Development of a TPC for the ILC

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Introduction

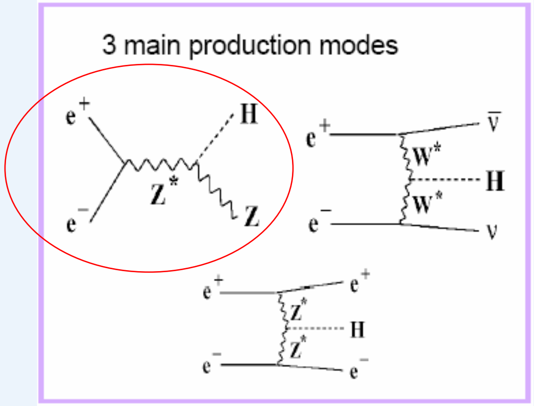
- Experimental Goals at the ILC (as they relate to tracking)
- Meeting the experimental goals with a Time Projection Chamber (TPC)
- Micro-Pattern-Gas-Detector (MPGD) gas amplification

Cornell involvement in the international TPC R&D and detector concept programs

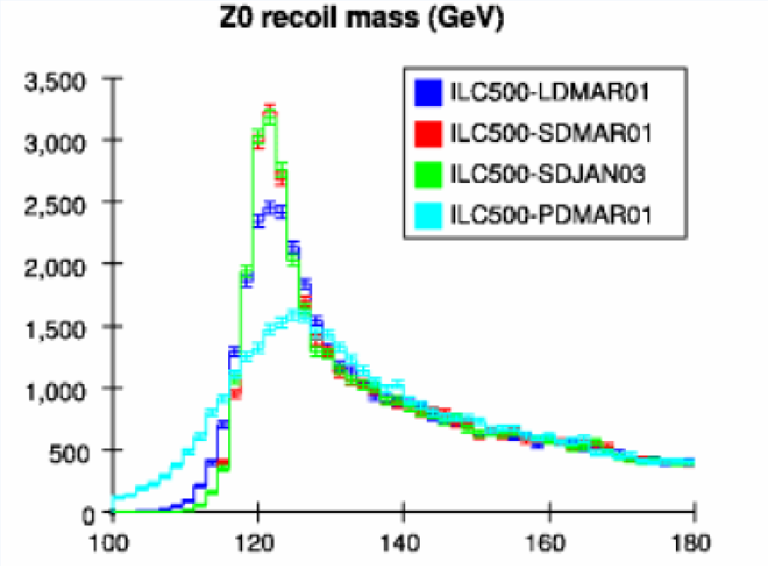
1) Simulation of Digitized TPC Signals / Track Reconstruction
2) Small Prototype Program at Cornell (in collaboration with Purdue, LC-TPC)
3) Contributions to the LDC (Large Detector Concept)
4) Large Prototype Program (in collaboration with LC-TPC)

Experimental Goals (as they relate to tracking)

Momentum resolution required to detect the Higgs:



ref: Yamashita, Snowmass (Higgs session), Aug 2005



ref: Hai-Jun Yang, Snowmass (tracking session), Aug 2005

measure the mass recoiling against $l^+ l^-$ in ($e^+ e^- \rightarrow HZ$, $Z \rightarrow l^+ l^-$)

$\delta P_t / P_t^2 = 2 \times 10^{-5}$ /GeV recoil mass resolution is dominated by other effects

$= 4 \times 10^{-5}$ /GeV recoil mass resolution is starting to deteriorate

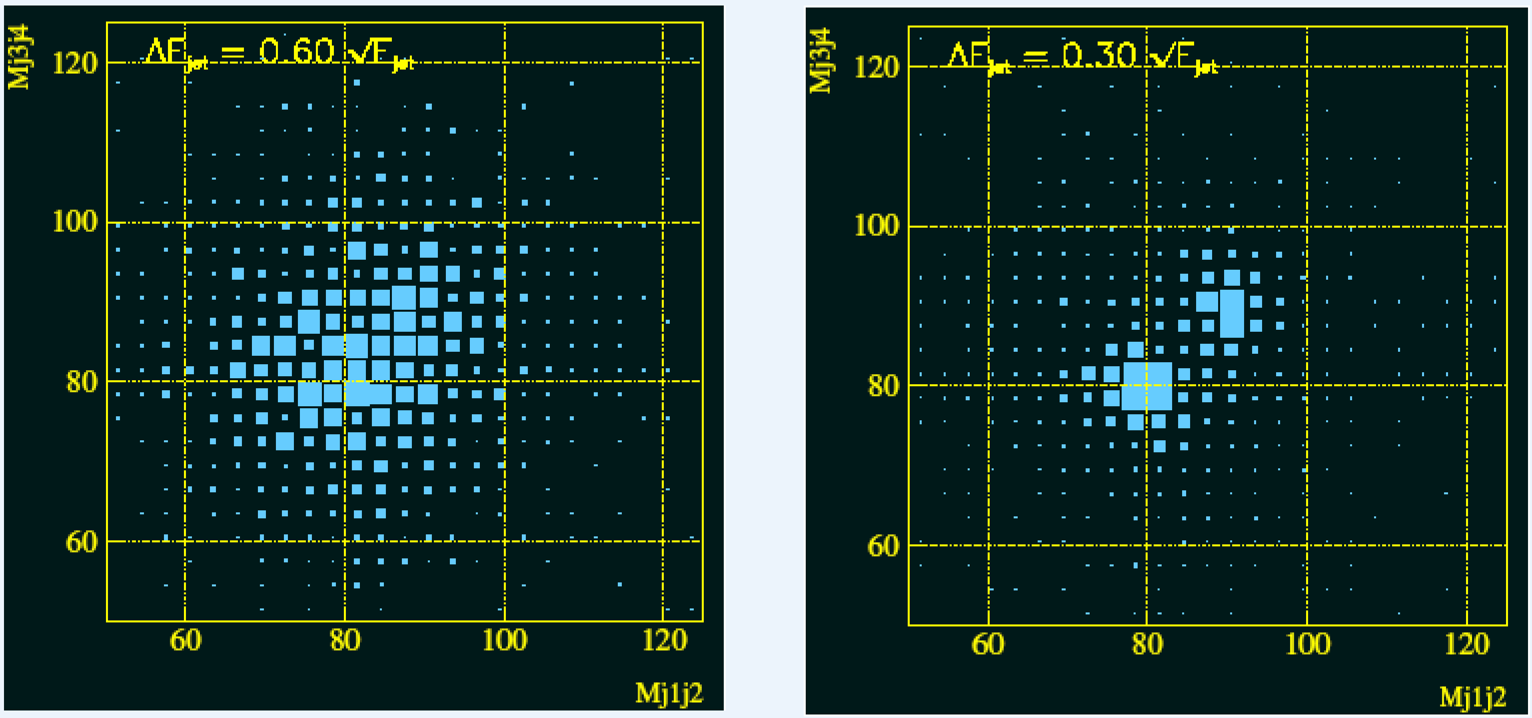
$= 7 \times 10^{-5}$ /GeV recoil mass resolution is dominated by momentum resolution

Experimental Goals (as they relate to tracking)

Jet energy resolution:

There are processes where WW and ZZ must be separated without beam constraints (example, $e^+e^- \to \nu\nu WW, \nu\nu ZZ$)

Ref: J-C Brient, H. Videau



Thus, the required jet energy resolution is about $\delta E/E = 30\% / \sqrt{E}$

Experimental Goals

Measuring the jet energy

Classical method: Calorimetry

typical event:

30% electromagnetic,
70% hadronic energy

typical resolution:

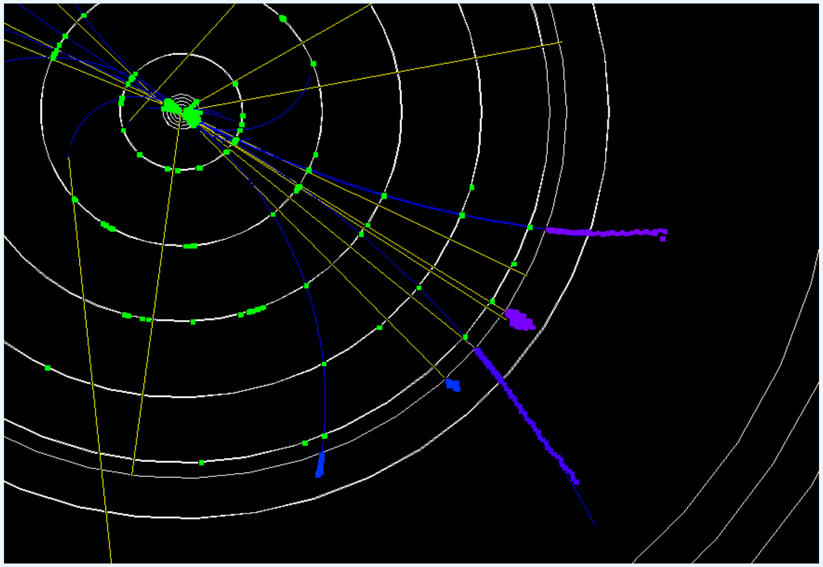
10% / √E   for ECAL
50% / √E   for HCAL
→ $\delta E/E$ > 45% / √E   for jets

