

# An ultra-light Drift Chamber with Particle Identification capabilities

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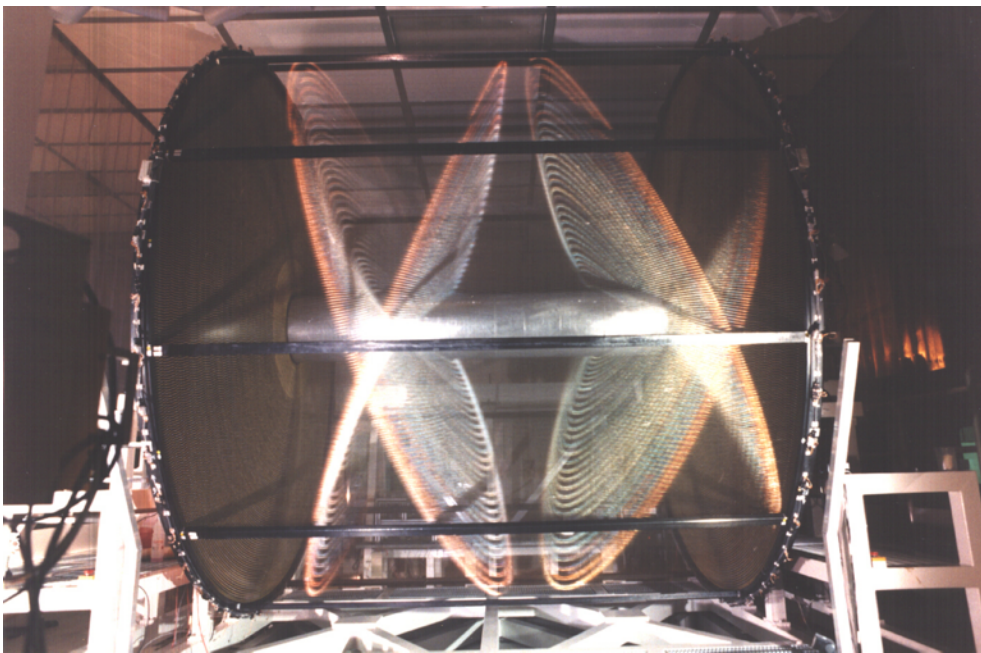
CEPC CDR International Review

IHEP Beijing, Sept. 14, 2018

# Road to IDEA D.C. proposal

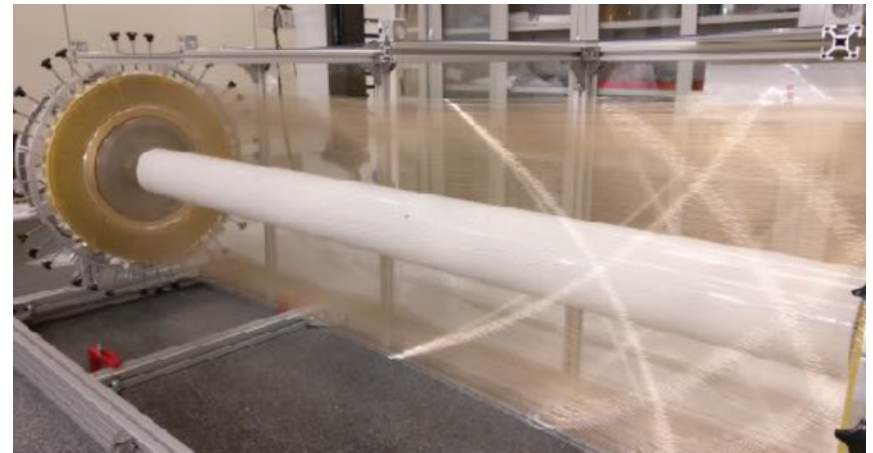
- Ancestor chamber: **KLOE** at **INFN LNF DaΦne φ factory** (commissioned in 1998 and currently operating)
- **CluCou** Chamber proposed for the **4<sup>th</sup>-Concept** at **ILC** (2009)
- **I-tracker** chamber proposed for the **Mu2e experiment** at **Fermilab** (2012)
- **DCH** for the **MEG2 upgrade** at **PSI** (under commissioning at PSI)

## KLOE Drift Chamber

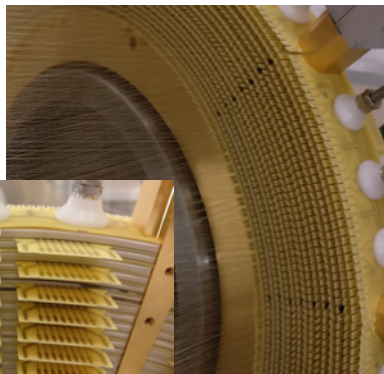


**fully stereo**  
**4 m diameter**  
**3.3 m length**  
**C-fiber structure**  
**90% He – 10%  $iC_4H_{10}$**   
 12,000 sense wires  
 52,000 total wires  
 80  $\mu m$  Al field wires  
 2x2 and 3x3  $cm^2$  cells

## MEG2 Drift Chamber



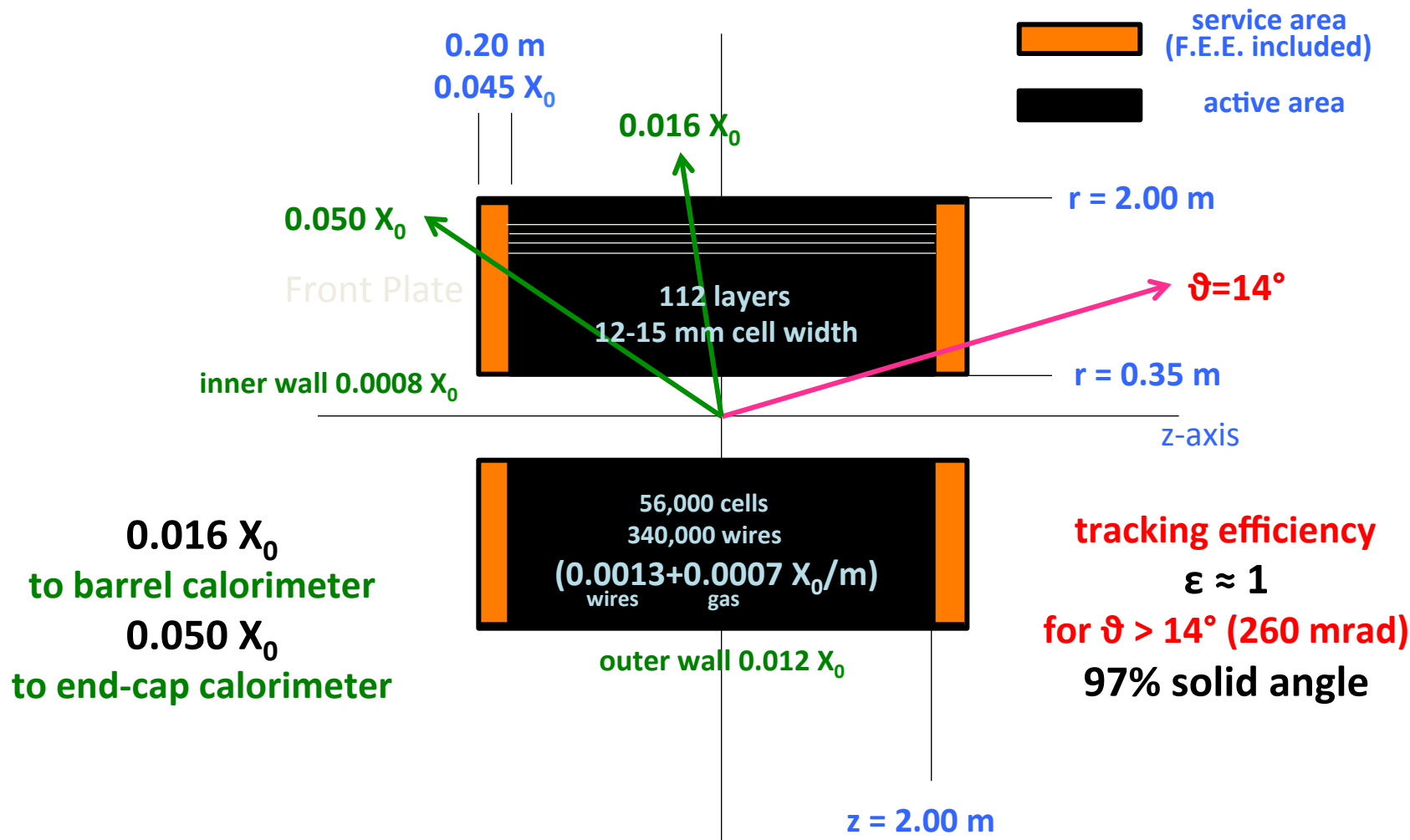
**fully stereo**  
**0.6 m diameter**  
**2.0 m length**  
**C-fiber structure**  
**85% He – 15%  $iC_4H_{10}$**   
 2,000 sense wires  
 12,000 total wires  
 40  $\mu m$  Al field wires  
 0.7x0.7  $cm^2$  cells  
**cluster tim/cou**



