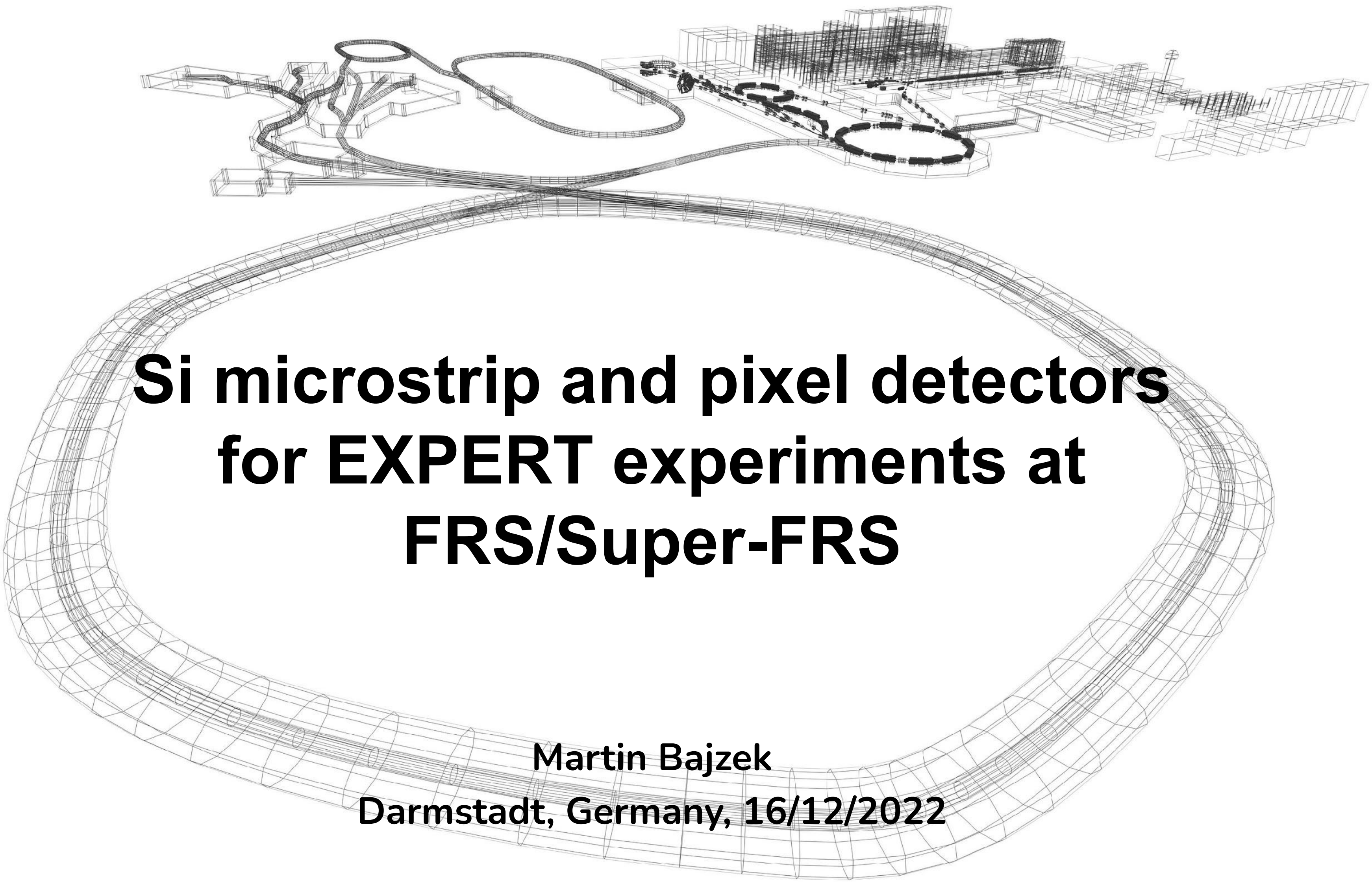
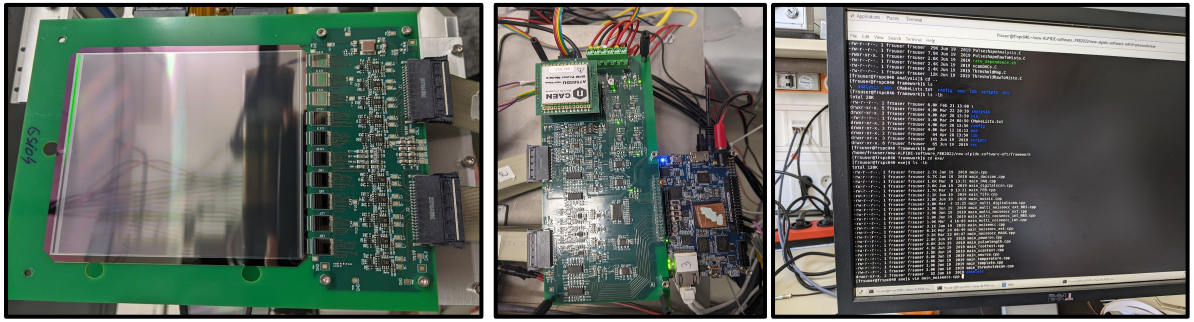


Si microstrip and pixel detectors for EXPERT experiments at FRS/Super-FRS

Martin Bajzek

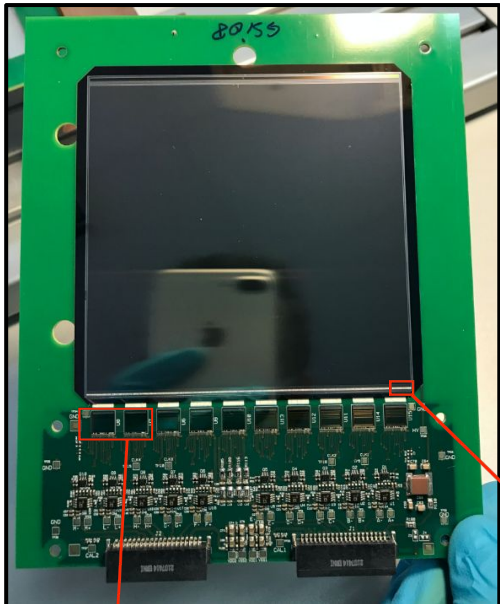
Darmstadt, Germany, 16/12/2022

FragmentatiOn Of Target (FOOT) detectors

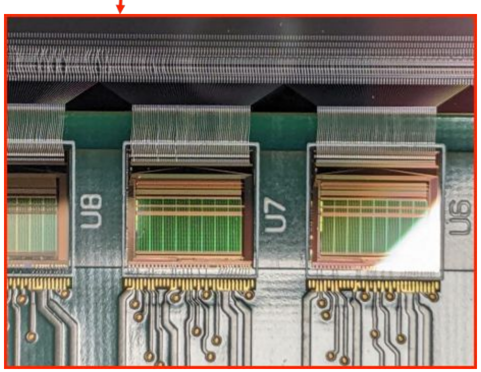


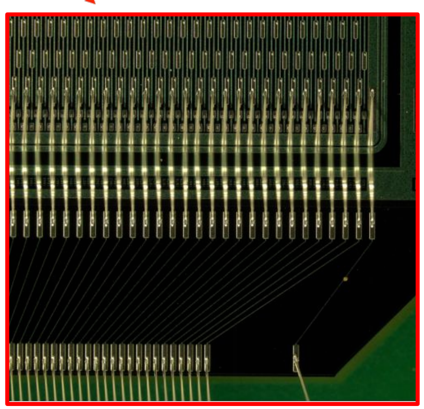
- Tracking of light charged particles (~MIP)
- Single-sided
- Replacement of old AMS detectors
- Reconstruction of outgoing angles with a (few) mrad resolution
- Vertex reconstruction with a <1 mm accuracy
- Additionally:
  - Tagging charge of final state products ($Z \lesssim 20$)
  - Resolving multiple particle tracks

