Gaseous Tracking

Daniel Peterson, Cornell University

19-June-2007 version3

Outline

- the global organizations
- directions in gaseous tracking
- development of a TPC for the central tracker
- simulations of track reconstruction and noise tolerance in a TPC
- forward tracking
- TPC pixel readout
- possible other contributions to the international effort

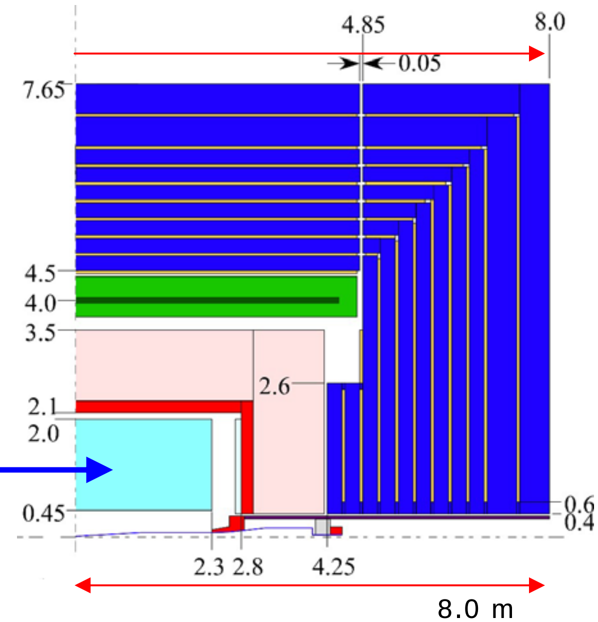
Global programs: the concepts

A Time Projection Chamber (TPC) is the central tracker in 2 of the ILC detector concepts.

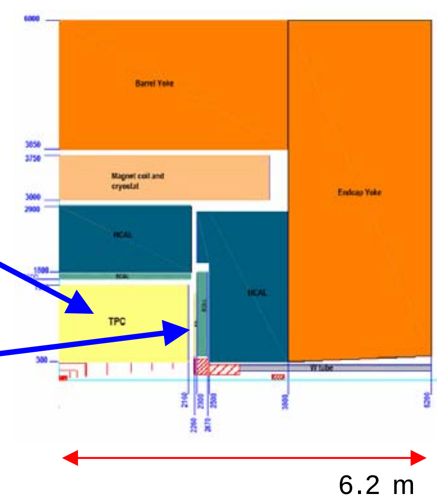
Goals: $\delta(1/P_t) \sim 2\text{-}5 \times 10^{-5}$/GeV

100% reconstruction efficiency

The **GLD** includes a 2.0 m outer radius TPC in a 3.0 Tesla field. ($Br^2 = 12.0$)



Large Detector Concept (LDC) includes a 1.58 m outer radius TPC in a 4.0 Tesla field. ($Br^2 = 10.0$)



In addition, the LDC design includes a GEM technology planar tracker covering the endcap of the TPC to define the exit point.

Global program: the TPC collaboration

LC-TPC is the international R&D organization

providing coordination and exchange of information in the "small prototype" program

and collaborating to build and study a series of large prototypes.

LC-TPC crosses the lines of LDC and GLD.

USA
Cornell
Indiana
LBNL
Louisiana Tech
Purdue (observer)

Canada
Carleton
Montreal
Victoria

Asia
Tsinghua
CDC:
Hiroshima
KEK
Kinki U
Saga
Kogakuin
Tokyo UA&T
U Tokyo
U Tsukuba
Minadano SU-IIT

Europe
LAL Orsay
IPN Orsay
CEA Saclay
Aachen
Bonn
DESY
U Hamburg
Freiburg
MPI-Munich
TU Munich (observer)
Rostock
Siegen
NIKHEF
Novosibirsk
Lund
CERN

LC-TPC milestones as reported at the Beijing Review, Feb 2007

2007-2010 small prototype and large prototypes

2008-2009 LP1
2009-2010 LP2

2011 Final design for ILC TPC

2012-2016 construction

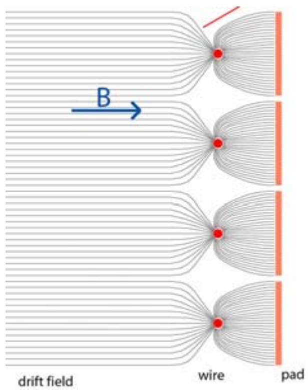
2017 commission

Directions in gaseous tracking

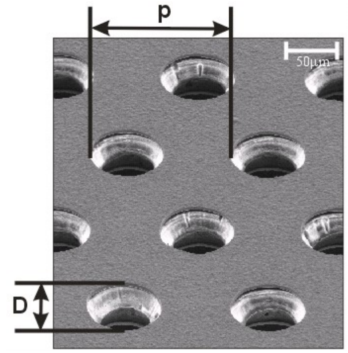
All gaseous tracking devices work on a principle
of collection ionization formed by passing charged particles,
and amplifying that ionization to create a detectable signal.

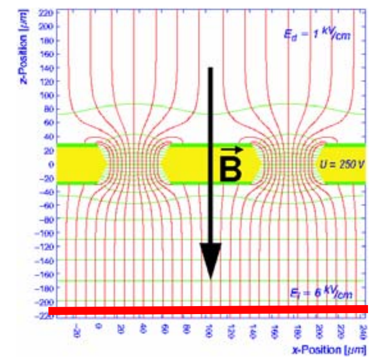
Meeting the ILC goals will require ~100 μm point resolution and 2-track-separation of ~2mm, each about 20-50% of s. o. art.

Wires have disadvantages
- inductive signal - wide
- wire spacing: ~ mm
- strong ExB effect



GEM

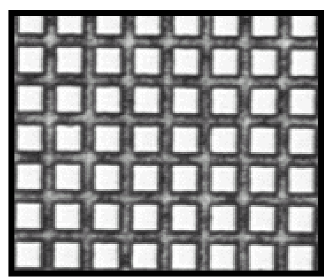


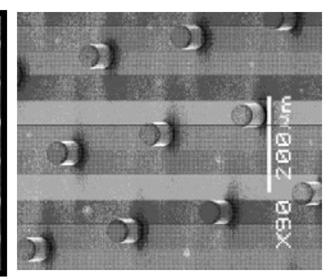


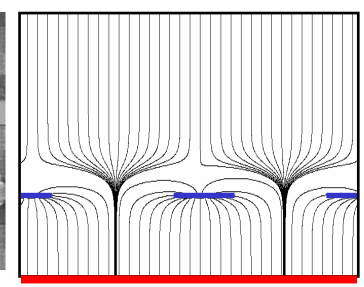
50 μm amplification region is displaced from the anode, p=140μm

anode

Micromegas



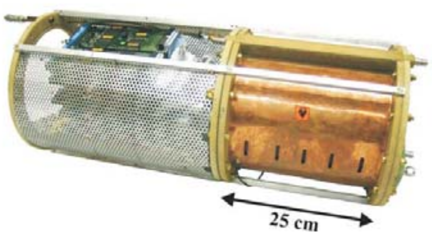


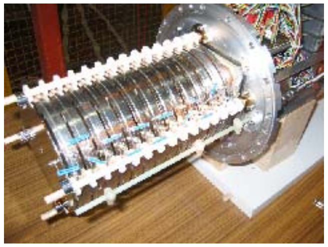


50 μm amplification region includes the anode

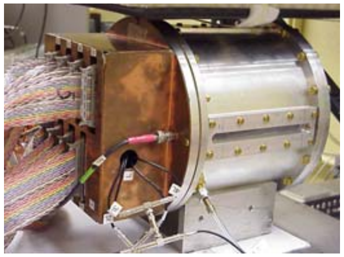
anode

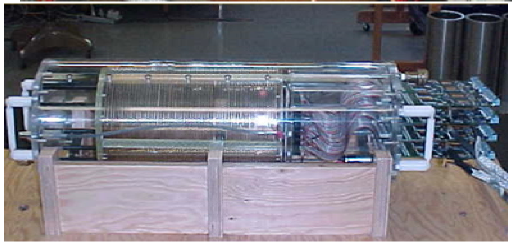
TPC small prototype program, Cornell/Purdue



