International Linear Collider (ILC) Large-Area Micromegas TPC R&D

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Berkeley – Orsay – Saclay
Micromegas TPC R&D Collaboration

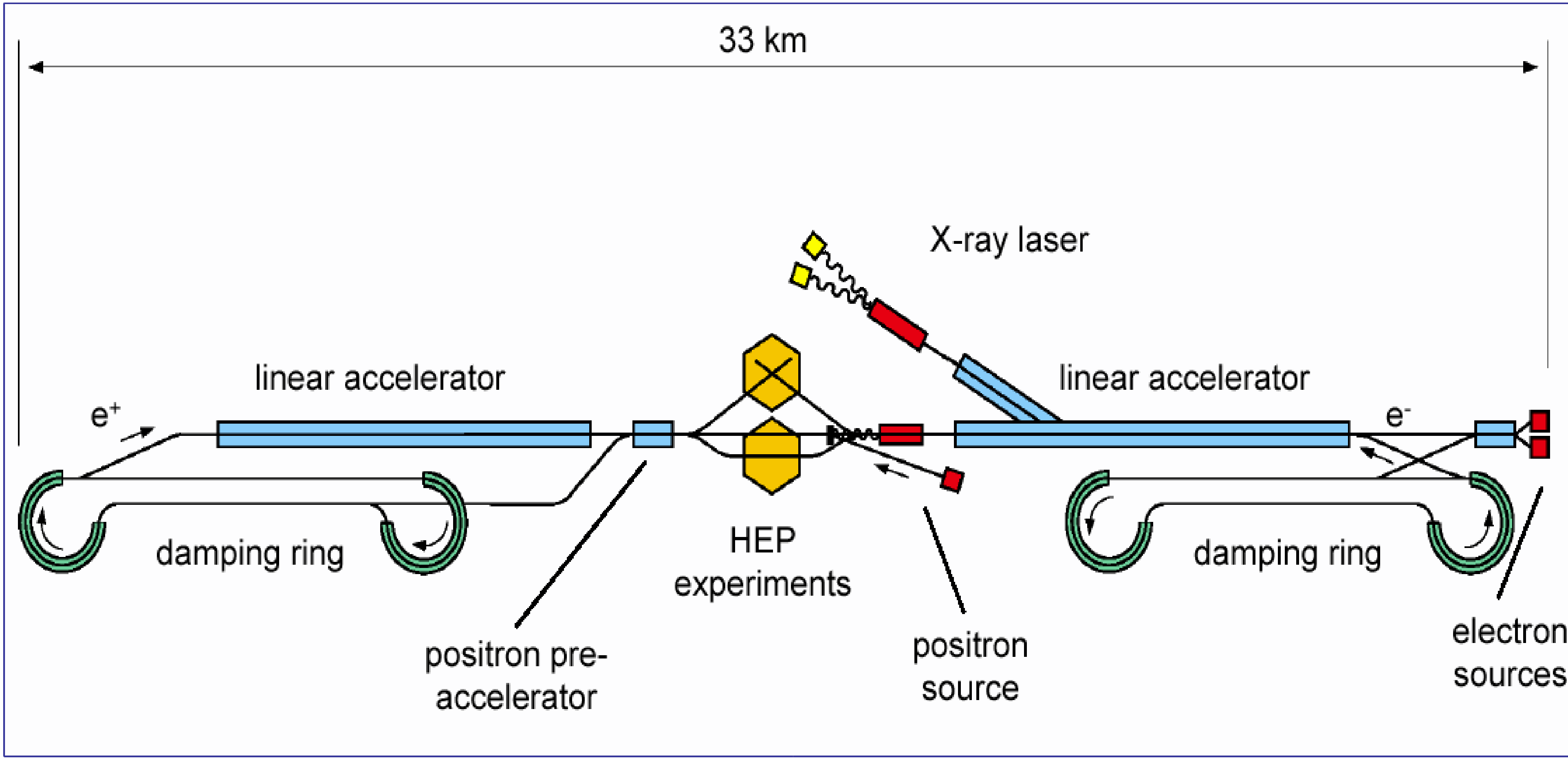
As presented at
Purdue, Fermilab & Carleton, 15-19 Nov. 2004

Outline

- Micromegas TPC Design
  - Construction, Purdue 3M Micromegas mesh
  - Anode pad layout
- Cosmic Test Configuration
- Measured Gas Properties
  - Drift velocity, Electron attachment, Transverse diffusion
- Micromegas TPC Performance Characteristics
  - Gain, stability, noise
  - Transverse position resolution
- Pixel TPC R&D
  - Setup, MediPix chip (2D) readout

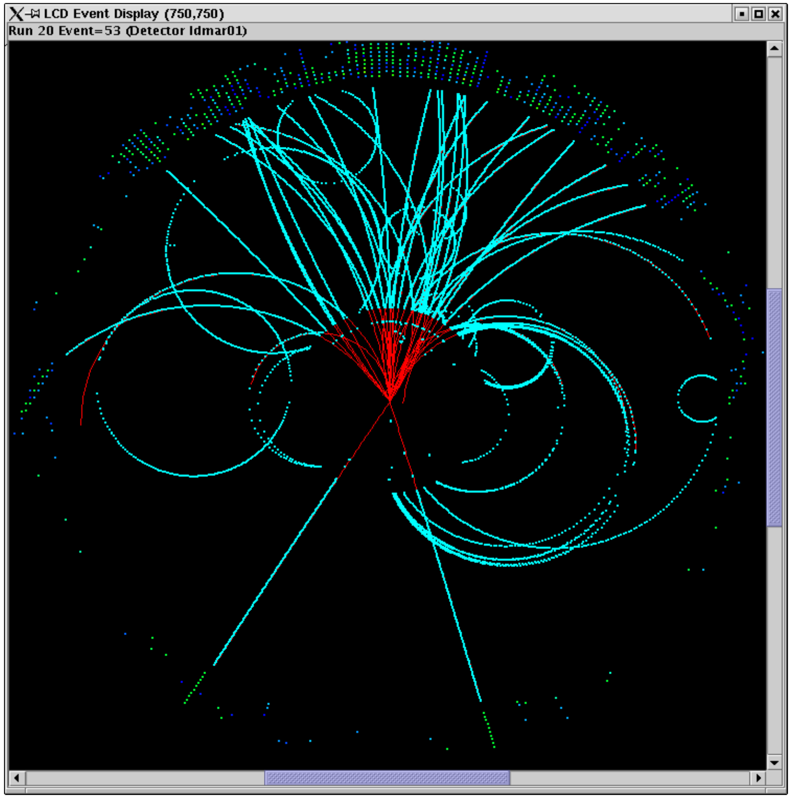
International Linear Collider (ILC)

It will look somethink like

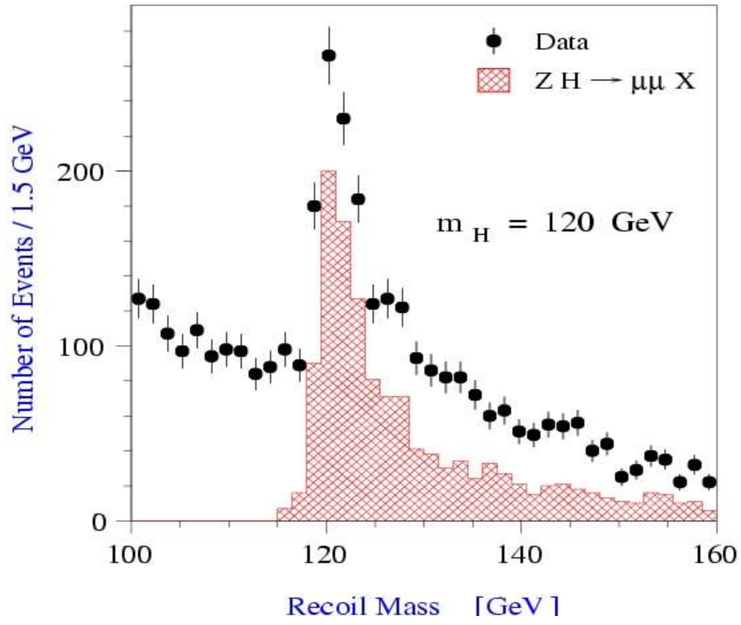


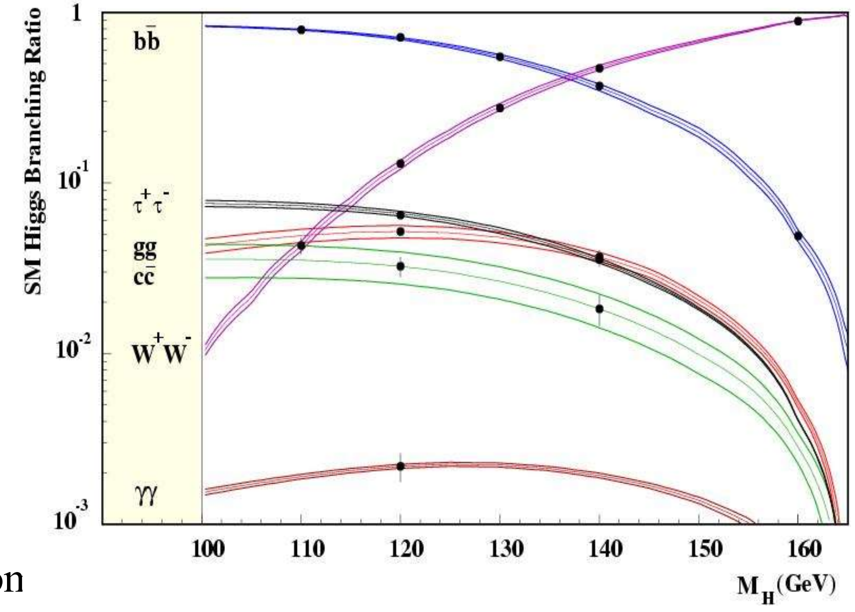
Linear Collider Higgs Physics

Use Higgstrahlung process e^+e^- --> ZH with Z decaying into leptons to measure / confirm Higgs mass from LHC, and to determine branching ratios precisely.



N.B. Also, need to calibrate Higgs multi-jet reconstruction efficiency.

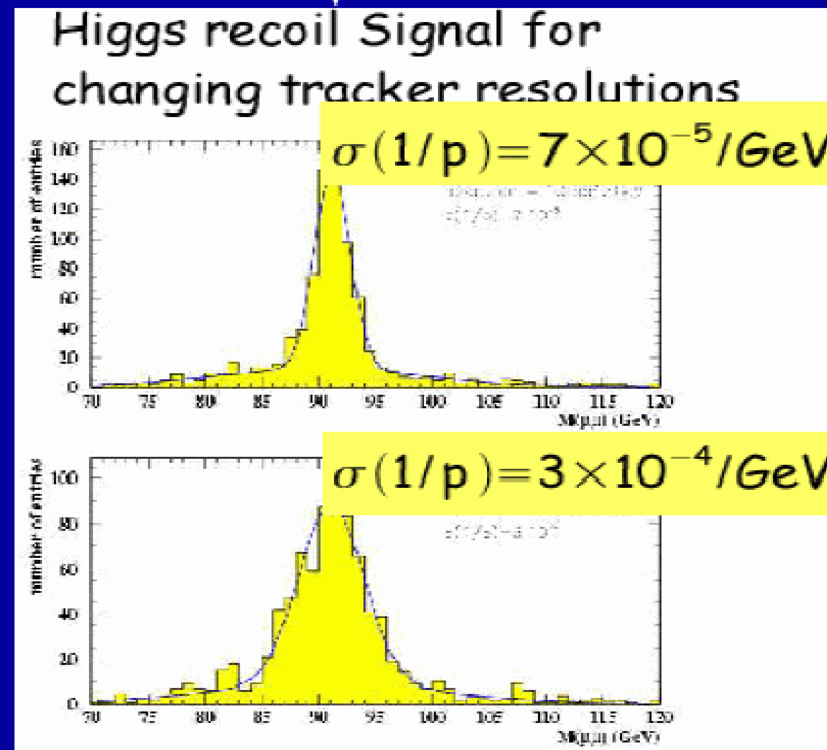




Momentum Resolution

$e^+e^- \to H^0Z^0,\ Z^0 \to \ell^+\ell^-$

AT $\sqrt{s}$=0.5 TeV



- ✧ Higgstrahlung reaction offers most stringent requirements on momentum resolution $\delta(1/p)$;
- ✧ other reactions, such as slepton mass reconstruction from momentum end-points in $\tilde{\ell}\tilde{\ell}$ are limited by beamstrahlung;

October 1, 2004
SLAC Seminar

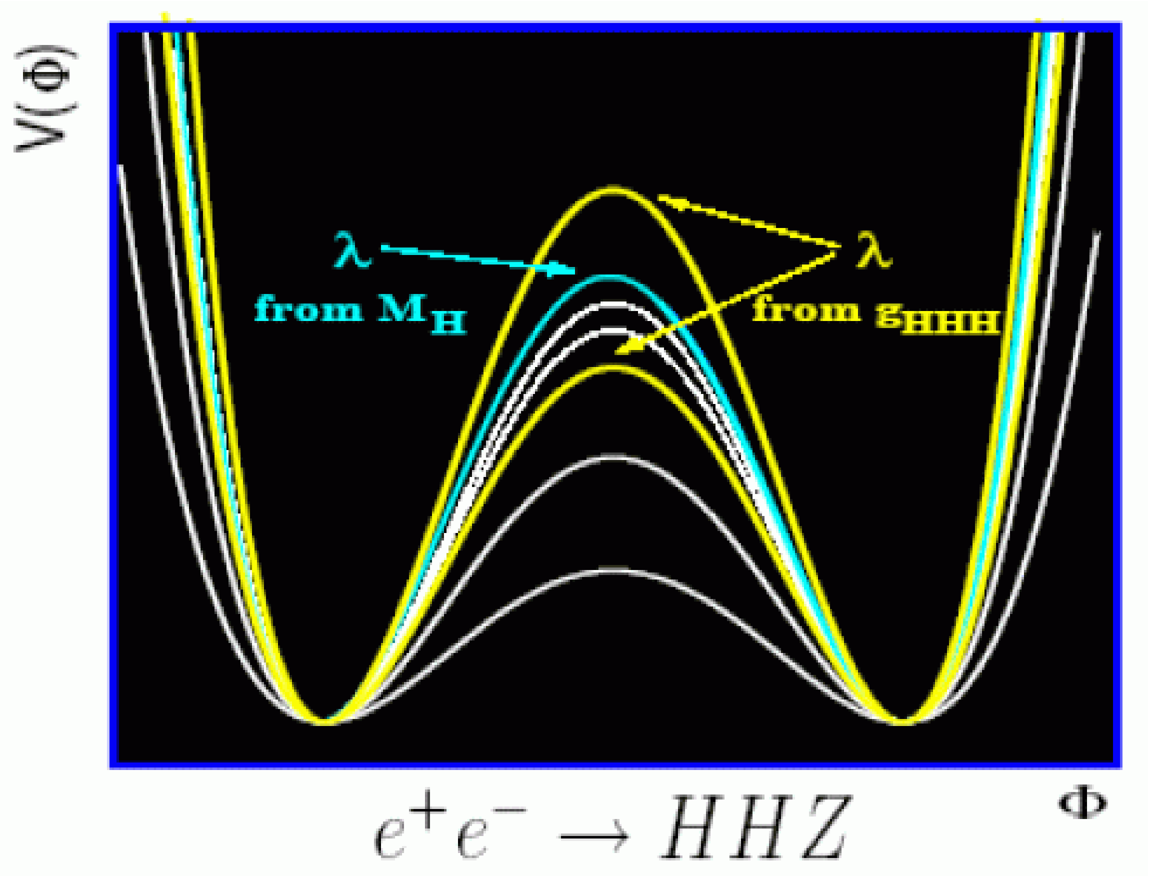
Benchmarking the LC Detector(s)
M. Battaglia

Page 10

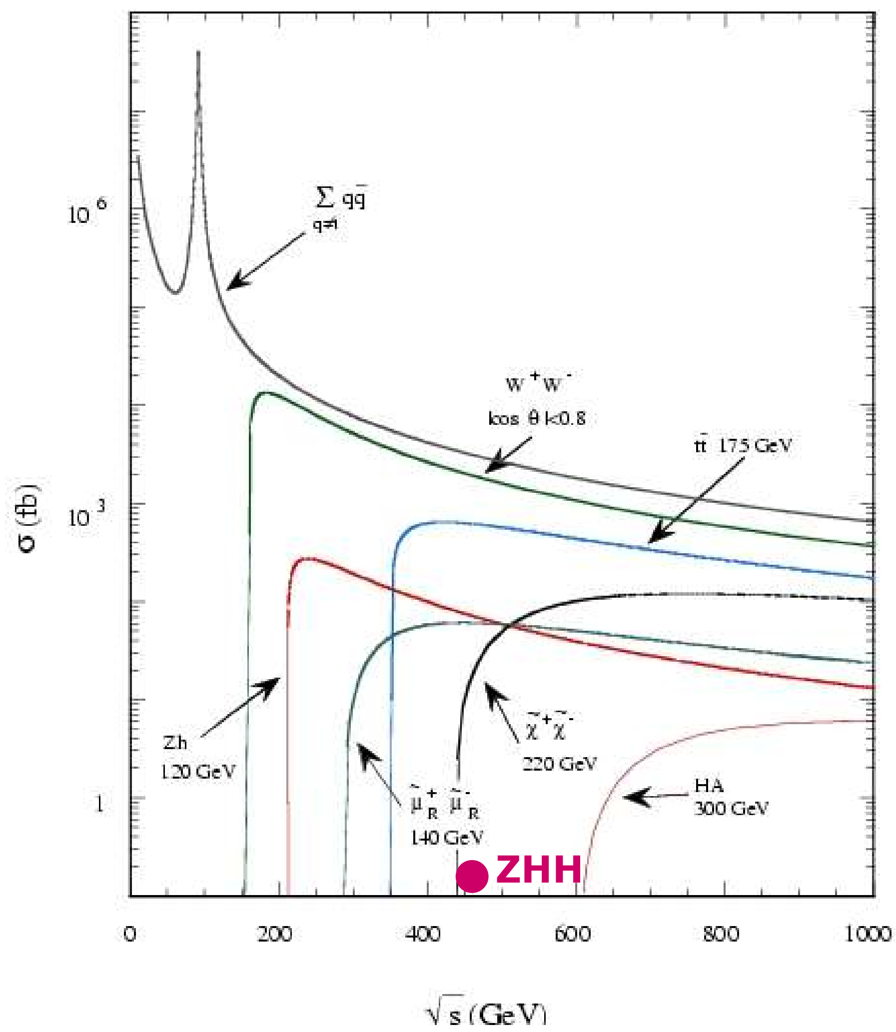
We'd like to use the "Double Higgstrahlung" process

e^+e^- --> ZHH --> 6 jets

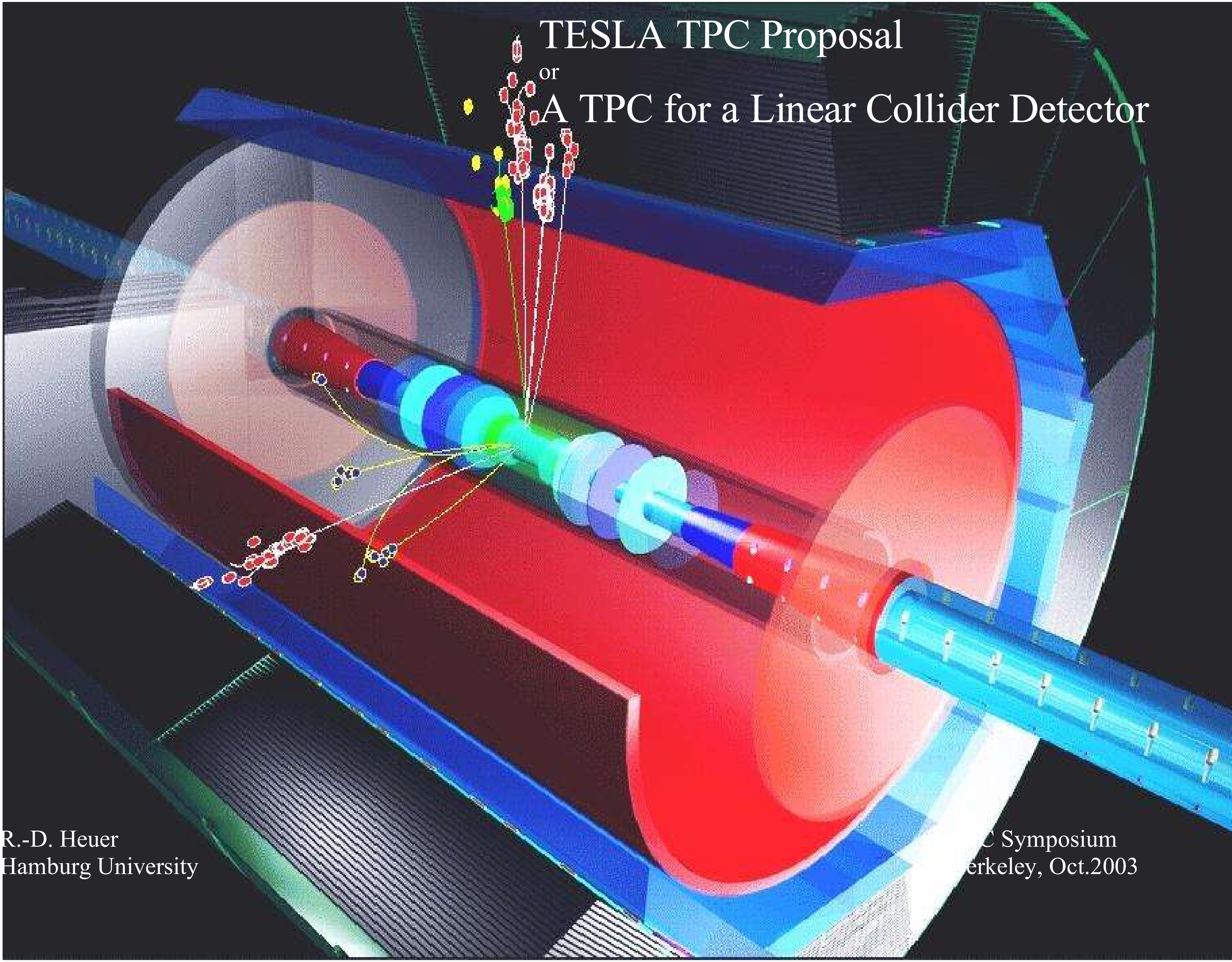
to measure Higgs self-coupling and to improve our understanding of the higgs potential.