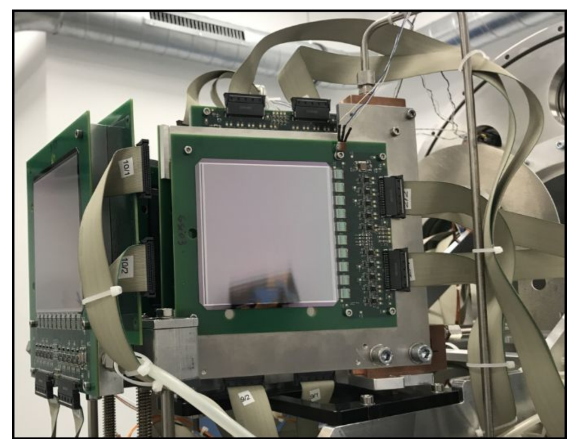
Sensor + ASICs + Front-end



- Single-sided sensors (HAMAMATSU), 150 μm thick
- 640 ch per detector (10 cm)
- Front-end architecture:
    - 10 charge-sensitive ASICs IDE1140 (IDEAS)
        - AC-coupling, linear response
    - 2x 40 pin connectors
- Differential signals from FE to ADC boards
- 15 detectors available at GSI

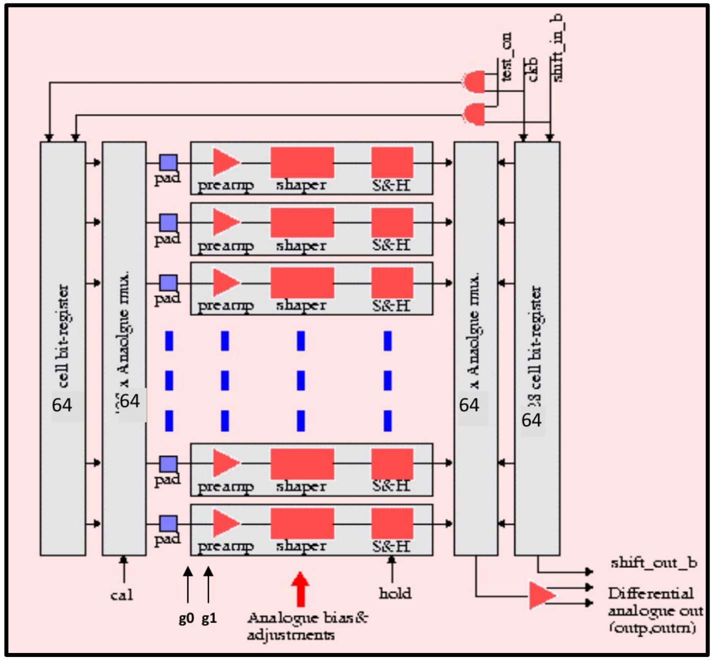


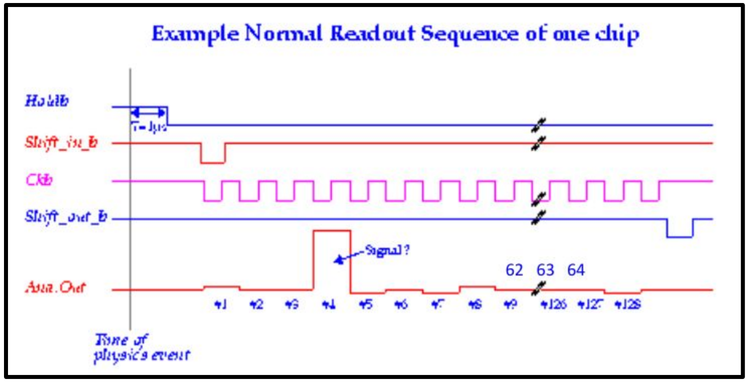




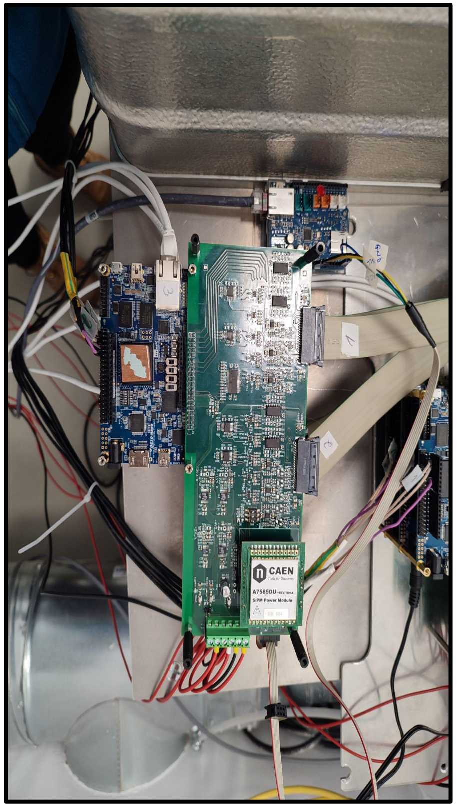
Signal processing schematic

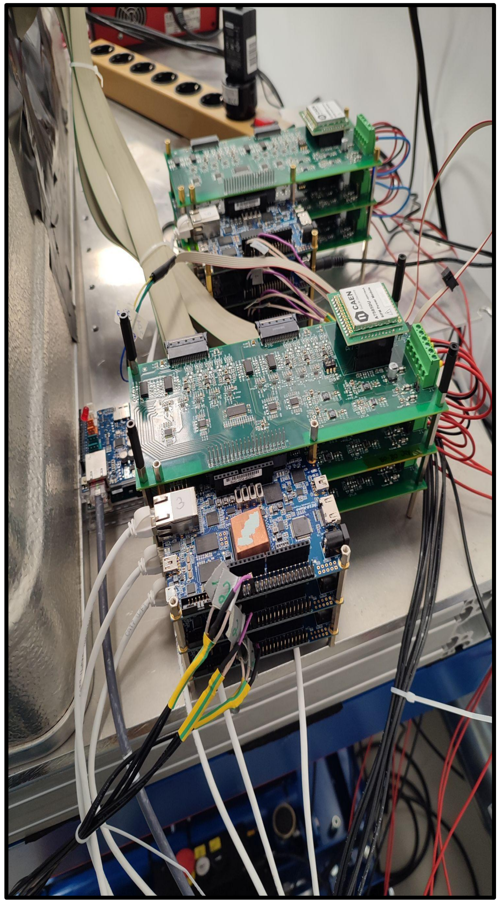
- Rising time of a charged particle hit signal 5-8 μs
- **Shape&Hold** - programmable indicator when the output of shaper gets sampled
  - Default 6.5 μs





ADC + FPGA



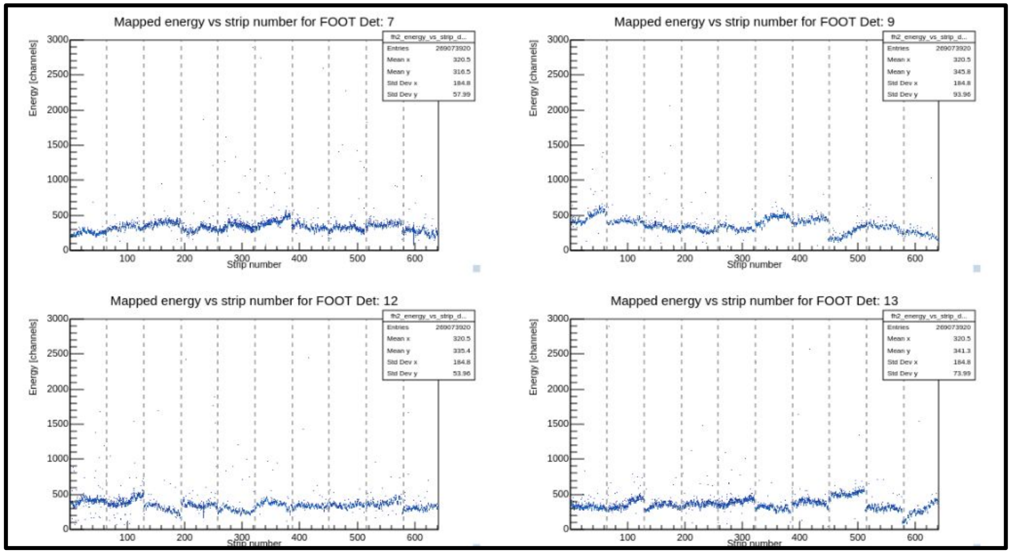


Timestamp source
http://web-docs.gsi.de/~bloeher/wrtclk/

- Custom ADC with two 40-pin connector input
- CAEN HV module steered by Arduino Uno Via I^2C
- **DE10-Nano**
  - Intel SoC FPGA
  - Processor, peripherals, high-speed DDR3 memory, ethernet capability
- Polls data from ADC, latches WR timestamp
- Sends event packets to a DAQ PC
- ~60 µs busy window, adjustable

