TraPId: An ultra-low mass **Drift Chamber** with **Particle Identification** capabilities for EIC

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Road to proposal

I. **KLOE** ancestor chamber at INFN LNF Daϕne φ factory (commissioned in 1998 and operating until 2018)

II. **CluCou** Chamber proposed for the **4th-Concept** at ILC (2009)

III. **I-tracker** chamber proposed for the **Mu2e experiment** at Fermilab (2012)

IV. **DCH** for the **MEG upgrade** at PSI (designed in 2014, completed at INFN and under commissioning at PSI)

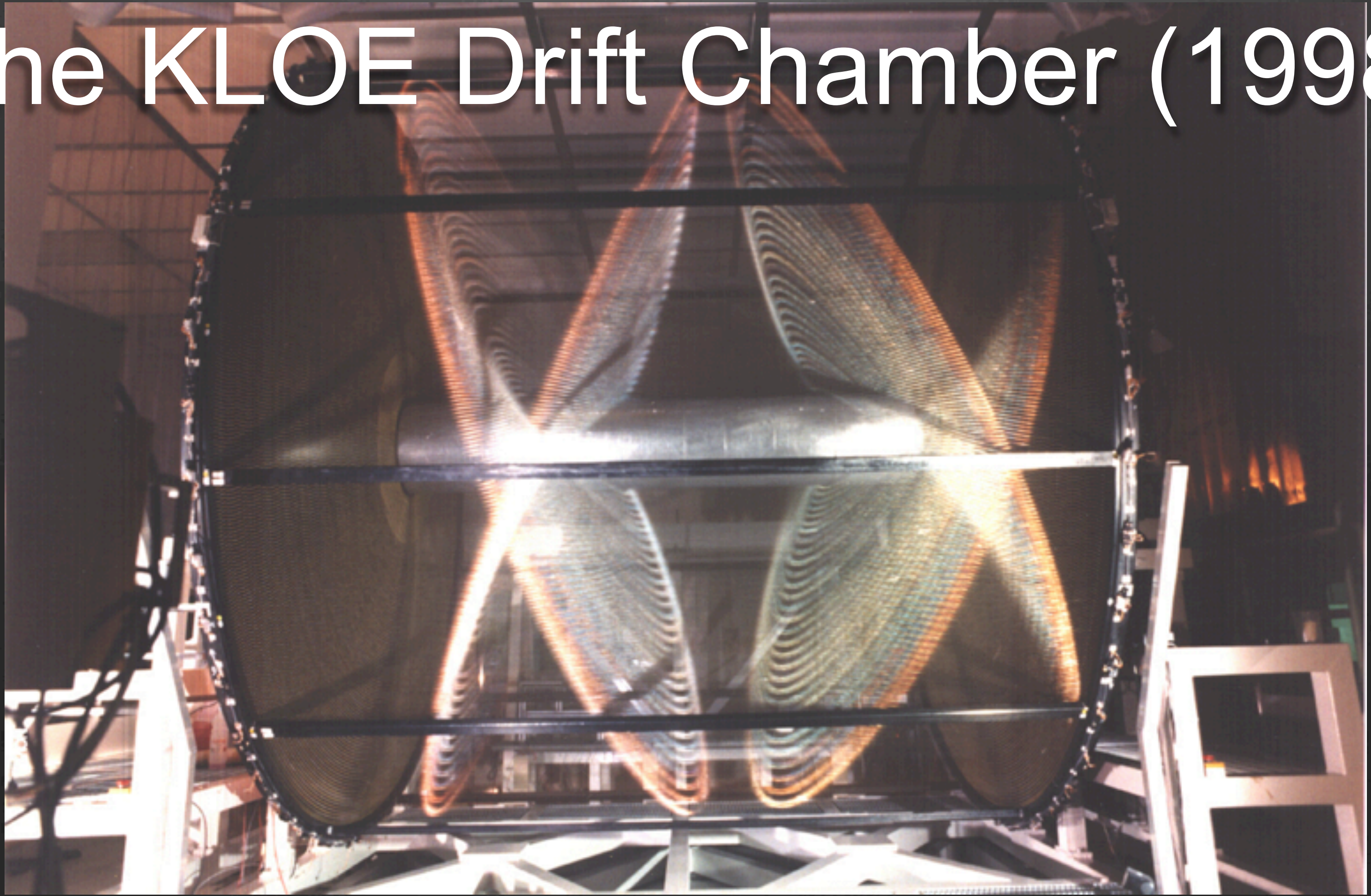
V. **IDEA** drift chamber proposal for FCC-ee and CEPC (TDR) (2016)

VI. **TraPiD** drift chamber proposal for EIC at JLab (2018)

VII. **TraPiD** drift chamber proposal for SCT at Novosibirsk (2019)

please, see F: Grancagnolo at INSTR2020:
https://indico.inp.nsk.su/event/20/session/2/contribution/200

The KLOE Drift Chamber (1998)



Drift Chamber "innovations" since KLOE

I. Separating **gas containment** from **wire support** functions

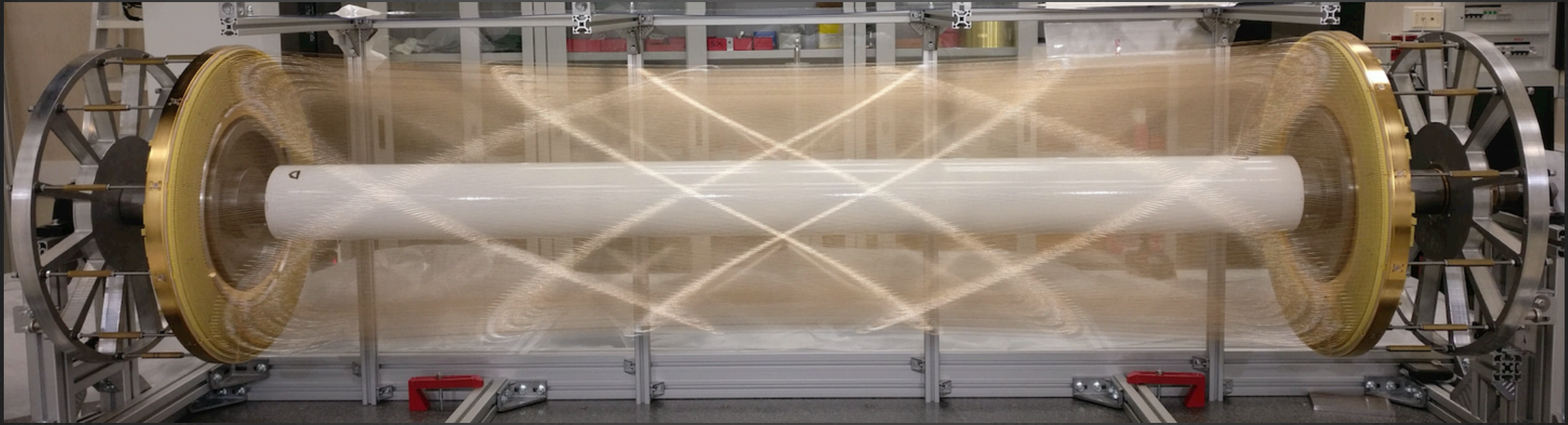
II. Using a **larger number** of **thinner** (and **lighter** wires)

