"Full" Simulation of the IDEA Drift Chamber at FCC-ee

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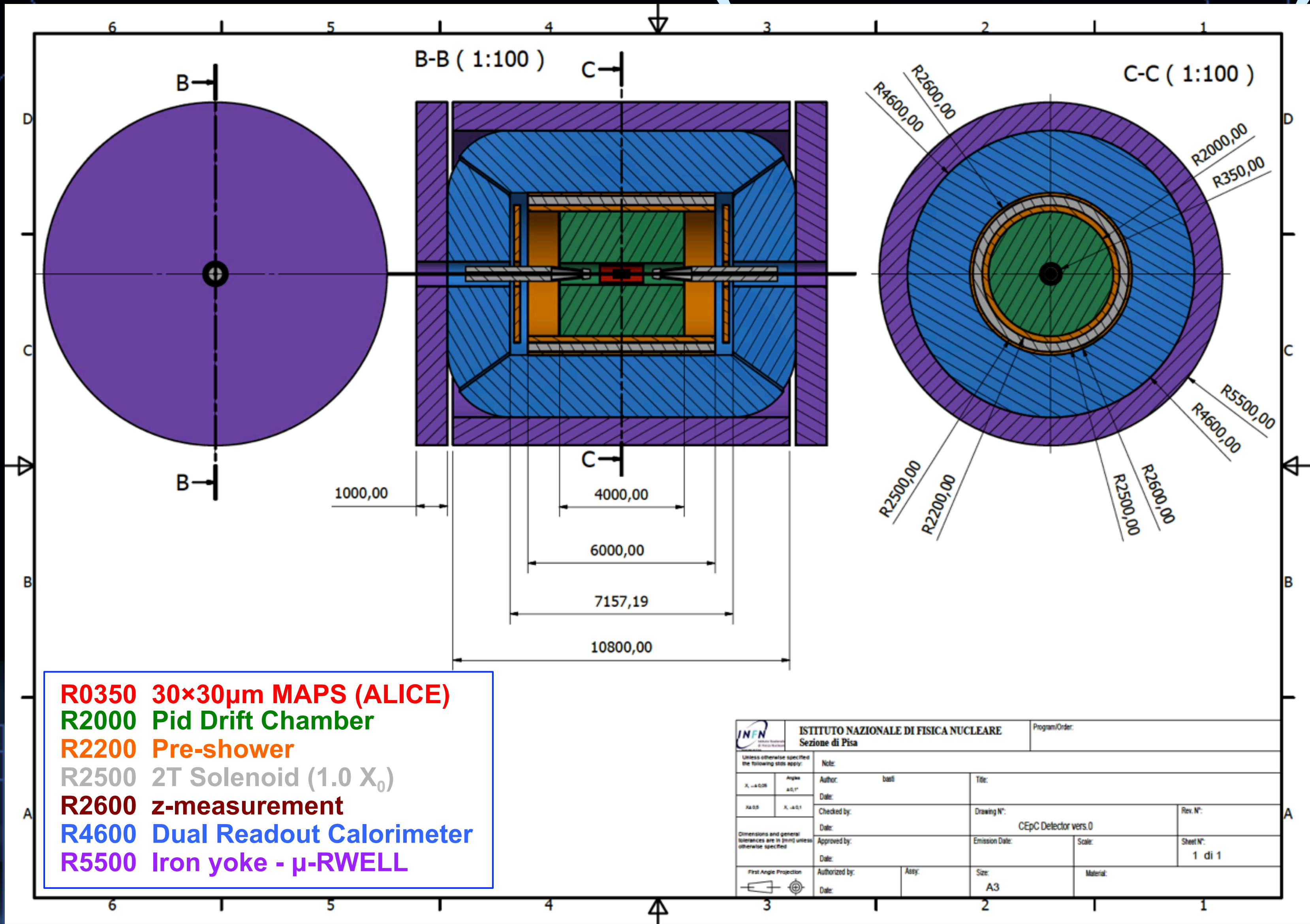
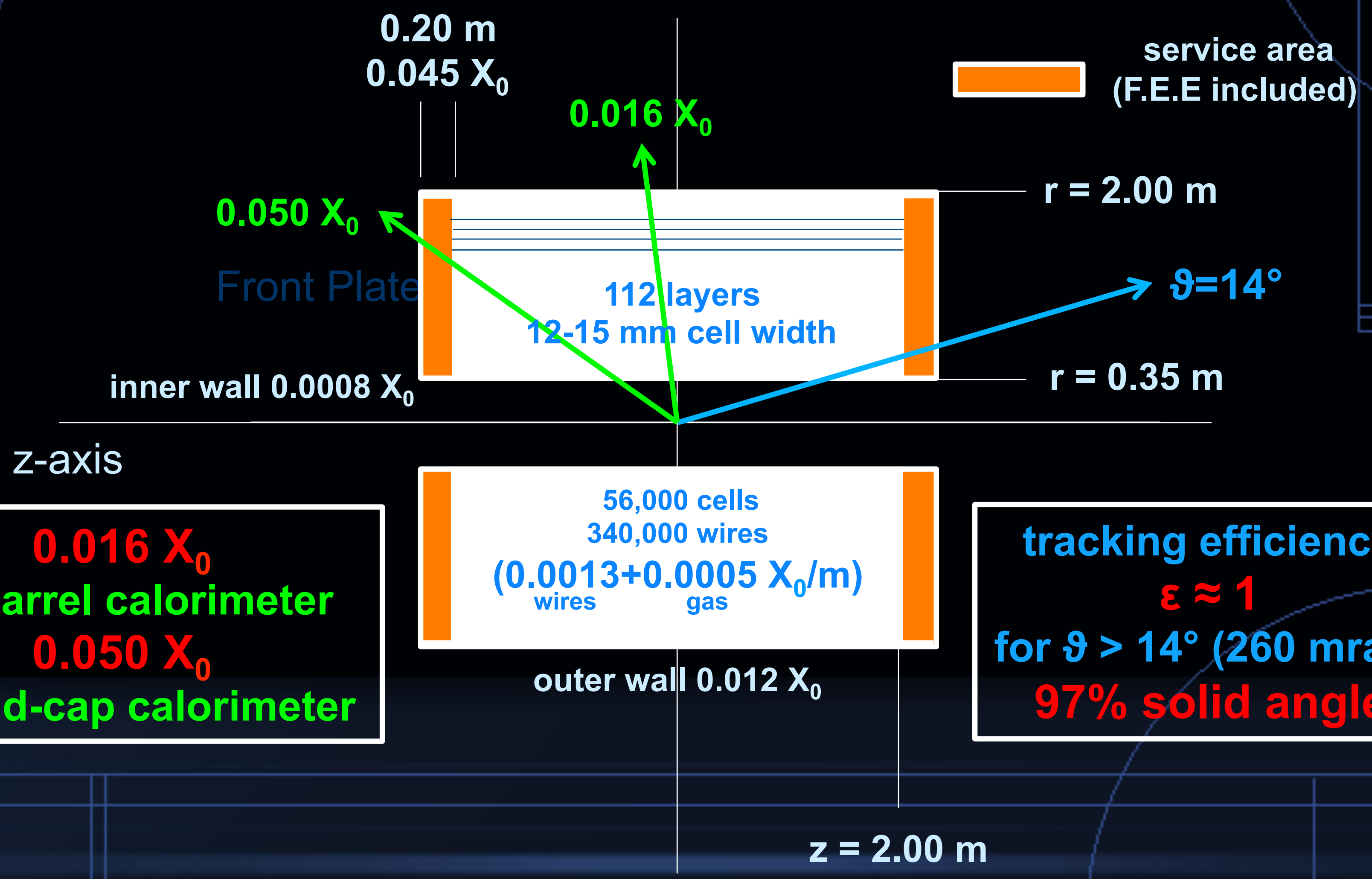
INFN – Lecce

WG11 Detector Design Meeting – CERN, May 11, 2017

IDEA Detector (F. Bedeschi)



