Next-generation electronics for the gaseous beam telescope of RD51

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CERN, University of Bonn

10th Beam Telescope and Test Beams Workshop

21 June 2022

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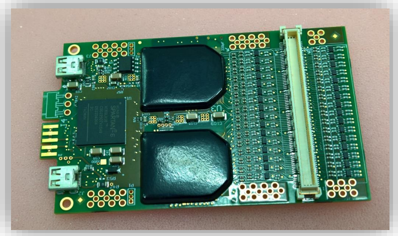
CERN UNIVERSITÄT BONN EP R&D AIDA innova GDD Gas Detectors Development Group

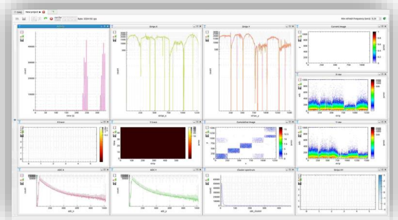
Outline

Background information

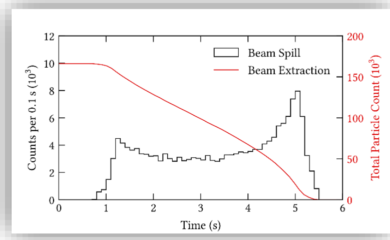
Hardware and electronics



Data processing



Results

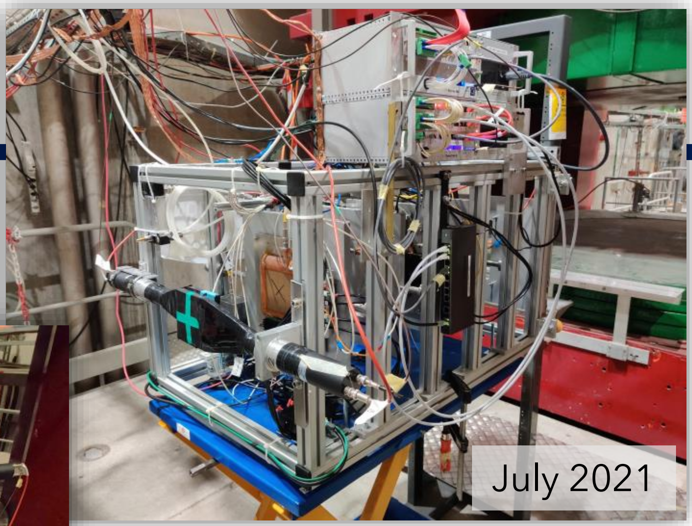


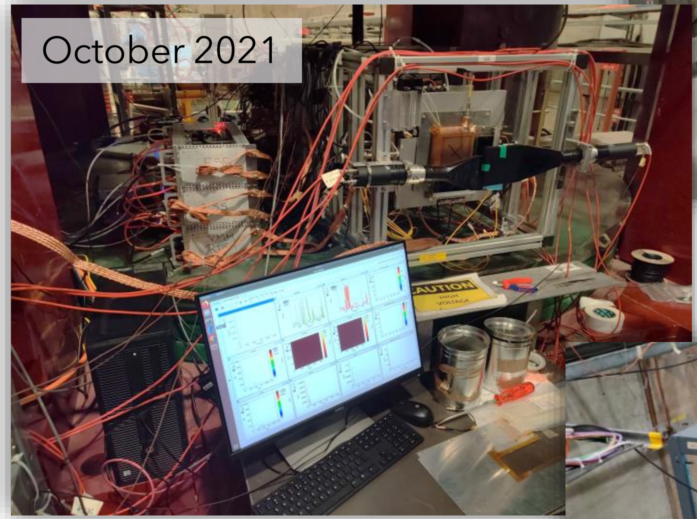
Test beam campaigns of RD51

- **RD51**: CERN-based R&D collaboration on the development of **Micro-Pattern Gaseous Detectors** (MPGDs)
  - ~75 institutes
  - ~450 members
- Test beam campaigns for detector tests
  - **H4 beam line @ CERN's SPS (PPE 134)**
- **Two beam telescopes** available, if needed by the users
  - Gas Electron Multiplier (GEM)-based
  - Micro-Mesh Gaseous Structure (MicroMegas)-based
  - 10 x 10 cm^2 active (beam facing) area
  - 3 tracking detectors + *n* DUTs
  - Read out with the RD51 Scalable Readout System (SRS)

Test beam campaigns of RD51

- **Third beam telescope** under development
  - GEM-based
  - **Commissioning of new SRS-based electronics**
  - **VMM3a front-end ASIC**
- So far: three test beams to commission and improve the system
  - Operation stability
  - Hardware, firmware and software optimisation
  - Understand/verify the capabilities and limitations
- Goal: **provide a read-out system that gives access to energy, space and time for various detector technologies** (as required by R&D collaboration)


July 2021

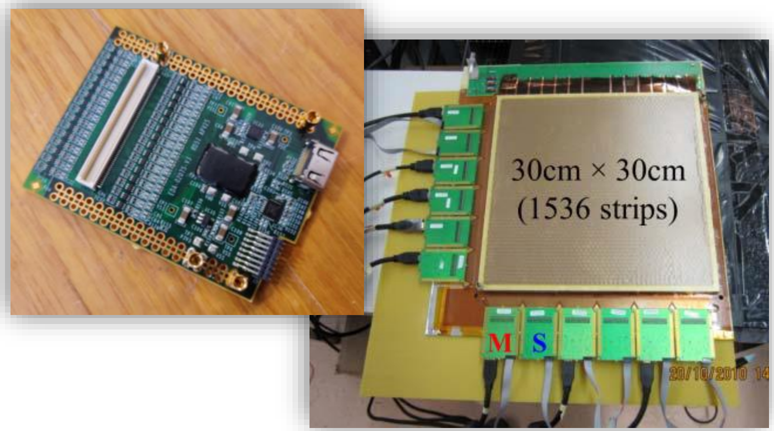

October 2021


May 2022

RD51 Scalable Readout System (SRS)

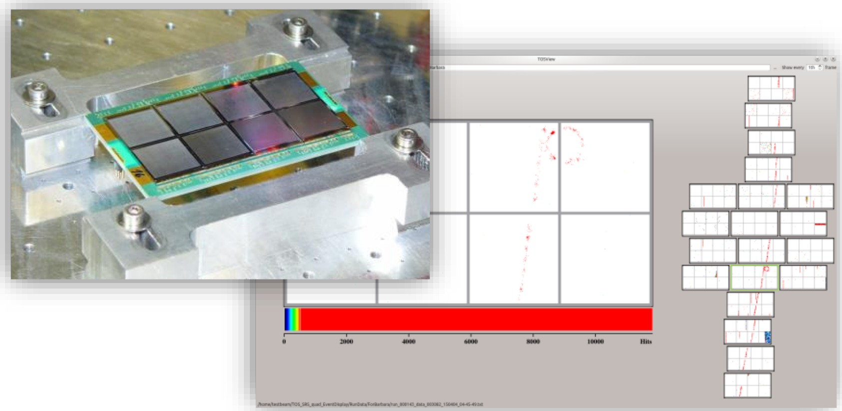
- Introduced in **2009**
- Developed by the RD51 collaboration to read out **Micro-Pattern Gaseous Detectors** (MPGDs)
- **Small R&D set-ups to mid-sized experiments** (10 x 10 cm² active area to several m²)
- Scalability concept combined with ASIC variety
- Most successful ASIC integrations: **APV25**, **Timepix & Timepix3** and **VMM3a**

APV25



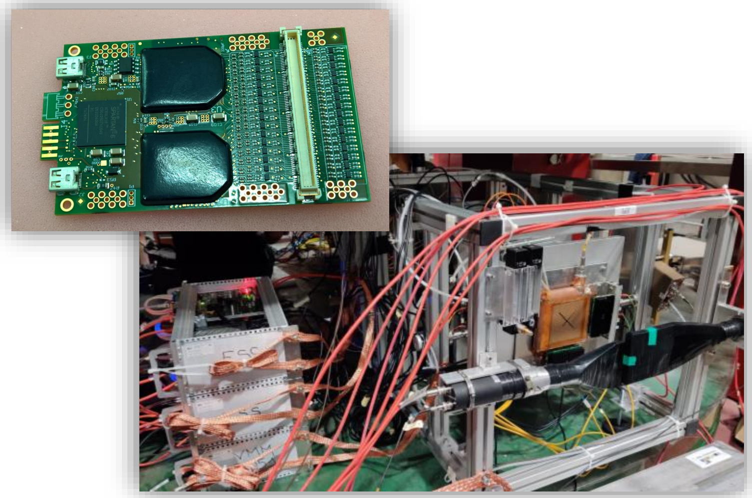
doi.org/10.1109/NSSMIC.2010.5873822

Timepix



https://indico.cern.ch/event/391665/contributions/1827282/

VMM3a



RD51 Scalable Readout System (SRS)