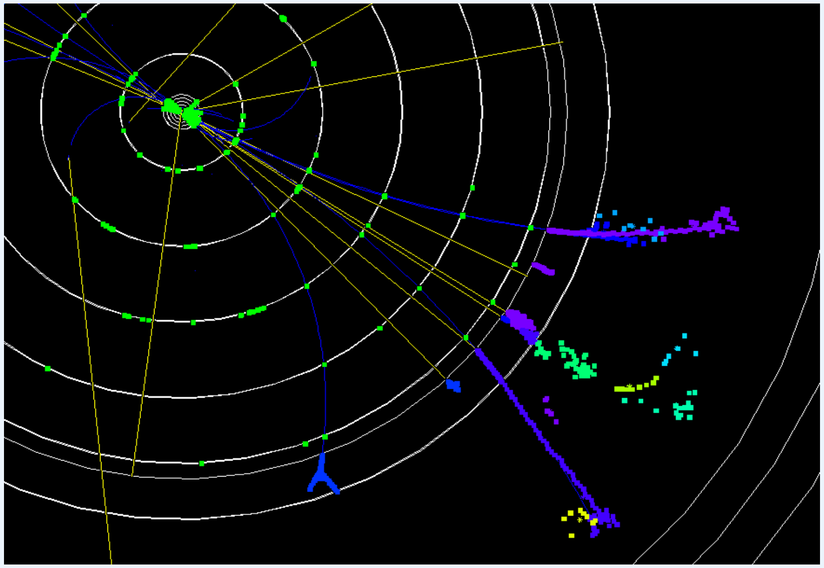
The Particle Flow Analysis method (PFA)

typical event:

60% charged tracks,
(tracking resolution negligible on this scale)
30% electromagnetic,
10% neutral hadronic energy

→ $\delta E/E$ = 20% / √E   for jets
is achievable, in principle



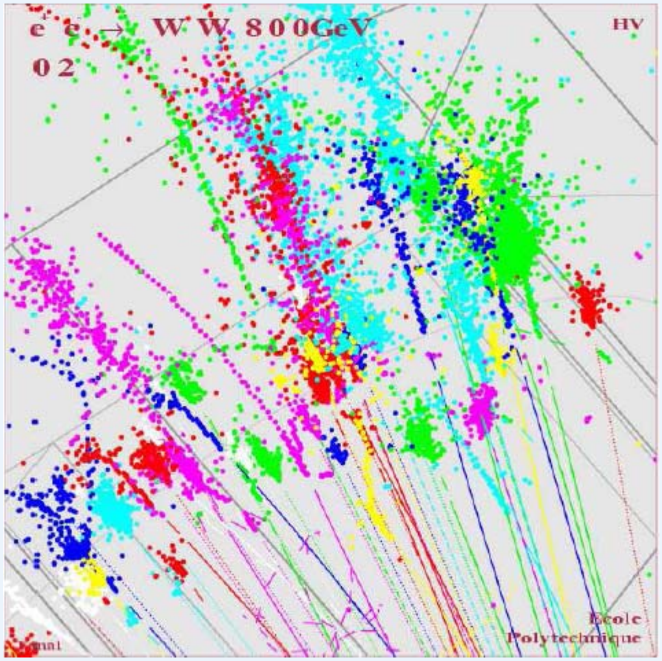


ref: Klaus Mönig, Vienna, Nov 2005
Steve Magill, Snowmass, Aug 2005

Experimental Goals

Particle Flow Analysis:

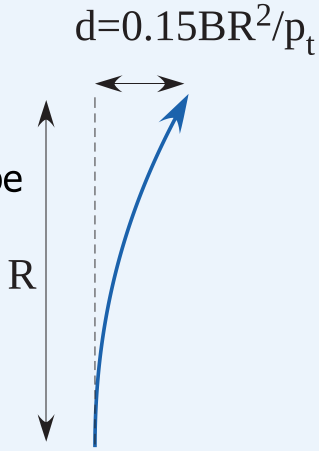
The main limitations are due to
cluster separation in the calorimeters and
tracking confusion which leads to mismatching.



The tracking system must deliver
"perfect" efficiency (and fake rejection)
for these dense jets.

There is some "momentum spreading",
possibly only by 1 cm at high momentum.
This is a difficult pattern recognition problem.

Momentum spreading can be
(loosely) quantified by BR^2.

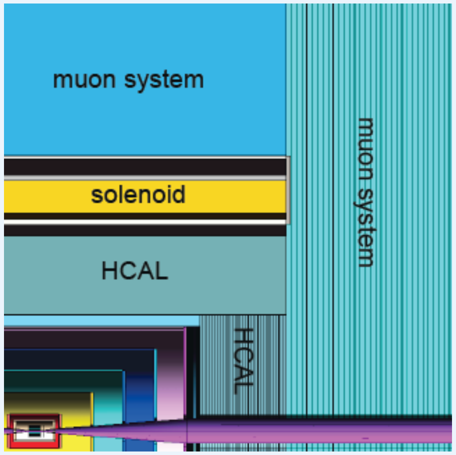


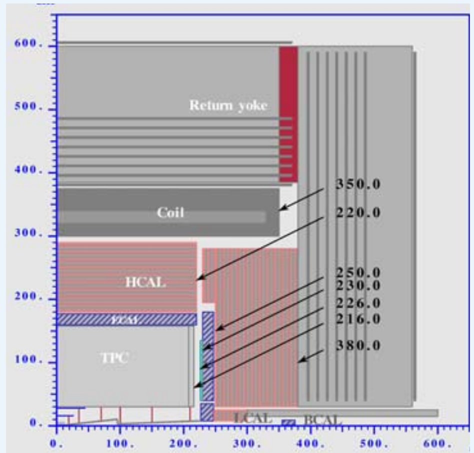
Momentum Resolution:

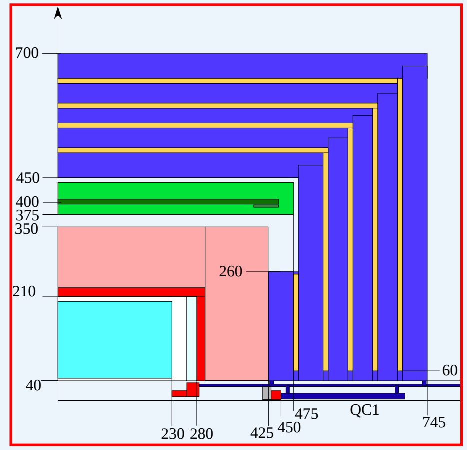
$\delta P_t / P_t^2 = 3 \times 10^{-5}$ /GeV ;

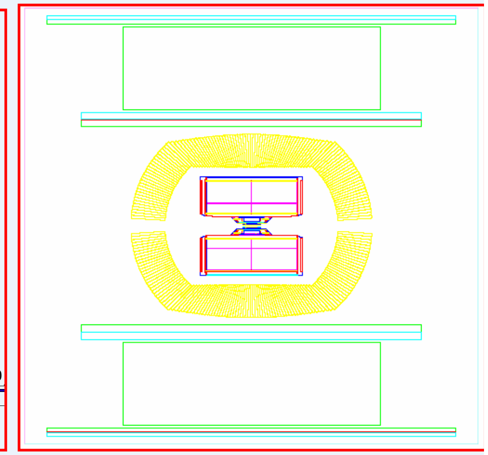
δ(sagitta) = 19 μm (for a 1.6 m radius, 4 Tesla)