Drift Chamber Proposal



0.016 X_0
to barrel calorimeter
0.050 X_0
to end-cap calorimeter

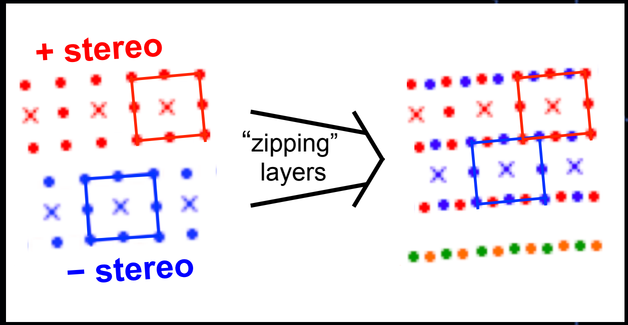
tracking efficiency
$\varepsilon \approx 1$
for ϑ > 14° (260 mrad)
97% solid angle

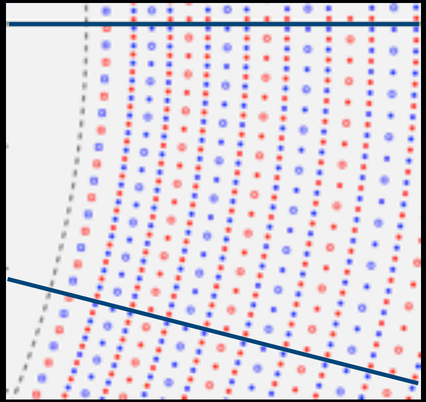
Drift Chamber Layout

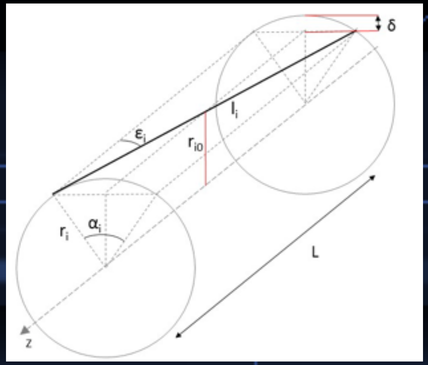
- 12÷15 mm wide square cells
  5 : 1 field to sense wires ratio
  56,448 cells

- 112 (14 x 8) co-axial layers in
  24 equal azimuthal (15°)
  sectors

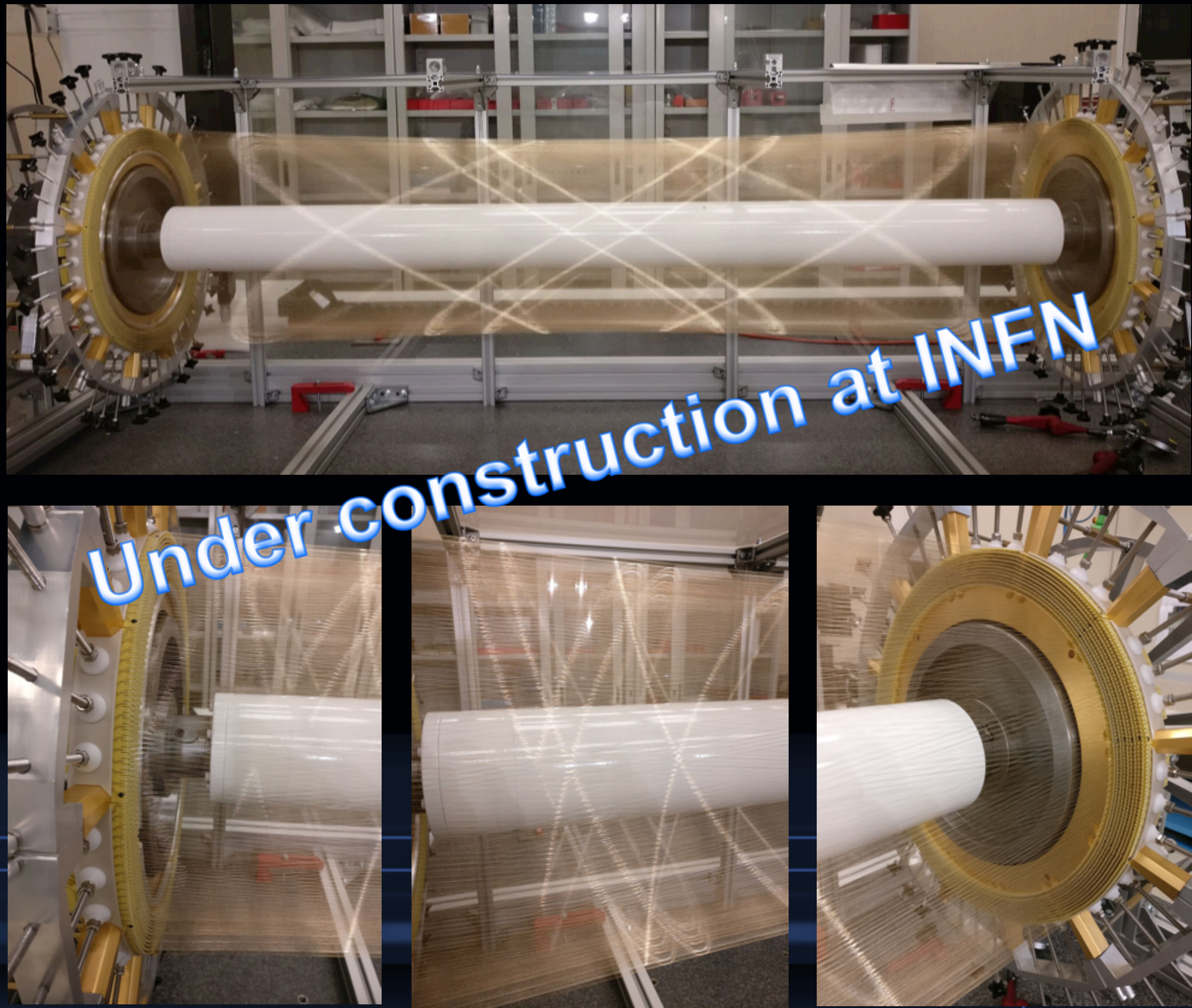
- alternating sign stereo angles
  ranging from 50 to 250 mrad







Drift Chamber MEG2



Drift Chamber El. Stability

sagitta due to electrostatic forces on sense wire displaced by Δ from central symmetry position

$$\delta = \frac{C^2 V_0^2 L^2}{4\pi\varepsilon T W^2}\Delta$$

C = wire capacitance per unit length
V_0 = wire voltage
L = wire length
T = wire mechanical tension
W/2 = wire distance from ground plane
R = sense wire radius

$$C = \frac{2\pi\varepsilon}{\ln\left(\frac{\{2\}W}{2R}\right)}$$

stability condition for MEG2
L = 2 m
W = 7 mm

$$T \geq \frac{\pi\varepsilon V_0^2 L^2}{W^2\left(\ln\frac{W}{R}\right)^2} \geq 0.12N$$

MEG2 sense wires are strung at ***T = 0.25 N***

For IDEA Drift Chamber, *L = 4 m*, *W = 12 mm*, same gas gain (V_0), same sense wire radius (*R*):

$T \geq 0.18N$ **or, for *T = 0.25 N*,** $L \leq 4.7m$

Drift Chamber Material Budget

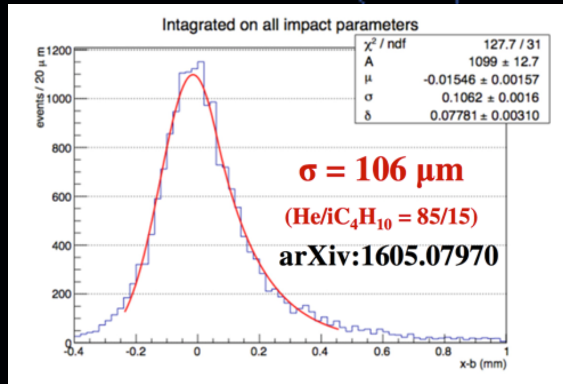
Conservative estimates:

- Inner wall (CMD3 drift chamber) **$8.4\times10^{-4}\ X_0$**
  200 μm Carbon fiber
- Gas (KLOE drift chamber) **$4.7\times10^{-4}\ X_0/m$**
  90% He – 10% iC_4H_{10}
- Wires (MEG2 drift chamber) **$1.3\times10^{-3}\ X_0/m$**
  20 μm W sense wires $4.2\times10^{-4}\ X_0/m$
  40 μm Al field wires $6.1\times10^{-4}\ X_0/m$
  50 μm Al guard wires $2.4\times10^{-4}\ X_0/m$
- Outer wall (Mu2e I-tracker studies) **$1.2\times10^{-2}\ X_0$**
  2 cm composite sandwich (7.7 Tons)
- End-plates (Mu2e I-tracker studies) **$4.5\times10^{-2}\ X_0$**
  wire cage + gas envelope
  incl. services (electronics,
  cables, ...)

