GRAAL

Gem Reconstruction And Analysis Library

by

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on behalf of the BESIII CGEM-IT group

BESIII

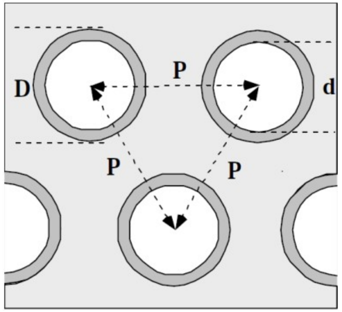
INFN

Istituto Nazionale di Fisica Nucleare

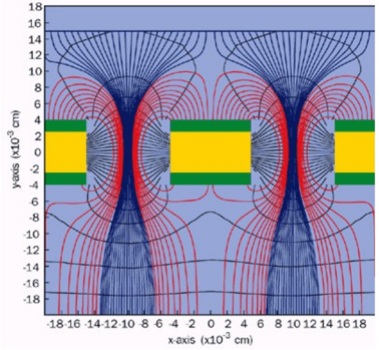
Outline

- The triple-GEM detectors and the setup configuration
- Data reconstruction
- Tracking and alignment algorithms
- Analysis procedures and results

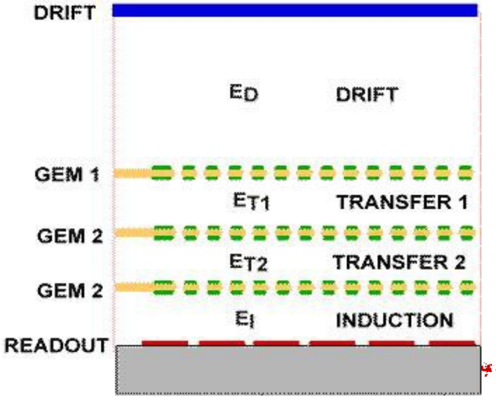
GEM - Gas Electron Multiplier



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)
→ the drifting electrons which enter the holes find a field intense (some tenth 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

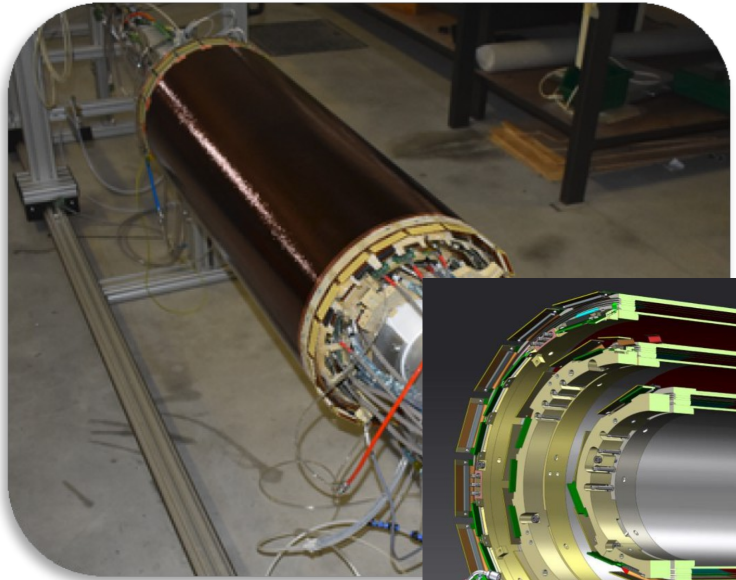
- double view anode → 3D position
- analog readout → time and charge
- intense magnetic field: 1T

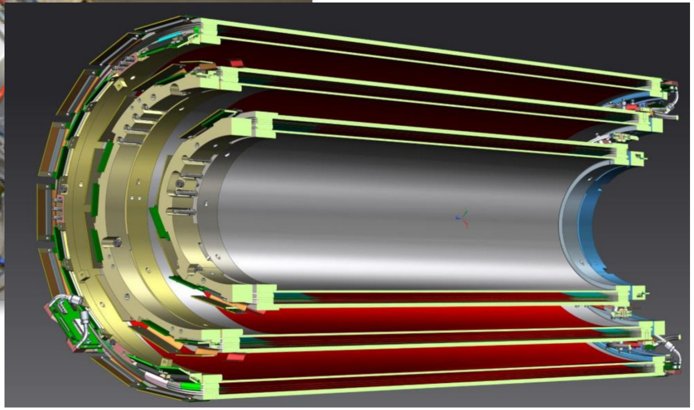
PERFORMANCES

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

POSITION RECONSTRUCTION

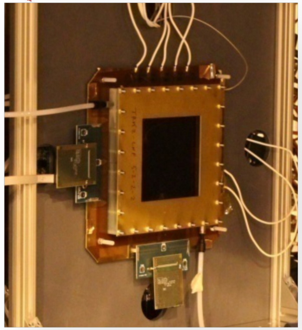
1. charge centroid
2. micro–TPC (μ–TPC)
3. merging of 1 and 2

