Development of a TPC for the ILC

Dan Peterson - Cornell University

ILC – the International Linear Collider

Experimental Goals (as they relate to tracking)

The Detector Concepts

Time Projection Chamber (TPC), and meeting the experimental goals

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

TPC R&D, international program

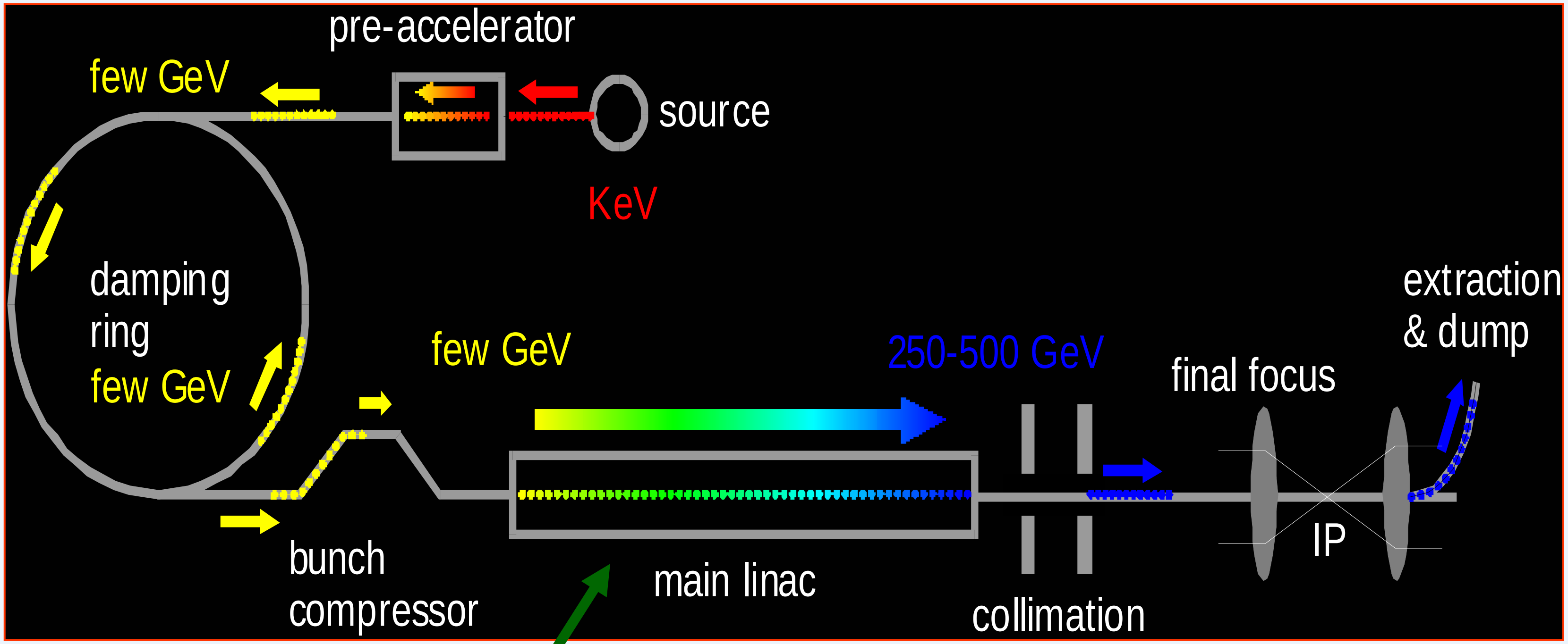
Cornell/Purdue program

Ion Feedback

Towards the Large Prototype

ILC – International Linear Collider

from Barry Barish, Snowmass, Aug 2005



Superconducting RF Main Linac

ILC – International Linear Collider

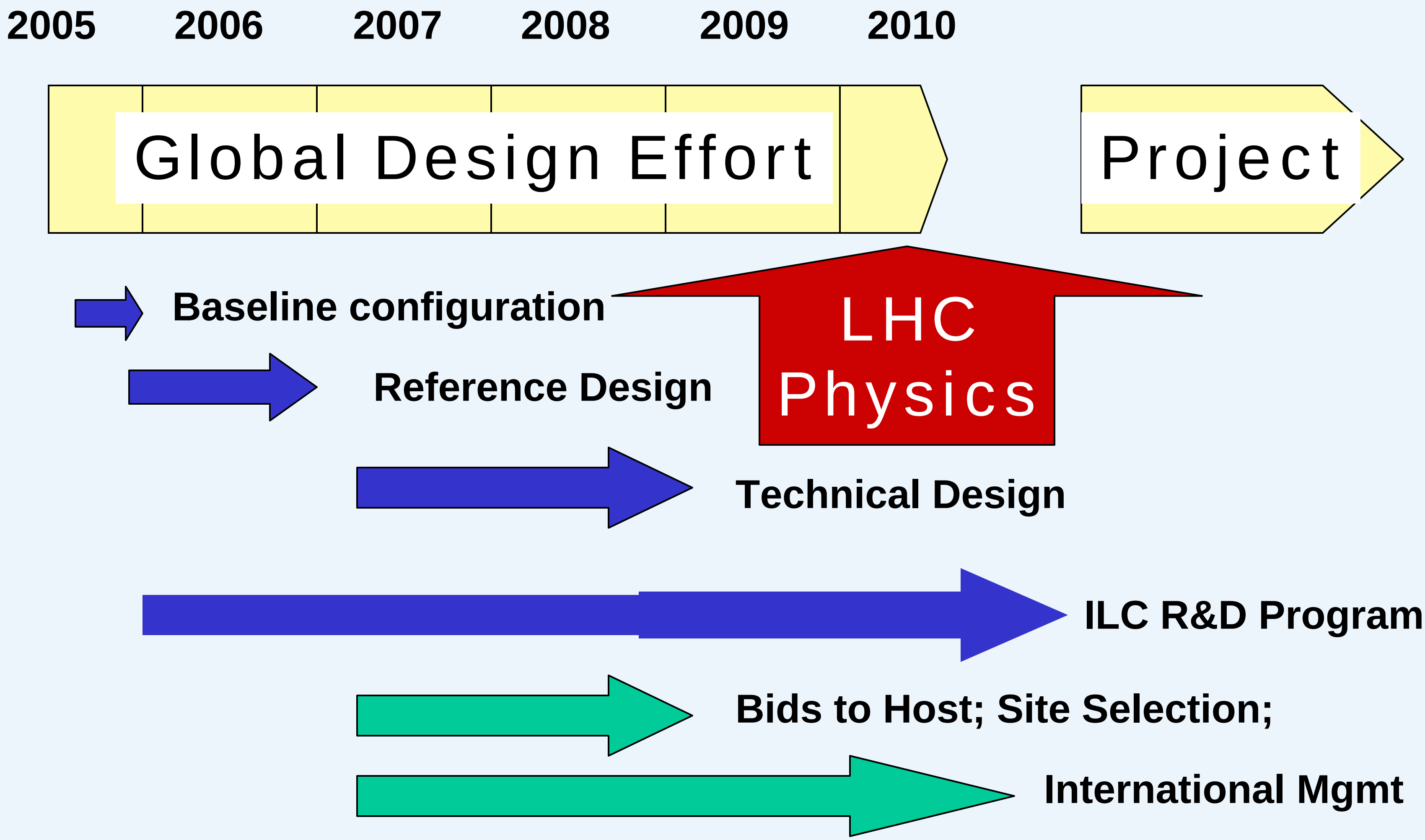
from Barry Barish, Snowmass, Aug 2005

- E_{cm} adjustable from 200 – 500 GeV
- Luminosity → $\int L dt$ = 500 fb^{-1} in 4 years
- Ability to scan between 200 and 500 GeV
- Energy stability and precision below 0.1%
- Electron polarization of at least 80%

- The machine must be upgradeable to 1 TeV

ILC – International Linear Collider

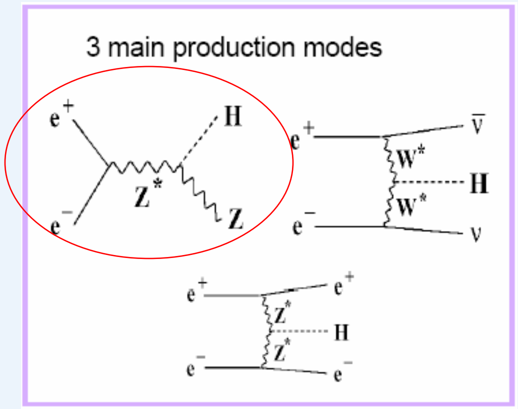
from Barry Barish, Snowmass, Aug 2005



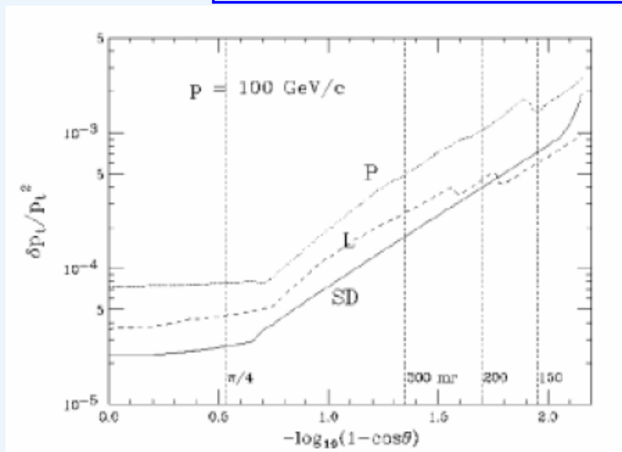
Experimental Goals (as they relate to tracking)

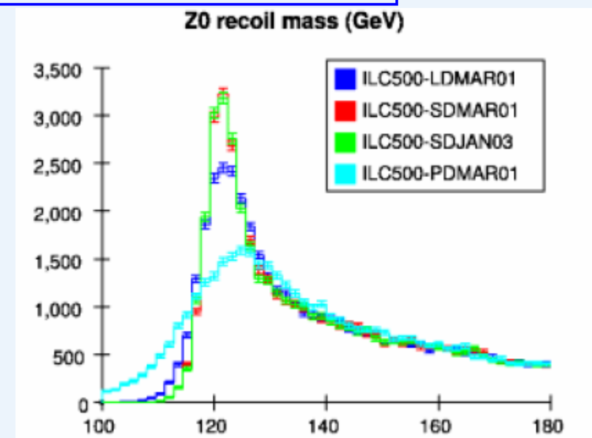
Momentum resolution:

from Yamashita, Snowmass (Higgs session), Aug 2005



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





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

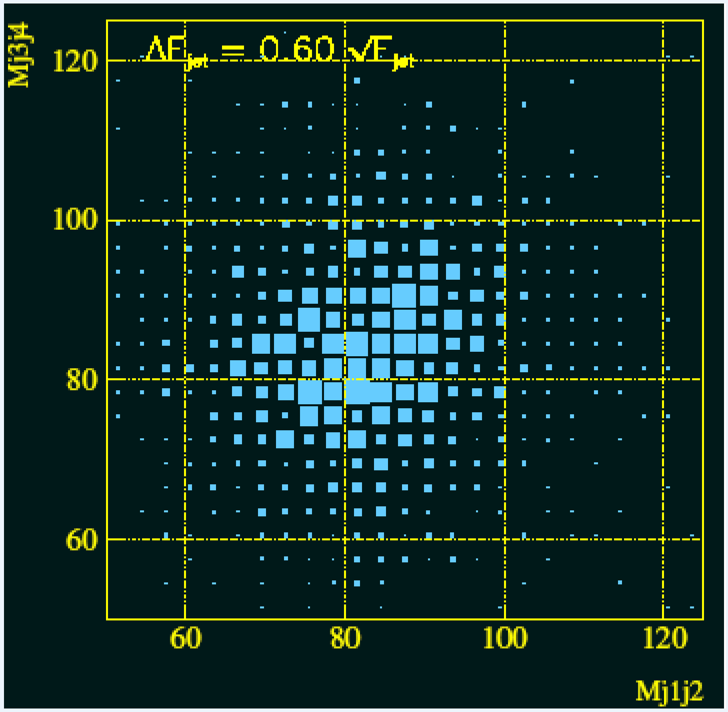
$\delta P_t / P_t^2 = 2 \times 10^{-5}$ /GeV recoil mass resolution is dominated by other effects

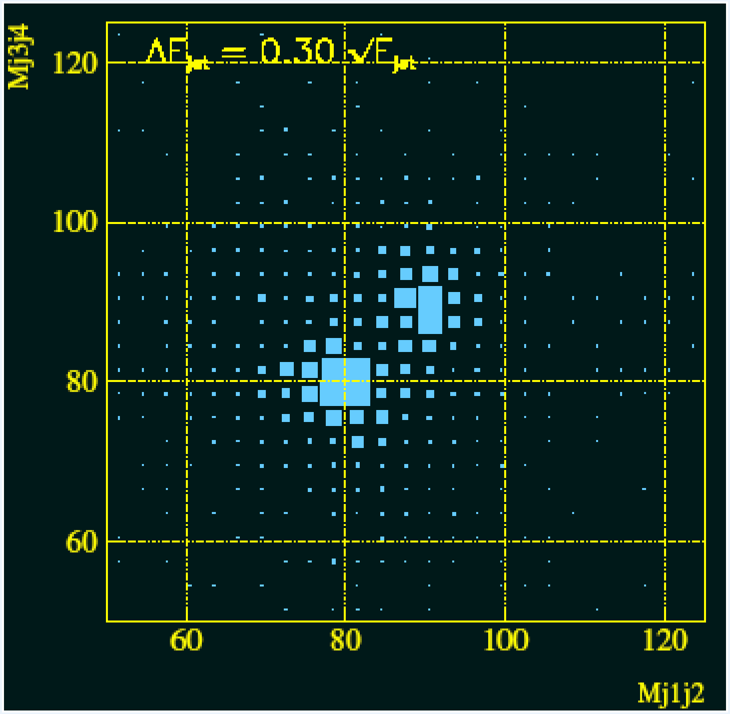
$\delta P_t / P_t^2 = 4 \times 10^{-5}$ /GeV recoil mass resolution is starting deteriorate

$\delta P_t / P_t^2 = 7 \times 10^{-5}$ /GeV recoil mass resolution is dominated by momentum resolution

Experimental Goals (as they relate to tracking)

Jet energy resolution:





from Klaus Mönig, Vienna, Nov 2005

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

The requires a jet energy resolution of about $\delta E/E = 30\% / E^{1/2}$

Experimental Goals (as they relate to tracking)

Measuring the jet energy

Classical method: Calorimetry

typical event:

30% electromagnetic,
70% hadronic energy

typical resolution:

10% / $E^{1/2}$ for ECAL
50% / $E^{1/2}$ for HCAL
→ $\delta E/E > 45\% / E^{1/2}$ for jets

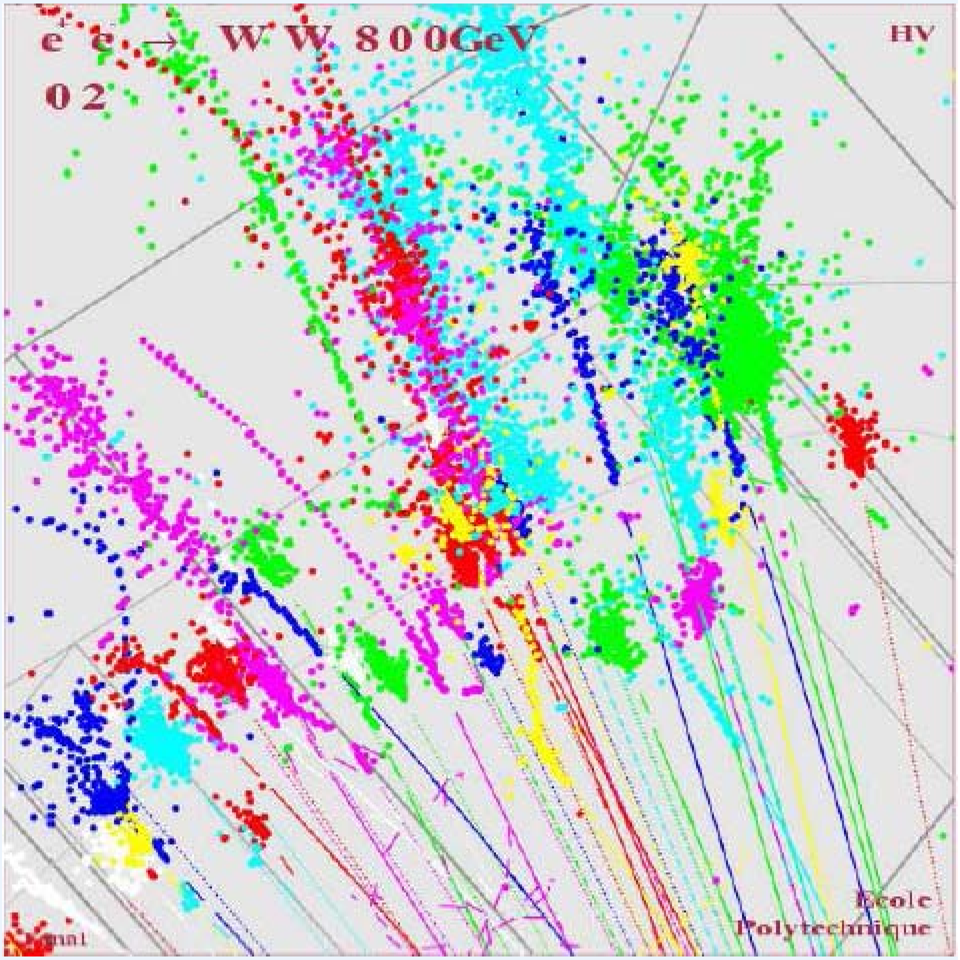
The particle flow method (PFA)

typical event:

60% charged tracks,
30% electromagnetic,
10% neutral hadronic energy

(tracking resolution negligible on this scale)

→ $\delta E/E = 20\% / E^{1/2}$ for jets
is achievable, in principle

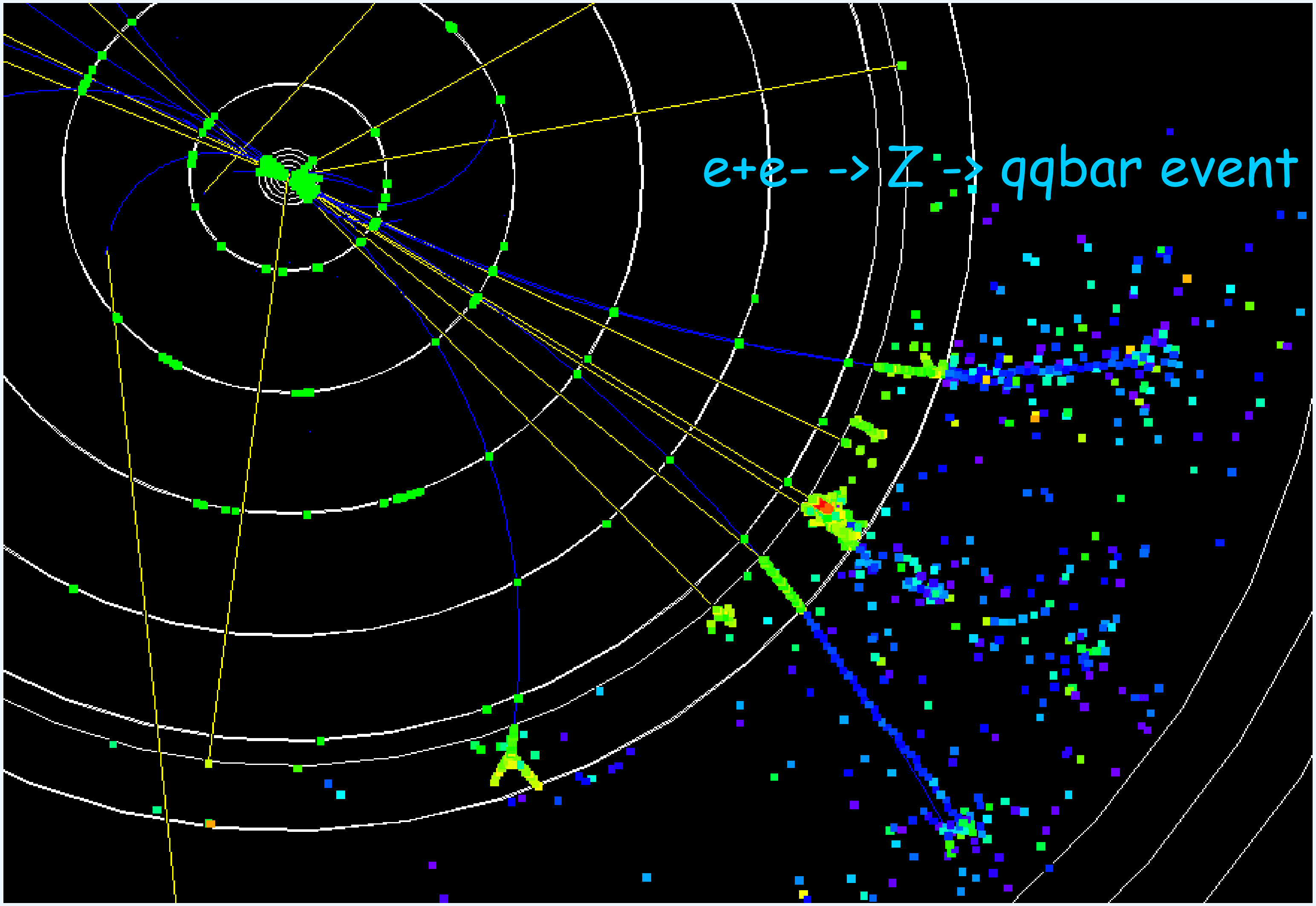


from Klaus Mönig, Vienna, Nov 2005

Full reconstruction with PFA

from Steve Magill, Snowmass, Aug 2005

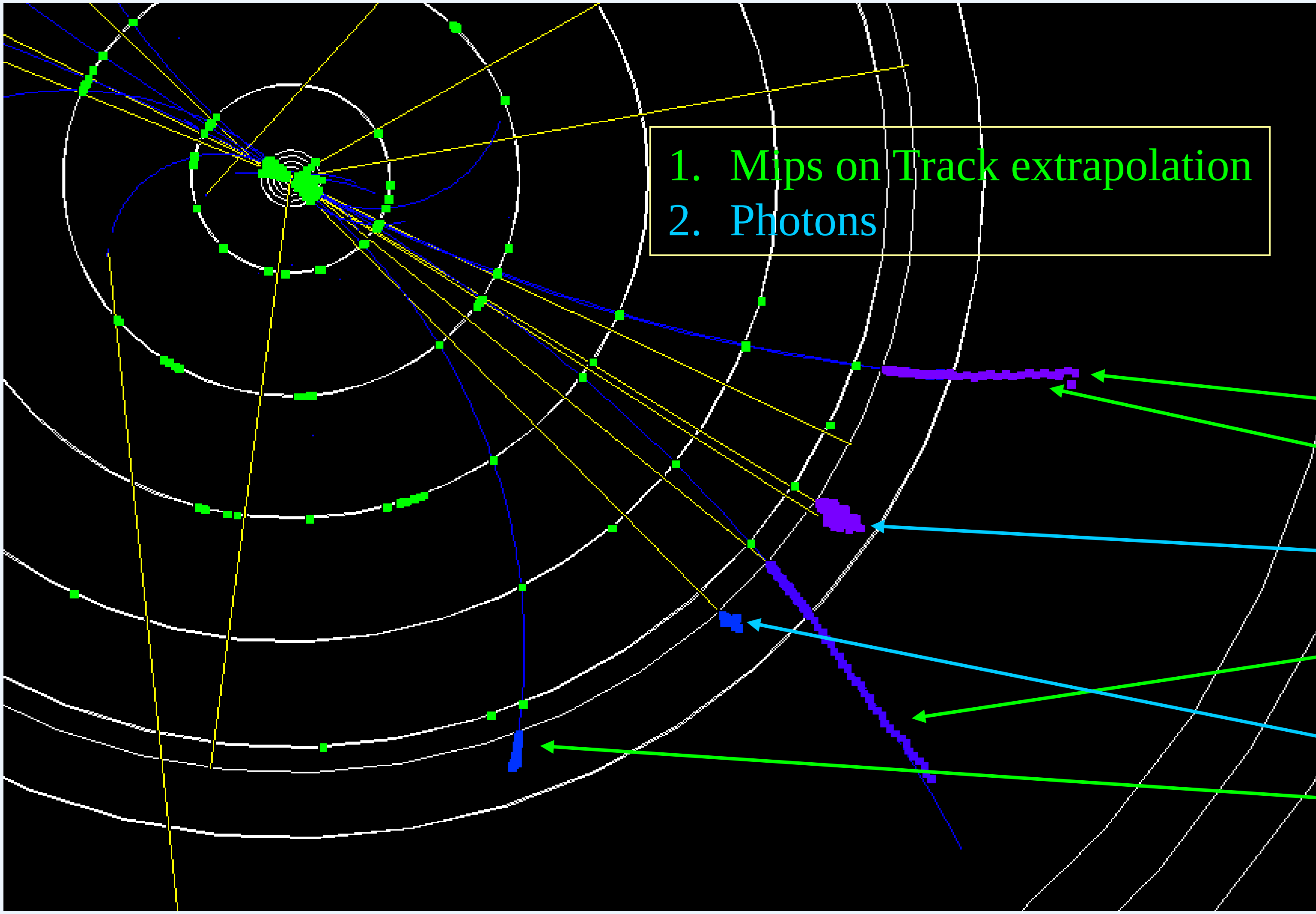
Calorimeters :
ECAL – W/Si
HCAL – W/Scintillator