Readout

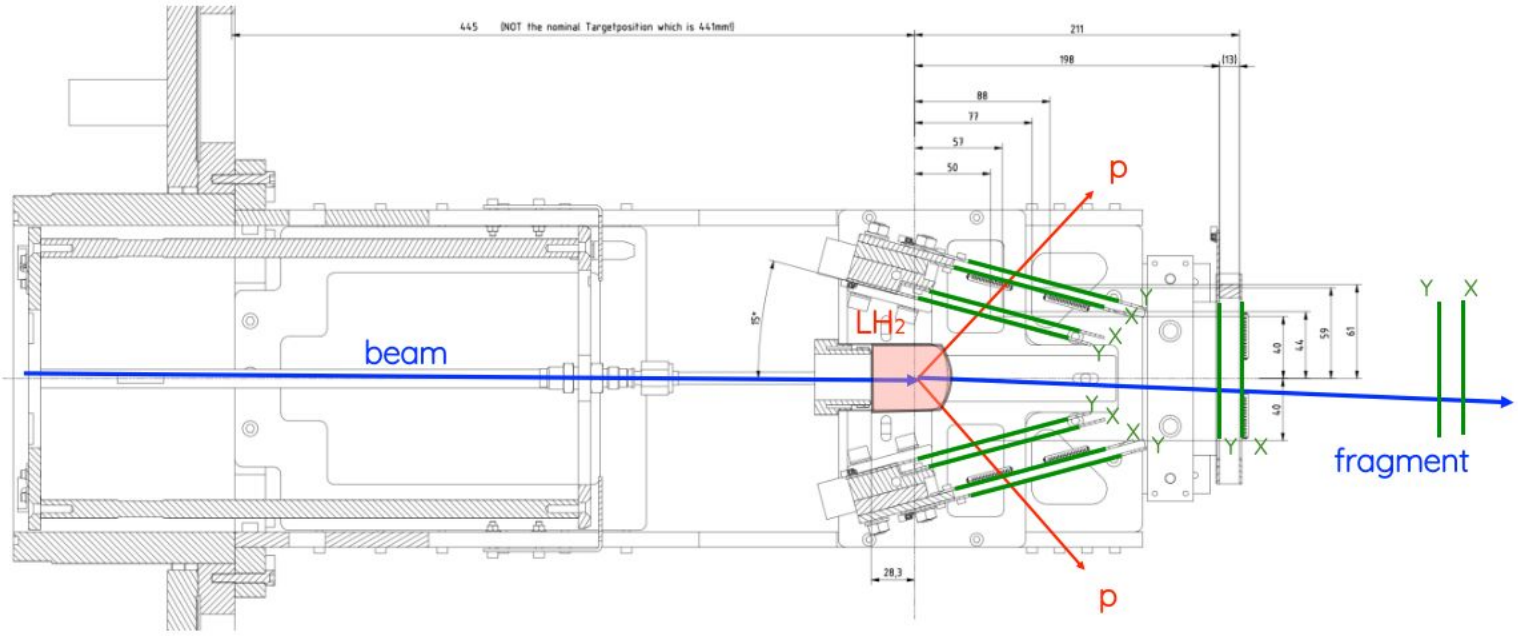
- drasi nodes running on DE10-Nano's, data transported to DAQ machine via 10 Gbps ethernet
- event-stitching & recording done on PC side
  - Synchronisation via WR and sync-trigger
- 1 subevent: ~800 bytes/detector, no pedestal removal
- LMD data output, data structure on https://wiki.r3b-nustar.de/detectors/foot/



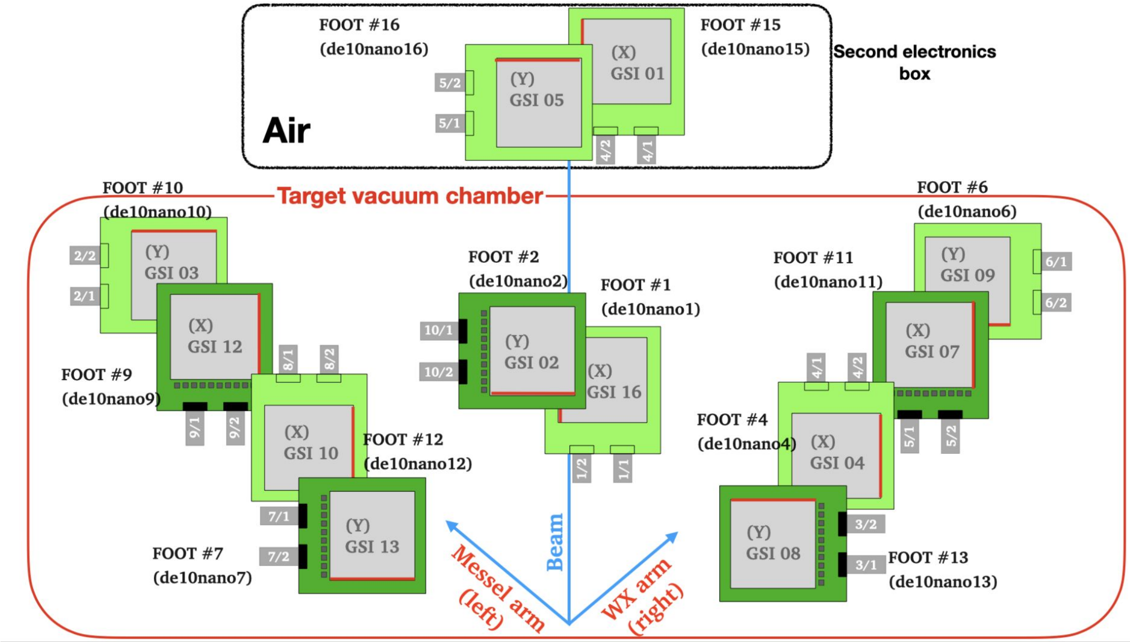
Raw (mapped) data

R^{3}B runs in May/June 2022 (II)

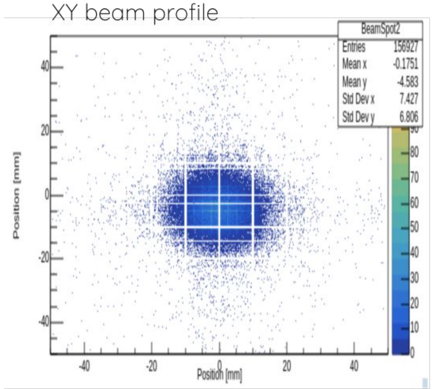
- Use in s509, s522 experiments in R^{3}B configuration in Cave-C, May/June, 2022
- Primary beam ^{18}O @1.3 AGeV, secondary ^{16}C, thick (50 mm) LH_2 target
- 12 detectors, 6 pairs measuring X,Y



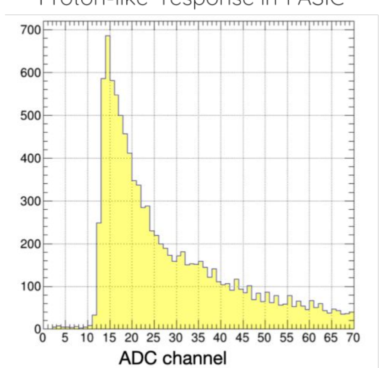
R3B runs in May/June 2022 (II)



