A Low Cost, High Dynamic Range Readout System for SiC Strip Detectors

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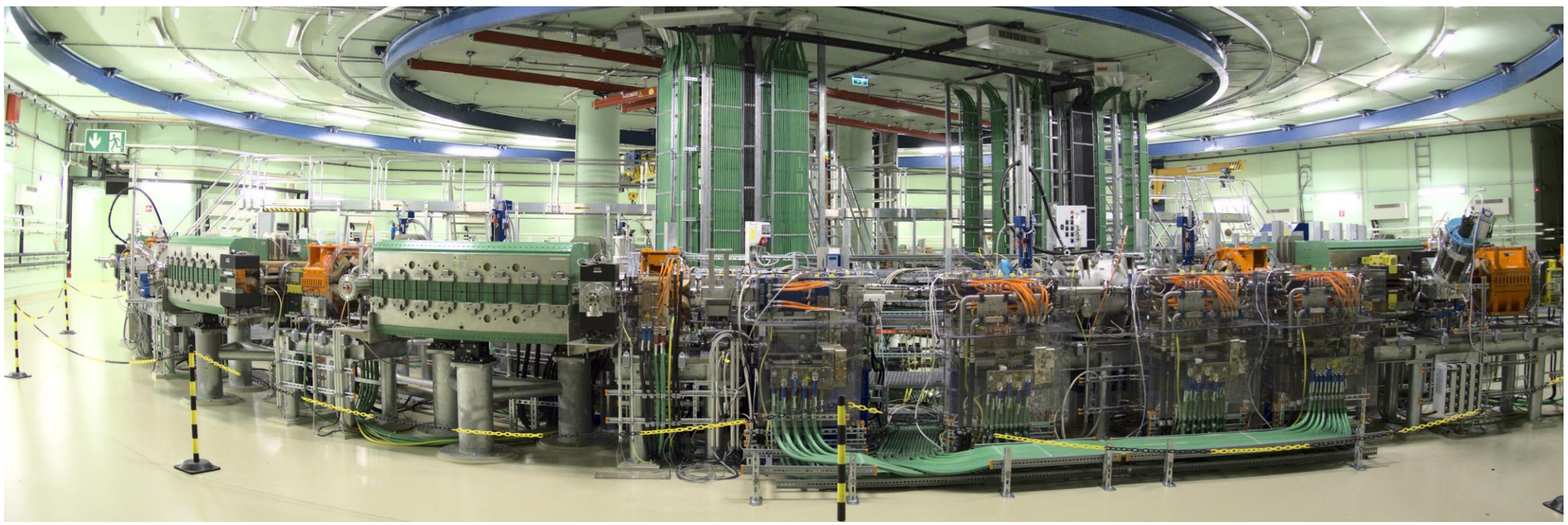
Outline

- Motivation
- ASIC vs COTS
- Properties of SiC
- Measurement results
- Summary/Outlook

Motivation

- The Medaustron accelerator is used for **cancer treatment** and **research**
- Primary beam particle **fluxes** range from **kHz** (research) to **GHz** (cancer treatment)
- Current beam detectors are blind for particle fluxes in the kHz regime
- Need for a beam monitor capable of covering the full range of particle fluxes



ASIC vs COTS

- Academic EDA licenses not viable when cooperating with a company

"Licensee may ship ICs/PCBs that incorporate the designs/output generated or validated by the Cadence Software to a non-commercial research institution for purposes of performing a non-commercial, Fundamental Research experiment; provided that (i) Licensee shall not sell, license, assign or otherwise transfer such ICs/PCBs without entering into a separate agreement with Cadence regarding the designs/output incorporated into such ICs/PCBs, which agreement may be subject to payment of additional fees to Cadence, and (ii) Licensee shall ensure that such ICs/PCBs shall be returned to Customer after the Fundamental Research experiment.„ [1]

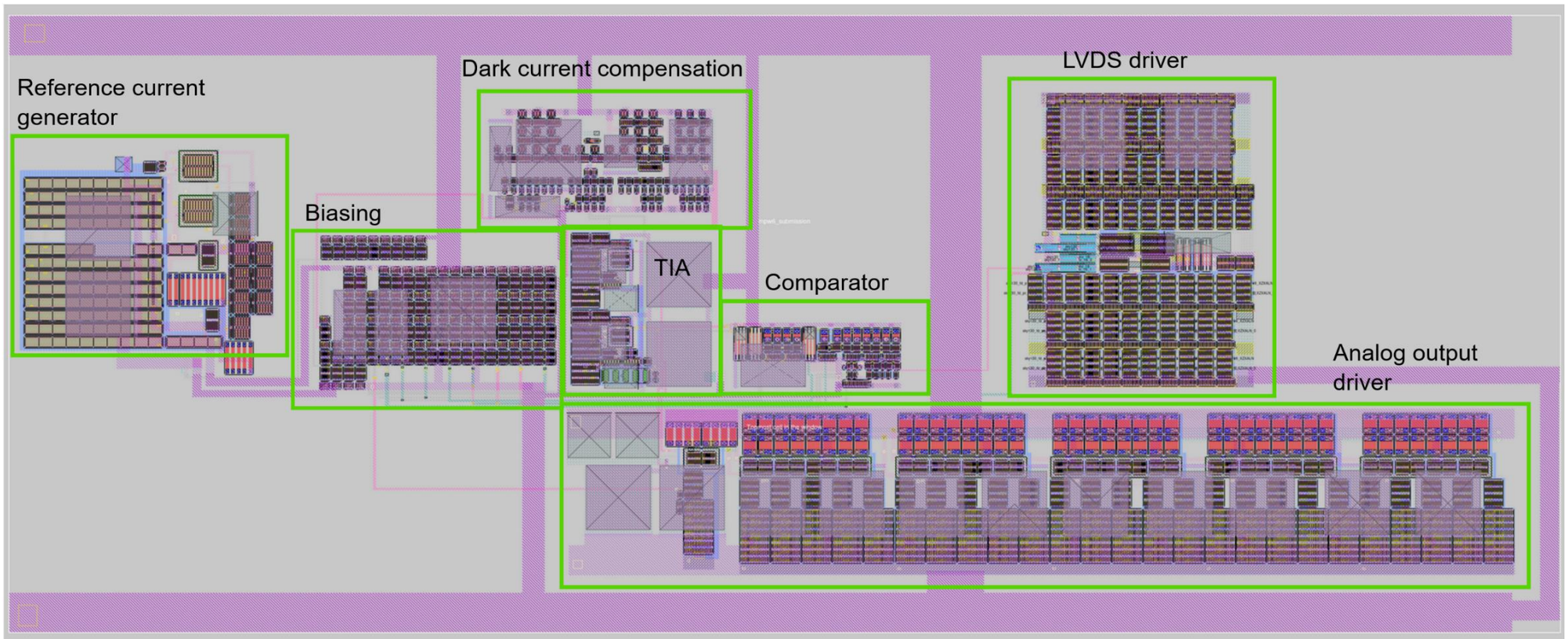
- Commercial EDA licenses not affordable for low-volume designs

- Open source workflows are potential alternatives. E.g. Skywater 130 nm and Global Foundries 180 nm
- **Can we read out our detector (SiC) using COTS?**

[1] https://www.cadence.com/content/dam/cadence-www/global/en_US/documents/terms-and-conditions/Cadence-TEN-AUA-v1.pdf