III. No **feed-through** wiring

IV. Using **cluster timing** for improved spatial resolution

V. Using **cluster counting** for particle identification

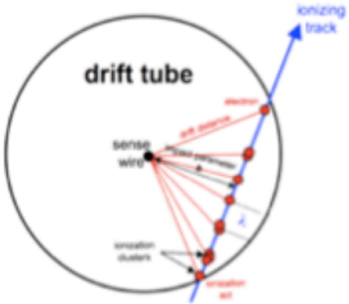
The MEG2 Drift Chamber (2018)



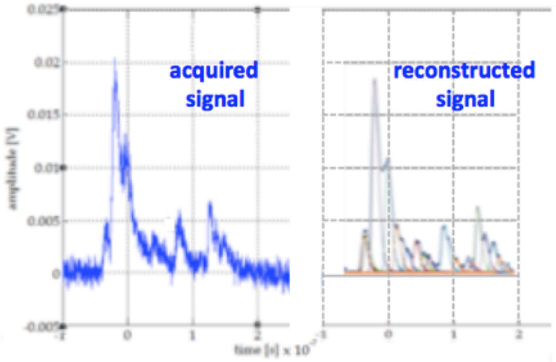
A unique volume, high granularity, all stereo, low mass cylindrical drift chamber, co-axial to B.
Rin = 18 cm, Rout = 30 cm, L = 2 m, 10 co-axial layers,
at alternating sign stereo angles from 100 mrad to 150 mrad ,
arranged in 12 identical azimuthal sectors.
Square cell size between 6.7 and 9.0 mm.
Total number of drift cells 1920. Total number of wires 12,678

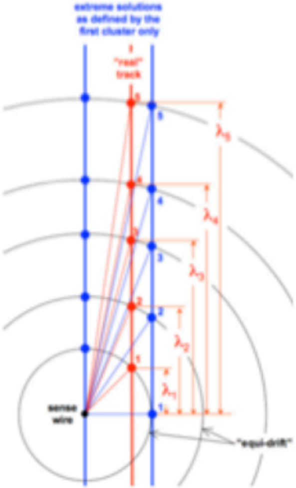
please, see G. Tassielli at INSTR2020:
https://indico.inp.nsk.su/event/20/session/2/contribution/68

Cluster Timing

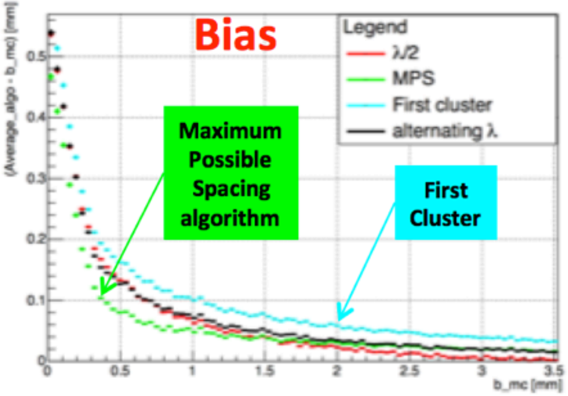


From the **ordered sequence of the electrons arrival times**, considering the average time separation between clusters and their time spread due to diffusion, **reconstruct the most probable sequence of clusters drift times:** $\boxed{\{t_i^{cl}\} \quad i=1,N_{cl}}$





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.



Cluster Counting

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

from *Walenta parameterization (1980)*

versus

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

from *Poisson distribution*

dE/dx

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

n **= 80** and **.8m track** at **1 atm** give

$\sigma \approx$ 6.7%

Increasing ***P*** to 2 atm improves resolution by 20% ($\sigma \approx$5.4%) but at a **considerable** cost of multiple scattering contribution to momentum and angular resolutions.

dN_{cl}/dx

δ_{cl} = 12.5/cm for He/iC_4H_{10}=90/10 and **.8m track** give

$\sigma \approx$ 3.2%

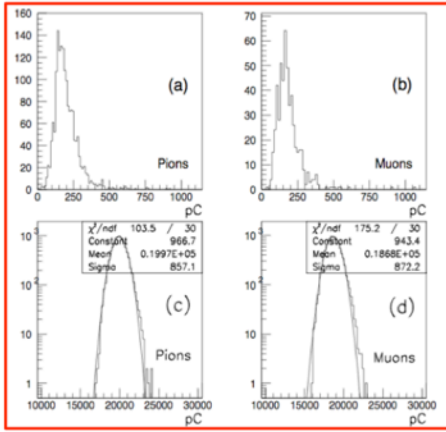
A small increment of iC_4H_{10} from 10% to 20% (δ_{cl} = 20/cm) improves resolution by 20% ($\sigma \approx$2.6%) at only a **reasonable** cost of multiple scattering contribution to momentum and angular resolutions.

Cluster Counting

The data shown refer to a beam of **μ and π at 200 MeV/c**, taken with a gas mixture **He/iC_4H_{10}=95/5, δ_{cl} = 9/cm, 100 samples, 2.6 cm** each **at 45°** (for a **total track length of 3.7 m**, corresponding to **N_{cl} = 3340, $1/\sqrt{N_{cl}}$ = 1.7%**).

Setup:
25 μm sense wire
(**gas gain 2×10^5**),
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)

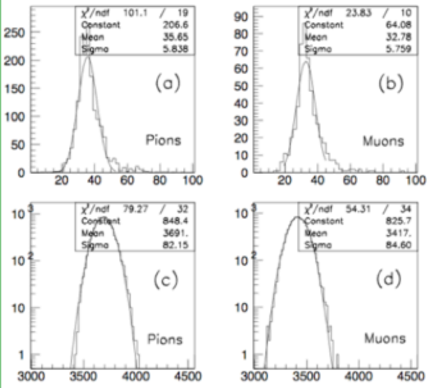


dE/dx

100 samples 3.7 cm

theory:
($\sigma = 0.41\, n^{-0.43} (L[m]P[atm])^{-0.32}$)
σ = 3.7%
≈ 2.0σ separation

experiment
20% truncated mean
σ = 4.5%
≈ 1.4σ separation



dN_{cl}/dx

theory
Poisson distribution
σ = 1.7%
≈ 5σ separation

experiment
σ = 2.5%
≈ 3.2σ separation

TraPId: A proposal for JLEIC

Geometrical constraints :

