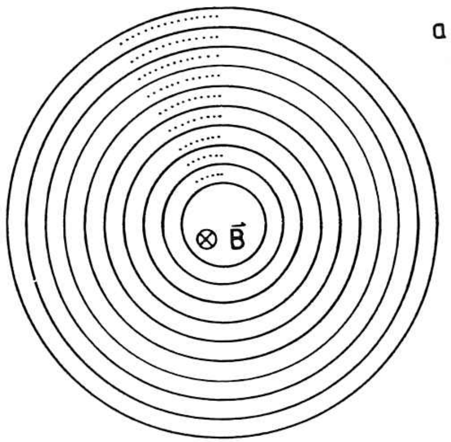
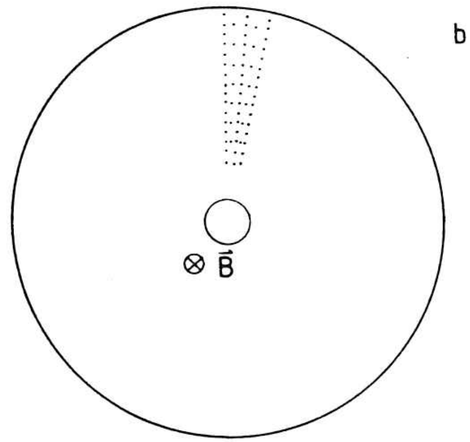
Different Realizations of Ionization Trackers

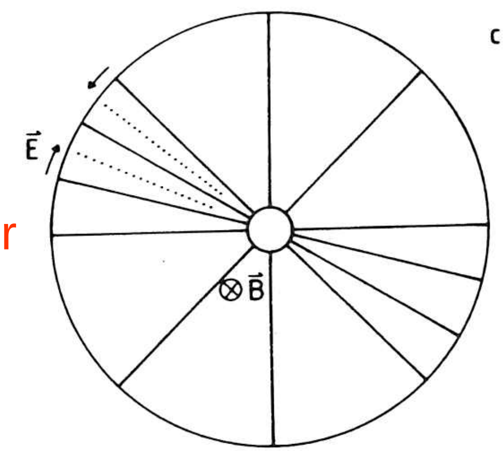
MWPC

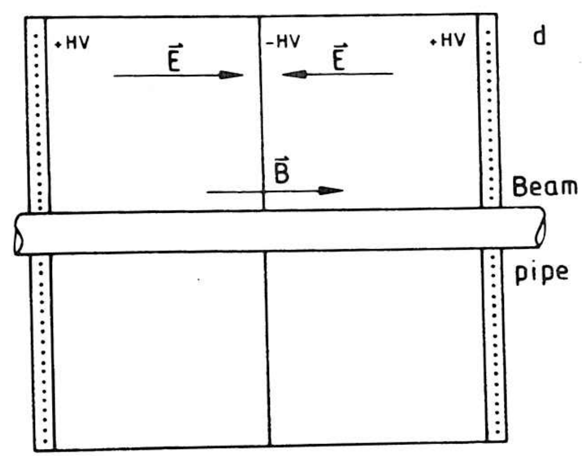




Drift Chamber

Jet Chamber





Time Projection Chamber

Drift Chamber Cell

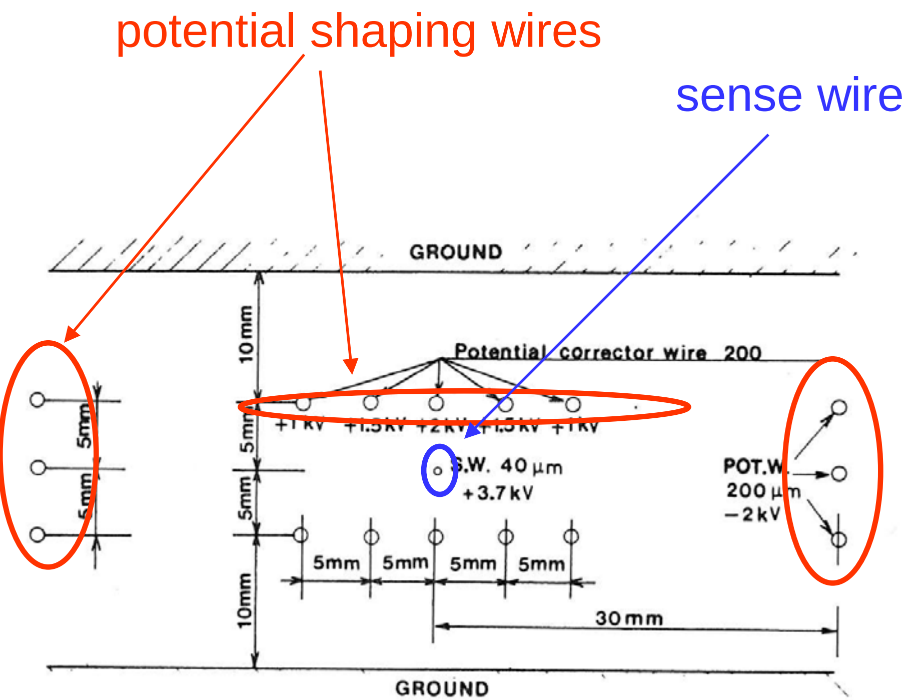


Fig. 11. Cell structure of large area drift chamber [MA 77].

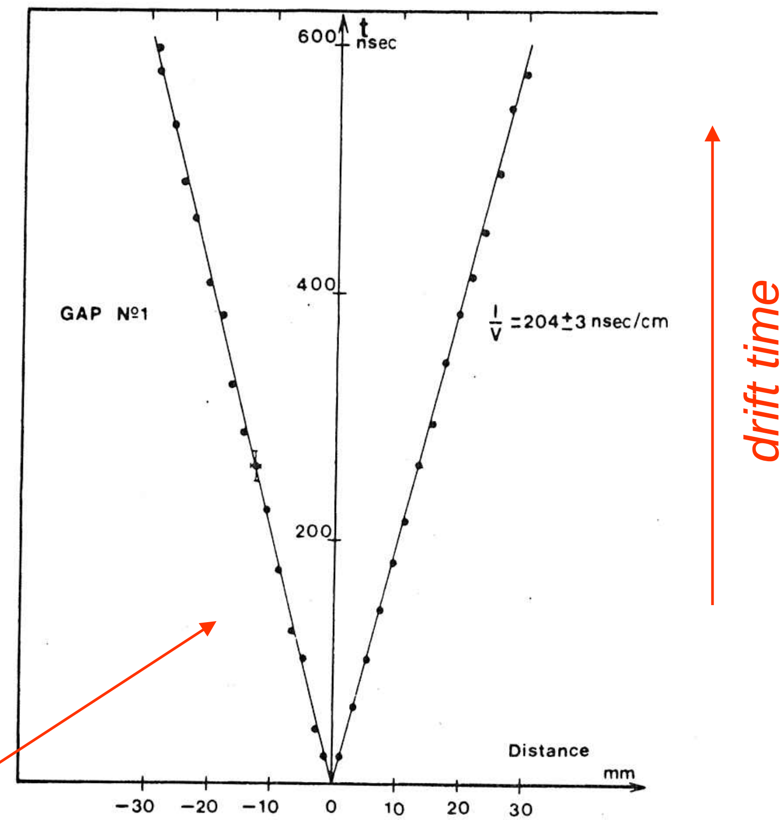
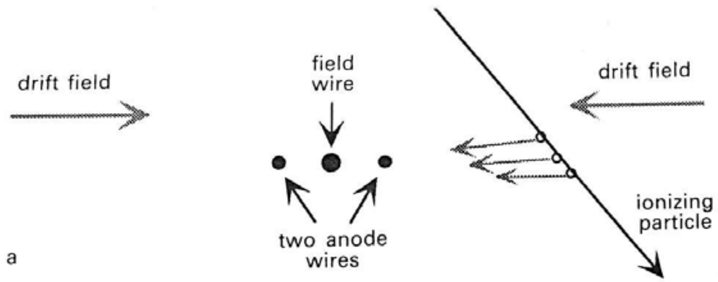


Fig. 12. Linear relation between drift time and position [MA 77].

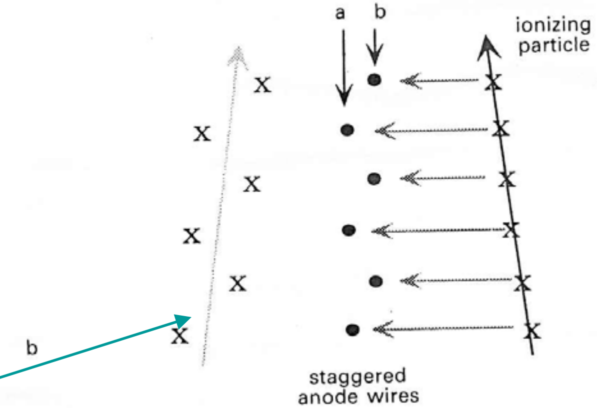
- Carefully shape potential (field lines)
- Optimize drift time – space relation

Left-Right Ambiguity Resolution

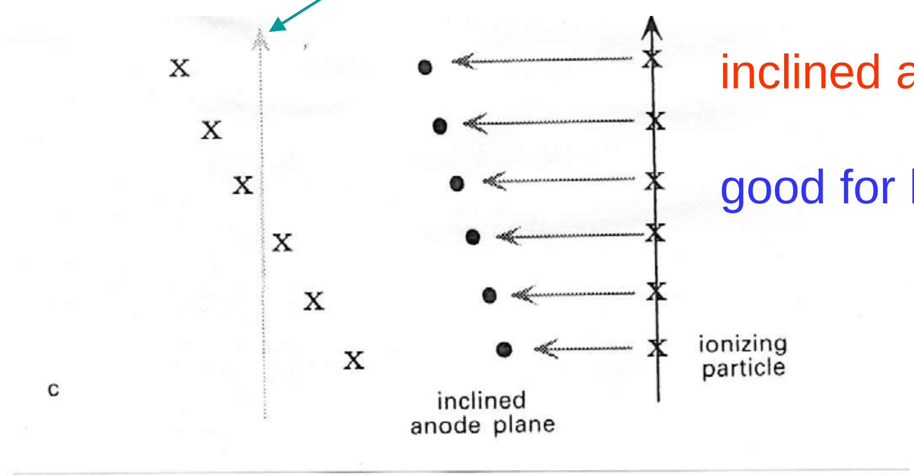
2 anode wires



staggered anode wires



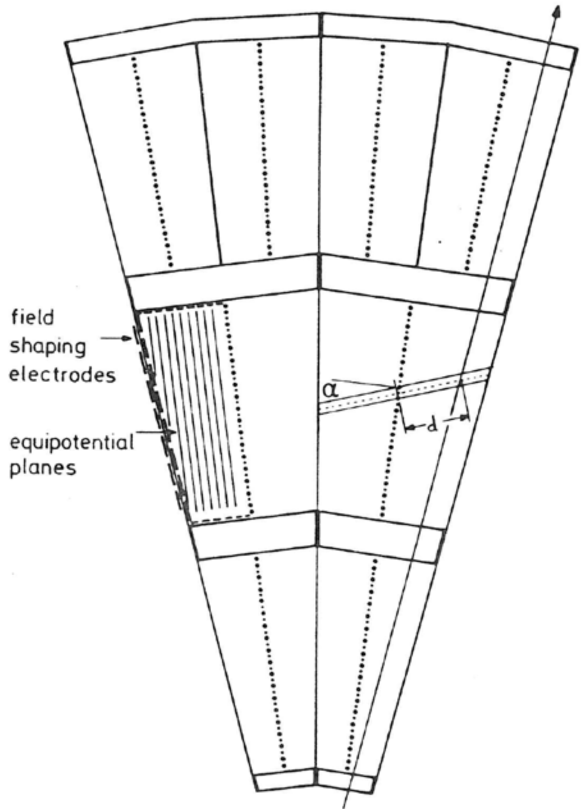
ghost track

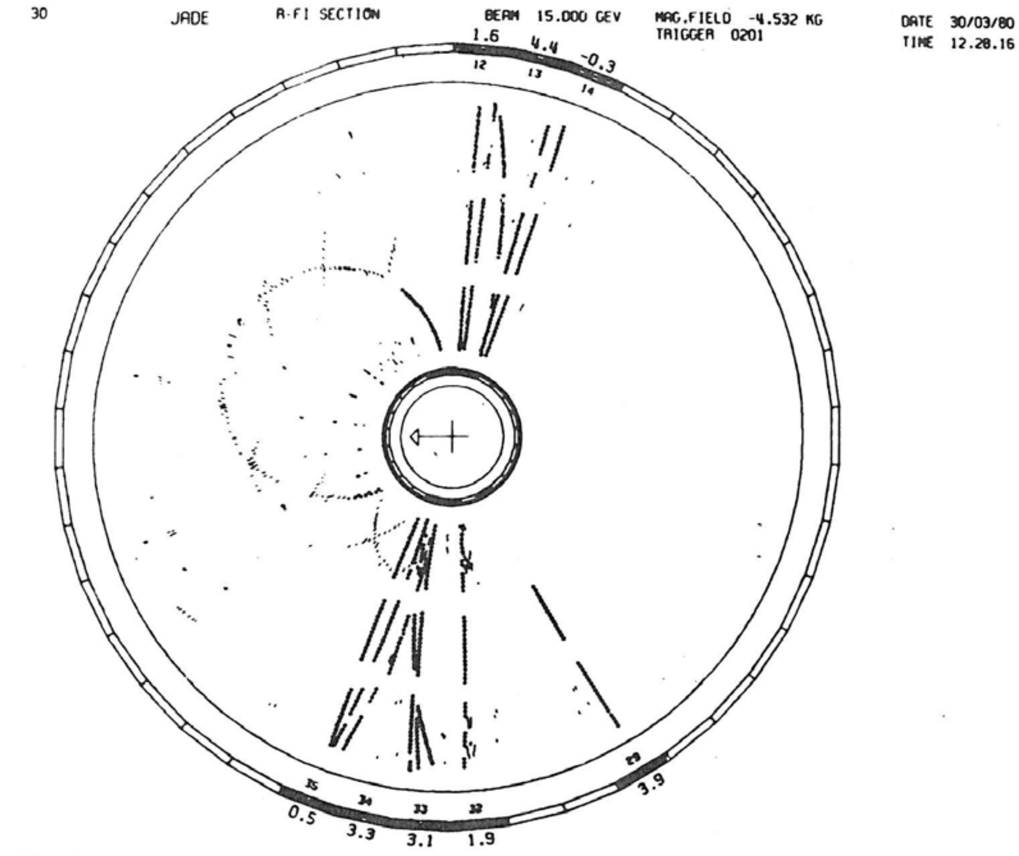


inclined anode plane

good for high magnetic field

Jet Chamber





e^+e^- annihilation at 30 GeV

Lorentz Angle – Drift Chamber in Magnetic Field

- Drifting electron will see

  Electric Field $\bar{E}$

  Magnetic Field $\bar{B}$

$$m\dot{\bar{v}} = q\left(\bar{E} + \bar{v} \times \bar{B}\right)$$

- Will also see stochastic force due to collisions with gas molecules

$$m\dot{\bar{v}} = q\left(\bar{E} + \bar{v} \times \bar{B}\right) + mA(t)$$

- Assume over time

$\bar{E}, \bar{B}$ acceleration = stochastic retardation

constant v_D

$$\dot{\bar{v}}_D = 0 = \frac{q\bar{E}}{m} + \left(\bar{v}_D \times \frac{q\bar{B}}{m}\right) - \left\langle A(t) \right\rangle$$

$$A(t) \to \frac{v_D}{\tau}$$ *mean time between collisions*

$$\frac{\bar{v}_D}{\tau} - \left(\bar{v}_D \times \frac{q\bar{B}}{m}\right) = \frac{q\bar{E}}{m}$$

solution:

(1) (3) (2)

$$\bar{v}_D = \frac{\mu}{1+\omega^2\tau^2}\left(\bar{E} + \frac{\bar{E} \times \bar{B}}{B}\omega\tau + \frac{\left(\bar{E} \bullet \bar{B}\right) \bullet \bar{B}}{B^2}\omega^2\tau^2\right)$$

$$\mu = \frac{q\tau}{m}$$ *electron mobility*

$$\omega = \frac{q\bar{B}}{m}$$ *cyclotron frequency*

Lorentz Angle – Drift Chamber in Magnetic Field

solution:

$$\overline{v}_D = \frac{\mu}{1+\omega^2\tau^2}\left(\underset{(1)}{\overline{E}} + \underset{(3)}{\frac{\overline{E}\times\overline{B}}{B}\omega\tau} + \underset{(2)}{\frac{\left(\overline{E}\bullet\overline{B}\right)\bullet\overline{B}}{B^2}\omega^2\tau^2} \right)$$

- Drift velocity has three components

  (1) parallel to $\overline{E}$

  (2) parallel to $\overline{B}$

  (3) perp to plane of $\overline{E}, \overline{B}$

- If $\overline{E}, \overline{B}$ perpendicular $\overline{E} = \left(E_x, 0, 0\right)$, $\overline{B} = \left(0, 0, B_z\right)$

$$v_x = \mu E_x \frac{1}{1+\omega^2\tau^2}$$

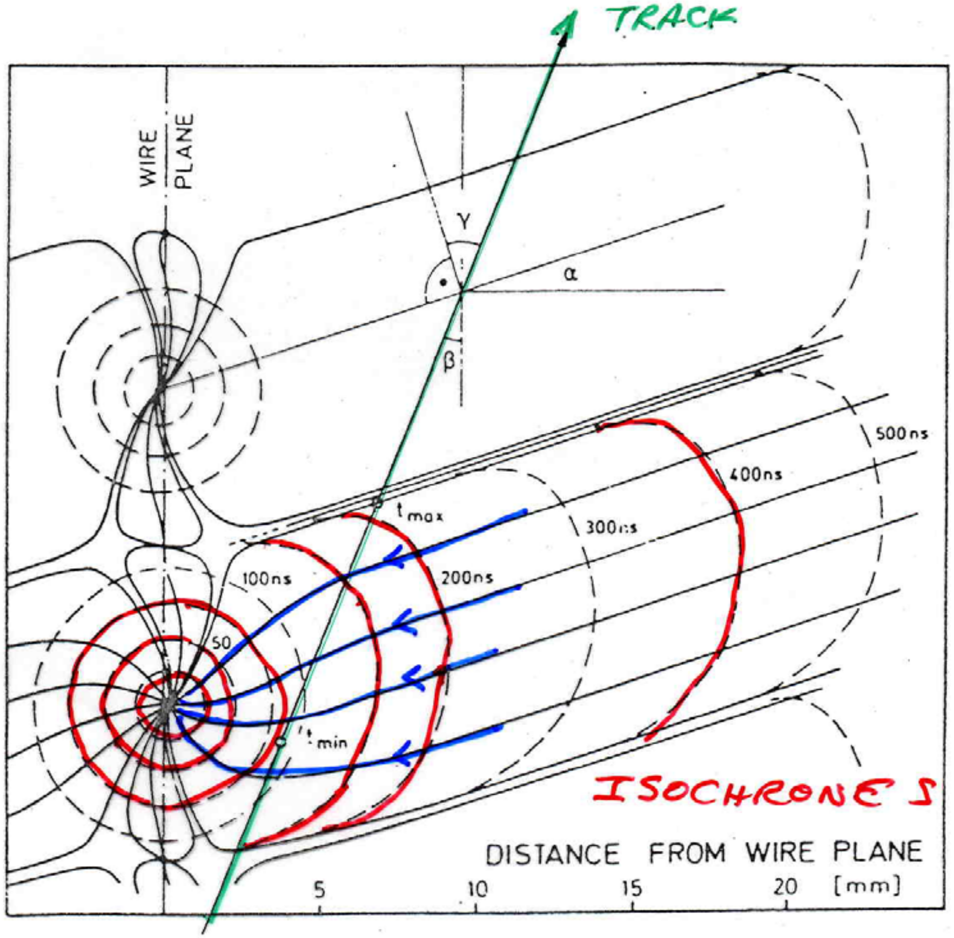
$$v_y = -\mu E_x \frac{\omega\tau}{1+\omega^2\tau^2}$$

$$v_z = 0$$

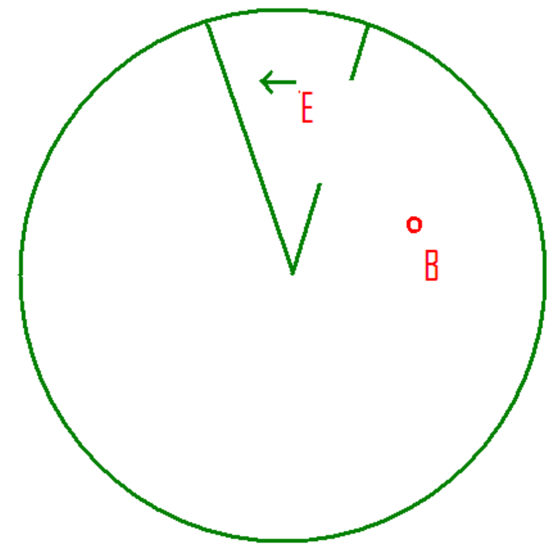
$$\tan\alpha = \omega\tau = \frac{v_y}{v_x}$$

$$\tan\alpha = \omega\tau = \frac{q\overline{B}}{m}\frac{m\mu}{q} = \mu B = \frac{v_D}{E}B$$