Cross sections

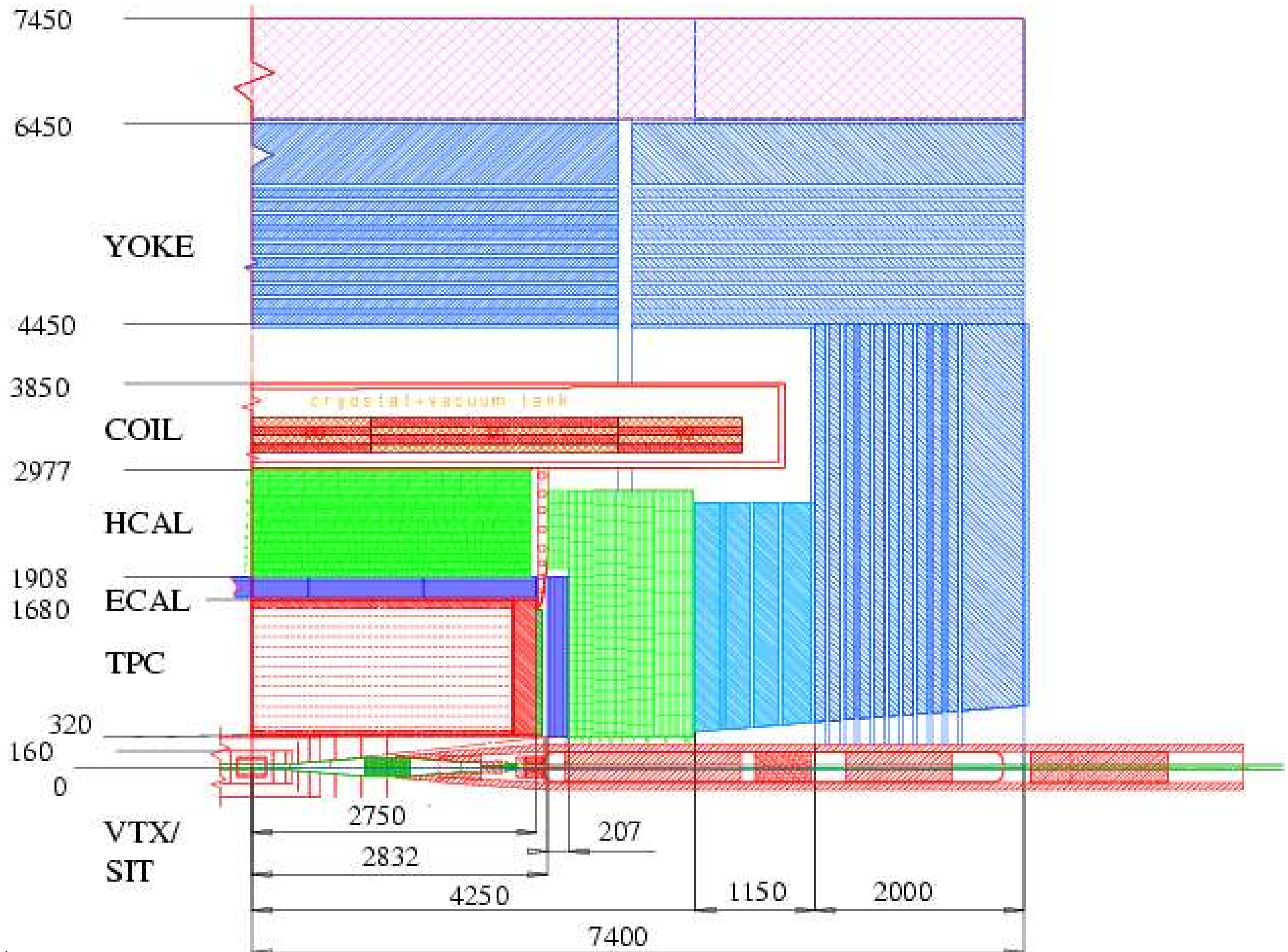


N.B. Need jet reconstruction resolution to be better than 30%/sqrt(E) in multi-jet events.


TESLA TPC Proposal
or
A TPC for a Linear Collider Detector
R.-D. Heuer
Hamburg University
C Symposium
erkeley, Oct.2003

ILC Gaseous TPC Detector Model

It might look somethink like



TPC studies of e+e- collisions

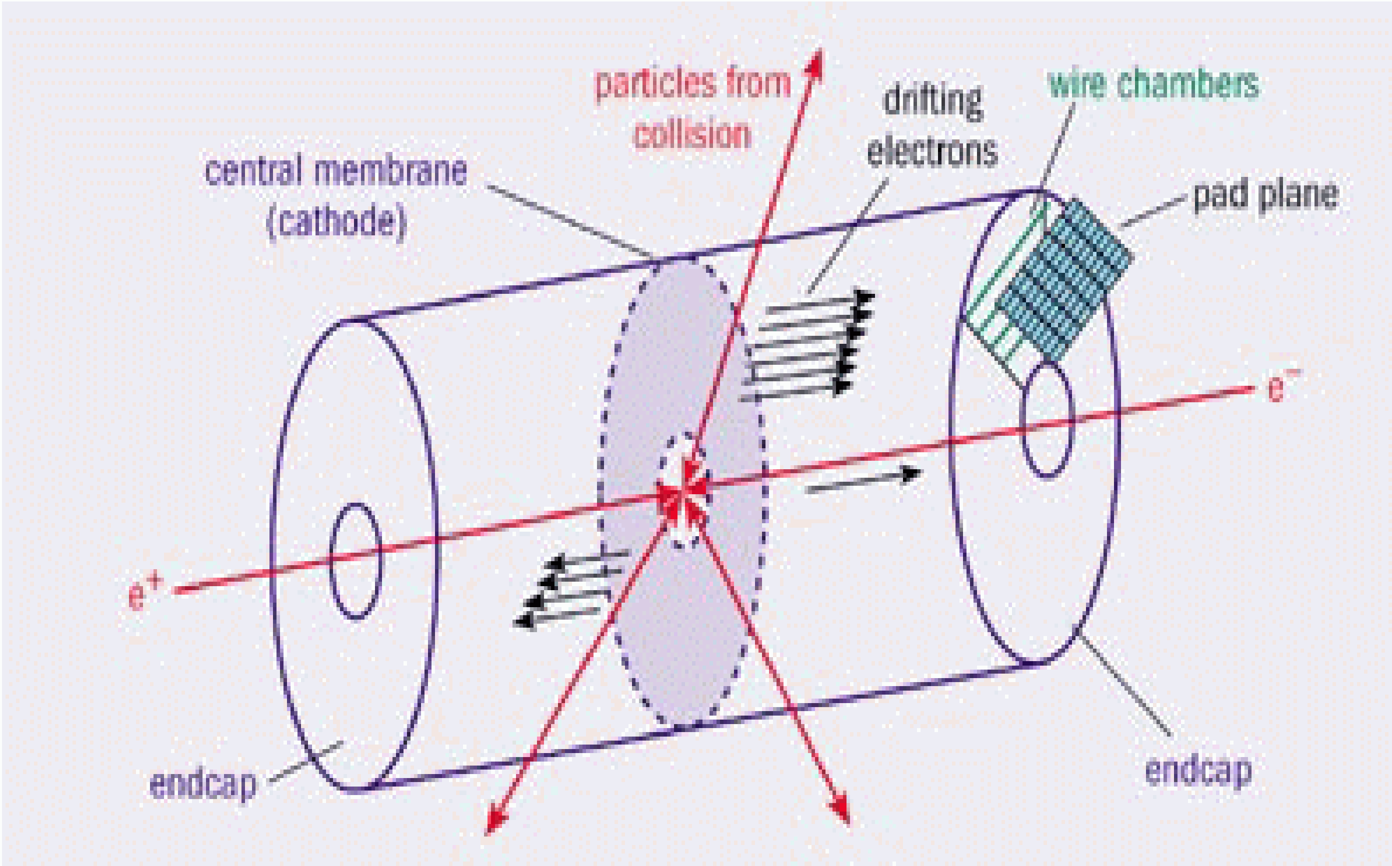
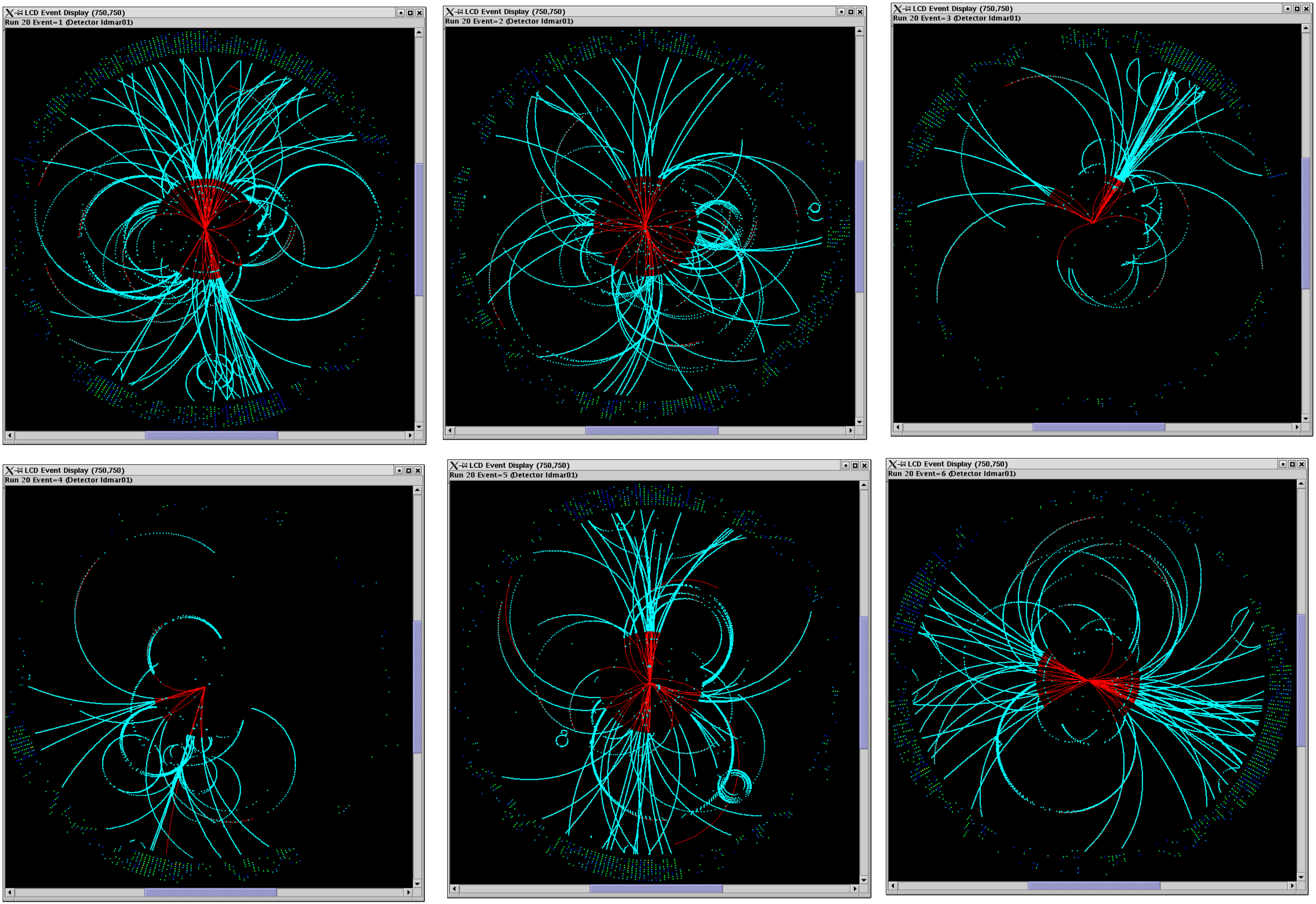


Fig. 2. A schematic view of the PEP-4 TPC showing the drift volume (dark blue), wire chambers (green) and pads (light blue).

From 2004 CERN Courier article by **Spencer Klein, LBNL**

Multijet Higgsstrahlung events

e.g. **e+e- --> Z + Higgs --> 2-4 jets**



Linear Collider Physics & Detector Studies

World Wide Study (WWS) organization

- Form international study groups to address global physics and detector design issues.

- Begin to focus on two detector concepts:

  Large Gaseous Detector models *

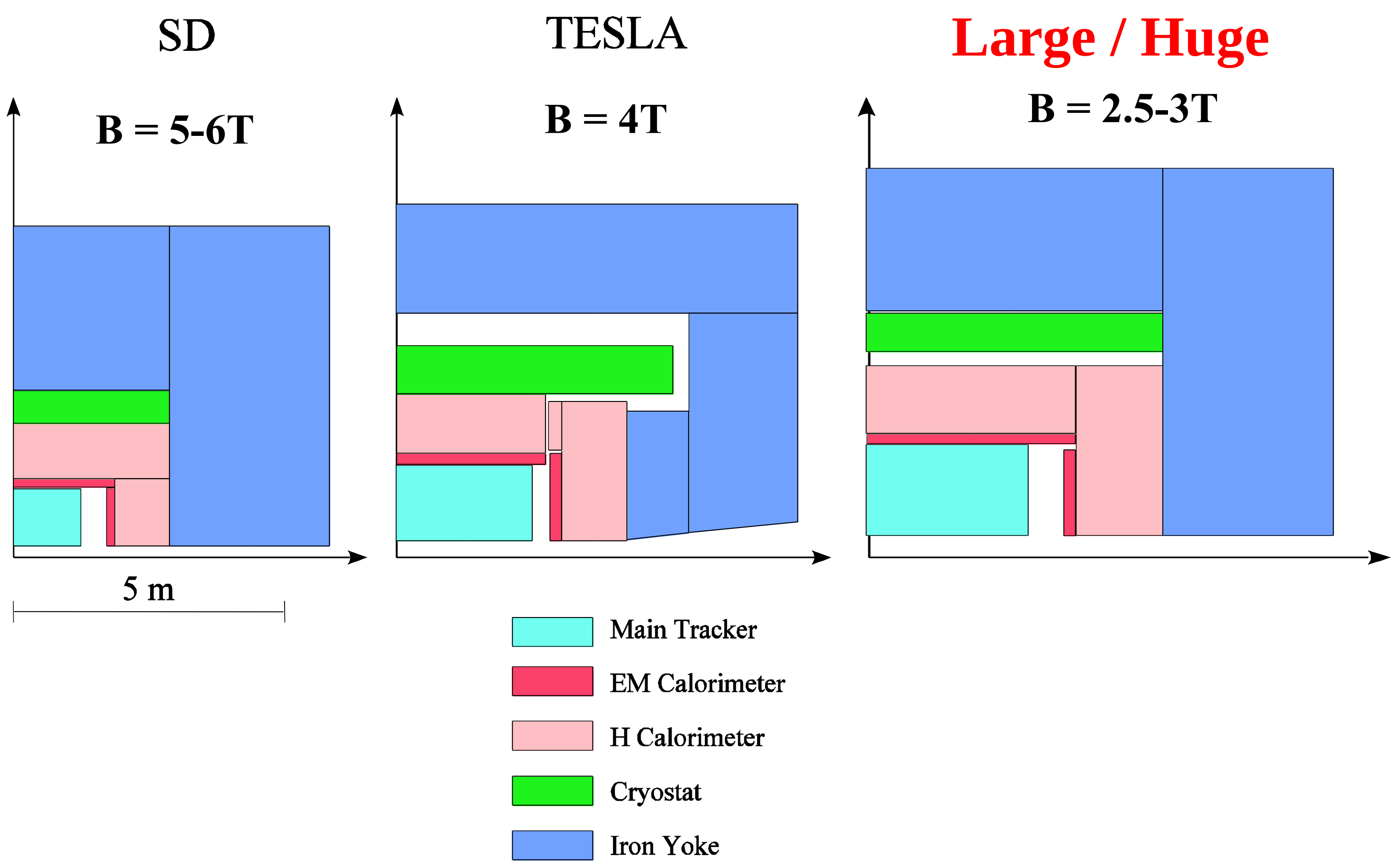
"medium"	TESLA TDR design	$B = 4T$, $R_{TPC} = 1.7$ m
"large"	American model	$B = 3T$, $R_{TPC} = 1.9$ m
"huge"	Asian model	$B = 2.5\text{-}3T$, $R_{TPC} = 2.1$ m

  A Silicon-based Detector model

"small"		$B = 5\text{-}6T$, $R_{ECal} = 1.5$ m

* **Note**: Significant differences in Calorimeter options, see below.

