Latest results and improvements of the RD51 VMM3a/SRS gaseous beam telescope

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

12th Beam Telescopes and Test Beams Workshop

17 April 2024

SPONSORED BY THE
Federal Ministry of Education and Research

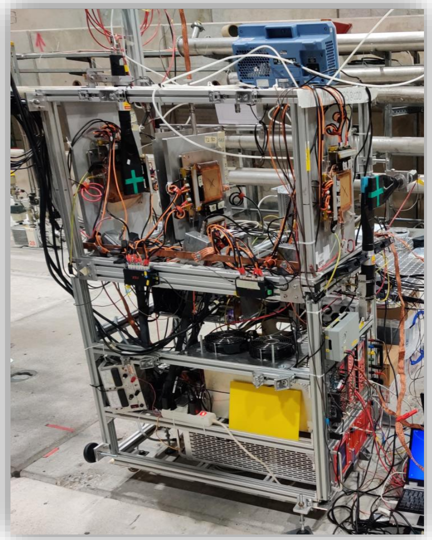
CERN · UNIVERSITÄT BONN · EP R&D · AIDA innova · ess EUROPEAN SPALLATION SOURCE · RD51 Collaboration · GDD Gas Detectors Development Group

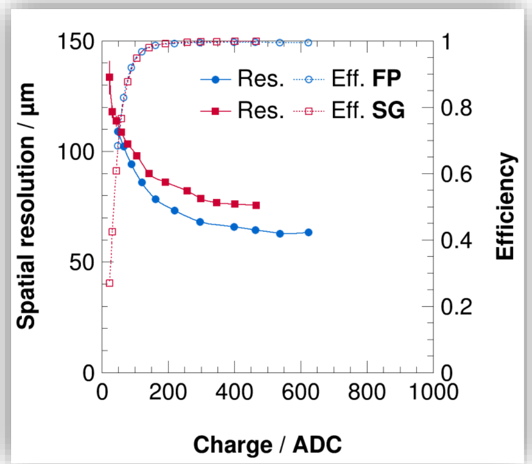
Outline

1. **Overview**
   - RD51 and DRD1 test beam campaigns
   - Infrastructure and beam telescopes
   - RD51 Scalable Readout System (SRS)

2. **Detector characterisation studies**
   - Resistive plane detectors
   - Finer-pitch GEM detectors for spatial resolution improvements
   - AMBER prototype detector

3. **Improvements of the telescope**
   - Power BoX (PBX)
   - Distributed system
   - Triggered readout mode





Test beam campaigns of RD51 and DRD1

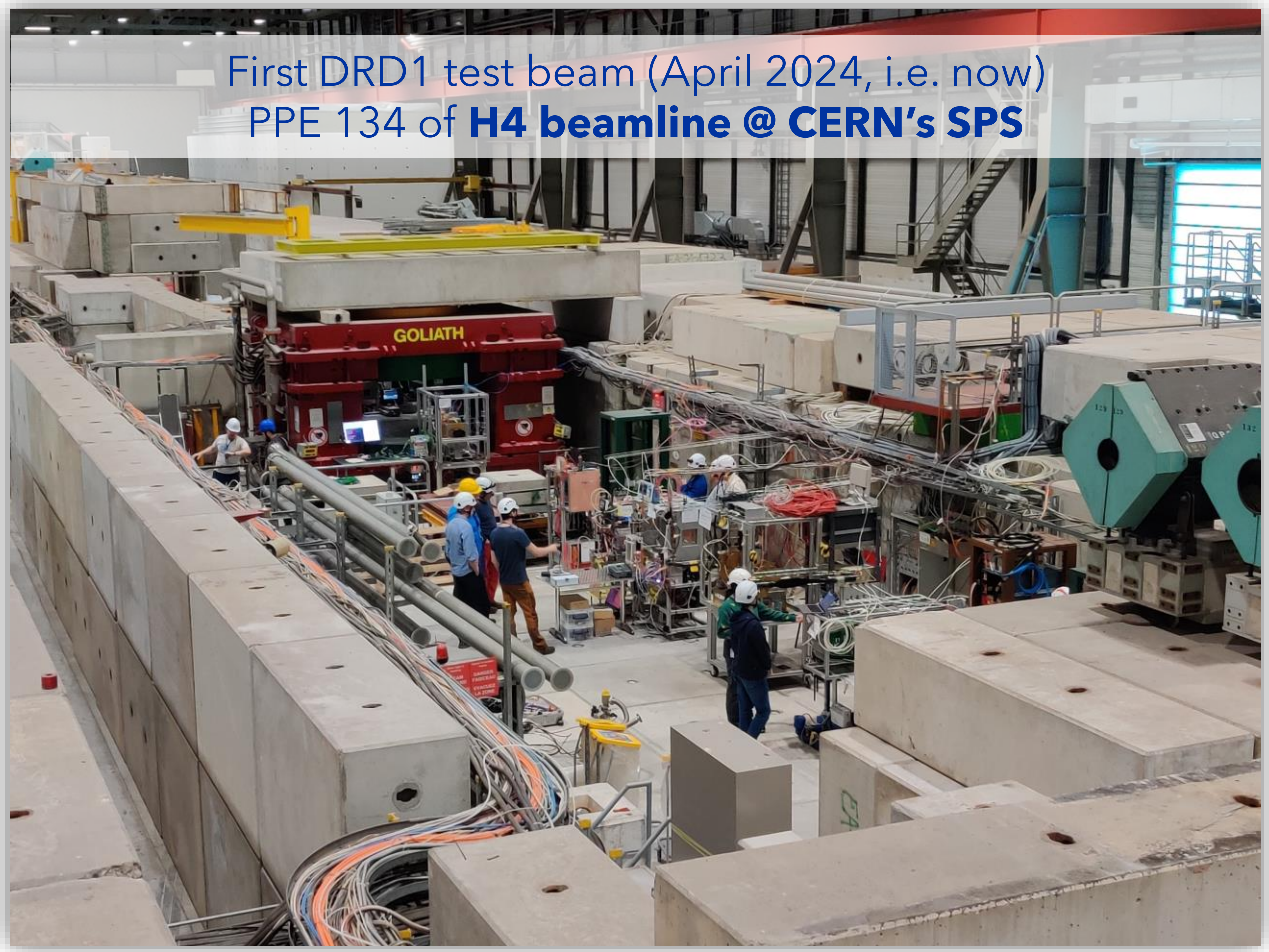
- CERN-based R&D collaborations

- **RD51:** Development of Micro-Pattern Gaseous Detectors (MPGDs)

  Ceased operation end of 2023

- Transitioned into **DRD1** (as part of ECFA Detector R&D Roadmap) to cover **all gaseous detector technologies**

- Continue with the joined test beam campaigns at CERN
- Infrastructure provided by RD51/DRD1 at CERN (lab and clean room infrastructure for detector assembly, gas supply, electronics and software support, **beam telescopes**)



First DRD1 test beam (April 2024, i.e. now)
PPE 134 of **H4 beamline @ CERN's SPS**

Test beam campaigns of RD51 and DRD1:
Beam telescope infrastructure

Two existing telescopes:

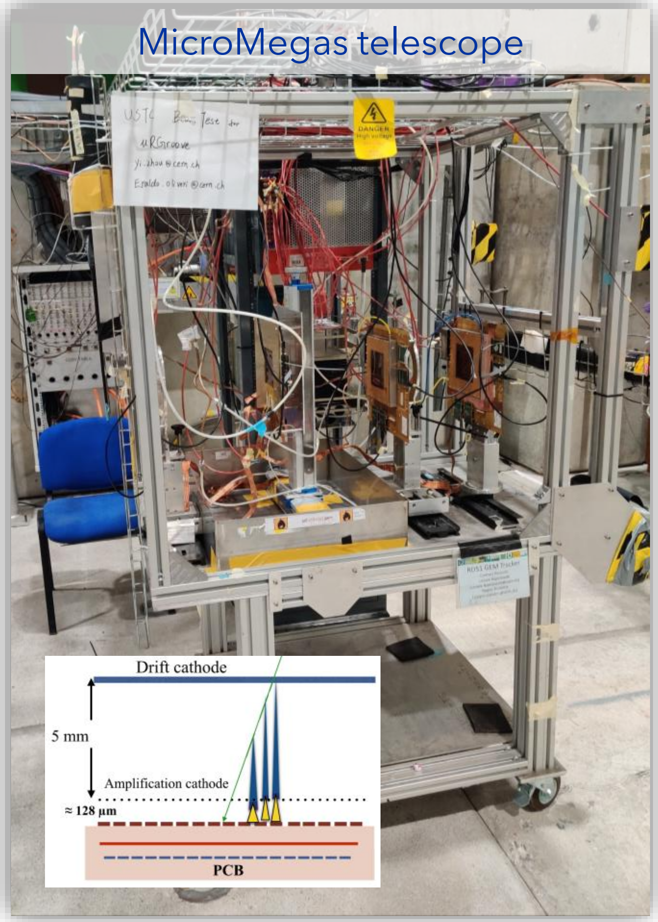
- **10 x 10 cm² active area**
- X-Y-strip readout
- 50 to 100 μm spatial resolution
- Read out with **RD51 Scalable Readout System (SRS)** [1]

