R&D progress on the Drift Chamber

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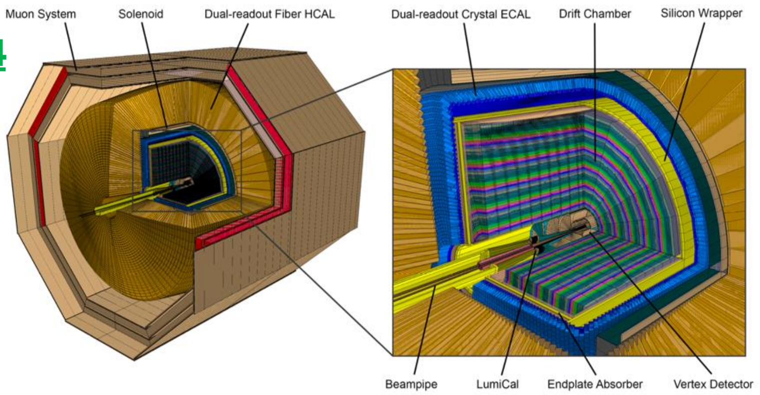
The IDEA Drift Chamber: new concepts

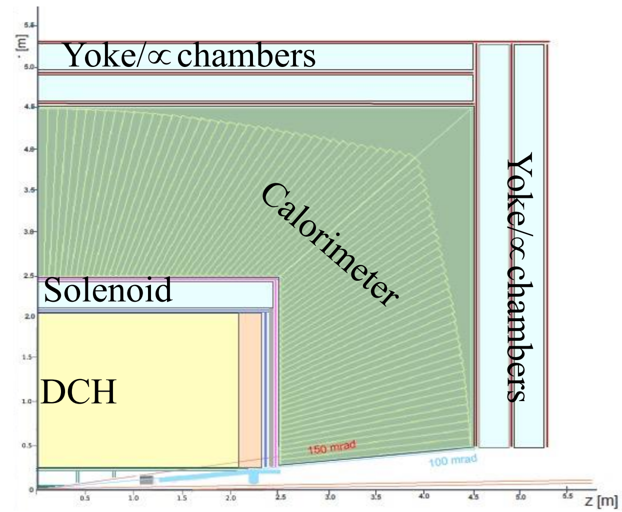
IDEA detector consists of: **arXiv:2502.21223v4**

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



drift chamber evolution **KLOE** (1998) → **CMD-2** (2006) → **MEG2** (2014) → **IDEA** (2017)

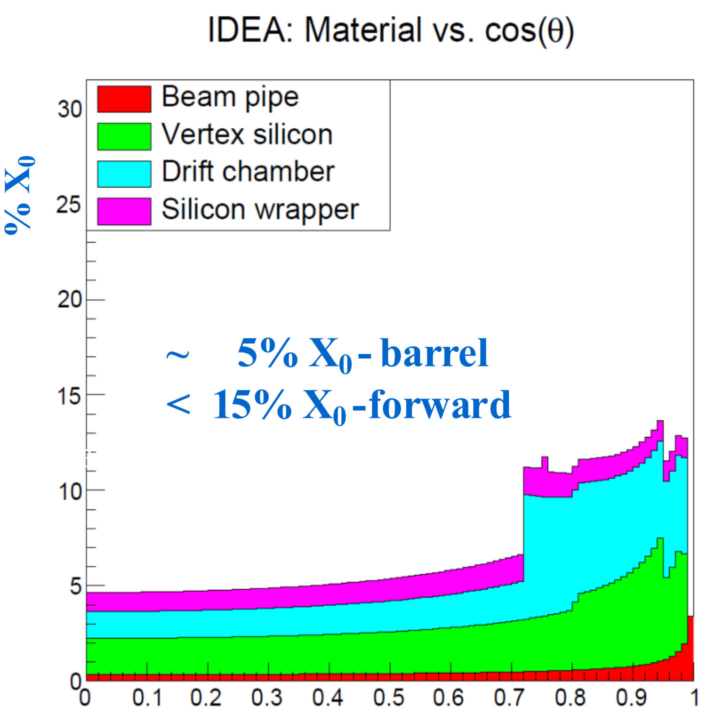
- New mechanical assembly procedure by separating the gas containment from the wire support functions
- New concepts for wire tension compensation resulting in end caps with a 5% X_0 (including front end electronics and cables) and 1.6% X_0 in the radial direction
- A larger number of thinner and lighter wires resulting in less total stress on end plates
- No use of massive feed-through → Feed-through-less wiring
- Use of cluster counting for particle identification
- Use of cluster timing for improving spatial resolution

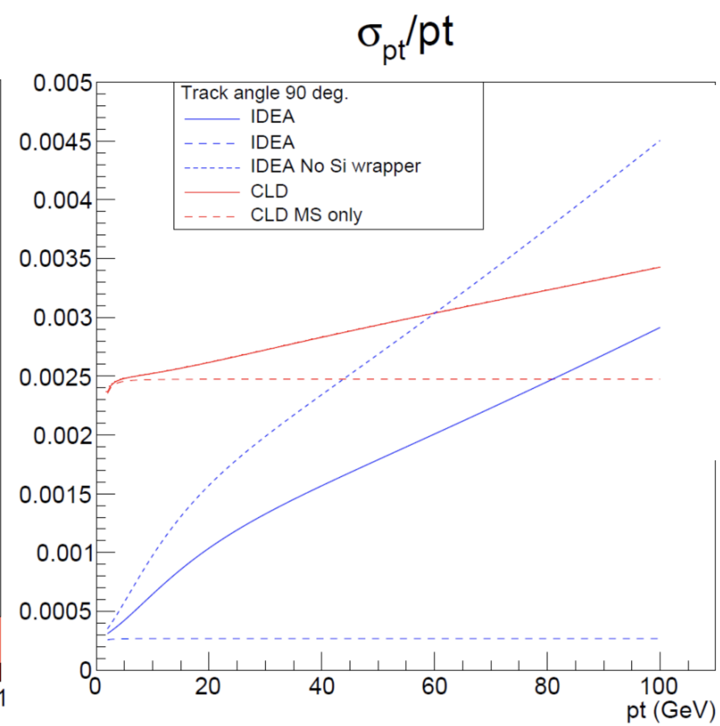


Design features of the IDEA Drift Chamber

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

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





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

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

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

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

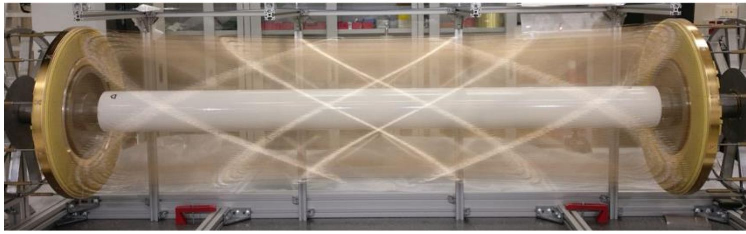
For 10 GeV (50 GeV) μ emitted at an angle of 90° w.r.t the detector axis, the p_T resolution is

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

The Drift Chamber of IDEA

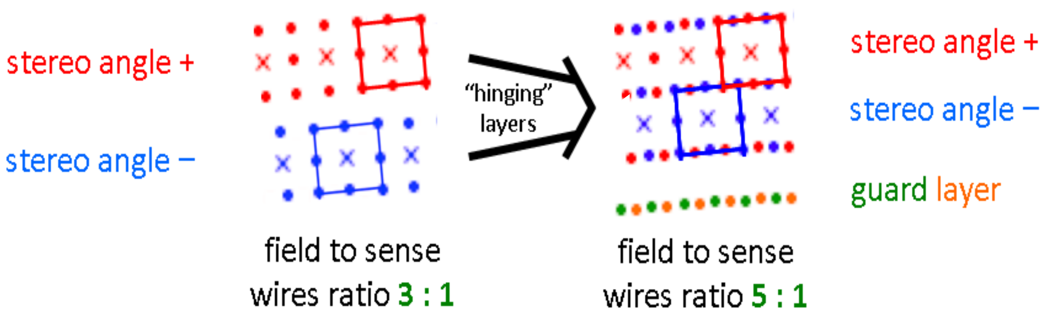
The IDEA DCH is:

- 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 (grouped in 14 superlayers of 8 layers), at alternating-sign stereo angles, in 24 azimuthal sectors



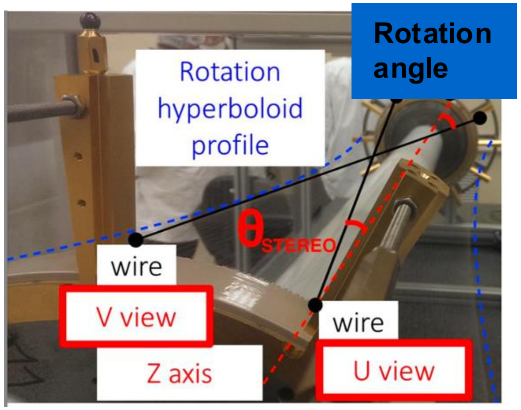
343968 wires in total:

