Fast-timing and high-granularity readout of MPGDs:

FastIC and Timepix4

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on behalf of the CERN EP-DT-DD GDD team

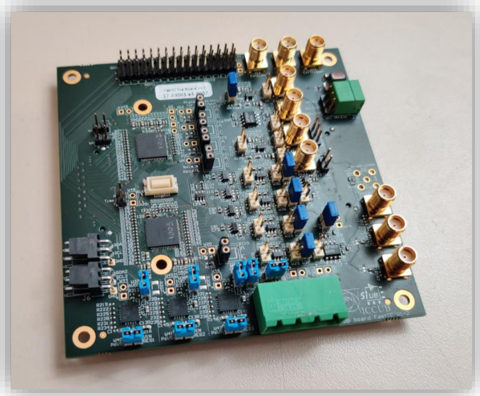
RD51 Collaboration Meeting (the last one)

06 December 2023

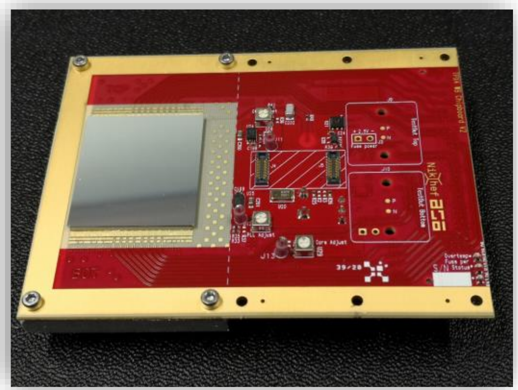
CERN EP R&D RD51 Collaboration PICOSEC Micromegas GDD Gas Detectors Development Group

Outline

FastIC:
Multi-channel fast-timing readout



Timepix4:
High-granularity readout



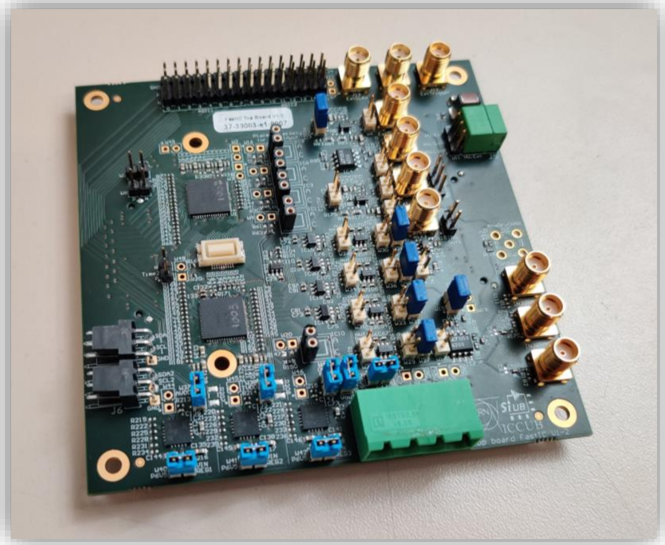
ASIC properties

Working principle/block diagram

Currently used readout/control system

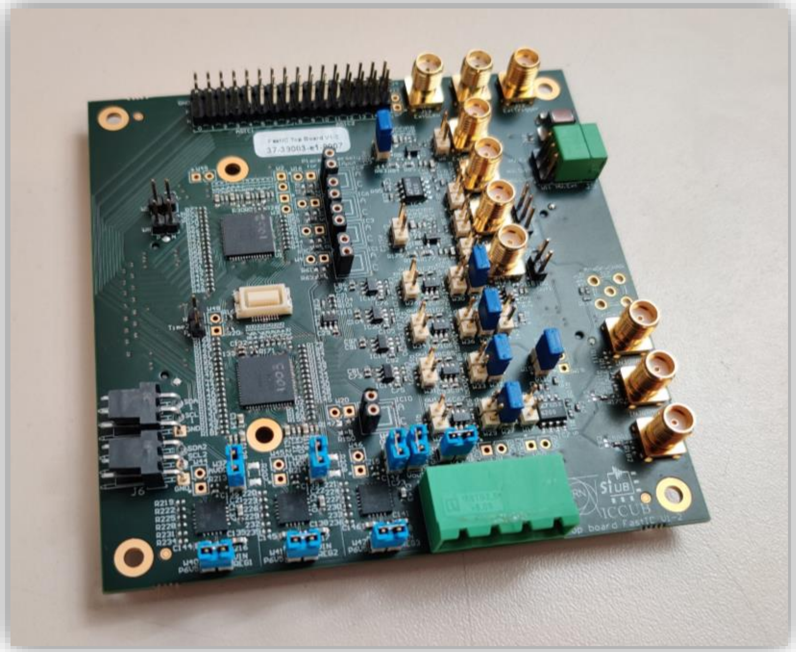
Experimental set-ups and/or first results

FastIC:
Multi-channel fast-timing readout



Basic properties

- Developed by University of Barcelona and CERN for generic fast-timing applications
- Positive or negative input polarity sensors with intrinsic amplification
- 8 readout channels
  - Power consumption: ~ 9 mW/ch
  - Dynamic range: 5 μA to 20 mA input current
- ~ 2 MHz rate capability per channel with time and energy information
- ~ 50 MHz rate capability per channel with time information only



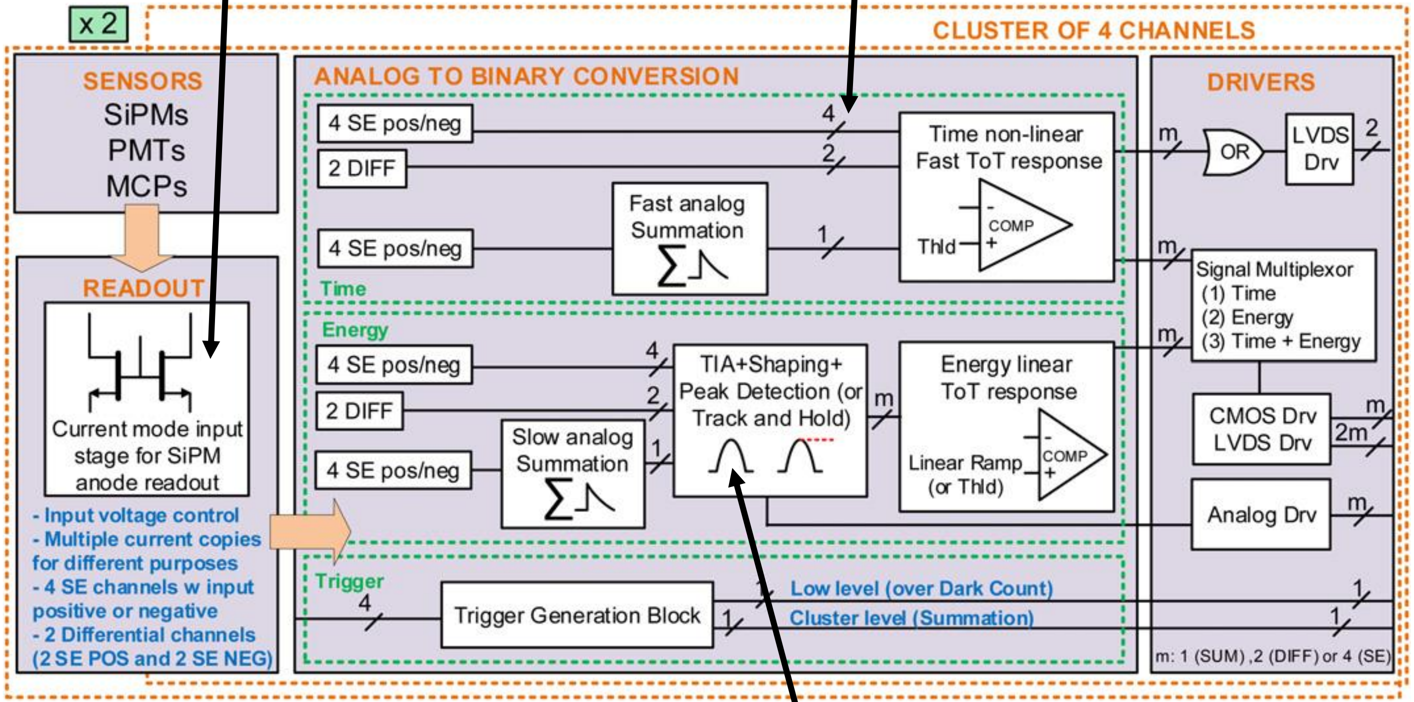
16-channel front-end board with 2 ASICs mounted