MicroMegas telescope

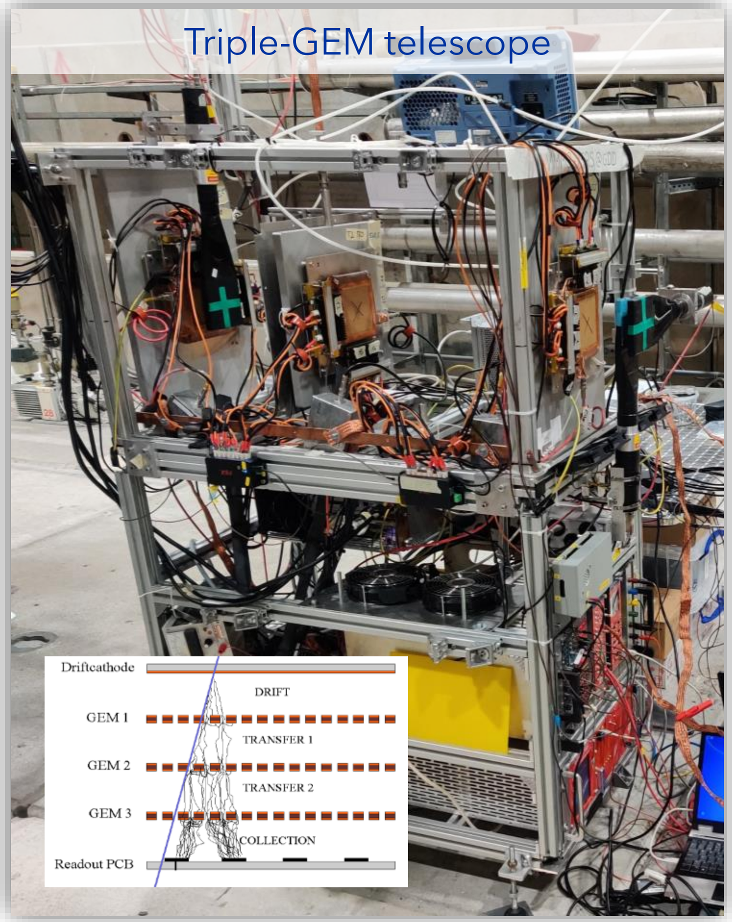
- APV25 front-end ASIC in SRS [1]
  - ~1 kHz trigger rate
  - ~10 ns time resolution

Triple-GEM telescope

- VMM3a front-end ASIC in SRS [2,3]
  - Self-triggered up to ~500 kHz
  - ~1 ns time resolution



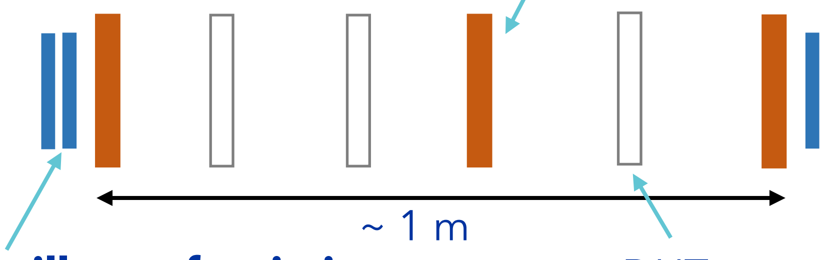
https://doi.org/10.1016/j.nima.2017.10.067



https://indico.cern.ch/event/574840/

[1] JINST **8** (2013) C03015
[2] NIM A **903** (2018) 91–98
[3] NIM A **1031** (2022) 166548

RD51 VMM3a/SRS triple-GEM beam telescope



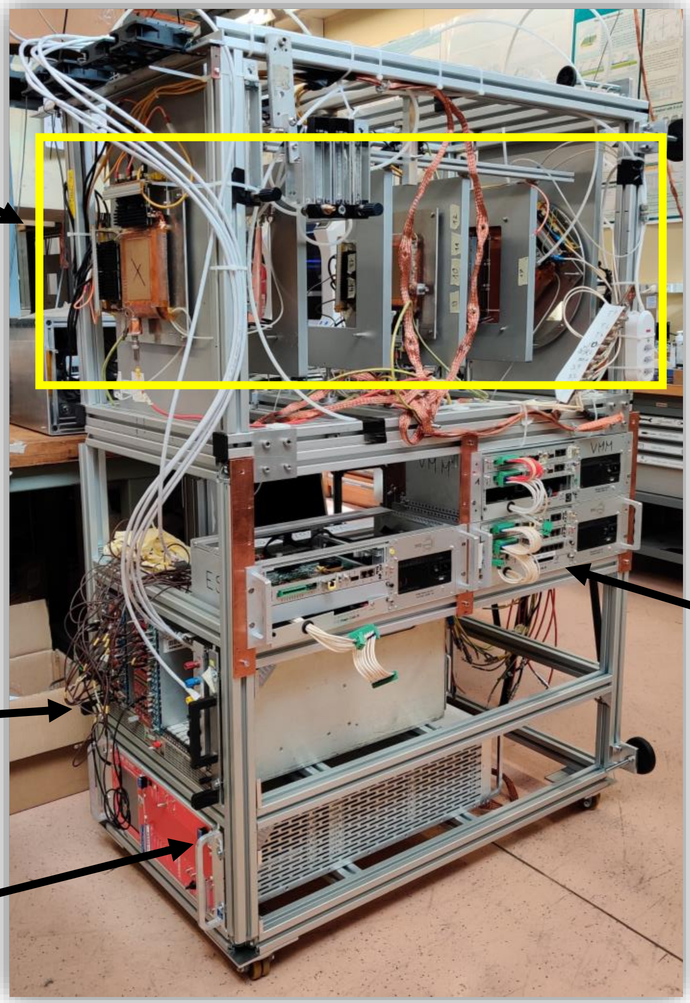
3 reference tracking detectors
→ X-Y-strips (256 + 256)

Scintillators for timing
~1 ns time resolution

DUTs

NIM-logic for scintillator/PMTs
(read out via VMM3a in the RD51 SRS)

High voltage for detectors



COMPASS-like triple-GEM detectors [4] for tracking
→ filled with Ar/CO_2 (70/30 %)
→ strips with 400 µm pitch

Use centroid (COG) for position reconstruction
~80 µm spatial resolution at gain = 10^4

RD51 SRS electronics with VMM3a front-end ASIC
More than 2k channels for DUTs
Up to ~500 kHz particle rate without losses (self-triggered)

[4] NIM A **490** (2002) 177

For more information see also: JINST **18** (2023) C05017

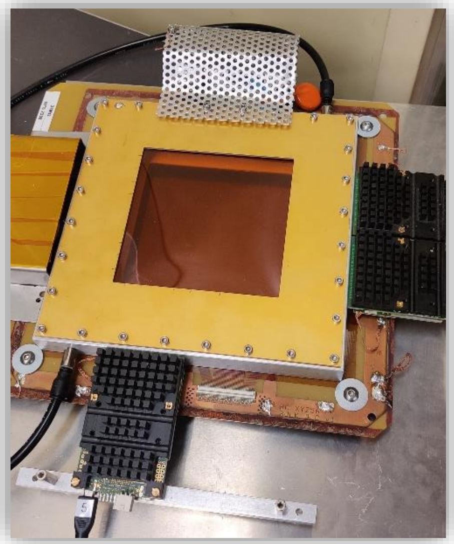
RD51 Scalable Readout System

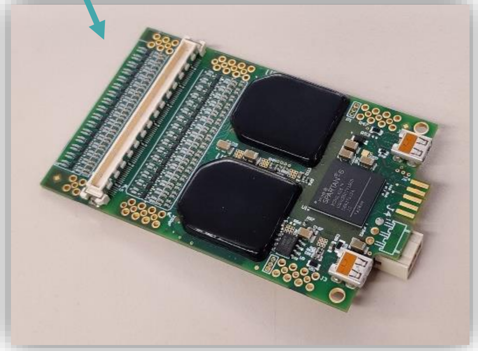
- Common **RD51 Scalable Readout System (SRS)** DAQ for small R&D set-ups and midsized experiments
- Originally introduced in 2009, with various front-end ASICs integrated (e.g. APV25, Timepix/Timepix3, VMM3a)
- Profit from the capabilities of the **ATLAS/BNL VMM3a** [5] front-end ASIC

Detector → *RD51 VMM hybrid* → Adapter card *DVMM* → Front-End Concentrator (FEC) card → DAQ PC

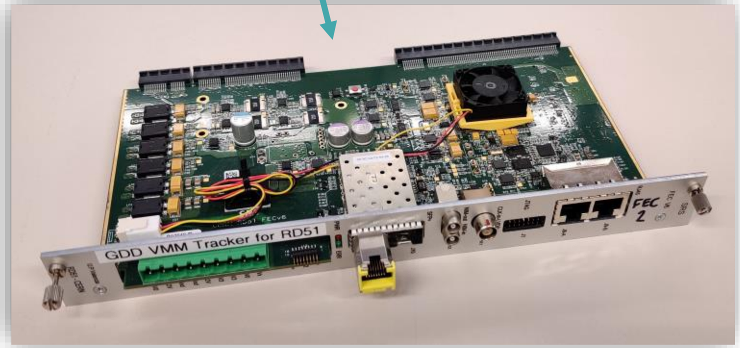
HDMI

Gigabit Ethernet





128 channels per hybrid



Up to 8 hybrids per FEC

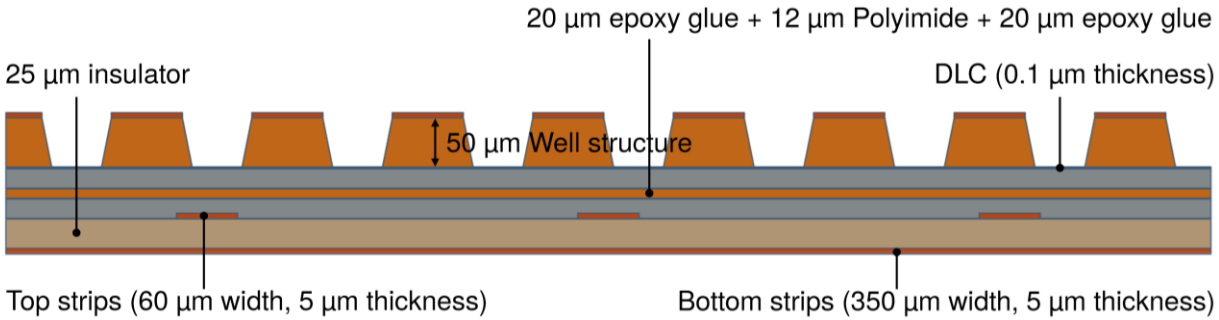
Most important VMM3a capabilities:

- 9 MHz hit rate per VMM
- Peak amplitude (10-bit)
- Time of peak O(ns) time resolution (12+8-bit)
- Adjustable peaking times
- Adjustable electronics gains
- Wide range of input capacitances (< 200 pF up to 1 nF)

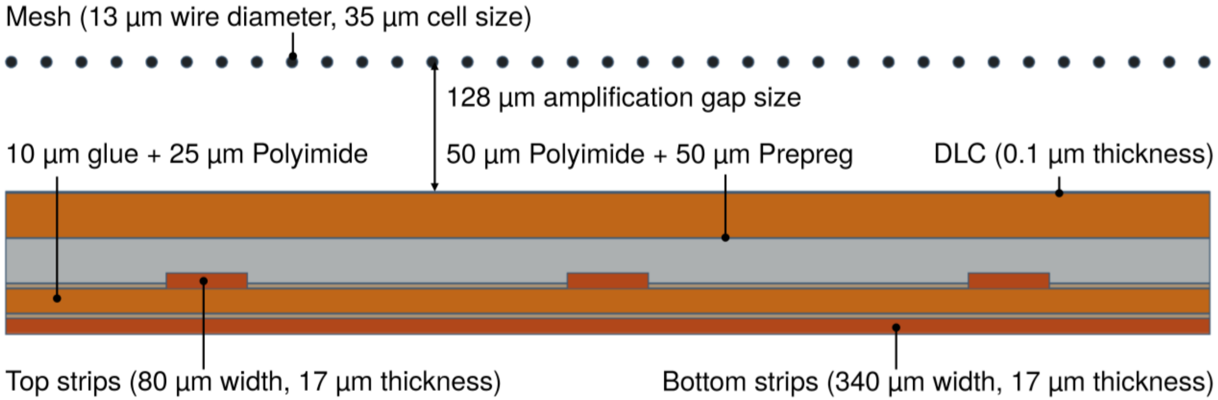
[5] IEEE TNS **69** (2022) 976

Detector R&D:
Resistive plane detectors

- Since the large-scale use of resistive strip MicroMegas detectors in the ATLAS New Small Wheel (NSW), more and more MPGDs employ **resistive elements to improve detector robustness** and signal tuning
- Already in 2022: investigation of two types of resistive plane MPGDs during RD51 test beam
  → **µRWELL:** to be used in a third DRD1 beam telescope



→ **MicroMegas with thin mesh:** R&D and stability tests



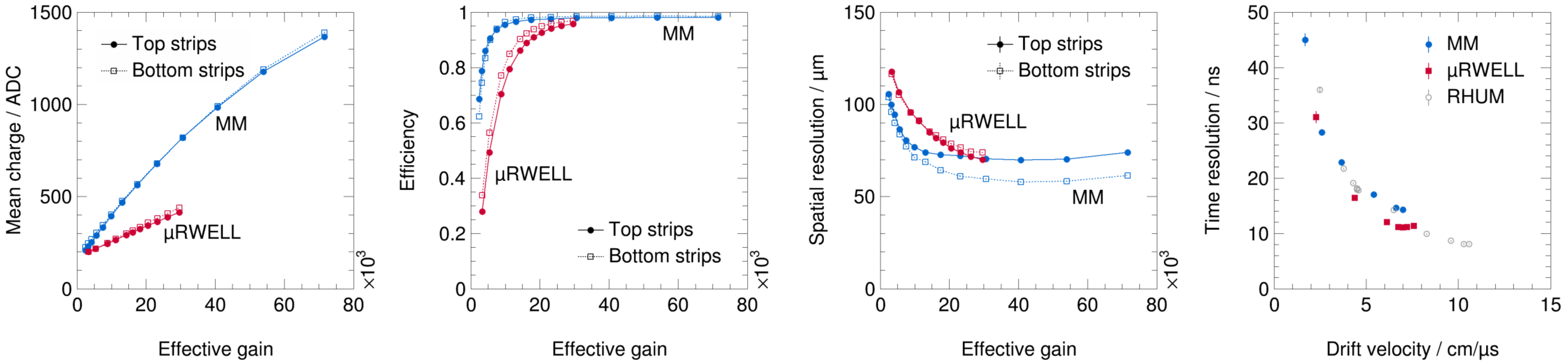
Diamond-like carbon (DLC) anode for both detectors

~40 MΩ/sq resistivity

Readout strips separated from anode through insulator

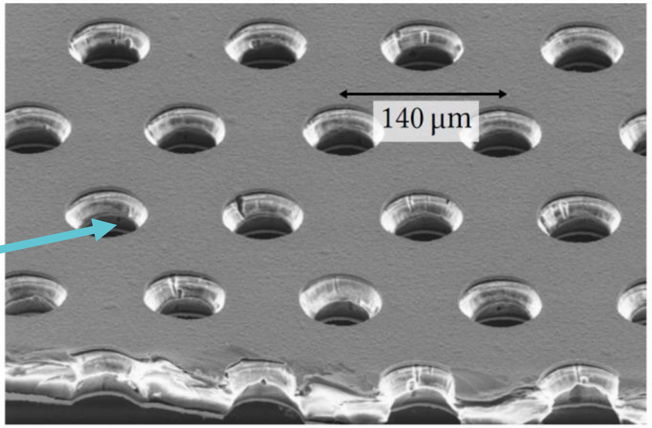
Detector R&D:
Resistive plane detectors

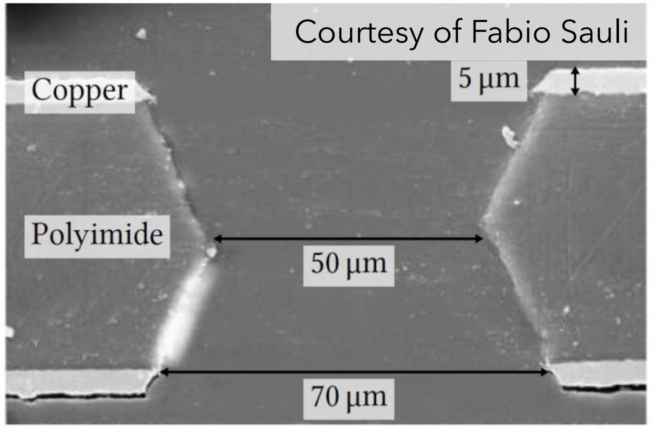
- Shows the importance of the signal induction
  → Big difference in the measured charge at the same detector gain
- Similar performance in terms of time and spatial resolution
- Thin mesh allows to go to much higher gains before discharges



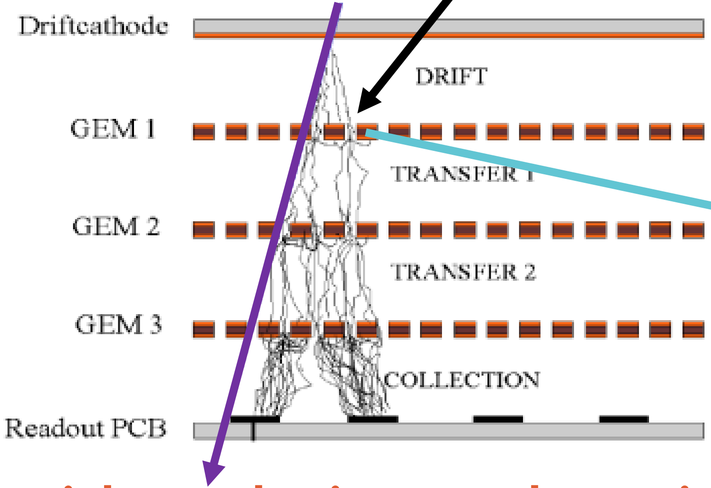
Detector R&D:
Finer-pitch GEMs (motivation)

Standard geometry of Gas Electron Multipliers (GEMs):
- 50 μm thickness
- 5 μm copper on top and bottom
- Holes for gas amplification with 140 μm pitch in hexagonal pattern

