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

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on behalf of the WP2 community

1st DRD1 Collaboration Meeting

CERN, January 29 - February 2

Participating institutes

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

Description of the project

The project aims to cover strategic R&D towards the development of large-volume drift chambers proposed as tracking and particle identification devices for experiments:

- for the next generation of lepton colliders both at FCC-ee (CERN) and at CEPC (China)
- for the next generation of flavor factories SCTF (Russia, China)
- for Electron-Ion Colliders.

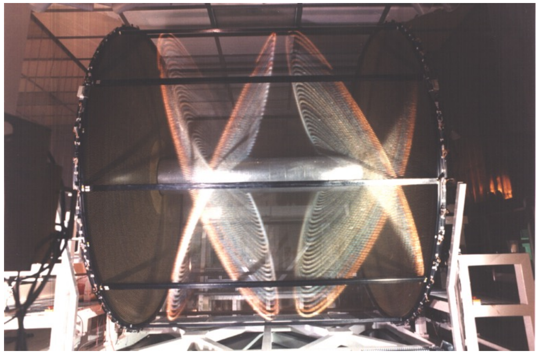
Drift chambers are designed to cope with:

- transparency against multiple scattering, more relevant than asymptotic resolution
- a high precision tracking measurement
- an excellent particle identification and separation by profiting from the cluster counting information

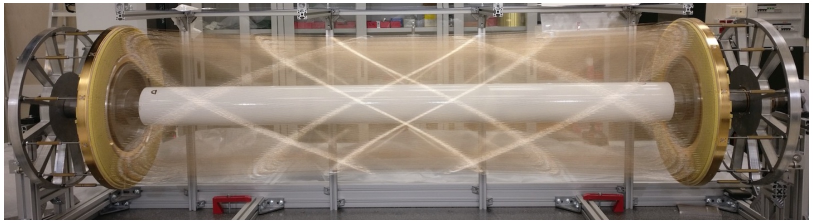
Key aspects for the R&D challenges are related to the mechanics, the electronics and the choice of gas mixture, etc.

Road to proposal

- KLOE ancestor chamber at INFN LNF Daϕne φ factory (commissioned in 1998 and operated for 20 years)



- CluCou Chamber proposed for the 4th-Concept at ILC (2009)
- I-tracker chamber proposed for the Mu2e experiment at Fermilab (2012)



- DCH for the MEG upgrade at PSI

- Belle I and II DCH
- IDEA drift chamber proposal for FCC-ee and CEPC

«Traditional» drift chambers

A cylindrically symmetric gas volume with (para-)axial wires defining a strong electric field, strung under mechanical tension for electrostatic stability and fixed at their extremities to the end walls by means of feed-through.

Constraints:

- the end walls, holding the feed-through (which limit the chamber granularity) the FE electronics and the relative cabling, must be rigid enough to transfer the load due to the wire tension (of the order of several Tons) to the outer cylindrical wall, without deforming.
- the inner cylindrical wall, usually, does not bear any load, to minimize the multiple scattering of incoming particles.
- the gas tightness relies on the hermetic properties of all surfaces (including the many tens of thousands feed-through holes) and of all their relative joints.

«Innovative» drift chambers

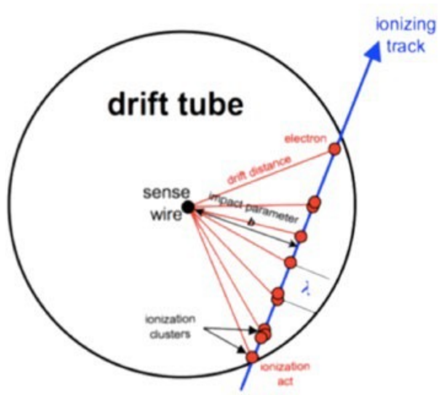
Guiding principles:

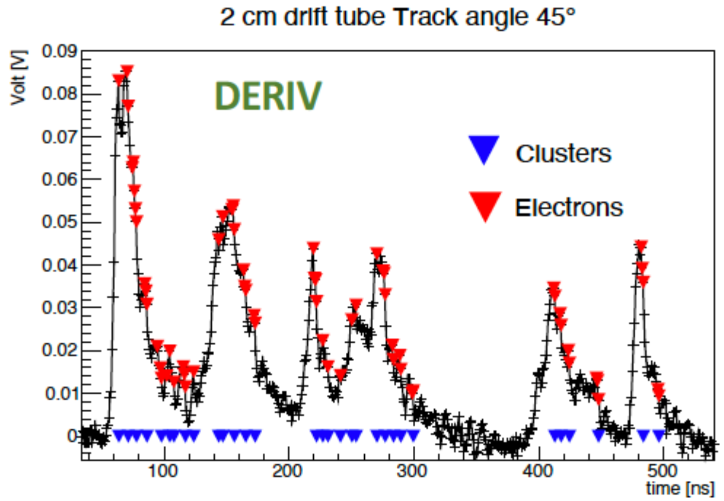
- separation of gas containment from wire support functions
- new concept for wire tension compensation
- feed-through-less wiring
- larger number of thinner (and lighter wires)
- cluster timing for improved spatial resolution
- cluster counting for particle identification

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 $\sigma_{dE/dx}$ **/(dE/dx)** ≈ 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%

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

T1 and T2: Data reduction and preprocessing

High speed digitization (2 GSa/s) for CC ⇒ Transfer rate of TB/s

- **Data reduction strategy:** transfer, for each hit drift cell, only the minimal information relevant to apply the **Cluster Counting/Timing (CCT) techniques**, i.e. the **amplitude** and the **arrival time of each peak** associated with **each individual ionisation electron** ⇒ **CCT algorithms!**

  ▶ Use of a **FPGA** for the **real-time data analysis** of drift chamber signals **digitized by an ADC.** Acquire the signals converted ⇒ process with cluster counting algorithms (aimed also at **reducing the data throughput**) ⇒ send the processed information to a back-end computer via an Ethernet interface.

- A fast read-out CCT algorithm has been developed as **VHDL/Verilog** code implemented on a **Virtex 6 FPGA (maximum input/output clock switching frequency of 710 MHz)**. The hardware setup includes also a **12-bit monolithic pipeline sampling ADC** at conversion rates up to **2.0 GSPS.**

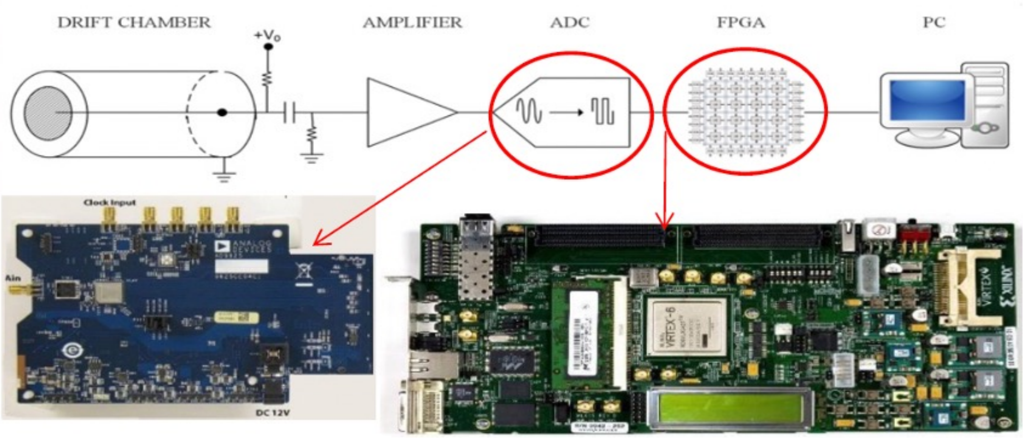
Goal

To implement on FPGA more sophisticated peak finding algorithms for the **parallel pre-processing** of **many ADC channels**:

- **reduce costs** and **system complexity**
- **gain on flexibility in determining proximity correlations** among hit cells for track segment finding and triggering purposes.

