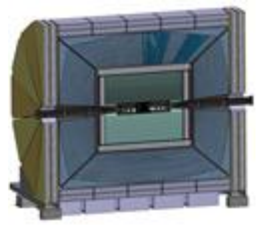
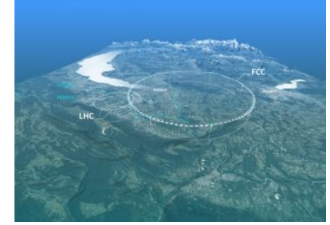
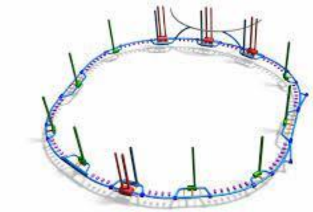






Drift Chamber project: overview and discussion

Nicola De Filippis
Politecnico and INFN Bari
for the DCH team

Tracker detectors at e^+e^- collider

past

SPEAR	MARK2	Drift Chamber
	MARK3	Drift Chamber
DORIS	PLUTO	MWPC
	ARGUS	Drift Chamber
CESR	CLEO1,2,3	Drift Chamber
VEPP2/4M	CMD-2	Drift Chamber
	KEDR	Drift Chamber
	NSD	Drift Chamber
PETRA	CELLO	MWPC + Drift Ch.
	JADE	Drift Chamber
	PLUTO	MWPC
	MARK-J	TEC + Drift Ch.
	TASSO	MWPC + Drift Ch.
TRISTAN	AMY	Drift Chamber
	VENUS	Drift Chamber
	TOPAZ	TPC

PEP	MARK2	Drift Chamber
	PEP-4	TPC
	MAC	Drift Chamber
	HRS	Drift Chamber
	DELCO	MWPC
BEPC	BES1,2	Drift Chamber
LEP	ALEPH	TPC
	DELPHI	TPC
	L3	Si + TEC
	OPAL	Drift Chamber
SLC	MARK2	Drift Chamber
	SLD	Drift Chamber
DAPHNE	KLOE	Drift Chamber
PEP2	BaBar	Drift Chamber
KEKB	Belle	Drift Chamber

present

VEPP2000	CMD-3	Drift Chamber
	KEDR	Drift Chamber
BEPC2	BES3	Drift Chamber
S.KEKB	Belle2	Drift Chamber

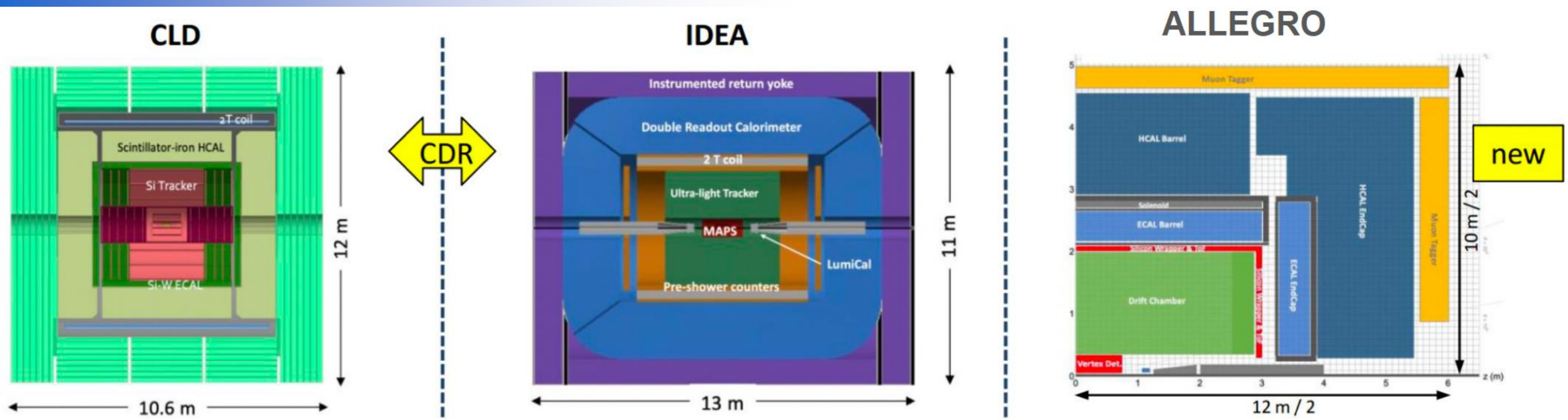
future

ILC	ILD	TPC
	SiD	Si
CLIC	CLIC	Si
FCC-ee	CLD	Si
	IDEA	Drift Chamber
CEPC	Baseline	TPC / Si
	4th	Si + Drift Chamber
	IDEA	Drift Chamber
SCTF	BINP	Drift Chamber
STCF	HIEPA	Drift Chamber

Activities discussed in the framework of:

- FCC-ee collaboration
- DRD1 Gaseous Detector – collaboration
  - WP2 - Inner and central tracking with PID (Drift Chambers)

FCC-ee detector concepts



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

- IDEA and ALLEGRO would both use a drift chamber as the main tracking device → any collaboration between Italian and French community is welcome

N. De Filippis

The Drift Chamber of IDEA

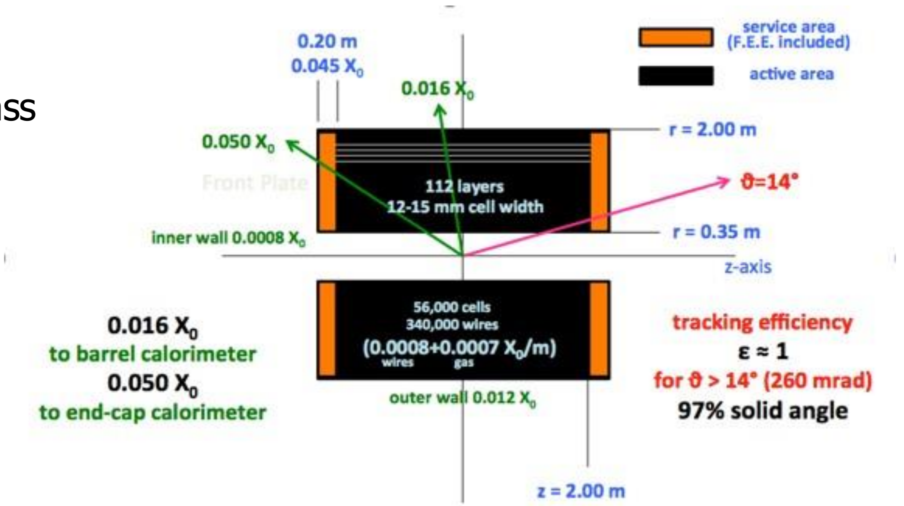
The DCH is:

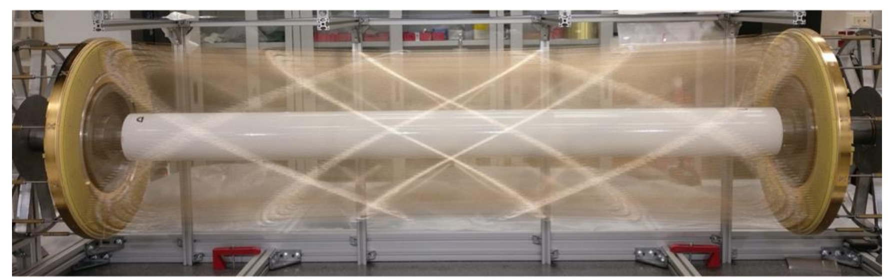
- a unique-volume, high granularity, fully stereo, low-mass cylindrical
- gas: He 90% - iC_4H_{10} 10%
- inner radius R_{in} = 0.35m, outer radius R_{out} = 2m
- length L = 4m
- drift length ~1 cm
- drift time up to 400ns
- $\sigma_{xy} < 100\ \mu m$, $\sigma_z < 1$ mm
- 12÷14.5 mm wide square cells, 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*

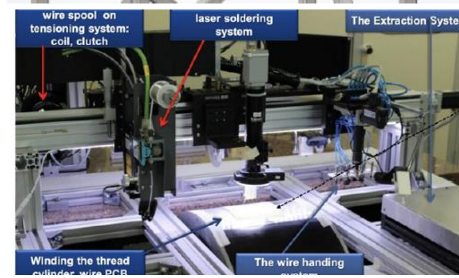
T_c **< 36 g** for 40 µm Al field wires (δ_{grav} = 190 μm)
T_c **< 24 g** for 20 µm W sense wires (δ_{grav} = 510 μm)

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

G. Charles group from IJCLAB (France)

- any test with wire material, choice for the prototype chosen but new ones could be tested. Produce charaterization of strength, with a micrometric motor. Test different kind of wires
- test also of anchoring the wire (crimp, gluing, soldering)

R & D Tasks for WP2



T5: Consolidation of new wire materials and 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 (Purdue U. in US ?)

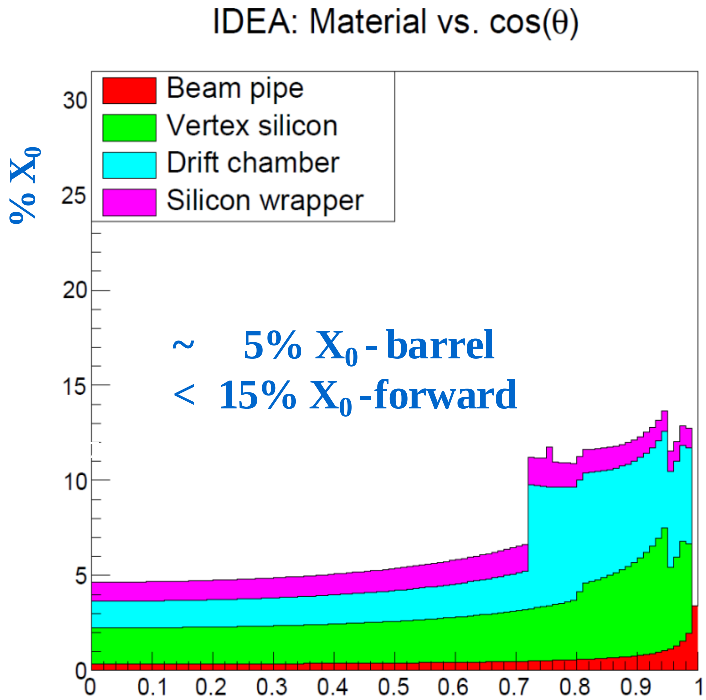
T6: Study ageing phenomena for new wire types

- 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

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, ...)

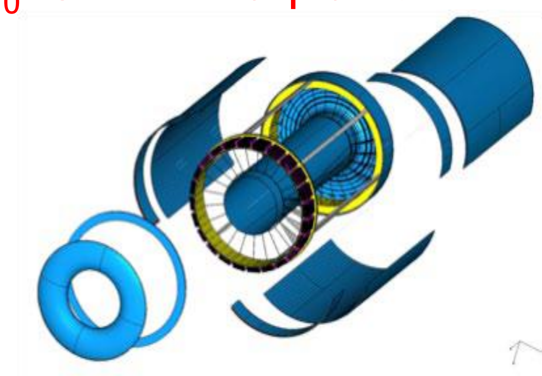


For 10 GeV (50 GeV) µ emitted at an angle of 90° w.r.t the detector axis, the p_T resolution is

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

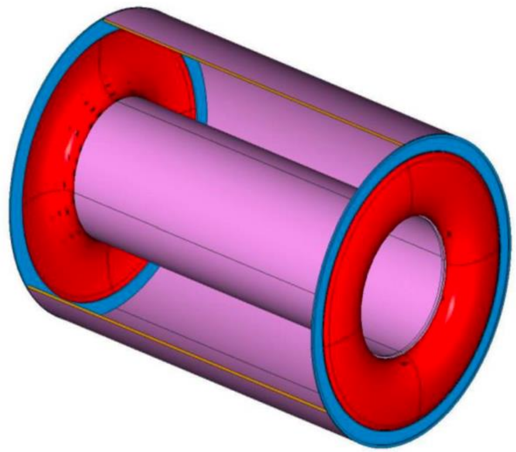
Mechanical structure of the DCH

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.



