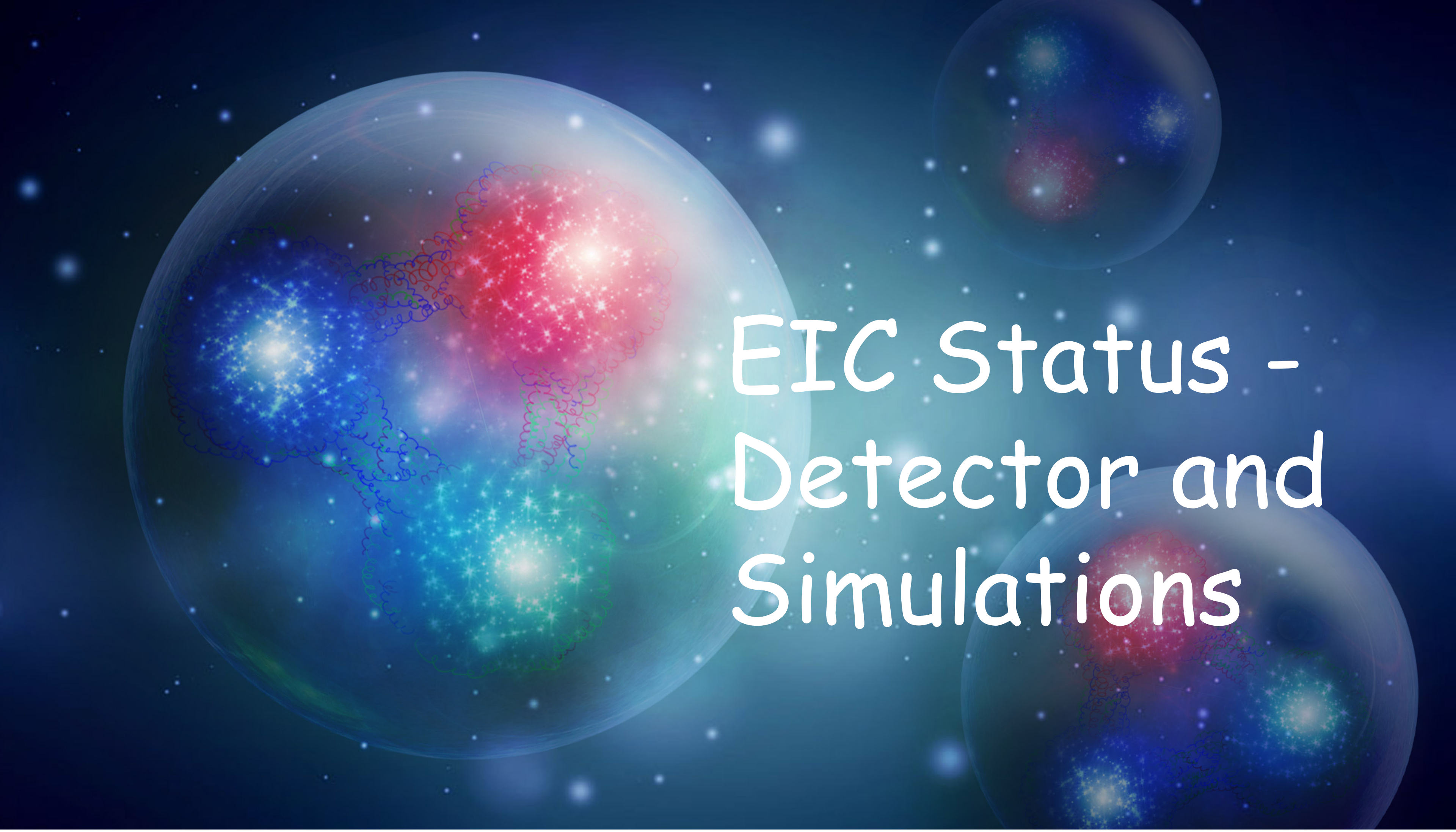


# EIC Status - Detector and Simulations

Yulia Furletova (JLAB)

HUGS lectures

# Outline

- Introduction to EIC
  - Highlights of EIC physics
  - EIC accelerators proposals
- Introduction to Deep Inelastic Scattering
  - DIS kinematic

Lecture-1

- EIC detector design
  - Tracking
  - Vertex

Lecture-2

  - Calorimeter
  - Muon detectors

Lecture-3

  - Particle Identification detectors
    - dE/dx
    - Time of flight
    - Cherenkov
    - Transition radiation

Lecture-4

- Detector simulation and reconstruction
- Conclusions

Lecture-5

# Tracking detectors:

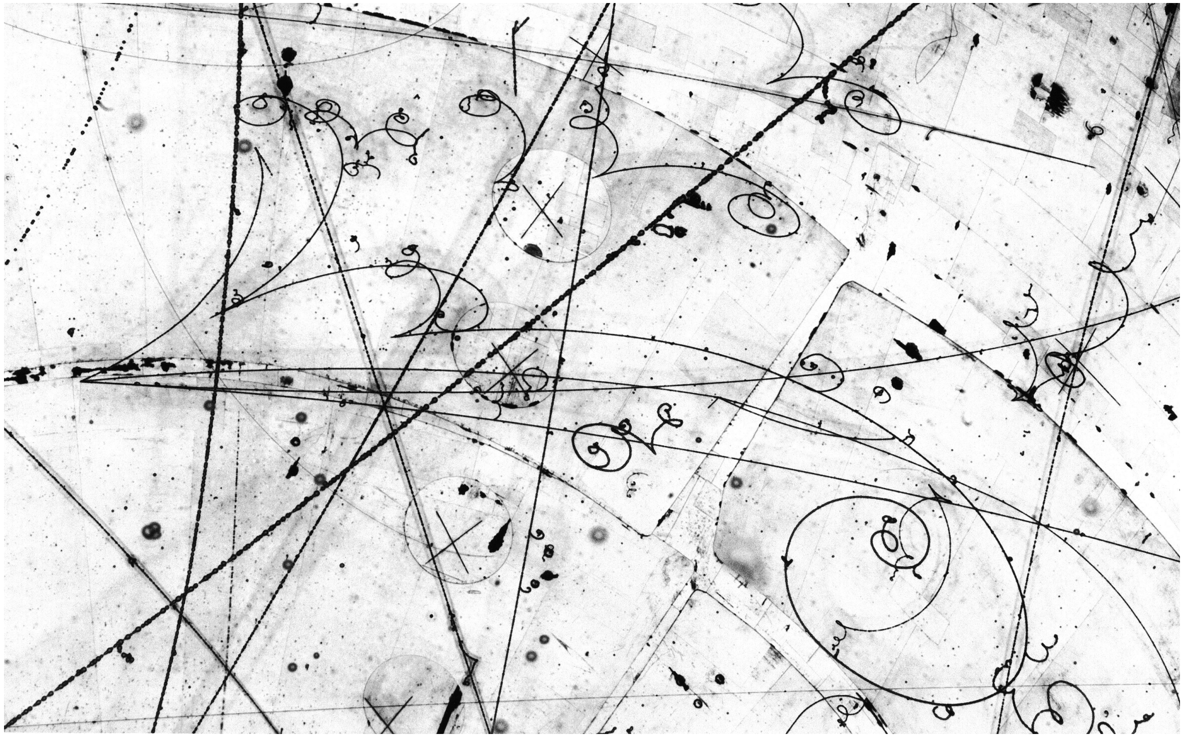
- Introduction to tracking
  - History
- Detector technology
  - Gaseous detectors:
    - Straw tubes
    - Multi-wire chambers
    - Time projection chambers
    - GEM
  - Silicon detectors
- Momentum measurements
  - Energy loss
  - Momentum reconstruction
  - Momentum resolution
    - Resolution of measured track
    - Multiple scattering

- Simulation, Reconstruction, etc.

Inspired by Erika Garutti's and Norbert Wermes's lectures

# Tracks

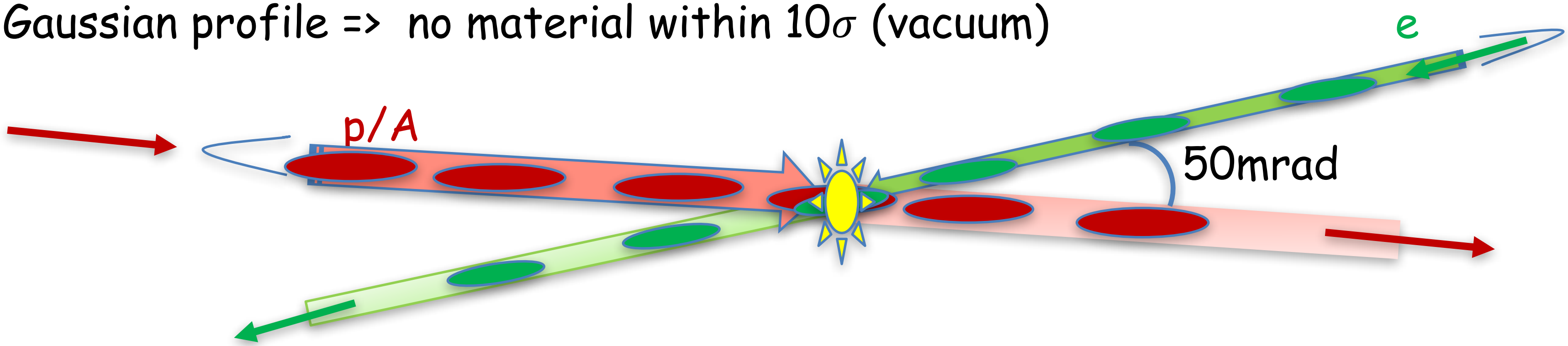
# Tracks in particle physics



- Particles have to interact with material of detector

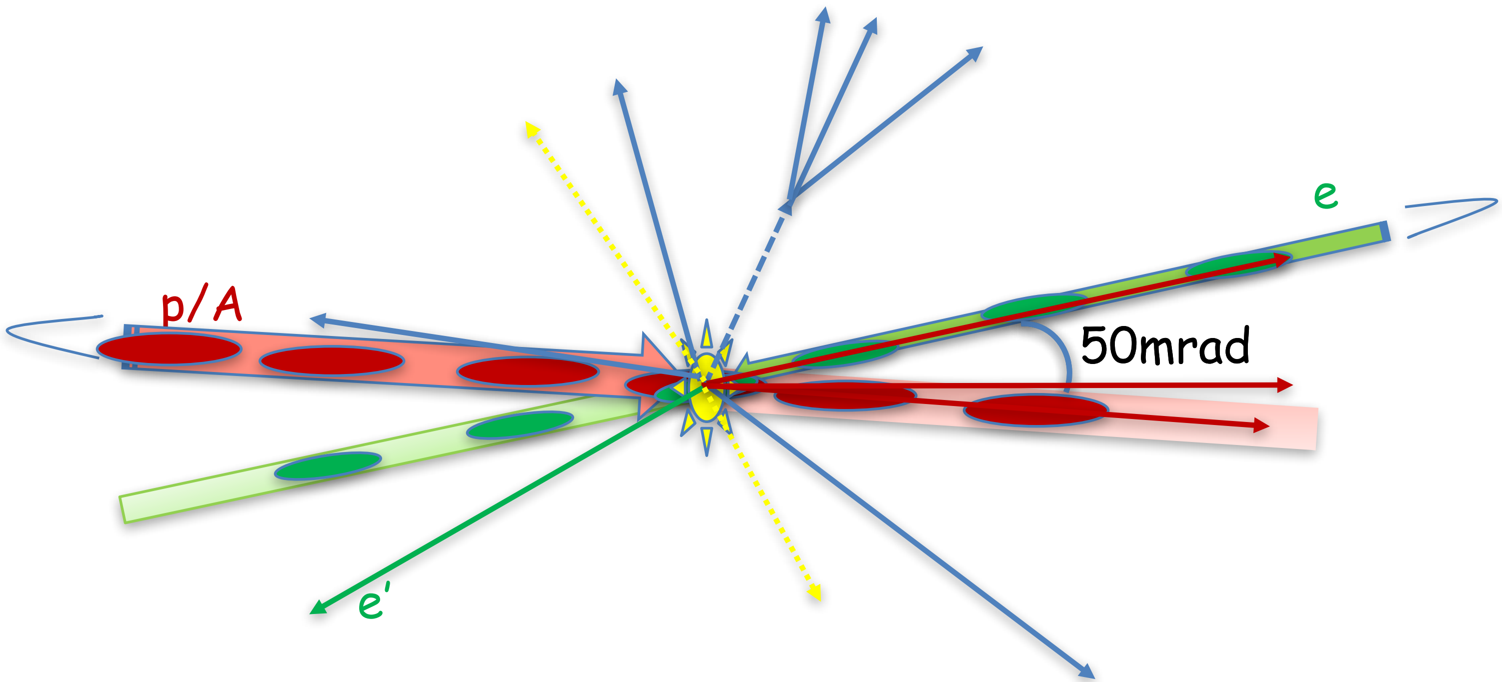
# Tracking detectors

Accelerator:
- -50mrad crossing angle
- -repetition: every 2ns new bunch
- -Bunches with $10^{10}$ particles in each
- -x-y Gaussian profile => no material within $10\sigma$ (vacuum)

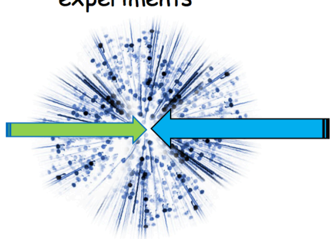


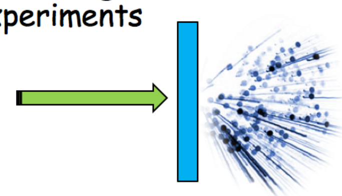

Beampipe radius: 3.2cm

# Tracking detectors: physics

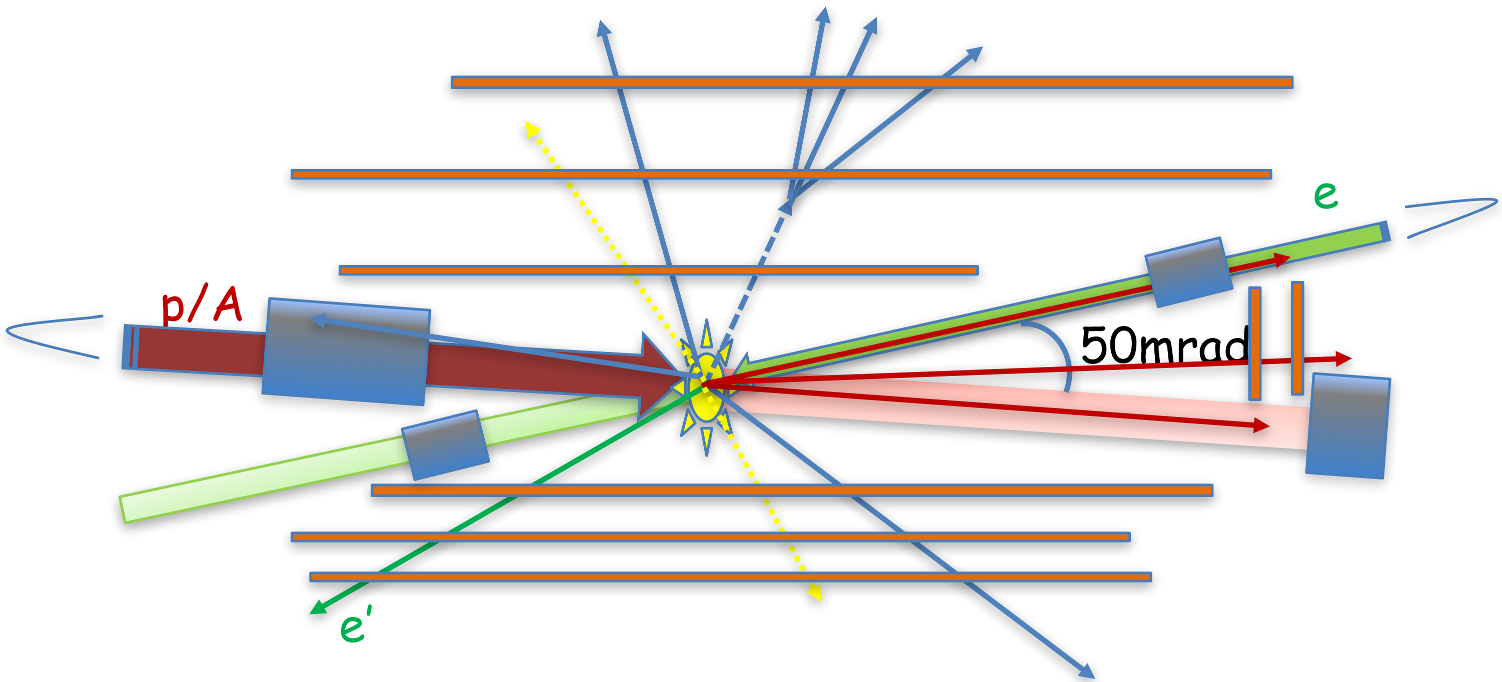



Physics:
- -particles going into $4\pi$
- -Particle origination (vertex)
- -what would be an event multiplicity?
- -What will happen with proton/ion remnant?



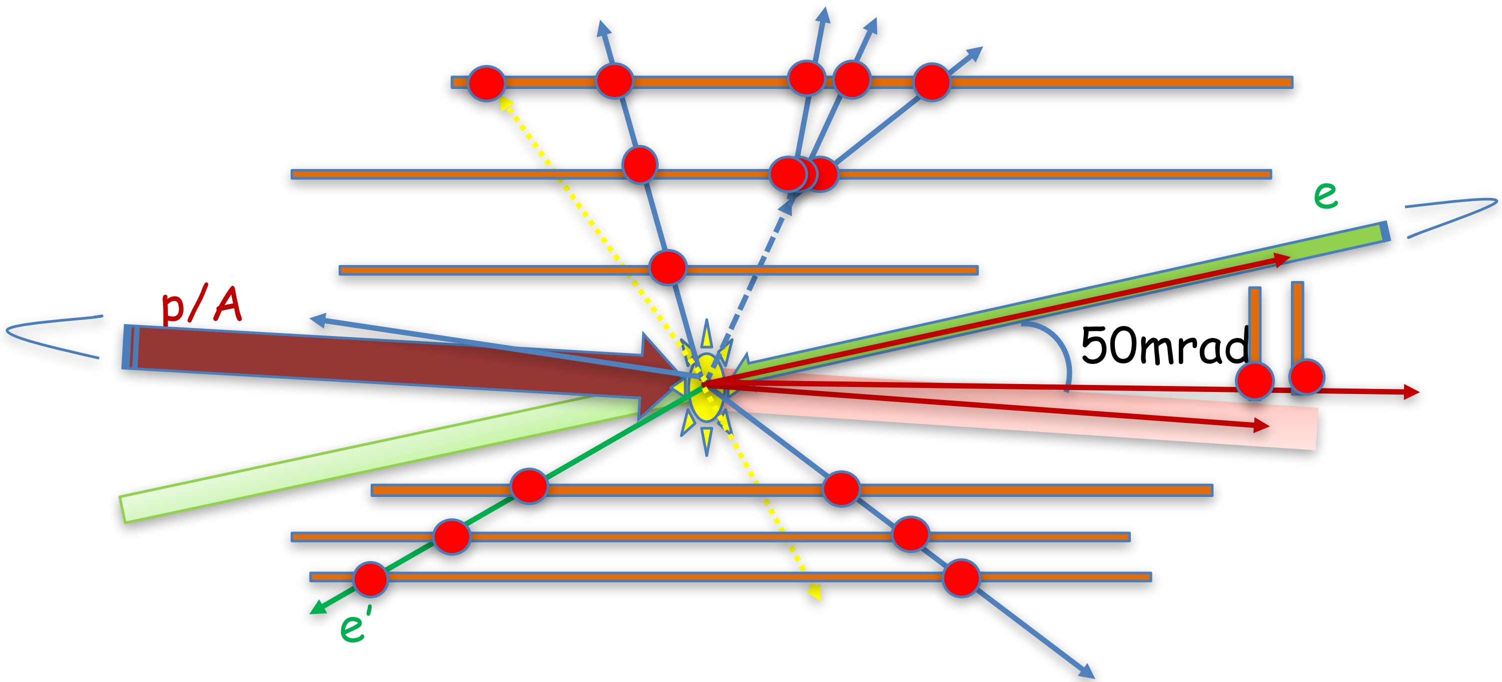
# Tracking: detectors




Detectors:

- Acceptance
- Beampipe/beam elements limit an acceptance
- Beampipe diameter (3.2 cm): closest position for detectors

# Tracking detectors: particles




- Particles have to interact with material of detector:
- 
  - ✓ Charged particles: leave energy along the track (dE/dx)
  - ✓ Gammas- depending on energy : no tracks

- Need to measure charge and momentum



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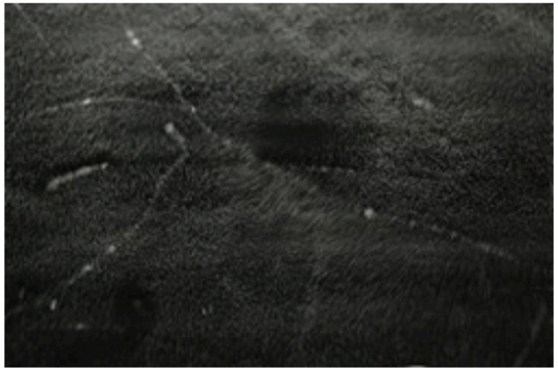
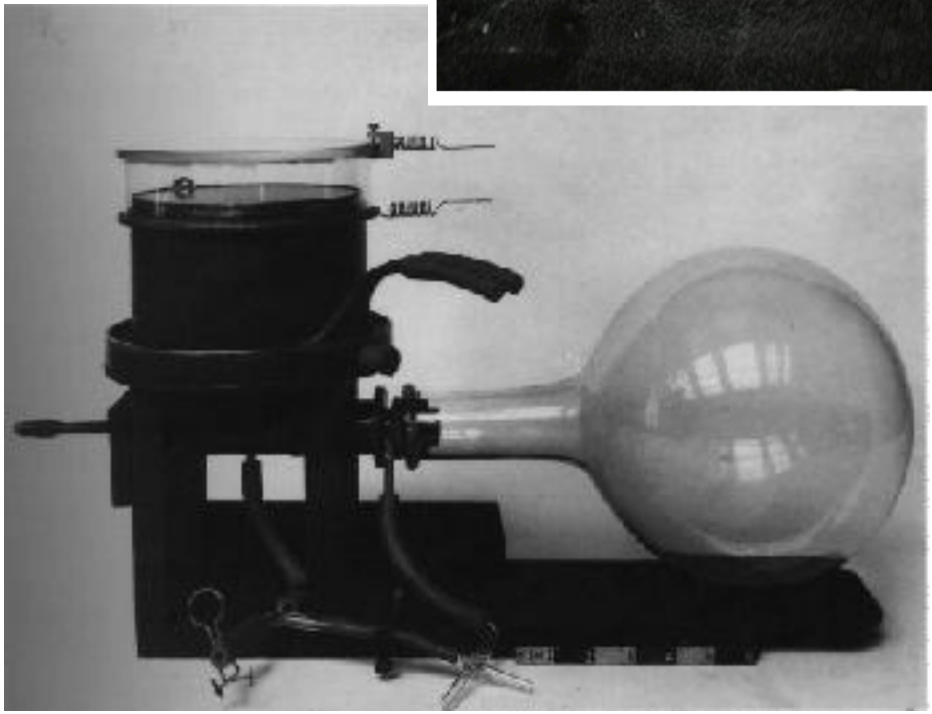
# Cloud chamber:

-Ionizing particle passed a supersaturated vapor
-Radiation disturbs the vapor (condensation)
-Track forms along the particle path
-Tracks can be seen in  real time





Wilson Cloud Chamber, 1911



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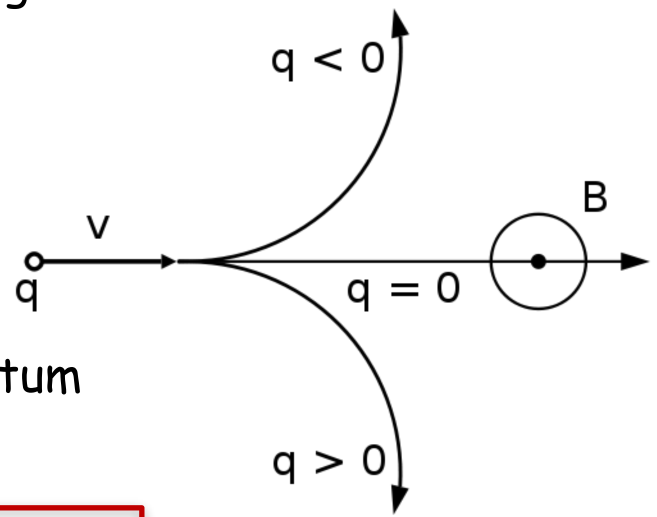
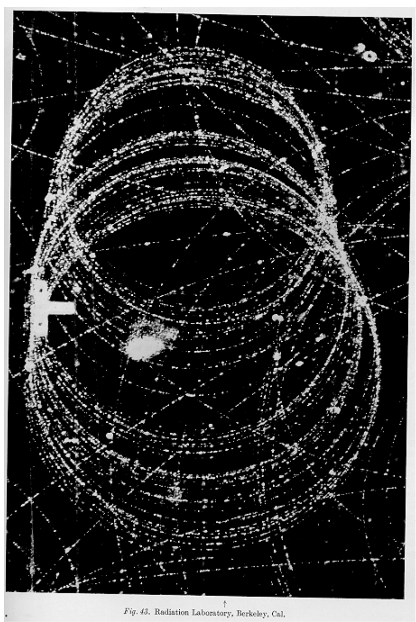
# Tracking detectors: magnetic field

