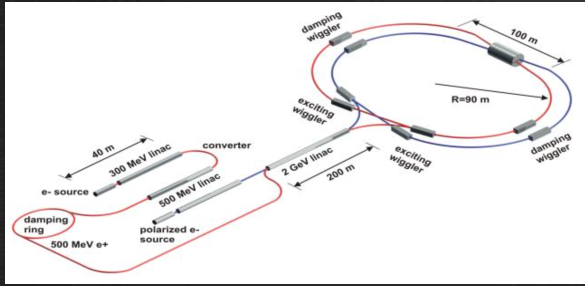
State-of-the-art of Drift Chambers

TraPId: An ultra-low mass Tracking Chamber with Particle Identification capabilities for SCTF at BINP



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Road to proposal

I. **KLOE** ancestor chamber at INFN LNF Daϕne φ factory (commissioned in 1998 and operating for the last 20 years)

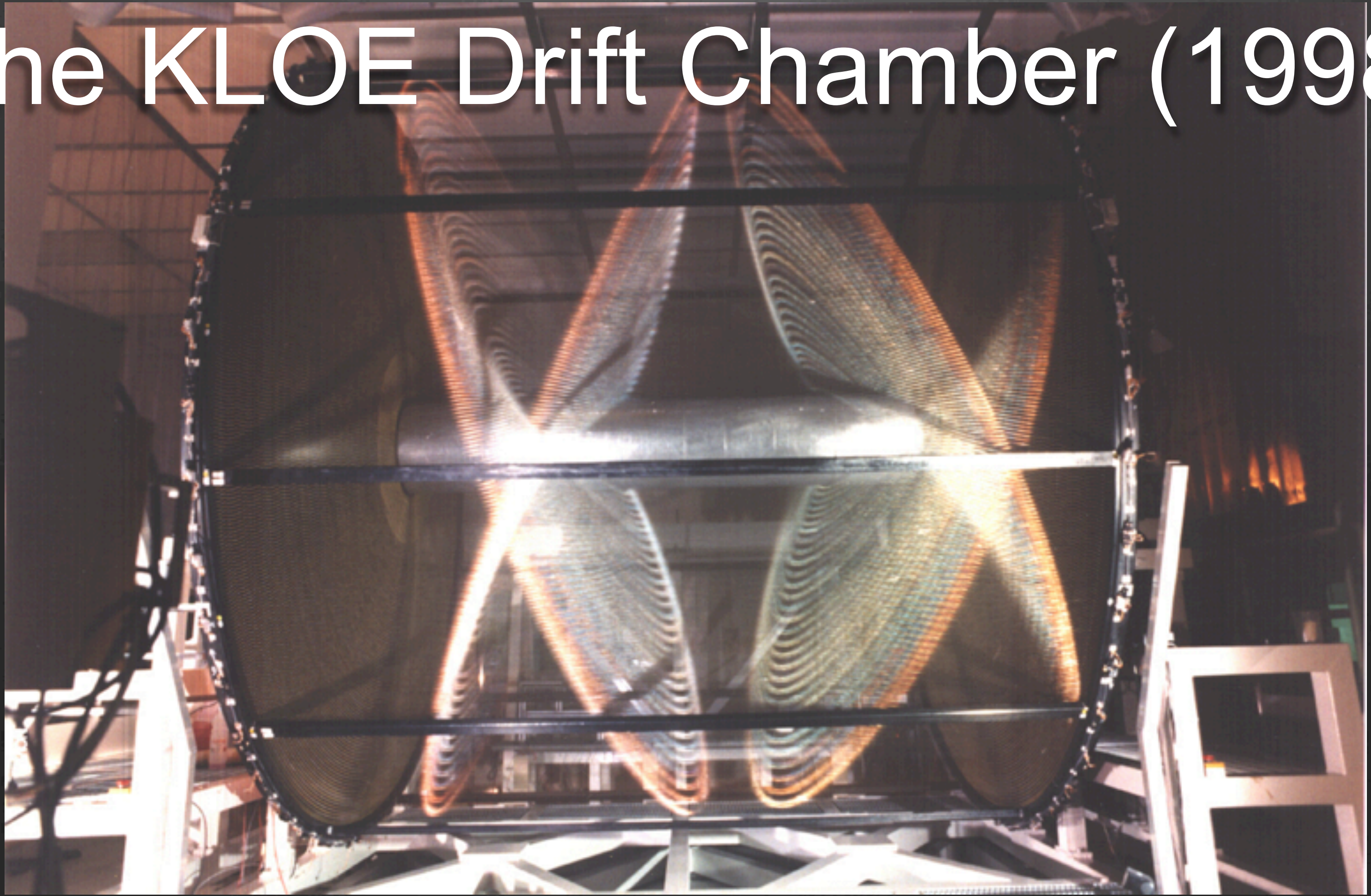
II. **CluCou** Chamber proposed for the **4th-Concept** at ILC (2009)

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

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

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

The KLOE Drift Chamber (1998)



Drift Chamber "innovations" introduced in KLOE

I. Wire configuration **fully stereo** (no axial layers)

II. new **light Aluminum** wires

III. Very light gas mixture **90% He – 10% iC_4H_{10}**

IV. Mechanical structure entirely in **Carbon Fiber**

V. Largest volume **drift chamber** ever built (45 m^3)

Drift Chamber "innovations" since KLOE

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

II. New concepts for **wire tension compensation**

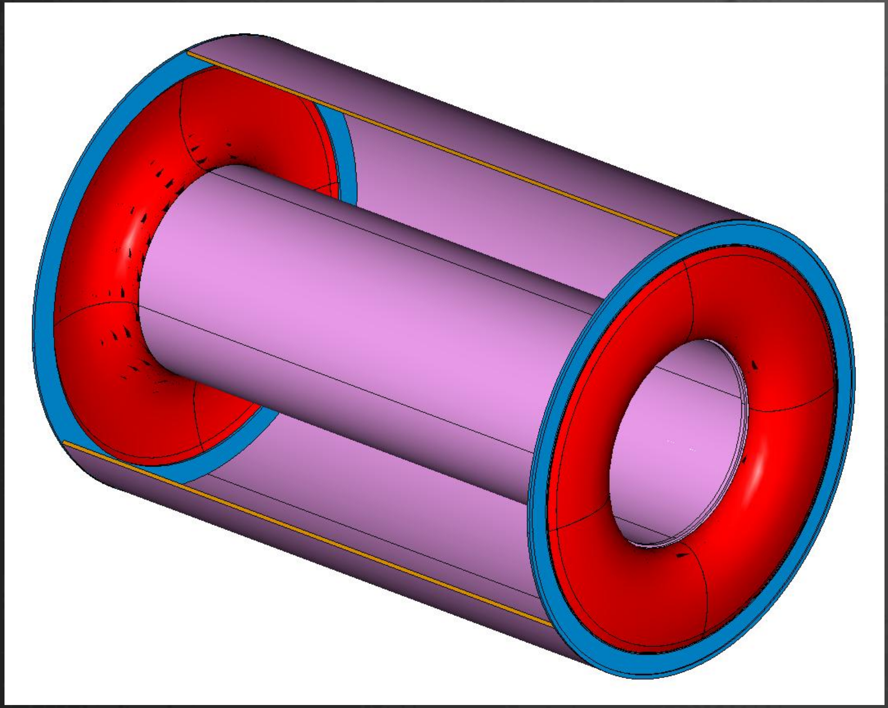
III. Using **a larger number** of **thinner** (and **lighter** wires)

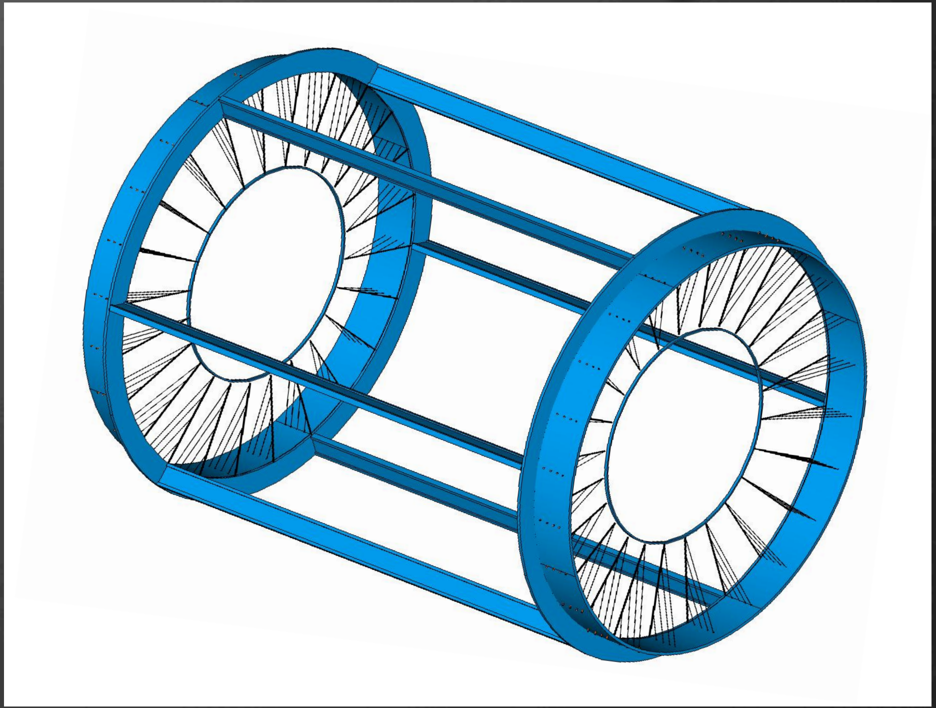
IV. No **feed-through** wiring

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

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

"Gas Envelope" and "Wire Cage"





Gas containment:

Gas envelope can freely deform without affecting the internal wire position and tension.

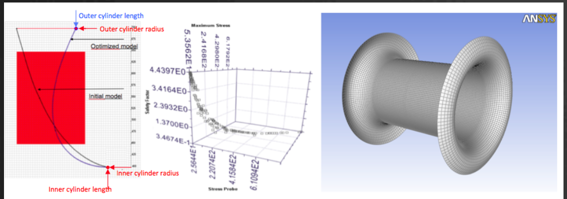
Wire support:

Wire cage structure not subject to differential pressure can be light and feed-through-less.