Meeting the experimental goals with a TPC







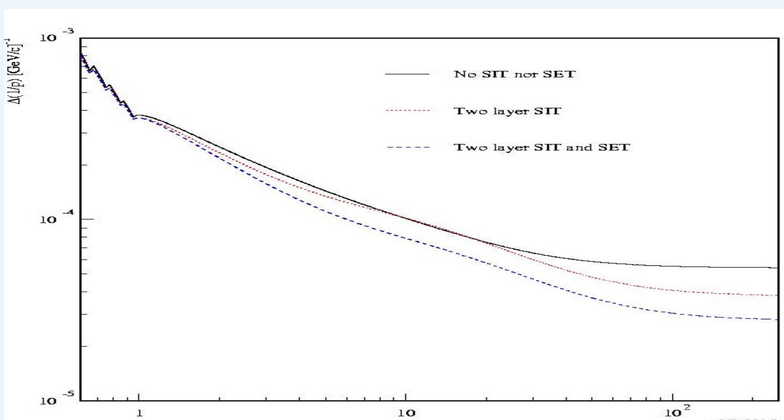


SiD 5 layer silicon tracker
1.25m, 5 Tesla
$BR^2 = 7.8\ Tm^2$

LDC ⇨ **TPC** ⇦
1.6 m, 4 Tesla
$BR^2 = 10.2\ Tm^2$

GLD ⇨ **TPC** ⇦
1.9 m, 3 Tesla
$BR^2 = 10.8\ Tm^2$

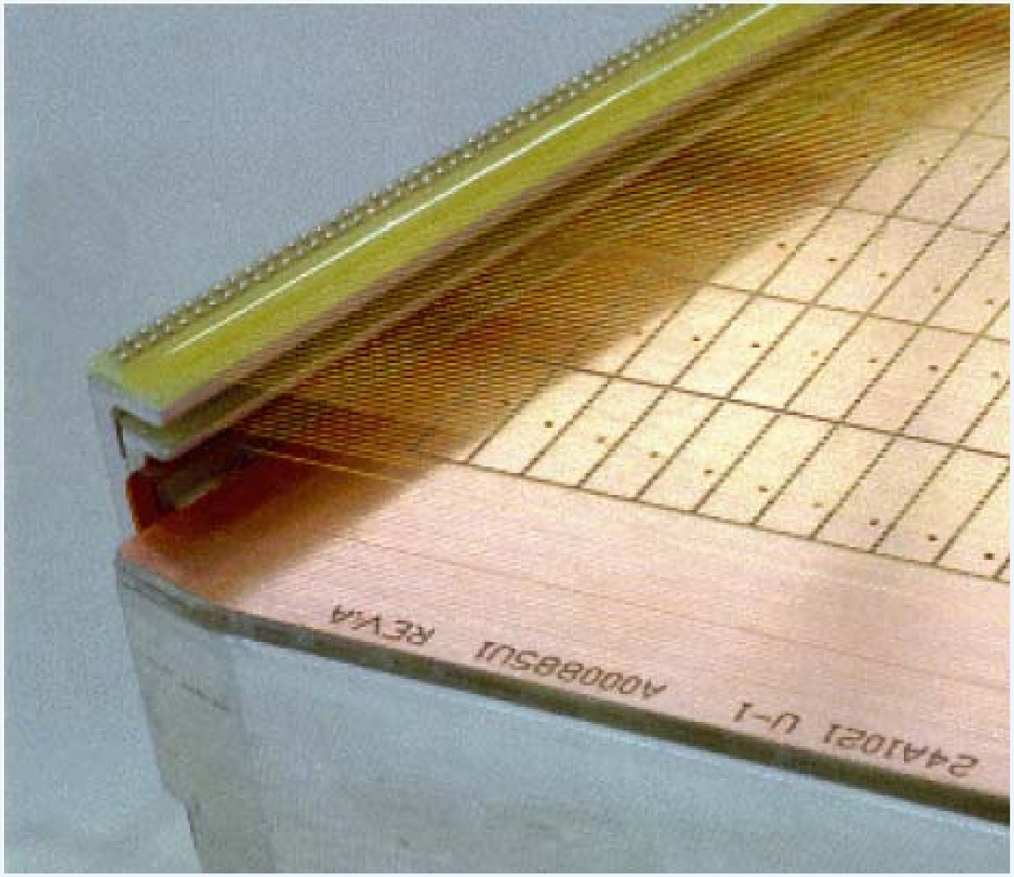
4th ⇨ **TPC** ⇦
1.3 m, 3.5 Tesla
$BR^2 = 6\ Tm^2$



3 of the 4 detector concepts
propose a TPC for the central tracking system.

In the LDC,
the TPC (with 100μm spatial resolution) + VD
provides $\delta P_t / P_t^2 = 5.3 \times 10^{-5}$ / GeV
with an intermediate silicon layer, → 3.9
and with an outer silicon envelope, → 2.9

Limitations of current TPCs

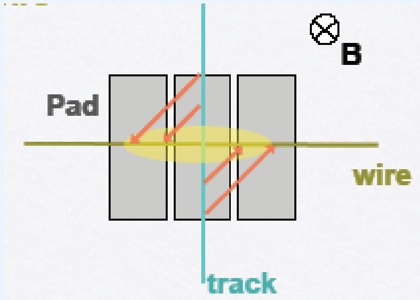


from Jim Thomas, 2001 Vienna, The STAR TPC

Large colliding-beam experiment TPCs have had MWPC gas amplification.

The wire anode readout is insufficient to meet the spatial resolution goal because the charge distribution is inductive and therefore wide.

The charge distribution is further broadened because of an ExB effect.



Typical 6mm pads are insufficient for track separation and efficiency goals.

Understanding and solving these problems is the goal of the world LC TPC program.

Simulation and Reconstruction studies at Cornell

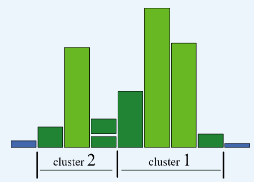
Presented at ILC workshops, Paris & Victoria, 2004

The simulation and reconstruction studies at Cornell address the design requirements of the TPC to meeting the reconstruction efficiency goal.

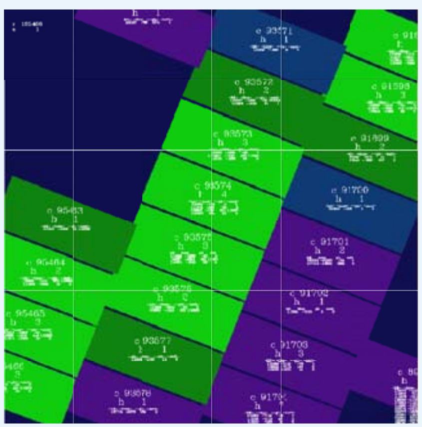
At what granularity will the TPC provide full efficiency in jet events?

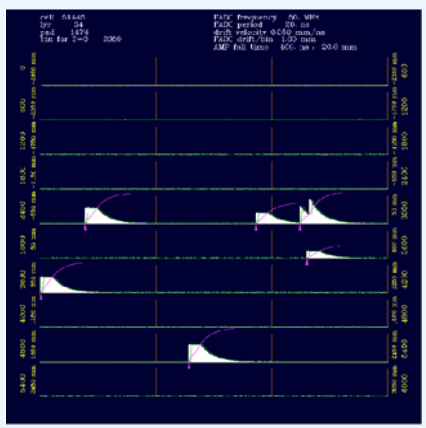
Simulation: takes the simple space points that describe the track crossings with ideal cylinders; Create charge, hits-on-pads, including a FADC pulse representation.

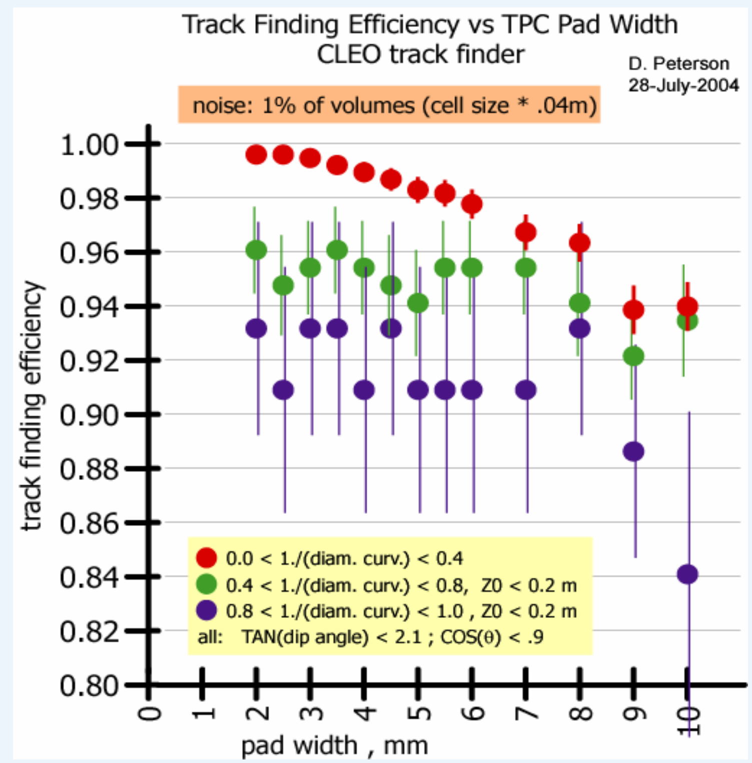
Reconstruction includes a FADC analysis on each channel and clustering in rϕ.



Studies indicate that ≤ 3mm pads are required.







(HZ events, 1.9 m radius, 3 Tesla)

Simulation and Reconstruction studies at Cornell

Presented at ILC workshop, Vienna, 2005

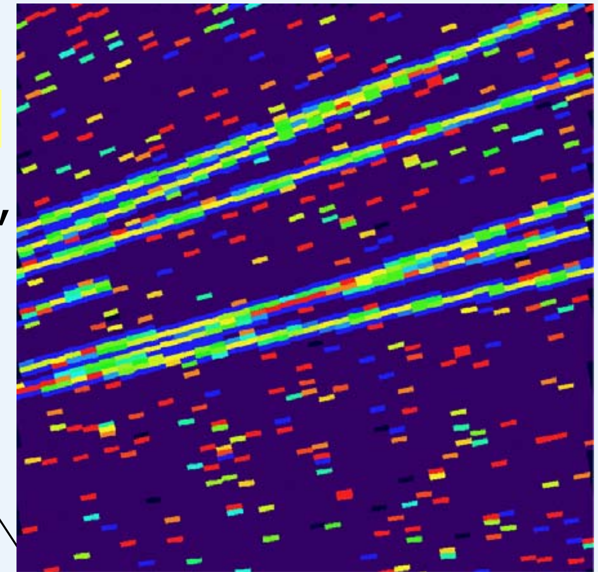
From the previous slide, reconstruction efficiency is 99.5%,
for 3mm pads, 400K channels (per side).

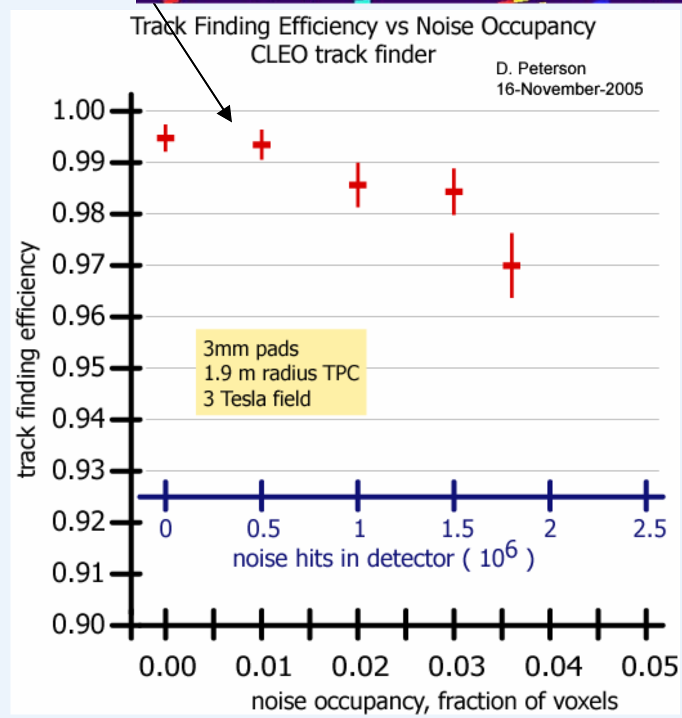
This is with the expected noise occupancy:
1% of time buckets on each pad, 500K noise hits.

