Karlsruhe Institute of Technology

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Karlsruhe Research Accelerator

Ultra-fast line-camera KALYPSO for electron beam diagnostics

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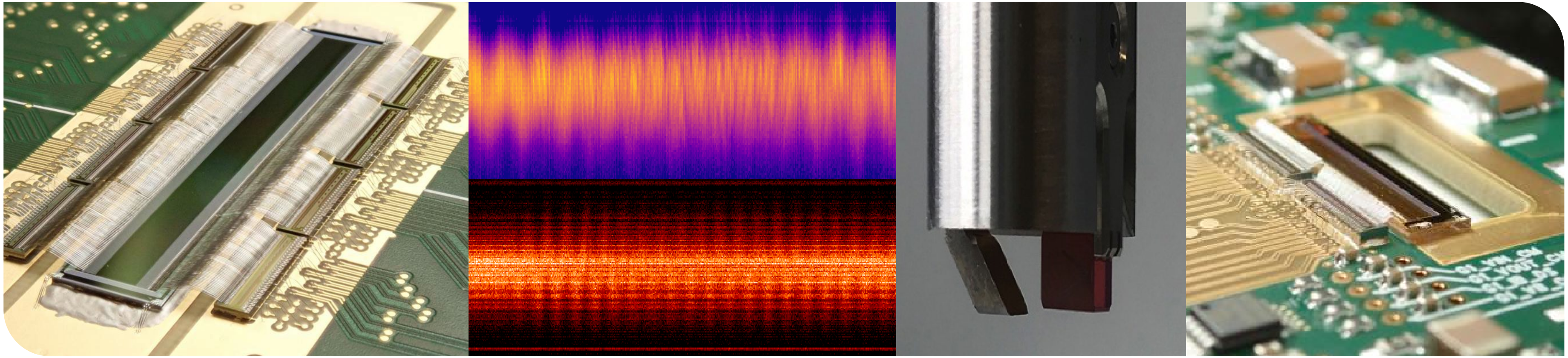
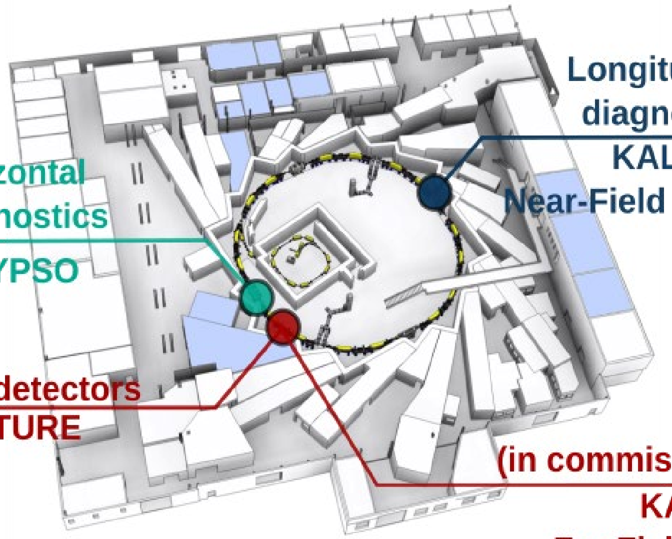


Karlsruhe Research Accelerator – KARA

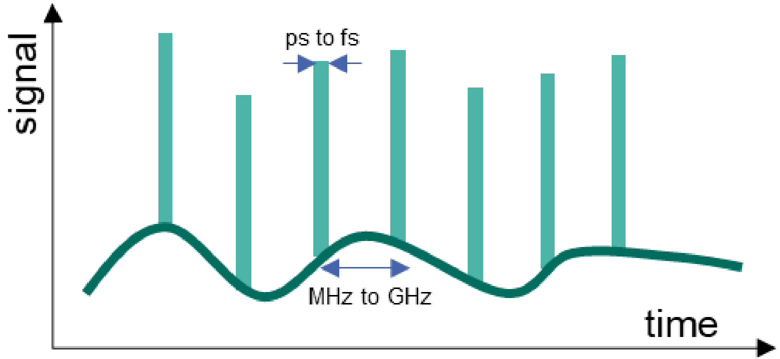
Distributed diagnostic detector network



- Accelerator test facility and synchrotron light source at KIT
- Circumference: 110.4 m
- Energy range: 500 MeV - 2.5 GeV
- Bunch spacing: 2 ns (500 MHz)
- Regular short bunch operation: low α_c
- Studies of micro-bunching instability

Why ultra-fast diagnostics?