# IDEA D.C. "Innovations"

- **Gas containment – wire support** functions separation
  - allows to reduce material to  $\approx 10^{-3} X_0$  for the inner cylinder and to a few  $\times 10^{-2} X_0$  for the end-plates, including FEE, HV supply and signal cables (Mu2e proposal design:  $1.5 \times 10^{-3} X_0$  and  $8 \times 10^{-3} X_0$ , respectively).
- **Feed-through-less wiring**
  - allows to increase chamber granularity and field/sense wire ratio to reduce multiple scattering and total tension on end plates due to wires
- **Cluster timing**
  - allows to reach spatial resolution  $< 100 \mu\text{m}$  for 8 mm drift cells in He based gas mixtures (such a technique is going to be implemented in the MEG2 drift chamber under construction)
- **Cluster counting**
  - allows to reach  $dN_c/dx$  resolution  $< 3\%$  for particle identification (a factor 2 better than  $dE/dx$  as measured in a beam test)

# IDEA D.C. Angular coverage



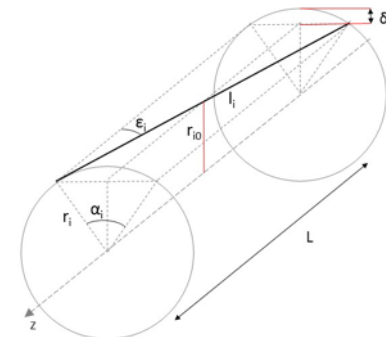
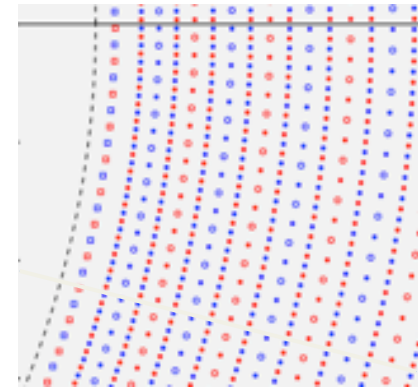
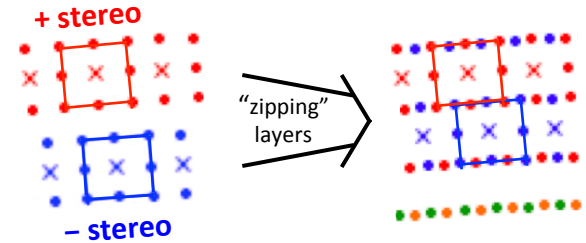
# IDEA D.C. Material budget

## Conservative estimates:

- Inner wall (from CMD3 drift chamber)  $8.4 \times 10^{-4} X_0$   
200  $\mu\text{m}$  Carbon fiber
- Gas (from KLOE drift chamber)  $7.1 \times 10^{-4} X_0/\text{m}$   
90% He – 10%  $\text{iC}_4\text{H}_{10}$
- Wires (from MEG2 drift chamber)  $1.3 \times 10^{-3} X_0/\text{m}$   
20  $\mu\text{m}$  W sense wires  $4.2 \times 10^{-4} X_0/\text{m}$   
40  $\mu\text{m}$  Al field wires  $6.1 \times 10^{-4} X_0/\text{m}$   
50  $\mu\text{m}$  Al guard wires  $2.4 \times 10^{-4} X_0/\text{m}$
- Outer wall (from Mu2e I-tracker studies)  $1.2 \times 10^{-2} X_0$   
2 cm composite sandwich (7.7 Tons)
- End-plates (from Mu2e I-tracker studies)  $4.5 \times 10^{-2} X_0$   
wire cage + gas envelope  
incl. services (electronics, cables, ...)

# IDEA D.C. Layout

- 12÷15 mm wide square cells 5 : 1  
field to sense wires ratio 56,448 cells
- 14 co-axial super-layers, 8 layers each  
(112 total) in 24 equal azimuthal (15°)  
sectors ( $N_i = 192 + (i - 1) \times 48$ )
- alternating sign stereo angles ranging  
from 50 to 250 mrad



# IDEA D.C. Electrostatic Stability

sagitta due to electrostatic forces  
on sense wire displaced by  $\Delta$  from  
central symmetry position

$$\delta_{e.s.} = \frac{C^2 V_0^2 L^2}{4\pi\epsilon T w^2} \Delta$$

$C$  = wire capacitance per unit length  $C = \frac{2\pi\epsilon}{\ln\left(\frac{\{2\}w}{2r}\right)}$   
 $V_0$  = wire voltage  
 $L$  = wire length  
 $T$  = wire mechanical tension  
 $w/2$  = wire distance from ground plane  
 $r$  = sense wire radius

**stability  
condition**

$$T \geq \frac{\pi\epsilon V_0^2 L^2}{w^2 \left( \ln \frac{w}{r} \right)^2}$$

**For IDEA D.C.:**

$V_0 = 1500 \text{ V}, L = 4 \text{ m},$   
 $w = 12 \text{ mm}, r = 20 \mu\text{m}:$

$$T \geq 0.16 \text{ N}$$

or, for  $T = 0.25 \text{ N}$   
 $(\delta_{\text{grav.}} = 400 \mu\text{m}):$

$$L \leq 4.9 \text{ m}$$

Smaller cell size (to mitigate higher occupancy at inner radius), e. g.  $w = 7 \text{ mm}$ ,  
 would require higher tension:  $T \geq 0.48 \text{ N}$ , which is at the limit of elasticity for  
 $20 \mu\text{m}$  diameter tungsten sense wire ( $YS \approx 1500 \text{ MPa}$ ):

⇒ shorten the wires (and loose angular coverage) and/or  
 increase the wire diameter (and mult. scatt. and  $\delta_{\text{grav.}}$ ) or  
**introduce new types of wires** (C wire?) with further  
 improvement of drift chamber transparency

# IDEA D.C. Expected resolution

## Transverse Momentum Resolution

$$\frac{\Delta p_t}{p_t} = \frac{8\sqrt{5}\sigma_{xy}}{.3BR_{out}\sqrt{N}} p_t \oplus \frac{0.0523[GeV/c]}{\beta BL} \sin\theta \sqrt{\frac{L}{X_0}}$$

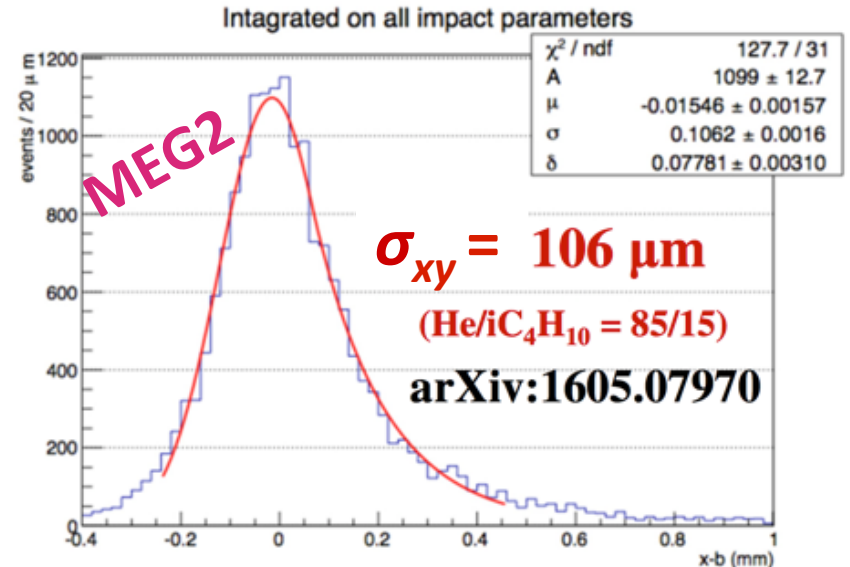
## Angular Resolutions

$$\Delta\varphi_0 = \frac{4\sqrt{3}\sigma_{xy}}{R_{out}\sqrt{N}} \oplus \frac{0.0136[GeV/c]}{\beta p} \sqrt{\frac{L}{X_0}}$$

$$\Delta\theta = \frac{\sqrt{12}\sigma_z}{R_{out}\sqrt{N}} \frac{1+\tan^2\theta}{\tan^2\theta} \oplus \frac{0.0136[GeV/c]}{\beta p} \sqrt{\frac{L}{X_0}}$$

