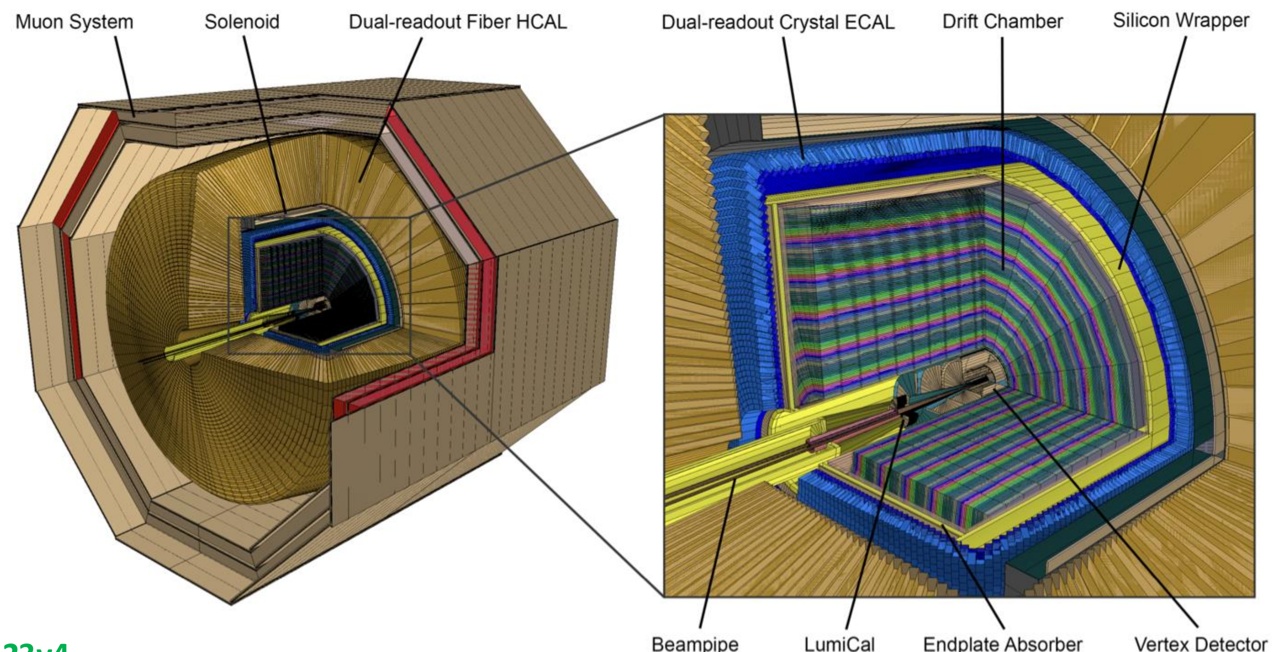
Progress on the Drift Chamber R&D for the IDEA detector concept at FCC-ee

M. Primavera, INFN-Lecce
On behalf of the IDEA DCH community

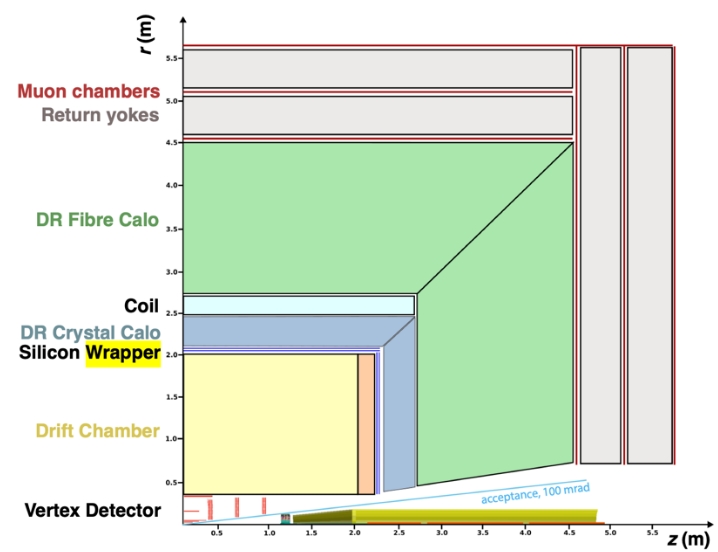
The 7th International Workshop on Future Tau Charm Facilities
Huangshan, 23-27 November 2025

The IDEA detector concept at FCC-ee

IDEA → Innovative Detector for E^+e^- Accelerator:



arXiv:2502.21223v4



- High resolution silicon pixel **Vertex** detector
- Large-volume and extremely low-mass **Drift Chamber …**
- … surrounded by a **wrapper** made of silicon sensors
- A finely segmented, **dual-readout crystal** electromagnetic calorimeter
- An ultra-thin, low-mass **superconducting solenoid**
- A **dual-readout fiber** hadronic calorimeter
- A muon detection system based on **µ-Rwell** detectors

Main features and new concepts of DCH design

IDEA DCH (INTREPID: INner TRacker Equipped with Particle IDentification) designed to provide:

- *efficient tracking, high precision momentum measurement and excellent particle identification* for particles of (relatively) low and medium momenta

Main features:

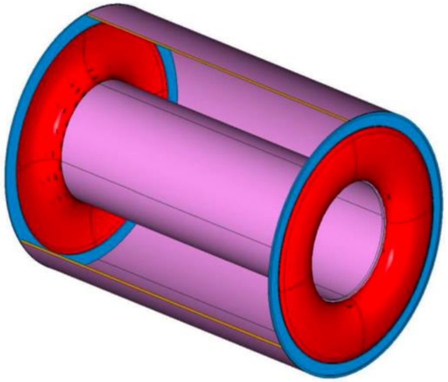
- *High granularity , Transparency, Particle Identification capability*

New concepts:

- *Thin wires+separation gas envelope/wire supporting structure ("feed-through-less" wiring)* → increase chamber granularity but reducing material, multiple scattering and total tension on end plates
- *Wire tension compensation system* to limit the structure deformations along the chamber axis
- Use of *Cluster Counting/Timing* for Pid/to improve spatial resolution

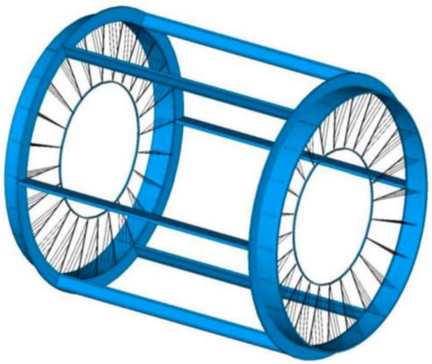
Gas containment

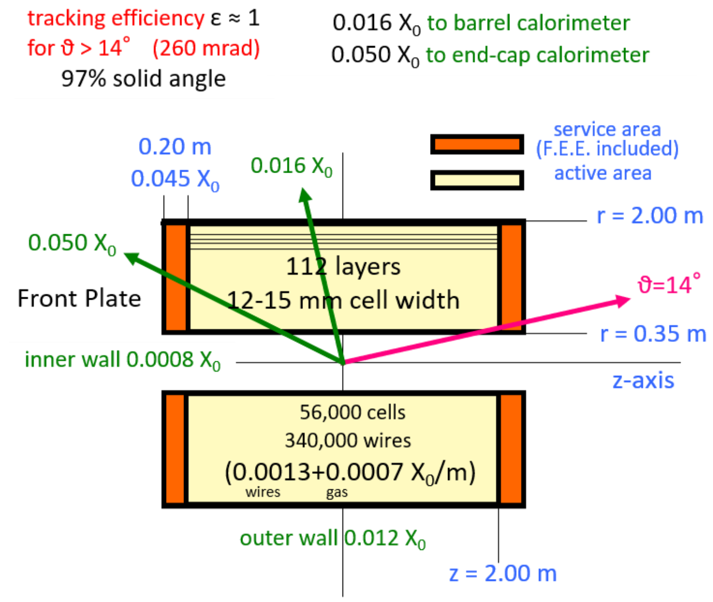
Gas vessel can freely deform → no impact on the internal wire position and mechanical tension.



Wire cage

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



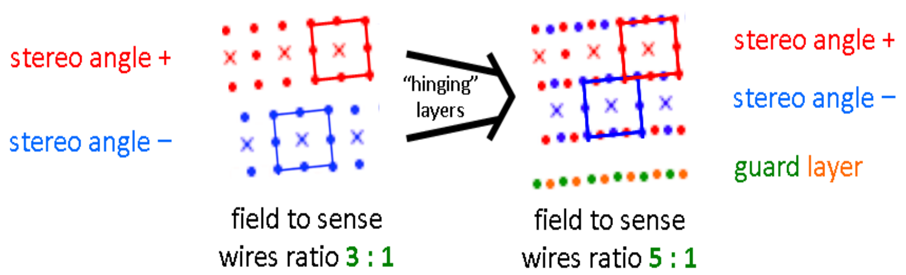


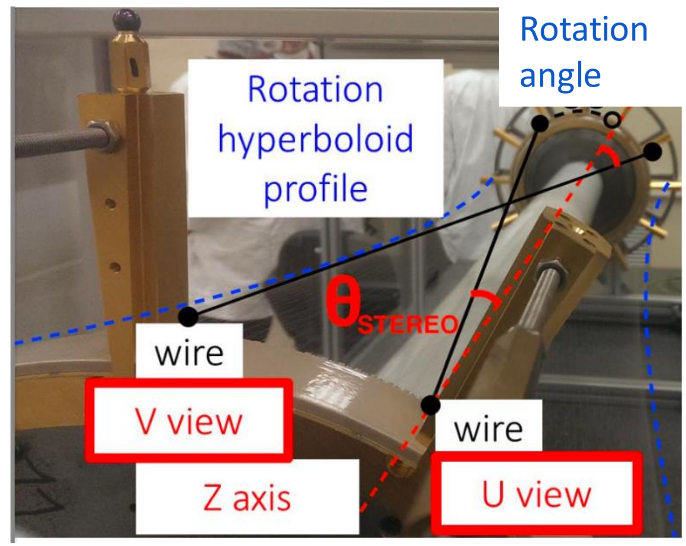
The IDEA DCH

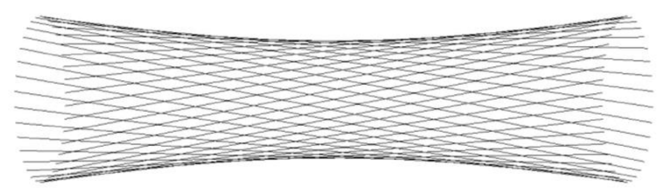
- Large volume: R_{in} = 0.35 m, R_{out} = 2 m, L = 4 m, Inner wall = 200 μm thick Carbon fiber, Outer wall = 2cm thick composite material sandwich
- Operating gas: He 90% - iC_4H_{10} 10%
- Full stereo: **112 co-axial layers**, arranged in 14 super-layers and in 24 (15°) identical azimuthal sectors, at alternating-sign stereo angles ranging from 50 to 250 mrad
- Granularity: 12÷14.5 mm (at z=0) wide square cells, 5 : 1 field to sense wires ratio
- drift length < 1 cm, drift time ~350-400 ns
- Expected resolution σ_{xy} ~ 100 μm, σ_z ~ 1 mm
- **56,448 cells and 343968 wires in total:**

sense wires →	20 μm diameter W(Au) =>	56448 wires
(**thin!!**) field wires →	40 μm diameter Al(Ag) =>	229056 wires
Field between sense and guard wires →	50 μm diameter Al(Ag) =>	58464 wires

combination of + and –wire orientation produces a more uniform equipotential surface → better E-field isotropy and smaller E×B asymmetries)

