

Scott Menary



YORK 



Wire Chambers

Example: You want to study charm quark production so you need to reconstruct D^0 ($c\bar{u}$) mesons ($m=1.864$ GeV) through their decays to $K^-\pi^+$.

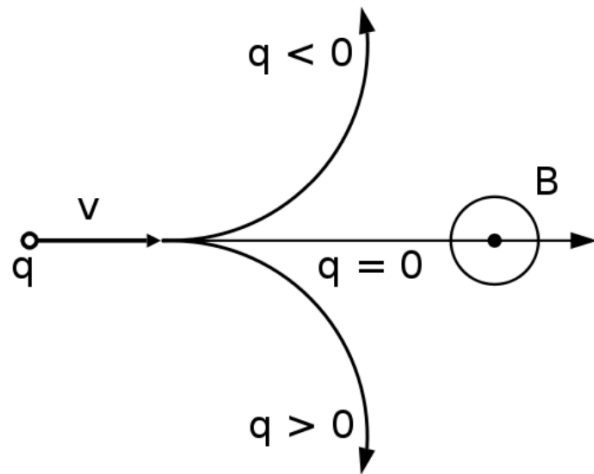
What do you need to do this? We have:

$$M_{D^0} = \sqrt{(E_K + E_\pi)^2 - (\vec{p}_K + \vec{p}_\pi)^2} \quad \text{with } E = \sqrt{\vec{p} \cdot \vec{p} + m^2}$$

Hence you have to:

- Reconstruct charged particle momentum (i.e., $\vec{p}$)
- Identify a reconstructed particle (i.e., m)
- Bonus: Reconstruct decay vertex if $\gamma c\tau \geq n\sigma_d$

The determination of the momentum of charged particles can be performed by measuring the bending of a particle trajectory (track) in a magnetic field



$$\vec{F} = q\vec{v} \times \vec{B}$$

$$\frac{mv^2}{r} = qvB$$

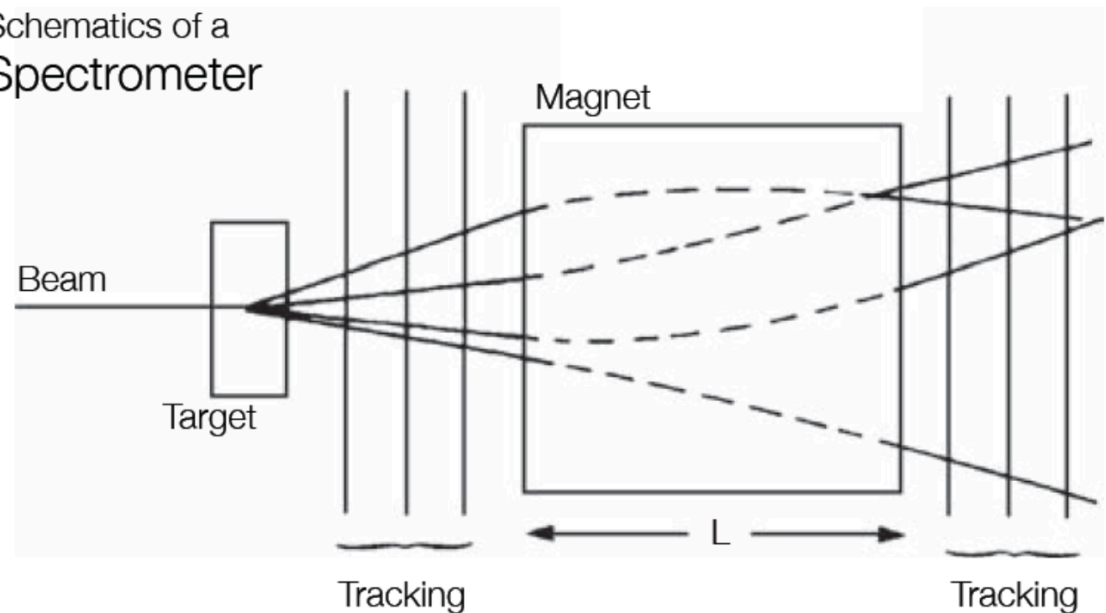
Lorentz force: is the force on a point charge due to electromagnetic fields

... for a particle in motion perpendicular to a constant B field

In practice:

- use layers of position sensitive detectors before and after (or inside) a magnetic field to measure a trajectory
- determine the bending radius

Schematics of a Spectrometer



Everything in HEP Starts with Rutherford

Rutherford-Geiger tube (1908)

An Electrical Method of Counting the Number of α -Particles from Radio-active Substances.

By E. RUTHERFORD, F.R.S., Professor of Physics, and H. GEIGER, Ph.D.,
John Harling Fellow, University of Manchester.

(Read June 18; MS. received July 17, 1908.)

In considering a possible method of counting the number of α -particles, their well-known property of producing scintillations in a preparation of phosphorescent zinc sulphide at once suggests itself. With the aid of a microscope, it is not very difficult to count the number of scintillations appearing per second on a screen of known area when exposed to a source of α -rays. The doubt, however, at once arises whether every α -particle produces a scintillation, for it is difficult to be certain that the zinc sulphide is homogeneous throughout.

It has been recognised for several years that it should be possible by refined methods to detect a single α -particle by measuring the ionisation it produces in its path.

A special apparatus (see fig. 2) was used to detect the emission of α -particles from weak radio-active substances like uranium and thorium.

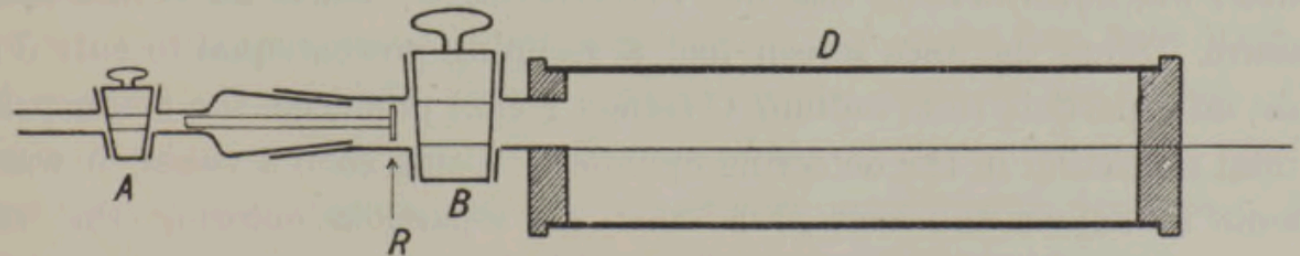


FIG. 2.

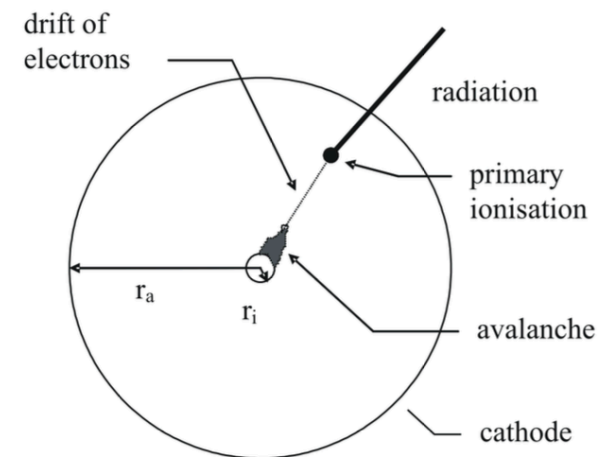
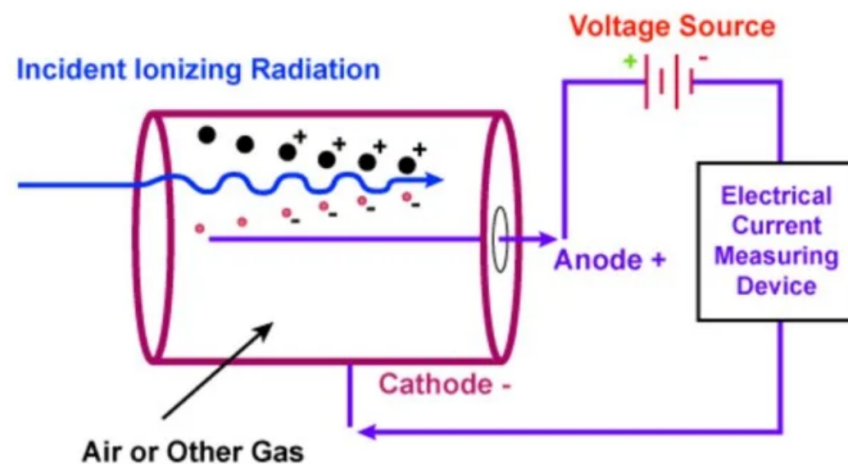
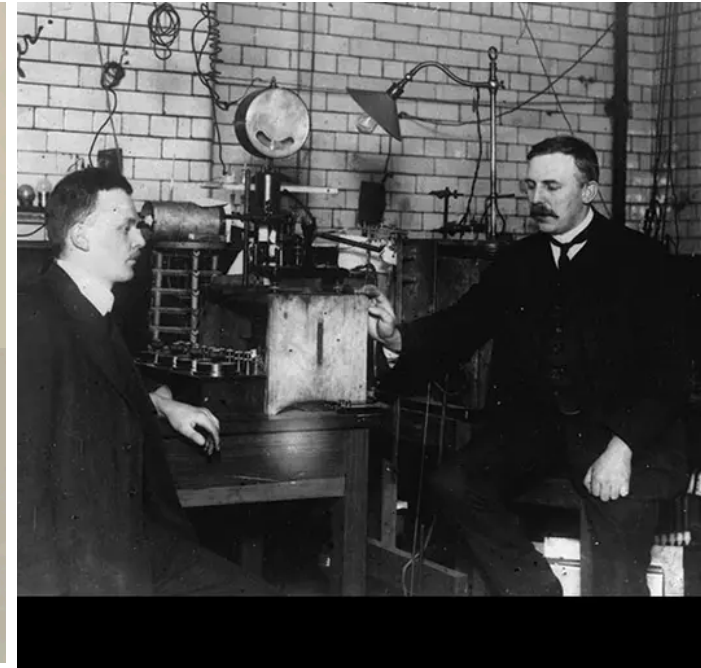
Summary of Results.

(1) By employing the principle of magnification of ionisation by collision, the electrical effect due to a single α -particle may be increased sufficiently to be readily observed by an ordinary electrometer.

(2) The magnitude of the electrical effect due to an α -particle depends upon the voltage employed, and can be varied within wide limits.

(5) The number of scintillations observed on a properly-prepared screen of zinc sulphide is, within the limit of experimental error, equal to the number of α -particles falling upon it, as counted by the electric method. It follows from this that each α -particle produces a scintillation.

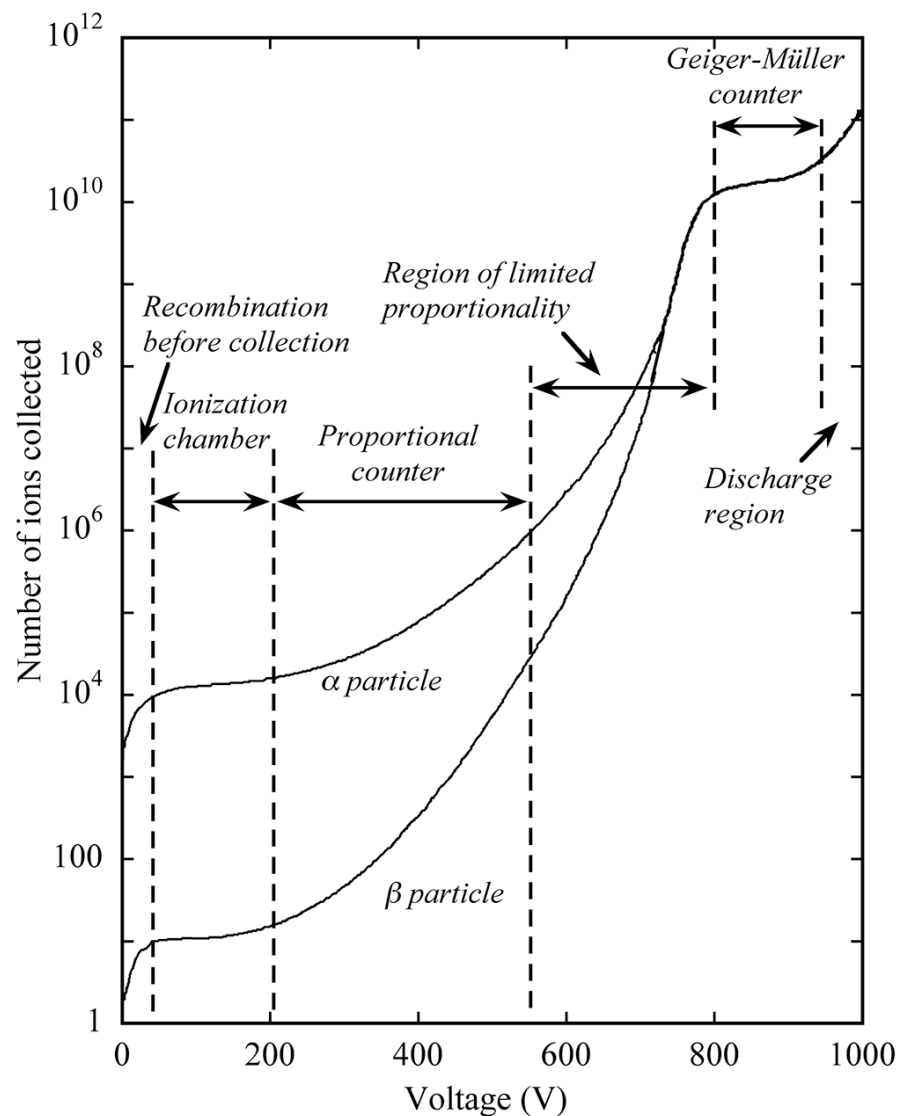
(6) The distribution of the α -particles in time is governed by the laws of probability.



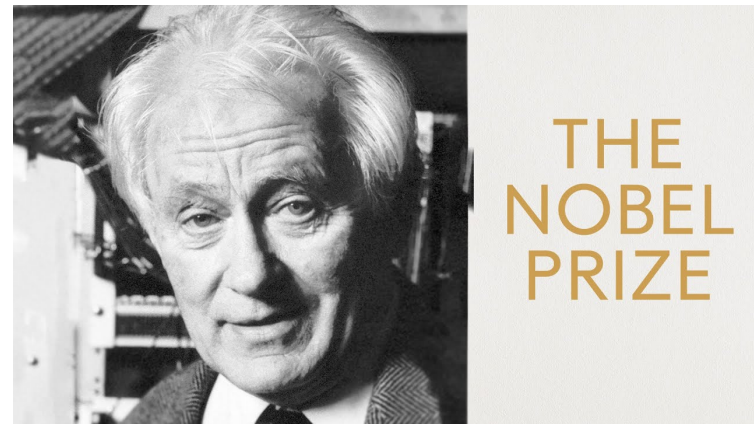
National Bureau of Standards Circular 490

Issued January 23 1950

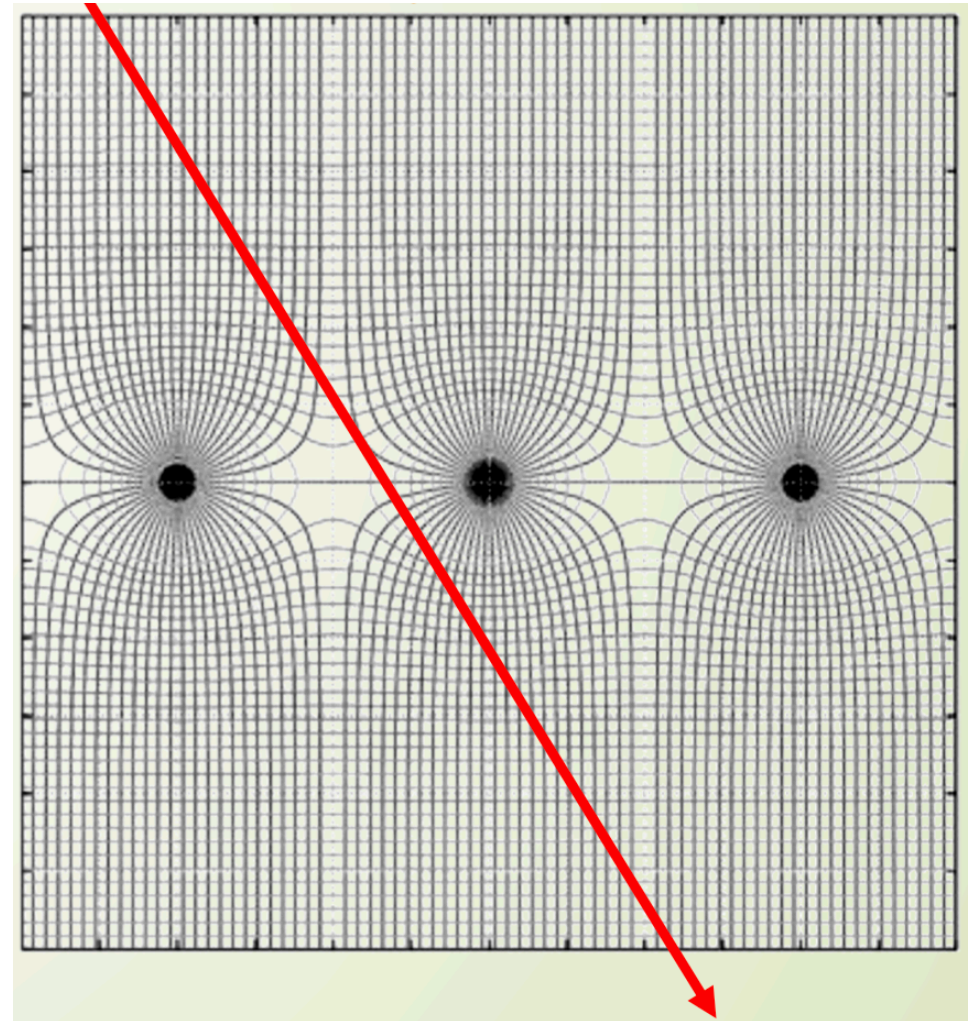
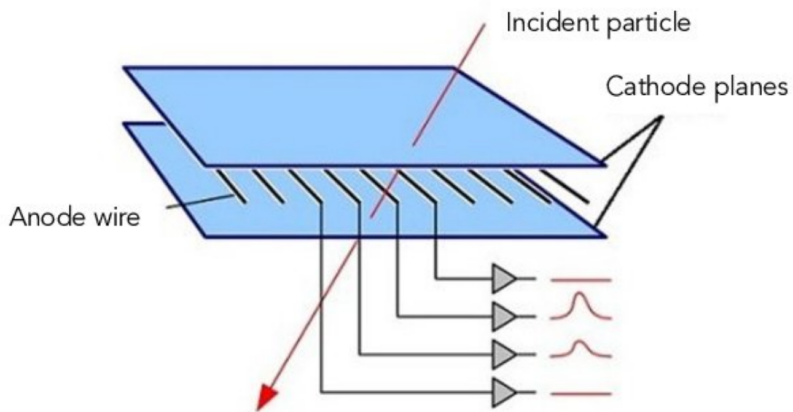
The counting chamber of figure 1 is not a Geiger-Müller counter, although in form it closely approximates such a device. The Geiger-Müller counter did not appear until 20 years after the development of the alpha-particle counting chamber. The chief differences in construction between the Geiger-Müller counter and these earlier devices consist in the use of a finer central wire. The gas pressures, the voltages, and the diameter of the tube are very nearly the same in both cases. The counting chamber described by Rutherford and Geiger had a tube 1.77 cm in diameter, operated at a pressure of 2 to 5 cm and at a voltage of 1,320 v. This corresponds roughly to the operating conditions for present-day counters. The reason that this counter operated as what is now known as a proportional counter instead of as a Geiger-Müller counter, apparently is that the center wire was larger than is required to provide Geiger-Müller operation at the voltage used. The wire used was 0.45 mm in diameter, which is 5 to 10 times the diameter of wires used in Geiger-Müller counters. Small variations of diameter of the center wire produce pronounced changes in the electric field, as shown