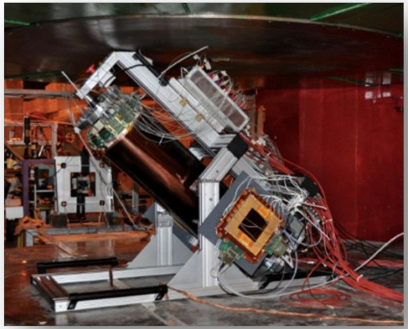




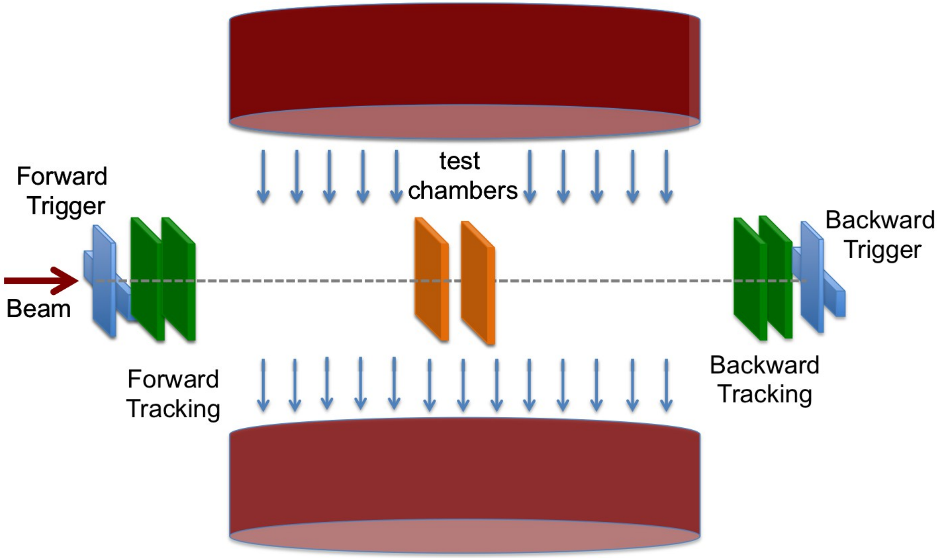
[A. Balla *et al.*, Nucl. Instr. and Meth. A 732, 221-224 (2013)]

Test Beam setup





Testbeams to set the GEM working point
- H4 beam line @ SPS, NA CERN
- GOLIATH dipole 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

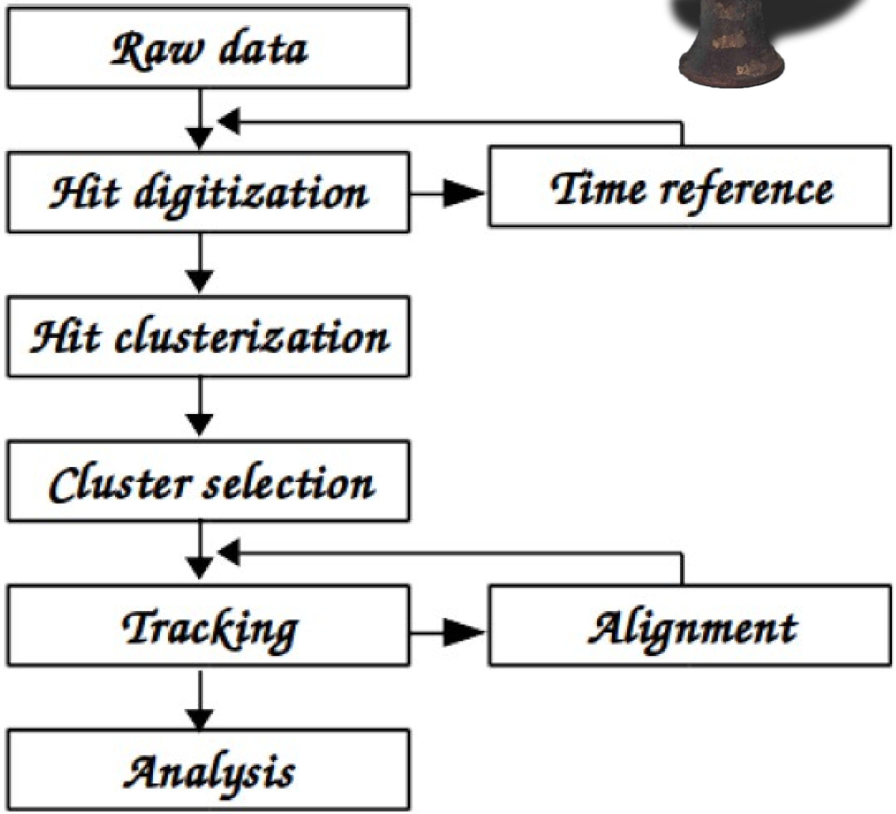
Data reconstruction: GRAAL

RECONSTRUCTION PROCEDURE

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

GRAAL performs

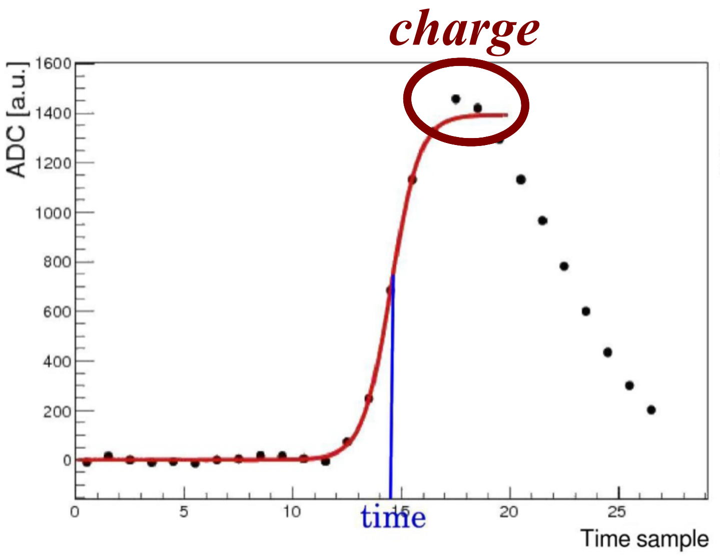
1. Selection of **hits** with charge higher than a threshold
2. Reconstruction of each hit time
3. Association of contiguous hits: **cluster**
4. Track reconstruction (from the trackers)
5. Residual calculation (on test detectors)
6. Alignment procedure
7. Final evaluation of the efficiency and resolution