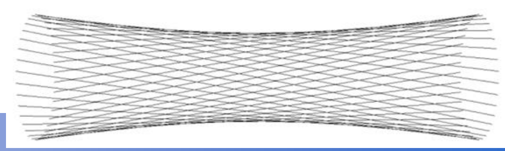
sense vires: 20 μm diameter W(Au) = > 56448 wires
field wires: 40 μm diameter Al(Ag) = > 229056 wires
f. and g. wires: 50 μm diameter Al(Ag) = > 58464 wires



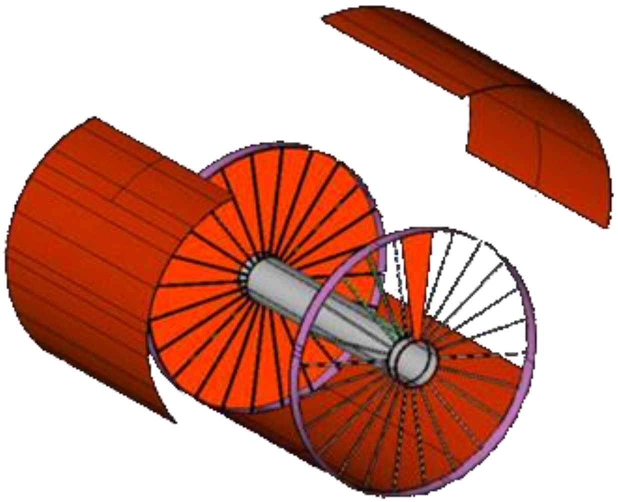
The wire net created by the combination of + and – orientation generates a more uniform equipotential surface

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





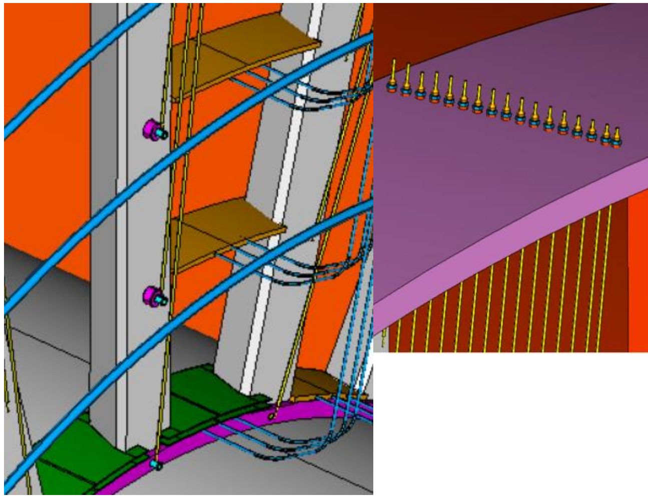
Mechanics for the IDEA DCH



- Outer cylinder made of 3 panels 2 cm thick made of 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 = 165 cm) is supported by 15 Stays.
- **10 tonnes** of total load on the endcap (30 gr per wire):
  - Load on spokes: 416 kg/spoke → 2.5 kg/cm average
  - Load on stays (14 stays/spoke): ~ 200 kg/stay
- Inner cylinder thickness 200 μm CF – not **structural**

The spoke deformation (due to wires tension) recovery system:

- loading is made with 15 stays;
- the first stay, from the bottom, is anchored directly to the inner ring;
- each stay is anchored to the spoke with a self-adjusting angle system;
- the stay tensioning system is achieved by moving a sphere glued directly onto the CF wire;
- the sphere is moved by a screw-insert system anchored directly into the outer ring.



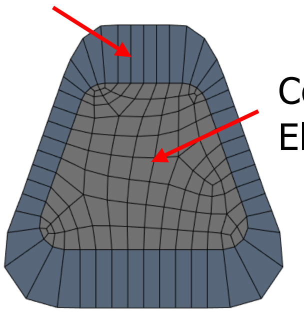
Mechanics for the IDEA DCH: spoke mock-up

A. Miccoli, F. Procacci

FEM analysis: single endcap simulation → Spokes and cable behaviour under wires pressure

- Goals: minimizing the deformation of the spokes using prestressing force in the cables.
  - Limit the deformation of the spokes to 200 μm while ensuring the structural integrity → few mm error on the sagitta
- Optimization of spoke cross section: investigated different shapes, finally:

Skin: Layered Shell Elements

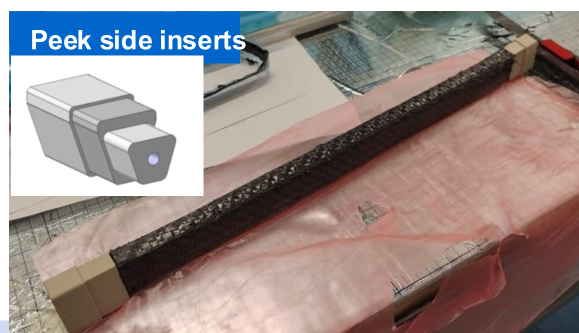


Core: Brick Elements

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

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

- 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



IDEA 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**

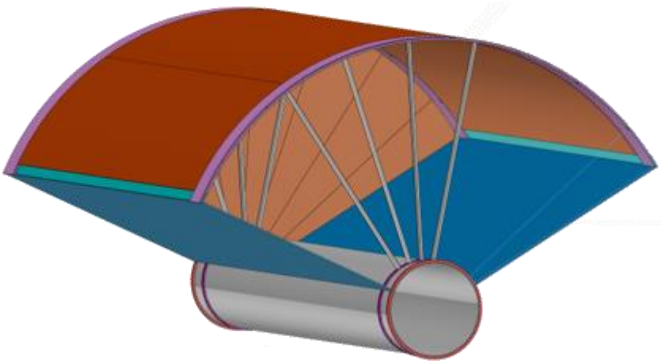
▸ ***Full-length prototype necessary***

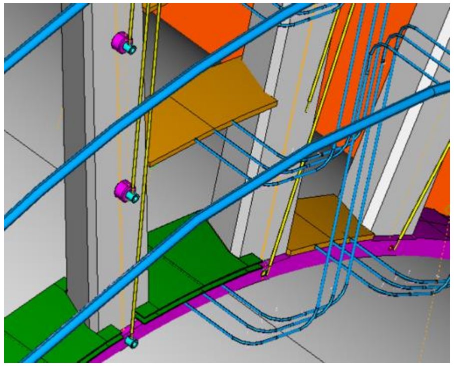
○ ***Can be done in parallel on small prototypes***

IDEA full-length prototype

F. Procacci, M. Saiel

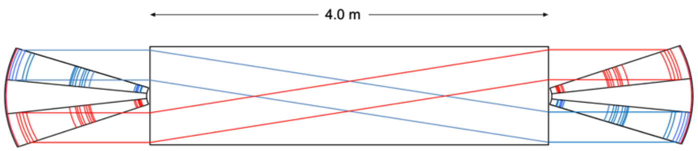
Target: a full length DCH prototype with 3 sectors per endcap

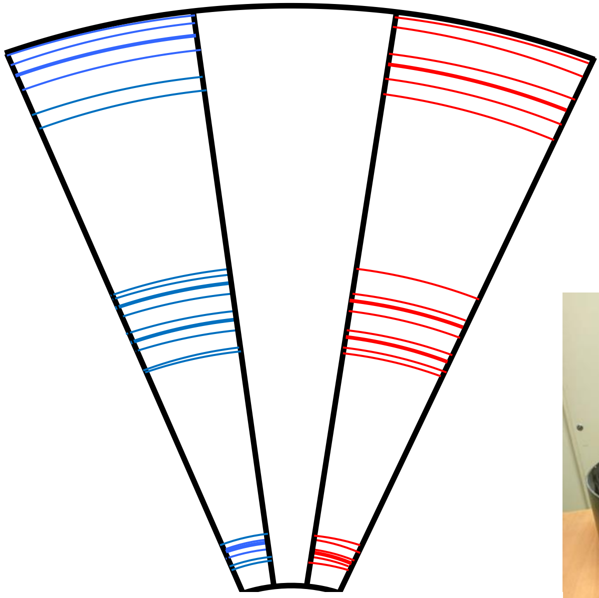




- 8 spokes (4 per endcap)
- Internal ring
- part of the outer ring
- part of the cylindrical panel

MAX COVERAGE





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

Internal ring and a spoke delivered recently → mechanical test will start soon

Clean room proposal

- A realistic option is to equip the semi-clean area (5m x 8m) used by the ALICE experiment in the past at INFN Bari.
- Dimensions are just marginal (even if not ``fully comfortable'' to host the wiring machine + prototype + desks)
- Status is fine: interventions of the clean room functionality recovery and safety adaptations to be carried out
- Performed simulation with CAD of the size and the motion of the prototype,

Realistic estimate of the costs to:

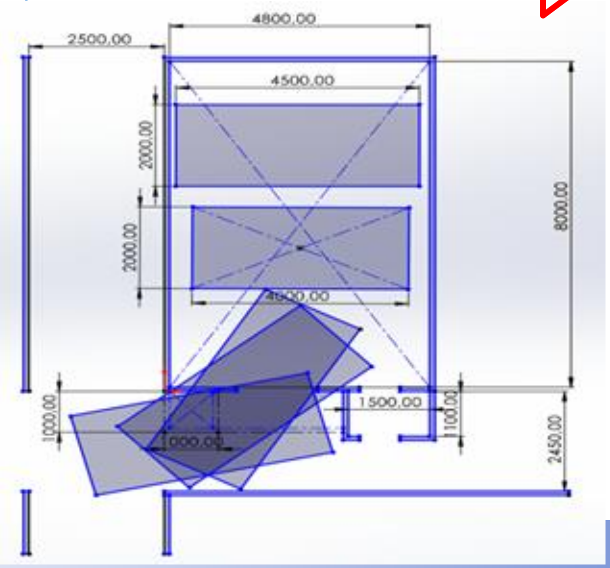
- restore the functionality of the clean room
- ensure safety operations (e.g.
  - Safe access to the air recirculation system)
- ensure maintenance and daily consumption

