TPC studies using GEM and Micromegas readouts, Ar-CF_4-isobutane gas, in a magnetic field

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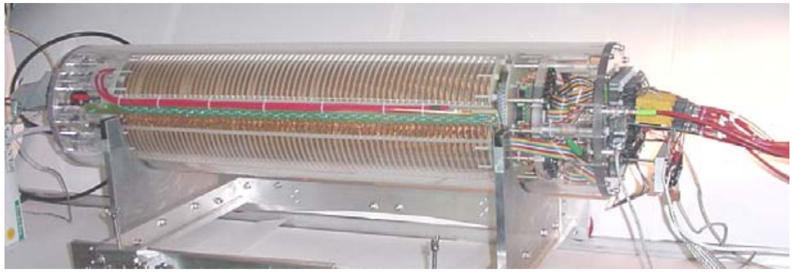
This project is supported, in part, by
the US National Science Foundation (LCDRD award)
and by the US Department of Energy (Purdue HEP group base grant).
This project is in collaboration with LC-TPC.

in this talk …

measurements using
the small prototype TPC at Cornell

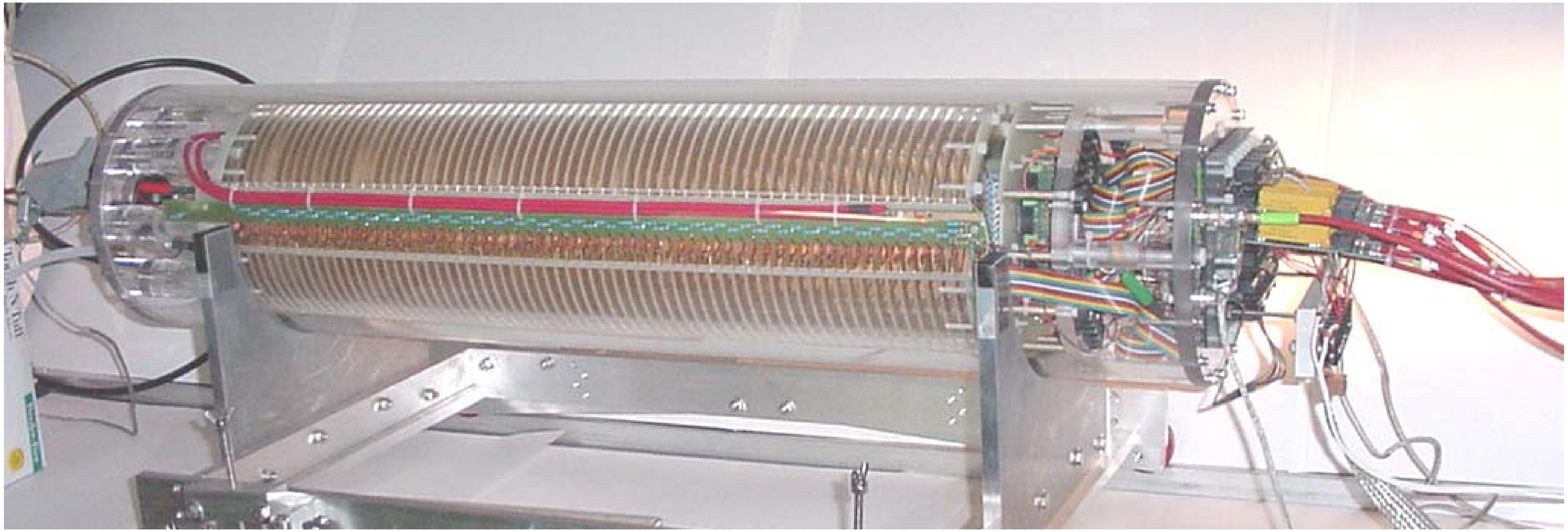


triple-GEM(standard) B=0, 1.0, 1.45 Tesla, T2K gas:Ar-CF_4-isobutane 95:3:2

bulk Micromegas B=0, 1.0, 1.45 Tesla, T2K gas

for calibration
triple-GEM B=1.0, TDR gas: Ar-CH_4-CO_2 93:5:2

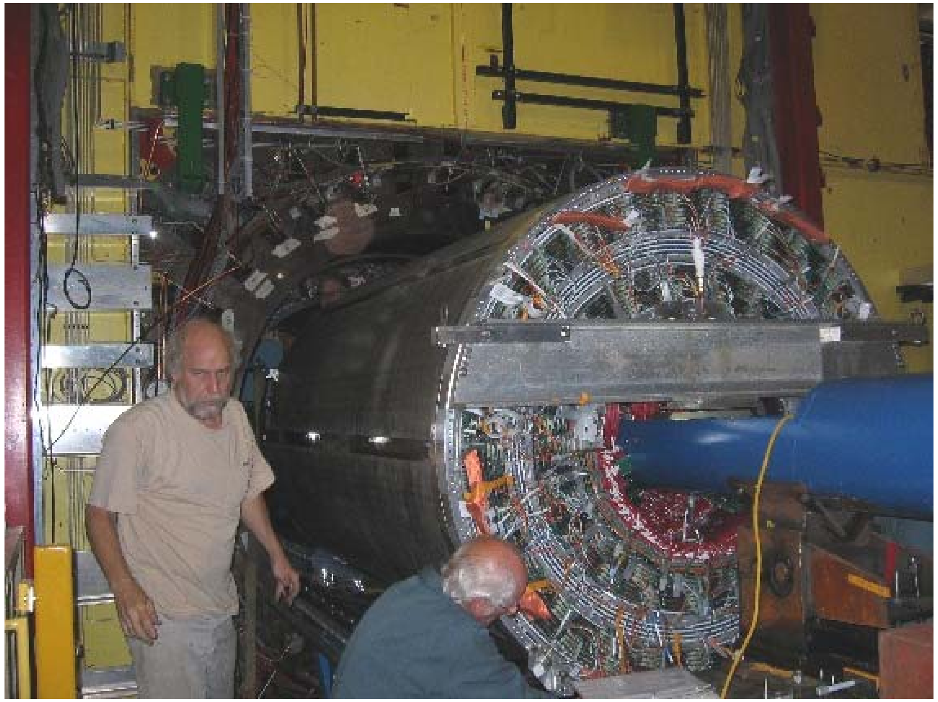
same chamber, gas, magnetic field, pad geometry, readout, analysis
unfortunately, different gain.