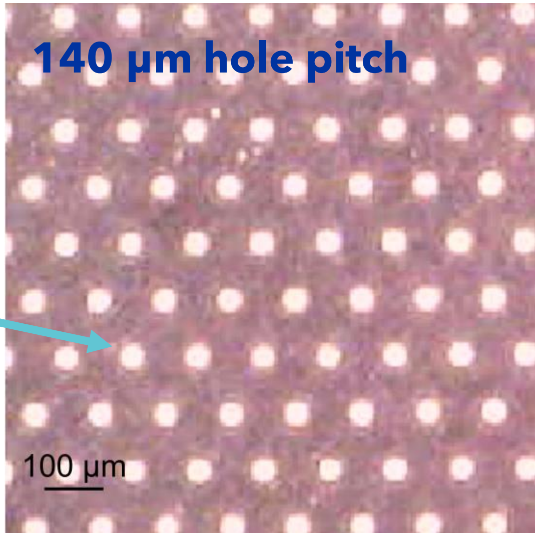


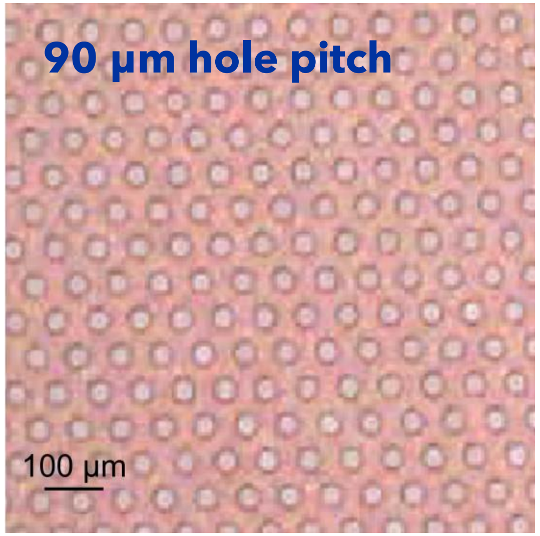


Increase hole density to improve sampling during charge collection

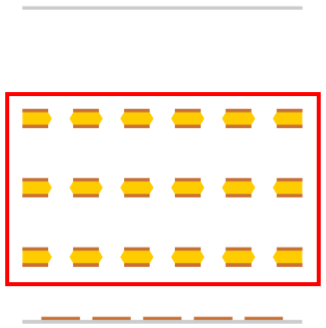


https://indico.cern.ch/event/574840/





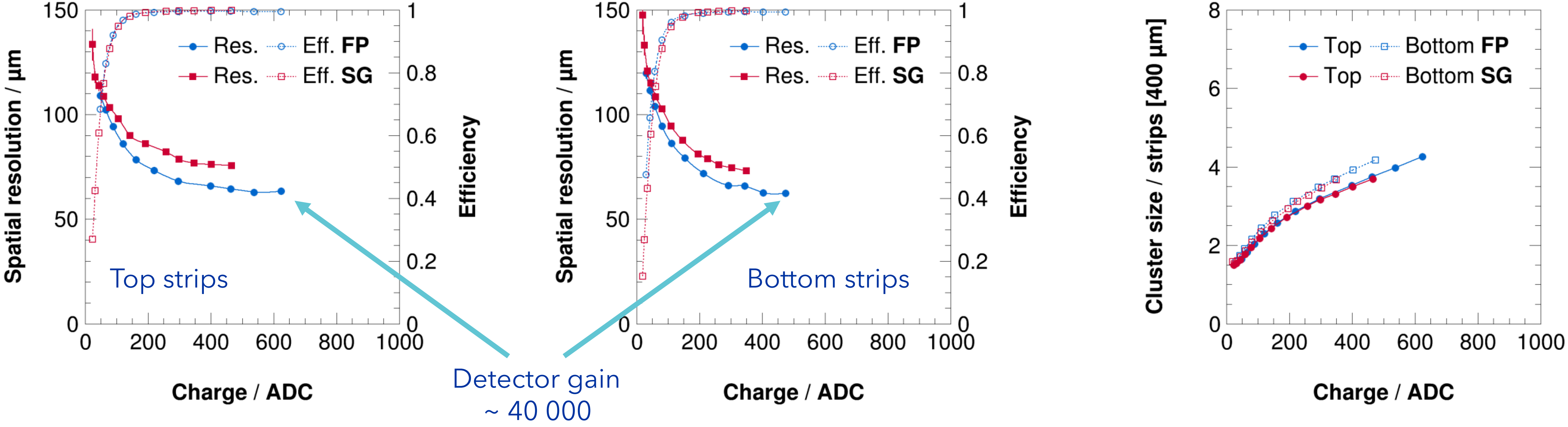
Can it be used to improve the spatial resolution?



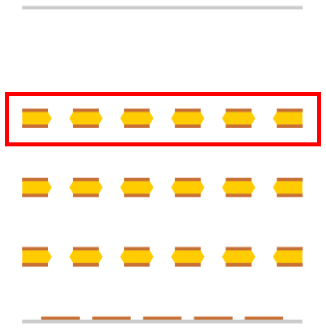
Detector R&D:
Finer-pitch GEMs (results)

PRELIMINARY

Fine-Pitch (FP) vs Standard Geometry (SG) for all three GEMs in the stack



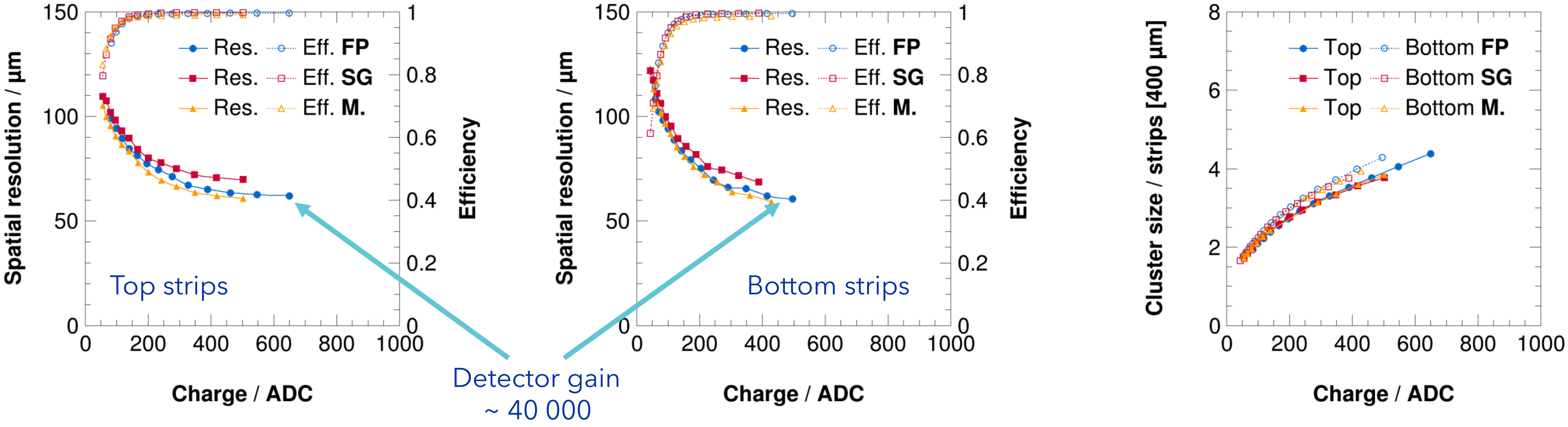
Minor spatial resolution improvement of ~10 µm due to finer pitch GEM



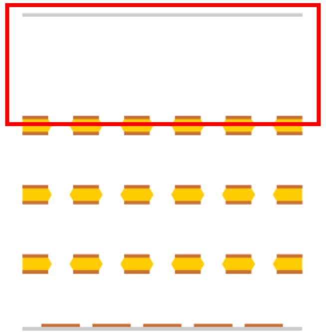
Detector R&D:
Finer-pitch GEMs (results)

PRELIMINARY

Variation of the **first GEM only** with different configurations
FP = all fine pitch
SG = all standard geometry
M = mixed, first GEM fine pitch, second GEM standard



Mixed configuration seems to be best, but requires still understanding why!

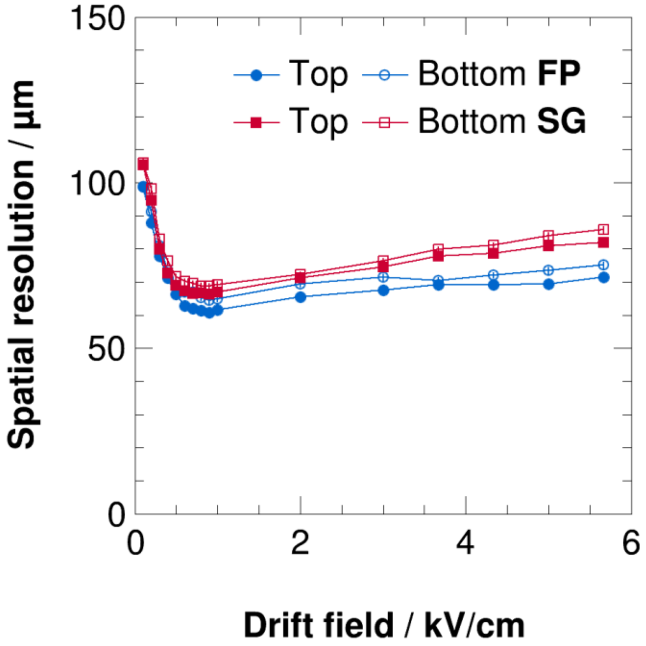


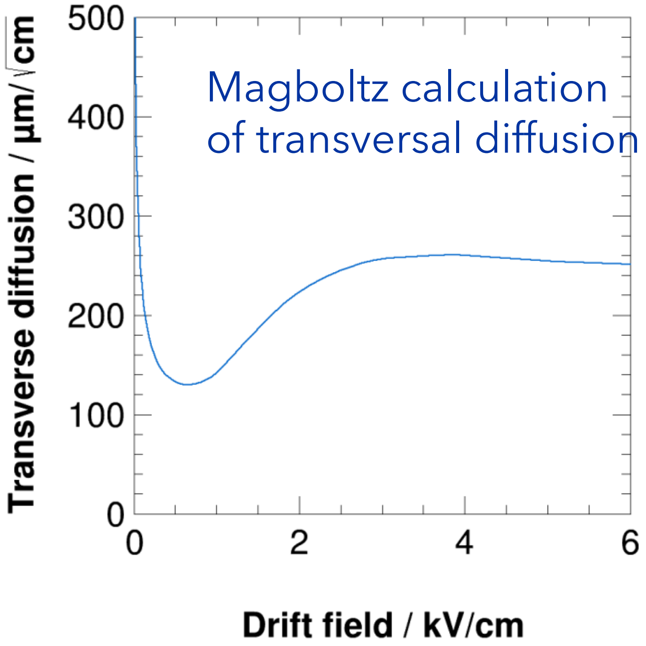
Detector R&D:
Finer-pitch GEMs (results)

