Time Projection Chamber (TPC) R&D

Mike Ronan
LBNL (Berkeley)

Outline

- TPC Chapters
  - "Proof of Concept" and **Bevatron** prototype
  - PEP-4 TPC experiment at **SLAC**
  - Upgrades and PEP-4/9 TPC/Two-Gamma experiment
  - 2nd generation **LEP** detectors (ALEPH & DELPHI)
  - High rate Mini-TPC for PEP-II/**B-Factory** commissioning
  - Pads partout and the STAR Detector at **RHIC**
- Micro-Pattern Gas Detectors (**MPGD**)
- International Linear Collider (**ILC**)
  - Detector studies and **LC-TPC** R&D
- Some Other TPC Applications

TPC Chapters

- Proof of TPC concept and **Bevatron** prototype
  - Confirmation after approval and some $M
- PEP-4 **TPC** experiment
  - Jet physics and dE/dx particle identification
- Upgrades and PEP-4/9 **TPC-Two Gamma** experiment
  - Gating grid, coated field cage, vertex detector, ... and new detector configuration
  - Study of b-quark jets, Tau lepton and gamma gamma process
- 2nd generation TPC detectors
  - **ALEPH**
  - **DELPHI**
- 3rd generation TPC (pads partout, FEE electronics, low mass, ...)
  - **STAR-TPC**
  - Gold-on-gold event

Time Projection Chamber concept

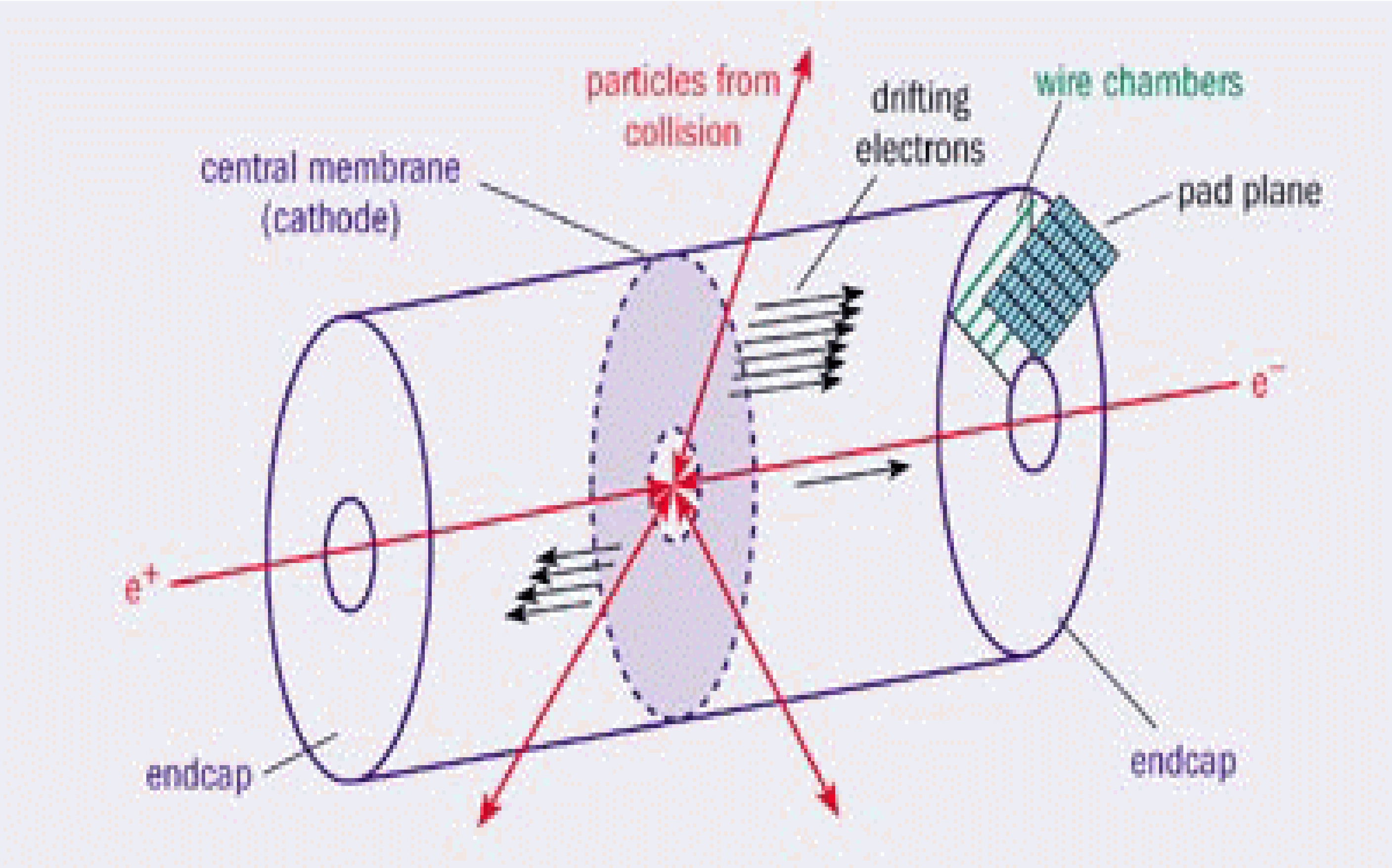

Fig. 2. A schematic view of the PEP-4 TPC showing the drift volume (dark blue), wire chambers (green) and pads (light blue).

Figure from 2004 CERN Courier article by **Spencer Klein, LBNL**

TPC concept:

A high magnetic field B parallel to drift electric fields E reduces transverse diffusion by a factor of

$\sim 1/\boldsymbol{\omega\tau}$

where $\boldsymbol{\omega}$ is the cyclotron frequency and $\boldsymbol{\tau}$ is the mean time between collisions in a chosen gas at a given pressure.

Multiple measurements of energy deposits provides dE/dx particle identification.

D. Nygren, 1974

- WELCOME
- GEMS
  - GENERAL
  - PERFORMANCES
  - FRAMING
  - ASSEMBLY
  - POWERING
  - DISCHARGES
  - READOUT
  - COMPASS
  - *NEW* TOTEM
  - PHOTON DET
  - *NEW* CYLINDRICAL
  - OTHERS
  - APPLICATIONS
  - GETTING GEMS
  - PATENTS
- PUBLICATIONS
- SEMINARS
- REFERENCE
- TOOLS
- GALLERY
- OLD WORKS
  - MSGC
- CERN HOME

NEW:
Ion feedback suppression in Time Projection Chambers

CERN

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
CH-1211 GENEVE 23 SWITZERLAND
PH-DT2-ST Gas Detectors Development

GDD WELCOME TO THE GAS DETECTORS DEVELOPMENT GROUP

INVENTORS OF THE GAS ELECTRON MULTIPLIER (GEM)

Created in the late sixties by Georges Charpak, inventor of the Multiwire Proportional Chamber and 1992 Nobel Laureate for Physics, the group has been active in the development and applications of advanced detectors for particle physics. After Charpak's retirement in the early nineties, the research is led by Fabio Sauli, who joined the group in 1969. After Sauli's retirement (March 2006) the research will be led by his collaborator Leszek Ropelewski.

Many detector designs have been introduced or developed over the years, mostly (but not only) to satisfy the increasingly demanding needs in high-energy physics. They include Multiwire Chambers (MWPC), Drift Chambers, (DC) Multi-Step Avalanche Chambers (MSAC), Ring Imaging Cherenkov Chambers (RICH), Multi-Drift Modules (MDM), Micro-Strip Gas Chambers (MSGC). Dedicated devices have been developed for applications in medicine and biology.

The group's recent activity has been centered on the development of the Gas Electron Multiplier (GEM) technology, invented in 1997 by Fabio Sauli. A set of large GEM tracking detectors is operating in the COMPASS experiment; a new tracker for TOTEM is in construction. Similar devices are under development in other groups for fast tracking, improved readout for large volume Drift and Time Projection Chambers, neutron detection. Applications in other fields are also being investigated, namely medical imaging, astrophysics, structure analysis.

Our offices and laboratories are located at CERN in Building 28 first and second floor.

A collection of photos of present, recent and former collaborators to the Gas Detectors development group can be seen in GALLERY.

George Charpak

Embassy of France in Canada

Science and Technology Department

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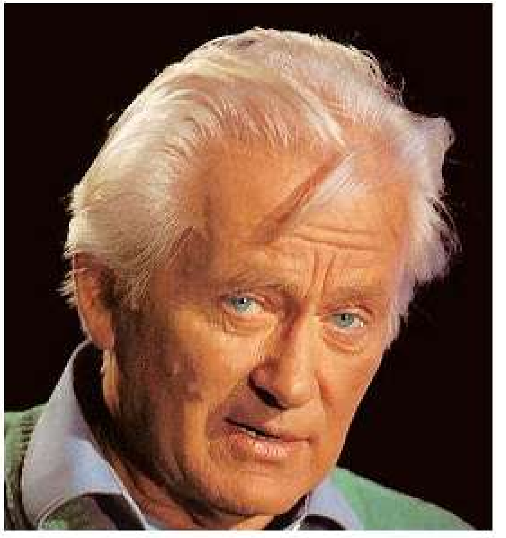
Charpak System :
Revolutionising radiology



"Il devrait être interdit de rassembler des physiciens sans qu'obligatoirement soient mêlés à eux des artistes!"

Georges Charpak, *La vie à fil tendu*

- Charpak system at the Saint-Vincent-de-Paul hospital in Paris
- Like a taut weave of fabric
- Two slots to reduce irradiation
- One line every 30 milliseconds
- One hundred times fewer X-rays
- Improved image quality
- 9 months and 250 patients
- Contact

Georges Charpak, 1992 Nobel Prize laureate, is well known in Canada. Invited in October 1994 by the Scientific Service, he gave a sparkling lecture and was given a tour of Ottawa's premier laboratories and met with its leading scientists. When he returned in 1995, he was made an honorary doctor of the University of Ottawa. For the occasion, he sponsored a Canada-Israel research grant put together by the French embassy.

The staff using it at Dr. Gabriel Kalifa's ward at the Saint-Vincent-de-Paul hospital in Paris have dubbed it the "Charpak System". The revolutionary equipment, now being tested for clinical evaluation over a nine-month period, is the result of research conducted by the French Nobel prize laureate Georges Charpak. The project developed by a company called Biospace Radiologie means that patients will be subjected to one hundred times fewer x-rays than before. The system also increases the amount of information conveyed by the image and provides direct digital data acquisition.

In the early 80's, Lev Schektmann, a physicist who then worked at the Georges Charpak detector research department at CERN1 in Geneva, came up with the idea of a medical radiology application for the wire chamber, which is commonly used in nuclear physics. The originality of the system is largely based on the way the wires are set up in the chamber.

In 1983, Lev Schektmann's research work at the Nuclear Physics Facility in Siberia led to the set-up of a diagnostic machine at the Moscow Mother and Children's Hospital, which specialises in scanning women's pelvis. Two detectors using 256 wire chambers were set up to heighten resolution. In 1987, the new type of detector was installed in the Novossibirsk hospital for standard radiology examinations, and more particularly for examinations of the spinal column and the lungs. Since 1988, a new version of the detector, with 640 detection components, has been used as an experimental machine at the Budker Institute. An identical model is now being evaluated at the Saint-Vincent-de-Paul hospital.

Like a taut weave of fabric

The originality of the different machines stems from the proportional multi-wire chamber or "Charpak detector", whose design and construction earned the French physicist the Nobel Prize in 1992. The proportional multi-wire chamber is a gas (a mix of xenon and CO2) particle detector. From the outside the detector is a 50 cm wide aluminium box with a small manometer on top, which serves to maintain xenon pressure at 3 bars.

When the box is opened, an alignment of wires can be seen inside. They are made of copper. Measuring 10 microns in diameter, they are pulled tight like the weft of fabric on a loom. The axis of each wire faces the x-ray source, 1.30 m away; the wires measure 5 cm and are separated from one another by a distance of 1.2 mm. Cathodes are set up on each side of the wire layout. The connections to the first electronic level are under the chamber. Each wire is connected to an amplifier, a selection component and a counter. All the components are on 32 cards inserted into a built-in hood on the chamber. The chamber-electronic counting unit is supported by an arm with x-ray tube fitted onto its other end.

Two slots to reduce irradiation

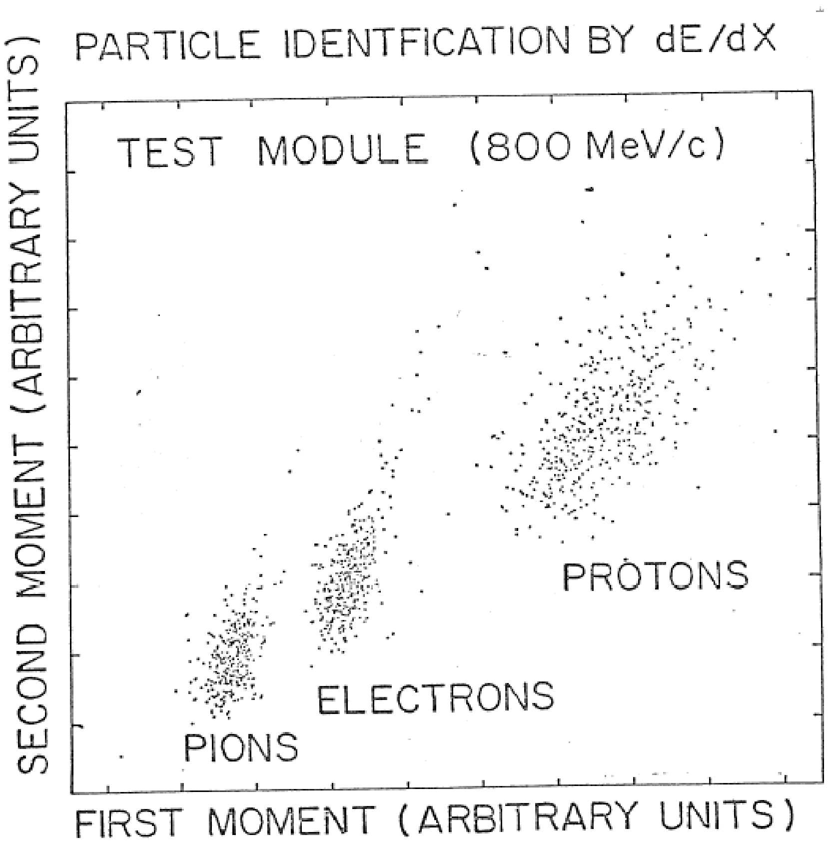
A small piece of furniture, which is separate from the detector, holds the power input electronics, the control systems and the data processing unit of the information conveyed by the detector. The data is then transmitted to a PC-type microcomputer that can display and process the images. X-rays are still sent out by a standard system, which does, however, have an electronically controlled generator and an ordinary store-brought tube.

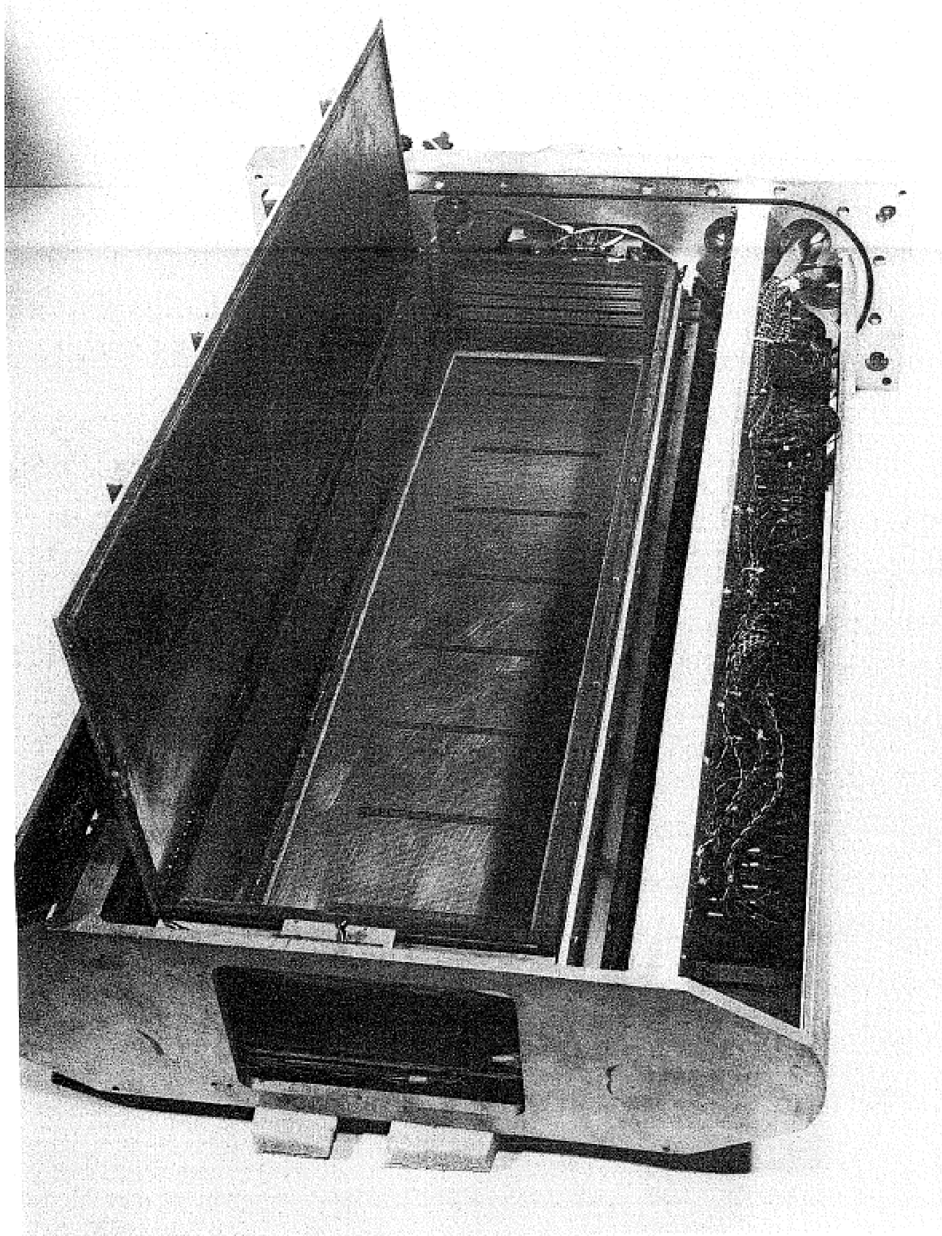
As the wire chamber is a linear detector which can record only one line at a time, the whole system has to scan the patient. The arm, with x-ray tube at one end and the detector at the other, is powered by an electronically controlled motor which moves the arm vertically. X-ray beam collimation slots have been fitted onto the arm to reduce patient irradiation radiation scattering effect. The equipment is computer-controlled and has a programme so the doctor can measure the distances between the objects on the image, the density of each point on the image and the average density of any fragment of the image. Other operations such as windowing, zooming, etc. are also possible.

One line every 30 milliseconds

A finely collimated x-ray beam scans one part of the patient's body during the examination. The detector records a line every 30 milliseconds and stores it in the computer memory bank. The line is then processed and displayed on the computer screen.

Bevatron Prototype TPC





CBB 787-9080

Fig. 6

Proposed TPC Detector

Dated Dec. 30, 1976

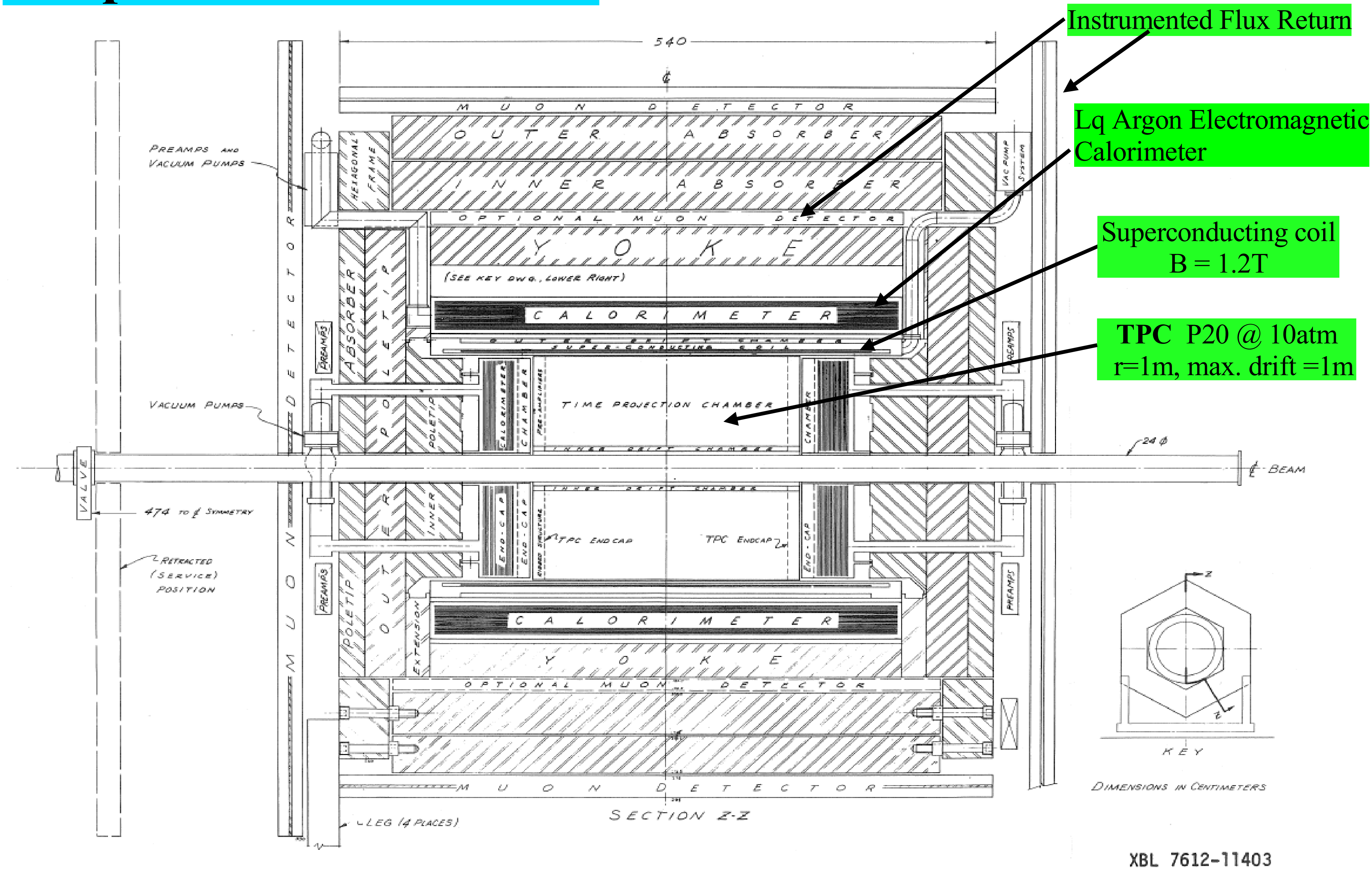
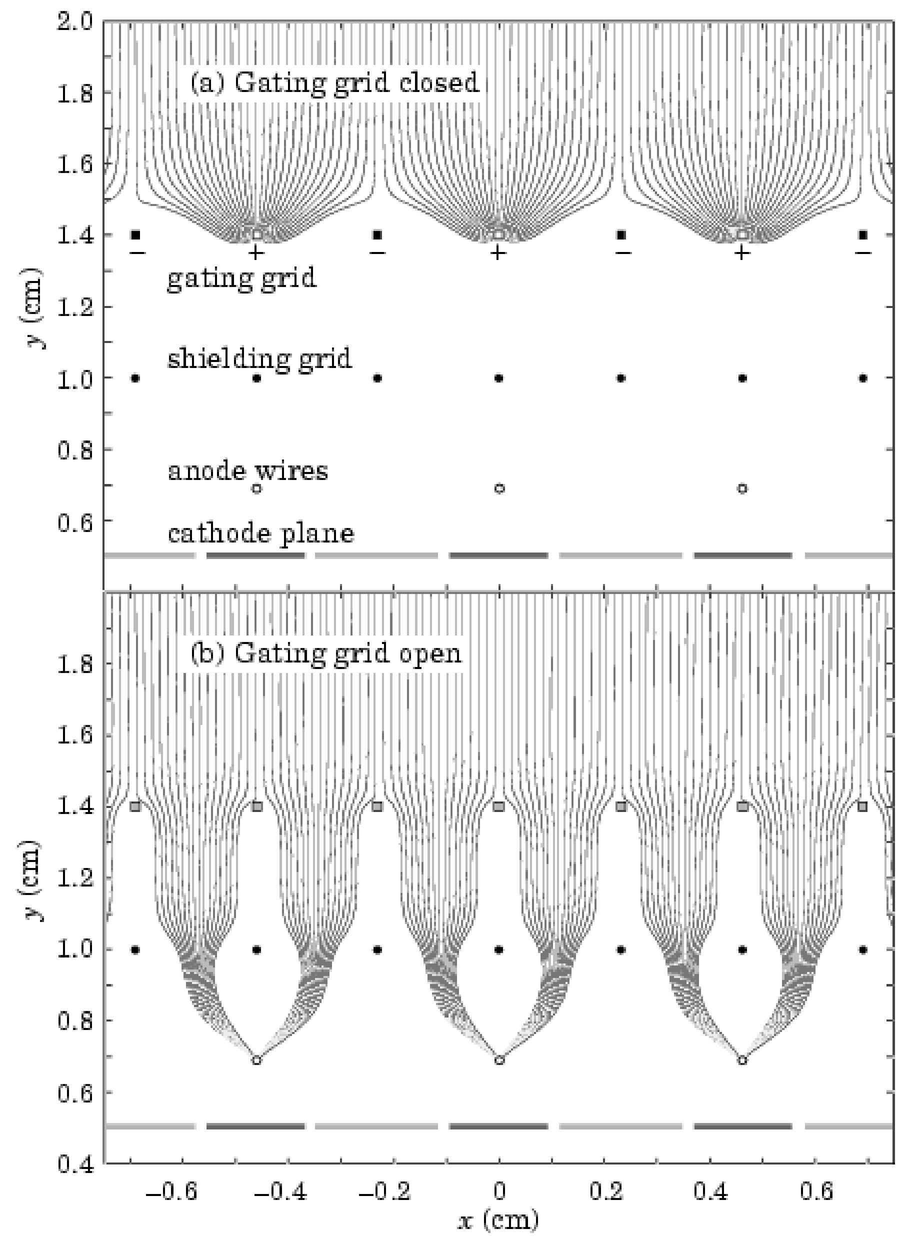


Fig. IIIH.1

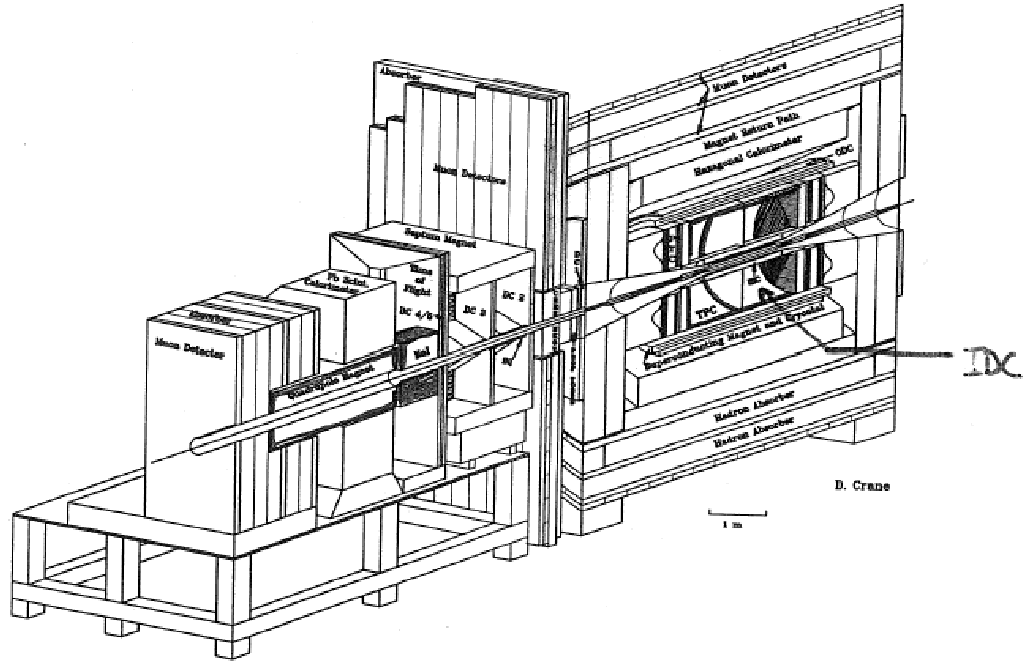
TPC Gating Grid

When closed a gating grid collects electrons drifting in from the central TPC region for high-rate gated operation. It also prevents positive ions generated in electron avalanche from drifting back and causing distortions.

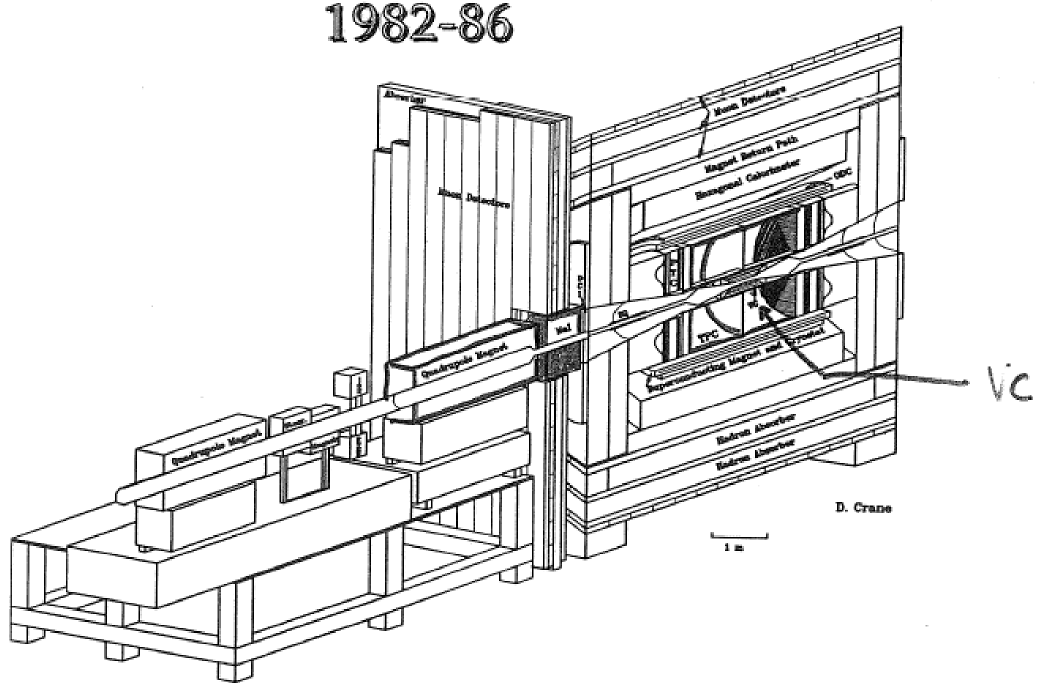
When open the gating grid allows electrons to drift towards amplification wires where they avalanche and generate a positive cloud. The positive ions drift slowly onto a segmented cathode pad plane below, spreading the signal over several pads.



TPC Detector and IR2 Upgrade



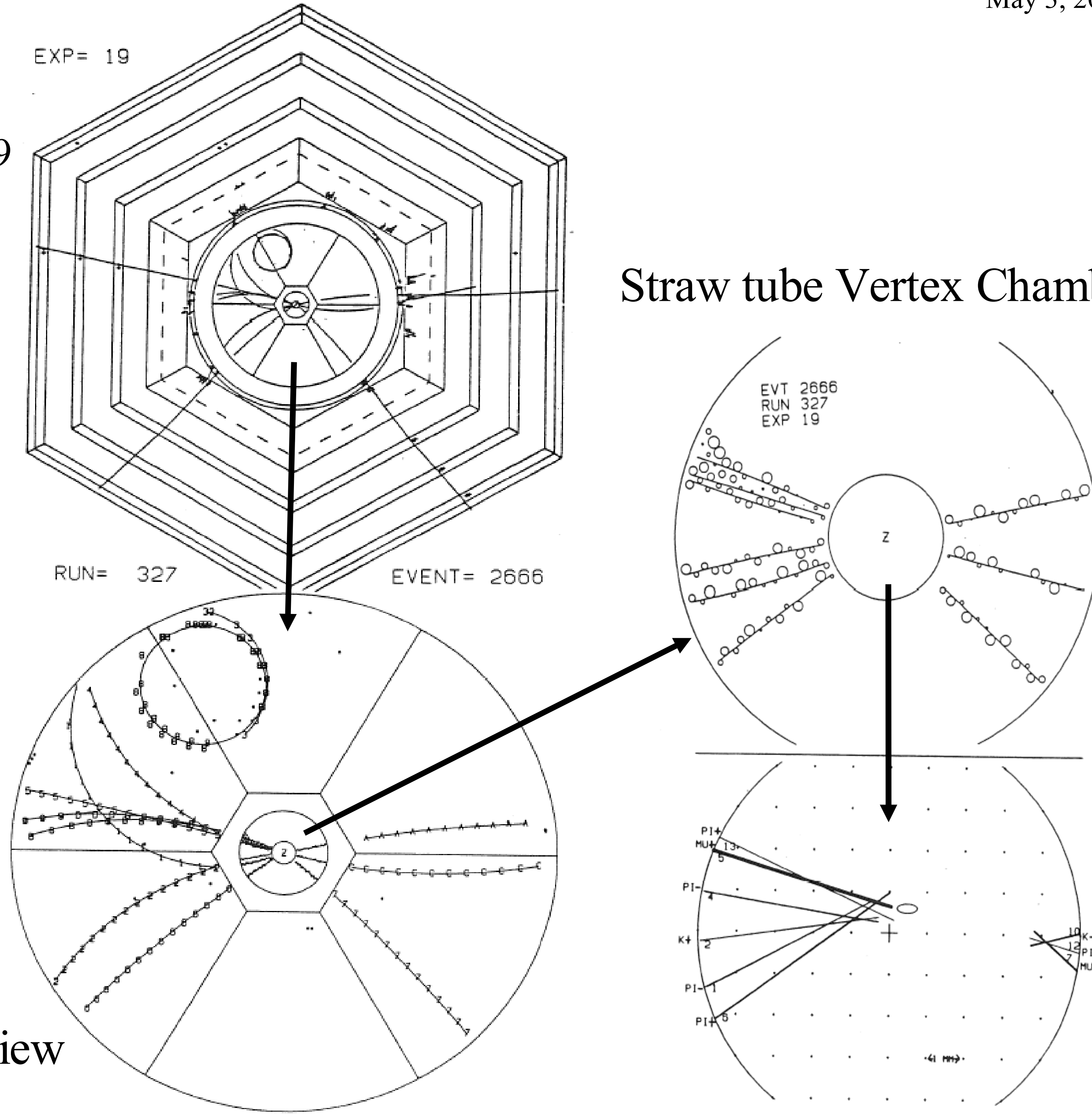
1982-86



1988

B Physics

One event from PEP4/9 commissioning run in 1989.