To understand complex beam dynamics occuring in short time scales, fast real-time measurements are essential

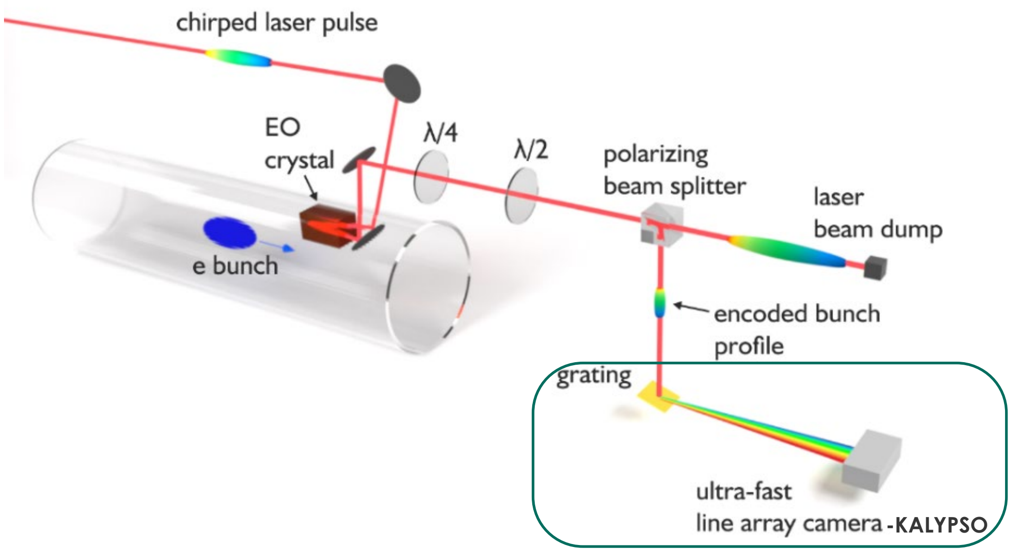


Requirements:

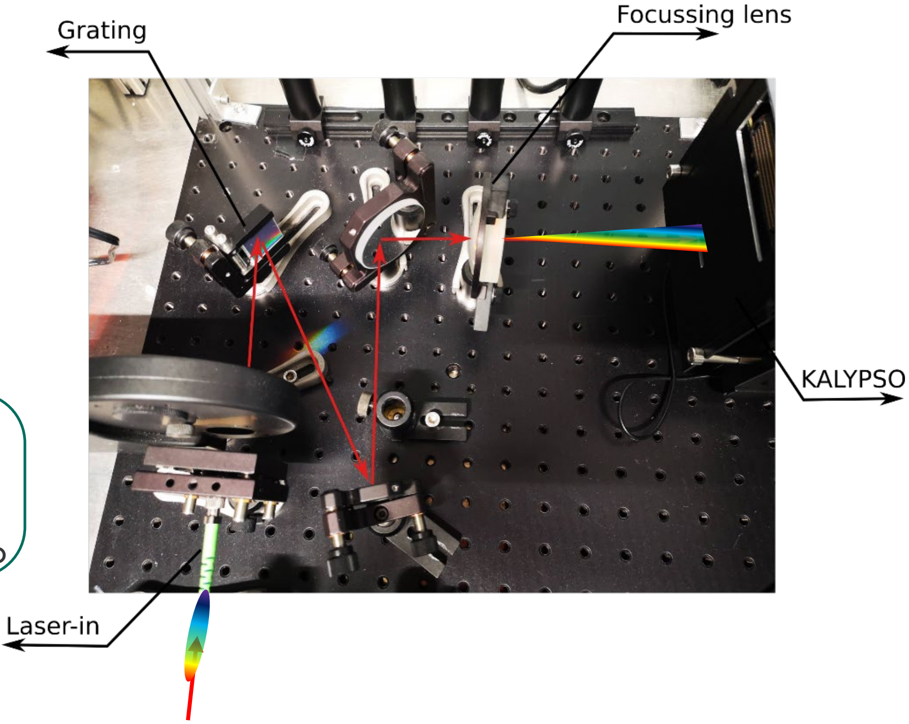
- Repetition rates in MHz regime and fs-ps time resolution
- High spatial resolution, broad field of view and wide spectral sensitivity
- Continous and long acquisiton time → secs to hours or days
- Synchronisation with other diagnostics

Longitudinal diagnostics

EO spectral decoding @ KARA



Spectrometer setup



S. Funkner, et.al, “Revealing the dynamics of ultrarelativistic non-equilibrium many-electron systems with phase space tomography,” in arXiv:1912.01323

