Berkeley-Orsay-Saclay (BOS) Micromegas TPC R&D Studies

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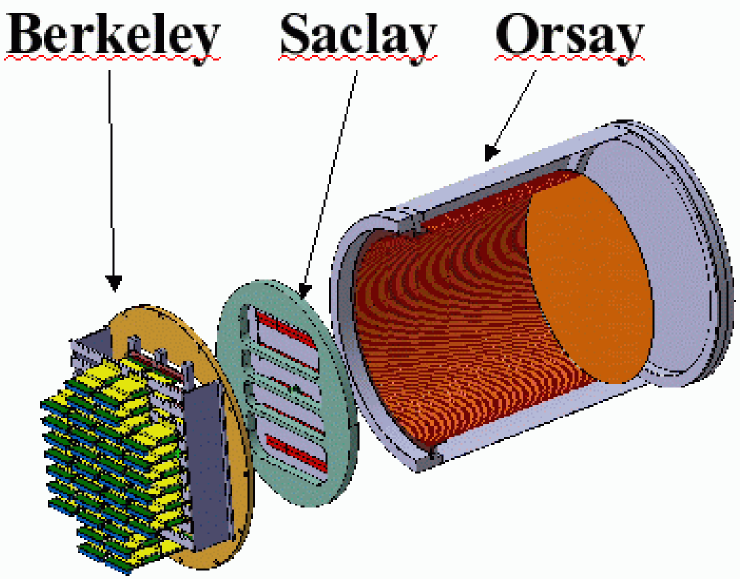
Outline

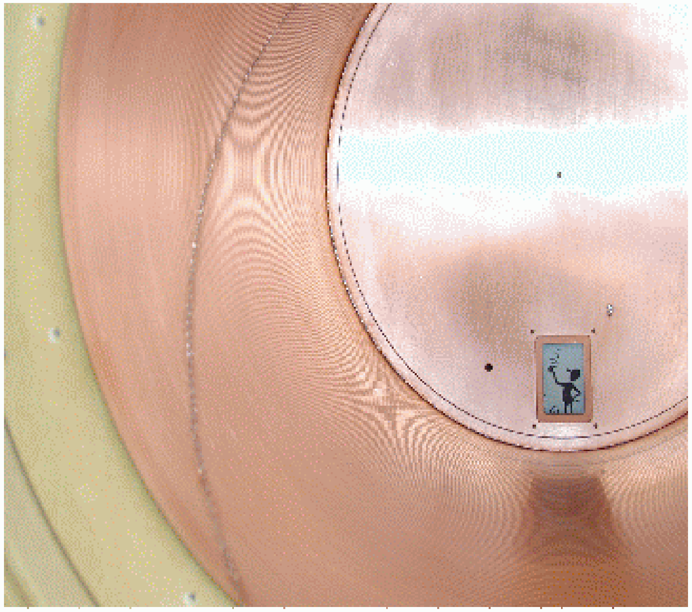
- BOS Large-Area Micromegas TPC
  - Chamber construction and anode pad layout
  - Cosmic ray event display
- Operation
  - Gas properties: drift velocity, diffusion, ...
- Performance
  - New analysis and systematic checks
  - Transverse position resolution
  - Do we understand ArCF4 operation?