Magnetic field to measure momentum and charge



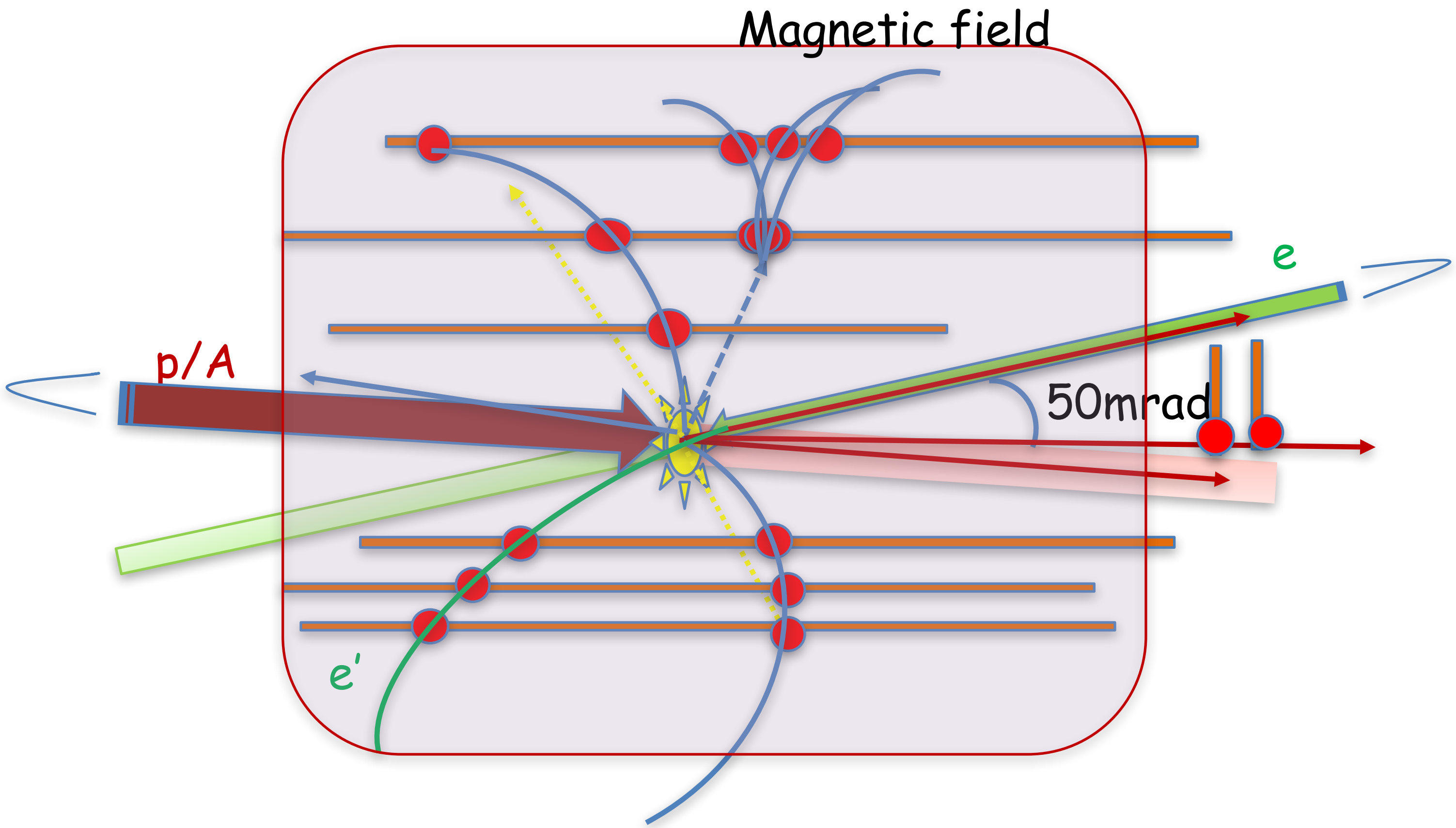

-bending radius depends on a particle momentum
-charge (right, left)

$$p[GeV] = 0.3 \cdot B\,[T] \cdot R\,[m]$$



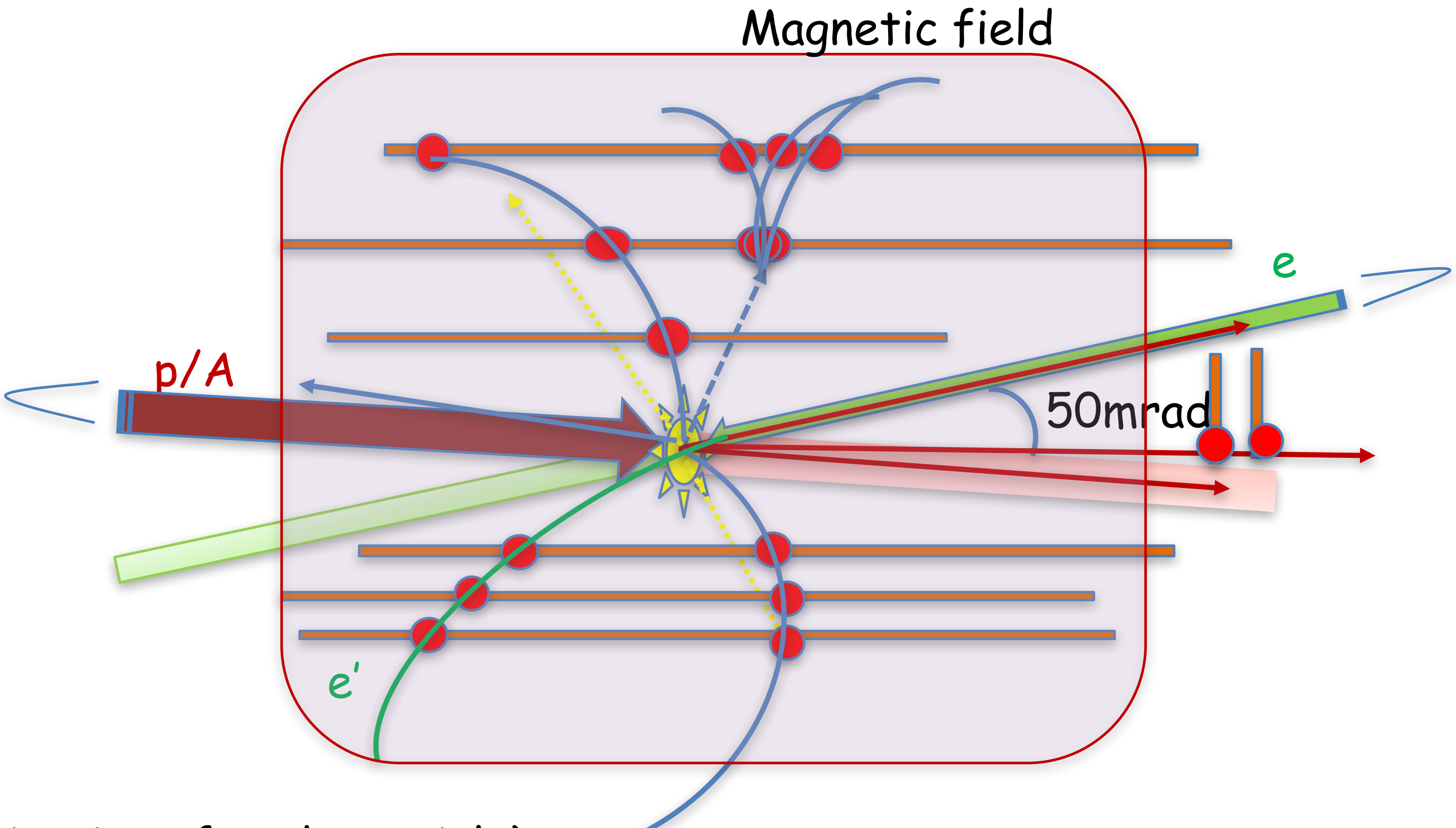

Electron in a magnetic field at the Bevatron, 1940

# Tracking detectors




Magnetic field to measure momentum and charge

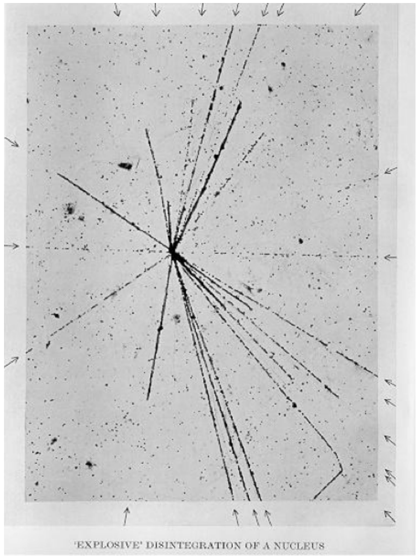
# Tracking detectors: physics



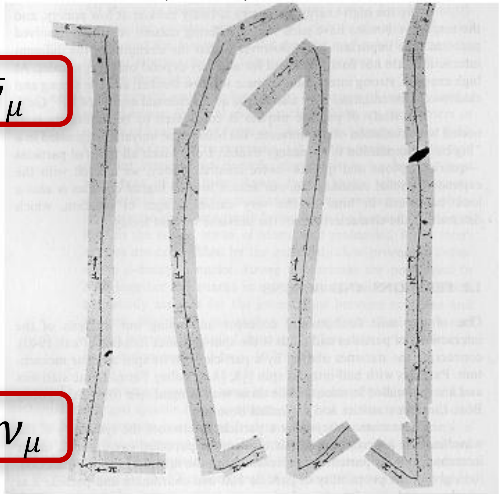

-Vertex (origination of each particle):
- ❖ Primary vertex (interaction point)
- ❖ Secondary vertices (how far?) :

# Emulsion:

nuclear disintegrations in 1937




Discovery of pion and muon



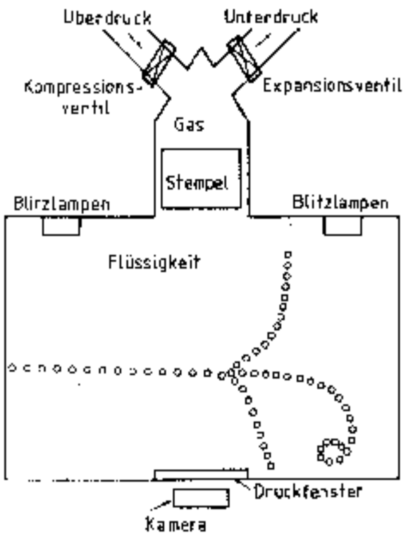
$\pi^- \to \mu^- \bar{\nu}_\mu$

$\mu^- \to e^- \bar{\nu}_e \nu_\mu$

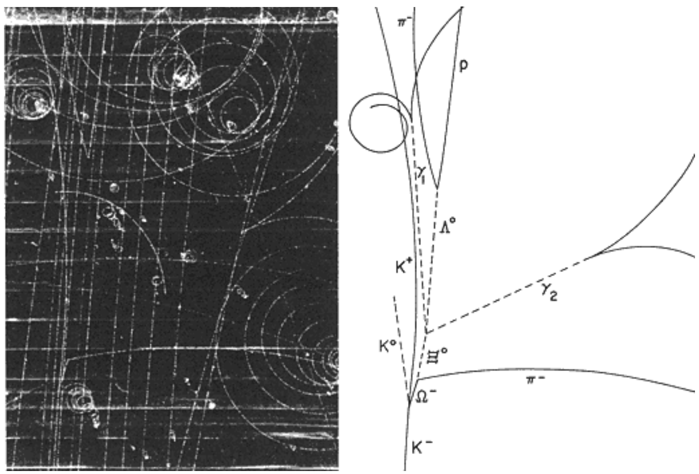
- Film played an important role in the discovery (and studying) radioactivity rather than photographing individual particles.
- Marietta Blau pioneered the nuclear emulsion technique (in 1920-30ies)
- For particle physics emulsions were exposed to cosmic rays at high altitude for a long time (months) and then analyzed under the microscope.
- Advantages: images are permanent and high precision.
- High density- easier to see energy loss and disintegrations.
- Length of the track showed a life time

# Bubble and Spark chambers:

The Spark Chamber was developed in 60ies.

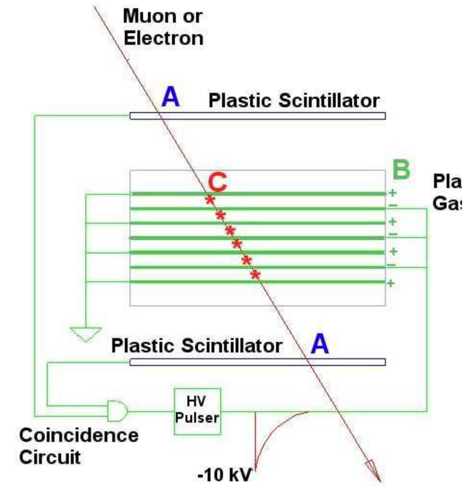



Bubble chamber

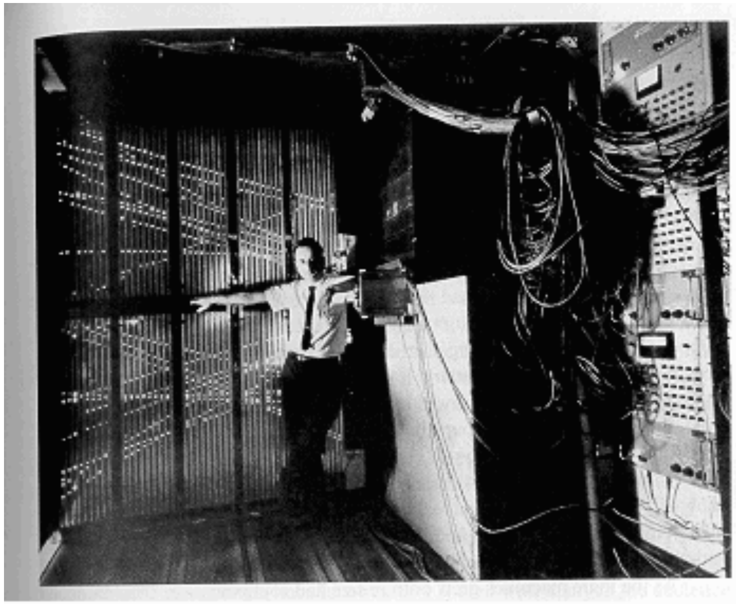



Discovery of the Ω in 1964

The scintillators trigger an HV pulse between the metal plates and sparks form in the place where the ionization from charged particle took place.




Spark chamber



every interaction must be photographed and millions of images must be analyzed manually by 'operators'.



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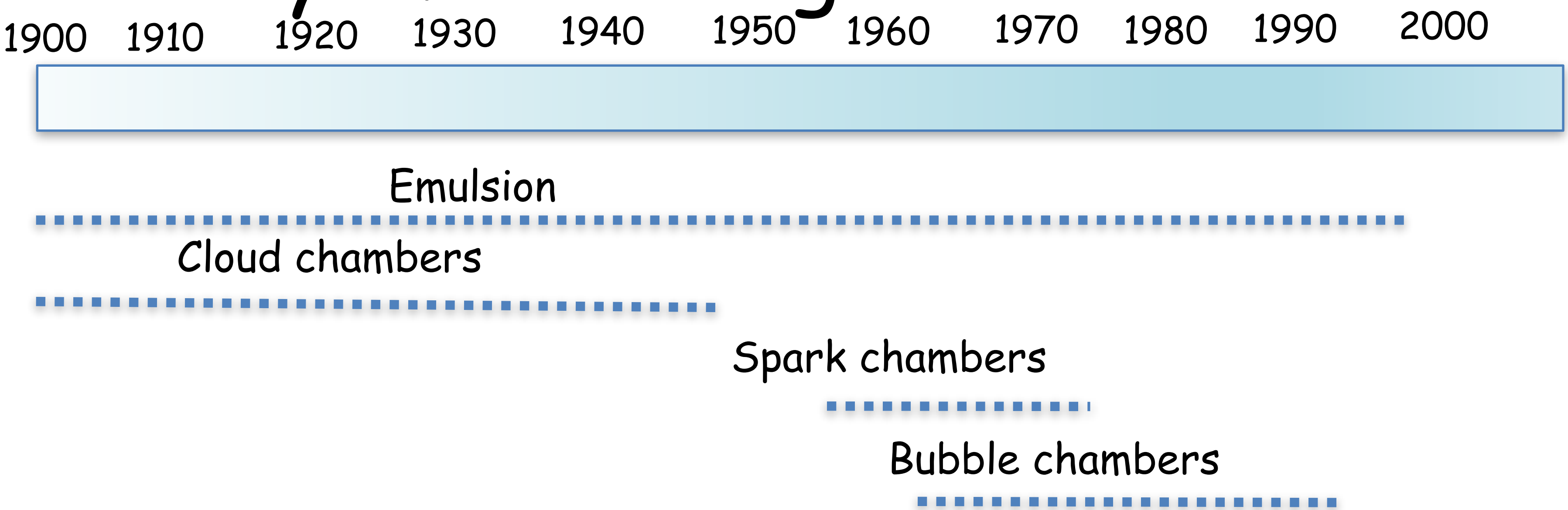
# History of tracking detectors:

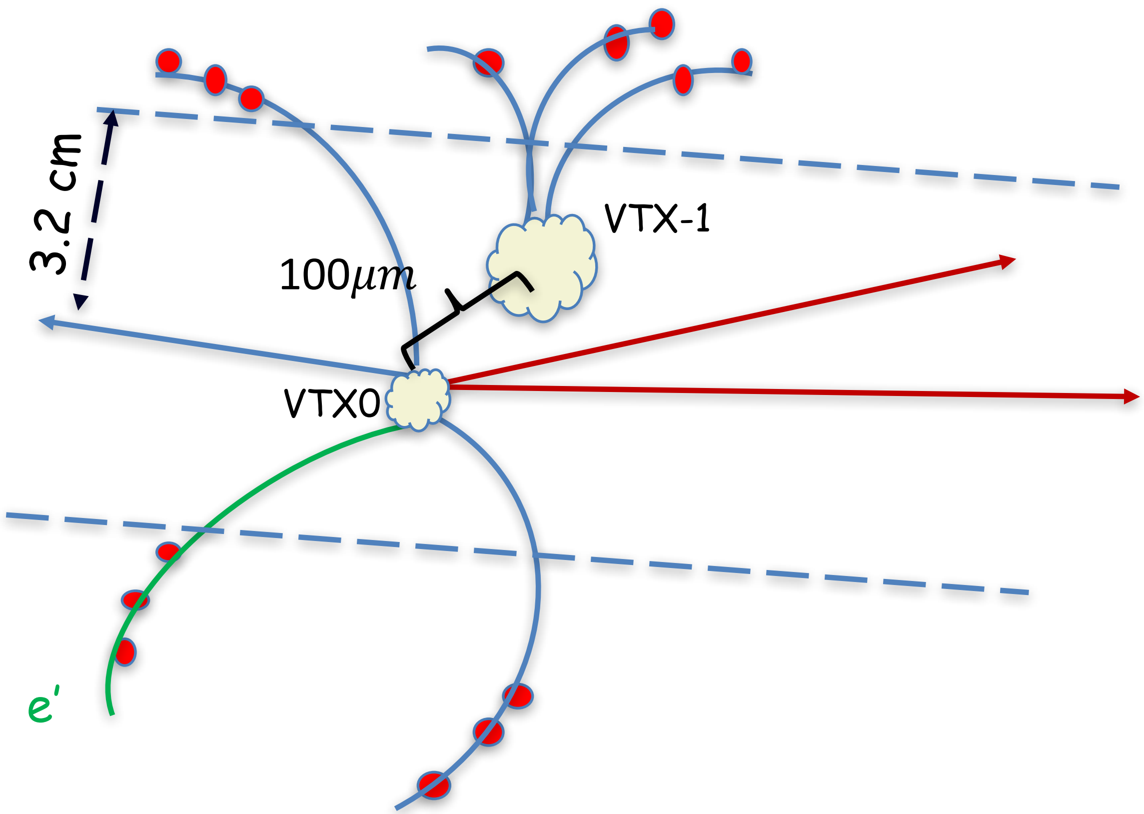


- Cloud chambers
- Emulsion
- Bubble chambers
- Spark chambers

We are not using them anymore at colliders

# Tracking detectors

For example, $D^+ \rightarrow \pi^- K^+ \pi^+$



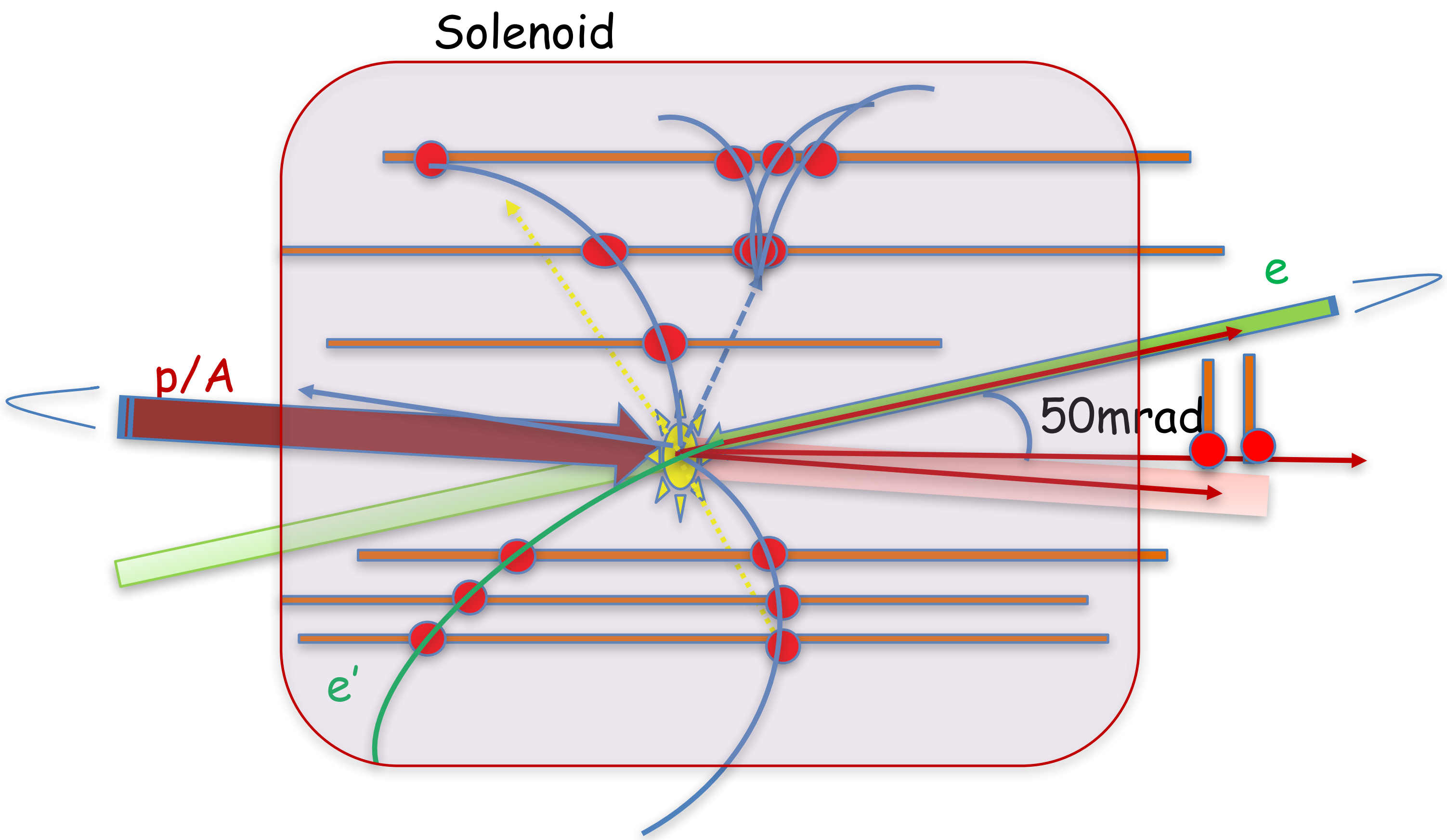

Challenge:

-Secondary vertices: D-mesons (lifetime) ca 100-300$\mu m$ ( our hair 50-150 $\mu m$)

-Beampipe radius: 3.2cm

=> Need to place High granularity and precision detector close to beampipe

# Tracking detectors




Challenge: Forward going particles:
- Going inside beampipe
- No Magnetic field.



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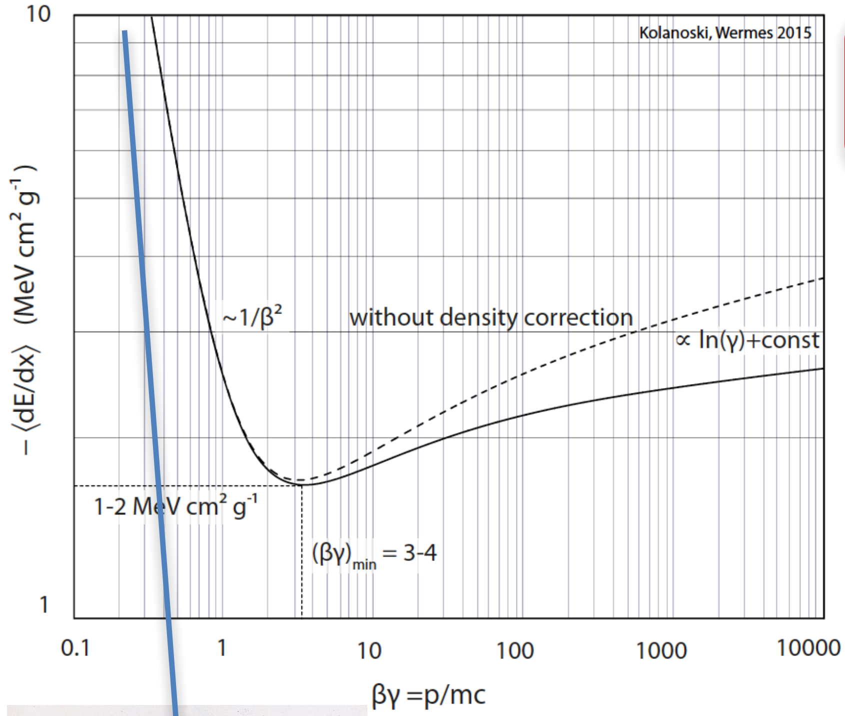
# Tracking detectors in particle physics (position sensitive detectors)

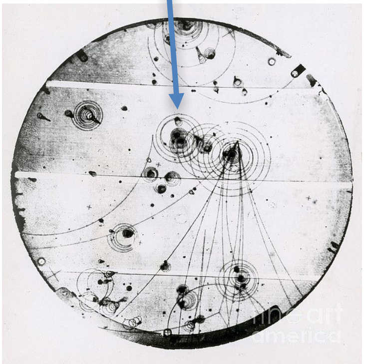
- Electronically recordable hits/tracks
- Provide precise space point coordinates/trajectory of charged particles
- Provide momentum measurements in magnetic (B) field
- Provide angle measurements
- Provide measurements of primary and secondary vertices
- Provide a multitrack separation
- Provide a particle identification (if possible ) -> next lectures
- Keep a minimum of material along the path of particles to minimize scattering and secondary interactions.

# Energy loss

➢ Particles have to interact with material of detector

Most tracking detectors are ionization detectors



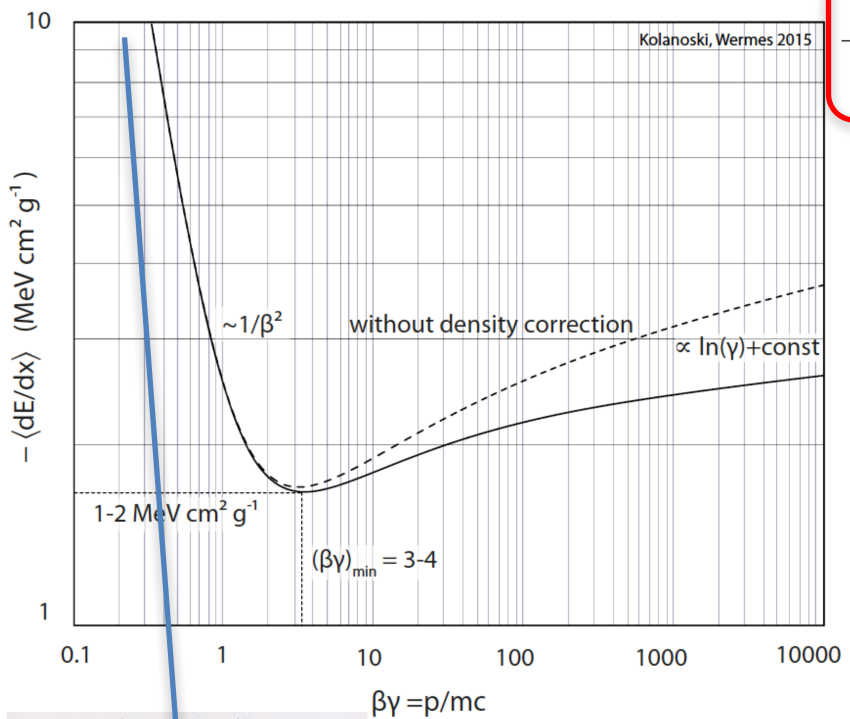
Bethe-Bloch formula:

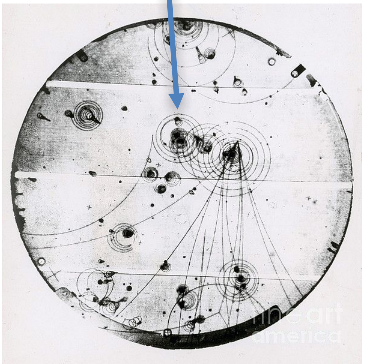
$$-\left\langle \frac{dE}{dx} \right\rangle = K \frac{Z}{A} \rho \frac{z^2}{\beta^2} \left[ \frac{1}{2} \ln \frac{2 m_e c^2 \beta^2 \gamma^2 T_{max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} - \frac{C(\beta\gamma, I)}{Z} \right]$$

- Almost does NOT depend on material (Z/A ~ ½)
- Proportional to $z^2$
- Depends on $\beta\gamma$ = p/E *E/m = p/m
- The same curve for all z=1 particles when plotted as a function of $\beta\gamma$ )
- Have a minimum at $\beta\gamma$ =3-4
- Plateau at high $\beta\gamma$
- But… different curves when plotted as function of p(momentum) -> particle identification

# Energy loss

Most tracking detectors are ionization detectors

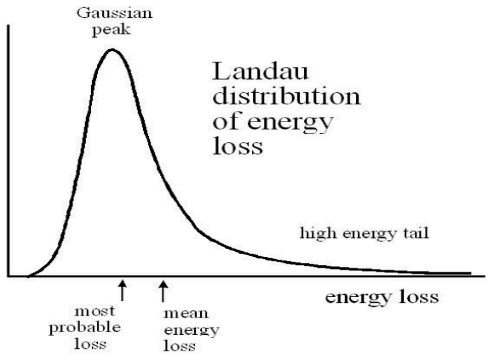


$$-\left\langle \frac{dE}{dx} \right\rangle = K \frac{Z}{A} \rho \frac{z^2}{\beta^2} \left[ \frac{1}{2} \ln \frac{2 m_e c^2 \beta^2 \gamma^2 T_{max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} - \frac{C(\beta\gamma, I)}{Z} \right]$$

- Examples of typical energy loss at minimum ionizing:
  - ✓ 1 meter air: 0.22 MeV
  - ✓ 300$\mu$m Si: 0.12 MeV
  - ✓ 1mm iron: 1.1 MeV

- Energy loss is a stochastic process (app. described by Landay distribution) with "infinitely" long tail.



