

TPC studies using GEM and Micromegas readouts, Ar-CF₄-isobutane gas, in a magnetic field

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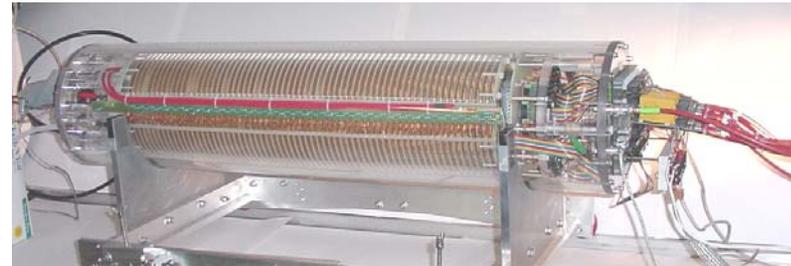
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the US National Science Foundation (LCDRD award)
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This project is in collaboration with LC-TPC.

in this talk ...

measurements using
the small prototype TPC at Cornell



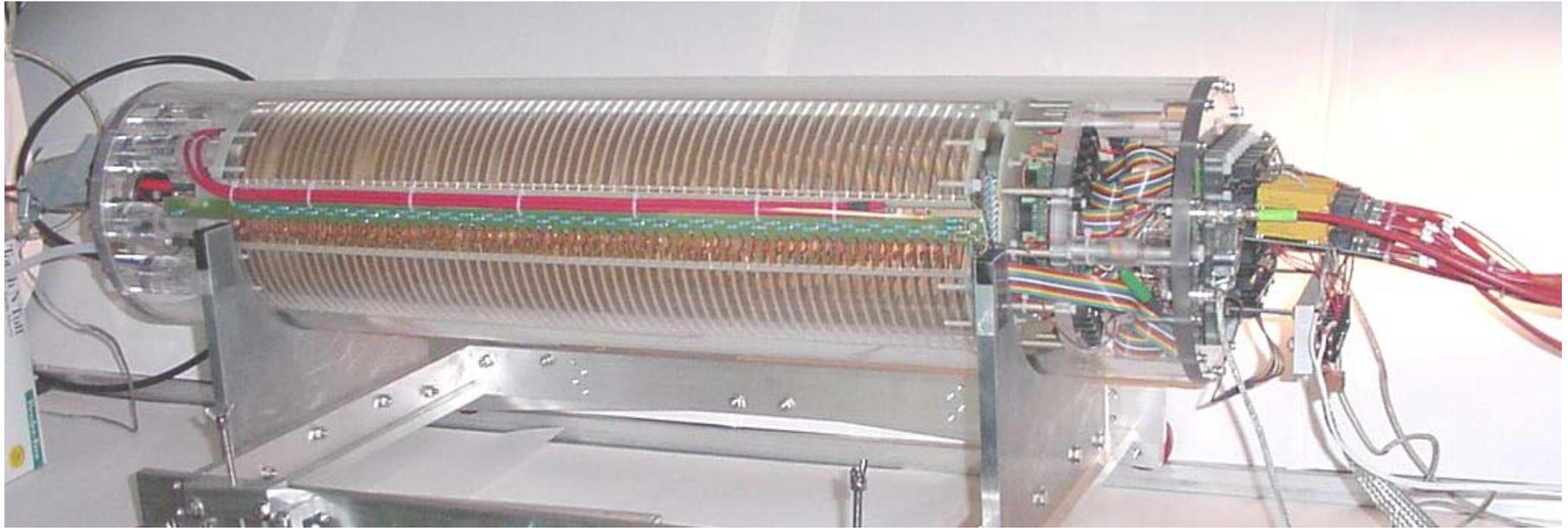
triple-GEM_(standard) B=0, 1.0, 1.45 Tesla, T2K gas:Ar-CF₄-isobutane 95:3:2