Chamber design and pad layout

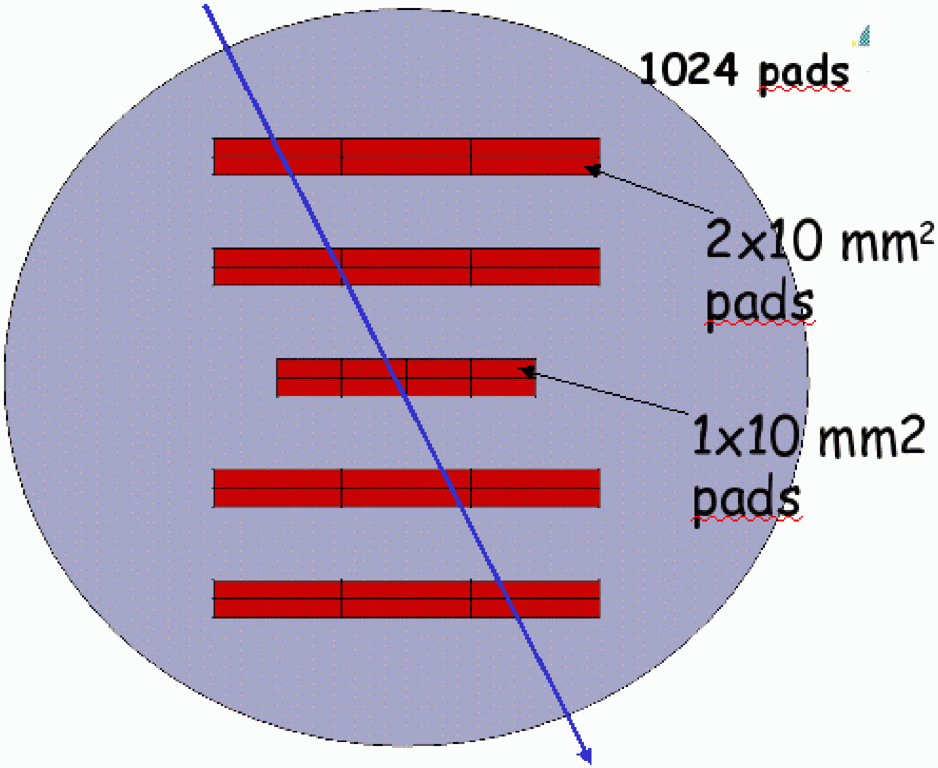


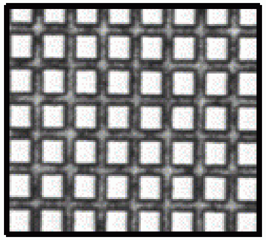
Chamber

diameter 50 cm
length 50 cm



Readout anode pad plane

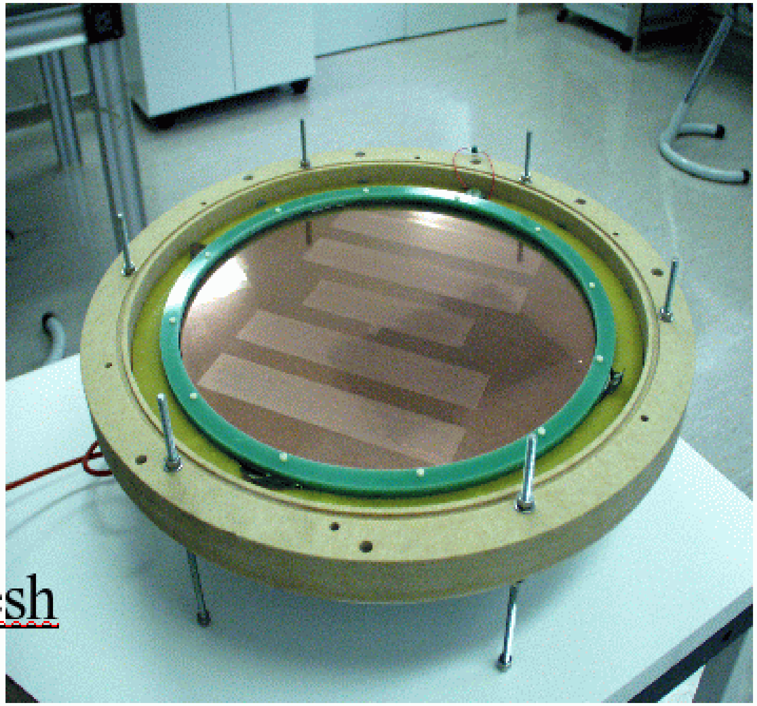




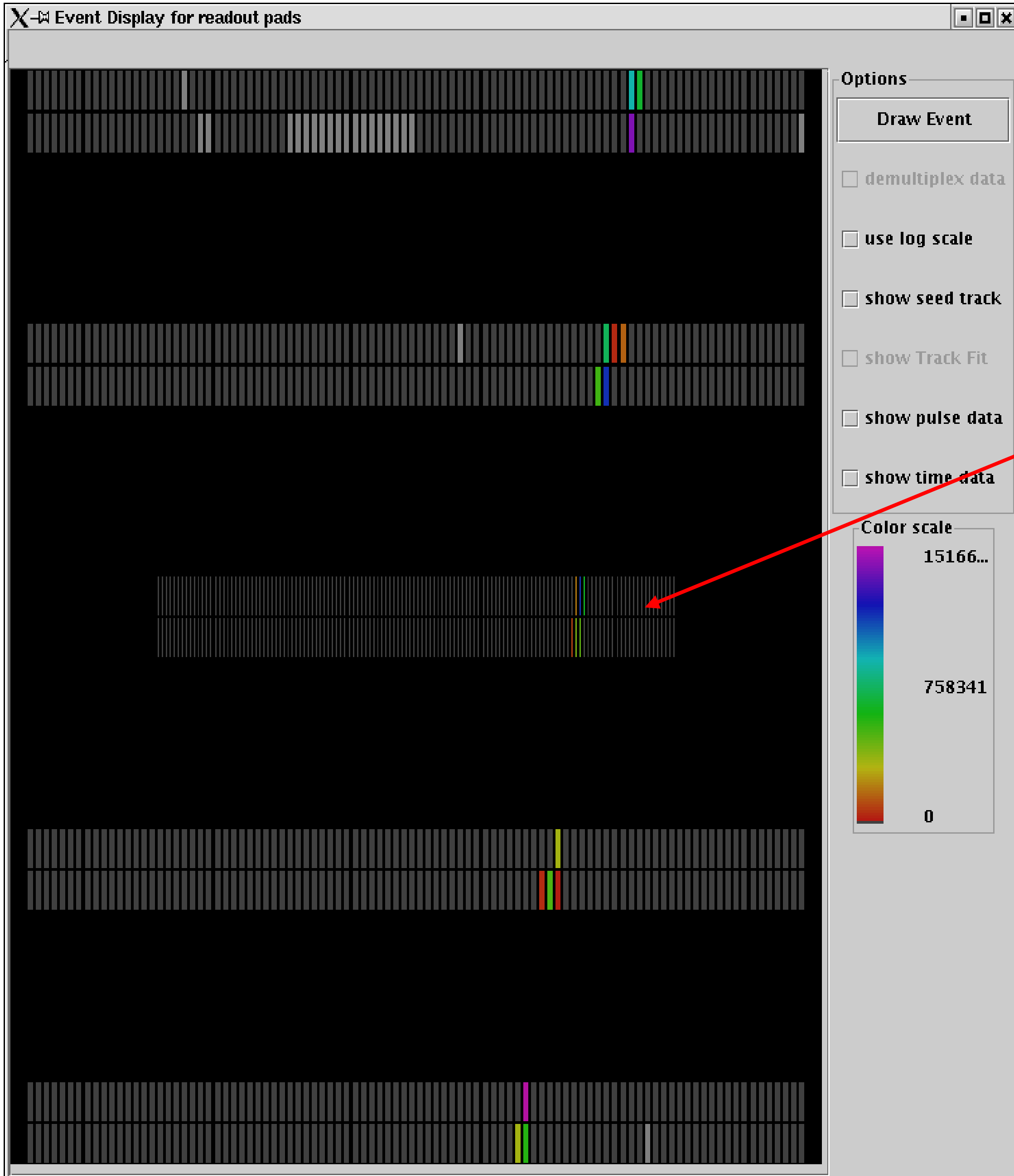
50 µm pitch

50 µm gap

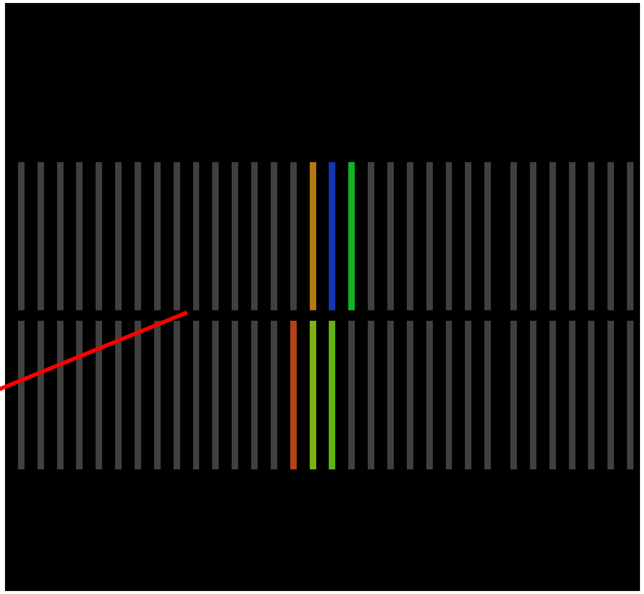
Copper Mesh

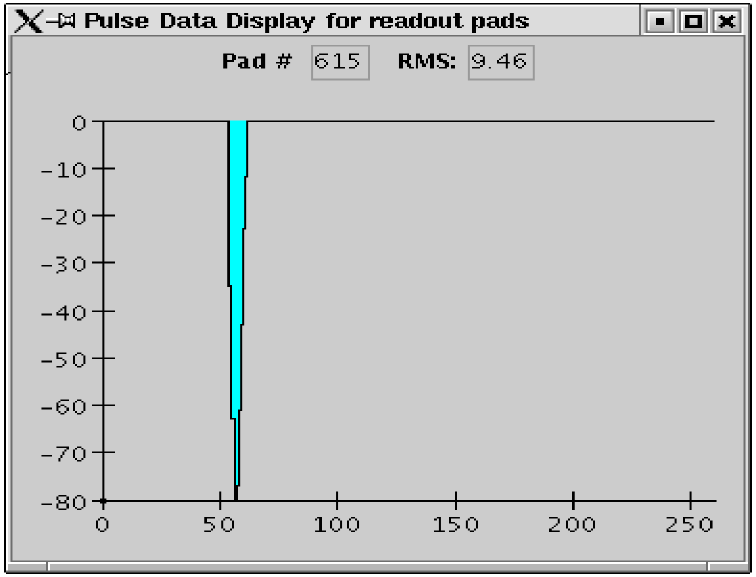


Online event display



Rows 4 & 5   1 X 10 mm^2





LC-TPC gas choices

Gases:

Ar-CH_4 e.g. P10 – 90:10 %

Standard TPC gas, but some concern about neutron background sensitivity with hydrogen.

Ar-CO_2

Slow gas, requiring larger drift fields.

Tesla TDR Gas (Ar-CH_4-CO_2)

Chosen for the reference design to have less hydrogen at a lower drift field.

Ar-Isobutane e.g. 95:5 %

High gains. Reasonably fast but larger diffusion.

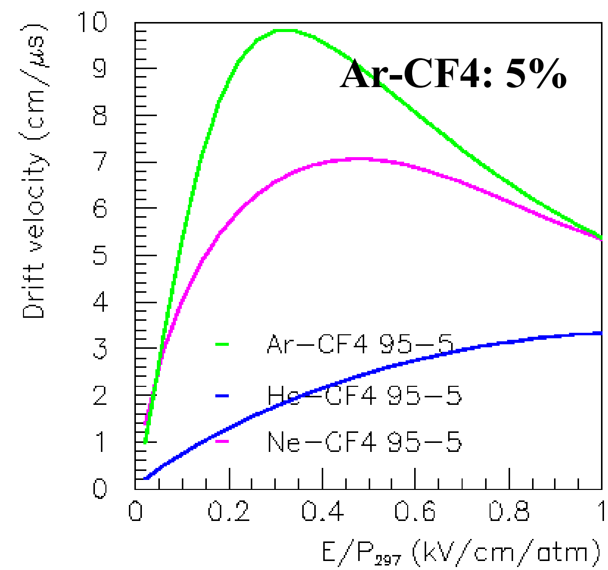
Ar-CF_4 e.g. 3-5 % CF_4

Very interesting! Very fast, no hydrogen.

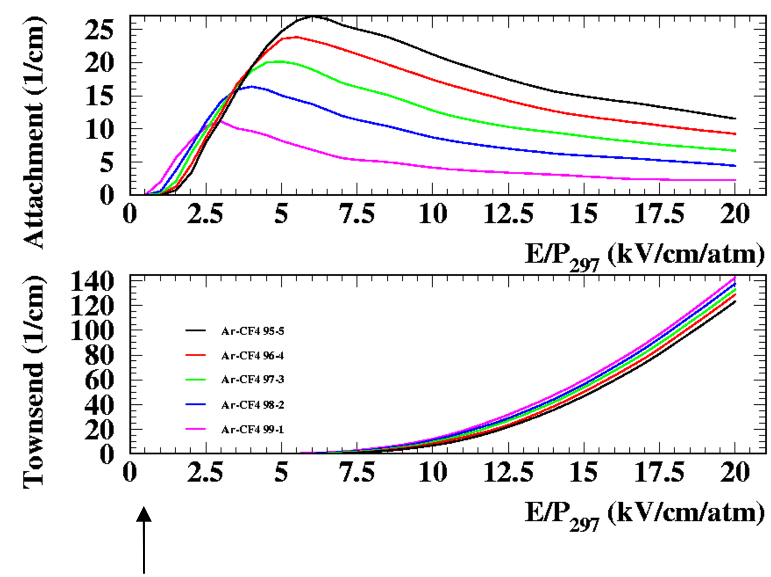
$\omega\tau$ ~20 @ B=4T
transverse diffusion less than 200 μm for drifts up to 1m.

However, need to worry about electron attachment and chemical reactions, e.g. aging.

Drift velocity



Ar-CF4 Attachment / Amplification



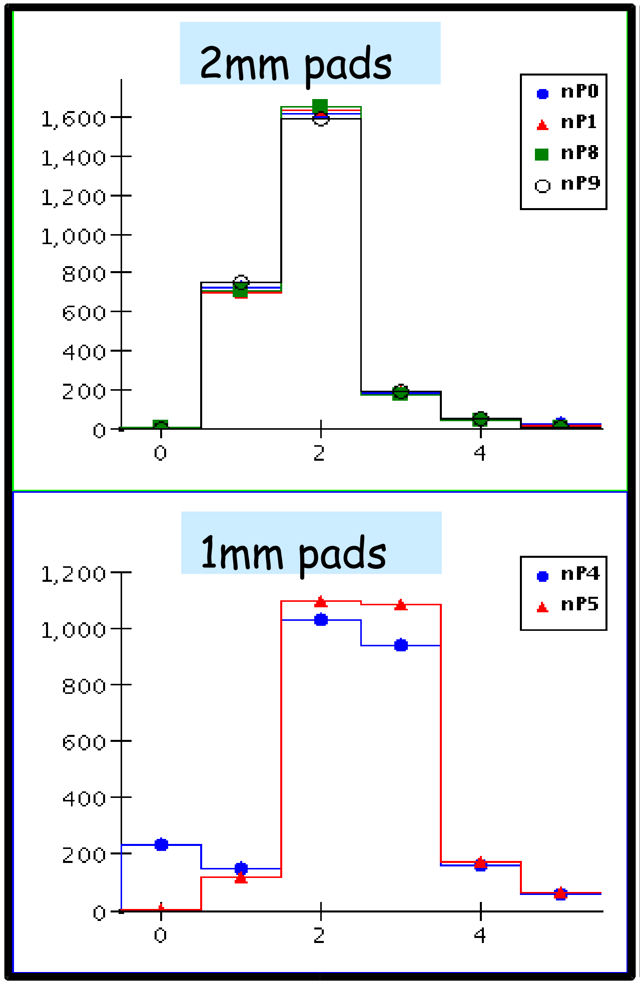
E_D~0.2V/cm

Micromegas TPC Operation

We found the chamber to have very uniform gain response, and the electronic noise to be quite low.

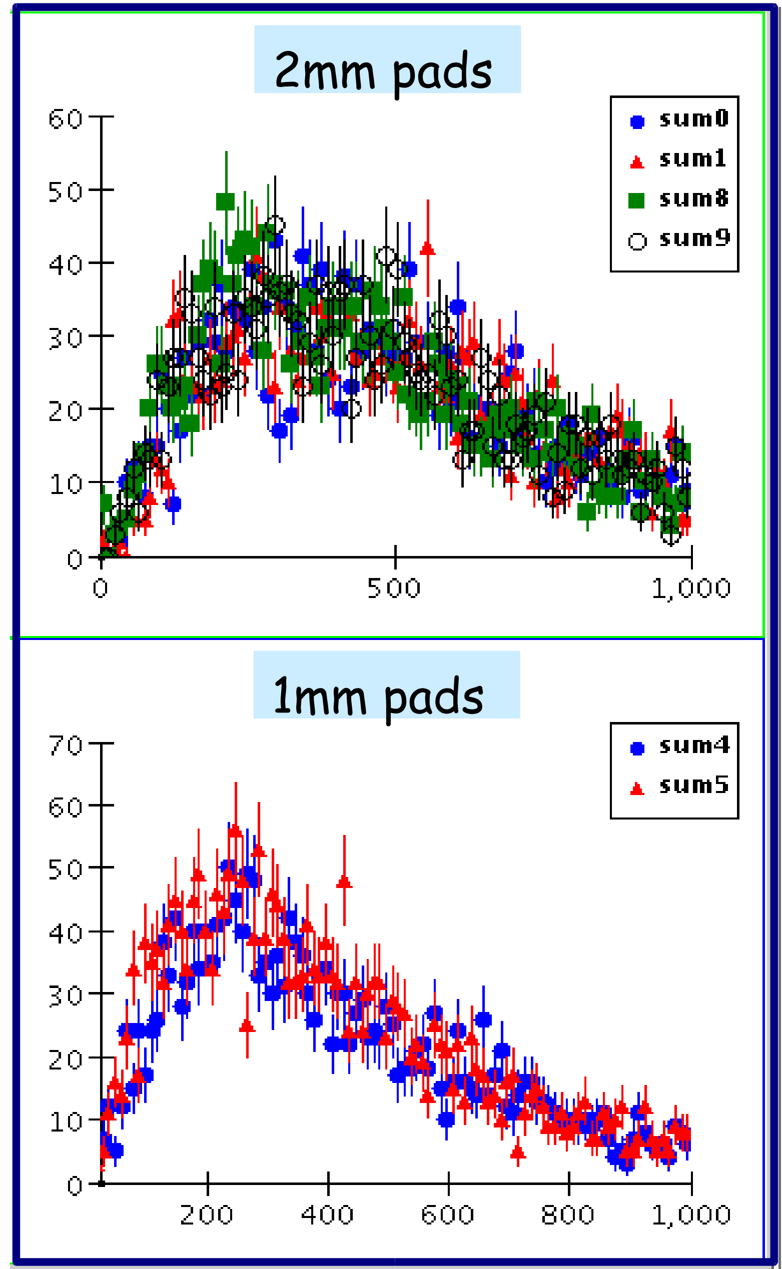
Plots are shown of the number of pads forming each cluster and of the summed amplitude signals for both 2X10 mm^2 pad rows (#0,#1,#8 & #9) and the 1X10 mm^2 pad rows (#4 & #5).

ArCF4: 3%
@ B=1T



 # pads hit

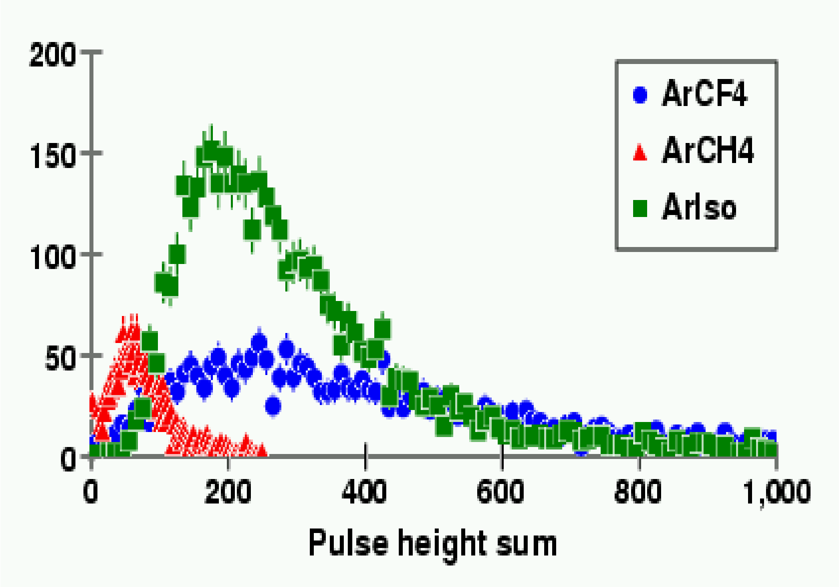
Pulse sums



Micromegas TPC Performance

- Gas gain

We obtained high gains (~5000) at modest mesh voltages, 300-350 V, except for ArCH4:10% (P10).