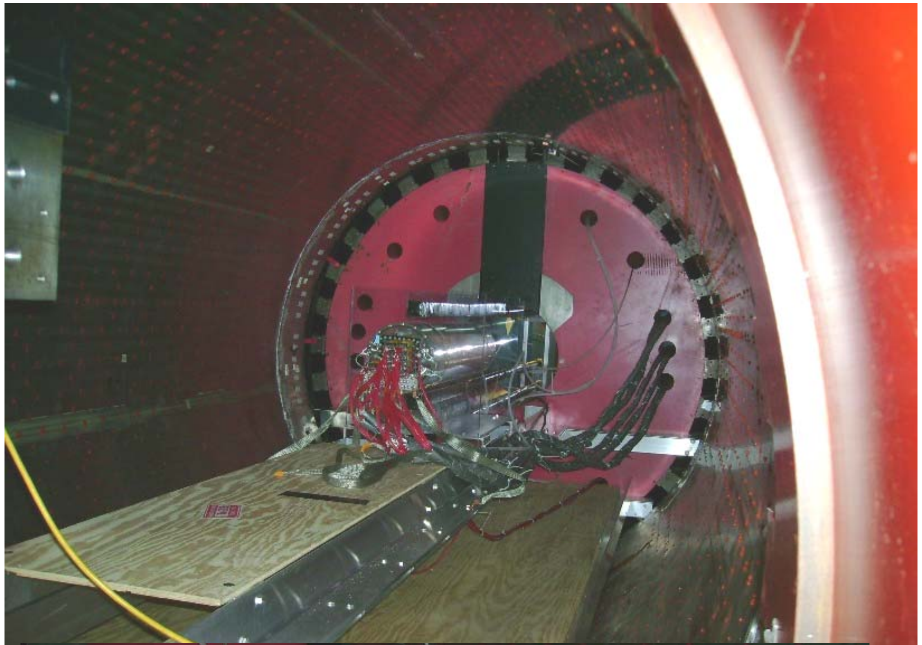


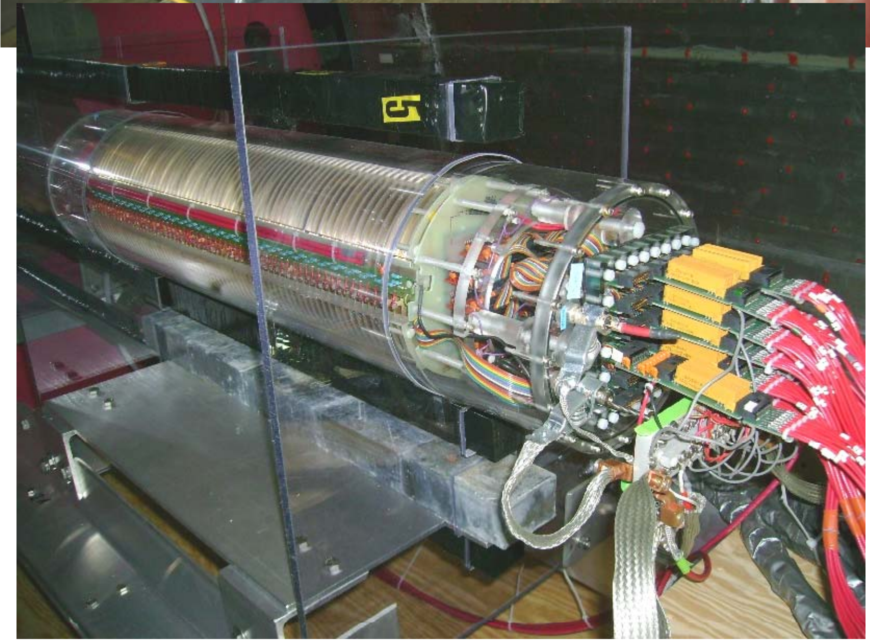
14.6 cm ID field cage - accommodates a 10 cm gas amplification device
64 cm drift field length
22.2 cm OD outer structure (8.75 inch)

HV is separately controlled on the cathode (20kV max) ,
field cage termination,
gas amplification device.
Voltage distribution differs from others; ground is at the end of the drift field,
allowing independent control of the gas amplification.

Readout is 88 channels, Struck FADC, 105 MHz (run at 25 MHz), circular buffer
14 bit, +/- 200 mV input (least count is 25 μV)







The CLEO magnet…
1.5 Tesla, 1 meter radius, 2 meter length

July 2008,
removed the tracking chambers and RICH
from the CLEO magnet

installed
small prototype TPC, and trigger scintillators
with room to spare.

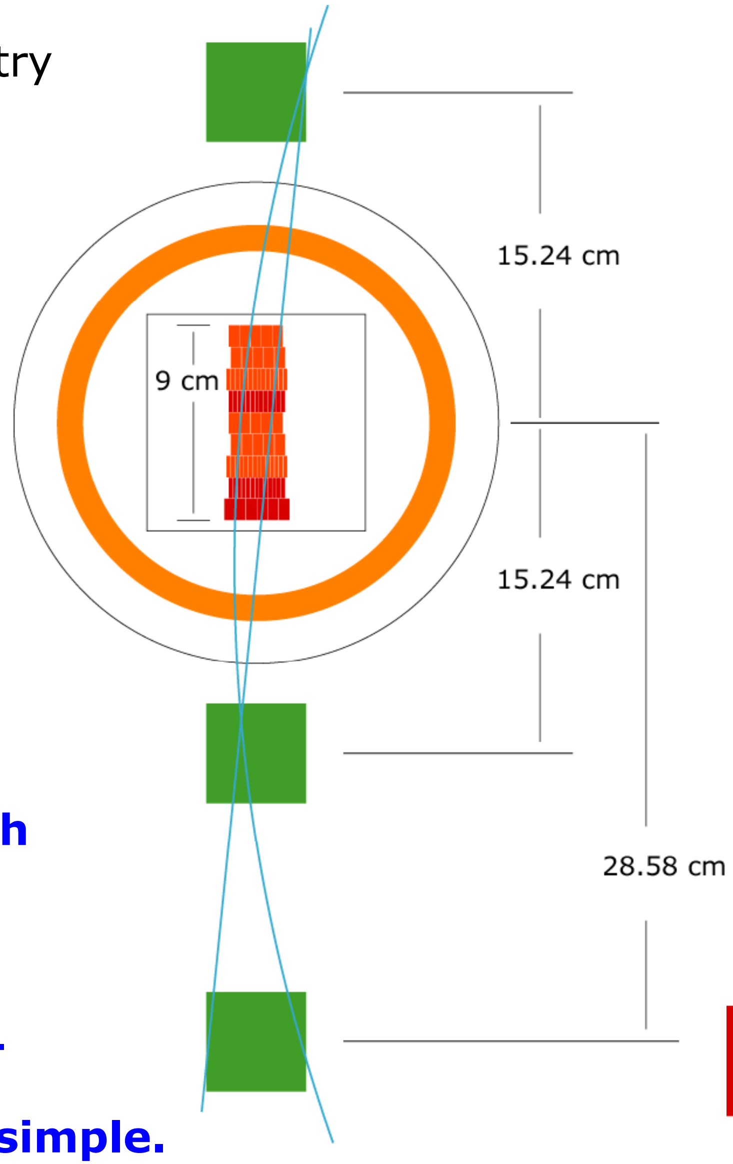
at near right:
TPC and Trigger scintillator geometry
3 scintillators, 4.6cm square

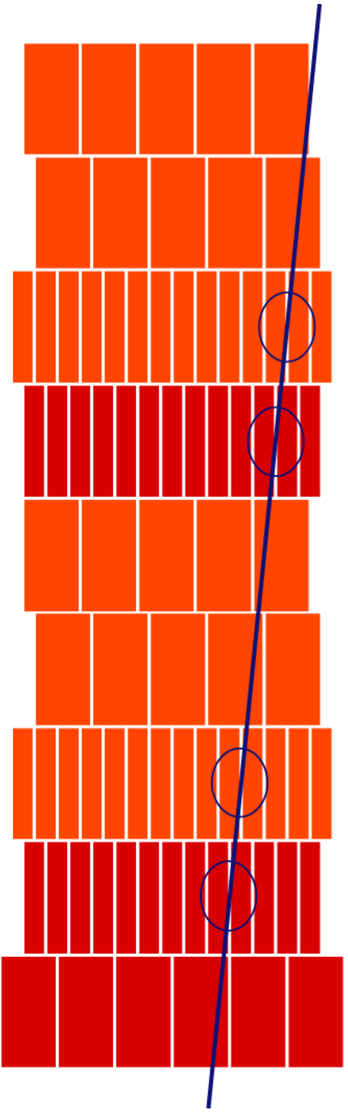
at far right:
Pad geometry
9 layers
4 layers have 2mm x 10 mm cells
5 layers have 5mm x 10mm cells

two tracks that satisfy the trigger:
1) straight, with TAN(θ)=0.1
2) diameter=1.6 meter
P=348 MeV/c at 1.45Tesla
(minimum momentum)