Drift Chamber 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

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

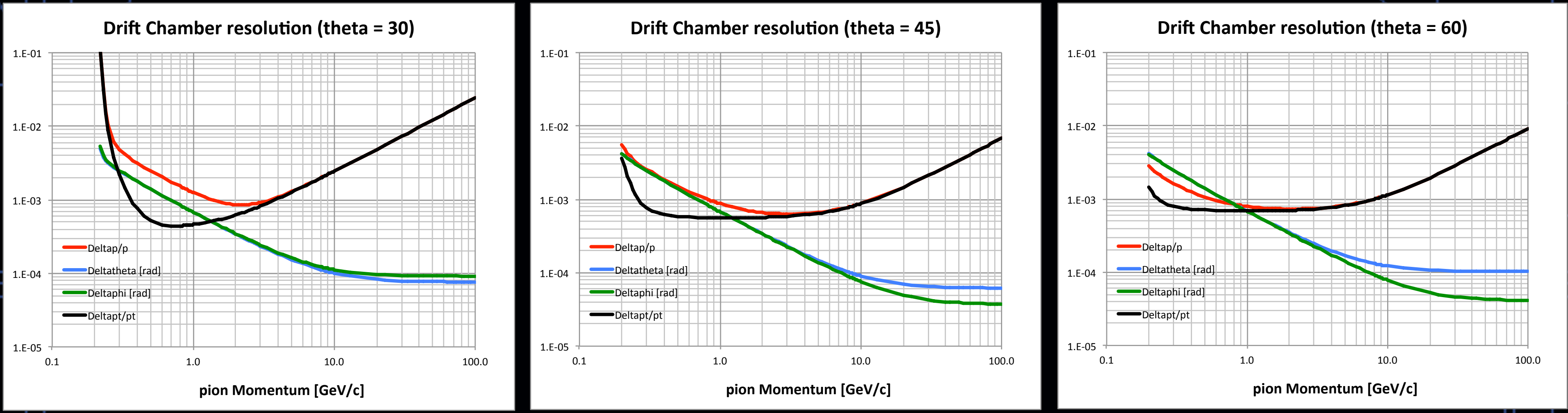
$$\Delta\theta = \frac{\sqrt{12}\sigma_z}{R_{out}\sqrt{N}} \frac{1+\tan^2\theta}{\tan^2\theta} \oplus \frac{0.0136[GeV/c]}{\beta p} \sqrt{\frac{L}{X_0}}$$

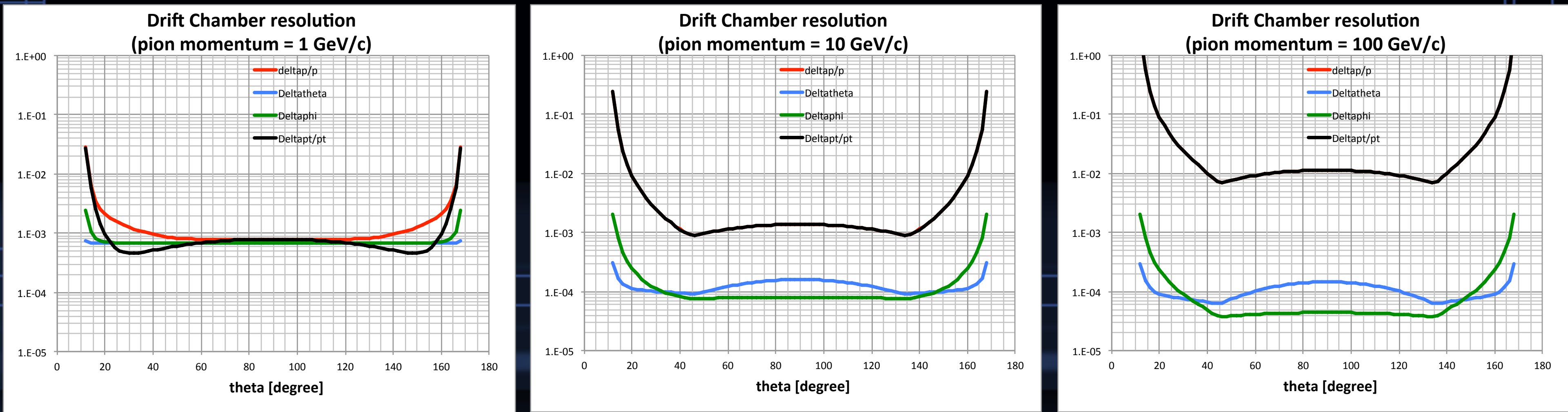
Momentum Resolution

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

σ_{xy}=110μm, σ_z=750μm, N=112, B=2T, R_{out}=2m, L=2.5×$10^{-3}X_0$

Drift Chamber Resolution





Drift Chamber Particle Id.

Cluster Counting

Thanks to the **Poisson nature of the ionization process**, by counting the total number of ionization clusters N_{cl} along the trajectory of a charged track, for all the hit cells, one can, in principle, reach a relative resolution of $\mathbf{N_{cl}^{-1/2}}$.

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**, **2.6cm** 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**), readout through a high bandwidth preamplifier (**1.7 GHz**, **gain 10**), digitized with a **2 GSa/s 1.1 GHz**, **8 bits** digital scope.

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

Drift Chamber Particle Id.

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

from *Walenta 1980*

versus

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

from *Poisson*

dE/dx

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

***n* = 112** and a **2m track** give **σ ≈ 4.3%**

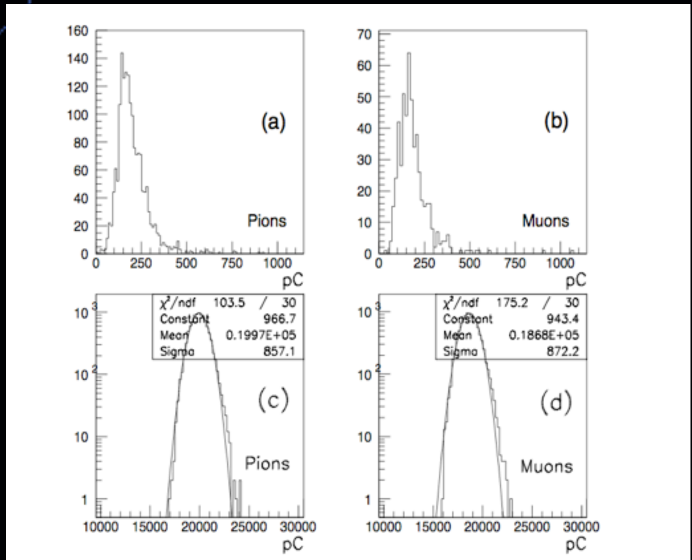
Increasing ***P*** to 2 atm improves resolution by 20% (σ ≈3.4%) but at a considerable cost of multiple scattering contribution to momentum and angular resolutions.