Block diagram

Bipolar **input stage** with current mirror

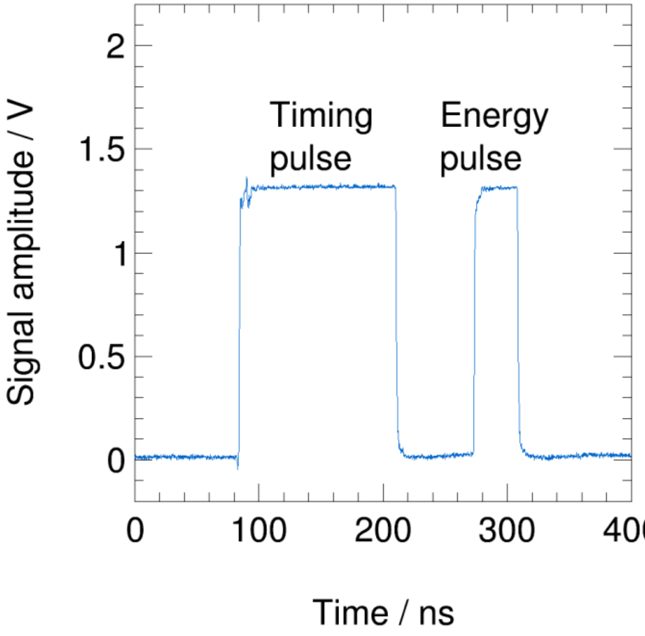
Timing branch with leading edge discriminator, **no amplification**

For our application, we had to run with custom amplifier between detector and FastIC. Needs to be further investigated!



[S. Gómez et al. JINST 17 (2022) C05027]

Binary output



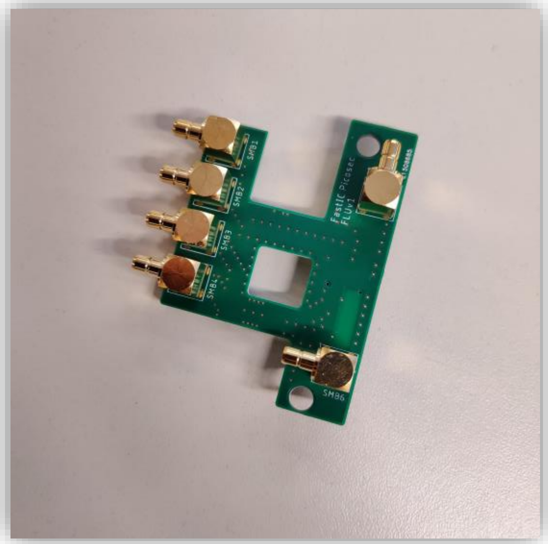
Timing pulse: rising edge = SAT
Energy pulse: width ∝ input charge

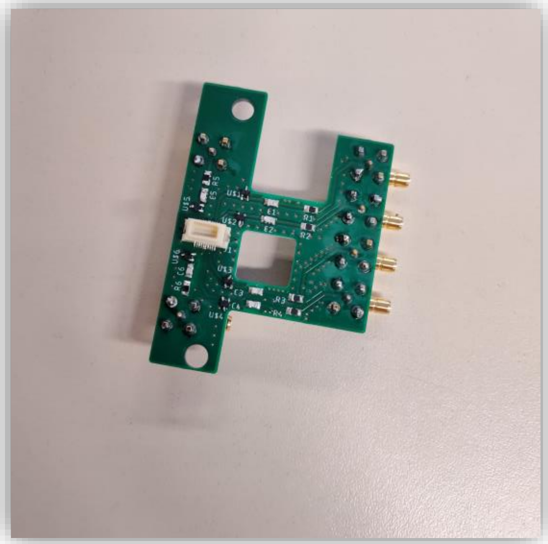
Energy branch with TIA, 25 ns (or 5 ns) PT shaper, peak-detection and hold, and amplitude to time conversion