Detector

↓

SRS front-end *"hybrid PCB"*

↓

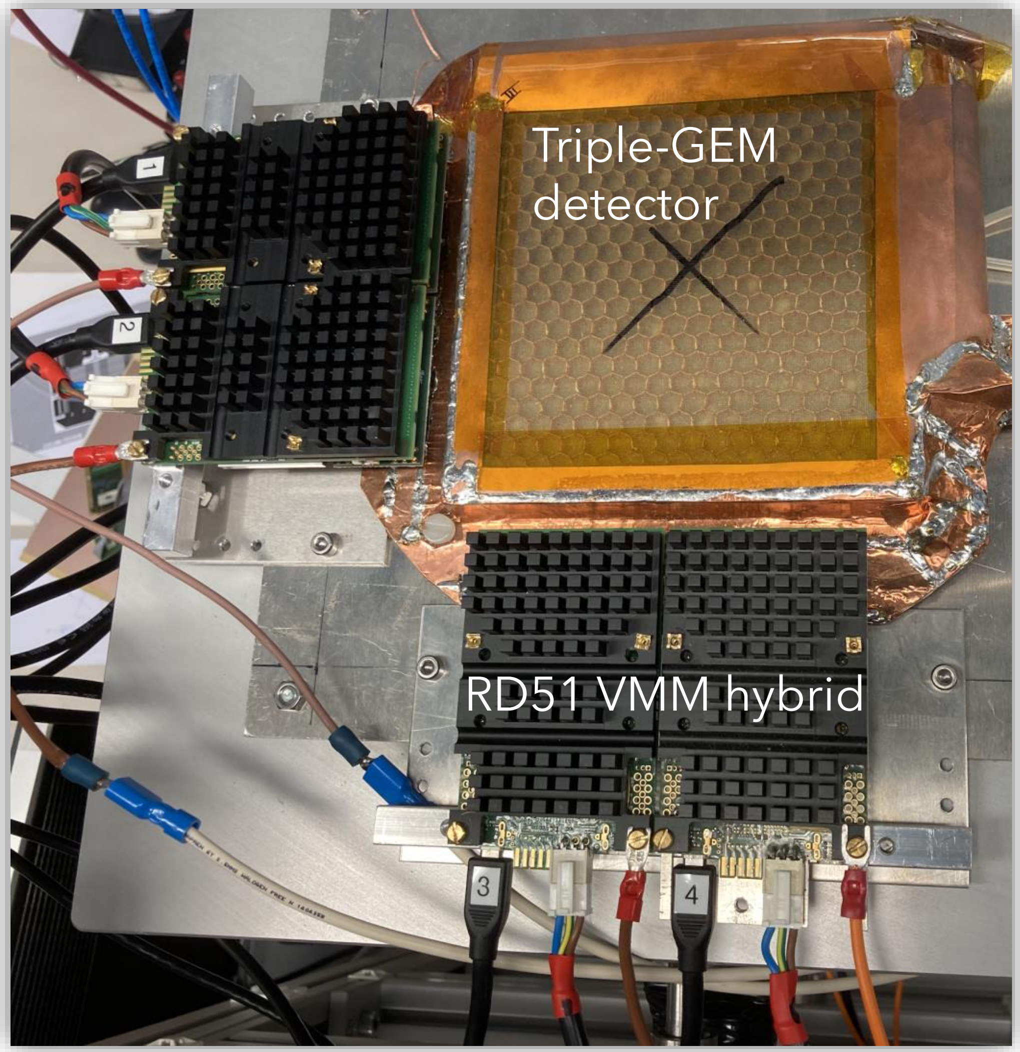
ASIC specific adapter card

↓

Front-End Concentrator (FEC) card

↓

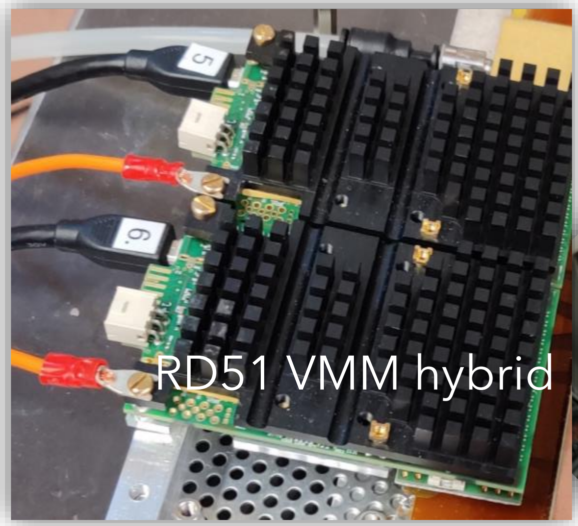
DAQ PC

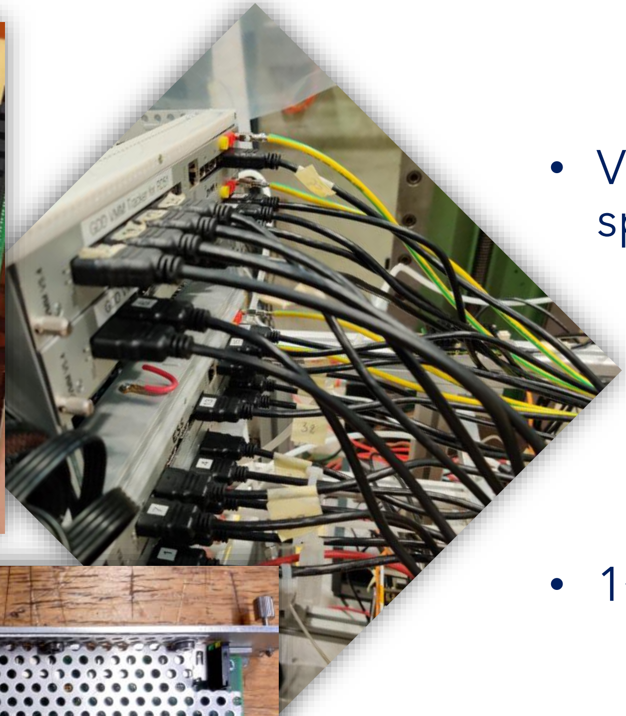


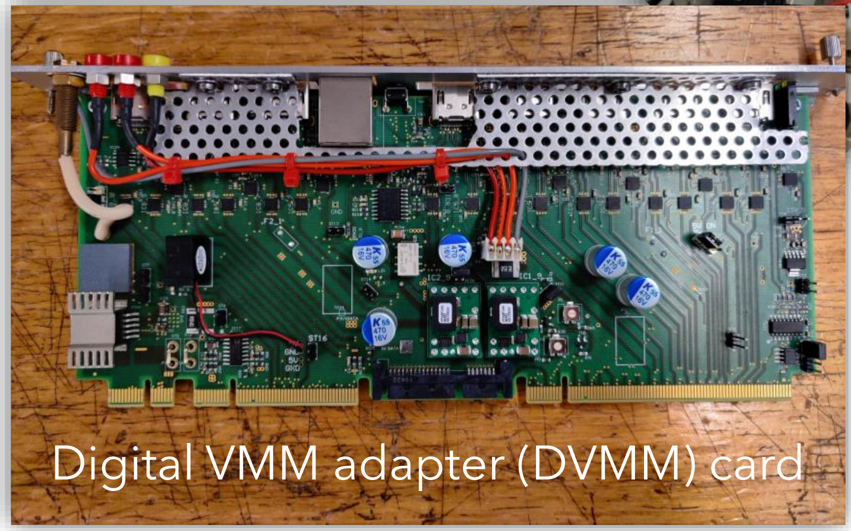
- Front-end electronics connected to read out anode of the detector
- Here: 256 + 256 x-y-strips (400 µm pitch)
- Allows to use various front-end ASICs, depending on the experimental needs

RD51 Scalable Readout System (SRS)

Detector
↓
SRS front-end *"hybrid PCB"*
↓
ASIC-specific adapter card
↓
Front-End Concentrator (FEC) card
↓
DAQ PC


RD51 VMM hybrid




Digital VMM adapter (DVMM) card

- Via HDMI to the ASIC-specific adapter card
  - Differential pairs used for LVDS signals
  - Single lines for i2c control signals
- 1st scalability option
  - Up to 8 hybrids per adapter card

RD51 Scalable Readout System (SRS)

Detector

↓

SRS front-end *"hybrid PCB"*

↓

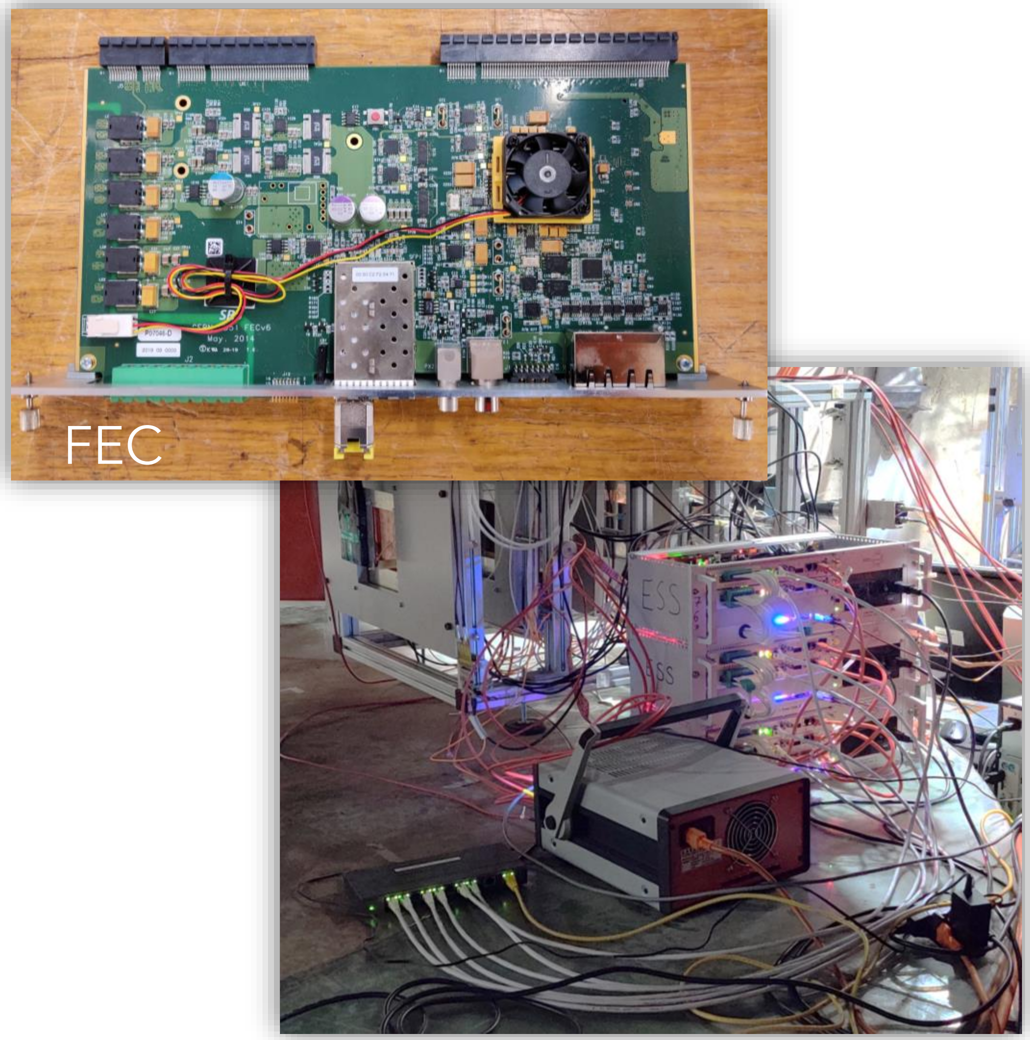
ASIC-specific adapter card

↓

Front-End Concentrator (FEC) card

↓

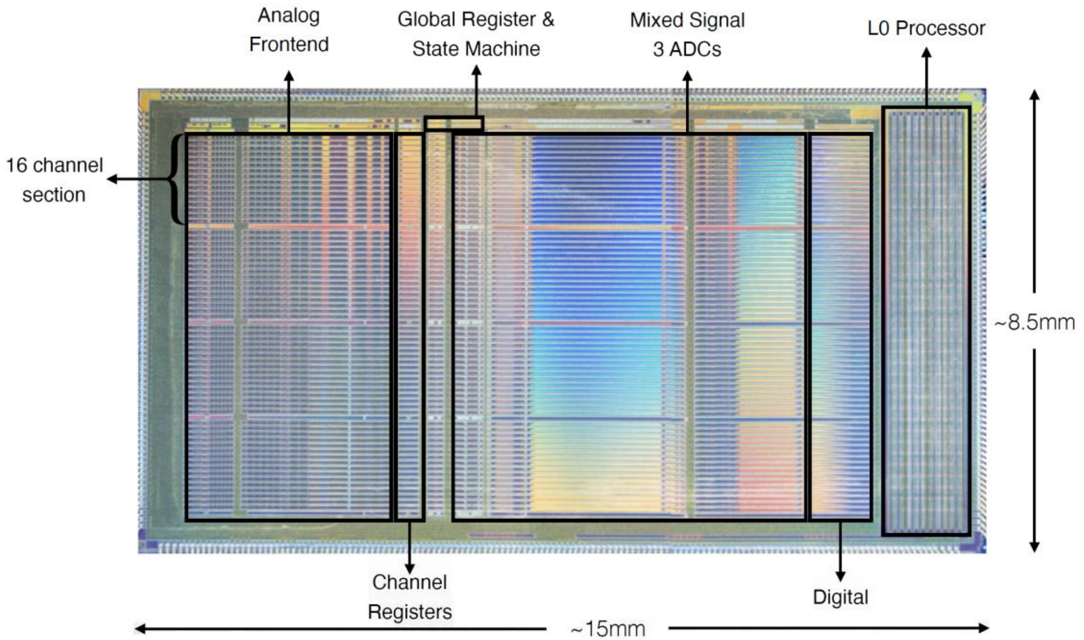
DAQ PC



- From adapter card via PCIe to FEC
- Common Front-End Concentrator (FEC) card
- Independent of the front-end ASIC
  - In terms of hardware
  - Requires ASIC-specific firmware
- 2^{nd} scalability option
  - Use of multiple FECs
  - Switch + clock synchronisation

ATLAS/BNL VMM3a front-end ASIC

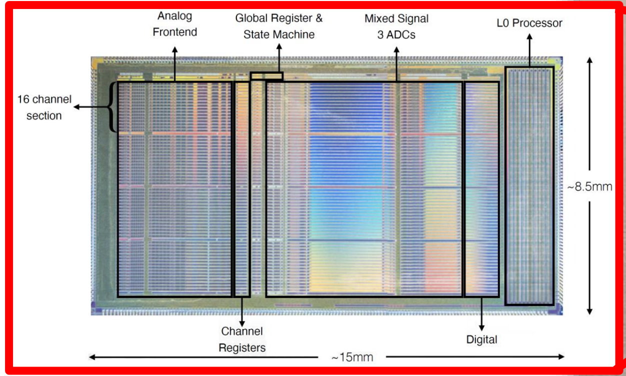
- VMM3a ASIC developed by BNL for the New Small Wheel (NSW) upgrade of ATLAS
- 64 readout channels
- **Self-triggered continuous readout in SRS implementation**
- 4 Mhits/s per channel, but max. **9 Mhits/s per VMM in SRS implementation**
- Integrated zero-suppression
- 10-bit **charge ADC**
- 12+8-bit **timing with O(ns) time resolution**
- **Adjustable peaking times** (25, 50, 100, 200 ns)
- **Adjustable electronics gains** (0.5, 1.0, 3.0, 4.5, 6.0, 9.0, 12.0, 16.0 mV/fC)
- **Neighbouring-logic**
- Subhysteresis discrimination
- **Input capacitances (< 200 pF up to 2 nF)**
- …