The Multiwire Proportional Chamber



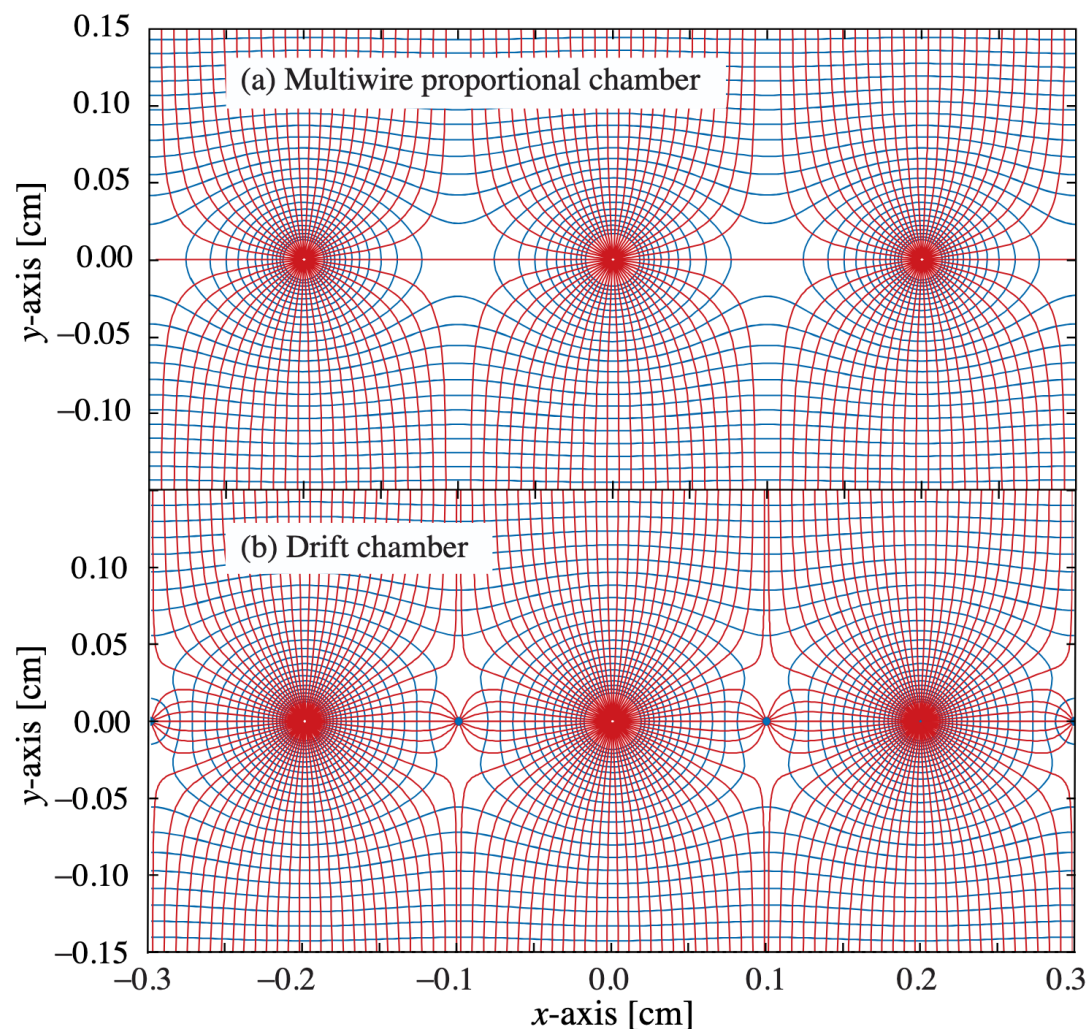
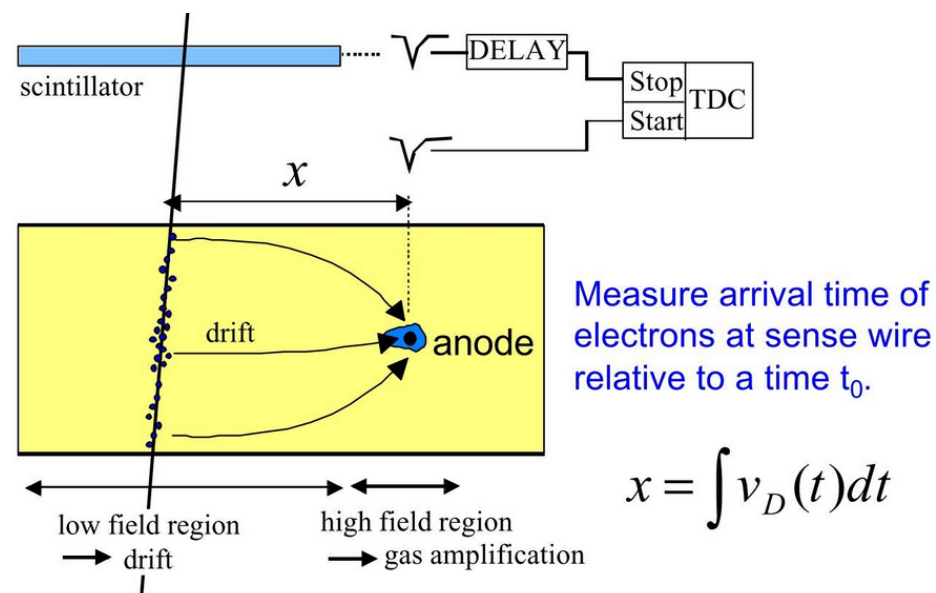
The Nobel Prize in Physics 1992 was awarded to Georges Charpak "for his invention and development of particle detectors, in particular the multiwire proportional chamber"



Some regions in MWPC there is no or very low field.

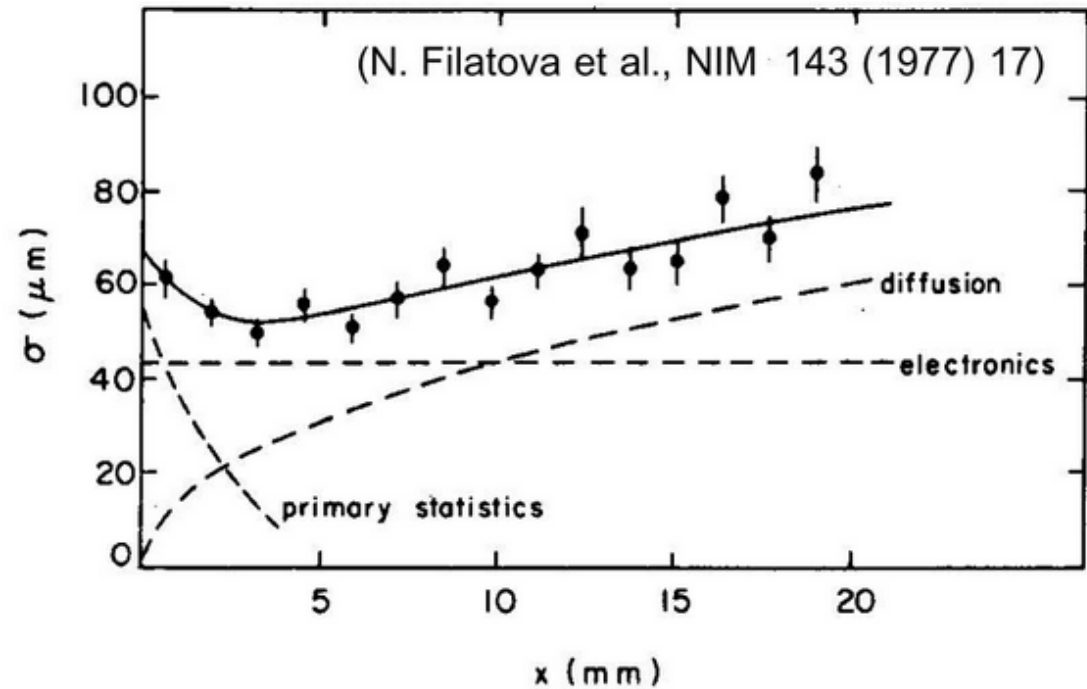
Add “field-shaping” wires to keep equipotential lines linear over a larger region.

Allows for improved spatial resolution by measuring ionization drift time.



Typical resolutions: $\sigma_x = 50\text{-}150\ \mu\text{m}$
depends on the length of the drift path

- primary ionization statistics: how many ion pairs, ionization fluctuations **dominates close to the wire**
- diffusion: diff. constant, drift length **dominates for large drift length**
- electronics: noise, shaping characteristics
constant contribution, **independent on drift length**



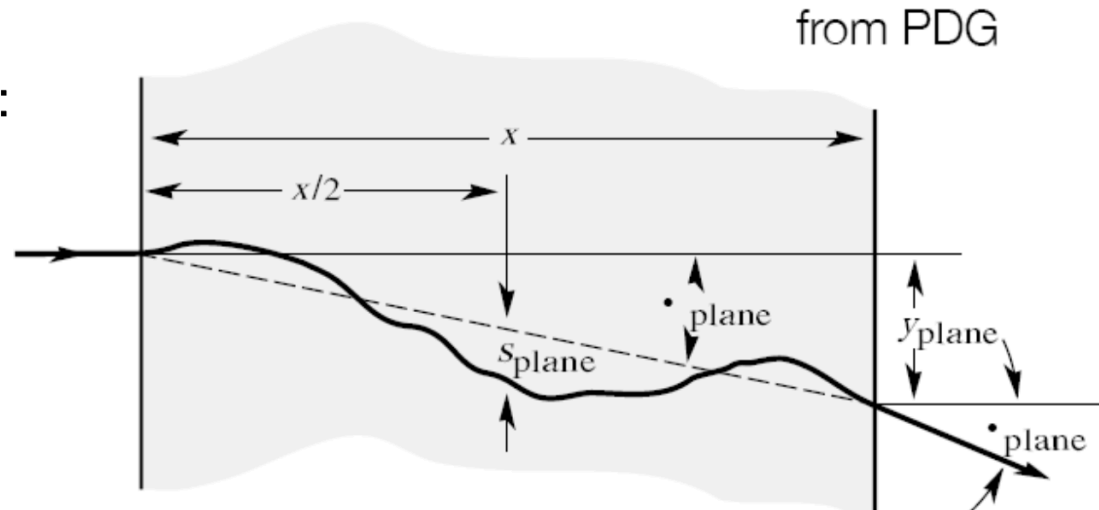
$$\sigma_x^2 = \underbrace{\left(\frac{1}{64N^2} \right) \cdot \frac{1}{x^2}}_{\text{1st ionization statistics}} + \underbrace{\frac{2D}{v_d} \cdot x}_{\text{diffusion}} + \underbrace{\sigma_{\text{const}}^2}_{\substack{\text{electronics} \\ \delta\text{-electrons}}}$$

Multiple scattering contribution:

$$\sigma_\phi \approx \frac{14 \text{ MeV}/c}{p} \sqrt{\frac{L}{X_0}}$$

$$\frac{\sigma_p}{p} = \frac{\sigma_R}{R} = \frac{\sigma_\phi}{\phi}$$

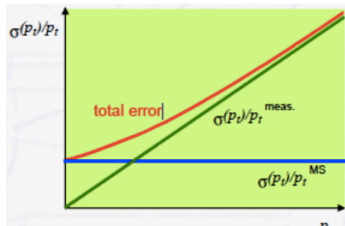
as $R = \frac{L}{\phi}$



At small momenta this limits resolution of momentum measurement ...

$$\frac{\sigma_p}{p} = \frac{\sigma_\phi}{\phi} = \frac{14 \text{ MeV}/c}{p} \sqrt{\frac{L}{X_0}} \cdot \frac{R}{L} = \frac{14 \text{ MeV}/c}{p} \sqrt{\frac{1}{LX_0}} \cdot \frac{p}{eB} \sim \frac{1}{\sqrt{LX_0}B}$$

momentum independent



$$\left(\frac{\sigma_{p_t}}{p_t} \right)^2 = \text{const} \cdot \left(\frac{p_t}{BL^2} \right)^2 + \text{const} \cdot \left(\frac{1}{B\sqrt{LX_0}} \right)^2$$

1

Credit: E. Garutti

Momentum determination in fixed target experiments ...

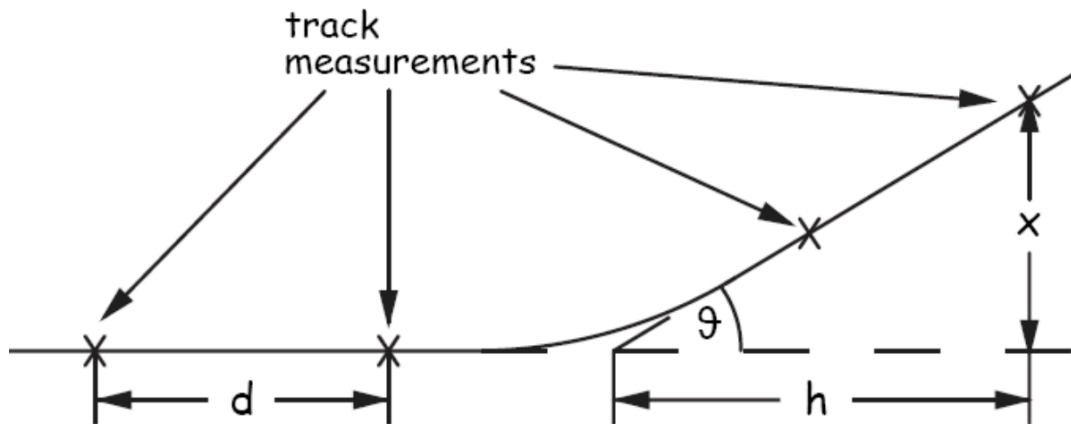
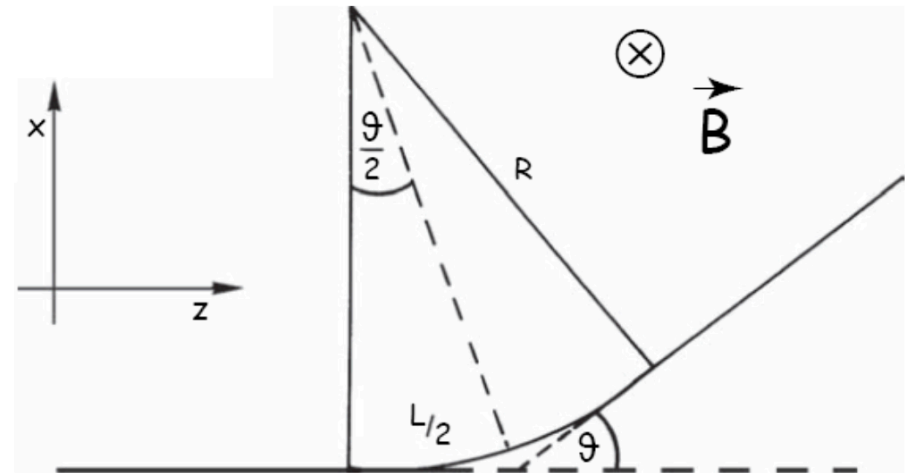
$$p = eRB \quad \vartheta = L/R$$

$$= L/p \cdot eB$$

$$p = eB \cdot L/\vartheta$$

Momentum
resolution:

$$\rightarrow \frac{\sigma_p}{p} = \frac{\sigma_\vartheta}{\vartheta} \quad \text{with} \quad \sigma_\vartheta \sim \sigma_x$$



Determination
of σ_p/p :

$$\vartheta = \frac{x}{h} \quad \sigma_\vartheta = \frac{\sigma_x}{h}$$

$$\frac{\sigma_p}{p} = \frac{\sigma_\vartheta}{\vartheta} = \frac{\sigma_x}{h} \cdot \frac{p}{eBL}$$

Long lever arm improves
momentum resolution ...

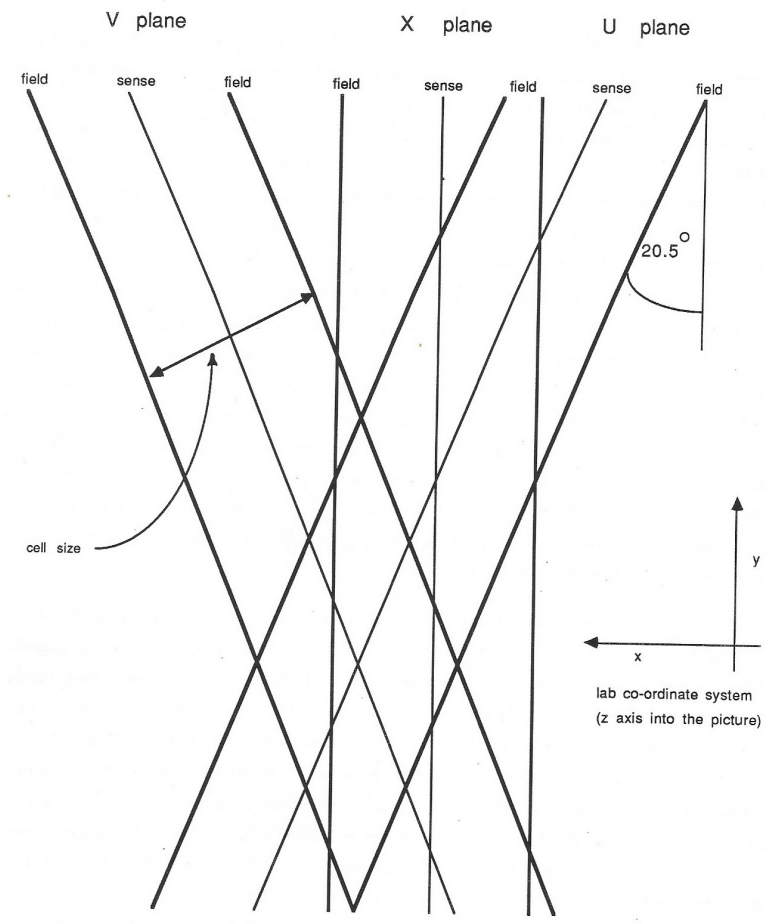
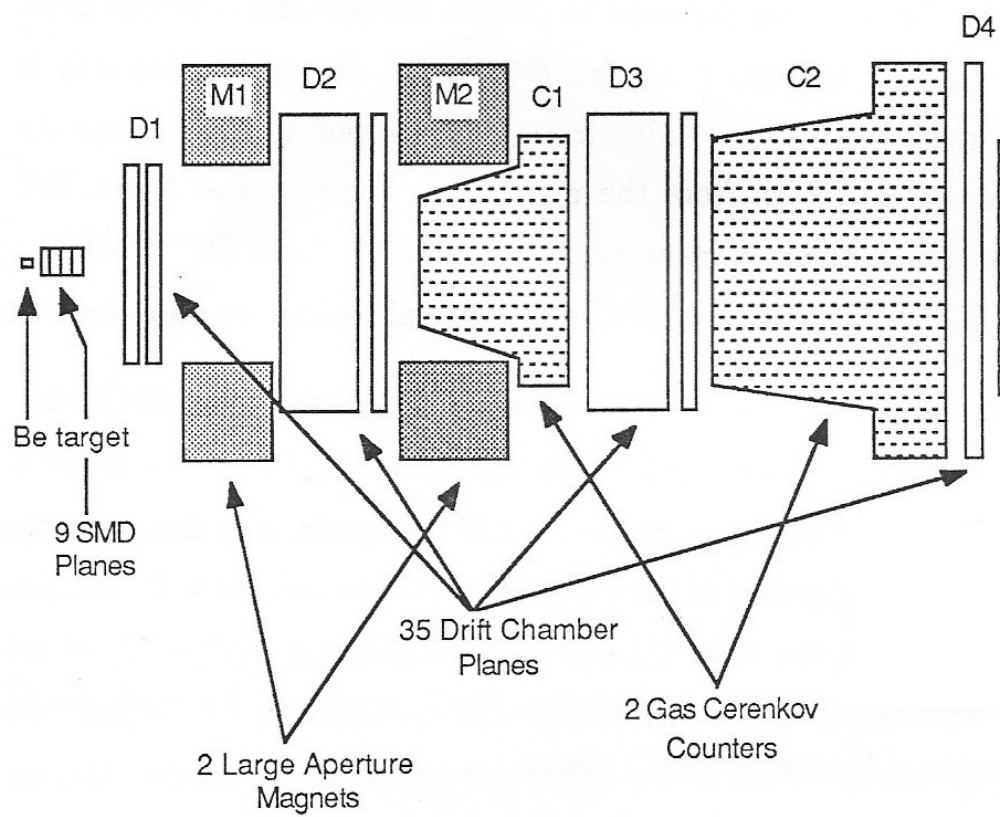
Credit: E. Garutti

Fermilab E691

Tagged Photon Spectrometer



Fermilab E691 - Tagged Photon Spectrometer (1985-86)



	$\int B \cdot dl$	p_t kick
M1	0.7 T·m	213 MeV
M2	1.07 T·m	321 MeV

Chamber	1	2	3	4
Sense Wire Voltage (kV)	0	0	0	+2.9
Field Wire Voltage (kV)	-1.6	-2.0	-2.0	-0.2
Cathode Plane Voltage (kV)	-2.3	-2.4	-2.4	0
U/V cell size (mm)	4.46	8.92	14.87	29.74
X/X' Cell Size (mm)	4.76	9.53	15.88	31.75
Number of U+V Wires	896	1536	1280	256
Number of X+X' Wires	640	848	672	160
Resolution (μm)	350	300	300	800

