PSI Center for Neutron and Muon Sciences

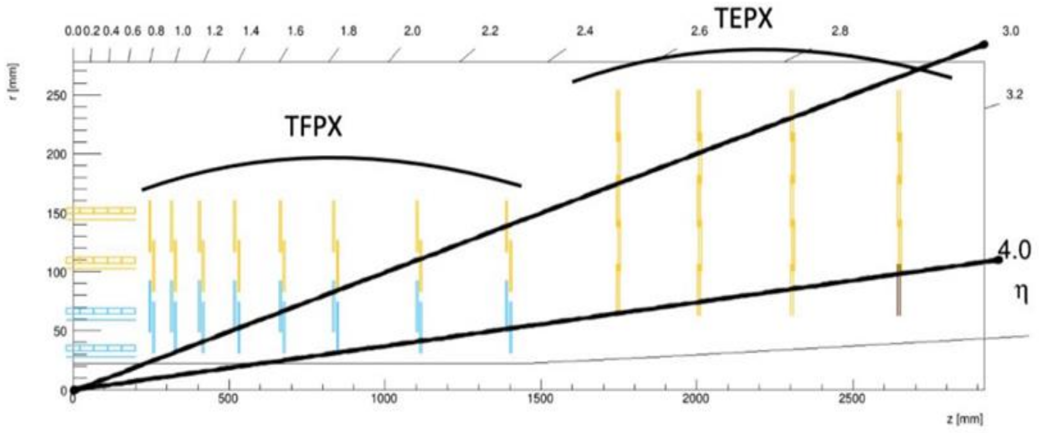
LIGHT01: A prototype LGAD pixel readout ASIC with ps timing resolution in 28 nm technology

Abderrahmane GHIMOUZ, On behalf of the HEP group

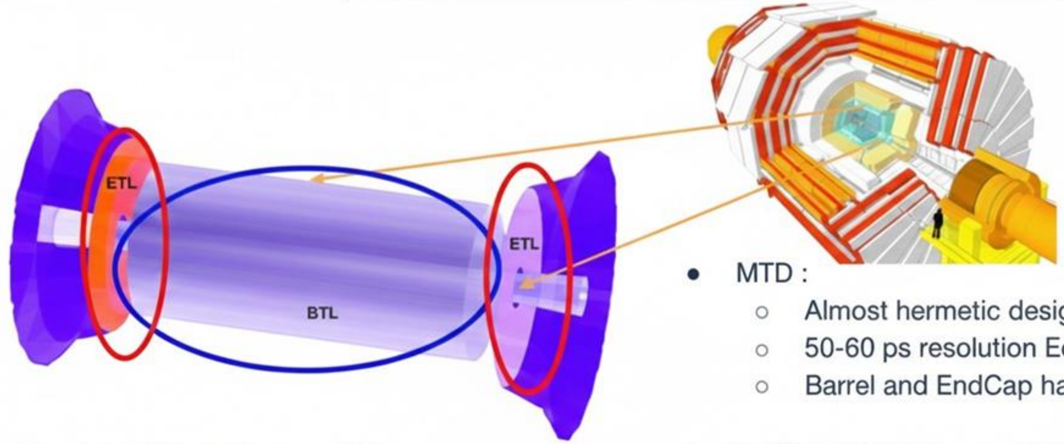
TIPP 2026, 05 Feb 2026

Need for timing

How to improve further ?



Credit : Dr. Wolfram Erdmann



- MTD :
  - Almost hermetic design, |η| < 3.0
  - 50-60 ps resolution EoL
  - Barrel and EndCap have different needs

- Barrel Timing Layer - BTL :
  - Sensors: LYSO+SiPM
  - Inner radius: 1148 mm - 40
  - Length: ± 2.6 m
  - Fluence at 3000 fb^{-1} ~$1.7x10^{14}$ n_{eq}/cm^2

- EndCap Timing Layer - ETL :
  - Sensors: LGAD
  - Radius: 315 mm < r < 1200 mm
  - z-position 3.0 m - 45 mm thick
  - Fluence at 3000 fb^{-1} ~ $1.6x10^{15}$ n_{eq}/cm^2

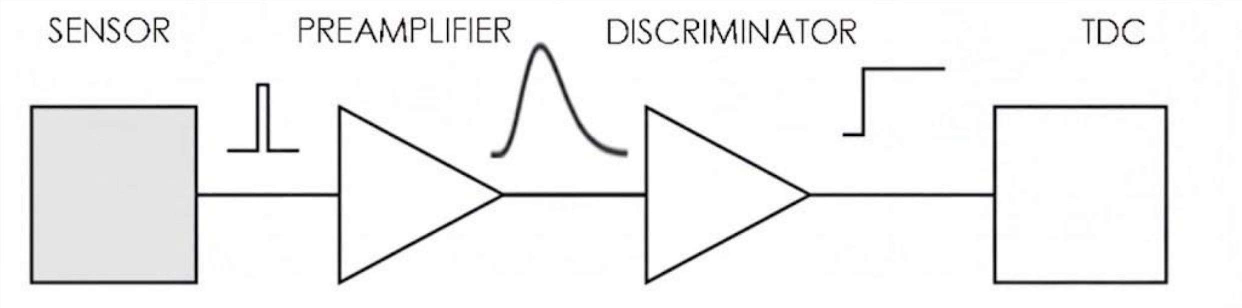
- CMS 'Phase 2' timing covers region up $|\eta| \leq 3$

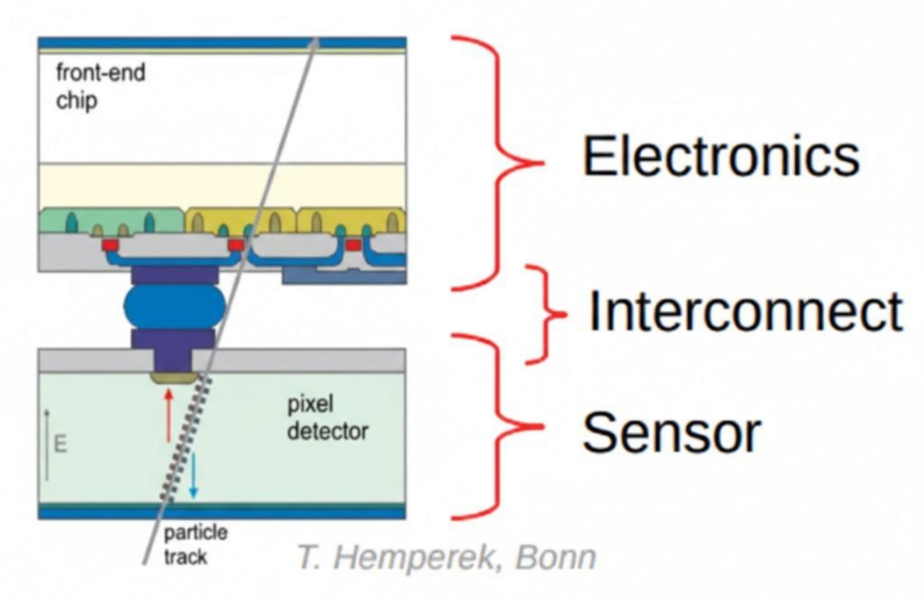
- Possible extension $|\eta| \approx 4$ in future upgrade replacing 1 or 2 TEPX pixel disks with LGAD pixels

Goal

To **design** a readout **ASIC** targeting a future **CMS** upgrade. It should be capable of operating with **pixel** detectors based on **LGAD** technology. It is designed in a **28 nm CMOS** technology, for **timing** measurements.

Timing equation



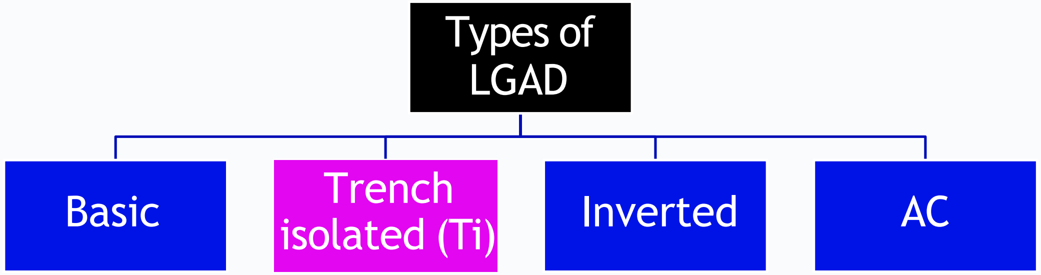


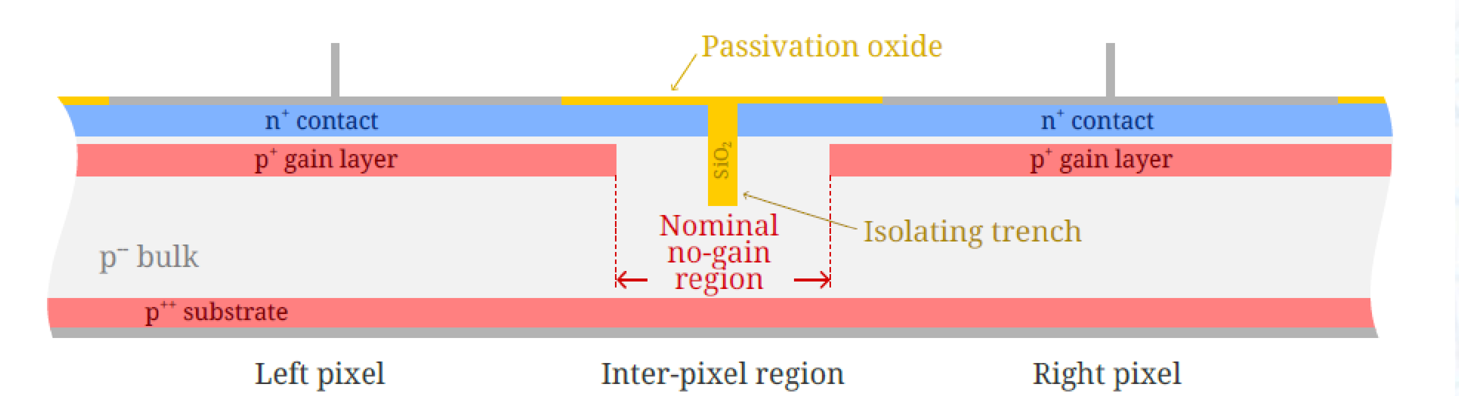
Time resolution of a timing measurement Front End Electronics (FEE)

$$\sigma_t^2 = \underbrace{\sigma_{\text{Landau}}^2 + \sigma_{\text{Distortion}}^2}_{\text{To understand (characterization)}} + \underbrace{\sigma_{\text{Timewalk}}^2 + \sigma_{\text{TDC}}^2 + \sigma_{\text{Jitter}}^2}_{\text{To model and optimize (FEE architecture)}}$$