Straw tube Vertex Chamber

TPC End view

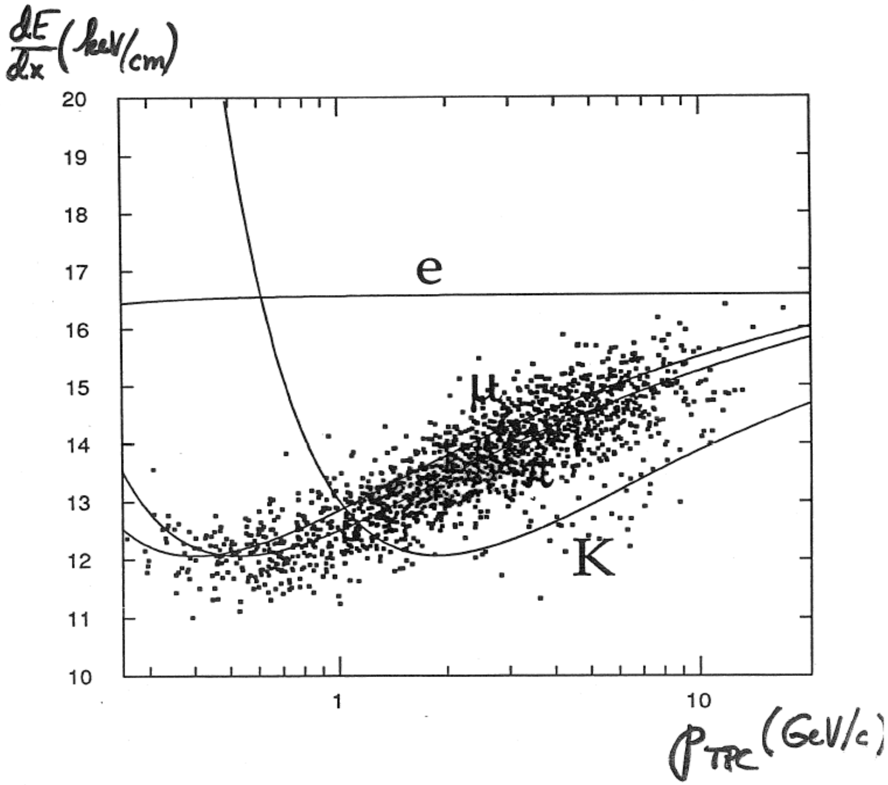
Tau Physics

M. Ronan
LBL

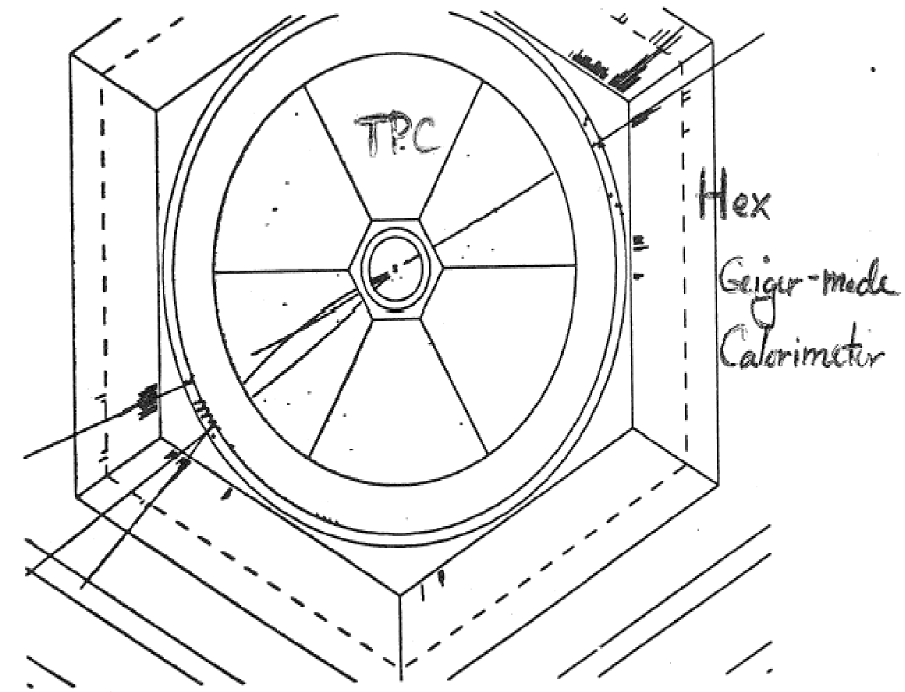
Oct 1993

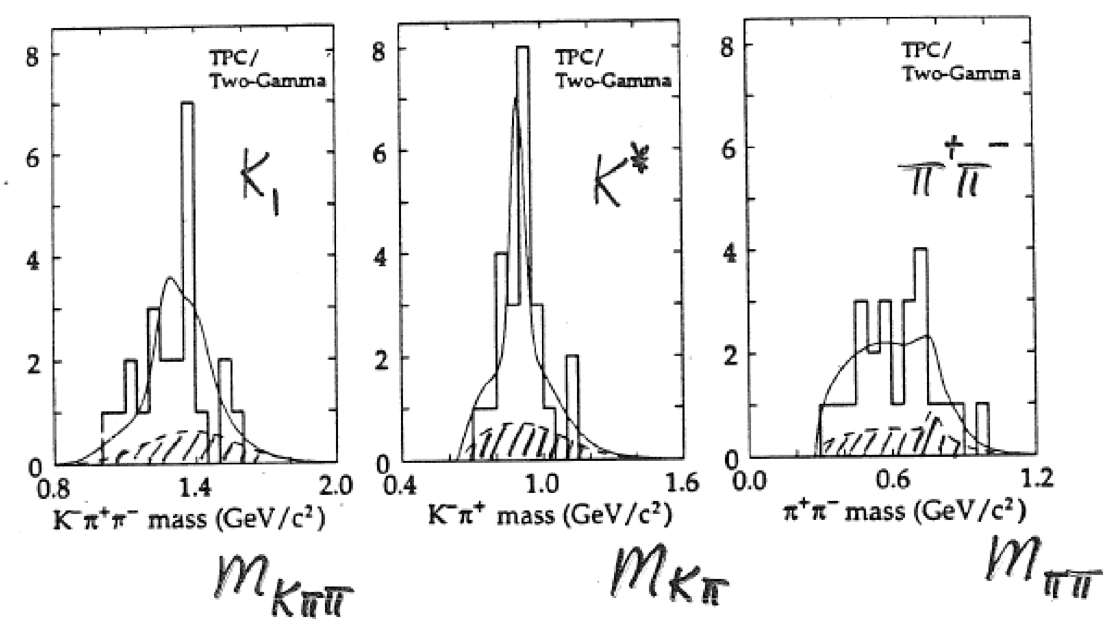
First observation of the $\tau \to K_1 \nu$, strange axial-vector, decay mode.

3-Prong dE/dx Spectrum



Tau 1-3 event



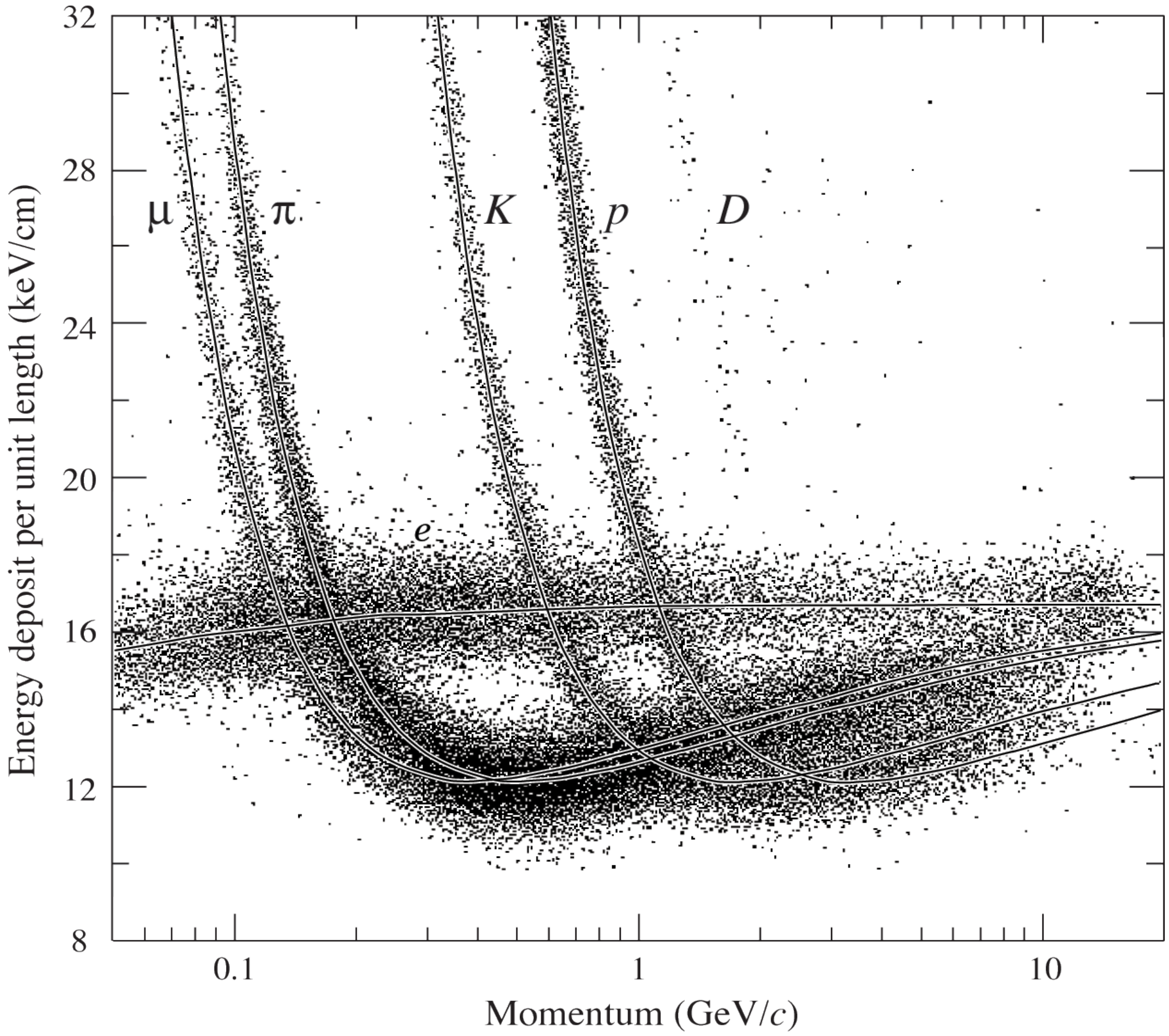


Ref. M.Ronan, 1993 Tau Lepton Workshop & PR D ...

dE/dx Particle Identification

PEP4/9-TPC energy-deposit measurements (185 samples @8.5 atm Ar-CH4 80-20%)

Electrons reach a Fermi plateau value of 1.4 times min. ionization. Muons from pion decays are separated from pions at low momentum; π/K are separated over all momenta except in the cross-over region. (Low-momentum protons and deuterons originate from hadron-nucleus collisions in inner materials such as the beam pipe.)



Time-projection chambers

Review of Particle Properties, P.L. **B 592**,1 ('04)   Written Nov. 1996 by **M.T. Ronan**

Detectors with long drift distances perpendicular to a multi-anode proportional (wire) plane provide three-dimensional information, with one being the time projection. A (typically strong) magnetic field parrallel to the drift direction suppresses transverse diffusion (s = r2Dt) by a factor D(B)/B(0) = 1/(1+w2t2), where D is the diffusion coefficient, w = eB/mc is the cyclotron frequency, and t is the mean time between collisions. Multiple measurements of energy deposit along the particle trajectory combined with the measurement of momentum in magnetic field allows excellent particle identification [91], as can be seen in Fig. 28.5. See next slide.

A typical gas-filled TPC consists of a long uniform drift region (1-2 m) generated by a central high-voltage membrane and precision concentric cylindrical field cages within a uniform, parallel magnetic field []. Details of construction and electron trajectories near the anode end are shown in Fig. 28.6. See following slide. Signal shaping and processing using analog storage devices or FADC's allows excellent pattern recognition, track reconstruction and particle identification within the same detector.

Typical values:

Gas: Ar + (10-20%) CH_4	Pressure(P) = 1-8.5 atm.
E/P = 100-200 V/cm/atm.	B = 1-1.5 Tesla
v_{drift} = 5-7 cm/us	$\omega\tau$ = 1-8
$\sigma_{x\ or\ y}$ = 100-200 um	σ_z = 0.2 – 1 mm
σ_{Edep} = 2.5-5.5 %	

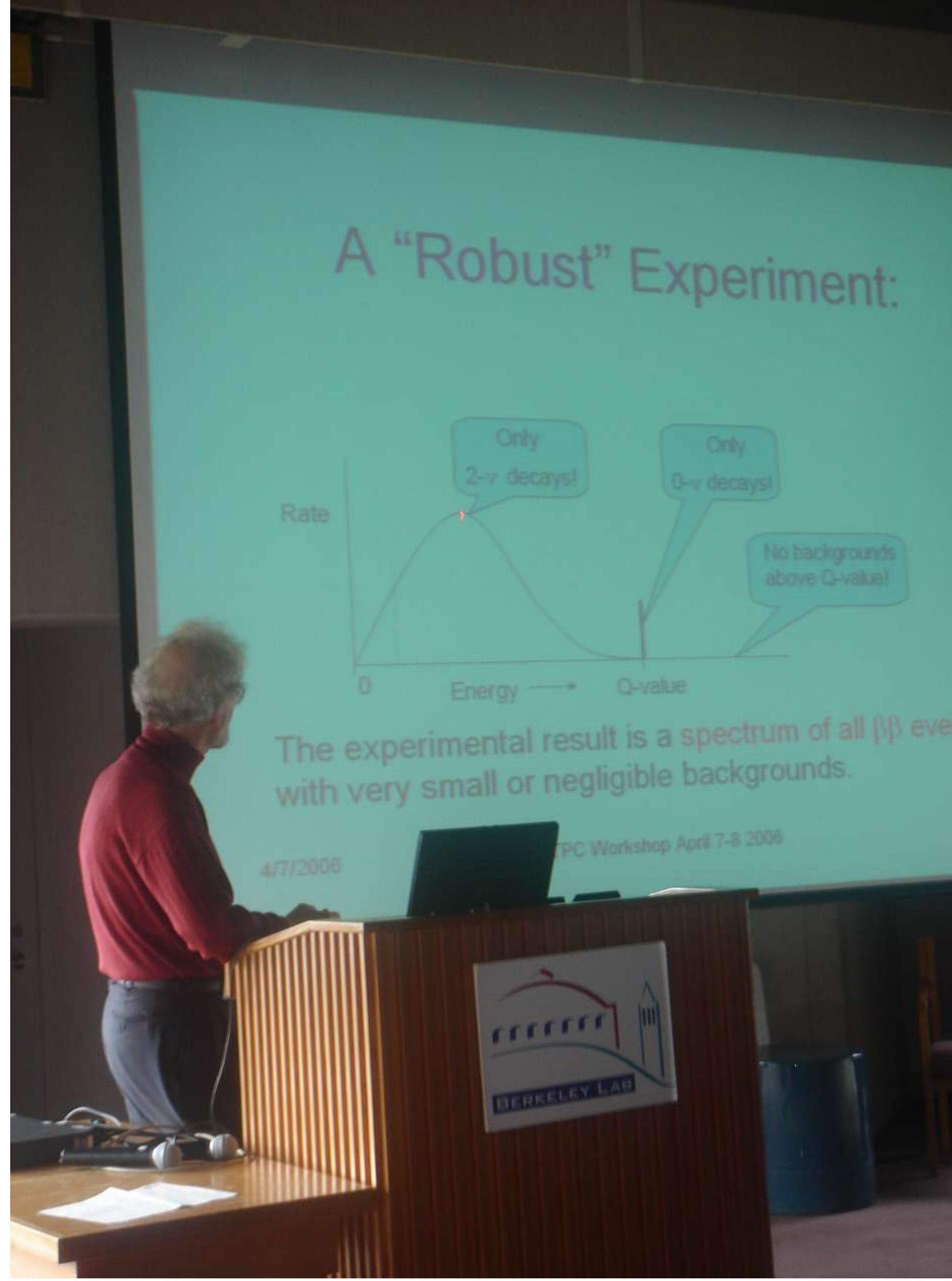
See also www-tpc.lbl.gov, i.e. www-tpc server at lbl.gov

Dave Nygren

At right, selling new concepts at the recent **TPC Applications Workshop**, Apr. 7-8, 2006, here at LBNL, see

http://www-tpc.lbl.gov/workshop06.

Below, at Spenger's for workshop dinner w/ Rebecca Nygren, Ron Settles (front right), Uwe Oberlach, ...



Following slides:

198x DOE **E.O. Lawrence award**
1993 LBNL **Distinguished Scientist**
1998 APS **W. Panofsky award**

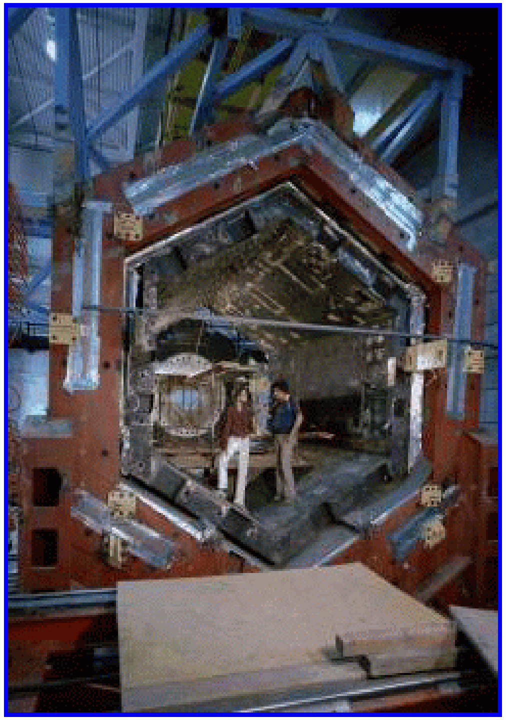
LBNL Image Library - Collection

Berkeley-Lab/Particle-Detection/Electronic-Detectors

Time Projection Chamber

May 1980

Image File
96703050
Title
Time Projection Chamber
Description
The Time Projection Chamber (TPC), shown with inventor David Nygren (left), was designated by LBL physicists for use at PEP, the positron- electron colliding beam ring at Stanford. The Laboratory has collaborated closely with the Stanford Linear Accelerator Center (SLAC), where a 20 BeV electron linac began to operate in 1967. Together they have designed and built a positron- electron colliding beam ring (PEP) that will provide collision energies. (The preceding information was excerpted from the text of the Fall 1981 issue of LBL Newsmagazine.)
Citation Caption
LBL News, Vol.6, No.3, Fall 1981, p. 99 | The Time Projection Chamber (TPC), shown with inventor David Nygren (left), was designed by LBL physicists for use at PEP, the positron-electron colliding beam ring at Stanford.
Date
May 1980
Division
Physics
People
David Nygren
Equipment
Time Project Chamber
Site
Berkeley



PEP-4 TPC Detector magnet cavity w/ Dave Nygren & Fred Catania at **SLAC IR2**

Berkeley Lab Currents – Dec. 15, 1995

Three at Berkeley Lab achieve Distinguished Scientist standing --

Nygren, Poskanzer and Stephens honored

By Ron Kolb

Three researchers who have achieved international acclaim for their accomplishments in designing unusual detector systems have been promoted to the rare Distinguished Scientist classification at Berkeley Lab.

David Nygren in the Physics Division and Arthur Poskanzer and Frank Stephens in the Nuclear Science Division were named by Laboratory Director Charles Shank to receive the prestigious "Distinguished" title, which is currently shared by just three others at the Lab.

In his appointment letters, Shank noted that the Distinguished Scientist rank is "reserved for the most exceptional senior scientists. It is expected that the Laboratory will have only a few such stars at any given time."

The Distinguished Staff Scientist/Engineer level is reserved for those who "have a sustained history of distinguished scientific and technical achievements and/or have directly contributed to the Laboratory's preeminence," according to the Lab Regulations and Procedures Manual. The incumbents are "seen as nationally or internationally recognized authorities and leaders in their field; their expertise is sought after by professional colleagues."

Nygren, 57, was nominated by Physics Division Director Robert Cahn, who cited his invention of the Time Projection Chamber (TPC), which has had a profound effect on both particle and nuclear physics, and his pioneering work on pixel detectors. Cahn also cited his innovative design for an x-ray imaging device based on silicon detectors and high-speed data acquisition, and his current work in very-large-scale neutrino detectors.

"The TPC opened new opportunities for experimentation across a broad range of particle and nuclear physics," Cahn said. "The purity and power of his proposal are why, more than 20 years later, new TPCs are still being built."

Nygren, who has been called the most distinguished developer of particle detection instruments in the country, has been with Berkeley Lab since 1973 and is a previous winner of the prestigious E. O. Lawrence Award.

1998 W. K. H. Panofsky Prize in Experimental Particle Physics to David Robert Nygren
Lawrence Berkeley National Laboratory

Citation:
"For the concept, development, and application of the time projection chamber (TPC), enabling unprecedented studies of complex topologies of charged particles produced in high energy collisions of interest to both high energy and nuclear physics."

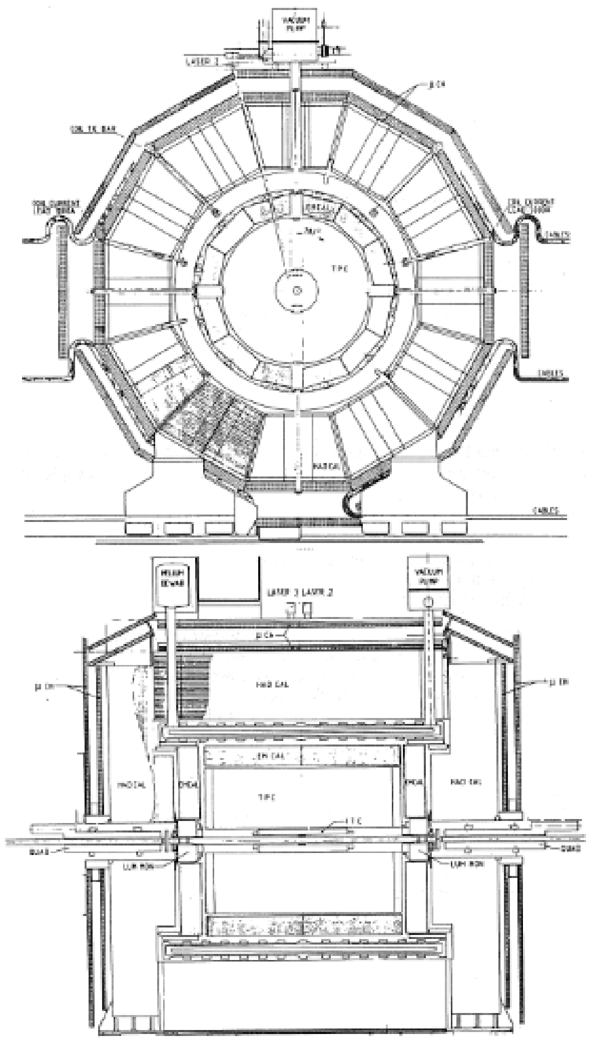
Background:

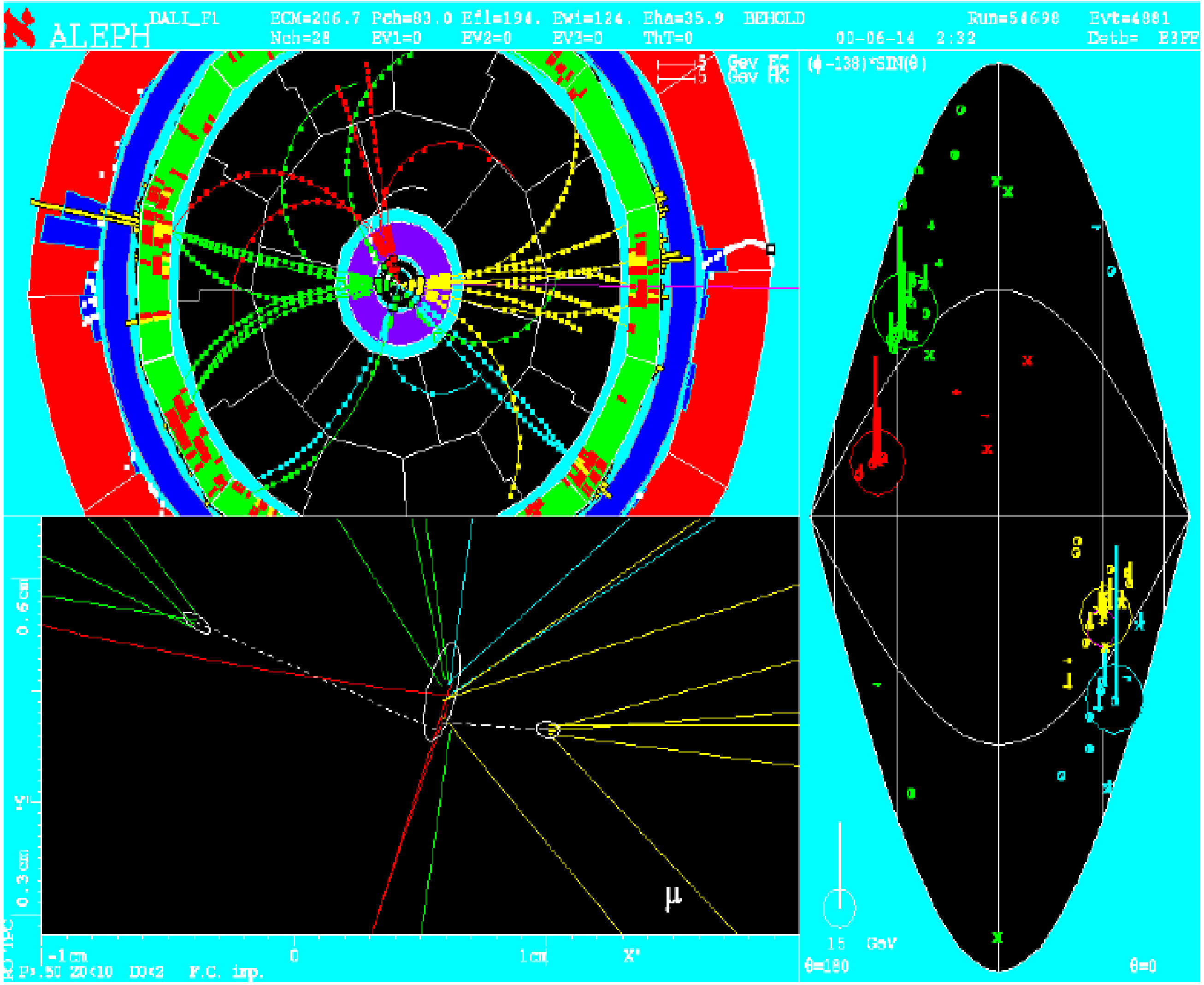
Dr. Nygren received his BA degree in 1960 from Whitman College in Mathematics and his Ph. D. from the University of Washington in Physics in 1967. He was a research associate at Nevis Laboratories at Columbia University and became an Associate Professor of physics at Columbia in 1969. He moved to Lawrence Berkeley National Laboratory in 1973 as a Division Fellow and has been a Senior Physicist at LBNL since 1975.

Dr. Nygren has been instrumental in the development of the Time Projection Chamber concept for tracking and identification of charged particles in high energy electron-positron collisions. The TPC concept provides 3-dimensional images of complex events with high resolution, and simultaneously determines the charged particle types. Under his direction, the pioneering TPC at LBNL operated a the Stanford Linear Accelerator Center PEP storage ring from 1981 to 1989. The TPC concept has been employed in a wide range of applications as well as several other large detector systems in Japan and Europe.

Dr. Nygren is a Fellow of the American Physical Society, a recipient of the E. O. Lawrence Award given by the U.S. Dept. of Energy, and most recently was a Distinguished Visiting Scientist at the Jet Propulsion Laboratory. He also has served on the Executive Committee for the APS Division of Particles and Fields, and several other distinguished, scientific panels and committees.

ALEPH

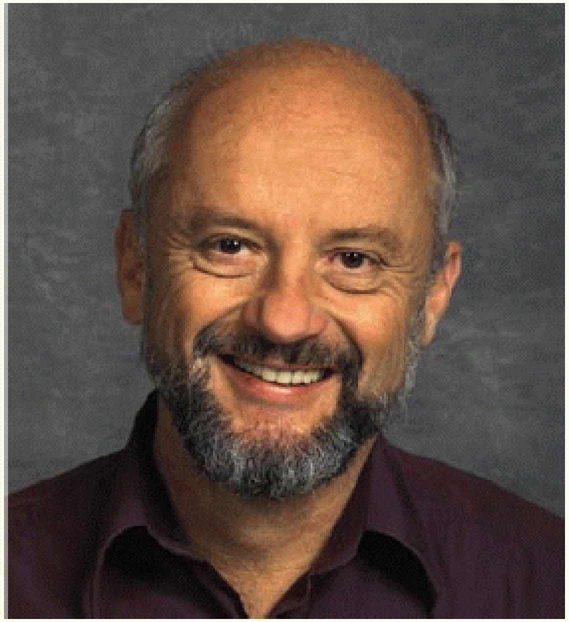


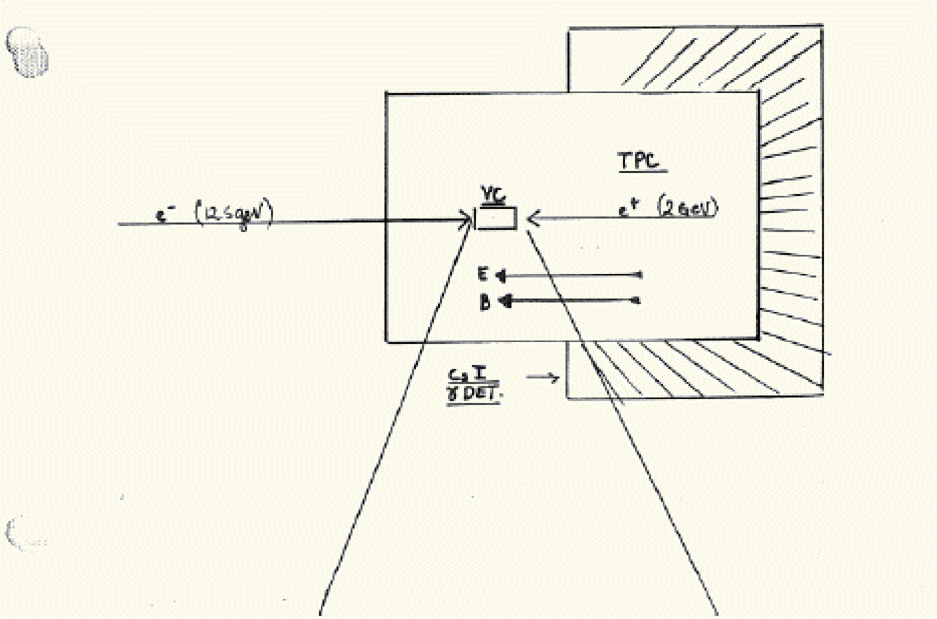


Presented by **Ron Settles**,
TPC Symposium, Oct. 2003
see **http://www-tpc.lbl.gov/symposium2003**

Conception of the B Factory

How can we do time-dependence measurements in the clean e^+e^- environment?.





Pier Oddone has won the 2005 Panofsky Prize "For his insightful proposal to use an asymmetric B-Factory to carry out precision measurements of CP violation in B-meson decays, and for his energetic leadership of the first conceptual design studies that demonstrated the feasibility of this approach."

PEP-II IR2 Commissioning

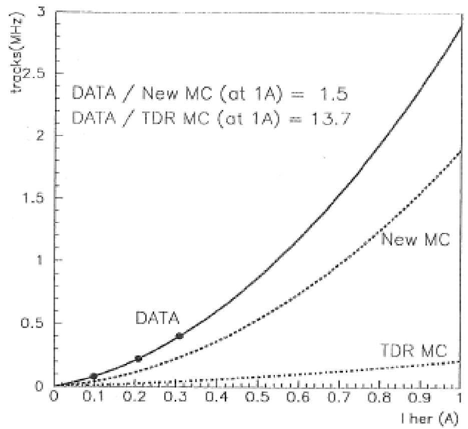


Figure 24: *Track rate in the mini-TPC as a function of beam current. Data are compared to Monte Carlo using either the pressure profiles of table 3, or a TDR-like model where zone 4 is neglected and values of 0.5 nT and 0.5 nT/A base and dynamic pressure are used for zones 1, 2 and 3.*

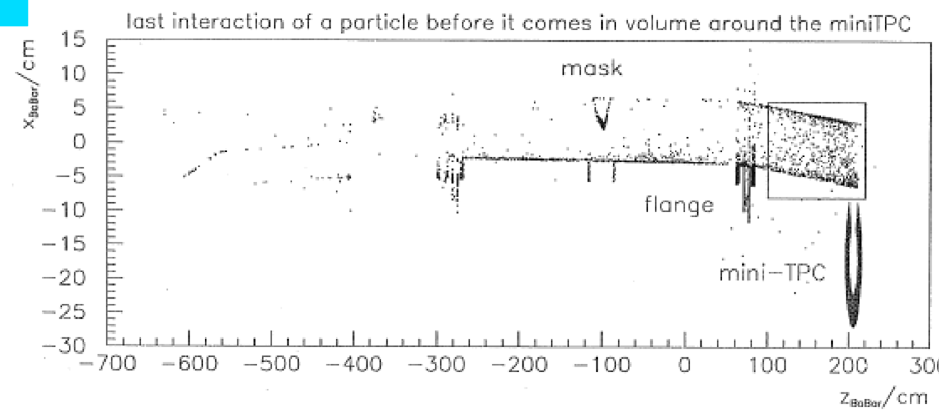


Figure 20: *Origin or point of last scattering of charged particles eventually traversing the mini-TPC or producing showers reaching it. in BaBar coordinates. The plot represents a view from above in the horizontal plane containing the beam line (see figure 6). The box indicates a "hot spot" of the beam pipe where an important component of mini-TPC backgrounds are produced in the showers of primary lost particles.*

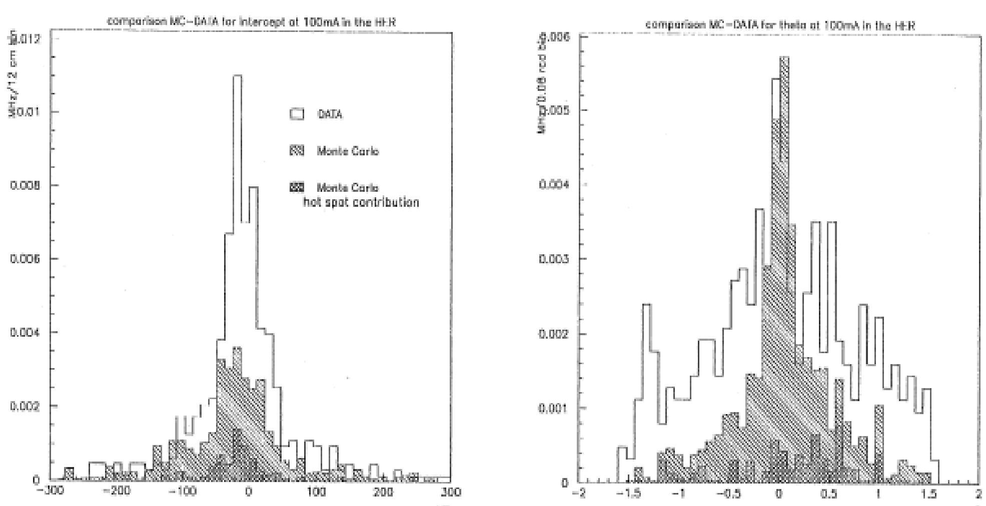
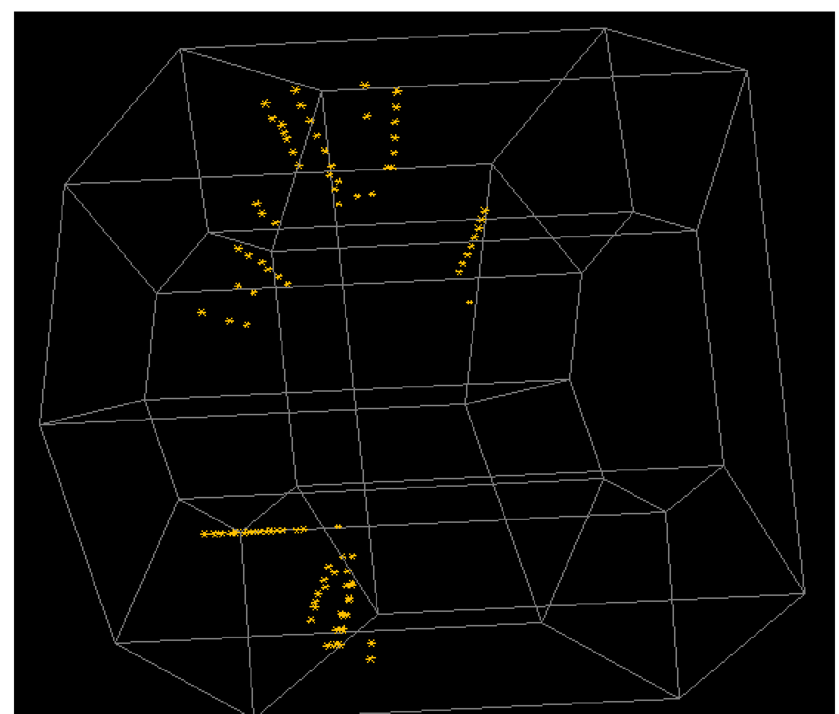