Sense wires are 25 micron gold plated tungsten
Field wires are 127 micron Be Cu

$$\frac{\Delta p}{p} = \frac{\Delta \theta}{p_T} p \simeq \frac{p}{q \int B \cdot dl} \sqrt{12 \left(\frac{\delta_u^2}{N_u l_u^2} + \frac{\delta_d^2}{N_d l_d^2} \right)}$$

	$\frac{\Delta p}{p}$
one magnet	0.1%p (GeV)
both magnets	0.05%p (GeV)
multiple scattering	0.5%

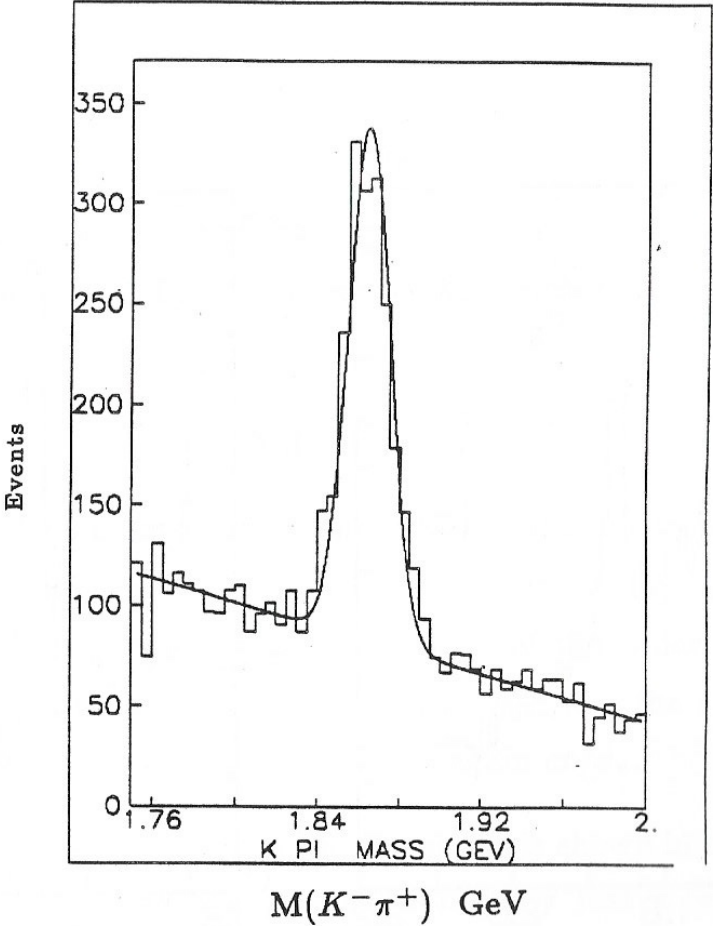
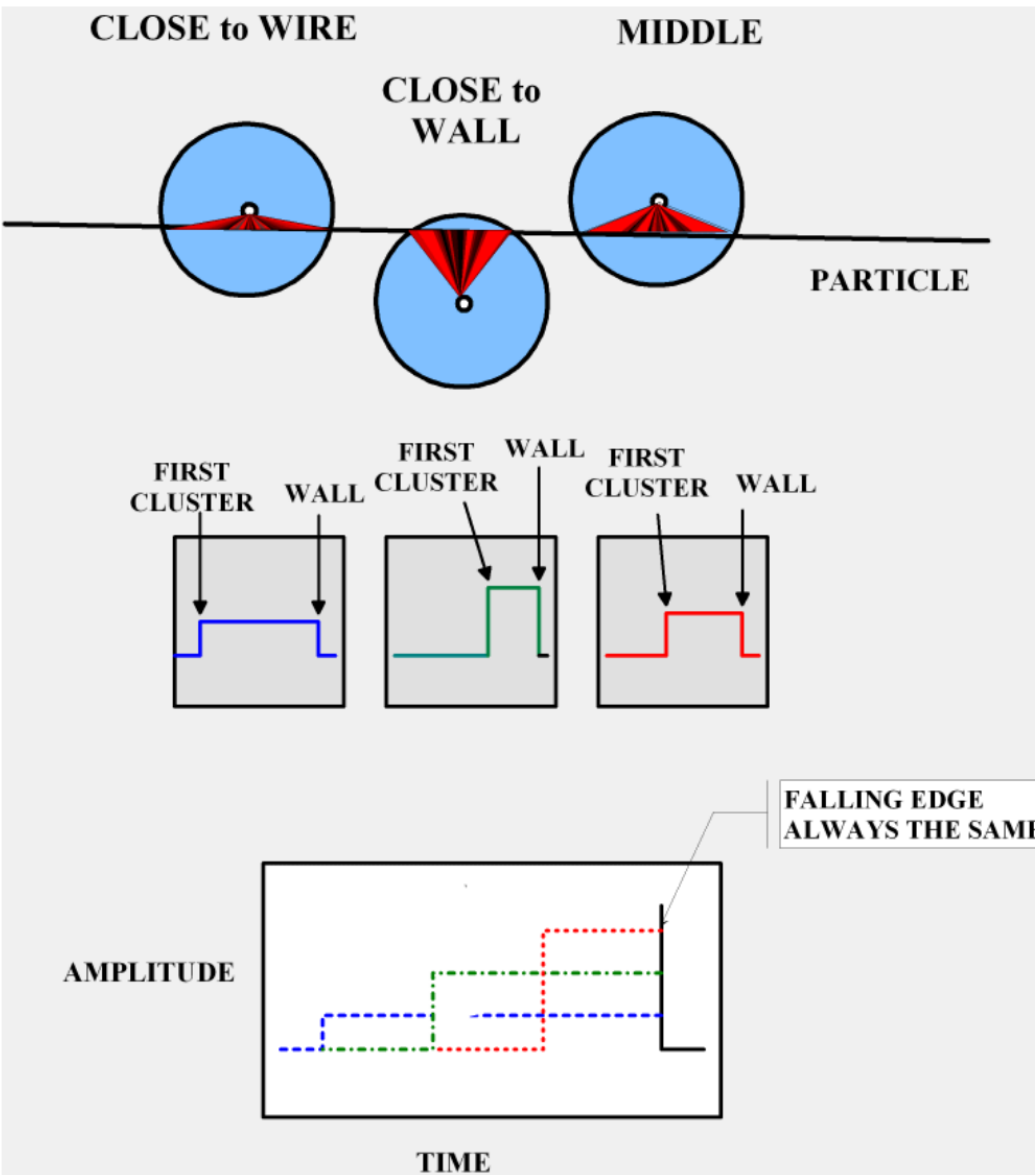
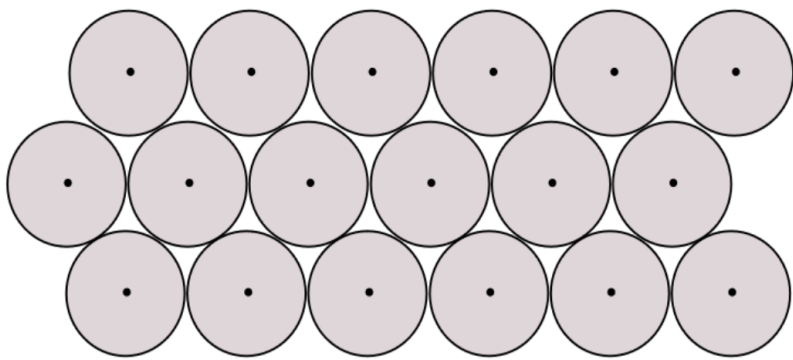
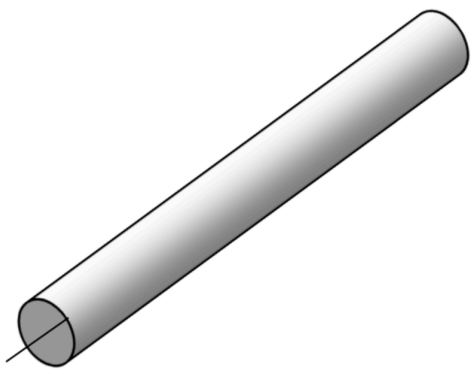


Figure 8.2-3 The $K^- \pi^+$ Mass Plot

One issue that complicates standard wire chambers - what if a wire breaks?

One solution: straw tube trackers



Straw tube tracking detector (STT) for ZEUS

S. Fourletov

York University, Toronto, 4700 Keele Street, Canada M3J 1P3

On behalf of the ZEUS STT Collaboration
Available online 19 August 2004

DESY, Hamburg, Germany



HERA

HERA



PETRA

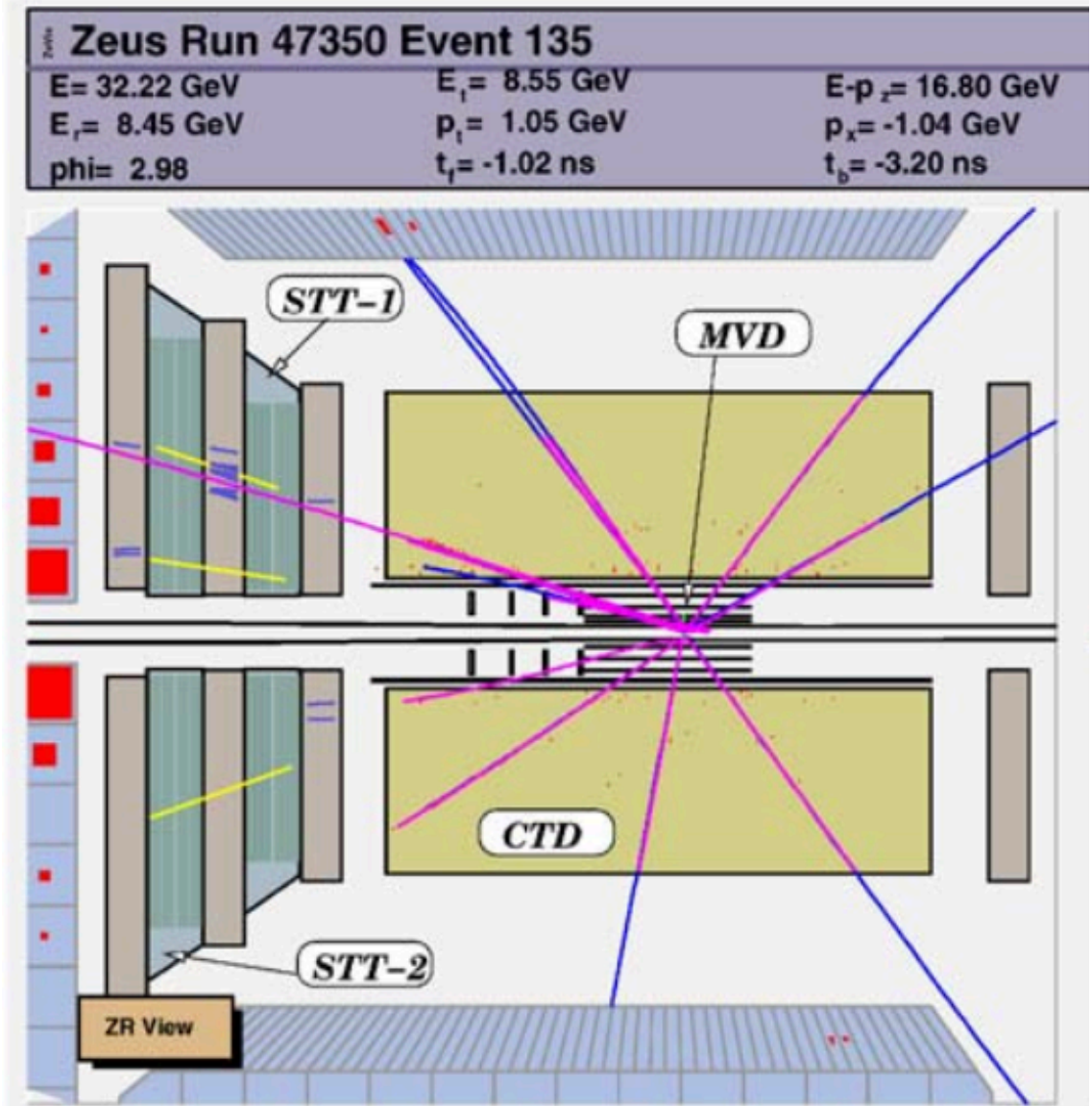
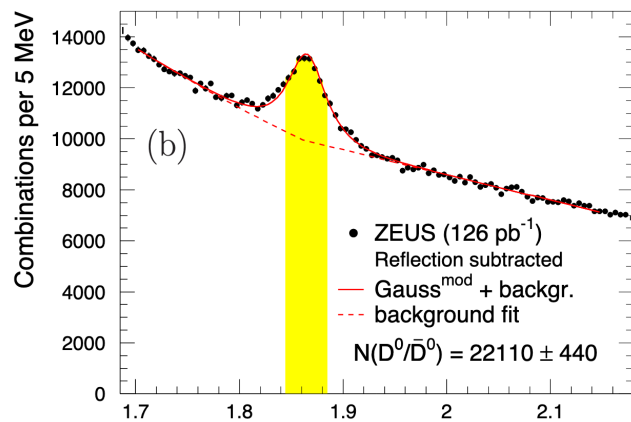
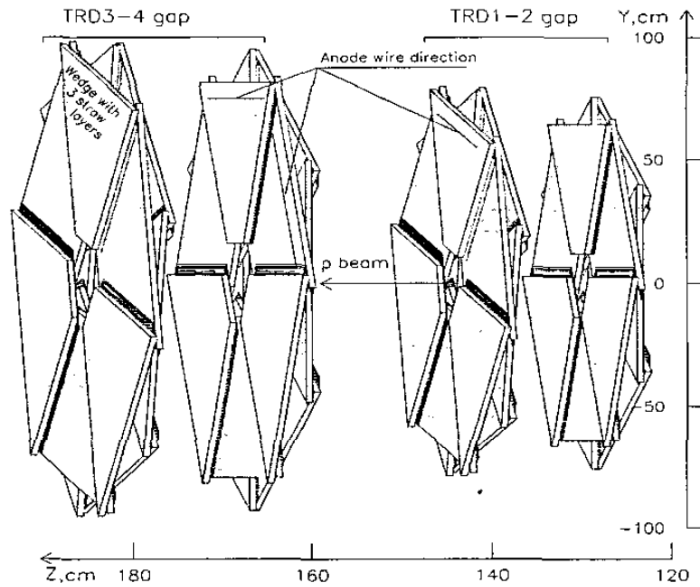
H1 and ZEUS



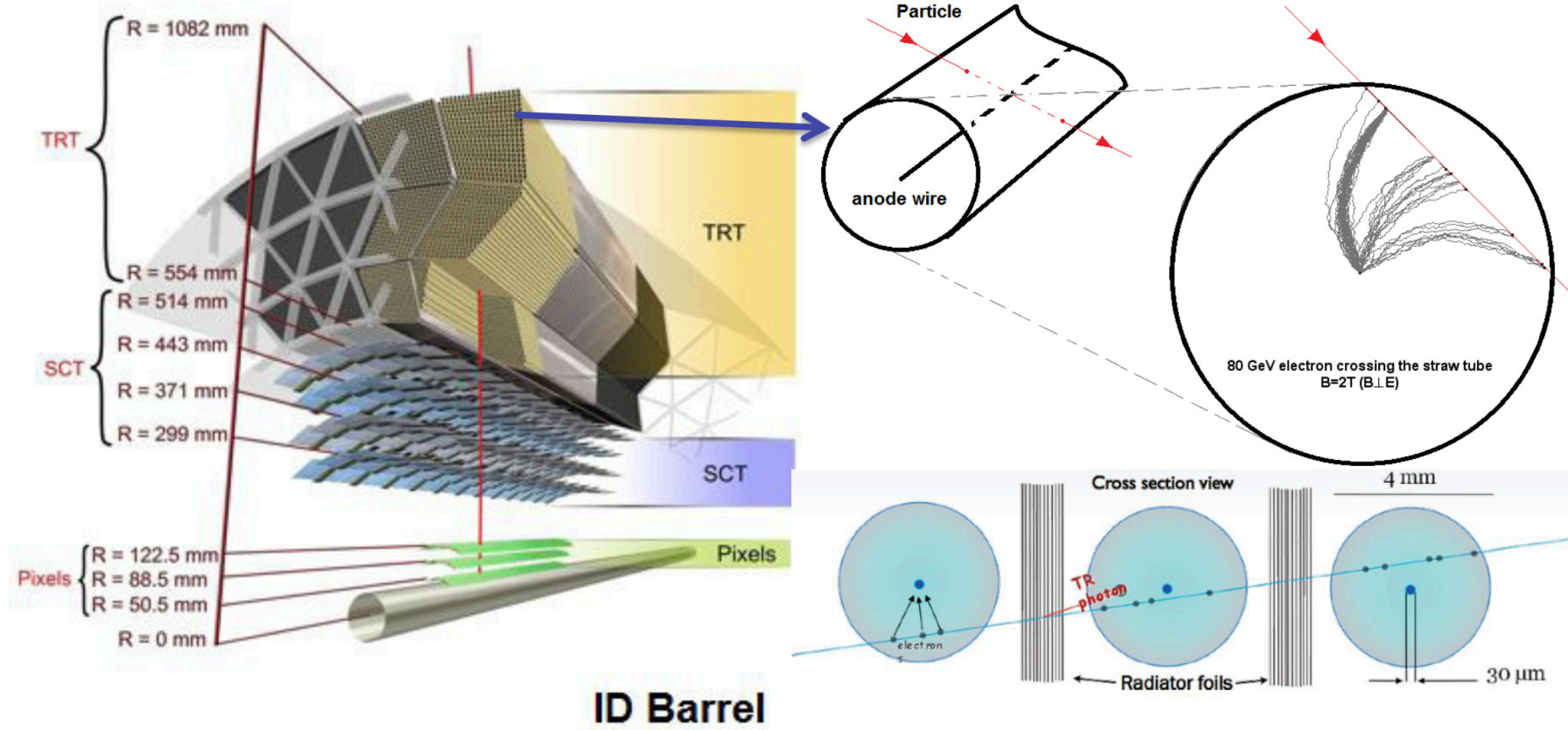
Each straw is made up of 2 layers of 50 micron kapton plus 20 micron Al coating for 120 micron wall thickness. The inner diameter is 7.5 mm. The wires are 50 micron copper-beryllium. The gas is 80:20 Argon:Carbon Dioxide. HV was around 2 kV



10,944 straws in 48 sectors with each sector consisting of 3 layers of straws



ATLAS Transition Radiation Tracker



Single point resolution:

120-130 μ m

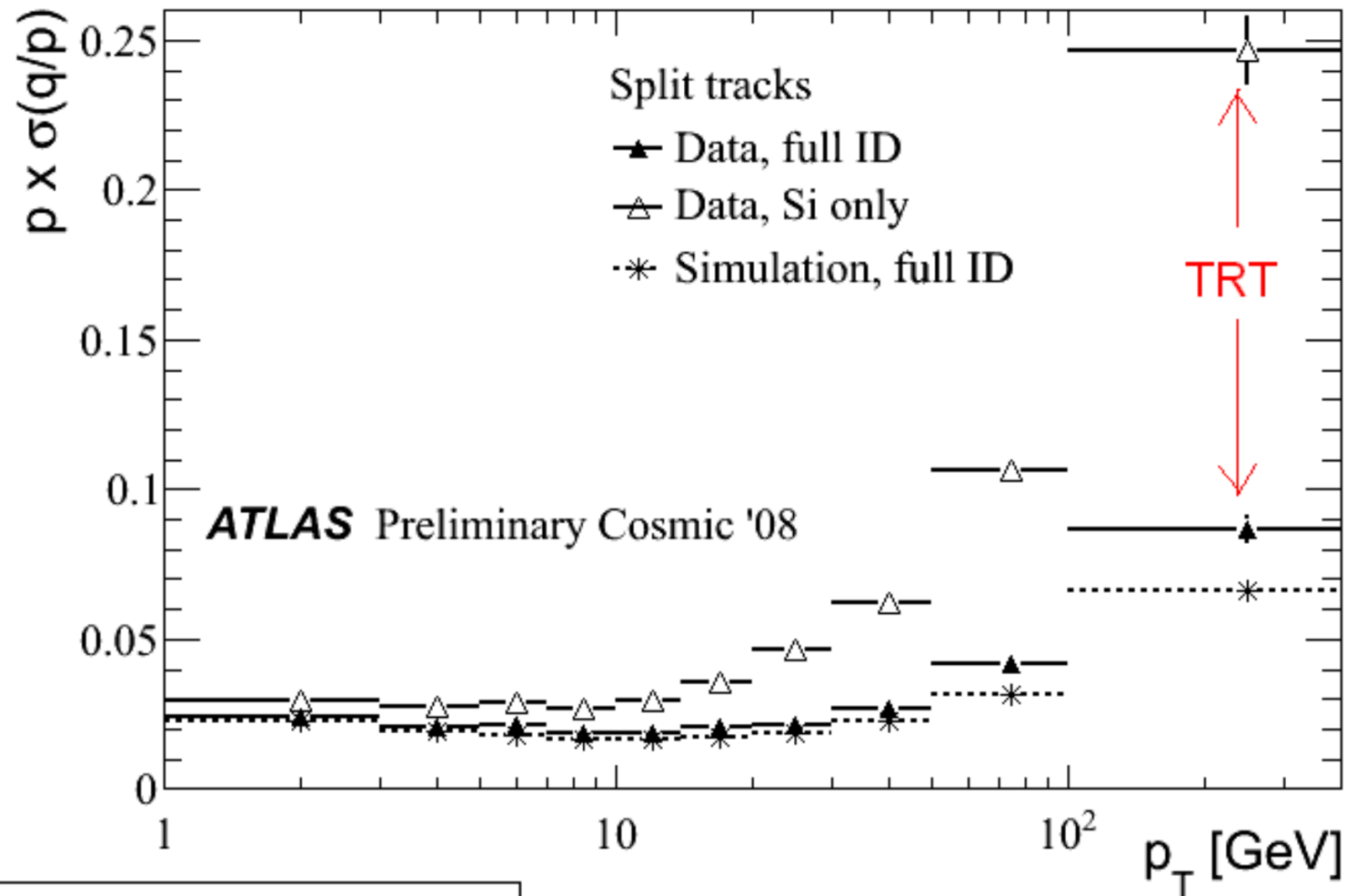
Points per track:

~30 over a long lever arm (extend silicon tracker)

Momentum resolution:



Credit: E. Garutti



Momentum Resolution:
 $\sigma(p_T)/p_T = 0.05\% p_T \oplus 1\%$

DUNE Near Detector complex at Fermilab
SAND: System for on-Axis Neutrino Detection

In preparation for first neutrino beam (~2030)

SAND

TMS/ND-GAr

ND-LAr

Straw Tube
Tracker (STT)
for SAND

84 modules
~220,000 straws

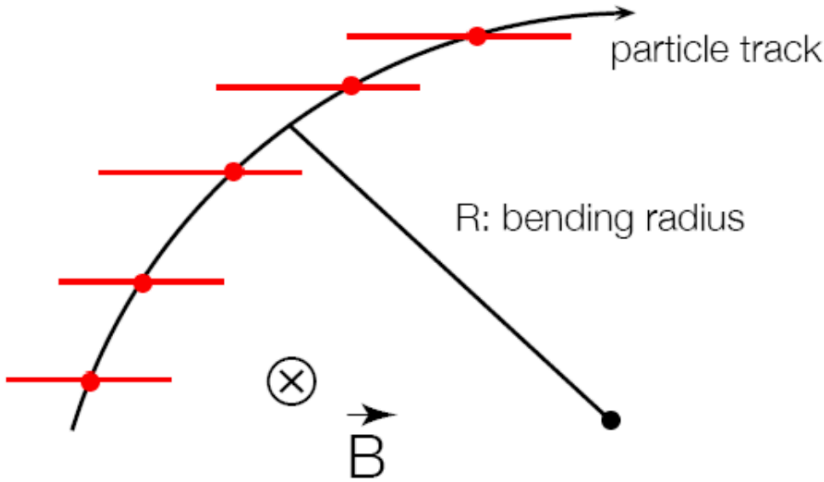
average straw length 3.2 m
maximal straw length 3.8 m
internal gas volume ~14 m³
nominal gas pressure ~2 bar
Gas mixtures:
Xe/CO₂ 70/30 & Ar/CO₂ 70/30

V

Momentum determination in a cylindrical drift chamber ...

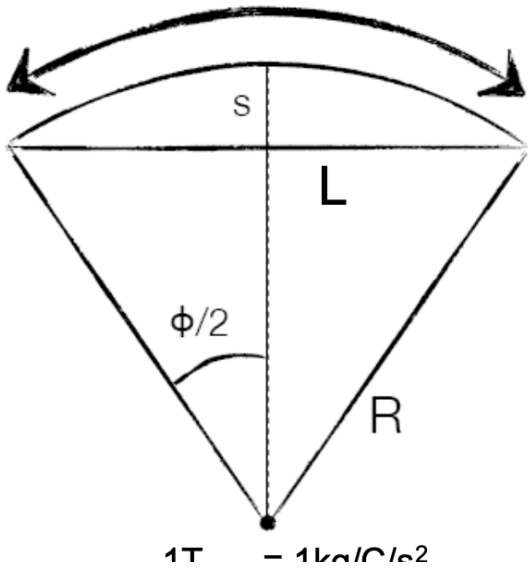
$$\frac{mv^2}{R} = evB \quad \rightarrow \quad p = eB \cdot R$$

$$p\left[\frac{\text{GeV}}{c}\right] = 0.3 \text{ B[T]} \text{ R[m]}$$



momentum component perpendicular to the B-field
transverse momentum p_t

For Sagitta s :



$$s = R - R \cos \frac{\phi}{2} \approx R \frac{\phi^2}{8}$$

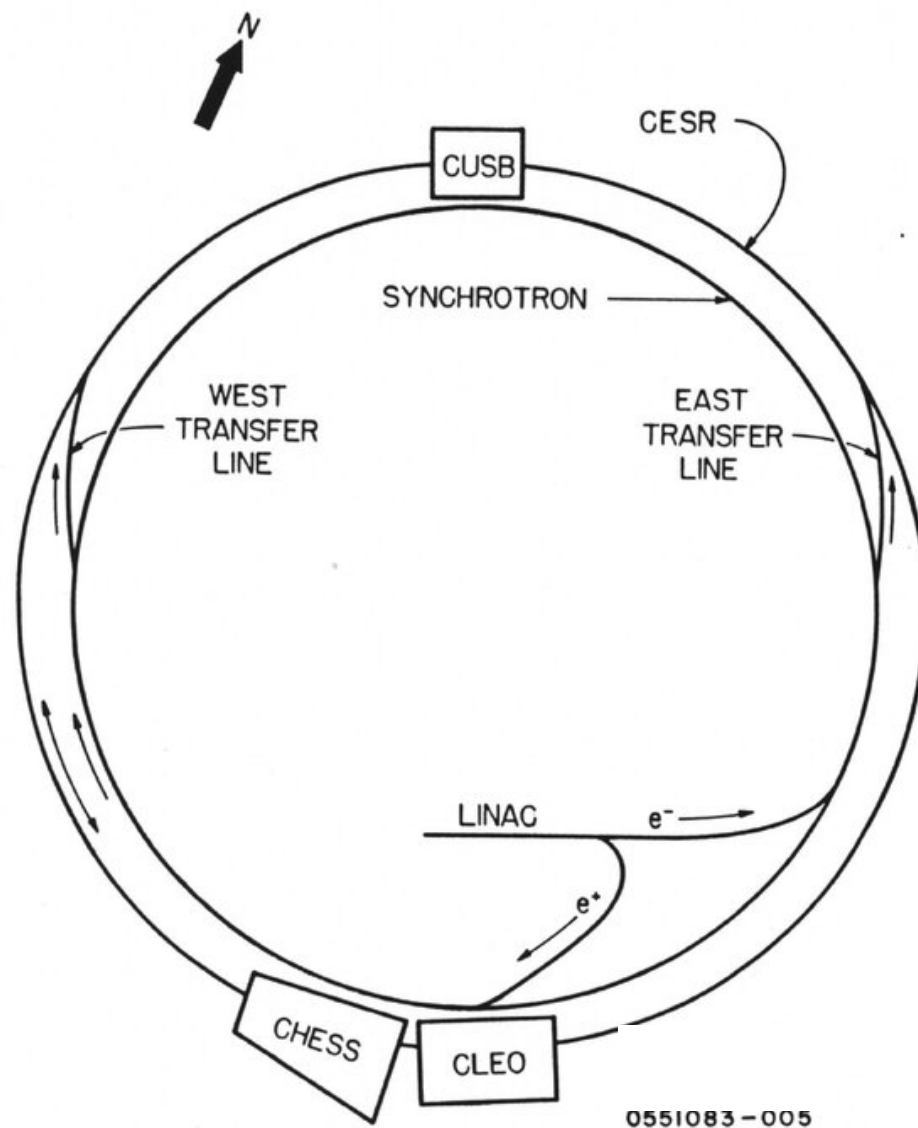
with $\phi = \frac{L}{R}$

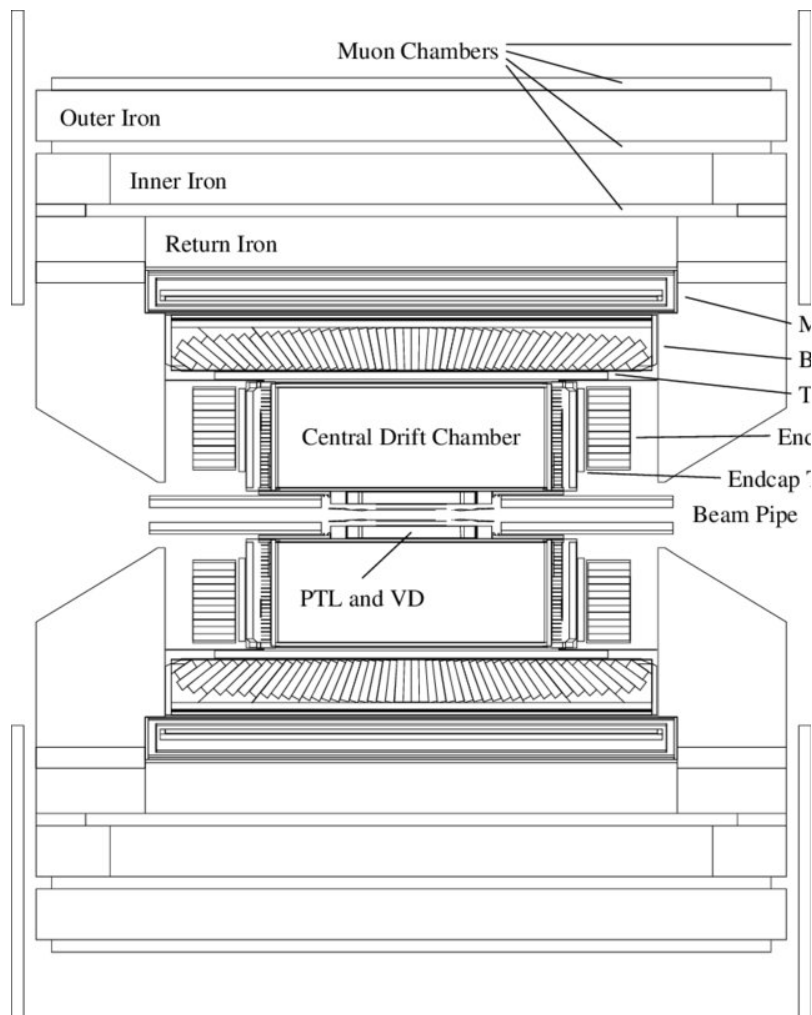
$$s = R \frac{L^2}{8R^2} = \frac{L^2}{8R} \quad \text{and} \quad R = \frac{L^2}{8s}$$

➔ radius is obtained by a
circle fit through
measurement points along
the track with point
resolution $\sigma_{r\phi}$

$$\rightarrow \frac{\Delta p}{p} = \frac{\Delta R}{R} = \frac{L^2}{8Rs} \cdot \frac{\Delta s}{s}$$

CLEO at CESR

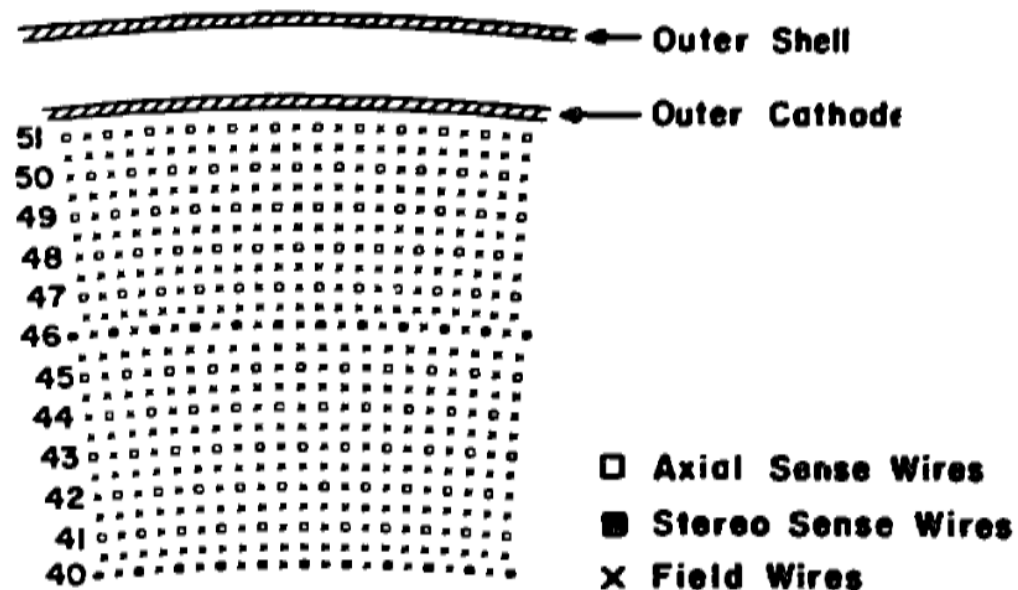


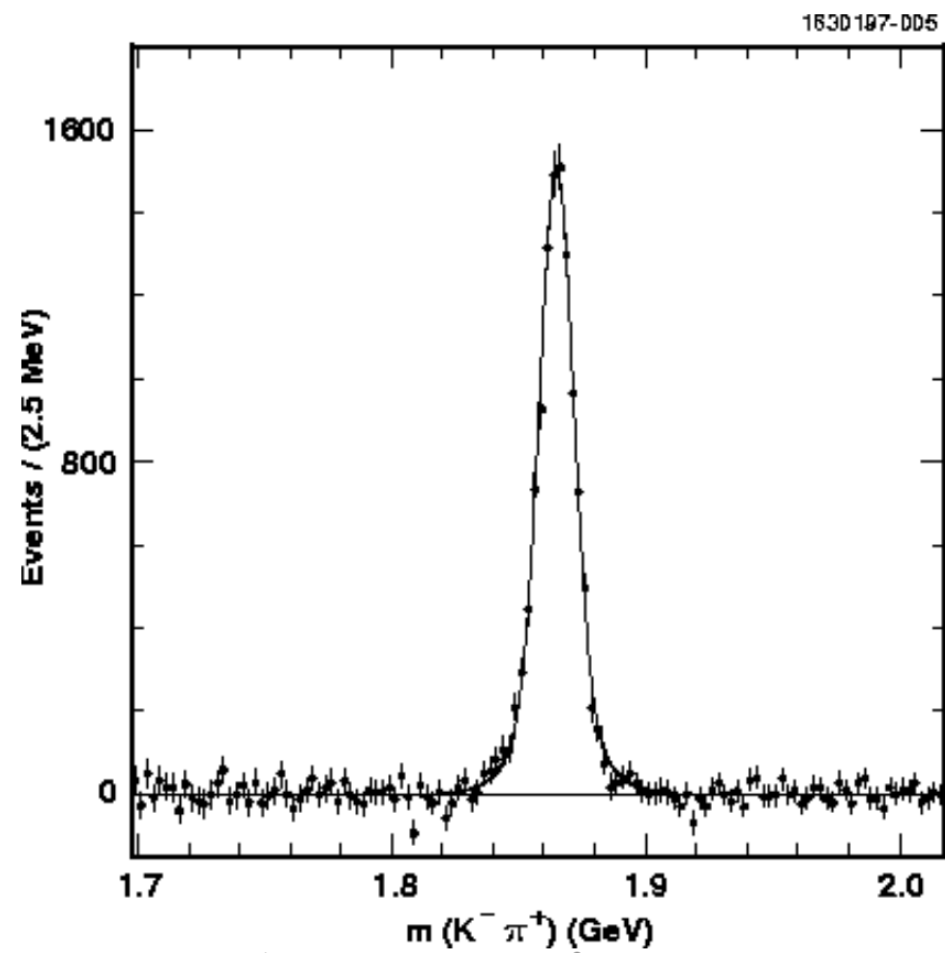
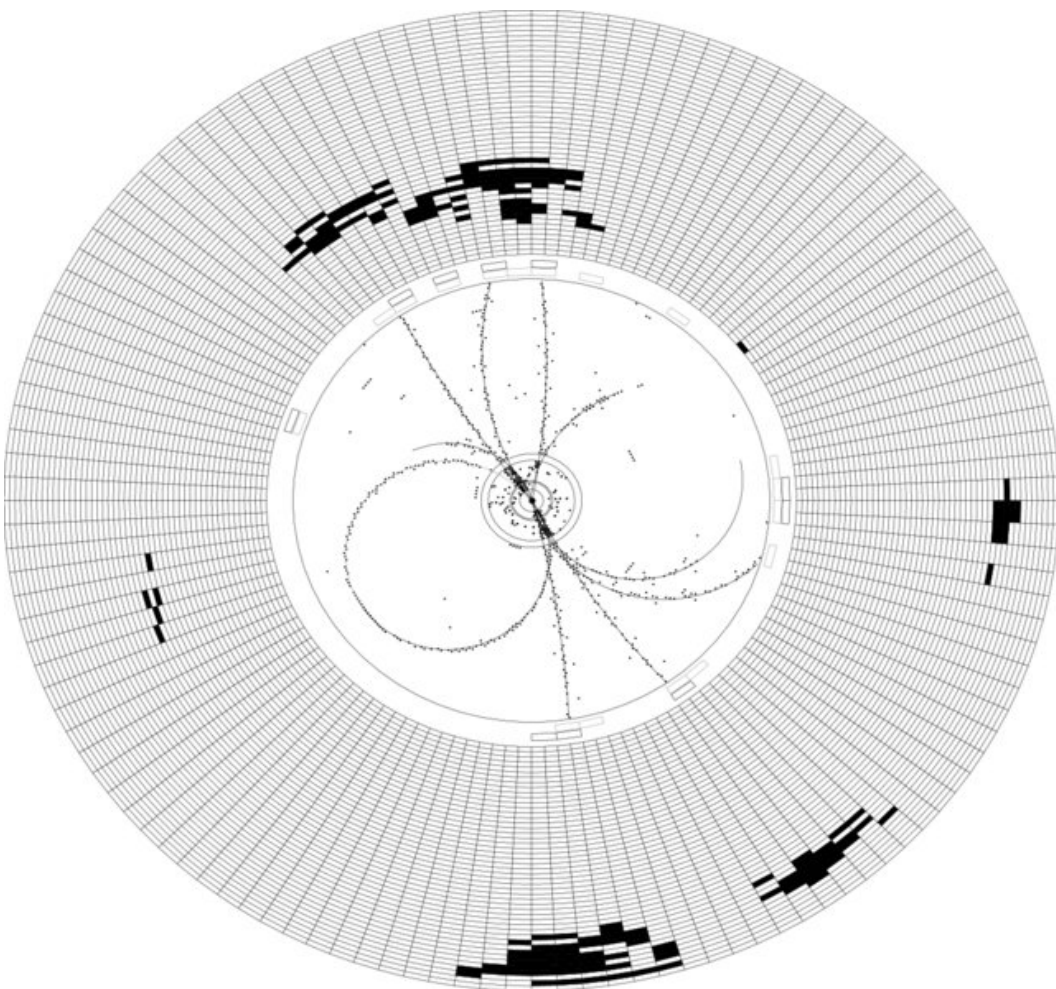


51 layers of cells with 3 field wires for each sense wire - for a total of 36,240 field wires and 12240 sense wires.

