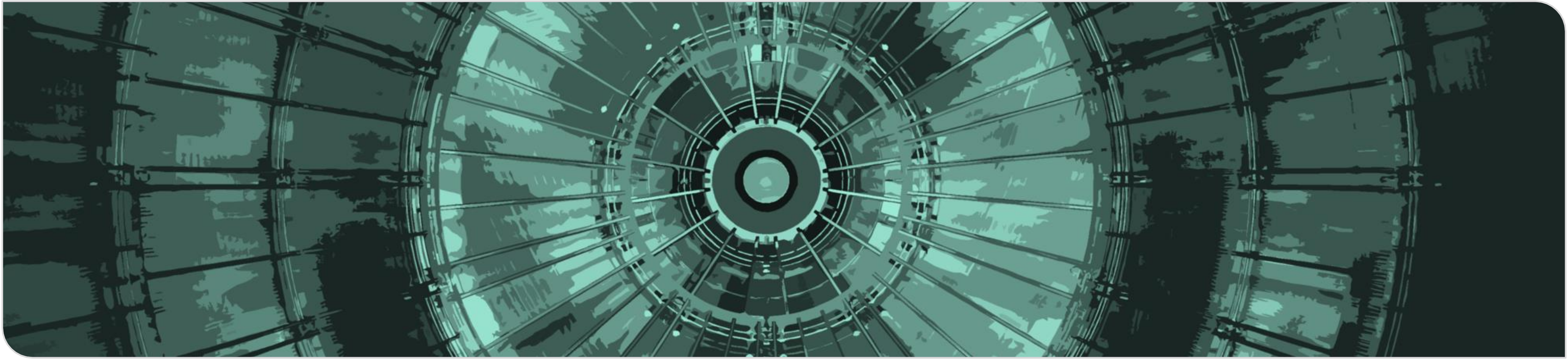
Karlsruhe Institute of Technology

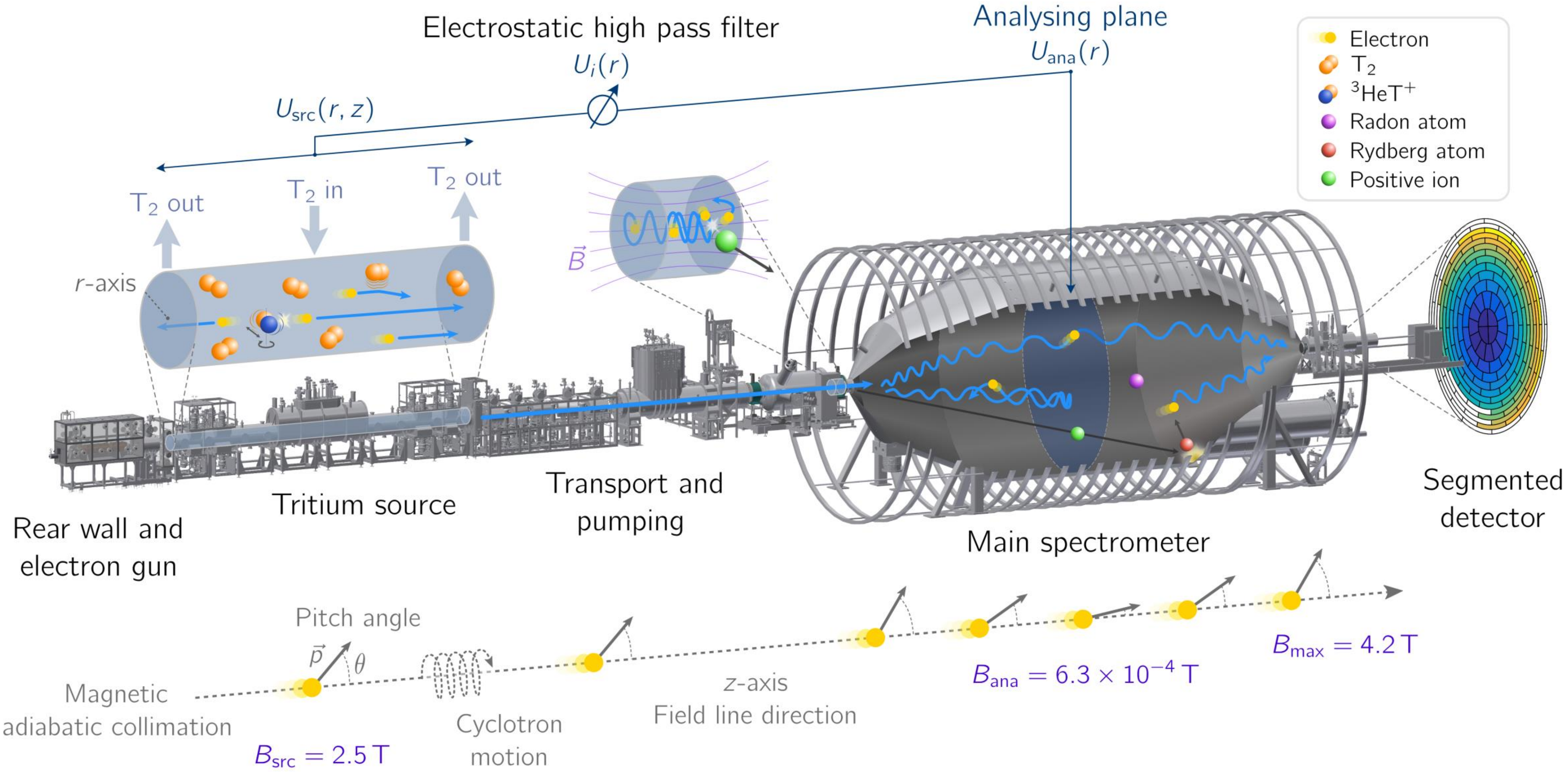
Use of micro-structured filters to explore the KATRIN background