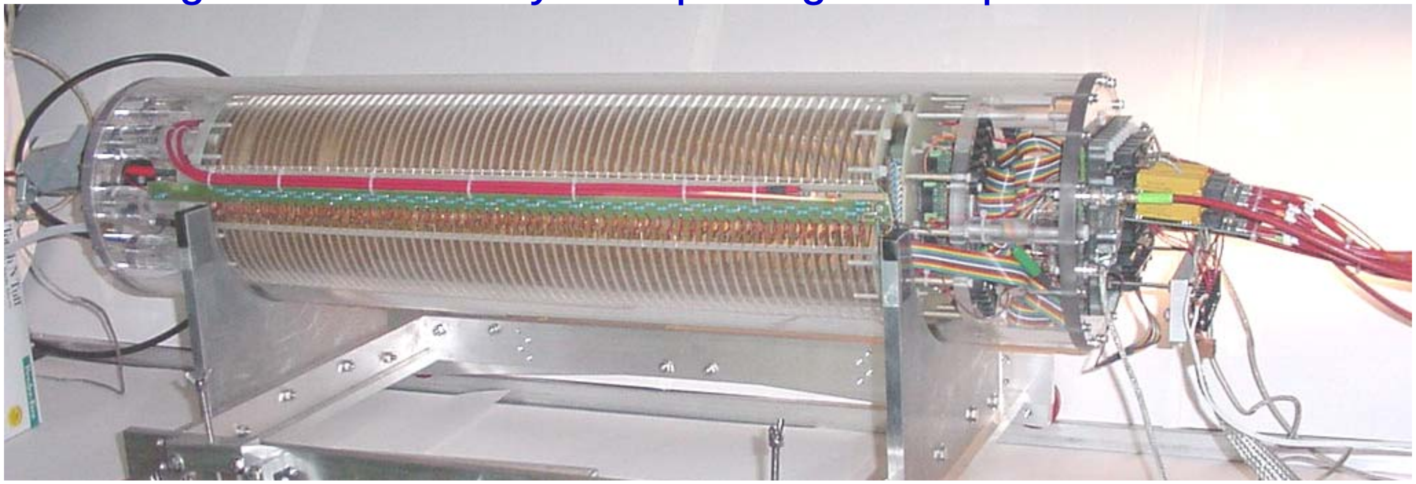


Several groups are working on
the development of a
GEM or Micromegas based TPC

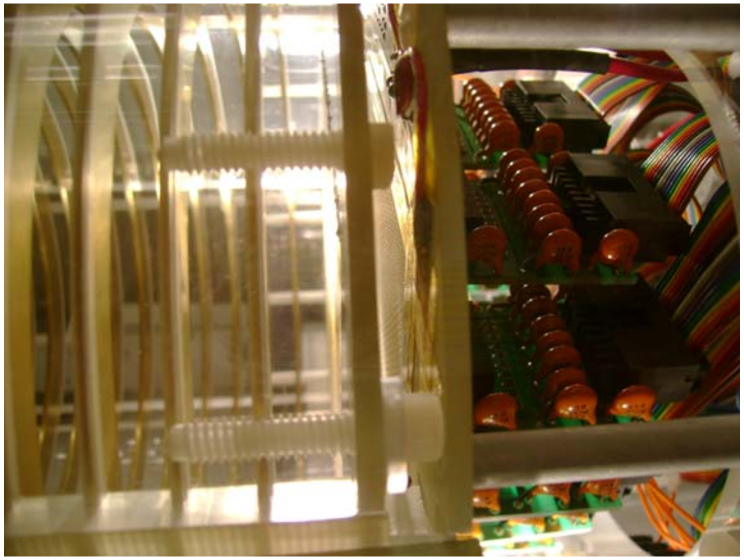


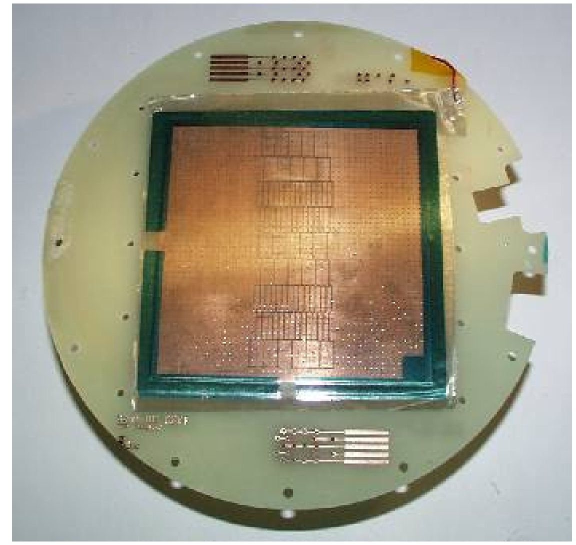


Cornell/Purdue chamber, 64cm drift,
interchangeable 10cm square gas-amplification
designed to directly compare gas-amplification technologies



TPC small prototype program, Cornell/Purdue



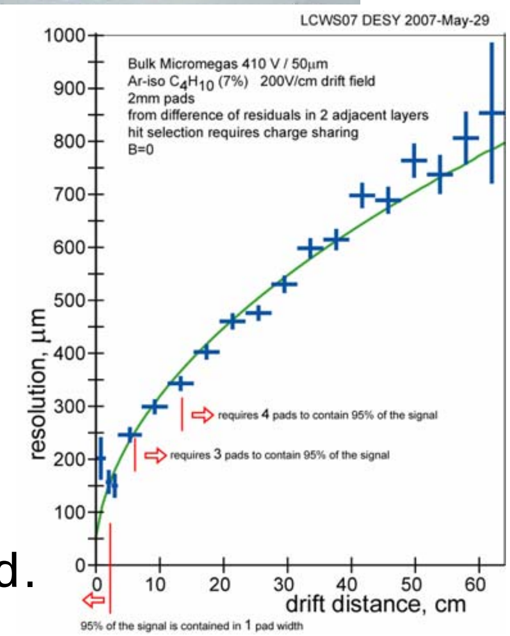


Studies with the Cornell/Purdue chamber involve independent characterization of the candidate gas amplification devices.

Shown: a “Bulk Micromegas” applied to the Cornell pad board by the Saclay group.

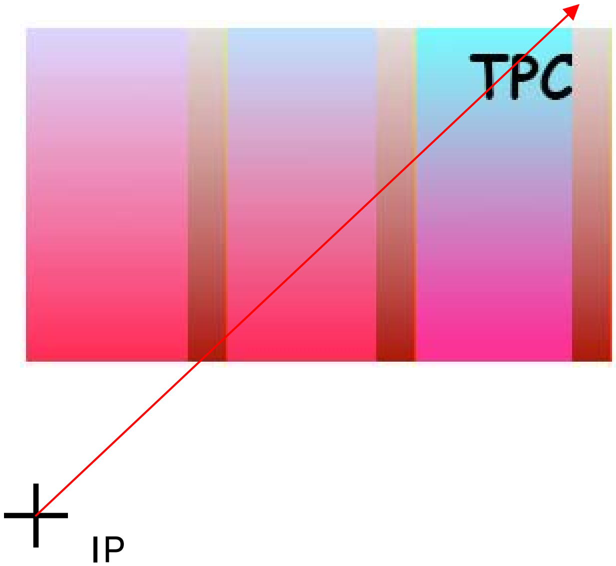
Resolution, extrapolating to zero diffusion, is 53 μm.

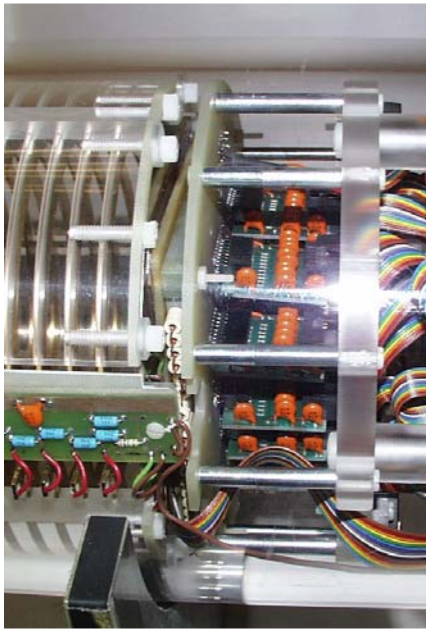
There is a need for such independent measures but this program has not had access to a magnetic field.

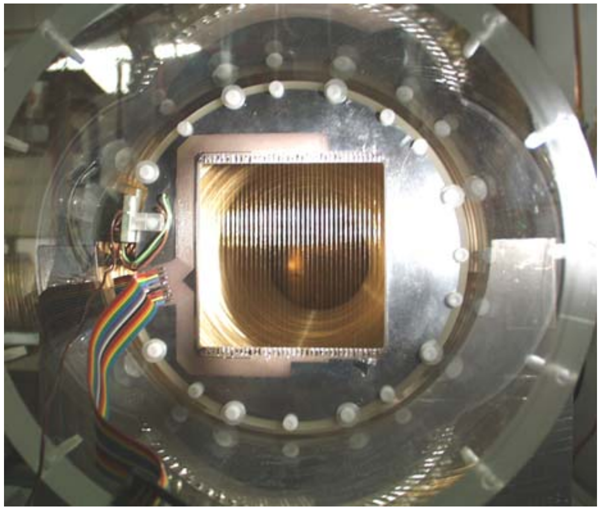


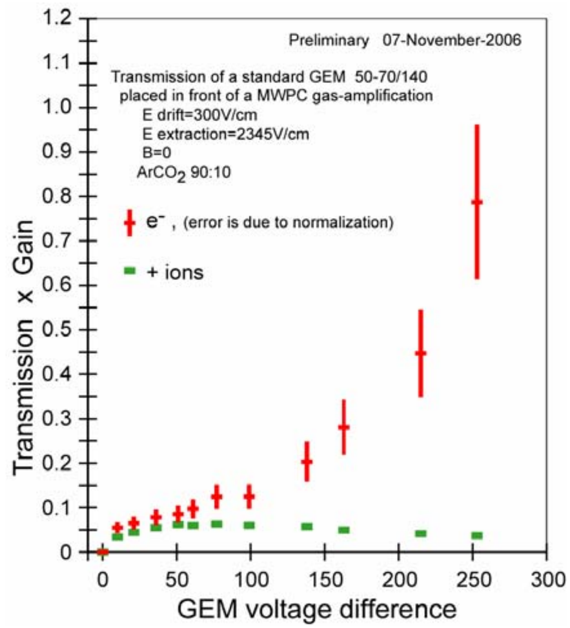
TPC small prototype program, Cornell/Purdue

Ionization in the TPC









Ions are produced at the gas amplification and drift (as sheets) into the field cage.

LCTPC is investigating ion gating technology, including a gated GEM.

Cornell/Purdue program includes measurements of ion transmission, and (future) ion feedback.

TPC small prototype program at Cornell

future plans

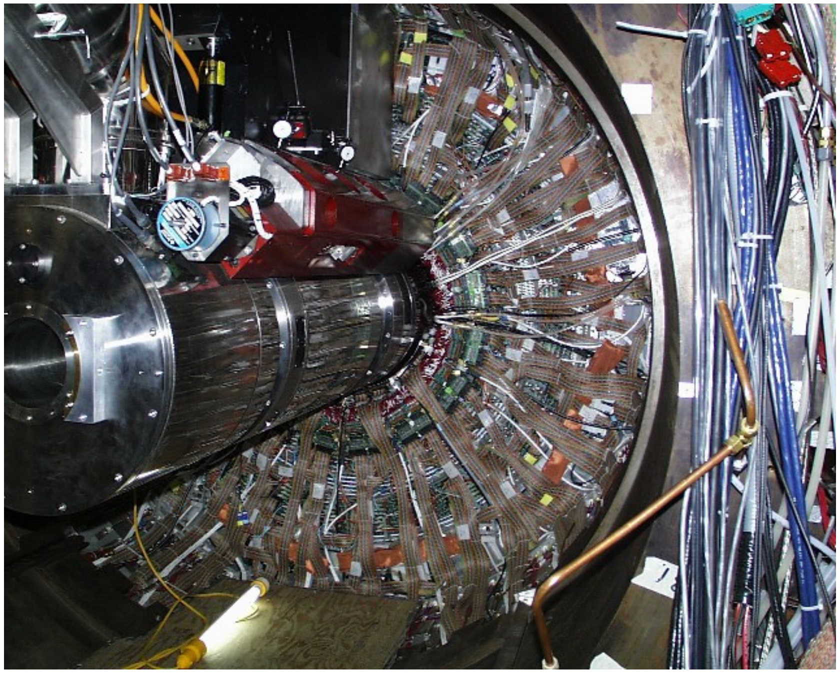
direct comparison of triple-GEM and Bulk Micromegas
(only the Munich/CDC chamber has made these comparisons,
there is need to duplicate these measurements)

Ion/electron transmission measurements,
with different configuration GEM

Ion feedback measurements

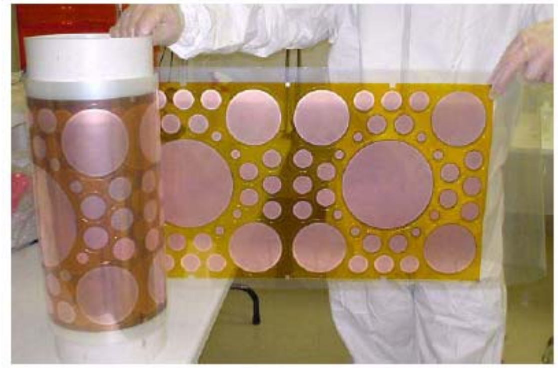
a possible magnetic field run
in the CLEO magnet
fit into the possible CESRTA schedule

It is very important for all of these
measurements in a magnetic field.



MPGD development, Purdue

Purdue started with development of GEMs with 3M, ALCPG 2003.



Micromegas is commercially made by the 3M corporation in a proprietary subtractive process starting with copper clad Kapton.

