IDEA
Drift Chamber
Status and Future Plans

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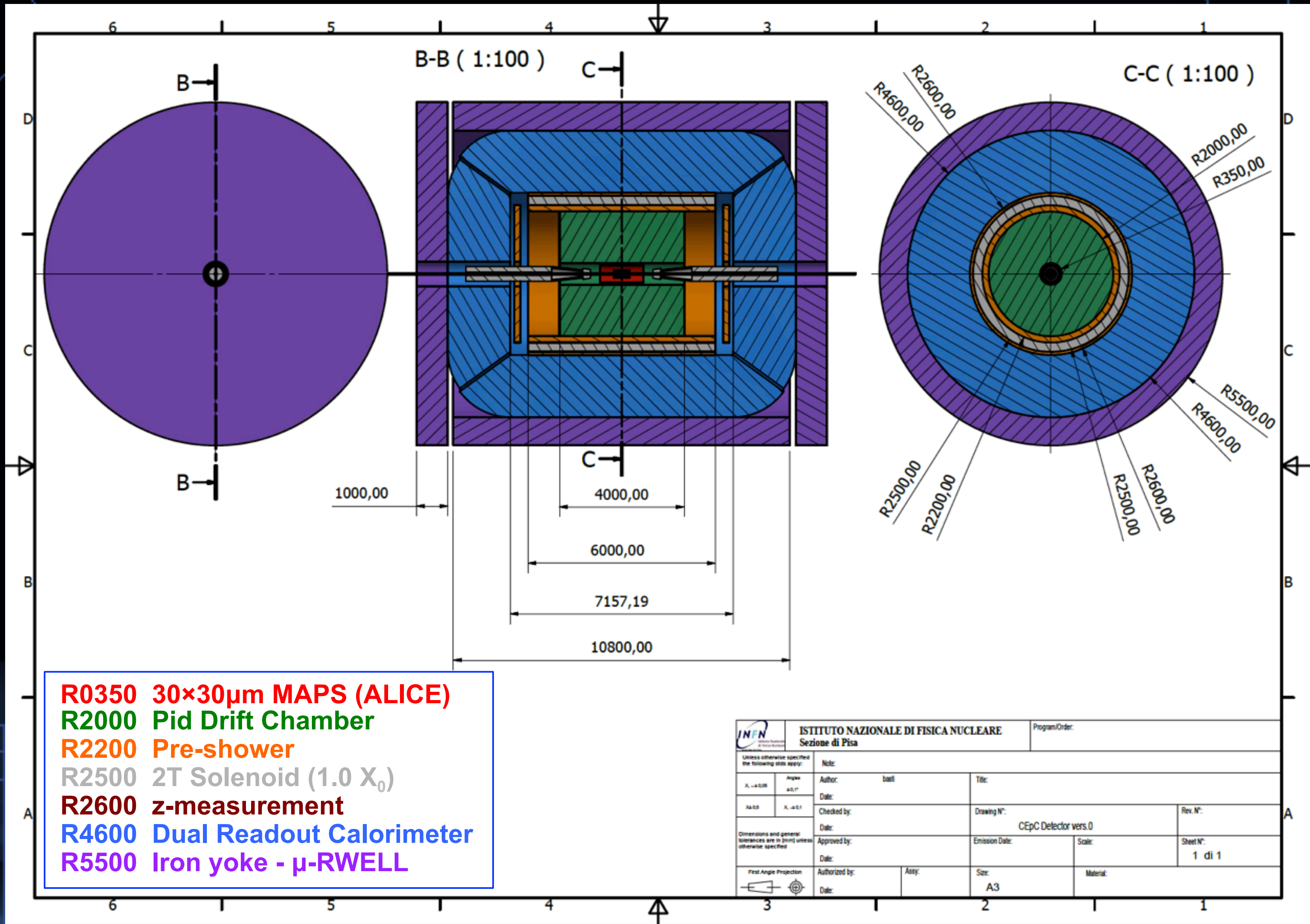
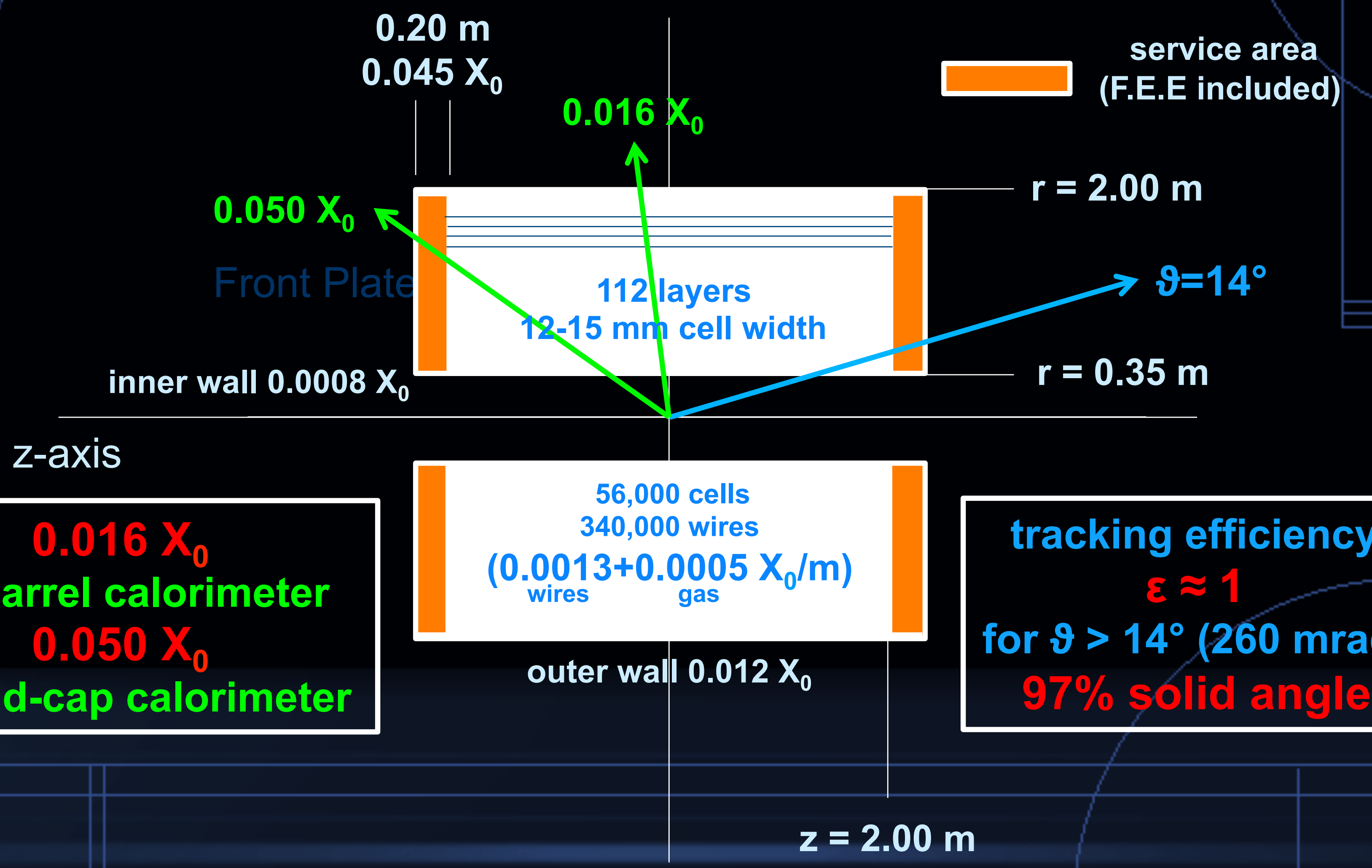
INFN – Lecce