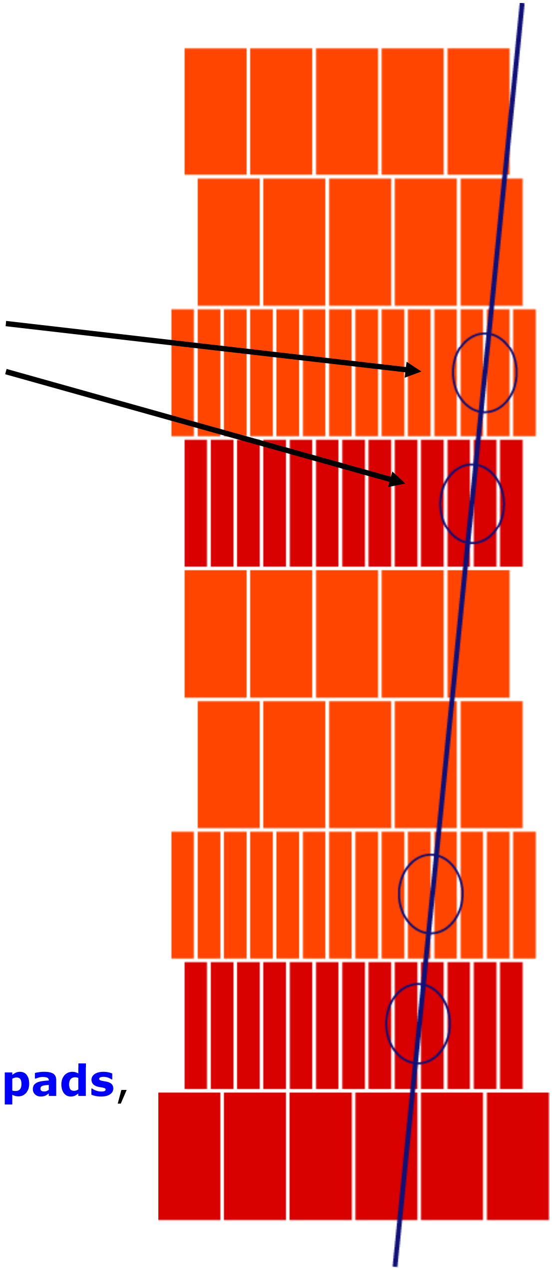
Measurements of the **charge-width** include a
contribution from the track angle,
distributed within the acceptance.
This is simply corrected/subtracted.

Other complications are not so simple.





Measurement of the **point-resolution** is complicated by the use of large (2mm) pads, coupled with narrow charge-width.



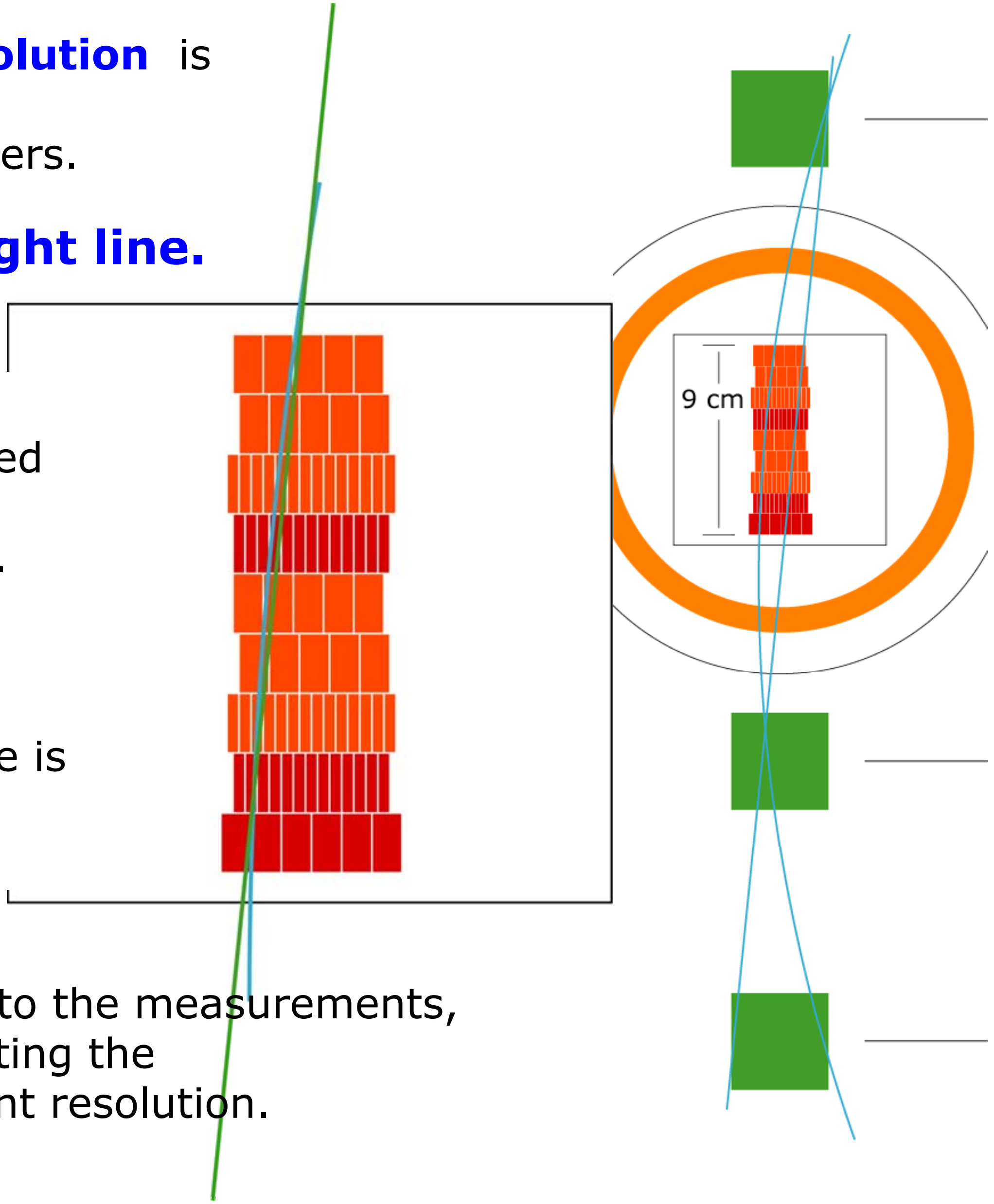
Resolution measurements are based on differences of residuals with respect to a track fit.
Note that this sample track, with TAN(θ)=0.1, can satisfy charge-sharing in pairs of layers , even with a charge-width of zero.
With small charge-width, and requiring charge-sharing, tracks will be selected, biased to this track angle.