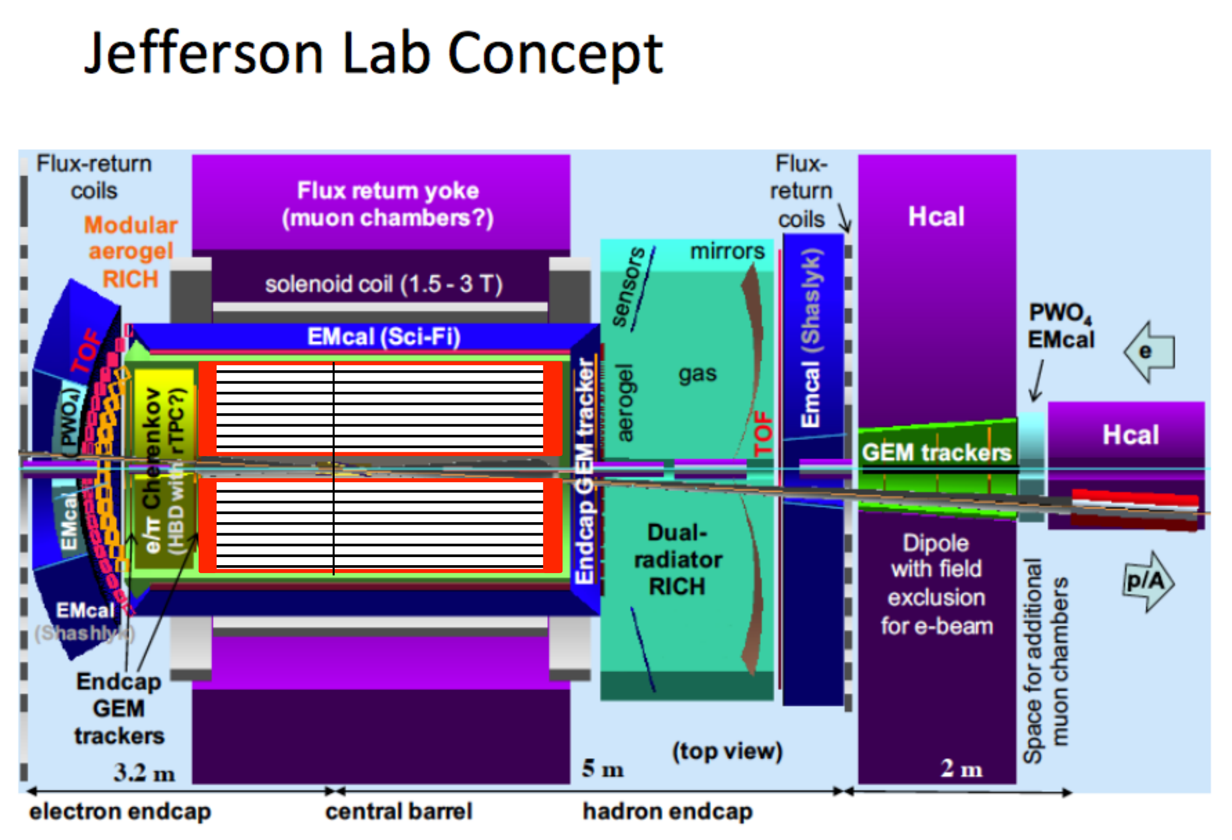
- Cyl. symmetry (asymmetric IP)
- Length ~320 cm, 270 cm active:
  180 cm forward hadrons
  90 cm forward electron
- R_{in} ~ 10 cm R_{out} ~ 90 cm
- Solenoid field 3 Tesla
- 10x8 layers in 24 sectors
- average stereo angle 100 mrad
- average square cell size 1.0 cm
- 25,000 drift cells, 150,000 wires

Material Budget :

- Inner wall $0.8\times10^{-3}\ X_0$
- Outer wall $1.2\times10^{-2}\ X_0$
- Instrumented end-pl. $4.0\times10^{-2}\ X_0$
- Gas + Wires $2.5\times10^{-3}\ X_0$

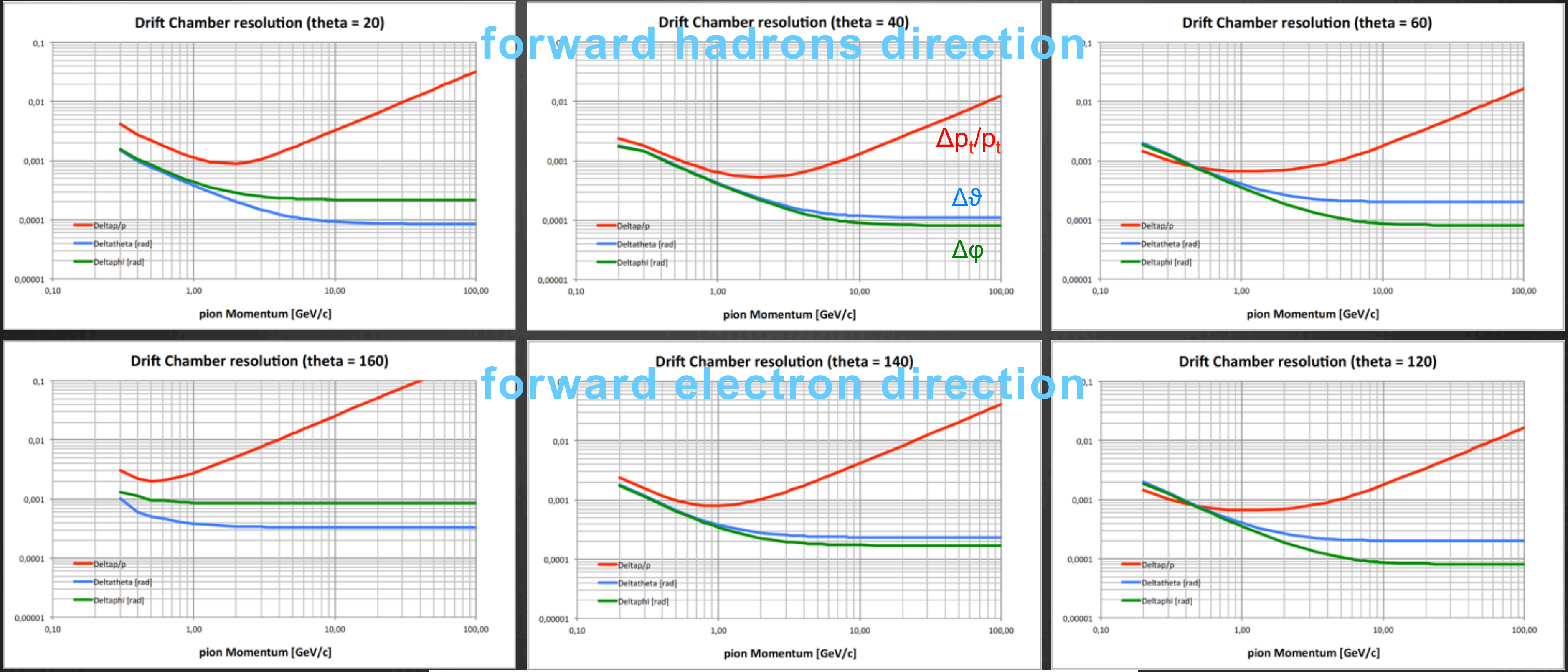
Performance:

- $\Delta p_t/p_t = (0.34p_t \oplus 1.1)\times10^{-3}$
- $\Delta\varphi = (0.23 \oplus 0.9/p_t)\times10^{-3}$ rad.
- $\Delta\vartheta = (0.24 \oplus 0.6/p_t)\times10^{-3}$ rad.
- $\sigma_{dN/dx}/dN/dx = 3.5\%$