RD_FA Collaboration Meeting – Bologna, July 3, 2017

IDEA Detector scketch



Drift Chamber



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

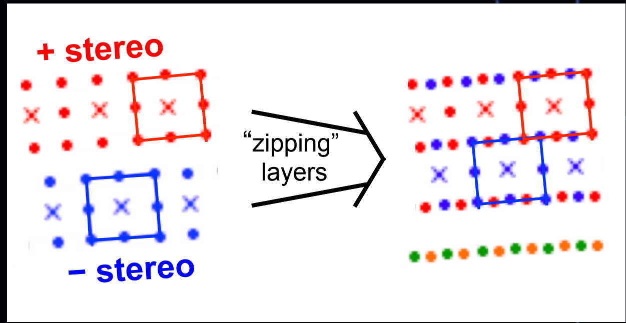
tracking efficiency
$\varepsilon \approx 1$
for ϑ > 14° (260 mrad)
97% solid angle

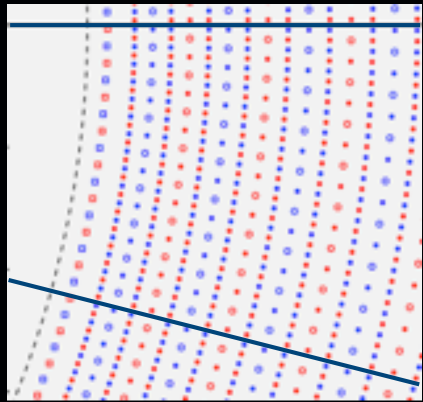
Drift Chamber Layout

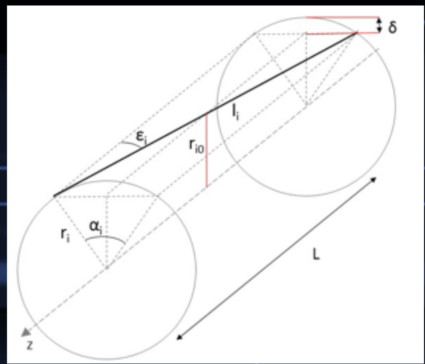
- 12÷15 mm wide square cells
  5 : 1 field to sense wires ratio
  56,448 cells