- Detector stability

Significant signal variation with magnetic field (larger at higher fields) was observd that is not understood at this time.

- Electronic noise

We operated the STAR front end electronics at very low noise levels (~1000 e's), typically 1-2 ADC counts.

- Point resolution measurement

We determine the point resolution by comparing the position measurements of the two center 1mm pad rows, correcting for track angles and for track fitting errors. The resolution measurements are binned in drift distance and fit with a linear dependence. We take the zero drift interept as the *intrinsic* Micromegas position resolution.

Gas Property Measurements

- Drift velocity

We measure the drift velocity of different gases using the data itself. The longest drift time tracks observed are from tracks passing through the far end of the chamber, 50 cm from the readout plane.

- Electron attachment

Using the variation in the average energy deposition, measured by the truncated mean, with drift distance allows us to determine the electron attachment coefficient.

- Transverse diffusion

Measured through maximim likelihood fits to the distribution of signals on pads collecting ionization electrons from individual tracks. Relevant pads with no signals provide information as well.

- Magnetic field suppression

We measure the variation in the transverse diffusion as a function of the magnetic field to determine the suppression factor defined as $(D_T[B]/D_T[0])^{-1/2} \sim \omega\tau$.

From 2004 Rome IEEE Nuclear Science Symposium,
Mike Ronan, LBNL
see http://www-ilc.lbl.gov/detector/talks

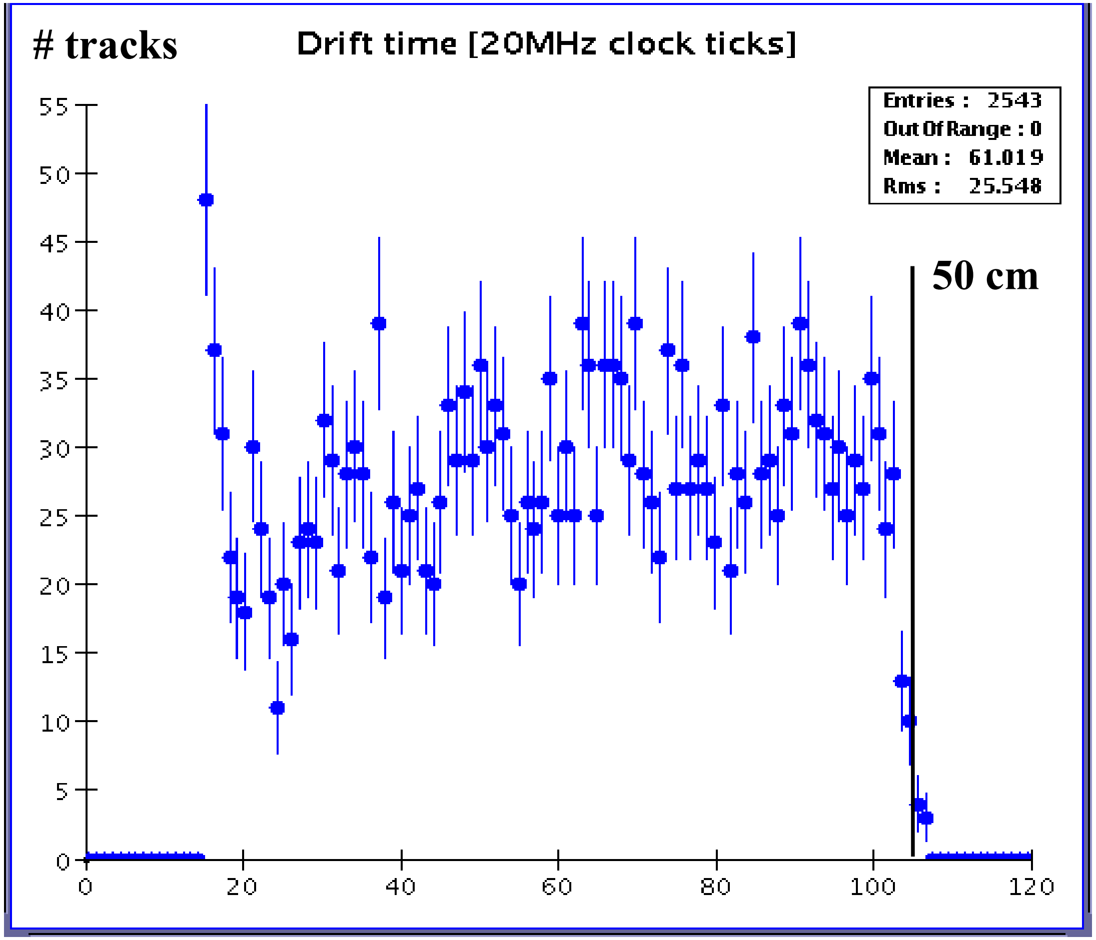
Drift velocity measurements

We measure the drift velocity from the drift time distribution of cosmic ray tracks as shown.

The trigger delay to the readout system and pedestal stabilization results in a loss of information for short drift times. The far end of the chamber at roughly 50 cm begins to cut off the distribution at about 100 clock ticks depending on track dip angle. We take the max. drift time from the distribution to be 105 +- 2 ticks.

We can also determine the drift velocity from individual tracks which are found to exit the far end of the chamber.

In time we'll develop a full Monte Carlo similation to improve the drift velocity determination.



Drift time

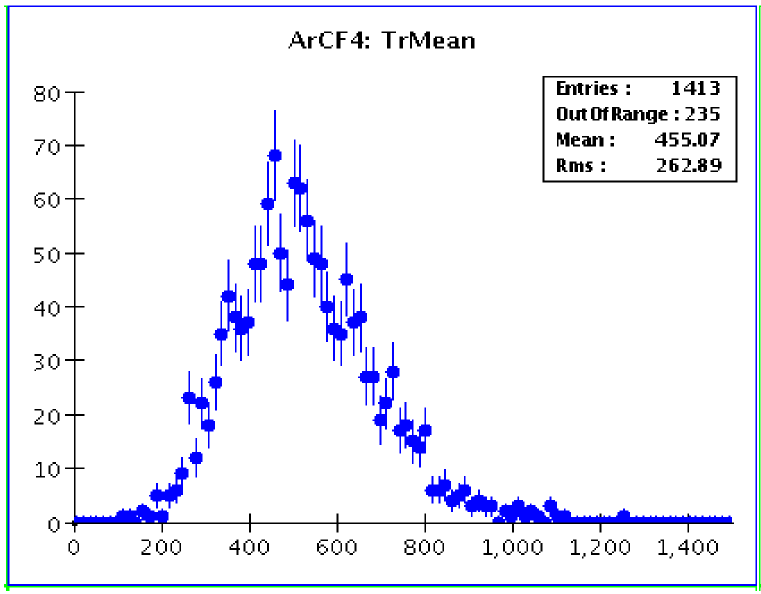
For Ar-CF4:3% we determine the drift velocity to be

$\mathbf{v_D}$ **= 8.8 +- 0.2 cm / microsec.**

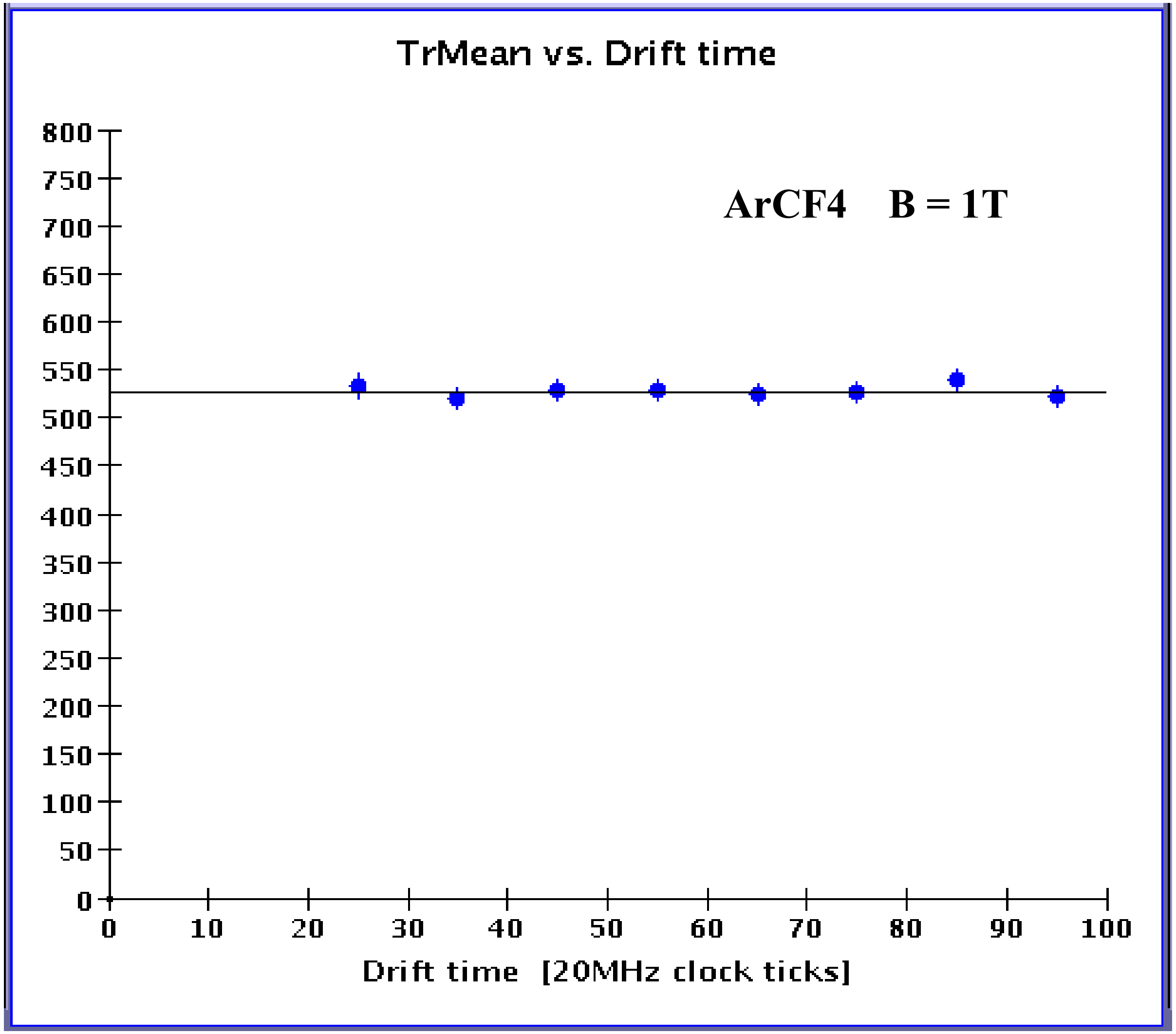
This corresponds to roughly 90 microns / nsec. So that an overall track absolute z position measurement error of about 100 microns yields track timing at 1 nsec level.

Electron attachment measurements

We have not studied dE/dx information very carefully but have made a truncated mean calculation using the lowest signals on 4 out of 6 pad rows.



Using the calculated *TrMean* we can check the attenuation length in **ArCF4** with our relatively long drift length.