TraPId: Performance

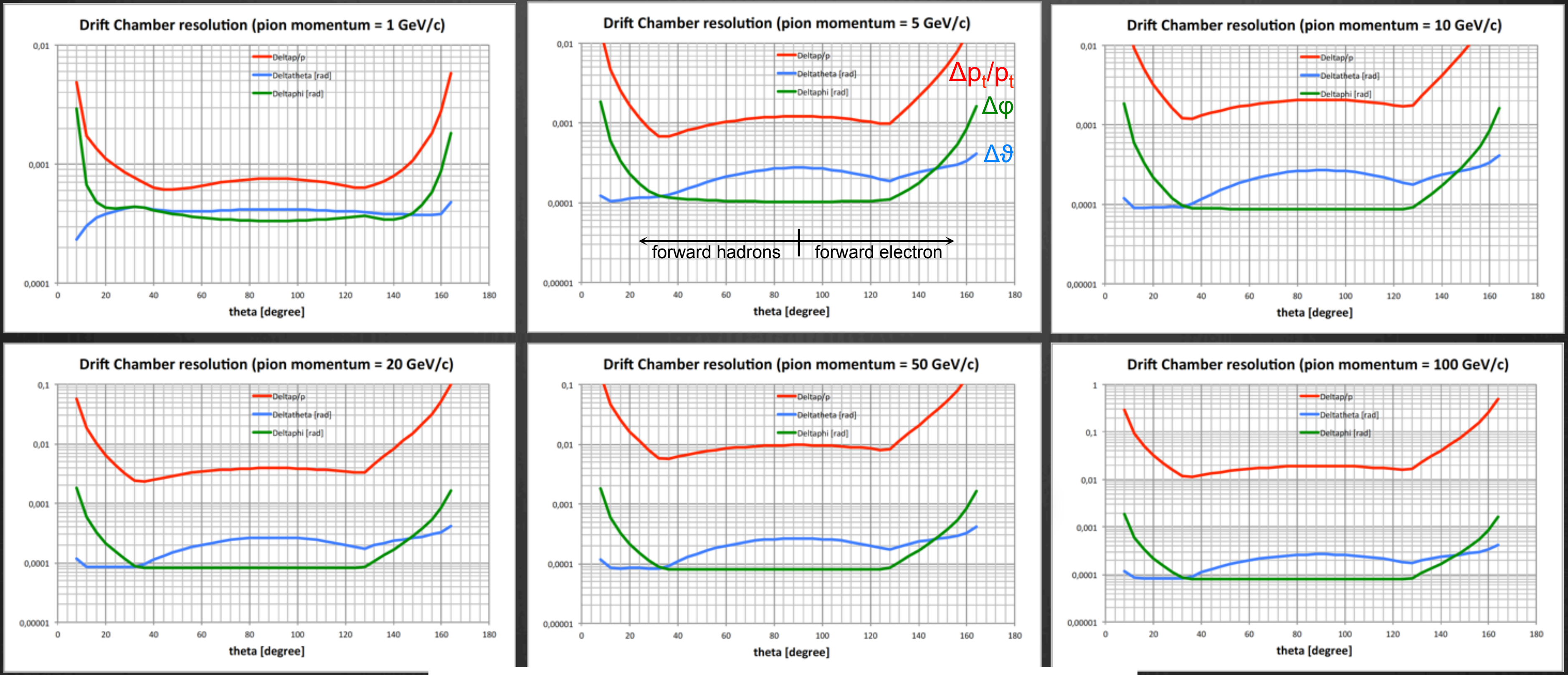
Analytic momentum and angular resolutions as functions of momentum



analytic calculations agree with detailed MC simulations in the cases of Mu2e and FCC-ee

TraPId: Performance

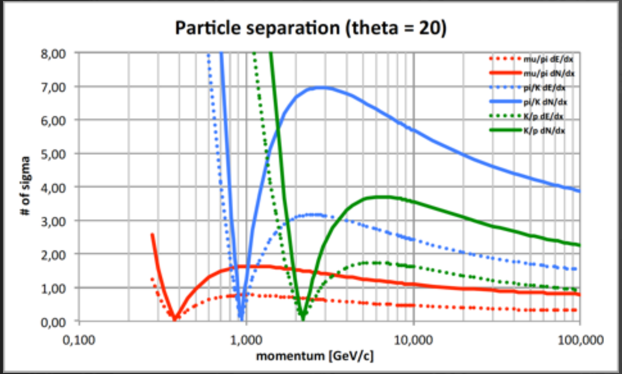
Analytic momentum and angular resolutions as functions of theta

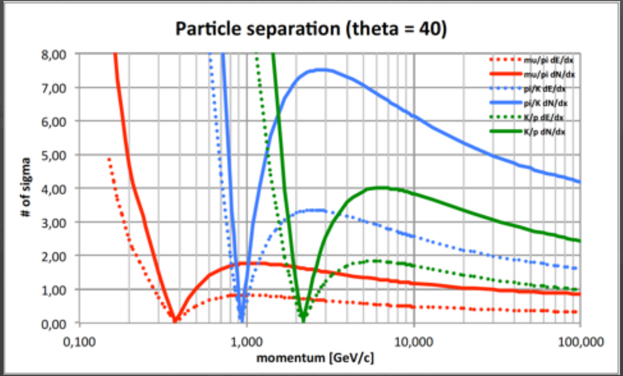


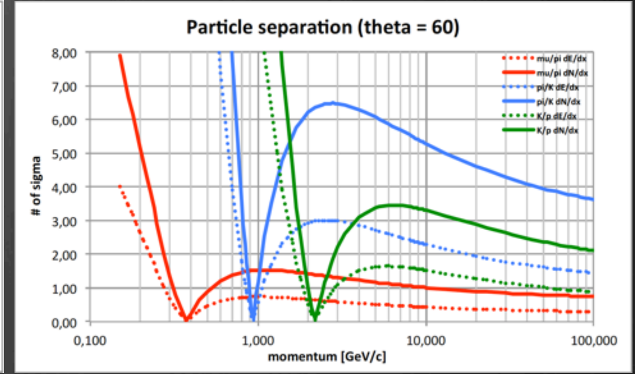
analytic calculations agree with detailed MC simulations in the cases of Mu2e and FCC-ee

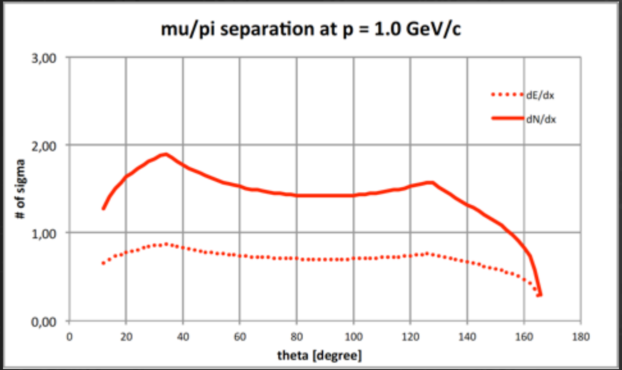
TraPId: Performance

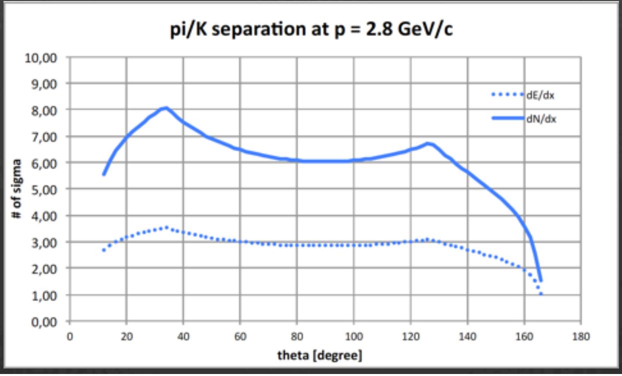
Particle identification as a function of momentum and of theta

