Camera a drift

Meeting con i referees di CSN1

July 18th 2025

N. De Filippis (INFN Bari e Politecnico), M. Primavera (INFN Lecce)
on behalf of the IDEA DCH Groups:

Bari: M. Abbrescia , N. De Filippis, D. Diacono, W. Elmetenawee, M. Louka, M. Numan Anwar , J.V. Palacios, G. Pappalettera, F.M. Procacci, M. Saiel

Lecce: A. Corvaglia, F. De Santis, E.M.V. Fasanelli , E. Gorini, F. Grancagnolo, S. Grancagnolo, F.G. Gravili, A. Leaci, S. Maggiore, A. Miccoli, F. Paladini, M. Panareo, M. Primavera, A. Ventura, C. Veri (+G.F. Tassielli)

EoI from Pisa: M. Chiappini and Marco Grassi to IDEA FCC DCH as “external consultants”.

Anagrafica RD_FCC Bari 2026

INFN- Bari	2026
N. De Filippis (Assoc. Prof.)	30%
M. Abbrescia (Assoc. Prof.)	15%
M. Louka (PhD)	100%
M. Saiel (PhD)	100%
A. Ali (PhD) (associazione in corso)	100%
M. Anwar (PhD)	25%
J. Verdeios Palacios (PhD)	50%
W. Elmetenawee (Postdoc INFN)	30%
D. Diacono (Tecn. INFN)	10%
F. Procacci (PhD)	100%
G. Pappalettera (Assoc. Prof.) (associazione da rinnovare)	0%
G. De Robertis (Tecn. INFN)	
TOT	**5.8 FTE**

Anagrafica RD_FCC Lecce 2026

Ricercatori/Tecnologi

E.M.V. Fasanelli 10% Primo Tec.
E. Gorini 30% PO
F. Grancagnolo 0%
S. Grancagnolo 30% RTDB
F.G. Gravili 30% Assegnista di ricerca
A. Leaci 40% PO
A. Miccoli 30% Tecnologo
M. Panareo 10% PA
M. Primavera 30% Primo Ric.
A. Ventura 30% PA

Personale tecnico

A. Corvaglia
S. Maggiore
F. Paladini
C. Veri

Totale: 2.4 f.t.e.

International Collaboration

INFN Bari + Lecce involved in all the tasks

INFN Pisa expression of interest of MEG DCH experts (M. Chiappini, M. Grassi)

INFN Perugia joining for tracking studies

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

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

- coating / manufacturing facility at composite center Purdue would allow manufacturing all kinds of materials
- reconstruction / tracking/GEANT work for implementing CF into simulation

G. Charles group from IJCLAB (France) :

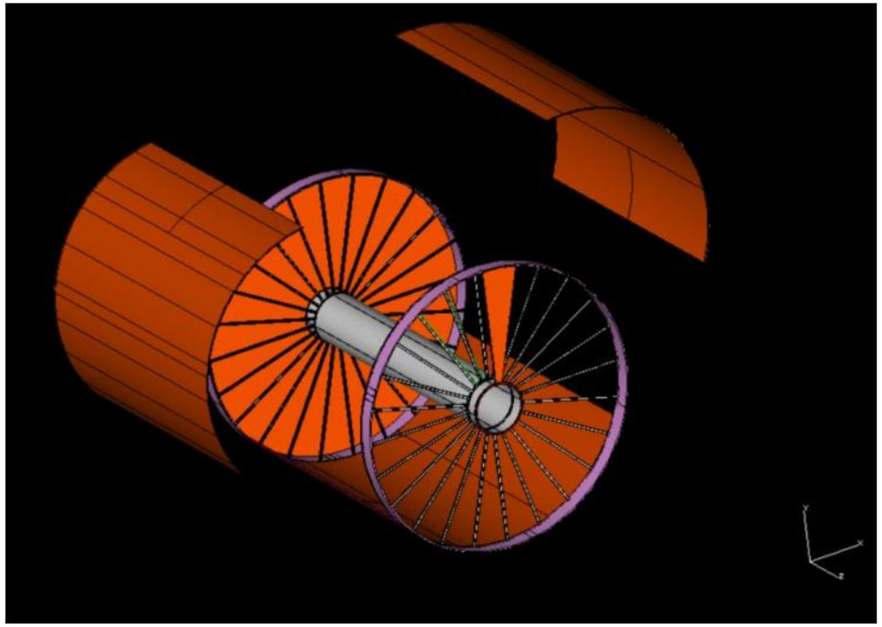
- any test with wire material
- test also of anchoring the wire (crimp, gluing, soldering)
- activity on mechanical design and realization of prototypes

China:

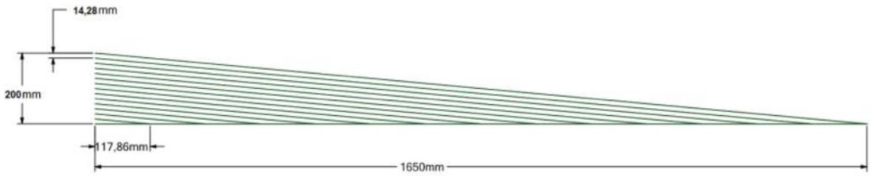
- well established collaboration with IHEP for NN-based cluster counting algorithm

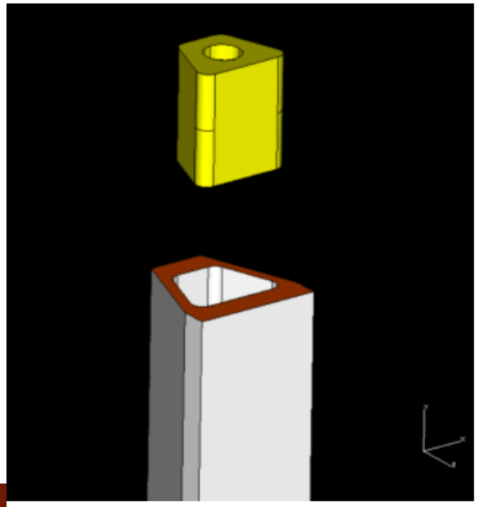
DCH mechanical design → updates and plans/1

IDEA DCH → ``INTREPID”



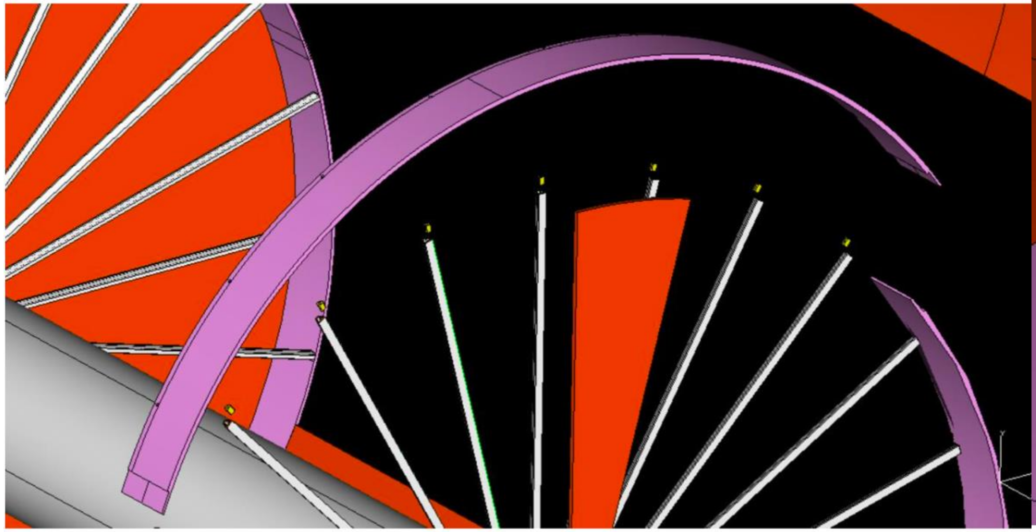
- **Outer cylinder** made of 3 panels **2 cm** thick →3 layers (2 monolithic CF with Al honeycomb structure in the middle)
- **External and internal ring** in monolithic CF
- **Endplates** made of 48 **Spokes** (24 per endcap), defining 24 azimuthal sectors.
- Each **spoke** (length **l = 165cm)** is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

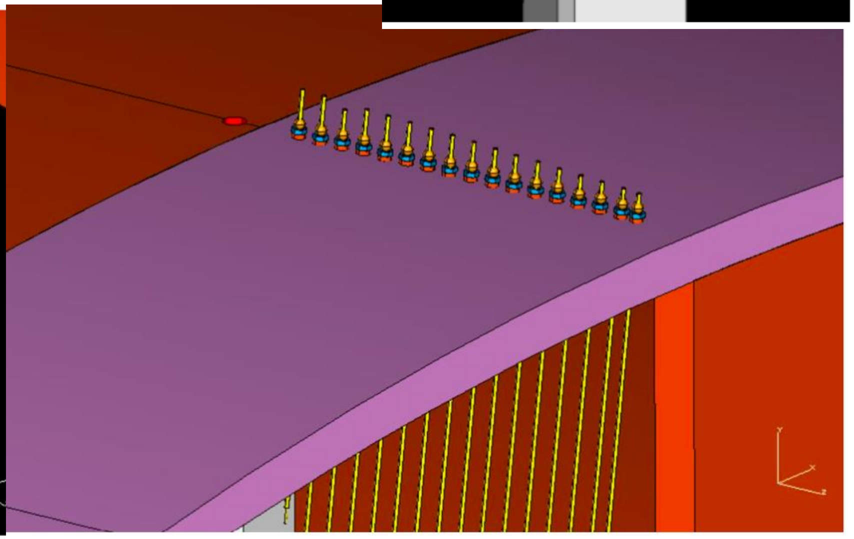




Outer ring/spoke details

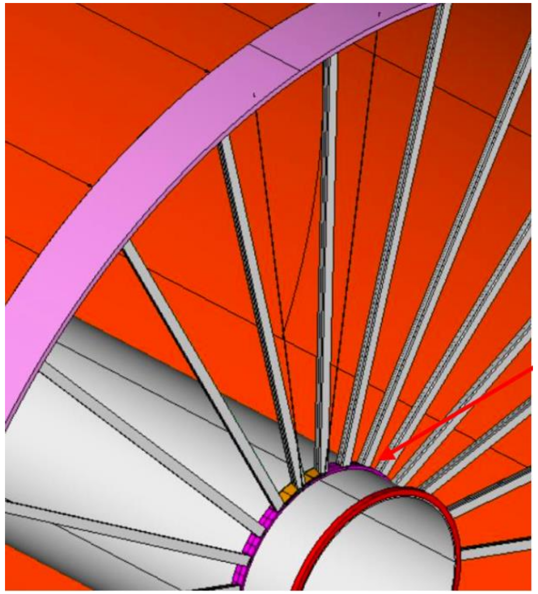
On the outer part the spoke has an internally glued female joint (yellow) which locks the spoke to the outer ring (pink)

