Phys. Lett. B 878 (2026) 140498

Contents lists available at ScienceDirect

Physics Letters B

journal homepage: www.elsevier.com/locate/physletb

Letter

Search for heavy long-lived charged particles with level-1 trigger scouting data from proton-proton collisions at $\sqrt{s} = 13.6$ TeV

The CMS Collaboration[1]

ARTICLE INFO

Editor: Dr. M. Doser

Keywords:
CMS
HSCP
Long-lived
Level-1 trigger
Data scouting

ABSTRACT

A search for heavy long-lived charged particles at the LHC is presented. Particles traversing the CMS muon detector across several bunch crossings are searched for using a data sample of proton-proton collisions at $\sqrt{s} =$ 13.6 TeV collected with the CMS detector in 2024, corresponding to an integrated luminosity of 3.7 fb^{-1}. This is the first search using the novel level-1 trigger scouting data set collected without any trigger selection, allowing correlations between bunch crossings to be analyzed. The results are interpreted as upper limits on the cross sections of several benchmark processes with pair production of heavy long-lived charged particles. Upper limits on the fiducial cross section of a heavy long-lived charged particle with $p_T > 500$ GeV and $|\eta| < 0.83$ are also set in different ranges of $\beta = v/c$. This analysis is a proof of concept for the level-1 trigger data scouting system and complements existing searches for heavy long-lived charged particles by extending the sensitivity to lower β values.

1. Introduction

Heavy long-lived charged-particle searches are motivated by multiple beyond the standard model scenarios [1–3], such as supersymmetry, extra dimensions, and other theoretical frameworks. These particles are generically referred to as heavy stable charged particles (HSCPs), even if they may be metastable. If produced in proton-proton (pp) collisions at the CERN LHC, HSCPs would traverse the detector leaving distinctive experimental signatures. Because of their large mass and long lifetime, slow-moving HSCPs typically exhibit high ionization energy loss and unusually long time-of-flight.

Past collider searches for HSCPs at the CERN LEP [4–8], Fermilab Tevatron [9–12], and LHC [13–31] have set stringent constraints on various models, with limits on gluino R-hadrons, top squark R-hadrons, and fourth-generation leptons reaching the TeV scale. The recent HSCP search by the CMS Collaboration [30] looks for an isolated high transverse momentum (p_T) track that deposits an anomalous energy per unit length in the silicon tracker and relies on muon-based triggers to select events online. Because of this triggering strategy, it is sensitive to HSCPs with $\beta = v/c \gtrsim 0.6$, which can cross the CMS detector within a single bunch crossing (BX). To pass muon-based triggers, the muon tracks reconstructed in the tracker and in the muon detector must be in the same BX. Very slow particles may take several BXs to reach and cross the muon detector, causing the trigger to fail. While it is possible to indirectly trigger on missing transverse momentum in the calorimeters, such triggers typically have low and model-dependent signal efficiency. Even when the event can be triggered on, low-β particles may not be fully reconstructed if their trajectories span several BXs. Because of this limitation, past LHC searches have only targeted HSCP masses up to 3 TeV.

The analysis presented in this Letter avoids the triggering and reconstruction constraints by relying on the data collected without trigger conditions by the novel CMS level-1 trigger data scouting (L1DS) system [32–35]. It probes the existence of HSCPs with mass between 1 and 6.5 TeV leaving a signature in the muon detector before decaying. The search is based on data collected in the second half of 2024 in pp collisions at $\sqrt{s} = 13.6$ TeV, corresponding to an integrated luminosity of 3.7 fb^{-1}. This is the first analysis relying on data from the L1DS system and, as such, it is a crucial proof of concept for the physics potential of the L1DS. Tabulated results are provided in the HEPData record for this analysis [36].

2. The CMS detector and its hardware muon trigger

The CMS apparatus [33,37] is a multipurpose, nearly hermetic detector. Its central feature is a superconducting solenoid of 6 m internal diameter, providing a magnetic field of 3.8 T. Events of interest are usually selected using a two-tiered trigger system, where the level-1 trigger (L1), composed of custom hardware processors, uses information from the calorimeters and muon detectors to select events at a rate of around 100 kHz within a fixed latency of 4 μs [38].

The L1 muons in the barrel ($|\eta| < 0.83$) are reconstructed with the Kalman-filter-based barrel muon track finder (kBMTF) [33], which re-

---

Contact: cms-publication-committee-chair@cern.ch.

[1] CERN, Geneva, Switzerland, Authors are listed at the end of this paper.

https://doi.org/10.1016/j.physletb.2026.140498
Received 27 January 2026; Received in revised form 25 April 2026; Accepted 28 April 2026
Available online 6 May 2026

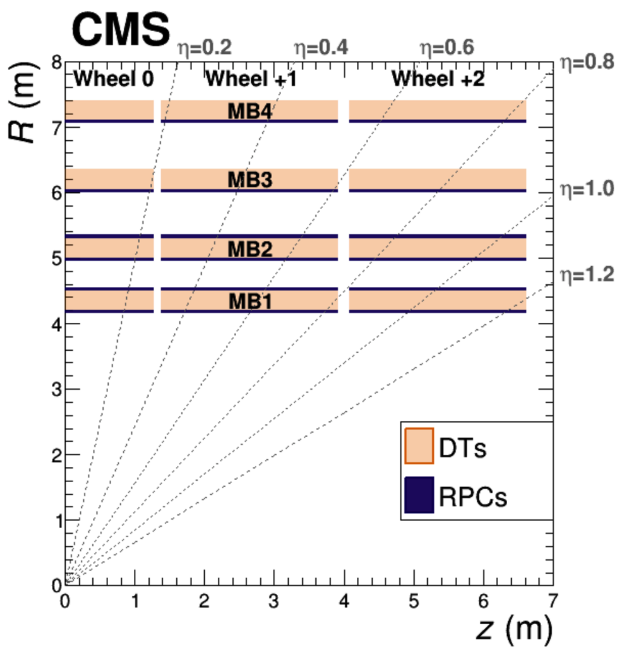


Fig. 1. The R–z projection of a quarter of the CMS barrel muon system, where R is the radial distance from the beamline.

lies on information from the drift tubes (DTs) and resistive-plate chambers (RPCs) of the muon detector in the barrel. The DT and RPC barrel systems consist of four cylindrical layers wrapped around the solenoid, called MB1–4 from the innermost to the outermost, each split into twelve wedges in ϕ and five wheels along the beam direction. The distance between MB1 and MB4 is about 3 m. The geometry of the muon detector in the barrel is illustrated in Fig. 1. The MB1 and MB2 layers both include two chambers of RPCs, whereas MB3 and MB4 only have one each.

The TwinMux system [39] merges segments in the DTs with RPC hits from the same layers into objects called stubs, which combine the better spatial resolution of the DTs with the more precise timing of the RPCs. The TwinMux processor sends the stubs to the kBMTF, which builds muon track candidates, assigns a quality to each, and measures the charge sign and p_{T} from the bending in the fringe field of the magnet yoke. Track quality is related to the estimated p_{T} resolution, and tracks with more stubs, particularly those in inner layers where the magnetic field is stronger, are assigned higher quality. Throughout the rest of the Letter, tracks refer to objects built from muon detector information only.

3. The L1 data scouting system

The L1DS system is a novel data collection scheme that acquires data directly from the L1 trigger, at the full BX rate of 40 MHz, corresponding to 25 ns between BXs [33]. It does not affect the L1 trigger accept decision. A subset of objects reconstructed by the L1 trigger (electrons, muons, hadronically decaying τ leptons, jets, energy sums, and muon stubs) are stored for events collected by the L1DS, corresponding to an average effective record size per BX of about four orders of magnitude smaller than that in regular CMS data taking. The L1DS system processes and stores data in orbits, each made of 3564 consecutive BXs. Unlike traditional data sets where the L1 trigger decision leads to reading out the detector information of a given BX, the L1DS system collects data from all BXs without any preselection. Because of storage limitations, the data are collected with a prescale factor N at the orbit level, corresponding to one orbit stored every N orbits. Different selection streams with requirements on L1 objects also exist, without any prescale factor.

While the L1DS system will reach its full capacity during the High-Luminosity LHC, a demonstrator started taking data in 2024. Since August 2024, stubs from the individual layers of the barrel muon detector have been included in the L1DS output for each BX. Offline, the stubs from different BXs can be fitted as muon-like tracks, as detailed in Section 5, effectively enabling the reconstruction of unit-charge particles with $0.15 \lesssim \beta \lesssim 0.80$. Below 0.15, the particles mostly get stopped before crossing the muon detector, whereas above 0.80, the particle trajectory is reconstructed within a same BX. These data were collected with a prescale factor of $N = 15$, corresponding to an effective integrated luminosity of 3.7 fb^{-1}, from a delivered one of about 55 fb^{-1}.

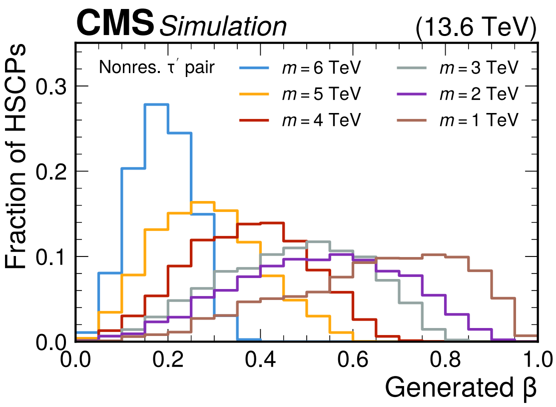


Fig. 2. Generated β distributions of the fourth-generation τ' leptons from nonresonant DY production, for various τ' masses m. The histograms are normalized to unity.

4. Signal and background simulation

Two lepton-like and one hadron-like signal models are used to interpret the results. The first lepton-like model consists of modified Drell–Yan (DY) production of long-lived massive fourth-generation fermions (τ') with spin 1/2 and unit charge, as considered in Ref. [30]. As they are neutral under both $\mathcal{SU}(3)_{\mathrm{C}}$ and $\mathcal{SU}(2)_{\mathrm{L}}$ groups, they couple only to the photon and the Z boson. Simulated event samples for τ' fermions are produced with masses $m_{\tau'}$ ranging from 1.0 to 6.5 TeV. Their generated β distributions are shown in Fig. 2 for different $m_{\tau'}$. The second lepton-like model consists of resonant production of two τ' leptons from the decay of a heavy Z′ boson, using a minimal simplified model. It is inspired by Ref. [40] but considers only unit-charge HSCPs. Masses of the τ' lepton between 1 and 6 TeV are probed, with the Z′ boson masses $m_{\mathrm{Z}'}$ in the range between twice and three times $m_{\tau'}$ to stay in the limit of low β, with a maximum $m_{\mathrm{Z}'}$ of 12 TeV. Signal samples with the same ratio between $m_{\mathrm{Z}'}$ and $m_{\tau'}$ have similar β distributions.

The hadron-like model consists of pair production of long-lived gluinos $\tilde{\mathrm{g}}$, which is a common signature of mini-split supersymmetric models where the $\tilde{\mathrm{g}}$ decay is highly suppressed by the large scalar quark mass [41–43]. In this analysis, a quasi-stable $\tilde{\mathrm{g}}$ is assumed and no $\tilde{\mathrm{g}}$ decay is considered. The fraction, f, of produced $\tilde{\mathrm{g}}$ hadronizing into a $\tilde{\mathrm{g}}$-gluon state (R-gluinoball) is a parameter of the hadronization model and corresponds to the fraction of R-hadrons that are neutral at production. We choose $f = 1$, such that these R-hadrons would escape analyses looking for anomalous ionization losses in the tracker, while they could leave a signature in the muon chambers if they become charged when crossing the detector through their interactions with matter, simulated using the model from Refs[44,45]. About one third of these R-hadrons are charged when they cross the muon detector. Their generated β distributions are similar to those shown in Fig. 2 for the fourth-generation τ' leptons produced in nonresonant DY production.

The leading-order (LO) PYTHIA generator v8.240 [46] with the tune CP5 [47] and the parton distribution function set NNPDF3.1 [48–50] at next-to-next-to-LO is used to simulate these three signal models. Backgrounds in the analysis are determined from data, but a DY simulation with dimuon decays (DY($\mu\mu$)) is used to calibrate the reconstructed objects. The MADGRAPH5_aMC@NLO 2.6.5 event generator is used to generate DY($\mu\mu$) events at next-to-LO with the FxFx jet matching and merging [51]. The response of the CMS detector is simulated with the GEANT4 package [52]. The simulated events are reconstructed using the same algorithms as used for data. In all samples, simulated minimum bias events are overlaid with the primary collision to produce the effect of additional pp interactions in the same or adjacent BXs, referred to as "pileup" [53].

5. Muon track reconstruction

In this analysis, HSCPs are reconstructed as muons from the stubs stored in the L1DS data set, using a modified version of the kBMTF. While standard L1 muons are built online from stubs in the same BX, the modified kBMTF algorithm is run offline using stubs that are separated in time by at most eight BXs. No constraint on the time ordering of stubs is applied at this stage to preserve unphysical orderings for background estimation purposes, as detailed in Section 7. The fit is performed independently of the BX information of individual stubs. The average p_T resolution of the muon tracks is measured to be 18% in a simulated DY($\mu\mu$) sample. While the p_T resolution is independent of β, it gets worse at significantly higher p_T values. For $p_T \gtrsim 650\,\text{GeV}$, the tracks in the muon detector are basically straight and different p_T values cannot be distinguished anymore.

The modified kBMTF reconstruction is validated in DY($\mu\mu$) events, which are also used to calibrate the p_T estimation and derive efficiency corrections used for simulated samples. The events are selected by requiring a pair of opposite-sign kBMTF tracks with $p_T > 15\,\text{GeV}$ and $|\eta| < 0.83$. The pair must have an invariant mass $m_{\mu\mu}$ larger than 50 GeV. The nonprompt background, originating mostly from processes like W + jets or QCD multijet events, with jets misidentified as leptons, is estimated by rescaling the data with same-sign kBMTF tracks to have perfect agreement between data and predictions in the opposite-sign events with $50 < m_{\mu\mu} < 55\,\text{GeV}$. While the tracks can be built from stubs in different BXs, most DY($\mu\mu$) tracks are reconstructed within the same BX. Five p_T-independent parameters are determined for the simulation: a multiplicative factor of the predicted p_T (compatible with 1.0), the width of a Gaussian smearing of the predicted p_T (about 10%), and an efficiency correction per stub multiplicity (up to 11% for 4-stub tracks). Fig. 3 shows the dimuon invariant mass and the stub multiplicity per muon track after the corrections have been applied, where good agreement between predictions and data is obtained by construction. In these events, about 25 (45, 30)% of the reconstructed muons have 2 (3, 4) stubs.

Depending on their β, HSCPs are reconstructed within different ranges of BXs. Fig. 4 shows the fraction of the tracks reconstructed in different BX signatures for unit-charge HSCPs. For $\beta > 0.7$, particles mostly cross the muon detector within the same BX as the hard scattering (dark blue). The same experimental signature of stubs within the same BX appears for most HSCPs with β around 0.5, but in that case the particle takes one BX to reach the first layer of the muon detector then crosses all the layers within the BX following that of the collision (lighter blue). Up to 30% of HSCPs with β around 0.3 also have the same experimental signature, but with the muon detector layers crossed at least 2 BXs after the hard scattering (lightest blue). About half of the HSCPs with $\beta = 0.6$ cross the muon detector during the collision BX and the following one (dark orange). HSCPs with $\beta = 0.4$ mostly take one BX to reach the first layer of the muon detector, and reach the last muon detector layer one BX later than the first layer (lighter orange), whereas a significant fraction of HSCPs with $\beta \lesssim 0.3$ need at least 2 BXs to reach the first layer, and cross the last layer one BX later (lightest orange). Different shades of a same color, corresponding to different BX intervals with respect to the collision BX, are indistinguishable experimentally since the production BX cannot be determined. For $\beta \lesssim 0.3$, a significant fraction of the tracks are reconstructed across 3 or 4 BXs (red or purple histograms, respectively), whereas the efficiency goes to zero for $\beta \lesssim 0.15$ because the particles get stopped in the detector. For $\beta \lesssim 0.5$, the efficiency for the reconstructed tracks to satisfy the single-muon high-level trigger (HLT) selection is zero, showing that such slow particles cannot be directly triggered on.

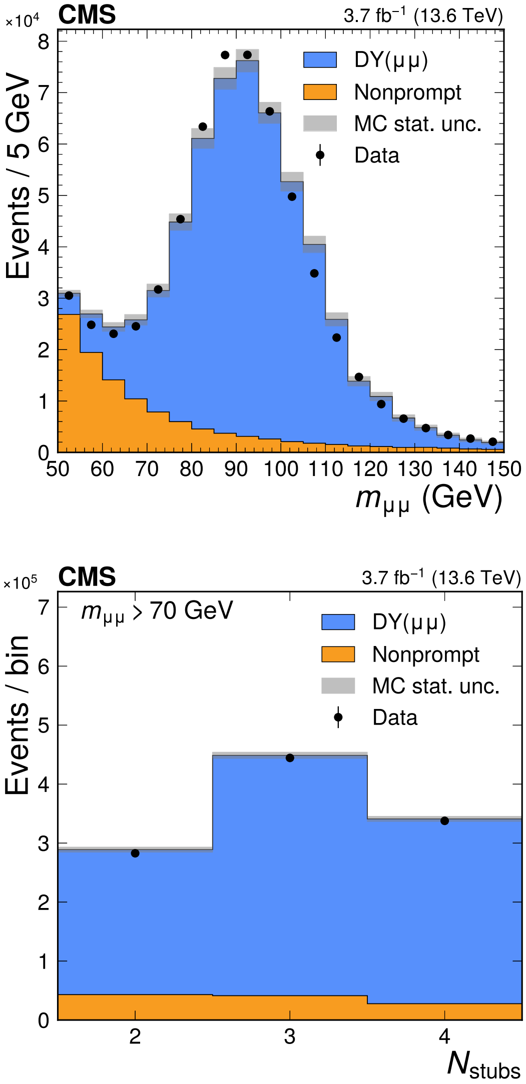


Fig. 3. Distributions of the dimuon invariant mass (upper) and per-track stub multiplicity (lower) for events with two opposite-sign modified kBMTF tracks reconstructed from individual stubs in the same or different BXs. The invariant mass is required to be greater than 70 GeV in the stub multiplicity distributions to increase the purity. The muons are selected with $p_T > 15\,\text{GeV}$ and $|\eta| < 0.83$. The nonprompt-background contribution is estimated by rescaling the data with two same-sign modified kBMTF tracks. The statistical uncertainty is indicated in the gray shaded area. The agreement between simulation and data is good by construction since the efficiency, energy scale, and energy smearing corrections derived from the same events have been applied.

6. Event selection, categories, and statistical analysis

Events containing at least one modified kBMTF track with 3 or 4 stubs, reconstructed across a minimum (maximum) of 2 (4) BXs, are selected. Tracks with 2 stubs are not considered because of the relatively larger background. Particles slow enough to cross the muon chambers in more than 4 BXs would mostly be stopped in the detector because of their large ionization losses. In the signal region (SR), hits must occur from the inner layers to the outer ones, i.e., a stub in an outer layer must be in the same BX or a later BX with respect to the stub in the

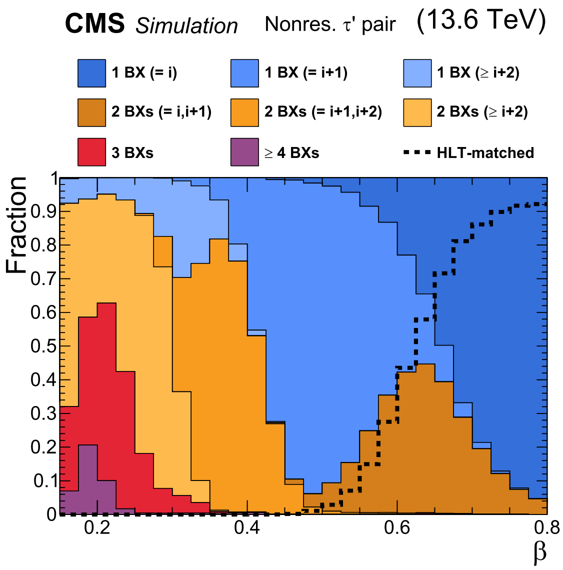


Fig. 4. Fractions of the BX signatures of tracks reconstructed with the modified kBMTF algorithm as functions of the generated particle β. This figure corresponds to the nonresonant fourth-generation lepton signal model with a mixture of HSCP masses between 1 and 6 TeV. The filled histograms are stacked to sum to unity. The blue histograms correspond to tracks reconstructed in a single BX. Different shades represent different BXs with respect to the collision BX (BX = i), as indicated in parentheses in the legend. The orange histograms correspond to tracks reconstructed over 2 BXs, with different shades corresponding to different BXs with respect to the collision BX. Different shades of the same color are indistinguishable experimentally since the production BX cannot be determined. The red and purple histograms represent tracks reconstructed over 3 or at least 4 BXs, respectively. The dashed line indicates the efficiency for the reconstructed tracks to satisfy the single-muon HLT selection. For $\beta < 0.15$, the efficiency goes to zero because the particles get stopped in the detector. For $\beta > 0.8$, the particles are increasingly reconstructed in the same BX, in which case the HLT selection is fully efficient.

closest inner layer. The muon tracks must have $|\eta| < 0.83$ and $p_T > 15$ GeV. If several such tracks are present, the slowest track (i.e., spanning the most BXs) is selected. If speeds are equal, the track with the largest stub multiplicity is chosen; if both the speed and stub multiplicity are equal, the highest p_T track is selected. The selected track is required to have a transverse distance of closest approach to the beamline center, d_{xy}, less than 32 cm, and to pass high-quality criteria calculated by the kBMTF algorithm. The coarse selection on d_{xy} is related to the low precision available from the L1 information and algorithms. Colliding bunches are determined per orbit on the basis of the LHC injection scheme. Events are discarded if the BX of the earliest stub and the five BXs preceding it are all noncolliding, since HSCPs cannot be produced in noncolliding bunches. For the simulated samples of the nonresonant DY production of τ' leptons, the product of the acceptance and efficiency of these selection criteria is 19% for $m_{\tau'} = 1$ TeV and as high as 47% for $m_{\tau'} = 5.5$ TeV.