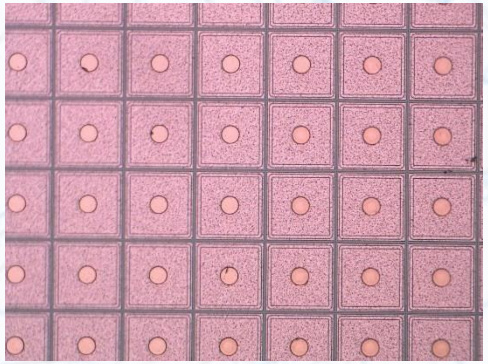
Type of LGAD sensors : Ti-LGAD

PSI





Credit : Matias Senger



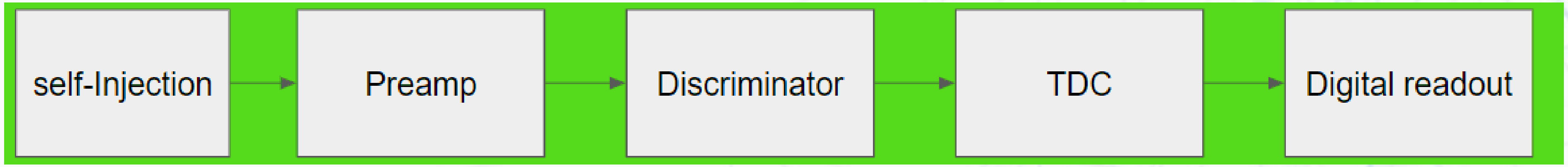
FBK@ AIDAinnova (DRD3)

- Sensor configuration: 30x30 pixel array
- Pixel dimensions: 100 x 100 µm² ➔ $C_{det}{\sim}0.12\ to\ 0.2\ pF$

Collaboration with the university of Zurich

System requirement

Property	Value
Pixel size	100 x 100 μm^2
Input capacitance	~ 0.2 pF (including parasitic)
Time res RMS	30 ps
Max dead time	< 250 ns
Total power density	1 W/cm2
Threshold level	< 2000 e^-
Dynamic range (Q)	Equivalent 2000 e^- to 150 Ke^-
Max hit rate per pixel	50 KHz



For a σ ~ **30ps** @MIP :

- 20ps : the jitter of the sensor*
- 5ps : the clock jitter and the remaining disturbances
- 20ps : the jitter of the FE
- 10ps : the resolution of TDC

Budget

$$\sigma = \sqrt{20^2 + 5^2 + 20^2 + 10^2}$$

*Matias SENGER https://doi.org/10.5167/uzh-263142

Specs of the first gen ASIC: LIGHT01

- **64 Channels in 8x8 Pixel Array**
    - Different preamplifier topologies, optimized for minimum timing jitter
    - Per-pixel TDC
    - Integrated calibration system : TOT, RO frequency
    - Standalone test structures for critical blocks
    - SPI for programming and readout
    - Zero suppression readout
    - Use of specific IPs from the CERN 28nm forum library : Rad-Hard PADs, SLVS Drivers.

- **Bump-Bonding to Ti-LGAD Sensor**

LGAD based Integrated Granular Hybrid Timing ASIC

Details about the ASIC (Future plan)

PSI

First gen

8 x 8

Submitted in fall 2025

Second Gen

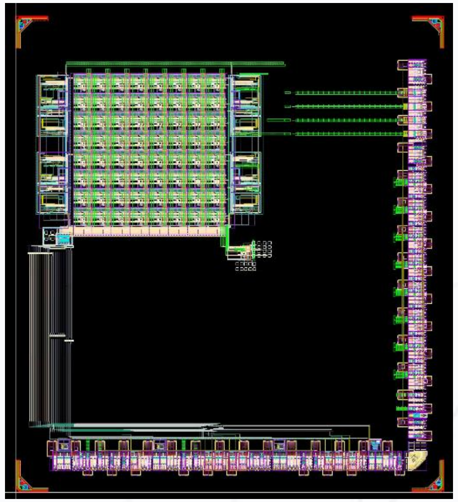
TBD

Submission in 2027

Gen three and beyond

30 x 30

2029



Demonstrator

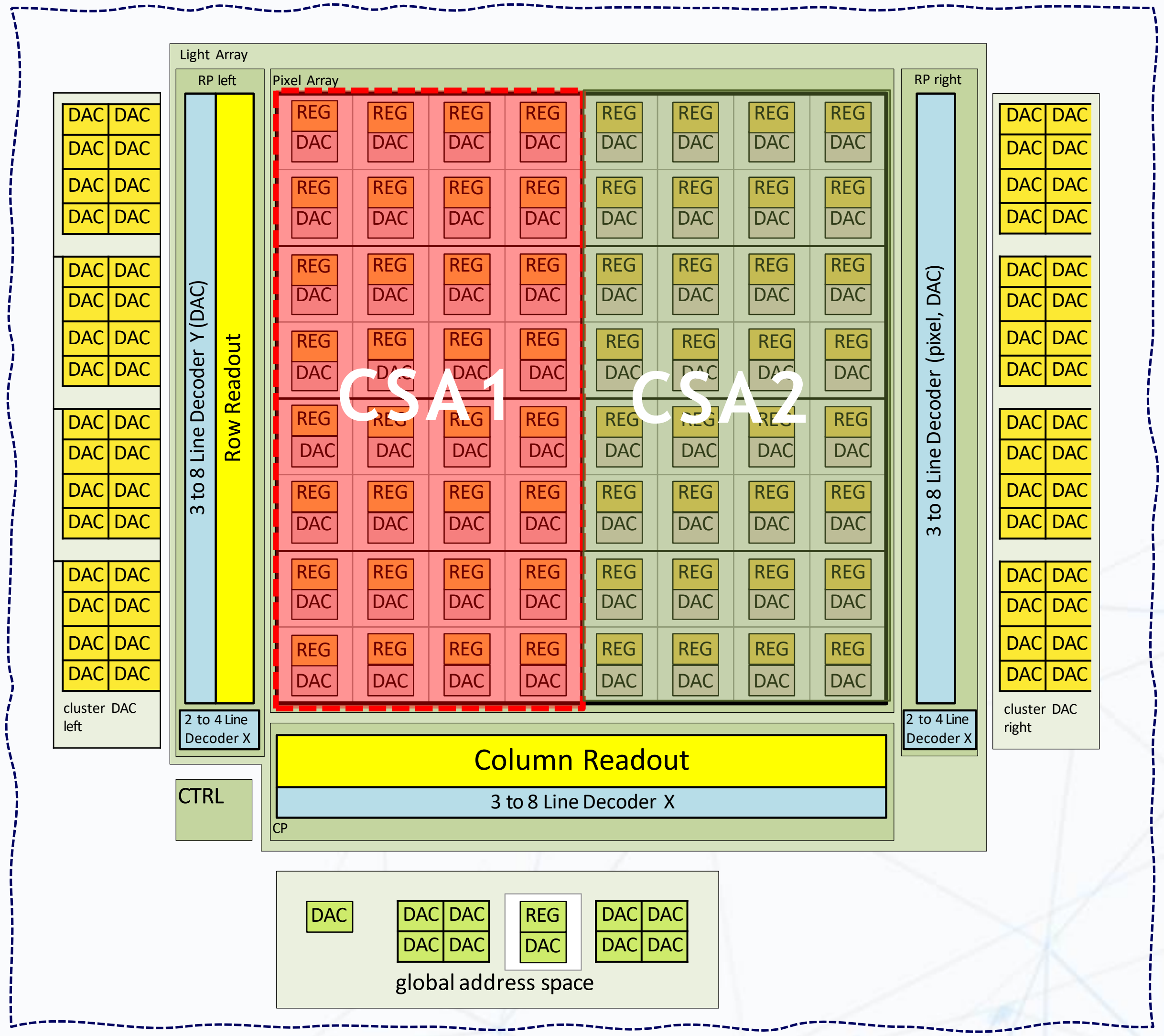
- Scaling study
- Architectural refinement