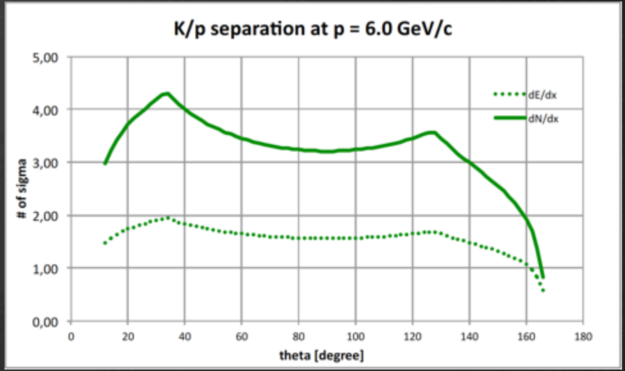








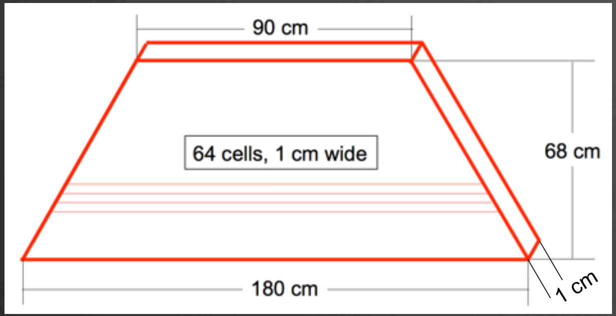




analytic calculations agree with detailed MC simulations in the cases of Mu2e and FCC-ee

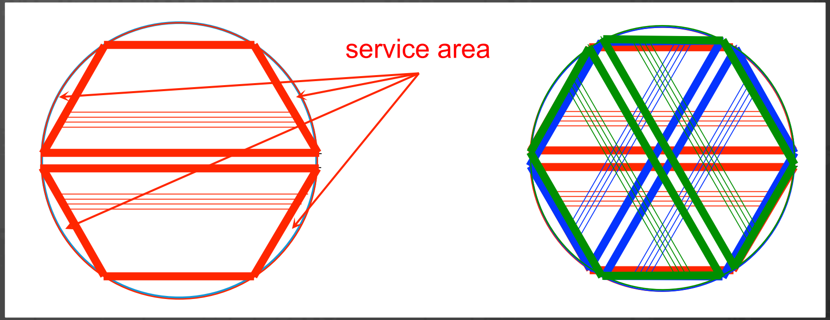
T-TraPId: a variant

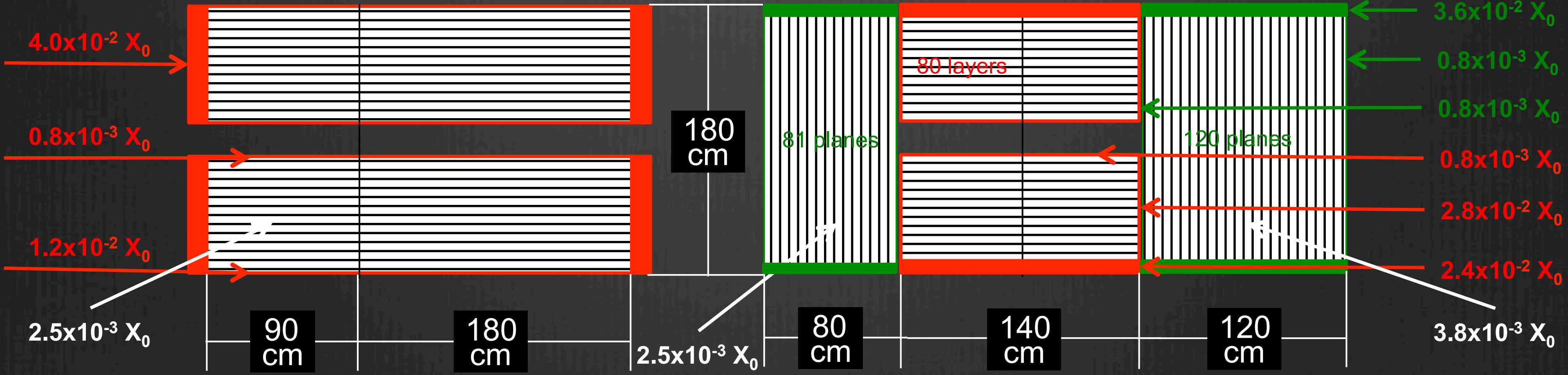
PLANAR DRIFT CHAMBER



ONE PLANE

THREE PLANES





T-TraPId: a variant

Cylindrical tracker:

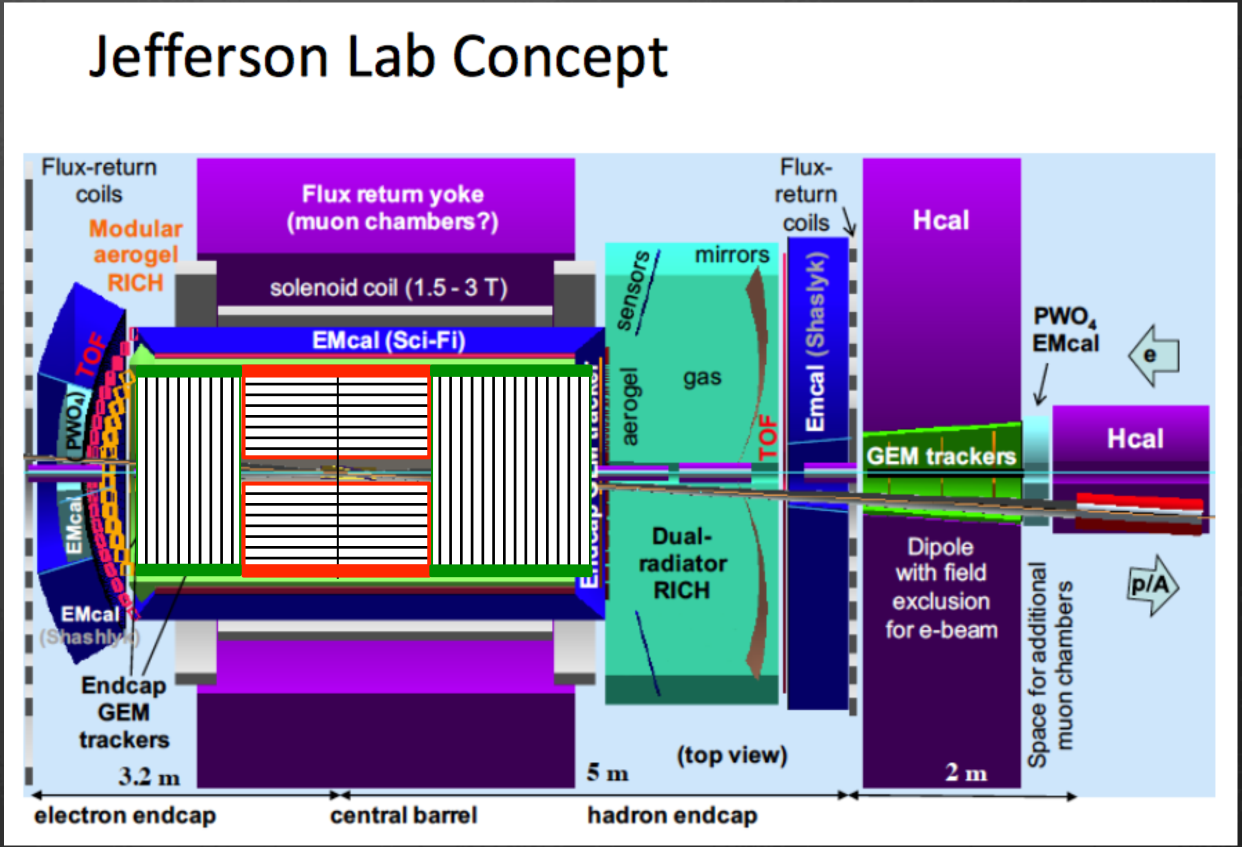
Length 140 cm, R_{in} ~ 10 cm R_{out} ~ 90 cm
|η| ≤ 0.7 (52° ≤ ϑ ≤ 142°)
Solenoid field 3 Tesla
10x8 layers in 24 sectors
average stereo angle 100 mrad
average square cell size 1.0 cm
25,000 drift cells, 150,000 wires

