FCC project in Italy

2nd FCC Italy & France workshop
November 4, 2024

Paolo Giacomelli
INFN Bologna

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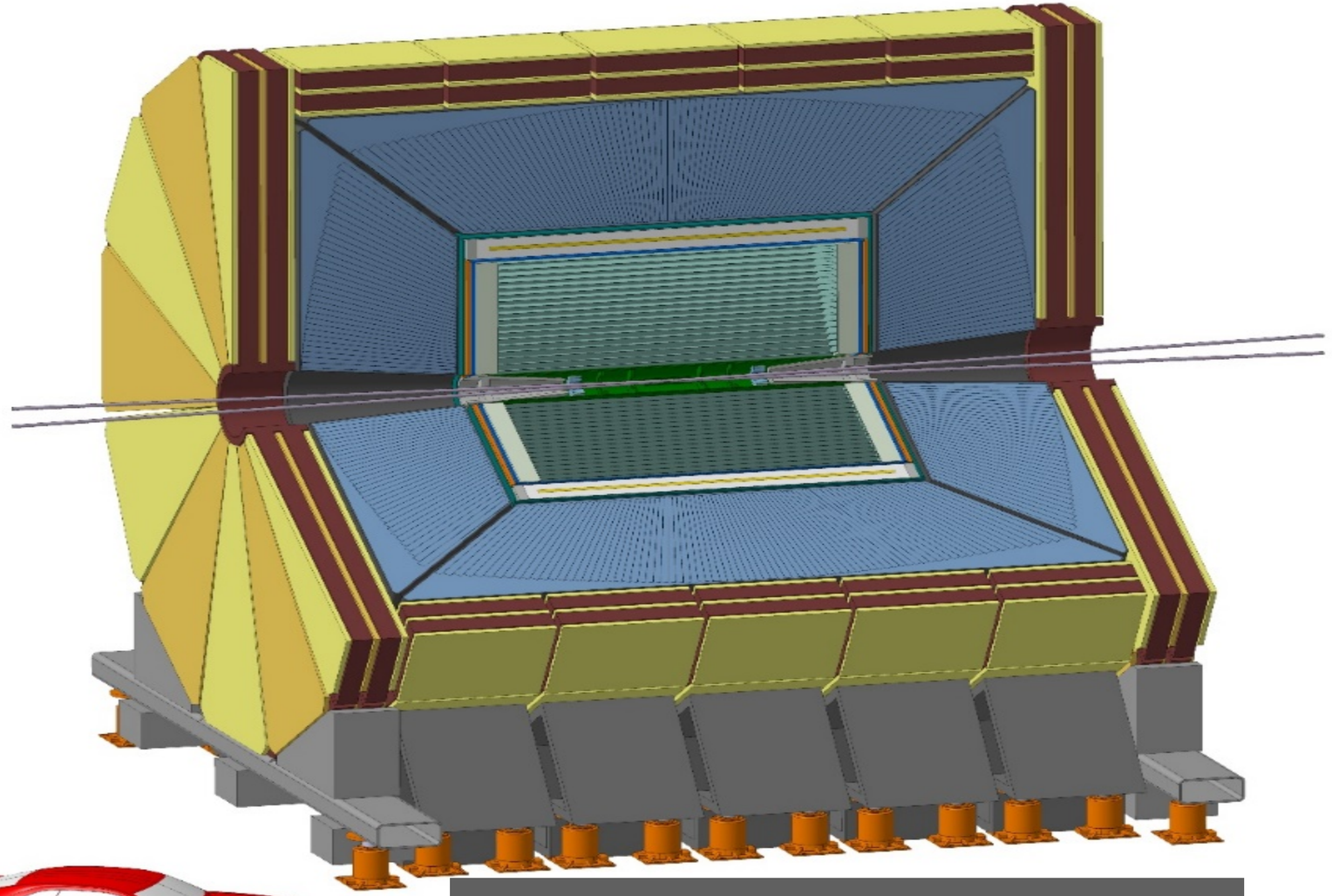
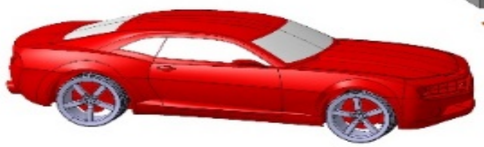
      - We are actively seeking to develop synergies and collaborate with many International colleagues
      - At this workshop we hope to initiate and foster many collaborations with French colleagues on several activities