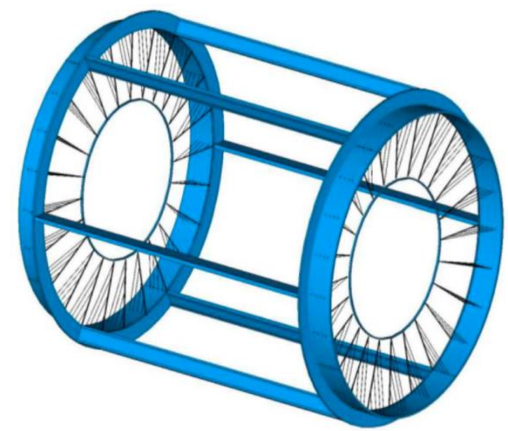
Gas containment

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

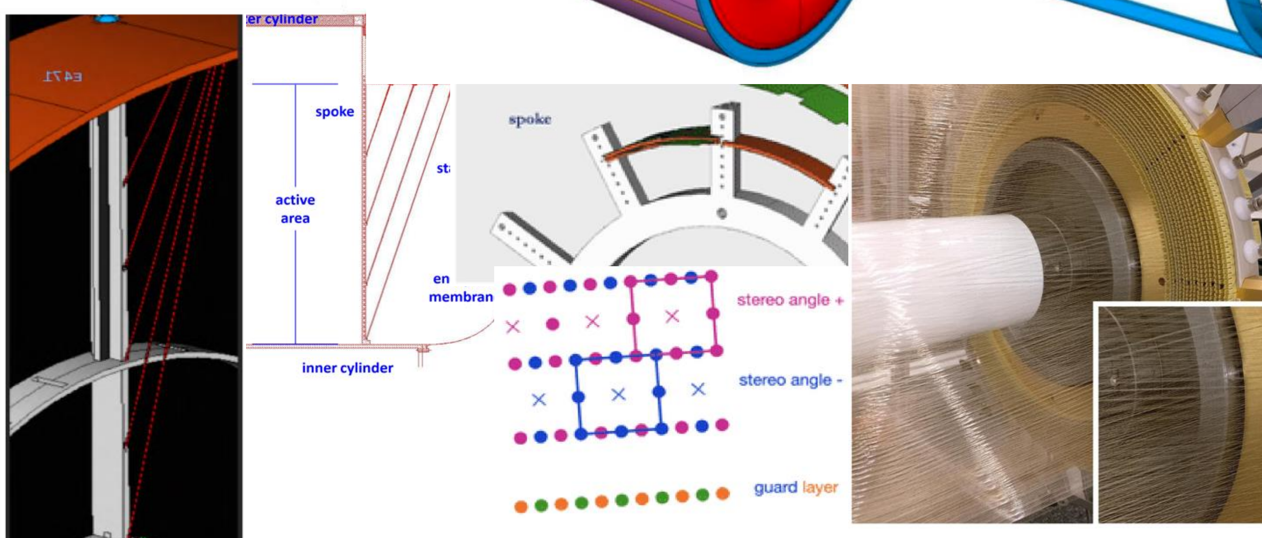


Wire cage

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

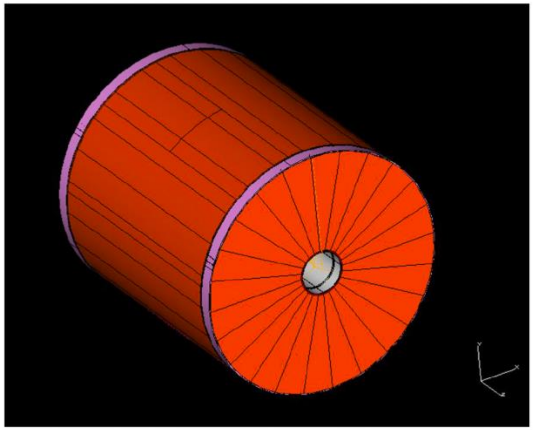


- New tension recovery schema
- Experience inherited from the MEG2 DCH



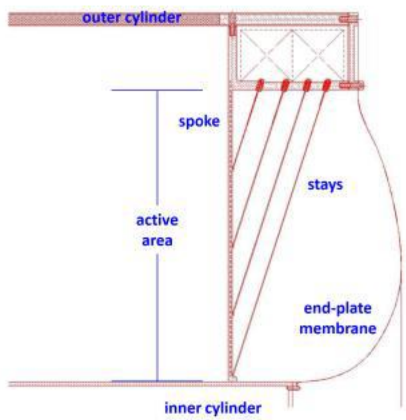
Mechanical structure of the DCH

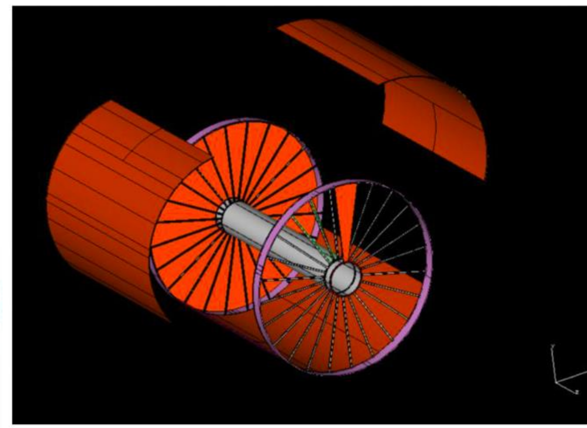
IDEA Drift Chamber



- 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)

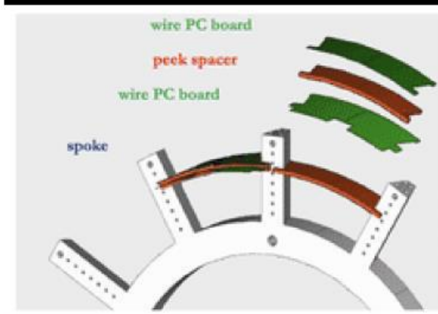
tension recovery system





- **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

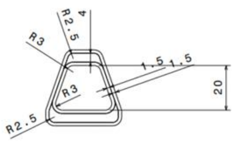
Mechanical structure with FEM

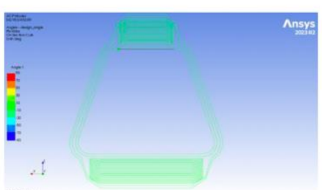
Big Problems to manage!

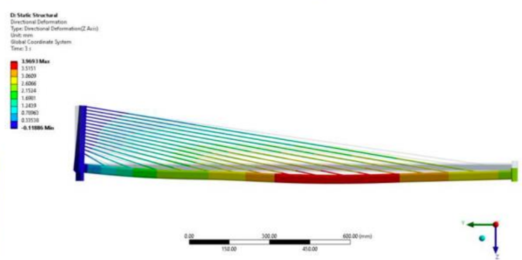
- σ_{xy} < **100 μm** → accuracy on the position of the anodic wires < **50 μm**.
- The anodic and cathodic wires should be parallel in space to preserve the constant electric field.
- A 20 μm tungsten wire, 4 m long, will bow about 400 μm at its middle point, if tensioned with a load of approximately 30 grams.

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

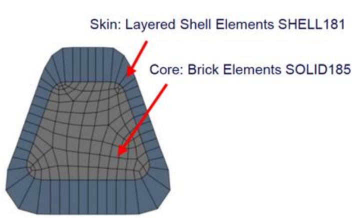
Simulation studies: progress about the final design of the cross section of the spoke







Statical structural simulation: deformation along z



Tabular Data

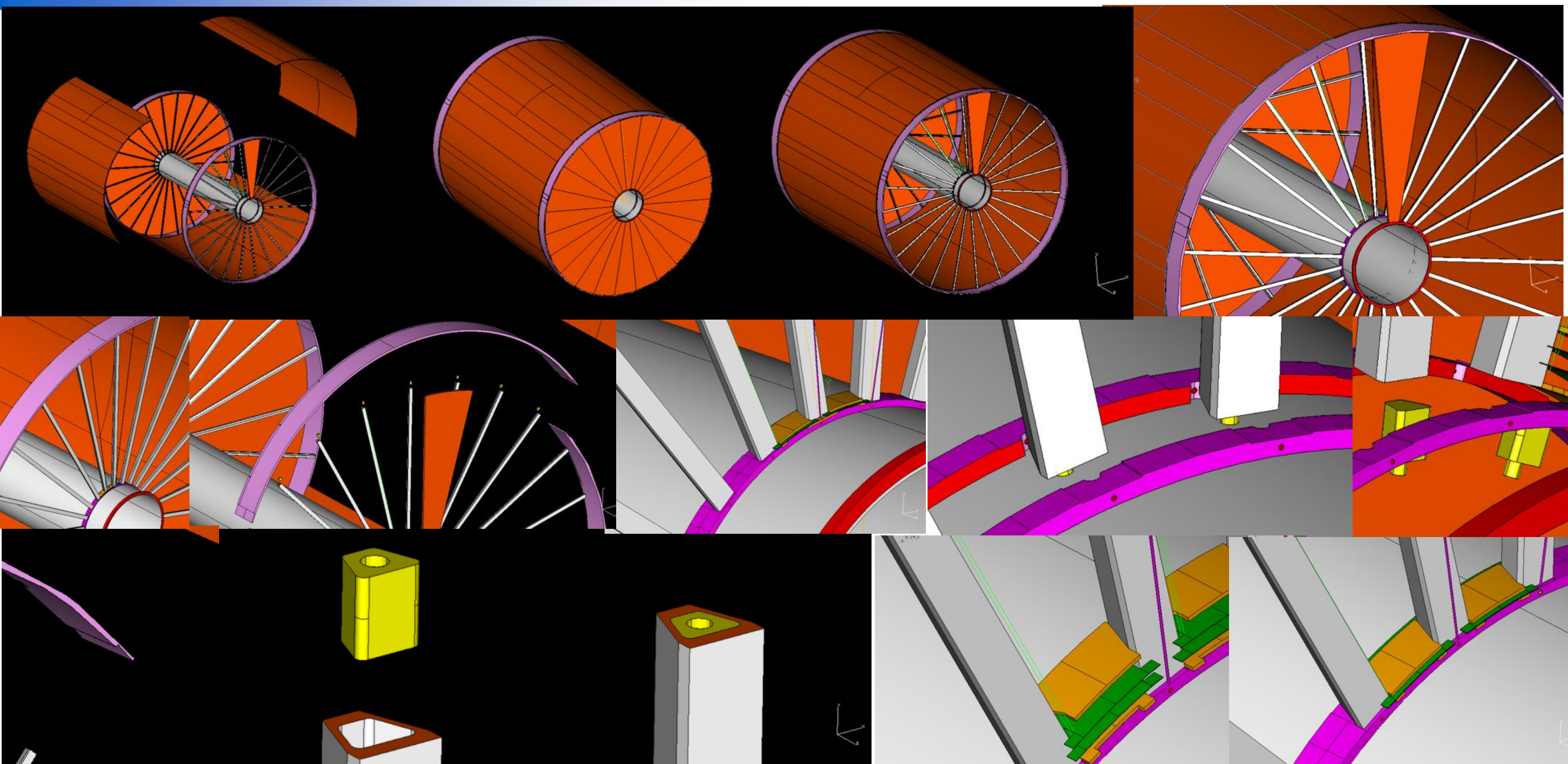
	Time [s]	Minimum [mm]	Maximum [mm]	Average [mm]
1	1.	-0.11291859	10.385392	5.6093398
2	2.	-0.12170477	6.1265187	3.3920221
3	3.	-0.11885951	3.9693396	2.5614909

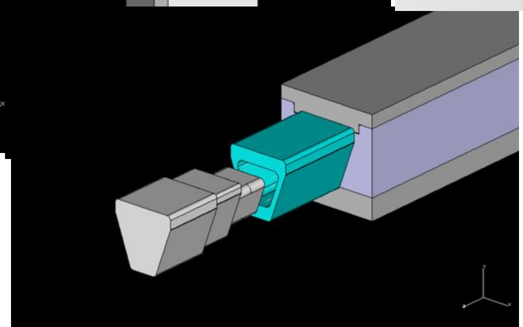
Our **main goal** was to limit the deformation of the spokes to **200 μm** while ensuring the structural integrity.