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

for calibration

triple-GEM B=1.0, TDR gas: Ar-CH₄-CO₂ 93:5:2

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

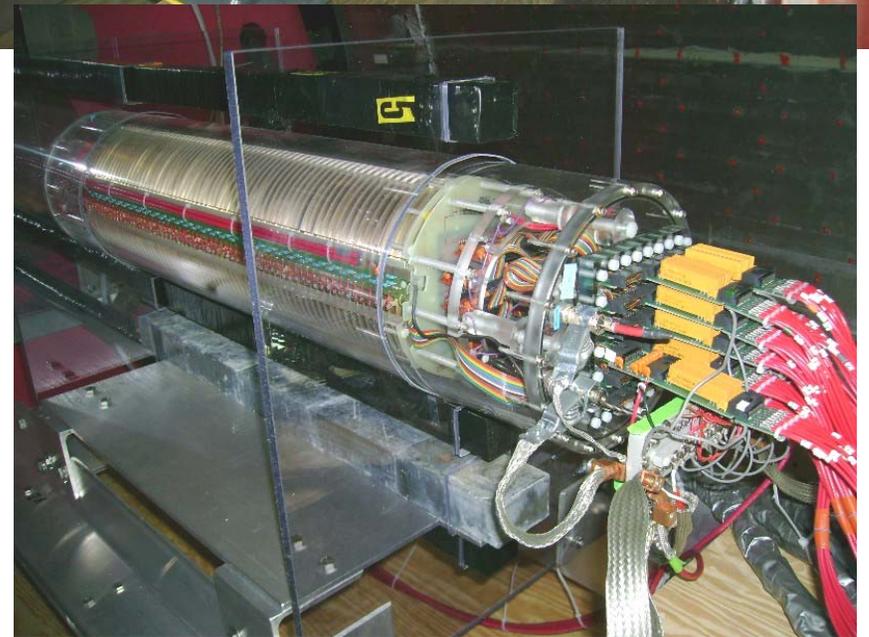
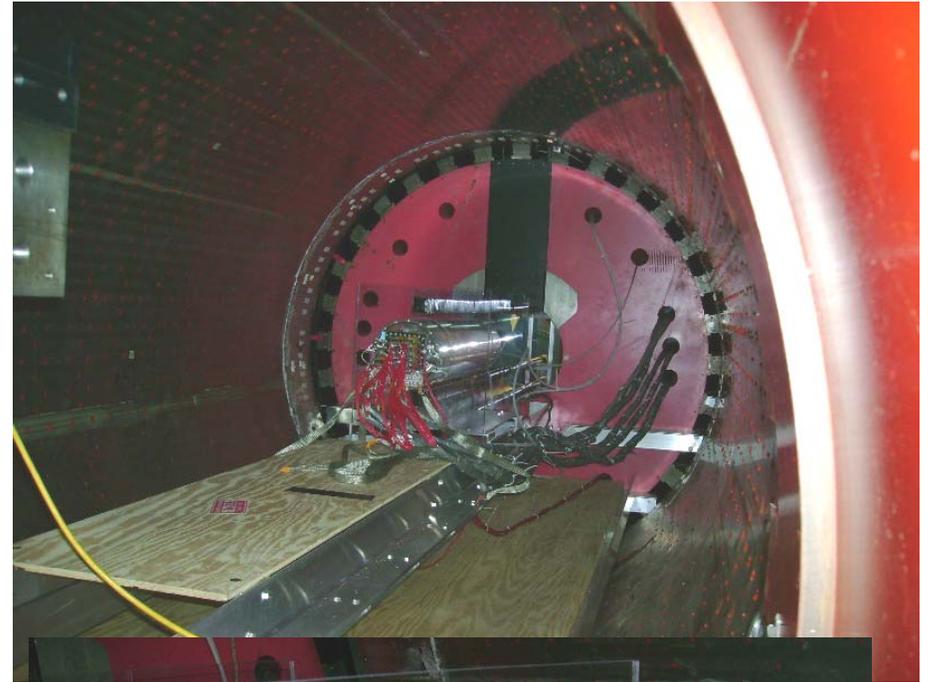
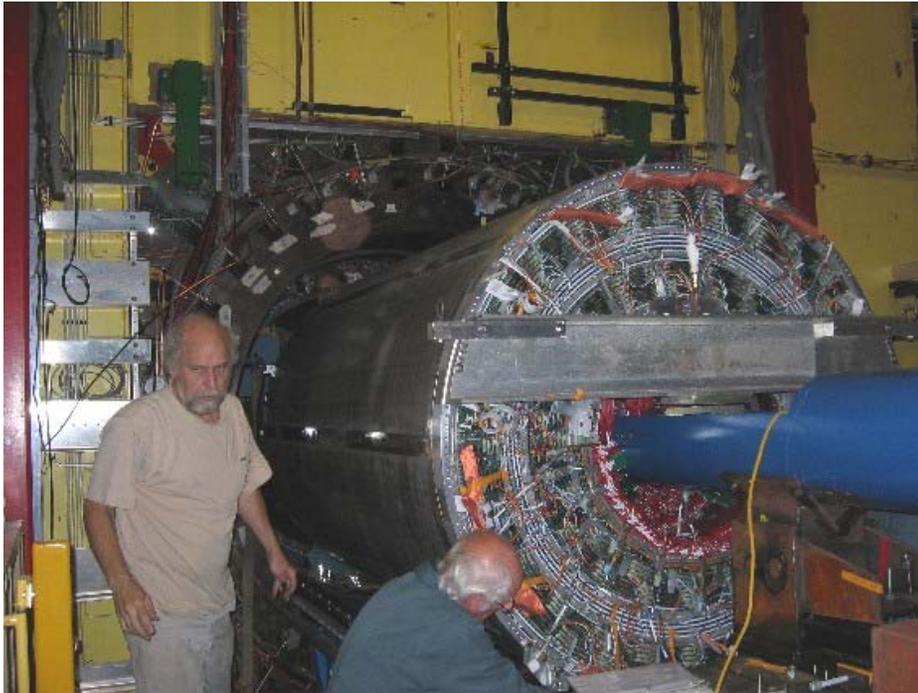


14.6 cm ID field cage - accommodates a 10 cm gas amplification device
64 cm drift field length
22.2 cm OD outer structure (8.75 inch)

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 μ V)



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.

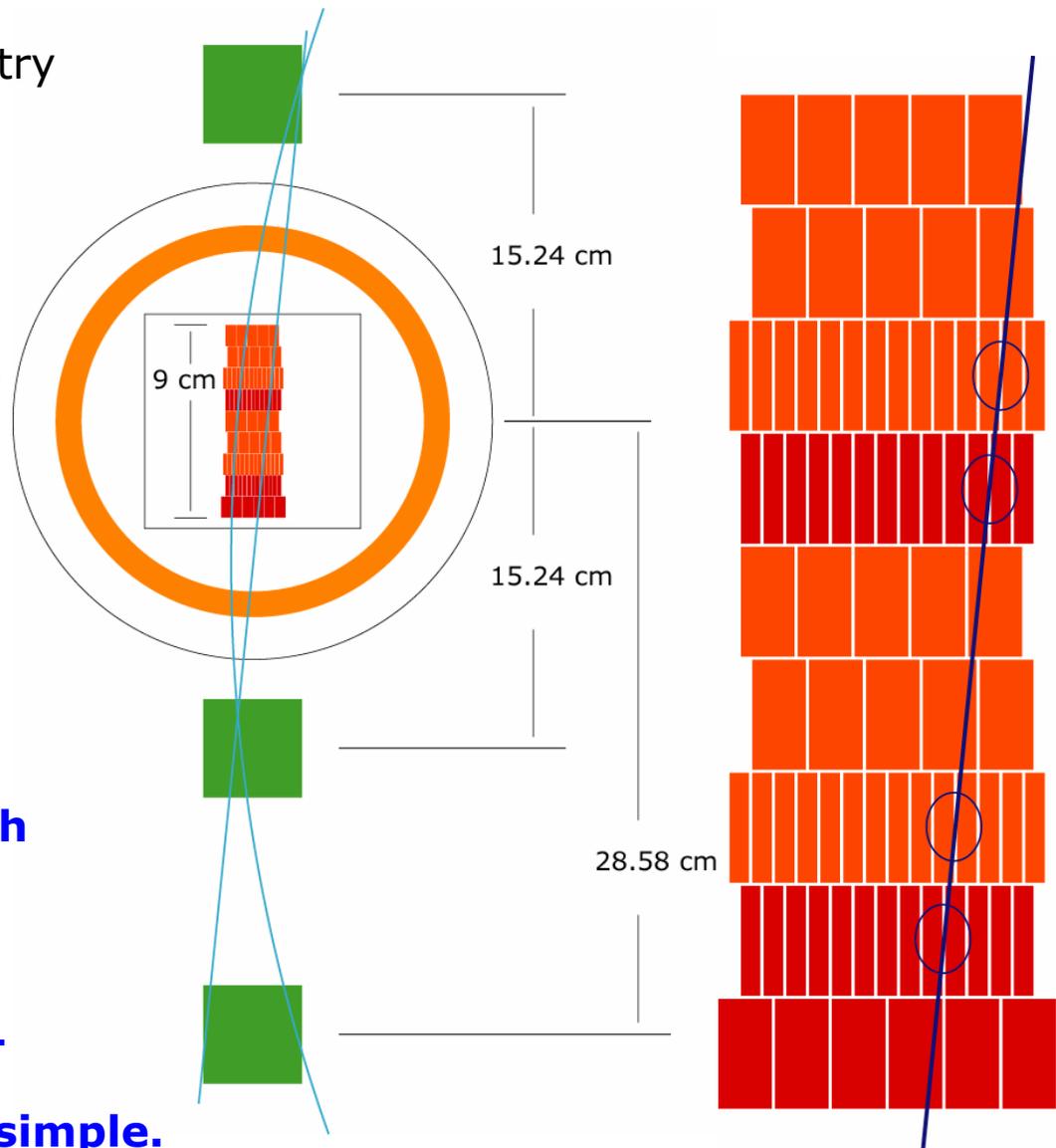
at near right:
TPC and Trigger scintillator geometry
3 scintillators, 4.6cm square