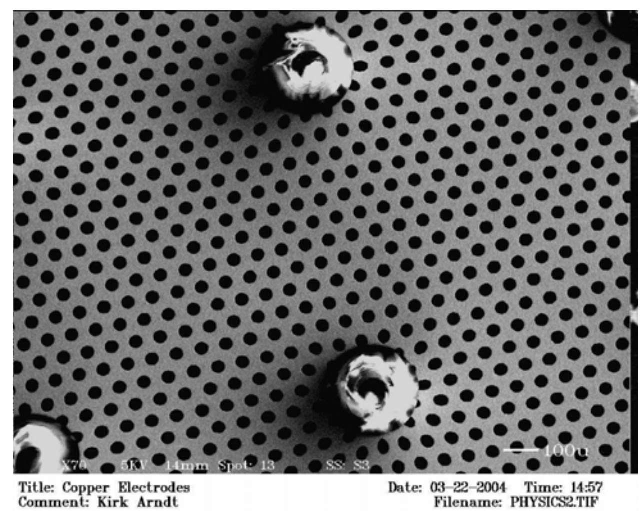
Holes are etched in the copper
- 70 μm spacing (smallest distance)
- 35 μm diameter

Copper thickness: 9 μm

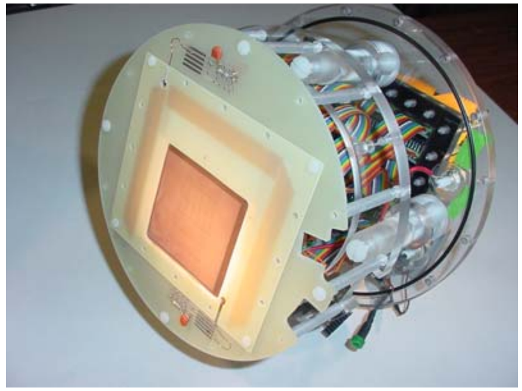
Pillars are the remains of etched Kapton.
- 50 mm height
- 300 mm diameter at base
- 1 mm spacing, square array

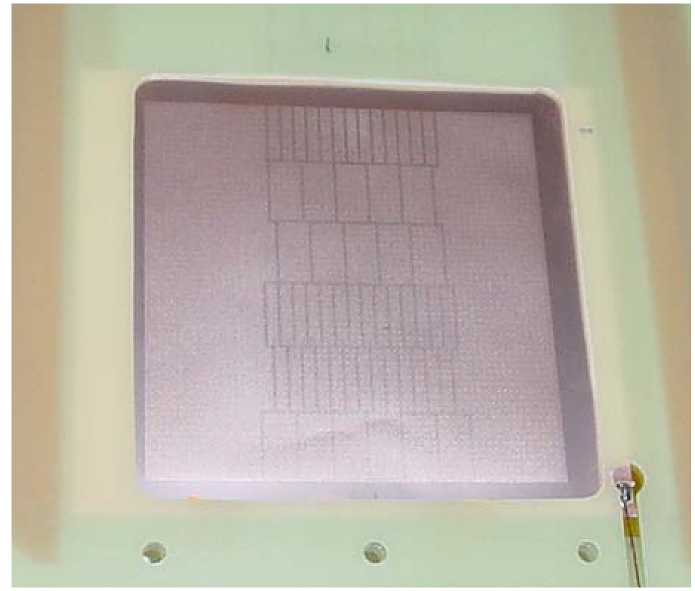
The shiny surface of the pillars is due to charge build-up from the electron microscope.

Has different physical characteristics and response compared to mesh Micromegas.



MPGD development, Purdue

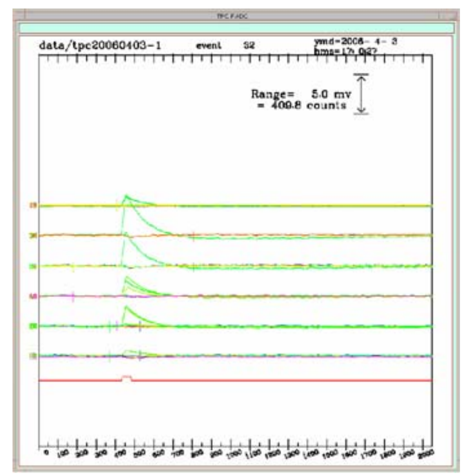




Purdue-3M Micromegas was tested
at Cornell in 2006.

Pulse height is 5X that is mesh Micromegas.

This device is also used in the
Berkeley VLSI TPC readout development
(below).



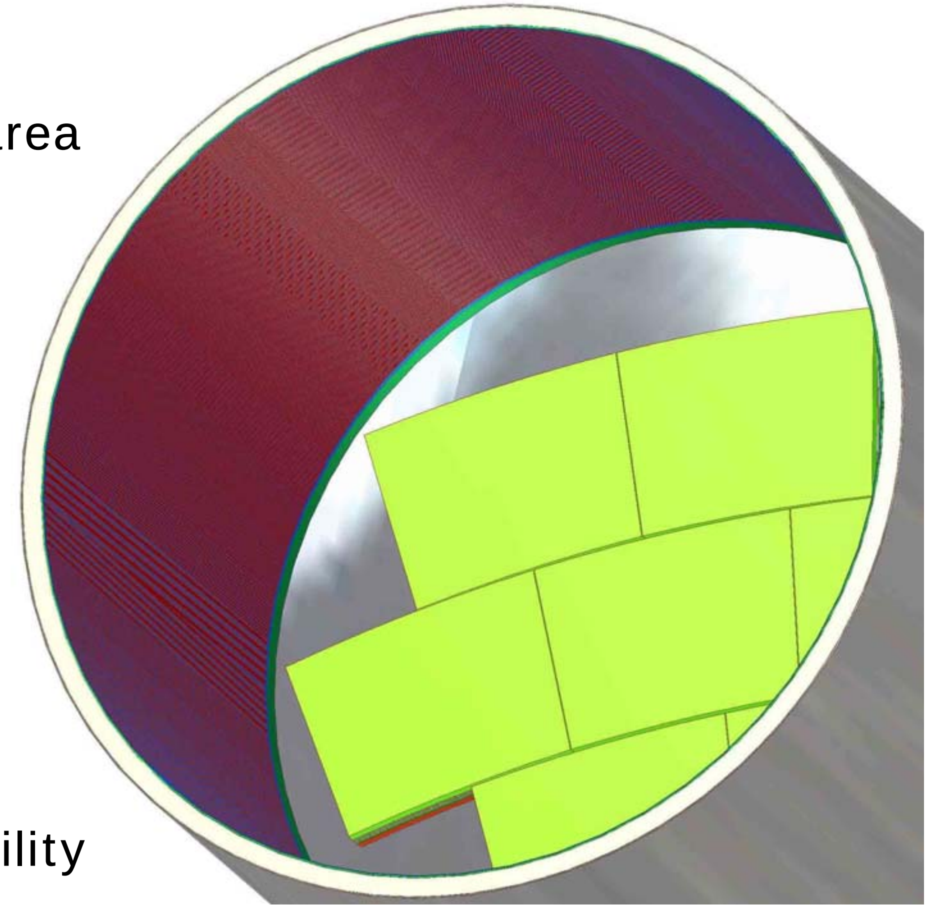
Future/possible development
- larger area
- thinner copper

costs ... $123K ($47K would be provided by Purdue)

TPC large prototype program, LC-TPC

immediate goals

- issues related to tiling of a large area
- system electronics
- track finding in a large scale
  Micro-Pattern-Gas-Detector
  based readout.



60 cm drift length
80 cm diameter
a cut-out region of an ILC TPC

magnet field run at DESY, EUDET facility
This is only a 1.3 Tesla field.
There is a need for higher magnet field and ILC beam structure
in the future to fully understand the running and data collection.

