GRAAL

Gem Reconstruction And Analysis Library

A novel package to reconstruct data of triple-GEM detectors

by

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on behalf of the BESIII CGEM-IT group

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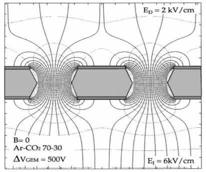
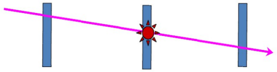
Outline



- The **triple-GEM** detectors and the setup configuration

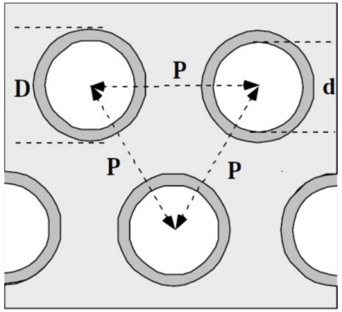
- Data reconstruction



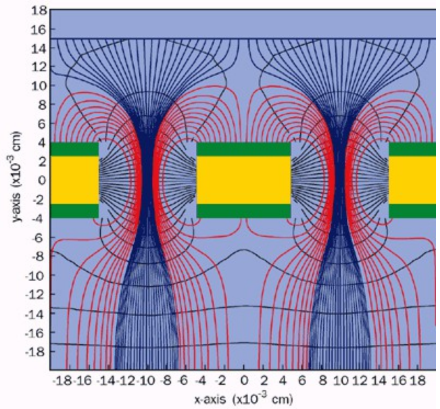
- Tracking and **alignment** algorithms

- **Analysis** procedures and results

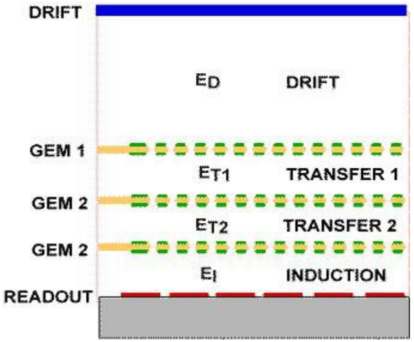
GEM - Gaseous Electron Multiplier



invented by F. Sauli in 1997*
- copper coated polymer foil
- pierced with thousands of **holes** Ø ~ 50 μm



HV is applied to its faces (200/400 V) and the drifting electrons which enter the holes find an intense field (some tens kV/cm) enough to create **avalanche multiplication**



By stacking more foils together high gain can be reached with lower HV
lower discharge rate
triple–GEM

* [F. Sauli, Nucl. Instr. and Meth. A 805, 2-24 (2016)]

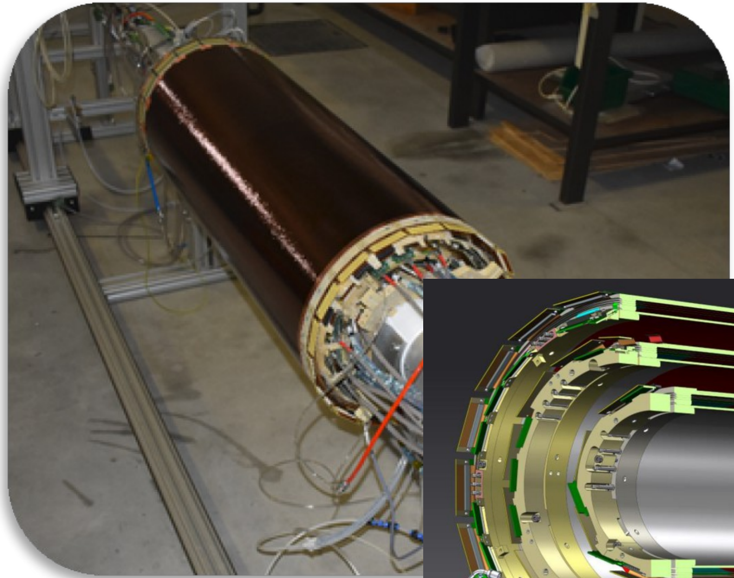
CGEM-IT - Cylindrical GEM Inner Tracker

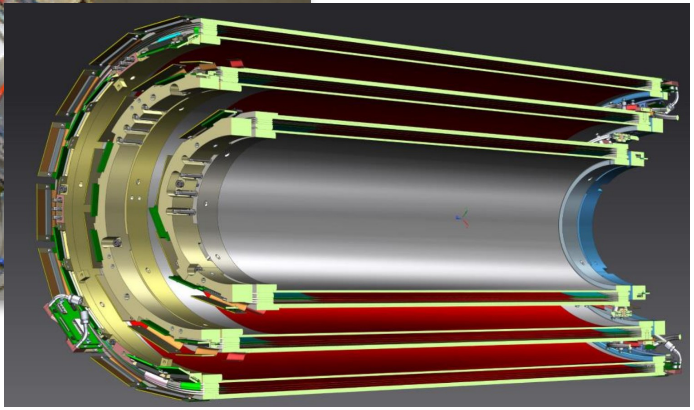
The first Cylindrical GEM was build by KLOE-2 (LNF) *

BESIII PECULIARITIES
- double view anode → 3D position
- analog readout → time and charge
- intense magnetic field: 1T

PERFORMANCES
- 130 μm on *xy* (orthogonal to the beam)
- < 1mm on *z* (parallel to the beam)

POSITION RECONSTRUCTION
1. charge centroid
2. micro–TPC
3. merging of 1 and 2

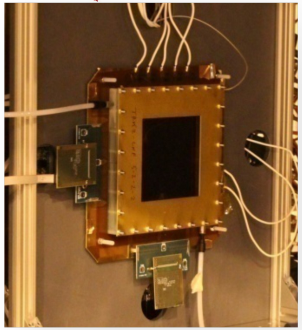


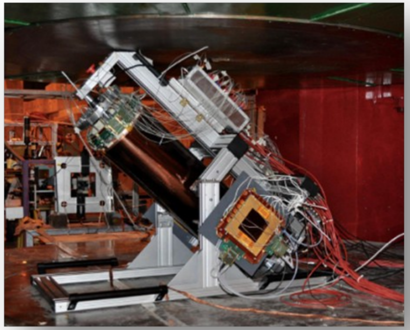


The new CGEM-IT developed will be installed in **BESIII** experiment hosted at BEPCII

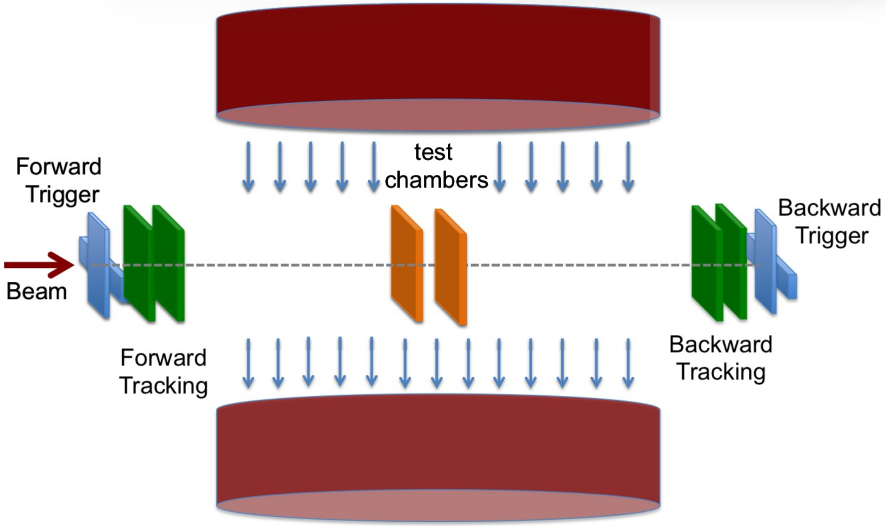
* [A. Balla et al., Nucl. Instr. and Meth. A 732, 221-224 (2013)]

Testbeam setup





Testbeams to set the GEM working point
- H4 beam line @ SPS, NA CERN
- GOLIATH dipole **B** in [-1.5, +1.5] T
- muons/pions @ 150 GeV/c

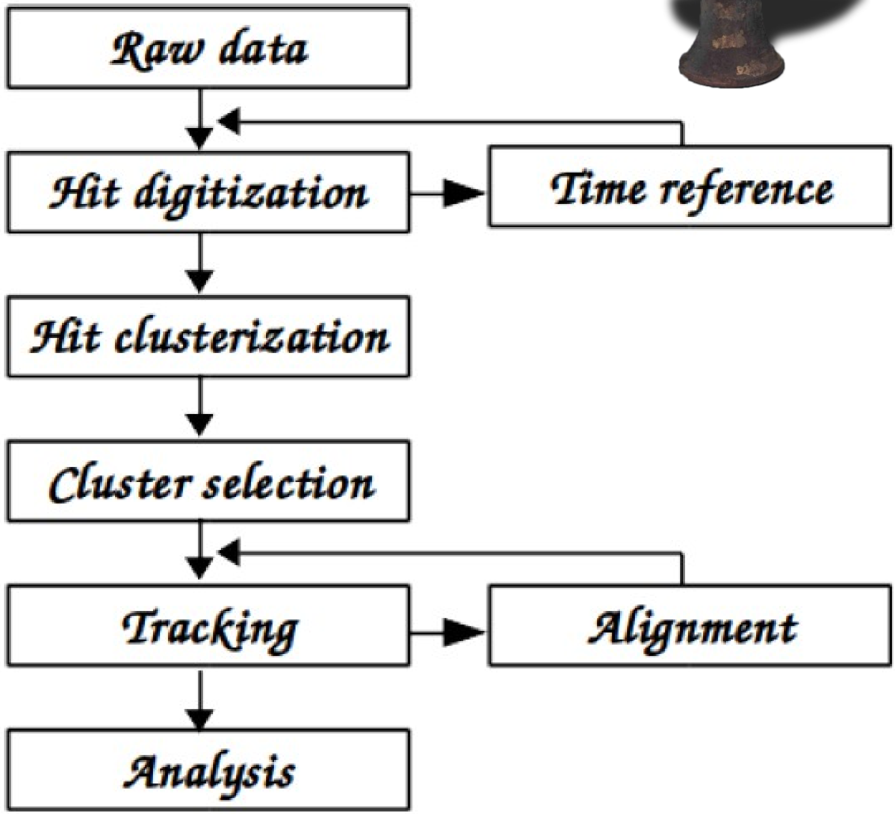


STANDARD SETUP
- Planar/Cylindrical chambers
- **Trigger**: plastic scintillators
- **Tracking stations**: triple–GEMs with double view readout
- **Test detectors**: planar/cylindrical triple–GEMs with different settings
- Electronics ASIC: APV-25, TIGER
- **More than 16 differents setups and several hundreds of runs** → large variability and diversification