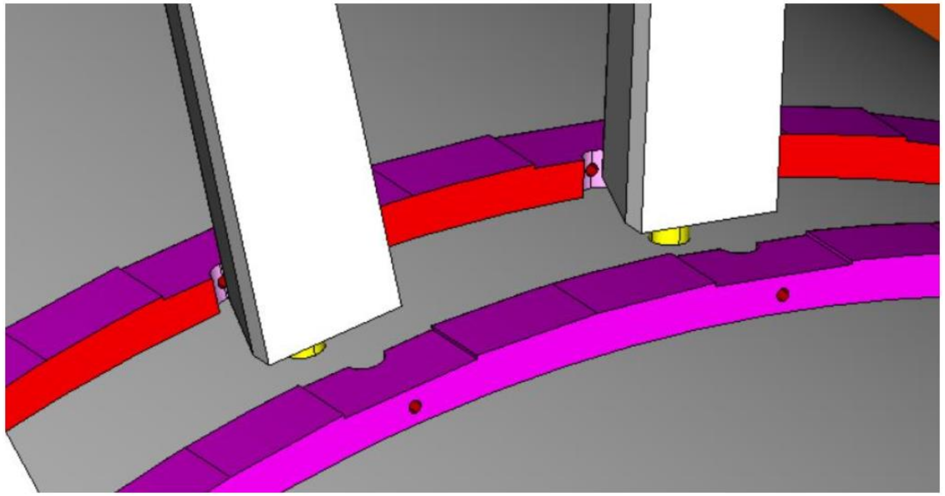


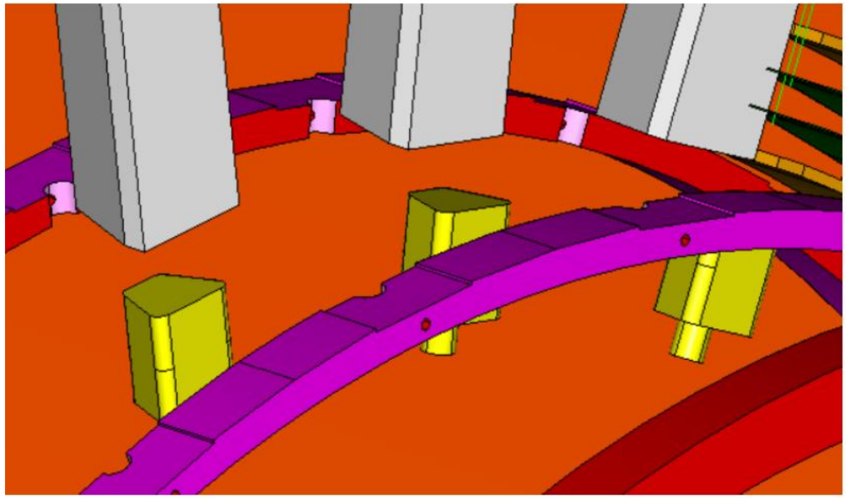


DCH mechanical design → updates and plans/2

Inner ring details

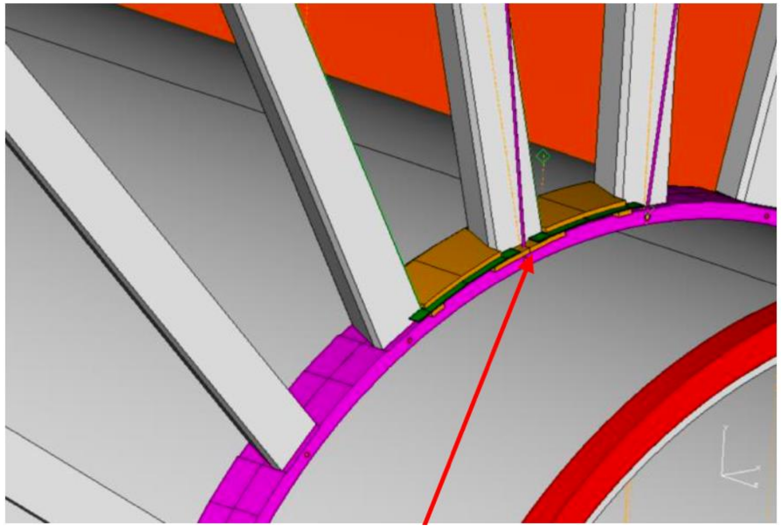






Two interlocking rings (violet) lock the spokes (grey)

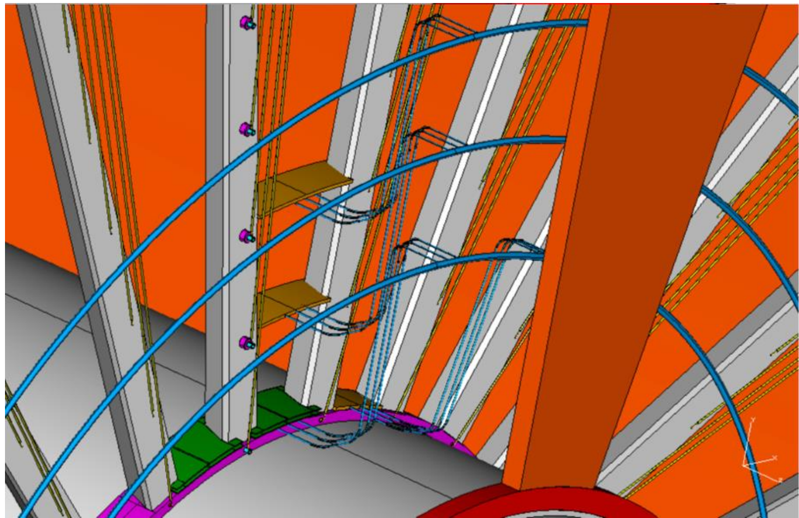
Each spoke has an internally glued male joint (yellow) that fits into the rings



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

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

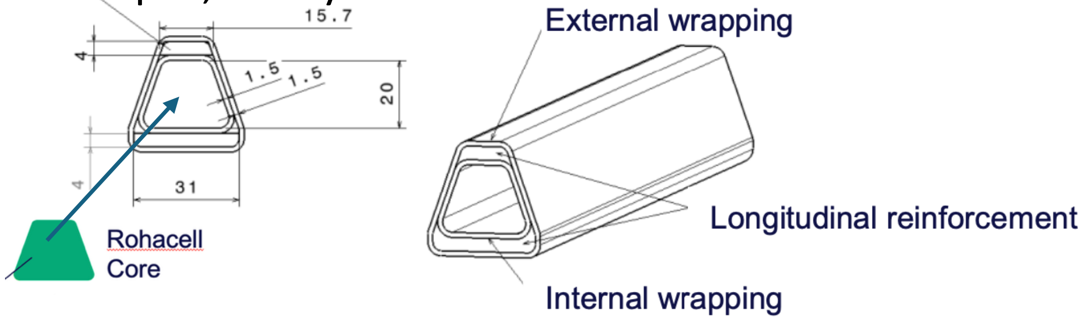
The supporting cables of the spokes are anchored to some spacers appropriately shaped



DCH mechanical design → updates and plans/3

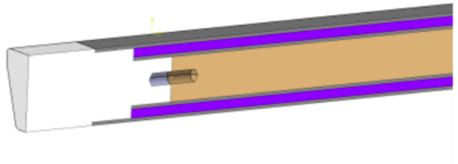
Optimization of spoke cross section: investigated 3 different shapes, finally:

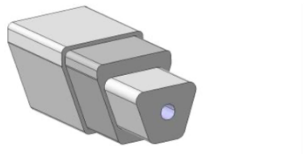
Carbon foam core **6x** lighter than aluminum (FOAM ROHACELL® 35 HTC)



Production of a spoke prototype (50 cm long):

- The core was milled with a numerically controlled machine.
- The winding foils were manually cut into strips of the sizes in figure
- The PEEK side inserts were glued with acrylic adhesive

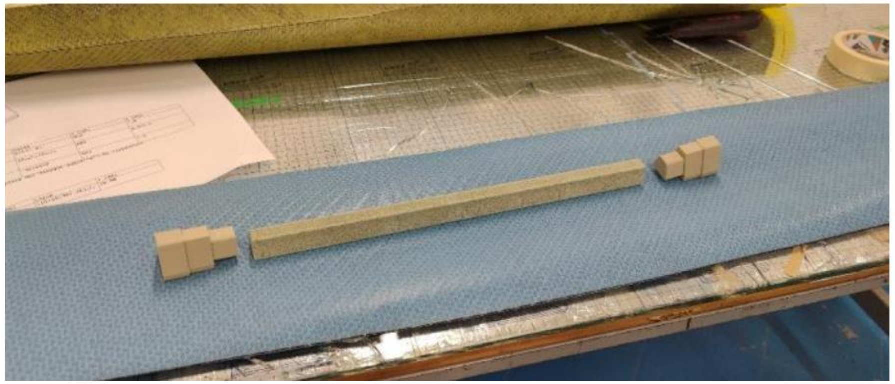




Peek side inserts

Item	Material	CPT (mm)	Layup	T (mm)
Internal wrapping	Prepreg Tissue 430g/m2	0.5	(0)3	1.5
Longitudinal reinforcement	Prepreg Tissue 800g/m2	0.86	(0)4	4
External wrapping	Prepreg Tissue 430g/m2	0.5	(0)3	1.5

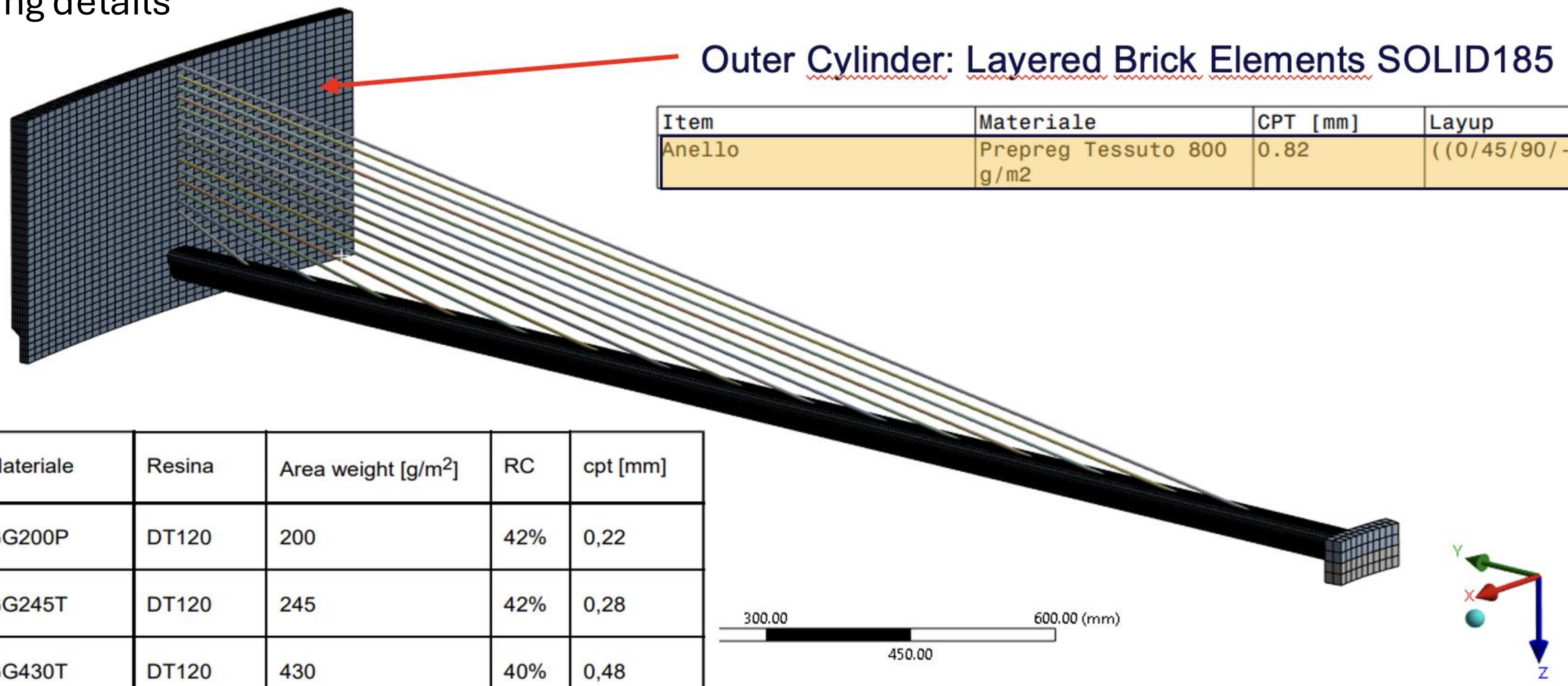
CF thickness # of CF layers total thickness



- **Simulation plans:**
  - Study the stability of the outer and inner rings with all the connections
  - Study the best solution for connect the stays at the spokes
  - Buckling analysis on outer cylinder
- **Production plans:**
  - More spokes prototypes
  - Mechanical test with torsion, compression, bending
  - Internal and external rings with the connections
- **Plans for test to be done in parallel:**
  - Characterize the wires we have (micrometer positioning stages)

DCH mechanical design → updates and plans/4

Outer ring details

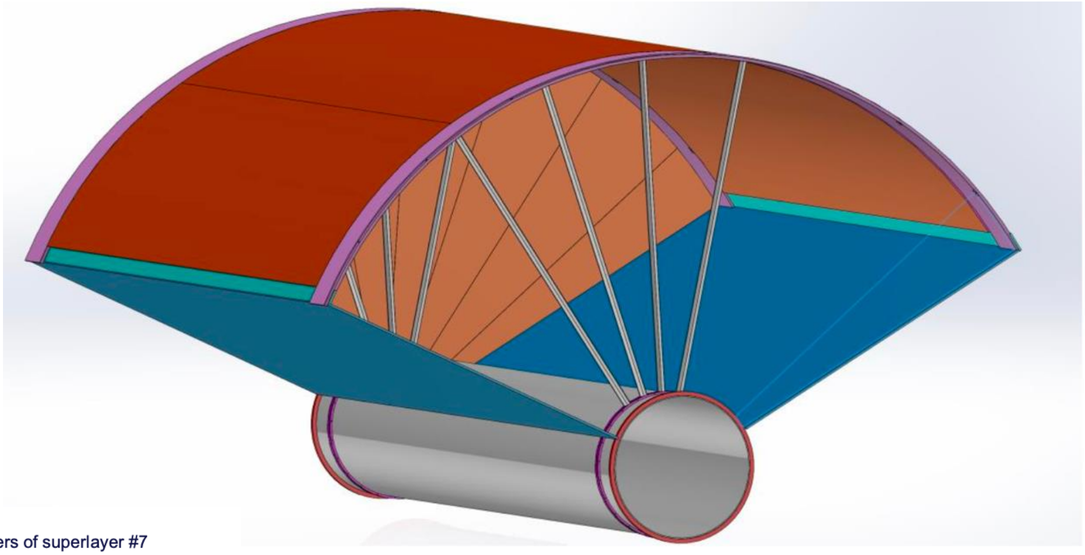


Item	Materiale	CPT [mm]	Layup	t [mm]
Anello	Prepreg Tessuto 800 g/m2	0.82	$((0/45/90/-45)_3)_s$	19.68