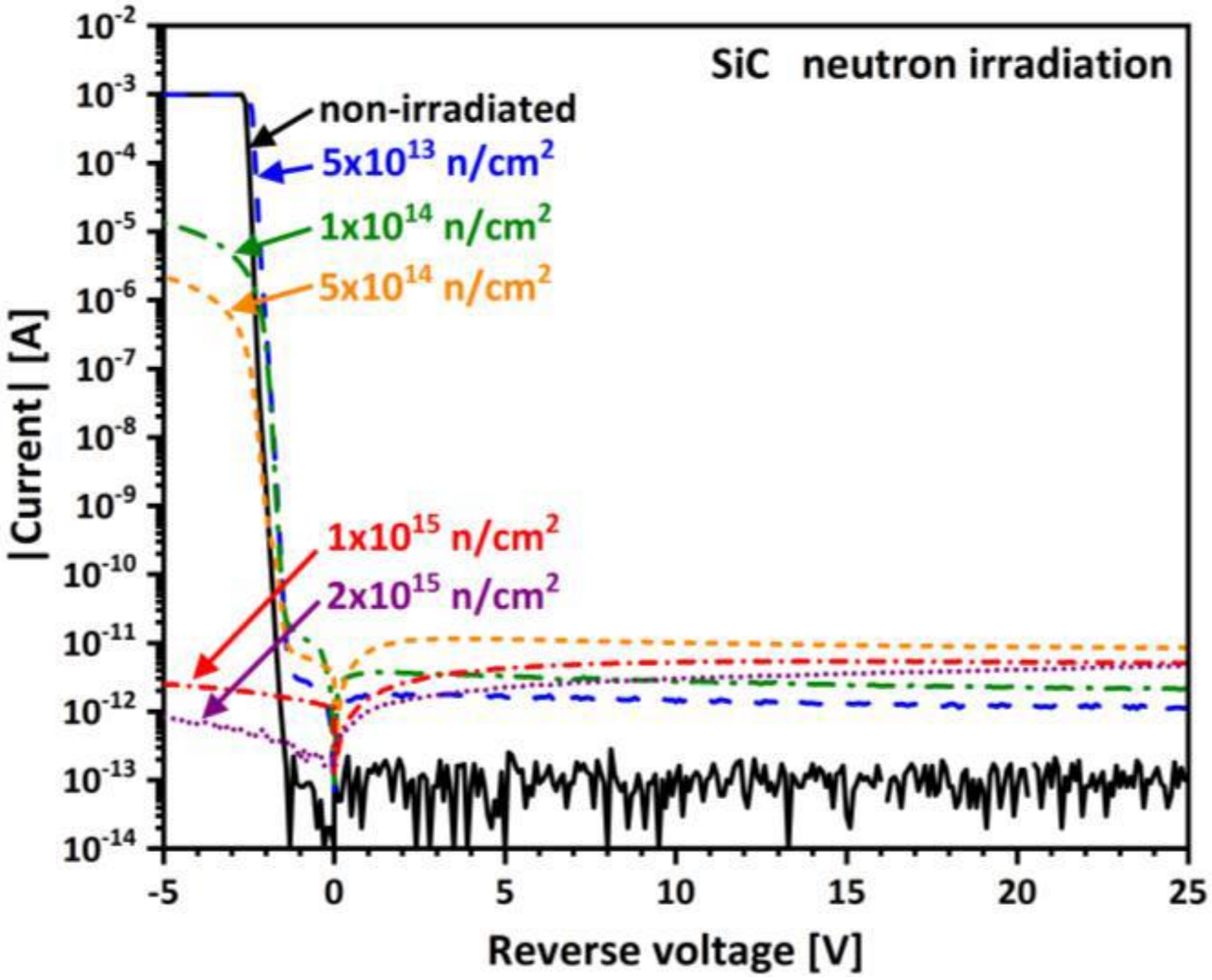
Towards Implementing an ASIC in SKY130A

- Implemented a TIA and other analog IP as a test balloon for the OSS workflow
- Tapeouts in March and July 2022. So far no chips returned.



Properties of SiC

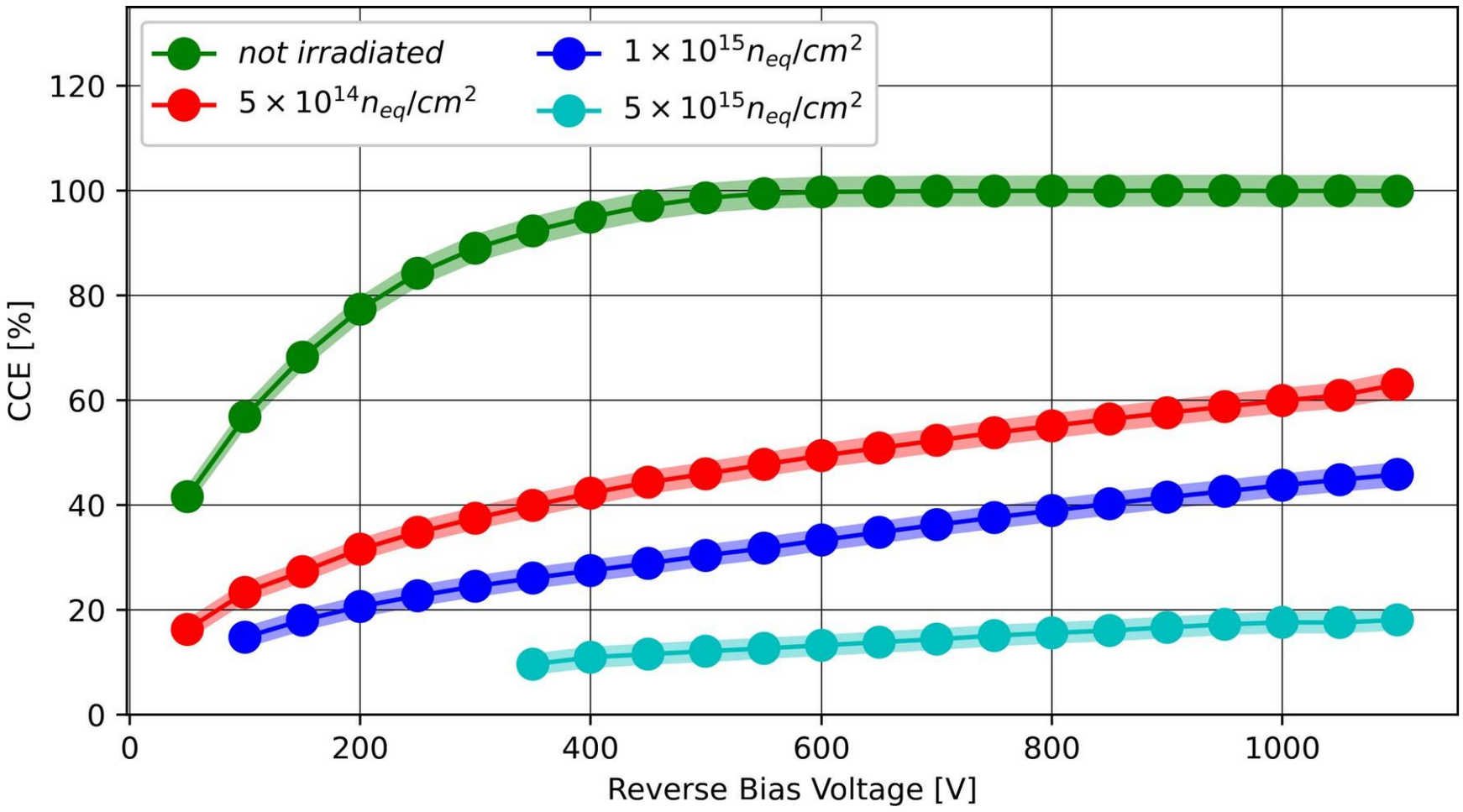
- No leakage when radiation damaged
  - **No dark current compensation needed**
  - **Can perform DC measurements for single particle detection**
  - No cooling needed
- Now commercially available!



Leakage current of 3x3 mm² SiC detectors exposed to 1MeV Neutron equivalent doses up to 2E15 neq/cm². Image source: [1]

[1] Joan Marc Rafí et al. IEEE Transactions on Nuclear Science PP(99):1-1 (2020), http://dx.doi.org/10.1109/TNS.2020.3029730

Radiation Hardness of SiC

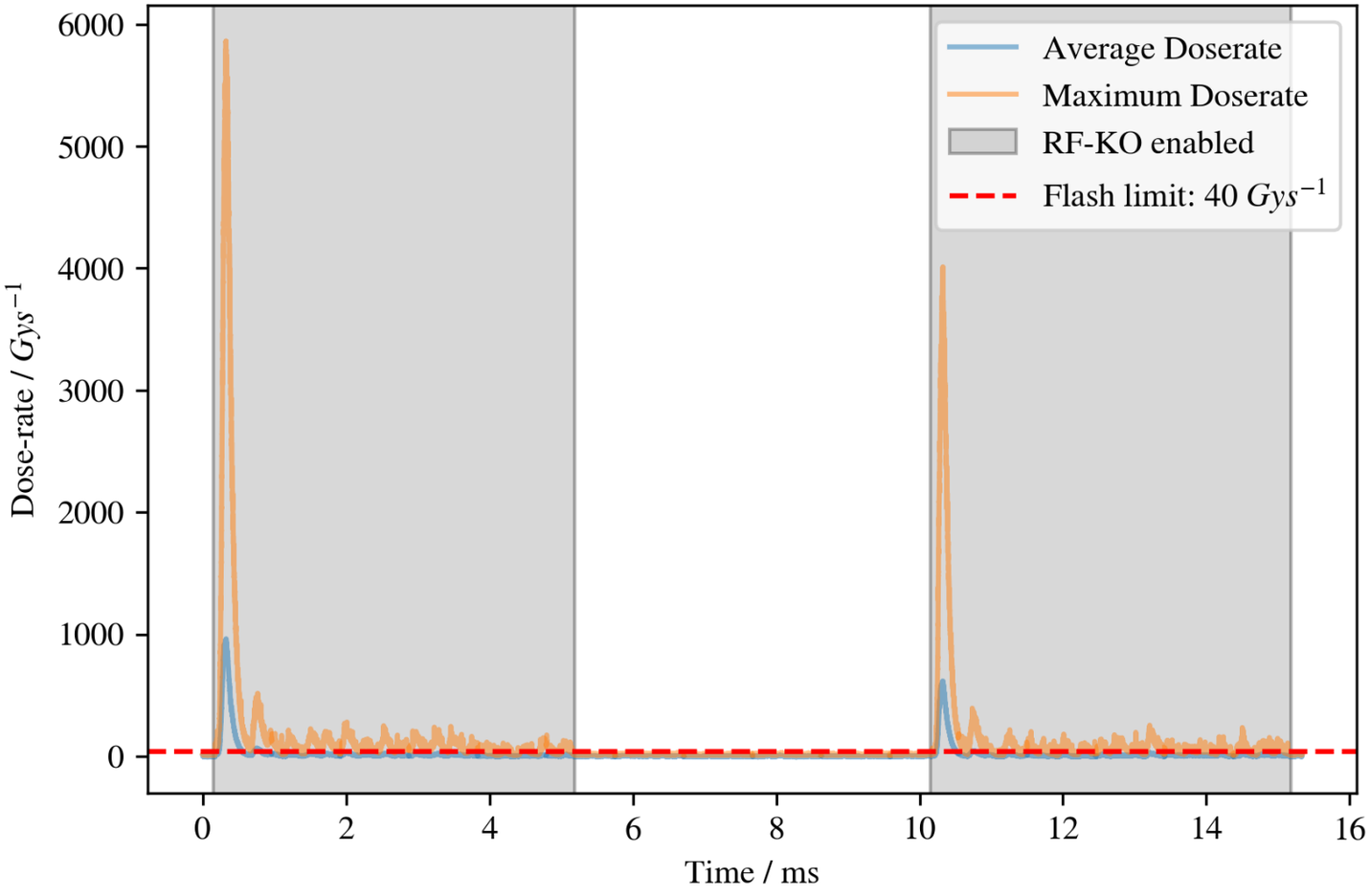


UV-TCT collection efficiency of 50µm thick 3x3 mm² SiC samples exposed to 1MeV Neutron equivalent doses up to 5E15 neq/cm² [1]