Data reconstruction: GRAAL

RECONSTRUCTION PROCEDURE

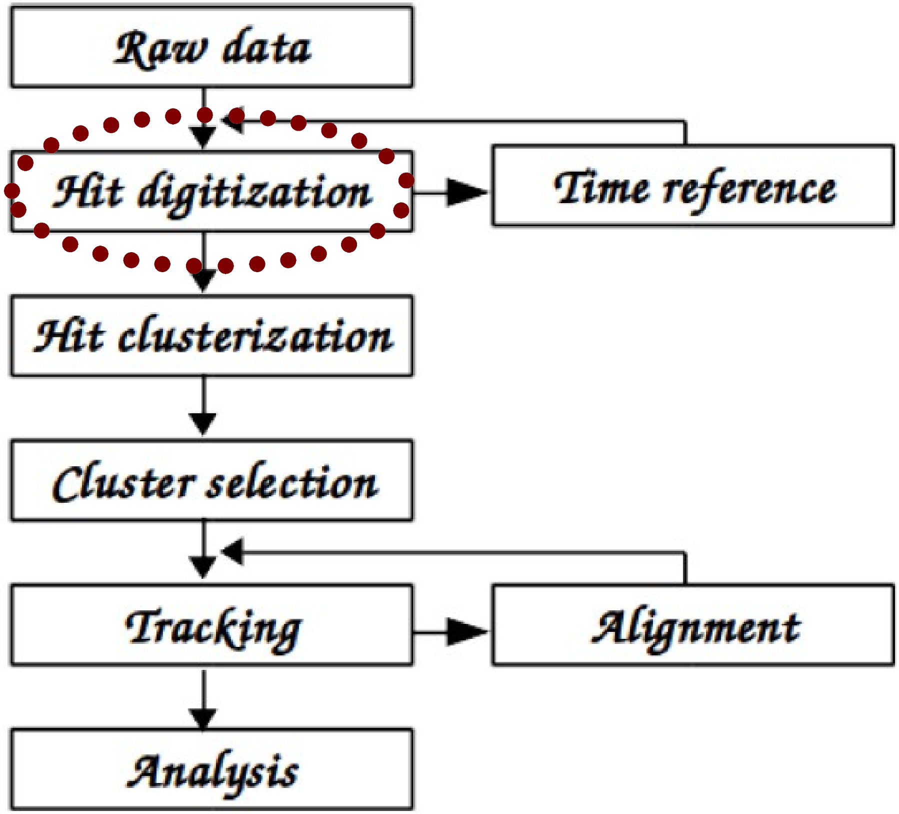
anode strip → **raw data** → *offline reconstruction*



GRAAL performs

1. Selection of **hits** with charge higher than a threshold
2. Reconstruction of each hit time
3. Association of contiguous hits: **cluster**
4. Track reconstruction (from the trackers)
5. Residual calculation (on test detectors)
6. Alignment procedure
7. Final evaluation of the efficiency and resolution

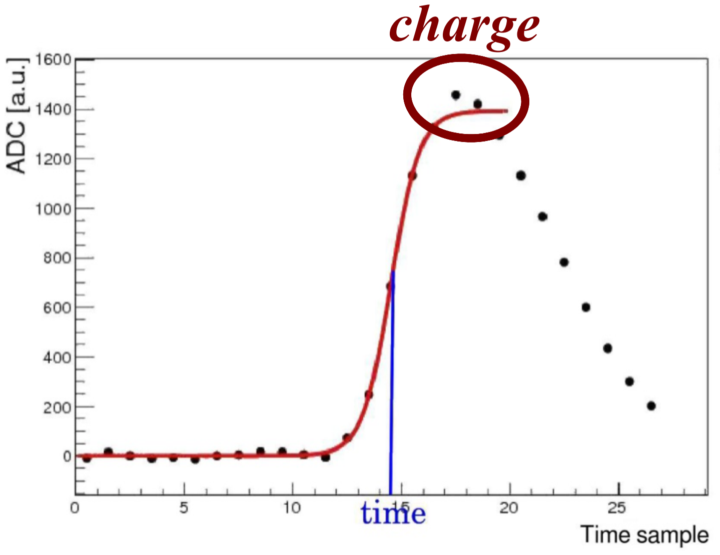
Data reconstruction: GRAAL



Hit digitization

two ASIC chips used:

1. **APV-25 ***
2. TIGER



- 128 channels
- 27 charge samplings (every 25 ns)
- a typical event lasts 4/5 time bins
- we obtain both **charge** and **time** for each strip
- the highest value of charge is the *hit* charge
- **time must be reconstructed**

fit the rising edge with a Fermi–Dirac function

$$Q(t) = Q_0 + \frac{Q_{\max}}{1 + \exp\left(-\frac{t - t_{FD}}{\sigma_{FD}}\right)}$$

to extract the hit time (t_{FD}) and error (σ_{FD})

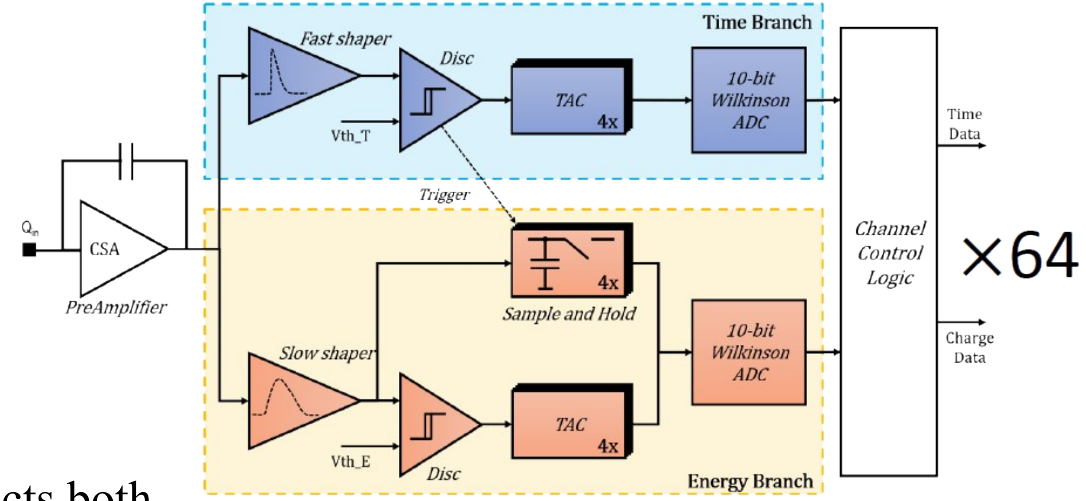
* [L. L. Jones *et al.*, Conf.Proc. C9909201,162-166 (1999); M. J. French *et al.*, Nucl. Instr. and Meth. A 466, 359-365 (2001)]

Hit digitization

two ASIC chips used:

1. APV-25
2. **TIGER** * – **T**orino **I**ntegrated **G**EM **E**lectronics for **R**eadout
   - Custom ASIC for the CGEM–IT