Machine learning in FPGA in place

Implmentend using a **single channel ADC**



R & D Tasks for WP2

T3: Mechanics: new wiring procedures and new endplate concepts

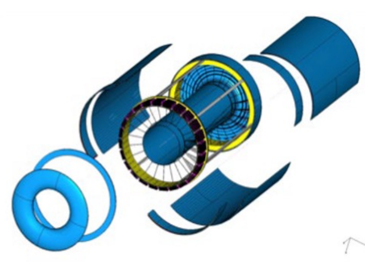
- Performance goal:
  - feed-through-less wiring procedures
  - more transparent endplates (< 5% X_0)
  - transverse geometry
- Main developments covered:
  - Separate the wire support function from the gas containment function
- Deliverables next 3y:
  - conceptual designs of novel wiring procedures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

T4: Increase rate capability and granularity

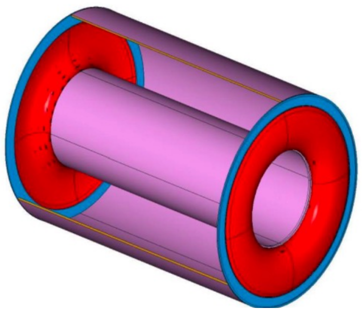
- Performance goal:
  - smaller cell size and shorter drift time
  - higher field-to-sense ratio
- Main developments covered:
  - higher field-to-sense ratio allows to increase the number of field wires, decreasing the wire contribution to multiple scattering
- Deliverables next 3y:
  - measurements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

T3: separation of functions and mechanical design

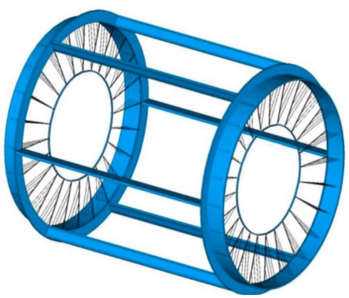
New concept of construction allows to reduce material to ≈ 10^{-3} X_0 for the barrel and to a few x 10^{-2} X_0 for the end-plates.

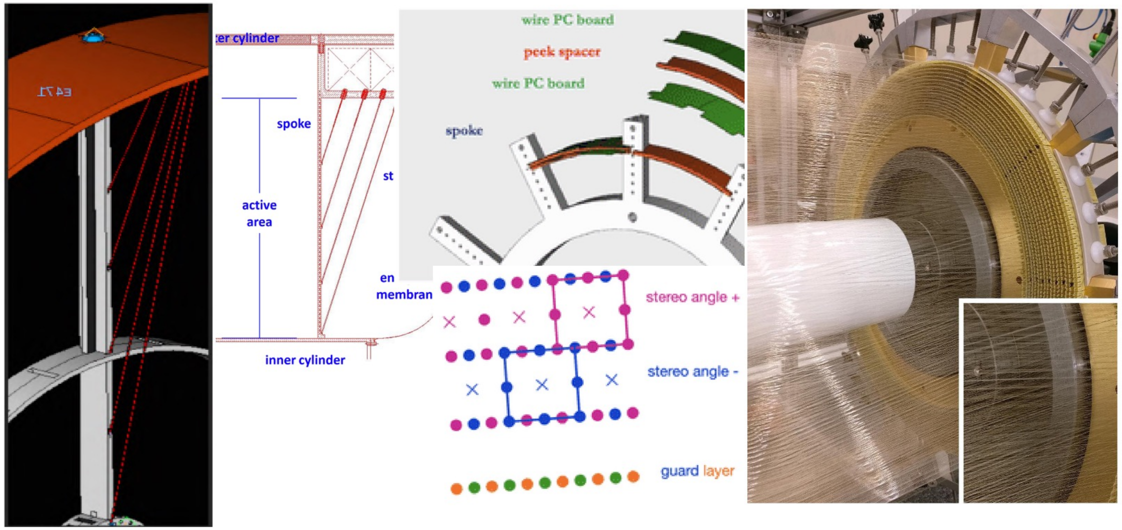


Gas containment
Gas vessel can freely deform without affecting the internal wire position and mechanical tension.