G. Charles group from IJCLAB (France)

- interest in activity on mechanical design and realization of prototypes

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

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

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**

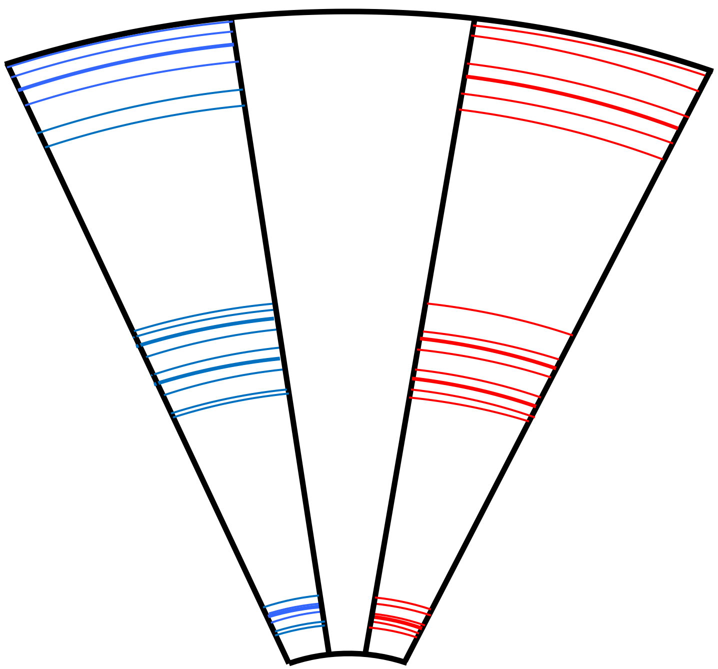
▸ ***Full-length prototype necessary***

○ ***Can be done in parallel on small prototypes***

2025 full-length prototype: Wiring

Target: a full length DCH prototype with:

- 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)

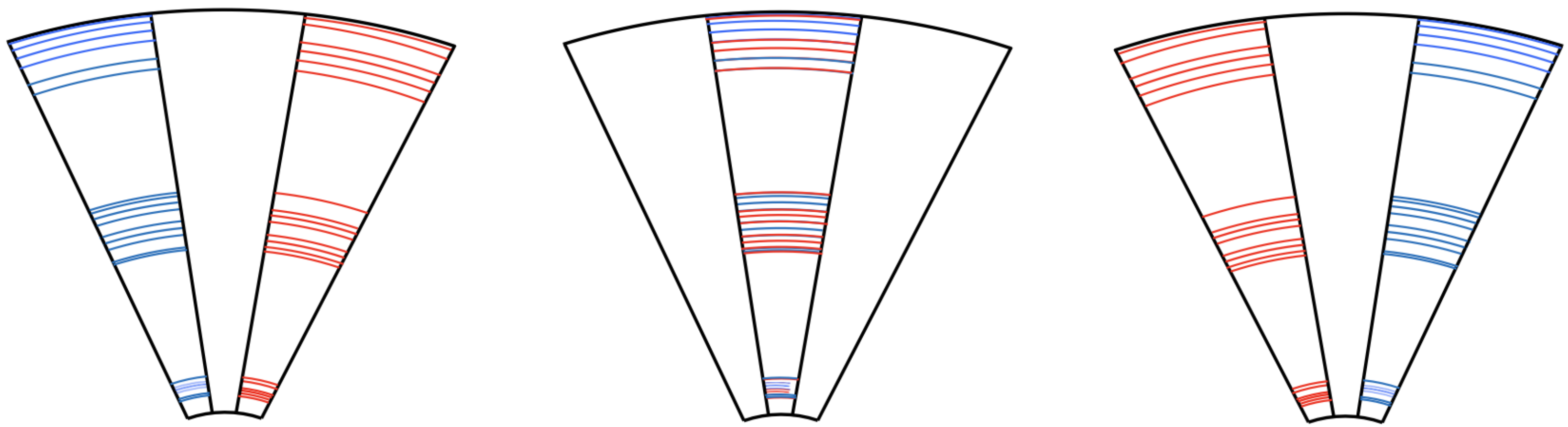
TOTAL LAYERS: 8
Sense wires: 168
Field wires: 965
Guard wires: 264

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

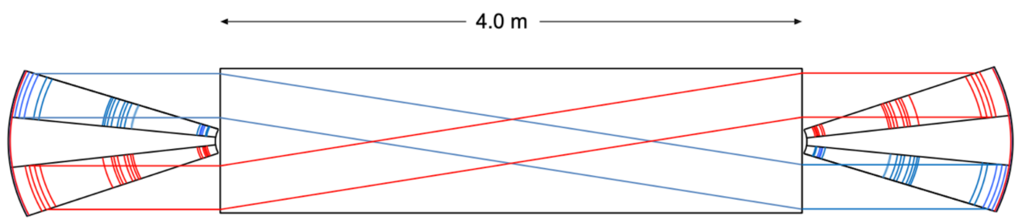
Readout channels: 8+8 +16+16+16+16 + 16+16 = 112

2025 full-length prototype: Coverage

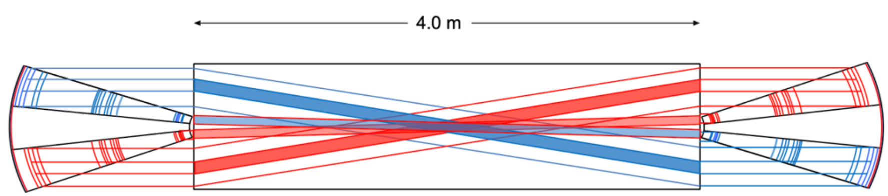
z = − 2.0 m   z = 0   z = + 2.0 m



MAX COVERAGE

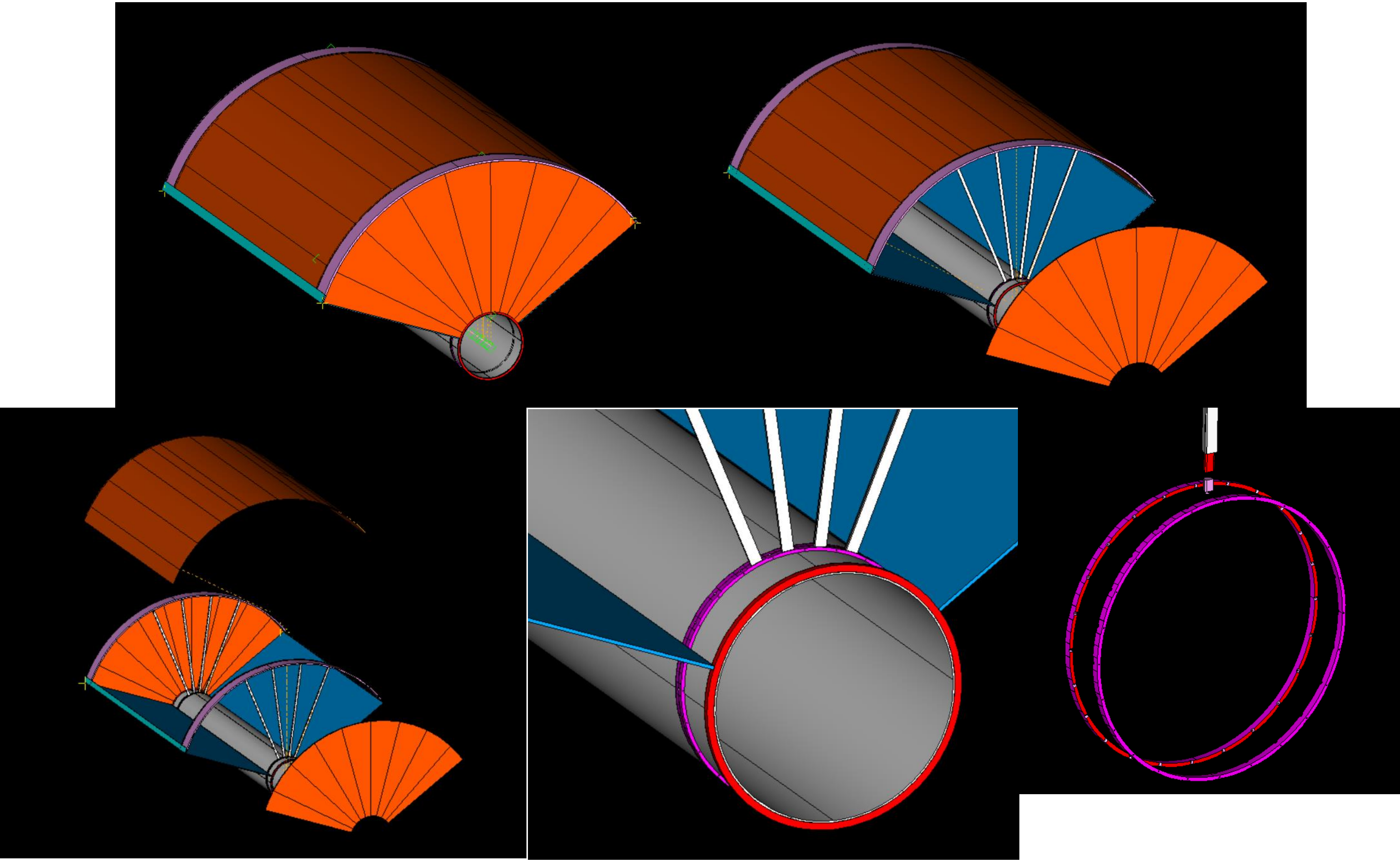


ELECTRONICS COVERAGE



Minimum stereo angle 50 mrad
Maximum stereo angle: 250 mrad

2025 full-length prototype: Model



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

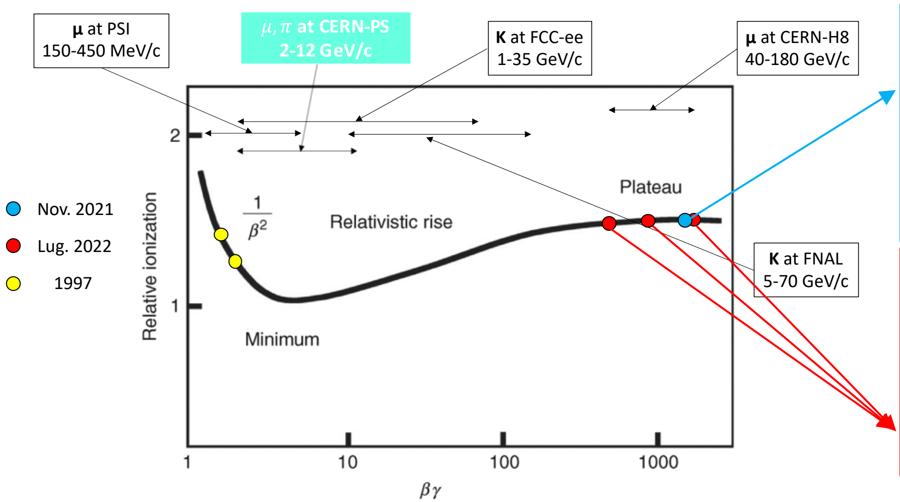
N. B. Aggressive schedule strongly depending on the funding