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 $\text{TAN}(\theta)=0.1$
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.

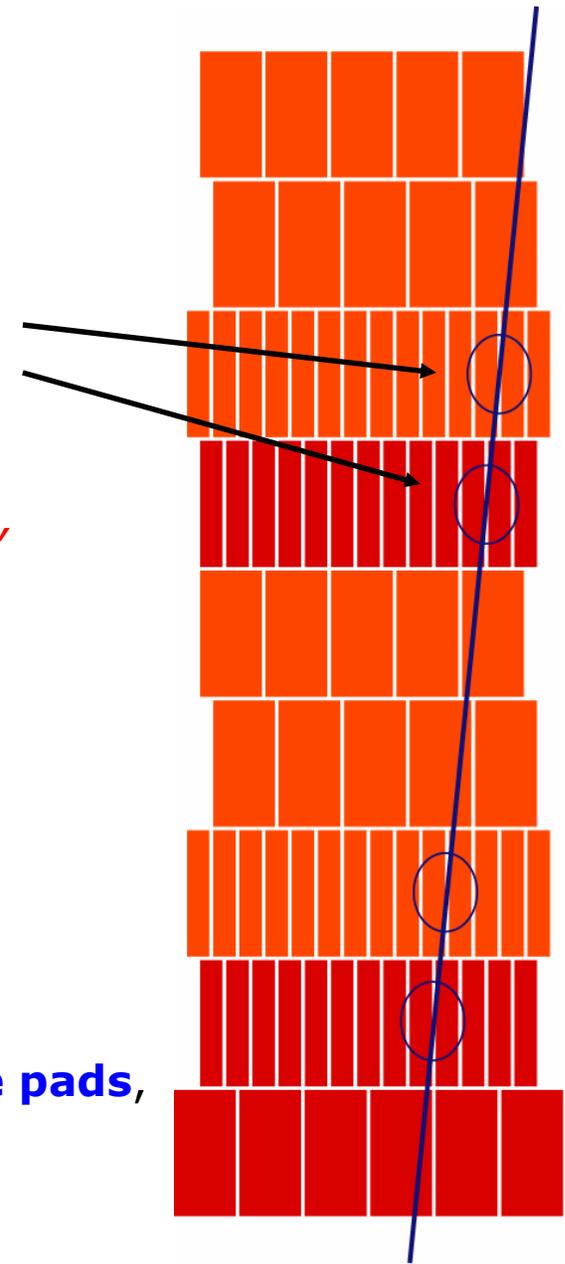


Measurement of the **point-resolution** is complicated by the use of large (2mm) pads, coupled with narrow charge-width.

Resolution measurements are based on differences of residuals with respect to a track fit. Note that this sample track, with $TAN(\theta)=0.1$, 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.

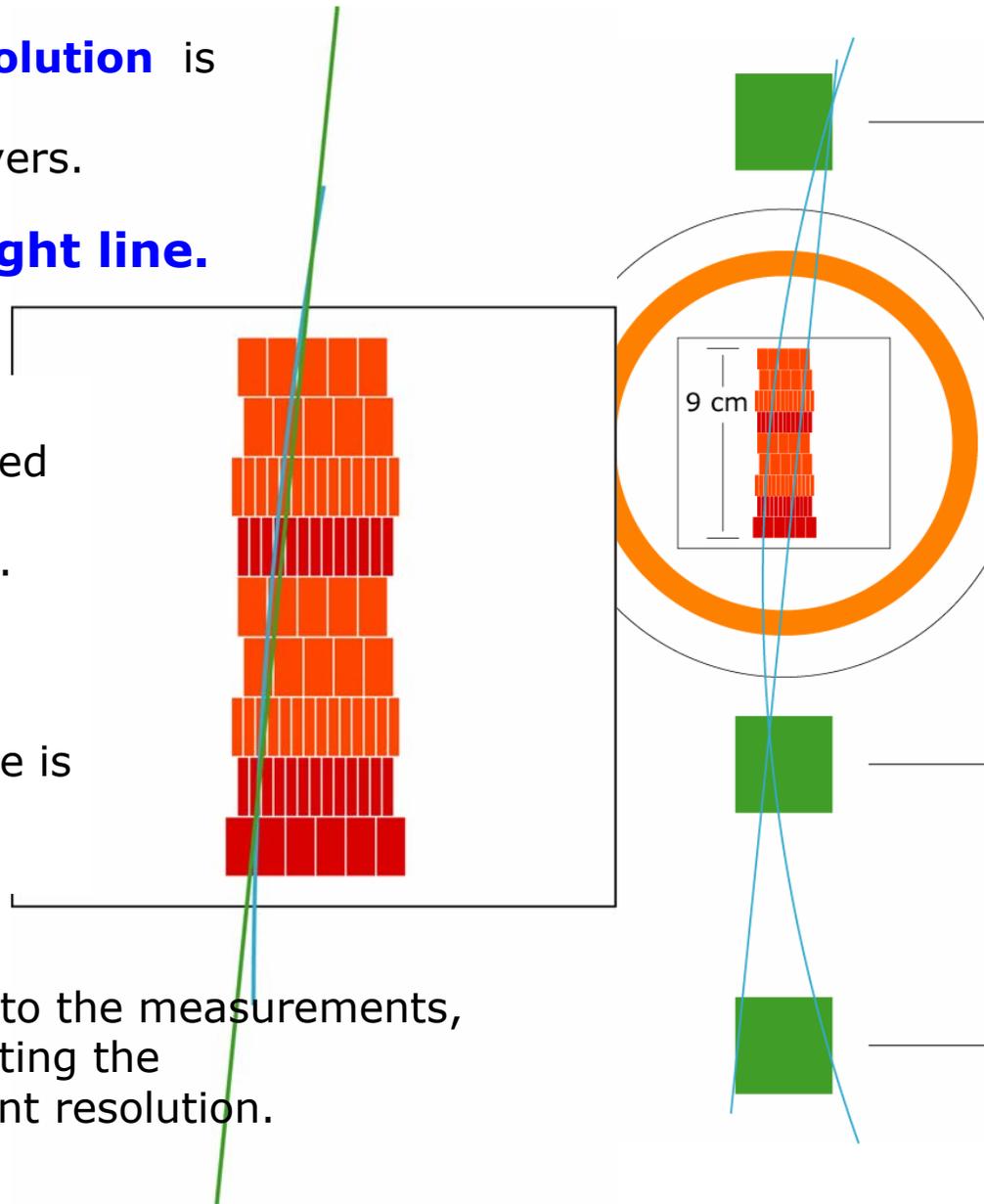
The track fit is to a straight line.

