Test Beam data analysis with CIVETTA: μ-TPC

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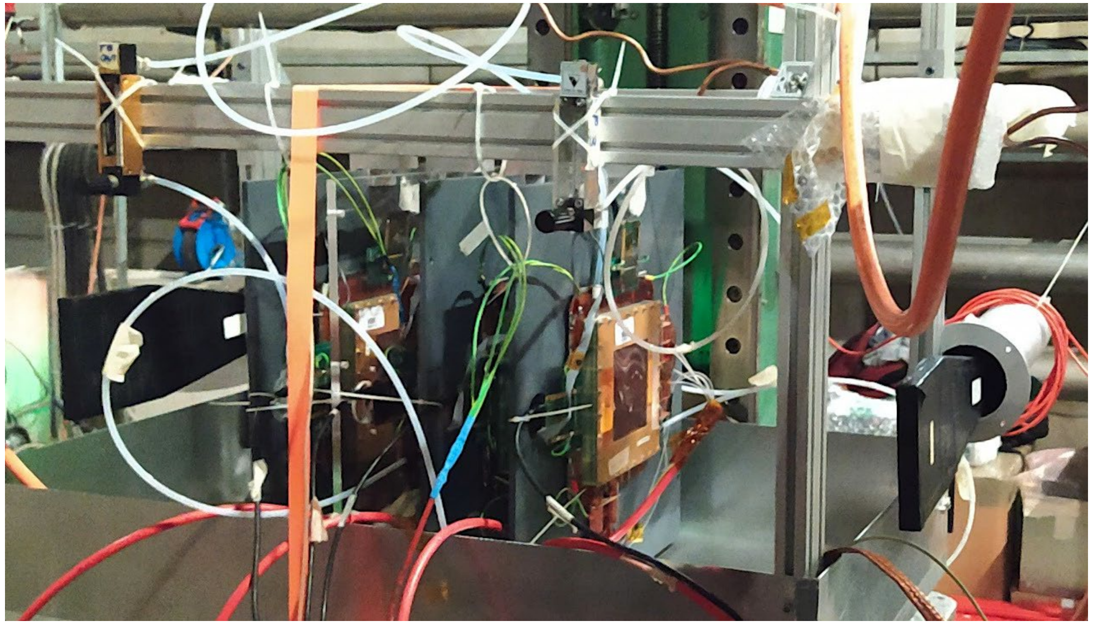
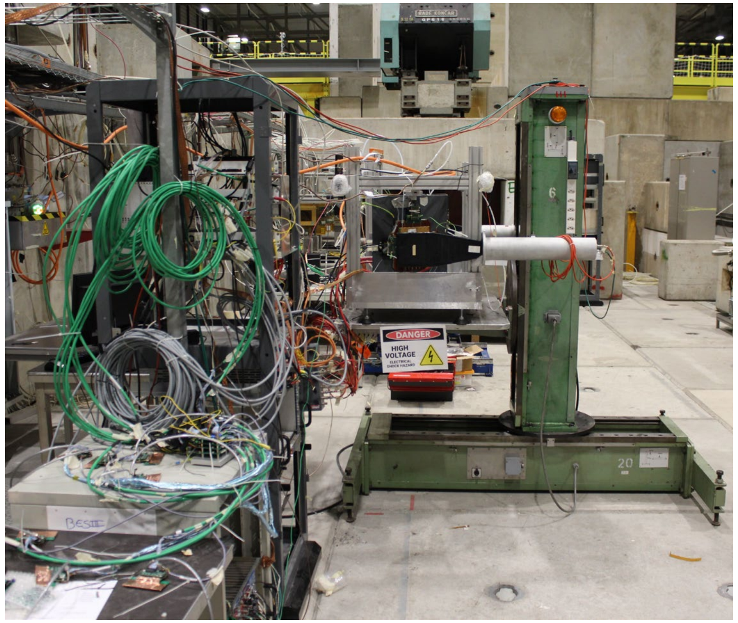
BESIII Italia, Torino – 29/09/2022

Test beam reminder

SPS H4 Beam Line
Muons (@ 80 GeV/c)
and Pions (@150 GeV/c)





4 planar detector
2 acquisition electronics tested:
-TIGER + GEMROC
-APV + SRS

Many scans:

- Angle
- Gain
- Drift Field
- Threshold
- Frontend settings

More than 250 milions triggers collected

CIVETTA - Performance

Performance evaluation offline

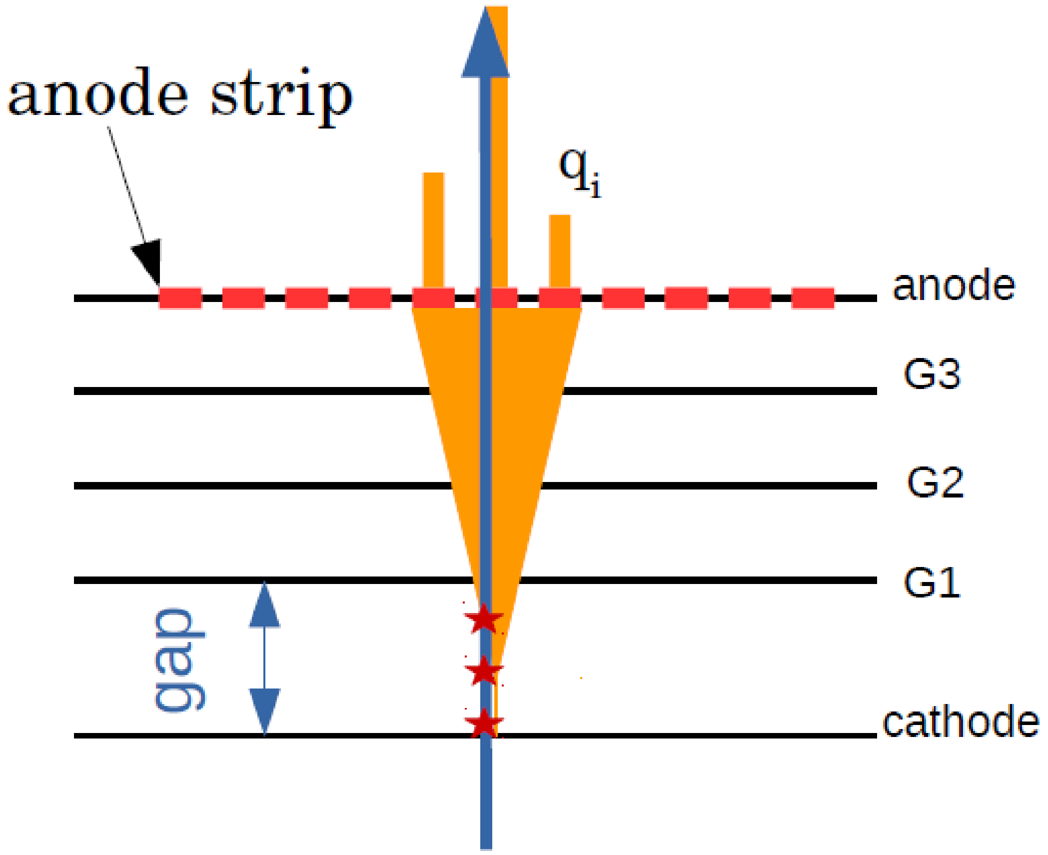
- Full statistics
- Alignment on each run

Event visualization

Efficiency

Resolution

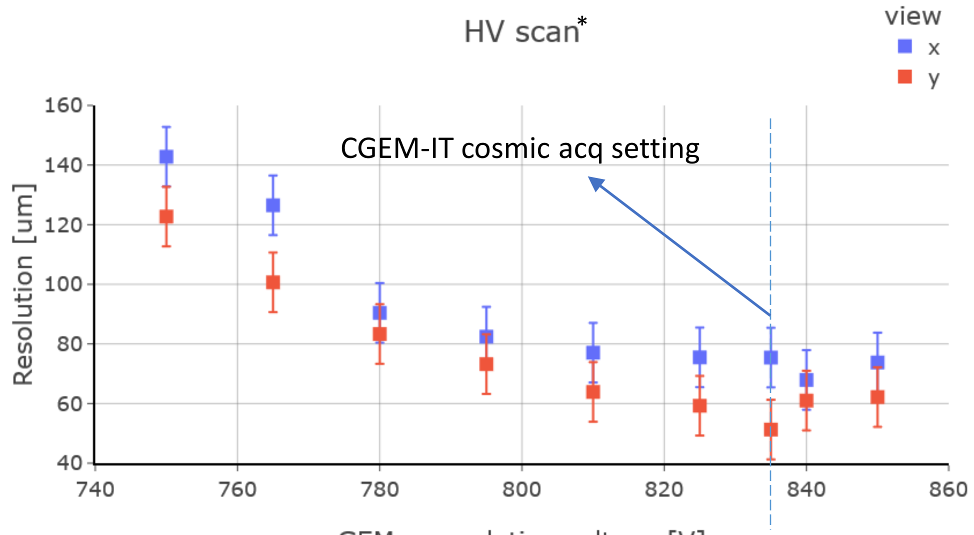
Charge Centroid

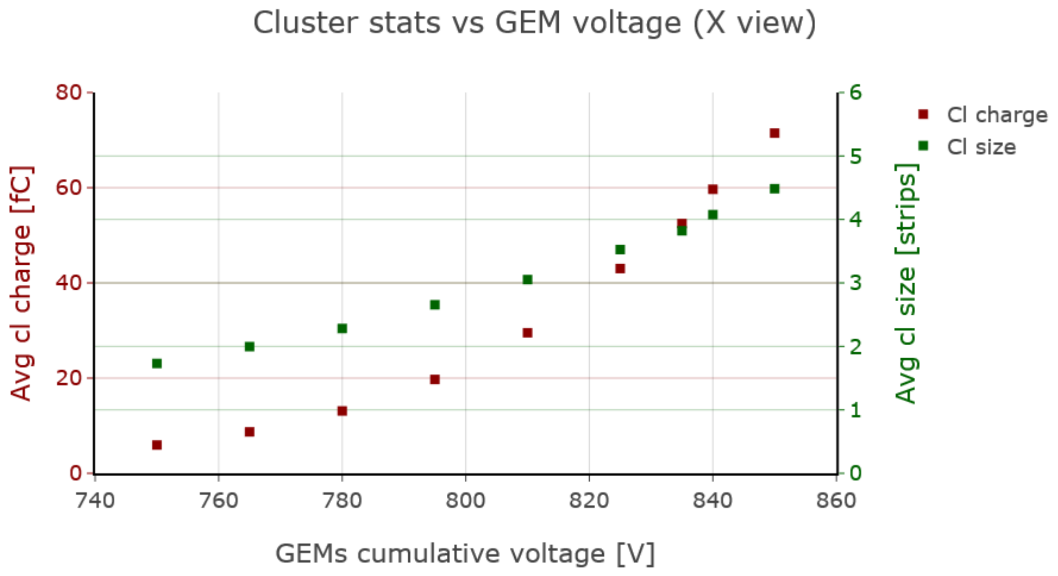


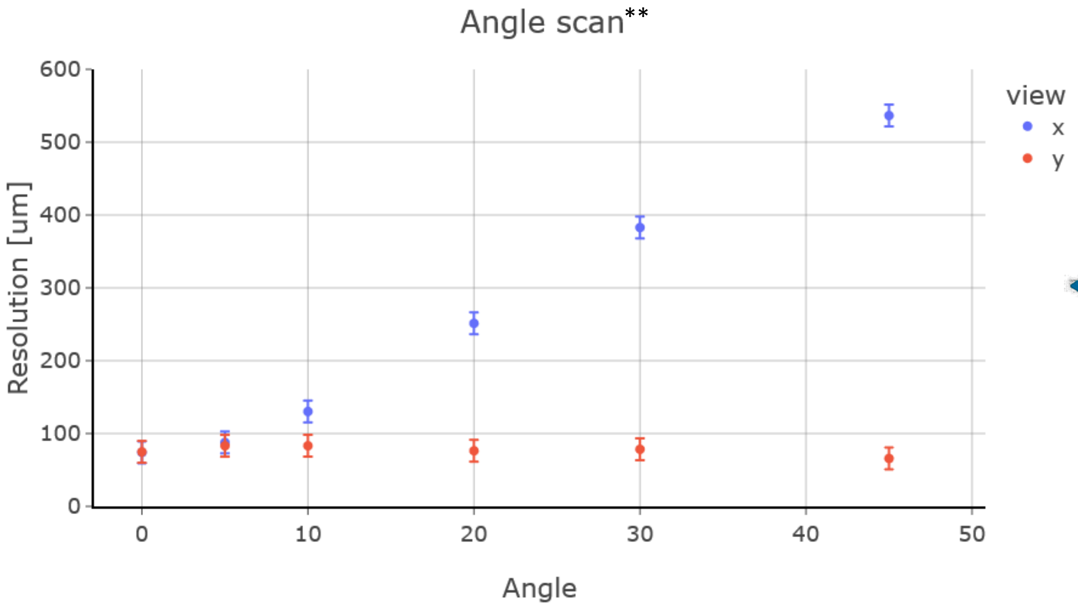
Gaussian charge distribution

$$<x> = \frac{\sum_i x_i q_i}{\sum_i q_i}$$

Some results – resolution (C. C.)