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

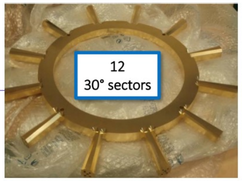




T3: wiring procedure/robot

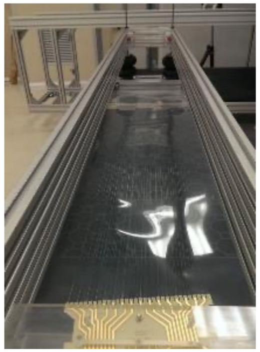
See talk. By G. Charles

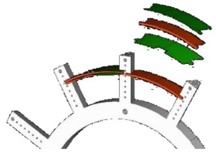
MEG II CDCH: Wiring Procedure

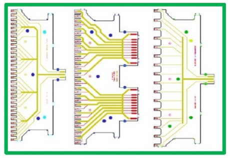


The basic element is a multiwire layer made of 32 parallel wires

- **end-plates** numerically machined from solid Aluminum (mechanical support only);
- **Field, Sense and Guard wires** placed azimuthally by Wiring Robot with better than one wire diameter accuracy;
- **wire PC board layers** (green) radially spaced by spacers
- **spacers** (red) numerically machined peek blocks (accuracy < 20 μm);
- wire tension defined by homogeneous winding and wire elongation ($\Delta L = 100\mu m$ corresponds to ≈ 0.5 g);
- Drift Chamber assembly done on a **3D digital measuring table**;
- build up of layers continuously checked and corrected during assembly
- End-plate gas sealing done with glue.





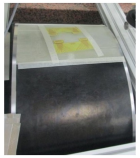


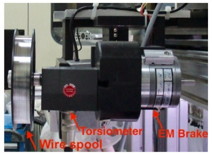
WIRING SYSTEM (*Klotho and Lachesis*)

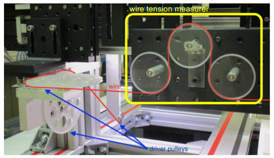
The **wiring system** is composed of:

- **a rotating cylinder**
- **a wire spool holder**
- **a system of pulleys.**

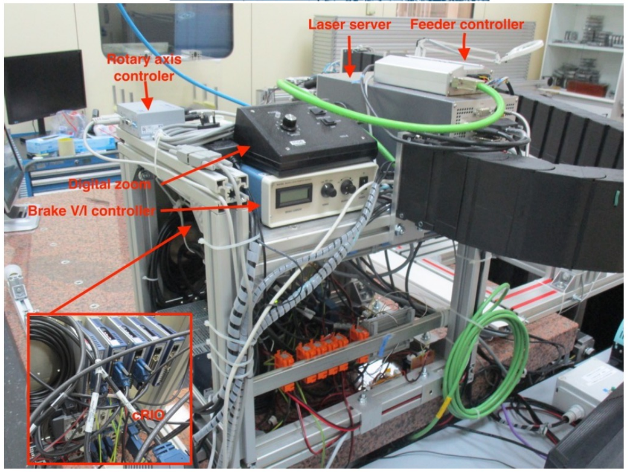
The wiring system has the task of distributing the wire along a **helicoidal trajectory (32 parallel wires)** with high precision and with a constant pre-defined mechanical tension.