General view of "Large/Huge" detector size



from Sachio Komamiya

Linear Collider Detector Studies

- Large TPC Reference Detector
  - Design parameters
    - Medium sized TESLA TPC reference model
  - Background studies
  - Multijet event reconstruction studies
  - LC-TPC R&D
- Large Detector Calorimeter Models
  - Present American Large “Compensating” model
  - Large Thin W-Si ECal model
  - Hybrid Calorimeter models

American Large Detector Design

Large reference tracking detector

Large TPC Chamber ~ size of STAR TPC

dimensions dia. 2 m, half-length 2.5 m
pad layout 144-256 pad rows pads partout
readout options: Wire or GEM or Micromegas

Electronics
Next generation fully integrated over 1M channels

Magnet
ECal and HCal inside. 3 T

Reconstruction **3D Pattern Recognition**

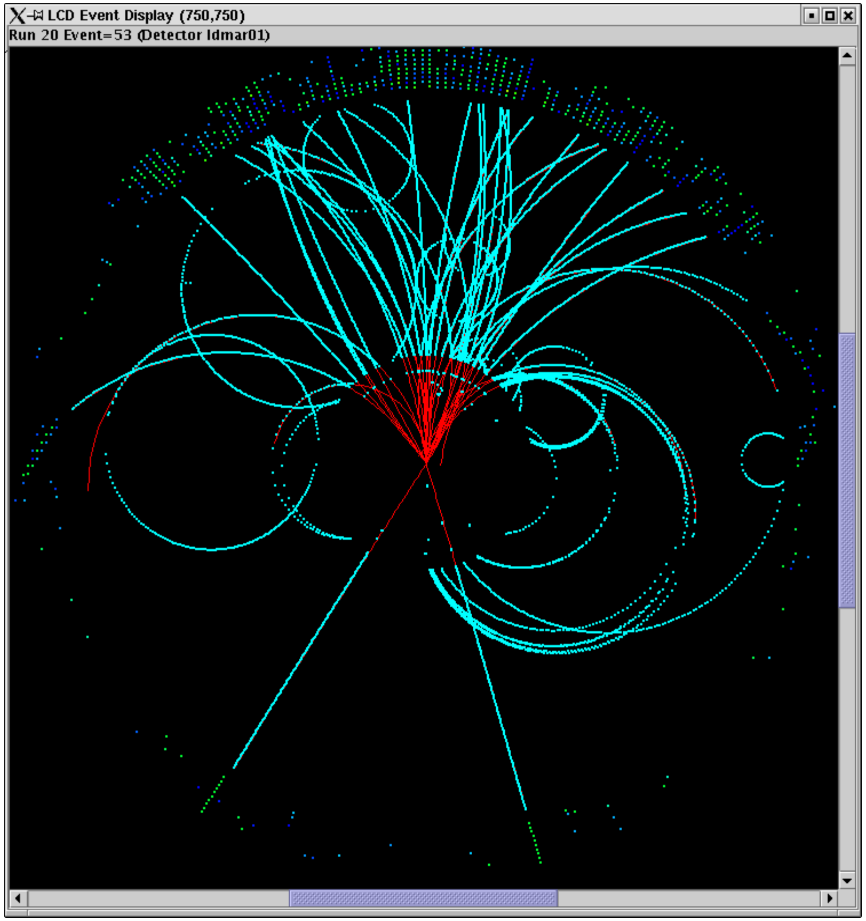
LCD Java Framework
modular design

TPC Simulation
smear space points with 100-140 μm resolution
no-detector effects

Tracking efficiency ~ 99% already

Detailed response simulation
being developed along with R&D studies.

Z(μμ) + H(jets) event



Hits: TPC points (cyan), EM Cal hits (blue)
Tracks (red), Clusters (green)

-- Overall momentum resolution

One can use **LCDTRK** to calculate the expected momentum resolution for different detector designs including intermediate and forward tracking.

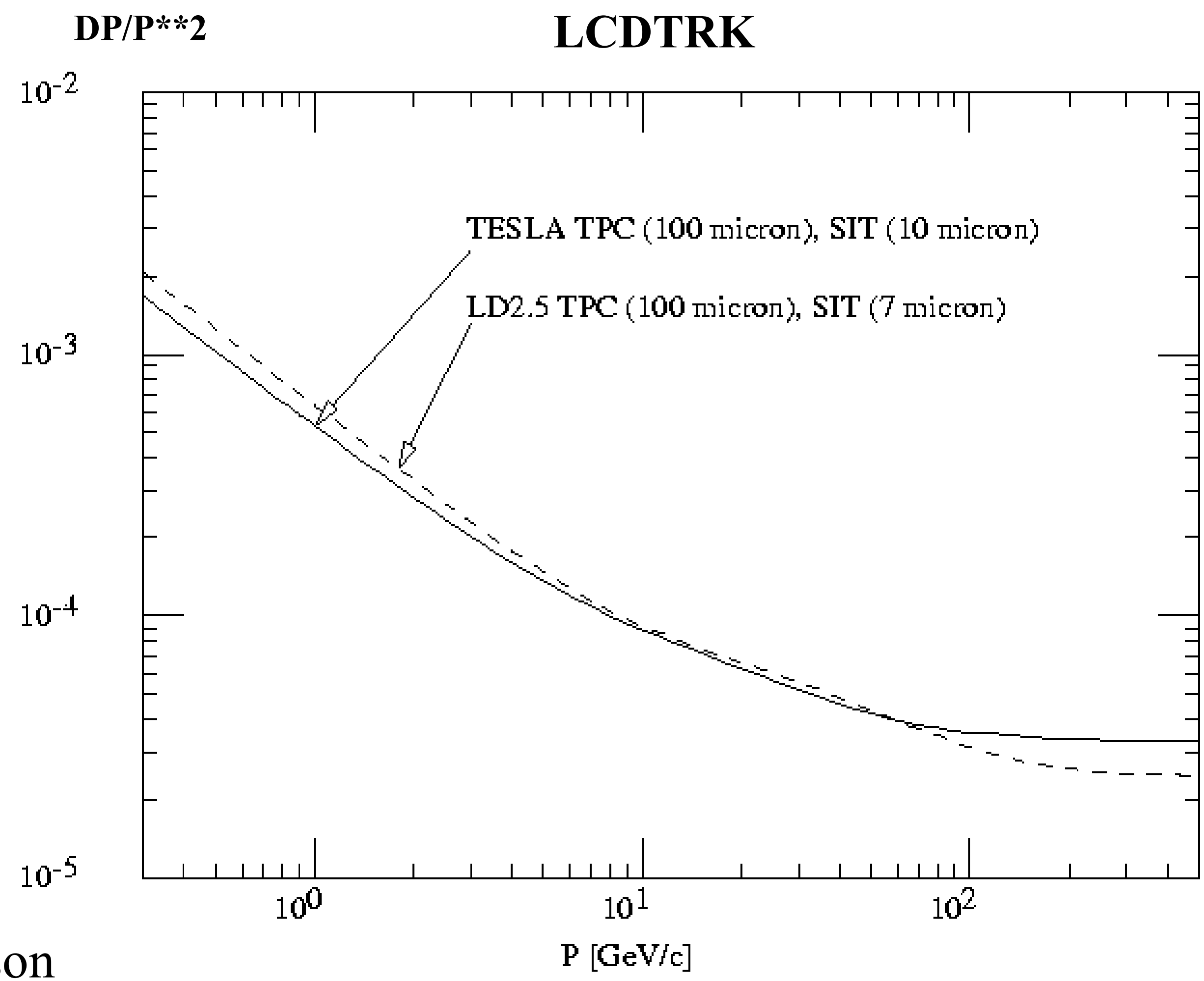
Here is a comparison of a modified version of the American LD detector to the TESLA TPC performance.

Both TPC's are taken to have the same pad size and point resolution.

The TESLA TPC has better low momentum resolution since its inner radius is smaller.

The assumed intermediate tracker resolutions are taken from the corresponding studies resulting in a difference at high momenta.

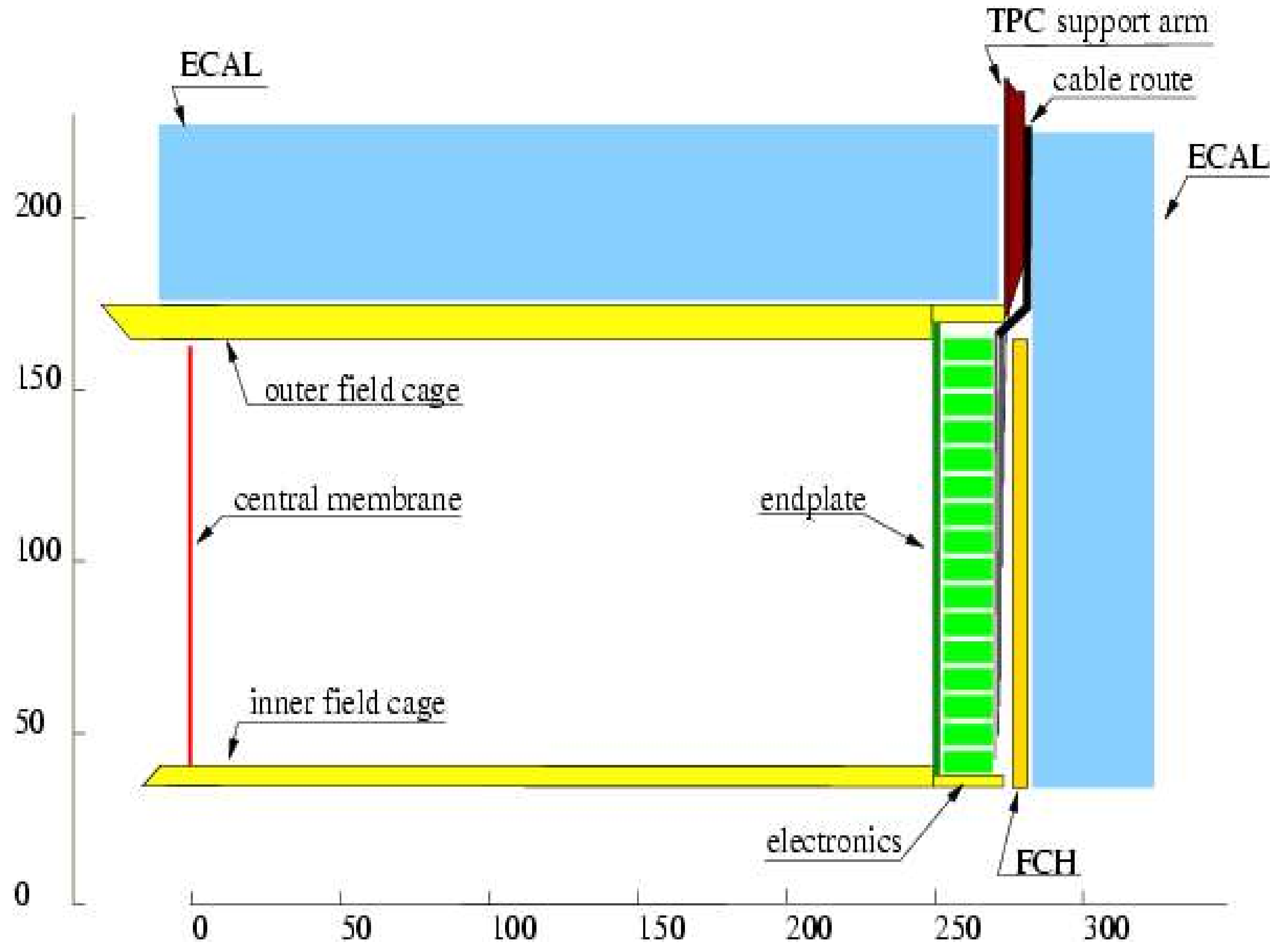
There should be no difference in the assumed SIT resolution. The comparison indicates how the SIT could improve overall momentum resolution.



Comparison of TESLA TPC and updated American Large Detector (LD2.5) momentum resolution.

ILC Time Projection Chamber (TPC)

It will look somethink like



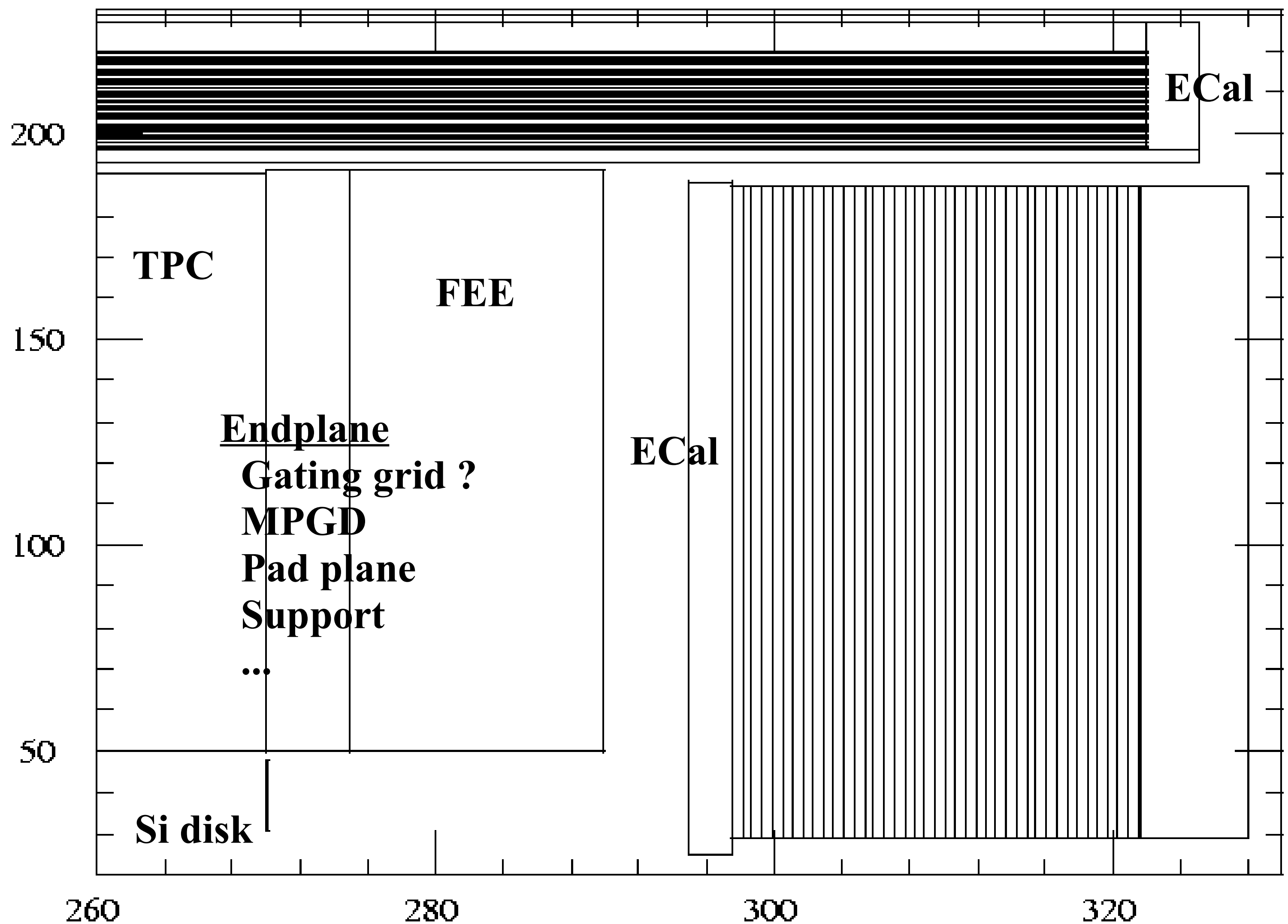
TPC Tracker Design and R&D

Current TPC design and R&D focus is on gas choice and readout technology. Hope to begin studying front-end electronics (FEE) designs soon.

Gas options:
- Ar CH4
- Ar CO2 CH4
- Ar CF4
- ...

Readout pad plane
- Gating device ??
- MPGD
  - GEM
  - Micromegas
- Pads partout

Electronics
- Very low noise
- Full integration ?

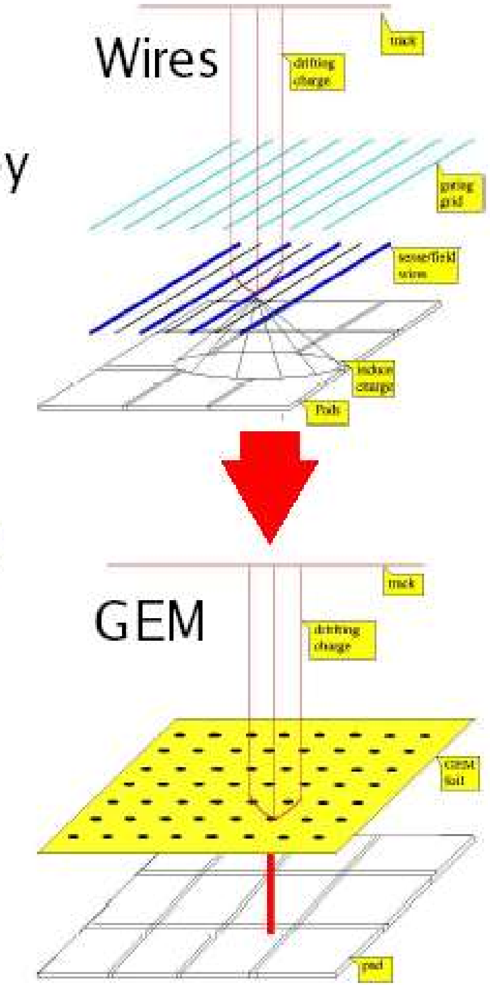


New Gas Amplification Systems

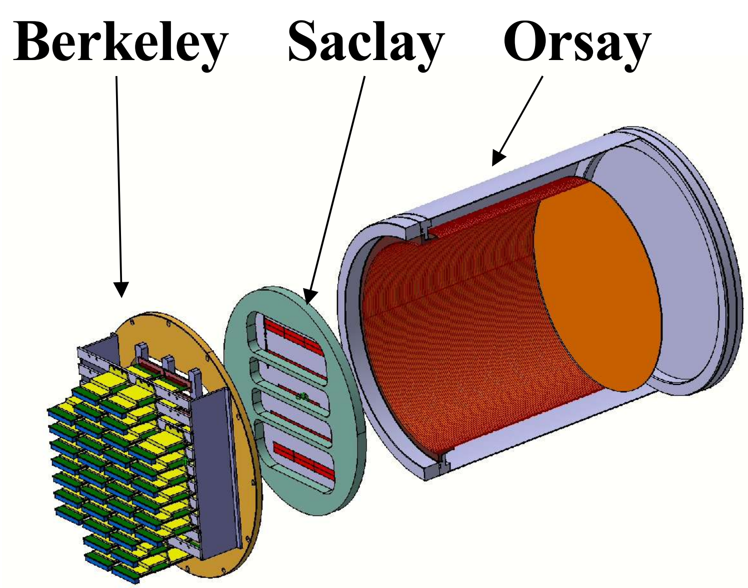
Replace conventional MWPC system (wires) by Micro Pattern Gas Detectors (MPGD):

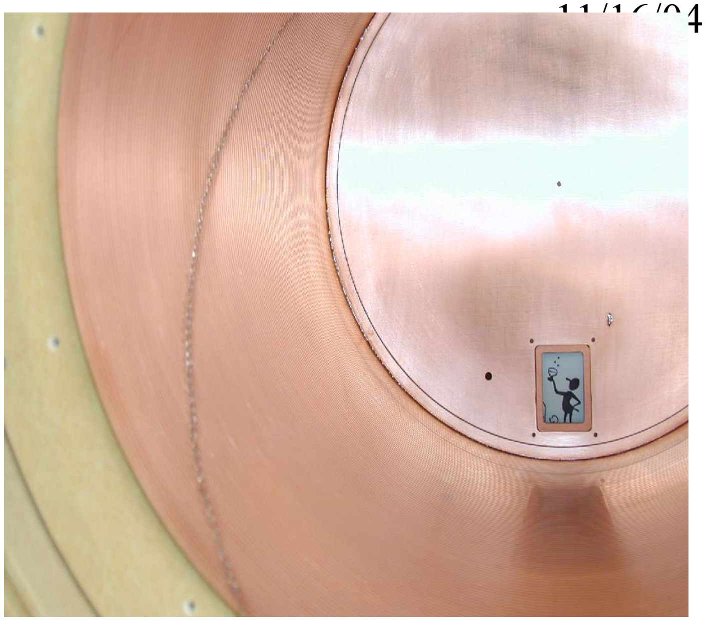
Most promising examples:

- Gas Electron Multiplier (GEM) (F. Sauli, 1997)
- Micromegas (Y. Giomataris *et. al.*, 1996)