[1] Gaggl et al.; 40th RD50 Workshop, 2022

Properties of SiC

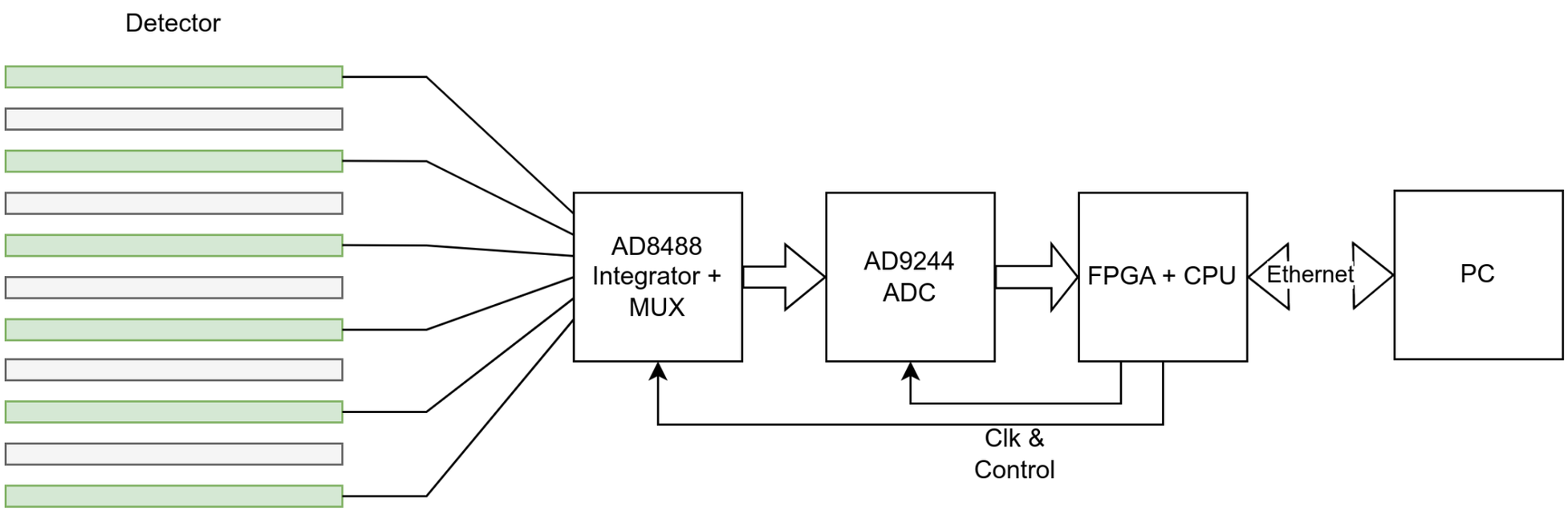
High dynamic range: Can detect single particles (delivers 57.1e/µm for a minimum ionizing particle [1]). Can work at dose rates up to the kGy/s regime



Preliminary data: 50µm SiC exposed to short Pulses of a 252.7 MeV proton beam

COTS Frontend: AD8488 for X-Ray TFT Panels

- Input referred noise: 993 electrons/sample (at 38pF input capacitance)
- 128 input channels integrator with integrate/hold and MUX elements
- Up to 37 kHz sampling rate (> 12µs integration, 15µs readout)
- Selectable amplification up to 44 dB (Full range current from +/- 3.6 nA To +/- 1.8 µA)



AD8488 Input Circuit

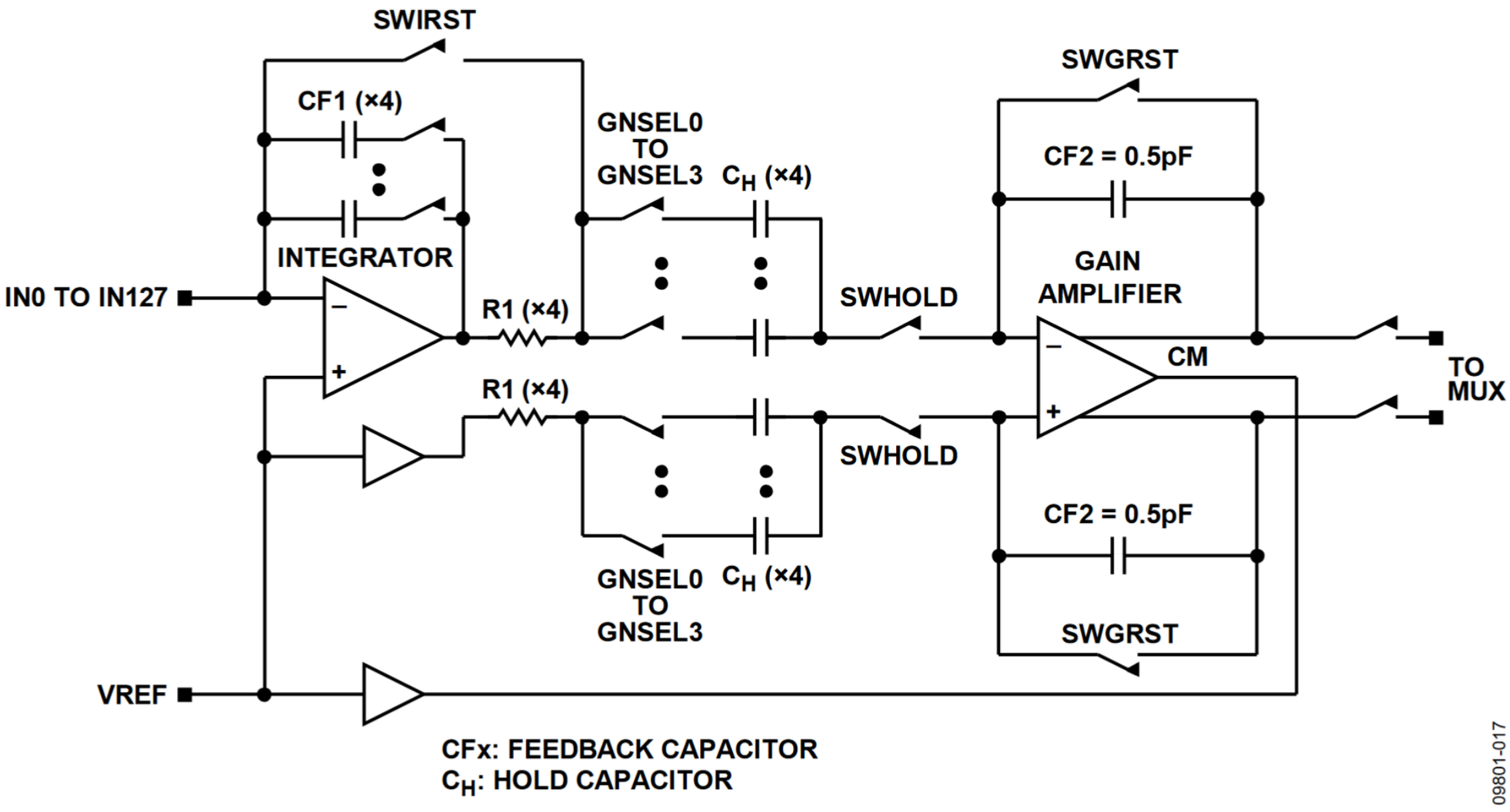
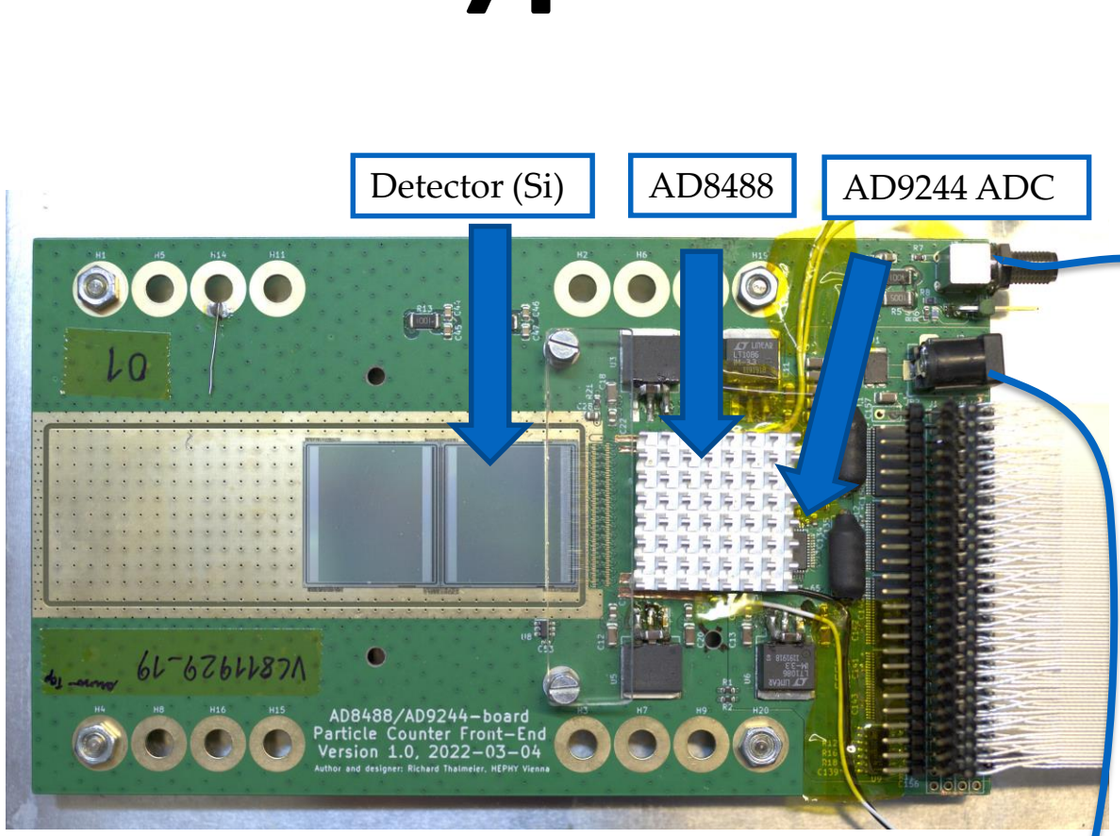
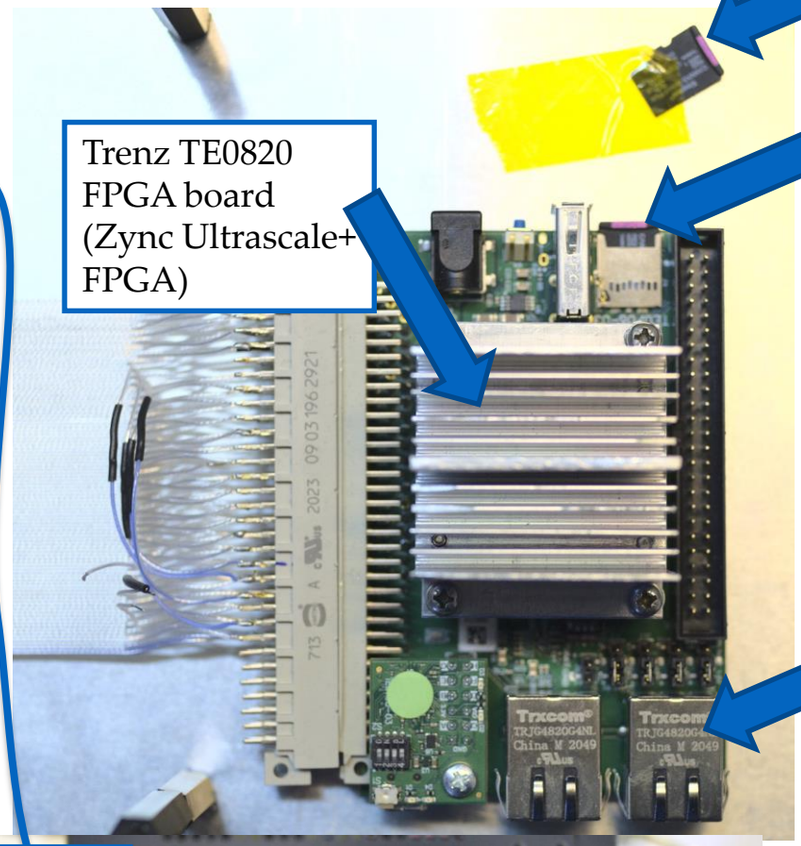
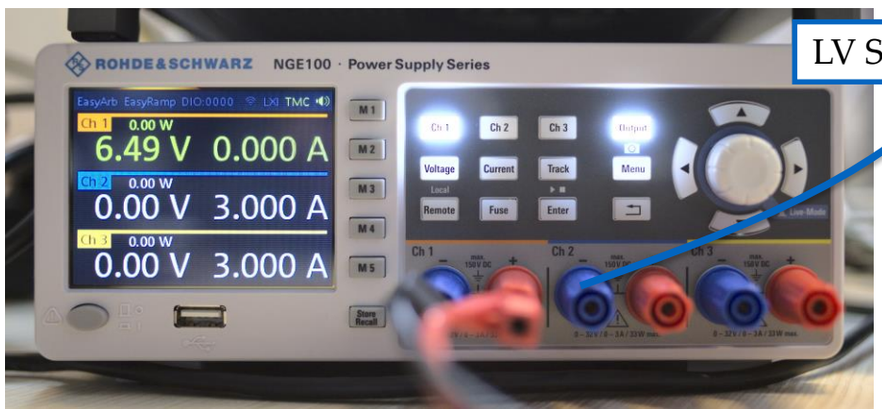