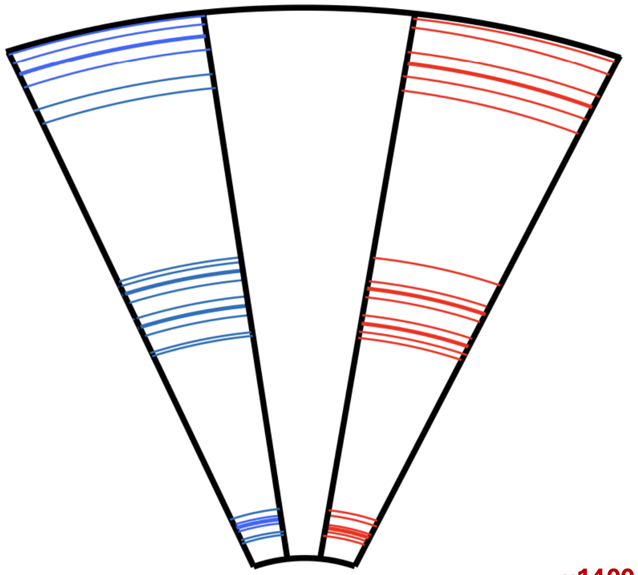
Materiale	Resina	Area weight [g/m^2]	RC	cpt [mm]
GG200P	DT120	200	42%	0,22
GG245T	DT120	245	42%	0,28
GG430T	DT120	430	40%	0,48
GG630T	DT120	630	37%	0,66
GG800T	DT120	800	36%	0,82
UD200	DT120	200	36%	0,2

DCH prototype → updates and plans/1

- Activities to start the construction of a **full-scale prototype** → to test the chamber mechanical and electrostatic stability
- Goal: construction a full length DCH prototype with 3 sectors per endcap:
  - 8 spokes (4 per endcap)
  - Internal ring
  - 1/3 outer ring
  - 1/3 cylindrical panel
- ***A clean room is needed for wiring the prototype***
  - large enough area **7 x (8+2) m^2** at least, **x 3.5 m height**
  - class 10,000 clean room
  - humidity control (+/- 5%) in order to avoid corrosion of the Al wires (as experienced in the construction of the MEG2 drift chamber)
  - temperature control (+/-1°C) because of the different thermal expansion coefficients of the various components



Length = 4 m (active) + 2 x 0.25 m (service area) **= 4.5 m**
Width = 3 active sectors + sides **= 2.5 m**
Height = 0.35 m (inner radius) + 2 m + space for cover **= 3 m**
Number of active electronics channels = 112



~1400 wires in total

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)

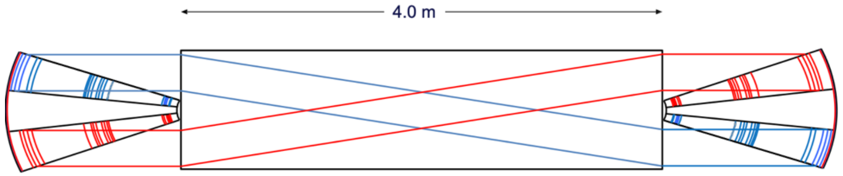
First two layers of superlayer #8
U field layer (46 field wires)
U layer (22 sense + 23 guard)
U and V field layers (2 x 46 field wires)
V layer (22 sense + 23 guard)
V and U field layers (2 x 46 field wires)
V and U guard layer (2 x 23 guard wires)

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

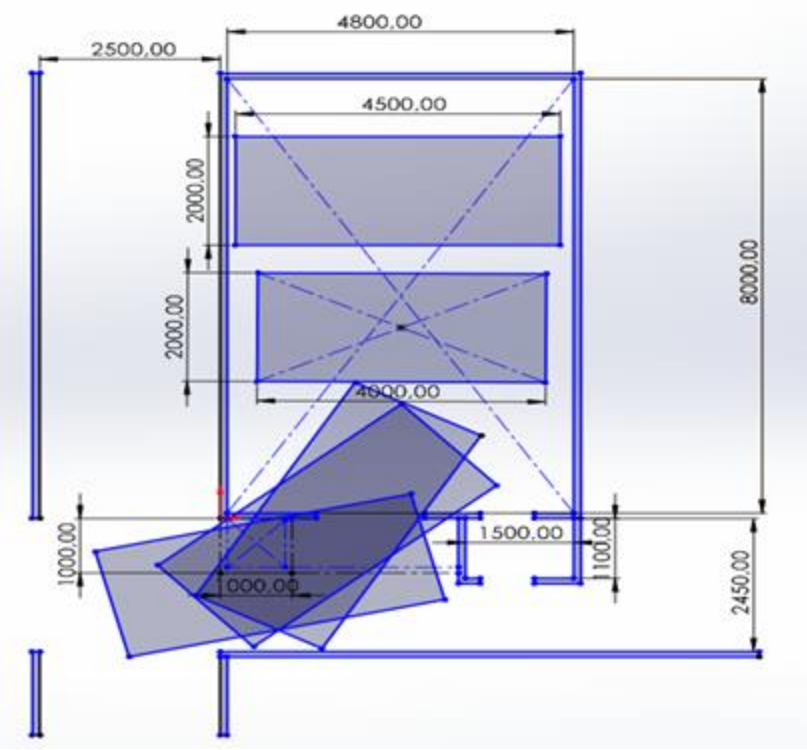
PCBoards wire layers: 42
Sense wire boards: 8
Field wire boards: 22
Guard wire boards: 12
HV values: 14

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



DCH prototype → updates and plans/2

- Several options evaluated for the clean room, but dimensions need to be large (~5m x ~8m) and it must not be already occupied, so there are not many possibilities. A realistic option is to equip the semi-clean area used by the ALICE experiment in the recent past at INFN Bari.
- Dimensions are fine (even if not ``fully comfortable'' to host the wiring machine + prototype + additional test desks)
- Status is fine: interventions of the clean room functionality recovery and further safety adaptations should be carried out
- Performed simulation with CAD of the size and the movements of the prototype, e.g. to be extracted from the clean room



Realistic estimate of the costs to:

- restore the functionality of the clean room
- ensure safety operations (e.g. Safe access to the air recirculation system)
- ensure maintenance and daily consumption

210-270 Keuro (A.I.R TECH. S.R.L., INNOVI AIR, FRIGO TECH S.A.S.)

Yearly Maintenance: 5Keuro (A.I.R TECH.)

Investment to be supported and requested to INFN "giunta" by the Bari INFN Director

DCH prototype → updates and plans/3

- First attempt (an exercise) to have a **time schedule** to realize the prototype → main steps, supposing T0 = OK from INFN to the clean room:

2025	*OK from INFN to give funds to make the clean room operational*
2026	*carry out the bureaucratic steps for entrusting the contract to a company*
2026	*Procurement of the needed materials/mechanics for the prototype*
2027	*clean room ready and operational*
2027	*prototype wiring in the clean room*
2027	*Procurement of the needed electronics for the prototype readout*
2028	*Test the prototype on cosmics*
2029	*Test the prototype on a beam facility*

And a **"spending profile"**:

2025:

prototype mechanics:

- spokes (already funded by EURIZON) 20 k€
- stays + strain gage controller elements +spares 5 k€ 120
- inner cylinder (probably only) half cylinder
- outer ring 1/6 (= 60°) of full ring 10 k€
- Controller misuratori di tensione per prototipo 2 k€
- outer cylinder 10 k€ 1/6 (= 60°) of full cylinder
- lateral panels
- spacers 10 k€ PEEK foils to be machined (Bari)
- wire PCB cards 15 k€ 200 cards of 42 different design + HV distribution + termination network
- field and guard wires 10 k€ 7+2 Km
- elettronica di lettura : 2 schede MOSAIC per sviluppo firmware ed hardware (6kEuro +IVA ciascuna)

2026: prototype wiring

• Bari clean room refurbishment:	200 k€	contribution by "Giunta" + CSN1 ?
• wiring robot refurbishment	15 k€	including transport from Pisa to Bari
• sense wires	2 k€	already procured
• consumables for wiring	10 k€	too many items to list

2027: prototype readout electronics

• cosmic trigger tiles	12 k€	24 tiles 30x30 in three planes + iron slab for low p cut + support system
• HV distribution	3 k€	HV power supply procured (14 different values) + distribution
• readout electronics (CAEN VX2751)	200 k€	(8 modules x 16 channels) to be negotiated with CAEN
• dedicated PC + ancillary equipment	5 k€	

2028: cosmic ray test:

• consumables	10 k€	gas system + gas consumption + ...

2029: beam test (assume CERN PS-T9/T10):

• transport	5 k€	two ways
• consumables	5 k€	gas consumption + miscellanea
• travel expenses	30 k€	2 weeks x 10 people

Totale 387 keuro (200 dei quali da capire meglio e 30 di missioni) + 200 giunta + ?? missioni Le-Ba per filatura)

DCH prototype → updates and plans/4

Costs already supported (in 2024):

- 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 LumaMetal: 10 Km of 20 µm W for sense (10 k€ from FCC-BA)
- Wires from Specialty Materials: 1km of 35 µm C monofilament (5 k€ from EURIZON-LE)

Sblocchi s.j. May 2025:

- **Lecce, 15 keuro (Consumo)**→ stays + controller and outer rings

CETMA ha già sviluppato componenti in composito (spokes) per la camera drift. Oggetto della nuova richiesta da parte di INFN sono:

- Progettazione di uno stampo per la produzione degli external ring;
- Realizzazione di n.2 external ring aventi le seguenti caratteristiche geometriche:
  - Outer Diameter: 4000 mm;
  - Inner Diameter: 700 mm;
  - Arc length: 2022 mm;
  - Thickness: 20 mm;

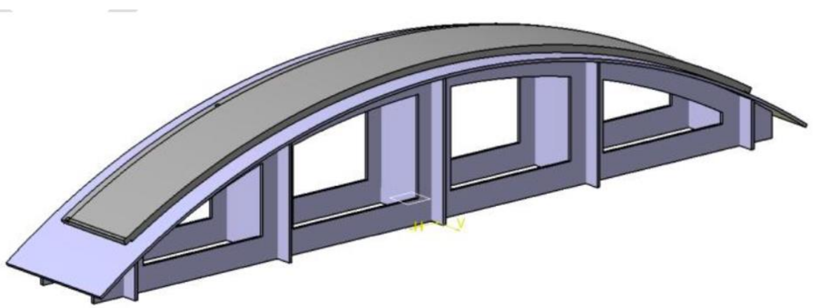


Figura 2 - Schema esemplificativo dello stampo

- **Bari, 15 keuro (Consumo)** → 2 schede MOSAIC per sviluppo firmware ed hardware (6kEuro +IVA ciascuna)

Sblocchi s.j. July 2025 (requested):

- **Lecce**

10 keuro (Inventario) →

controller misuratori di tensione 2 keuro

Cercafughe di elio 5 keuro (anticipati da Dot 1 e da consumi sbloccati a Maggio, ma vanno restituiti)

Plug-in WPHD-RK-8B10B D 3 keuro

8b10b Decode Option per oscilloscopio

WavePro HD Lecroy (a completamento dell'oscilloscopio molto costoso, che potra' essere usato in elettronica per il lavoro sull'analisi delle forme d'onda per il cluster counting)

15 keuro (Consumo) → pannello strutturale esterno prototipo e lavorazioni pannelli laterali e frontali 15 keuro

- **Bari, 30 keuro (Consumo/Inventario)**

field (40micron) and guard wires (50micron) for full length prototype (8+2 Km) 20 keuro

peek sheets for prototype spacers/endcaps areas and machining costs ($6m^2$, 2cm thickness) 8 keuro

rotating table for detector setup for testbeam: 2 keuro

Consider that:

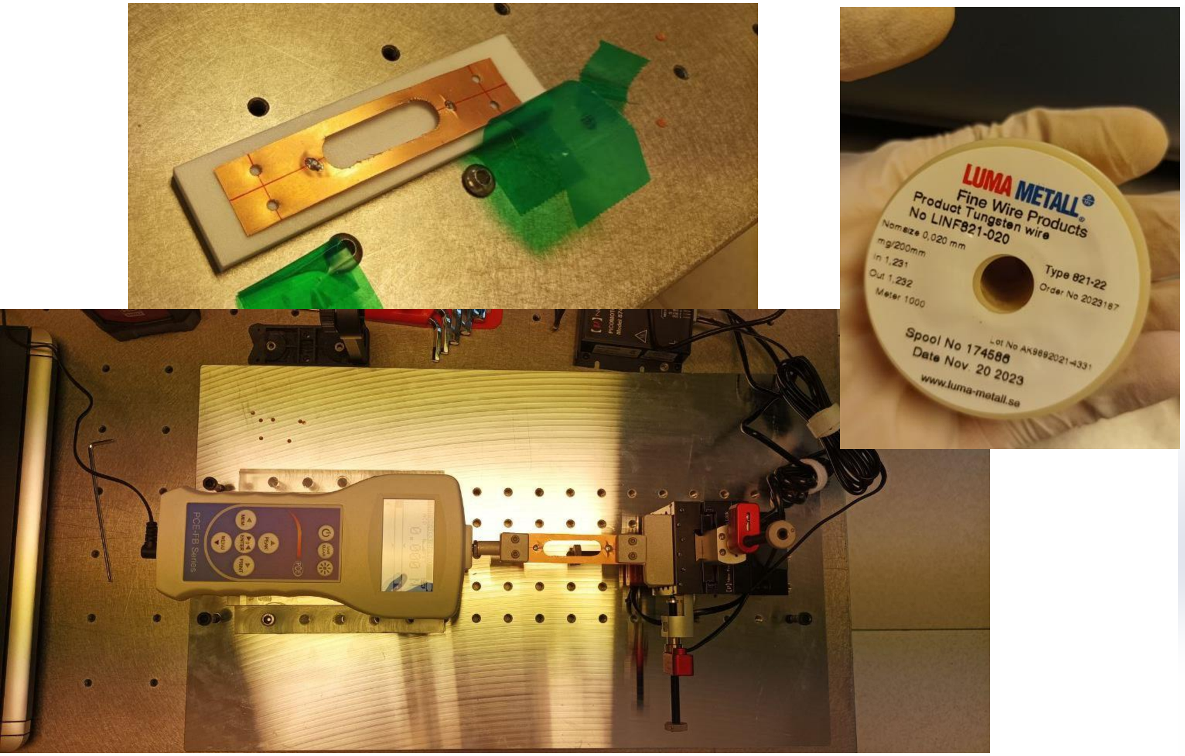
I test da fare fuori da una camera pulita (**e prima di pensare alla filatura**) sono per esempio: test dei sistemi di ancoraggio e regolazione degli stays, test di flessione degli spokes in funzione del carico (simulato) dei fili e di come questo è distribuito, misura dello stress residuo sul cilindro interno in funzione del carico (simulato) dei fili e delle regolazioni sugli stays. Occorreranno: gli stays, struttura in alluminio di supporto (oltre 4 m per 2 m, deve sostenerlo senza deformarsi) e righe ottiche (per posizionare i sensori, microscopi elettronici e sistemi laser, in modo da poter rilevare il corretto posizionamento delle parti meccaniche)

Wire tests → updates and plans/1

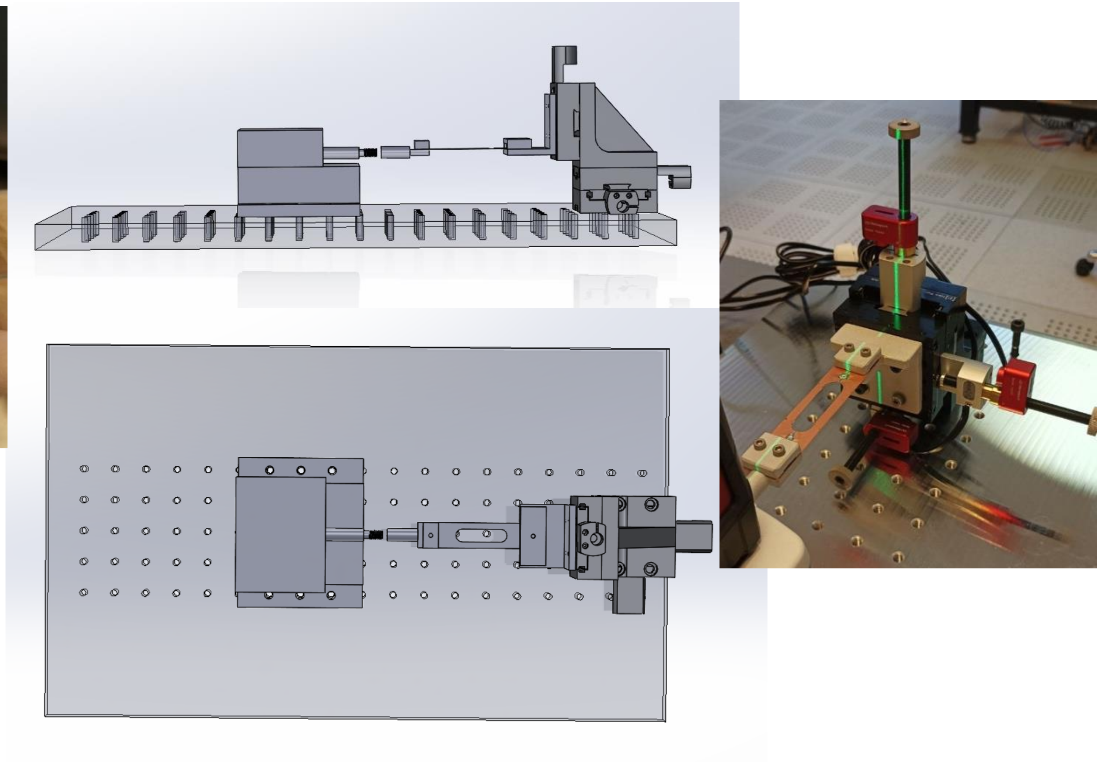
- Wire tests started in a Bari clean room, through traction following ASTM 3379-75 (Standard Test Method for Tensile Strength and Young's Modulus), then analised looking at the breaking points with Scanning Electron Microscope (SEM).

Setup:

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



Testing samples



Tensioning machine

Wire tests → updates and plans/2

➢ W+Au wire test

Wire diameter: 20µm

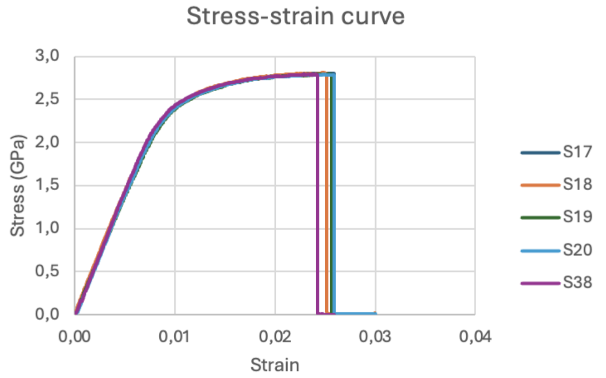
Specimen number	Tensile Strength - UTS (GPa)	Young module (Gpa)	R^2	Effective test time (s)	Total wire elongation (mm)	Elongation (%)	Yield Tensile Strength - YTS (GPa)	
1	2.811	220.833	0.9986	34.15	2.049	3.415	1.237	
2	2.820	212.381	0.9979	35.23	2.114	3.523	1.325	v=60 µm/s l=60mm
3	2.814	214.348	0.9995	38.90	2.334	3.890	1.249	
4	2.718	207.523	0.9997	40.00	2.400	4.000	1.307	
5	2.833	221.242	0.9990	34.88	2.093	3.488	1.267	
Av. Set	2.799	215.265	0.9989	36.63	2.198	3.663	1.277	
St.Dev.	0.046	5.827	0.0007	2.63	0.158	0.263	0.038	
11	2.843	226.744	0.9993	33.70	2.022	4.044	1.345	
33	2.827	228.538	0.9992	29.30	1.758	3.516	1.329	v=60 µm/s l=50mm
34	2.839	265.360	0.9987	26.48	1.589	3.177	1.567	
35	2.820	262.116	0.9996	25.13	1.508	3.015	1.550	
36	2.820	207.422	0.9994	29.13	1.748	3.495	1.230	
Av. Set	2.830	238.036	0.9992	28.75	1.725	3.449	1.404	
St.Dev.	0.011	24.907	0.0003	3.29	0.197	0.395	0.148	
12	2.817	297.947	0.9998	45.58	1.367	2.735	1.324	
13	2.811	296.225	0.9995	40.53	1.216	2.432	1.312	
15	2.820	283.525	0.9998	47.95	1.439	2.877	1.242	
16	2.814	303.444	0.9997	43.55	1.307	2.613	1.320	v=20 µm/ l=40mm
37	2.843	308.218	0.9998	41.90	1.257	2.514	1.605	
Av. Set	2.821	297.872	0.9997	43.90	1.317	2.634	1.361	
St.Dev.	0.013	9.309	0.0001	2.95	0.088	0.177	0.140	
17	2.807	281.131	0.9998	64.75	1.295	2.590	1.672	
18	2.811	283.814	0.9997	62.95	1.259	2.518	1.725	
19	2.792	274.393	0.9997	64.15	1.283	2.566	1.642	
20	2.792	282.702	0.9996	64.75	1.295	2.590	1.661	v=20 µm/ l=50mm
38	2.792	291.537	0.9997	60.63	1.213	2.425	1.719	
Av. Set	2.799	282.716	0.9997	63.45	1.269	2.538	1.684	
St.Dev.	0.010	6.140	0.0001	1.74	0.035	0.070	0.037	

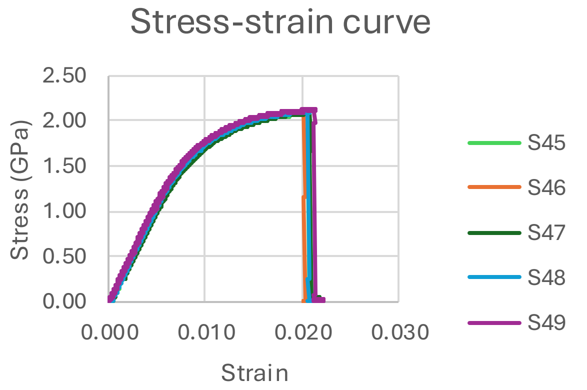
➢ Mo+Au wire test

Wire diameter: 20µm

v=20 µm/s
l=50mm

Specimen number	Tensile Strength - UTS (GPa)	Young module (Gpa)	R^2	Effective test time (s)	Total wire elongation (mm)	Elongation (%)	Yield Tensile Strength - YTS (GPa)
45	2.091	220.031	0.9992	51.68	1.034	2.067	1.098
46	2.107	226.061	0.9995	50.28	1.006	2.011	1.128
47	2.101	206.040	0.9979	54.18	1.084	2.167	1.028
48	2.110	222.461	0.9997	51.70	1.034	2.068	1.110
49	2.123	224.851	0.9993	53.08	1.062	2.123	1.122
Average Set	2.107	219.889	0.9991	52.18	1.044	2.087	1.097
St. Dev.	0.012	8.080	0.0007	1.49	0.030	0.060	0.040

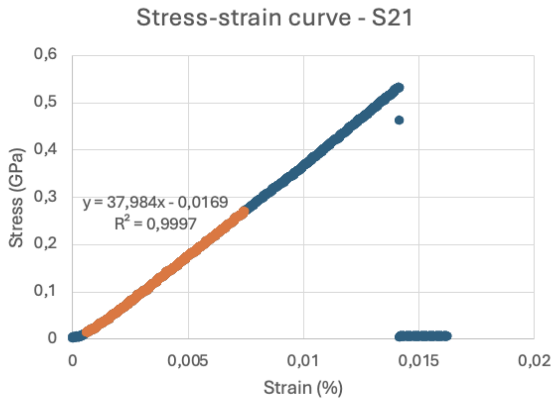




➢ Monofilament C wire test

Wire diameter: 33.5µm

Specimen number	Tensile Strength - UTS (GPa)	Young module (Gpa)	R^2	Effective test time (s)	Total wire elongation (mm)	Elongation (%)	
21	0.531	37.984	0.9997	28.35	0.567	1.418	
22	0.636	37.791	0.9996	33.73	0.675	1.686	
23	0.779	38.190	0.9999	41.38	0.828	2.069	v = 20 µm/s
24	0.825	36.083	0.9986	45.65	0.913	2.283	
25	0.825	39.638	0.9996	41.43	0.829	2.071	
26	0.675	37.779	0.9996	36.38	0.728	1.819	
Average Set	0.712	37.911	0.9995	37.82	0.756	1.891	
St. Dev.	0.118	1.135	0.0005	6.25	0.125	0.313	
28	0.809	41.277	0.9997	78.50	0.785	1.963	
30	0.775	38.965	0.9993	80.55	0.806	2.014	v = 10 µm/s
50	0.628	41.876	0.9997	59.60	0.596	1.490	
51	0.770	39.984	0.9996	79.98	0.800	1.999	
52	0.728	38.547	0.9977	74.55	0.746	1.864	
Average Set	0.742	40.130	0.9992	74.64	0.746	1.866	
St. Dev.	0.070	1.436	0.0009	8.72	0.087	0.218	
54	0.873	41.089	0.9996	58.03	0.870	2.176	
55	0.796	39.863	0.9994	54.48	0.817	2.043	
56	0.851	42.731	0.9993	53.43	0.801	2.003	
57	0.843	40.242	0.9998	56.43	0.846	2.116	v = 15 µm/s
58	0.865	42.277	0.9999	55.08	0.826	2.065	
Average Set	0.846	41.240	0.9996	55.49	0.832	2.081	
St. Dev.	0.030	1.246	0.0003	1.79	0.027	0.067	



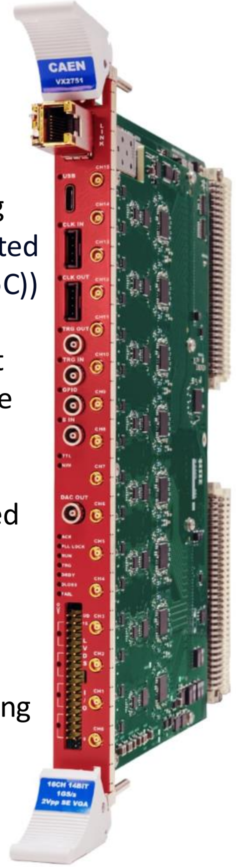
Electronics→ updates and plans/1

➢ Lecce

- The **CAEN VX2751** is a 16-channel digital signal processor offering, independently for each of the 16 channels, the full acquisition chain, from the input signal sampling in the ADC to the processing of the signal and readout. At the end of January 2025, CAEN has commercially released the first version of the VX2751.