Dominic Hinz for the KATRIN collaboration

DPG 24: 04.03.2024 – 08.03.2024 Karlsruhe



The KATRIN Experiment

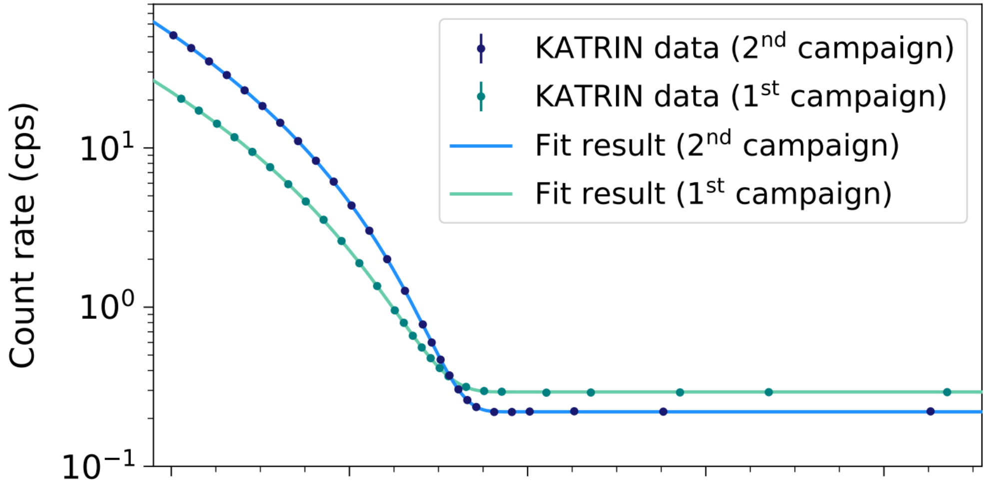


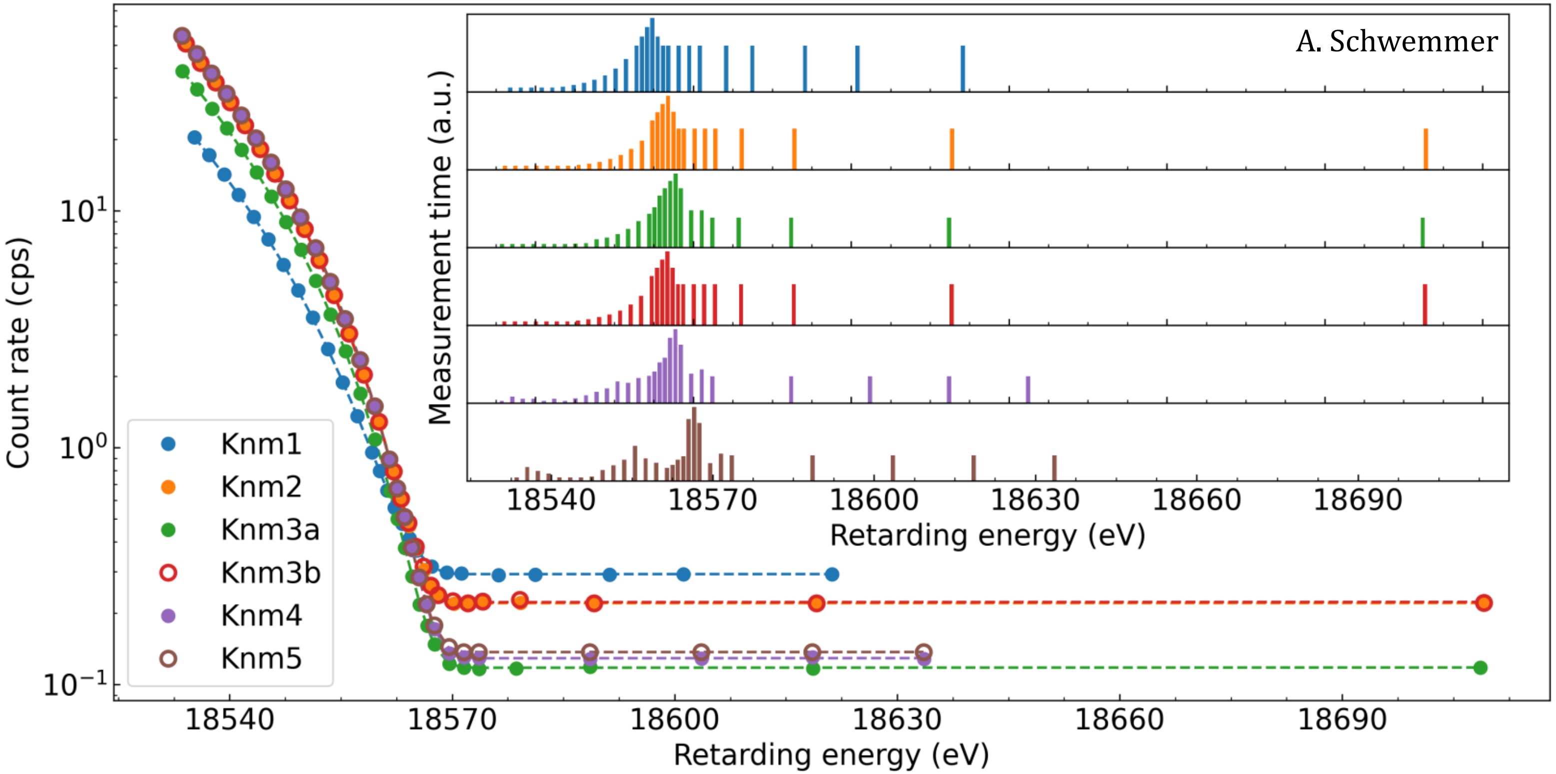
Current results

- Upper limit on neutrino mass: $m(\upsilon_e) < 0.8\ \mathrm{eV}/c^2$ (90% C.L.)