Hit digitization

two ASIC chips used:

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



- CMS Collaboration
- 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

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

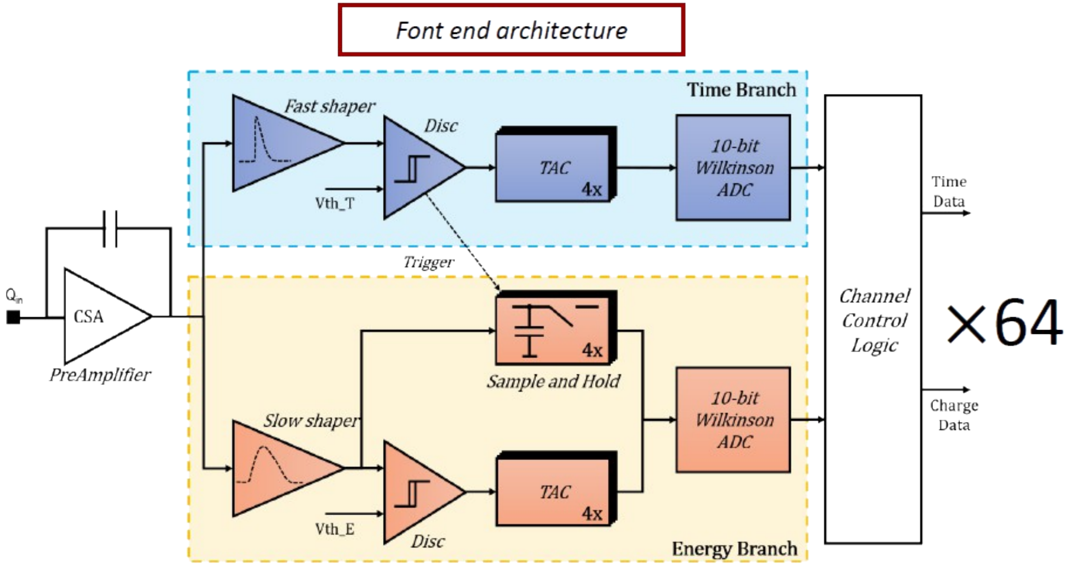
to extract the hit time (t_{FD}) and error (σ_{FD})

[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



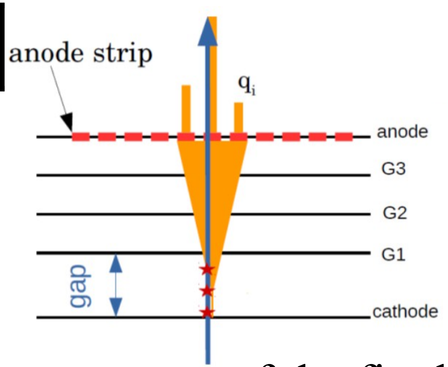
- GRAAL reconstructs both
- In the following only APV-25 data will be presented

Cluster digitization

- contiguous strips with charge higher than the threshold

particle position reconstruction → two algorithms:

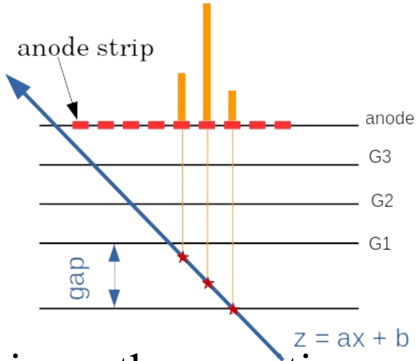
Charge Centroid



position reconstructed as average of the fired strip 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



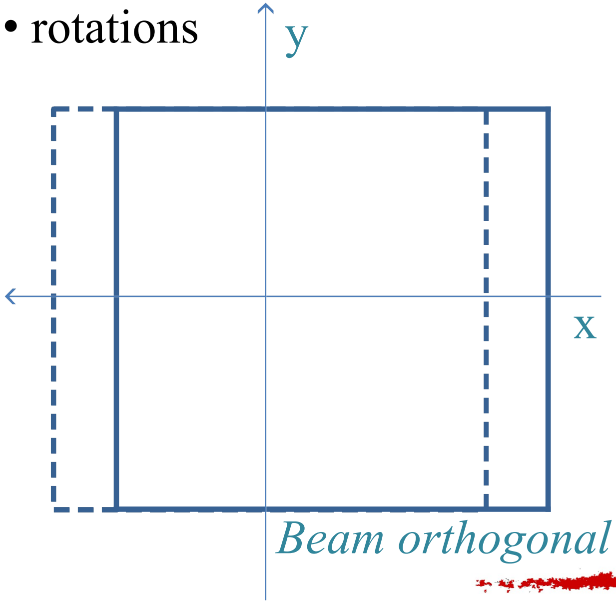
drift gap as a TPC gives the position of each ionization by the drift time and velocity → linear fit