Fourteen categories are built to target signals with different β, characterized by different crossing times of the detector. The categories are also based on the stub multiplicity since the signal-to-background ratio improves with the number of stubs. The categories are defined in Table 1. The most sensitive category, BX123, is illustrated in Fig. 5, whereas the illustrations of all categories can be found in Appendix A.

The categories with tracks across 2 BXs, namely with 3/2 or 4/2 layers/BXs, suffer from a large background from per-stub BX misidentification, which is below 1% for muon detector layers with two working layers of RPCs, and up to 6% when no layer of RPCs is working [54]. Additional model-dependent selection criteria based on the pair-production hypothesis can significantly reduce the background. In these categories, a second good-quality track with $|\eta| < 0.83$ and $p_T > 100$ GeV is required, with at least one stub in the same BX as one of the stubs of the first track. This reduces the background by almost two orders of magnitude, while retaining about half of the signal. The original categories without the additional selection criterion are kept to set model-independent limits on the fiducial cross section of slow particles, without relying on the description of the rest of the event.

Table 1
Categories based on muon detector layers with stubs and speed expressed as the number of crossed layers divided by the number of BXs spent to cross them. The BX1234 category includes 4-stub tracks for which the 4 stubs are in 4 subsequent BXs. For 3-stub (4-stub) tracks, the BX123 categories correspond to 3 (4) stubs in 3 different BXs across a range of 3 BXs, whereas the BX124/134 categories correspond to 3 (4) stubs in 3 different BXs across a range of 4 BXs. The 4-stub category BX1112 (1122, 1222) corresponds to 3 (2, 1) stubs in the first BX, and 1 (2, 3) stubs in the next BX. Similarly, the 3-stub categories BX112 (122) correspond to 2 (1) stubs in the first BX and 1 (2) stub in the next BX. The 3-stub categories are further separated into fast and slow subcategories: those denoted "fast" feature a track with the first stub in MB1 and the last one in MB4, corresponding to a longer distance crossed in the same amount of time as their "slow" counterparts, which do have exactly one stub within the innermost and outermost detector layers. The symbol ⊕ represents the exclusive "or", whereas ∧ is the logical "and".

Stub config.	Layers / BXs				
	3/4	3/3 or 4/4	4/3	3/2	4/2
4 stubs	—	BX1234 BX124/134	BX123	—	BX1112 BX1122 BX1222
3 stubs, MB1 ⊕ MB4	BX124/134 slow	BX123 slow	—	BX112 slow BX122 slow	—
3 stubs, MB1 ∧ MB4	—	BX124/134 fast	BX123 fast	—	BX112 fast BX122 fast

The results are extracted with a maximum likelihood fit of binned distributions in each category. The observable is chosen to be the track p_T because the signal is characterized by harder objects than the background. Indeed, particles with low β reaching the muon chambers must be heavy and produced with significant momentum. To avoid overconstraining the background estimate from low-p_T bins with large event yields, the p_T threshold is increased to 50 (150) GeV in the categories with tracks across 2 BXs with (without) a requirement on the presence of a second track, and to 50 GeV in all categories across more than 2 BXs, except the BX1234 category where the p_T threshold is 15 GeV because of the lower background expectation.

7. Background estimation and validation

Backgrounds arise mostly from ultra-relativistic particles with BX misidentification in the individual muon detector layers, and from combining unrelated ultra-relativistic particles from different BXs at the same place in the detector, but also from noncollision processes and noise in the detector. Contributions from slow particles originating from the experimental cavern are negligible because the time ordering of their stubs is not compatible with a particle produced at the beam spot and exiting the CMS detector. The track p_T distribution of the backgrounds in each category is estimated using tracks with an asynchronous time ordering of the stubs within the muon detector layers. The synchronous signal-like ordering is when the stub in each layer occurs in the same or a later BX compared to the stubs in the layers inside it. The other synchronous ordering, where the inner stubs occur later, is not signal-like and signifies a track that enters the detector from the outside. Other combinations are asynchronous. Because of BX misidentification, some asynchronous combinations include significant contributions from physical processes entering the detector, such as slow neutrons originating from the experimental cavern, which may have a different p_T distribution from that of the backgrounds in the SR. To remove this

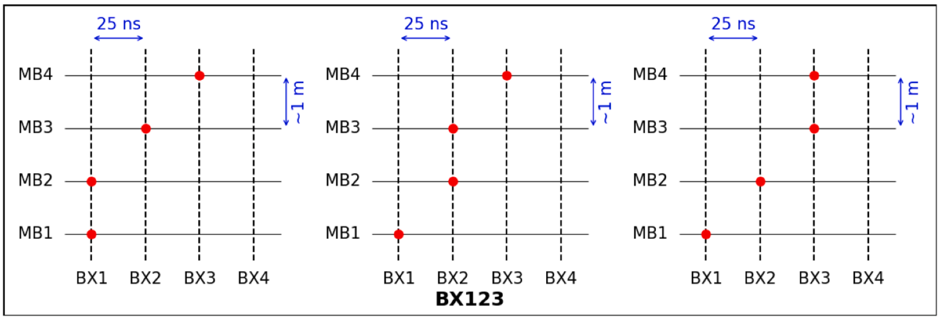


Fig. 5. Schematic definition of the BX123 category.

contribution, only the tracks where either the innermost stub is in the earliest BX or the outermost stub in the latest BX are used to estimate the background p_T distribution in the SR. Signal contributions to events with asynchronous orderings are below the percent level and therefore are neglected. The configurations considered to estimate the background in the BX1234 and BX1112 categories are illustrated in Appendix A. The background normalization is left floating in each category in the binned maximum likelihood fit, where it gets constrained by the signal-depleted low-p_T bins.

The background estimation is verified in two orthogonal validation regions (VRs): (i) events in colliding bunches where the track fails the quality criteria, and (ii) events with a high-quality track where the BX of the earliest stub and the five BXs preceding it are noncolliding. A maximum likelihood fit to the data is performed using the systematic uncertainties described in Section 8. In both VRs, good agreement between the observed data and predicted background is observed, as shown in Figs. 6 and 7. The VR with low track quality criteria is significantly more populated than the SR, making it a stringent test of the background estimation method. The noncolliding VR is significantly less populated than the SR, but provides a useful validation for events with signal-like high-quality tracks.

8. Systematic uncertainties

The dominant systematic uncertainties come from the background estimation. While the background normalization is left floating in the fit independently for each category, one systematic uncertainty affecting the p_T distribution is considered in each category. These uncertainties are incorporated in the likelihood as nuisance parameters with a Gaussian prior. The alternative p_T distributions corresponding to a ± 1 standard deviation (s.d.) are built from either a subset of the tracks used to estimate the nominal p_T distribution, or from an orthogonal set, as described in the next paragraphs and summarized in Table 2.

In the categories with tracks across more than 2 BXs, as well as in BX1122, the p_T-dependent systematic uncertainty corresponding to a $+1$ (-1) s.d. is determined by considering uniquely the subset of asynchronous orderings where the innermost (outermost) stub is in the earliest (latest) BX. This results in an uncertainty in the range 5–60% for tracks with $p_T > 450\,\text{GeV}$.

This method does not work in the other categories because these two asynchronous orderings do not both exist or are not distinct. In BX1112 and BX1222, the alternative p_T distribution corresponding to a $+1$ (-1) s.d. is taken from the subset of asynchronous orderings where the stub detected in a different BX than the other three stubs is in MB2 (MB3), leading to normalization effects of 5–30% for events with tracks with $p_T > 450\,\text{GeV}$.

In the remaining 3-stub categories spanning exactly 2 BXs, namely BX112 slow, BX112 fast, BX122 slow, and BX122 fast, the shape uncertainty is obtained by considering the p_T distribution of a different set of tracks with asynchronous orderings, failing the quality criteria, and symmetrizing it with respect to the nominal distribution. It has an effect of 5–75% for events with tracks with $p_T > 450\,\text{GeV}$.

Table 2
Definition of asynchronous track orderings used to build the alternative p_T distributions corresponding to a ± 1 s.d. of the background systematic uncertainty.

Categories	+1 s.d.	−1 s.d.
BX1122, BX123, BX124/134, BX124/134 slow, BX124/134 fast, BX123 slow, BX123 fast, BX1234	Asynchronous orderings where the innermost stub is in the earliest BX	Asynchronous orderings where the outermost stub is in the latest BX
BX1112, BX1222	Asynchronous orderings where the stub detected in a different BX is in MB2	Asynchronous orderings where the stub detected in a different BX is in MB3
BX112 slow, BX112 fast, BX122 slow, BX122 fast	Asynchronous orderings failing the quality criteria	Symmetric distribution with respect to nominal

The background p_T-dependent uncertainties on average get constrained by the maximum likelihood fit to 50% of their initial magnitudes. Overall, systematic uncertainties have a small impact on the analysis, which is statistically limited by the number of events selected in the high-p_T bins of the SR.

The signal normalization uncertainty, coming from the selection efficiency, as well as the integrated luminosity, is determined from the efficiency correction derived from DY($\mu\mu$) events, which includes effects related to the reconstruction and identification of muon-like particles, as well as overall normalization effects, such as the DY($\mu\mu$) cross section and the integrated luminosity. An additional uncertainty comes from the limited size of the DY($\mu\mu$) simulation used to derive the correction. This results in an uncertainty of about 3 (2)% in categories with tracks with 3 (4) stubs, partially correlated between stub multiplicity categories.

9. Results

The results are extracted with a binned maximum likelihood fit to the observed p_T distributions in the different SRs. The systematic uncertainties described in Section 8 are considered as nuisance parameters in the statistical procedure. The results have been determined using the CMS statistical analysis tool COMBINE [55]. The SR distributions are shown in Fig. 8. No significant excess of data is observed above the standard model expectation.

Upper limits at 95% confidence level (CL) are computed using the modified frequentist CL_s criterion [56,57], using the asymptotic approximation [58]. The limits on the signal cross section are shown in Fig. 9, as a function of the HSCP mass for the nonresonant τ' (upper) and gluino R-hadron (lower) scenarios. The sensitivity is driven by 4-stub categories, in particular by the BX123 category, which features a 4-stub track across 3 BXs. The 3-stub categories perform better for hadron-like models than for lepton-like ones, because the hadron-like HSCPs tend to be reconstructed with fewer stubs. The relative sensitivity of the different categories is mass-dependent because heavier HSCPs typically have lower β and take longer to cross the muon chambers. The structure around $m = 3$ TeV arises from the significant fraction of HSCPs

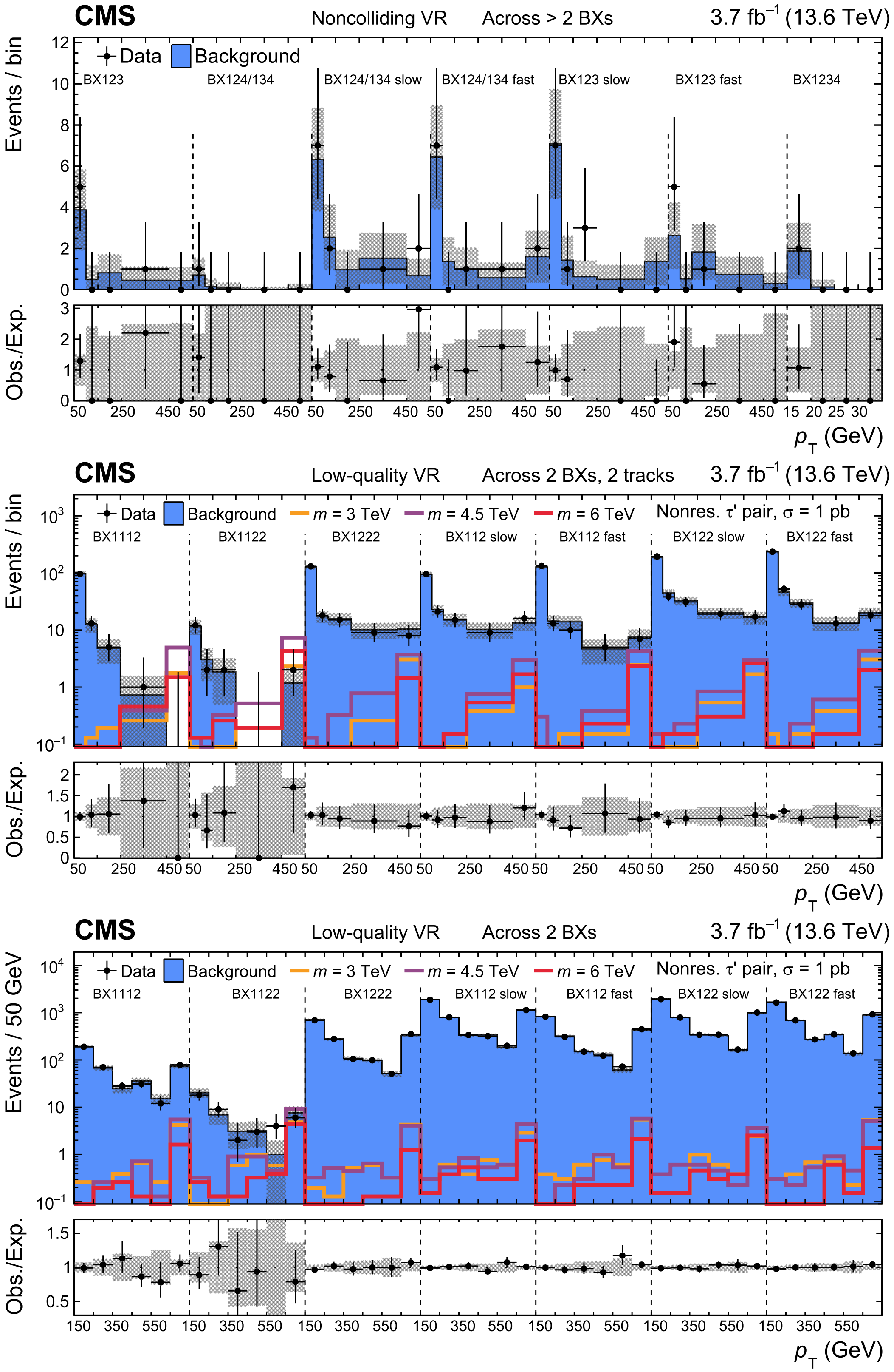


Fig. 6. Low-track-quality validation region distributions for the categories with tracks across >2 (=2, =2) BXs without (with, without) additional track requirement are shown in the upper (center, lower) part of the figure. The expected background distributions are the result of the maximum likelihood fit. The uncertainty bands account for all sources of background uncertainty, systematic as well as statistical, after the maximum likelihood fit. The signal is shown for a few mass hypotheses of the nonresonant fourth-generation lepton model, using a production cross section of 1 pb. The lower panels show the observed to expected ratio. The last p_T bins include the overflow.

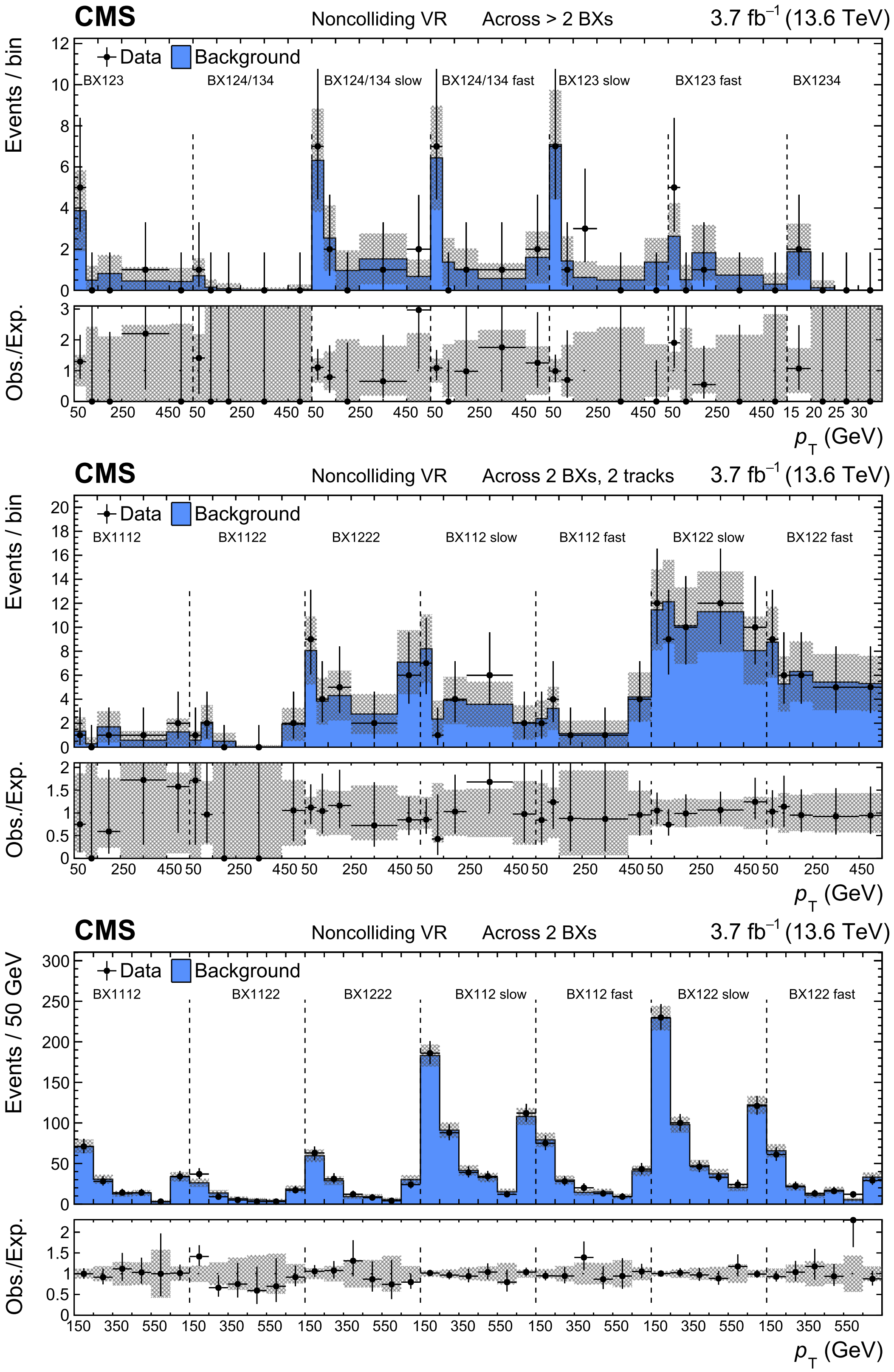


Fig. 7. Noncolliding validation region distributions for the categories with tracks across >2 (=2, =2) BXs without (with, without) additional track requirement are shown in the upper (center, lower) part of the figure. The expected background distributions are the result of the maximum likelihood fit. The uncertainty bands account for all sources of background uncertainty, systematic as well as statistical, after the maximum likelihood fit. The lower panels show the observed to expected ratio. The last p_T bins include the overflow.