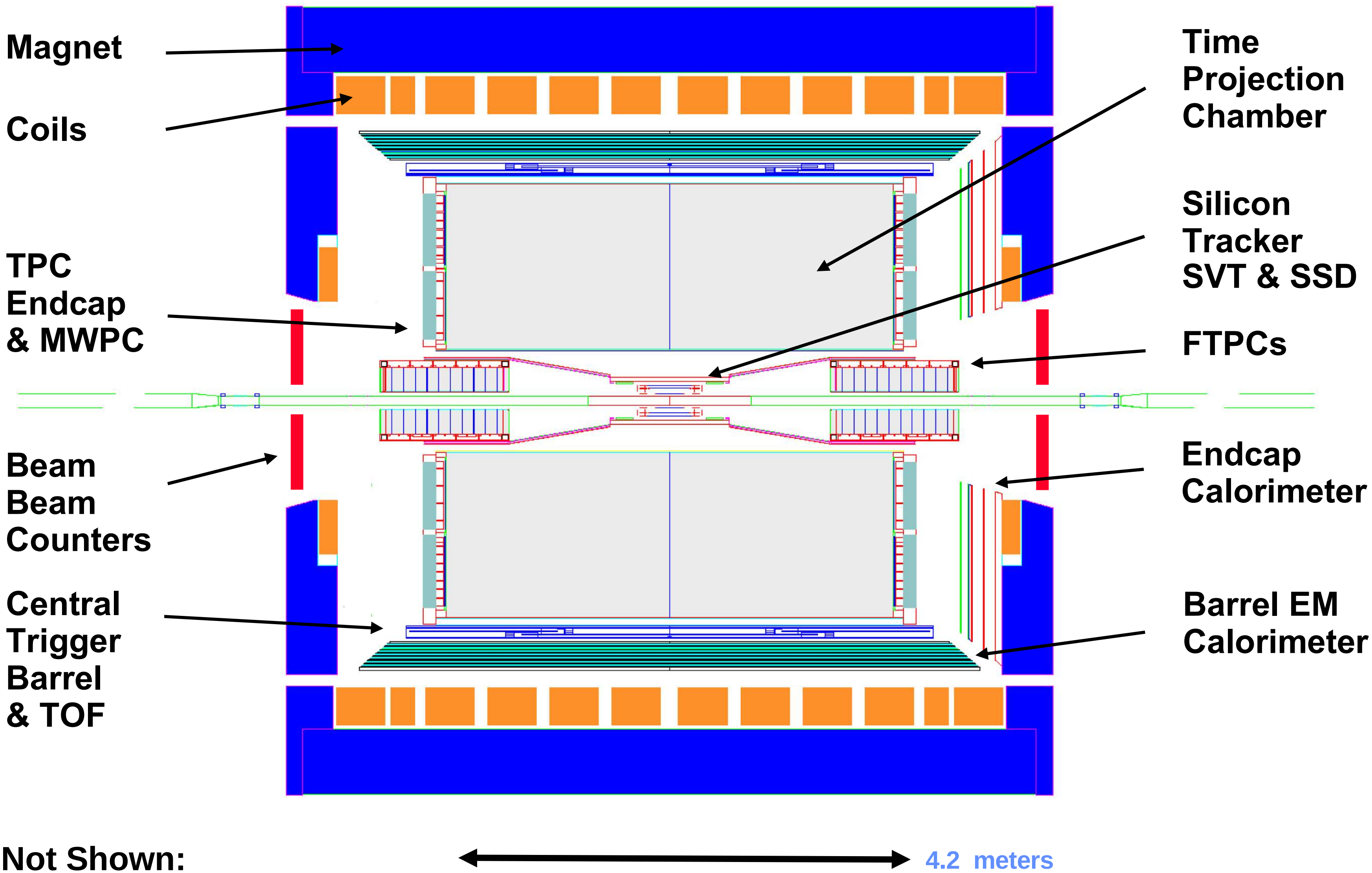
Figure 26: *Spatial distributions for tracks in the mini-TPC: intercept to the beam in the horizontal plane (left) and angle θ in the vertical plane (right). Data from the 100 mA run of January 31 are compared to Monte Carlo. The component of expected backgrounds coming from the "hot spot" of the beam pipe (see figure 20) is also indicated.*

First Asymmetric e+e- annihilation event



e^+ (3.1 GeV) ⟶ ⟵ e^- (9 GeV)

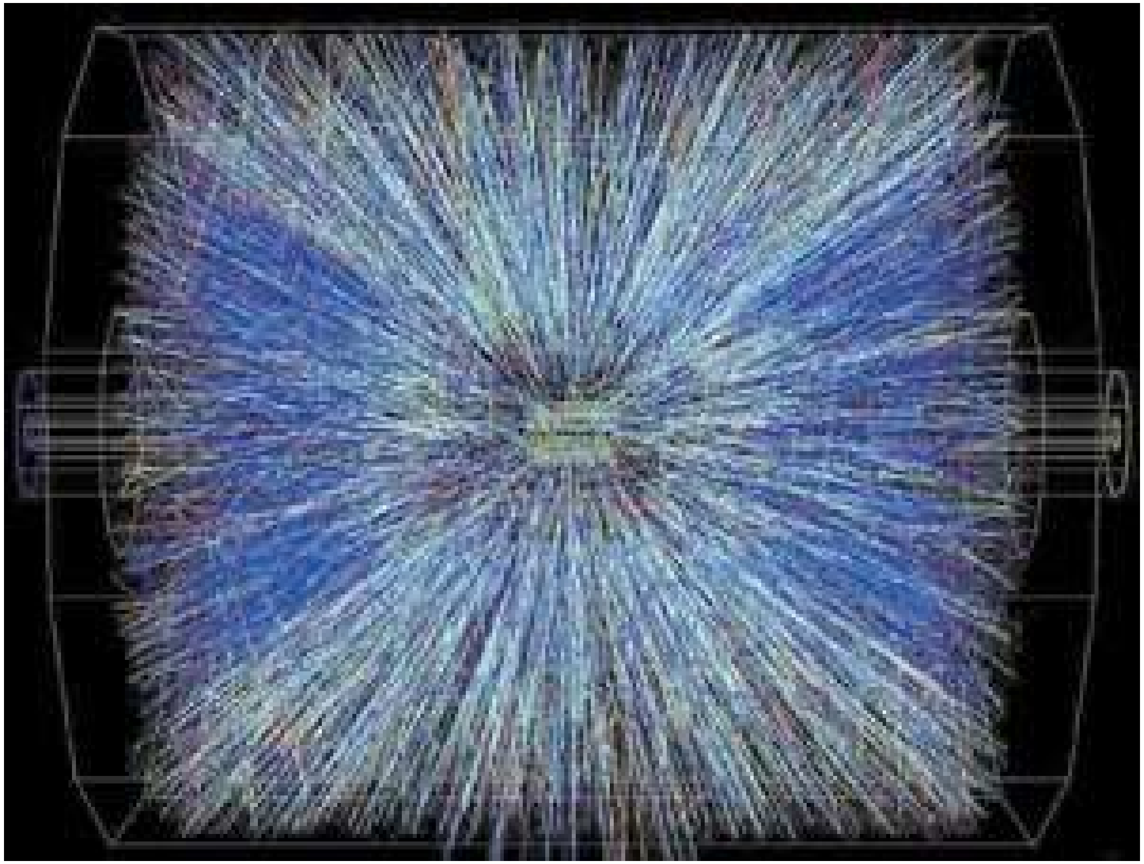
A TPC lies at the heart of STAR



Not Shown:
pVPDs, ZDCs, PMD, and FPDs

Presented by **Jim Thomas,**
First TPC Symposium, Oct. 2003
see **http://www-tpc.lbl.gov/symposium2003**

STAR-TPC Au-Au Event



A side view of tracks from 200 GeV per nucleon for a gold-on-gold collision at RHIC, as reconstructed in the TPC of the STAR experiment

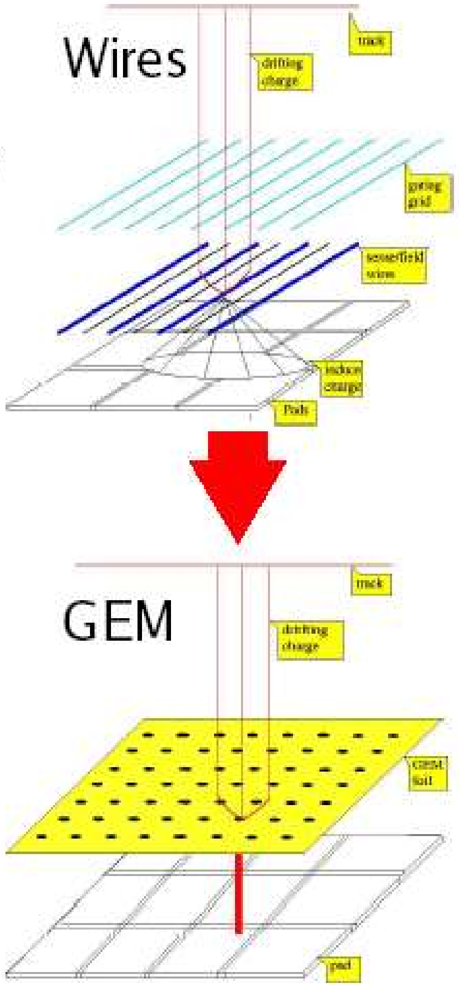
From 2004 CERN Courier article by **Spencer Klein, LBNL**

New Gas Amplification Systems

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

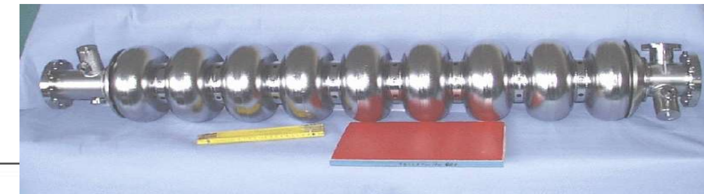
Most promising examples:

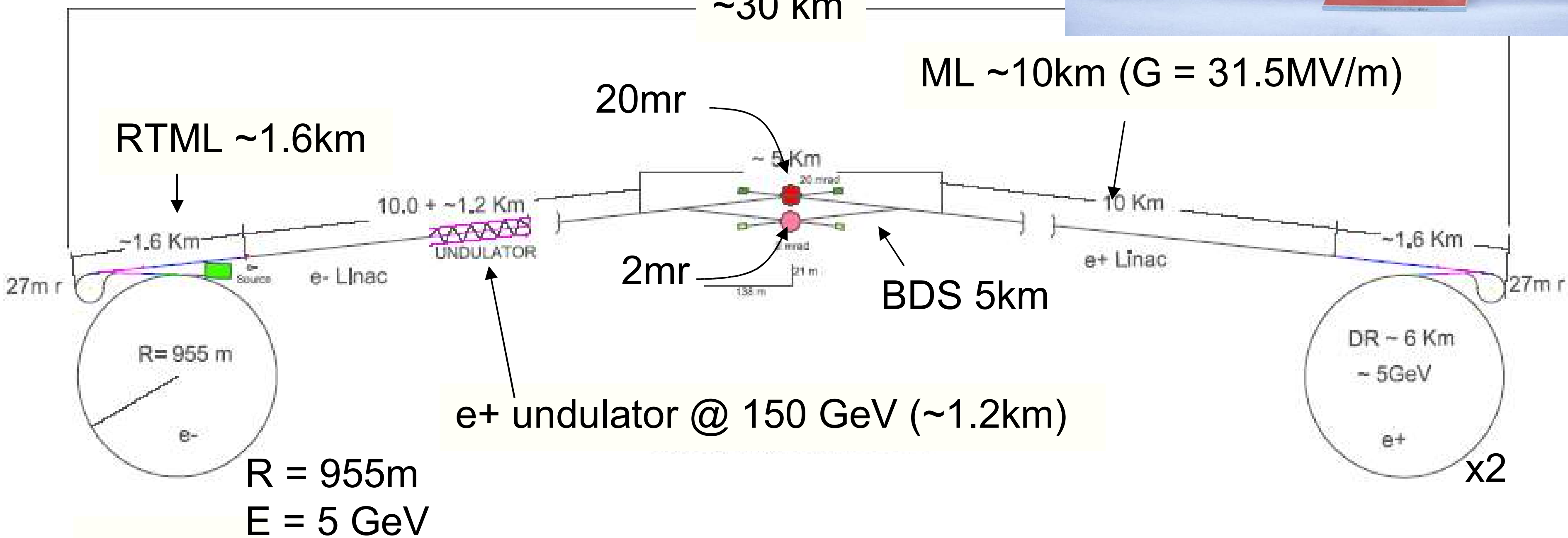
- Gas Electron Multiplier (GEM) (F. Sauli, 1997)
- Micromegas (Y. Giomataris *et. al.*, 1996)



The ILC baseline machine

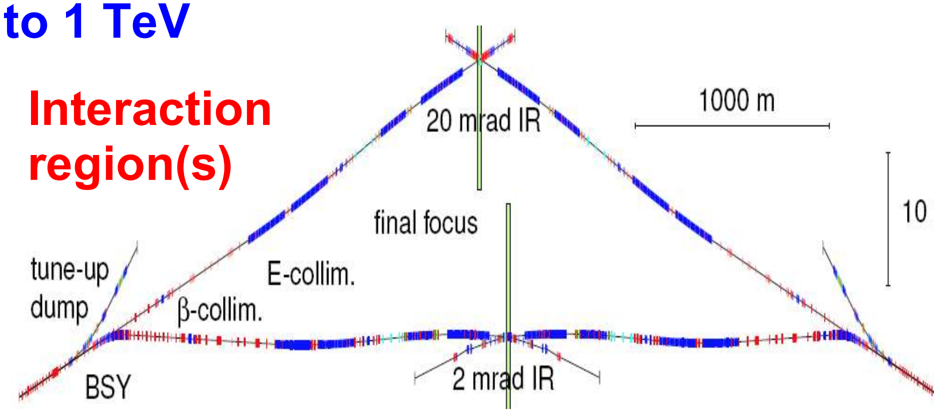
Proposed baseline machine @ 500 GeV
(not to scale)



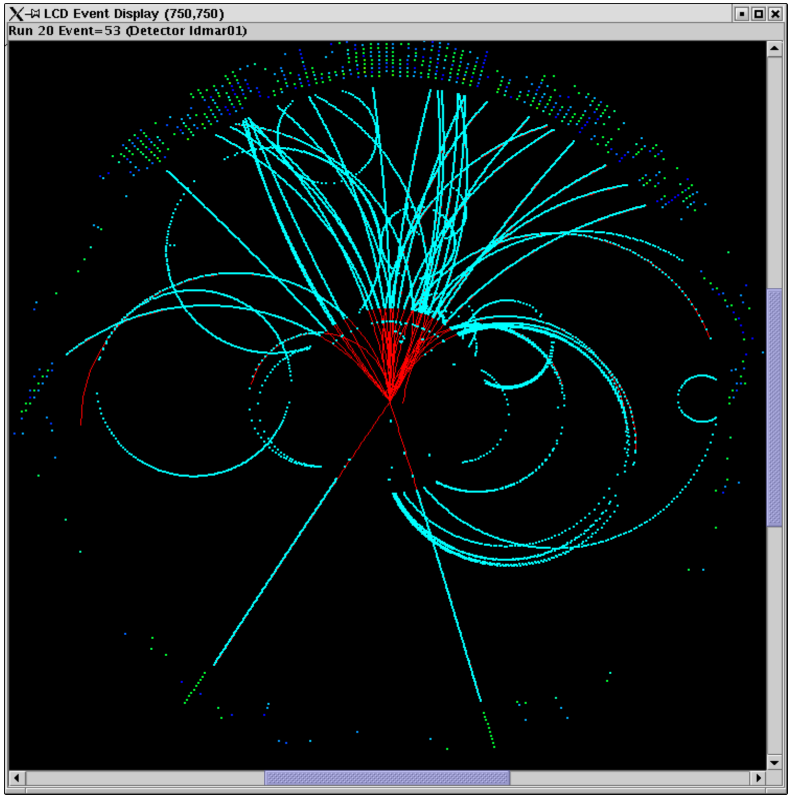


- **e^+e^- linear collider, E_{CM}=500 GeV, upgradable to 1 TeV**
- **30 km long**
- **Superconducting RF technology**
- **2 IR's, 20/2 mrad, 2 experiments (?)**
- **Plan to start construction in 2012**

Interaction region(s)

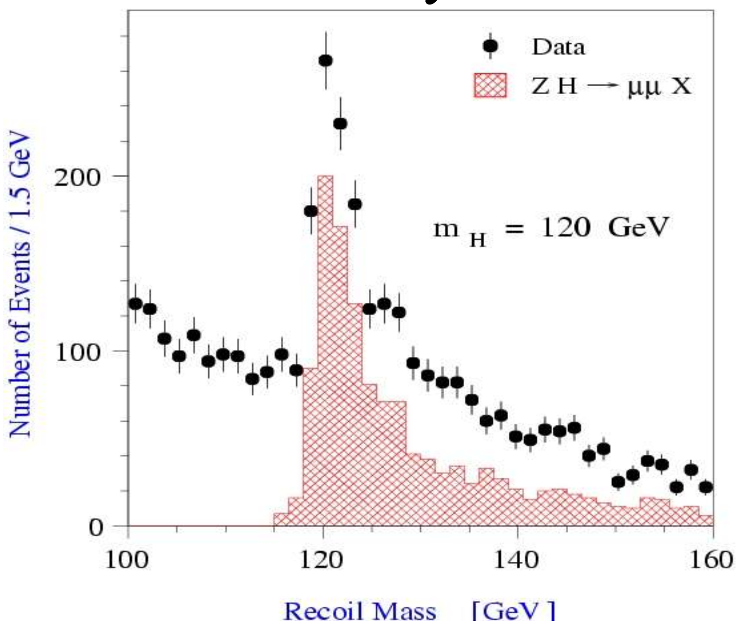


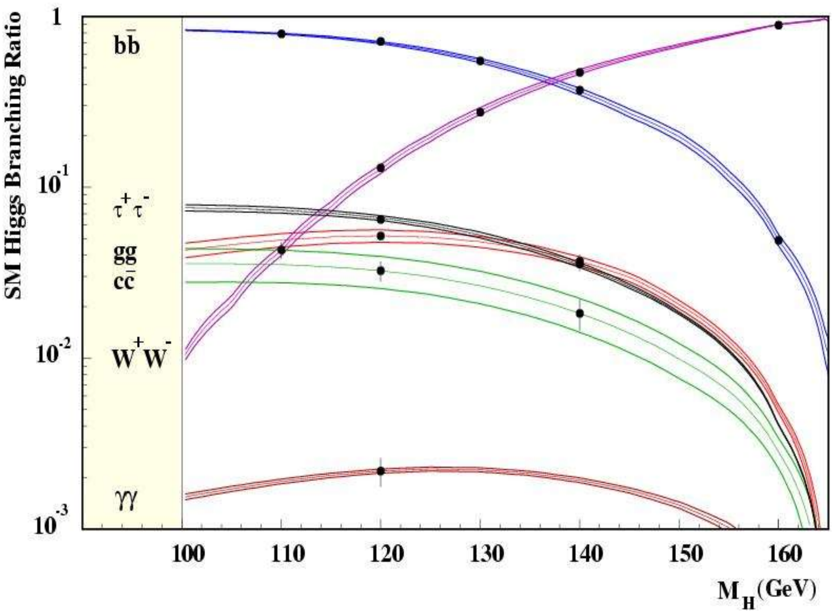
Linear Collider Higgs Physics

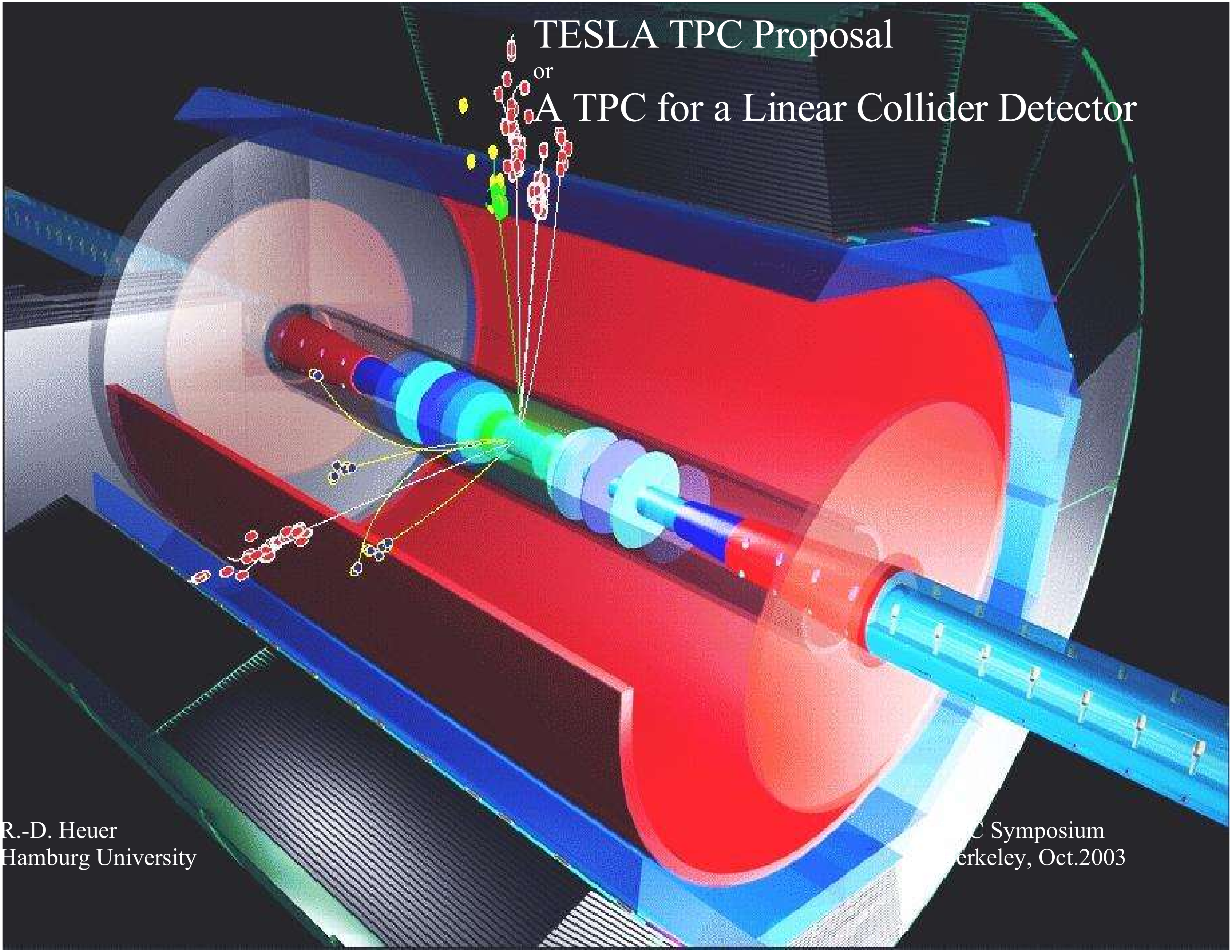


Use Higgstrahlung process e^+e^- --> ZH with Z decaying into leptons to measure / confirm Higgs mass from LHC, and to determine branching ratios precisely.

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

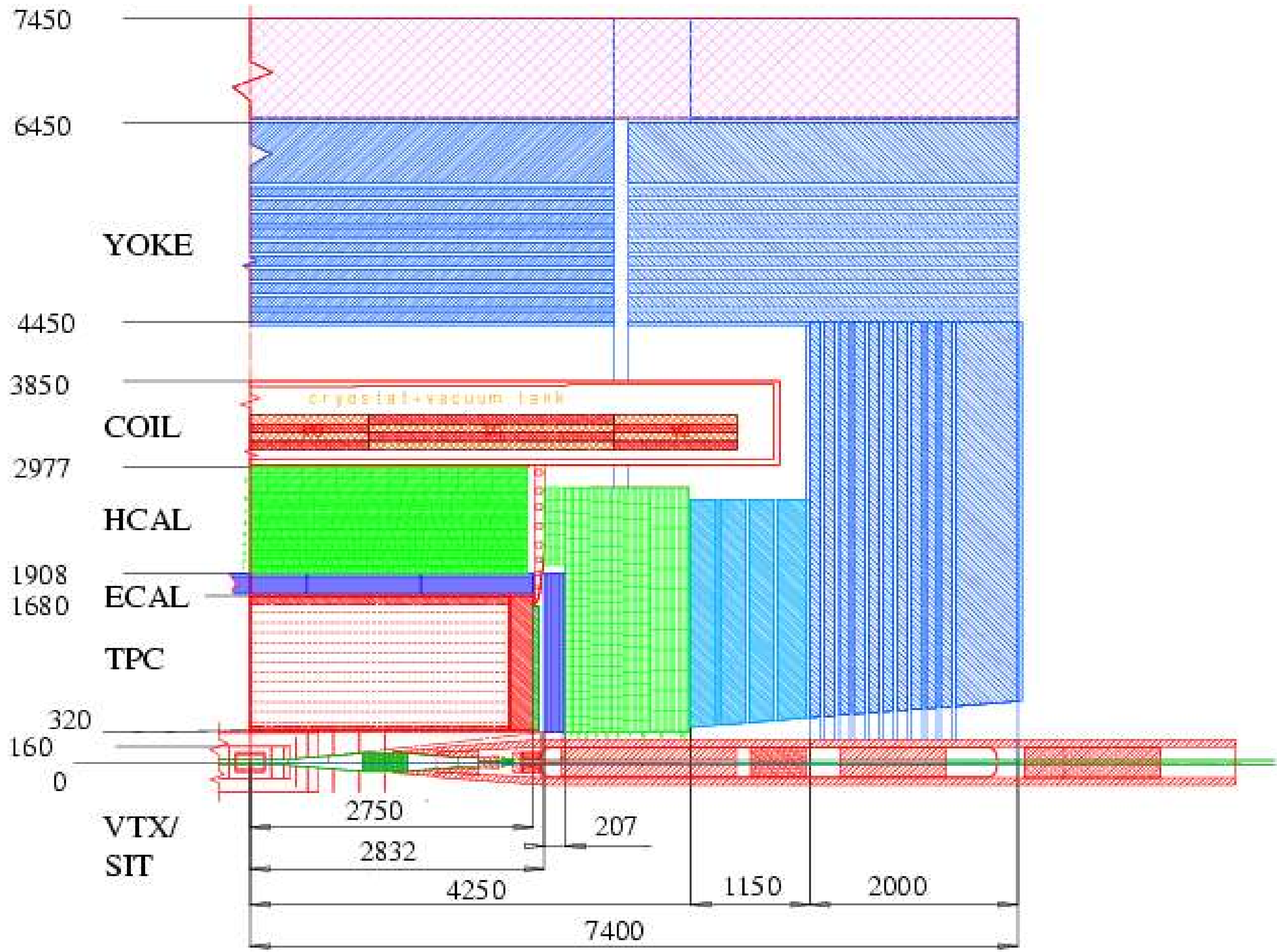





TESLA TPC Proposal
or
A TPC for a Linear Collider Detector
R.-D. Heuer
Hamburg University
C Symposium
erkeley, Oct.2003

ILC Gaseous TPC Detector Model

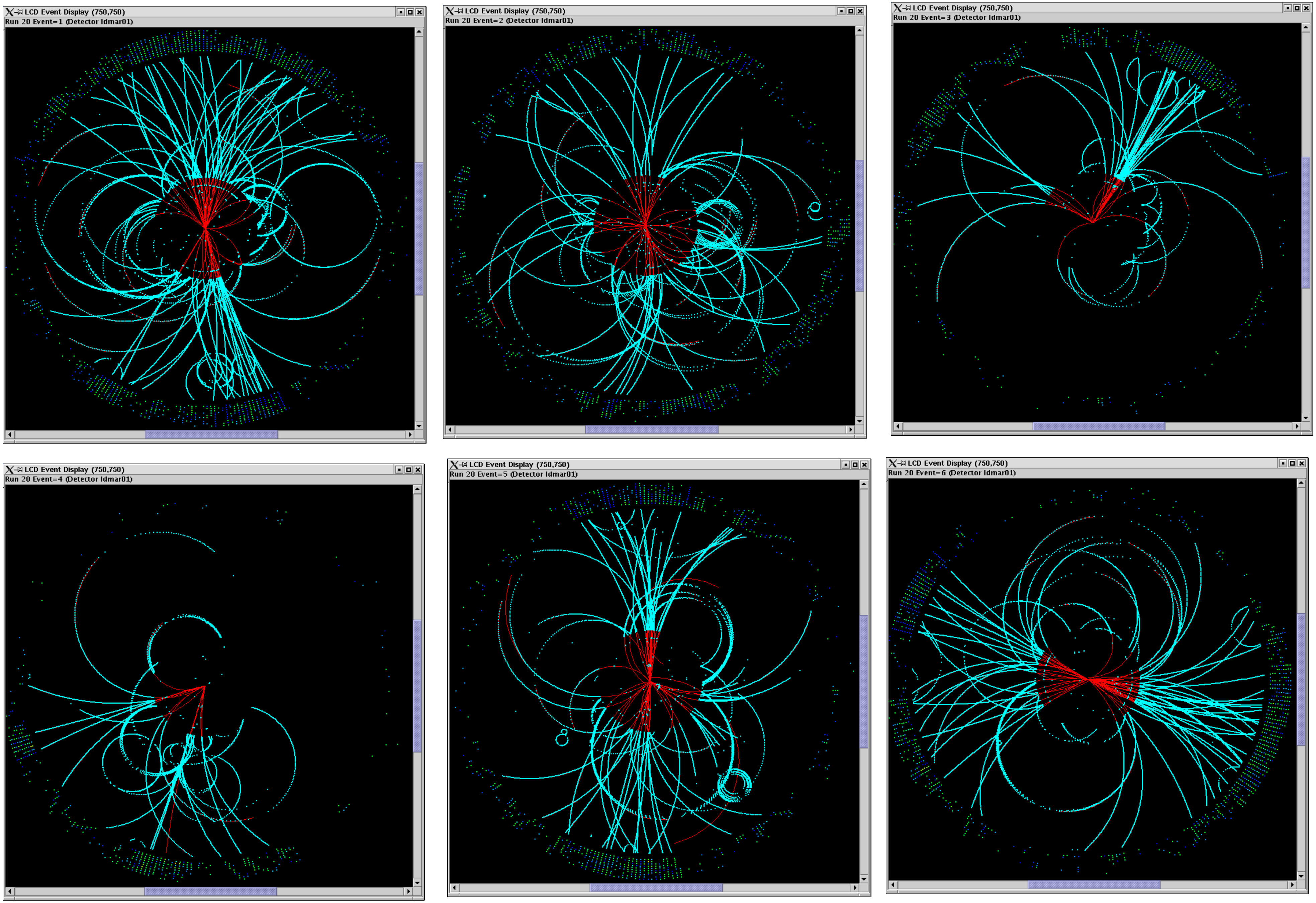
It might look somethink like



Multi-Jet Higgsstrahlung Events

May 3, 2006

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



-- Overall momentum resolution

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

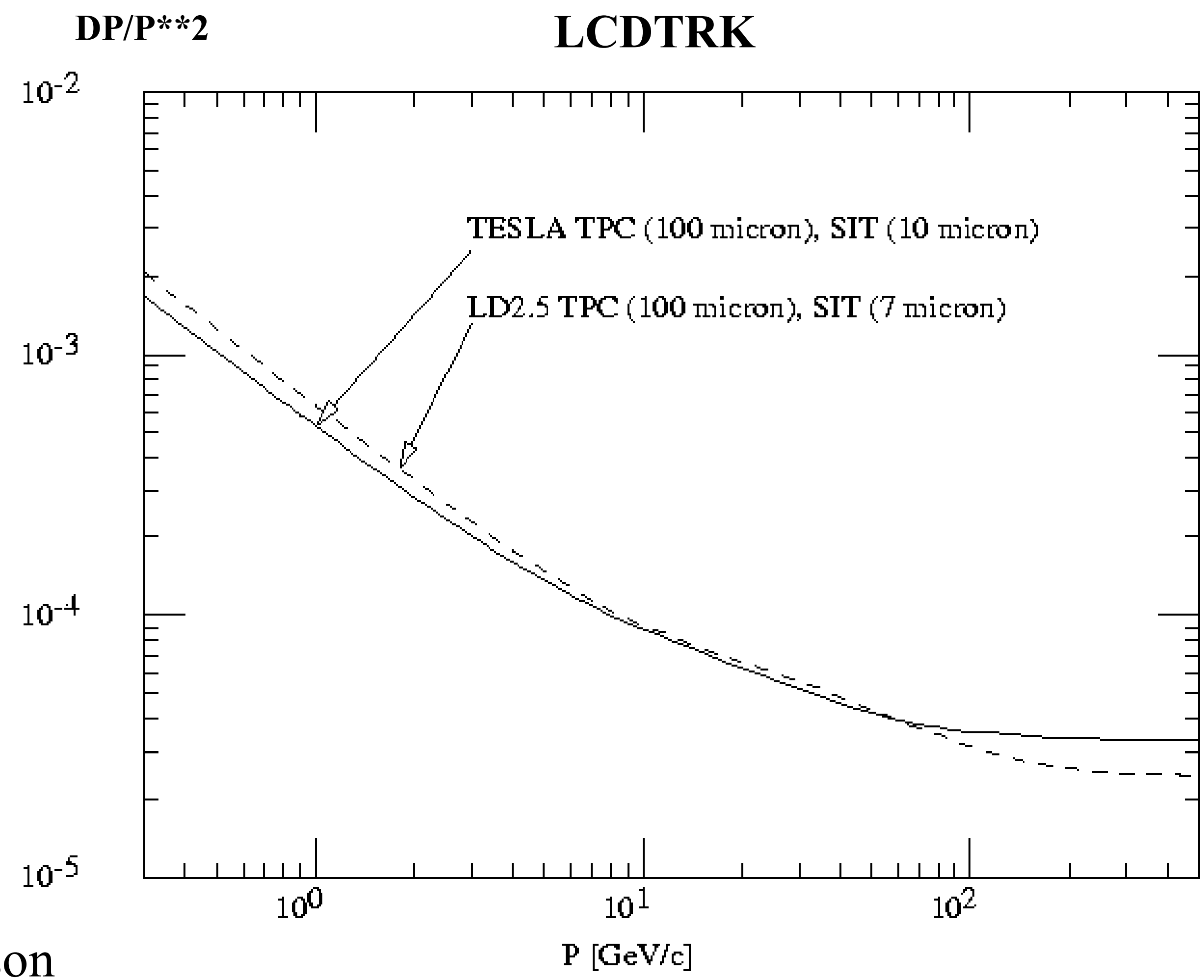
Here is a comparison of a modified version of the American LD detector to the TESLA TPC performance.

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.

American Large Detector Simulations

e+e- -> ZH -> 4 jets

Geant4 Detector Simulation

Provides detector hits

LCD Analysis Modules:

Hit smearing

TPC Pattern recognition

Calorimeter clustering

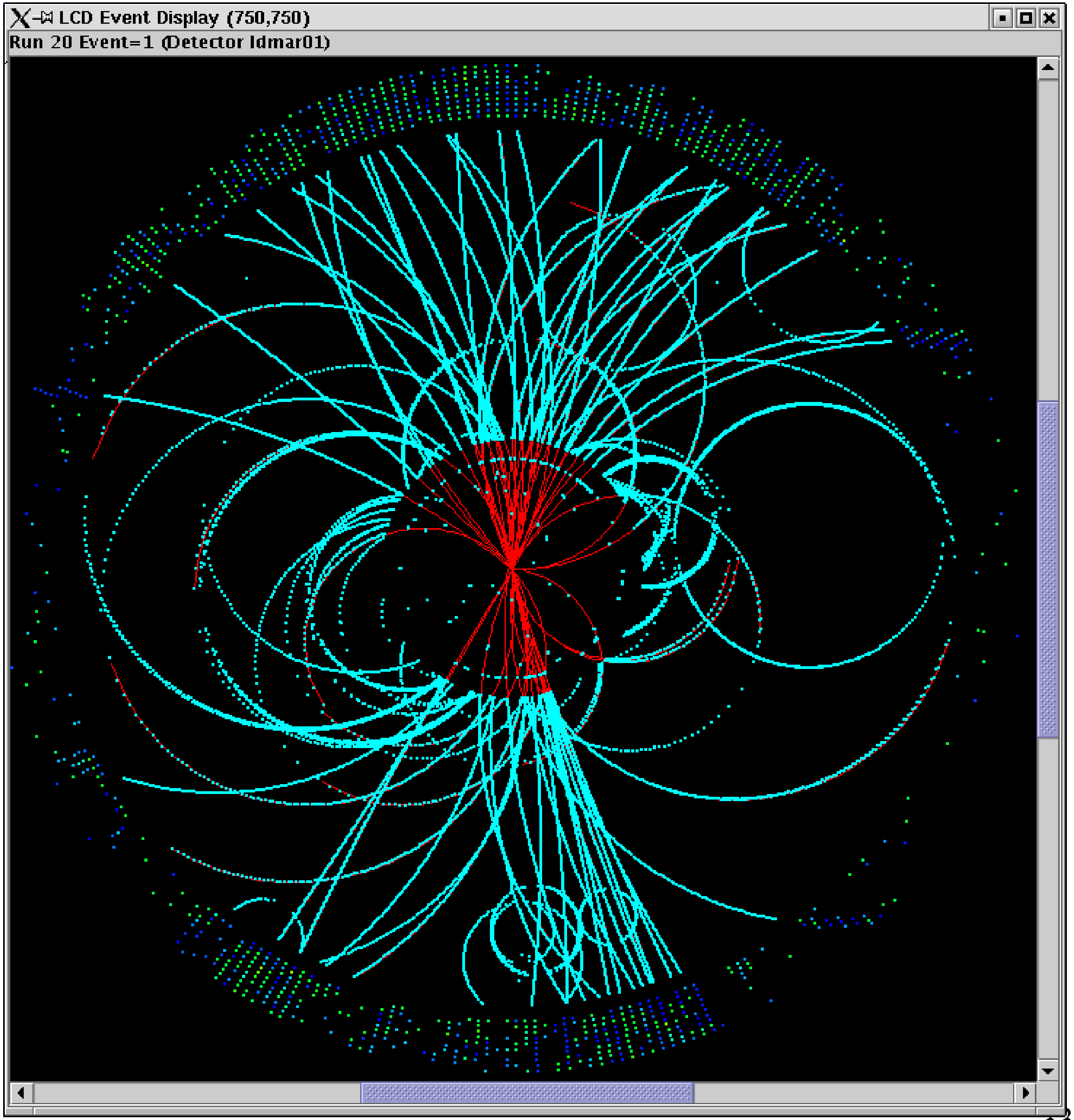
Event display

...