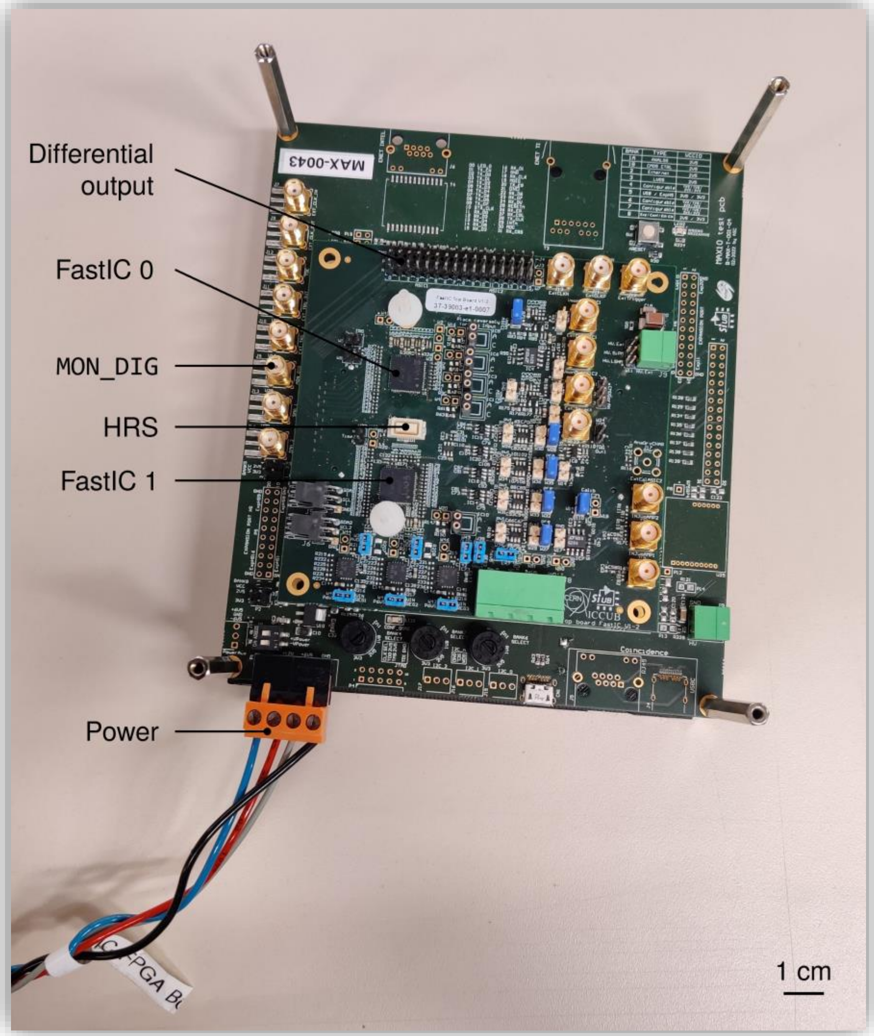
FastIC FPGA board

- Front-end board mounted on FPGA board
- FPGA board provides additional outputs + USB interface to computer
- Although TDC on FPGA board available, measure binary FastIC output with oscilloscope

- Small interface board to send Picosec signals into FastIC
- Access via HRS connector



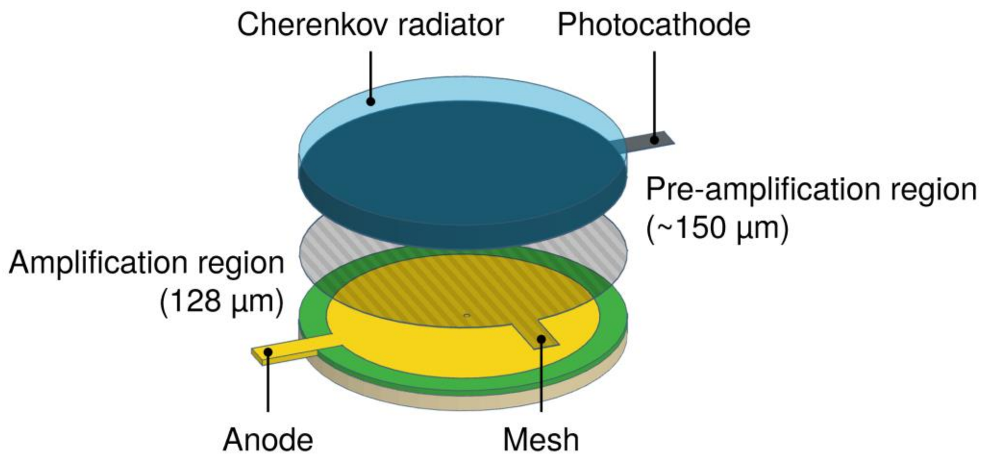




Experimental set-up

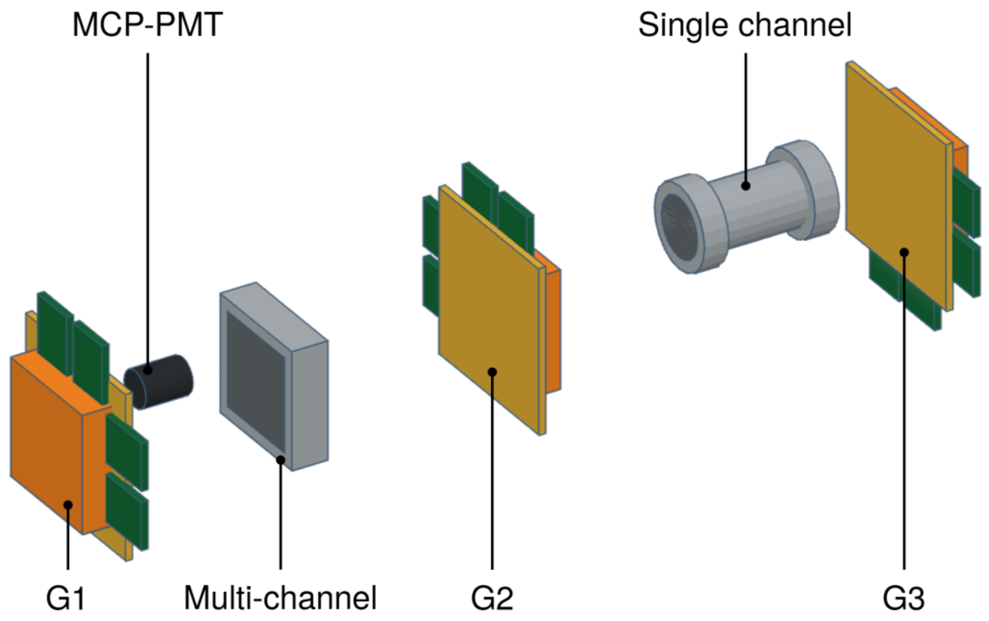
Two detectors read out at test beams at H4 with Picosec MicroMegas:

- Single channel Picosec
  - 150 μm pre-amplification
  - Resisitive anode with 82 MOhm/sq
  - CsI photocathode
- 10 x 10 multi-pad detector
  - 180 μm pre-amplification
  - 1 cm² pads with metallised anode
  - DLC photocathode



Beam telescope with

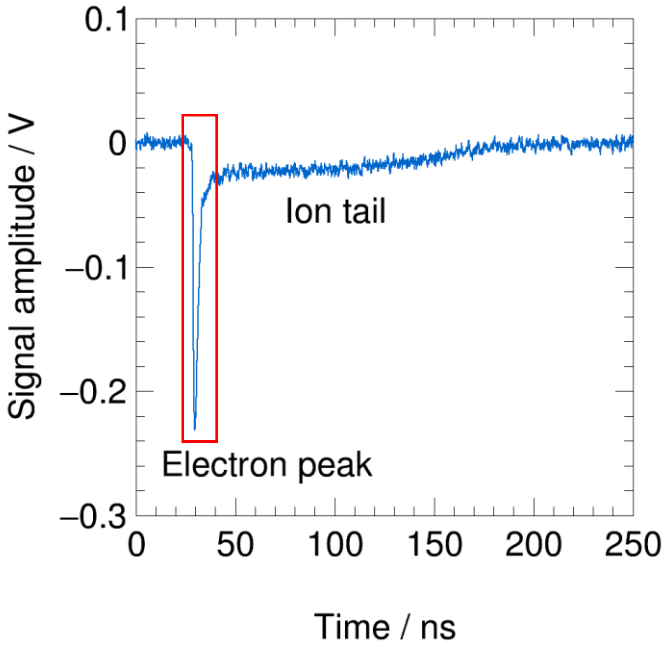
- MCP-PMT as time reference and trigger
- 3 COMPASS-like triple-GEM detectors for position information with APV25/SRS readout



