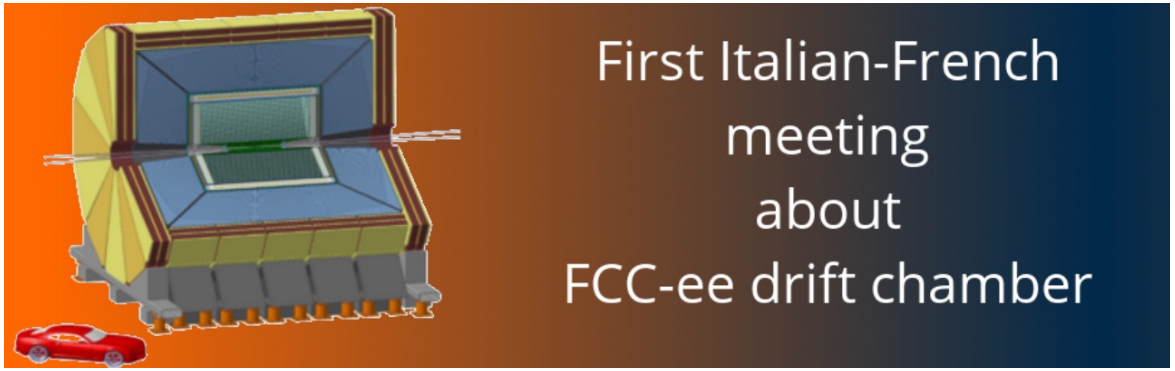

Drift chamber design and status of for the IDEA concept

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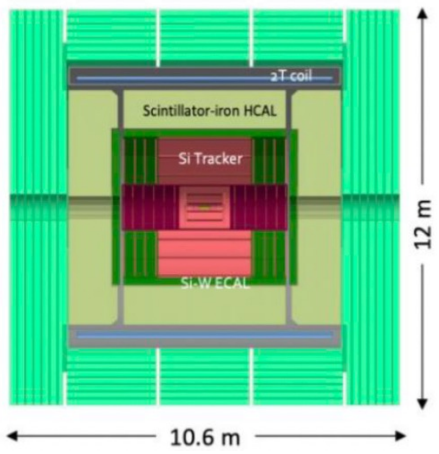
de' remi facemmo ali POLITECNICO DI BARI 1990

28-29 ott 2024, IJCLab

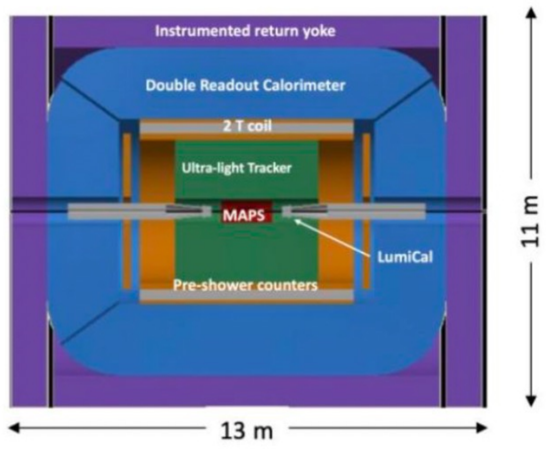
FCC-ee detector concepts

CLD

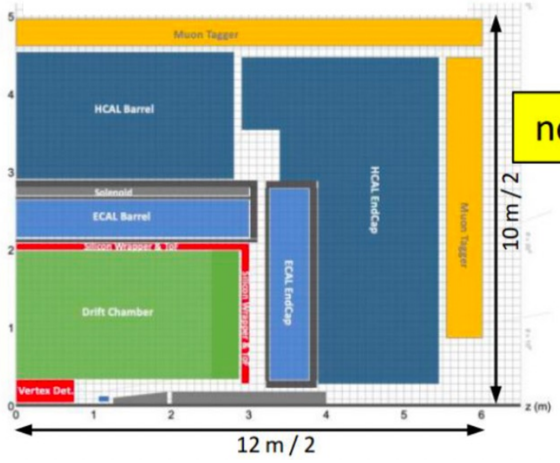


CDR

IDEA



ALLEGRO



new

Imported from CLIC
- Full Si tracker
- SiW Ecal HG
- SciFe Hcal HG
- Large coil outside

FCCee specific design
- Si Vtx + wrapper (LGAD)
- Large drift chamber (PID)
- DR calorimeter
- Small coil inside

FCCee specific design
- Tracker as IDEA
- LAr EM calorimeter
- Coil integrated
- Hcal not specified

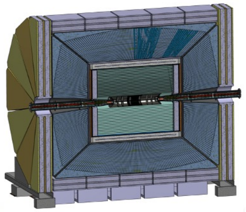
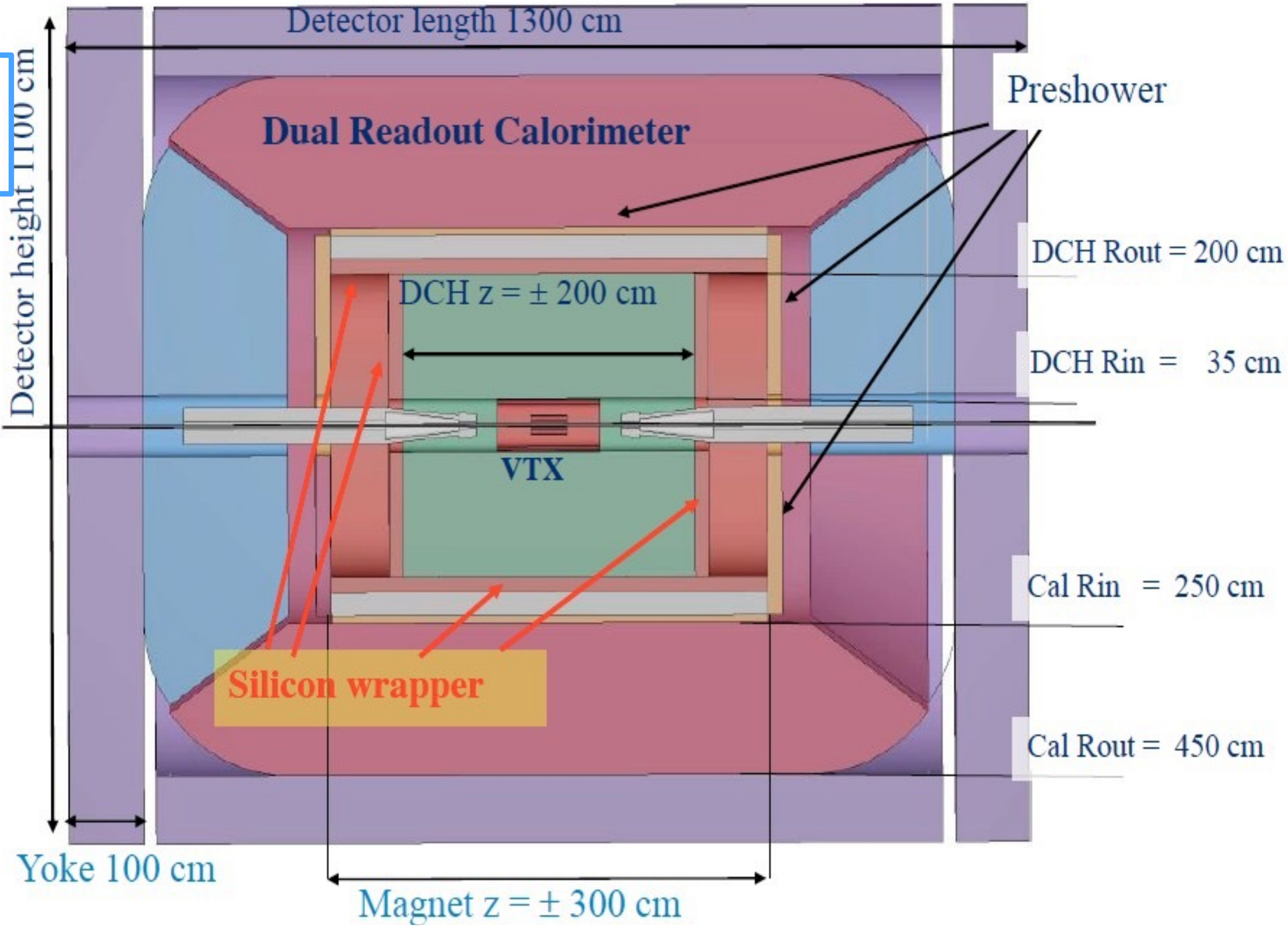
- High luminosity required for the physics → constraints on the design of the detectors close to the machine components, in particular the LumiCal and VTX detectors

The IDEA detector at e^+e^- colliders

Innovative Detector for E+e- Accelerator

IDEA consists of:

- a silicon pixel vertex detector
- a large-volume extremely-light **drift chamber**
- surrounded by a layer of silicon micro-strip detectors
- a thin low-mass superconducting solenoid coil
- a preshower detector based on **μ-WELL technology**
- a dual read-out calorimeter
- muon chambers inside the magnet return yoke, based on **μ-WELL technology**

Low field detector solenoid to maximize luminosity (to contain the vertical emittance at Z pole).

→ optimized at 2 T

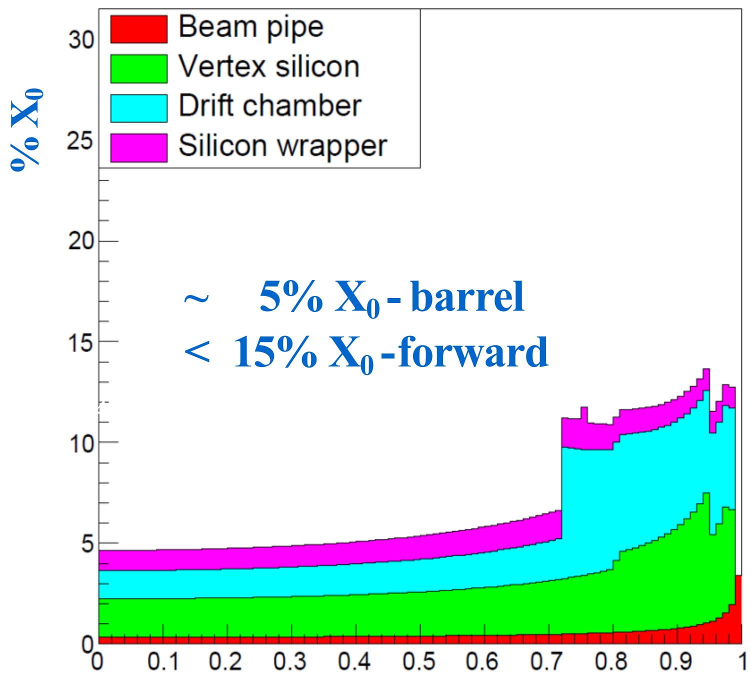
→ large tracking radius needed to recover momentum resolution

Design features of the IDEA Drift Chamber

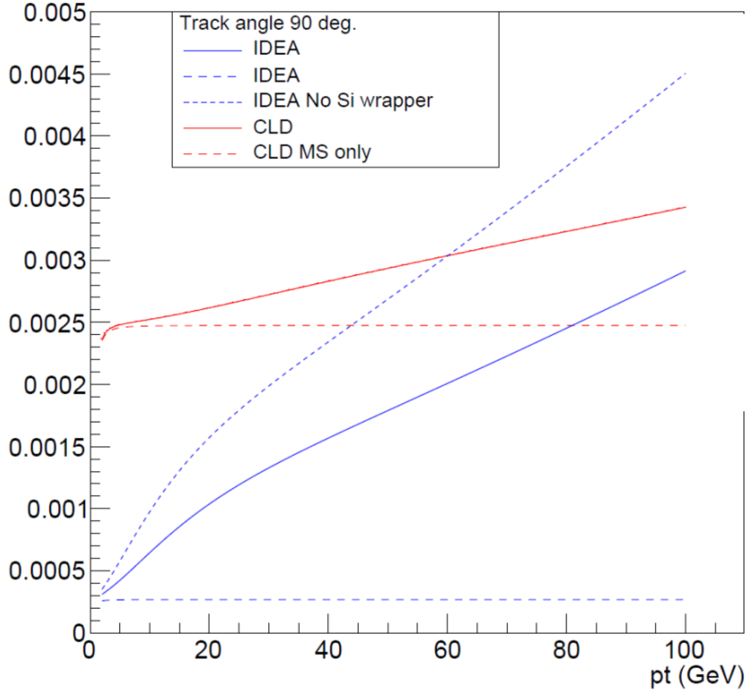
For the purpose of tracking and ID at low and medium momenta mostly for heavy flavour and Higgs decays, the IDEA drift chamber is designed to cope with:

- transparency against multiple scattering, more relevant than asymptotic resolution
- a high precision momentum measurement
- an excellent particle identification and separation

IDEA: Material vs. cos(θ)



σ_{pt}/pt



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

For 10 GeV (50 GeV) μ emitted at an angle of 90° w.r.t the detector axis, the p_T resolution is

- about 0.05 % (0.15%) with the very light IDEA DCH

The Drift Chamber of IDEA

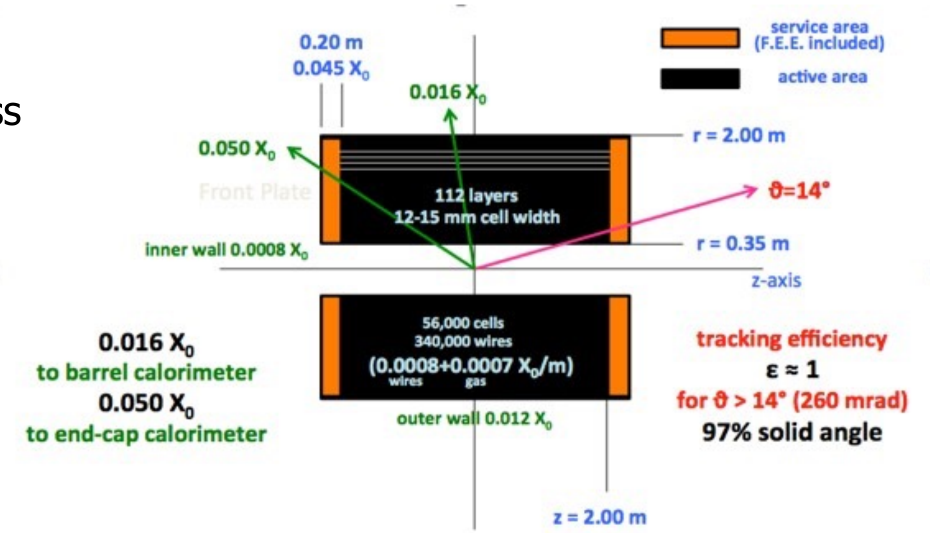
The DCH is:

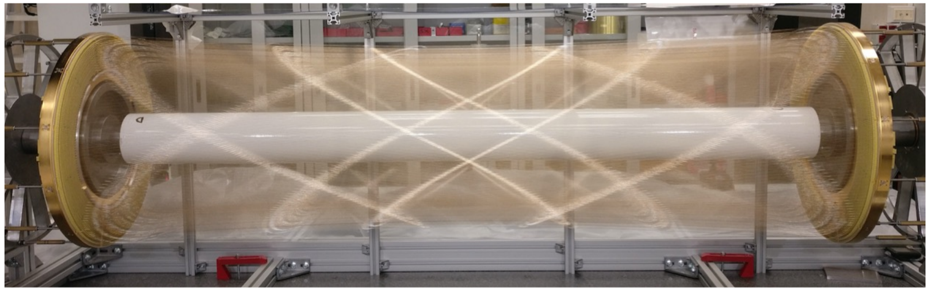
- a unique-volume, high granularity, fully stereo, low-mass cylindrical
- gas: He 90% - iC_4H_{10} 10%
- inner radius R_{in} = 0.35m, outer radius R_{out} = 2m
- length L = 4m
- drift length ~1 cm
- drift time up to 400ns
- $\sigma_{xy} < 100\ \mu m$, $\sigma_z < 1$ mm
- 12÷14.5 mm wide square cells, 5 : 1 field to sense wires ratio
- 112 co-axial layers, at alternating-sign stereo angles, arranged in 24 identical azimuthal sectors, with frontend electronics
- 343968 wires in total:

  sense vires: 20 μm diameter W(Au) => 56448 wires

  field wires: 40 μm diameter Al(Ag) => 229056 wires

  f. and g. wires: 50 μm diameter Al(Ag) => 58464 wires





- the wire net created by the combination of + and – orientation generates a more uniform equipotential surface → better E-field isotropy and smaller ExB asymmetries)

- thin wires → increase the chamber granularity → reducing both multiple scattering and the overall tension on the endplates

Challenges: wire studies

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 = 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

The proposed drift chambers for FCC-ee and CEPC have lengths **L = 4 m** and plan to exploit the cluster counting technique, which requires gas gains **~5×10^5**.
This poses serious constraints on the drift cell width (**w**) and on the wire material (**YTS**).

