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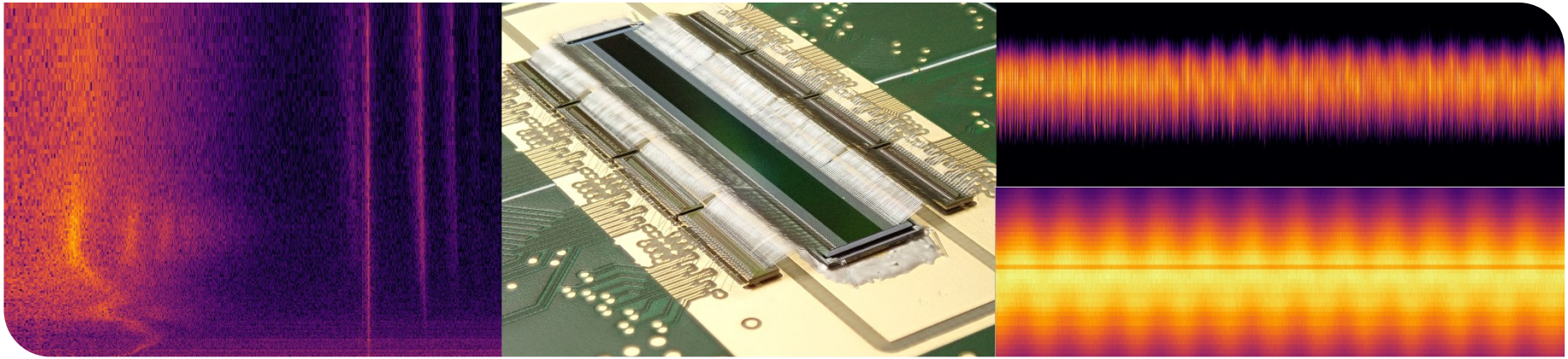
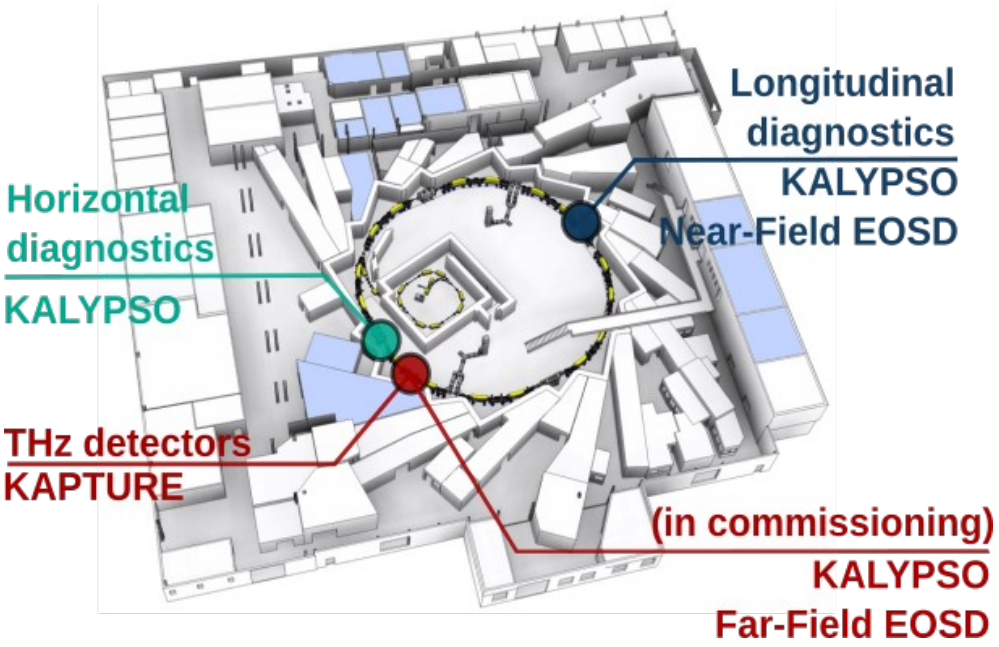
KALYPSO LGAD - A MHz repetition rate line camera based on trench isolated low gain avalanche detector

M. Patil*[1], M. Caselle*[1], E. Bründermann[1], S. Chilingarayan[1], A. Kopmann[1], G. Niehues[1], J. Steinmann[1], S. Stankov[1], A.-S. Müller[1], G. Borghi[2], G. Paternoster[2], M. C. Vignali[2], M. Boscardin[2]

*michele.caselle@kit.edu, *meghana.patil@kit.edu [1] KIT (Karlsruhe, Germany), [2] FBK (Trento, Italy)

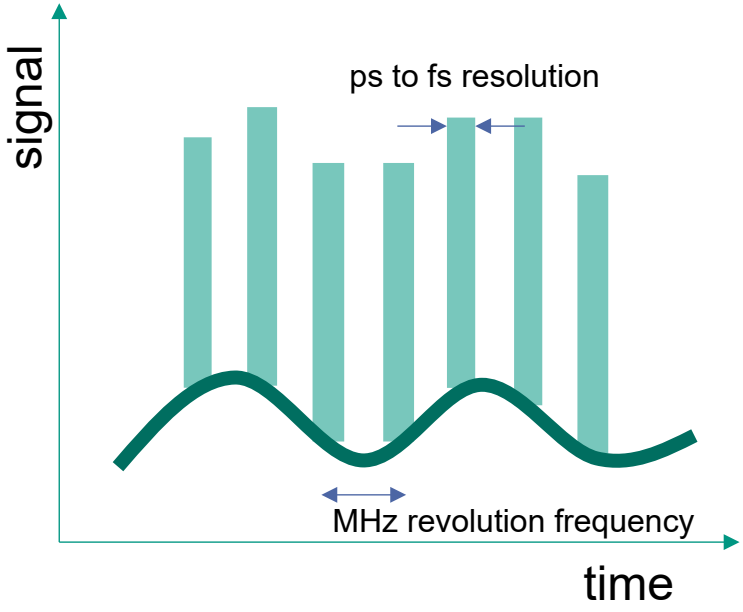


Karlsruhe Research Accelerator - KARA



- Accelerator test facility and synchrotron light source at KIT
- Circumference: 110.4 m
- Energy range: 500 MeV - 2.5 GeV
- Bunch spacing: 2 ns
- Total number of bunches: 184
- Short bunch operation: $\sigma_z \sim 4$ ps
- Studies of micro-bunching instability