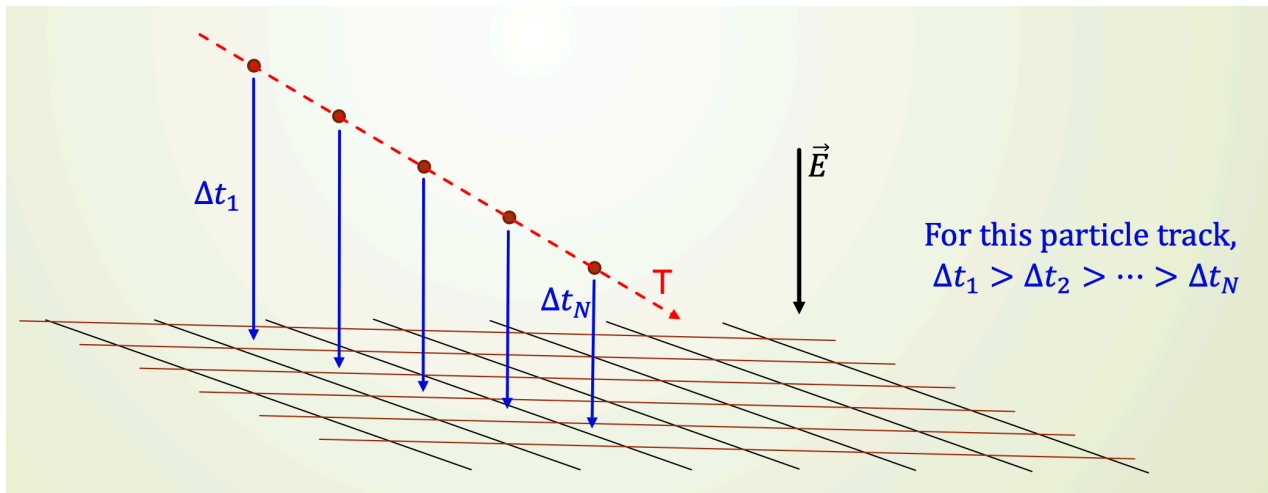
Sequential layers are offset by 1/2 a cell to resolve left-right ambiguity.

Sense wires are 20 micron gold plated tungsten while field wires are 110 micron gold plated aluminum.



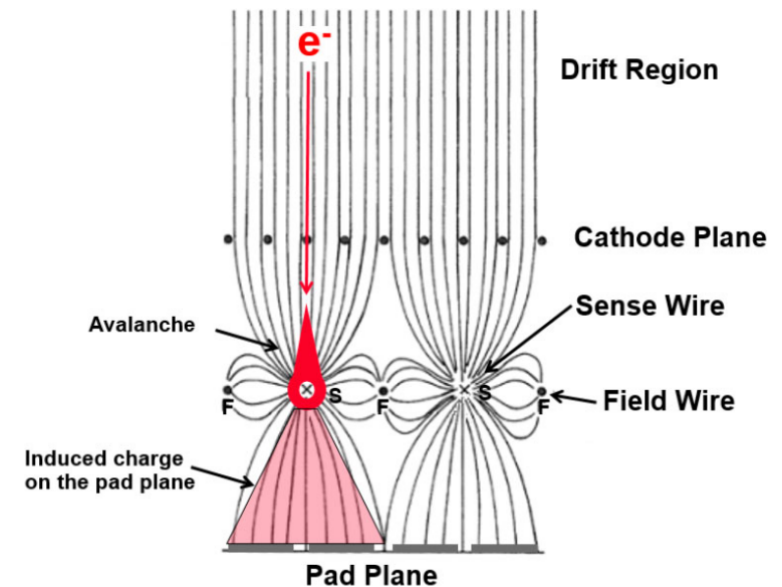
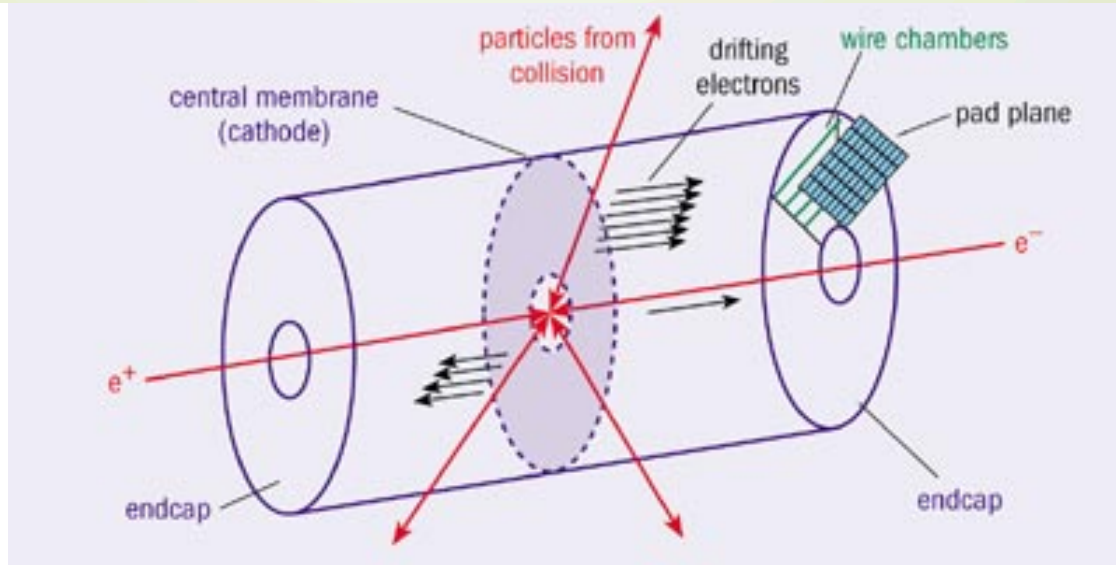


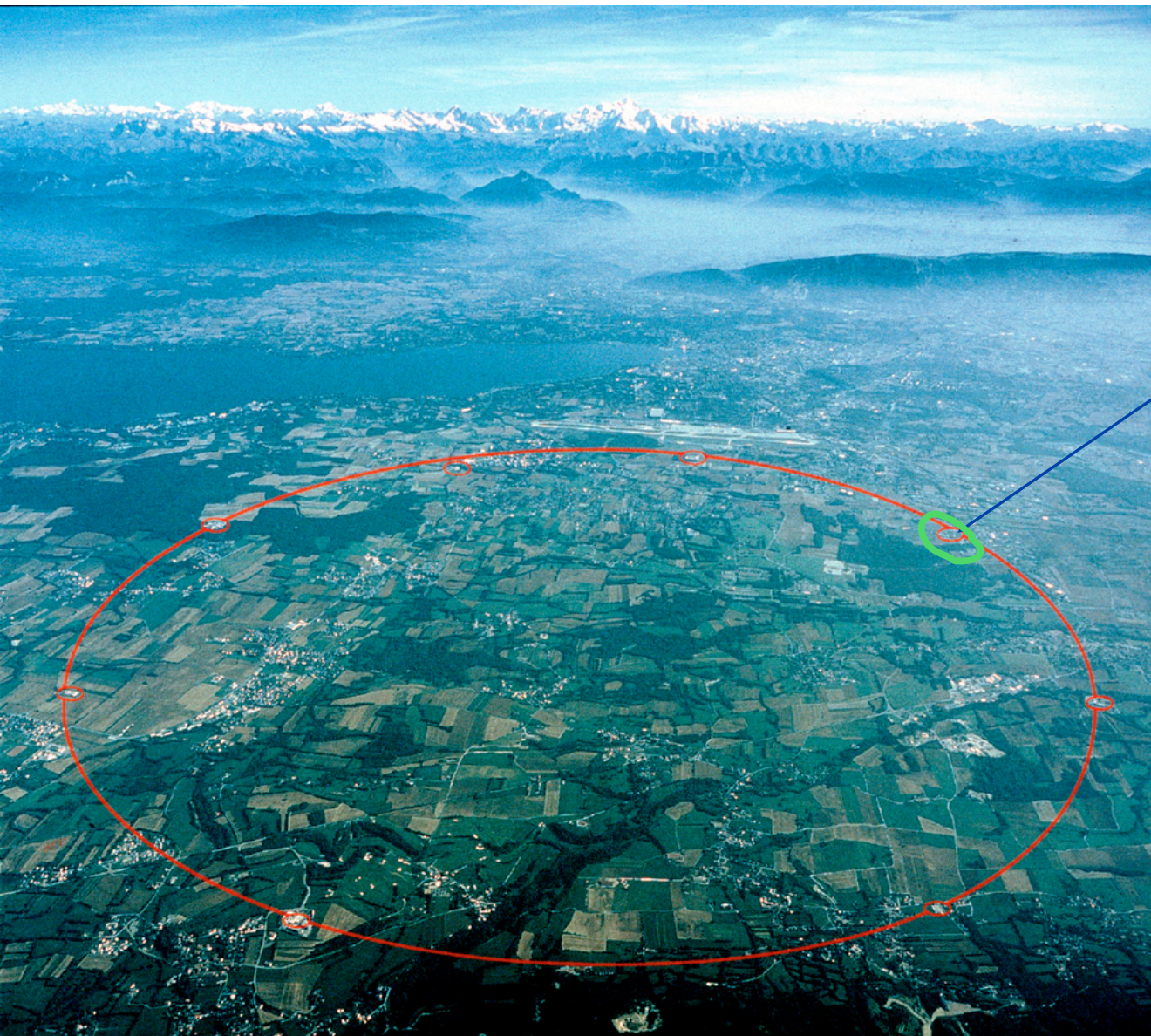
The Time Projection Chamber



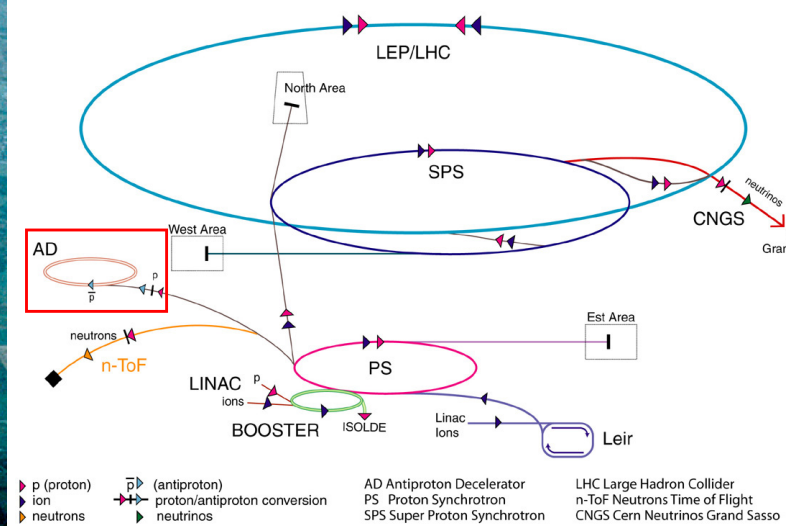
To get the third dimension using standard DCs would require using many of them to get decent z resolution.

Solution: measure drift time to a 2D analysis plane incorporating wires and pads



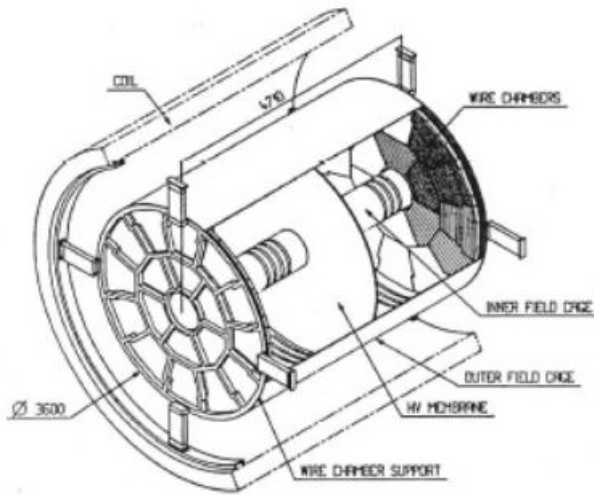


Accelerator chain of CERN (operating or approved projects)



ALEPH at LEP

TPC

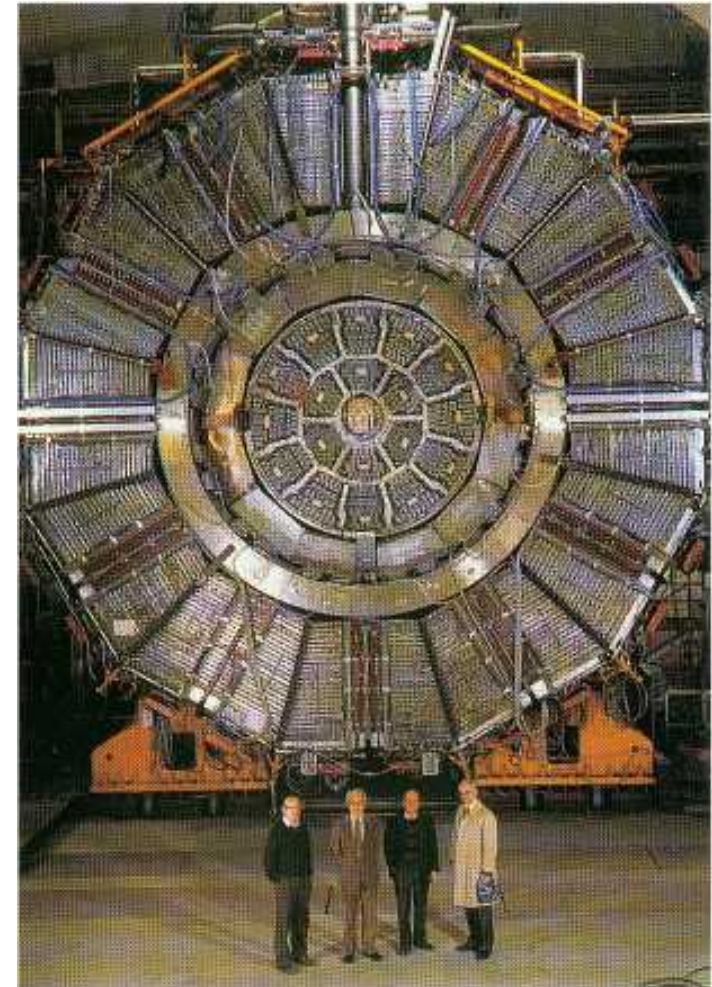


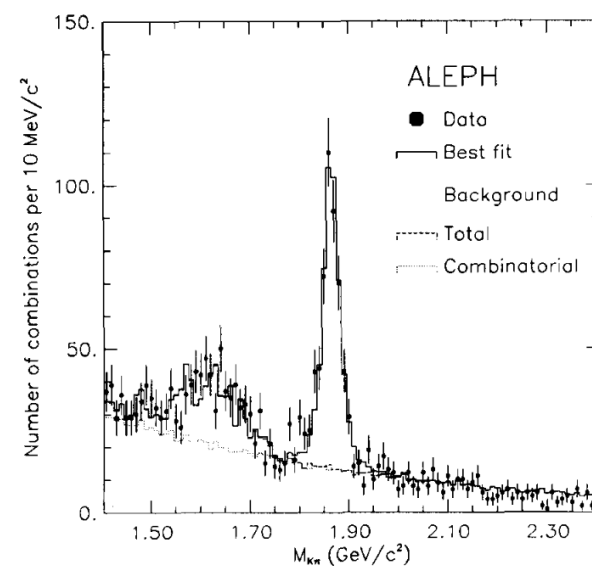
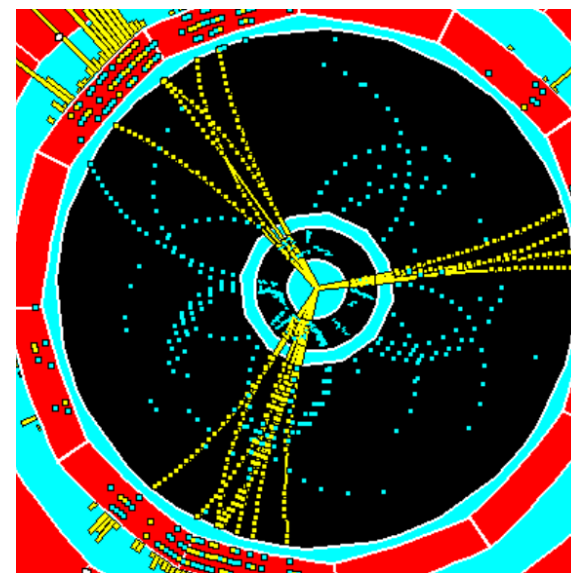
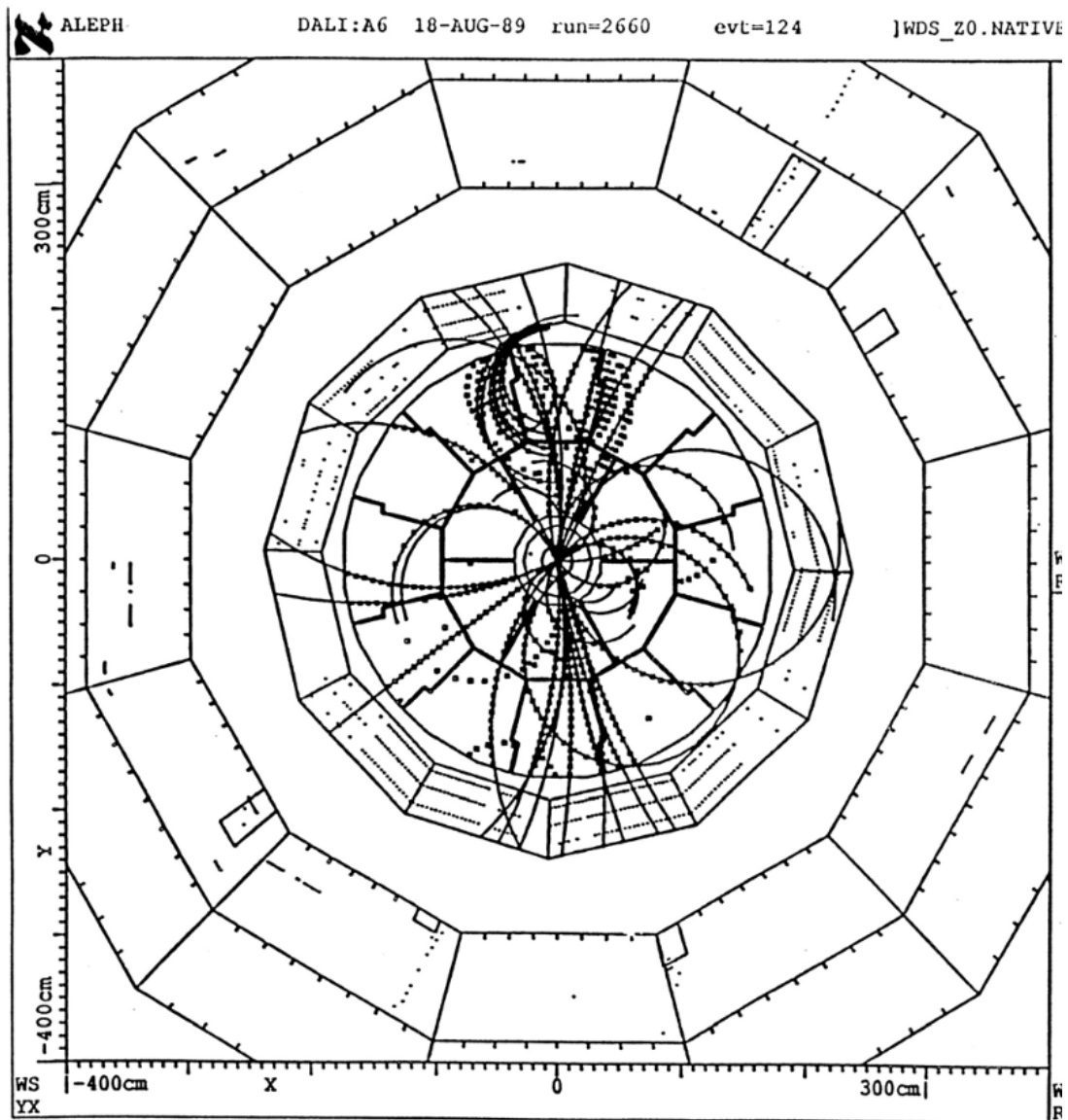
- $r\phi$ from pad position
- z from drift time (pads + wires)
- dE/dx from wires and pads

$r\phi$ -resolution : $180 \mu\text{m}$

z -resolution (pads + wires) : $500 \mu\text{m}$

- Length = 4.7 m
- Outer radius = 1.8 m
- Total weight = 3.6 t
- Drift length $2 \times 2.2\text{m}$
- Up to 21 space points / track
- 18 wire chambers / endplate
- 47340 channels in total
- $B = 15 \text{ kG}$
- HV (Membrane) = -27.5 kV
- Gas
 - Volume 43 m^3
 - Argon/Methan (91:9) at atmospheric pressure
- Angular coverage
 - 2π in ϕ
 - 21 pad rows hit for $|\cos\theta| \leq 0.8$
 - At least 3 pad rows for $|\cos\theta| \leq 0.97$