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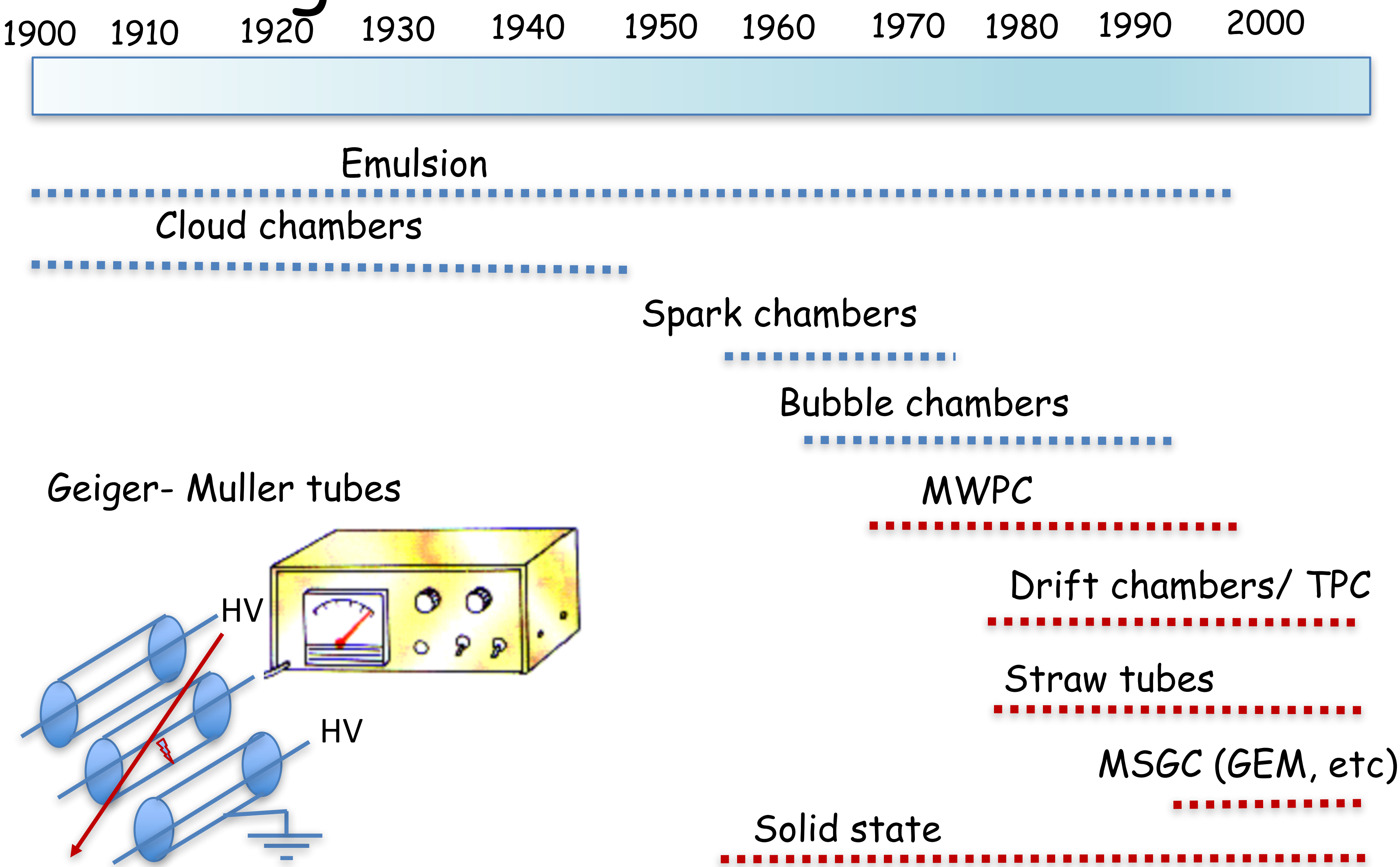
# Tracking detectors: overview

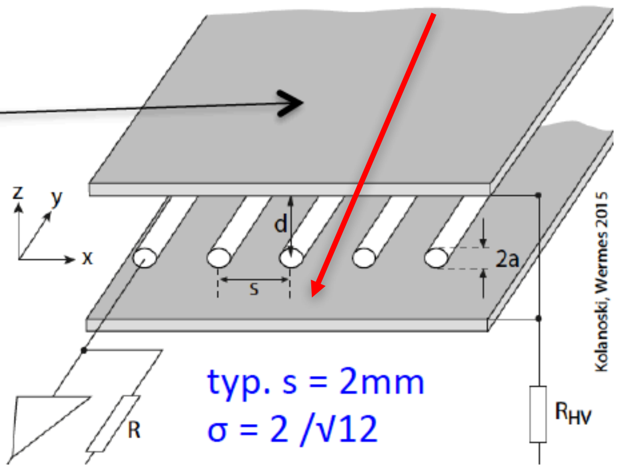



Discharge, hit/no hit

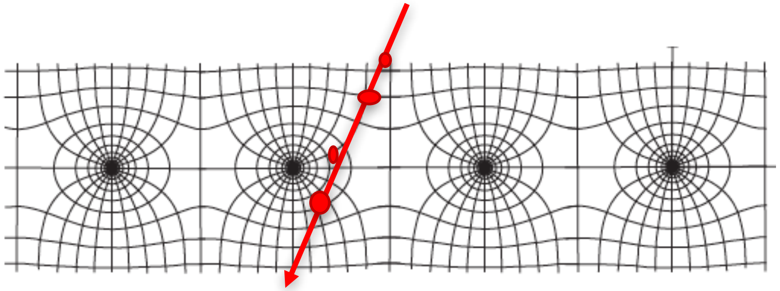
# Multi-wire proportional chamber


- mother of all wire chambers (1960ies)
- break through in tracking, because tracks became **electronically recordable**
- Measured ionization is proportional to energy loss of the incident particle (dE/dx)
- Nobel Prize 1992

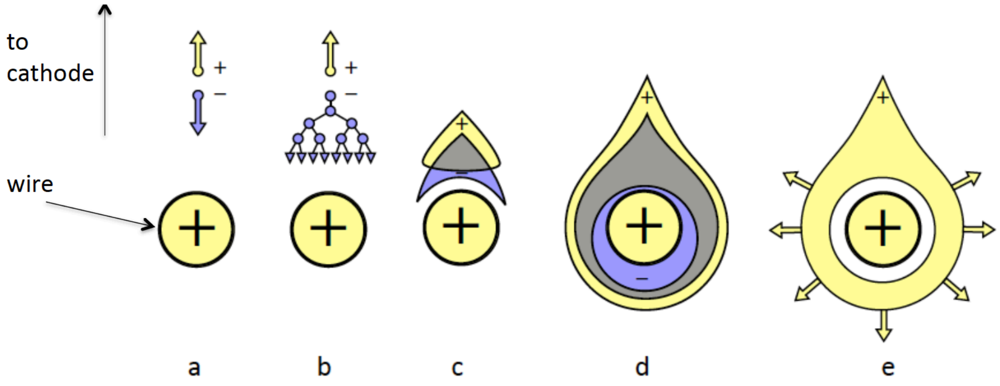
cathodes often patterned for 2nd coordinate

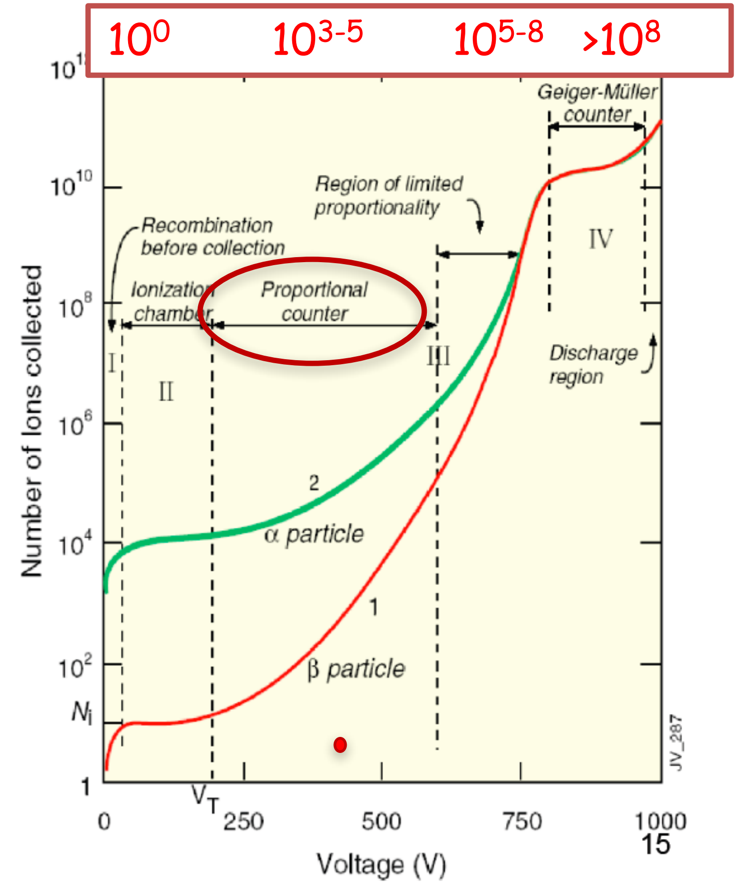



typ. s = 2mm
σ = 2 /√12



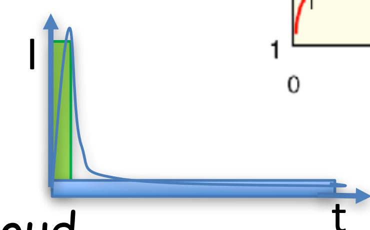
# Signal development in a wire chamber



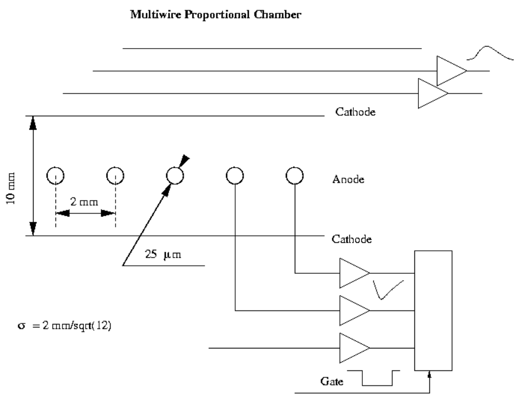

- Field shape: 1/r dependence
- operation point depends on configuration and gas mixture: gain > $10^6$ strong secondary ionization

- Fast signal from elections and long tail coming from ion cloud



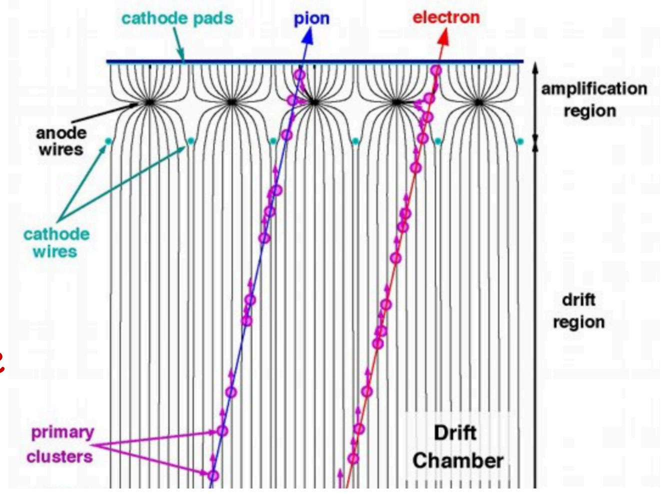

- space charge effects (stationary ion cloud decreases the electric field at the anode) destroy 1/r shape near wire => with a **high track multiplicity** could create an effect of space charge

# MWPC vs Drift chamber

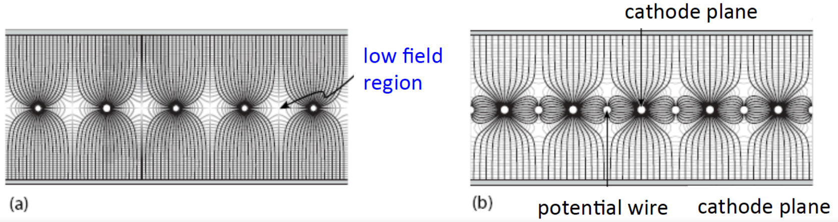



- MWPC limited resolution: for very narrow wire spacing due to electrostatic repulsion: typ.: s > 1mm (for ~10 µm wire) , Z ~25cm. Spatial resolution is determined by anode wire spacing.
- Space point resolution ~ $1/\sqrt{12}\, mm$

- Obtain better resolution by measurement of arrival time of the electron cloud : 50-150 $\mu m$



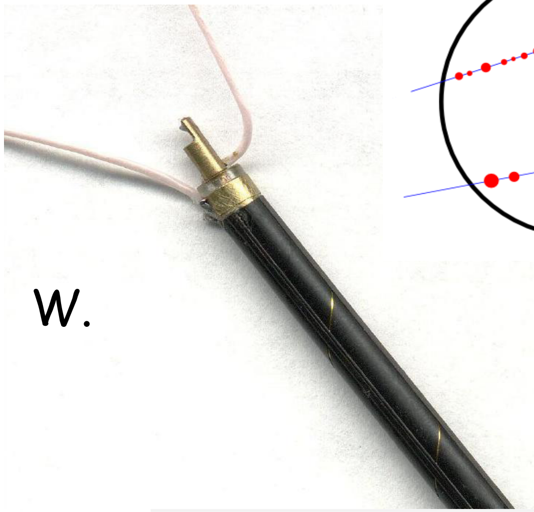

- Drift chamber distance between anode wires is increased to 2-4 cm
- need additional "potential wire" to avoid low field regions

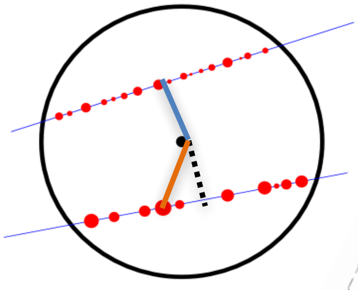


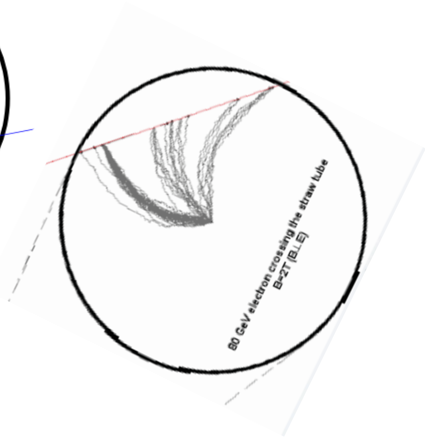

- Disadvantages: Single broken wire: remove/repair a whole sector.

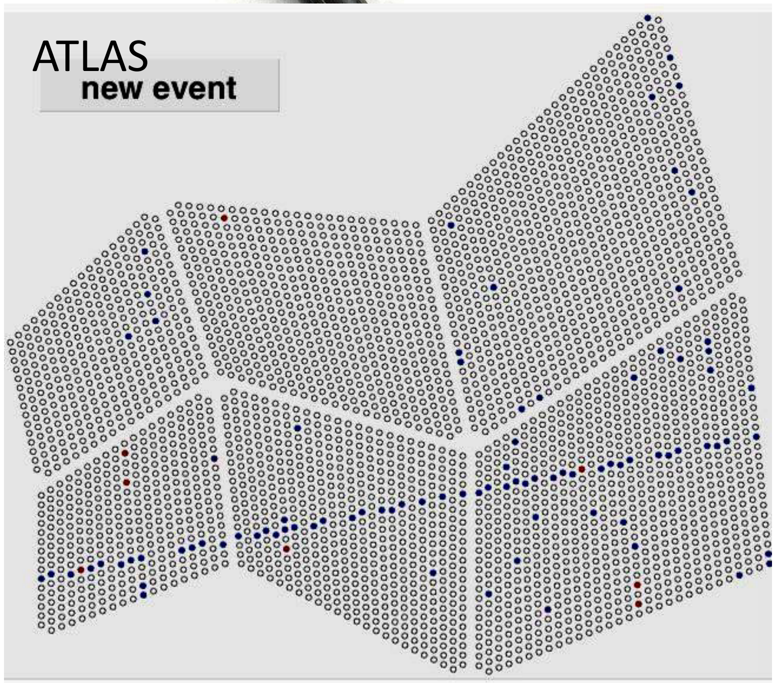
# Straw tube tracker

- Individual cathodes for each wire diameter 4-10 mm Al +C coated kapton
- wire: 50-30 μm goldplated W.
- Drift time measurements
- Need to know arrival time of a cluster, closest to a wire, precisely to determinate distance.









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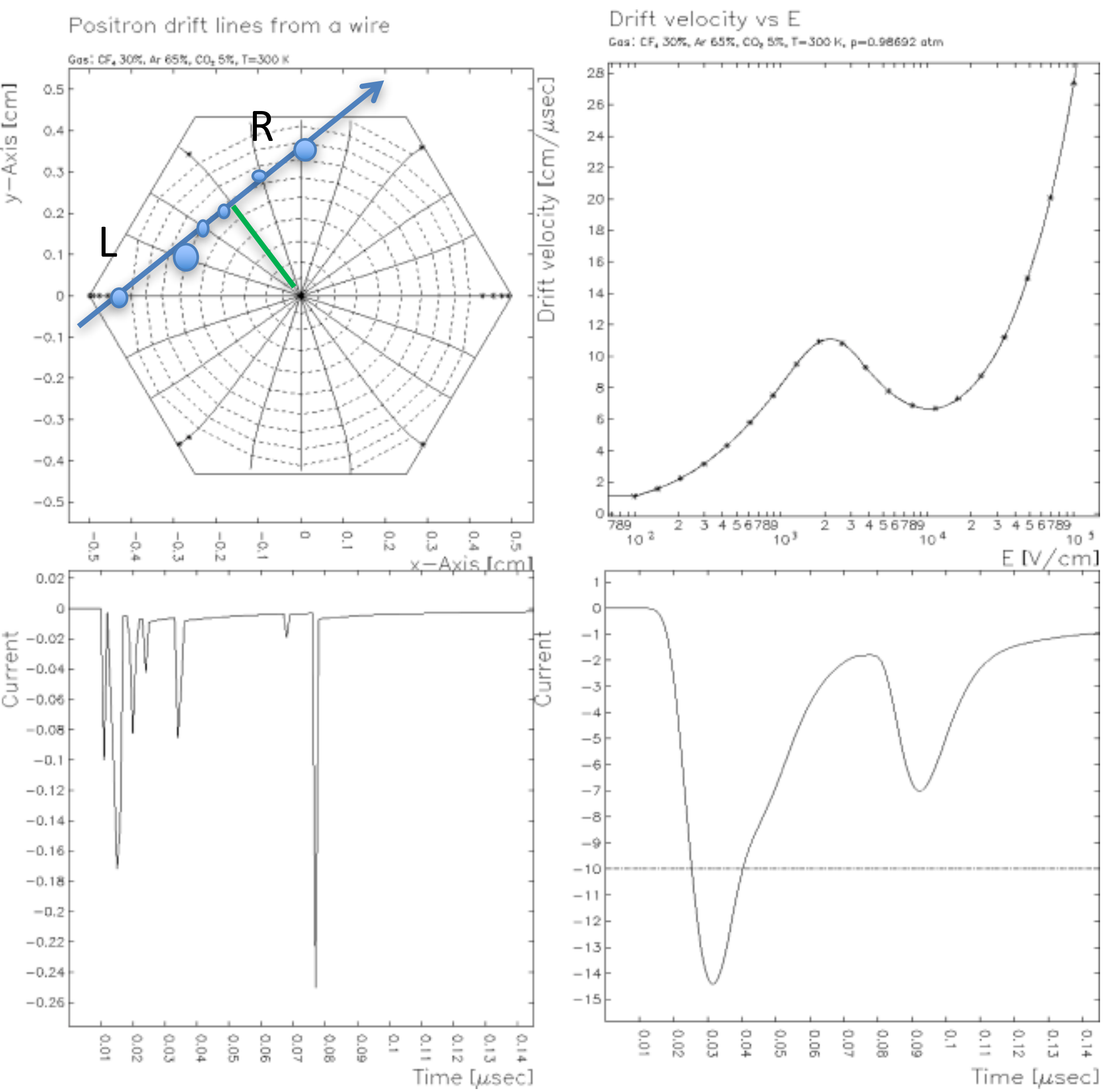
# Cell Simulation Tools (GARFIELD, MAGBOLZ)

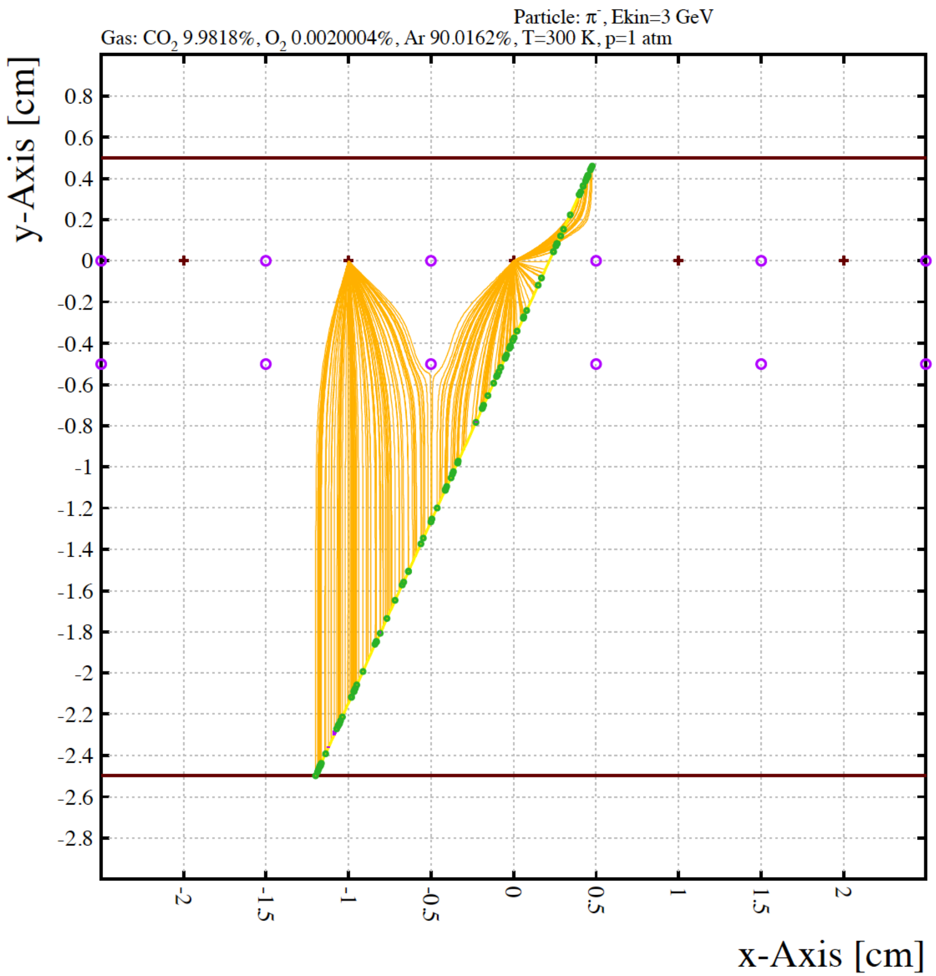


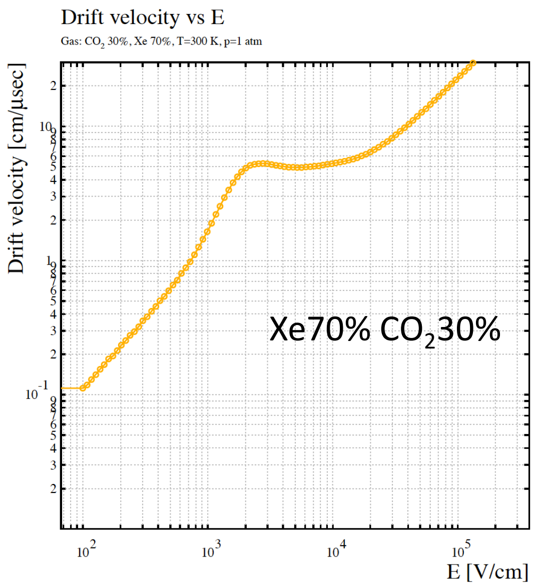

Procedure of simulation:

- Simulation of primary ionization PAI (virtual Photon Atom Interactions) model for a thin gas layers
- Determination of drift velocity as a function of electric field and gas mixture (MAGBOLZ)
- Convolution of all arrived signals with a response function of an amplifier for determination of output signal
- Determination of a time when an output signal crosses a threshold.
- Right-Left uncertainties

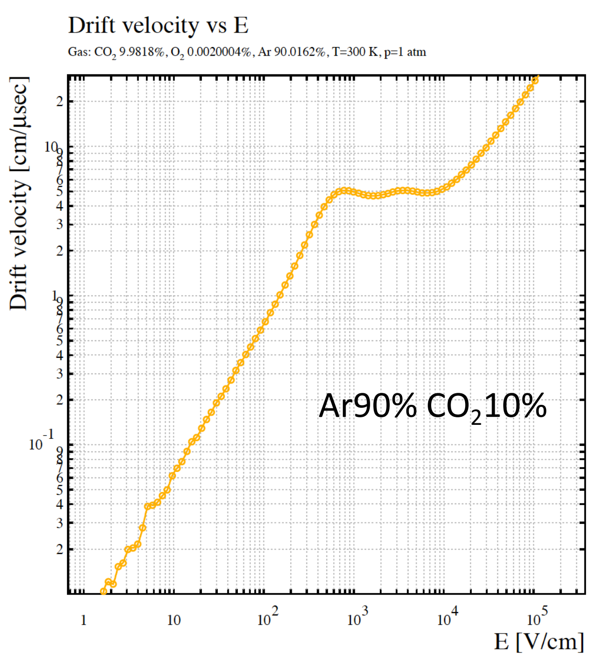
# Cell Simulation Tools (GARFIELD, MAGBOLZ)