## Momentum Resolution

$$\frac{\Delta p}{p} = \frac{\Delta p_t}{p_t} \oplus \frac{\Delta\theta}{\tan\theta}$$



no cluster timing, 7x7 mm<sup>2</sup>

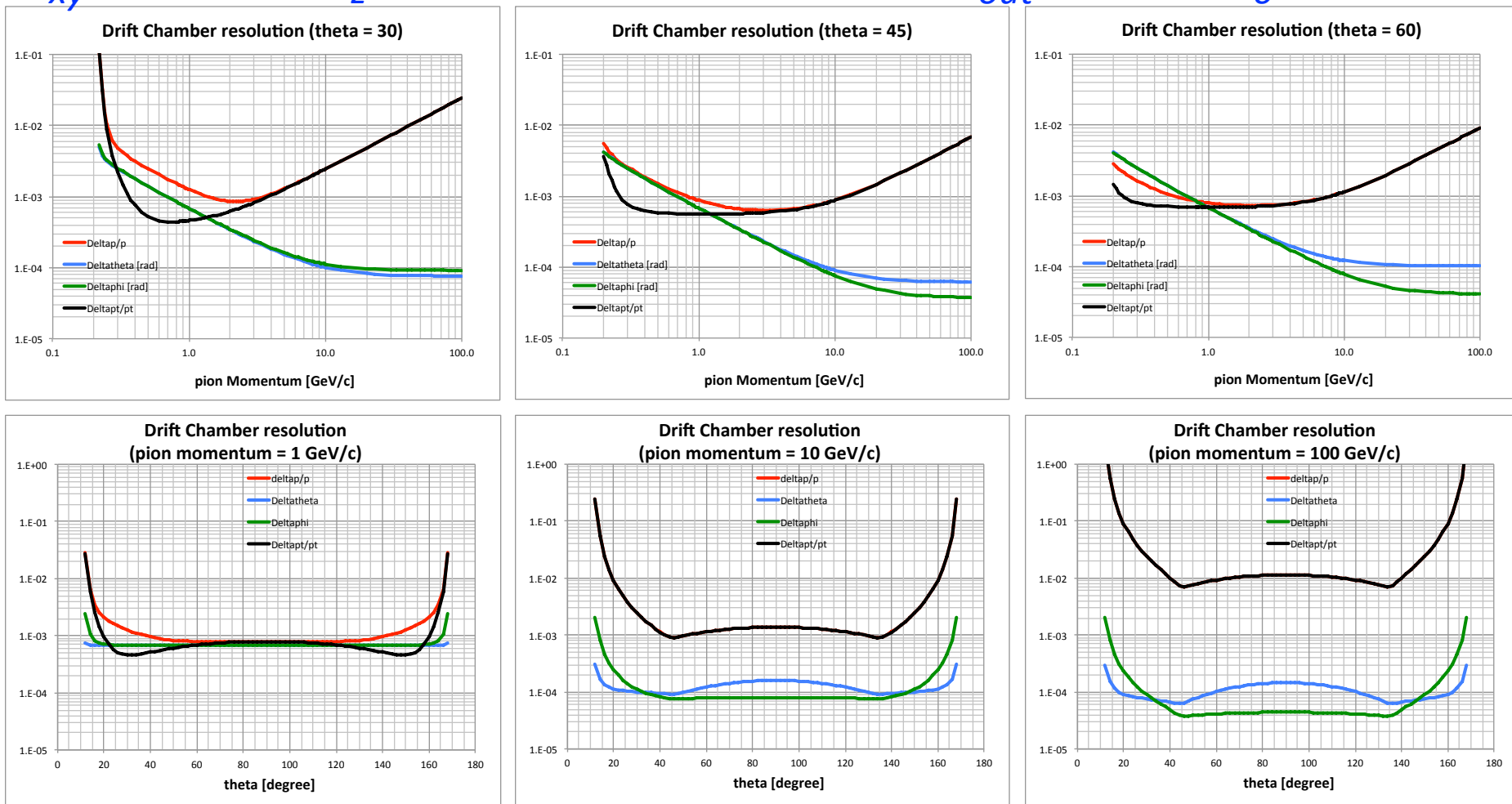
12x12 mm<sup>2</sup>  $\leq 100 \mu\text{m}$

cluster timing  $\rightarrow$  -20%

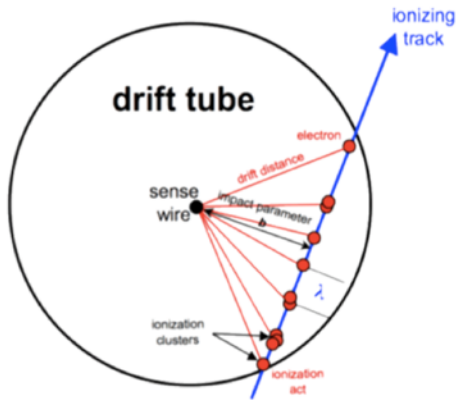
**IDEA expected  $\sigma_{xy} \approx 80 \mu\text{m}$**

# IDEA D.C. Expected resolution

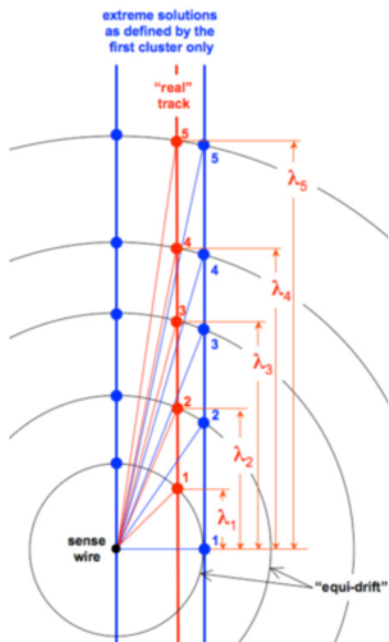
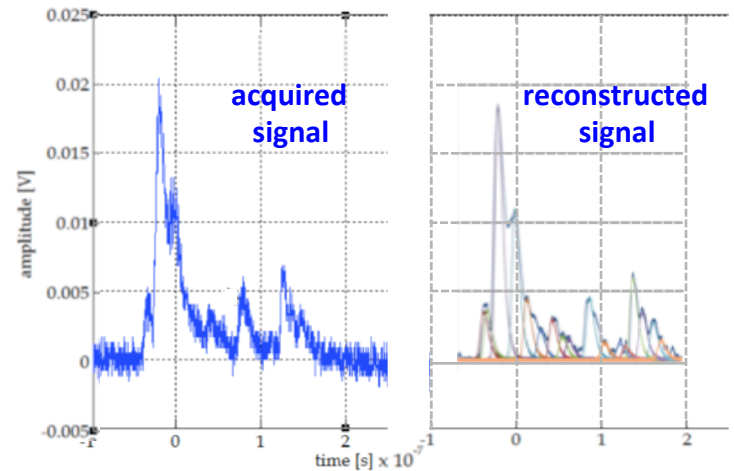
$$\sigma_{xy}=100\mu\text{m}, \sigma_z=1.0\text{mm}, N=112, B=2\text{T}, R_{out}=2\text{m}, L/X_0=2.5\times 10^{-3}$$



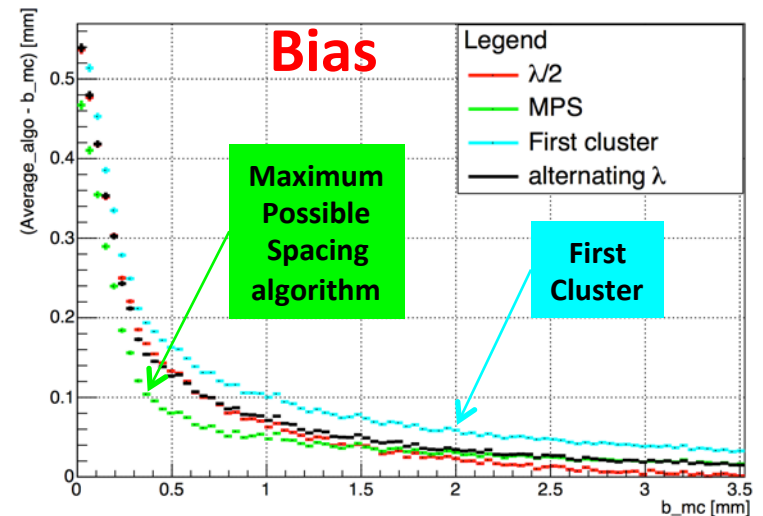
# Cluster Timing/Counting



From the **ordered sequence of the electrons arrival times**, considering the average time separation between clusters and their time spread due to diffusion, **reconstruct the most probable sequence of clusters drift times**:  $\{t_i^{cl}\} \quad i = 1, N_{cl}$



For any given first cluster (FC) drift time, the **cluster timing technique** exploits the drift time distribution of all successive clusters  $\{t_i^{cl}\}$  to determine the most probable impact parameter, thus reducing the **bias** and the average **drift distance resolution** with respect to those obtained from with the FC method alone.



# Particle Identification (in theory)

$$\frac{\sigma_{dE/dx}}{(dE/dx)} = 0.41 \cdot n^{-0.43} \cdot (L_{track} [m] \cdot P[atm])^{-0.32}$$

from *Walenta parameterization (1980)*

**$dE/dx$**

truncated mean cut (70-80%) reduces the amount of collected information

**$n = 112$**  and a **2m track** at **1 atm** give, at best

**$\sigma \approx 4.3\%$**

Increasing  **$P$**  to 2 atm improves resolution by 20% ( $\sigma \approx 3.4\%$ ) but at a **considerable** cost of multiple scattering contribution to momentum and angular resolutions.

**versus**

$$\frac{\sigma_{dN_{cl}/dx}}{(dN_{cl}/dx)} = (\delta_{cl} \cdot L_{track})^{-1/2}$$

from *Poisson distribution*

**$dN_{cl}/dx$**

**$\delta_{cl} = 12.5/\text{cm}$**  for He/iC<sub>4</sub>H<sub>10</sub>=90/10 and a **2m track** give, in principle

**$\sigma \approx 2.0\%$**

A small increment of iC<sub>4</sub>H<sub>10</sub> from 10% to 20% ( $\delta_{cl} = 20/\text{cm}$ ) improves resolution by 20% ( $\sigma \approx 1.6\%$ ) at only a **reasonable** cost of multiple scattering contribution to momentum and angular resolutions.