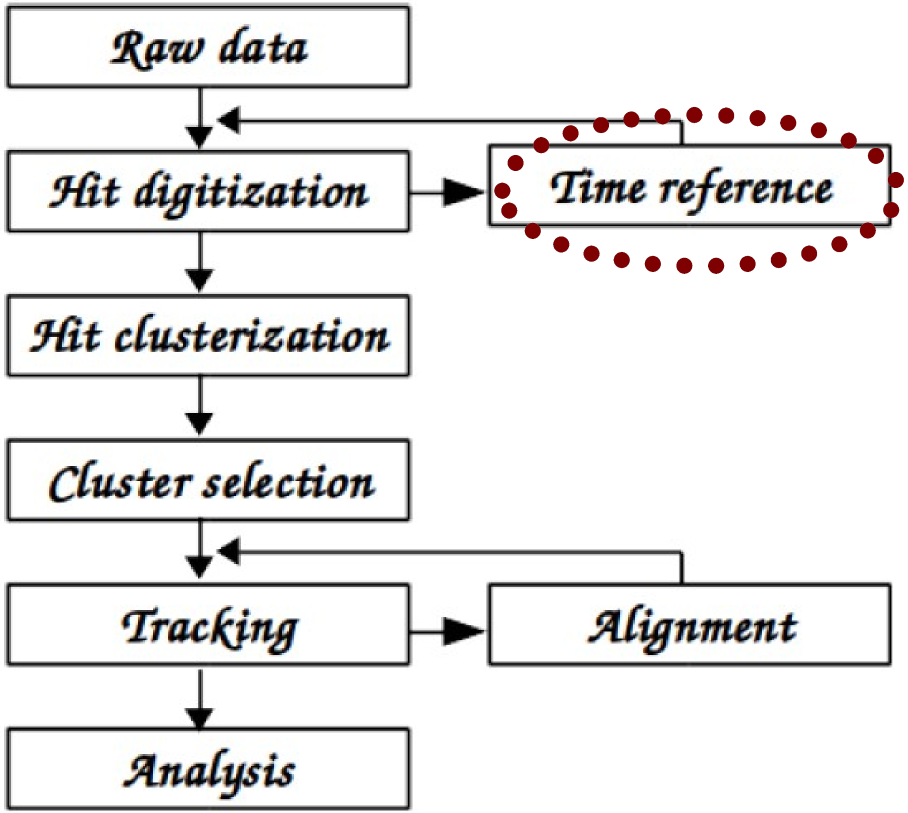
Font end architecture



- GRAAL reconstructs both
- In the following only APV-25 data will be presented

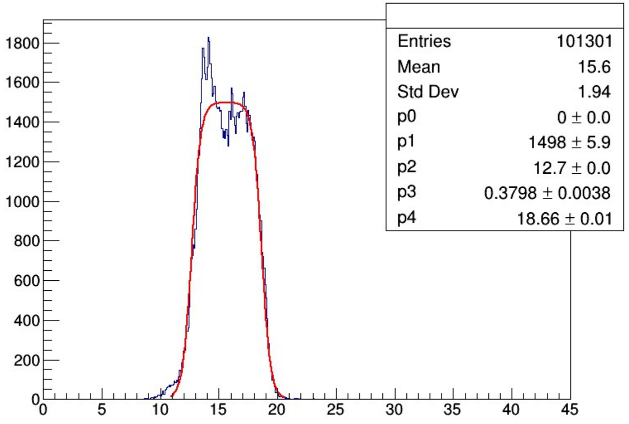
* C. Y. Leng *et al.*, IEEE NSS conference record (2016);
S. Marcello *et al.*, PoS EPS-HEP2017 505 (2017)

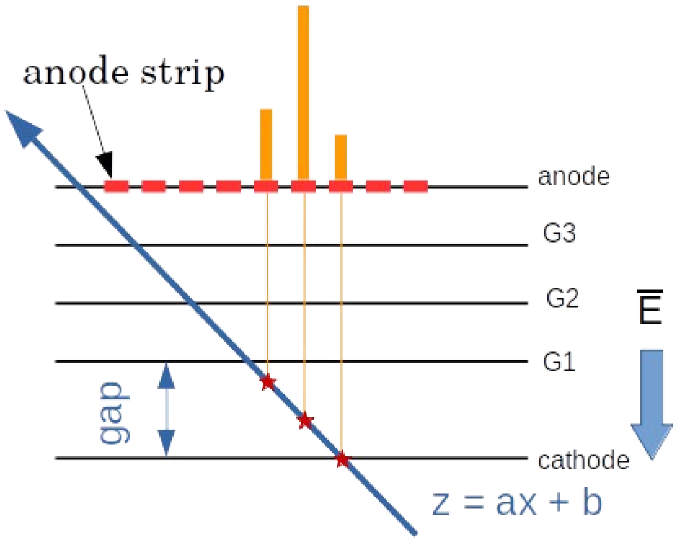
Data reconstruction: GRAAL



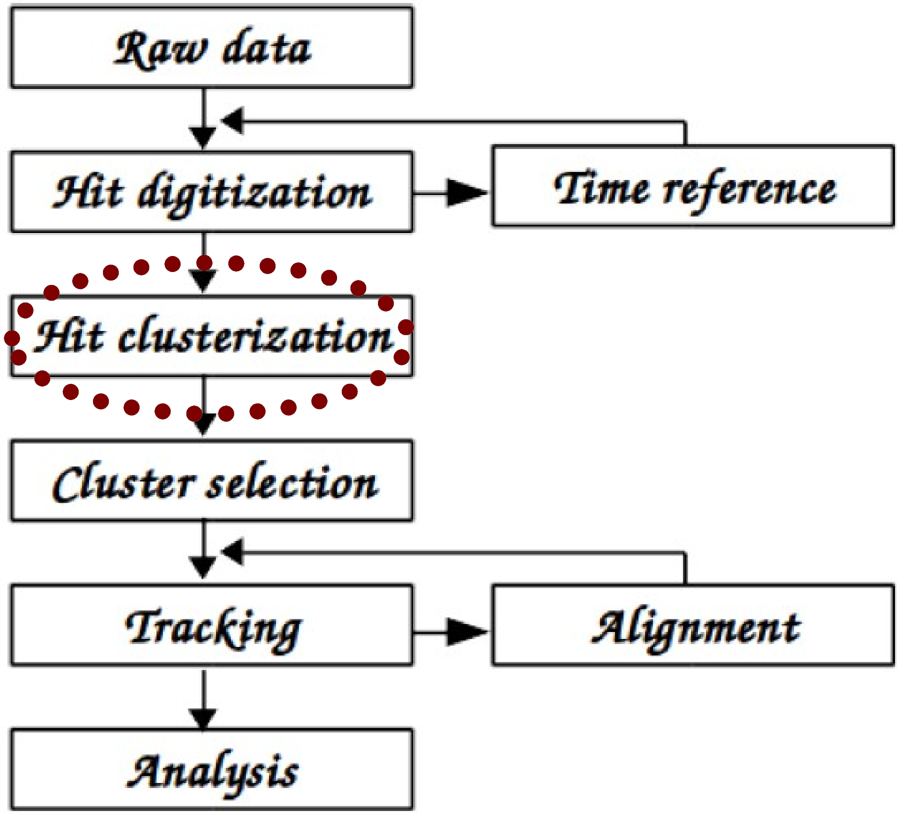
Hit digitization: Time reference

- The measured time is the one between the trigger and the induction of the charge to the anode
- Only the time between the primary electron formation and their drift up to the first GEM is needed to use the μTPC
- A **Fermi-Dirac fit** is used to measure the rising time. Another Fermi-Dirac fits the leading time. They describe the time distribution
- The rising time of the time distribution represents the mean time taken by an electron to go from the first GEM to the anode
- **The leading time is subtracted** from the measured time then the time-based reconstruction algorithm is used





Data reconstruction: GRAAL

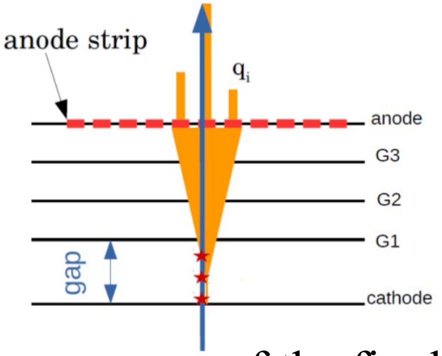


Cluster digitization

• contiguous strips with charge higher than the threshold

particle position reconstruction → two algorithms are used:

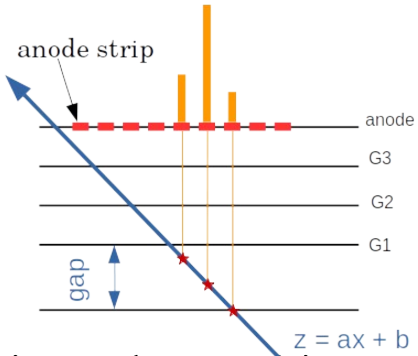
Charge Centroid



position reconstructed as average of the fired strips weighted by the charge on each strip

$$x_{\rm CC} = \frac{\sum_i^{N_{\rm hit}} Q_{{\rm hit},i}\, x_{{\rm hit},i}}{\sum_i^{N_{\rm hit}} Q_{{\rm hit},i}}$$

micro-TPC*

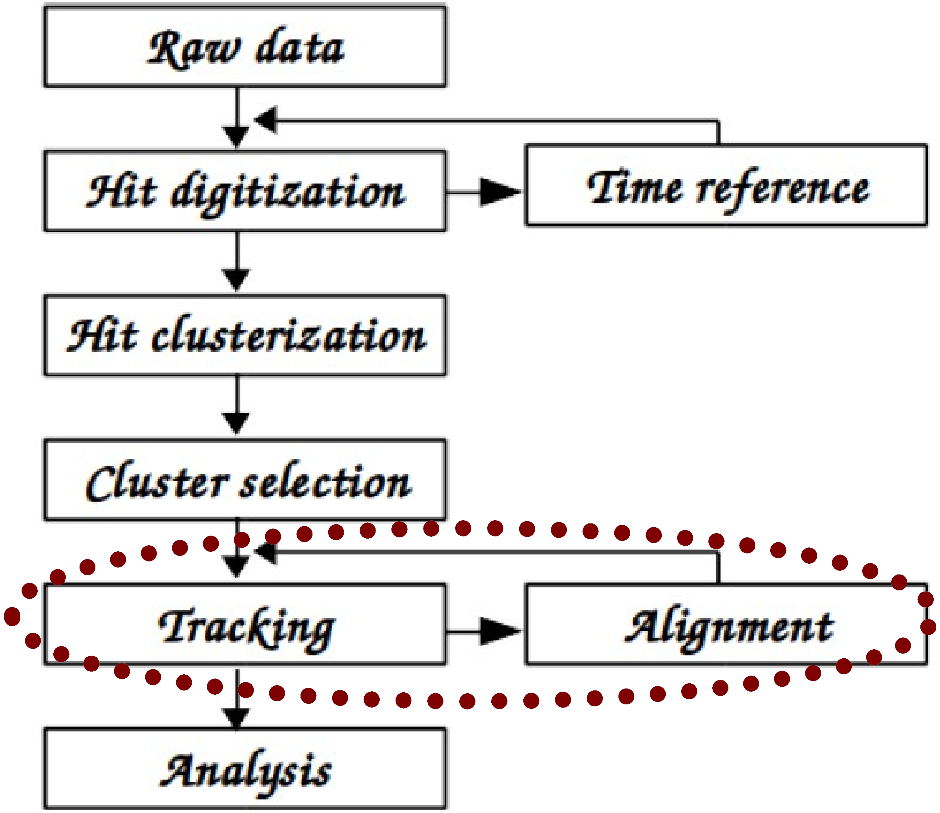


drift gap as a TPC gives the position of each ionization by the drift time and velocity → linear fit

$$x_{\mu\rm TPC} = \frac{gap/2 - b}{a}$$

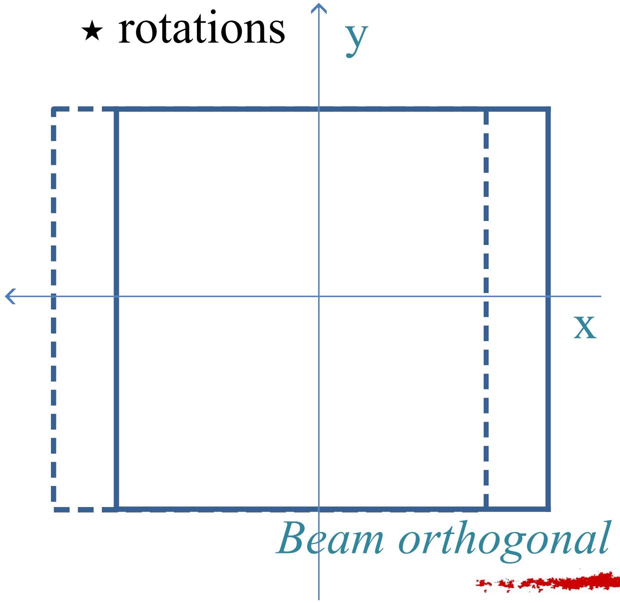
* T. Alexopoulos *et al.*, Nucl. Instr. And Meth. A617 (2010) 161;
M. Alexeev *et al* 2019 *JINST* **14** P08018