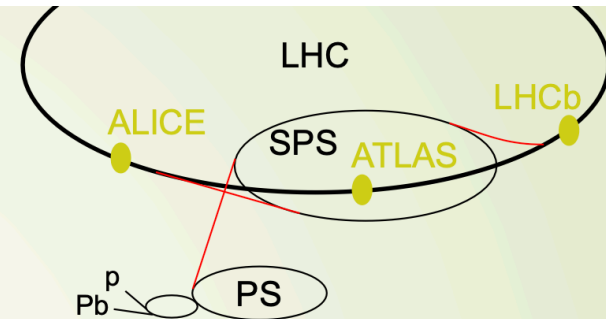




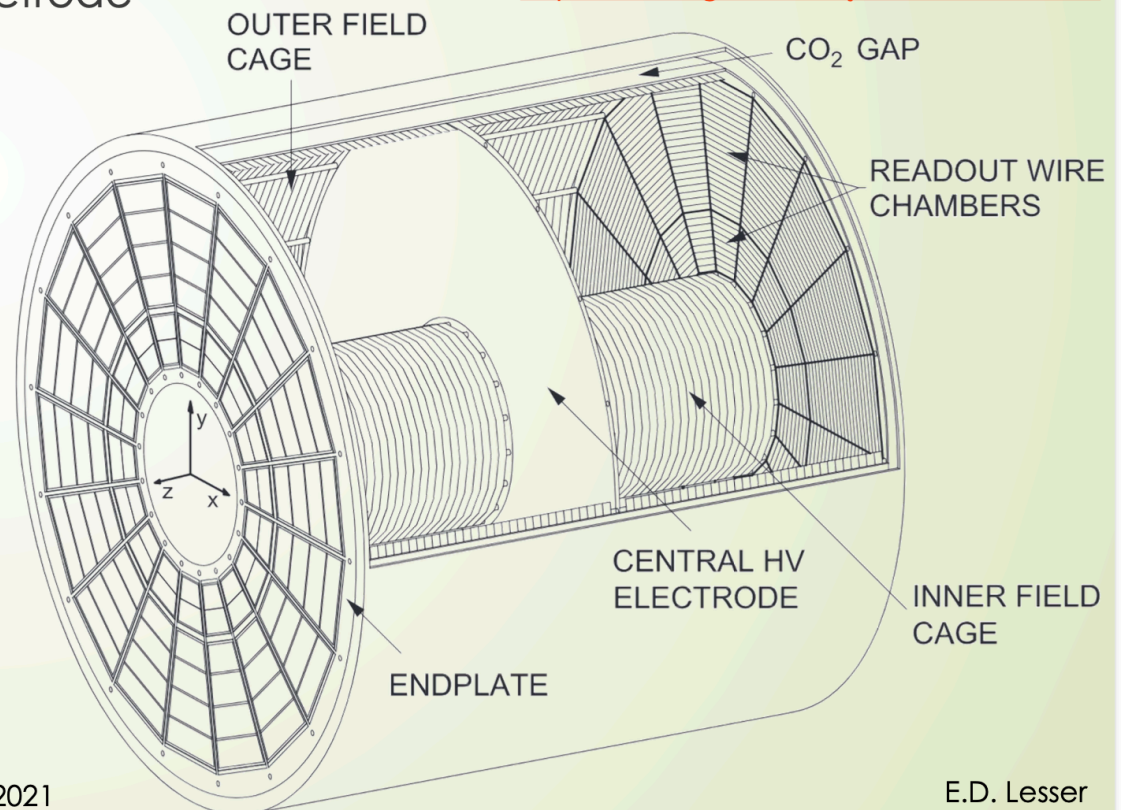
ALICE TPC [4] [5]

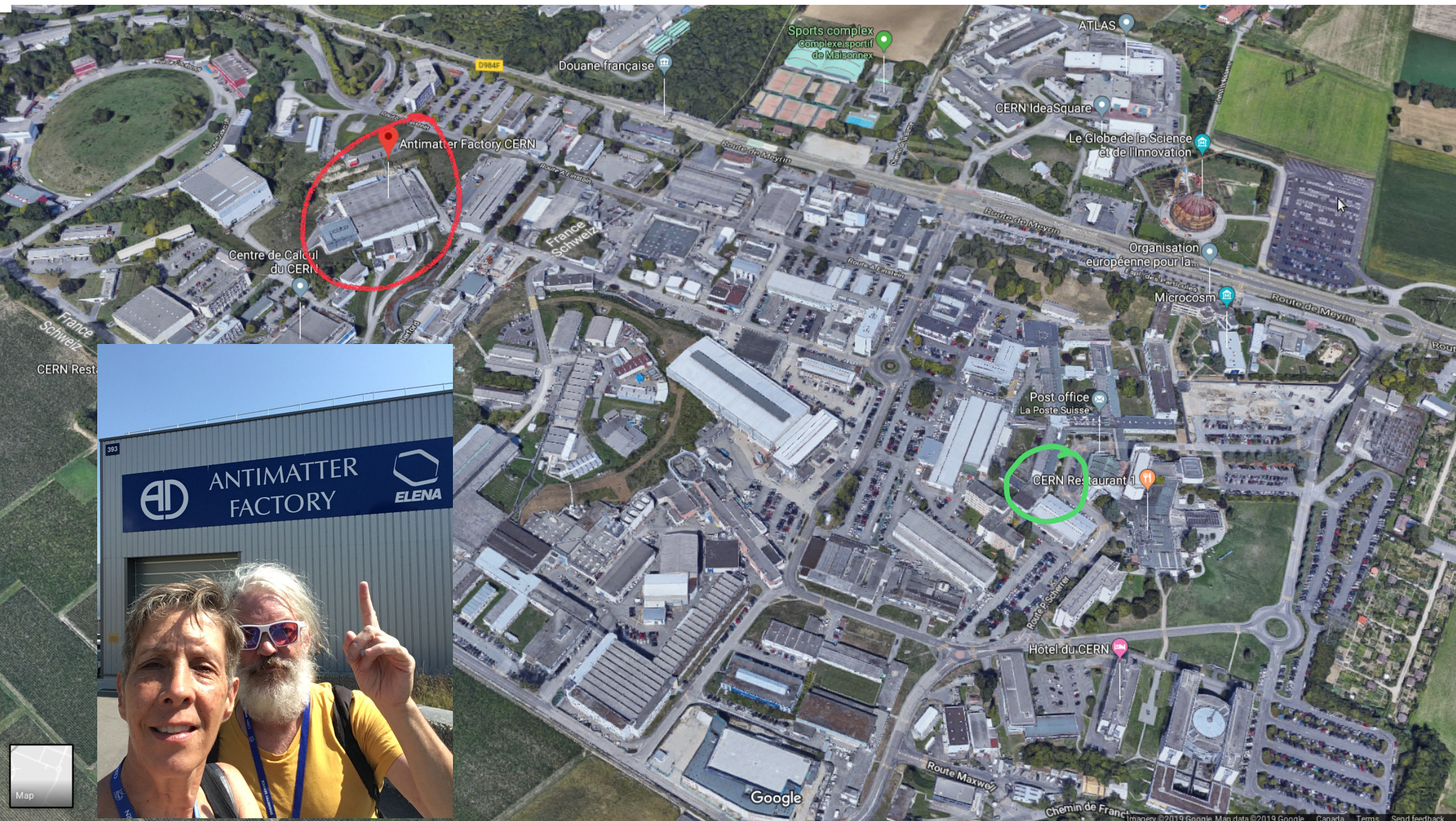


- Dimensions: 5 m length, 2.5 m radius $\rightarrow$ 88 m³ of Ne/CO₂/N₂ (90-10-5) gas mixture
- High voltage: -100 kV at a central electrode (400 V/cm throughout)
- Total drift time: 92 μ s
- End-cap detectors: 32 m² with 557 568 readout pads
- Gain: $> 10^4$
- Diffusion: $\sigma_{\perp} = 250 \mu\text{m}$
- Resolution: $\sigma_x \approx 0.2 \text{ mm}$; $\sigma_p/p \approx 1\% p$; $\sigma_{dE/dx} / (dE/dx) \approx 5\%$
- Magnetic field: $|\vec{B}| = 0.5 \text{ T}$
- Temperature control: $dT < 0.1 \text{ K}$

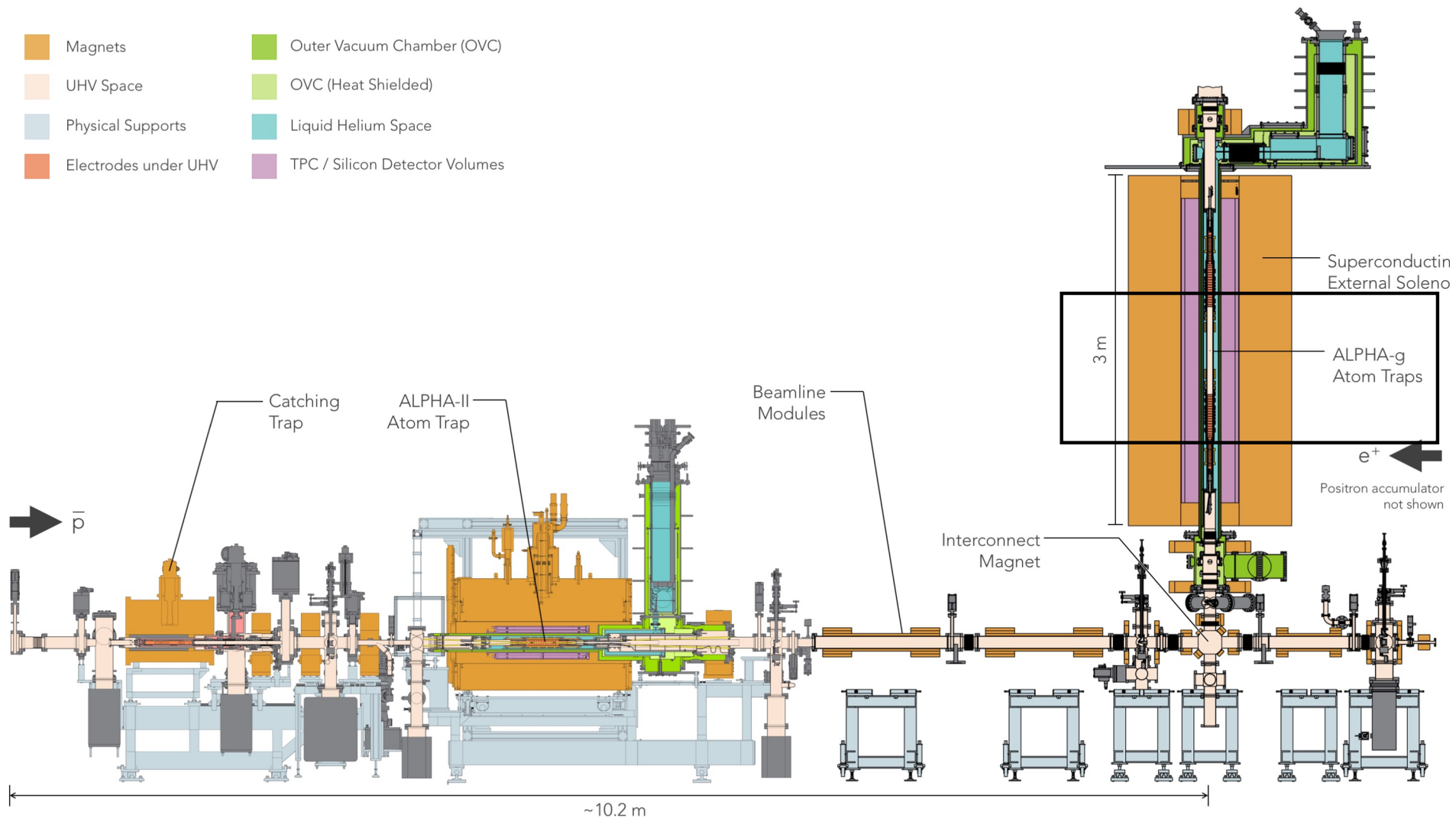


[5] <https://doi.org/10.1016/j.nima.2010.04.042>



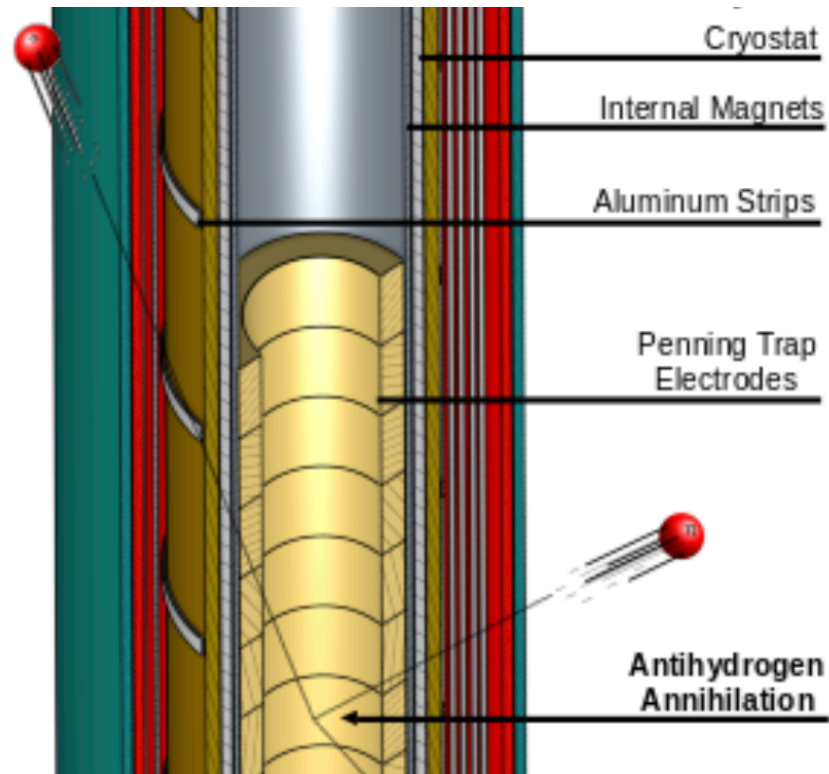
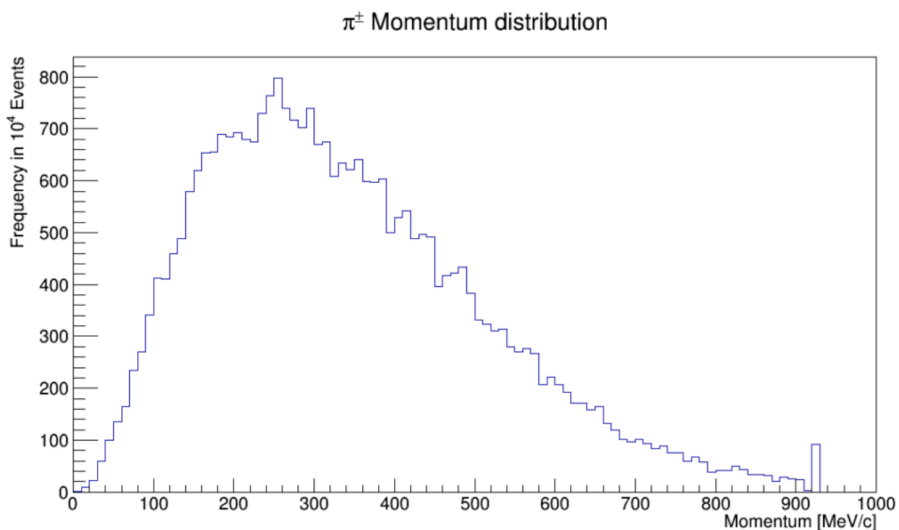


ALPHA Antihydrogen Trapping Experiments @ CERN AD



The antiproton in the antihydrogen annihilates with a nucleon (proton or neutron) in the trap wall producing charged and neutral pions.

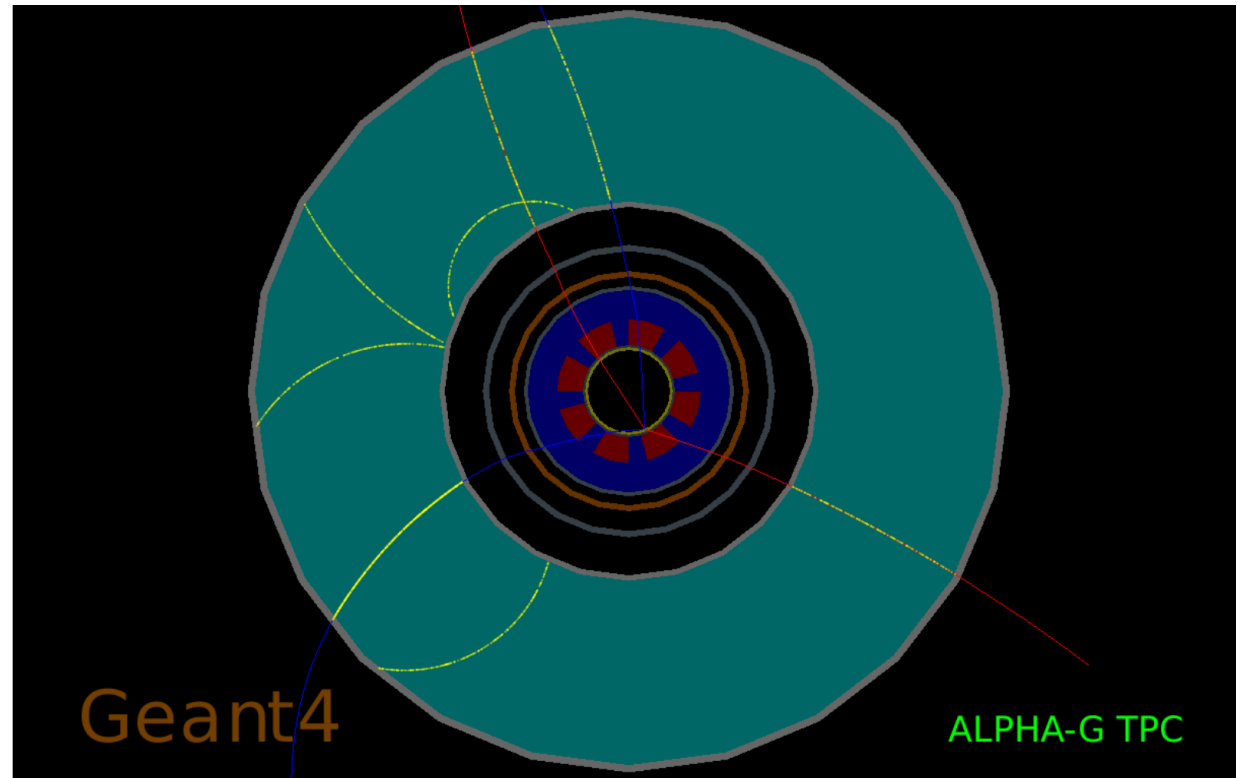
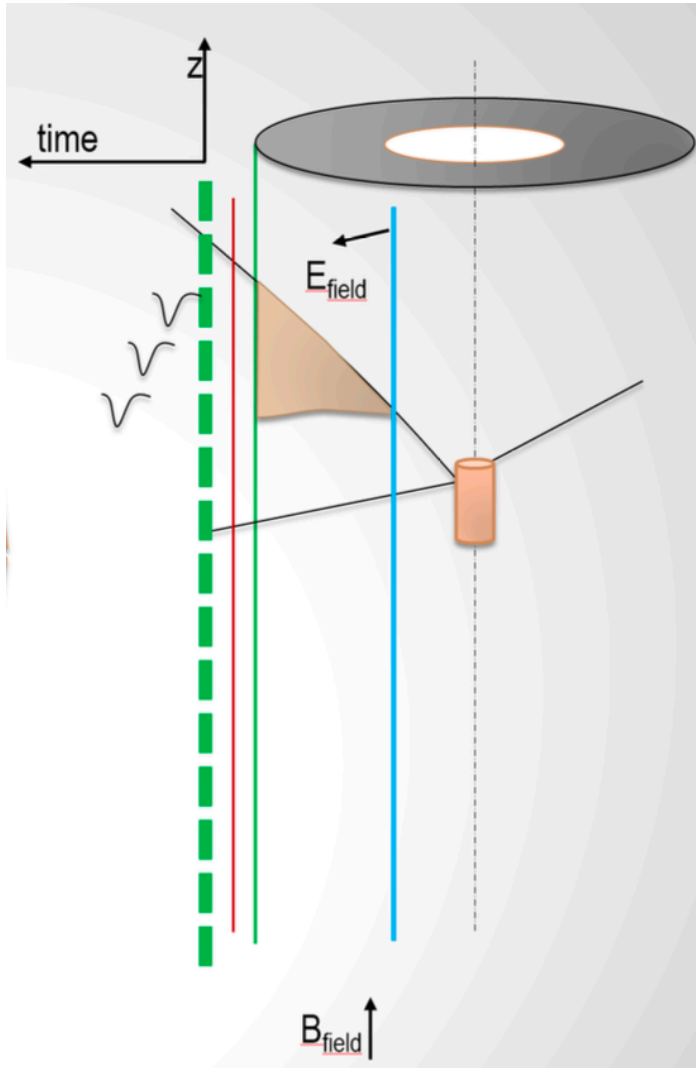
For example : $\bar{p}n \rightarrow \pi^+\pi^-\pi^-\pi^0$



Unfortunately there's lots of material between annihilation point and first potential tracking layer — multiple scattering dominates position resolution.