The Mu2e I-Tracker proposal

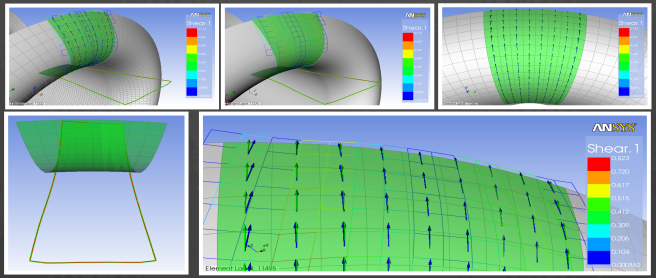
Gas envelope

- A structural multivariate analysis software to find the optimal shape for the **end plates profile** by minimizing the maximum stress and the stress on the inner cylinder



parameters	Initial model	Optimized model
Maximum stress	357.5 MPa	58.7 MPa
Stress at inner boundary	267.4 MPa	26.6 MPa
Safety factor	0.783	4.44

- A proper unidirectional pre-preg to form **ply draping** of the laminates and **flat-wrap** of the optimized model



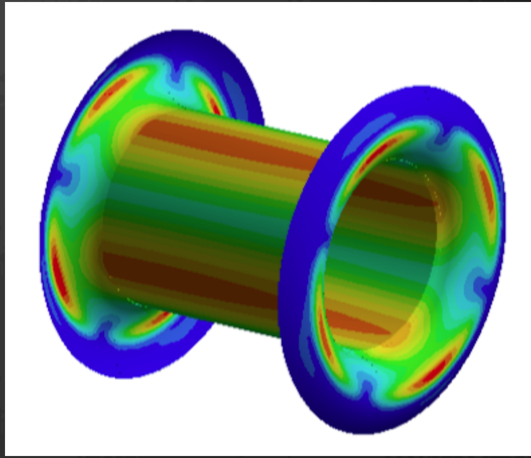
End plate:

4-ply × 38μm/ply
orthotropic (0/90/90/0)
0.021 g/cm²
6×10^{-4} X_0

Inner cylinder:

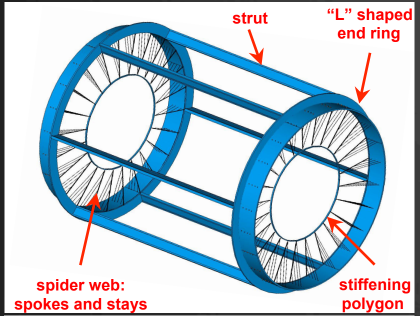
2 C-fiber skins, 2-ply,
+ 5 mm C-foam core
0.036 g/cm²
8×10^{-4} X_0

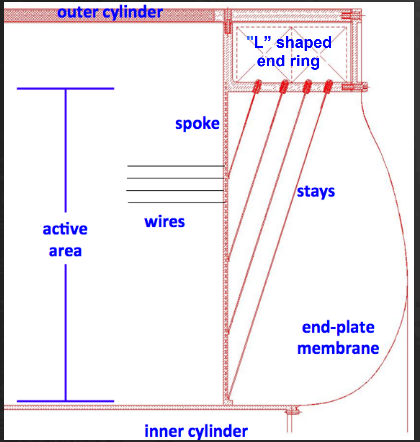
- reduce inner cylinder buckling by increasing the **moment of inertia** with proper light core composite sandwich



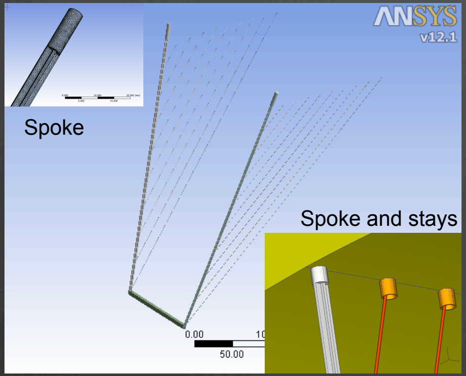
The Mu2e I-Tracker proposal

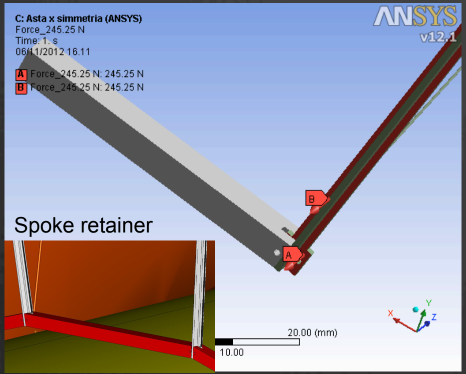
Wire cage



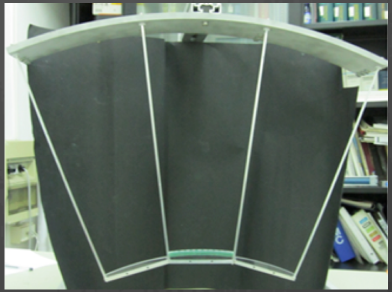


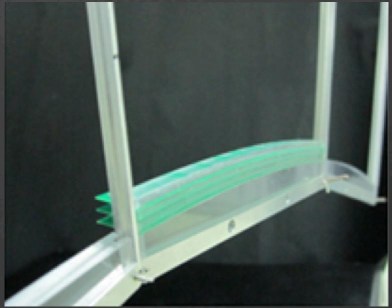
ANSYS FEM analysis





scale 1:1 model





- **feed-through-less chamber** allows for reducing wire spacing, thus increasing cell granularity:
  - **smaller cells**
  - **larger ratios of field to sense wires**
- **larger ratios of field to sense wires** allows for thinner field wires, thus reducing
  - **wire contribution to multiple scattering**
  - **total wire tension**

Instrumented end-plate:

wire PCB, spacers, HV distrib. and cables, limiting R, decoupling C and signal cables

0.28 g/cm^2

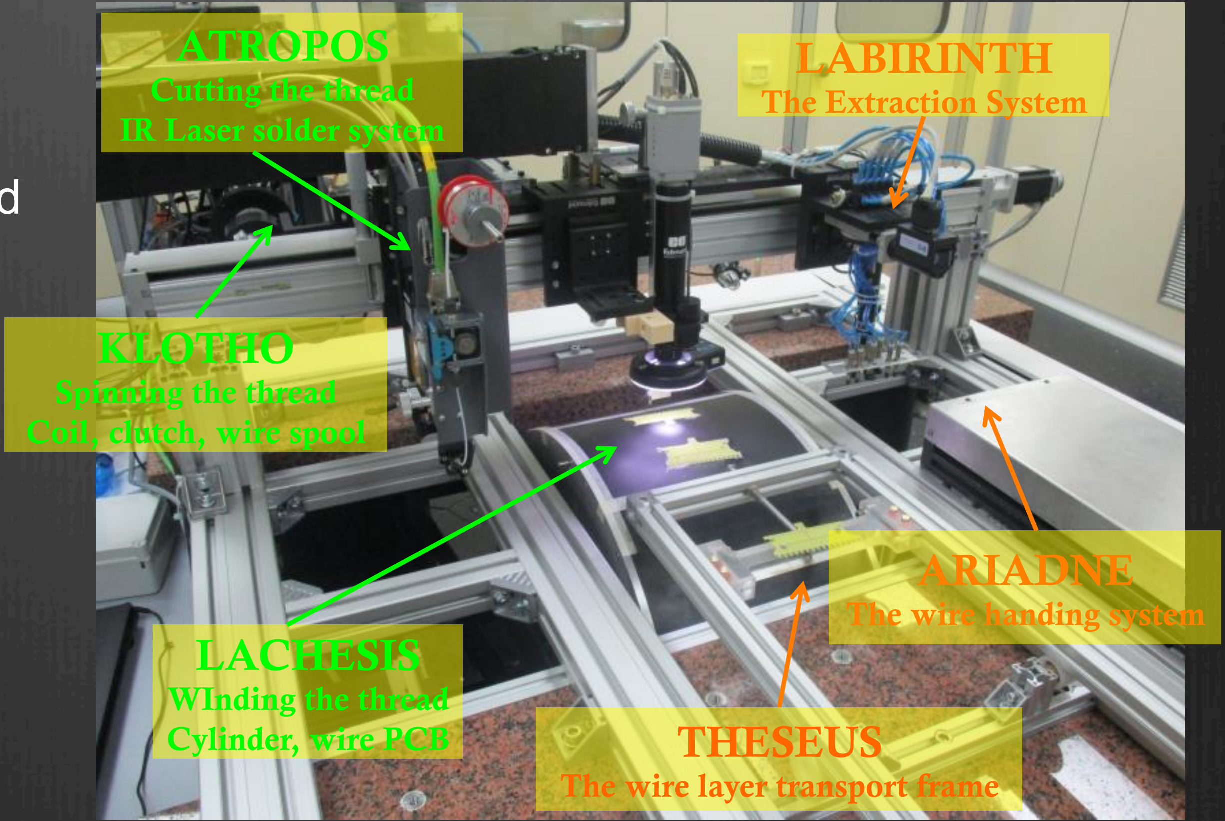
$1\times10^{-2}\ X_0$

THE NEW WIRING APPROACH:
OLIMPUS: THE ROBOT

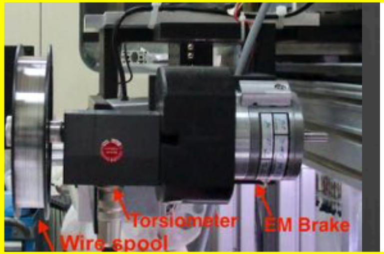
... however,
large numbers of wires
require complicated and time consuming **wiring** and **assembly procedures**

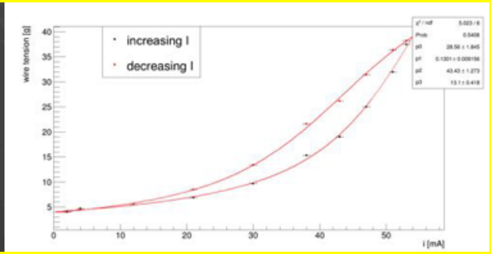
Bernardo Strozzi – Le tre Parche – Venezia, circa 1620