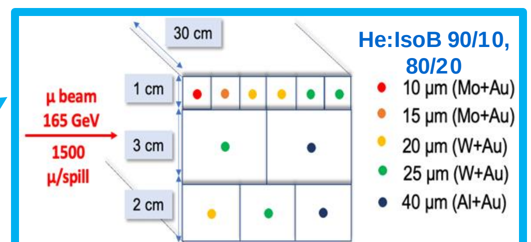
Testbeam data analysis

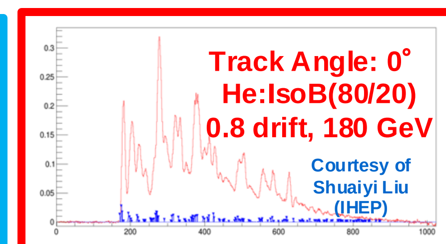
Beam tests in 2021,2022, 2023 and 2024

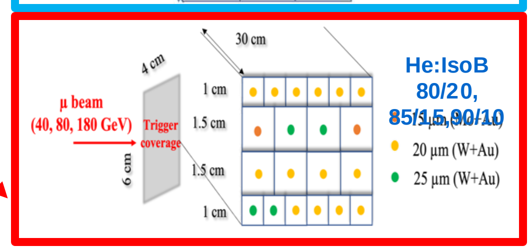
Beam tests to experimentally asses and optimize the **performance of the cluster counting/timing** techniques:

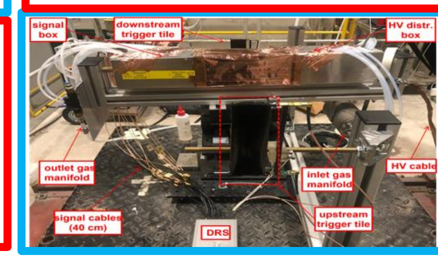
- Two **muon beam tests** performed at **CERN-H8 ($\beta\gamma$ > 400)** in Nov. 2021 and July 2022 (p_T = 165/180 GeV).
- A **muon beam test** (from 4 to 12 GeV momentum) in 2023 performed at **CERN**. A new testbeam with the same configuration done on July 10, 2024
- Ultimate test at **FNAL-MT6** in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





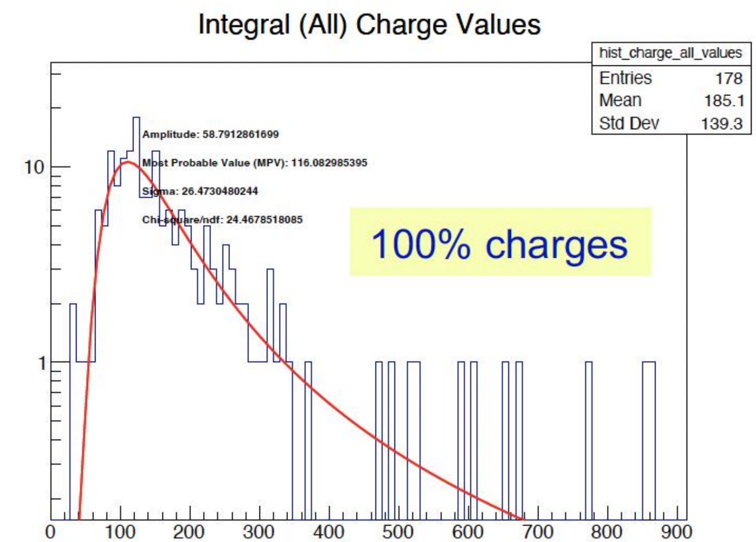


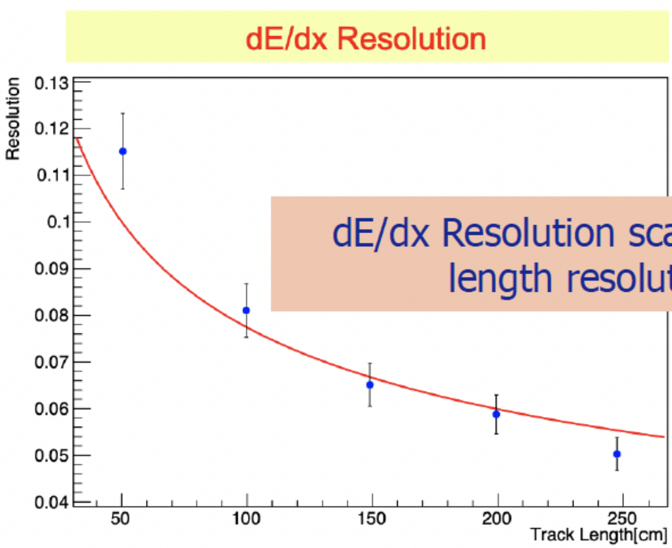




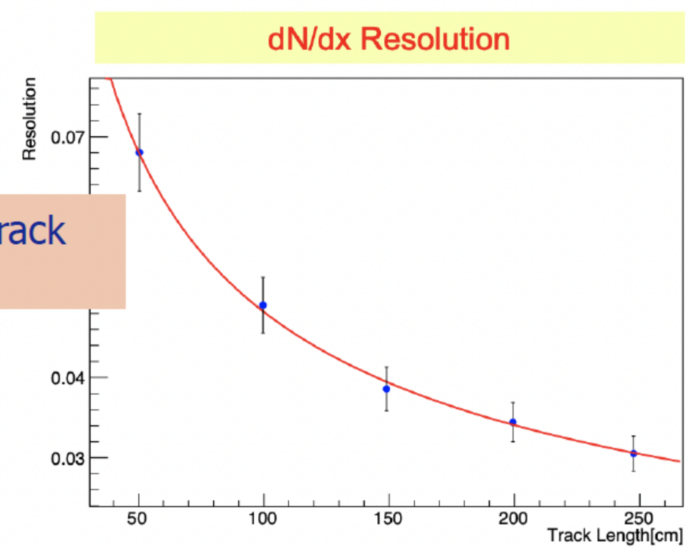
2021/2022 beam test results: resolutions

- **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**





dE/dx Resolution scan vs track length resolution



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

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

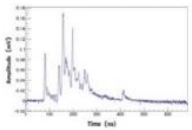
~ **2 times** improvement in the resolution using dN/dx method

Electronics

Challenge: Data reduction and pre-processing

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.

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**

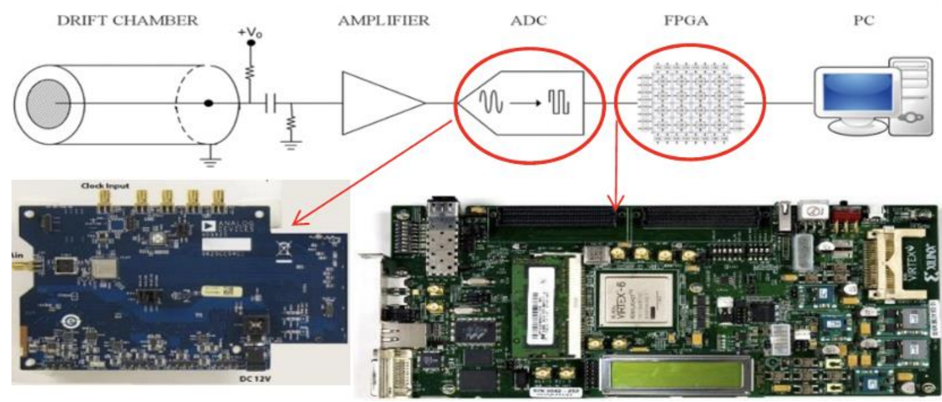
- 100 KHz of Z decays with 20 charged tracks/event multiplicity
- 30 KHz of $\gamma\gamma \longrightarrow$ hadrons with10 charged tracks/event multiplicity
- 2.5% occupancy due to beam noise
- 2.5% occupancy due to hits with isolated peaks

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.

Interest by any French institute ?

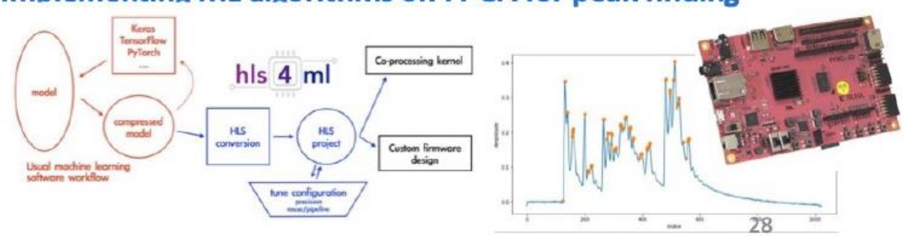


Single channel solution has been successfully verified.

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



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

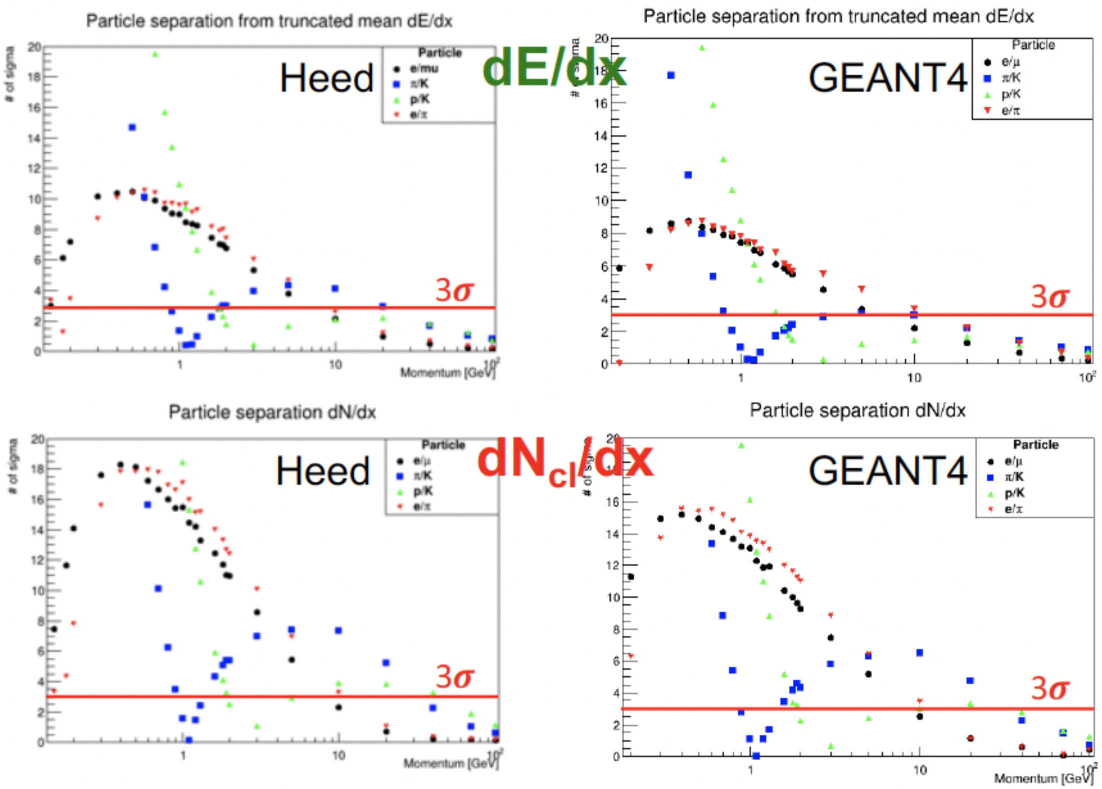
- Performance goal:
  - High sampling rate
  - Dead-time-less
  - Event time stamping
  - Track triggering
- Main developments covered:
  - FPGA based architecture
  - ML algorithms-based firmware
- Deliverables next 3y:
  - working prototype of a scalable multichannel DAQ board

Full simulation and physics analyses

Simulation of Cluster Counting/Timing and PID: GARFIELD

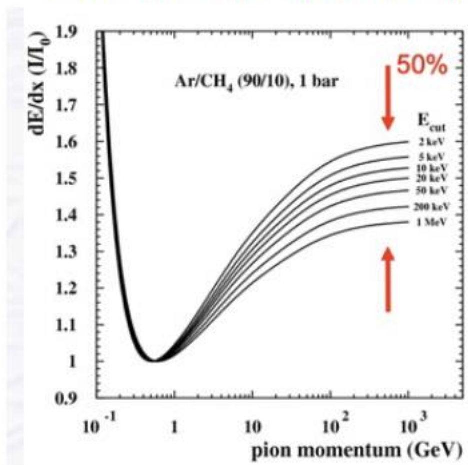
2.0 m long tracks in 90/10 He/iC_4H_{10}

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)