Image source: Analog Devices AD8488 Data Sheet Rev. A

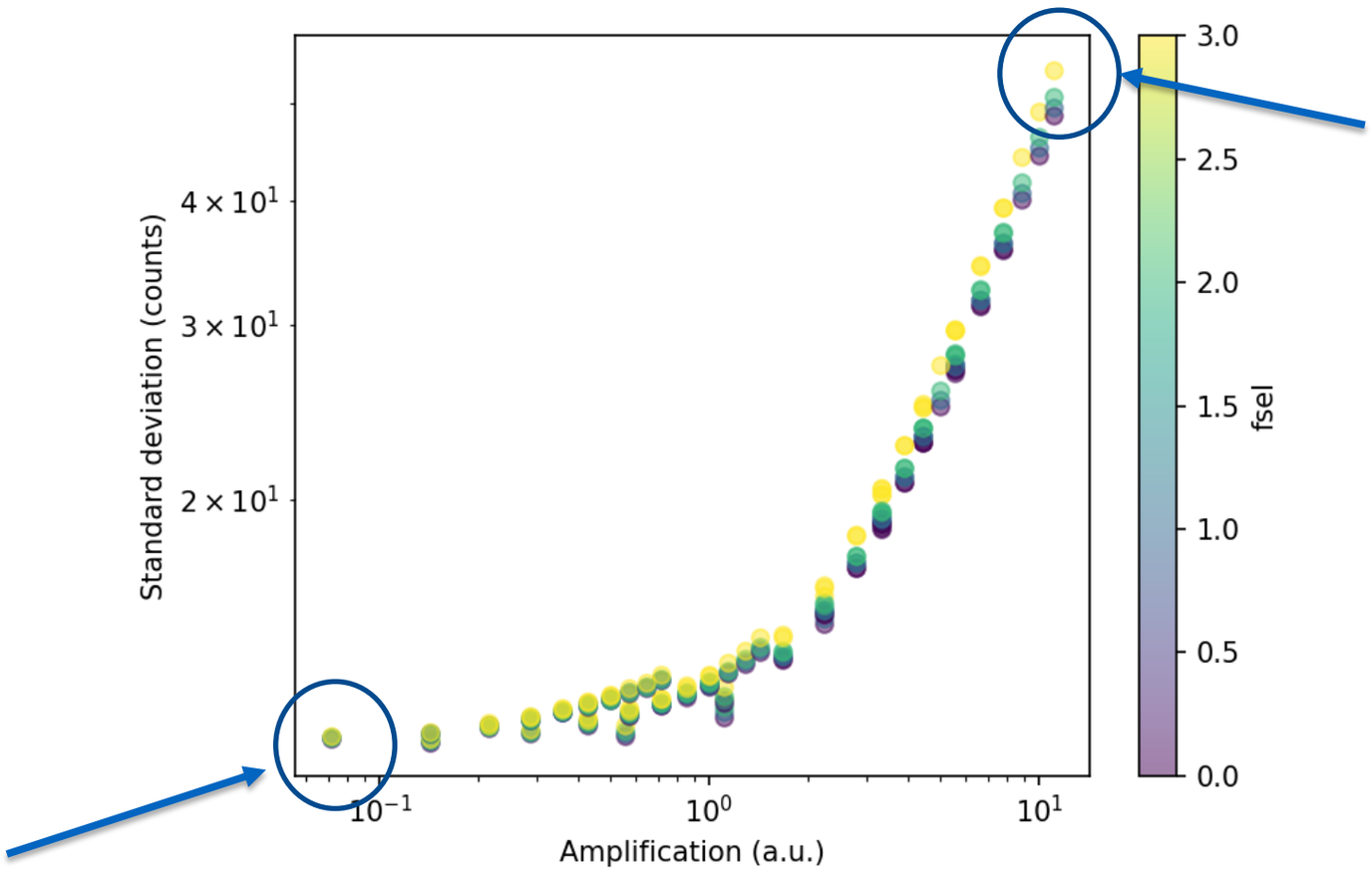
Prototype Measurement Setup







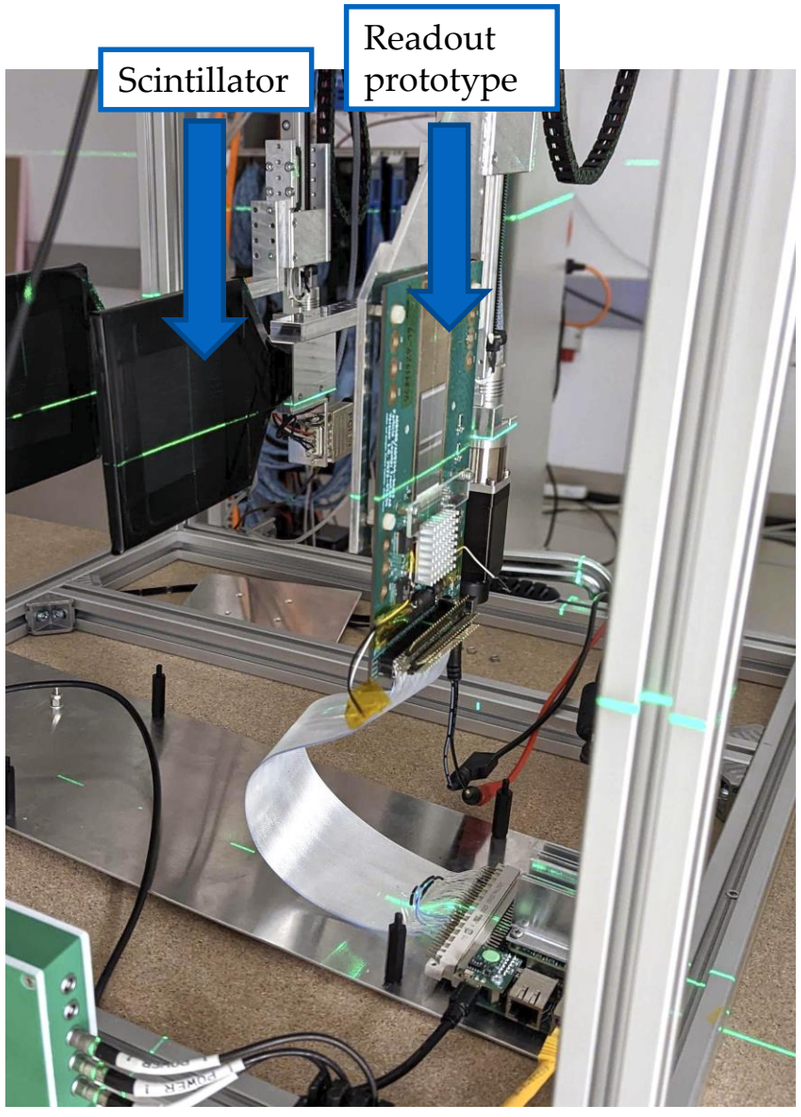
Characterization of noise



- Single particle detection. Noise ~1700 e-
- Expected signal from future 100µm SiC detector: ~5700 e- per event.