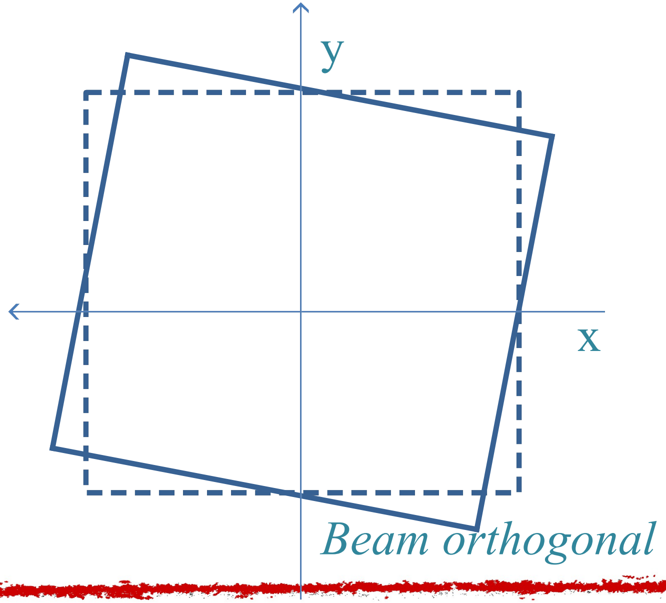
Data reconstruction: GRAAL

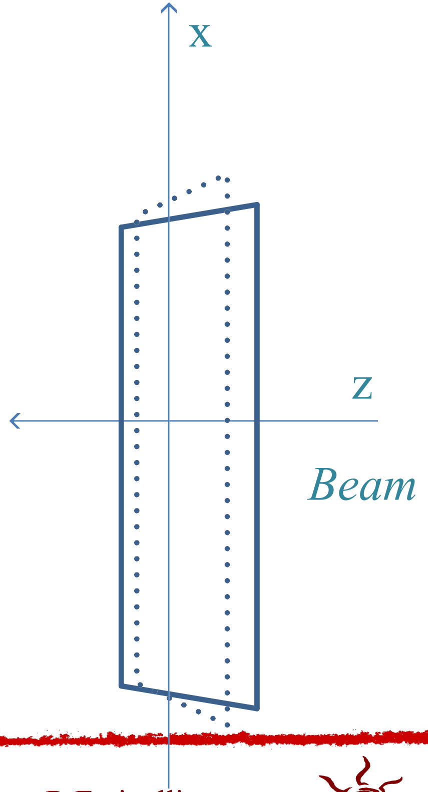


Tracking and alignment: planar chamber

- trackers are used to fit a track
- the point where the track passes on the test detector planes is used to compute the residuals as " $x_{EXPECTED} - x_{TEST}$ "
- used for alignment to account for:
  - ⋆ displacements
  - ⋆ tilts
  - ⋆ rotations







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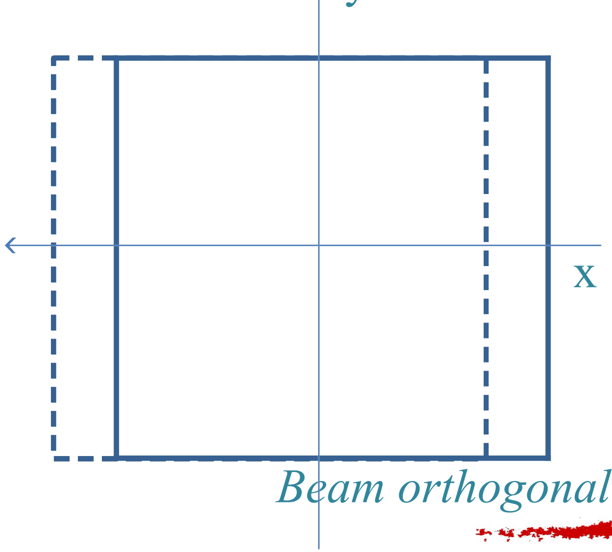

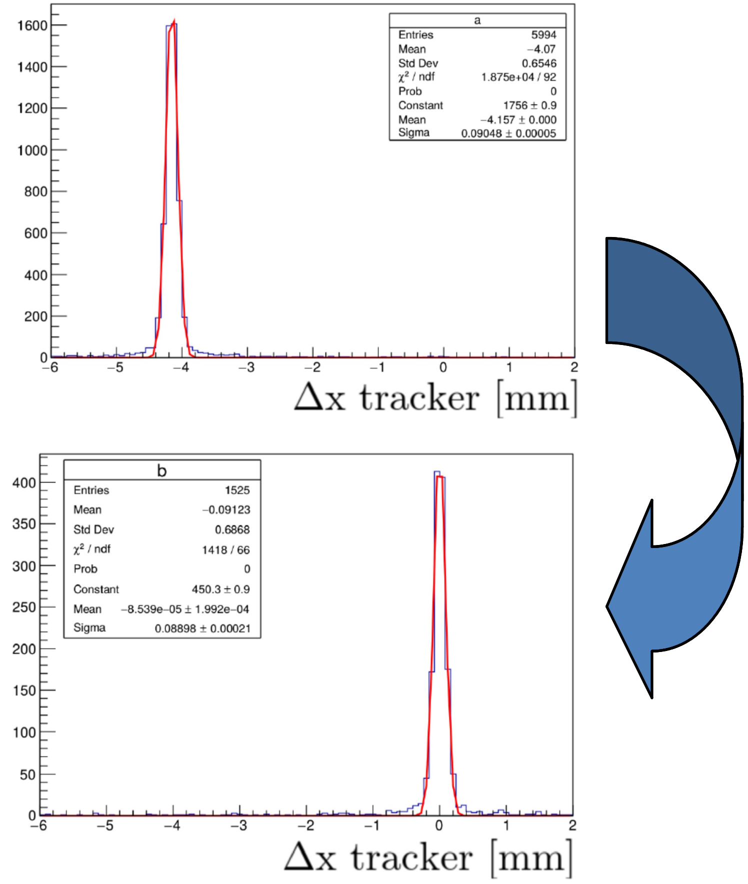

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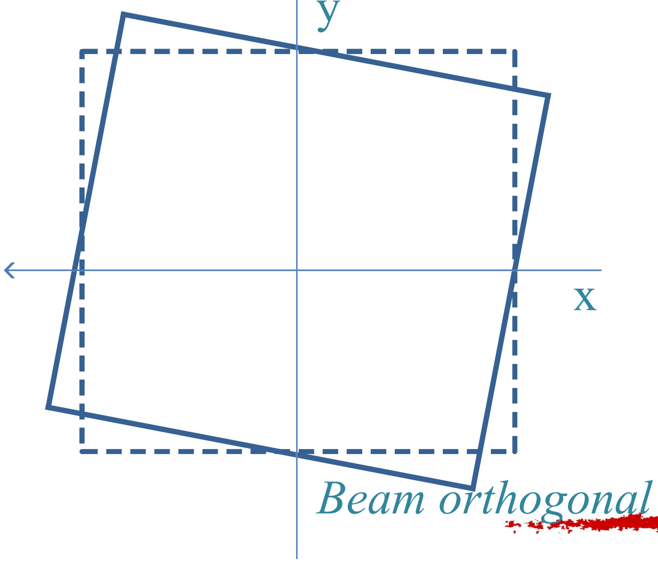
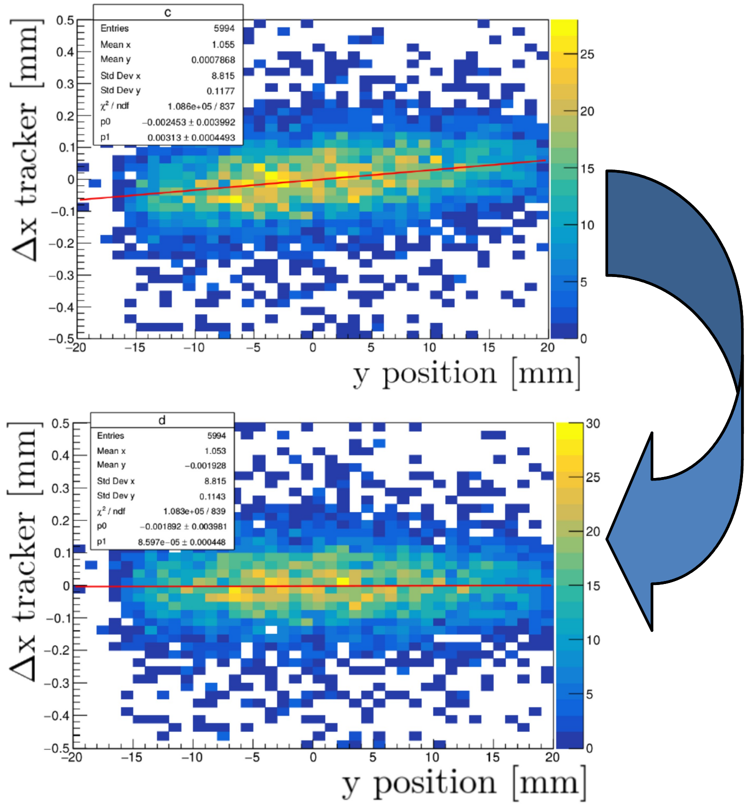
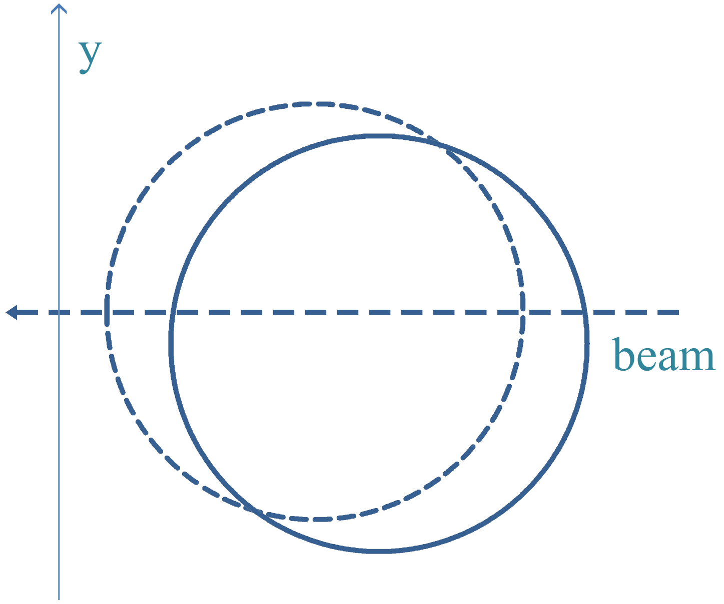