⇒ new wire material studies

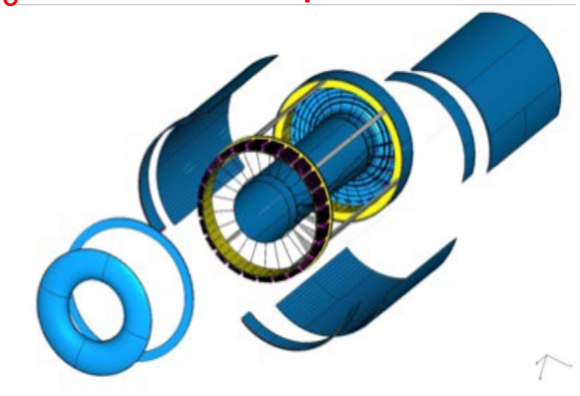
Challenges: minimization of the material budget

current Material budget estimates

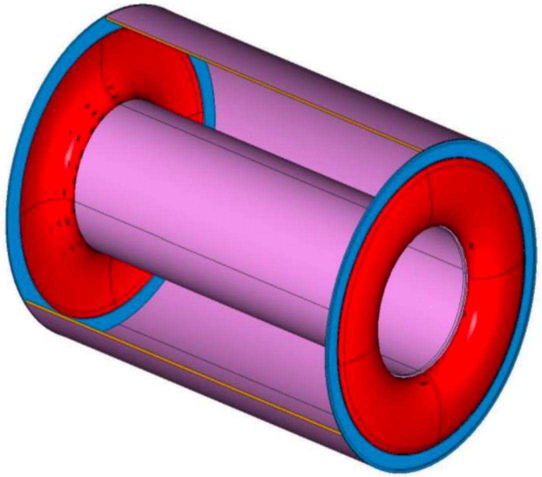
- Inner wall (from CMD3 drift chamber) — **$8.4\times10^{-4}\ X_0$**
  200 µm Carbon fiber
- Gas (from KLOE drift chamber) — $1.3\times10^{-3}\ X_0$
  90% He – 10% iC_4H_{10}
- Wires (from MEG2 drift chamber) — $1.3\times10^{-3}\ X_0$
  20 µm W sense wires $6.8\times10^{-4}\ X_0$
  40 µm Al field wires $4.3\times10^{-4}\ X_0$
  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, ...)

Mechanical structure of the DCH

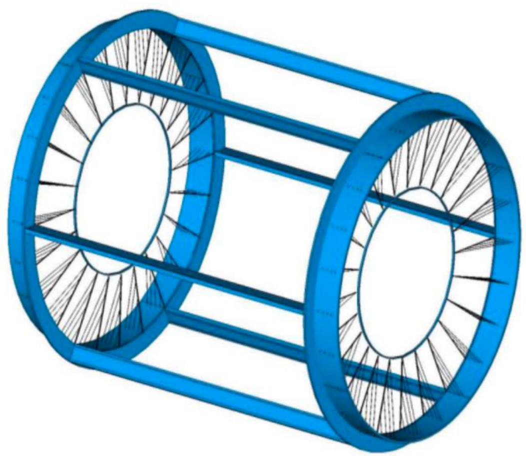
New concept of construction allows to reduce material to ≈ 10^{-3} X_0 for the barrel and to a few x 10^{-2} X_0 for the end-plates.



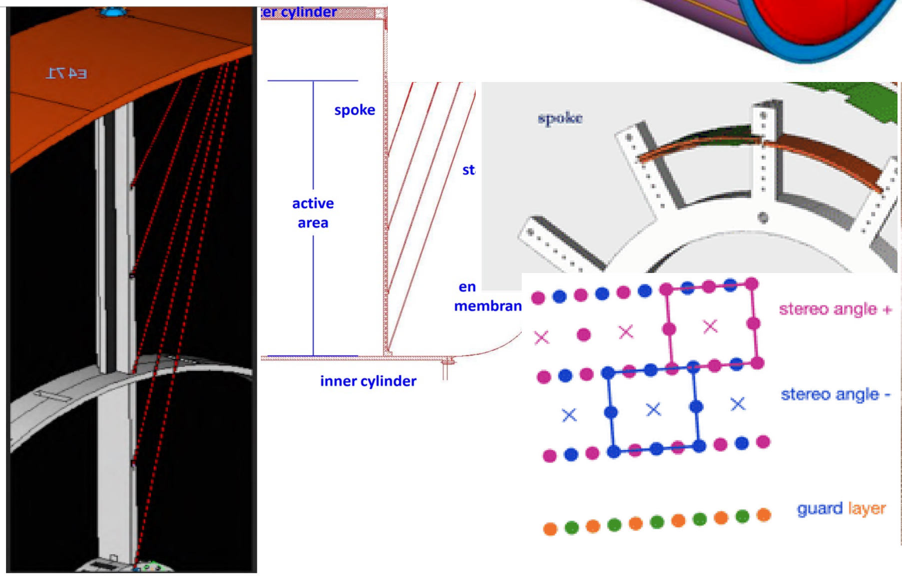
Gas containment
Gas vessel can freely deform without affecting the internal wire position and mechanical tension.



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

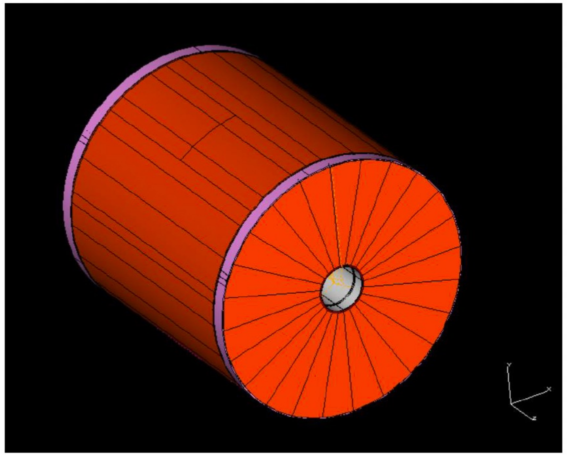


- New tension recovery schema
- Experience inherited from the MEG2 DCH



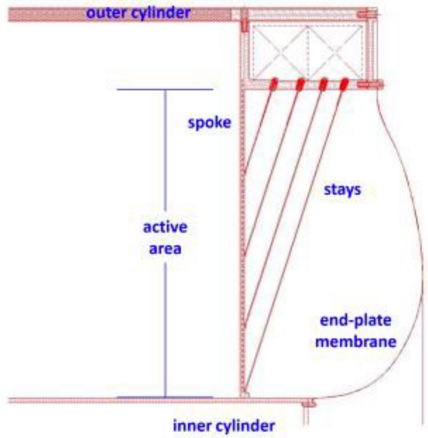
Mechanical structure of the DCH

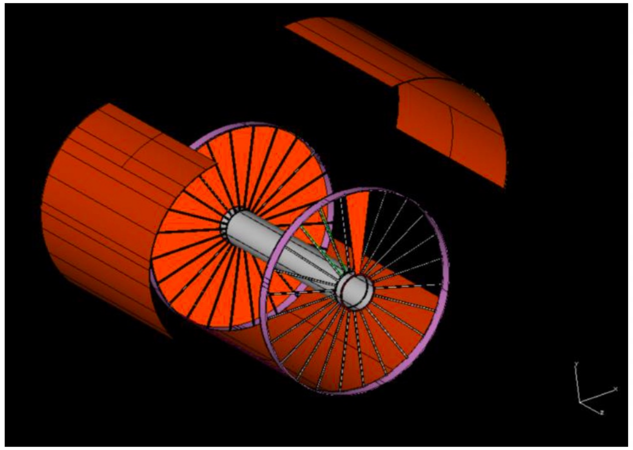
IDEA Drift Chamber



- Inner radius **R_{in} = 35 cm**, outer radius **R_{out} = 200 cm**
- Length **L = 400 cm**
- Inner wall thickness **200 μm** Carbon fiber
- Outer wall thickness **2cm** composite material sandwich (honeycomb structure)

tension recovery system



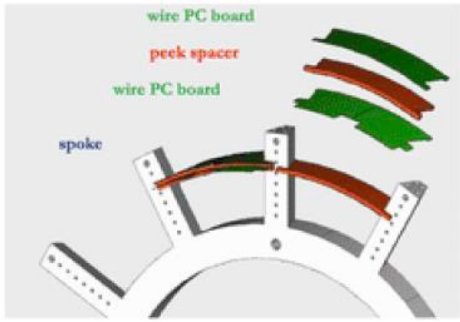


- **Inner cylinder** and **Outer cylinder** are connected with 48 **Spokes** (24 per endcap) forming 24 azimuthal sectors.
- Each spoke is supported by 15 **Cables.**
- Spoke length **l =** 165cm

IDEA Drift Chamber: wire cage

- **343968 wires** in total:
  - 56448 sense wires – 20 μm diameter W(Au)
  - 229056 field wires – 40 μm diameter Al(Ag)
  - 58464 field and guard wires – 50 μm diameter Al(Ag)

- The **Wires** are soldered to the PCB and inserted between the spokes.
- **112 co-axial layers** (grouped in 14 superlayers of 8 layers each) **of para-axial wires**, at alternating-sign stereo angles, arranged in 24 identical azimuthal sectors.
- **Stereo configuration:** one sector is connected with the second corresponding sector in the opposite endcap (hyperbolic profile).



MEG2 drift chamber

N. De Filippis

Mechanical structure with FEM

Big Problems to manage!

- σ_{xy} < **100 μm** → accuracy on the position of the anodic wires < **50 μm**.
- The anodic and cathodic wires should be parallel in space to preserve the constant 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 grams.

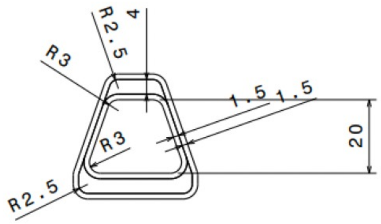
30 gr tension for each wire → **10 tonnes** of total load on the **endcap**

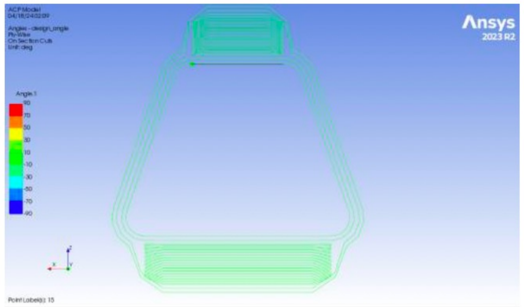
Load on spokes (24 sectors): 416 Kg/spoke => 2.5 Kg/cm average

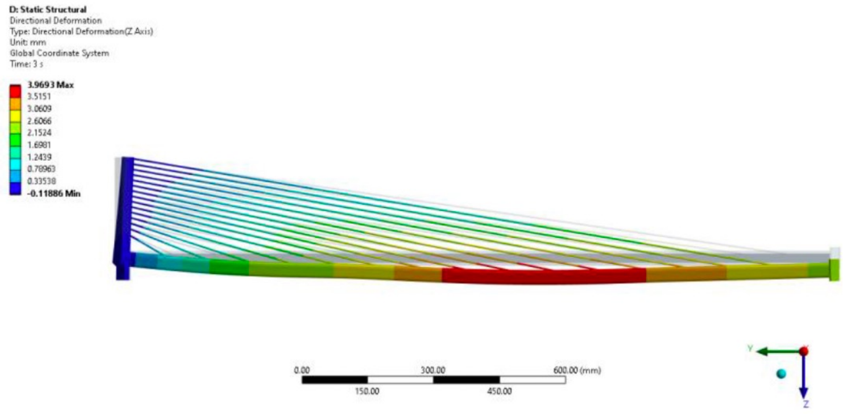
Load on stays (14 stays/spoke) - 416 Kg/14/sin 8.6° = 200 Kg/stay

Mechanical structure: FEM simulation studies

Simulation studies: progress about the final design of the cross section of the spoke

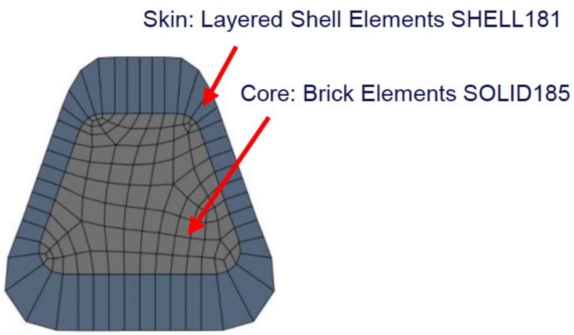






Statical structure simulation:

deformation along r



Our main goal is to limit the deformation of the spokes to **200 μm**, while ensuring the structural integrity

- Including **prestressing of spokes**
- Investigate more **composite structures**
- **Buckling** analysis on outer cylinder

Meachnical desing for DCH with FEM analysis

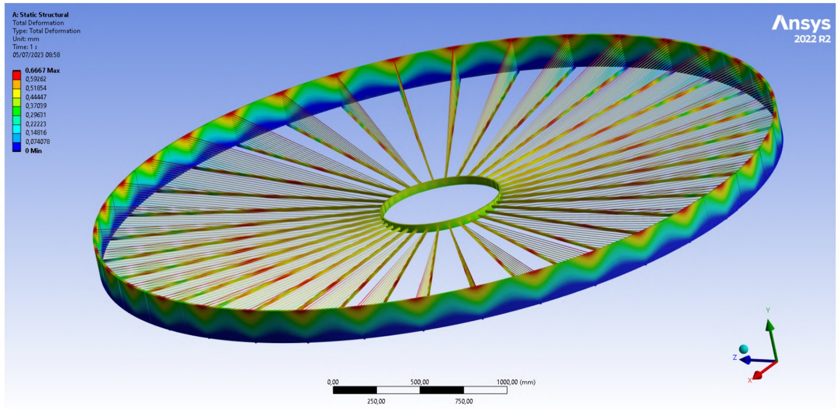
- defined the the section of the spokes
- working on the design of he structure of the composite material and the behaviour under stress
- started the analysis for the stability of the external cylinder

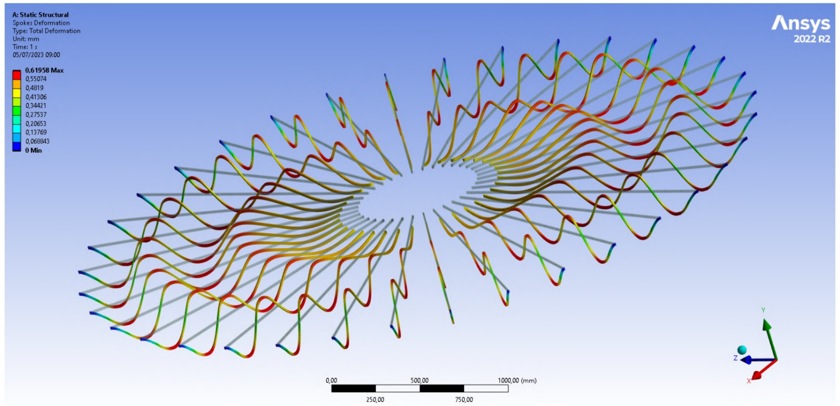
Mechanical structure with FEM: Example of prestressing

Goal: minimizing the deformation of the spokes using prestressing force in the cables

Finding the correct prestressing force in 14 cables → solving 15 dimensional optimization problem

Total deformation (mm) of the drift chamber with the edge of the outer cylinders fixed			
No prestress		Prestress in the cables	
Spokes	Outer cylinder	Spokes	Outer cylinder
14.099	0.63	0.62	0.67