EO spectral decoding @ KARA

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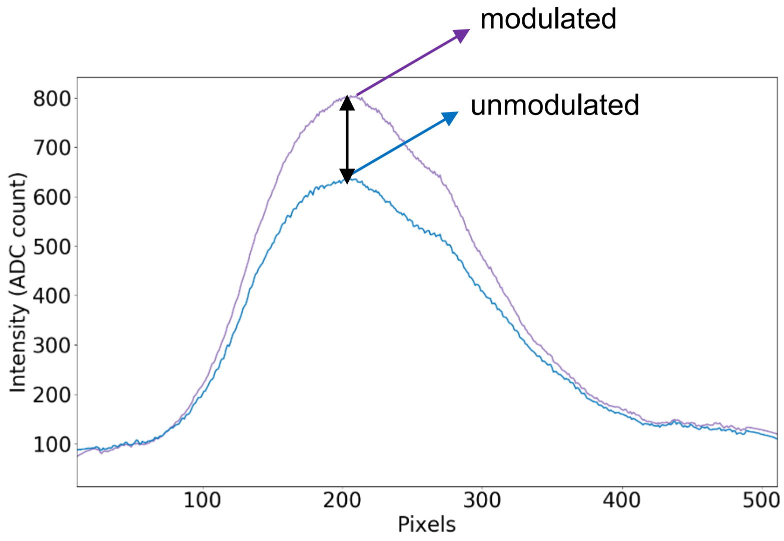
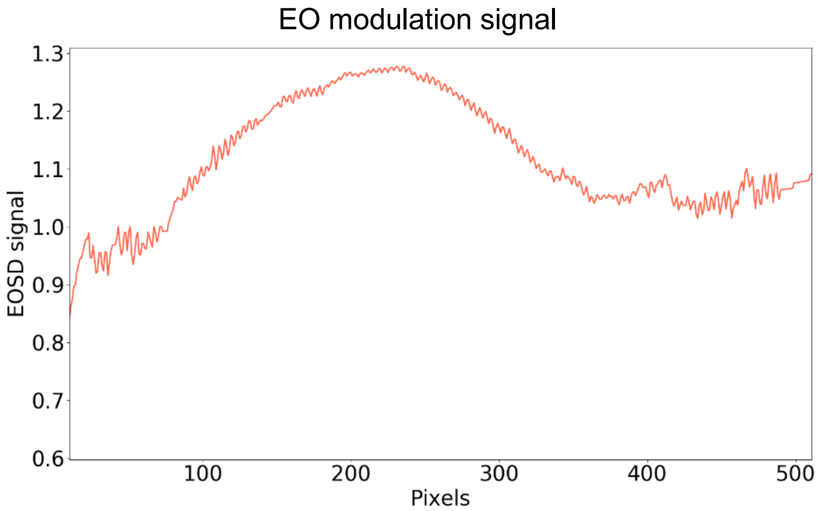


Single shot spectrally decode laser pulse



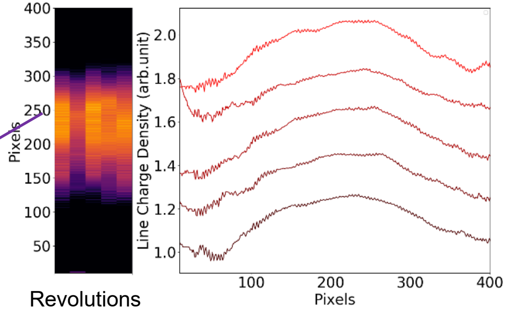
Modulation → ratio of modulated to unmodulated amplitude

$$Modulation = \frac{modulated\ (-background)}{unmodulated\ (-background)}$$

Patil, M. M. et.al, 2021. Proc. IBIC'21. Ed.: C. Kim, 1–6, JACoW Publishing. doi:10.18429/JACoW-IBIC2021-MOOB01