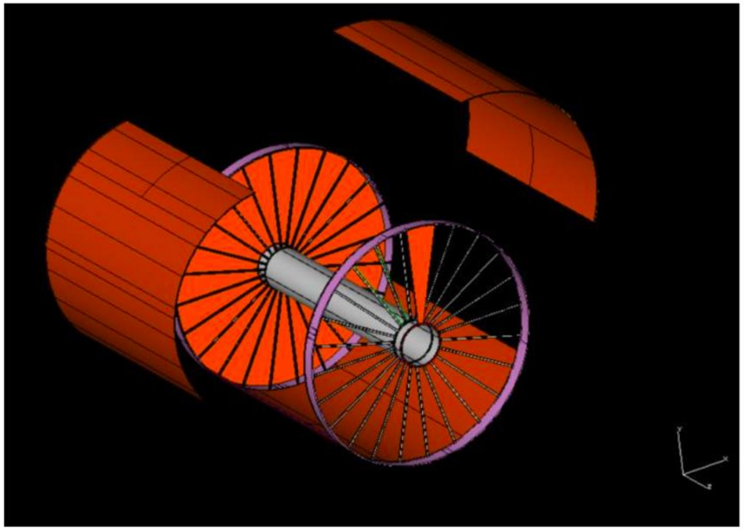




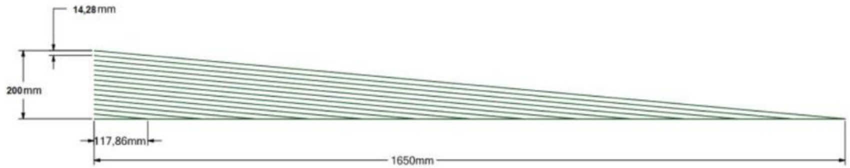


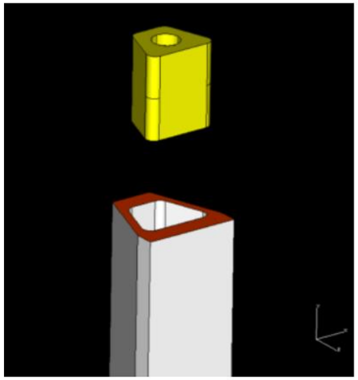
one sector is connected with the first sector next to the corresponding one on the opposite endcap (hyperboloid envelope of stereo wires)

IDEA DCH: mechanical structure/1



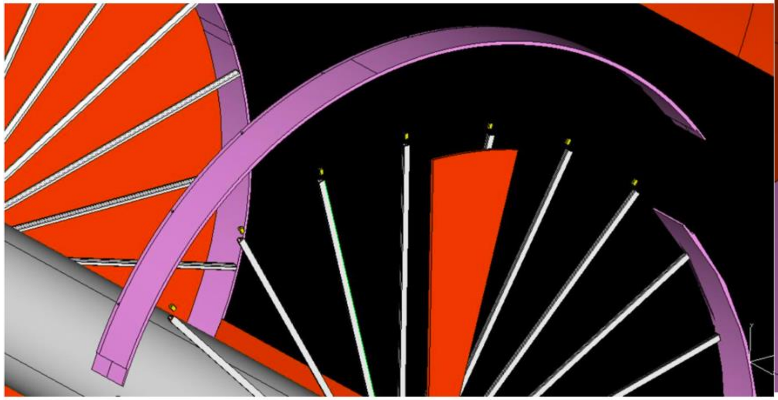
- **Outer cylinder** made of 3 panels **2 cm** thick →3 layers (2 monolithic CF with Al honeycomb structure in the middle)
- **External and internal ring** in monolithic CF
- **Endplates** made of 48 **Spokes** (24 per endcap), defining 24 azimuthal sectors.
- Each **spoke** (length **l = 165cm)** is supported by 15 **Stays.**
- **Inner cylinder** thickness **200 µm** CF – not structural

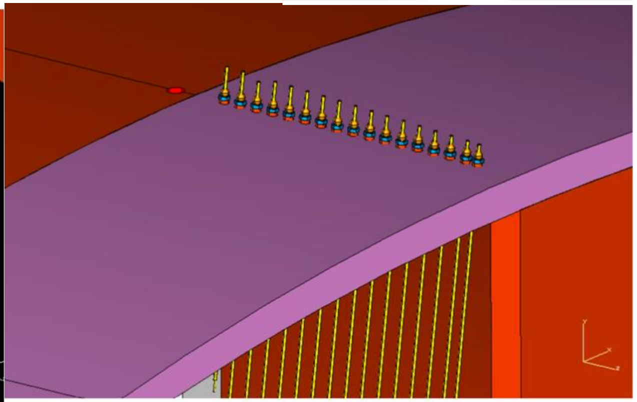




Outer ring/spoke details

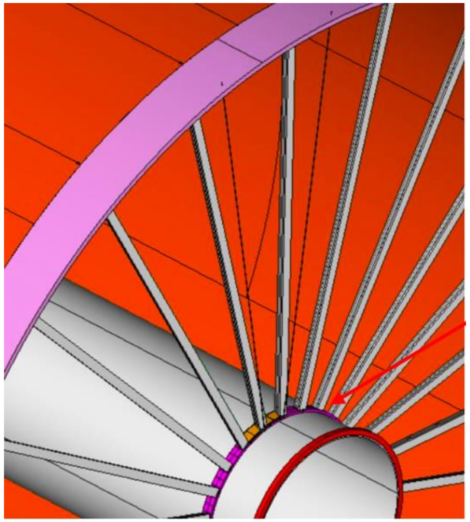
On the outer part the spoke has an internally glued female joint (yellow) which locks the spoke to the outer ring (pink)

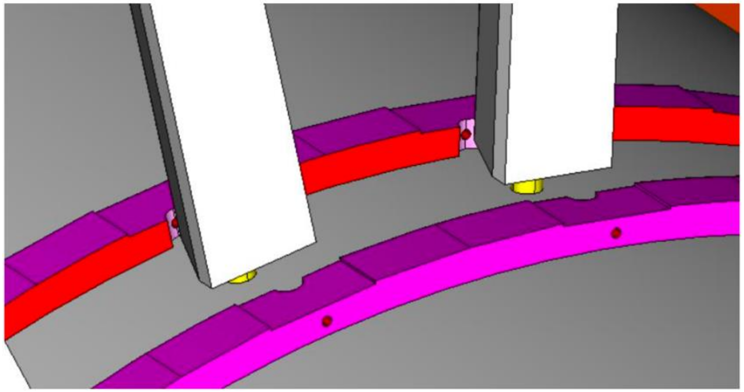


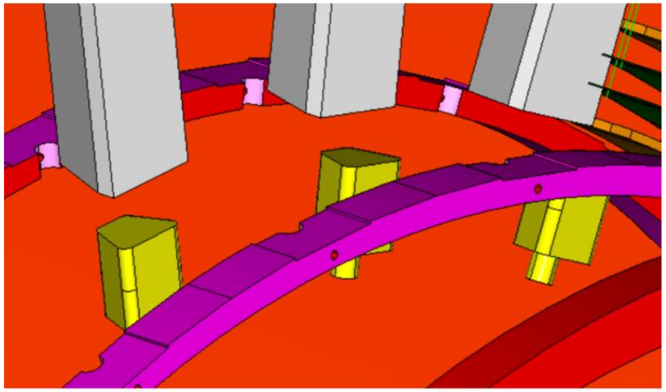


IDEA DCH: mechanical structure/2

Inner ring details

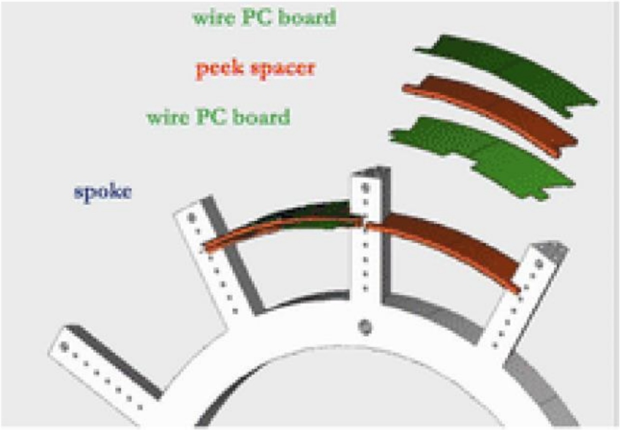






Two interlocking rings (violet) lock the spokes (grey)

Each spoke has an internally glued male joint (yellow) that fits into the rings

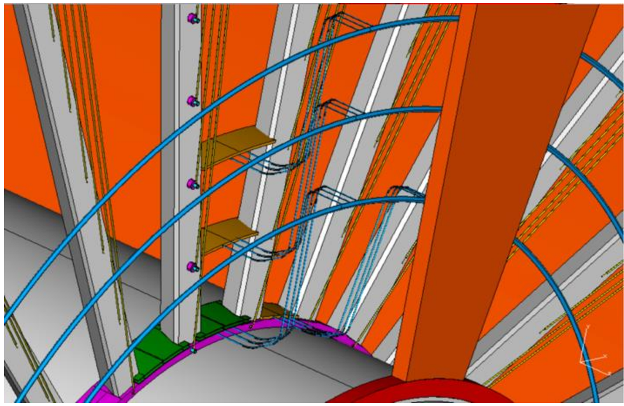


Wires soldered to the PCB

Spacers (red) and PCBs (green) are inserted between the spokes. The spacers have holes for the gas distribution

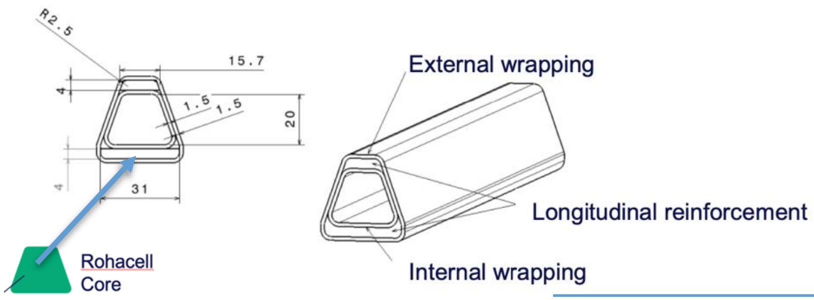
The edge of the PCB acts as a stop on the spoke, providing a reference.