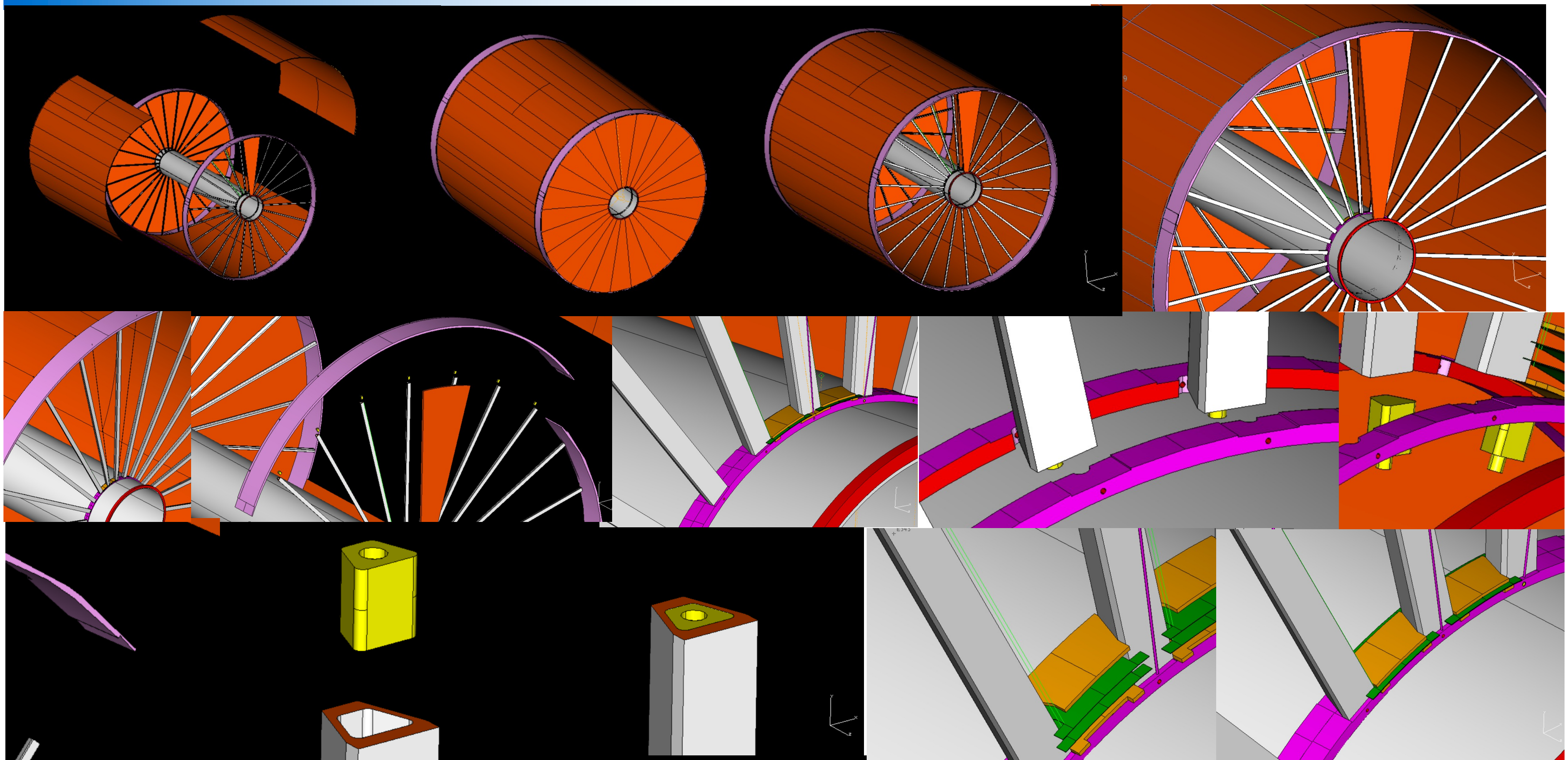


N.B.

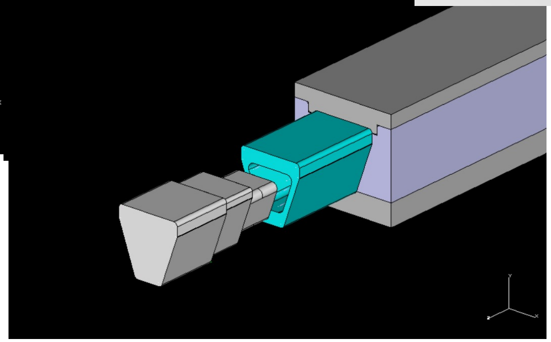
- Prestressing not yet optimized
- 24 → 36 spokes considered for this study

The structure exhibited a deformation of 600 μm but our goal was to limit the deformation of the spokes to 200 μm while ensuring the structural integrity.

Mechanical structure: a complete model



Plan to start the construction of a DCH prototype full lenght, three sectors



A realistic complete model ready:

- mechanically accurate
- precise definition of the connections of the cables on the structure
- connections of the wires on the PCB
- location of the necessary spacers
- connection between wire cage and gas containment structure

2025 full-length prototype: Goals

- **Check the limits of the wires' electrostatic stability at full length and at nominal stereo angles**

- **Test different wires**: uncoated Al, C monofilaments, Mo sense wires, …, of different diameters
  - Test different wire anchoring procedures (soldering, welding, gluing, crimping, …) to the wire PCBs
  - Test different materials and production procedures for spokes, stays, support structures and spacers
  - Test compatibility of proposed materials with drift chamber operation (outgassing, aging, creeping, …)

- Validate the **concept of the wire tension recovery scheme** with respect to the tolerances on the wire positions
  - Optimize the layout of the wires' PCBs (sense, field and guard), according to the wire anchoring procedures, with aim at minimizing the end-plate total material budget

- Starting from the new concepts implemented in the MEG2 DCH robot, **optimize the wiring strategy**, by taking into account the 4m long wires arranged in multi-wire layers

- Define and validate **the assembly scheme** (with respect to mechanical tolerances) of the multi-wire layers on the end plates
  - Define the front-end cards channel multiplicity and their location (cooling system necessary?)

- **Optimize the High Voltage and signal distribution** (cables and connectors)

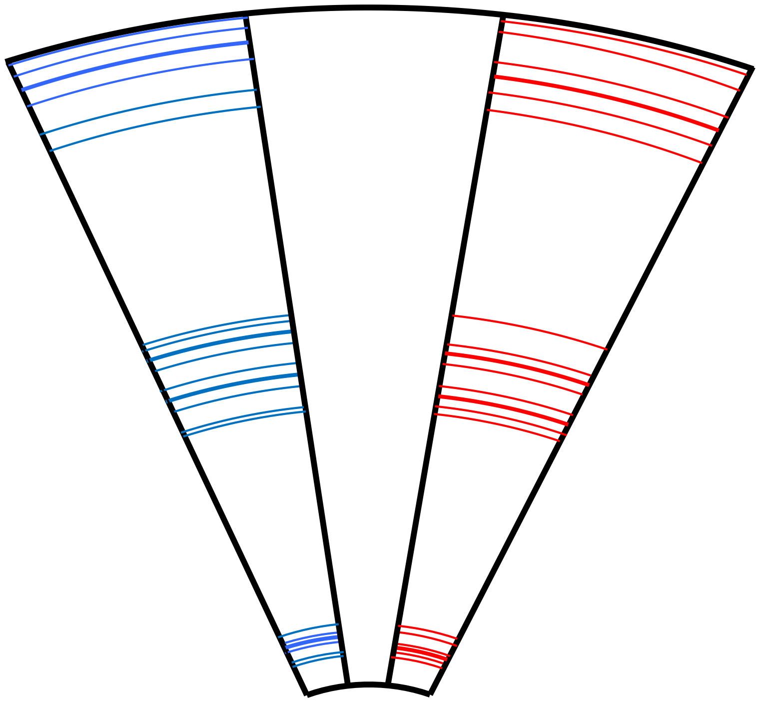
- Test performance of **different versions of front-end, digitization and acquisition chain**

▸ ***Full-length prototype necessary*** ○ ***Can be done in parallel on small prototypes***

2025 full-length prototype: Wiring

Target: a full length DCH prototype with 3 sectors per endcap

- 8 spokes (4 per endcap)
- Internal ring
- part of the outer ring
- part of the cylindrical panel



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)

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)

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)

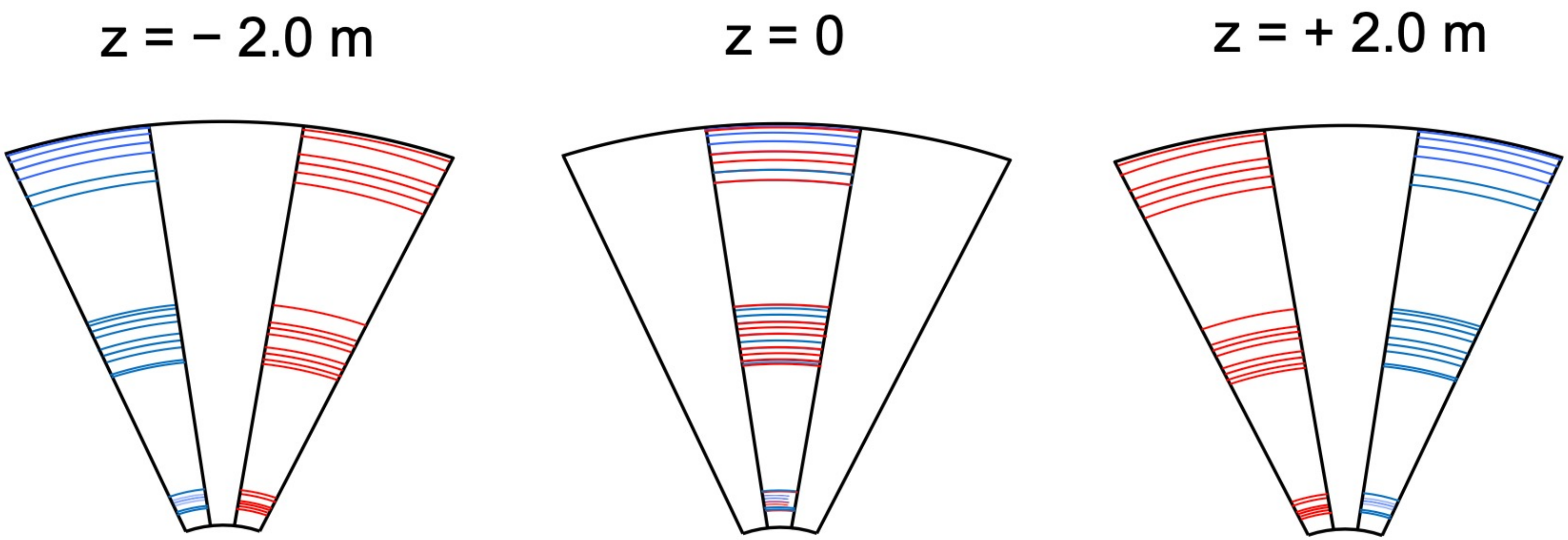
Last two layers of superlayer #14
V and U guard layers (2 x 35 guard wires)
V and U field layers (2 x 70 field wires)
U layer (34 sense + 35 guard)
U and V field layers (2 x 70 field wires)
V layer (34 sense + 35 guard)
V and U field layers (2 x 70 field wires)
V and U guard layer (2 x 35 guard wires)

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

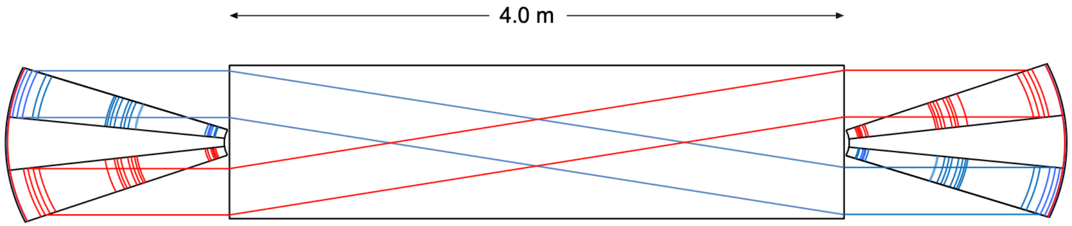
PCBoards wire layers: 42
Sense wire boards: 8
Field wire boards: 22
Guard wire boards: 12
HV values: 14

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

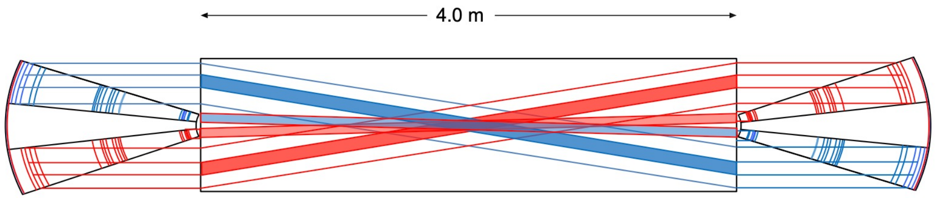
2025 full-length prototype: Coverage



MAX COVERAGE

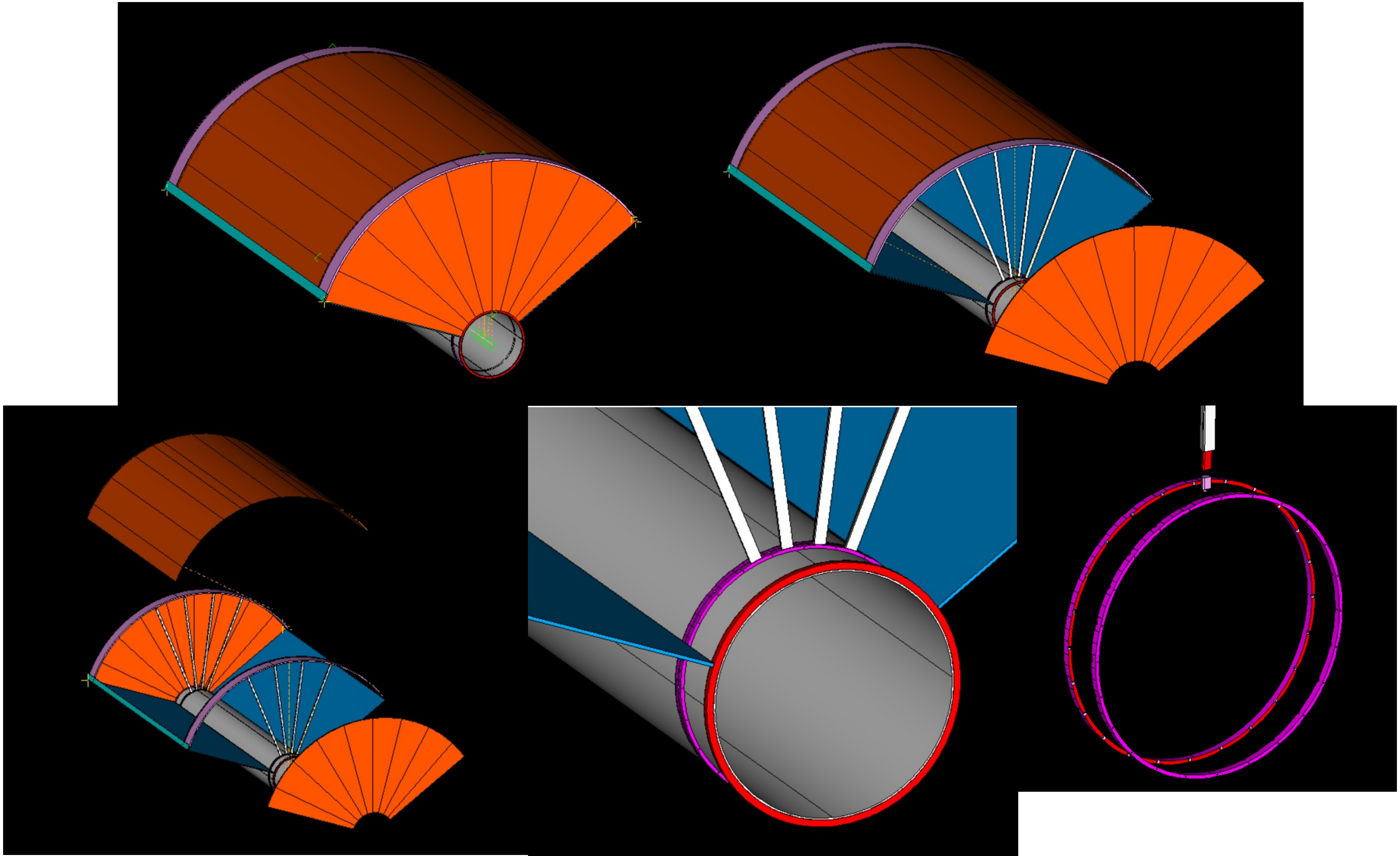


ELECTRONICS COVERAGE



Minimum stereo angle 50 mrad
Maximum stereo angle: 250 mrad

2025 full-length prototype: Model



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2025 full-length: some arguments

- Three sectors is the minimum for the two stereo views.

- It is necessary to test the innermost layer, with the smallest cells, the outermost layer with the maximum stereo angle and two intermediate layers at the transition of two superlayers, where the pitch of the wires changes for the increase of cells from one superlayer to the next . So, 4 layers for two views, or 8 layers.

- It is necessary to cover the entire sector in azimuth with the wires to distribute the electric field in order to test the electrostatic stability with stereo configurations. Further reducing the number of field wires would involve the introduction of edge effects that would affect the innermost sense wires.

- It is necessary to cover the entire sector in azimuth with wires to control the spinning on PCBs which become approximately 50 cm long at the outermost layer with obvious difficulties in maintaining geometric tolerances.

- Regarding the number of reading channels, we read the two internal views (all 8+8 channels), the four intermediate views (16+16+16+16 channels on 20+20+22+22 sense wires) and the two external views (16+16 channels on 34+34). All this gives a coverage of about 2 dm^2 for vertical cosmic rays.