## Drift chamber




Xe70% $CO_2$30%




Ar90% $CO_2$10%

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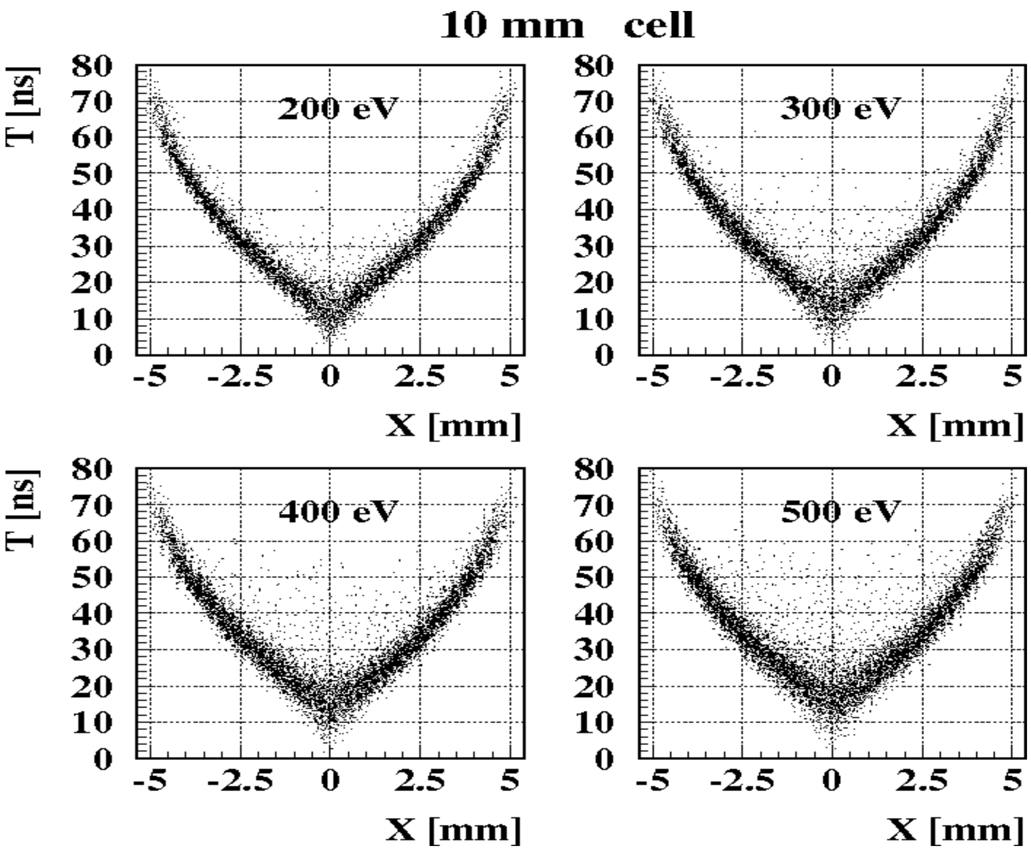
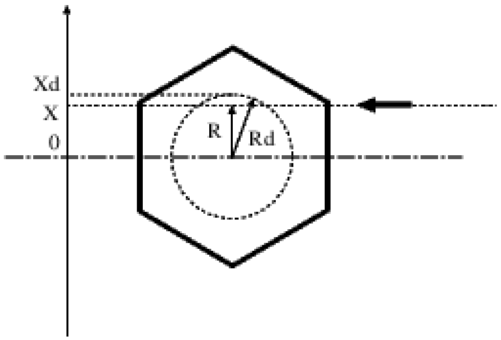
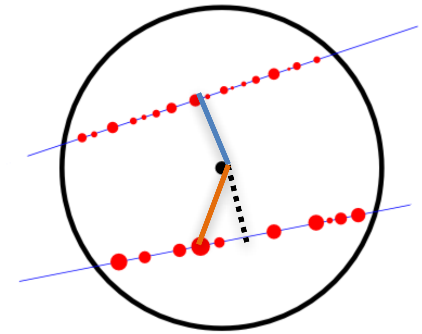
# R-T dependence



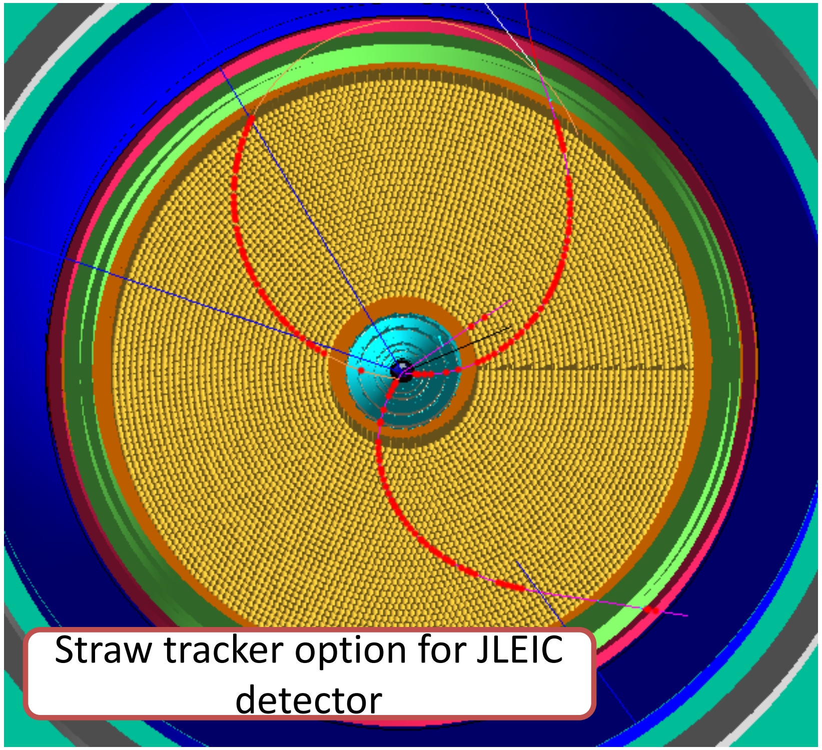



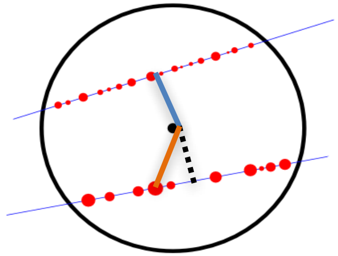
For real DATA:

shift along T axis-TDC offset,
shift along X axis -misalignment

# Other coordinate?

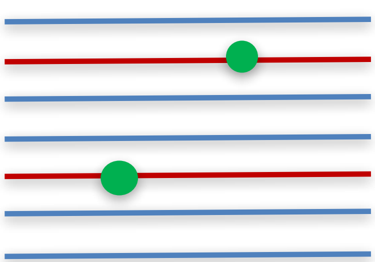



X-Y coordinate



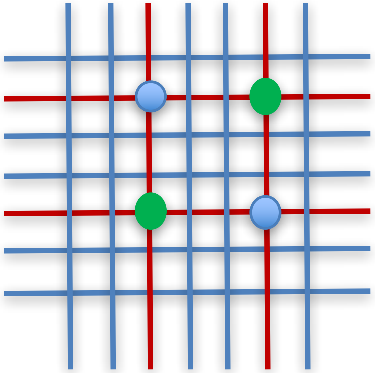
Z coordinate ??
Length upto 4m long

Z coordinate ??



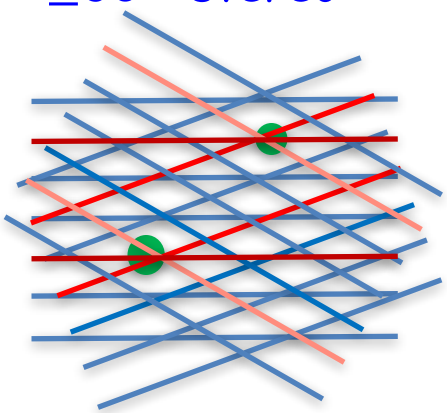
No Z coordinate

90° "stereo"



- ✓ Good in terms of resolution
- ✓ but $n^2$ "ghost" hits

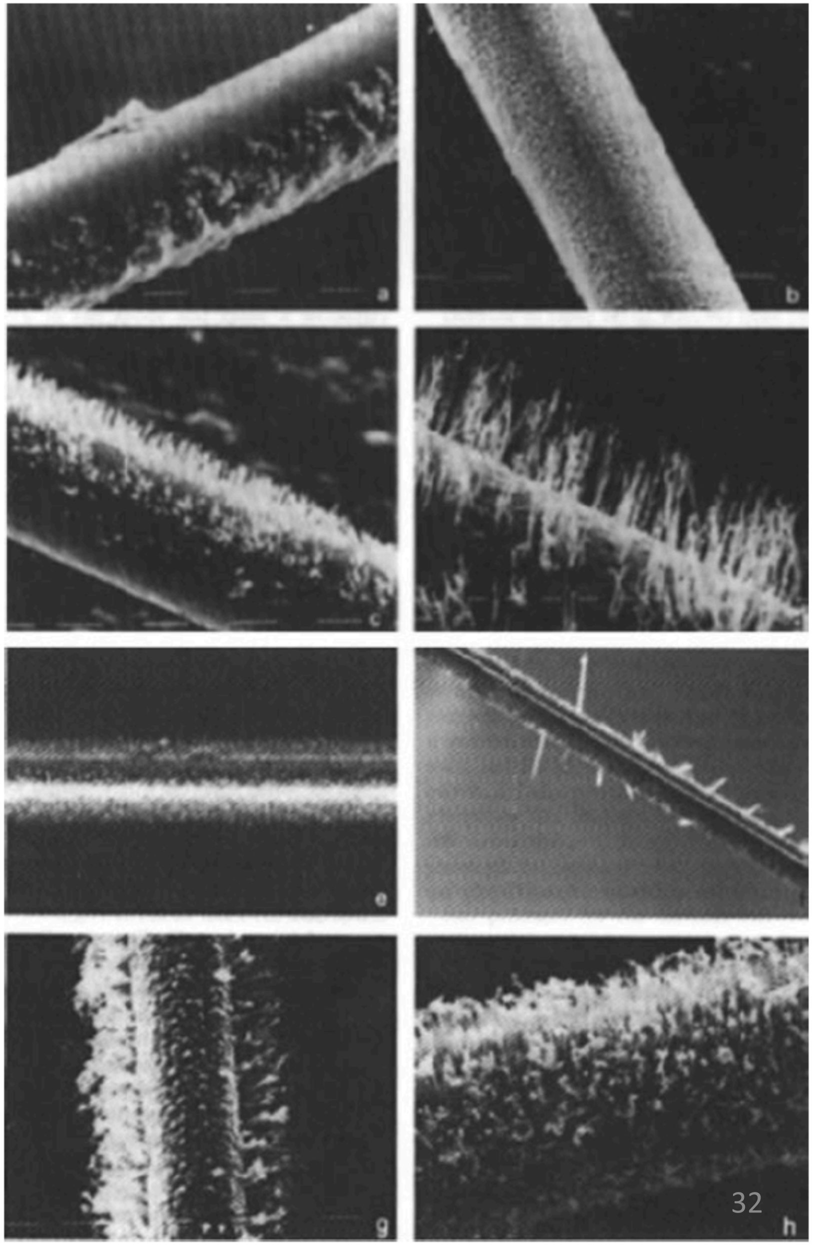
±30° "stereo"



- ✓ (3 layers)
- ✓ no ghosts
- ✓ Problem with pattern reconstruction

# Aging of wires

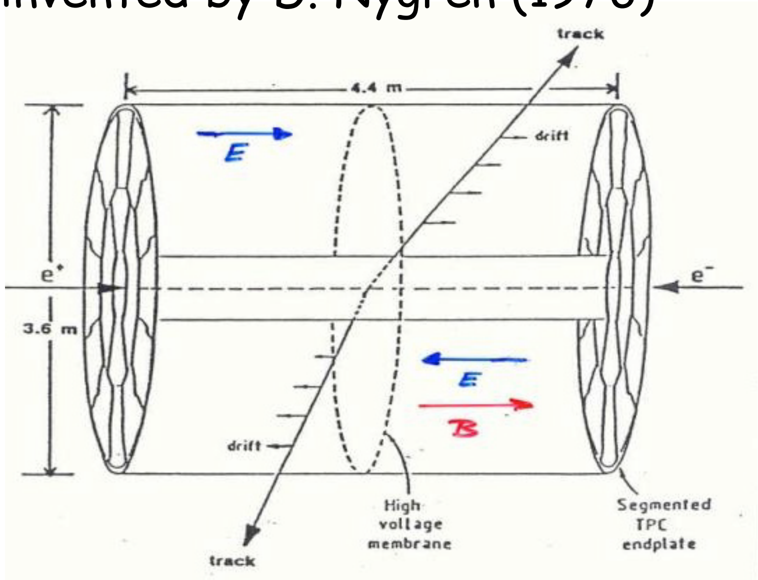
- During operation with a high radiation facility radicals (molecule fragments) could be formed close to wire (avalanche formation is similar to micro plasma discharge )
- Long chain molecules (polymers) attached to electrodes.
- Reduction of gas amplification
- Or lead to HV discharge



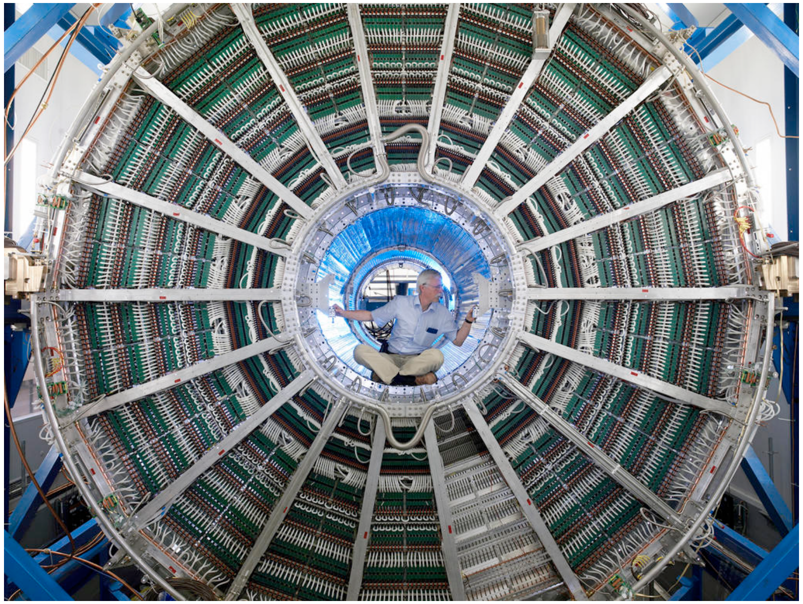
Could wires be avoid?

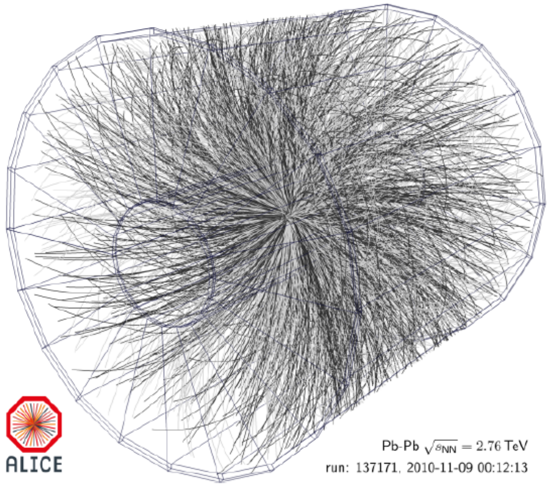
# Time projection chamber (TPC)

invented by D. Nygren (1976)




ALICE TPC



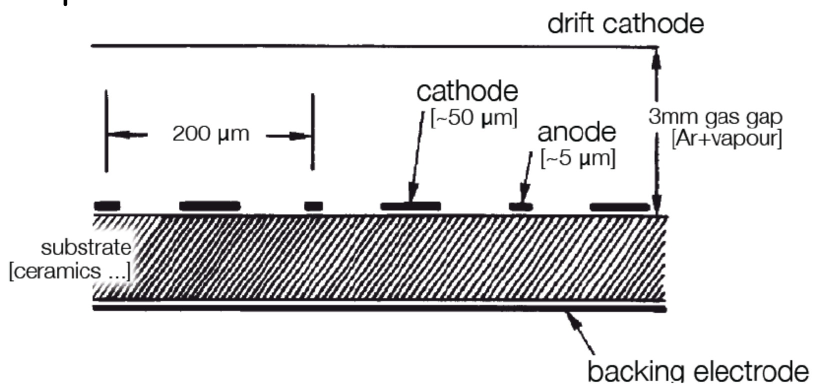



- full 3-D reconstruction (xy from wire/pad geometry at the end flanges; z from drift time)
- 3D track information recorded -> good momentum resolution
- large field cage necessary
- typical resolutions: in rφ = 150-400 μm in z ≈ mm
- challenges
  - long drift time -> limited rate capability
  - large volume -> geometrical precision
  - large voltages -> potential discharges

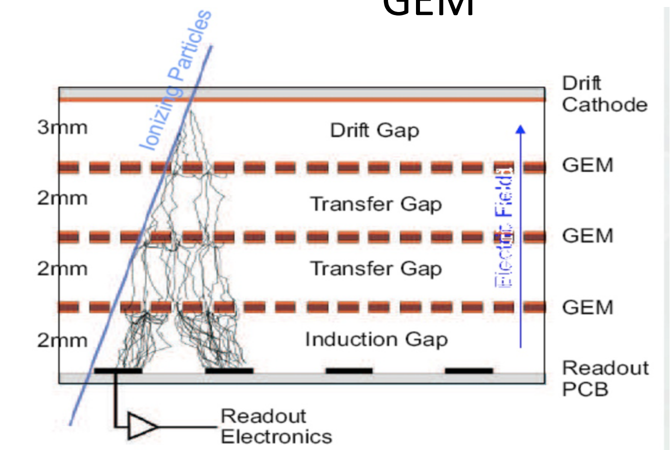
# Micro Strip Gas Chambers

First MSGC (Micro Strip Gas Chambers) developed in 1990ies.:
Micromegas, GEM [Sauli 1997]

Simple construction

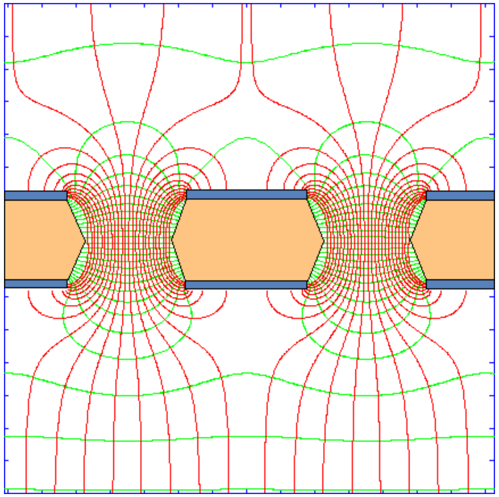



GEM



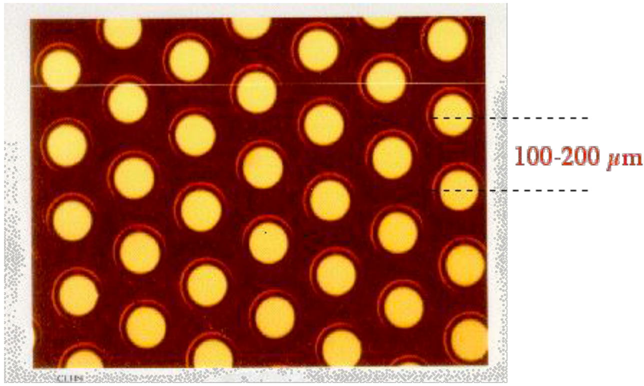

-drift time ~300ns

-resolution ~30-50 μm.



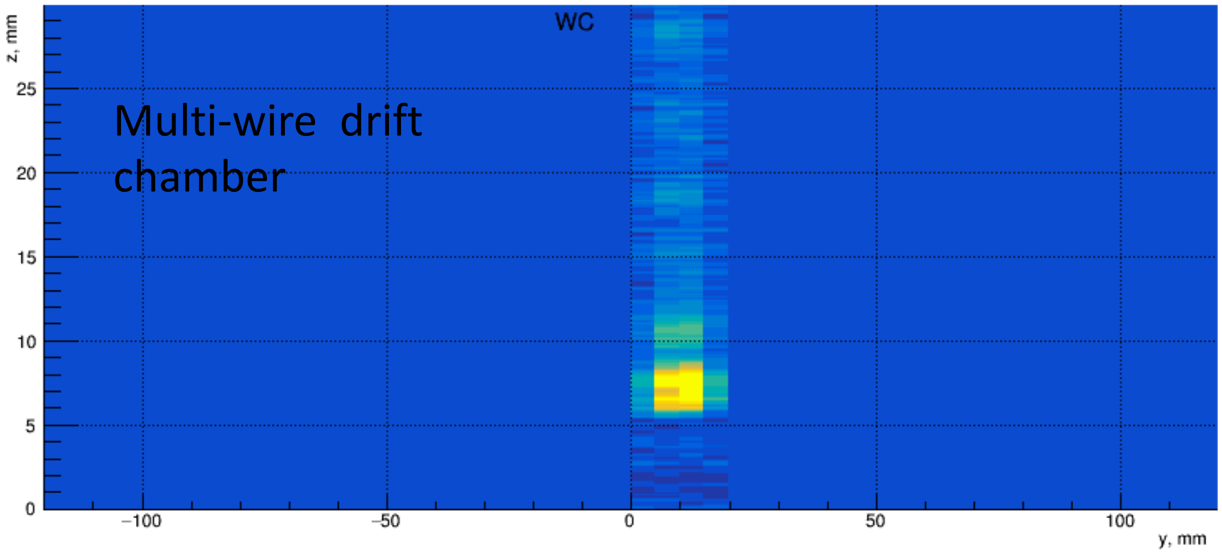
Thin metal-coated polymer foil chemically pierced by a high density of holes.

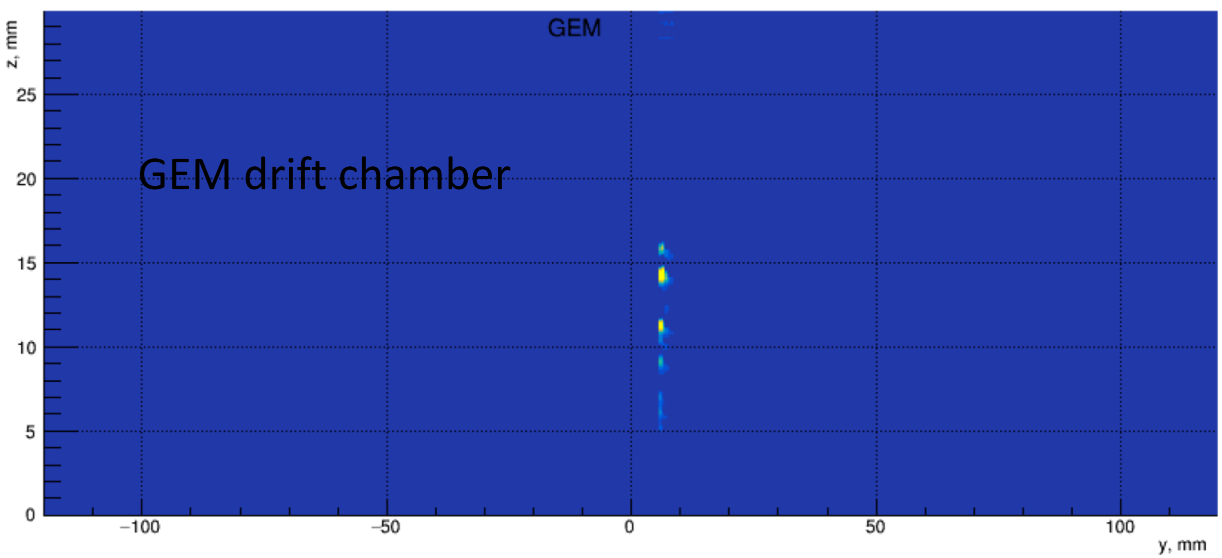
Proportional gains above $10^3$ are obtained in most common gases.