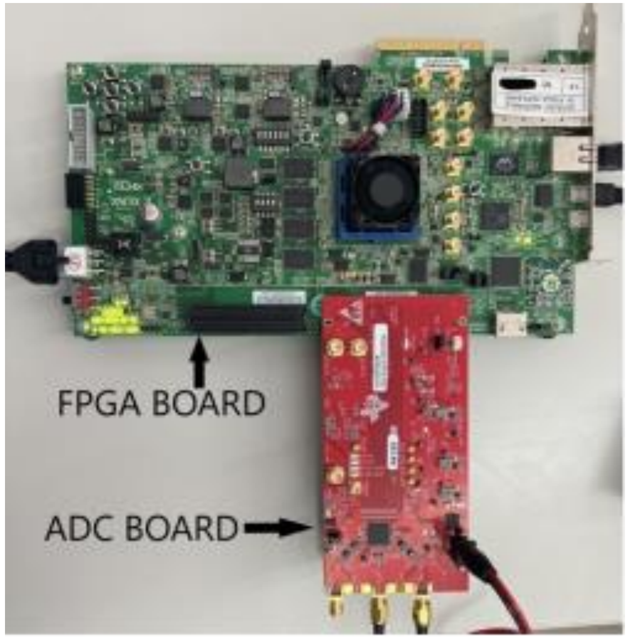
- The analog single-ended input channels, with software selectable input gain up to x100 and *500 MHz* bandwidth, are digitized with a *14 bit*, *1 GSa/s* ADC, compatible with the minimal requirements for CC. The sampled data are managed in the FPGA at the firmware level, where different firmware types, including custom algorithms, like DERIV and RTA, can be selected via software. Besides VHDL programming language, the available Sci-Compiler software, a block-diagram-based graphic tool, offers a very flexible and user-friendly way to build up more complex algorithms.

- **The CAEN quoted *500 MHz* bandwidth sounds marginal. Furthermore presently sw/fw to test VX2751 with Sci-Compiler are not available. However we are going to test the module acquiring real tube signals in the lab with WaveDump2**



- Meanwhile: collaboration with SLAC (Julia Gonski), where they are developing embedded FPGAs (integrated into a system on a chip (SoC)) which could offer a way to design a front-end readout ASIC running a configurable ML algorithm for the drift chamber. Peak finding algorithm might be adapted for the eFPGA target.

- Our Chinese colleagues Guang/Linghui, who developed a ML peak finding algorithm, RNN based, provided the code to Julia



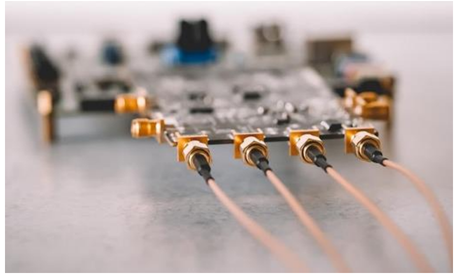
- The **ADC32RF45** is a *14-bit, 3.0 GSa/s*, dual-channel ADC that supports waveform sampling with input frequencies up to *4 GHz* and beyond. It is designed for high signal-to-noise ratio (*SNR*), and channel isolation over a large input frequency range. It supports the *JESD204B* serial interface, a system-level software providing a performance optimized framework to integrate the ADC with various FPGA platforms.

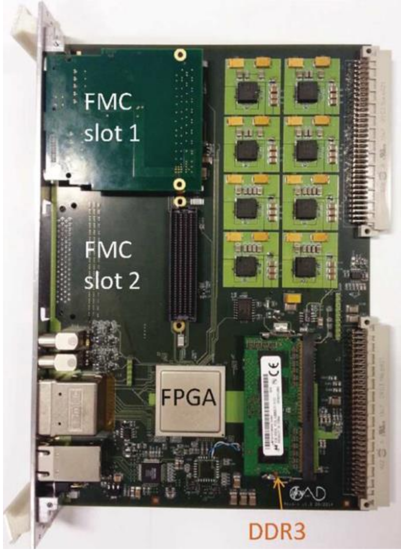
- The Xilinx's **KCU105** evaluation board is a powerful FPGA development platform specifically designed to provide high-performance computing, enabling wide-band data acquisition over *JESD204B* high-speed serial connectivity. It utilizes the Xilinx *Vivado* development environment and it is equipped with 64-bit DDR4 component memory, offering robust storage and memory management, efficient data handling, and supporting faster processing speeds. **Vivado license acquired to use JESD204B protocol, work on-going to configure the system In VHDL.**

Electronics→ updates and plans/2

➢ Bari

- Develop a dedicated communication block to interface the HDSoC v1 waveform digitizer with the MOSAIC board.
- Integrate this firmware into the existing hardware/software stack of MOSAIC.
- **MOSAIC Board**
  - FPGA-based DAQ board for high-energy physics applications
  - FPGA: Xilinx XC7A200T
    - 215360 Logic Cells, 730 BRAMS (12.8Mb)
    - 16 Low-Power Gigabit Transceivers (up to 6.6 Gb/s)
    - DDR3 interface for high-speed data storage (already implemented)
    - Gigabit Ethernet (120 MB/s)
    - Internal 8-bit CPU for control & configuration
  - Supports communication over Wishbone bus
- **HDSoC v1 (Naluscientific) – Waveform Digitizer**
  - Sampling Rate: 1 GSa/s
  - Channels: 32
  - Sample Buffer: 2k
  - Analog Bandwidth: >600 MHz
  - Triggering: Internally configurable schemes
  - Communicates via high-speed serial protocol





- Hardware (FPGA Firmware)
  - Serializer / Deserializer
    - Developed in SystemVerilog
    - Verified through RTL simulation and testbench
  - Both modules are ready for integration and testing with MOSAIC..

Activities	Estimated time
Integrate firmware blocks into MOSAIC and validate internal communication	2-3 weeks
Develop C++ driver to interface MOSAIC's internal CPU with the new firmware	2-3 weeks
Perform full system test with real HDSoC v1 board	2-3 weeks

Test beam → updates and plans/1

- New results from the 2021/2022 beam tests at CERN H8 ($\beta\gamma$ > 400)

Prepared for submission to JINST

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

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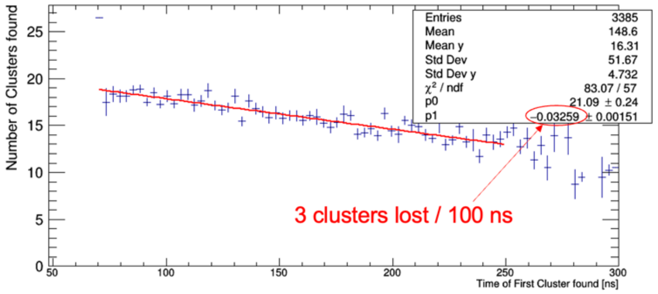
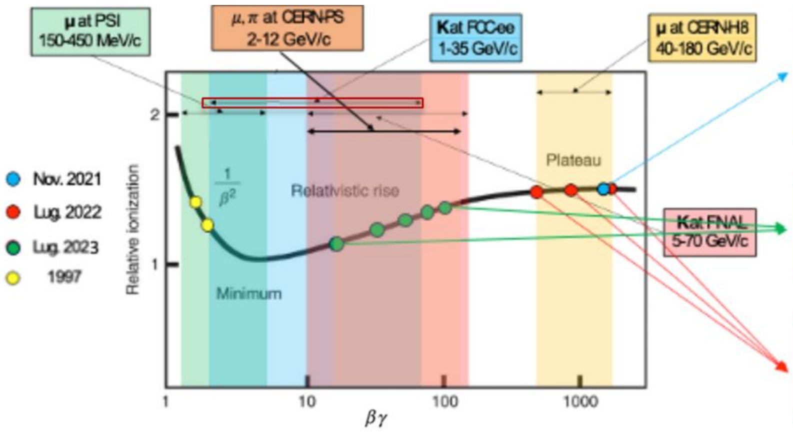
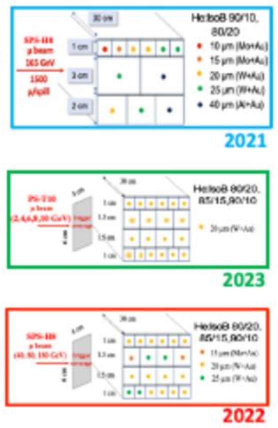
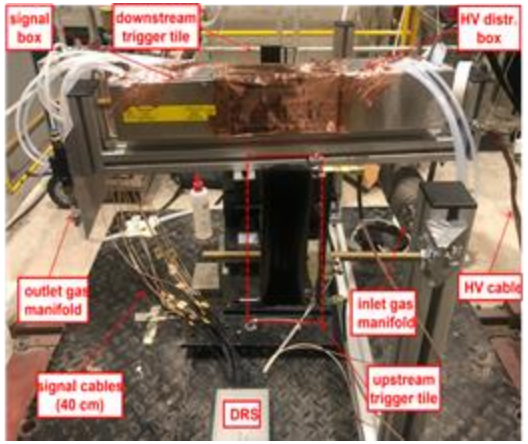
Abstract: Particle identification in gaseous detectors traditionally relies on energy loss measurements (dE/dx); however, uncertainties in total energy deposition limit its resolution. The cluster counting technique (dN/dx) offers an alternative approach by leveraging the Poisson-distributed nature of primary ionization, providing a statistically robust method for mass determination. Simulation studies with Garfield++ and Geant4 indicate that dN/dx can achieve twice the resolution of dE/dx in helium-based drift chambers. However, experimental implementation is challenging due to signal overlap in the time domain, complicating the identification of electron peaks and ionization clusters. This paper presents novel algorithms and modern computational techniques to address these challenges, facilitating accurate cluster recognition in experimental data. The effectiveness of these algorithms is validated through four beam tests conducted at CERN, utilizing various helium gas mixtures, gas gains, and wire orientations relative to ionizing tracks. The experiments employ a muon beam (1 GeV/c–180 GeV/c) with drift tubes of different sizes and sense wire diameters. The analysis explores the Poisson nature of cluster formation, evaluates the performance of different clustering algorithms, and examines the dependence of counting efficiency on the beam particle impact parameter. Furthermore, a comparative study of the resolution achieved using dN/dx and dE/dx is presented.

Keywords: Gaseous detectors, drift chambers, cluster finding, algorithms



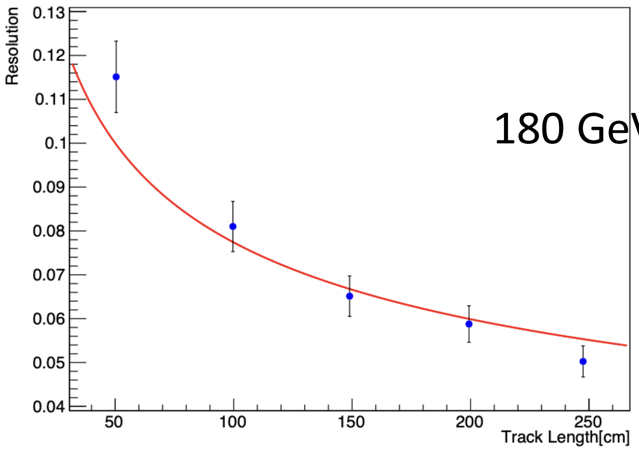




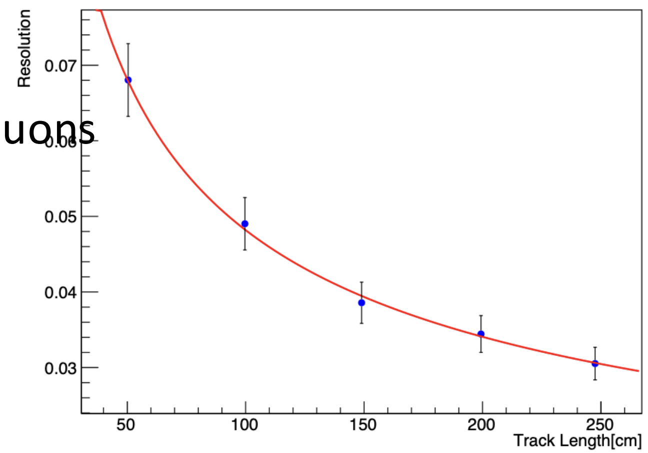


dE/dx Resolution scan vs track lenght

dN/dx Resolution scan vs track lenght



180 GeV/c muons



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

Further improvement in dN/dx resolution from: waveform "cleaning" (3%->2.38% for 2m tracks); event-by-event time-based correction to compensate for the cluster loss for Recombination and Attachment Effects (2.38%->2.28% for 2m tracks)

Test beam → updates and plans/2

Plans

- Finalize data analysis of the two test beams at CERN T10 performed in July 2023 and July 2024 with muons (1-12 GeV)

- Original plan for 2025/2026: test beam at **FNAL-MT6** with **π** and **K ($\beta\gamma$ = 10–140)** → important to fully exploit the relativitic rise. **This option does not seem feasible at the moment** (TB facility at FNAL is closed at least until the end of 2025, due to an accident occurred), then we are exploring the option to perform the test beam at CERN. **Requested** to the responsibles at CERN:

  - We are interested in a beam of π and K in the range between 1 and 30 GeV/c.
  - Any wide interval contained in this range will suits us.
  - Momentum spread up to a few % is acceptable.
  - Beam intensity of the order of 1E4 over a 10x10 cm^2 is our target.
  - A π/K discrimination is necessary (Cherenkov)
  - We could probably sort out a muon veto and/or an electron filter.
  - It looks like that positive beam at T9 might be the best option with K identified in the range 4.5 to 16 GeV/c, but T10 could also be ok.