LORENTZ ANGLE

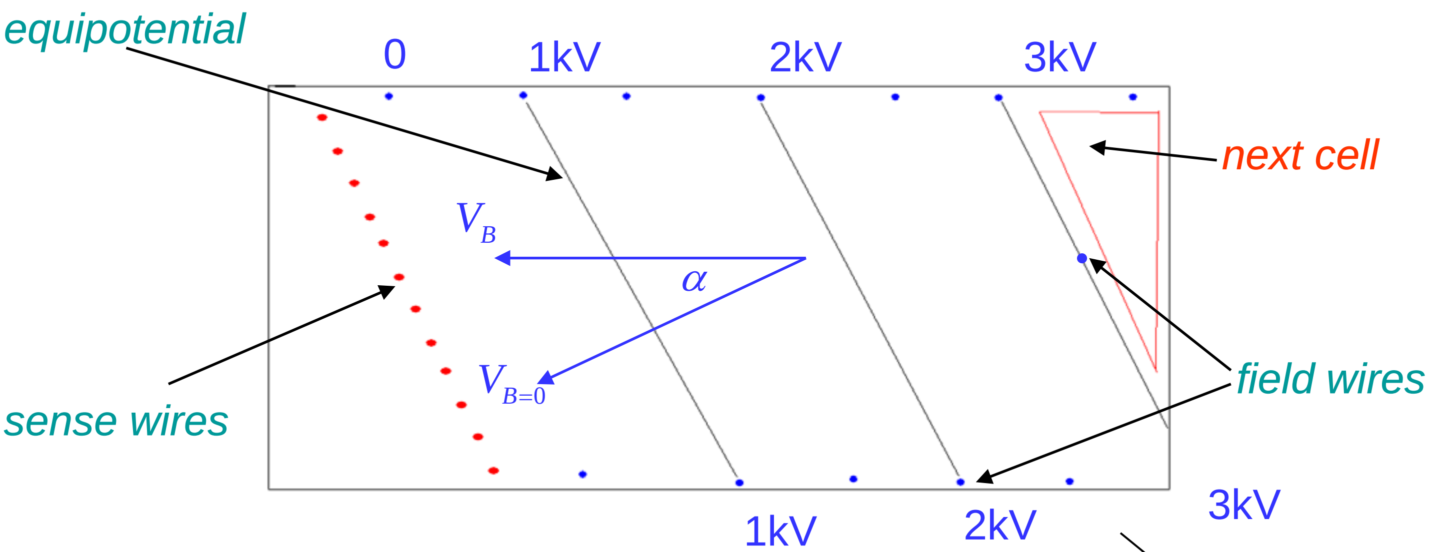


DRIFT PATH

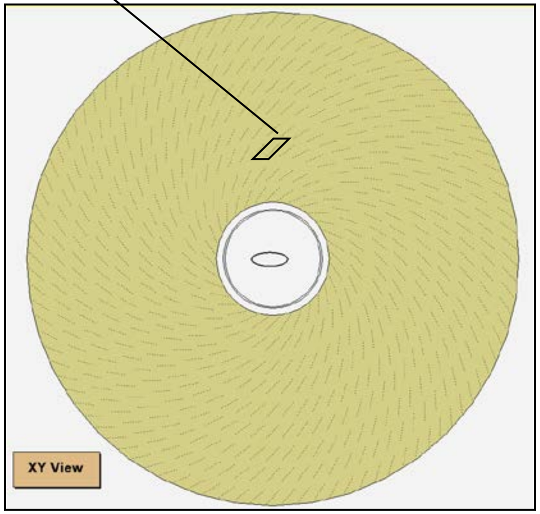


$\bar{E} \times \bar{B}$ v_{DRIFT} DEVIATES FROM ELECTRIC FIELD DIRECTION

$$\tan \alpha = \frac{v_D}{E} B$$



$$\tan\alpha = \frac{v_D}{E} B$$

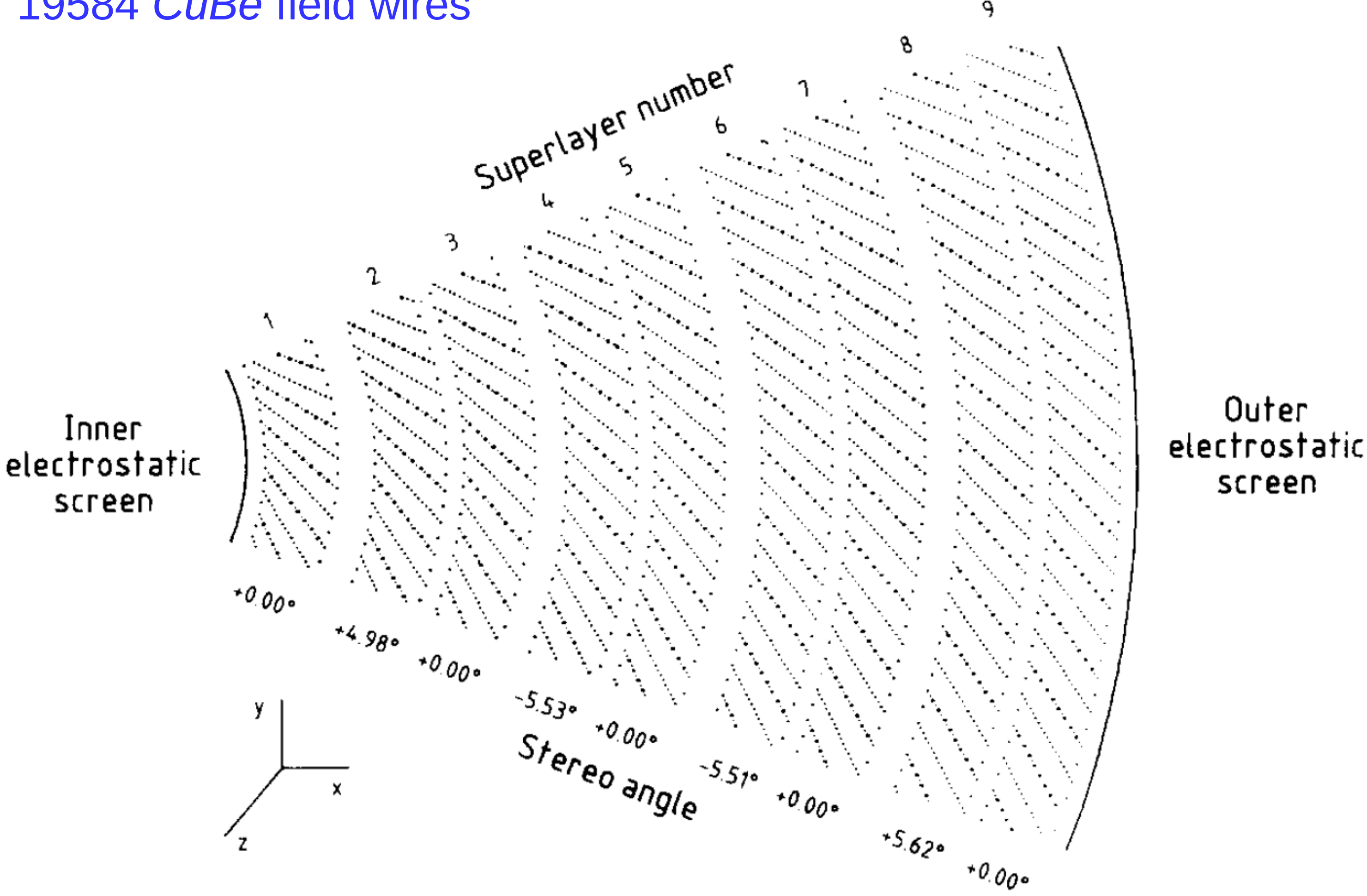


Compensate for Lorentz angle by tilting electric field in drift cells

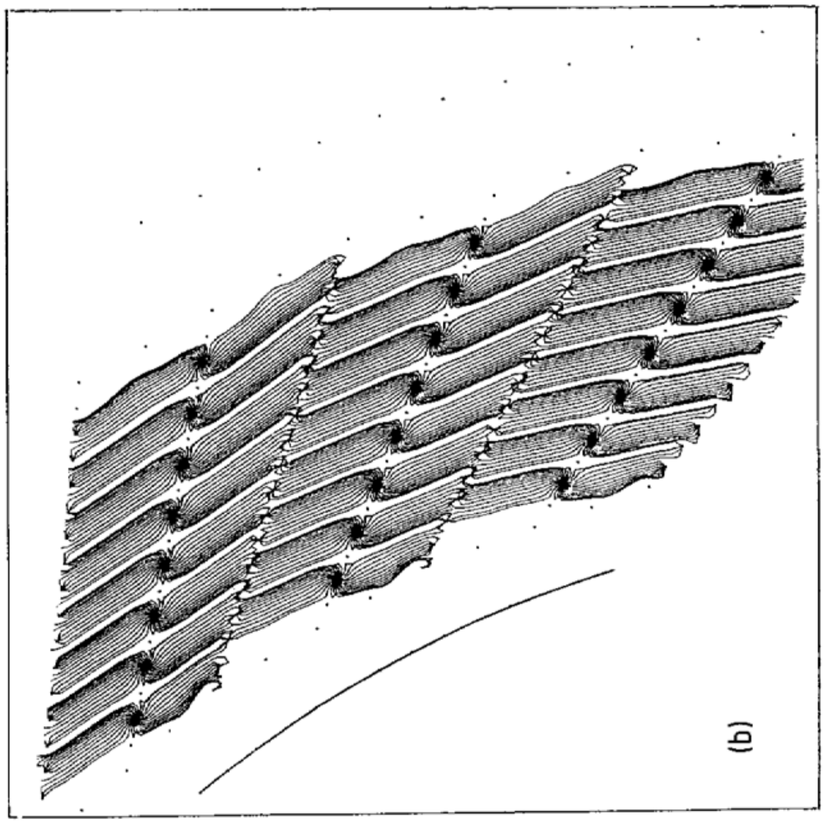
Structure of ZEUS DC

- Total wire tension 12 tons
- 4608 *W* sense wires (30 micron)
- 19584 *CuBe* field wires

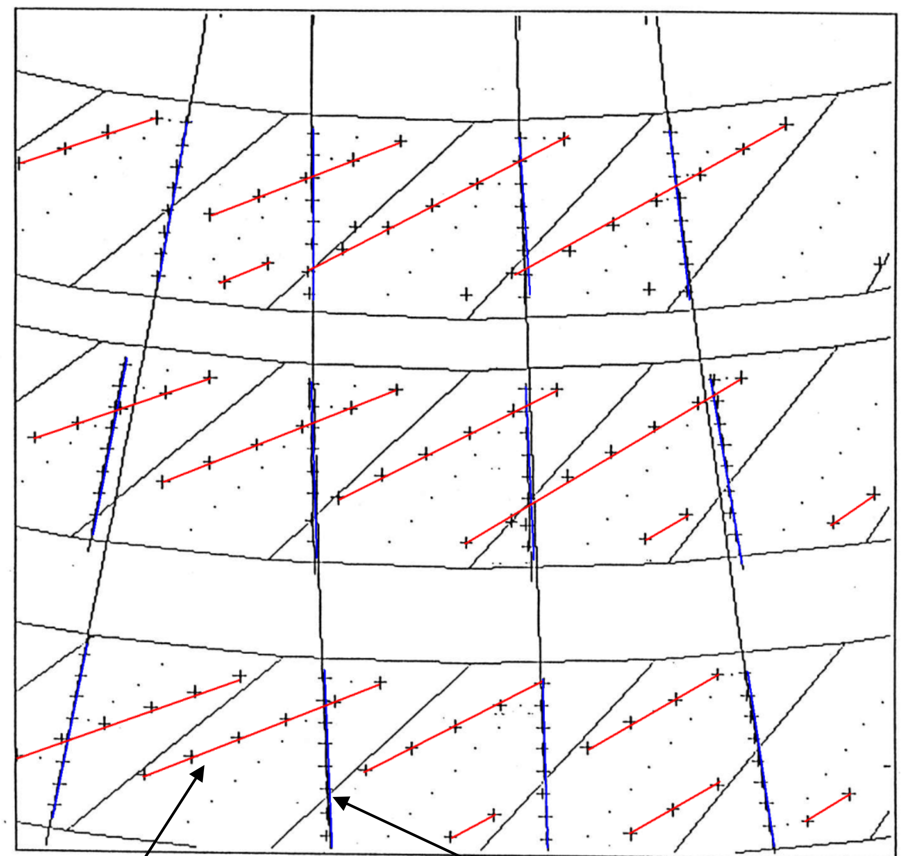
- 120 micron space resolution
- 2.5mm 2 track resolution
- 500 ns max drift time



Tilted E Field – R-L ambiguity resolution



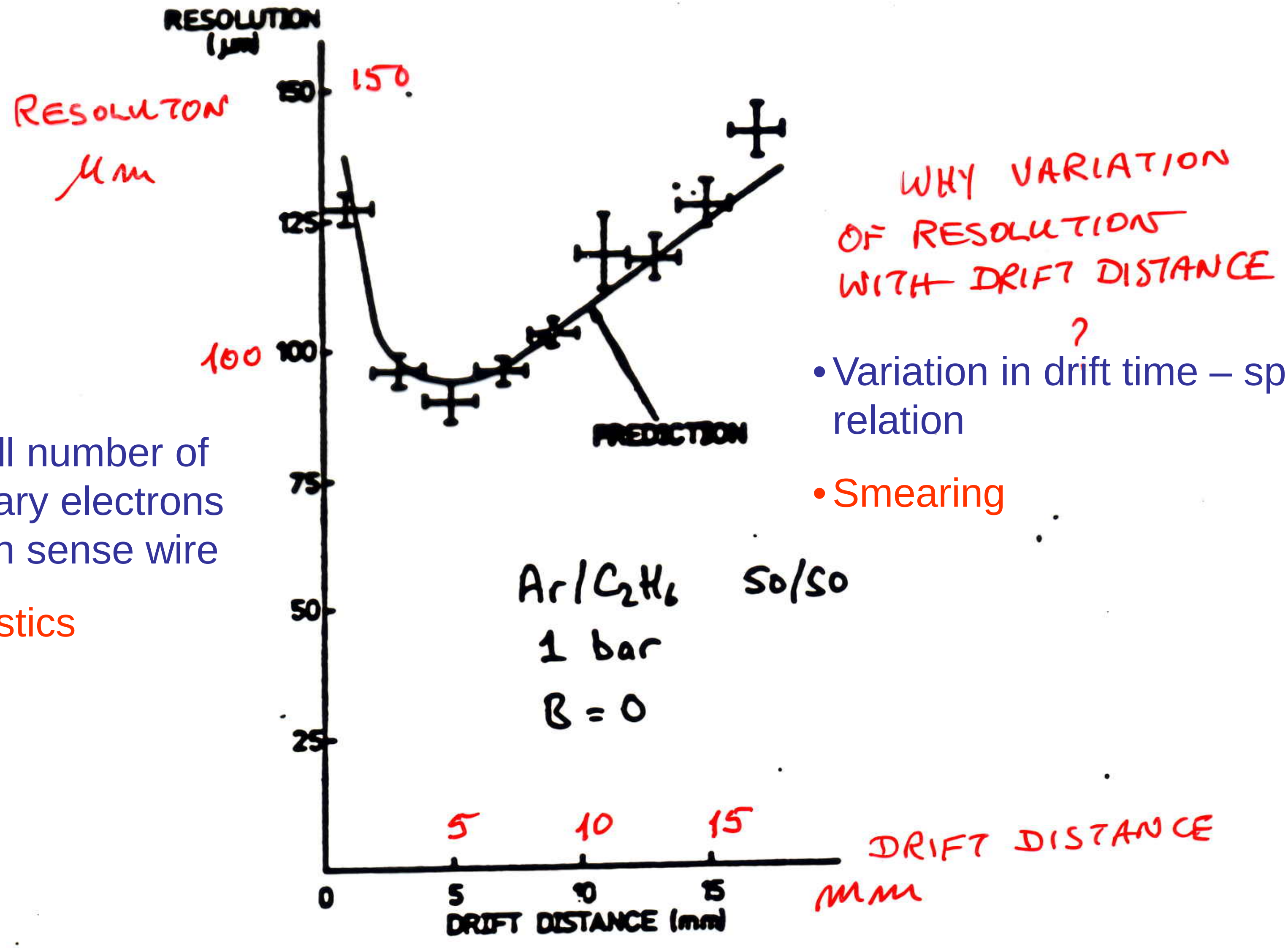
Zeus CTD Event Display



real track segments

reflected ghost segments

Spatial Resolution

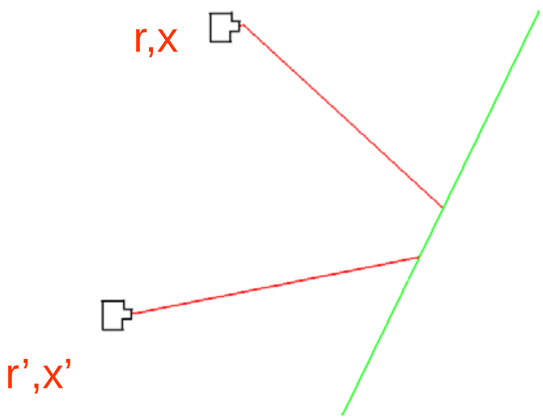


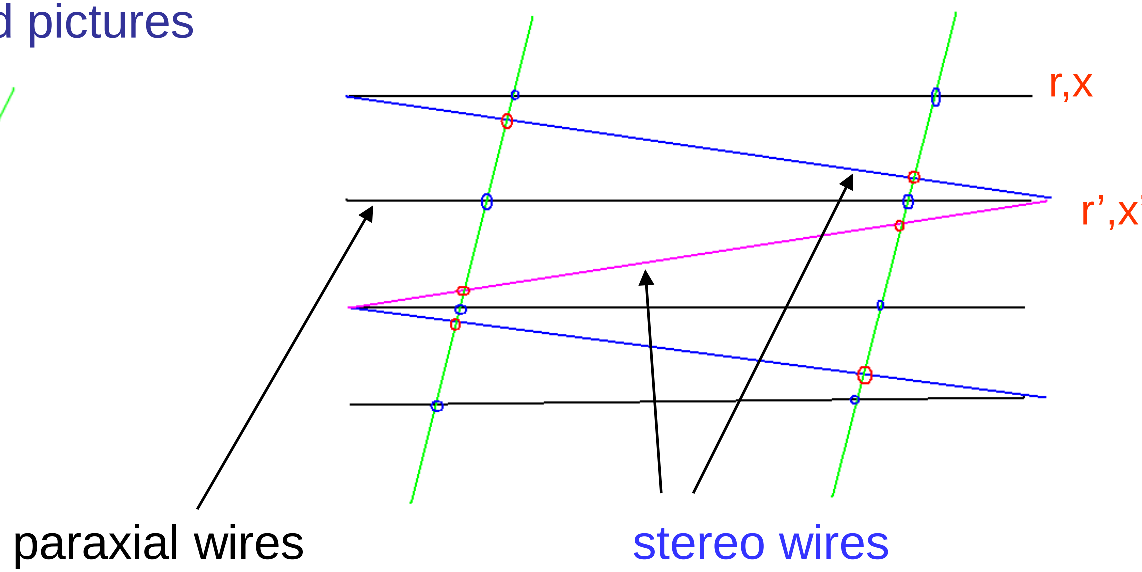
- Small number of primary electrons reach sense wire
- Statistics