The IDEA detector concept for FCC-ee



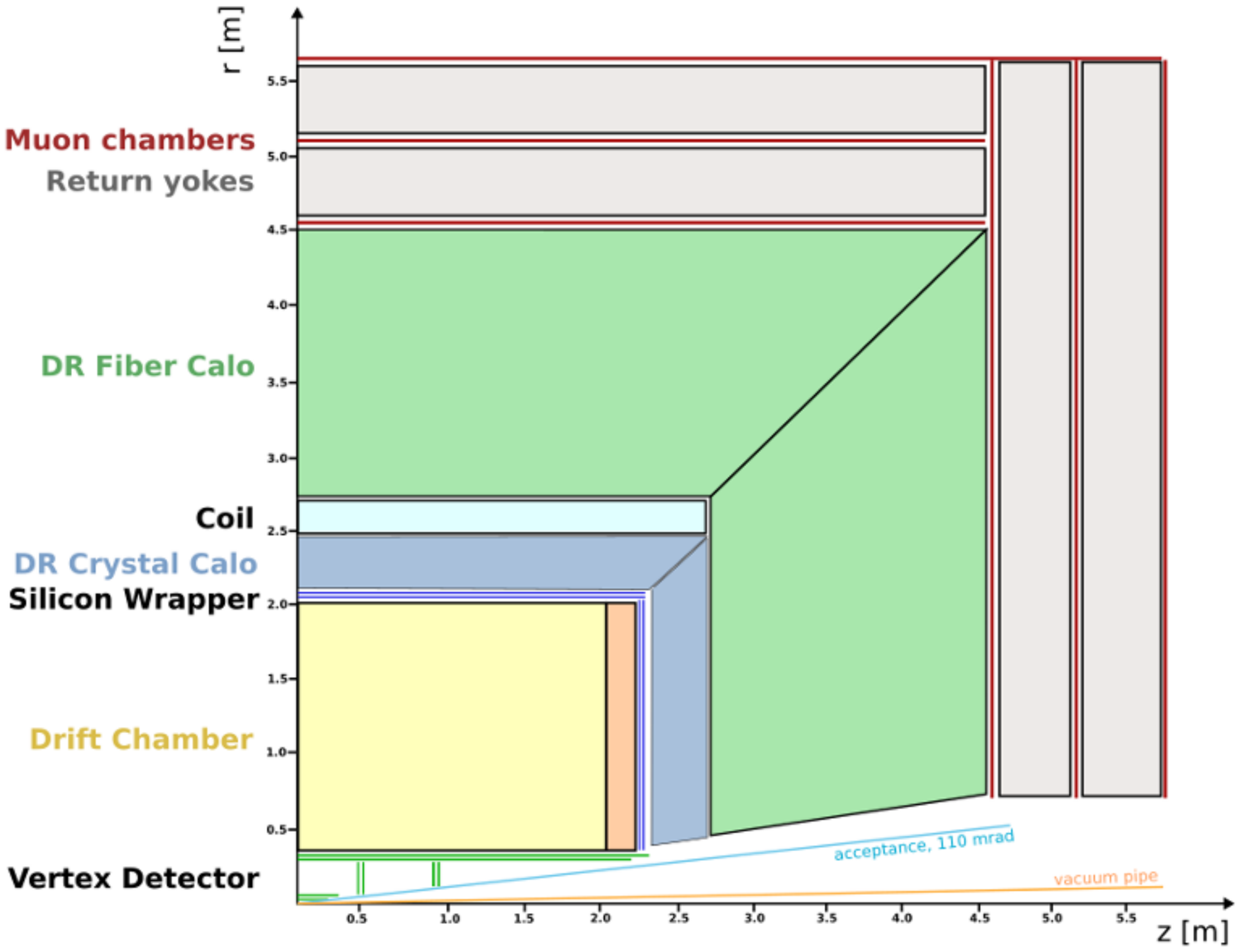


IDEA concept (proposed in FCC CDR)
Innovative Detector for e^+e^- Accelerator

- **New, innovative, possibly more cost-effective concept**
  - Silicon vertex detector
  - Short-drift, ultra-light wire chamber
  - Dual-readout calorimeter
  - Thin and light solenoid coil *inside* calorimeter system
    - Small magnet ⇒ small yoke
  - Muon system made of 3 layers of μ-RWELL detectors in the return yoke