66 MeV γ
6 GeV π-
5 GeV π-
131 MeV γ
12 GeV γ
12 GeV K_L^0
5 GeV π+
2 GeV n
400 MeV γ
2 GeV π+
40 MeV γ

Full reconstruction with PFA

from Steve Magill, Snowmass, Aug 2005



66 MeV γ
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2 GeV n
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Full reconstruction with PFA

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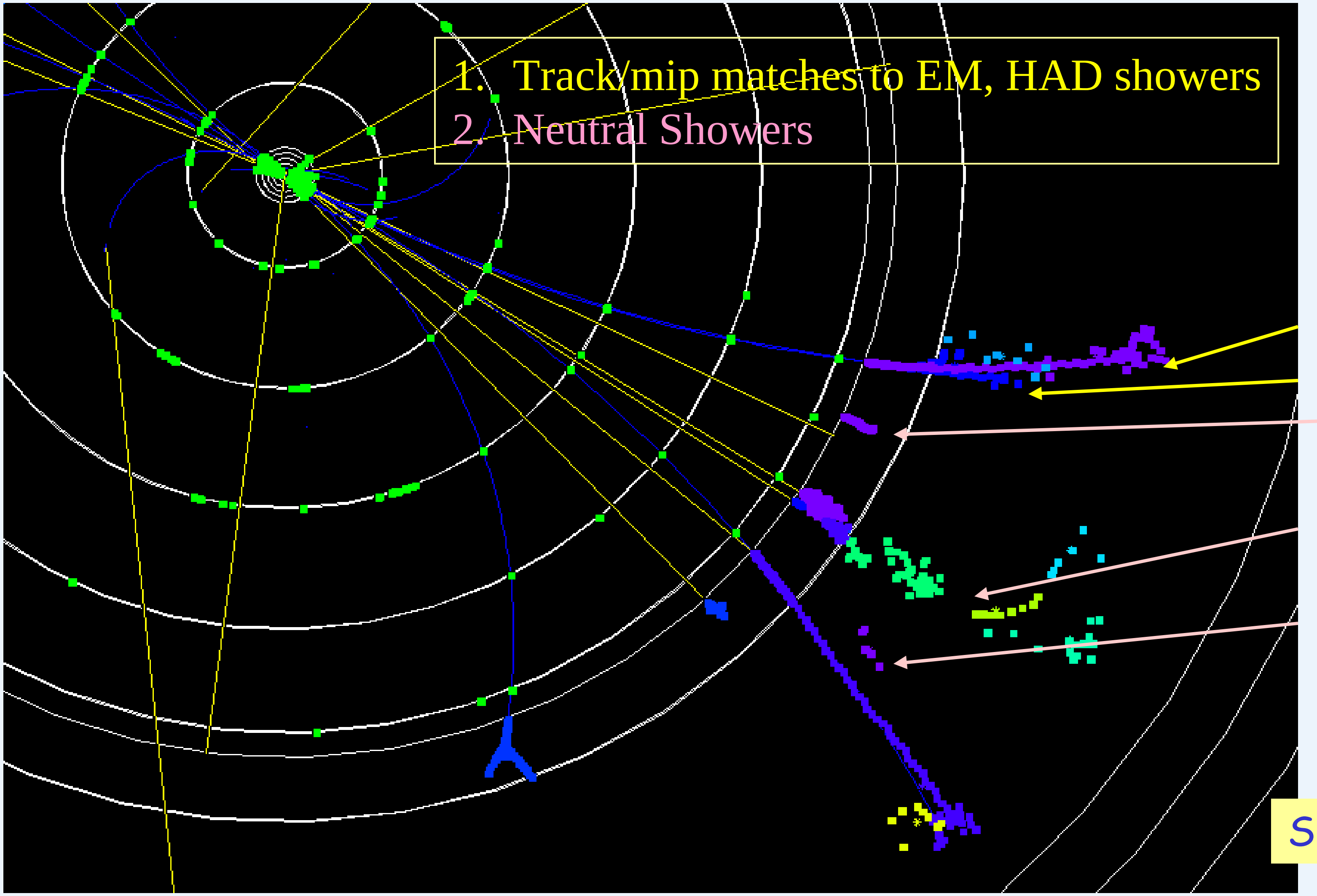
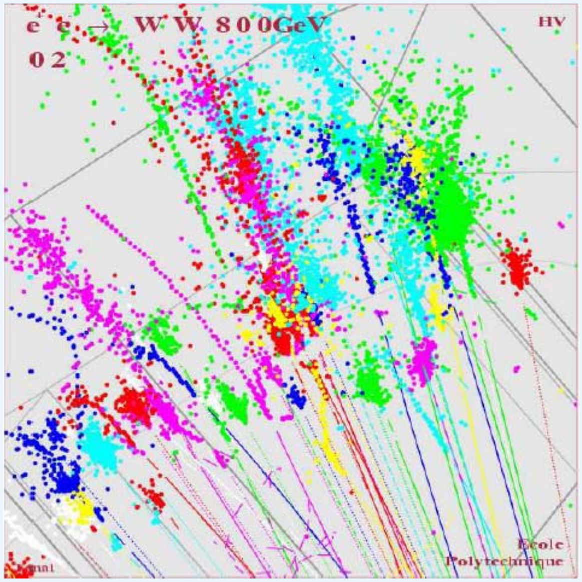


66 MeV γ
6 GeV π-
5 GeV π-
131 MeV γ
12 GeV γ
12 GeV K_L^0
5 GeV π+
2 GeV n
400 MeV γ
2 GeV π+
40 MeV γ

Sum ~45 GeV

Experimental Goals (as they relate to tracking)

Particle Flow Analysis:

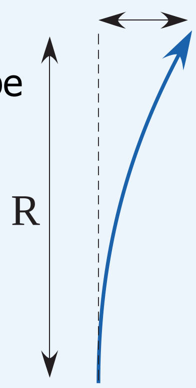


The main limitation is tracking confusion.

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:

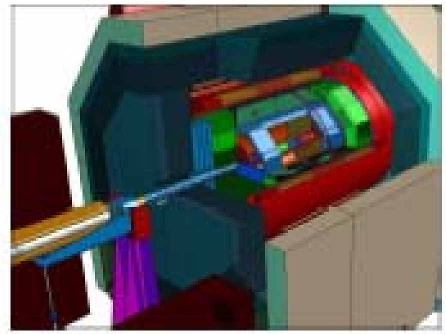
$\delta P_t / P_t^2 = 3 \times 10^{-5}$ /GeV ;

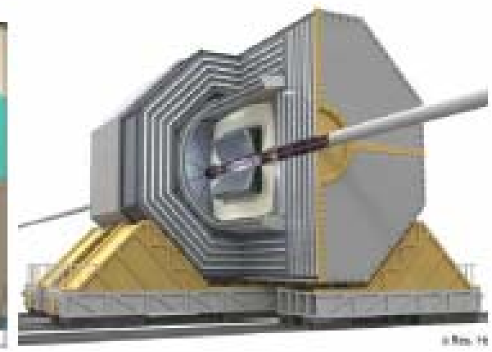
δ(sagitta) = 12 μm (for a 1.6 m radius, 4 Tesla)

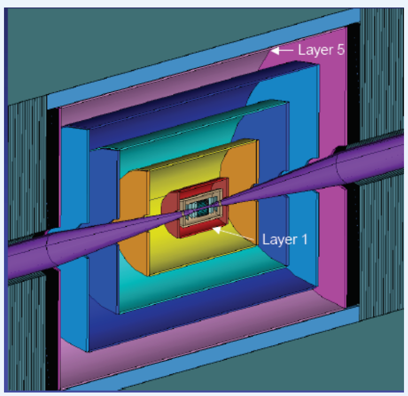
Tracking systems of the 3 detector "concepts"

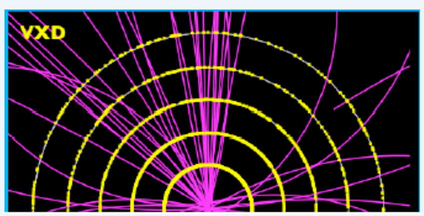
3 detector "concepts"

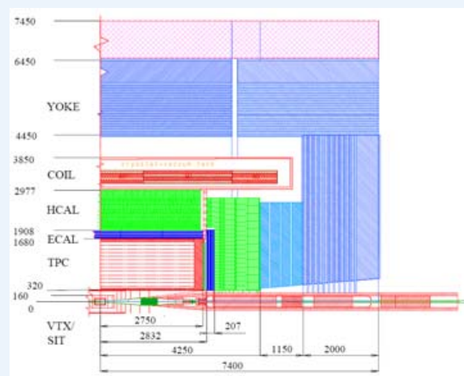
SiD , LDC, GLD

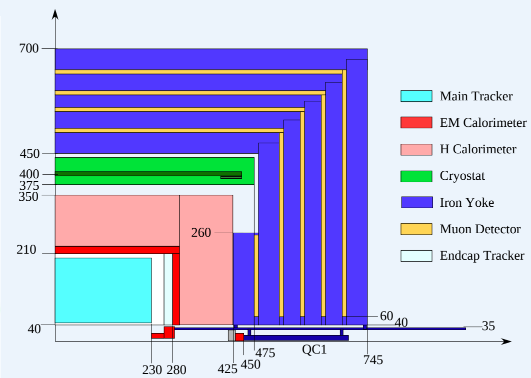












SiD

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

pat.rec
is done with
the vertexer

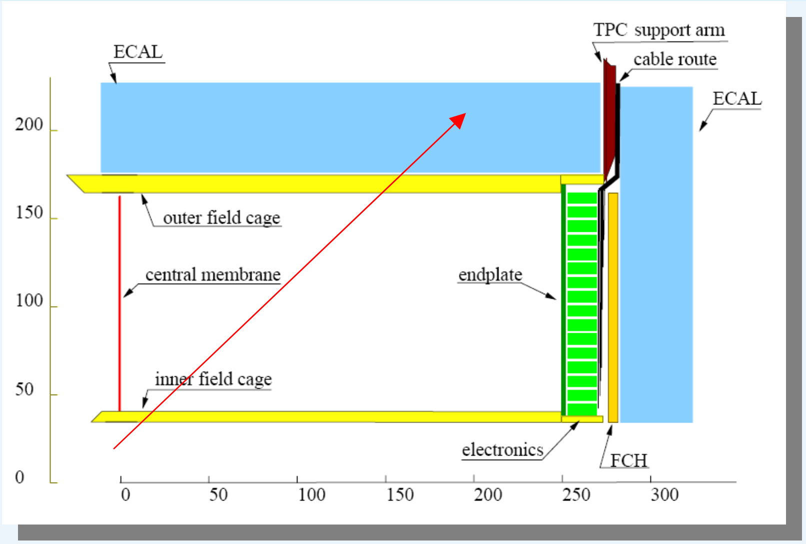
LDC

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

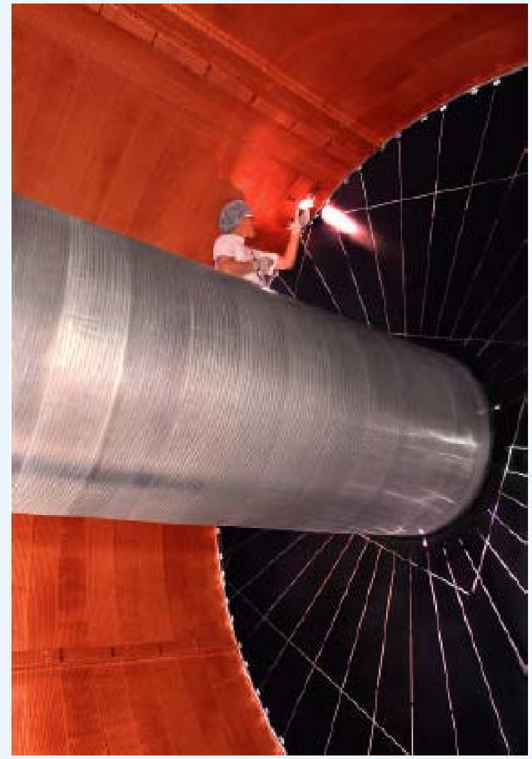
GLD

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

Time Projection Chamber: TPC



from Dean Karlen, Snowmass, Aug 2005, LDC



from Jim Thomas, 2001 Vienna, STAR

track goes through

gas is ionized

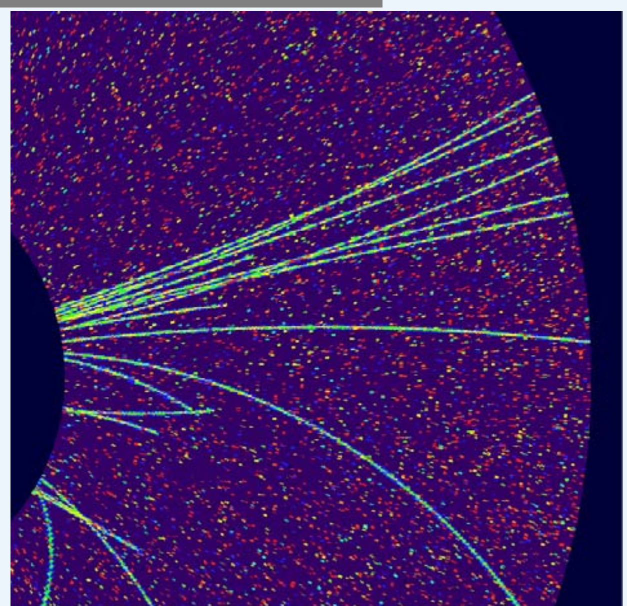
electrons drift ~2 m

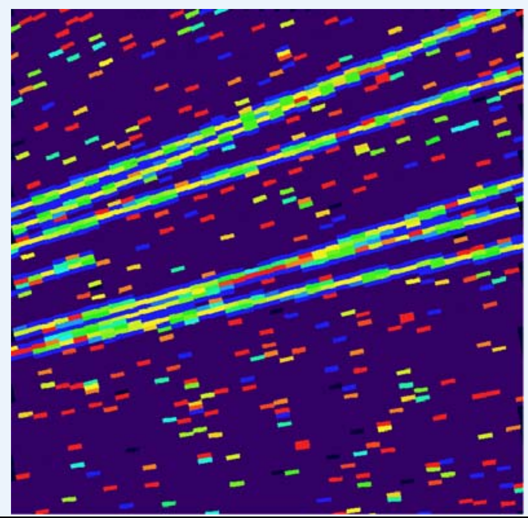
gas-amplification device

signals on pads

drift time: z coordinate

find tracks





Understanding the momentum resolution requirement

$\delta(1/R)=\sigma/L^2 \left(720/(N+4)\right)^{.5}$

"L" is the measured track length

"σ" is the measurement error

PHYSICS GOAL:

$\delta(1/P_t)=3 \times 10^{-5}$ / GeV

$R=P_t$ / (.3 GeV/Tesla B)

Pinning the fit at the IP improves resolution by ~ 2/3

$$\delta(1/P_t)=\frac{\sigma/L^2 \left(720/(N+4)\right)^{.5}}{(.3 \text{ GeV/Tesla } B)}$$

use measurement length:

L = 2 meters (GLD)

use N = 100

σ/B = 20 micron/Tesla, or

σ = 60 micron resolution, with B = 3 Tesla (GLD)

Meeting the momentum resolution requirement

$\delta(1/P_t)$= goal is difficult with
tracking chamber
and vertex detector alone.

Try an intermediate silicon device,

R=.45 meter, $S_{r\phi}$ = 10μm, N=2

tracker 100 μm → $\delta(1/P_t)$= 5.0 x 10^{-5} /GeV
with VD only, no int. tracker (consistent with previous slide)

The TPC based concepts can achieve the resolution goal !!

tracker 100 μm → $\delta(1/P_t)$= 3.5 x 10^{-5} /GeV
with VD and int. tracker

tracker 150 μm → $\delta(1/P_t)$= 4.2 x 10^{-5} /GeV
with VD and int. tracker

* Results from Dan's fast MC

tracker 150 μm → $\delta(1/P_t)$= 6.0 x 10^{-5} /GeV
with VD and int. tracker (misaligned by 25 μm, 1 mil)

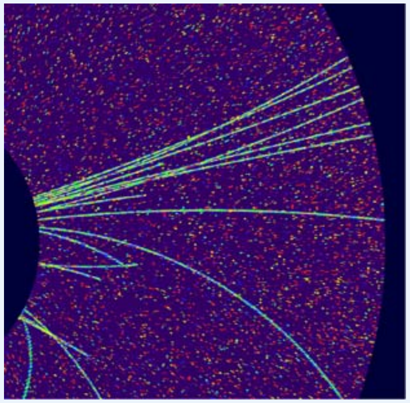
The track reconstruction efficiency goal

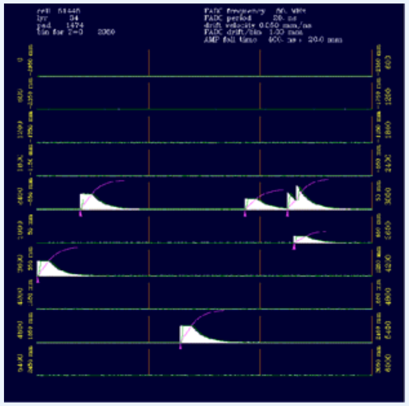
Reconstruction efficiency is required for the Jet energy measurement.

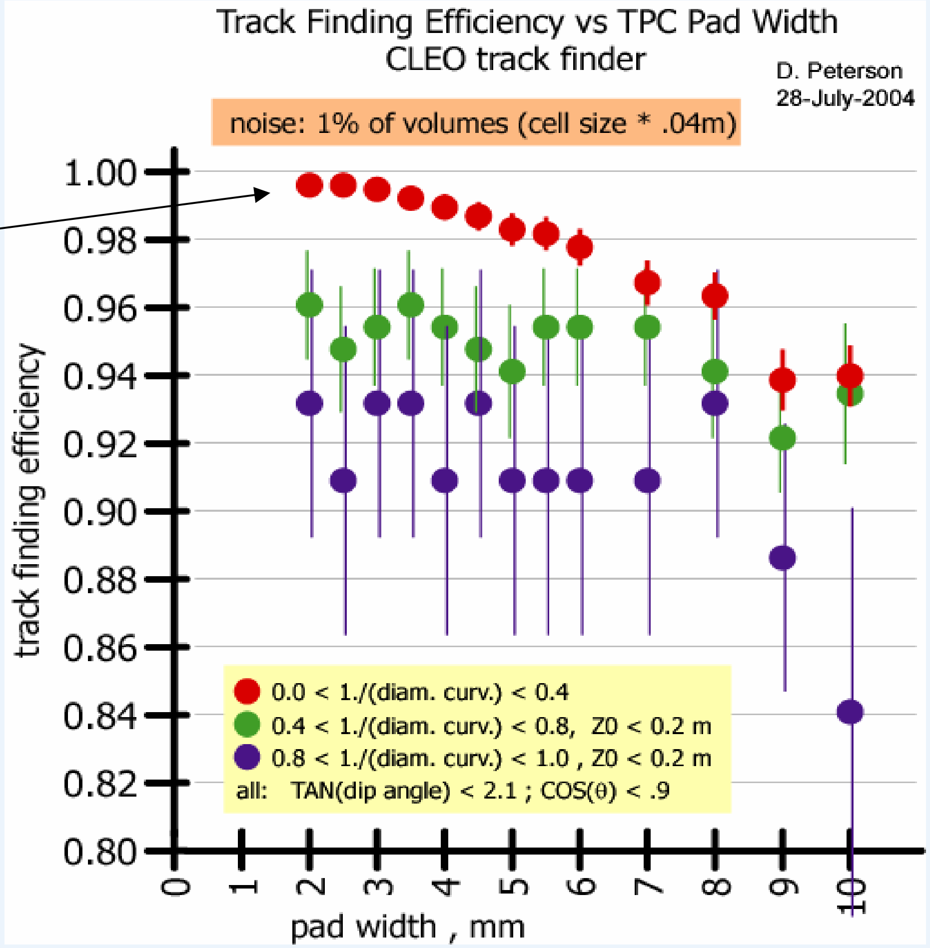
At what granularity will the TPC provide full efficiency in jet events?