PRELIMINARY

Study of charge collection by the first GEM, through variation of the drift field

Spatial resolution depending on the drift field

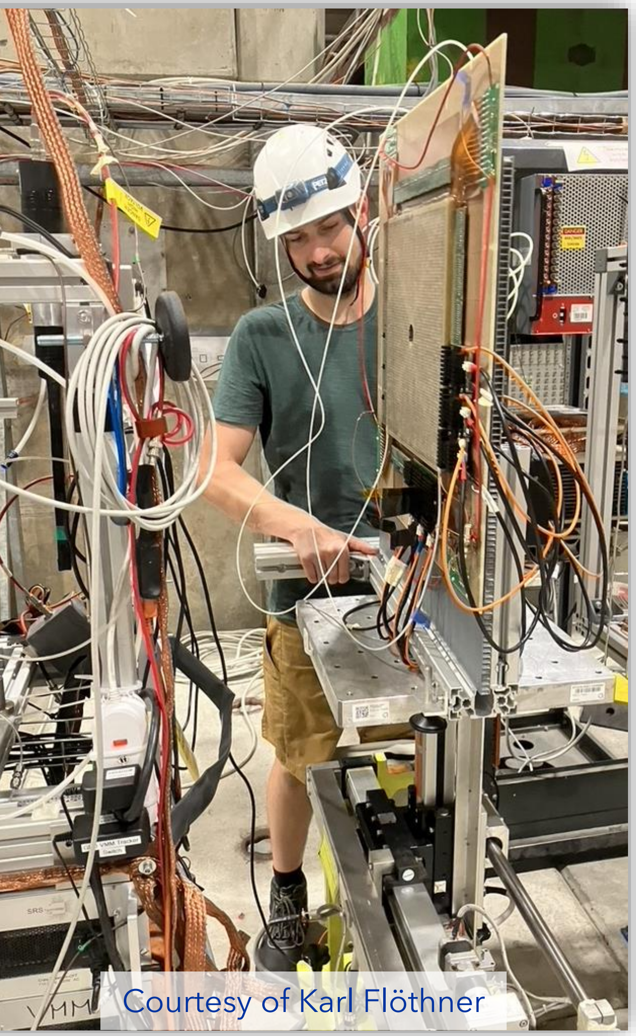




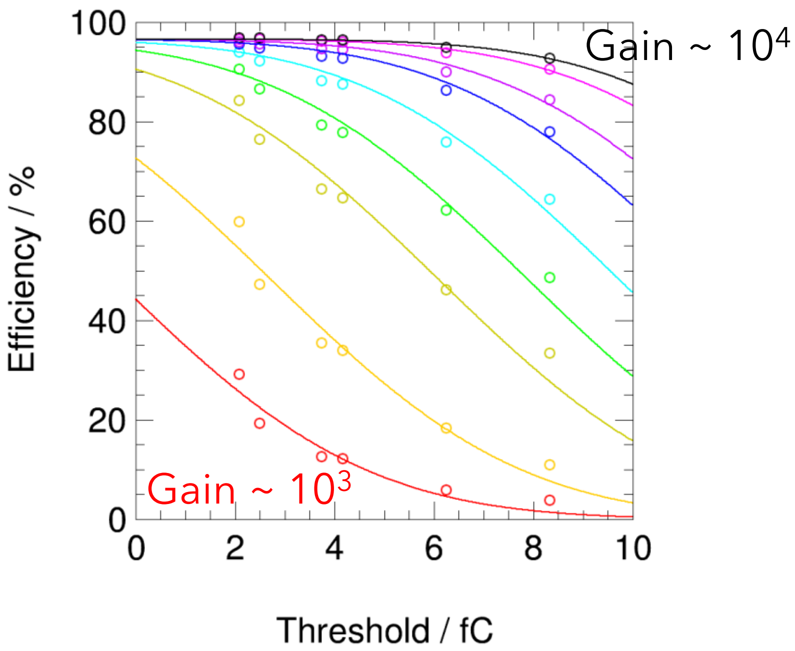
Minor spatial resolution improvement.

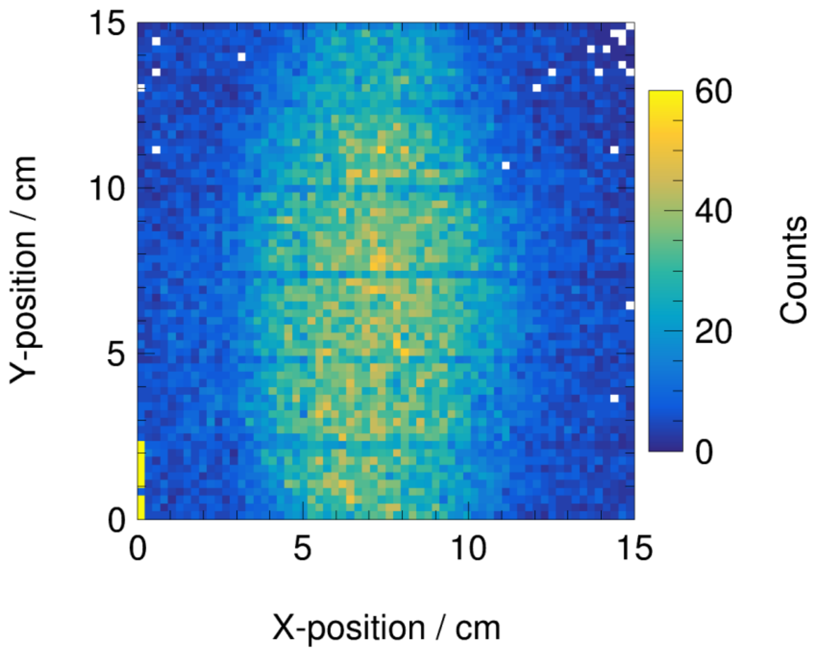
Improvement gets larger towards higher drift fields, i.e. where field lines and thus primary ionisation electrons start to end up on the copper of the GEM. With higher hole density this effect is weaker.

Detector characterisation for experiments:
Prototype tracking detector for AMBER



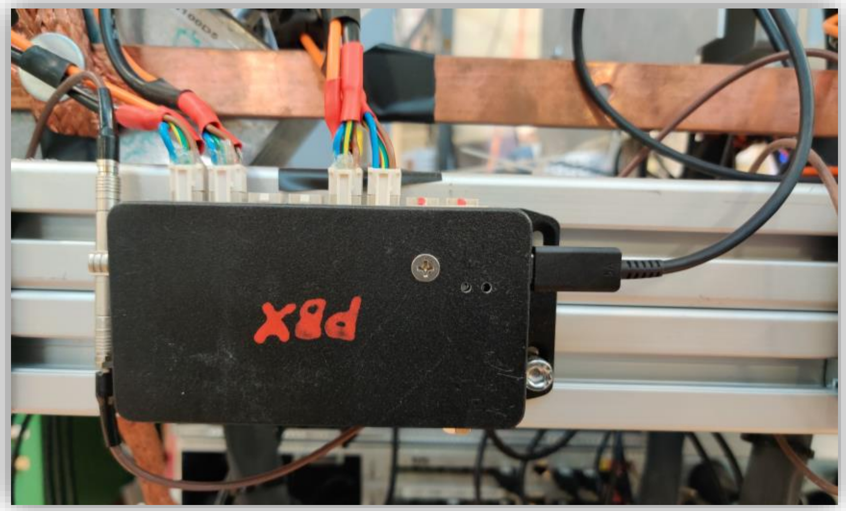
- Several **30 x 30 cm² triple-GEM** detectors utilised by AMBER
- **Characterisation of new tracking detector prototype for the AMBER experiment**
- Not only at RD51 test beam, but also directly at AMBER
- **Test of the VMM3a as possible front-end ASIC for the experiment**