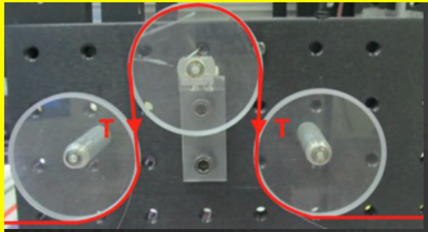
and the need for a **novel approach** to the problem

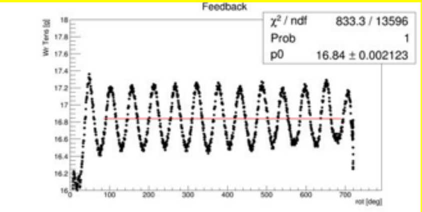


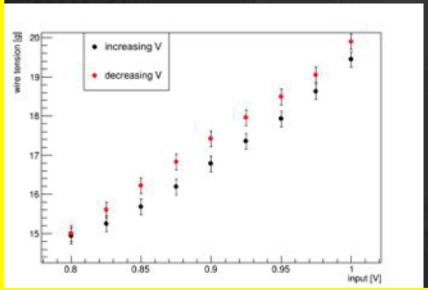
THE MEG2 DC APPROACH:

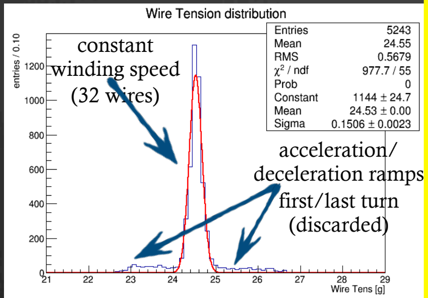


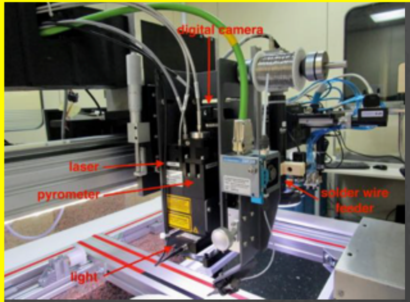


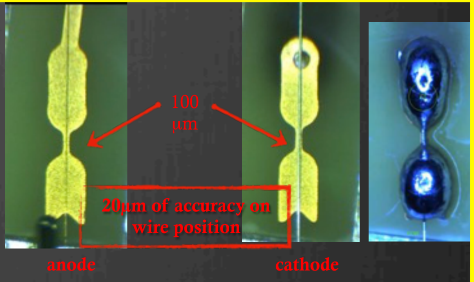


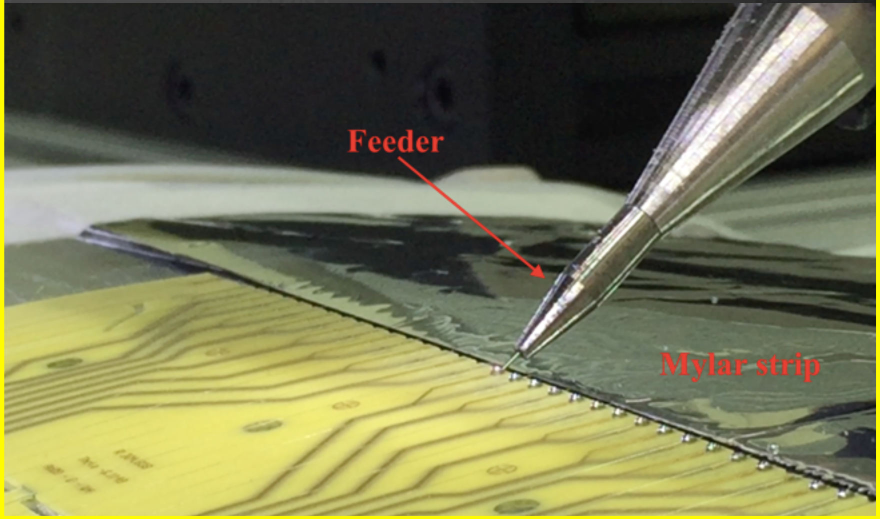












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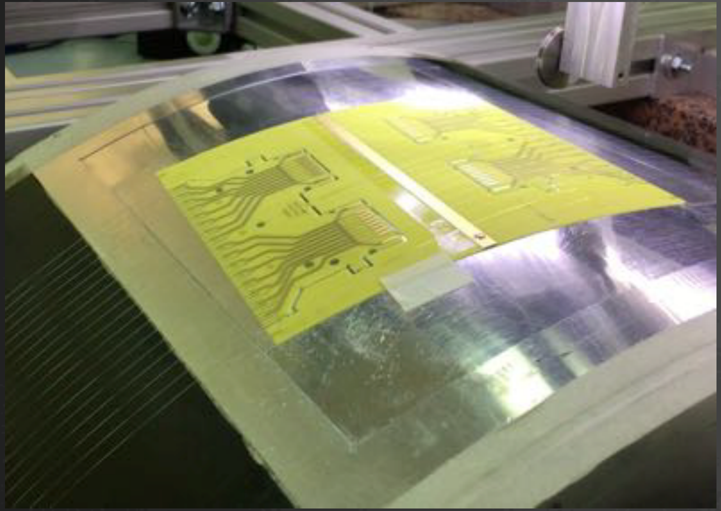