- The 112 channels → asked support for the two 64-channel NALU cards in addition to the two 16-channel CAEN VX2751 digitizers for comparison and to test the current division reading and the time difference between the two ends of the wires

2025 full-length prototype: Schedule

- First phase of conceptual design of full chamber completed as of today by a collaboration of EnginSoft and INFN-LE mechanical service (+ a PhD student from Bari Politecnico): final draft of technical report ready
- Full design of full-scale prototype completed by summer 2024 by EnginSoft (purchase order issued) with INFN-LE mechanical service
- Preparation of samples of prototype components (molds and machining) ready by fall 2024 by CETMA consortium
- All mechanical parts (wires, wire PCBs, spacers, end plates) ready by end of 2024
- MEG2 CDCH2 Wiring robot transported from INFN-PI (being used for MEG2 CDCH2 until May 2024) to INFN-LE/BA, refurbished and re-adapted, to be operational by spring 2025
- Wiring and assembling clean rooms:
  - INFN-LE clean room currently occupied by ATLAS ITK assembly (until 2026 ?)
  - Investigating the possibility of renovate a clean room at INFN-BA or at CNR-LE (subject to agreement between INFN and CNR)
- Wiring and assembling operations would occur during second half of 2025
- Prototype built by end of 2025/beginning 2026 and ready to be tested during 2026

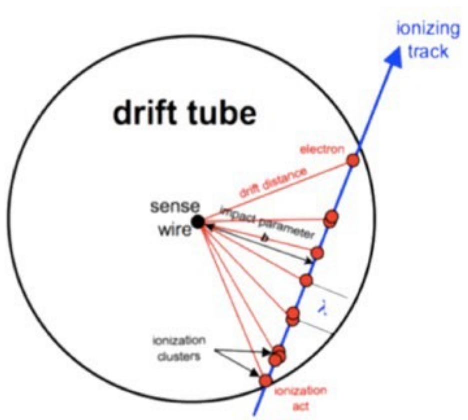
N. B. Aggressive schedule strongly depending on the funding

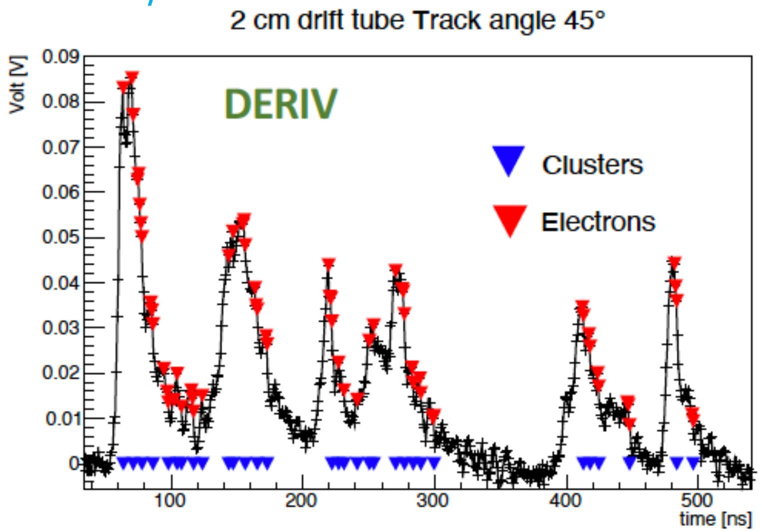
Testbeam data analysis

The Drift Chamber: Cluster Counting/Timing and PID

Principle: In He based gas mixtures the signals from each ionization act can be spread in time to few ns. With the help of a fast read-out electronics they can be identified efficiently.

- By counting the number of ionization acts per unit length (dN/dx), it is possible to identify the particles (P.Id.) with a better resolution w.r.t the dE/dx method.





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

Requirements

fast front-end electronics

(**bandwidth ~ 1 GHz**)

high sampling rate digitization

(**~ 2 GSa/s, 12 bits, >3 KB**)

- Landau distribution of dE/dx originated by the mixing of primary and secondary ionizations, has large fluctuations and limits separation power of PID → primary ionization is a Poisson process, has small fluctuations

- The cluster counting is based on replacing the measurement of an ANALOG information (the [truncated] mean dE/dX) with a DIGITAL one, the number of ionisation clusters per unit length:

dE/dx: truncated mean cut (70-80%), with a 2m track at 1 atm give $\sigma \approx$ 4.3%

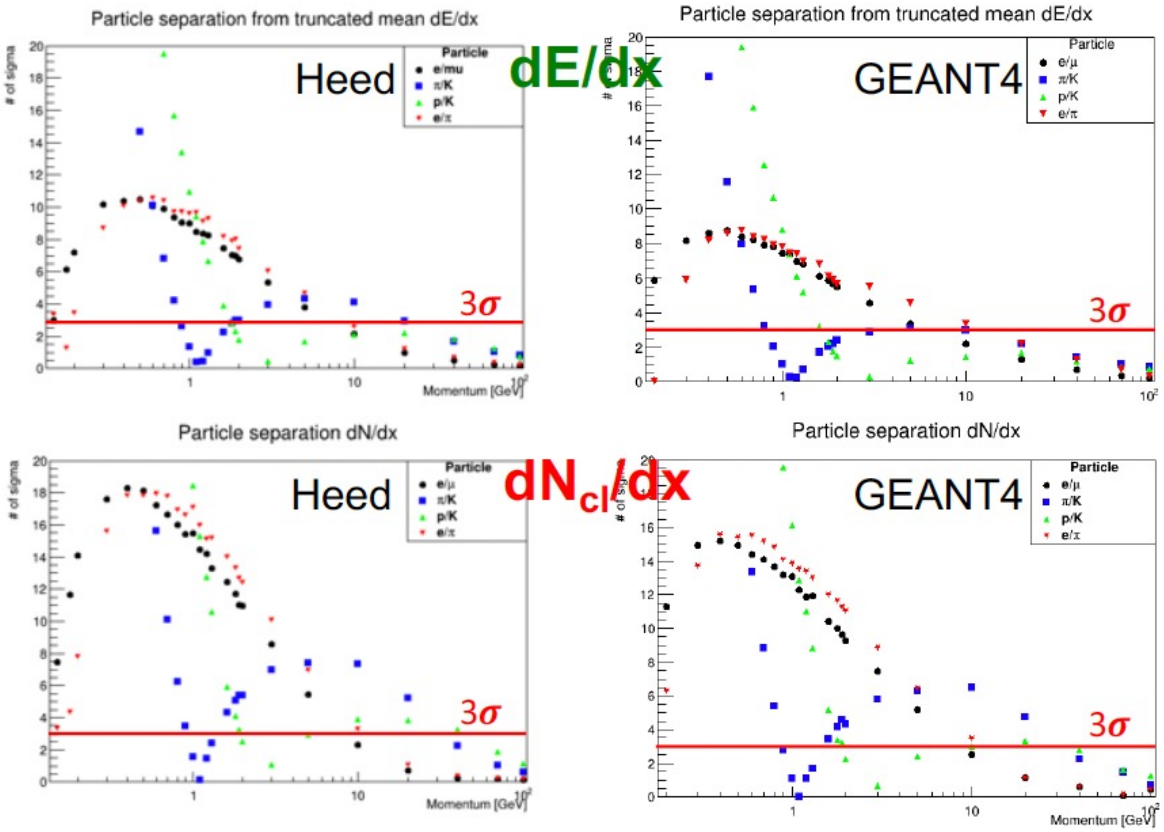
dN_{cl}/dx: for He/iC_4H_{10}=90/10 and a 2m track gives $\sigma_{dNcl/dx}$ **/(dN_{cl}/dx)** < 2.0%

N. De Filippis

The Drift Chamber: Cluster Counting/Timing and PID

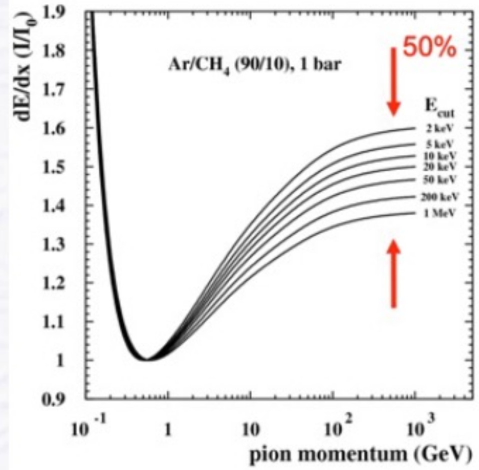
2.0 m long tracks in 90/10 He/iC_4H_{10}

full simulation



F. Cuna, N. De Filippis, F. Grancagnolo, G. Tassielli, Simulation of particle identification with the cluster counting technique, arXiv:2105.07064v1 [physics.ins-det] 14 May 2021

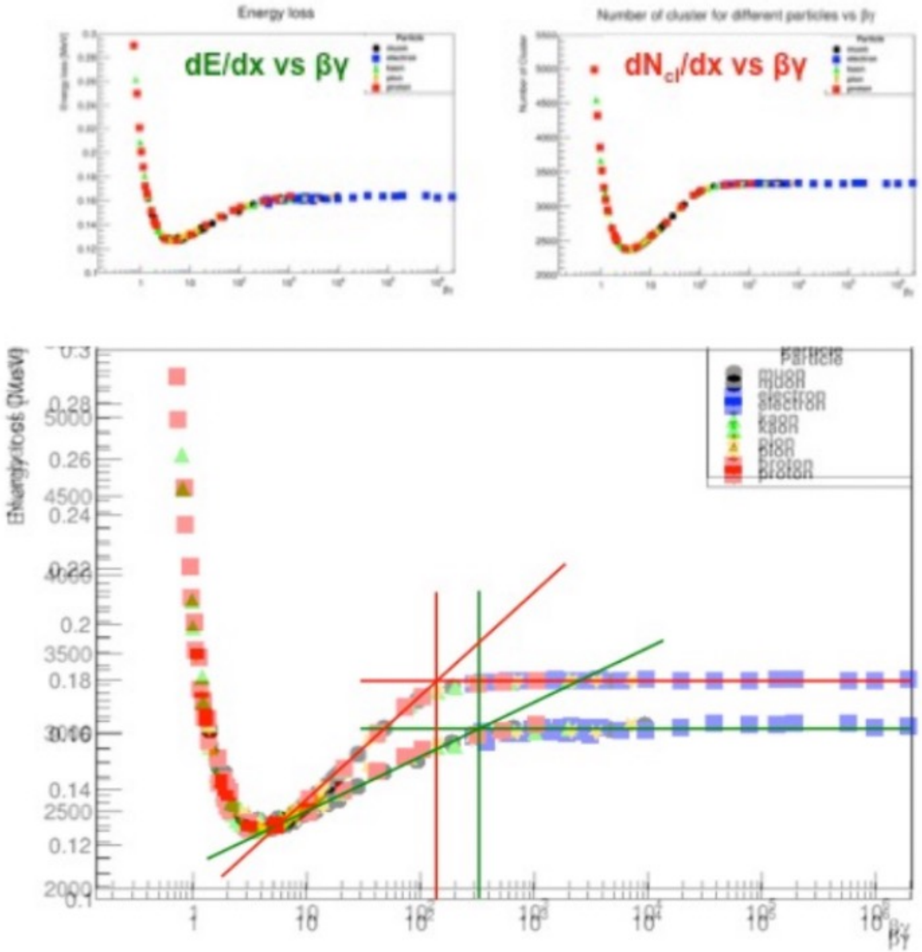
Geant4 uses the cluster density and the cluster size distributions derived from **Heed**, however, they **disagree**, most likely, due to a different choice of the **E_{cut}** parameter (the maximum energy of an electron still associated to a track in the simulation)



M. Hauschild Progress in dE/dx techniques used for particle identification NIM A379(1996) 436

The Drift Chamber: Cluster Counting/Timing and PID

GEANT4 with **HEED** clusterization model



F. Cuna, N. De Filippis, F. Grancagnolo, G. Tassielli, Simulation of particle identification with the cluster counting technique, arXiv:2105.07064v1 [physics.ins-det] 14 May 2021

Higher values of Fermi plateau for dN_{cl}/dx w.r.t. dE/dx, yet reached at lower $\beta\gamma$ values and with a steeper slope

due to a choice of E_{cut} (the maximum energy of an electron still associated to a track in the simulation) parameter?

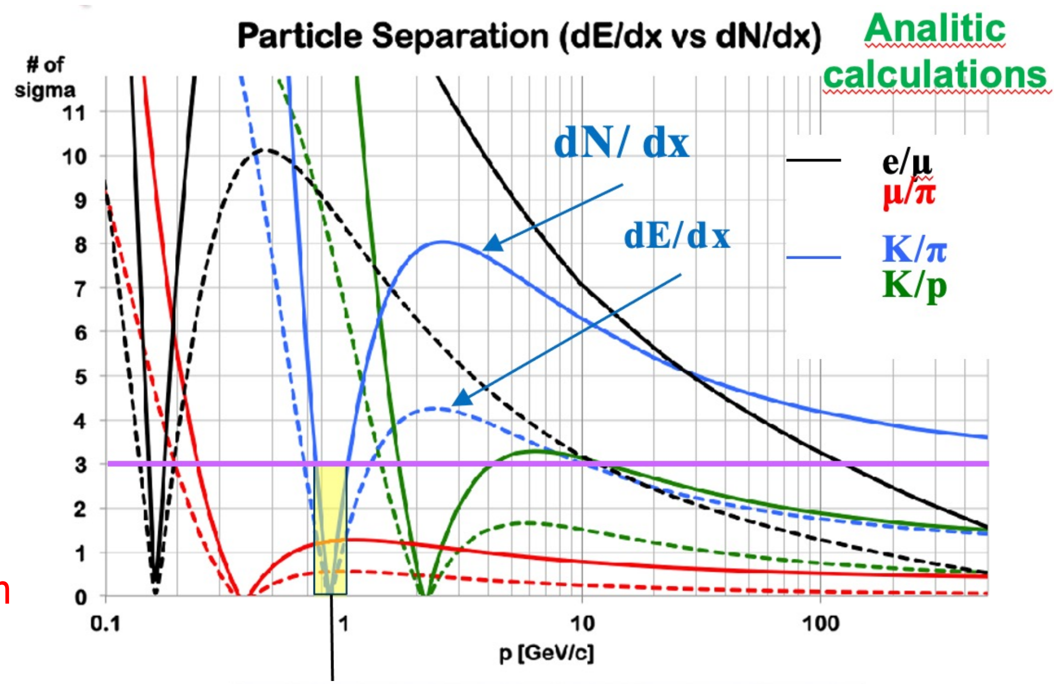
⇩

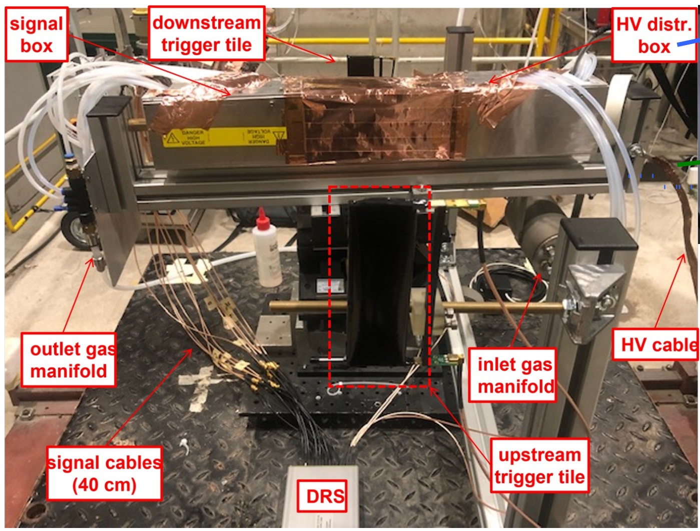
Experimental beam test campaign needed

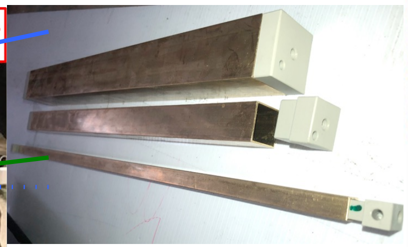
The Drift Chamber: Cluster Counting/Timing and PID

- Analitic calculations: Expected excellent K/π separation over the entire range except 0.85<p<1.05 GeV (blue lines)