Limited to ~3 mm in z (up/down) direction

Solution: use a wire chamber. Choice for ALPHA-g — radial TPC

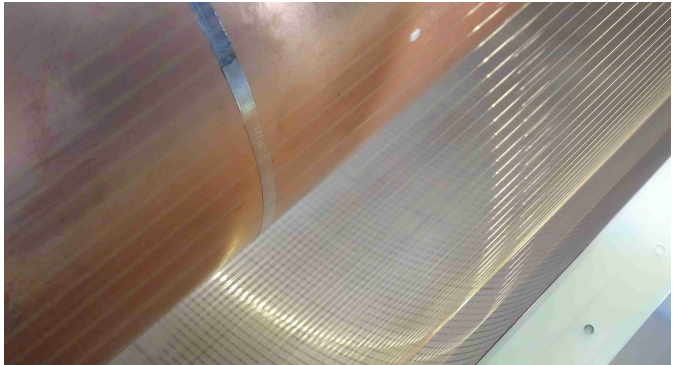
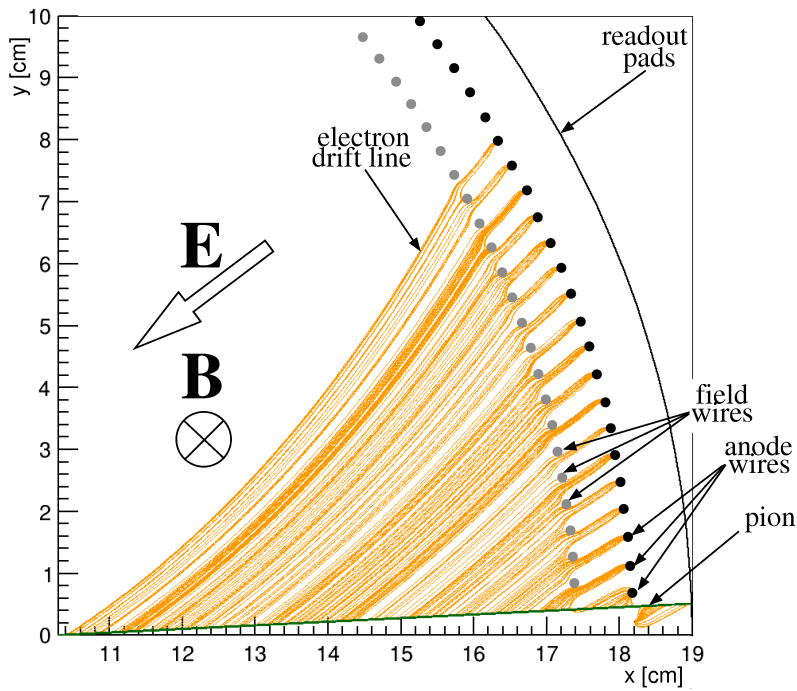


The radial Time Projection Chamber (rTPC)

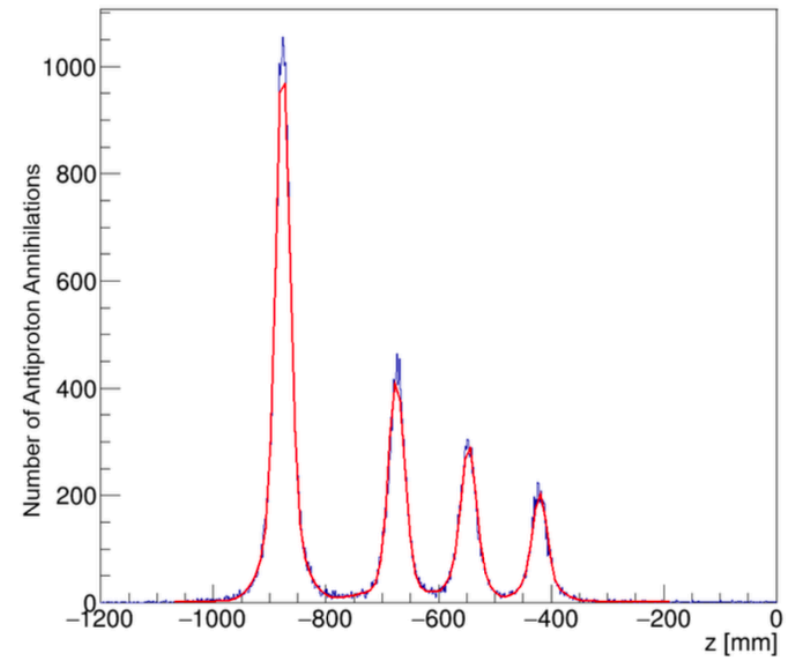
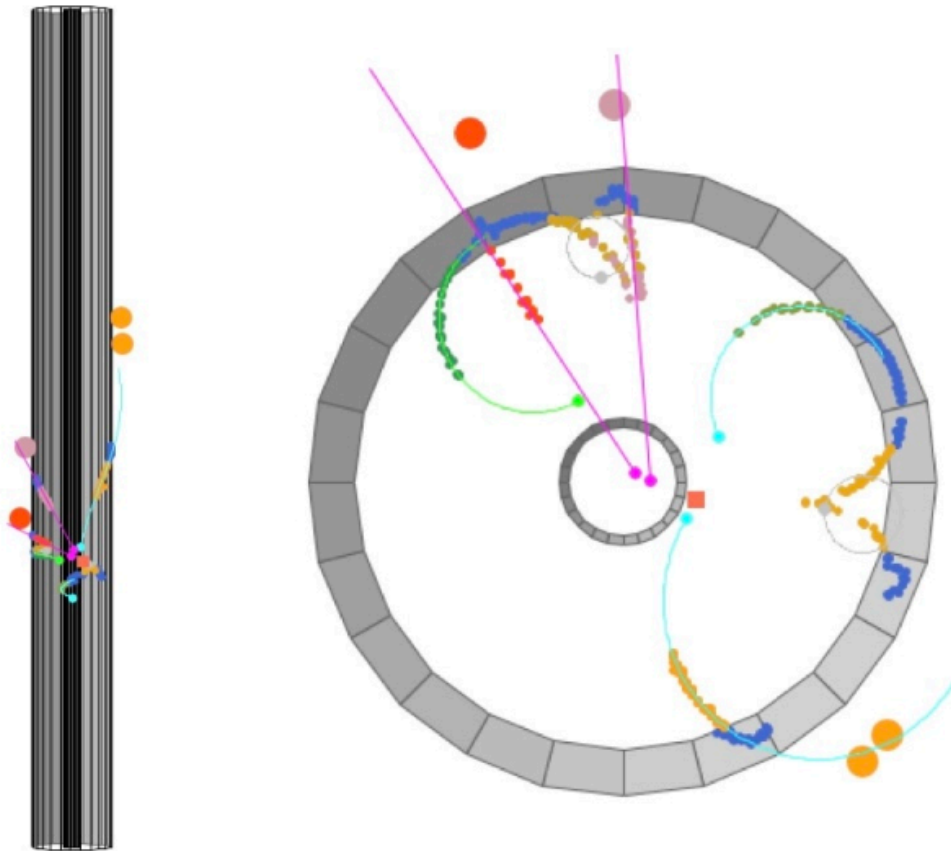


- 2.3 m long, 20 cm inner diameter, 40 cm outer diameter
- 256 wires, 18,432 pads
- Resolutions:
 - ~ 5 mm in z
 - ~ 9 mm in r
 - $\sim 18^\circ$ in azimuth

inner cathode	-4000 V
field wires	-100 V
anode wires	+3200 V
outer cathode	ground

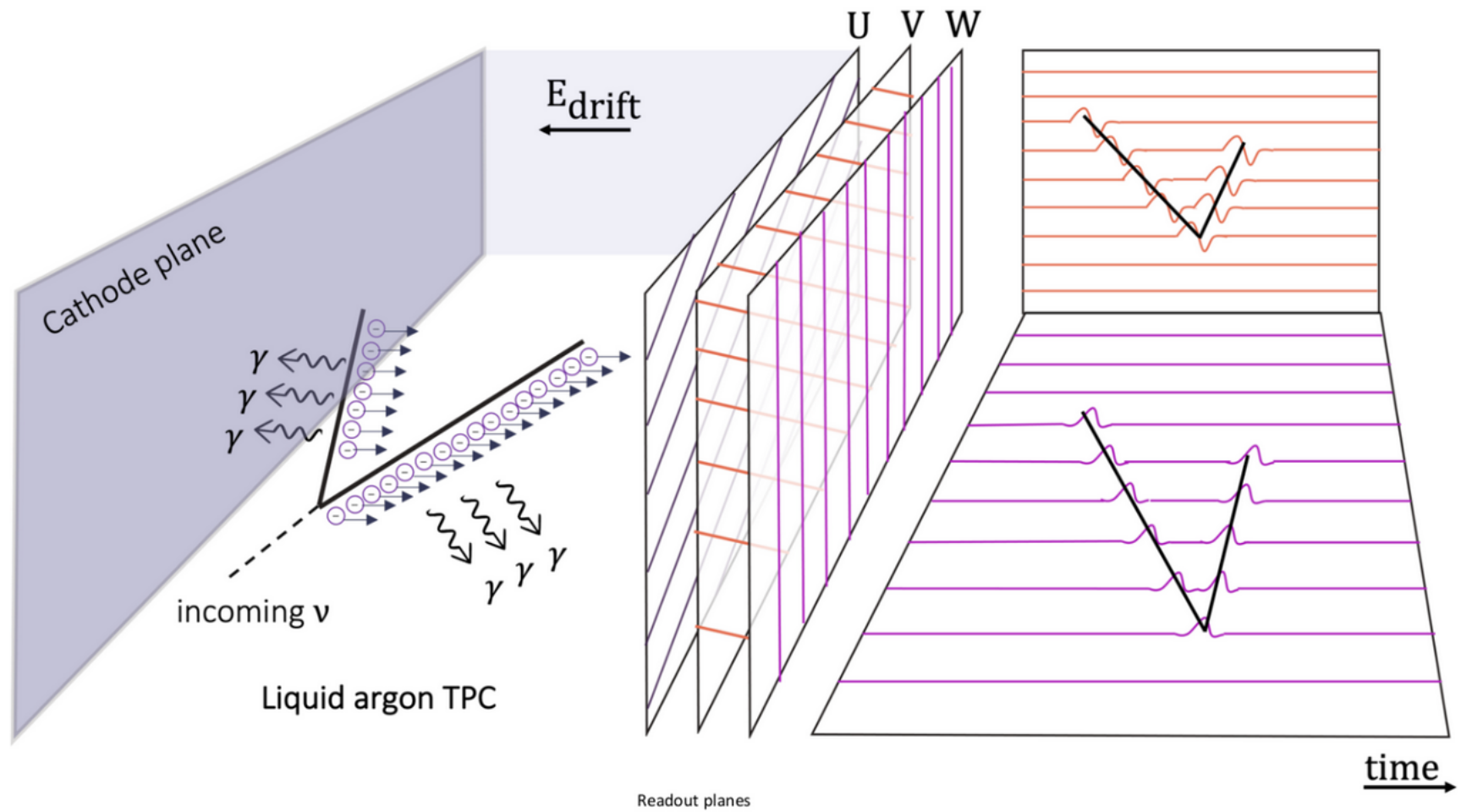


Reconstructed event in ALPHA



Reconstructed vertex position
for antiprotons trapped at
selected electrodes

Liquid Argon TPC



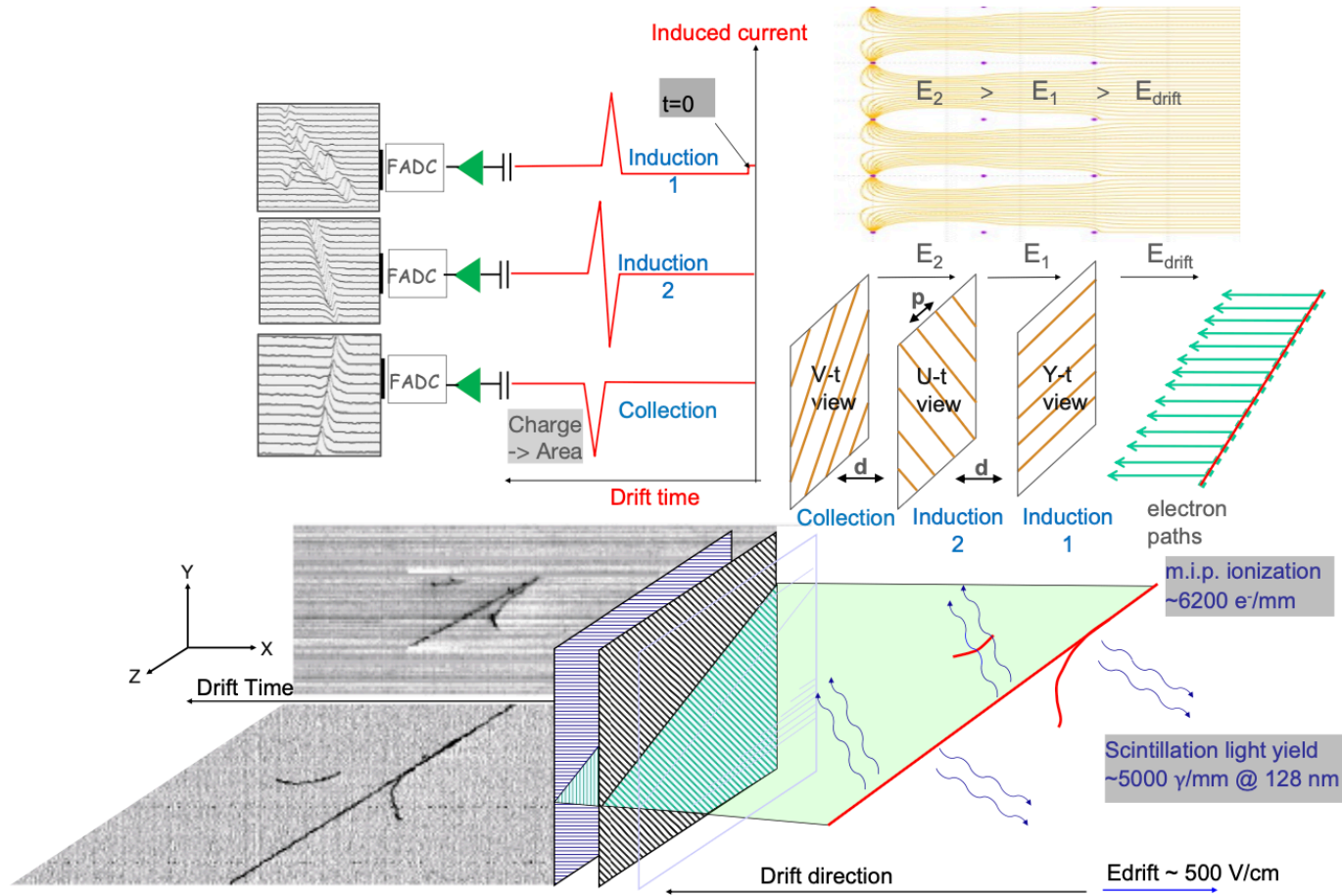


Figure 35.23: Schematic of an event in the ICARUS 3 t LAr TPC; *Top (from right to left):* field lines from drift region to collection wires, electron flow & arrangement of wire-planes, signal shapes on the wires, and wave-forms from the continuous readout and digitization; *Bottom:* the passage of a muon. The gray scale on the track indicates the ionization density.

Credit: PDG review

A Large Liquid Argon Time Projection Chamber for Long-baseline, Off-Axis
Neutrino Oscillation Physics with the NuMI Beam