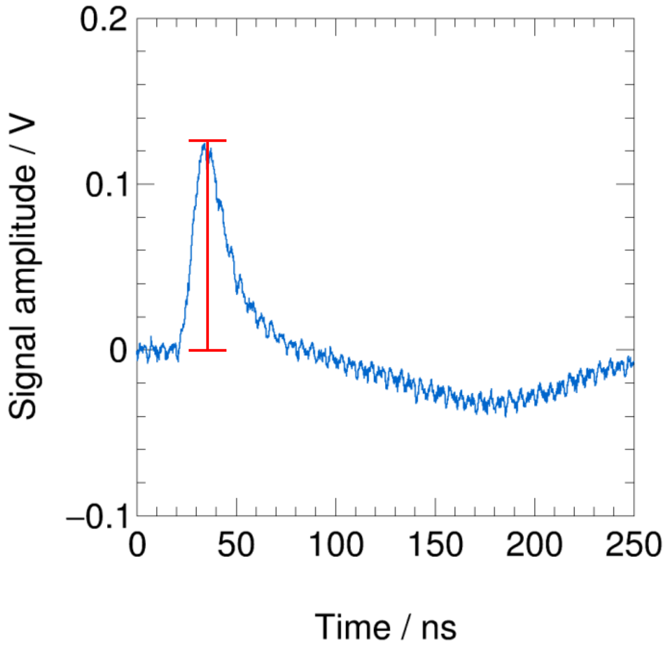
Results:
Charge processing

Main point of investigation: how will the 25 ns PT shaper handle the typical Picosec MM waveform?

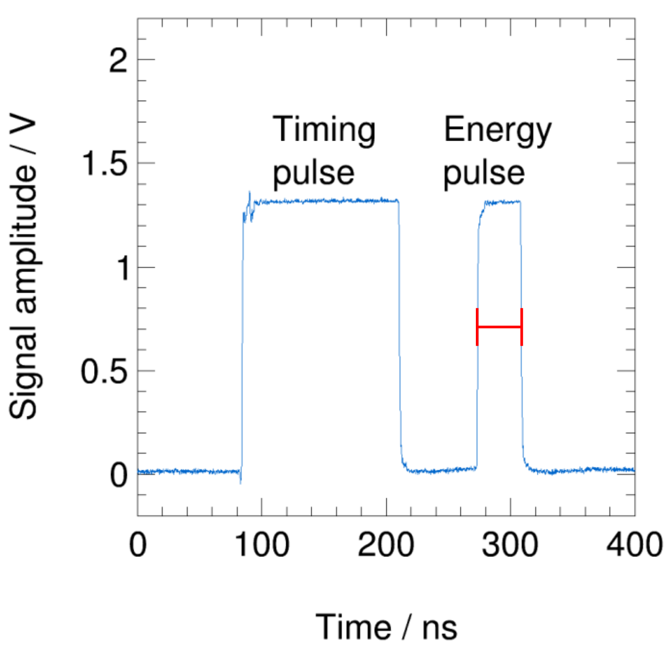
Typical Picosec waveform



Analogue shaper output of FastIC



Binary recorded output

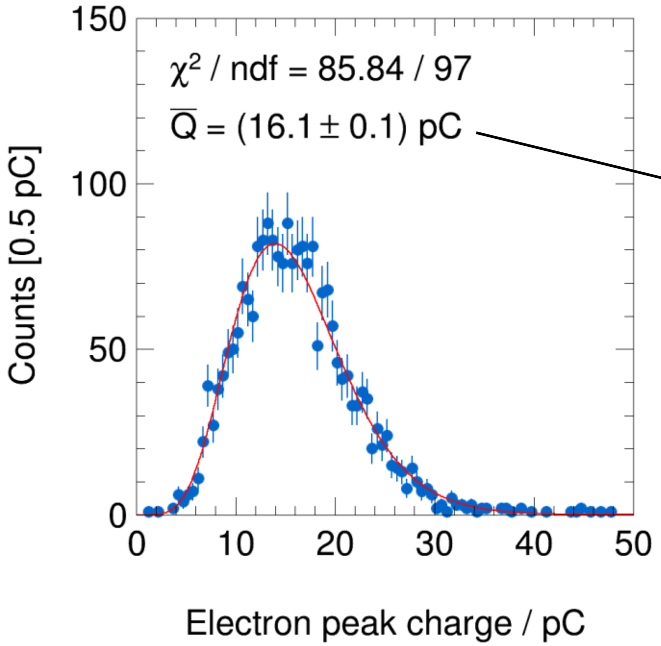


→ Investigate dependence of shaper peak amplitude and energy pulse width on electron peak charge

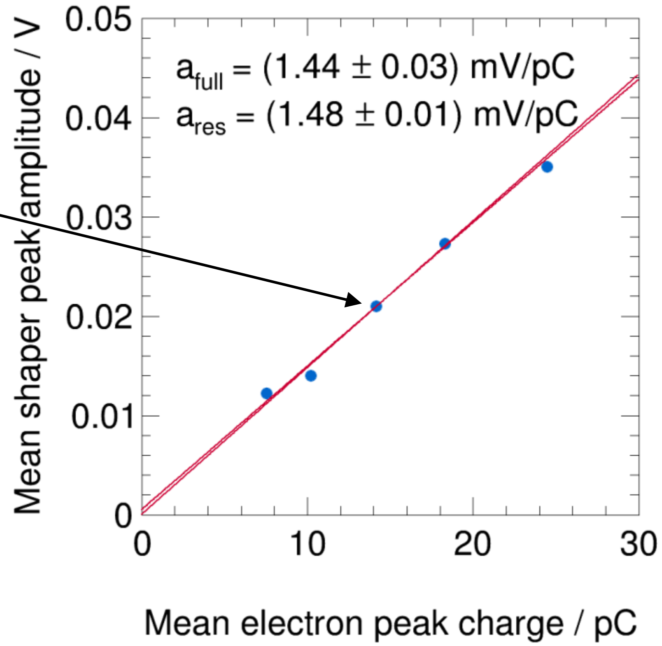
Results:
Charge processing

Main point of investigation: how will the 25 ns PT shaper handle the typical Picosec MM waveform?