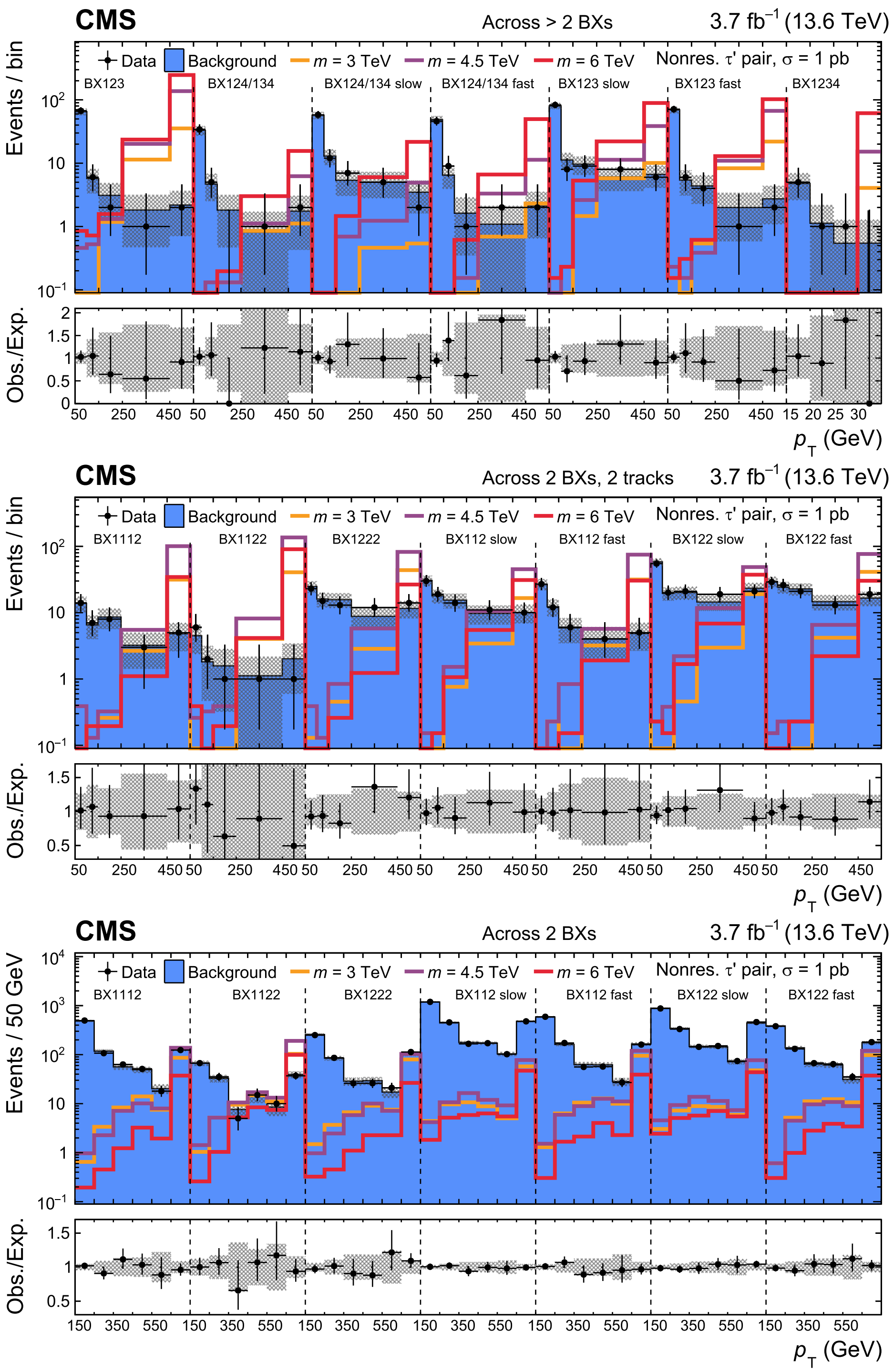


Fig. 8. The p_T distributions in the signal region for the categories with tracks across >2 (=2, =2) BXs without (with, without) additional track requirement are shown in the upper (center, lower) part of the figure. The expected background distributions are the result of the maximum likelihood fit. The uncertainty bands account for all sources of background uncertainty, systematic as well as statistical, after the maximum likelihood fit. The lower panels show the observed to expected ratio. The signal is shown for a few mass hypotheses of the nonresonant fourth-generation lepton model, using a production cross section of 1 pb. The last p_T bins include the overflow.

with $\beta \approx 0.5$, for which the analysis has limited acceptance since they tend to cross the muon detector entirely during the BX that follows the collision. Around $m = 6$ TeV, the limits degrade because the HSCPs are mostly produced with $\beta \lesssim 0.15$ and are stopped before crossing the muon detector. The previous CMS analysis based on an ionization-loss signature [30] provided an interpretation up to $m = 2.6$ TeV, where the limits are about two orders of magnitude tighter than the result presented in this paper, because of the larger data set available, larger η acceptance, and higher-level information. However, unlike the present search, the ionization-loss signature analysis does not have sensitivity to scenarios with $m \gtrsim 4.5$ TeV because its HLT efficiency is zero at such low β values. This analysis has unique sensitivity at high mass where all HSCPs have low β, and to the gluino R-hadron scenario with $f = 1$, where there is no ionization loss signature in the tracker since the R-hadron is neutral

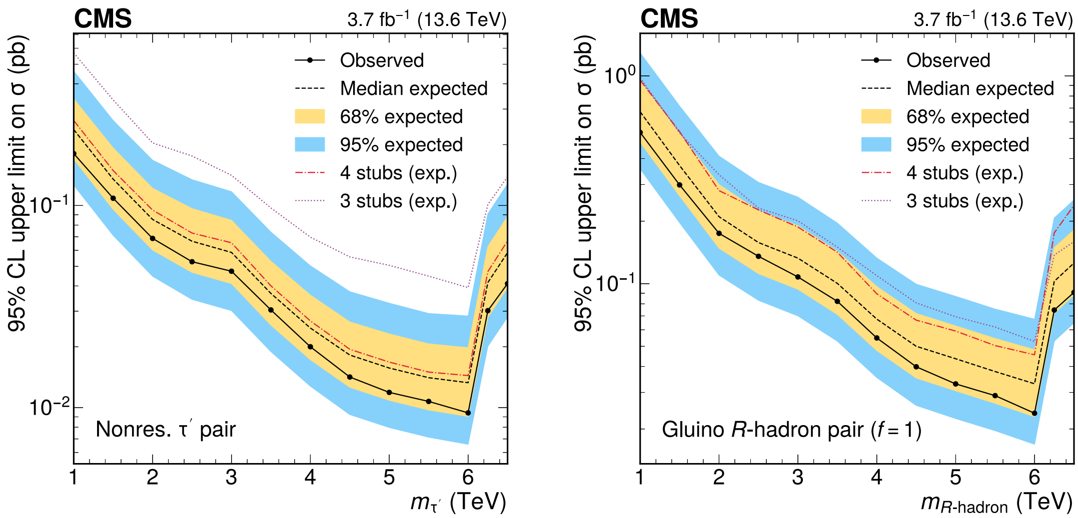


Fig. 9. Observed (solid line with markers) and expected (dashed black line) upper limits at 95% CL on the production cross section of heavy fourth-generation leptons through nonresonant DY production (left) and of a gluino *R*-hadron pair with $f = 1$ (right). The inner (yellow) and the outer (blue) bands indicate the regions containing 68 and 95%, respectively, of the distribution of limits expected under the background-only hypothesis. The expected limits for the combinations of 3-stub (dashed purple line) and 4-stub (dashed-red line) categories are also shown.

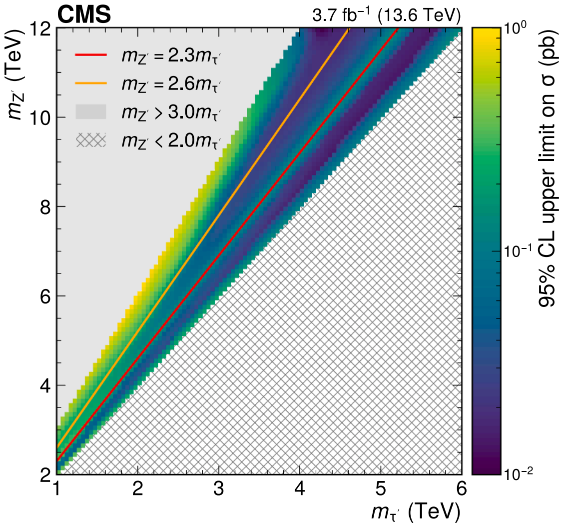


Fig. 10. Observed upper limits at 95% CL on the production cross section of heavy fourth-generation leptons through Z′ boson decays. Lines indicate different values of the ratio of Z′ to τ′ masses, for which β values are typically similar. Signal hypotheses with $2m_{\tau'} < m_{Z'} < 3m_{\tau'}$ are probed. For $m_{Z'} > 3m_{\tau'}$, the HSCPs typically have high β and are reconstructed in the same BX. The lowest limits are obtained for $m_{Z'}/m_{\tau'} \approx 2.15$ (2.60), for which HSCPs are dominantly produced with $\beta \approx 0.2$ (0.6). The higher limits for $m_{Z'}/m_{\tau'} \approx 2.30$ are related to the low analysis acceptance for HSCPs produced with $\beta \approx 0.5$ and largely reconstructed in a single BX.

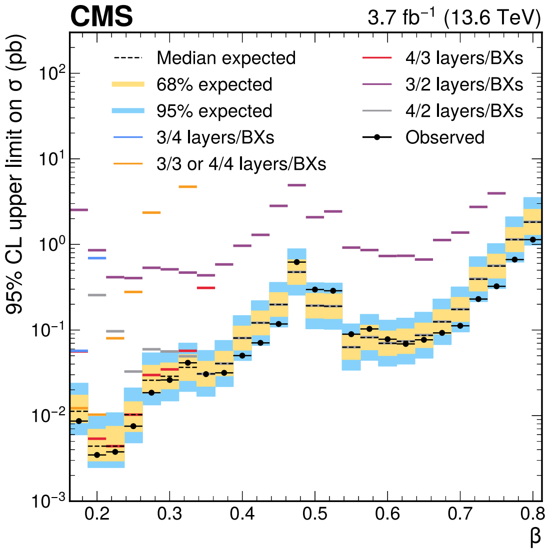


Fig. 11. Observed and expected upper limits at 95% CL on the fiducial cross section of a heavy particle leaving a signature in the muon detector with $|\eta| < 0.83$, $p_T > 500$ GeV, in bins of β. The inner (yellow) and the outer (blue) bands indicate the regions containing 68 and 95%, respectively, of the distribution of limits expected under the background-only hypothesis. The expected limits for groups of categories corresponding to a given number of muon detector layers across a given number of BXs are also shown with colored dashed lines. The limited sensitivity around $\beta = 0.5$ corresponds to a loss of acceptance from particles reconstructed entirely in the BX that followed the collision.

in that part of the detector. Two-dimensional upper limits are shown in Fig. 10 for the τ′ pair production from a Z′ boson decay, with unique sensitivity for $m_{Z'} \lesssim 2.5 m_{\tau'}$, corresponding to HSCPs with $\beta \lesssim 0.6$. For all mass points, the observed limits are within the band containing 68% of the limits expected under the background-only hypothesis.

Upper limits are also set on the fiducial cross section of a lepton-like particle leaving a signature in the muon detector and produced with $p_T > 500$ GeV, $|\eta| < 0.83$, and a given range of β, assuming there is no contribution from particles produced with other β values. These results are extracted from the SRs without additional track requirement in order not to rely on the pair production assumption. The signal distributions are built using particles from the simulated samples described in Section 4 satisfying $p_T > 500$ GeV, $|\eta| < 0.83$, and the β range restriction. These distributions are independent from the signal model. As shown in Fig. 11, upper limits as low as 3.5 fb can be set for particles produced with $0.1875 < \beta < 0.2125$, where the sensitivity mostly comes from the categories where the particle takes 3 BXs to cross all four muon layers. For lower β values, the sensitivity sharply decreases as the particles get stopped before entering the muon detector because of their large ionization loss. The patterns in the limits align with the signatures of the slow particles as a function of β, shown in Fig. 4. For $\beta > 0.35$, the categories where the particle takes 2 BXs to cross the four muon layers dominate the sensitivity. The sensitivity is low around $\beta = 0.5$, because the particle is likely to be reconstructed entirely in the BX following the collision, where the analysis has no acceptance since the track experimentally looks like that of an ultra-relativistic particle.

10. Summary

A search for long-lived massive charged particles has been presented, exploiting a muon-like signature in the barrel muon detectors spread across several LHC proton bunch crossings. This is the first time that an analysis relies on the novel CMS level-1 trigger scouting data set, for which no trigger selection is applied. A method based on control samples in data is used to estimate the backgrounds, relying on tracks not compatible in time with the expectations from a slow particle exiting the detector. No significant excess of data above the predicted standard model backgrounds is observed. Upper limits are set on the production cross section of heavy stable charged particles in several models, and fiducial upper limits on the production cross section for different $\beta = v/c$ ranges are also set for a model-independent interpretation. The analysis has unique sensitivity to particles with $0.15 \lesssim \beta \lesssim 0.5$, which are challenging to trigger on, and to neutral particles that acquire a charge when crossing the detector, which do not leave an ionization-loss signature in the tracker. Upper limits as low as 3.5 fb at 95% confidence level are set on the fiducial production cross section of lepton-like charged particles with $|\eta| < 0.83$ and $p_T > 500\,\text{GeV}$, in several bins of β, extending the reach of the existing searches to higher masses and lower values of β.

Data availability

Release and preservation of data used by the CMS Collaboration as the basis for publications is guided by the CMS data preservation, re-use and open access policy.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC and thank the technical and administrative staffs at CERN and at other CMS institutes for their contributions to the success of the CMS effort. In addition, we gratefully acknowledge the computing centers and personnel of the Worldwide LHC Computing Grid and other centers for delivering so effectively the computing infrastructure essential to our analyses. Finally, we acknowledge the enduring support for the construction and operation of the LHC, the CMS detector, and the supporting computing infrastructure provided by the following funding agencies: SC (Armenia), BMBWF and FWF (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, FAPERGS, and FAPESP (Brazil); MES and BNSF (Bulgaria); CERN; CAS, MoST, and NSFC (China); MINCIENCIAS (Colombia); MSES and CSF (Croatia); RIF (Cyprus); SENESCYT (Ecuador); ERC PRG, TARISTU24-TK10 and MoER TK202 (Estonia); Academy of Finland, MEC, and HIP (Finland); CEA and CNRS/IN2P3 (France); SRNSF (Georgia); BMFTR, DFG, and HGF (Germany); GSRI (Greece); NKFIH (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); MSIT and NRF (Republic of Korea); MES (Latvia); LMTLT (Lithuania); MOE and UM (Malaysia); BUAP, CINVESTAV, CONACYT, LNS, SEP, and UASLP-FAI (Mexico); MOS (Montenegro); MBIE (New Zealand); PAEC (Pakistan); MES, NSC, and NAWA (Poland); FCT (Portugal); MESTD (Serbia); MICIU/AEI and PCTI (Spain); MOSTR (Sri Lanka); Swiss Funding Agencies (Switzerland); MST (Taipei); MHESI (Thailand); TUBITAK and TENMAK (Türkiye); NASU (Ukraine); STFC (United Kingdom); DOE and NSF (USA).

Individuals have received support from the Marie-Curie program and the European Research Council and Horizon 2020 Grant, contract Nos. 675440, 724704, 752730, 758316, 765710, 824093, 101115353, 101002207, 101001205, and COST Action CA16108 (European Union); the Leventis Foundation; the Alfred P. Sloan Foundation; the Alexander von Humboldt Foundation; the Science Committee, project no. 22rl-037 (Armenia); the Fonds pour la Formation à la Recherche dans l'Industrie et dans l'Agriculture (FRIA) and Fonds voor Wetenschappelijk Onderzoek contract No. 1228724N (Belgium); the Beijing Municipal Science & Technology Commission, No. Z191100007219010, the Fundamental Research Funds for the Central Universities, the Ministry of Science and Technology of China under Grant No. 2023YFA1605804, the Natural Science Foundation of China under Grant No. 12535004, and USTC Research Funds of the Double First-Class Initiative No. YD2030002017 (China); the Ministry of Education, Youth and Sports (MEYS) of the Czech Republic; the Shota Rustaveli National Science Foundation, grant FR-22-985 (Georgia); the Deutsche Forschungsgemeinschaft (DFG), among others, under Germany's Excellence Strategy – EXC 2121 "Quantum Universe" – 390833306, and under project number 400140256 - GRK2497; the Hellenic Foundation for Research and Innovation (HFRI), Project Number 2288 (Greece); the Hungarian Academy of Sciences, the New National Excellence Program - ÚNKP, the NKFIH research grants K 131991, K 133046, K 138136, K 143460, K 143477, K 146913, K 146914, K 147048, 2020-2.2.1-ED-2021-00181, TKP2021-NKTA-64, and 2025-1.1.5-NEMZ_KI-2025-00004 (Hungary); the Council of Science and Industrial Research, India; ICSC – National Research Center for High Performance Computing, Big Data and Quantum Computing, FAIR – Future Artificial Intelligence Research, and CUP I53D23001070006 (Mission 4 Component 1), funded by the NextGenerationEU program (Italy); the Latvian Council of Science; the Ministry of Education and Science, project no. 2022/WK/14, and the National Science Center, contracts Opus 2021/41/B/ST2/01369, 2021/43/B/ST2/01552, 2023/49/B/ST2/03273, and the NAWA contract BPN/PPO/2021/1/00011 (Poland); the Fundação para a Ciência e a Tecnologia, grant CEECIND/01334/2018 (Portugal); the National Priorities Research Program by Qatar National Research Fund; MICIU/AEI/10.13039/501100011033, ERDF/EU, "European Union NextGenerationEU/PRTR", and Programa Severo Ochoa del Principado de Asturias (Spain); the Chulalongkorn Academic into Its 2nd Century Project Advancement Project, the National Science, Research and Innovation Fund program IND_FF_68_369_2300_097, and the Program Management Unit for Human Resources & Institutional Development, Research and Innovation, grant B39G680009 (Thailand); the Kavli Foundation; the Nvidia Corporation; the SuperMicro Corporation; the Welch Foundation, contract C-1845; and the Weston Havens Foundation (USA).

Appendix A. Schematic illustration of the categories

The event categories are illustrated in Figs. A.12–A.14. The track configurations used to estimate the background in the BX1234 and BX1112 categories are illustrated in Figs. A.15 and A.16, respectively.

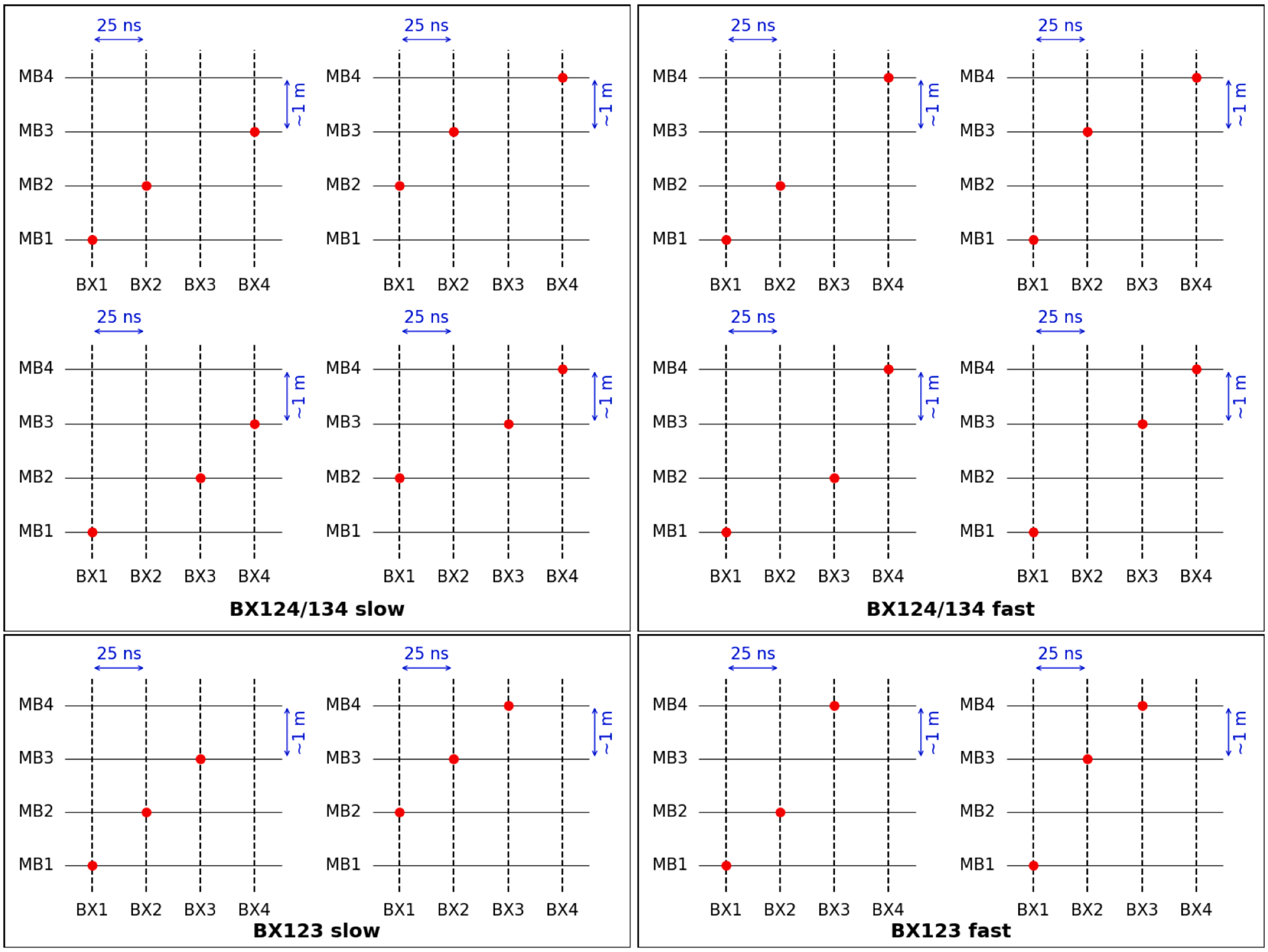


Fig. A.12. Schematic definition of the 3-stub categories with tracks across >2 BXs.