Noise tolerance is an important design consideration.

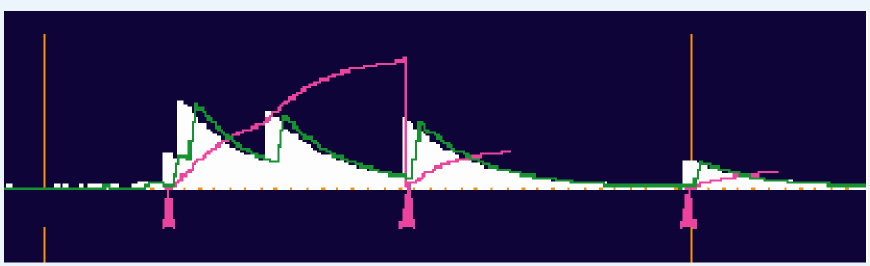
This simulation also was used to find the noise limit.

With x 3.6 noise (random), the efficiency is 97%.
(20% of hits are “touched” by noise.)





Studies must be integrated into a framework,
expanded to investigate other event types,
realistic noise, and other detector configurations.

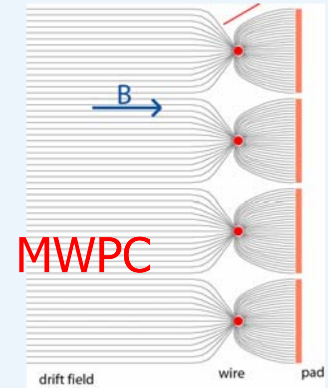


Micro-Pattern-Gas-Detector (MPGD) gas amplification

The required readout segmentation is not possible with a MWPC (wire anode) readout.

The goal of the international TPC R&D program is to develop a TPC with a readout incorporating a MPGD device.

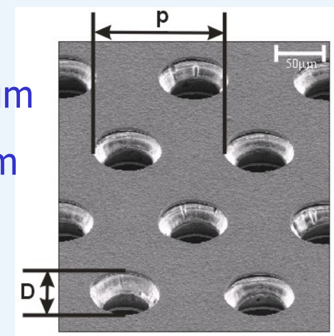
The anode is the pads; the signal is due to charge transfer, offering improved resolution, reduced ExB and ion feedback.

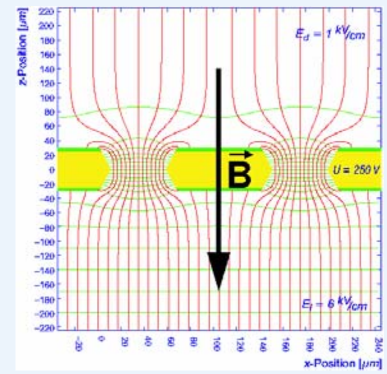


GEM
Two copper foils
separated by kapton,
multiplication takes place in holes,
uses 2 or 3 stages

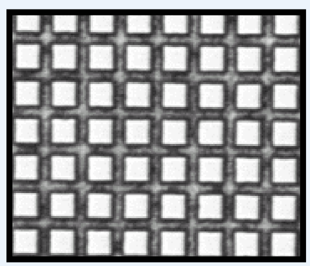
P~140 µm

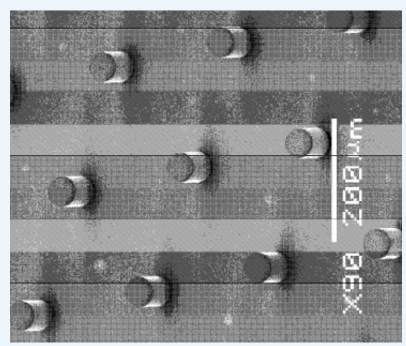
D~60 µm

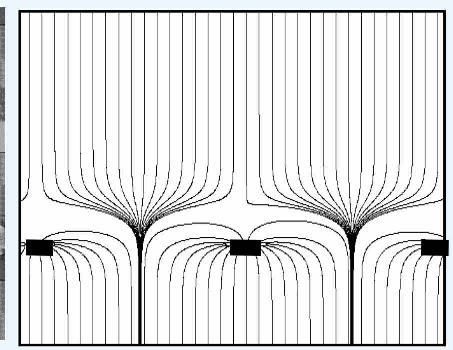




Micromegas
mesh supported by
50µm (height) pillars,
multiplication is between
anode and mesh, one stage







TPC R&D, international program

With a goal of developing
a TPC for the ILC

based on
MPGD gas amplification,
with a spatial resolution
$\sigma < 100\ \mu m$,

studies include

GEM,
Micromegas,
+ resistive dispersion,

gas studies
pad studies
ion feedback
performance in magnet fields
field cage studies

Aachen

DESY-
Hamburg

Karlsruhe

MPI, Asia

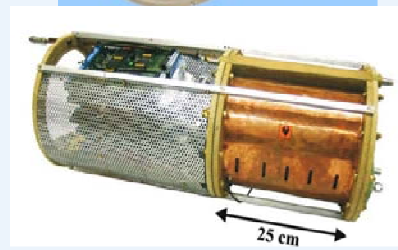
Carleton

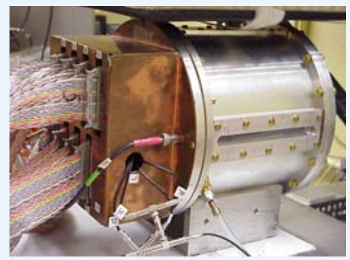
Berkeley,
Orsay, Saclay

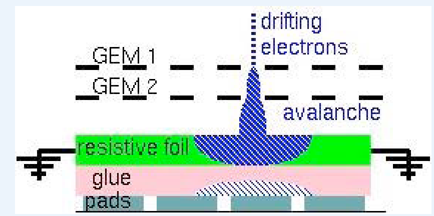
Victoria

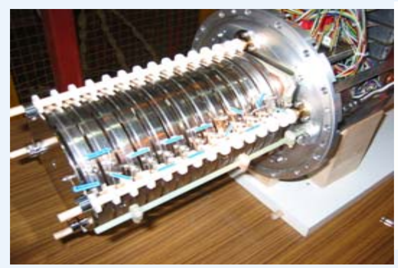
+ others

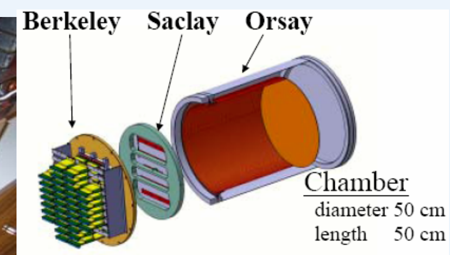
and
Cornell/Purdue

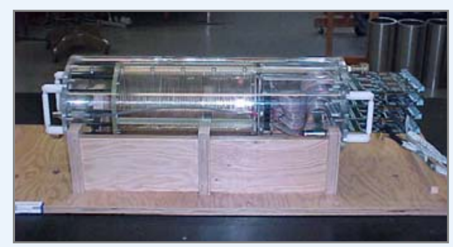












TPC R&D, the international program

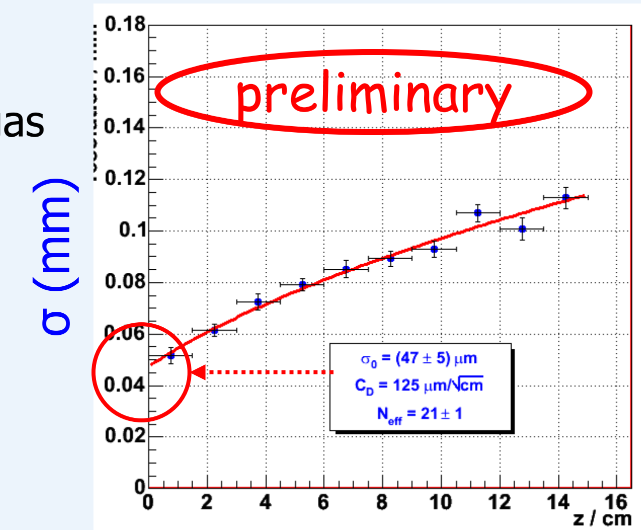
Results are encouraging.

Groups observe
resolution < 100 μm.

But,
there is a need to make
comparative measurements
with common systematics
(in the same chamber).

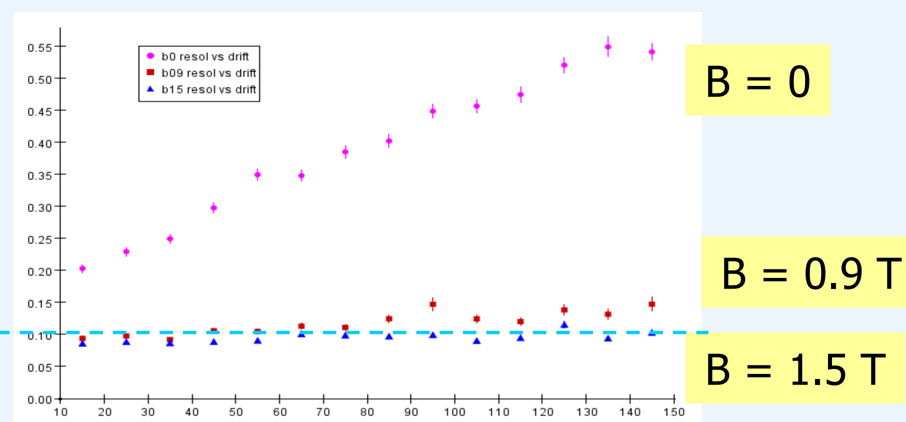
There are also
open questions:
ion feedback,
reliability.