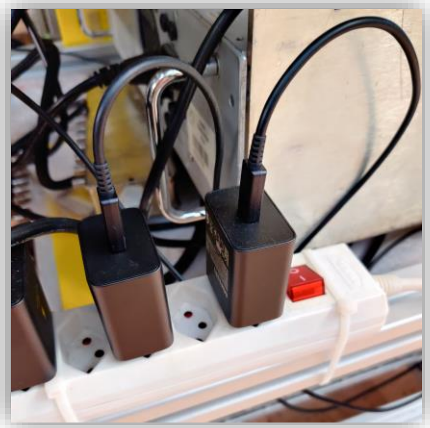




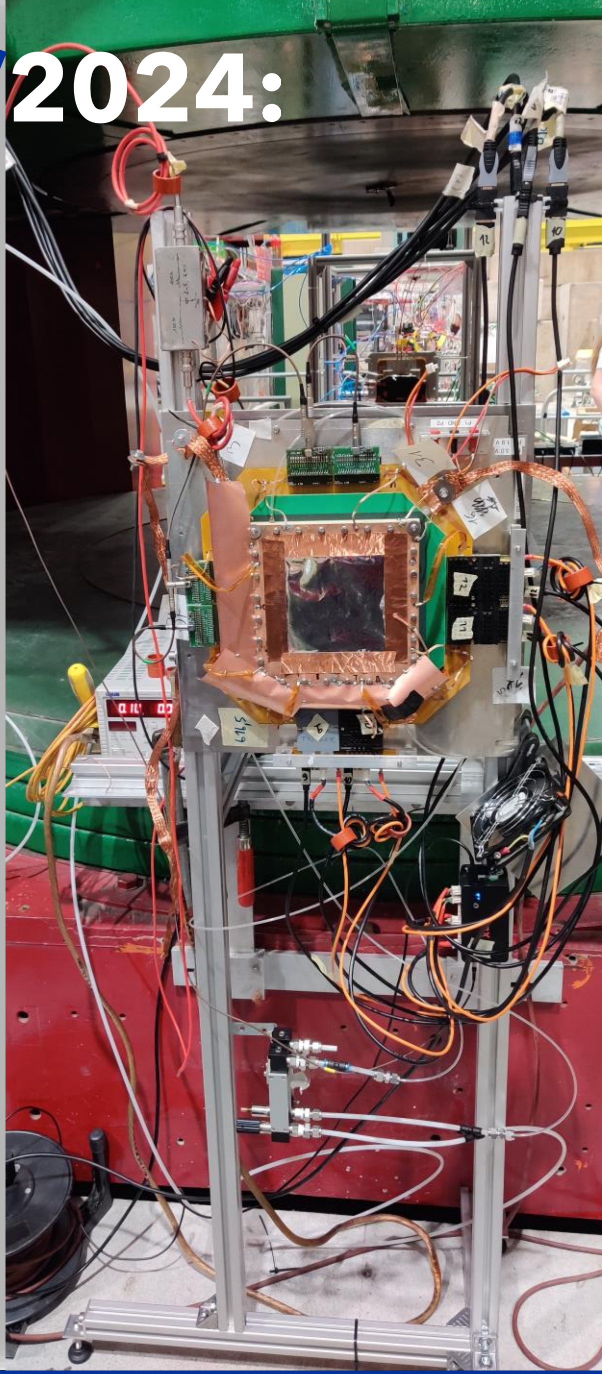
Upgrades to the telescope in 2023:
Power Box (PBX)

- Default low-voltage powering scheme for front-end electronics: power-over-HDMI
  - Limited to 2 m long HDMI cables
- External **Power BoX (PBX)** as new alternative for (geometrically) large systems
- For more details: K.J. Flöthner and H. Muller @ RD51 Collaboration Meeting (June 2023)
- Up to 8 hybrids (1k front-end channels) per PBX
- Power from standard (30 Watt) USB-C phone charger





Upgrades to the telescope in 2023/2024:
Distributed readout system



- Distributed readout system
  → **Long lever arm telescope, several 10's of meters length**
  → Separate low-voltage power supply via PBX
  → R/O with VMM3a/SRS from central telescope (e.g. 20 m HDMI cables)

- Possible applications
  → Experiments with high angular resolution requirements (e.g. NA61)
  → Interest within DRD1 community for test beams and potentially for GIF++
  → **Fermilab test beam area** (see Joe's presentation from Monday)

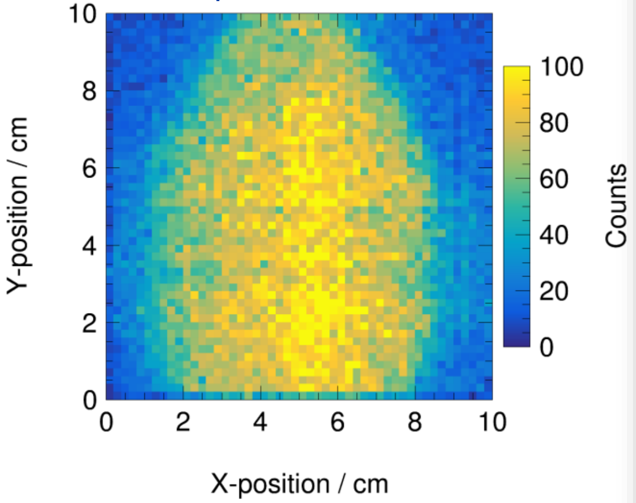
- Initially tested in August 2023 with smaller system
  → **Currently characterised April 2024 test beam**
  → Satellite tracking station, separated by 13 m from beam telescope

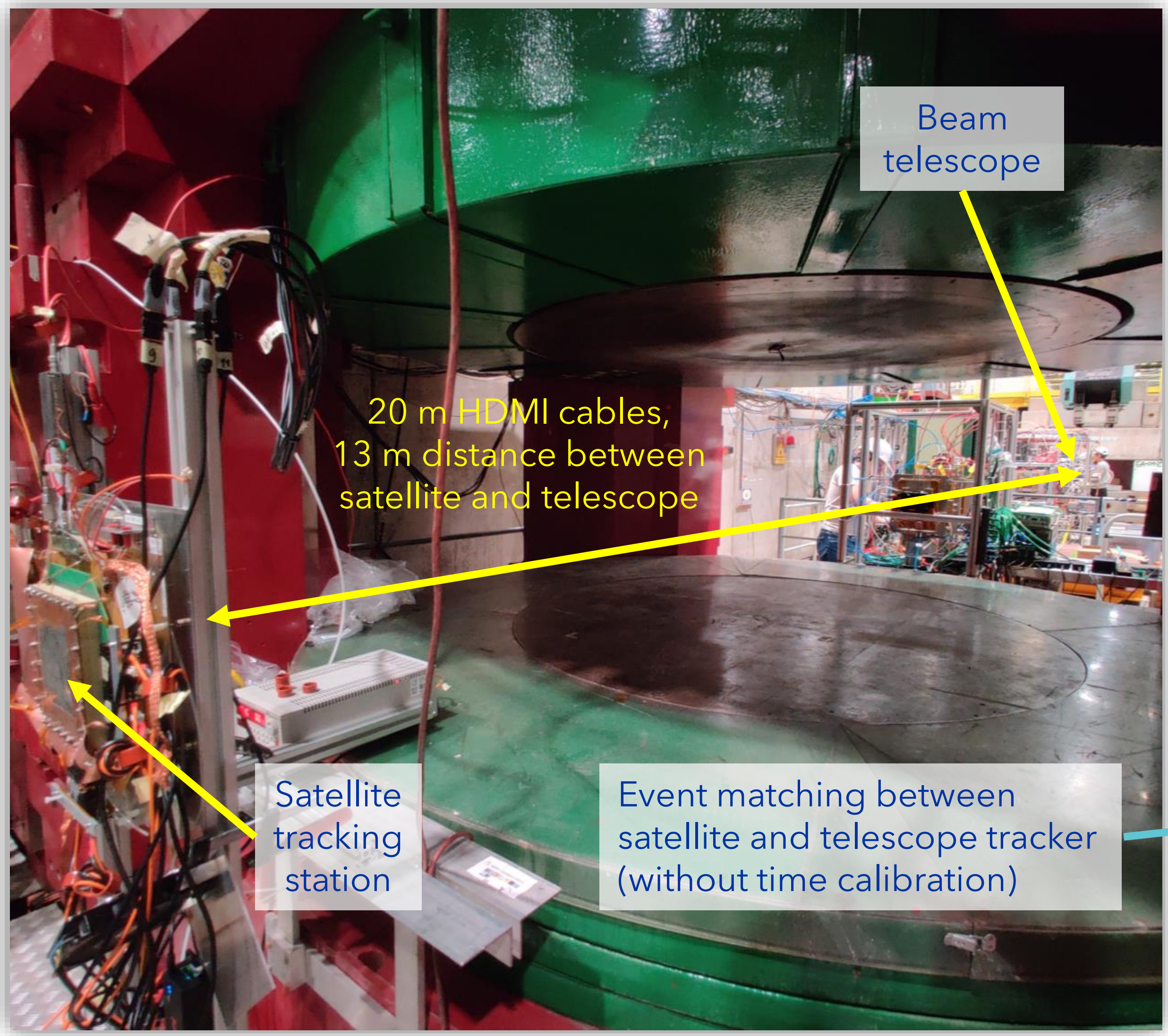
Upgrades to the telescope in 2023/2024:
Distributed readout system

First results from **14 m lever arm telescope**

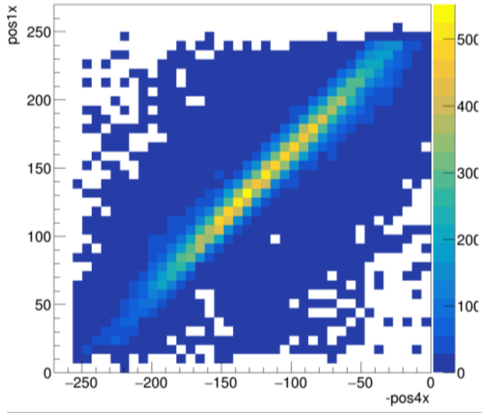
Beam profiles and event building in time