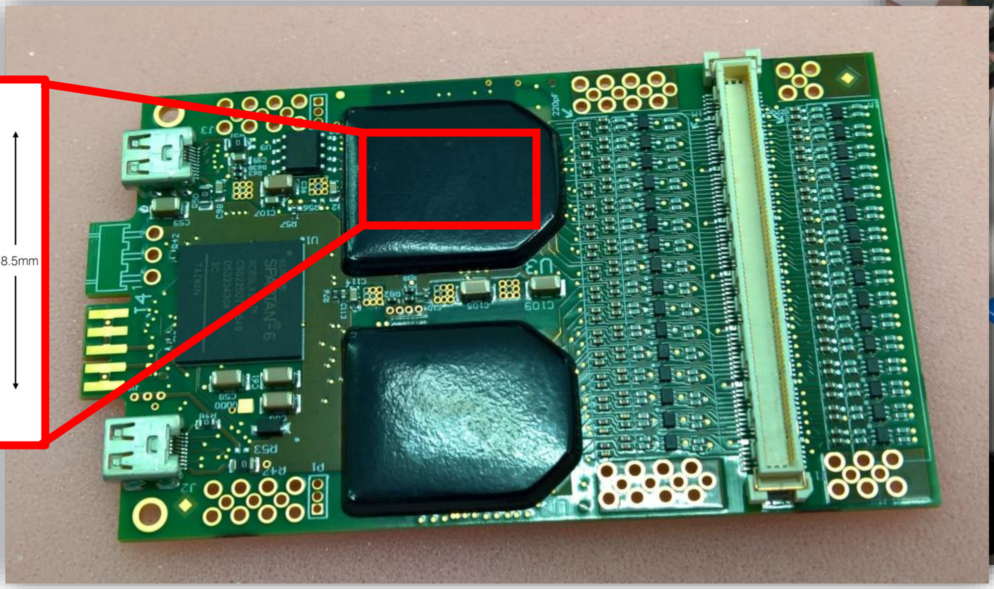


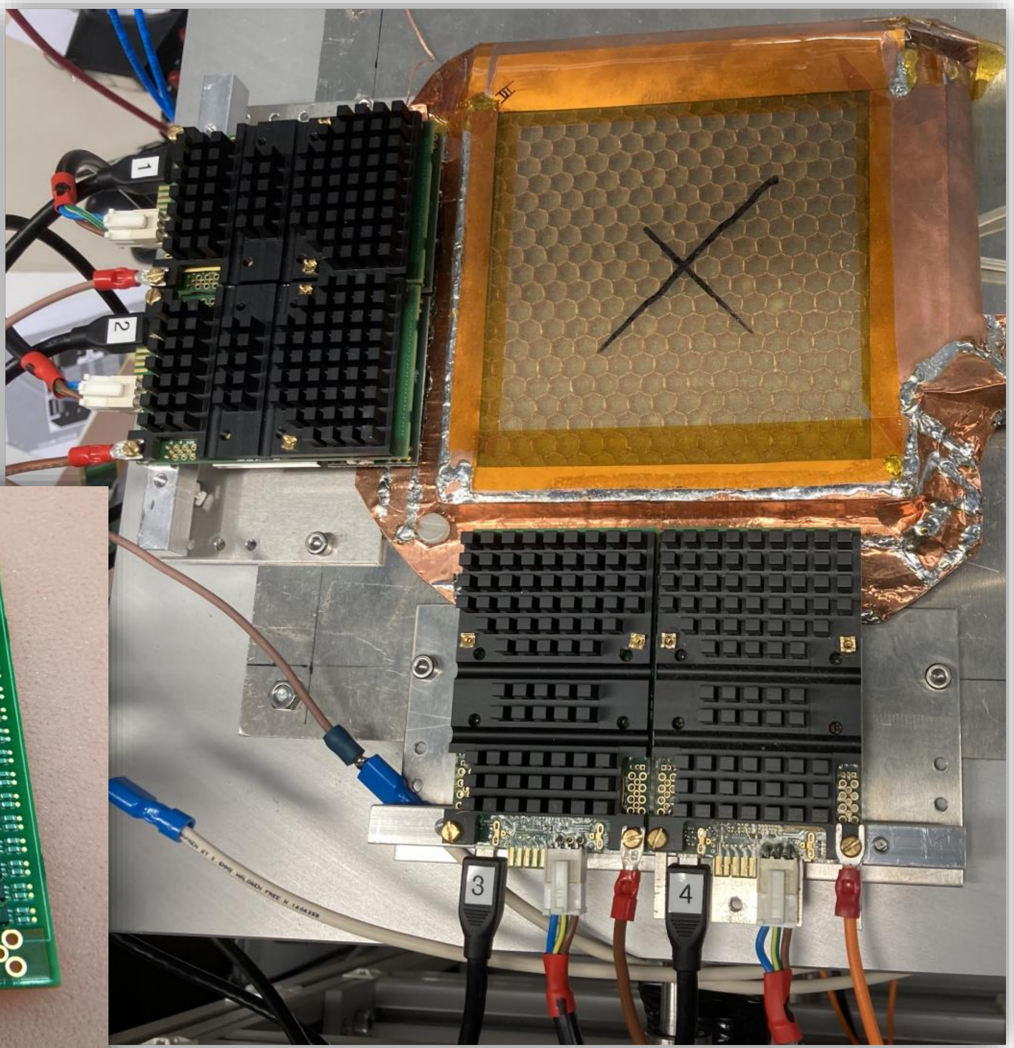
https://indico.cern.ch/event/1040996/contributions/4402617/

VMM3a front-end of the SRS

- 2 VMMs combined on a single hybrid
  Match common SRS 128-channel count
- 1 FPGA (Spartan-6 and Spartan-7) to provide clocks and other signals
- LDOs for VMM and FPGA power
- Channel input protection circuit
- ID chip







Data handling and processing

FEC

FEC

FEC

⋮

→ Switch → DAQ PC → tcpdump → Cluster reco. → Track reco.

DAQ PC ↓ EFU → kafka → Online monitor.

Custom control software

https://gitlab.cern.ch/rd51-slow-control/vmmsc

Offline analysis

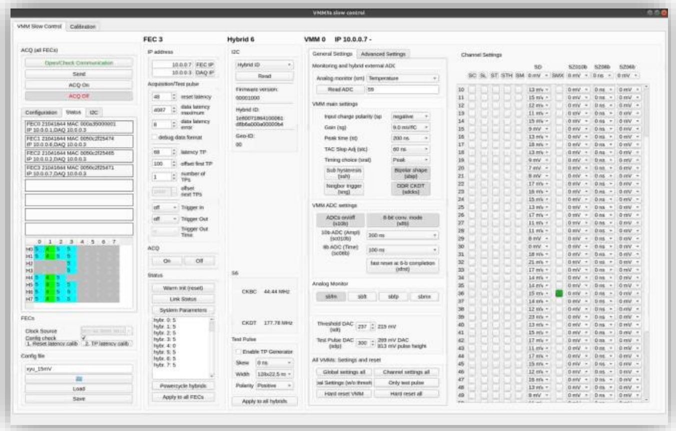
https://github.com/ess-dmsc/vmm-sdat

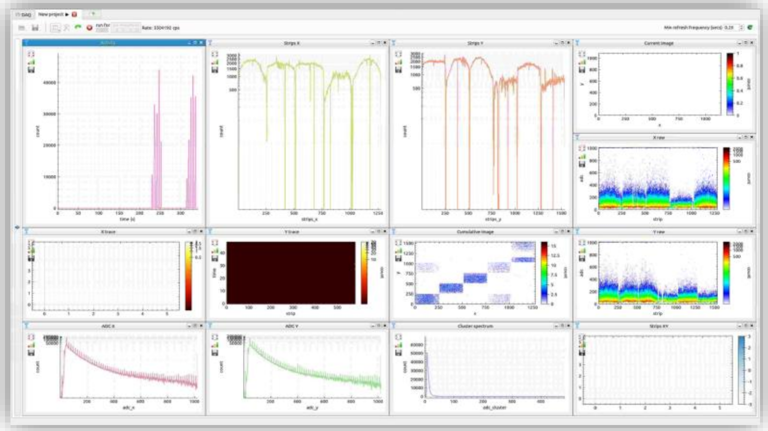
https://gitlab.physik.uni-muenchen.de/Jonathan.Bortfeldt/anamicom

Online monitoring of clusters

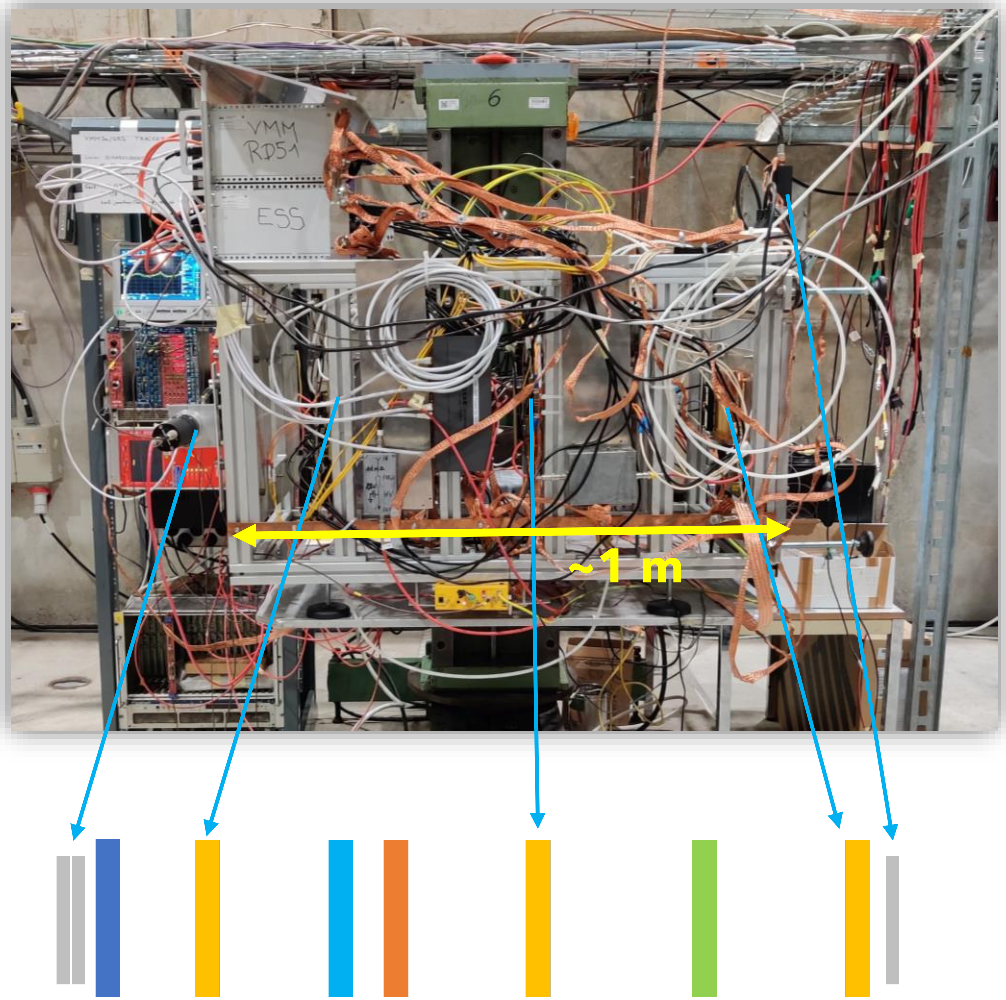
https://github.com/ess-dmsc/event-formation-unit

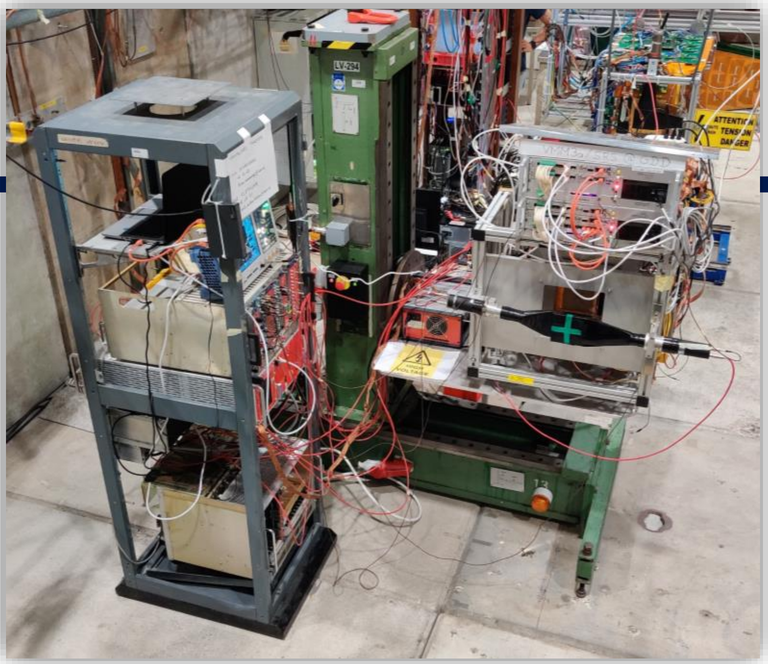
https://github.com/ess-dmsc/daquiri





Experimental set-up (May 2022)