Efficiency is measured with
a full simulation, including
a FADC analysis on each channel.

(HZ events, 1.9 m radius, 3 Tesla)





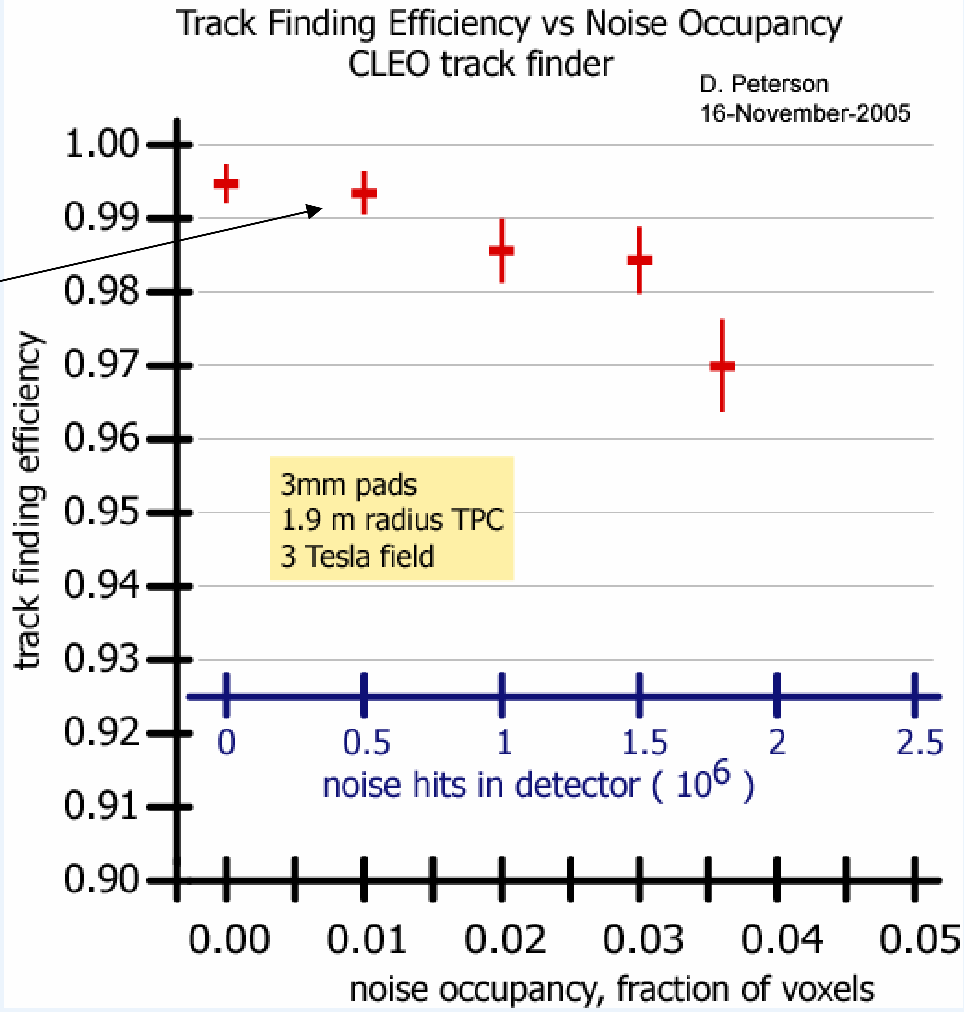


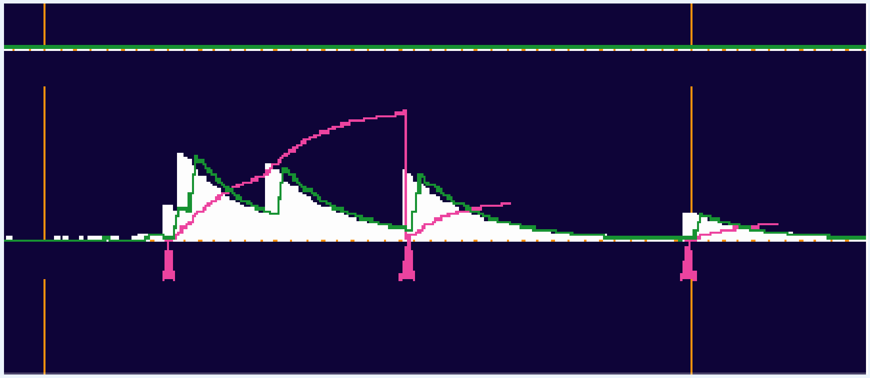
The track reconstruction efficiency goal

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.

With x 4 noise, the efficiency is 97%.
(20% of hits are "touched" by noise.)





Resolution and efficiency goal conclusion

A TPC is a good candidate to meet the tracking goals of the ILC.

Resolution: $\delta(1/p) = 3.5 \times 10^{-5}$ /GeV

GLD 1.9 m radius TPC, 3 Tesla, 10μm VD, 10μm intermediate tracker

LCD or 1.6 m radius TPC, 4 Tesla, + VD and intermediate tracker

Reconstruction Efficiency: 99.5 % (and fake rate = ?)

1.9 m radius TPC, 3 Tesla, 3mm x 10mm cells (400K cells/side)

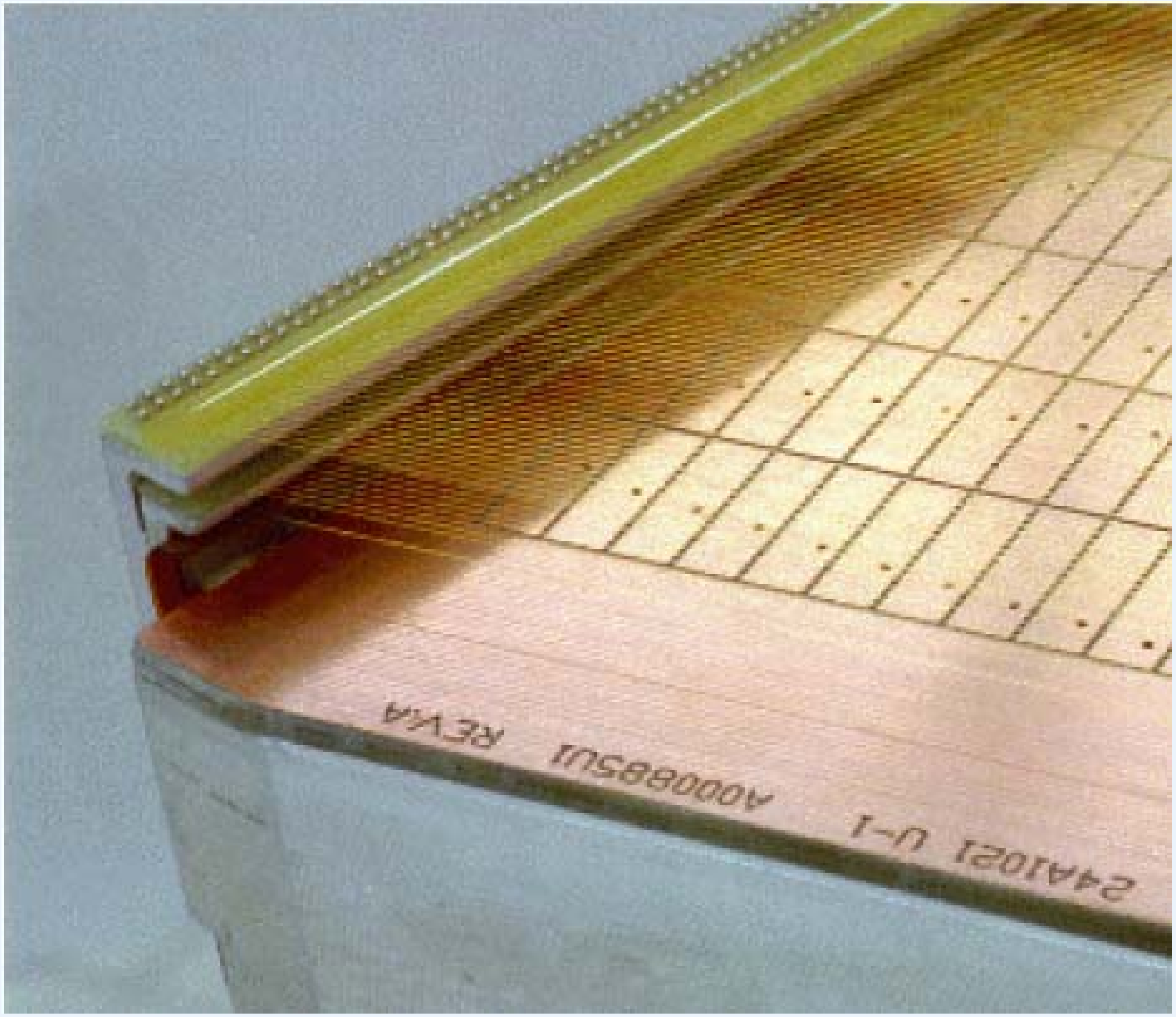
1.6 m radius TPC, 4 Tesla, 2.5mm x 8mm cells (400K cells/side)

Are we ready to build this device ? **NO**

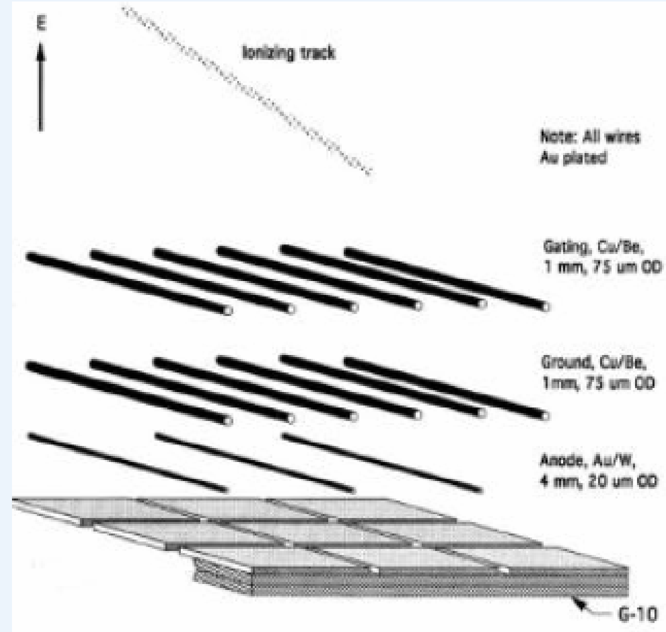
There are limitations to the segmentation and resolution of current technology (MWPC gas-amplification) TPCs.

This leads to the international program for a Micro-Pattern-Gas-Detector gas-amplification TPC (the rest of the talk).

MWPC gas amplification TPCs



from Jim Thomas, 2001 Vienna, The STAR TPC



There are 3 layers of wires:
gating grid (more about that later).
ground, and the **anode**

The pad size shown is 6mm.
(This chamber has 2.85 mm pads.)

The avalanche is at the anode wire, resulting in an induced (1/r) pad response.
The response width (~ 1cm) is determined by the wire spacing.

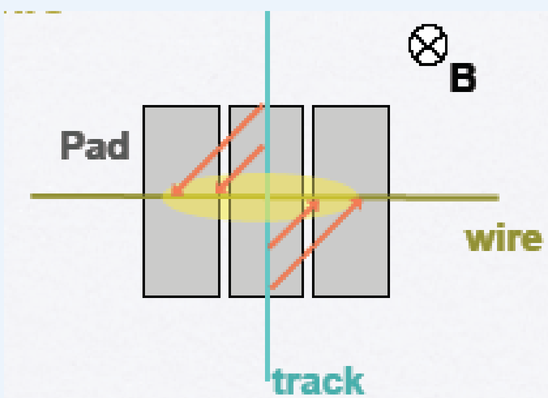
ExB effect in MWPC TPCs

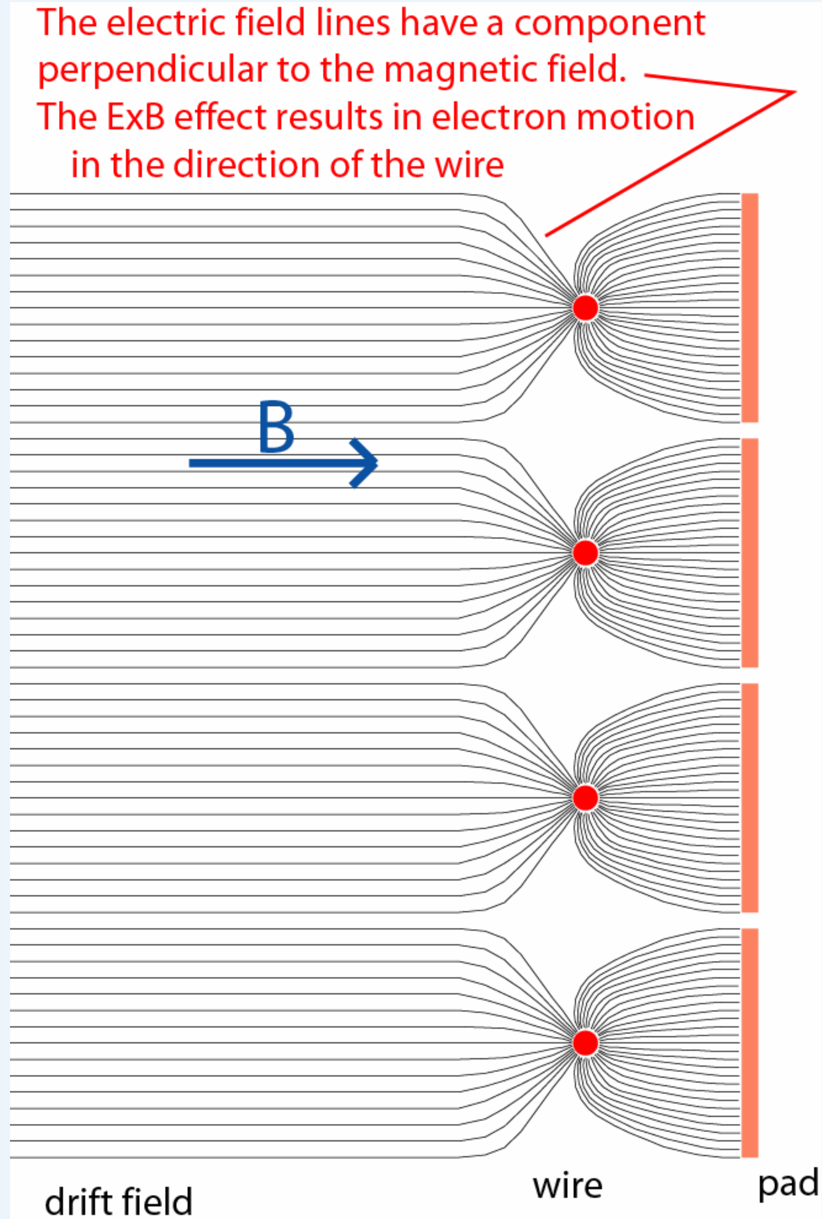
The inductive pad response function
is not the end of the problems.

The TPC is operated in a magnetic field.

The ExB effect
further broadens the charge distribution
at the wire.

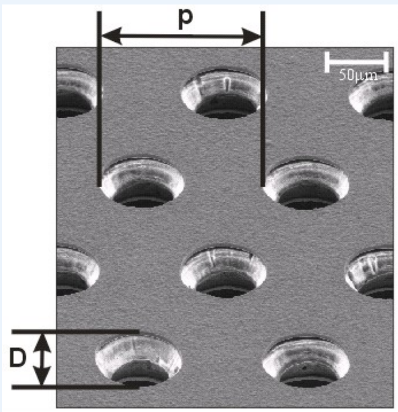
With MWPC gas-amplification, we
will not achieve the required segmentation.





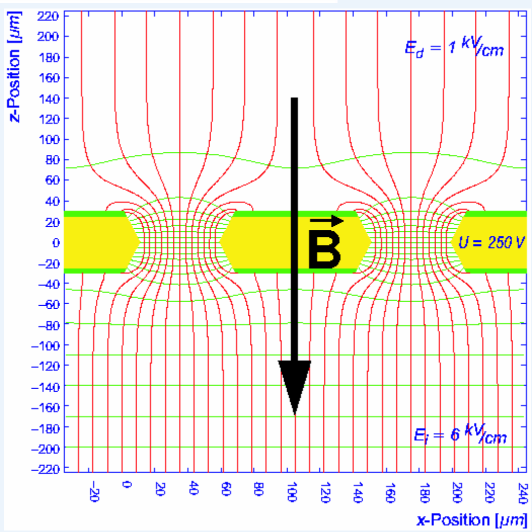
Micro-Pattern-Gas-Detector (MPGD) gas amplification

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

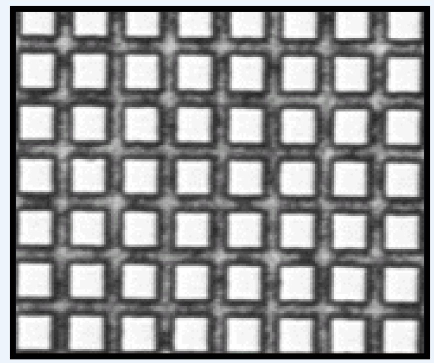


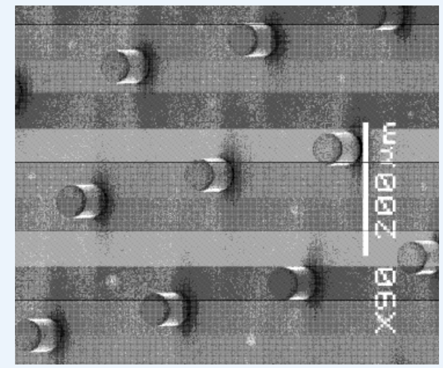
P~140 µm

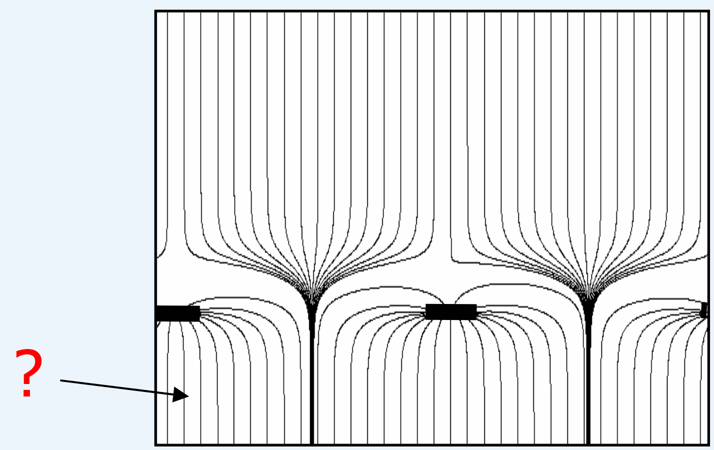
D~60 µm



Micromegas: micromesh sustained by 50µm pillars, multiplication between anode and mesh, one stage







GEM and Micromegas

GEM and Micromegas gas-amplification promises to overcome several problems with MWPCs.

The signal is direct charge collection;
the pads are the anode;
the ExB effect is limited by the hole pitch.

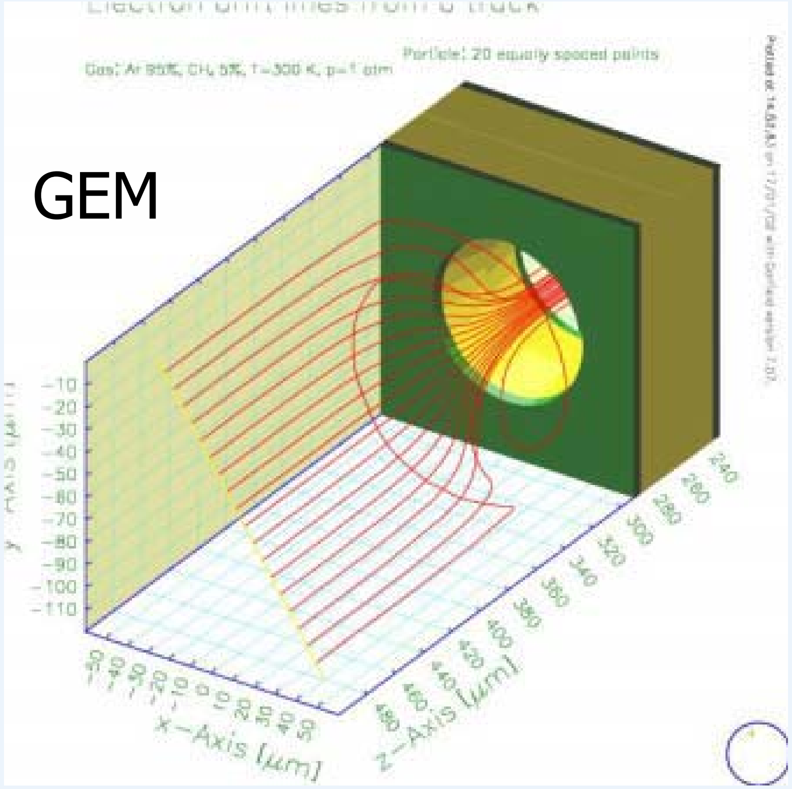
The pad response function is narrow.

Pad response is broadened only by diffusion;
the pad response function is too narrow.

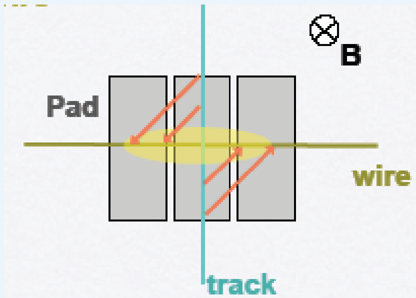
The **international R&D program** is an effort to optimize the

resolution and operating stability.