Requirements for beam diagnostics

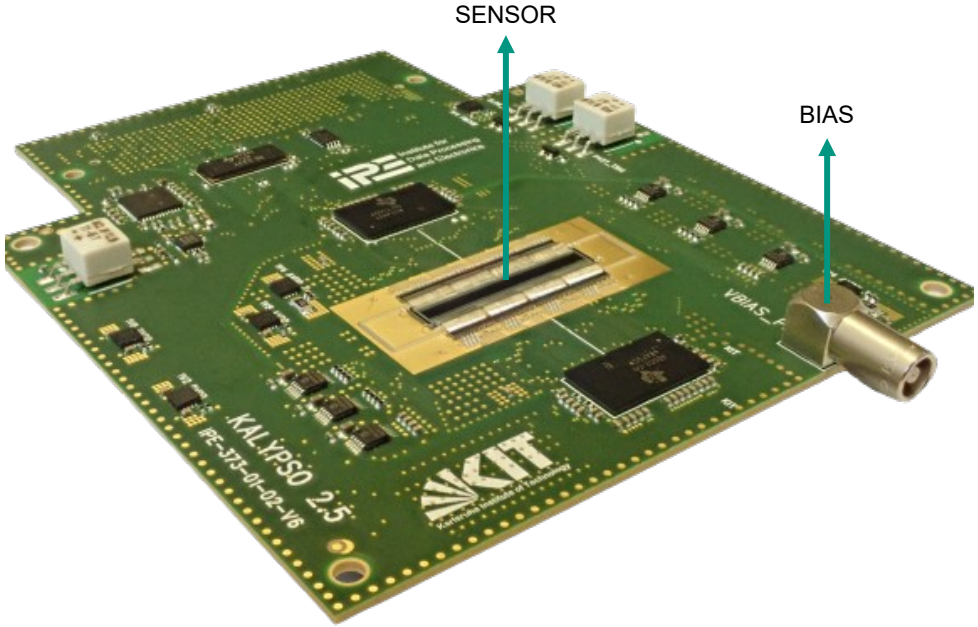


Parameter	Value
High frame rate	> 1 Mfps
High resolution	256 channels < 50 µm pitch
Wide spectral sensitivity	NUV, VIS, NIR, mid-IR
Long observation times	Milliseconds to hours
Synchronization	Correlating measurements at different setups

KALYPSO

KArlsruhe Linear arraY detector for MHz rePetition rate SpectrOscopy

- **Sensor**: Si (Vis) , InGaAs (NIR), PbS, PbSe (Mid-IR), LGAD (Vis)



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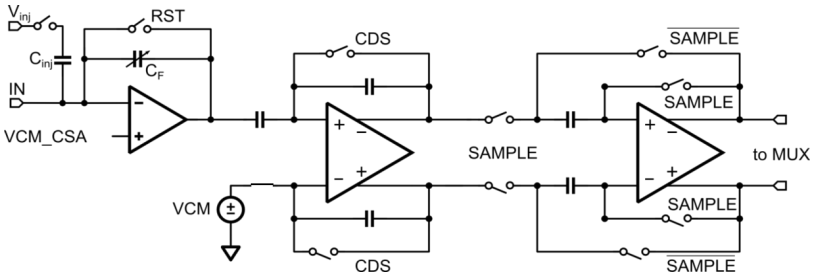
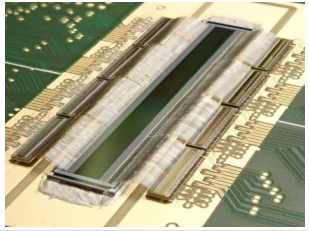
- **Sensor**: Si, InGaAs, PbS, PbSe, LGAD
- **ASIC – Gotthard-KIT**: Low-noise and MHz frame rate

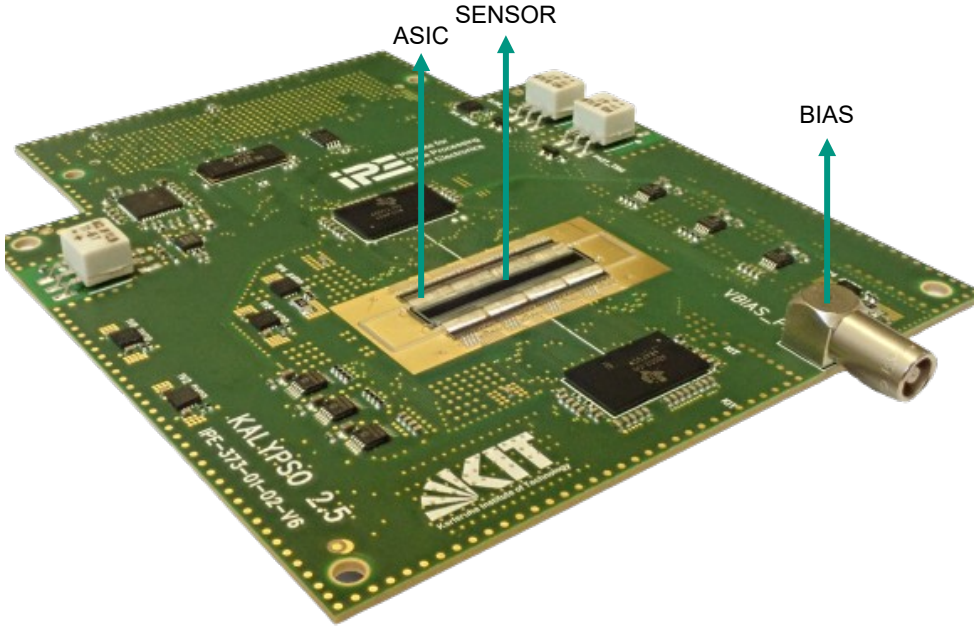


Courtesy: M. Caselle

- **Interconnects :**



~1400 wire-bondings!



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- **Sensor**: Si, InGaAs, PbS, PbSe, LGAD
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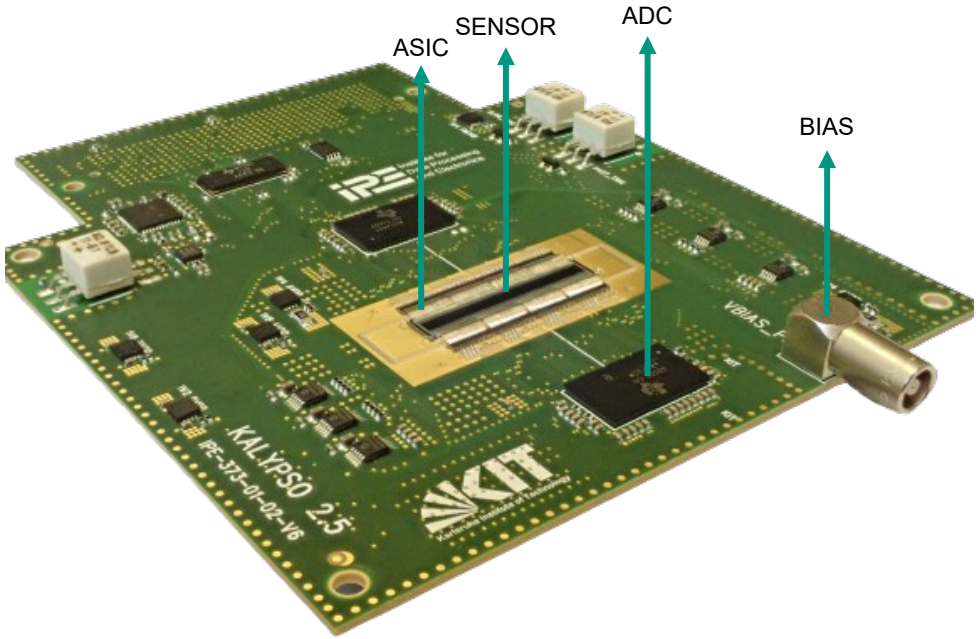
- **ADCs**: Up to 32 parallel ADC channels (64 time -interleaved) each operating up to 125 MS/s