When charge is shared, it is spread over only 2 pads.
"Precision" measurements require knowledge of the charge-width-dependent, **non-linear mapping**, from the charge-center-position to the charge-sharing.
This will be described later. (slide 10)

The charge-width, used in the mapping above, must include the **contribution from the track angle projected onto the pads**, applied track-by-track.

Measurement of the **point-resolution** is further complicated by the limited number of 2mm pad layers.

The track fit is to a straight line.

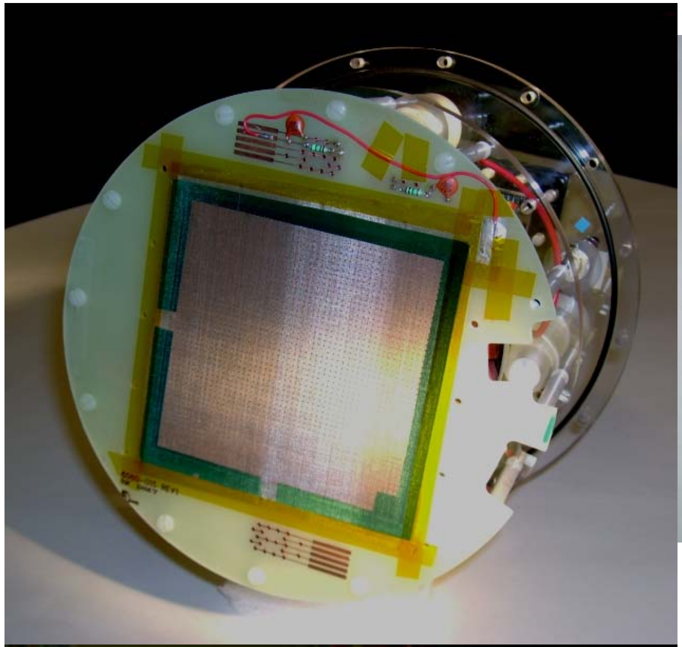


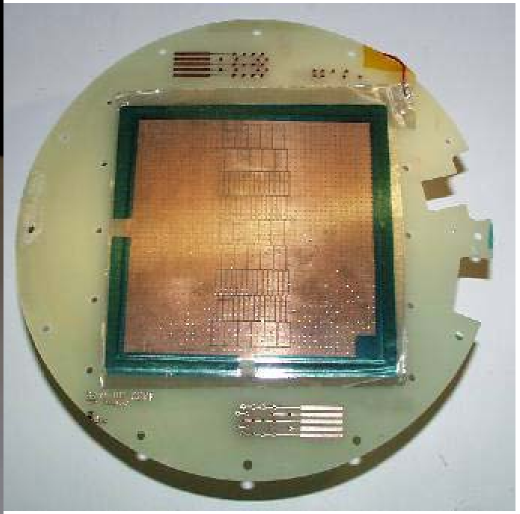
The resulting error in the residual difference was calculated for tracks within the phase space of accepted tracks.

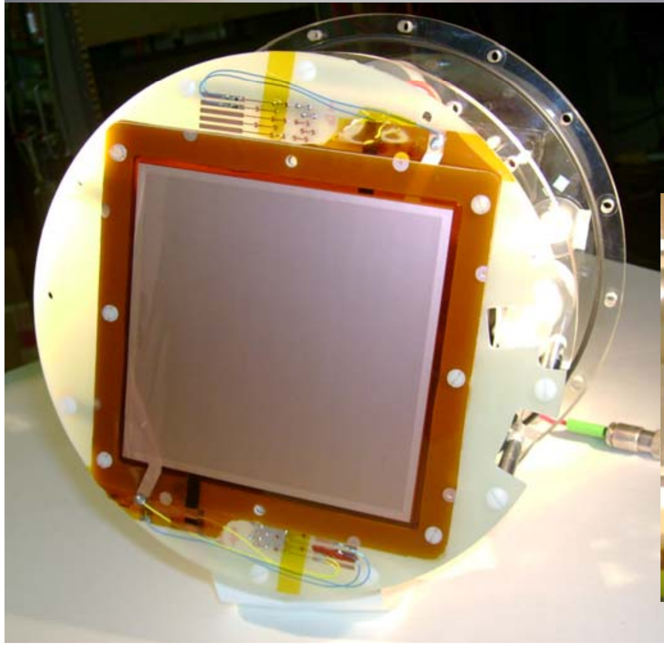
The contribution to the point resolution width, from using a fit to a straight line is

$\sigma \sim 102\ \mu m$.

Understanding the corrections to the measurements, there is still a chance of extracting the inherent charge width and point resolution.







Measurements with
2 gas-amplification devices.

The Micromegas is a
50µm bulk

prepared by
LCTPC collaborators
at Saclay

The triple-GEM is
standard CERN GEMs

prepared by
colleagues at Purdue.

Micromegas

T2K gas, Ar-CF4-isobutane 95-3-2, Edrift=150V/cm
Micromegas voltage: 350 V

Gain is 2.15 x 10^4 (Paul Colas)
The gain was constant from B=0 to 1.45 Tesla, 105 counts

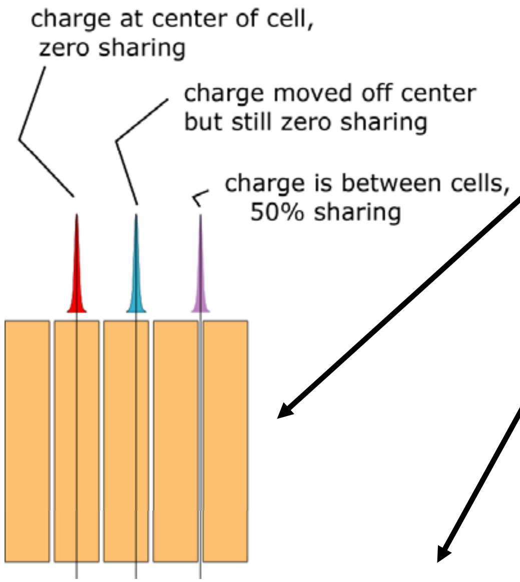
GEM

T2K gas, Ar-CF_4-isobutane 95-3-2, E_{drift}=150V/cm
GEM voltages: 235, 235, 239 V
transfers fields: 1.65 mm, 1540V/cm
1.65 mm, 1550V/cm
1.65 mm, 1454V/cm induction

At B=0, the gain was set to be 1.10 x the gain of the Micromegas.
At B=1.0 and 1.45 Tesla, the gain increased by 1.71,
is **1.88** x the gain of the Micromegas.)

TDR gas, Ar-CH_4-CO_2 93:5:2, E_{drift}=220V/cm
GEM voltages: 315, 315, 315 V
transfers fields: 1.65 mm, 2060V/cm
1.65 mm, 2060V/cm
1.65 mm, 1930V/cm induction

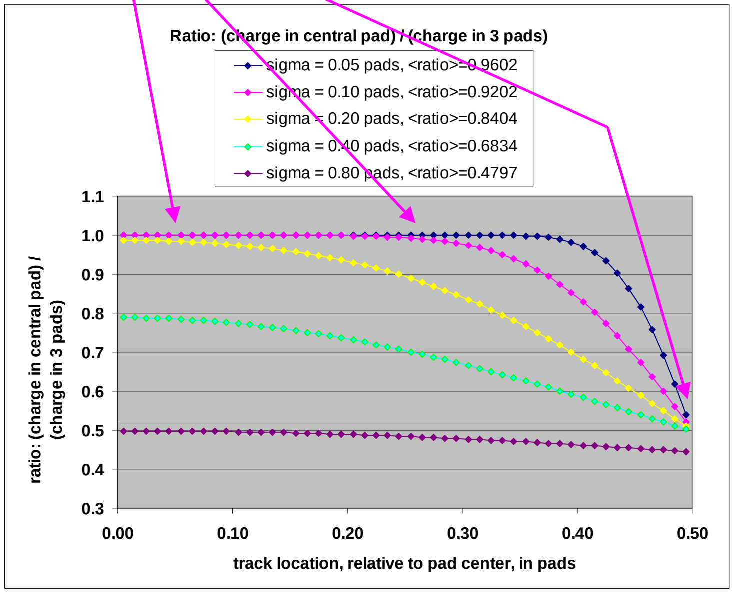
At B=1 Tesla, the gain is 1.35 x the GEM with T2K gas setting,
2.5 x the Micromegas with T2K gas.