Beam profile in satellite

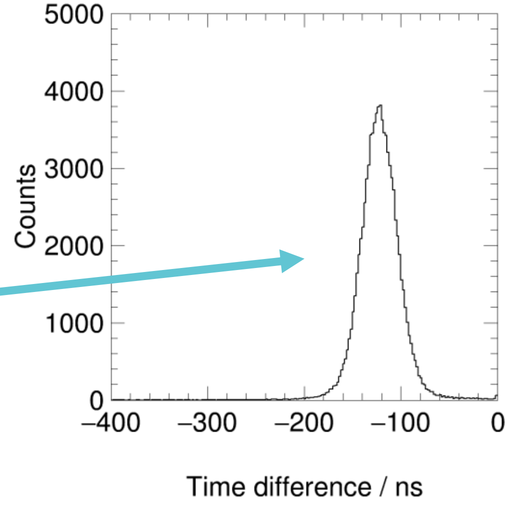




Position correlation between satellite and telescope



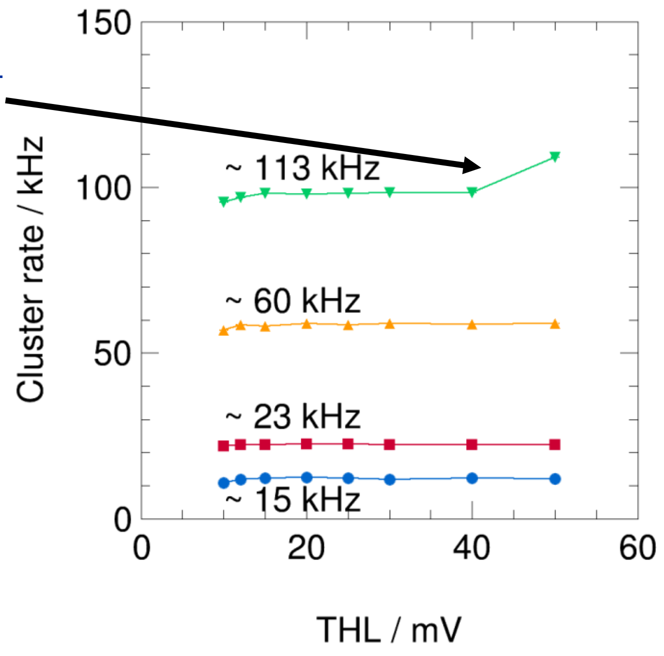
Courtesy of Karl Flöthner

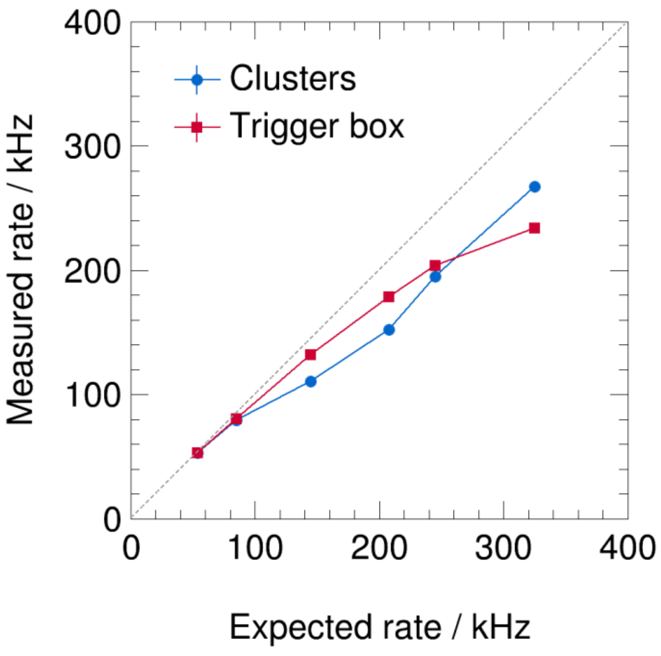


Upgrades to the telescope in 2023/2024:
Triggered readout mode

- RD51/DRD1 community requested the use of externally triggered readout mode
  - Bot for experiment and beam applications
- Two readout modes implemented by colleagues from FRIB @ MSU
  - Custom triggered mode on the SRS-FEC level
  - ATLAS L0 mode of the VMM3a
- Custom triggered mode, tested with X-rays in the GDD lab @ CERN

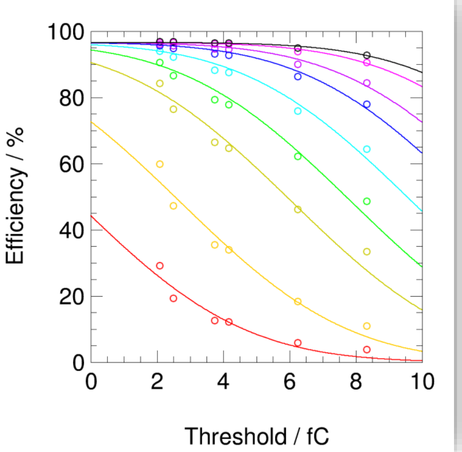
Occasionally, locked front-end channels observed. Was identified to be related to an firmware issue. Seems to be fixed.



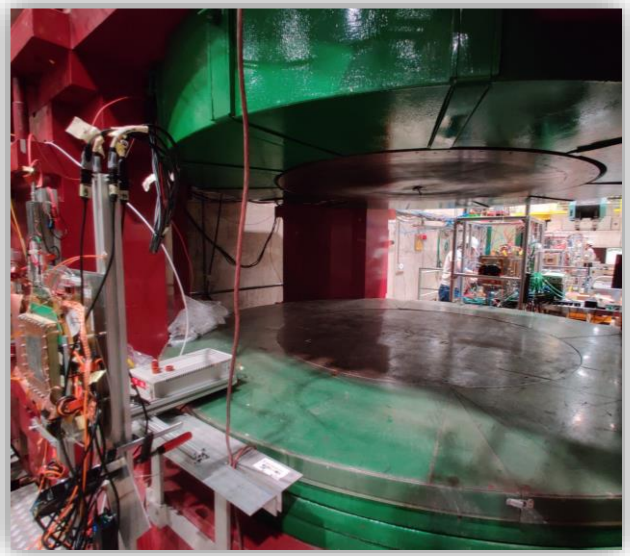


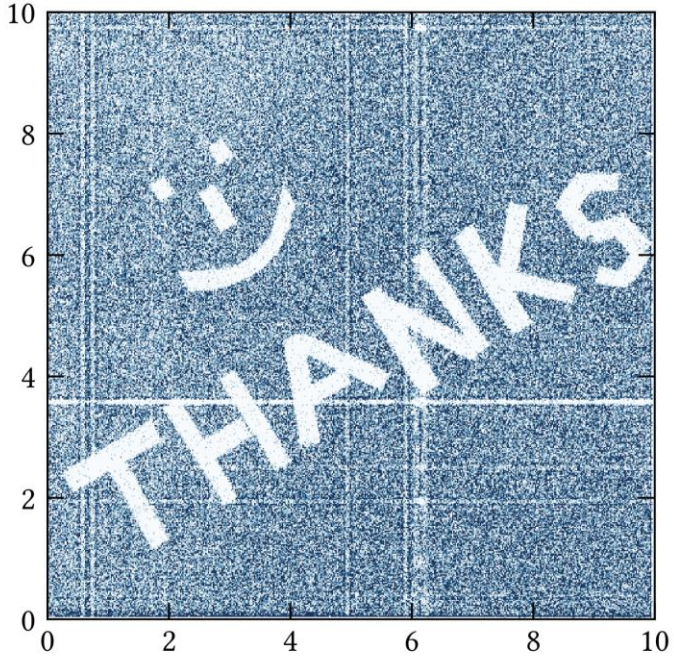
To be characterised in much more detail in this year's test beam campaigns

Summary



- Beam telescope commissioned in the last few years
- Less measurements for telescope characterisation and **more detector characterisation studies**
  - Studies of resistive plane detectors
  - Improvement of spatial resolution by finer-pitch GEMs
  - Detector characterisation for experiments, here AMBER
- **Upgrades to the telescope infrastructure based on community input**
  - Powering scheme and distributed readout system
  - Externally triggered readout mode





for your attention!

SPONSORED BY THE
Federal Ministry of Education and Research

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

The work has been supported by the CERN Strategic Programme on Technologies for Future Experiments. https://ep-rnd.web.cern.ch/

References

RD51 Scalable Readout System

[1] S. Martoiu et al., JINST **8** (2013) C03015. https://doi.org/10.1088/1748-0221/8/03/C03015

[2] M. Lupberger et al., NIM A **903** (2018) 91–98. https://doi.org/10.1016/j.nima.2018.06.046

[3] D. Pfeiffer et al., NIM A **1031** (2022) 166548. https://doi.org/10.1016/j.nima.2022.166548

Detectors

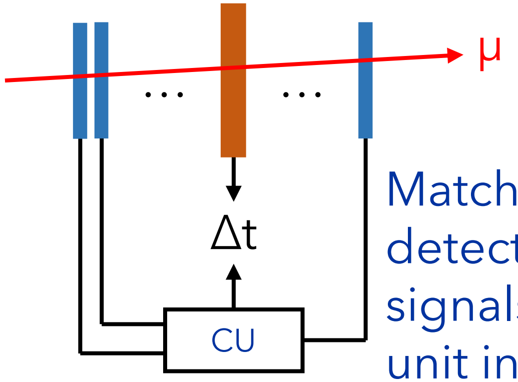
[4] C. Altunbas et al., NIM A **490** (2002) 177. https://doi.org/10.1016/S0168-9002(02)00910-5