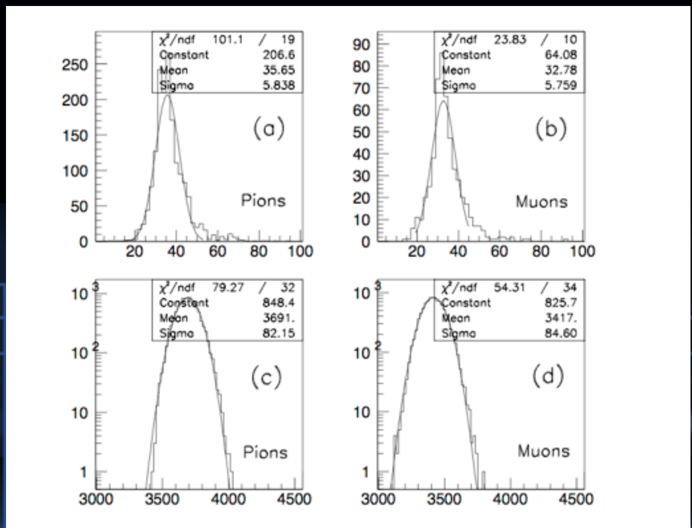
dN_{cl}/dx

δ_{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} 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.

Drift Chamber Particle Id.





dE/dx

100 samples 3.7 cm

(σ[%]=40.7 $n^{-0.43}$ $L[m]^{-0.32}$)

σ = 3.7%

≈ 2.0σ separation

the best one can do (Walenta parameterization)

20% truncated mean

σ = 4.5%

≈ 1.4σ separation

experimental result

μ−π 200 MeV/c

dN_{cl}/dx

Poisson distribution

σ = 1.7%

≈ 5σ separation

the best one can do

Experimental distribution

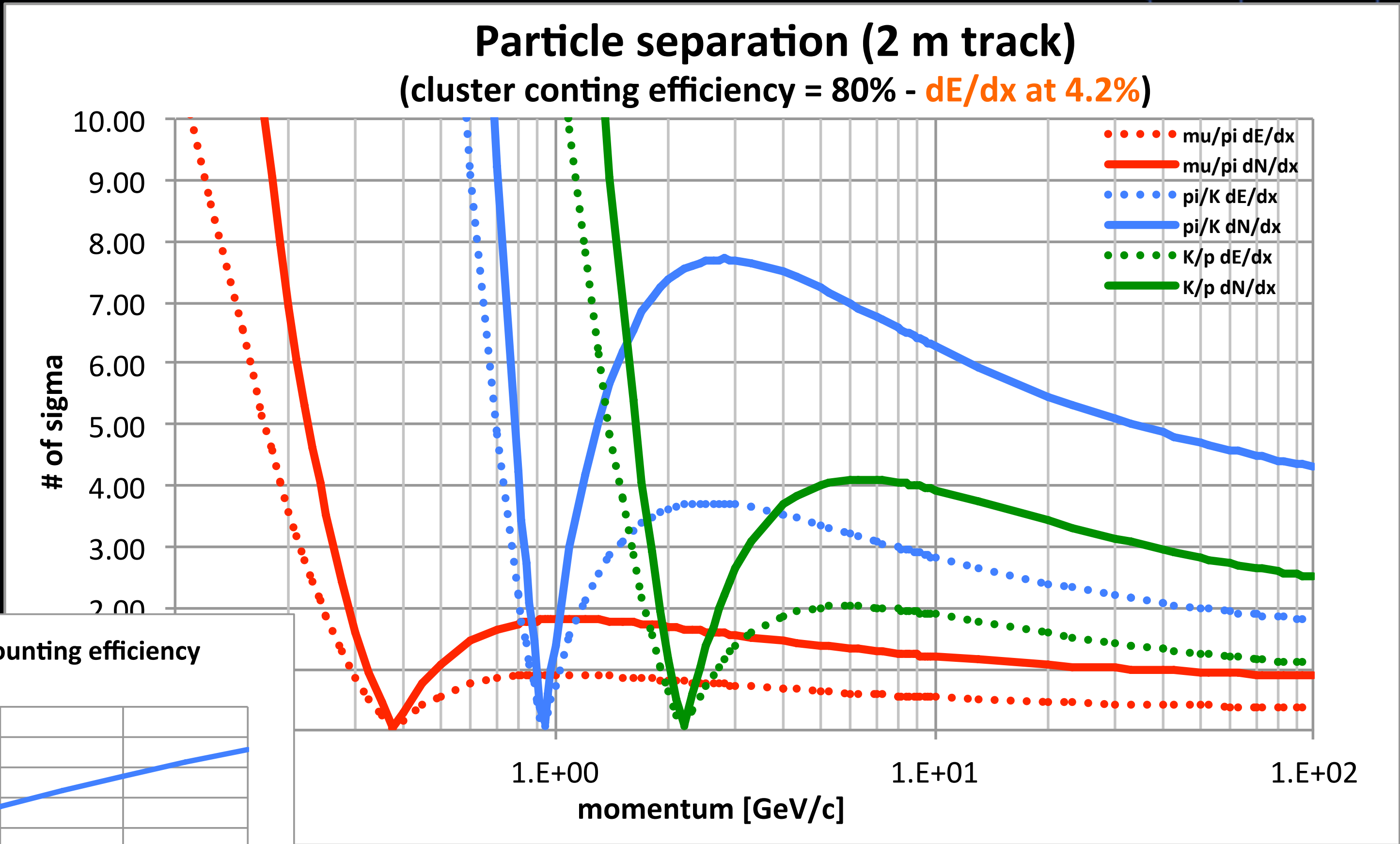
σ = 2.5%

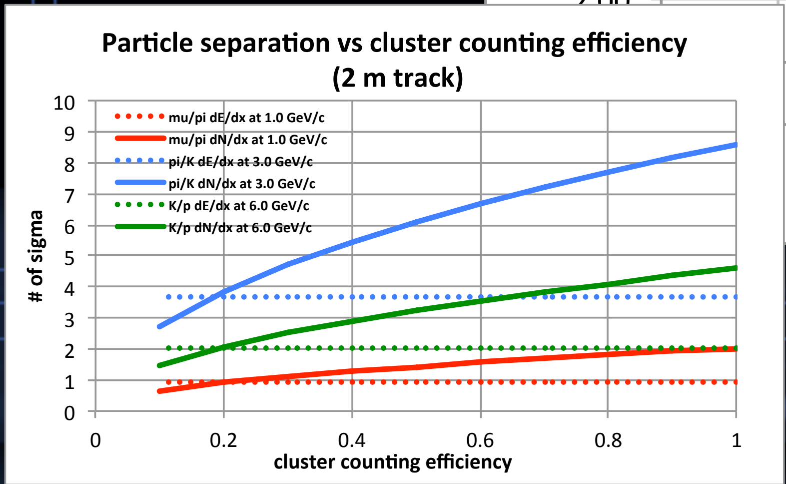
≈ 3.2σ separation

experimental result

μ−π 200 MeV/c

Drift Chamber Particle Id.





Drift Chamber Simulation

A standalone Geant4 simulation as a starting point has been implemented:

- Geant4 10.01 p03
- Physics List: QGSP_BERT 4.0
- 2T Constant Magnetic Field, G4ClassicalRK4 particle motion integrator engine
- particles generator used: General Particle Source

The code is organized in a **modular** way, the geometry description is **"quite" plug and play**, it is possible to import it in any framework with minor changes.