- Variation in drift time – space relation
- Smearing

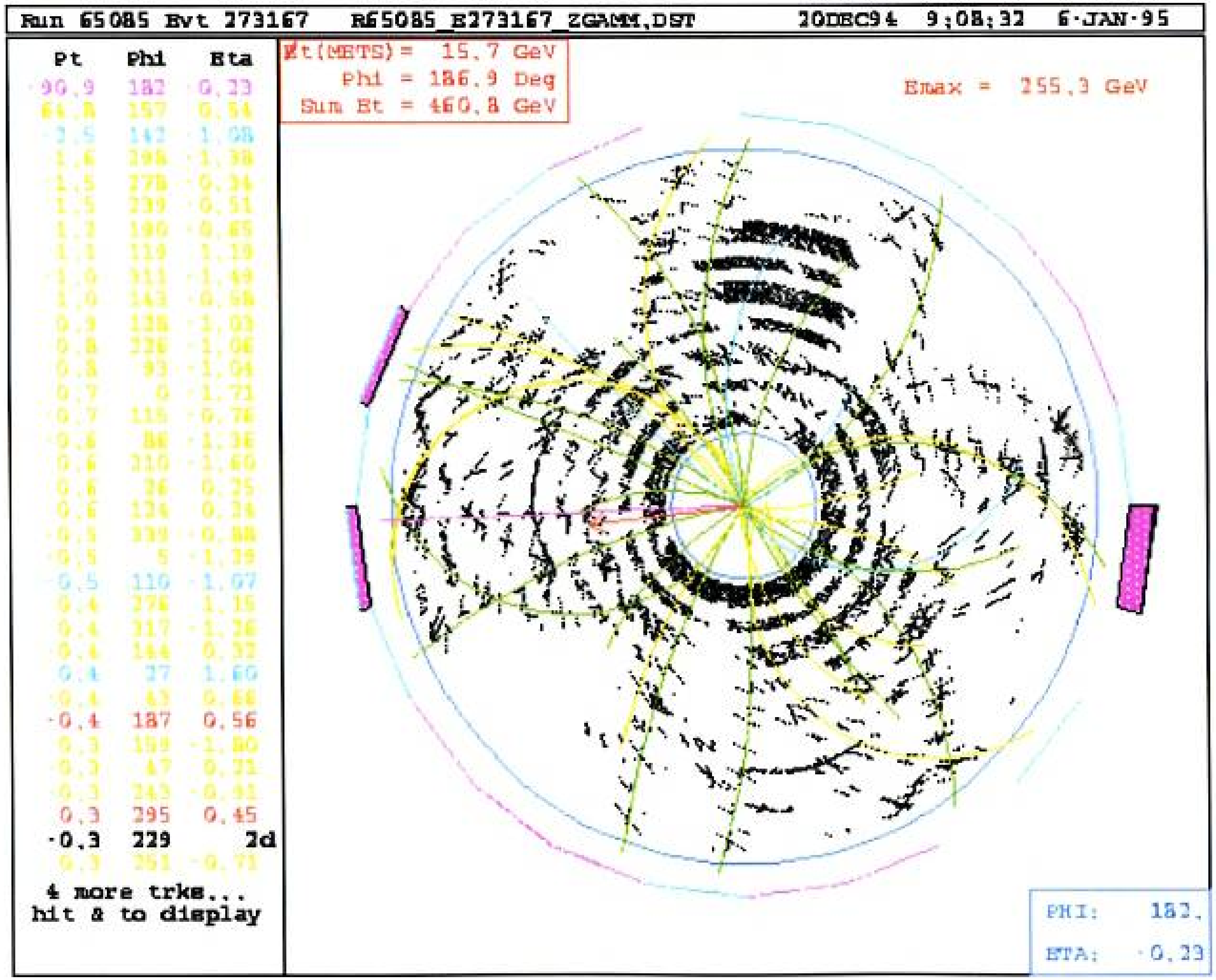
Stereo Wires – 3-d Reconstruction

stereo cameras – 3-d pictures



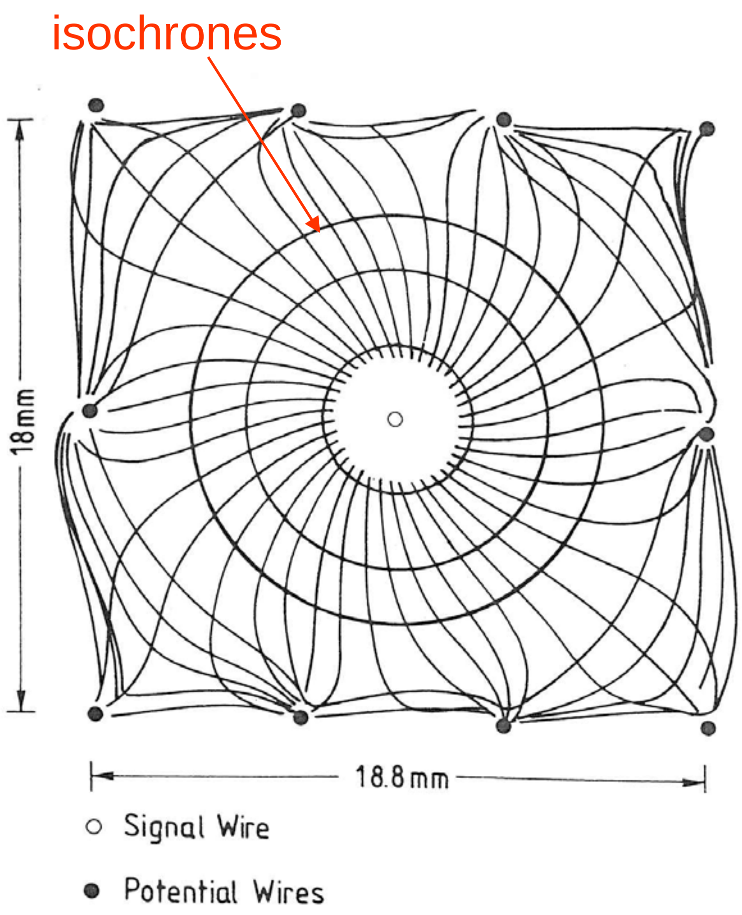


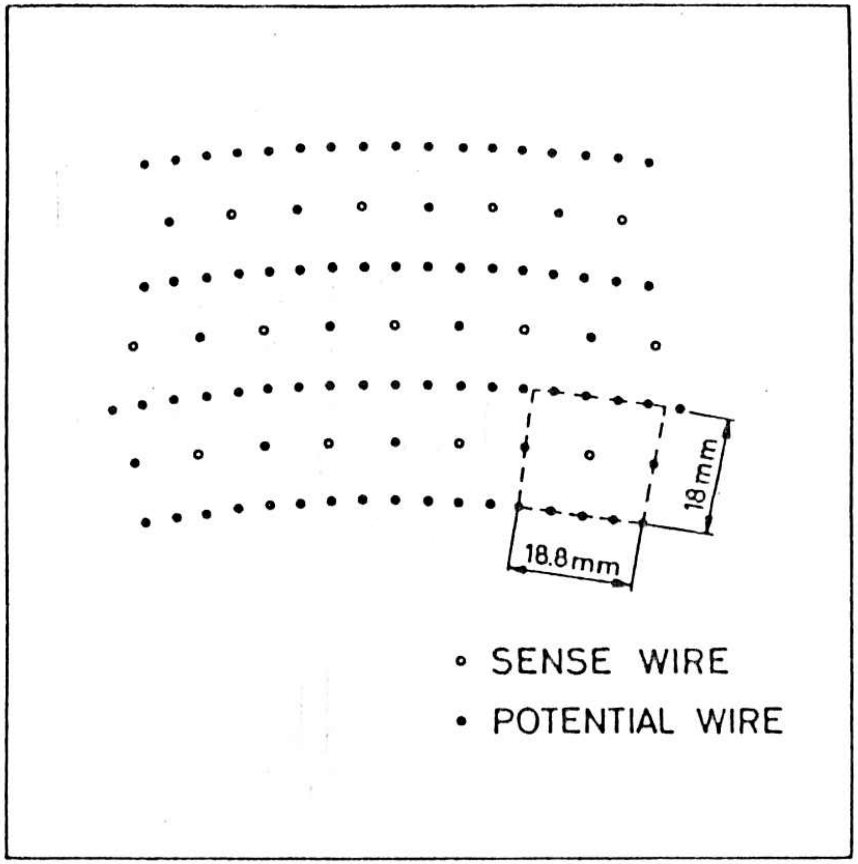

R.T.D. END
PROTON BEAM



Run 65085 Evt 273167
R65085_E273167_ZGAMM,DST
20DEC94 9:08:32 6-JAN-95
Pt Phi Eta
-90.9 182 -0.23
-0.4 187 0.56
0.3 295 0.45
-0.3 229 2d
4 more trks...
hit & to display
Et(MBTS) = 15.7 GeV
Phi = 186.9 Deg
Sum Et = 460.8 GeV
Emax = 255.3 GeV
PHI: 182.
ETA: -0.23

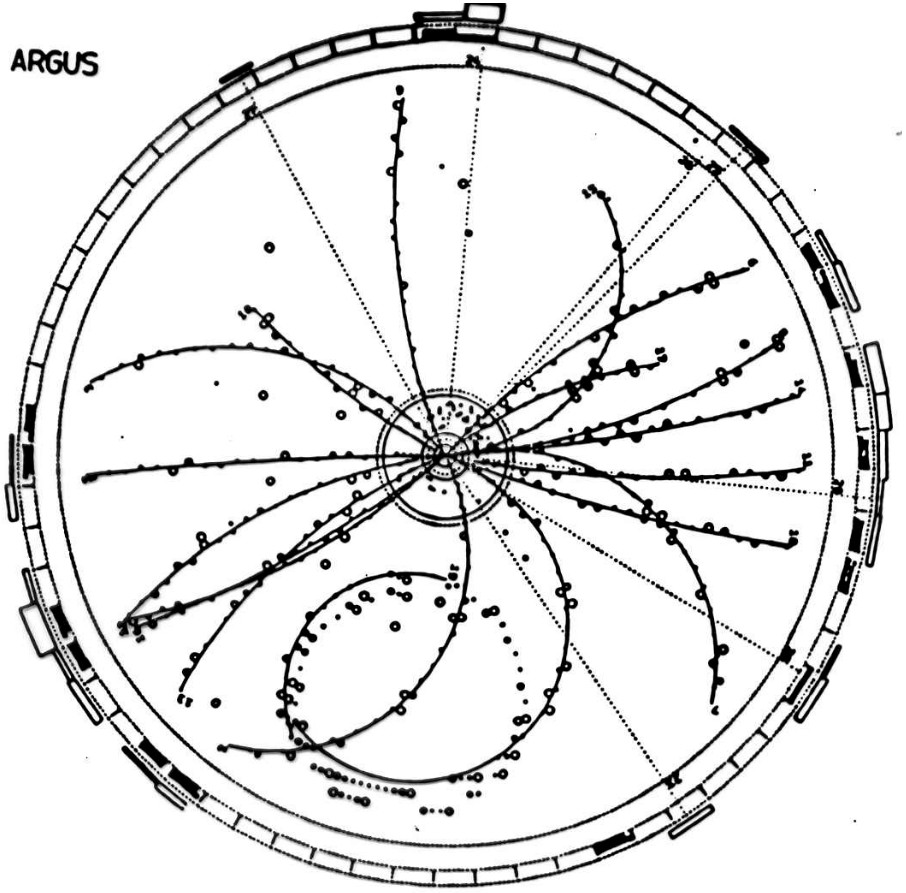
Square Drift Cells - ARGUS

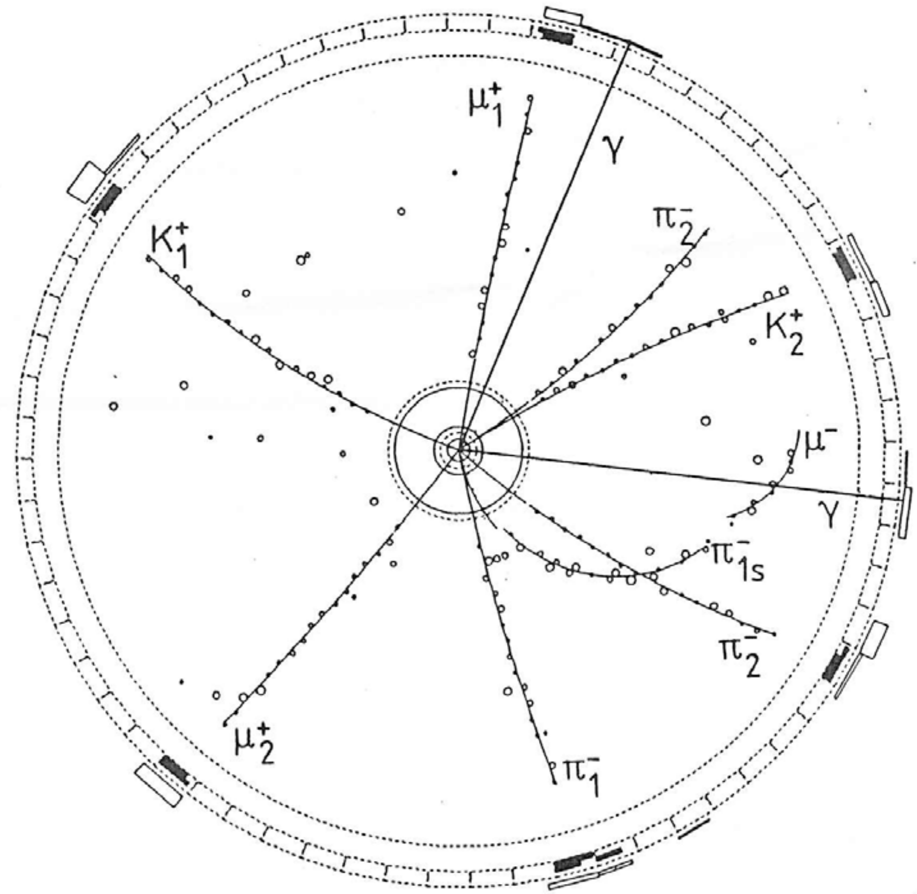




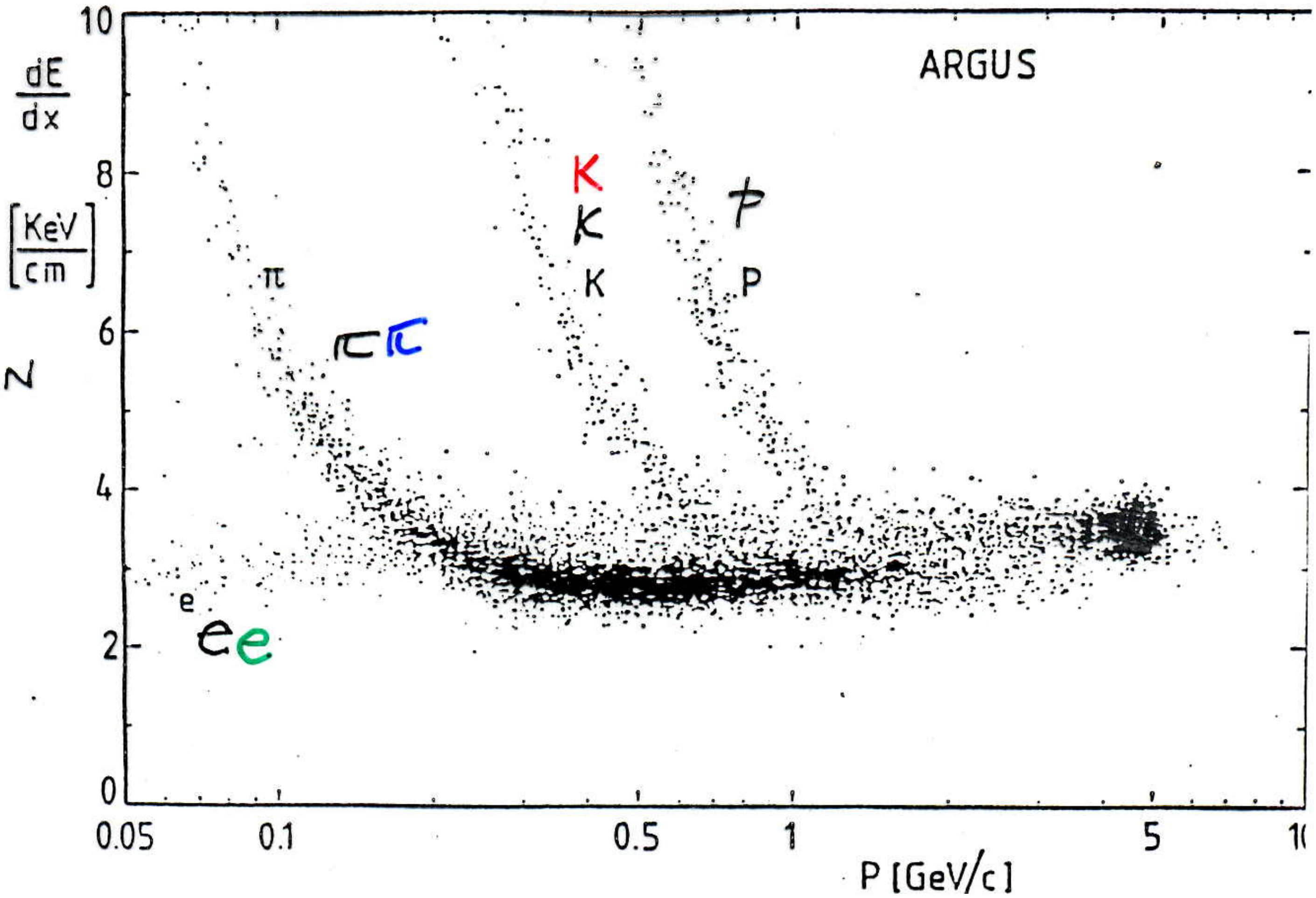
- Precision
- High Density of Information
- Pattern recognition complex ⇨ R-L ambiguity resolved by trying all possible combinations