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

- alternating sign stereo angles
  ranging from 50 to 250 mrad

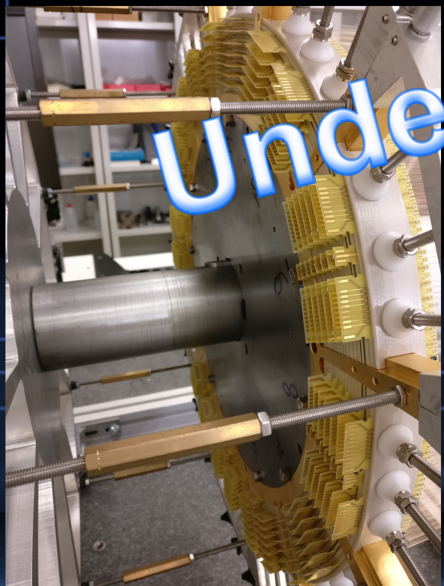


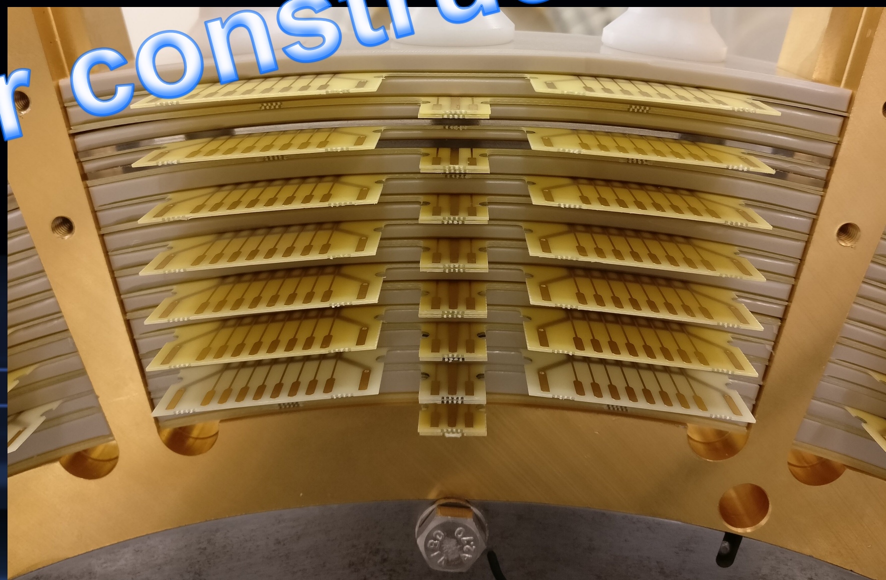


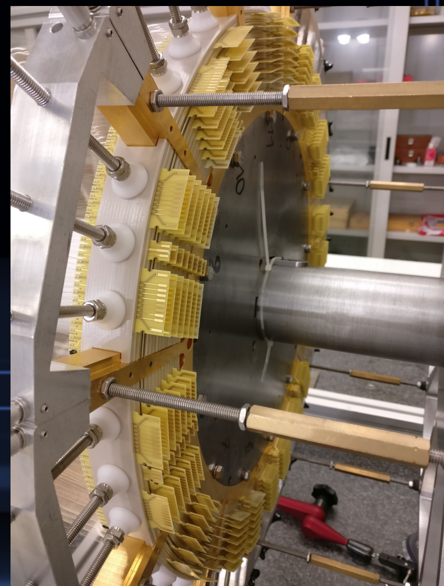


MEG2 Drift Chamber

Under construction at INFN







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

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

MEG2 drift chamber: *L = 2 m, W = 7 mm*

T ≥ 0.12 N

(MEG2 wires are strung at ***T = 0.25 N***)

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

$$T \geq 0.16N$$ or, for ***T = 0.25 N***, $$L \leq 4.9m$$

Drift Chamber Material Budget

Conservative estimates:

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

Drift Chamber Resolution

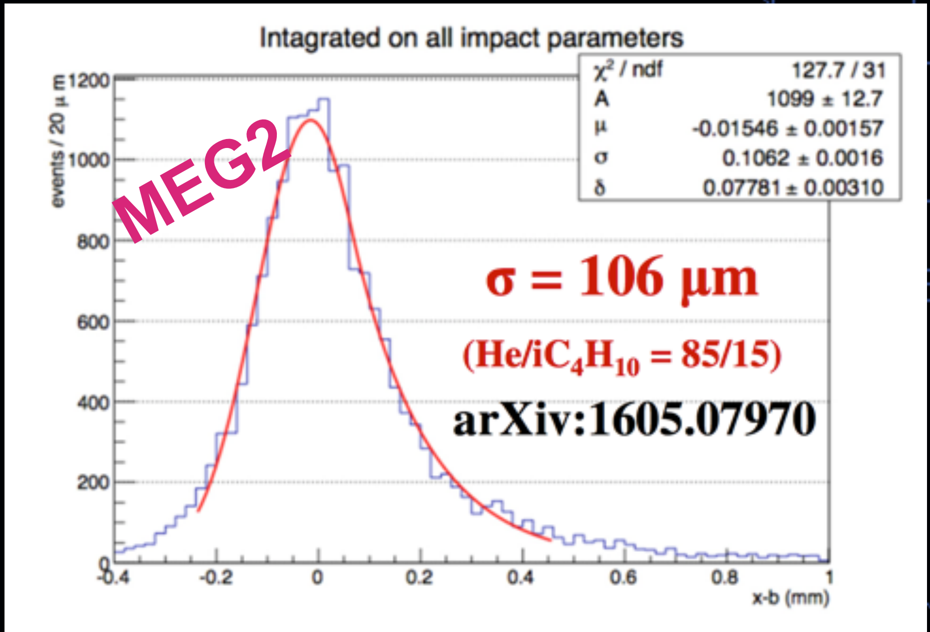
Transverse Momentum Resolution

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

Angular Resolutions

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

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



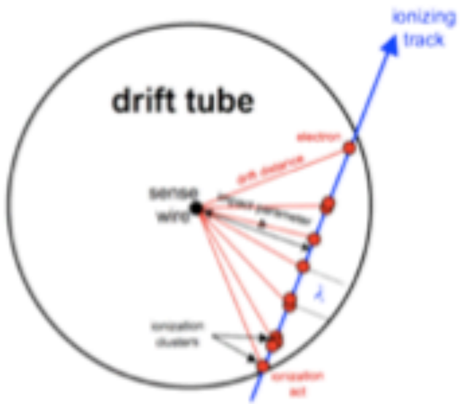
no cluster timing, 7x7 mm²

Momentum Resolution

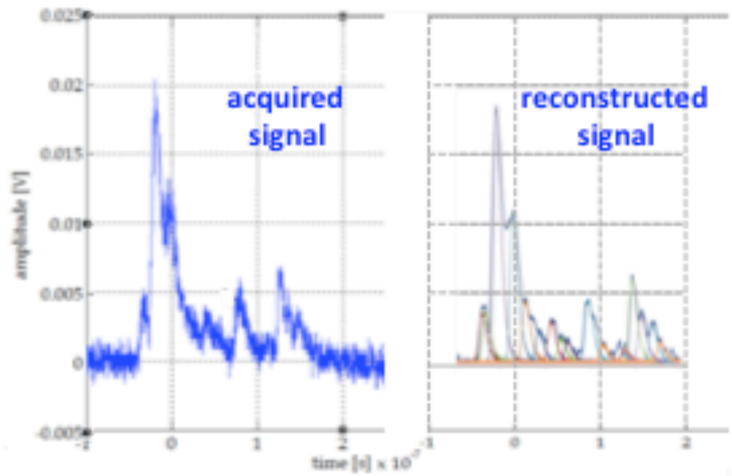
$$\frac{\Delta p}{p} = \frac{\Delta p_t}{p_t} \oplus \frac{\Delta\theta}{\tan\theta}$$

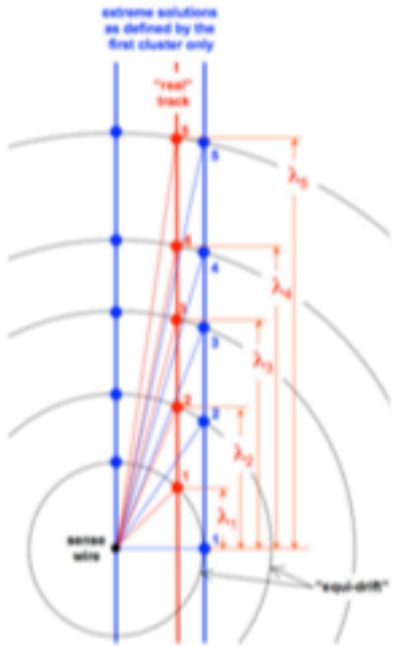
12x12 mm² -> 95 μm
cluster timing -> -20%
IDEA expected -> 75 μm