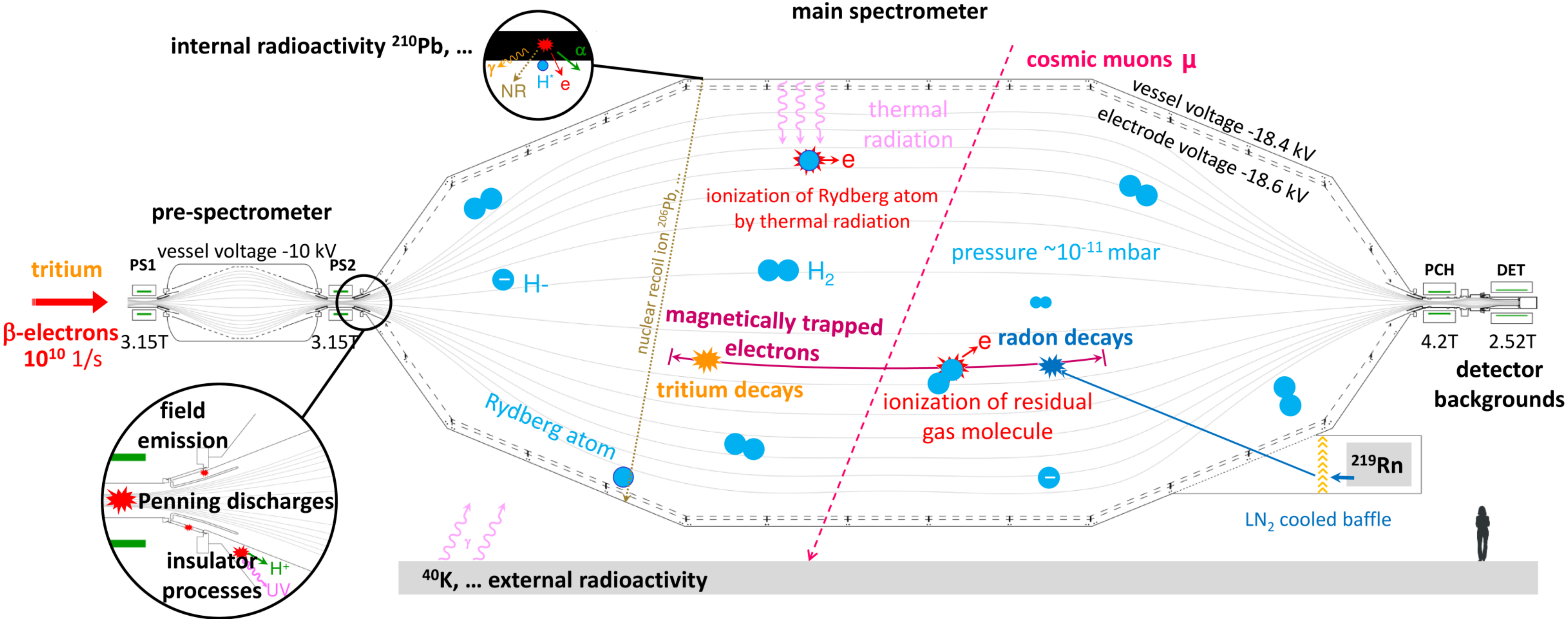
- Background rate limits sensitivity

- Upcoming release of new results



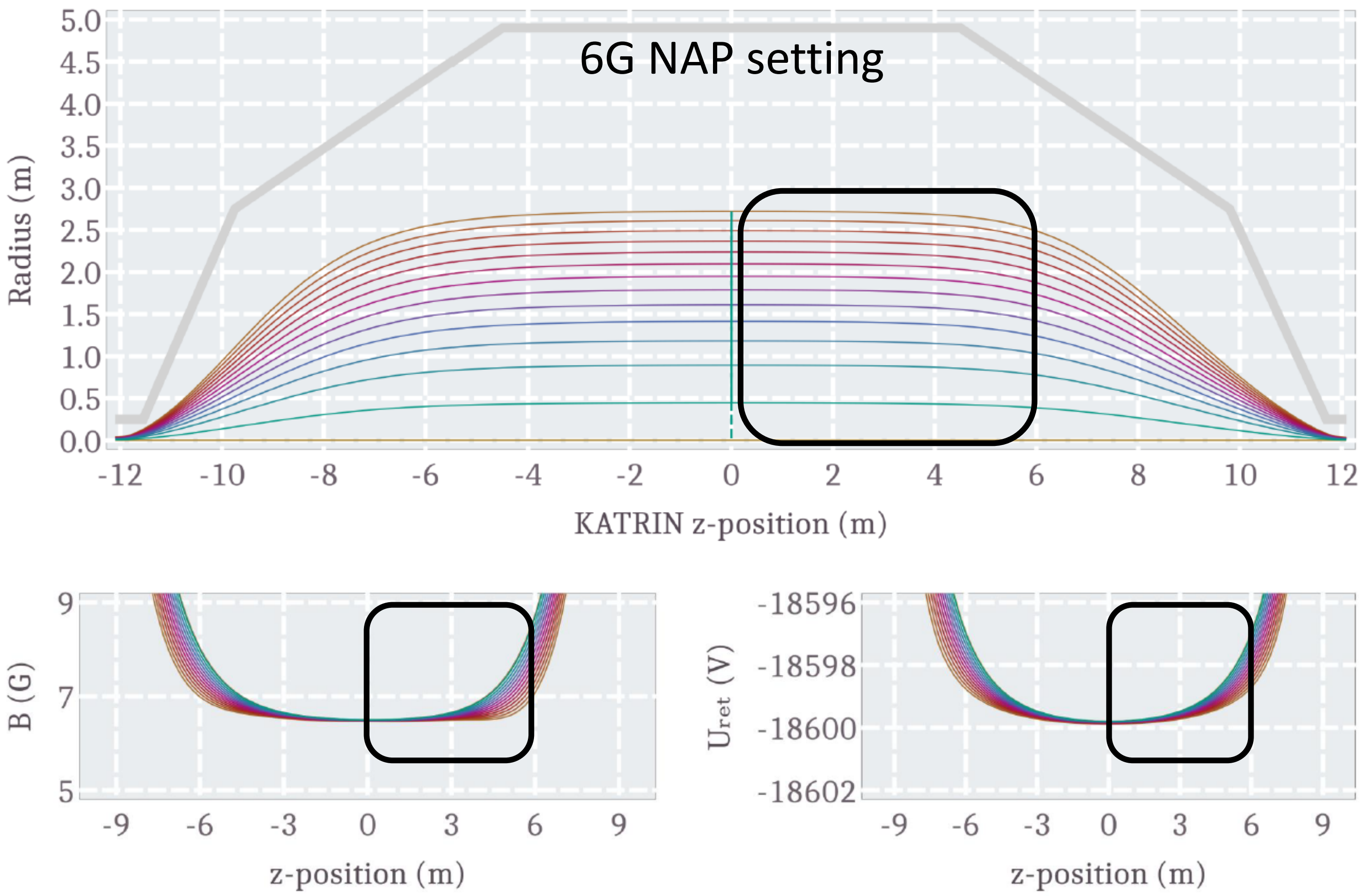


Main spectrometer background: scenario



Main spectrometer background: conditions

- Homogeneous magnetic and electric field layout
- Electron with small energy $(E < \Delta E)$ are transmitted to detector
- Cannot distinguish from beta electrons at detector
- Neutral messenger from MS surface
  - Rydberg background model
  - Very small energy O(meV)