The supporting cables of the spokes are anchored to some spacers appropriately shaped



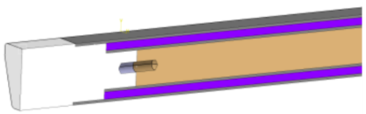
IDEA DCH: mechanical structure/3

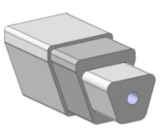
- **FEM analysis:** single endcap simulation → Spokes and cable behaviour under wires pressure
- **Goals:** minimizing the deformation of the spokes using prestressing force in the cables. Limit the deformation of the spokes to **200 μm** while ensuring the structural integrity → few μm error on the sagitta
- Optimization of spoke cross section: investigated different shapes, finally:



Carbon foam core **6x** lighter than aluminum (FOAM ROHACELL® 35 HTC)

- Production of a spoke prototype (50 cm long):
- The core was milled with a numerically controlled machine.
- The winding foils were manually cut into strips of the sizes in figure
- The PEEK side inserts were glued with acrylic adhesive

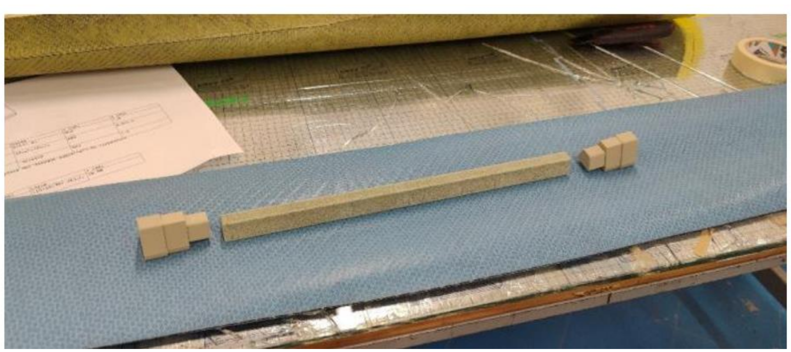




Peek side inserts

Item	Prepreg Tissue	CPT (mm)	Layup	T (mm)
Internal wrapping	430g/m^2	0.5	(0)3	1.5
Longitudinal reinforcement	800g/m^2	0.86	(0)4	4
External wrapping	430g/m^2	0.5	(0)3	1.5

CF thickness   # of CF layers   total thickness



Simulation plans:

- Study the stability of the outer and inner rings with all the connections
- Study the best solution to connect the stays at the spokes
- Buckling analysis on outer cylinder

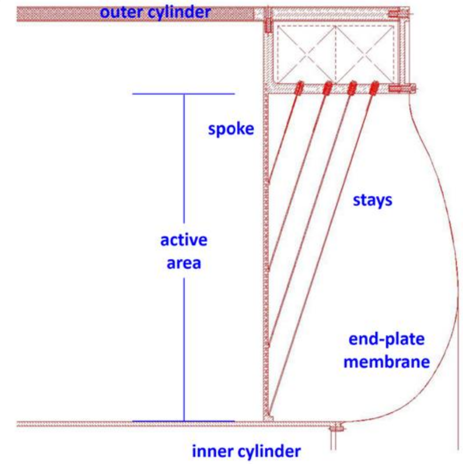
Production plans:

- More spokes prototypes
- Mechanical test with torsion, compression, bending
- Internal and external rings with the connections

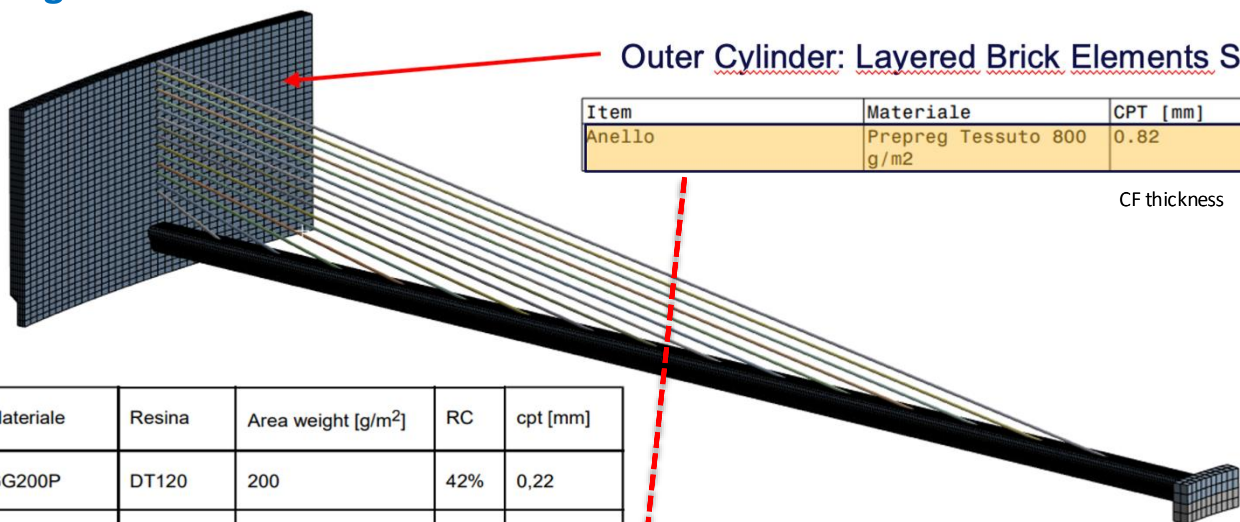
IDEA DCH: mechanical structure/4

Challenges:

- the accuracy of the position has to be in the range of 100-200 μm
- the position of the anodic wire in space must be known with an accuracy better than 50μm at most
- the anodic and cathodic wires should be parallel in space to preserve the uniformity of the electric field
- a 20 μm tungsten wire, 4 m long, will bow about 400 μm at its middle point, if tensioned with a load of approximately 30 gr → 30 gr tension for each wire → 10 tons of total load on the endcap



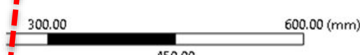
Outer ring details

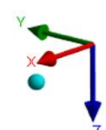


Outer Cylinder: Layered Brick Elements SOLID185

Item	Materiale	CPT [mm]	Layup	t [mm]
Anello	Prepreg Tessuto 800 g/m2	0.82	$((0/45/90/-45)_3)_s$	19.68

CF thickness — # of CF layers — total thickness





Materiale	Resina	Area weight [g/m^2]	RC	cpt [mm]
GG200P	DT120	200	42%	0,22
GG245T	DT120	245	42%	0,28
GG430T	DT120	430	40%	0,48
GG630T	DT120	630	37%	0,66
GG800T	DT120	800	36%	0,82
UD200	DT120	200	36%	0,2

Load on spokes (24 sectors): 416 Kg/spoke => 2.5 Kg/cm average

Load on stays (15 stays/spoke): 416 Kg/15/sin 8.6^{o} = > 185 Kg/stay average

IDEA DCH: wires/1

Wire constraints

Electrostatic stability condition

$$T_c \geq \frac{C^2 V_0^2}{4\pi\epsilon w^2} L^2$$

T_c wire tension
w cell width
L wire length

C capacitance per unit length
V_0 voltage anode-cathode

For w = 1 cm, L = 4 m:

T_c > 26 g for 40 µm Al field wires (δ_{grav} = 260 μm)
T_c > 21 g for 20 µm W sense wires (δ_{grav} = 580 μm)

Elastic limit condition

$$T_c < YTS \times \pi \cdot r_w^2$$

YTS Yield Tensile Strenght
YTS = 750 Mpa for W, *290 Mpa for Al*

T_c < 36 g for 40 µm Al field wires (δ_{grav} = 190 μm)
T_c < 24 g for 20 µm W sense wires (δ_{grav} = 510 μm)

The drift chamber length (**L = 4 m**) imposes strong constraints on the drift cell size (**w = 1 cm**)
Very little margin left ⇒ increase wires radii or cell size
⇒ use different types of wires

Furthermore, the cluster counting technique requires gas gains ~5x10^5
so imposes constraints on the drift cell width (w) and then on the wire material (YTS)

IDEA DCH: wires/2

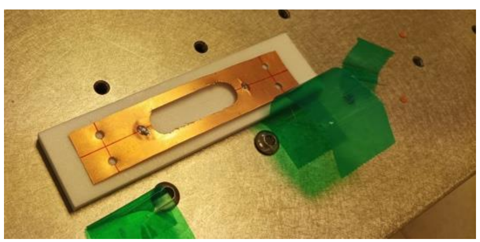
Wire tests started in a Bari clean room, through traction following ASTM 3379-75 (Standard Test Method for Tensile Strength and Young's Modulus), then analised looking at the breaking points with Scanning Electron Microscope (SEM).

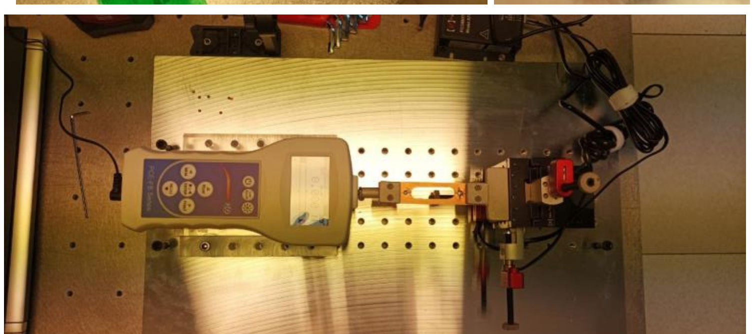
Setup:

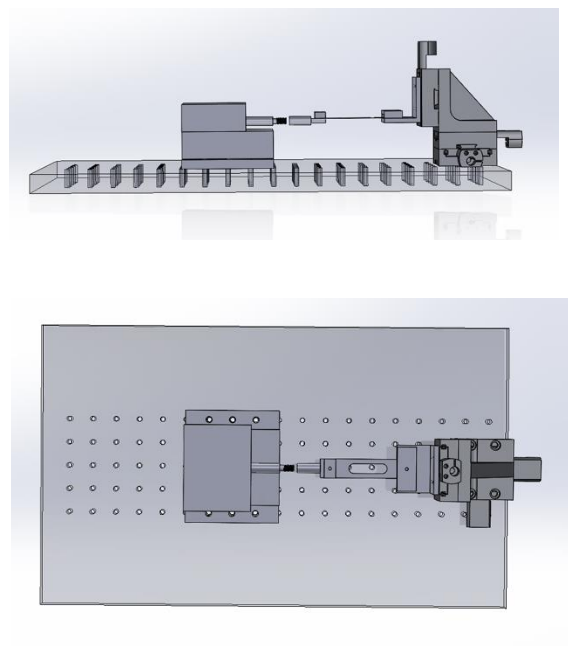
- 3 axis picometer motor (30nm step)
- Digital dynamometer (acc. 0.001N)
- The filaments are center-line mounted on special slotted tabs. The tabs are gripped so that the test specimen is aligned axially in the jaws of a constant-speed-movable crosshead test machine. The filaments are then stressed to failure at a constant strain rate

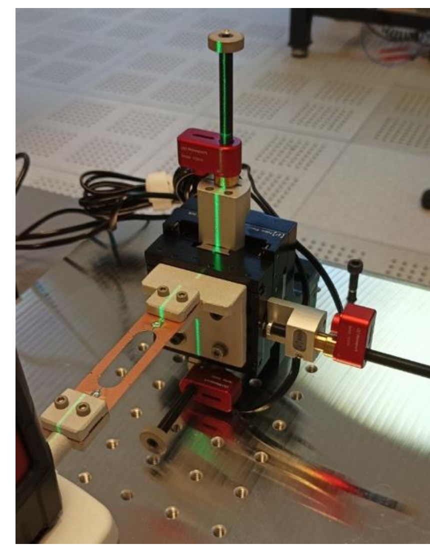
Tests:

- 20 μm diameter tungsten wire coated with gold
- 20 μm diameter molibdenum coated with gold
- 33.5 μm diameter carbon monofilament
- aluminium field wires to be tested