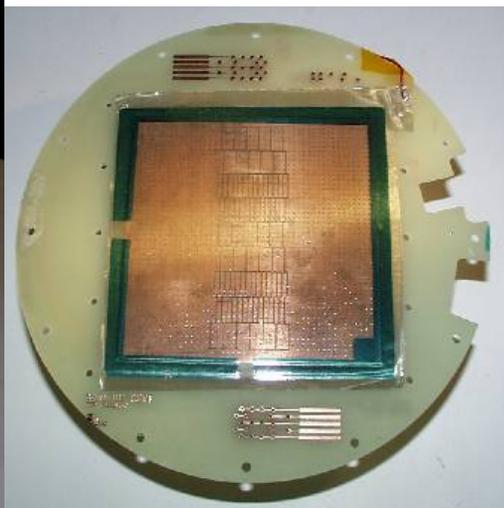
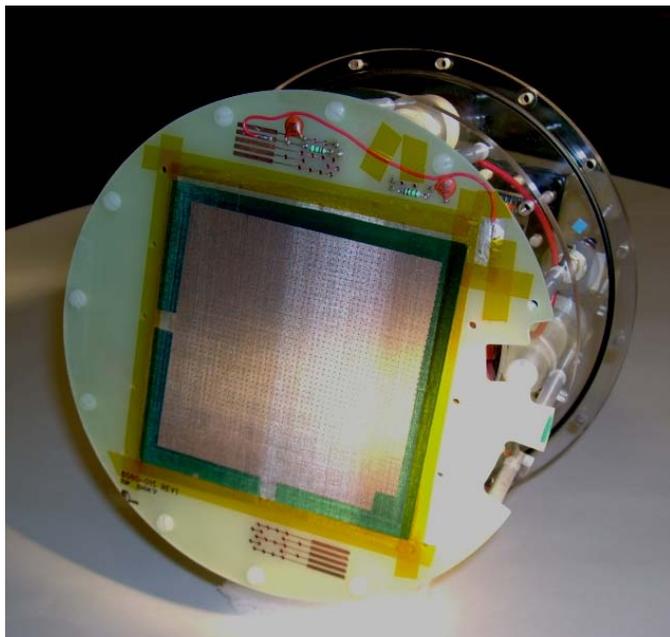
The resulting error in the residual difference was calculated for tracks within the phase space of accepted tracks.

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

$$\sigma \sim 102 \mu\text{m}.$$

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

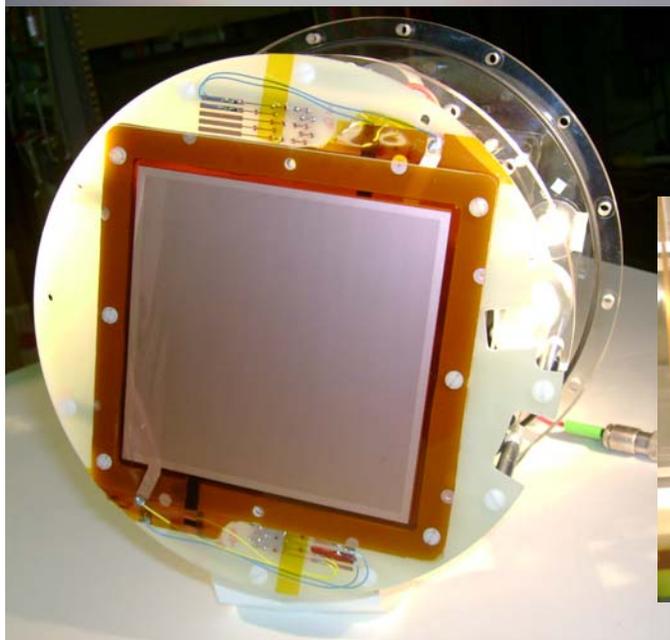




Measurements with
2 gas-amplification devices.

The Micromegas is a
50 μ m 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, E_{drift}=150V/cm

Micromegas voltage: 350 V

Gain is 2.15×10^4 (Paul Colas)

The gain was constant from B=0 to 1.45 Tesla, 105 counts

GEM

T2K gas, Ar-CF₄-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-CH₄-CO₂ 93:5:2, E_{drift}=220V/cm