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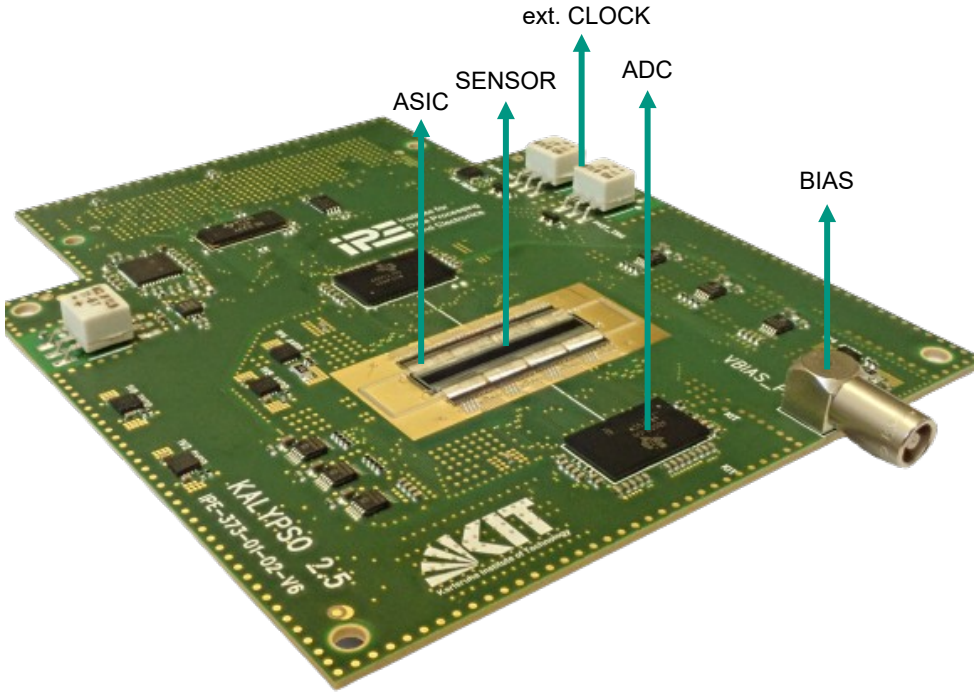

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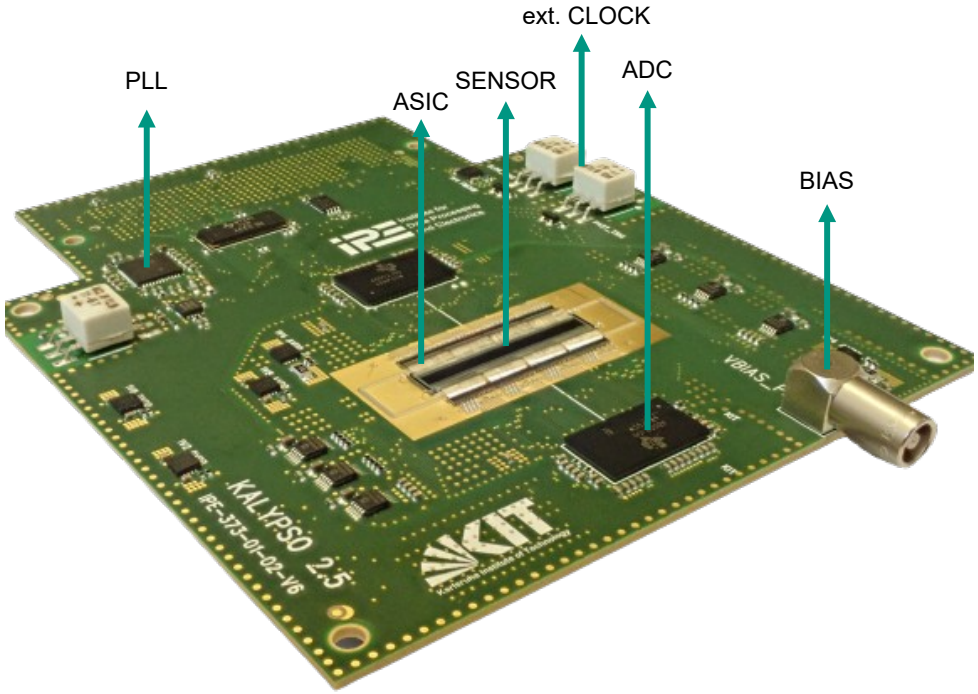