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

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

Costs not affordable today:

→ moving to a proposal for a «controlled area»



Activities: clean room vs controlled area

Tests in a controlled area (aka temperature has to be controlled within 1°C):

- tests of the stay anchoring and adjustment systems
- tests of the spoke bending based on the (simulated) load of the wire and their distribution
- measuring the residual stress on the internal cylinder based on the (simulated) load of the wires

what is needed apart from the stays:

- an aluminum support structure
- optical scales (in order to determine the correct positioning of the mechanical parts)

N.B:

- the mechanical structure of the support for the prototype stretches of 90μm /1°C so making useless the technique used to compensate the mechanical tension of the structure (to be kept within a deformation of 200μm at most)
- the carbon fiber panels for the prototype's side enclosure have a virtually zero thermal expansion coefficient → creating tension between the various parts and complicating the prototype's mechanical characterization even without wires
- humidity control, however, is less crucial if we don't use silver-coated aluminum wires, which are extremely sensitive to humidity above 30% (MEG2 teaches us this!), but it's still a limitation, and we don't know if other problems could arise (we imagine that many of the polymers used for the stays are hygroscopic, and this affects their choice, as well as complicating the stress compensation measurements).

Activities: clean room vs controlled area

Mandatory tests in a clean room:

- ….in addition to previous tests
- WIRING of the prototype
- closing and sealing of the prototype

Proposal for a «controlled area»:

- Pipes are already available for air conditioning
- Replacement of the current unit for air conditioning
- Infrastructure could be ready in order of months to start mounting the pieces available for the «full lenght» prototype and move on with mechanical tests and measurements → **strong need from our community to prove the mechanical design and innovative choices**
- «Green light» from INFN Bari director for the area
- displacement of activities existing there in different areas already decided

Wire tests with standard protocol

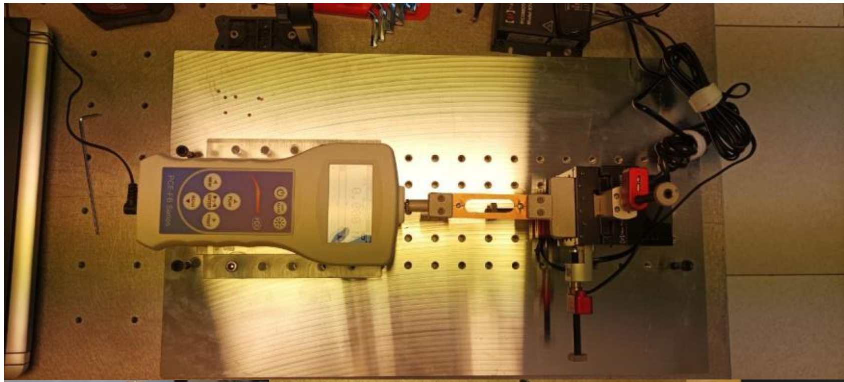
F. Procacci, M. Saiel

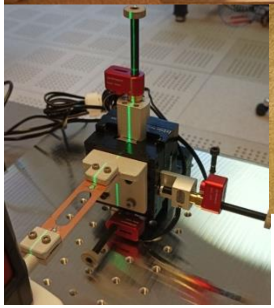
Tests made in a clean room at INFN Bari:

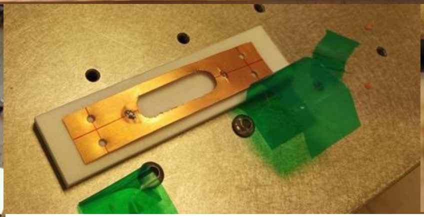
- 20 μm diameter tungsten wire coated with gold
- 20 μm diameter molibdenum coated with gold
- 33.5 μm diameter carbon monofilament
- 40 μm aluminium field wires tested but the wire is slipping at the glued point → new glue

Setup:

- 3 axis picometer slides (30nm step)
- digital dynamometer (acc. 0.001N)

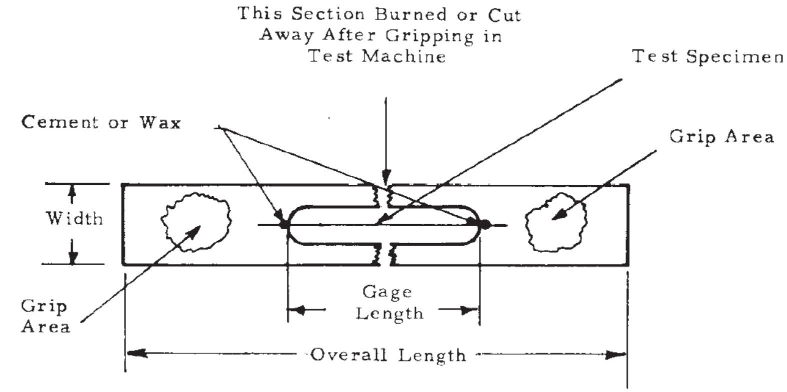






Protocol for measurements (ASTM D 3379 – 75):

- **Scope**: Tensile Strength and Young's modulus for High-Modulus (>21 GPa) Single-Filament Materials (gauge length > 2000*wire diameter)
- **Summary**:
- 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 stressed to failure



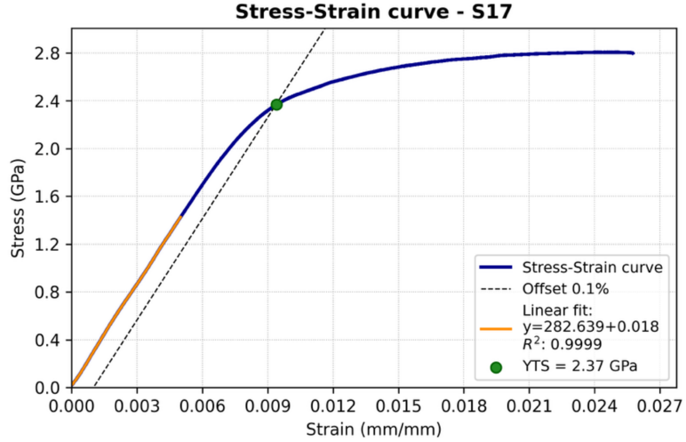
Full report at the last DRD1 coll. meeting:
https://indico.cern.ch/event/1632132/contributions/6923854/

Wire tests: curves

F. Procacci, M. Saiel

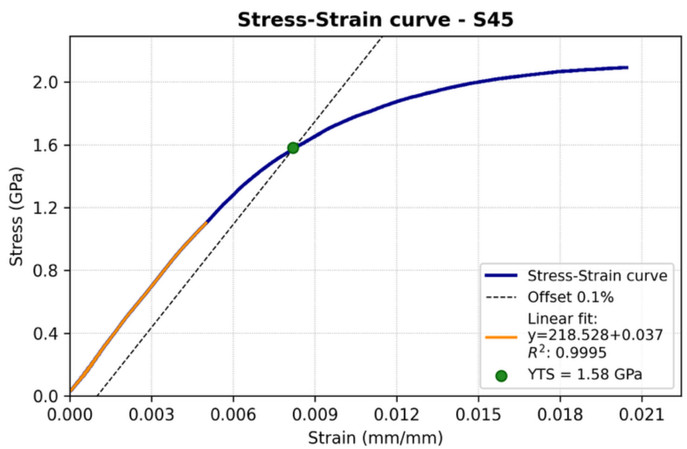
W (Z=74)+Au wire test

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



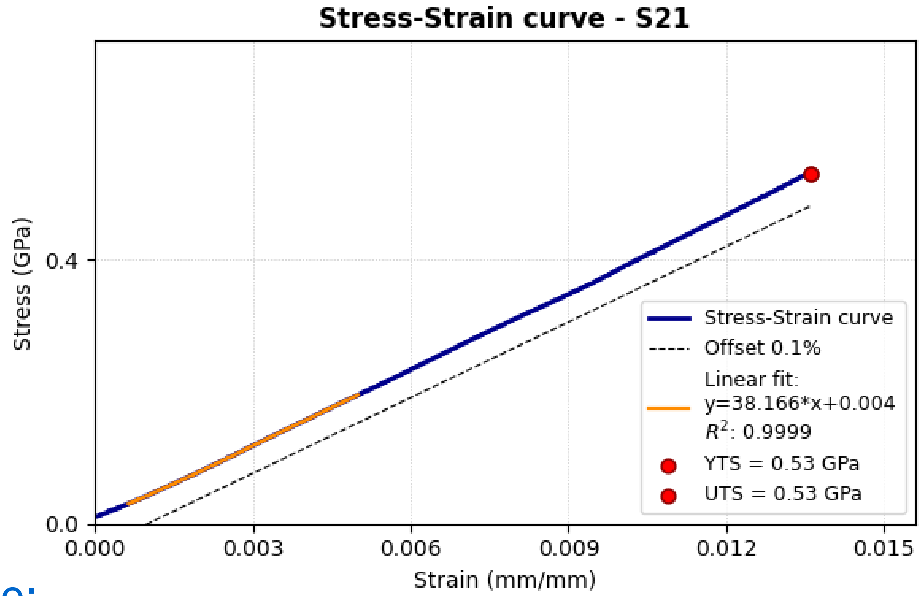
Mo (Z= 42)+Au wire test

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



Monofilament C (Z=6) wire test

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



Also:

- Aluminium wire: mechanical studies ongoing for the best gripping system.
- Steel wire: other candidate under study with diameter of 30µm and 50µm

Wire tests: results

F. Procacci, M. Saiel

- Gold-plated Tungsten (20 µm)
  - UTS ≈ 2.80 Gpa
  - Young's Modulus ≈ 285.5 GPa
  - Very stable elastic behavior

Statistics	Ultimate Tensile Strength - UTS (GPa)	Effective time test (s)	Total wire elongation (mm)	Elongation (%)	Elastic limit strain (mm/mm)	Yield Tensile Strength - YTS (GPa)	Young module - E (GPa)
Mean	2.80	63.13	1.26	2.53	0.0092	2.34	285.51
Std. Dev.	0.01	1.70	0.03	0.06	0.0002	0.02	6.04

- Gold-plated Molybdenum (20 µm)
  - UTS ≈ 2.11 Gpa
  - Young's Modulus ≈ 219.2 GPa
  - Slightly lower stiffness compared to W

Statistics	Ultimate Tensile Strength - UTS (GPa)	Effective time test (s)	Total wire elongation (mm)	Elongation (%)	Elastic limit strain (mm/mm)	Yield Tensile Strength - YTS (GPa)	Young module - E (GPa)
Mean	2.11	51.08	1.02	2.04	0.0084	1.61	219.17
Std. Dev.	0.01	1.03	0.02	0.04	0.0003	0.03	7.62

- Carbon Monofilament (33.5 µm)
  - UTS ≈ 0.69 Gpa
  - Young's Modulus ≈ 0.69 GPa.
  - Brittle behavior (no plastic region)
  - Requires coating and further optimization

Plan: long-term load-bearing test for 4m wire (+ aging)

Statistics	Ultimate Tensile Strength - UTS (GPa)	Strain at UTS (mm/mm)	Young module - E (GPa)	Yield Tensile Strength - YTS (GPa)	Elastic limit strain (mm/mm)	Effective time test (s)	Total wire elongation (mm)	Elongation (%)
Mean	0.69	0.0176	38.24	0.69	0.0176	35.12	0.70	1.75
Std. Dev.	0.12	0.0028	0.53	0.12	0.0028	5.67	0.11	0.29

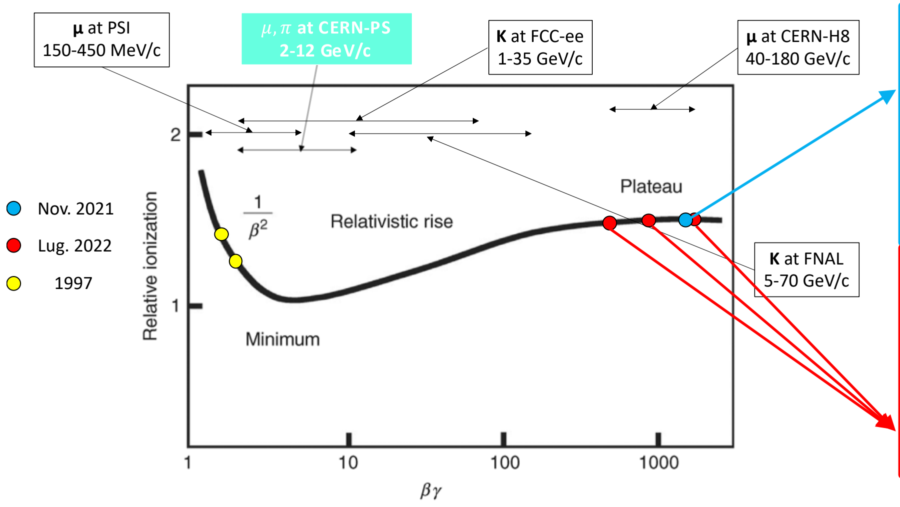
Testbeam activities

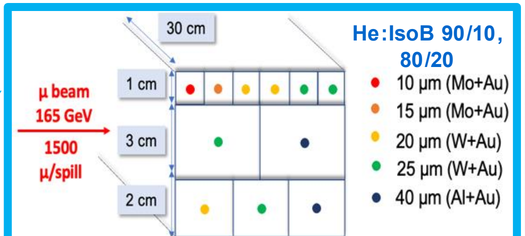
Testbeam campaigns

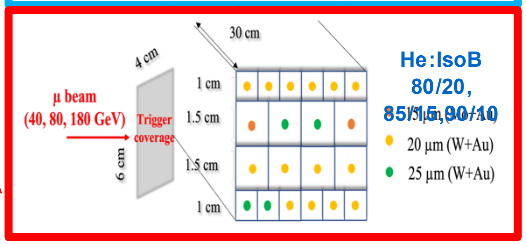
F. Procacci, N. De Filippis, W. Elmetenawee, M. Louka

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

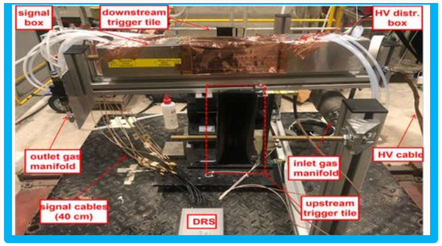
- two **muon beam tests** performed at **CERN-H8 (βγ > 400)** in Nov. 2021 and July 2022 (p_T = 165/180 GeV) → **publication in next slide**
- a **muon beam test** (from 4 to 12 GeV momentum) in 2023 and 2024 performed at **CERN T10 – analysis under finalization**
- test at **CERN T9** made on **May 27-June 10, 2026** with □ , **K** and μ at low momenta (2-16 GeV) to exploit the relative rise and the **particle separation with the cluster counting (for the first time)**





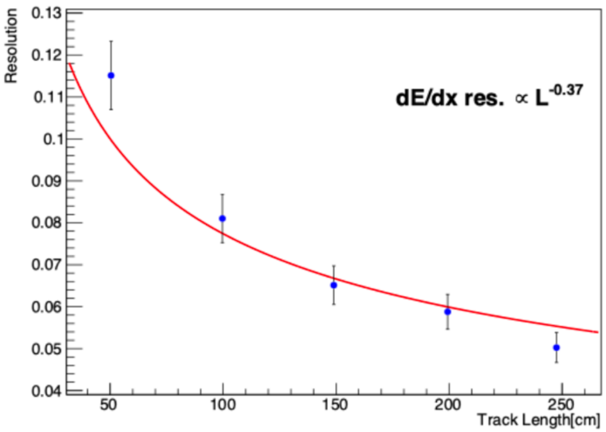


90%He-10%iC_4H_{10}
nominal HV+20, 45°,
Gas gain ~ $2 \cdot 10^5$,
165 GeV/c



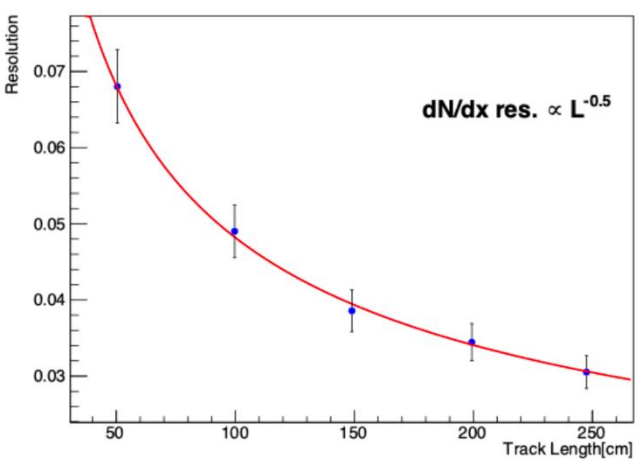
2021/2022 beam test results: performance plots

dE/dx Resolution



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

dN/dx Resolution



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Enhancing particle identification in helium-based drift chambers using cluster counting: insights from beam test studies