# $\mu/\pi$ separation at 200 MeV/c (exp.)

The data shown refer to a beam of  $\mu$  and  $\pi$  at 200 MeV/c, taken with a gas mixture

$\text{He}/\text{iC}_4\text{H}_{10} = 95/5$ ,  $\delta_{\text{cl}} = 9/\text{cm}$ ,  
100 samples, 2.6 cm each at  $45^\circ$   
(for a total track length of 3.7 m,  
corresponding to  $N_{\text{cl}} = 3340$ ,  
 $1/\sqrt{N_{\text{cl}}} = 1.7\%$ ).

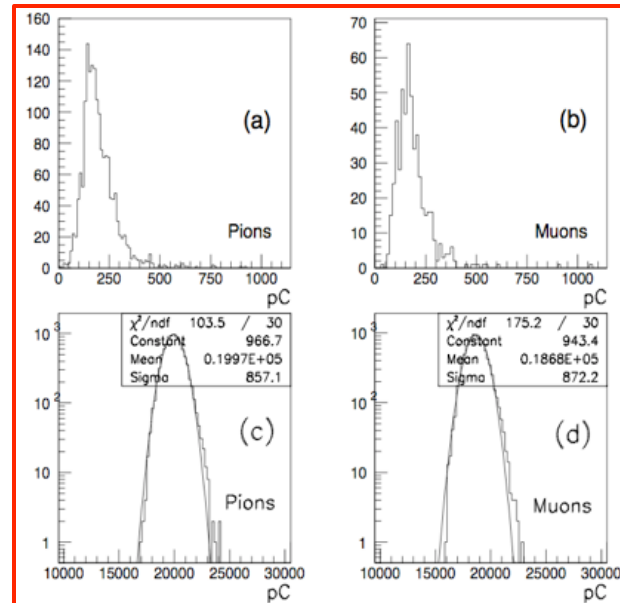
## Setup:

25  $\mu\text{m}$  sense wire  
(gas gain  $2 \times 10^5$ ),

through a high BW preamplifier  
(1.7 GHz, gain 10),

digitized at  
2 GSa/s, 1.1 GHz, 8 bits

(*NIM A386 (1997) 458-469 and references therein*)



$dE/dx$

100 samples 3.7 cm

theory:

$$(\sigma = 0.41 n^{-0.43} (L[\text{m}]P[\text{atm}])^{-0.32})$$

$\sigma = 3.7\%$

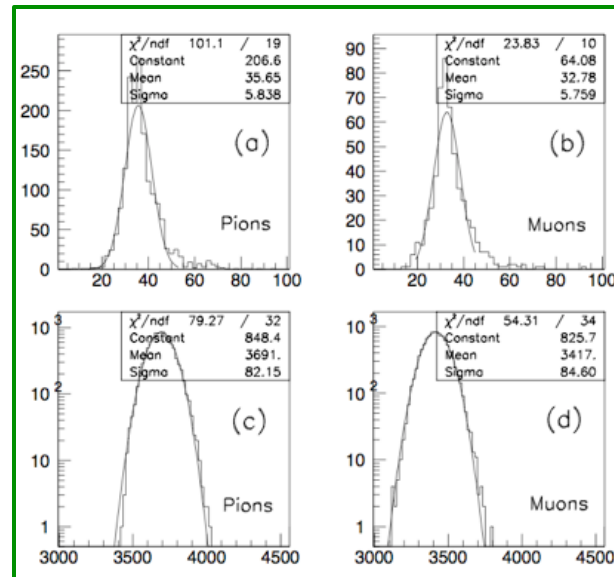
$\approx 2.0\sigma$  separation

experiment

20% truncated mean

$\sigma = 4.5\%$

$\approx 1.4\sigma$  separation



$dN_c/dx$

theory

Poisson distribution

$\sigma = 1.7\%$

$\approx 5\sigma$  separation

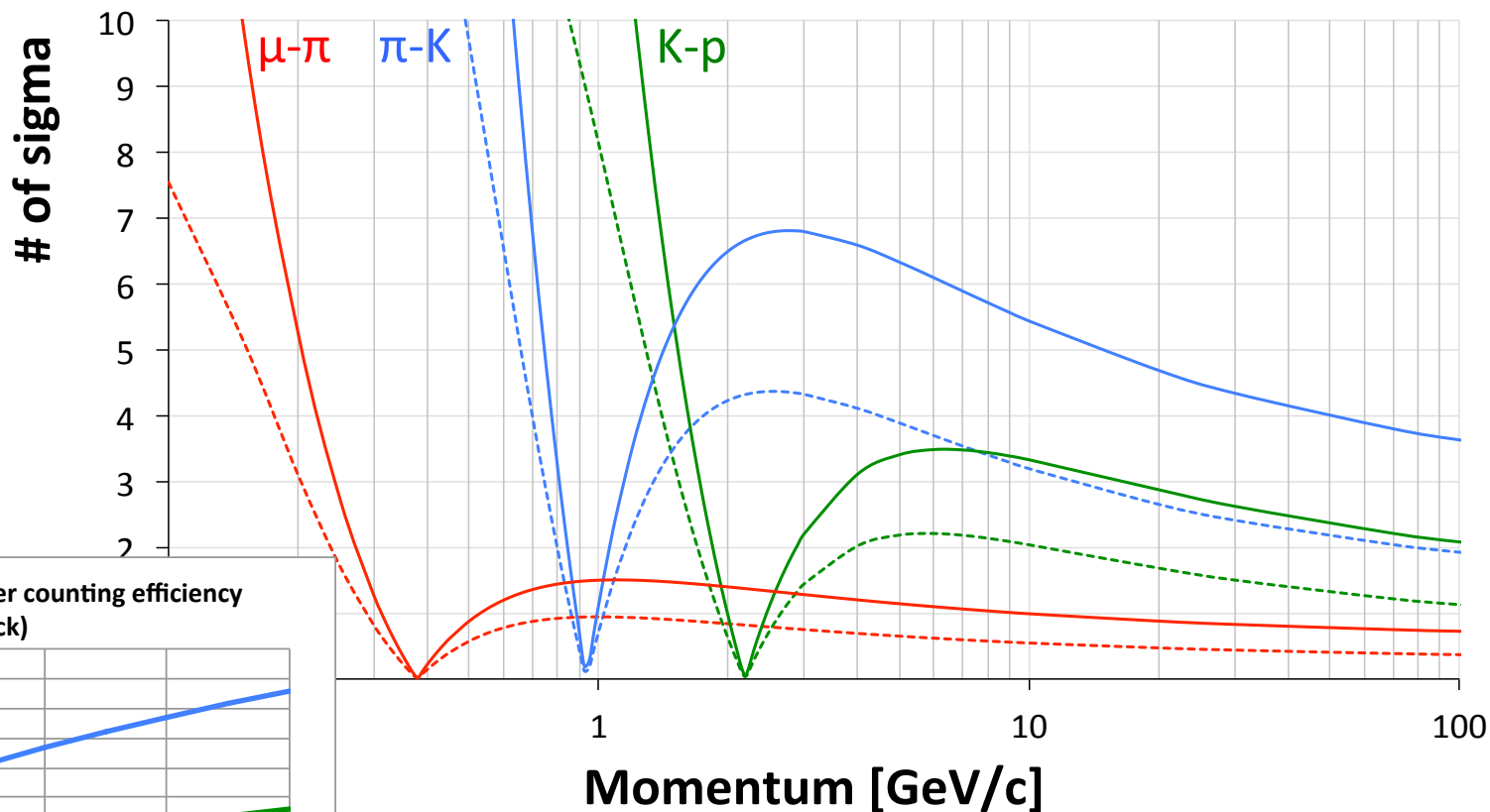
experiment

$\sigma = 2.5\%$

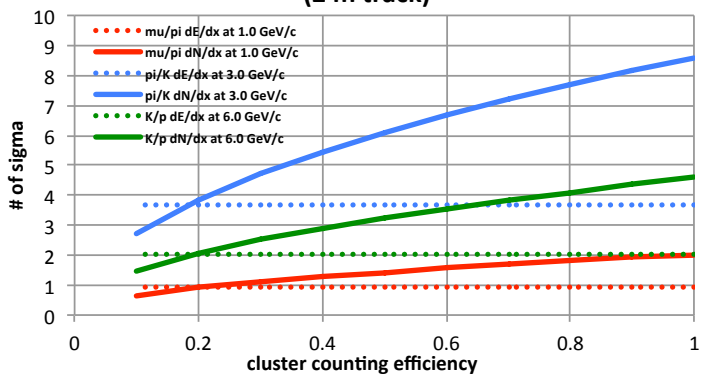
$\approx 3.2\sigma$  separation

# IDEA D.C. expected Particle Id.

## Particle Separation ( $dE/dx$ vs $dN/dx$ )



Particle separation vs cluster counting efficiency  
(2 m track)



# Cluster Timing/Counting

Recipe for cluster timing/counting  
in He based gas mixtures:

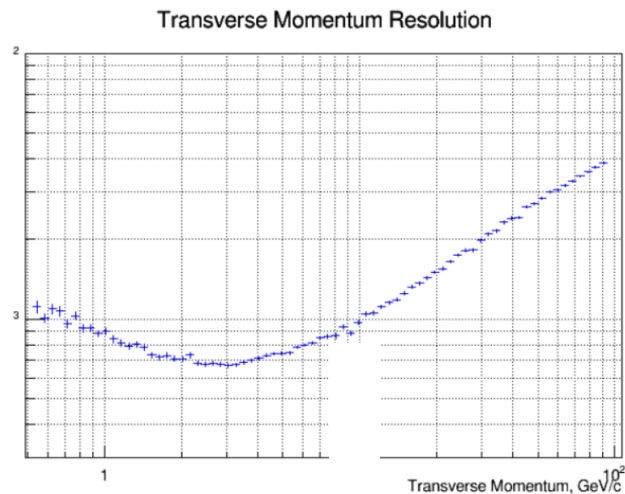
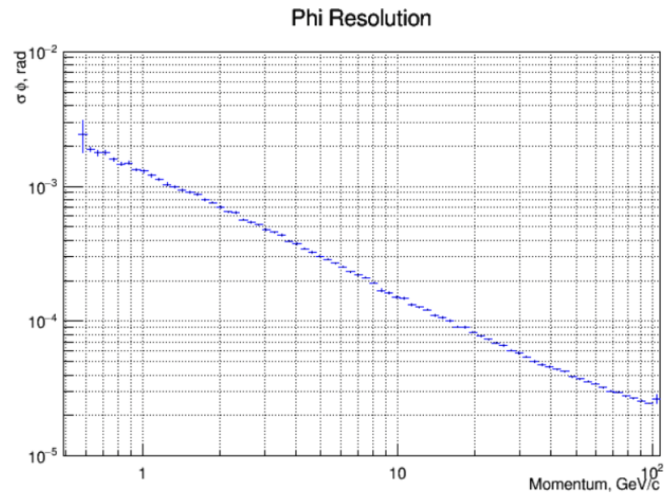
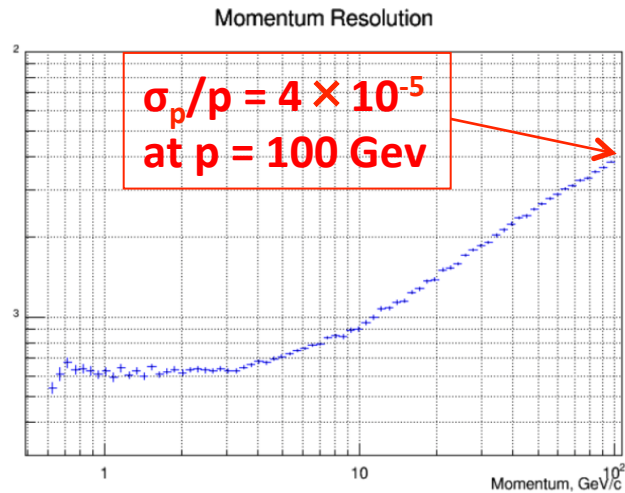
**FEE: 1 GHz BW, x10 gain (S/N ratio  $\approx 8$ )**

**digitizer: 2 GSa/s sampling rate, >8 bits**

expected results:

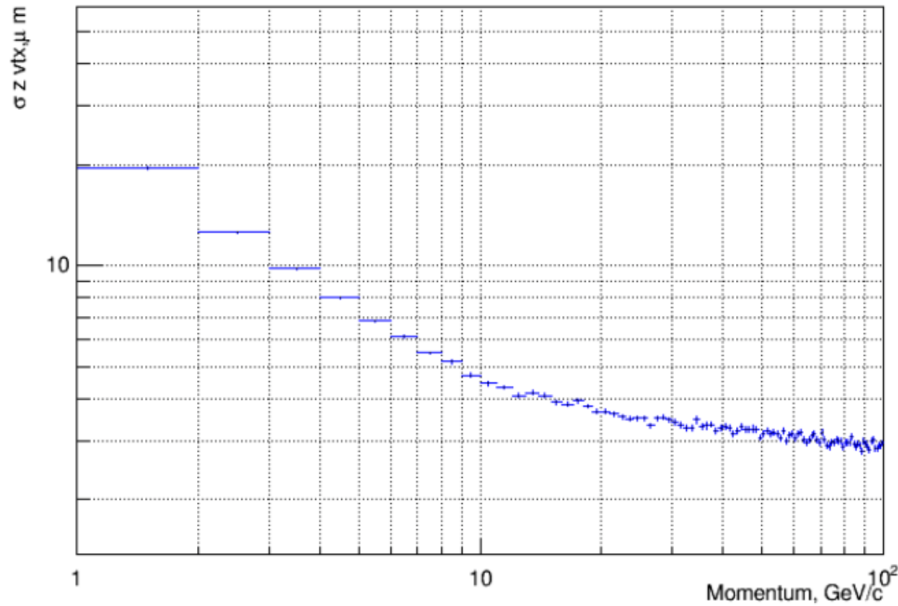
$$\sigma_{xy} \approx 80 \text{ } \mu\text{m} - dN_{cl}/dx \approx 2.5\%$$

# IDEA integrated track simulation

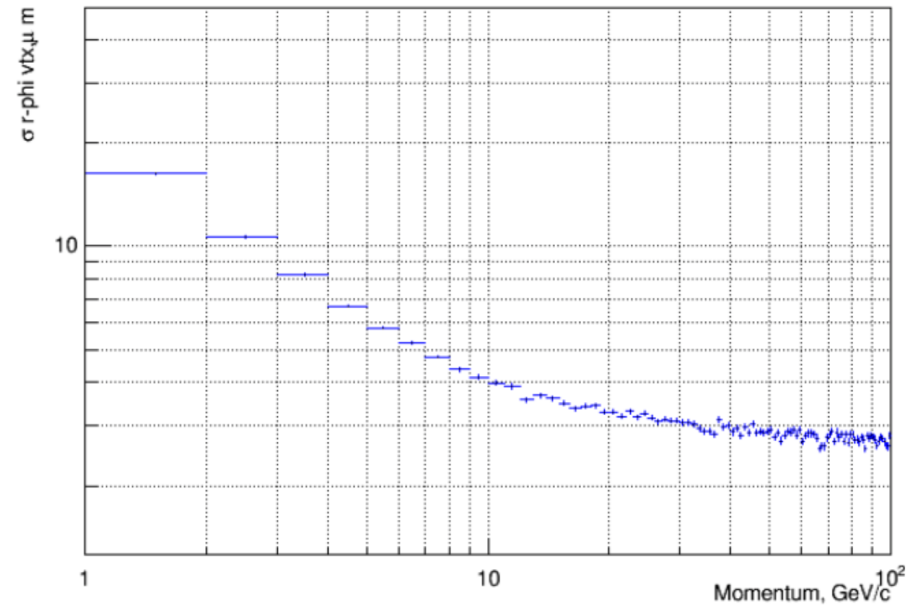


# IDEA integrated track simulation

Z vtx Resolution



R-phi vtx Resolution



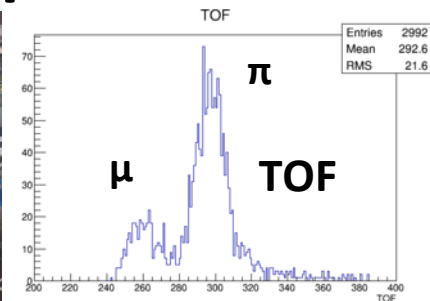
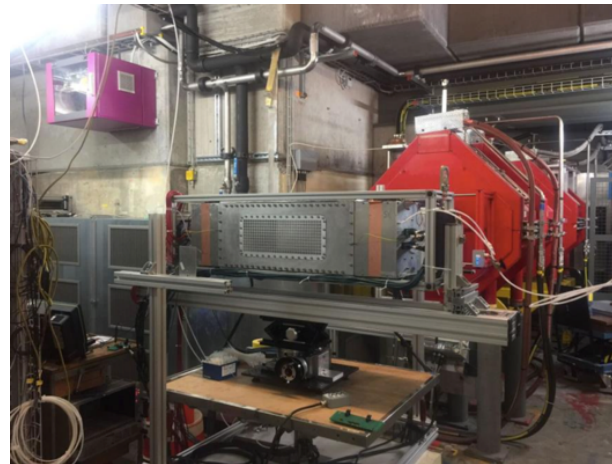
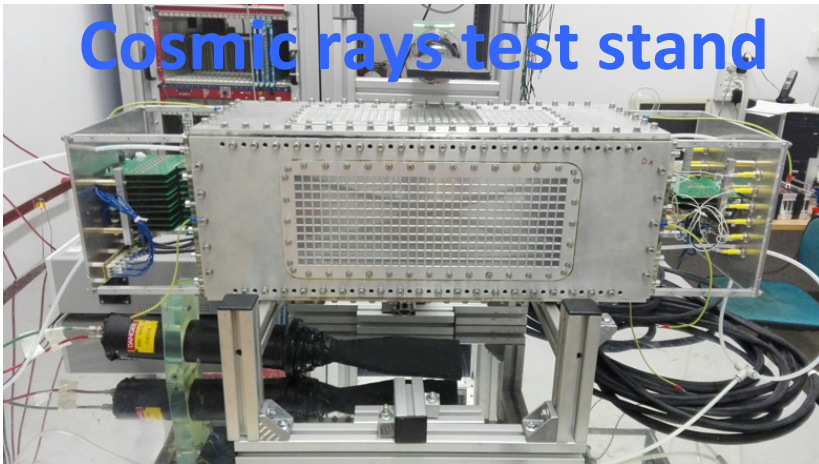
$$\sigma_{d_0} = a \oplus \frac{b}{p \sin^{3/2} \vartheta}$$

$$a = 3 \mu m$$

$$b = 15 \mu m$$

# 60 cm, 144 cells prototype

Cosmic rays test stand



Beam test at PSI  
last September



Beam test at CERN of a full IDEA slice:  
drift chamber, pre-shower, D.R. calo.  
μ-counter.