Tracking and alignment: cylindrical chamber

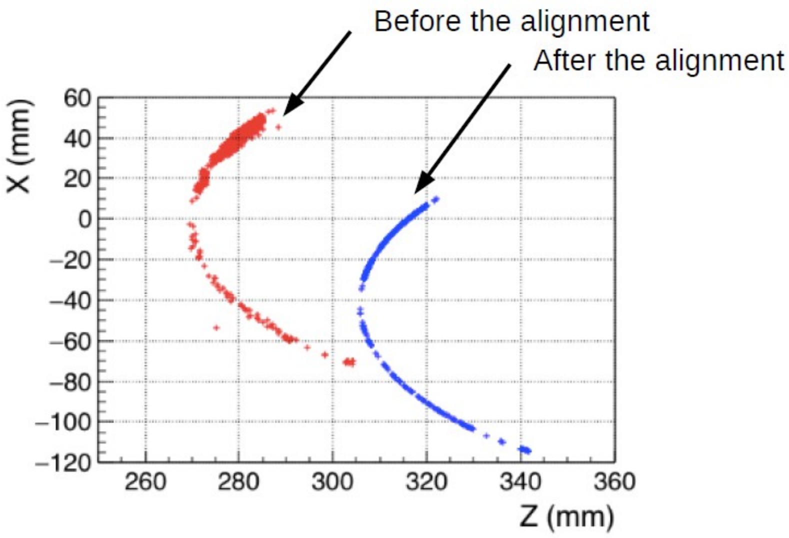


Analogous to planar chambers:

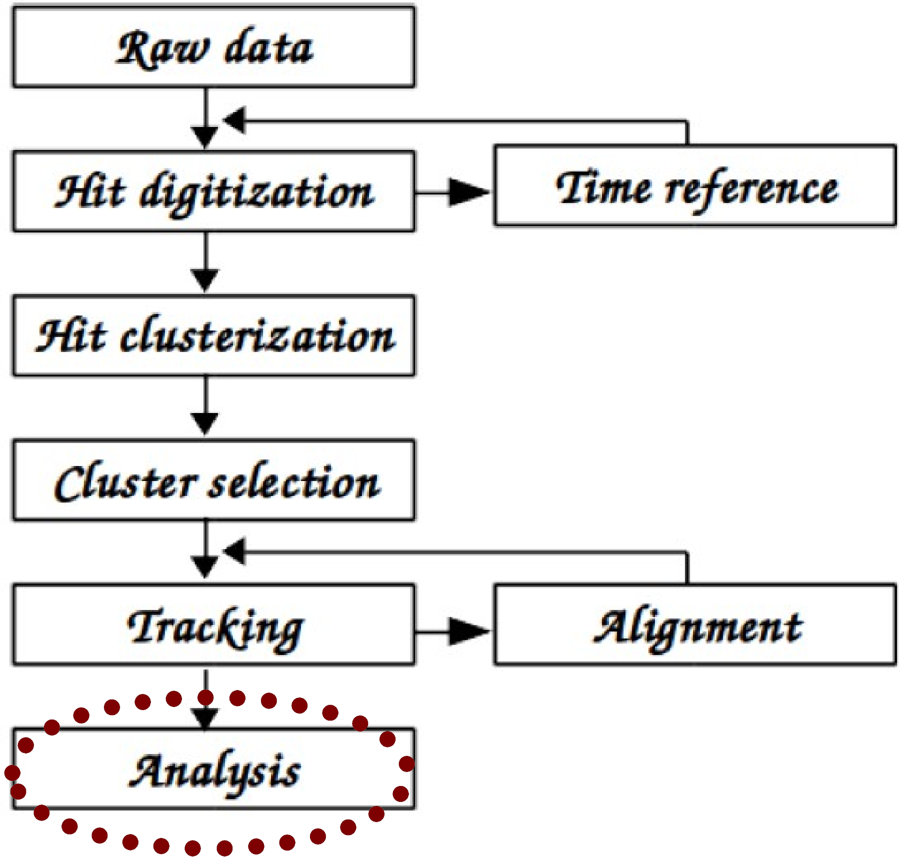
- compute residuals " $\phi_{EXPECTED} - \phi_{TEST}$ "

→ correct for:

- ⋆ shift of the center
- ⋆ rotations around cylinder axis



Data reconstruction: GRAAL



Analysis: efficiency

Residual of one chamber against the other: $\Delta x_{1,2} = x_{\text{detector},1} - x_{\text{detector},2}$

- to reduce systematics
- to eliminate the effect of tracking

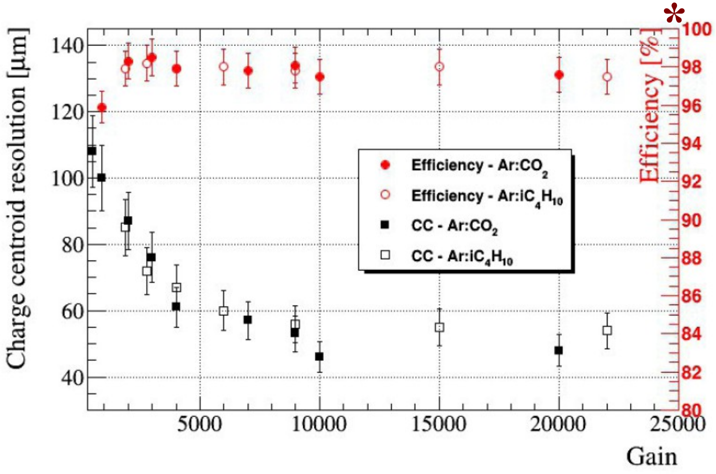
Assumption: both chambers have the same **efficiency**

$$\varepsilon_{1\&2} = \varepsilon_1 \varepsilon_2 = \frac{N_\varepsilon}{D_\varepsilon}, \text{ if } \varepsilon_1 = \varepsilon_2 = \varepsilon \rightarrow \varepsilon = \sqrt{\frac{N_\varepsilon}{D_\varepsilon}}$$

Dε = # events with succesful track reconstruction

Nε = # events with residual within 5 sigma

- Planar chambers
- Ar:i-C_4H_{10} 90:10
- B = 0T
- Incident angle = 0°
- E_{DRIFT} = 1.5 kV/cm
- Drift gap = 5 mm
- **different HV settings**



* M. Alexeev *et al* 2019 *JINST* **14** P08018, R. Farinelli, 2019 JINST TH 002)

Analysis: resolution

Residual of one chamber against the other: $\Delta x_{1,2} = x_{\text{detector},1} - x_{\text{detector},2}$

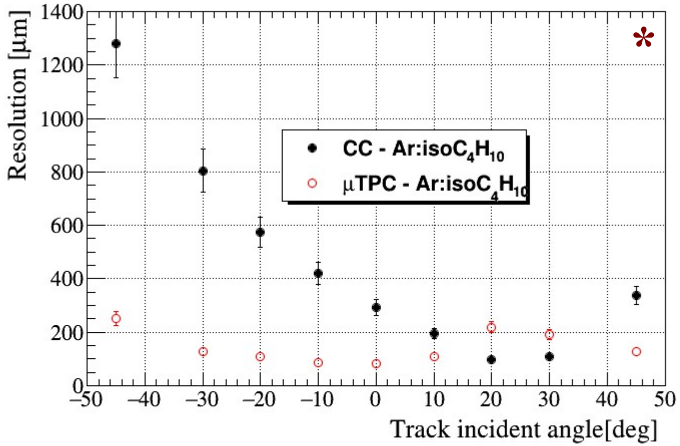
- to reduce systematics
- to eliminate the effect of tracking