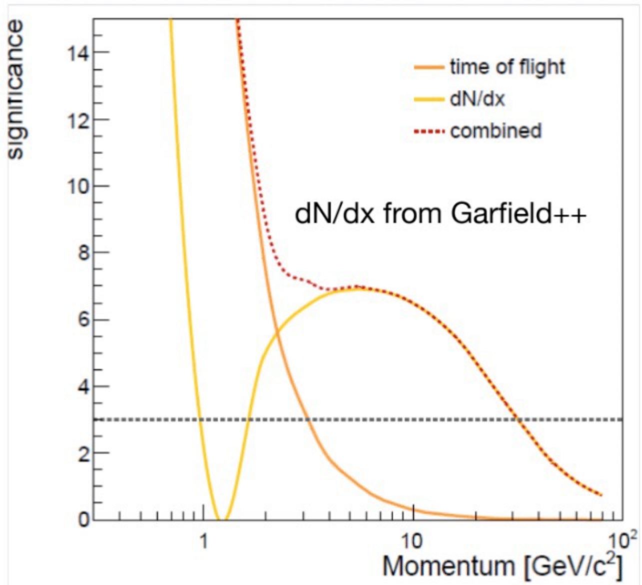
- Simulation with Garfield++ and with the Garfield model ported in GEANT4:
  - the particle separation, both with dE/dx and with dN_{cl}/dx, in GEANT4 found considerably worse than in Garfield
  - the dN_{cl}/dx Fermi plateau with respect to dE/dx is reached at lower values of $\beta\gamma$ with a steeper slope
  - finding answers by using real data from beam tests







90%He-10%iC_4H_{10}
nominal HV+20, 45°,
Gas gain ~ 2 · 10^5,
165 GeV/c

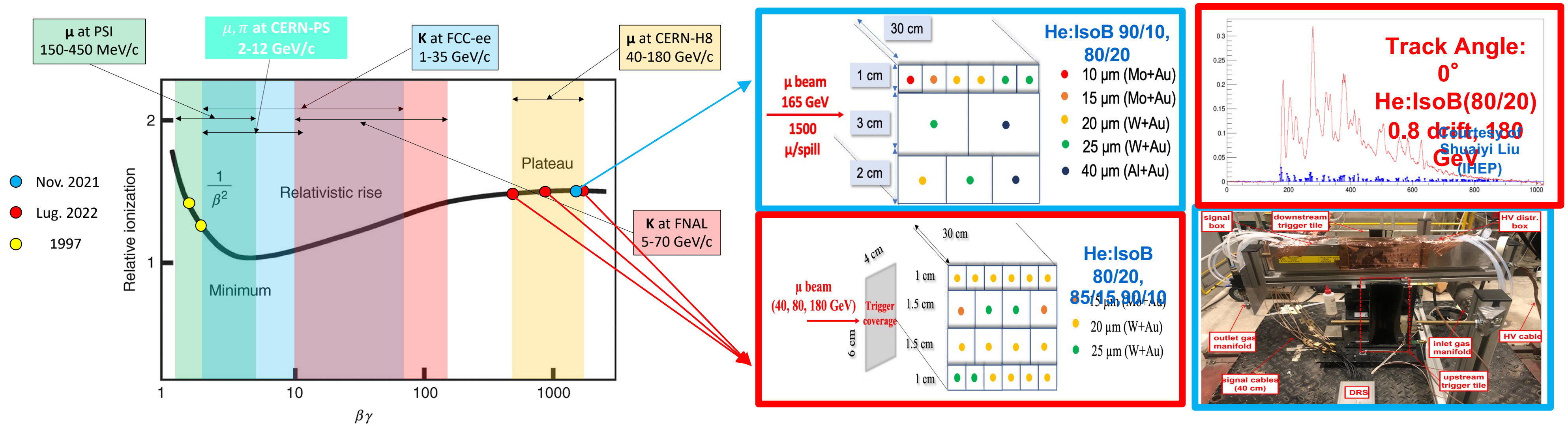


N. De Filippis

Beam tests in 2021,2022, 2023 and 2024

Beam tests to experimentally asses and optimize the **performance of the cluster counting/timing** techniques:

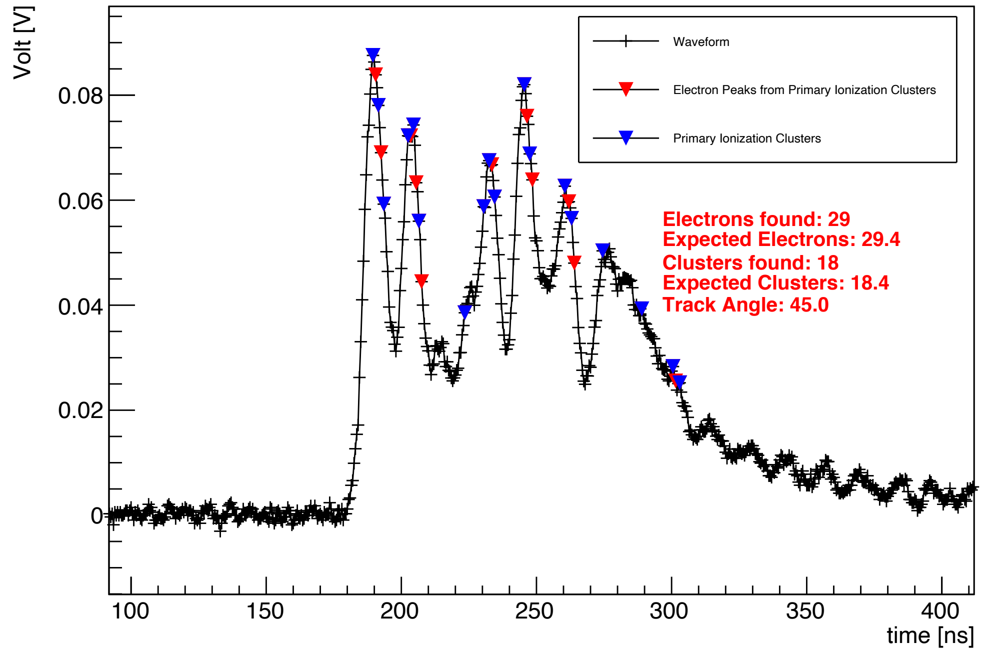
- Two **muon beam tests** performed at **CERN-H8** (**βγ > 400**) in Nov. 2021 and July 2022 (p_T = 165/180 GeV).
- A **muon beam test** (from 4 to 12 GeV momentum) in 2023 performed at **CERN**. A new testbeam with the same configuration done on July 10, 2024
- Ultimate test at **FNAL-MT6** in 2025 with π and **K (βγ = 10−140)** to fully exploit the relativitic rise.



2021/2022 beam test results: performance plots

- Several algorithms developed for electron peak finding:
  - ✓ Derivative Algorithm (DERIV)
  - ✓ and Running Template Algorithm (RTA)
  - ✓ NN-based approach (developed by IHEP)
- Clusterization algorithm to merge electron peaks in consecutive bins
- Poissonian distribution for the number of clusters as expected
- Different scans have been done to check the performance: (HV, Angle, gas gain, template scan)

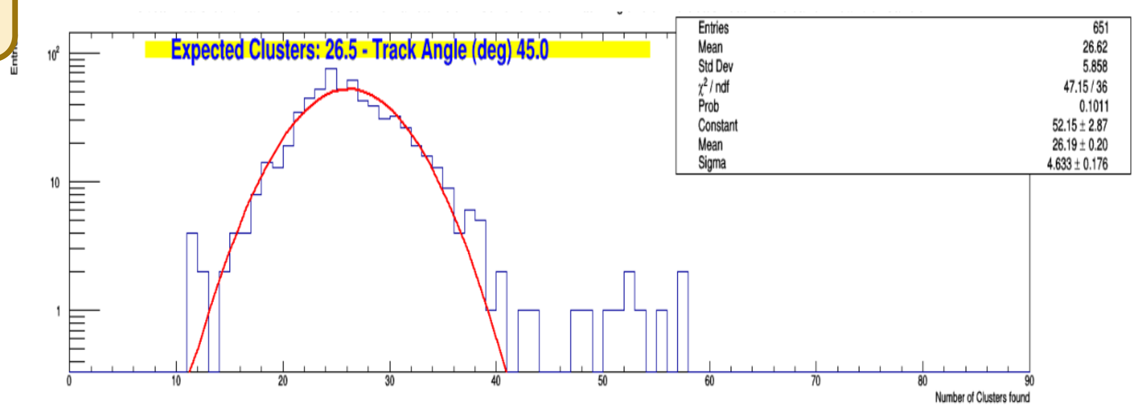
Sense Wire Diameter 15 μm; Cell Size 1.0 cm
Track Angle 45; Sampling rate 2 GSa/s
Gas Mixture He:IsoB 80/20



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 muon track w.r.t. normal direction to the sense wire
- δ cluster/cm (M.I.P) changes from 12, 15, 18 respectively for He:IsoB 90/10, 85/15 and 80/20 gas mixtures.
- drift tube size are 0.8, 1.2, and 1.8 respectively for 1 cm, 1.5 cm, and 2 cm cell size tubes.

Poissonian distribution for the number of clusters

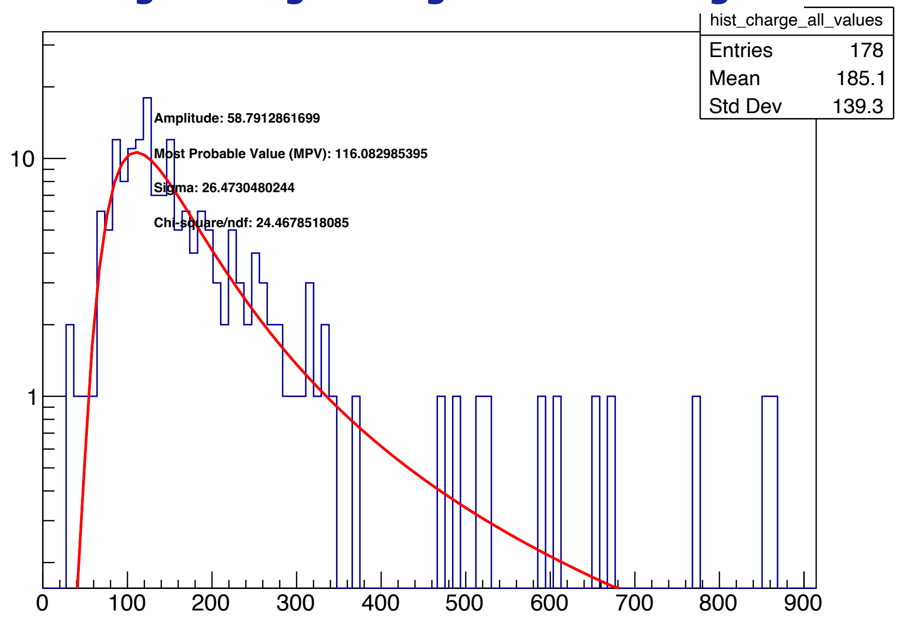


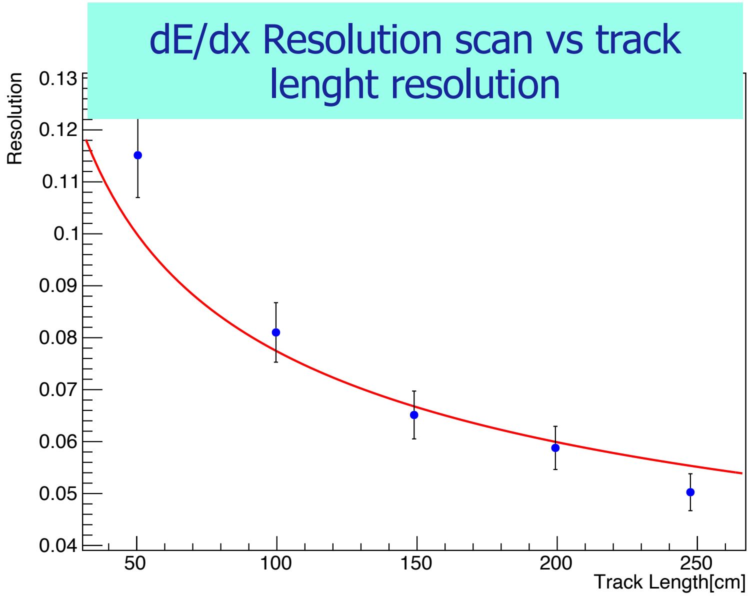
[1] H. Fischle, J. Heintze and B. Schmidt, Experimental determination of ionization cluster size distributions in counting gases, NIMA 301 (1991)

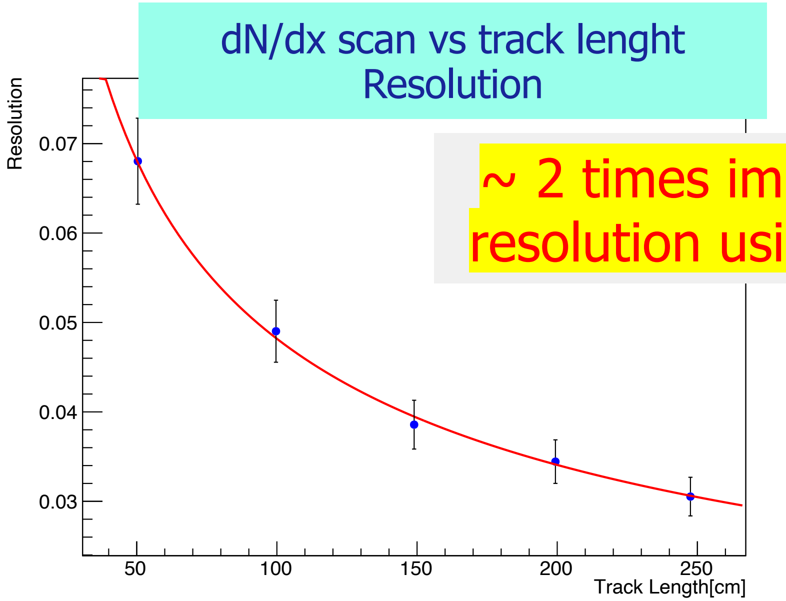
2021/2022 beam test results: resolutions

- Landau distribution for the charge along a track
- Selected the distribution with 80% of the charges for the dE/dx truncation, to be compared with dN/dx
- **NEW results**

Integral charges along a 2 m track length







~ 2 times improvement in the resolution using dN/dx method

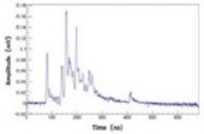
A complete report given at ICHEP

dE/dx resolution dependence on the track length $L^{-0.37}$

dN/dx resolution dependence on the track length $L^{-0.5}$

Challenge: Data reduction and pre-processing

The excellent performance of the **cluster finding** algorithms in offline analysis, relies on the assumption of being able to transfer the full spectrum of the digitized drift signals.
However ...



according to the **IDEA drift chamber operating conditions**:

- 56448 drift cells in 112 layers (~130 hits/track)
- maximum drift time of 500 ns
- cluster density of 20 clusters/cm
- signal digitization 12 bits at 2 Gsa/s

... and to the **FCC-ee running conditions at the Z-pole**

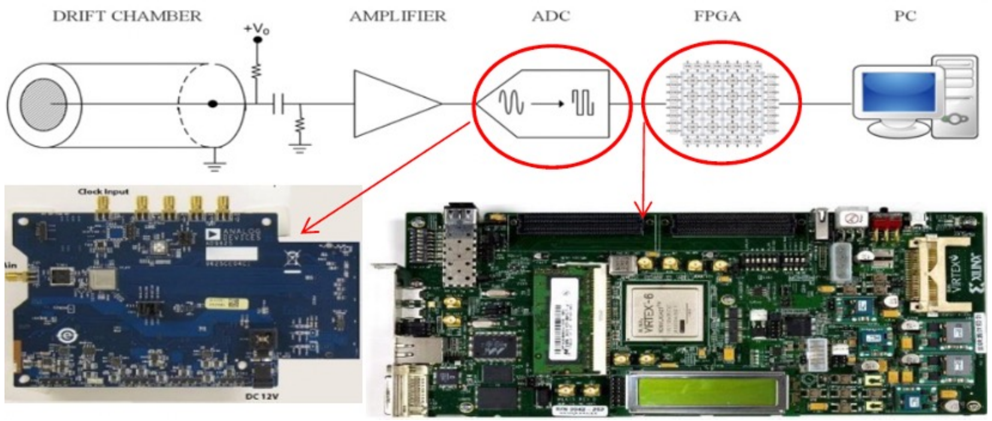
- 100 KHz of Z decays with 20 charged tracks/event multiplicity
- 30 KHz of $\gamma\gamma \longrightarrow$ hadrons with10 charged tracks/event multiplicity
- 2.5% occupancy due to beam noise
- 2.5% occupancy due to hits with isolated peaks

Reading both ends of the wires, ⇨ data rate ≥ 1 TB/s !

Solution consists in transferring, for each hit drift cell, instead of the full signal spectrum, only the minimal information relevant to the application of the **cluster timing/counting techniques**, i.e.:

the amplitude and **the arrival time** of each peak
associated with each individual ionisation electron.

This can be accomplished by using a **FPGA** for the **real time analysis** of the data generated by the drift chamber and successively digitized by an ADC.