GEM

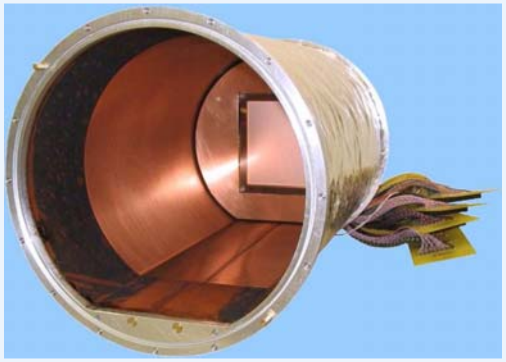


WIRE



TPC R&D, the international program

Aachen

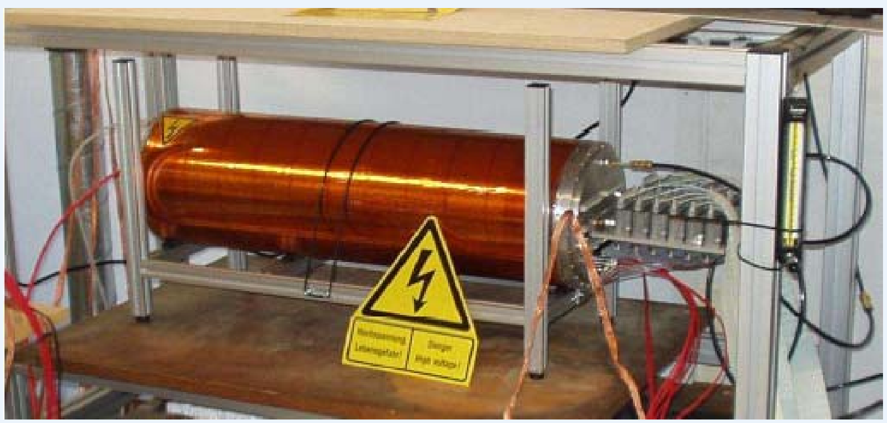


Thin field cage

TPC for further Ion feedback measurements

DESY-
Hamburg

GEM



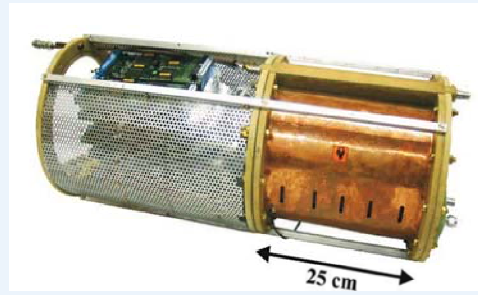
80 cm drift, 25 cm diameter, TPC

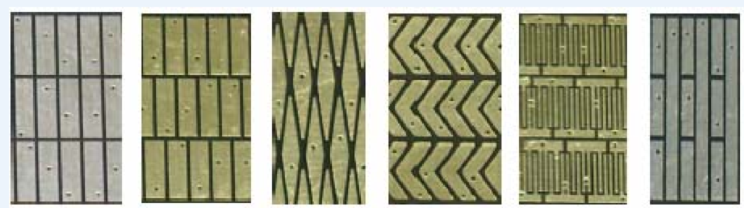
5 Tesla magnet

TPC R&D, the international program

Karlsruhe

GEM

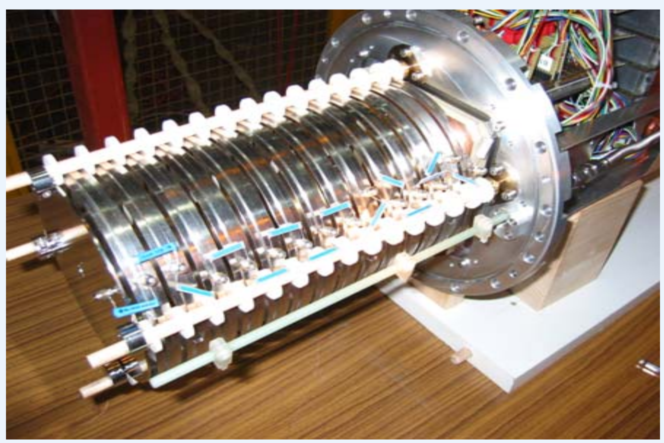




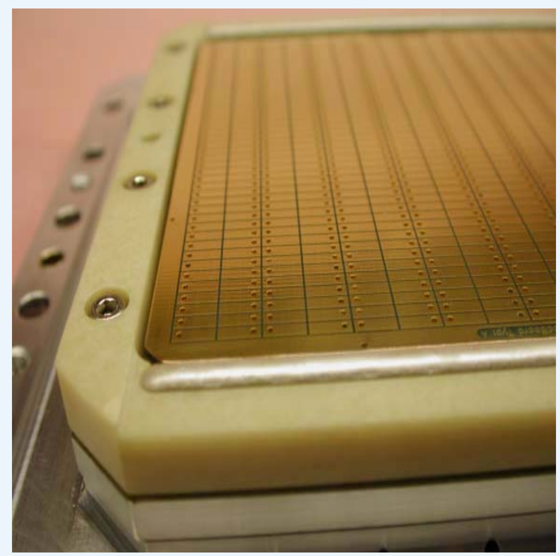
various pad patterns

MPI – CDC (Asia groups)

GEM
Micromegas
Wires

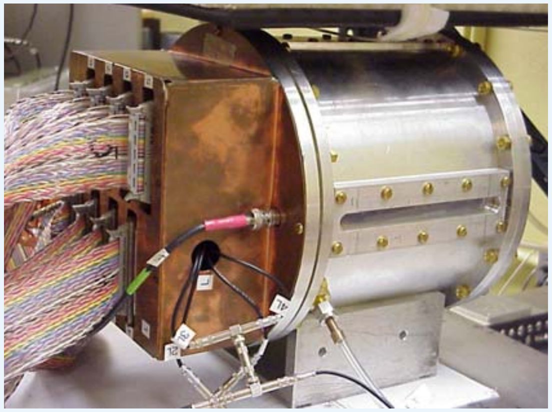


26 cm drift TPC

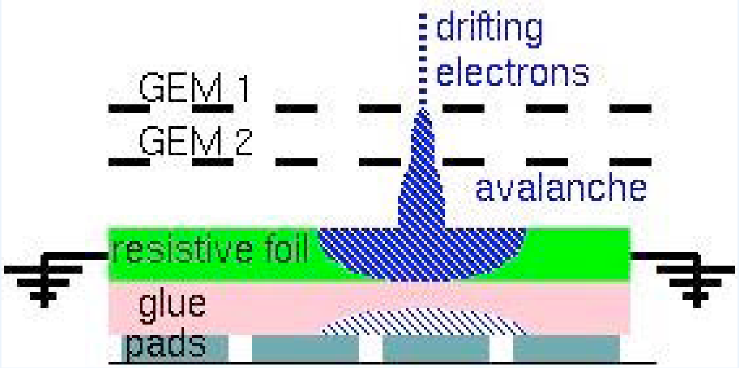


TPC R&D, the international program

Carleton



16 cm drift TPC

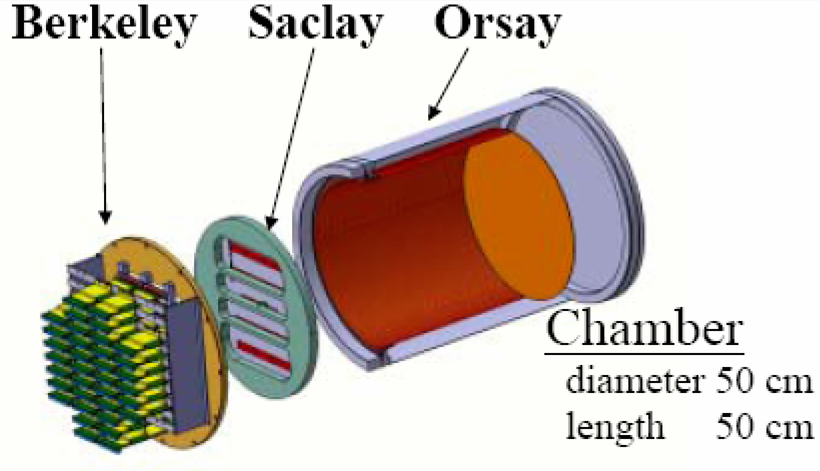


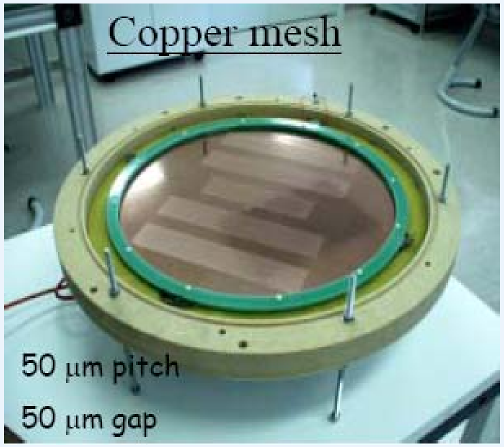
Charge dispersion with resistive anode

Berkeley, Orsay, Saclay

Micromegas

(Giomataris is at Saclay)



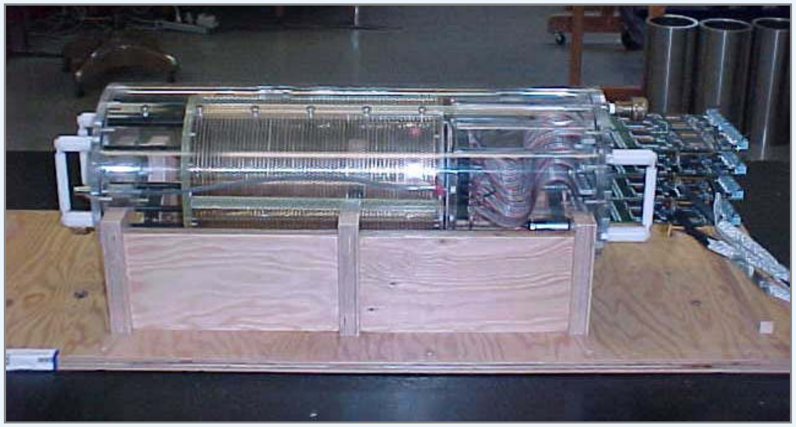


Micromegas

TPC R&D, the international program

Victoria

GEM
(and Micromegas)

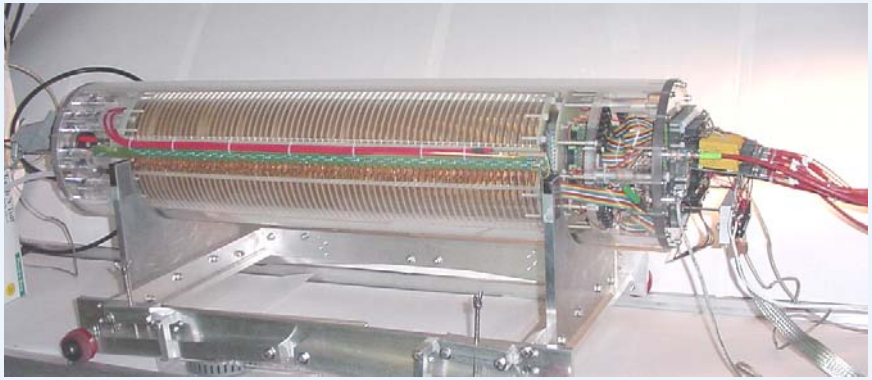


30 cm drift TPC

Laser delivery

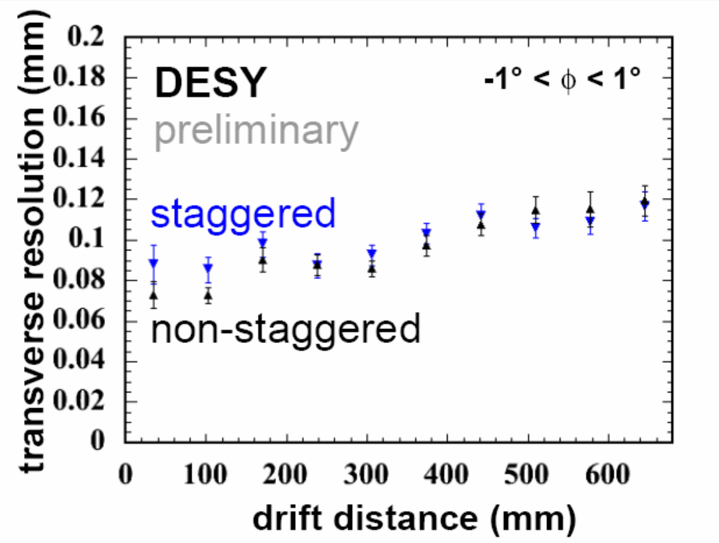
Cornell

64 cm drift TPC

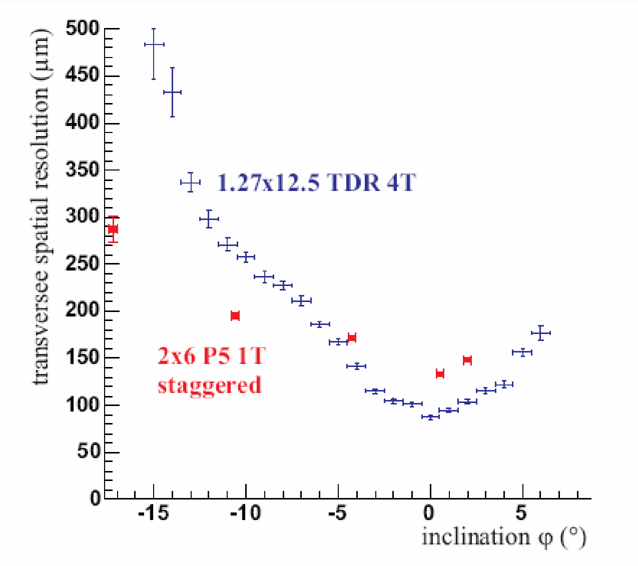


TPC R&D, the international program

DESY-Hamburg, Stanford 05
3-GEM
"TESLA TDR gas" ($Ar:CH_4:CO_2$ 93:5:2)
2mm x 6mm pads (selected events)
5 Tesla

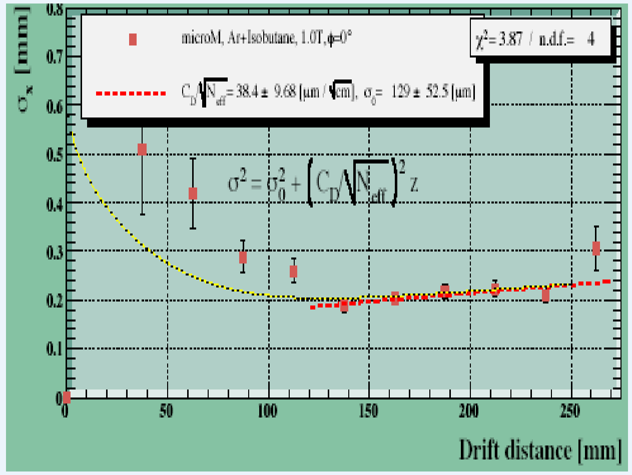


Karlsruhe, Vienna05
2-GEM
"TESLA TDR gas" and P5 (Ar:CH4 95:5)

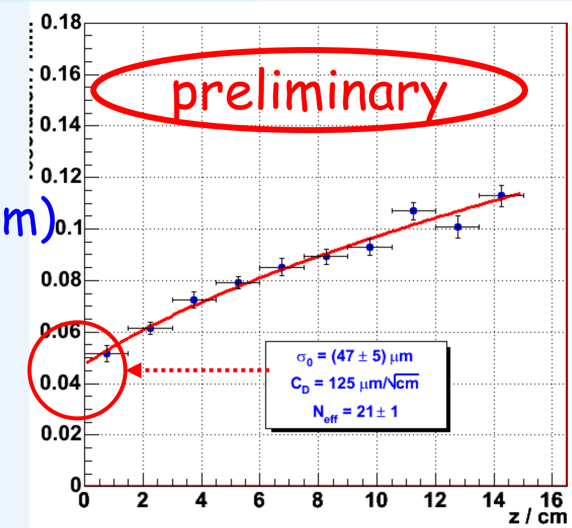


TPC R&D, the international program

Orsay, Saclay Micromegas
at KEK test facility
MPI and Carleton TPC
π beam
1 Tesla
Ar iC_4H_{10} 95:5 gas



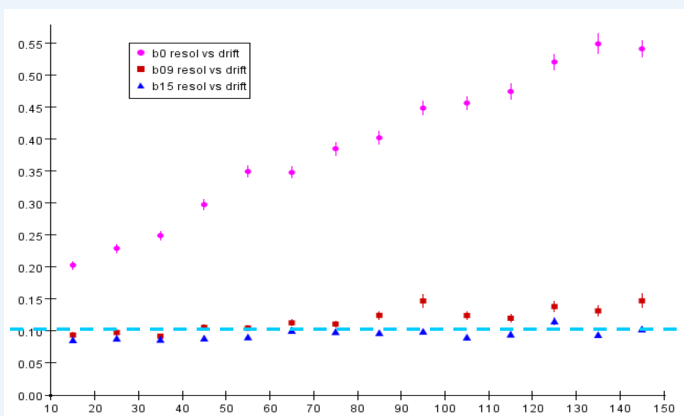
without charge dispersion
(note resolution at small z)



with charge dispersion

Victoria
2-GEM
P5 gas

100 micron



B = 0

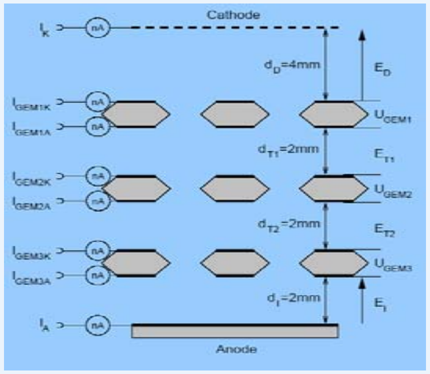
B = 0.9 T

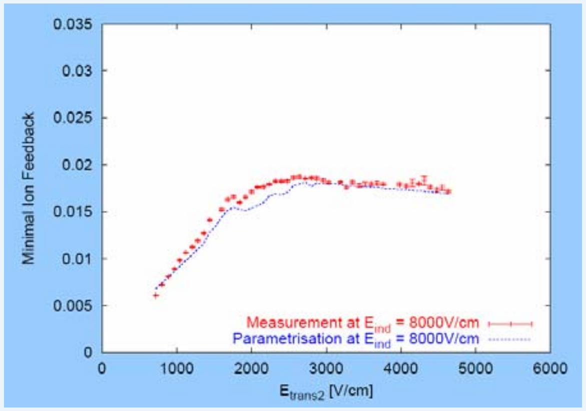
B = 1.5 T

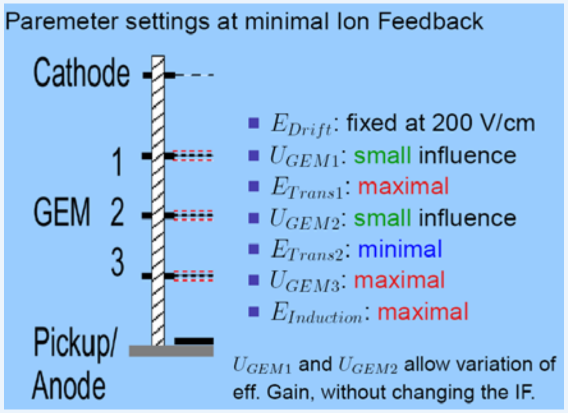
3 cm drift 30 cm

Ion feedback measurements at Aachen and Orsay/Saclay

Aachen
4mm drift

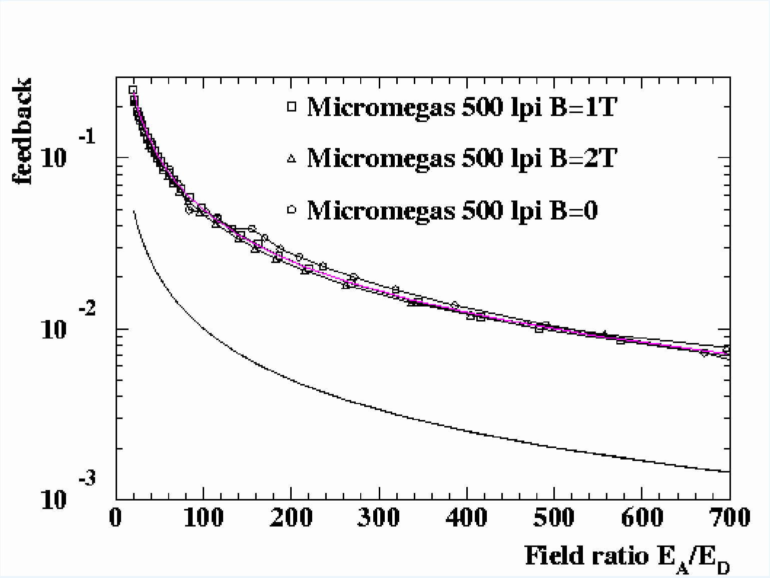






Orsay,
Saclay
15 cm drift

Fe^{55} source



Ion feedback with Micromegas, P10

Cornell/Purdue TPC Program

Cornell University	Purdue University
D. P. Peterson	G. Bolla
L. Fields	I. P. J. Shipsey
R. S. Galik	
P. Onyisi	

* presentation at	ECFA 2005 Vienna	24-November-2005
* presentation at	ALCPG Snowmass	23-August-2005
* presentation at	LCWS05, Stanford	21-March-2005
* presentation at	TPC mini-workshop, Orsay	12-January-2005

Information available at the web site:
http://w4.lns.cornell.edu/~dpp/tpc_test_lab_info.html

This project is supported by the US National Science Foundation (LEPP cooperative agreement)
and by the US Department of Energy (HEP group base grant)
and by an LCRD/UCLC consortium grant