The Chamber geometry is described at a great level of details (see next slide)

A simplified Hit creation module is used for preliminary studies:

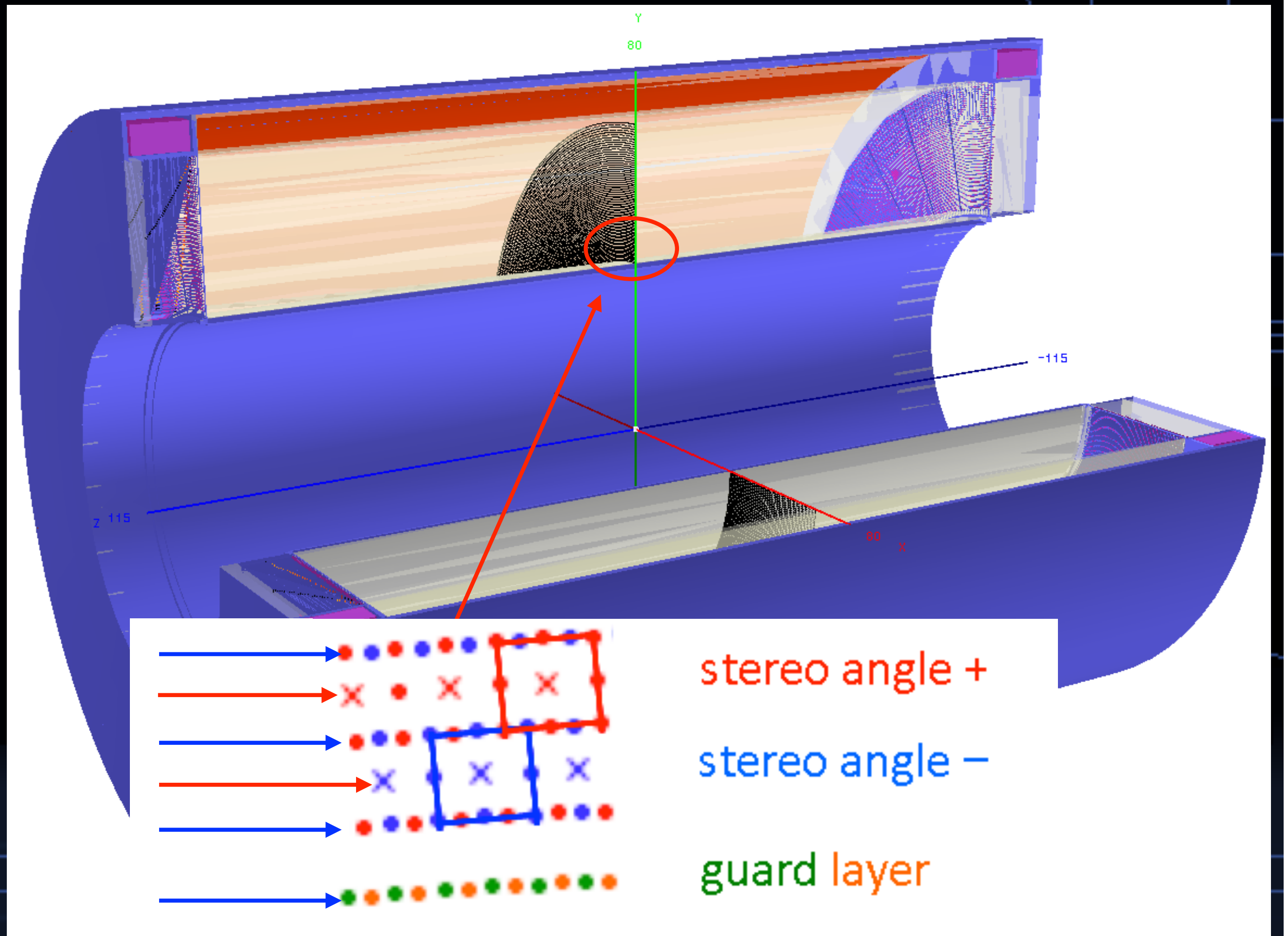
- no XT relation used (is easy to switch it on), only pure geometrical information are used
- eventual tracks hits pile-up is marginally taken into account
- Space resolution is assumed to be constant and gaussian throughout the cell at 120 μm

The simulation is interfaced with GenFit2 to perform a preliminary study on the expected DCH performances on reconstruction. Pattern Recognition is by-passed.

Drift Chamber Simulation

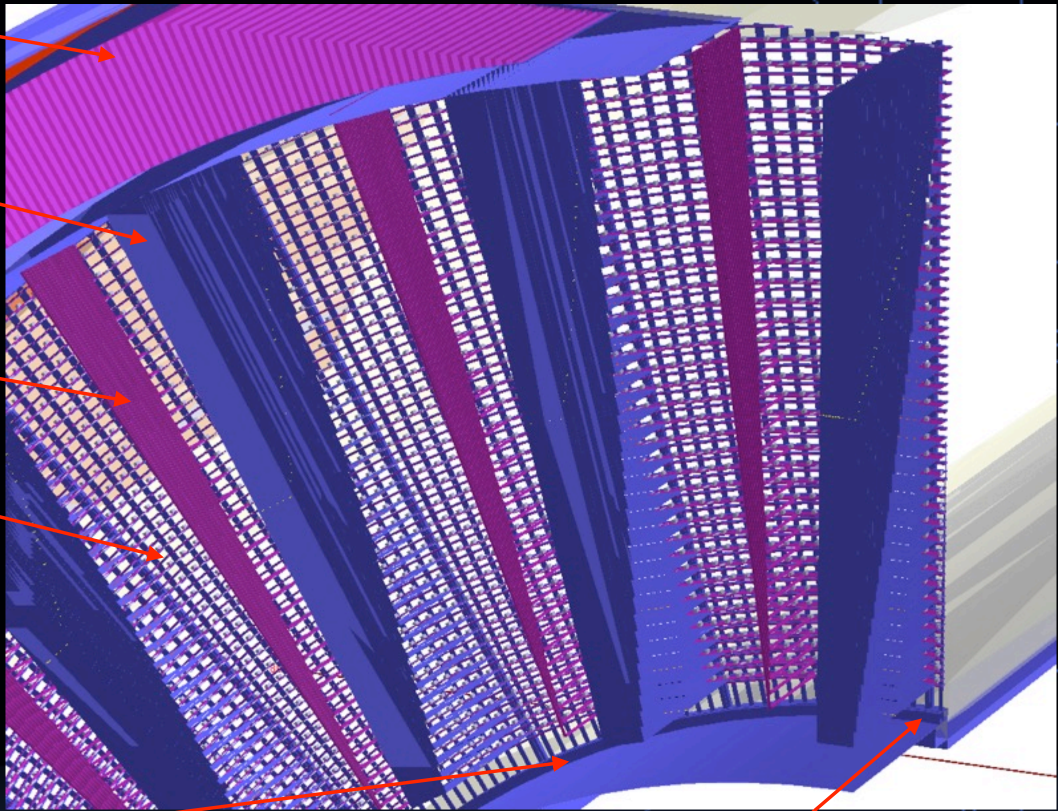
high level of details (~99%)
***fully parametric*.**

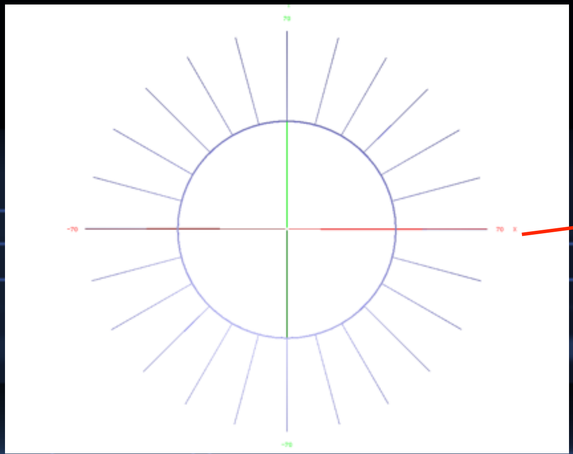
The geometry description is optimized for geant4 navigation (then run time).
The gas volume is divided in a set of hyperboloid shells and the right voxelization factor is chosen for each layer.
Blue ones contain only field wires.
Red ones contain only sense and guard wires.