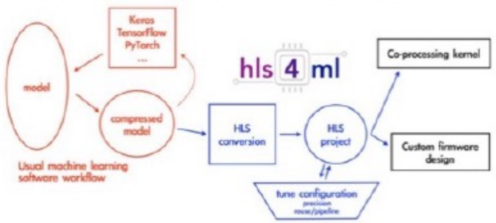


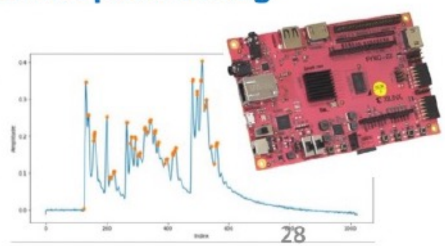
Single channel solution has been successfully verified.

G. Chiarello et al., The Use of FPGA in Drift Chambers for High Energy Physics Experiments May 31, 2017
DOI: 10.5772/66853

With this procedure **data transfer rate is reduced to ~ 25 GB/s**
Extension to a 4-channel board is in progress. Ultimate goal is a multi-ch. board (128 or 256 channels) to **reduce cost** and complexity of the system and to gain flexibility in determining the **proximity correlations** between hit cells for track **segment finding** and for **triggering** purposes.

Implementing ML algorithms on FPGA for peak finding





Activity in IJCLab

Institute A.1: Laboratoire de Physique des 2 Infinis Irène Joliot-Curie (IJCLab-IN2P3)

The contact person of IJCLab for the DRD1 is Gabriel CHARLES. IJCLab has 1 active specialist of gaseous detectors. Though, a technical team composed of 6 engineers and technicians is capable to build drift chambers. The group has an extensive track record in building drift chambers such as the drift chambers for the di-muon arm of ALICE, local experiments, R&D prototypes as well as the ALERT hyperbolic drift chamber that will be installed at the center of the CLAS12 experiment in Hall B of Jefferson Lab, Virginia. The main interest R&D tasks of the group are T3, T4, T5 and T6. Before the DRD1 community was created, two aspects were developed. The first one is about placing 30 µm diameter wires less than 2 mm apart in a hyperbolic drift chamber. The second one aspect focuses on finding new wires (resistive or not) to reduce the constraints on the mechanics as well as the quantity of material in the active area.

- **D 4.1 Performance on prototypes of drift cells at different granularities and with different field configurations**
- **D 5.1 Construction of a magnetron sputtering facility for metal coating of carbon wires**

Summary/Conclusions

Good progress reported on:

- mechanical structure design
- on going effort to build a full-length prototype next year
- testbeam data analysis → NEW results

Plenty of areas for collaboration (also in the context of DRD1 WP2):

- detector design, construction, beam test, performance
- local and global reconstruction, full simulation
- physics performance and impact
- etc.

Effort to build a international collaboration enforced

- well established collaboration with IHEP for NN-based cluster counting algorithms
- started to collaborate with US people from BNL

Backup

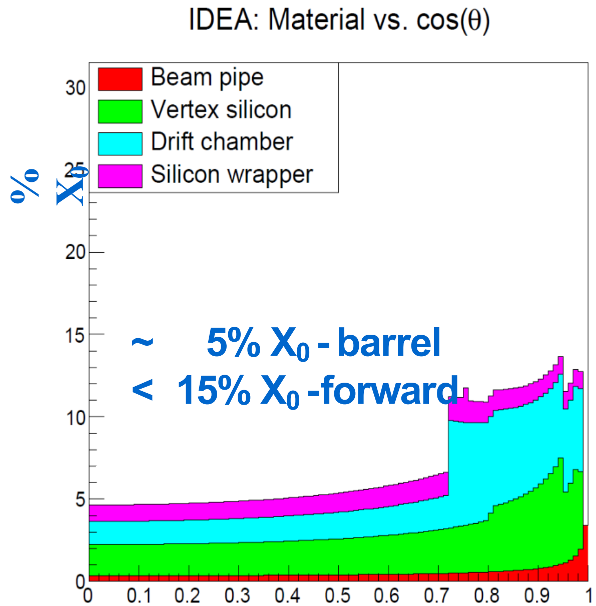
Requirements on track momentum resolution

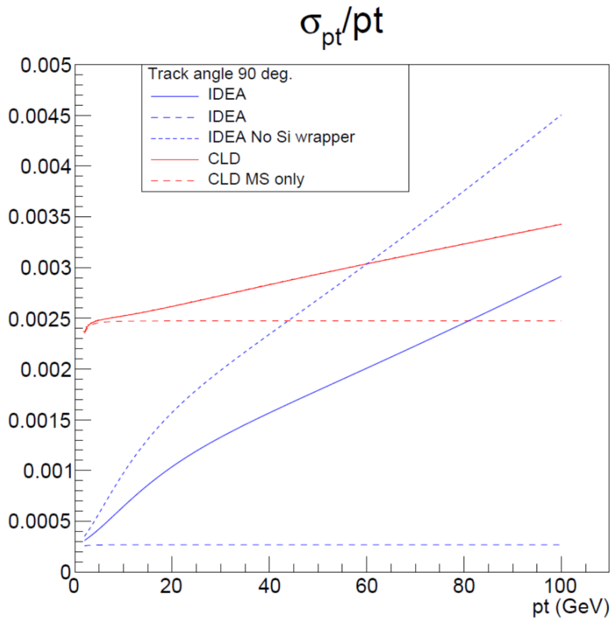
The IDEA Drift Chamber is designed to cope with transparency

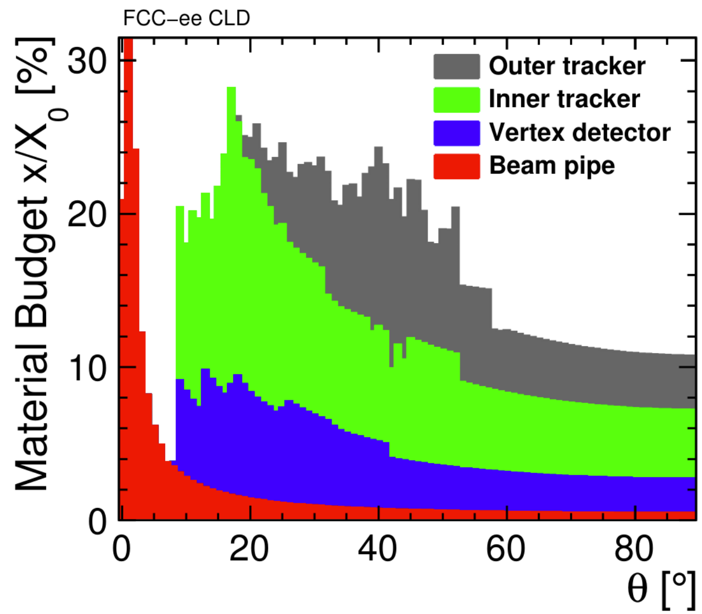
- a unique-volume, high granularity, fully stereo, low-mass cylindrical
- gas: He 90% - iC_4H_{10} 10%
- inner radius 0.35m, outer radius 2m
- length L = 4m

The CLD silicon tracker is made of:

- six barrel layers, at radii ranging between 12.7 cm and 2.1 m, and of eleven disks.
- the material budget for the tracker modules is estimated to be 1.1 − 2.1% of a radiation length per layer







For 10 GeV (50 GeV) μ emitted at an angle of 90° w.r.t the detector axis, the p_T resolution is

- about 0.05 % (0.15%) with the very light IDEA DCH
- about 0.25% (0.3%) with the CLD full silicon tracker, being dominated by the effect of MS

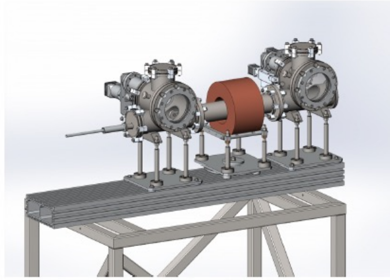
Challenges for large-volume drift chambers

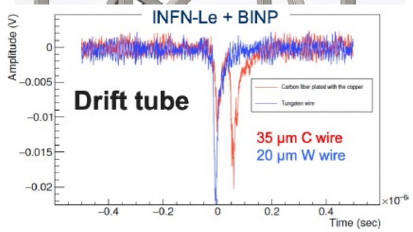
- **Electrostatic stability** condition: $\frac{\lambda^2}{4\pi\varepsilon}\frac{L^2}{w^2} < \textit{wire tension} < YTS \cdot \pi r_w^2$

λ = linear charge density (gas gain)
L = wire length, r_w wire radius, w = drift cell width
YTS = wire material yield strength

  The proposed drift chambers for FCC-ee and CEPC have lengths **L = 4 m** and plan to exploit the **cluster counting** technique, which requires gas gains **~5×10⁵**.
  This poses serious constraints on the drift cell width (**w**) and on the wire material (**YTS**).

  ⇒ new wire material studies



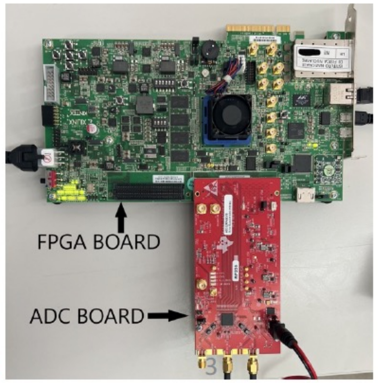


- **Non-flammable gas / recirculating gas systems**
  Safety requirements (**ATEX**) demands stringent limitations on flammable gases;
  Continuous increase of **noble gases cost**

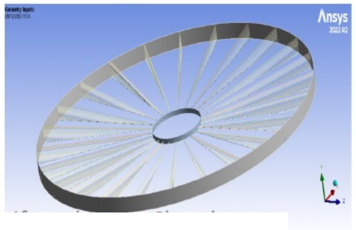
  ⇒ gas studies

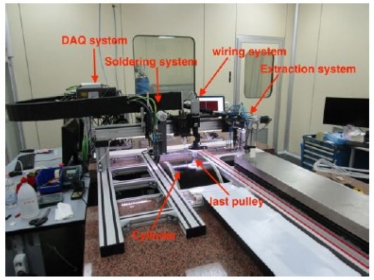
- **Data throughput**
  Large number of channels, high signal sampling rate, long drift times (slow drift velocity), required for **cluster counting**, and high physics trigger rate (Z_0-pole at FCC-ee) imply data transfer rates in excess of **~1 TB/s**

  ⇒ on-line real time data reduction algorithms



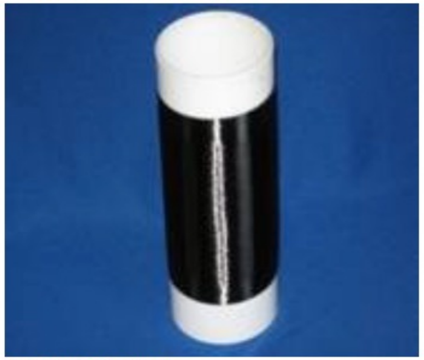
- **New wiring systems for high granularities / / new end-plates / new materials**





1st CHALLENGES: wire types – Carbon monofilament

SPECIALTY MATERIALS, INC.
Manufacturers of Boron and SCS Silicon Carbide Fibers and Boron Nanopowder
CARBON MONOFILAMENT



TYPICAL PROPERTIES

Diameter:	0.00136 +/- 0.0001" (34.5 +/- 2.5 µm)	
Tensile Strength:	125 ksi (0.86 GPa)	0.65 GPa
Tensile Modulus:	6 msi (41.5 GPa)	
Electrical Resistivity:	3.6 x 10⁻³ ohm cm	37 KΩ/m
Density:	1.8 g/cc	

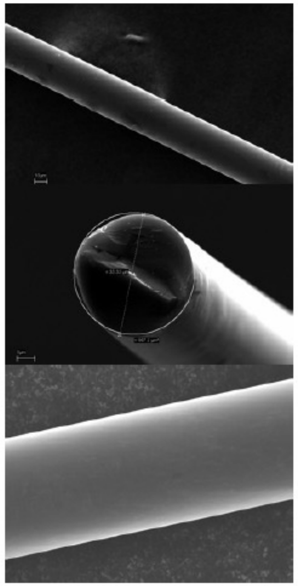
Specialty Materials, Inc.
1449 Middlesex Street
Lowell, Massachusetts 01851

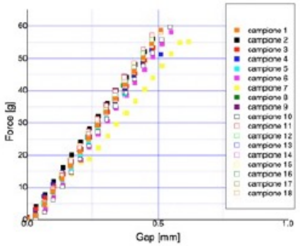
Phone: 978-322-1900
Fax: 978-322-1970

CARBON MONOFILAMENT PRODUCT PRICE LIST
Effective October 1, 2017

CARBON MONOFILAMENT PRODUCT PRICE LIST EFFECTIVE APRIL 1, 2019

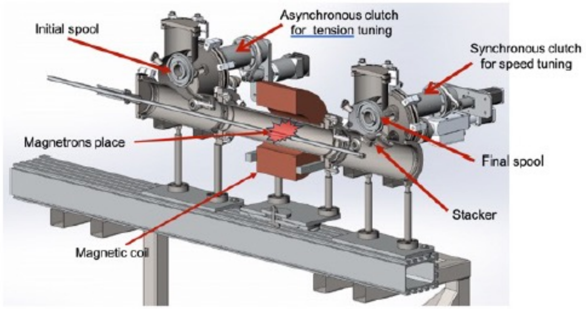
Product	Quantity	Price per LF
CARBON MONOFILAMENT	1 Million LF	$0.02 60 €/Km
	500,000 LF	$0.03
	1,000 LF	$0.94

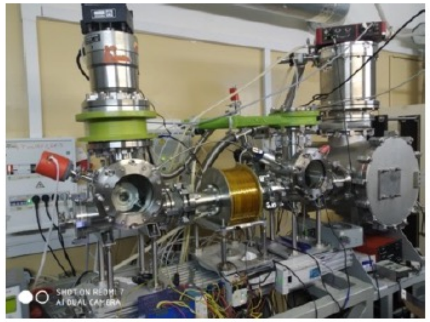


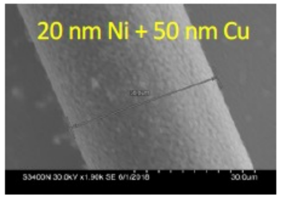


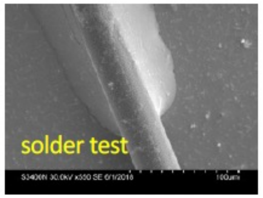
Metal coating by HiPIMS: High-power impulse magnetron sputtering

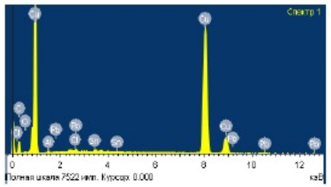
physical vapor deposition (PVD) of thin films based on magnetron sputter deposition (extremely high power densities of the order of kW/cm² in short pulses of tens of microseconds at low duty cycle <10%)

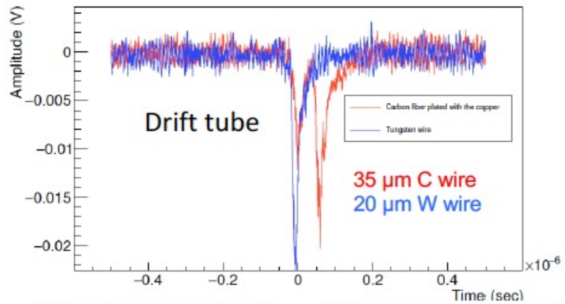


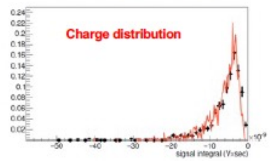


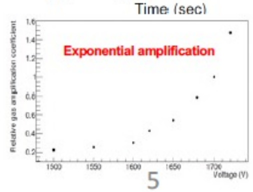










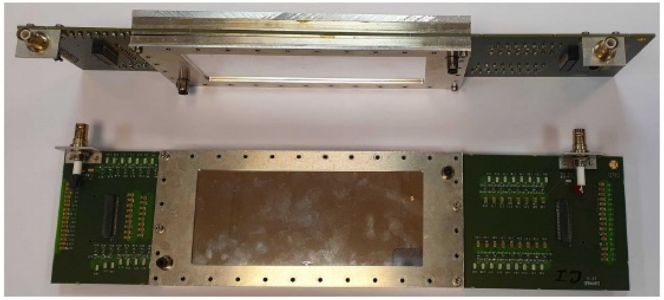


N. De Filippis

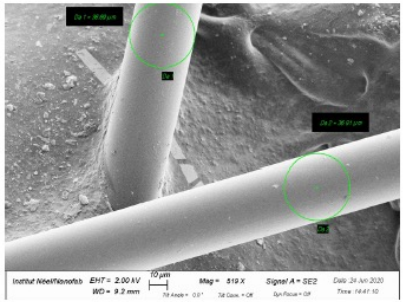
1st CHALLENGES: wire types – Carbon monofilament

Blue Sky R&D at in2p3 to find new wire material

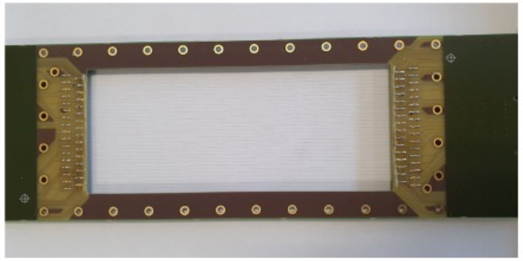
3 groups implied
2 with wiring
machines



Design a simple detector (active area 17x7 cm^2) to test different types of wires



Carbone wires seen from SEM



Carbon wire chamber soldered then glued

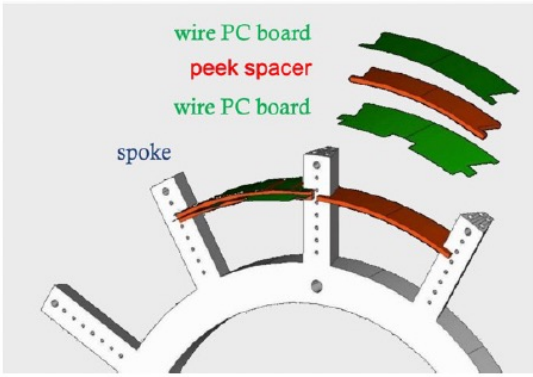
First results in 2017 *Carbon wire chamber at sub-atmospheric pressure, G. Charles et al., NIM A*

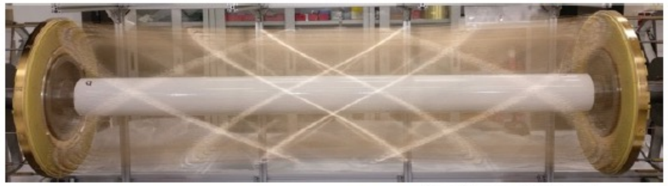
Tests with radioactive sources at 1 atm are on going for carbon wires and soldered AlMg5 wires.