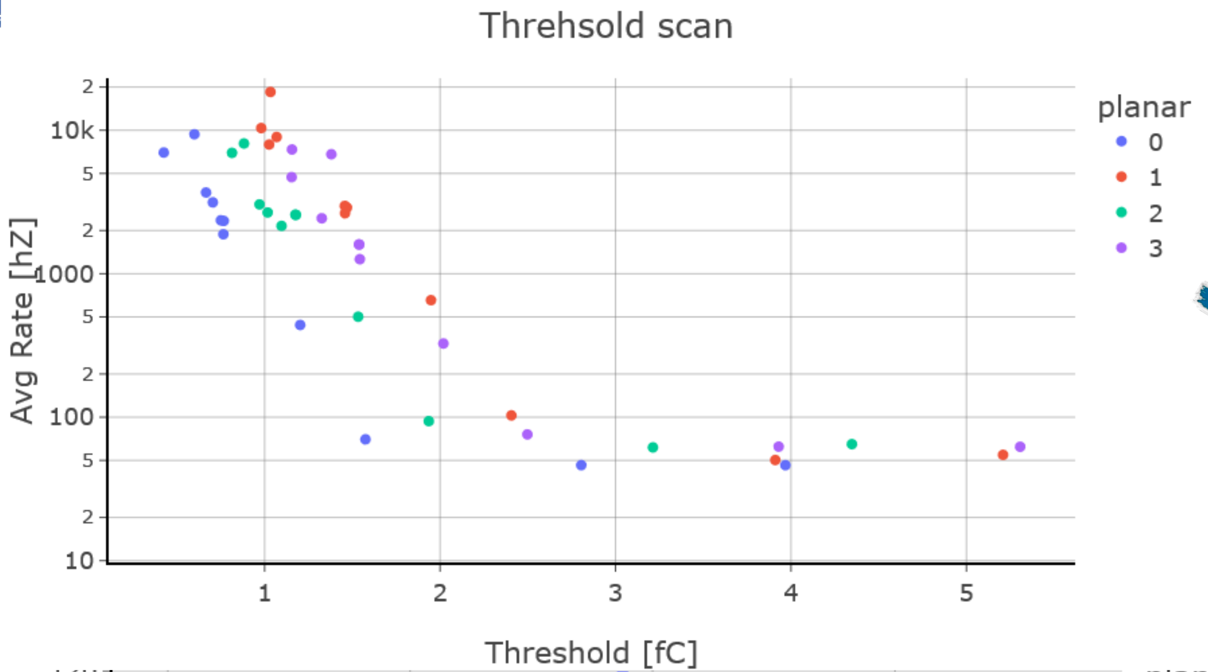
The error is estimated to be 15 µm from the dispersion of the beam spread measure (preliminary)

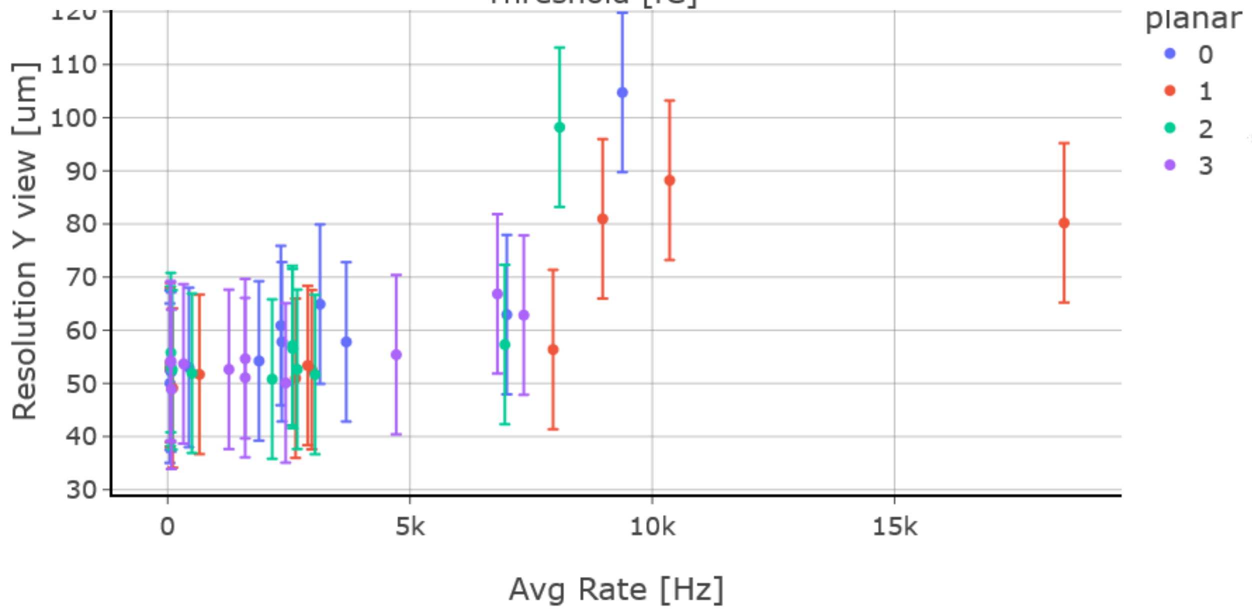
* 0° incident angle, drift field 1500 V/cm

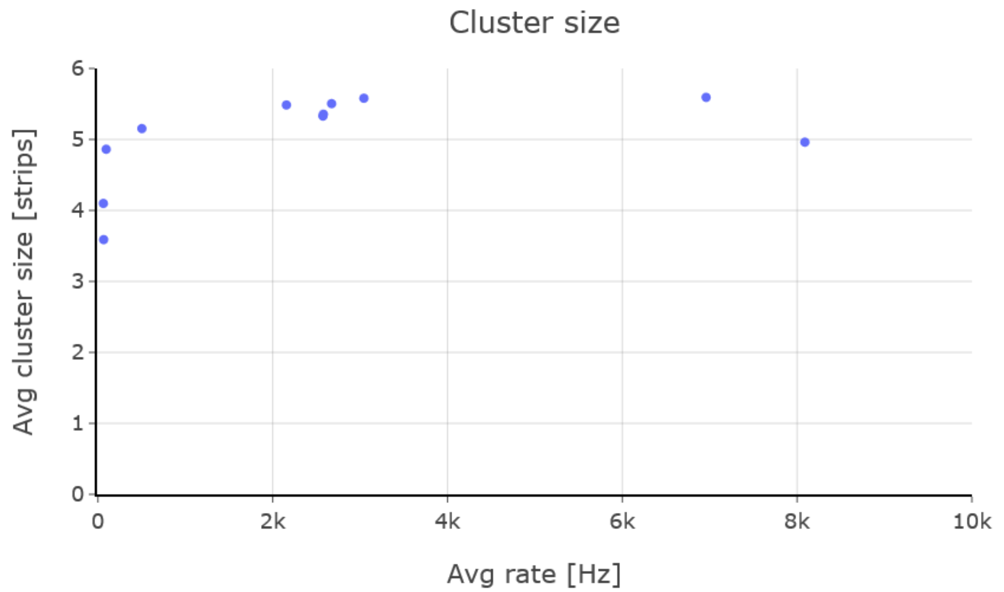
** GEMs 835V, drift field 1500 V/cm

Resolution vs threshold setting

The error is estimated to be 15 µm from the dispersion of the beam spread measure (preliminary)

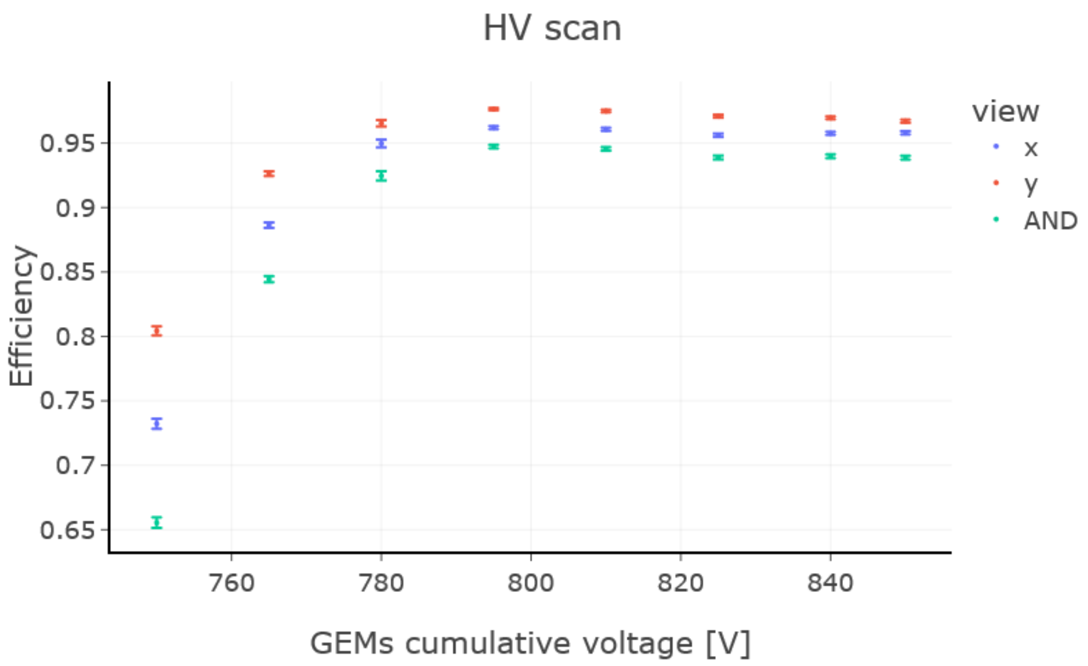


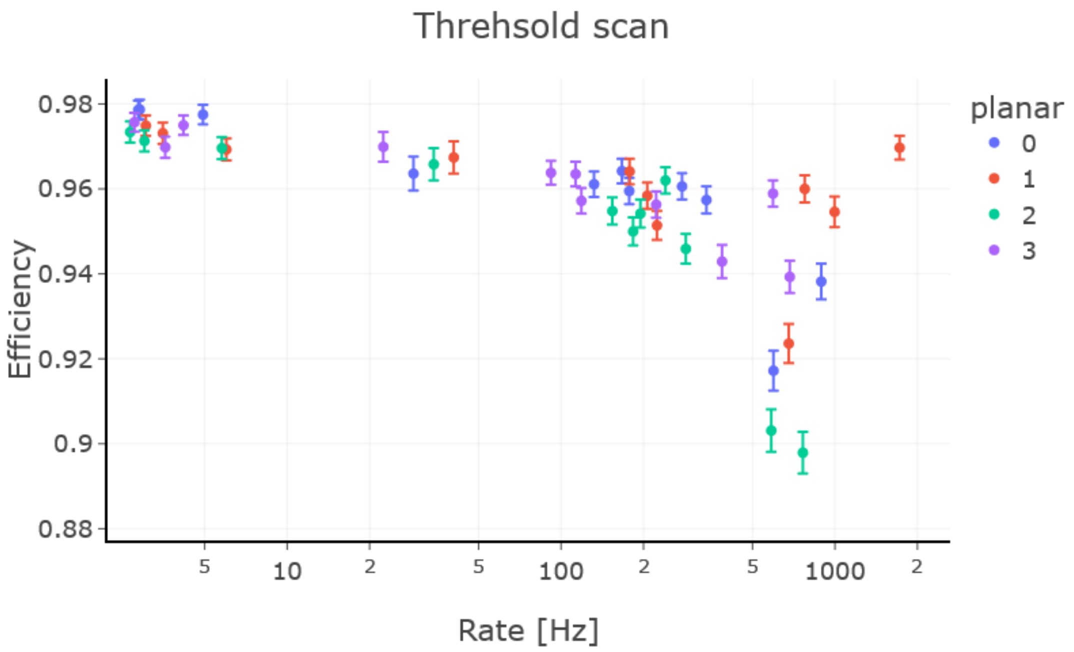




Planar 1

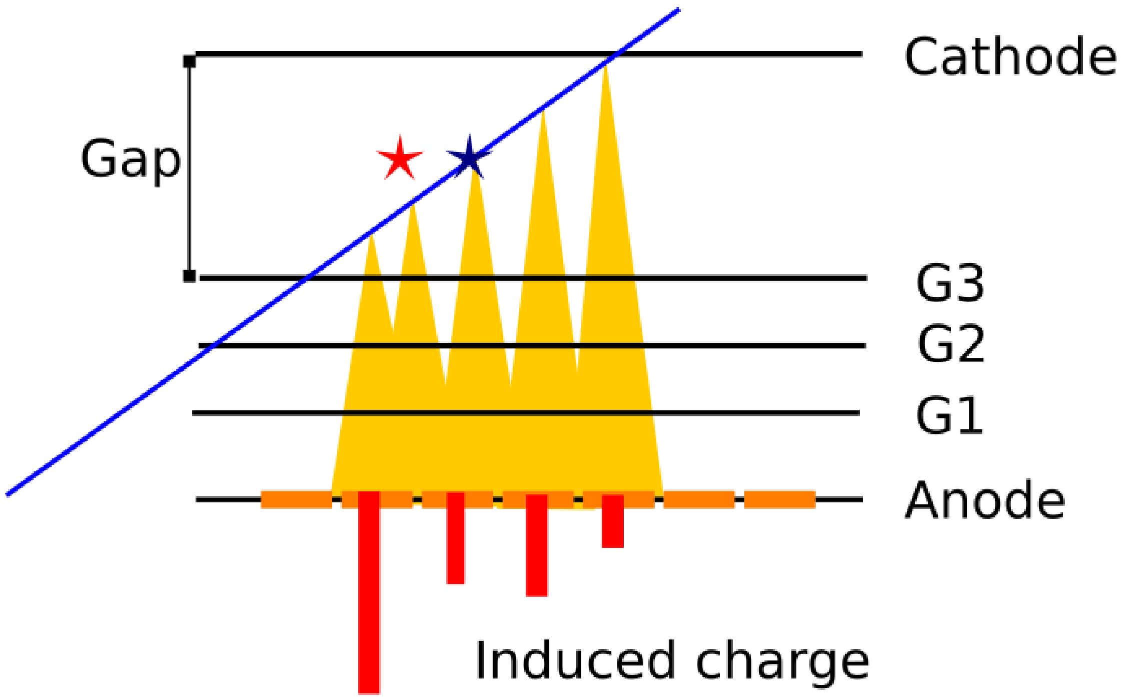
Some results – efficiency





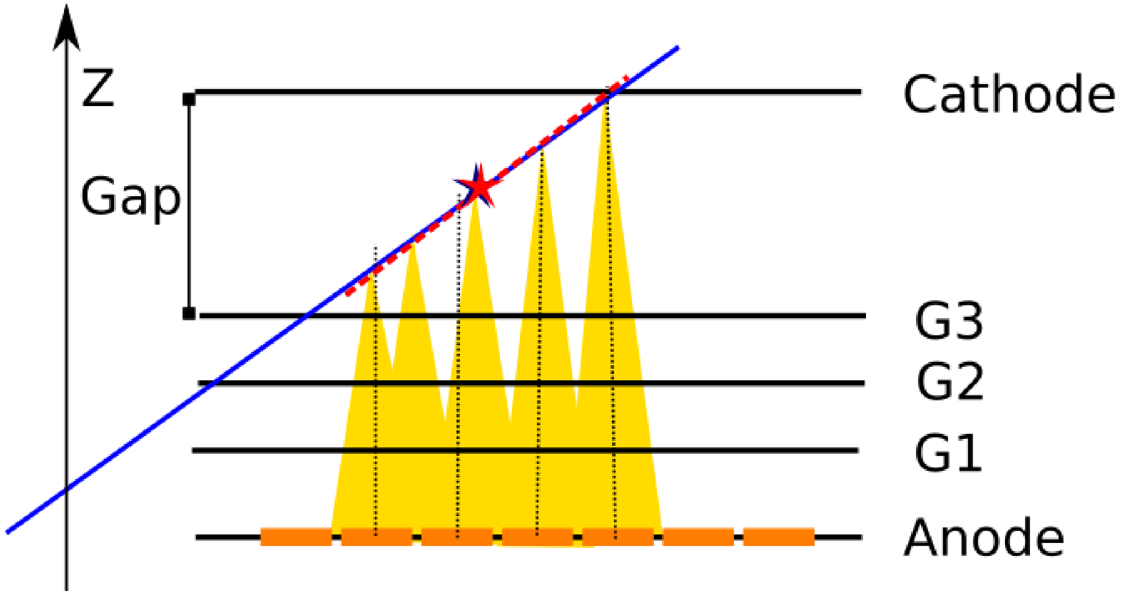
The error is purely statistical and analitically propagated