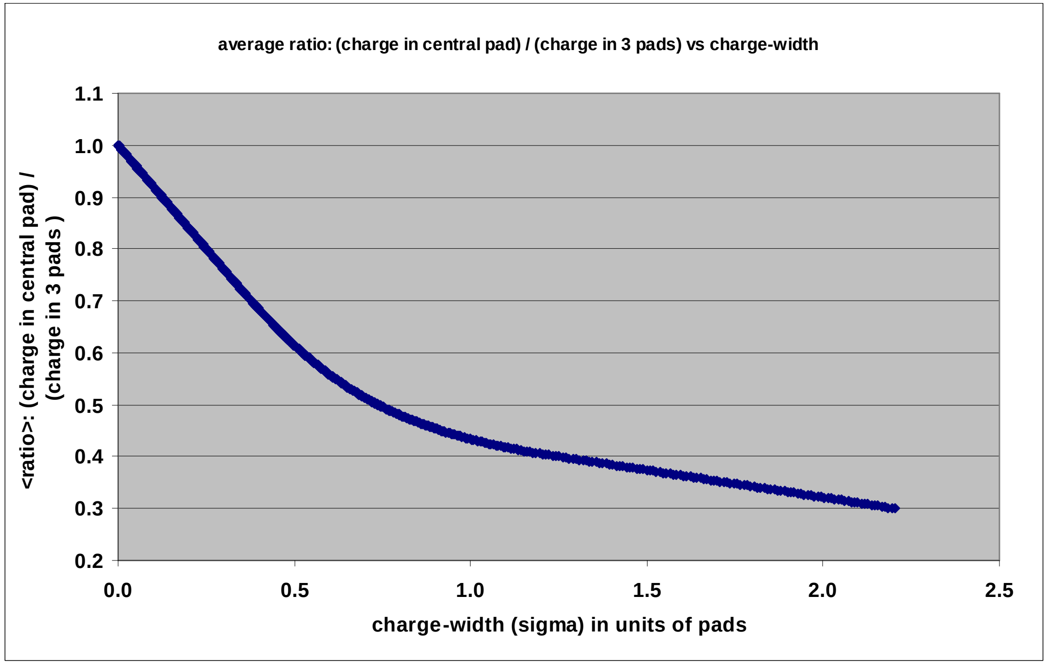


A particular charge-width results in a non-linear response of charge-sharing, w.r.t. charge position.

A family of curves for various values of charge-width. Each results in an *average charge-sharing*.

Plot the *average charge-sharing*, w.r.t. charge-width. This is used to **extract the charge-width** from the **observed average charge-sharing**.





As a comparison,
triple-GEM, TDR gas, 1 Tesla, 220V/cm

Fit to data:

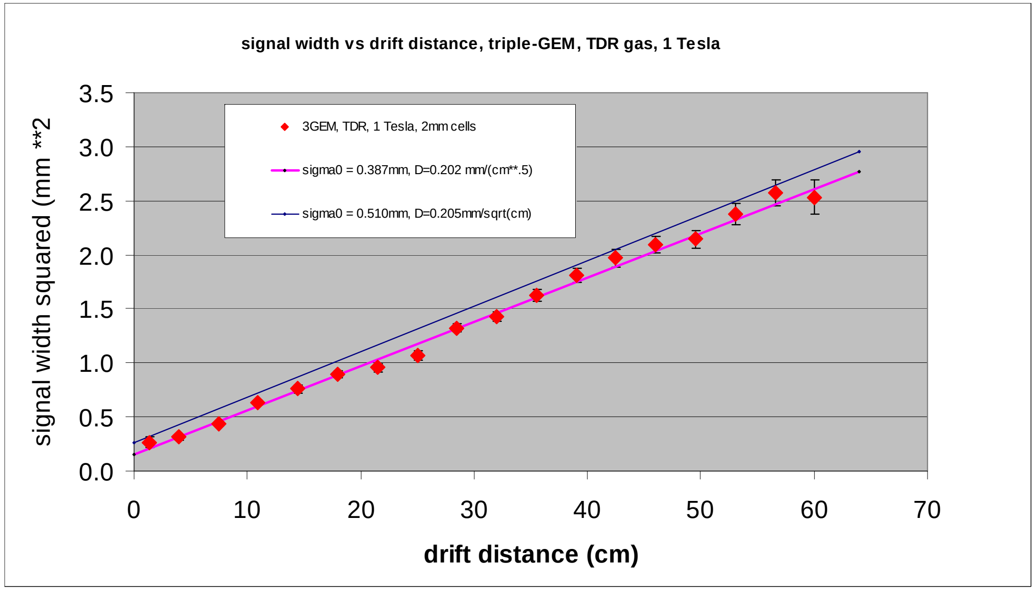
σ_o = 0.387 ± .020 mm

The fitted charge-width includes a contribution from the average track angle, (ref slide 5) TAN(θ)=0.054 :

$0.054 * 10\text{mm} / 12^{1/2} = 0.156$ mm

removing the track angle contribution,

σ_0 (physical) = 0.354 mm .



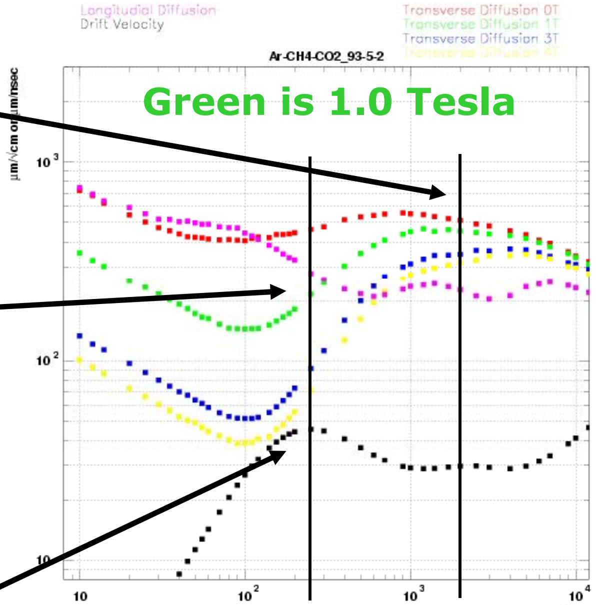
σ_0 is due to diffusion in the gas amplification,.
From Magboltz, with electric field, E=1.9-2.1kV/cm,
D(GEM, Magboltz)=0.45 mm/(cm½),
with drift length in GEM =0.495 cm,
D(GEM, meas)=0.50±0.03 mm/(cm½) 110% of calculated

expect D_t ~0.205 mm /(cm½) Magboltz calculations (Ishikawa),
Victoria result: 0.205 (Karlen, Snowmass 2005)
MPTPC result: 0.207 (M. Kobayashi,Bangalore 2006)

Fit to data:

D_t(this result) = 0.202 ± .002 mm/(cm$^{1/2}$)

drift velocity, observe V_d=43 mm/μs , expect V_d = 45mm/μs,



http://www-hep.phys.saga-u.ac.jp:80/ILC-TPC/gas/

Charge width, T2K gas

σ_0 (mm)	3-GEM	Micromegas
B=0	fixed	fixed
B=1.0 T	(.417±.013)	(.142±.018)
B=1.45 T	(.421±.005)	(.155±.005)
average	.420	.154

(The measured σ_0 does not vary with B, although it is not expected to be.)