Assumption: both chambers have the same **resolution**

$$\sigma^2_{\text{residual}} = \sigma^2_{\text{detector},1} + \sigma^2_{\text{detector},2}$$

$$\sigma_{\text{detector},1} = \sigma_{\text{detector},2} = \sigma_{\text{detector}} \rightarrow \sigma_{\text{detector}} = \frac{\sigma_{\text{residual}}}{\sqrt{2}}$$

- Planar chambers
- Ar:*i*-C_4H_{10} 90:10
- B = 1T
- **different angles**
- E_{DRIFT} = 1.5 kV/cm
- Drift gap = 5 mm
- 10k gain



Analysis: merge CC w/ μTPC

CC and μ–TPC opportunely weighted provide an optimum solution

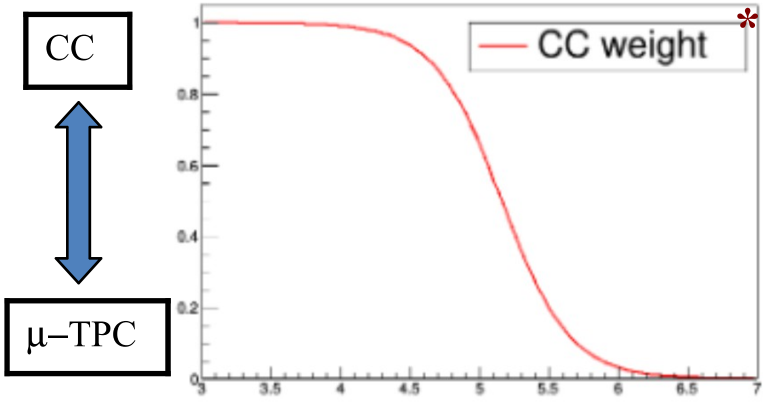
$$x_{\mathrm{merge}} = w_{\mathrm{cc}}\left(x_{\mathrm{cc}} - \Delta_{\mathrm{cc}}\right) + \left(1 - w_{\mathrm{cc}}\right) x_{\mathrm{tpc}}$$

- Choice of $\boldsymbol{w_{CC}}$ and $\boldsymbol{w_{tpc}}$ is **data driven, with no bias**

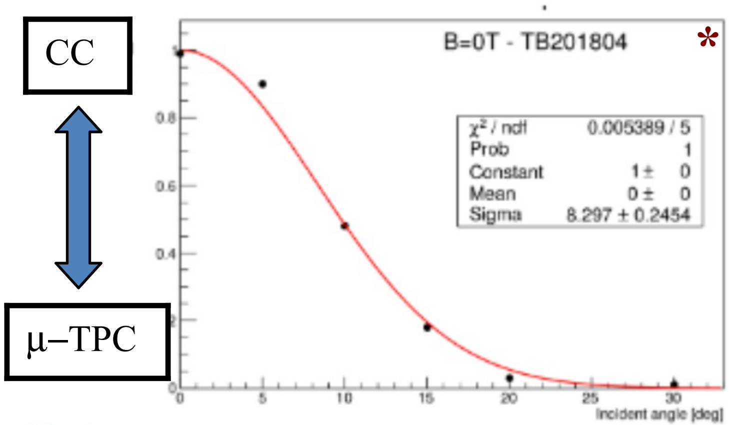
→ selection of data different from the sample on which it is applied

- Two procedures, weighting according to cluster size or incident angle

CL. SIZE WEIGHTING



INC. ANGLE WEIGHTING



* [M. Alexeev *et al* 2019 *JINST* **14** P08018, R. Farinelli, 2019 JINST TH 002)]

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- Planar chambers
- Ar:i-C_4H_{10} 90:10
- B = 1T
- **different angles**
- E_{DRIFT} = 1.5 kV/cm
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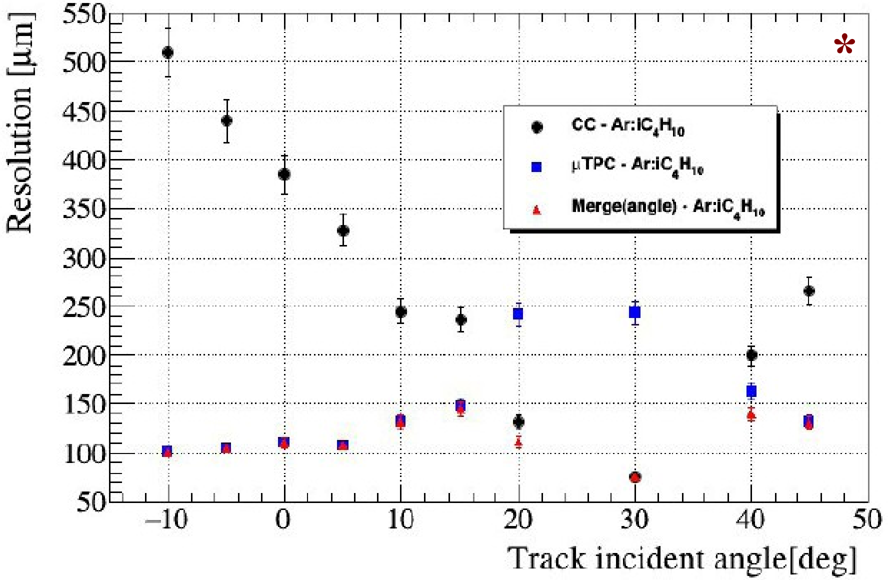
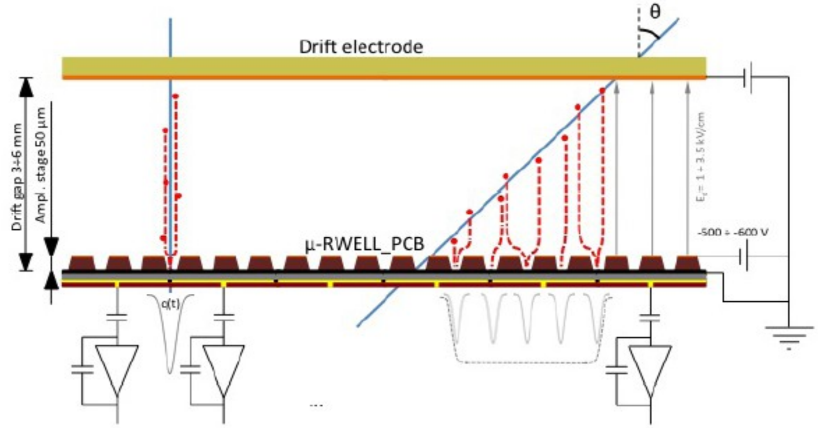
- 10k gain

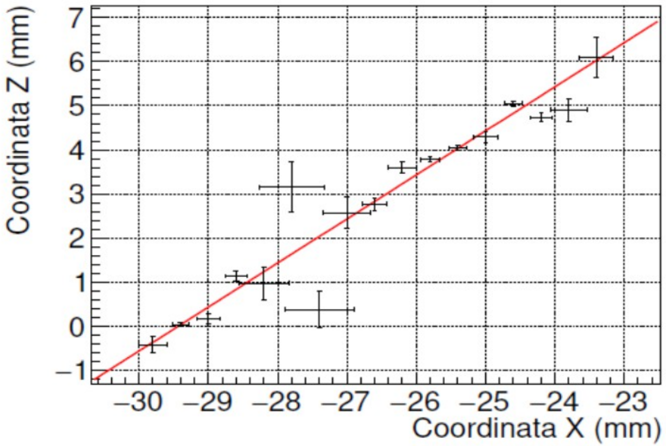


Conclusion

• GRAAL is a tool that can be applied not only to GEM, planar and cylindrical, but also to other MPGDs with segmented anode
• Currently also it is used for μ–RWELL reconstruction *



μ–RWELL scheme



μ–TPC reconstructed track in a μ–RWELL
drift gap = 6mm, incident angle 45°

* [M. Giovannetti, Master Thesis, Univ. La Sapienza, Roma (2019)]

Conclusion

• GRAAL is a tool that can be applied not only to GEM, planar and cylindrical, but also to other MPGDs with segmented anode
• Currently also it is used for μ–RWELL reconstruction

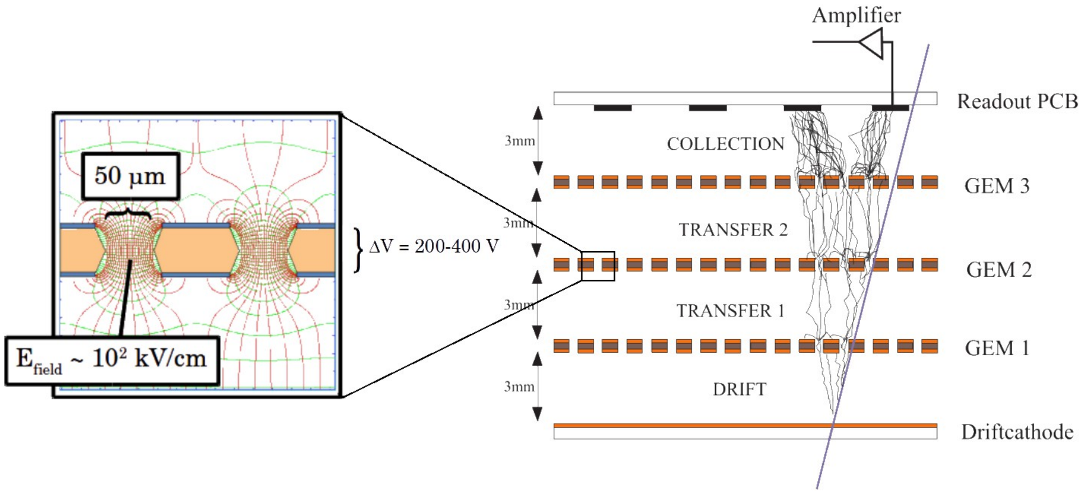
• The software returns a complete analysis of the detector performance for each different configuration tested and taking into account:
→ shift and spatial changes of the tested setup
→ different behaviour of the gas mixtures used and the electrical field involved
→ presence of magnetic field