ARGUS Events



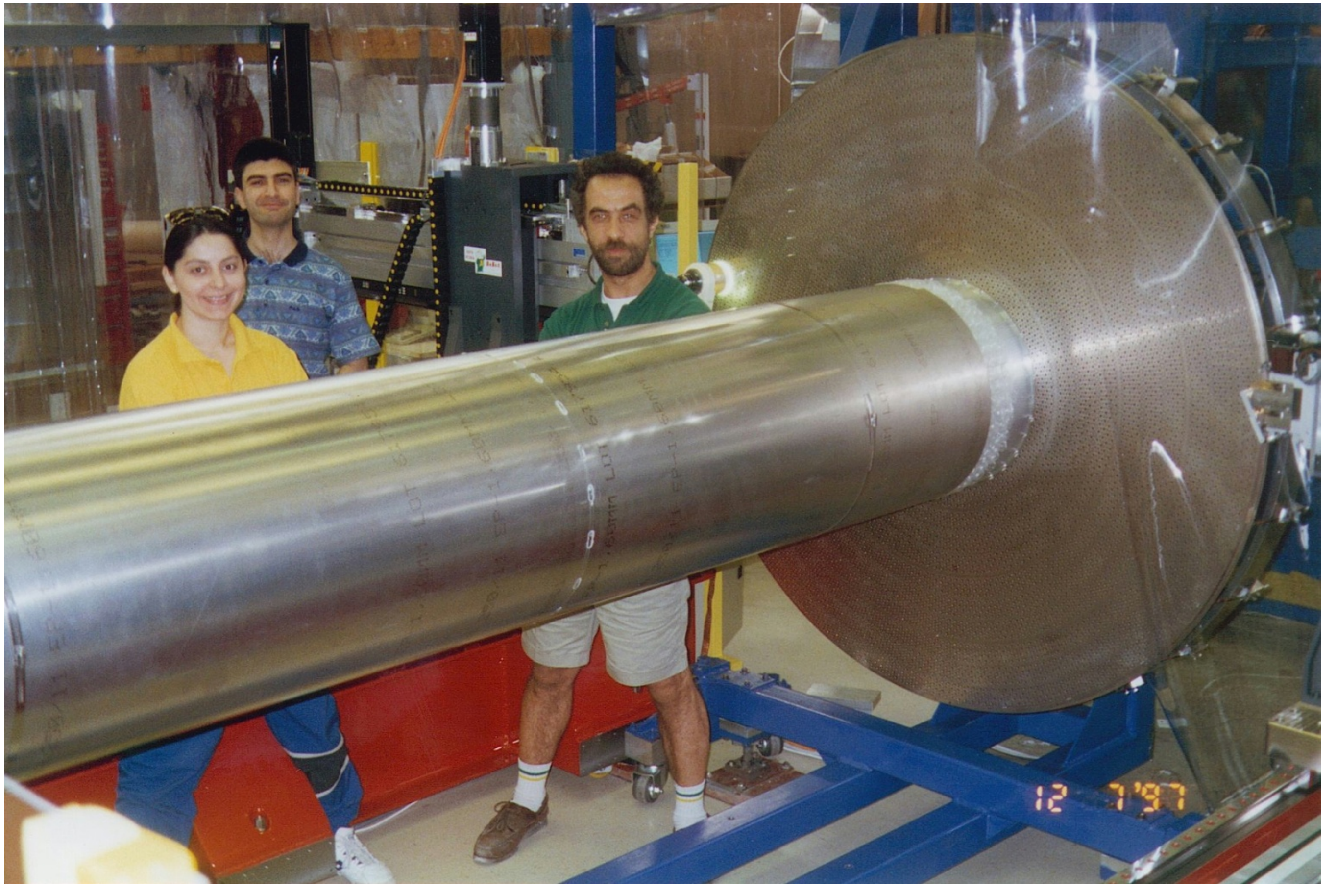


dE/dx Particle Identification



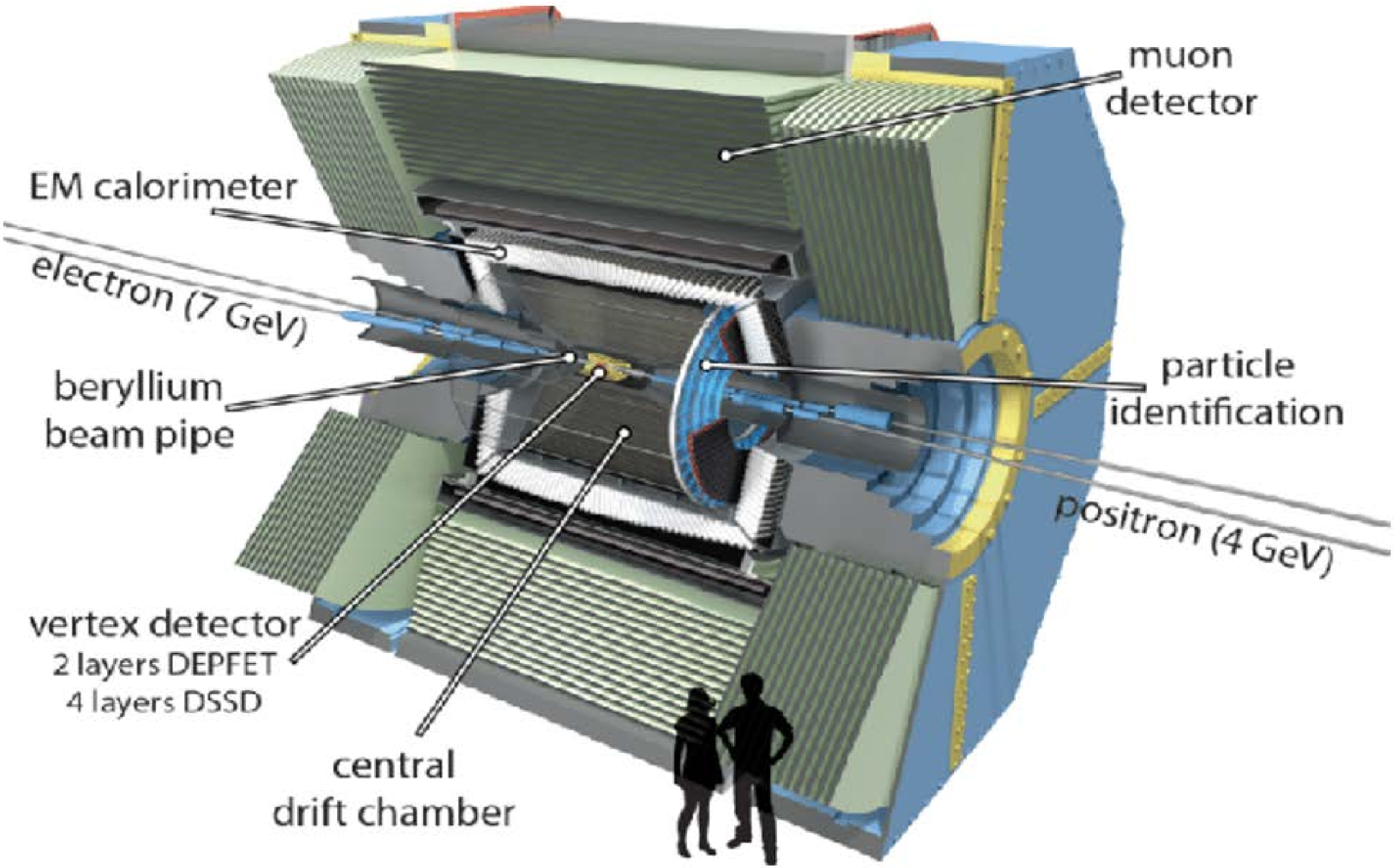
$\frac{dE}{dx}$ RESLN $\sim 5\%$

BaBar Drift Chamber



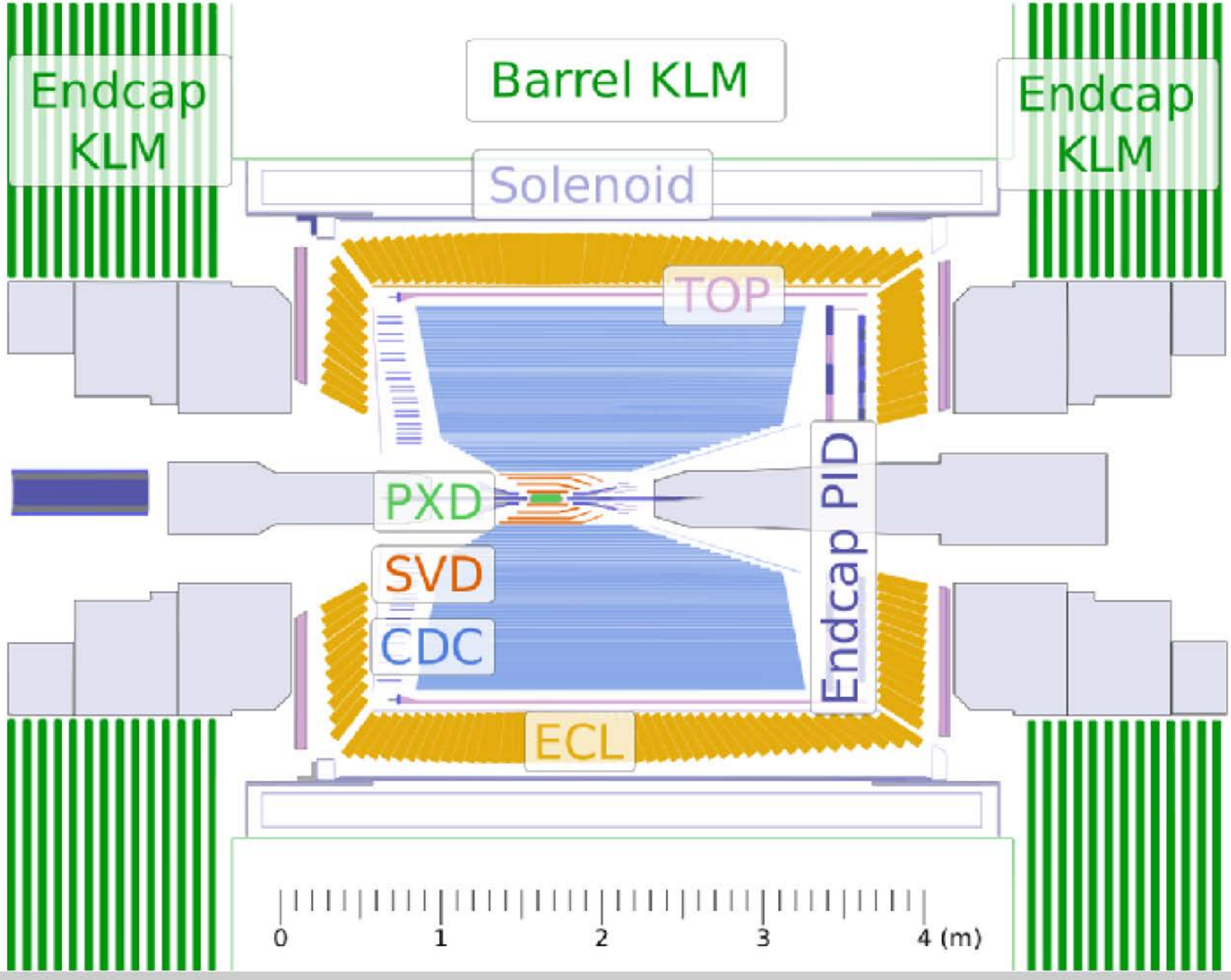
constructed at TRIUMF

Belle II



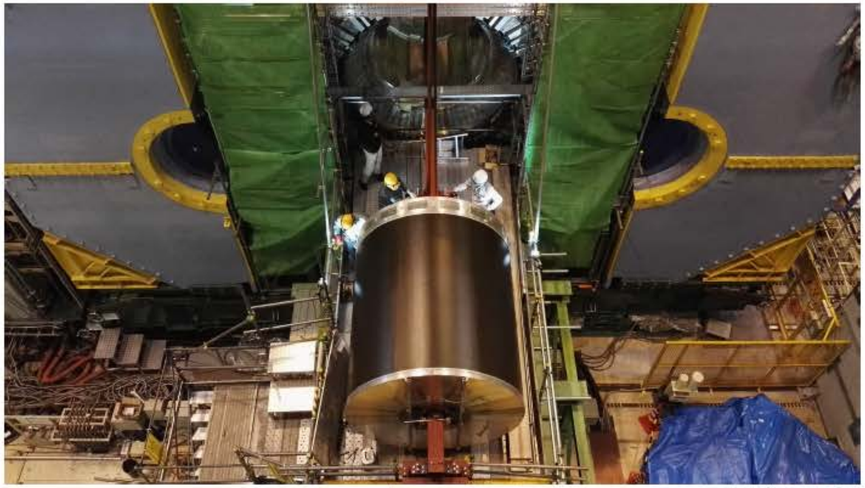
muon
detector
EM calorimeter
electron (7 GeV)
beryllium
beam pipe
particle
identification
positron (4 GeV)
vertex detector
2 layers DEPFET
4 layers DSSD
central
drift chamber

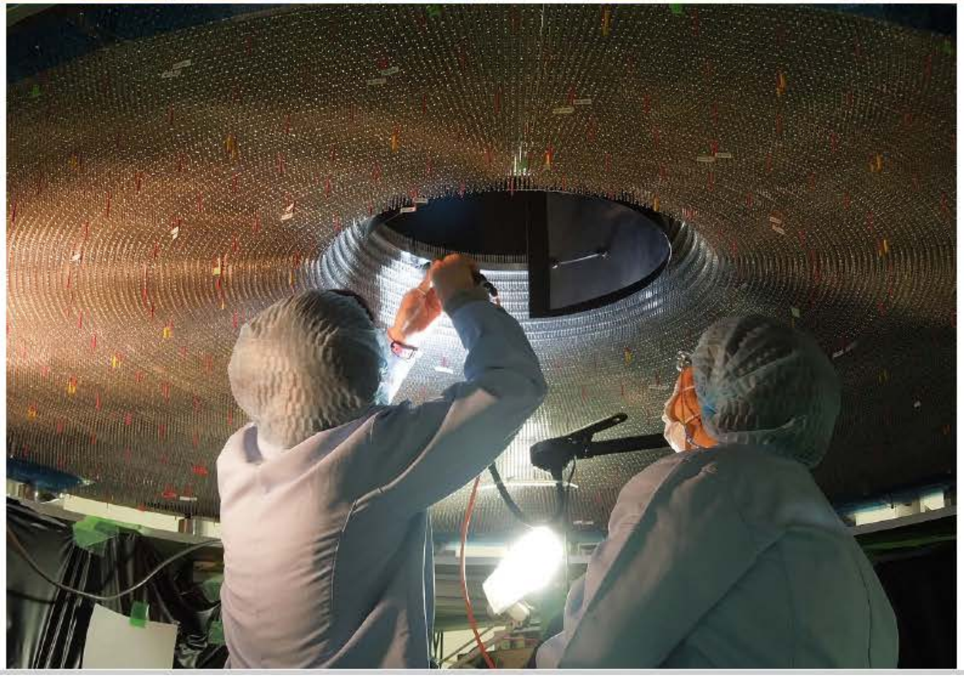
The Belle 2 detector



.04 x 3.78 in

CDC in pictures





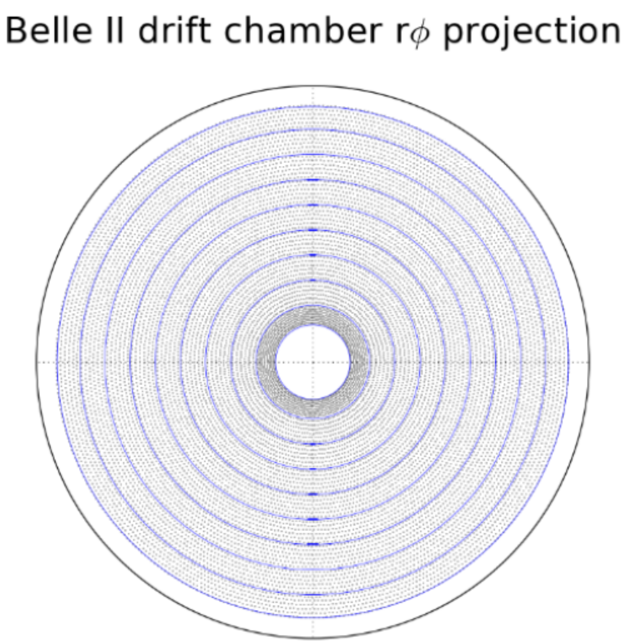
CDC and CDC wires

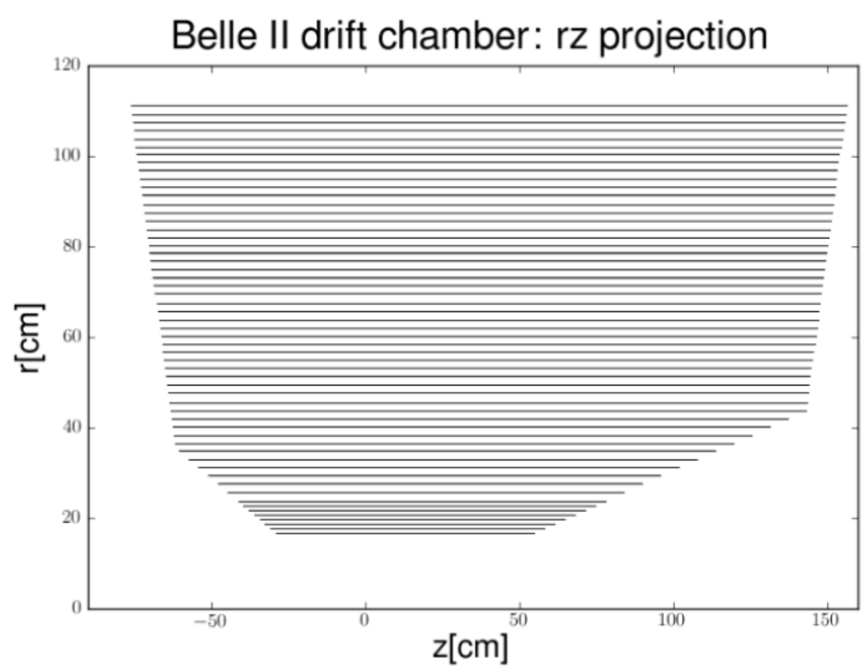
CDC is composed of:

- 9 super layers

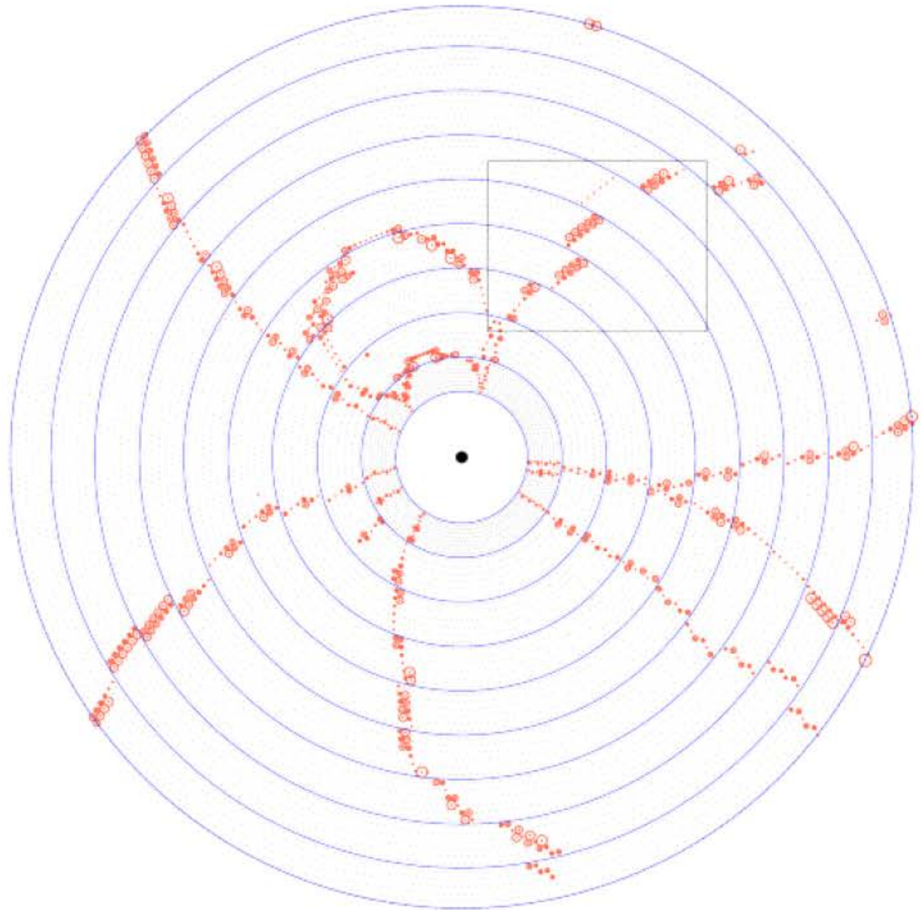
which consist of

- 56 layers (grouped to 1x8 and 8x6)
- 14336 wires (160 - 384 wires in a layer).