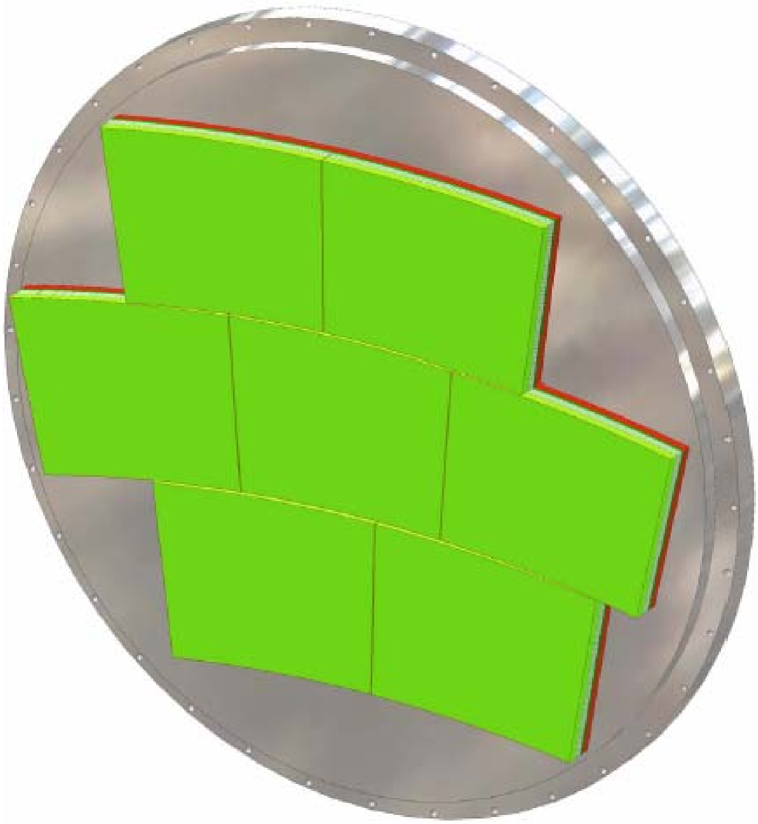
TPC large prototype program, Cornell

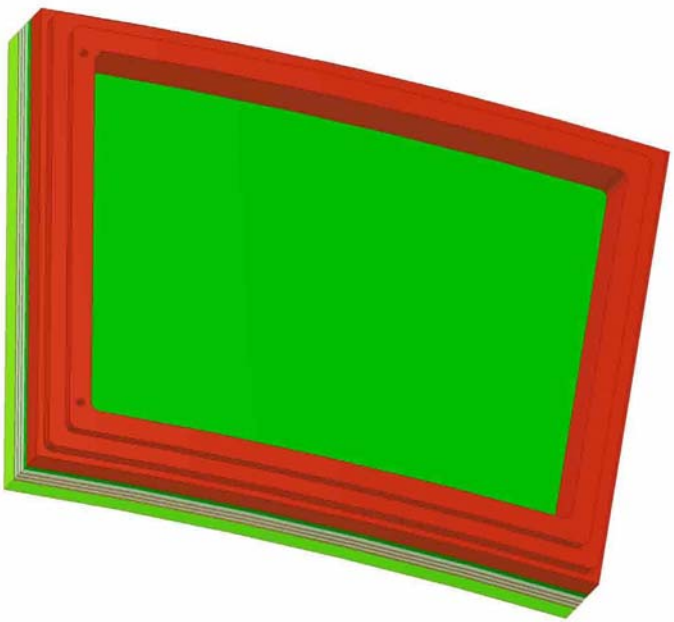
Cornell responsibility…

- endplate
- mating module frames

requirements…

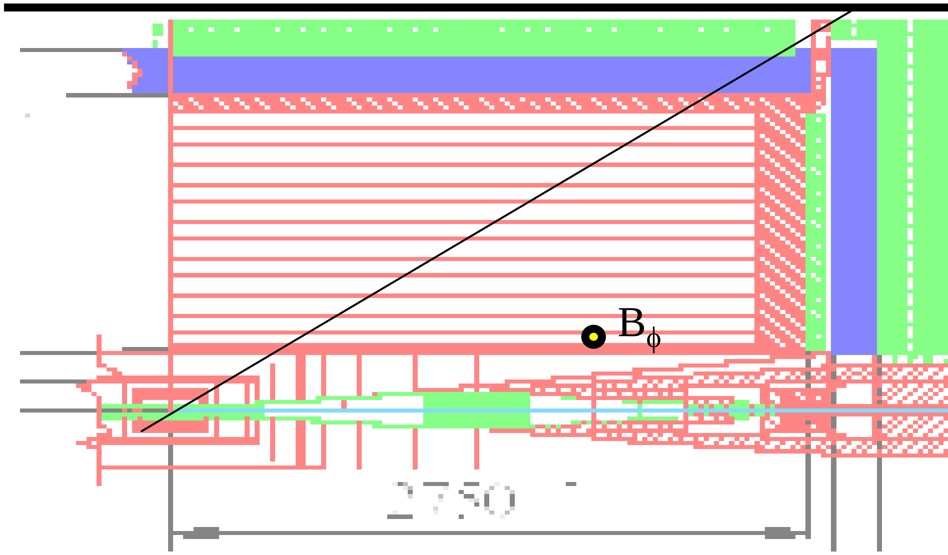
- dimensional tolerances
- minimal material
- maximum instrumented area

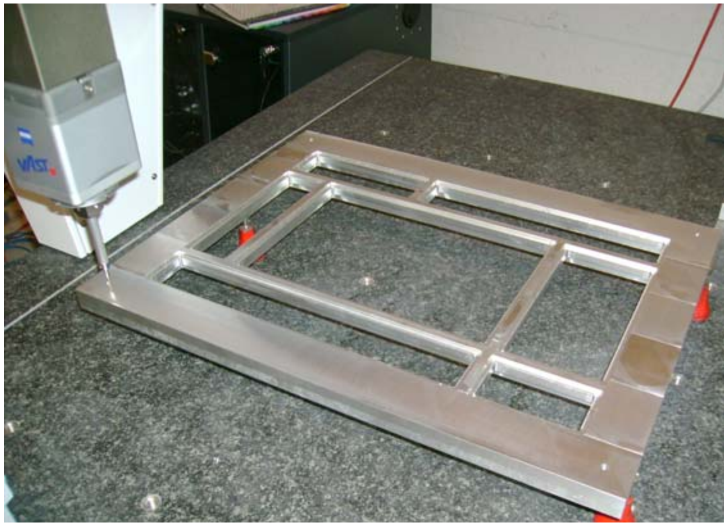




Endplates are being designed in coordination with the field cage at DESY and module requirements from institutions in France (Micromegas) and Japan (GEM)

TPC large prototype program, Cornell





Momentum measurements are

affected by field distortions changing the particle trajectory and

affected by field distortions changing the drifted electron trajectory.

Momentum resolution requirement, $\delta(1/p_t) < 2\text{-}5 \times 10^{-5}$/GeV,

results in a requirement on the knowledge of the magnetic field

$\delta B/B < 2\text{-}5 \times 10^{-5}$ (p_t above the multiple scattering dominated range.)

Previous demonstrated B-field mapping: $\delta B/B \sim 10^{-4}$.

While it is possible to improve B-field mapping with track-based survey,

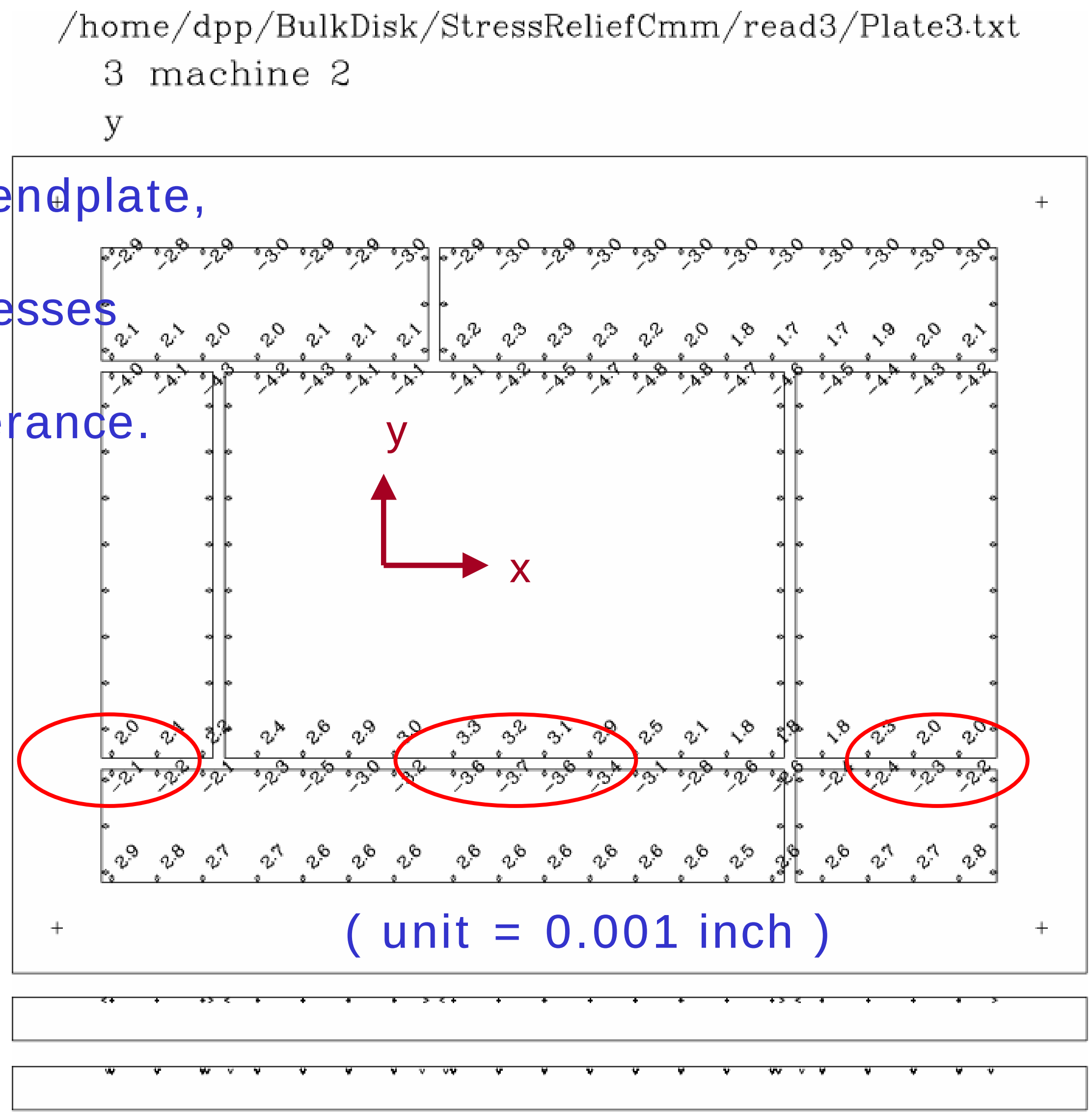
tracks are usually used to improve the readout module survey.

Must decouple these surveys with mechanical tolerances: ~ 25μm.

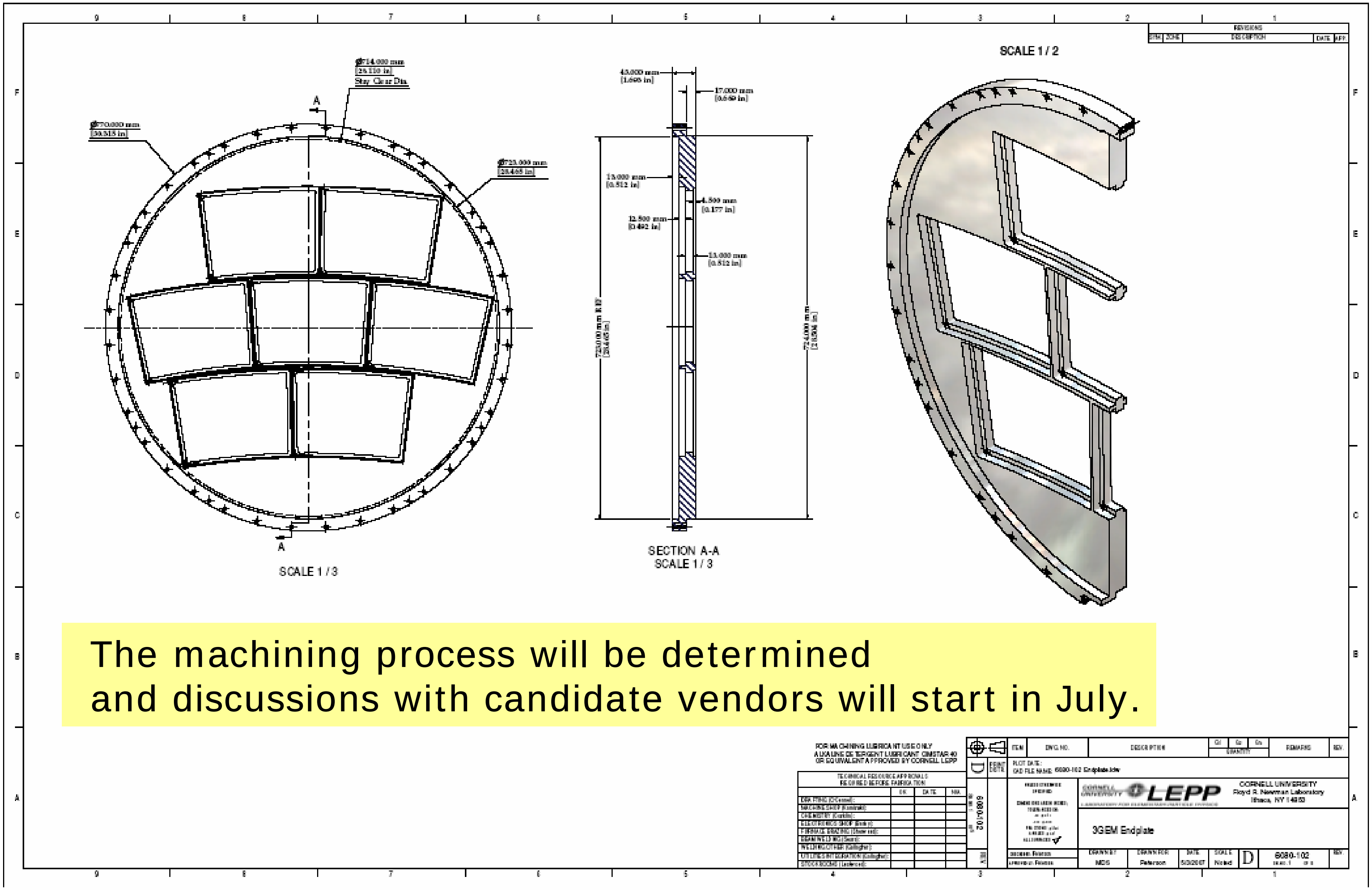
TPC large prototype program, Cornell

Preliminary to producing the endplate,
Cornell is studying various
machining / stress relief processes

to achieve the 0.001 inch tolerance.