XY beam profile



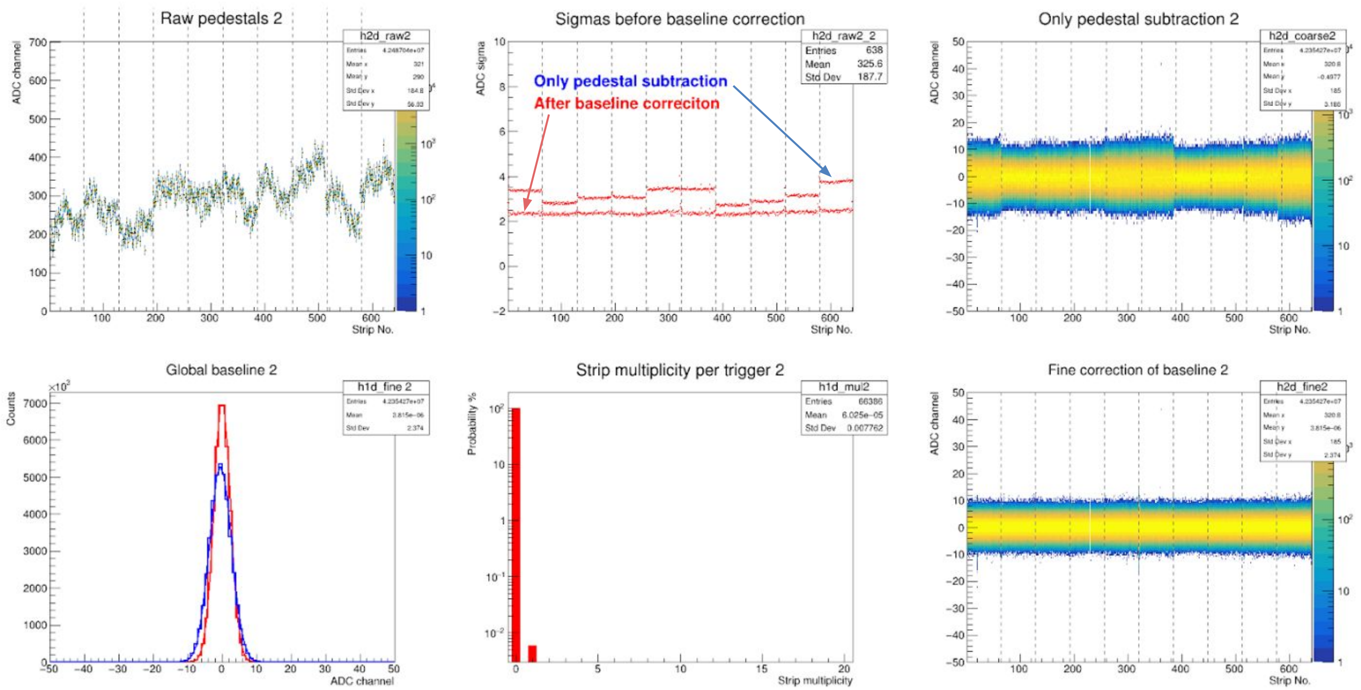
"Proton-like" response in 1 ASIC



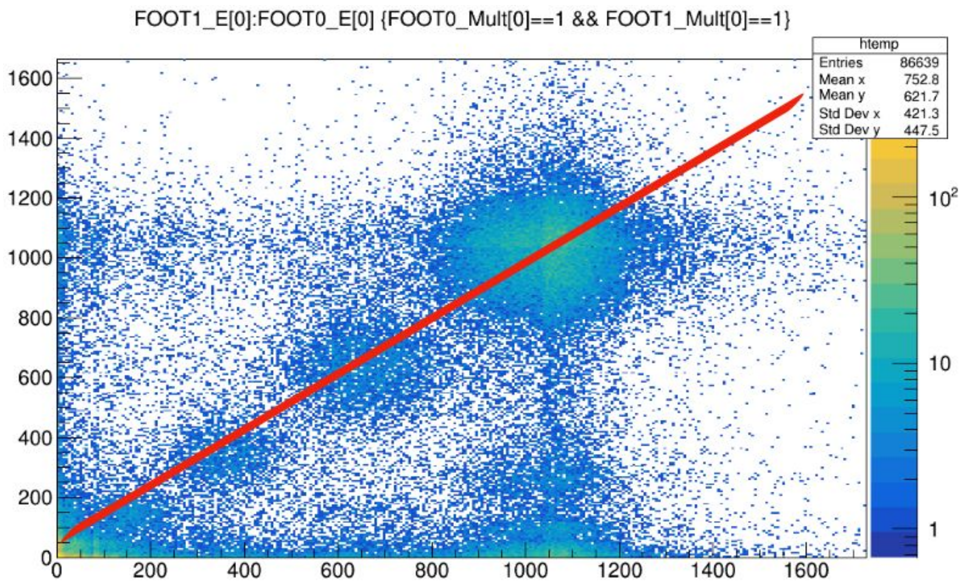
Courtesy of Dr. Valerii Panin

Analysis procedure

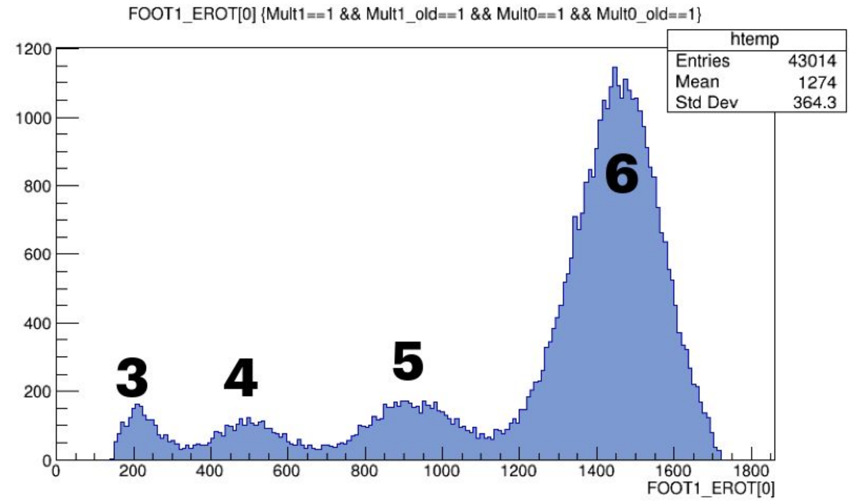
1. Global baseline subtraction (strip-by-strip)
2. Fine correction event-by-event
3. Interstrip hit correction (*η-correction*) & clustering