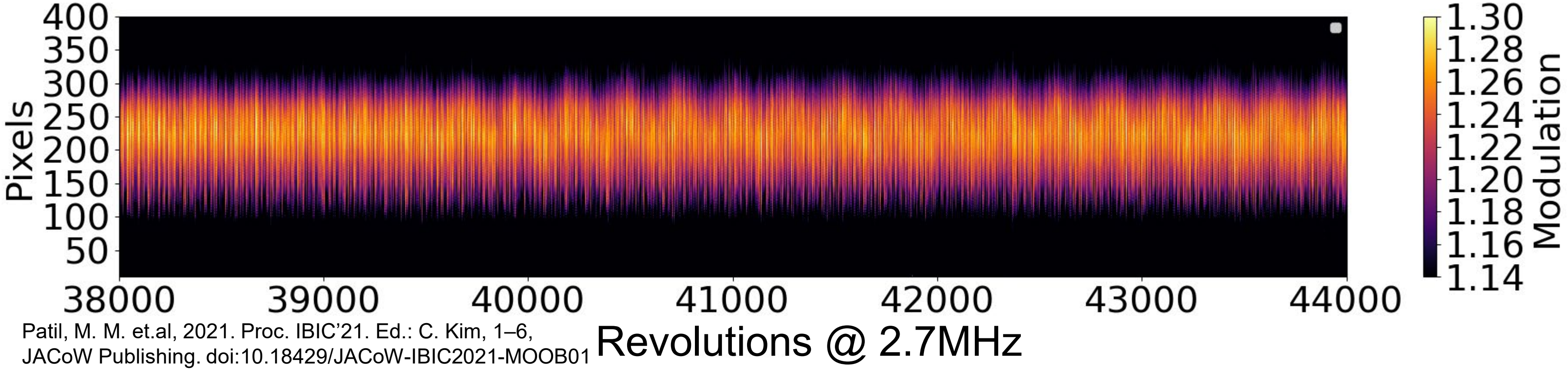
EO spectral decoding @ KARA

- Resolving electron bunch profile in every turn @ 2.7 MHz
- Capable of uninterrupted data acquisition for up to several seconds



5 consecutive bunch profiles

Section of a measurement dataset acquired by KALYPSO consisting of the longitudinal bunch profile evolution of 100000 turns



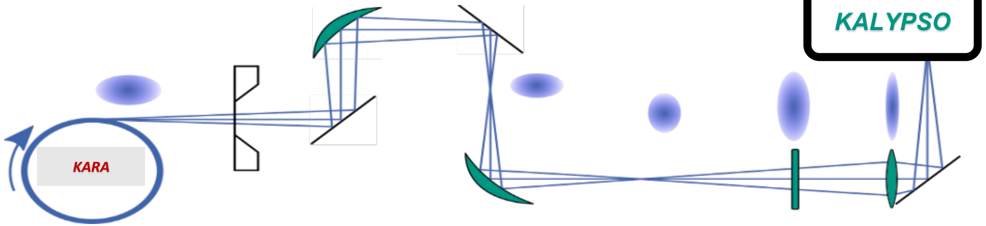
Patil, M. M. et.al, 2021. Proc. IBIC'21. Ed.: C. Kim, 1–6, JACoW Publishing. doi:10.18429/JACoW-IBIC2021-MOOB01

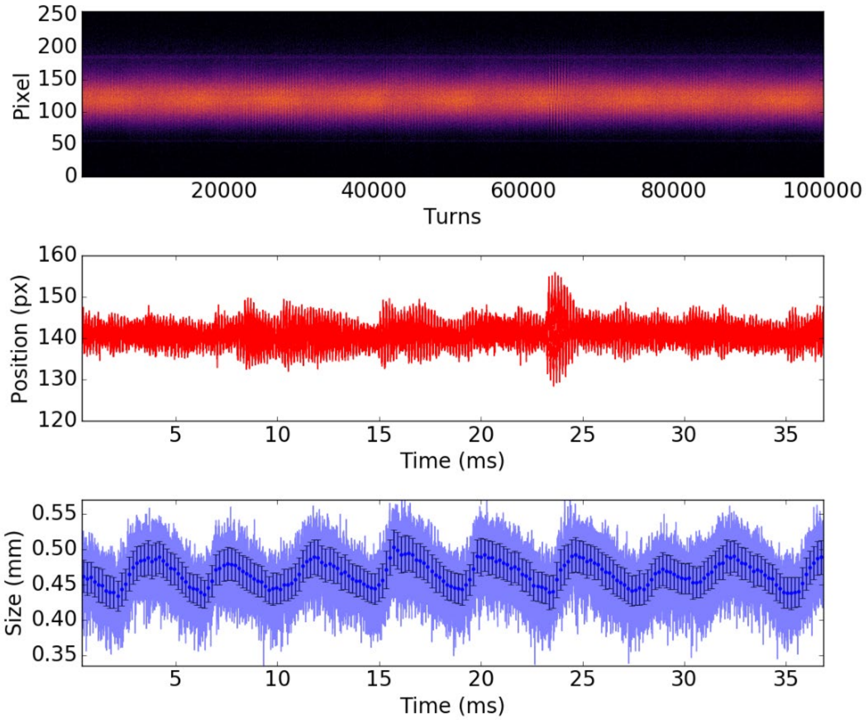
Transverse diagnostics

Horizontal bunch profile measurements

- Energy spread of electron bunches is an important parameter to understand micro-bunching instability, but it cannot be measured directly
- Horizontal bunch profile measurements in a dispersive section
- Measuring emitted incoherent synchrotron radiation (> 400 nm)