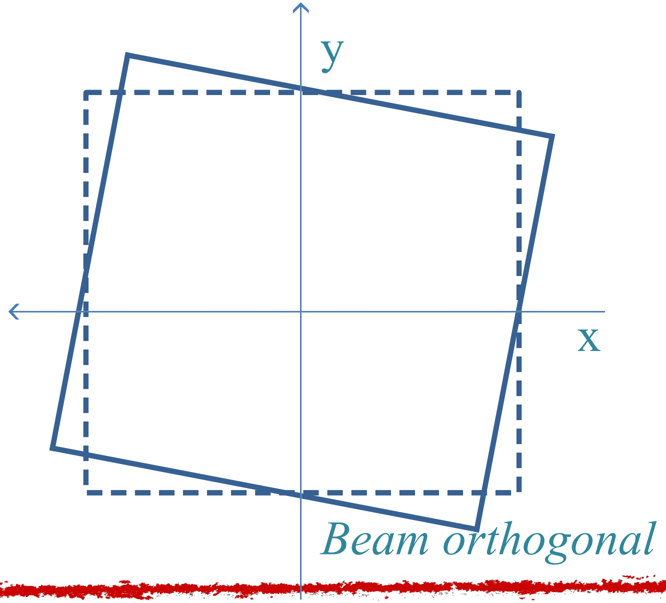
$$x_{\mu\rm TPC} = \frac{gap/2 - b}{a}$$

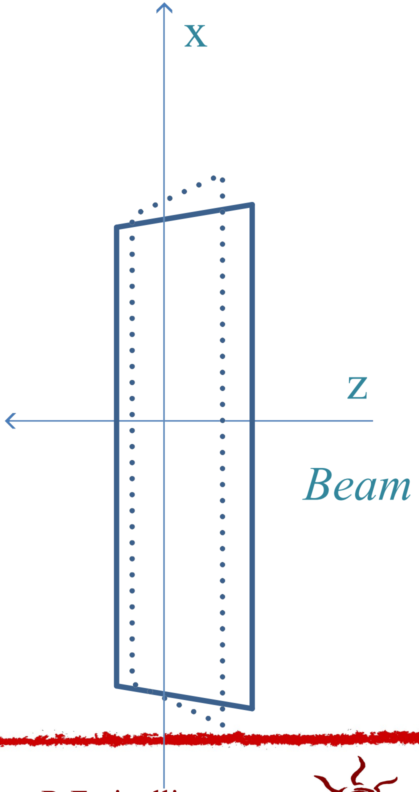
T. Alexopoulos *et al*,, Nucl. Instr. And Meth. A617 (2010) 161;

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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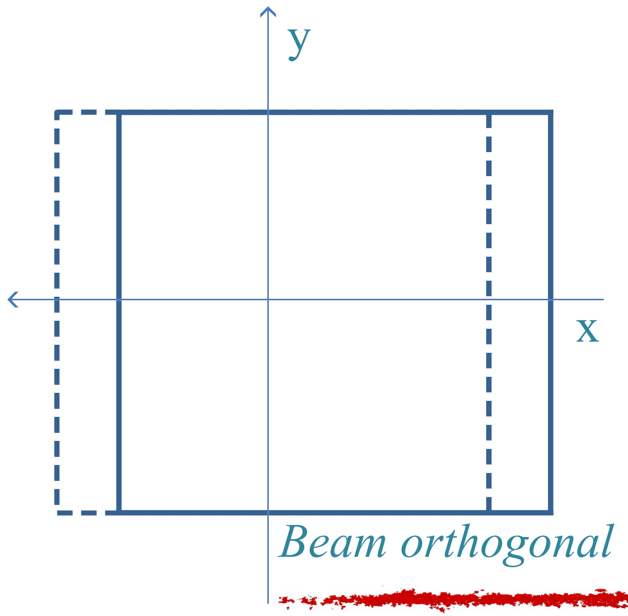