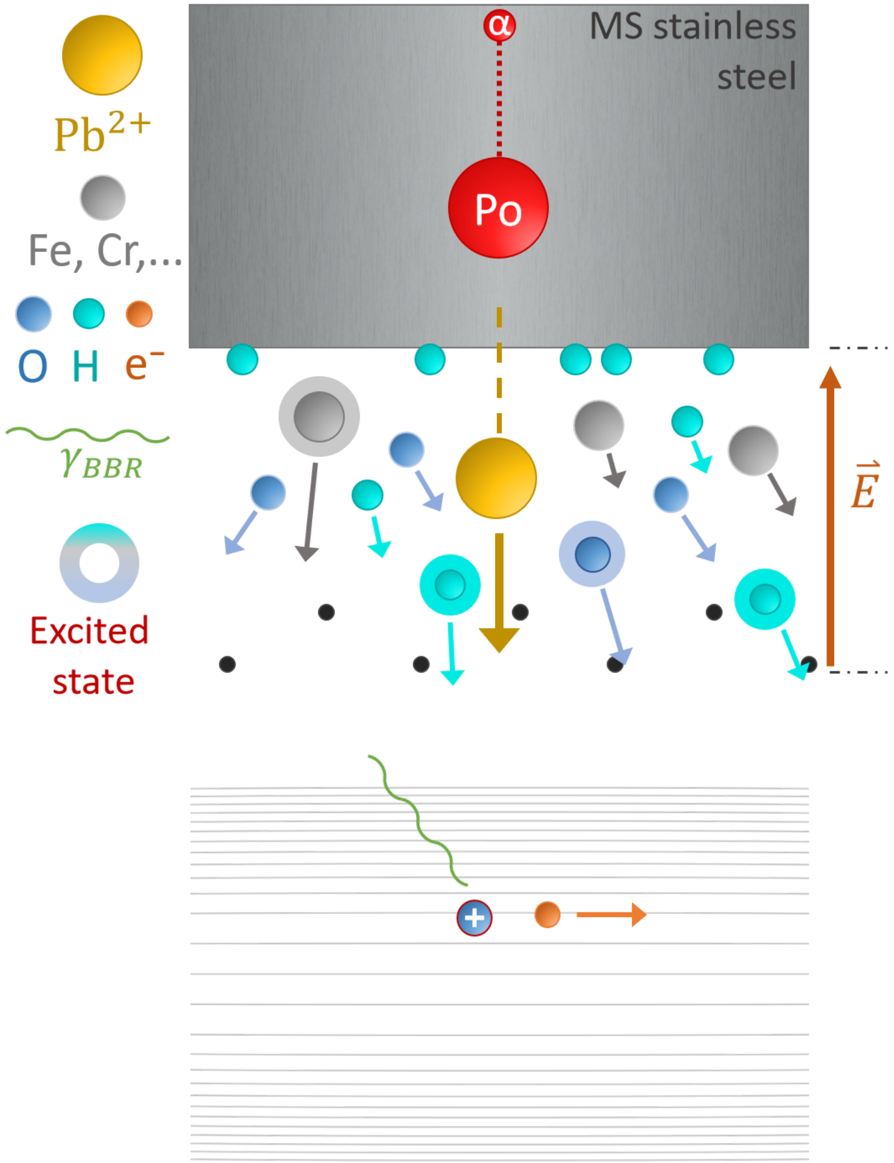
Rydberg background model

- MS surface with implanted radioactive impurities
  - ^{210}Pb with $t_{1/2} = 22\ y$
  - → beta decays to ^{210}Po
  - → alpha decay to stable ^{206}Pb (103 keV)

- → Sputtering of neutral atoms from surface
  - $v \sim 10\,\frac{\text{km}}{\text{s}} \rightarrow t_{tof} \sim 1\text{ ms}$

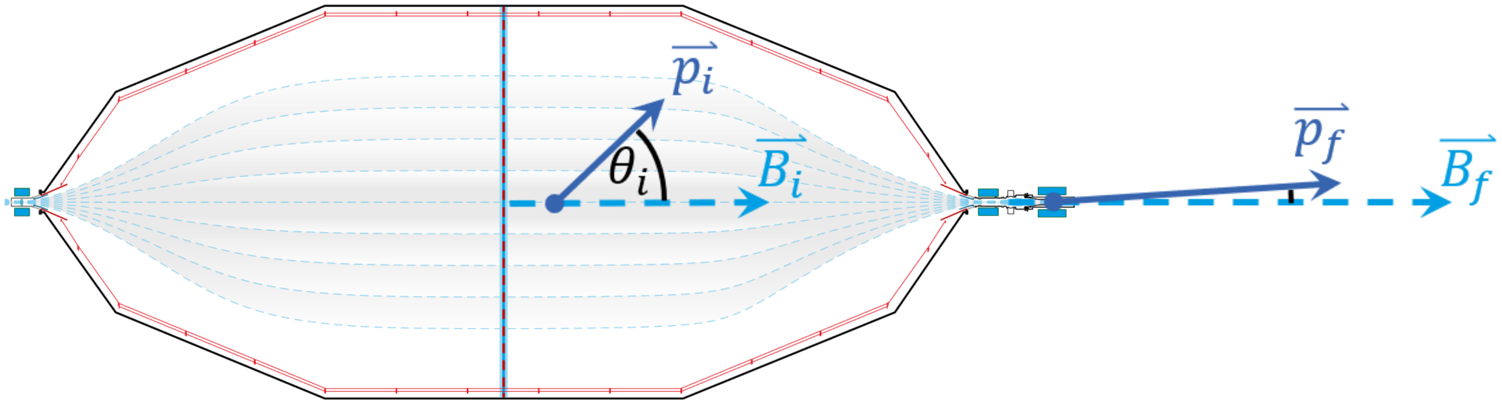
- Excited states – Rydberg atoms (n > 7)