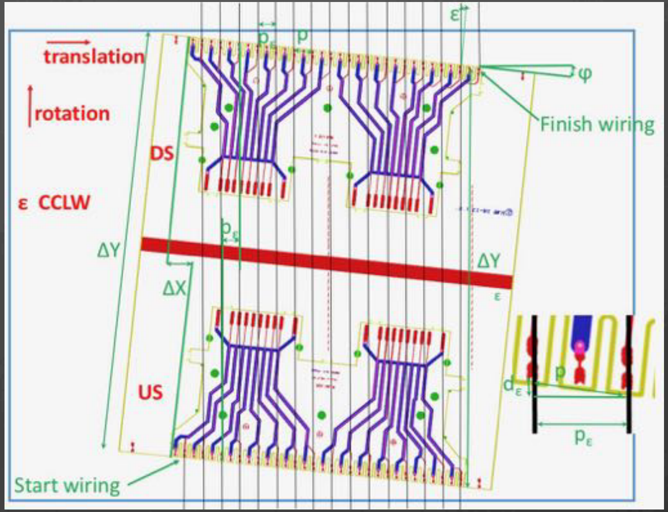

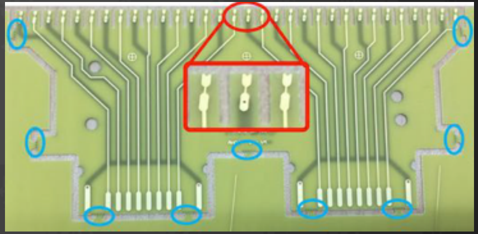

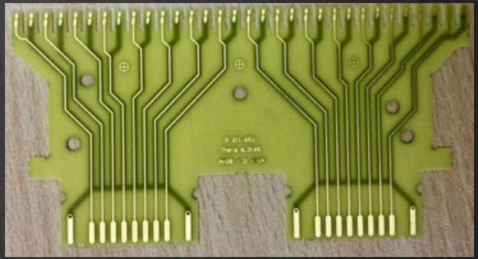

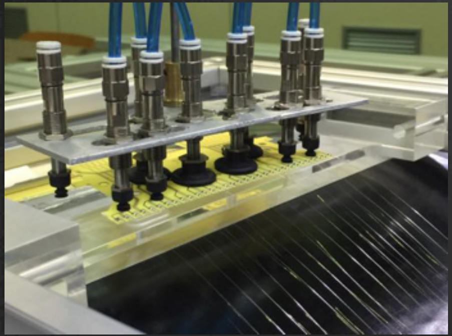

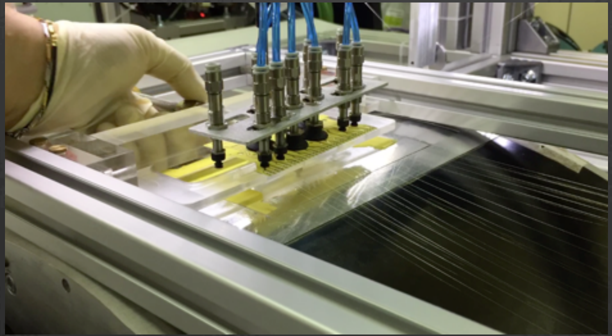

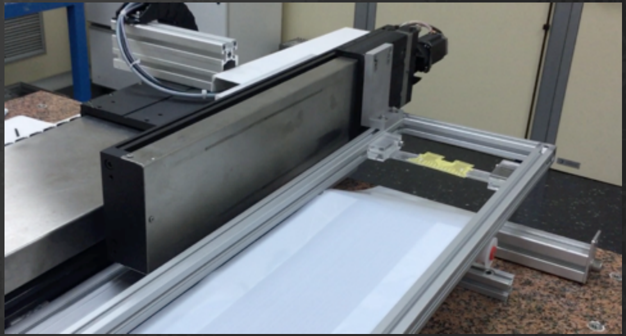

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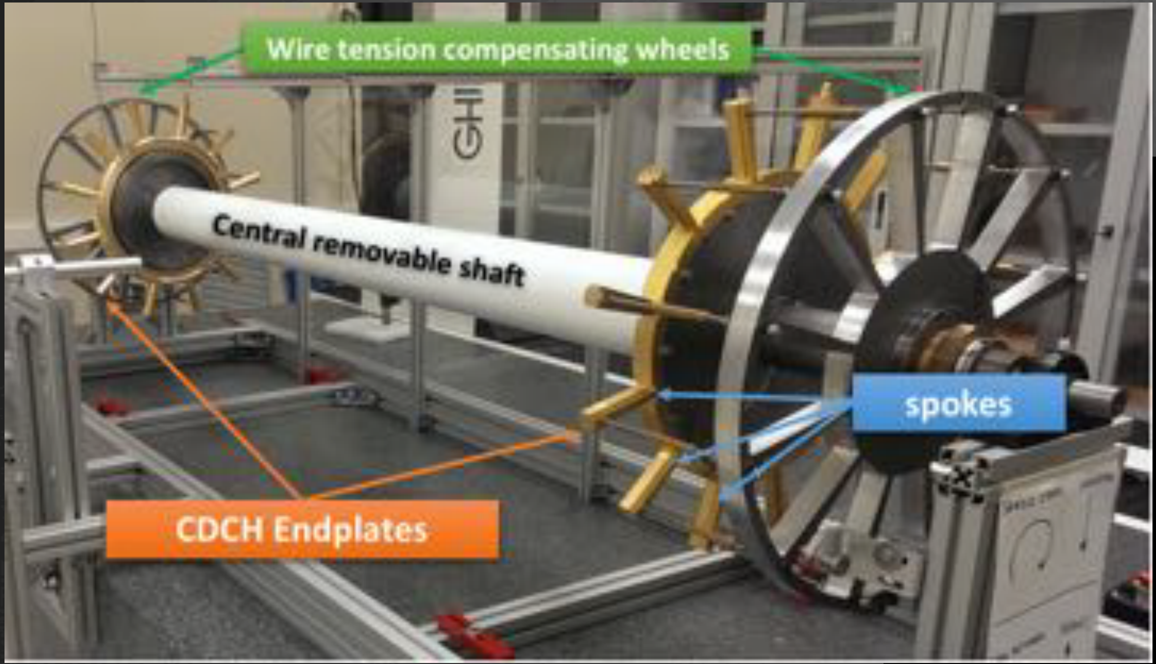
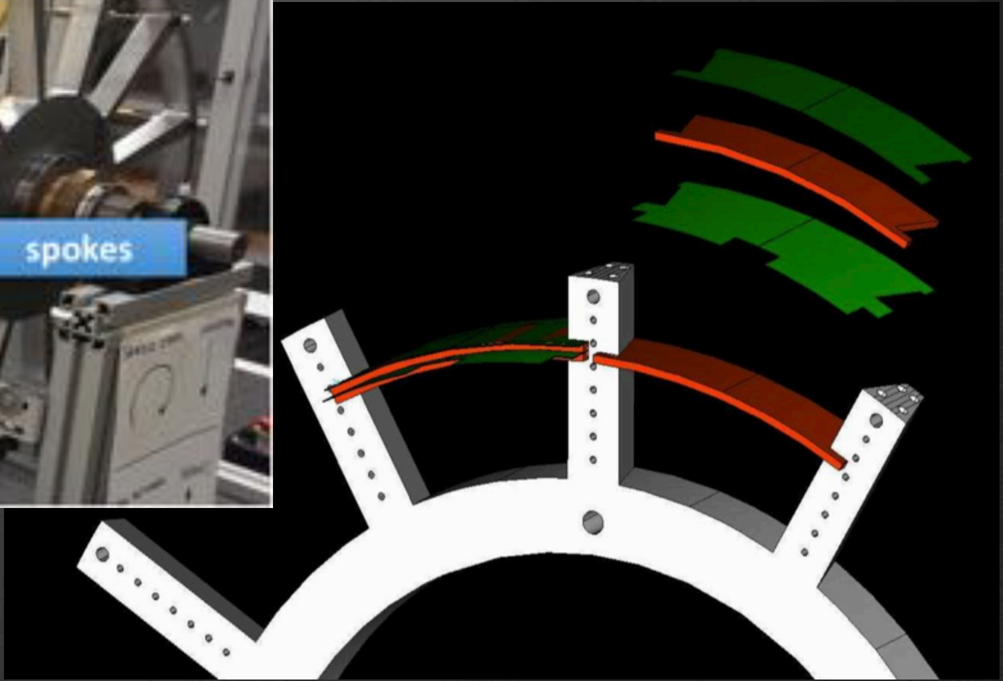
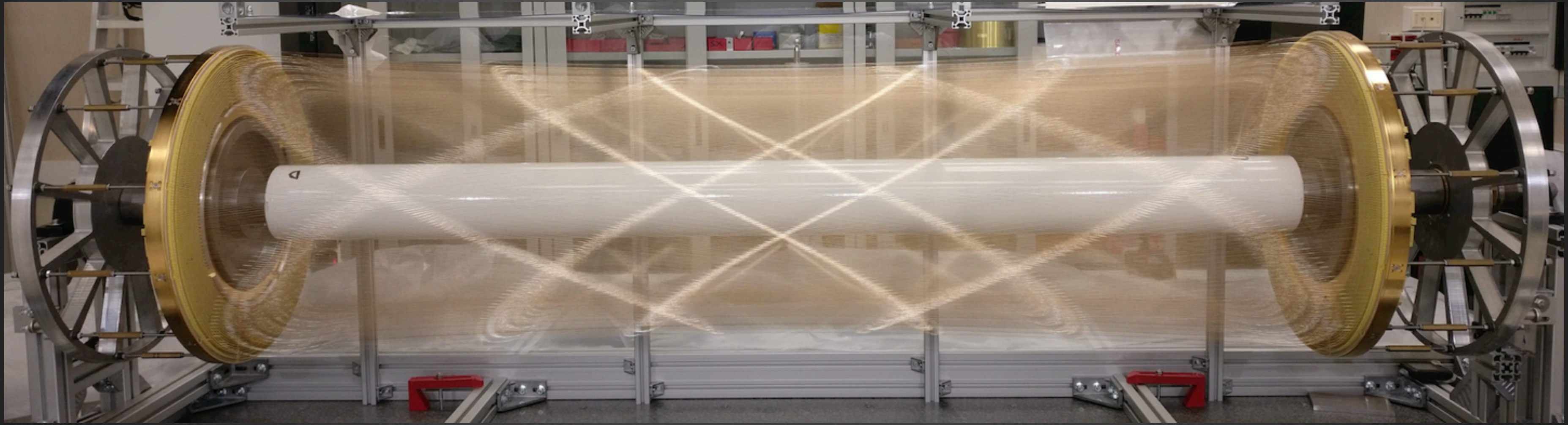




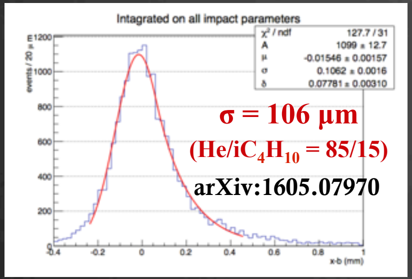
The MEG2 Drift Chamber

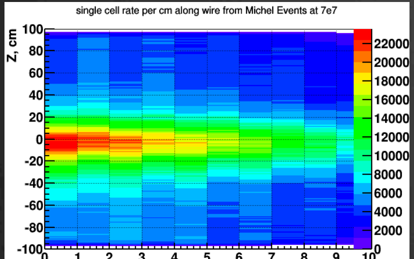


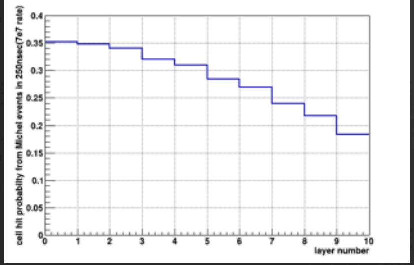
A unique volume, high granularity, all stereo, low mass cylindrical drift chamber, co-axial to B.
Rin = 18 cm, Rout = 30 cm, L = 2 m, 10 co-axial layers,
at alternating sign stereo angles from 100 mrad to 150 mrad ,
arranged in 12 identical azimuthal sectors.
Square cell size between 6.7 and 9.0 mm.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