Drift Chamber Cluster Timing

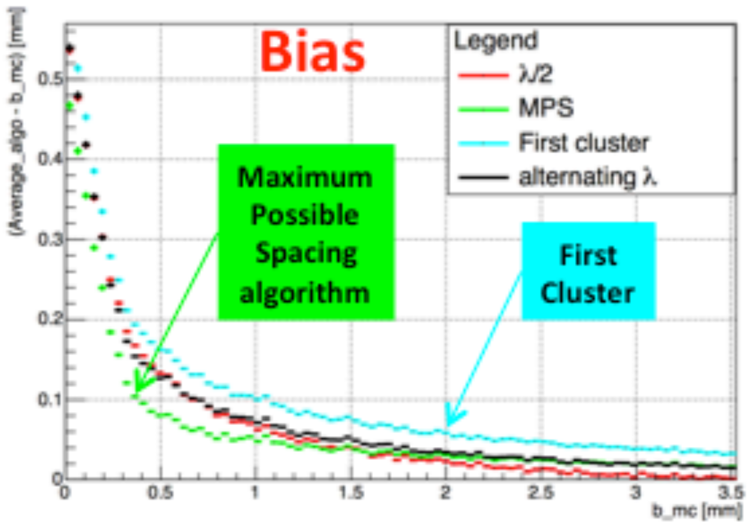


From the **ordered sequence of the electrons arrival times**, considering the average time separation between clusters and their time spread due to diffusion, **reconstruct the most probable sequence of clusters drift times:** $\{t_i^{cl}\} \quad i = 1, N_{cl}$



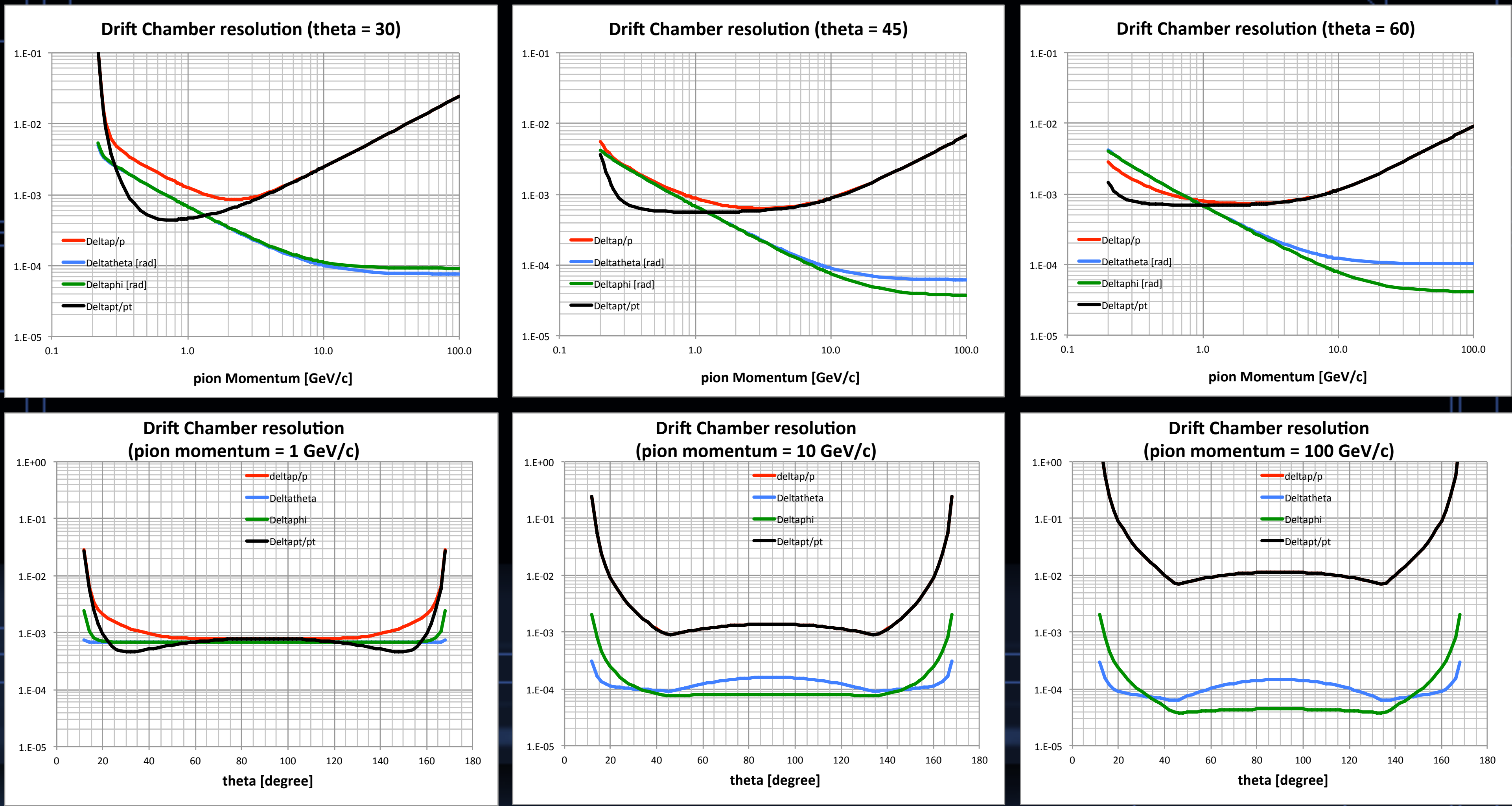


For any given first cluster (**FC**) drift time, the **cluster timing technique** exploits the drift time distribution of all successive clusters $\{t_i^{cl}\}$ to determine the most probable impact parameter, thus reducing the **bias** and the average **drift distance resolution** with respect to those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



Drift Chamber Resolution

σ_{xy}=100µm, σ_z=750µm, N=112, B=2T, R_{out}=2m, $L/X_0=2.5\times10^{-3}$



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 $\mathbf{N_{cl}^{-1/2}}$.