Forward/Backward trackers:

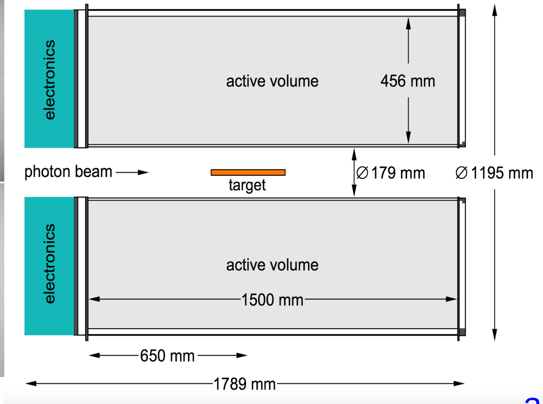
hadrons:
- L = 120 cm, 120 planes
- 0.7 ≤ η ≤ 3.5 (3.6° ≤ ϑ ≤ 52°)

electrons:
- L = 80 cm, 81 planes
- −0.7 ≤ η ≤ −3.2 (142 °≤ ϑ ≤ 175.2°)

wires orientations 0°, ±60°
square cell size 1.0 cm
128 drift cells, 640 wires /plane
15,360 + 10,368 drift cells, 130,000 wires



GLUEX Drift Chamber



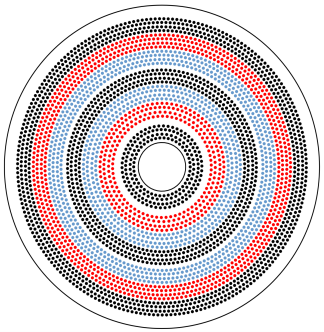
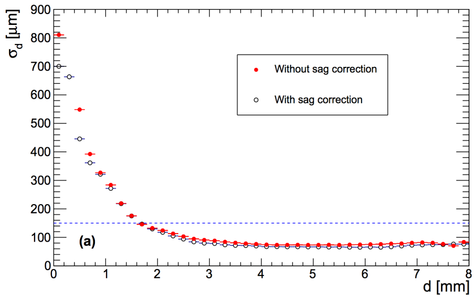


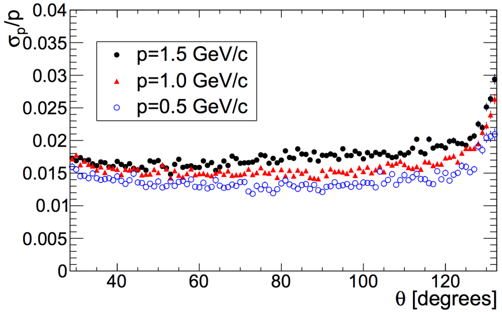
Table 1: The geometry of the CDC.

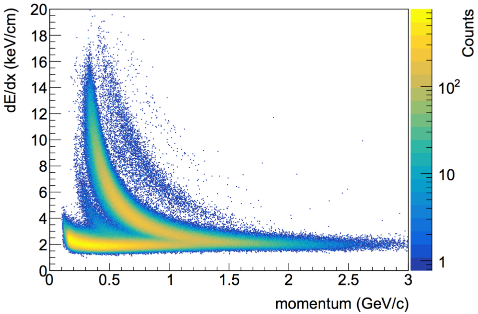
Active volume inner radius	99.2 mm
Active volume outer radius	555.4 mm
Active length	1500.0 mm
Chamber assembly inner radius	87.5 mm
Chamber assembly outer radius	597.4 mm
Upstream gas plenum length	31.8 mm
Downstream gas plenum length	25.4 mm
Thickness of 28 straws, mylar	2.22 % Rad.Length
Thickness of 28 straws, gas	0.34 % Rad.Length
Thickness of downstream endplate	2.14 % Rad.Length

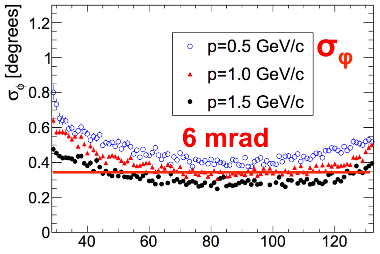
16 mm Mylar straw tubes
(109 μm + 0.1 μm Al)
20 μm W(Au) sense wire
3522 tubes
28 layers
(12 axial, 8+8 ±6° stereo)
50% Ar + 50% CO_2
B-field 1.3÷1.95 T

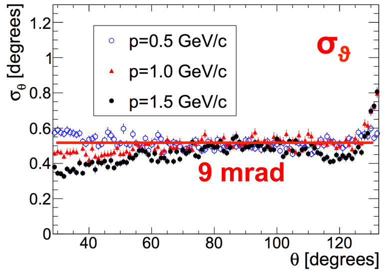
The Central Drift Chamber for GlueX
arXiv:1910.07602v2 [physics.ins-det] 27 Feb 2020









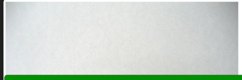


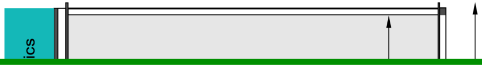
$\sigma_{r\varphi} \approx 150\ \mu m$

$\Delta p_t/p_t = (0.9p_t \oplus 1.2)\times 10^{-2}$

$\sigma_{dE/dx}/dE/dx \approx 12\%$

GLUEX Drift Chamber





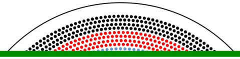


Table 1: The geometry of the CDC.