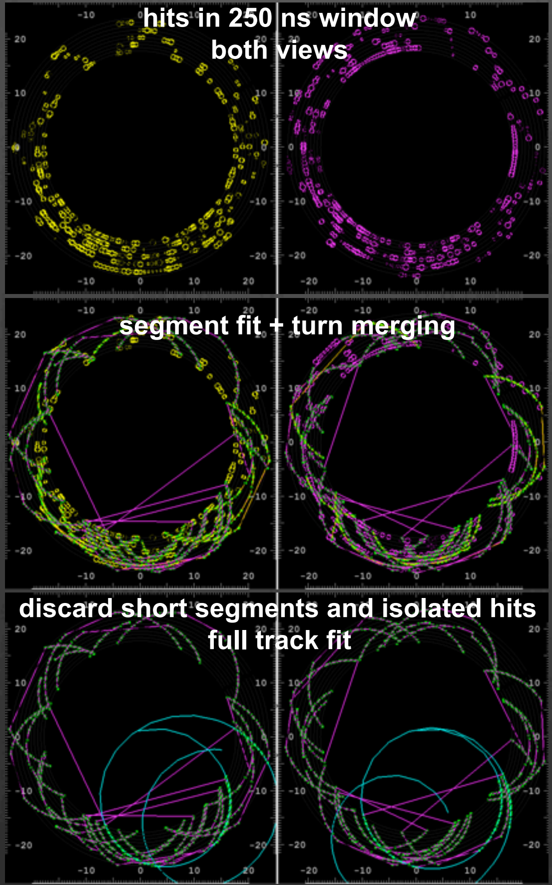
The MEG2 Drift Chamber Performance

spatial resolution on 7 mm cell

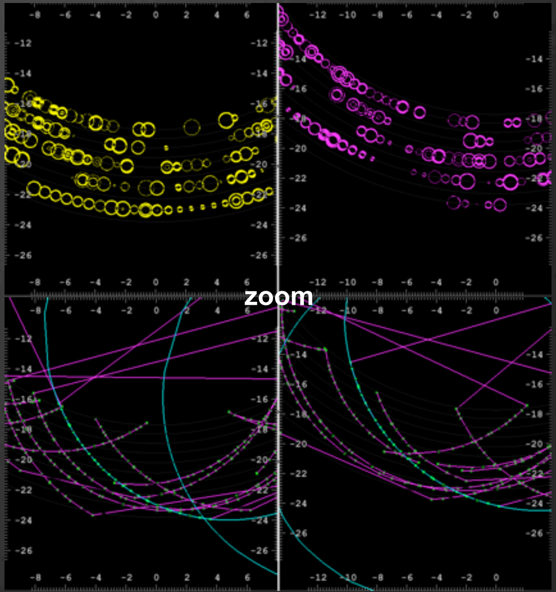








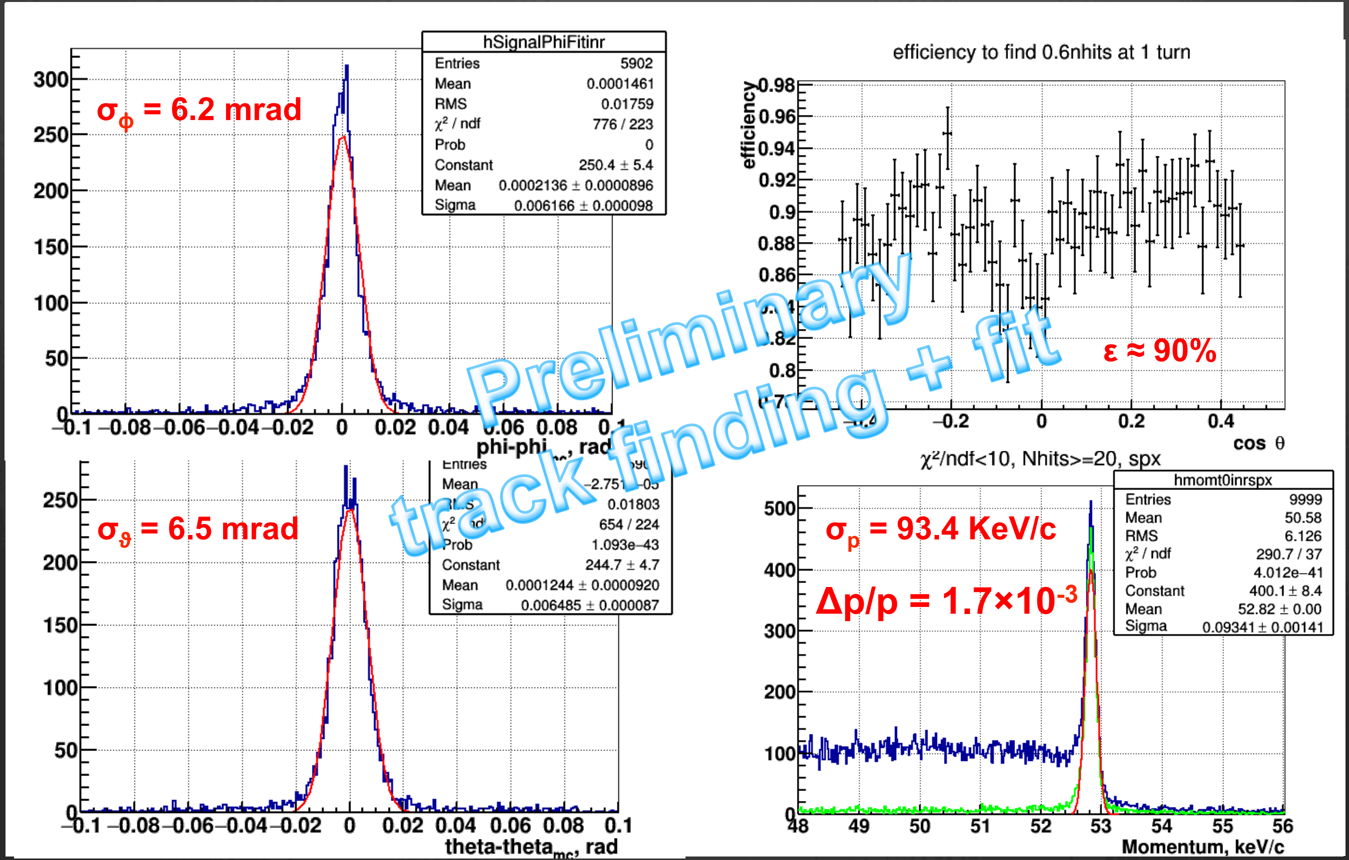
3D track finding and fit



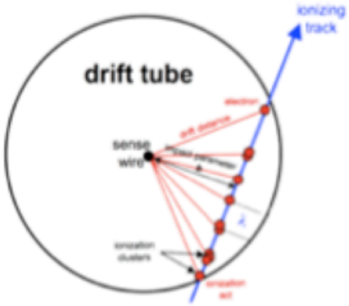
signal track

michel tracks

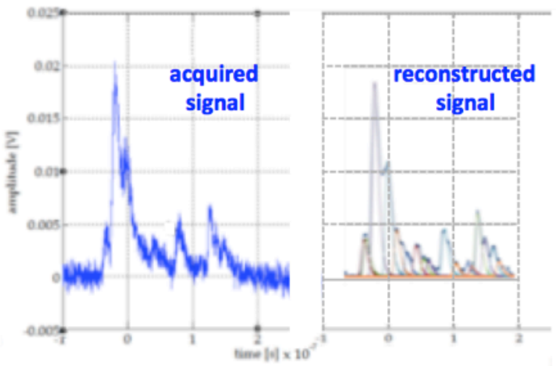
The MEG2 Drift Chamber Performance

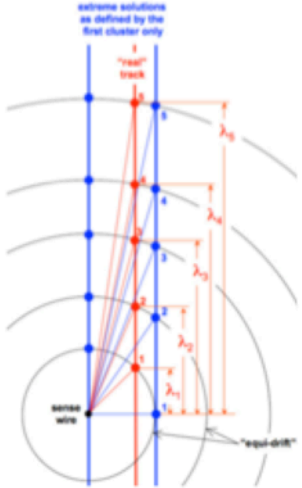


Cluster Timing

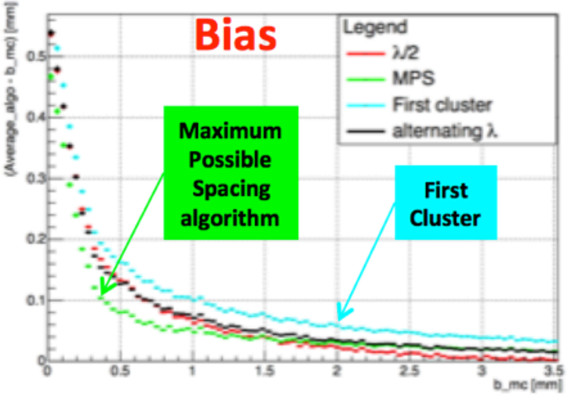


From the **ordered sequence of the electrons arrival times,** considering the average time separation between clusters and their time spread due to diffusion, **reconstruct the most probable sequence of clusters drift times:** $\{t_i^{cl}\} \quad i = 1, N_{cl}$





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 **= 112** and a **2m track** at **1 atm** give

σ ≈ 4.3%

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

dN_{cl}/dx

$\boldsymbol{\delta_{cl}}$ **= 12.5/cm** for He/iC_4H_{10}=90/10 and a **2m track** give

σ ≈ 2.0%

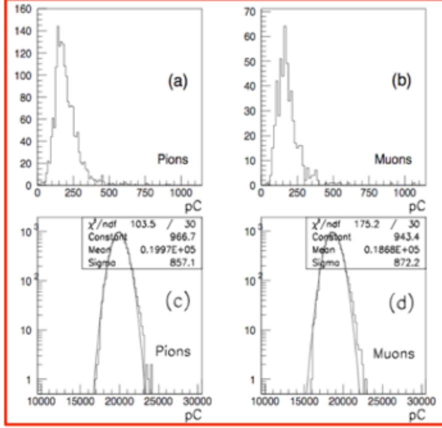
A small increment of iC_4H_{10} from 10% to 20% (δ_{cl} = 20/cm) improves resolution by 20% (σ ≈1.6%) at only a **reasonable** cost of multiple scattering contribution to momentum and angular resolutions.

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 2x10^5),
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)