VMM3a/SRS:
- 25 hybrids
- 4 FECs + DVMMs
- 1 CTF
- **3200 channels**

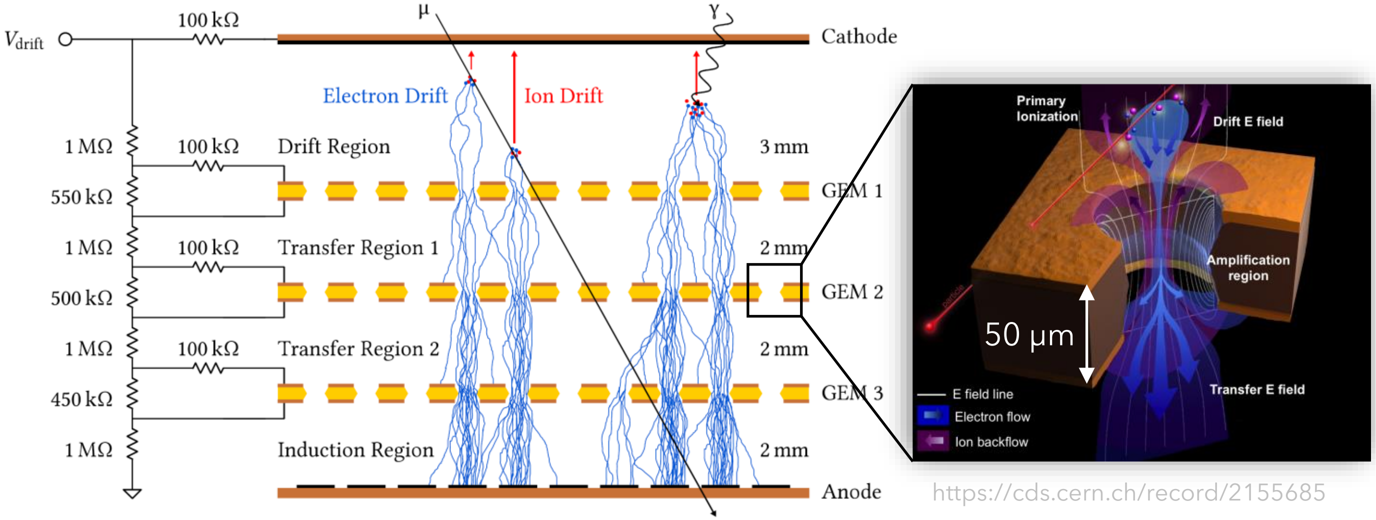
Beam telescope **(1536 + 128 channels)**: 10 x 10 cm²
- Trackers: 3 COMPASS-like triple-GEM detectors
- 1 scintillator adapter

Detectors under test **(1536 channels)**: 10 x 10 cm²
- 1 COMPASS-like triple-GEM detector (reference)
- 1 small-pitch GEM detector
- 1 resistive thin-mesh MicroMegas
- 1 XYU GEM detector (in exchange for small-pitch and MM)

In previous test beam: also TPC and straw tubes read out

Detector efficiency

- Self-triggered continuous read-out: **each signal that goes above threshold will be processed**
- Too low thresholds not desirable
  - Too many noise hits have to be processed
  - Big data files in case of too low THL
  - Worst case: blocking of bandwidth
- Best threshold achieved during beam
  - 1.5 fC ~ 10^4 electrons per channel



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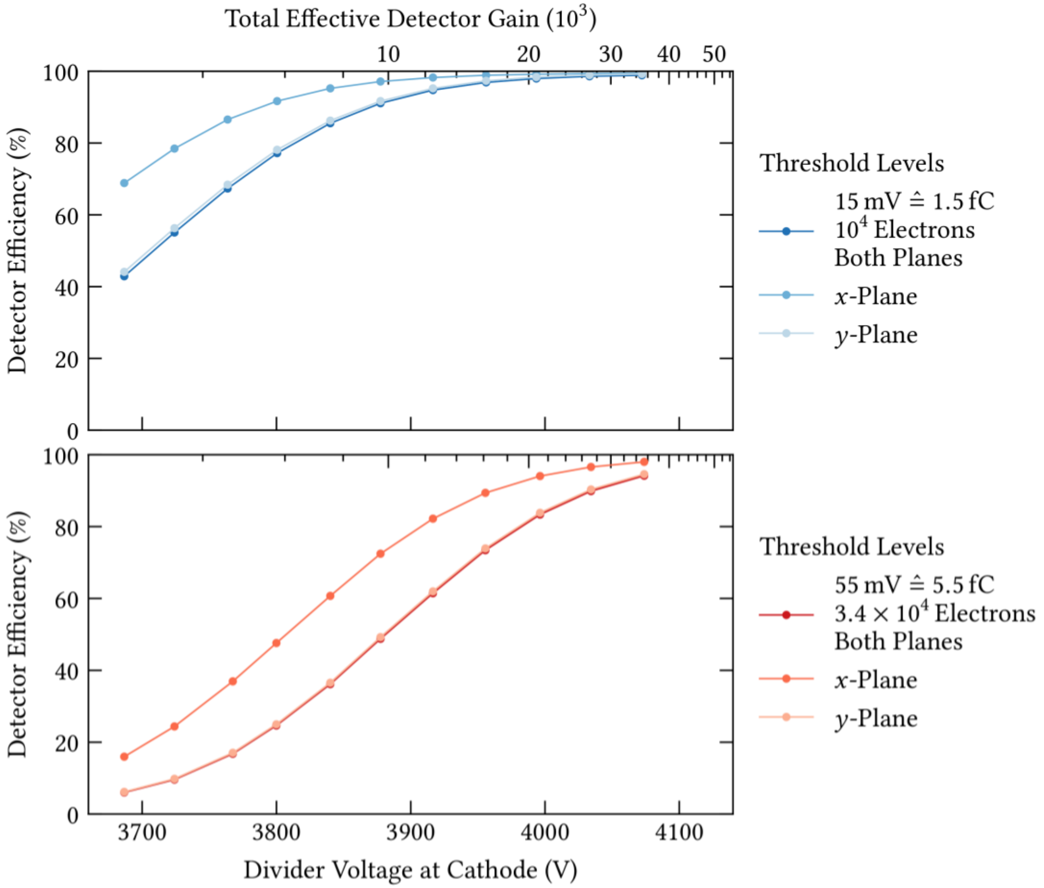

Detector efficiency

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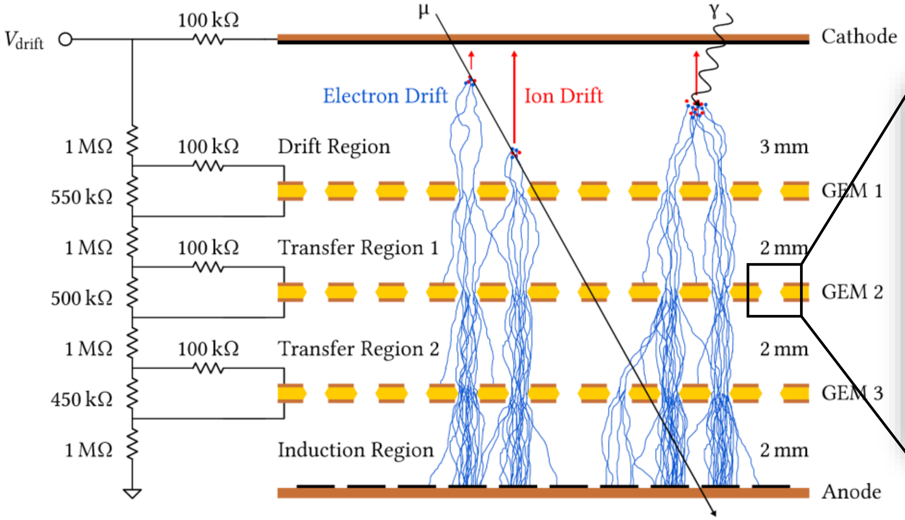
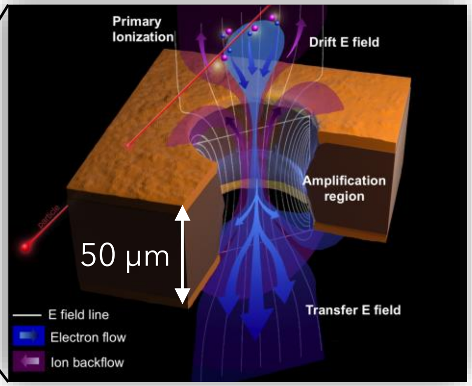
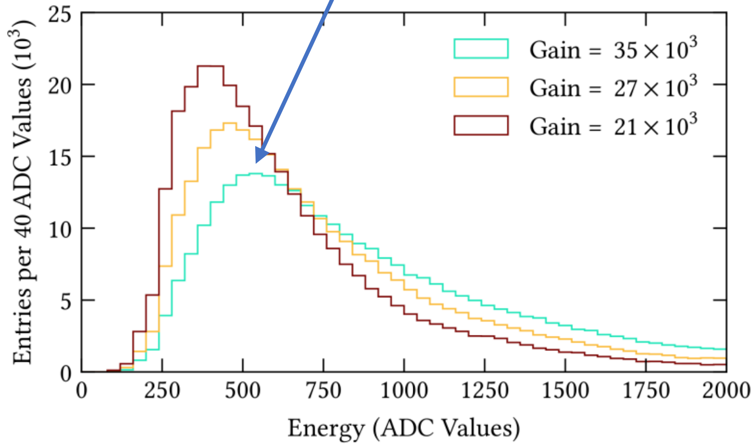




https://cds.cern.ch/record/2155685

3 mm drift: most probable
8 primary electrons



Even with gain > 10^4:
THL of 10^4 electrons rather high

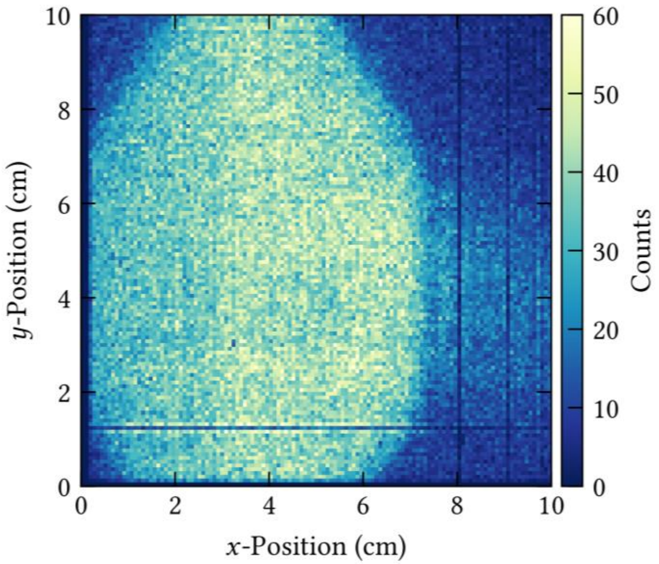
Further optimisation required

Continuous read-out

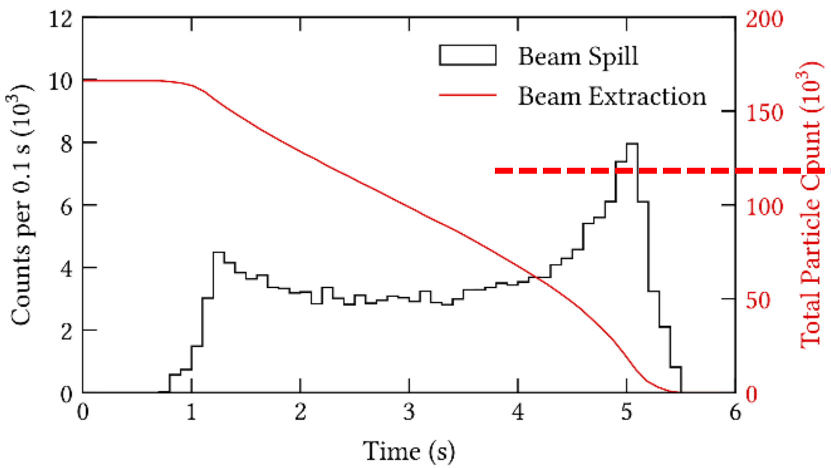
Self-triggered readout
High-rate capability
Position sensitivity