this week

# Conclusions

- We have presented an innovative tracking system for the IDEA detector at CEPC, based on a "**ultra-light drift chamber with peculiar particle identification capabilities**" using cluster timing/counting techniques.
- It consists of a full stereo, single sense wire, square cells drift chamber:
  - $R_{in} = 35 \text{ cm}$ ;  $R_{out} = 200 \text{ cm}$ ;  $L = 400 \text{ cm}$ ; 112 layers; 56,000 cells (12 to 15 mm); stereo angles ranging from 50 mrad to 150 mrad; fully efficient down to  $\cos\vartheta = 0.97$ ;
  - 2%  $X_0$  in the barrel region
  - 5%  $X_0$  (including services) to the end cap region
- Expected spatial resolutions:  $\sigma_{r\phi} < 100 \text{ }\mu\text{m}$ ,  $\sigma_z < 1 \text{ mm}$
- Expected momentum resolutions:  $\Delta p/p^2 = 4 \times 10^{-5} (\text{GeV}/c)^{-1}$ , angular resolutions:  $\Delta\vartheta = 2.0 \times 10^{-5} \text{ rad}$  and  $\Delta\varphi = 3.0 \times 10^{-5} \text{ rad}$  at  $p=100 \text{ GeV}/c$  (with vertex detector and pre-shower)
- Expected  $\pi/\kappa$  separation  $> 3\sigma$  for  $p < 850 \text{ MeV}/c$  and  $p > 1050 \text{ MeV}/c$

# Back up slides

# Cluster Timing/Counting Read Out

**Recipe for cluster timing/counting in He based gas mixtures:**

**FEE: 1 GHz BW, x10 gain (S/N ratio  $\approx 8$ )**

**digitizer: 2 GSa/s sampling rate, >8 bits**

**However:**

suppose a trigger rate of 10 kHz, an average occupancy of 20% over the 56,000 drift cells, a maximum drift time of 250 ns readout at 2 GSa/s =>

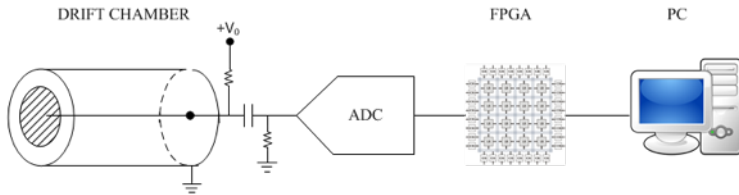
**500 GB/s ! (unsustainable!)**

**Solution:**

analyze in real time the signal waveform: find the ionization peaks; register and transfer only the time and amplitude of each peak with a short relative delay with respect to the trigger. This represents a data reduction of about 50, equivalent to a data transfer of

**10 GB/s (manageable!)**

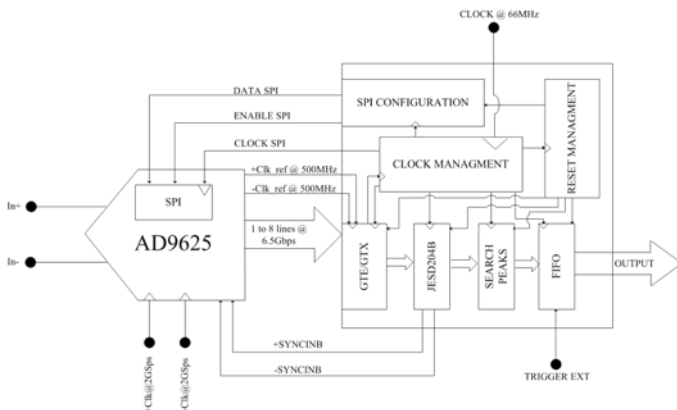
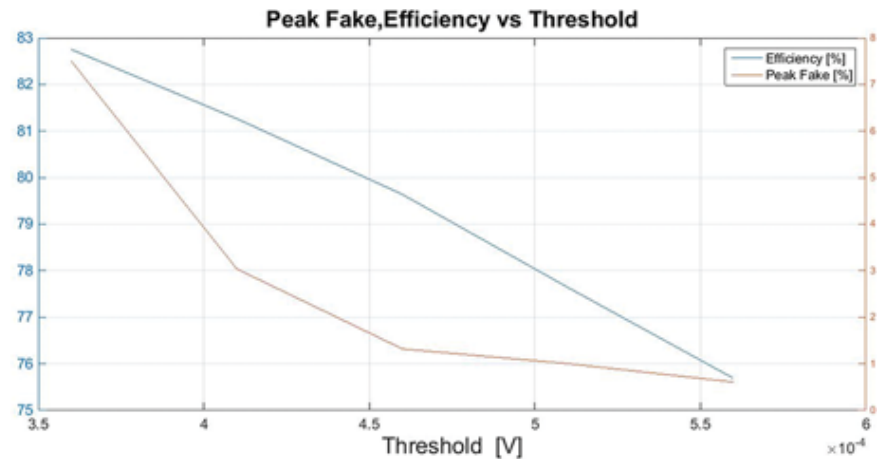
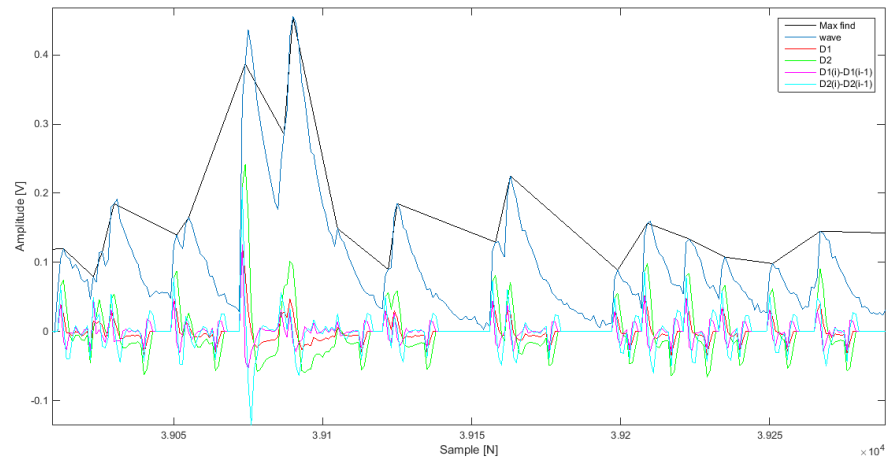
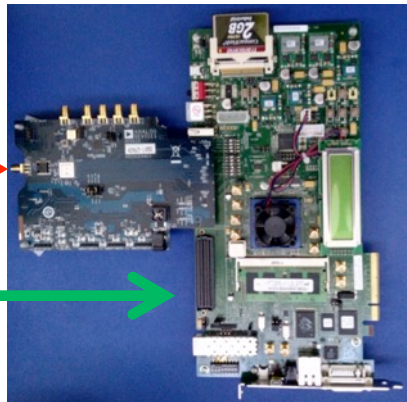
# Cluster Timing/Counting Read Out