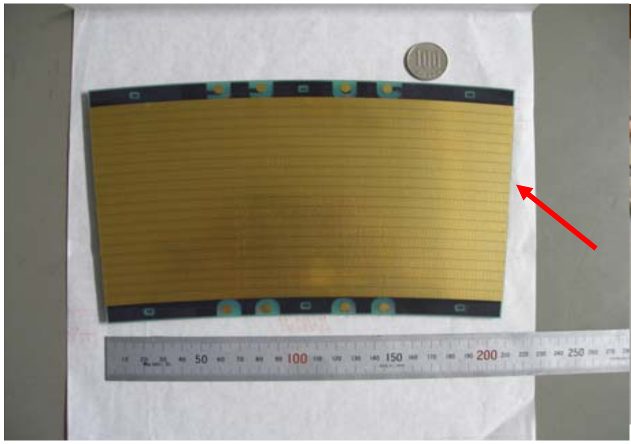


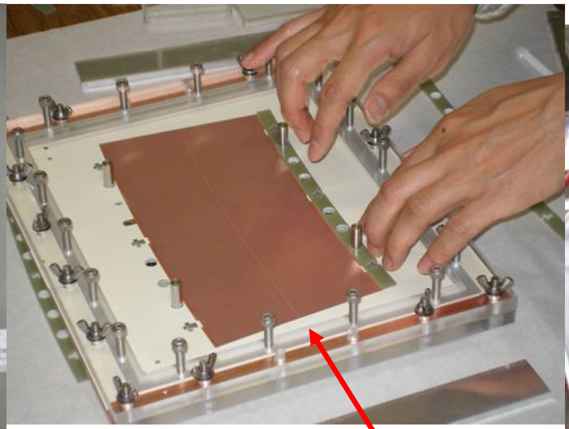
TPC large prototype program, Cornell

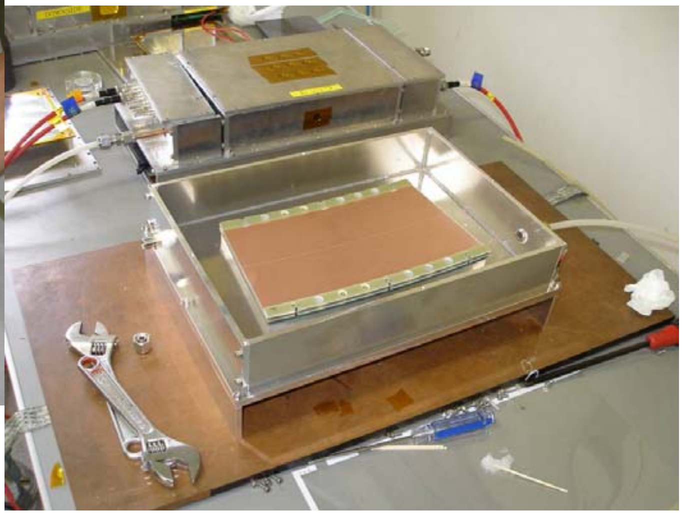


The machining process will be determined
and discussions with candidate vendors will start in July.

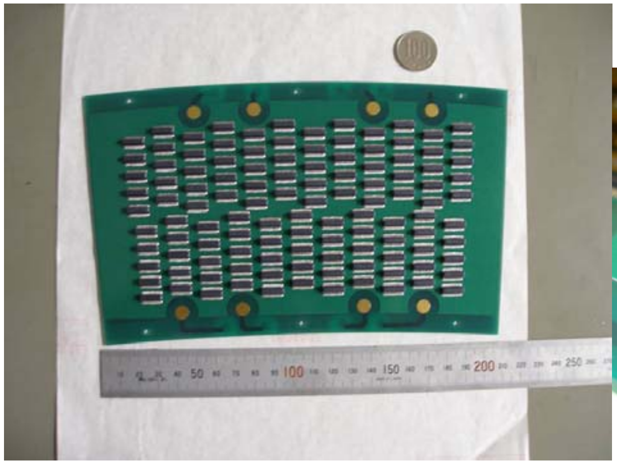
Large prototype, module - LC-TPC, Japan

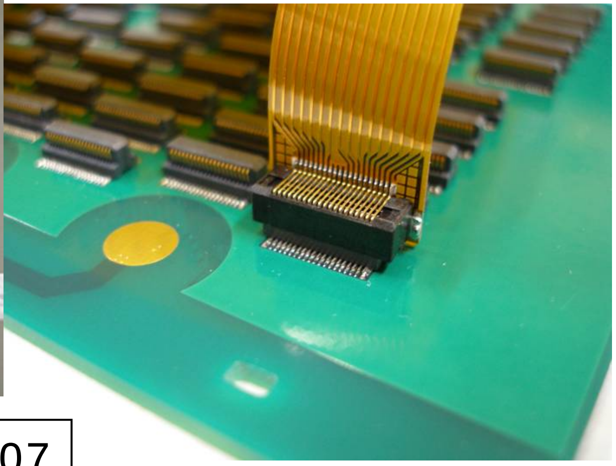






The challenge is constructing a HV-stable module with no losses in instrumented area in r-f.





A preliminary module has been constructed to mate to Cornell endplate.

pad board
stretching a GEM
module in test box
(back) connectors

Gain tests have been done.

See A. Ishikawa, LCWS07

TPC large prototype program, Cornell

schedule (as of May 2007)

Construct endplate and module frames - End of 2007
Deliver and commission Jan 2008

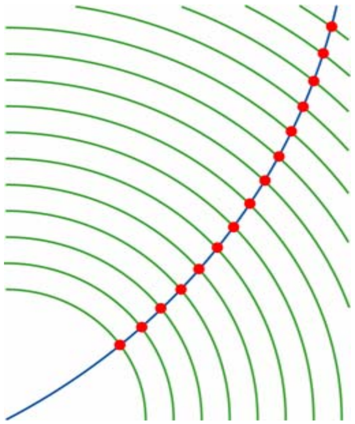
We currently plan to deliver 2 endplates
(contingent on time and budget)
1 - for assembly of a GEM readout in Japan
2 – for assembly of a Micromegas readout in France

Study tracking and alignment issues 2008 - 2009

future plans

low scattering material, but high stability, construction
for the "LP2", the last prototype before ILC detector construction
2009 - 2010

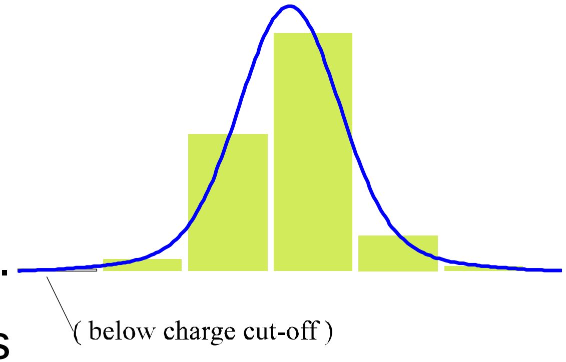
Background studies for the TPC, Cornell



"ionization centers"

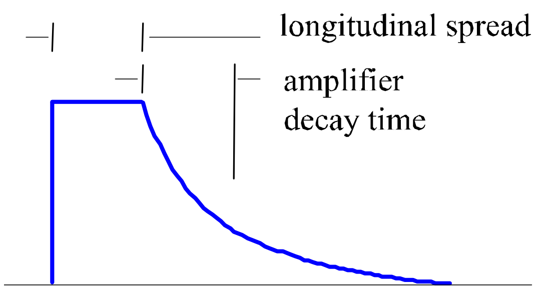
Charged particle reconstruction,
in the TPC based concepts,
requires full pattern recognition
in the TPC.
This provides a redundant system
in addition to the vertex detector.

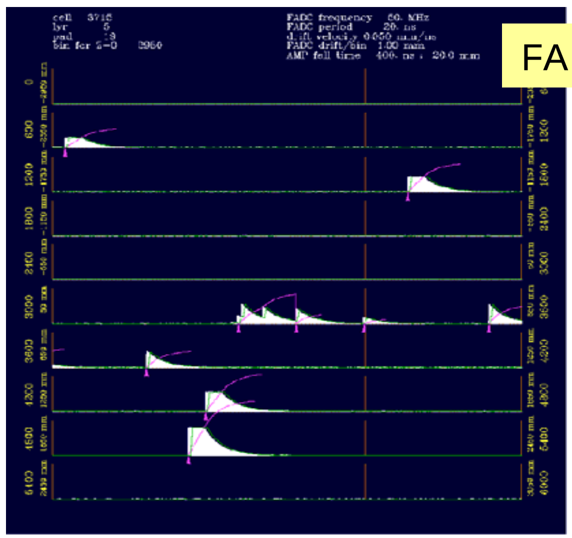
charge spread



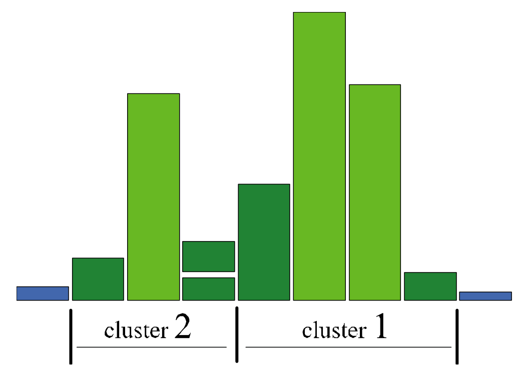
Studies of the effects of backgrounds
on the ability to reconstruct tracks in the TPC
require full simulation of the FADC response.
Work at Cornell addresses this need.