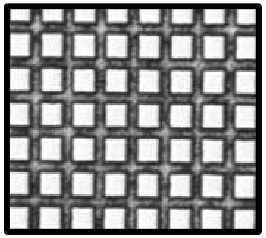
Chamber design and pad layout





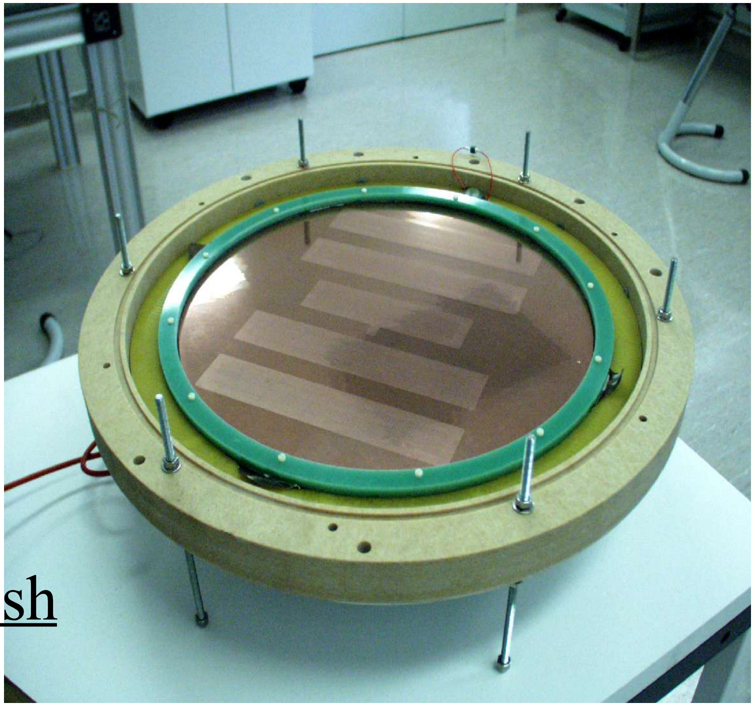
Chamber

diameter 50 cm
length 50 cm

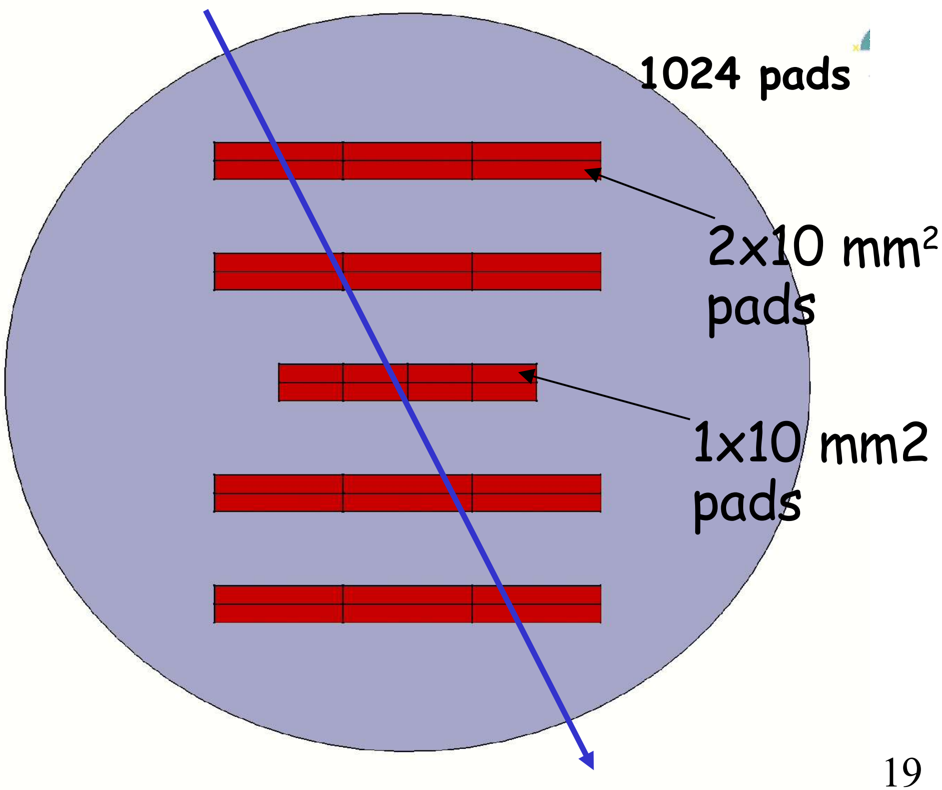


50 μm pitch
50 μm gap

Copper Mesh



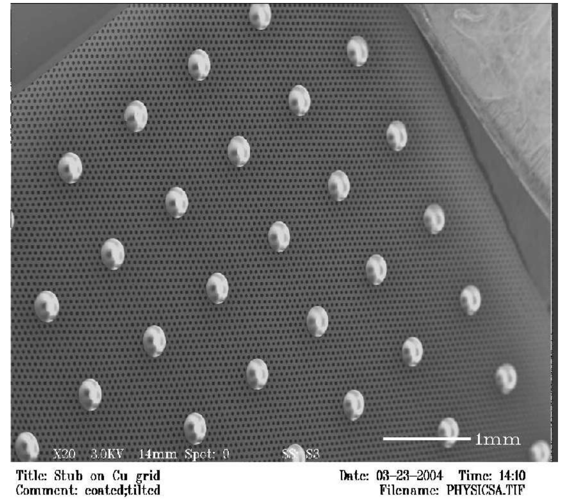
Readout anode pad plane

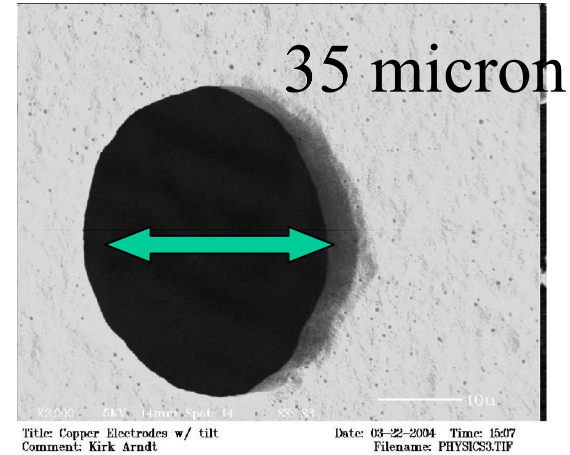


Purdue U.

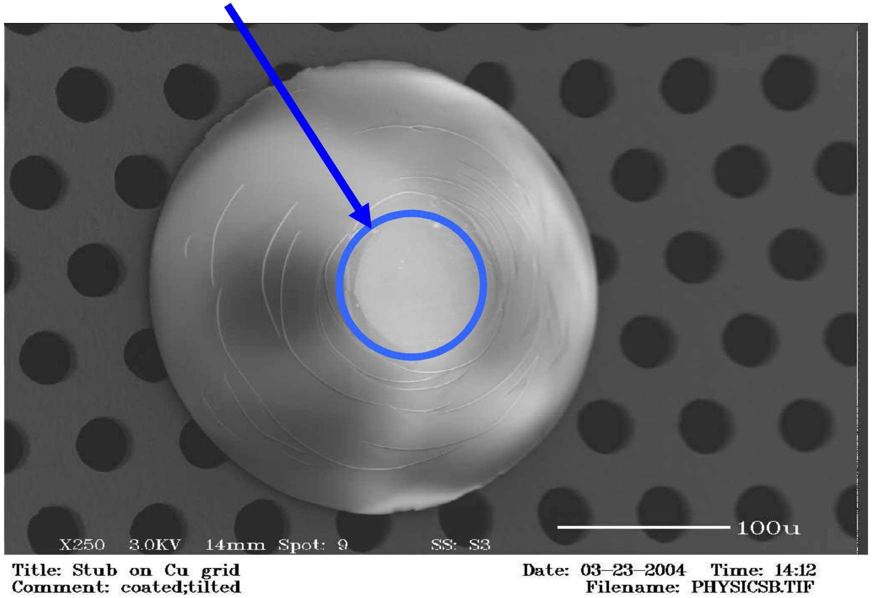
1st Mass Production of Micromegas

1. Industrially mass produced MICROMEGAS using 3M's FLEX circuit technology
2. Conical pillars (1 mm pitch) to create a 50 mm gap.

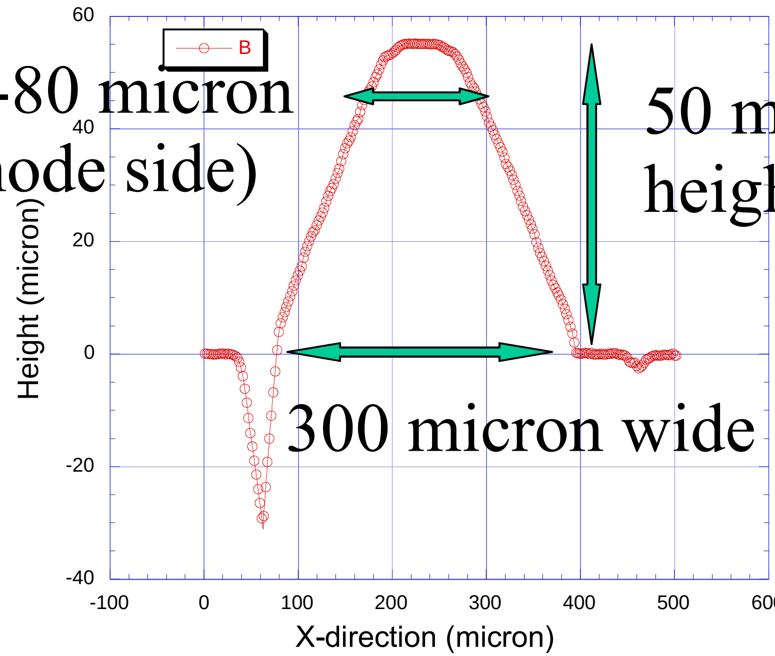




The flat area that has contact with the anode board



Pillar cross section profile

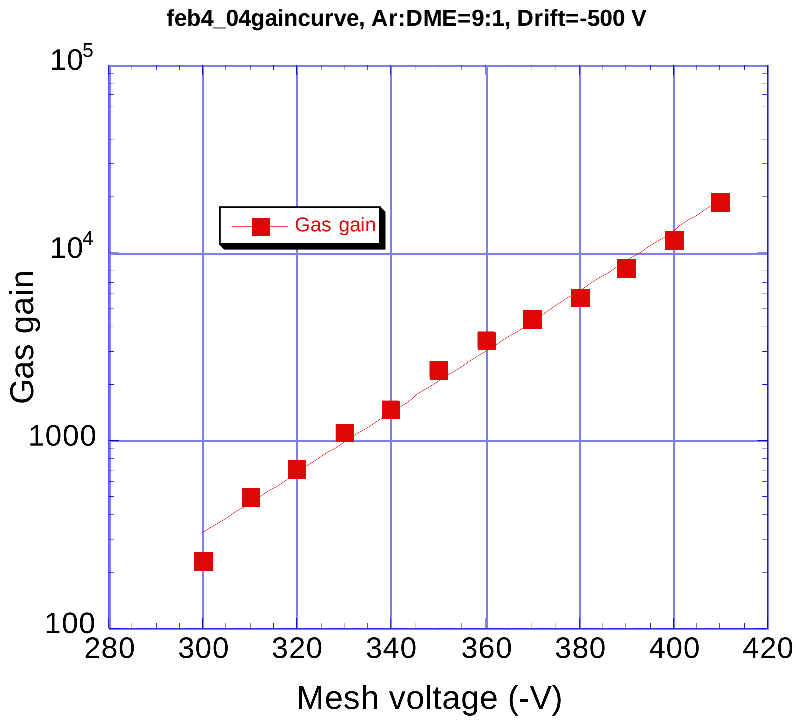


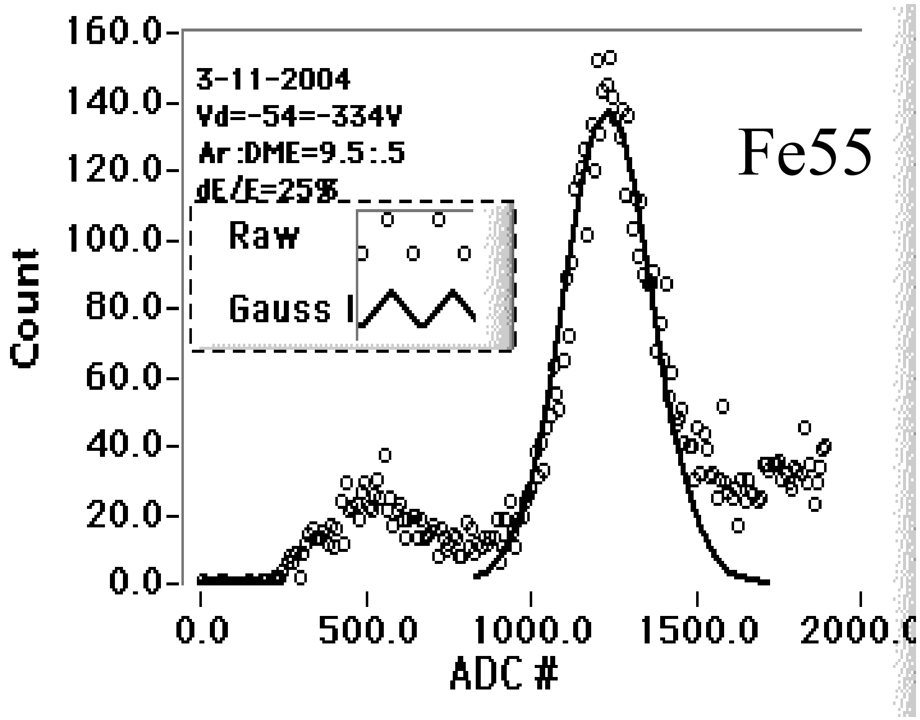
Presented at ALCPG SLAC Jan '04

Purdue U.

1^{st} Mass Production of Micromegas

First Results
Ar:DME 9:1





Fe55

Radiation hardness under study

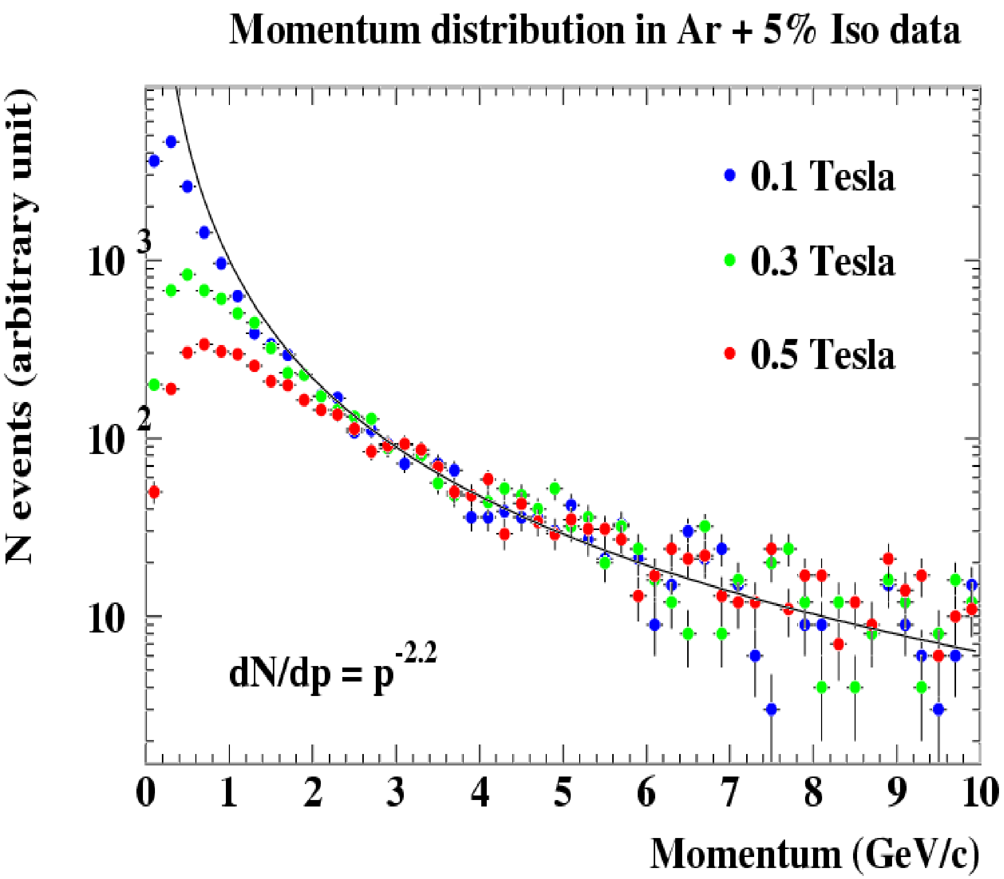
25% energy resolution

Presented at ALCPG Victoria July '04

Cosmic ray test stand

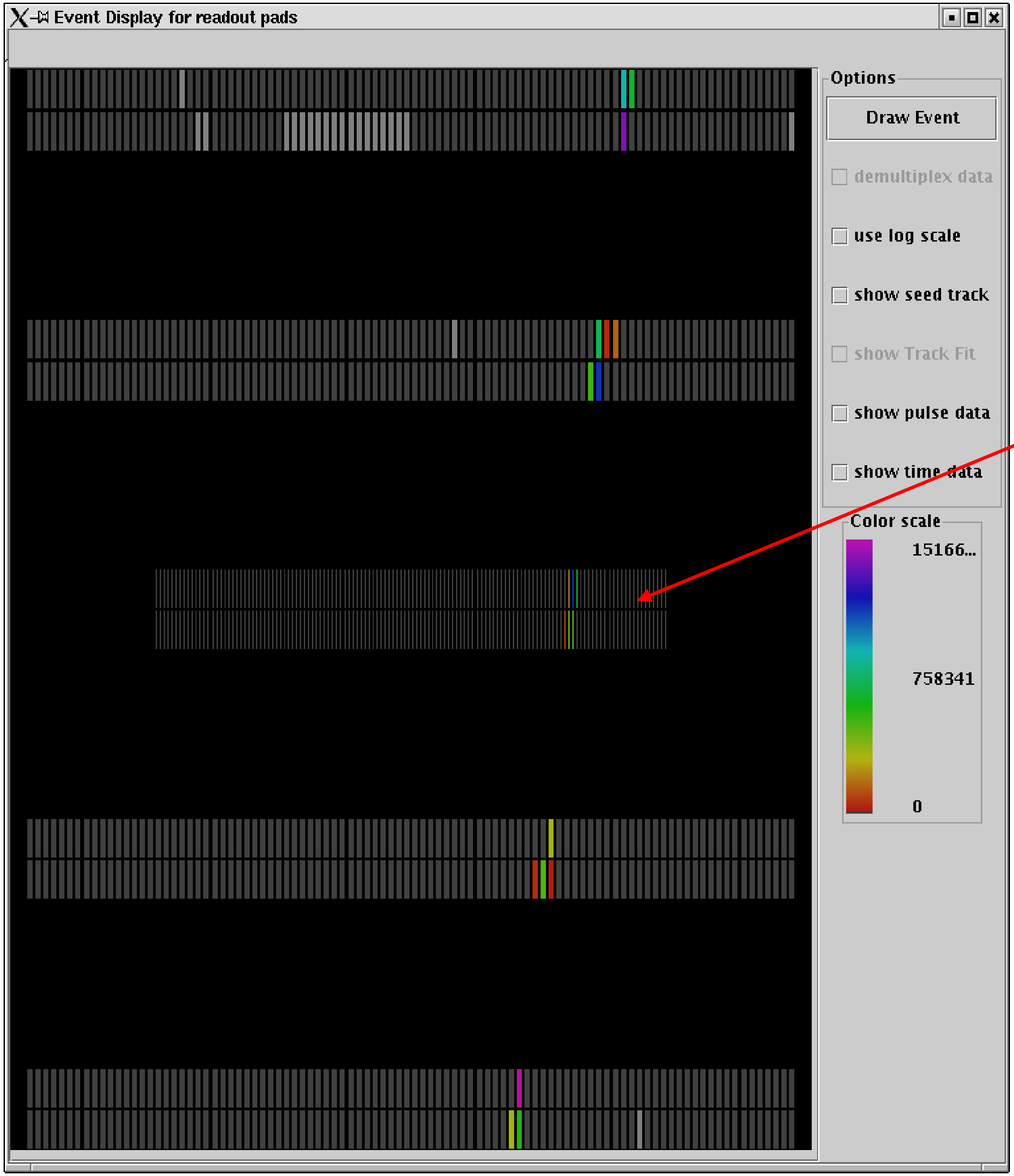
Superconducting magnet
Data runs at
0.1, 0.3, 0.5, 0.7, 1, 1.5 & 2 Tesla