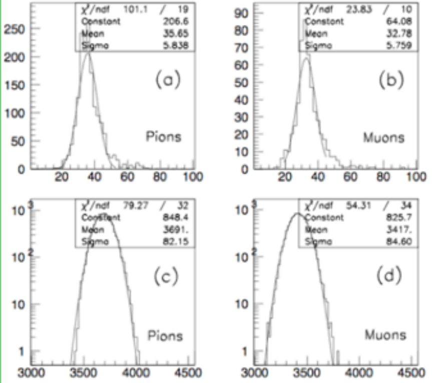


dE/dx

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



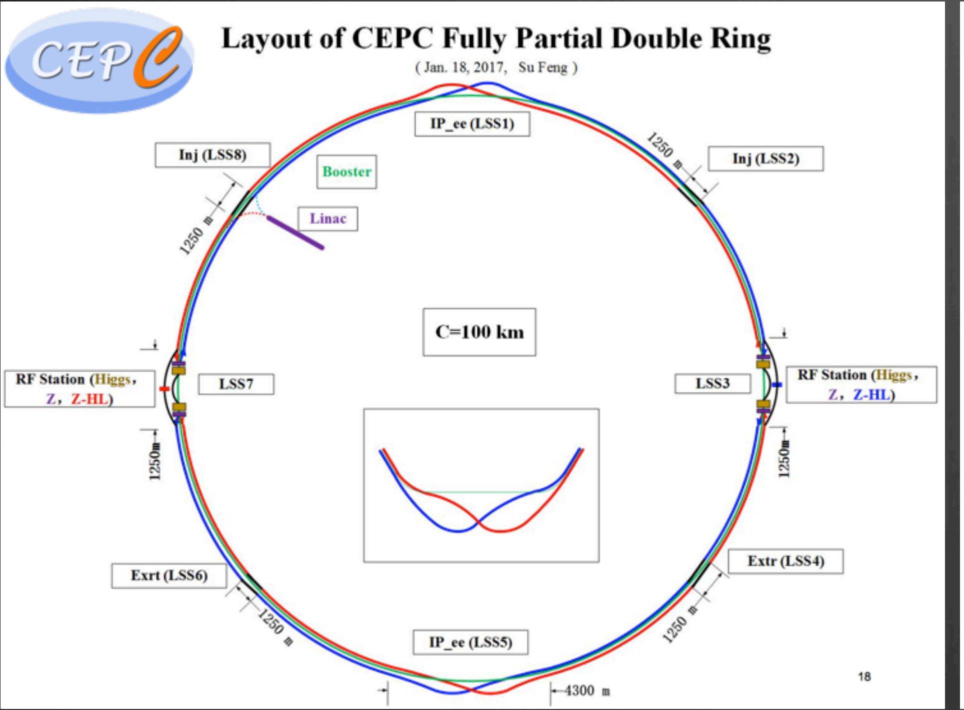
dN_{cl}/dx

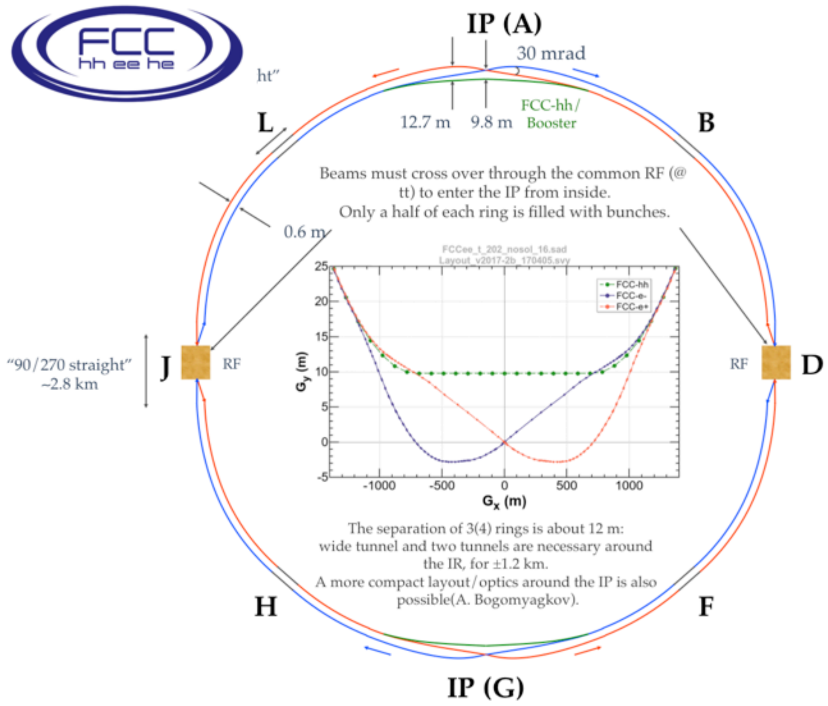
theory
Poisson distribution
σ = 1.7%
≈ 5σ separation

experiment
σ = 2.5%
≈ 3.2σ separation

The Future e⁺e⁻ Circular Machines

Very similar projects at CERN (FCC-ee) and IHEP-China (CEPC):
staging of an e^+e^- machine in the range of 90 GeV (Giga-Z) – 160 GeV (WW) – 250 GeV (Higgs factory) – 350 GeV (ttbar), aimed at a 100 TeV pp collider, 100 Km circumference, following the steps of LEP – LHC