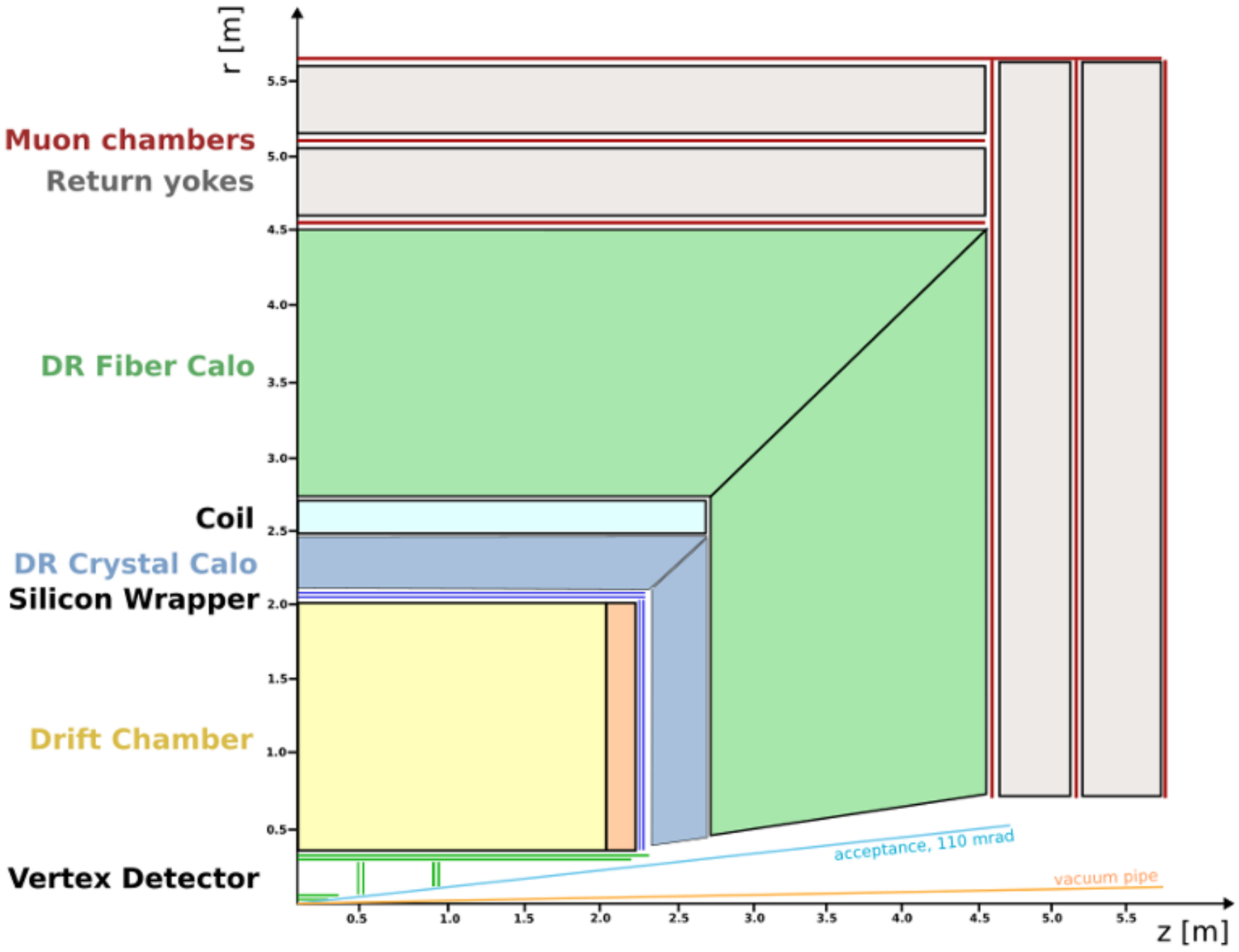
https://pos.sissa.it/390/

IDEA detector new baseline layout



IDEA detector new baseline layout

Beam pipe: R~1.0 cm



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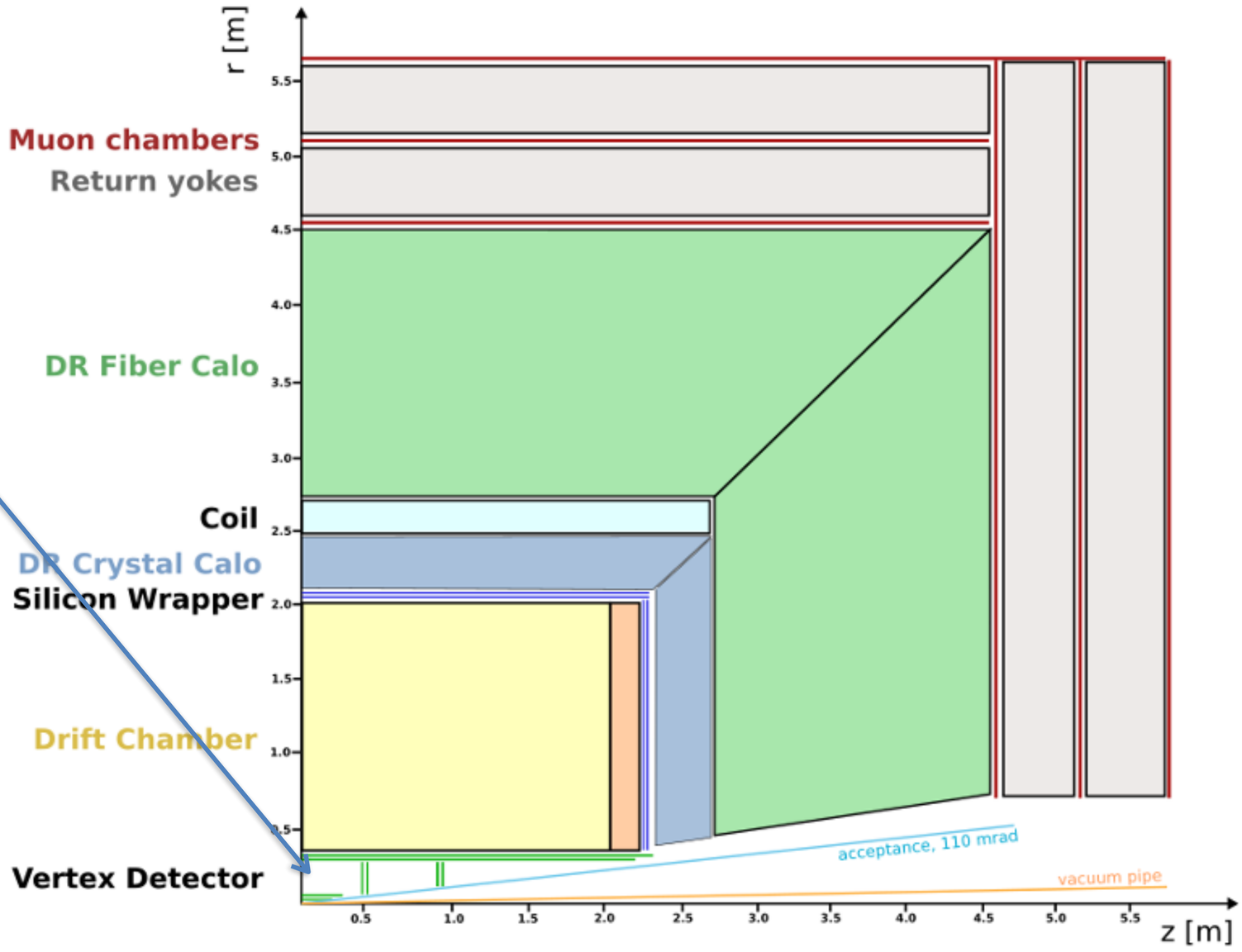
Vertex:

5 MAPS layers

R = 1.37-31.5 cm



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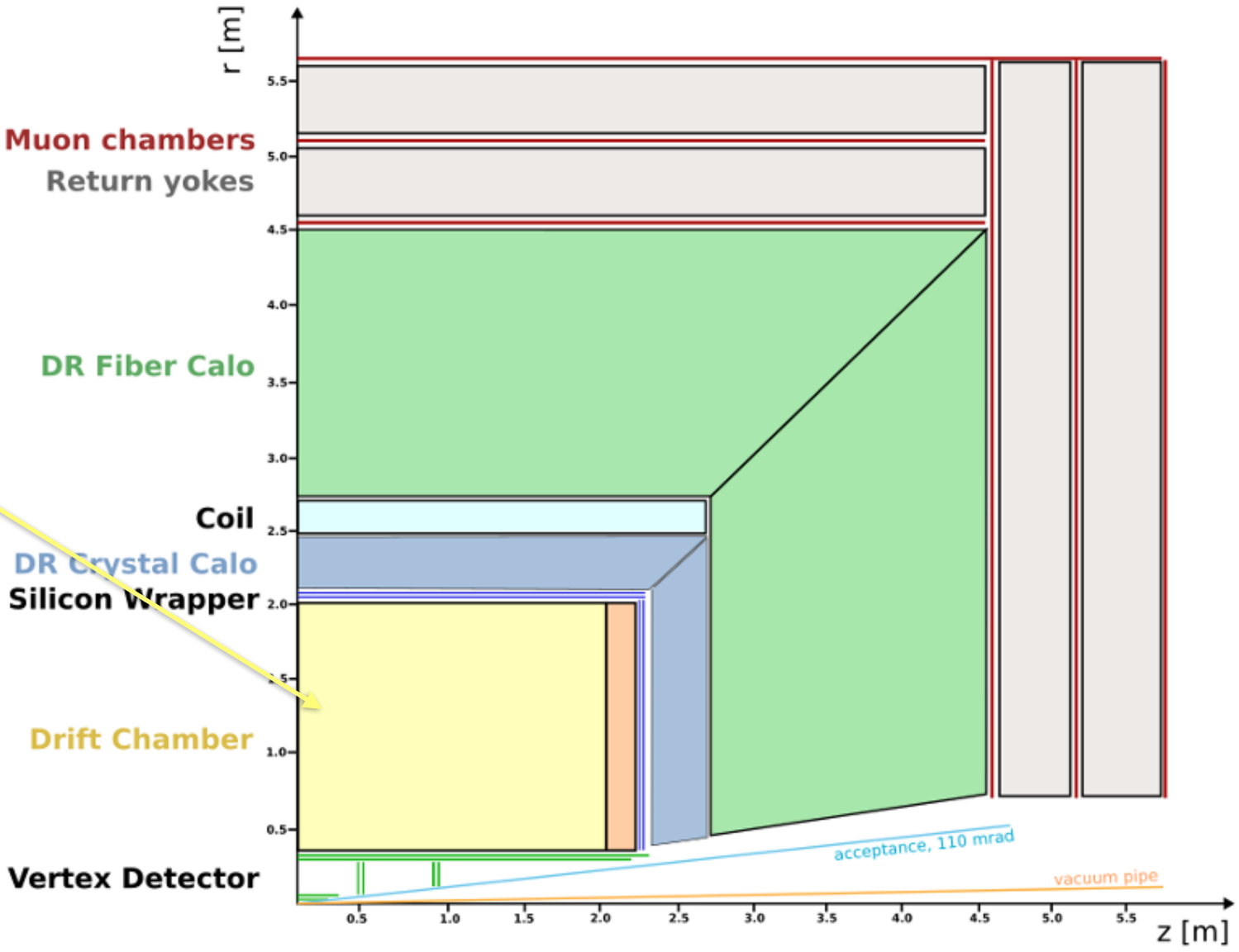
Drift Chamber: 112 layers

4 m long, R = 35-200 cm



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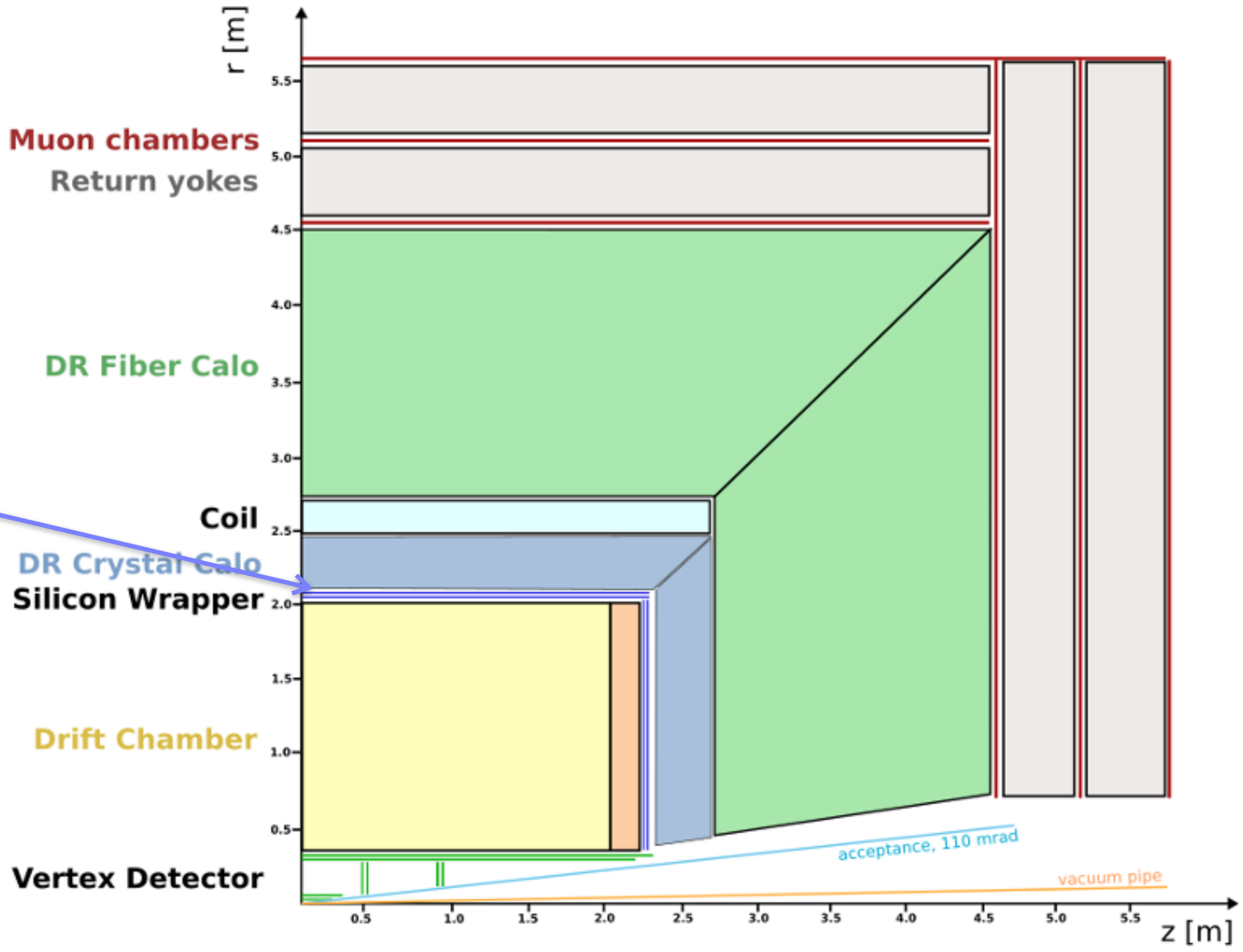
Outer Silicon wrapper:

R = 200-215 cm



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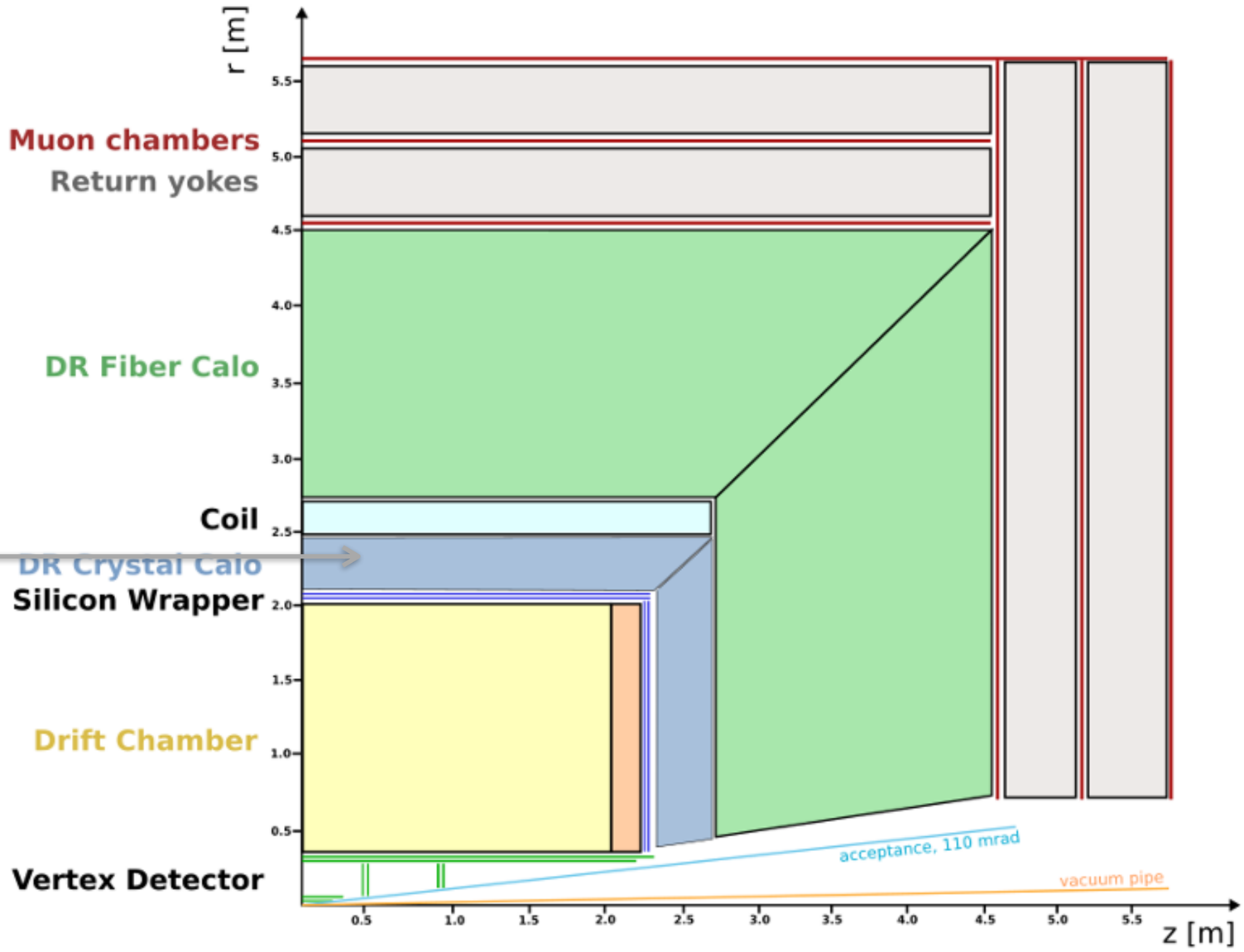
DR crystal ecal: ~ 22 X_0