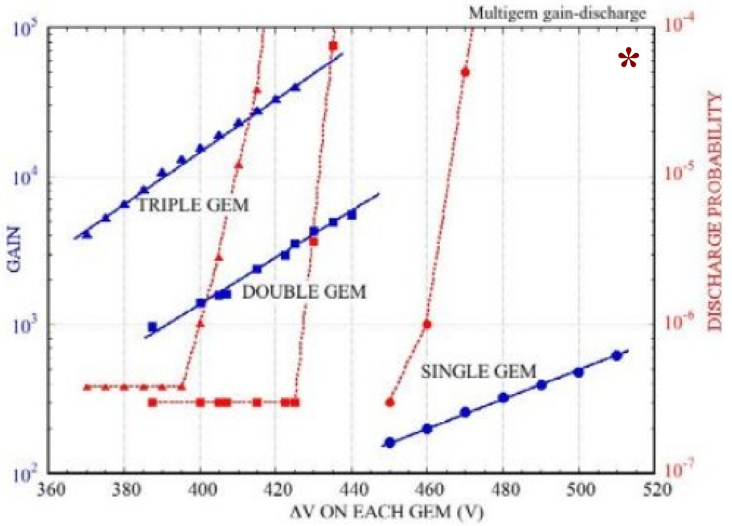
• The contribution of the systematic errors have been minimized.
• The results achieved have been confirmed in several testbeams and they have shown a good stability of the analysis processes

Thanks

Backup

Triple-GEM in a nutshell

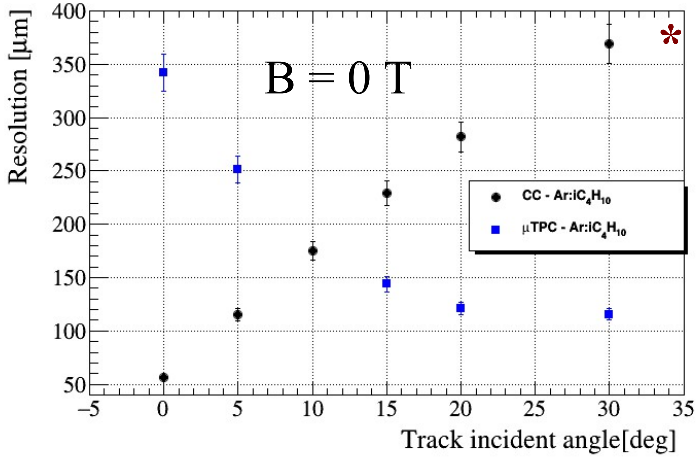


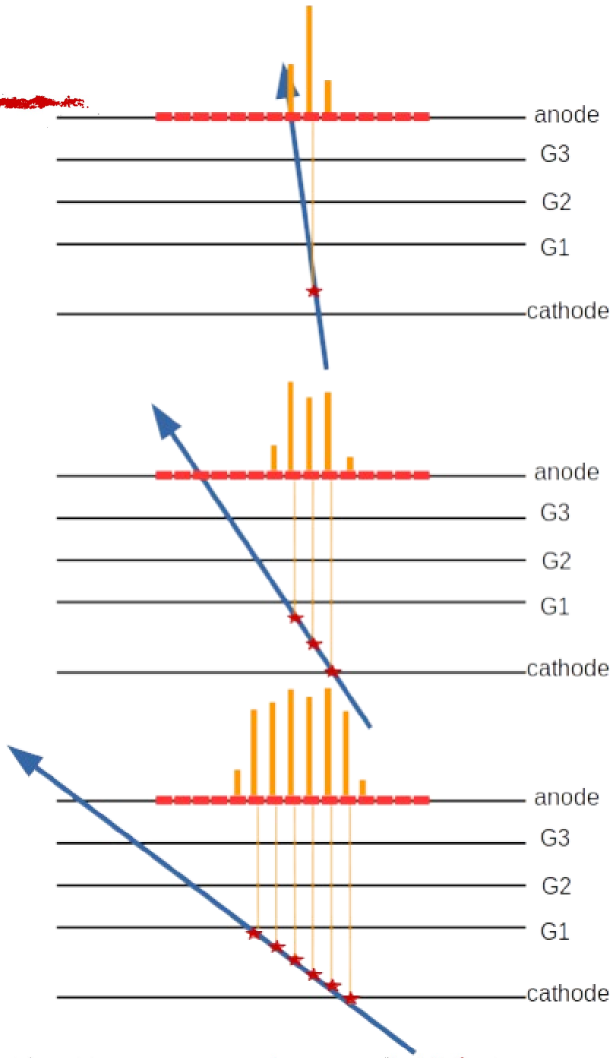


- A proper **gas mixture** fills the volume
- Three amplification stages allow the triple-GEM to reach a **gain** of 10^3 - 10^4 while the **discharge probability** is below 10^{-5}
- Primary electrons from ionizing particles generate signals that are collected on the anode

* Nucl. Instr. Meth. A438, 376-408 (1999)

CC and μTPC w/ sloped tracks

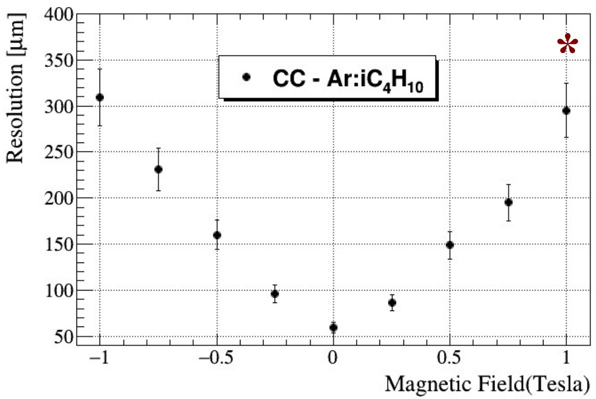


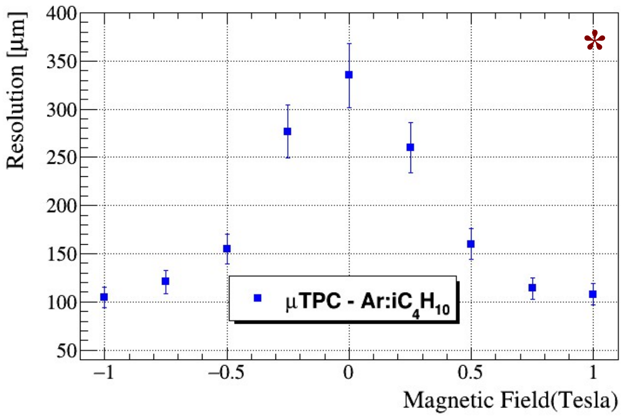


- As the incident angle departs from the orthogonal direction:
  - the **cluster size increases** improving the μTPC performance
  - the **charge** distribution becomes **no more Gaussian** and it degrades the CC resolution

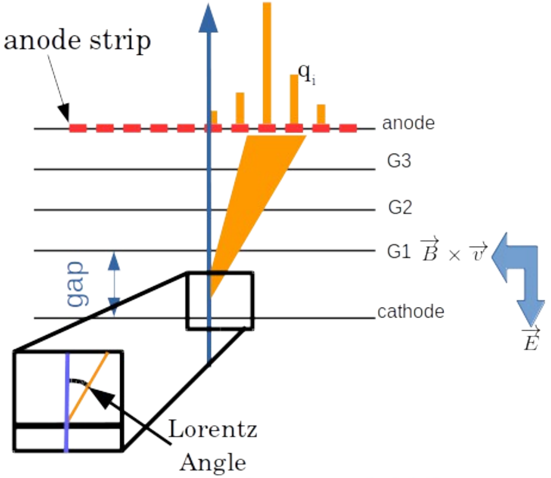
* [R. Farinelli, 2019 JINST TH 002)]

CC and μTPC w/ magnetic field





- The magnetic field affects the electronic avalanche:
  - the Lorentz force drifts the electrons
  - the magnetic field **enlarges the charge distribution** and the multiplicity largely increases
  - similarly to the previous case, μTPC improves as the **Lorentz angle** increases and the CC gets worse