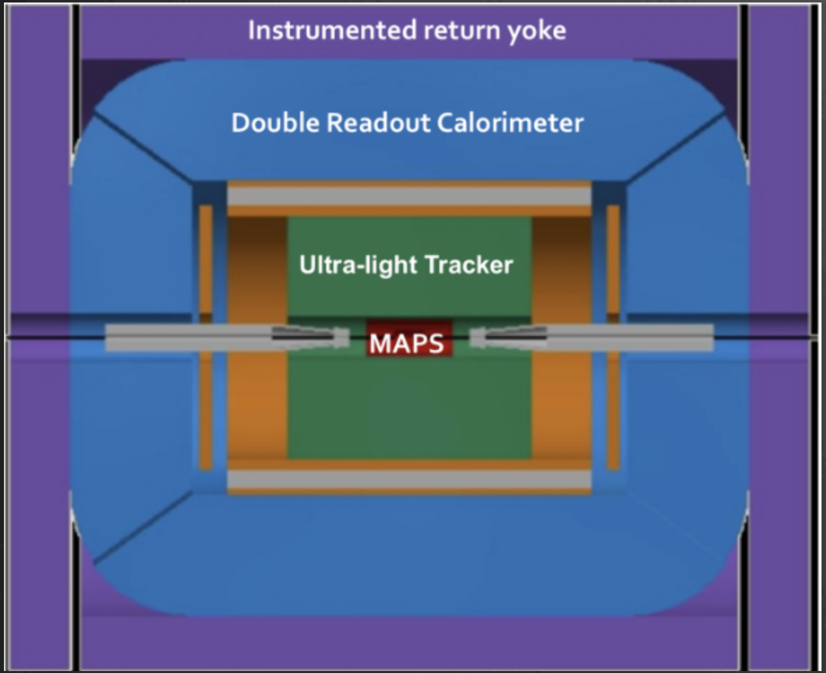


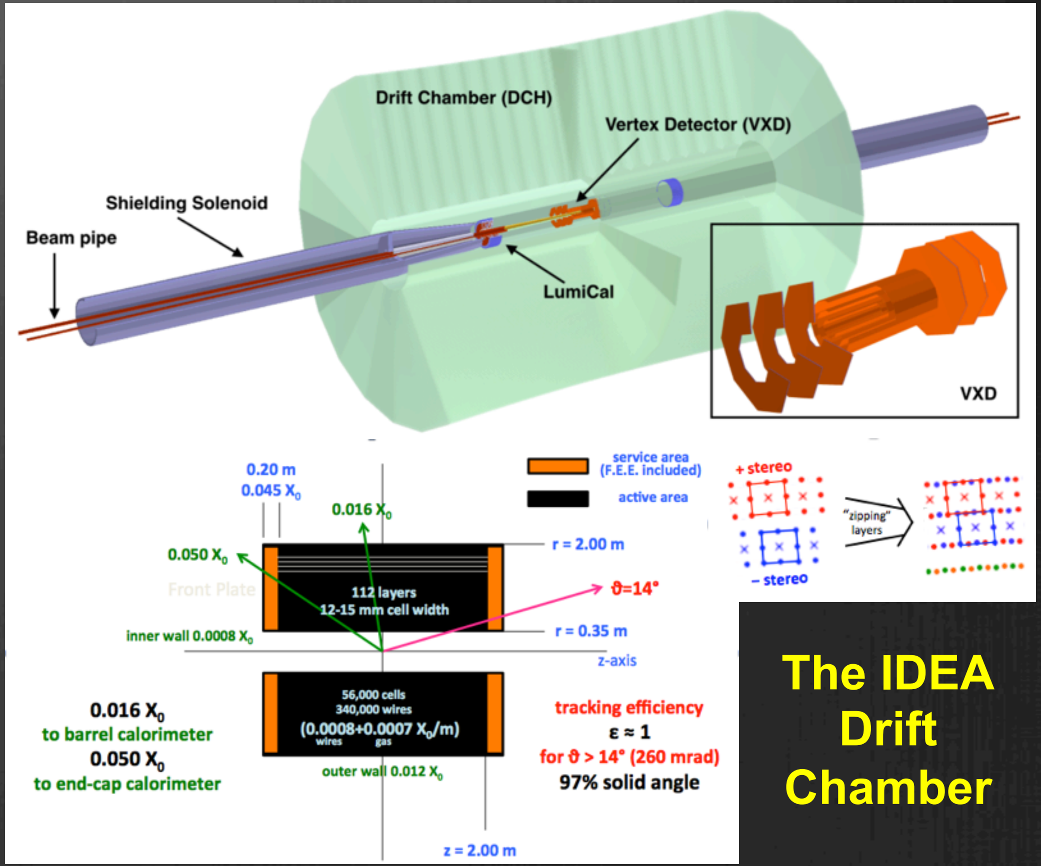
The IDEA Drift Chamber

The **IDEA** Detector at

FCC-ee at CERN

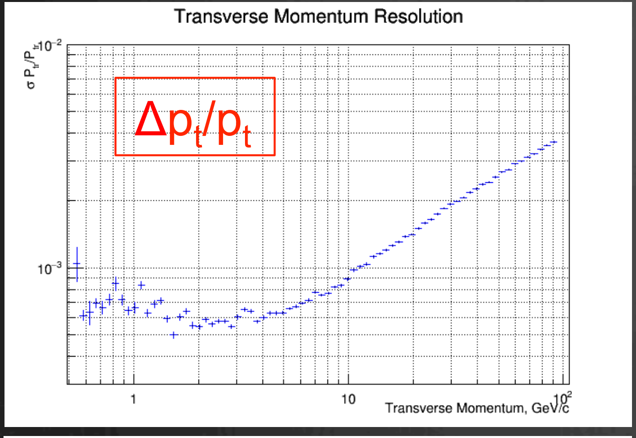
CEPC at IHEP-China

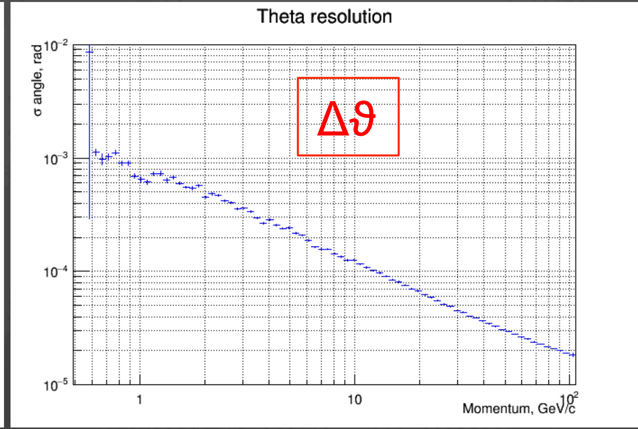


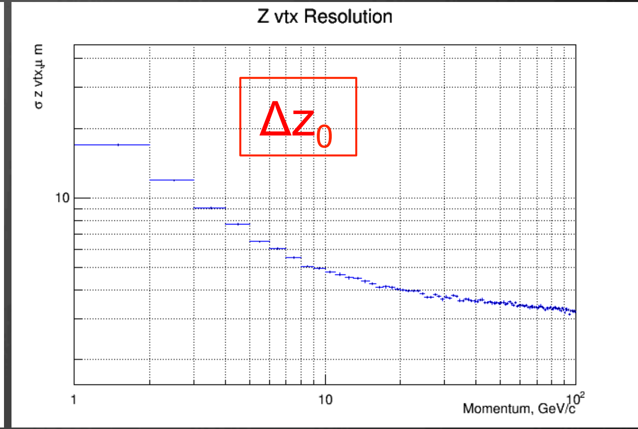


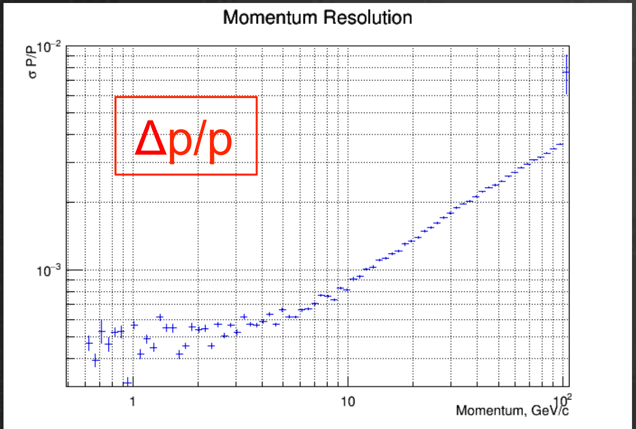
The IDEA Drift Chamber

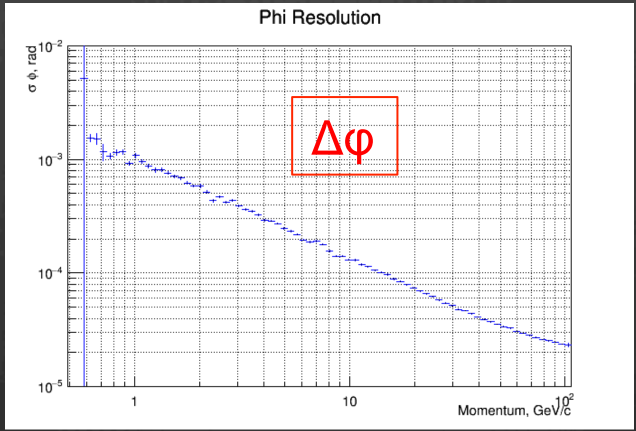
The IDEA Drift Chamber Performance

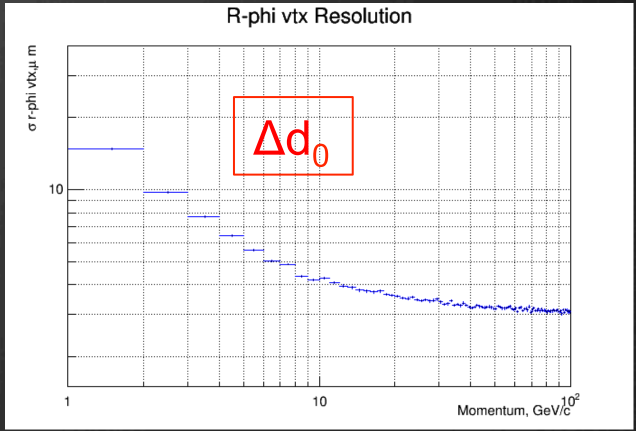




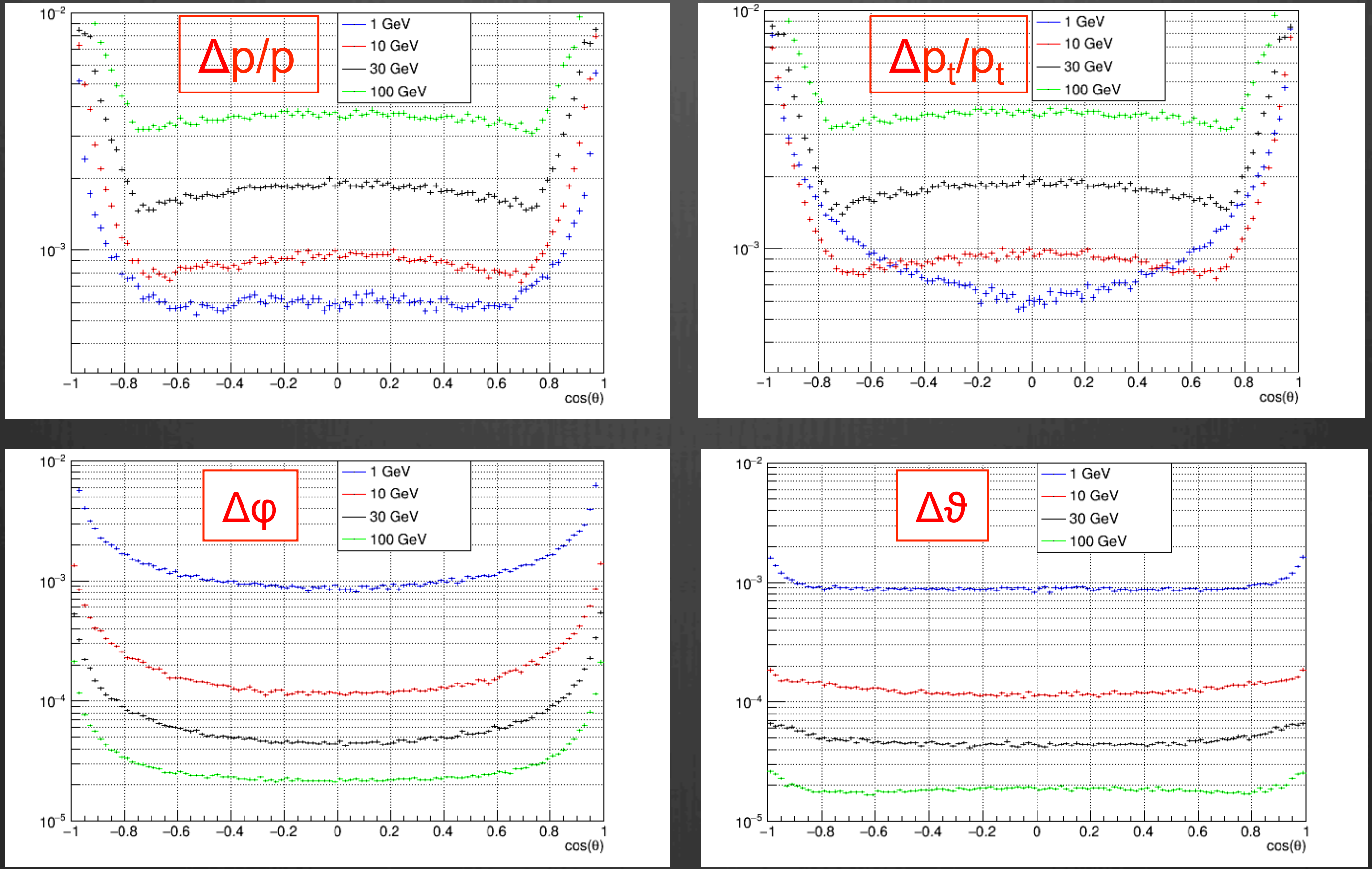






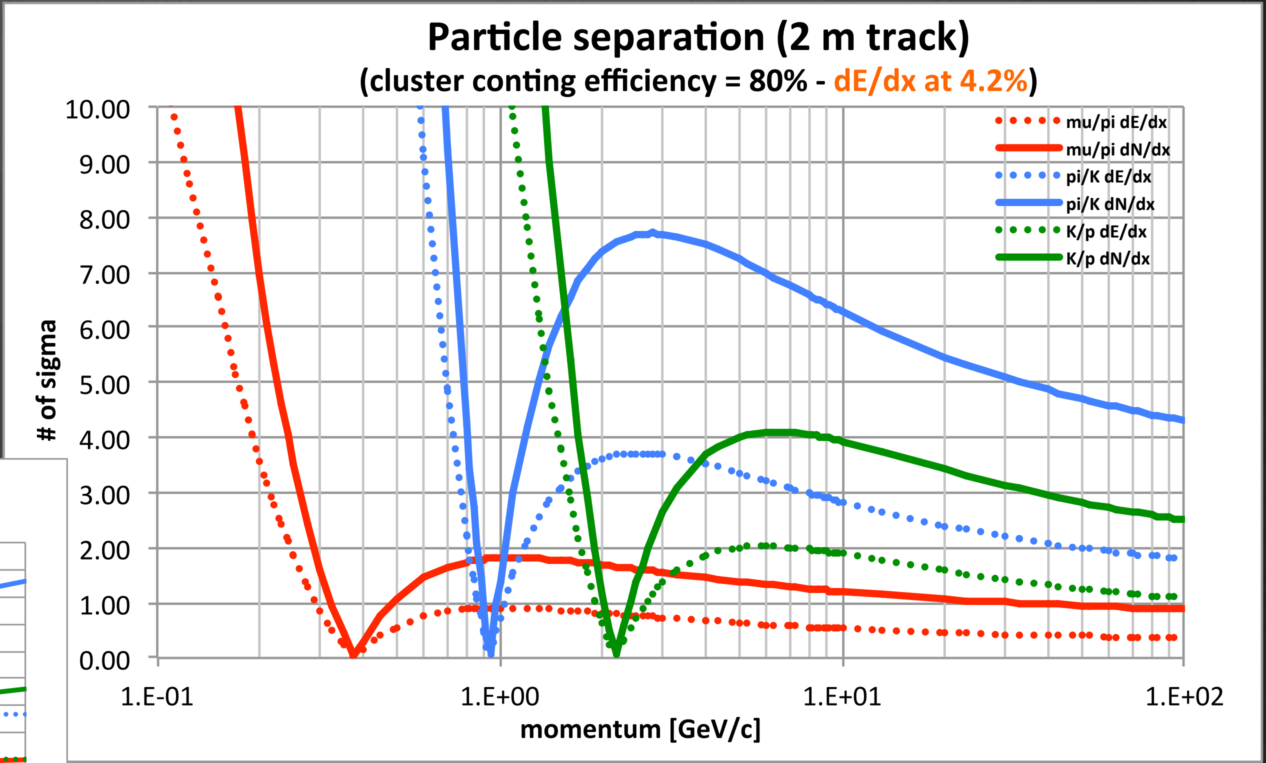


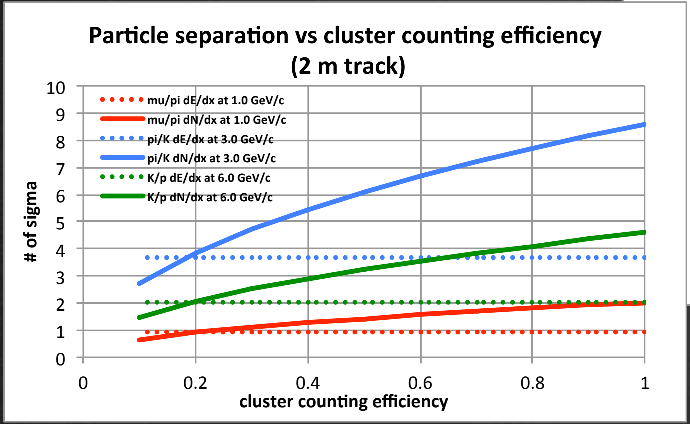
The IDEA Drift Chamber Performance



The IDEA Drift Chamber Performance

Analytical calculations
to be checked with
detailed simulations
(in progress)
and **beam tests**
(next fall at CERN)