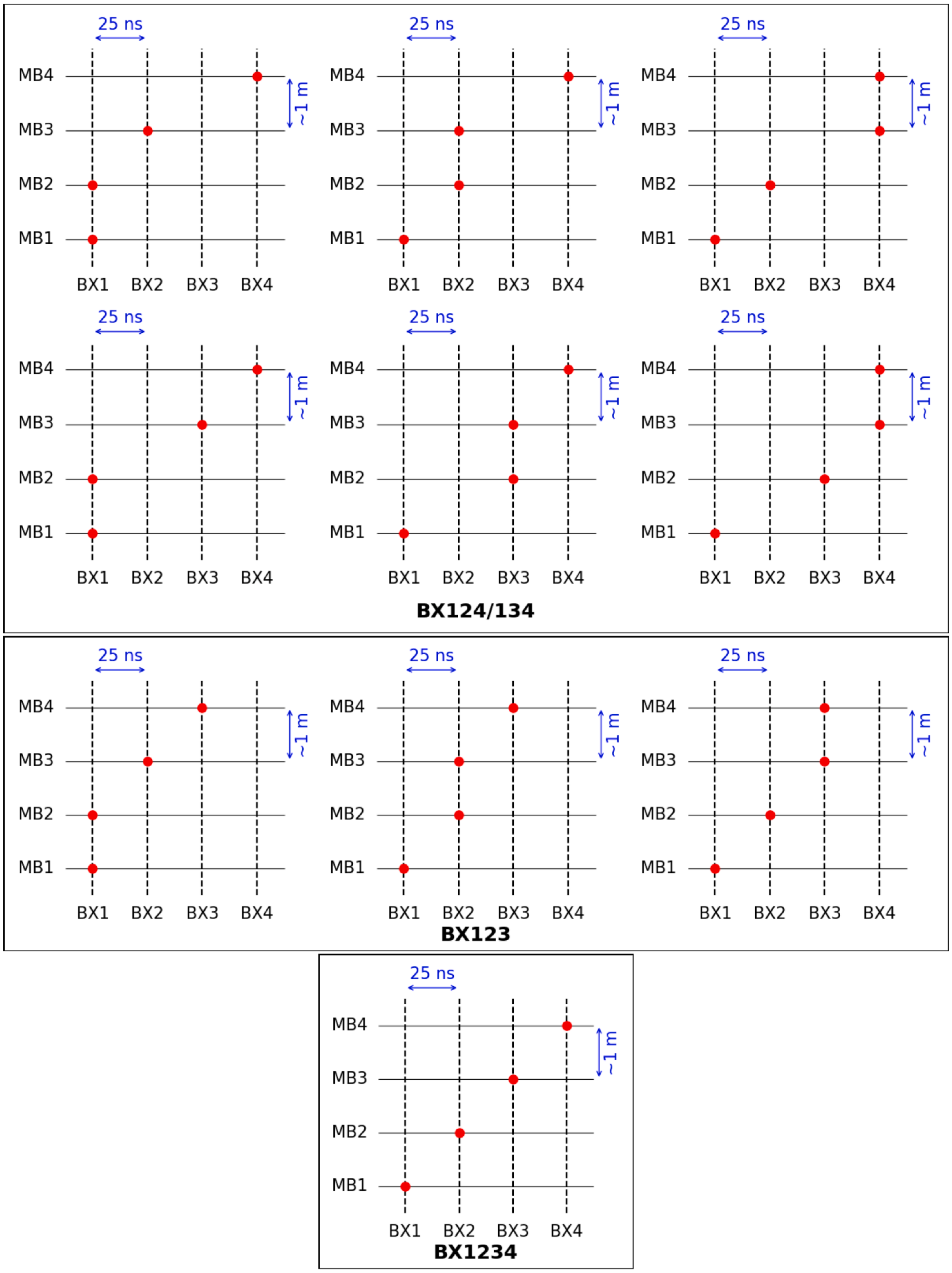
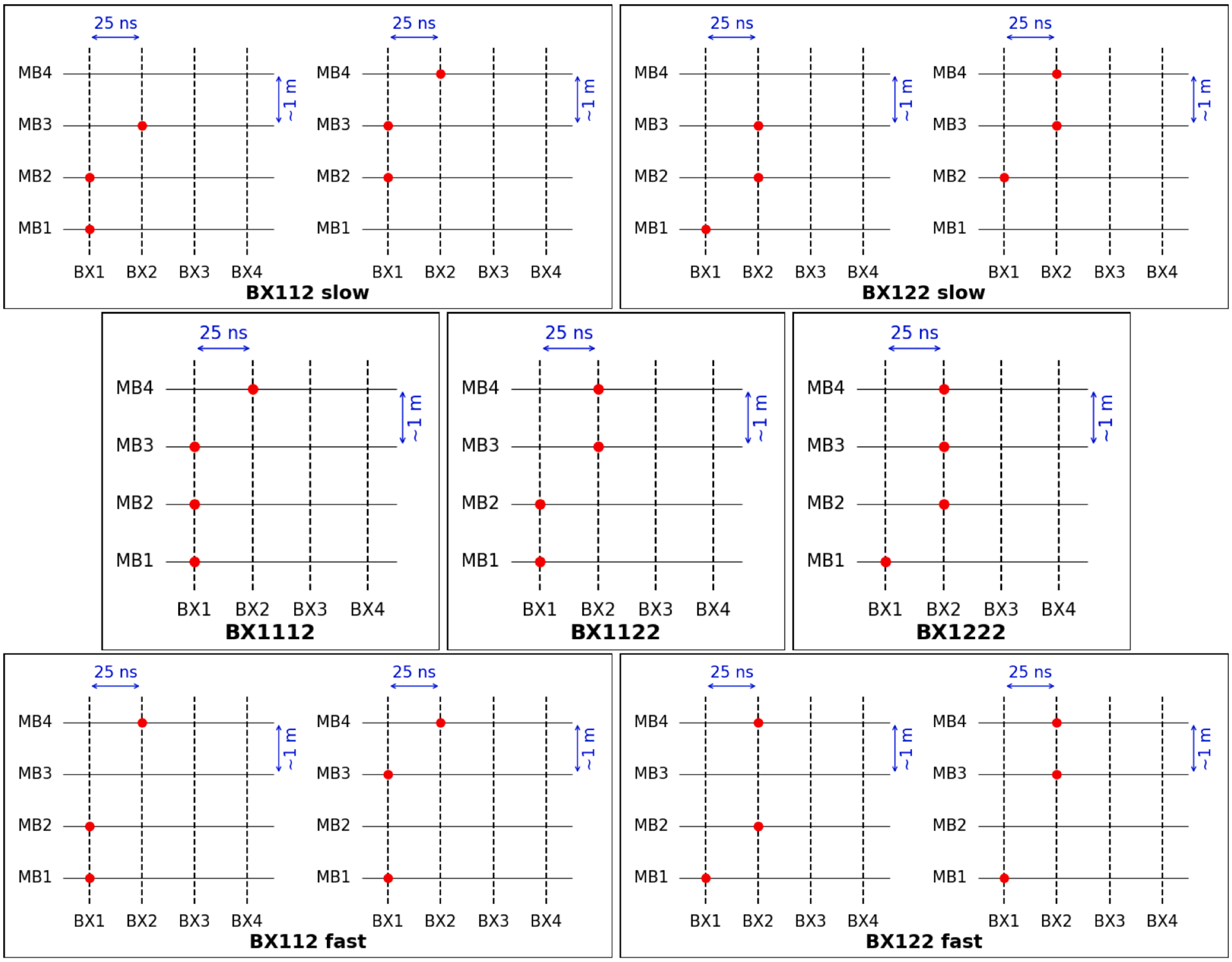


Fig. A.13. Schematic definition of the 4-stub categories with tracks across >2 BXs.


BX112 slow

BX122 slow

BX1112

BX1122

BX1222

BX112 fast

BX122 fast

Fig. A.14. Schematic definition of the categories with tracks across 2 BXs.

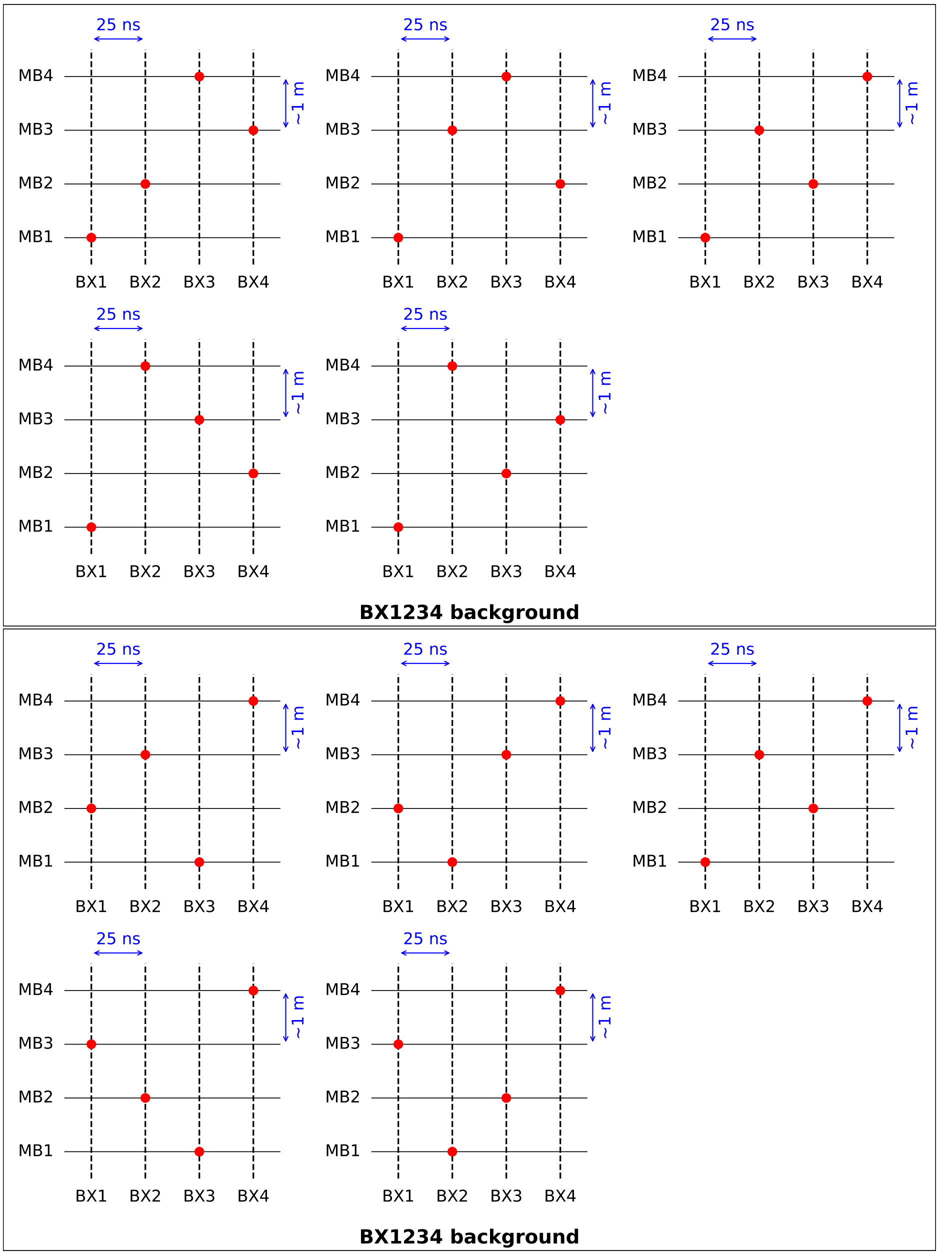


Fig. A.15. Schematic definition of the asynchronous orderings used to estimate the backgrounds in the BX1234 category. The upper (lower) half includes orderings with the first (last) stub in MB1 (MB4).

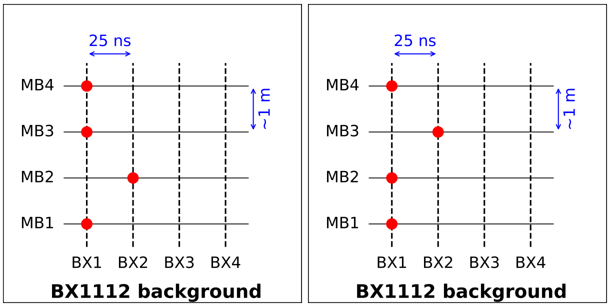


Fig. A.16. Schematic definition of the asynchronous orderings used to estimate the backgrounds in the BX1112 category. The left (right) diagram shows the ordering where the stub detected in a different BX than the other three stubs is in MB2 (MB3).

The CMS Collaboration

A. Hayrapetyan[1], V. Makarenko[1], A. Tumasyan[I,1], W. Adam[2], L. Benato[2], T. Bergauer[2], M. Dragicevic[2], P.S. Hussain[2], M. Jeitler[II,2], N. Krammer[2], A. Li[2], D. Liko[2], M. Matthewman[2], J. Schieck[II,2], R. Schöfbeck[II,2], M. Shooshtari[2], M. Sonawane[2], W. Waltenberger[2], C.-E. Wulz[II,2], T. Janssen[3], H. Kwon[3], D. Ocampo Henao[3], T. Van Laer[3], P. Van Mechelen[3], J. Bierkens[4], N. Breugelmans[4], J. D'Hondt[4], S. Dansana[4], A. De Moor[4], M. Delcourt[4], F. Heyen[4], Y. Hong[4], P. Kashko[4], S. Lowette[4], I. Makarenko[4], D. Müller[4], S. Tavernier[4], M. Tytgat[4,6], G.P. Van Onsem[4], S. Van Putte[4], D. Vannerom[4], B. Bilin[5], B. Clerbaux[5], A.K. Das[5], I. De Bruyn[5], G. De Lentdecker[5], H. Evard[5], L. Favart[5], P. Gianneios[5], A. Khalilzadeh[5], F.A. Khan[5], A. Malara[5], M.A. Shahzad[5], A. Sharma[5], L. Thomas[5], M. Vanden Bemden[5], C. Vander Velde[5], P. Vanlaer[5], F. Zhang[5], M. De Coen[6], D. Dobur[6], C. Giordano[6], G. Gokbulut[6], K. Kaspar[6], D. Kavtaradze[6], D. Marckx[6], K. Skovpen[6], A.M. Tomaru[6], N. Van Den Bossche[6], J. van der Linden[6], J. Vandenbroeck[6], H. Aarup Petersen[7], S. Bein[7], A. Benecke[7], A. Bethani[7], G. Bruno[7], A. Cappati[7], J. De Favereau De Jeneret[7], C. Delaere[7], F. Gameiro Casalinho[7], A. Giammanco[7], A.O. Guzel[7], V. Lemaitre[7], J. Lidrych[7], P. Malek[7], P. Mastrapasqua[7], S. Turkcapar[7], G.A. Alves[8], M. Barroso Ferreira Filho[8], E. Coelho[8], C. Hensel[8], D. Matos Figueiredo[8], T. Menezes De Oliveira[8], C. Mora Herrera[8], P. Rebello Teles[8], M. Soeiro[8], E.J. Tonelli Manganote[III,8], A. Vilela Pereira[8], W.L. Aldá Júnior[9], H. Brandao Malbouisson[9], W. Carvalho[9], J. Chinellato[VI,9], M. Costa Reis[9], E.M. Da Costa[9], G.G. Da Silveira[V,9], D. De Jesus Damiao[9], S. Fonseca De Souza[9], R. Gomes De Souza[9], S. S. Jesus[9], T. Laux Kuhn[V,9], M. Macedo[9], K. Mota Amarilo[9], L. Mundim[9], H. Nogima[9], J.P. Pinheiro[9], A. Santoro[9], A. Sznajder[9], M. Thiel[9], F. Torres Da Silva De Araujo[IV,9], C.A. Bernardes[V,10], L. Calligaris[10], F. Damas[10], T.R. Fernandez Perez Tomei[10], E.M. Gregores[10], B. Lopes Da Costa[10], I. Maietto Silverio[10], P.G. Mercadante[10], S.F. Novaes[10], Sandra S. Padula[10], V. Scheurer[10], A. Aleksandrov[11], G. Antchev[11], P. Danev[11], R. Hadjiiska[11], P. Iaydjiev[11], M. Shopova[11], G. Sultanov[11], A. Dimitrov[12], L. Litov[12], B. Pavlov[12], P. Petkov[12], A. Petrov[12], S. Keshri[13], D. Laroze[13], S. Thakur[13], W. Brooks[14], T. Cheng[15], T. Javaid[15], L. Wang[15], L. Yuan[15], Z. Hu[16], Z. Liang[16], J. Liu[16], X. Wang[16], H. Yang[16], G.M. Chen[IX,17], H.S. Chen[IX,17], M. Chen[IX,17], Y. Chen[17], Q. Hou[17], X. Hou[17], F. Iemmi[17], C.H. Jiang[17], H. Liao[17], G. Liu[17], Z.-A. Liu[VII,17], J.N. Song[VII,17], S. Song[17], J. Tao[17], C. Wang[IX,17], J. Wang[17], H. Zhang[17], J. Zhao[17], A. Agapitos[18], Y. Ban[18], A. Carvalho Antunes De Oliveira[18], S. Deng[18], B. Guo[18], Q. Guo[18], C. Jiang[18], A. Levin[18], C. Li[18], Q. Li[18], Y. Mao[18], S. Qian[18], S.J. Qian[18], X. Qin[18], C. Quaranta[18], X. Sun[18], D. Wang[18], J. Wang[18], M. Zhang[18], Y. Zhao[18], C. Zhou[18], S. Yang[19], Z. You[20], N. Lu[21], G. Bauer[XII,X,22], Z. Cui[X,22], B. Li[XI,22], H. Wang[22], K. Yi[22,206], J. Zhang[22], Y. Li[23], Y. Zhou[23,22], Z. Lin[24], C. Lu[24], M. Xiao[VIII,24], C. Avila[25], D.A. Barbosa Trujillo[25], A. Cabrera[25], C. Florez[25], J. Fraga[25], J.A. Reyes Vega[25], C. Rendón[26], M. Rodriguez[26], A.A. Ruales Barbosa[26], J.D. Ruiz Alvarez[26], N. Godinovic[27], D. Lelas[27], A. Sculac[27], M. Kovac[28], A. Petkovic[28], T. Sculac[28], P. Bargassa[29], V. Brigljevic[29], B.K. Chitroda[29], D. Ferencek[29], K. Jakovcic[29], A. Starodumov[29], T. Susa[29], A. Attikis[30], K. Christoforou[30], S. Konstantinou[30], C. Leonidou[30], L. Paizanos[30], F. Ptochos[30], P.A. Razis[30], H. Rykaczewski[30], H. Saka[30], A. Stepennov[30], M. Finger[LXX,31], M. Finger Jr.[31], E. Ayala[32], E. Carrera Jarrin[33], A.A. Abdelalim[XIV,XV,34], R. Aly[XIII,XIV,34], A. Hussein[35], H. Mohammed[35], K. Jaffel[36], M. Kadastik[36], T. Lange[36], C. Nielsen[36], J. Pata[36], M. Raidal[36], N. Seeba[36], L. Tani[36], E. Brücken[37], A. Milieva[37], K. Osterberg[37], M. Voutilainen[37], F. Garcia[38], P. Inkaew[38], K.T.S. Kallonen[38], R. Kumar Verma[38], T. Lampén[38], K. Lassila-Perini[38], B. Lehtela[38], S. Lehti[38], T. Lindén[38], N.R. Mancilla Xinto[38], M. Myllymäki[38], M.m. Rantanen[38], S. Saariokari[38], N.T. Toikka[38], J. Tuominiemi[38], N. Bin Norjoharuddeen[39], H. Kirschenmann[39], P. Luukka[39], H. Petrow[39], M. Besancon[40], F. Couderc[40], M. Dejardin[40], D. Denegri[40], P. Devouge[40], J.L. Faure[40], F. Ferri[40], P. Gaigne[40], S. Ganjour[40], P. Gras[40], F. Guilloux[40], G. Hamel de Monchenault[40], M. Kumar[40], V. Lohezic[40], Y. Maidannyk[40], J. Malcles[40], F. Orlandi[40], L. Portales[40], S. Ronchi[40], M.Ö. Sahin[40], P. Simkina[40], M. Titov[40], M. Tornago[40], R. Amella Ranz[41], F. Beaudette[41], G. Boldrini[41], P. Busson[41], C. Charlot[41], M. Chiusi[41], T.D. Cuisset[41], O. Davignon[41], A. De Wit[41], T. Debnath[41], I.T. Ehle[41], S. Ghosh[41], A. Gilbert[41], R. Granier de Cassagnac[41], L. Kalipoliti[41], M. Manoni[41], M. Nguyen[41], S. Obraztsov[41], C. Ochando[41], R. Salerno[41], J.B. Sauvan[41], Y. Sirois[41], G. Sokmen[41], Y. Song[41], L. Urda Gómez[41], A. Zabi[41], A. Zghiche[41], J.-L. Agram[XVI,42], J. Andrea[42], D. Bloch[42], J.-M. Brom[42], E.C. Chabert[42], C. Collard[42], G. Coulon[42], S. Falke[42], U. Goerlach[42], R. Haeberle[42], A.-C. Le Bihan[42], M. Meena[42], O. Poncet[42], G. Saha[42], A. Savoy-Navarro[42,221], P. Vaucelle[42], A. Di Florio[43], B. Orzari[43], D. Amram[44], S. Beauceron[44], B. Blancon[44], G. Boudoul[44], N. Chanon[44], D. Contardo[44], P. Depasse[44], H. El Mamouni[44], J. Fay[44], E. Fillaudeau[44], S. Gascon[44], M. Gouzevitch[44], C. Greenberg[44], G. Grenier[44], B. Ille[44], E. Jourd'Huy[44], M. Lethuillier[44], B. Massoteau[44], L. Mirabito[44], A. Purohit[44], M. Vander Donckt[44], C. Verollet[44], J. Xiao[44], I. Lomidze[45], T. Toriashvili[XVII,45], Z. Tsamalaidze[LXVII,45], V. Botta[46], S. Consuegra Rodríguez[46], L. Feld[46], K. Klein[46], M. Lipinski[46], P. Nattland[46], V. Oppenländer[46], A. Pauls[46], D. Pérez Adán[46], N. Röwert[46], C. Daumann[47], S. Diekmann[47], N. Eich[47], D. Eliseev[47], F. Engelke[47], J. Erdmann[47], M. Erdmann[47], B. Fischer[47], T. Hebbeker[47], K. Hoepfner[47], F. Ivone[47], A. Jung[47], N. Kumar[47], M.y. Lee[47], F. Mausolf[47], M. Merschmeyer[47], A. Meyer[47], A. Pozdnyakov[47], W. Redjeb[47], H. Reithler[47], U. Sarkar[47], V. Sarkisovi[47], A. Schmidt[47], C. Seth[47], A. Sharma[47], J.L. Spah[47], V. Vaulin[47], S. Zaleski[47], M.R. Beckers[48], C. Dziwok[48], G. Flügge[48], N. Hoeflich[48], T. Kress[48], A. Nowack[48], O. Pooth[48], A. Stahl[48], A. Zotz[48], A. Abel[49], M. Aldaya Martin[49], J. Alimena[49], S. Amoroso[49], Y. An[49], I. Andreev[49], J. Bach[49], S. Baxter[49], H. Becerril Gonzalez[49], O. Behnke[49], A. Belvedere[49], F. Blekman[49,50], K. Borras[49,47], A. Campbell[49], S. Chatterjee[49], L.X. Coll Saravia[49], G. Eckerlin[49], D. Eckstein[49], E. Gallo[49,50], A. Geiser[49], M. Guthoff[49], A. Hinzmann[49], L. Jeppe[49], M. Kasemann[49], C. Kleinwort[49], R. Kogler[49], M. Komm[49], D. Krücker[49], W. Lange[49], D. Leyva Pernia[49], K.-Y. Lin[49], K. Lipka[XX,49], W. Lohmann[XVIII,49], J. Malvaso[49], R. Mankel[49], I.-A. Melzer-Pellmann[49], M. Mendizabal Morentin[49], A.B. Meyer[49], G. Milella[49], K. Moral Figueroa[49], A. Mussgiller[49], L.P. Nair[49], J. Niedziela[49], A. Nürnberg[49], J. Park[49], E. Ranken[49], A. Raspereza[49], D. Rastorguev[49], L. Rygaard[49], M. Scham[XIX,49,47], S. Schnake[49,47], P. Schütze[49], C. Schwanenberger[49,50], D. Schwarz[49], D. Selivanova[49], K. Sharko[49], M. Shchedrolosiev[49], D. Stafford[49], M. Torkian[49], A. Ventura Barroso[49], R. Walsh[49], D. Wang[49], Q. Wang[49], K. Wichmann[49], L. Wiens[49,47], C. Wissing[49], Y. Yang[49], S. Zakharov[49], A. Zimermmane Castro Santos[49], A.R. Alves Andrade[50], M. Antonello[50], S. Bollweg[50], M. Bonanomi[50], L. Ebeling[50], K. El Morabit[50], Y. Fischer[50], M. Frahm[50], E. Garutti[50], A. Grohsjean[50], A.A. Guvenli[50], J. Haller[50], D. Hundhausen[50], G. Kasieczka[50], P. Keicher[50], R. Klanner[50], W. Korcari[50], T. Kramer[50], C.c. Kuo[50], F. Labe[50], J. Lange[50], A. Lobanov[50], J. Matthiesen[50], L. Moureaux[50], K. Nikolopoulos[50], A. Paasch[50], K.J. Pena Rodriguez[50], N. Prouvost[50], B. Raciti[50], M. Rieger[50], D. Savoiu[50], P. Schleper[50], M. Schröder[50], J. Schwandt[50], M. Sommerhalder[50], H. Stadie[50], G. Steinbrück[50], R. Ward[50], B. Wiederspan[50], M. Wolf[50], C. Yede[50], S. Brommer[51], A. Brusamolino[51], E. Butz[51], Y.M. Chen[51], T. Chwalek[51], A. Dierlamm[51], G.G. Dincer[51], D. Druzhkin[51], U. Elicabuk[51], N. Faltermann[51], M. Giffels[51], A. Gottmann[51], F. Hartmann[51,165], M. Horzela[51],