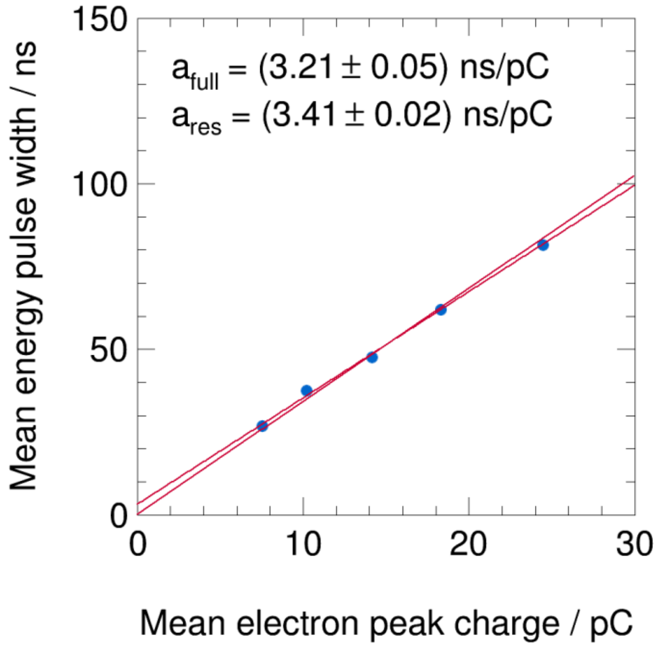
Typical charge distribution



Shaper output



Energy pulse width

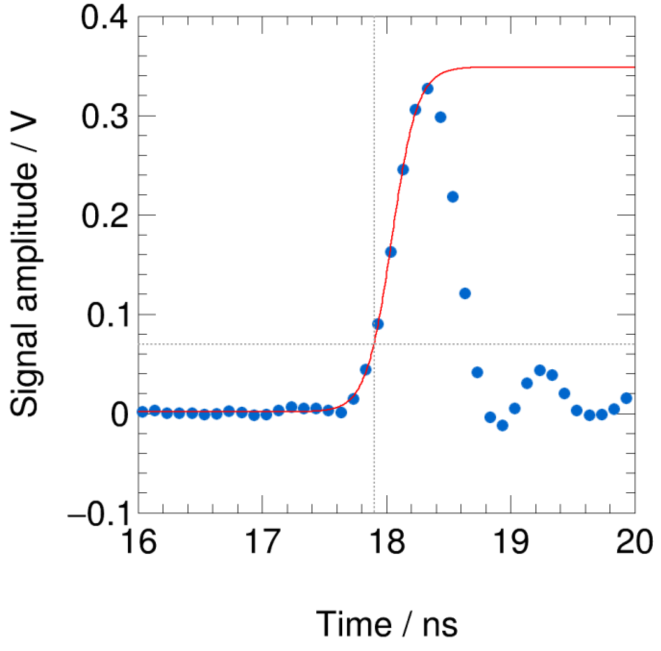


Two types of linear fits: 'full' linear fit and 'restricted' fit with intercept forced to go through origin
→ Linear relation confirmed. **Charge information well processed for time walk correction.**

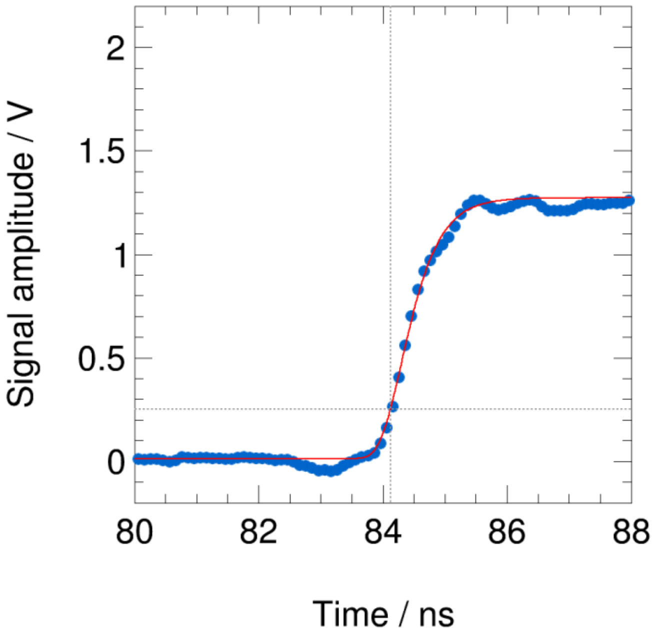
Results:
Time walk

- Fit sigmoid function to MCP-PMT reference timing pulse and Picosec waveform
- Signal Arrival Time (SAT) defined as 20 % value of the fit (effectively a software CFD)
- Same for binary FastIC signal: **beware of leading edge discriminator within the FastIC**
- ~1 ns time walk with FastIC: 'sampling' the rise time of the Picosec electron peak