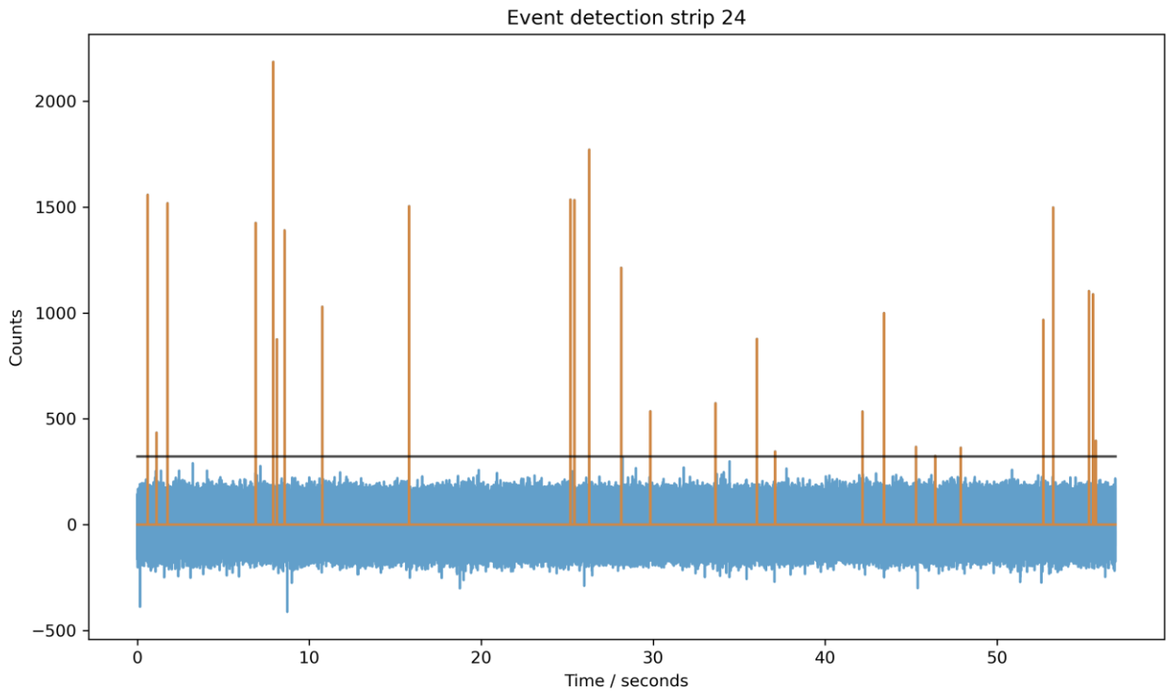
Clinical rates:
~ 9 bit net ADC resolution

Prototype Tests

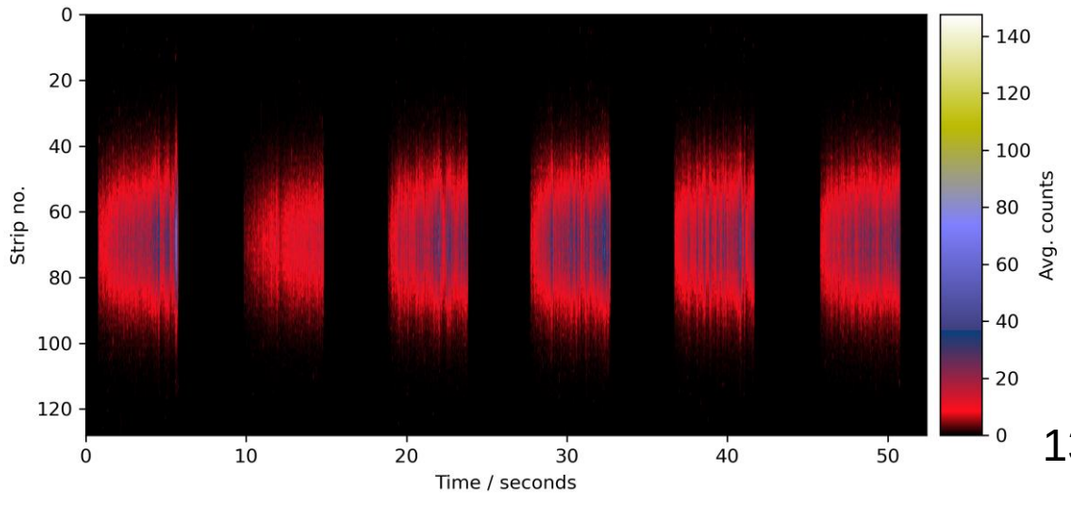


Readout prototype, equipped with a Si strip detector ready for test beam

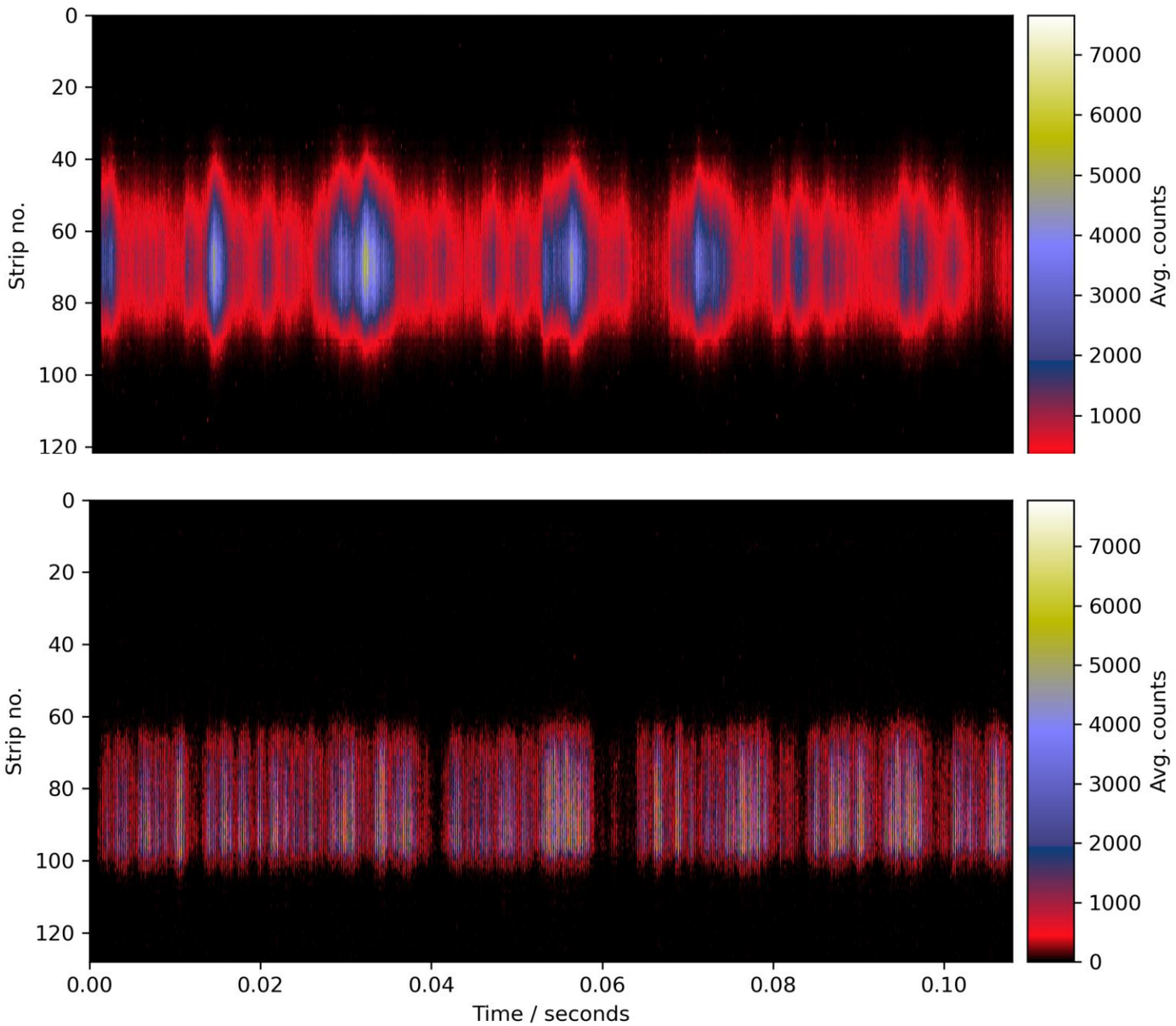
Detection of single events at 3 kHz nominal particle rate, 252.7 MeV protons