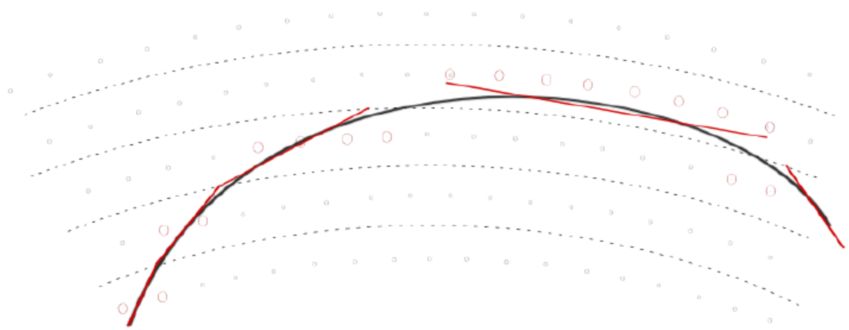
An example typical event of $\Upsilon(4S)$ decay (no beam background)



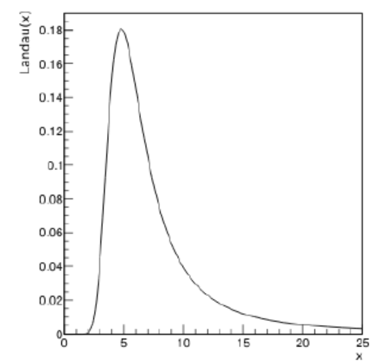
dE/dx measurements and PID

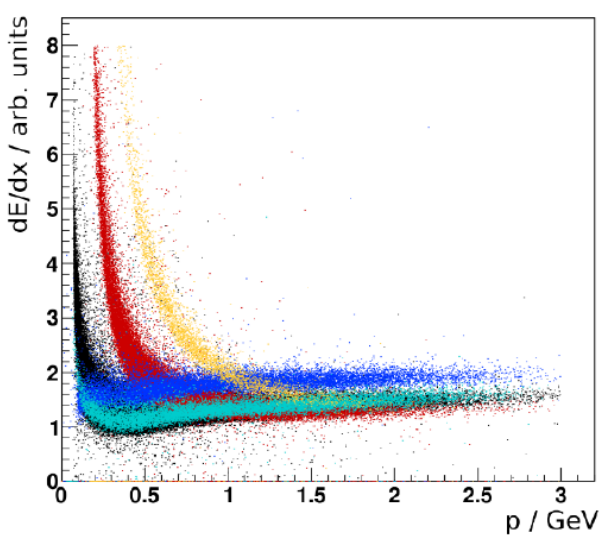
Ionisation is $\sim$ distance traversed, so charge/distance is used:

- Charge in each layer summed.
- Distance approximated as straight line to next layer.



$\mathrm{d}E/\mathrm{d}x$ - extracted as avg ionisation:

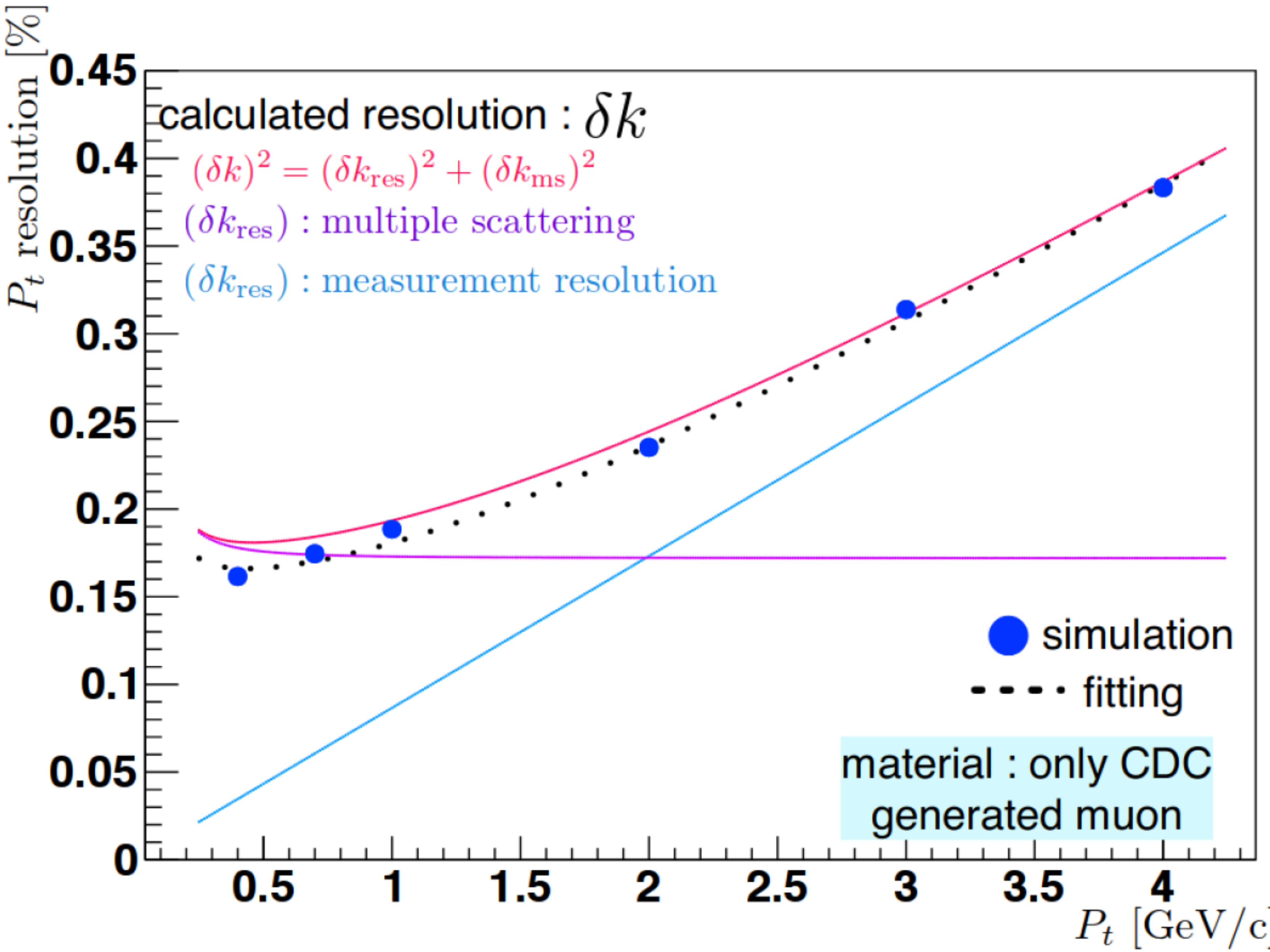




electrons, muons, pions, kaons, protons.

$\rightarrow$ PID possible by comparing with distributions.

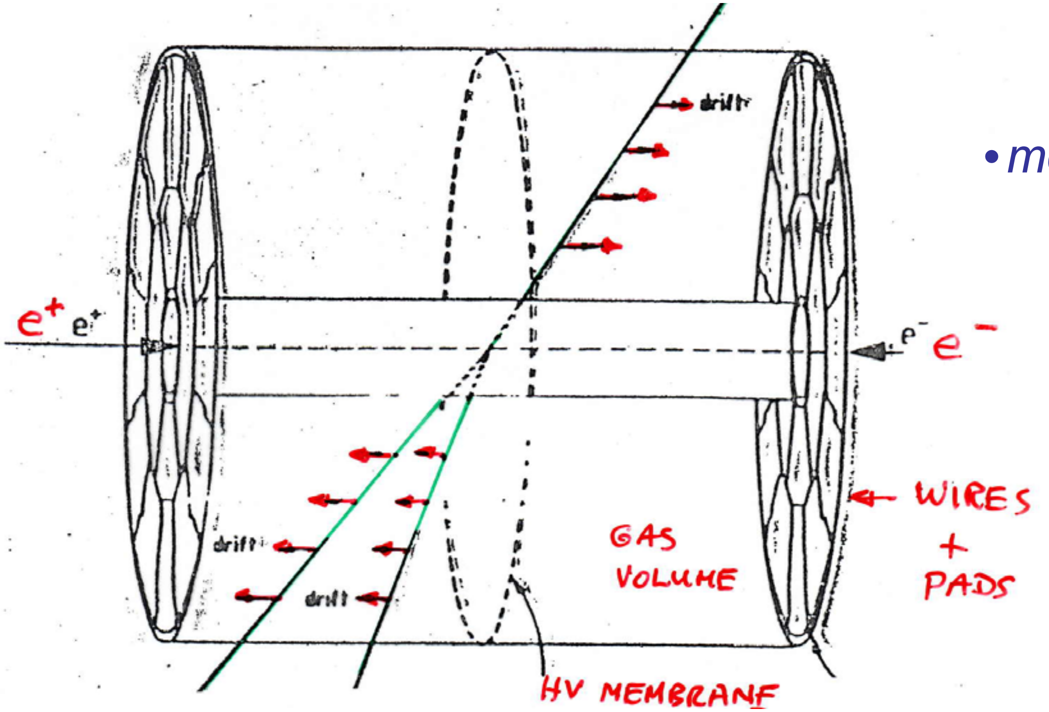
& combining with $\mathrm{d}E/\mathrm{d}x$ from PXD/SVD.



P_t resolution [%]
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
calculated resolution : δk
$(\delta k)^2 = (\delta k_{\mathrm{res}})^2 + (\delta k_{\mathrm{ms}})^2$
$(\delta k_{\mathrm{res}})$: multiple scattering
$(\delta k_{\mathrm{res}})$: measurement resolution
simulation
fitting
material : only CDC
generated muon
0.5
1
1.5
2
2.5
3
3.5
4
P_t [GeV/c]

Time Projection Chamber

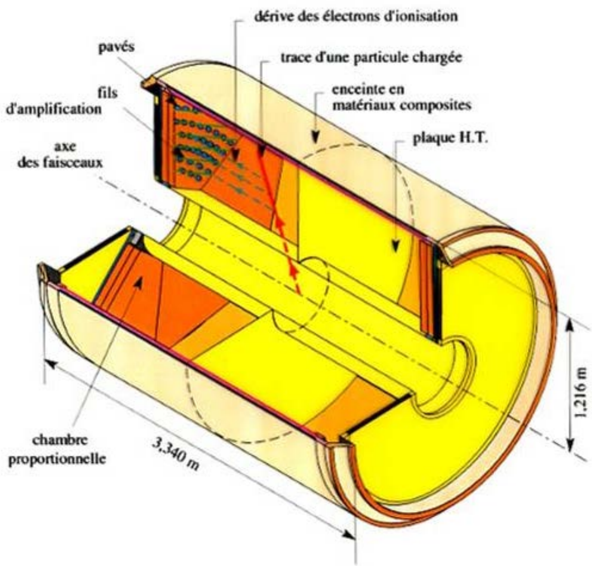
- Only two drift cells
- $\bar{E}$ parallel to $\bar{B}$, so no Lorentz angle

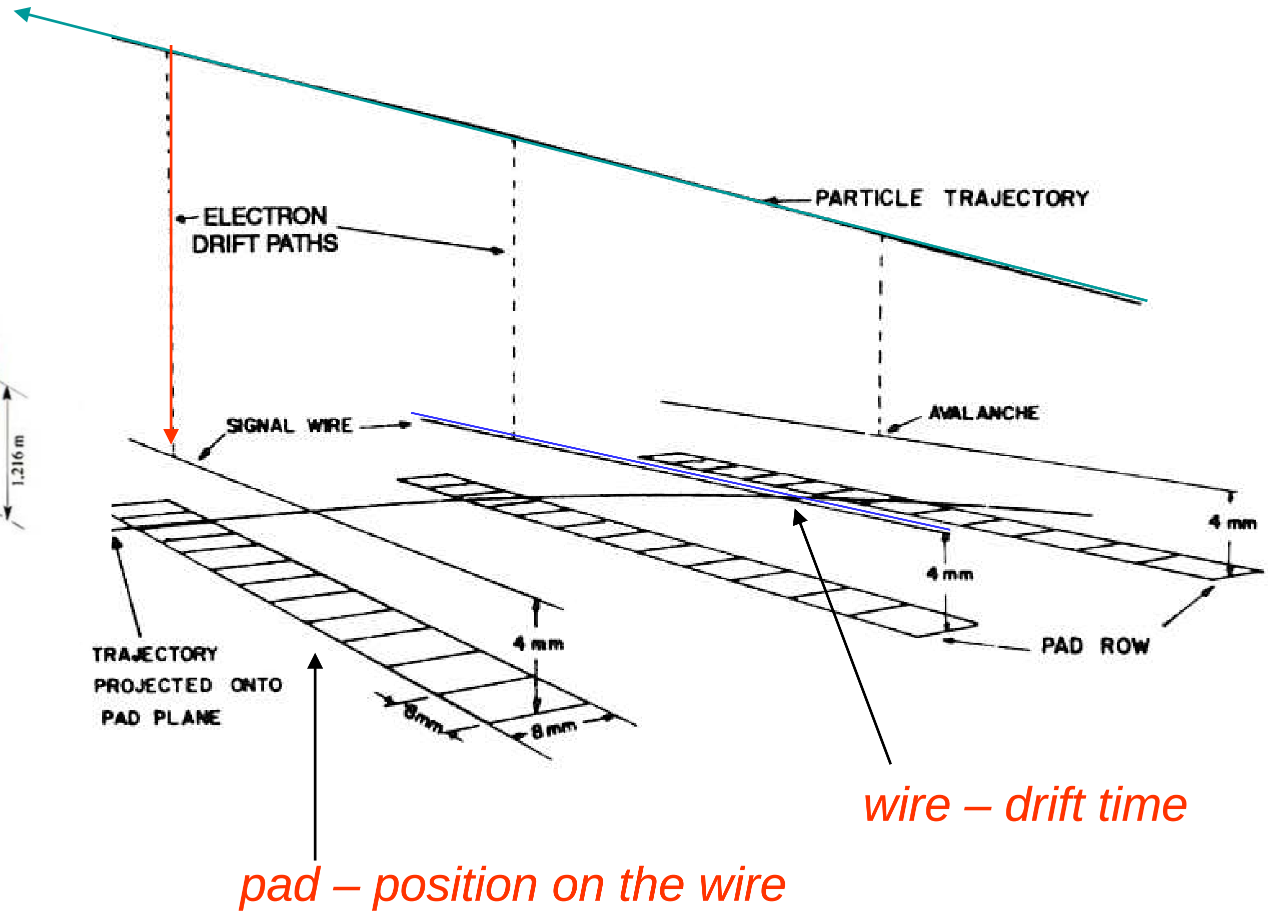


- *measure z,θ from drift time* $\sigma_{r,\phi} \sim 180\mu$
- *measure r,Φ from pads and wires on endplates* $\sigma_z \sim 200\mu$

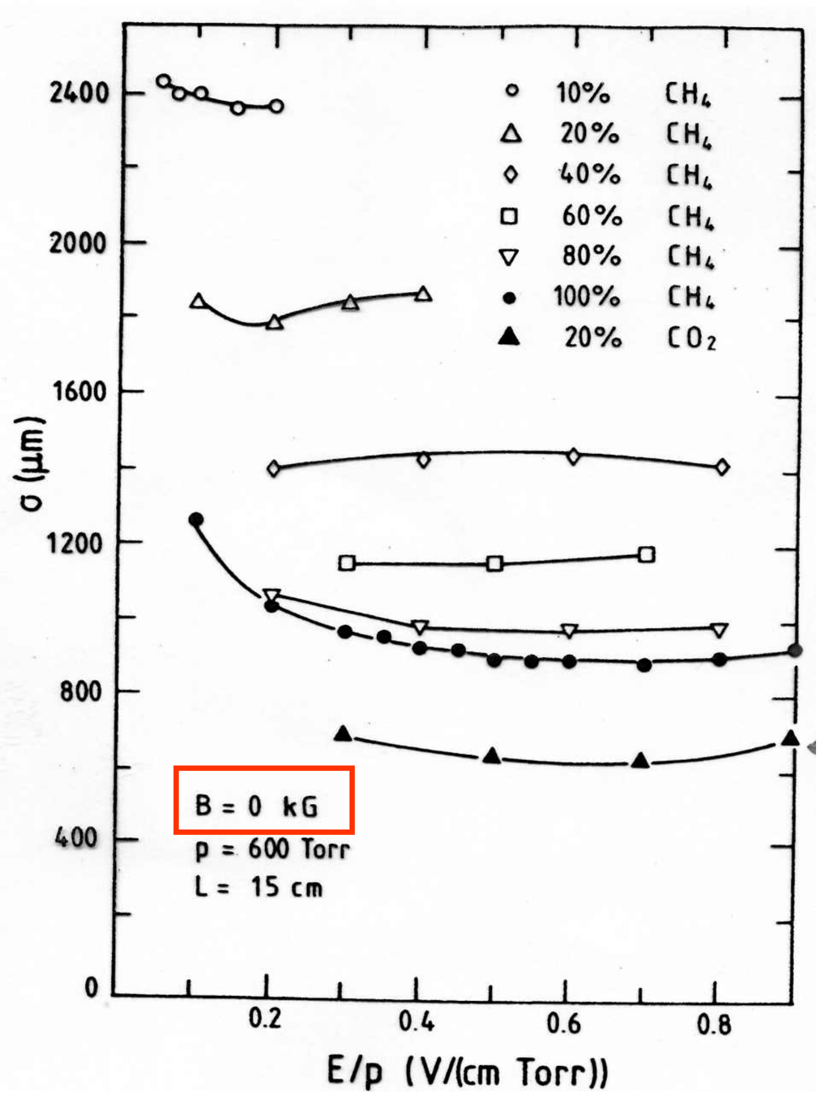
- Good pattern recognition and precision in medium multiplicity environment → space charge limitation

DELPHI Time Projection Chamber





Diffusion in TPC



Why does diffusion not ruin resolution?