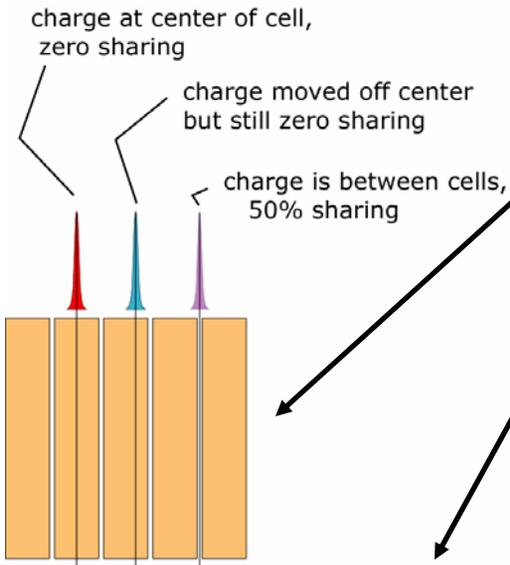
GEM voltages: 315, 315, 315 V

transfers fields: 1.65 mm, 2060V/cm

1.65 mm, 2060V/cm

1.65 mm, 1930V/cm induction

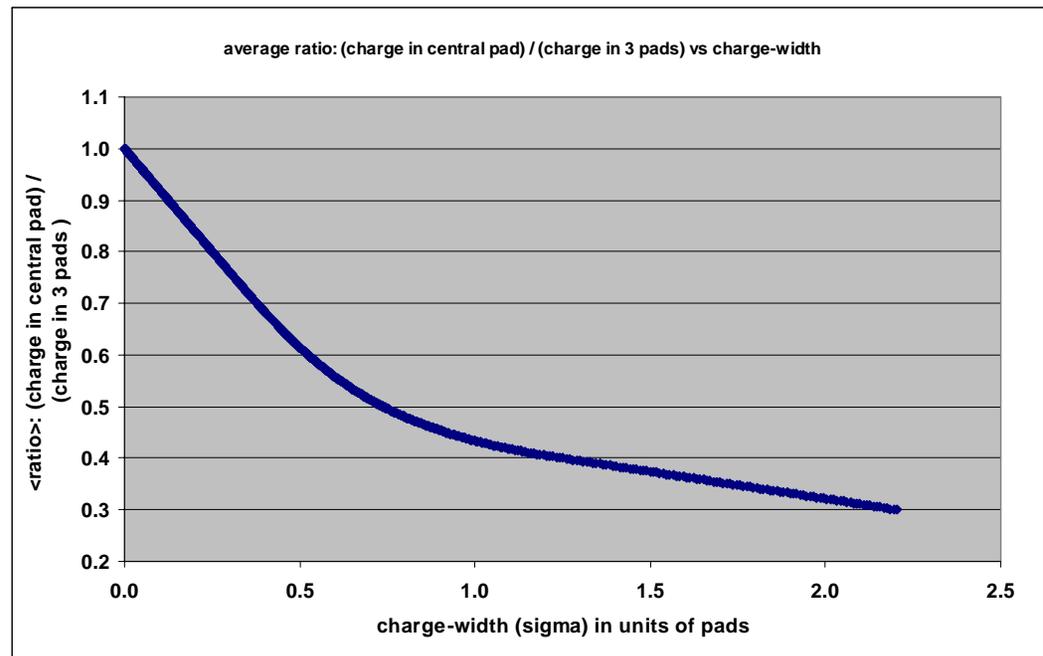
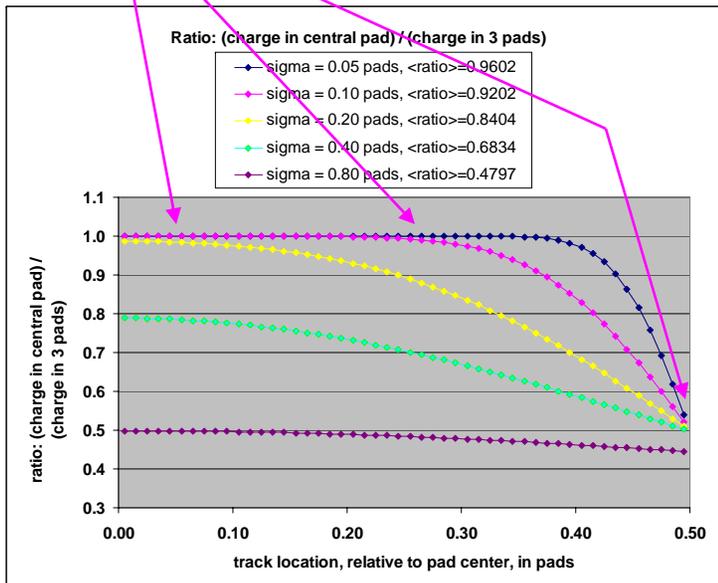
At B=1 Tesla, the gain is 1.35 x the GEM with T2K gas setting,
2.5 x the Micromegas with T2K gas.



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:

$$\sigma_0 = 0.387 \pm .020 \text{ mm}$$

The fitted charge-width includes a contribution from the average track angle, (ref slide 5) $\text{TAN}(\theta)=0.054$:

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

removing the track angle contribution,

$$\sigma_0 \text{ (physical)} = 0.354 \text{ mm} .$$

σ_0 is due to diffusion in the gas amplification,.

From Magboltz, with electric field, $E=1.9\text{-}2.1\text{kV/cm}$,

$D(\text{GEM, Magboltz})=0.45 \text{ mm}/(\text{cm}^{1/2})$,

with drift length in GEM =0.495 cm,

$D(\text{GEM, meas})=0.50\pm0.03 \text{ mm}/(\text{cm}^{1/2})$ 110% of calculated

expect $D_t \sim 0.205 \text{ mm}/(\text{cm}^{1/2})$ Magboltz calculations (Ishikawa),

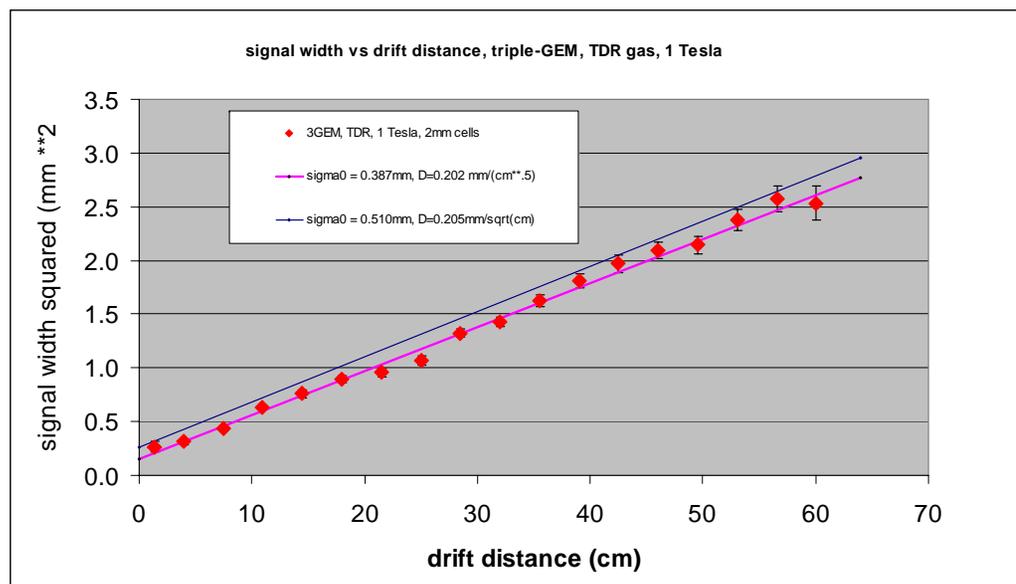
Victoria result: 0.205 (Karlen, Snowmass 2005)