Charge Centroid – tilted tracks



- With tilted tracks the charge distribution is not Gaussian
- Reconstructed position (red star) can differ from mid-gap position (blue star)

µicro –Time Projection Chamber



$$z = v_{drift} * t$$

$$z = a + x * b$$

$$x_{gap} = \frac{\frac{gap}{2} - b}{a}$$

To estimate the *Z* position, we need **a good time measurement**

- To have a good time measurement, we need:
  - Time reference
  - Drift velocity
  - Time walk correction
  - Error estimation

Time reference: difference between TIGERS

Planar 0

tiger	Mean time	Entries	
0	1407.458581	7231	X
1	1407.708581	6887	X
2	1409.202358	9246	Y
3	1409.772637	9531	Y

Planar 2

tiger	Mean time	Entries	
0	1404.111593	7384	X
1	1403.941340	6836	X
2	1404.463017	13425	Y
3	1404.596573	10329	Y

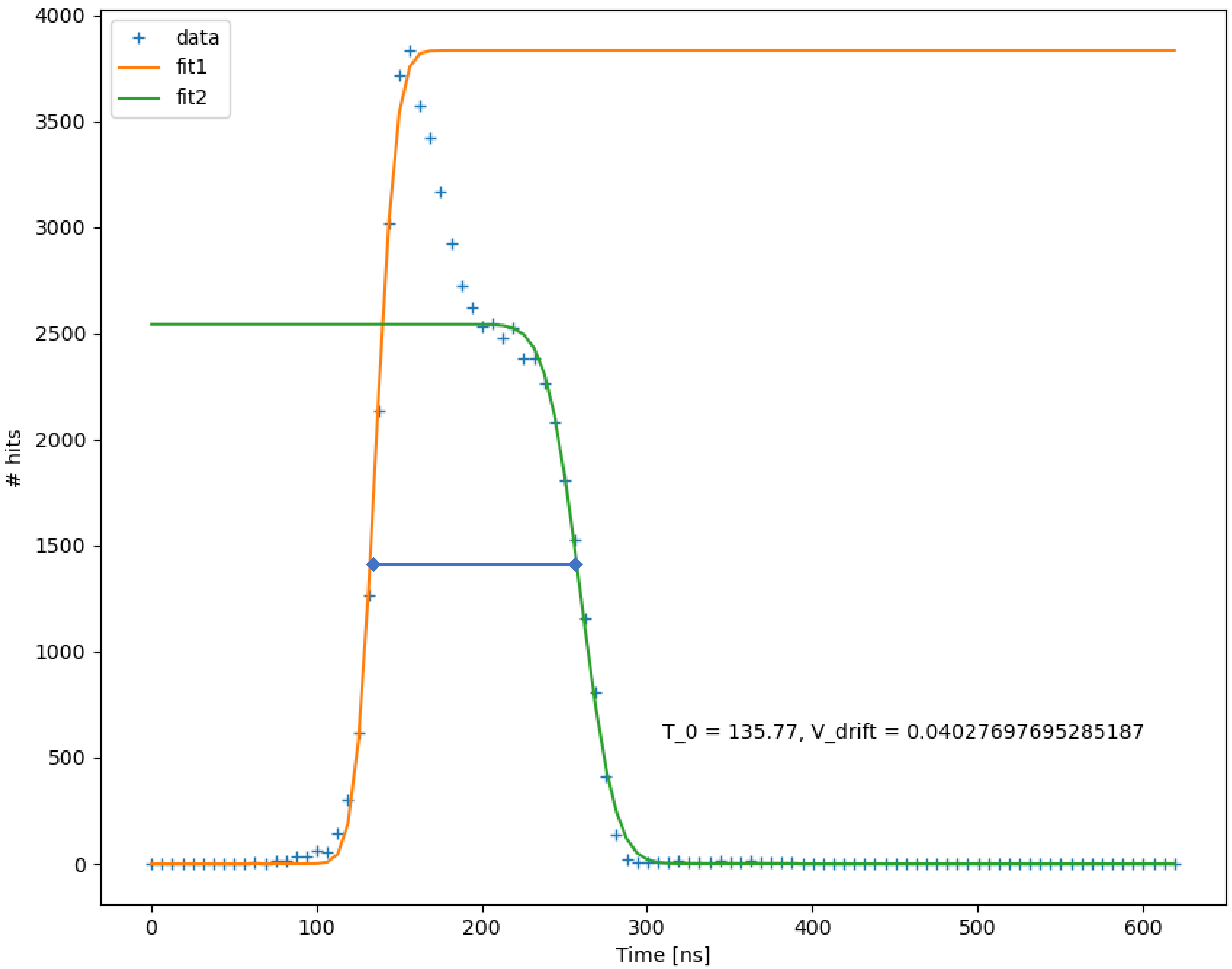
- Similar in the same FEB (view)
- Differences between views and detectors

↓

One time reference per view

Selection:
0°, GEM HV = 825 V
Clusters from efficient event, no holes and good charge sharing
Hit charges >35 fC , time from the most charged hit.

Time reference and drift velocity



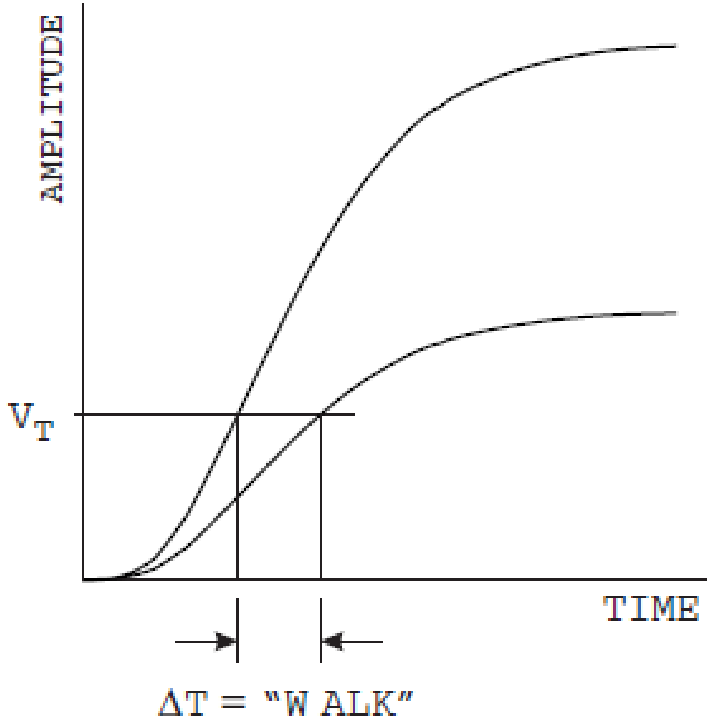
T_0 and v_{drift} obtained fitting the hit time distribution with two error functions

It's a good estimation of v_{drift} only for tracks angles > 30°*

* Performance studies of resistive-strip bulk micromegas detectors in view of the ATLAS New Small Wheel upgrade.
Alexopoulos et al.

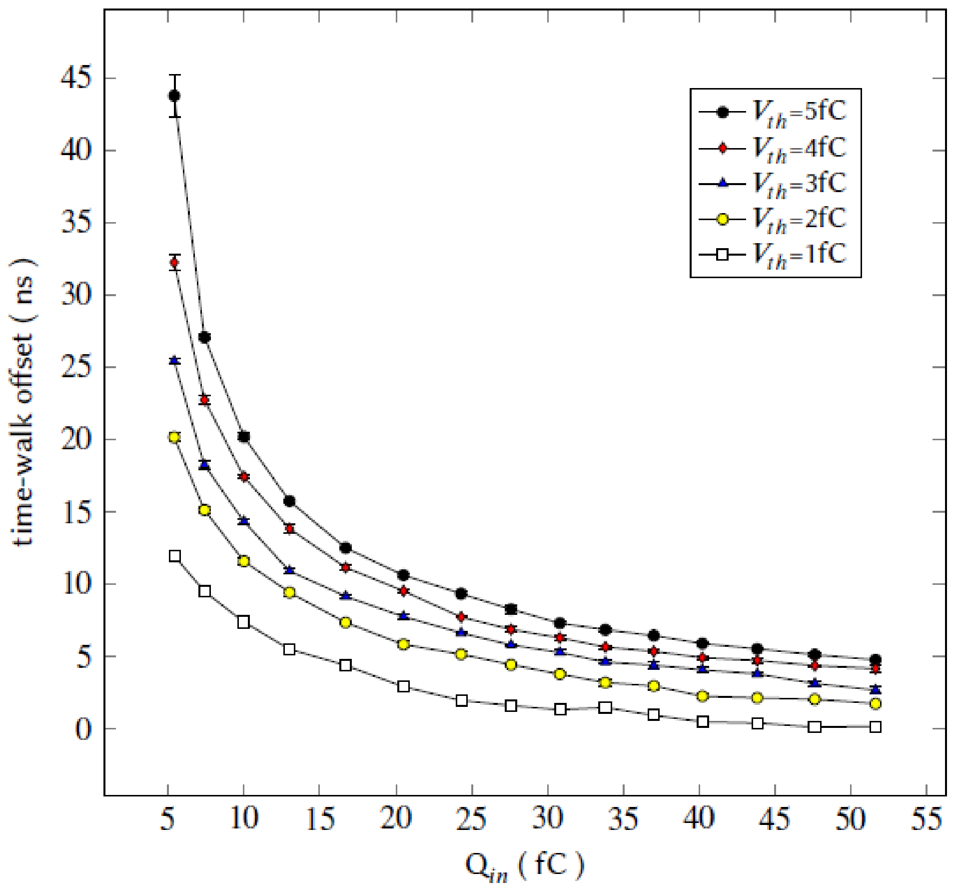
Time walk

"Time walk" is also a Magic card
on sale for more than € 5.000



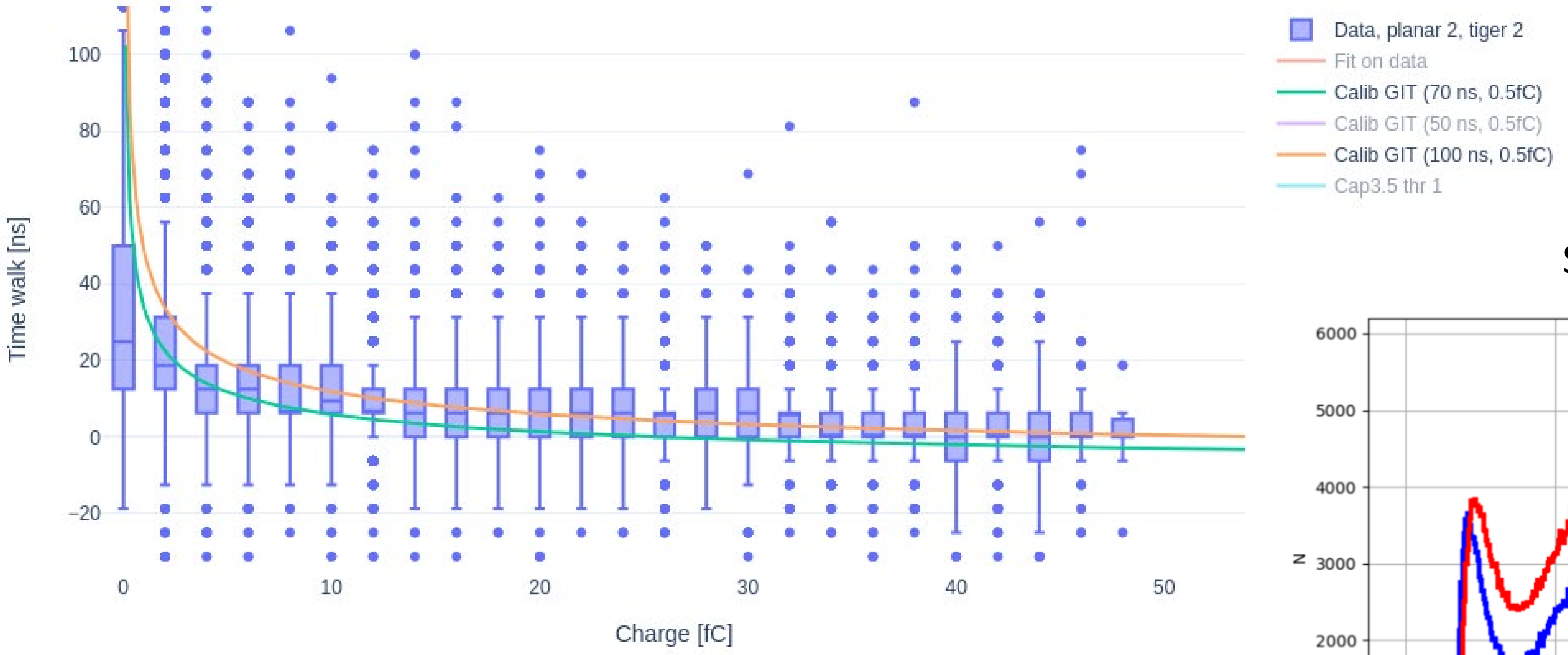
Semiconductor Detector Systems, H. Spieler, OUP Oxford, 2005