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- **External clock inputs**: Synchronization to experimental setup
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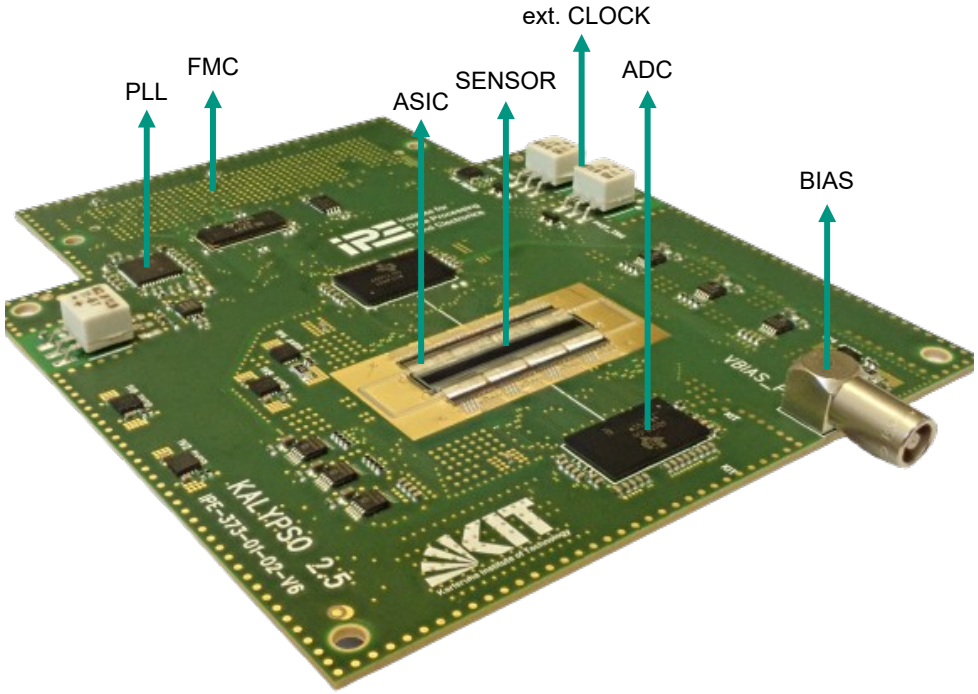
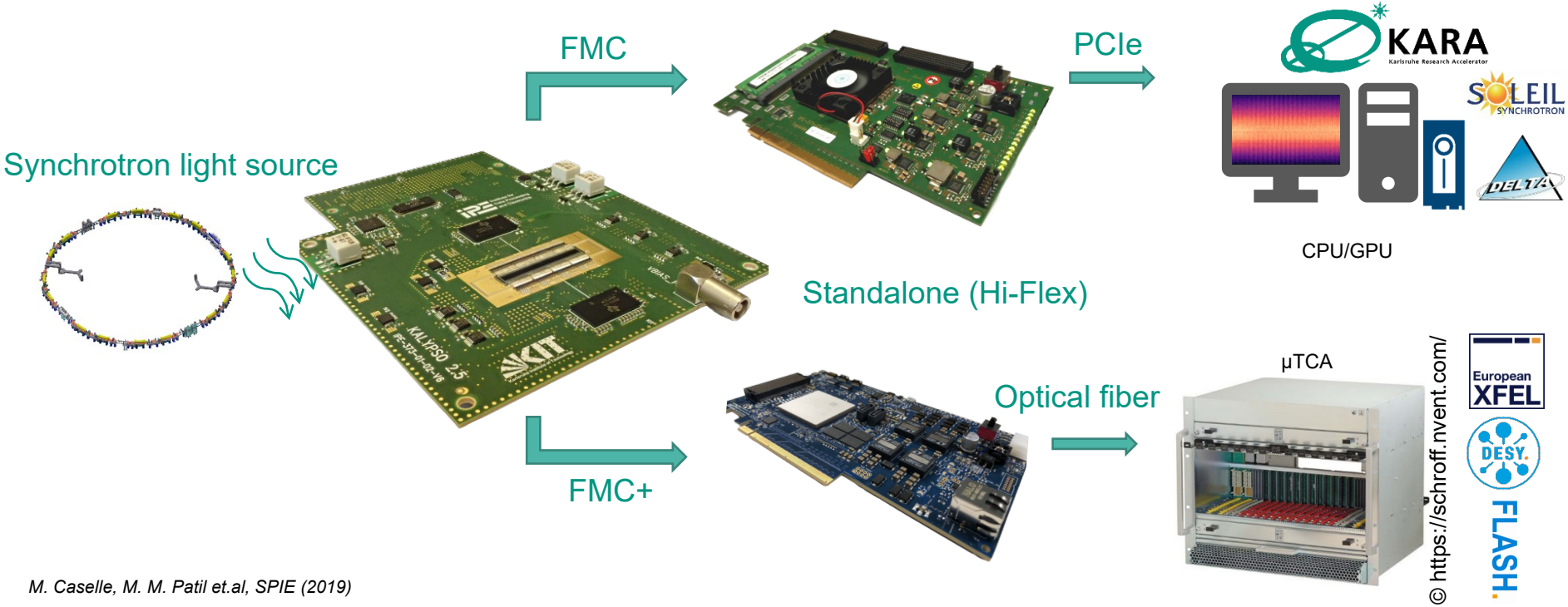
- **FMC/FMC+ connector**: Compatible with standalone and µTCA based DAQ system