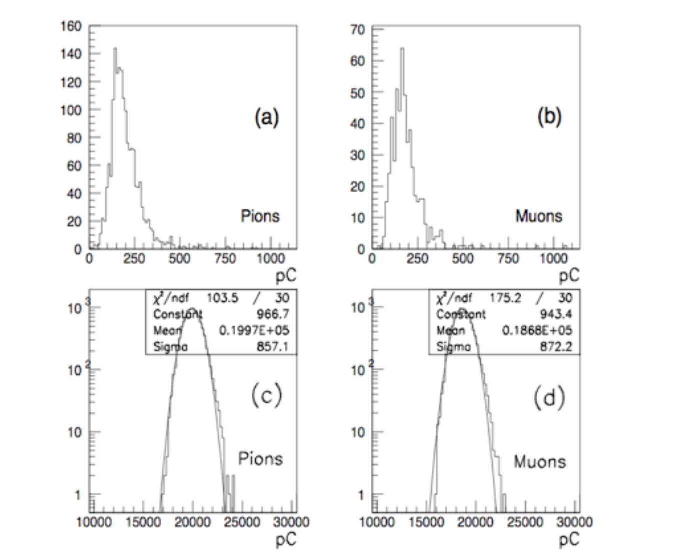
The data shown refer to a beam of **μ and π at 200 MeV/c**, taken with a gas mixture **He/iC_4H_{10}=95/5**, **δ_{cl} = 9/cm**, **100 samples**, **2.6cm** each **at 45°** (for a **total track length of 3.7 m**, corresponding to **N_{cl} = 3340**, **$1/\sqrt{N_{cl}}$ = 1.7%**).

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 Cluster Counting



dE/dx

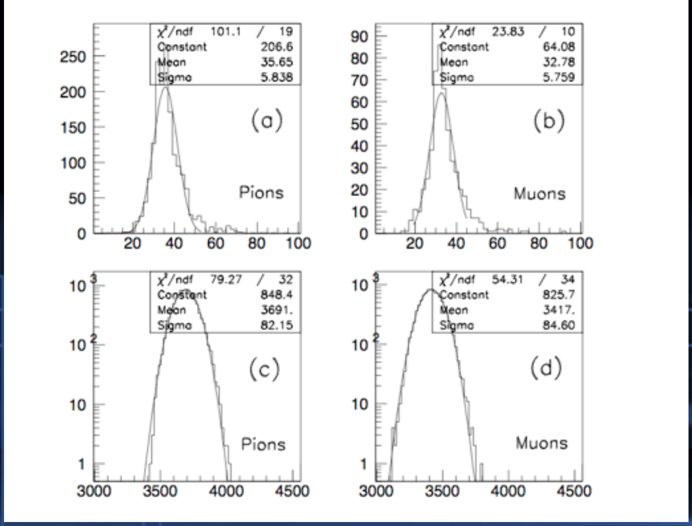
100 samples 3.7 cm
($\sigma[\%]=40.7\ n^{-0.43}\ L[m]^{-0.32}$)
σ = 3.7%
≈ 2.0σ separation

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.

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

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%**

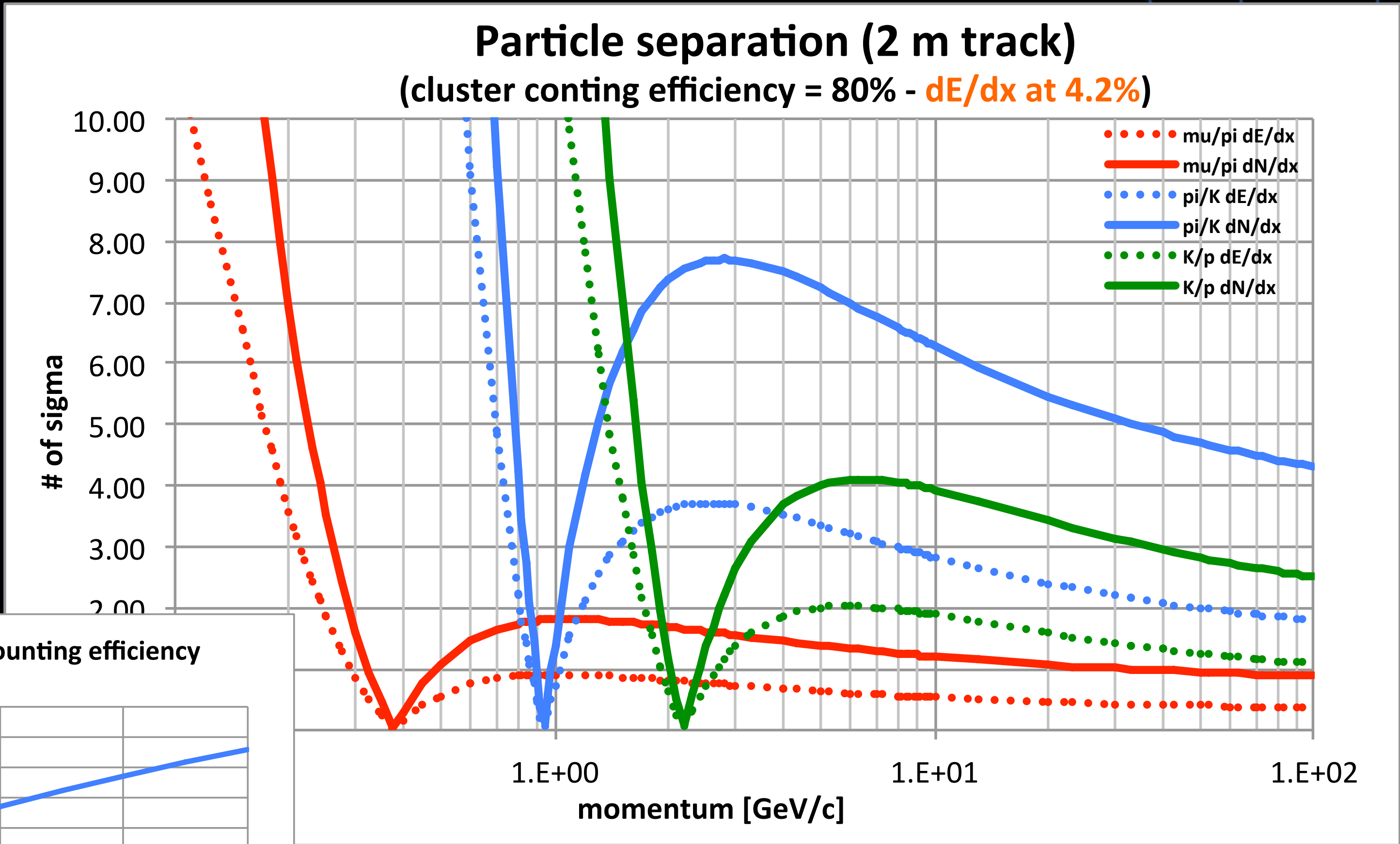
Increasing ***P*** to 2 atm improves resolution by 20% (σ ≈3.4%) but at a considerable cost of multiple scattering contribution to momentum and angular resolutions.