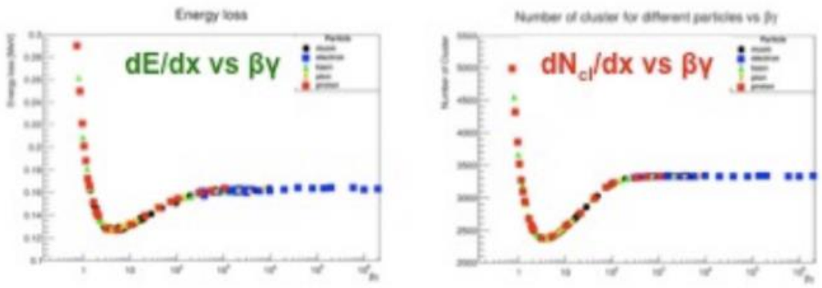


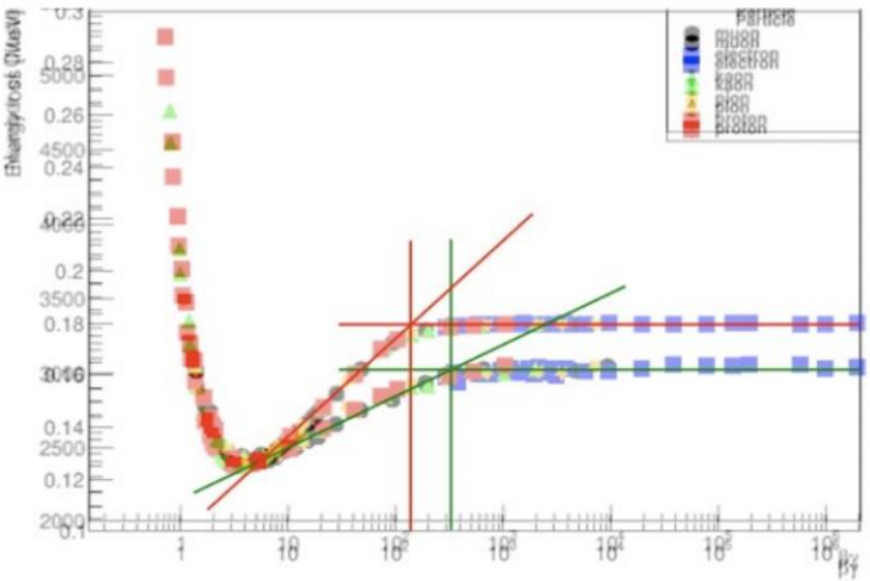
M. Hauschild Progress in dE/dx techniques used for particle identification NIM A379(1996) 436

N. De Filippis

Simulation of Cluster Counting/Timing and PID: GARFIELD

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

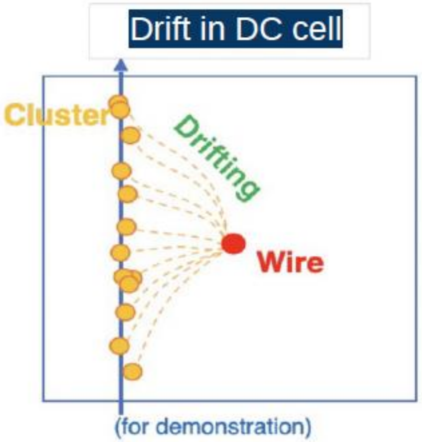
due to a choice of **E$_{cut}$** (the maximum energy of an electron still associated to a track in the simulation) parameter?

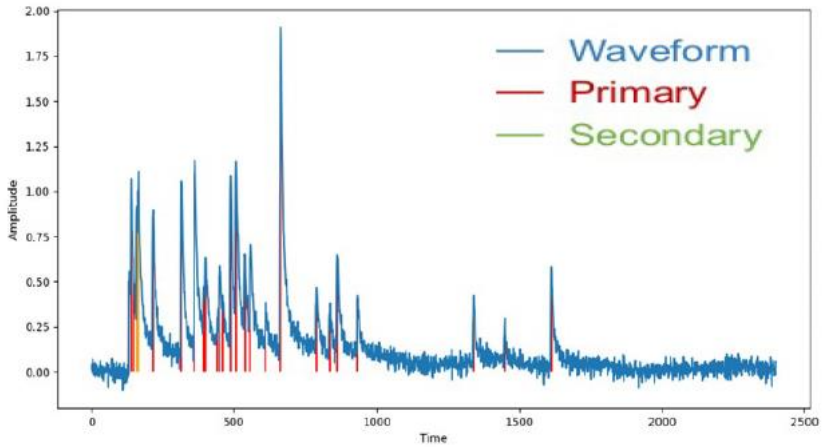
⇩

Experimental beam test campaign needed

Simulation of Cluster Counting: GARFIELD + NN

IHEP + M. Anwar (Bari Politecnico)





Digitizer in place → to be exported in Key4HEP

- A muon particle is passed through mixture of gases (90% He and 10% C_4H_{10}) generate electron-ion pairs causing a read out signal (induce current). 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

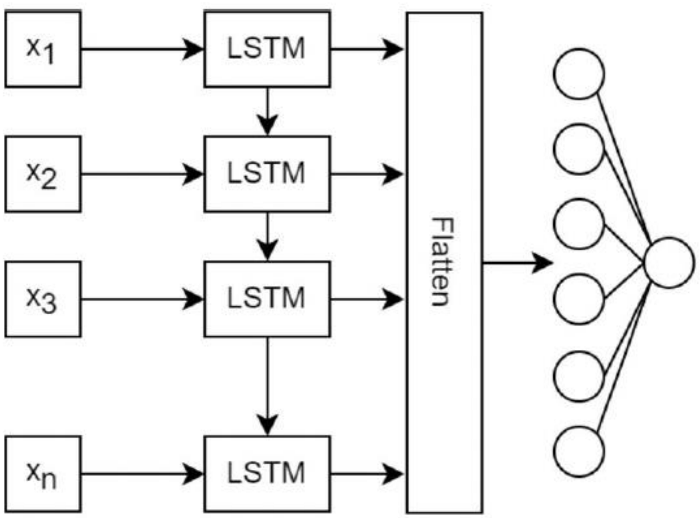
• Two Step Reconstruction Algorithm:

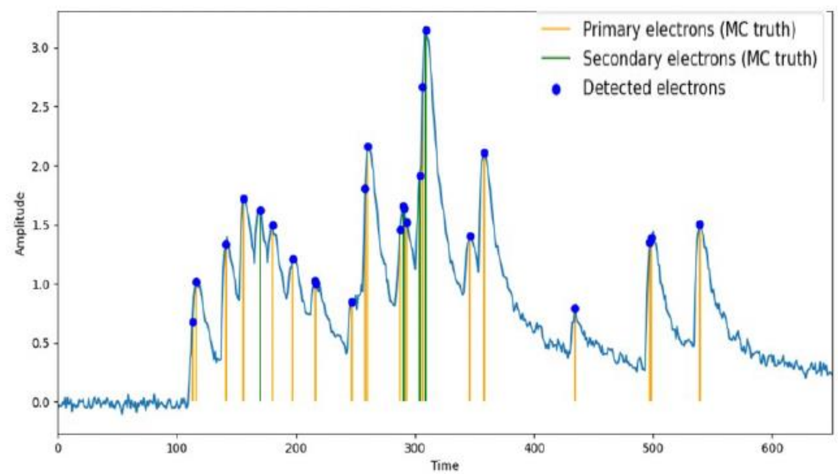
- **Peak finding: Find all peaks (primary and secondary) in the waveform**
- **Clusterization: Determine the primary peaks from the founded peaks in step 1**

Simulation of Cluster Counting: GARFIELD + NN

The task of peak finding can be framed as a classification problem in machine learning

- The waveforms are divided into segments, each comprising 15 bins. Each segment can represent either a signal or a noise
- The list of the amplitudes of a segment, subtracted by their mean and normalized by their standard deviation, is served as the input feature for the neural network
- The data of waveform is time sequence data, which suitable for especially Long Short Term Memory Model

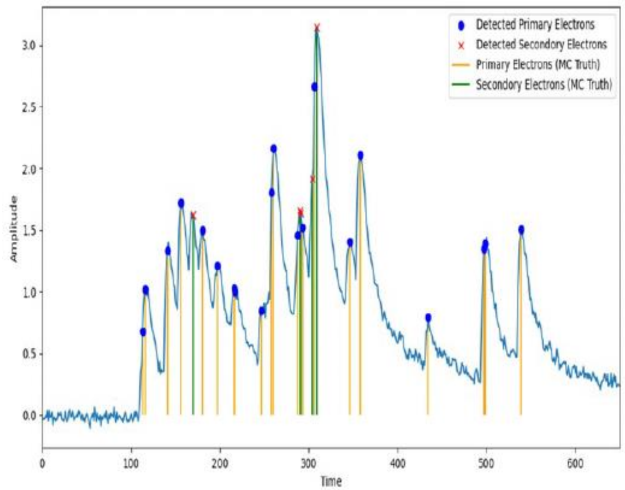


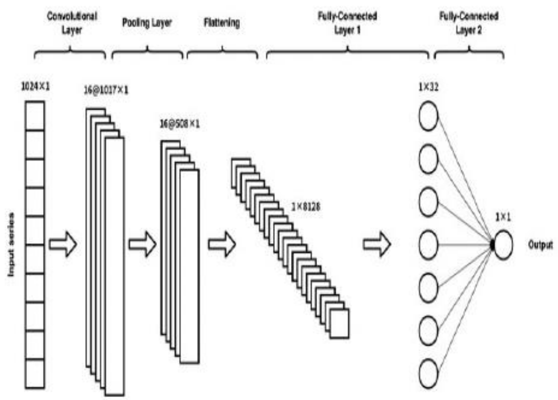


- **We applied a Long Short-Term Memory (LSTM) model to the waveform to classify signals (primary and secondary electrons) from the Noise using a peak-finding algorithm known as classification**

- **Detected peaks from both primary and secondary electrons are shown by blue dots**

Simulation of Cluster Counting: GARFIELD + NN

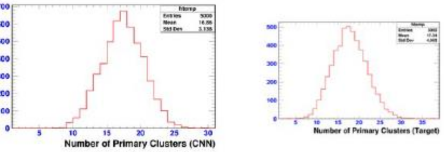




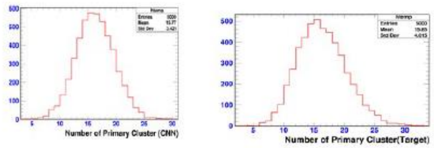
- A regression problem to predict Number of primary clusters based on the primary detected peaks by using Convolutional Neural Network (CNN) model
- The peaks found by peak finding algorithm would be training sample of this algorithm

- Labels: Number of clusters from MC truth
- Features: Time list of the detected times in the previous step encoding in an (1024, 1) array.
- A regression problem

Simulation of Cluster Counting: GARFIELD + NN



- The above distrubitions shows us the number of primary clusters detected by CNN and Target(LSTM) for 10 GeV Momentum



- The above distrubitions shows us the number of primary clusters detected by CNN and Target(LSTM) for 4 GeV Momentum