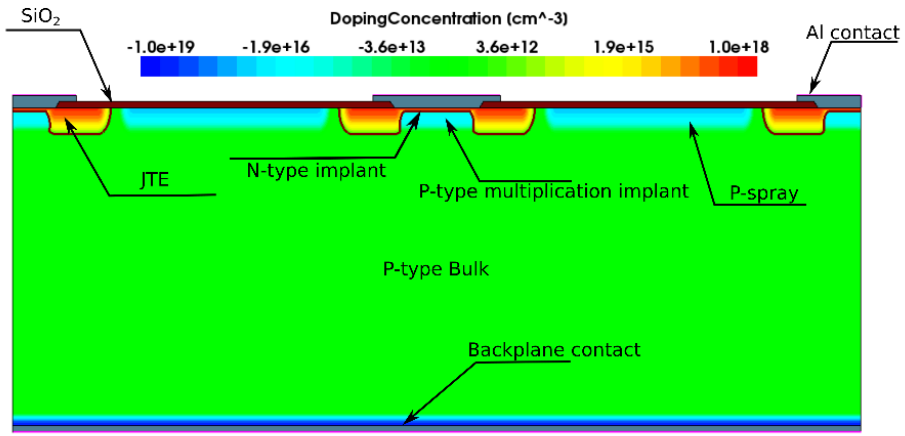


Data Acquisition Flow



M. Caselle, M. M. Patil et.al, SPIE (2019)

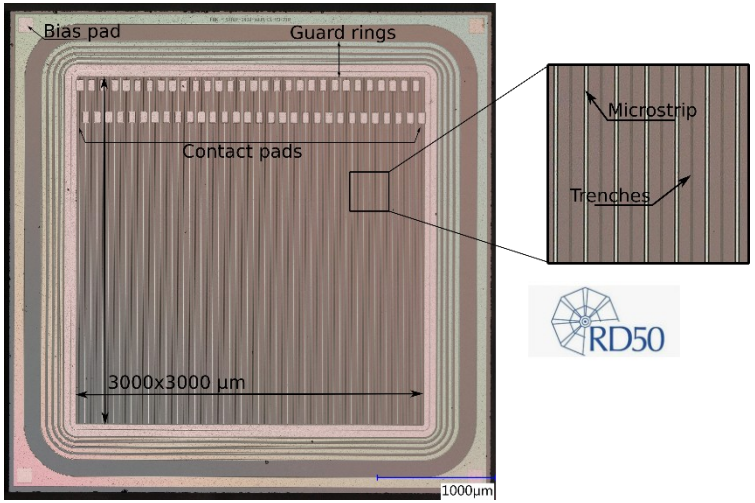
LGAD – Low Gain Avalanche Detector

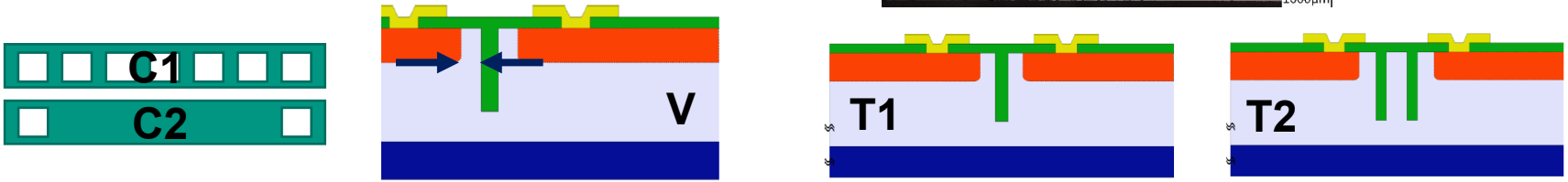


- An additional layer called „gain layer“ below the microstrip implant
- A highly localized electric field below breakdown of Si initiates an avalanche process
  → 3 x 10^5 V/cm
- Junction Termination Extension (JTE) required to prevent edge breakdown
- Isolation between strips → p-spray/p-stop process

Deep trench isolated LGADs (TI-LGADs)

- Fill factor improved from <50 % to >80 %
- First prototyping within **RD50**, sensor with a very small active region →3x3 mm^2
- Designed for particle physics as well as photon science
- Characterization performed from device level to system level
- Very low dark current → in the order of a few hundred pA/channel





Picture courtesy of G. Paternoster (FBK), Work performed in the framework of RD50

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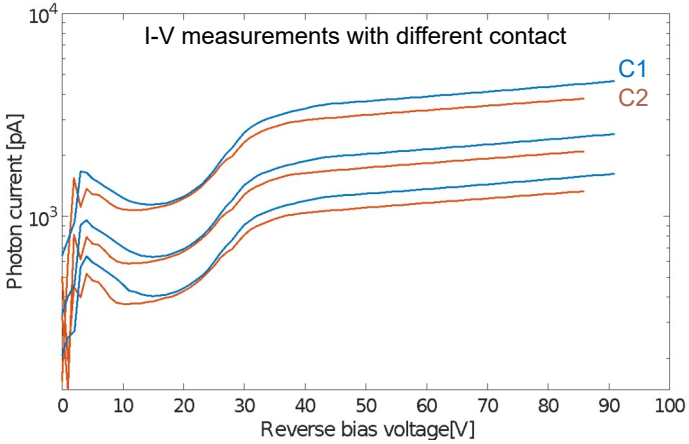
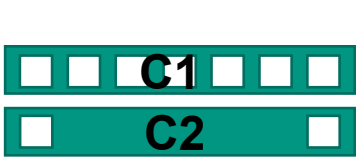
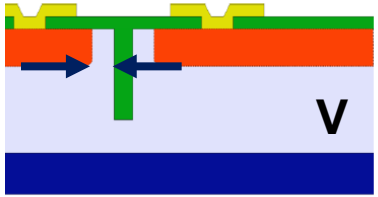
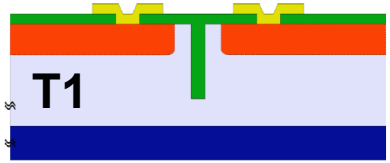
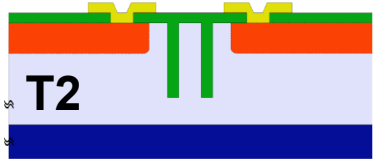




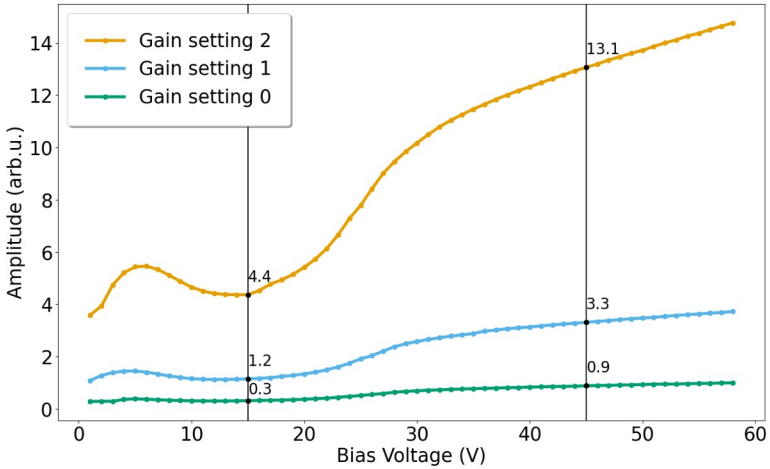






Picture courtesy of G. Paternoster (FBK), Work performed in the framework of RD50

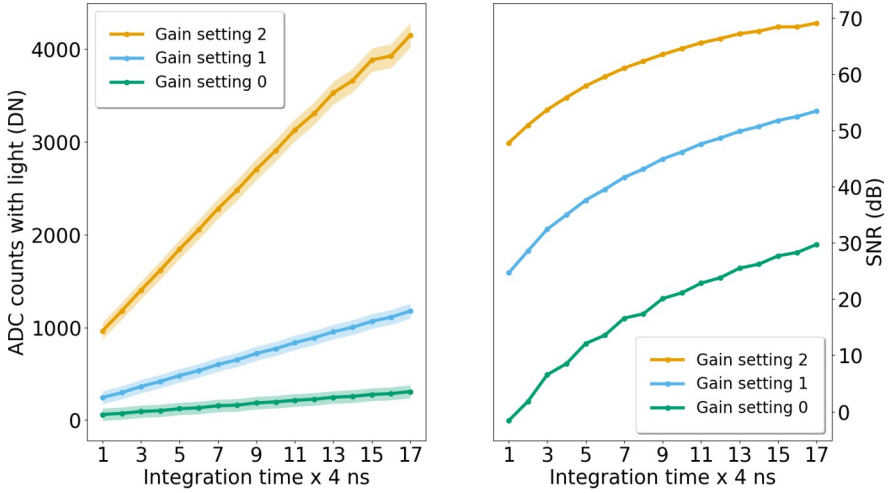
Characterization of full readout chain



- The TI-LGAD-based line camera shows increased sensitivity with higher gain settings, particularly evident with Gain setting 2, which sharply amplifies the signal at higher bias voltages
- Three gain settings help in measuring a wide range of visible light intensity
- For synchrotron radiation @ bunch currents > 2 mA gain 0 or 1 is used
- For synchrotron radiation @ bunch current < 2 mA gain 2 is used (more interesting region for radiation study)