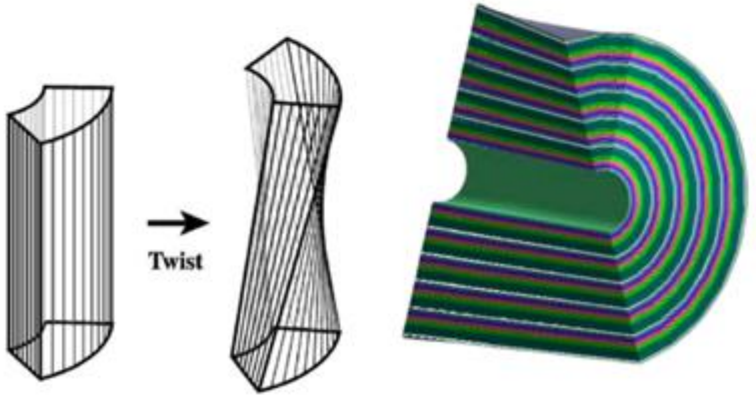
Reply from the PS/SPS Physics Coordinator: currently the T9/T10 beam lines fully booked for 2025, there is some possibility to have some late minute cancellations, but staying in a waiting list.

Simulation → updates and plans/1

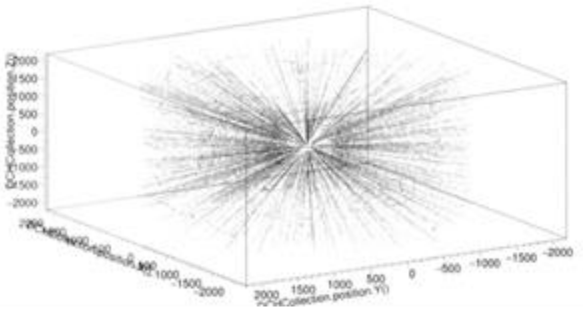
- Full simulation of the IDEA drift chamber in DD4HEP

Large-volume extremely light drift wire chamber Evolving from the detectors built for KLOE and MEG2 experiments: is a full-stereo unique volume, co-axial with the 2T solenoid field, with high granularity, low mass and short drift path.

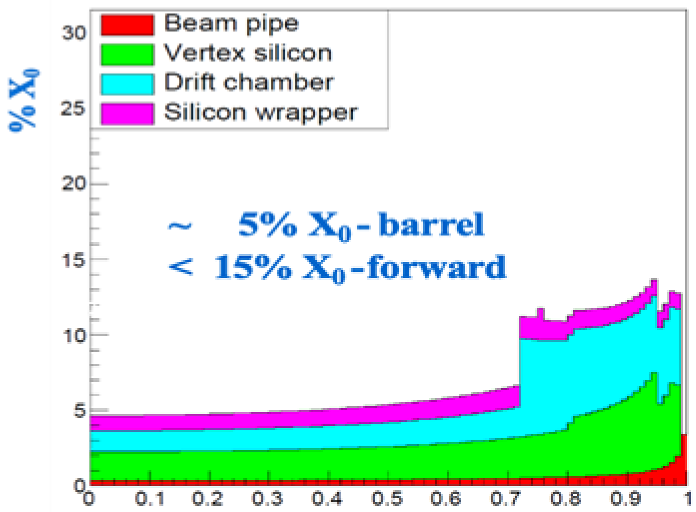
- Cylindrical wall made of carbon fiber
- Cylindrical volume filled of gas mixture.
- 112 hyperboloidal layers filled with gas mix.
- Cells are twisted tubes (twisted tube results from layer segmentation in phi, keeping the twist angle), made of gas mix. These cells are the sensitive volumes!
- Field (x5) and sense (x1) wires inside each cell.
- The new version (v02) is in k4geo.



DriftChamber o1_v02 Twisted tubes.



Activity started (in collaboration with CERN)



Activity started (in collaboration with Purdue U.) to derive the material budget by using the latest implementation of the DCH in DD4HEP/Geant4

→

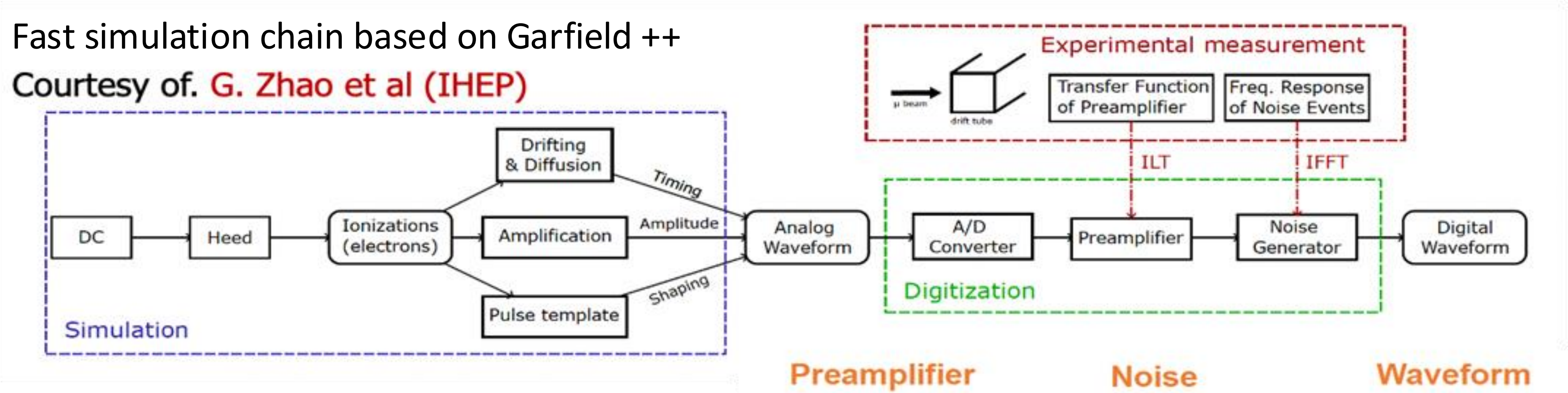
- Strategy of digitization for the IDEA DCH now in FCC software

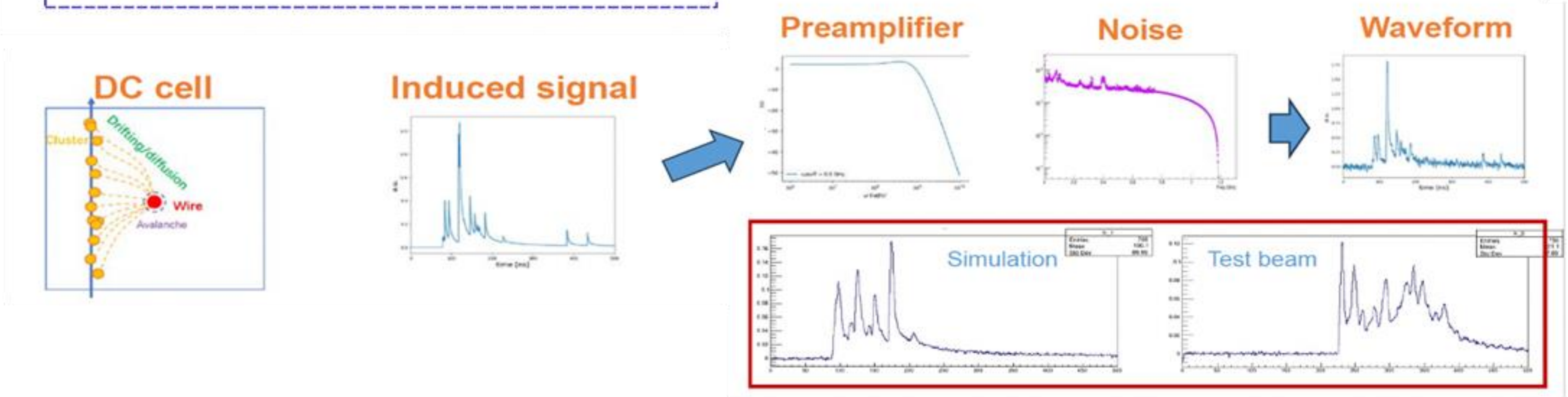
Simulation → updates and plans/2

IHEP+Bari

- Fast simulation chain based on Garfield ++

Courtesy of. G. Zhao et al (IHEP)





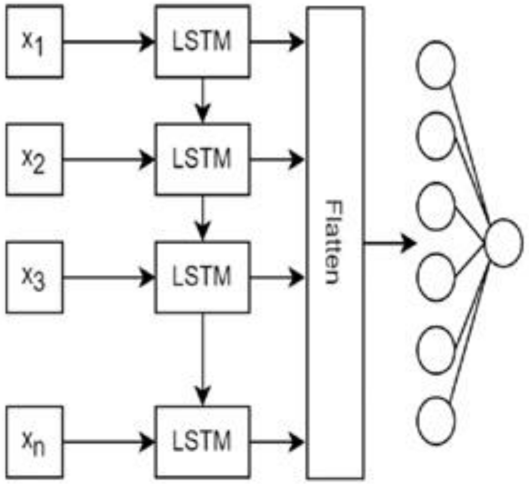
The simulation package creates analog induced current waveforms from ionizations (HEED). The digitization package incorporates electronics responses taken from experimental measurements and generates realistic digital waveforms

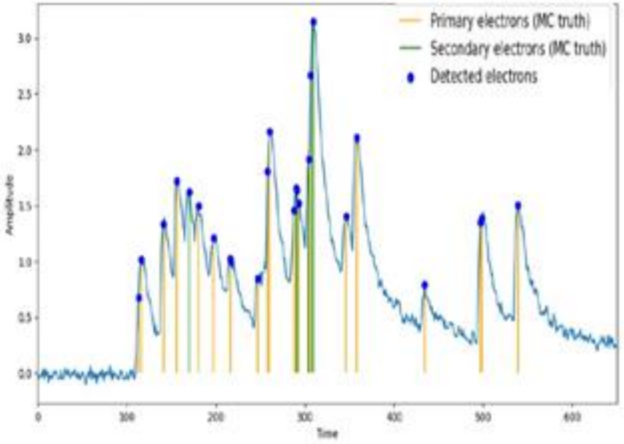
Simulation → updates and plans/3

IHEP+Bari

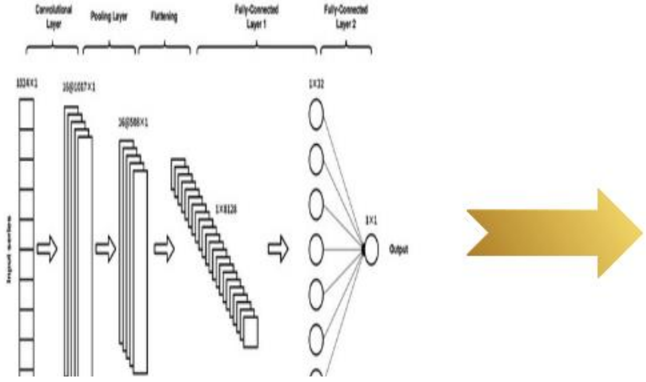
- Simulation of Cluster Counting: GARFIELD + NN

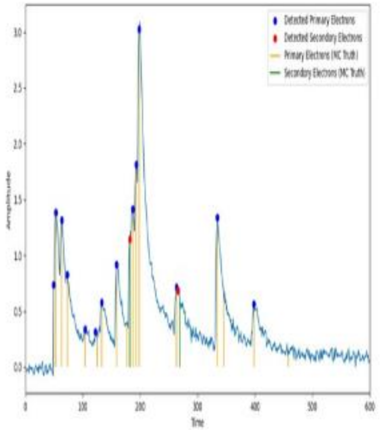
Step1: The task of peak finding can be framed as a classification problem in machine learning
Step2: The number of primary clusters is detected based on the detected peaks by using best CNN clusterization model.