LCIO

JAS histograms

AIDA tuples



Detector: **ldmar01**

Hits: TPC (cyan),

Inner trackers (cyan)

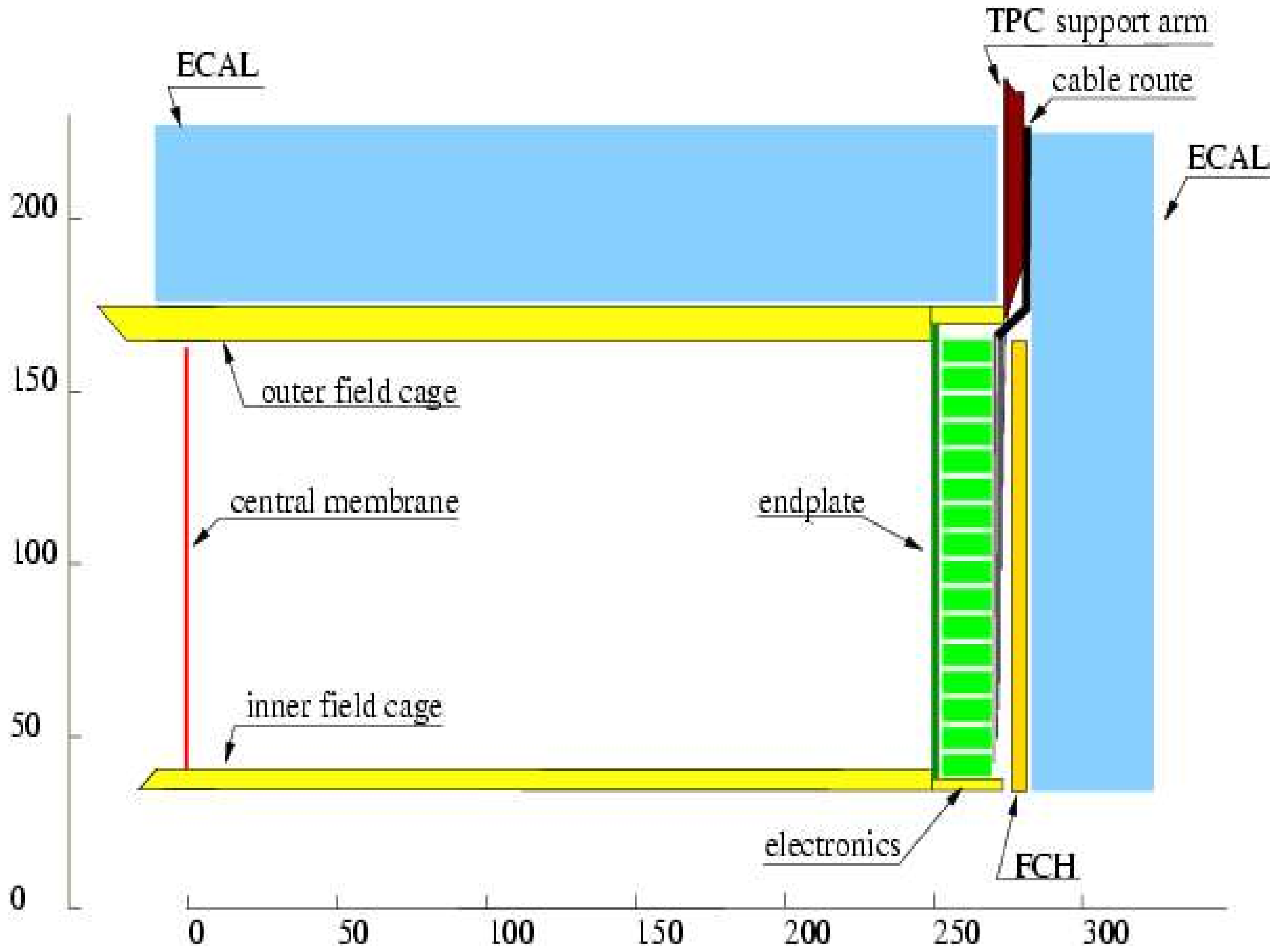
EM Cal (blue)

Tracks (red)

Clusters (green)

ILC Time Projection Chamber (TPC)

It will look something like

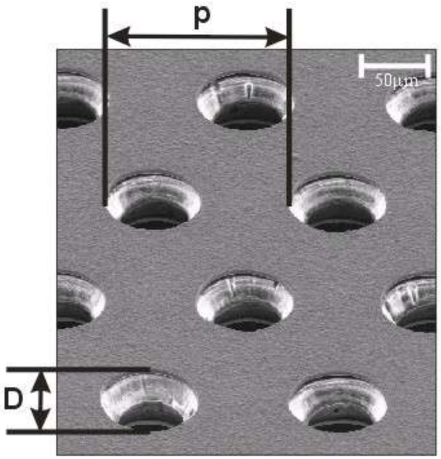


Micro-Pattern Gas Detectors

- Gas Electron Multiplier
  - Fabio Sauli
  - ...
- Micromegas
  - Georges Charpak, Ioannis Giomataris et al.
  - ...
- Commercial devices
- Micro...

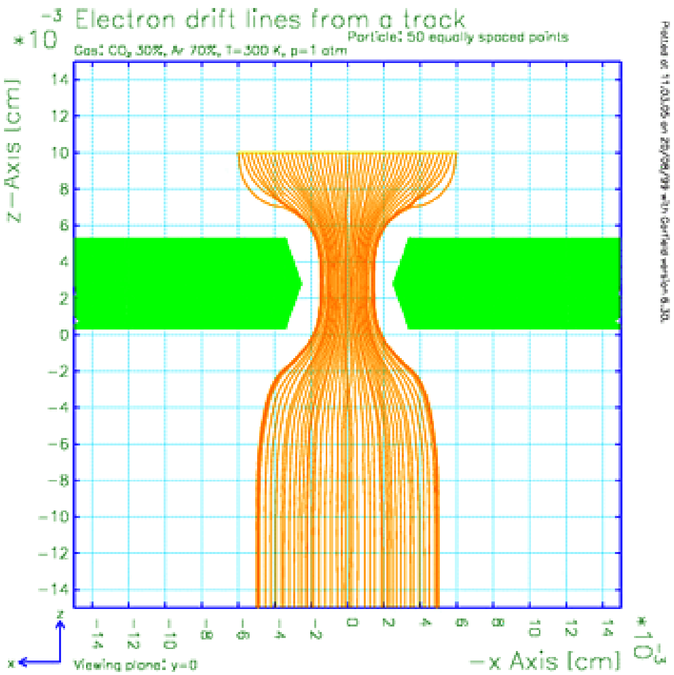
See many examples in **TPC References**, ***http://www-tpc.lbl.gov/References.html***

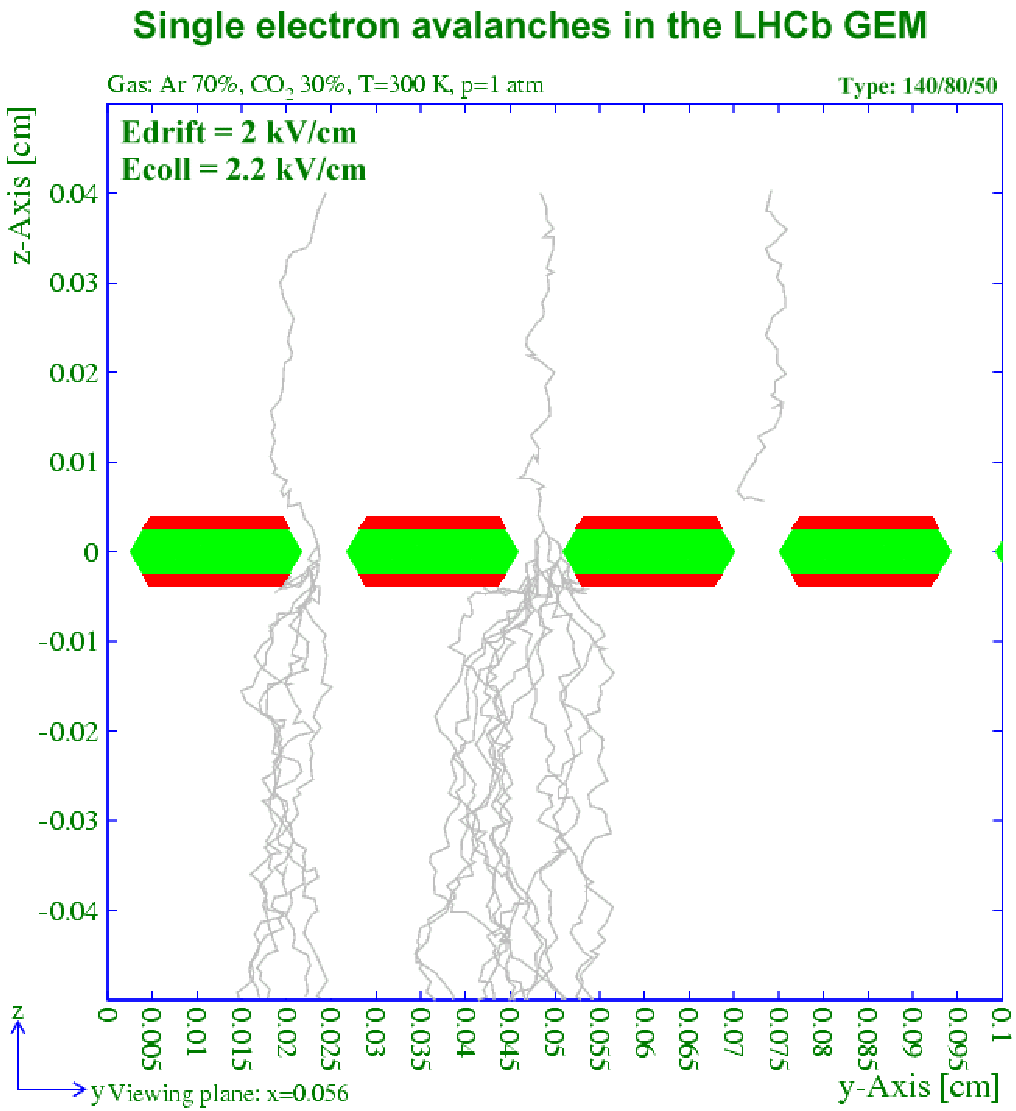
Gas Electron Multiplier (GEM)



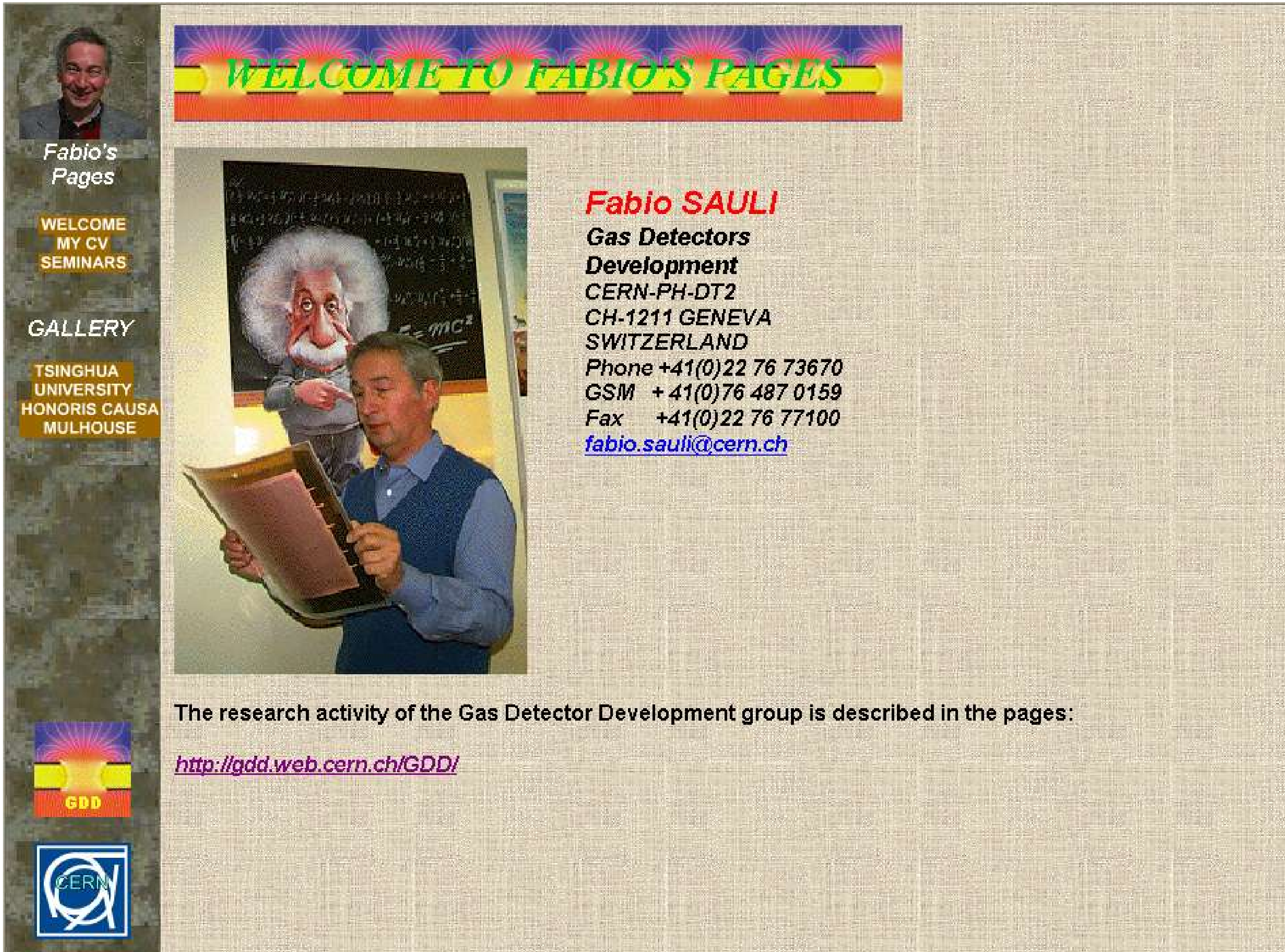
P~140 µm

D~60 µm





Fabio Sauli


WELCOME TO FABIO'S PAGES
Fabio's Pages
WELCOME
MY CV
SEMINARS
GALLERY
TSINGHUA UNIVERSITY
HONORIS CAUSA MULHOUSE
GDD
CERN
Fabio SAULI
Gas Detectors Development
CERN-PH-DT2
CH-1211 GENEVA
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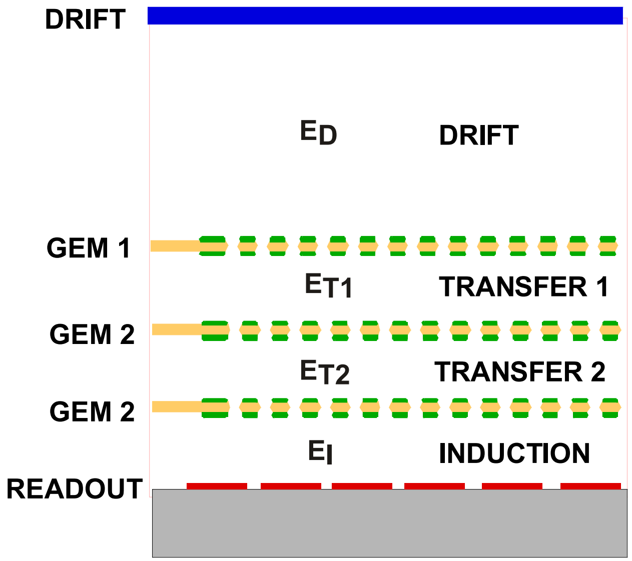
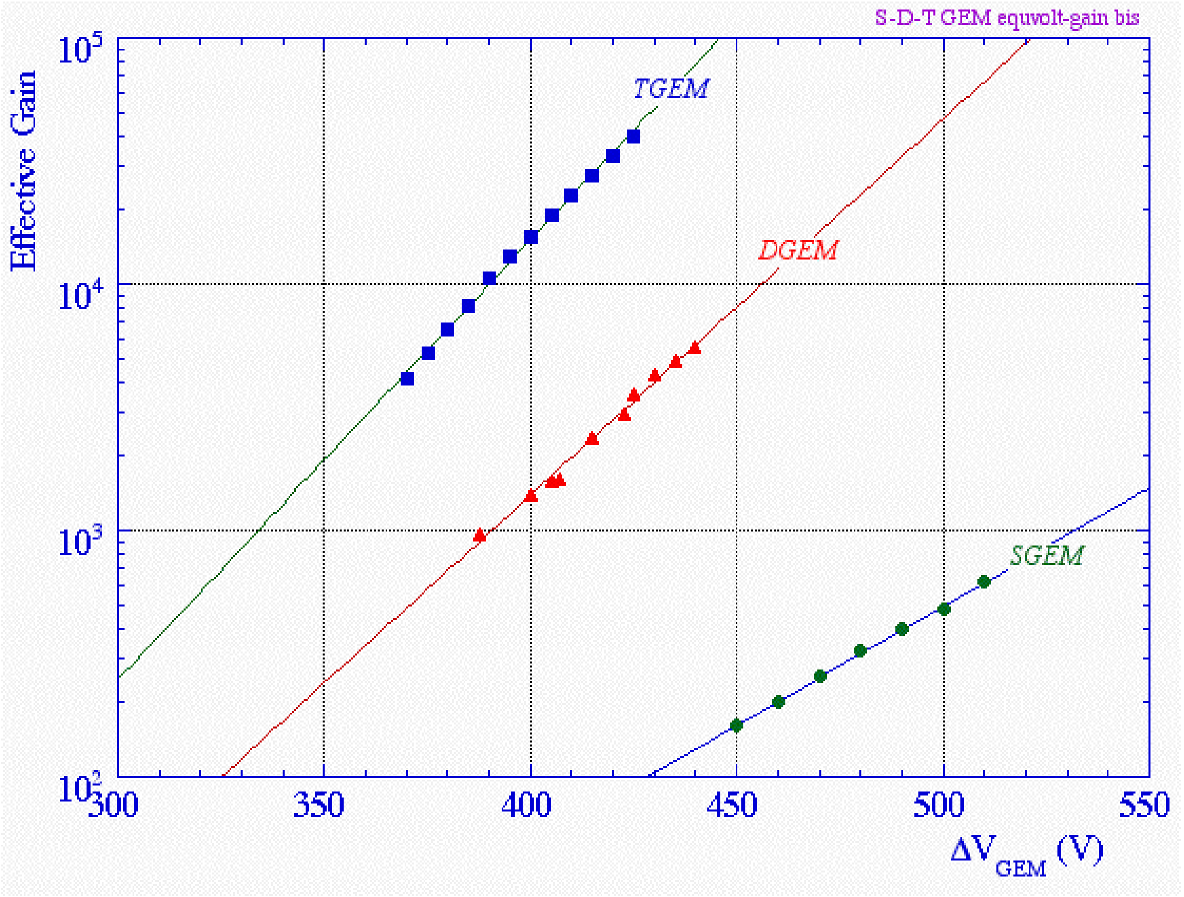
Phone +41(0)22 76 73670
GSM + 41(0)76 487 0159
Fax +41(0)22 76 77100
fabio.sauli@cern.ch
The research activity of the Gas Detector Development group is described in the pages:
http://gdd.web.cern.ch/GDD/

Multiple GEM's (e.g. a "Triple GEM")

Cascaded GEMs allow larger gains and safer operation in harsh environments

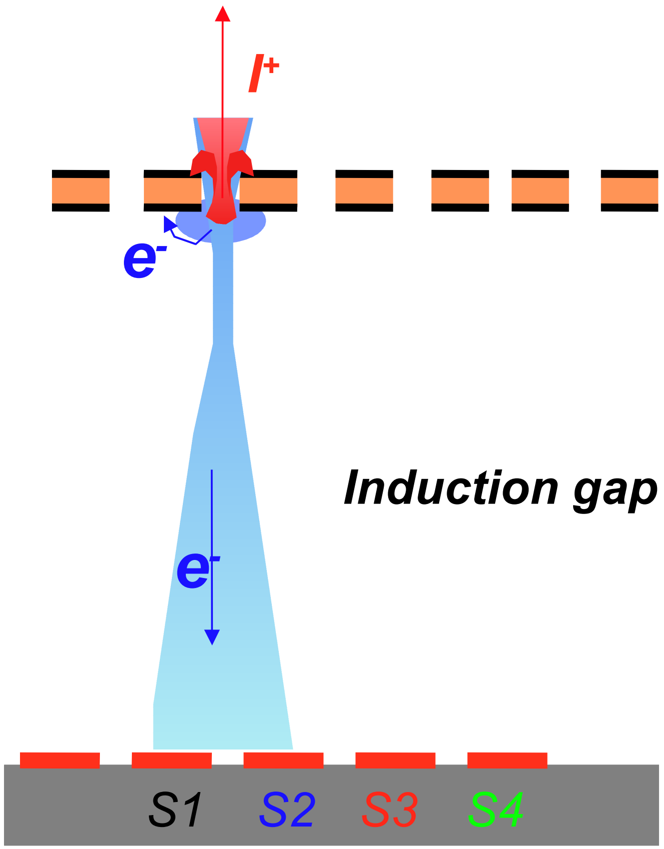
Triple GEM:

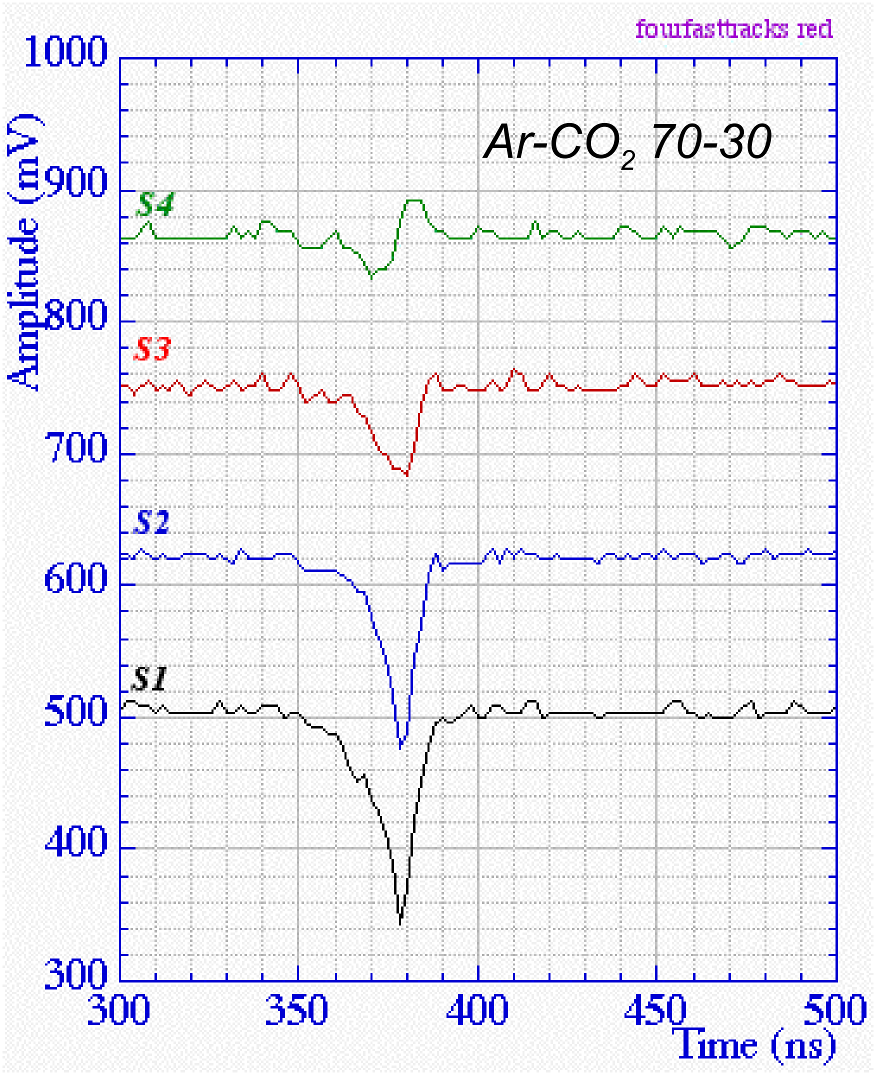




C. Buttner et al, Nucl. Instr. and Meth. A 409(1998)79
S. Bachmann et al, Nucl. Instr. and Meth. A 443(1999)464

Fast Electron Signals

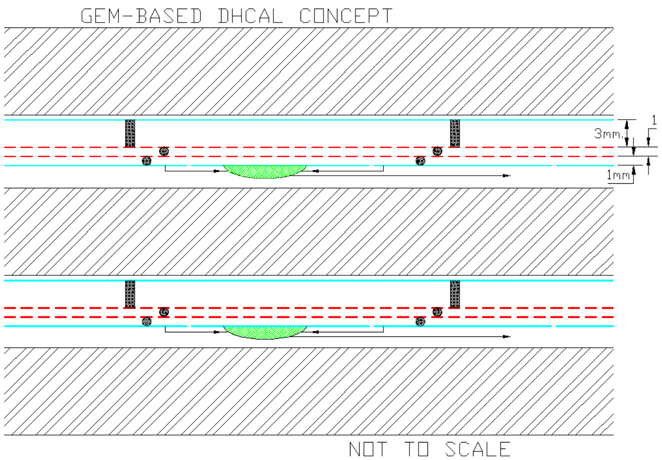


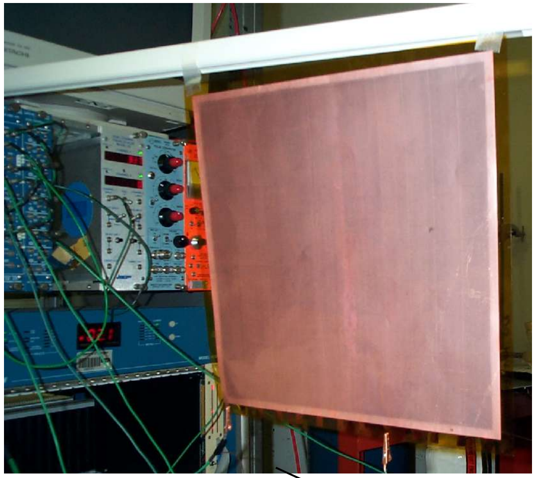


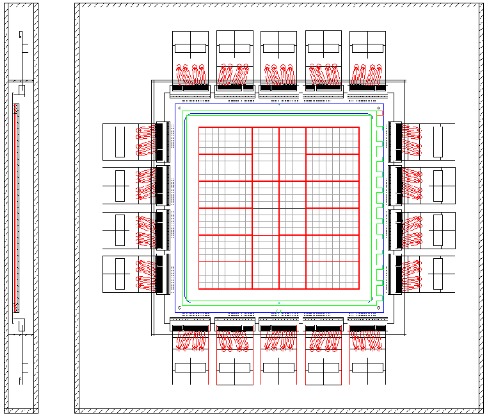
No positive ion tail ⟶ very good multi-track and time resolution

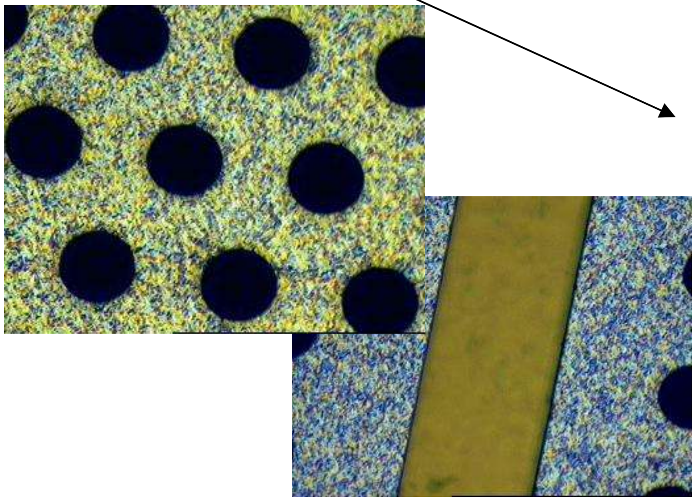
Hadron Calorimeter – CALICE/digital

(1) Gas Electron Multiplier (GEM) – based DHCAL

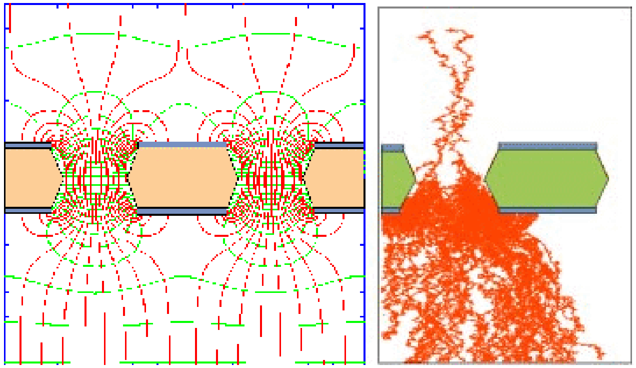






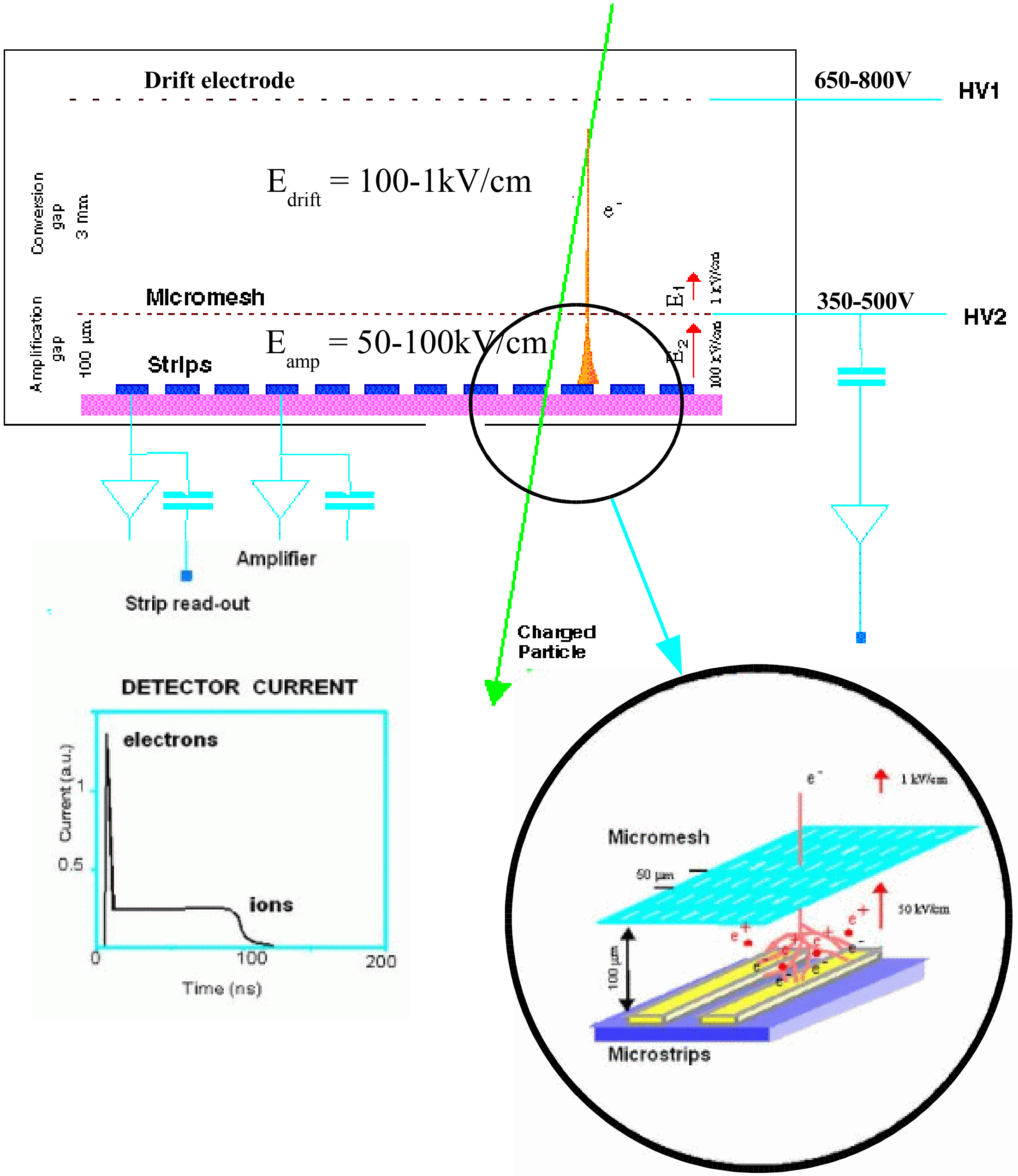


500 channel/5-layer test 30x30cm² foils

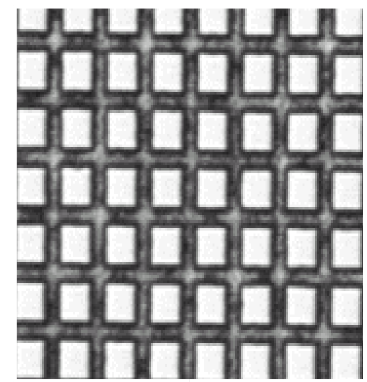


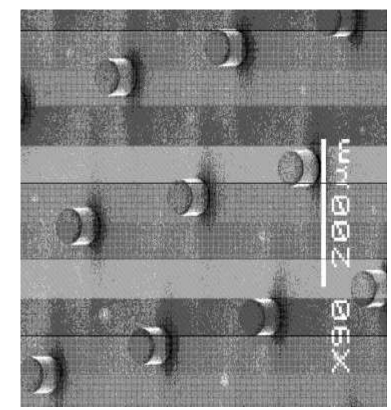
Details of new 30cm x 30cm foils from 3M

MICRO Mesh Gas Structure (Micromegas)



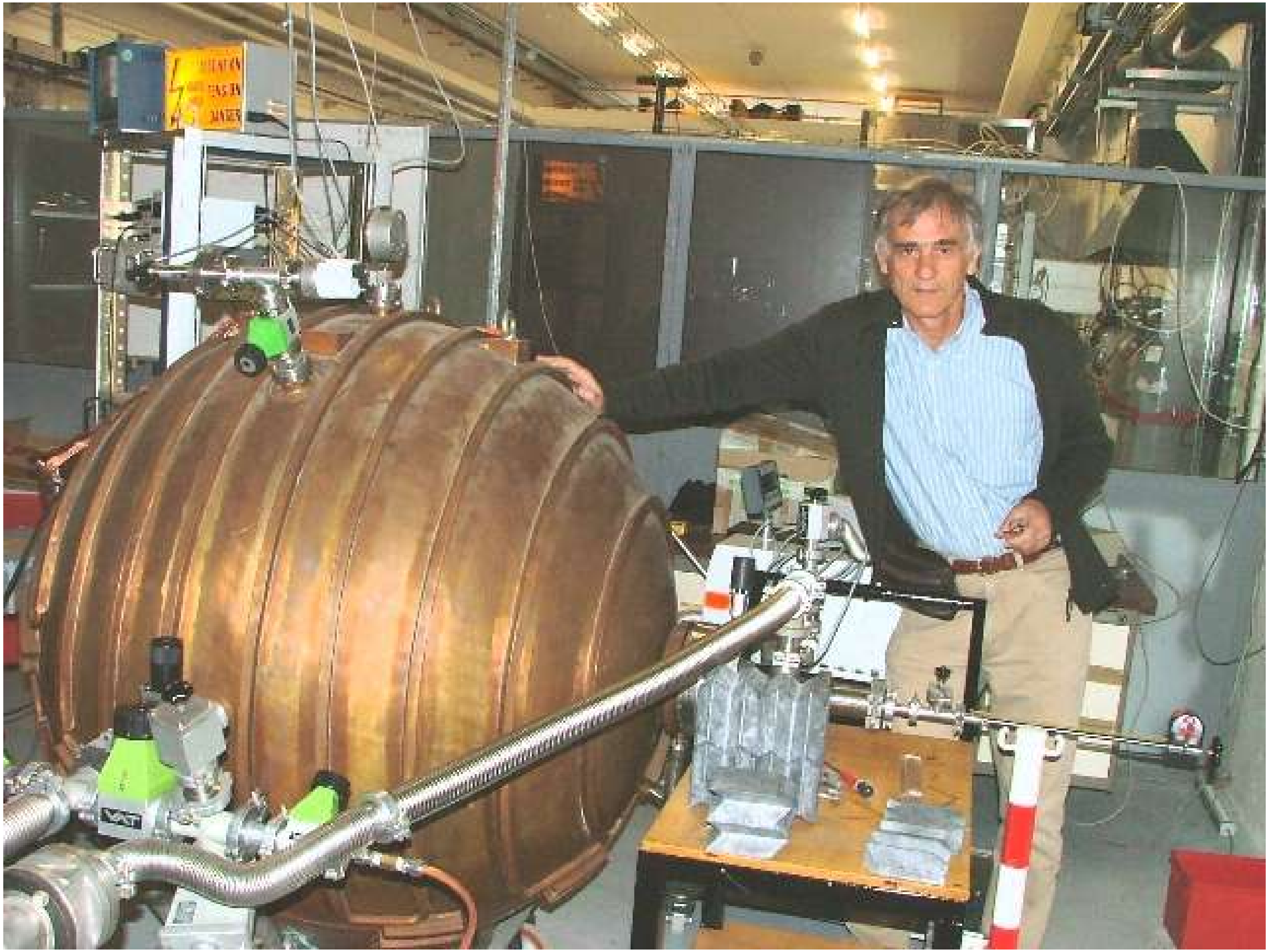
Micromegas: A metalic woven or electro-produced micromesh sustained by 50-100µm pillars over anode plane.