- Rydberg atoms subsequently ionised by BBR



Key characteristics of our background electrons

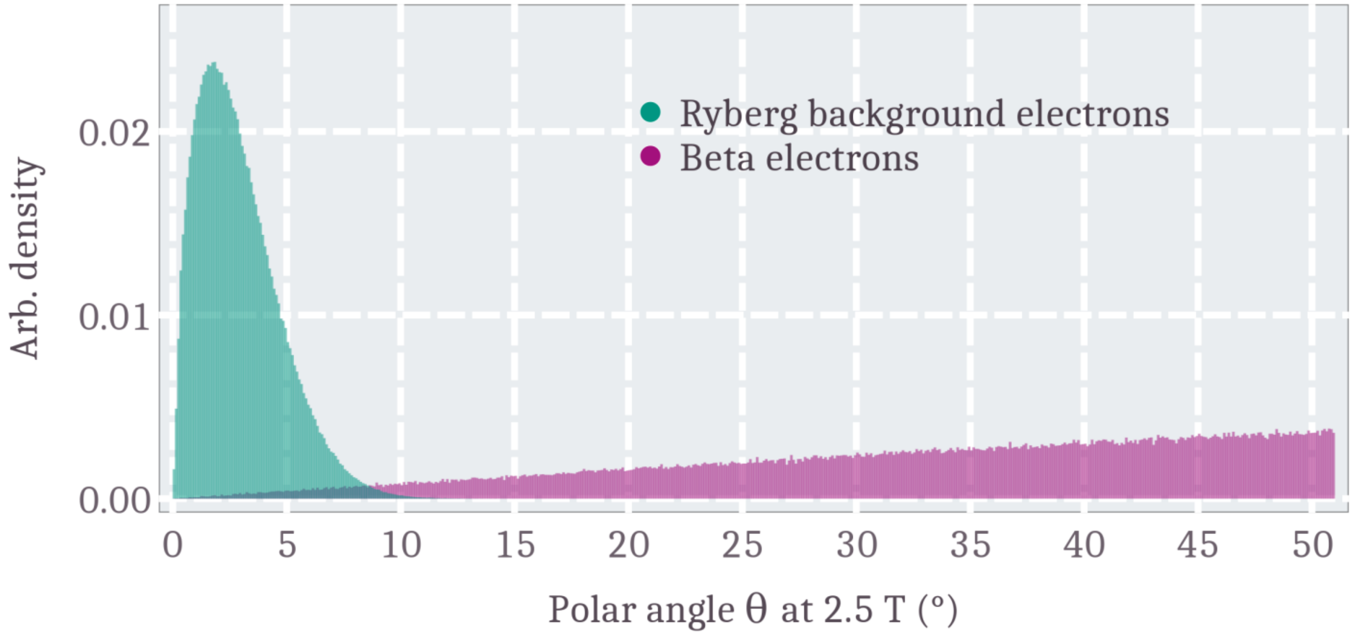
- Small energy: no trapping in MAC-E filter main spectrometer
  - Assumption ionisation of Rydberg atoms → E: 1 μeV … 100 meV
- Start in regions of very low magnetic field and high electric potentials
  - → acceleration towards detector
  - Angle to magnetic field θ decreases



- Adiabatic motion – magnetic moment conserved → Transformation of θ
  - $\theta_{\text{final}} = \arcsin\left(\underbrace{\sqrt{\frac{E_\text{i}}{E_\text{f}} \cdot \frac{B_\text{f}}{B_\text{i}} \cdot \sin^2(\theta_\text{i})}}_{\leq 1}\right) \rightarrow E_t \leq \frac{B_\text{i}}{B_\text{f}} \cdot E_\text{f}$

Difference of background and beta electrons

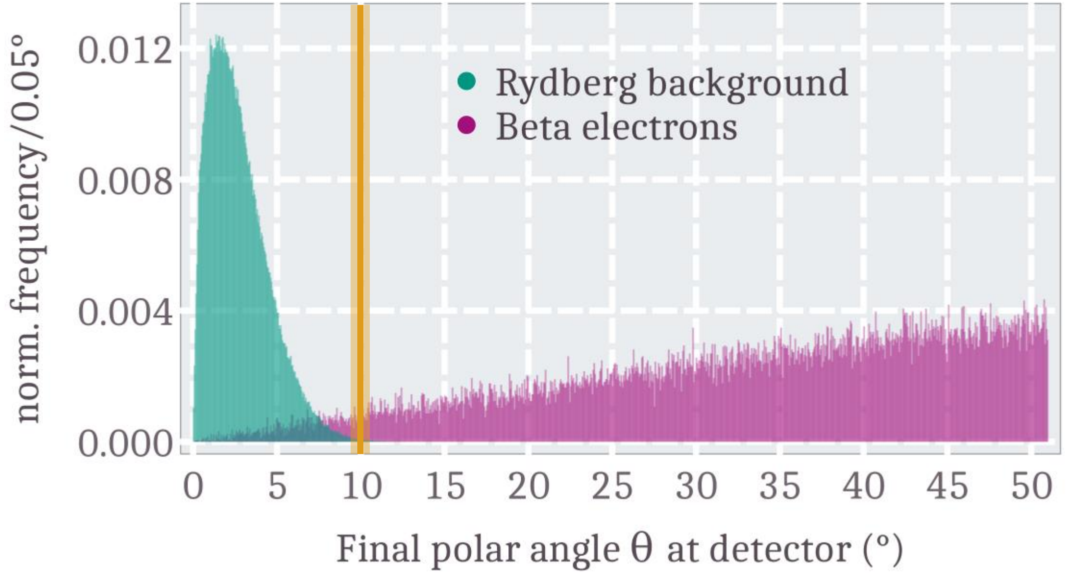
- Beta electrons from source
  - magnetic field (2.5T)
  - no potential
  - energy close to E_0 (18.57 keV)
  - Isotropic → Cut by acceptance angle
- Background electrons from MS volume
  - small magnetic field (~0.5 mT)
  - high potential (-18.57 kV)
  - low energy (~meV)
  - Isotropic → Transmission through pinch magnet