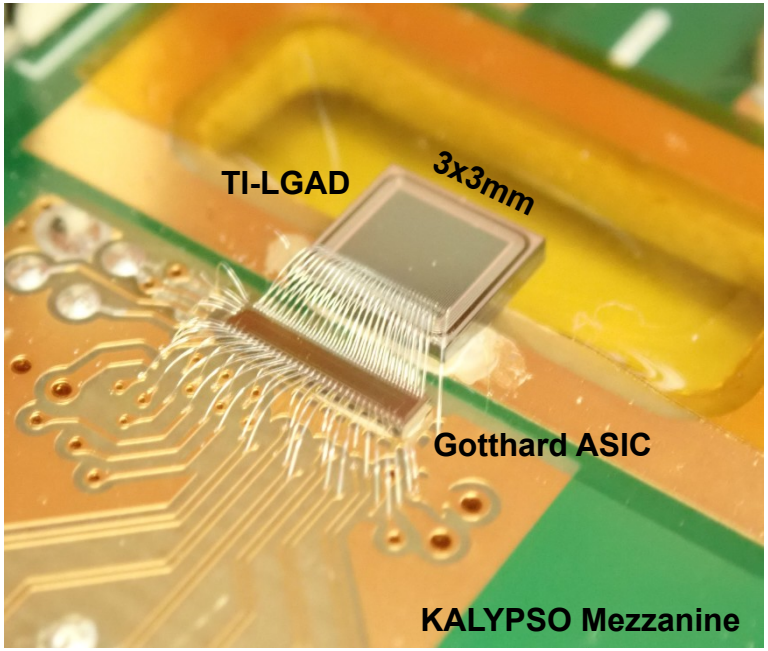
Integration time scan

- A CW source with uniform illumination across the sensor has been used
- The ADC counts exhibit a nearly linear increase with extended integration time across all gain settings, with Gain setting 2 achieving the highest signal levels
- Consistent SNR trends across integration times
- Adjusting integration time for each gain setting could optimize dynamic range, balancing signal fidelity and noise.



LGAD for horizontal bunch size measurements

- Sensitive to radiation in the visible spectrum
- Readout by Gotthard-KIT developed at KIT
- Maximum possible framerate is 12 Mfps in full occupancy
- Setup at the VLD port working at 2.7 Mfps for single bunch mode



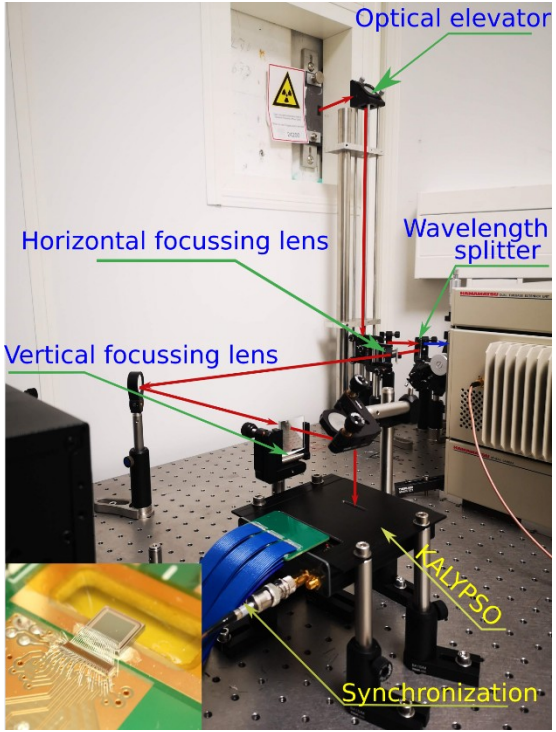
Horizontal bunch size measurement with LGAD

- Energy spread σ_δ cannot be measured directly
  →Measuring the horizontal bunch profile σ_x at the dispersive section

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

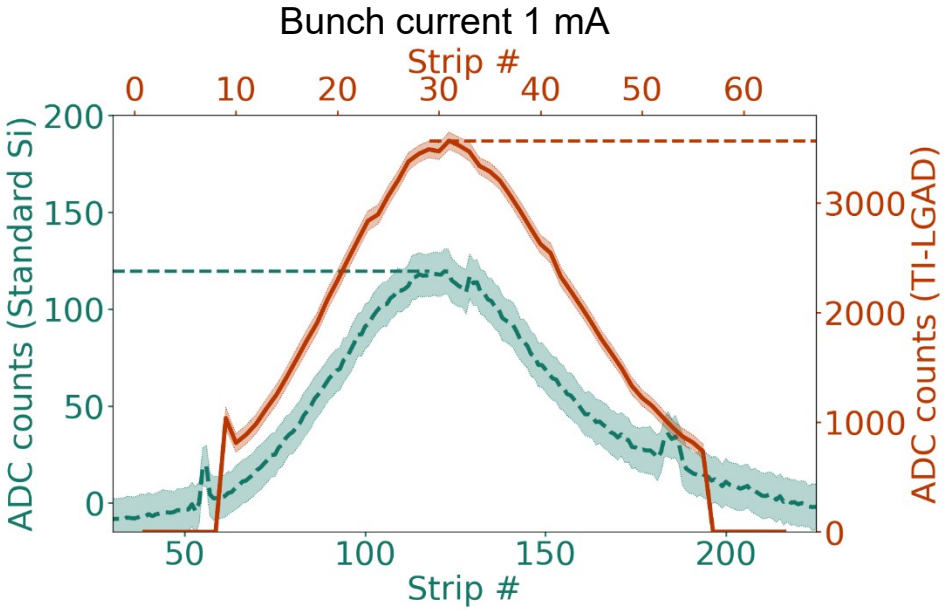
β_x-Beta function, ϵ_x- Emittance, D_x- Dispersion

- Measuring the incoherent synchrotron radiation (ISR) at a 5° port of a dipole bending magnet
- Radiation in the visible region HPF 450 nm