TraPId: A proposal for SCTF

Extend the main features of the MEG2 and IDEA solutions to the SCTF case by taking into account:

- Constraints dictated by different geometry
- Constraints dictated by different kinematics

TraPId: A proposal for SCTF

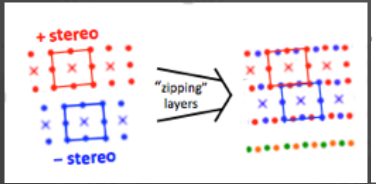
Geometrical constraints :

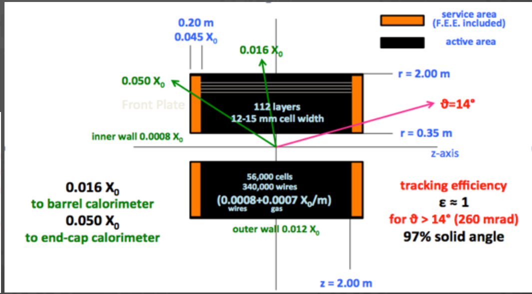
- Cylindrical symmetry
- Length 200 cm
- R_{in} 20 cm R_{out} 80 cm
- Solenoid field 1 Tesla
- 8x8 layers in 12 sectors
- average stereo angle 130 mrad
- square cell size 7.2 to 9.3 mm
- 23,000 drift cells, 140,000 wires

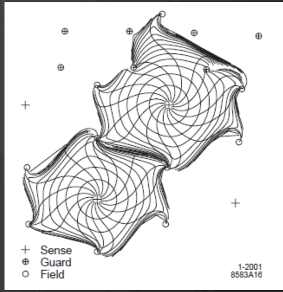
Material Budget :

- Inner wall 0.8×10^{-3} X_0
- Outer wall 1.2×10^{-2} X_0
- Instrumented end-pl. 4.0×10^{-2} X_0
- Gas + Wires 1.2×10^{-3} X_0

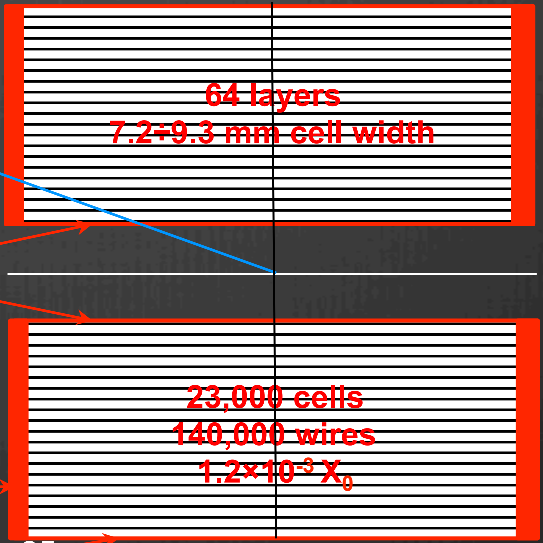
The IDEA Drift Chamber







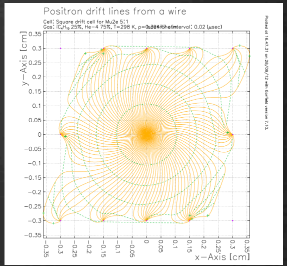
ε = 1
for ϑ>16°
(280 mrad)
96% solid angle

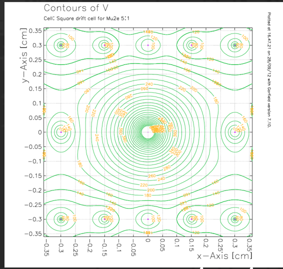


inner wall
0.008 X_0

service area
(f.e.e. included)
0.04 X_0

outer wall
0.012 X_0





TraPId: Tracking Performance

Expected Performance: Track parameters resolutions

$n = 64$, $B = 1.0$ T, $R_{out} = 0.8$ m, $L = 2.0$ m, $1.2\times10^{-3}\ X_0$, $\sigma_{xy} = 100\ \mu m$, $\sigma_z = 1.0$ mm

measurement

$$\frac{\Delta p_\perp}{p_\perp} = \frac{8\sqrt{5}\sigma}{.3BR_{out}^2\sqrt{n}}p_\perp = 1.2\times10^{-3}p_\perp\left[GeV/c\right]$$

$$\Delta\phi_0 = \frac{4\sqrt{3}\sigma}{R_{out}\sqrt{n}} = 1.1\times10^{-4}$$

$$\Delta\theta = \frac{\sqrt{12}\sigma_z}{R_{out}\sqrt{n}}\frac{1+\tan^2\theta}{\tan^2\theta} = 5.4\times10^{-4}\frac{1+\tan^2\theta}{\tan^2\theta}$$

multiple scattering (gas + wires)

$$\frac{\Delta p_\perp}{p_\perp} = \frac{0.0523\left[GeV/c\right]}{\beta BL}\sqrt{\frac{L}{X_0}} = \frac{1.7\times10^{-3}\left[GeV/c\right]}{\beta}$$

$$\Delta\phi_0 = \frac{13.6\times10^{-3}\left[GeV/c\right]}{\beta p}\sqrt{\frac{L}{X_0}} = \frac{6.7\times10^{-4}\left[GeV/c\right]}{\beta p}$$

$$\Delta\theta = \frac{13.6\times10^{-3}\left[GeV/c\right]}{\beta p}\sqrt{\frac{L}{X_0}} = \frac{6.7\times10^{-4}\left[GeV/c\right]}{\beta p}$$

$$\frac{\Delta p_\perp}{p_\perp} = 1.2\times10^{-3}p_\perp \oplus 1.7\times10^{-3}$$

$(1.2 \rightarrow 1.0$ with cluster timing$)$

TraPId: PId Performance

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

from *Walenta parameterization (1980)*

$L_{track} = 1\ m$
$P = 1\ atm$
$n = 40$

$$\frac{\sigma_{dE/dx}}{(dE/dx)} = 8.4\%$$

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

from *Poisson distribution*

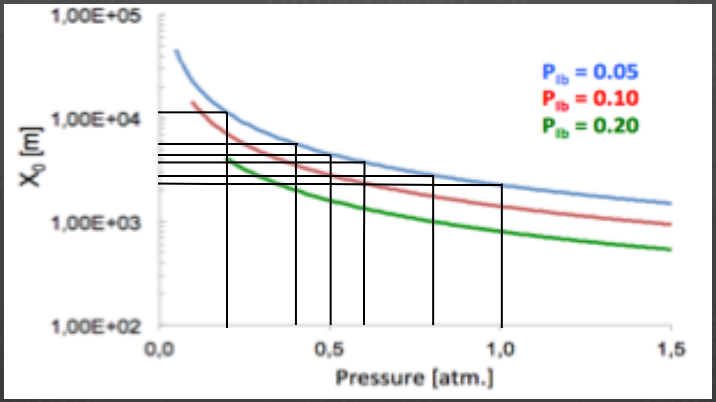
$L_{track} = 1\ m$
$\delta_{cl} = 12/cm$

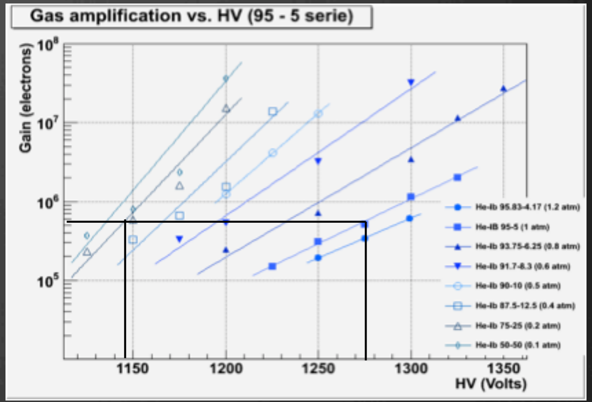
$$\frac{\sigma_{dN_{cl}/dx}}{(dN_{cl}/dx)} = 2.9\%$$

TraPId: Performance

How to further improve on multiple scattering contribution to Δp/p

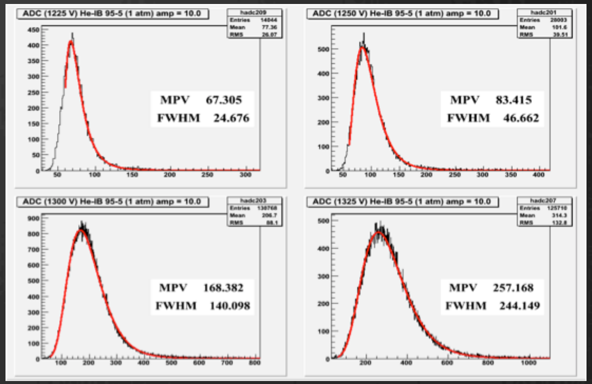
Keeping the quencher partial pressure constant can operate the chamber at constant gas gain.





He/iC_4H_{10} =95/5 @ 1 atm.
V_0 = 1275 V
X_0 = 2000 m, δ_{cl} = 8/cm

He/iC_4H_{10} = 75/25 @ 0.2 atm.
V_0 = 1145 V
X_0 = 10000 m, δ_{cl} = 4/cm



10% gain in operating high voltage
55% gain in multiple scattering contribution to Δp/p
43% degradation in dN_{cl}/dx (3.5% → 5.0%)

CONCLUSIONS

I. An ultra-low mass drift chamber for SCTF with a material budget of 1.5×10^{-2} X_0 in the radial direction and of 4.5×10^{-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

II. $\boldsymbol{\Delta p_t/p_t = 1.2 \times 10^{-3} p_t \oplus 1.7 \times 10^{-3}}$.

III. Angular resolutions of better than a fraction of a mrad at any angle and for all momenta can be reached.

IV. Particle identification at the level of a few percent with cluster counting and π/K separation $\geq 3\sigma$ are feasible for a wide range of momenta.

V. Further gain in momentum resolution, besides cluster timing, can be obtained by operating the chamber at lower pressures, with moderate degradation on PId performance