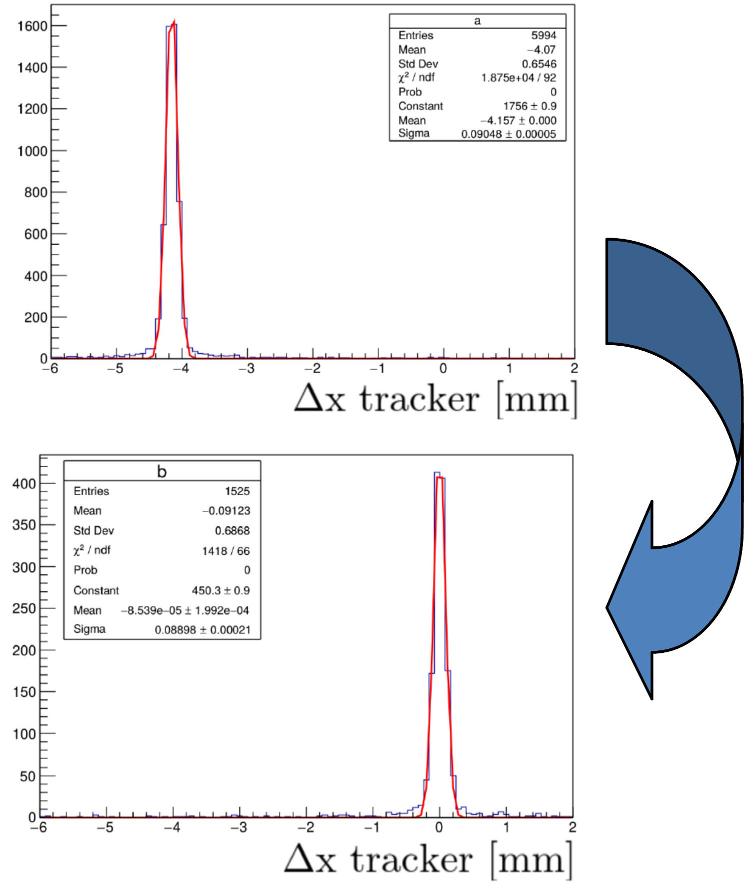

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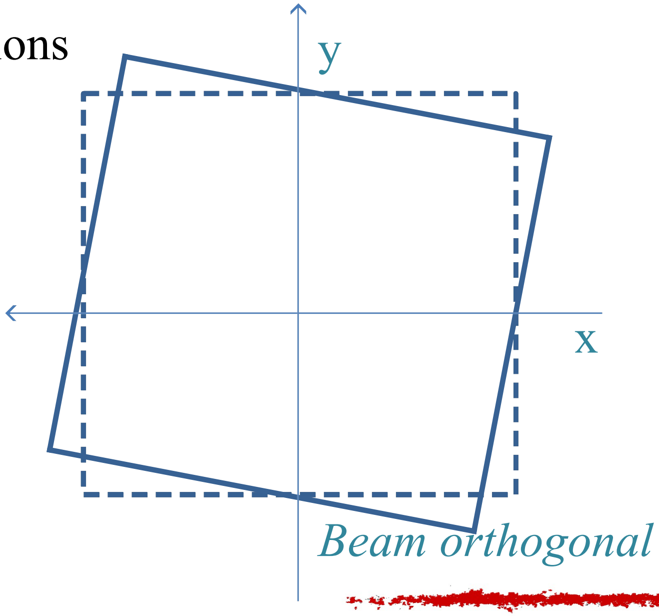
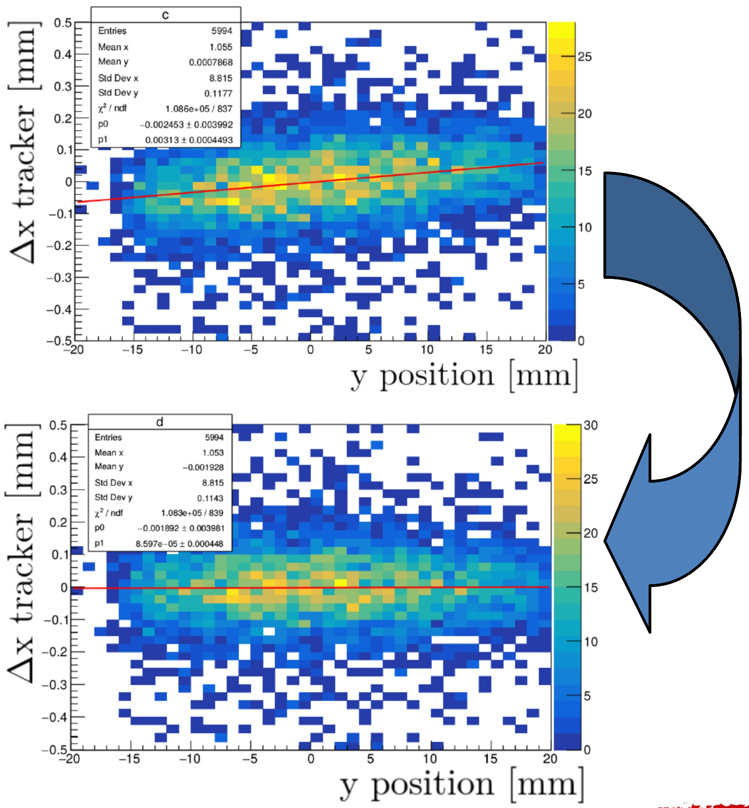
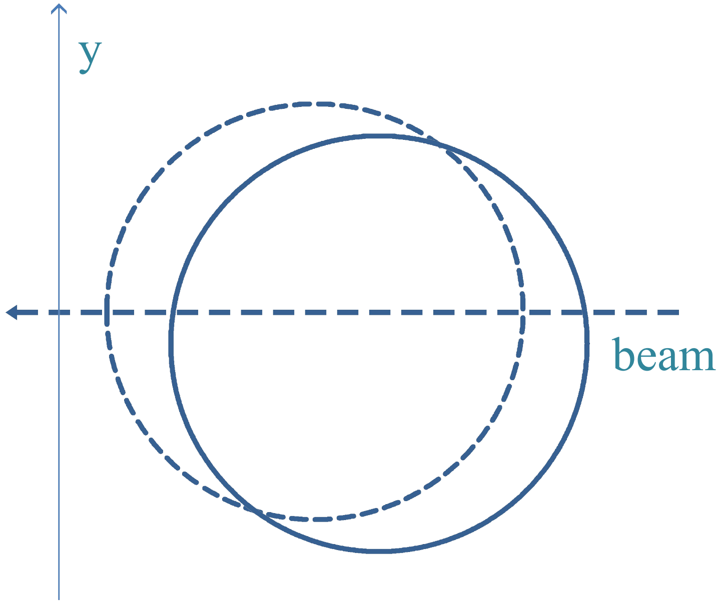