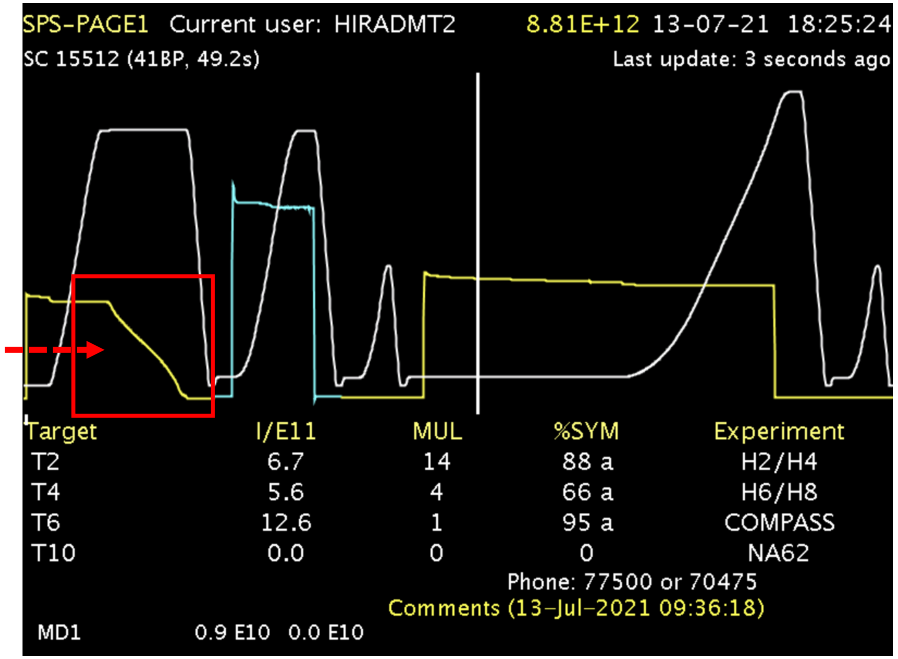
- Due to rate-capability (here rather low)
  Reconstruction of (more or less) each individual beam particle
- Reconstruction of the extraction profile of the SPS beam spills to the North Area
  Compatible with SPS Page 1

Image of the muon beam during beam tuning in July 2021



Spill and spill extraction

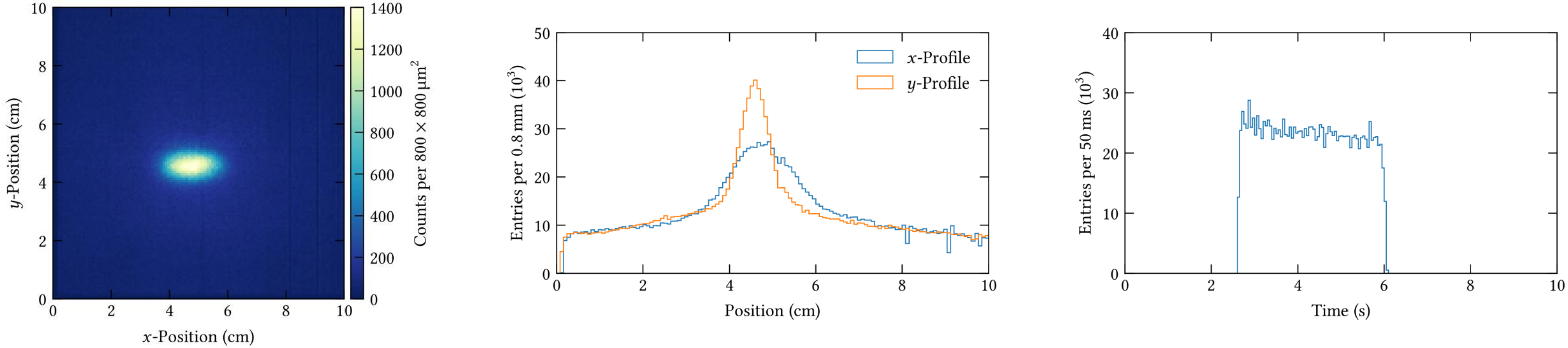




Continuous read-out

Self-triggered readout
High-rate capability
Position sensitivity

- Operation in pion beam with higher rate

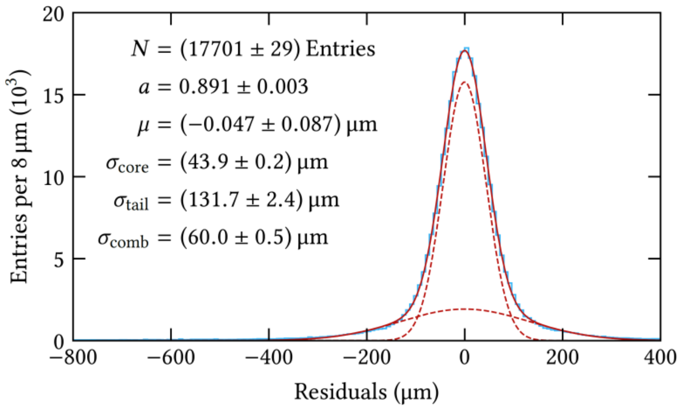


- Here: ~1.5 x 10^6 particles / spill
- With ~5 x 10^6 particles / spill and more (1 MHz particle rate)
  Bandwidth saturation of Gbps transceiver

Spatial resolution measurements

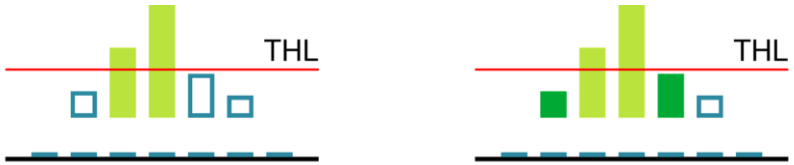
Position sensitivity
Charge information

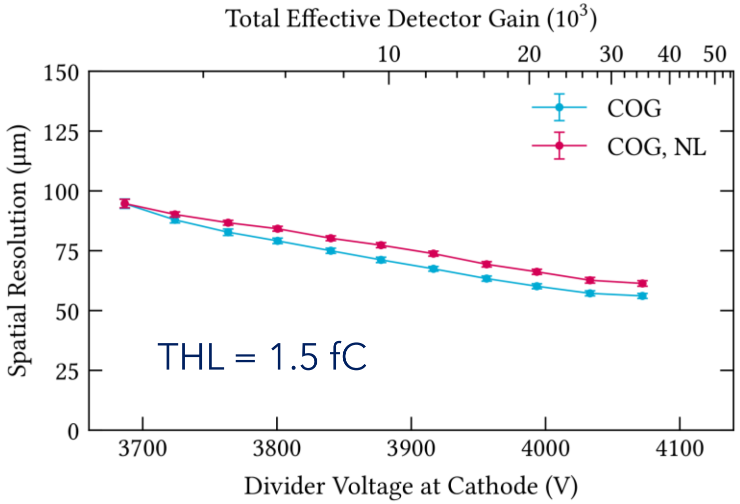
- Position reconstruction via **Centre-Of-Gravity** (COG)
- Due to diffusion: **spread of charge** over several read-out channels

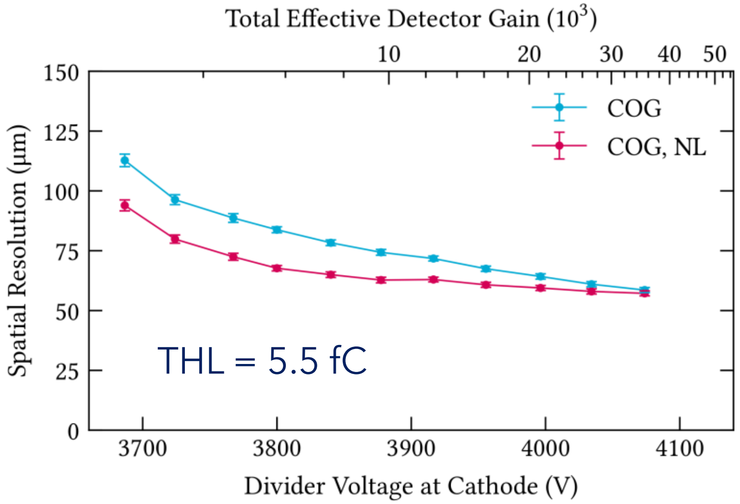


$$x_c = \frac{\sum_i Q_i x_i}{\sum_i Q_i}$$

- Investigation of VMM's neighbouring-logic (**recover charge below THL**)

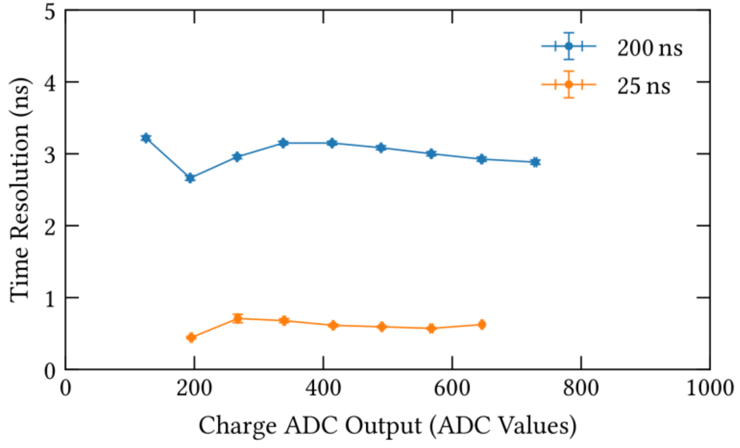


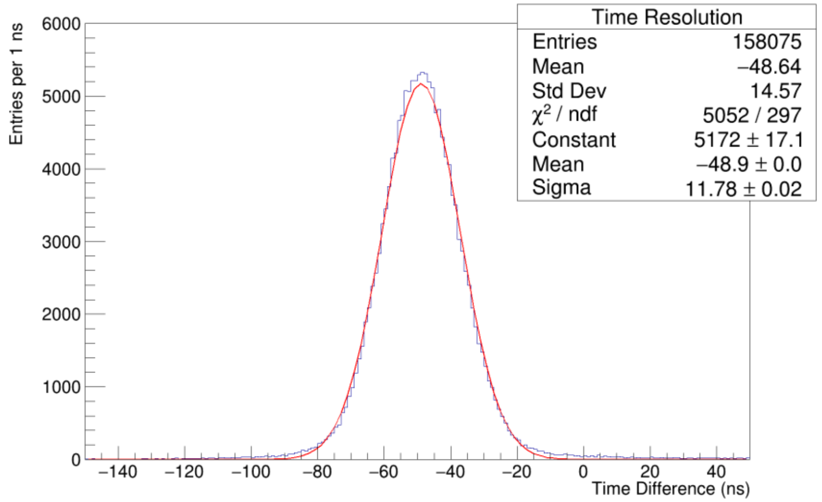


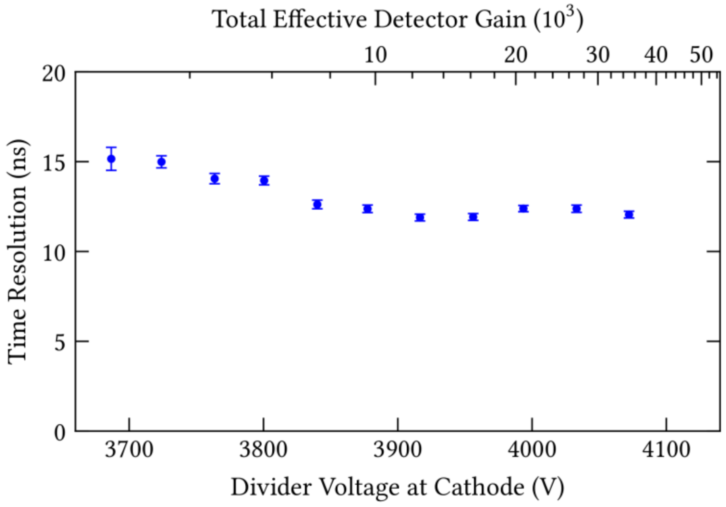


Time resolution measurements

- Time resolution of the electronics below a few ns
  - Before VMM3a/SRS: external TDC required (and reference time required)
  - Now: all integrated within a single system
- Time resolution determined by comparison with one of the trackers
- Extracted time resolution from trackers by cross-comparison





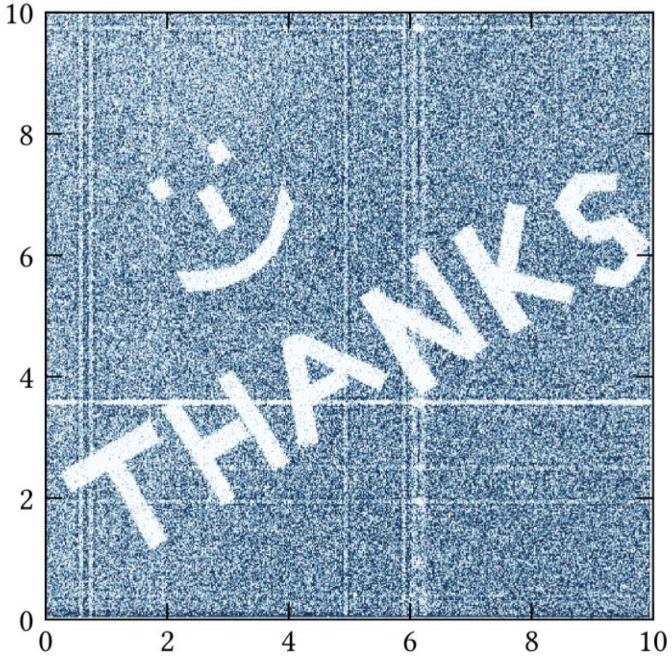


Compatible with previously measured (using external TDC) values from: DOI: 10.1016/j.nima.2004.07.146

Summary

- Integration of VMM3a front-end ASIC into RD51 Scalable Readout System (SRS) provides
  - Fully integrated system for gaseous detector characterisation in test beams
  - Access to energy, space and time information over larger areas (minimum 10 x 10 cm^2)
  - High-rate capability (~1 MHz interaction rate)
  - Fast data taking (single spill is sufficient)

  } Potential upgrade planned to improve the bandwidth issue
- Can be used for various detector technologies
  - Gas Electron Multiplier (GEM)
  - Micro-Mesh Gaseous Structure (MicroMegas)
  - Straw tubes
  - TPCs
  - Strip read-out, pad read-out
- Further optimisation required (e.g. threshold or system operation)



for your attention!