Very high gain electron multiplication between anode and mesh in one stage. Electron preamplification is possible with GEM's or Micromegas.

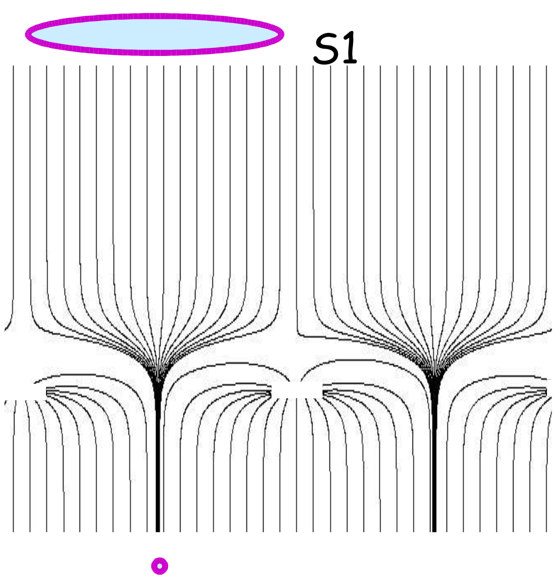
Ioannis Giomataris



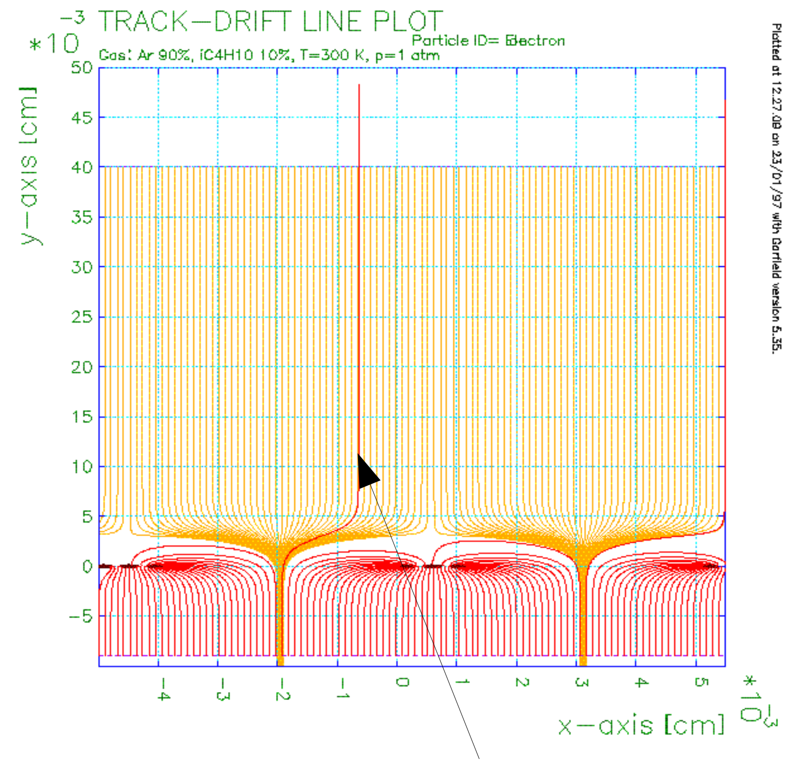
Positive Ion Feedback

"Funnel effect"

$S1/S2 \sim E_{amplif} / E_{drift}$



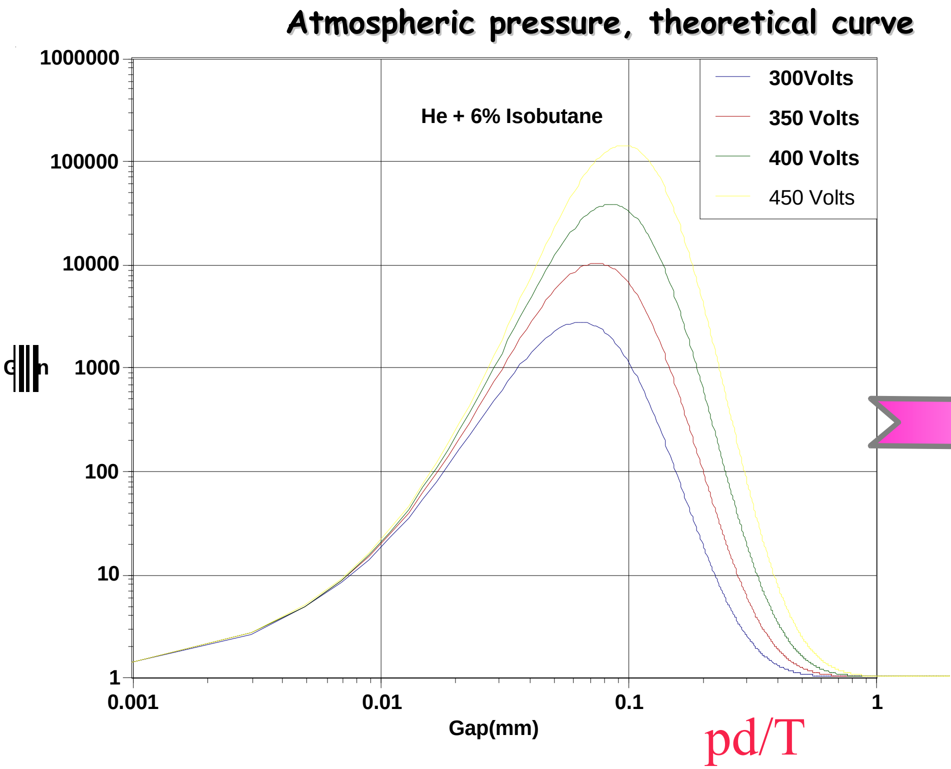
Calculated drift lines for electrons and positive ions from **GarField**, CERN



positive ion feedback

Note: Electron diffusion is limited in drift region (100-200 V/cm) but increases dramatically in the Micromegas high field region (50-100 kV/cm) causing the avalanche to spread across the anode surface, and reducing the positive ion feedback to field ratio $\mathbf{E_{drift}/E_{amp} \sim 0.1\%}$.

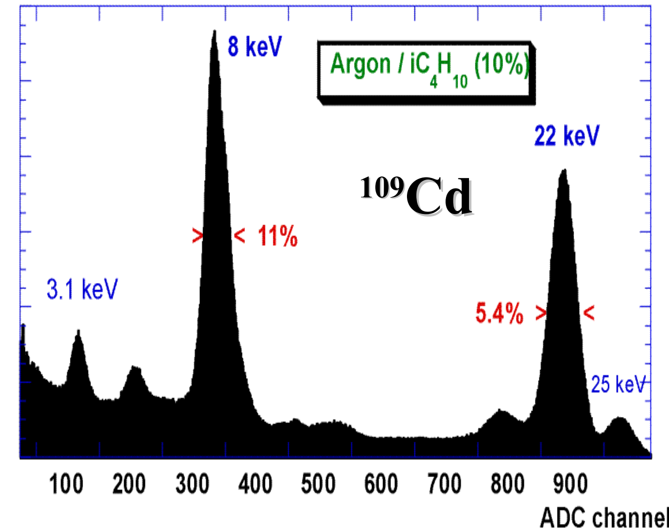
Gain stability



Optimum gap : 30 - 100 microns

Ref: Y. Giomataris, NIM A419, p239 (1998)

Good energy resolution



Ref: A. Delbart et al, NIM A461, p84 (2001)

- Stable gain and relative immunity to flatness defects or pressure variation
- Good energy resolution

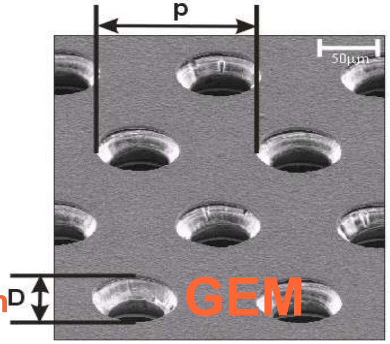
LC-TPC R&D

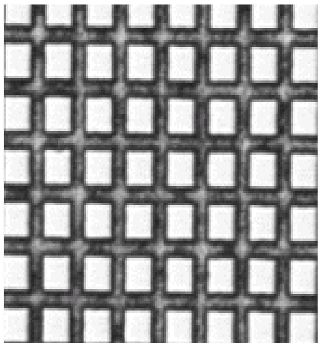
- GEM
  - Aachen, **DESY**, Karlsruhe, Munich, ...
  - Carleton, Victoria and **KEK**, ... Also **BNL**, **JLab**, MIT & Yale
- Micromegas
  - Berkeley, Orsay & Saclay collaboration
  - KEK, Phillipines, ...
- Digital TPC
  - **NIKHEF** & Saclay
  - Freiburg, ...
- Resistive foil technique
  - M.Dixit et al., Carleton
- Latest
  - **InGrid**, ...

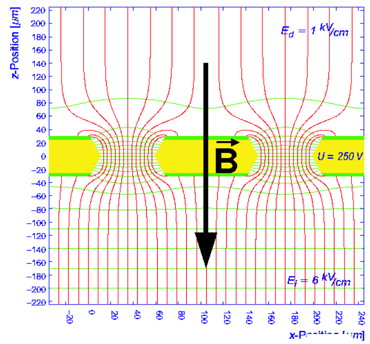
R&D on Gaseous Tracking

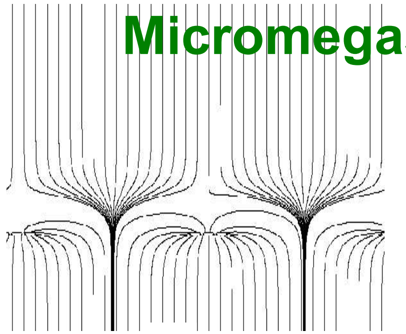
- The goal: position resolution ~100 µm, good 2-track separation with drift~m
- Strong inter-regional LC-TPC Collaboration on Micro Pattern Gas Detector (MPGD) readout TPC (GEM, Micromegas)
- Start from small prototypes test, aim at large prototype (d~75 cm, drift~1 m) in next 3 years

(R. Settles, MPI Munich)



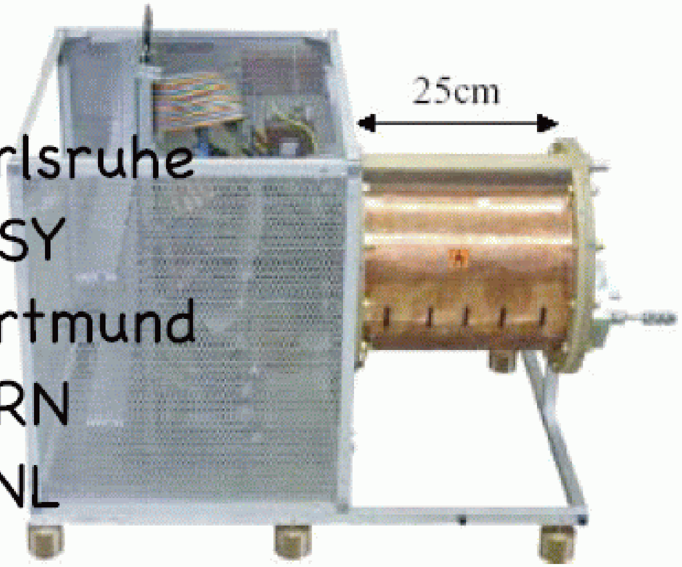


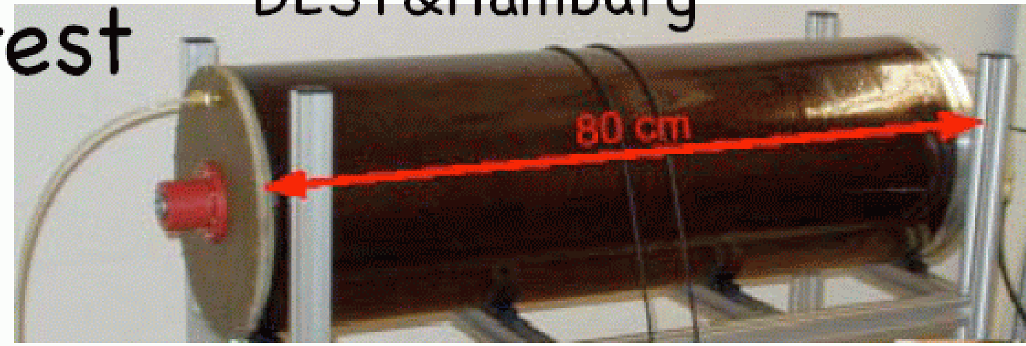


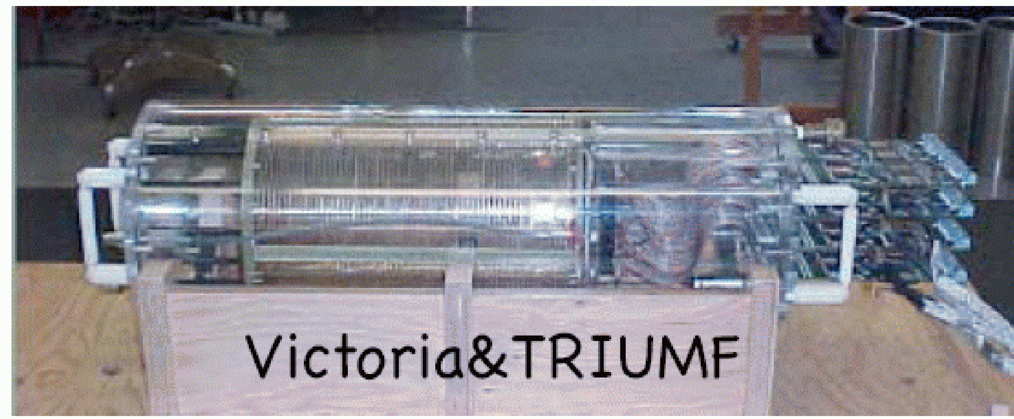


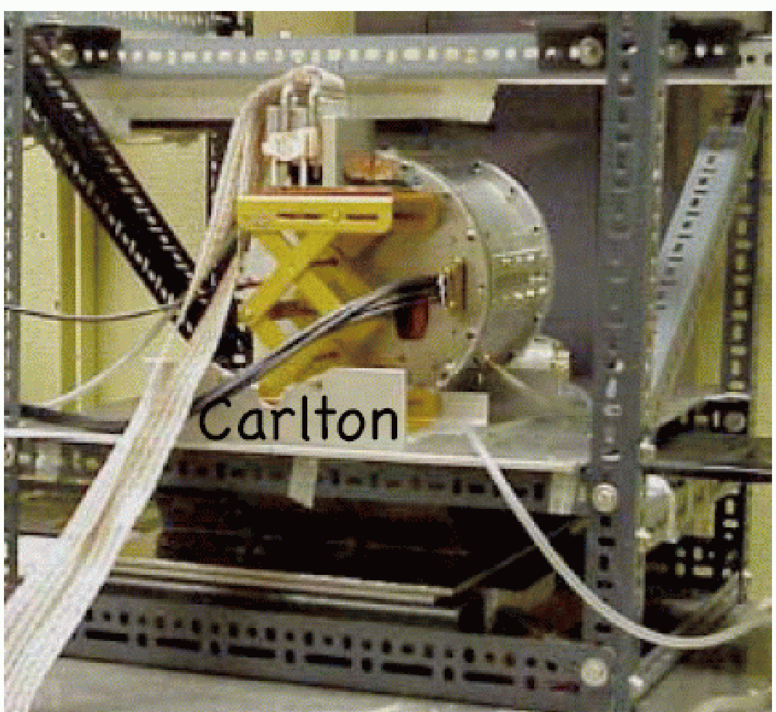
- Multi Technologies Testing (MT3) Collaboration: beam-test with 4 GeV/c π at KEK of MWPC, GEM and Micromegas TPC

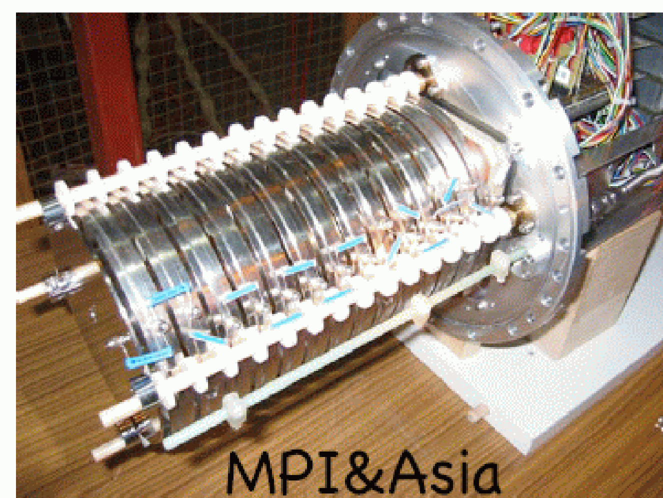
Resolution/prototype test



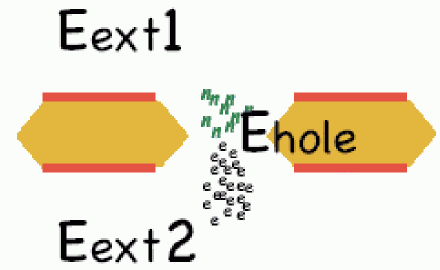






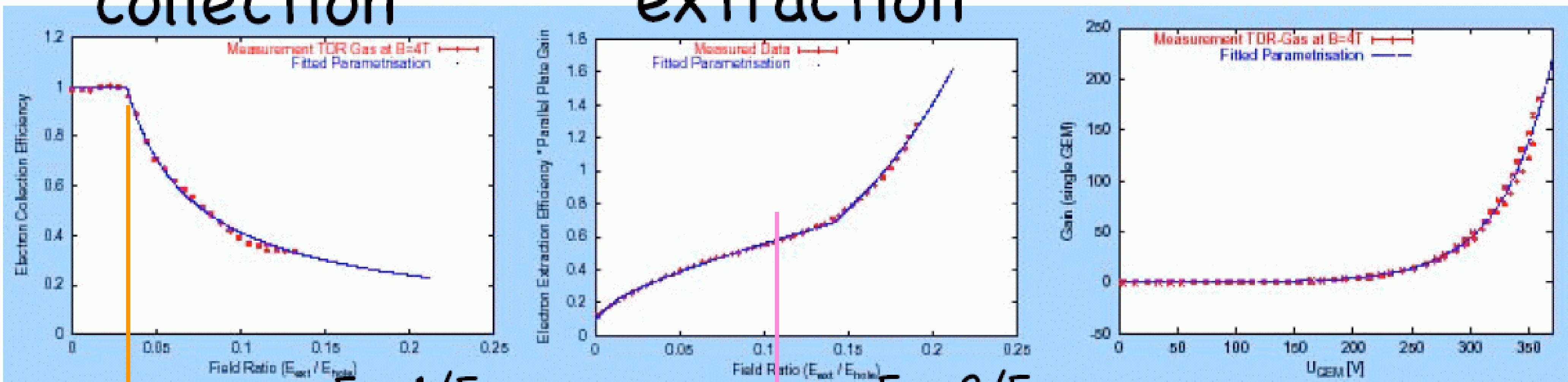


Electron collection/extraction to/from GEM



Aachen

collection extraction



Eext1/Ehole Eext2/Ehole

Drift Field

This requirement must be satisfied in the first GEM

Transfer gap need high E field

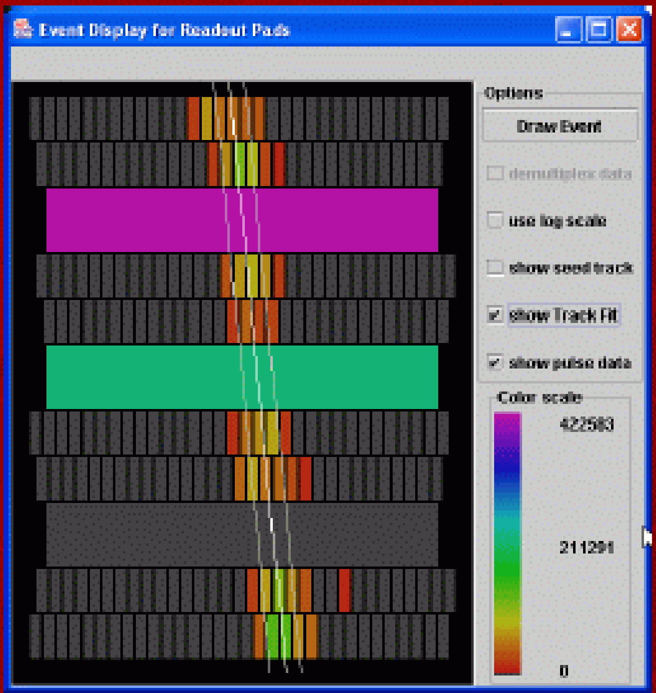
how about the second GEM ?

Next

Example events at ~25 cm drift

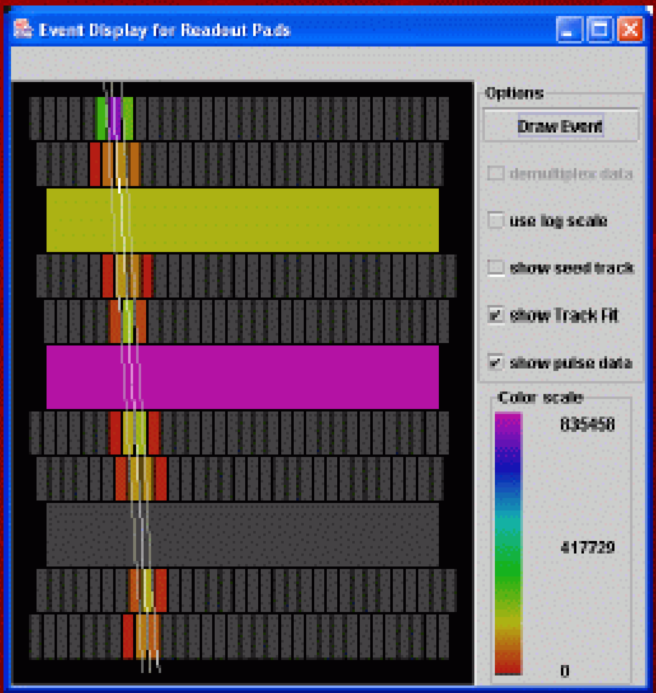
Gas: P10

0 Tesla



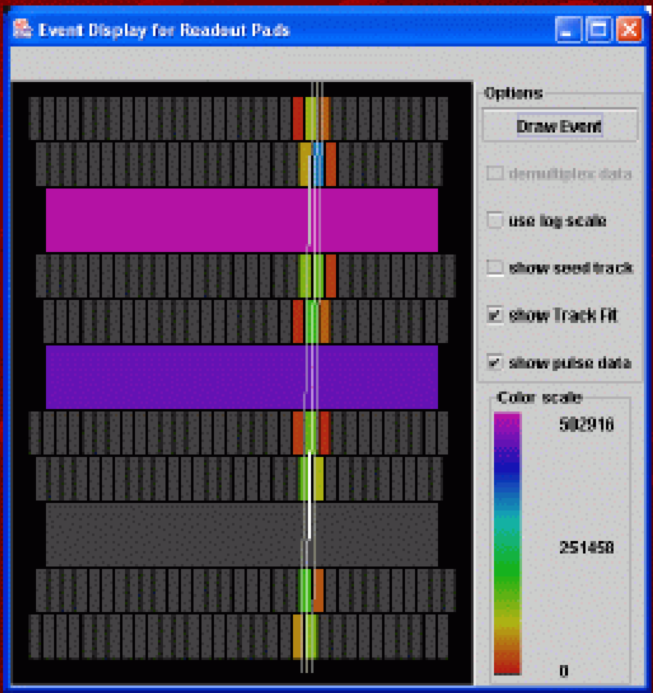
$\sigma = 2.3$ mm

0.45 Tesla



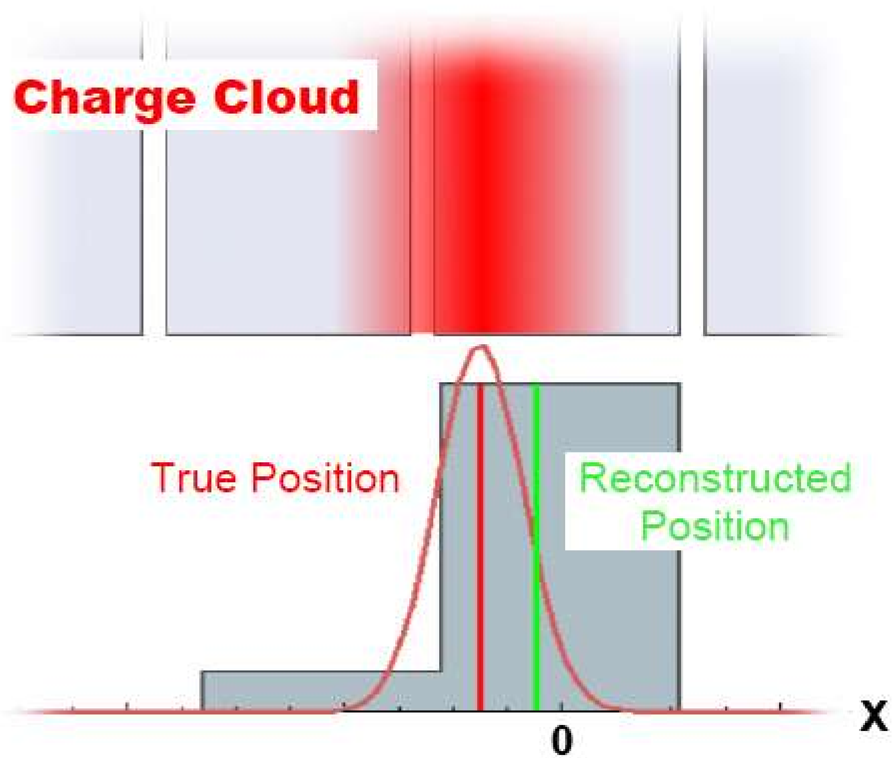
$\sigma = 1.2$ mm

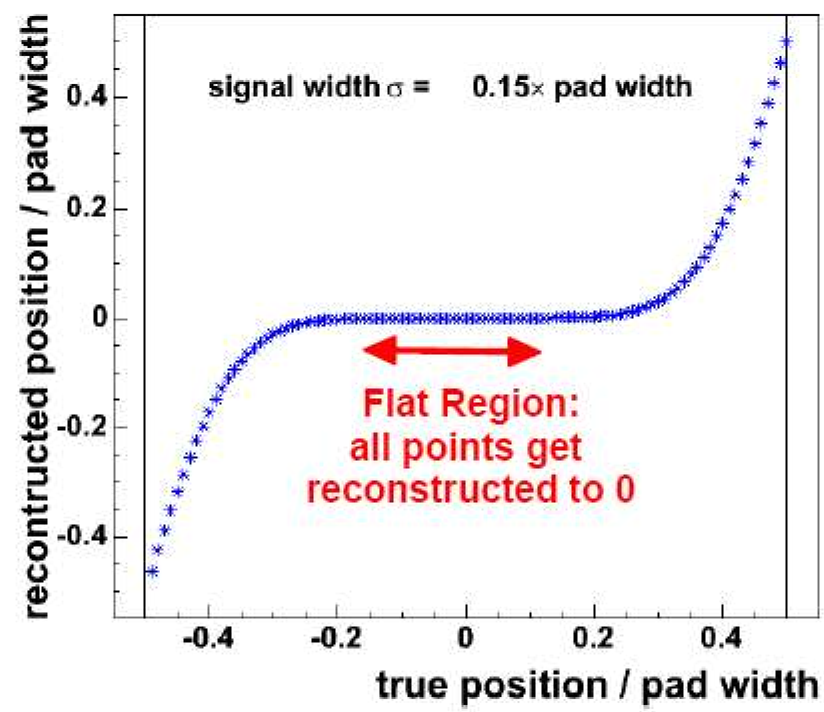
0.9 Tesla



$\sigma = 0.8$ mm

Pad Response Function





- Signal on „not enough“ pads → too small charge sharing
- Instead of at the true position, hits get reconstructed towards the middle of the pad with highest signal