Trigger: 2-3 fold scintillator
efficiency 10 – 50 %
(lower at high fields)

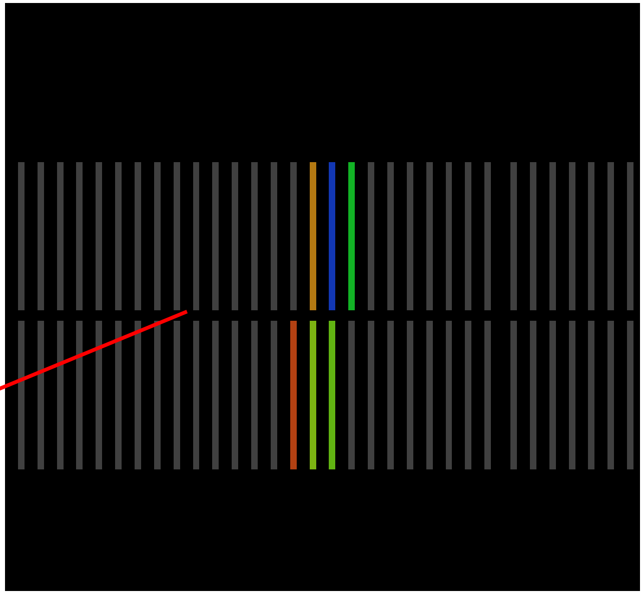


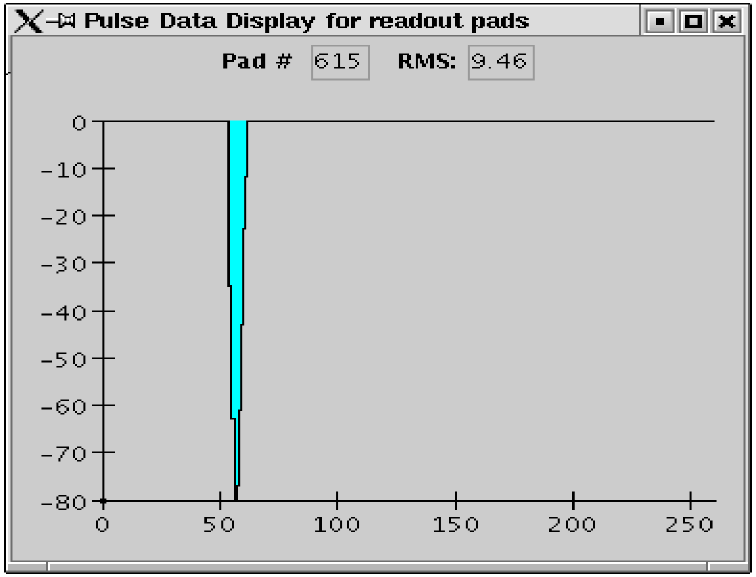
Data acquisition:
STAR FEE, VME readout w/
direct memory transfer
(no selection, formatting, ...)
overall improvement X20

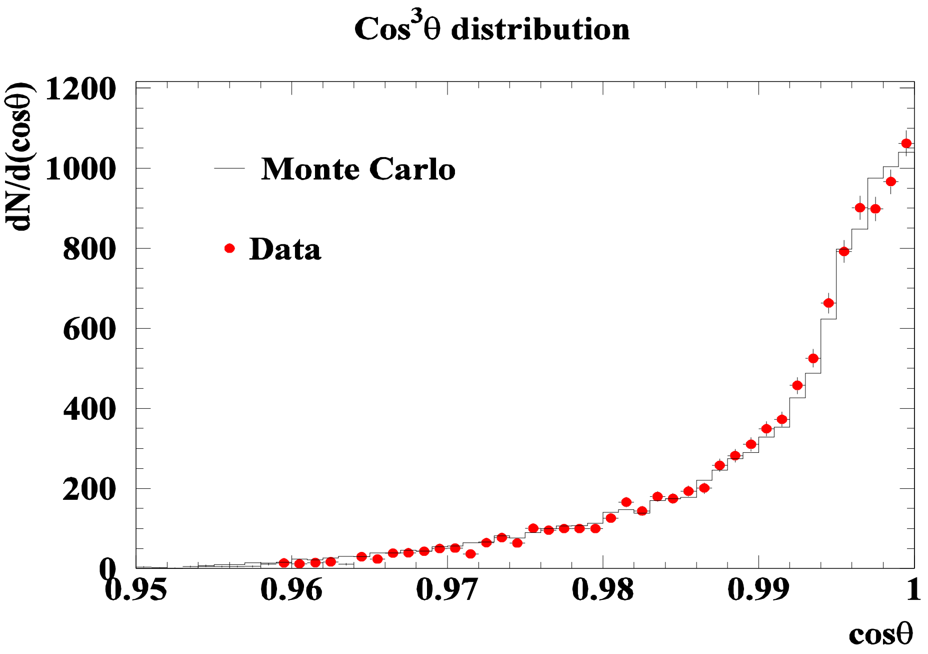
Online event display



Rows 4 & 5   1 X 10 mm^2







Simulation and analysis by
Max. Chefdeville &
Paul Colas, Saclay.

Trigger simulation shows good understanding of angular distribution.

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. <u>3-5 %</u> CF_4

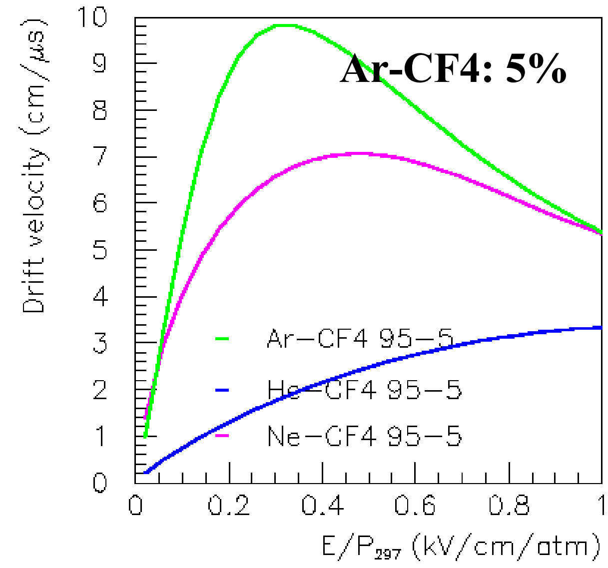
Very interesting! Very fast, no hydrogen.

$\omega\tau$ ~20 @ B=4T

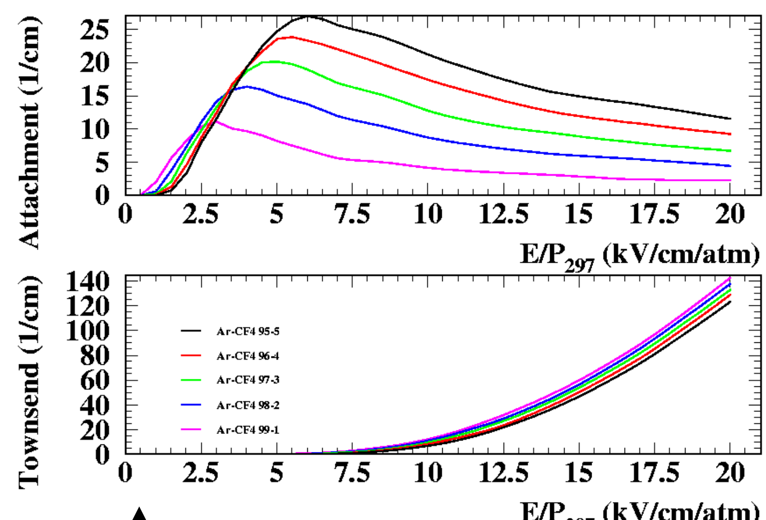
transverse diffusion less than 200 μm for drifts up to 1m.

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

Drift velocity



Ar-CF4 Attachment / Amplification



↑

E_D~0.2V/cm

Data taking and processing

We took data with 3 different gases:

Ar-CF4:3% B = 0.1, 0.3, 0.5, 0.7, 1.0 T

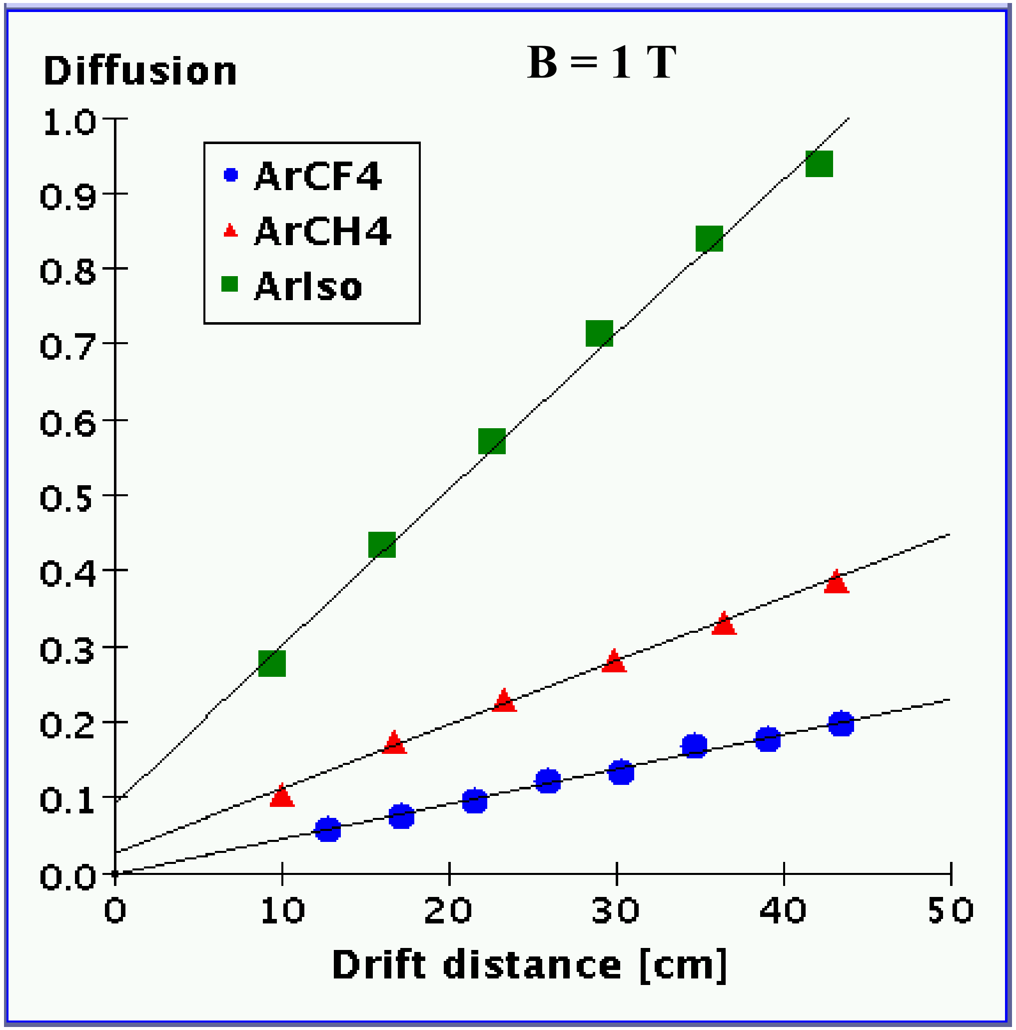
Ar-CH4:10% (P10) B = 0.1, ..., 1.0, 1.5, 2 T

Ar-Isobutane: 5% B = 0.1, ..., 1.0, 1.5 T

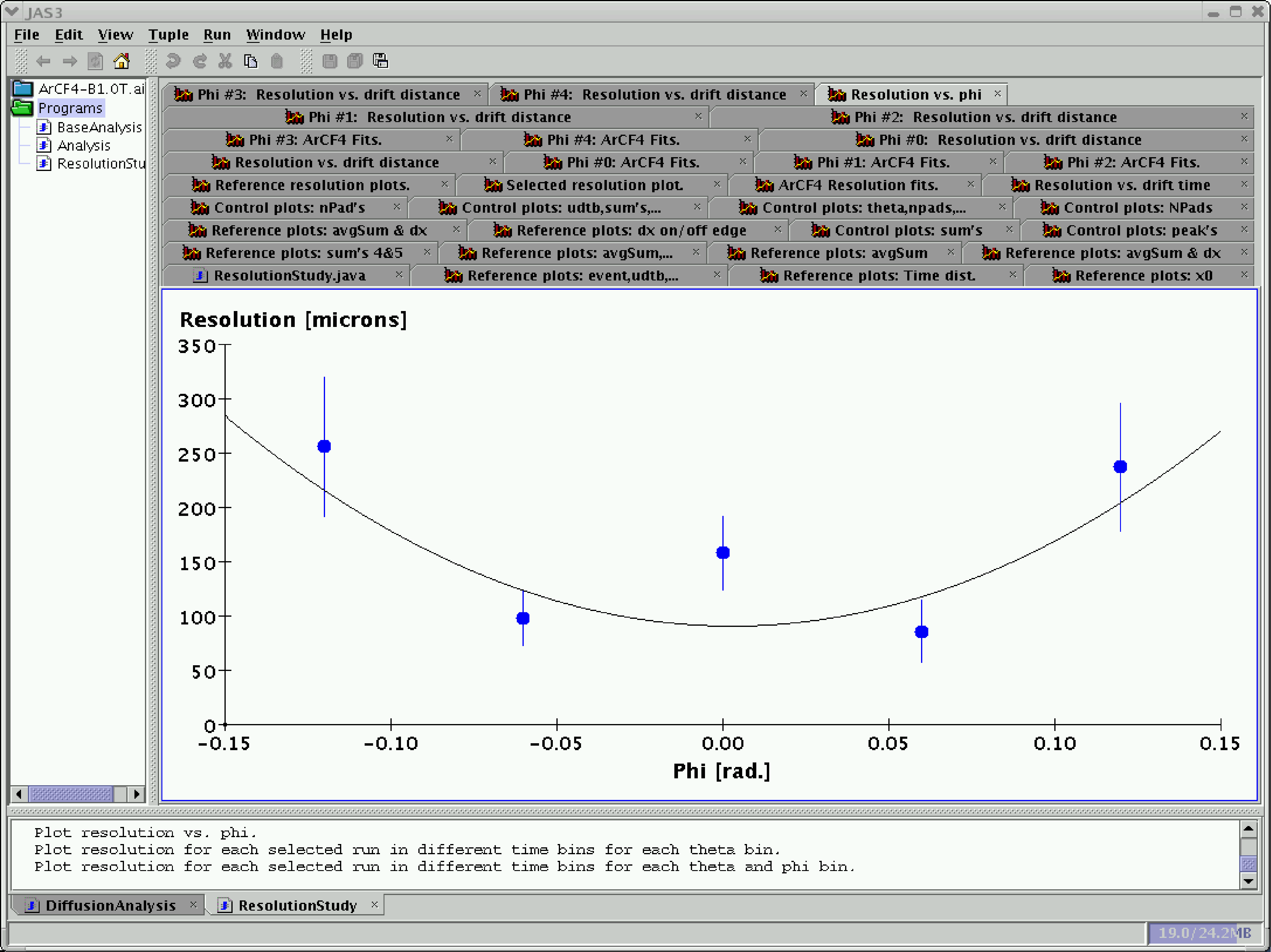
High statistics runs were taken at B = 0.5T and 1T.

Data processing ran in parallel with data taking writing zero-suppressed LCIO files and Java ntuples. We had online results like the plot shown comparing the diffusion for different gases.

We're still developing the analysis and expect to learn more about Micromegas operation and calibration in preparing final results.



Track width squared (mm^2) as function of drift distance for ArCF4, ArCH4 and Ar-Isobutane gases at B = 1T.

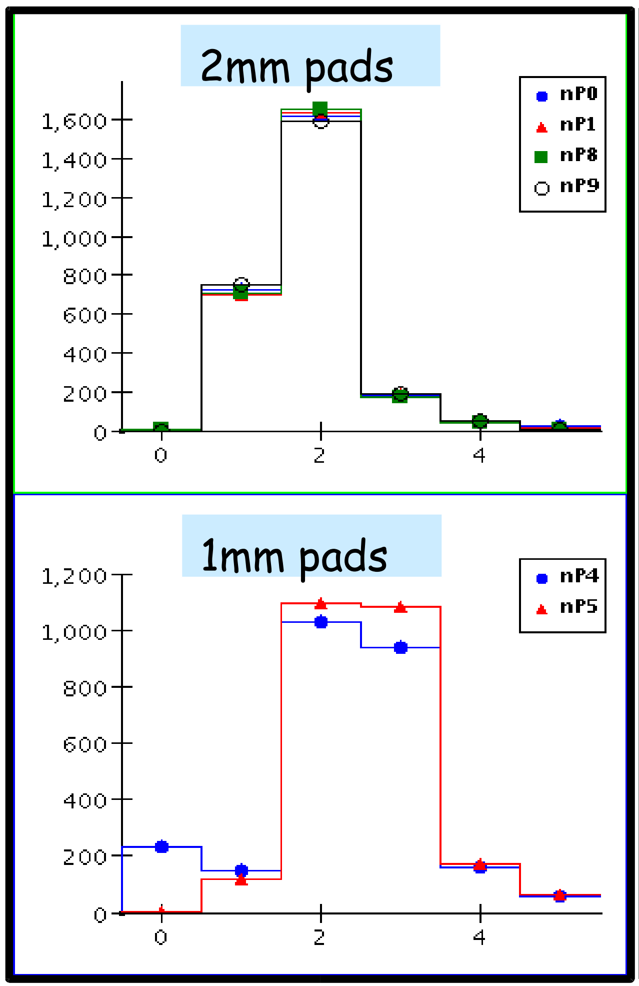

JAS3
File Edit View Tuple Run Window Help
ArCF4-B1.0T.ai
Programs
BaseAnalysis
Analysis
ResolutionStu
Phi #3: Resolution vs. drift distance
Phi #4: Resolution vs. drift distance
Resolution vs. phi
Phi #1: Resolution vs. drift distance
Phi #2: Resolution vs. drift distance
Phi #3: ArCF4 Fits.
Phi #4: ArCF4 Fits.
Phi #0: Resolution vs. drift distance
Resolution vs. drift distance
Phi #0: ArCF4 Fits.
Phi #1: ArCF4 Fits.
Phi #2: ArCF4 Fits.
Reference resolution plots.
Selected resolution plot.
ArCF4 Resolution fits.
Resolution vs. drift time
Control plots: nPad's
Control plots: udtb,sum's,...
Control plots: theta,npads,...
Control plots: NPads
Reference plots: avgSum & dx
Reference plots: dx on/off edge
Control plots: sum's
Control plots: peak's
Reference plots: sum's 4&5
Reference plots: avgSum,...
Reference plots: avgSum
Reference plots: avgSum & dx
ResolutionStudy.java
Reference plots: event,udtb,...
Reference plots: Time dist.
Reference plots: x0
Resolution [microns]
350
300
250
200
150
100
50
0
-0.15
-0.10
-0.05
0.00
0.05
0.10
0.15
Phi [rad.]
Plot resolution vs. phi.
Plot resolution for each selected run in different time bins for each theta bin.
Plot resolution for each selected run in different time bins for each theta and phi bin.
DiffusionAnalysis
ResolutionStudy
19.0/24.2MB

Micromegas TPC Operation

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

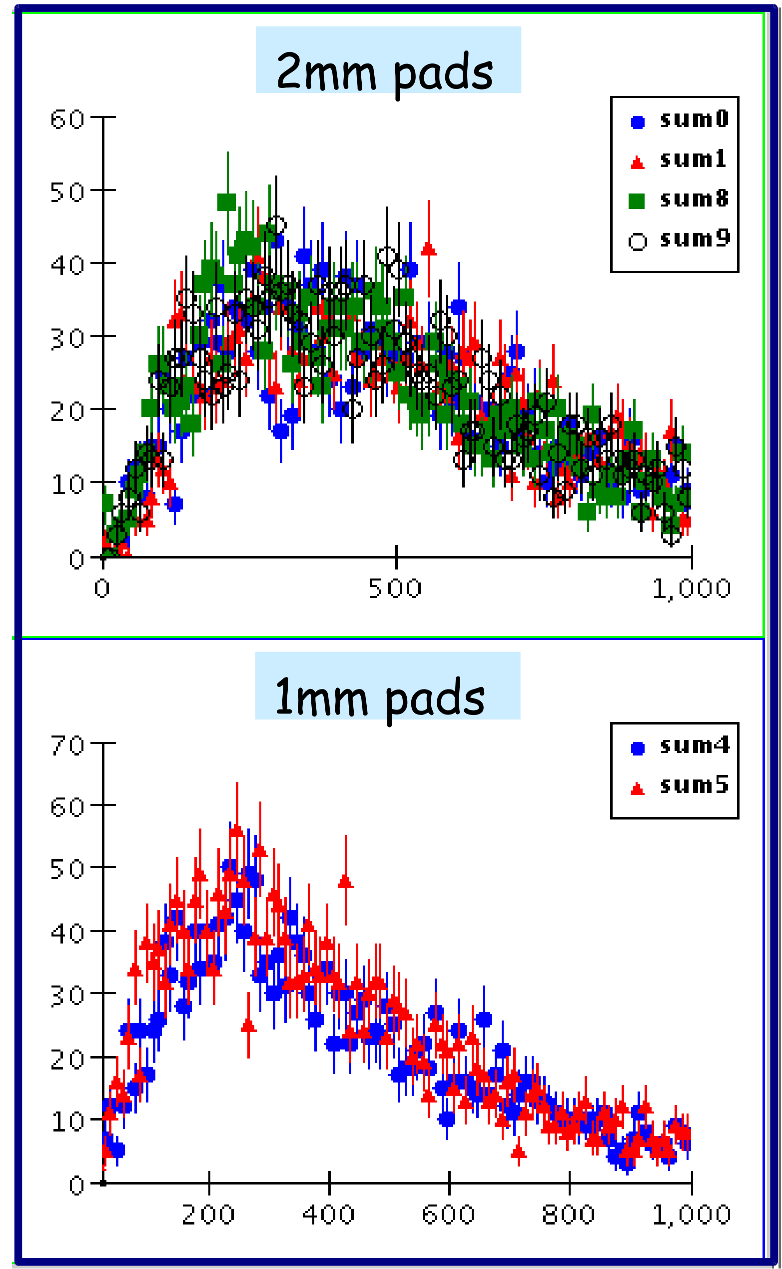
Plots are shown of the number of pads forming each cluster and of the summed amplitude signals for both 2X10 mm^2 pad rows (#0,#1,#8 & #9) and the 1X10 mm^2 pad rows (#4 & #5).