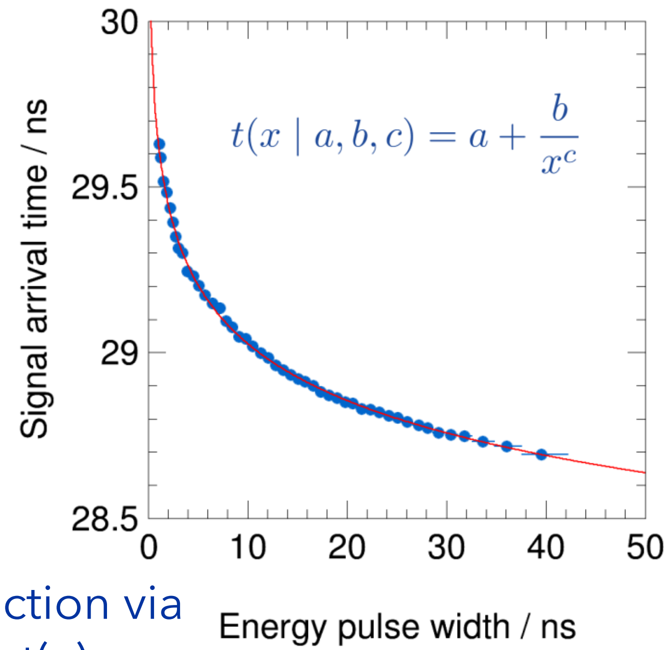
MCP-PMT fit



FastIC fit



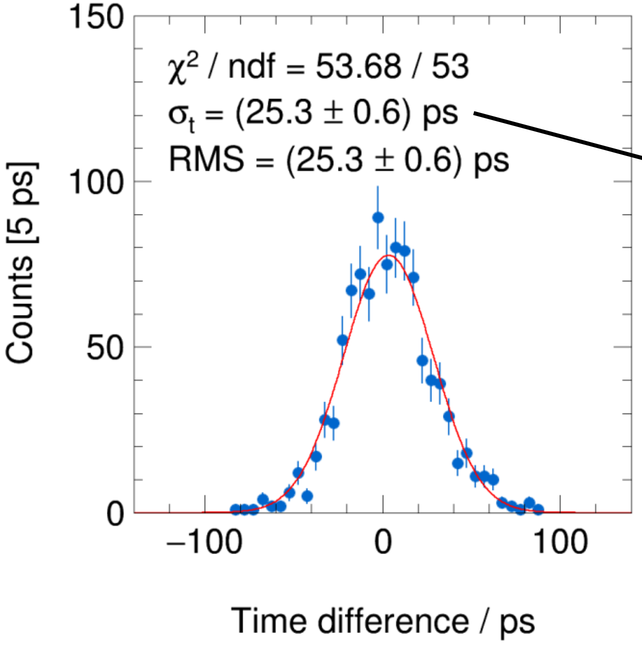
Time difference →



Time walk correction via $t_{corr}(x) = SAT(x) - t(x)$

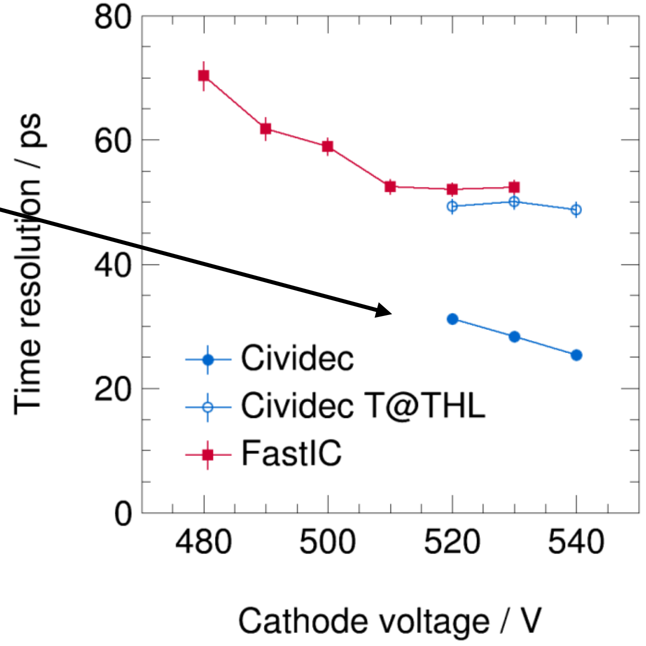
Results:
Time resolution and efficiency

Time difference distribution
after time walk correction



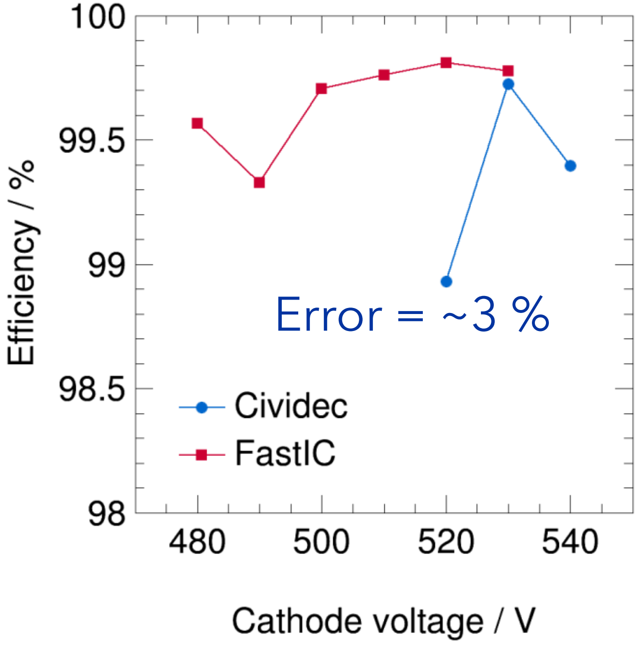
Single Gauss fit
σ_t = time resolution

Time resolution depending
on pre-amplification voltage



Despite ~1 ns time walk
due to T@THL, time resolution of ~50 ps

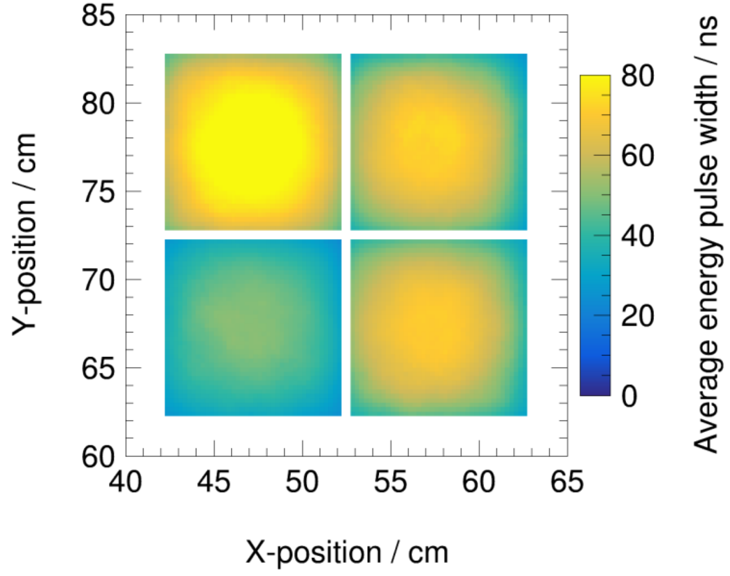
N_{DUT} = Number of interactions in detector
N_t = Number of MCP-PMT triggers as reference

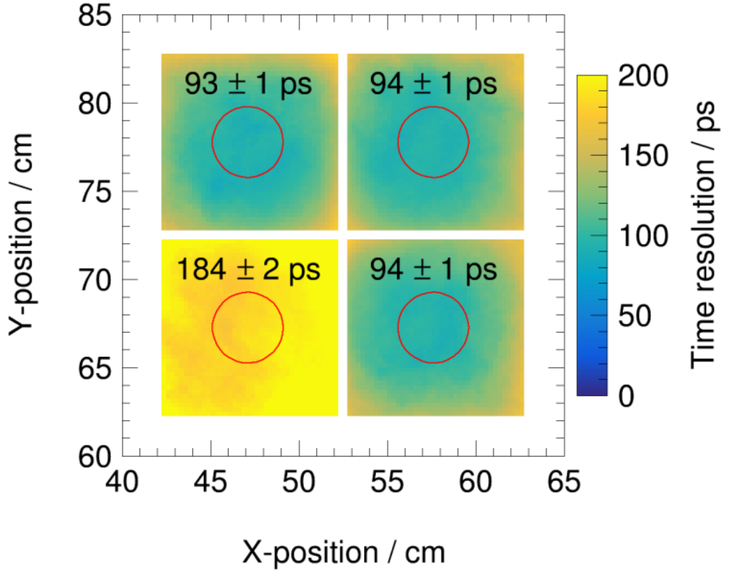


$$\epsilon(V_c) = \frac{\widetilde{N}_{DUT}(V_c)}{\widetilde{N}_t}$$

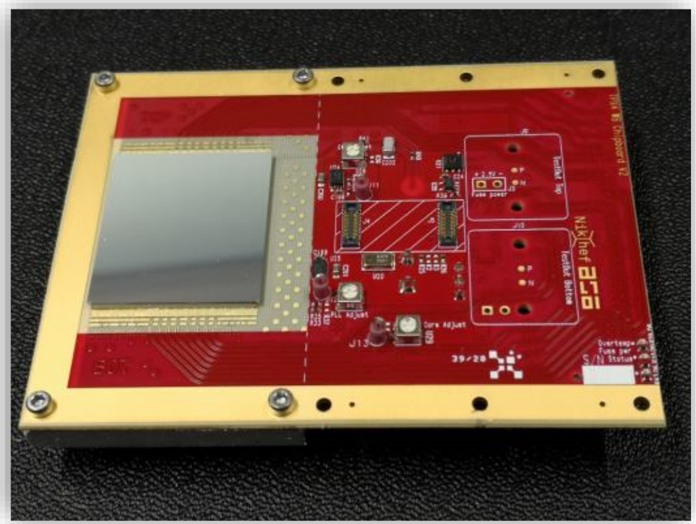
Results:
Multi-channel readout

- Multi-channel readout: pads 15, 16, 25 and 26 of multi-pad detector
- Reconstruct the pads individually
- Just to demonstrate that we can read out multiple channels at once
- Issues in the signal transmission (badly made adapter cables) decreased the time resolution
- Pads 15, 16 and 25 show similar response (<10% variation), as expected from previous studies [Marta's presentation from yesterday]