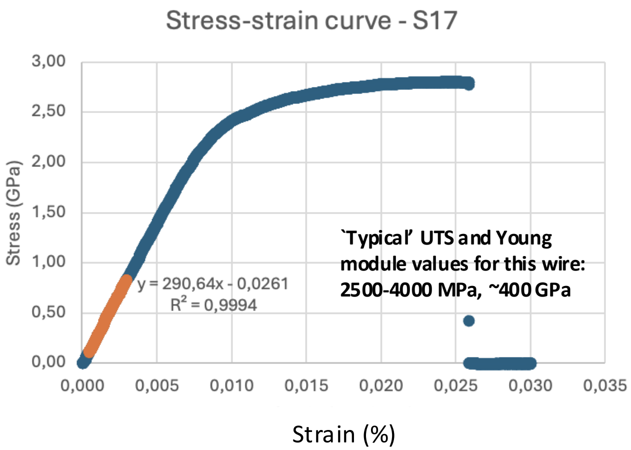


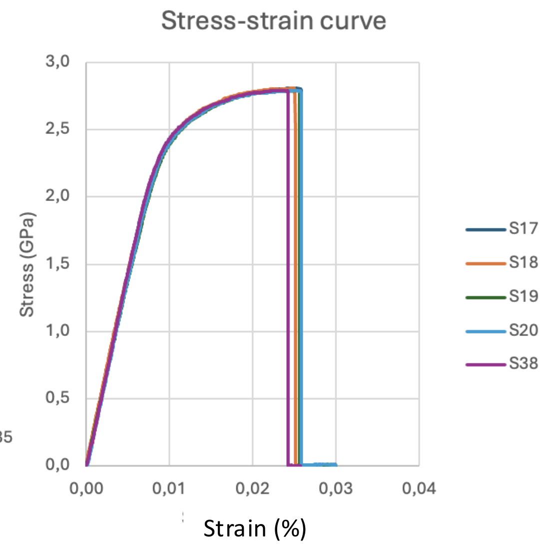
Tensioning machine

IDEA DCH: wires/3

W (Z=74)+Au wire test

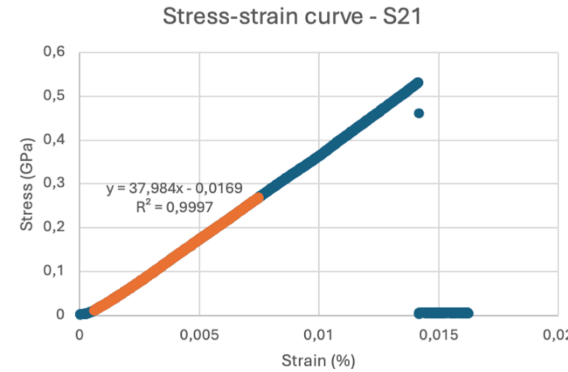
- conductive, easy to solder
- Wire diameter: 20 μm, filaments (S#) 40-60 mm long

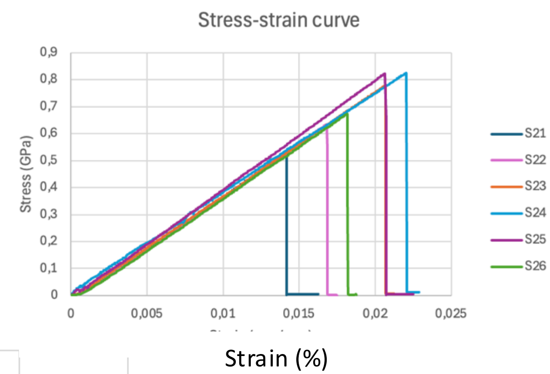




Monofilament C (Z=6) wire test

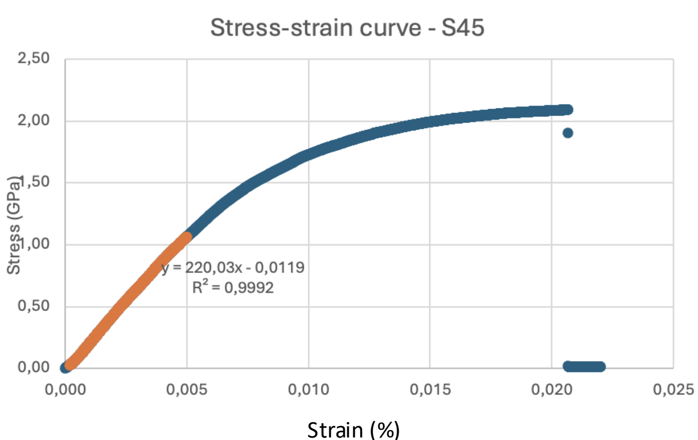
- Not conductive (requires coating)
- Wire diameter: 33.3 μm, filaments (S#) 40 mm long

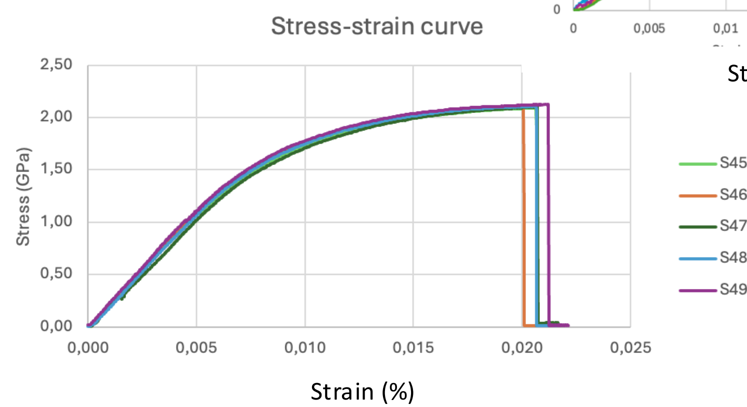




Mo (Z= 42)+Au wire test

- conductive, easy to solder
- Wire diameter: 20 μm, filaments (S#) 50 mm long





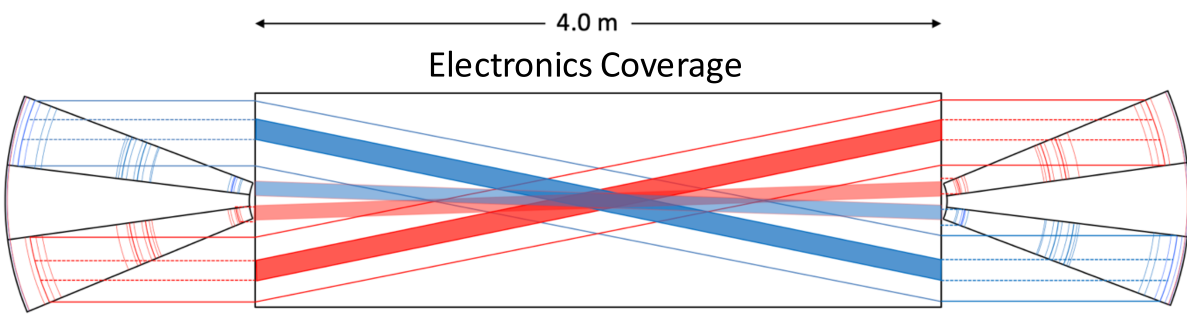
IDEA DCH full length prototype/1

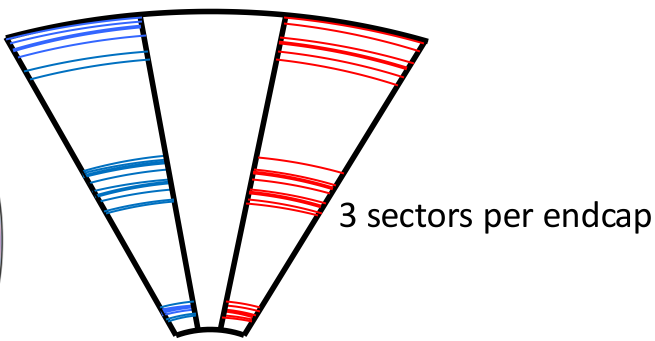
Aiming to realize a **DCH full length prototype:**

- to check the wires' electrostatic stability at the design length and stereo angle configuration
- to test materials and production procedures of the mechanical components (spokes, stays…)
- to test different wires (uncoated Al field wires, Mo sense wires, …) and wire anchoring techniques (soldering, glueing,…) to the PCB
- to test the wire tension recovery scheme with respect to the tolerances on the wire positions
- to optimize the wiring procedure, the assembly scheme, the HV and signal distribution
- to test different front-end, digitization and acquisition chains

Design guidelines

- Enough layers to be effective, but limit # of wires and complexity
- Close to the most updated DCH design





Cell size 1.2 - 1.4 cm

Minimum stereo angle 50 mrad
Maximum stereo angle: 250 mrad

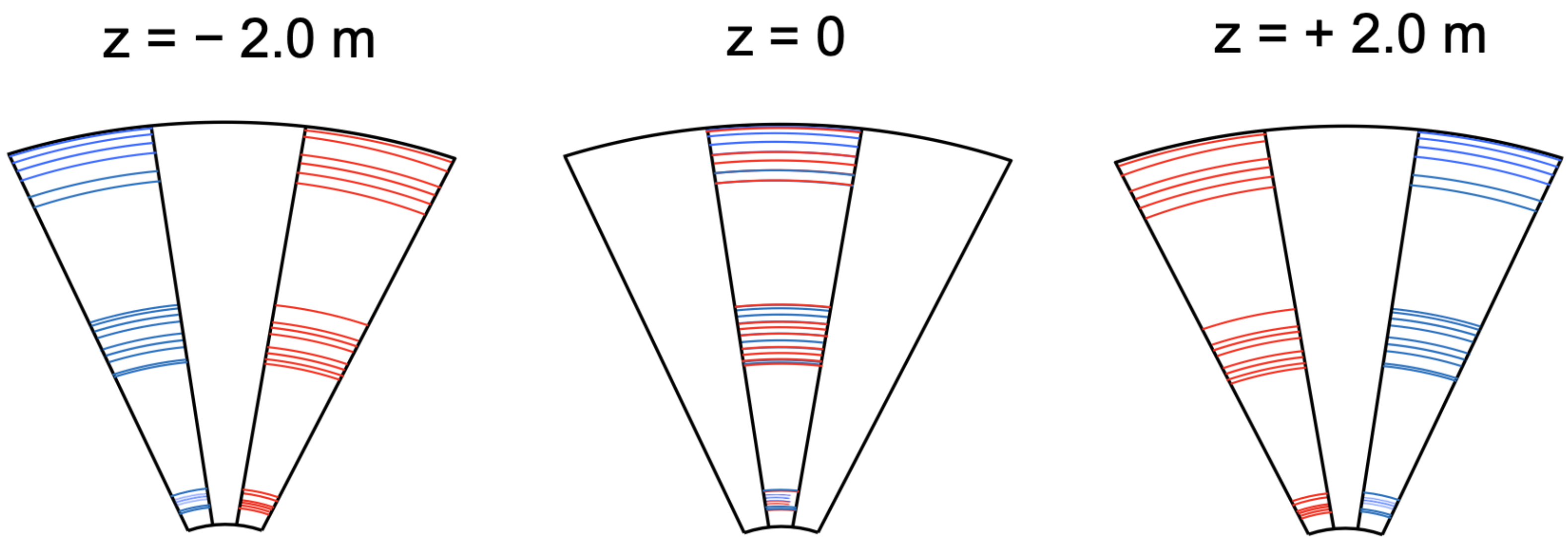
~1400 wires in total

TOTAL LAYERS: 8
Sense wires: 168
Field wires: 965
Guard wires: 264

PCBoards wire layers: 42
Sense wire boards: 8
Field wire boards: 22
Guard wire boards: 12
HV values: 14

Readout channels: 8+8 +16+16+16+16+16+16 = 112

IDEA DCH full length prototype/2



First two layers of superlayer #1
V and U guard layers (2 x 9 guard wires)
V and U field layers (2 x 18 field wires)
U layer (8 sense + 9 guard)
U and V field layers (2 x 18 field wires)
V layer (8 sense + 9 guard)
V and U field layers (2 x 18 field wires)
V and U guard layer (2 x 9 guard wires)

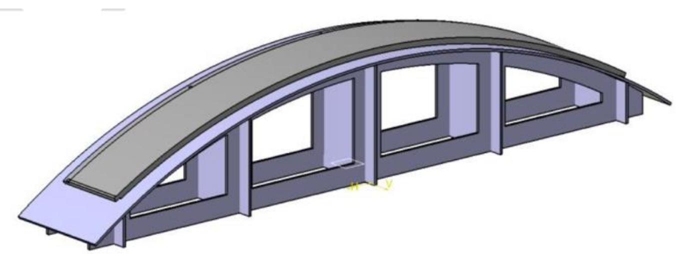
First two layers of superlayer #8
U field layer (46 field wires)
U layer (22 sense + 23 guard)
U and V field layers (2 x 46 field wires)
V layer (22 sense + 23 guard)
V and U field layers (2 x 46 field wires)
V and U guard layer (2 x 23 guard wires)

Last two layers of superlayer #7
V and U guard layers (2 x 21 guard wires)
V and U field layers (2 x 42 field wires)
U layer (20 sense + 21 guard)
U and V field layers (2 x 42 field wires)
V layer (20 sense + 21 guard)
V field layer (42 field wires)