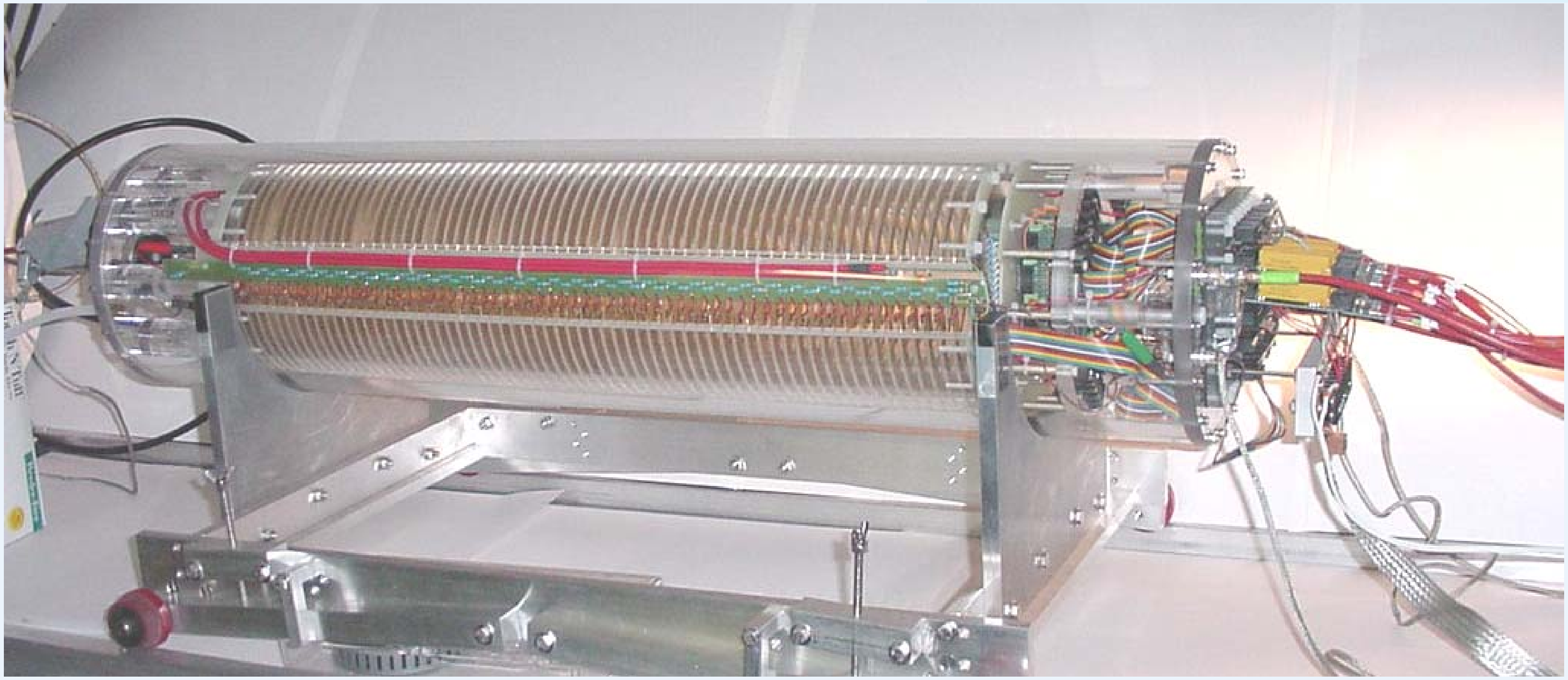
TPC

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

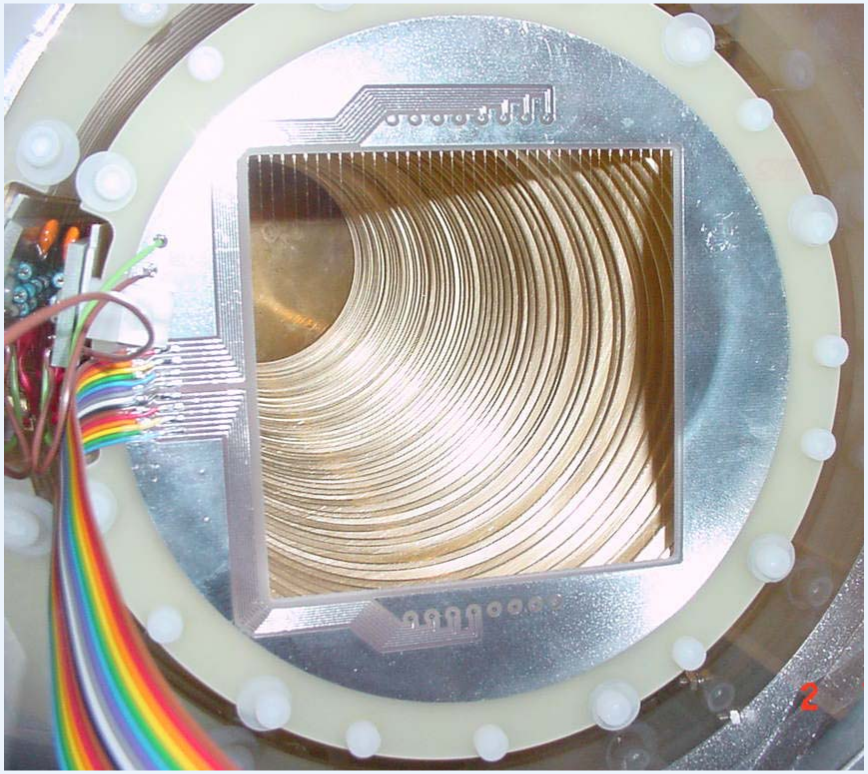
14.6 cm ID field cage - accommodates a 10 cm GEM
64 cm drift field length
22.2 cm OD outer structure (8.75 inch)

"field cage termination" and "final" return lines for the field cage HV distribution allow trimming the termination bias voltage.

Read-out end:
- field cage termination
- readout pad and amplification module
- pad biasing boards
- CLEO II cathode preamps

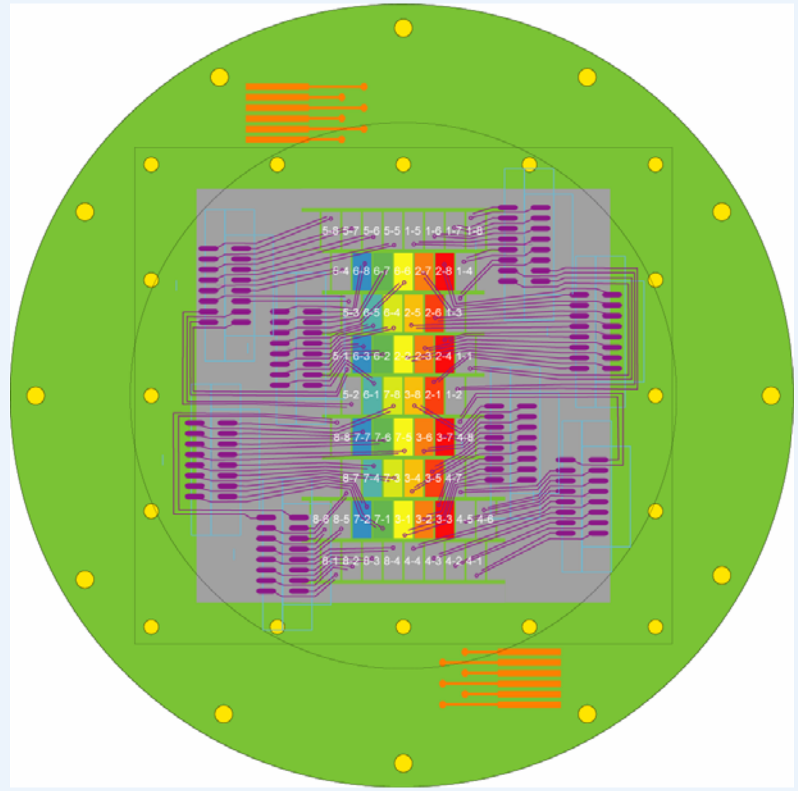


Field cage termination



10 cm

Field cage termination area is 10cm square

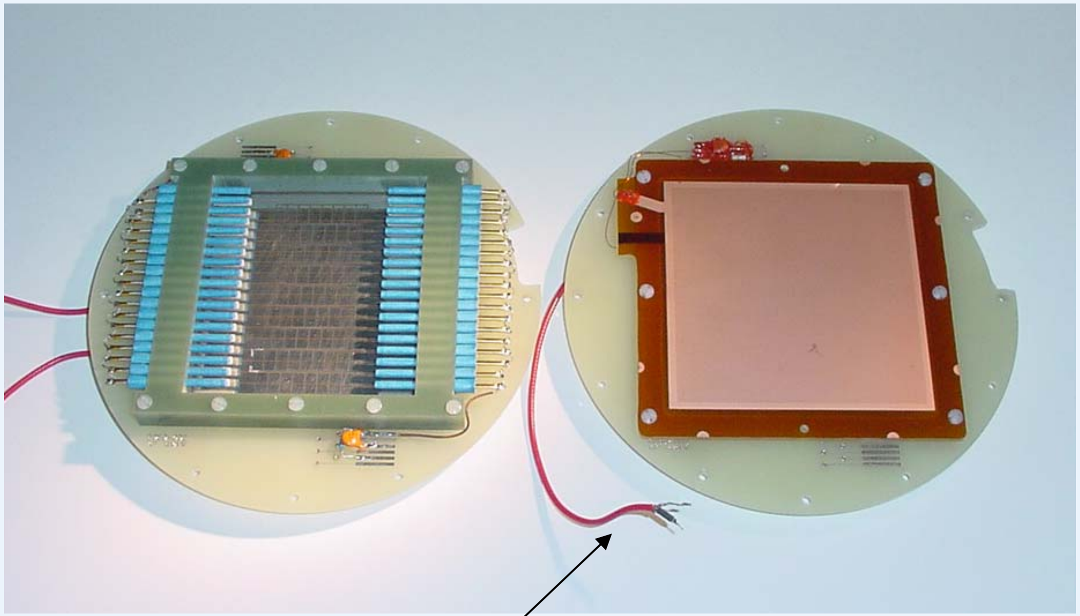


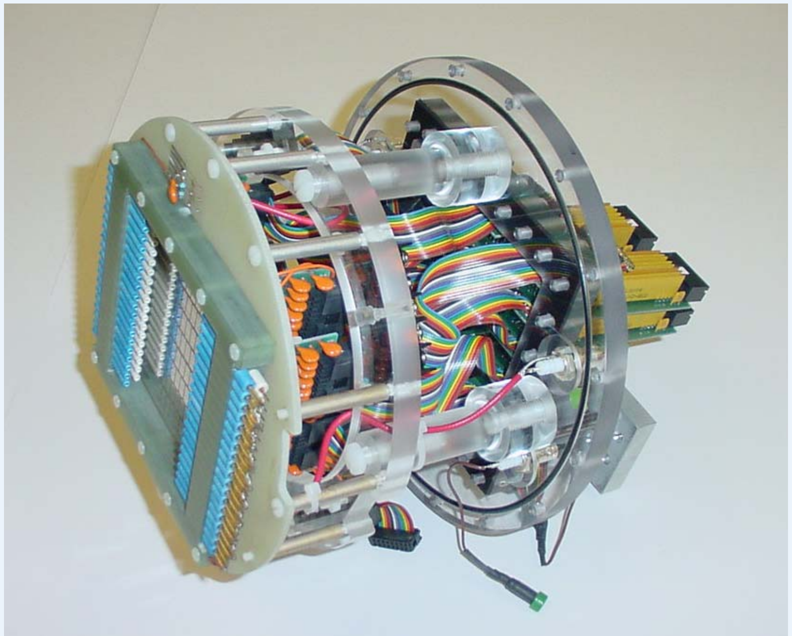
The instrumented readout area is
~2 cm x7 cm , 32 pads.

The biased area is 10cm square.

(This pad board allows ~3 x 9 cm , 62 pads.)

MPWC and GEM amplification





10 cm

The readout module including the amplification device mounted on pad board

Shown: single-GEM
Will discuss Single-GEM and double-GEM.

The instrumented readout area is ~2cm x7 cm , 32 pads.

The biased area is 10cm square.

(This pad board allows ~3 x 9 cm , 62 pads.)

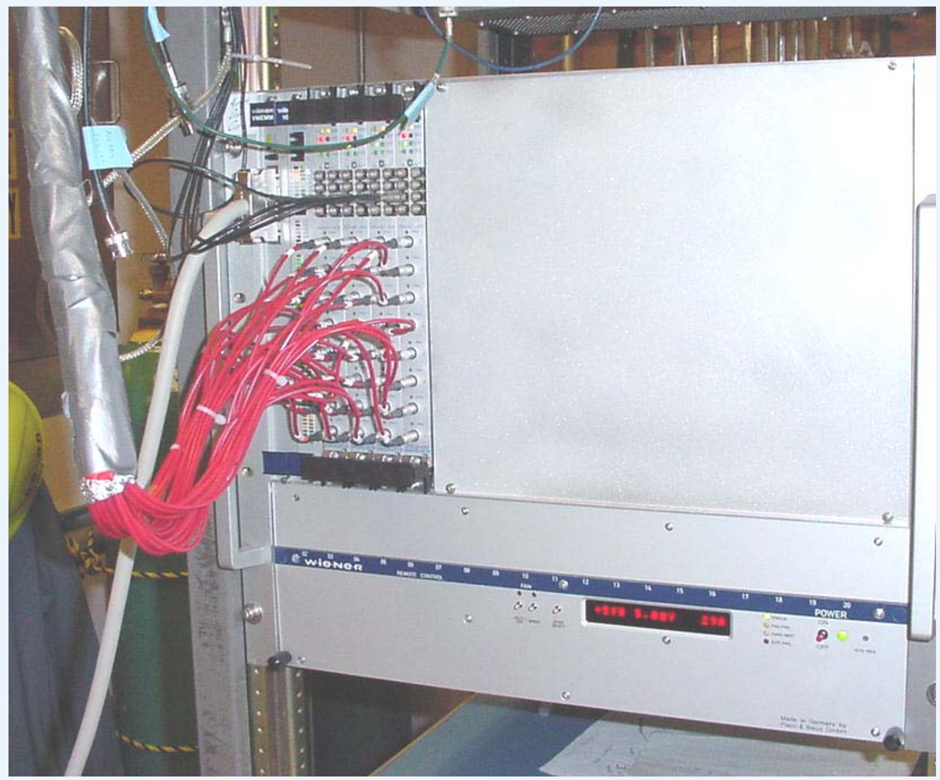
Electronics

High voltage system:
 -20 kV module, 2 channels available
 -2 kV module, 4 channels available

(not part of interfaced system +2 kV)
(but +2 kV module has been added)

Readout:
 VME crate
  PC interface card
   LabView

 Struck FADC
  32 channels (expanded to 56)
  105 M Hz
  14 bit
  +/- 200 mV input range
   (least count is 0.025mV)
  NIM external trigger input
  circular memory buffer



MWPC gas-amplification

MWPC
built at Cornell with
CLEO III drift chamber
spare parts.

mounted Dec-2004

biasing:
field cage, -20kV, **300 V/cm**
termination: -900V

termination:grid 10mm, **300V/cm**

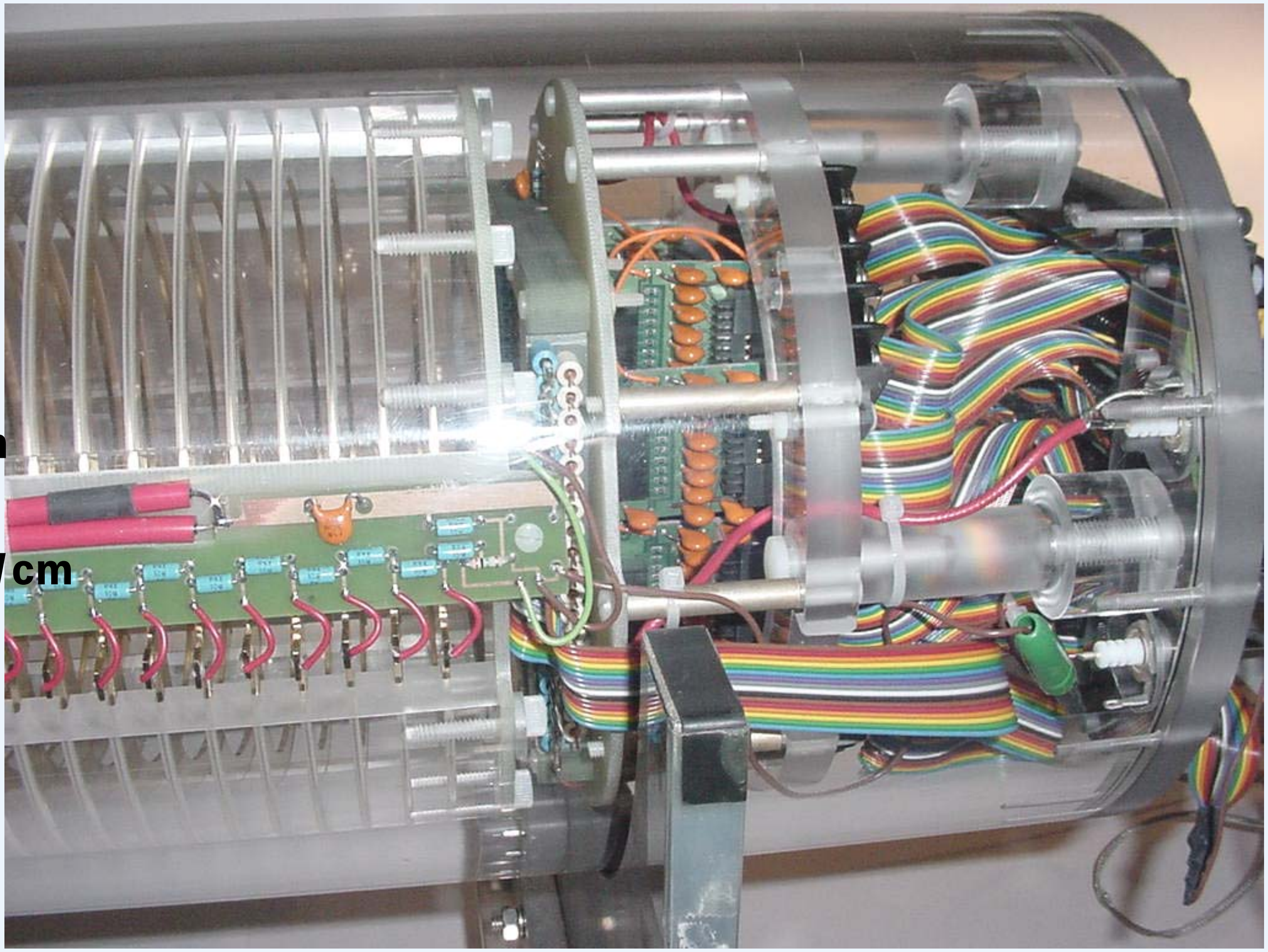
grid: -600V

grid:anode 5mm

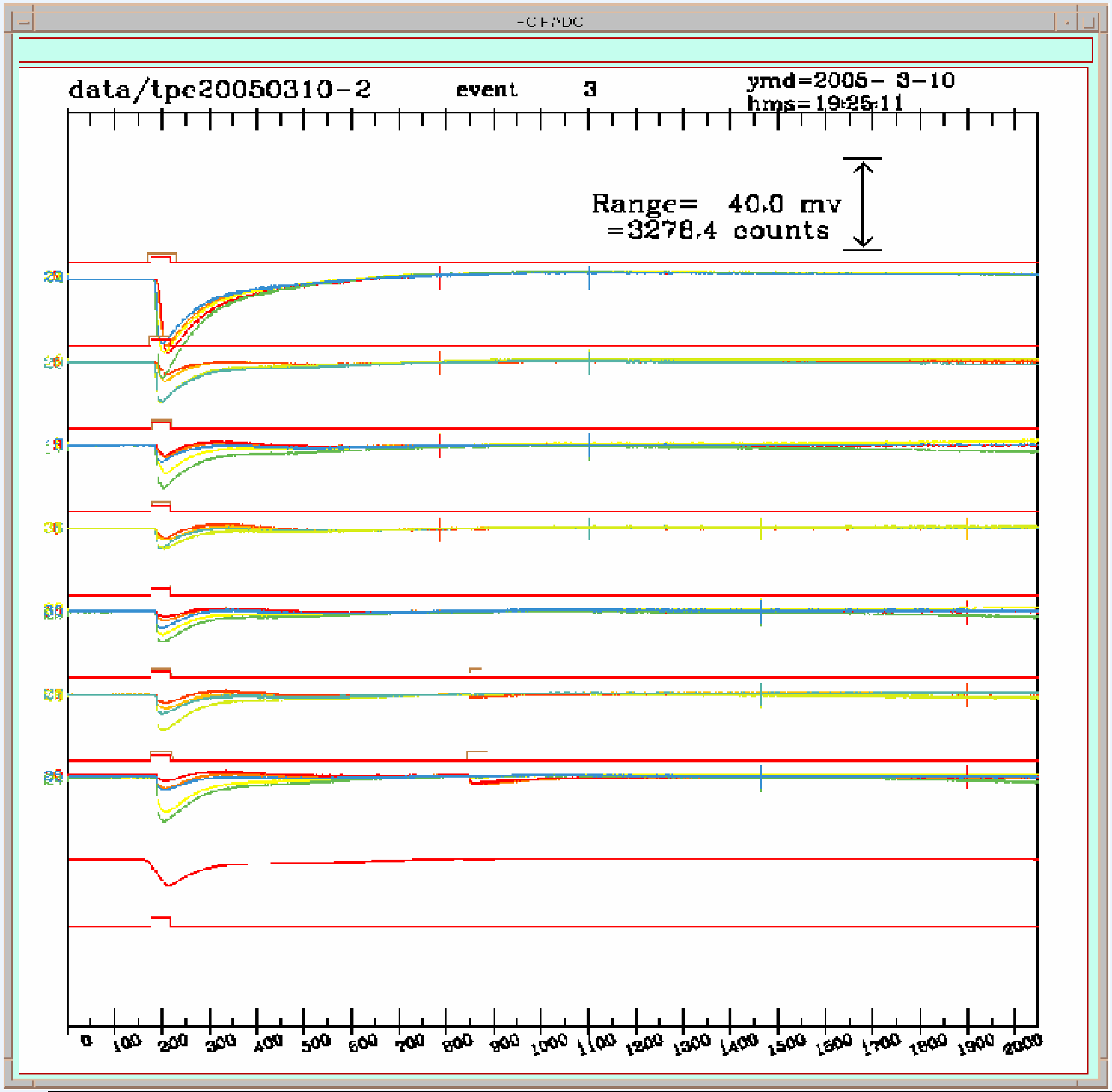
anode: +550V

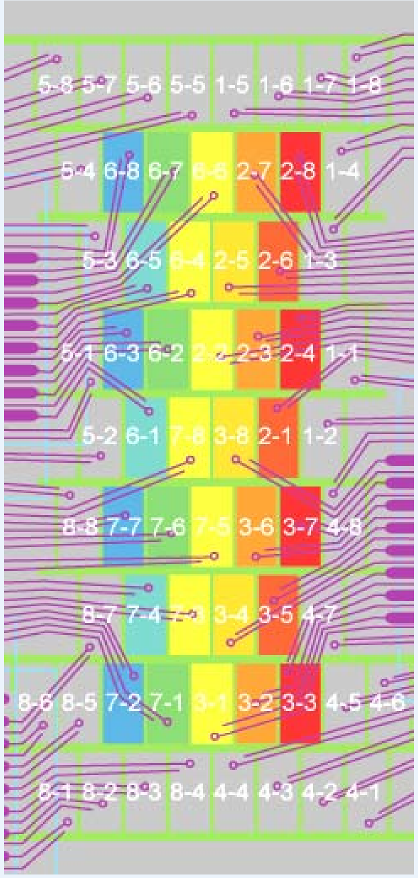
anode:pads 5mm

pads: -2000V



MWPC event (typical)