Time walk in TIGER (measured)



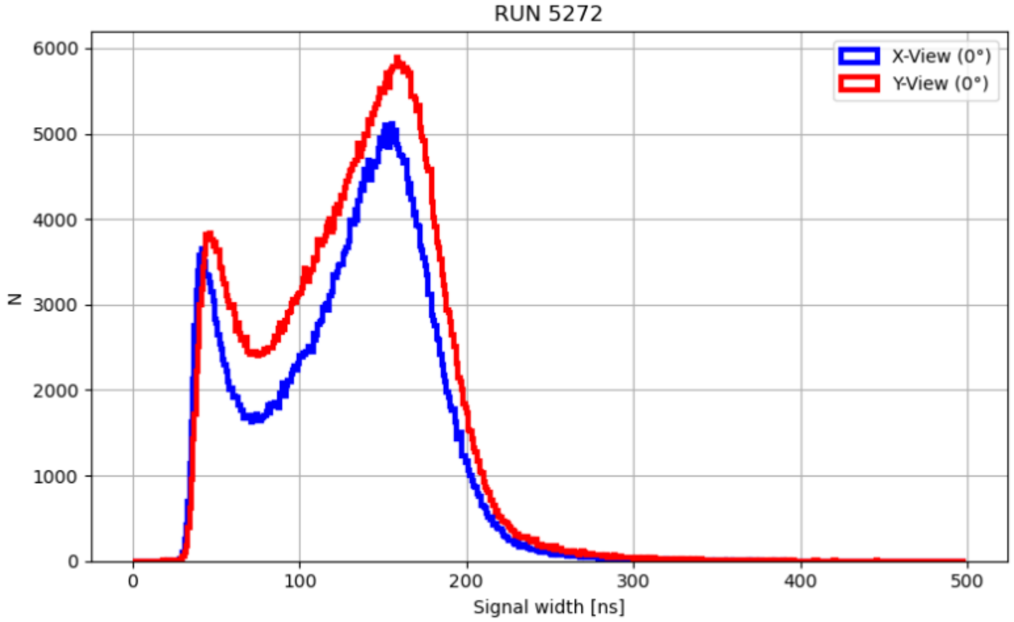
A mixed-signal ASIC for time and charge measurements with GEM detectors
F. Cossio. PhD Thesis

Time walk



TIGER simulation (Fabio)

Signals differ in duration



See last meeting Fabio's presentation

Selection:
0°, GEM HV = 825 V
Clusters from efficient event, no holes and good charge sharing
Time reference from the most charged hit in the cluster, if at least one hit charges has charge >35 fC

Time walk estimation

Sorting the channels in 4 groups, depending on their effective threshold
< 0.5 fC, < 1 fC,< 2 fC, > 2 fC

Get the simulated curve from Fabio's Github assuming
$T_{signal} = 80\ ns$
https://github.com/fabio-cossio/TIGER/tree/master/TimeWalk/

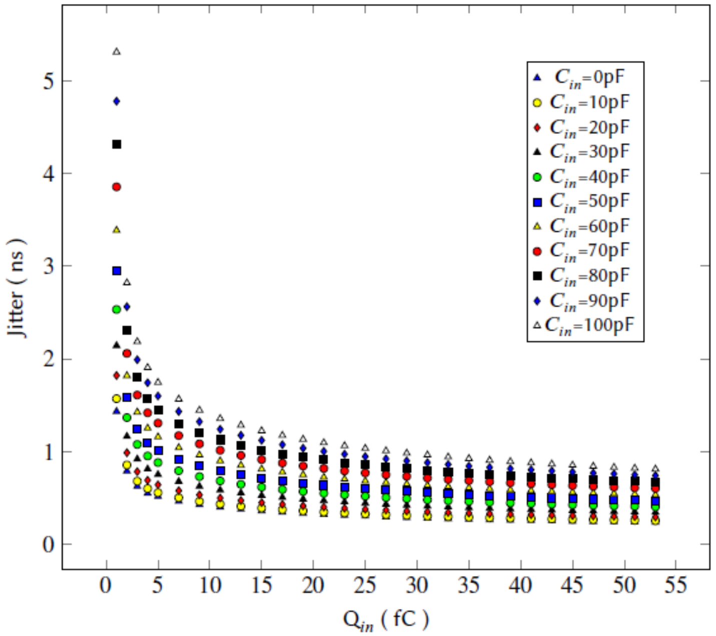
Apply it to the hit time

Time error

$$\sigma_t^2 \geq \sigma_q^2 + \sigma_j^2 + \sigma_{tw}^2 + \sigma_D^2$$

σ_q Quantization error ($\frac{6.25ns}{\sqrt{12}} \sim 1{,}8\ ns$)

σ_j Jitter



Depends on charge

σ_{tw} Error on the time walk correction → Depends on charge → Error on charge measurement

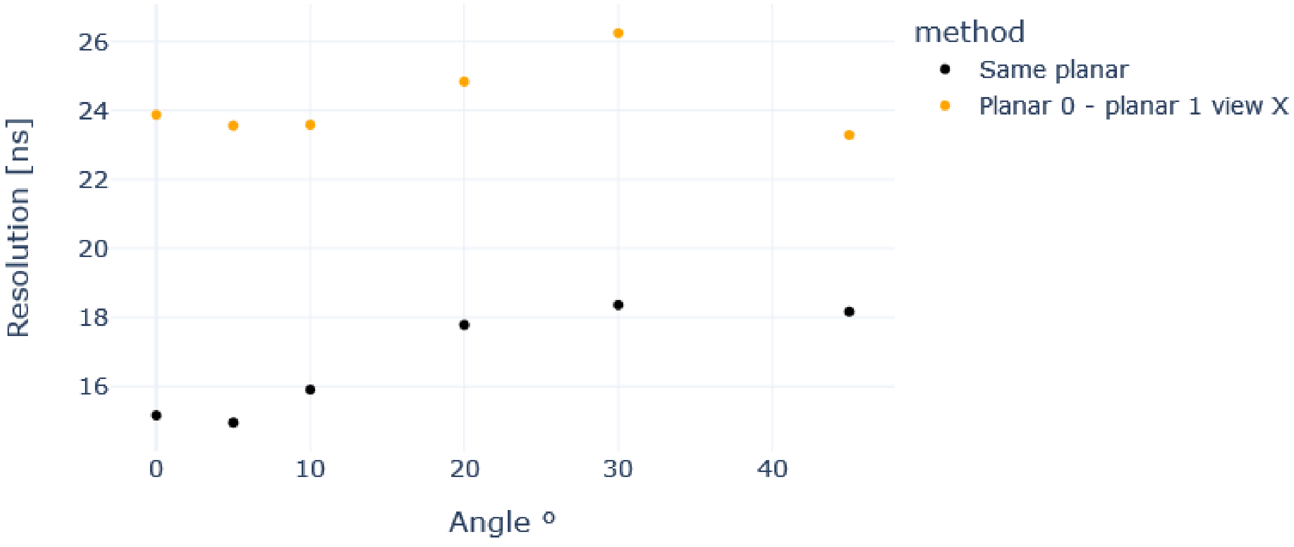
Affected by signal duration spread
(see last meeting Fabio's presentation)

σ_D Detector time resolution

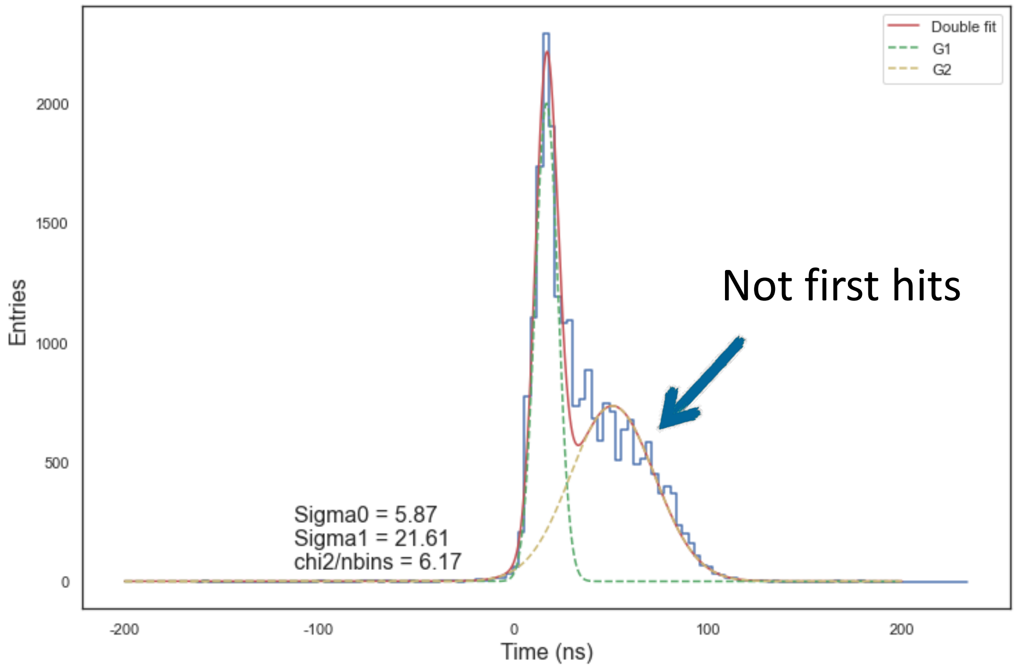
Time resolution estimation

Time difference between first hit arrival time, on different detectors or same detectors but different views.

Double gaussian fit, sigma average / $\sqrt{2}$:

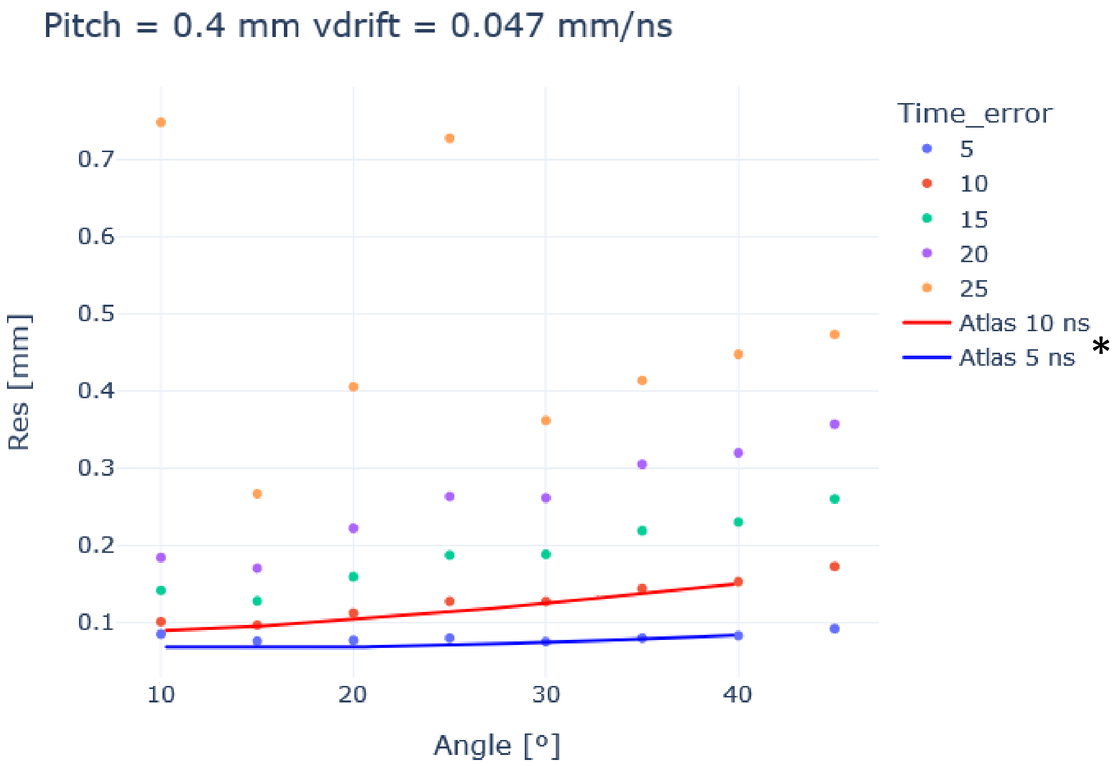


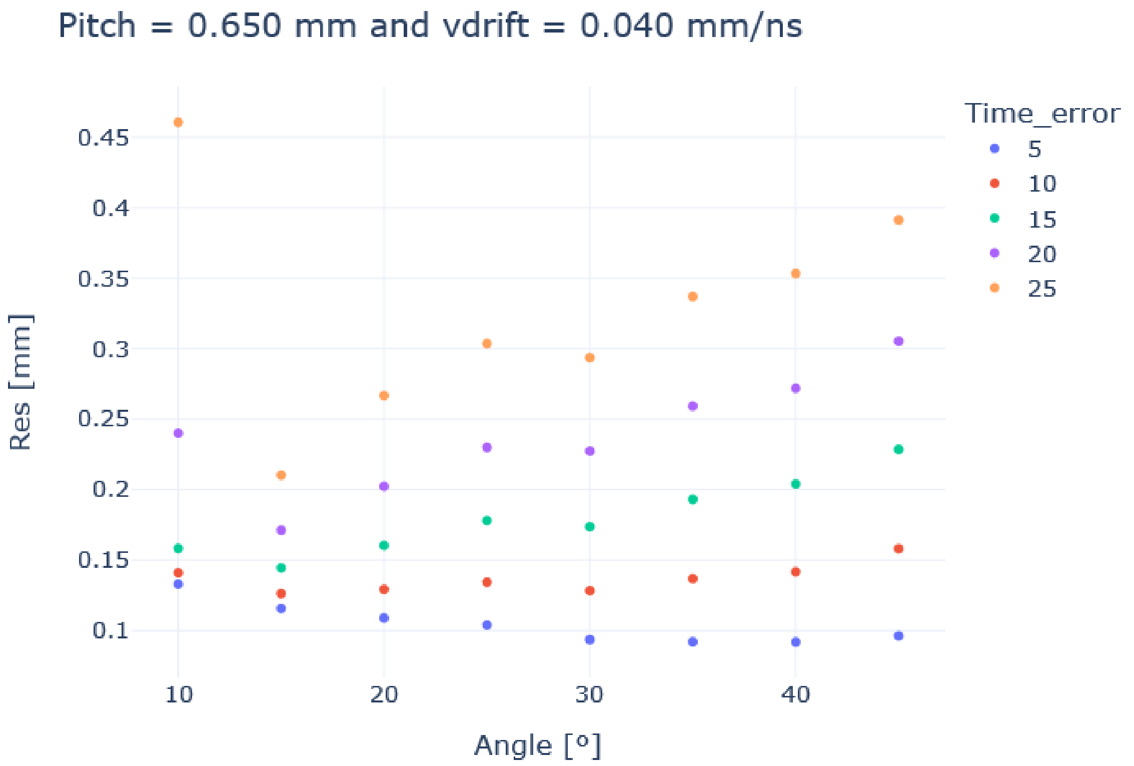
Same detector, only charge> 30 fC



A simple toy MC for μ-TPC resolution

- Random generated tracks (same angle).
- X scattered with $\sigma_x = pitch/\sqrt{12}$ and y with $\sigma_y = v_{drift} * \sigma_t$
- Position reconstructed with μ-TPC.





*Study of μTPC Single Chamber Spatial Resolution Form July Test beam data
Mauro Iodice, ATLAS Muon Chamber R&D Meeting, 2012, MC by V.Lavorini

Error estimation

X error

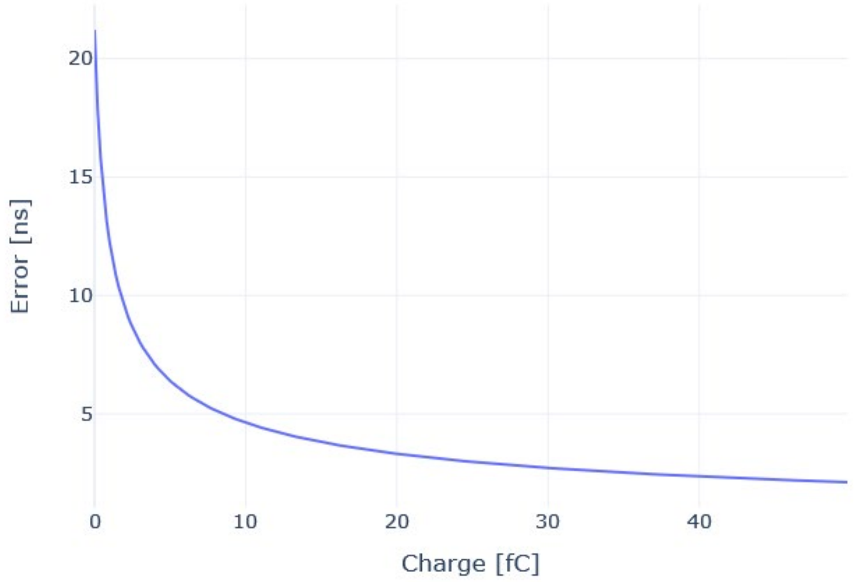
$$\sigma_x = \frac{pitch}{\sqrt{12}} \sqrt{\left(1 + \frac{q_{cl}}{size_{cl} q_{hit}}\right)}$$

Like Riccardo* and others

T error

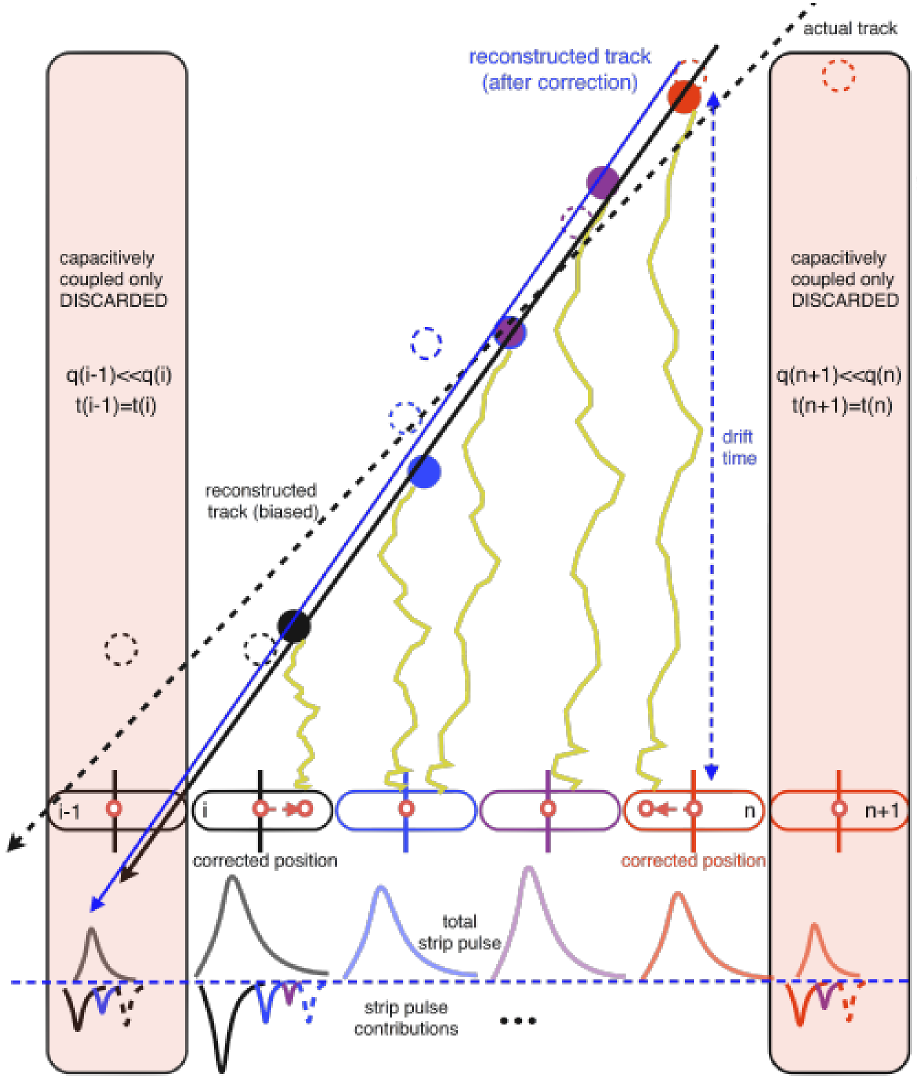
$$error_t = \frac{15ns}{\sqrt{q_{hit} + 0.5}}$$

Empirical



*Research and development in cylindrical triple-GEM detector with μTPC readout for the BESIII experiment, R. Farinelli, PhD Thesis

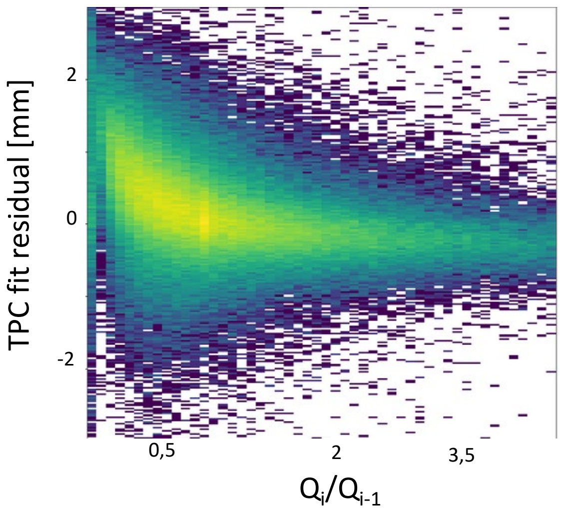
Corrections



Capacitive corrections

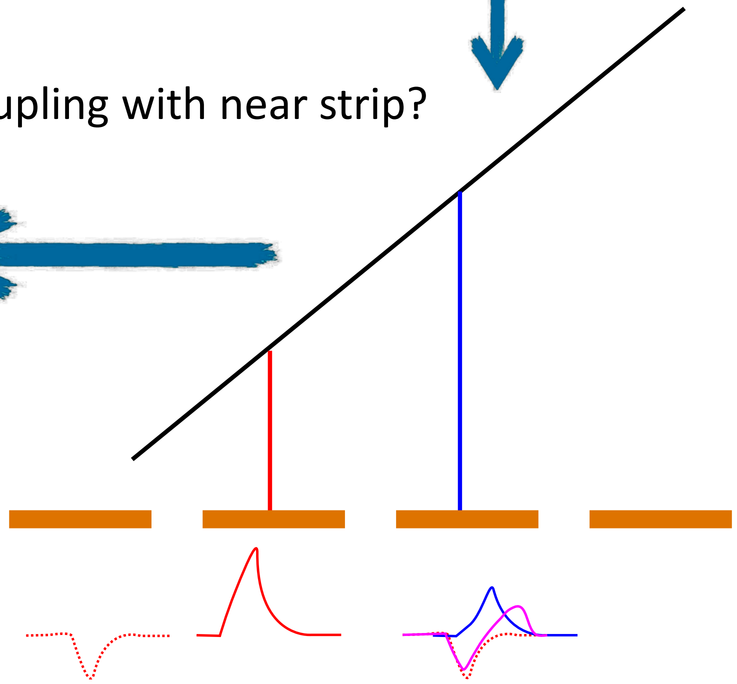
First \ last strip correction

From data:



Maybe coupling with near strip?

Previous strip correction



Performance characterization of the Micromegas detector for the New Small Wheel upgrade and Development and improvement of the Muon Spectrometer Detector Control System in the ATLAS experiment
K.A. Ntekas

Results (up to now)

Resolution C.C.

45° -> ~ 520 µm

35° -> ~ 390 µm

Resolution µTPC

45° -> ~ 310 µm

35° -> ~ 220µm

Rough corrections →

Resolution µTPC

45° -> ~ 280 µm

35° -> ~ 180µm

Summary and outlook

- CIVETTA now includes μ-TPC
- A specific approach is needed to evaluate the data acquired with TIGER
- The resolution is improving with various adjustments and corrections

Next steps

- Improve the time resolution estimation
- Fine tune the existing corrections and add more

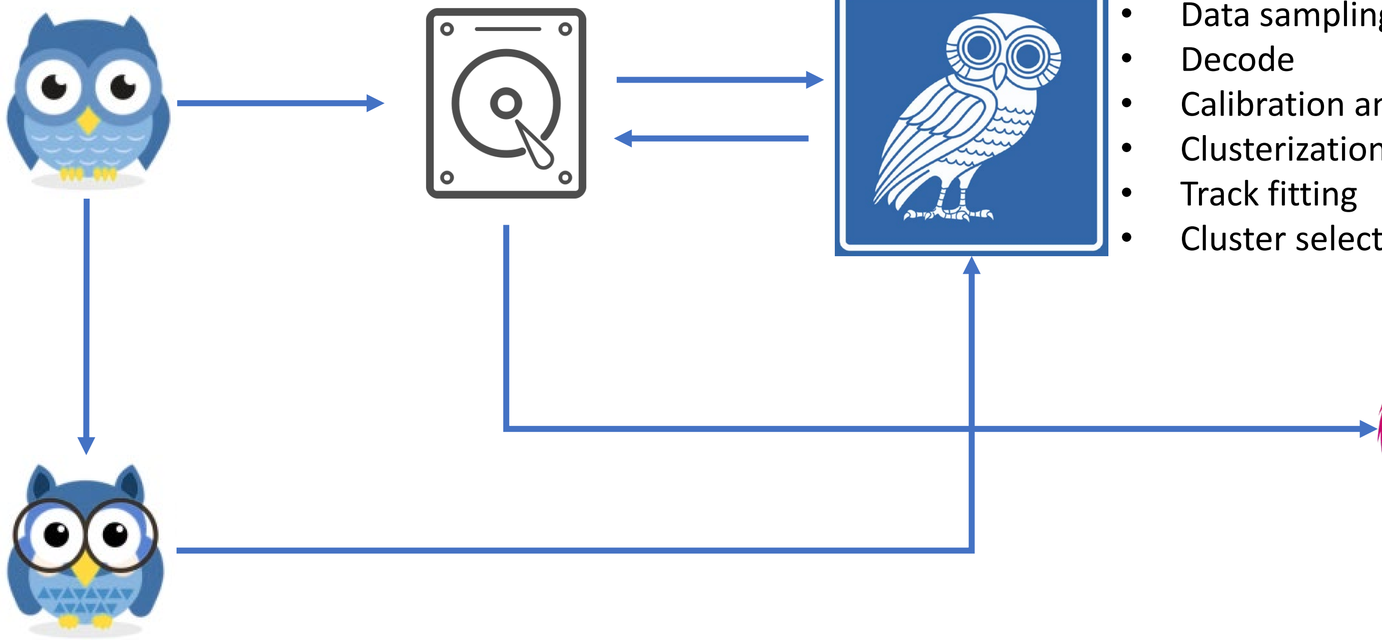
Grazie per l’attenzione

AI generated image from the string
«Time projection chamber» (Mindjourney)