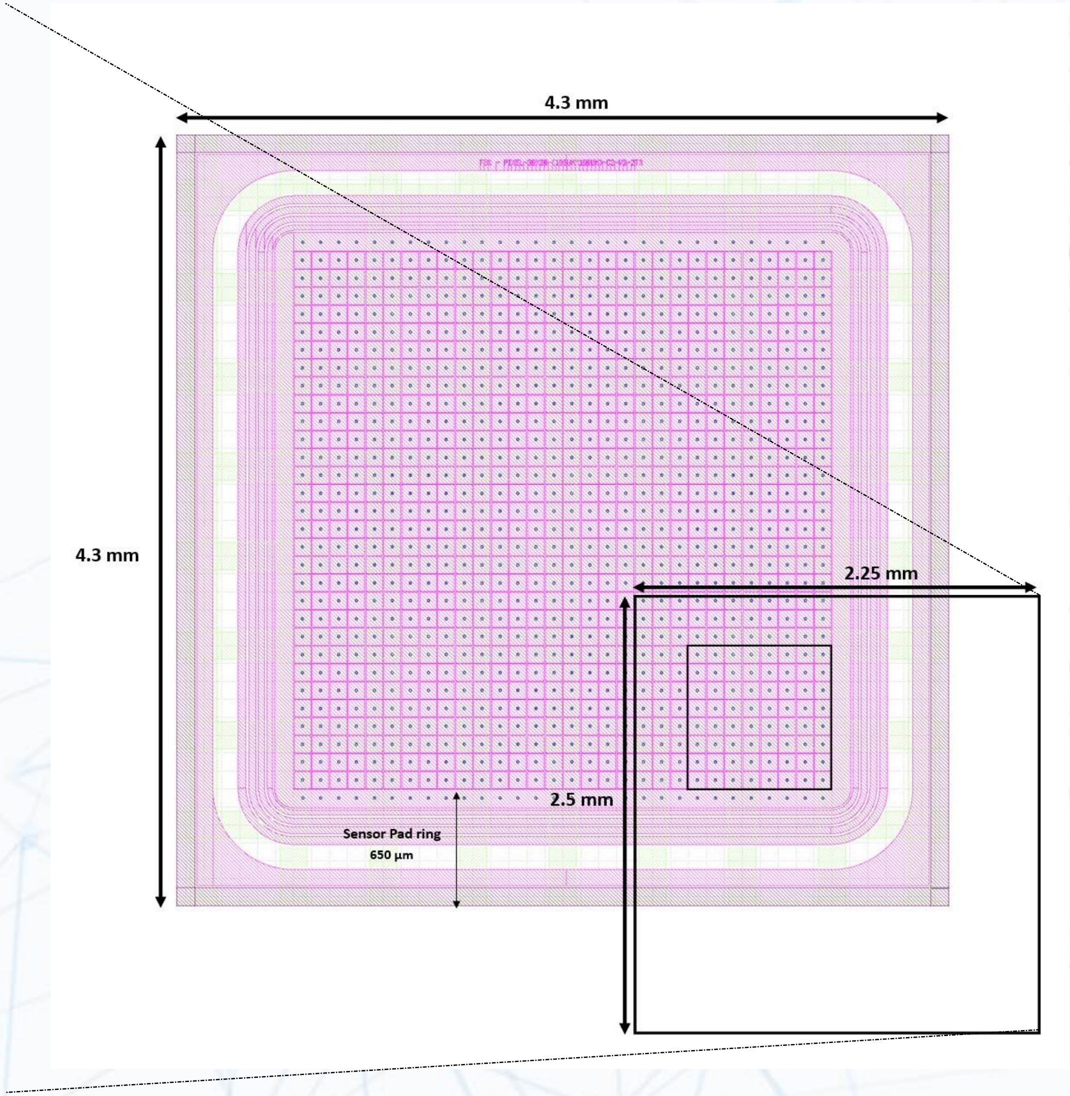
- System Integration
- Experiment driven

Join the collaboration !

Details about the first gen ASIC: LIGHT01

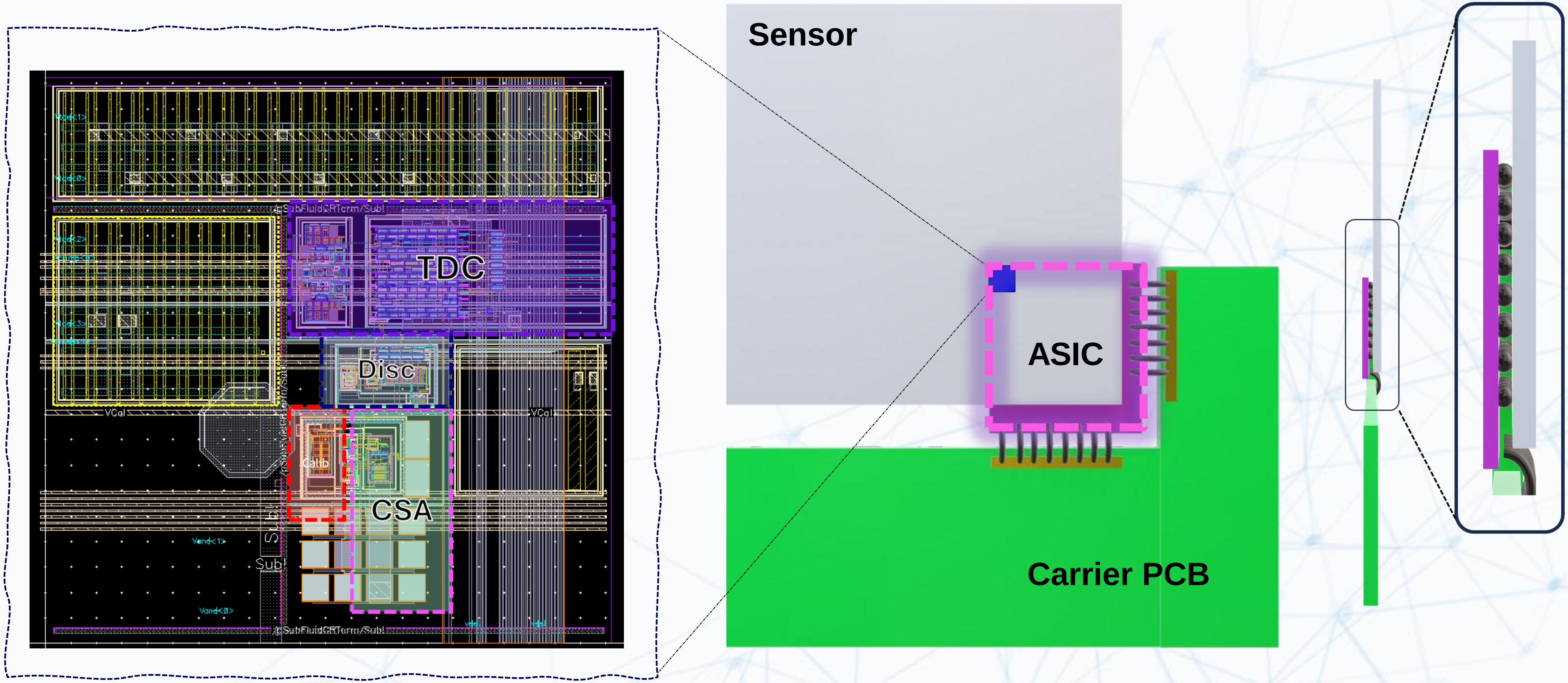
Structure





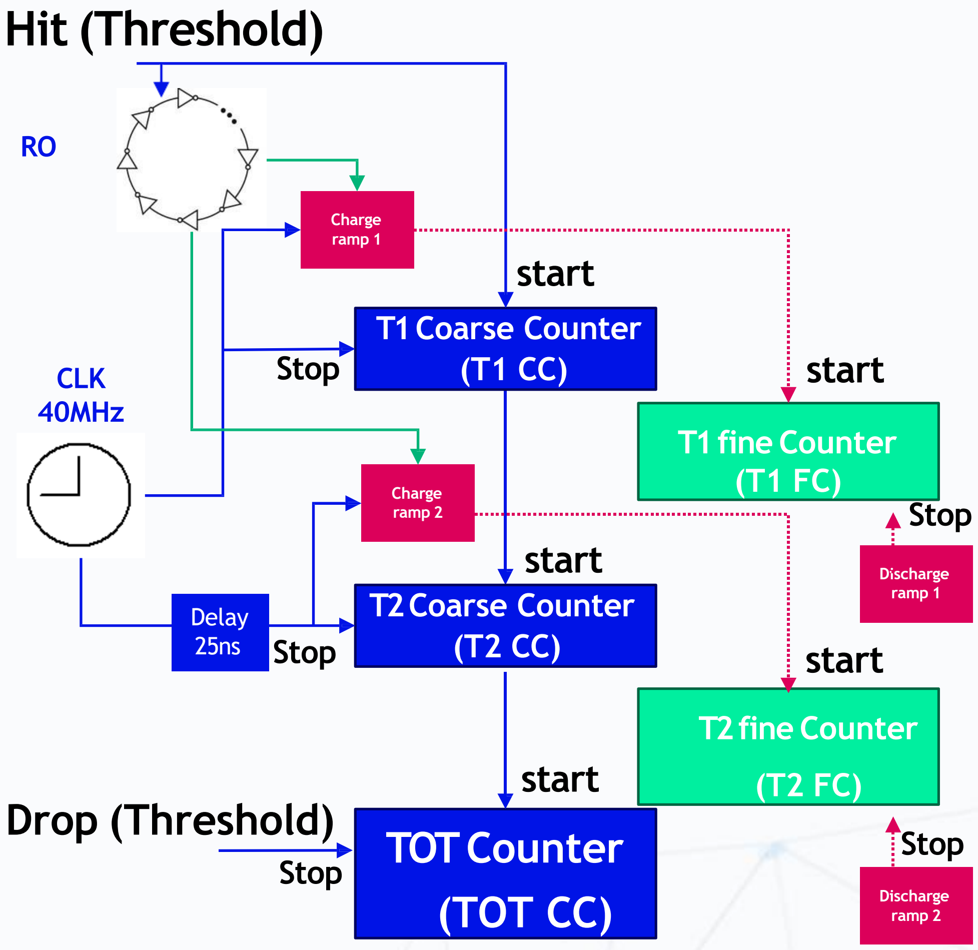
Details about the first gen ASIC: LIGHT01