F. Hummer[51], U. Husemann[51], J. Kieseler[51], M. Klute[51], J. Knolle[51], R. Kunnilan Muhammed Rafeek[51], O. Lavoryk[51], J.M. Lawhorn[51], S. Maier[51], A.A. Monsch[51], M. Mormile[51], Th. Müller[51], E. Pfeffer[51], M. Presilla[51], G. Quast[51], K. Rabbertz[51], B. Regnery[51], R. Schmieder[51], N. Shadskiy[51], I. Shvetsov[51], H.J. Simonis[51], L. Sowa[51], L. Stockmeier[51], K. Tauqeer[51], M. Toms[51], B. Topko[51], N. Trevisani[51], C. Verstege[51], T. Voigtländer[51], R.F. Von Cube[51], J. Von Den Driesch[51], C. Winter[51], R. Wolf[51], W.D. Zeuner[51], X. Zuo[51], G. Anagnostou[52], G. Daskalakis[52], A. Kyriakis[52], G. Melachroinos[53], Z. Painesis[53], I. Paraskevas[53], N. Saoulidou[53], K. Theofilatos[53], E. Tziaferi[53], E. Tzovara[53], K. Vellidis[53], I. Zisopoulos[53], T. Chatzistavrou[54], G. Karapostoli[54], K. Kousouris[54], E. Siamarkou[54], G. Tsipolitis[54], I. Bestintzanos[55], I. Evangelou[55], C. Foudas[55], P. Katsoulis[55], P. Kokkas[55], P.G. Kosmoglou Kioseoglou[55], N. Manthos[55], I. Papadopoulos[55], J. Strologas[55], C. Hajdu[56], D. Horvath[XXII,56,59], Á. Kadlecsik[56], K. Márton[56], A.J. Rádl[56,57], F. Sikler[56], V. Veszpremi[56], M. Csanád[57], K. Farkas[57], A. Fehérkuti[57,56], M.M.A. Gadallah[XXI,57], M. León Coello[57], G. Pásztor[57], G.I. Veres[57], B. Ujvari[58], G. Zilizi[58], G. Bencze[59], S. Czellar[59], J. Molnar[59], Z. Szillasi[59], T. Csorgo[60,56], F. Nemes[60,56], T. Novak[60], I. Szanyi[60,208], S. Bahinipati[61], S. Nayak[61], R. Raturi[61], S. Bansal[62], S.B. Beri[62], V. Bhatnagar[62], S. Chauhan[62], N. Dhingra[XXV,62], A. Kaur[62], H. Kaur[62], M. Kaur[62], S. Kumar[62], T. Sheokand[62], J.B. Singh[62], A. Singla[62], A. Bhardwaj[63], A. Chhetri[63], B.C. Choudhary[63], A. Kumar[63], A. Kumar[63], M. Naimuddin[63], S. Phor[63], K. Ranjan[63], M.K. Saini[63], P. Palni[64], S. Acharya[65,65], B. Gomber[65], S. Mukherjee[66], S. Bhattacharya[67], S. Das Gupta[67], S. Dutta[67], S. Dutta[67], S. Sarkar[67], M.M. Ameen[68], P.K. Behera[68], S. Chatterjee[68], G. Dash[68], A. Dattamunsi[68], P. Jana[68], P. Kalbhor[68], S. Kamble[68], J.R. Komaragiri[XXIII,68], T. Mishra[68], P.R. Pujahari[68], A.K. Sikdar[68], R.K. Singh[68], P. Verma[68], S. Verma[68], A. Vijay[68], B.K. Sirasva[69], L. Bhatt[70], S. Dugad[70], G.B. Mohanty[70], M. Shelake[70], P. Suryadevara[70], A. Bala[71], S. Banerjee[71], S. Barman[XXVI,71], R.M. Chatterjee[71], M. Guchait[71], Sh. Jain[71], A. Jaiswal[71], S. Kumar[71], M. Maity[XXVI,71], G. Majumder[71], K. Mazumdar[71], S. Parolia[71], R. Saxena[71], A. Thachayath[71], D. Maity[XXIV,72], P. Mal[72], K. Naskar[XXIV,72], A. Nayak[XXIV,72], K. Pal[72], P. Sadangi[72], S.K. Swain[72], S. Varghese[XXIV,72], D. Vats[XXIV,72], S. Dube[73], P. Hazarika[73], B. Kansal[73], A. Laha[73], R. Sharma[73], S. Sharma[73], K.Y. Vaish[73], S. Ghosh[74], H. Bakhshiansohi[75,49], A. Jafari[75,75], V. Sedighzadeh Dalavi[75], M. Zeinali[XXIX,75], S. Bashiri[76], S. Chenarani[XXVIII,76], S.M. Etesami[76], Y. Hosseini[76], M. Khakzad[76], E. Khazaie[76], M. Mohammadi Najafabadi[76], S. Tizchang[XXVII,76], M. Felcini[77], M. Grunewald[77], M. Abbrescia[79,80], M. Barbieri[79,80], M. Buonsante[79,80], A. Colaleo[79,80], D. Creanza[79,81], N. De Filippis[79,81], M. De Palma[79,80], W. Elmetenawee[XIV,79,80], N. Ferrara[79,81], L. Fiore[79], L. Generoso[79,80], L. Longo[79], M. Louka[79,80], G. Maggi[79,81], M. Maggi[79], I. Margjeka[79], V. Mastrapasqua[79,80], S. My[79,80], F. Nenna[79,80], S. Nuzzo[79,80], A. Pellecchia[79,80], A. Pompili[79,80], G. Pugliese[79,81], R. Radogna[79,80], D. Ramos[79], A. Ranieri[79], L. Silvestris[79], F.M. Simone[79,81], Ü. Sözbilir[79], A. Stamerra[79,80], D. Troiano[79,80], R. Venditti[79,80], P. Verwilligen[79], A. Zaza[79,80], G. Abbiendi[83], C. Battilana[83,84], D. Bonacorsi[83,84], P. Capiluppi[83,84], M. Cuffiani[83,84], G.M. Dallavalle[83], T. Diotalevi[83,84], F. Fabbri[83], A. Fanfani[83,84], R. Farinelli[83], D. Fasanella[83], P. Giacomelli[83], C. Grandi[83], L. Guiducci[83,84], M. Lorusso[83,84], L. Lunerti[83], S. Marcellini[83], G. Masetti[83], F.L. Navarria[83,84], G. Paggi[83,84], A. Perrotta[83], A.M. Rossi[83,84], S. Rossi Tisbeni[83,84], T. Rovelli[83,84], G.P. Siroli[83,84], S. Costa[XXX,86,87], A. Di Mattia[86], A. Lapertosa[86], R. Potenza[86,87], A. Tricomi[XXX,86,87], J. Altork[89,90], P. Assiouras[89], G. Barbagli[89], G. Bardelli[89], M. Bartolini[89,90], A. Calandri[89,90], B. Camaiani[89,90], A. Cassese[89], R. Ceccarelli[89], V. Ciulli[89,90], C. Civinini[89], R. D'Alessandro[89,90], L. Damenti[89,90], E. Focardi[89,90], T. Kello[89], G. Latino[89,90], P. Lenzi[89,90], M. Lizzo[89], M. Meschini[89], S. Paoletti[89], A. Papanastassiou[89,90], G. Sguazzoni[89], L. Viliani[89], L. Benussi[91], S. Bianco[91], S. Meola[XXXV,91], D. Piccolo[91], M. Alves Gallo Pereira[93], F. Ferro[93], E. Robutti[93], S. Tosi[93,94], A. Benaglia[96], F. Brivio[96], V. Camagni[96,97], F. Cetorelli[96,97], F. De Guio[96,97], M.E. Dinardo[96,97], P. Dini[96], S. Gennai[96], R. Gerosa[96,97], A. Ghezzi[96,97], P. Govoni[96,97], L. Guzzi[96], M.R. Kim[96], G. Lavizzari[96,97], M.T. Lucchini[96,97], M. Malberti[96], S. Malvezzi[96], A. Massironi[96], D. Menasce[96], L. Moroni[96], M. Paganoni[96,97], S. Palluotto[96,97], D. Pedrini[96], A. Perego[96,97], G. Pizzati[96,97], T. Tabarelli de Fatis[96,97], S. Buontempo[99], C. Di Fraia[99,100], F. Fabozzi[99,101], L. Favilla[99,102], A.O.M. Iorio[99,100], L. Lista[XXXIV,99,100], P. Paolucci[99,165], B. Rossi[99], P. Azzi[104], N. Bacchetta[104,201], D. Bisello[104,105], L. Borella[104], P. Bortignon[104,106], G. Bortolato[104,105], A.C.M. Bulla[104,106], R. Carlin[104,105], P. Checchia[104], T. Dorigo[XXXIII,104], U. Gasparini[104,105], S. Giorgetti[104], F. Gonella[104], E. Lusiani[104], M. Margoni[104,105], A.T. Meneguzzo[104,105], J. Pazzini[104,105], F. Primavera[104,105], P. Ronchese[104,105], R. Rossin[104,105], M. Tosi[104,105], A. Triossi[104,105], S. Ventura[104], M. Zanetti[104,105], P. Zotto[104,105], A. Zucchetta[104,105], G. Zumerle[104,105], A. Braghieri[108], M. Brunoldi[108,109], S. Calzaferri[108,109], P. Montagna[108,109], M. Pelliccioni[108,109], V. Re[108], C. Riccardi[108,109], P. Salvini[108], I. Vai[108,109], P. Vitulo[108,109], S. Ajmal[111,112], M.E. Ascioti[111,112], G.M. Bilei[LXX,111], C. Carrivale[111,112], D. Ciangottini[111,112], L. Della Penna[111,112], L. Fanò[111,112], V. Mariani[111,112], M. Menichelli[111], F. Moscatelli[XXXII,111], A. Rossi[111,112], A. Santocchia[111,112], D. Spiga[111], T. Tedeschi[111,112], C. Aimè[114,115], C.A. Alexe[114,116], P. Asenov[114,115], P. Azzurri[114], G. Bagliesi[114], L. Bianchini[114,115], T. Boccali[114], E. Bossini[114], D. Bruschini[114,116], R. Castaldi[114], F. Cattafesta[114,116], M.A. Ciocci[114,117], M. Cipriani[114,115], R. Dell'Orso[114], S. Donato[114,115], R. Forti[114,115], A. Giassi[114], F. Ligabue[114,116], A.C. Marini[114,115], A. Messineo[114,115], S. Mishra[114], V.K. Muraleedharan Nair Bindhu[114,115], S. Nandan[114], F. Palla[114], M. Riggirello[114,116], A. Rizzi[114,115], G. Rolandi[114,116], S. Roy Chowdhury[XXXI,114], T. Sarkar[114], A. Scribano[114], P. Solanki[114,115], P. Spagnolo[114], F. Tenchini[114,115], R. Tenchini[114], G. Tonelli[114,115], N. Turini[114,117], F. Vaselli[114,116], A. Venturi[114], P.G. Verdini[114], P. Akrap[119,120], C. Basile[119,120], S.C. Behera[119], F. Cavallari[119], L. Cunqueiro Mendez[119,120], F. De Riggi[119,120], D. Del Re[119,120], M. Del Vecchio[119,120], E. Di Marco[119], M. Diemoz[119], F. Errico[119], L. Frosina[119,120], R. Gargiulo[119,120], B. Harikrishnan[119,120], F. Lombardi[119,120], E. Longo[119,120], L. Martikainen[119,120], J. Mijuskovic[119,120], G. Organtini[119,120], N. Palmeri[119,120], R. Paramatti[119,120], T. Pauletto[119,120], S. Rahatlou[119,120], C. Rovelli[119], F. Santanastasio[119,120], L. Soffi[119], V. Vladimirov[119,120], N. Amapane[122,123], R. Arcidiacono[122,124], S. Argiro[122,123], M. Arneodo[LXX,122,124], N. Bartosik[122,124], R. Bellan[122,123], A. Bellora[122,123], C. Biino[122], C. Borca[122,123], N. Cartiglia[122], M. Costa[122,123], R. Covarelli[122,123], N. Demaria[122], L. Finco[122], M. Grippo[122,123], B. Kiani[122,123], L. Lanteri[122,123], F. Legger[122], F. Luongo[122,123], C. Mariotti[122], S. Maselli[122], A. Mecca[122,123], L. Menzio[122,123], P. Meridiani[122], E. Migliore[122,123], M. Monteno[122], M.M. Obertino[122,123], G. Ortona[122], L. Pacher[122,123], N. Pastrone[122], M. Ruspa[122,124], F. Siviero[122,123], V. Sola[122,123], A. Solano[122,123], A. Staiano[122], C. Tarricone[122,123], D. Trocino[122], G. Umoret[122,123], E. Vlasov[122,123], R. White[122,123], J. Babbar[XXXI,126,127], S. Belforte[126], V. Candelise[126,127], M. Casarsa[126], F. Cossutti[126], K. De Leo[126], G. Della Ricca[126,127], R. Delli Gatti[126,127], S. Dogra[128], J. Hong[128], J. Kim[128], T. Kim[128], D. Lee[128], H. Lee[128], J. Lee[128], S.W. Lee[128], C.S. Moon[128], Y.D. Oh[128], S. Sekmen[128], B. Tae[128], Y.C. Yang[128], M.S. Kim[129], G. Bak[130], P. Gwak[130], H. Kim[130], D.H. Moon[130], J. Seo[130], E. Asilar[131], F. Carnevali[131], J. Choi[131,44], T.J. Kim[131], Y. Ryou[131], J. Song[131], S. Ha[132], S. Han[132], B. Hong[132], J. Kim[132], K. Lee[132], K.S. Lee[132], S. Lee[132], J. Yoo[132], J. Goh[133], J. Shin[133], S. Yang[133], Y. Kang[134], H. S. Kim[134], Y. Kim[134], B. Ko[134], S.