BACKUP

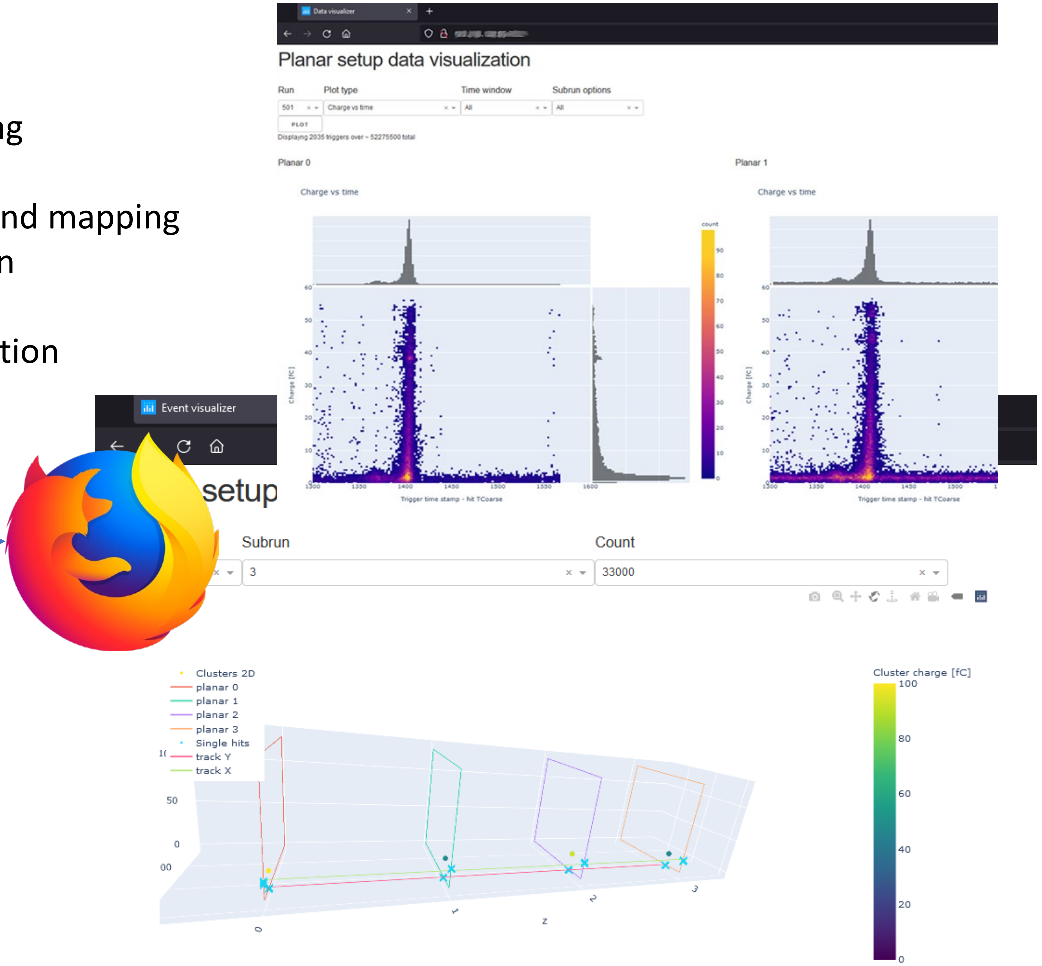
Online monitoring during acquisition

GUFI



CIVETTA

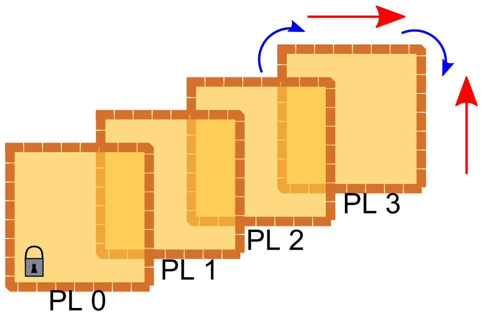
- Data sampling
- Decode
- Calibration and mapping
- Clusterization
- Track fitting
- Cluster selection



GUFI ON

Efficiency

Shift and angular alignment

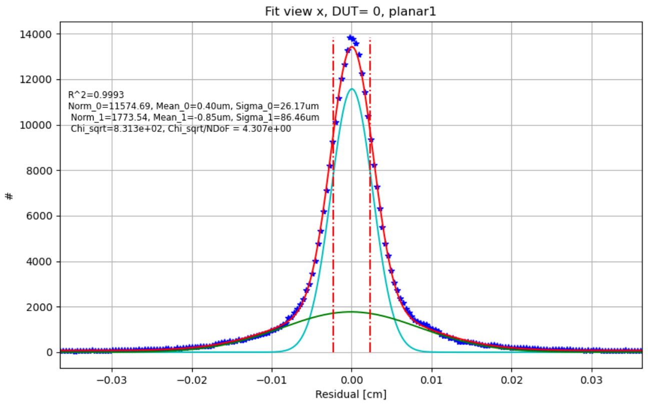


$$\Delta x = ky + c_x$$
$$\Delta y = kx + c_y$$

On the trackers

(3 out of 4 detectors)

Track selection using χ^2 on residual distribution



On the detector under test

- Alignment performed using the reconstructed position on the other view
- Efficiency calculation
- Noise contribution calculation

Example:
X: 0.9716 +/- 0.0009
Prob noise eff = 7.337E-03 +/- 2.882E-06
Real eff = 0.9714 +/- 0.0009

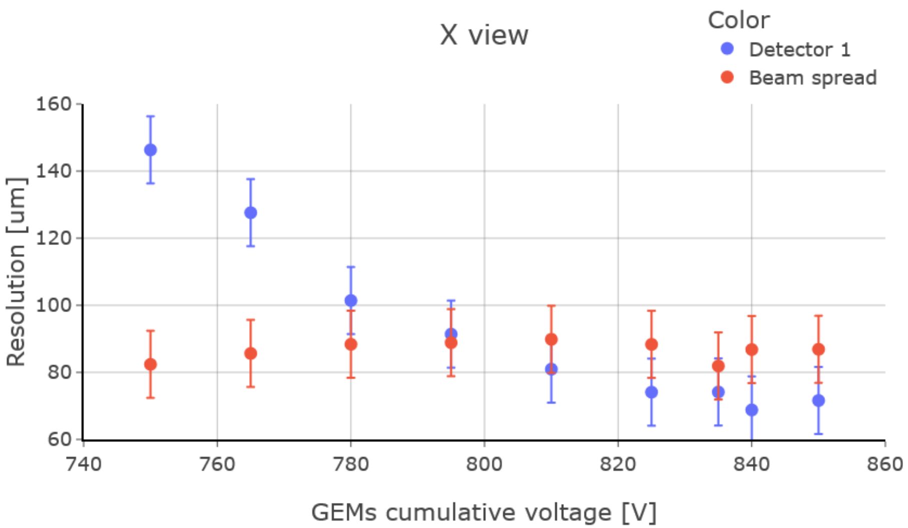
Y: 0.9663 +/- 0.0010
Prob noise eff = 4.977E-03 +/- 3.356E-06
Real eff = 0.9662 +/- 0.0010

Resolution

Taking into account the beam spread, the reconstructed position on each planar is compared with the one reconstructed by the others

Verified with:

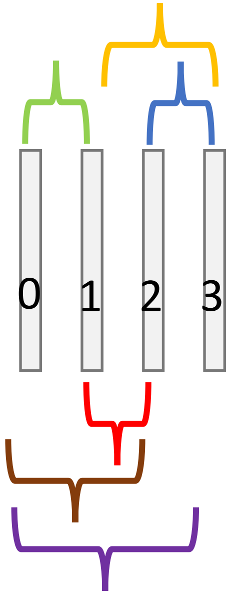
- Toy Montecarlo
- $\sigma_\Theta \sim 3\sigma_\theta$
- Beam spread doesn't change with HV scan:



Std dev of the distribution:
positions measured by 0 – positions measured by 1

Resolution planar 0

Beam spread



$$\sigma_{01} = \sqrt{\sigma_0{}^2 + \sigma_1{}^2 + \sigma_\theta{}^2}$$

$$\sigma_{12} = \sqrt{\sigma_1{}^2 + \sigma_2{}^2 + \sigma_\theta{}^2}$$

$$\sigma_{23} = \sqrt{\sigma_2{}^2 + \sigma_3{}^2 + \sigma_\theta{}^2}$$

$$\sigma_{02} = \sqrt{\sigma_0{}^2 + \sigma_2{}^2 + (2\sigma_\theta)^2}$$

$$\sigma_{13} = \sqrt{\sigma_1{}^2 + \sigma_3{}^2 + (2\sigma_\theta)^2}$$

$$\sigma_{03} = \sqrt{\sigma_0{}^2 + \sigma_3{}^2 + \sigma_\Theta{}^2}$$

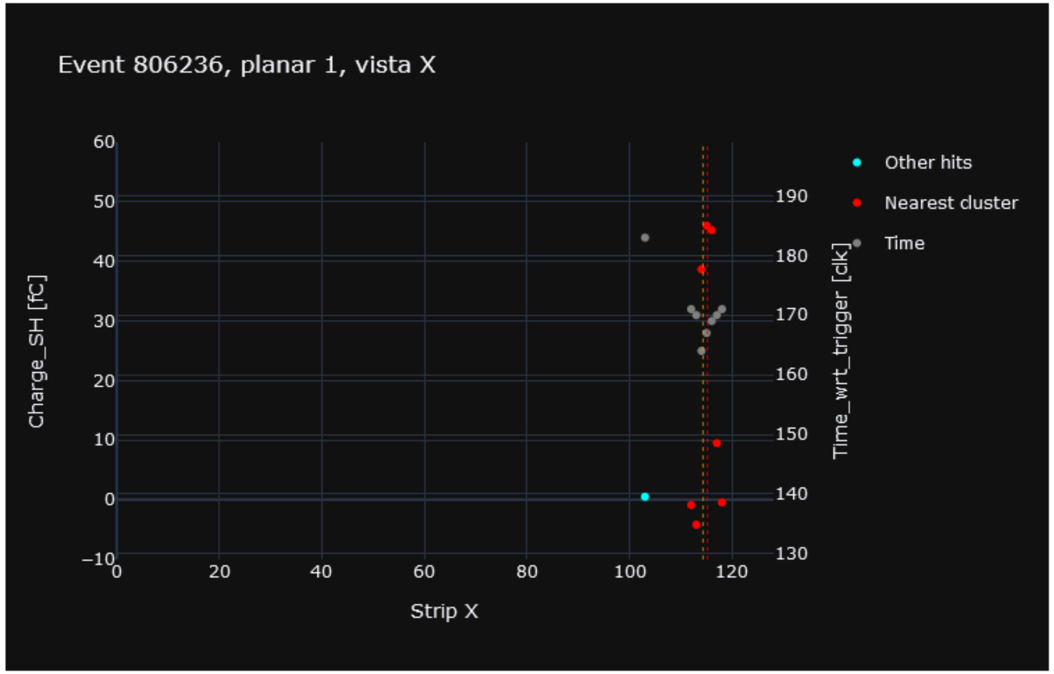
$\sigma_\Theta \sim 3\sigma_\theta$

Similar to:

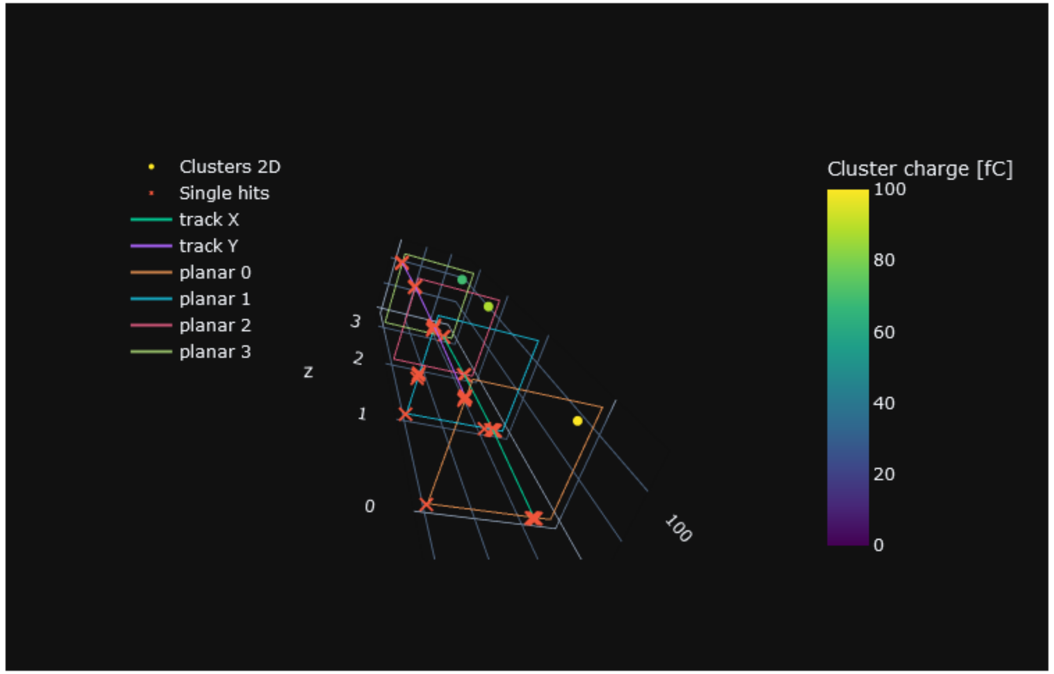
Performance studies of resistive-strip bulk micromegas detectors in view of the ATLAS New Small Wheel upgrade
T. Alexopoulos

Example:
σ_0 = 92 µm
σ_1 = 81 µm
σ_2 = 78 µm
σ_3 = 77 µm
σ_θ = 90 µm
σ_Θ = 267 µm