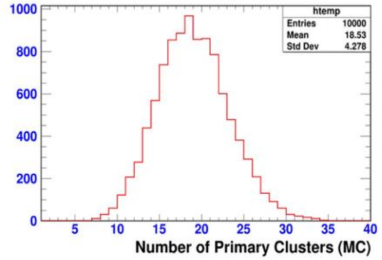


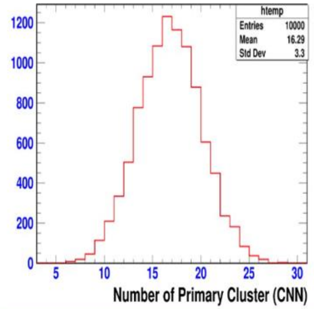


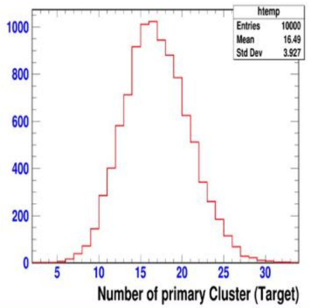
- We applied a Long Short-Term Memory (LSTM) model to the waveform to classify signals (primary and secondary electrons) from the Noise using a peak-finding algorithm known as classification
- Detected peaks from both primary and secondary electrons are shown by blue dots











The above distributions shows us the mean value of the number of primary cluster (MC), number of primary clusters detected by CNN and Target(LSTM) for 10 GeV Momentum of Muon

Richieste RD_FCC Bari 2026

Capitolo	Descrizione	Parziali (k€)		Totale (k€)	
		Richieste	SJ	Richieste	SJ
altri_cons	25 TB di spazio disco per archiviazione dati da testbeam e campioni Monte Carlo per analisi di fisica FCC	4.00	0.00	4	0
consumo	Consumable for wiring	10.00	0.00	32	0
	Partial refurbishing of the wiring robot and transportation (Filatura su piano: sistema di trasporto dei fili su 4m + saldatura a infrarossi + motori passo passo della National Instruments, scheda di controllo):	20.00	0.00		
	Gas e servizi come costi per testbeam @ FNAL/CERN	2.00	0.00		
missioni	Testbeam al CERN/Fermilab nel 2026: missioni per 2 settimane, 3 persone.	10.00	0.00	37	0
	Missioni a INFN per attivita di design e test di componenti per prototipo e tubi a drift per testbeam (5 persone)	5.00	0.00		
	Partecipazione a scuola DRD1 (3 persone compreso gli studenti)	2.00	0.00		
	Missioni per meeting, workshop, trasferte (5 FTE)	20.00	0.00		
inventario	DRD1, WP2 (responsabile N. De Filippis): box ATEX portatile per testbeam con sistema di controllo, regolazione e miscelamento di gas	5.00	0.00	5	0
manutenzione	Manutenzione centralina e sistema di controllo del gas e delle bombole	1.00	0.00	1	0
trasporti	Transportation of the wiring robot from Pisa to Bari	5.00	0.00	5	0
Totale				84	0

Richieste RD_FCC Lecce 2026

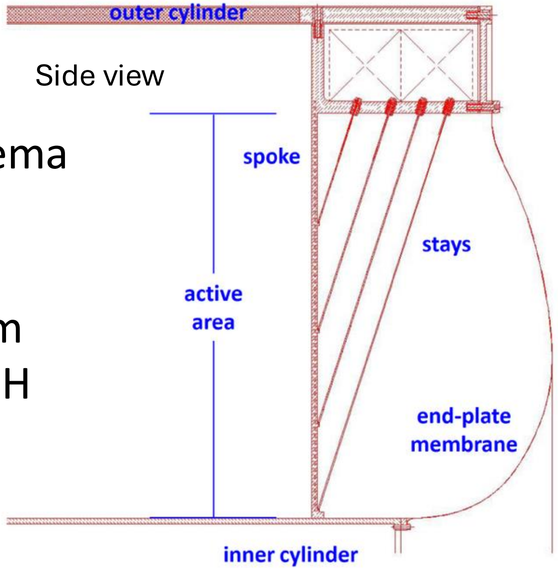
Capitolo	Descrizione	Parziali (k€)		Rimuovi	Modifica	Totale (k€)	
		Richieste	SJ			Richieste	SJ
consumo	Consumi metabolici (2.4 f.t.e.)	3.00	0.00			21.5	0
	200 PCB + componenti elettronica per prototipo full scale della camera a deriva	15.00	0.00				
	costi per testbeam Fermilab (gas+servizi)	2.00	0.00				
	Componenti elettronici (attivi, passivi, PCB, connettori) per lo sviluppo di un preamplificatore multicanale a larga banda per lâ��acquisizione dei segnali del prototipo full scale	1.50	0.00				
missioni	Testbeam al CERN/Fermilab nel 2026 per test di separazione pi/K nel range di interesse di FCCee (2 settimane per 3 persone)	10.00	0.00			17	0
	Missioni a INFN Bari per test sui fili metallici e in fibra di carbonio	5.00	0.00				
	DRD1 WG8: partecipazione a scuola DRD1 come tutors per esercizi di laboratorio e docenti di lezioni, 2 persone per 1 settimana	2.00	0.00				
trasporti	Trasporto del setup di test a CERN/Fermilab	4.00	0.00			4	0
Totale						42.5	0

Mancano qui Metabolismo per Meetings, workshop, contatti (2.4 f.t.e.) → 11 keuro (Resp. Nazionale)
DRD1: missioni al CERN, M. Primavera (segretaria Collaboration Board di DRD1) → 2 keuro (Coordinatore GR1)

Backup

DCH mechanical structure

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

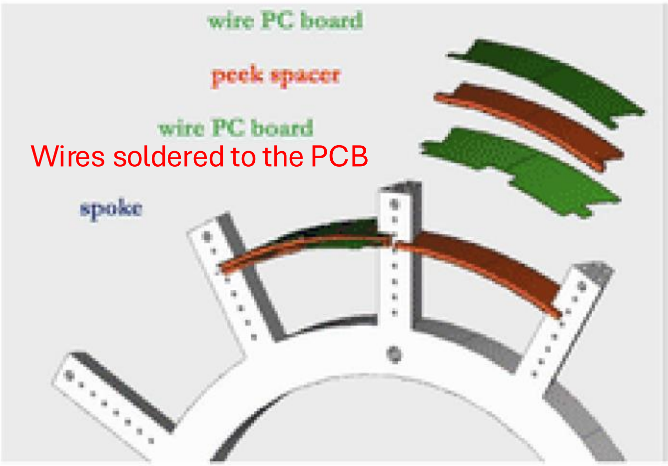


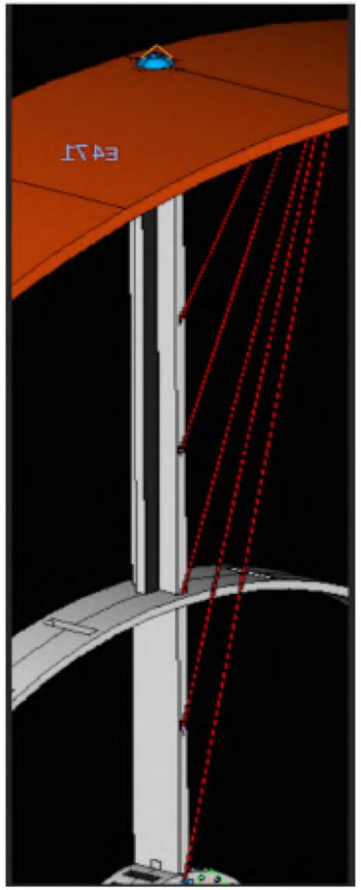
Inner cylinder and Outer cylinder connected with 48 Spokes (24 per Each side) forming 24 azimuthal sectors.

Each spoke supported by 15 Cables/Stays.

Spoke length = 160cm

Material: Epoxy Carbon Prepeg for cylinders and spokes, Structural steel for the cables.



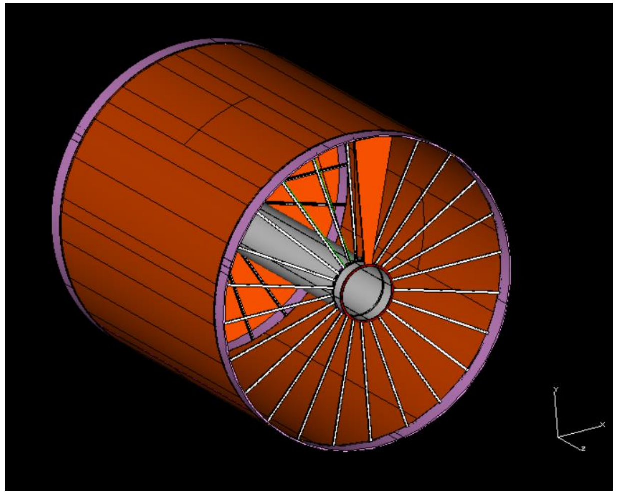


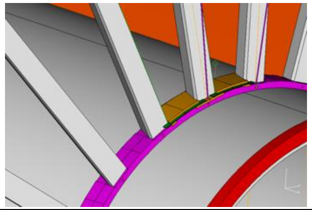
Our **main goal** was to limit the deformation of the spokes to **200 µm** while ensuring the structural integrity.

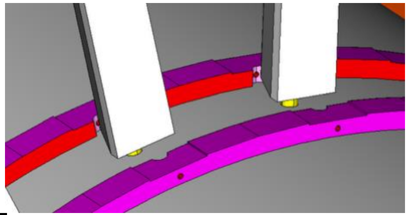
FEM Parametric Design exploration → varying input parameters in some possible ranges in order to see how the system responds - Response Surface Methodology (RSM) is used.

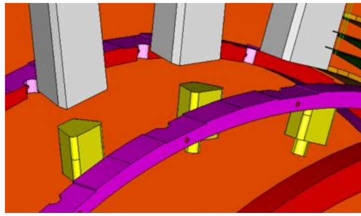
A realistic complete model ready:

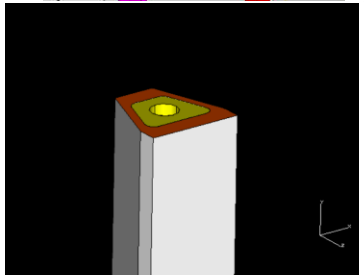
- mechanically accurate
- precise definition of the connections of the cables on the structure
- connections of the wires on the PCB
- location of the necessary spacers
- connection between wire cage and gas containment structure

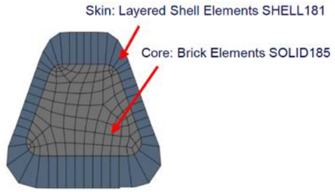


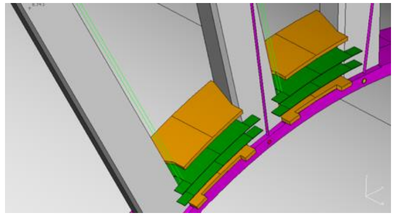












Plan to start the construction of a DCH prototype full lenght, three sectors per EC

IDEA Drift Chamber: cell size

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 ($\delta_{grav} = 260\ \mu m$)
T_c > 21 g for 20 µm W sense wires ($\delta_{grav} = 580\ \mu m$)

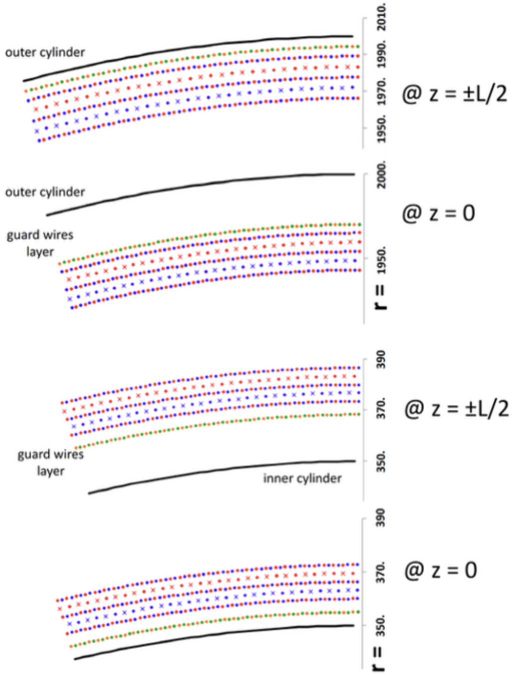
Elastic limit condition

$T_c < YTS \times \pi \cdot r_w^2$ *YTS = 750 Mpa* for W, *290 Mpa for Al*

T_c < 36 g for 40 µm Al field wires ($\delta_{grav} = 190\ \mu m$)
T_c < 24 g for 20 µm W sense wires ($\delta_{grav} = 510\ \mu m$)