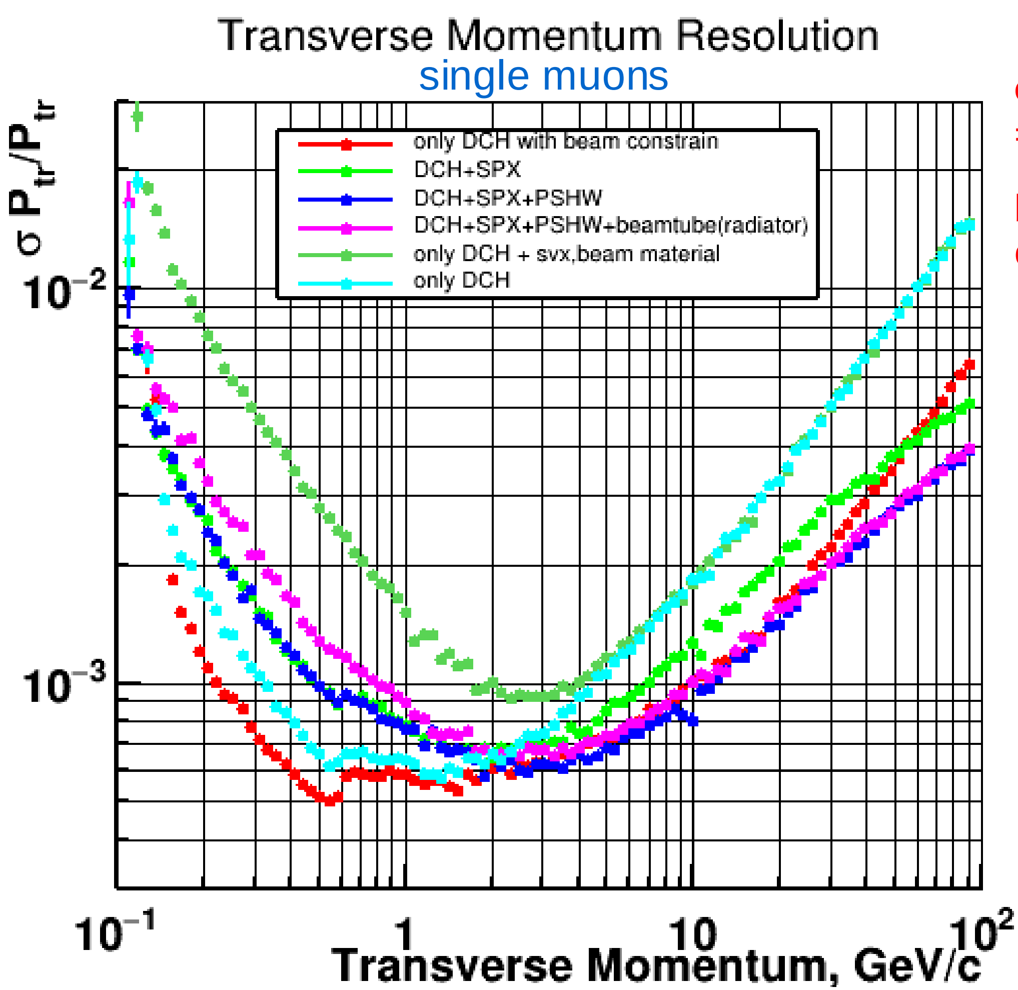
Momentum of Muon	Primary Cluster(MC)	Standard Deviation (MC)	Cluster Size (Full Range)	Primary Cluster(LSTM	Standard Deviation (LSTM)	Primary Cluster (CNN)	Standard Deviation (CNN)
2 Gev/c	15.85	3.9	1.55	14.4	3.75	14.26	3.2
4 GeV/c	17.16	4.189	1.54	15.85	4.015	15.77	3.42
6 GeV/c	17.65	4.178	1.605	16.47	4.104	16.21	3.43
8 GeV/c	18.38	4.228	1.54	16.96	4.05	16.57	3.37
10 Gev/c	18.61	4.282	1.54	17.34	4.065	16.86	3.13

Full simulation of IDEA: performance of the IDEA (old) + tracking + background studies

For the Geant4 based simulation framework code:

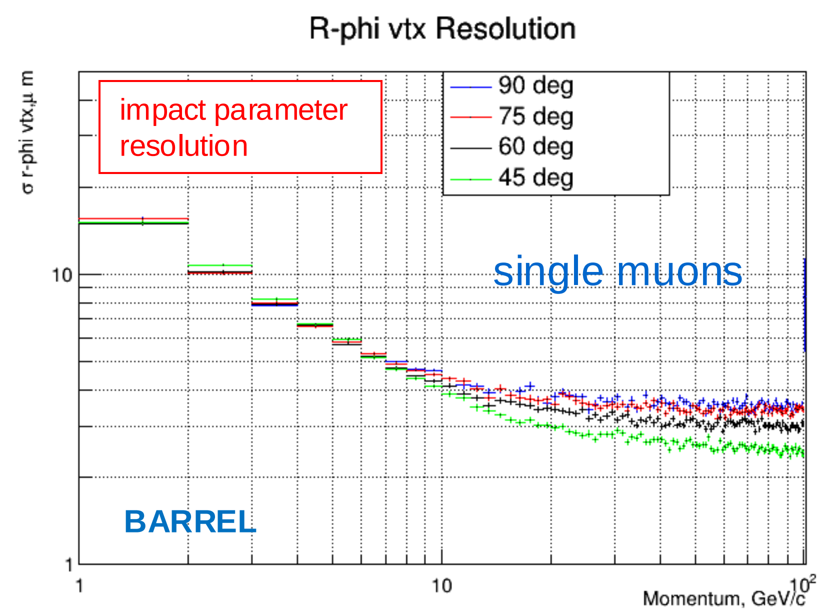
$$\frac{\Delta p_T}{p_T}\Big|_{res.} = \frac{\sigma_{r\phi}\, p_T}{0.3\, B_0 L_0^2}\sqrt{\frac{720 N^3}{(N-1)(N+1)(N+2)(N+3)}} \approx \frac{12\, \sigma_{r\phi}\, p_T}{0.3\, B_0 L_0^2}\sqrt{\frac{5}{N+5}}$$

$$\frac{\Delta p_T}{p_T}\Big|_{m.s.} = \frac{N}{\sqrt{(N+1)(N-1)}}\,\frac{0.0136\,\mathrm{GeV/c}}{0.3\beta\, B_0 L_0}\sqrt{\frac{d_{tot}}{X_0\,\sin\theta}}\left(1+0.038\ln\frac{d}{X_0\,\sin\theta}\right)$$



$\sigma(p_t)/p_t$ (100 GeV) = 3×10^{-3}

but new studies ongoing



$\sigma(d_0)$ (100 GeV) = 2μm

N. De Filippis

Any interest by the French community ?

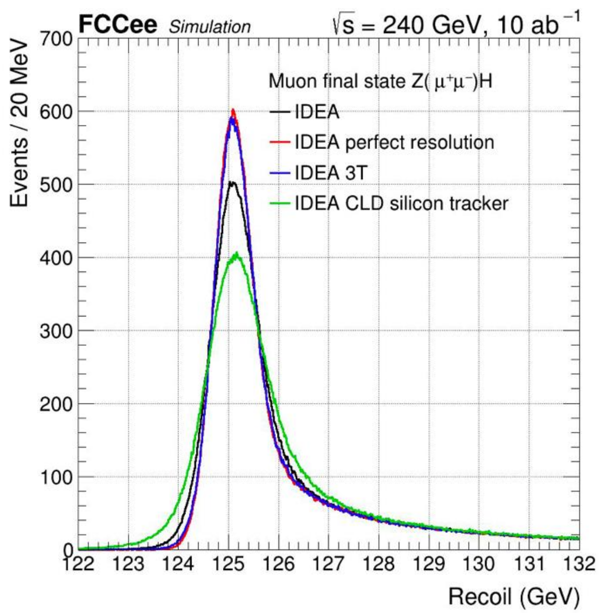
Full simulation of IDEA → physics analysis studies

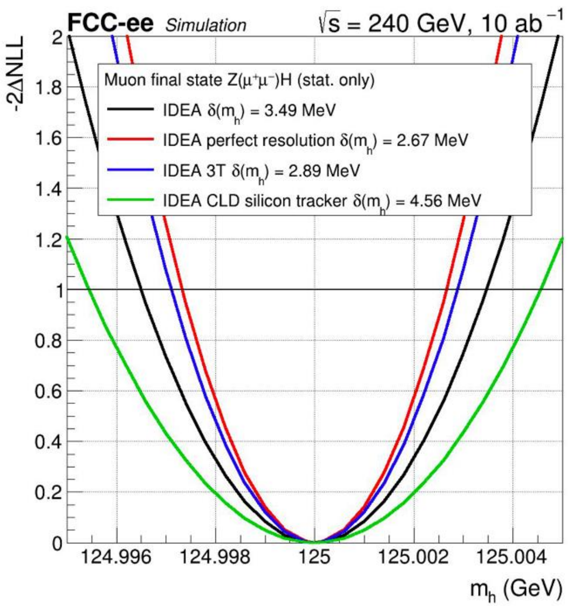
+ PID studies for H→ss, B-physics

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}

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

International collaboration

G. Iakovidis group from BNL (US): wire procurement

A. Jung group from Purdue U. (US):

- coating / manufacturing facility at composite center Purdue would allow manufacturing all kinds of materials
- existing supported R&D on US side
  - composite R&D for thicker high TC / electric C CFs
  - reconstruction / tracking for FCC folded GEANT work of implementing CF into sim
  - prototype of CF and reference of tungsten being constructed in lab

G. Charles group from IJCLAB (France)

- any test with wire material, choice for the prototype chosen but new ones could be tested. Produce charaterization of strength, maybe with a micrometric motor. Test different kind of wires
- test also of anchoring the wire (crimp, gluing, soldering)
- activity on mechanical design and realization of prototypes
- Garfield simulation studies, participation to testbeam campaigns
- Activity on electronics to be verified with IN2P3

IHEP (China): Effort to build a international collaboration enforced

- well established collaboration with IHEP for NN-based cluster counting algorithm

Summary/Conclusions

Progress reported on:

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

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

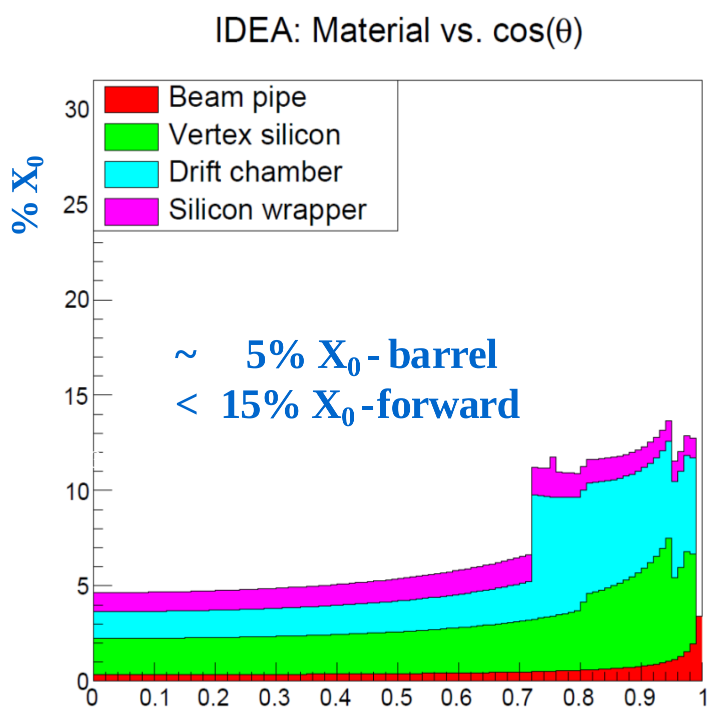
- detector design, construction, beam test, performance
- local and global reconstruction, full simulation
- physics performance and impact
- etc.