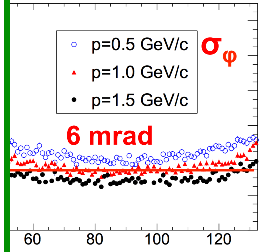
Active volume inner radius	99.2 mm

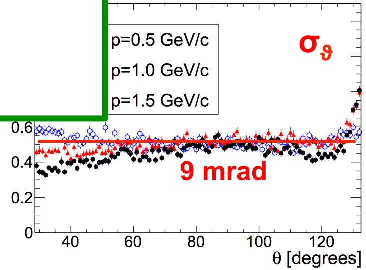
16 mm Mylar straw tubes
(100 μm + 0.1 μm Al)
W(Au) sense wire
ubes
ers
xial, 8+8 ±6° stereo)
r + 50% CO_2
1.3÷1.95 T

TraPId-like Drift Chamber
replacing
GLUEX Drift Chamber

$\sigma_{r\varphi} \approx 100$ μm $\quad \Delta p_t/p_t = (4.1 p_t \oplus 0.22)\times 10^{-3} \quad \sigma_{dN/dx}/dN/dx \approx 4.8\%$

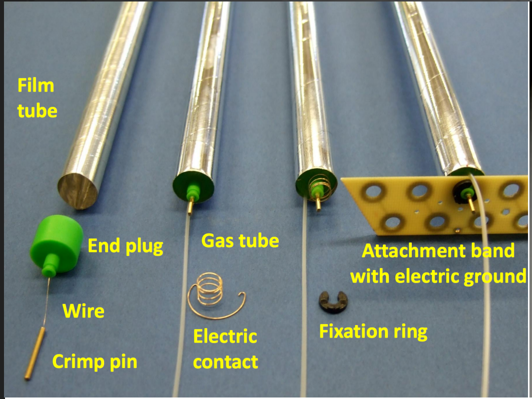
$\Delta\varphi = (0.61 \oplus 0.56/p_t)$ mrad $\quad \Delta\vartheta = (0.55 \oplus 0.45/p_t)$ mrad

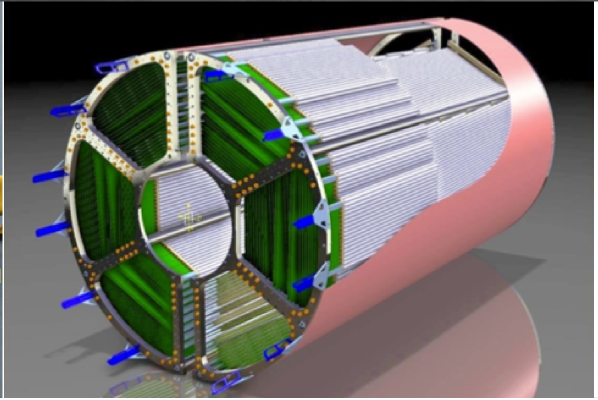


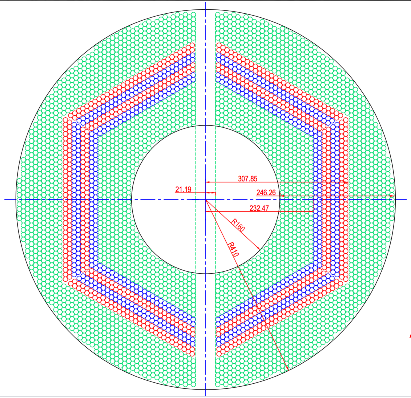


$\sigma_{r\varphi} \approx 150$ μm $\quad \Delta p_t/p_t = (0.9 p_t \oplus 1.2)\times 10^{-2} \quad \sigma_{dE/dx}/dE/dx \approx 12\%$

PANDA Drift Chamber





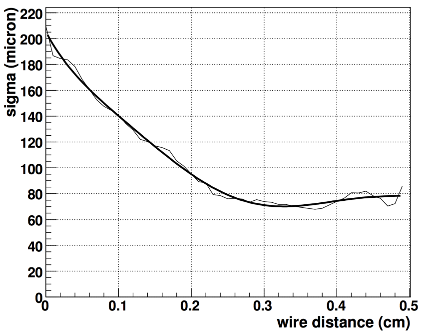


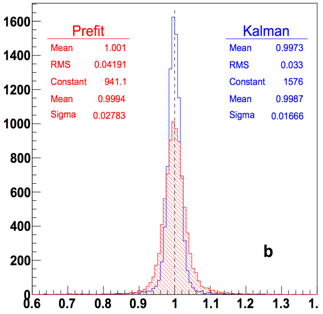
10 mm Mylar straw tubes
(27 µm + 2×0.03 µm Al)
20 µm W-<<re(Au) s. w.
4636 tubes
26 layers
(18 axial, 4+4 ±2.9° stereo)
90% Ar + 10% CO_2 at 2 bar
B-field 2.0 T

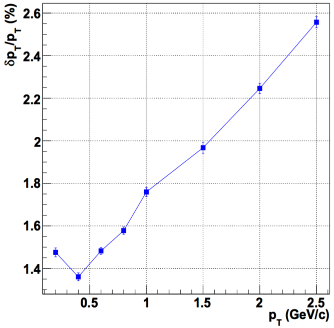
$\Delta\varphi = (1.8 \oplus 3.4/p_t)\times10^{-3}$

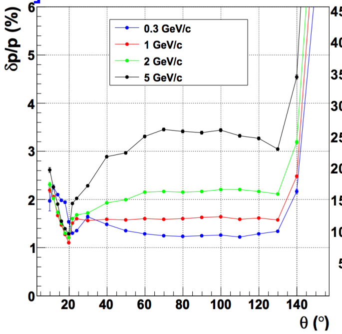
$\Delta\vartheta = (4.0 \oplus 1.5/p_t)\times10^{-3}$

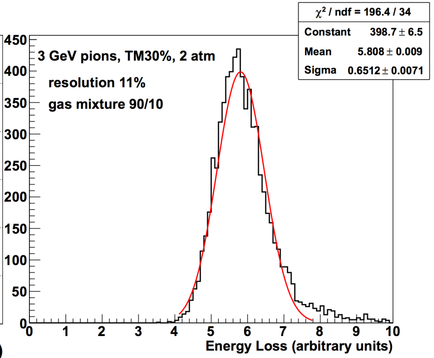
Technical Design Report for the: PANDA Straw Tube Tracker
arXiv:1205.5441 [physics.ins-det]











$\sigma_{r\varphi} \approx 100$ µm

$\Delta p_t/p_t = (0.9p_t \oplus 1.4)\times10^{-2}$

$\sigma_{dE/dx}/dE/dx \approx 11\%$

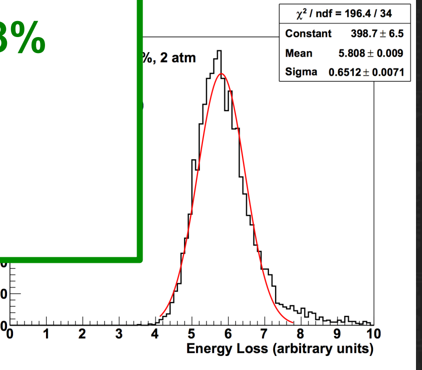
PANDA Drift Chamber

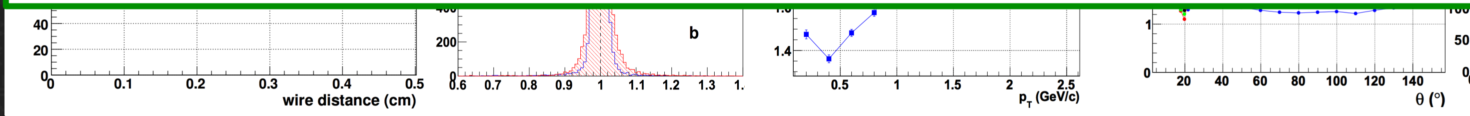
10 mm Mylar straw tubes
µm + 2×0.03 µm Al)
n W-<<re(Au) s. w.
tubes
yers
axial, 4+4 ±2.9° stereo)
Ar + 10% CO_2 at 2 bar
d 2.0 T
$(1.8 \oplus 3.4/p_t)\times10^{-3}$
$(4.0 \oplus 1.5/p_t)\times10^{-3}$