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

- Drift length ~ 1 cm, drift time ~150 ns, **σ_{xy} < 100** µm σ_z < 1 mm
- Ratio of field wires to sense wires = **5 : 1**
- 192 (at inner layer), 816 (at outer layer) **square drift cells** (16 per sector)
- **Cell size** ranging from 11.8 mm at the innermost layer, to 14.9 mm at the outermost one



Radii (at z = 0)		
Inner Cylinder	350	mm
Guard wires layer	354	mm
First active layer	356	mm
Last (112th) active layer	1915	mm
Guard wires layer	1927	mm
Outer Cylinder	2000	mm

Radii (at end plate)		
Inner Cylinder	350	mm
Guard wires layer	366	mm
First active layer	369	mm
Last (112th) active layer	1982	mm
Guard wires layer	1995	mm
Outer Cylinder	2000	mm

Active length	2000	mm
Number of super-layers (8 layers) Number of sectors	(14x8) = 112 24	
Number of cells per layer / per sector	192÷816 / 16	
Cell size (at z=0)	11.8 ÷ 14.9	mm
2α angle	30°	
Stereo angle	43 ÷ 223	mrad
Stereo drop	12.5 ÷ 68.0	mm

sense wires	56 448
field wires	284 256
guard wires	2 016
Total wires	342 720

Finite Element Analysis (FEA) of the spoke

Materials:

- Epoxy-Carbon UD (395 GPa) Prepreg ➔ skins of the spoke
- Epoxy Carbon UD (230 GPa) Prepreg ➔ core of the spoke
- Aluminum Alloy ➔ inner and outer cylindrical walls

Loads & Boundary Conditions:

The effect of the PCBs' wire tension was defined as a pressure radially varying a from 0 to 0.159 MPa corresponding to a total load acting on the spoke of 444 kgf. Constraint fixed on top and bottom of spoke

Reaction forces:

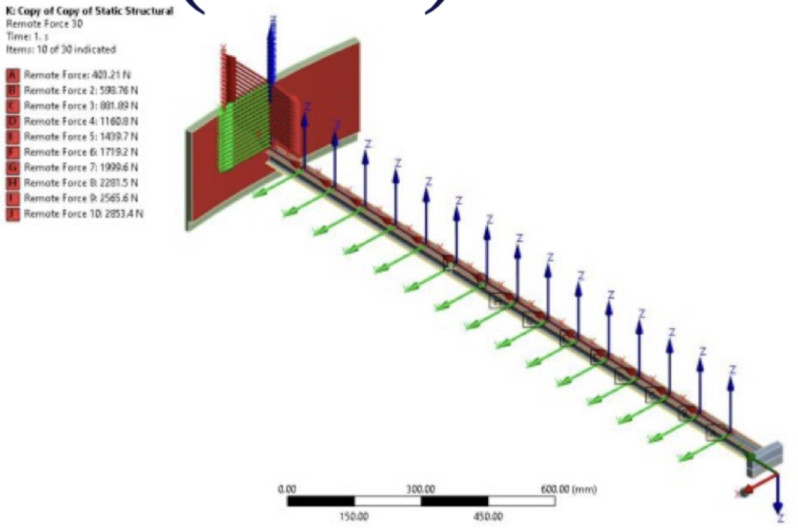
The number of stays has been estimated in 15.

The reaction forces on these constraints are the vertical components of the tensile force each stay should apply to the spoke.

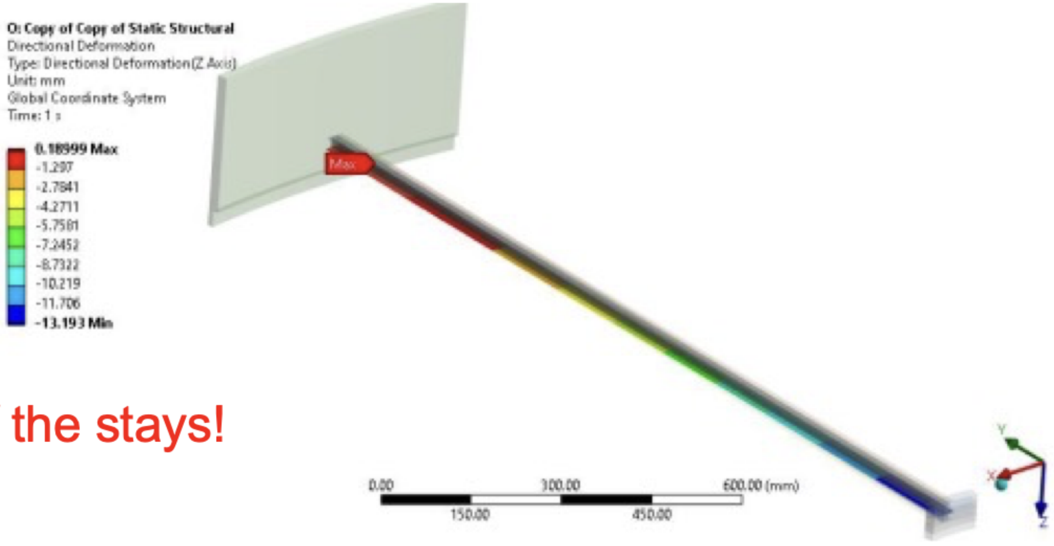
Result:

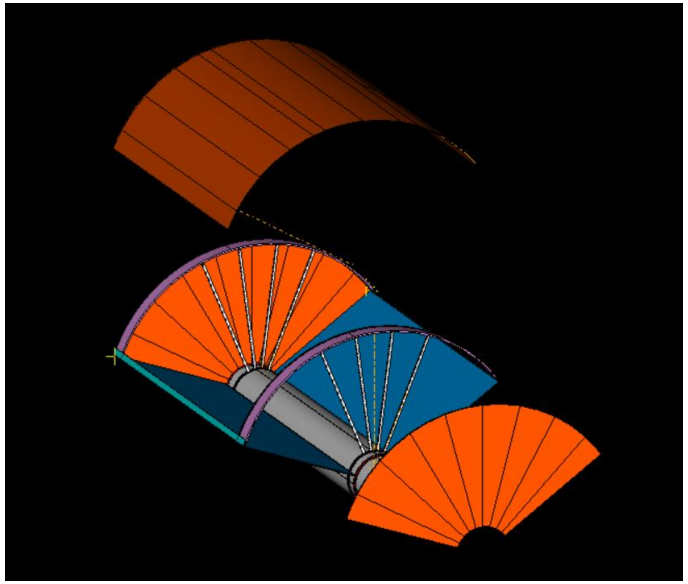
Such forces were applied to the system obtaining a directional **deformation of 0.19 mm** in its maximum value.

A possible improvement with pretension of the stays!



Vforce [N]	Hforce [N]
47.7	400.4
70.8	594.6
104.2	875.7
137.1	1152.7
169.9	1429.6
202.7	1707.2
235.4	1985.6
268.2	2265.7
301.1	2547.9
334.0	2833.8
367.1	3125.6
400.7	3430.7
440.6	3805.1
468.4	4116.5
499.9	4621.2

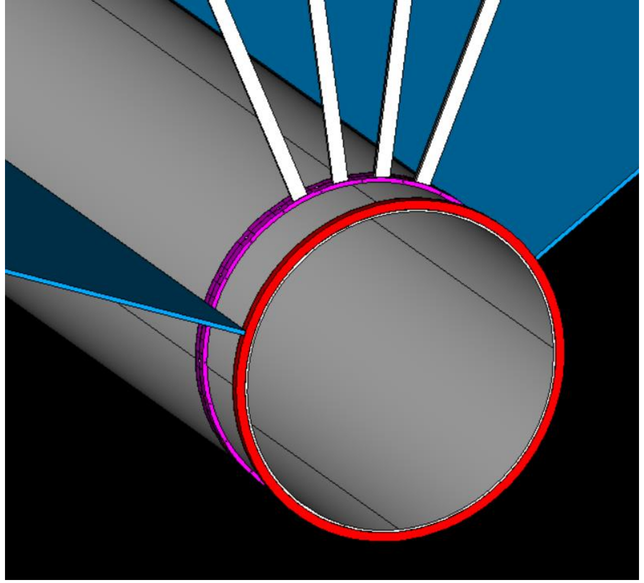




DCH full length prototype

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

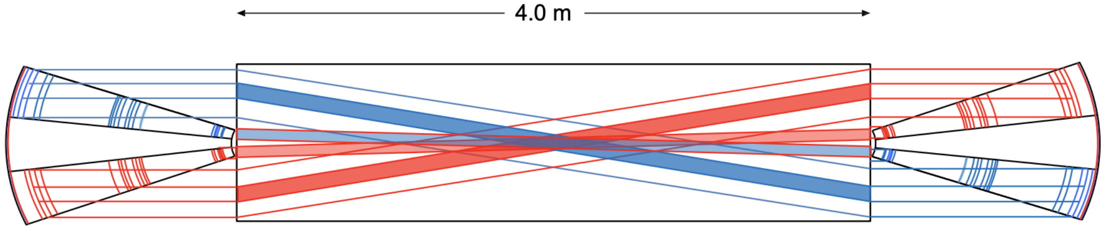
TOTAL LAYERS: 8
Sense wires: 168
Field wires: 965
Guard wires: 264



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

ELECTRONICS COVERAGE



Minimum stereo angle	50 mrad
Maximum stereo angle:	250 mrad

- Check the limits of the wires' electrostatic stability at full length and at nominal stereo angles
- Test different wires, different wire anchoring procedures (soldering, welding, gluing, crimping, …) to the wire PCBs, different materials and production procedures for spokes, stays, support structures and spacers, 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
- optimize the wiring strategy, the High Voltage and signal distribution, test performance of different versions of front-end, digitization and acquisition chain

Controller per il tensionamento fili prototipo.
= 4 (spokes) x 2 (lati) x 15 stays —> 120 canali / 23 canali == 6 controllers

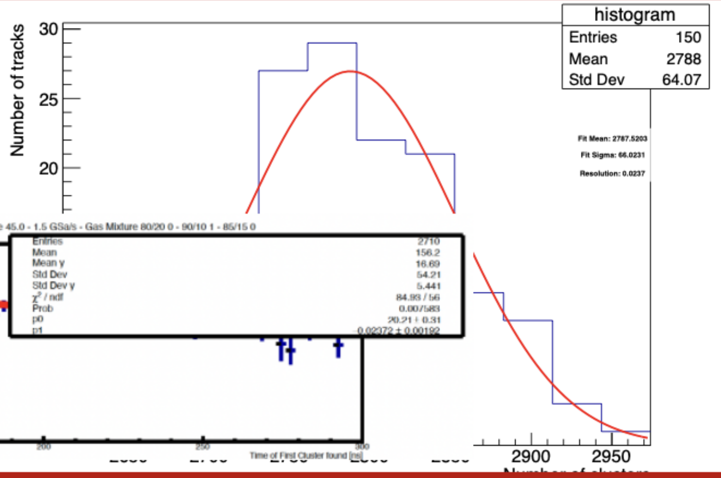
Cercafughe di He

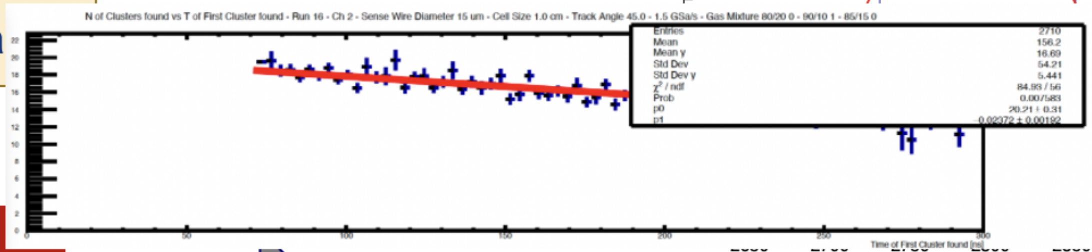
Dimensioni	320mm x 80mm x 55mm (approssimativamente)
Portata	2 cc/min
Batteria	Durata: 20 ore
Sensibilità	• Elio:5x10-6 • Idrogeno: 3.8 x10-6

Waveform Cleaning for Improved dN/dx Resolution:

- Applied cleaning criteria to reject distorted or incomplete waveforms
- Required cluster time span to stay within a physically reasonable range
- Suppressed tracks with wide or noisy signa

Resulted in improved dN/dx resolution: from 3.00% to 2.38% for 2-meter tracks





Correction for Recombination and Attachment Effects

- Ionization electrons can be lost due to recombination or attachment during drift
- Applied a time-based correction to compensate for cluster loss:
  - Derived from the trend of cluster count vs. time
  - Used 2D histograms (clusters vs. time)
  - Fitted time profiles with a linear (first-order) function
- Correction applied event-by-event to account for spatial variations.

Resulted in improved dN/dx resolution: from 2.38% to 2.28% for 2-meter tracks