Lee[134], J. Almond[135], J.H. Bhyun[135], J. Choi[135], J. Choi[135], W. Jun[135], H. Kim[135], J. Kim[135], T. Kim[135], Y. Kim[135], Y.W. Kim[135], S. Ko[135], H. Lee[135], J. Lee[135], J. Lee[135], B.H. Oh[135], J. Shin[135], U.K. Yang[135], I. Yoon[135], W. Jang[136], D. Kim[136], S. Kim[136], J.S.H. Lee[136], Y. Lee[136], I.C. Park[136], Y. Roh[136], I.J. Watson[136], G. Cho[137], K. Hwang[137], B. Kim[137], S. Kim[137], K. Lee[137], H.D. Yoo[137], Y. Lee[138], I. Yu[138], T. Beyrouthy[139], Y. Gharbia[139], F. Alazemi[140], K. Dreimanis[141], O.M. Eberlins[141], A. Gaile[141], C. Munoz Diaz[141], D. Osite[141], G. Pikurs[141], R. Plese[141], A. Potrebko[141], M. Seidel[141], D. Sidiropoulos Kontos[141], N.R. Strautnieks[142], M. Ambrozas[143], A. Juodagalvis[143], S. Nargelas[143], A. Rinkevicius[143], G. Tamulaitis[143], I. Yusuff[XXXVI,144], Z. Zolkapli[144], J.F. Benitez[145], A. Castaneda Hernandez[145], A. Cota Rodriguez[145], L.E. Cuevas Picos[145], H.A. Encinas Acosta[145], L.G. Gallegos Maríñez[145], J.A. Murillo Quijada[145], L. Valencia Palomo[145], G. Ayala[146], H. Castilla-Valdez[146], H. Crotte Ledesma[146], R. Lopez-Fernandez[146], J. Mejia Guisao[146], R. Reyes-Almanza[146], A. Sánchez Hernández[146], C. Oropeza Barrera[147], D.L. Ramirez Guadarrama[147], M. Ramírez García[147], I. Bautista[148], F.E. Neri Huerta[148], I. Pedraza[148], H.A. Salazar Ibarguen[148], C. Uribe Estrada[148], I. Bubanja[149], N. Raicevic[149], P.H. Butler[150], A. Ahmad[151], M.I. Asghar[151], A. Awais[151], M.I.M. Awan[151], W.A. Khan[151], V. Avati[152], L. Forthomme[152], L. Grzanka[152], M. Malawski[152], K. Piotrzkowski[152], M. Bluj[153], M. Górski[153], M. Kazana[153], M. Szleper[153], P. Zalewski[153], K. Bunkowski[154], K. Doroba[154], A. Kalinowski[154], M. Konecki[154], J. Krolikowski[154], A. Muhammad[154], P. Fokow[155], K. Pozniak[155], W. Zabolotny[155], M. Araujo[156], D. Bastos[156], C. Beirão Da Cruz E Silva[156], A. Boletti[156], M. Bozzo[156], T. Camporesi[156], G. Da Molin[156], M. Gallinaro[156], J. Hollar[156], N. Leonardo[156], G.B. Marozzo[156], A. Petrilli[156], M. Pisano[156], J. Seixas[156], J. Varela[156], J.W. Wulff[156], P. Adzic[157], L. Markovic[157], P. Milenovic[157], V. Milosevic[157], D. Devetak[158], M. Dordevic[158], J. Milosevic[158], L. Nadderd[158], V. Rekovic[158], M. Stojanovic[158], M. Alcalde Martinez[159], J. Alcaraz Maestre[159], Cristina F. Bedoya[159], J.A. Brochero Cifuentes[159], Oliver M. Carretero[159], M. Cepeda[159], M. Cerrada[159], N. Colino[159], B. De La Cruz[159], A. Delgado Peris[159], A. Escalante Del Valle[159], D. Fernández Del Val[159], J.P. Fernández Ramos[159], J. Flix[159], M.C. Fouz[159], M. Gonzalez Hernandez[159], O. Gonzalez Lopez[159], S. Goy Lopez[159], J.M. Hernandez[159], M.I. Josa[159], J. Llorente Merino[159], C. Martin Perez[159], E. Martin Viscasillas[159], D. Moran[159], C. M. Morcillo Perez[159], Á. Navarro Tobar[159], R. Paz Herrera[159], A. Pérez-Calero Yzquierdo[159], J. Puerta Pelayo[159], I. Redondo[159], J. Vazquez Escobar[159], J.F. de Trocóniz[160], B. Alvarez Gonzalez[161], J. Ayllon Torresano[161], A. Cardini[161], J. Cuevas[161], J. Del Riego Badas[161], D. Estrada Acevedo[161], J. Fernandez Menendez[161], S. Folgueras[161], I. Gonzalez Caballero[161], P. Leguina[161], M. Obeso Menendez[161], E. Palencia Cortezon[161], J. Prado Pico[161], A. Soto Rodríguez[161], P. Vischia[161], S. Blanco Fernández[162], I.J. Cabrillo[162], A. Calderon[162], J. Duarte Campderros[162], M. Fernandez[162], G. Gomez[162], C. Lasaosa García[162], R. Lopez Ruiz[162], C. Martinez Rivero[162], P. Martinez Ruiz del Arbol[162], F. Matorras[162], P. Matorras Cuevas[162], E. Navarrete Ramos[162], J. Piedra Gomez[162], C. Quintana San Emeterio[162], L. Scodellaro[162], I. Vila[162], R. Vilar Cortabitarte[162], J.M. Vizan Garcia[162], B. Kailasapathy[XXXVIII,163], D.D.C. Wickramarathna[163], W.G.D. Dharmaratna[XXXVII,164], K. Liyanage[164], N. Perera[164], D. Abbaneo[165], C. Amendola[165], R. Ardino[165], E. Auffray[165], J. Baechler[165], D. Barney[165], J. Bendavid[165], M. Bianco[165], A. Bocci[165], L. Borgonovi[165], C. Botta[165], A. Bragagnolo[165], C.E. Brown[165], C. Caillol[165], G. Cerminara[165], P. Connor[165], K. Cormier[165], D. d'Enterria[165], A. Dabrowski[165], A. David[165], A. De Roeck[165], M.M. Defranchis[165], M. Deile[165], M. Dobson[165], P.J. Fernández Manteca[165], B.A. Fontana Santos Alves[165], E. Fontanesi[165], W. Funk[165], A. Gaddi[165], S. Giani[165], D. Gigi[165], K. Gill[165], F. Glege[165], M. Glowacki[165], A. Gruber[165], J. Hegeman[165], J.K. Heikkilä[165], R. Hofsaess[165], B. Huber[165], T. James[165], P. Janot[165], O. Kaluzinska[165], O. Karacheban[XVIII,165], G. Karathanasis[165], S. Laurila[165], P. Lecoq[165], E. Leutgeb[165], C. Lourenço[165], A.-M. Lyon[165], M. Magherini[165], L. Malgeri[165], M. Mannelli[165], A. Mehta[165], F. Meijers[165], J.A. Merlin[165], S. Mersi[165], E. Meschi[165], M. Migliorini[165], F. Monti[165], F. Moortgat[165], M. Mulders[165], M. Musich[165], I. Neutelings[165], S. Orfanelli[165], F. Pantaleo[165], M. Pari[165], G. Petrucciani[165], A. Pfeiffer[165], M. Pierini[165], M. Pitt[165], H. Qu[165], D. Rabady[165], A. Reimers[165], B. Ribeiro Lopes[165], F. Riti[165], P. Rosado[165], M. Rovere[165], H. Sakulin[165], R. Salvatico[165], S. Sanchez Cruz[165], S. Scarfi[165], M. Selvaggi[165], K. Shchelina[165], P. Silva[165], P. Sphicas[165,53], A.G. Stahl Leiton[165], A. Steen[165], S. Summers[165], D. Treille[165], P. Tropea[165], E. Vernazza[165], J. Wanczyk[XXXIX,165], S. Wuchterl[165], M. Zarucki[165], P. Zehetner[165], P. Zejdl[165], G. Zevi Della Porta[165], L. Caminada[166,168], W. Erdmann[166], R. Horisberger[166], Q. Ingram[166], H.C. Kaestli[166], D. Kotlinski[166], C. Lange[166], U. Langenegger[166], A. Nigamova[166], L. Noehte[166,168], T. Rohe[166], A. Samalan[166], T.K. Aarrestad[167], M. Backhaus[167], T. Bevilacqua[167,168], G. Bonomelli[167], C. Cazzaniga[167], K. Datta[167], P. De Bryas Dexmiers D'Archiacchiac[XXXIX,167], A. De Cosa[167], G. Dissertori[167], M. Dittmar[167], M. Donegà[167], F. Glessgen[167], C. Grab[167], N. Härringer[167], T.G. Harte[167], W. Lustermann[167], M. Malucchi[167], R.A. Manzoni[167], L. Marchese[167], A. Mascellani[XXXIX,167], F. Nessi-Tedaldi[167], F. Pauss[167], B. Ristic[167], R. Seidita[167], J. Steggemann[XXXIX,167], A. Tarabini[167], D. Valsecchi[167], R. Wallny[167], C. Amsler[XL,168], P. Bärtschi[168], F. Bilandzija[168], M.F. Canelli[168], G. Celotto[168], V. Guglielmi[168], A. Jofrehei[168], B. Kilminster[168], T.H. Kwok[168], S. Leontsinis[168], V. Lukashenko[168], A. Macchiolo[168], F. Meng[168], M. Missiroli[168], J. Motta[168], P. Robmann[168], E. Shokr[168], F. Stäger[168], R. Tramontano[168], P. Viscone[168], D. Bhowmik[169], C.M. Kuo[169], P.K. Rout[169], S. Taj[169], P.C. Tiwari[XXIII,169], L. Ceard[170], K.F. Chen[170], Z.g. Chen[170], A. De Iorio[170], W.-S. Hou[170], T.h. Hsu[170], Y.w. Kao[170], S. Karmakar[170], G. Kole[170], Y.y. Li[170], R.-S. Lu[170], E. Paganis[170], X.f. Su[170], J. Thomas-Wilsker[170], L.s. Tsai[170], D. Tsionou[170], H.y. Wu[170], E. Yazgan[170], C. Asawatangtrakuldee[171], N. Srimanobhas[171], Y. Maghrbi[172], D. Agyel[173], F. Dolek[173], I. Dumanoglu[LI,173], Y. Guler[XLIX,173], E. Gurpinar Guler[XLIX,173], C. Isik[173], O. Kara[LIII,173], A. Kayis Topaksu[173], Y. Komurcu[173], G. Onengut[173], K. Ozdemir[XLVII,173], B. Tali[XLI,173], U.G. Tok[173], E. Uslan[173], I.S. Zorbakir[173], S. Sen[174], M. Yalvac[LIV,175], B. Akgun[176], I.O. Atakisi[XLV,176], E. Gülmez[176], M. Kaya[L,176], O. Kaya[XLVI,176], M.A. Sarkisla[XLII,176], S. Tekten[XLVIII,176], D. Boncukcu[177], A. Cakir[177], K. Cankocak[LI,LII,177], B. Hacisahinoglu[178], I. Hos[XLIII,178], B. Kaynak[178], S. Ozkorucuklu[178], O. Potok[178], H. Sert[178], C. Simsek[178], C. Zorbilmez[178], S. Cerci[179], C. Dozen[XLIV,179], B. Isildak[179], E. Simsek[179], D. Sunar Cerci[179], T. Yetkin[XLIV,179], A. Boyaryntsev[180], O. Dadazhanova[180], B. Grynyov[180], L. Levchuk[181], J.J. Brooke[182], A. Bundock[182], F. Bury[182], E. Clement[182], D. Cussans[182], D. Dharmender[182], H. Flacher[182], J. Goldstein[182], H.F. Heath[182], M.-L. Holmberg[182], L. Kreczko[182], S. Paramesvaran[182], L. Robertshaw[182], M.S. Sanjrani[182,49], J. Segal[182], V.J. Smith[182], A.H. Ball[183], K.W. Bell[183], A. Belyaev[LXV,183], C. Brew[183], R.M. Brown[183], D.J.A. Cockerill[183], A. Elliot[183], K.V. Ellis[183], J. Gajownik[183], K. Harder[183], S. Harper[183], J. Linacre[183], K. Manolopoulos[183], M. Moallemi[183], D.M. Newbold[183], E. Olaiya[183], D. Petyt[183], T. Reis[183], A.R. Sahasransu[183], G. Salvi[183], T. Schuh[183], C.H. Shepherd-Themistocleous[183], I.R. Tomalin[183], K.C. Whalen[183], T. Williams[183], I. Andreou[184], R. Bainbridge[184], P. Bloch[184], O. Buchmuller[184], C.A. Carrillo Montoya[184], D. Colling[184], I. Das[184], P. Dauncey[184], G. Davies[184], M. Della Negra[184], S. Fayer[184], G. Fedi[184], G. Hall[184], H.R. Hoorani[184], A. Howard[184], G. Iles[184], C.R. Knight[184], P. Krueper[184], J. Langford[184], K.H. Law[184], J. León Holgado[184], L. Lyons[184], A.-M. Magnan[184], B. Maier[184], S. Mallios[184], A. Mastronikolis[184], M.

Mieskolainen[184], J. Nash[LXIV,184], M. Pesaresi[184], P.B. Pradeep[184], B.C. Radburn-Smith[184], A. Richards[184], A. Rose[184], L. Russell[184], K. Savva[184], R. Schmitz[184], C. Seez[184], R. Shukla[184], A. Tapper[184], K. Uchida[184], G.P. Uttley[184], T. Virdee[184,165], M. Vojinovic[184], N. Wardle[184], D. Winterbottom[184], J.E. Cole[185], A. Khan[185], P. Kyberd[185], I.D. Reid[185], S. Abdullin[186], A. Brinkerhoff[186], E. Collins[186], M.R. Darwish[186], J. Dittmann[186], K. Hatakeyama[186], V. Hegde[186], J. Hiltbrand[186], B. McMaster[186], J. Samudio[186], S. Sawant[186], C. Sutantawibul[186], J. Wilson[186], J.M. Hogan[187], R. Bartek[188], A. Dominguez[188], S. Raj[188], B. Sahu[188], A.E. Simsek[188], S.S. Yu[188], B. Bam[189], A. Buchot Perraguin[189], S. Campbell[189], R. Chudasama[189], S.I. Cooper[189], C. Crovella[189], G. Fidalgo[189], S.V. Gleyzer[189], A. Khukhunaishvili[189], K. Matchev[189], E. Pearson[189], P. Rumerio[LXIII,189], E. Usai[189], R. Yi[189], S. Cholak[190], G. De Castro[190], Z. Demiragli[190], C. Erice[190], C. Fangmeier[190], C. Fernandez Madrazo[190], J. Fulcher[190], F. Golf[190], S. Jeon[190], J. O'Cain[190], I. Reed[190], J. Rohlf[190], K. Salyer[190], D. Sperka[190], D. Spitzbart[190], I. Suarez[190], A. Tsatsos[190], E. Wurtz[190], A.G. Zecchinelli[190], G. Barone[191], G. Benelli[191], D. Cutts[191], S. Ellis[191], L. Gouskos[191], M. Hadley[191], U. Heintz[191], K.W. Ho[191], T. Kwon[191], L. Lambrecht[191], G. Landsberg[191], K.T. Lau[191], J. Luo[191], S. Mondal[191], J. Roloff[191], T. Russell[191], S. Sagir[LIX,191], X. Shen[191], M. Stamenkovic[191], N. Venkatasubramanian[191], S. Abbott[192], S. Baradia[192], B. Barton[192], R. Breedon[192], H. Cai[192], M. Calderon De La Barca Sanchez[192], E. Cannaert[192], M. Chertok[192], M. Citron[192], J. Conway[192], P.T. Cox[192], F. Eble[192], R. Erbacher[192], O. Kukral[192], G. Mocellin[192], S. Ostrom[192], I. Salazar Segovia[192], J.S. Tafoya Vargas[192], W. Wei[192], S. Yoo[192], K. Adamidis[193], M. Bachtis[193], D. Campos[193], R. Cousins[193], S. Crossley[193], G. Flores Avila[193], J. Hauser[193], M. Ignatenko[193], M.A. Iqbal[193], T. Lam[193], Y.f. Lo[193], E. Manca[193], A. Nunez Del Prado[193], D. Saltzberg[193], V. Valuev[193], R. Clare[194], J.W. Gary[194], G. Hanson[194], A. Aportela[195], A. Arora[195], J.G. Branson[195], S. Cittolin[195], S. Cooperstein[195], B. D'Anzi[195], D. Diaz[195], J. Duarte[195], L. Giannini[195], Y. Gu[195], J. Guiang[195], V. Krutelyov[195], R. Lee[195], J. Letts[195], H. Li[195], M. Masciovecchio[195], F. Mokhtar[195], S. Mukherjee[195], M. Pieri[195], D. Primosch[195], M. Quinnan[195], V. Sharma[195], M. Tadel[195], E. Vourliotis[195], F. Würthwein[195], A. Yagil[195], Z. Zhao[195], A. Barzdukas[196], L. Brennan[196], C. Campagnari[196], S. Carron Montero[LVIII,196], K. Downham[196], C. Grieco[196], M.M. Hussain[196], J. Incandela[196], M.W.K. Lai[196], A.J. Li[196], P. Masterson[196], J. Richman[196], S.N. Santpur[196], D. Stuart[196], T.Á. Vámi[196], X. Yan[196], D. Zhang[196], A. Albert[197], S. Bhattacharya[197], A. Bornheim[197], O. Cerri[197], R. Kansal[197], H.B. Newman[197], G. Reales Gutiérrez[197], T. Sievert[197], M. Spiropulu[197], J.R. Vlimant[197], R.A. Wynne[197], S. Xie[197], J. Alison[198], S. An[198], M. Cremonesi[198], V. Dutta[198], E.Y. Ertorer[198], T. Ferguson[198], T.A. Gómez Espinosa[198], A. Harilal[198], A. Kallil Tharayil[198], M. Kanemura[198], C. Liu[198], M. Marchegiani[198], P. Meiring[198], S. Murthy[198], P. Palit[198], K. Park[198], M. Paulini[198], A. Roberts[198], A. Sanchez[198], W. Terrill[198], J.P. Cumalat[199], W.T. Ford[199], A. Hart[199], S. Kwan[199], J. Pearkes[199], C. Savard[199], N. Schonbeck[199], K. Stenson[199], K.A. Ulmer[199], S.R. Wagner[199], N. Zipper[199], D. Zuolo[199], J. Alexander[200], X. Chen[200], J. Dickinson[200], A. Duquette[200], J. Fan[200], X. Fan[200], J. Grassi[200], S. Hogan[200], P. Kotamnives[200], J. Monroy[200], G. Niendorf[200], M. Oshiro[200], J.R. Patterson[200], A. Ryd[200], J. Thom[200], P. Wittich[200], R. Zou[200], L. Zygala[200], M. Albrow[201], M. Alyari[201], O. Amram[201], G. Apollinari[201], A. Apresyan[201], L.A.T. Bauerdick[201], D. Berry[201], J. Berryhill[201], P.C. Bhat[201], K. Burkett[201], J.N. Butler[201], A. Canepa[201], G.B. Cerati[201], H.W.K. Cheung[201], F. Chlebana[201], C. Cosby[201], G. Cummings[201], I. Dutta[201], V.D. Elvira[201], J. Freeman[201], A. Gandrakota[201], Z. Gecse[201], L. Gray[201], D. Green[201], A. Grummer[201], S. Grünendahl[201], D. Guerrero[201], O. Gutsche[201], R.M. Harris[201], J. Hirschauer[201], V. Innocente[201], B. Jayatilaka[201], S. Jindariani[201], M. Johnson[201], U. Joshi[201], B. Klima[201], S. Lammel[201], C. Lee[201], D. Lincoln[201], R. Lipton[201], T. Liu[201], K. Maeshima[201], D. Mason[201], P. McBride[201], P. Merkel[201], S. Mrenna[201], S. Nahn[201], J. Ngadiuba[201], D. Noonan[201], S. Norberg[201], V. Papadimitriou[201], N. Pastika[201], K. Pedro[201], C. Pena[201,197], C.E. Perez Lara[201], V. Perovic[201], F. Ravera[201], A. Reinsvold Hall[LV,201], L. Ristori[201], M. Safdari[201], E. Sexton-Kennedy[201], E. Smith[201], N. Smith[201], A. Soha[201], L. Spiegel[201], S. Stoynev[201], J. Strait[201], L. Taylor[201], S. Tkaczyk[201], N.V. Tran[201], L. Uplegger[201], E.W. Vaandering[201], C. Wang[201], I. Zoi[201], C. Aruta[202], P. Avery[202], D. Bourilkov[202], P. Chang[202], V. Cherepanov[202], R.D. Field[202], C. Huh[202], E. Koenig[202], M. Kolosova[202], J. Konigsberg[202], A. Korytov[202], G. Mitselmakher[202], K. Mohrman[202], A. Muthirakalayil Madhu[202], N. Rawal[202], S. Rosenzweig[202], V. Sulimov[202], Y. Takahashi[202], J. Wang[202], T. Adams[203], A. Al Kadhim[203], A. Askew[203], S. Bower[203], R. Goff[203], R. Hashmi[203], A. Hassani[203], R.S. Kim[203], T. Kolberg[203], G. Martinez[203], M. Mazza[203], H. Prosper[203], P.R. Prova[203], R. Yohay[203], B. Alsufyani[204], S. Butalla[204], S. Das[204], M. Hohlmann[204], M. Lavinsky[204], E. Yanes[204], M.R. Adams[205], N. Barnett[205], A. Baty[205], C. Bennett[205], R. Cavanaugh[205], R. Escobar Franco[205], O. Evdokimov[205], C.E. Gerber[205], H. Gupta[205], M. Hawksworth[205], A. Hingrajiya[205], D.J. Hofman[205], Z. Huang[205], J.h. Lee[205], C. Mills[205], S. Nanda[205], G. Nigmatkulov[205], B. Ozek[205], T. Phan[205], D. Pilipovic[205], R. Pradhan[205], E. Prifti[205], P. Roy[205], T. Roy[205], D. Shekar[205], N. Singh[205], A. Thielen[205], M.B. Tonjes[205], N. Varelas[205], M.A. Wadud[205], J. Yoo[205], M. Alhusseini[206], D. Blend[206], K. Dilsiz[LVI,206], O.K. Köseyan[206], A. Mestvirishvili[206,45], O. Neogi[206], H. Ogul[LXII,206], Y. Onel[206], A. Penzo[206], C. Snyder[206], E. Tiras[LX,206], B. Blumenfeld[207], J. Davis[207], A.V. Gritsan[207], L. Kang[207], S. Kyriacou[207], P. Maksimovic[207], M. Roguljic[207], S. Sekhar[207], M.V. Srivastav[207], M. Swartz[207], A. Abreu[208], L.F. Alcerro Alcerro[208], J. Anguiano[208], S. Arteaga Escatel[208], P. Baringer[208], A. Bean[208], R. Bhattacharya[208], Z. Flowers[208], D. Grove[208], J. King[208], G. Krintiras[208], M. Lazarovits[208], C. Le Mahieu[208], J. Marquez[208], M. Murray[208], M. Nickel[208], S. Popescu[LVII,208], C. Rogan[208], C. Royon[208], S. Rudrabhatla[208], S. Sanders[208], C. Smith[208], G. Wilson[208], B. Allmond[209], N. Islam[209], A. Ivanov[209], K. Kaadze[209], Y. Maravin[209], J. Natoli[209], G.G. Reddy[209], D. Roy[209], G. Sorrentino[209], A. Baden[210], A. Belloni[210], J. Bistany-riebman[210], S.C. Eno[210], N.J. Hadley[210], S. Jabeen[210], R.G. Kellogg[210], T. Koeth[210], B. Kronheim[210], S. Lascio[210], P. Major[210], A.C. Mignerey[210], C. Palmer[210], C. Papageorgakis[210], M.M. Paranjpe[210], E. Popova[LXIX,210], A. Shevelev[210], L. Zhang[210], C. Baldenegro Barrera[211], H. Bossi[211], S. Bright-Thonney[211], I.A. Cali[211], Y.c. Chen[211], P.c. Chou[211], M. D'Alfonso[211], J. Eysermans[211], C. Freer[211], G. Gomez-Ceballos[211], M. Goncharov[211], G. Grosso[211], P. Harris[211], D. Hoang[211], G.M. Innocenti[211], K. Ivanov[211], G. Kopp[211], D. Kovalskyi[211], J. Krupa[211], L. Lavezzo[211], Y.-J. Lee[211], K. Long[211], C. Mcginn[211], A. Novak[211], M.I. Park[211], C. Paus[211], C. Reissel[211], C. Roland[211], G. Roland[211], S. Rothman[211], T.a. Sheng[211], G.S.F. Stephans[211], D. Walter[211], J. Wang[211], Z. Wang[211], B. Wyslouch[211], T. J. Yang[211], A. Alpana[212], B. Crossman[212], W.J. Jackson[212], C. Kapsiak[212], M. Krohn[212], D. Mahon[212], J. Mans[212], B. Marzocchi[212], R. Rusack[212], O. Sancar[212], R. Saradhy[212], N. Strobbe[212], K. Bloom[213], D.R. Claes[213], G. Haza[213], J. Hossain[213], C. Joo[213], I. Kravchenko[213], K.H.M. Kwok[213], A. Rohilla[213], J.E. Siado[213], W. Tabb[213], A. Vagnerini[213], A. Wightman[213], F. Yan[213], H. Bandyopadhyay[214], L. Hay[214], H.w. Hsia[214], I. Iashvili[214], A. Kalogeropoulos[214], A. Kharchilava[214], A. Mandal[214], M. Morris[214], D. Nguyen[214], S. Rappoccio[214], H. Rejeb Sfar[214], A. Williams[214], D. Yu[214], A. Aarif[215], G. Alverson[215], E. Barberis[215], J. Bonilla[215], B. Bylsma[215], M. Campana[215], J. Dervan[215], Y. Haddad[215], Y. Han[215], I. Israr[215], A. Krishna[215], M. Lu[215], N. Manganelli[215], R. Mccarthy[215], D.M. Morse[215],