Orsay, Saclay Micromegas
Carleton TPC
π beam
1 Tesla
Ar iC_4H_{10} 95:5 gas



with charge dispersion

Victoria TPC
double-GEM
P5 gas



100 micron

3 cm drift 30 cm

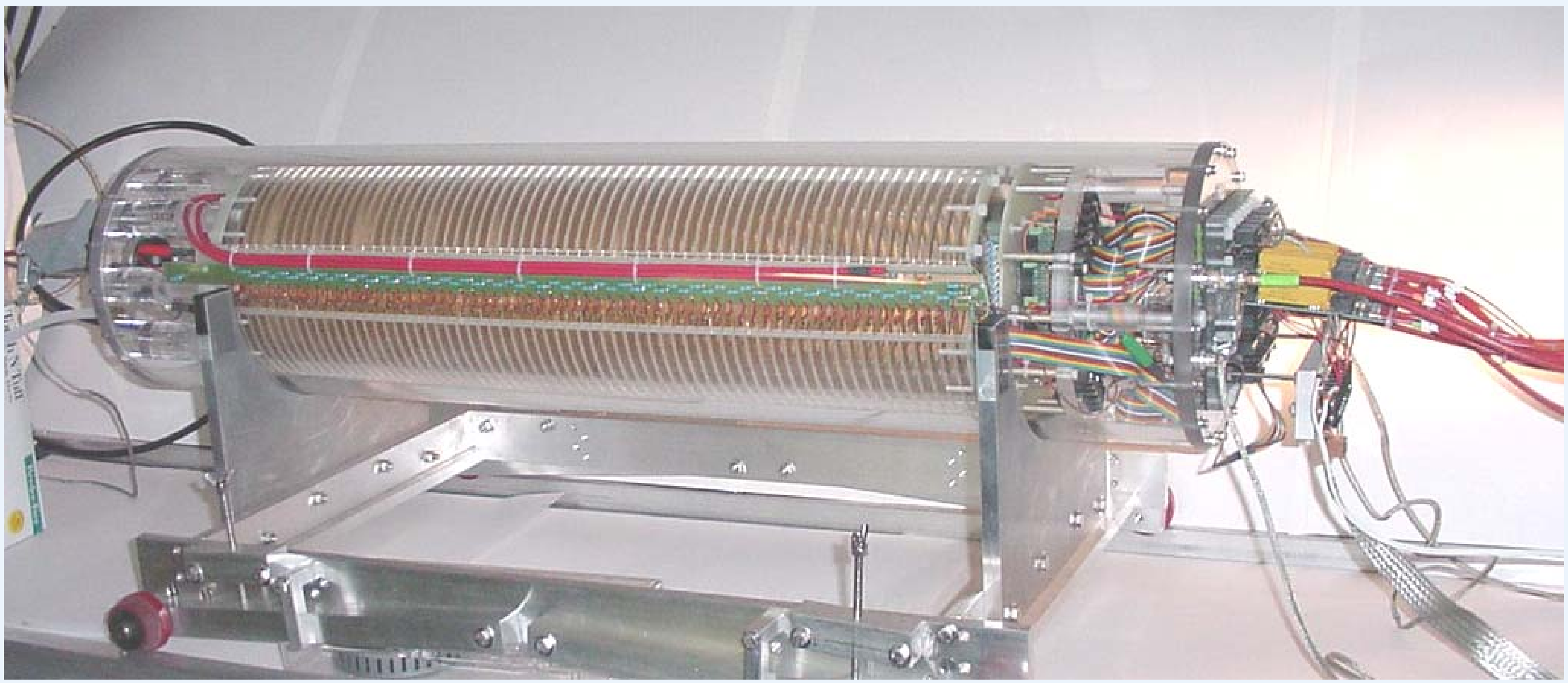
Small prototype program at Cornell

In collaboration with
Purdue University

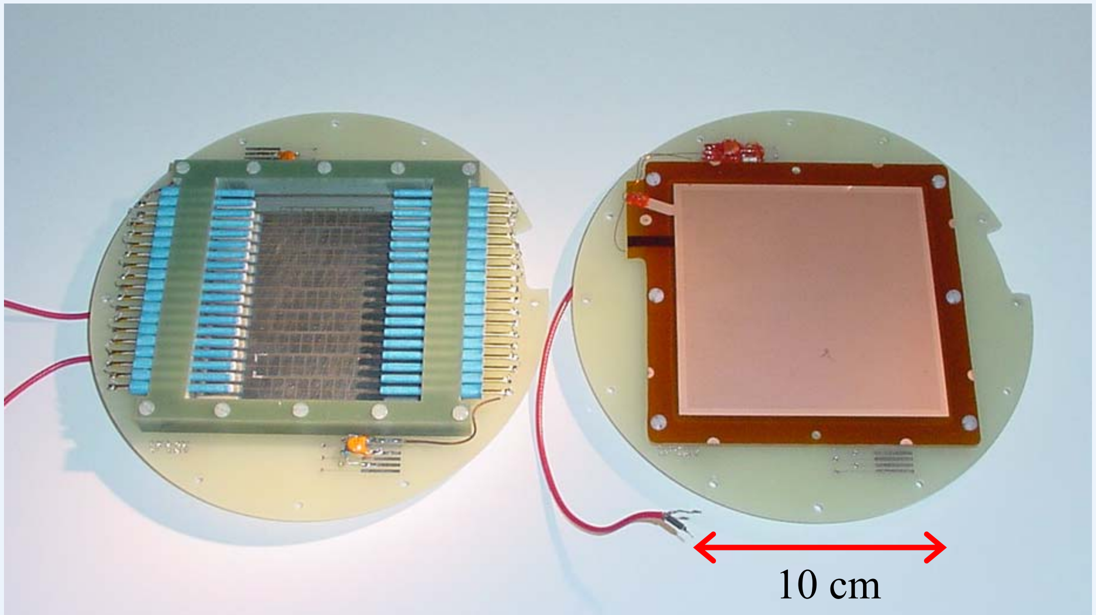
K. Arndt
G. Bolla
I. P. J. Shipsey

The construction is influenced by our research goal:
to compare the various amplification technologies
in a common environment.

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

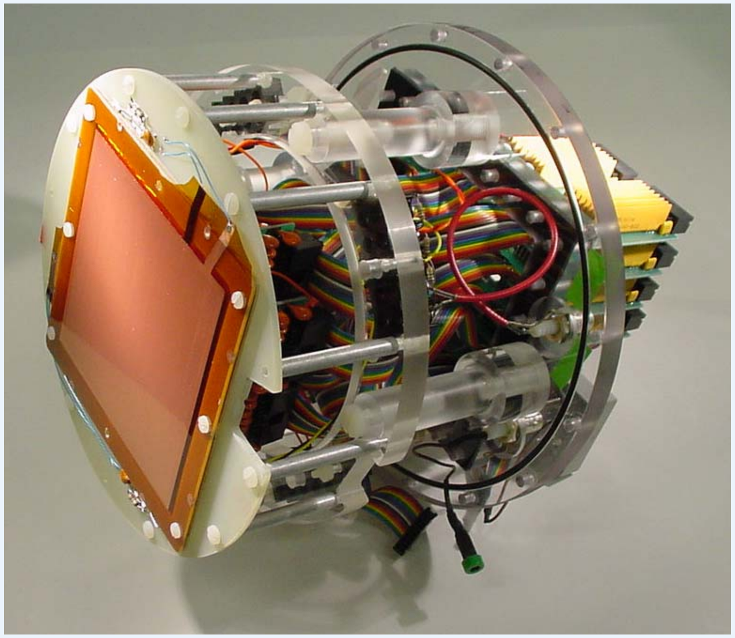


Small prototype program at Cornell



MWPC amplification mounted on a pad board
(5mm x 10mm pads)

single-GEM amplification mounted on a pad board
(5mm x 10mm pads)

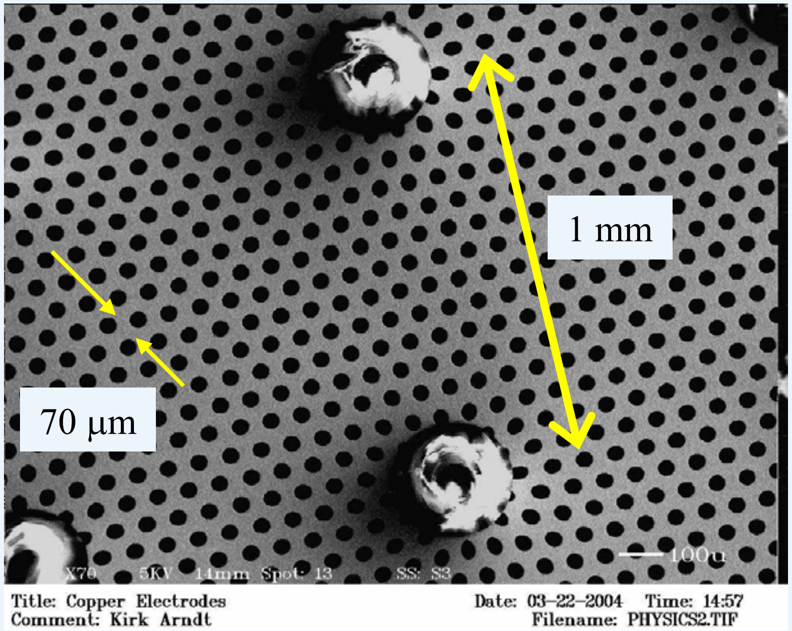


readout module including double-GEM amplification mounted on a pad board

2005 - Demonstration data, taken with 5 mm width pads and 32 channels of FADC readout
This is insufficient for resolution measurements.