- In-beam detectors can separate some charged states

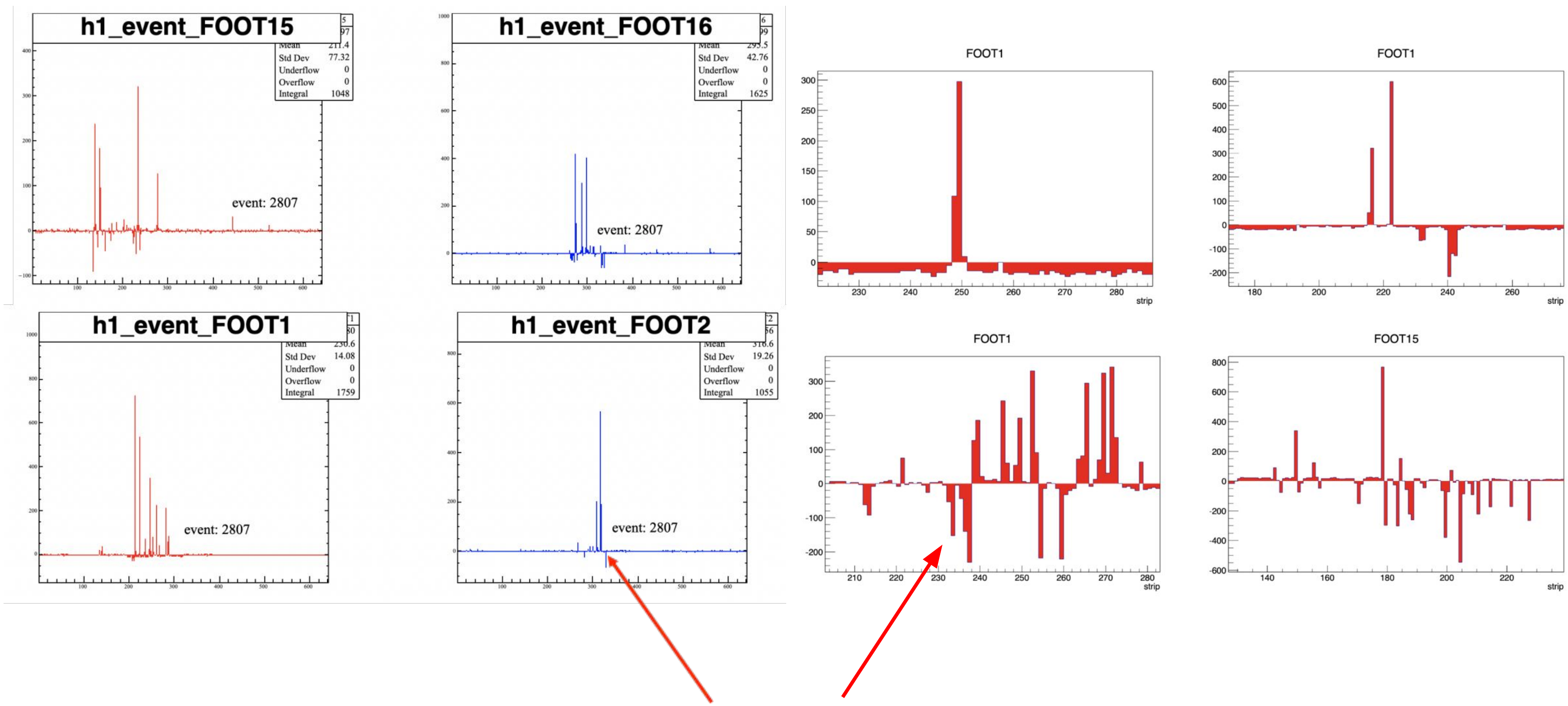


FOOT1 vs FOOT0 correlation (ADC units)



Charge Z identified by correlating with ToFD (tof-wall)

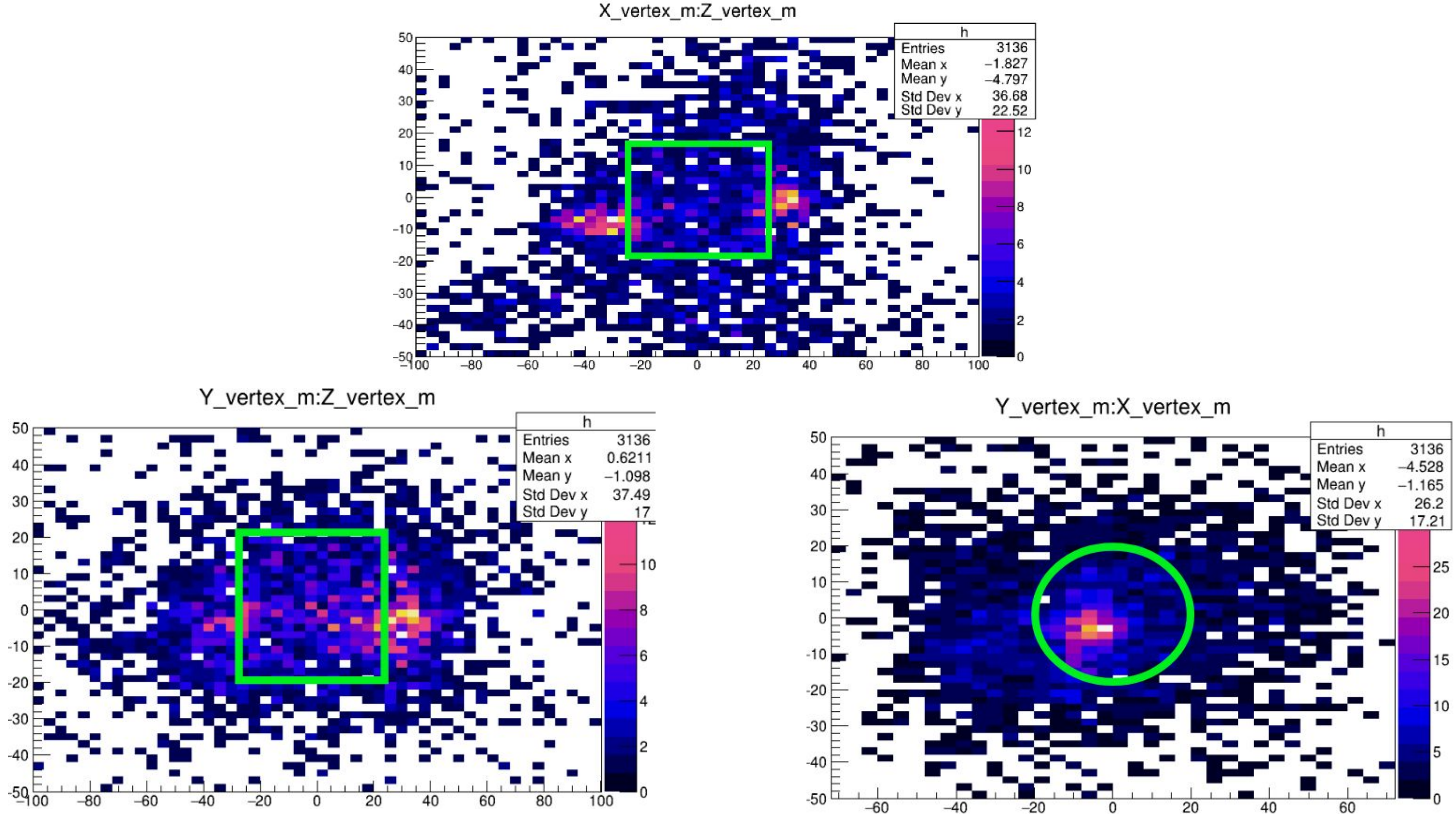
R^{3}B Analysis results (s522, preliminary)



Negative energy response

- Multihits generate large charge on the ASIC - baseline drop (known from AMS)

Vertex reconstruction

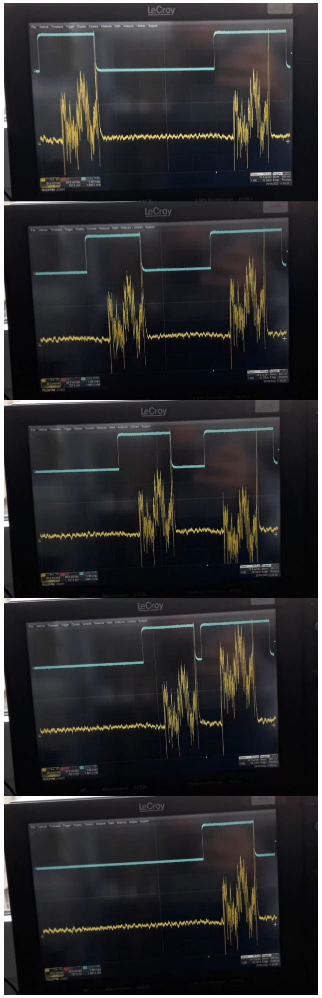


Area enclosed in green is the nominal boundary of LH2 target. Scale is **mm**.