charge signal time characteristics



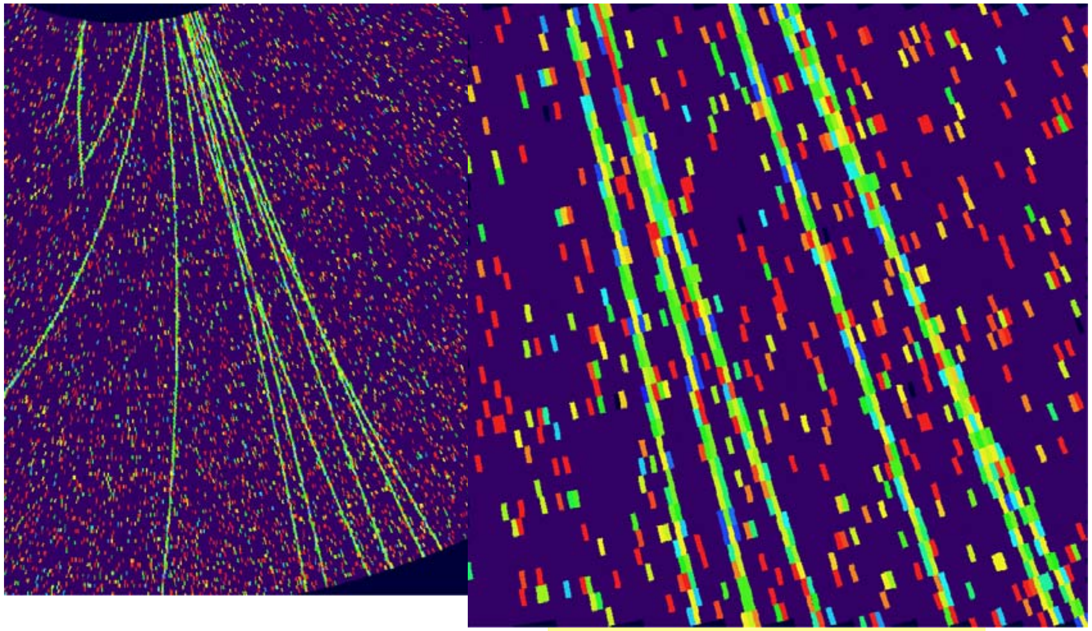


FADC response

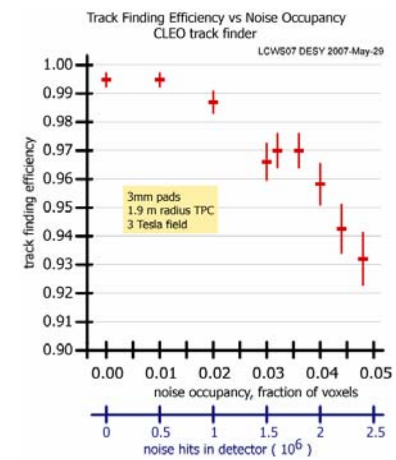


pad cluster recognition

Background studies for the TPC, Cornell

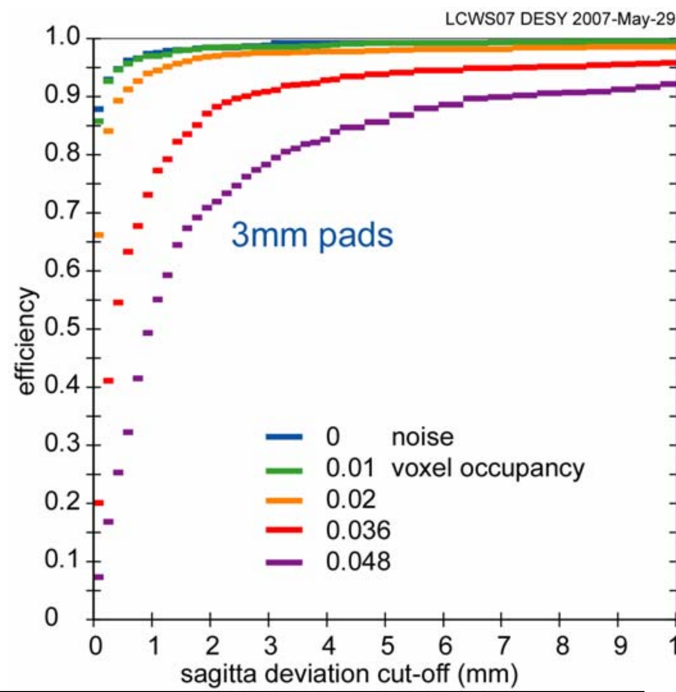


4.8% occupancy



Full simulation of the FADC response is followed by pattern recognition based on the FADC signals.

Efficiency and TPC-only resolution are unaffected at 1% (voxel) occupancy. (LCWS07)



Background studies for the TPC - LC-TPC

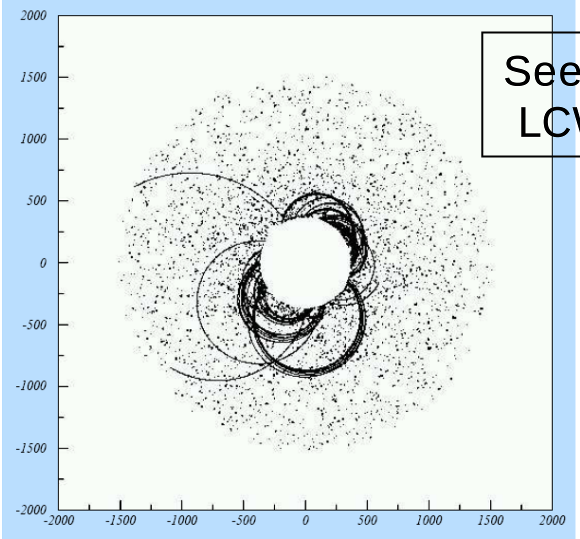
While the Cornell study indicates that a 1% uniform occupancy will not affect pattern recognition or TPC resolution,

detailed studies of expected beam-related backgrounds are required to predict the occupancy. (CPU years)

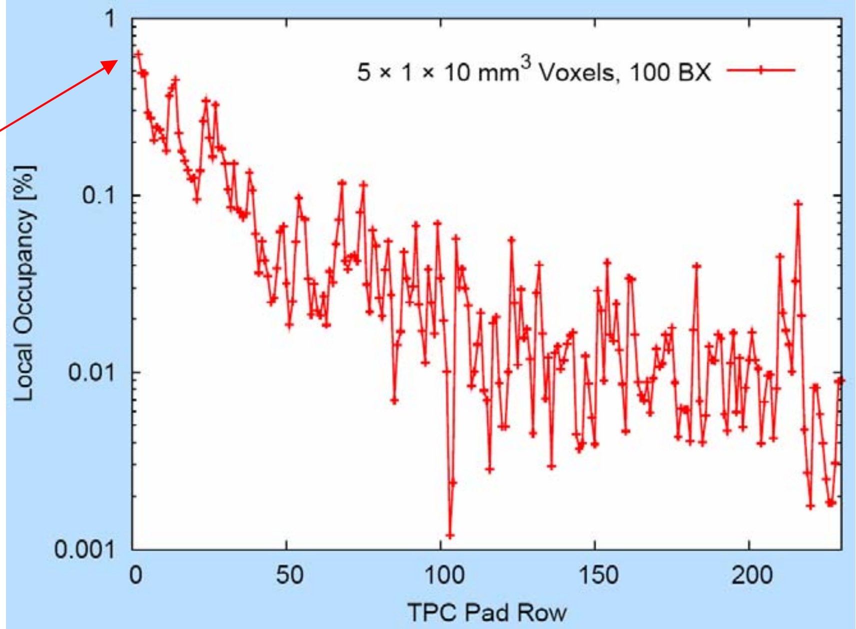
These studies are done by DESY/Hamburg, predicting 1% (maximum) occupancy.

These two studies provide the LC-TPC response to questions about occupancy.

Occupancy < 1%, which is negligible.

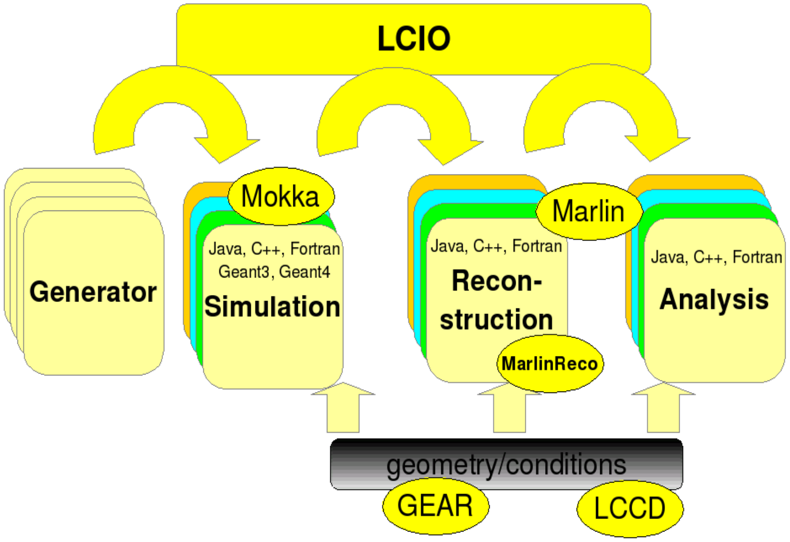


See A. Vogel LCWS07



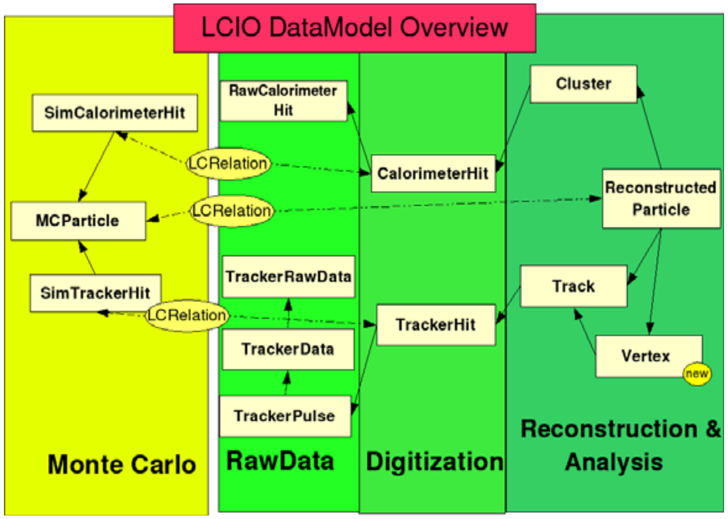
Mokka , Marlin, LCIO

The Cornell simulation/reconstruction described in the previous slides is based on an older framework and is therefore not available to others.

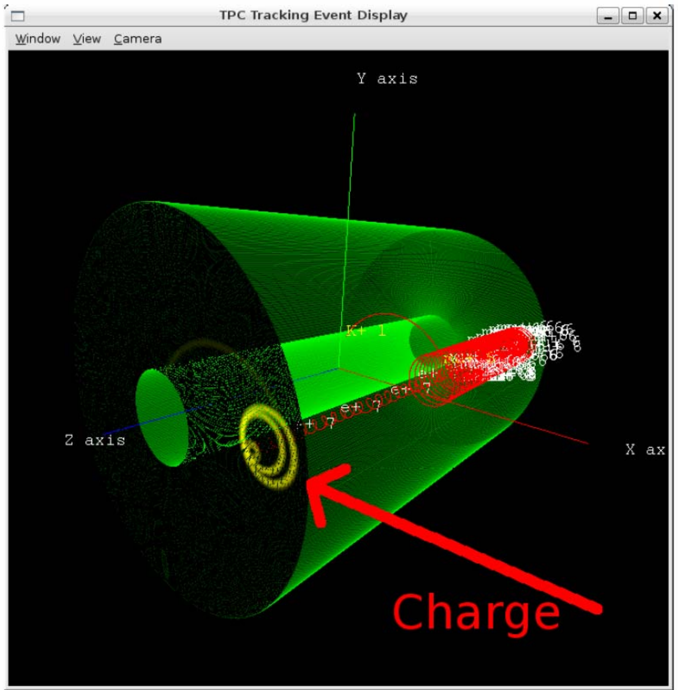


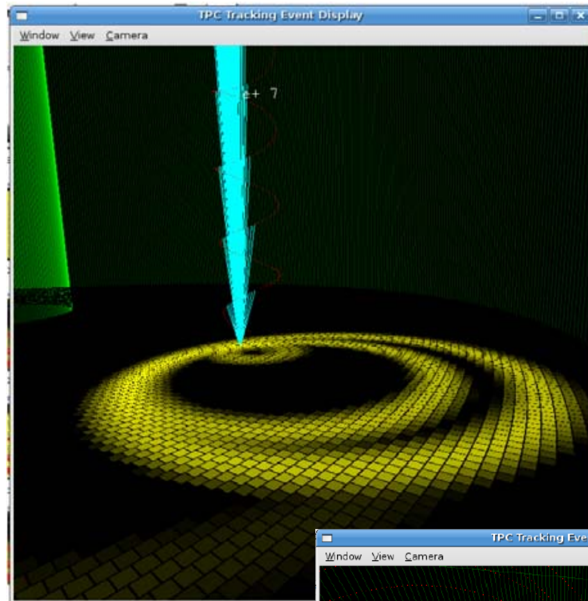
Cornell works most closely with the European groups, where a simulation/reconstruction framework is being developed.