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This work has been sponsored by the Wolfgang Gentner Programme of the German Federal Ministry of Education and Research (grant no. 13E18CHA)

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under GA no 101004761.

EP R&D

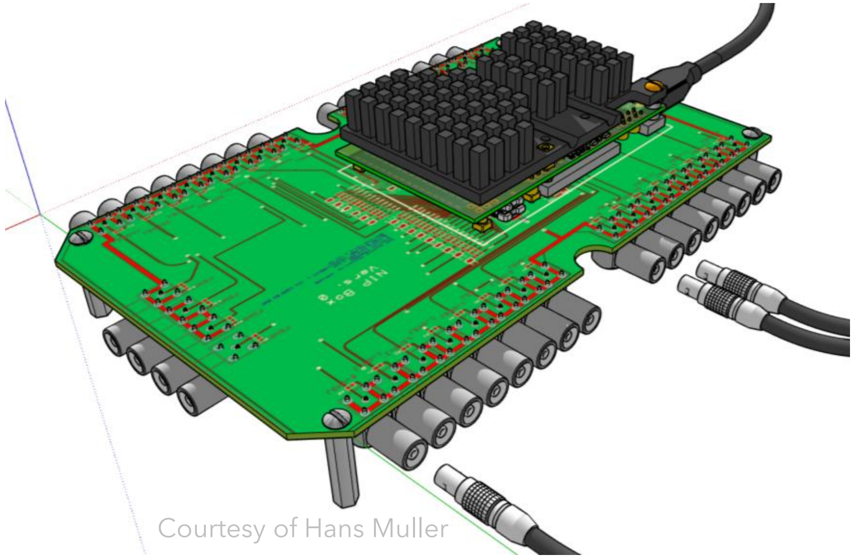
Back-up slides

Outlook

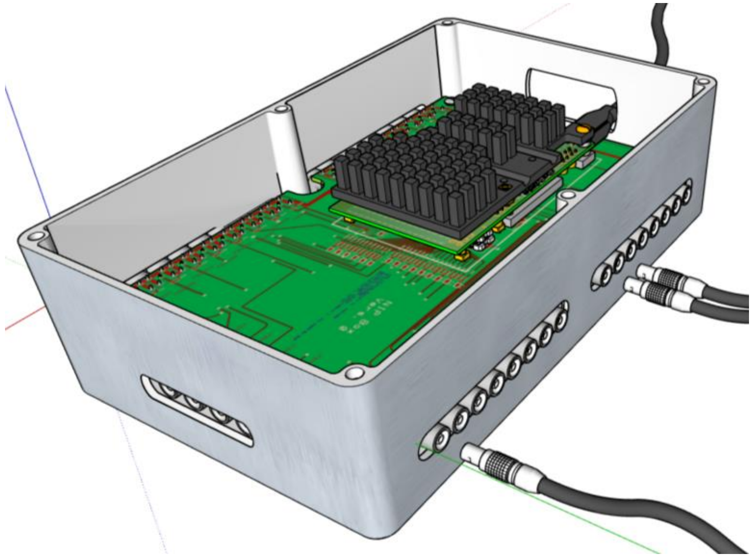
Self-triggered in an triggered experiment

PRELIMINARY

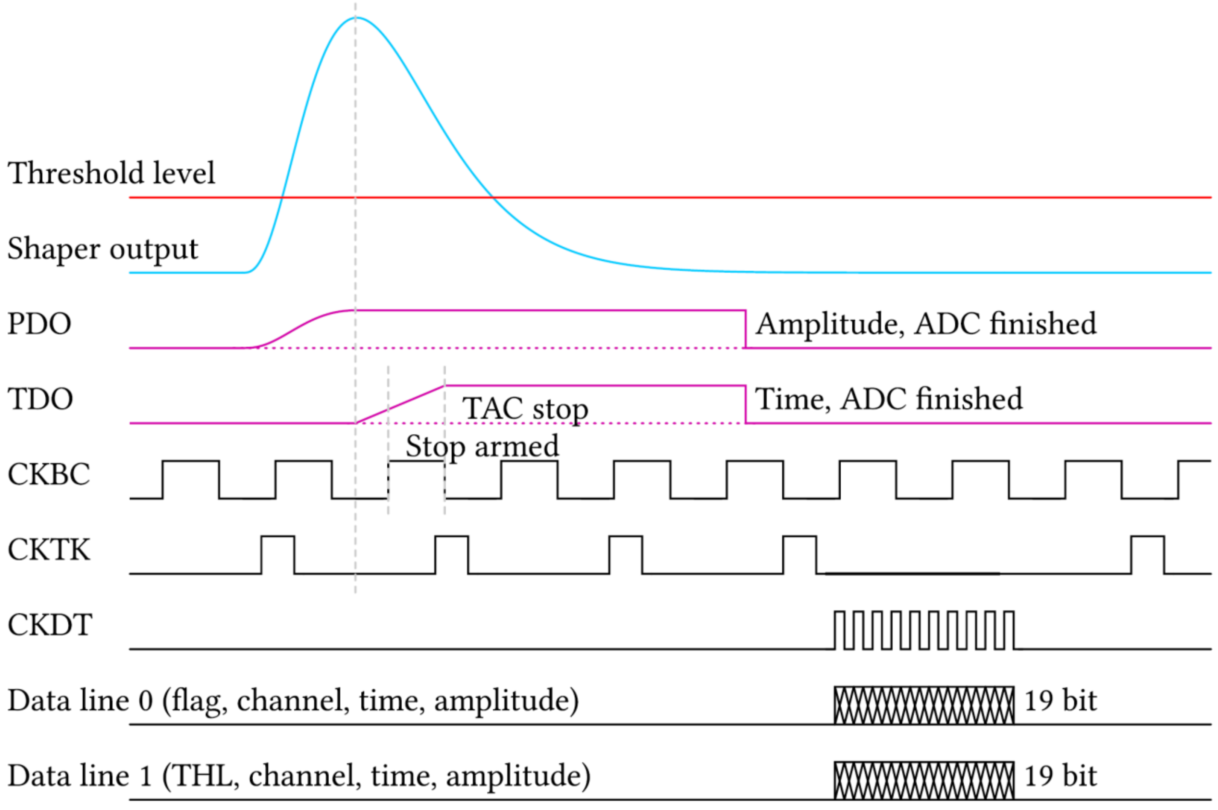
- How to integrate a self-triggered readout system into a triggered experiment?
  - Event counter adapter
- Development of trigger adapter, which can read bit-wise an event counter
- Split each event-counter bit into one LEMO input
  - 32-bit event counter = 32 LEMO connector
  - +4 spares
- To be tested during next test beam

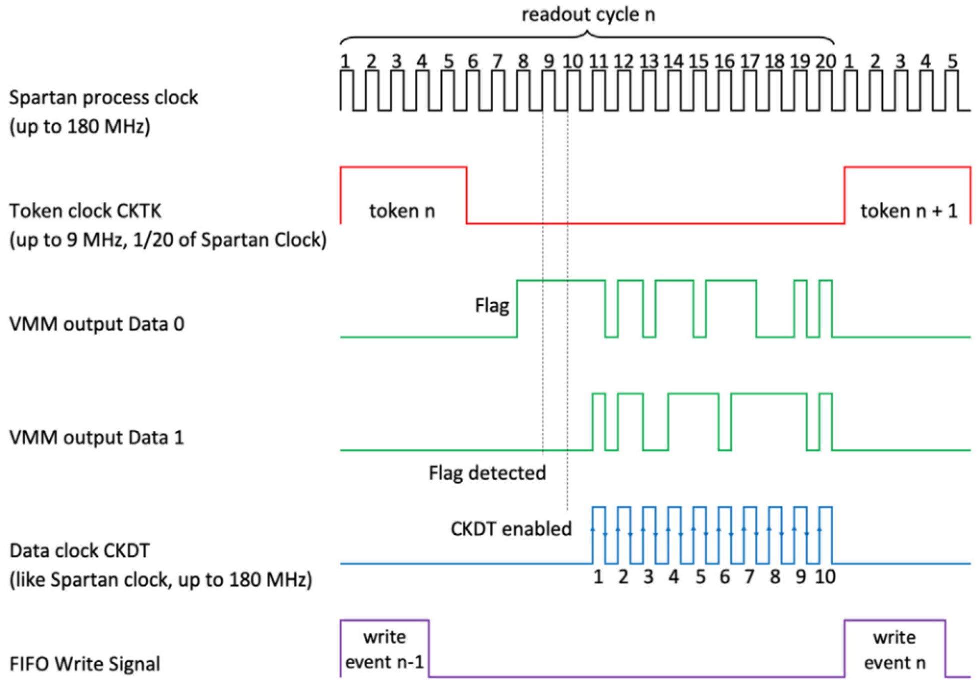


Courtesy of Hans Muller



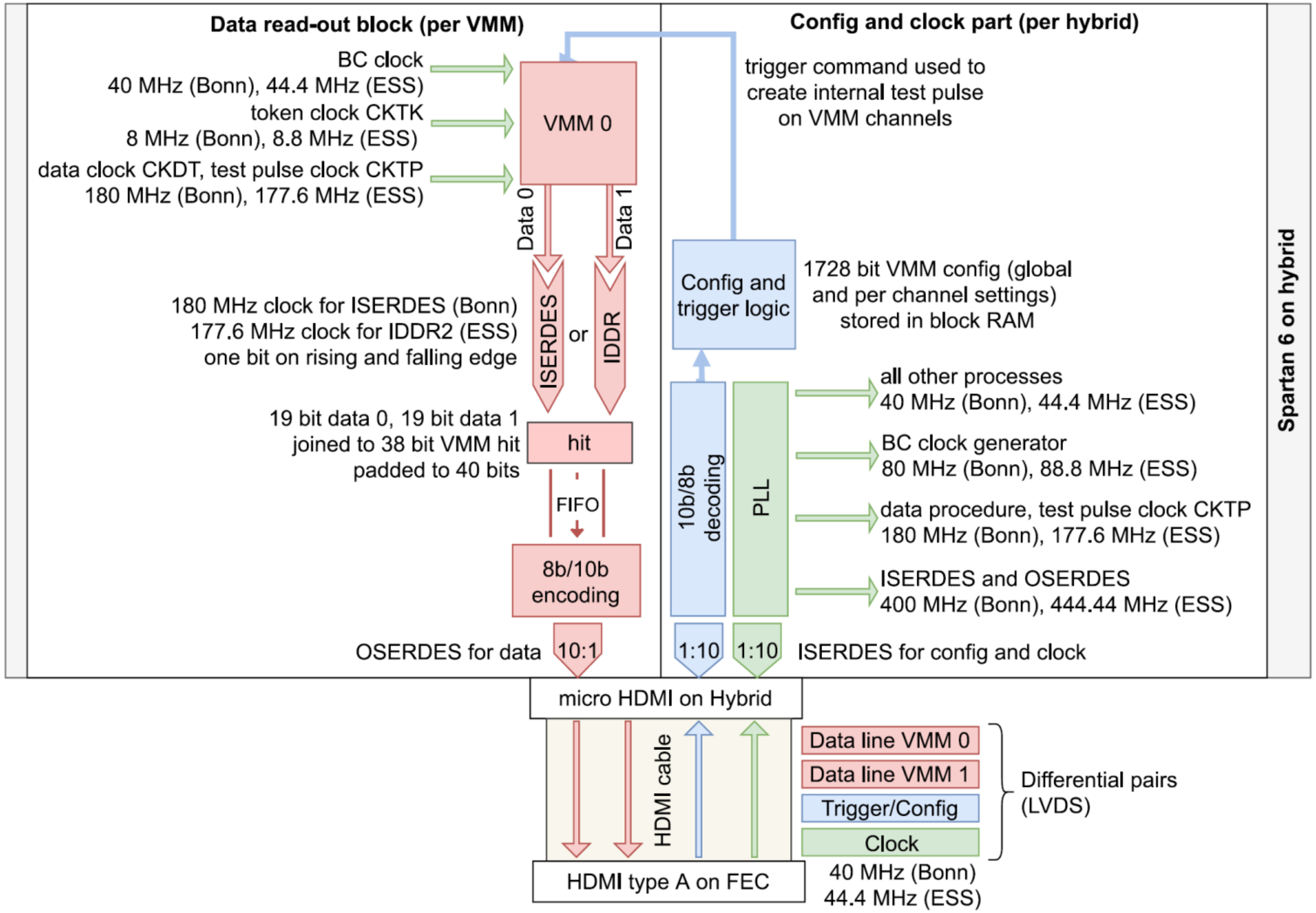
VMM timing diagram





https://doi.org/10.1016/j.nima.2022.166548

VMM3a/SRS firmware (hybrid)