Last two layers of superlayer #14
V and U guard layers (2 x 35 guard wires)
V and U field layers (2 x 70 field wires)
U layer (34 sense + 35 guard)
U and V field layers (2 x 70 field wires)
V layer (34 sense + 35 guard)
V and U field layers (2 x 70 field wires)
V and U guard layer (2 x 35 guard wires)

Developed/acquired:

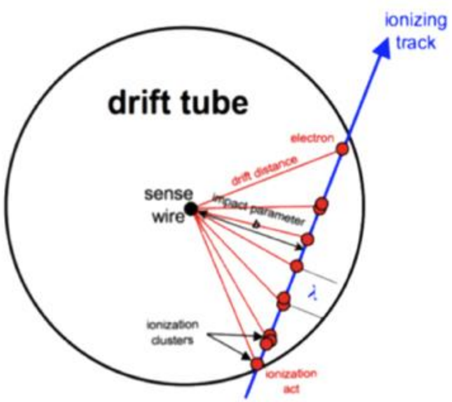
- Prototype design and material tradeoffs (molds and machining)
- Inner cylinder, 8 spokes (4 per endcap)
- Wires from LumaMetal: 10 Km of 20 µm W for sense
- Wires from Specialty Materials: 1km of 35 µm C monofilament
- Purchase order recently issued for the 2 outer rings:

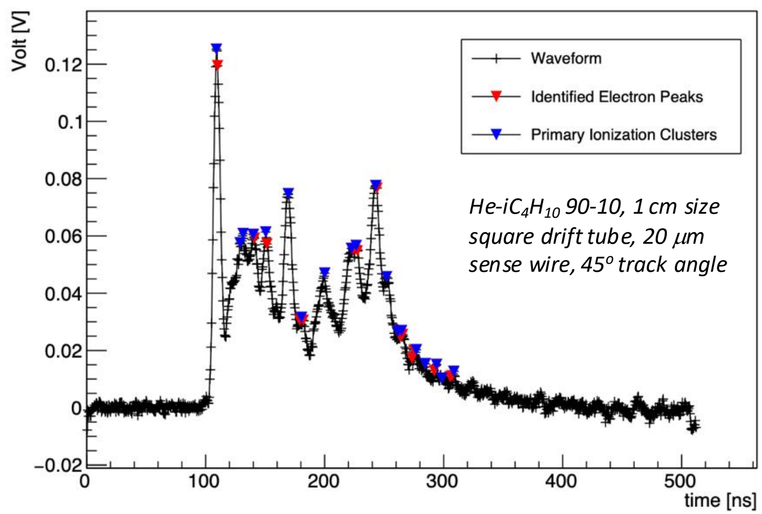


Outer Diameter: 4000 mm;
Inner Diameter: 700 mm;
Arc length: 2022 mm;
Thickness: 20 mm;

IDEA DCH: Particle Identification/1

- He based gas mixtures → signals from ionization acts are spread in time to few ns
- Fast read-out electronics → efficiently identify them
- Counting dN_{cl}/dx (# of ionization acts per unit length) → make possible to identify particles (P.Id.) with a better resolution than dE/dx





- collect signal and identify peaks
- record the arrival time of the clusters generated in every ionisation act
- reconstruct the trajectory at the most likely position

dN_{cl}/dx provides:

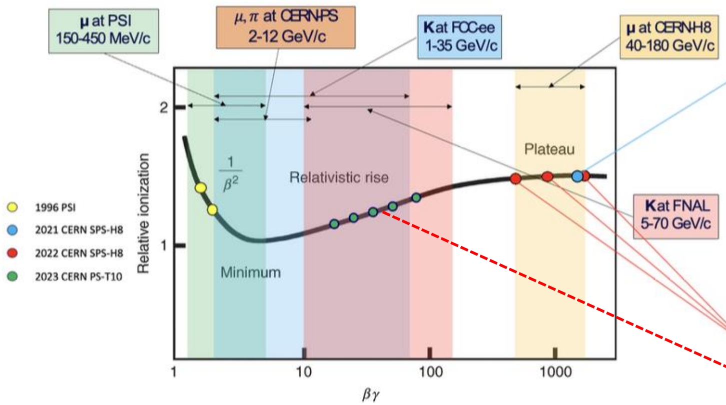
- Measurement of the # of ionization clusters per unit length, Poisson distributed and with smaller fluctuations wrt the Landau distribution of dE/dx

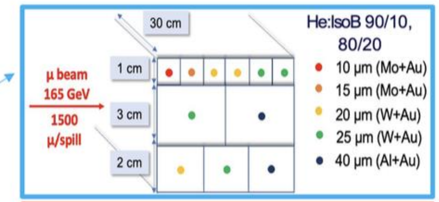
dN_{cl}/dx requires:

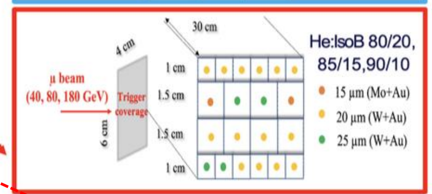
- read-out electronics with ~1GHz bandwidth
- high sampling rate digitization (~ 2GSa/s, 12 bits)
- sophisticated counting algorithms

For δ_{cl} = 12./cm in He/iC_4H_{10}=90/10 and a 2 m track → expected from dN_{cl}/dx: σ ≈ 2.0%
For # of hits n = 112 and a 2 m track at 1 atm → expected from dE/dx with truncated mean cut (70-80%): σ ≈ 4.3%

IDEA DCH: Particle Identification/2







Several beam tests performed at CERN during the last years to study the performance of the dN_{cl}/dx counting technique:

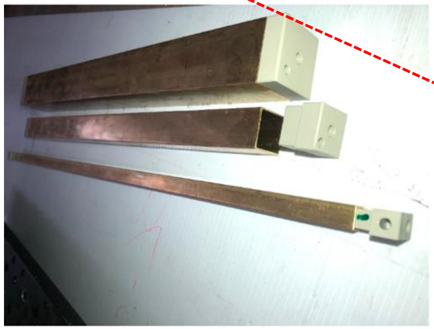
- Two **muon beam tests** performed at **CERN-H8 (βγ > 400)** in Nov. 2021 and July 2022 (165/180 GeV). *Data acquired with different: He-iC_4H_{10} mixtures (90-10,85-15,80-20), tube sizes (1-3 cm), sense wire materials and diameters (10-40 μm). Gas gain scans vs HV performed at different angles*

- A **muon beam test** (from 4 to 12 GeV momentum) in 2023 performed at **CERN PS**. A new beam test with the same configuration done in July 2024

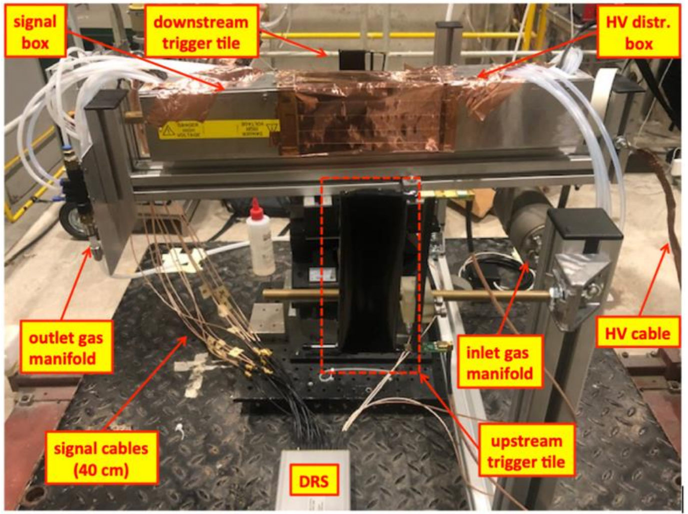
- A test at **CERN/FNAL-MT6** in 2026 with **π** and **K** **(βγ = 10–140)** could be very important to fully exploit the relativitic rise

Different **electron peak finding** algorithms used in analizing 2021/2022 data:

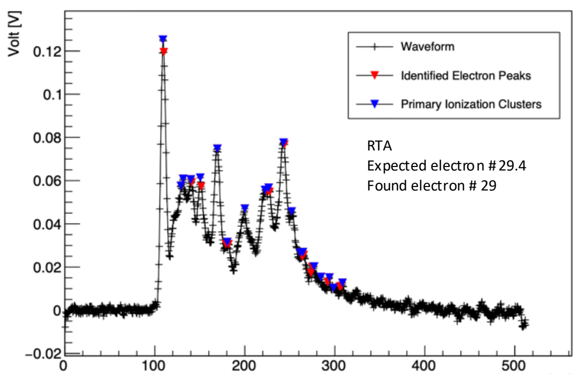
- First and Second Derivative (DERIV)
- Running Template Algorithm (RTA)
- NN-based Machine Learning Algorithm (developed at IHEP)



Clusterization algorithm to merge electron peaks in consecutive bins → primary ionization clusters



(90-10, 1 cm size tube, 20 μm sense wire, 45° track angle):



https://arxiv.org/abs/2509.21883

Expected number of electrons = δ cluster/cm (M.I.P.) * drift tube size [cm] * 1.3 (relativistic rise) * 1.6 electrons/cluster * 1/cos(α)

α → angle of the track w.r.t. normal direction to the sense wire
δ cluster/cm (M.I.P) → 12, 15, 18 for 90/10, 85/15 and 80/20 gas mixtures.
drift tube size → 0.8, 1.2, and 1.8 for 1 cm, 1.5 cm, and 2 cm cell size tubes.

IDEA DCH: Particle Identification/3

Paper submitted and accepted to JINST: https://arxiv.org/abs/2509.21883

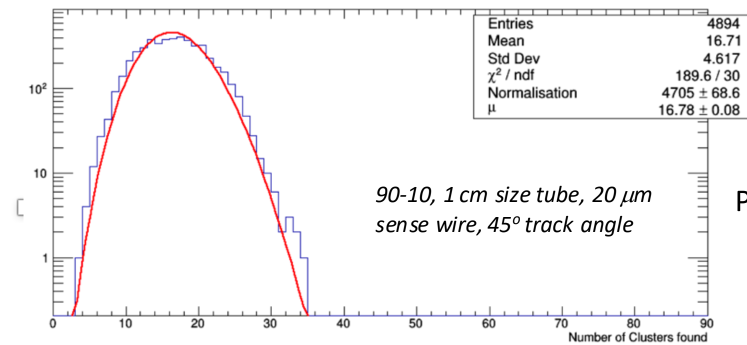
arXiv:2509.21883v2 [physics.ins-det] 30 Sep 2025

Enhancing Particle Identification in Helium-Based Drift Chambers Using Cluster Counting: Insights from Beam Test Studies

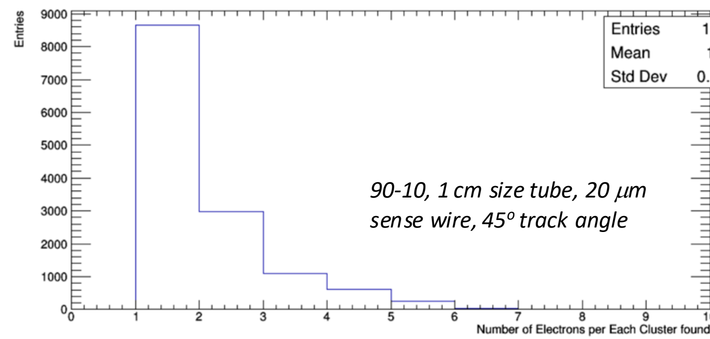
W. Elmetenawee[a,m,1] M. Abbrescia[a,b] M. Anwar[a,d] C. Caputo[n] G. Chiarello[l] A. Corvaglia[c] F. Cuna[a] B. D'Anzi[a,b] N. De Filippis[a,d] F. De Santis[c,e] M. Dong[g,h] E. Gorini[c,e] F. Grancagnolo[c] S. Grancagnolo[c,e] F.G. Gravili[c,e] M. Greco[j] K.F. Johnson[f] S. Liu[g] M. Louka[a,b] P. Mastrapasqua[n] A. Miccoli[c] M. Panareo[c,e] M. Primavera[c] F.M. Procacci[a,d] A. Taliercio[i] G.F. Tassielli[c,k] A. Ventura[c,e] L. Wu[g] G. Zhao[g]