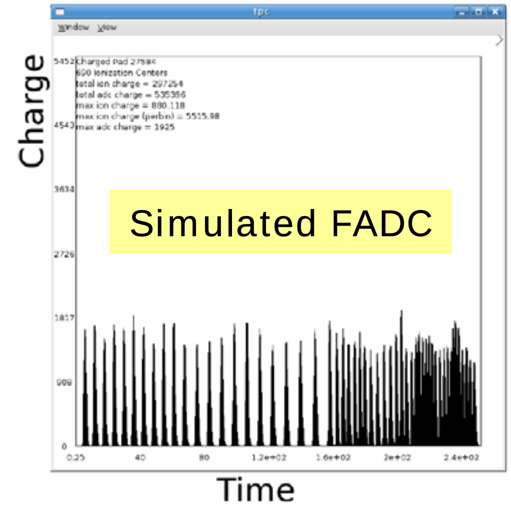
LCIO
  data model & persistency
Marlin
  C++ application framework
LCCD
  conditions data toolkit
GEAR
  geometry description
MarlinReco
  Marlin based reconstruction

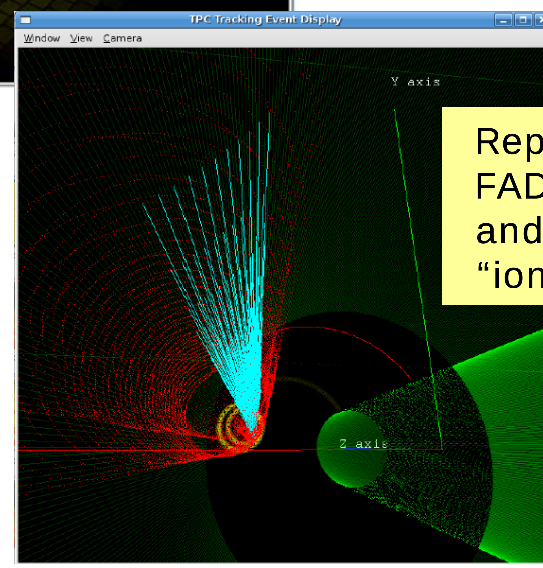


Simulation framework contributions, Cornell









Representation of FADC pulse heights and association with “ionization centers”.

The FADC simulation has been recently upgraded by a Cornell student to a C++ Marlin processor, complete with diagnostic tools.

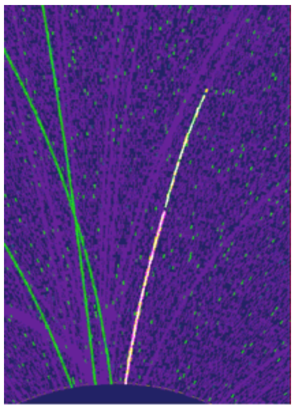
This is being integrated into the Marlin system (DESY) to allow use of the simulation in general tracking studies .

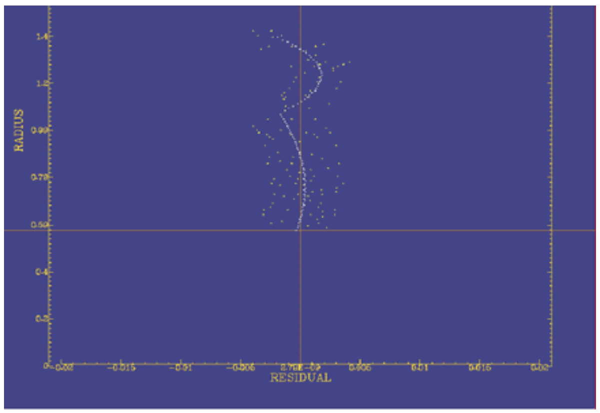
Reconstruction within Marlin framework, Cornell

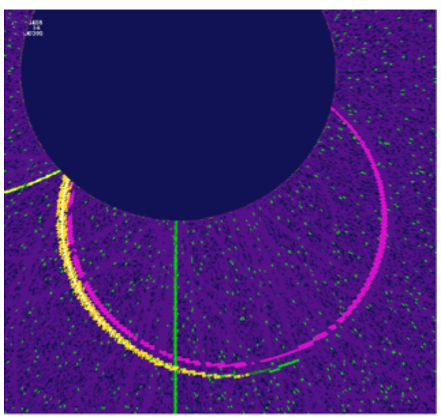
Implementation of CLEO/Cornell reconstruction in Marlin

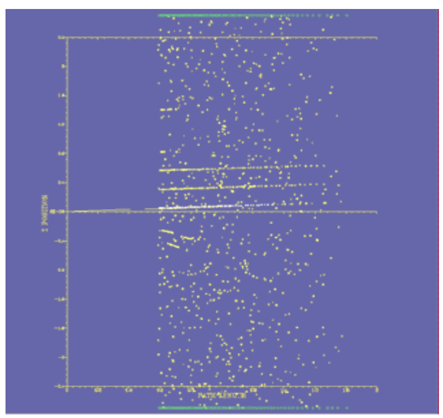
will provide high efficiency, ability to understand and resolve pathologies (as recognized by the MarlinTPC leaders).

Full translation of the Cornell program will require a student/post-doc.





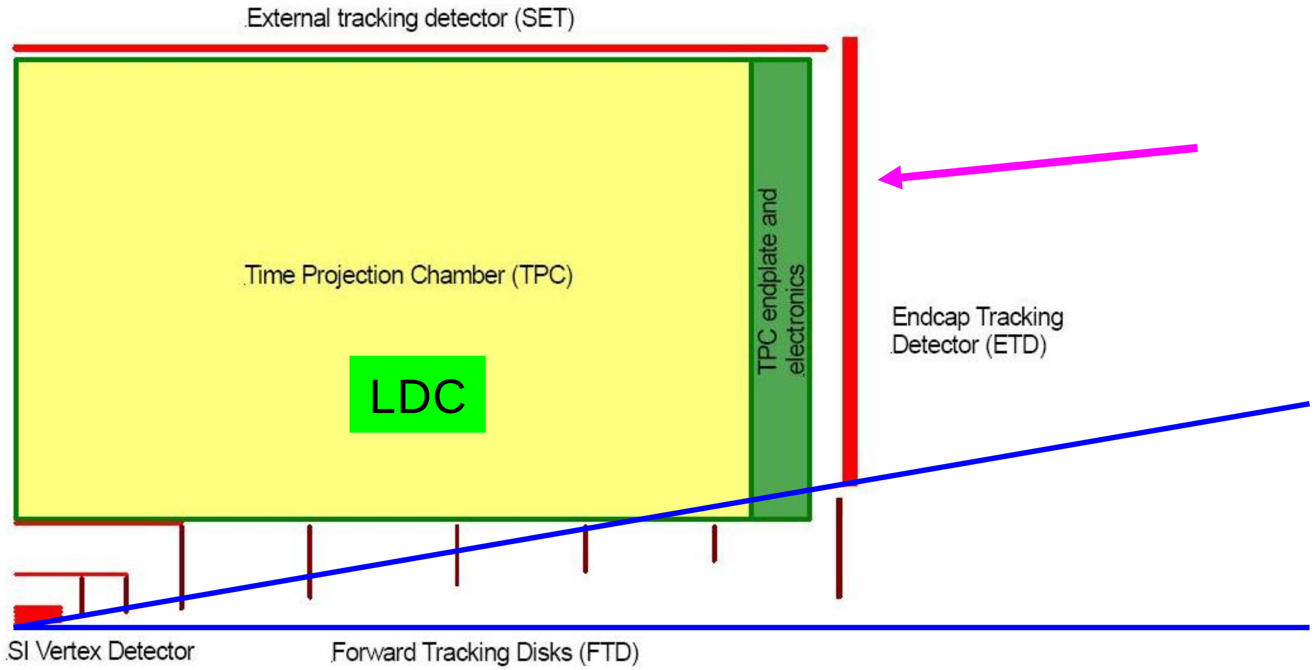




The current track finder in the Marlin reconstruction is preliminary.

Data structure	Processor name	input/output collection name
TrackerRawData		TPCRawData
	TrackerRawData2DataConverter	
TrackerData		TPCConvertedRawData
	PedestalSubtractor ChannelByChannelCorrector LinearityCorrector TimeShiftCorrector	
TrackerData		TPCData
	PulseFinder ChannelMapper GainCorrector	
TrackerPulse		TPCPulses
	HitFinder HitPRFCorrector	
TrackerHit		TPCHits
	TrackFinder[Method]	
Track		TPCSeedTracks
	TrackFitter[Method]	
Track		TPCTracks

End-cap tracker studies, Louisiana Tech

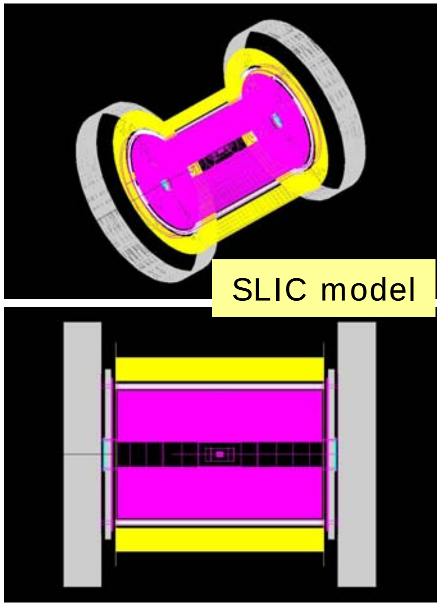


Current LDC:
10 degrees
174 mRad
cos(θ)=0.98

An **endcap tracking detector** is motivated by
- hermiticity, improvement in resolution at low angle,
- improved tracking in the very forward *(high background)* region,
- extension of differential Bhabha cross section beyond "LUMCAL".