transverse diffusion

Diffusion limits spatial resolution

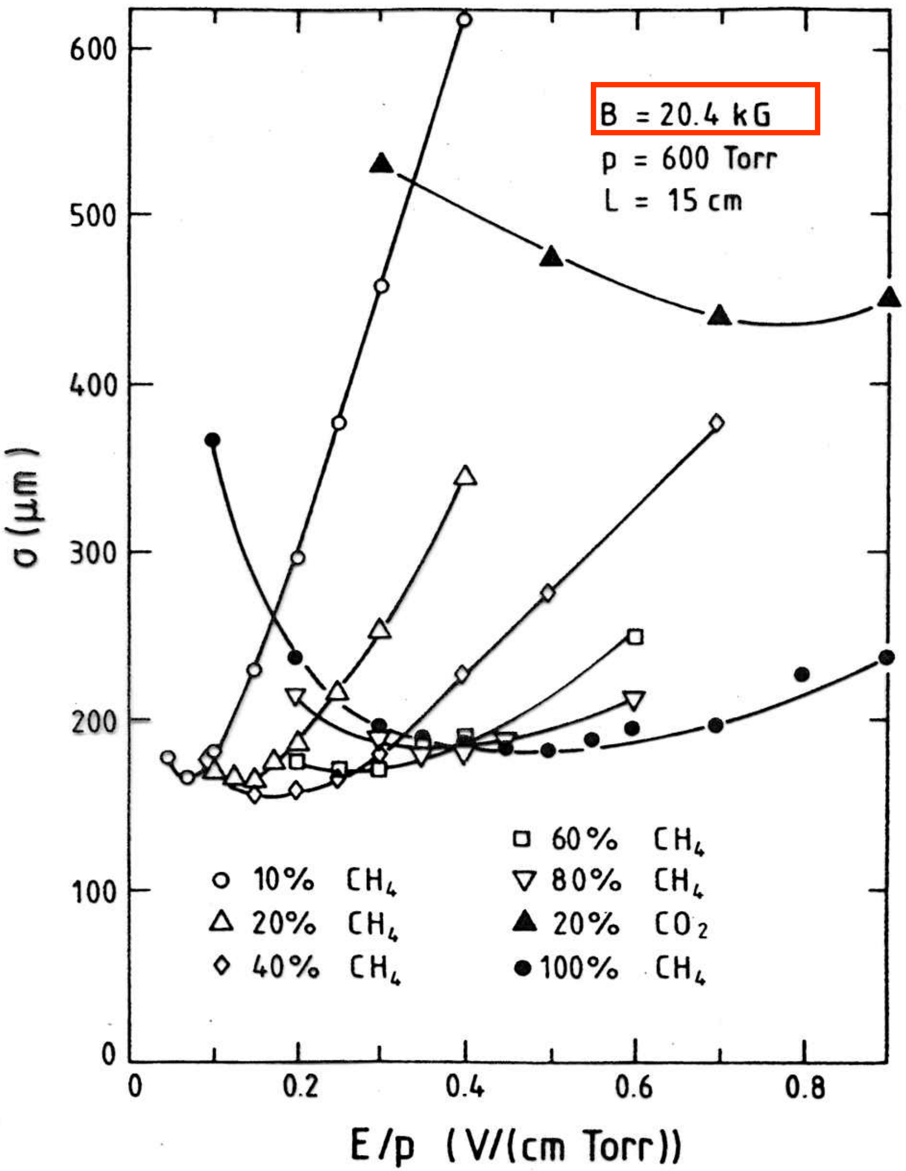
drift length

$$\sigma = \sqrt{\frac{2L}{3v_D} u\lambda}$$

mean free path

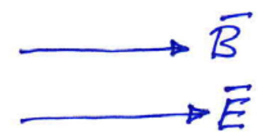
mean electron velocity

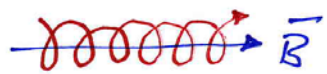
Diffusion in TPC



Compare this to previous plot with B=0

$\bar{B} \neq 0$ reduces diffusion if $\bar{E} \times \bar{B} = 0$





particles drift along tight helices

transverse diffusion reduced by

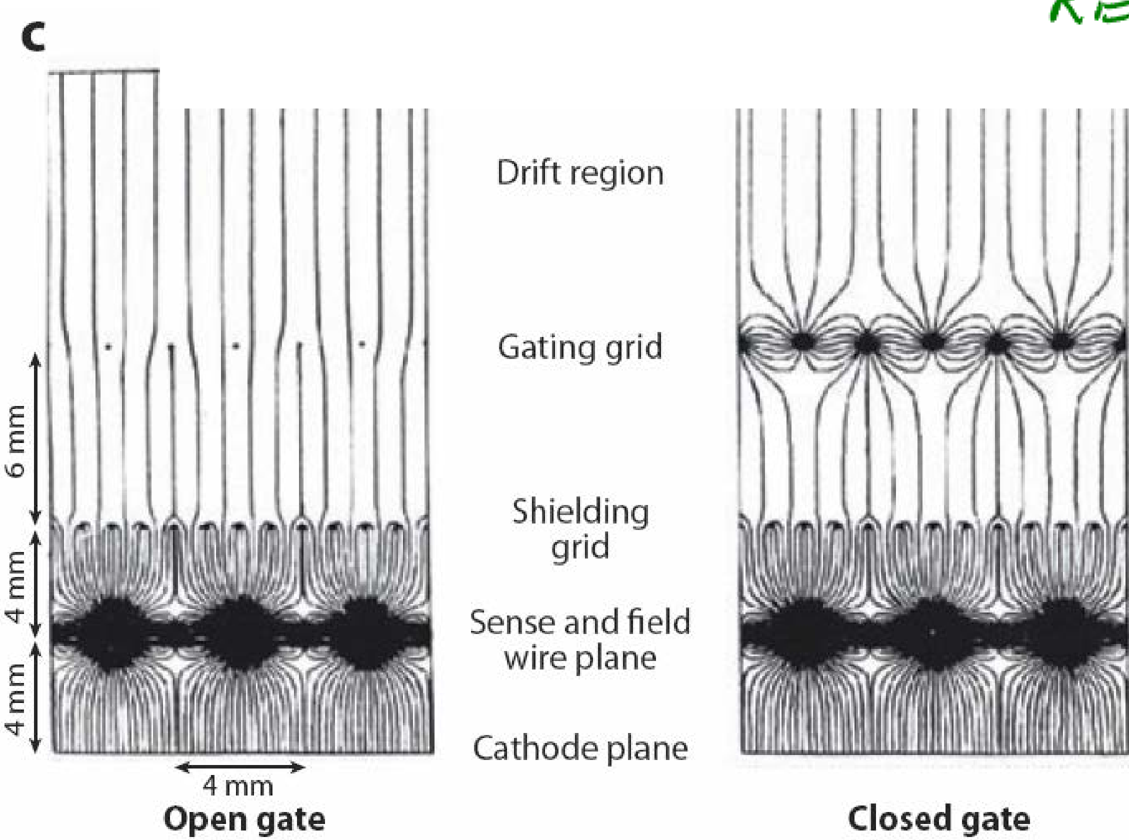
$$\frac{1}{1+\omega^2\tau^2};\ \omega = \frac{eB}{m}$$

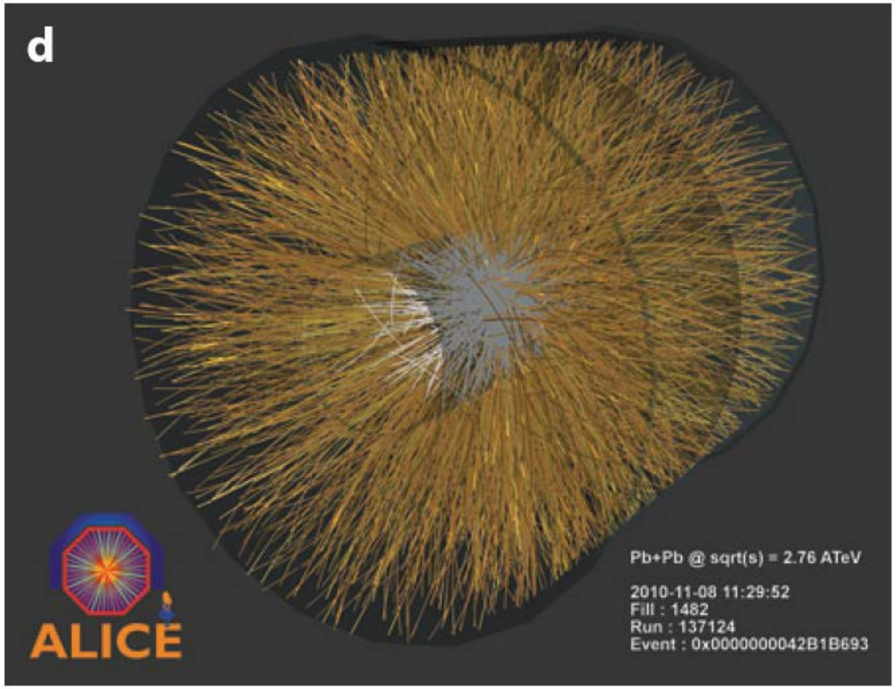
SPACE CHARGE LIMITATIONS

HEAVY IONS PRODUCED BY GAS AMPLIFICATION

→ DISTORT ELECTRIC FIELD

USE GATED GRID → ONLY ALLOW ELECTRONS INTO AMPLIFICATION REGION FOR GOOD TRIGGERS



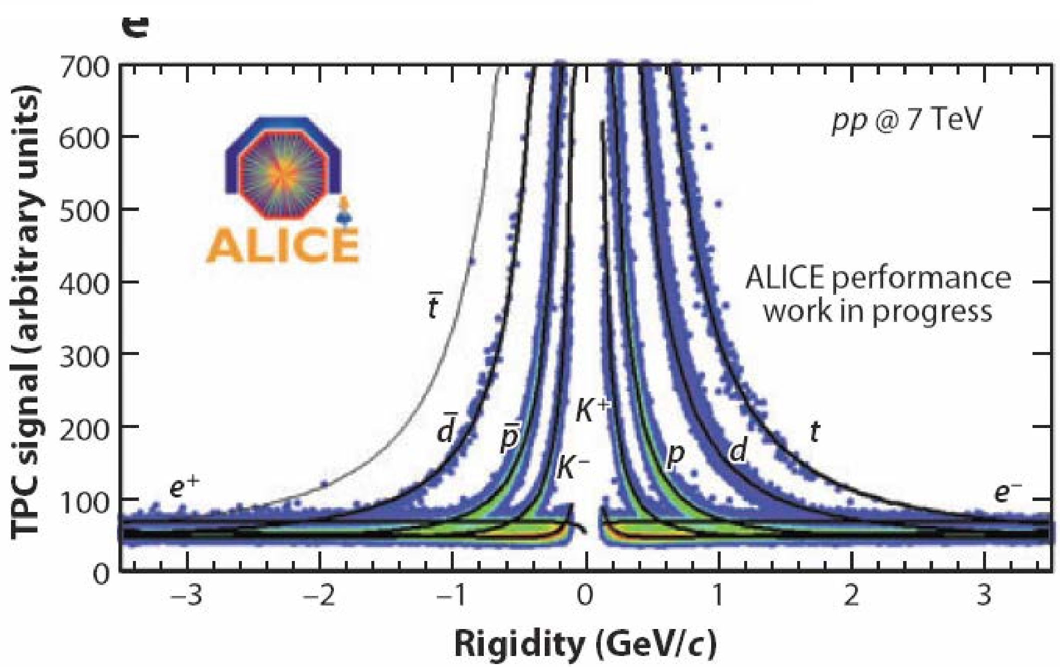


ALICE

TPC → HIGH MULTIPLICITY

GOOD PATTERN RECOGNITION

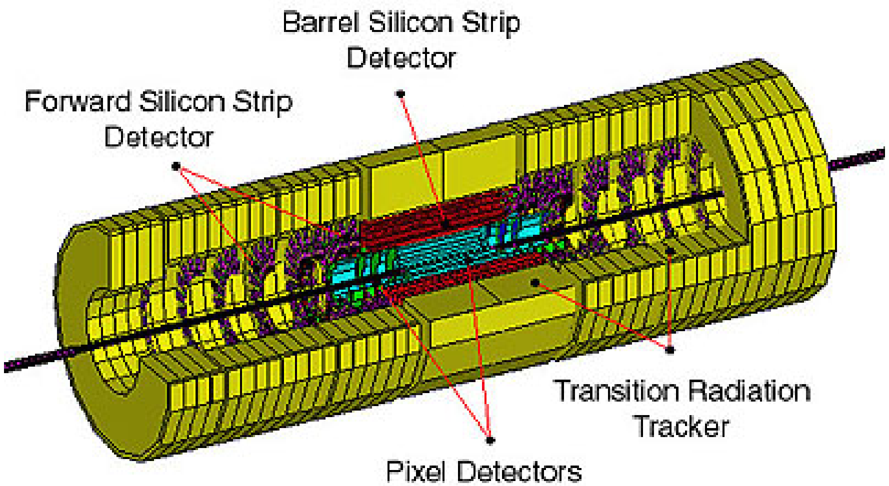
→ LOW RADE



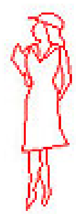
→ GOOD dE/dx

PARTICLE IDENTIFICATION

ATLAS Tracker

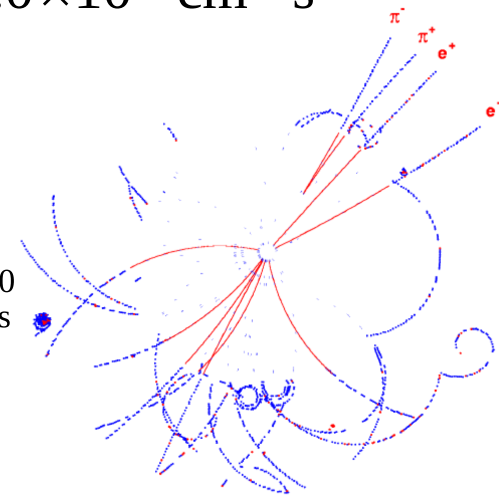


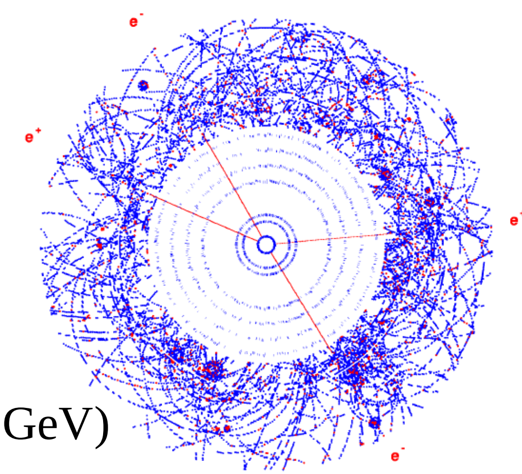
Inner Tracker



$3.0\times10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$

$B_d^0 \rightarrow J/\psi\, K_s^0$

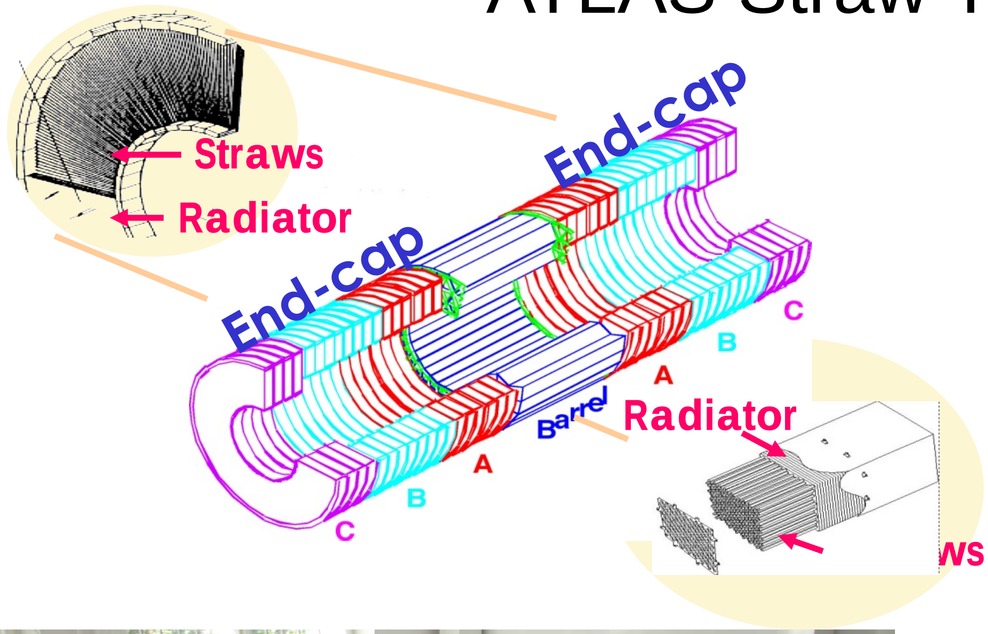


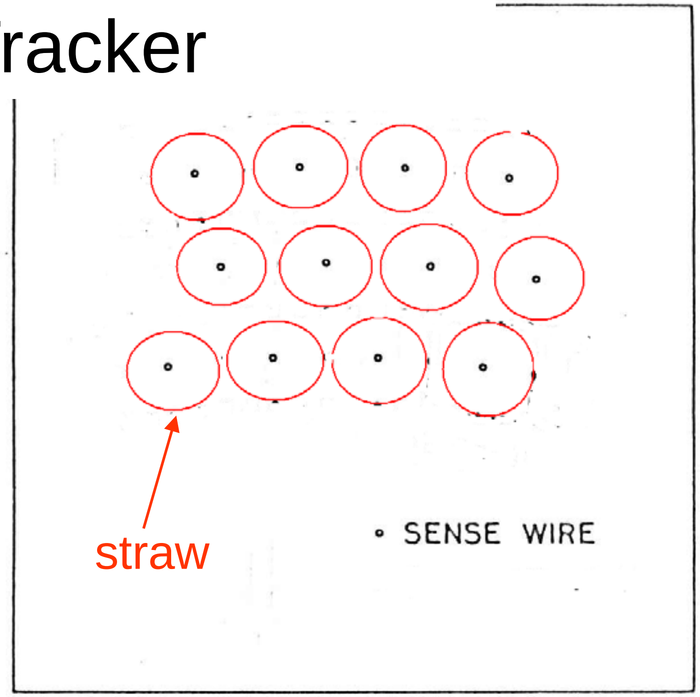


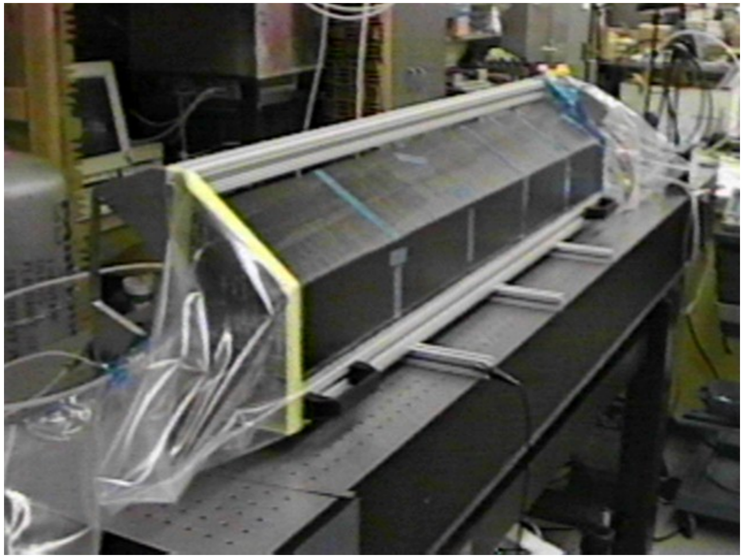
$10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$