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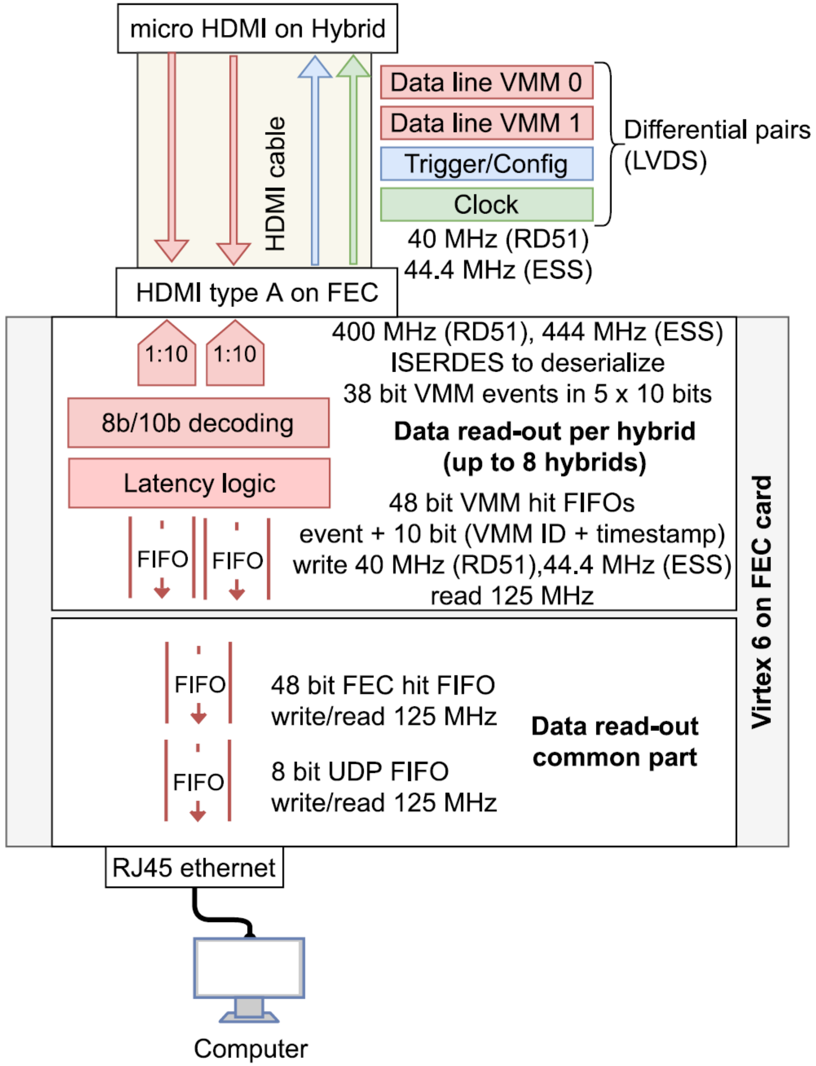
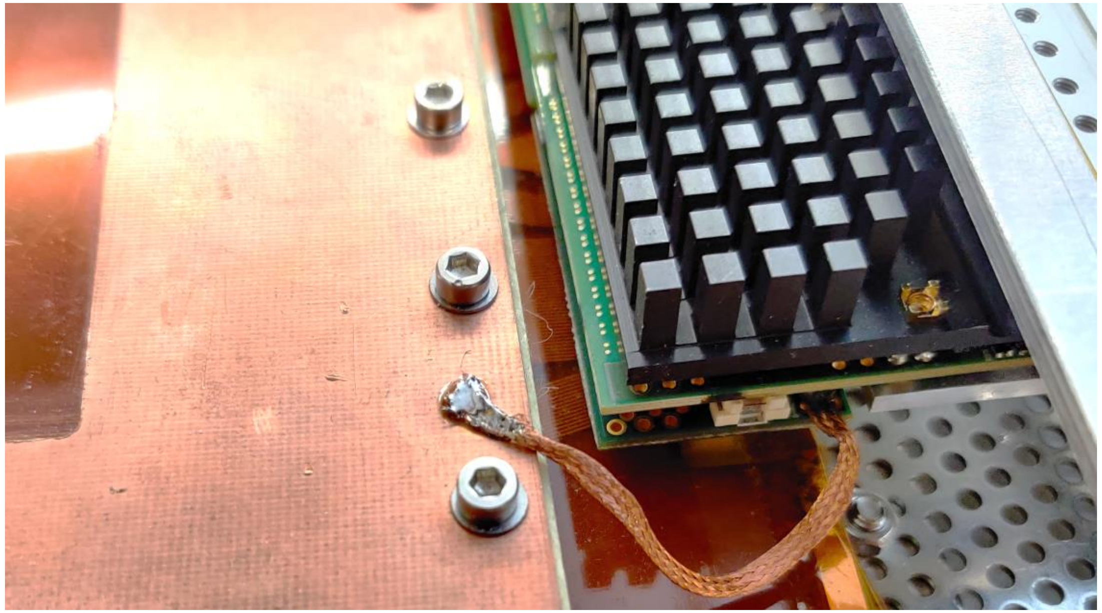
VMM3a/SRS firmware (FEC)

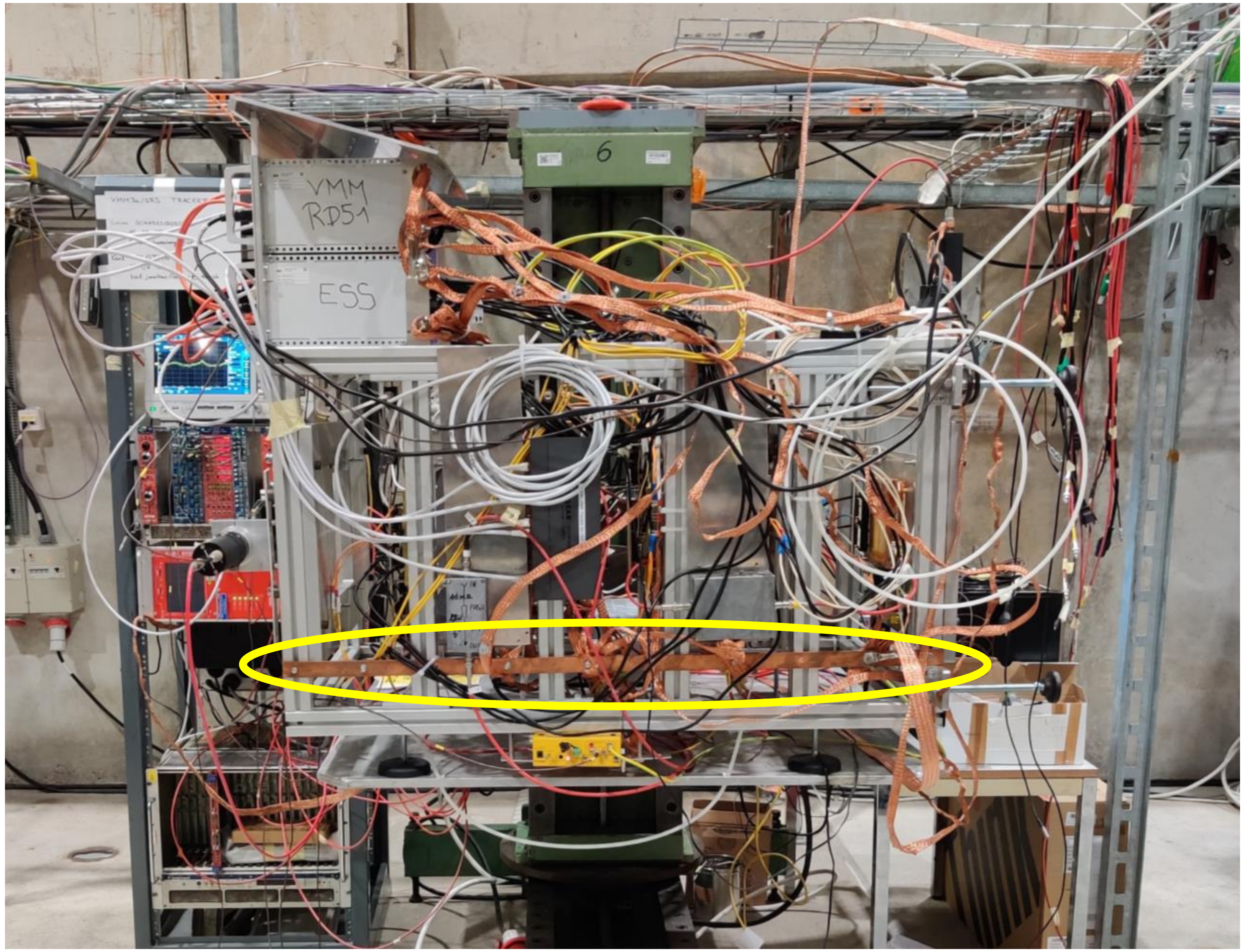


https://doi.org/10.1016/j.nima.2022.166548

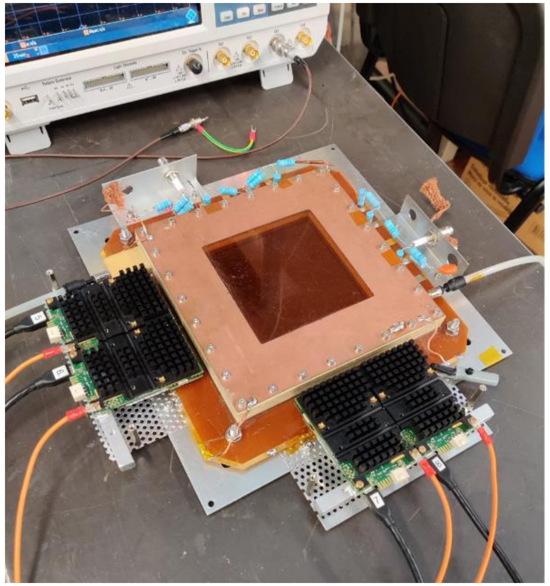
Grounding for low threshold operation

- Improved the common ground
- Improved the analogue and detector ground
  => Adapter between hybrid and old detector connector introduces lots of noise if not grounded