Courtesy of Andrea Lagni & Antoine Barrière

On-going issues with FOOT

- Problem of 150 μs induced deadtime due to pedestal fluctuation
  - Baseline offset if pair of triggers too close in time (< 100 μs)
- Multihits in one ASIC



Blue: Input trigger
Yellow: FE output

Courtesy of Dr. K. Koch & Dr. N. Kurz

FOOT Summary

- Stable operation at R^3B (p,2p) experiments with < 1 year of R&D
- In-beam FOOTs not ideal - beam rate limitation
- Reasonable performance of arm detectors
- Bad signals at the edge channels of each ASIC

To do:

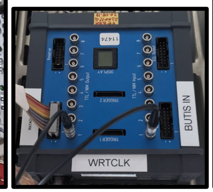
- FE operation not ideal
    - Research about trigger-rate limitations
    - Infrared laser to inject charge into Si-strips as a way to study multihits
- Determine efficiency for MIPs

Monolithic Active Pixel Sensor (ALPIDE)

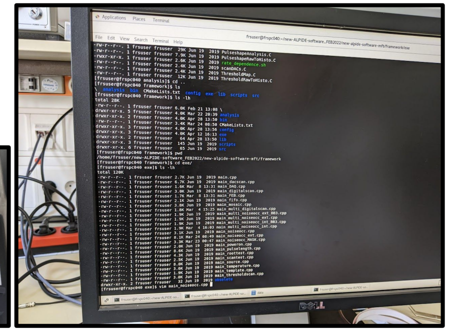
FAIR GSI

Detector

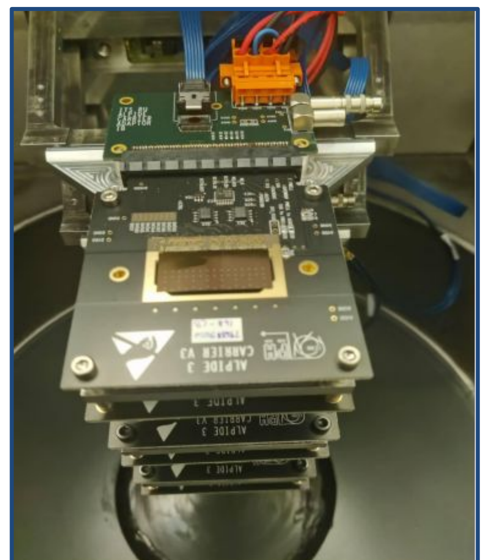
Readout FPGA



Timestamp Source

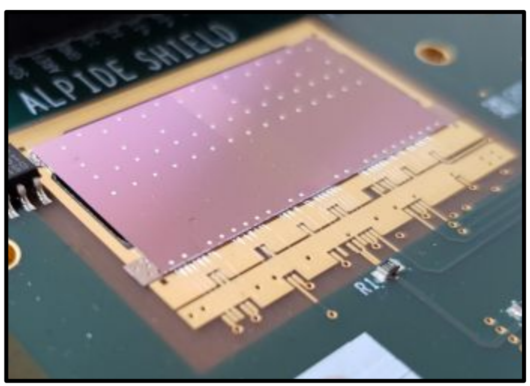


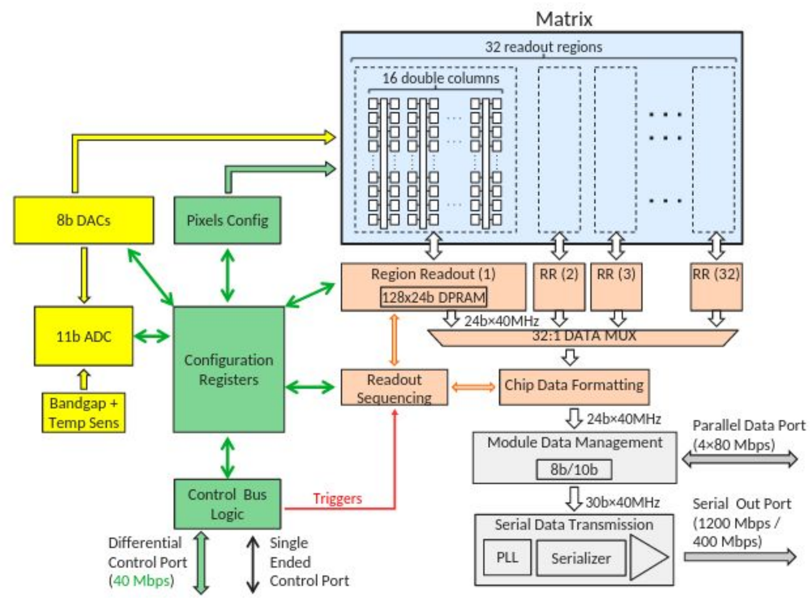
Readout Software



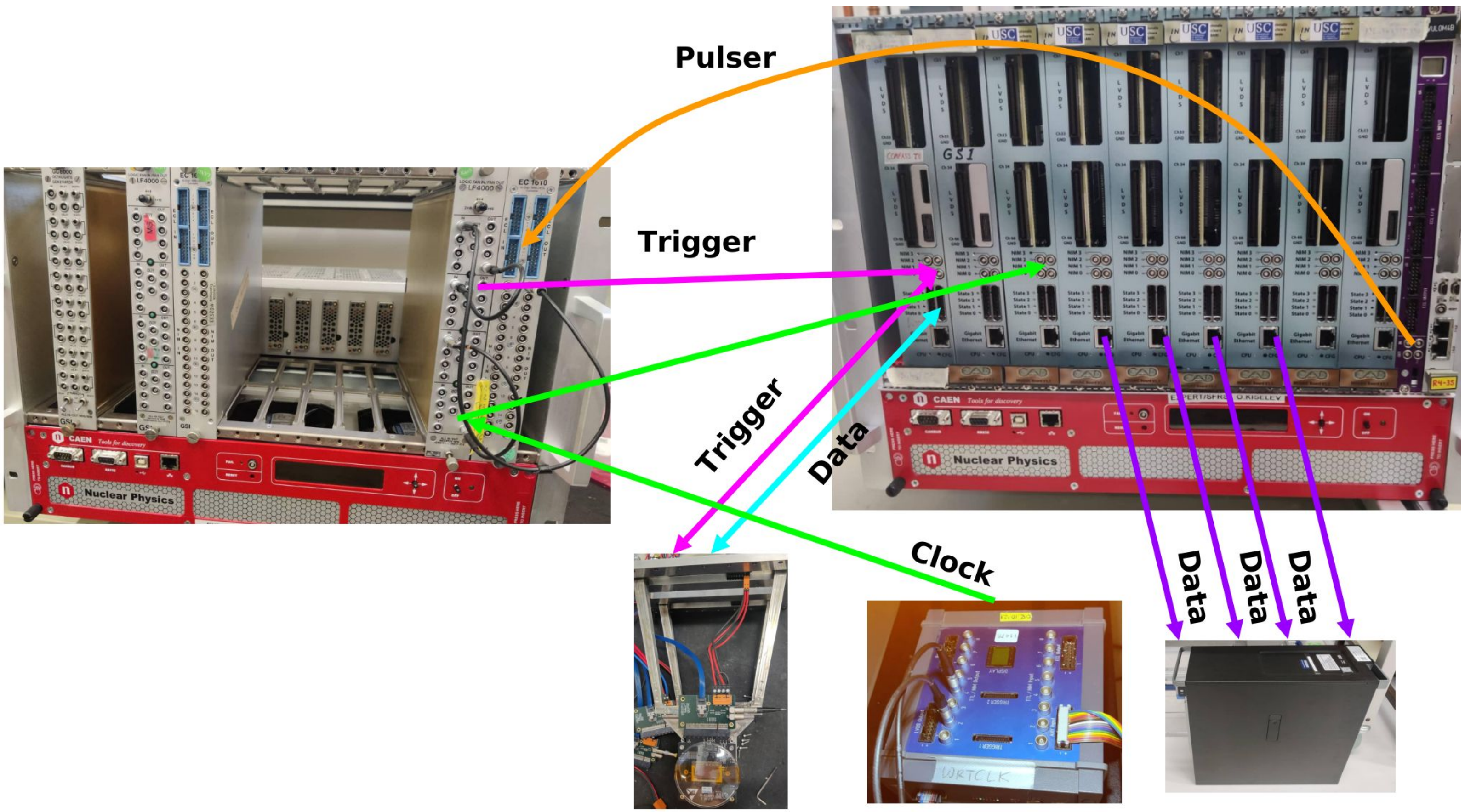
ALPIDE Sensor

- 15 mm (Y) × 30 mm (X) sensor of a 512 x 1024 pixels
  - CMOS chip, made for ALICE Inner Tracking System (ITS 2)
  - 29.24 x 26.88 (X × Y) μm^2 . Thickness 50 µm
- Front-end built-in electronics: amplifying & shaping circuit, discriminator
  - Multi-event buffer (3x hit registers), pixel masking
  - Peaking time of 2 µs
- Common threshold for all pixels
- Pixel hit latched to storage register if STROBE pulse applied while FE output above threshold
  - Internal & external triggering
- Injection of test charge to input of FE
- 1.2 Gb/s Serial Data port with differential signaling