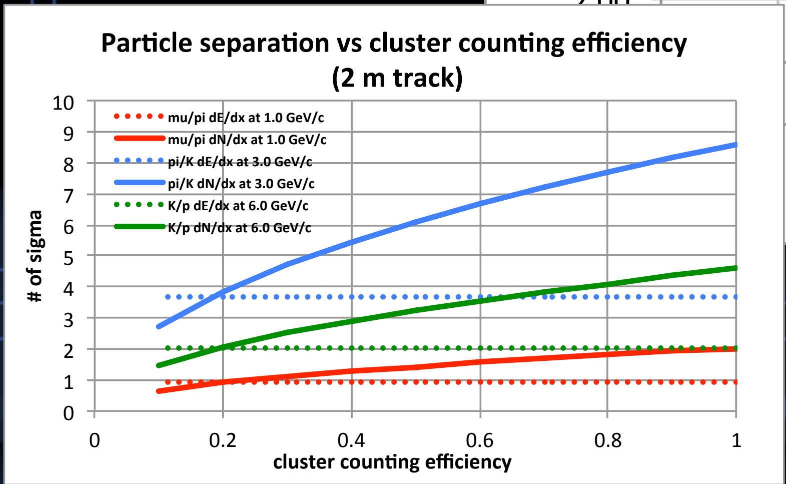
dN_{cl}/dx

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.





Drift Chamber Simulation and Preliminary performance plots

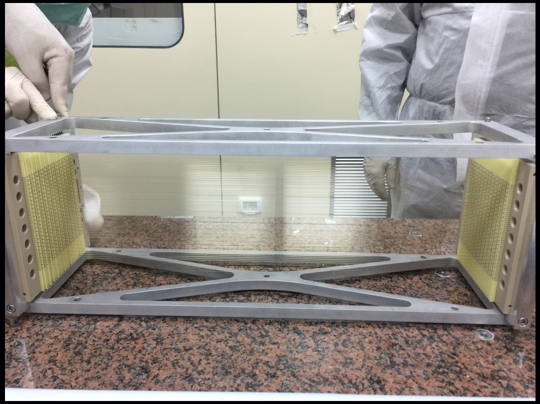
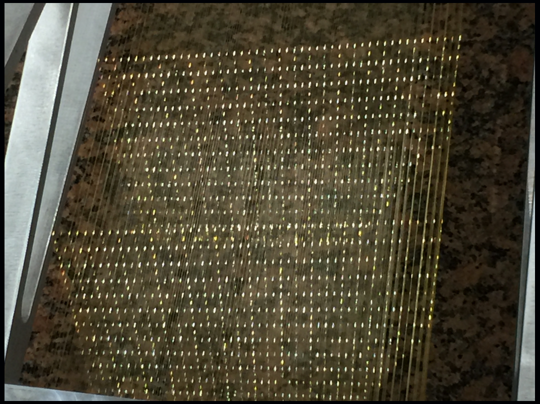
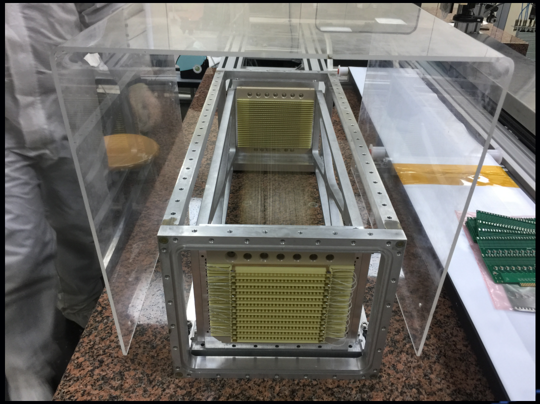
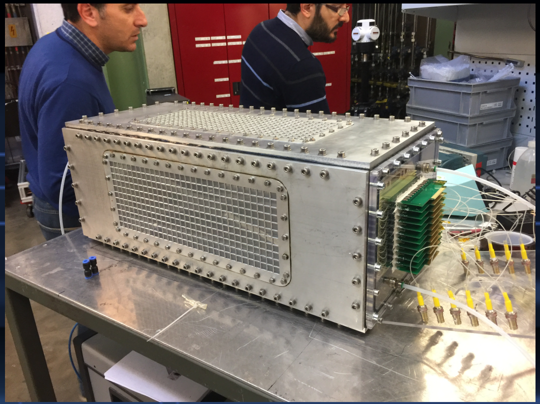
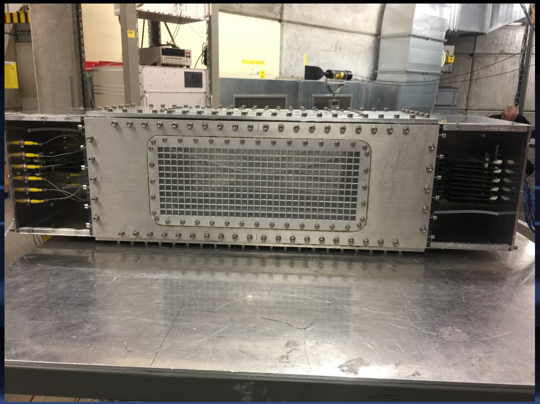
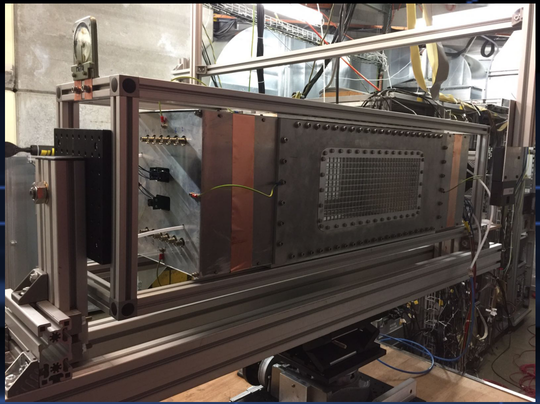
see next talk by Gianfranco Tassielli.