MPTPC result: 0.207 (M. Kobayashi, Bangalore 2006)

Fit to data:

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

drift velocity, observe $V_d=43 \text{ mm}/\mu\text{s}$, expect $V_d = 45\text{mm}/\mu\text{s}$,



<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

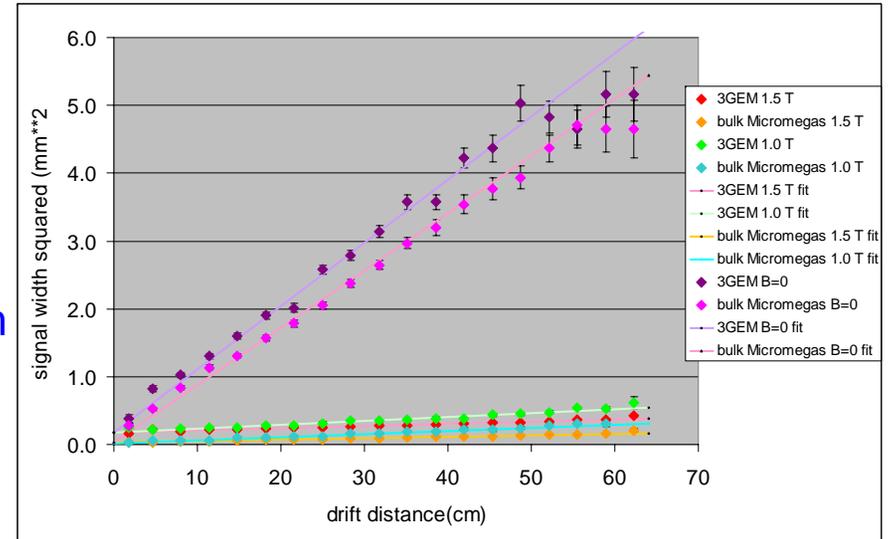
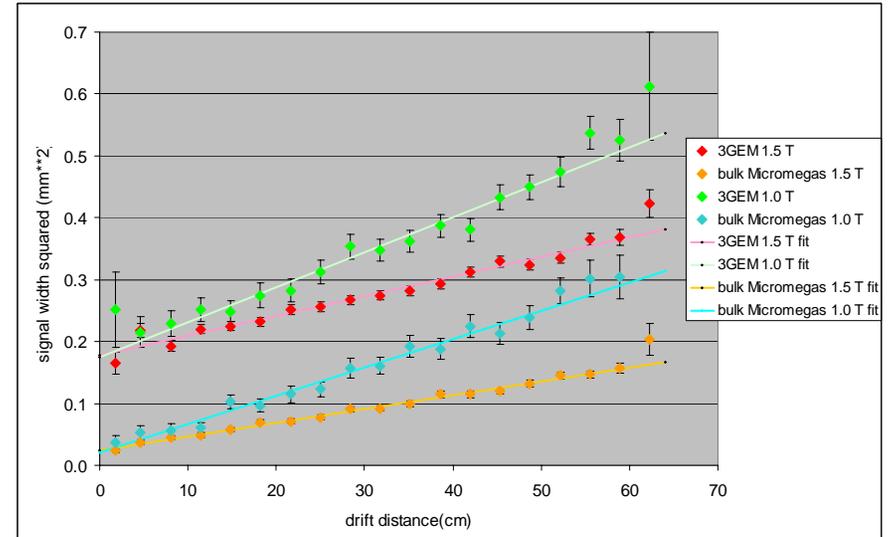
σ_0 average .390 mm 0

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

$D(\text{GEM, meas}) = 0.55 \text{ mm}/(\text{cm}^{1/2})$ at 1500V/cm

D_t 3-GEM Micromegas Ave.
 mm/(cm^{1/2})

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 mm/(cm^{1/2})
about 1.4 x calculated