Performance of KALYPSO-LGAD

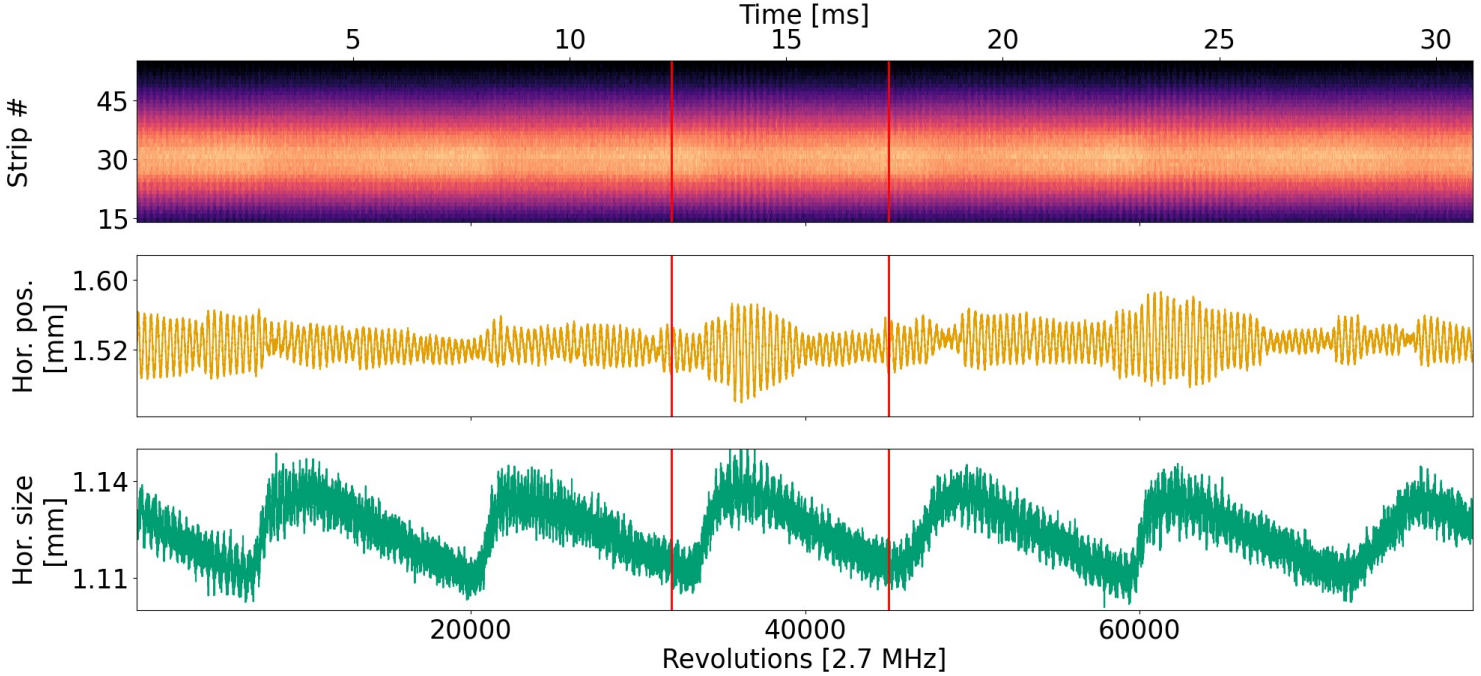
- Gain factor of ~15 , with multiplication from Gotthard x2
- Better SNR 45 dB → 60 dB
- Average ENC of 500 e^-
- Sensitivity toward low bunch charges
  257 pC (0.7 mA) → 18 pC (50 µA)
- Good spatial resolution < 50 µm
- A prototype version hence limited active area †



Horizontal bunch profile

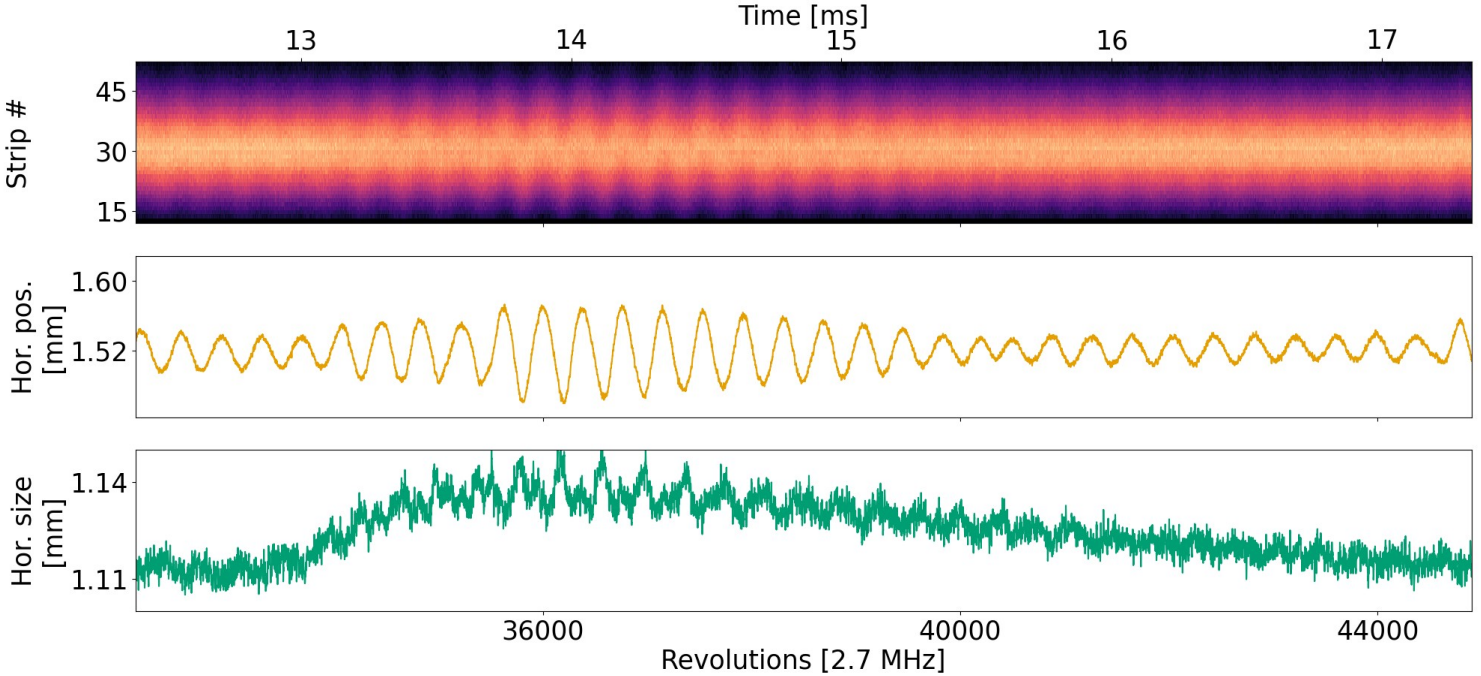
† An engineering run is scheduled to produce custom sensors

Horizontal bunch size measurement with LGAD



- Up to **2 million** single shot acquisition → 736 ms
- Longer observation times → acquistions up to 6 hours, more possible (limitation: storage size)