Tracking and alignment: cylindrical chamber

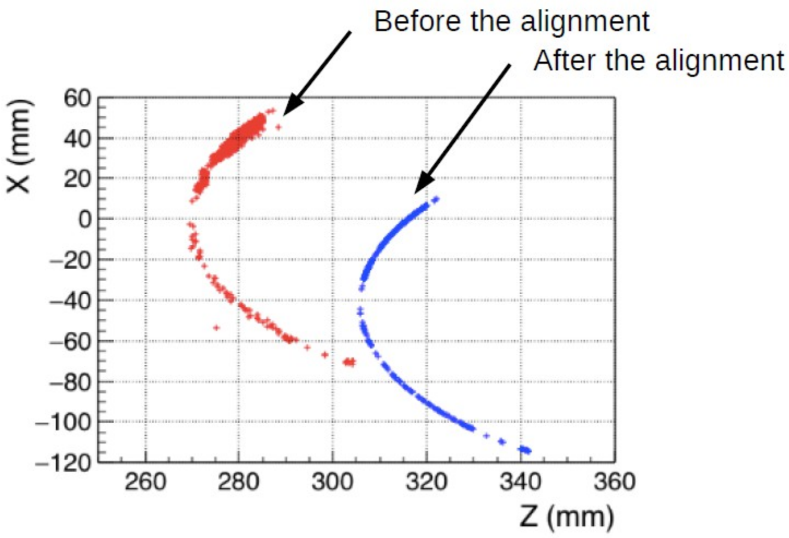


Analogous to planar chambers:

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

→ correct for:

- shift of the center along x/y
- shift of the center along the beam dir.
- rotations around cylinder axis



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

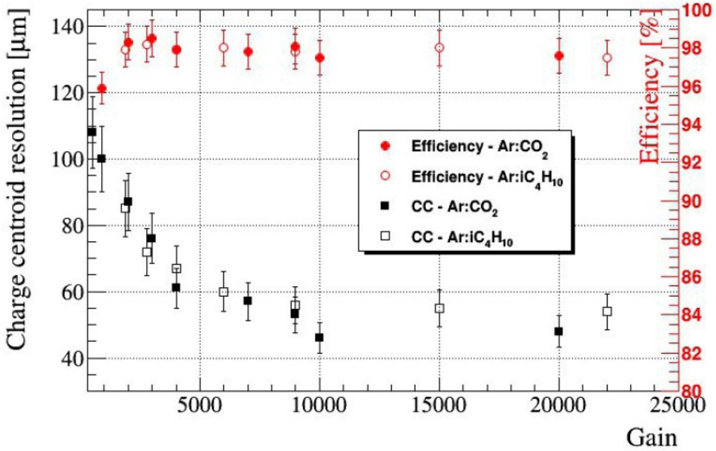
Assumption: both chamber have the same efficiency:

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

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:

$$\Delta x_{1,2} = x_{\text{detector},1} - x_{\text{detector},2}$$

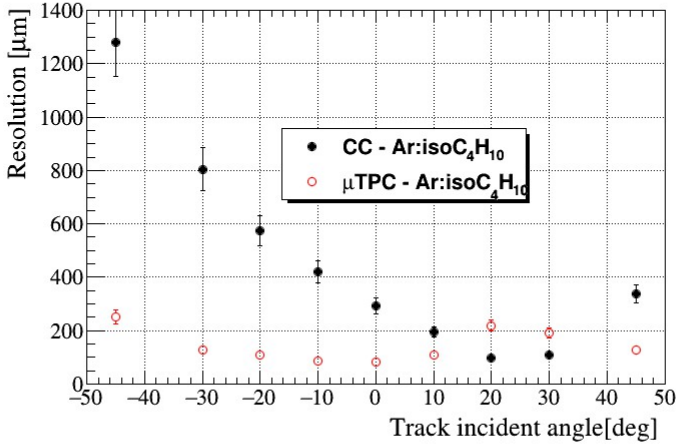
- to reduce systematics
- to eliminate the effect of tracking

Assumption: both chamber 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



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

Analysis: merge CC w/ μTPC

CC and μ–TPC opportunely weighted provide an optimum solution

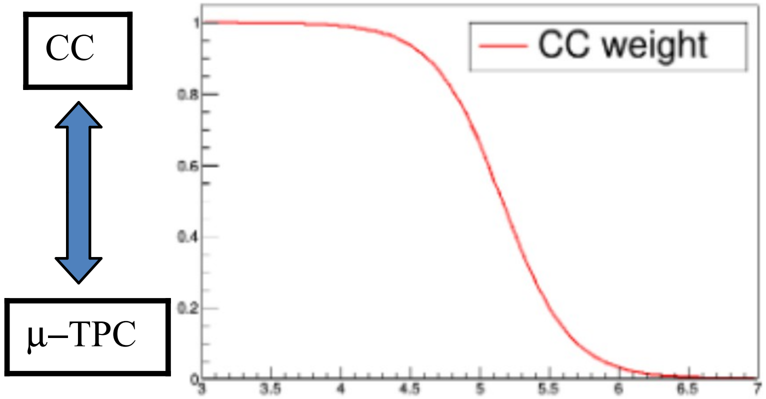
$$x_{\rm merge} = w_{\rm cc}\,(x_{\rm cc} - \Delta_{\rm cc}) + (1 - w_{\rm cc})\,x_{\rm tpc}$$