$ArCO_2$ (10%) , 300V/cm
25 MHz , 40 ns
2048 time buckets (81.92 μs)

single GEM gas-amplification

CERN GEM
mounted, tested by Purdue

installed 11-March-2005

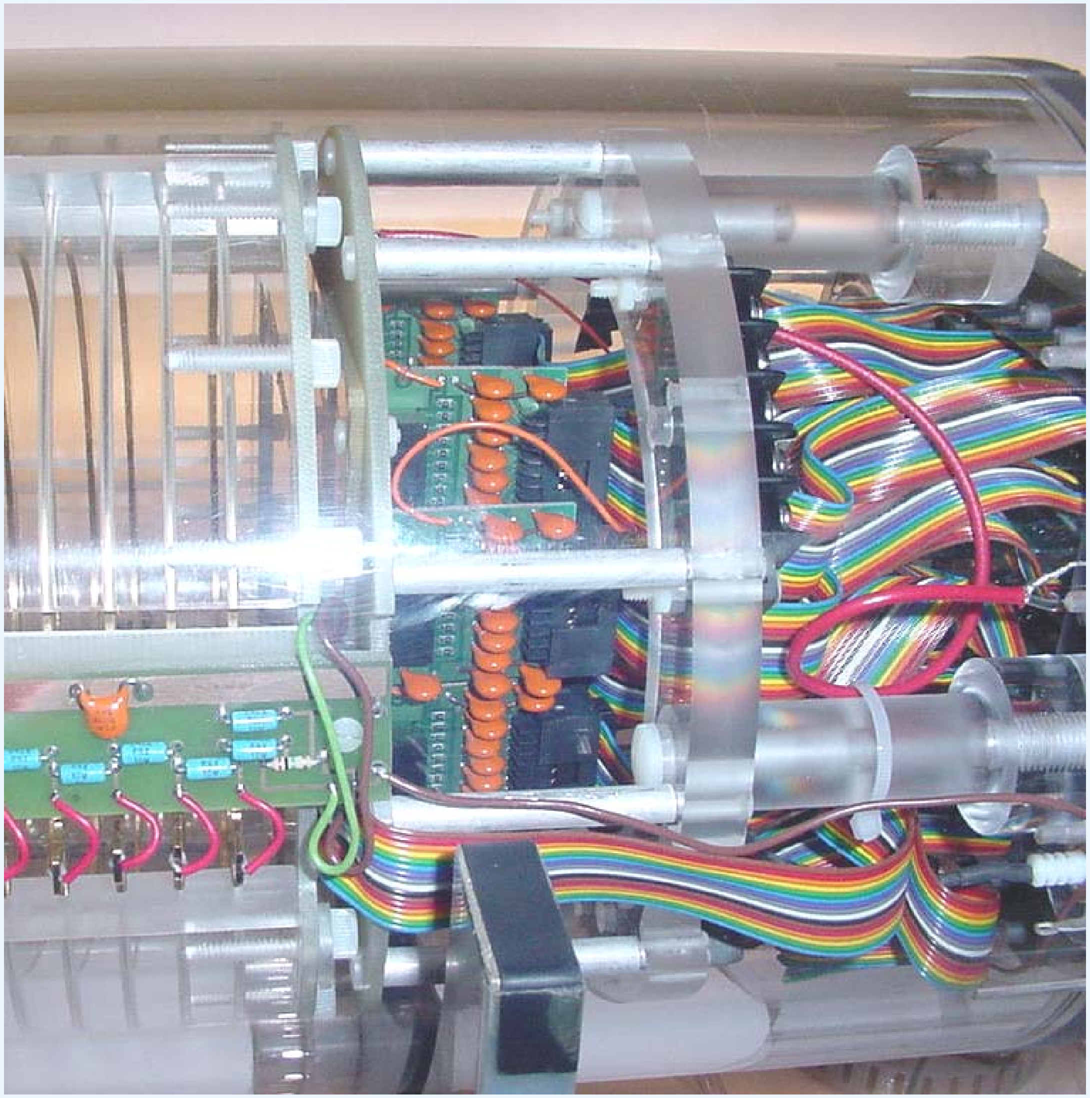
biasing:
field cage, -20kV, 300 V/cm
termination: -900V

termination : GEM **960V/cm** , 0.5 cm

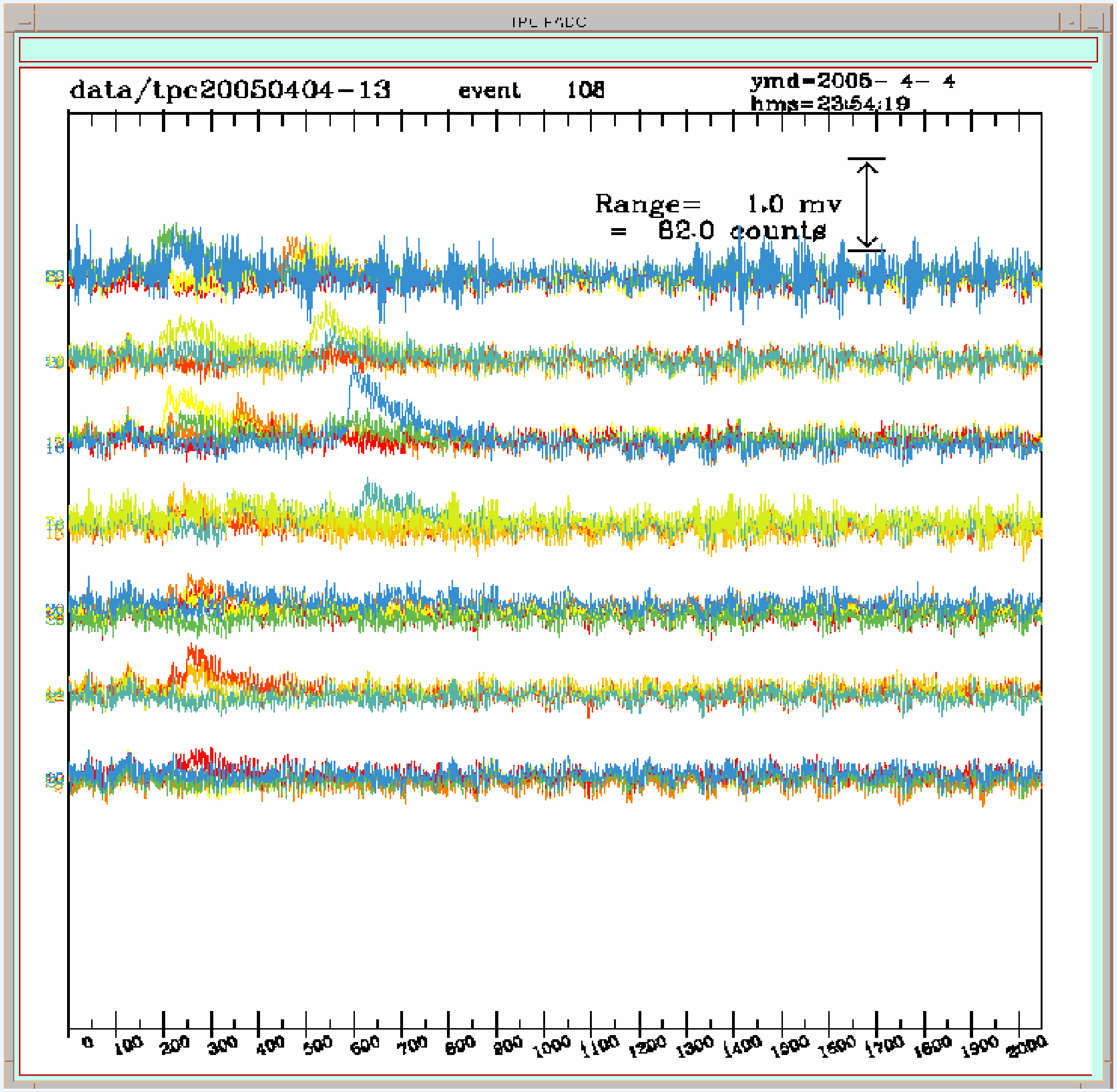
GEM voltage: -400V , -400V:0V
(Gas amplification ~100.)

GEM : pads: **5000V/cm** , 0.3 cm,

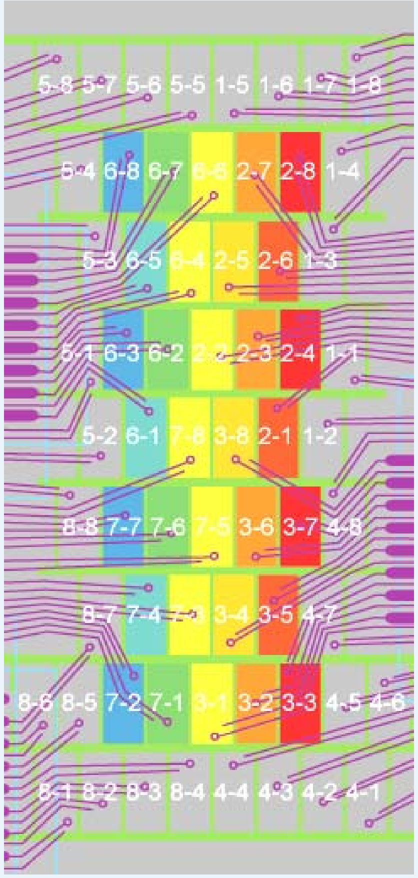
pads: +1500 V



single-GEM event

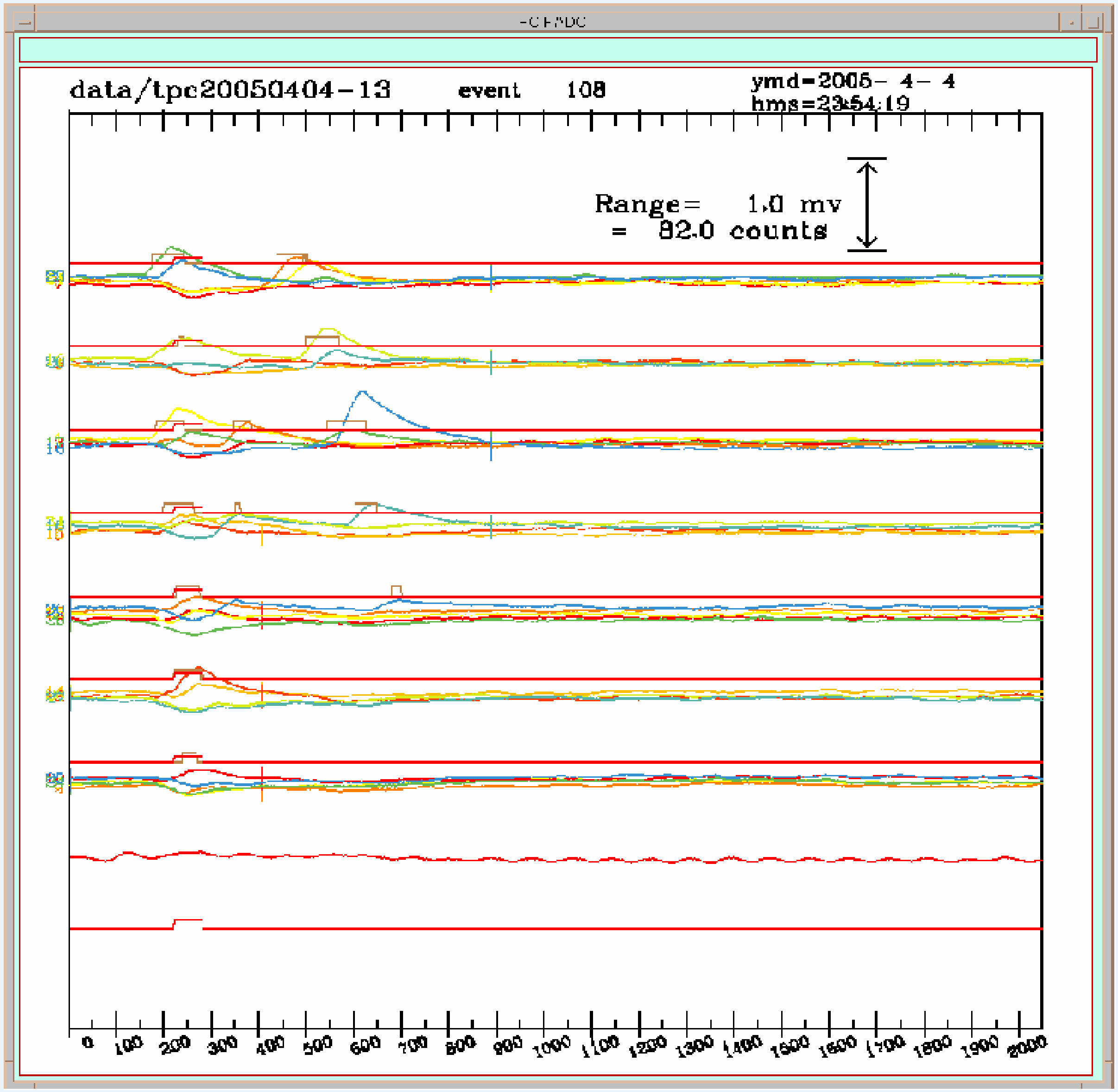


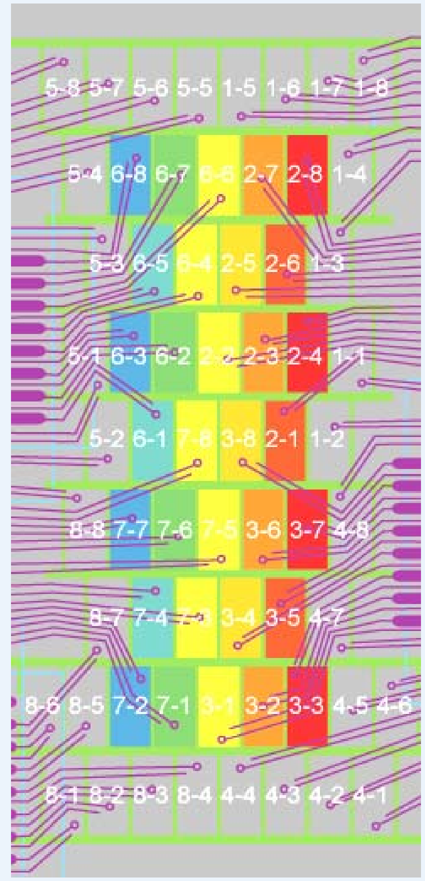
Note the 1 mv scale.
Gas amplification is about 100



$ArCO_2$ (10%) , 300V/cm
25 MHz , 40 ns
2048 time buckets (81.92 μs)

single-GEM after smoothing & common noise subtraction





$ArCO_2$ (10%) , 300V/cm
25 MHz , 40 ns
2048 time buckets (81.92 μs)

double-GEM gas-amplification

CERN GEM
mounted, tested by Purdue

installed 20-October-2005

biasing:
field cage, -20kV, 300 V/cm
termination: -919V

termination : GEM2 **300V/cm** , 0.432 cm

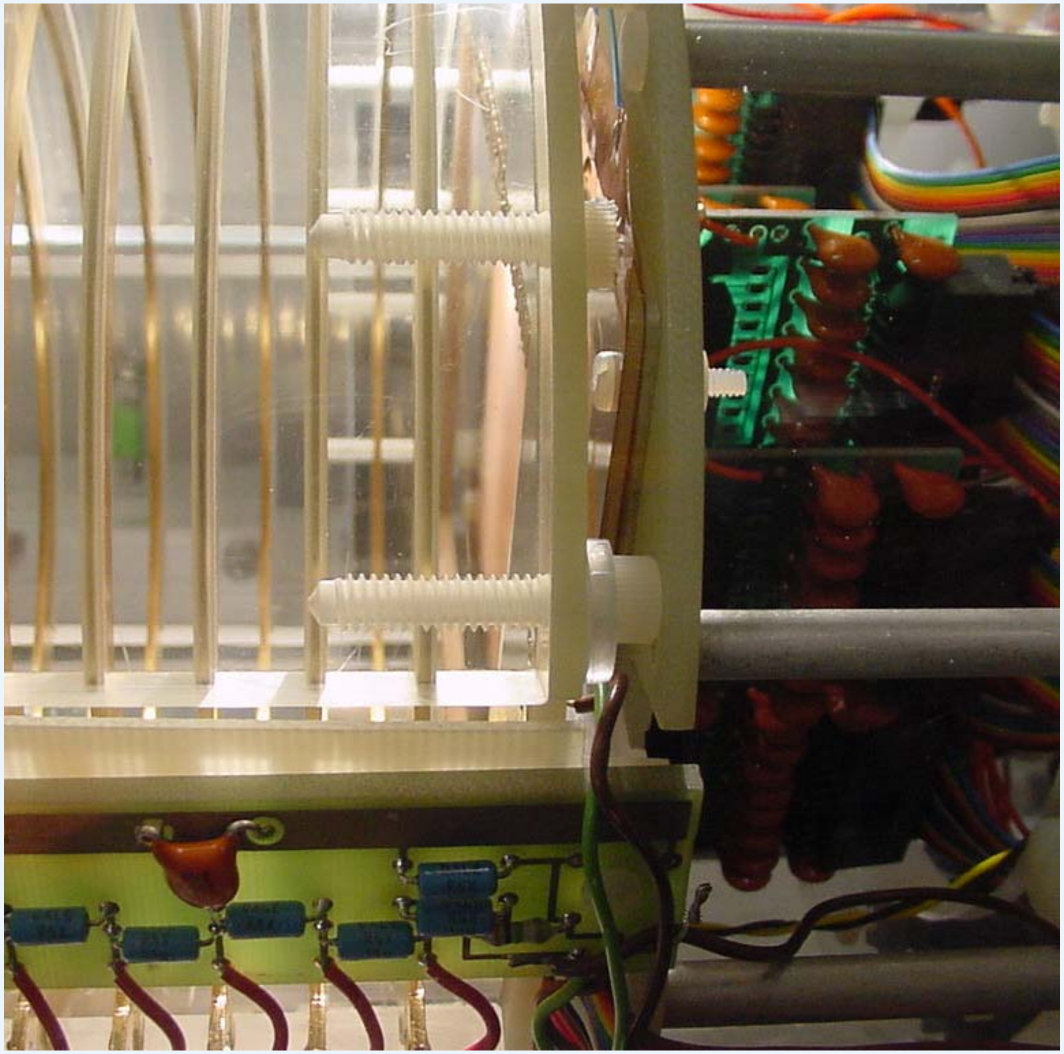
GEM2 voltage: -370V , -789V:-419V

GEM2:GEM1 300V/cm , .165cm

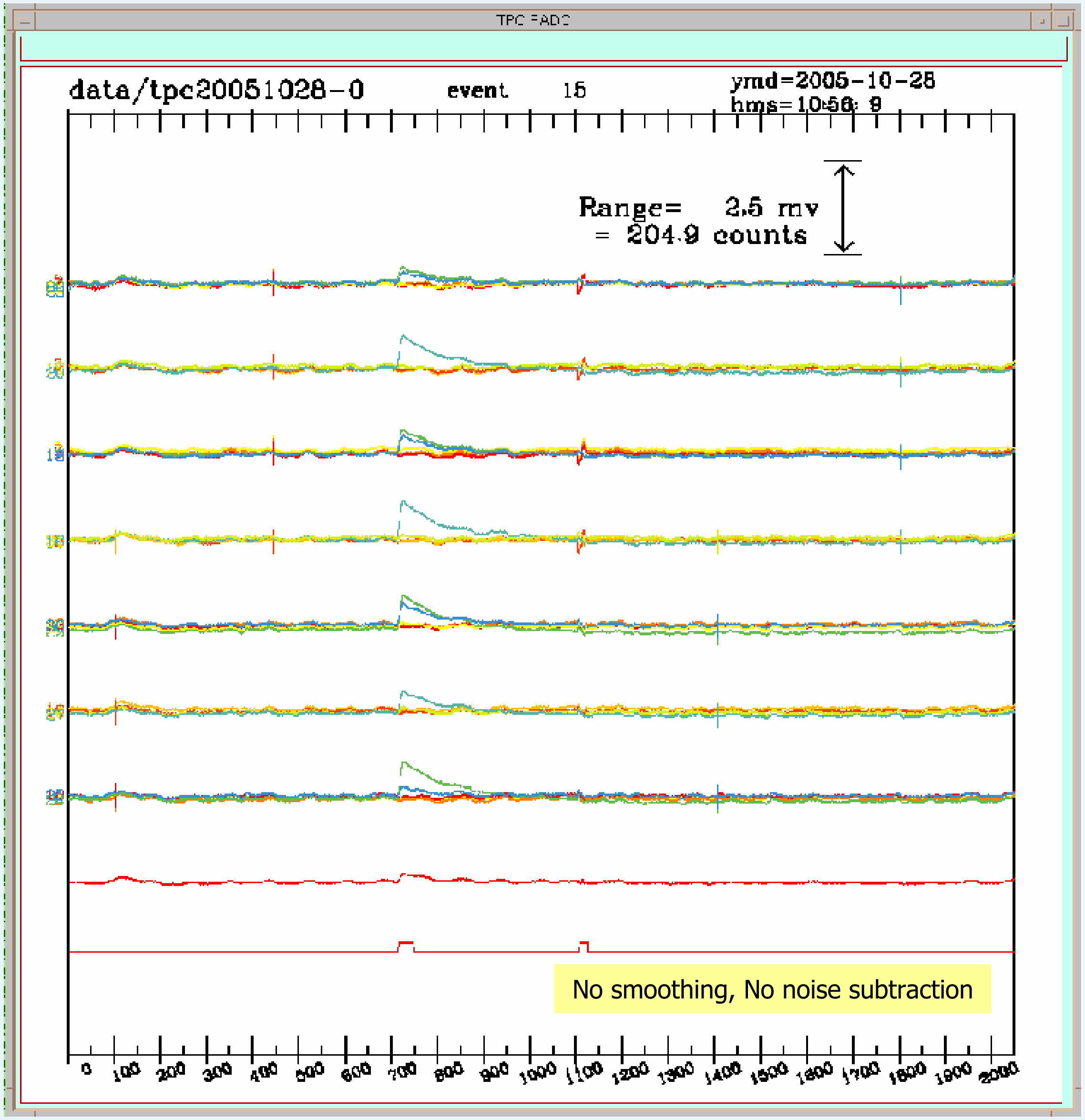
GEM1 voltage: -370V , -370V: 0

GEM1: pads **5000V/cm** , .165cm

pads: +825 V

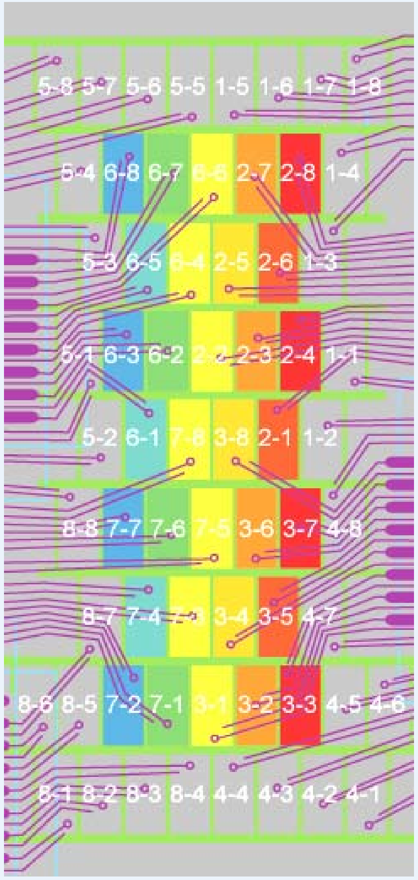


double-GEM event



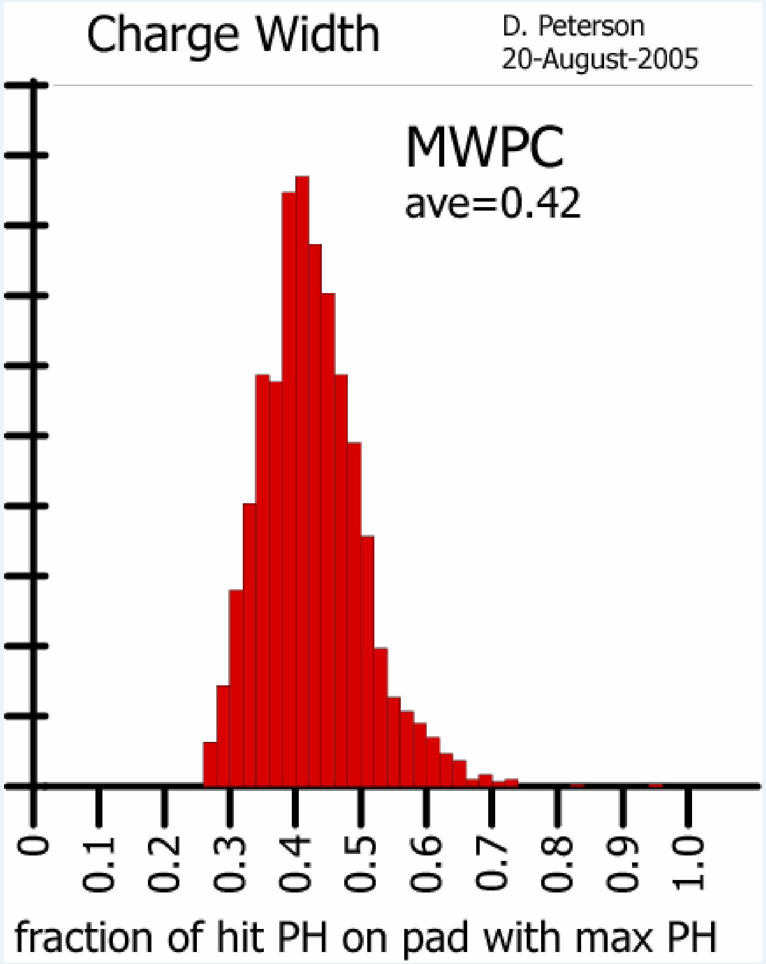
$ArCO_2$ (10%) , 300V/cm
drift velocity = 22 μm/ns