[a]Istituto Nazionale di Fisica Nucleare Sezione di Bari, Via E. Orabona 4, 70126 Bari , Italy
[b]Universitá di Bari "Aldo Moro", Via E. Orabona 4, 70126 Bari, Italy
[c]Istituto Nazionale di Fisica Nucleare Sezione di Lecce, Via Arnesano, 73100 Lecce, Italy
[d]Politecnico di Bari, Via Amendola 126/b, 70126 Bari, Italy
[e]Universitá del Salento, Via Arnesano, 73100 Lecce, Italy
[f]Florida State University, 600 W College Ave, Tallahassee FL, 32306, United States
[g]Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China
[h]University of Chinese Academy of Sciences, Beijing 100049, China
[i]Northwestern University, 2025 Campus Dr, Evanston, Illinois 60208, United States
[j]Max-Planck-Institut für Physik, Boltzmannstr. 8, 85748 Garching, Germany
[k]Universitas Mercatorum, Piazza Mattei 10, Roma, RM 00186, Italy
[l]Department of Engineering, University of Palermo, Viale delle Scienze 9, Palermo, 90128, Italy
[m]Physics Department, Faculty of Science, Helwan University, Cairo, 11792 Helwan, Egypt
[n]Universite Catholique de Louvain (UCL), Pl. de l'Université 1, 1348 Ottignies-Louvain-la-Neuve, Belgium

E-mail: walaa.elmetenawee@ba.infn.it

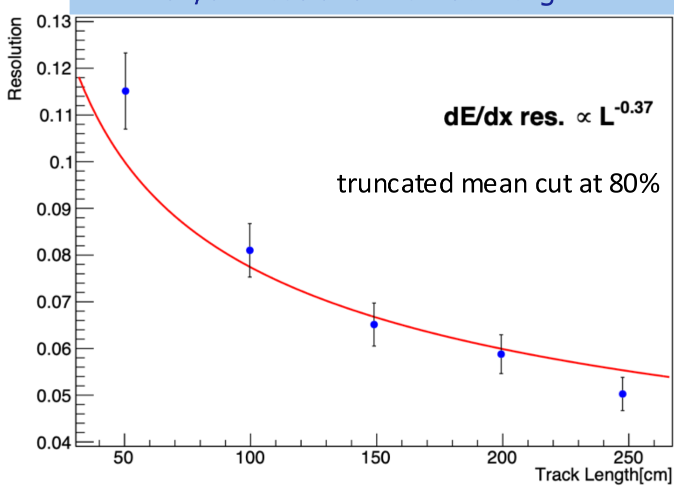


Poisson distributed # of clusters



<#> of electrons per cluster in good agreement with experimental measurements(H. Fischle et al,Nucl.Instr.Meth A301 (1991))

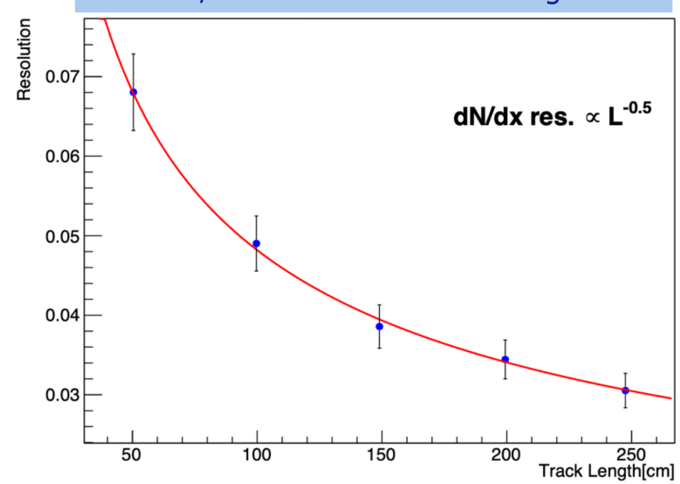
dE/dx Resolution vs track lenght



~2 times improvement in resolution using dN/dx

event-by-event time-based correction to compensate for the cluster loss for recombination and attachment effects

dN/dx Resolution vs track lenght



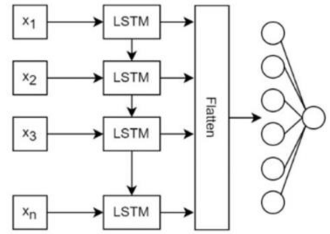
IDEA DCH: Particle Identification/4

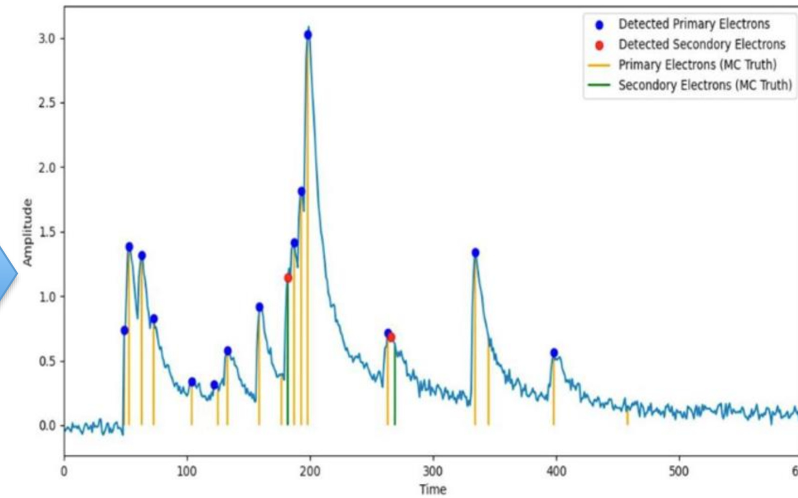
Peak finding with LSTM(*)

Simulation of Cluster Counting: GARFIELD + NN Algorithms

Why LSTM? Waveforms are time series

- Architecture: LSTM (RNN-based)
- Method: Binary classification of signals and noises on slide windows of peak candidates

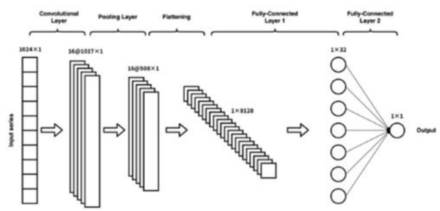




Clusterization with DGCNN(**)

Why DGCNN? Locality of the electrons in the same primary cluster, perform message-passing through neighbour nodes in GNN.

- Architecture: DGCNN (GNN-based)
- Method: Binary classification of primary and secondary electrons



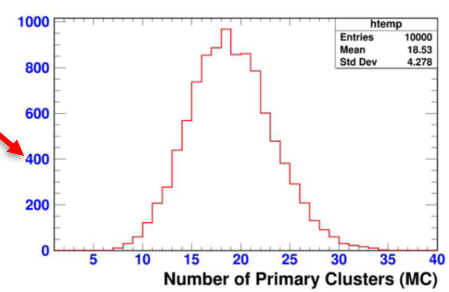
Step1: The task of peak finding can be framed as a classification problem in machine learning
Step2: The number of primary clusters is detected based on the detected peaks by using best CNN clusterization model.

(*) LSTM: Long Short-Term Memory (**) DGCNN: Dynamic Graph Convolutional Neural Networks

Different Momenta of Muon (GeV)	2	4	6	8	10	180
Monte Carlo (MC)						
Primary Cluster (MC)	15.89	16.99	17.81	18.28	18.53	19.10
Std. Deviation (MC)	4.01	4.10	4.12	4.30	4.20	4.30
LSTM Model						
Primary Cluster (LSTM)	14.45	15.37	16.06	16.34	16.49	17.30
Std. Deviation (LSTM)	3.77	3.84	3.90	3.90	3.90	4.02
CNN Model						
Primary Cluster (CNN)	14.38	15.00	15.38	15.77	16.29	16.76
Std. Deviation (CNN)	3.37	3.20	3.20	3.10	3.30	3.20

Table 1: Primary cluster means and standard deviations from MC, LSTM, and CNN across different muon momenta.

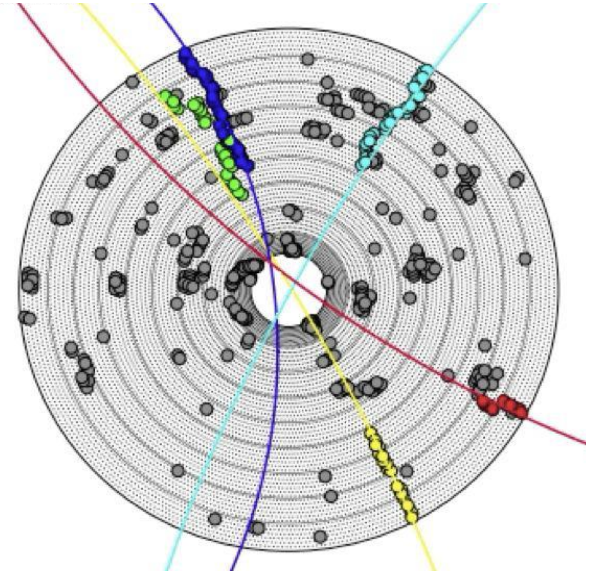
Mean number of primary clusters at 10 GeV muon momentum



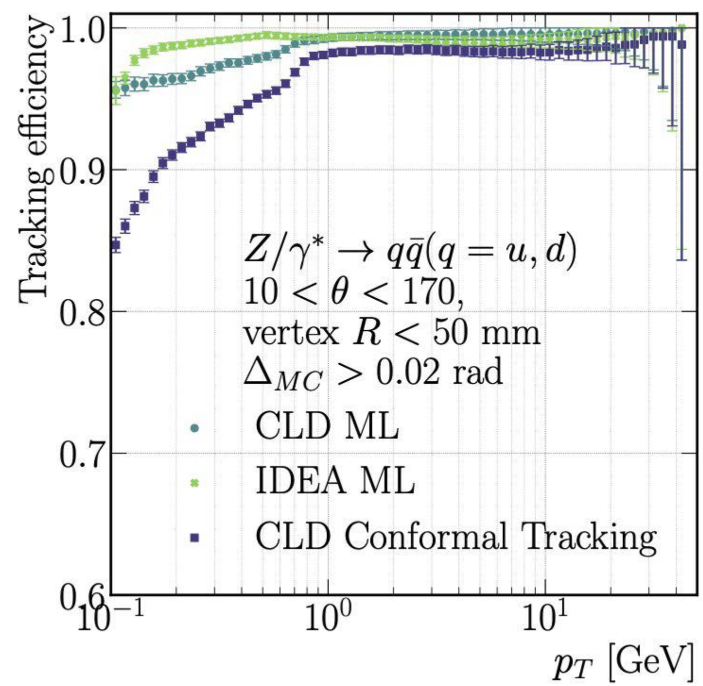
- working on comparing simulation with real data from test beams
- tuning the simulation to compare with data
- use NN to infer the number of cluster for any waveform

IDEA DCH: Simulation/1

- IDEA DCH performance was studied with a detailed standalone Geant4 simulation;
- Physics studies are on going with DELPHES (performance tuned on Geant4 simulation);
- IDEA DCH DD4HEP description in the FCC framework is done (optimizations are ongoing):
  - Geometry description;
  - Digitization;
  - Track reconstruction:
    - A new ML based Pattern Recognition was developed (Geometric Graph Track Finding);
    - Kalman filter (GENFIT2) implemented;
    - ML Particle Flow.