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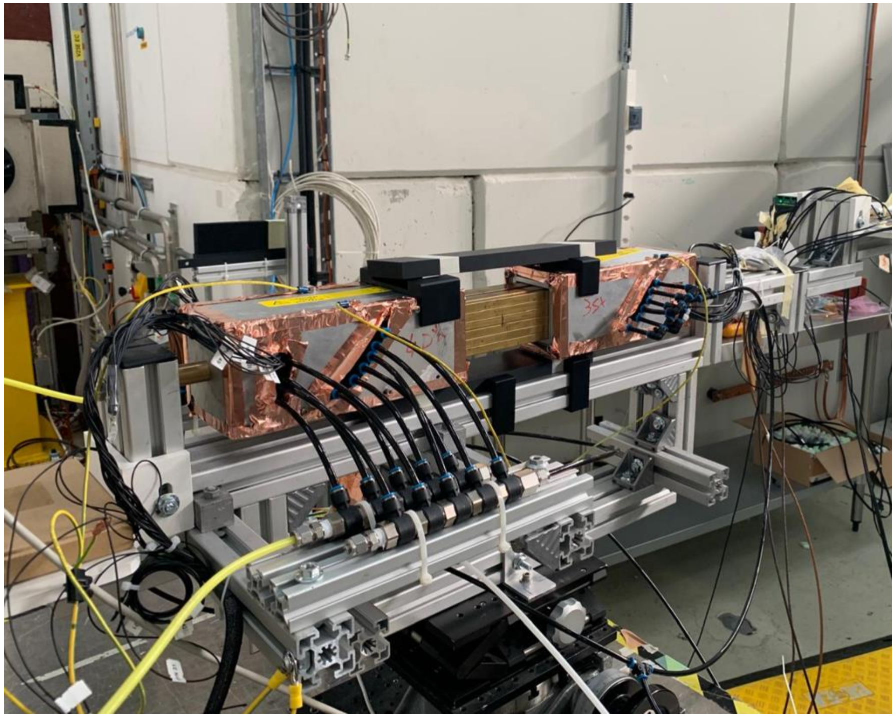
Abstract: Particle identification in gaseous detectors traditionally relies on energy loss measurements (dE/dx); however, uncertainties in total energy deposition limit its resolution. The cluster counting technique (dN/dx) offers an alternative approach by exploiting the Poisson-distributed nature of 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,

2025 JINST 20 P11019

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

Beam test preparation at CERN T9 in 2026

Both the IDEA and IHEP CEPC team joined the test and work together



Box with 20 drift tubes:

- 1(effective 0.8) and 1.5(effective 1.1) cm cell size
- 20μm Au-plated tungsten

Drift chamber prototype:

- 10 layers, 6 cells/layer, 60 cells
- Cell size: 12 mm × 12 mm
- Length of protopype: 530 mm
- Sense wire: 20 μm Au-plated tungsten
- Field wire: 70 μm Aluminum
- Length of wire: 250 mm

Shared gas mixture and distribution system, shared trigger signal, different readout electronics

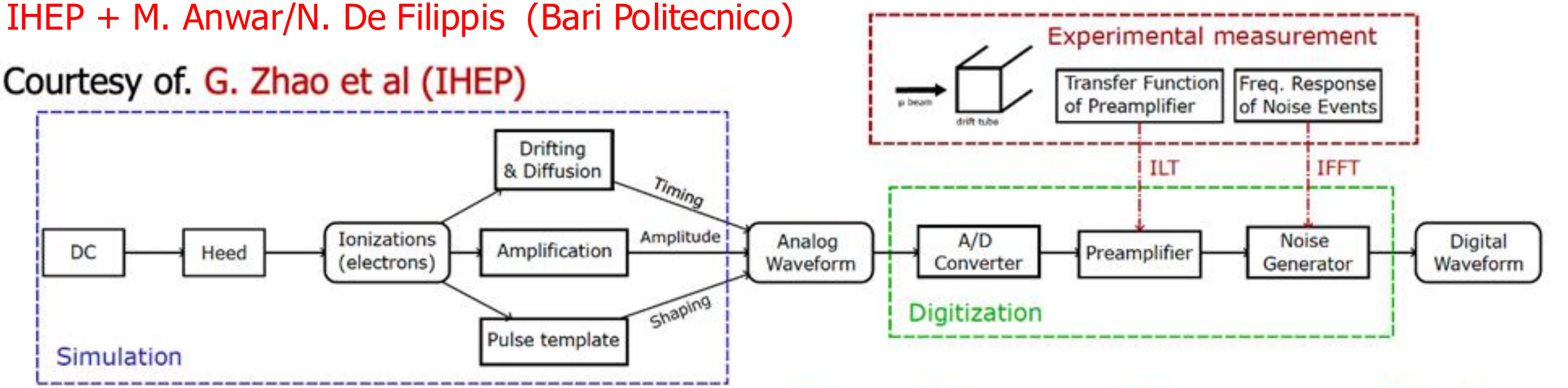
Collected data for muon in the momentum range 2-12 GeV, negative pions (95% pure) and kaons in the momentum range 6-15 GeV

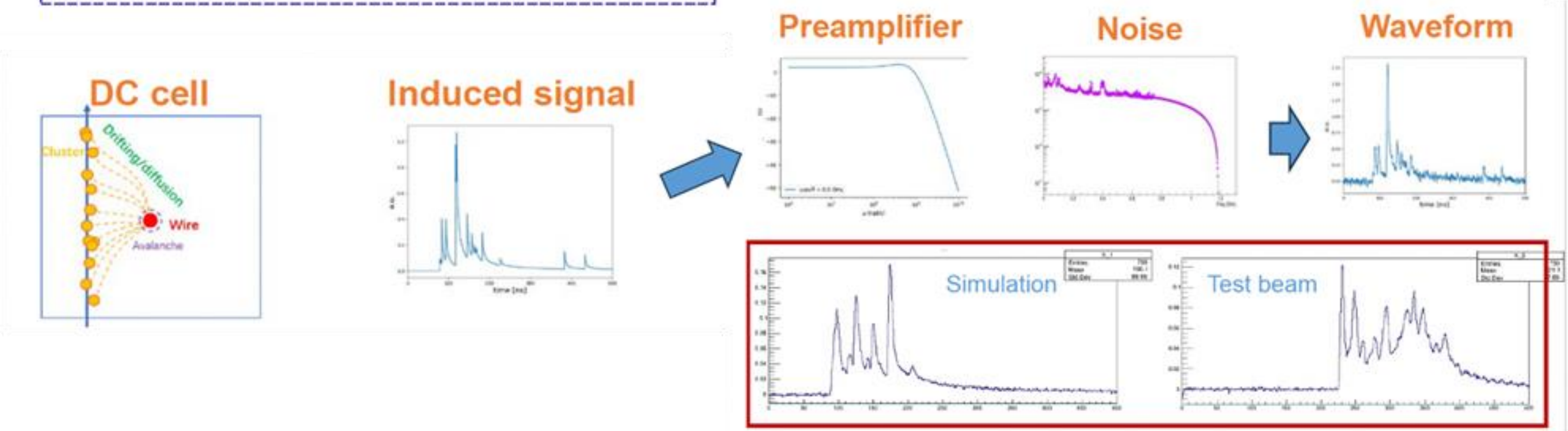
Software development

IDEA: Garfield fast/full simulation chain

IHEP + M. Anwar/N. De Filippis (Bari Politecnico)

Courtesy of. G. Zhao et al (IHEP)





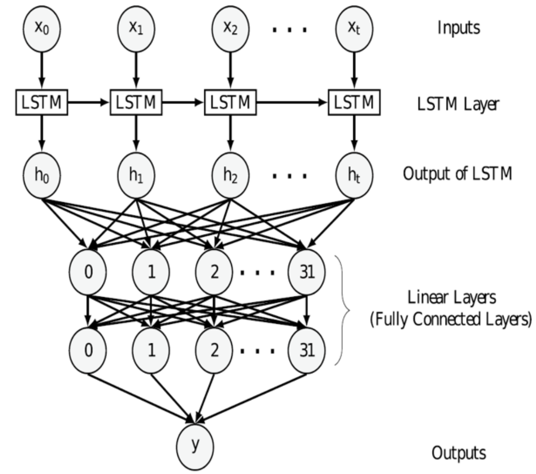
"Peak finding algorithm for cluster counting with domain adaptation"

Comp. Phys. Comm., 300, 2024, 109208, https://doi.org/10.1016/j.cpc.2024.109208

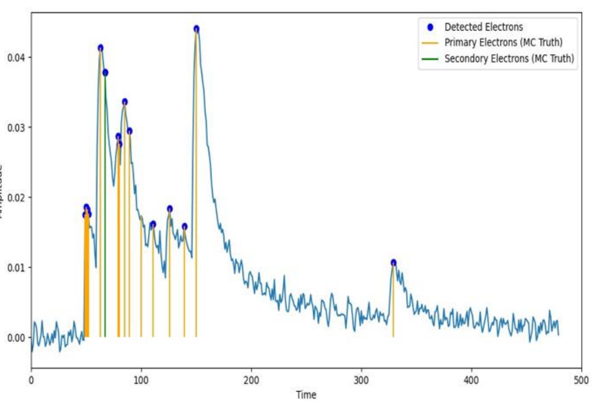
IDEA: Reconstruction with Deep Learning

- Two DL models have been developed:
  - Simulated samples (Nucl. Sci. Tech. 36, 113)
    - Supervised model: LSTM peak-finding + DGCNN clusterization
  - Test beam samples (Comp. Phys. Comm. 300, 109208)
    - Simi-supervised domain adaptation: DNN + Optimal Transport
- Collaboration between IHEP and INFN group on 2021/2022 test beam analysis
  - MC fine tuning to match real data
  - Trained LSTM + CNN with MC, and apply on test beam 2022 data