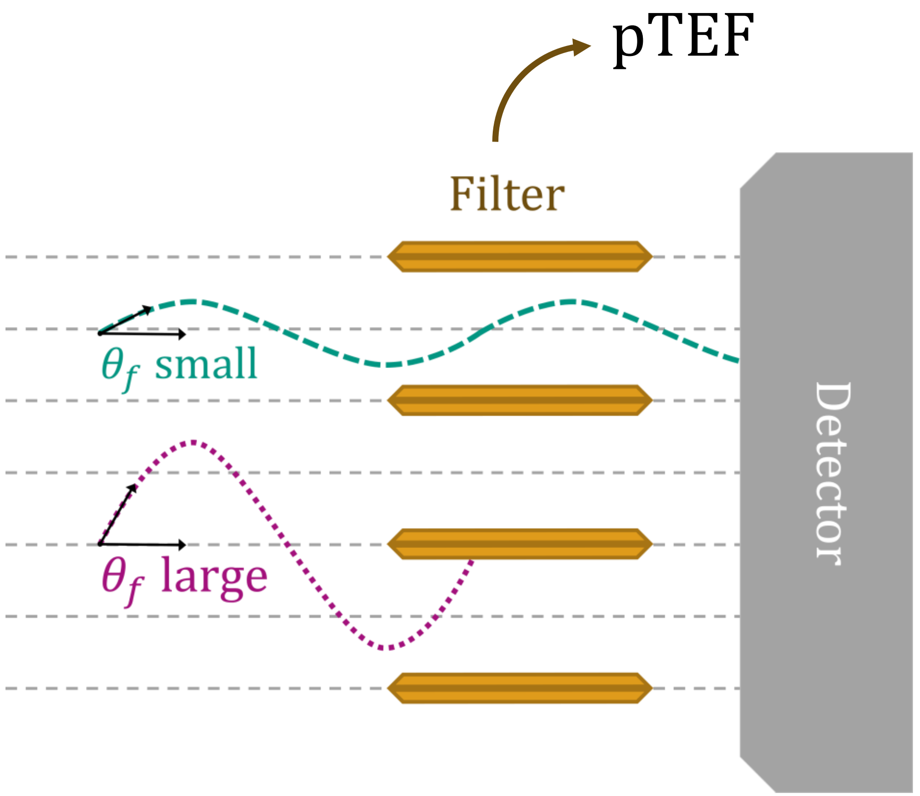


Basic principle of Transverse Energy Filter (TEF)

- Radius of cyclotron motion defines polar angle θ → transverse energy
- Distribution for Rydberg background and beta electrons differ strongly

- Passive filter: Transmits electrons with small transverse energy



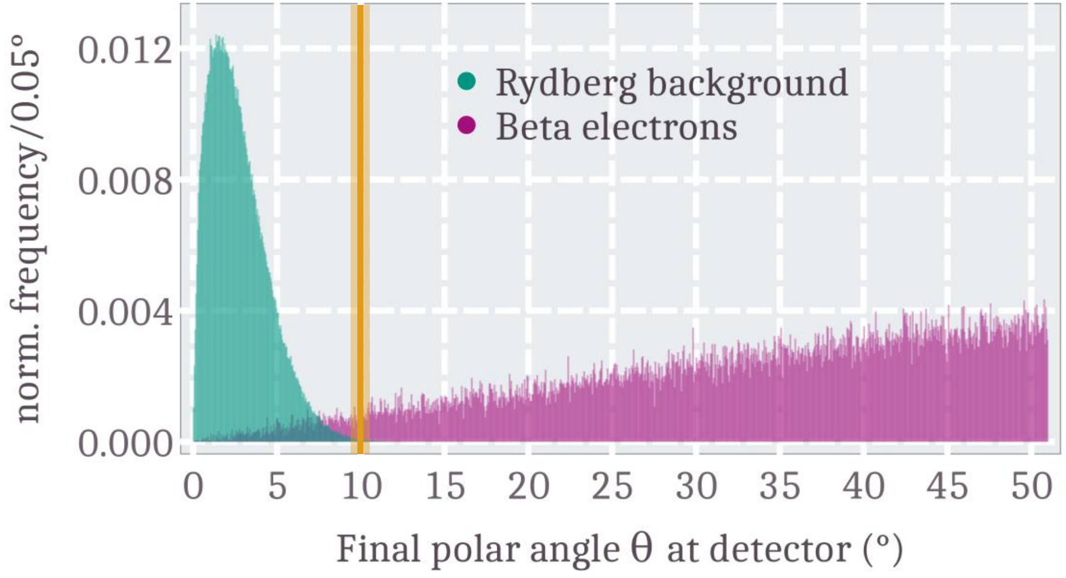


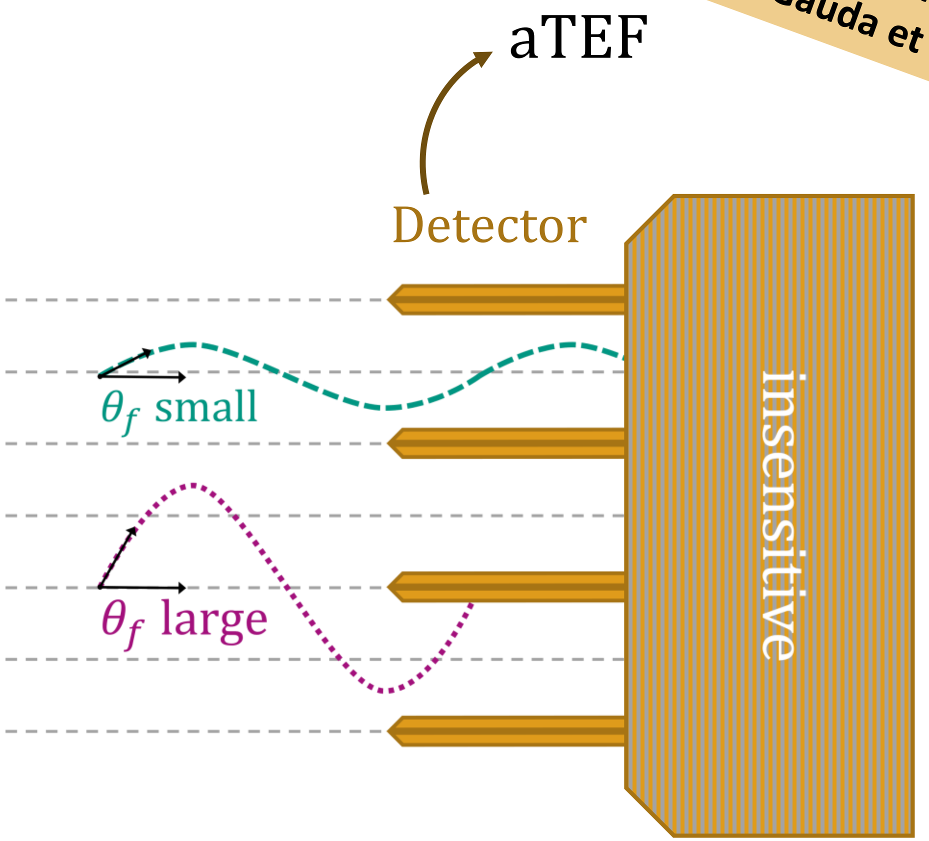
Basic principle of Transverse Energy Filter (TEF)

- Radius of cyclotron motion defines polar angle θ → transverse energy
- Distribution for Rydberg background and beta electrons differ strongly