Spill structure acquired at at 300 kHz nominal particle rate, 252.7 MeV protons



Clinical intensities



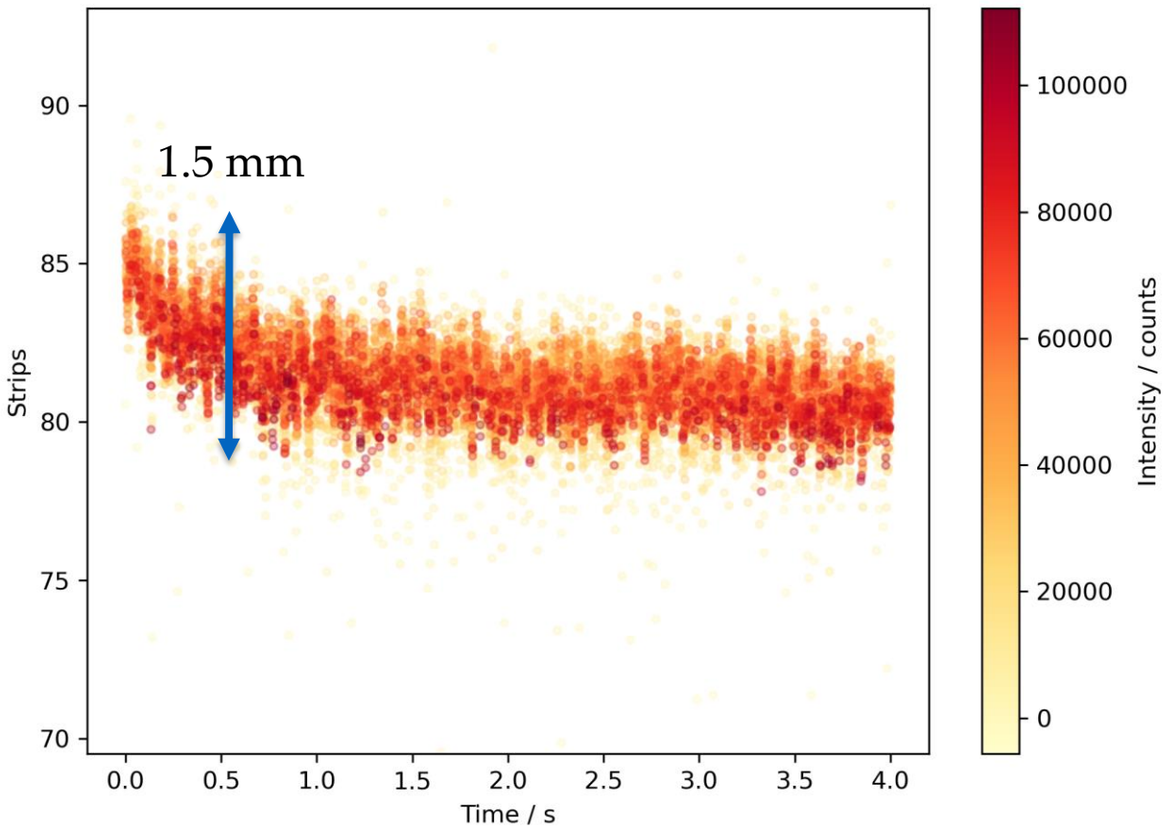
Time resolved shape of a 252.7 MeV clinical proton beam (1GHz) at Medaustron

Time resolved shape of a 402 MeV clinical carbon beam at Medaustron

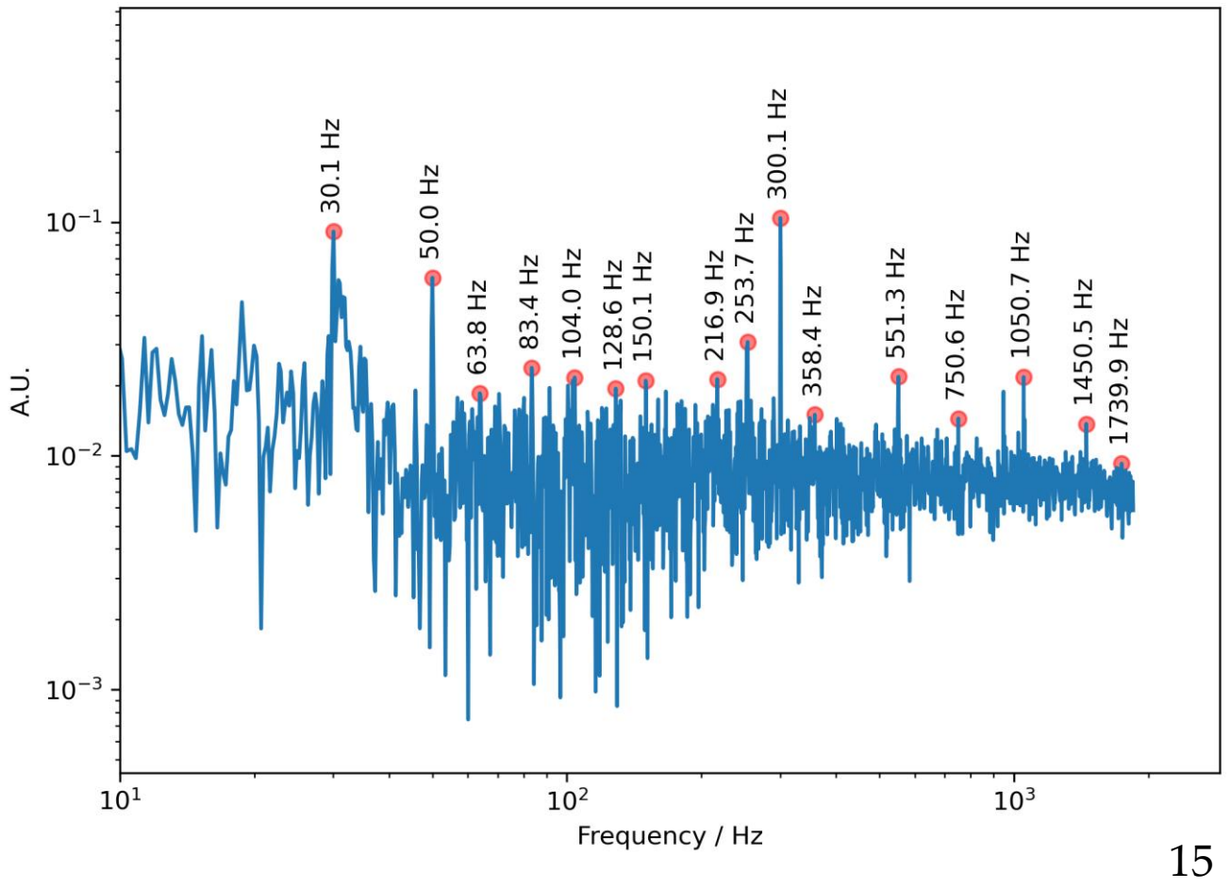
Use as a Beam Monitor

Exemplary extraction of beam parameters: Center of mass

Center of mass, 402 MeV carbon ions, resampled to 3.7kHz sampling frequency



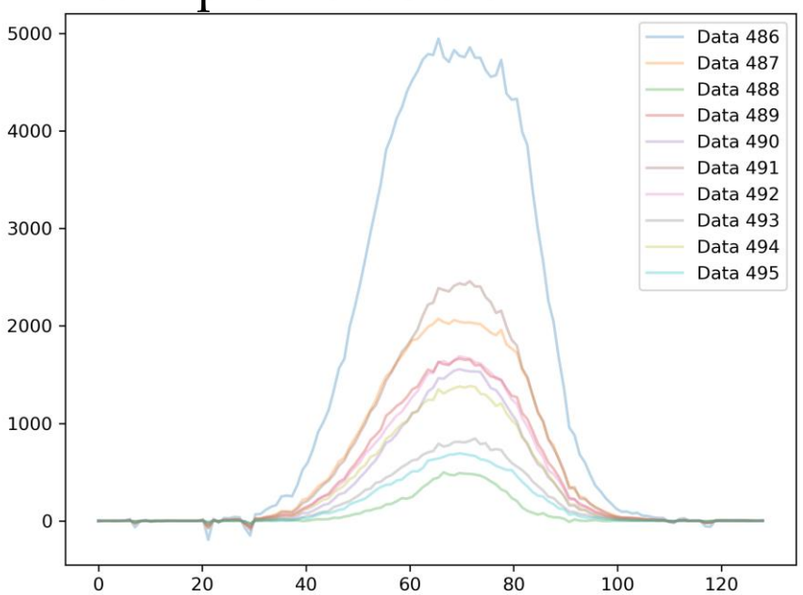
FFT of the data shown in the figure on the left