Defocusing effect

high trans. diffusion @ high E field

Example: P5

$$\sigma_x = \sqrt{2Dt} = \sqrt{2\frac{D}{v}L}$$

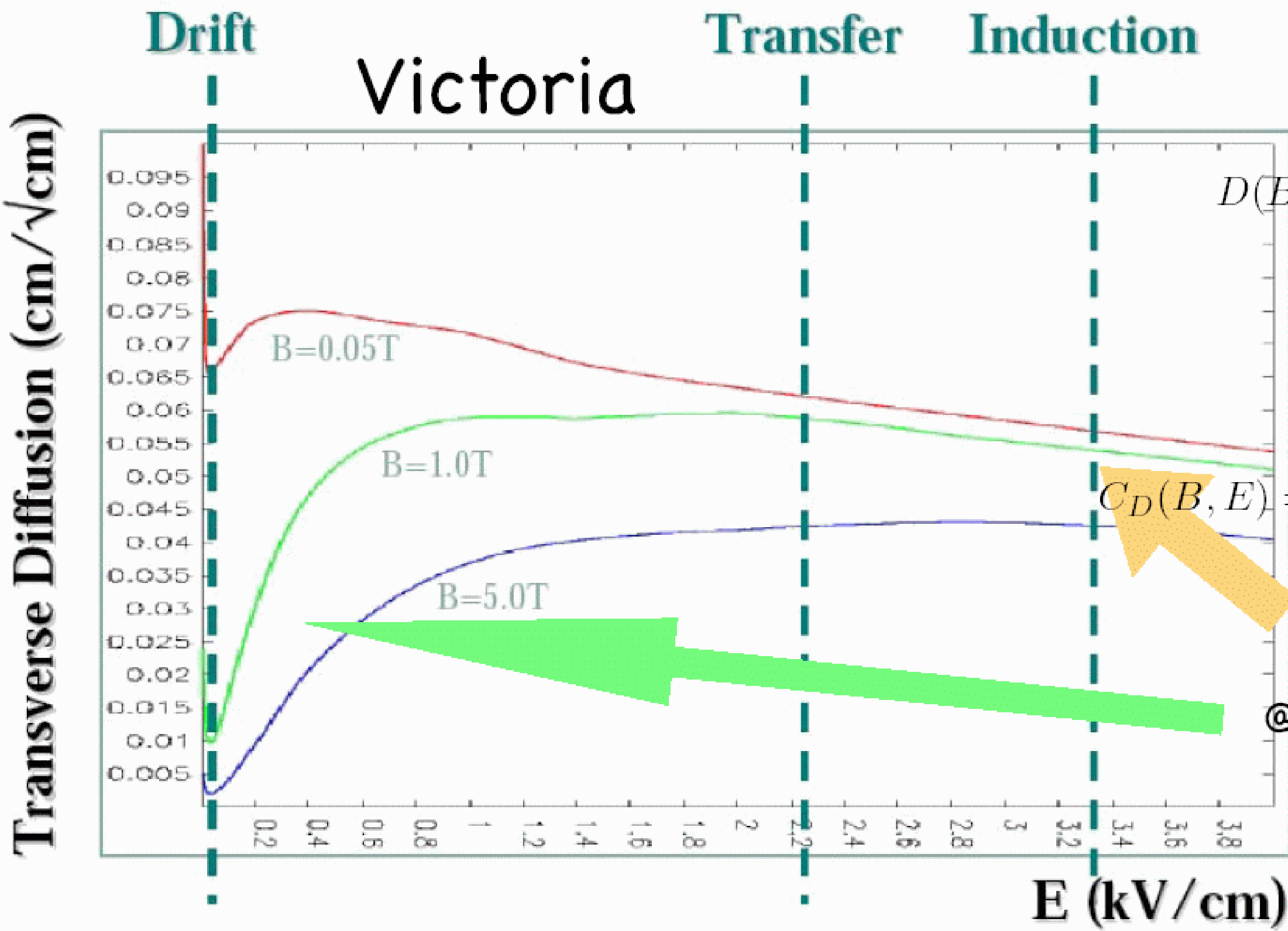
$$C_D = \sqrt{\frac{D}{v}}$$

$$D(B,E) = \frac{1}{1+\omega^2\tau^2}D(0,E)$$

$$\omega = \frac{eB}{m}$$

$$\tau \sim \frac{mv}{eE}$$

$$C_D(B,E) = \frac{1}{\sqrt{1+(\frac{B}{E})^2 v^2}}C_D(0,E)$$



@saturated velocity

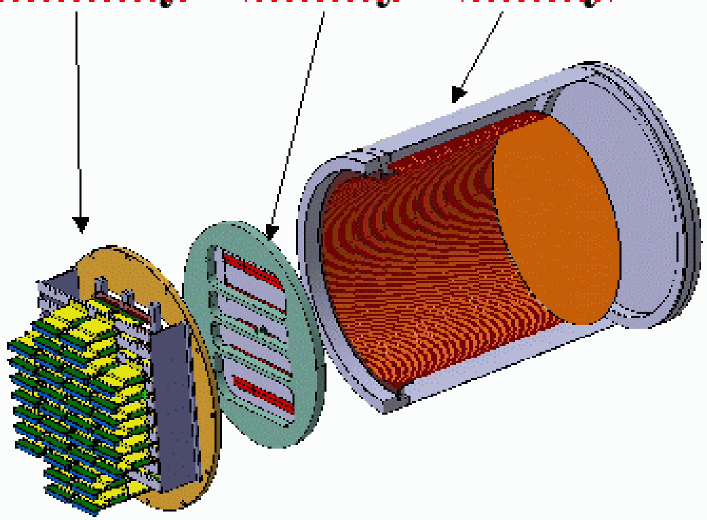
$v = \mathrm{const.}$

@non-saturated velocity

$v = \mu E$

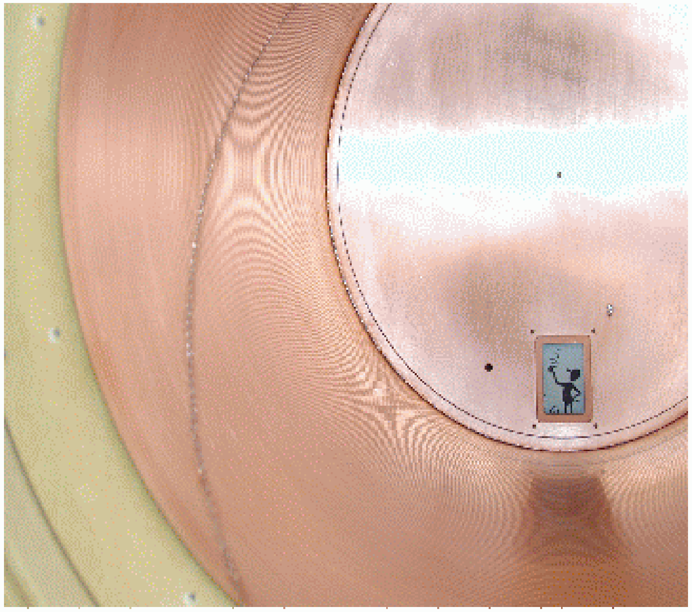
Chamber design and pad layout

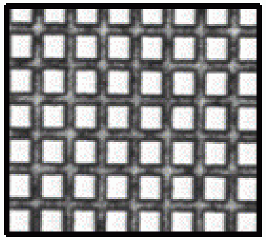
Berkeley Saclay Orsay



Chamber

diameter 50 cm
length 50 cm

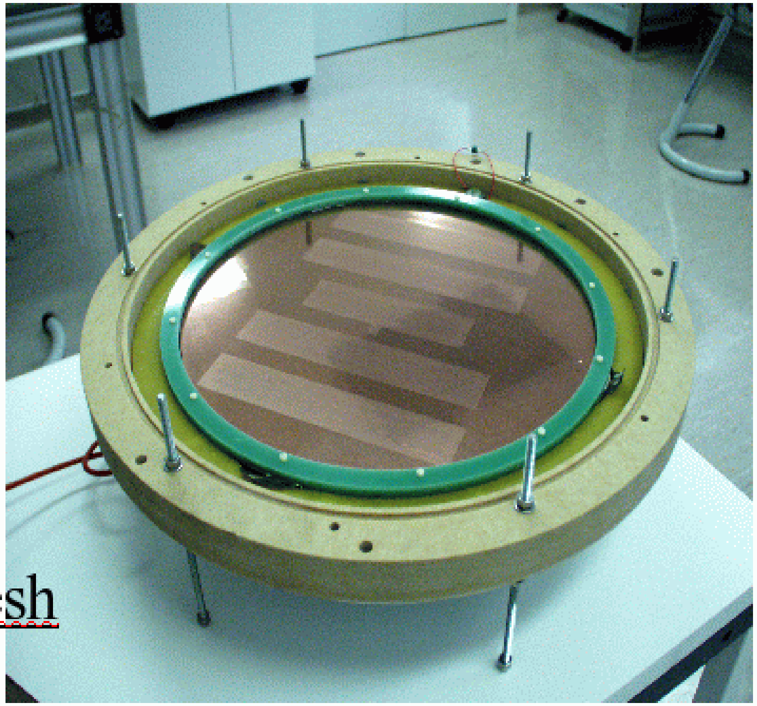




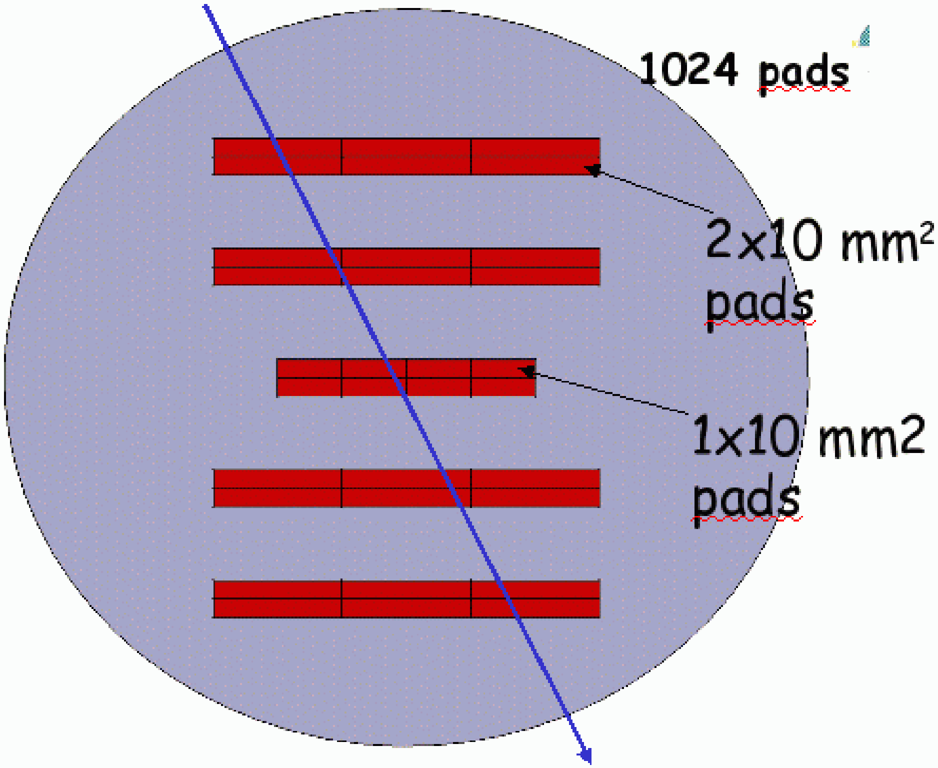
50 µm pitch

50 µm gap

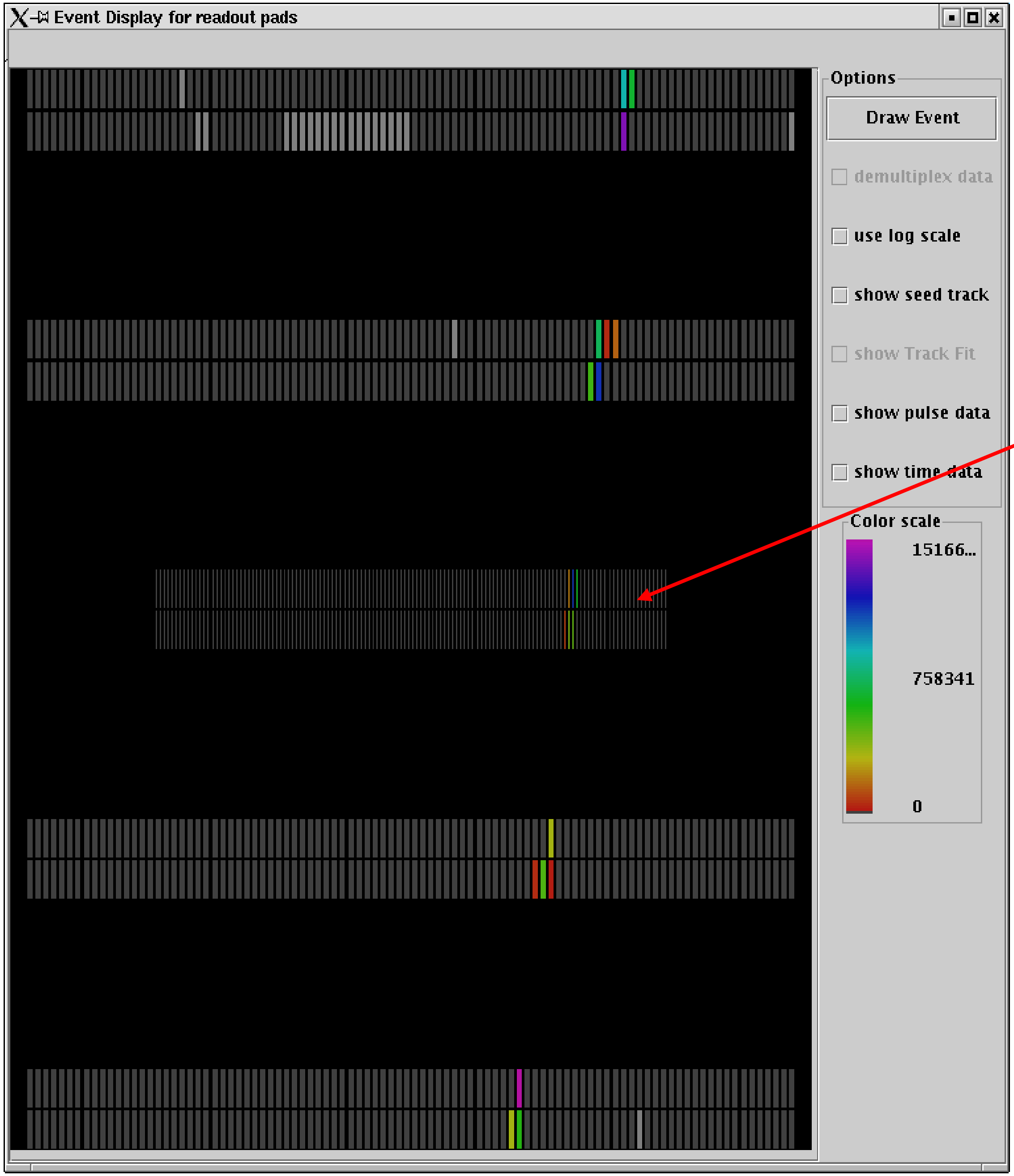
Copper Mesh



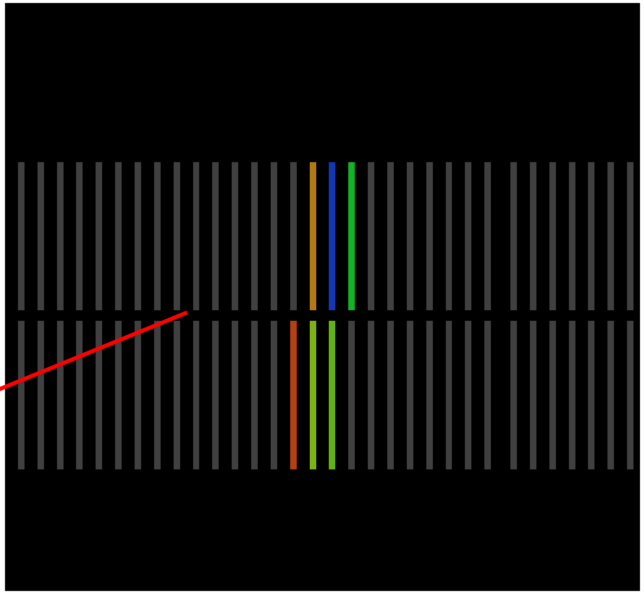
Readout anode pad plane

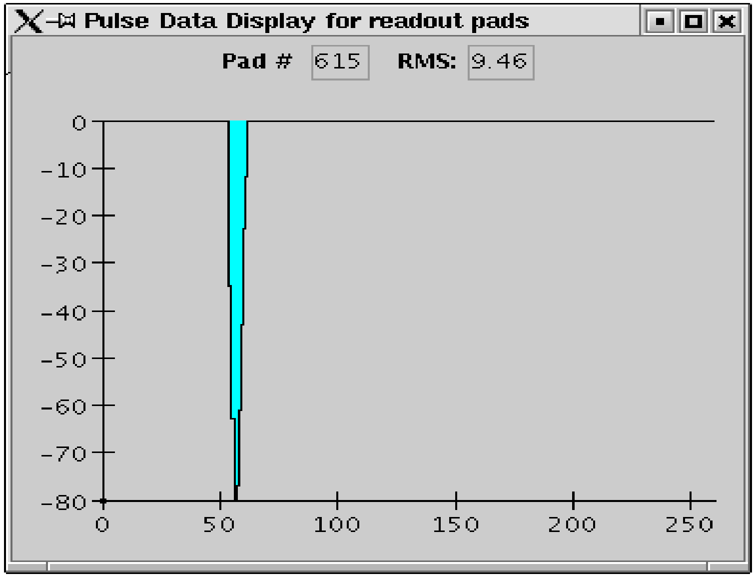


Online event display



Rows 4 & 5   1 X 10 mm^2





LC-TPC gas choices

May 3, 2006

Gases:

Ar-CH_4 e.g. P10 – 90:10 %

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

Ar-CO_2

Slow gas, requiring larger drift fields.

Tesla TDR Gas (Ar-CH_4-CO_2)

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

Ar-Isobutane e.g. 95:5 %

High gains. Reasonably fast but larger diffusion.

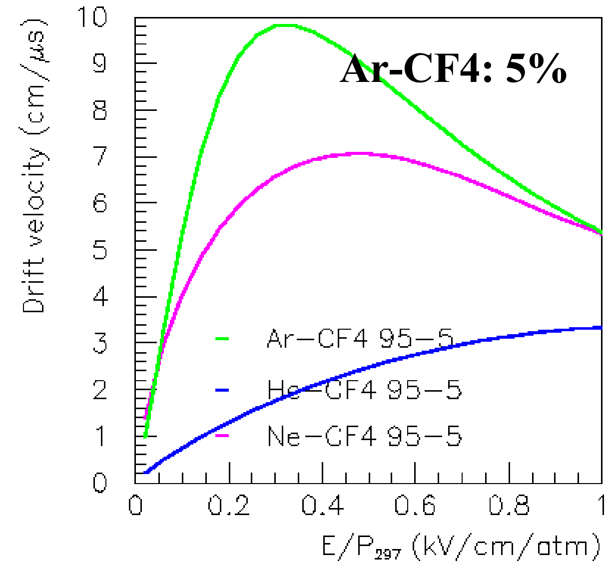
Ar-CF_4 e.g. 3-5 % CF_4

Very interesting! Very fast, no hydrogen.

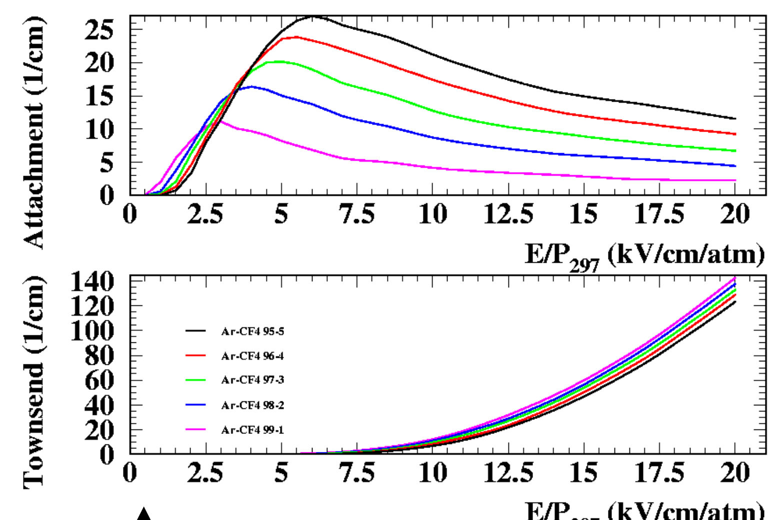
$\omega\tau$ ~20 @ B=4T
transverse diffusion less than 200 μm for drifts up to 1m.

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

Drift velocity



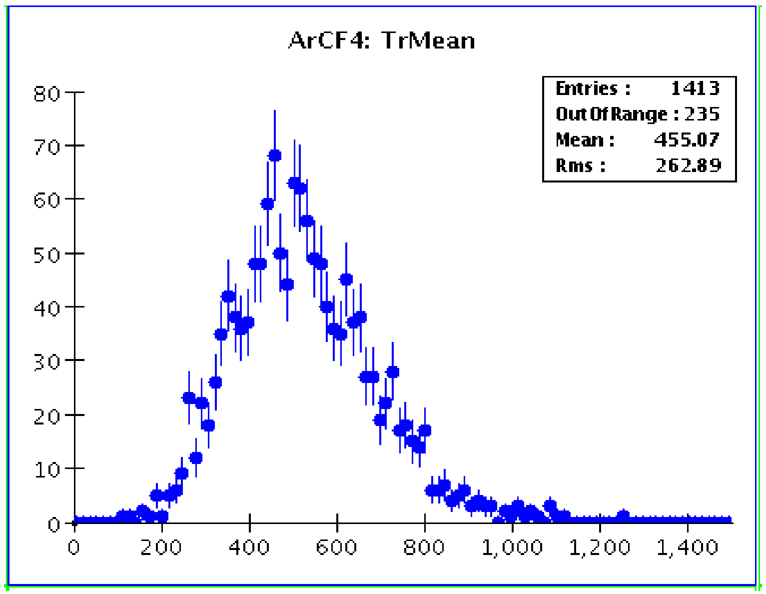
Ar-CF4 Attachment / Amplification



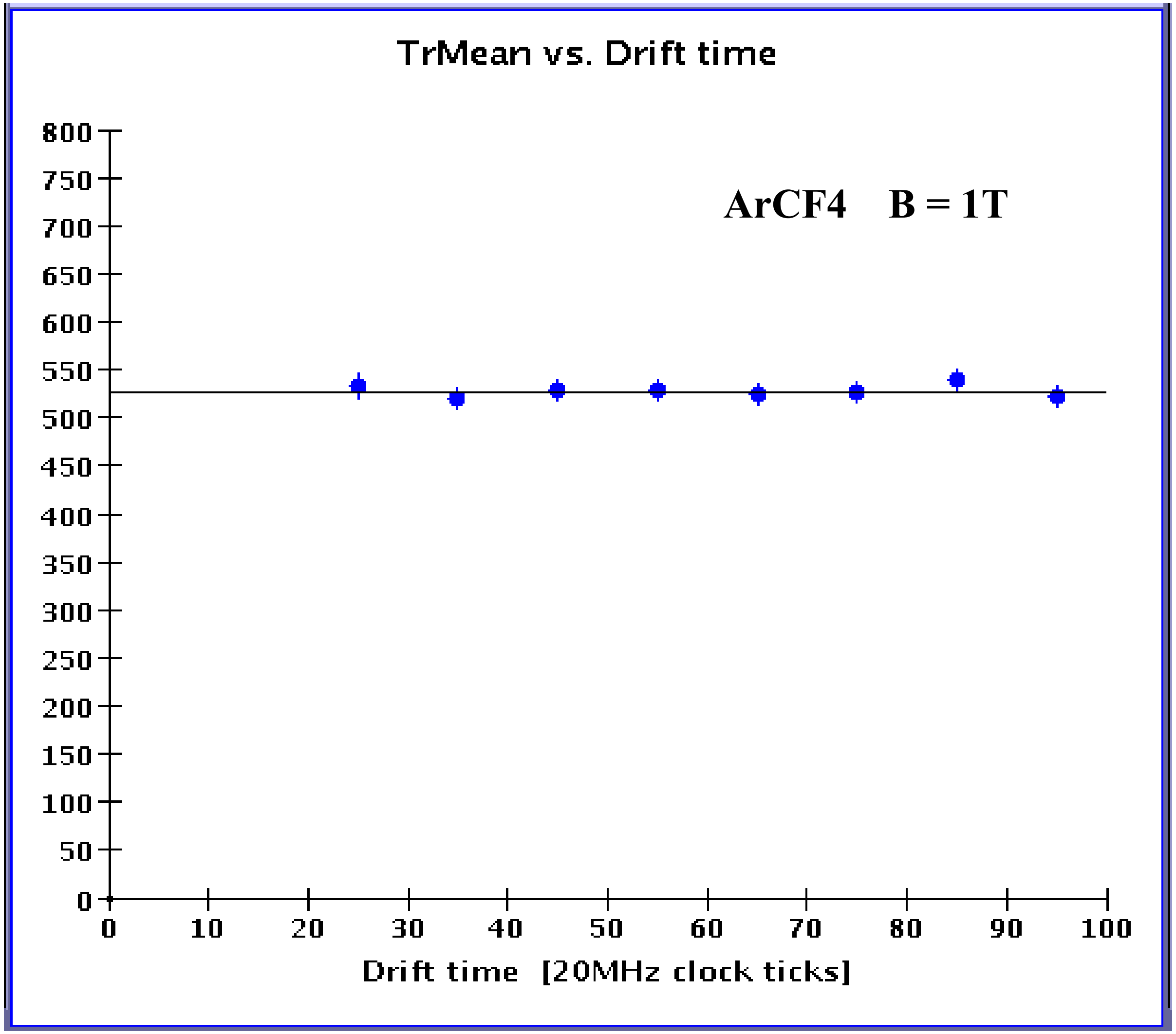
E_D~0.2V/cm

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.

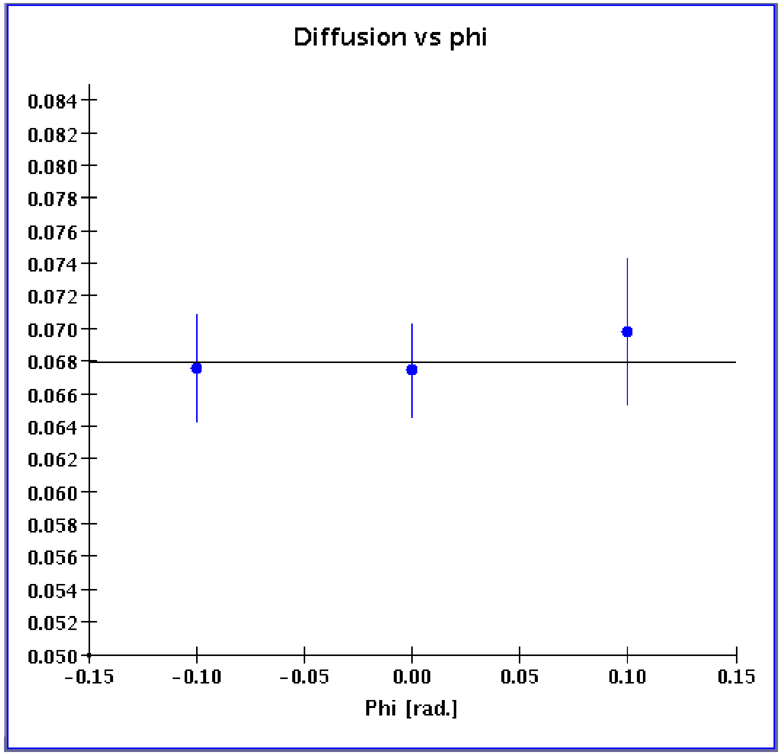


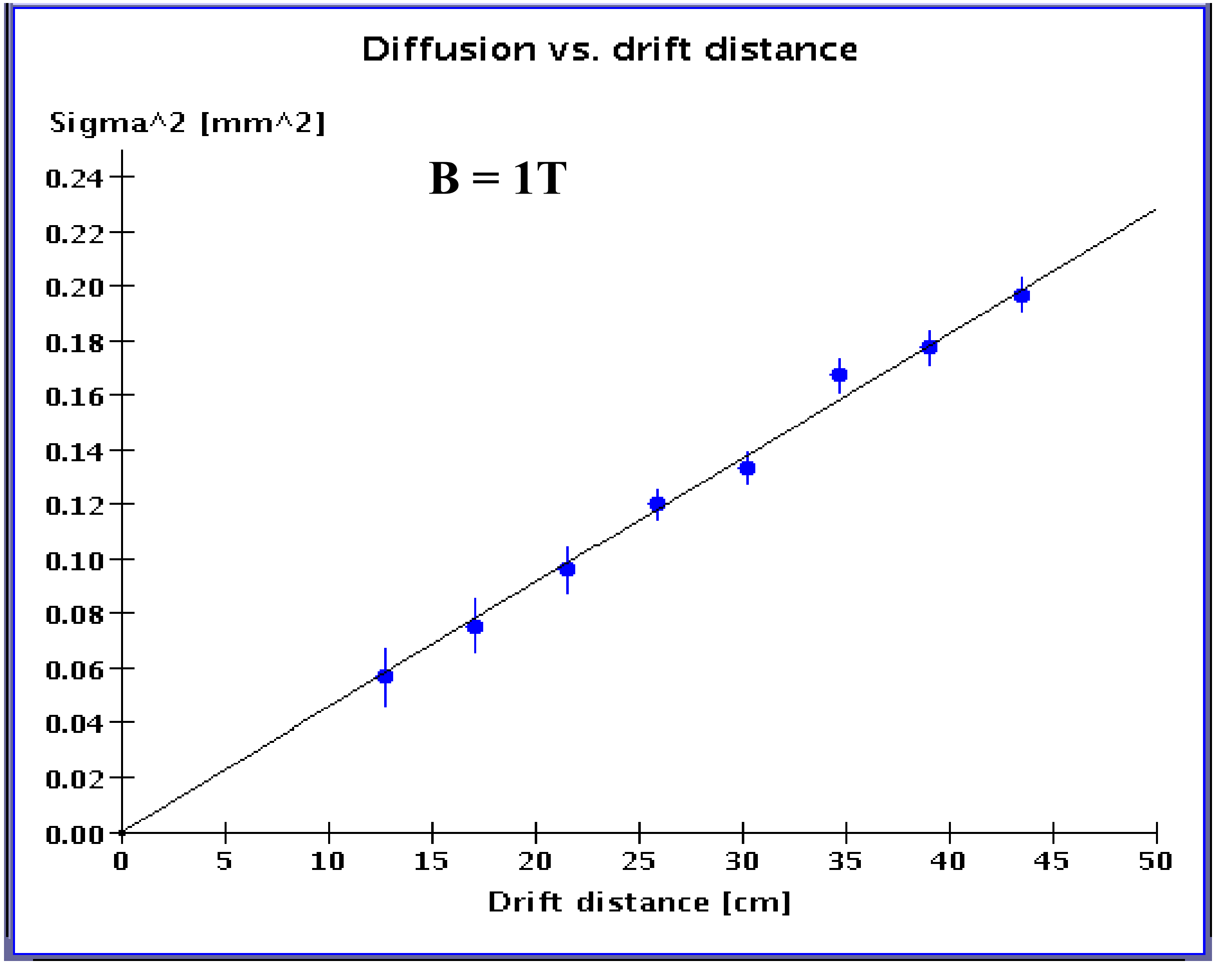
We find that the attenuation length due to electron attachment in **ArCF4** is larger than **4.4 m** at **90%** confidence.

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.





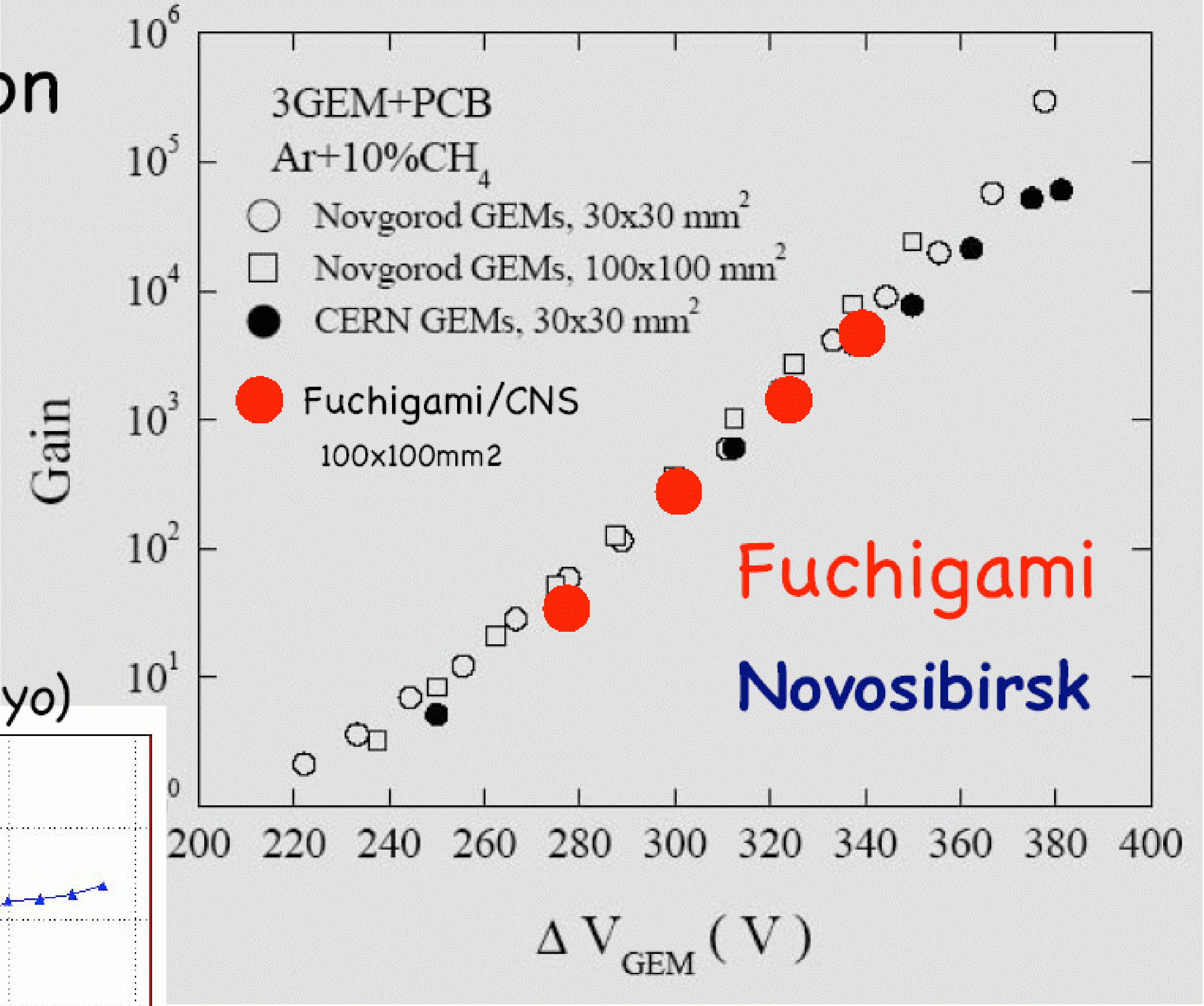
For Ar-CF4:3% at B = 1 Tesla, we measure in one analysis

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

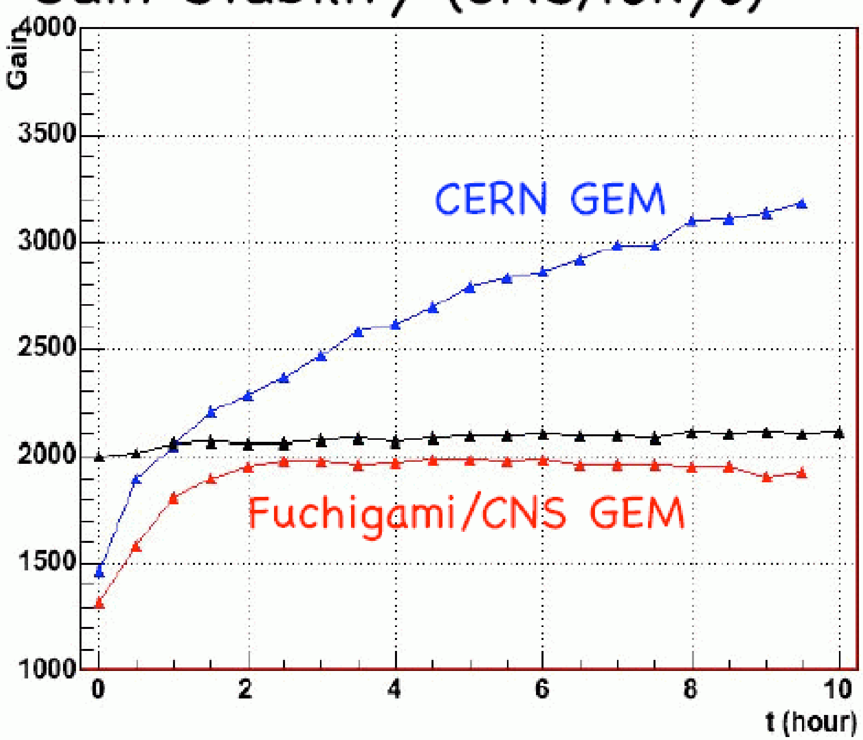
This implies an expected transverse spread of about 360 microns after 2.5 m drift in a 3 Tesla magnetic field, and a diffusion limited point resolution of 60 microns for 6 mm pads.

Gas Amplification

Fuchigami GEM
gain a little lower
due to geom.



Gain Stability (CNS,Tokyo)

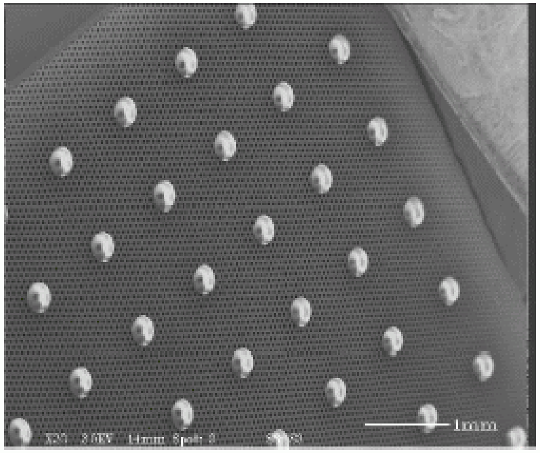


charge up in hole seems to
be smaller

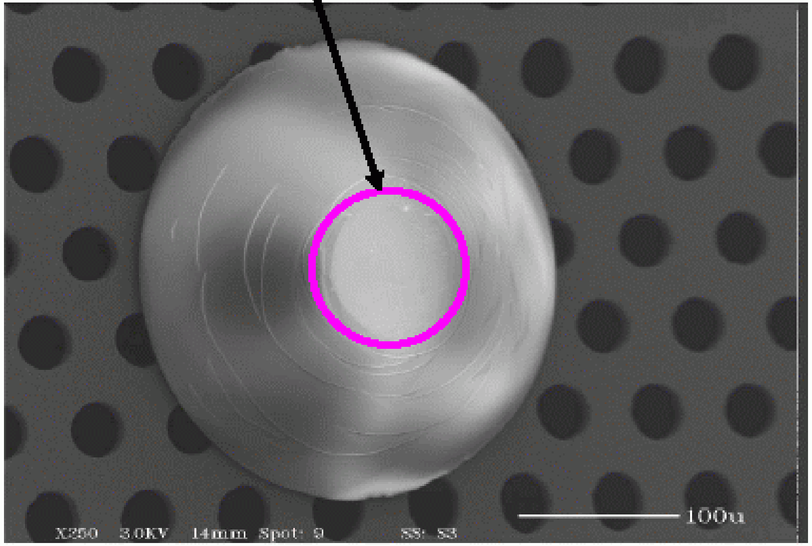
PURDUE UNIVERSITY

Mass Production of Micromegas

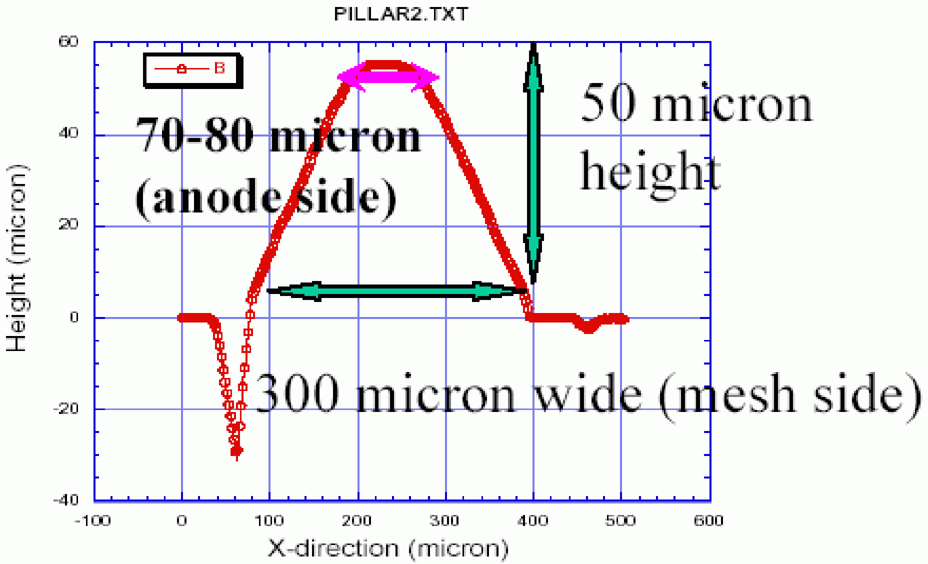
Conical pillars (1 mm pitch) to create a 50 µm gap.