ArCF4: 3%
@ B=1T



 # pads hit

Pulse sums



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 $(D_T[B]/D_T[0])^{-1/2} \sim \omega\tau$.

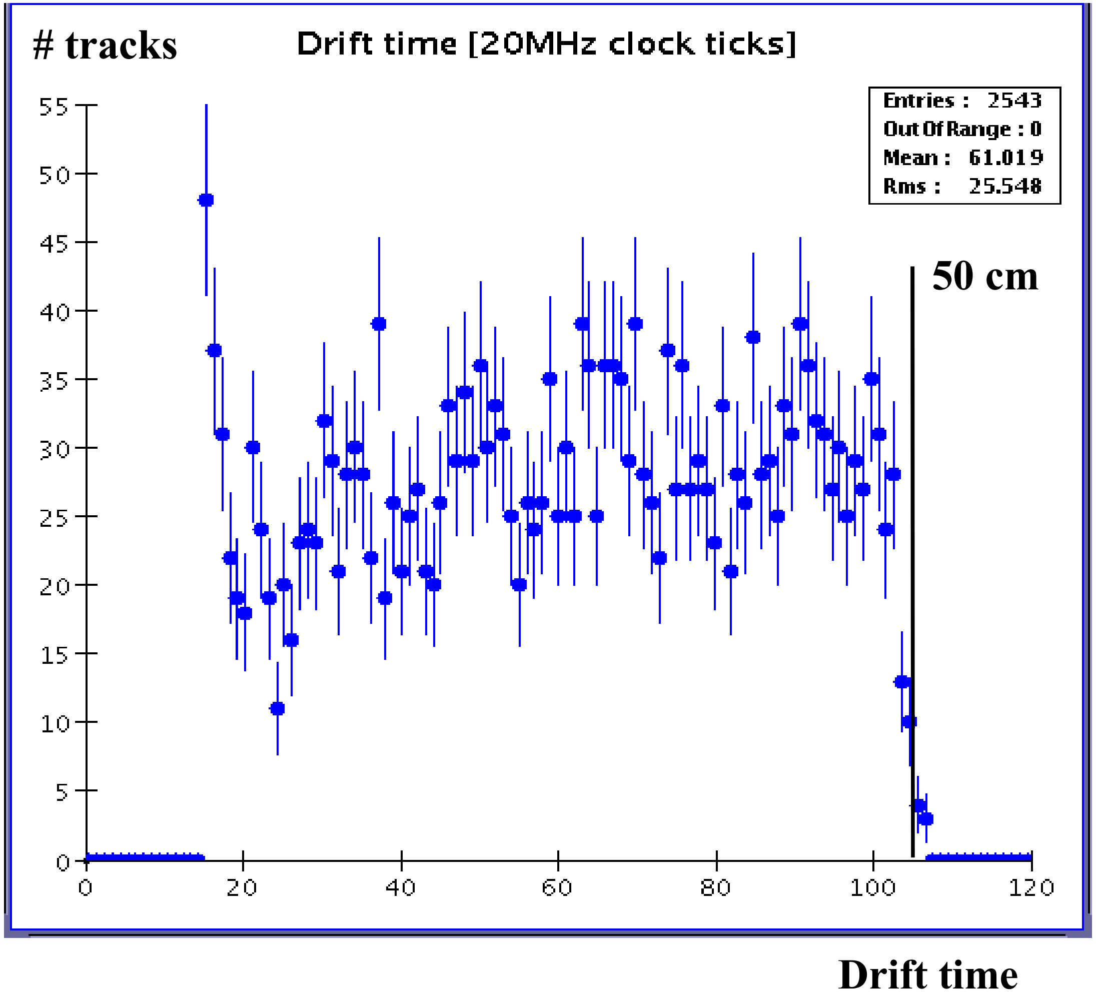
Drift velocity measurements

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.



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

v_D = 8.8 +- 0.2 cm / microsec.

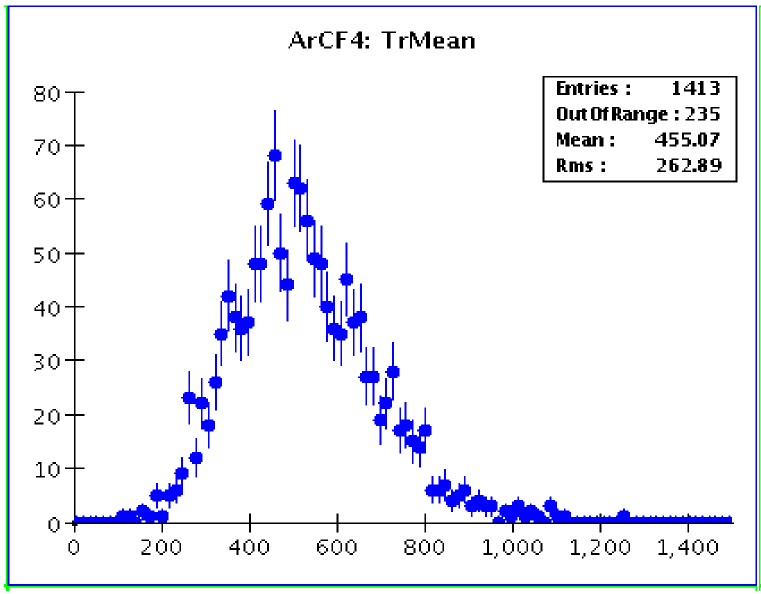
This corresponds to roughly 90 microns / nsec. So that an overall track absolute z position measurement error of about 100 microns yields track timing at 1 nsec level.

Comparisons to MagBoltz

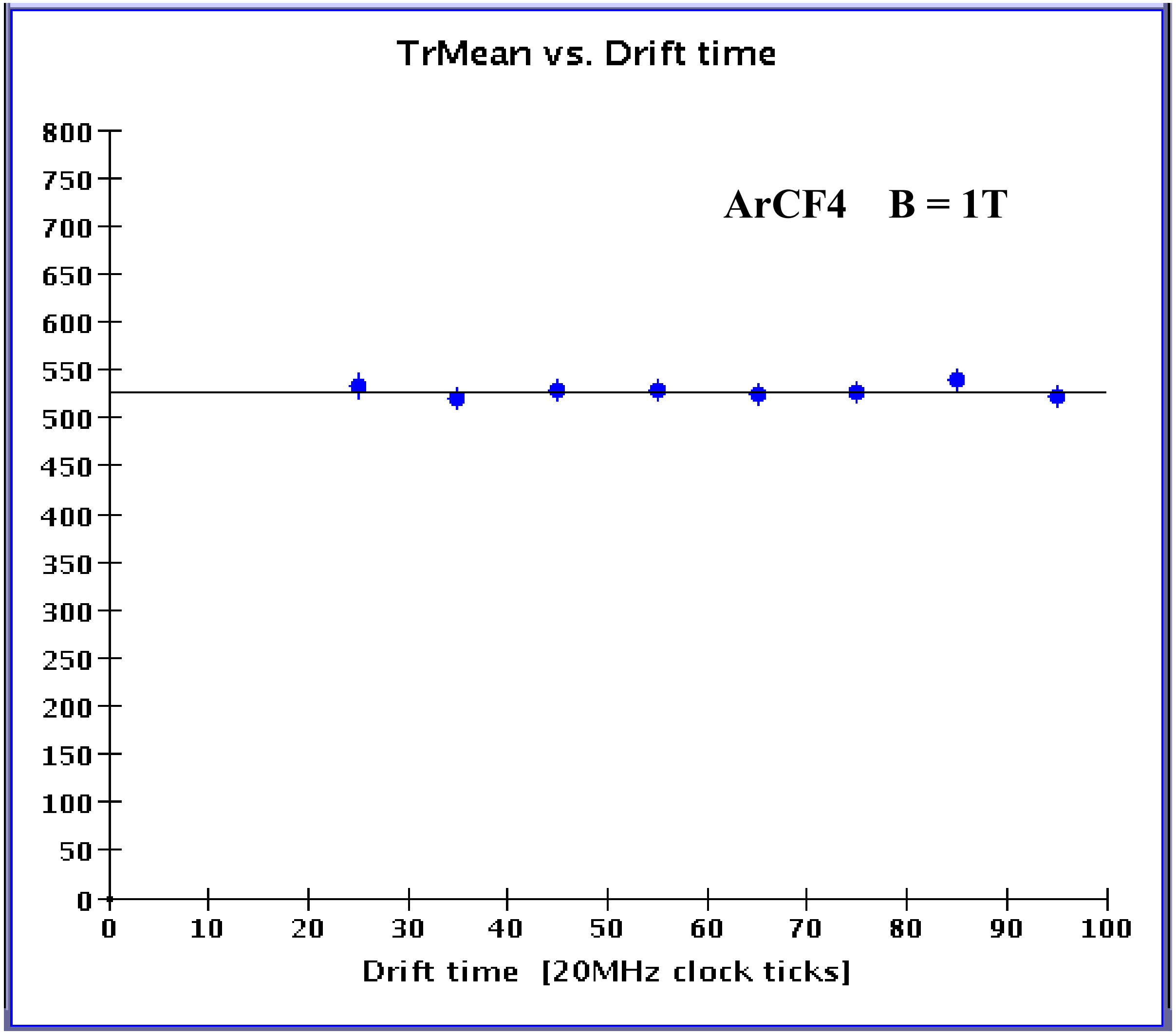
Gas mixture	E drift (V/cm)	V_{drift} (cm/μs)	Magboltz
Ar+5%iso	210	4.24±0.08	4.18
P10	66	4.43±0.07	4.38
P10	150	5.61±0.09	5.48
Ar+3%CF_4	200	8.8±0.2	8.6

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.

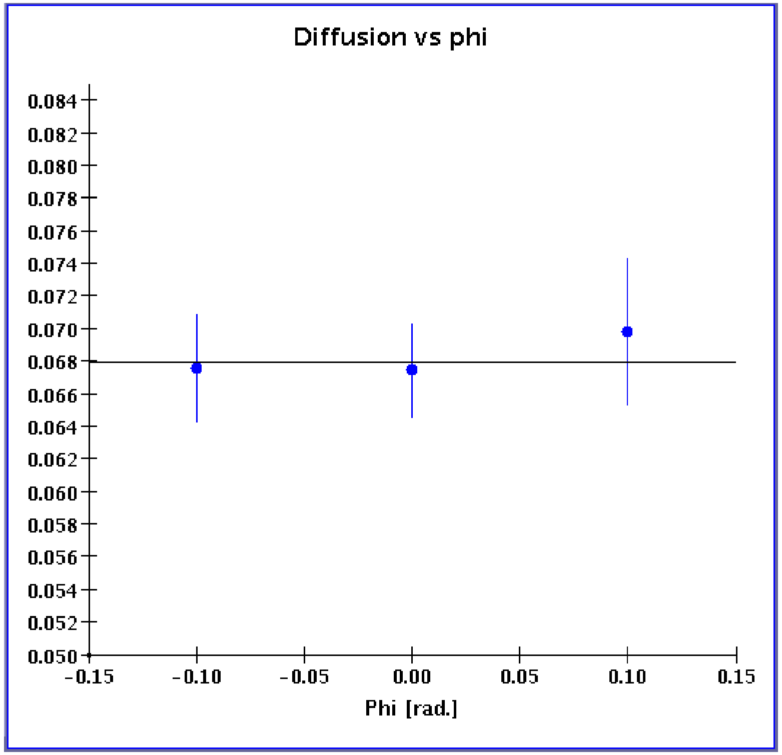


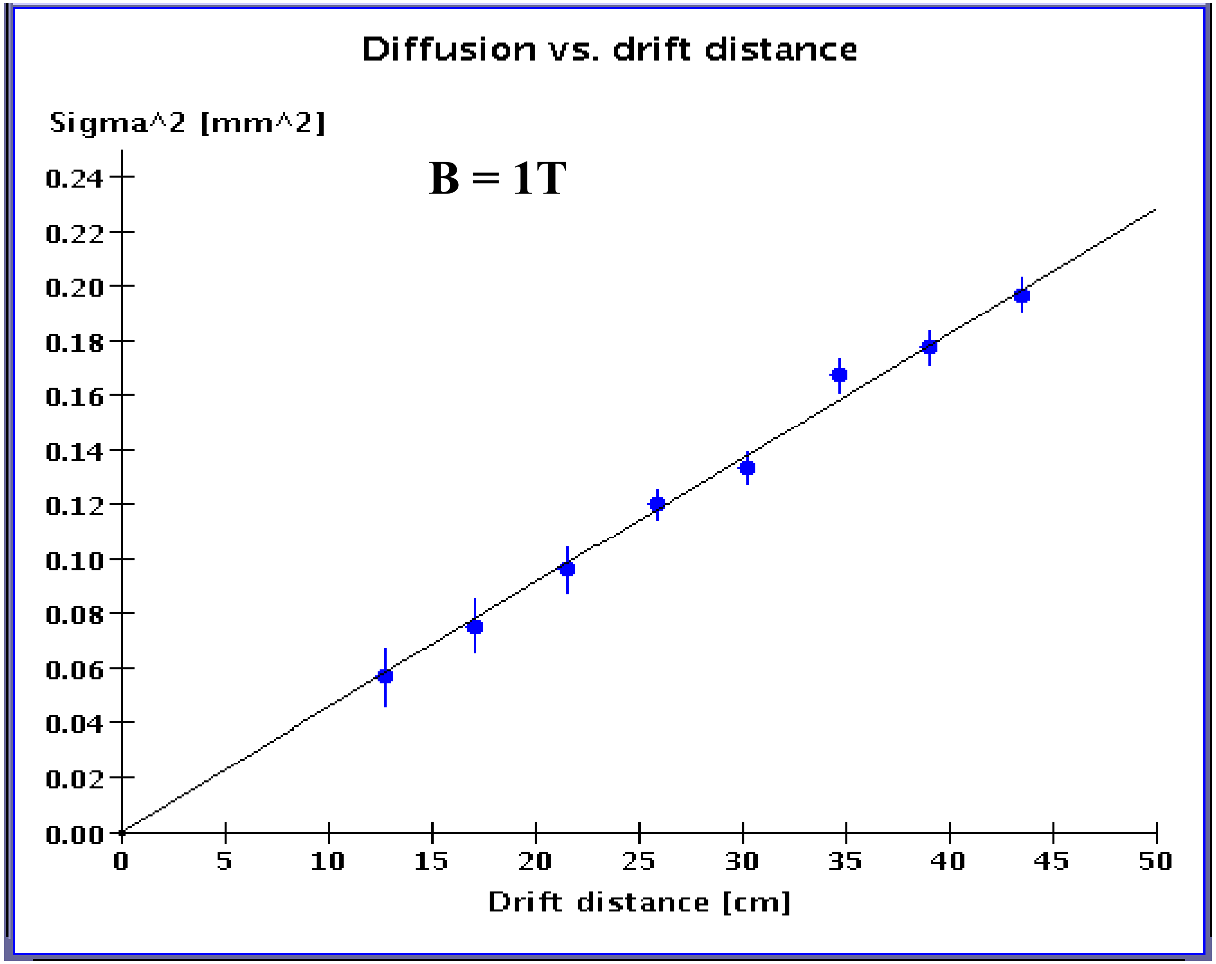
We find that the attenuation length due to electron attachment in **ArCF4** is larger than **4.4 m** at **90%** confidence.

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.