2006 - With an increase to 56 channels, reconfigured pad layout with 2mm pads,
capable of comparative resolution measurements.

Small prototype program at Cornell

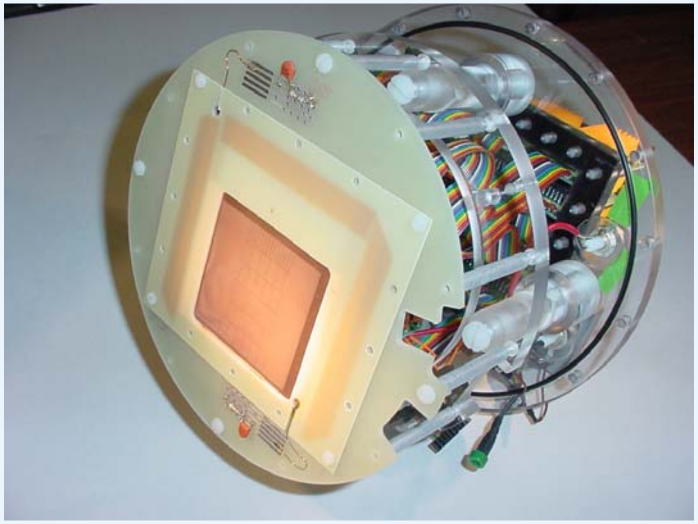


Layout including 2mm and 5mm pads

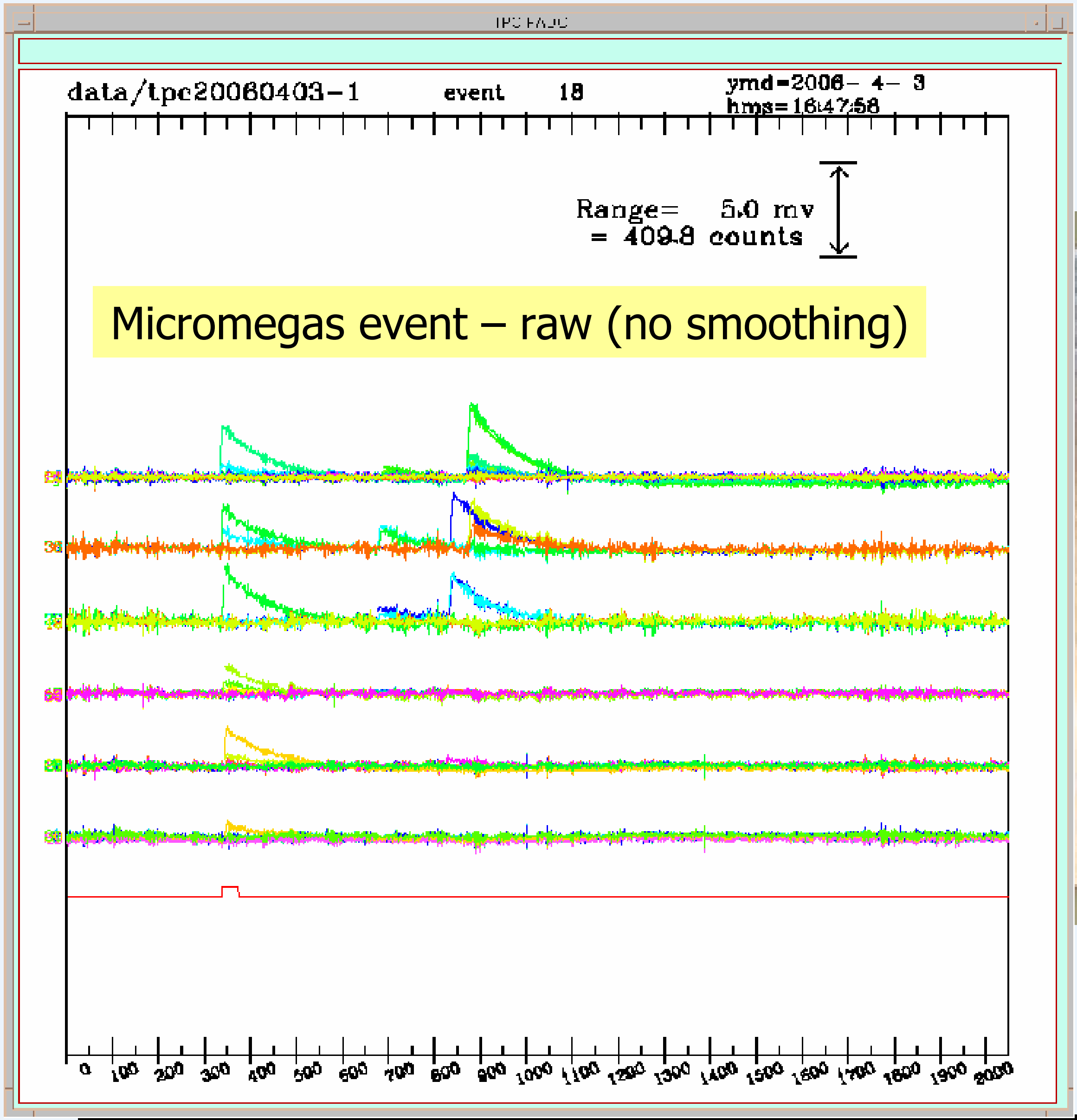
We have made the first measurements
in a TPC of the
mass-produced Purdue-3M Micromegas .

This is a perforated copper layer,
rather than the typical woven screen,
supported by Kapton pillars.

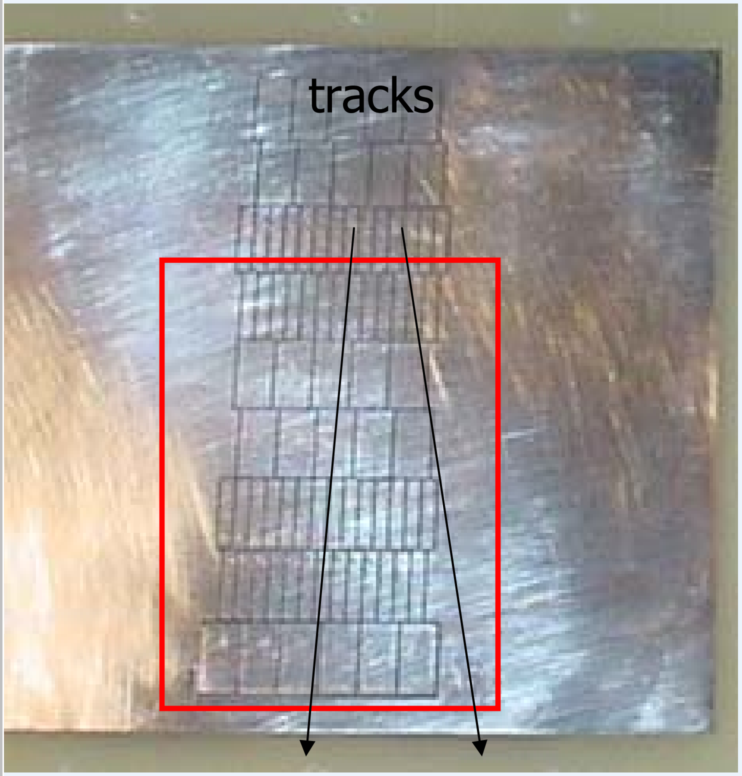
The device is etched from copper clad Kapton.



Small prototype program at Cornell



$ArCO_2$ (10%) , 300V/cm
Micromegas: 430V / 50 μm
Gas gain: ~ 300



25 MHz , 40 ns
2048 time buckets (81.92 μs)

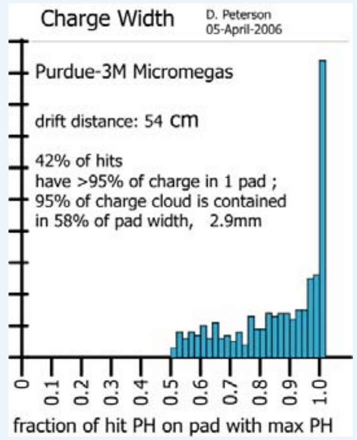
Small prototype program at Cornell

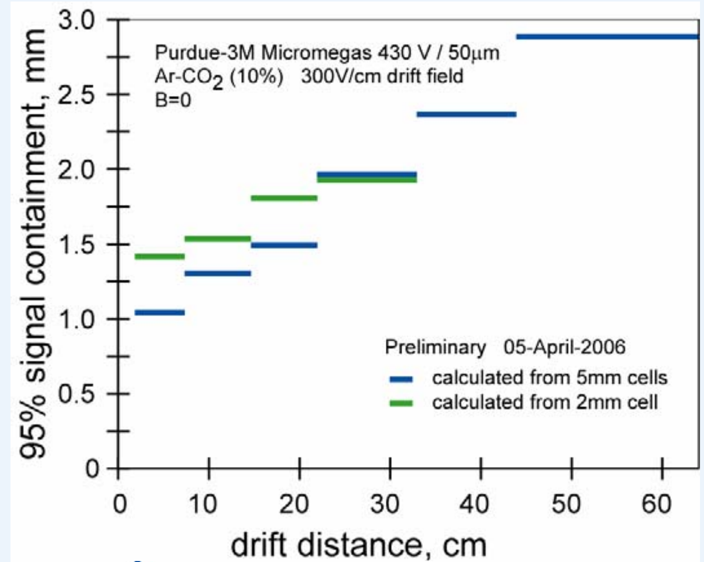
Presented at TPC workshop, Berkeley, 08-April, 2006

charge width
(or pad distribution function)
measurements are derived from the fraction of the pulse height on the central pad of a cluster.