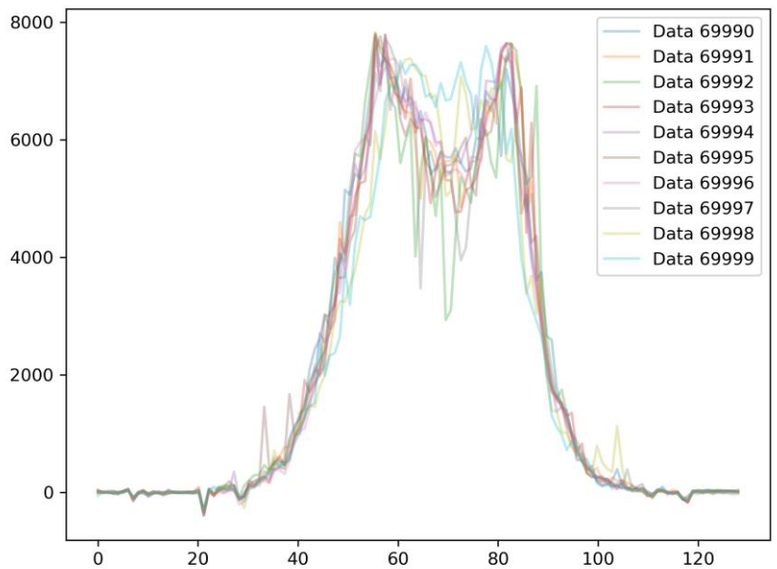
Is There Saturation?

- Tested using a 300µm thick Si detector to simulate a future SiC LGAD.
- Further need to increase dynamic range ➔ Build attenuator (planned 26 dB attenuation ➔ 70 dB tunable range).

252.7 MeV, Good case:
Beam profile visible



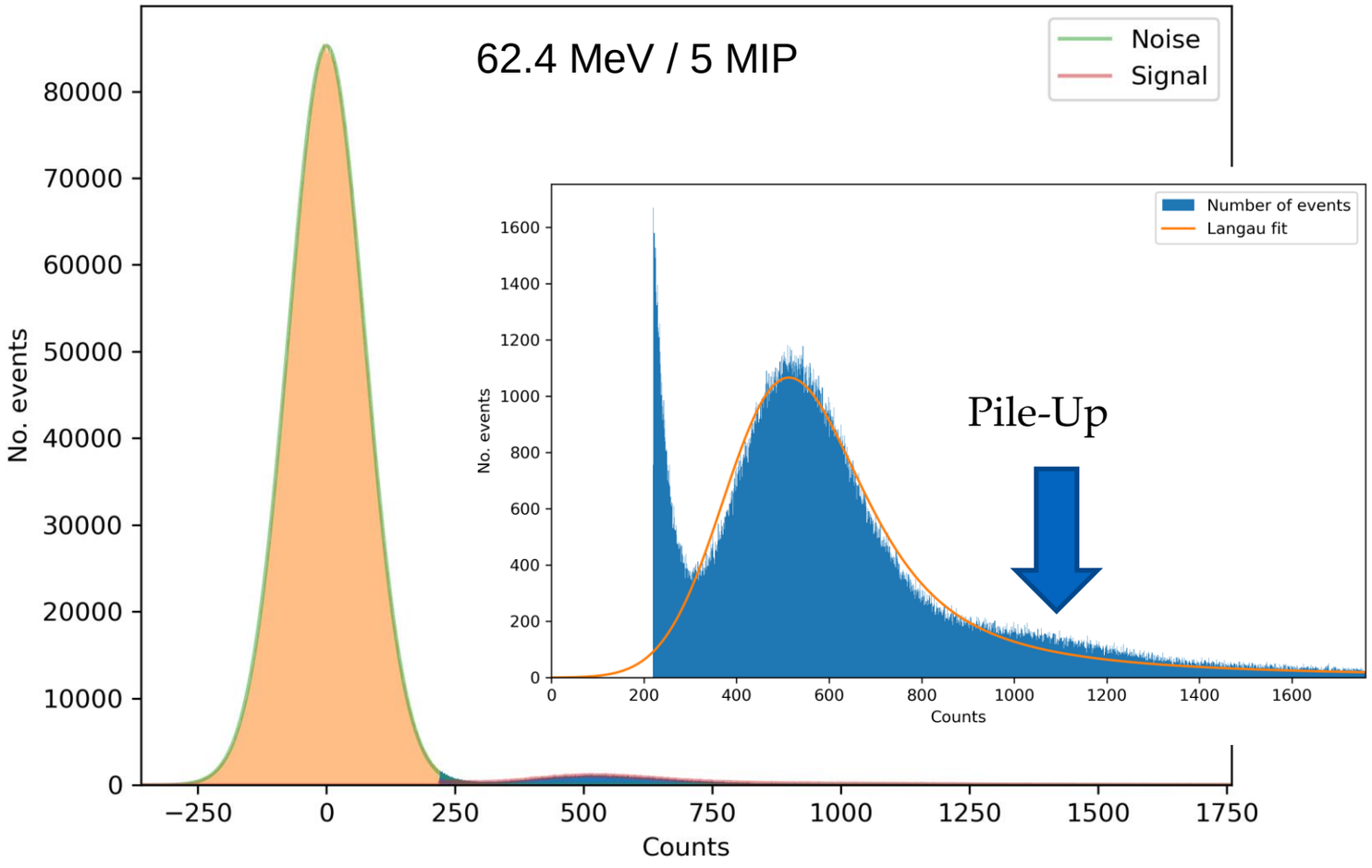
252.7 MeV, Bad case:
Frontend saturates

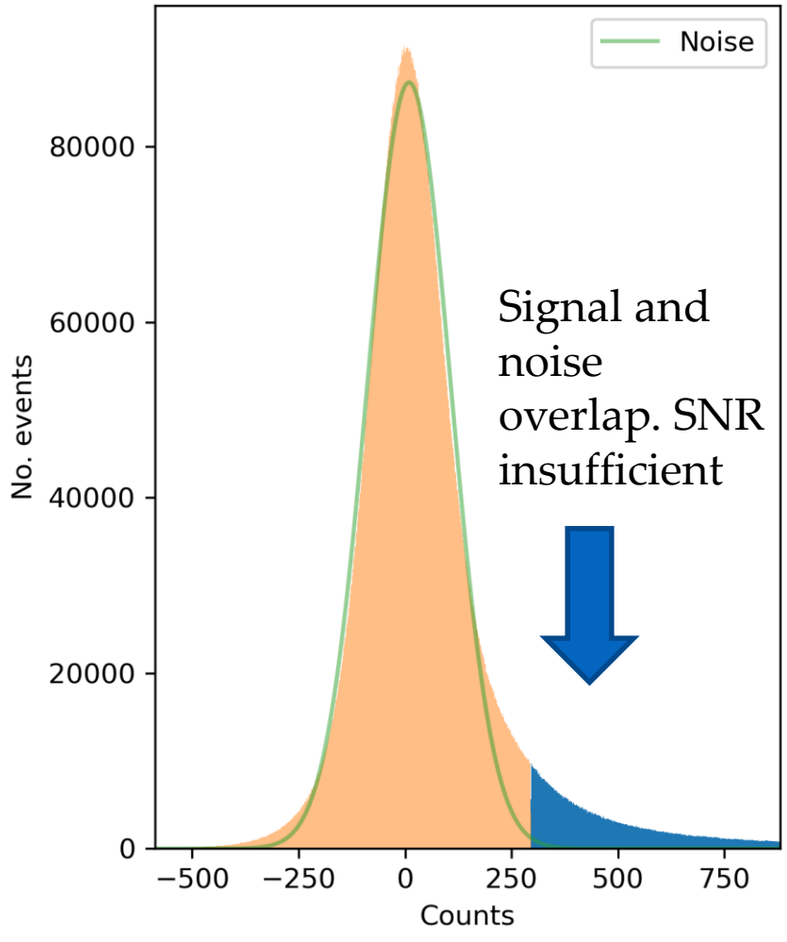


Single Particle Detection

- 50 µm thick SiC diode
- 3x3 mm² pad
- One channel only
- Noise 2500 electrons / sample

252.7 MeV / 2 MIP





Summary

- A 128 channel strip detector frontend was built using COTS
- Using a 50µm SiC pad detector, single particles can be detected; SNR needs improvement
- Using a 300µm Si detector, beam profiles at clinical particle rates (e.g. 1GHz Protons) were measured. Rare cases of saturation were observed.