$$\sigma_x = \sqrt{\beta_x \epsilon_x + (D_x \sigma_\delta)^2}$$





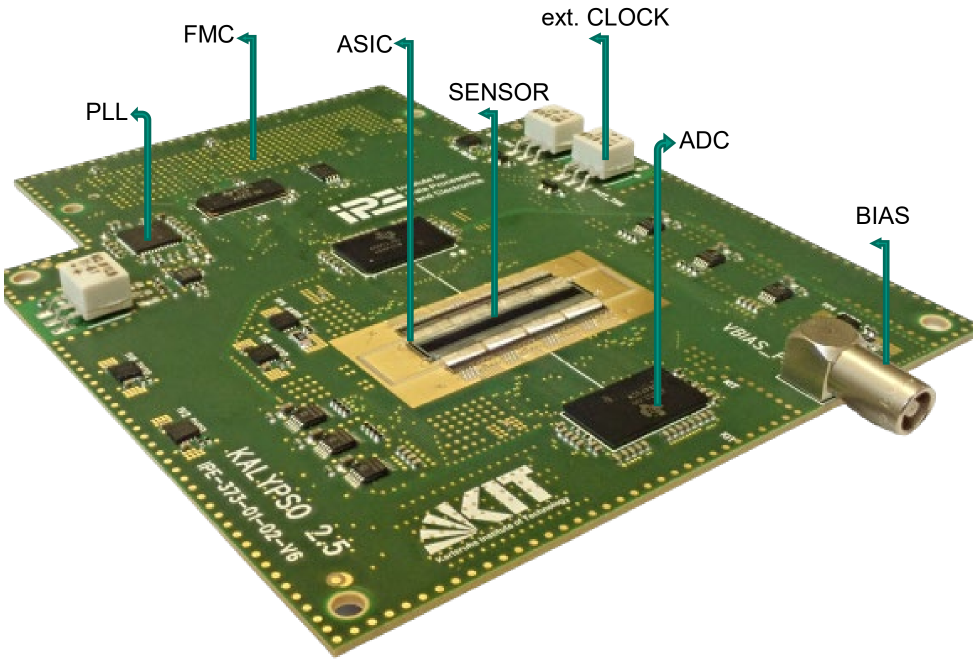
B. Kehrer, et.al, 10.1103/PhysRevAccelBeams.21.102803

KALYPSO

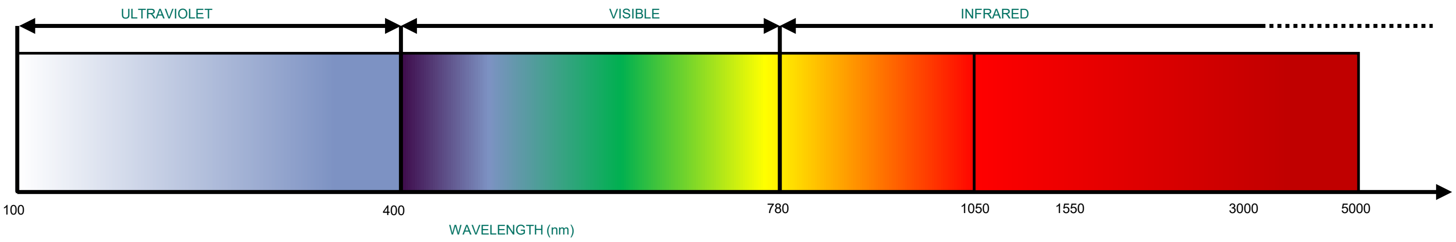
KALYPSO

(KArlsruhe Linear arraY detector for MHz rePetition rate SpectrOscopy)

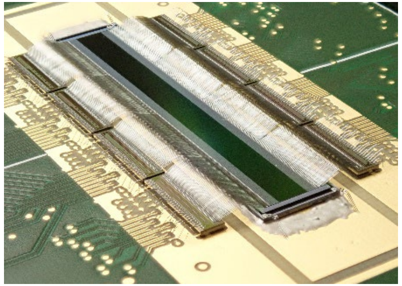
- **Sensor** : Si, InGaAs, PbS, PbSe
- **ASIC – Gotthard-KIT** : Low-noise and MHz frame rate
- **ADCs** : Up to 64 parallel ADC channels each operating up to 125 MS/s
- **External clock inputs** : Synchronization to experimental setup
- **Femtosecond time jitter clock distribution** : Programmable for user applications
- **FMC Vita-57.1 connector** : Compatible with any FMC carried card including µTCA based DAQ system