Drift Chamber Simulation

- (Switchable) preamplifier boards: 12 cm x 6 cm x 3mm G10 (FR4);
- signal cables (only dwnstrm): 2.032 cm x 25 µm Kapton + 40 µm 16 pairs of Copper wires;
- HV cables (only upstrm): 500 µm Copper wire + 500 µm Teflon insulation;
- Wire anchoring (see next slide);
- Carbon fiber wire support.





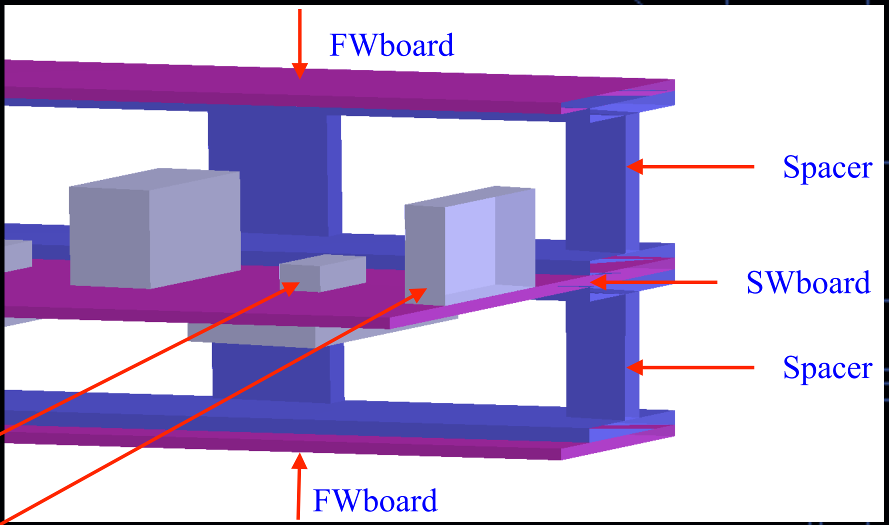
Connecting ring is described as a circular layer: 0.5 cm x 1.5 cm Carbon fiber

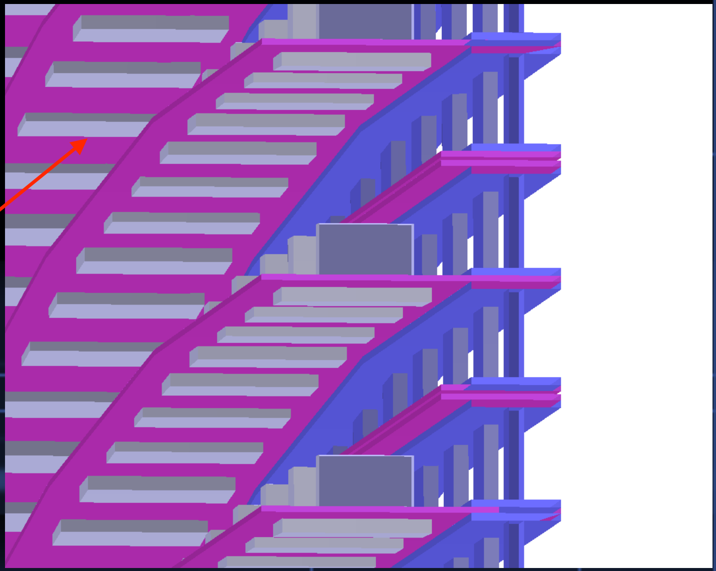
Drift Chamber Simulation

The wire anchoring system:

- Field wire board:
  4 mm x 200 μm G10;
- Spacer: polycarbonate,
  Sense wire board:
  1 cm x 200 μm G10 plus components:

  1) termination resistance:
     1.6 mm x 800 μm x 450 μm
     (Aluminum);
  2) HV Capacitance:
     3.17 mm x 1.57 mm x 1.7 mm
     (Aluminum);
  3) HV resistance (only dwnstrm):
     5 mm x 2.5 mm x 550 μm
     (Aluminum).





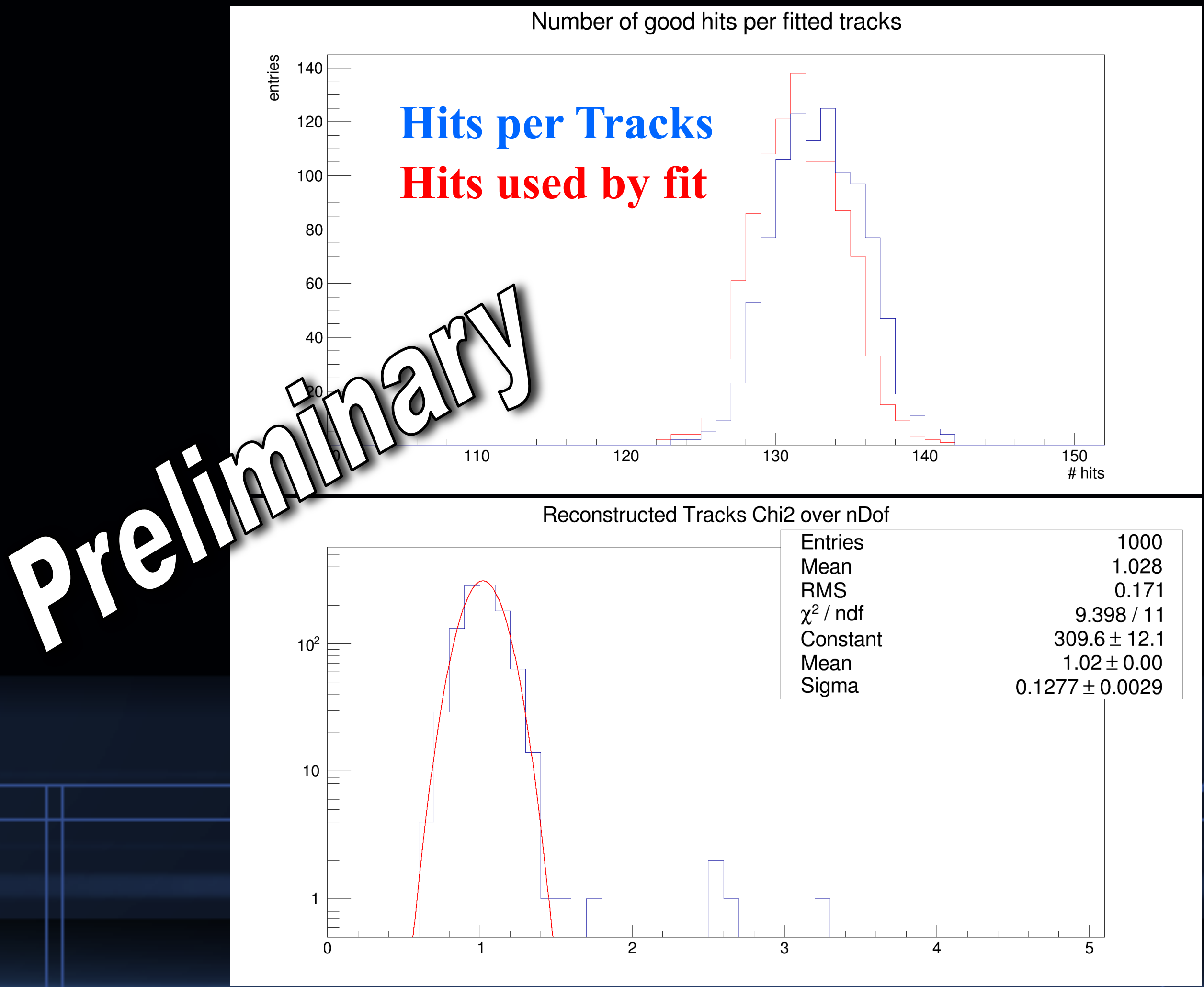
Drift Chamber Hit Creation

- **Common steps:**
  - reject the ionizations acts releasing <10 eV or having a G4Step length <5μm;
  - assign the G4Step to the corresponding drift cell (resolve some geometric equations);
  - evaluate the Distance of Closest Approach for each track crossing a cell;
  - convert the DCA in time, smear it with the resolution (converted in time) and sum it to the signal propagation time along the wire and to the particle time of flight;
  - time order all the obtained hit times within a cell.
- **Simple model for hit creation:**
  - use constant drift velocity (ex. 2 cm/μs), B field effect neglected;
  - use spatial resolution, gaussian and constant through the drift cell, (~ 120μm);
  - group together the hits with a time difference shorter than the maximum cell drift time;
  - evaluate the expected number of clusters;
  - create the hit needed by the reconstruction;
- **Detailed model:**
  - use a realistic distance-to-time relation obtained from experimental data;
  - simulate properly the ionization cluster generation and the signal waveforms;
  - analyze the waveform and extract the impact parameter, dN/dx and dE/dx.