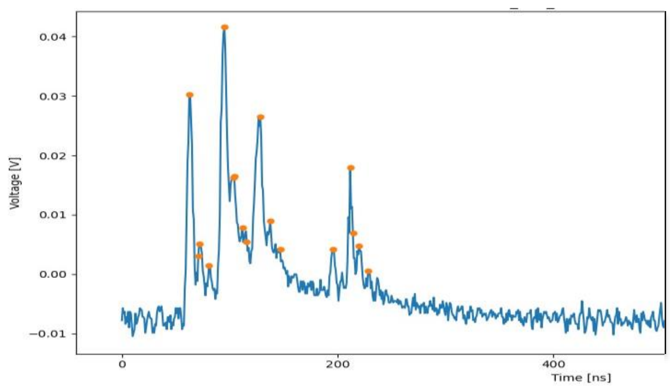
LSTM Peak-Finding Model



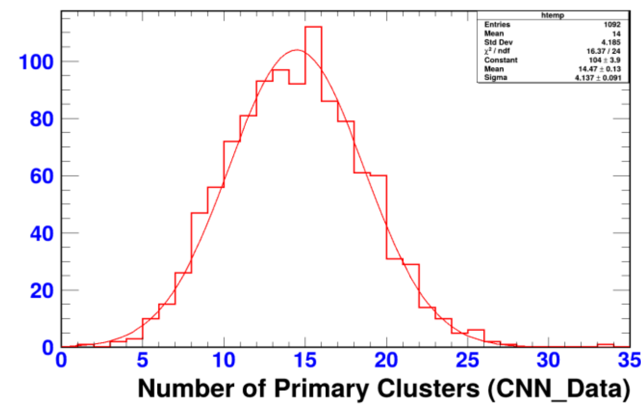
Tuned MC Waveform



Read Data Waveform



# of Clusters in Data



IDEA: PID with Deep Learning

IHEP + M. Anwar/A. Alì /N. De Filippis (Bari Poliba)

muons

Momentum	Monte Carlo Mean / Std	Peak Finding Mean / Std	Clusterization Regression Mean / Std	Clusterization Classification Mean / Std
10 GeV	17.74/4.22	16.48/3.92	16.43/3.32	16.54/3.82
8 GeV	17.33/4.19	16.10/3.89	16.15/3.32	16.27/3.79
6 GeV	16.95/4.05	15.93/3.83	16.04/3.33	16.20/3.82
4 GeV	16.33/4.01	15.37/3.81	15.61/3.35	15.81/3.80
2 GeV	15.18/3.93	14.34/3.72	14.68/3.38	15.10/3.83

pions

Momentum	Monte Carlo Mean / Std	Peak Finding Mean / Std	Clusterization Regression Mean / Std	Clusterization Classification Mean / Std
10 GeV	17.32/4.18	16.03/3.86	15.87/3.30	16.12/3.76
8 GeV	17.02/4.12	15.76/3.82	15.64/3.32	15.95/3.79
6 GeV	16.57/4.04	15.52/3.78	15.48/3.33	15.80/3.77
4 GeV	15.85/4.01	14.86/3.79	14.98/3.37	15.32/3.82
2 GeV	14.61/3.82	13.75/3.61	13.96/3.28	14.44/3.70

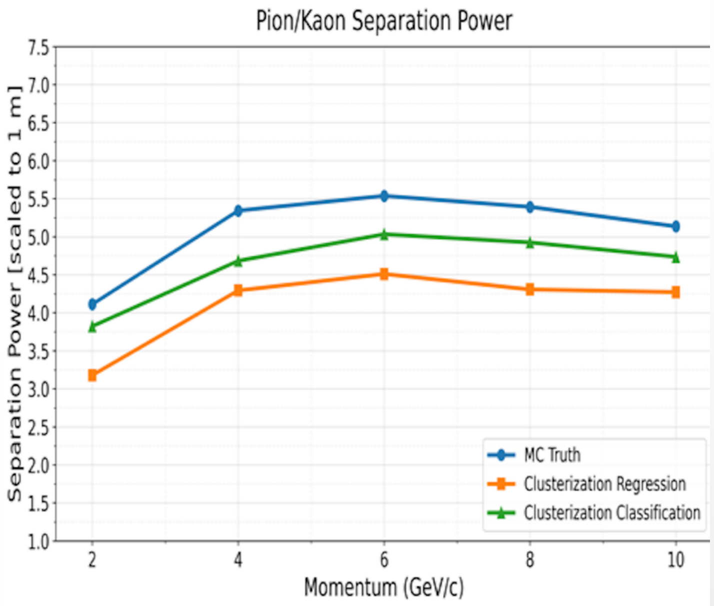
IDEA: PID with Deep Learning

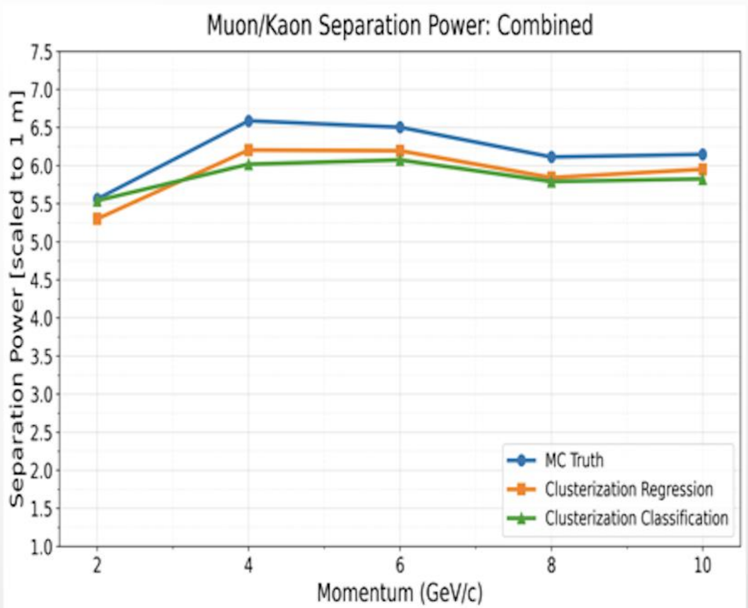
IHEP + M. Anwar/A. Alì /N. De Filippis (Bari Poliba)

Kaons

Momentum	Monte Carlo Mean / Std	Peak Finding Mean / Std	Clusterization Regression Mean / Std	Clusterization Classification Mean / Std
10 GeV	15.25/3.88	14.17/3.61	14.46/3.30	14.37/3.63
8 GeV	14.86/3.89	13.82/3.62	14.21/3.32	14.13/3.60
6 GeV	14.41/3.76	13.52/3.55	13.98/3.32	13.94/3.62
4 GeV	13.79/3.70	12.99/3.51	13.55‘/3.29	13.58/3.61
2 GeV	13.08/3.62	12.35/3.43	12.92/3.26	13.05/3.57

$$S = \frac{|\mu_A - \mu_B|}{(\sigma_A + \sigma_B)/2}$$





IDEA: Digitization for the drift chamber in FCCSW

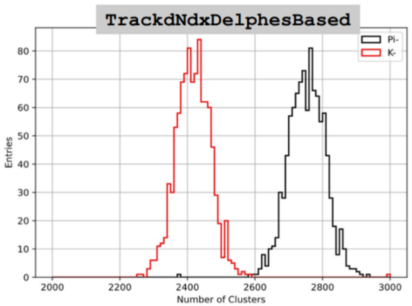
CERN + M. Saiel and input from IHEP

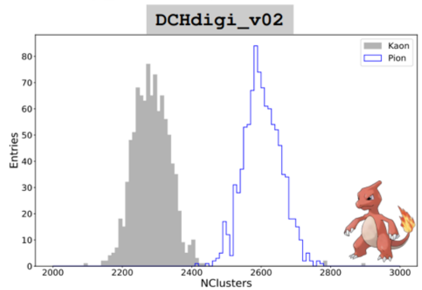
Complete strategy at link:

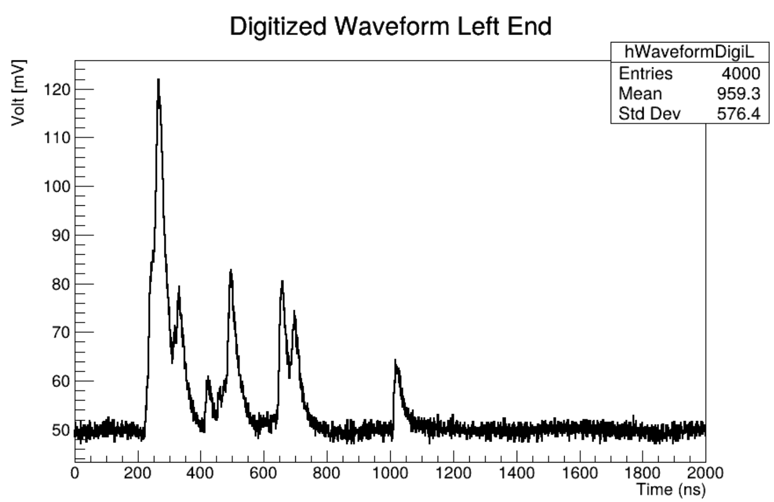
https://indico.cern.ch/event/1439509/contributions/6289570/attachments/2997087/5280386/DeFilippis_Digitizer_v1.pdf

DCHdigi_v02 - Andreas Loeschcke Centeno

- Ncluster comparison between 1k Pions and Kaons @ 10GeV
- Use the TrackdNdxDelphesBased and new DCHdigi_v02 to compute Nclusters







DCHdigi_v0X - Muhammad Saiel

Intersect the physical particle trajectory with the space volume defined by the fired cell (input to digitization).