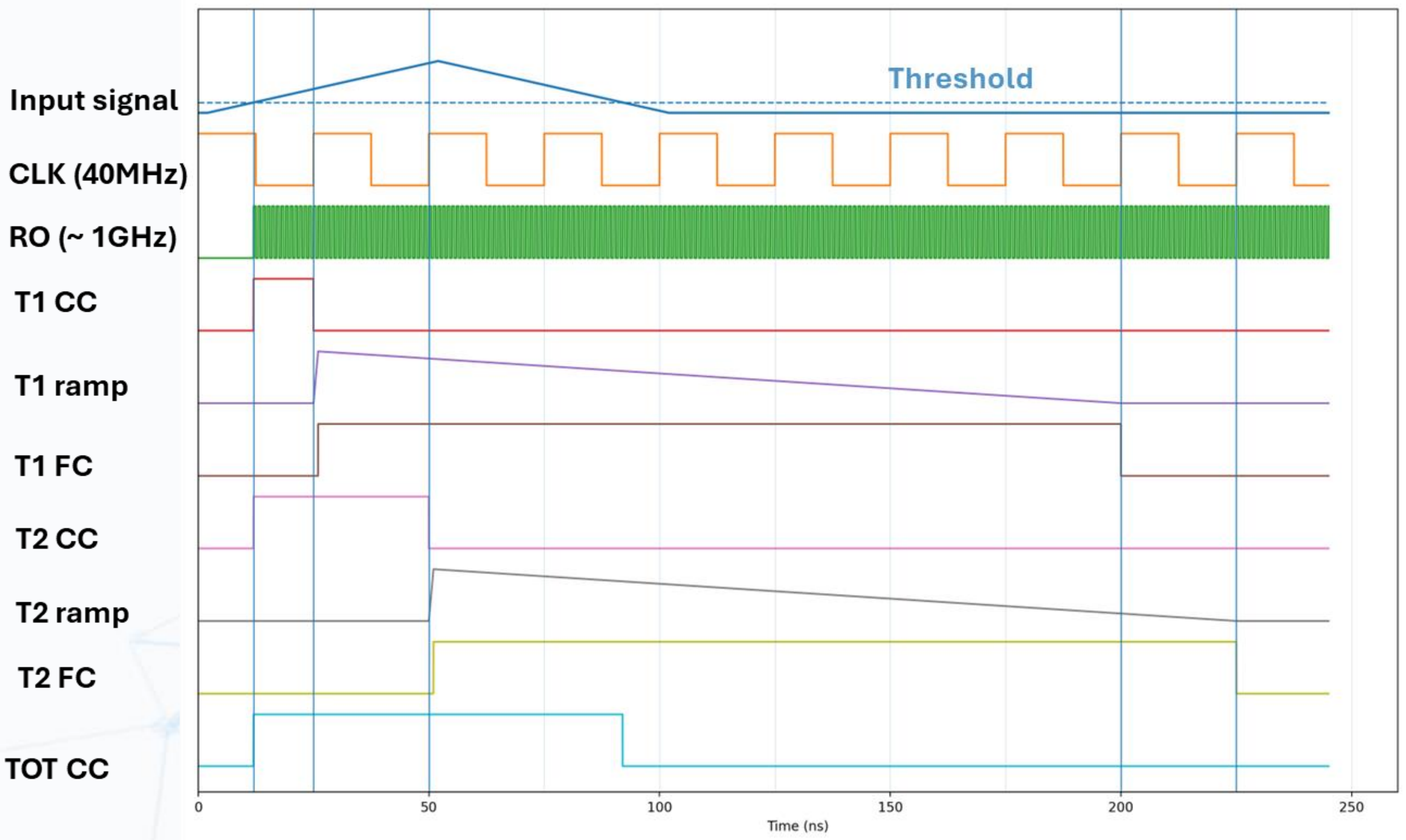
Integration



TDC details

PSI





All counters are 8-bit

Estimated performance (Post-layout sims)

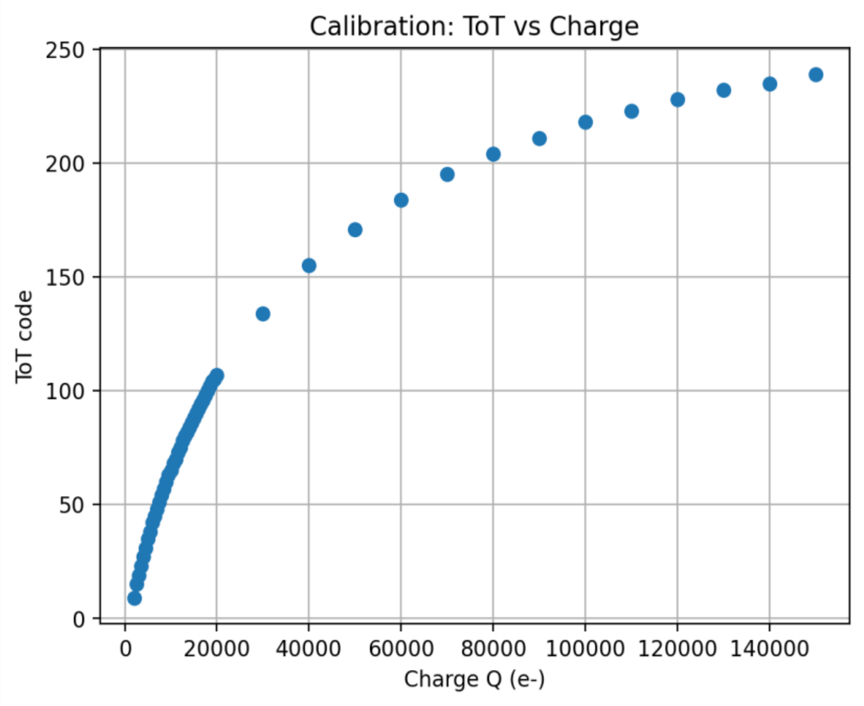
ToTcorrection

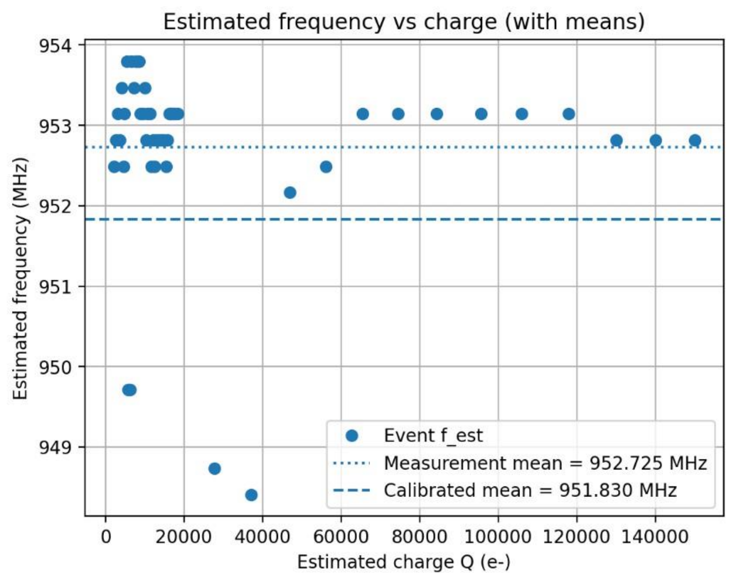
Calibration

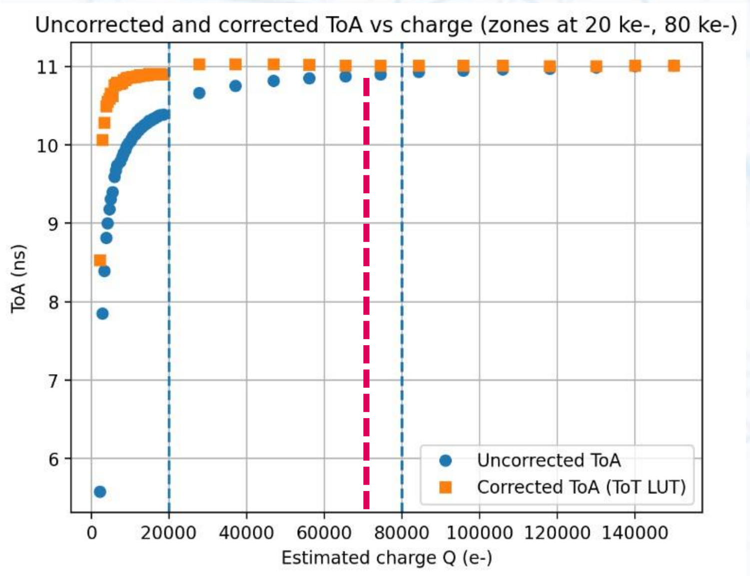
Fine slop normalization → Recursive frequency estimation → Calculation of the fine values → Calculation of T1, T2, ToT → Generation of ToT LUT