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

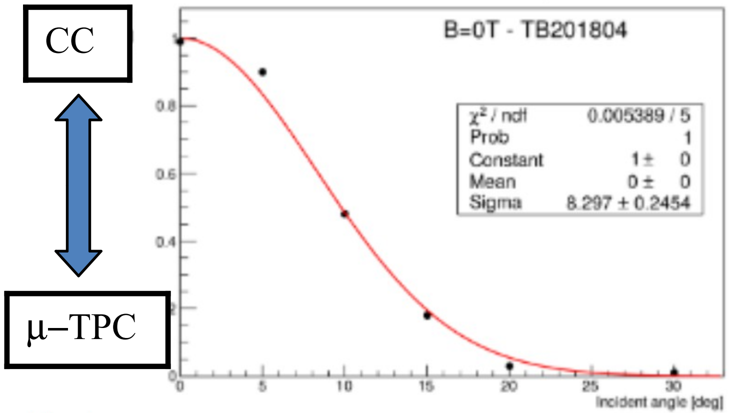
→ selection of data different from the sample on which it is applied

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

CL. SIZE WEIGHTING



INC. ANGLE WEIGHTING



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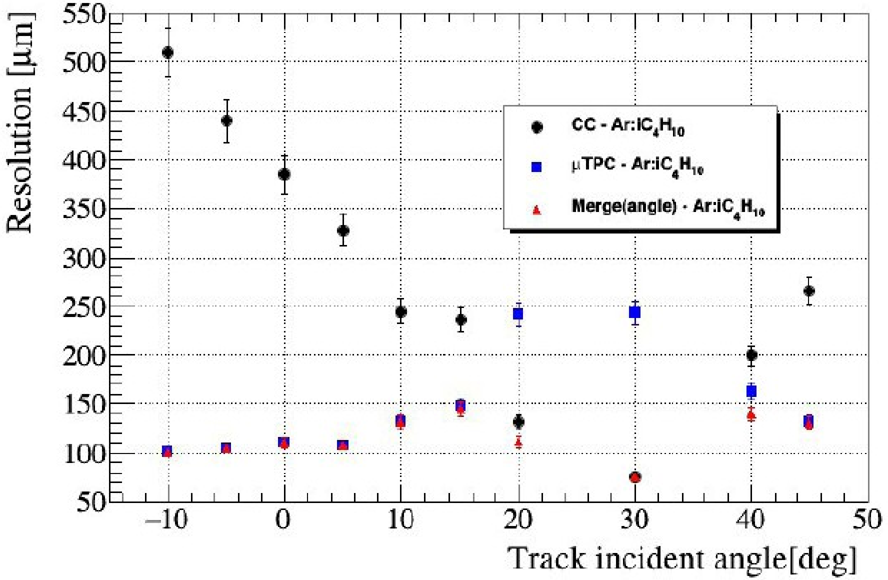
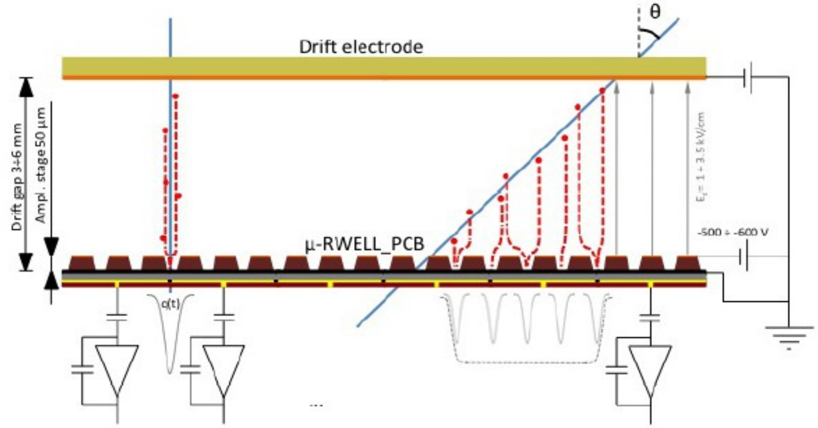


[R. Farinelli, 2019 JINST TH 002)]

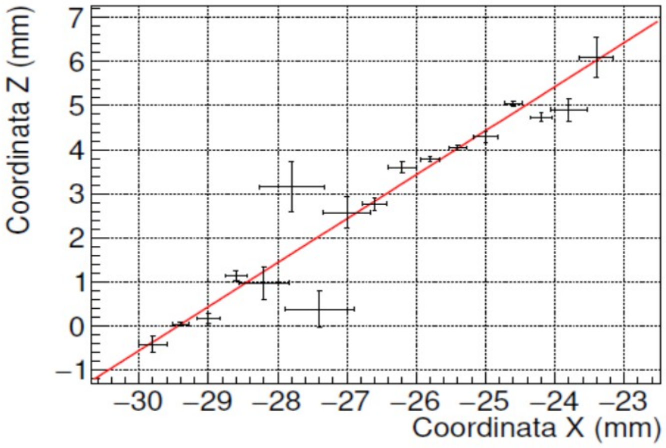
Conclusion

• GRAAL is a tool that can be applied not only to GEM, planar and cylindrical, but also to other MPGDs with segmented anode