1. Define the ionization length L (Geant4 weighted step length) of the particle track within the cell volume.
2. Extract a number of ionization acts n_{cl} according to a Poisson distribution with peak value $(dN_{cl}/dx) \times L$, and distribute them along L using exponential spacings with a mean free path $1/(dN_{cl}/dx)$.
   dN_{cl}/dx is a tabulated function only of the particle $\beta\gamma$
   I. This function can be provided by the test beam Experimental result.
   II. At the moment we are relying on the Bethe-Bloch parameterization.

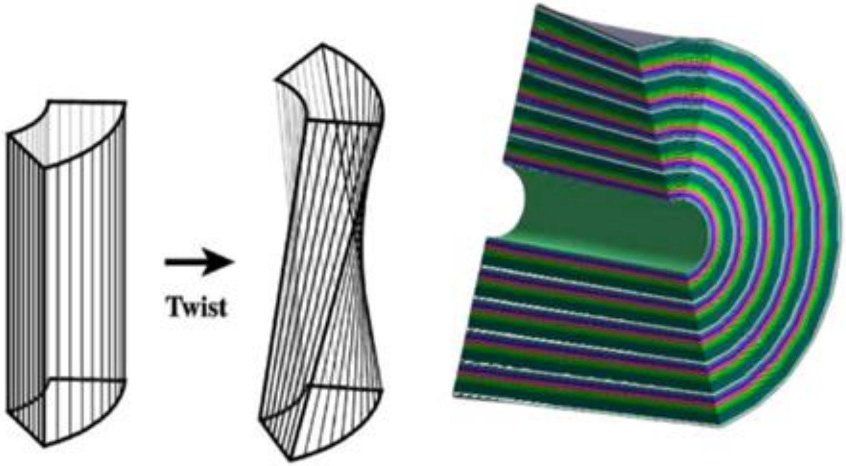
- Starting from **Geant4 simulated hits** and producing realistic **digitized waveforms** **(L_0)**.
- Ionization is modeled through **cluster generation and electron multiplication**, using **βγ-dependent dNcl/dx**, experimental cluster-size distributions.
- Electron drift times are computed using **tabulated X–T relations (2D LUT)** with **diffusion smearing**, ensuring a fast yet realistic transport to the sense wire.
- Each **drifting electron** is assigned an **avalanche charge (gain)**.
- Individual electron pulses are shaped using **measured rise/fall times**, summed to form the **analog waveform**, propagated along the wire, and processed through **electronics response and FFT-based noise injection**.
- The digitization outputs a **fully realistic waveform**, enabling **cluster counting, peak finding**.

Full simulation of the IDEA drift chamber in DD4HEP

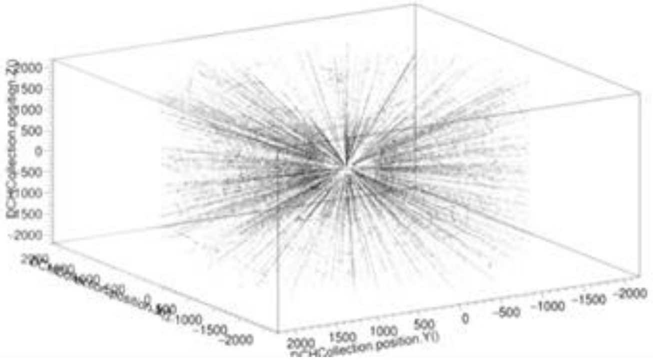
CERN + W. Elmetenawee

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.

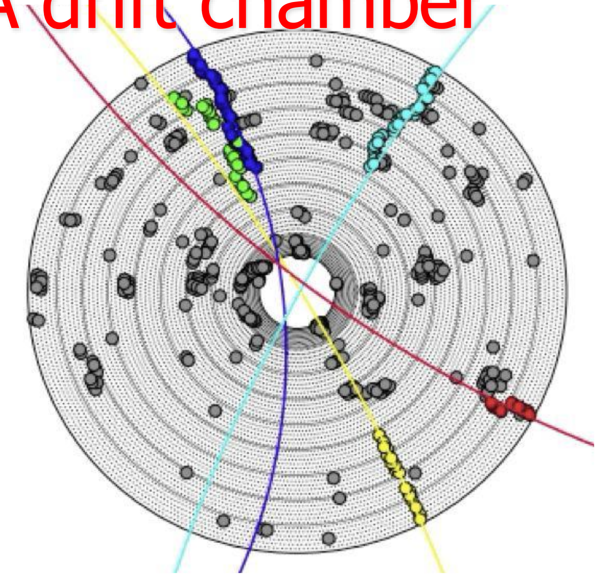


DriftChamber o1_v02 Twisted tubes.

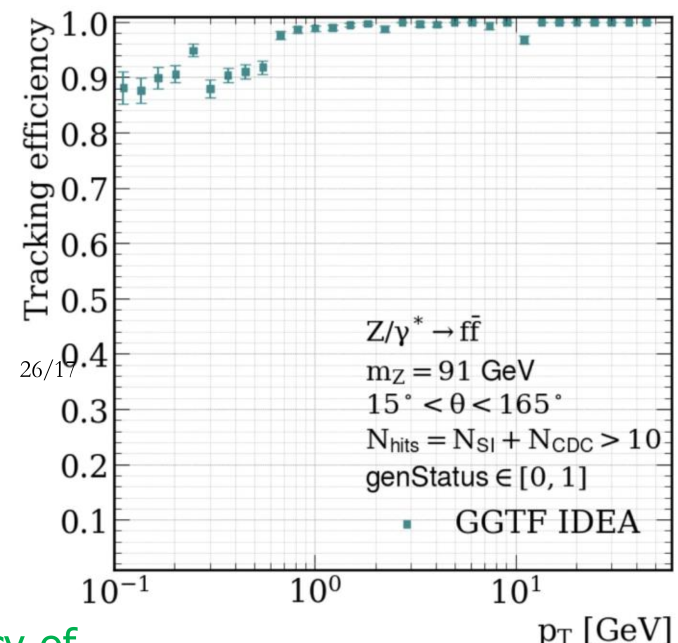


Track reconstruction with the IDEA drift chamber

A. De Vita, P. Azzi (PD)
+CERN+MIT



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



Plan: physics analysis studies for benchmark B and Higgs channels starting with full simulation and reconstruction

Urgent: realistic studies about the background and occupancy of the drift chamber

ZH, Z→(qq/νν) H→ZZ*→4l studies

A. Alì, N. De Filippis (Y. Mahmoud previously)

Simulated samples: WHIZARD+PYTHIA+ Delphes (IDEA datacard), Winter 2023 campaign at √s=240 GeV and L=10.7 fb^{-1}

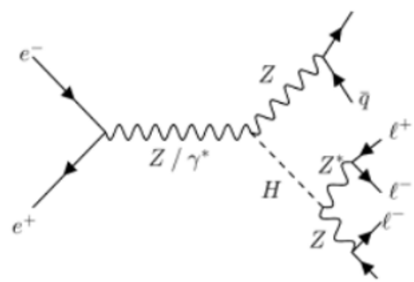
Final: state: ZH, Z→(qq/νν) H→ZZ*→4l

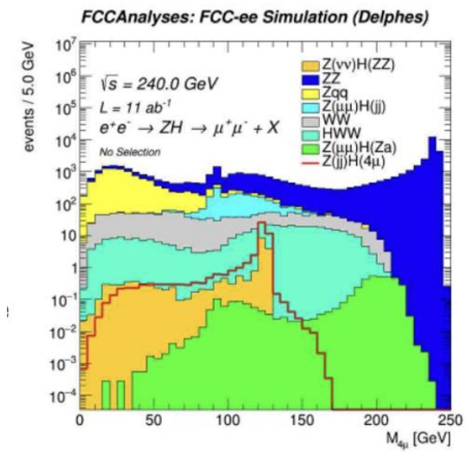
Background: ZZ/WW/Zqq/HWW/Hjj/Hza

Lepton Selection criteria:

- First leptons pair fitting the on-shell Z
- Second leptons pair for the off-shell Z
  - largest scalar momentum oppositely charged pair between the remaining pairs

Few kinematical cuts: on visible energy, missing, m_{ll}



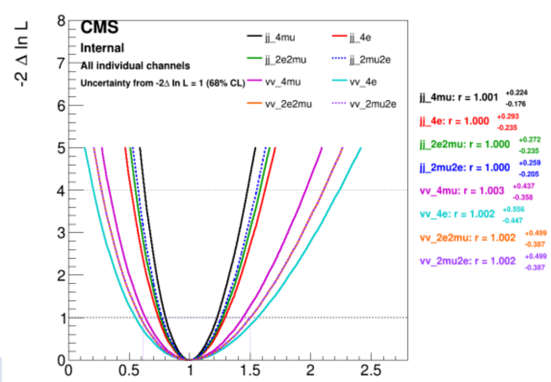


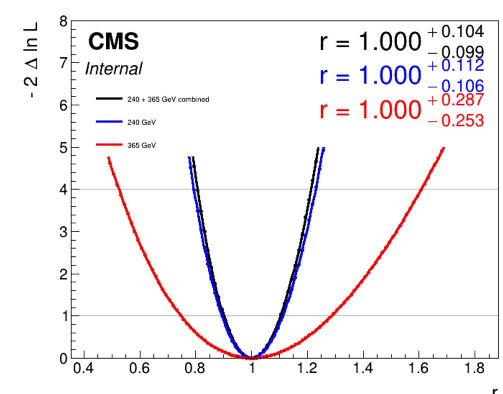
FCC public note (@√s=240 GeV): https://doi.org/10.17181/ey2ff-hqv83

Selection	ZZ	Zqq	$Z(\mu\mu)$ H(jj)	WW	HWW	$Z(\mu\mu)$ $H(\tau\tau)$	$Z(\mu\mu)$ $H(Z\gamma)$	$Z(jj)$ $H(4\mu)$	Total Bckg	$S/\sqrt{S+B}$
No cuts	37559	9585	1605	1206	391	114	4	47	50464	0.20912
$p_{\text{min}} > 5$ GeV	31710	2516	1010	442	278	95	3	43	36054	0.22632
$p_{\text{miss}} < 20$ GeV	25983	344	532	7	5	0	3	39	26874	0.23772
$E_{\text{vis}}^{\text{other}} > 95$ GeV	1584	299	436	7	2	0	0	36	2328	0.74042
$10 < M_{Z^*} < 65$ GeV	784	214	177	2	1	0	0	36	1178	1.03322
$124 < M_{4\mu} < 125.5$ GeV	2	0	1	0	0	0	0	25	3	4.72455

The study was recently made for √s=365 GeV and L=3 fb^{-1} and the two results combined.