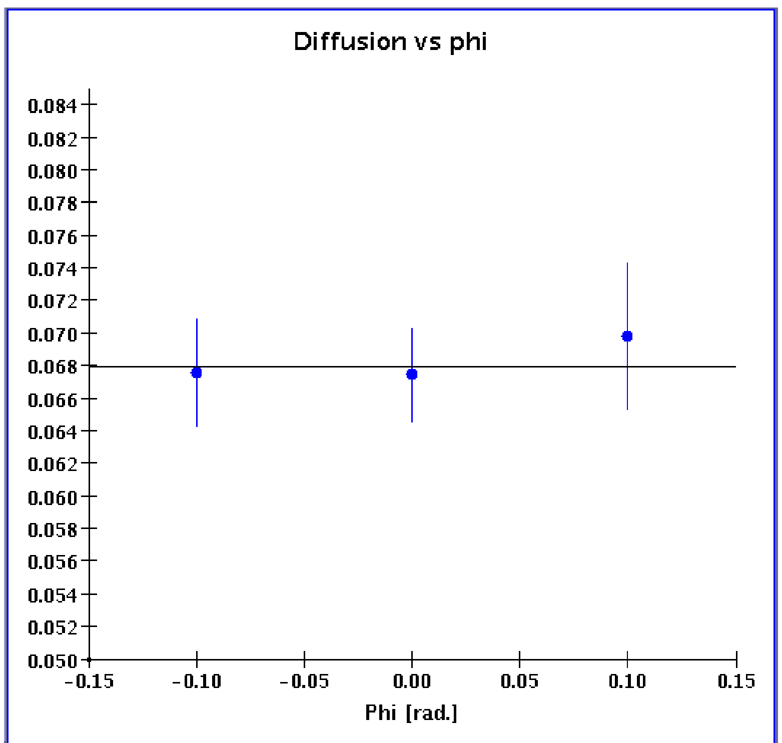


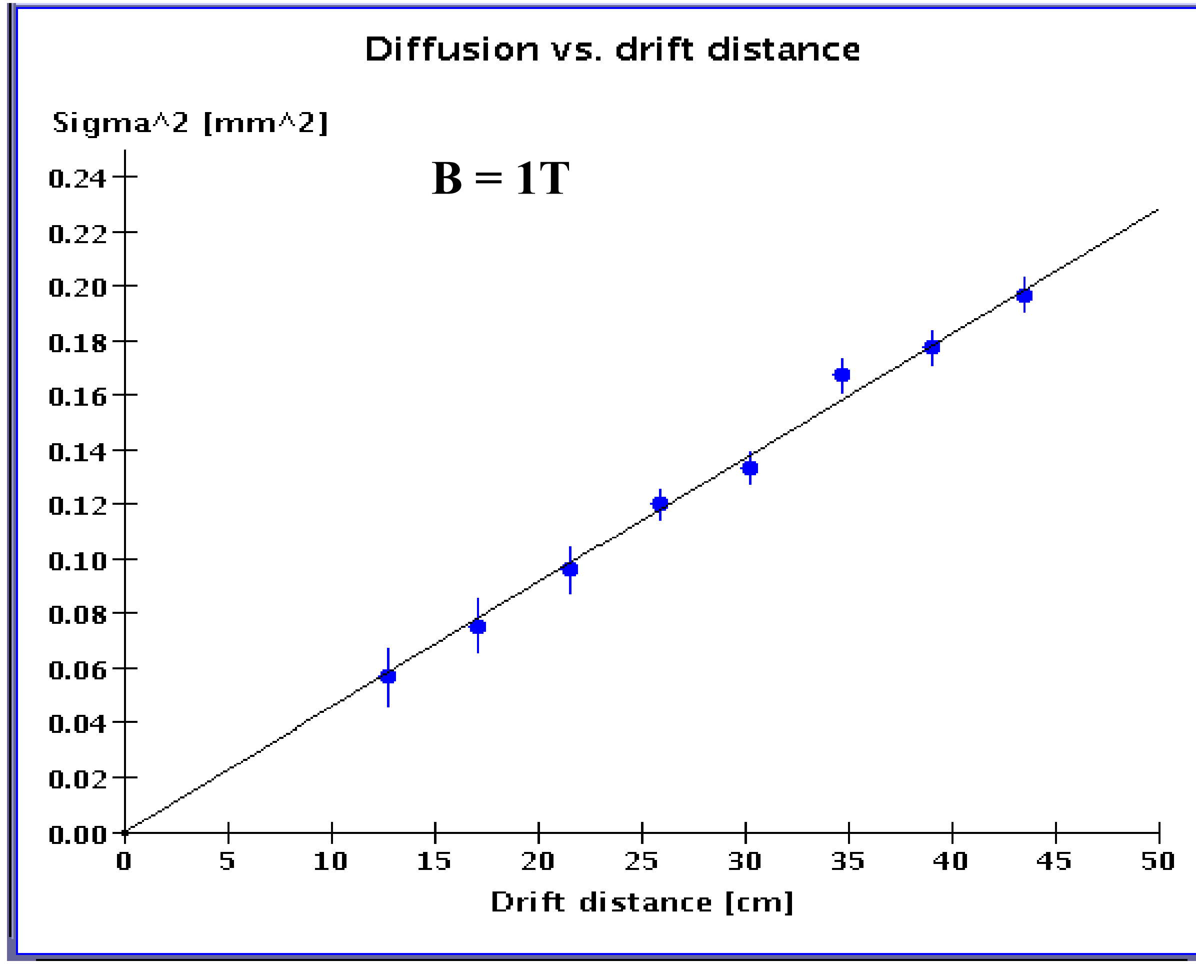
We find that the attenuation length due to electron attachment in **ArCF4** is larger than **4.4 m** at **90%** confidence.

Transverse diffusion measurements

We determine the transverse diffusion from max. likelihood fits to individual anode pad signals on 6 pad rows (4 w/ 2mm pitch and 2 rows w/ 1mm pitch). The fitted track spread is used to measure the transverse diffusion.

We find no evidence of any track angle dependence in the measurement, shown below, as expected.

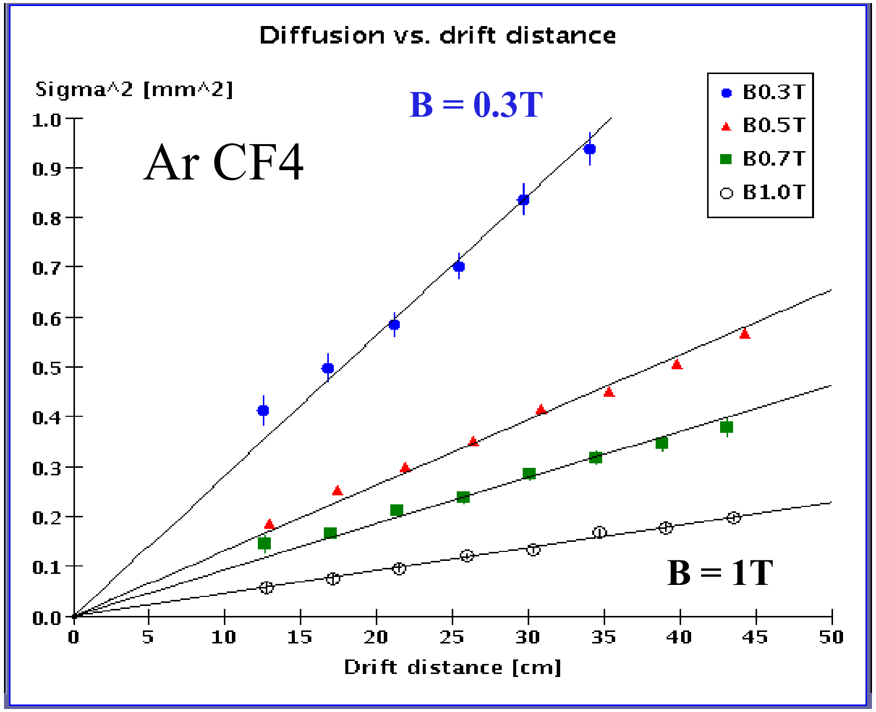


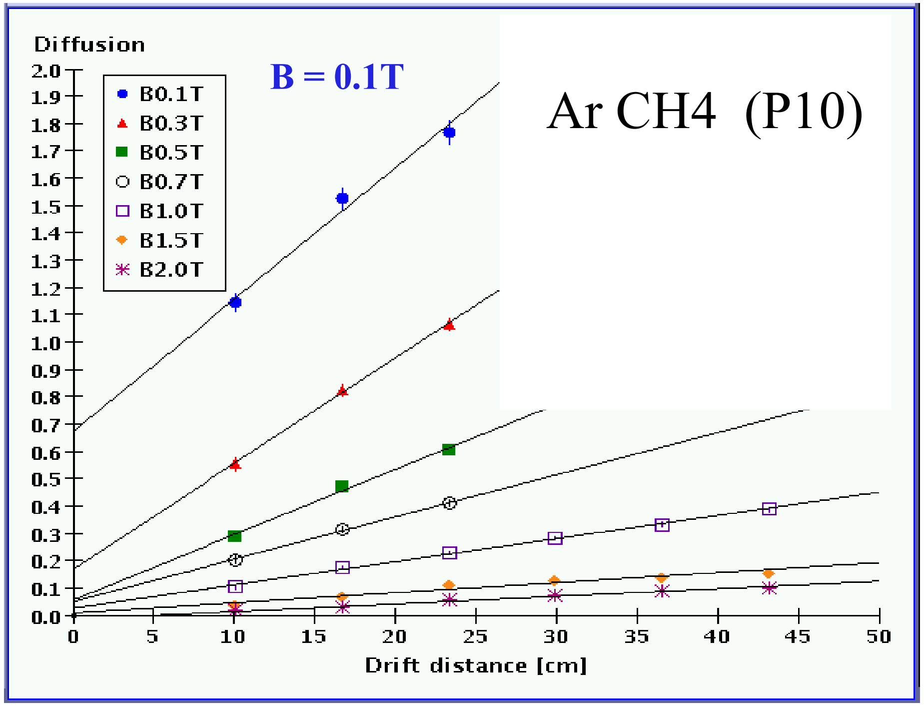


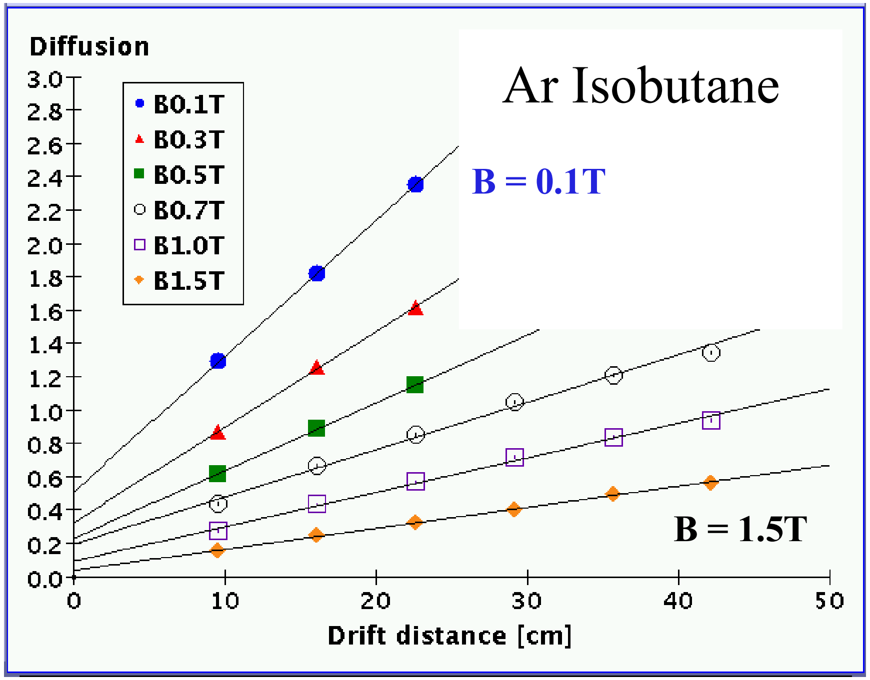
For Ar-CF4:3% at B = 1 Tesla, we measure in one analysis

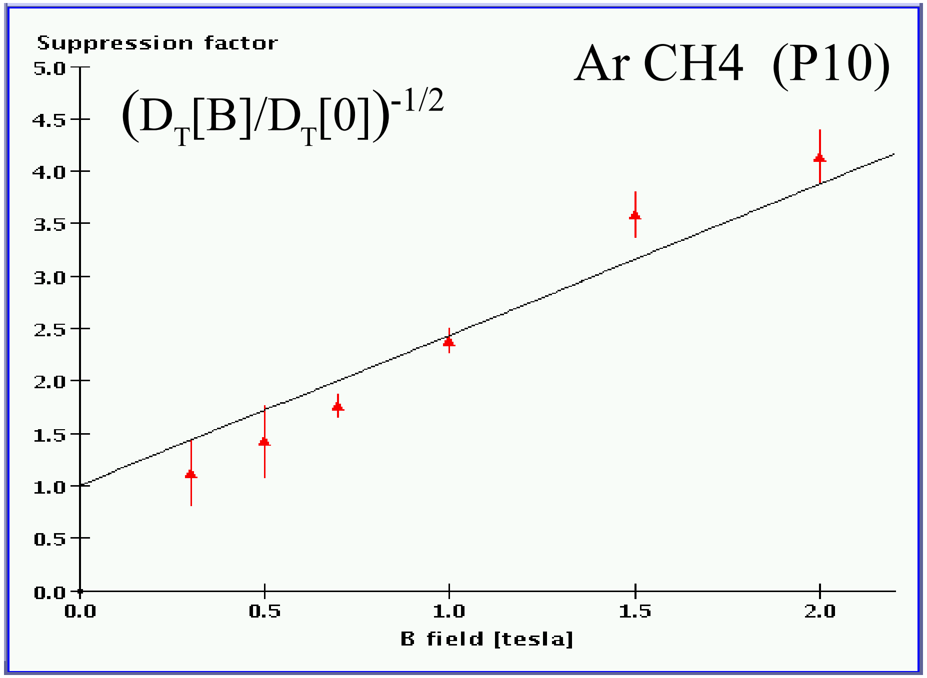
D_T = 68 +- 0.9 +- 3 microns / sqrt(cm)

This implies an expected transverse spread of about 360 microns after 2.5 m drift in a 3 Tesla magnetic field, and a diffusion limited point resolution of 60 microns for 6 mm pads.