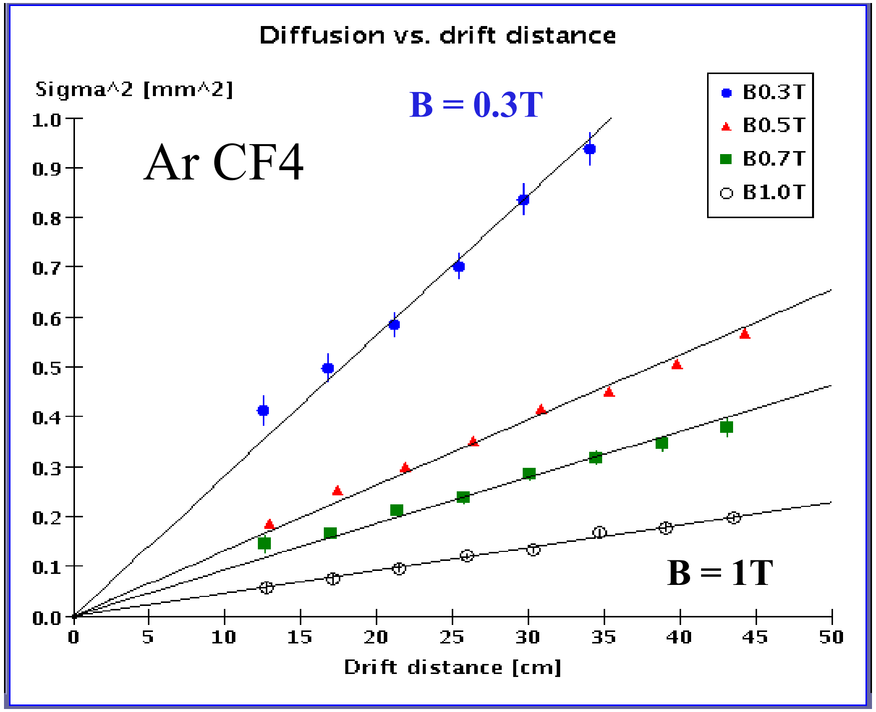


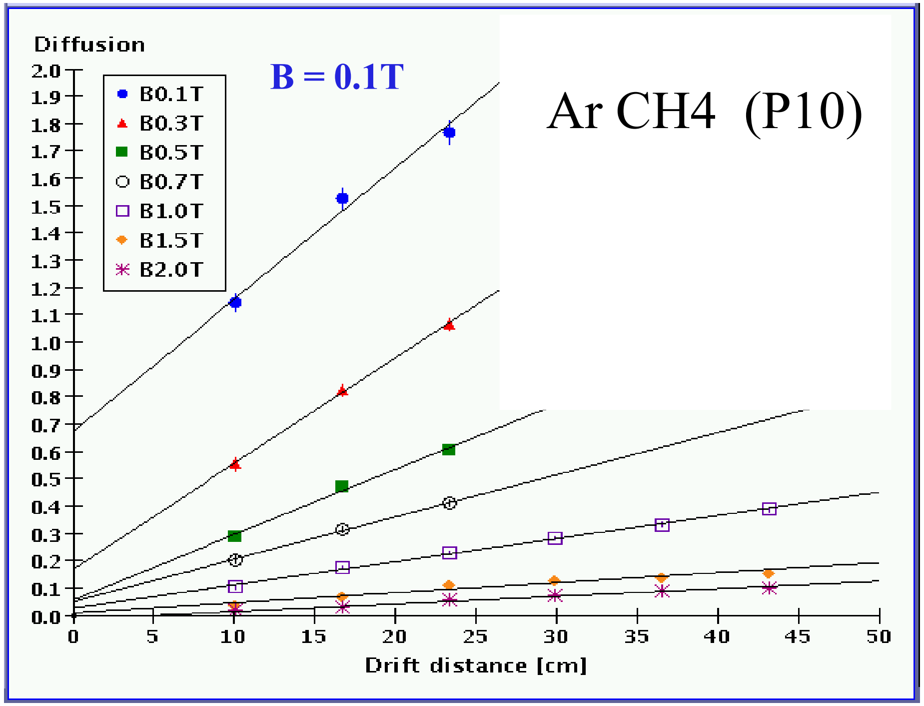


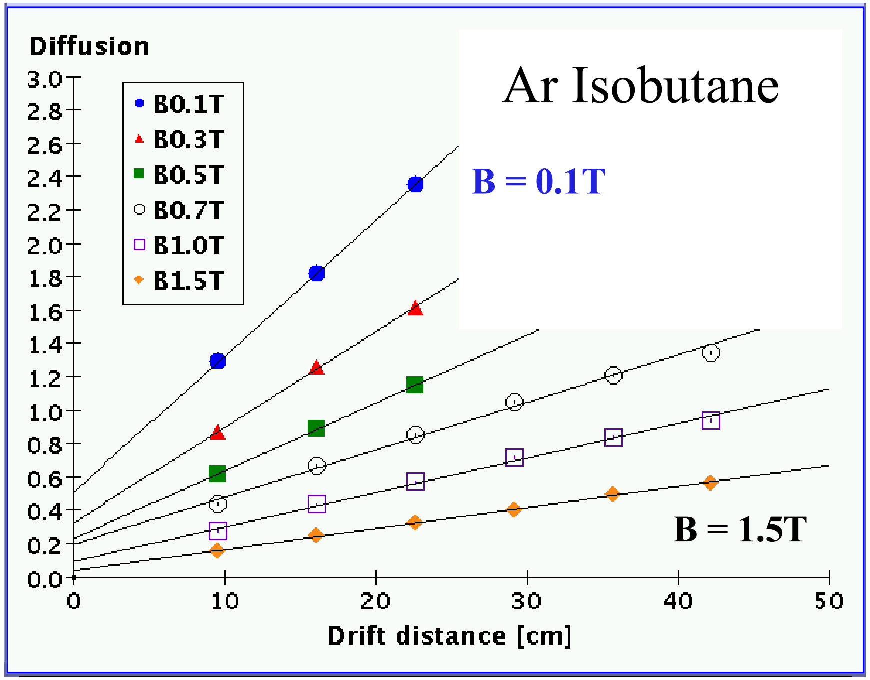
For Ar-CF4:3% at B = 1 Tesla, we measure in one analysis

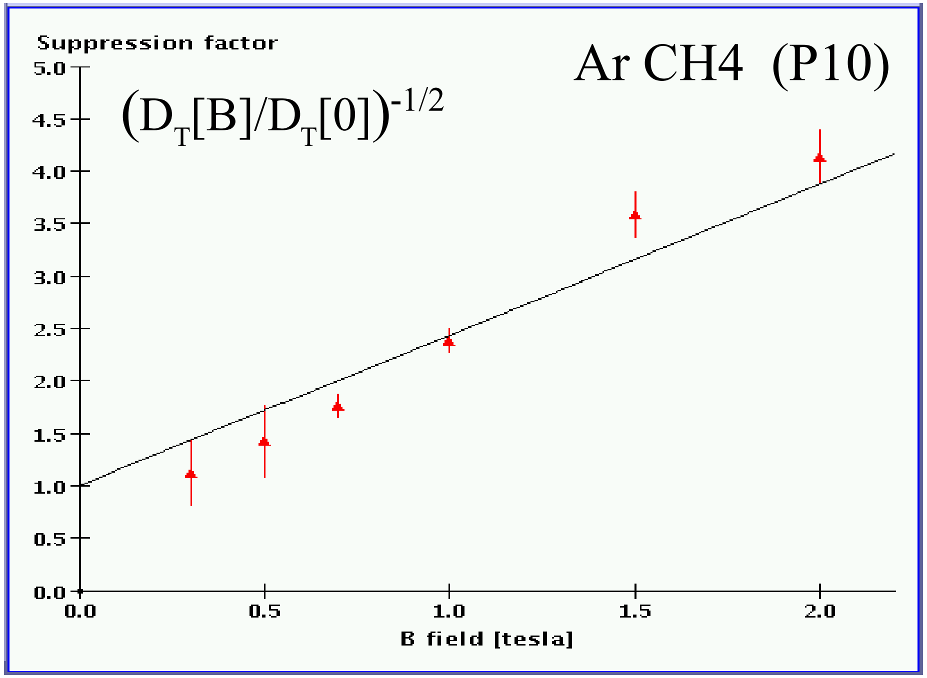
D_T = 68 +- 0.9 +- 3 microns / sqrt(cm)

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]

Measured Gas Properties

- Drift velocity

First Micromegas TPC results @ B = 1T

We measure the drift velocities for the 3 gases being studied using the time distribution of cosmic ray tracks in our Micromegas TPC. We find at ***B = 1T***

Ar-CF4: 3%	v_{drift} = **8.8 +- 0.2 (stat.) cm / µsec.**	
Ar-CH4: 10%	v_{drift} = **5.7 +- 0.1 (stat.) cm / µsec.**	~ **10% systematic errors**
Ar-Isobutane: 5%	v_{drift} = **4.4 +- 0.1 (stat.) cm / µsec.**	

Electron attachment

We measure electron attachment by drift distance variation in the truncated mean.

Ar-CF4: 3% $\lambda_{attachment}$ > **4.4 m** @ 90% confidence

- Transverse diffusion

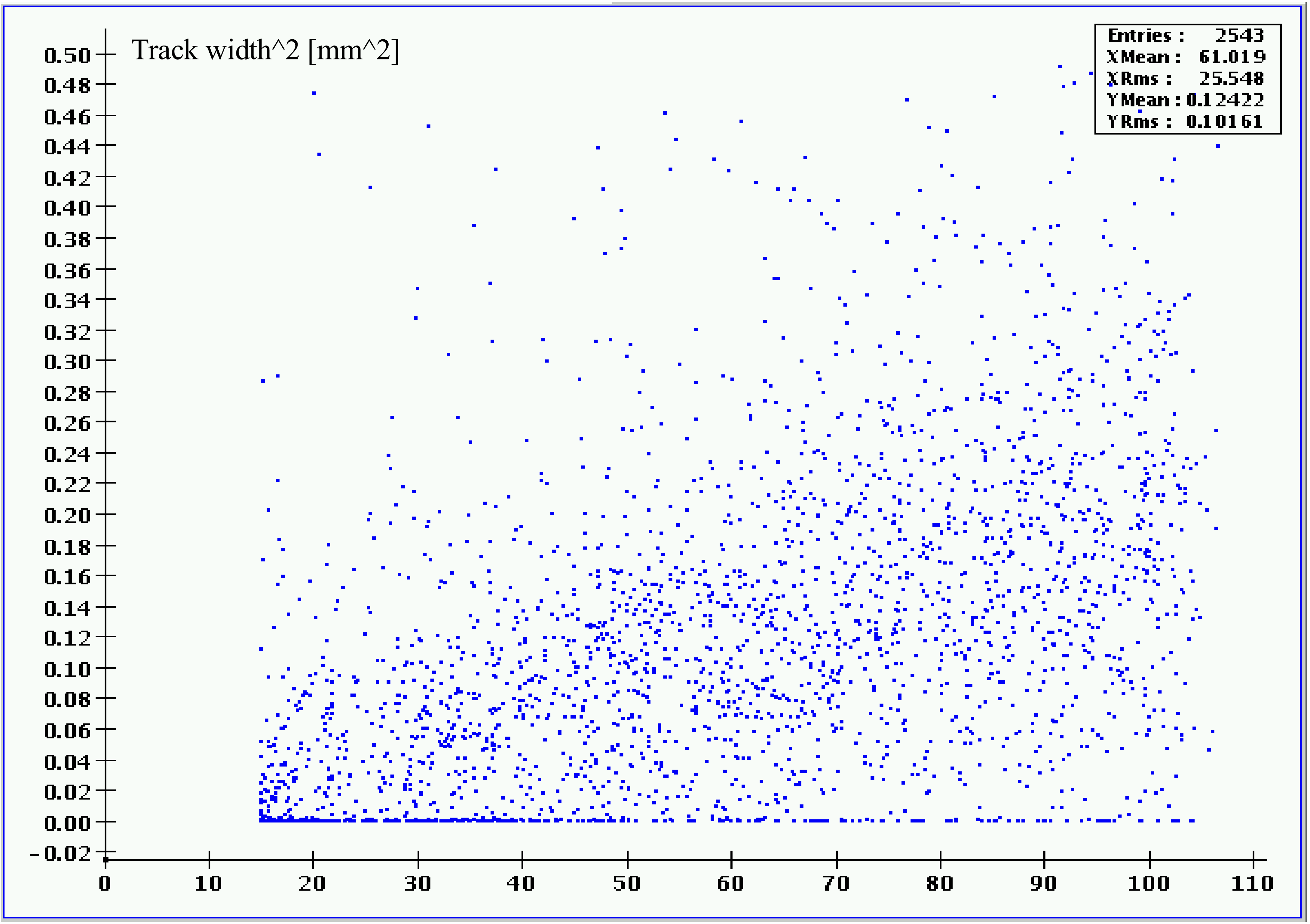
We measure the diffusion from maximum fits to the track ionization spread on pads in each row. We find at ***B = 1T***

Ar-CF4: 3%	D_T = **75 +- 2 (stat.) +- 7 (sys.) µm / sqrt(cm)**
Ar-CH4: 10%	D_T = **100 +- 1.4 (stat.) +- 10 (sys.) µm / sqrt(cm)**
Ar-Isobutane: 5%	D_T = **160 +- 1.0 (stat.) +- 16 (sys.) µm / sqrt(cm)**

Systematics study

- Detector response function. How to calibrate the detector and electronics ?
- Drift velocity endpoint determination.
- Diffusion measurements
  - Differences between Java/Fortran and with MagBoltz
  - Zero track width measurements (thresholds, ...)
  - Non-linearities in large diff. Measurements
  - Fit range variations, diffusion offsets
  - Fits to different drift time/distance bins
- dE/dx measurements
- Transverse position resolution
  - Need to improve statistics in final analysis
- Pulse shaping

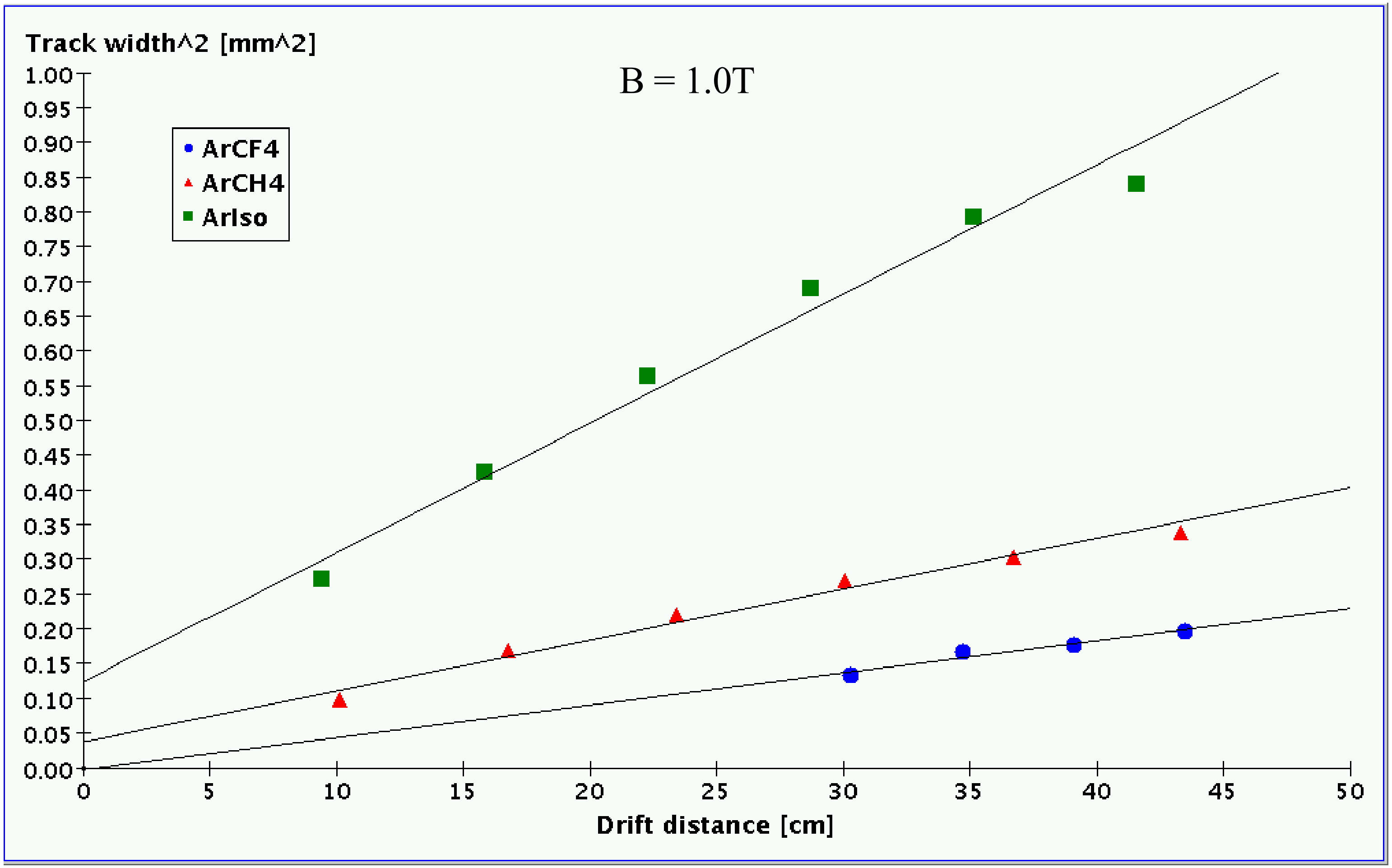
ArCF4 B=1T ωτ ~



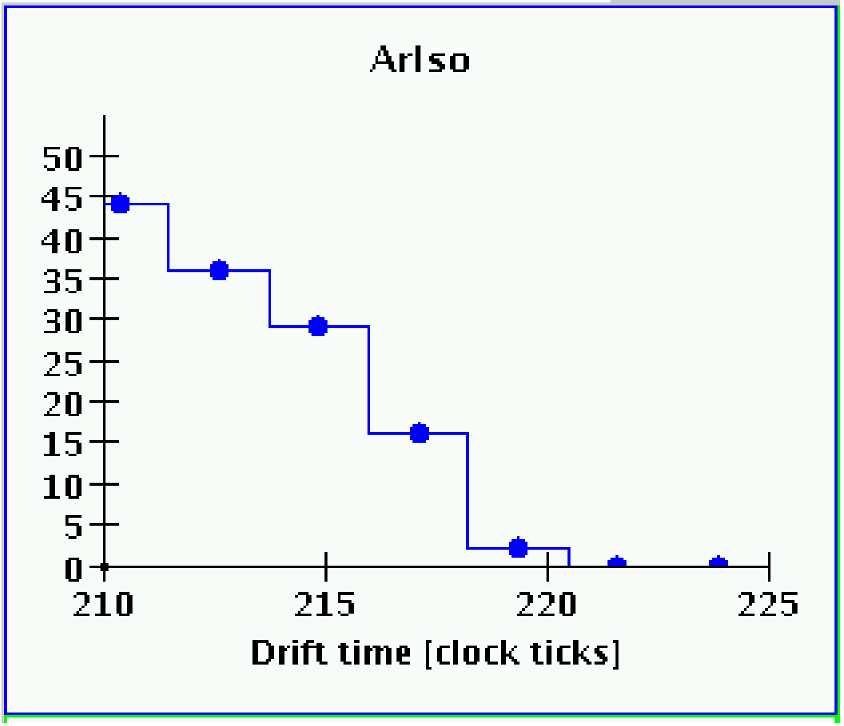
Drift time [50 nsec ticks]