Medium term plans: Simulations

- **Layout optimization**
  - study occupancy with beam related backgrounds;
  - define optimal cell size (as function of radius?) (max drift time for pile up at highest $\mathcal{L}$);
  - maximize resolutions (both spatial and particle id. – gas and gain).
- **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 and dE/dx.
- **Optimization of track finding and fit to the momentum ranges**
- **Embedding the Drift Chamber simulation package in FCCSW and Mokka (CepC) frameworks as well as Vertex, Pre-shower, Dual Readout and Muons**
- **Simulation and analysis of bench mark physics events**

Short term plans: Hardware 1

- **Beam test at PSI (two weeks in September)**
  - in conjunction with MEG2 and FIRB (Renga-Tassielli)
  - **cluster timing** for spatial resolution (impact parameter bias)
  - **cluster counting** for particle identification (e/μ/π 100÷400 MeV/c)

Medium term plans: Hardware 2

- **Studies on different wire materials**

  suppose occupancy impose inner layer cell size be reduced from W = 12 mm to 7 mm
  stability condition requires **T ≥ 0.47 N (1500 MPa):** above W wire YS!
  Solutions:

  $$\delta = \frac{\pi r^2 \rho}{8}\left(\frac{g}{T}\right)L^2$$

  - shorten wire length for inner layers from L = 4 m to 2.3 m ⟹ **loss of solid angle**
  - increase wire radius R = 20 μm to 35 μm ⟹ **increment of X_0, grav. sag., end plate tension**
  - **find new materials: higher YS and lower density** ⟹ **reduction of X_0, grav sag, ep tension**

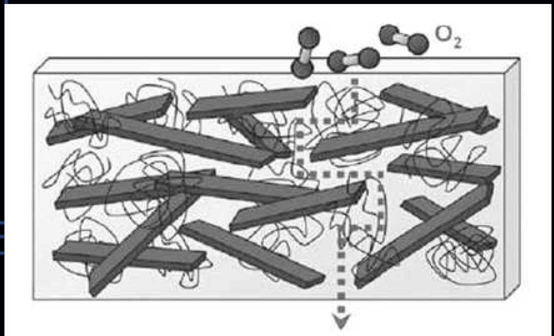
wire material	W	Mo	Ti	Al	C
δ [g/cm^3]	19.3	10.2	4.5	2.7	2.2
X_0 [cm]	0.35	0.96	3.6	8.9	19.3
X_0 [g/cm^2]	6.8	9.8	16.2	24.0	42.7
Y.S. [MPa]	1500	550	800	240	6000

wire coating	Au	Ag	Sn	Cr
δ [g/cm^3]	19.3	10.5	7.2	7.2
X_0 [cm]	0.33	0.85	1.2	2.1
X_0 [g/cm^2]	6.5	9.0	8.8	14.9

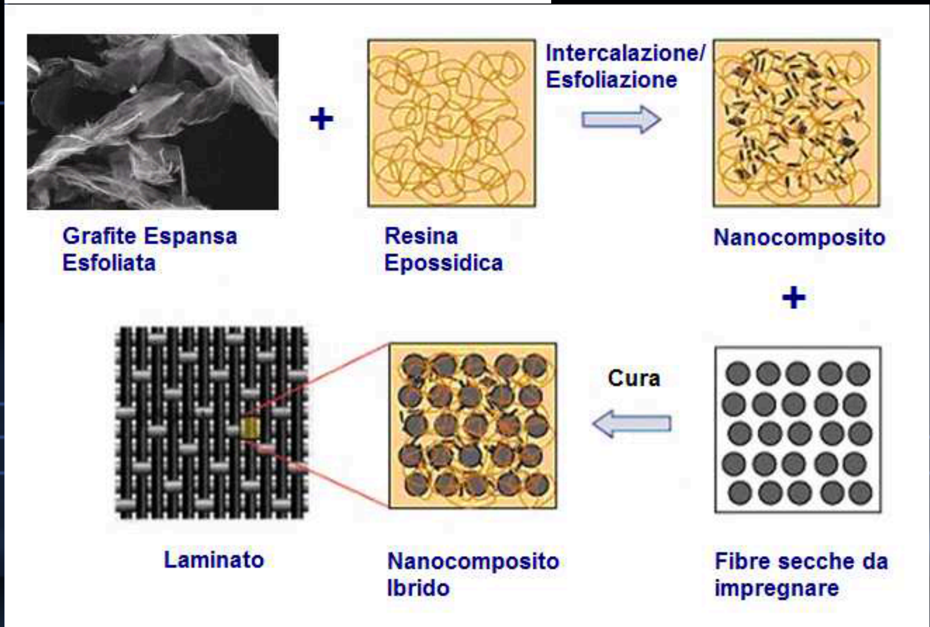
- Large diameters C wires can be obtained with bundled 6-8 μm filaments (tow) – **to be studied**
- C wires cannot be crimped (transverse fragility) or soldered, unless metal coated
- Metal coating processes **to be studied** (need at least 2 μm skin depth for 1-2 GHz bandwidth, depending on metal)

Medium term plans: Hardware 3

- **High transparency Mechanics: new materials**



I **nanocompositi grafene-polimero** riducono la **permeabilità ai gas** grazie all'elevato rapporto di forma delle lamelle, alla loro orientazione e alla frazione volumetrica di grafene, aumentando la tortuosità del cammino delle molecole di gas nella loro diffusione attraverso il polimero (modello di Nielsen).
Inoltre, grazie alle proprietà del grafene, aumentano la conducibilità elettrica e, quindi, lo **schermaggio elettrostatico e a radiofrequenza**, limitando, così, gli spessori di eventuali rivestimenti metallici.