VMM3a

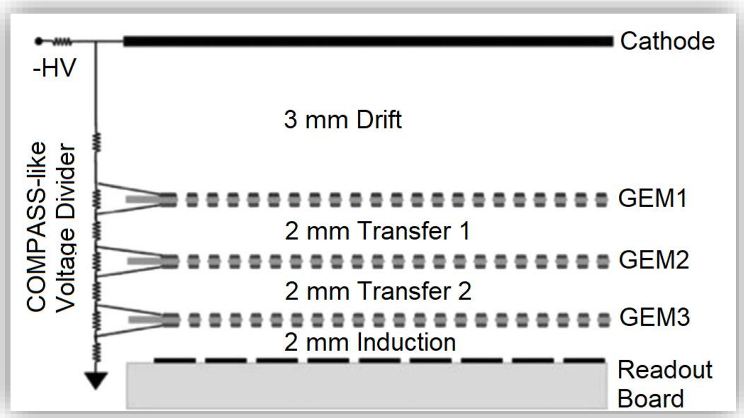
[5] G. de Geronimo, IEEE TNS **69** (2022) 976. https://doi.org/10.1109/TNS.2022.3155818

Back-up slides

Beam telescope's performance:
Detector-based studies

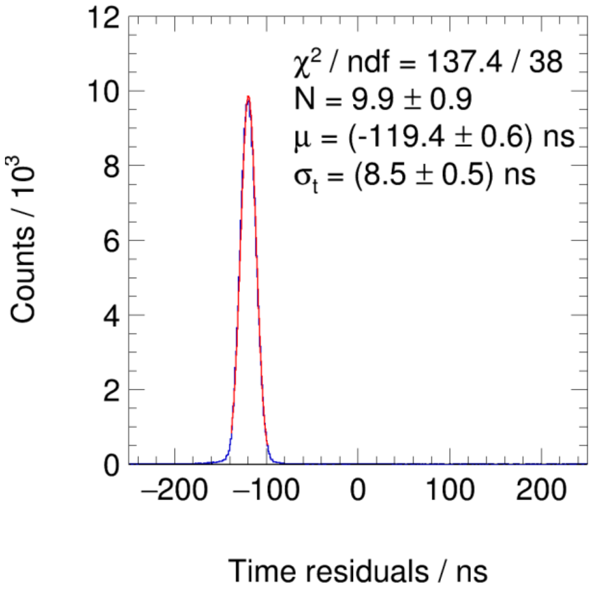


Event building based on signal arrival time, using *vmm-sdat* [a]

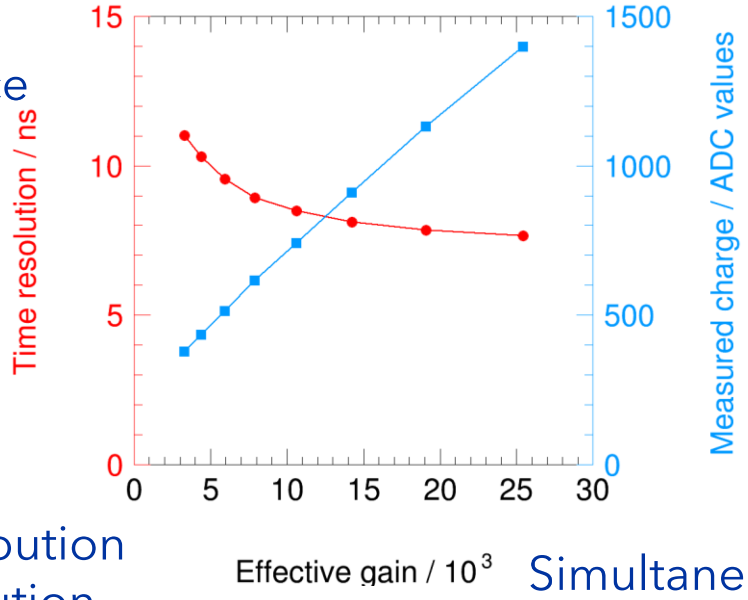


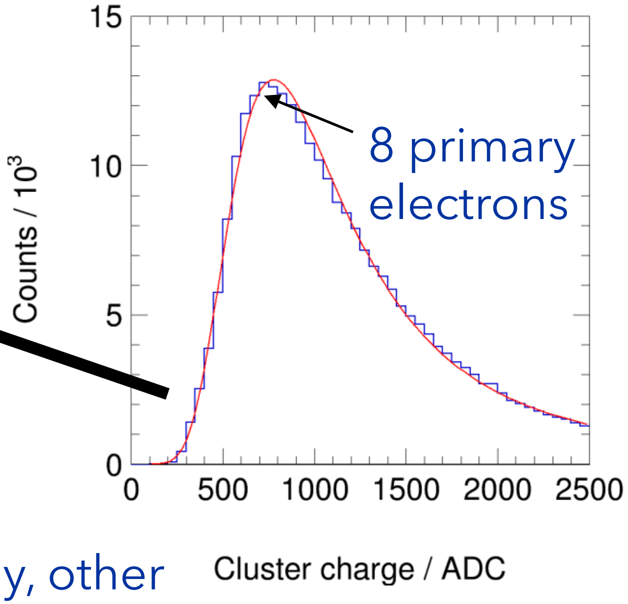
NIM A **805** (2016) 2-24

Match clusters from detector with NIM signals from coincidence unit in time



Width of time difference distribution gives time resolution



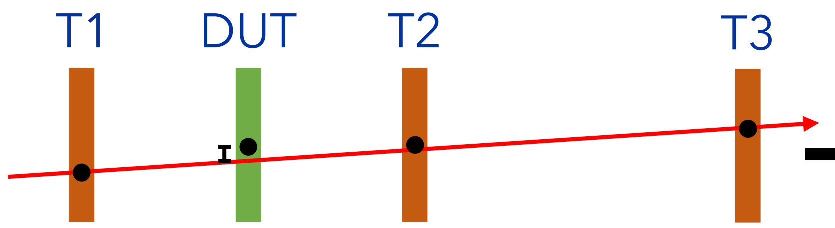


Simultaneously, other information from clusters with matching time provided

[a] vmm-sdat

Beam telescope's performance:
Track-based studies

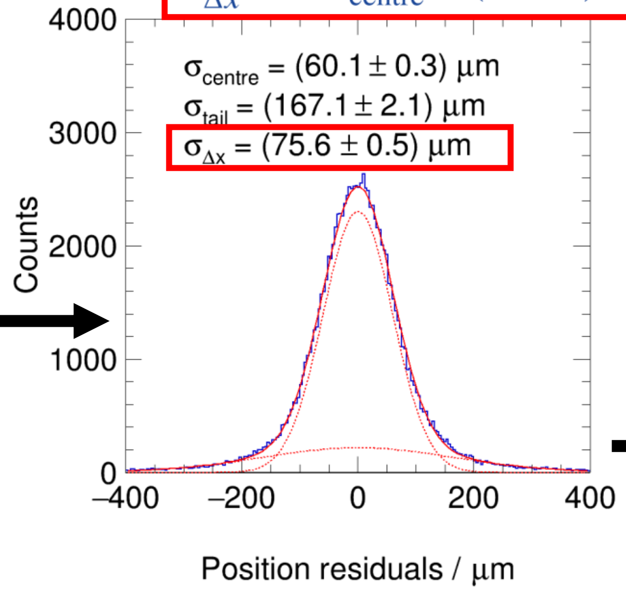
- Position determination: **Centre-of-gravity (COG)**
- Event-building based on cluster time
- Tracking with **Kalman filter** via *anamicom* [a]
- **Spatial resolution studies** as in [b]
- Tracking error as in [c]



$\sigma_{\text{pos}} = \sqrt{\sigma_{\text{in}}\sigma_{\text{ex}}}$ [d] $\sigma_{\text{pos}} = \sqrt{\sigma_{\text{ex}}^2 - \sigma_{\text{track}}^2}$

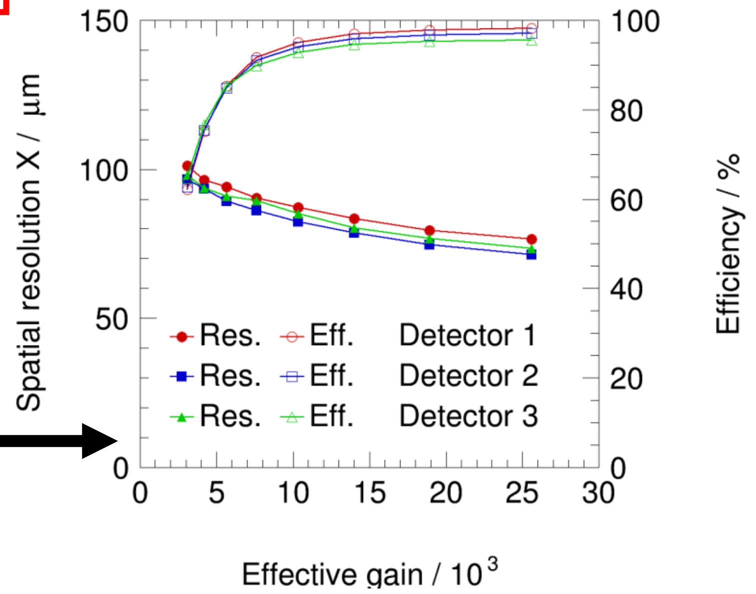
- Efficiency $\epsilon = \frac{N_{\text{matched}}}{N_{\text{total}}}$

$$\sigma_{\Delta x}^2 = w\sigma_{\text{centre}}^2 + (1-w)\sigma_{\text{tail}}^2$$



~10 kHz recorded interaction rate

Efficiency not @ 100% due to geometrical effects and non-working readout channels



[a] anamicom [b] J. Bortfeldt (PhD thesis)
[c] S. Horvat (PhD thesis) [d] NIM A **538** (2004) 372-383

Detector R&D:
Resistive plane MicroMegas

- Difference between top and bottom strips, caused by difference in signal induction
- Shape of the induced charge distribution differs between the layers