• currently it is used for μ–RWELL reconstruction



μ–RWELL scheme



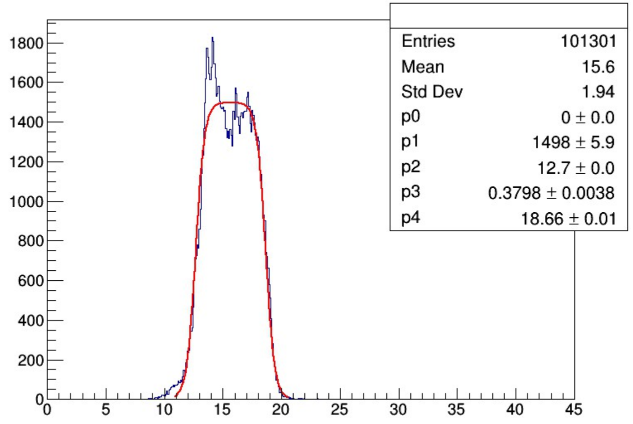
μ–TPC reconstructed track in a μ–RWELL drift gap = 6mm, incident angle 45°

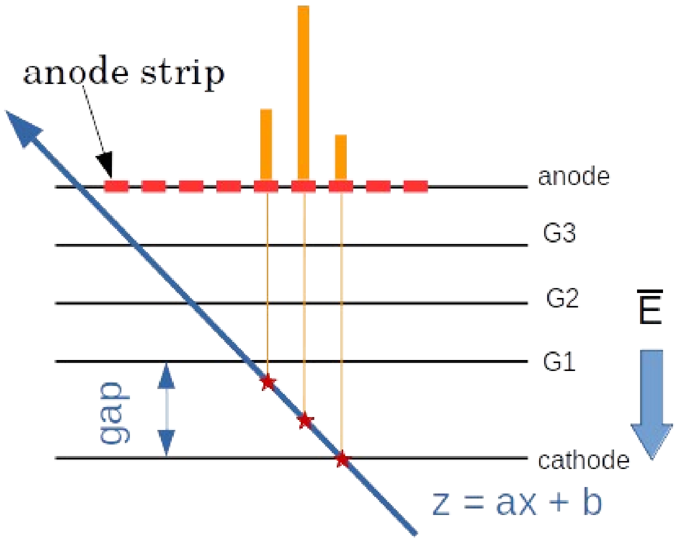
Thanks

Backup

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 μTPC is used





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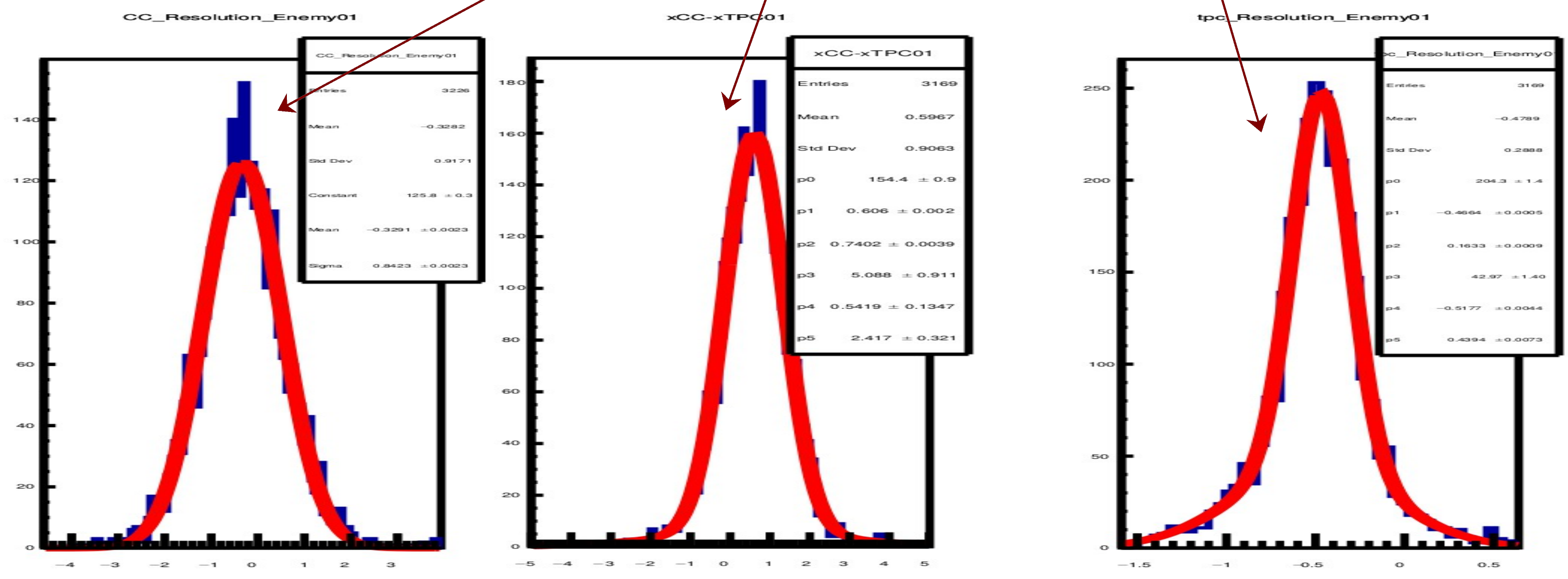

Example of GRAAL output