Diffusion vs. drift distance
Sigma^2 [mm^2]
B = 0.3T
Ar CF4
B0.3T
B0.5T
B0.7T
B1.0T
B = 1T
Drift distance [cm]


Diffusion
B = 0.1T
Ar CH4 (P10)
B0.1T
B0.3T
B0.5T
B0.7T
B1.0T
B1.5T
B2.0T
Drift distance [cm]


Diffusion
Ar Isobutane
B0.1T
B0.3T
B0.5T
B0.7T
B1.0T
B1.5T
B = 0.1T
B = 1.5T
Drift distance [cm]


Suppression factor
Ar CH4 (P10)
$(D_T[B]/D_T[0])^{-1/2}$
B field [tesla]

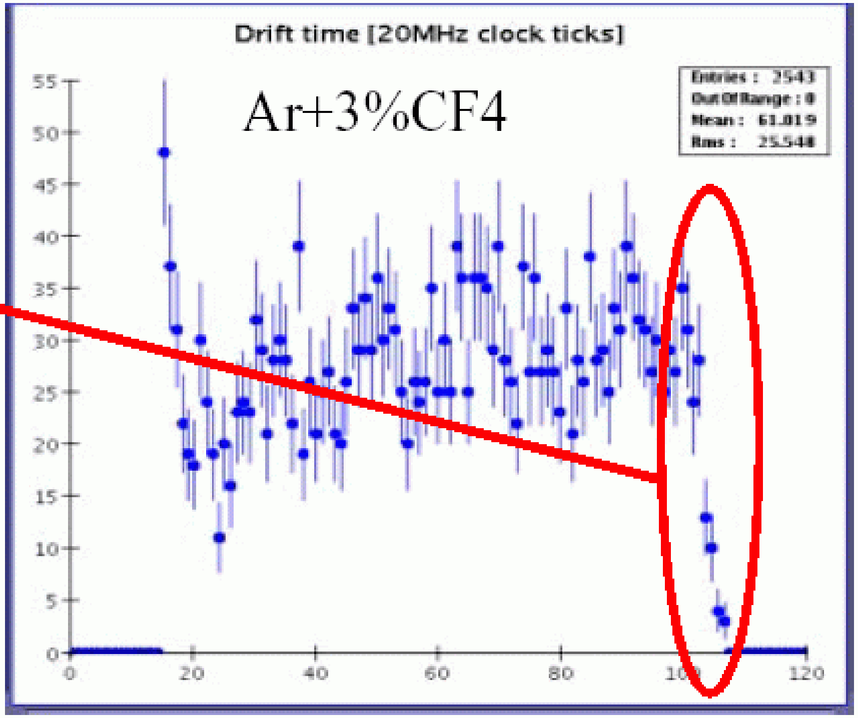
Preliminary Results

- Drift velocity measurements.
- Transverse diffusion

Drift velocity measurements

Select tracks near the far end. Look at the time at which they exit the chamber. Add offset 200+-100 ns (trigger delay)

Divide by the length (47.9 cm)



Excellent agreement with Magboltz

(S. Biaggi, 2004)

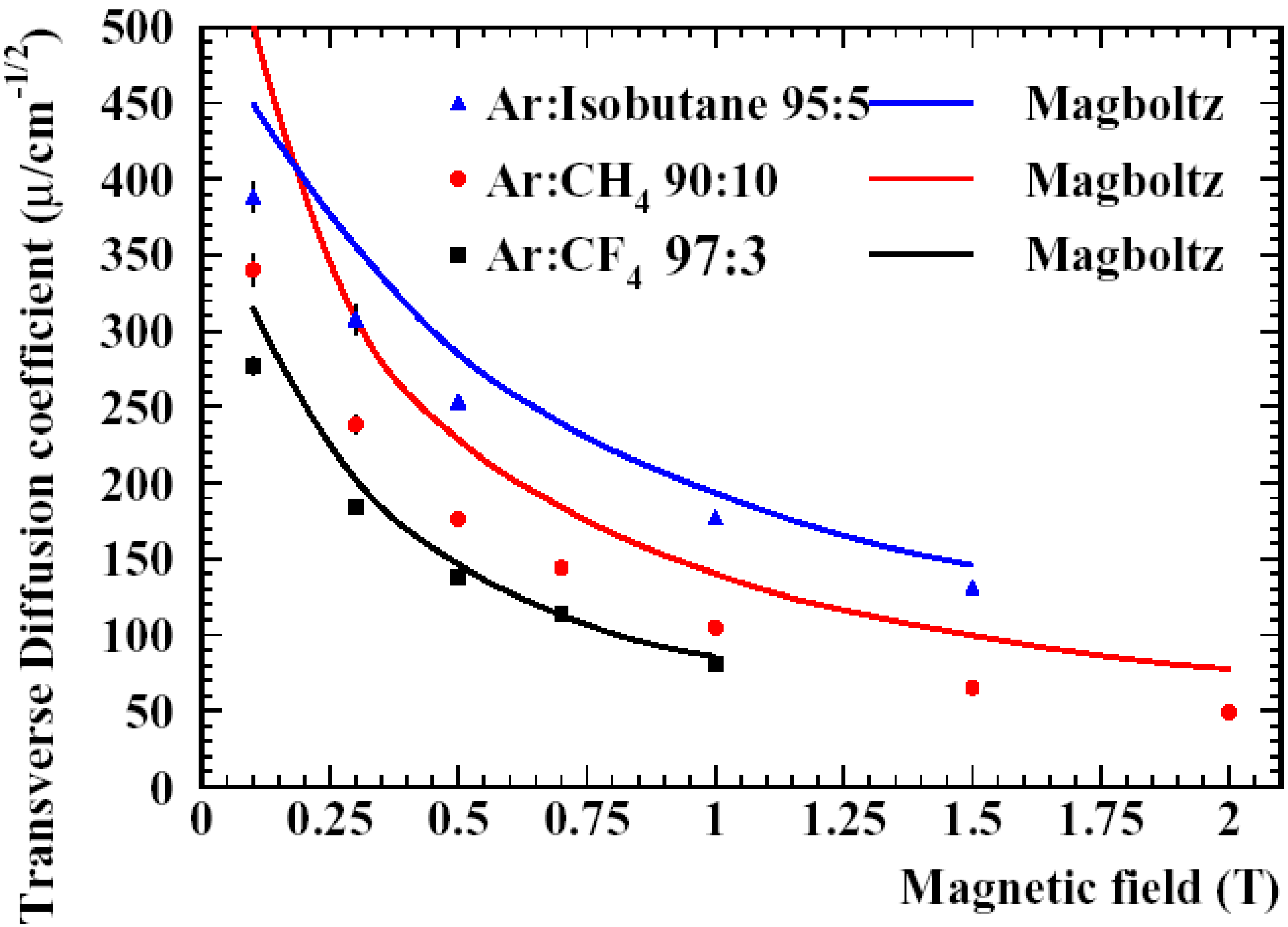
within 2% accuracy!

Gas mixture	E drift (V/cm)	V_{drift} (cm/µs)	Magboltz
Ar+5%iso	210	4.24±0.08	4.17
P10	66	4.43±0.07	4.46
P10	150	5.61±0.09	5.50
Ar+3%CF_4	200	8.8±0.2	8.51

Presented by Paul Colas, DAPNIA (Saclay) at the 2005 LCWS.

Transverse diffusion Results

PRELIMINARY



Presented by Paul Colas, DAPNIA (Saclay) at the 2005 LCWS.

Track reconstruction

Subtract pedestals, using the first 15 time buckets + 15 after the chamber end

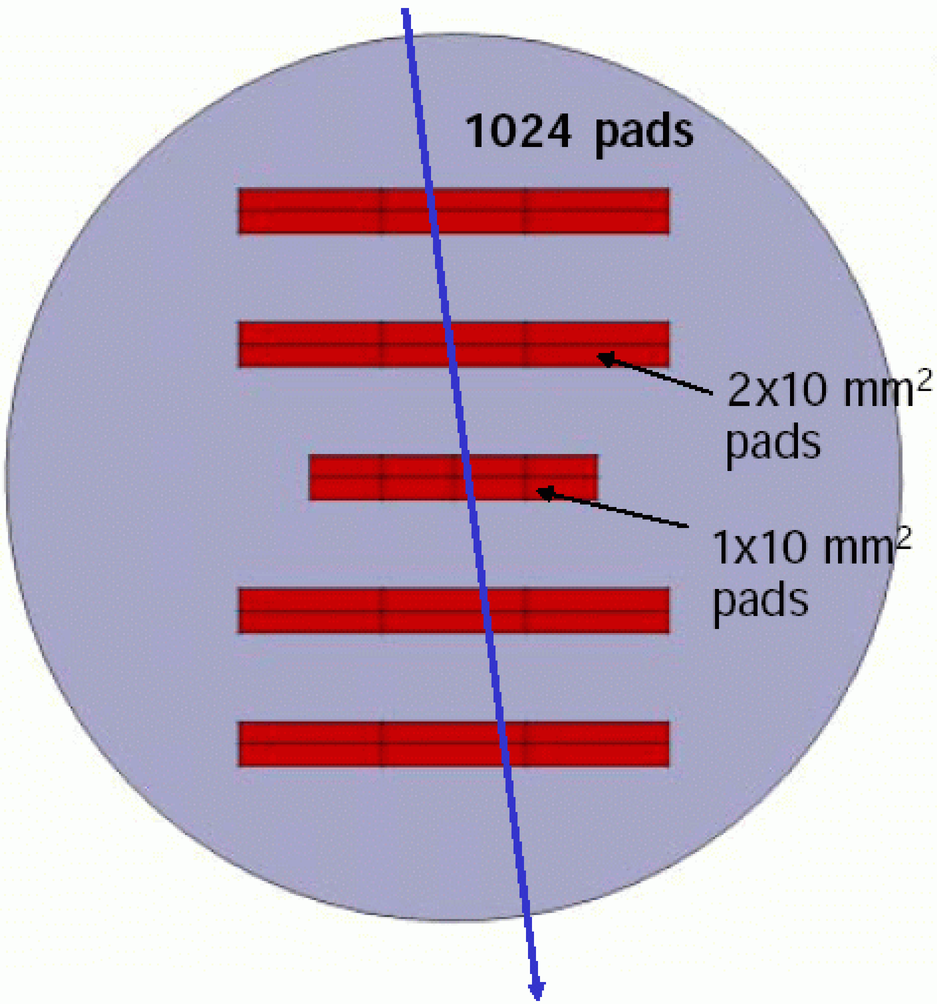
Max-likelihood fit the distribution of the number of electrons per pad with 4 parameters :

$(x_0, \phi, 1/R, \sigma)$

σ is the track width

2 programs: one by D. Karlen, adapted by M. Ronan, in Java, and one by K. Sachs in F95, adapted by P.C. and T. Zerguerras.