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

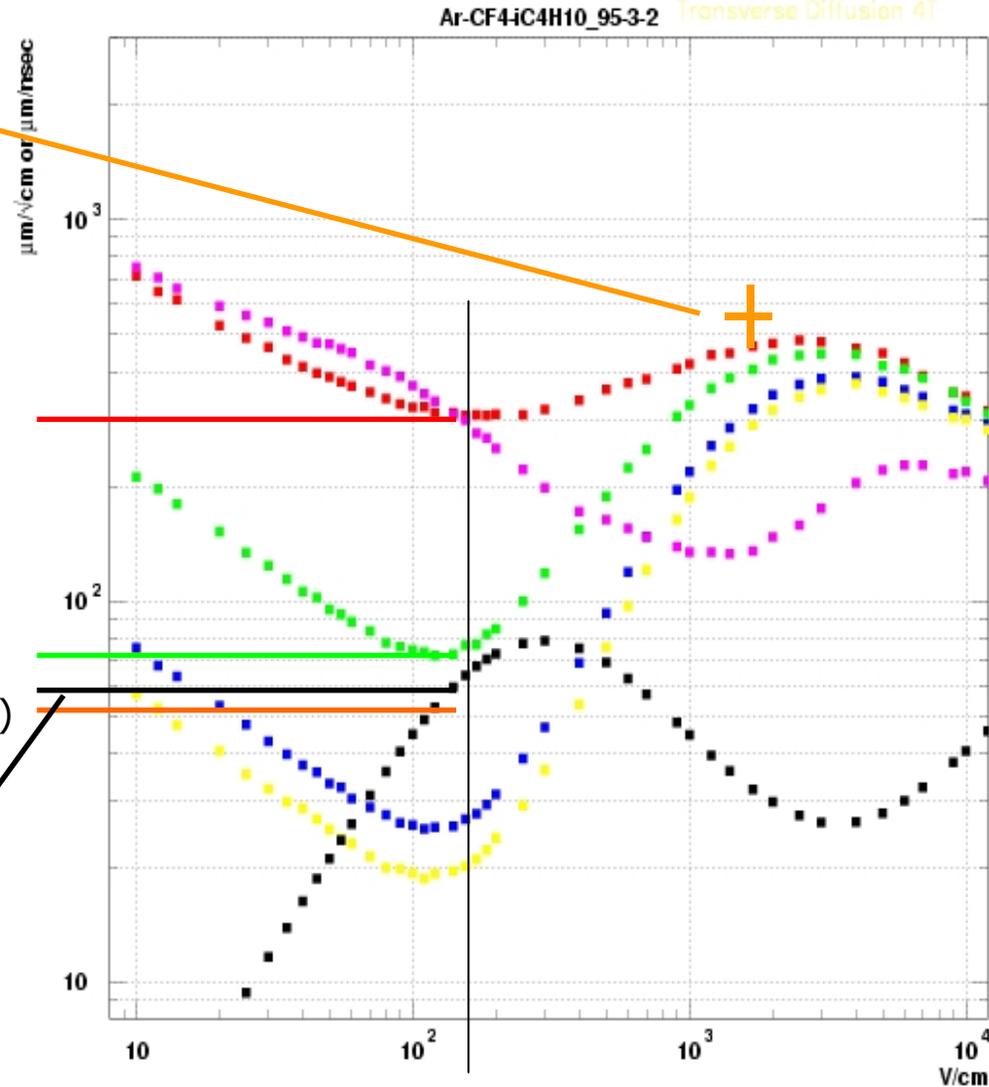
D_t, B=1.0T, measured 0.071 mm/(cm^{1/2})

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

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

Longitudinal Diffusion
Drift Velocity

Transverse Diffusion 0T
Transverse Diffusion 1T
Transverse Diffusion 3T
Transverse Diffusion 4T



Cut list for the point resolution measurements

$|\text{track angle}| < 0.16$

2mm rows in fit ≥ 3

$|\text{location of hit}| < 11.5\text{mm}$ (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 charge 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 $TAN(\theta)=\pm 0.1$ are selected for small charge-width.

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

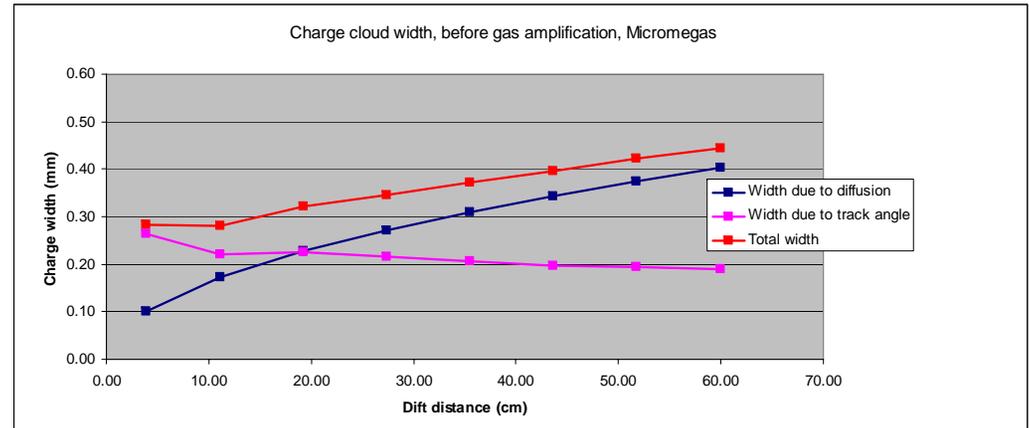
The width of the contribution to the charge-width is $\sigma(\text{charge-width})=0.1*10\text{mm}/12^{1/2} = 0.29 \text{ mm}$

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

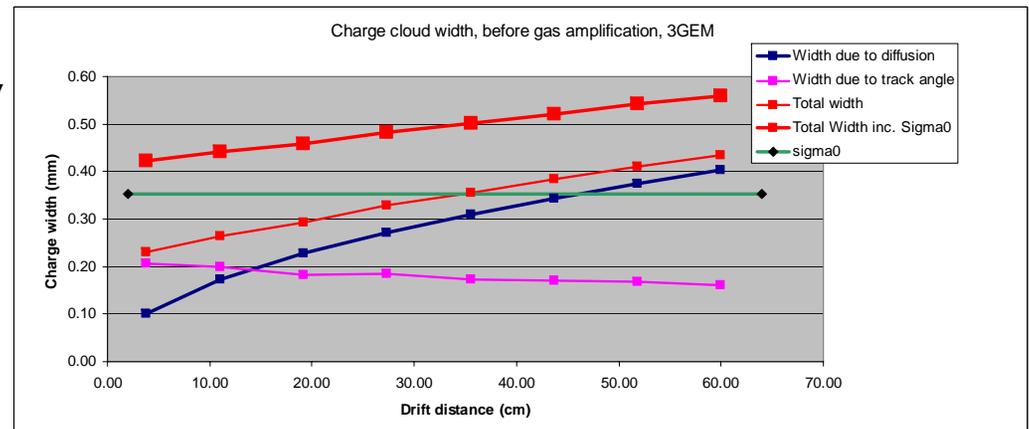
before entering the gas-amplification, based on measured track angle (*ave*), based on diffusion in the drift field, and, from diffusion in the in the GEM.