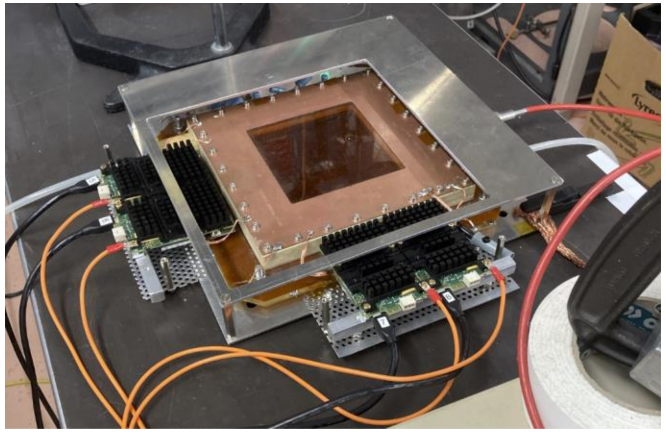


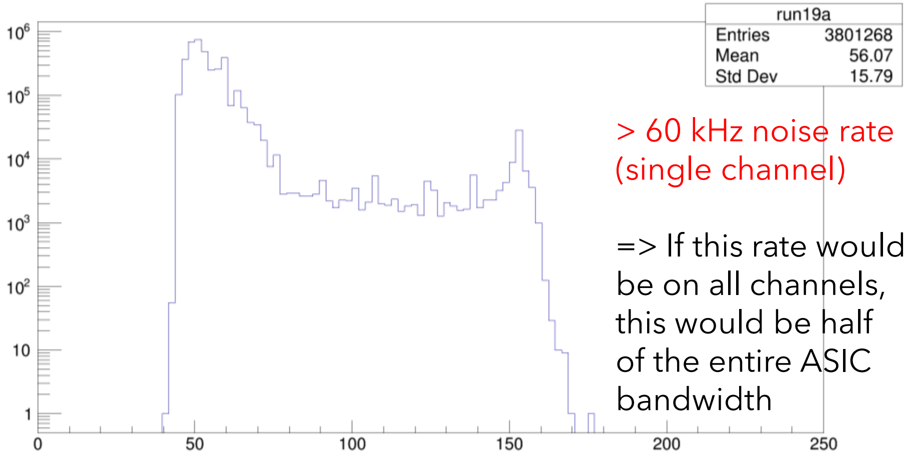


Grounding for low threshold operation



Common ground
Without HV
No adapter ground

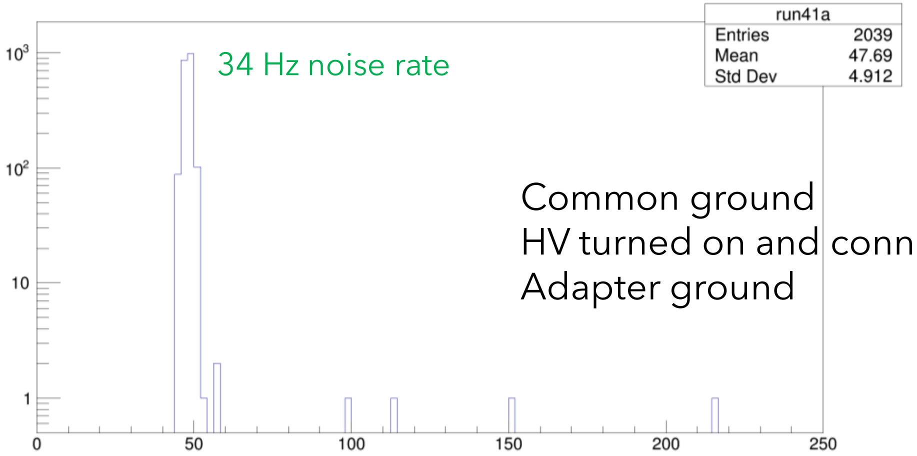




> 60 kHz noise rate
(single channel)

=> If this rate would be on all channels, this would be half of the entire ASIC bandwidth

5 mV THL
60 s of acquisition
Single channel

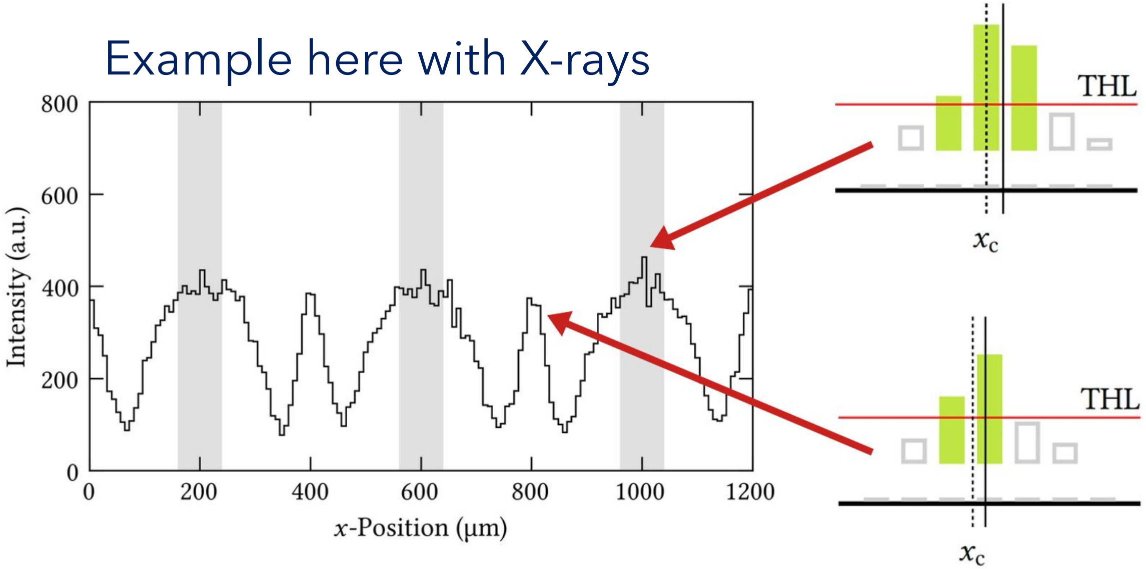


Common ground
HV turned on and connected
Adapter ground

Position reconstruction with Q²

- Loss of charge information by segmentation of readout and threshold level
- Bias in reconstructed position
  - Deviation between true cluster position and reconstruction position
  - odd strip count clusters "forced" close to central strip
  - even strip count "forced" in between the two central strips
- Influenced by strips just slightly above THL => give less weight to them => tried n = 2

Example here with X-rays



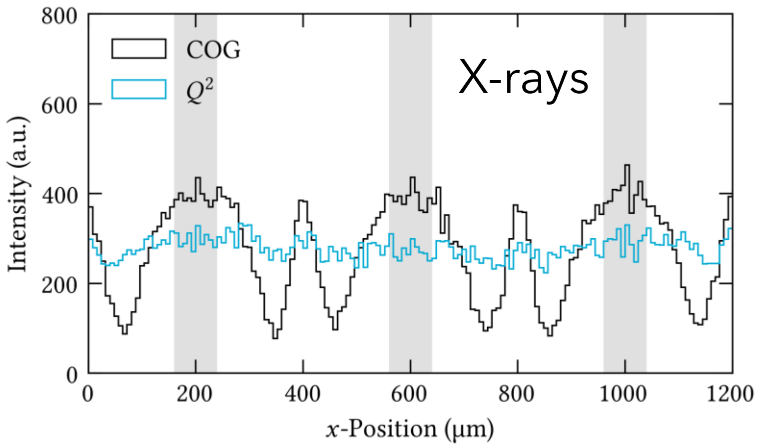
$$x_c = \frac{\sum_i Q_i^n x_i}{\sum_i Q_i^n}$$

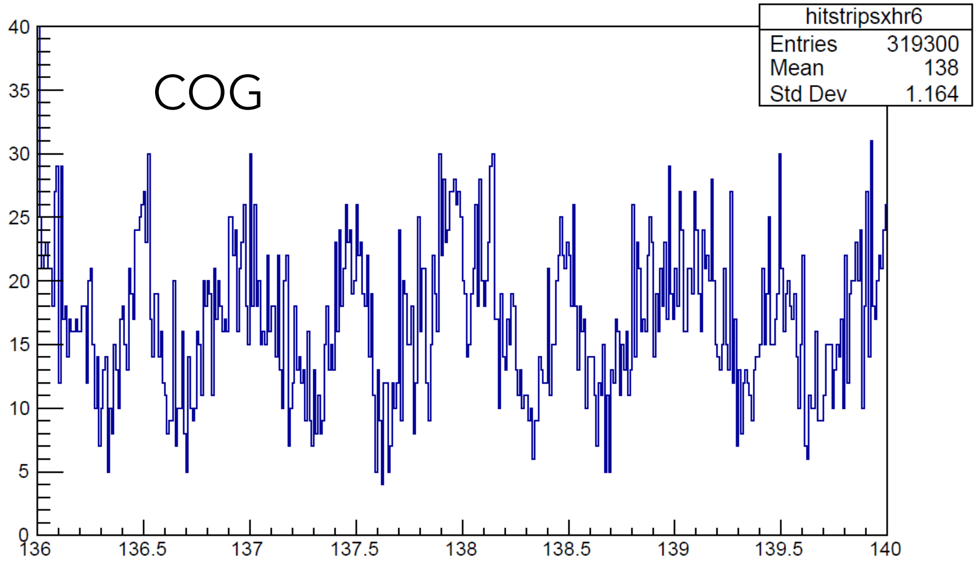
Known phenomenon:

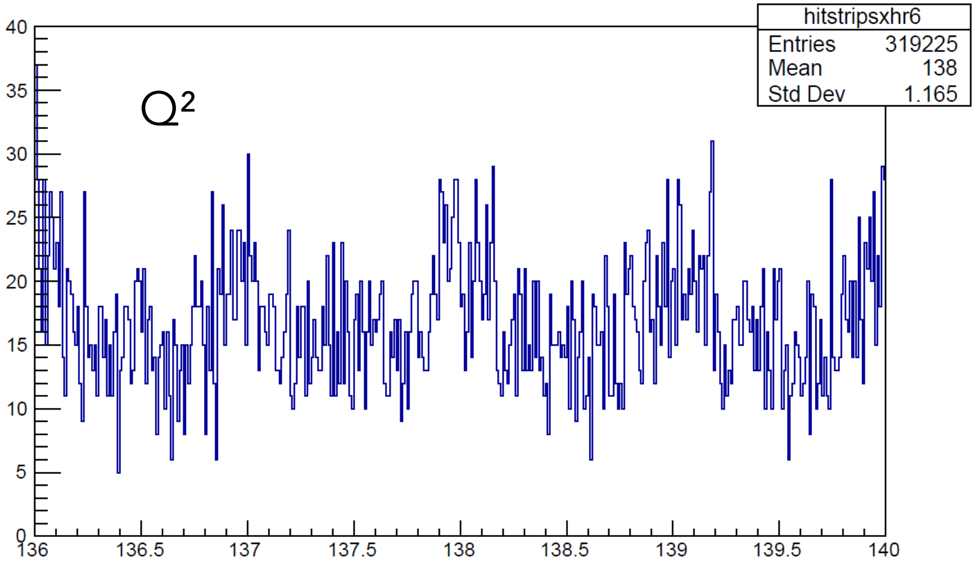
- Observed with MWPC: https://doi.org/10.1016/0029-554X(82)90113-6
- Observed in simulations: https://indico.cern.ch/event/889369/contributions/4039478/

Position reconstruction with Q^2

- Q^2 effect on position distribution
- Improvement with X-rays stronger than with MIPs
- Q^2 reduces read-out modulation effect and gives better spatial resolution



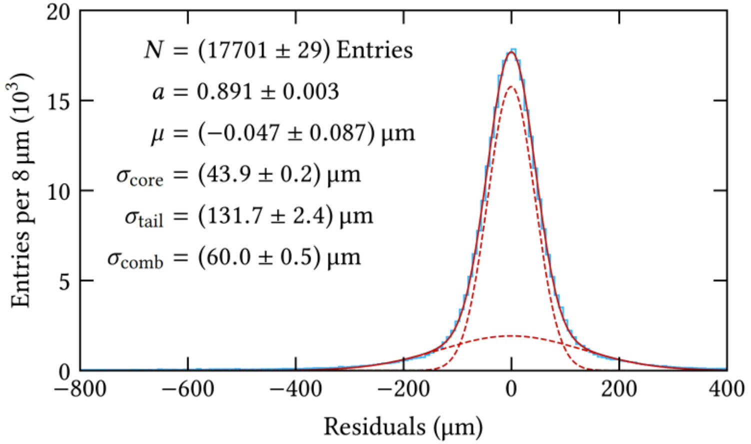




Spatial resolution measurements

- Position reconstruction via **Centre-Of-Gravity** (COG)
- Due to diffusion: **spread of charge** over several read-out channels
- Test also modification of COG: **charge² as weight**
  - Give less weight to the tails of the cluster
  - Successfully tested in X-ray imaging
- Investigation of VMM's neighbouring-logic (**recover charge below THL**)

Example of residual distribution



Spatial resolution measurements

- Position reconstruction via **Centre-Of-Gravity** (COG)
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