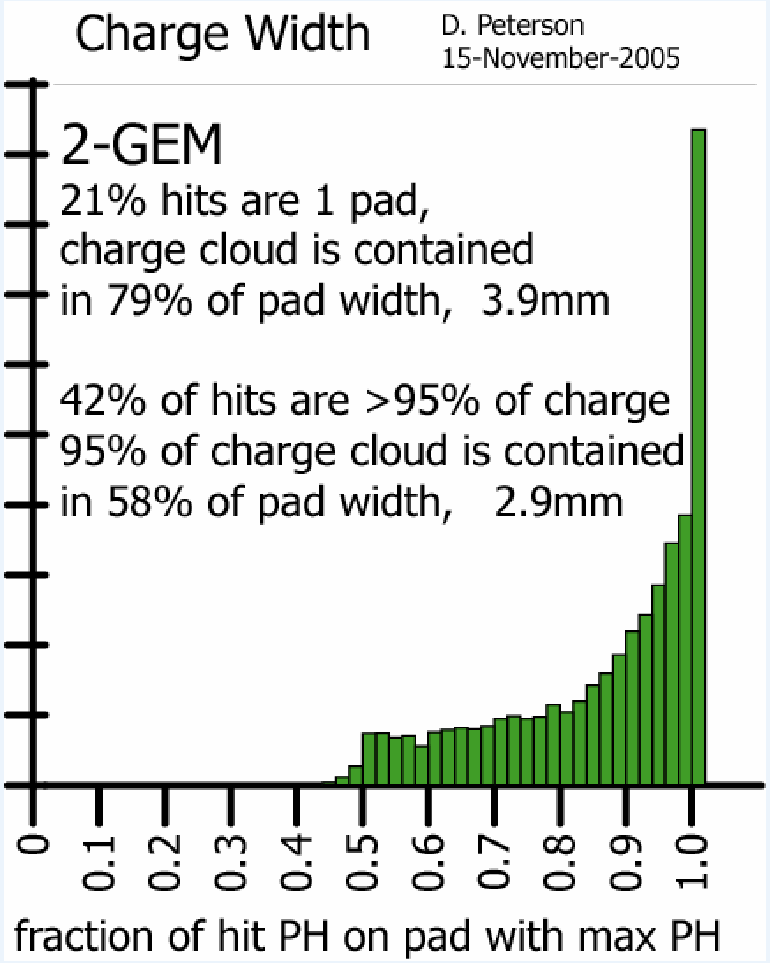
drift distance (this event) ~55 cm



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

charge width





hit resolution (5mm pad)

find tracks - require time coincident signals
MWPC: 6 layers, GEM: 5 layers

find PH center using maximum PH pad
plus nearest neighbors (total 2 or 3 pads)

MWPC: select clean, "contained" hits
require the hit PH sum to
contain 70% of layer PH sum

require 5 layers with interior hits
(Max. ph pad is NOT on the edge.)

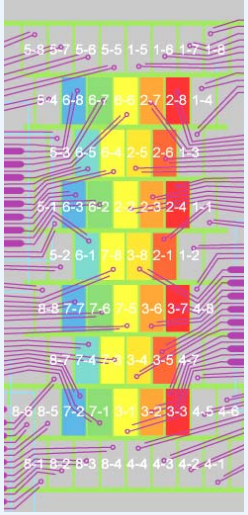
fit to a line
may eliminate 1 hit with residual > 2.5mm
(Still require 5 layers with interior hits.)

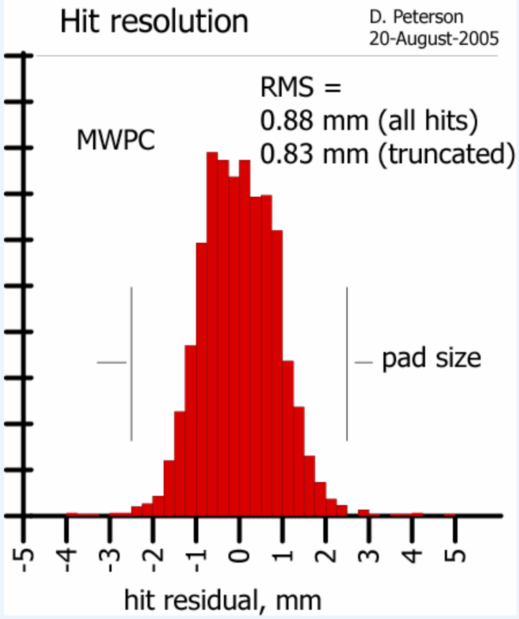
refit

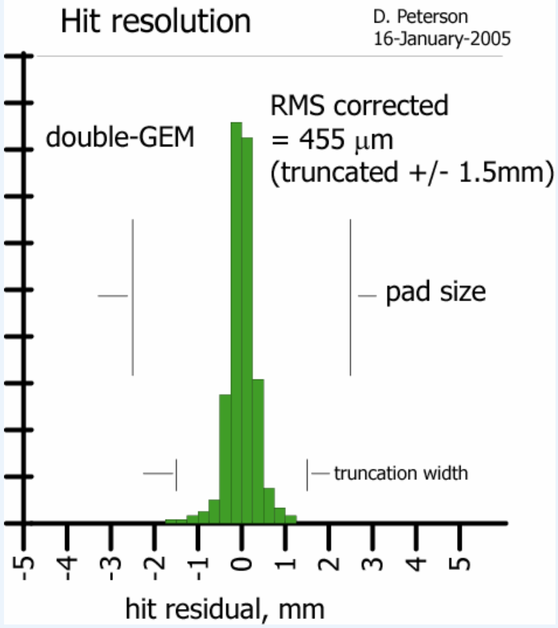
double-GEM: select 4 clean, charge-share hits
require sum of 2 pads > 96% of layer pulse height
require peak pad PH < 92% of layer
require 4 hits, 1 each in layers (1,2) (3,4,5) (6,7)

fit

corrected: $\sigma^2 = \Sigma r^2/DOF$; $\sigma =$ RMS * $(points/DOF)^{1/2}$







Transverse resolution

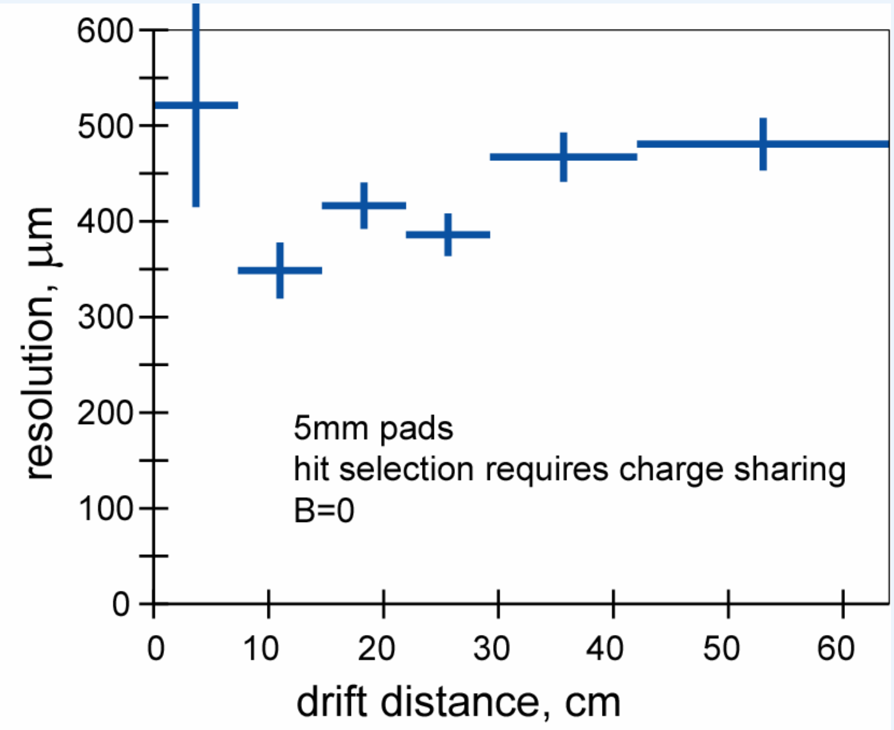
Cornell TPC / Purdue 2-GEM
Resolution vs drift distance

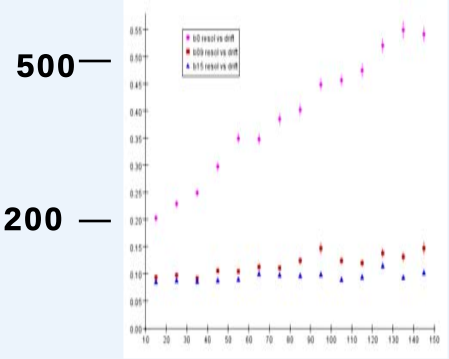
Ar CO_2 90:10 gas (swg gas)
B=0

5 mm pads
All hits are 2-pad, not 3-pad.

The resolution should improve with smaller pads.

Increase in resolution at drift < 7 cm is probably a fluctuation.





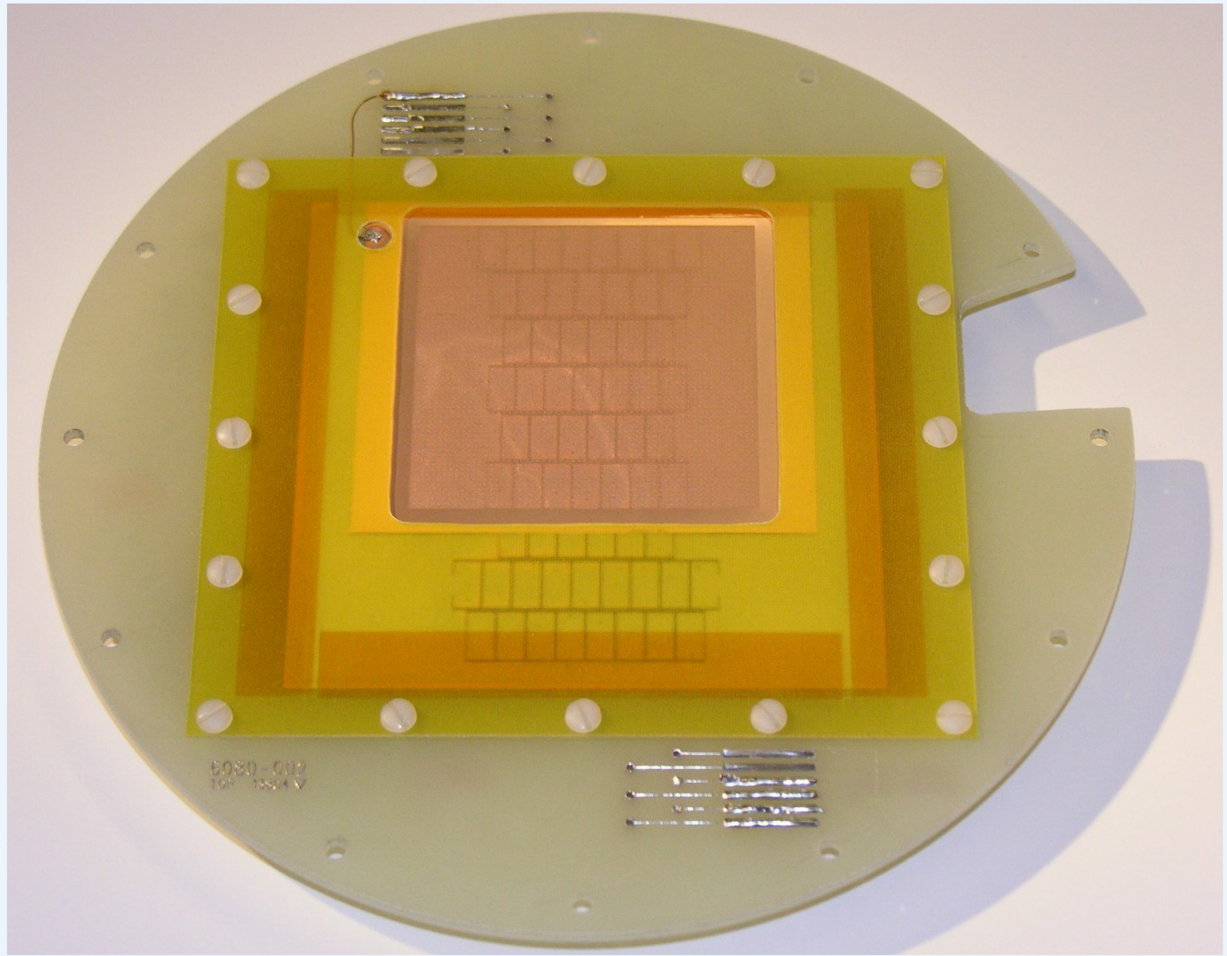
Victoria
from a previous slide
P5 gas

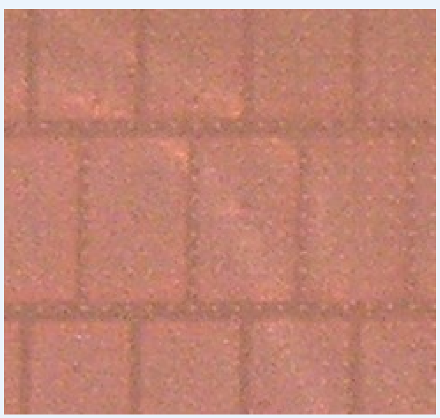
Next: Micromegas

Micromegas
manufactured by 3M,
developed by
Ian Shipsey and 3M.

smaller
but we can use full width

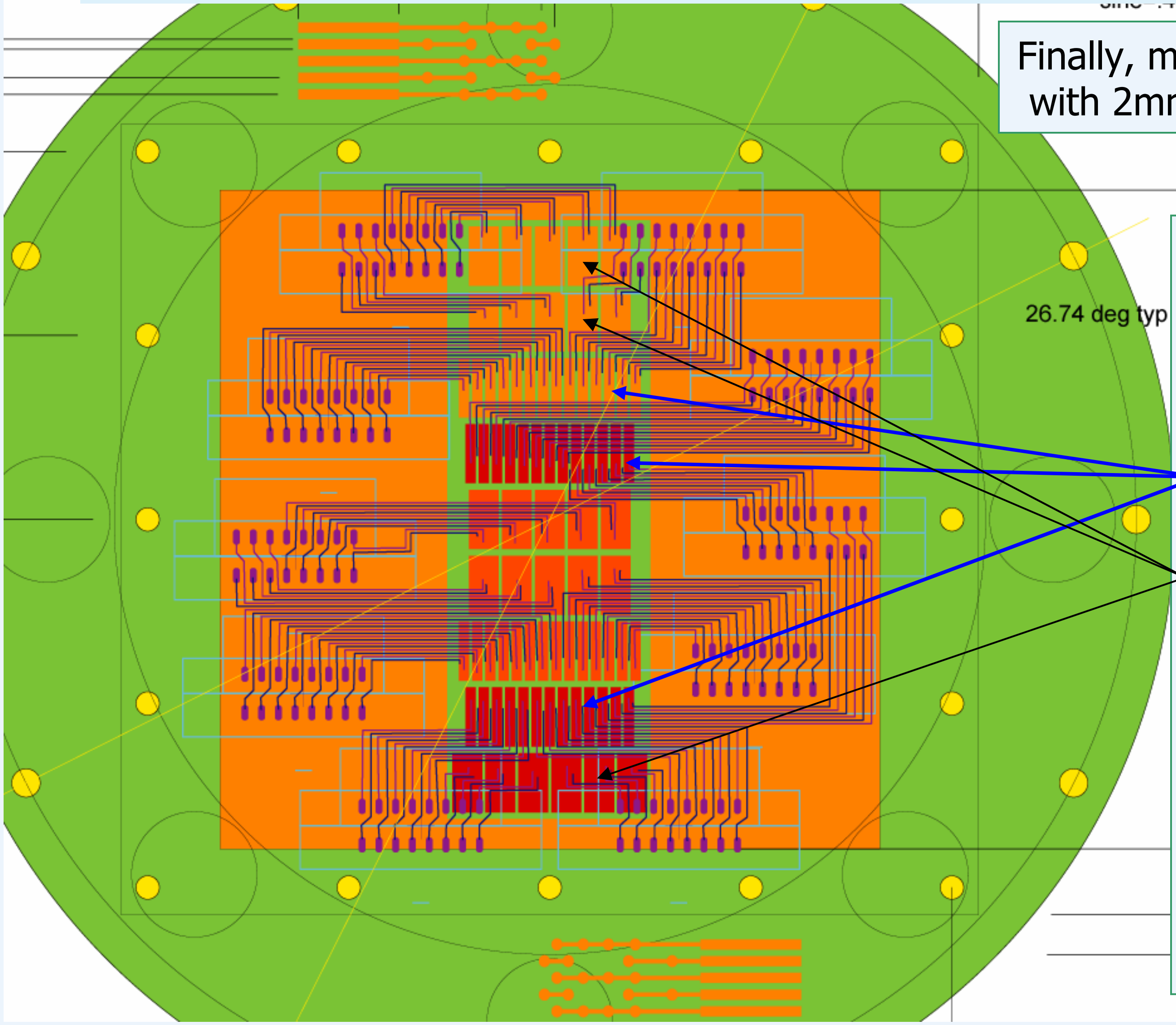
will arrive next week





You can see the stand-offs

Future: finer segmentation pad board



Finally, make resolution measurements with 2mm pads

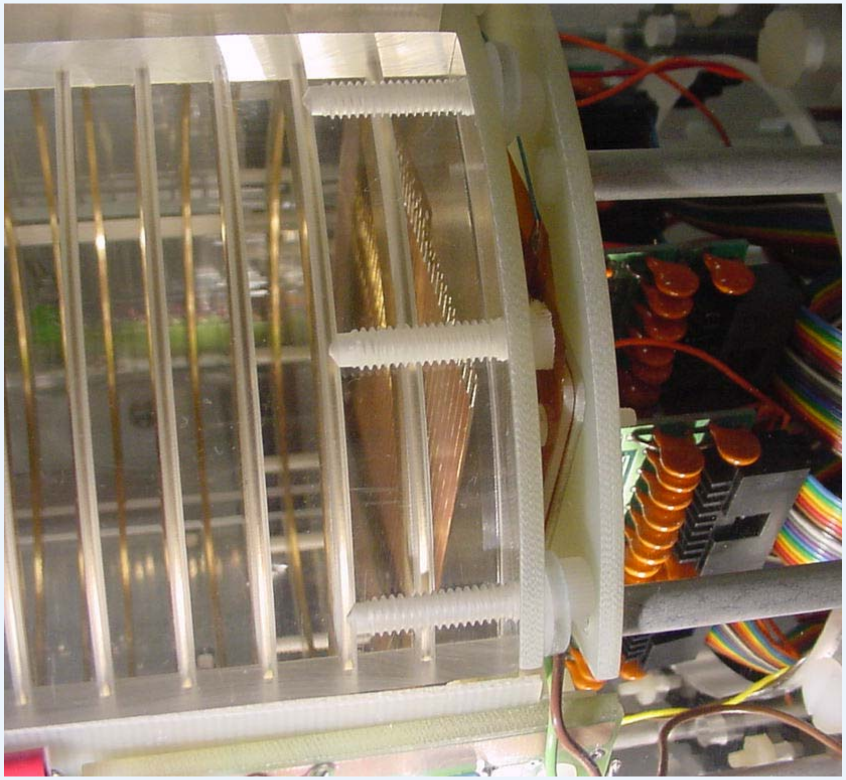
We have purchased 24 additional FADC channels.