T. Orimoto[215], L. Skinnari[215], C.S. Thoreson[215], E. Tsai[215], D. Wood[215], S. Dittmer[216], K.A. Hahn[216], M. Mcginnis[216], Y. Miao[216], D.G. Monk[216], M.H. Schmitt[216], A. Taliercio[216], M. Velasco[216], J. Wang[216], G. Agarwal[217], R. Band[217], R. Bucci[217], S. Castells[217], A. Das[217], A. Datta[217], A. Ehnis[217], R. Goldouzian[217], M. Hildreth[217], K. Hurtado Anampa[217], T. Ivanov[217], C. Jessop[217], A. Karneyeu[217], K. Lannon[217], J. Lawrence[217], N. Loukas[217], L. Lutton[217], J. Mariano[217], N. Marinelli[217], T. McCauley[217], C. Mcgrady[217], C. Moore[217], Y. Musienko[LXIX,217], H. Nelson[217], M. Osherson[217], A. Piccinelli[217], R. Ruchti[217], A. Townsend[217], Y. Wan[217], M. Wayne[217], H. Yockey[217], M. Carrigan[218], R. De Los Santos[218], L.S. Durkin[218], C. Hill[218], M. Joyce[218], D.A. Wenzl[218], B.L. Winer[218], B. R. Yates[218], H. Bouchamaoui[219], G. Dezoort[219], P. Elmer[219], A. Frankenthal[219], M. Galli[219], B. Greenberg[219], N. Haubrich[219], K. Kennedy[219], Y. Lai[219], D. Lange[219], A. Loeliger[219], D. Marlow[219], I. Ojalvo[219], J. Olsen[219], F. Simpson[219], D. Stickland[219], C. Tully[219], S. Malik[220], R. Sharma[220], S. Chandra[221], A. Gu[221], L. Gutay[221], M. Huwiler[221], M. Jones[221], A.W. Jung[221], D. Kondratyev[221], J. Li[221], M. Liu[221], G. Negro[221], N. Neumeister[221], G. Paspalaki[221], S. Piperov[221], N.R. Saha[221], J.F. Schulte[221], F. Wang[221], A. Wildridge[221], W. Xie[221], Y. Yao[221], Y. Zhong[221], N. Parashar[222], A. Pathak[222], E. Shumka[222], D. Acosta[223], A. Agrawal[223], C. Arbour[223], T. Carnahan[223], P. Das[223], K.M. Ecklund[223], F.J.M. Geurts[223], T. Huang[223], I. Krommydas[223], N. Lewis[223], W. Li[223], J. Lin[223], O. Miguel Colin[223], B.P. Padley[223], R. Redjimi[223], J. Rotter[223], C. Vico Villalba[223], M. Wulansatiti[223], E. Yigitbasi[223], Y. Zhang[223], O. Bessidskaia Bylund[224], A. Bodek[224], P. de Barbaro[LXX,224], R. Demina[224], A. Garcia-Bellido[224], H.S. Hare[224], O. Hindrichs[224], N. Parmar[224], P. Parygin[LXIX,224], H. Seo[224], R. Taus[224], Y.h. Yu[224], B. Chiarito[225], J.P. Chou[225], S.V. Clark[225], S. Donnelly[225], D. Gadkari[225], Y. Gershtein[225], E. Halkiadakis[225], C. Houghton[225], D. Jaroslawski[225], A. Kobert[225], I. Laflotte[225], A. Lath[225], J. Martins[225], M. Perez Prada[225], B. Rand[225], J. Reichert[225], P. Saha[225], S. Salur[225], S. Somalwar[225], R. Stone[225], S.A. Thayil[225], S. Thomas[225], J. Vora[225], D. Ally[226], A.G. Delannoy[226], S. Fiorendi[226], J. Harris[226], T. Holmes[226], A.R. Kanuganti[226], N. Karunarathna[226], J. Lawless[226], L. Lee[226], E. Nibigira[226], B. Skipworth[226], S. Spanier[226], D. Aebi[227], M. Ahmad[227], T. Akhter[227], K. Androsov[227], A. Basnet[227], A. Bolshov[227], O. Bouhali[LXI,227], A. Cagnotta[227], V. D'Amante[227], R. Eusebi[227], P. Flanagan[227], J. Gilmore[227], Y. Guo[227], T. Kamon[227], S. Luo[227], R. Mueller[227], A. Safonov[227], N. Akchurin[228], J. Damgov[228], Y. Feng[228], N. Gogate[228], W. Jin[228], S.W. Lee[228], C. Madrid[228], A. Mankel[228], T. Peltola[228], I. Volobouev[228], E. Appelt[229], Y. Chen[229], S. Greene[229], A. Gurrola[229], W. Johns[229], R. Kunnawalkam Elayavalli[229], A. Melo[229], D. Rathjens[229], F. Romeo[229], P. Sheldon[229], S. Tuo[229], J. Velkovska[229], J. Viinikainen[229], J. Zhang[229], B. Cardwell[230], H. Chung[230], B. Cox[230], J. Hakala[230], G. Hamilton Ilha Machado[230], R. Hirosky[230], M. Jose[230], A. Ledovskoy[230], C. Mantilla[230], C. Neu[230], C. Ramón Álvarez[230], Z. Wu[230], S. Bhattacharya[231], P.E. Karchin[231], A. Aravind[232], S. Banerjee[232], K. Black[232], T. Bose[232], E. Chavez[232], S. Dasu[232], P. Everaerts[232], C. Galloni[232], H. He[232], M. Herndon[232], A. Herve[232], C.K. Koraka[232], S. Lomte[232], R. Loveless[232], A. Mallampalli[232], A. Mohammadi[232], S. Mondal[232], T. Nelson[232], G. Parida[232], L. Pétré[232], D. Pinna[232], A. Savin[232], V. Shang[232], V. Sharma[232], W.H. Smith[232], D. Teague[232], A. Warden[232], S. Afanasiev[LXVI,136], V. Alexakhin[LXVI,136], Yu. Andreev[LXVI,136], T. Aushev[LXVI,136], D. Budkouski[LXVI,136], R. Chistov[LXVI,136], M. Danilov[LXVI,136], T. Dimova[LXVI,136], A. Ershov[LXVI,136], S. Gninenko[LXVI,136], I. Gorbunov[LXVI,136], A. Kamenev[LXVI,136], V. Karjavine[LXVI,136], M. Kirsanov[LXVI,136], V. Klyukhin[LXVI,136], O. Kodolova[LXVI,136,1], V. Korenkov[LXVI,136], I. Korsakov[LXVI,182], A. Kozyrev[LXVI,136], N. Krasnikov[LXVI,136], A. Lanev[LXVI,136], A. Malakhov[LXVI,136], V. Matveev[LXVI,136], A. Nikitenko[LXVI,136,184,1], V. Palichik[LXVI,136], V. Perelygin[LXVI,136], S. Petrushanko[LXVI,136], O. Radchenko[LXVI,136], M. Savina[LXVI,136], V. Shalaev[LXVI,136], S. Shmatov[LXVI,136], S. Shulha[LXVI,136], Y. Skovpen[LXVI,136], K. Slizhevskiy[LXVI,182], V. Smirnov[LXVI,136], O. Teryaev[LXVI,136], I. Tlisova[LXVI,136], A. Toropin[LXVI,136], N. Voytishin[LXVI,136], A. Zarubin[LXVI,136], I. Zhizhin[LXVI,136], L. Dudko[LXVIII,136], V. Kim[LXVIII,LXIX,136], V. Murzin[LXVIII,136], V. Oreshkin[LXVIII,136], D. Sosnov[LXVIII,136], E. Boos[LXVIII,136], V. Bunichev[LXVIII,136], M. Dubinin[LXVIII,136,197], A. Gribushin[LXVIII,136], V. Savrin[LXVIII,136], A. Snigirev[LXVIII,136]

Affiliation Notes

[I] Also at Yerevan State University, Yerevan, Armenia
[II] Also at TU Wien, Vienna, Austria
[III] Also at FACAMP - Faculdades de Campinas, Sao Paulo, Brazil
[IV] Also at The University of the State of Amazonas, Manaus, Brazil
[V] Also at Federal University of Rio Grande do Sul, Porto Alegre, Brazil
[VI] Also at Universidade Estadual de Campinas, Campinas, Brazil
[VII] Also at University of Chinese Academy of Sciences, Beijing, China
[VIII] Also at Center for High Energy Physics, Peking University, Beijing, China
[IX] Also at University of Chinese Academy of Sciences, Beijing, China
[X] Also at Henan Normal University, Xinxiang, China
[XI] Also at University of Shanghai for Science and Technology, Shanghai, China
[XII] Also at School of Physics, Zhengzhou University, Zhengzhou, China
[XIII] Also at British University in Egypt, Cairo, Egypt
[XIV] Also at Helwan University, Cairo, Egypt
[XV] Also at Zewail City of Science and Technology, Zewail, Egypt
[XVI] Also at Université de Haute Alsace, Mulhouse, France
[XVII] Also at Tbilisi State University, Tbilisi, Georgia
[XVIII] Also at Brandenburg University of Technology, Cottbus, Germany
[XIX] Also at Forschungszentrum Jülich, Juelich, Germany
[XX] Also at Bergische University Wuppertal (BUW), Wuppertal, Germany
[XXI] Also at Physics Department, Faculty of Science, Assiut University, Assiut, Egypt
[XXII] Also at Universitatea Babes-Bolyai - Facultatea de Fizica, Cluj-Napoca, Romania
[XXIII] Also at Indian Institute of Science (IISc), Bangalore, India
[XXIV] Also at Institute of Physics, Bhubaneswar, India
[XXV] Also at Punjab Agricultural University, Ludhiana, India
[XXVI] Also at University of Visva-Bharati, Santiniketan, India
[XXVII] Also at Department of Physics, Faculty of Science, Arak University, ARAK, Iran
[XXVIII] Also at Department of Physics, University of Science and Technology of Mazandaran, Behshahr, Iran
[XXIX] Also at Sharif University of Technology, Tehran, Iran
[XXX] Also at Centro Siciliano di Fisica Nucleare e di Struttura Della Materia, Catania, Italy
[XXXI] Also at UPES - University of Petroleum and Energy Studies, Dehradun, India
[XXXII] Also at Consiglio Nazionale delle Ricerche - Istituto Officina dei Materiali, Perugia, Italy
[XXXIII] Also at Lulea University of Technology, Lulea, Sweden
[XXXIV] Also at Scuola Superiore Meridionale, Università di Napoli 'Federico II', Napoli, Italy
[XXXV] Also at Università degli Studi Guglielmo Marconi, Roma, Italy
[XXXVI] Also at Department of Applied Physics, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, Bangi, Malaysia
[XXXVII] Also at Saegis Campus, Nugegoda, Sri Lanka
[XXXVIII] Also at Trincomalee Campus, Eastern University, Sri Lanka, Nilaveli, Sri Lanka
[XXXIX] Also at Ecole Polytechnique Fédérale Lausanne, Lausanne, Switzerland
[XL] Also at Stefan Meyer Institute for Subatomic Physics, Vienna, Austria
[XLI] Also at Adiyaman University, Adiyaman, Turkey

[XLII] Also at Informatics and Information Security Research Center, Gebze/Kocaeli, Turkey
[XLIII] Also at Istanbul University - Cerrahpasa, Faculty of Engineering, Istanbul, Turkey
[XLIV] Also at Istinye University, Istanbul, Turkey
[XLV] Also at Istanbul Sabahattin Zaim University, Istanbul, Turkey
[XLVI] Also at Milli Savunma University, Istanbul, Turkey
[XLVII] Also at Izmir Bakircay University, Izmir, Turkey
[XLVIII] Also at Kafkas University, Kars, Turkey
[XLIX] Also at Konya Technical University, Konya, Turkey
[L] Also at Marmara University, Istanbul, Turkey
[LI] Also at Near East University, Research Center of Experimental Health Science, Mersin, Turkey
[LII] Also at Istanbul Okan University, Istanbul, Turkey
[LIII] Also at Istanbul Topkapi University, Istanbul, Turkey
[LIV] Also at Bozok Universitetesi Rektörlügü, Yozgat, Turkey
[LV] Also at United States Naval Academy, Annapolis, Maryland, USA
[LVI] Also at Bingol University, Bingol, Turkey
[LVII] Also at Horia Hulubei National Institute of Physics and Nuclear Engineering (IFIN-HH), Bucharest, Romania
[LVIII] Also at California Lutheran University;, Thousand Oaks, California, USA
[LIX] Also at Karamanoğlu Mehmetbey University, Karaman, Turkey
[LX] Also at Erciyes University, Kayseri, Turkey
[LXI] Also at Hamad Bin Khalifa University (HBKU), Doha, Qatar
[LXII] Also at Sinop University, Sinop, Turkey
[LXIII] Also at Università di Torino, Torino, Italy
[LXIV] Also at Monash University, Faculty of Science, Clayton, Australia
[LXV] Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom
[LXVI] Also at An institute or international laboratory covered by a cooperation agreement with CERN
[LXVII] Also at Another institute or international laboratory covered by a cooperation agreement with CERN
[LXVIII] Also at An institute formerly covered by a cooperation agreement with CERN
[LXIX] Also at Another institute formerly covered by a cooperation agreement with CERN
[LXX] Deceased

Collaboration Institutes

[1] Yerevan Physics Institute, Yerevan, Armenia
[2] Institut für Hochenergiephysik, Vienna, Austria
[3] Universiteit Antwerpen, Antwerpen, Belgium
[4] Vrije Universiteit Brussel, Brussel, Belgium
[5] Université Libre de Bruxelles, Bruxelles, Belgium
[6] Ghent University, Ghent, Belgium
[7] Université Catholique de Louvain, Louvain-la-Neuve, Belgium
[8] Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil
[9] Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil
[10] Universidade Estadual Paulista, Universidade Federal do ABC, São Paulo, Brazil
[11] Institute for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, Sofia, Bulgaria
[12] University of Sofia, Sofia, Bulgaria
[13] Instituto De Alta Investigación, Universidad de Tarapacá, Casilla 7 D, Arica, Chile
[14] Universidad Tecnica Federico Santa Maria, Valparaiso, Chile
[15] Beihang University, Beijing, China
[16] Department of Physics, Tsinghua University, Beijing, China
[17] Institute of High Energy Physics, Beijing, China
[18] State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China
[19] State Key Laboratory of Nuclear Physics and Technology, Institute of Quantum Matter, South China Normal University, Guangzhou, China
[20] Sun Yat-Sen University, Guangzhou, China
[21] University of Science and Technology of China, Hefei, China
[22] Nanjing Normal University, Nanjing, China
[23] Institute of Modern Physics and Key Laboratory of Nuclear Physics and Ion-beam Application (MOE) - Fudan University, Shanghai, China
[24] Zhejiang University, Hangzhou, Zhejiang, China
[25] Universidad de Los Andes, Bogota, Colombia
[26] Universidad de Antioquia, Medellin, Colombia
[27] University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Split, Croatia
[28] University of Split, Faculty of Science, Split, Croatia
[29] Institute Rudjer Boskovic, Zagreb, Croatia
[30] University of Cyprus, Nicosia, Cyprus
[31] Charles University, Prague, Czech Republic
[32] Escuela Politecnica Nacional, Quito, Ecuador
[33] Universidad San Francisco de Quito, Quito, Ecuador
[34] Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt
[35] Center for High Energy Physics (CHEP-FU), Fayoum University, El-Fayoum, Egypt
[36] National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
[37] Department of Physics, University of Helsinki, Helsinki, Finland
[38] Helsinki Institute of Physics, Helsinki, Finland
[39] Lappeenranta-Lahti University of Technology, Lappeenranta, Finland
[40] IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France
[41] Laboratoire Leprince-Ringuet, CNRS/IN2P3, Ecole Polytechnique, Institut Polytechnique de Paris, Palaiseau, France
[42] Université de Strasbourg, CNRS, IPHCUMR 7178, Strasbourg, France
[43] Centre de Calcul de l'Institut National de Physique Nucleaire et de Physique des Particules, CNRS/IN2P3, Villeurbanne, France
[44] Institut de Physique des 2 Infinis de Lyon (IP2I), Villeurbanne, France
[45] Georgian Technical University, Tbilisi, Georgia
[46] RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany
[47] RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany
[48] RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany
[49] Deutsches Elektronen-Synchrotron, Hamburg, Germany
[50] University of Hamburg, Hamburg, Germany
[51] Karlsruher Institut fuer Technologie, Karlsruhe, Germany
[52] Institute of Nuclear and Particle Physics (INPP), NCSR Demokritos, Aghia Paraskevi, Greece
[53] National and Kapodistrian University of Athens, Athens, Greece
[54] National Technical University of Athens, Athens, Greece
[55] University of Ioánnina, Ioánnina, Greece
[56] HUN-REN Wigner Research Centre for Physics, Budapest, Hungary
[57] MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary
[58] Faculty of Informatics, University of Debrecen, Debrecen, Hungary
[59] HUN-REN ATOMKI - Institute of Nuclear Research, Debrecen, Hungary
[60] Karoly Robert Campus, MATE Institute of Technology, Gyongyos, Hungary
[61] IIT Bhubaneswar, Bhubaneswar, India
[62] Panjab University, Chandigarh, India
[63] University of Delhi, Delhi, India
[64] Indian Institute of Technology Mandi (IIT-Mandi), Himachal Pradesh, India
[65] University of Hyderabad, Hyderabad, India
[66] Indian Institute of Technology Kanpur, Kanpur, India
[67] Saha Institute of Nuclear Physics, HBNI, Kolkata, India
[68] Indian Institute of Technology Madras, Madras, India
[69] IISER Mohali, India, Mohali, India
[70] Tata Institute of Fundamental Research-A, Mumbai, India
[71] Tata Institute of Fundamental Research-B, Mumbai, India

[72] National Institute of Science Education and Research, An OCC of Homi Bhabha National Institute, Bhubaneswar, Odisha, India
[73] Indian Institute of Science Education and Research (IISER), Pune, India
[74] Indian Institute of Technology Hyderabad, Telangana, India
[75] Isfahan University of Technology, Isfahan, Iran
[76] Institute for Research in Fundamental Sciences (IPM), Tehran, Iran
[77] University College Dublin, Dublin, Ireland
[78] INFN Sezione di Bari, Università di Bari, Politecnico di Bari, Bari, Italy
[79] INFN Sezione di Bari, Bari, Italy
[80] Università di Bari, Bari, Italy
[81] Politecnico di Bari, Bari, Italy
[82] INFN Sezione di Bologna, Università di Bologna, Bologna, Italy
[83] INFN Sezione di Bologna, Bologna, Italy
[84] Università di Bologna, Bologna, Italy
[85] INFN Sezione di Catania, Università di Catania, Catania, Italy
[86] INFN Sezione di Catania, Catania, Italy
[87] Università di Catania, Catania, Italy
[88] INFN Sezione di Firenze, Università di Firenze, Firenze, Italy
[89] INFN Sezione di Firenze, Firenze, Italy
[90] Università di Firenze, Firenze, Italy
[91] INFN Laboratori Nazionali di Frascati, Frascati, Italy
[92] INFN Sezione di Genova, Università di Genova, Genova, Italy
[93] INFN Sezione di Genova, Genova, Italy
[94] Università di Genova, Genova, Italy
[95] INFN Sezione di Milano-Bicocca, Università di Milano-Bicocca, Milano, Italy
[96] INFN Sezione di Milano-Bicocca, Milano, Italy
[97] Università di Milano-Bicocca, Milano, Italy
[98] INFN Sezione di Napoli, Università di Napoli 'Federico II', Napoli, Italy, Università della Basilicata, Potenza, Italy, Scuola Superiore Meridionale (SSM), Napoli, Italy
[99] INFN Sezione di Napoli, Napoli, Italy
[100] Università di Napoli 'Federico II', Napoli, Italy
[101] Università della Basilicata, Potenza, Italy
[102] Scuola Superiore Meridionale (SSM), Napoli, Italy
[103] INFN Sezione di Padova, Università di Padova, Padova, Italy, Universita degli Studi di Cagliari, Cagliari, Italy
[104] INFN Sezione di Padova, Padova, Italy
[105] Università di Padova, Padova, Italy
[106] Universita degli Studi di Cagliari, Cagliari, Italy
[107] INFN Sezione di Pavia, Università di Pavia, Pavia, Italy
[108] INFN Sezione di Pavia, Pavia, Italy
[109] Università di Pavia, Pavia, Italy
[110] INFN Sezione di Perugia, Università di Perugia, Perugia, Italy
[111] INFN Sezione di Perugia, Perugia, Italy
[112] Università di Perugia, Perugia, Italy
[113] INFN Sezione di Pisa, Università di Pisa, Scuola Normale Superiore di Pisa, Pisa Italy, Università di Siena, Siena, Italy
[114] INFN Sezione di Pisa, Pisa, Italy
[115] Università di Pisa, Pisa, Italy
[116] Scuola Normale Superiore di Pisa, Pisa, Italy
[117] Università di Siena, Siena, Italy
[118] INFN Sezione di Roma, Sapienza Università di Roma, Roma, Italy
[119] INFN Sezione di Roma, Roma, Italy
[120] Sapienza Università di Roma, Roma, Italy
[121] INFN Sezione di Torino, Università di Torino, Torino, Italy, Università del Piemonte Orientale, Novara, Italy
[122] INFN Sezione di Torino, Torino, Italy
[123] Università di Torino, Torino, Italy
[124] Università del Piemonte Orientale, Novara, Italy
[125] INFN Sezione di Trieste, Università di Trieste, Trieste, Italy
[126] INFN Sezione di Trieste, Trieste, Italy
[127] Università di Trieste, Trieste, Italy
[128] Kyungpook National University, Daegu, Korea
[129] Department of Mathematics and Physics - GWNU, Gangneung, Korea
[130] Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea
[131] Hanyang University, Seoul, Korea
[132] Korea University, Seoul, Korea
[133] Kyung Hee University, Department of Physics, Seoul, Korea
[134] Sejong University, Seoul, Korea
[135] Seoul National University, Seoul, Korea
[136] University of Seoul, Seoul, Korea
[137] Yonsei University, Department of Physics, Seoul, Korea
[138] Sungkyunkwan University, Suwon, Korea
[139] College of Engineering and Technology, American University of the Middle East (AUM), Dasman, Kuwait
[140] Kuwait University - College of Science - Department of Physics, Safat, Kuwait
[141] Riga Technical University, Riga, Latvia
[142] University of Latvia (LU), Riga, Latvia
[143] Vilnius University, Vilnius, Lithuania
[144] National Centre for Particle Physics, Universiti Malaya, Kuala Lumpur, Malaysia
[145] Universidad de Sonora (UNISON), Hermosillo, Mexico
[146] Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico
[147] Universidad Iberoamericana, Mexico City, Mexico
[148] Benemerita Universidad Autonoma de Puebla, Puebla, Mexico
[149] University of Montenegro, Podgorica, Montenegro
[150] University of Canterbury, Christchurch, New Zealand
[151] National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan
[152] AGH University of Krakow, Krakow, Poland
[153] National Centre for Nuclear Research, Swierk, Poland
[154] Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland
[155] Warsaw University of Technology, Warsaw, Poland
[156] Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal
[157] Faculty of Physics, University of Belgrade, Belgrade, Serbia
[158] VINCA Institute of Nuclear Sciences, University of Belgrade, Belgrade, Serbia
[159] Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain
[160] Universidad Autónoma de Madrid, Madrid, Spain
[161] Universidad de Oviedo, Instituto Universitario de Ciencias y Tecnologías Espaciales de Asturias (ICTEA), Oviedo, Spain
[162] Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain
[163] University of Colombo, Colombo, Sri Lanka
[164] University of Ruhuna, Department of Physics, Matara, Sri Lanka
[165] CERN, European Organization for Nuclear Research, Geneva, Switzerland
[166] PSI Center for Neutron and Muon Sciences, Villigen, Switzerland
[167] ETH Zurich - Institute for Particle Physics and Astrophysics (IPA), Zurich, Switzerland
[168] Universität Zürich, Zurich, Switzerland
[169] National Central University, Chung-Li, Taiwan
[170] National Taiwan University (NTU), Taipei, Taiwan
[171] High Energy Physics Research Unit, Department of Physics, Faculty of Science, Chulalongkorn University, Bangkok, Thailand
[172] Tunis El Manar University, Tunis, Tunisia
[173] Çukurova University, Physics Department, Science and Art Faculty, Adana, Turkey
[174] Hacettepe University, Ankara, Turkey
[175] Middle East Technical University, Physics Department, Ankara, Turkey
[176] Bogazici University, Istanbul, Turkey
[177] Istanbul Technical University, Istanbul, Turkey
[178] Istanbul University, Istanbul, Turkey