Event visualization



1D, single view, charge and time

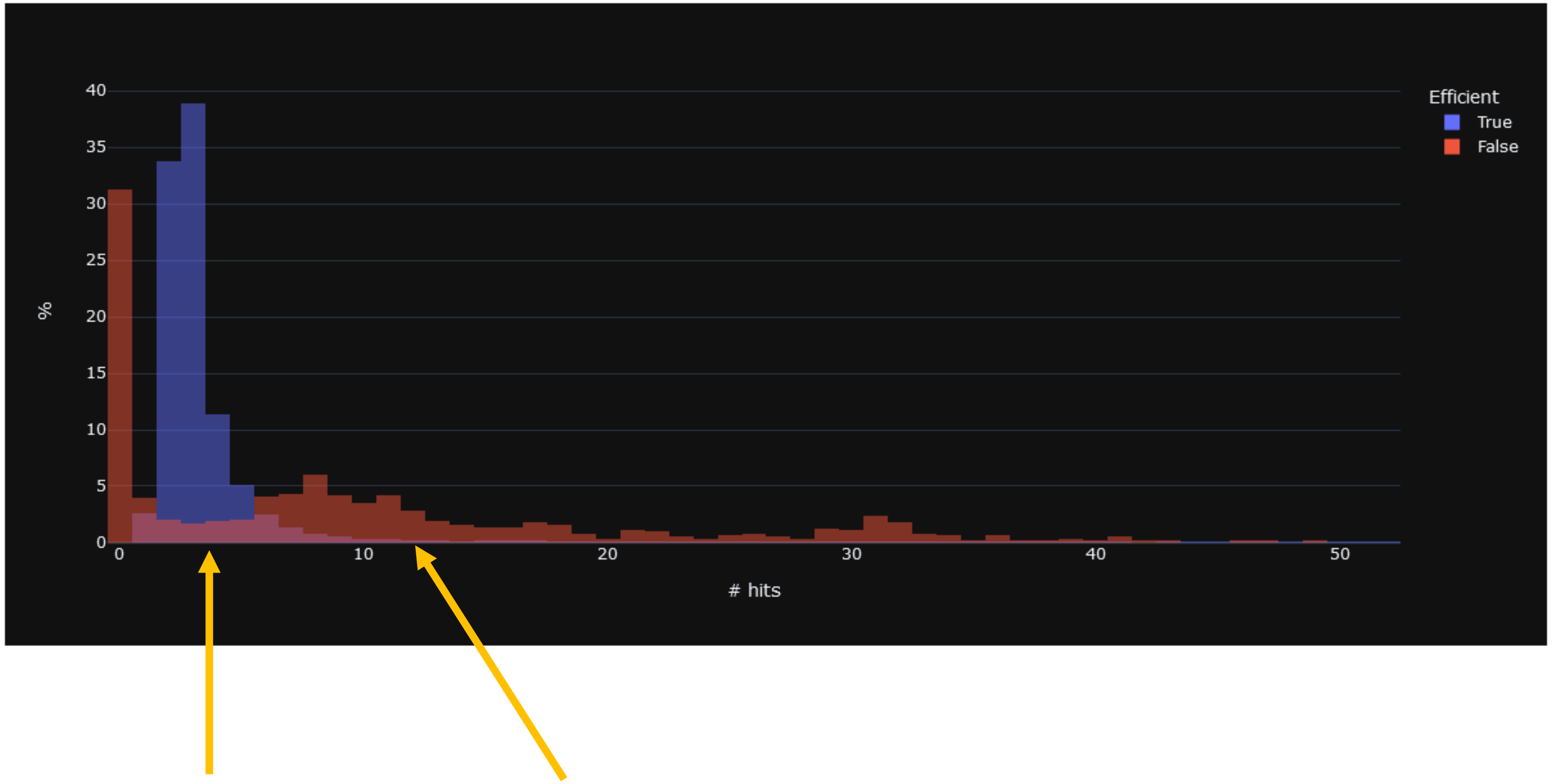


3D, full system

Useful to study non efficient events

Non efficient events

Two kind of non efficient events



Not enough hits

Too many hits

Example run:
4.7 % events non efficient on X view

Non efficient events: **too many** hits

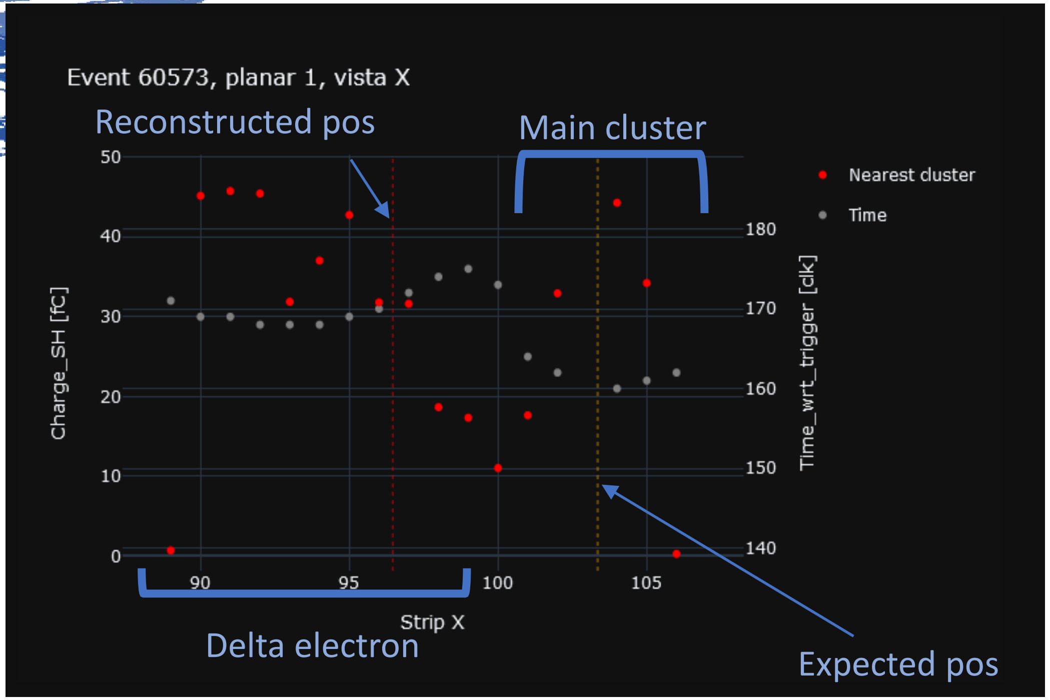
Two kinds of events:

Delta ray (many hits, high charge):

Intrinsic detector phenomenon

Main cluster can be reconstructed with advanced analysis method

Example run:
~38 % event non efficient on X view
~1.8 % of total events



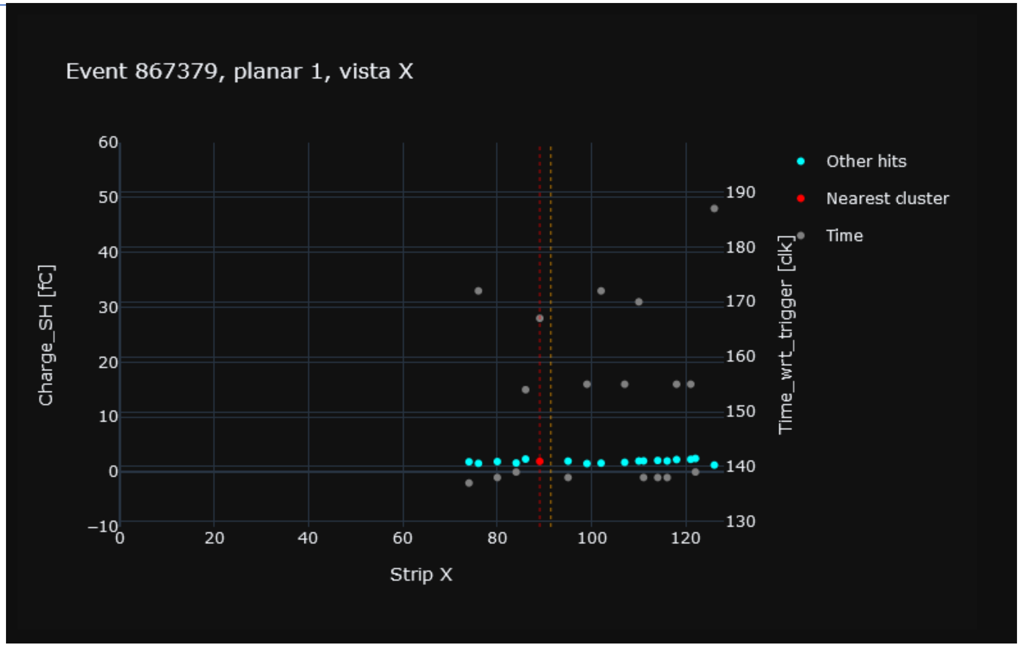
Noise spikes (many hits, low charge):

Fluctuation on the common levels causes many channels on the same TIGER to fire

I am working on:

- Use TIGER integrated Hysteresis on the discriminators to filter the noise keeping the same threshold
- Expand the GEMROC buffering capabilities
- Search for similar noise sources on the CGEM-IT

Example run:
~22 % event non efficient on X view



Non efficient events: **too few** hits

Two kind of events:

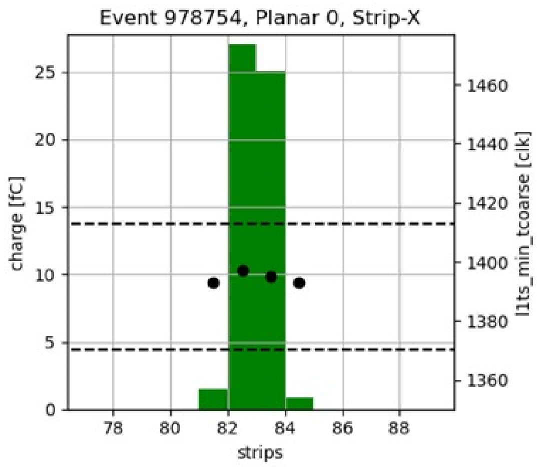
Empty events

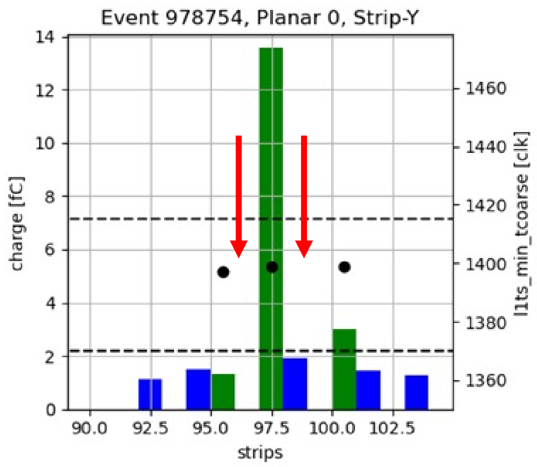
Probably due to a previous noise peak

Example run:
~21 % of non efficient events

Firmware solution under test

Single missing hits





Efficiency – initial elements

Alignment:

In the shape $\Delta x = ky + c$ e $\Delta y = kx + c$ (corrected reference)

1D clusters :

Position with Charge Centroid (planar reference)

Track building

1 Detector under test
3 Tracking detectors

1. For each tracker, the cluster with more charge is selected
2. Only events with at least one cluster on each view, on each tracker are selected
3. The position of the cluster on each view is corrected using the position on the other view
4. Track fit (3 points)

Track selection

1. The residual on each tracking detector is calculated and fit with a double gaussian
2. The standard deviation of this distribution is calculated averaging the standard deviation off each gaussian weigthed over their integral
3. For each track, the χ^2 is calculated as:

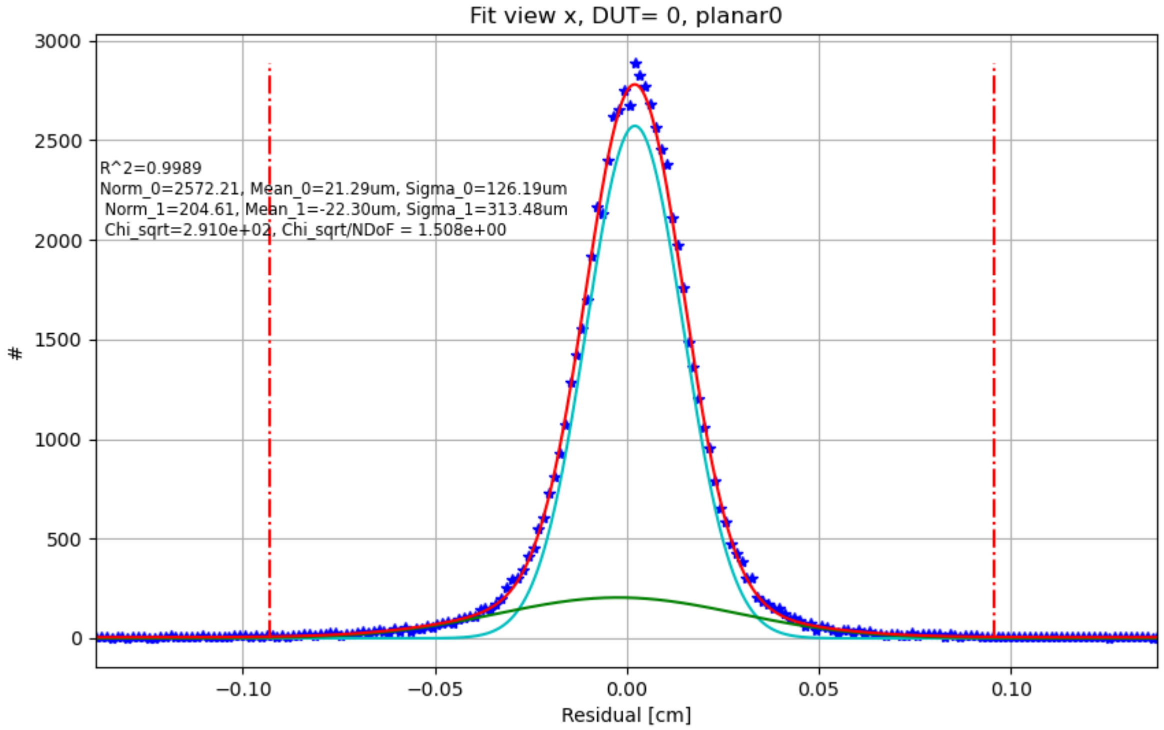
$$\chi^2 = \sum_{i=1}^{6} \left(\frac{r_i}{\sigma_i} \right)^2$$

With:
r_i residual (2 view, 3 detectors)
σ_i standard deviation of the residual distribution

4. Cut track with χ^2 >20

Efficiency interval calculation

1. From all the good tracks, take the 4 points events
2. Calculate the non inclusive residual on the test detector
3. Double gaussian fit
4. Double gaussian standard deviation as the average of the deviations weighted over the integral
5. The interval considered for the efficiency is at 6 standard deviations. The percentage of integral from the residual distribution under this interval is stored in the log file.