**ANALOG  
DEVICES**

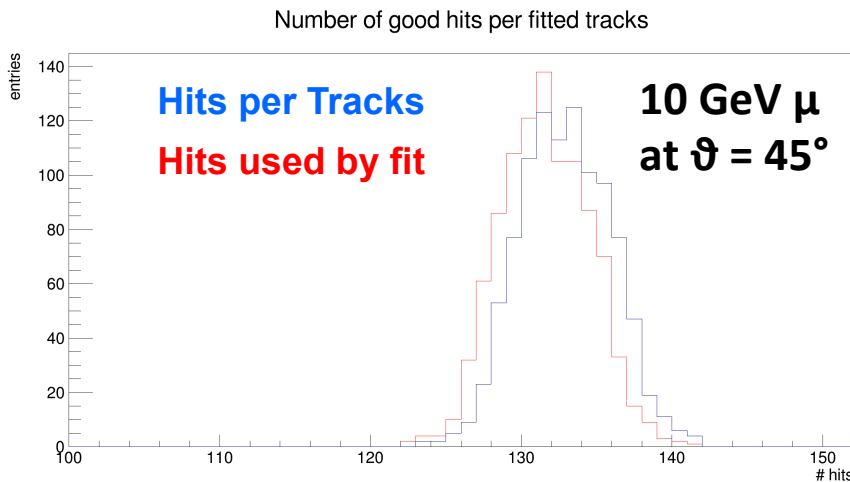
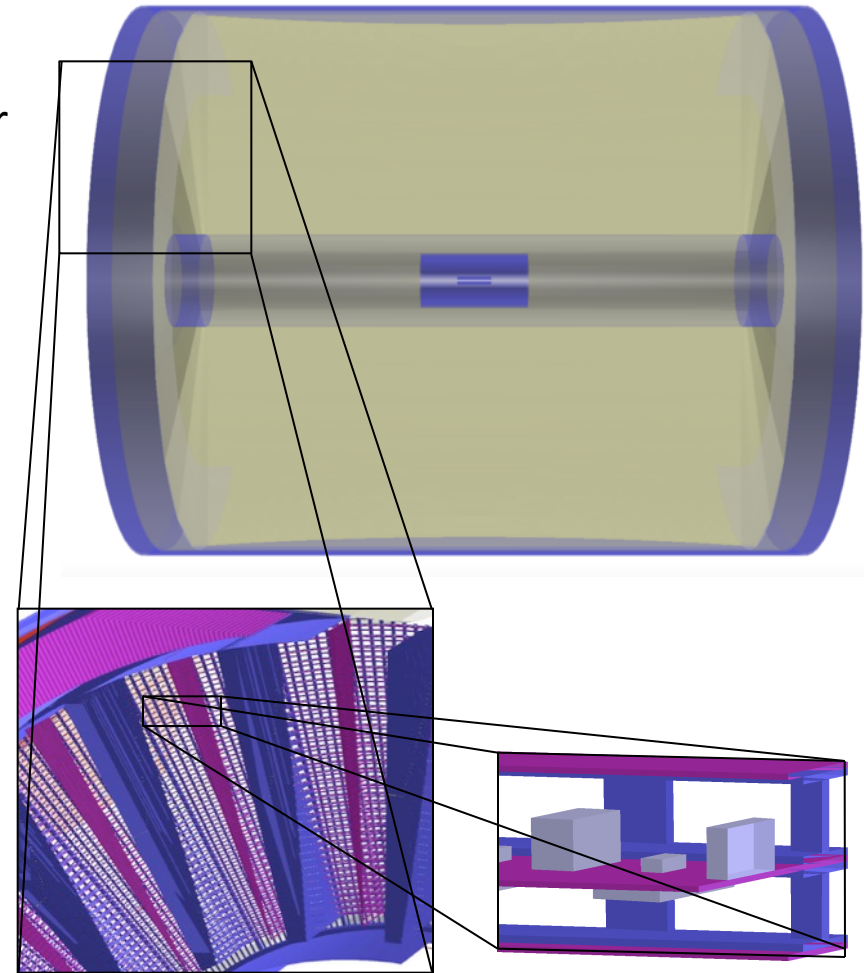
AD9625-2.0EBZ

**XILINX®**  
UG534 ML605



# IDEA D.C. full simulation

- Detailed **geometry** description (Geant4 stand alone **and** Mokka (Yin Xu – CEPC note))
- Amount of **materials** accurately accounted for
- Simple model of **hit generation**, no time-to-d, gaussian resol.(detailed model in progress)
- **Cluster timing/counting** to be simulated (no particle id. yet)
- **Track finding** algorithms at preliminary stages
- **Track fitting** (Genfit2 Kalman filter)



# IDEA integrated track simulation

## Geometry description (**baseline**):

- Beam pipe: **15.6 mm** radius, **0.0  $X_0$  – 0.24%  $X_0$  – 0.48%  $X_0$**  thick (**0-0.8-1.6 mm Be**)
- Vertex detector: **17 – 23 – 31 – 180 – 200 – 330 – 340 mm** radii (20  $\mu\text{m}$  pixels)  
**0.3 – 0.3 – 0.3 – 1.0 – 1.0 – 1.0 – 1.0 %  $X_0$**  thick (incl. cooling)  
**250 – 800 – 1500 mm** long
- Tracker: **IDEA D.C.**
- Pre-shower: **2004 – 2014 mm** radii Pb radiators, **1.0 – 2.0%  $X_0$**  thick, **4800 mm** long  
**2010 – 2027 mm** radii pixel planes (70  $\mu\text{m}$ ), **1.0 – 1.0%  $X_0$**  thick, **4800 mm** l.

## Configurations comparisons:

**baseline vertex detector versus** vertex detector without mid-stations

**baseline vertex detector versus** vertex detector without outer-stations

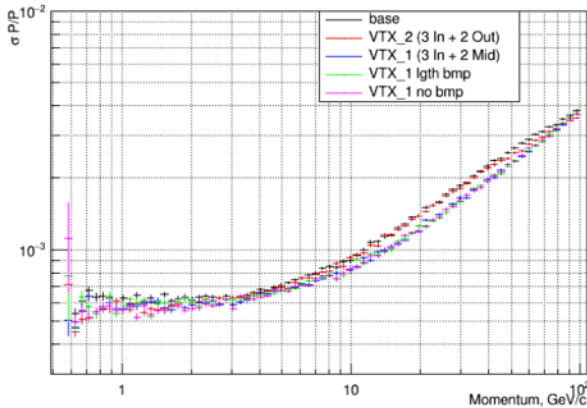
vertex detector without outer-stations **versus** thinner beam pipe