Correction

Recursive frequency estimation → Calculation of the fine values → Calculation of T1, T2, ToT → Mapping calculated ToT to LUT → Correction of T1 (Timewalk)







$MIP \approx 70\ Ke$

Fine LSB ≈ 8.57 ps → $\sigma_{TDC} \approx 2.5$ ps

$\sigma_{TOT\ correction} \approx 7.58\ ps$

$\sigma_{TDC_{eff}} \approx 8\ ps$

Estimated performance (Post-layout sims)

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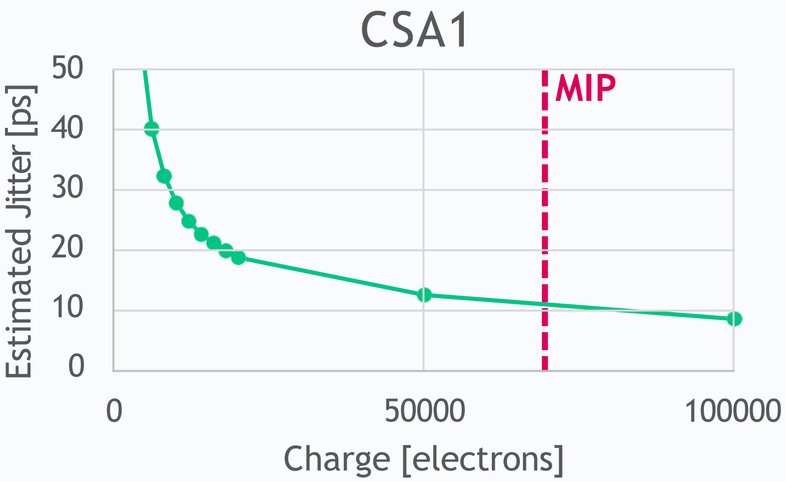
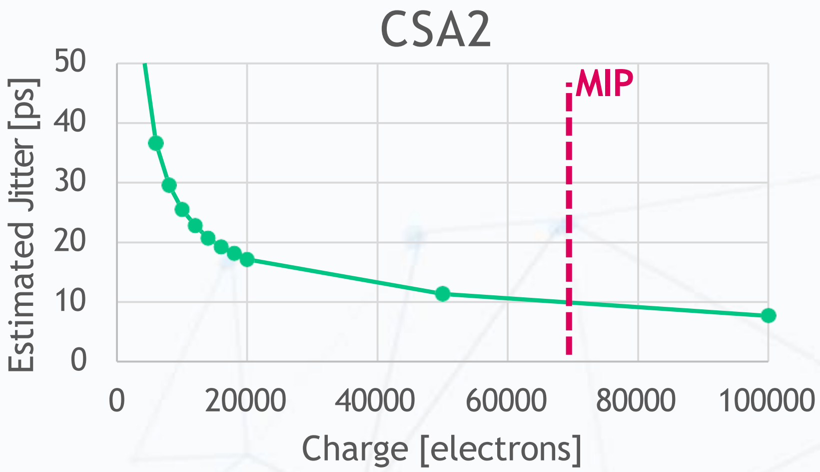




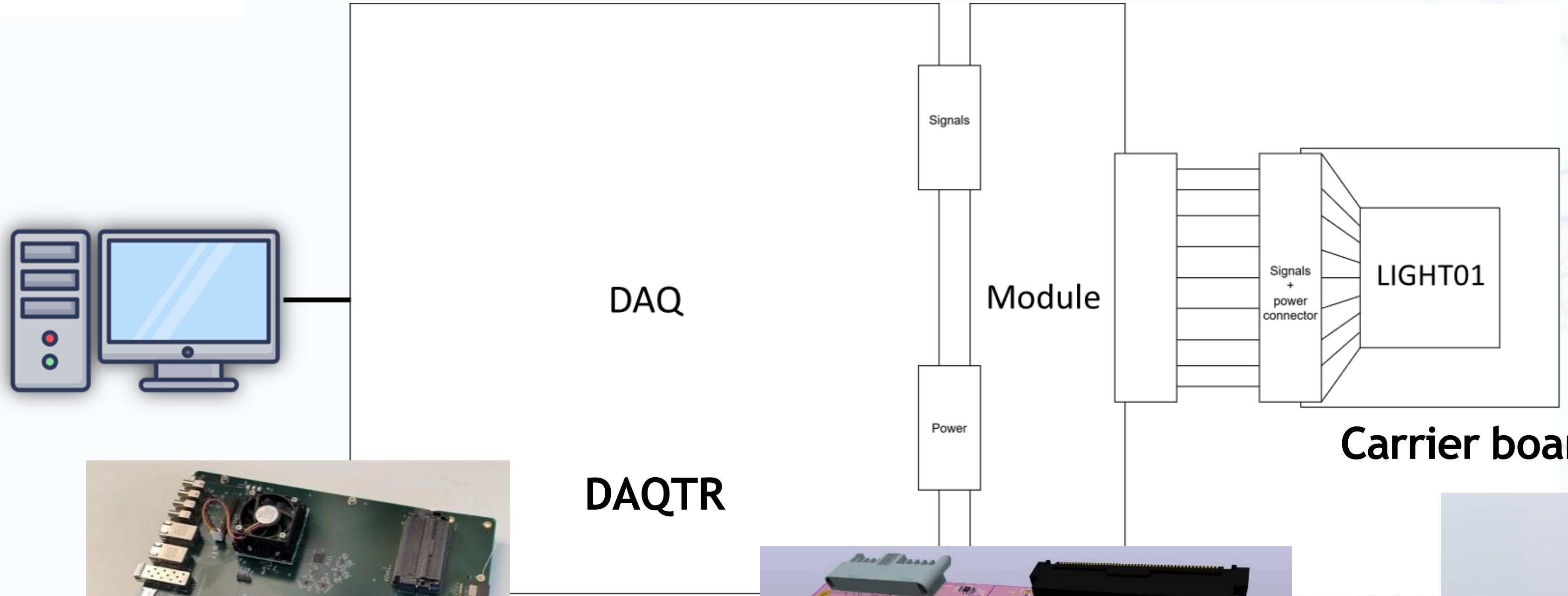
Results of the preliminary post-layout simulations (around the MIP):

- **20ps : the jitter of the sensor**
- **5ps : the clock jitter and the remaining disturbances**
- **~ 10 ps : the jitter of FEE**
- **~11 ps : the resolution of the TDC**

$$\sigma = \sqrt{20^2 + 5^2 + 10^2 + 8^2}$$

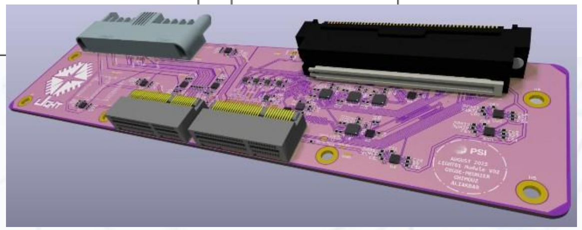
$$\boldsymbol{\sigma \approx 24.3\ ps < 30\ ps}$$

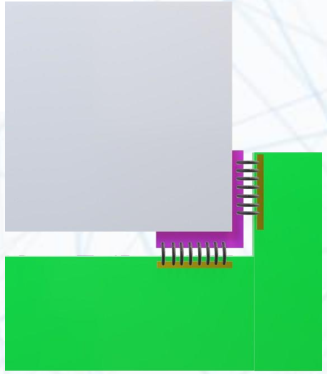
Test strategy



Carrier board

DAQTR





- Zynq UltraScale+ MPSoc (Power of CPU + flexibility of FPGA)
- Provide multiple power domains
- Supports SPI protocol
- Supports Ethernet and Optical fibers
- Bank of DACs, ADCs and LDOs
- Variable clocks reaching 400 MHz

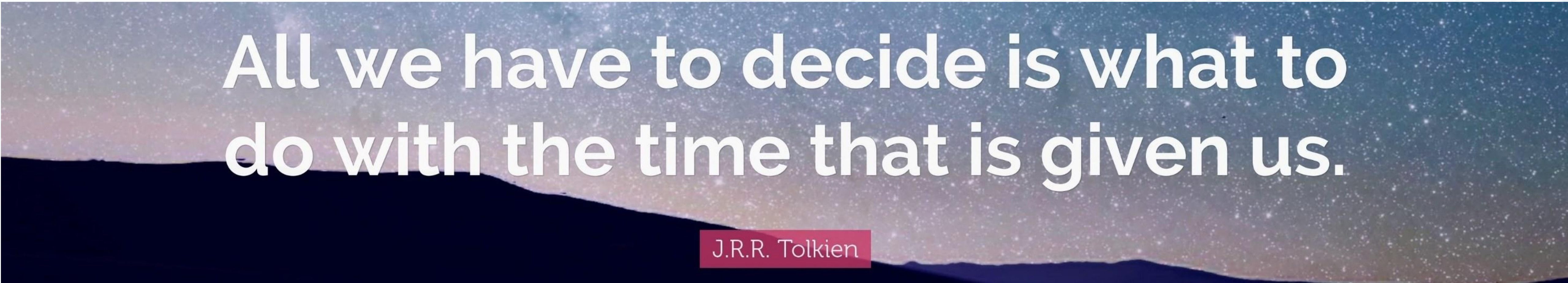
- Fully controllable delay line
- Covers the full 25ns window with 10 ps (4 ps after tuning) steps
- Adaptation of signals from/to DAQ
- Local LDOs for critical components

Conclusion

PSI

- **First generation of timing ASICs : LIGHT01** ➔ Submitted in fall 2025.
- **The preliminary post-layout simulation results** indicates promising results.
- **ASIC/Sensor integration**➔ Bump bonding procedure is under development.
- **Test strategy** ➔ New versatile DAQ board + custom module board for timing measurement was fabricated. Firmware development is progressing.