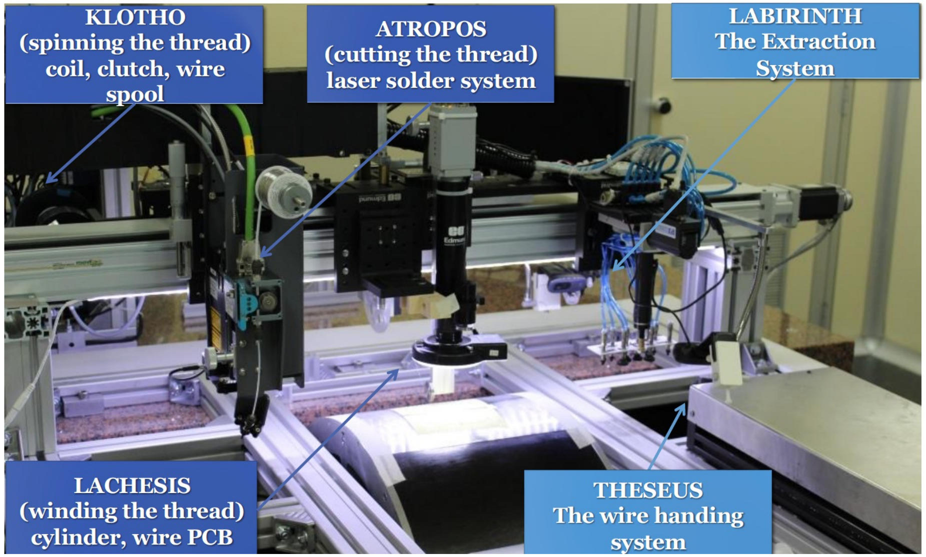




Hardware



MEG II CDCH: The wiring robot

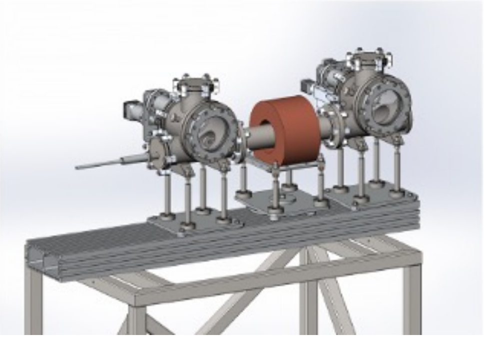


The wiring robot manages the positioning of a large quantity of wires with precise alignment and mechanical tension.

R & D Tasks for WP2

T5: Consolidation of new wire materials and wire metal coating

- Performance goal:
  - Electrostatic stability
  - High YTS (wire material yield strength)
  - Low mass, low Z
  - High conductivity
- Main developments covered:
  - Develop contacts with companies producing new wires
  - List companies
  - Metal coating of carbon wires
- Deliverables next 3y:
  - construction of a magnetron sputtering facility for metal coating of carbon wires



T6: Study ageing phenomena for new wire types

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

R & D Tasks for WP2

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

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

Final Table

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

Examples:

Drift Chamber for the IDEA detector proposal

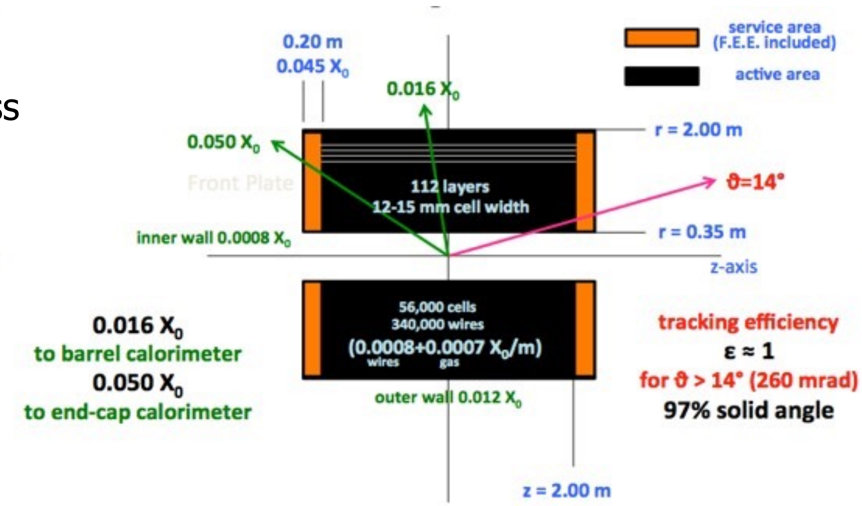
The DCH is:

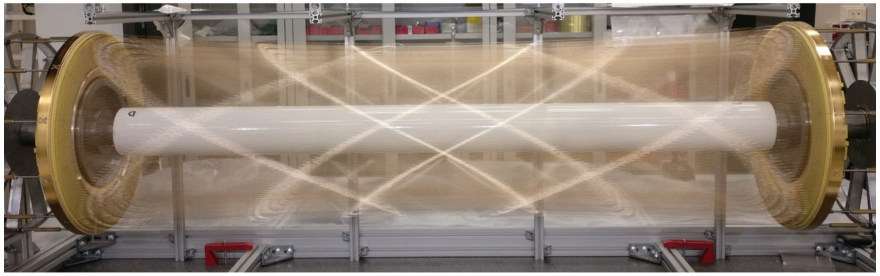
- a unique-volume, high granularity, fully stereo, low-mass cylindrical
- gas: He 90% - iC_4H_{10} 10%
- inner radius R_{in} = 0.35m, outer radius R_{out} = 2m
- length L = 4m
- drift length ~1 cm
- drift time ~150ns
- σ_{xy} < 100 μm, σ_z < 1 mm
- 12÷14.5 mm wide square cells, 5 : 1 field to sense wires 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





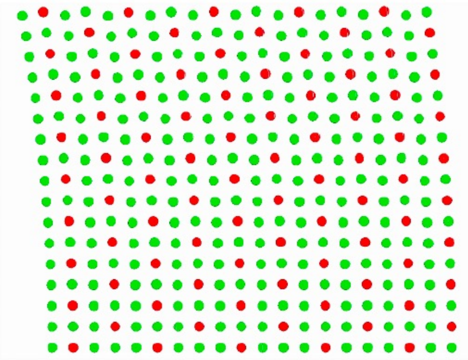
- the wire net created by the combination of + and – orientation generates a more uniform equipotential surface → better E-field isotropy and smaller ExB asymmetries)

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

Drift Chamber for CEPC experiment

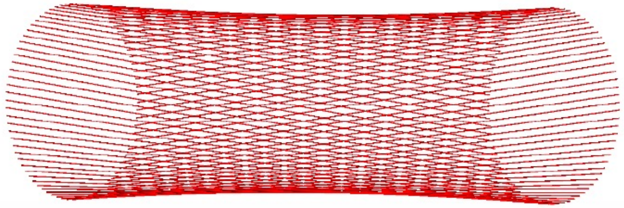
- The drift chamber covers
  - radial range from 800 mm to 1,800 mm
  - Z range from -2,980 mm to 2,980 mm
- A small cell design is chosen to obtain enough number of track hits at the outer radius
  - purely made of stereo wires
  - the sense wire is made of gold-plated tungsten with a diameter of 20 μm
  - the field wire is made of silver-plated aluminium with a diameter of 40 μm
  - organized into 55 co-axial layers
- The working gas is
  - a mixture of helium and C_4H_{10} with a mixing ratio of 90:10
- Both inner and outer cylinders are made of carbon fibre

Geometry Parameters	Value
Half length	2980 mm
Inner and outer radius	800 mm ~ 1800 mm
The number of layers	55
Cell size	18 mm × 18 mm
Gas	90%He+10%C_4H_{10}
Single wire resolution	110 μm
Sense to field wire ratio	1:8
Total number of sense wire	25,357
Stereo angle	0.028 rad~0.062 rad
Sense wire	Gold plated Tungsten ϕ = 20 μm
Field wire	Silver plated Aluminum ϕ = 40 μm
Wall	Carbon fiber 0.2 mm(inner) and 2.8 mm(outer)



$r-\phi$ projection of a proportion of the first 10 layers of wires

Sense wires of each layer forms a rotating hyperboloid surface



Conclusions/next steps/organization aspects

- strategy of WP2 well defined
- 13 participating institutes
- tasks, goals, deliverable defined and shared between the groups
- activity already started on many aspects
- WP2 meeting are going to be restated

Backup

Beam tests in 2021,2022 and 2023

Beam tests to experimentally asses and optimize the **performance of the cluster counting/timing** techniques in strict collaboration with the IHEP Beijing group:

- Two **muon beam tests** performed at **CERN-H8** **(βγ > 400)** in Nov. 2021 and July 2022.
- A **muon beam test** (from 4 to 12 GeV momentum) in 2023 performed at **CERN**.
- Ultimate test at **FNAL-MT6** in 2024 with π and **K** **(βγ = 10−140)** to fully exploit the relativitic rise.