R = 215-250 cm



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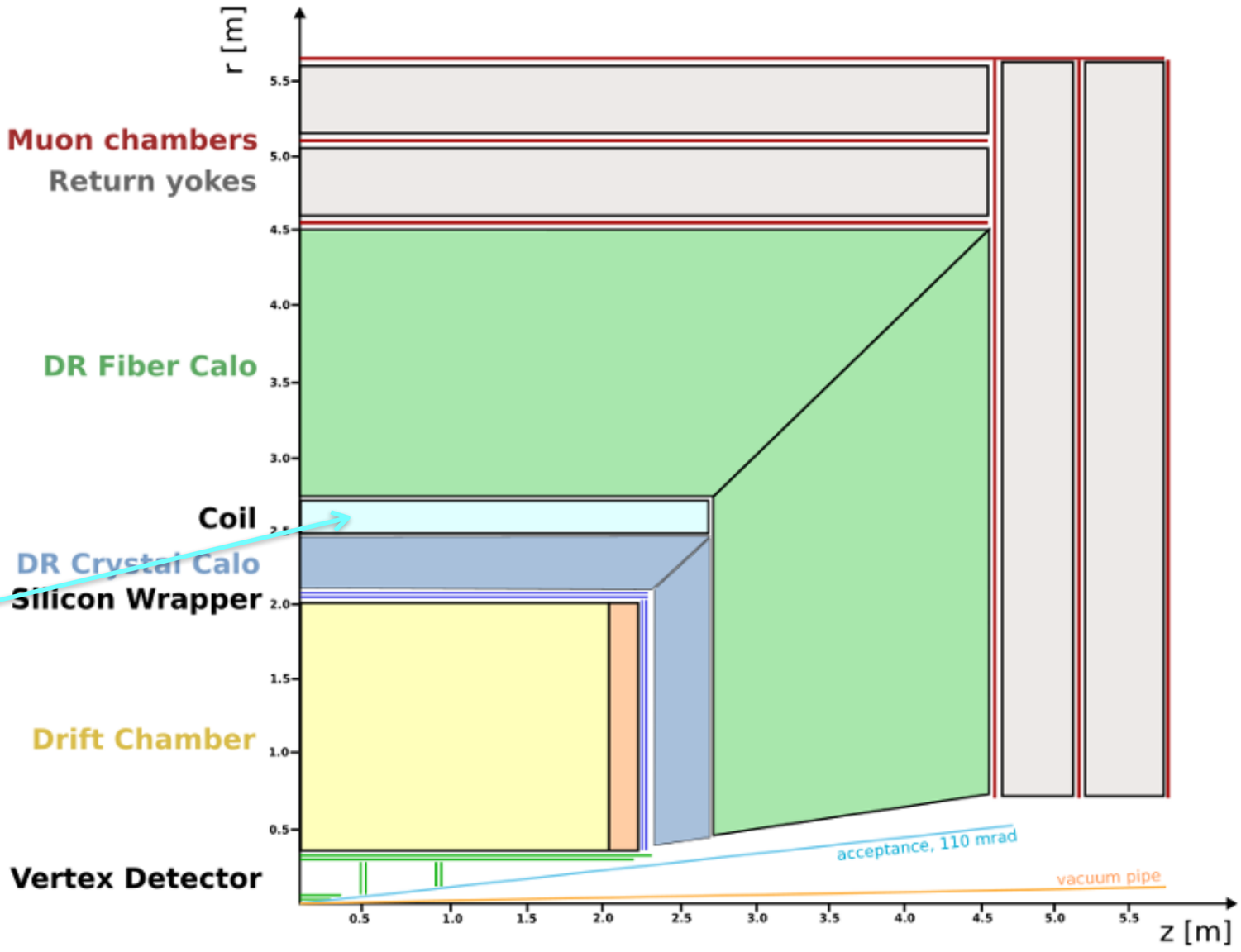
Superconducting solenoid coil:

3 T, R ~ 2.5-2.8 m



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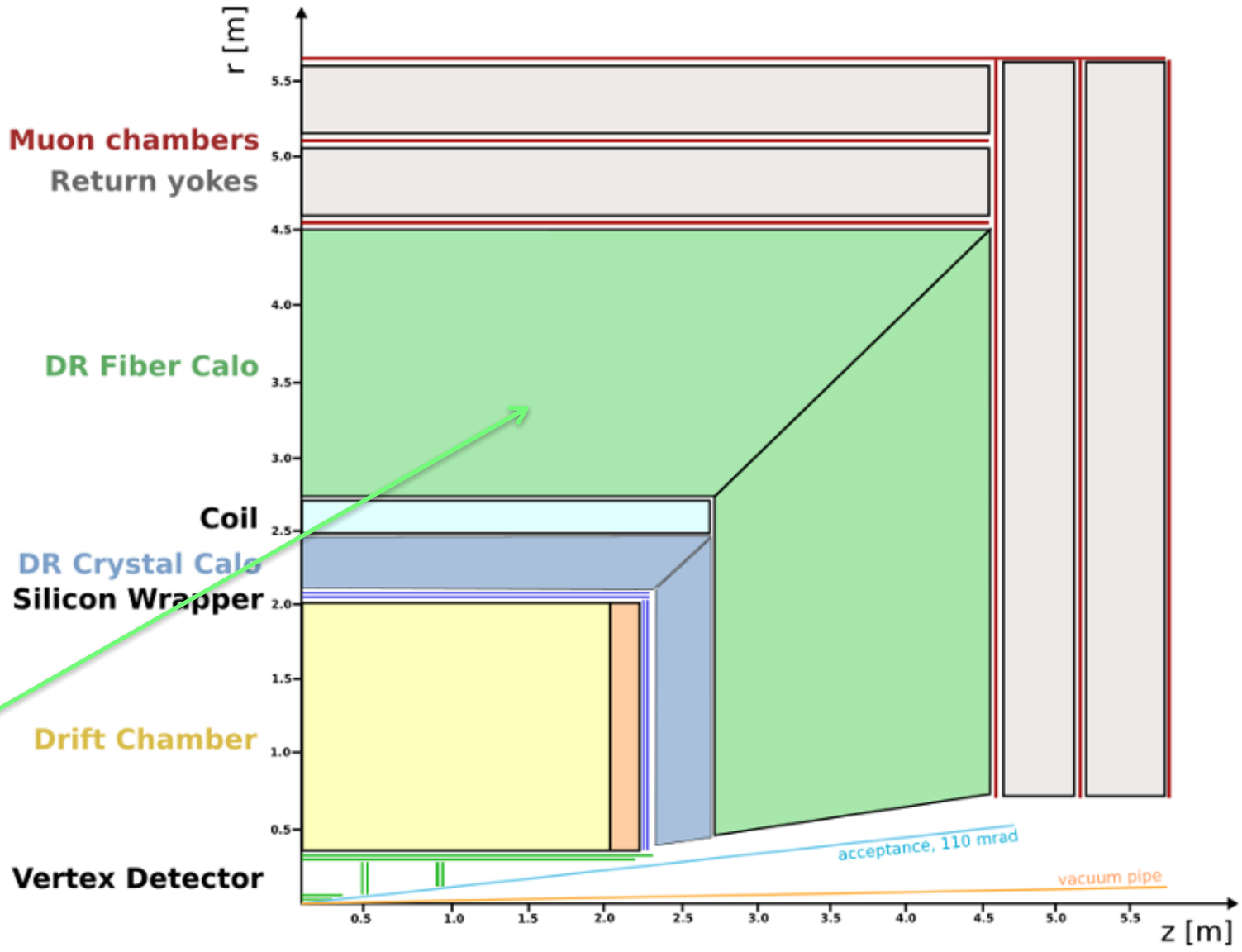
Dual-Readout Calorimeter:

R = 280-460 cm



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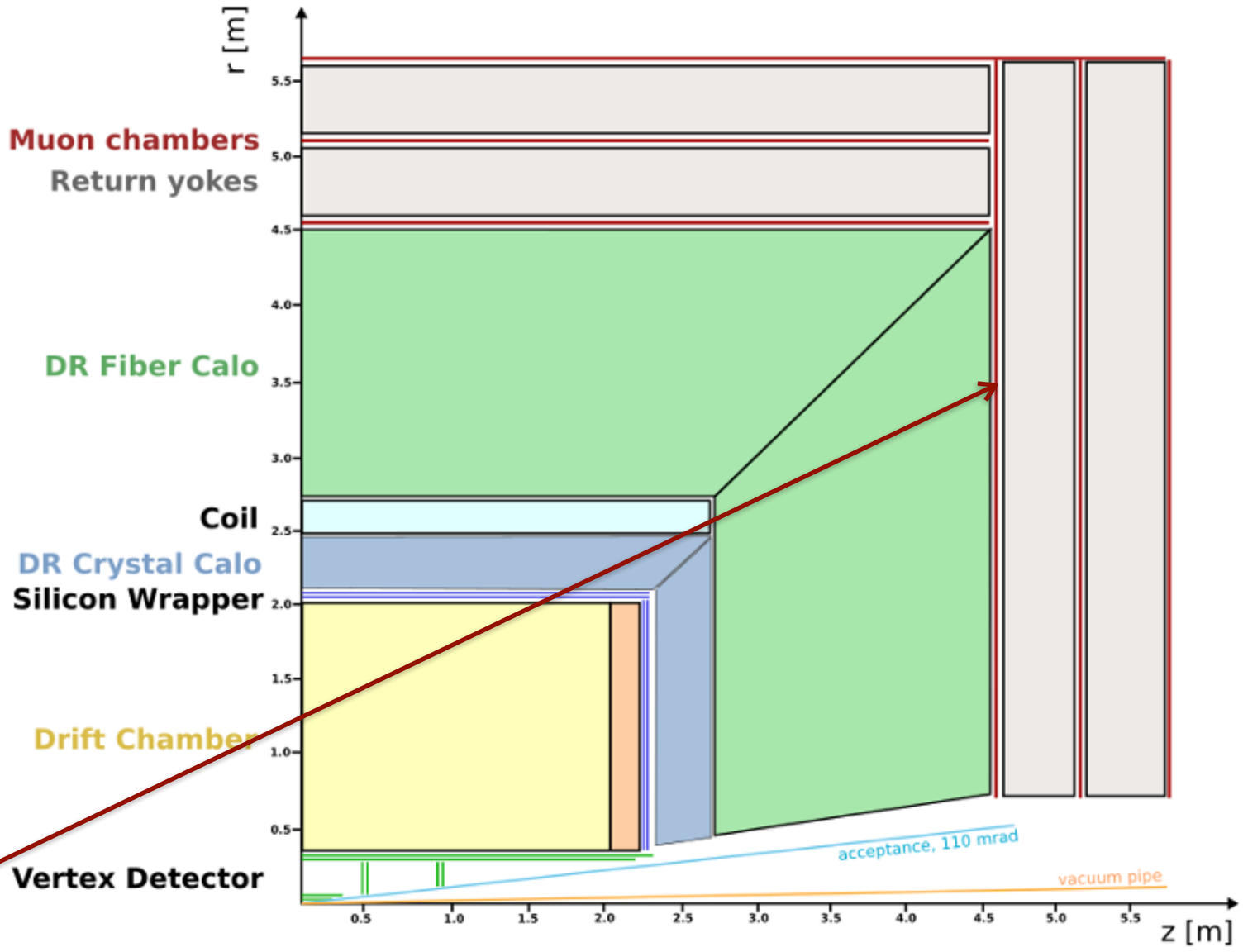
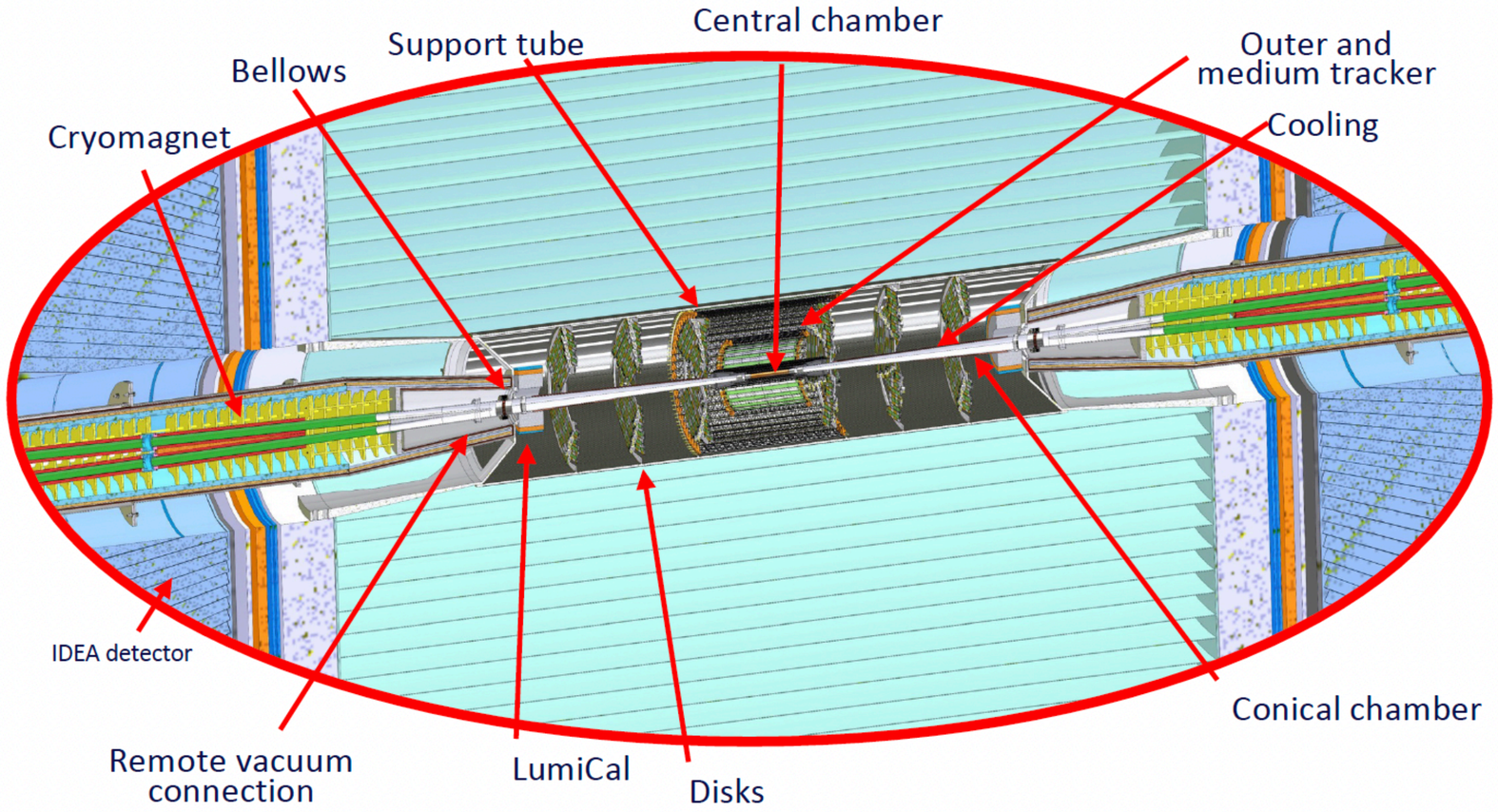
Yoke + Muon chambers