Drift Chamber Single tracks

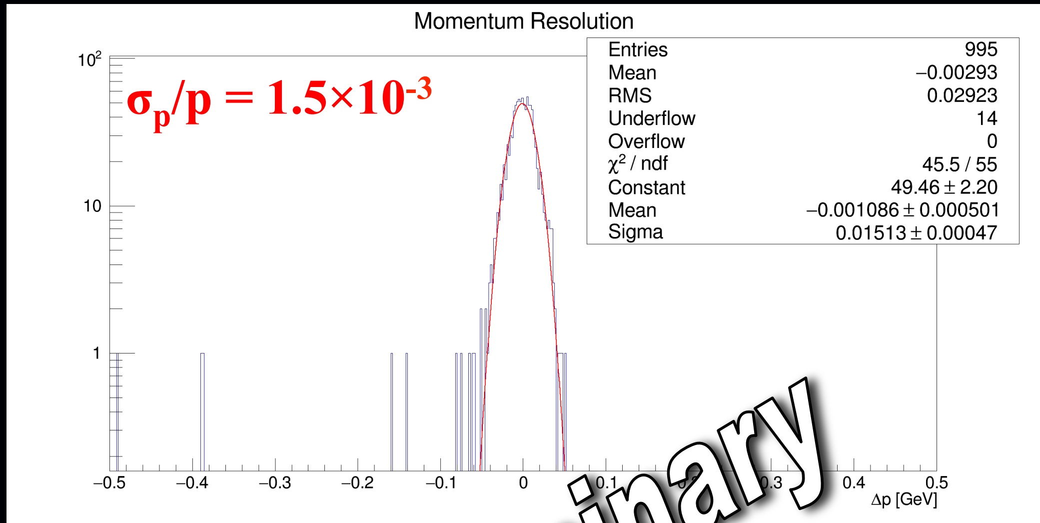
Simulated 1000 Event of e- tracks with ϑ=45° and p=1, 10, 20, 50, 100 GeV

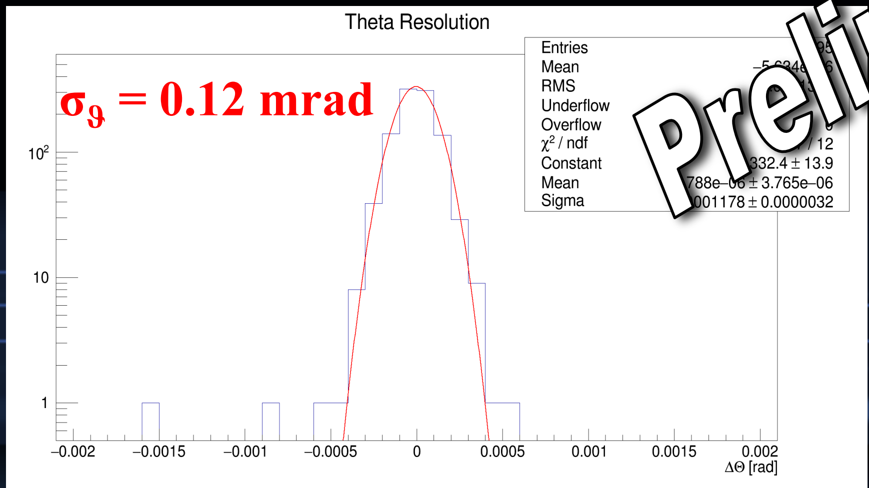
Some distribution at 10 GeV:

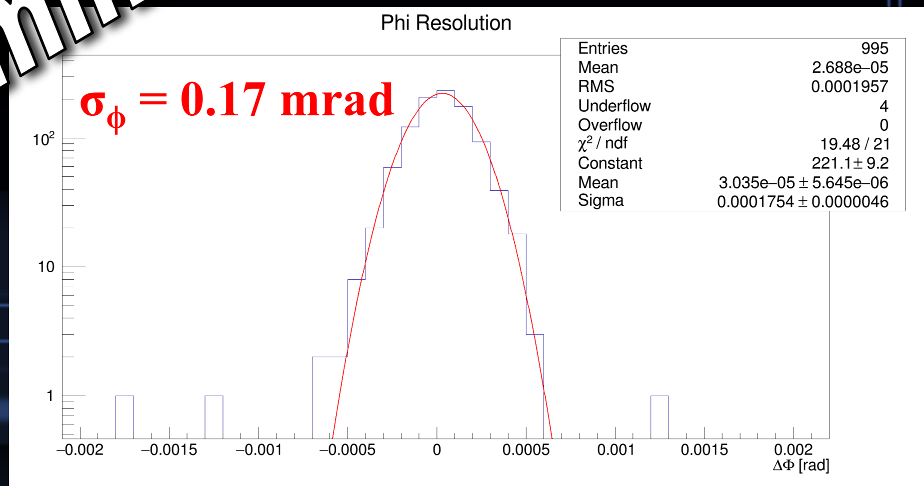


Drift Chamber Single tracks

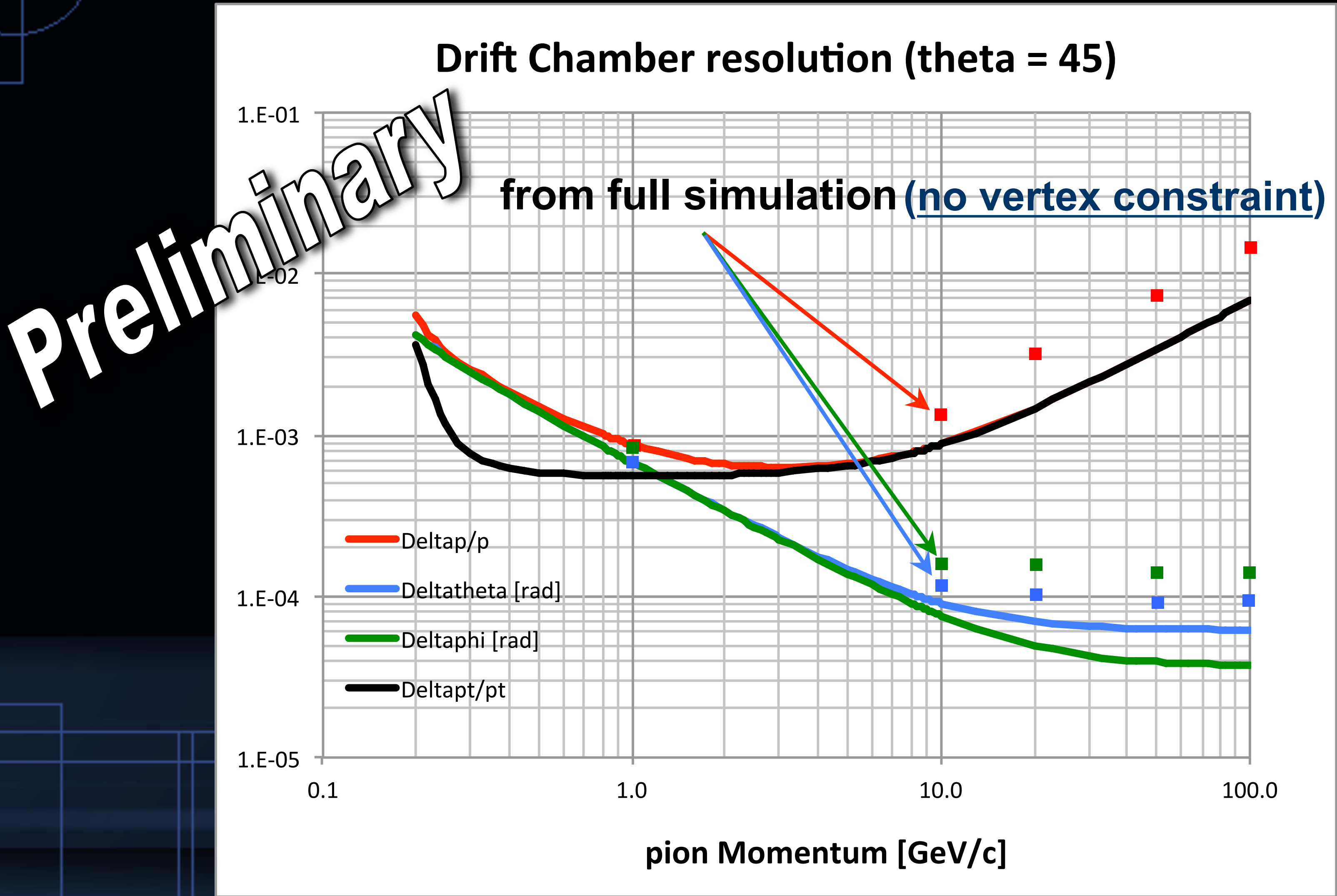
Some distribution at 10 GeV:







Drift Chamber Single tracks



Simulation: to be done

- **Detailed model for hit creation:**
  - introduce empirical distance-to-time relations as functions of gas gain (V_0);
  - simulate properly the cluster generation along the ionizing track and produce the digitized signal waveforms;
  - analyze the signal waveform to extract, within the hit cells:
    - unbiased impact parameter,
    - dN_{cl}/dx,
    - dE/dx.
- **Optimize track finding and fit to the momentum range**
- **Embed the Drift Chamber simulation package in the same framework as Vertex, (Pre-shower), Dual Readout and Muons**
- **Simulate and analyze bench mark events**

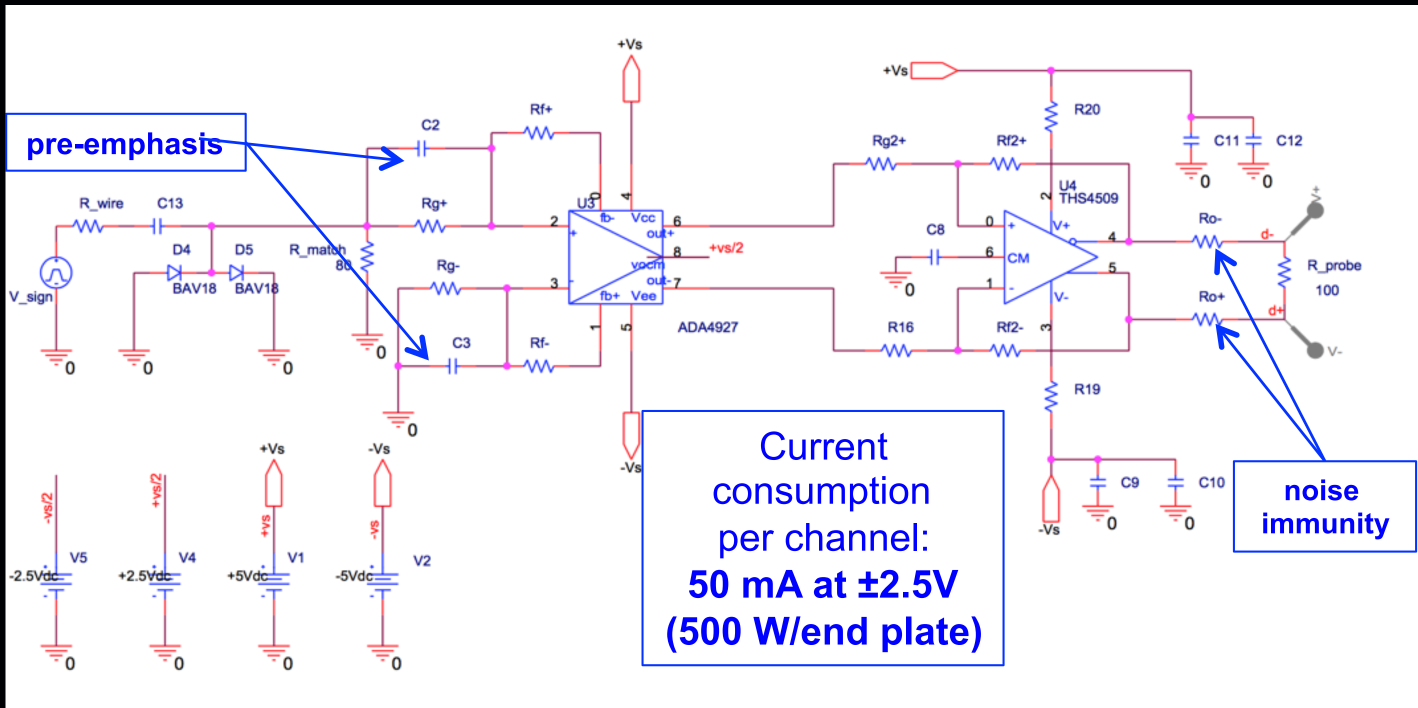
Conclusions

We have presented a proposal of a drift chamber, which can be built with technology available today:

- very low material budget
- good momentum and angular resolutions
- excellent particle identification capabilities
- well established construction techniques (MEG2)
- front end and DAQ for cluster counting/timing designed and prototyped
- well advanced simulation package
- track finding and fitting algorithms defined

Prototype (60 cm, 144 cells) under test beam next fall at PSI
Commissioning of MEG2 drift chamber next winter at PSI

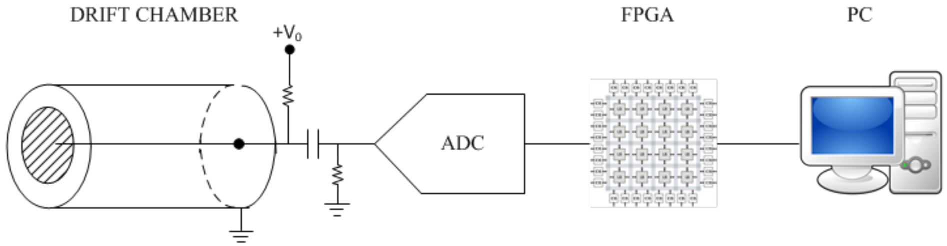
Drift Chamber pre-amp (MEG2)



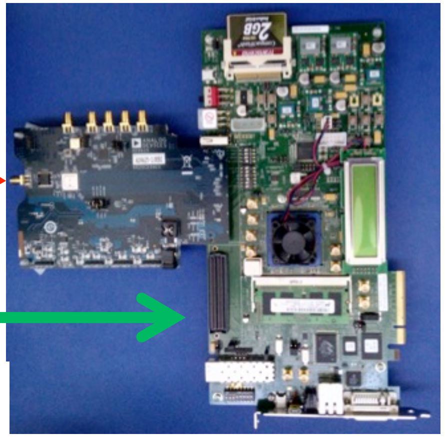
Op-amp **ADA4927** first gain stage: low noise, ultralow distortion, high speed, current feedback differential amplifier achieving wide bandwidth, low distortion, and low noise (1.3 nV/√Hz) and low power consumption.

THS4509 second gain stage and output driver: wideband, fully differential op- amp, very low noise (1.9 nV/√Hz), extremely low distortion, ideal for pulsed applications.

Drift Chamber Readout



ANALOG DEVICES
AD9625-2.0EBZ



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