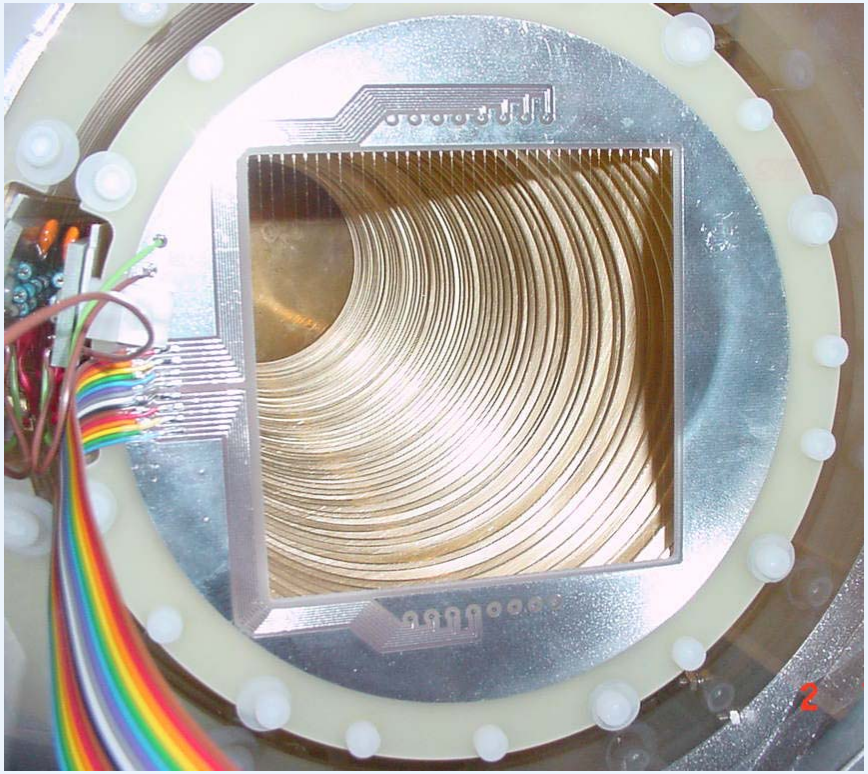
56 channels will allow …
3 rows of 2mm pads
plus
3 rows of 5mm pads
for track definition

Or..
2 row of 2mm pads
4 rows of 5mm pads

8 channels for positive ion feedback measurement

Future: Ion Feedback Measurement





Positive ions are created in the amplification and drift back into the field cage.

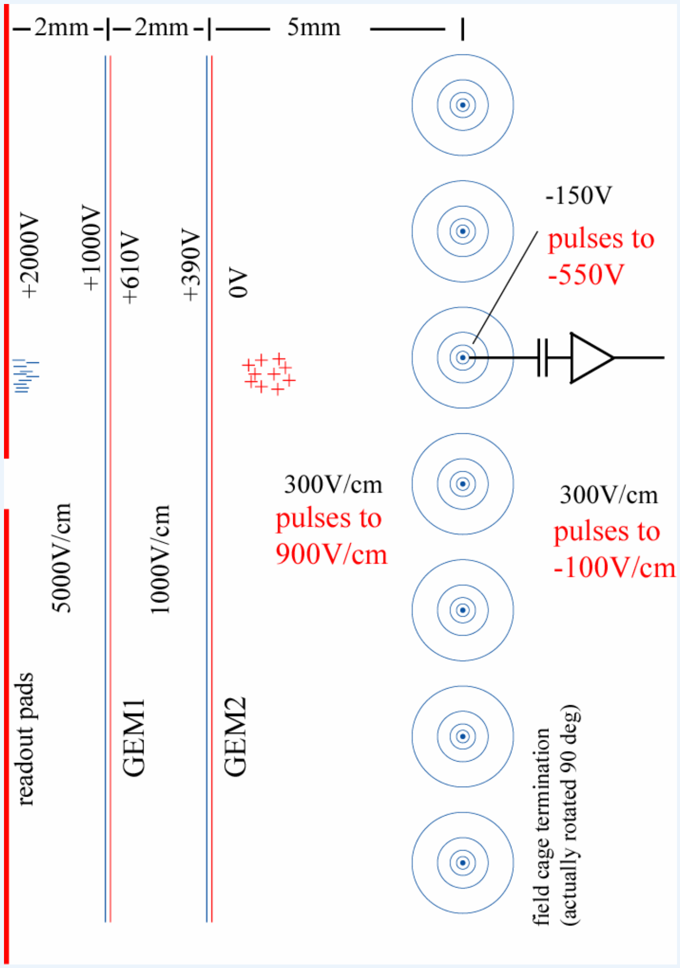
Ion feedback is expected to be much reduced with GEM or Micromegas relative to MWPC.

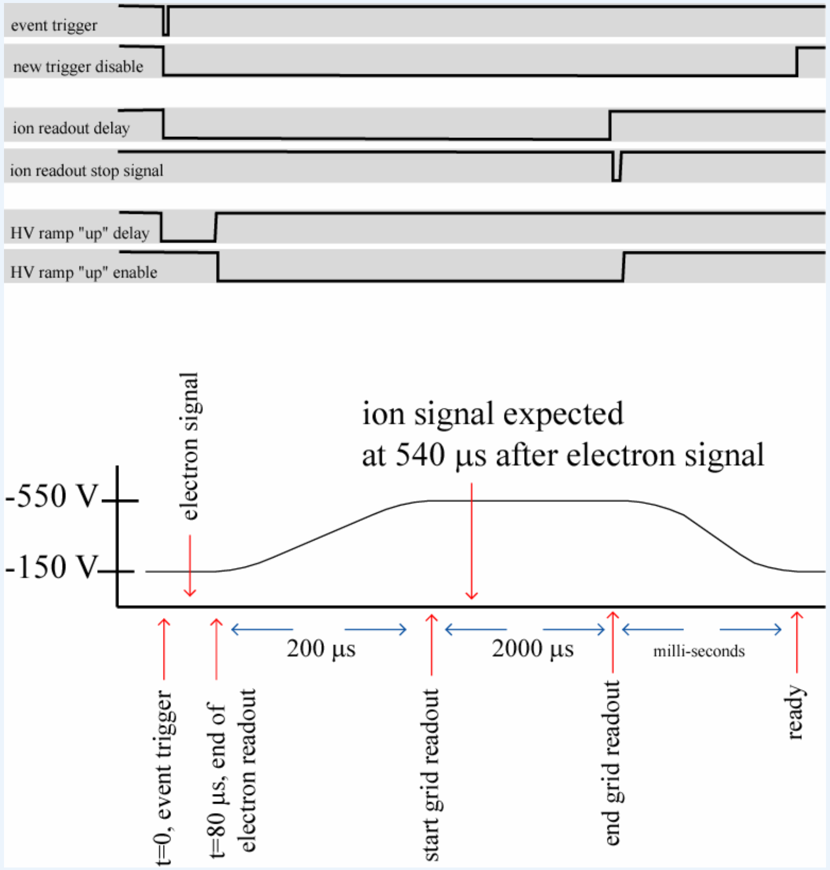
If ion feedback is not sufficiently suppressed, a gating grid will be required.

We will attempt to measure the ion feedback on the field cage termination plane, for individual tracks.

The method differs from that used by Saclay/Orsay on MicroMegas and by Aachen on GEM.
For those measurements, a source was used to create ionization. Current was measured on the cathode.

Ion Feedback Measurement





Require small ion drift time to reduce diffusion.
(Expect ~7 µs diffusion at 540 µs drift.)

Require large ion drift time because
the amplifiers saturate during the voltage ramp.
New amplifiers will have a recovery time
less than this drift time.

Small prototype program: next 1 year

Cornell/Purdue:

Equipment upgrades affect all measurements

low noise, +2000 HV **anode supply** (wire in MWPC, pads for GEM/Micromegas)
increase from 32 to 56 **FADC** channels

Compare 2-GEM, 3-GEM, Micromegas, and Wires within the same TPC.

Compare multiple assemblies of "identical" gas-amplification devices.
Measure resolution vs. drift distance, details of biasing, gas, (location on pad).
Purdue has mounted a **3M MicroMegas** on the old pad board
Measurements with various gas mixtures: $ArCO_2$ 90:10, "TESLA TDR gas", P5,….

Ion feedback measurements

with the various gas-amplification devices
will require development of new instrumentation for the bias control
However, the method can be demonstrated this summer,
with constant bias, with MWPC gas amplification only (an REU project).

Carleton: Contact with Alain Bellerive and Madhu Dixit:
will mount a resistive charge dispersion assembly on the Cornell read-out board.

Orsay/Saclay: Contact with Paul Colas: will mount a "bulk Micromegas" on the Cornell board.

Long term ILC TPC development: the Large Prototype

Schedule for the LC-TPC group

2005	Continue testing small prototypes, start organization for Large Prototype
2006-2009	(Build) / Test Large Prototype, decide technology
2010	Final design for LC TPC
2014	Complete four years of construction
2015	Commission and install TPC in ILC detector

Ron Settles, Large Prototype, Vienna

enter EUDET

Initiative to improve test beam infrastructures for the ILC detector(s)

55% for tracking and vertexing

Electronics, slow control, telescopes, TPC field cage, magnet (from Japan) and part of the R&D.

7 M€ of funding by EU

Open to all countries, transportable.

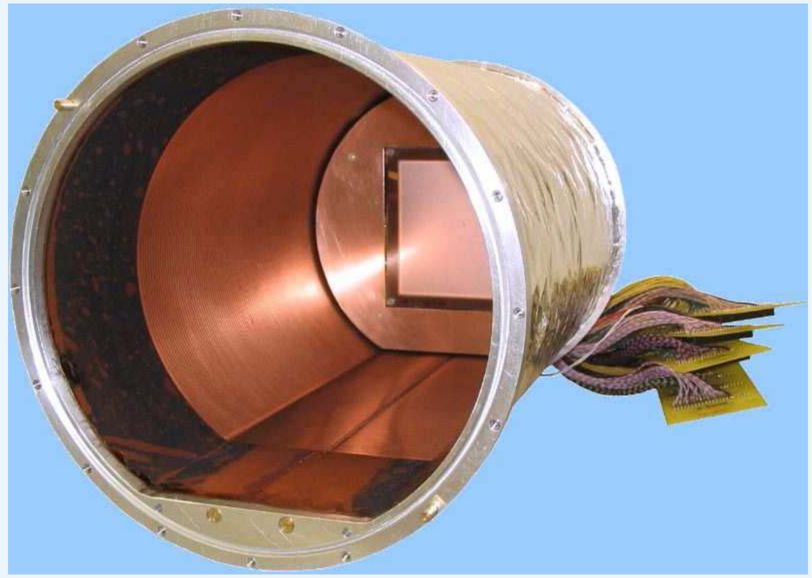
(J. Mnich, Coordinator)

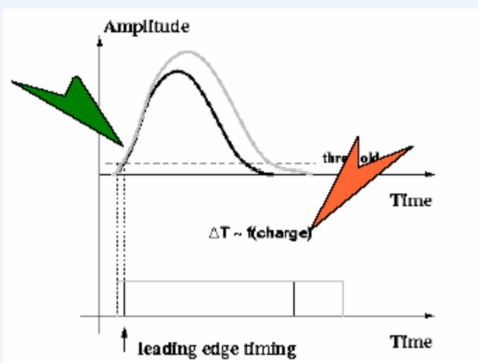
Paul Colas, tracking summary, Snowmass

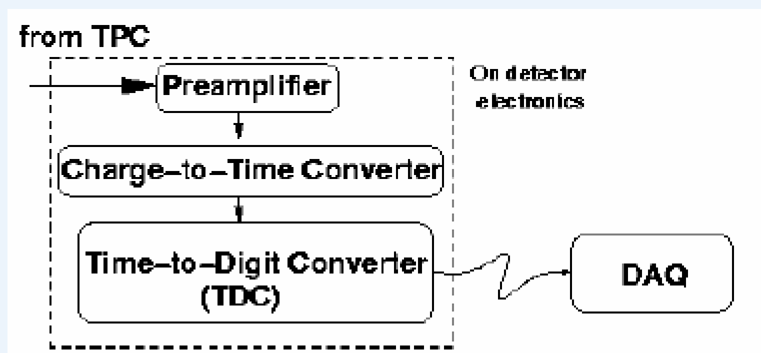
EUDET contribution to the large prototype

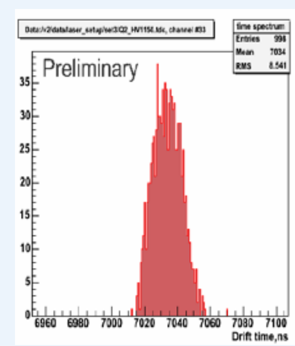
DESY (EUDET funds)
responsible for field cage

(scaled-up version of
Aachen design)









0.4mm “time” resolution

DESY-Hamburg-Rostock, (EUDET funds) TDC based read-out (TQT board)

LC-TPC LP expressed interest

The remainder of the contributions to the large prototype must come from outside of EUDET.

There is interest in Cornell designing and building an endplate for the large prototype.

Diameter = 82 cm, half the size of DR3.

There are significant mechanical problems due to magnetic field considerations.

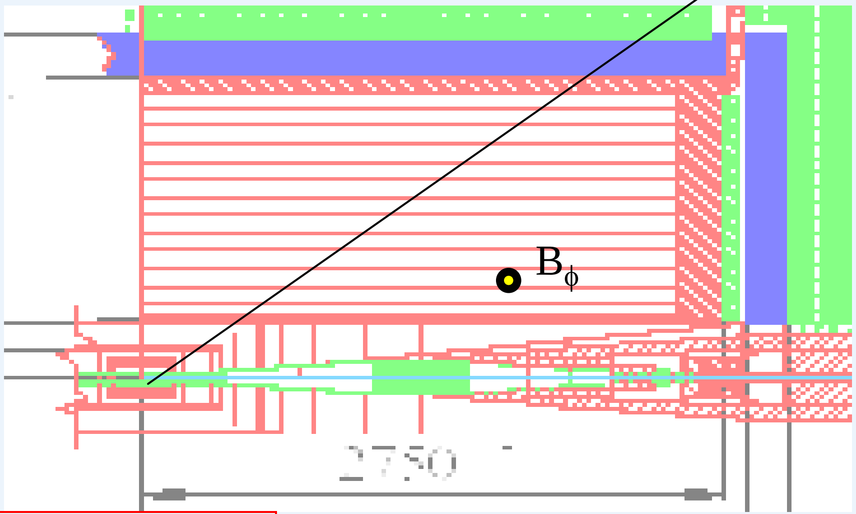
LP TPC workpackages, including relevant ILC TPC work

Workpackages	Groups expressing interest (other groups?->welcome under every WP)
1) Workpackage Mechanics	
a) Overall LP design	Desy/HH, IPN Orsay
b) Fieldcage, laser	Eudet, St.Petersburg
c) GEM endplate	Aachen, Carleton, Cornell, Desy/HH, Kek/CDC, Victoria
d) Micromegas endplate	Carleton, Cornell, Kek/CDC, Saclay/Orsay
e) Pixel endplate	Freiburg, Kek/CDC, Nikhef, Saclay/Orsay
2) Workpackage Electronics	
a) "Standard" RO electr:	Aachen, Kek/CDC, CERN, Desy/HH, Lund, Montreal, Rostock, Tsinghua
b) DAQ system	Saclay (T2K)?
c) CMOS RO electr:	Freiburg, Nikhef, Saclay (Ingrid)?
3) Workpackage Software/Simulation	
a) LP software	Desy/HH, Kek/CDC
b) TPC simulation, backgrounds	Aachen, Cornell, Desy/HH, CERN, Kek/CDC, Victoria
c) Full detector simulation	Desy/HH, Kek/CDC
d) Simulation/reconstruction framework	Eudet, Victoria
4) Workpackage on Monitoring/Calibration/Infrastructure	
a) Field map	CERN?
b) Alignment	Kek/CDC?
c) Gas/HV	Eudet, Victoria
d) Distortion correction	CERN?, Victoria

Magnetic Field Considerations

from DPP, "LDC question TR_7", Snowmass, Aug 2005

Consider a specific case of
magnetic field distortions in the drift path,
in particular, the effect of
a B_ϕ with the following characteristics.
B_ϕ=0 at z=0,
and increases linearly with z.
B_ϕ is maximum at R=0,
and decreases linearly to zero at mid-radius.

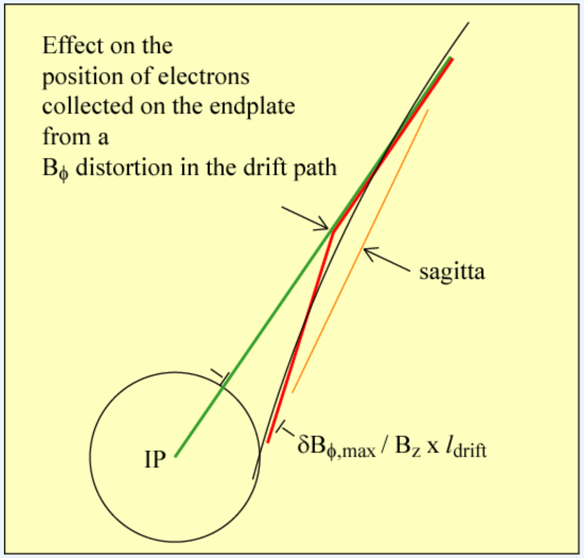


This particular magnetic field distortion,
with magnitude 1% ,
creates an error in sagitta, $\Delta s = 2.8 \times 10^{-3}$ m .

The sagitta limit is $\delta s < 6 \times 10^{-6}$ m based on a limit of a 5% increase in the system momentum resolution.

Thus the requirement accuracy of the field mapping is
$\delta B/B < 1\% \ (6 \times 10^{-6}) / (2.8 \times 10^{-3}) = 2 \times 10^{-5}$.

This is an order of magnitude better than Aleph.

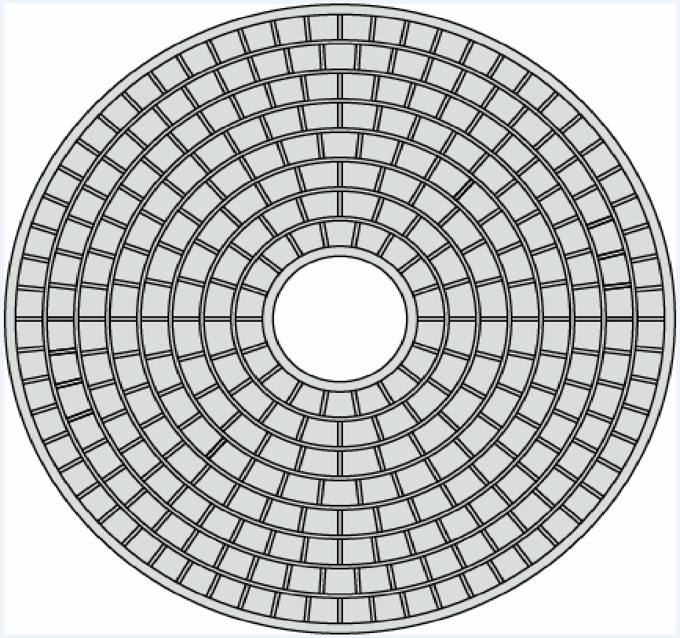


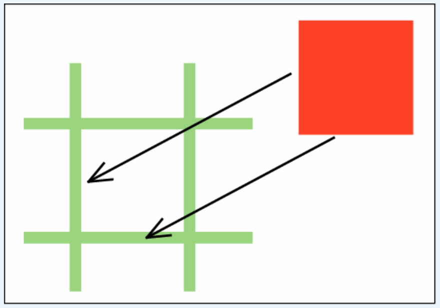
Relevance of the Magnetic Field Distortions

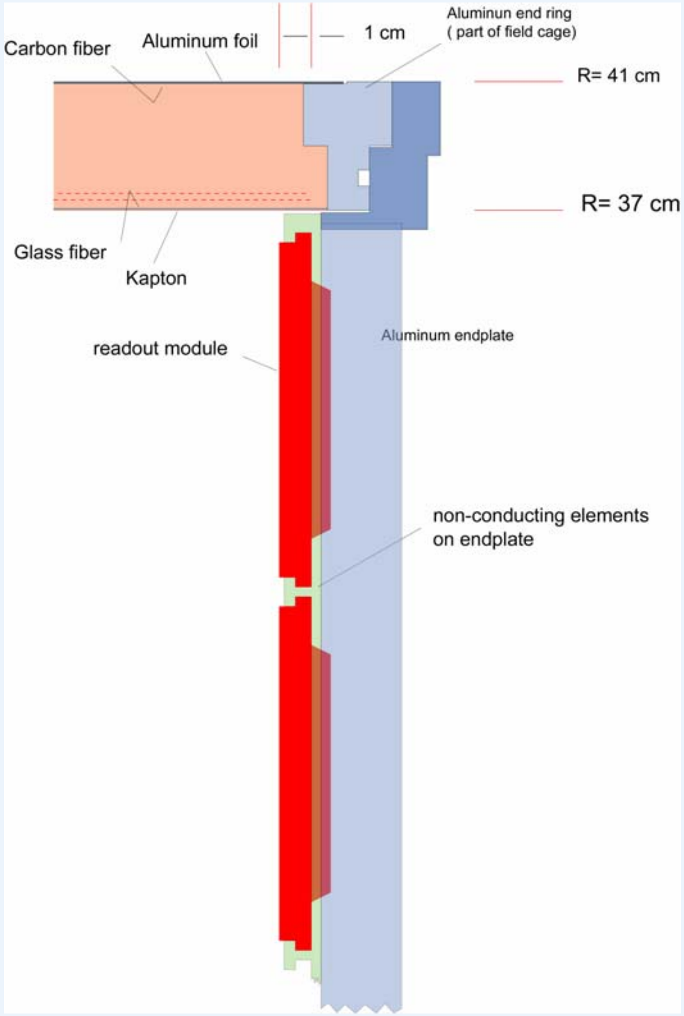
The TPC endplate will be tiled with read-out modules.

Magnetic field measurements will not be sufficiently accurate to align the modules with tracks.

The modules must be positioned to an accuracy that does not degrade the resolution, 100μm or .004 inch. Modules locations must be known to 0.001 inch.







Conclusion

LC-TPC is a large international effort to design a TPC for the ILC.

Cornell can play important roles in that effort.

Small prototype program

Contributing to the direct comparison of GEM and Micromegas
This compliments the work being done with the MPI chamber.

Measurement of the ion feedback
(If ion feedback suppression in GEM/Micromeags is insufficient, the gating grid required to control significant ion feedback creates significant complexity and material in the endplate.)

Large prototype program

Develop a light, rigid, accurate, endplate.
We require reproducible and stabile placement to 0.001 inch.

Industrialize the production of readout module to populate the endplate.