vertex detector without outer-stations **versus** no beam pipe

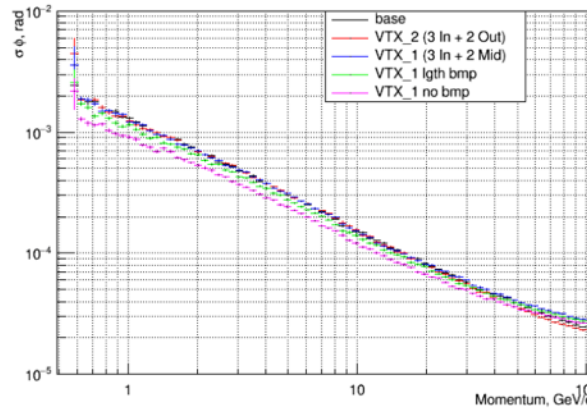
# IDEA integrated track simulation

$\mu$  at  $\vartheta = 65^\circ$

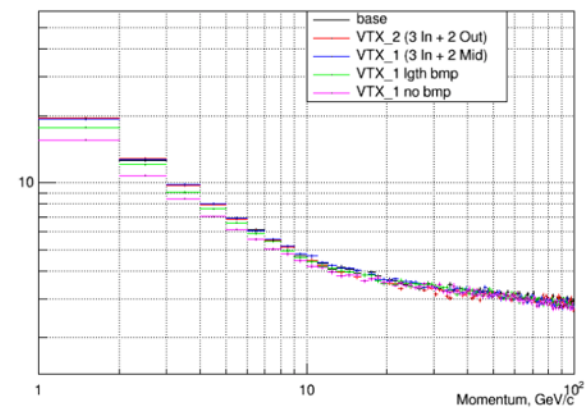
Momentum Resolution



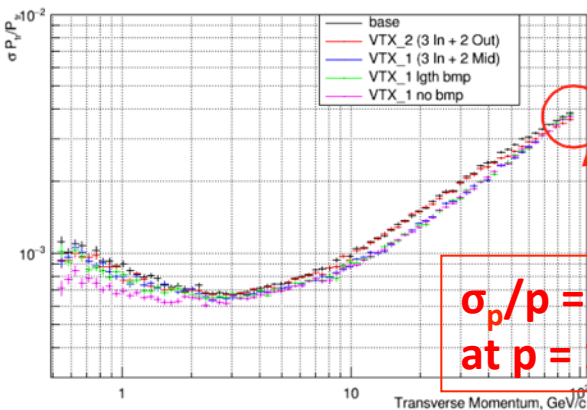
Phi Resolution



Z vtx Resolution

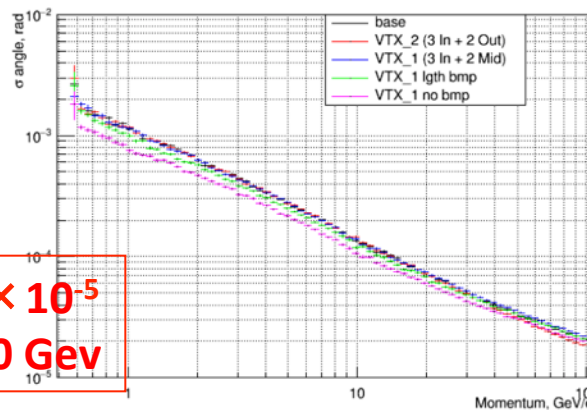


Transverse Momentum Resolution

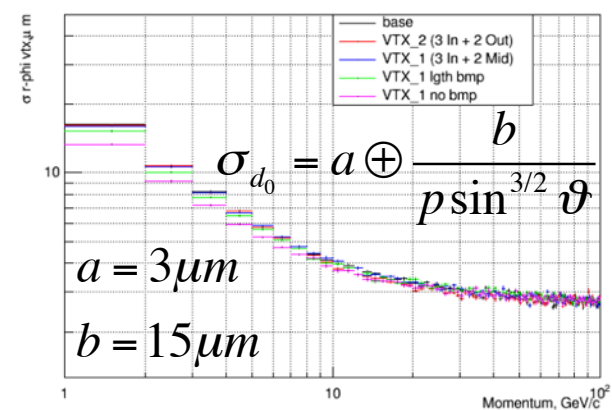


$\sigma_p/p = 4 \times 10^{-5}$   
at  $p = 100 \text{ GeV}$

Theta resolution



R-phi vtx Resolution

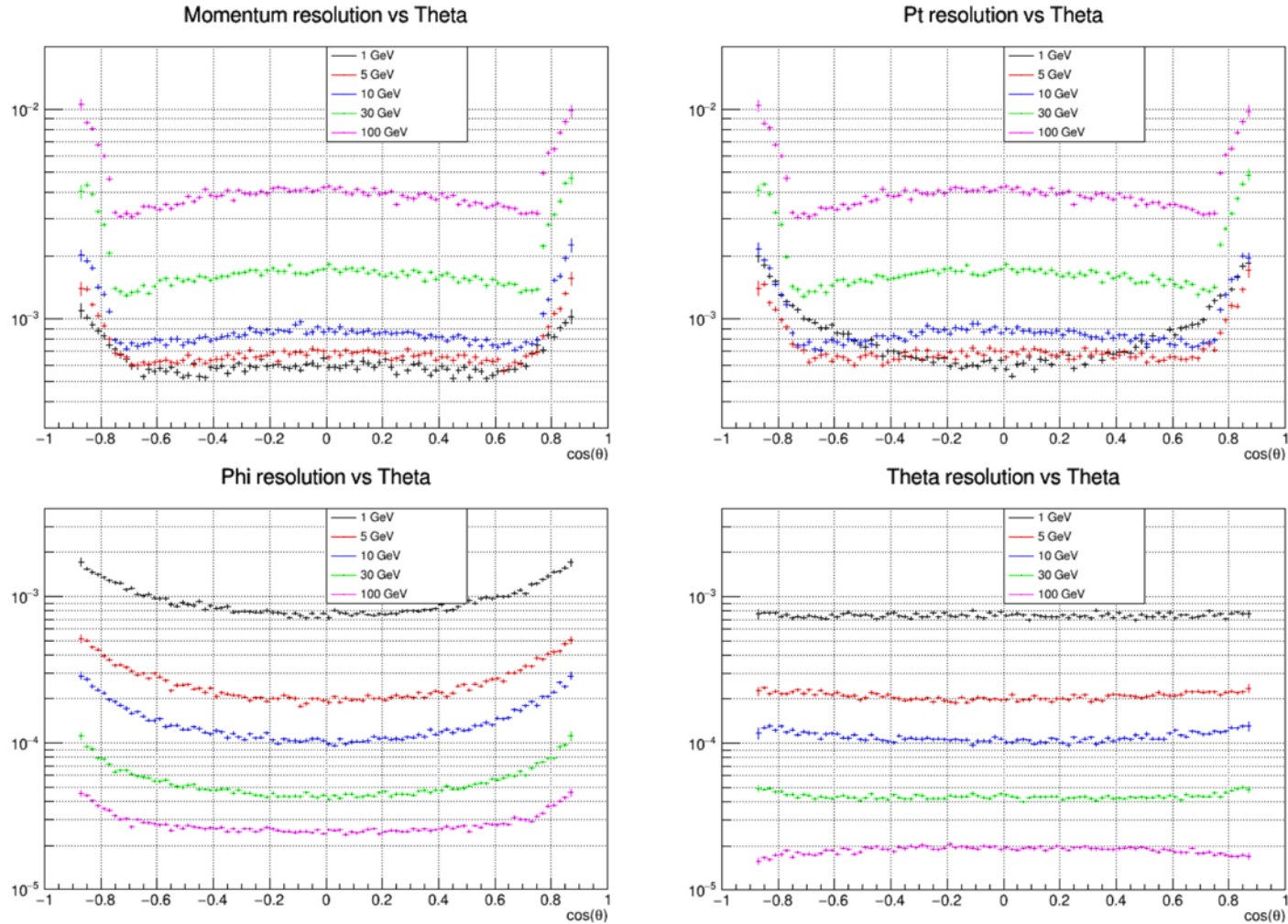


$$\sigma_{d_0} = a \oplus \frac{b}{p \sin^{3/2} \vartheta}$$

$$a = 3 \mu\text{m}$$

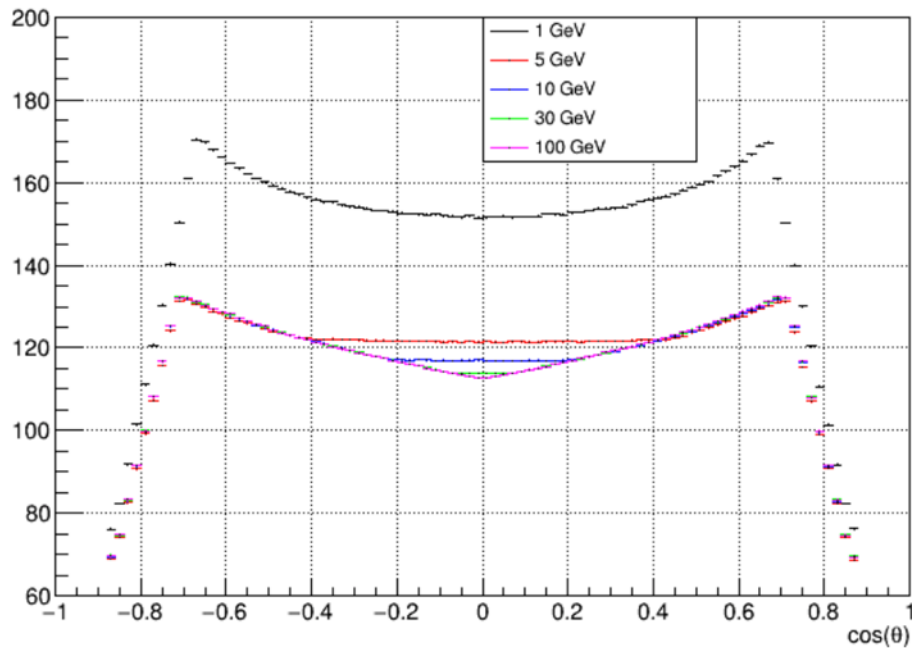
$$b = 15 \mu\text{m}$$

# IDEA integrated track simulation

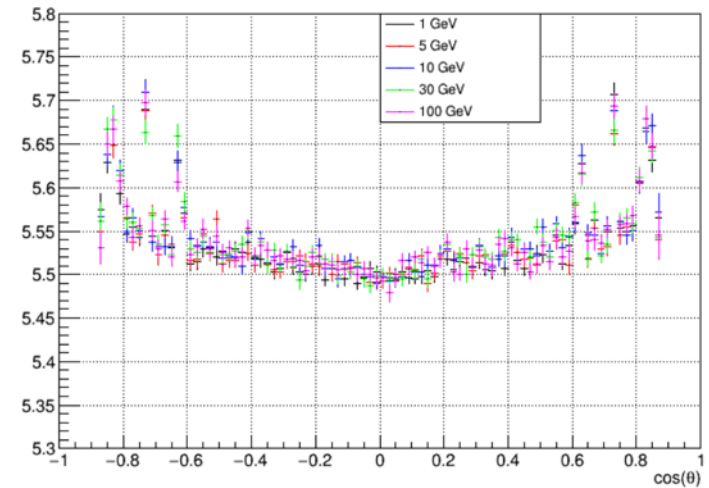


# IDEA integrated track simulation

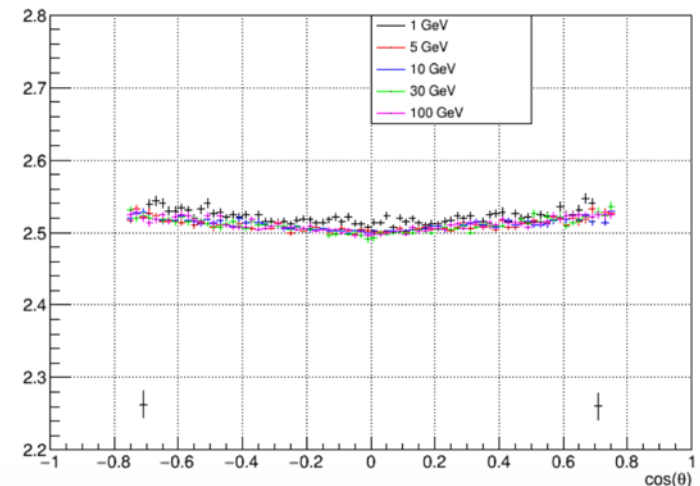
N. good Hits DCH resolution vs Theta



N. good Hits SVX resolution vs Theta



N. good Hits PSHW resolution vs Theta



# IDEA integrated track simulation

## A lot to be done yet:

- Detailed hit creation and ionization clusters formation
- Time-to-distance relations in 2T B-field
- Signal waveform generation
- More efficient waveform analysis for timing and counting clusters
- More efficient track finding algorithms
- Realistic geometries for vertex detector (forward disks) and pre-shower counters (endplate regions)
- Hit creation and digitization (technologies)
- Full validation of Mokka simulation with Geant4 standalone version