Readout anode pad plane

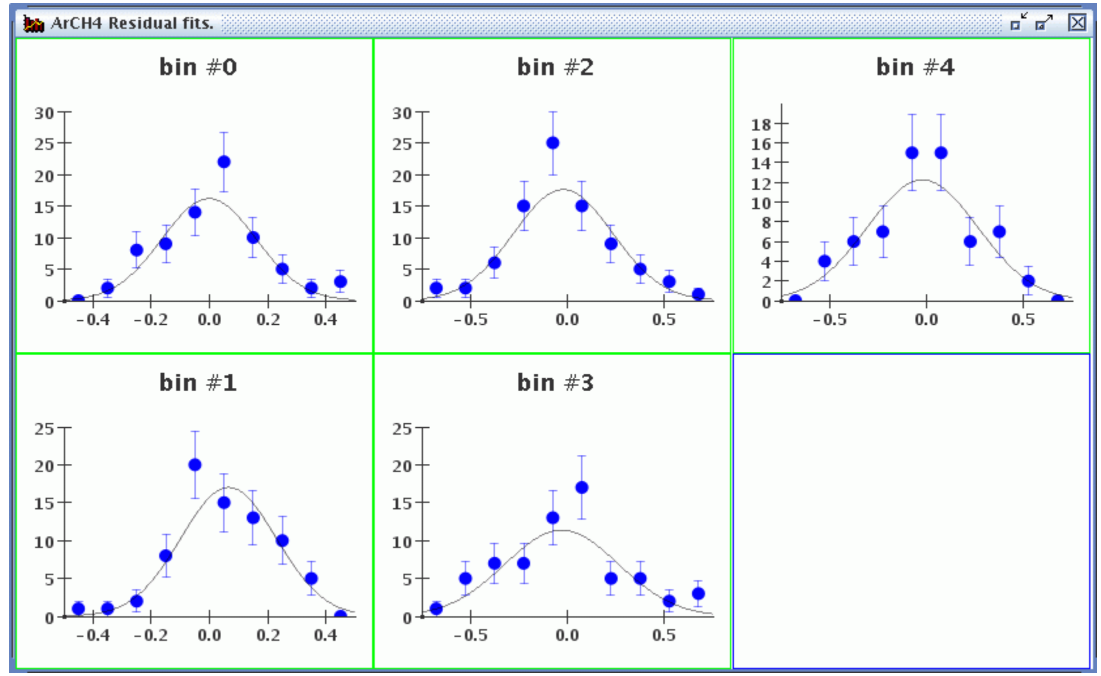


Point resolution

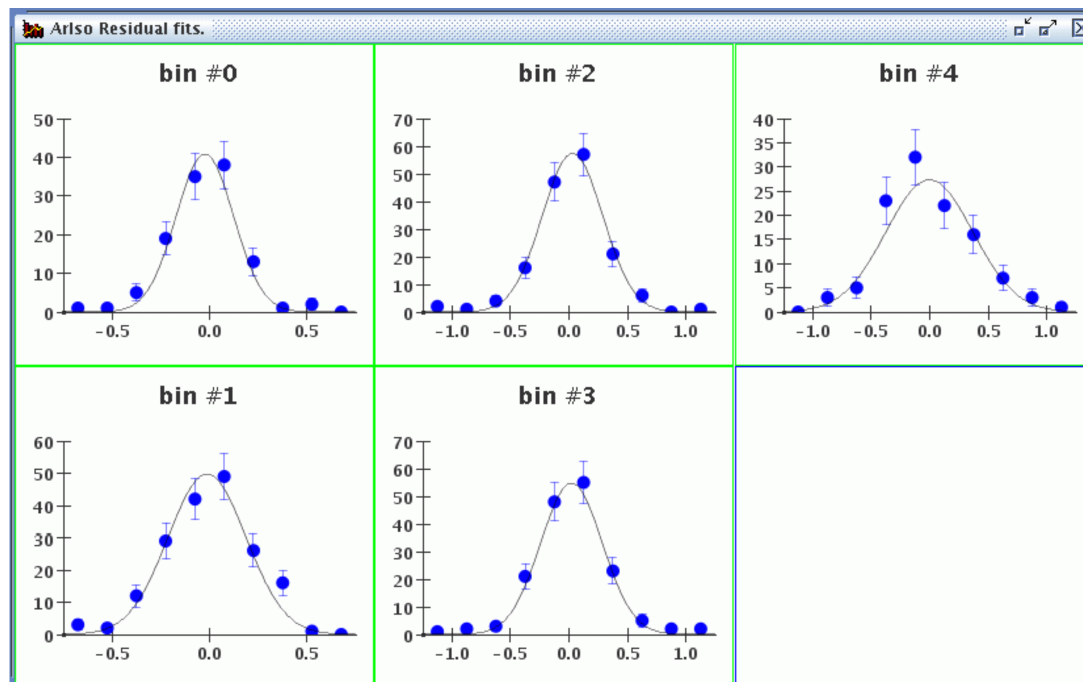
We've recently developed new techniques for measuring the point resolution for the anode pad layout of our Micromegas detector.

Fit residuals are shown for the Ar-CH4 and Ar-Isobutane data at B=1.0T in 5 drift time bins. The residuals in all drift bins are gaussian.

Ar-CH4 10% B = 1.0 T



Ar-Isobutane 5% B = 1.0 T



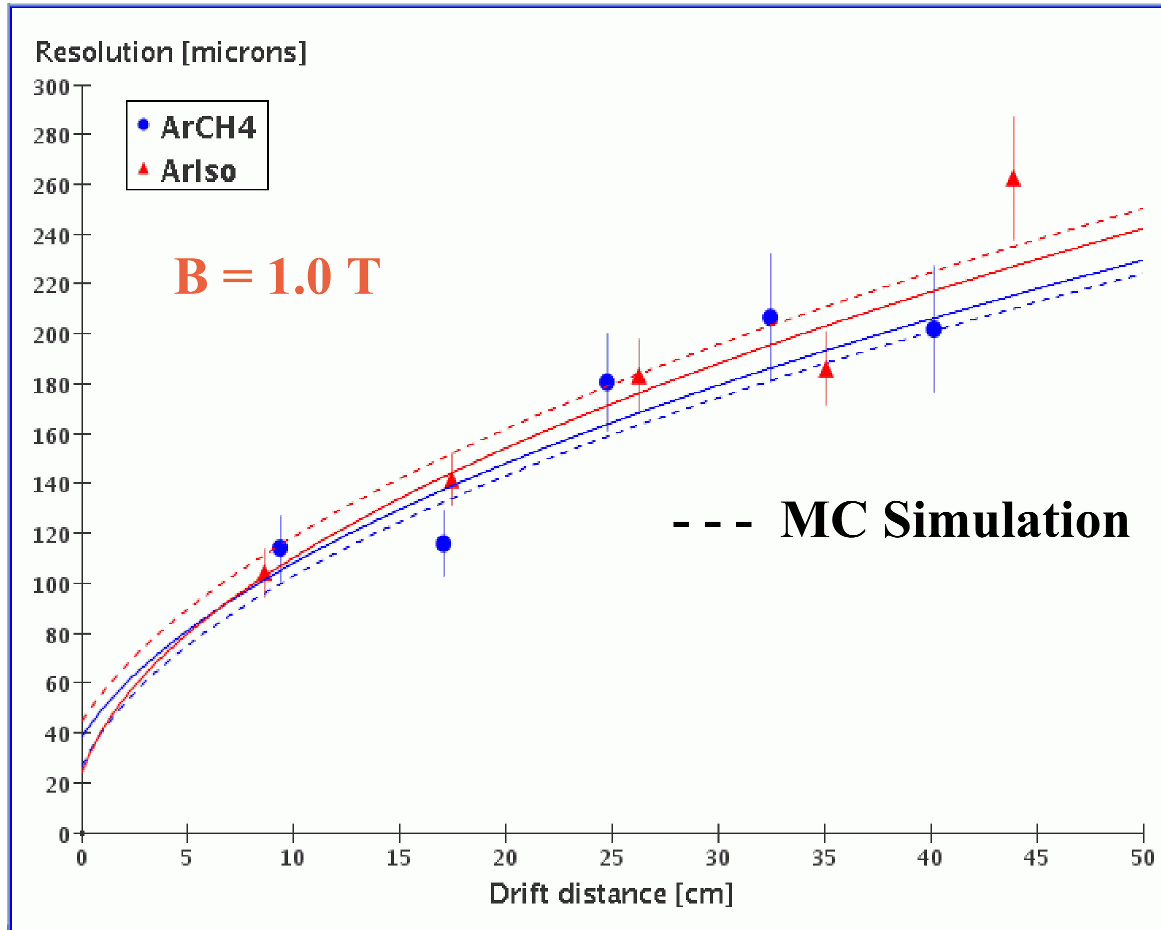
Point resolution vs. Drift distance

Similar point resolution results were obtained for both **Ar-Methane: 10% (P10)** and **Ar-Isobutane: 5%**. The larger diffusion in Ar-Isobutane is compensated by a larger number of effective electrons.

We find

	Data	Monte Carlo
Ar CH4	19.1 +- 4.6	19.4 +- 0.5
Ar Isobutane	32.1 +- 4.8	30.8 +- 1.3

The extrapolated point resolution at zero drift is at or below 50 microns for both gases.



Measured Micromegas TPC point resolution vs. drift distance for Argon-Methane: 10% (P10) and Argon-Isobutane: 5% at a magnetic field of 1. tesla. A Monte Carlo simulation of primary ionization, electron drift and avalanche, and TPC readout is found to be in excellent agreement with the measurements.

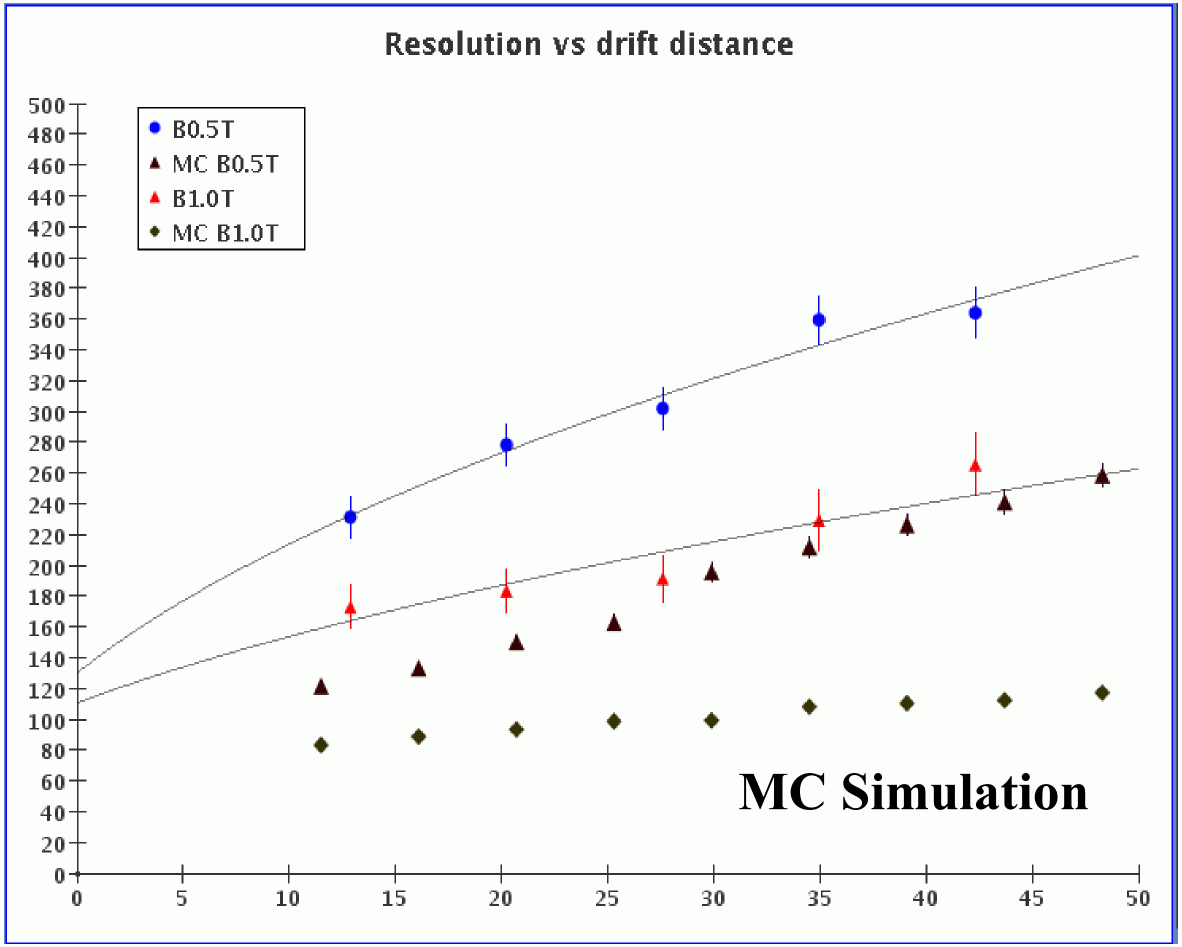
<u>However, Ar-CF4 is quite different.</u>

ArCF4: Point resolution

The point resolution for **Ar-CF4: 3%** is quite different than what is expected from MC simulation. Although transverse diffusion is much smaller in this fast gas because of the large omega-tau, the number of effective electrons is much smaller than expected.