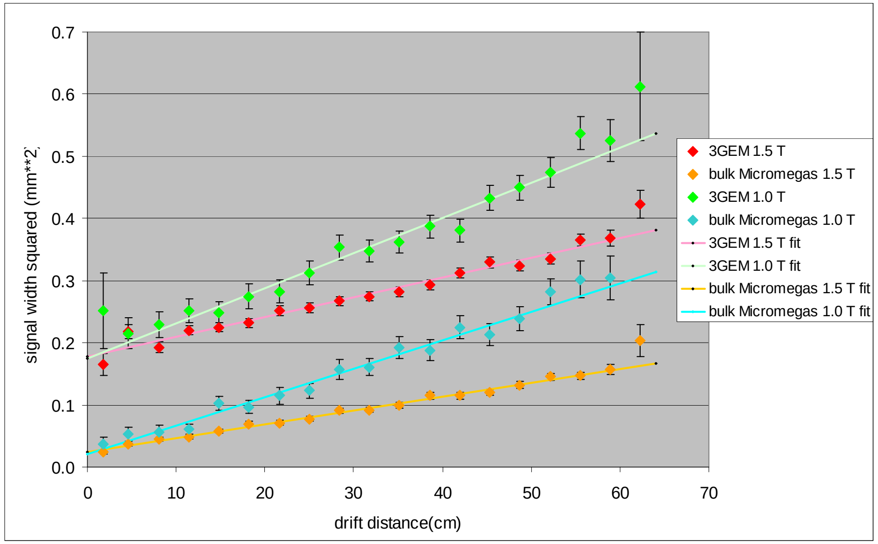
after removing the contribution to the width from the track angle, .156 mm

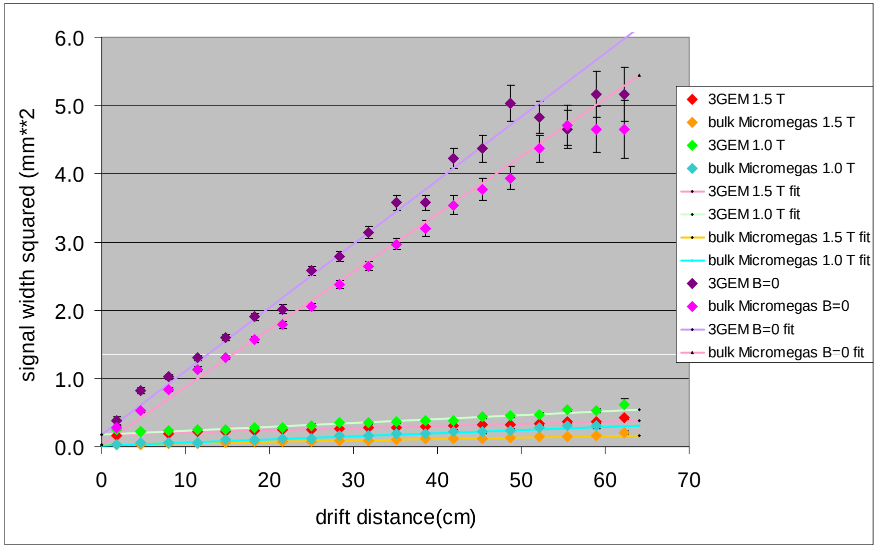
σ_0 average .390 mm 0

The measured diffusion constant in the GEM, with drift 0.495cm

D(GEM,meas)=0.55 mm/(cm½) at 1500V/cm

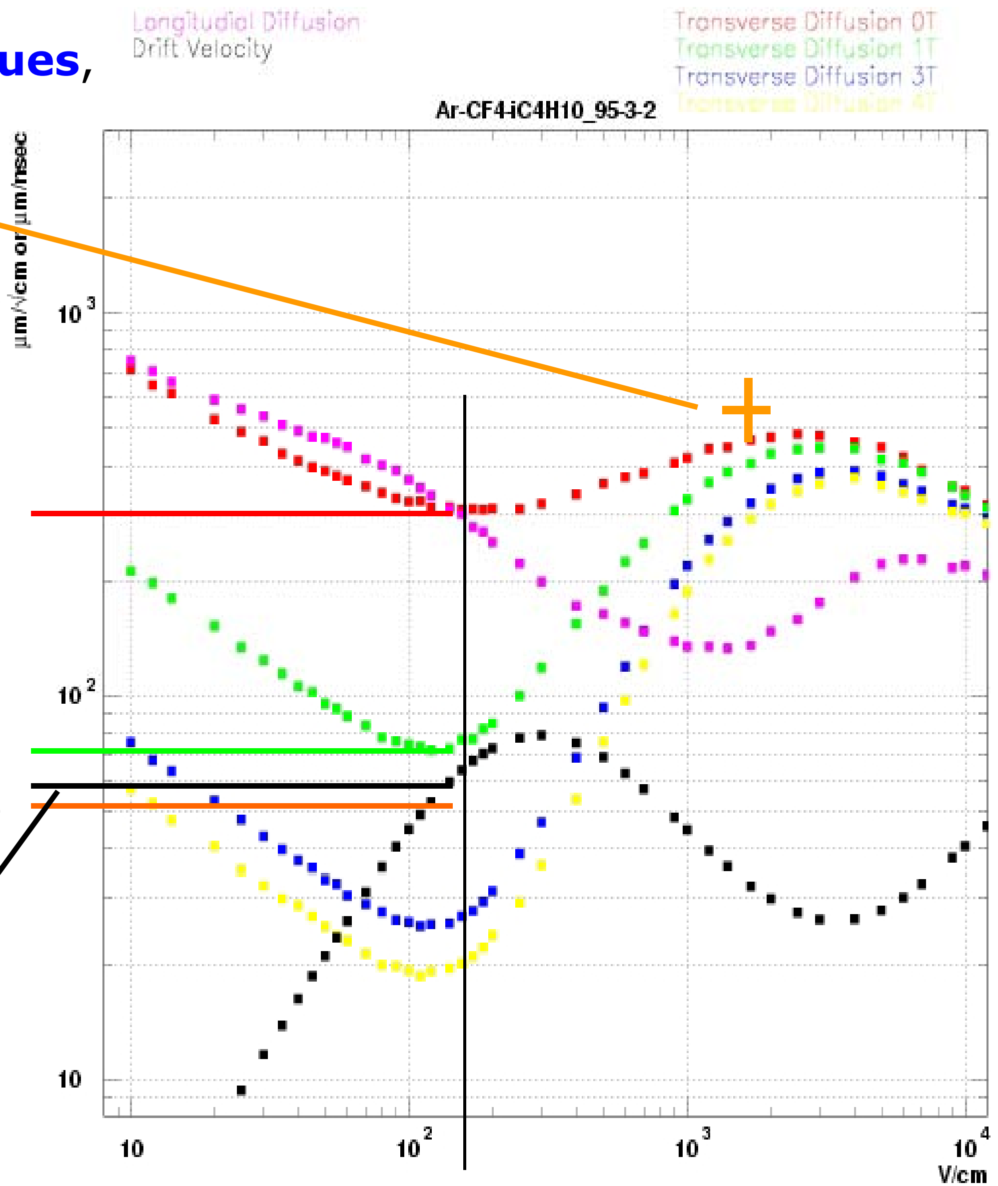
D_t mm/(cm½)	3-GEM	Micromegas	Ave.
B=0	(.306±.001)	(.291±.001)	.298
B=1.0T	(.075±.002)	(.068±.001)	.071
B=1.45T	(.057±.001)	(.047±.001)	.052