- **This project** carried out in collaboration between PSI, UZH, CERN 28nm Community and CERN DRD3/7 ➔ Looking for more collaborators.



TIPP 2026 International Conference on Technology and Instrumentation in Particle Physics

Thank you
Questions are welcome

On the behalf of the HEP group

ABDERRAHMANE GHIMOUZ

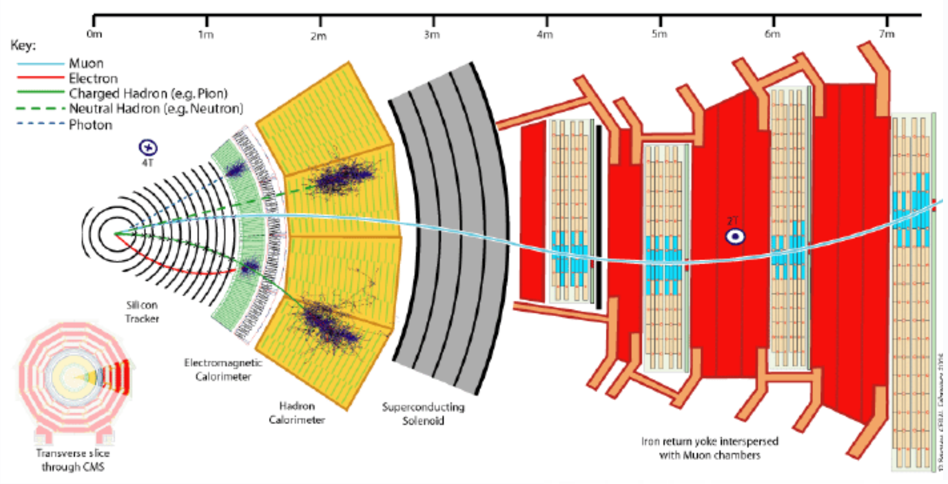
5th Feb. 2026

Join the collaboration !

ANNEXE

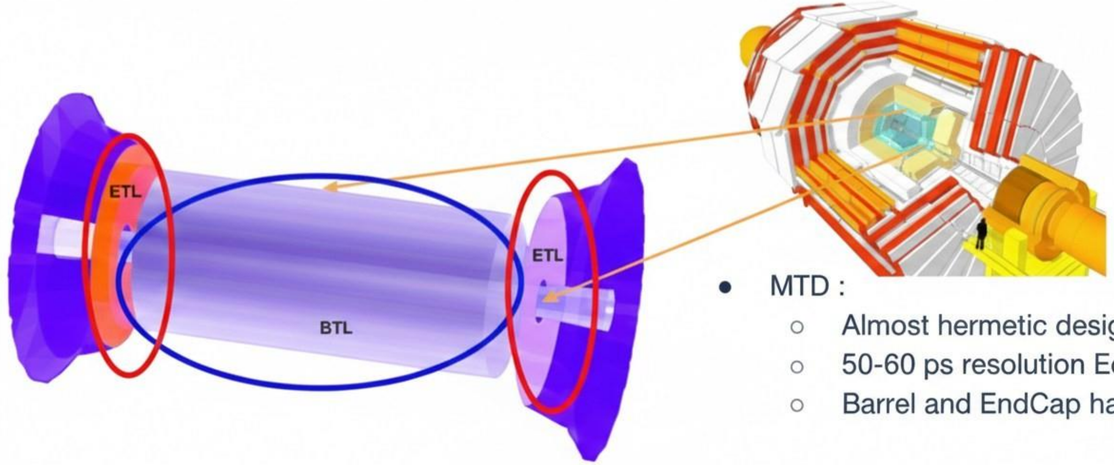
Need for timing

Current state



The need for timing measurement with the CMS detector for the HL-LHC upgrade:

- **Pile-Up Mitigation:** achieves 30-40 picoseconds resolution to separate up to 200 overlapping collisions.
- **Particle Identification:** utilizes precise timing to distinguish particles with speed differences as small as 0.1%.
- **New Physics Sensitivity:** improves detection capability for rare events and particles beyond the standard model.



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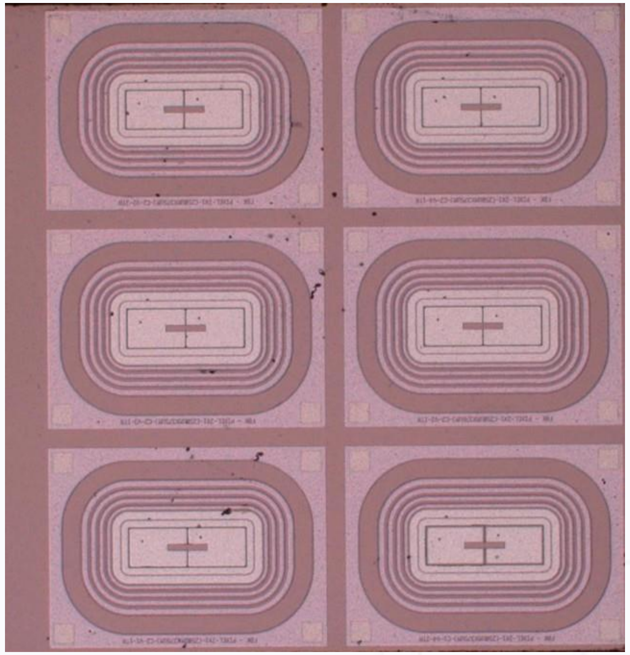
Part 1
LGAD Sensor

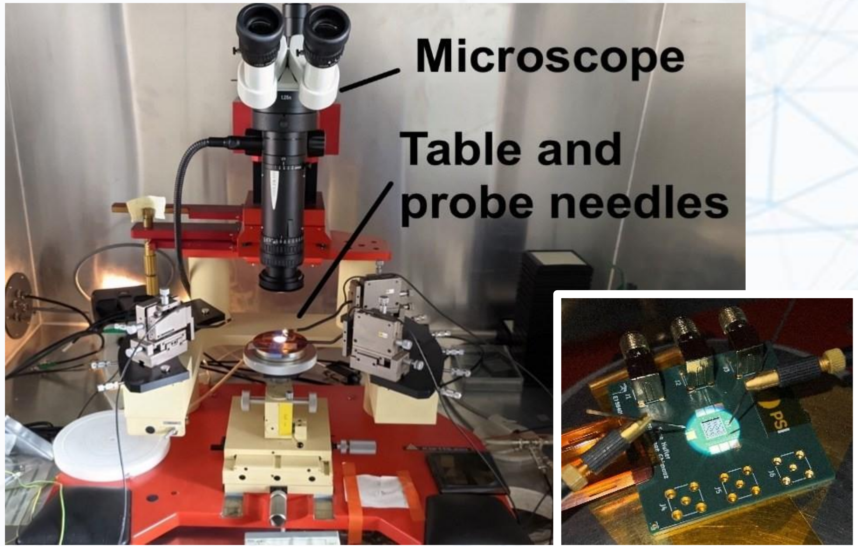
Characterization of Ti-LGAD sensors (setup)

ETHZ Student project (Fynn Hufler)

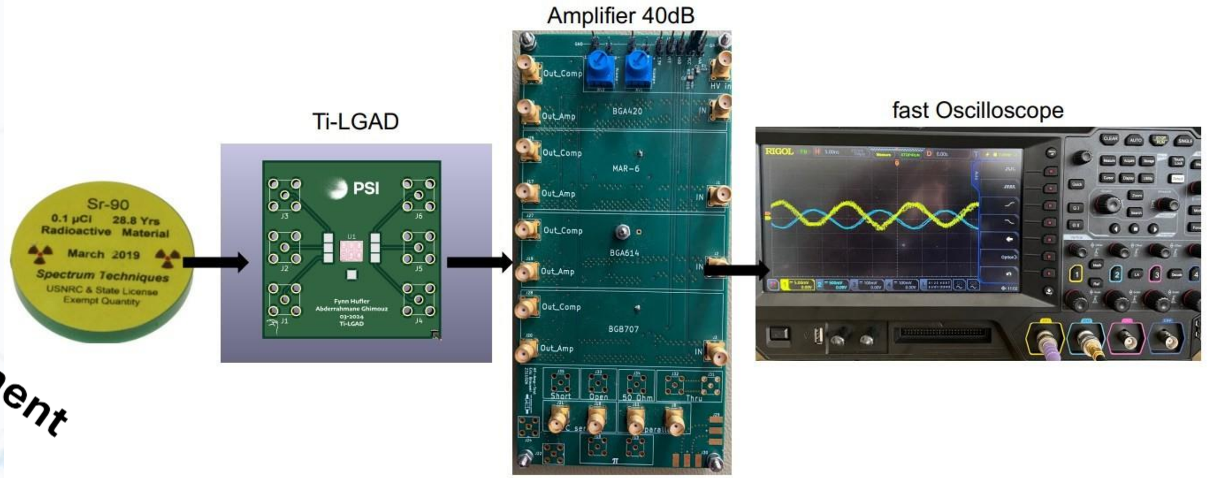


Ti-LGAD sensor sample
(Large pixels : 250 x 375 μm^2)