- Active filter: Electron detection with <u>high</u> transverse energy

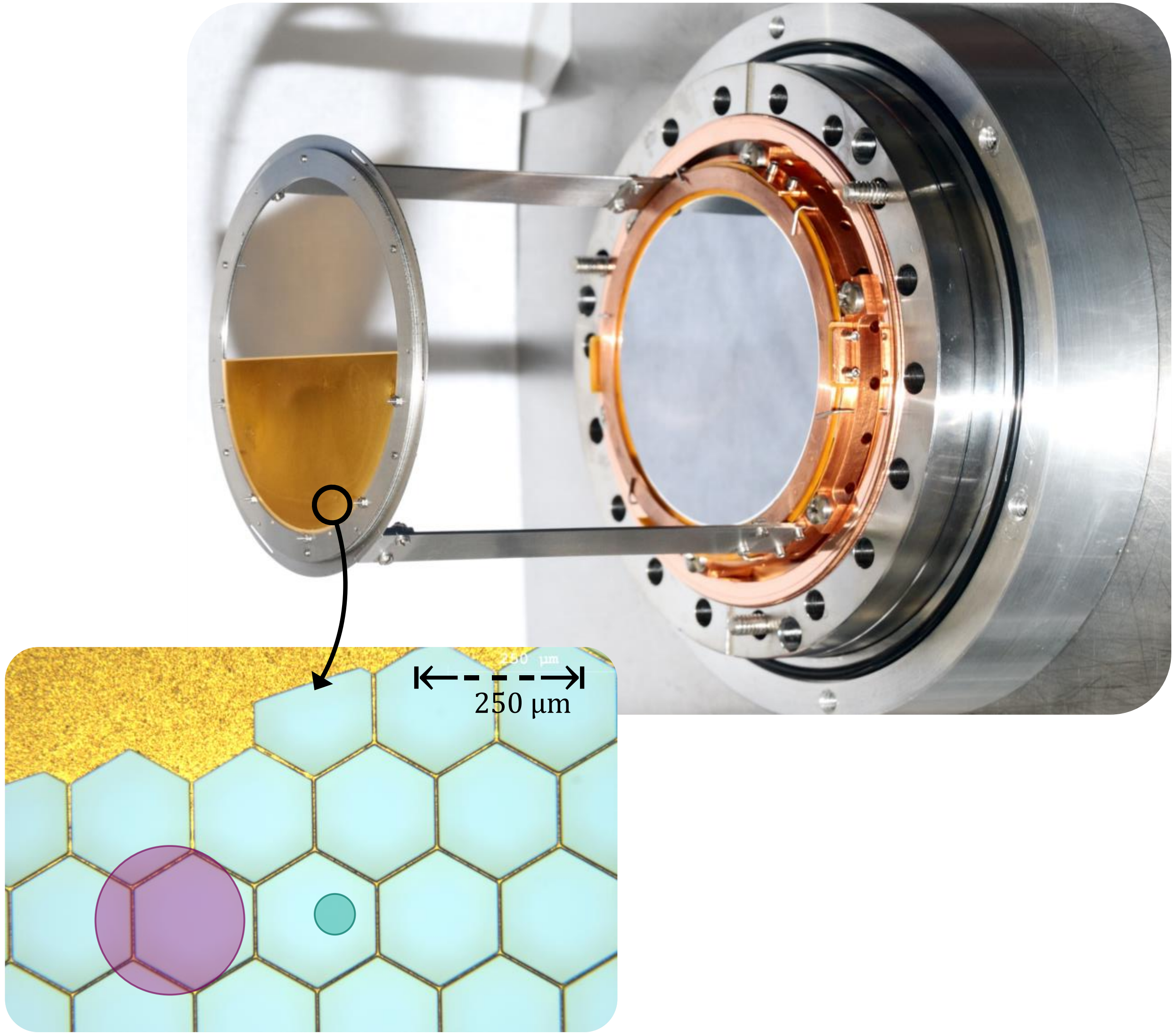
T 40.1 Nathanael Gutknecht
T 92.5 Kevin Gauda et al.





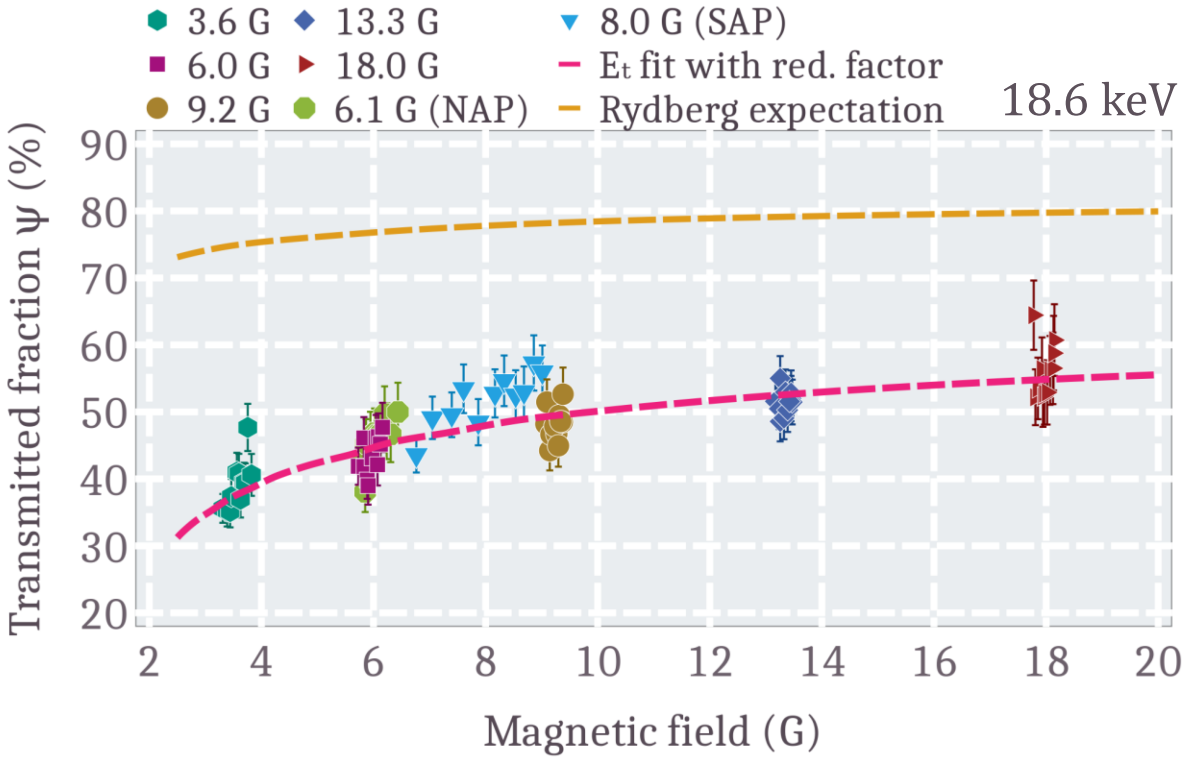
Test our Rydberg background hypothesis with a filter