Submission to NuSAG

September 15, 2005

D. Finley, D. Jensen, H. Jostlein, A. Marchionni, S. Pordes, P. A. Rapidis

Fermi National Accelerator Laboratory, Batavia, Illinois

C. Bromberg

Michigan State University

C. Lu, K. T. McDonald

Princeton University

H. Gallagher, A. Mann, J. Schneps

Tufts University

D. Cline, F. Sergiampietri, H. Wang

University of California at Los Angeles

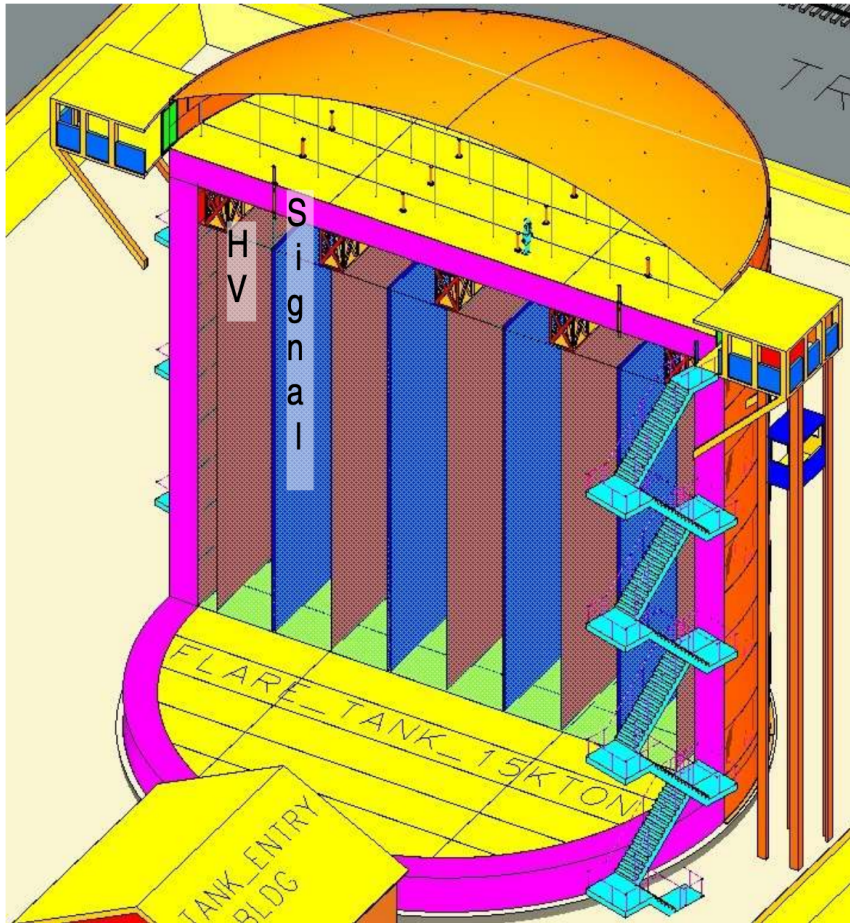
A. Curioni, B. T. Fleming

Yale University

S. Menary

York University

Engineering has begun on a large multi- kton Device



A 15 kton Device

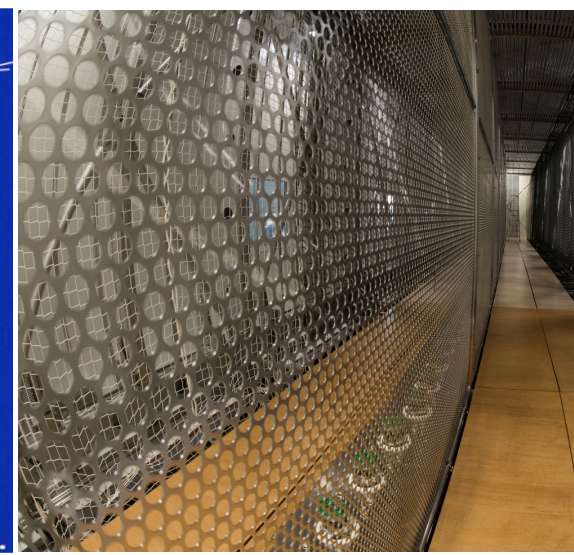
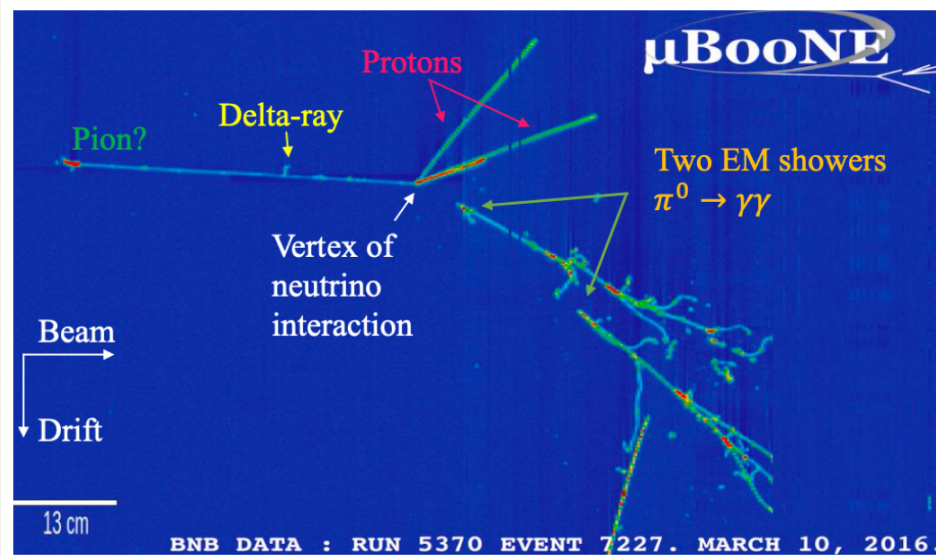
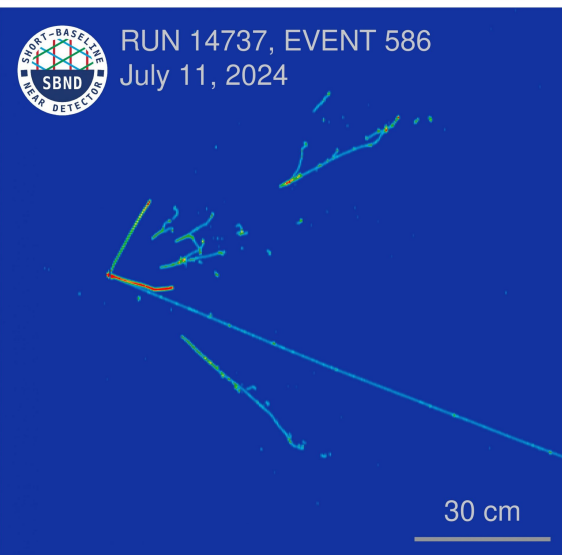
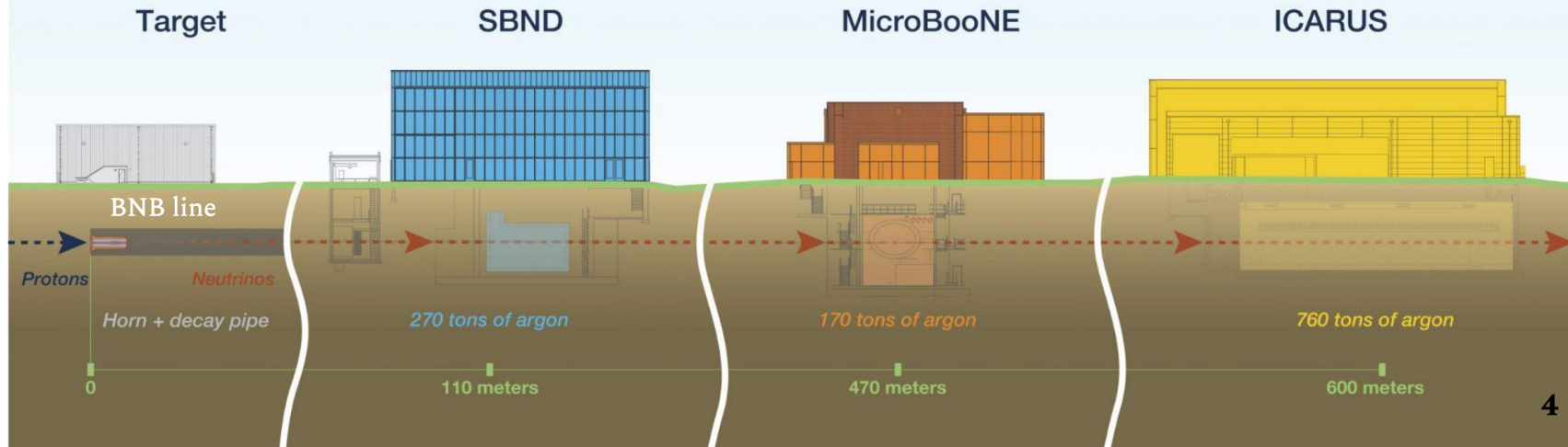
Inner tank dimensions:

26 m diameter by 21 m height

Changes from standard LNG tank:

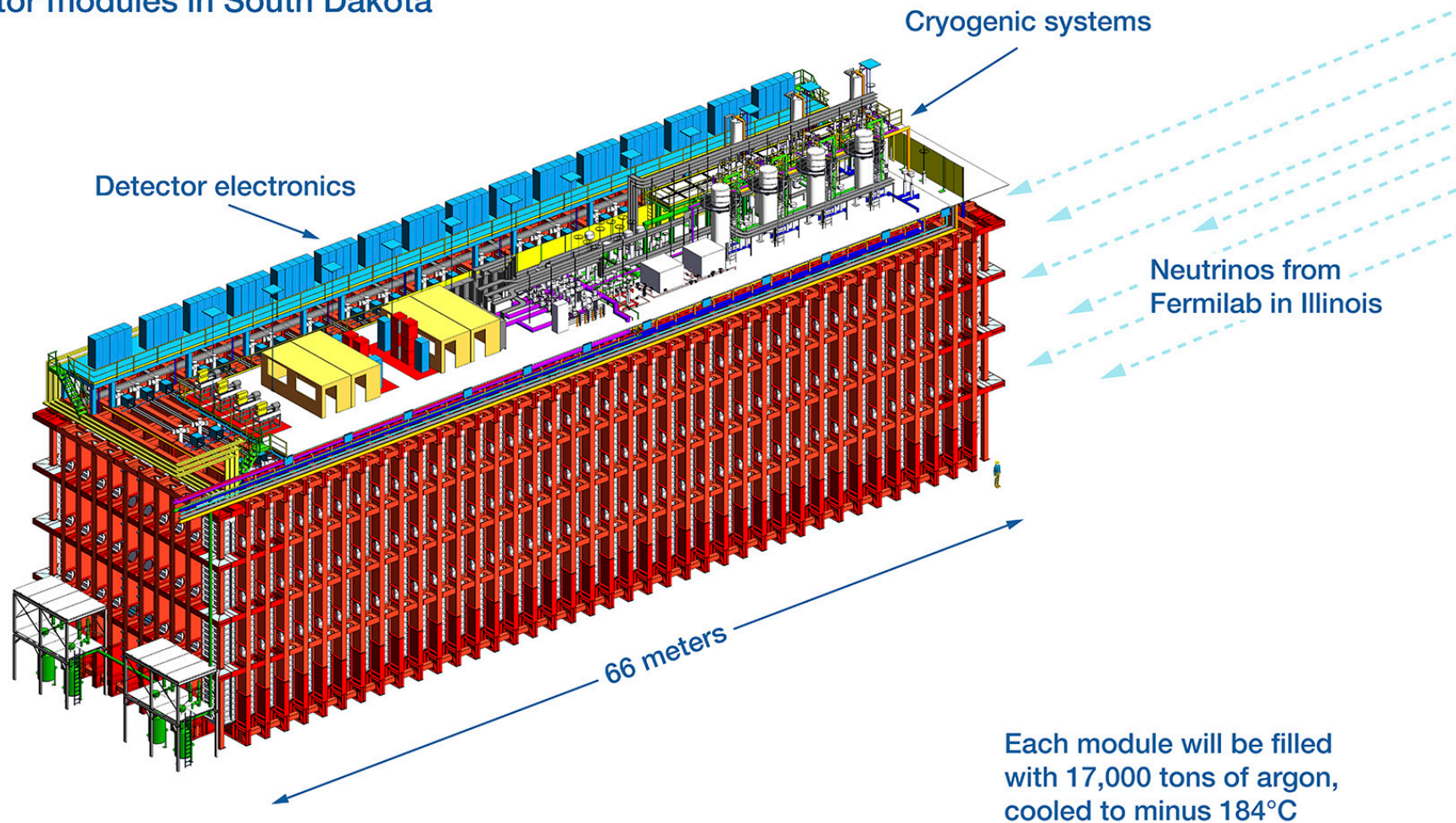
- *inner tank wall thickness increased*
 - *LAr is 2 x density of LNG;*
- *trusses in inner tank to take load of the wires;*
- *penetrations for signals from inner tank to floor supported from roof of outer tank,*

The Short Baseline Neutrino Program



Deep Underground Neutrino Experiment

One of four detector modules in South Dakota



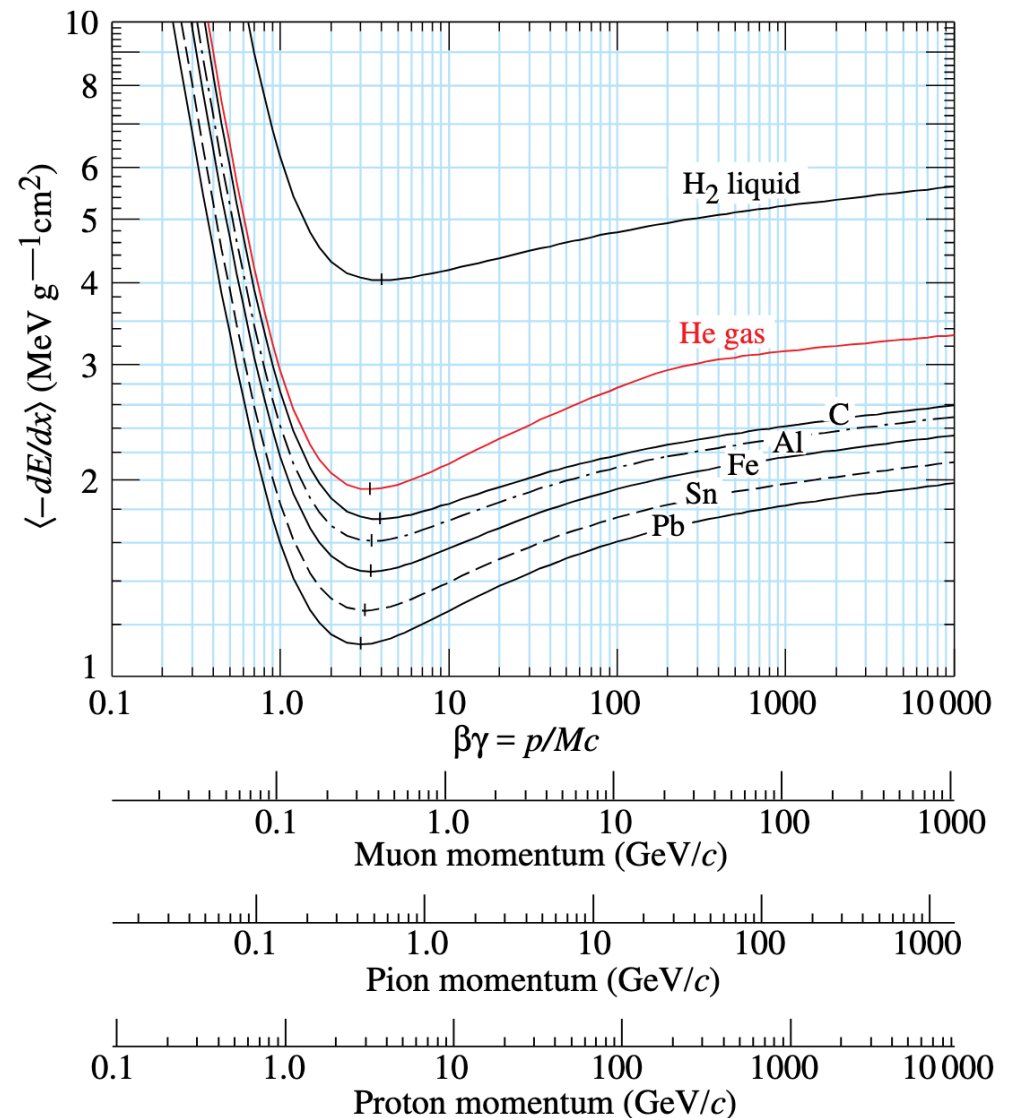
Detector located 1.5 kilometers underground at Sanford Lab

Particle ID via dE/dx

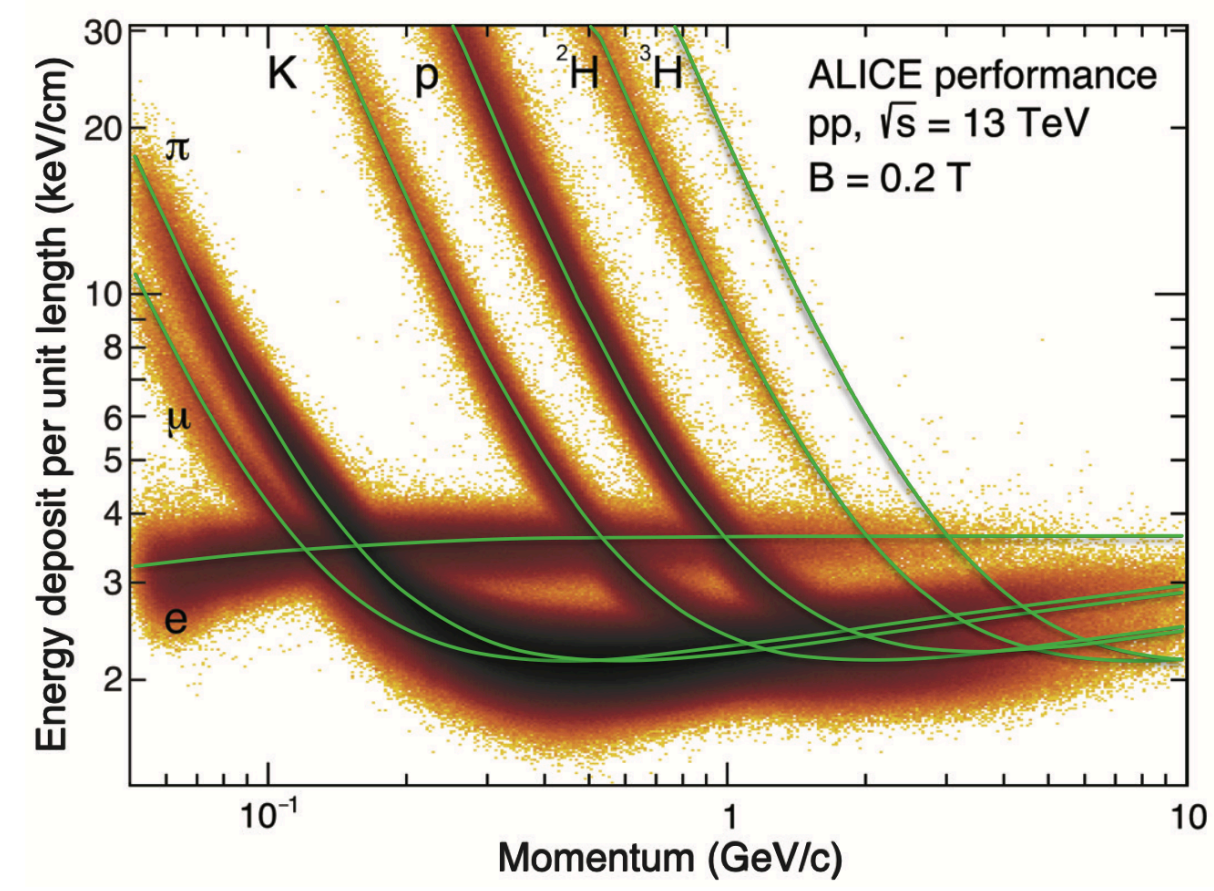
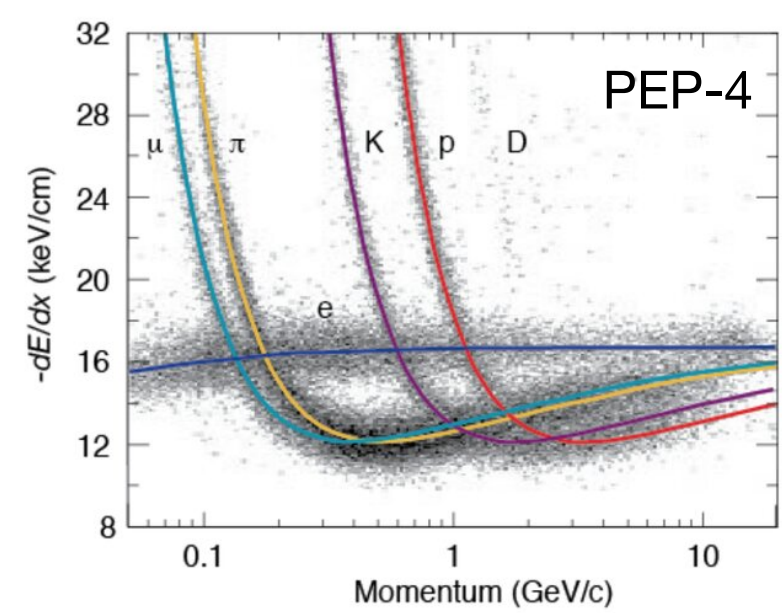
Energy loss (Bethe-Bloch)

$$-\frac{dE}{dx} = Kz^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\ln \frac{2mv^2}{J(1-\beta^2)} - \beta^2 - \frac{\delta}{2} \right]$$

m mass of electron
 z, v charge and velocity of incident particle
 J mean ionization energy
 δ density effect term



Good for differentiating pion, kaon, and proton tracks in the ~100 MeV to ~800 MeV momentum range



Conclusions



Wire chambers have been a critical component of particle physics experiments for over 50 years (or I guess ~120 years if you count the Rutherford-Geiger tube) and continue to be used in experiments exploring a wide range of physics topics — from the Higgs to neutrinos to dark matter.

While silicon detectors offer much greater spacepoint precision, wire chambers continue to be useful due to their durability, efficiency, and low cost/volume.

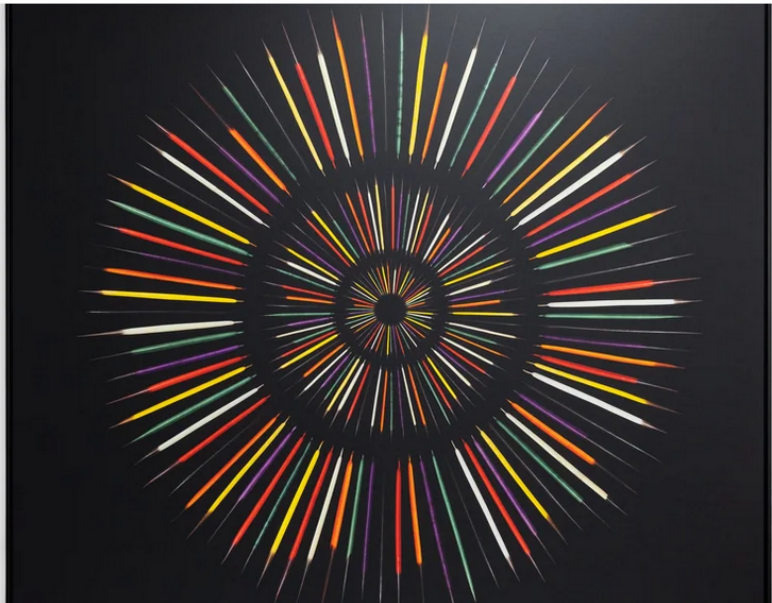
The capability to sample a track many times along its path allows, in conjunction with a magnetic field, measurements of charged particle momenta. Track segments from wire chambers are also utilized to augment decay vertex reconstruction.

Who knows but maybe wire chambers will be around for another 50 years!

Visual artist and plant scientist Daphne Boyer presents *Li bootee mishiwayitay — The Beauty of It All*, a powerful new exhibition that weaves together Métis peoples’ traditional handwork, digital technologies, plant materials, and porcupine quills.



Moss Bag Beading, 2021, 244 x 76 cm — 96 x 30"



My maternal grandmother Clémence was born on a hunting expedition and raised in an outpost by her hunter and trapper father and itinerant midwife mother. As a young woman, she served as a translator of Michif, Cree and French.

Clémence subsequently married a French colonist, claimed French identity and vehemently denied her Indigenous ancestry to protect her 15 children from racism and residential schools.

For Clémence is an imagined view out of a tipi smoke hole that reclaims grandma’s Métis identity. The work is inspired by the tipis set up by her First Nations friends at their summer camp close to her home in Meadow Lake, Saskatchewan.

The sharp quills represent Clémence’s tough, audacious character; the bold colours and ever-expanding concentric circles represent the growing power of younger generations to create a more inclusive, equitable society for all.