Sensor Technology

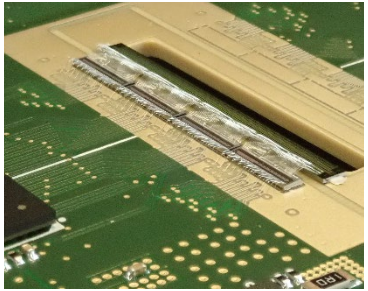


350-1050 nm



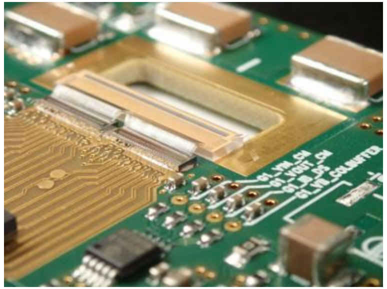
Si

950-2000 nm



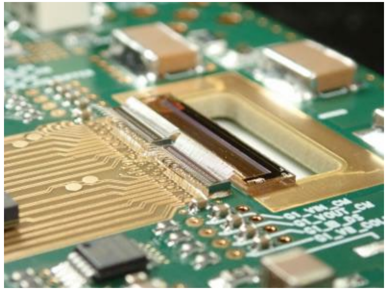
InGaAs

1000-3300 nm



PbS

1000-5000 nm



PbSe

Designed @ KIT

Hamamatsu Photonics

Infrared

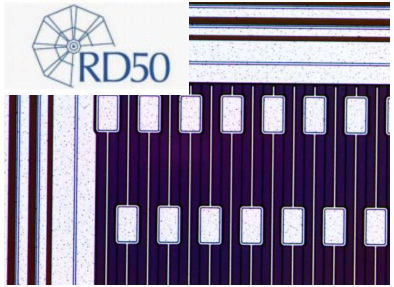
Trinamix

KALYPSO current development

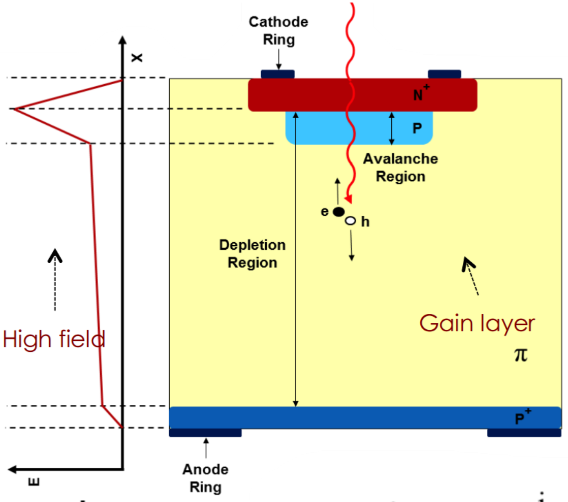
LGAD - Low Gain Avalanche Detector

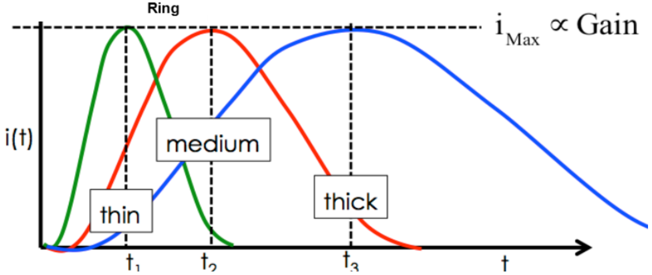
Shot-to-shot measurements of at hundreds Mfps

- Internal gain of ~ few tens
- Gain variable with bias voltage
- Rise time in few tens of ps
- Continuous data acquisition at hundreds of MHz
- High dynamic range for low intensity incoherent synchrotron radiation



Microstrip sensors
50 × 3000 μm²



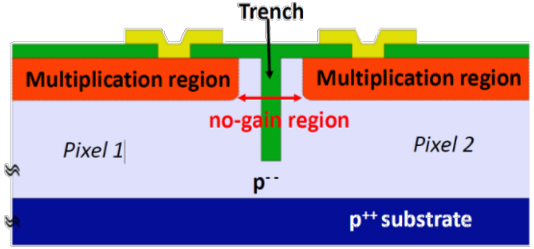


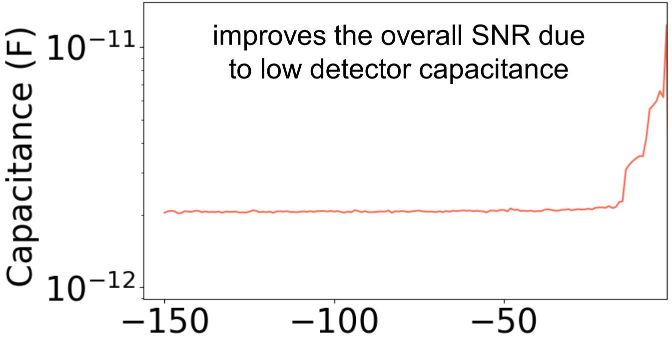
Courtesy of G. Paternoster , Giacomo Borghi (FBK) Work performed in the framework of RD50