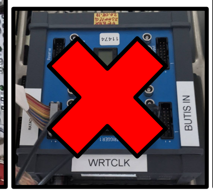
ALPIDE DAQ Setup (CERN, 2022)



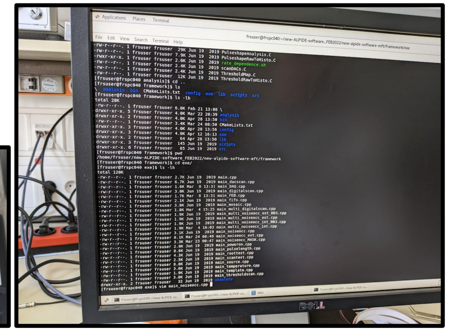
Test at COSY (March 2022)

Detector

Readout FPGA



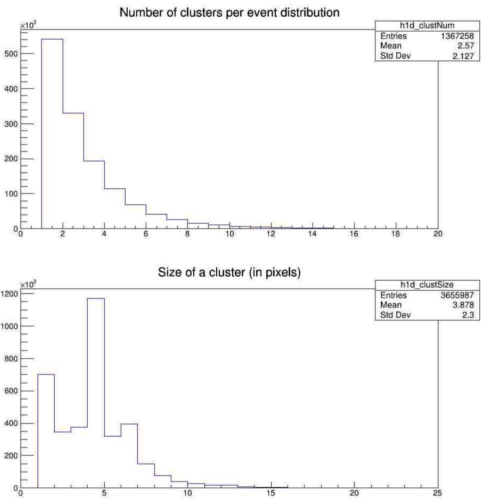
Timestamp Source



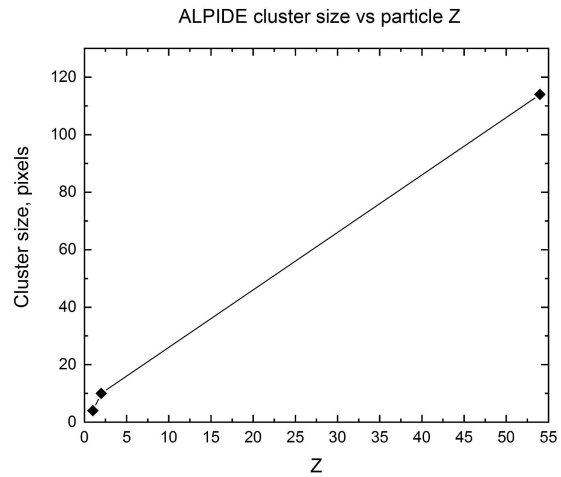
Readout Software

- 1 ALPIDE detector, d^+, p^+ beams @1 GeV/u, 800 MeV/u
- Readout software framework provided by ALICE
    - Not understood, hard to refactor
- No masking of noisy pixels - huge overhead
- Internal trigger only
- No proper analysis macros

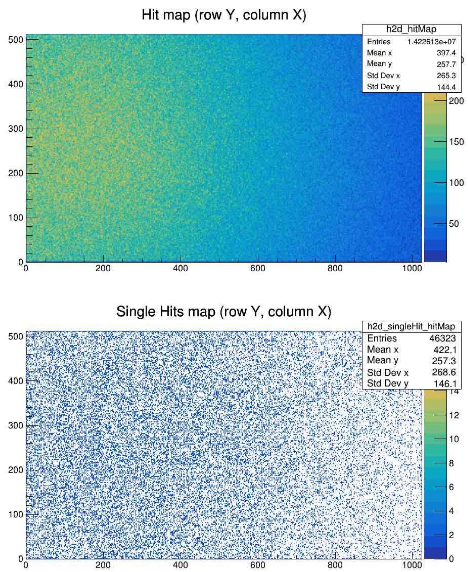
Test at COSY (March 2022) II



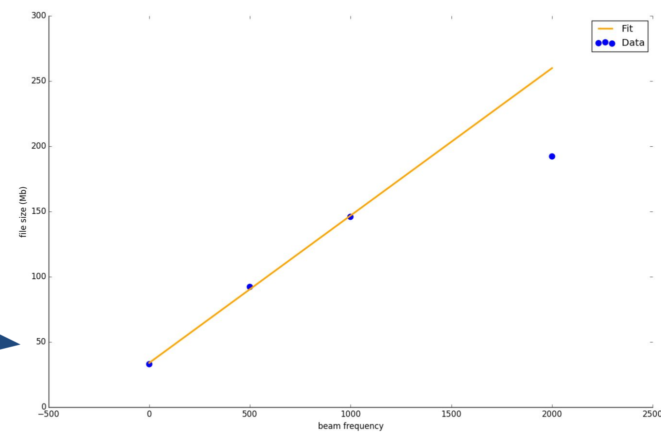
R^{3}B data, d$^+$ beam



ALICE data

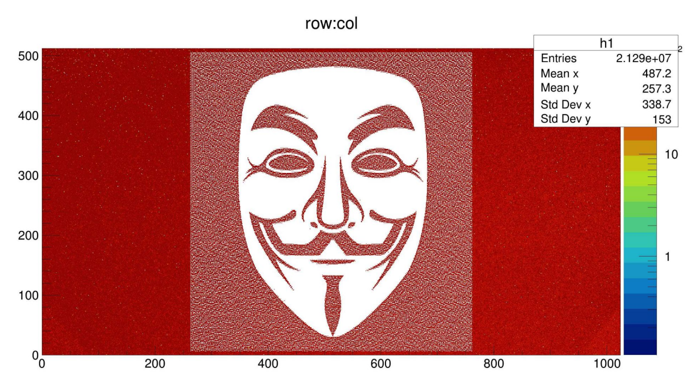


- Experiment goals:
  - Measure efficiency
  - Optimal threshold
  - Conclusions from cluster distribution
- At low trigger rate, data dominated by ‘hot pixels’
- Efficiency problem as DAQ parameters unknown
  - Crude estimate based on file size



R&D at GSI (summer 2022)

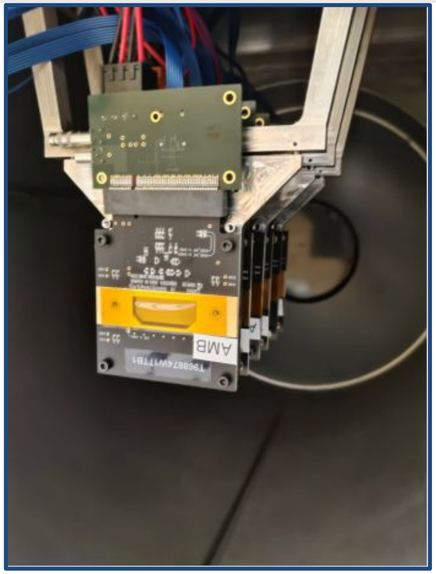
- Drasi DAQ solution
  - Integrated with libraries from CERN test-DAQ
  - FPGA firmware update to handle white-rabbit timestamp input & sync trigger
    - **Synchronisation of multiple readout nodes**
- Able to run distinct of common drasi instance between FPGA's
- ucesb unpacker
- Implementation of externally triggered mode
  - Up to now only internal (software) triggered mode working
- Laser tests - mapping check, passed
- β-source test - didn't work for new sensors received in August
  - Problem of unknown optimal threshold parameters
  - Figured out later at CERN
- Recording files with multiple detectors synchronisation check with WR, passed
- Threshold scan software implementation, ongoing