$H \rightarrow ZZ^* \rightarrow e^+e^-e^+e^- \quad (m_H = 130\,\mathrm{GeV})$

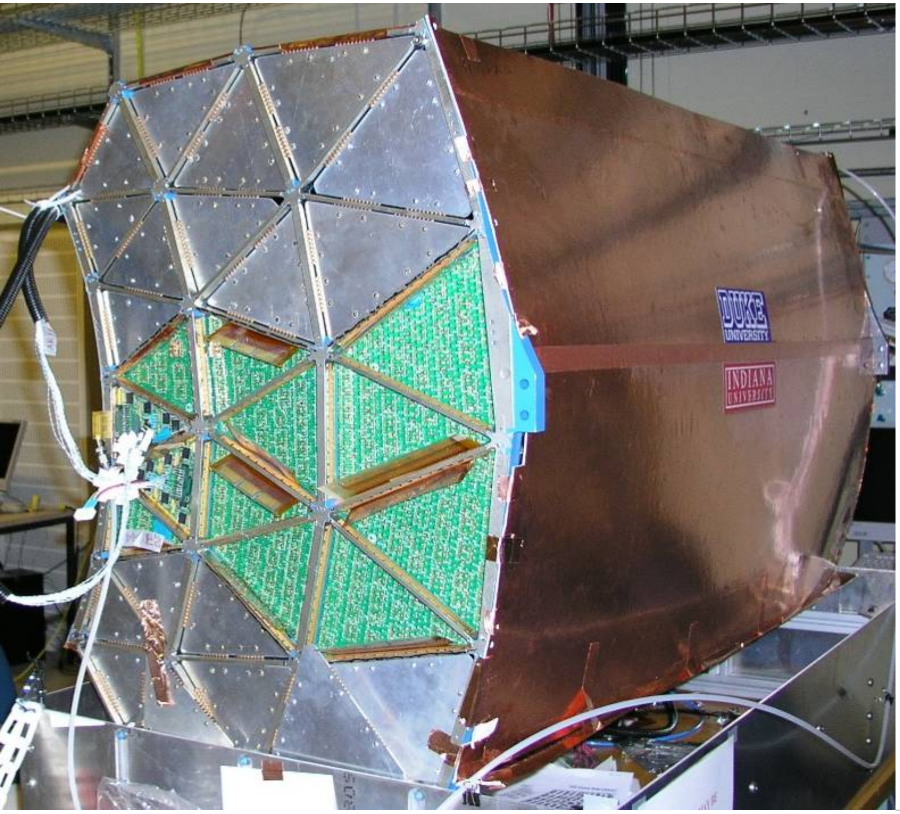
ATLAS Straw Tracker

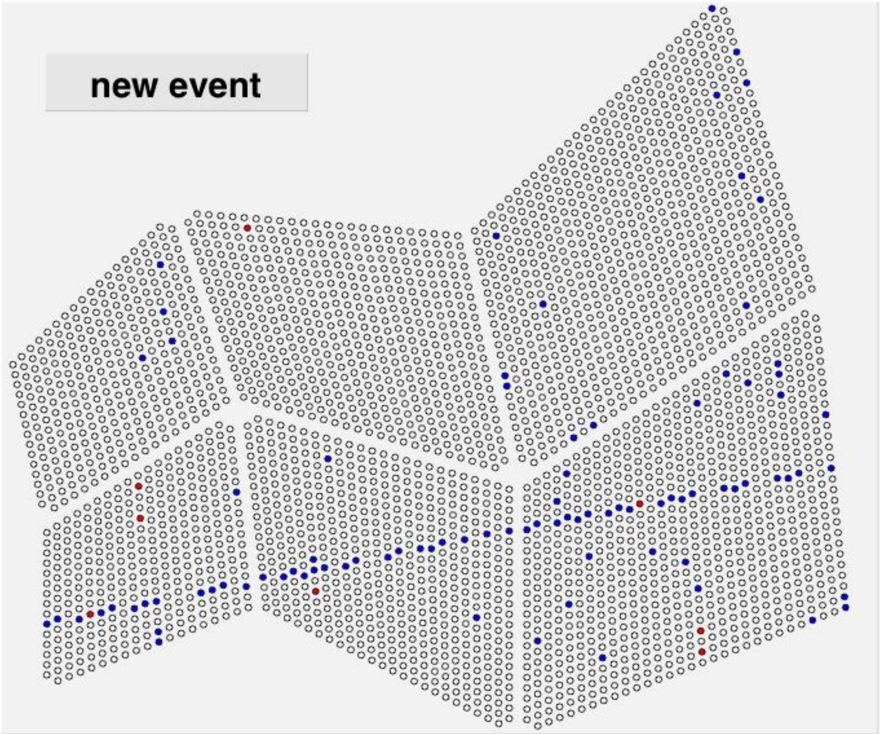




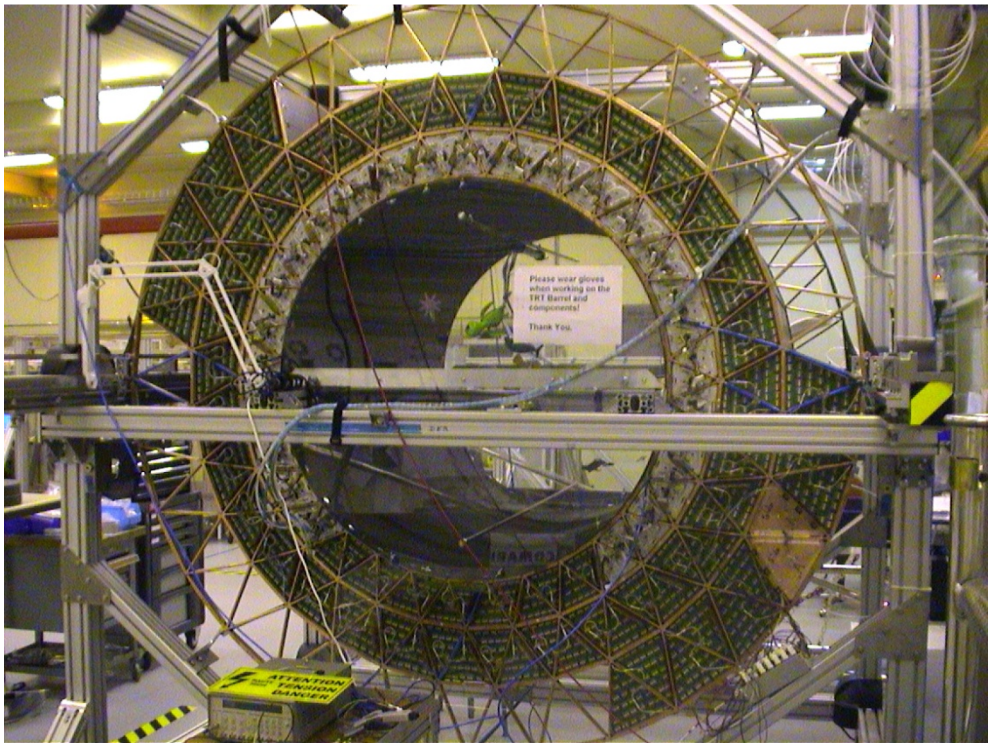


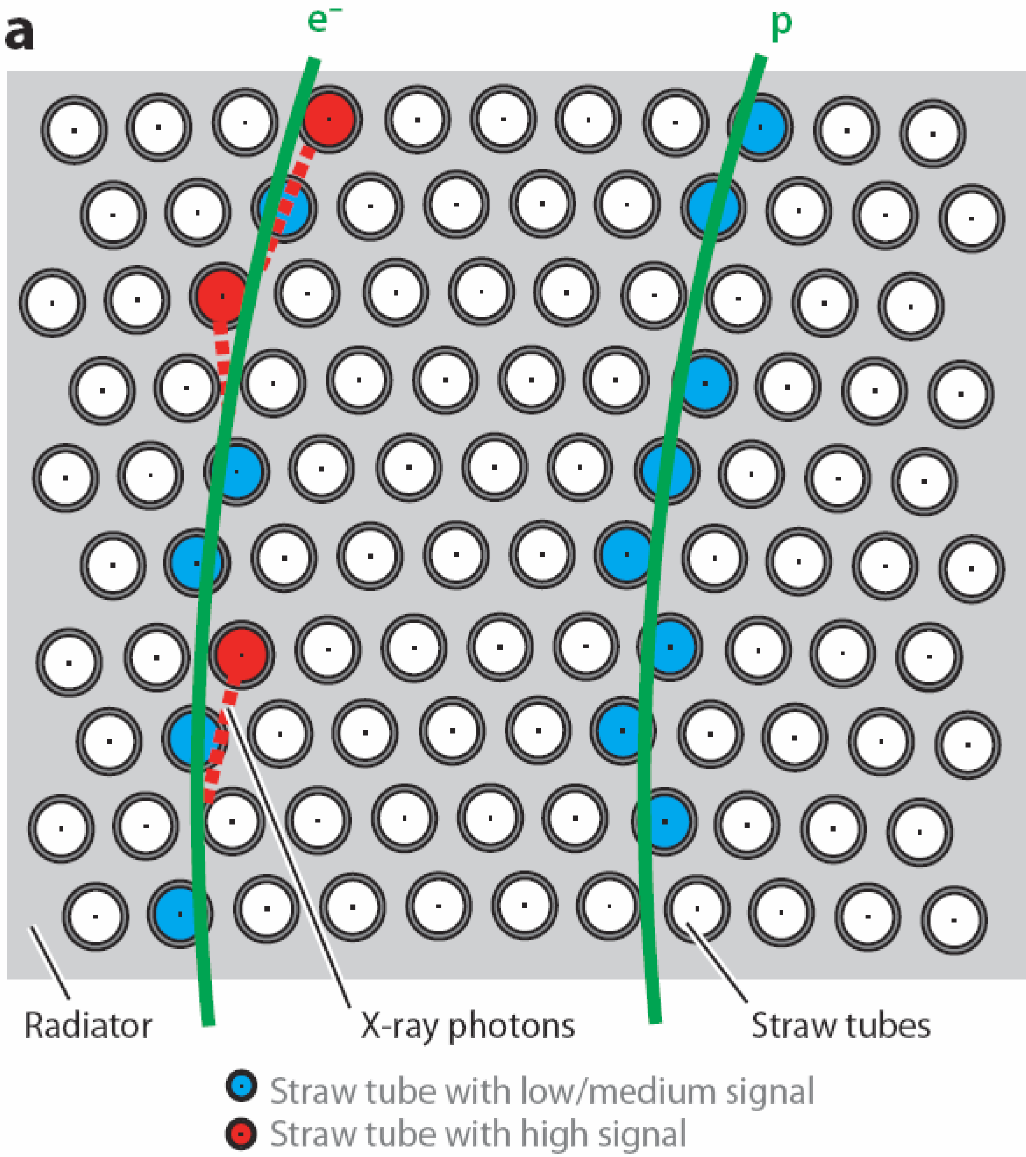
Straw tracker test beam module





Assembly of straw tracker





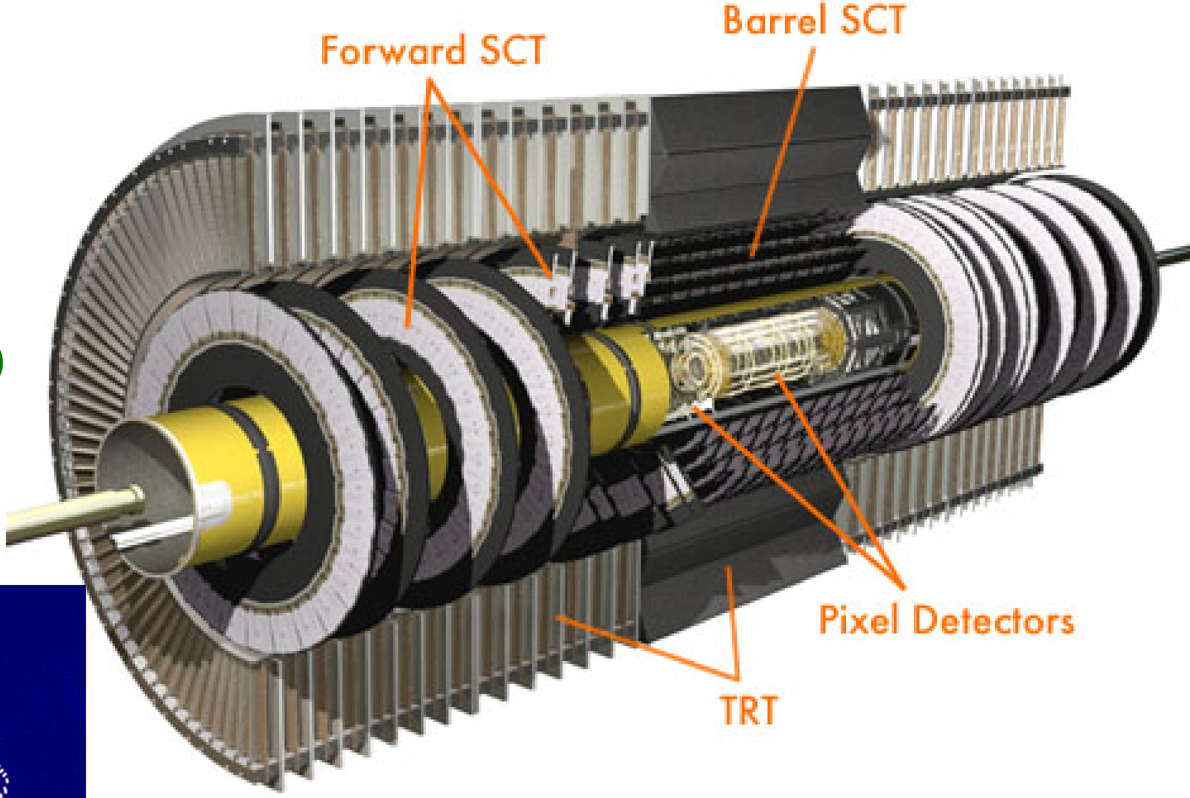
PARTICLE ID IN ATLAS STRAW TRACKER

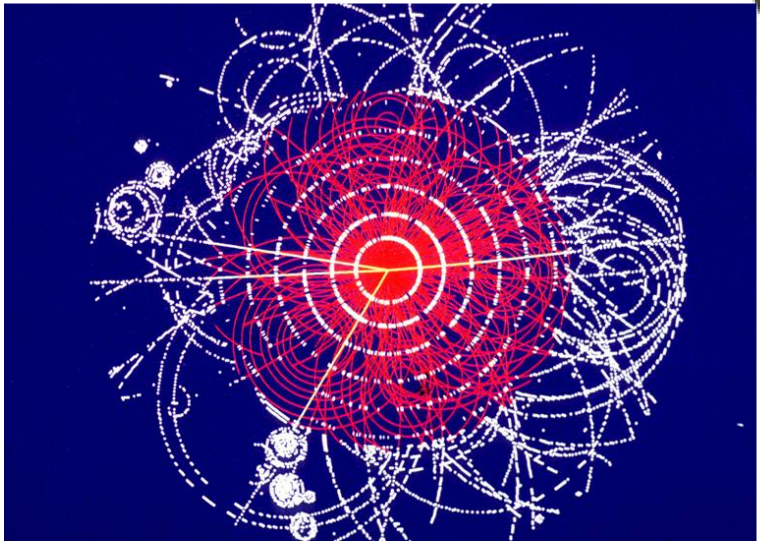
→ TRANSITION RADIATION

Inner Detector (ID)

The Inner Detector (ID) comprises four sub-systems:

- Pixels (0.8 10^8 channels)
- Silicon Tracker (SCT) (6 10^6 channels)
- Transition Radiation Tracker (TRT) (4 10^5 channels)
- Common ID items



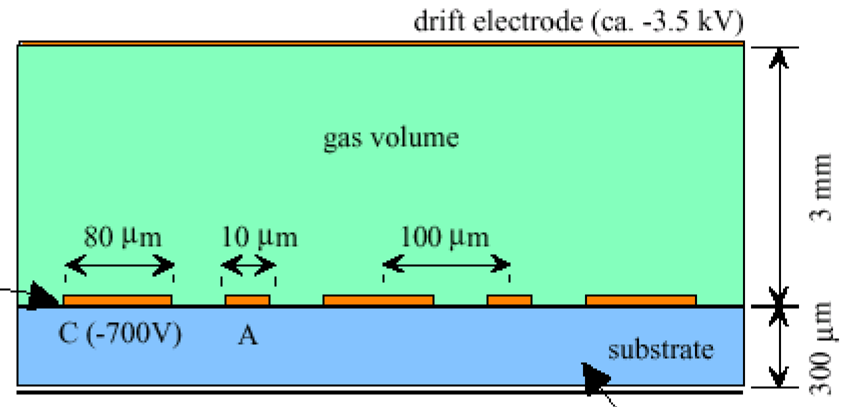


◆ Microstrip gas chambers

(A. Oed, NIM A 263 (1988) 352)

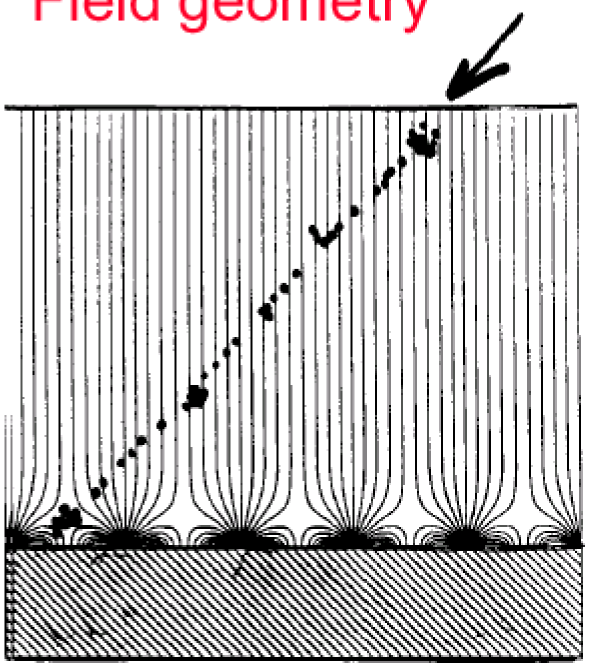
geometry and typical dimensions
(former CMS standard)

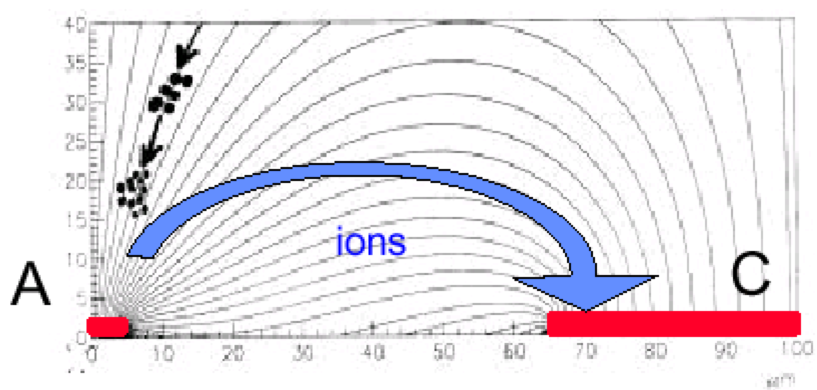
Gold strips
+ Cr underlayer



Glass DESAG AF45 + S8900
semiconducting glass coating,
$\rho = 10^{16}\ \Omega/\square$

Field geometry





Fast ion evacuation → high rate capability
≈ 10^6 /(mm^2·s)