The flat area that has a contact with the anode board

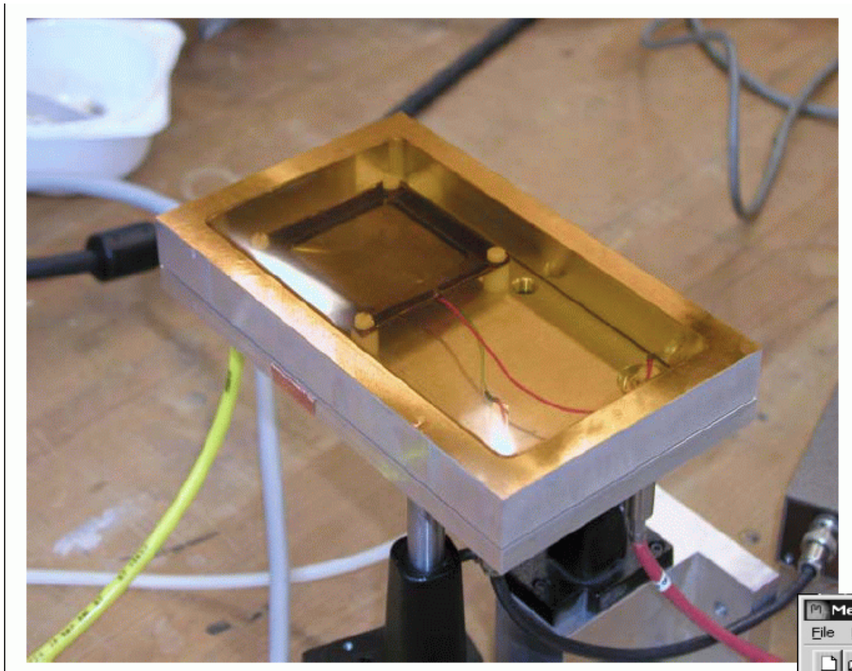


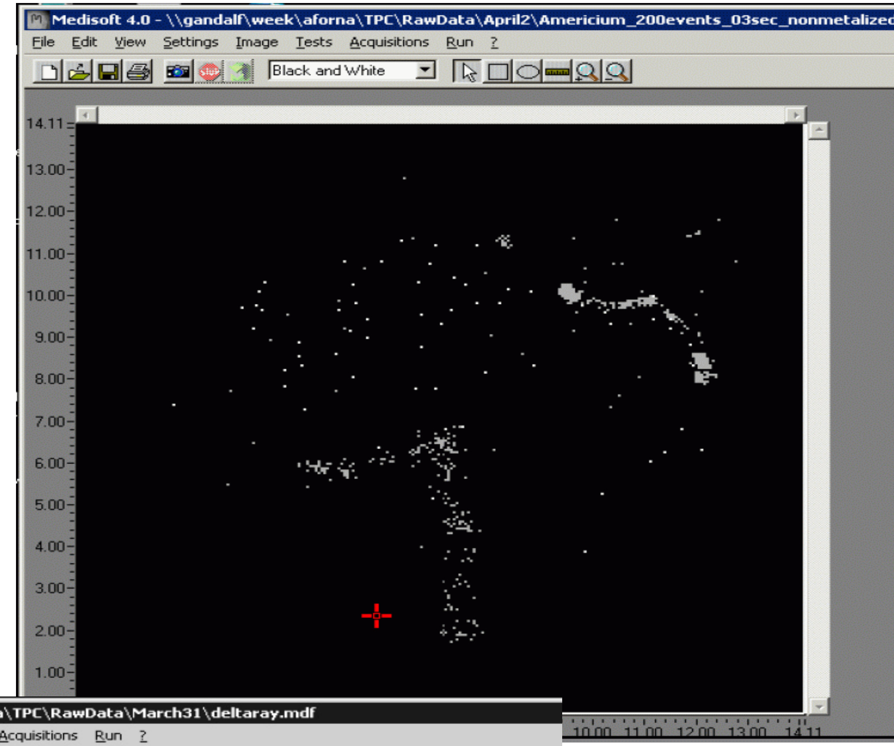
Pillar cross section profile

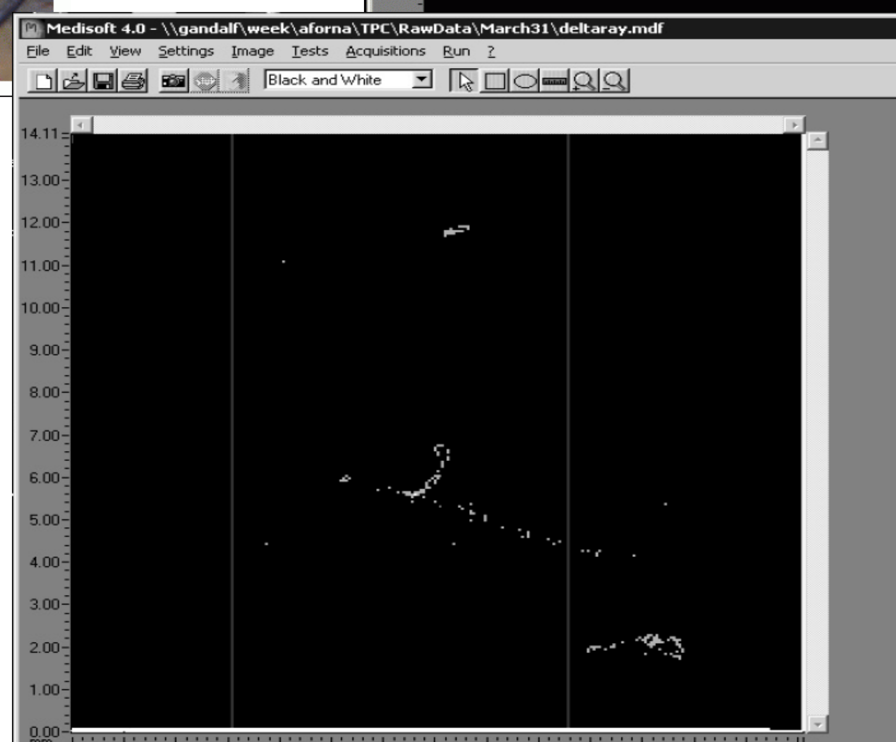


Pixel TPC

Americium source







Cosmic ray
w/ delta ray

Micromegas electron gas amplification

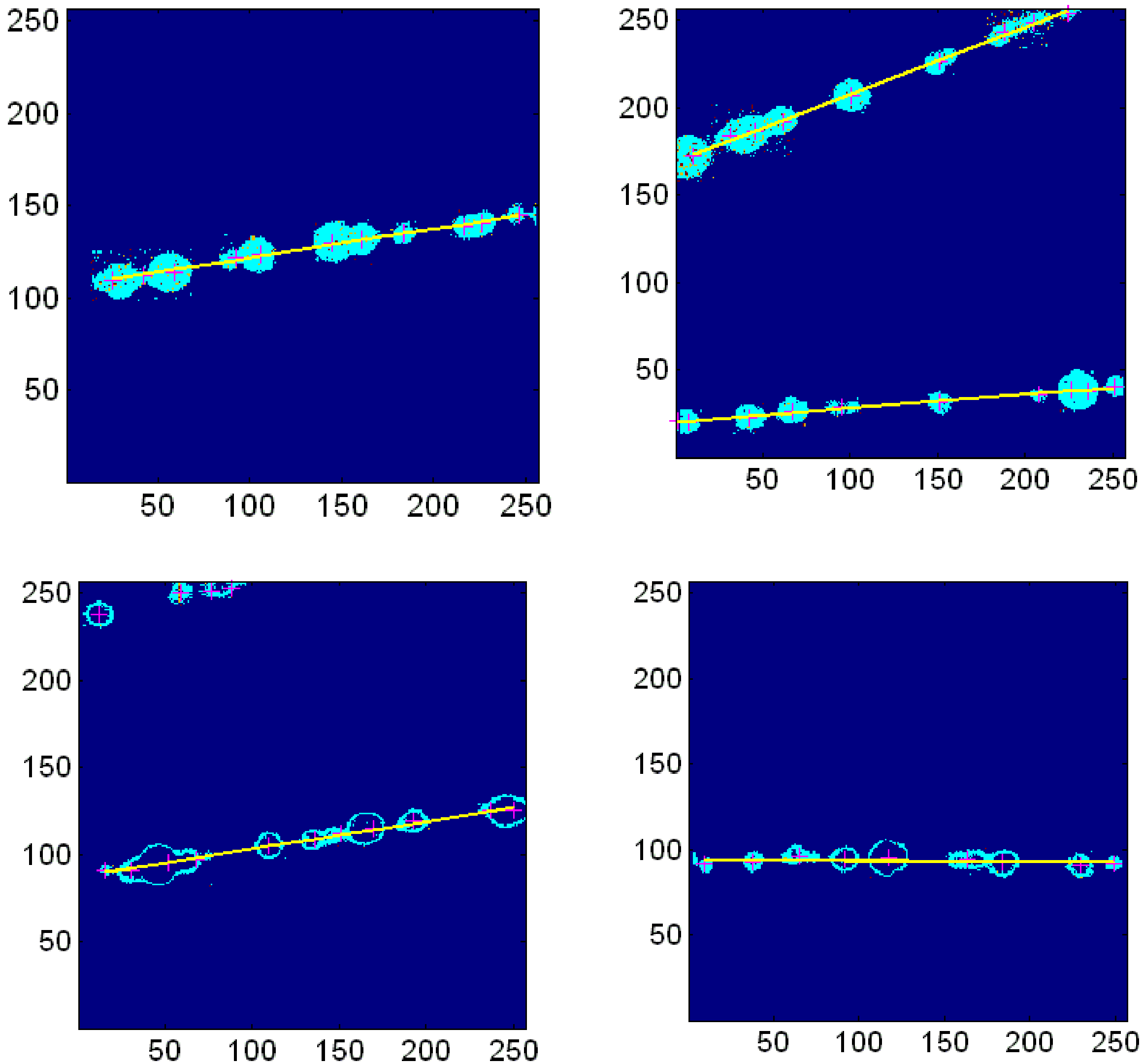
He-Isobutane 20%

gain ~ 20000

MediPix2 pixel readout chip

50 x 50 micron

GEM Digital TPC



using lower thresh. only

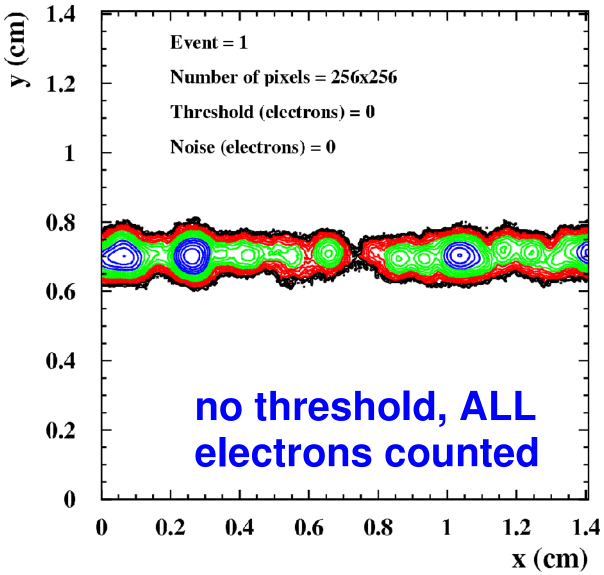
using upper and lower threshold

Tracks from ^{106}Ru

M. Hauschild

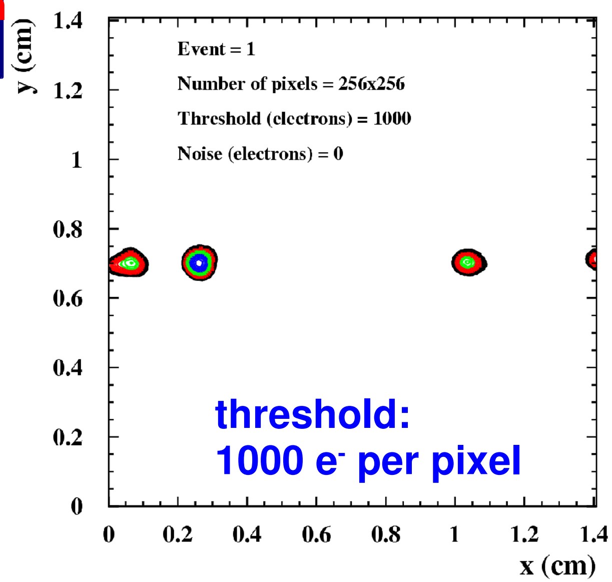
Electron Charge Distributions

electron charge distribution on MediPix surface

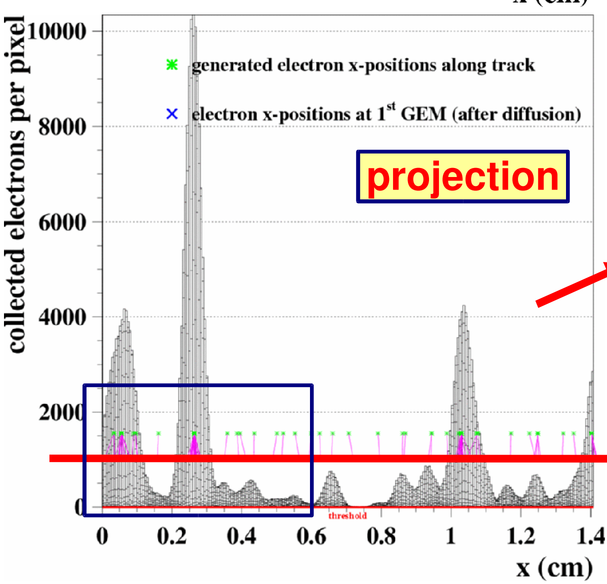


no threshold, ALL electrons counted

with typical MediPix threshold of ~1000 e^- most pixels stay below threshold

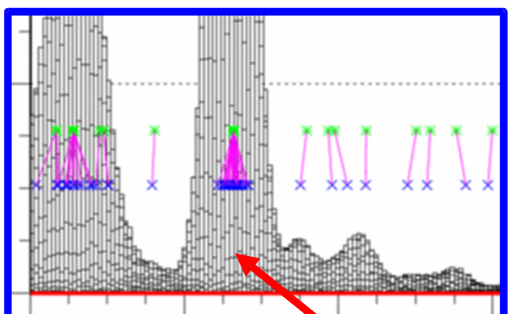


threshold: 1000 e^- per pixel



projection

1000 e^- threshold



generated e^- positions

e^- positions after diffusion (on top of first GEM)

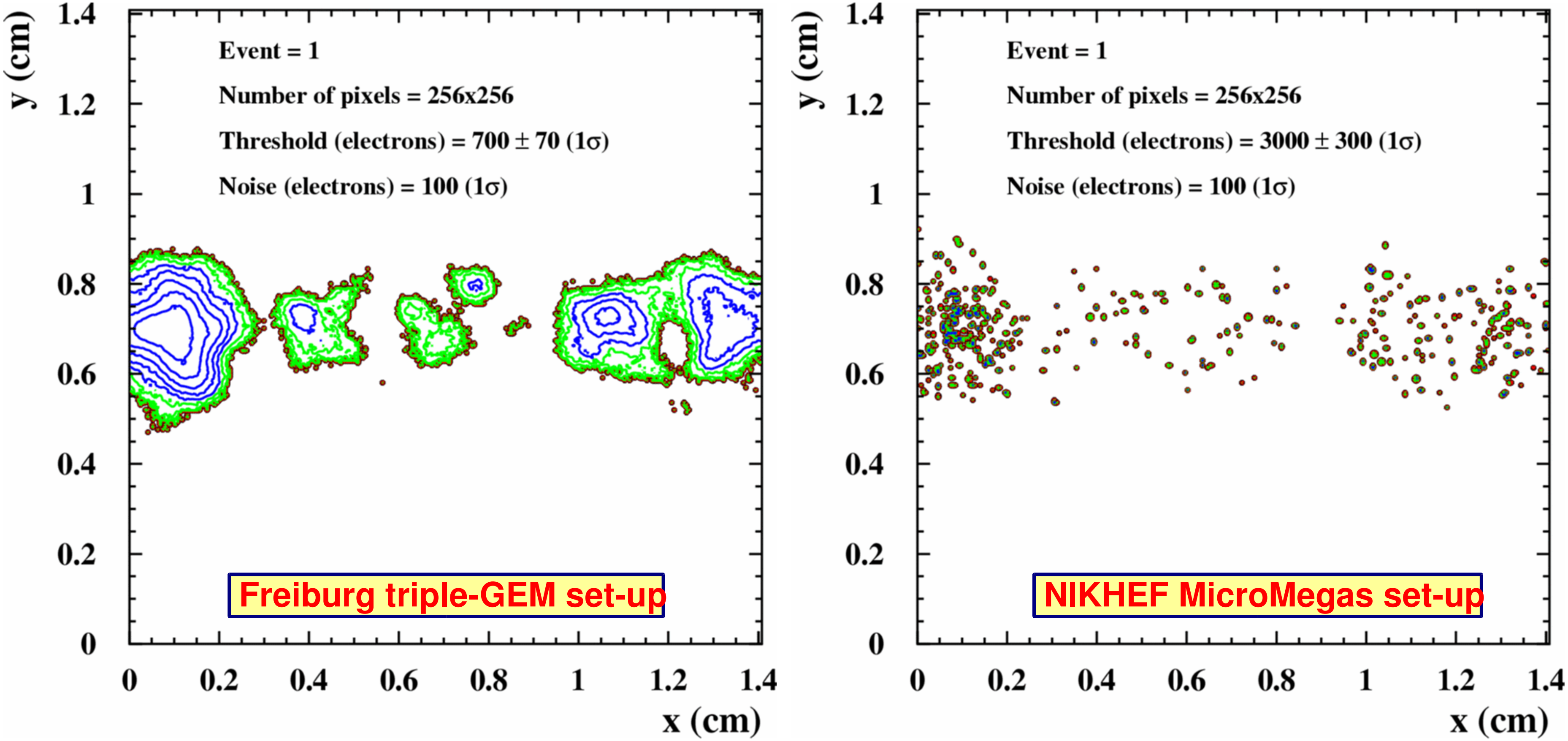
multi-electron cluster, only clusters with > 1 electron reach the MediPix threshold
(or many dense single-electron clusters)

M. Hauschild

Digital TPC

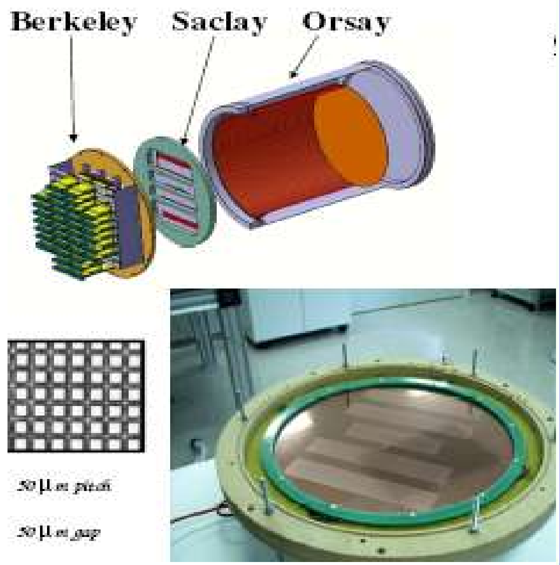
- ...at the ILC...
  - 100 GeV muon, B = 4 T, TESLA-TDR gas, 100 cm drift

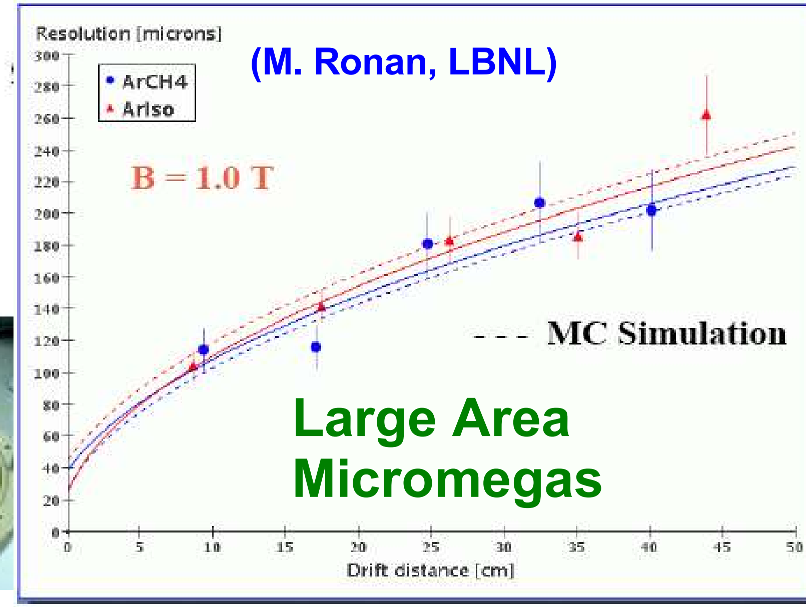
identical events: same generated primary clusters/electrons



Analog vs Digital TPC readout

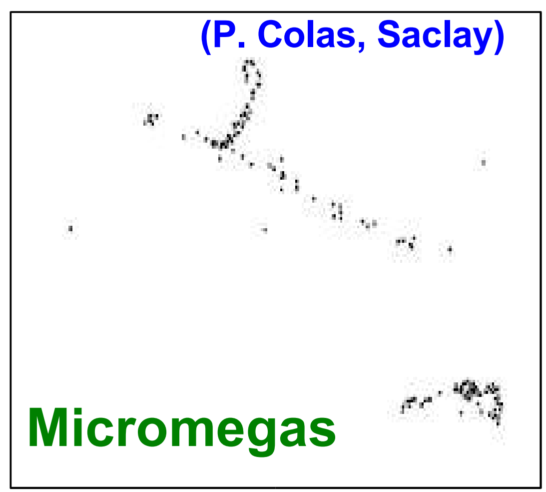
- **Analog readout**
  - **MPGD TPC allows resolution <100 µm**
  - **Understand better MC simulation**
  - **Choose gases**

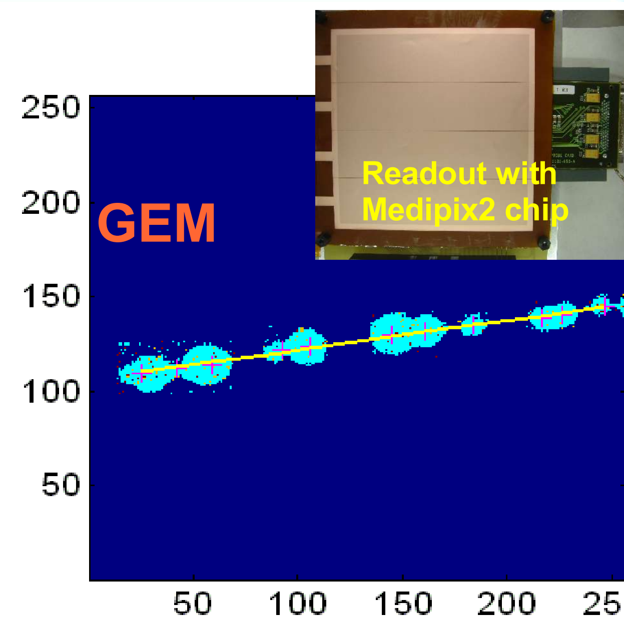




- **Digital TPC**: readout a TPC with CMOS VLSI chips
  - **Test with e$^-$ from ^{106}Ru**
  - **Reconstruct tracks e$^-$ by e$^-$ or cluster by cluster with Micromegas or GEM**
  - **Resolution~50-60 µm achievable**

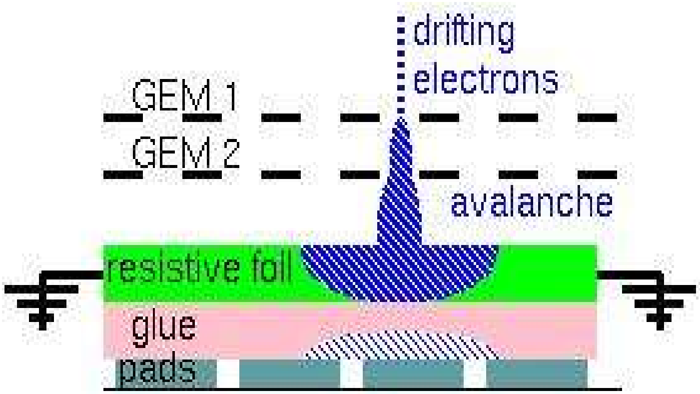
on-going work also @ LBNL



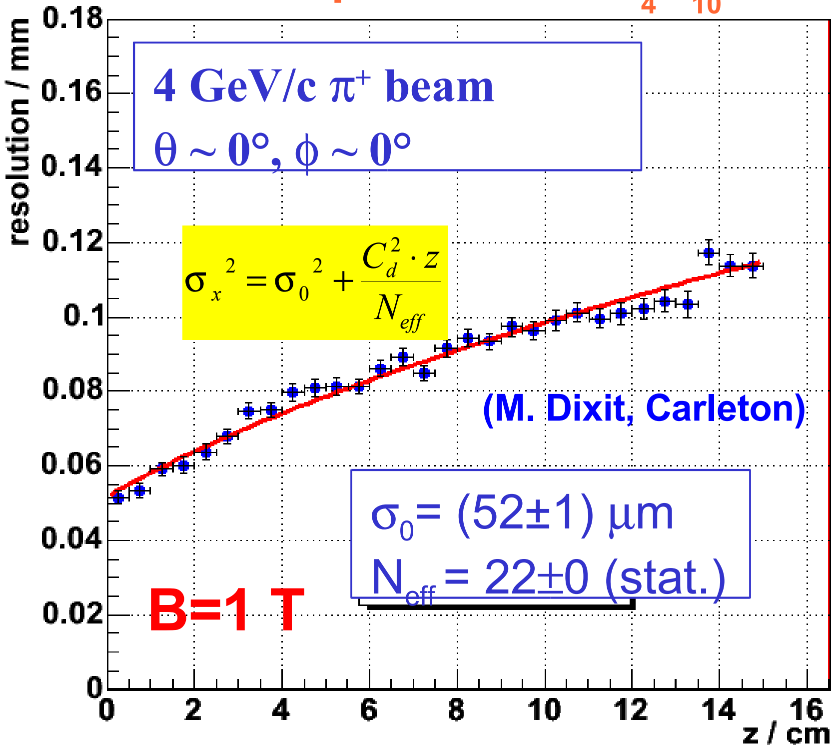


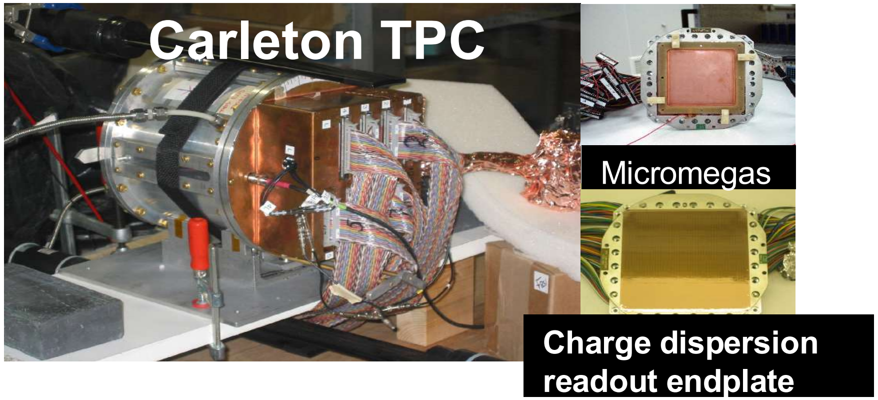
Improving TPC resolution: resistive readout

- MPGD-TPC resolution limited by pad size
- TPC resolution should only be limited by transverse diffusion!
- Charge dispersion readout: modified anode with high-resistivity film insulated from readout plane
- Tested @ KEK both with Micromegas & GEM



2x6 mm^2 pads   Ar:C_4H_{10} 95:5



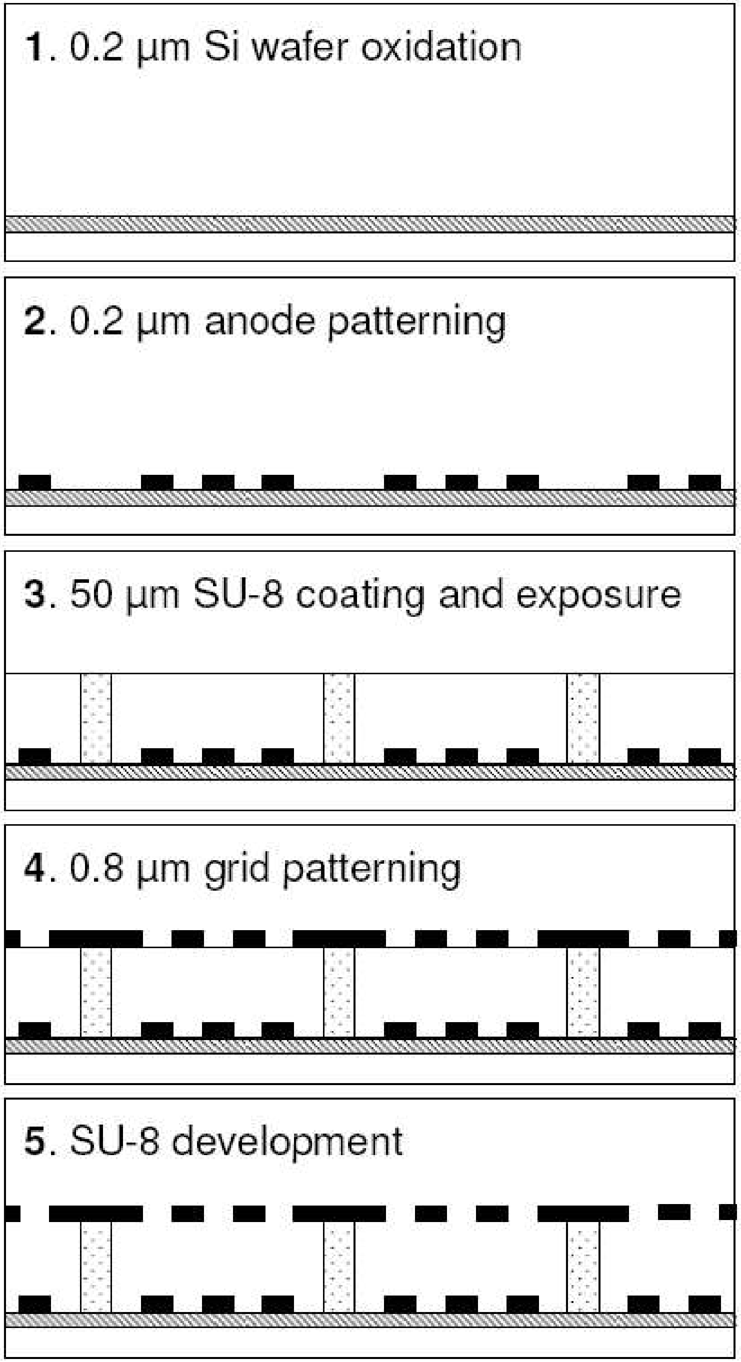


- Significant suppression of transverse diffusion
- Extrapolate from present data to B=4T: resolution(2 mm pads) ~100 µm (2 m drift)

InGrid process

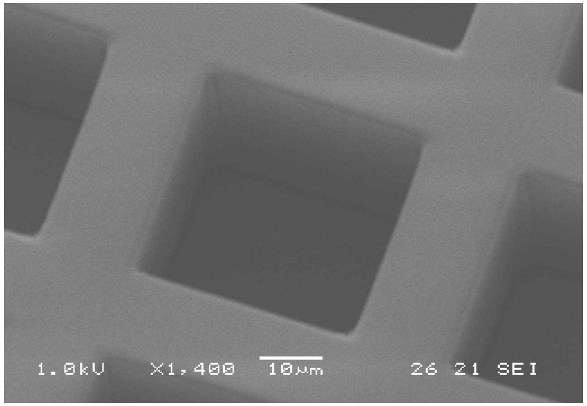
1) Oxide the Si wafer, insulating SiO_2 layer on top
2) Deposition of 0.2 μm of Al for anode, and patterning
3) Deposition of 50 μm photo-resist and UV exposure
4) Deposition and patterning of the grid: 0.8 μm of pure Al
5) Removal of the exposed photoresist

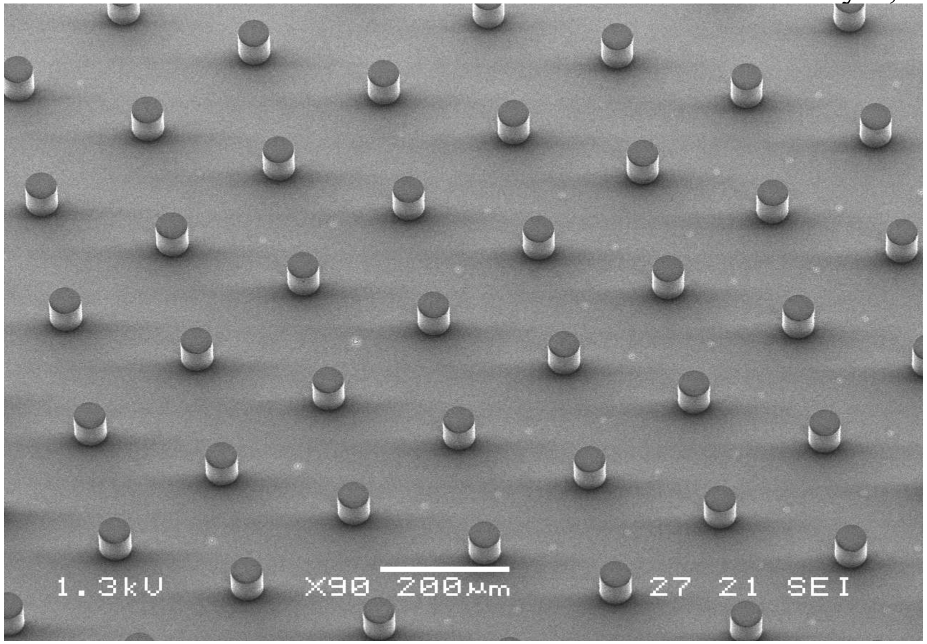
RESULT : a thin mesh (0.8 μm compared to 3-5 μm with best standard techniques), sustained at an accurate 50 μm from the anode.