Comparison with calculated values,

http://www-hep.phys.saga-u.ac.jp:80/ILC-TPC/gas/



D(GEM), B=1.45 or 1.0 Tesla
measured 0.55 $\mathrm{mm/(cm^{1/2})}$
about 1.4 x calculated

D_t, B=0, measured 0.298 $\mathrm{mm/(cm^{1/2})}$

D_t, B=1.0T, measured 0.071 $\mathrm{mm/(cm^{1/2})}$

D_t, B=1.45T, measured 0.052 $\mathrm{mm/(cm^{1/2})}$

Drift velocity: (370-87) bins
40ns/bin, 65cm drift length
V_d =57mm/μs

Cut list for the point resolution measurements

| track angle | < 0.16

2mm rows in fit >/= 3

|location of hit| < 11.5mm (width of pad row ± 13 mm)

largest row PH in event (GEM) < 2800 (Micromegas) < 1400

PH of core 2 pads in hit (GEM) 30 : 1700 (Micromegas) 20 : 850

The two selection criteria above reduce noise due to charge deposition that is too small compared to background and unusually large chare depositions. They are different for GEM and Micromegas because the gains are different.

fraction of PH in max pad 0.44 : 0.92

The above criteria selects hits with sufficient charge-sharing for a position measurement.

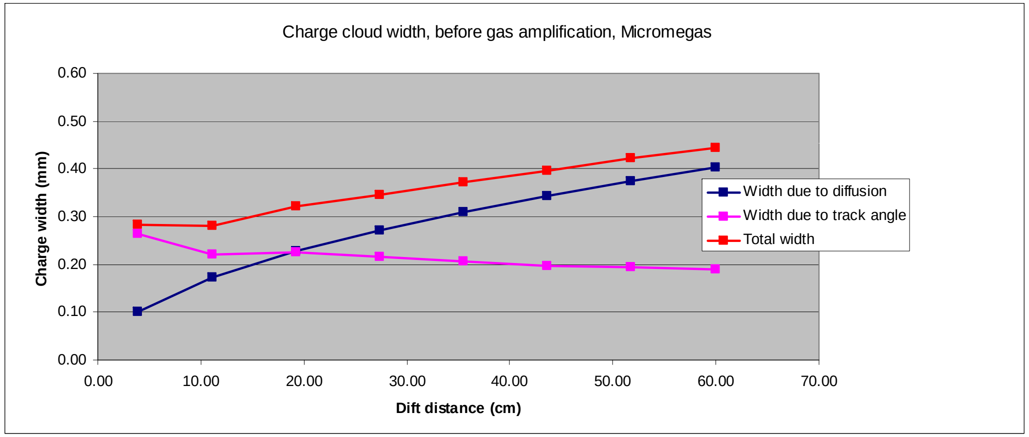
fraction of PH in 2 pads > 0.8

Previously (slide 6) described how tracks with $\mathrm{TAN}(\theta)=\pm 0.1$ are selected for small charge-width.

The width of the angle distribution for tracks with $\mathrm{TAN}(\theta)=\pm 0.1$ is
simply, $\sigma(\mathrm{TAN}(\theta)) = 0.1$

The width of the contribution to the charge-width is
$\sigma(\text{charge-width})=0.1*10\text{mm}/12^{1/2}$
$= 0.29$ mm

Micromegas

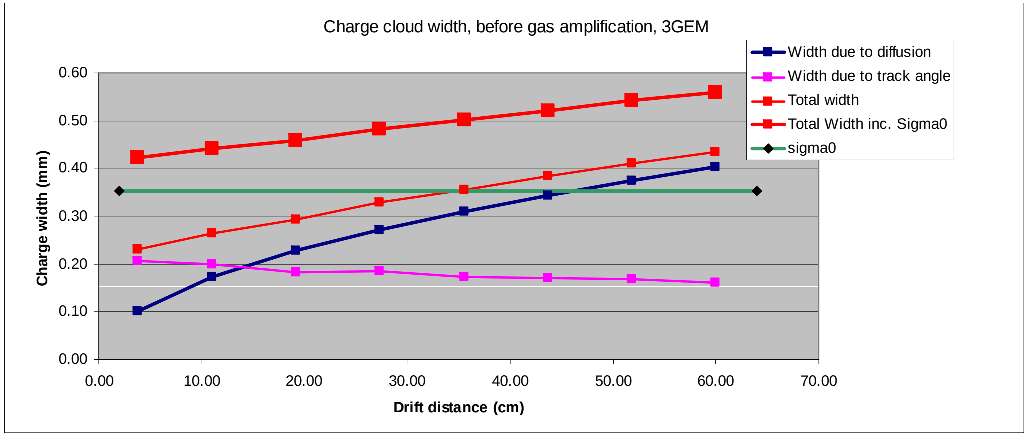


Plots show the contributions to the charge-width,
for both triple-GEM and Micromegas:

before entering the gas-amplification,
based on measured track angle (*ave*),
based on diffusion in the drift field,
and,
from diffusion in the in the GEM.

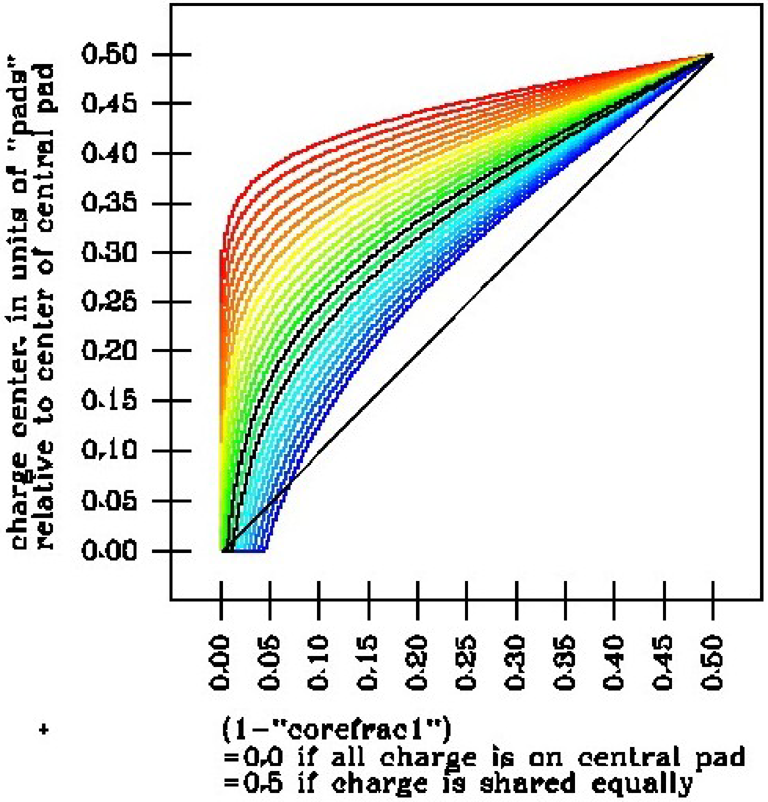
The result is the charge-width used when mapping the charge-sharing to charge-center-position, hit-by-hit.