It is significantly less than 2mm for small drift distance.

Width increase is expected from diffusion.

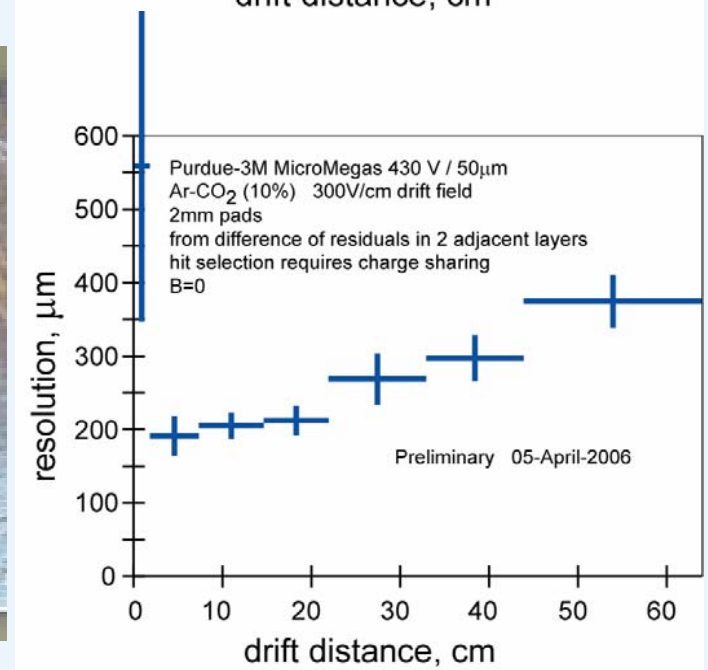




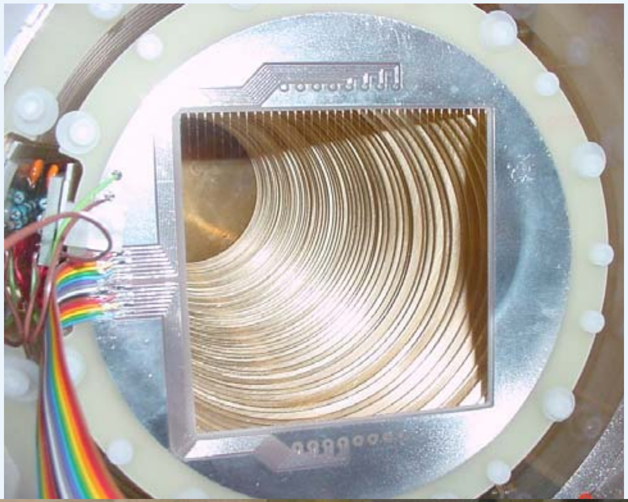
spatial resolution
measurements are derived from the RMS / √2 of the residual difference in the 2 adjacent rows (2mm pad width).

expect $\sigma = \sqrt{\sigma_0^2 + C_d^2/N * z}$
C_d (diffusion constant) = 230 μm/√cm
N = number of electrons

roughly, N=24, σ_0=150μm



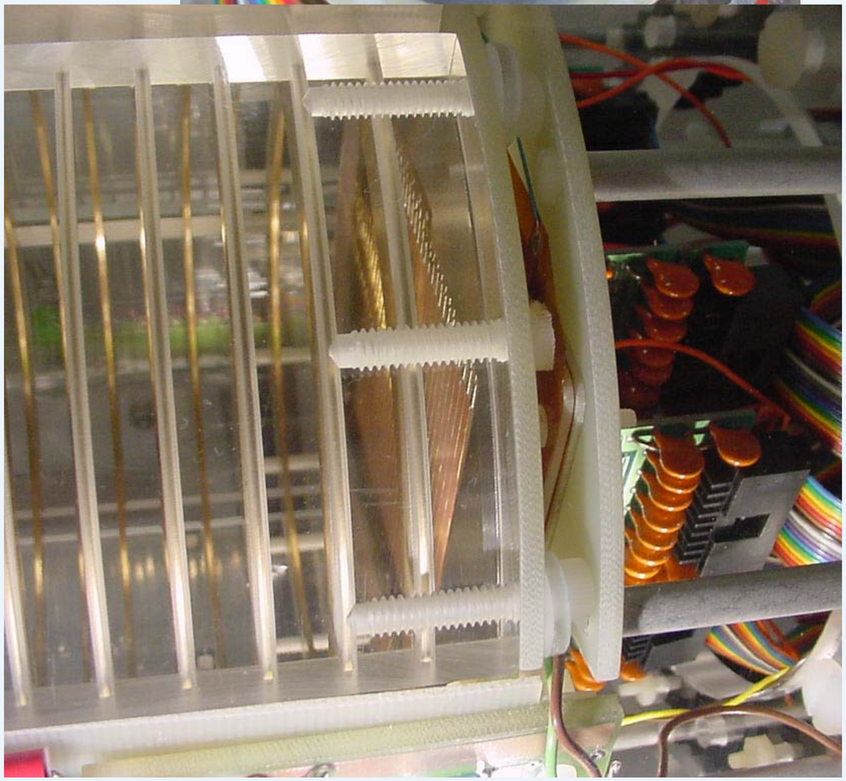
Small prototype program at Cornell



Future plans include comparative measurements of several amplification devices with common systematics.

1-GEM, 2-GEM, 3-GEM
Purdue-3M Micromegas
Saclay/CERN "bulk" Micromegas (col. with Saclay)
Carleton resistive charge dispersion (col. with Carleton)

We have a high dynamic range, low noise readout. After terminating an identified (last week) source, we will be capable of measuring with gas gains as low as 50.



Plans also include measurement of the **positive ion feedback (or back-drift),** positive ions created in the amplification that drift back into the field cage.

- Positive ions will be collected on the field cage termination

If ion feedback is not sufficiently suppressed, a gating grid will be required.

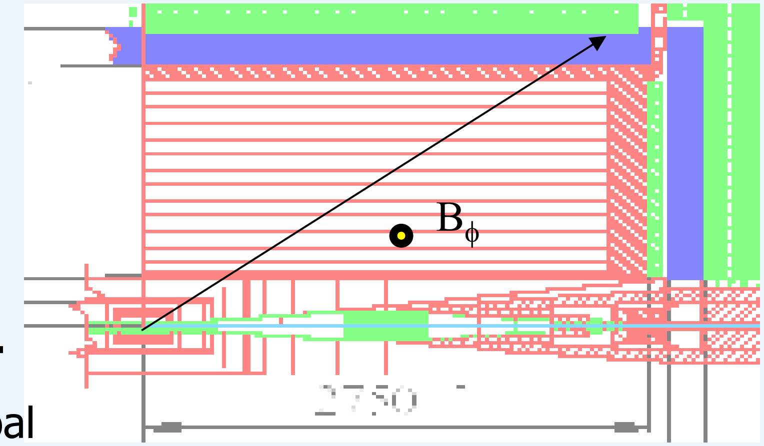
Contributions to the LDC (Large Detector Concept)

LDC draws on the Cornell tracking experience:

"LDC question TR_7", presented at Snowmass, 2005

DPP is responsible for the tracking performance section of the LDC Detector Outline Document

(which will contribute to the ILC Reference Design Report).



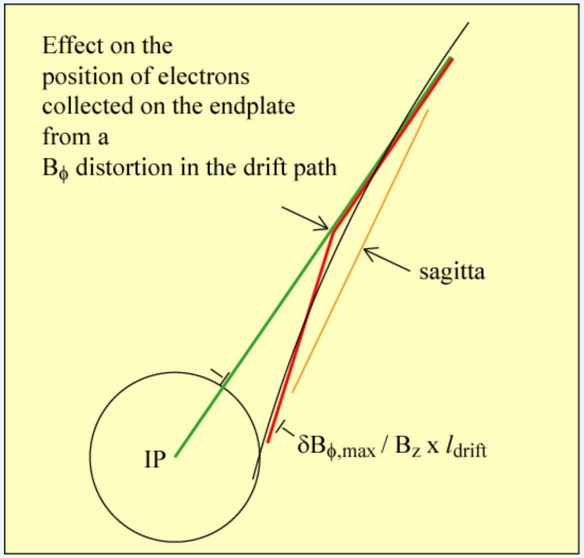
DPP was asked to consider and coordinate the questions regarding the effects of magnetic field distortions at Snowmass (2005).

Example conclusion: The system momentum resolution goal is equivalent to a limit on the sagitta error: $\delta s < 19 \times 10^{-6}$ m.

Magnetic field distortions affect both the track trajectory and the electron drift trajectory.

Certain plausible distortions lead to large errors in sagitta.

Limiting the effect of the distortions to a 5% degradation in the system momentum resolution leads to a required field mapping accuracy of $\delta B/B < 2 \times 10^{-5}$.



This is an order of magnitude better than Aleph and can not be achieved by sensor mapping alone.