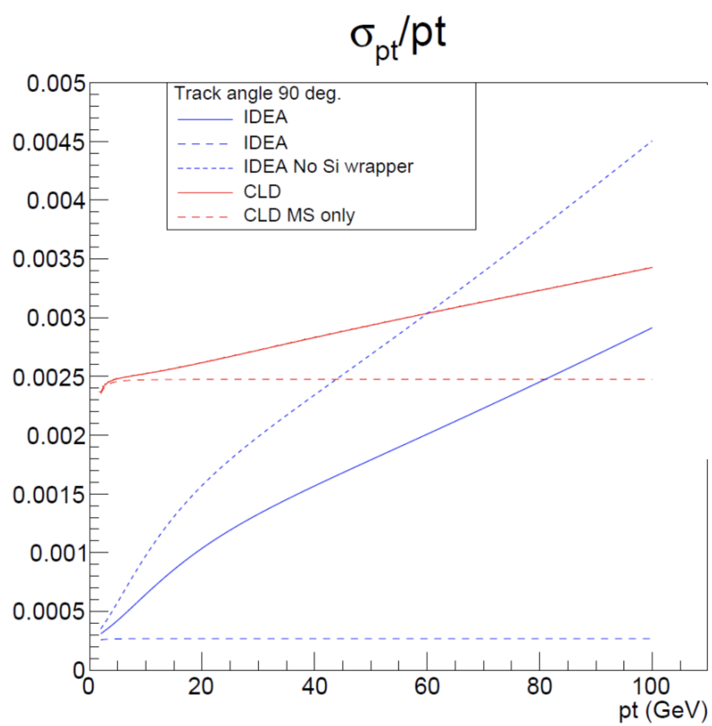
Backup

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





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

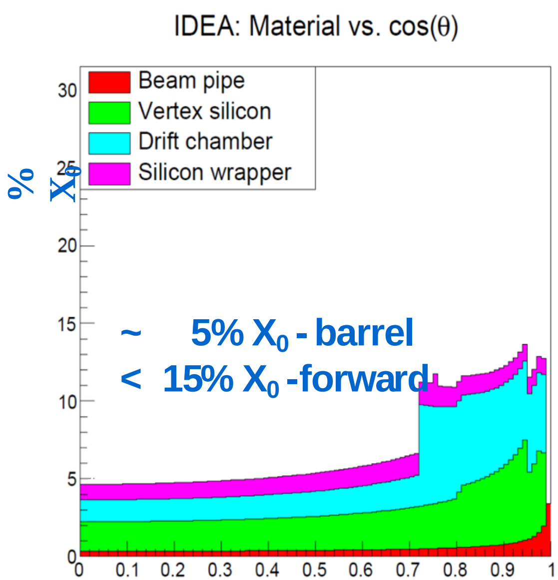
Requirements on track momentum resolution

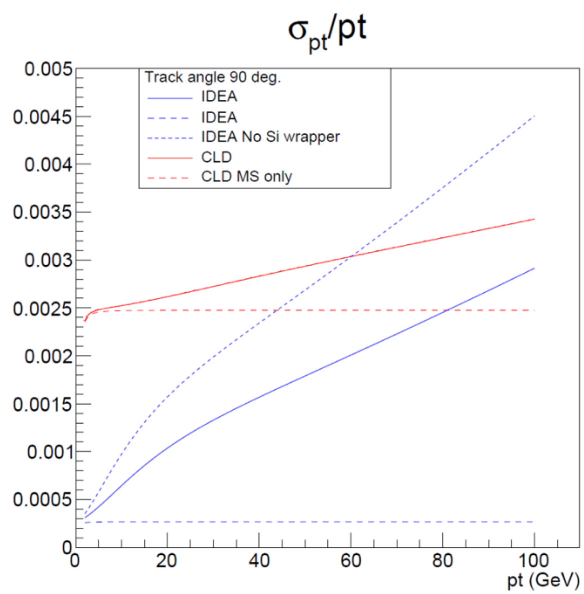
The IDEA Drift Chamber is designed to cope with transparency

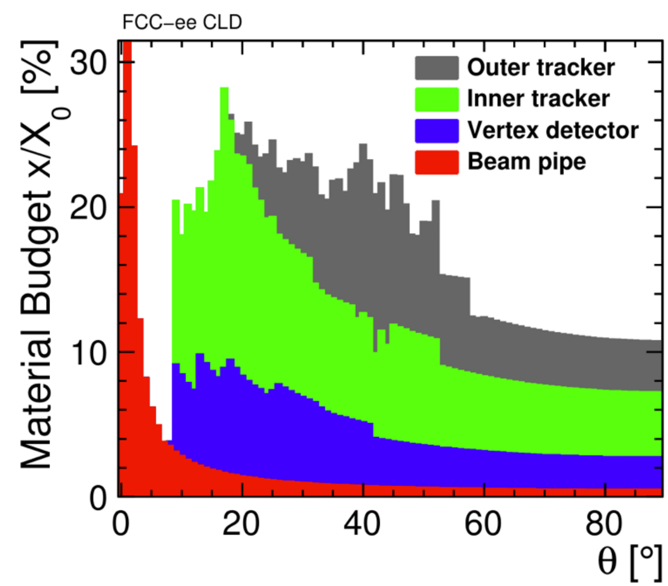
- a unique-volume, high granularity, fully stereo, low-mass cylindrical
- gas: He 90% - iC_4H_{10} 10%
- inner radius 0.35m, outer radius 2m
- length L = 4m

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

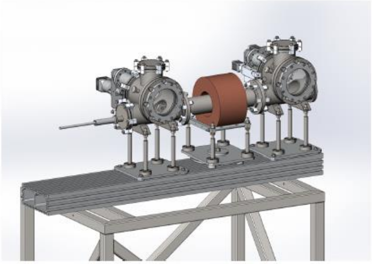
Challenges for large-volume drift chambers

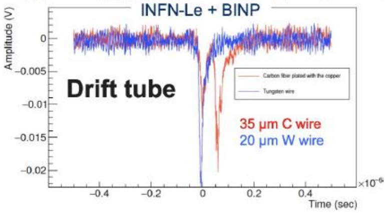
- **Electrostatic stability** condition: $\frac{\lambda^2}{4\pi\varepsilon}\frac{L^2}{w^2} < wire\ tension < YTS \cdot \pi r_w^2$

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**

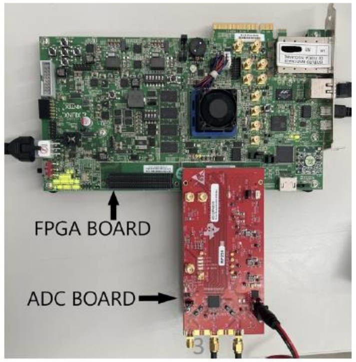
Safety requirements (**ATEX**) demands stringent limitations on flammable gases;
Continuous increase of **noble gases cost**

⇒ **gas studies**

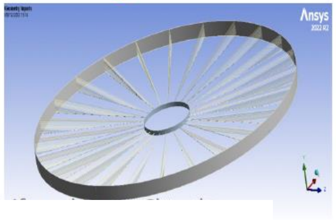
- **Data throughput**

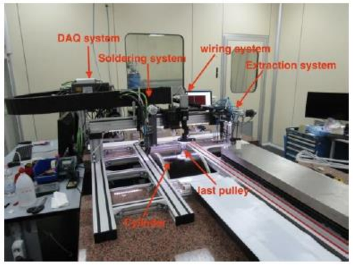
Large number of channels, high signal sampling rate, long drift times (slow drift velocity), required for cluster counting, and high physics trigger rate (Z_0-pole at FCC-ee) imply data transfer rates in excess of **~1 TB/s**

⇒ **on-line real time data reduction algorithms**



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



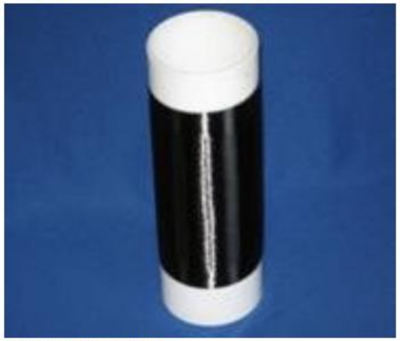


1st CHALLENGES: wire types – Carbon monofilament

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

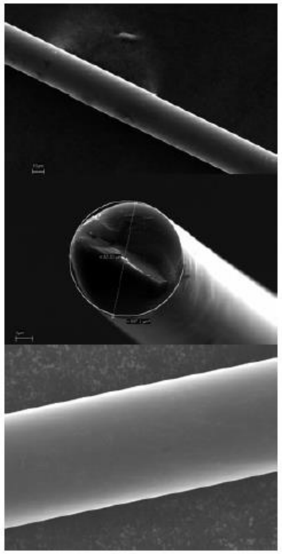
Phone: 978-322-1900
Fax: 978-322-1970

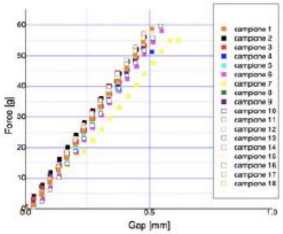
CARBON MONOFILAMENT PRODUCT PRICE LIST
Effective October 1, 2017

Product	Quantity	Price LF
CARBON MONOFILAMENT	1 Million LF	$0.02
	500,000 LF	$0.03
	1,000 LF	$0.93

CARBON MONOFILAMENT PRODUCT PRICE LIST EFFECTIVE APRIL 1, 2019

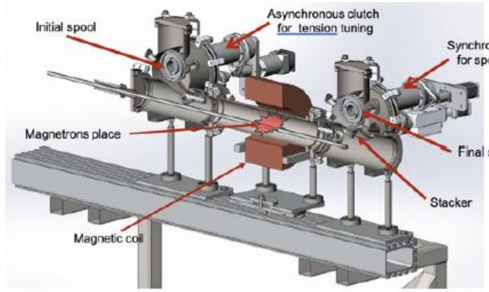
Product	Quantity	Price per LF	
CARBON MONOFILAMENT	1 Million LF	$0.02	60 €/Km
	500,000 LF	$0.03	
	1,000 LF	$0.94	

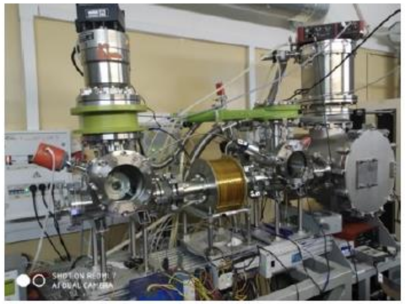


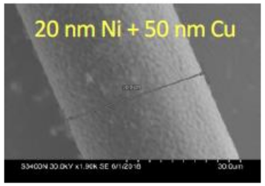


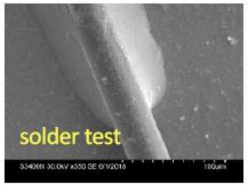
Metal coating by HiPIMS: High-power impulse magnetron sputtering

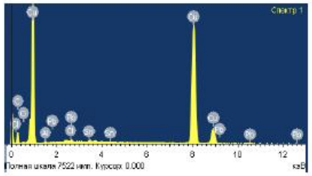
physical vapor deposition (PVD) of thin films based on magnetron sputter deposition (extremely high power densities of the order of kW/cm² in short pulses of tens of microseconds at low duty cycle <10%)

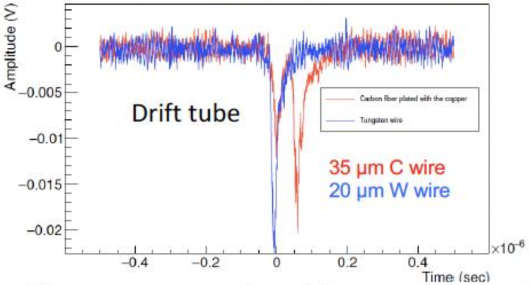


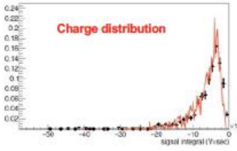


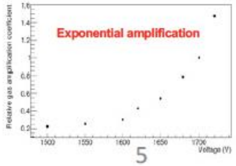












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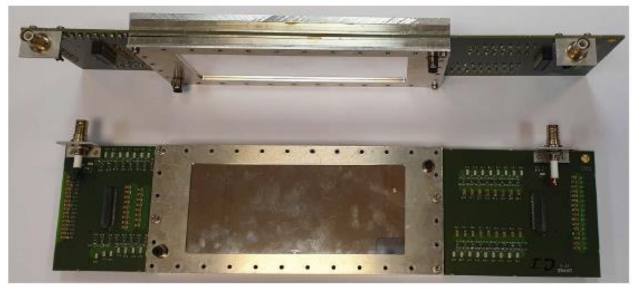
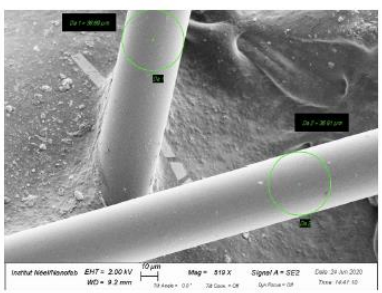
1st CHALLENGES: wire types – Carbon monofilament

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

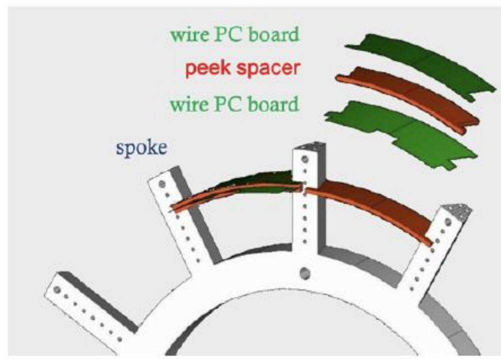
First results in 2017 *Carbon wire chamber at sub-atmospheric pressure, G. Charles et al., NIM A*

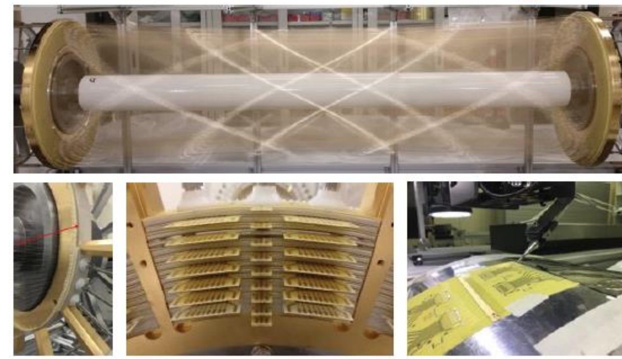
Tests with radioactive sources at 1 atm are on going for carbon wires and soldered AlMg5 wires.