Graphene Properties:

Young modulus ≈ 1100 GPa
Breaking strength ≈ 130 GPa
Thermal conductivity > 2500 W/m·K
Electrical conductivity ≈ 10^6 S/m

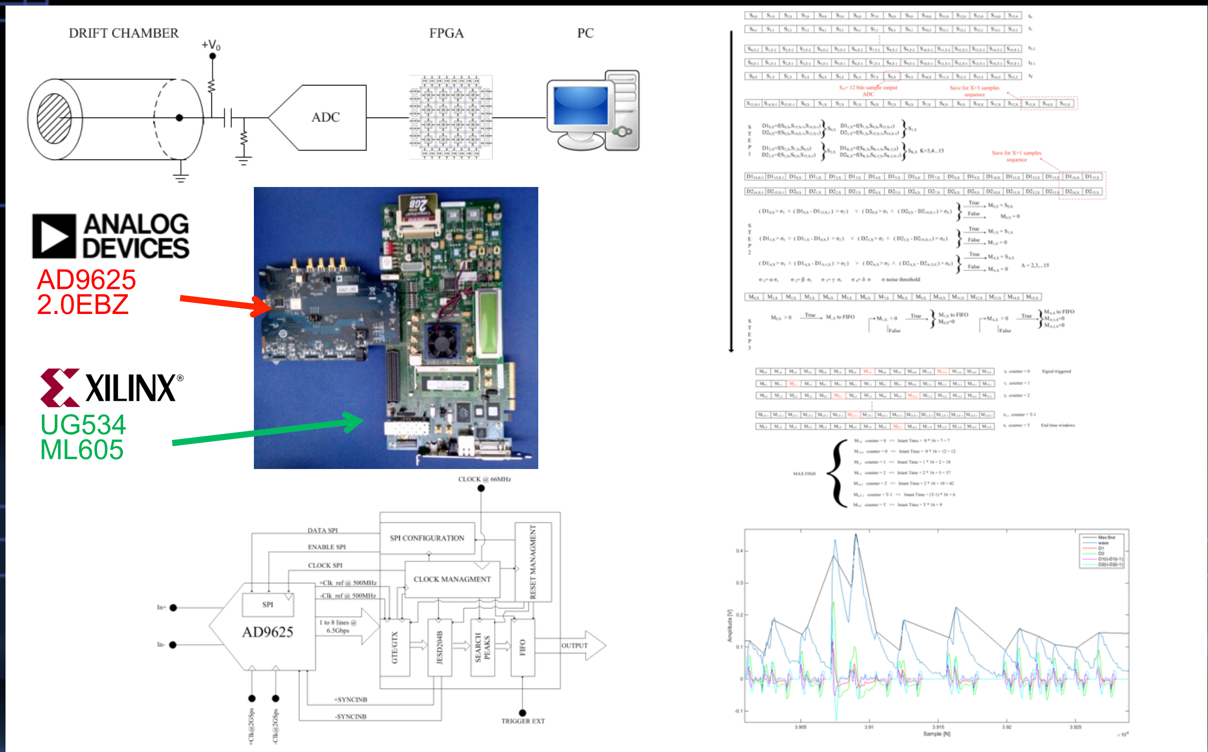
da A. L'Erario
Definizione e caratterizzazione dei materiali costituenti rivelatori traccianti ad alta trasparenza, 2014, Tesi di Dottorato in Ingegneria dei Materiali e delle Strutture. Università del Salento, Lecce.

Medium term plans: Hardware 4

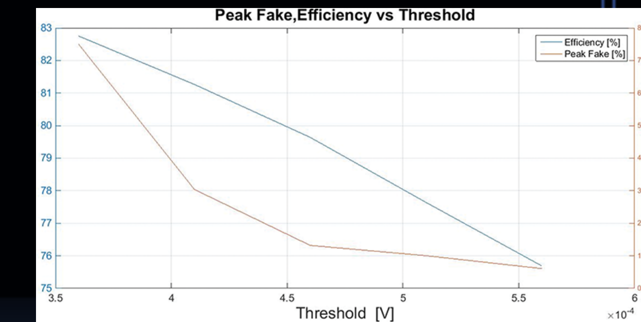
- **Readout of digitized waveforms**

suppose a trigger rate of 10 kHz, an average occupancy of 10% over the 56,000 drift cells, a maximum drift time of 500 ns readout at 2 GSa/s => **500 GB/s ! (<u>unsustainable</u>!)**

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 (<u>manageable</u>!)**



Proof of principle demonstrated for one FPGA per single channel on evaluation boards.



Need to implement it on a multi-ch board with a single FPGA.

"Field - Programmable Gate Array," ISBN 978-953-51-3208-0
http://www.intechopen.com/articles/show/title/the-use-of-fpga-in-drift-chambers-for-high-energy-physics-experiments

Long term plans: Hardware

- Beam test of MEG2 prototype at CERN (π/K separation, 2T B field?)
- Full length prototype (≥ 4 m, few (25?) cells, C (?) wires)
  - test electrostatic stability
  - cosmic ray tests
  - longitudinal coord. measurement
- Optimization of mechanical design
  - choice of materials for the helm shaped spokes of the end plates (a la MEG2)
  - wire PCB dimensions (kapton boards instead of G-10?)
  - materials for spacers (3D printed?)
- Front-end electronics (pre-amp, digitizer, DAQ)
- HV distribution
- Gas system
- FCCee CDR (next summer?)

Summary 1

The proposal of the drift chamber for the detector IDEA at future circular e^+e^- colliders (FCCee, CepC), can be built today with present technologies.

Status:

- basic design based on KLOE and MEG2 drift chambers completed
- full simulation of drift chamber satisfactorily done
- momentum and angular resolutions according to the requirements
- excellent particle identification capabilities
- front end and DAQ for cluster counting/timing designed and prototyped
- well established construction techniques (MEG2)

Summary 2

Future Plans:

- cell/layer layout optimization (occupancy, pile up)
- detailed model of hit creation (simulations)
- track finding and fitting algorithms to be adapted to the different momentum range
- beam test of the MEG2/FIRB prototype to assess cluster counting/timing performance next fall at PSI
- studies on different wire materials
- new materials for higher transparency mechanics
- readout and data reduction of multi-channels boards
- beam test of MEG2/FIRB prototype at CERN (π/K sep. 2T B field)
- optimization of mechanical design
- commissioning of MEG2 drift chamber during first half of 2018

today **tomorrow** **the day after tomorrow**