LC-TPC Large Prototype Program

The LC-TPC group is designing a large prototype (82cm diameter)

to answer questions including readout technology,
tiling design, alignment, cooling, and tracking algorithms.

The program should be completed in 2009 to allow final design decisions in 2010.

EUDET funding will provide
- TPC field cage,
- magnet (from Japan),
- electronics,
- slow control,
- telescopes.

Success will require participation and funding from outside of EUDET membership.

1.5 Tesla, 90 cm bore, magnet

LC-TPC Large Prototype Program

Recognizing the Cornell group's experience in designing, constructing and calibrating gaseous tracking chambers for the CLEO experiment,
DPP was selected "convener" of the Large Prototype endplate design.

As presented at

Bangalore

and the April 2006 TPC workshop at Berkeley.

Work Packages and conveners for the LC TPC Large Prototype

1) Workpackage MECHANICS

Ron Settles

Work package / convener	Groups expressing interest to date(others?)
a) LP design (incl. endplate structure) Dan Peterson	Cornell, Desy, IPNOrsay, MPI, +contribution from Eudet
b) Fieldcage, laser, gas Ties Behnke	Aachen, Desy, St.Petersburg, +contribution from Eudet
c) GEM panels for endplate Akira Sugiyama	Aachen, Carleton, Cornell, Desy/HH, Karlsruhe, Kek/XCDC, Novosibirsk, Victoria
d) Micromegas panels for endplate Paul Colas	Carleton, Cornell, Kek/XCDC, Saclay/Orsay
e) Pixel panels for endplate Jan Timmermans	Cern,Freiburg,Nikhef,Saclay,Kek/XCDC, +contribution from Eudet
f) Resistive foil for endplate Madhu Dixit	Carleton, Kek/XCDC, Saclay/Orsay

LC-TPC Large Prototype Program

A subset of conveners met at Berkeley, 08-April, to discuss 00th designs.

The TPC endplate will necessarily be tiled with read-out modules because of the gas-amplification designs.

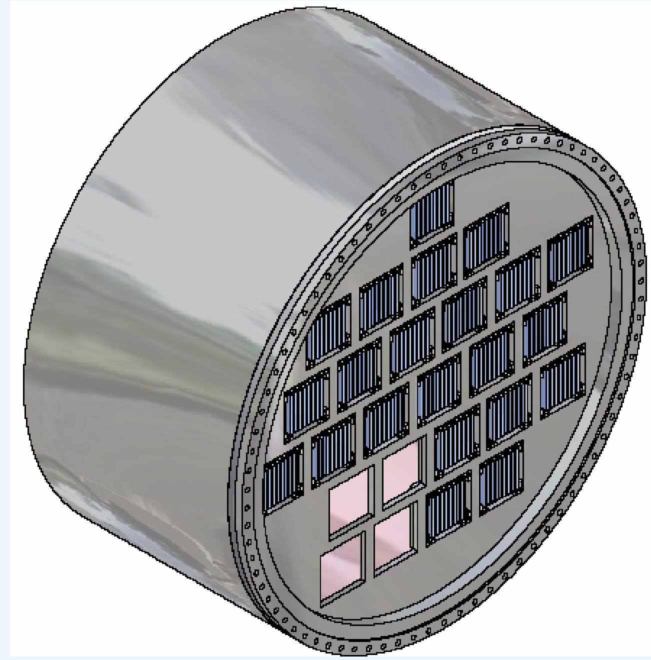
A goal is a coordinated module/endplate system providing optimal coverage and maintainability.

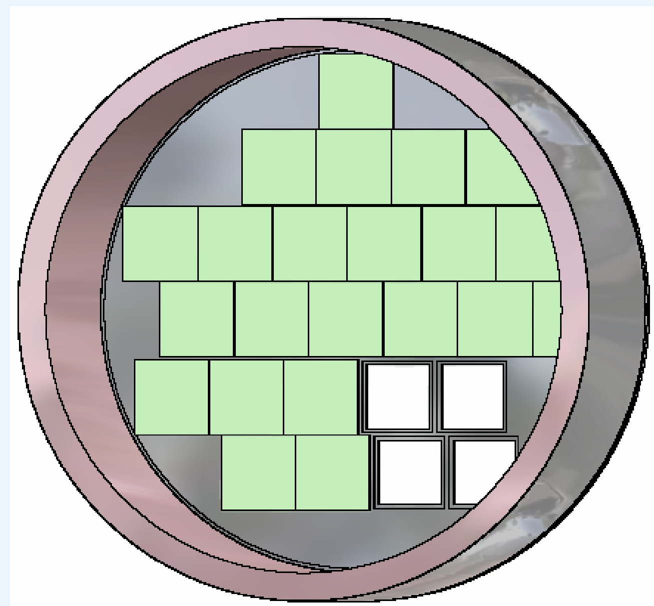
The large prototype should address the issues in the final detector of tolerance and stability.

The next design (0th) will include larger, curved panels to reproduce a section of final detector.

The design period will be about a year including machining/measurement studies of preliminary endplates.

Construction will follow in 2007.



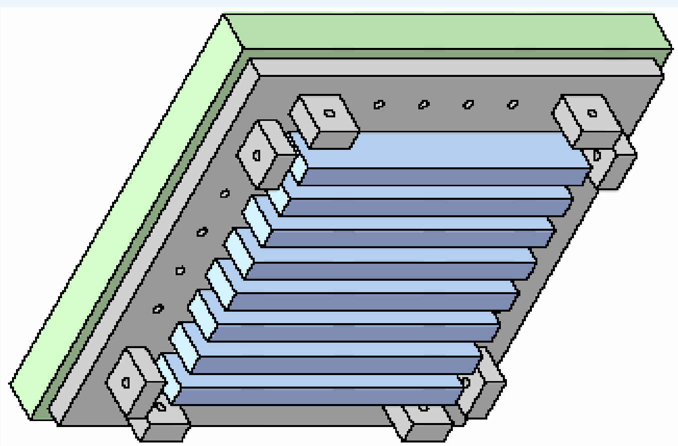


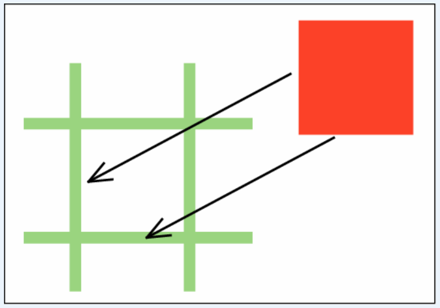
LC-TPC Large Prototype Program

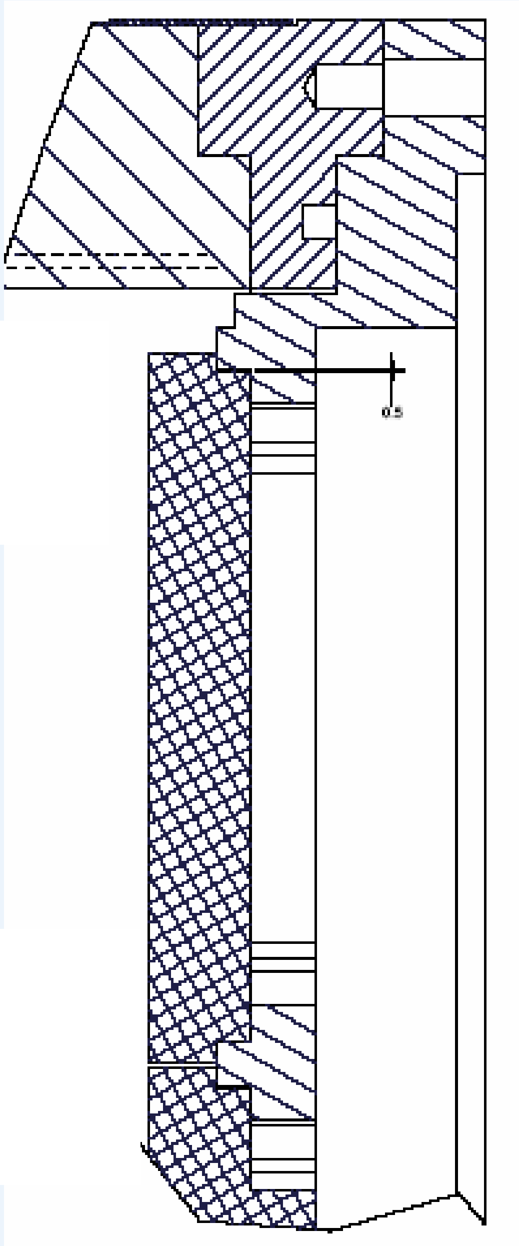
There are significant mechanical challenges due to the magnetic field requirements.

Modules must be positioned to an accuracy that does not degrade the spatial resolution, 100μm or 0.004 inch.

Thus, endplate tiles must be aligned and maintained to an accuracy of 20 μm, without the aid of tracks.
Tracks must be used to improve the magnetic field mapping.







Conclusion

Momentum resolution requirements lead to unprecedented spatial resolution.

Particle Flow Analysis demands unprecedented reconstruction efficiency.

Momentum resolution requirements demand significant improvements in the magnetic field and endplate positioning calibrations.

Cornell is integrally involved in the international LC-TPC and LDC programs.

1) Simulation of Digitized TPC Signals / Track Reconstruction
   Studies will be integrated into a framework and expanded.

2) Small Prototype Program at Cornell
   Future studies will include comparisons of amplification devices and ion feedback.

3) Contributions to the LDC (Large Detector Concept)

4) Large Prototype Program
   Endplates and readout modules will be designed in 2006.