Efficiency measurement

For each good track:

1. Extrapolate the position on the detector under test
2. Take the 1D clusters and apply the alignment using the position from the track on the other view
3. If at least one cluster is in the efficiency interval, the event is efficient in its view

$$E_m = \frac{k}{n}$$

Efficiency measured ← E_m

k → Efficient events

n → Good tracks

$$\sigma_{E_m} = \sqrt{\frac{(k+1)*(k+2)}{(n+2)*(n+3)} - \frac{(k+1)^2}{(n+2)^2}}$$

https://arxiv.org/pdf/physics/0701199v1.pdf
https://indico.cern.ch/event/66256/contributions/2071577/attachments/1017176/1447814/EfficiencyErrors.pdf

Ex:
-Eff dut 0:
X:0.9702 Y:0.9643

Efficiency in range [3.2,7.8]

X: 0.9733 +/- 0.0009

Y: 0.9660 +/- 0.0010

Noise impact

$$E_m = P_+$$

P_+ Positive porbability
E_m Measured efficiency

$$P_- = 1 - P_+ = (1 - P_N) \cdot (1 - P_E)$$

$$1 - P_+ = 1 - P_N - P_E + P_N P_E$$

$$P_+ = P_N + P_E - P_N P_E$$

$$P_E = \frac{P_+ - P_N}{1 - P_N}$$

P_N Noise probability (false positive)
P_- Negative probability
P_E Efficient probability (real positive)

$$P_N = 1 - \overline{P_N}$$

$$\overline{P_N} = f(k;l)^n$$

$f(k;l)$ Poisson distr. k = 0, l = rate noise
n Number of strips in the efficiency interval

$$n = round\left(\frac{t \cdot 2}{0.00650}\right)$$

t Efficiency interval

Ex
Planar 0
X: 0.9716 +/- 0.0009
Prob noise eff = 7.337E-03 +/- 2.882E-06
Real eff = 0.9714 +/- 0.0009

Y: 0.9663 +/- 0.0010
Prob noise eff = 4.977E-03 +/- 3.356E-06
Real eff = 0.9662 +/- 0.0010

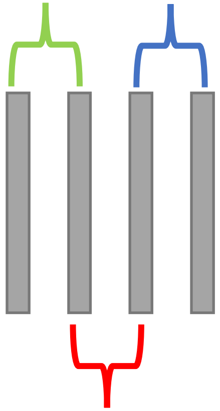
Detailed resolution procedure

From Alexopoulos article

The spatial resolution σx is determined by comparing the positions reconstructed in two chambers of the same type. This method assumes that within the distance d between the two chambers the angular spread of the beam $\sigma\theta$ is negligible with respect to $\sigma x/d$. For the typical case of $d \sim$ 20 cm and $\sigma\theta \sim$ 100 µrad the contribution from he beam divergence to the micromegas spatial resolution amounts to $\sim$20 µm, to be added in quadrature to the intrinsic spatial resolution of the detectors.

Performance studies of resistive-strip bulk micromegas detectors in view of the ATLAS New Small Wheel upgrade
T. Alexopoulos

Residual with respect to next detector

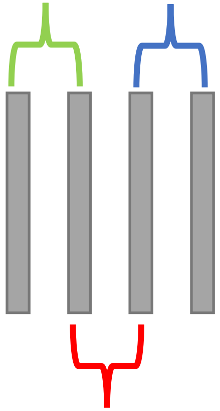


$$\sigma_{01} = \sqrt{{\sigma_0}^2 + {\sigma_1}^2 + {\sigma_\theta}^2}$$
$$\sigma_{12} = \sqrt{{\sigma_1}^2 + {\sigma_2}^2 + {\sigma_\theta}^2}$$
$$\sigma_{23} = \sqrt{{\sigma_2}^2 + {\sigma_3}^2 + {\sigma_\theta}^2}$$

σ_{ij}	Sigma (from gauss fit) of the enemy distribution between palanar i ad j
σ_i	Detector i intrinsic resolution
σ_θ	Beam spread contribution in 10 cm

3 equations, 4 unknown values

Without beam divergence



$$\sigma_{01} = \sqrt{{\sigma_0}^2 + {\sigma_1}^2 + {\sigma_\theta}^2}$$
$$\sigma_{12} = \sqrt{{\sigma_1}^2 + {\sigma_2}^2 + {\sigma_\theta}^2}$$
$$\sigma_{23} = \sqrt{{\sigma_2}^2 + {\sigma_3}^2 + {\sigma_\theta}^2}$$

σ_{ij}	Sigma (from gauss fit) of the enemy distribution between palanar i ad j
σ_i	Detector i intrinsic resolution
σ_θ	Beam spread contribution in 10 cm

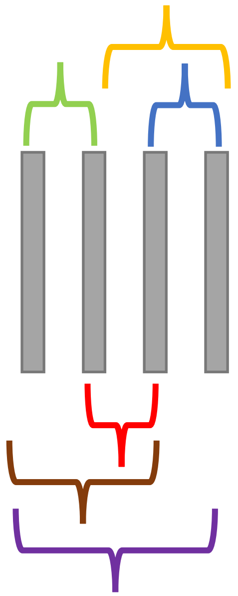
Ex. taking $\sigma_0 \sim \sigma_1$ e $\sigma_\theta << \sigma_0$

$\sigma_{01} = 152\ \mu\text{m}$
$\sigma_{12} = 144\ \mu\text{m}$ →
$\sigma_{23} = 142\ \mu\text{m}$

$$\sigma_0 = \frac{\sigma_{01}}{\sqrt{2}} = 107\ \mu\text{m}$$
$$\sigma_1 = \frac{(\sigma_{01}+\sigma_{12})}{2\sqrt{2}} = 105\ \mu\text{m}$$
$$\sigma_2 = \frac{(\sigma_{12}+\sigma_{23})}{2\sqrt{2}} = 101\ \mu\text{m}$$
$$\sigma_3 = \frac{\sigma_{23}}{\sqrt{2}} = 100\ \mu\text{m}$$

$\sigma_\theta << \sigma_0$?
https://cds.cern.ch/record/2650989/files/PBC%20Report.pdf
Depends by beam setting

Adding more equation



$$\sigma_{01} = \sqrt{\sigma_0{}^2 + \sigma_1{}^2 + \sigma_\theta{}^2}$$

$$\sigma_{12} = \sqrt{\sigma_1{}^2 + \sigma_2{}^2 + \sigma_\theta{}^2}$$

$$\sigma_{23} = \sqrt{\sigma_2{}^2 + \sigma_3{}^2 + \sigma_\theta{}^2}$$

$$\sigma_{02} = \sqrt{\sigma_0{}^2 + \sigma_2{}^2 + (2\sigma_\theta)^2}$$

$$\sigma_{13} = \sqrt{\sigma_1{}^2 + \sigma_3{}^2 + (2\sigma_\theta)^2}$$

$$\sigma_{03} = \sqrt{\sigma_0{}^2 + \sigma_3{}^2 + \sigma_\Theta{}^2}$$

To check:
$\sigma_\Theta \sim 3\sigma_\theta$

6 equations, 6 unknown values

Example

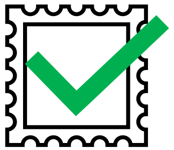
System solution [μm]:

σ_0 = 92
σ_1 = 81
σ_2 = 78
σ_3 = 77
σ_θ = 90
σ_Θ = 267

Test 1:

$$\sigma_\Theta \sim 3\sigma_\theta$$

σ_Θ = 267
$3\sigma_\theta$ = 270



Test 2

Montecarlo simulation

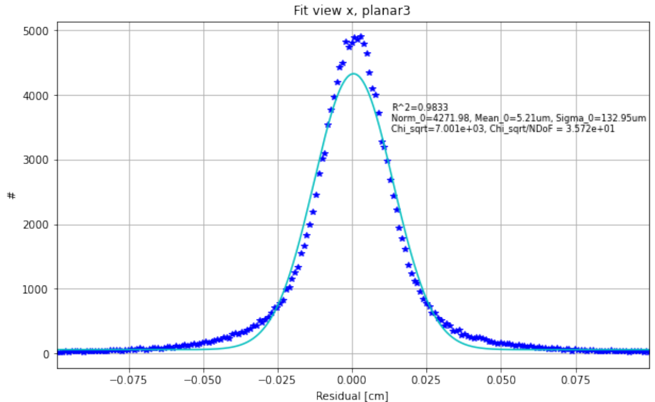
20.000 simulated tracks on 4 planes. Using the calculated resolution for the 4 detectors check what how the residual changes to the residuals

Std dev residual distribution without beam divergence:

190 μm
125 μm
120 μm
185 μm

Std dev residual distribution with beam divergence:

154 μm
99 μm
94 μm
147 μm



Std dev residual (single gaussian fitting):

146 μm
94 μm
81 μm
132 μm

Example: run 564

Efficiency

Planar 0
X: 0.9732 +/- 0.0010
Prob noise eff = 9.259E-03 +/- 3.743E-06
Real eff = 0.9729 +/- 0.0010

Y: 0.9676 +/- 0.0010
Prob noise eff = 6.645E-03 +/- 4.194E-06
Real eff = 0.9674 +/- 0.0011

AND eff
AND: 0.9469 +/- 0.0013
Prob noise eff = 2.644E-05 +/- 2.995E-08
Real eff = 0.9469 +/- 0.0013

Planar 1
X: 0.9609 +/- 0.0012
Prob noise eff = 5.938E-03 +/- 3.963E-06
Real eff = 0.9607 +/- 0.0012

Y: 0.9755 +/- 0.0009
Prob noise eff = 2.415E-02 +/- 9.333E-06
Real eff = 0.9749 +/- 0.0010

AND eff
AND: 0.9455 +/- 0.0014
Prob noise eff = 7.181E-05 +/- 9.965E-08
Real eff = 0.9455 +/- 0.0014

Planar 2
X: 0.9551 +/- 0.0012
Prob noise eff = 6.460E-03 +/- 4.134E-06
Real eff = 0.9549 +/- 0.0012

Y: 0.9623 +/- 0.0011
Prob noise eff = 2.739E-03 +/- 3.803E-06
Real eff = 0.9622 +/- 0.0011

AND eff
AND: 0.9300 +/- 0.0015
Prob noise eff = 8.862E-06 +/- 1.672E-08
Real eff = 0.9300 +/- 0.0015

Planar 3
X: 0.9664 +/- 0.0011
Prob noise eff = 1.010E-02 +/- 4.225E-06
Real eff = 0.9661 +/- 0.0011

Y: 0.9684 +/- 0.0010
Prob noise eff = 3.941E-03 +/- 3.725E-06
Real eff = 0.9683 +/- 0.0010

AND eff
AND: 0.9437 +/- 0.0014
Prob noise eff = 1.995E-05 +/- 2.515E-08
Real eff = 0.9437 +/- 0.0014

Resolution

Planar 0 view x: Sigma_0=112.07 um, Sigma_1=259.82 um, error tracking: 95.67 um
Planar 0 view y: Sigma_0=109.32 um, Sigma_1=305.45 um, error tracking: 95.92 um
Planar 1 view x: Sigma_0=70.38 um, Sigma_1=158.98 um, error tracking: 36.13 um
Planar 1 view y: Sigma_0=68.25 um, Sigma_1=191.18 um, error tracking: 33.39 um
Planar 2 view x: Sigma_0=64.14 um, Sigma_1=157.80 um, error tracking: 41.10 um
Planar 2 view y: Sigma_0=62.09 um, Sigma_1=132.52 um, error tracking: 52.63 um
Planar 3 view x: Sigma_0=98.10 um, Sigma_1=250.02 um, error tracking: 99.66 um
Planar 3 view y: Sigma_0=97.91 um, Sigma_1=232.22 um, error tracking: 128.84 um

--Enemy residual--

--Enemy residual x--

Couple: (0, 1): 0.015198357672251805 cm
Couple: (1, 2): 0.014404786859136154 cm
Couple: (2, 3): 0.014189314977784806 cm
Couple: (0, 2): 0.02165354472714759 cm
Couple: (1, 3): 0.021162411951882787 cm
Couple: (0, 3): 0.029306071005829548 cm
System solution:
(0.00920426246712921, 0.00809560402131984, 0.00782472083126620, 0.00770568488530741, 0.00898514462320344, 0.0267348044818596)

--Enemy residual y--

Couple: (0, 1): 0.015198357672251805 cm
Couple: (1, 2): 0.014404786859136154 cm
Couple: (2, 3): 0.014189314977784806 cm
Couple: (0, 2): 0.02165354472714759 cm
Couple: (1, 3): 0.021162411951882787 cm
Couple: (0, 3): 0.029306071005829548 cm
System solution:
(0.00920426246712921, 0.00809560402131984, 0.00782472083126620, 0.00770568488530741, 0.00898514462320344, 0.0267348044818596)

Study on the χ^2 cut