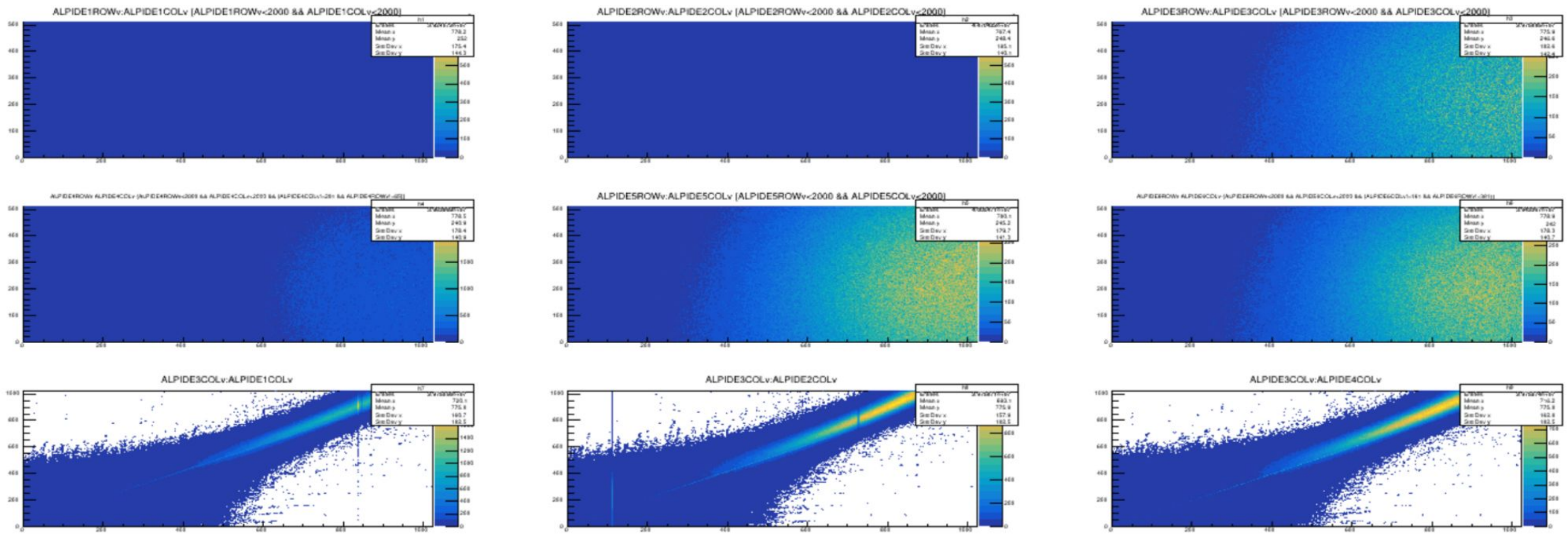


Complex pixel mask feasible

AMBER beamtime at CERN (Fall 2022)

- 6 ALPIDE detectors in a telescope
- SPS Accelerator -> muon beam at 160 GeV + parasitic p^+ beam
- External trigger test with double-pulses (5 µs separation), passed
- BUSY output - only signals that buffers are full, useless
- Trigger rate >20 kHz leads to data corruption
  - Wrong order of headers and hit-data in event format
  - Temp. solution: limit deadtime to 50 µs. Unknown cause
- Experiment goals:
  - Test synchronisation, works
  - Measure position resolution, on-going

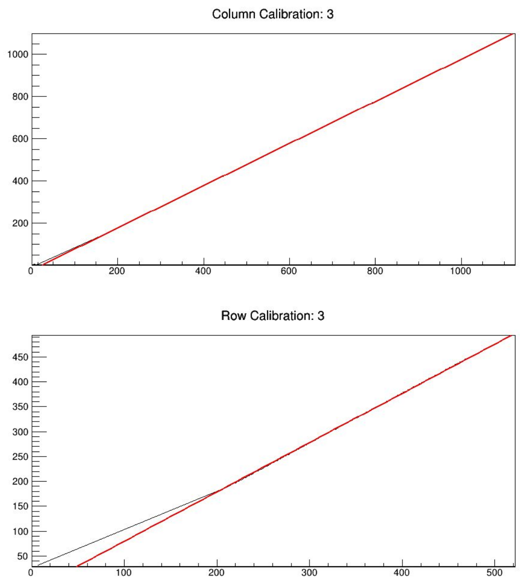




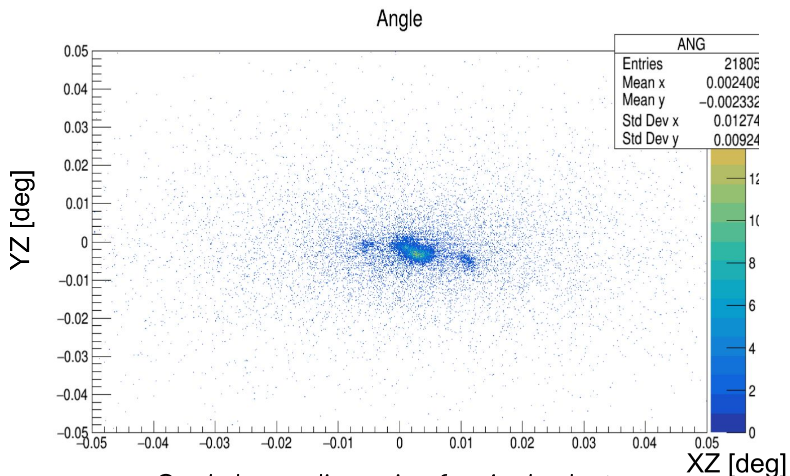
Analysis (preliminary)

- Ongoing writing of object-oriented offline analysis framework (started Dec. 2022)
- 3 step procedure:

1. Conversion of raw data to clustered data, works
2. Calibration of (ΔX, ΔY) for each detector with respect to a referent ALPIDE, works
    a. Slope coefficients should be 1 for perfectly aligned telescope
    b. Calculation based on correlation plot
3. Track reconstruction, on-going



Black data; Red fit. Skewing at small rows is due to not enough statistics at those points (and they were disregarded from the fit)



Crude beam dispersion for single cluster
*(0.01/180)*π = 0.00017* rad ↦ *170* μrad *over 14* cm

```
----- run_ts_299022_coarse_cl.root -----
Det 2 :: Col coeffs :: Slope: 0.99984 +- 0.00006  | Offset: -4.86528 +- 0.03803
         Row coeffs :: Slope: 0.99984 +- 0.00006  | Offset: -4.86528 +- 0.03803
Det 3 :: Col coeffs :: Slope: 1.00014 +- 0.00017  | Offset: -22.38965 +- 0.09832
         Row coeffs :: Slope: 0.98975 +- 0.00134  | Offset: -18.67385 +- 0.48453
Det 4 :: Col coeffs :: Slope: 0.99725 +- 0.00039  | Offset: -24.00366 +- 0.26694
         Row coeffs :: Slope: 0.99999 +- 0.00013  | Offset: -26.00635 +- 0.04504
Det 5 :: Col coeffs :: Slope: 1.00016 +- 0.00012  | Offset: -8.97912 +- 0.06862
         Row coeffs :: Slope: 0.99916 +- 0.00033  | Offset: -8.60974 +- 0.13376
Det 6 :: Col coeffs :: Slope: 1.00100 +- 0.00018  | Offset: -14.96609 +- 0.10678
         Row coeffs :: Slope: 0.98614 +- 0.00229  | Offset: -9.97228 +- 0.79463
```

ALPIDE Summary

- Stable operation in November, 2022, tested @CERN and @COSY (Jülich)
- Data looks reasonable, analysis in process
- DAQ Integration successful

To do (hardware):

- Build and test bigger ALPIDE stations which house multiple chips (O. Kiselev)
- Cooling frames
- Multiplexing solution for >1 chip per FPGA

To do (software):

- Finalize LMD data format
- Matrix threshold scan
- Build offline and online analysis frameworks

On-campus testing:

- Optimization of (>10) programmable chip parameters
- DAQ benchmark
- Laser tests

- Control system engineer 👷
- Offline analysis 🦸
- github/gitlab PR reviewer 🕵️
- Online analysis 🦸

We're 'hiring' :)

- DAQ Wizard 🧙
- FPGA expert 🥷
- Documentation buddy 🤵
- Master of cables 🧛

Thank you for your attention!