triple-GEM

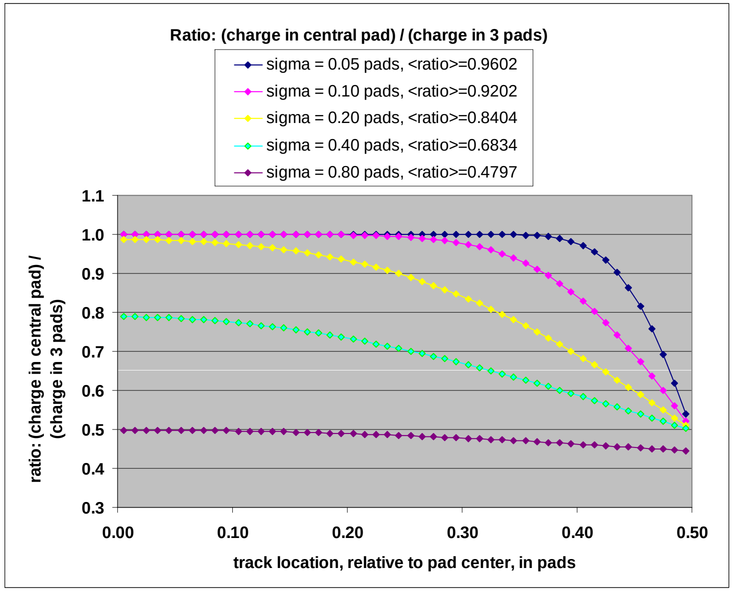


Point-resolution measurements:
the charge-center-location is calculated using inverted map
from the measured charge-sharing.

(The fraction is relative to the charge on 2 pads, rather than 3 as below.)



The charge center calculation is shown for the fraction of charge on the central pad varying from 0 to 50% and for the width of the charge distribution varying from σ=0.07pads (red) to σ=0.29 pads (blue). Black lines indicate values for σ=0.20 pads and σ=0.22 pads. The diagonal black line represents simple charge weighting. Note that for larger vales of charge width, zero sharing is not possible.



For reference, the plot from slide 10 of the mapping from charge-center-location to charge-sharing.

Typically, we plot the (resolution)^2 vs. (drift distance)

But, this is a guided by ignoring the contribution from the track angle:

$\sigma^2 = \sigma_0^2 + (\text{charge-width})^2 / N$, where $(\text{charge-width})^2 = D_t^2 Z$

In this measurement, the contribution from the track angle is included:

$\sigma^2 = \sigma_0^2 + (D_t^2 Z + \sigma^2(\text{average track angle})) / N$

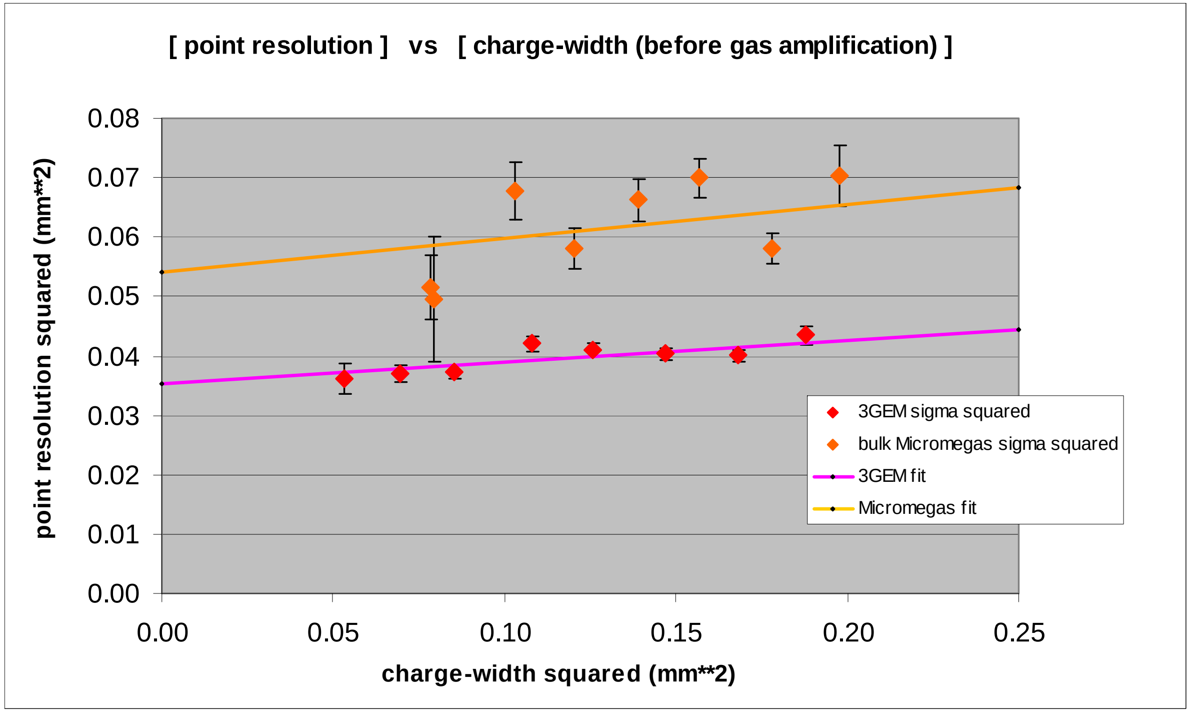
the intercept is σ_0^2,
the slope is 1/N

N	
3GEM	27 ± 7
Micromegas	18 ± 7

σ_0 (fit)		
3GEM	188 ± 4 μm	*
Micromegas	233 ± 13 μm	

after removing contribution from using a straight track

σ_0 ("corrected")	
3GEM	158 μm
Micromegas	209 μm



* (these errors look a little funny)

Summary

diffusion with a triple-GEM, TDR gas,

The agreement of D_t in the drift field is excellent,
compared to previous measurements and Magboltz.

The measured value of D in the GEM transfer field is about 10% high.

diffusion with a triple-GEM and Micromegas, in T2K gas

same chamber, gas, magnetic field, pad geometry, readout, analysis,

The agreement of D_t in the drift field is excellent, compared to Magboltz.

The measured value of D in the GEM transfer field is about 40% high.
Measured diffusion in the Micromegas is zero.

point resolution with a triple-GEM and Micromegas, in T2K gas

unfortunately, the gain of the triple-GEM is 1.88 that of the Micromegas

This is a difficult measurement with 4 layers of 2mm pads!

The number of primary ions, triple-GEM and Micromegas, agrees.

The point resolution, σ_0, with the triple-GEM is 158 µm – not so good.
The point resolution, σ_0, with the Micromegas is 209 µm – worse.
The gain is about half that of the triple-GEM, affecting the signal/noise.