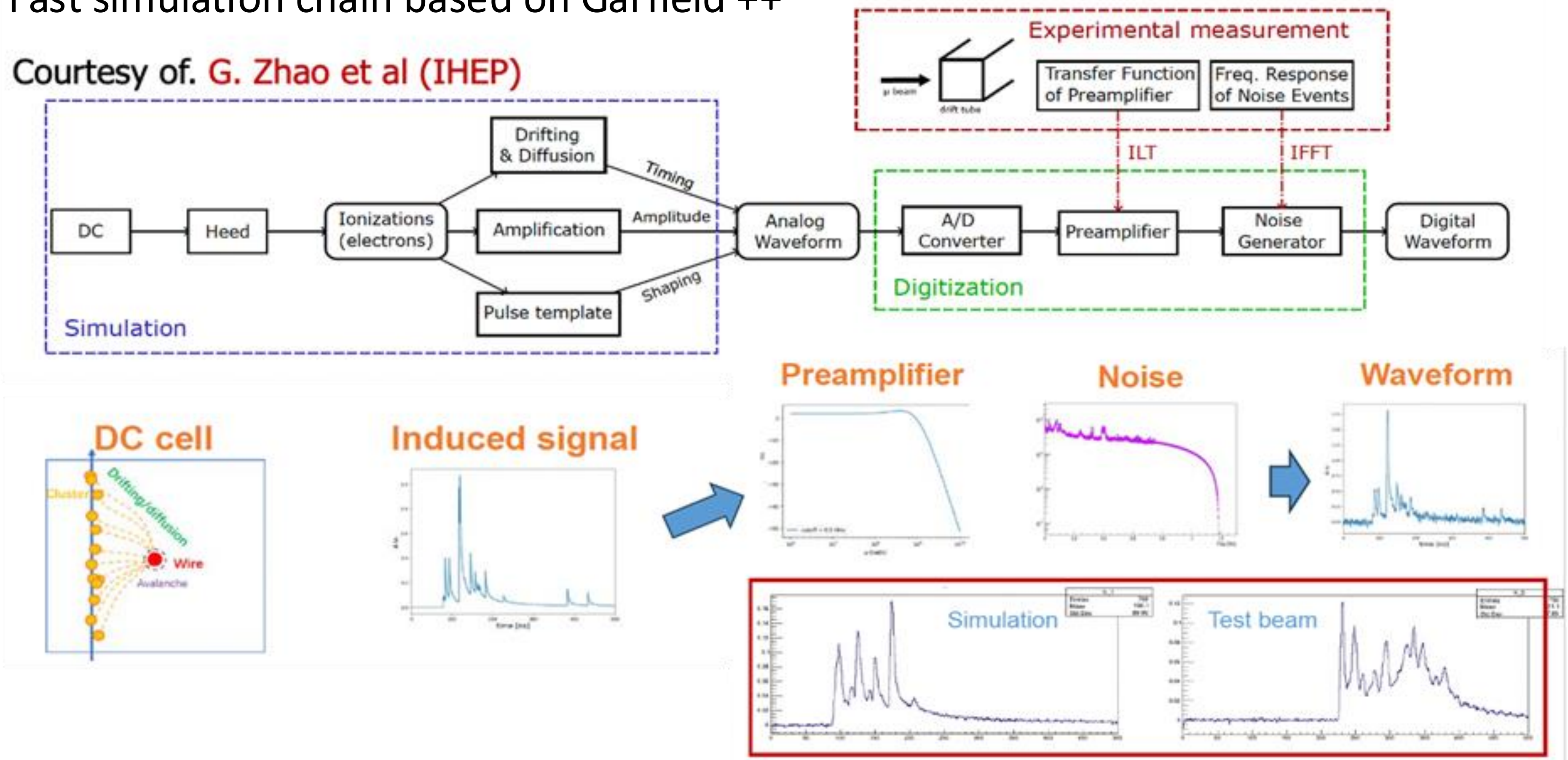


(A. De Vita: https://agenda.infn.it/event/48681/)



IDEA DCH: Simulation/2

Fast simulation chain based on Garfield ++



"Peak finding algorithm for cluster counting with domain adaptation"
Comp. Phys. Comm., 300, 2024, 109208, https://doi.org/10.1016/j.cpc.2024.109208

The simulation package creates analog induced current waveforms from ionizations (HEED).
The digitization package incorporates electronics responses taken from experimental measurements and generates realistic digital waveforms

Conclusion

Progress on the IDEA DCH R&D reported on:

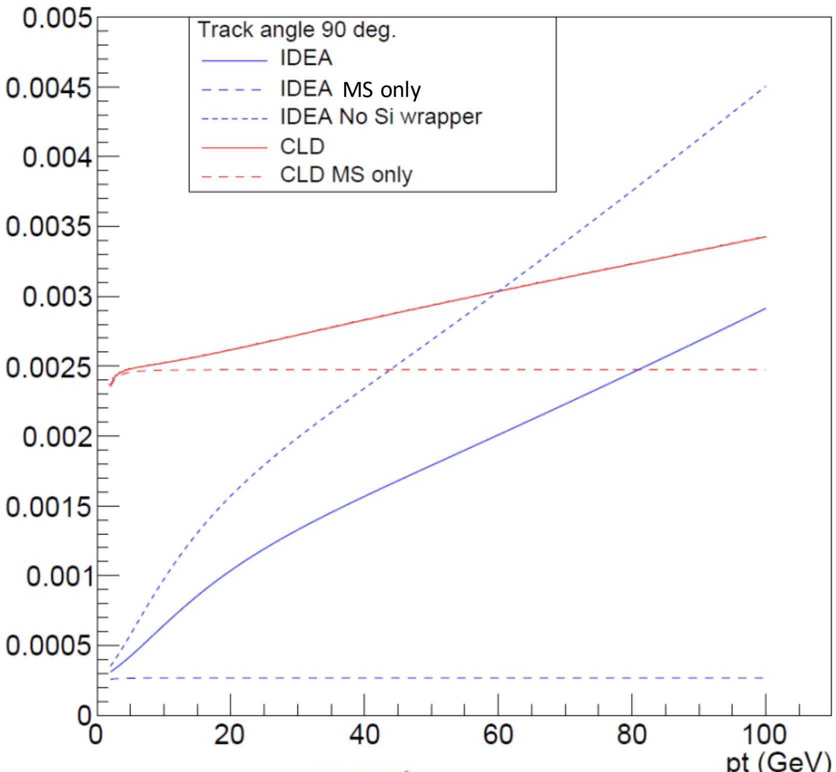
- Mechanical structure → new results on design, materials, components
- Full length prototype → ongoing efforts
- Cluster counting technique → new results on test beam data analysis
- Simulation → geometry, digitization, cluster counting

Thank you for your attention!

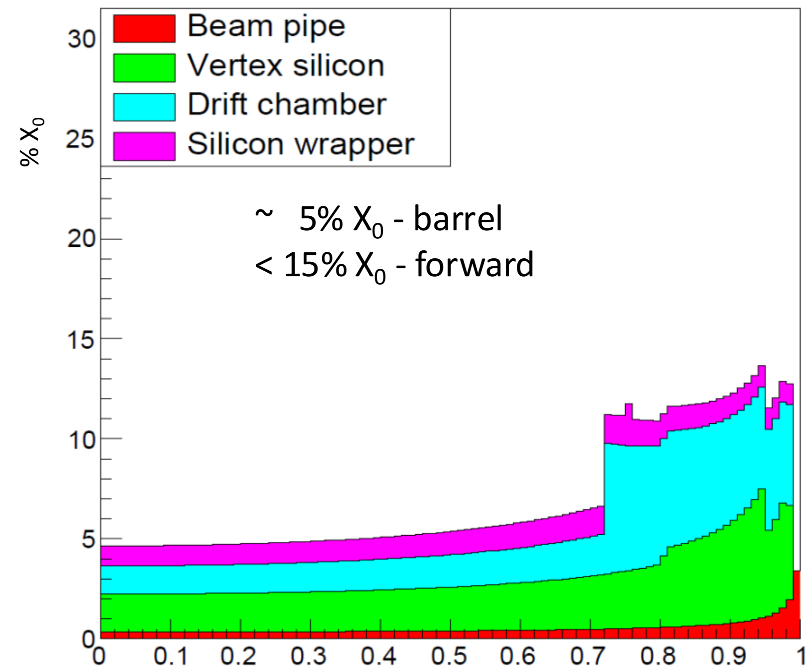
Backup slides

Main features: transparency

σ_{pt}/pt



IDEA: Material vs. cos(θ)



current Material budget estimates

- Inner wall (from CMD3 drift chamber) — $8.4\times10^{-4}\,X_0$
  - 200 μm Carbon fiber
- Gas (from KLOE drift chamber) — $1.3\times10^{-3}\,X_0$
  - 90% He – 10% iC_4H_{10}
- Wires (from MEG2 drift chamber) — $1.3\times10^{-3}\,X_0$
  - 20 μm W sense wires $6.8\times10^{-4}\,X_0$
  - 40 μm Al field wires $4.3\times10^{-4}\,X_0$
  - 50 μm Al guard wires $1.6\times10^{-4}\,X_0$
- Outer wall (from Mu2e I-tracker studies) — $1.2\times10^{-2}\,X_0$
  - 2 cm composite sandwich (7.7 Tons)
- End-plates (from Mu2e I-tracker studies) — $4.5\times10^{-2}\,X_0$
  - wire cage + gas envelope
  - incl. services (electronics, cables, ...)

Particle momentum range far from the asymptotic limit where MS is negligible

$$\frac{\Delta p_T}{p_T}\Big|_{res.} \approx \frac{12\,\sigma_{r\phi}\,p_T}{0.3\,B_0 L_0^2}\sqrt{\frac{5}{N+5}}$$

$$\frac{\Delta p_T}{p_T}\Big|_{m.s.} \approx \frac{0.0136\,\mathrm{GeV/c}}{0.3\beta\,B_0 L_0}\sqrt{\frac{d_{tot}}{X_0\,\sin\theta}}$$

Drasal, Riegler,
https://doi.org/10.1016/j.nima.2018.08.078

dE/dx and dN_{cl}/dx

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

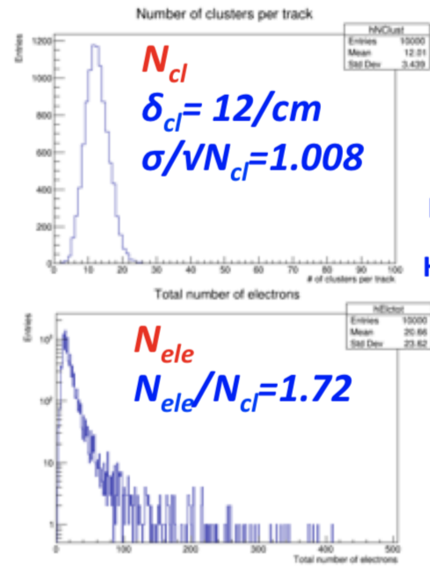
Walenta

Empirical parameterization of dE/dx resolution in gas (limited by Landau fluctuations)

"It has been experimentally confirmed that the relativistic rise is mainly due to the increased number of the primary clusters, rather than due to the energy of clusters."