Timepix4:
High-granularity readout



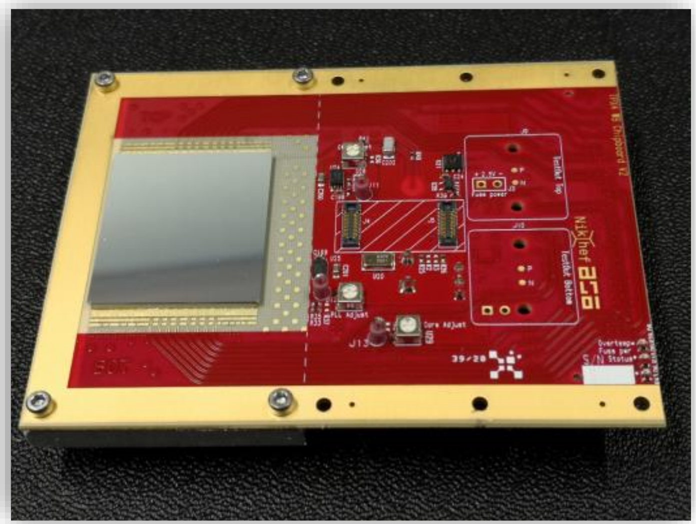
Basic properties

- Developed within Medipix4 collaboration at CERN as large-area hybrid pixel ASIC
  → Use bump-bond pads for Si-sensor instead as anode pads for charge collection

- 448 x 512 square pixels with 55 μm pitch
  - 2.47 x 3.0 cm^2 active area = 7.4 cm^2
  - 229 376 channels
  - Power consumption limited to ~ 1 W/cm^2, typically 0.2 W/cm^2
  - Bipolar front-end, optimised for negative charge

- 4-side tileable → no dead area for multi-chip readout anode

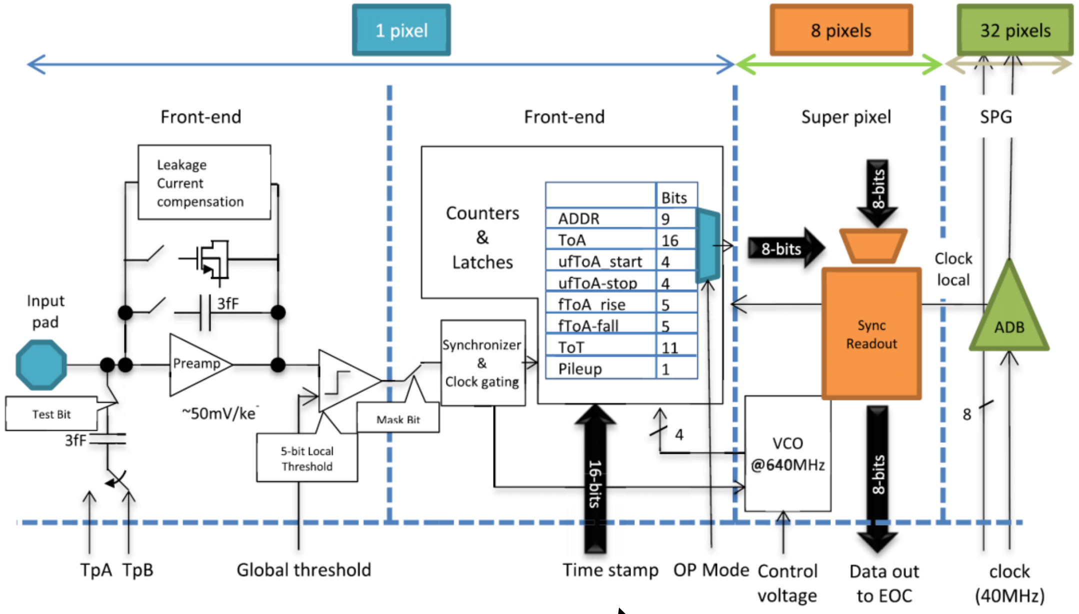
- Two readout modes
  - Data-driven RO mode with high rate-capability (up to 3.6 MHz/mm^2)
  - Frame-based RO mode (up to 5 GHz/mm^2 count rate)

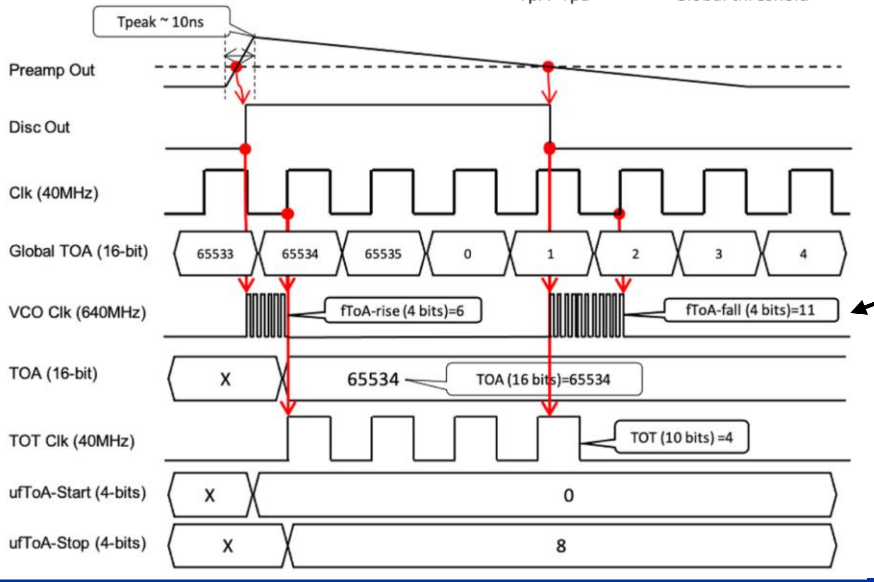


Timepix4 on SPIDR4 carrier
[X. Llopart @ iWoRID 2021]

Block diagram and digitisation

- High gain mode with 3 fF feedback capacitor (gain ~225 mV/fC)
- Low gain mode with 6 fF feedback capacitor (gain ~125 mV/fC)
- Dynamic range ~500 e- (0.1 fC) to ~250 ke- (40 fC) input charge
- ~10 ns peaking time
- Particle time of arrival (ToA) information with 195 ps time bins
- Charge information via time over threshold (ToT) with ~700 e- resolution (FWHM)