Studies at Louisiana Tech (and collaborators)
- cover both simulation and detector prototyping

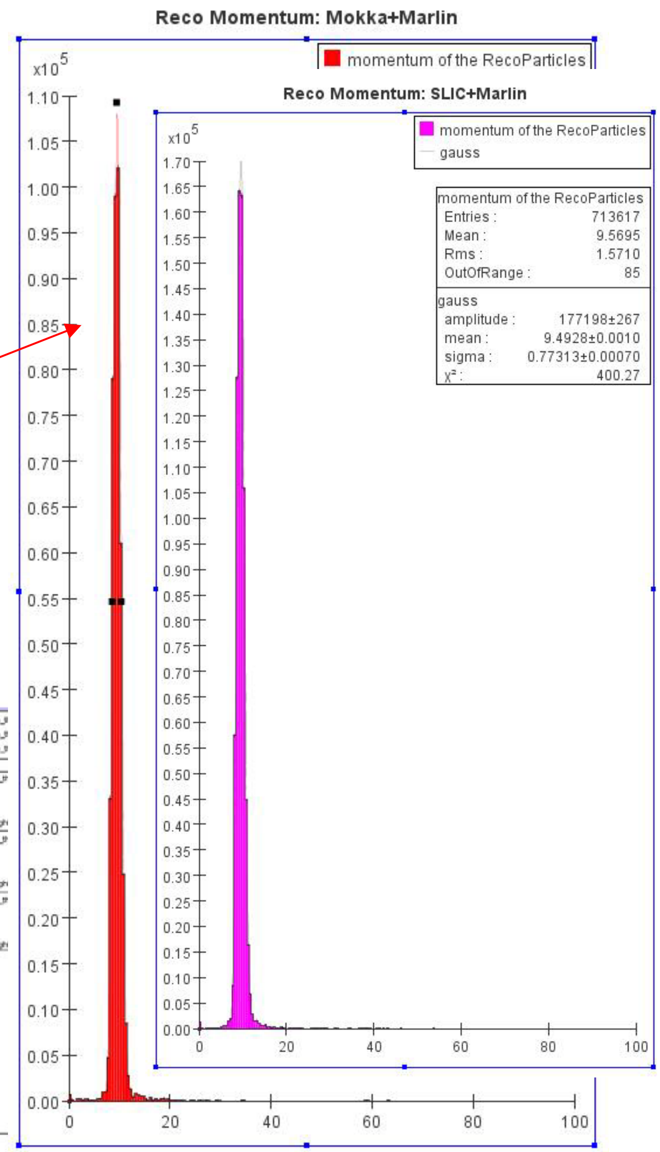
End-cap tracker studies, Louisiana Tech



Simulations in both
Mokka (Europe) and
SLIC (USA)

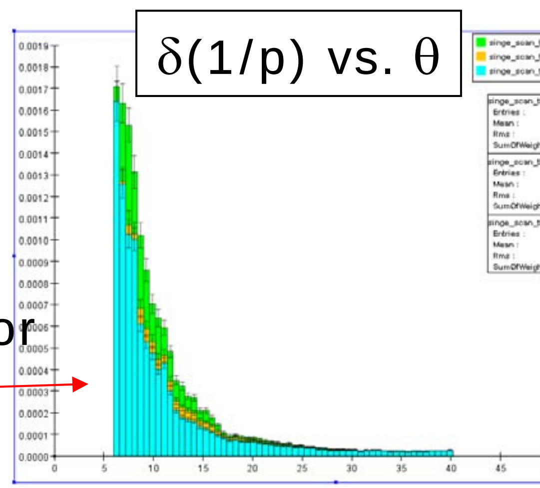
Became a developer in
Mokka/Marlin earlier than
other US groups

(comparison of μ momentum
in Mokka vs. SLIC)

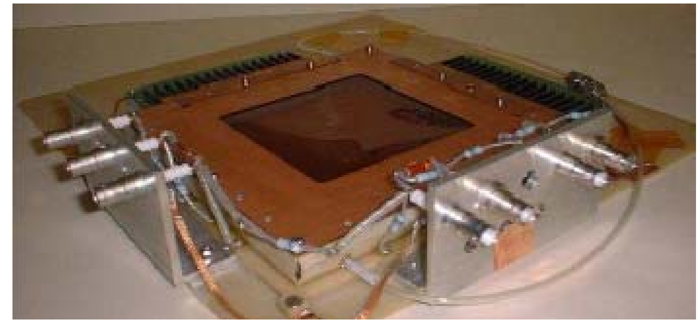


Contributions to the
LDC "outline document"

to evaluate effectiveness
of endcap tracking detector

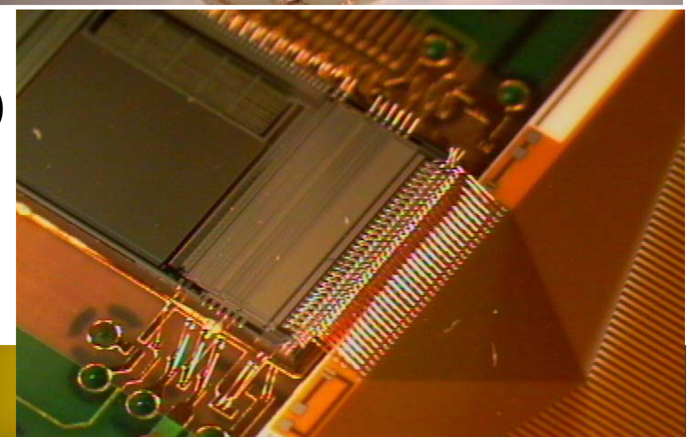


End-cap tracker studies, Louisiana Tech



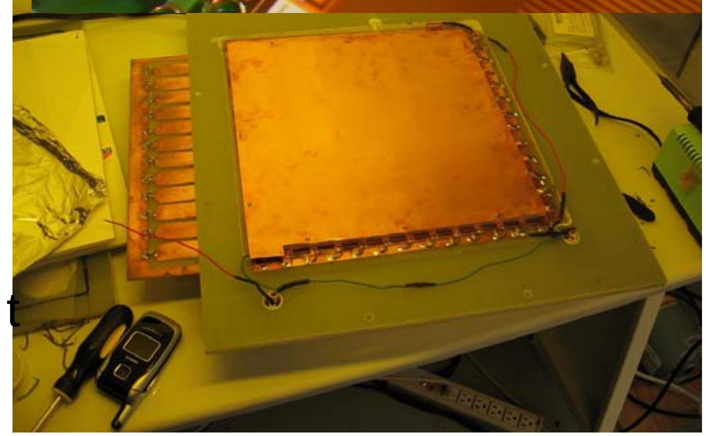
10cm x 10cm prototype built and tested
(in collaboration with QWEAK Nuclear group at La Tech).

pressure effects, voltage optimization



HELIX readout chip tested (mixed results)
pursuing other preamp/digitizers (ALRO, VFAT)

30cm x 30cm chamber built in Fall 2006
using FNAL QPA02 preamp
Second chamber under construction,
variable drift/gap



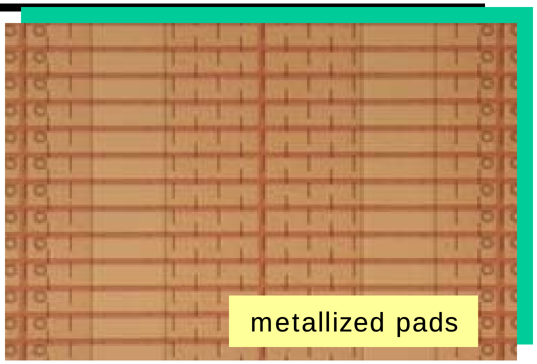
Design of readout board for
endcap geometry is underway.

Addition of Indiana U. and Oklahoma U.
test beam studies and electronics development
forward tracking algorithms

VLSI TPC readout, Berkeley

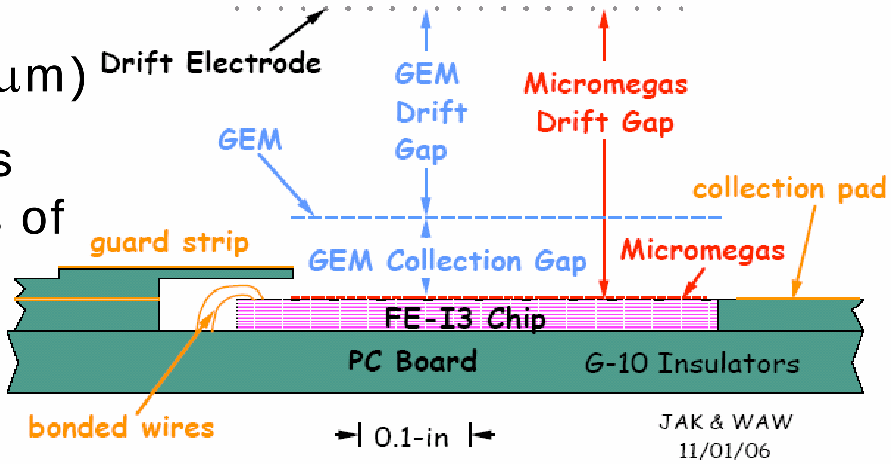
Pixel readout, similar in function to the TimePix readout being developed in Europe.

ATLAS pixel chip FE-13
  timing: 40 MHz (25 ns) (TimePix is 48MHz)
  Time Over Threshold readout
  configurable thresholds.



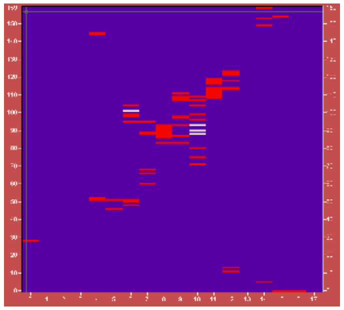
400 x 50 μm pads (TimePix is 55 x 55 μm)

Charge collection is on the bonding pads
(may not have the (TimePix) problems of positioning the HV close to silicon.)



Requires metallization of bonding pads;
metallization performed on 30 chips

Cosmic ray,
  with Double GEM gas amplification.



Project is in early stage and may be more suited to an upgrade of an ILC TPC, as is the TimePix configuration.

Expansion of US LC-TPC LP involvement

The LC-TPC program and the US presence would be strengthened by involvement of another group working in gaseous tracking.

Need for more help in large prototype

slow control
gas system
calibration software tools *to achieve the required resolution*

Beyond

ALTRO chip evolution to 130nm technology - testing
optical link
readout electronics

Any of these projects would require the addition of a small group: Faculty, 1-2 post-doc, 1-2 students .

Summary

US groups have important and integral roles in the international TPC development and gaseous tracking within detector concept studies, which, if supported, can lead to a US presence in ILC detectors .

Increased support is required
to guarantee visible US contributions, in

Large prototype - including the 1st and 2nd phases
endplates and possible other needed contributions

Small prototype – where important contributions can be made
in ion feed back measurements
and comparative gas-amplification measurements

Simulation and Reconstruction software –
where the advances in reconstruction techniques
can fully realize the reconstruction power of a TPC

Endplate tracking – development of the GEM device is unique to the US
and selected as the base technology for LDC