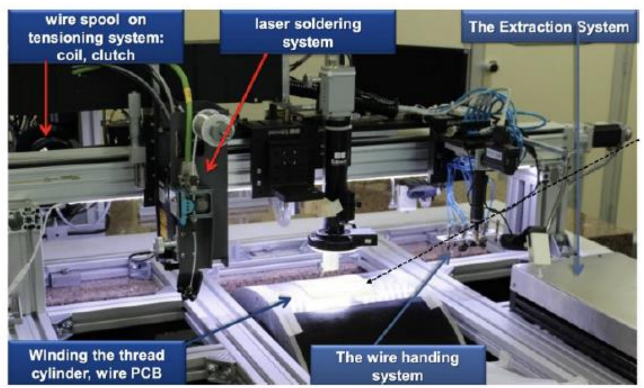
Next step will be beam tests and **internationalize the collaboration**.

2^{nd} 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€)

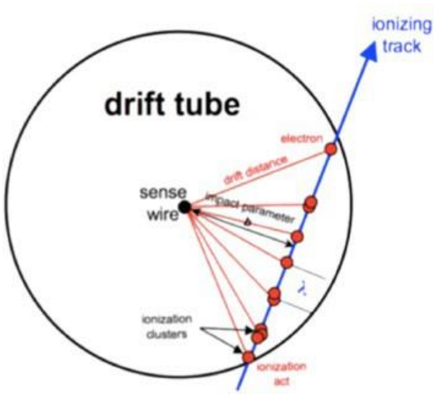
Costs to be borne (late 2024 and 2025)

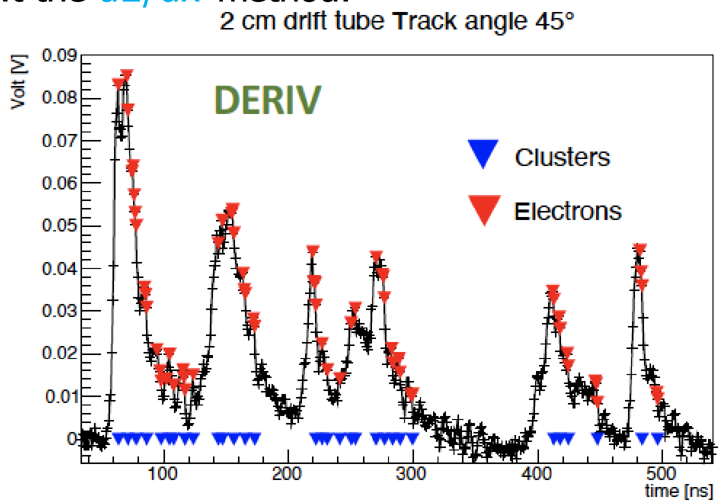
- Additional wires
- Wire PCBs
- Peek spacer
- Wiring robot refurbishing
- Mechanical support and gas envelope
- Front-end, digitizers and acquisition electronics

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 $\sigma_{dN_{cl}/dx}$ **$/(dN_{cl}/dx)$** < 2.0%

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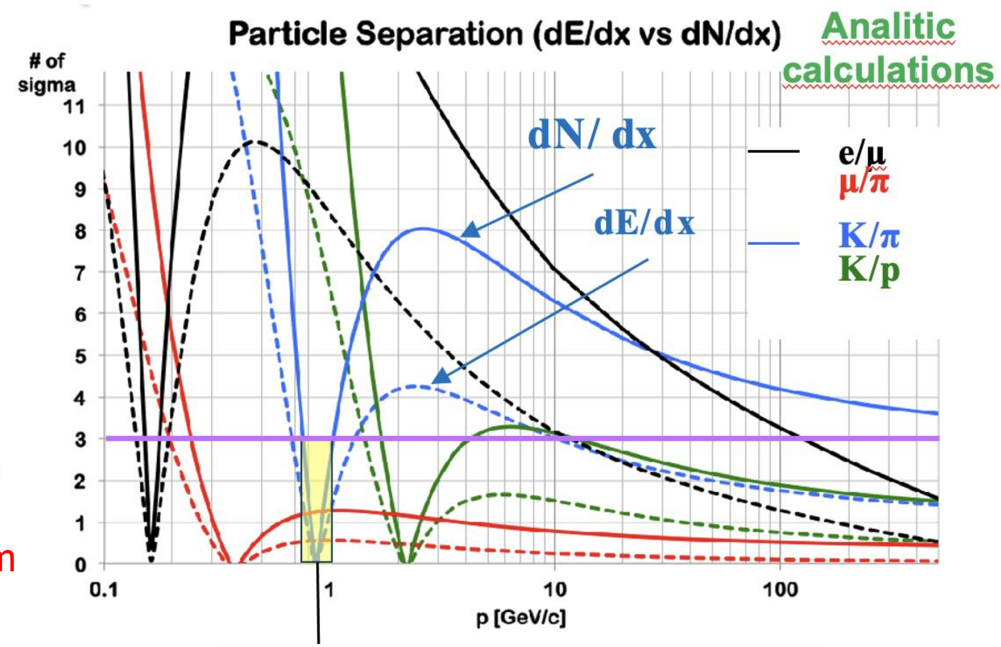
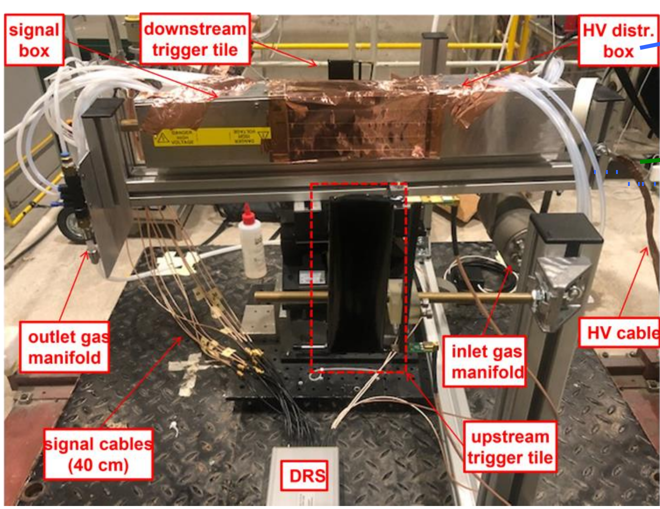
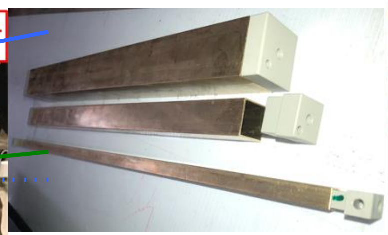
The Drift Chamber: Cluster Counting/Timing and PID

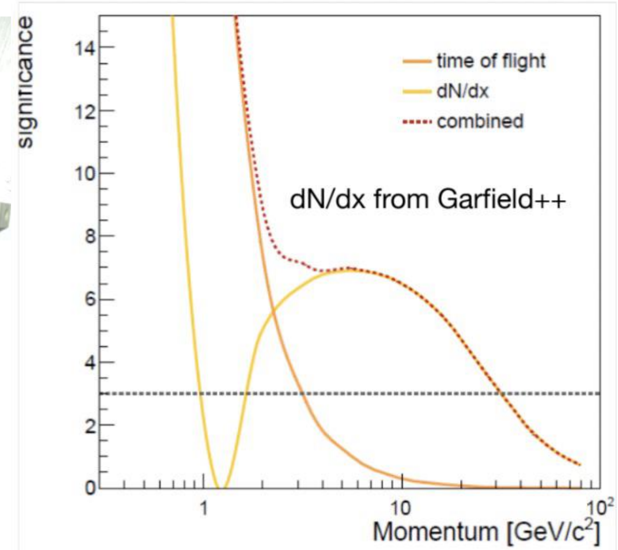
- Analitic calculations: Expected excellent K/π separation over the entire range except 0.85<p<1.05 GeV (blue lines)
- Simulation with Garfield++ and with the Garfield model ported in GEANT4:
  - the particle separation, both with dE/dx and with dN_{cl}/dx, in GEANT4 found considerably worse than in Garfield
  - the dN_{cl}/dx Fermi plateau with respect to dE/dx is reached at lower values of βγ 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 ~ $2 \cdot 10^5$,
165 GeV/c

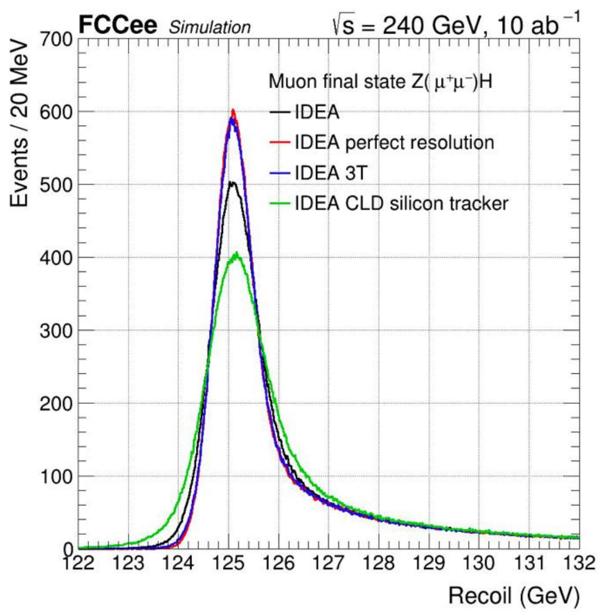


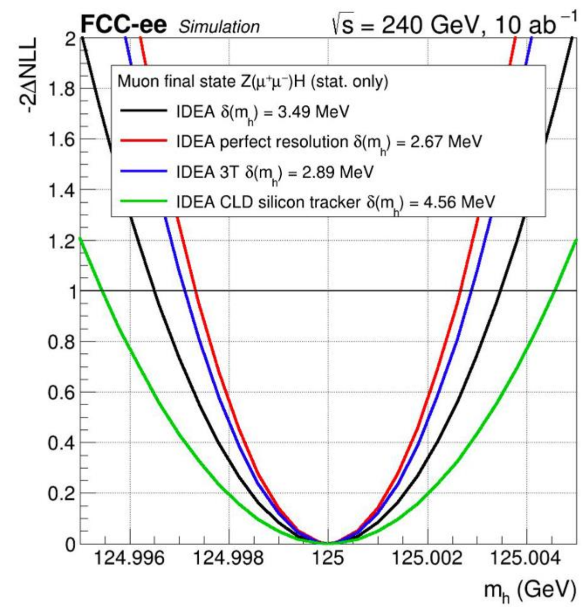
Constraint from Higgs Mass measurement

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

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