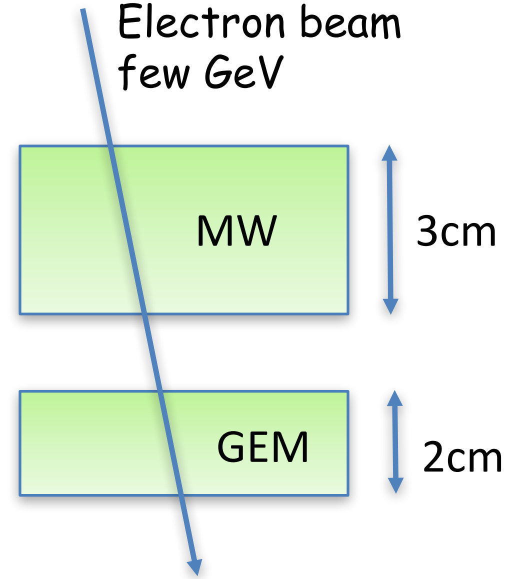


# Tracking accuracy comparisons

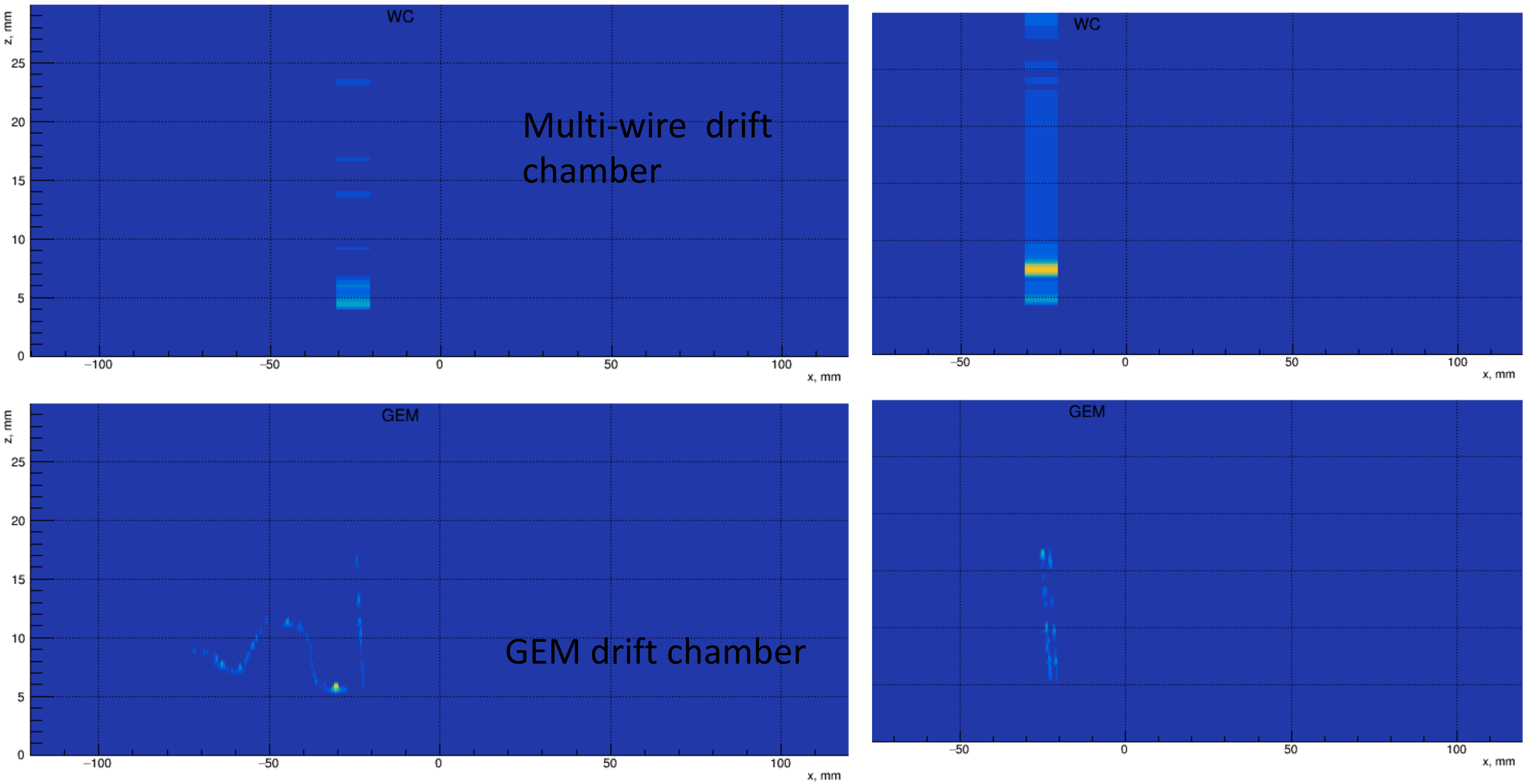
Electron, few GeV



# Tracking accuracy comparisons




Yulia Furletova

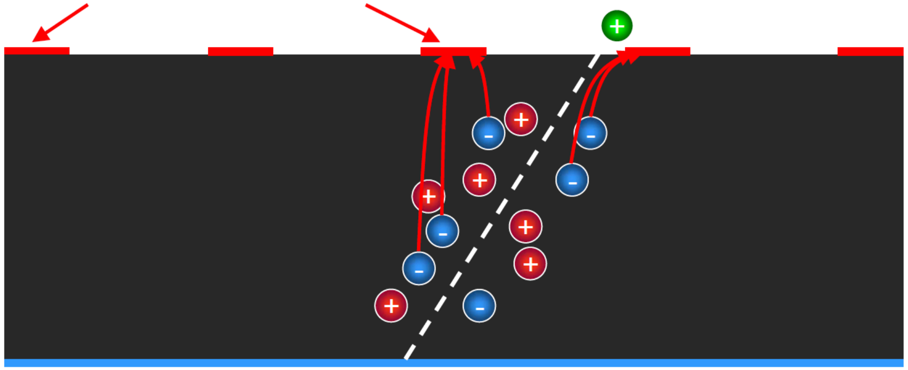
# Vertex detectors: pixel detectors

From gas to Silicon :

- near interaction point, close to beam => radiation damage, track density is higher
- Improve space point resolution (better then 50$\mu m$)
- But … material
- … And price:
  - Covered areas: gas detectors for larger areas, silicon for small areas (vertex)

# Silicon detectors: principle of operation

- ✓ Most semiconductor detectors are ionization chambers
- ✓ Charged particle crosses detector and creates electron/ hole pairs
- ✓ These drift to nearest electrodes position determination = closest electrode

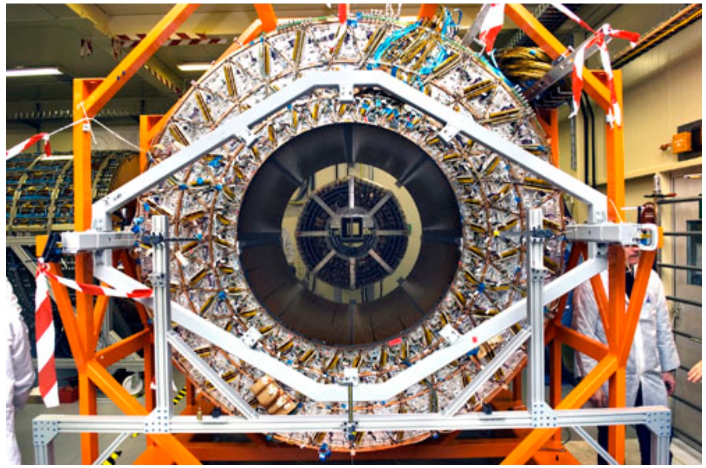


# Gas and semiconductor detectors

Gas field:
(Multi- Wire chambers, Straw tubes, Time projection chambers (TPC), Micro-pattern gas detectors (MPGD):GEM

Semiconductor detector
Strips, pixels (DEPFET, MAPS,CMOS)

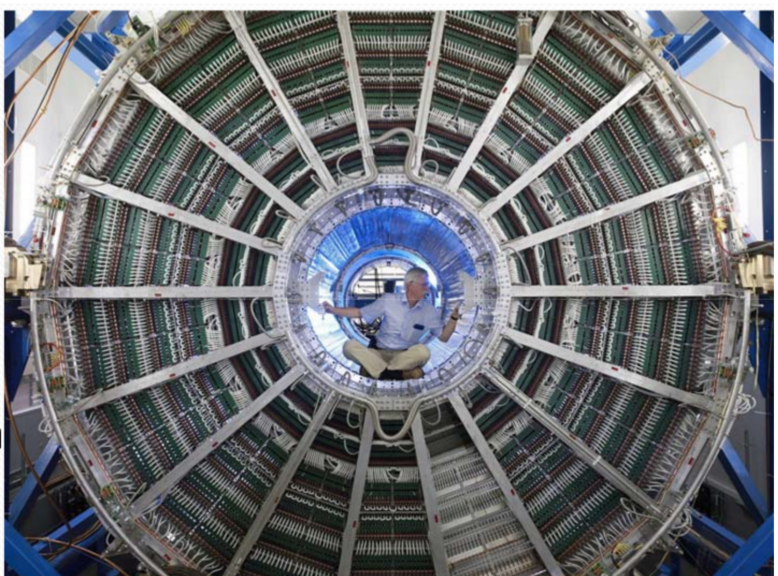
ATLAS Straw Tracker, CERN



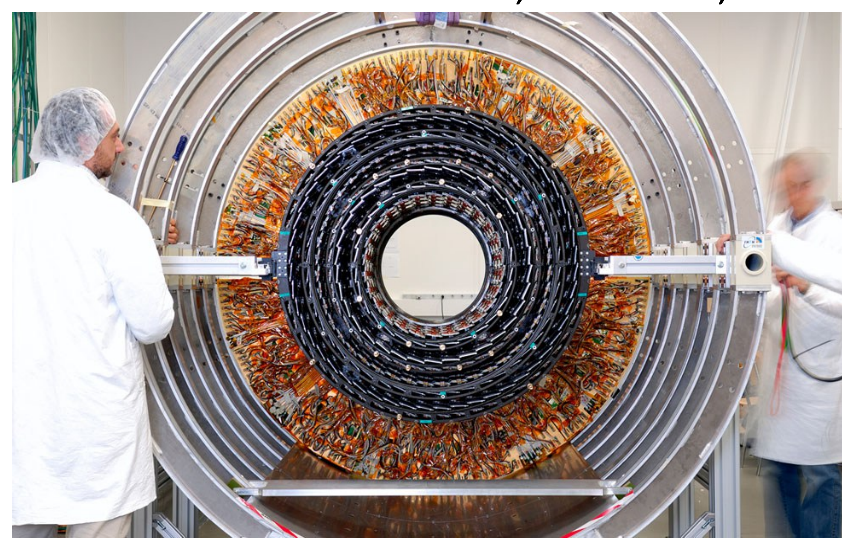
BELLE-2 pixels

BABAR vertex

ALICE TPC, CERN



CMS, Si-tracker, CERN



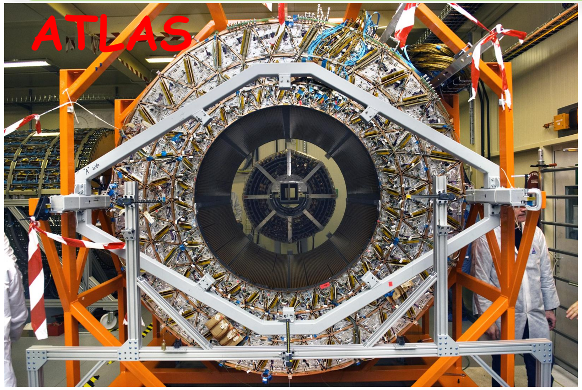
# Gas detectors vs Silicon


**Gas**

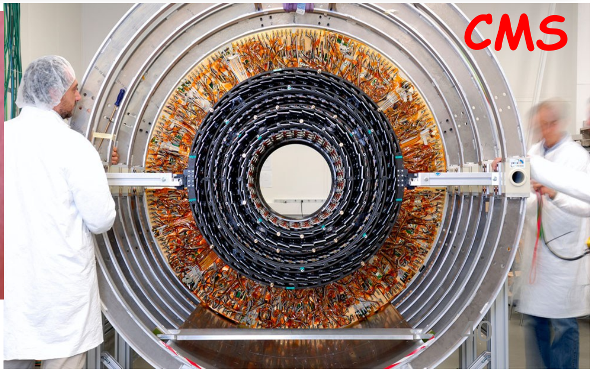
- 26 eV needed to produce e/ion pair
- 96 e/ion pairs per cm
- Intrinsic amplification $10^6$
- Typical noise > 3000 e-
- Material : a little
- Cost: low
- Resolution: 100$\mu m$

**Silicon**

- 3.65 eV needed to produce e/hole pair
- $10^6$ e/h pairs per cm (scale to size ~ 100 $\mu m$)
- No intrinsic amplification (except some)
- Typical nose ~100e- (pixels) ~1000e- (strips)
- Material: a lot
- Cost: high
- Resolution: 1-10$\mu m$



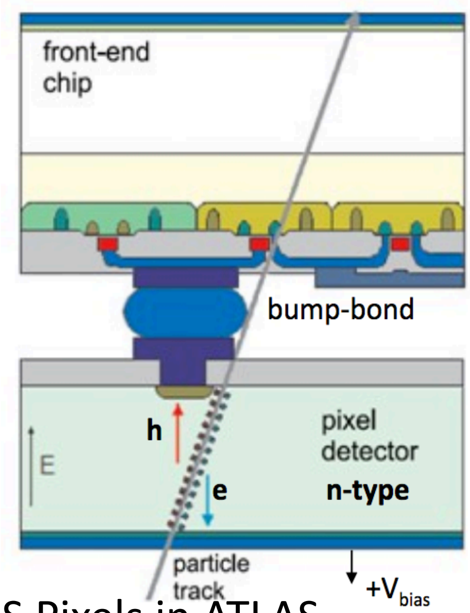




# Hybrid pixels

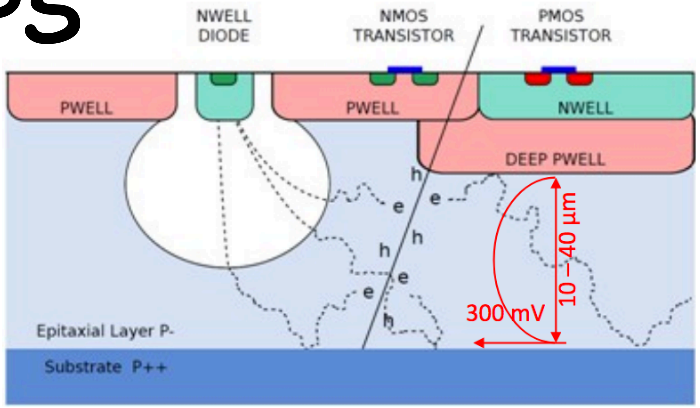
- Electronics bump-bonded to each pixel =>
- A lot of material (200$\mu$m sensors + 200 $\mu$m electronics)
- **But Fast readout (10ns) all in parallael**

Giovanni Darbo – INFN / Genova



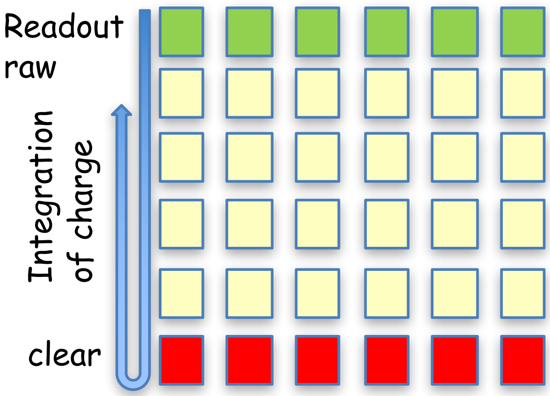

CMOS Pixels in ATLAS

# MAPS

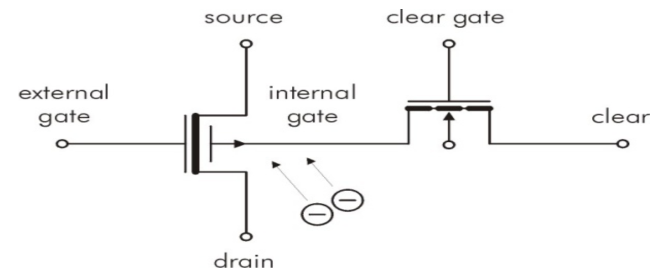



- Readout row-by-row (rolling shutter) (to reduce material)
- Epilayer ~10-40$\mu$m
- Charge collection by diffusion (random walk, recombination)

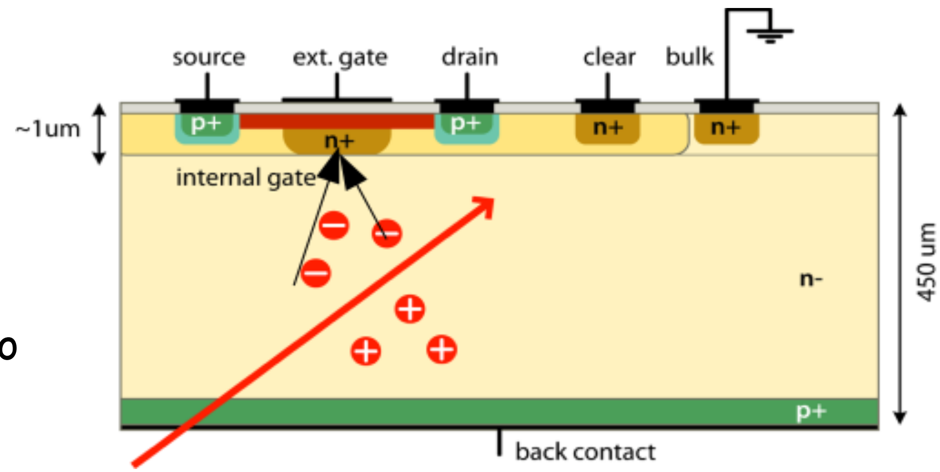
Rolling shutter



# Depleted Field Effect Transistor (DEPFET) pixel detector




- Each pixel - p-channel FET (**detection and amplification within one pixel**/device (charge-to-current conversion and amplification) : the signal results in a modulation of the current of the transistor
- The entire **bulk is depleted** and sensitive to incident radiation(**no stitching, 100% fill factor**) (sidewards depletion)
- Fast charge collection **by drift!**
- Accumulated charge can be removed by a clear contract.
- Readout: rolling shutter mode
- All Si ( self-supporting structure).



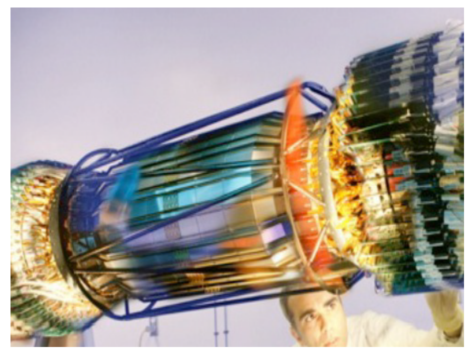

**PXD BELLE-II:**
-8 millions pixels
-1 ladder : **0.19 % $X_0$**
-thickness 50µm
(all Si **self-supporting**)
-Pitch 20-70$\mu m$
-Point resolution: ~ 1$\mu m$
-Integration time **~10µs**
-BELLE-2 vertex resolution **~23µm**

# Silicon vertex and tracker

PXD BELLE-II:

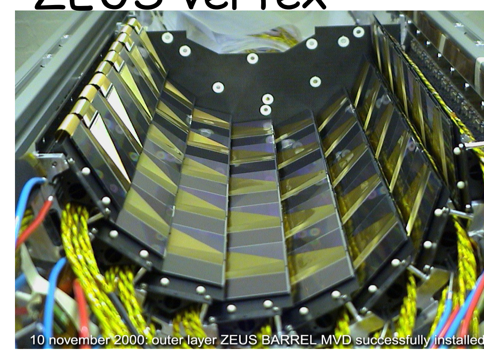

8 millions pixels
-thickness 50µm
-Pitch 20-70$\mu m$
-Point resolution: ~ 1$\mu m$
-Integration time **~10µs**
-BELLE-2 vertex resolution **~23µm**

BABAR vertex



5 layers
- two-sided silicon strip
- 300µm thick
- pitch: 50-200 µm
- space resolution: 10-30 µm

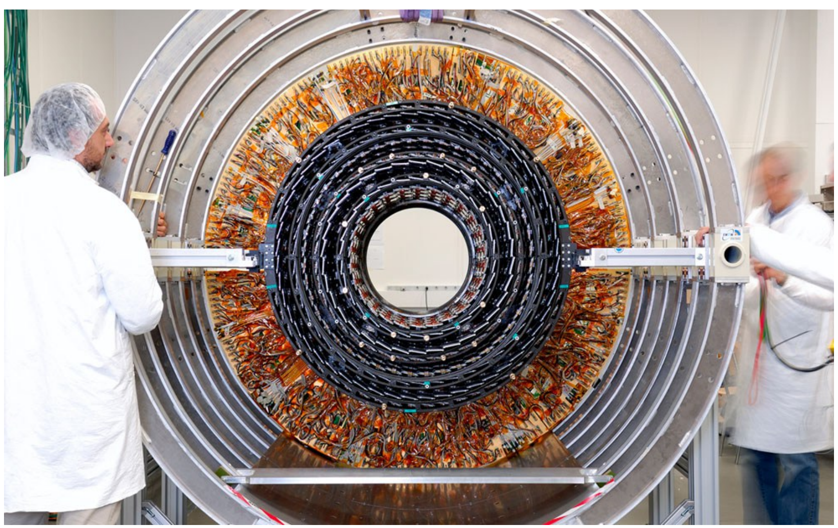
ZEUS vertex



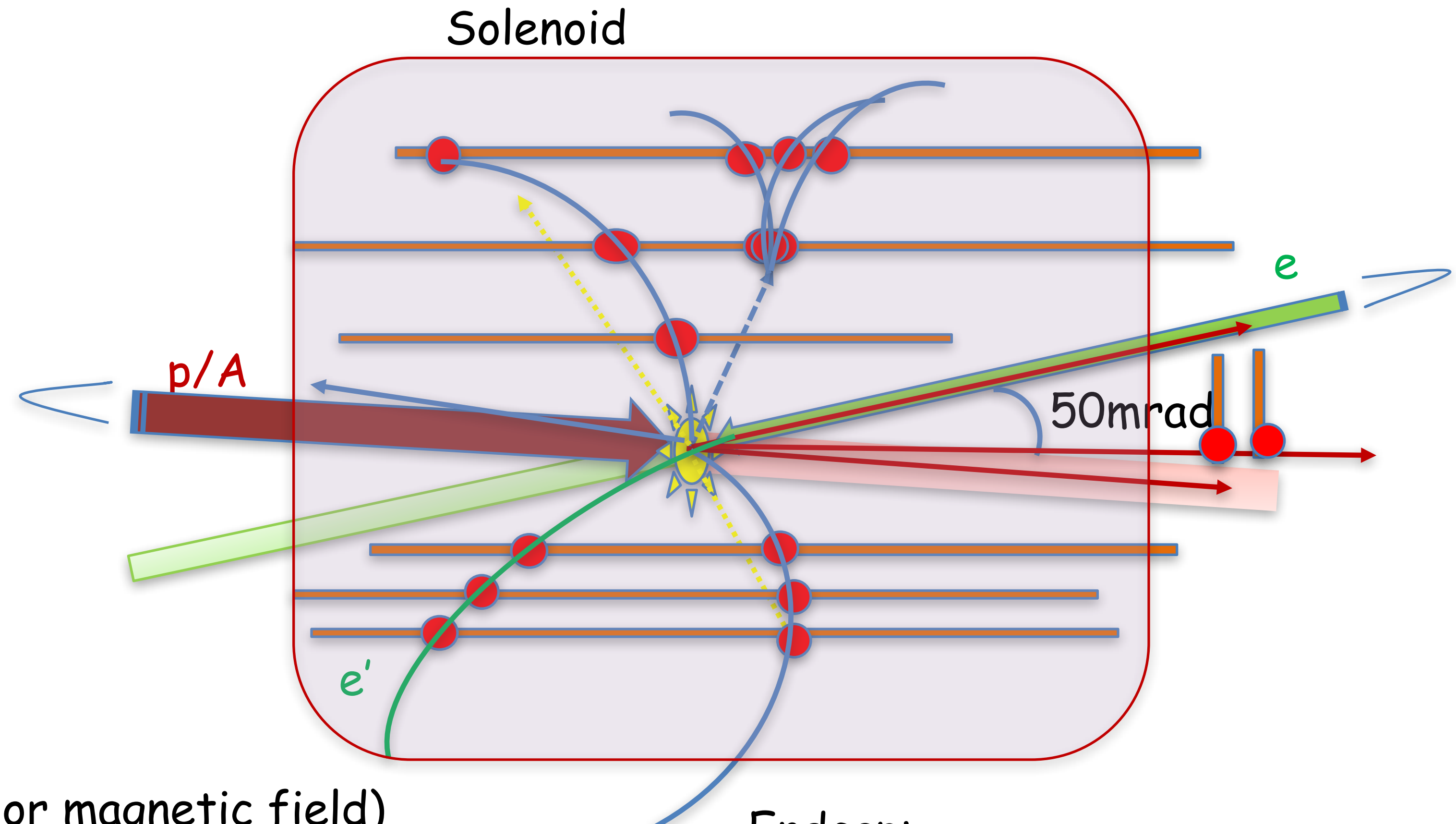

3 layers (barrel)
+ 4 wheels (forward)

- silicon thickness: 330µm
- readout pitch: 120µm
- space resolution: ~8µm

CMS tracker



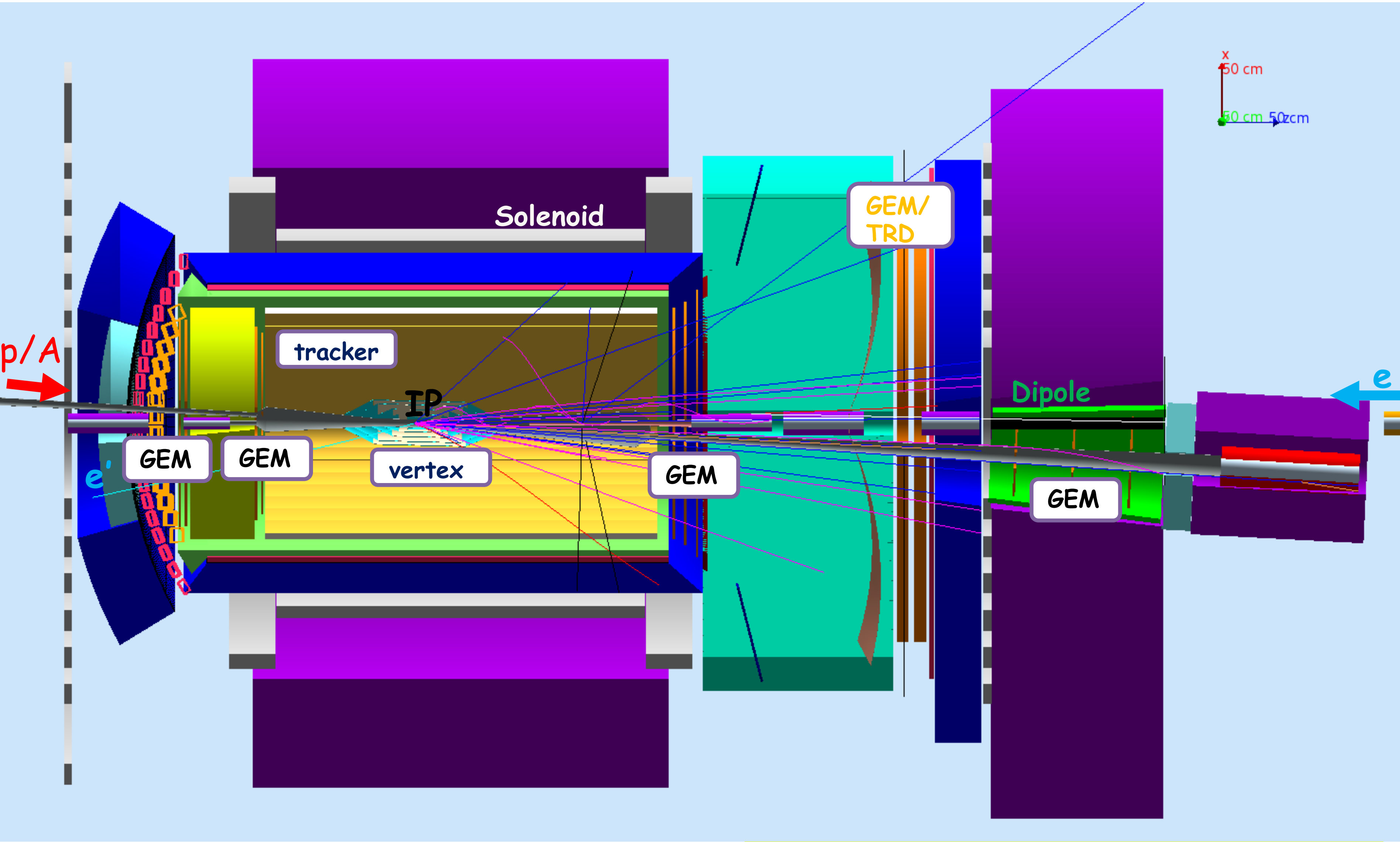
# Tracking detectors for JLEIC




Barrel:
- Solenoid ( for magnetic field)
- Outer layers of tracking: TPC (like in ALICE) , straws (like in PANDA), low mass drift chamber (like in MEG2), all Silicon (like in CMS)
- Vertex: MAPS, DEPFET

Endcap:
- Dipole ( for magnetic field)
- GEM

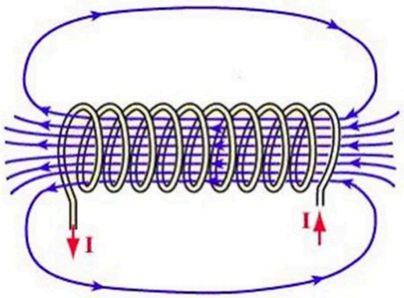
# EIC Central detector overview: tracking