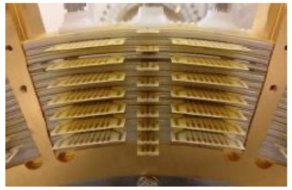
Next step will be beam tests and **internationalize the collaboration**.

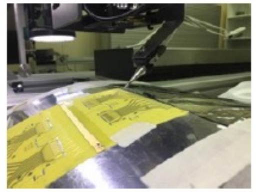
2nd CHALLENGE: 350,000 wires!

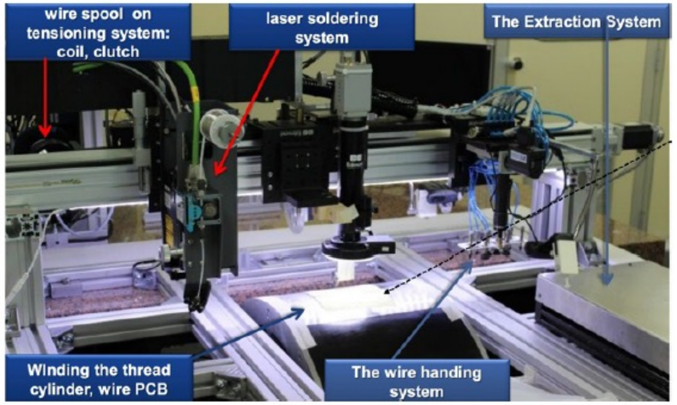
Evolution of the MEG2 drift chamber wiring











Wiring robot at INFN Lecce:
32 wires at once

MEG2: 12 wires/cm^2
IDEA: 4 wires/cm^2

Very different dimensions!
+ tension recovery scheme

2025 full-length prototype: Costs

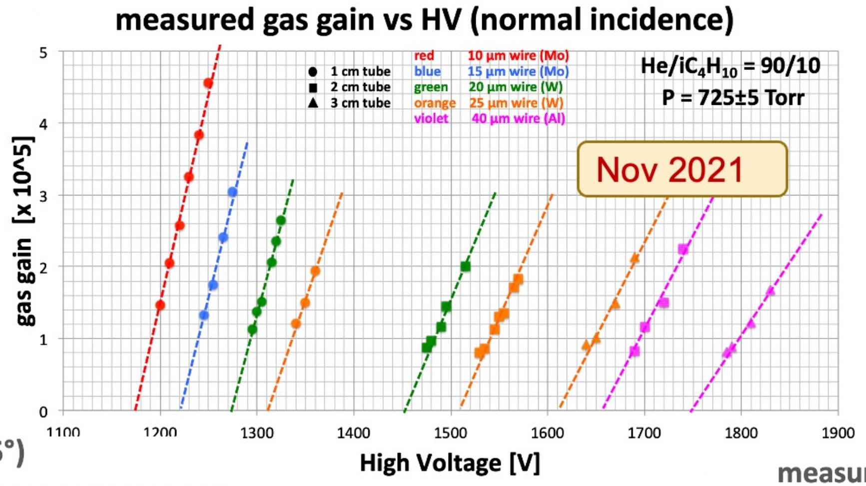
- Drift Chamber conceptual design (20 k€ from EURIZON-LE, invoice paid to EnginSoft)
- Full-Scale Prototype design (20 k€ from EURIZON-LE, purchase order issued to EnginSoft)
- Full-Scale Prototype design and material tradeoffs (molds and machining) (20 k€ from EURIZON-LE, purchase order issued to CETMA)
- Full-Scale Prototype components (inner cylinder and 8 spokes) (20 k€ from EURIZON-LE, purchase order issued to CETMA)
- Wires from CFW: 10 Km of 50 μm Al for field and guard; 1 Km of 20 μm W for sense (15 k€ from EURIZON-BA)
- Wires from Specialty Materials: 900 m of 35 μm C monofilament (5 k€ from EURIZON-LE)
- Wiring robot from MEG2 CDCH CSN1 funds to INFN-LE (estimated 100 k€)

Costs to be borne (late 2024 and 2025)

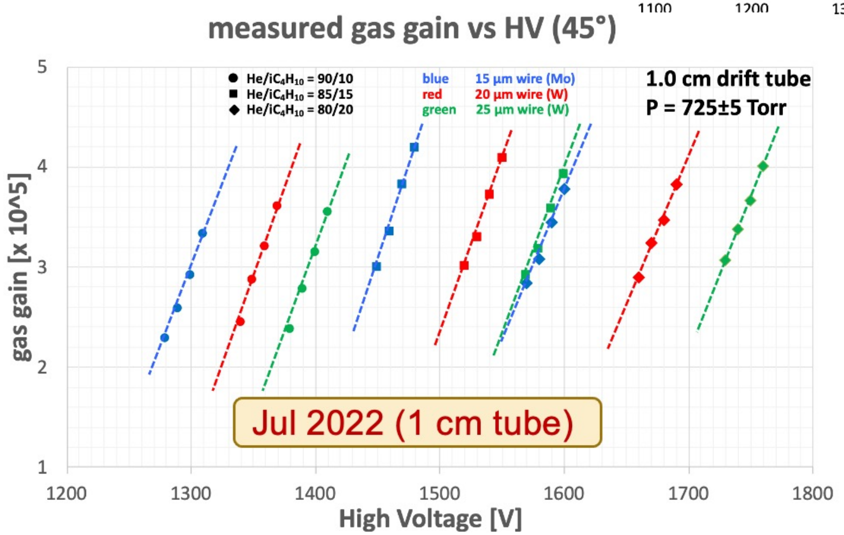
- Additional wires
- Wire PCBs
- Peek spacer
- Wiring robot refurbishing
- Mechanical support and gas envelope
- Front-end, digitizers and acquisition electronics

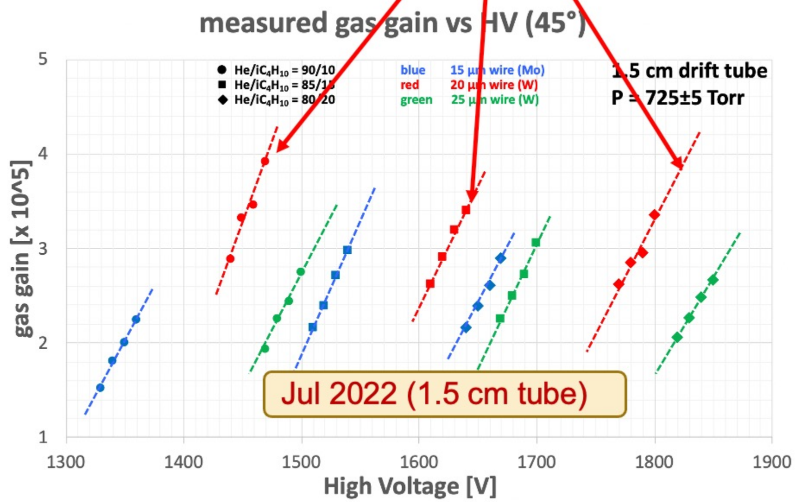
2021/2022 beam test results: gas gain scan

The range of gas gain, independently of the drift tube configuration (drift length, sense wire diameter, gas mixture), lies within 1×10^5 and 5×10^5.



20µm wire excluded from physical quantities mean computation





Peak finding algos: Derivative vs RTA

Derivative Algorithm (DERIV)

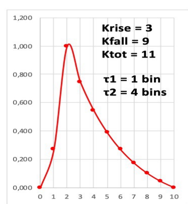
Find good electron peak candidates at position bin n and amplitude A_n :

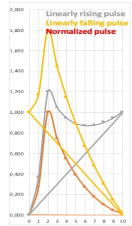
- Compute the first and second derivative from the amplitude average over two times the timing resolution and require that, at the peak candidate position, they are less than a r.m.s. signal-related small quantity and they increase (decrease) before (after) the peak candidate position of a r.m.s. signal-related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

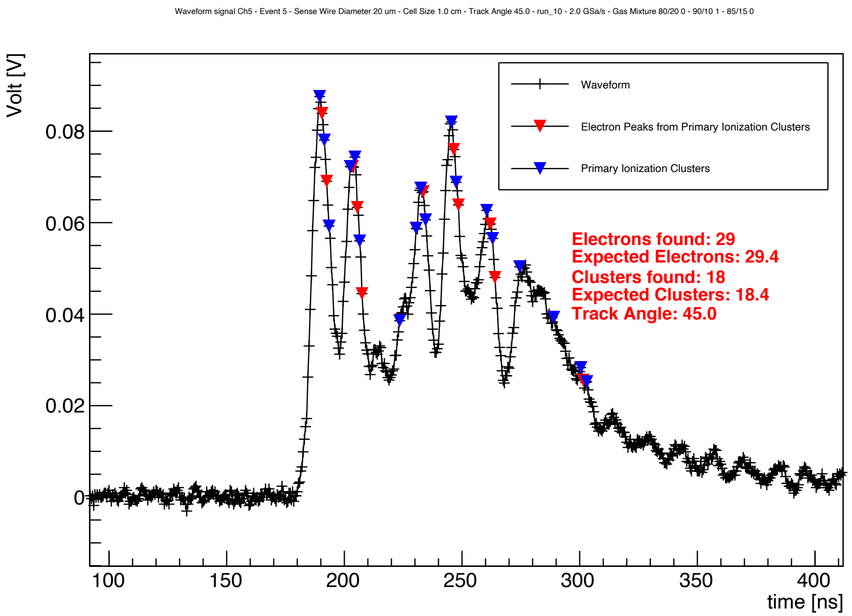




Peak finding algos: clusterization algo

Sense Wire Diameter 15 μm; Cell Size 1.0 cm; Track Angle 45; Sampling rate 2 GSa/s; Gas Mixture He:IsoB 80/20

- ***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 ~$\sqrt{t_{ElectronPeak}}$ 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!***



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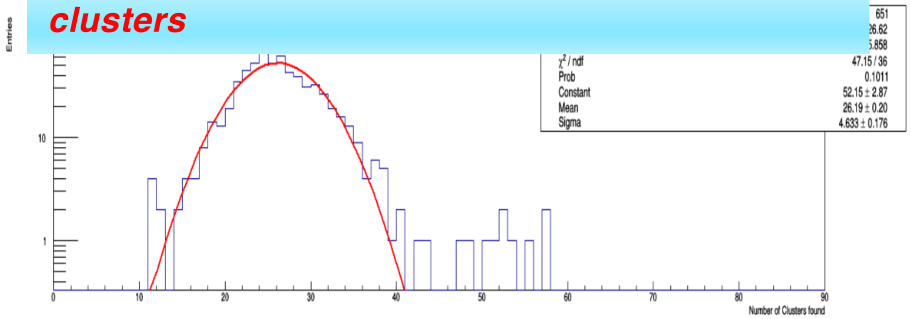
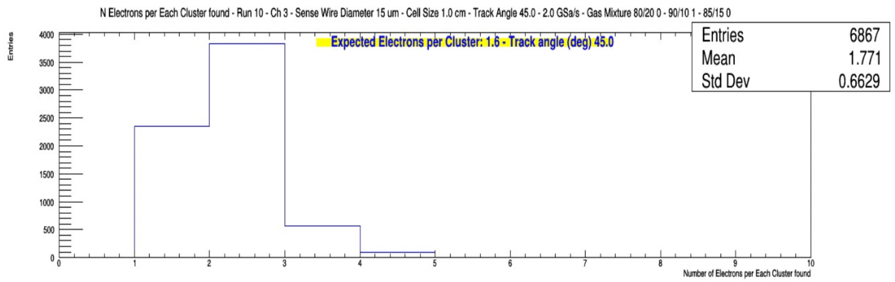
Reconstruction of primary ionization clusters

Sense Wire Diameter 15 μm; Cell Size 1.0 cm; Track Angle 45; Sampling rate 2 GSa/s; Gas Mixture He:IsoB 80/20

Poissonian distribution for the number of clusters



Electrons per cluster distribution



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

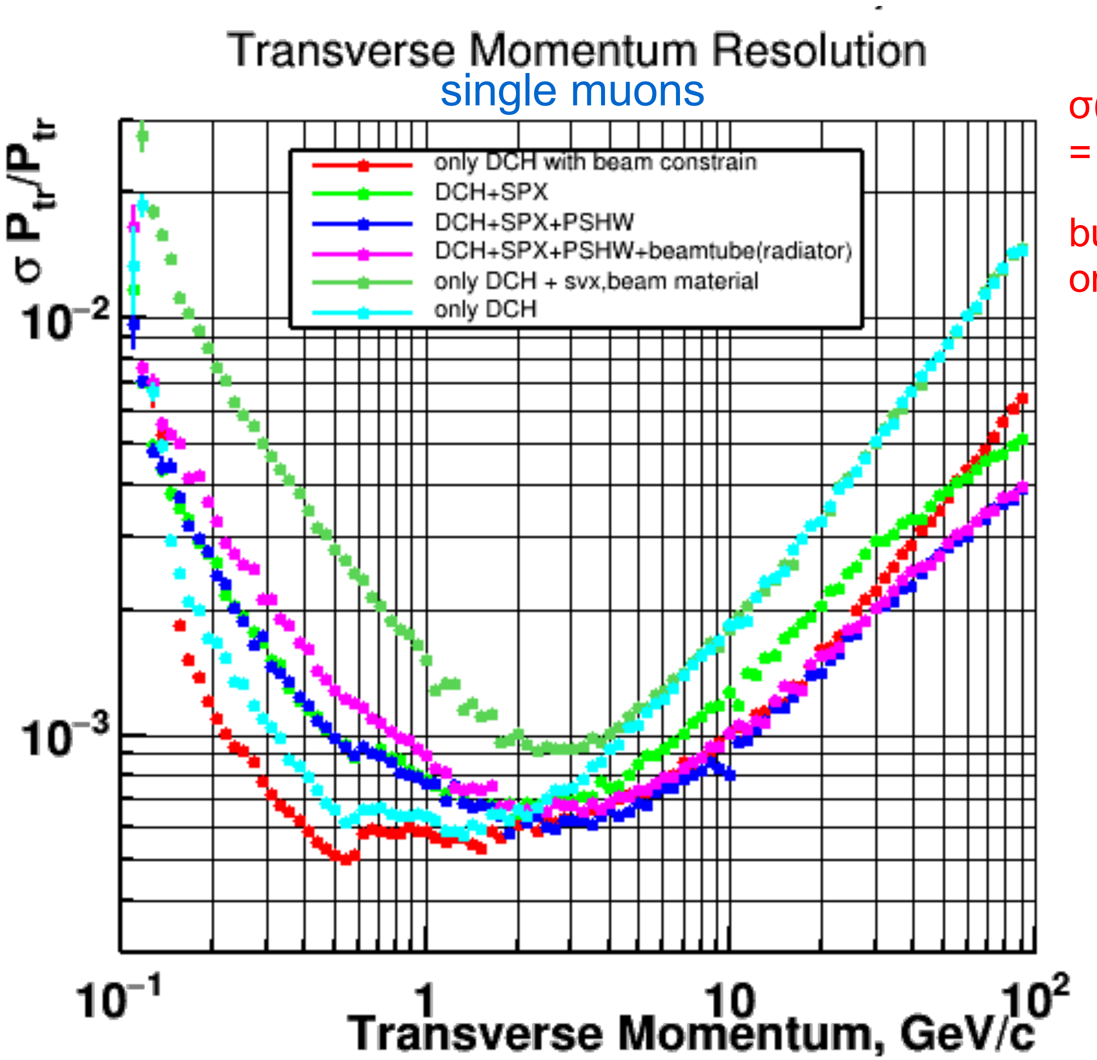
α = angle of the muon track w.r.t. normal direction to the sense wire.
δ cluster/cm (mip) changes from 12, 15, 18 respectively for He:IsoB 90/10, 85/15 and 80/20 gas mixtures.
drift tube size are 0.8, 1.2, and 1.8 respectively for 1 cm, 1.5 cm, and 2 cm cell size tubes.