Systematic Checks

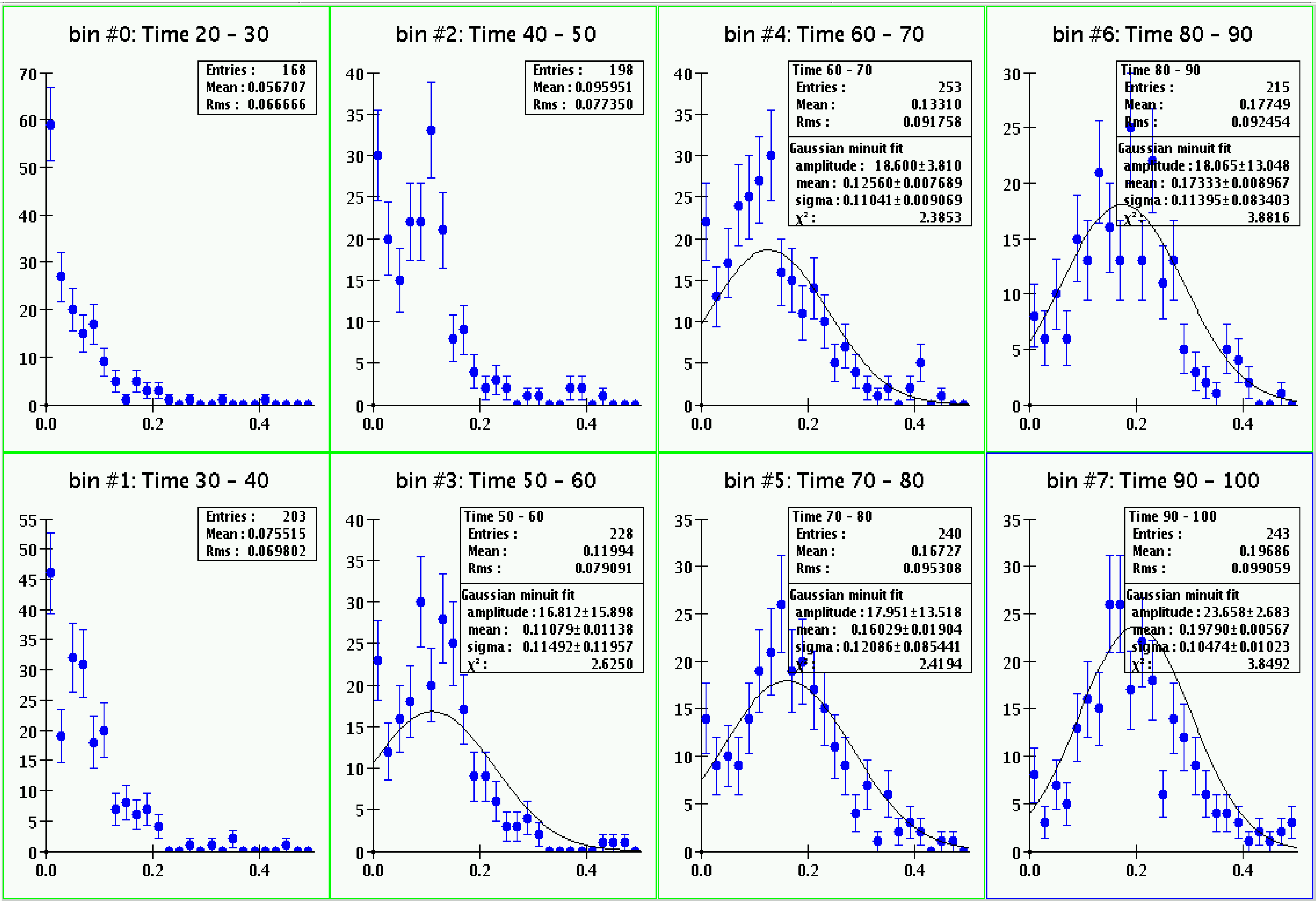
Vary fit range



End point determination



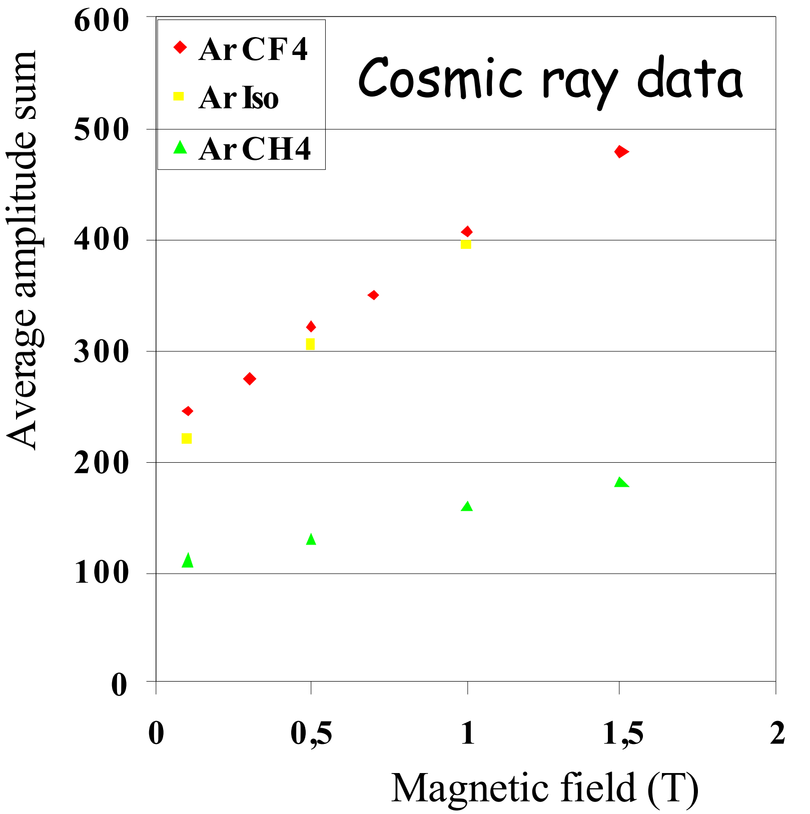
ArCF4 B=1.0T

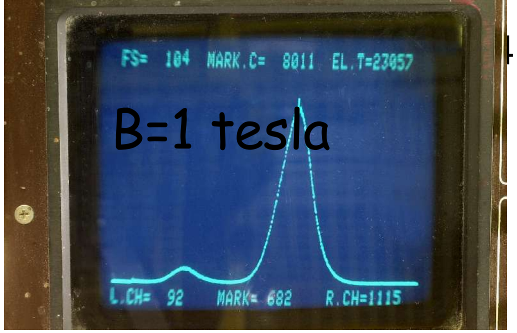

bin #0: Time 20 - 30
Entries : 168
Mean : 0.056707
Rms : 0.066666
bin #2: Time 40 - 50
Entries : 198
Mean : 0.095951
Rms : 0.077350
bin #4: Time 60 - 70
Time 60 - 70
Entries : 253
Mean : 0.13310
Rms : 0.091758
Gaussian minuit fit
amplitude : 18.600±3.810
mean : 0.12560±0.007689
sigma : 0.11041±0.009069
χ² : 2.3853
bin #6: Time 80 - 90
Time 80 - 90
Entries : 215
Mean : 0.17749
Rms : 0.092454
Gaussian minuit fit
amplitude : 18.065±13.048
mean : 0.17333±0.008967
sigma : 0.11395±0.083403
χ² : 3.8816
bin #1: Time 30 - 40
Entries : 203
Mean : 0.075515
Rms : 0.069802
bin #3: Time 50 - 60
Time 50 - 60
Entries : 228
Mean : 0.11994
Rms : 0.079091
Gaussian minuit fit
amplitude : 16.812±15.898
mean : 0.11079±0.01138
sigma : 0.11492±0.11957
χ² : 2.6250
bin #5: Time 70 - 80
Time 70 - 80
Entries : 240
Mean : 0.16727
Rms : 0.095308
Gaussian minuit fit
amplitude : 17.951±13.518
mean : 0.16029±0.01904
sigma : 0.12086±0.085441
χ² : 2.4194
bin #7: Time 90 - 100
Time 90 - 100
Entries : 243
Mean : 0.19686
Rms : 0.099059
Gaussian minuit fit
amplitude : 23.658±2.683
mean : 0.19790±0.00567
sigma : 0.10474±0.01023
χ² : 3.8492

Surprise

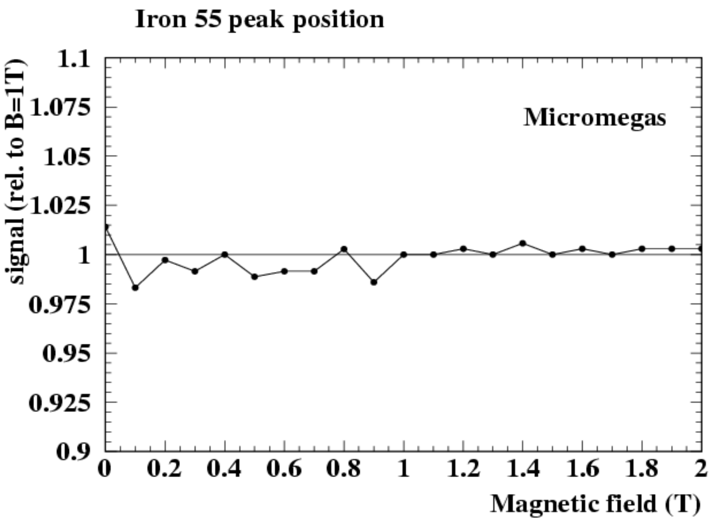
Presented by P. Colas at Durham ECFA meeting.

We observe a strong dependence of the total amplitude on the magnetic field.
Not explained by relativistic rise of dE/dx
Electronics? Mechanical effect on mesh?





Apparent contradiction with previous measurements with a ^{55}Fe source!

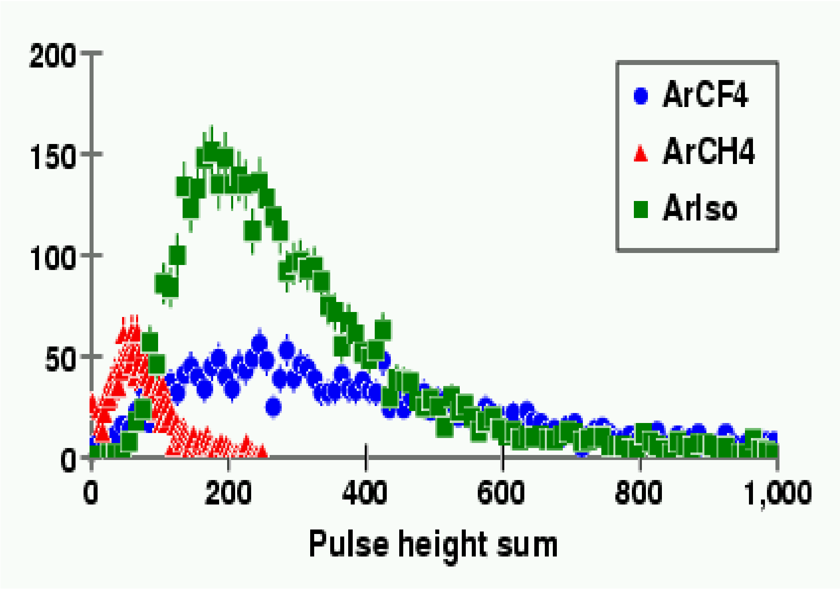


To be investigated…
(harmless anyway)

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

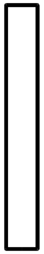
We operated the STAR front end electronics at very low noise levels (~1000 e's), typically 1-2 ADC counts.

- 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.

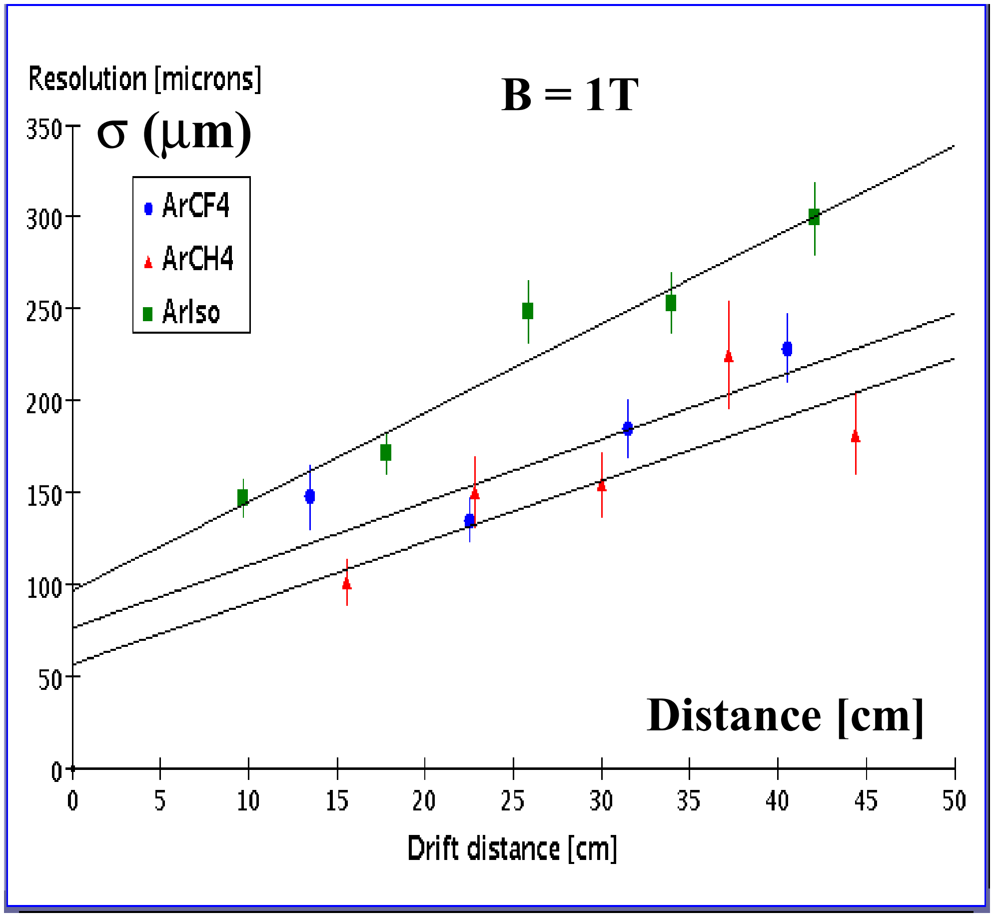
Note: We measure *intrinsic* ("zero-drift") Micromegas resolutions of **60-100 microns**, even with ArCH4 (P10) operating at low gain (~1000) as shown above.

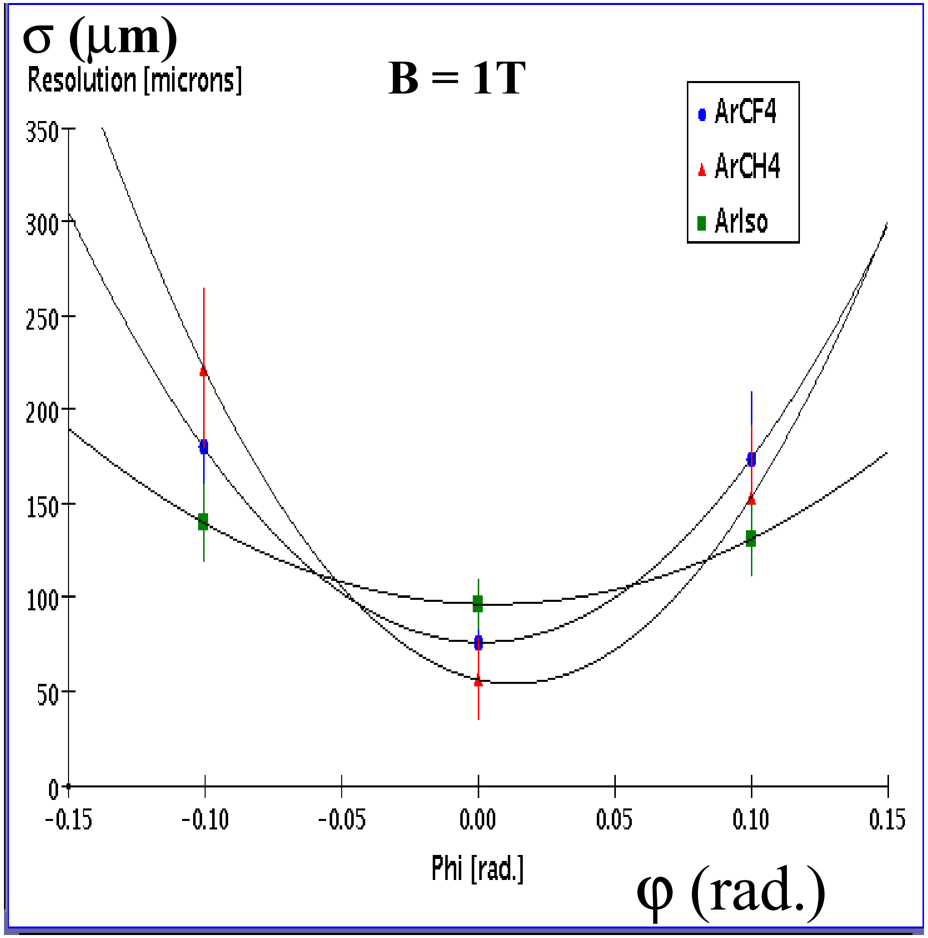
Transverse position resolution measurements



For near vertical tracks at small angles, we measure Micromegas intrinsic ("zero drift") resolutions of roughly **60**, **80** and **100 microns** for **Ar-CF4**, **Ar-CH4** and **Ar-Isobutane** gas mixtures, respectively.

We measure a large (X2) angular dependence of the resolution due to our elongated **1X10 mm²** anode pads.





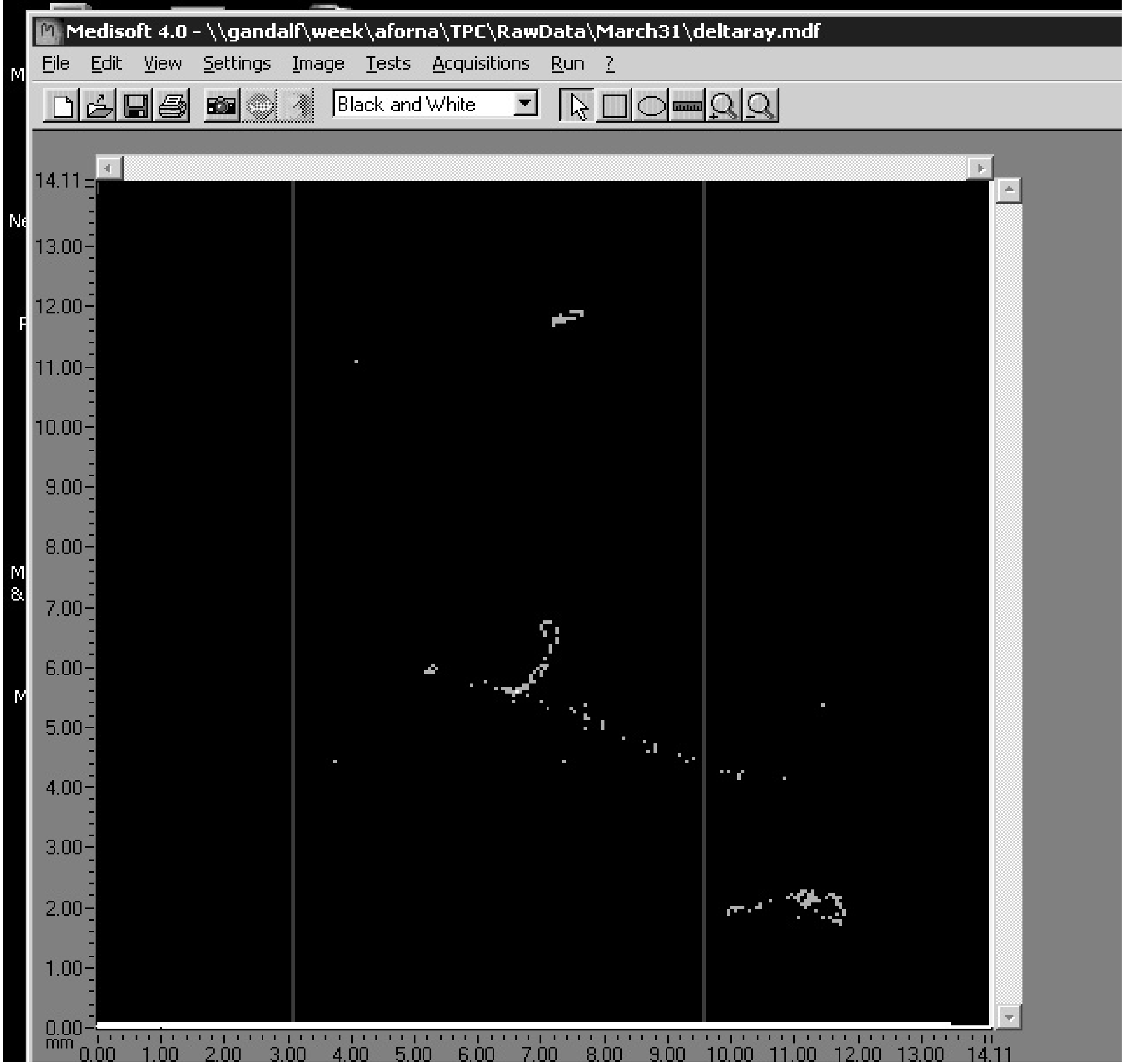
We obtain position resolutions as small as **60 - 80 microns** for near vertical tracks using our 1X10 mm² pads.

Micromegas pixel-TPC R&D

New results from
NIKHEF / Saclay
Pixel-TPC Collaboration

Rome IEEE Nuclear Science Symposium

- First GEM gas detector pixel readout R. Bellazini et al, Pisa
- NIKHEF / Saclay Micromegas Pixel TPC readout
-



Medisoft 4.0 - \\gandalf\week\aforna\TPC\RawData\March31\deltaray.mdf
File Edit View Settings Image Tests Acquisitions Run ?
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Summary

- Micro-pattern Gas Detectors (MPGD's) offer significant improvements for future TPC applications, such as the ILC. An extensive R&D program is required to fully realize the benefits and to completely understand the limitations.
- A large-area Micromegas TPC has been operated successfully for a year with no significant problems.
- New high-precision gas property measurements have been made for three gases: **ArCF4** 3%, **ArCH4** 10% (P10) and **Argon-Isobutane** 5%.
- The Micromegas TPC performance measures are very exciting and improvements can be expected.
- Plans
  - ***Continue analysis to learn how to calibrate, to understand systematics and to measure other properties such as dE/dx resolution and pulse time shaping.***
  - Future data taking is being planned for tests of ***charge spreading techniques, and for long operation in a reasonably intense beam.***