- The best precision is obtained at 240 GeV due to the larger Higgs-strahlung signal statistics.
- The hadronic channel is more sensitive because of its higher selected signal yield and better signal-to-background separation.





Computing for Tier2 Bari

A. Italiano, N. De Filippis

- Tier 2 Bari: the only one in Italy configured for FCC and tested (in add. to CNAF T1)
- Hosting the MC campaing (delphes) used for the Feasibility Study (about 8 TB)

Slides presented by G. Guerrieri at the FCC week in June «Towards an FCC Computing Model»

Step 1: storage

Because let's be honest, we need a lot of it

We started establishing a storage federation based on Rucio.

This is **unpledged** storage. **No guarantee (yet) that the space allocation is permanent!**

- ✅ (500+TB) **CERN:** online
- ✅ (100TB) **BARI:** online
- ✅ (300TB) **MIT:** online
- ✅ (>100TB) **IEPSAS:** online
- ✅ (100TB) **CNAF:** online
- ✅ (>100TB) **DESY:** online

- 🚧 (300TB) **GLASGOW:** debugging a VO issue
- ⚠️ **BNL:** negotiating
- ⚠️ **PIC/BSC:** negotiating
- ⚠️ **IN2P3:** negotiating

Activity in DRD1 WP 2

N. De Filippis:

convener of WP2
«Inner and Central Tracking with Particle Identification Capability – Drift Chambers»

Technological representative in the DRD1 Management Board

Going towards the endorsement of the WP2 activites, documentation to be ready by end of July

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

Conclusions

Good progress by the IDEA and CEPC teams on:

- mechanical structure design
- on going effort to build prototypes
- testbeam organization and data analysis → progressing
- software for full simulation, digitization, track reconstruction → in place
- very good collaboration between INFN and IHEP (thanks to FEST EU project)

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

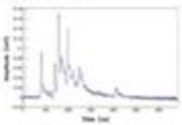
- detector design, construction, beam test, performance
- local and global reconstruction, full simulation
- physics performance and impact
- etc.

Backup

Read-out electronics

Challenge: Data reduction and pre-processing

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



according to the **IDEA drift chamber operating conditions**:
- 56448 drift cells in 112 layers (~130 hits/track)
- maximum drift time of 500 ns
- cluster density of 20 clusters/cm
- signal digitization 12 bits at 2 Gsa/s

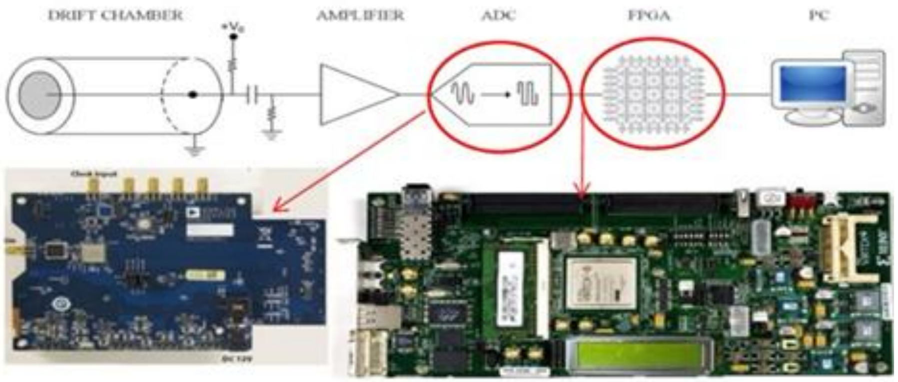
... and to the **FCC-ee running conditions at the Z-pole**
- 100 KHz of Z decays with 20 charged tracks/event multiplicity
- 30 KHz of $\gamma\gamma \longrightarrow$ hadrons with10 charged tracks/event multiplicity
- 2.5% occupancy due to beam noise
- 2.5% occupancy due to hits with isolated peaks

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

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

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

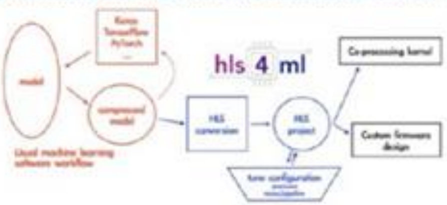
This can be accomplished by using a **FPGA** for the **real time analysis** of the data generated by the drift chamber and successively digitized by an ADC.

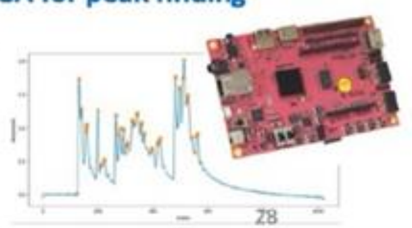


Single channel solution has been successfully verified.
G. Chiarello et al., The Use of FPGA in Drift Chambers for High Energy Physics Experiments May 31, 2017
DOI: 10.5772/66853

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

Implementing ML algorithms on FPGA for peak finding





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System overview - MOSAIC and HDSoC v1 integration

Activity @ INFN Bari

J. Verdeios Palacios, G. De Robertis

- **Objective**
  - **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..**

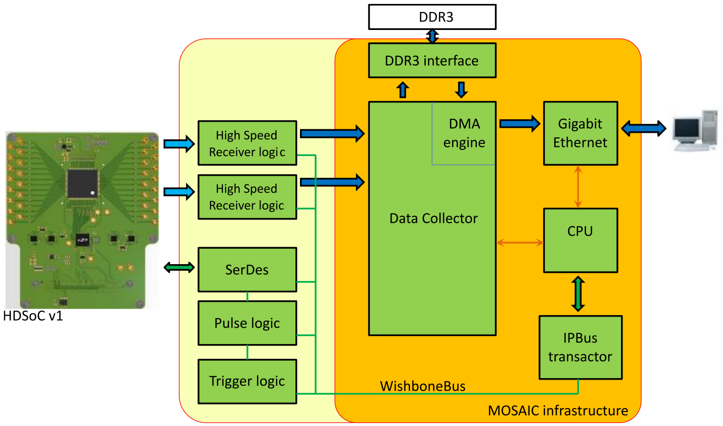
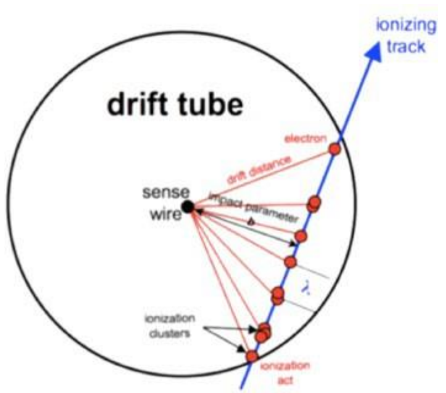


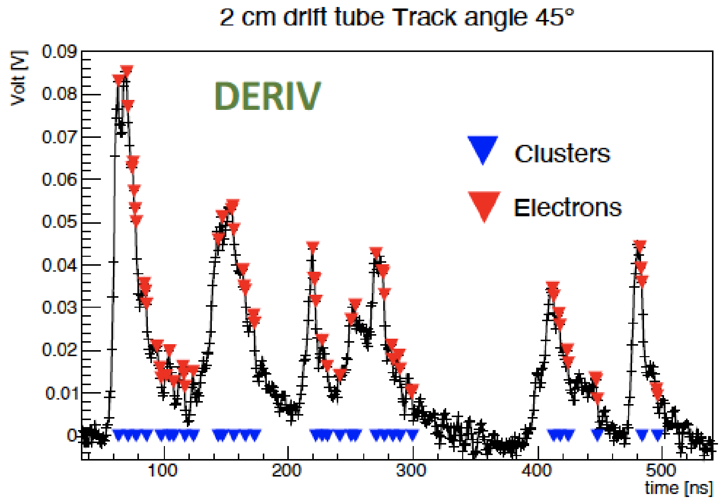
Fig.1. Digitizer-FPGA Communication via SerDes with Wishbone Bus Interface

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

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

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

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

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