We find

	Data	Monte Carlo
B = 0.5 T		
B = 1. T		



Measured Micromegas TPC point resolution vs. drift distance for **Argon-CF4: 3%** at magnetic fields of **0.5** and **1. tesla**. A Monte Carlo simulation of primary ionization, electron drift and avalanche, and TPC readout is shown for comparison.

Systematic Checks

- Comparison of resolution measurements for ArCH4 and Argon-Isobutane at B=0.5 and 1. tesla to detailed Monte Carlo ionization, drift, avalanche and anode-pad readout.
- New position resolution measurement and comparison to resolution obtained from JTPC fit to selected rows.
- New transverse diffusion measurements and comparison to track width from JTPC maximum-likelihood fit

Monte Carlo checks

Good agreement with detailed MC simulations of ionization, electron drift and avalanche, and of anode pad readout for B=0.5 and 1.0 T.

Ar-CH4 10%

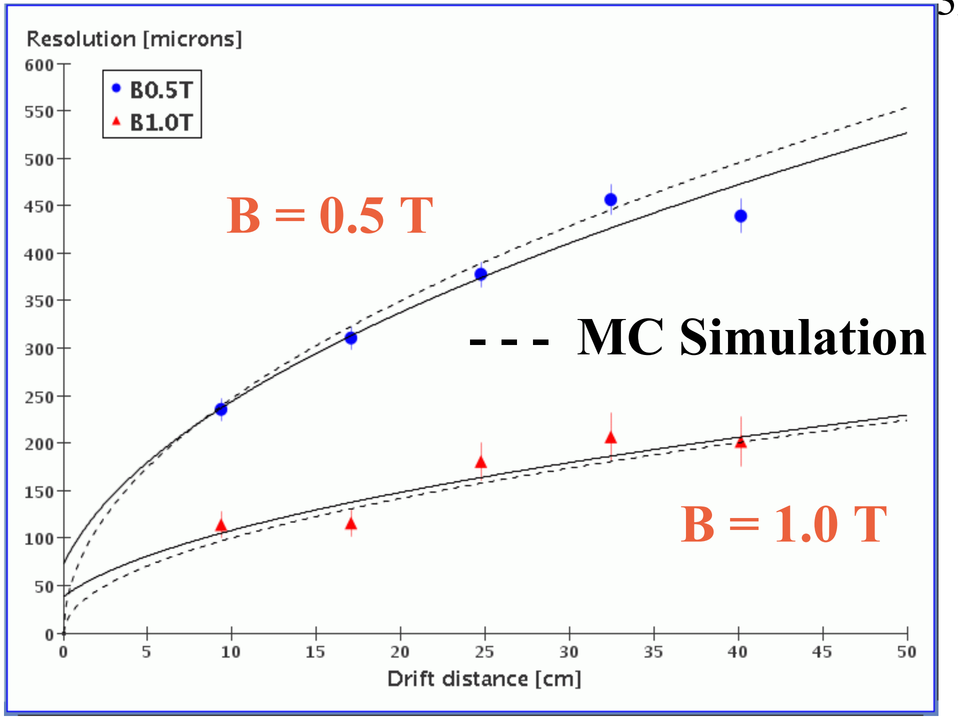
We find for the number of effective electrons (Neff) in P10

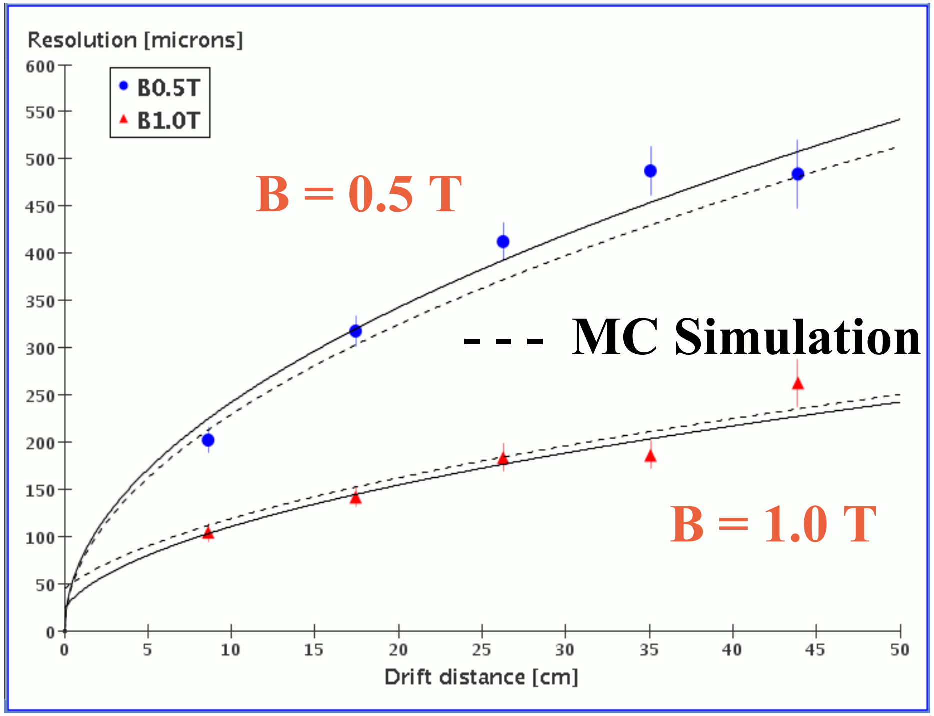
	Data	Monte Carlo
B = 0.5 T	16.5 +- 1.3	10.8 +- 0.2
B = 1.0 T	19.1 +- 4.6	19.4 +- 0.5

Ar-Isobutane 5%

In Ar-Isobutane we find for Neff

	Data	Monte Carlo
B = 0.5 T	15.4 +- 0.8	17.1 +- 0.4
B = 1.0 T	32.1 +- 4.8	30.8 +- 1.3

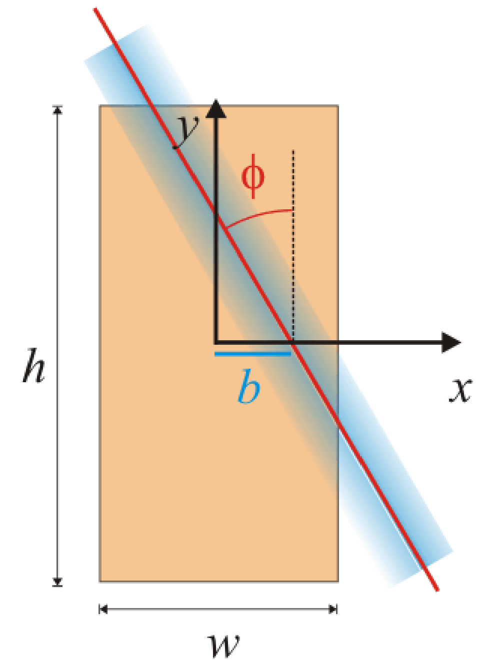




Likelihood track fit

- The likelihood for a single row is calculated according to the Gaussian diffusion model
  - consider the segment of the track sampled by the row
  - I_i is the integral of the charge density over pad i
    - depends on b, ϕ, σ
  - the probability for an electron to hit pad i is:

$$p_i = I_i / \sum I_i$$



$$I(b,\phi,\sigma,h,w) = \int_{-w/2}^{w/2} dx \int_{-h/2}^{h/2} dy \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{[(x-b)\cos\phi + y\sin\phi]^2}{2\sigma^2}}$$
$$= \eta(b,\phi,\sigma,h,w) - \eta(b,\phi,\sigma,-h,w) + \eta(b,\phi,\sigma,-h,-w) - \eta(b,\phi,\sigma,h,-w)$$

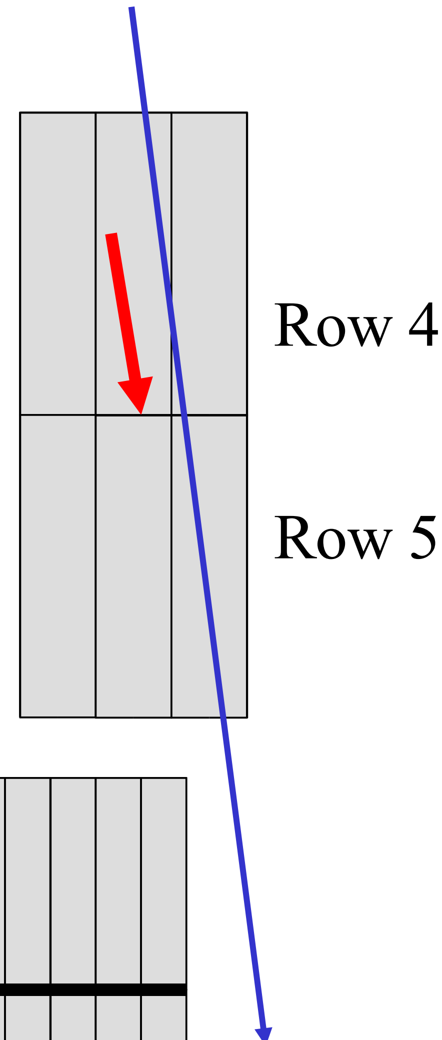
$$\eta(b,\phi,\sigma,h,w) = \frac{1}{\cos\phi\sin\phi}\xi\left((b+\frac{w}{2})\cos\phi + \frac{h}{2}\sin\phi, \sigma\right)$$
$$\xi(u,\sigma) = \frac{u}{2}\mathrm{erf}\left(\frac{u}{\sqrt{2}\sigma}\right) + \frac{\sigma}{\sqrt{2\pi}}\exp\left(\frac{-u^2}{2\sigma^2}\right)$$