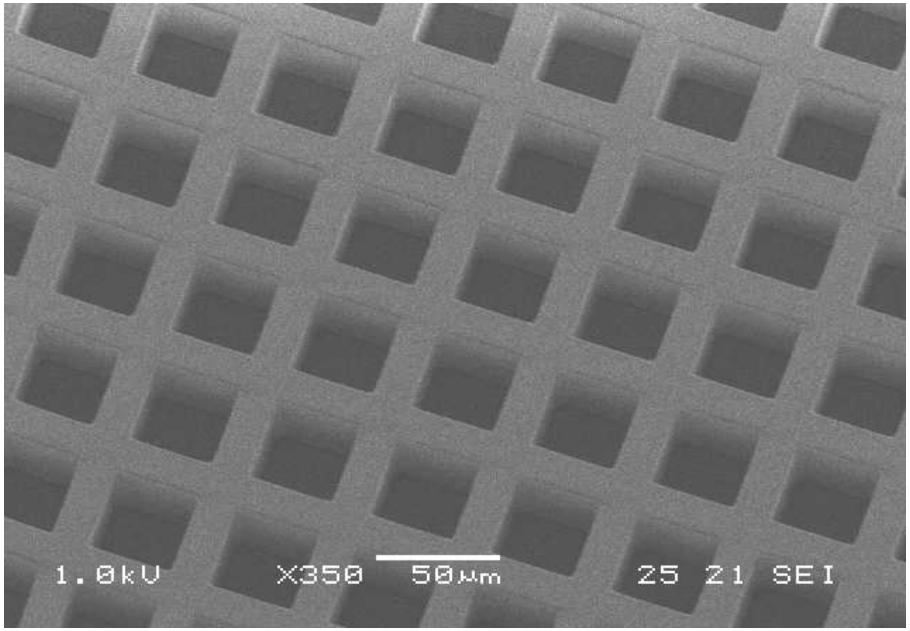


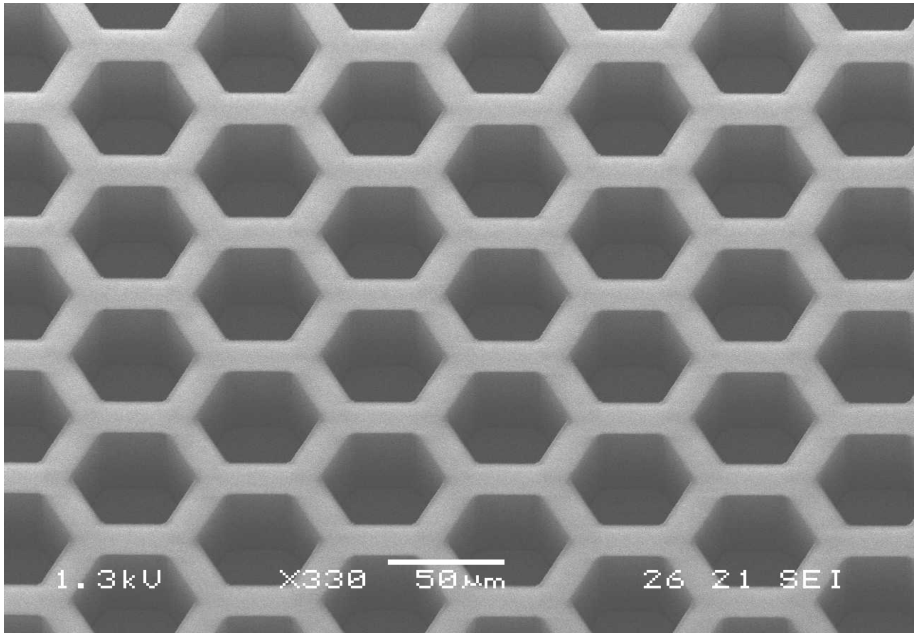
INGRID: some first trials

Various pitches, shapes





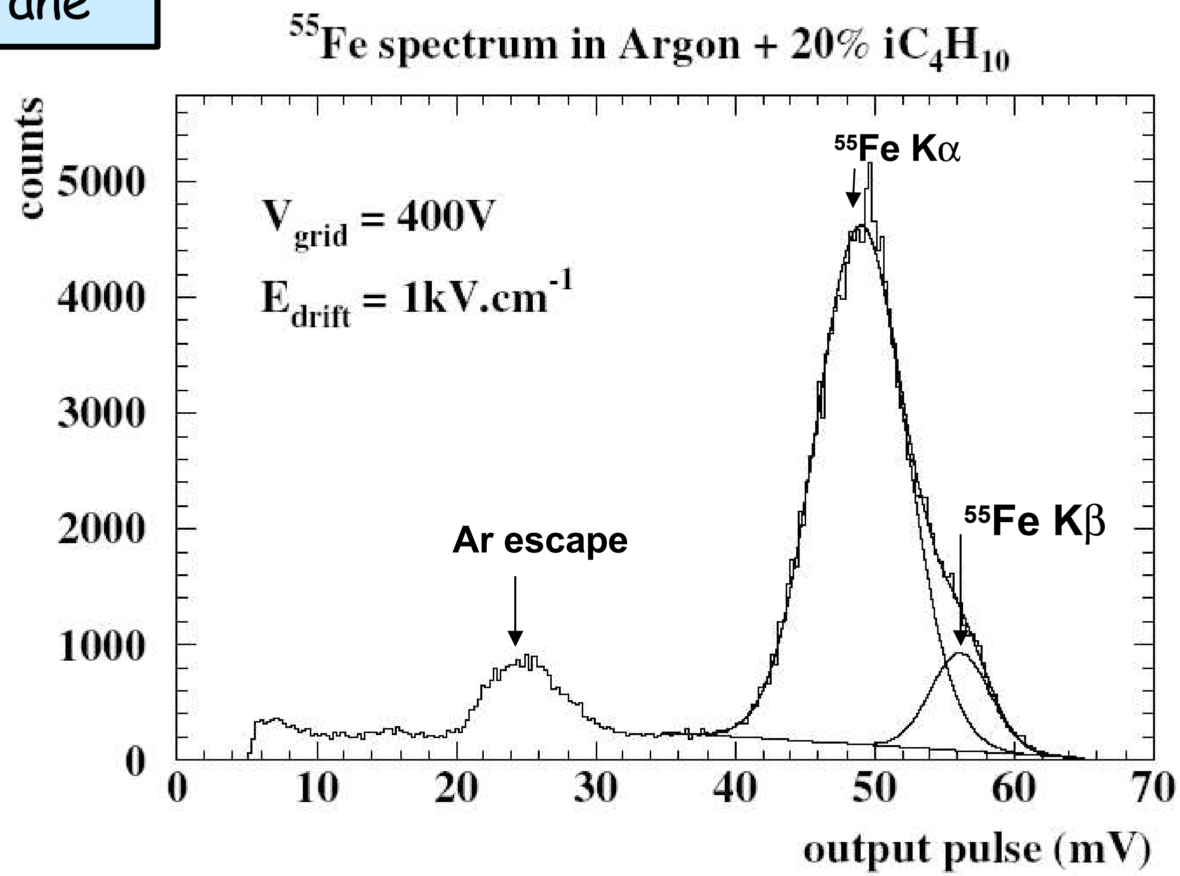




Results in Argon + 20% isobutane

Advantages

- grid thinness & robustness
- gap accuracy (unprecedented resolution (6.5%) and uniformity)
- no frame (no loss of active surface)
- possibility to fragment the mesh (noise reduction and extra-localization usable for zero-suppression)

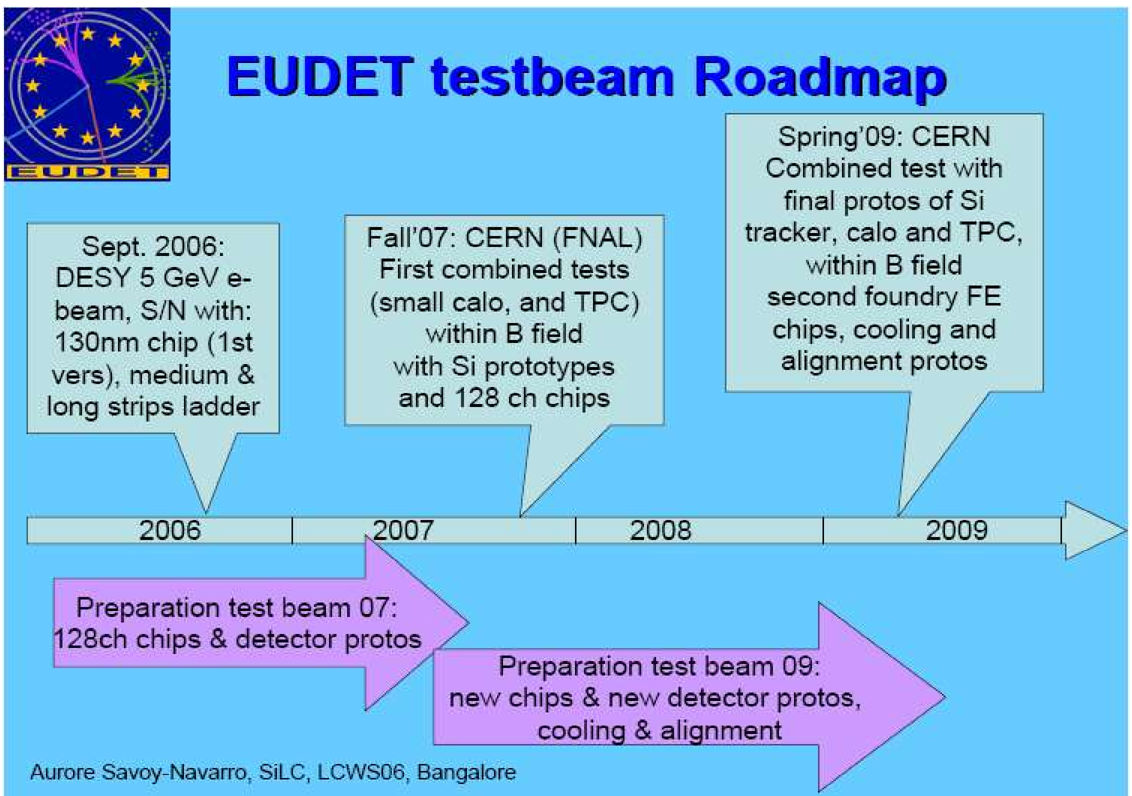


Future : Si TPC (with the Timepix VLSI CMOS readout) 55 μm pads

EUDET-funded

R&D infrastructure for ILC: EUDET

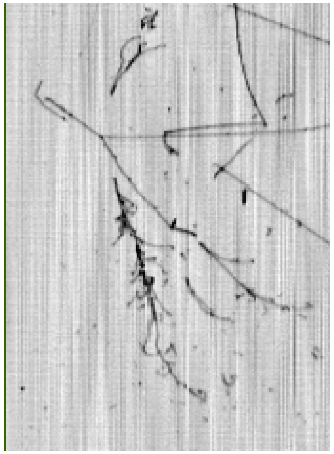
- EU funded 4-year program ("Integrated Infrastructure Initiative") to improve infrastructure for ILC detector R&D
- Total budget 21.5M€, EU-funded: 7M€, remainder from participating institutes
- Coordinating Lab: DESY – Participants from all over Europe, contribution from Japan (magnets)

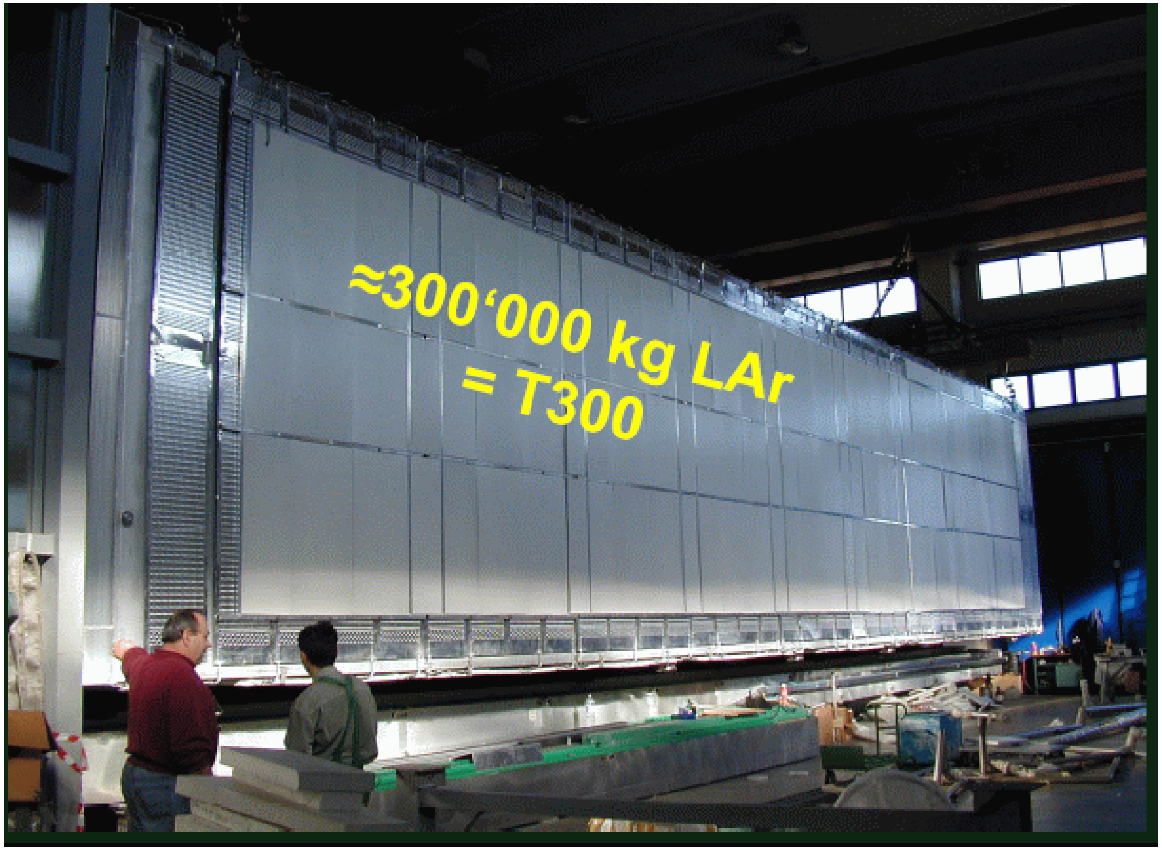


- Workpackages on
  - Testbeam infrastructure
  - Tracking infrastructure
  - Calorimetry infrastructure
  - Common tasks (Software, Computing, Chip-Design)
- This infrastructure is open to the world!

ICARUS

The technology of the Liquid Argon Time Projection Chamber (**LqTPC**), first proposed by C. Rubbia in 1997, provides completely uniform imaging with high accuracy for massive volumes.





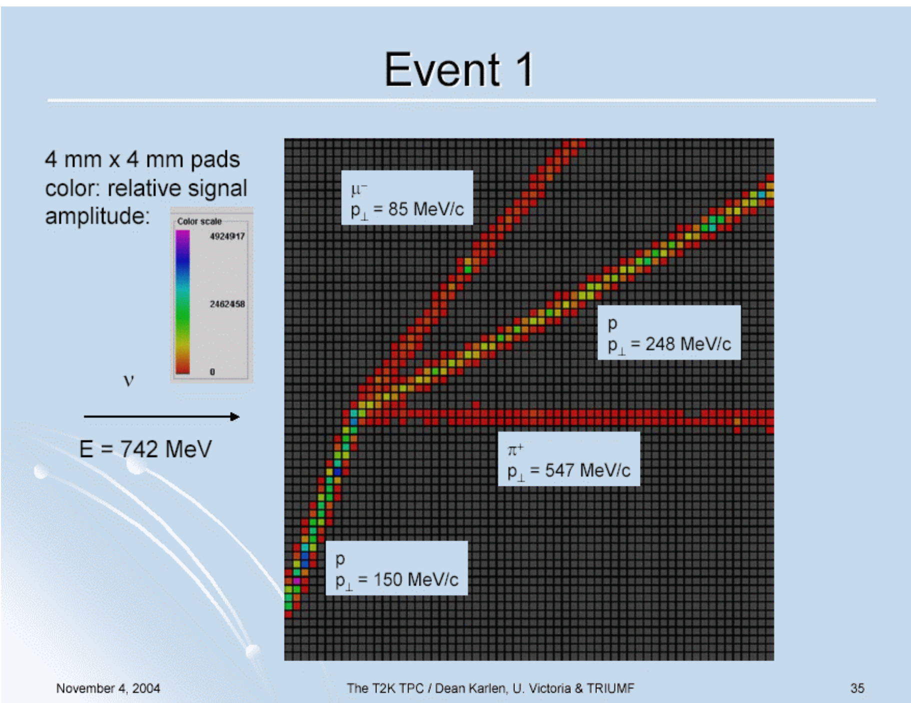
Being developed at the INFN Gran Sasso Laboratory for study of

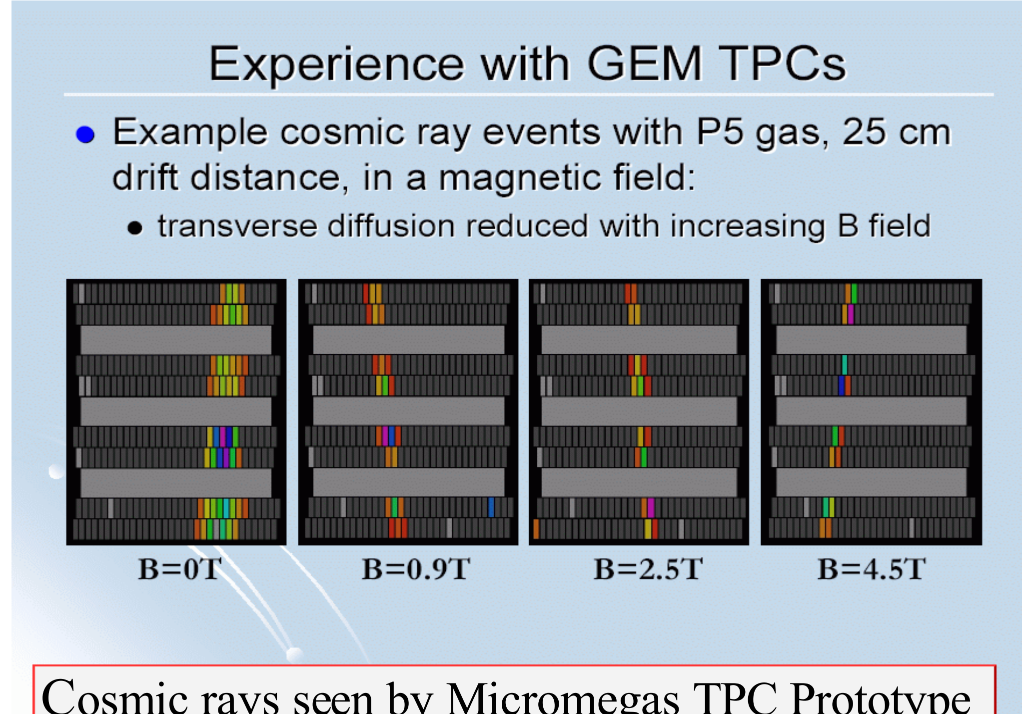
- solar and atmospheric neutrinos
- nucleon decay
- neutrinos from Supernovae
- accelerator neutrino oscillations

Large T600 detector system test was carried out on surface in 2001.

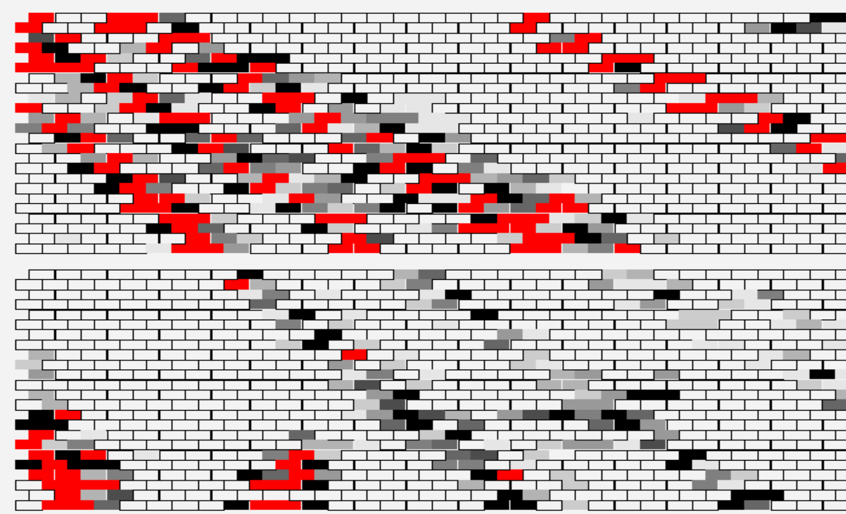
T2K TPC

Large GEM or Micromegas TPC for studying systematics of neutrino detection in Tokai to Kamioka (T2K) experiment.

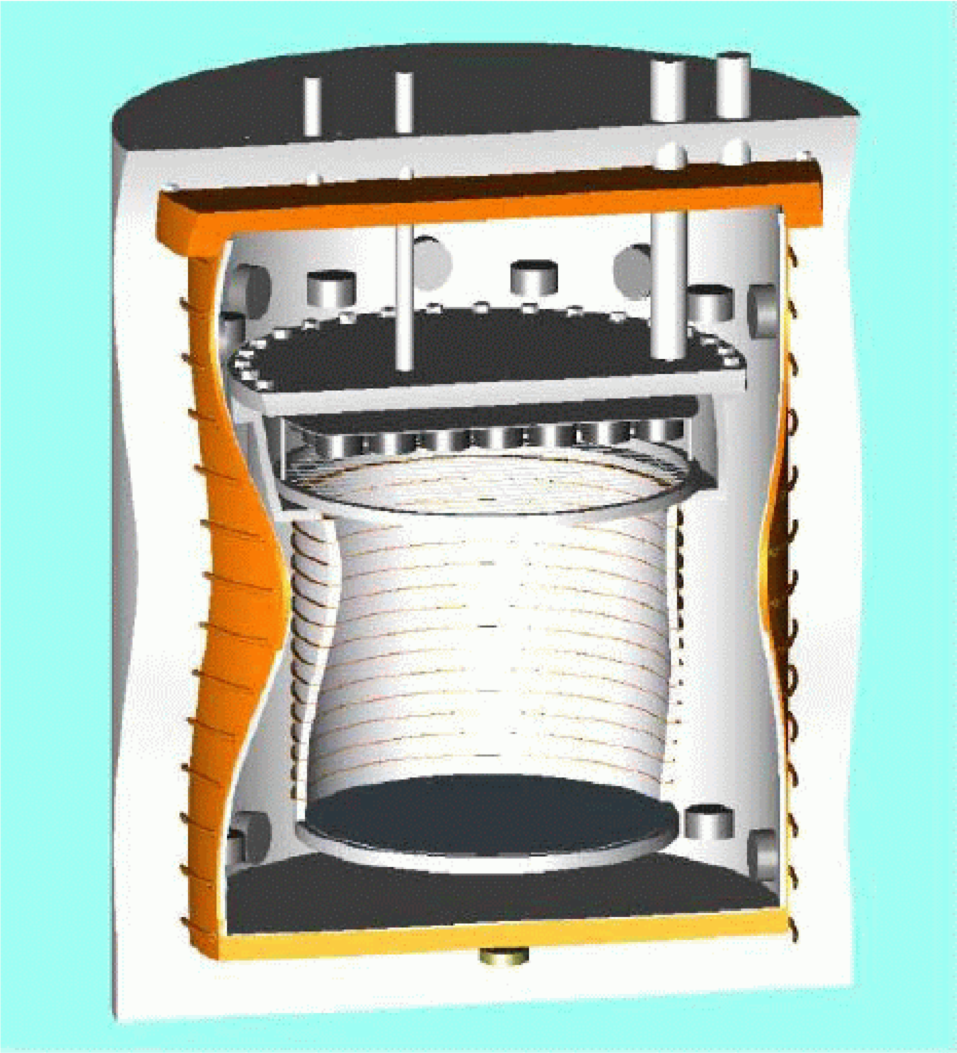




Cosmic rays seen by Micromegas TPC Prototype



The XENON Dark Matter Experiment



- Dual Phase Liq/Gas Xe
- The XENON design is modular.

  Multiple 3D position sensitive LXeTPC modules, each with a 100 kg active Xe mass --> 1-tonne scale experiment.
- The 100 kg fiducial LXe volume of each module is shielded by additional 50 kg LXe. Active shield very effective for charged and neutral background rejection
  - Proposed Sept. 2001.
  - Funded Sept. 2002.
  - Currently - R&D towards 10 kg prototype.
  - Deployment goal: 100 kg

Elena Aprile

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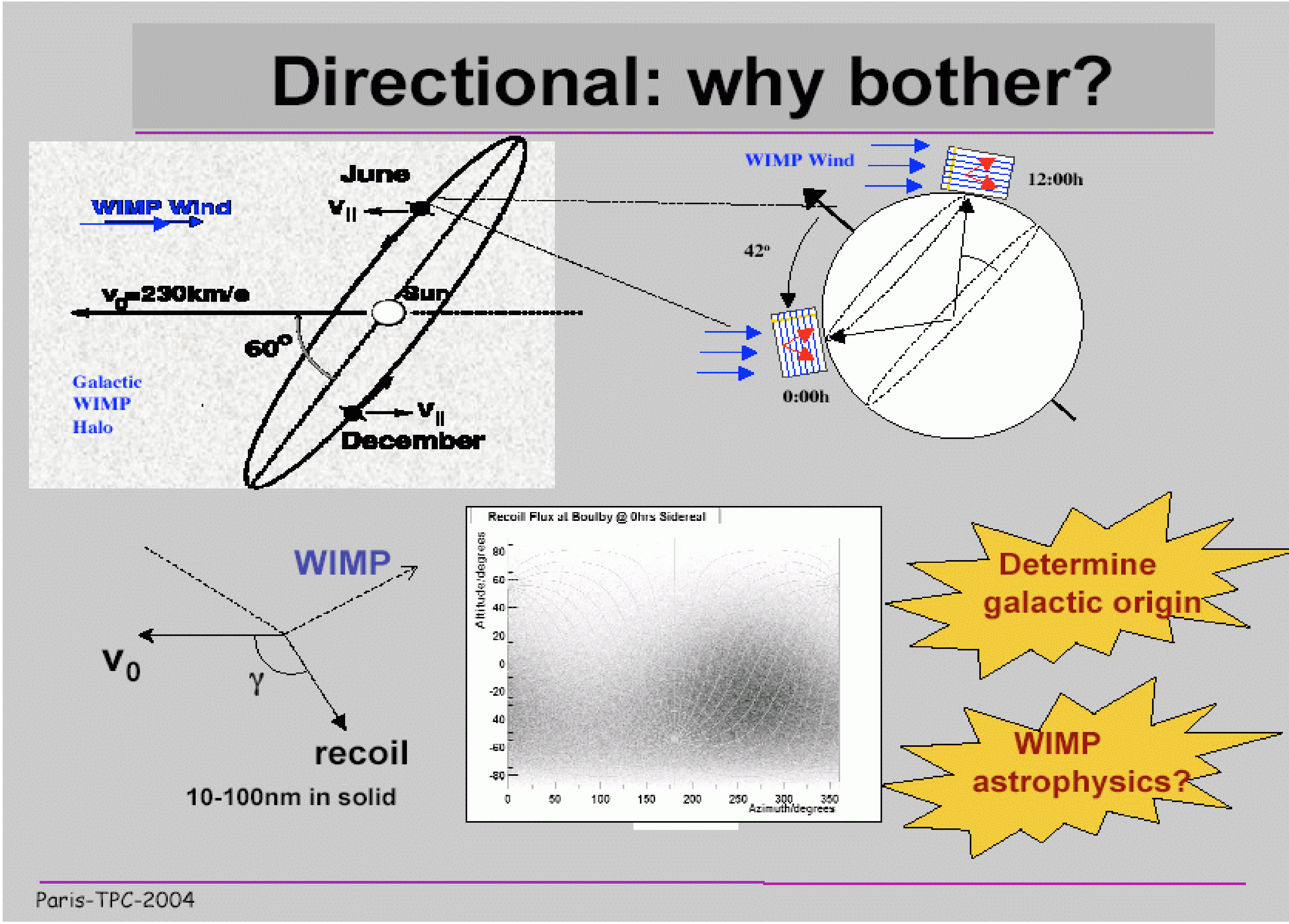
Presented by Elena Aprile, Columbia at the 2003 TPC Symposium, see http://www-tpc.lbl.gov/symposium03.

WIMP Direction

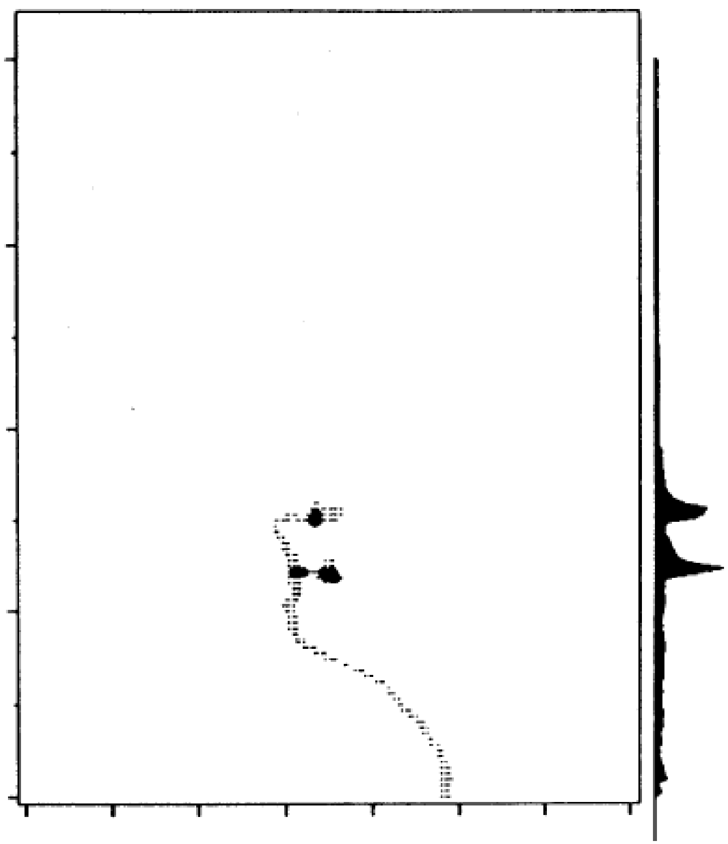


Presented by Neil Spooner at the 2004 Paris TPC Meeting,
see http://www.unine.ch/phys/tpc.html

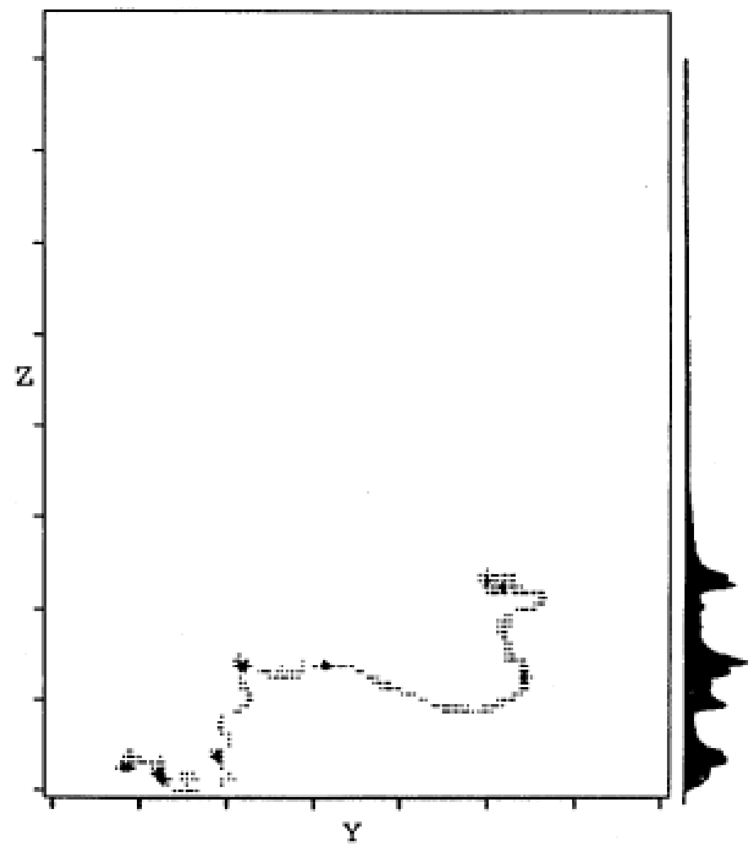
The Gotthard Xenon TPC (1993)

180 liters of xenon at 5 atmospheres (5 kg)

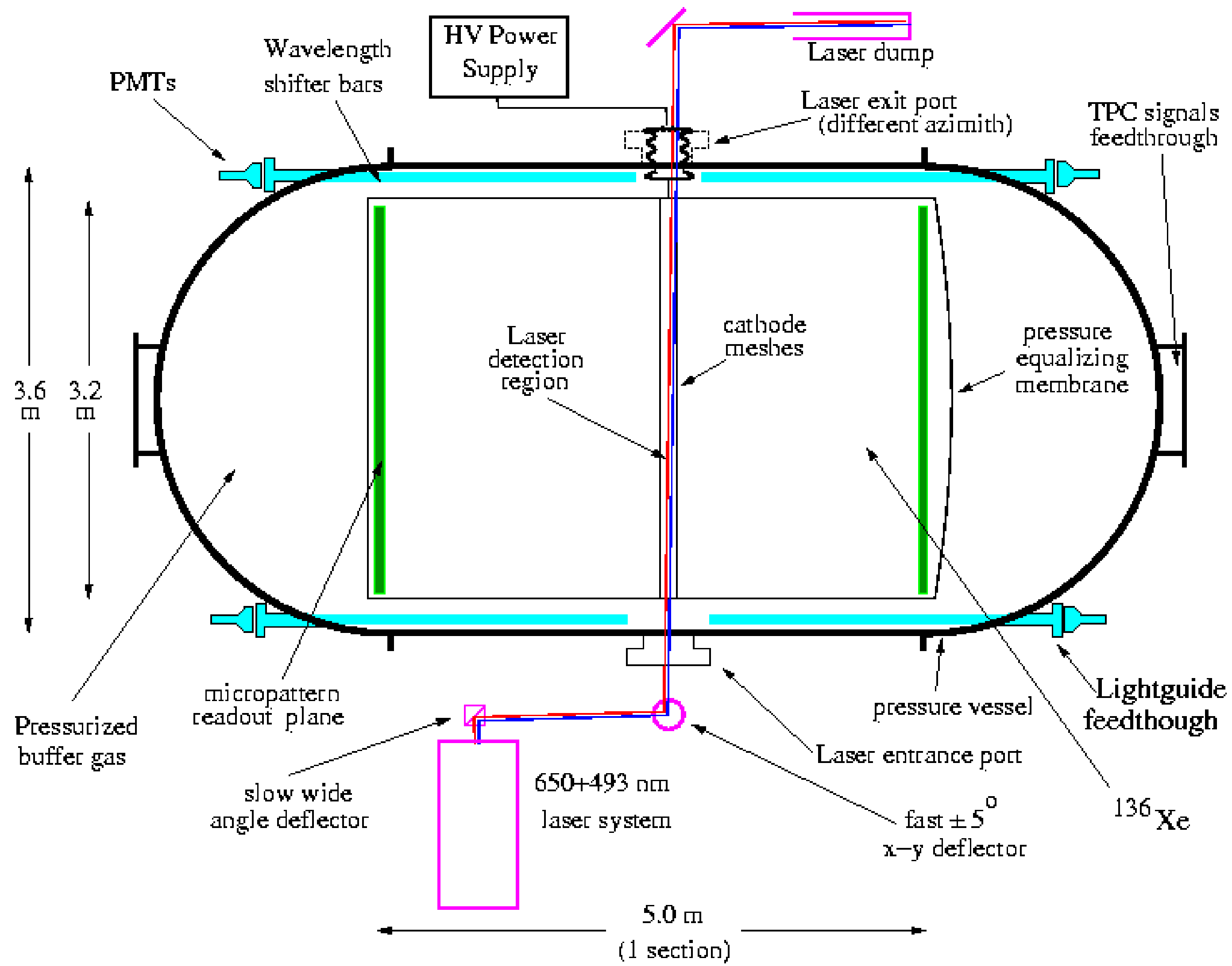
Single electron event



Double beta candidate



Gas TPC EXO: conceptual design

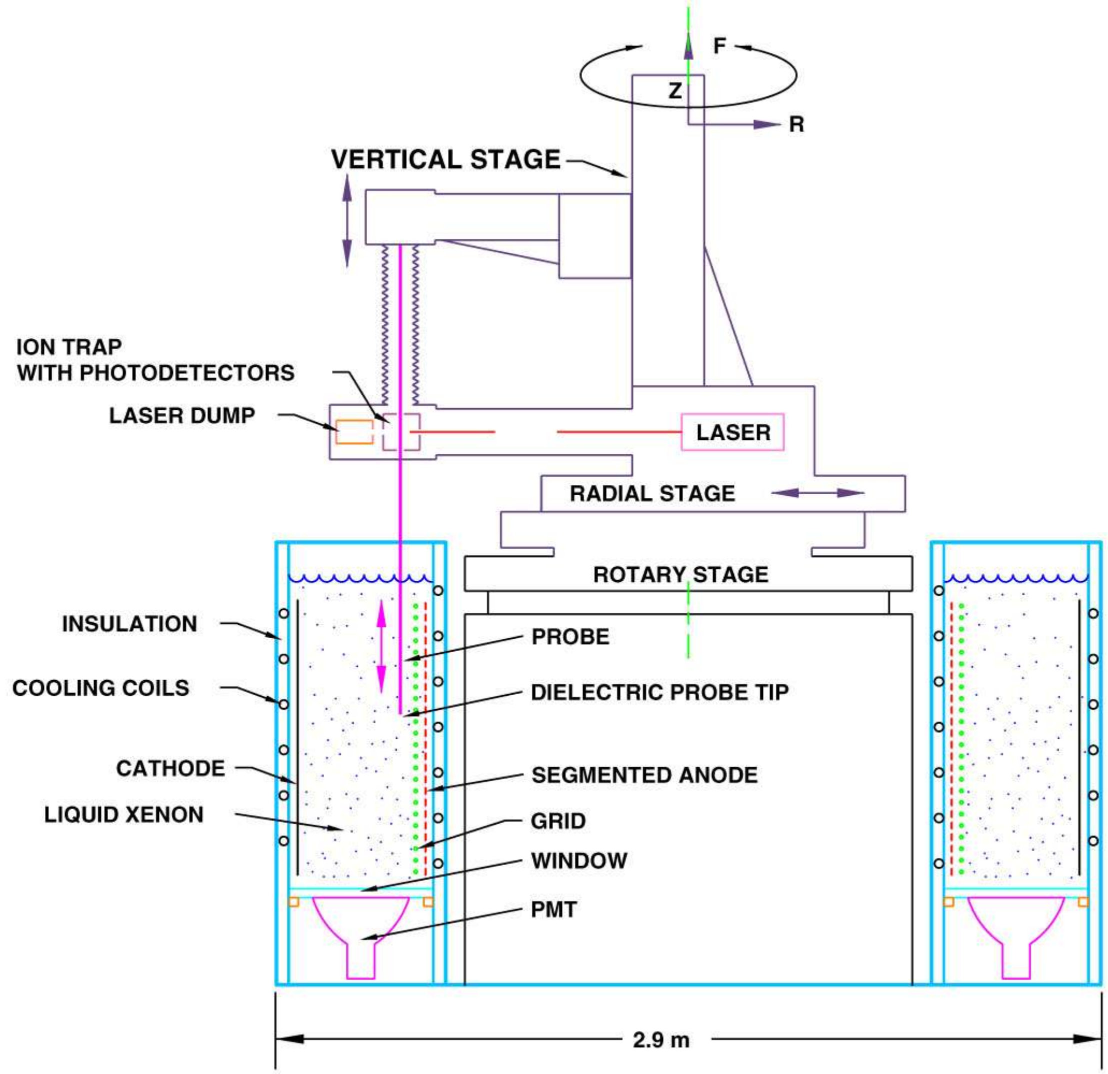


Liquid Xenon EXO conceptual design

- Use ionization and scintillation light in the TPC to determine the event location, and to do precise calorimetry.

- Extract the Barium ion from the event location (electrostatic probe)

- Deliver the Barium to a laser system for Ba^{136} identification.



Summary

- Long 30 year **TPC** history in science, especially at LBNL.
- Large gaseous detector designs for the International Linear Collider (**ILC**) focus on TPC-based tracking.
- New micro-pattern gas detectors (**MPGD**'s) and **ASIC**'s offer significant improvements in expected LC-TPC performance:
  - X3 improvement in intrinsic point resolution (from roughly 180 to ~60 microns)
  - X2 reduction in long diffusion limited drifts
  - X10 increased segmentation in space and time, i.e. transverse and longitudinal
  - X3 – X10 reduction in endplane material, hopefully
- Many new TPC applications:
  - Neutrino oscillation and double-beta decay physics
  - Dark matter detection
  - Beam instrumentation, ...
- Interesting new TPC detector R&D in progress.