Horizontal bunch size measurement with LGAD

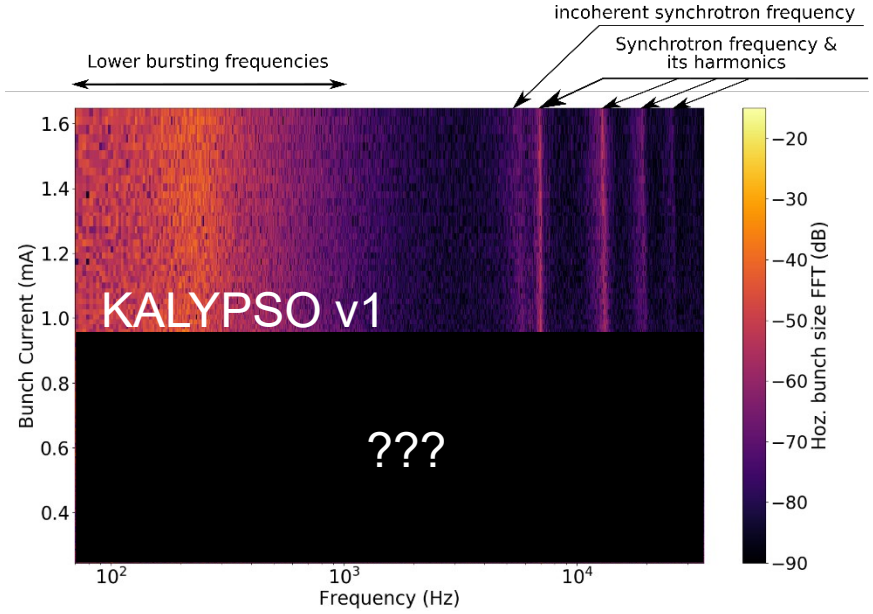


- Horizontal bunch size and THz emission modulate with the same frequency
- Synchronous motion of the electron bunch can be measured

Current decay analysis

- Previous detectors
  - Fast gated camera: Low bunch charges possible, limited frame rate and observation time with only every 6th turn, with a max of 80 samples
  - KALYPSO v1: Low bunch currents limited, but high frame rate and long observation time,
  - turn by turn measurements possible

Rota, L. (2018, PhD thesis, https://doi.org/10.5445/ir/1000082349



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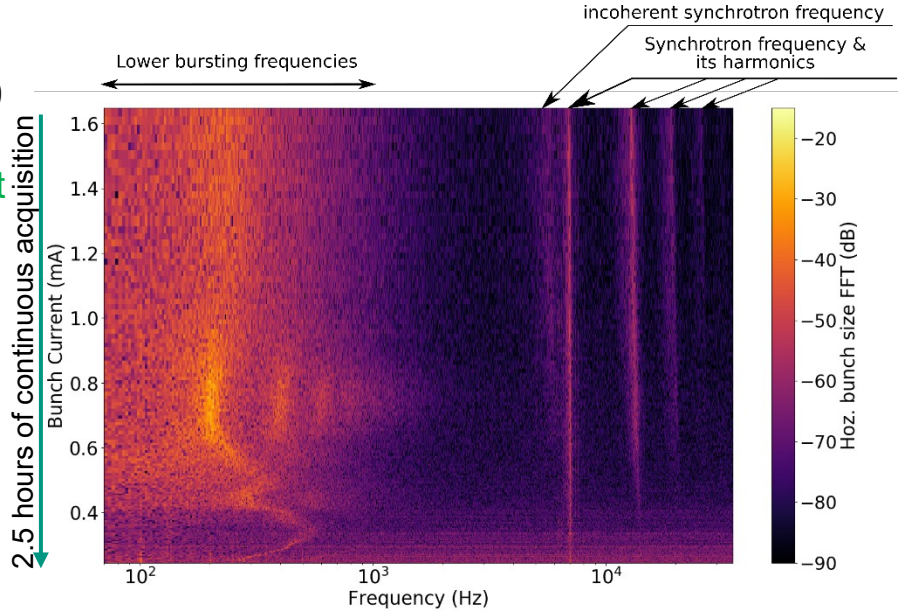
- New setup - **KALYPSO-LGAD**
  - Low bunch currents down to 50 µA
  - High framerate and long observation time **1,000,000** samples per dataset per bunch current acquired
  - Turn by turn measurements



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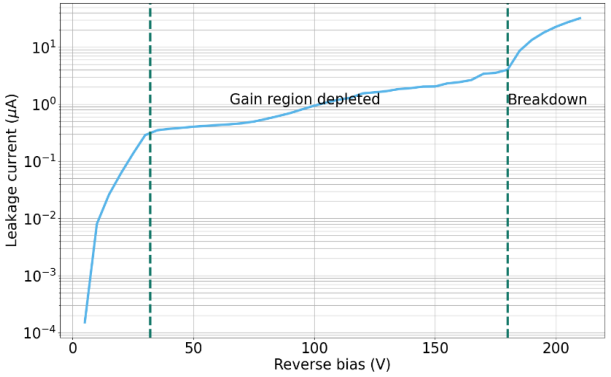
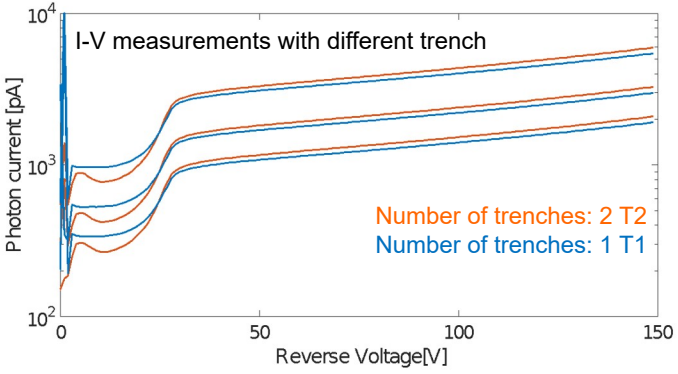
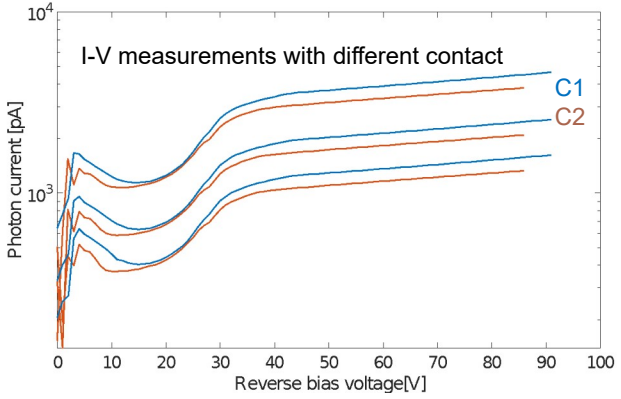
Thank you for your attention

LGAD characteristics – IV curve

- I-V curve measurements
- Dark current approximately 1 µA across 64 channels
- Breakdown voltage observed at approximately –180V
- T2 shows higher gain than T1 due to reduced dead area
- C1 (Dist. Contact) shows higher gain when compared to C2 (Peri. Contact)







Master thesis : J. Deutsch