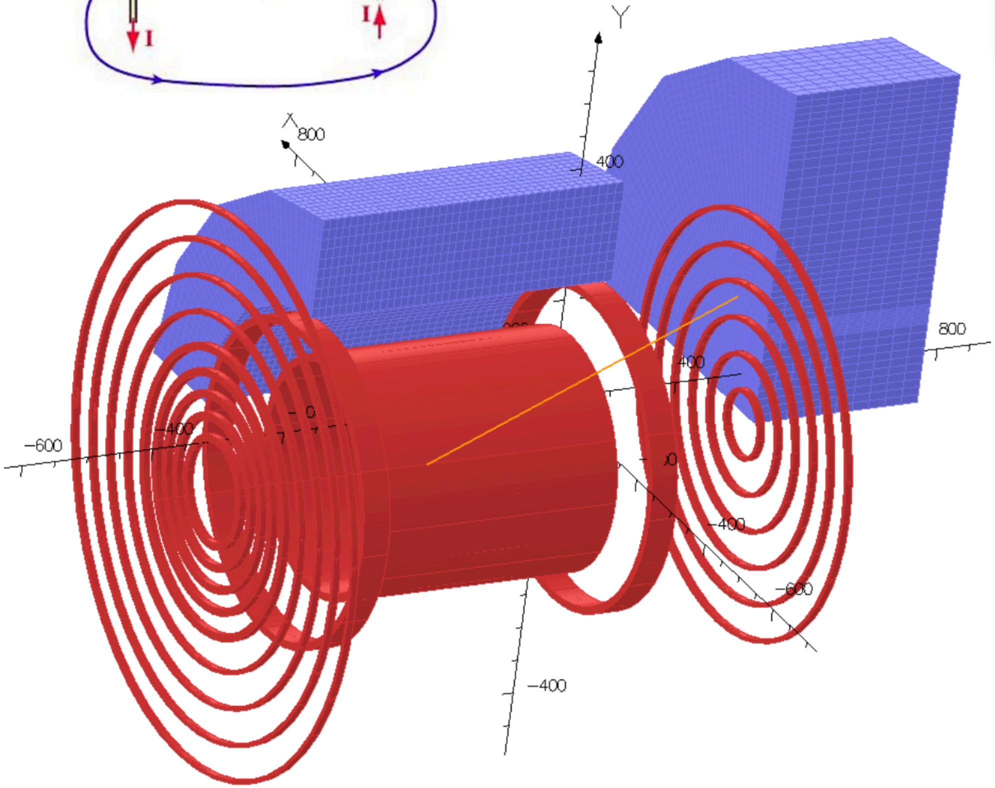



Modular design of the central detector

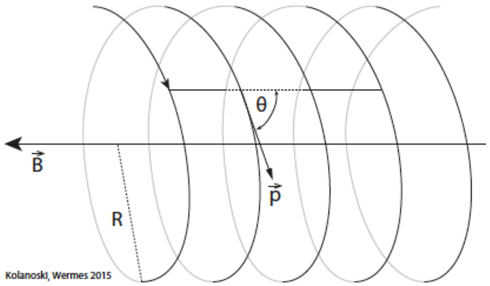
# JLEIC design: Solenoid

- around Interaction point
- Strong homogeneous field (1.5-3) Tesla

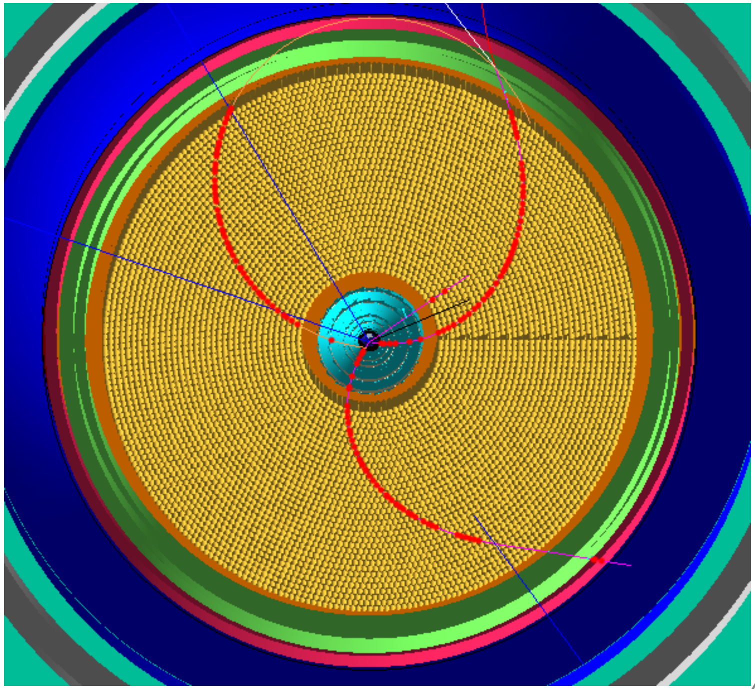



In a homogeneous B-field the motion of a charged particle is a helix.




$$p_T\,[GeV] = 0.3 \cdot B\,[T] \cdot R\,[m]$$



JLEIC tracker design with straws



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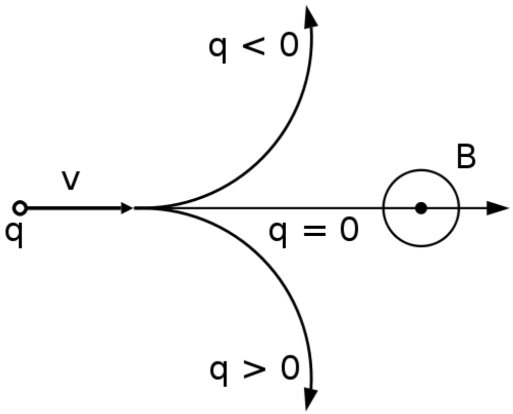
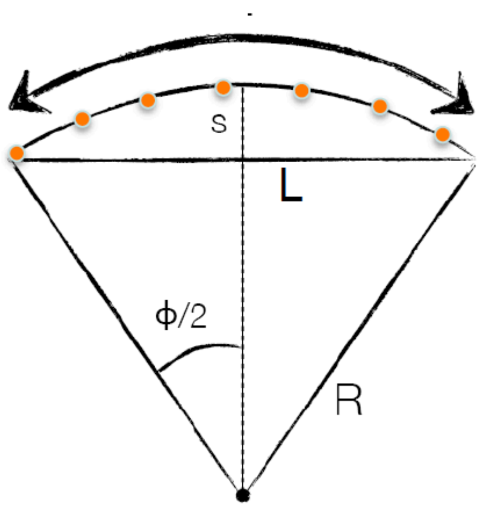
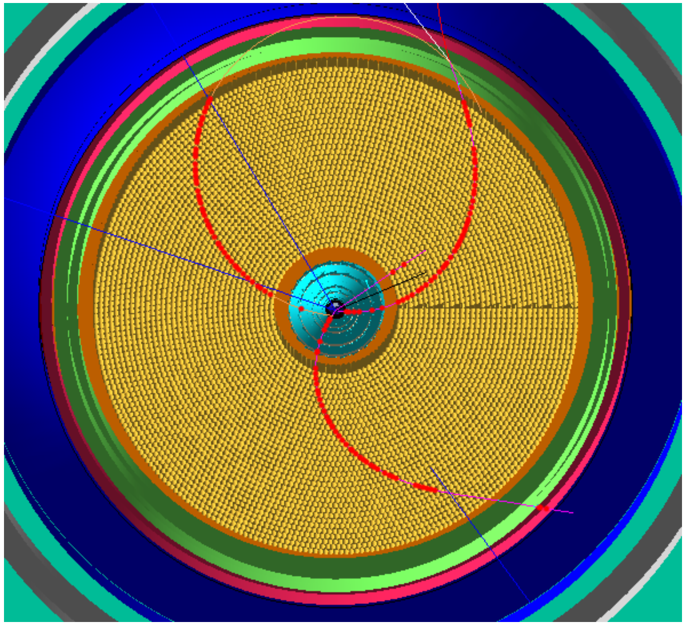
# Momentum reconstruction

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



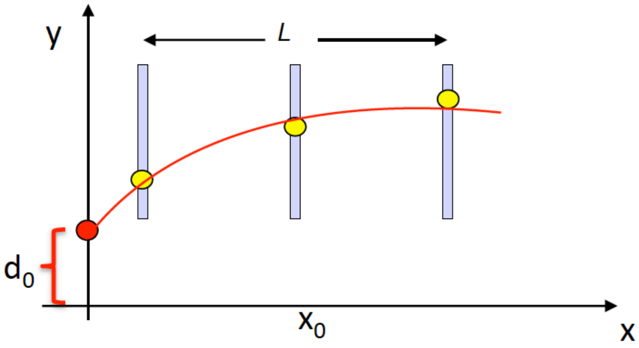



$s = L^2 / 8R$

# Momentum resolution

The projection can be parametrized by a linearized circle




$$y = y_0 + \sqrt{R^2 - (x - x_0)^2}$$

$$y \approx a + bx + \tfrac{1}{2}cx^2$$

the errors on the track coordinates y
at a given x for a N equidistant measurements

$$\sigma_a^2 = \sigma^2 \frac{3N^2 - 7}{4(N-2)N(N+2)}$$

$$\sigma_b^2 = \frac{\sigma^2}{L^2} \frac{12(N-1)}{N(N+1)}$$ slope

$$\sigma_c^2 = \frac{\sigma^2}{L^4} \frac{720(N-1)^3}{(N-2)N(N+1)(N+2)}$$ curvature

$$\sigma_{ab} = \sigma_{bc} = 0$$

$$\sigma_{ac} = \frac{\sigma^2}{L^2} \frac{30N}{(N-2)(N+2)}$$

Position resolution (N>10) :

$$\frac{\sigma(p_T)}{p_T}^{\text{meas}} = \frac{\sigma(x) \cdot p_T}{0.3BL^2} \sqrt{\frac{720}{N+4}}$$

Linear dependence on $p_T$

# Examples

Position resolution only:

$$\frac{\sigma(p_T)}{p_T} = \frac{\sigma(x)\cdot p_T}{0.3BL^2}\sqrt{\frac{720}{N+4}}$$

CMS $\Delta pt/pt = 1.5\cdot 10^{-4}\,pt + 0.005$
(pt ~ 50-500GeV, 4T, L~1.1m σx~50μm for 100GeV 1.5%, $\eta=0$ )

ATLAS: $\Delta pt/pt = 5\cdot 10^{-4}\,pt + 0.01$
( pt ~ 50-500GeV, 2T, L~1m σx~200μm, for 100GeV 3.8%, $\eta=0$ )

EIC:
( pt ~ 1-10 GeV , 3T σx~100μm for 100GeV ~ 3% , for 10GeV ~0.3%)

ZEUS: $\Delta pt/pt = 58\cdot 10^{-4}\,pt + 0.0065$ (pt ~ 1-200 GeV 1.8T)



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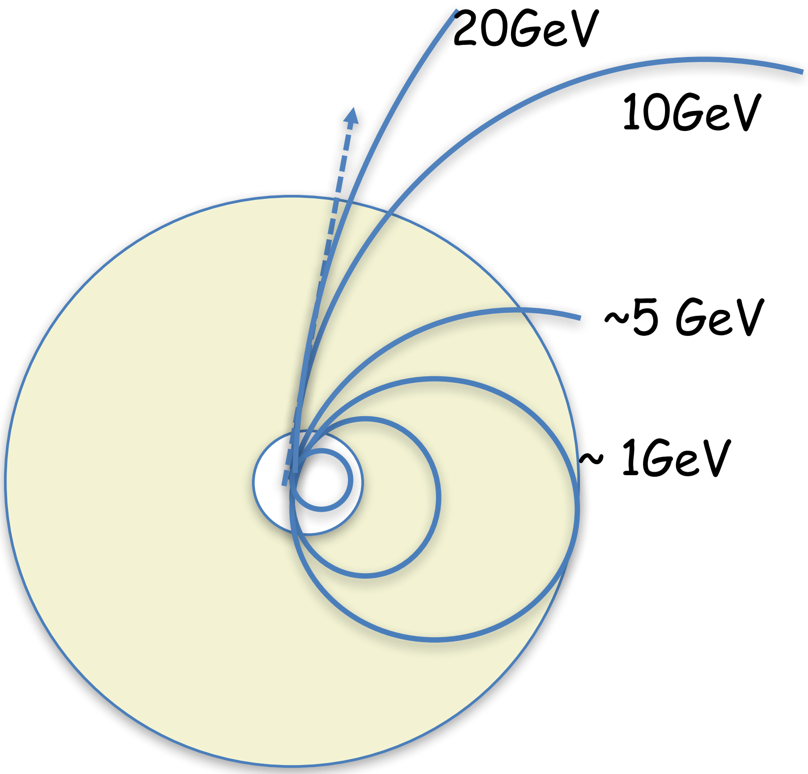
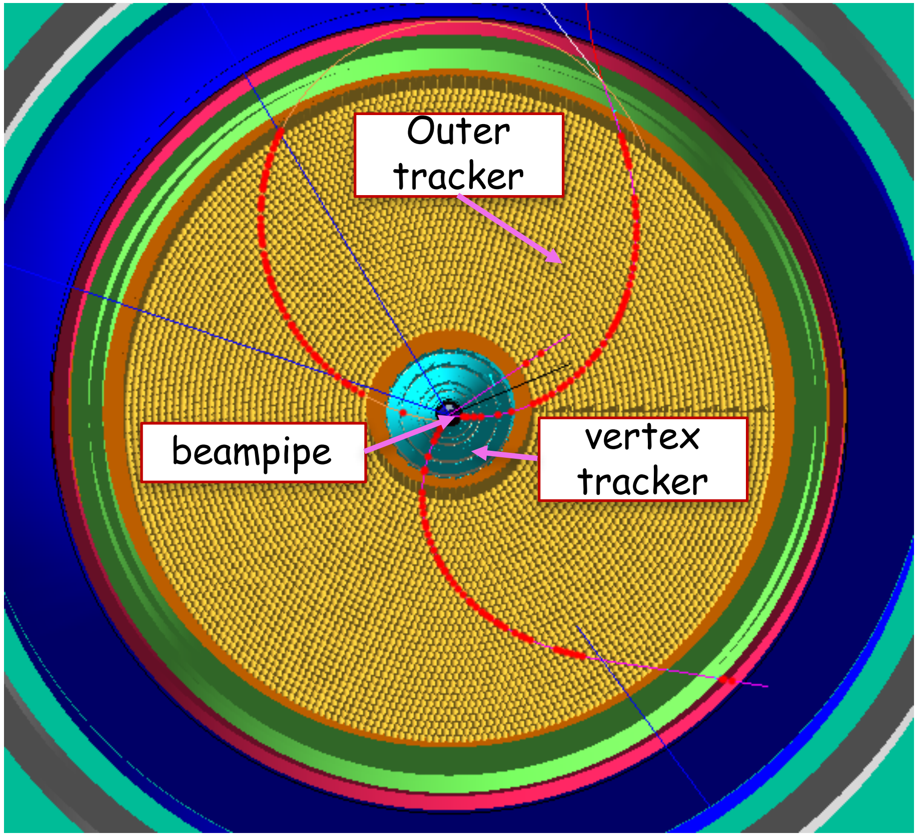
# Momentum reconstruction



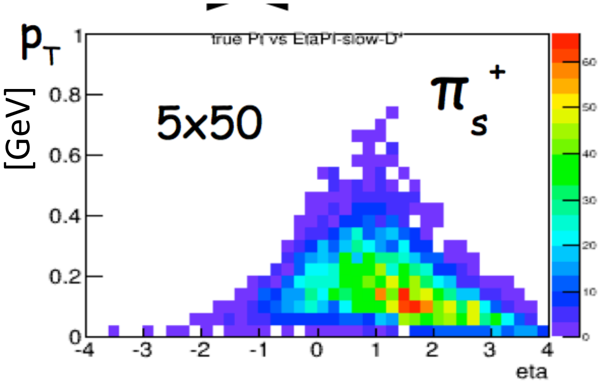




- Need high magnetic field to reconstruct bending radius: for high momentum particles, otherwise straight segment (no momentum measurements, no charge) – depends on resolution of tracker.
- Too high magnetic field: low momentum particles fly along beampipe without detection

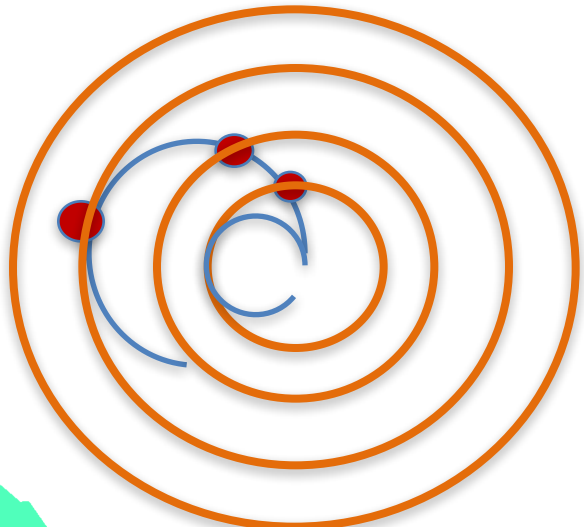
# Low momentum particles

Problem of too high magnetic field:

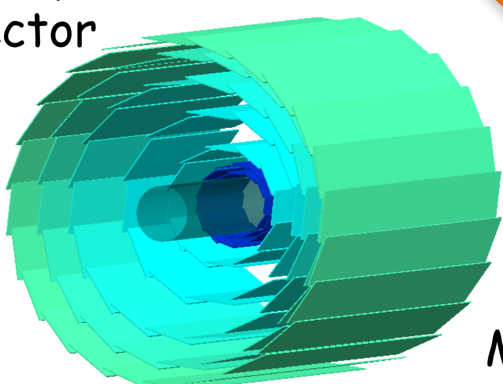
$$D^{*+} \rightarrow D^0 \pi_s^+ \rightarrow (K^- \pi^+) \pi_s^+$$




- Layered structure of vertex detectors
- For track reconstruction slow particles have to pass at least 3 layers of tracking detector



Barrel part of vertex detector

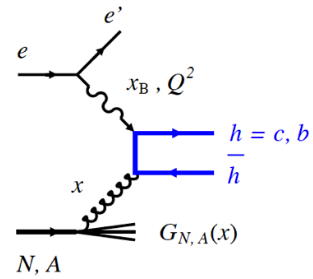


$p_T$ [GeV] = 0.3· B [T] · R [m]

Beampipe: 3.2cm
Inner layer of outer tracker: 20 cm

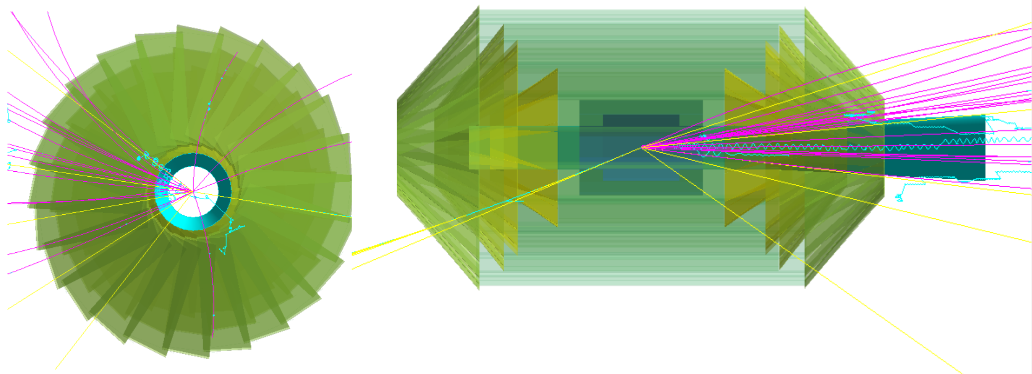
Minimum pT possible to detect for 3T (at 6cm): ~ 30MeV

# Vertex detector

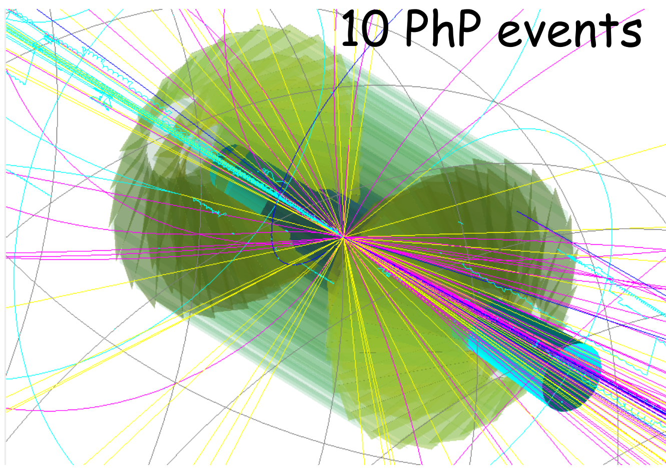



| | | |
|---|---|---|
| D0 | 1864,8 MeV | 123 $\mu m$ |
| D* | 2010.2 MeV | - |
| D+ | 1869.5 MeV | 315 $\mu m$ |
| Ds+ | 1967 MeV | 147 $\mu m$ |
| Λc | 2286.5 MeV | 60$\mu m$ |
| Ξc | | 132 $\mu m$ |

- Excellent vertex resolution (<25 um) for charm physics:
  - Need at least 2 layers of high granularity pixels
  - as close as possible to the IP



- Endcap is needed
  - forward boosted kinematics
- Proper shielding /masking of synchrotron radiation (background)
- Readout time: 10 us? (MAPS/DEPFET)




Pythia Minbias EIC (Q2> $10^{-6}$ ) σ ~ 200 μb
(HERA ~165 μb )
N events = σ·L ~ 2· $10^6$ ev. per sec (2MHz)
~ 2 events / μs or ~ 20 events per readout

- Background ?!
- Minimum material:
  - Minimize multiple scattering => 50 um thick



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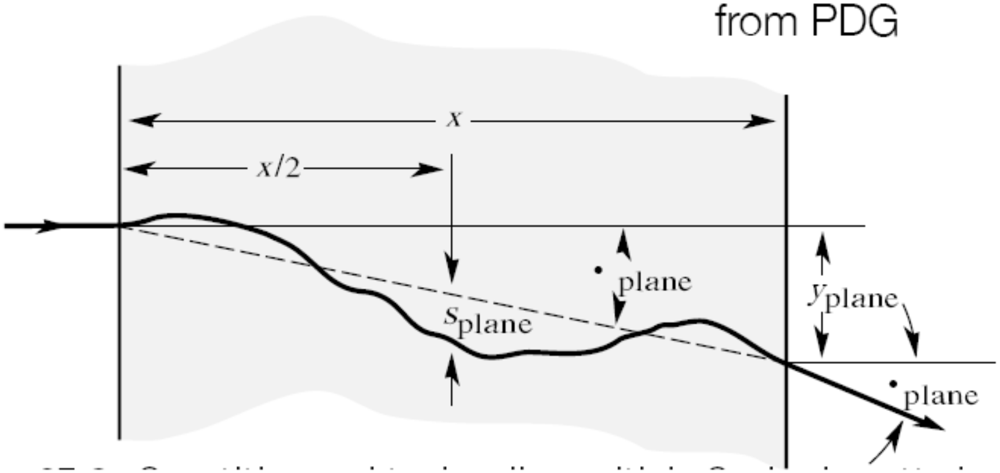
# Multiple scattering

-Multiple scattering change the trajectory of charged particle (that's why we hate it! )

-The smaller the momentum of the particle, the higher the effect of multiple scattering

-Depends on distance and density of a material

from PDG




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

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

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

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

Momentum independent!

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

# Momentum resolution

$$\frac{\sigma_{p_T}}{p_T} = \sqrt{\left(\frac{\sigma_{p_T}}{p_T}\right)^2_{\text{meas}} + \left(\frac{\sigma_{p_T}}{p_T}\right)^2_{\text{MS}}}$$

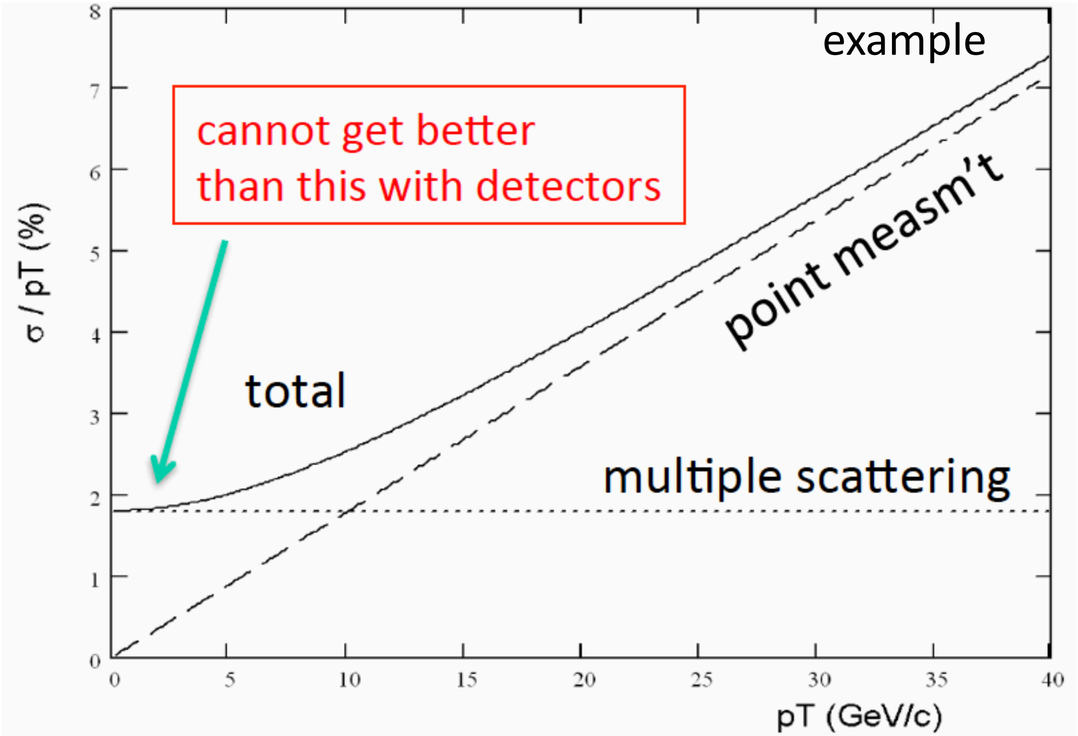
Position resolution (N>10) :

$$\frac{\sigma(p_T)^{\text{meas}}}{p_T} = \frac{\sigma(x)\cdot p_T}{0.3BL^2}\sqrt{\frac{720}{N+4}}$$