Capacitance measurement

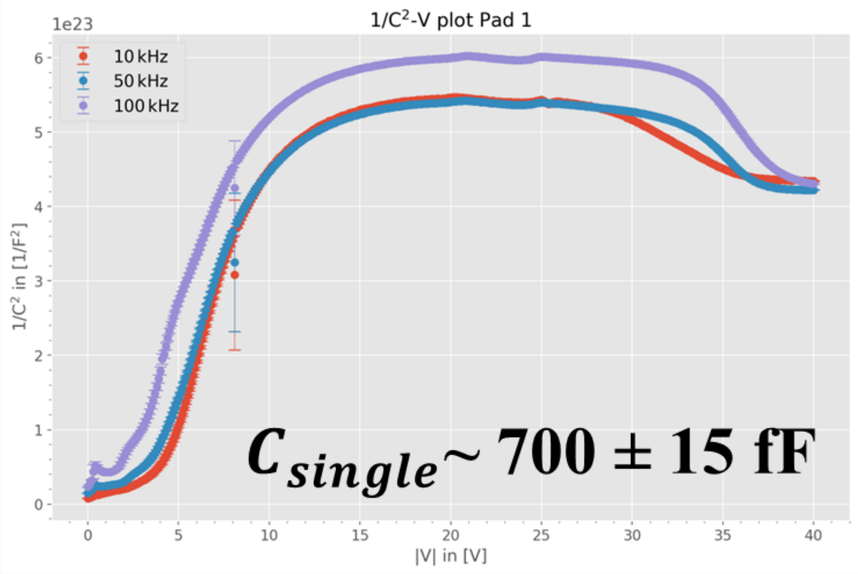


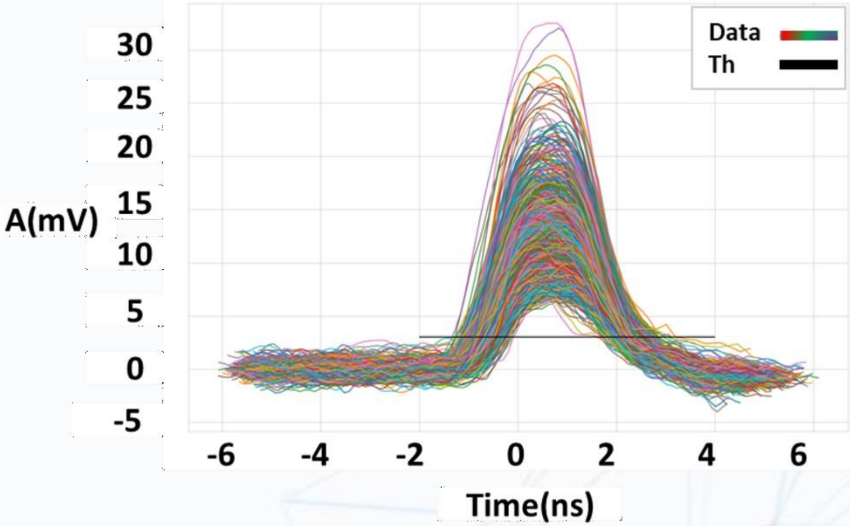
Charge measurement

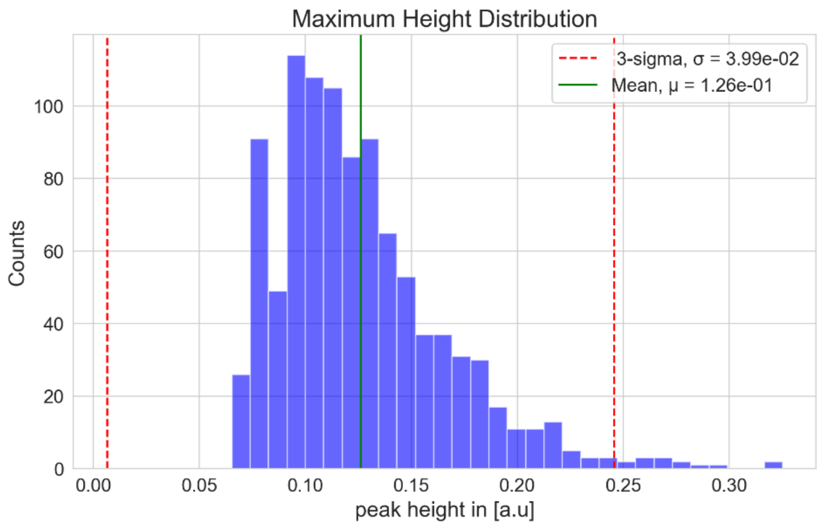


Characterization of Ti-LGAD sensors (results)

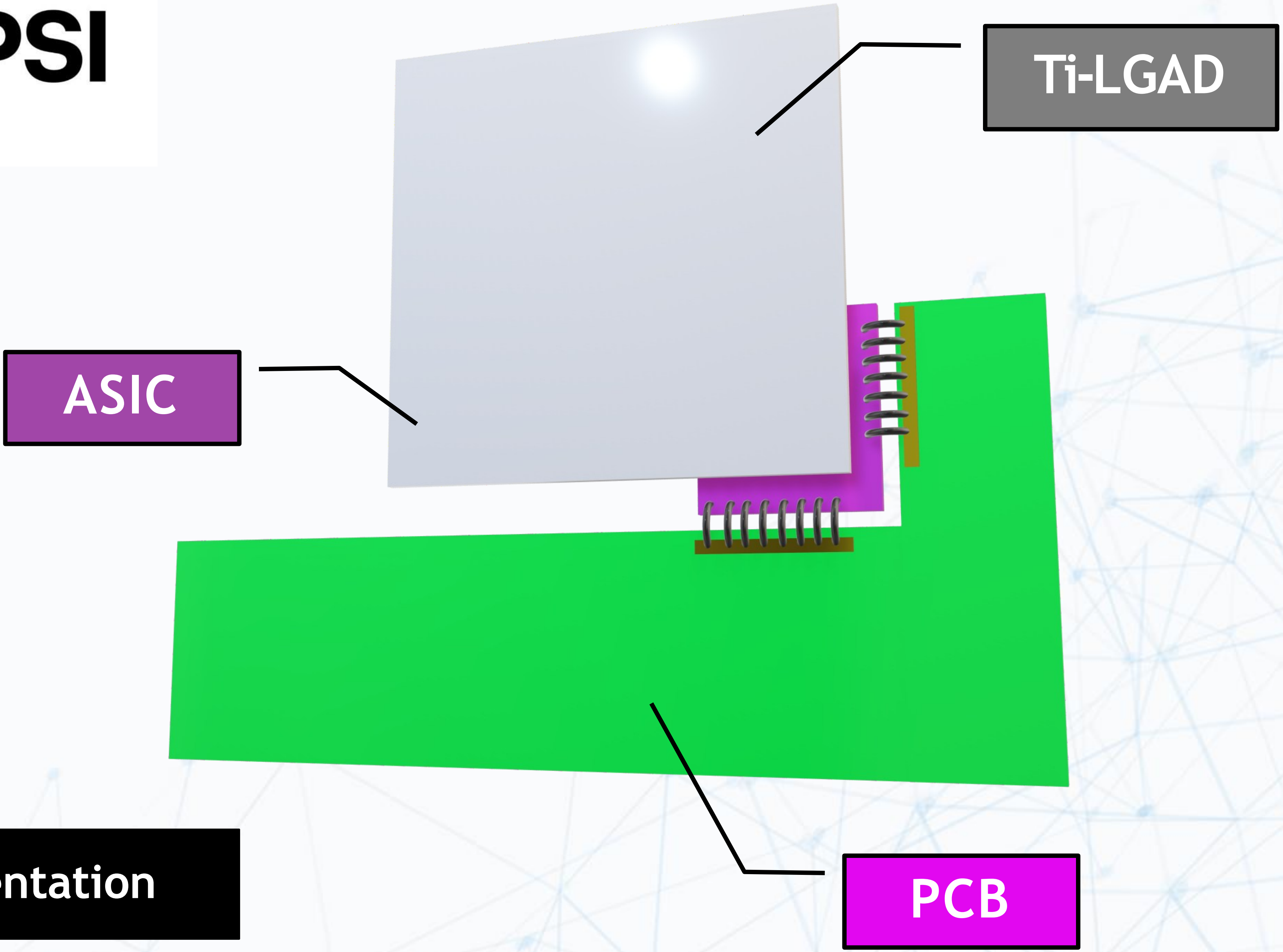
ETHZ Student project (Fynn Hufler)