TraPId-like Drift Chamber replacing PANDA Drift Chamber

$\sigma_{r\varphi} \approx 100\ \mu m$ $\Delta p_t/p_t = (0.80p_t \oplus 0.50)\times10^{-2}$ $\sigma_{dN/dx}/dN/dx \approx 4.8\%$

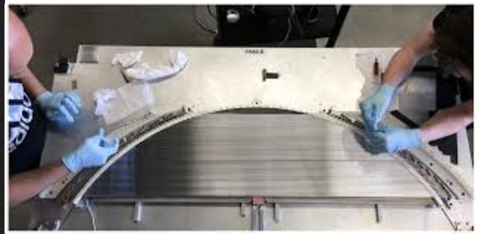
$\Delta\varphi = (1.8 \oplus 0.9/p_t)$ mrad $\Delta\vartheta = (1.3 \oplus 0.4/p_t)$ mrad

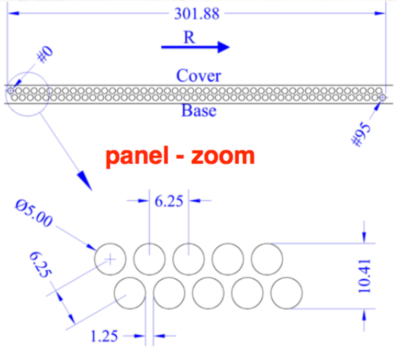




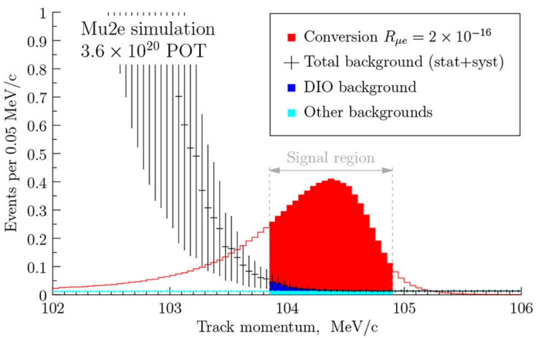
$\sigma_{r\varphi} \approx 100\ \mu m$ $\Delta p_t/p_t = (0.9p_t \oplus 1.4)\times10^{-2}$ $\sigma_{dE/dx}/dE/dx \approx 11\%$

Mu2e straw tubes tracker

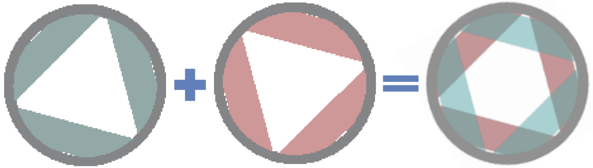




- ~ 20k straws employed in the tracker
- Multiple scattering is the major contributor to dp
  - ✓ straw material budget is comparable to the gas
- Straw specs:
  - ✓ 5 mm diameter, 2x6.25 µm Mylar walls Au and Al coated
  - ✓ 25 µm Au-plated W sense wire
  - ✓ 80/20 Ar/CO_2 with HV ~ 1500 V
- Straw length varies from 44 to 114 cm

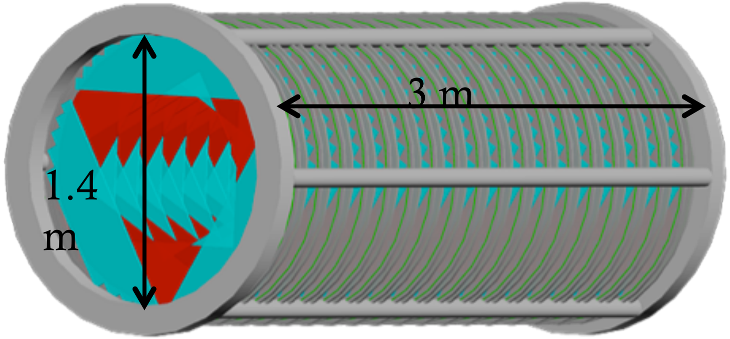


Δp ≈ 200 keV
(2×10^{-3} for p = 105 MeV/c)



3 panels + 3 panels = 1 plane

1 plane + 1 plane = 1 station



18 stations = tracker

Straw tubes vs open drift cells

- broken wire contained within the straw;
- robust mechanical stability if the straws are arranged in close-packed multi-layers;
  (however, close-packing depends on tube creeping and on gas pressure)
- robust electrostatic configuration;
  (however, wire centering crucial: different gravitational sag for wire and tube; tube creeping with time)
- in principle, simple calibration of the space-time relations due to the cylindrical isochrone shape;
  (provided good wire centering)
- small radiation length, X/X_0 ~ 0.05 % per tube, if straws with thinnest (~30 μm) film tubes;
  (however, still a factor 16 larger than a drift cell of same size, strongly limiting the momentum and angular resolutions)
- dead zones between tubes;
- difficult arrangement for para-axial configuration;
- complex mechanical structure and construction procedures.

CONCLUSIONS

- An ultra-low mass drift chamber for JLEIC with a material budget of $0.33 \times 10^{-2}\ X_0$ in the radial direction and of $4.5 \times 10^{-2}\ X_0$ in the forward and backward directions (including HV and FEE services) can be built with the novel technique adopted for the successful construction of the MEG2 drift chamber and proposed for the IDEA drift chamber at FCC-ee and CEPC.
- At 1.0 GeV/c, the expected resolutions (multiple scattering dominated) are:

  $$\Delta p_t/p_t = 1.2\times10^{-3},\ \Delta\varphi < 1\ \text{mrad},\ \Delta\vartheta < 1\ \text{mrad}$$

- Particle identification at the level of $\sigma_{dN/dx}/dN/dx = 3.5\%$ with cluster counting and π/K separation above 3σ in the range < 820 MeV/c and > 1.05 GeV/c is expected.
- A transverse variant of the cylindrical proposal has also been introduced in the case of optimizing the very forward and backward tracking.
- A corresponding straw tube chamber GLUEX-like (PANDA-like) would perform at least a factor **4 (2)** worse in transverse momentum resolution, **10 (3)** in angular resolutions and **2-3** in particle identification

Backup

Comments on broken wires

The KLOE drift chamber case:

All the wire breakings in KLOE, 27 sense and 12 field wires, occurred within few weeks from the assembly and could be easily repaired before installation. After that, **no further breaking occurred in more than 20 years of operation**. Given 12,600 sense wires and 40,000 field wires in KLOE, we can set a **MTBF** limit of greater than **250,000** and of **800,000 wire-years** respectively for sense and field wires. Scaling to **TraPId** (14,000 sense and 72,000 field wires) one gets a

MTBF of **10 years** for the sense wires and of **6.5 years** for the field wires.

Scaling is appropriate since the field wires are planned to be strung at the same fraction of YTS, whereas, for the sense wires, TraPId gains an extra 25% with respect to KLOE. By adding the **experience from other chambers**, like CLEO2, BaBar, Belle, which used similar wires, one can considerably **improve** these limits.

Further improvement comes from the safer technique of low temperature wire soldering plus gluing, proposed for TraPId, as opposed to mechanical wire crimping used in KLOE.

Broken wires consequences:

A broken wire fragment might impair a region of the chamber, the size of which depends on the HV segmentation and on the length of the fragment. Intelligent segmentations may limit the damage to no more than 1% of the active channels. Procedure to **removing wire fragments** and **wire replacement** strategies need to be envisioned.