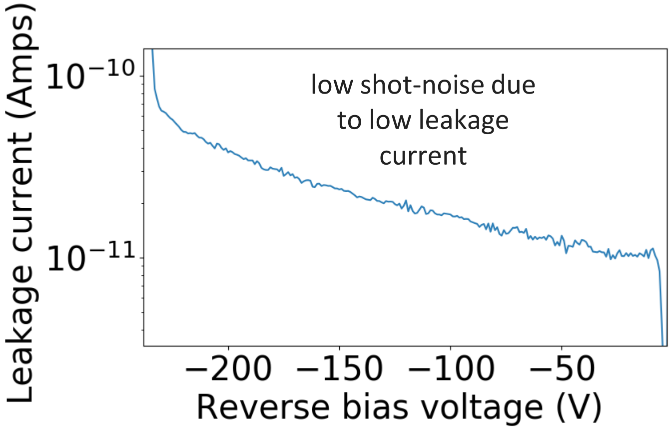
LGAD - Low Gain Avalanche Detector
Shot-to-shot measurements of at hundreds Mfps

- Internal gain of ~ few tens
- Gain variable with bias voltage
- Rise time in few tens of ps
- Continuous data acquisition at hundreds of MHz

Trench isolated LGAD structure
no-gain region of ~ few μm





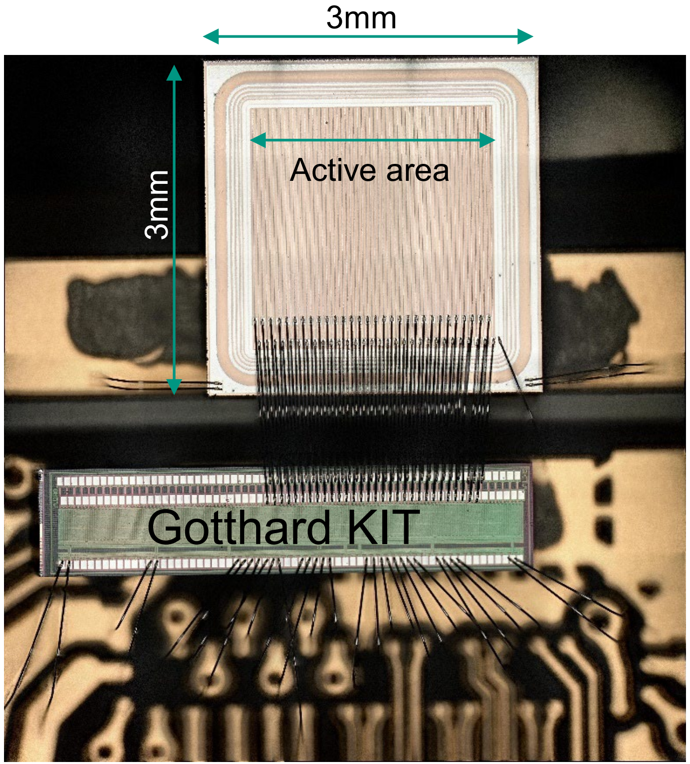


Courtesy of G. Paternoster , Giacomo Borghi (FBK)   Work performed in the framework of RD50

Transverse beam diagnostics with KALYPSO-LGAD

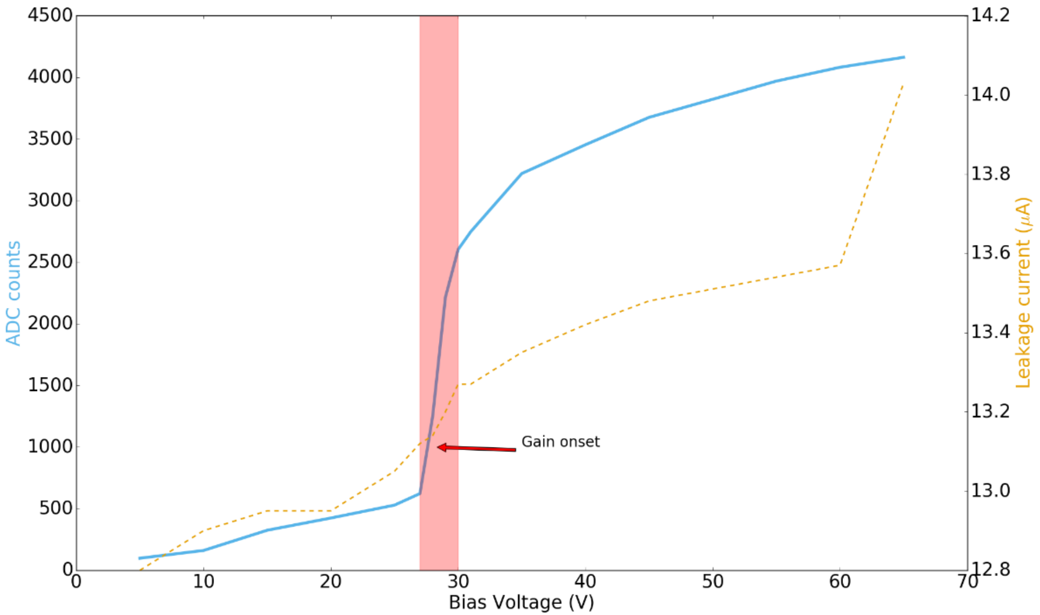
LGAD for horizontal bunch size measurements