CHARGE BUILD UP ON MICROSTRIPS

THE SUBSTRATE ON MICROSTRIPS HAS A HIGH RESISTANCE

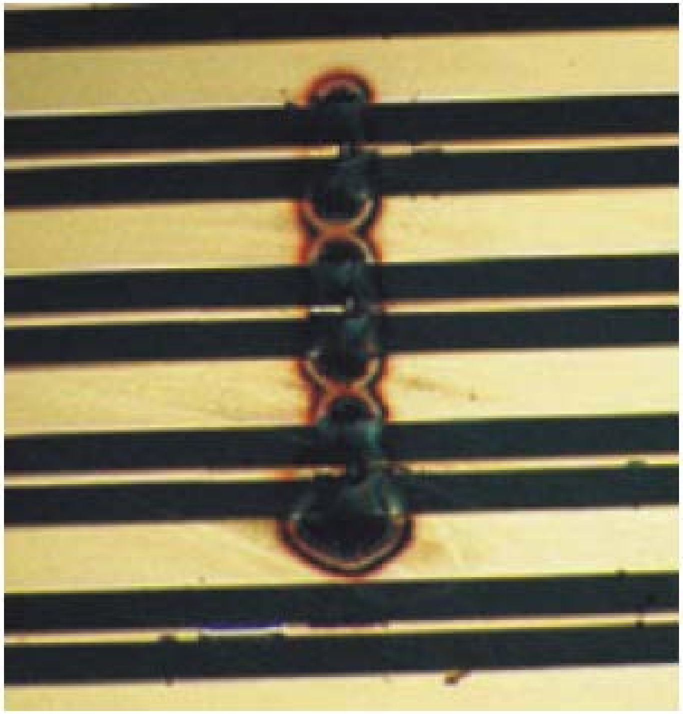
IN VERY HIGH RATE ENVIRONMENT

→ CHARGE BUILD UP

→ DISCHARGE

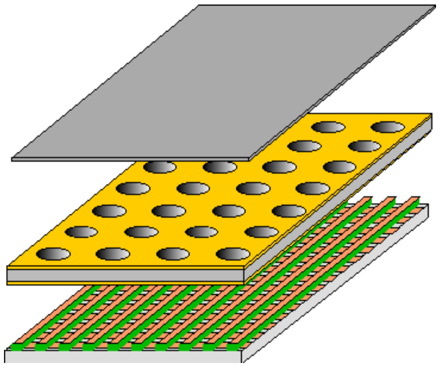
→ DAMAGE

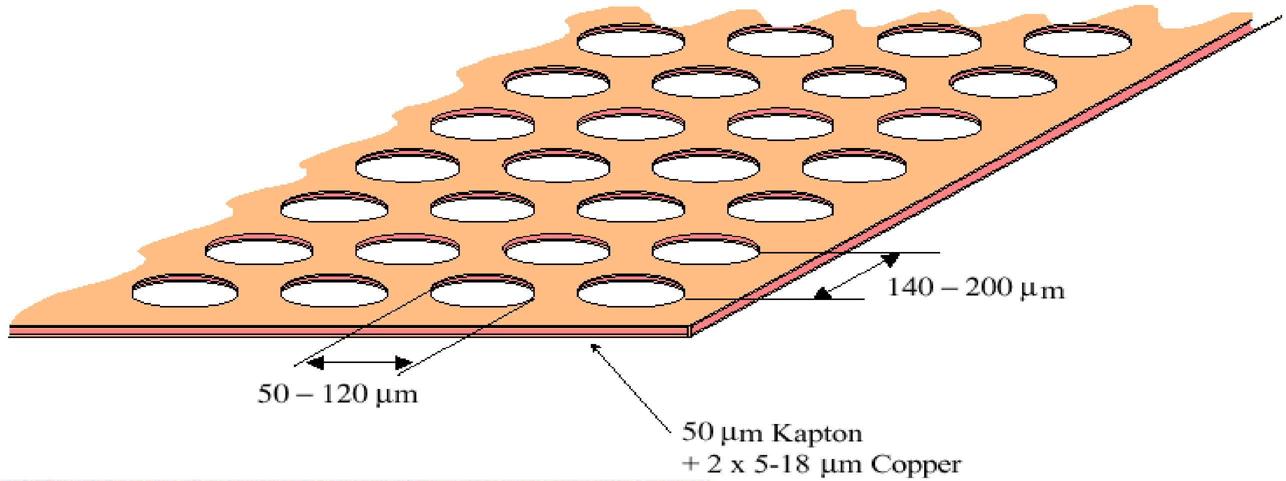
b

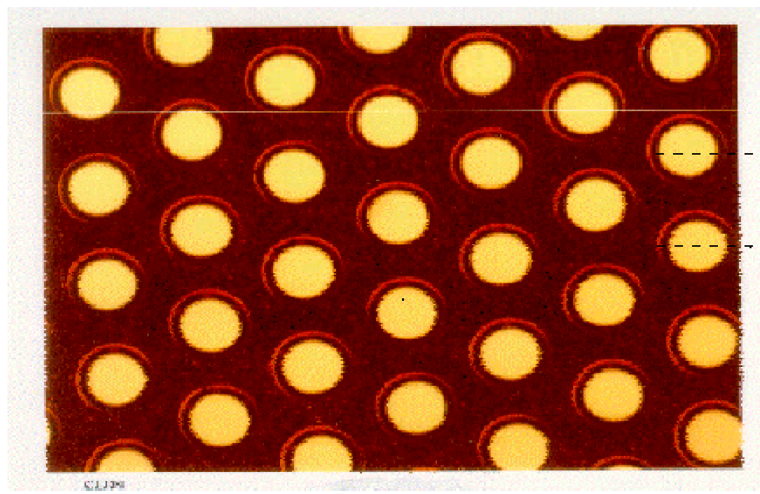


GEM: The Gas Electron Multiplier

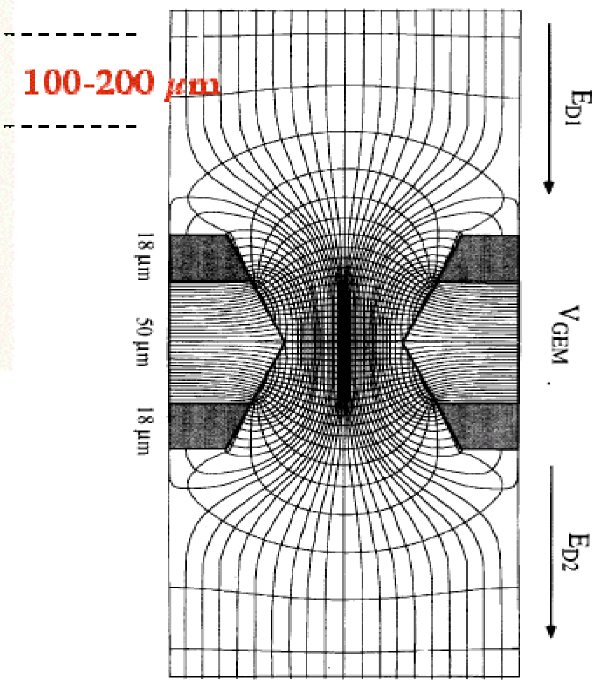
(R. Bouclier et al., NIM A 396 (1997) 50)

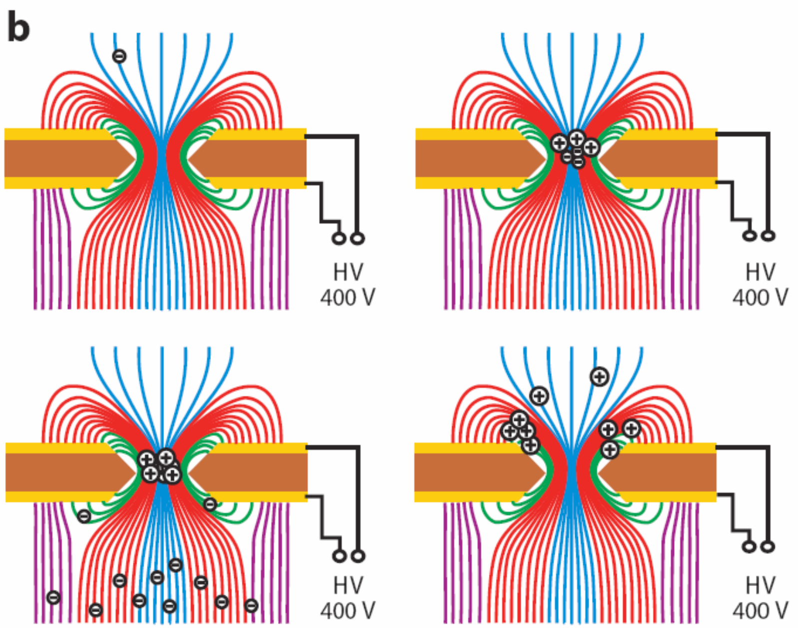


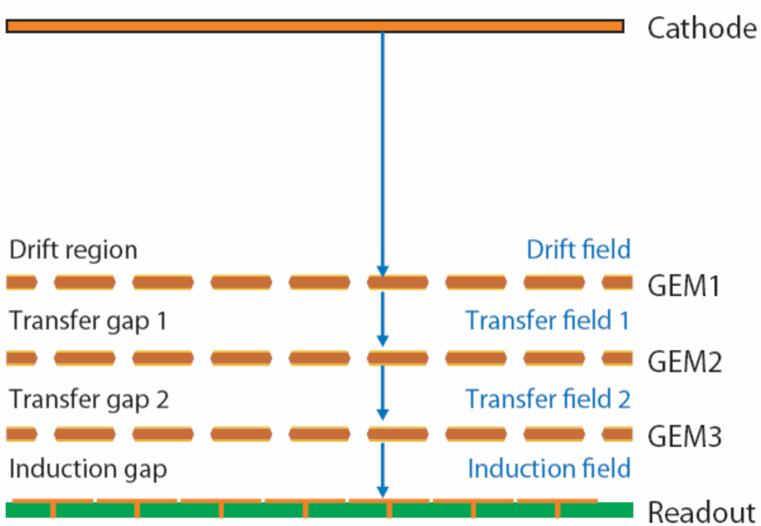




Micro photo of a GEM foil







IN THE GEM

GAS AMPLIFICATION DECOUPLED FROM READ OUT REGION

→ HIGH RATE

→ NO SPACE CHARGE

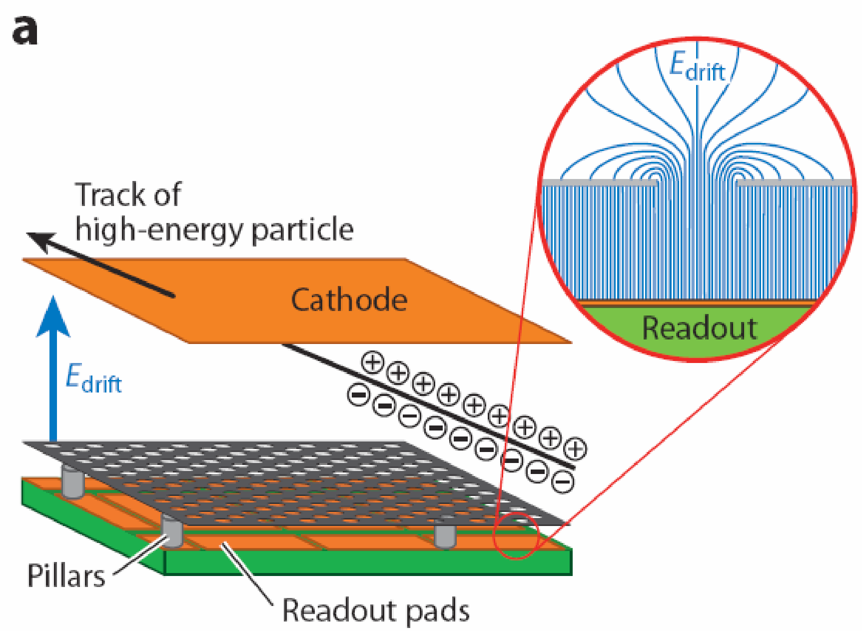
→ NO BREAKDOWN

BECAUSE IONS DO NOT PENETRATE GEM FOIL

CAN CASCADE FOILS TO GET LARGE ENOUGH GAIN

$\sim 10^4$

MICRO MEGA



TWO STAGE DETECTOR

LARGE DRIFT REGION

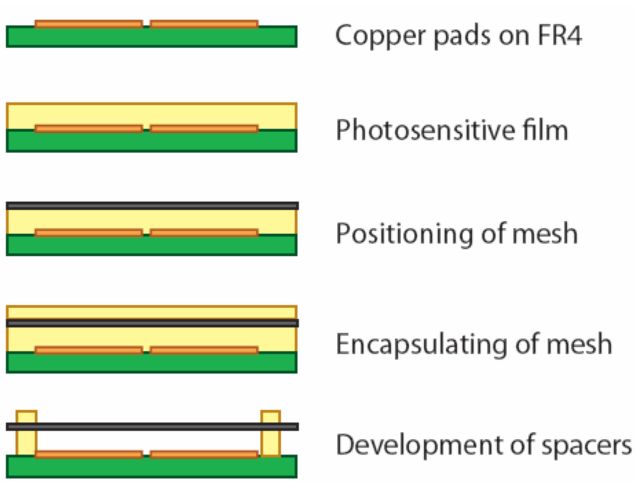
~ 100 V / cm

SMALL AMPLIFICATION REGION

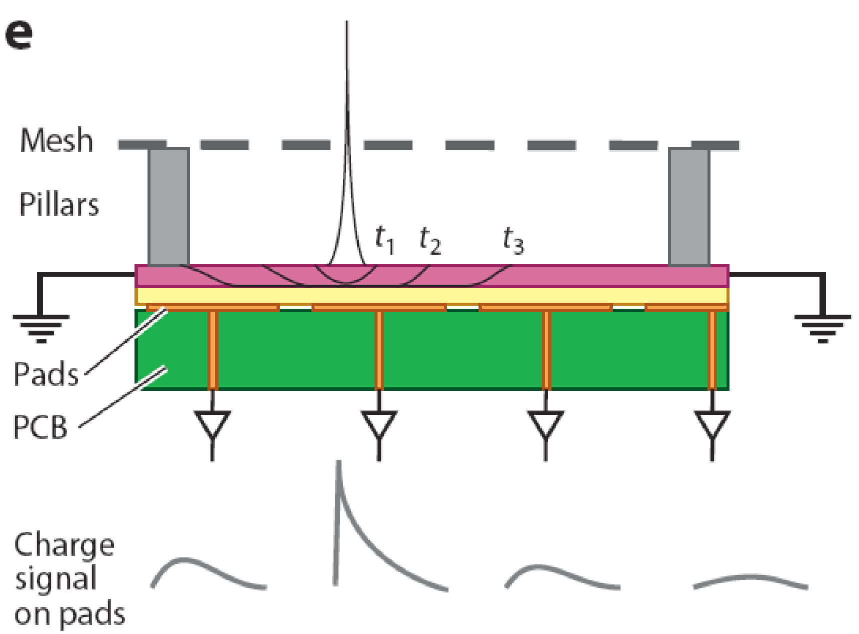
~ 10 kV / cm

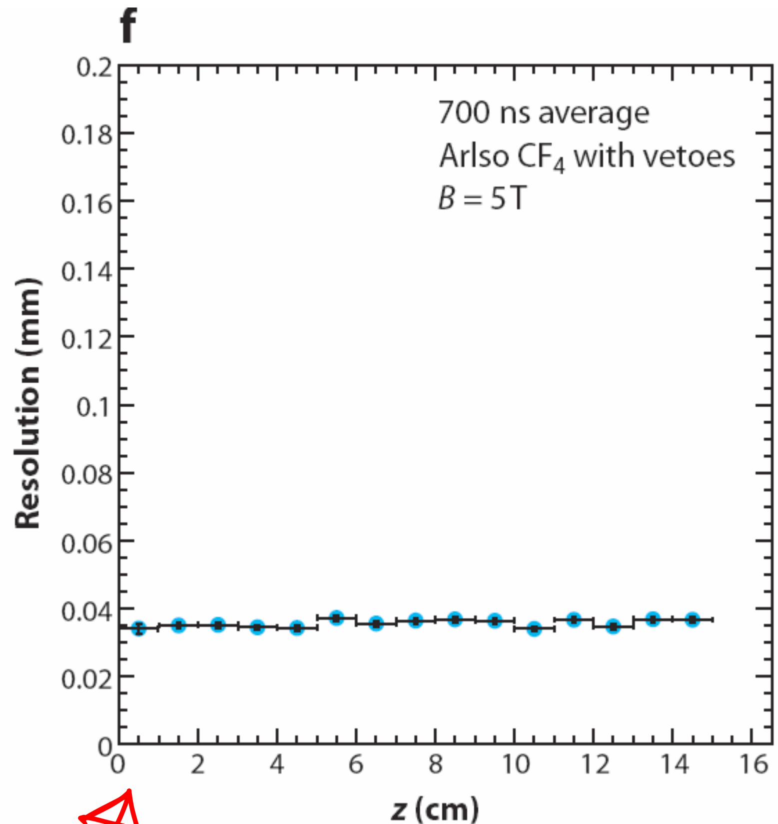
GAS GAIN ~ 10^4

RESOLUTION ~ 70 μm



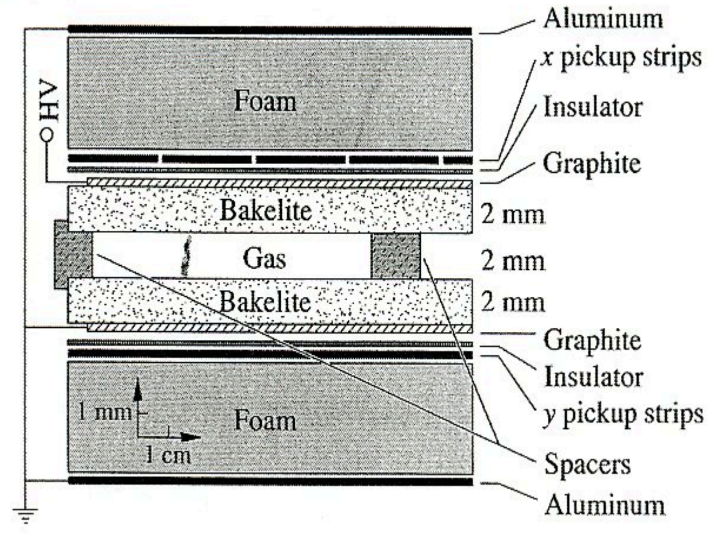
TYPICAL CONSTRUCTION



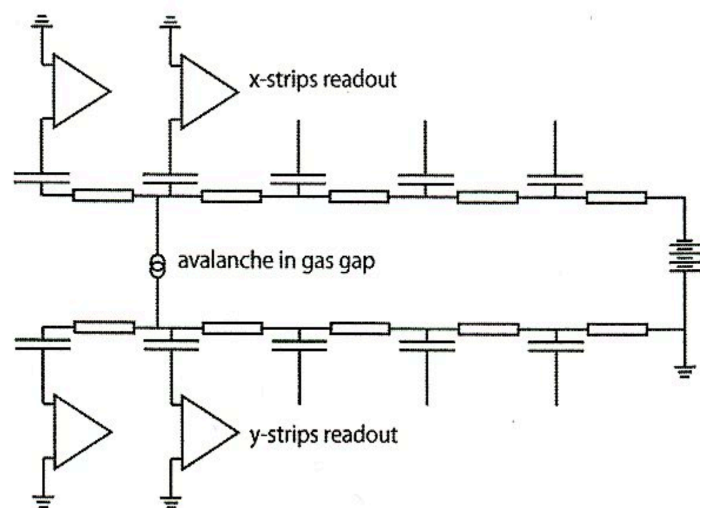


MICROMEGA USED AS READ OUT IN TPC

→ RESISTIVE PAD CHARGE SHARING FOR IMPROVED SPATIAL PRECISION



(a)



(b)

Fig. 4.25 (**a**) Typical structure of a resistive plate chamber (RPC). Figure from Ref. [6] in Chap. 1, with permission. (**b**) Equivalent electric circuit representing the readout of an RPC