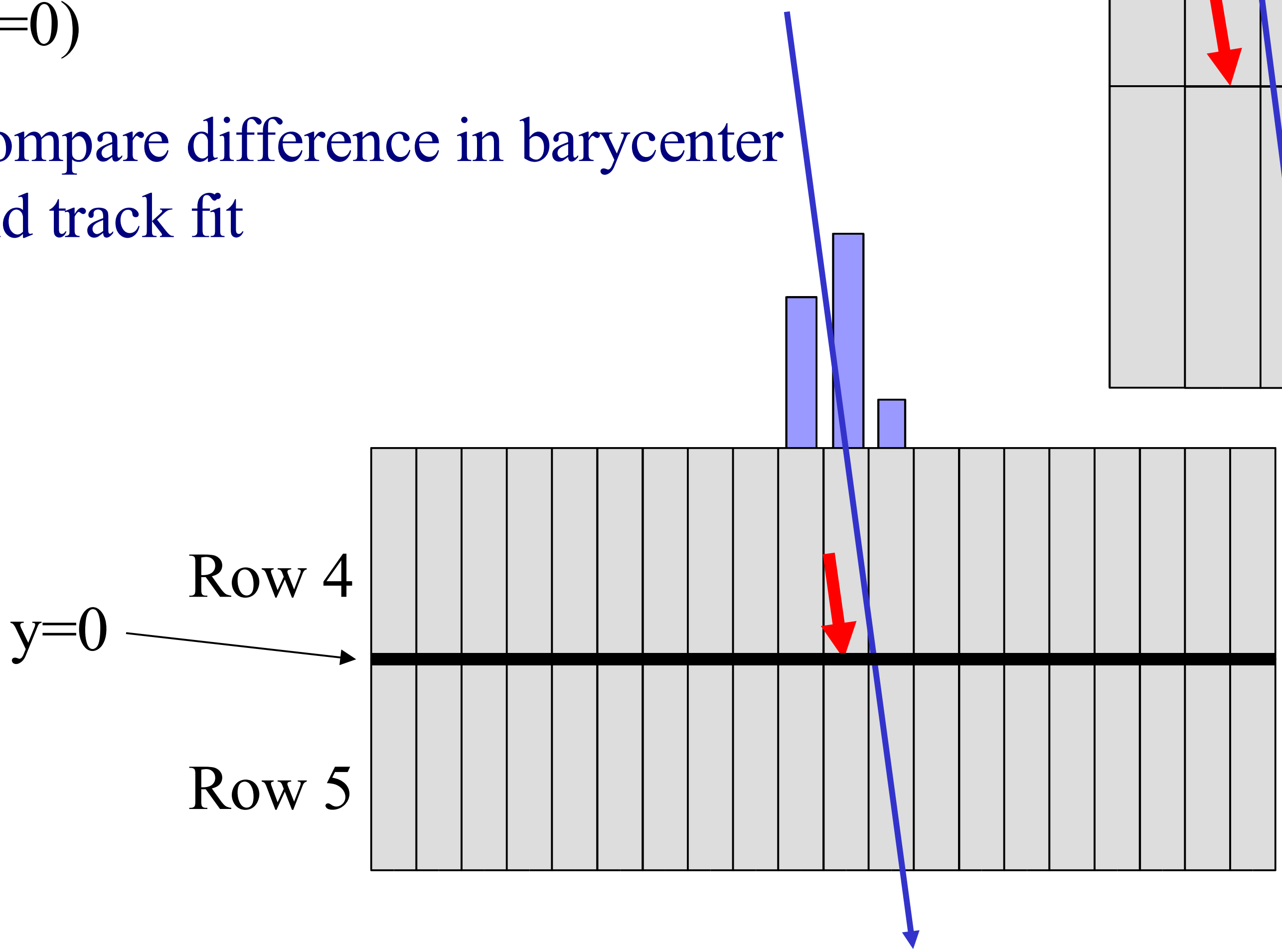
From the presentation by Dean Karlen, U. Victoria at the 2006 TPC Analysis Jamboree.

Track reconstruction

Take barycenter of row (pad width = 1.0mm) and extrapolate to middle of pad layout (y=0)

Compare difference in barycenter and track fit





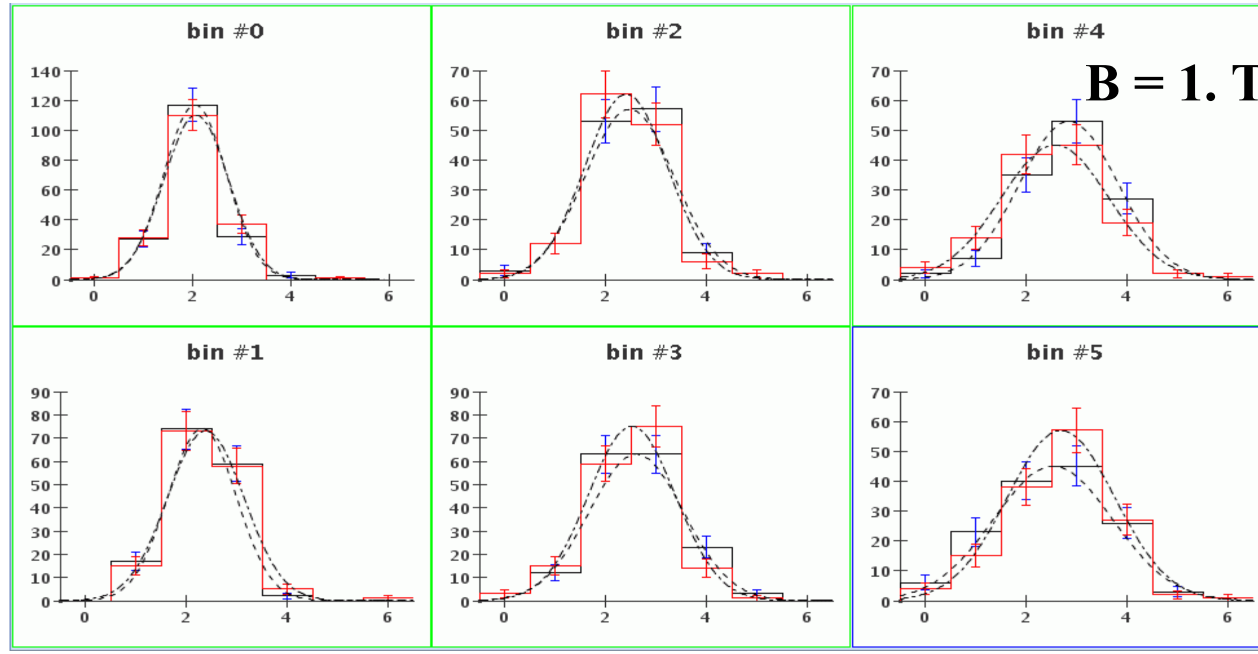
From the presentation by Dan Burke, DAPNIA (Saclay) at the 2006 TPC Analysis Jamboree.

Track width checks

P10

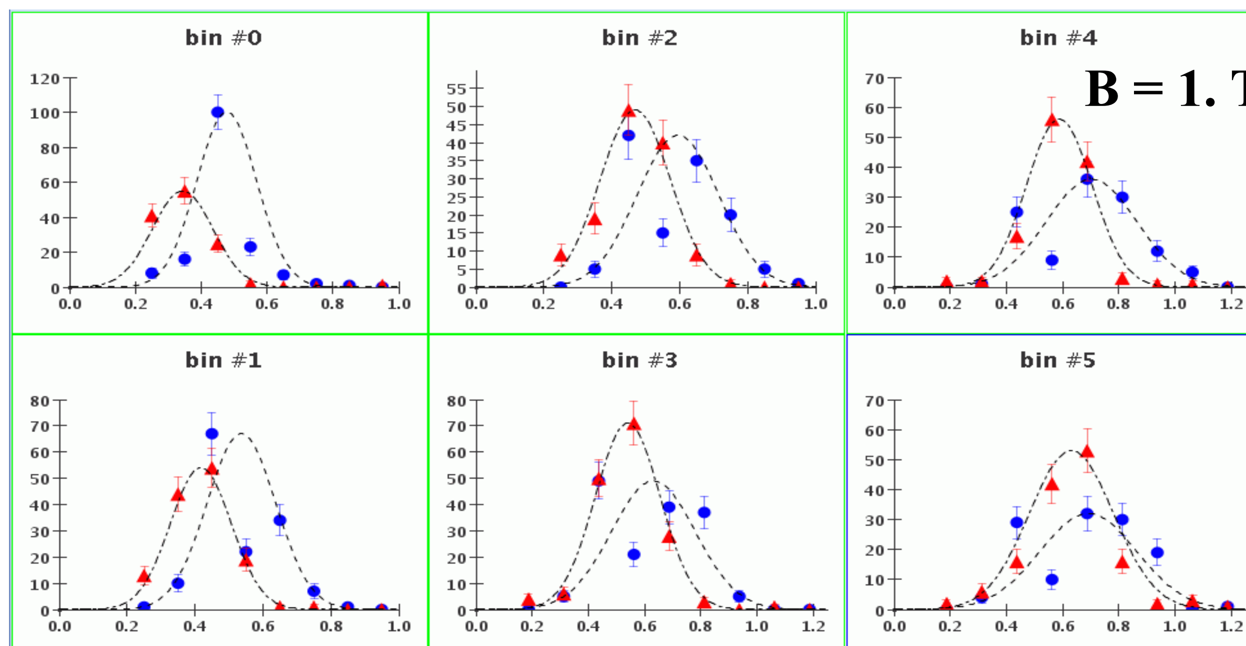
For tracks with 3 or more hits in 1 mm pad rows, measure transverse width from gaussian fit to transverse pulse height distribution in different z bins.

 # pads hits



Comparison to track width from maximum likelihood fits shows a systematic difference between the two measurements.

Diffusion measurements

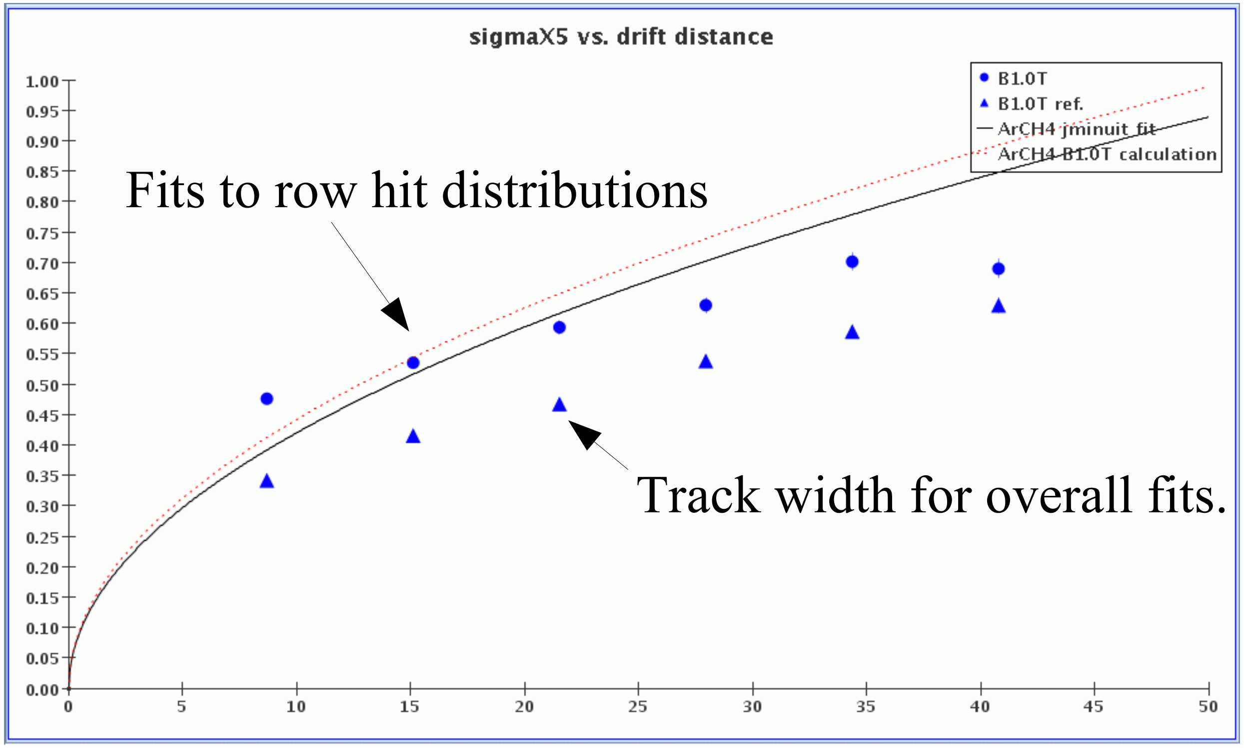


MagBoltz comparison

The transverse diffusion measurement from the width of the hit distribution in the 1 mm pad rows is in better agreement with MagBoltz simulations than diffusion determined from transverse track width obtained from the maximumlikelihood fits.

P10

B = 1. T



Summary

- The Berkeley-Orsay-Saclay (BOS) Large-Area Micromegas TPC was run in cosmic-ray tests of three gases, ArCH4 (P10), Ar-Isobutane and ArCF4, in varying magnetic fields up to 2 Tesla.
- The detector operated stabily at gains up to 3500, measured to be very uniform across the chamber.
- Measurements of drift velocity, transverse diffusion and attenuation were made for all 3 gases.
- The tranverse position resolution measurements were in good agreement with Monte Carlo simulations for P10 and Argon-Isobutane. The intrinsic resolution from extrapolation to zero drift is about 50 microns.
- The transverse position resolution for ArCF4 is much worse than expected and not fully understood at this time.
- Systematic checks are in progress.