- Sensor with a very small active region < 3x3 mm
- Sensitive to radiation in the visible spectrum
- Readout by Gotthard (proto) developed at KIT
- Maximum possible framerate is 12 MHz
- Setup at the VLD port working at 2.7 MHz for single bunch mode



KALYPSO - LGAD characteristics

- Gain layer activated at 28 V
- Gradual gain increase > 30 V



Comparison Novel Si vs LGAD

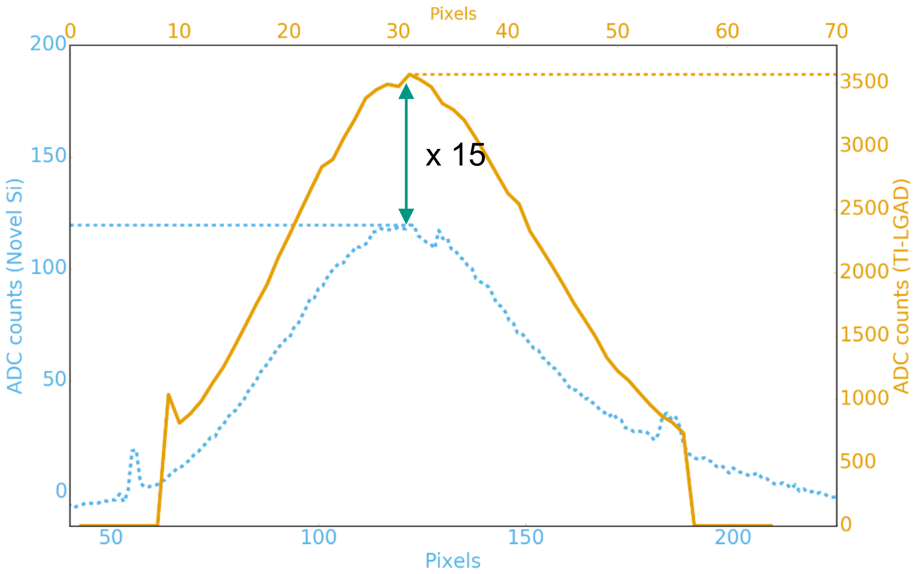
Pros

- Gain factor of ~15
- Better SNR
- Wide dynamic range (sensitive to very low radiation)
- Good spatial resolution – 50µm

Cons

- A prototype version hence limited active area†

Bunch current 1 mA

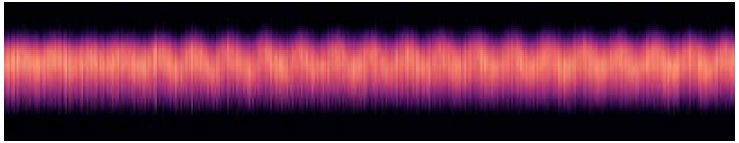


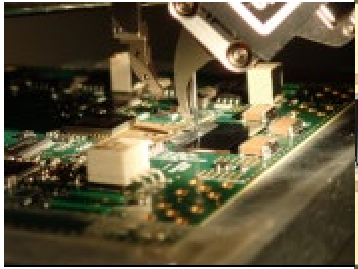
Horizontal bunch profile

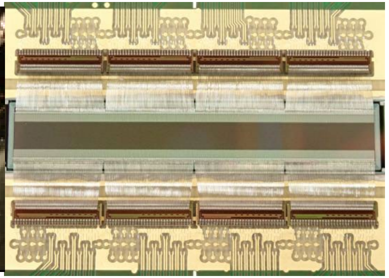
†An engineering run is scheduled to produce custom sensors

Summary

- LGAD based KALYPSO has been tested successfully at the VLD port at KARA
- Proof of concept for the use of LGAD not only for HEP but also for photon science experiments
- The system shows significant improvement in SNR, dynamic range
- Next step to use the system in a multi-bunch environment and study its timing characteristics, eg. Pile up, TCT







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THANK YOU