Outlook

- Improve SNR
  - Improve noise suppression from HV, Improve electronics to reduce background noise from 1700-2500 electrons/sample towards 1000 electrons/sample
  - Improve signal intensity from the detector: Thicker diode or LGAD structure
- Improve dynamic range by adding a switchable attenuator
- Continue work SKY130A IP, parts will be open sourced

Thank you for your attention!

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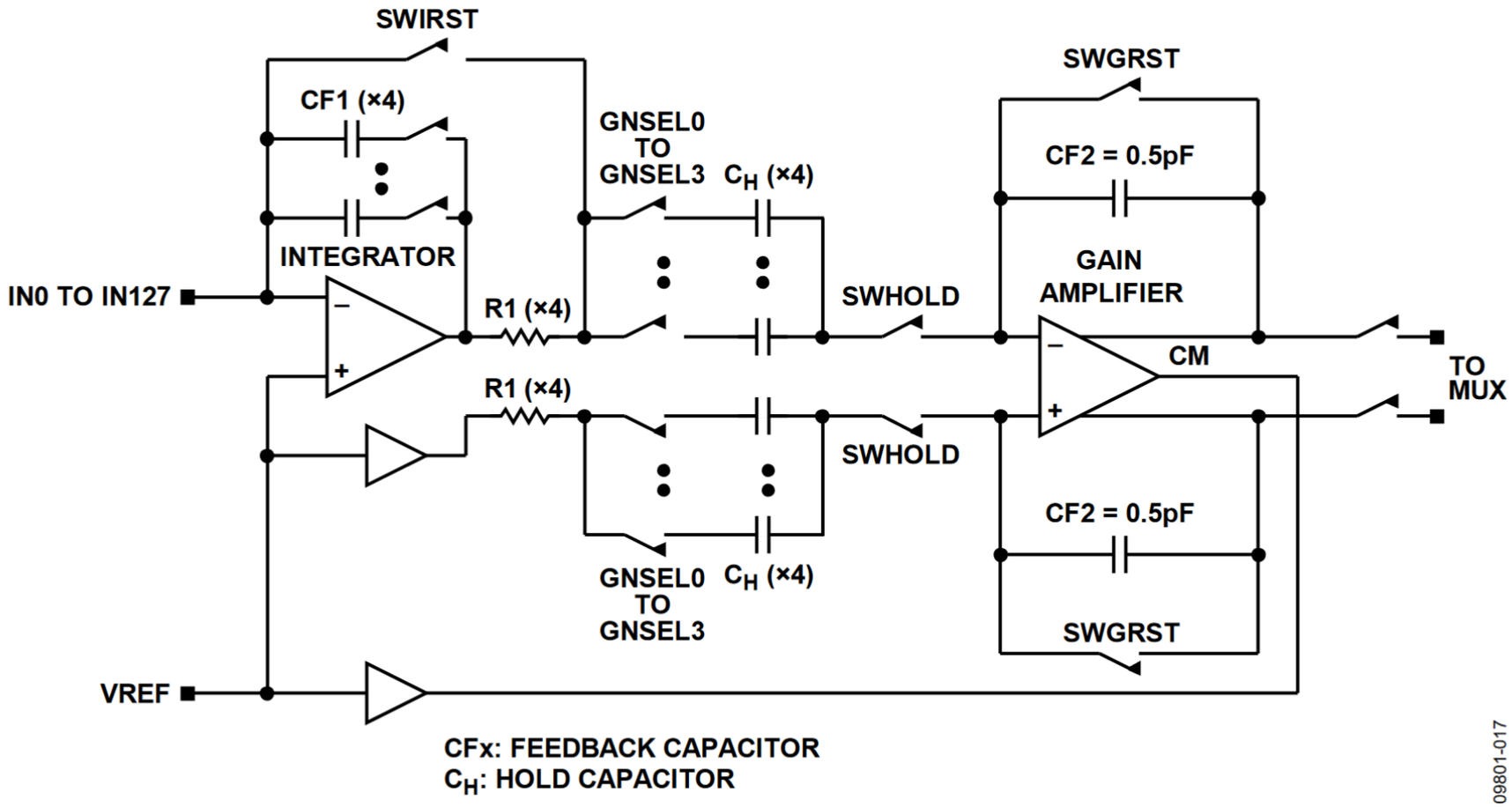
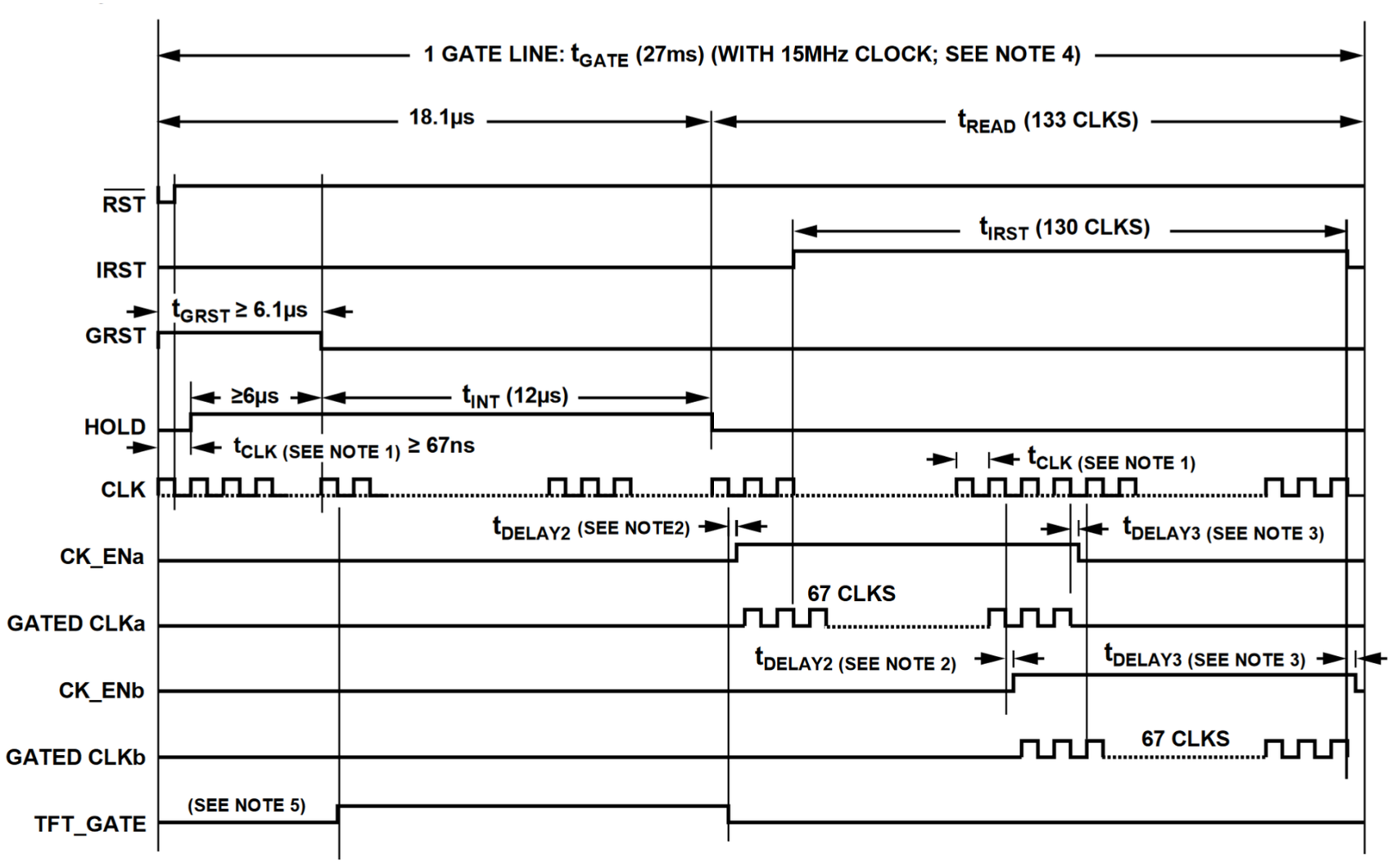
Readout


SWIRST
CF1 (×4)
GNSEL0
TO
GNSEL3
C_H (×4)
SWGRST
CF2 = 0.5pF
INTEGRATOR
GAIN
AMPLIFIER
IN0 TO IN127
R1 (×4)
SWHOLD
CM
TO
MUX
R1 (×4)
SWHOLD
CF2 = 0.5pF
GNSEL0
TO
GNSEL3
C_H (×4)
SWGRST
VREF
CFx: FEEDBACK CAPACITOR
C_H: HOLD CAPACITOR
09801-017

Readout


1 GATE LINE: t_{GATE} (27ms) (WITH 15MHz CLOCK; SEE NOTE 4)
18.1µs
t_{READ} (133 CLKS)
RST
t_{IRST} (130 CLKS)
IRST
t_{GRST} ≥ 6.1µs
GRST
≥6µs
t_{INT} (12µs)
HOLD
t_{CLK} (SEE NOTE 1) ≥ 67ns
t_{CLK} (SEE NOTE 1)
CLK
t_{DELAY2} (SEE NOTE2)
t_{DELAY3} (SEE NOTE 3)
CK_ENa
67 CLKS
GATED CLKa
t_{DELAY2} (SEE NOTE 2)
t_{DELAY3} (SEE NOTE 3)
CK_ENb
67 CLKS
GATED CLKb
(SEE NOTE 5)
TFT_GATE