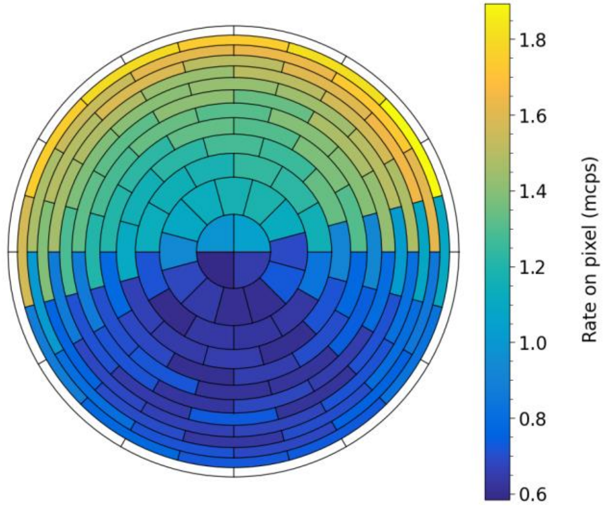
- Passive transverse energy filter (pTEF)
  - Filters electrons with larger angles (beta electrons)
  - Background electrons with small angles transmitted on to detector
- Semi-circle gold plate
  - Side length: 100 µm
  - Wall thickness: 8 µm
  - Depth: 250 µm
  - Open-area-ratio: 91.4%
- Installed in front of detector in high magnetic field strength B_{det}
- Transmission and detector response simulation with Geant4



pTEF measurements and results

- Polar angle of e^- can be varies by changing U_{HV} and B_{MS}
- Clear signature on FPD
  - Rate drops behind filter to ~50%





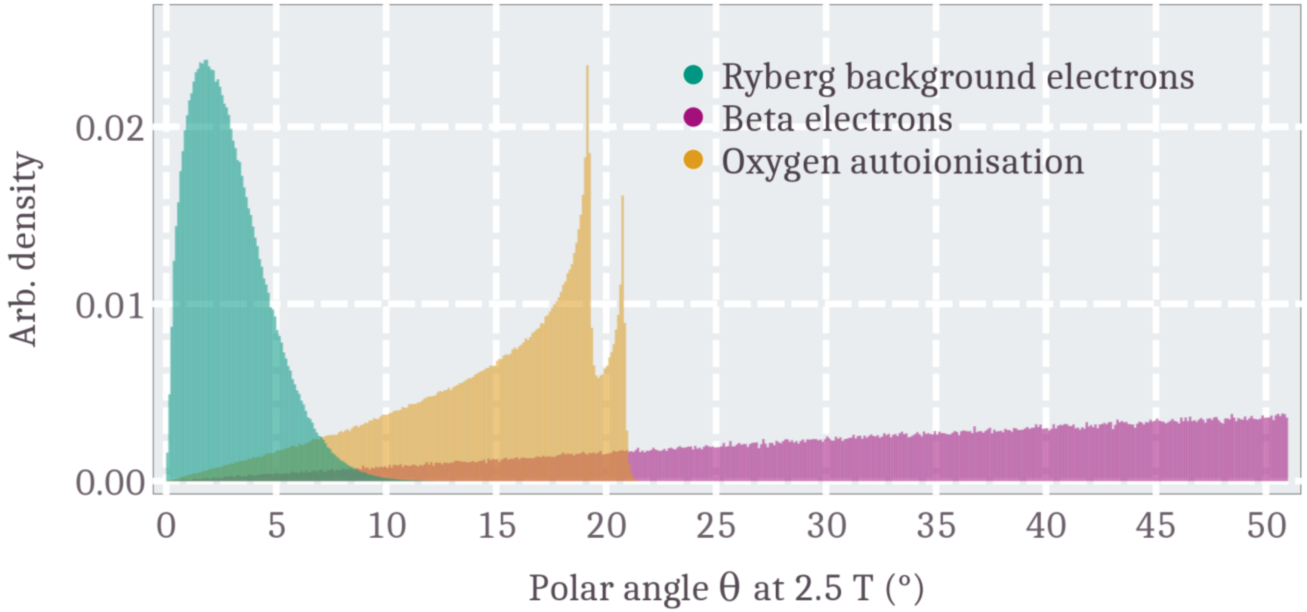
- Mean initial transverse energy
  - $E_t \approx 220(20)$ meV
  - $E_{t,\text{Rydberg}} \approx 15$ meV
- → Model extension

Model extension

- Ionisation of hydrogen Rydberg atoms by BBR photons does not exclusively cause our background
- Implementation of other mechanisms
  - Higher electron energies by autoionisation of O-16

Autoionisation:
- Exotic excited state of atom
- $\sum_i E_{i,exc} > E_{ionisation}$ (> 2 e^- excited)
- Lifetime can be larger due to forbidden transitions

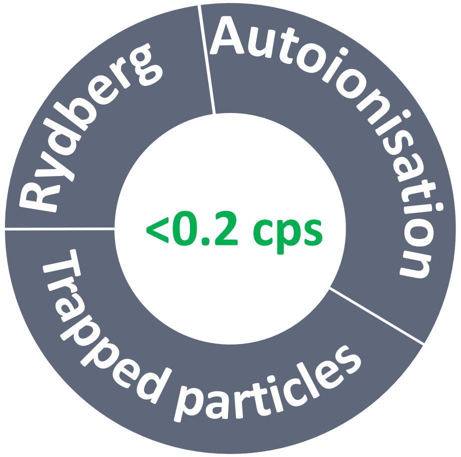
- Autoionisation of oxygen atoms
  - Additional higher energies (up to 2.5 eV)
  - Dominant long-lived states
    - 420 meV
    - 495 meV



- → New hypothesis of background contribution
- Open questions
  - Which states can contribute?
  - Any other effect possible?

Summary and Outlook

- The KATRIN background from the Main spectrometer is not fully understood
- The current rate limits our final sensitivity to < 0.3 $\frac{\mathrm{eV}}{\mathrm{c}^2}$
  - No systematic budget – only statistical
- Mitigation strategies
- Further use-cases for micro-structures currently under investigation
  - Major systematic given due to electron back-scattering at RW for TRISTAN



Rear wall backscattering and systematics
T 53.2 **Kerstin Trost**
T 53.3 **Tom Geigle**

TRISTAN for KATRIN
T 78.2 **Frank Ezdards**