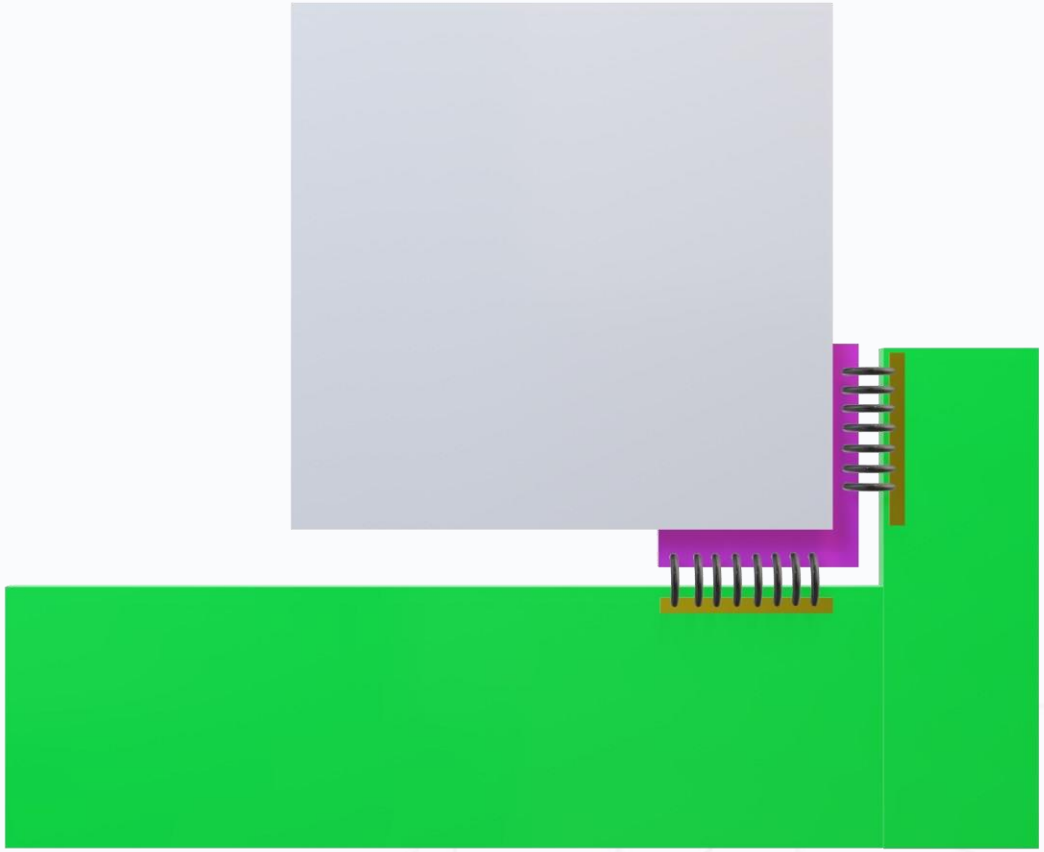


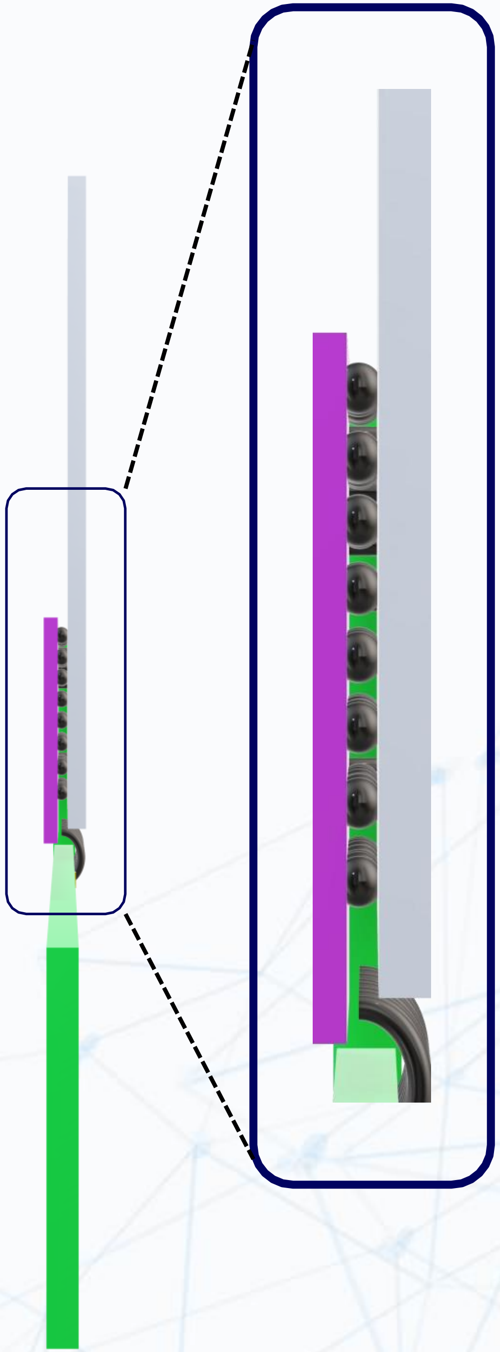


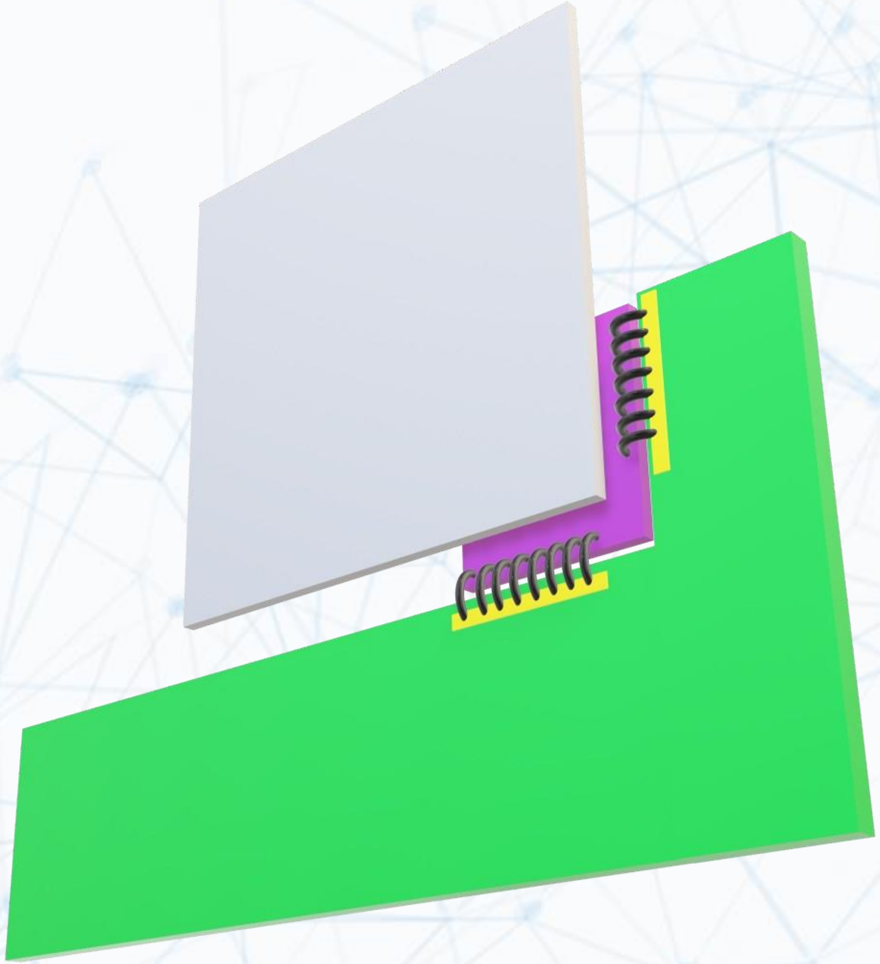
- ✓ Capacitance measurements of Ti-LGAD sensors showed uniform values with stable performance across conditions and mean capacitance for single pixels (250×375 μm²) is ~ 0.70 pF
  ➔ for the 100×100 μm² Ti-LGAD @ same 50 μm thickness : backplane-only estimation is ~0.075 pF including inter-pixel: ~0.12-0.20 pF (typical ballpark)
- ✓ The expected features of the generated signals were confirmed.



Implementation





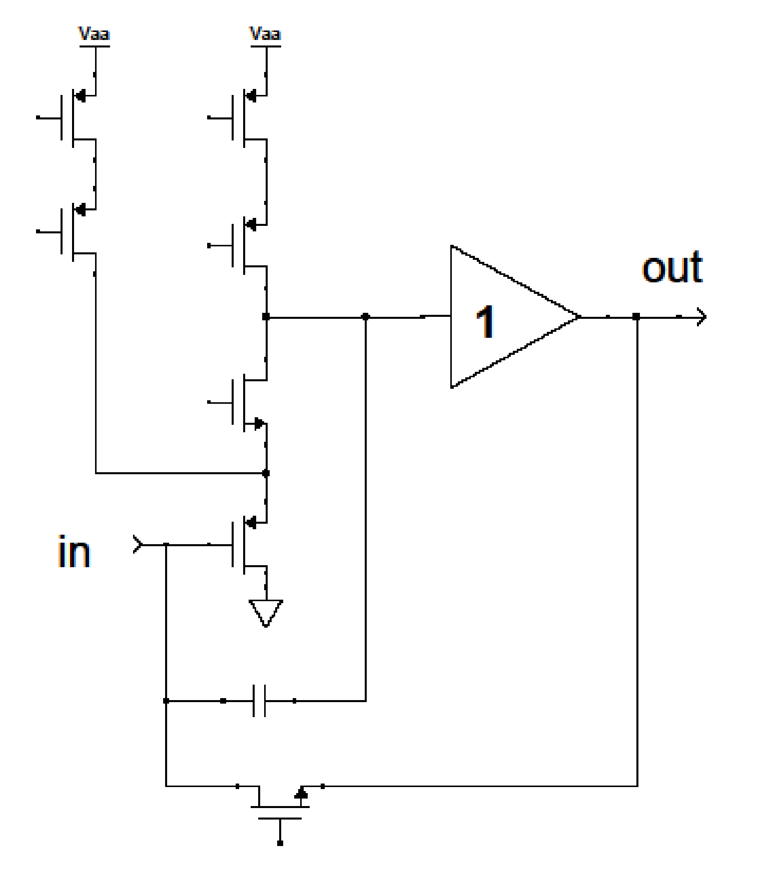


Implementation

Part 3
Preamplifier

First flavour CSA (Hans-Christian Kaestli)

Concept



Initial post-layout simulations results