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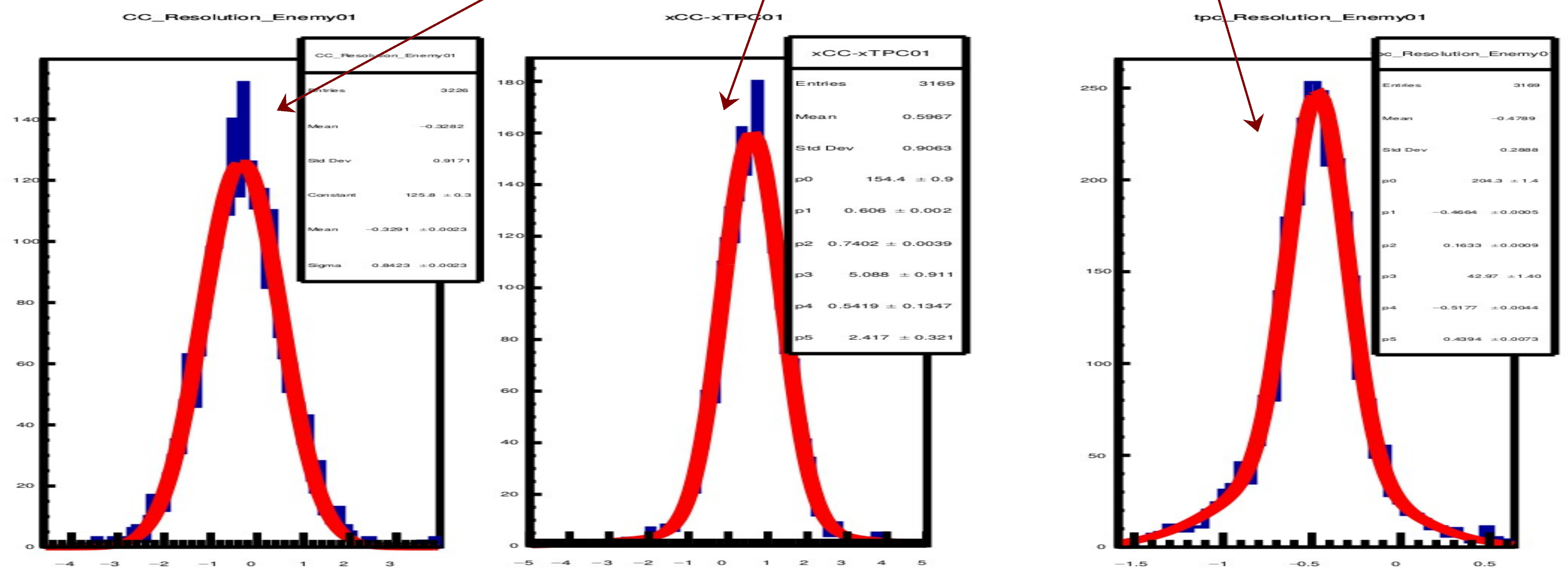
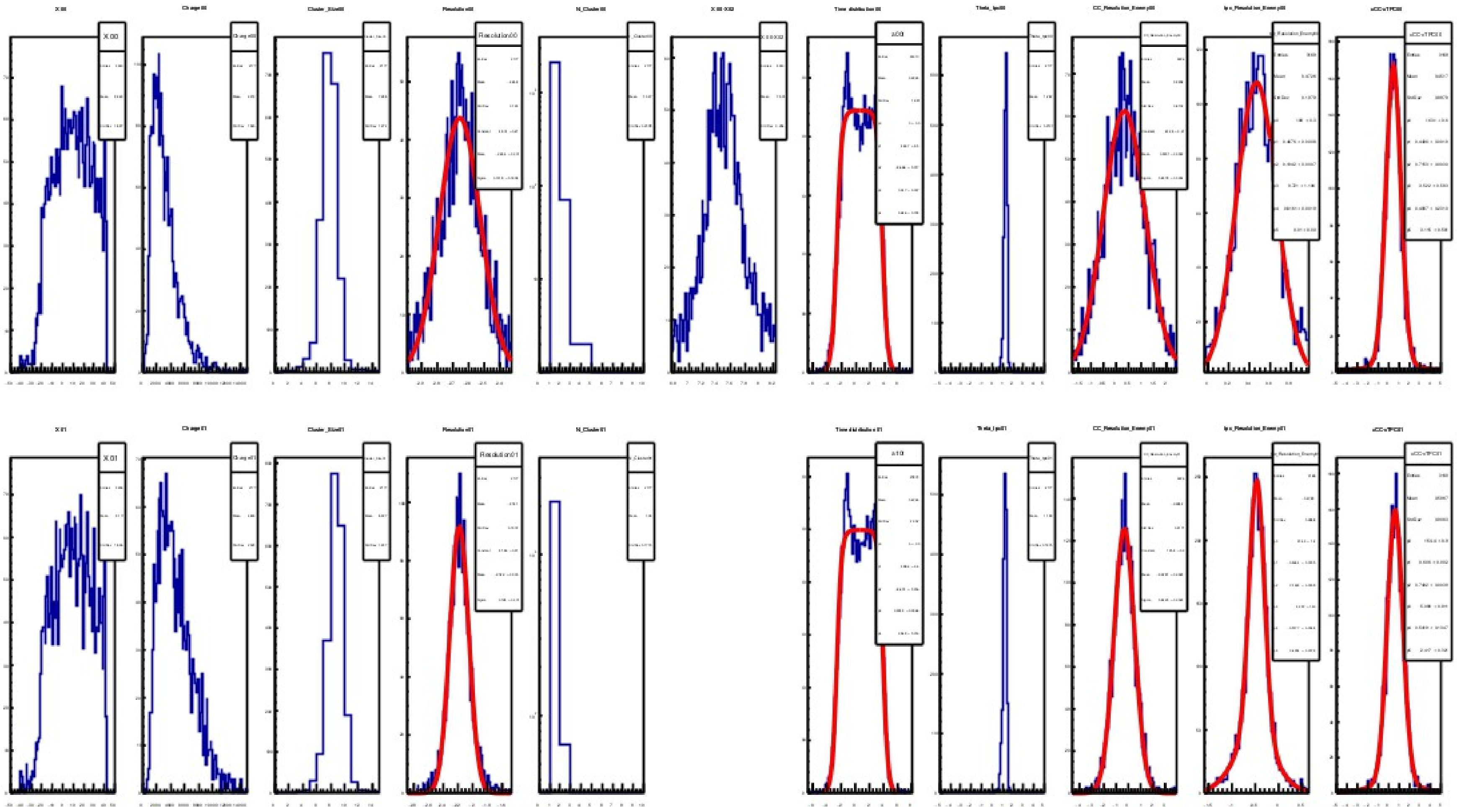
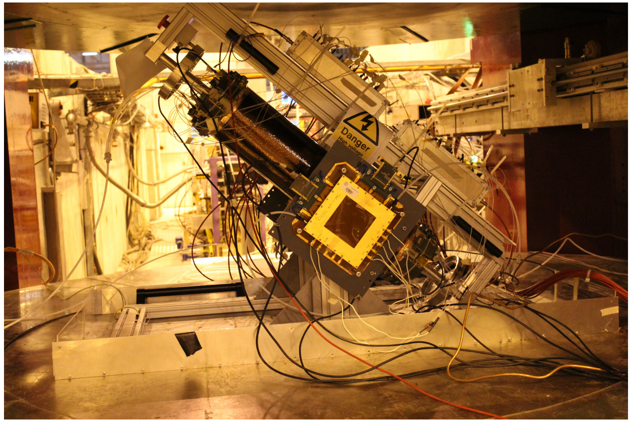


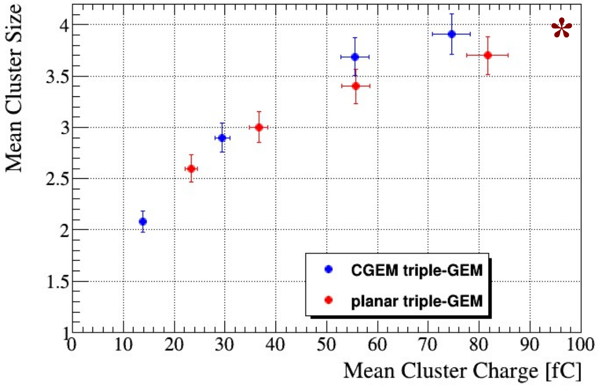
Example of GRAAL output

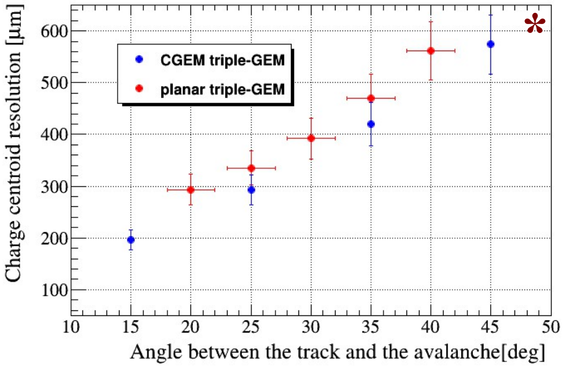


Comparison planar and cylindrical GEM

- Test beams performed at CERN with muons and pions beam in magnetic field
- Two test beams have been performed with:
  - CGEM – **Layer 1**
  - CGEM – **Layer 2**-like
- **Signal shape and CC performance agree** between planar GEM and CGEM



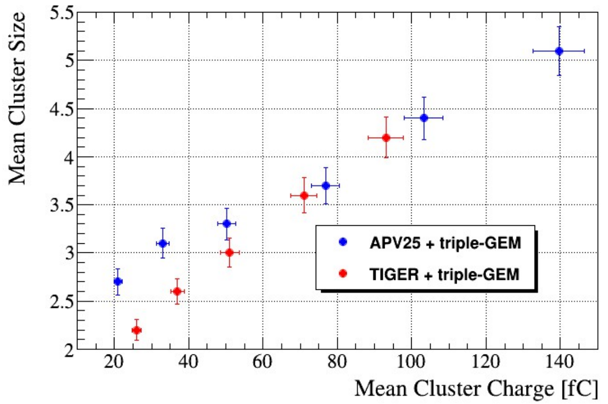


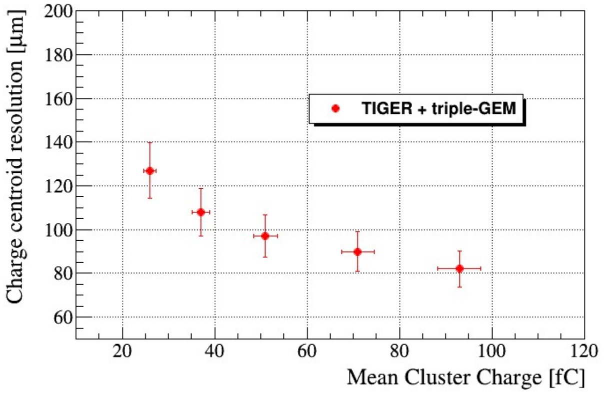


* [R. Farinelli, 2019 JINST TH 002)]

Comparison APV25 and TIGER asic

- **TIGER**: Torino Integrated Gem Electronics for Readout is a chip that provides **time and charge measurement** and features a fully digital output
- The chip is **designed for the CGEM-IT** of BESIII, it is optimized to match the strip capacitance and the GEM signal
- The TIGER has two branches to measure the charge:
  - **QDC** is more precise but it shows saturation effect
  - **TOT** does not suffer saturation but its values range is smaller
- The chip is chilled to keep stable the temperature, then the threshold
- The **results show a good agreement** between the data collected with APV25 chip and TIGER chip





* [R. Farinelli, 2019 JINST TH 002)]