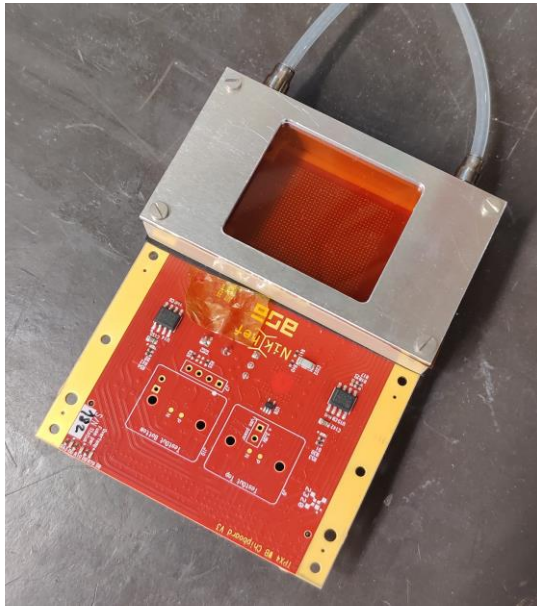




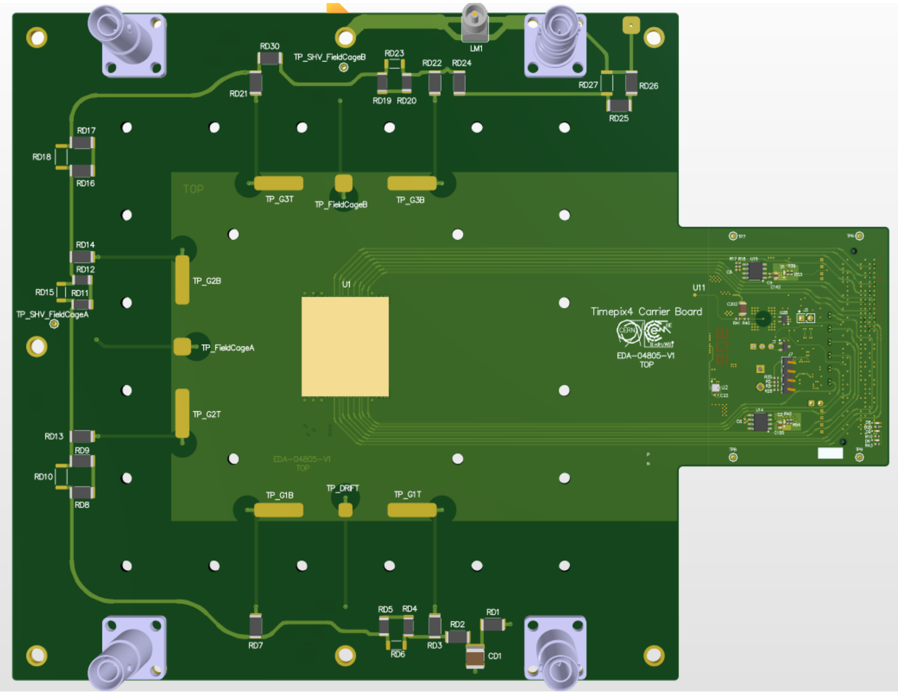
Block diagram and digitisation procedure from JINST 17 (2022) C01044

Experimental set-up

- Readout system: Speedy Pixel Detector Readout (SPIDR4) → arrived today (one hour ago)
- Various kinds of detectors planned
  - Triple-GEM as Timepix GEM TPC from University of Bonn or GEMPix from F. Murtas
    - a) directly on SPIDR4 carrier (similar to T. Schiffer's GridPix3 detector for SPIDR)
    - b) 5 x 5 cm² triple-GEM detector
  - µRWELL with embedded Timepix4 (inspired by Magnus Mager's presentation at MPGD 2022)
- Foreseen application (near future): low-material budget, high-granularity TPC



Small 7 cm² active area detector on SPIDR4 carrier
[Thanks to Jerome Alozy and Miranda van Stenis]



Timepix4 PCB for 5 x 5 cm² GEMs
[Courtesy of William Billereau]

Summary and references

Summary

- **FastIC: multi-channel readout for fast-timing applications**
  - Successful readout of Picosec MicroMegas detectors
  - Despite timing at threshold resulting in large time walk for Picosec signals (~ 1 ns), time resolutions of around 50 ps can be achieved
  - With MCP-PMTs (less time walk) time resolutions of ~20 to 25 ps achieved (not shown here)
  - FastIC+ in the future with integrated TDC for fully digital output

- **Timepix4: high-granularity readout of MPGDs**
  - ~ 7 cm^2 active area with 230k square pixels providing simultaneously charge (700 e- resolution), time information (200 ps resolution) and high-granularity position information
  - Project just at the beginning
  - Readout of triple-GEM and μRWELL intended
  - Near-future application: low material budget TPC

References

- **FastIC: multi-channel readout for fast-timing applications**
  - S. Gomez et al., J. Instrum. **17** (2022) C05027: https://doi.org/10.1088/1748-0221/17/05/C05027
  - D. Sanchez et al., IEEE Trans. Radiat. Plasma Med. Sci. **6** (2022) 51: https://doi.org/10.1109/TRPMS.2021.3066426
  - Documentation: https://icc-ub.gitlab.io/instrumentation/clues/fastic_doc/index.html

- **Timepix4: high-granularity readout of MPGDs**
  - X. Llopart et al., J. Instrum. 17 (2022) C01044: https://doi.org/10.1088/1748-0221/17/01/C01044
  - Documentation (only for Medipix4 members): https://timepix4.web.cern.ch/timepix4/
  - SPIDR4 documentation: https://spidr4.nikhef.nl/

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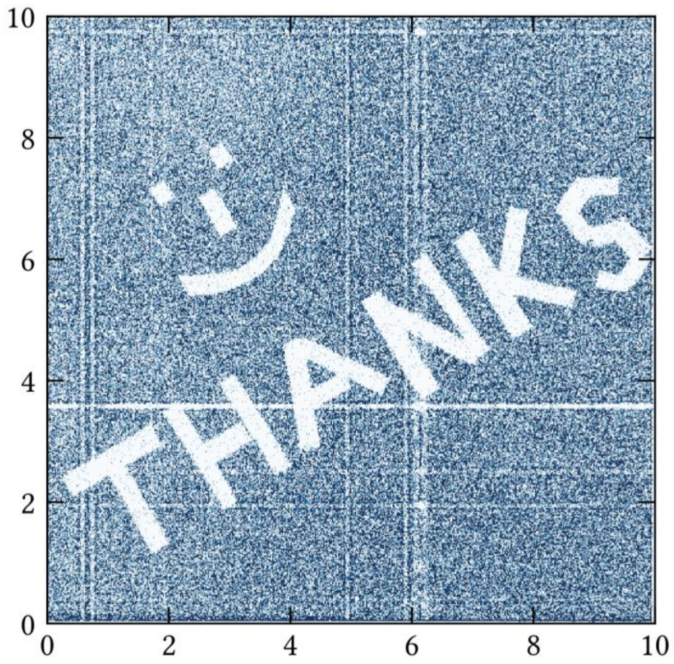

for your attention!

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