Multiple scattering:

$$\frac{\sigma(pT)^{\text{MS}}}{p_T} \approx \frac{1}{\sqrt{LX_0}B}$$

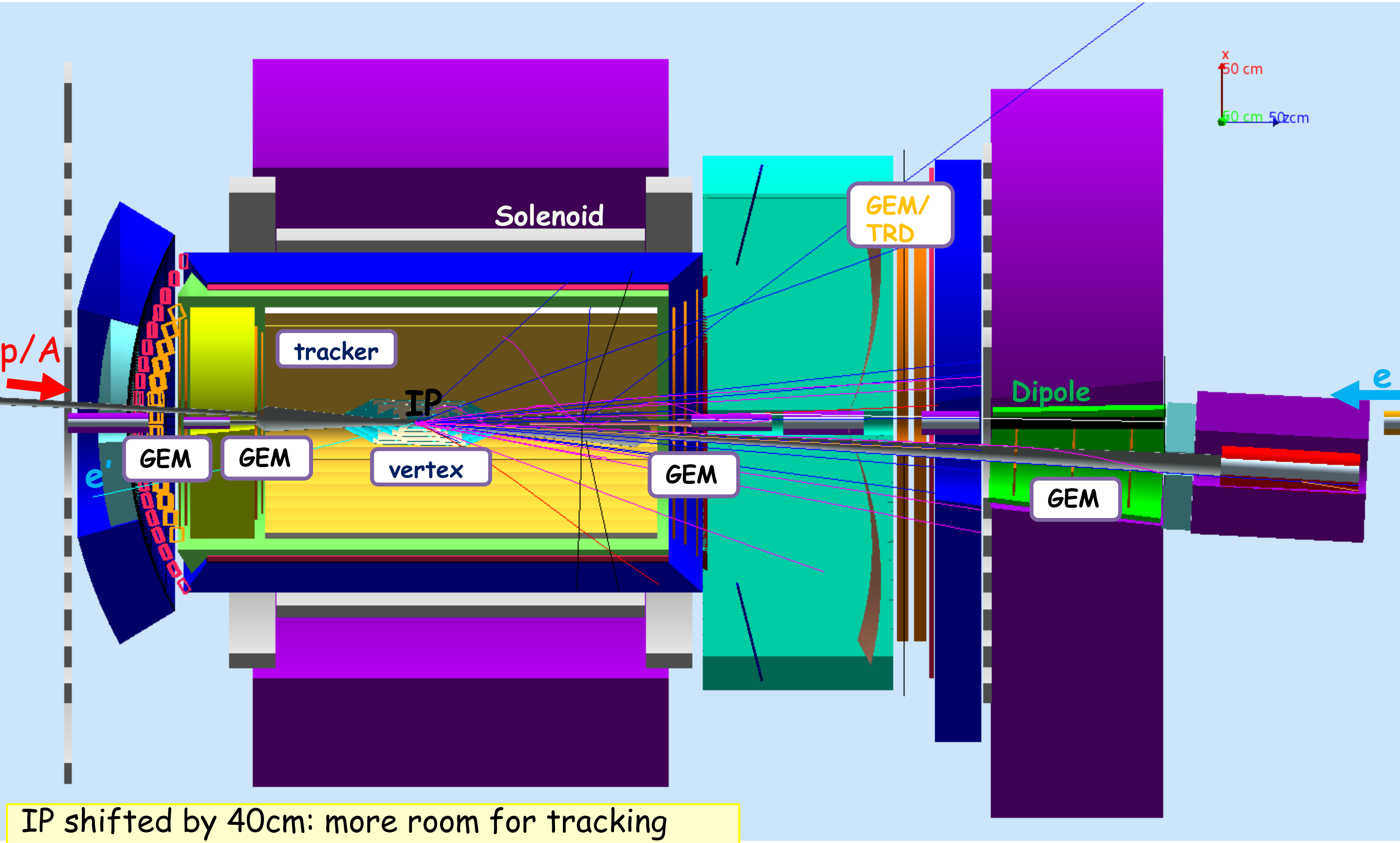
$p_T$ [GeV] = 0.3· B [T] · R [m]




Conclusion:

- -Optimize material effects (multiple scattering ) optimize amount of material along particle track (sensitive area (Si), support structure, cables.. )
- -The longer L is better ($1/L^2$)
- -Place first plane as near as possible to IP
- -$P_T$ is linearly better with B-field, but…
- -Increase N (but only as $1/\sqrt{N}$)
- -Improve hit point resolution ($\sigma_{\text{meas}}$ )

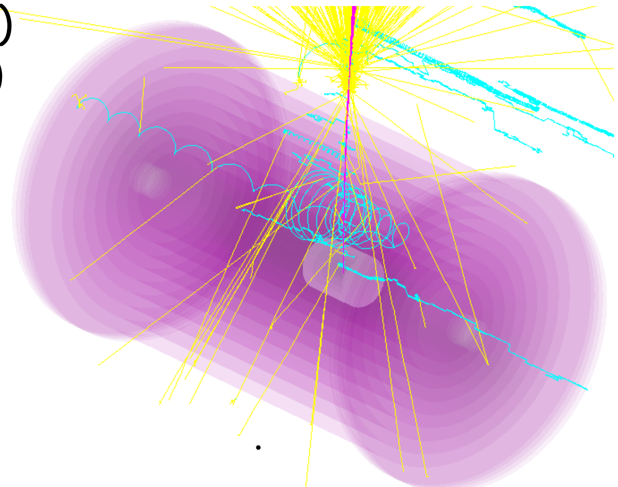
# EIC Central detector overview: tracking

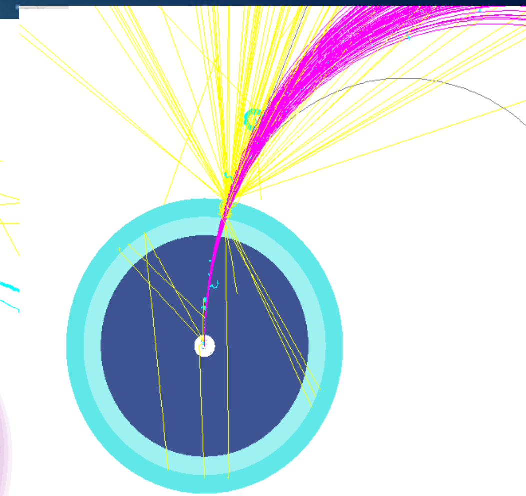


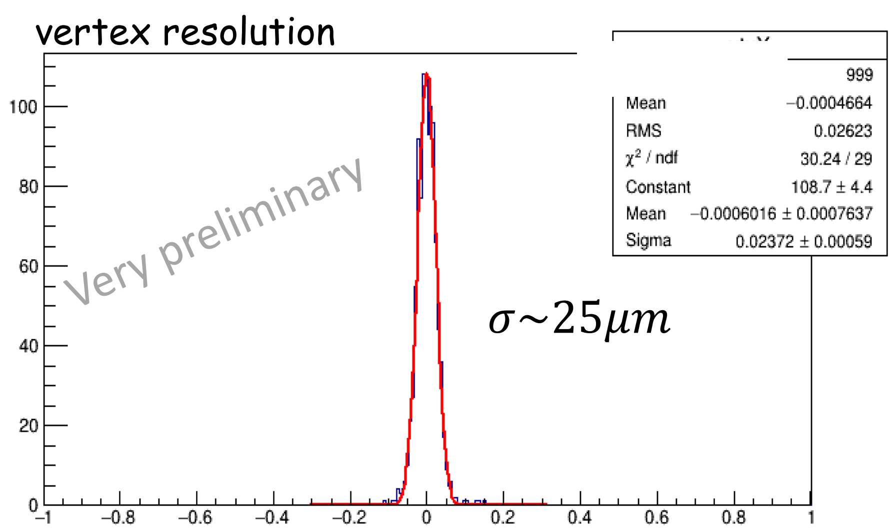

IP shifted by 40cm: more room for tracking
Forward going particles

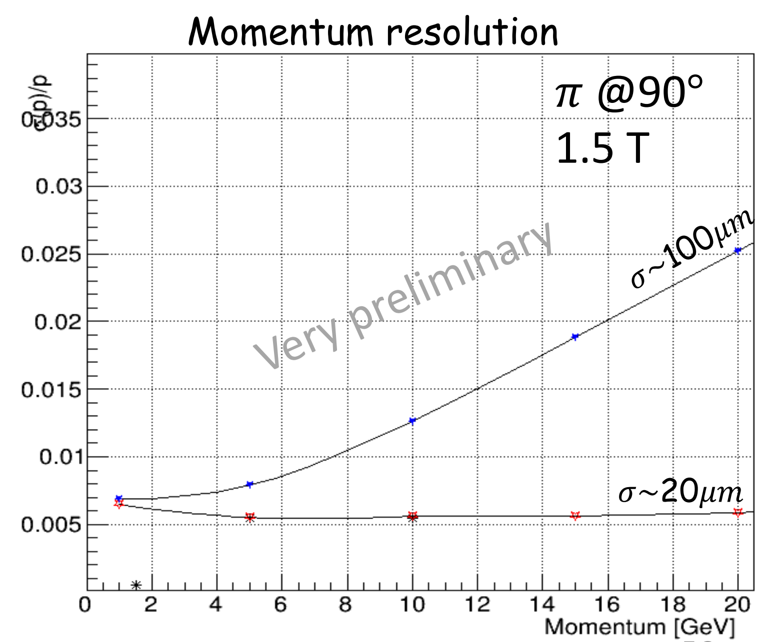
# JLEIC Central tracker

- Event generator (Pythia /HERWIG) -> GEANT4 ->Genfit ->RAVE (later)
- Position and granularity of first layers in vertex det. defines vertex resolution
- Benchmarks of tracking and vertex performance are ongoing







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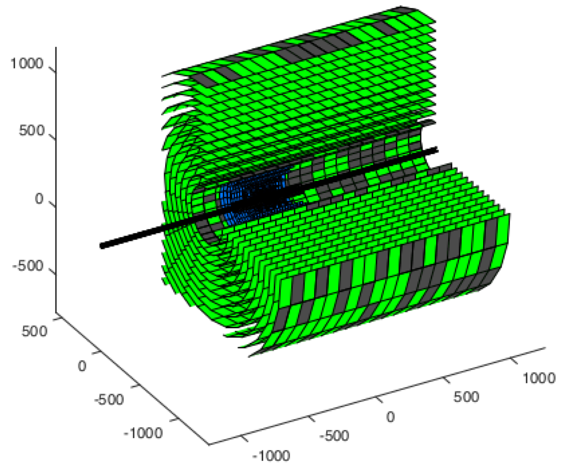
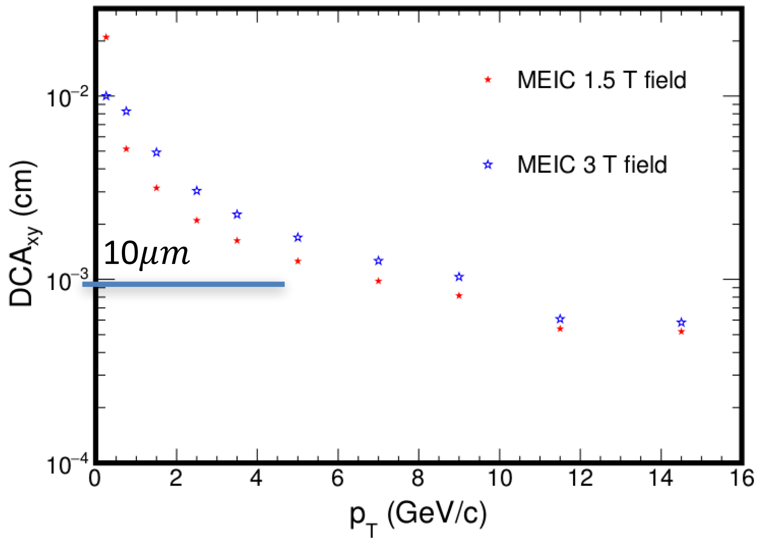
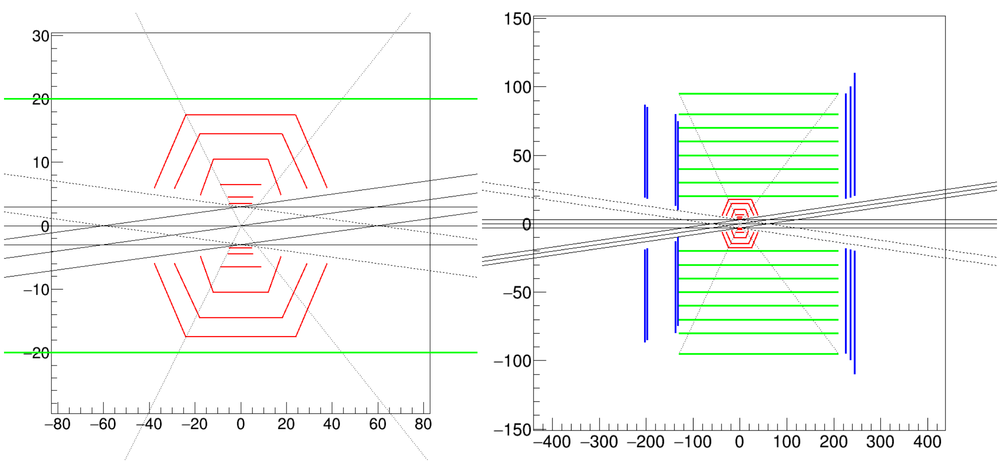
# JLEIC CENTRAL TRACKER:

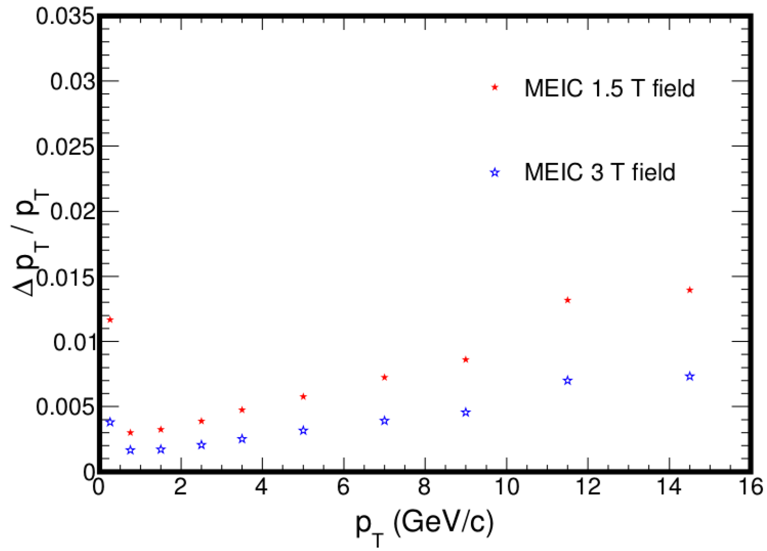
Michael Lomnitz, LBNL

- LiC code with JLEIC geometry
- Tracking based on Kalman Filter.
- RAVE for vertexing
- Take into account geometry and material





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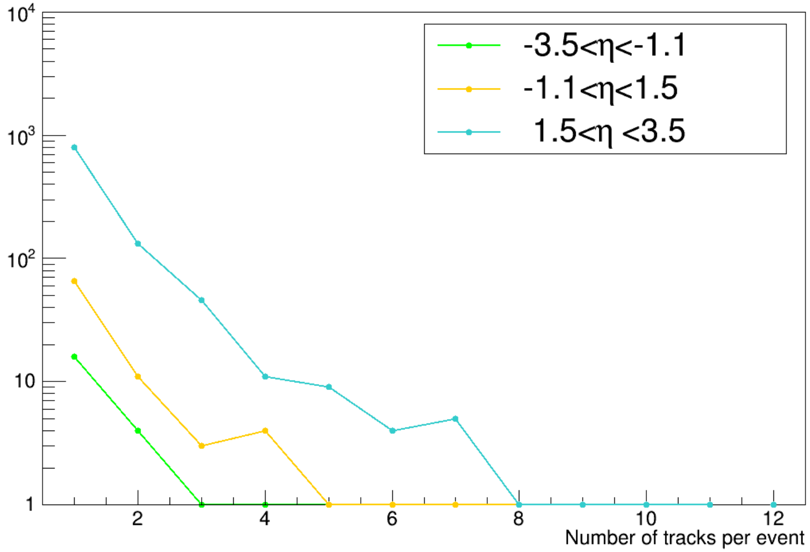
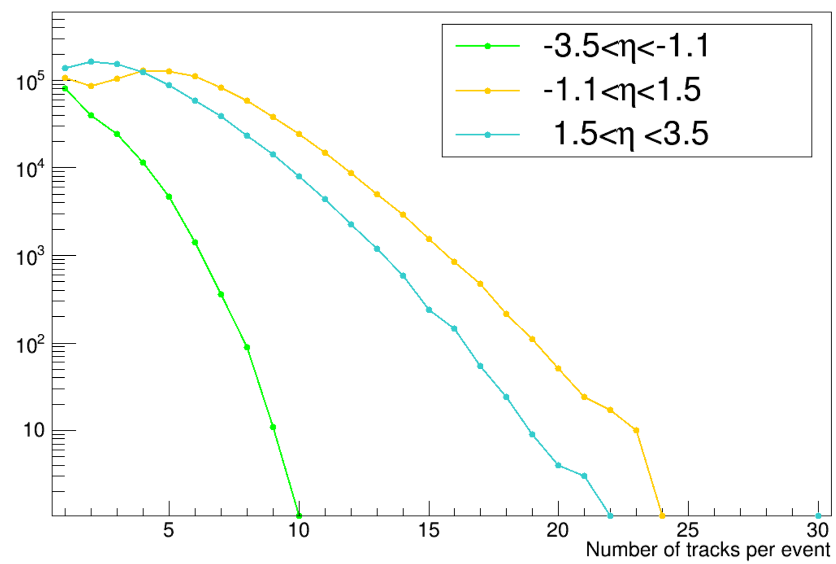
# Track multiplicity, per event

Low $Q^2$ <1GeV



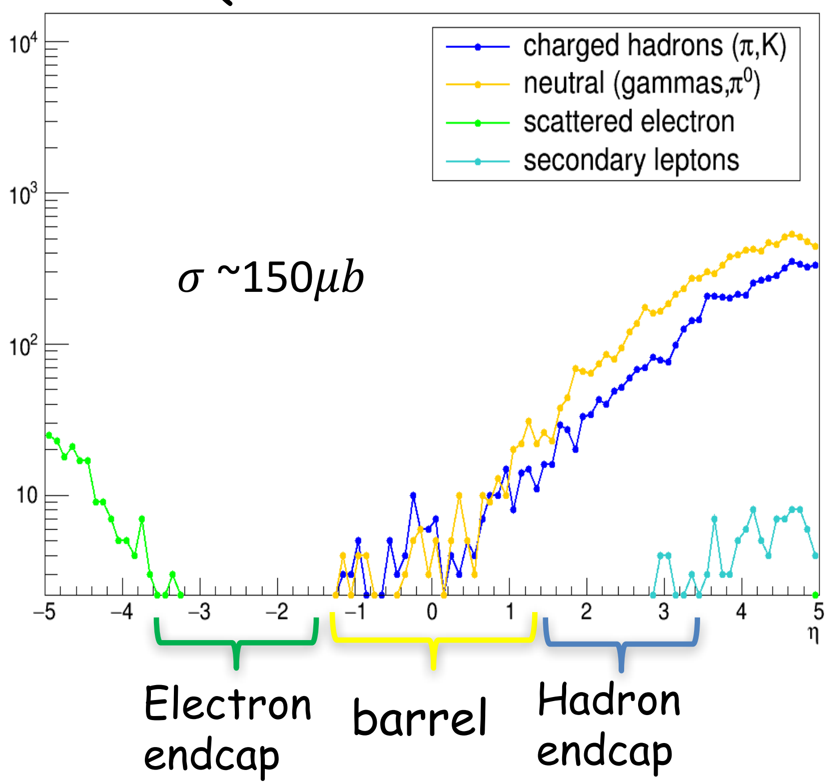

$Q^2$ > 1GeV



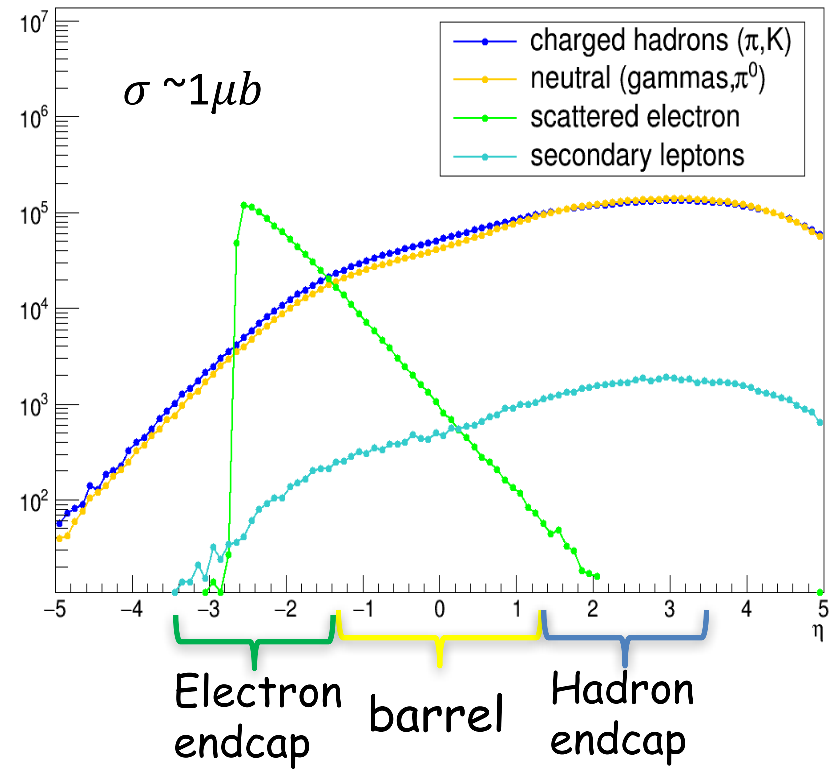

ep 10GeV x 100 GeV, not normalized

# Track multiplicity

Low $Q^2$ <1GeV



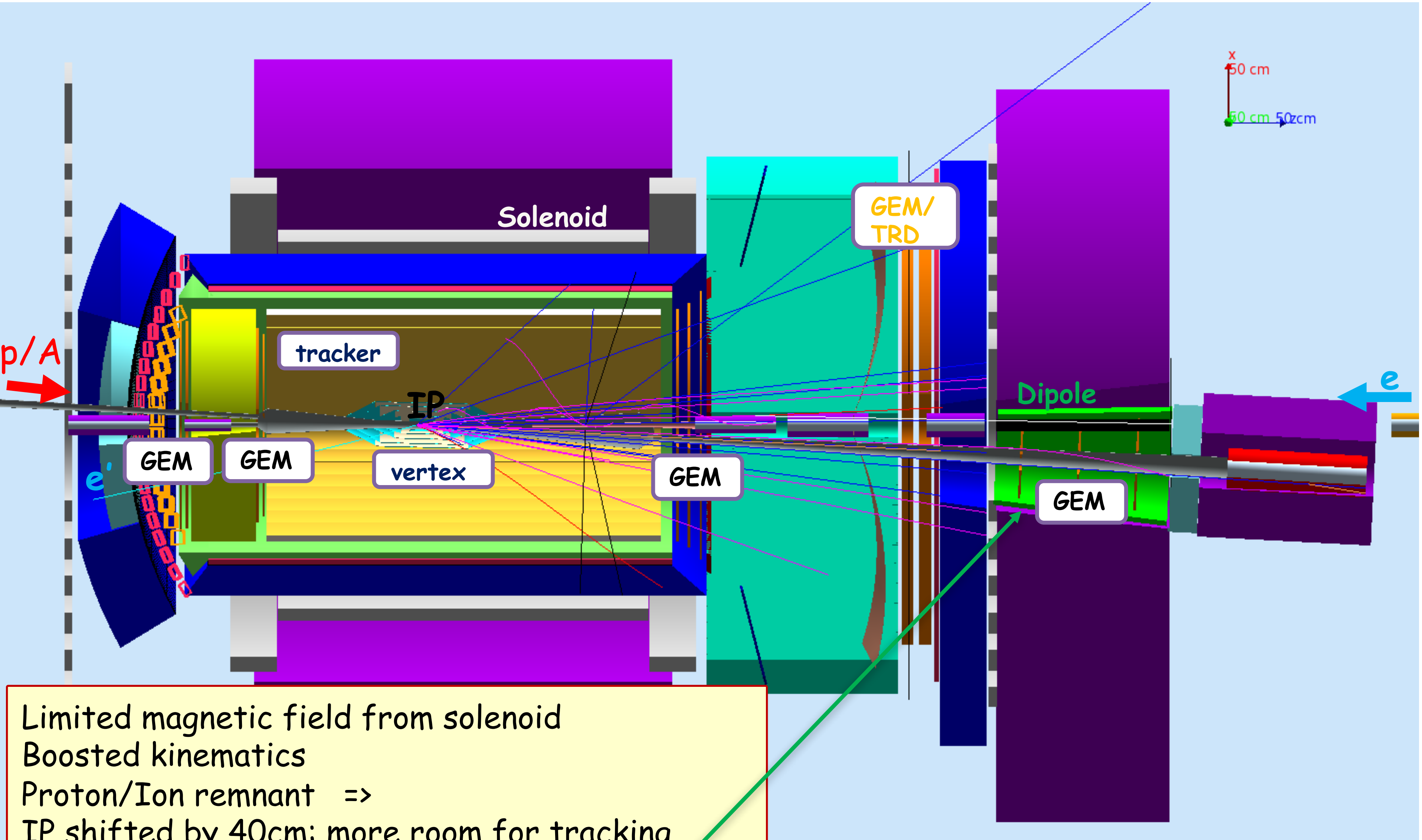

1< $Q^2$ > 10 GeV




ep 10GeV x 100 GeV, not normalized

High granularity tracking in hadron endcap

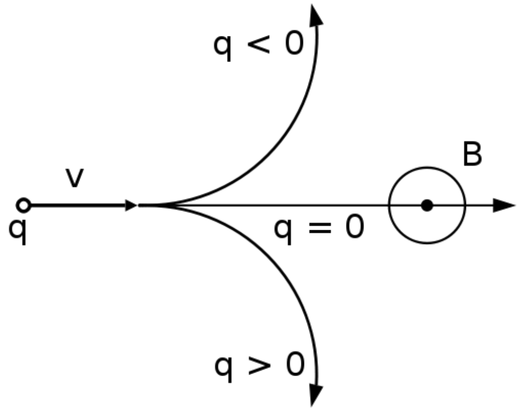
# EIC tracking: hadron endcap



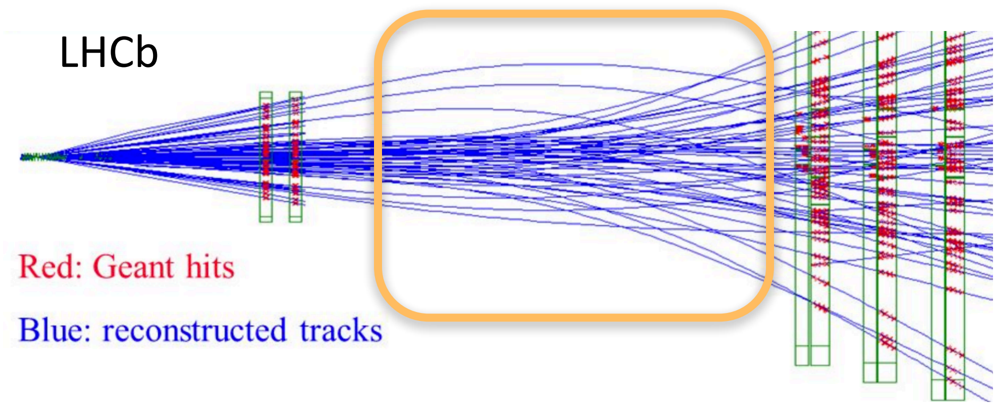

Limited magnetic field from solenoid
Boosted kinematics
Proton/Ion remnant =>
IP shifted by 40cm: more room for tracking
Forward dipole field