Poissonian distribution of the number of clusters and cluster size in acceptance with the expectation

Track finding: performance of the current IDEA

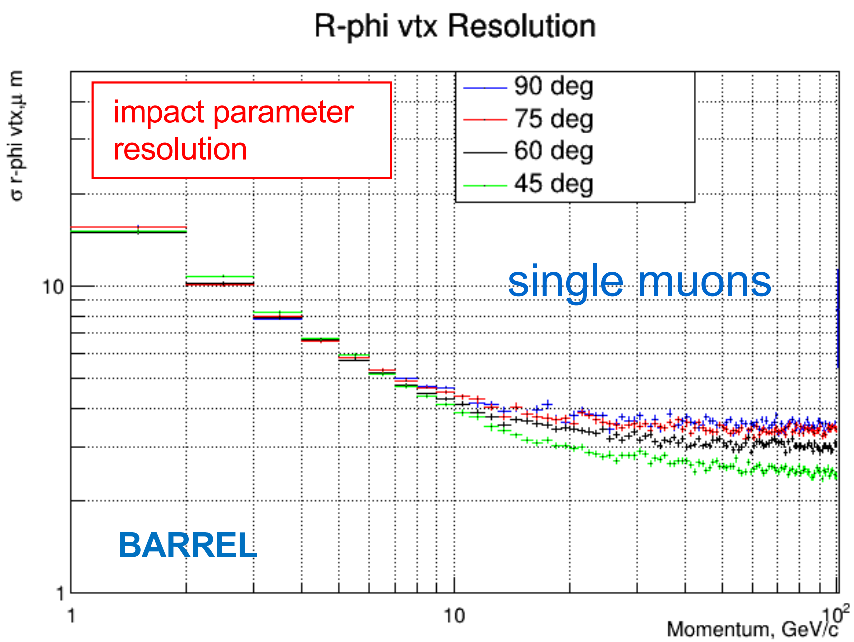
For the Geant4 based simulation framework code:

$$\frac{\Delta p_T}{p_T}\Big|_{res.} = \frac{\sigma_{r\phi}\, p_T}{0.3\, B_0 L_0^2}\sqrt{\frac{720N^3}{(N-1)(N+1)(N+2)(N+3)}}$$
$$\approx \frac{12\,\sigma_{r\phi}\, p_T}{0.3\, B_0 L_0^2}\sqrt{\frac{5}{N+5}}$$
$$\frac{\Delta p_T}{p_T}\Big|_{m.s.} = \frac{N}{\sqrt{(N+1)(N-1)}}\,\frac{0.0136\,\mathrm{GeV/c}}{0.3\beta\, B_0 L_0}\sqrt{\frac{d_{tot}}{X_0\,\sin\theta}}\left(1+0.038\ln\frac{d}{X_0\,\sin\theta}\right)$$



$\sigma(p_t)/p_t$ (100 GeV) $= 3\times10^{-3}$

but new studies ongoing



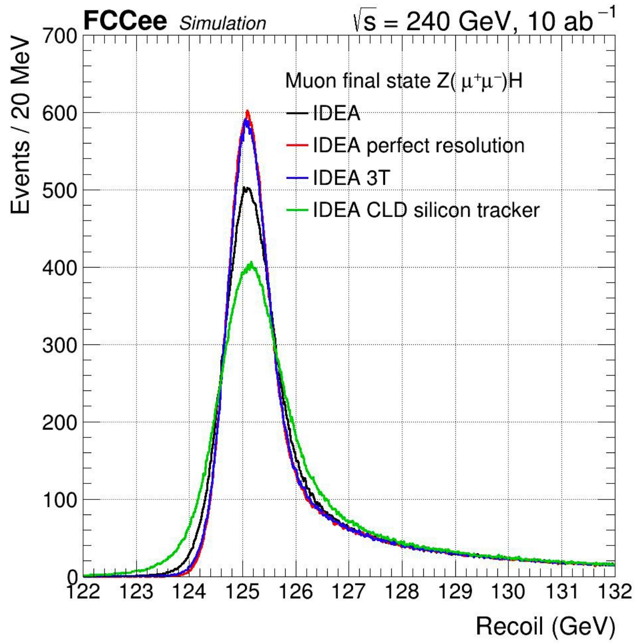
$\sigma(d_0)$ (100 GeV) = 2μm

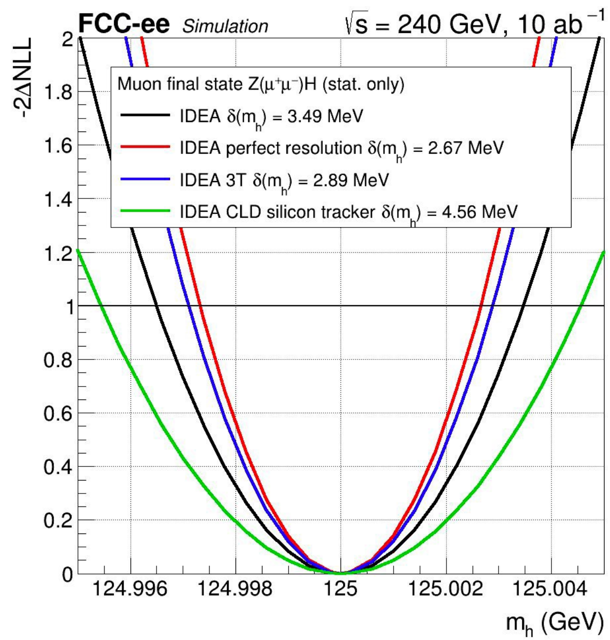
Constraint from Higgs Mass measurement

Higgs boson mass to be measured with a precision better than its natural width (4MeV), in view of a potential run at the Higgs resonance

Higgs mass reconstructed as the recoil mass against the Z, M_{recoil} , and solely from the Z

$$M^2_{recoil} = (\sqrt{s} - E_{l\bar{l}})^2 - p^2_{l\bar{l}} = s - 2E_{l\bar{l}}\sqrt{s} + m^2_{l\bar{l}}$$





μ from Z, with momentum of O(50) GeV, to be measured with a p_T resolution smaller than the BES in order for the momentum measurement not to limit the mass resolution

- achieved with the baseline IDEA detector → uncertainty of 4.27 MeV with 10 ab^{-1}
- CLD performs less well because of the larger amount of material → larger effects of MS

If the B increased from 2T to 3T → 50% improvement of the momentum resolution
14% improvement on the total mass uncertainty

DRD1 Gaseous Detector - collaboration

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

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Participating institutes

- Laboratoire de Physique des 2 Infinis Irène Joliot-Curie(IJCLab-IN2P3)
- INFN, Bari (INFN-BA)
- INFN, Lecce (INFN-LE)
- INFN, Rome (INFN-RM)
- US cluster (US)
- Nankai University (Nankai U.)
- Tsinghua University (Tsinghua U.)
- Institute of High Energy Physics, Chinese Academy of Sciences (IHEP-CAS)
- Wuhan University (Wuhan U.)
- Jilin University (Jilin U.)
- University of Science and Technology of China (USTC)
- Institute of Modern Physics, Chinese Academy of Sciences (IMP-CAS)
- Bose Institute (Bose)

R & D Tasks for WP2

T1: Development of front-end ASIC for cluster counting

- Performance goal:
  - High bandwidth and gain pre-amplifiers
  - Low power
  - Low mass
- Main developments covered:
  - achieve efficient cluster counting and cluster timing performances
- Deliverables next 3y:
  - full design/construction/test of a prototype of the frontend ASIC for cluster counting

T2: Development of a scalable multichannel DAQ board

- Performance goal:
  - High sampling rate
  - Dead-time-less
  - Event time stamping
  - Track triggering
- Main developments covered:
  - FPGA based architecture
  - ML algorithms-based firmware
- Deliverables next 3y:
  - working prototype of a scalable multichannel DAQ board

R & D Tasks for WP2

T3: Mechanics: new wiring procedures and new endplate concepts

- Performance goal:
  - feed-through-less wiring procedures
  - more transparent endplates (< 5% X_0)
  - transverse geometry
- Main developments covered:
  - Separate the wire support function from the gas containment function
- Deliverables next 3y:
  - conceptual designs of novel wiring procedures
  - full design of innovative concepts of endplate

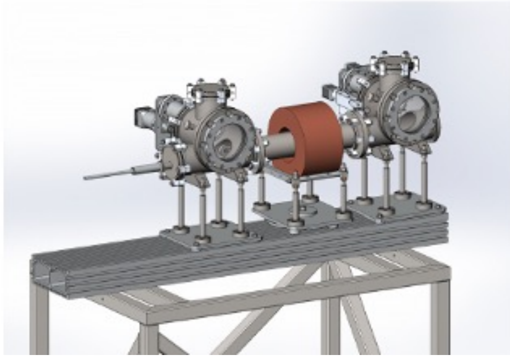
T4: Increase rate capability and granularity

- Performance goal:
  - smaller cell size and shorter drift time
  - higher field-to-sense ratio
- Main developments covered:
  - higher field-to-sense ratio allows to increase the number of field wires, decreasing the wire contribution to multiple scattering
- Deliverables next 3y:
  - measurements of performance on prototypes of drift cells at different granularities and with different field configurations

R & D Tasks for WP2

T5: Consolidation of new wire materials and wire metal coating

- Performance goal:
  - Electrostatic stability
  - High YTS (wire material yield strength)
  - Low mass, low Z
  - High conductivity



- Main developments covered:
  - Develop contacts with companies producing new wires
  - List companies
  - Metal coating of carbon wires
- Deliverables next 3y:
  - construction of a magnetron sputtering facility for metal coating of carbon wires

T6: Study ageing phenomena for new wire types

- Performance goal:
  - Establish charge collection limits for carbon wires as field and sense wires
- Main developments covered:
  - Build prototypes of drift chamber with new wires as field and sense wires
- Deliverables next 3y:
  - Tests of prototypes built with new wire types at beams and irradiation facilities
  - Measurement of performance on total integrated charge

R & D Tasks for WP2

T7: Optimization of gas mixing, recuperation, purification and recirculation systems

- Performance goal:
  - Non-flammable gas
  - High quenching power
  - Low-Z
  - High radiation length
  - High primary ions
- Main developments covered:
  - ATEX and safety requirements
  - cost of gas
  - Hydrocarbon-free mixtures
- Deliverables next 3y:
  - Performance of hydrocarbon-free gas mixtures
  - full design of a recirculating system

Final Table

#	Task	Performance goal	DRD1 WGs	ECFA DRDT	Milestones/Deliverable			Institutes
					12M	24M	36M	
T1	Front-end ASIC for cluster counting	- High bandwidth - High gain - Low power - Low mass	WG5, WG7.2	1.1 1.2	M1: **Achieving efficient cluster counting and cluster timing** performances by using FPGA based architecture → prototype of the front-end ASIC for cluster counting [T1]	M2: **Completion of a cylindrical sector** of a full length drift chamber prototype aimed at testing all mechanical properties [T3]	D: **Performance of K-pi separation** in the momentum range from 2 to 30 GeV/c based on a scalable front-end/digitizer/DAQ electronics chain for cluster counting.[T2]	INFN-BA, INFN-LE, INFN-RM BNL, FIT, U. Mass Amherst, U. Michigan, Irvine, Tufts U., U. Florida, U. Wisconsin IHEP-CAS, Nankai U., Tsinghua U.. USTC, IMP-CAS, Wuhan U, Jilin U., IJCLab-IN2P3. Bose. .
T2	Scalable multichannel DAQ board	- High sampling rate - Dead-time-less - DSP and filtering - Event time stamping - Track triggering	WG5 WG7.2	1.1 1.2				
T3	Mechanics: wiring procedures New endplate concepts	- feed-through-less wiring procedures - More transparent endplates (< 5% X_0) - transverse geometry	WG3 3.1C	1.1 1.3				
T4	High rate High granularity	- smaller cell size and shorter drift time - higher field-to-sense ratio	WG3 3.2E, WG7.2	1.3				
T5	New wire materials and wire metal coating	- Electrostatic stability - High YTS - Low mass, low Z - High conductivity - Aging	WG3 3.1C	1.1 1.2				
T6	Ageing of new wire types	- Establish charge collection limits for carbon wires as field and sense wires	WG3 3.2B WG7.3,4	1.1 1.2				
T7	Gas mixing, recuperation, purification and recirculation systems	- Non-flammable gas - High quenching power - Low-Z - High radiation length - High primary ions	WG3 3.1B 3.2C WG4, WG7.4	1.3				

Final Table

#	Task	Performance goal	DRD1 WGs	ECFA DRDT	Main developments covered	Deliverables next 3 y	Institutes
T1	Front-end ASIC for cluster counting	- High bandwidth - High gain - Low power - Low mass	WG5, WG7.2	1.1 1.2	achieve efficient cluster counting and cluster timing performances	full design, construction and test of a first prototype of the front-end ASIC for cluster counting	INFN-BA, INFN-LE, BNL, FIT, U. Michigan, IHEP-CAS
T2	Scalable multichannel DAQ board	- High sampling rate - Dead-time-less - DSP and filtering - Event time stamping - Track triggering	WG5 WG7.2	1.1 1.2	- FPGA based architecture - ML algorithms-based firmware	working prototype of a scalable multichannel DAQ board	INFN-BA, INFN-LE
T3	Mechanics: wiring procedures New endplate concepts	- feed-through-less wiring procedures - More transparent endplates (< 5% X.) - transverse geometry	WG3 3.1C	1.1 1.3	Separate the wire support function from the gas containment function	Conceptual designs of novel wiring procedures Full design of innovative concepts of endplate	INFN-BA, INFN-LE, U. Mass Amherst, Michigan, Irvine, Tufts U., IHEP-CAS, IJCLab-IN2P3.
T4	High rate High granularity	- smaller cell size and shorter drift time - higher field-to-sense ratio	WG3 3.2E, WG7.2	1.3	higher field-to-sense ratio allows to increase the number of field wires, decreasing the wire contribution to multiple scattering	Measurements of performance on prototypes of drift cells at different granularities and with different field configurations	INFN-BA, INFN-LE, INFN-RM, IHEP-CAS, USTC, IMP-CAS, Nankai U., Wuhan U., Jilin U., IJCLab-IN2P3
T5	New wire materials and wire metal coating	- Electrostatic stability - High YTS - Low mass, low Z - High conductivity - Aging	WG3 3.1C	1.1 1.2	Develop contacts with companies producing new wires List companies Metal coating of carbon wires	construction of a magnetron sputtering facility for metal coating of carbon wires	INFN-LE, INFN-BA, INFN-RM, IJCLab-IN2P3.
T6	Ageing of new wire types	- Establish charge collection limits for carbon wires as field and sense wires	WG3 3.2B WG7.3,4	1.1 1.2	Build prototypes of drift chamber with new wires as field and sense wires	Tests of prototypes built with new wire types at beams and irradiation facilities Measurement of performance on total integrated charge	INFN-LE, INFN-BA, INFN-RM, IJCLab-IN2P3, USTC, IMP-CAS, Bose.
T7	Gas mixing, recuperation, purification and recirculation systems	- Non-flammable gas - High quenching power - Low-Z - High radiation length - High primary ions	WG3 3.1B 3.2C WG4, WG7.4	1.3	- ATEX and safety requirements - cost of gas - Hydrocarbon-free mixtures	Performance of hydrocarbon-free gas mixtures full Design of a recirculating system	INFN-LE, INFN-BA, INFN-RM, U. Florida, Tufts U., U. Wisconsin, U. Michigan, IHEP-CAS, Bose.