[179] Yildiz Technical University, Istanbul, Turkey
[180] Institute for Scintillation Materials of National Academy of Science of Ukraine, Kharkiv, Ukraine
[181] National Science Centre, Kharkiv Institute of Physics and Technology, Kharkiv, Ukraine
[182] University of Bristol, Bristol, United Kingdom
[183] Rutherford Appleton Laboratory, Didcot, United Kingdom
[184] Imperial College, London, United Kingdom
[185] Brunel University, Uxbridge, United Kingdom
[186] Baylor University, Waco, Texas, USA
[187] Bethel University, St. Paul, Minnesota, USA
[188] Catholic University of America, Washington, DC, USA
[189] The University of Alabama, Tuscaloosa, Alabama, USA
[190] Boston University, Boston, Massachusetts, USA
[191] Brown University, Providence, Rhode Island, USA
[192] University of California, Davis, Davis, California, USA
[193] University of California, Los Angeles, California, USA
[194] University of California, Riverside, California, USA
[195] University of California, San Diego, La Jolla, California, USA
[196] University of California, Santa Barbara - Department of Physics, Santa Barbara, California, USA
[197] California Institute of Technology, Pasadena, California, USA
[198] Carnegie Mellon University, Pittsburgh, Pennsylvania, USA
[199] University of Colorado Boulder, Boulder, Colorado, USA
[200] Cornell University, Ithaca, New York, USA
[201] Fermi National Accelerator Laboratory, Batavia, Illinois, USA
[202] University of Florida, Gainesville, Florida, USA
[203] Florida State University, Tallahassee, Florida, USA
[204] Florida Institute of Technology, Melbourne, Florida, USA
[205] University of Illinois Chicago, Chicago, Illinois, USA
[206] The University of Iowa, Iowa City, Iowa, USA
[207] Johns Hopkins University, Baltimore, Maryland, USA
[208] The University of Kansas, Lawrence, Kansas, USA
[209] Kansas State University, Manhattan, Kansas, USA
[210] University of Maryland, College Park, Maryland, USA
[211] Massachusetts Institute of Technology, Cambridge, Massachusetts, USA
[212] University of Minnesota, Minneapolis, Minnesota, USA
[213] University of Nebraska-Lincoln, Lincoln, Nebraska, USA
[214] State University of New York at Buffalo, Buffalo, New York, USA
[215] Northeastern University, Boston, Massachusetts, USA
[216] Northwestern University, Evanston, Illinois, USA
[217] University of Notre Dame, Notre Dame, Indiana, USA
[218] The Ohio State University, Columbus, Ohio, USA
[219] Princeton University, Princeton, New Jersey, USA
[220] University of Puerto Rico, Mayaguez, Puerto Rico, USA
[221] Purdue University, West Lafayette, Indiana, USA
[222] Purdue University Northwest, Hammond, Indiana, USA
[223] Rice University, Houston, Texas, USA
[224] University of Rochester, Rochester, New York, USA
[225] Rutgers, The State University of New Jersey, Piscataway, New Jersey, USA
[226] University of Tennessee, Knoxville, Tennessee, USA
[227] Texas A&M University, College Station, Texas, USA
[228] Texas Tech University, Lubbock, Texas, USA
[229] Vanderbilt University, Nashville, Tennessee, USA
[230] University of Virginia, Charlottesville, Virginia, USA
[231] Wayne State University, Detroit, Michigan, USA
[232] University of Wisconsin - Madison, Madison, Wisconsin, USA

References

[1] M. Fairbairn, A.C. Kraan, D.A. Milstead, T. Sjostrand, P.Z. Skands, T. Sloan, Stable massive particles at colliders, Phys. Rept. 438 (2007) 1. arXiv:hep-ph/0611040, https://doi.org/10.1016/j.physrep.2006.10.002

[2] M.J. Strassler, K.M. Zurek, Echoes of a hidden valley at hadron colliders, Phys. Lett. B 651 (2007) 374. arXiv:hep-ph/0604261, https://doi.org/10.1016/j.physletb.2007.06.055

[3] C.W. Bauer, Z. Ligeti, M. Schmaltz, J. Thaler, D.G.E. Walker, Supermodels for early LHC, Phys. Lett. B 690 (2010) 280. arXiv:0909.5213, https://doi.org/10.1016/j.physletb.2010.05.032

[4] R. Barate, et al., (ALEPH), Search for pair production of longlived heavy charged particles in e^+e^- annihilation, Phys. Lett. B 405 (1997) 379. arXiv:hep-ex/9706013, https://doi.org/10.1016/S0370-2693(97)00715-6

[5] P. Abreu, et al., (DELPHI), Search for heavy stable and longlived particles in e^+e^- collisions at $\sqrt{s} = 189$ GeV, Phys. Lett. B 478 (2000) 65. arXiv:hep-ex/0103038, https://doi.org/10.1016/S0370-2693(00)00265-3

[6] P. Achard, et al., (L3), Search for heavy neutral and charged leptons in e^+e^- annihilation at LEP, Phys. Lett. B 517 (2001) 75. arXiv:hep-ex/0107015, https://doi.org/10.1016/S0370-2693(01)01005-X

[7] G. Abbiendi, et al., (OPAL), Search for stable and longlived massive charged particles in e^+e^- collisions at $\sqrt{s} = 130$ GeV to 209 GeV, Phys. Lett. B 572 (2003) 8. arXiv:hep-ex/0305031, https://doi.org/10.1016/S0370-2693(03)00639-7

[8] A. Aktas, et al., (H1), Measurement of anti-deuteron photoproduction and a search for heavy stable charged particles at HERA, Eur. Phys. J. C 36 (2004) 413. arXiv:hep-ex/0403056, https://doi.org/10.1140/epjc/s2004-01978-x

[9] T. Aaltonen, et al., (CDF), Search for long-lived massive charged particles in 1.96 TeV $\bar{p}p$ collisions, Phys. Rev. Lett. 103 (2009) 021802. arXiv:0902.1266, https://doi.org/10.1103/PhysRevLett.103.021802

[10] V.M. Abazov, et al., (D0), Search for long-lived charged massive particles with the D0 detector, Phys. Rev. Lett. 102 (2009) 161802. arXiv:0809.4472, https://doi.org/10.1103/PhysRevLett.102.161802

[11] V.M. Abazov, et al., (D0), A search for charged massive long-lived particles, Phys. Rev. Lett. 108 (2012) 121802. arXiv:1110.3302, https://doi.org/10.1103/PhysRevLett.108.121802

[12] D0, (D0), Search for charged massive long-lived particles at $\sqrt{s} = 1.96$ TeV, Phys. Rev. D 87 (2013) 052011. arXiv:1211.2466, https://doi.org/10.1103/PhysRevD.87.052011

[13] ATLAS Collaboration, Search for heavy long-lived charged particles with the ATLAS detector in pp collisions at $\sqrt{s} = 7$ TeV, Phys. Lett. B 703 (2011) 428. arXiv:1106.4495, https://doi.org/10.1016/j.physletb.2011.08.042

[14] ATLAS Collaboration, Search for stable hadronising squarks and gluinos with the ATLAS experiment at the LHC, Phys. Lett. B 701 (2011) 1. arXiv:1103.1984, https://doi.org/10.1016/j.physletb.2011.05.010

[15] ATLAS Collaboration, Search for massive long-lived highly ionising particles with the ATLAS detector at the LHC, Phys. Lett. B 698 (2011) 353. arXiv:1102.0459, https://doi.org/10.1016/j.physletb.2011.03.033

[16] ATLAS Collaboration, Searches for heavy long-lived sleptons and R-Hadrons with the ATLAS detector in pp collisions at $\sqrt{s} = 7$ TeV, Phys. Lett. B 720 (2013) 277. arXiv:1211.1597, https://doi.org/10.1016/j.physletb.2013.02.015

[17] ATLAS Collaboration, Search for long-lived, multi-charged particles in pp collisions at $\sqrt{s} = 7$ TeV using the ATLAS detector, Phys. Lett. B 722 (2013) 305. arXiv:1301.5272, https://doi.org/10.1016/j.physletb.2013.04.036

[18] ATLAS Collaboration, Searches for heavy long-lived charged particles with the ATLAS detector in proton-proton collisions at $\sqrt{s} = 8$ TeV, JHEP 01 (2015) 068. arXiv:1411.6795, https://doi.org/10.1007/JHEP01(2015)068

[19] ATLAS Collaboration, Search for heavy long-lived multi-charged particles in pp collisions at $\sqrt{s} = 8$ TeV using the ATLAS detector, Eur. Phys. J. C 75 (2015) 362. arXiv:1504.04188, https://doi.org/10.1140/epjc/s10052-015-3534-2

[20] ATLAS Collaboration, Search for metastable heavy charged particles with large ionisation energy loss in pp collisions at $\sqrt{s} = 8$ TeV using the ATLAS experiment, Eur. Phys. J. C 75 (2015) 407. arXiv:1506.05332, https://doi.org/10.1140/epjc/s10052-015-3609-0

[21] ATLAS Collaboration, Search for metastable heavy charged particles with large ionization energy loss in pp collisions at $\sqrt{s} = 13$ TeV using the ATLAS experiment, Phys. Rev. D 93 (2016) 112015. arXiv:1604.04520, https://doi.org/10.1103/PhysRevD.93.112015

[22] ATLAS Collaboration, Search for heavy long-lived charged R-hadrons with the ATLAS detector in 3.2 fb^{-1} of proton–proton collision data at $\sqrt{s} = 13$ TeV, Phys. Lett. B 760 (2016) 647. arXiv:1606.05129, https://doi.org/10.1016/j.physletb.2016.07.042

[23] CMS Collaboration, Search for heavy stable charged particles in pp collisions at $\sqrt{s} = 7$ TeV, JHEP 03 (2011) 024. arXiv:1101.1645, https://doi.org/10.1007/JHEP03(2011)024

[24] CMS Collaboration, Search for fractionally charged particles in pp collisions at $\sqrt{s} = 7$ TeV, Phys. Rev. D 87 (2013) 092008. [Erratum: 10.1103/PhysRevD.106.099903]. arXiv:1210.2311, https://doi.org/10.1103/PhysRevD.87.092008

[25] CMS Collaboration, Search for heavy long-lived charged particles in pp collisions at $\sqrt{s} = 7$ TeV, Phys. Lett. B 713 (2012) 408. arXiv:1205.0272, https://doi.org/10.1016/j.physletb.2012.06.023

[26] CMS Collaboration, Searches for long-lived charged particles in pp collisions at $\sqrt{s} = 7$ and 8 TeV, JHEP 07 (2013) 122. [Erratum: 10.1007/JHEP11(2022)149]. arXiv:1305.0491, https://doi.org/10.1007/JHEP07(2013)122

[27] CMS Collaboration, Search for long-lived charged particles in proton-proton collisions at $\sqrt{s} = 13$ TeV, Phys. Rev. D 94 (2016) 112004. arXiv:1609.08382, https://doi.org/10.1103/PhysRevD.94.112004

[28] ATLAS Collaboration, Search for heavy, long-lived, charged particles with large ionisation energy loss in pp collisions at $\sqrt{s} = 13$ TeV using the ATLAS experiment and the full Run 2 dataset, JHEP 06 (2023) 158. arXiv:2205.06013, https://doi.org/10.1007/JHEP06(2023)158

[29] CMS Collaboration, Search for fractionally charged particles in proton-proton collisions at $\sqrt{s} = 13$ TeV, Phys. Rev. Lett. 134 (2025) 131802. arXiv:2402.09932, https://doi.org/10.1103/PhysRevLett.134.131802

[30] CMS Collaboration, Search for heavy long-lived charged particles with large ionization energy loss in proton-proton collisions at $\sqrt{s} = 13$ TeV, JHEP 04 (2025) 109. arXiv:2410.09164, https://doi.org/10.1007/JHEP04(2025)109

[31] ATLAS Collaboration, Search for long-lived charged particles using large specific ionisation loss and time of flight in 140 fb^{-1} of pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, JHEP 07 (2025) 140. arXiv:2502.06694, https://doi.org/10.1007/JHEP07(2025)140

[32] CMS Collaboration, The Phase-2 Upgrade of the CMS Level-1 Trigger, CMS Technical Design Report CERN-LHCC-2020-004 ; CMS-TDR-021, 2020. https://cds.cern.ch/record/2714892.

[33] CMS Collaboration, Development of the CMS detector for the CERN LHC Run 3, JINST 19 (2024) P05064. arXiv:2309.05466, https://doi.org/10.1088/1748-0221/19/05/P05064

[34] M. Migliorini, 40 MHz Scouting at the CMS Experiment, Ph.D. thesis, Padua University, 2024. CERN-THESIS-2024-288, https://repository.cern/records/3rrqb-tha31.

[35] R. Ardino, Search for Rare Boson Decays with the CMS Detector at LHC and the CMS Level-1 Trigger Data Scouting, Ph.D. thesis, Padua University, 2024. CERN-THESIS-2024-303, https://repository.cern/records/5sv24-ff274.

[36] 2025, HEPData record for this analysis. https://doi.org/10.17182/hepdata.166216

[37] CMS Collaboration, The CMS experiment at the CERN LHC, JINST 3 (2008) S08004. https://doi.org/10.1088/1748-0221/3/08/S08004

[38] CMS Collaboration, Performance of the CMS Level-1 trigger in proton-proton collisions at $\sqrt{s} = 13$ TeV, JINST 15 (2020) P10017. arXiv:2006.10165, https://doi.org/10.1088/1748-0221/15/10/P10017

[39] CMS Collaboration, The CMS Barrel Muon trigger upgrade, JINST 12 (2017) C01095. https://doi.org/10.1088/1748-0221/12/01/C01095

[40] G.F. Giudice, M. McCullough, D. Teresi, dE/dx from boosted long-lived particles, JHEP 08 (2022) 012. arXiv:2205.04473, https://doi.org/10.1007/JHEP08(2022)012

[41] G.R. Farrar, P. Fayet, Phenomenology of the production, decay, and detection of new hadronic states associated with supersymmetry, Phys. Lett. B 76 (1978) 575. https://doi.org/10.1016/0370-2693(78)90858-4

[42] G.F. Giudice, A. Romanino, Split supersymmetry, Nucl. Phys. B 699 (2004) 65. [Erratum: 10.1016/j.nuclphysb.2004.11.048]. arXiv:hep-ph/0406088, https://doi.org/10.1016/j.nuclphysb.2004.08.001

[43] N. Arkani-Hamed, S. Dimopoulos, Supersymmetric unification without low energy supersymmetry and signatures for fine-tuning at the LHC, JHEP 06 (2005) 073. arXiv:hep-th/0405159, https://doi.org/10.1088/1126-6708/2005/06/073

[44] A.C. Kraan, Interactions of heavy stable hadronizing particles, Eur. Phys. J. C 37 (2004) 91. arXiv:hep-ex/0404001, https://doi.org/10.1140/epjc/s2004-01946-6

[45] R. Mackeprang, A. Rizzi, Interactions of coloured heavy stable particles in matter, Eur. Phys. J. C 50 (2007) 353. arXiv:hep-ph/0612161, https://doi.org/10.1140/epjc/s10052-007-0252-4

[46] T. Sjöstrand, S. Ask, J.R. Christiansen, R. Corke, N. Desai, P. Ilten, S. Mrenna, S. Prestel, C.O. Rasmussen, P.Z. Skands, An introduction to PYTHIA 8.2, Comput. Phys. Commun. 191 (2015) 159. arXiv:1410.3012, https://doi.org/10.1016/j.cpc.2015.01.024

[47] CMS Collaboration, Extraction and validation of a new set of CMS PYTHIA8 tunes from underlying-event measurements, Eur. Phys. J. C 80 (2020) 4. arXiv:1903.12179, https://doi.org/10.1140/epjc/s10052-019-7499-4

[48] R.D. Ball, V. Bertone, F. Cerutti, L. Del Debbio, S. Forte, A. Guffanti, J.I. Latorre, J. Rojo, M. Ubiali, Unbiased global determination of parton distributions and their uncertainties at NNLO and at LO, Nucl. Phys. B 855 (2012) 153. arXiv:1107.2652, https://doi.org/10.1016/j.nuclphysb.2011.09.024

[49] R.D. Ball, V. Bertone, S. Carrazza, L. Del Debbio, S. Forte, A. Guffanti, N.P. Hartland, J. Rojo, (NNPDF), Parton distributions with QED corrections, Nucl. Phys. B 877 (2013) 290. arXiv:1308.0598, https://doi.org/10.1016/j.nuclphysb.2013.10.010

[50] R.D. Ball, et al., (NNPDF), Parton distributions from high-precision collider data, Eur. Phys. J. C 77 (2017) 663. arXiv:1706.00428, https://doi.org/10.1140/epjc/s10052-017-5199-5

[51] R. Frederix, S. Frixione, Merging meets matching in MC@NLO, JHEP 12 (2012) 061. arXiv:1209.6215, https://doi.org/10.1007/JHEP12(2012)061

[52] S. Agostinelli, et al., (GEANT4), GEANT4— a simulation toolkit, Nucl. Instrum. Meth. A 506 (2003) 250. https://doi.org/10.1016/S0168-9002(03)01368-8

[53] D.J. Lange, M. Hildreth, V.N. Ivantchenko, I. Osborne, (for the CMS Collaboration), Upgrades for the CMS simulation, J. Phys.: Conf. Ser. 608 (2015) 012056. https://doi.org/10.1088/1742-6596/608/1/012056

[54] CMS Collaboration, Bunch crossing identification studies for the CMS muon barrel local trigger, CMS Detector Performance Note CMS-DP-2025-008, 2025. https://cds.cern.ch/record/2924488.

[55] CMS Collaboration, The CMS statistical analysis and combination tool: combine, Comput. Softw. Big Sci. 8 (2024) 19. arXiv:2404.06614, https://doi.org/10.1007/s41781-024-00121-4

[56] T. Junk, Confidence level computation for combining searches with small statistics, Nucl. Instrum. Meth. A 434 (1999) 435. arXiv:hep-ex/9902006, https://doi.org/10.1016/S0168-9002(99)00498-2

[57] A.L. Read, Presentation of search results: the CL_s technique, J. Phys. G 28 (2002) 2693. https://doi.org/10.1088/0954-3899/28/10/313

[58] G. Cowan, K. Cranmer, E. Gross, O. Vitells, Asymptotic formulae for likelihood-based tests of new physics, Eur. Phys. J. C 71 (2011) 1554. [Erratum: 10.1140/epjc/s10052-013-2501-z]. arXiv:1007.1727, https://doi.org/10.1140/epjc/s10052-011-1554-0