P. Rehak, *A.H. Walenta, IEEE Trans. Nucl. Sci. NS-27 (1980) 54*

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



HEED simulation 1 cm He/iC_4H_{10} - 90/10

dE/dx

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

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

$\sigma \approx 4.3\%$

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.

dN_{cl}/dx

δ_{cl} = 12.5/cm for He/iC_4H_{10}=90/10 and a **2m track** give

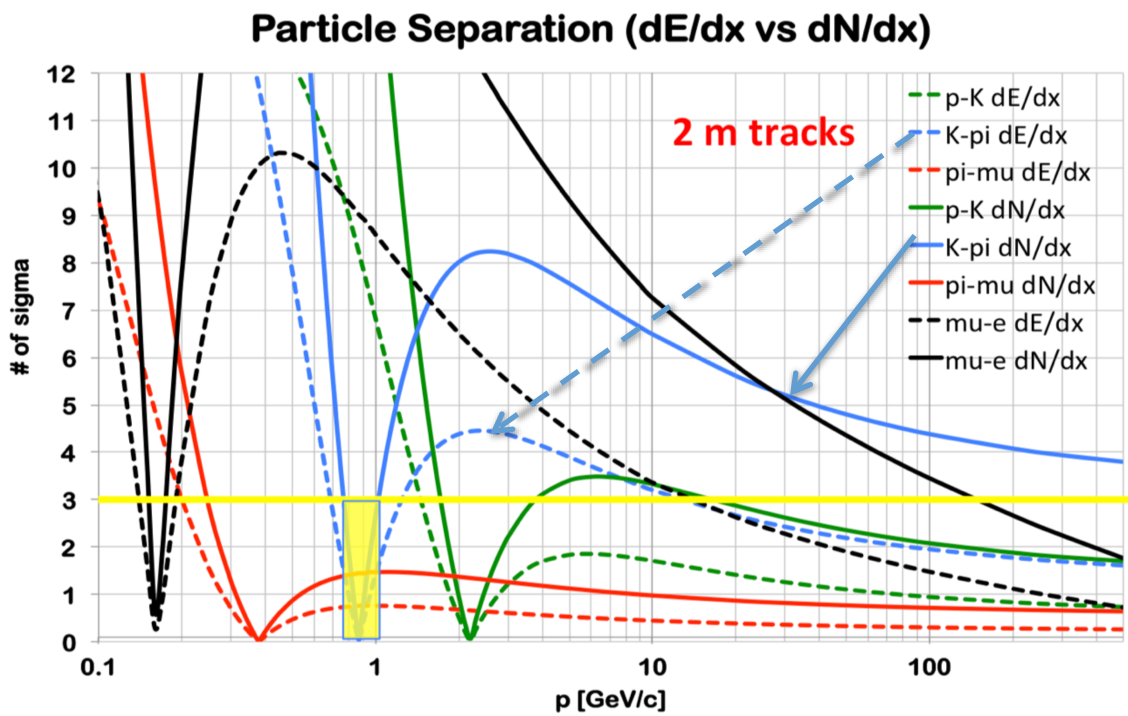
$\sigma \approx 2.0\%$

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

Conditions to be satisfied for cluster counting→ pulses from electrons belonging to different clusters must have a little chance of overlapping in time and, at the same time, the time distance between pulses generated by electrons coming from the same cluster must be small enough to prevent over-counting. **The optimal counting condition can be reached only as a result of the equilibrium** between the fluctuations of those processes which forbid a **full cluster detection efficiency** and of the ones enhancing the **time separation among different ionization events**. *(F. Grancagnolo - PId with dE/dx, IAS Program on High Energy Physics (HEP 2021), Hong Kong, 15 January 2021)*

dE/dx and dN_{cl}/dx

Analytical calculations → predict excellent K/π separation over the full range of momenta except 0.85<p<1.05 GeV

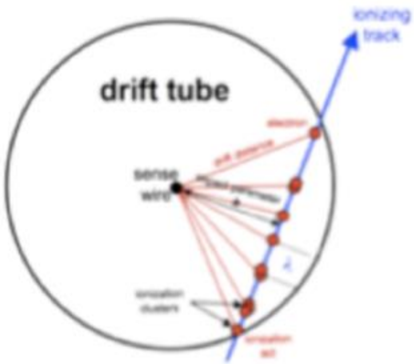


Analitic calculations:
He/iC_4H_{10} 90/10 δ_{cl}=12 cm^{-1}
σ(dE/dx)/(dE/dx) =4.3%
80% cluster counting efficiency

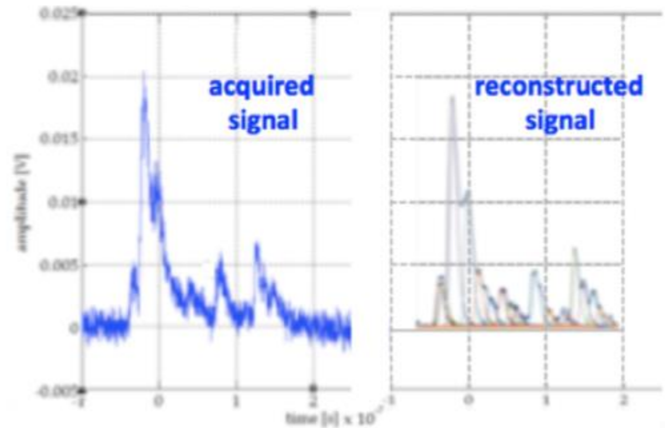
Simulation with Garfield++ and with the Garfield model ported in GEANT4:

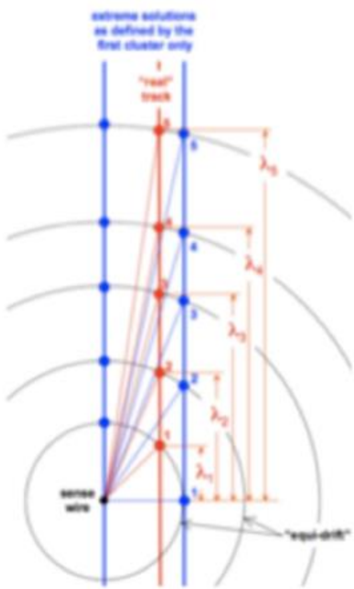
- the particle separation, both with dE/dx and with dN_{cl}/dx, in GEANT4 found considerably worse than in Garfield
- the dN_{cl}/dx Fermi plateau with respect to dE/dx is reached at lower values of βγ with a steeper slope
- Results on real data from beam tests are crucial

Cluster timing

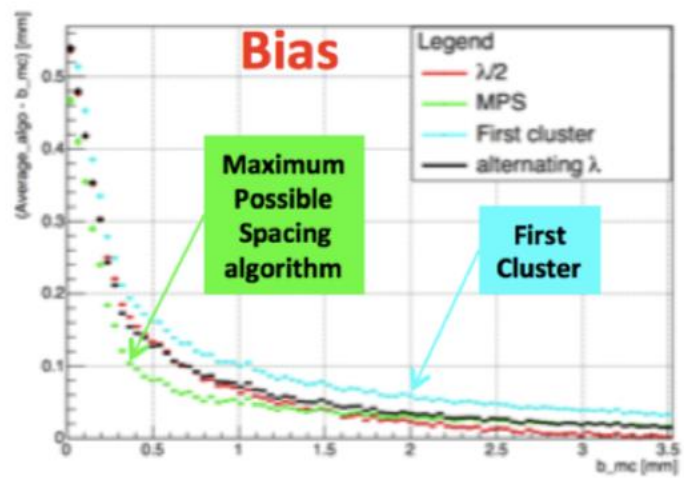


From the **ordered sequence of the electrons arrival times**, considering the average time separation between clusters and their time spread due to diffusion, **reconstruct the most probable sequence of clusters drift times:** $\{t_i^{cl}\} \quad i = 1, N_{cl}$





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.



Spatial resolution could be improved → < 100 μm for 8 mm drift cells in He based gas mixtures

Electron peak finding and clusterization algorithms

Derivative Algorithm (DERIV)

Find good electron peak candidates at position bin n and amplitude A_n :

- **Compute the first and second derivative from the amplitude average over two times the timing resolution** and require that, at the peak candidate position, they are less than a r.m.s. signal-related small quantity and they increase (decrease) before (after) the peak candidate position of a r.m.s. signal-related small quantity.

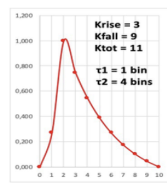
- Require that the amplitude at the peak candidate position is greater than a r.m.s. signal-related small quantity and the amplitude difference among the peak candidate and the previous (next) signal amplitude is greater (less) than a r.m.s. signal-related small quantity.

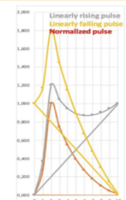
- NOTE: r.m.s. is a measurements of the noise level in the analog signal from first bins.

Running Template Algorithm (RTA)

- Define an electron pulse template based on experimental data.
- Raising and falling exponential over a fixed number of bins (Ktot).
- Digitize it (A(k)) according to the data sampling rate.
- The algorithm scan the wave form and run over Ktot bins by comparing it to the subtracted and normalized data (build a sort of χ^2).
- Define a cut on χ^2.
- Subtract the found peak to the signal spectrum.
- Iterate the search.
- Stop when no new peak is found.

k	A(k)
0	0.0
1	0.269
2	1.0
3	0.744
4	0.545
5	0.390
6	0.269
7	0.175
8	0.102
9	0.044
10	0.0





- ***Merging of electron peaks*** *in consecutive bins in a single electron to reduce fake electrons counting.*

- ***Contiguous electrons peaks*** *which are compatible with the electrons' diffusion time (it has a* $\sim\sqrt{t_{ElectronPeak}}$ *dependence, different for each gas mixture) must be considered belonging to the* ***same ionization cluster****. For them, a counter for electrons per each cluster is incremented.*

- ***Position and amplitude*** *of the clusters corresponds to the position and height of the electron having the maximum amplitude in the cluster.*

- ***Poissonian distribution for the number of clusters!***

In the DRD1 (Gaseous detectors) context

WP2 - Inner and central tracking with PID (Drift Chambers)

Task ID	Task	Performance Goal	ECFA DRD Theme
T1	Development of front-end ASIC for cluster counting	Design/construction/test of a prototype of the frontend ASIC for cluster counting (with High bandwidth, High gain, Low power consumption, Low mass)	1.1, 1.2, 1.3
T2	Development of a scalable multichannel DAQ board	Working prototype of a scalable multichannel DAQ board (with High sampling rate, Dead-time-less, DSP and filtering ability, Event time stamping, for Track triggering)	
T3	Mechanics: new wiring procedures and new endplate concepts	Conceptual designs of novel wiring procedures (feed-through-less wiring procedures) and full design of innovative concepts of more transparent endplate (< 5% X_0).	
T4	Increase rate capability and granularity	Measurements of performance on prototypes of drift cells at different granularities (smaller cell size and shorter drift time) and with different field configurations (higher field-to-sense ratio).	
T5	Consolidation of new wire materials and wire metal coating	Evaluation of the electrostatic stability of wires with High yield strength, Low mass, low Z, High conductivity. Study of aging effects. Evaluation of existing or a sputtering facility for metal coating of carbon wires.	
T6	Study ageing phenomena for new wire types	Tests of prototypes built with new wire types at beams and irradiation facilities. Measurement of performance on total integrated charge and establish charge collection limits.	
T7	Optimization of gas mixing, recuperation, purification and recirculation systems	Measurement of the performance of hydrocarbon-free gas mixtures with High quenching power, Low-Z, High radiation length. Design of a recirculating system.	

STARTED

STARTED

ADVANCED

TO BE RESTARTED

STARTED

TO BE STARTED

NOT STARTED

Challenges

- The maximum drift time (400ns) will impose an overlap of some (20 at Z pole) bunch crossings bringing the hit occupancy to ~ 10% in the inner-most drift cells. Based on MEG-II experience, this occupancy, which allows over 100 hits to be recorded per track on average in the DCH, is deemed manageable.

- However, signals from photons can be effectively suppressed at the data acquisition level by requiring that at least three ionization clusters appear within a time window of 50 ns.

- In addition, cluster signals separated by more than 100 ns are not from the same signals, this effectively bring the BXs pile-up from 20 to 4