# Magnets: Forward Dipole

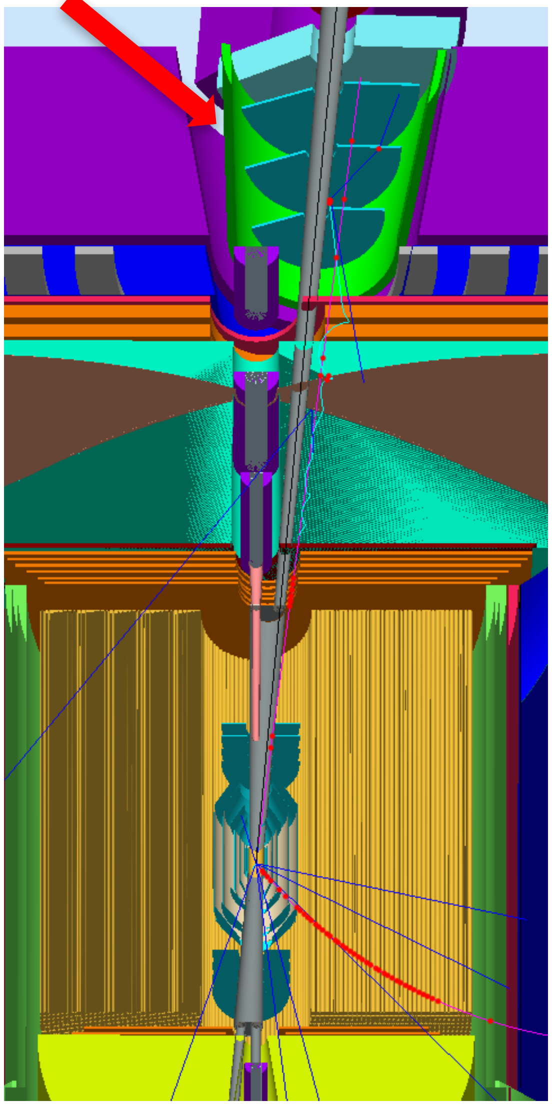
End-caps: similar to fixed target facility



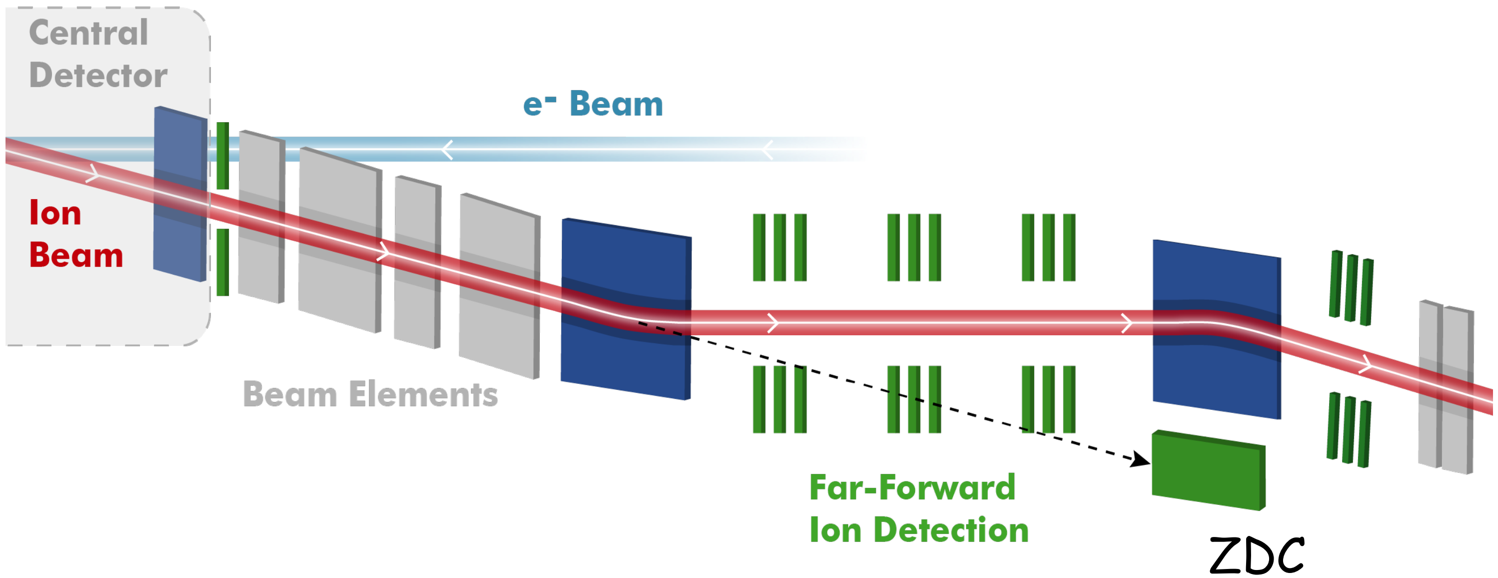

p[GeV]= 0.3· B [T]· R [m]




Forward Dipole at JLEIC



# Far-forward ion direction area

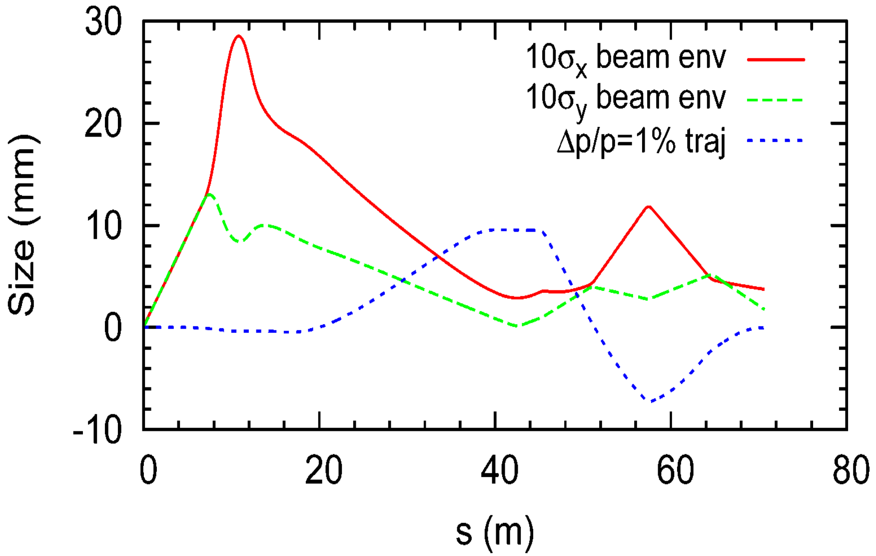


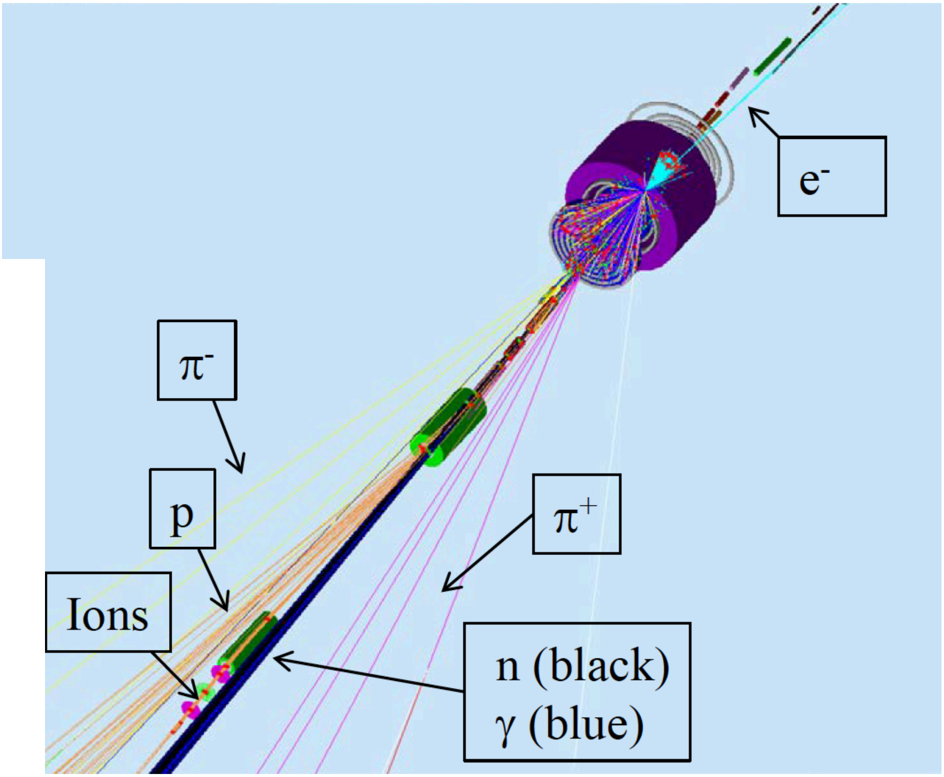

- **Tracking detectors** (decay products of $\Lambda', \Sigma$ $(\pi$,K))
- **Roman-pots** for (p)-tagging
- **Zero degree calorimeter** for (n)-tagging

# Far-forward ion direction area

V. Morozov

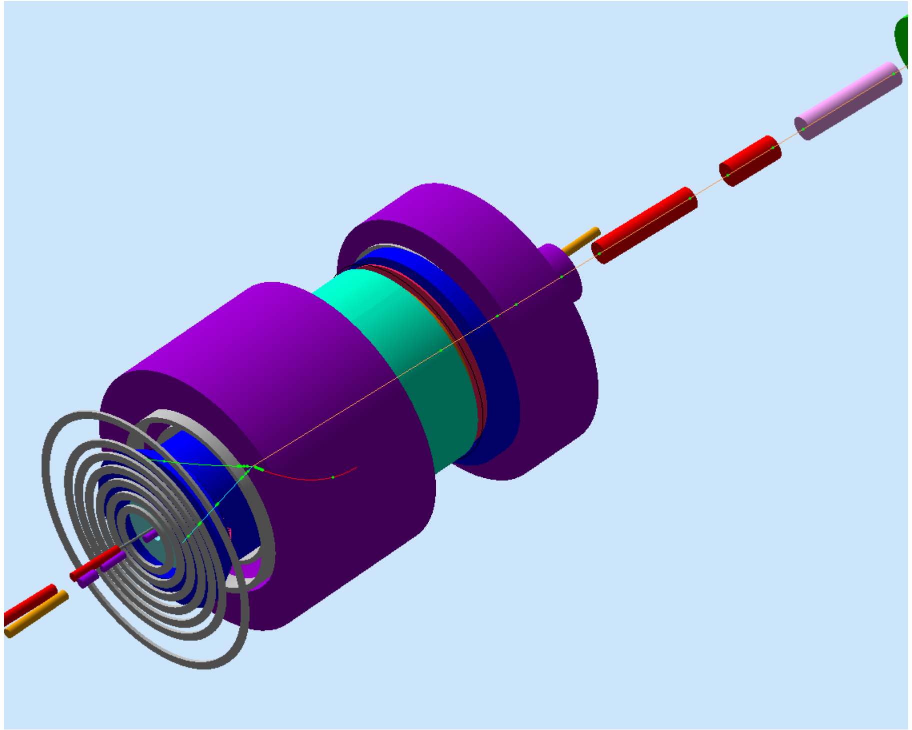
- Main beam is focused
- High dispersion for off momentum particles

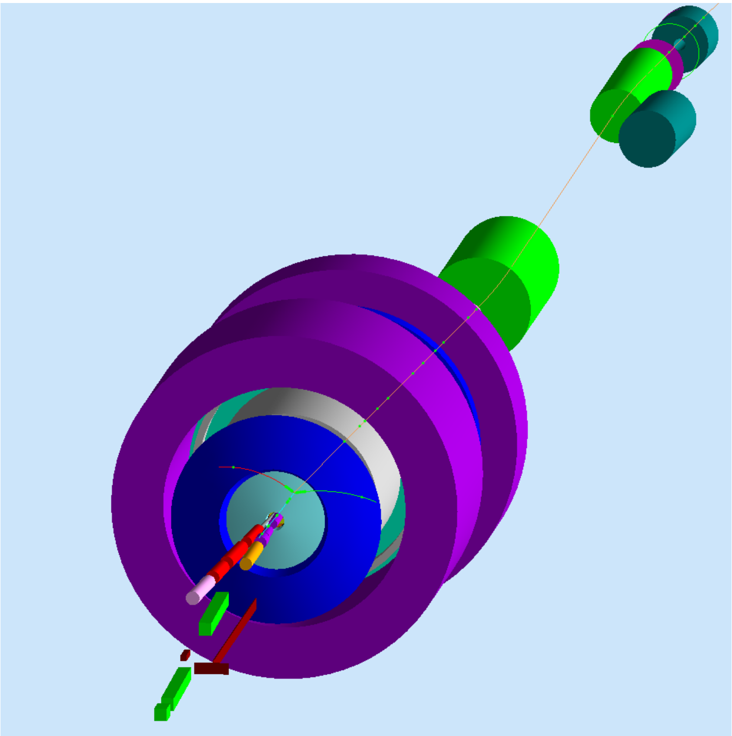


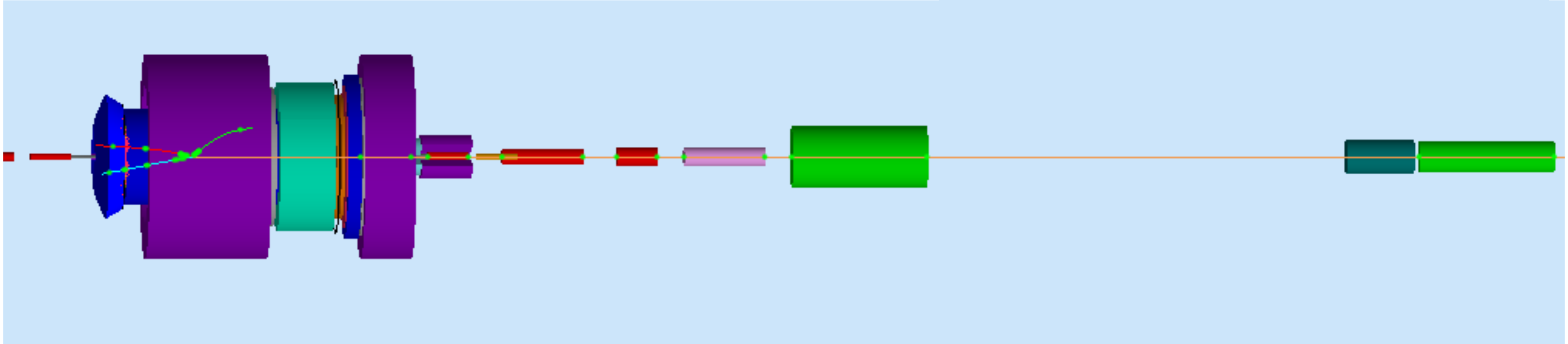




- **Tracking detectors** (decay products of $\Lambda', \Sigma$ $(\pi, K)$)
- **Roman-pots** for (p)-tagging
- **Zero degree calorimeter** for (n)-tagging

# Far-forward ion direction area

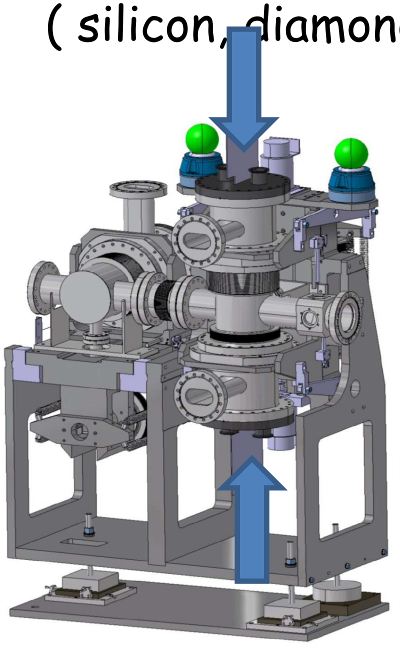






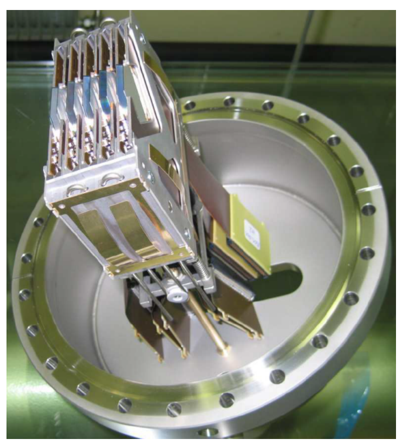
# ROMAN POTS:

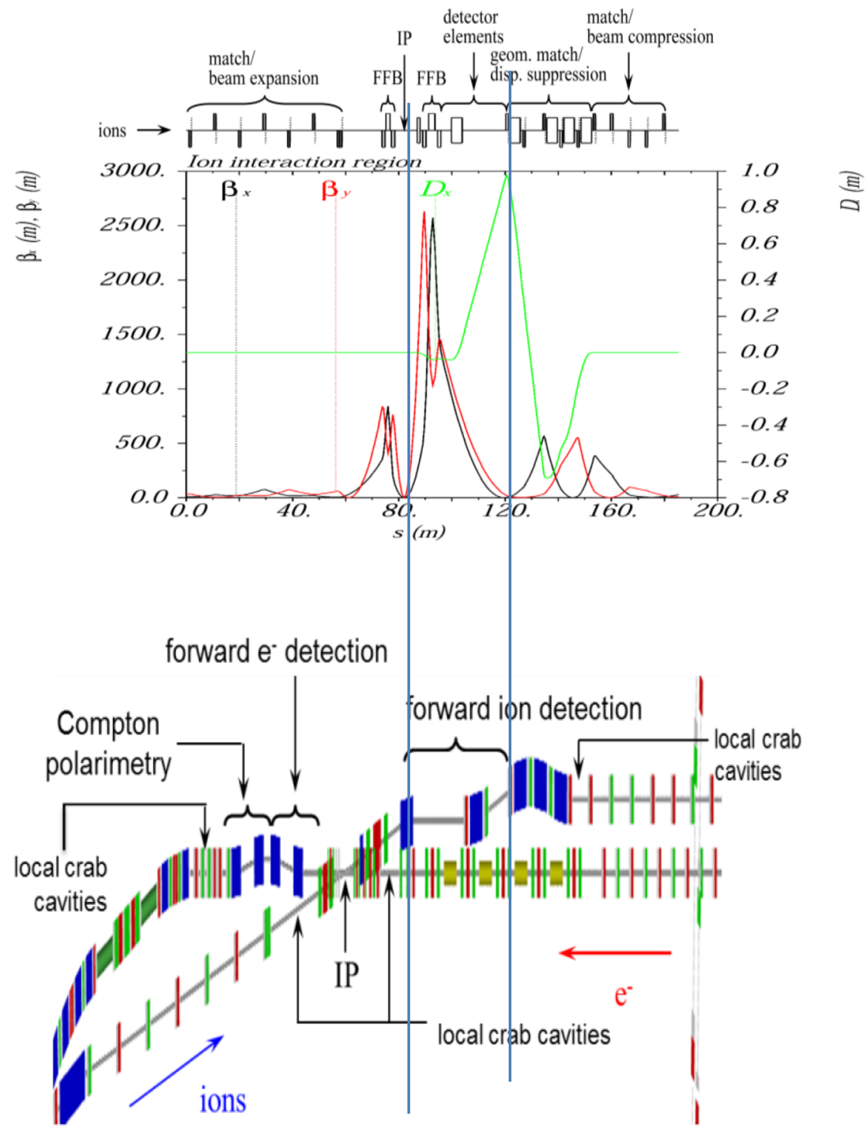
- Ion ring forward detection
- Maximum focusing to allow to place detector as close as possible to the beam ( up to 1mm at LHC)
- Dispersion maximum for best moment resolution
- several planes of solid state detector ( silicon, diamond, LGAD )



Marco Oriunno SLAC

Example TOTEM

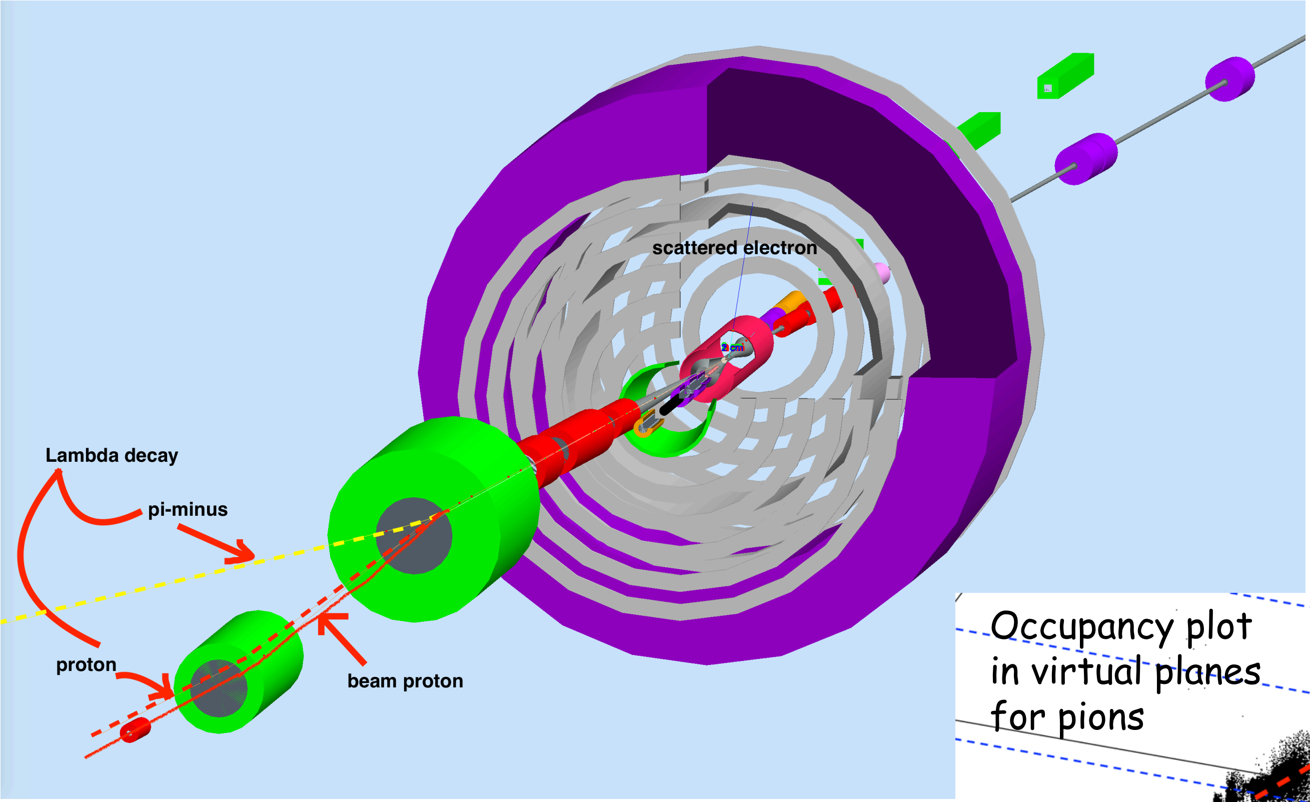


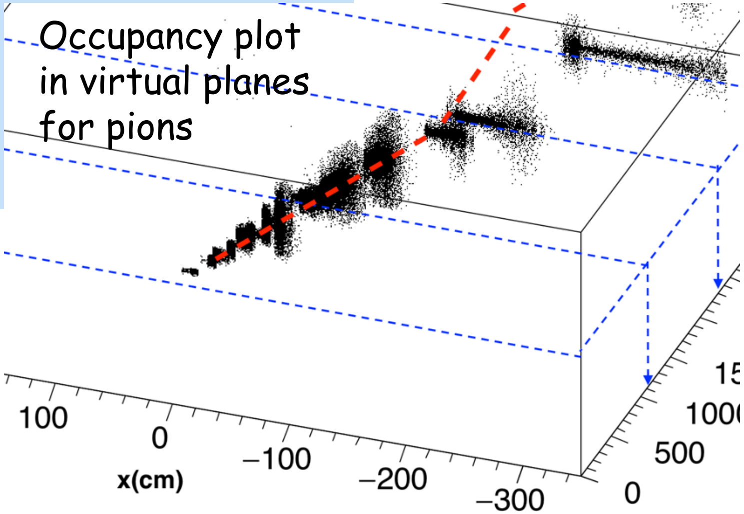


# FAR-FORWARD AREA:

Kijun Park

- Tracking for Tagged DIS events
- $\Lambda$ -> p+ $\pi$

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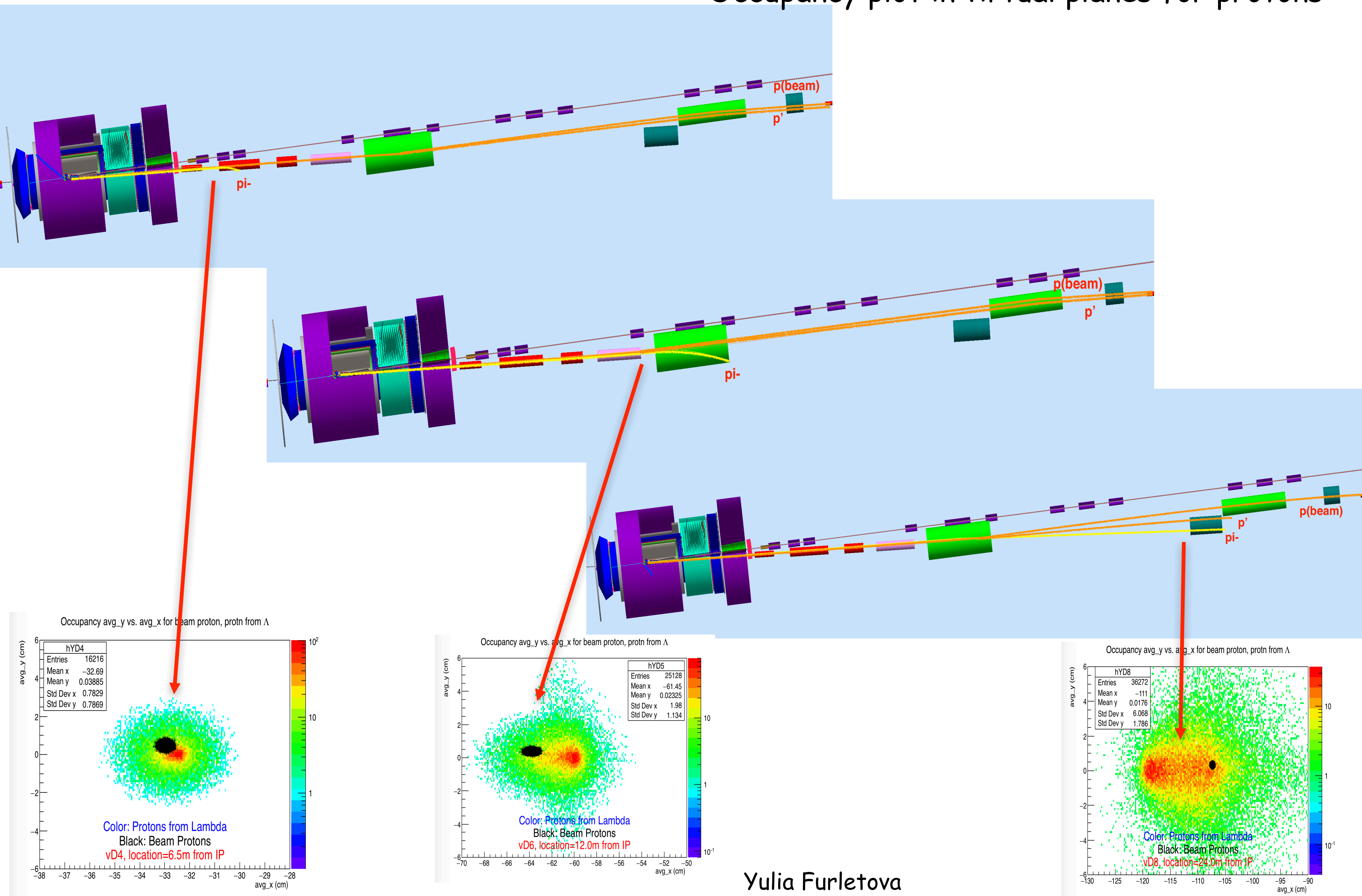
# FAR-FORWARD AREA:

Kijun Park

Occupancy plot in virtual planes for protons

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# Not covered

- Background
- Track reconstruction (Kalman filter)
- Alignment

# Thank you!

# Vertex reconstruction