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

Micromegas

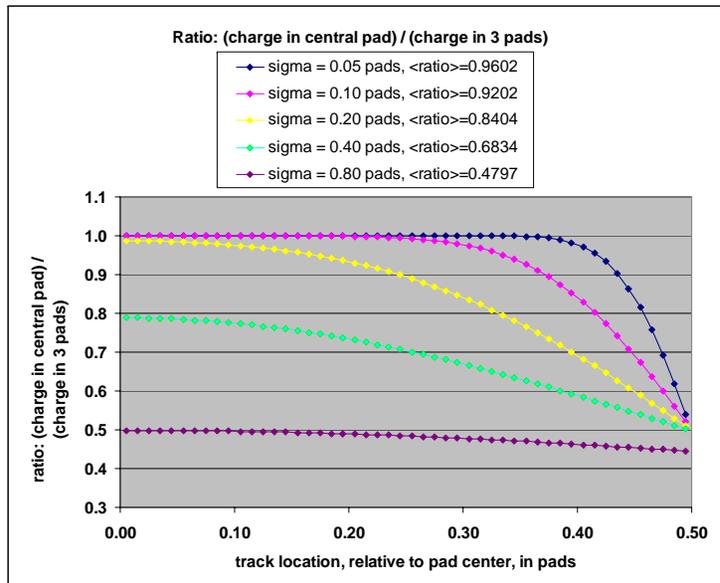


triple-GEM

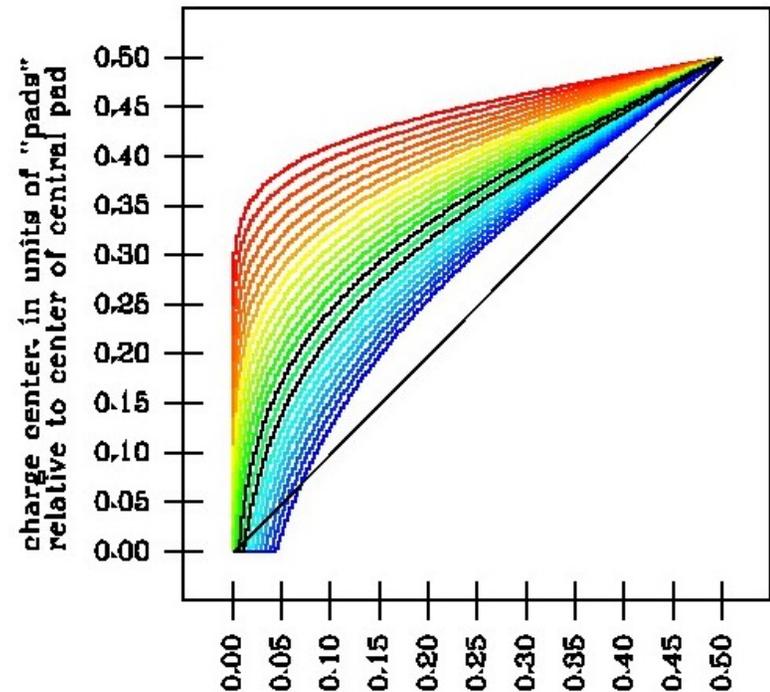


Point-resolution measurements:
 the charge-center-location is calculated
 using inverted map
 from the measured charge-sharing.

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



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



+ (1 - "corefrac1")
 = 0.0 if all charge is on central pad
 = 0.5 if charge is shared equally

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 $\sigma=0.07$ pads (red)
 to $\sigma=0.29$ pads (blue). Black lines indicate
 values for $\sigma=0.20$ pads and $\sigma=0.22$ pads.
 The diagonal black line represents simple charge
 weighting. Note that for larger values of charge
 width, zero sharing is not possible.

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

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

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

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

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

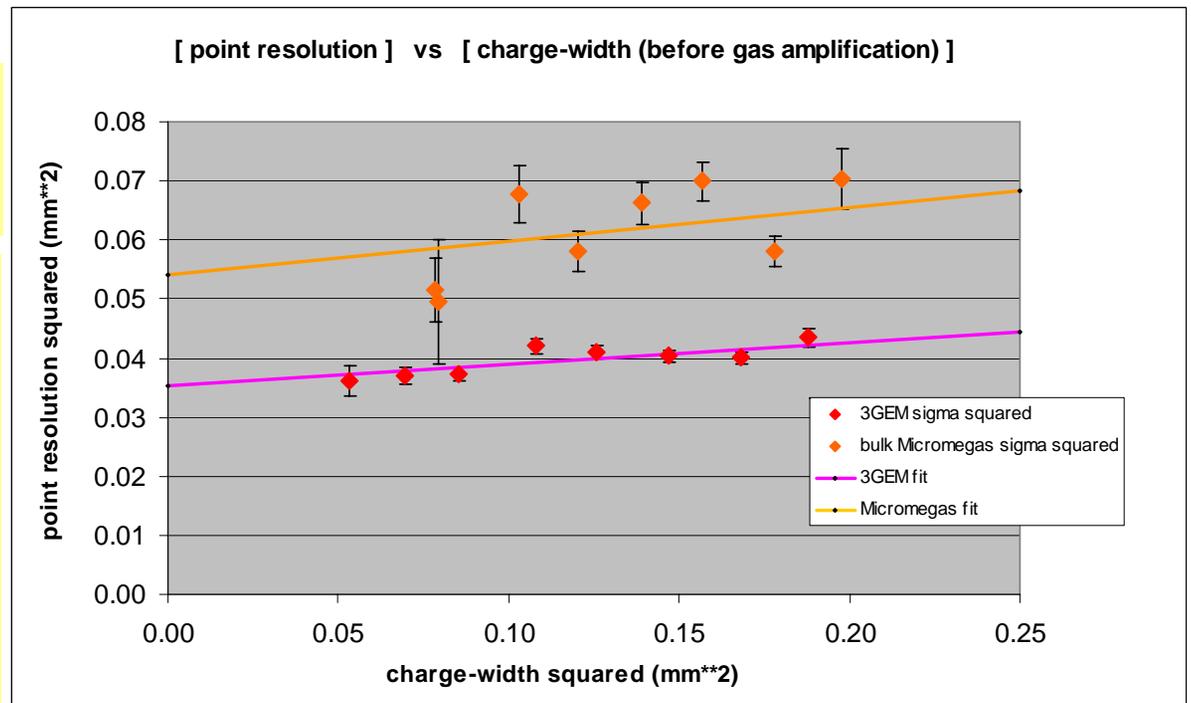
the intercept is σ_0^2 ,
the slope is $1/N$

| N | |
|------------|------------|
| 3GEM | 27 ± 7 |
| Micromegas | 18 ± 7 |

| σ_0 (fit) | |
|------------------|---------------------------|
| 3GEM | $188 \pm 4 \mu\text{m} *$ |
| Micromegas | $233 \pm 13 \mu\text{m}$ |

after removing contribution from using a straight track

| σ_0 ("corrected") | |
|--------------------------|-------------------|
| 3GEM | $158 \mu\text{m}$ |
| Micromegas | $209 \mu\text{m}$ |



* (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.