R = 460-570 cm



IDEA MDI

FCC-ee engineered Interaction Region



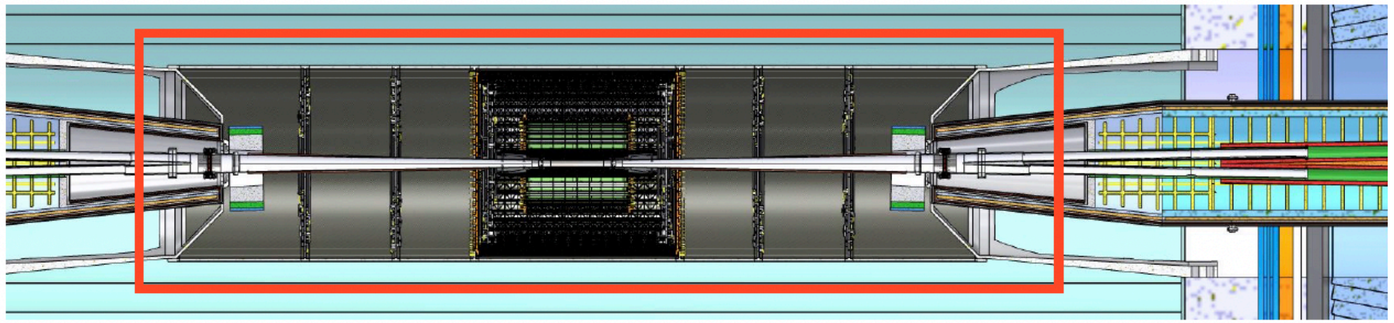
Ref: M. Boscolo, F. Palla, et al., *Mechanical model for the FCC-ee MDI,* EPJ+ Techn. and Instr., https://doi.org/10.1140/epjti/s40485-023-00103-7

IR mockup

IR mockup

Goal is to prove state-of-the-art technological solutions and test its feasibility
LNF, CERN and INFN-Pisa collaboration (LNF-CERN MoU)

central region ±1.2 m



The mockup project has received a great deal of interest within the FCC community

- **primarily for technology validation of the MDI design for the Feasibility Study**
- **Integrating vertex and chambers "on paper" has been proven to be difficult, more surprises expected with a real mock-up!**
- **Global assembly sequence to be studied**

Main components

- ✓ Central vacuum chamber with paraffin cooling system
- ✓ Lateral vacuum chamber with water cooling system
- IR Bellows
- Support tube – carbon fibre + honeycomb
- Inner vertex detector with air cooling system + outer tracker and services routings
- Luminosity calorimeter and services routings

M. Boscolo - INFN LNF

New IDEA solenoid studies

New proposal of INFN MI - LASA

Study of an HTS solenoid for IDEA

Detector magnets are all based on aluminum-stabilized NbTi:

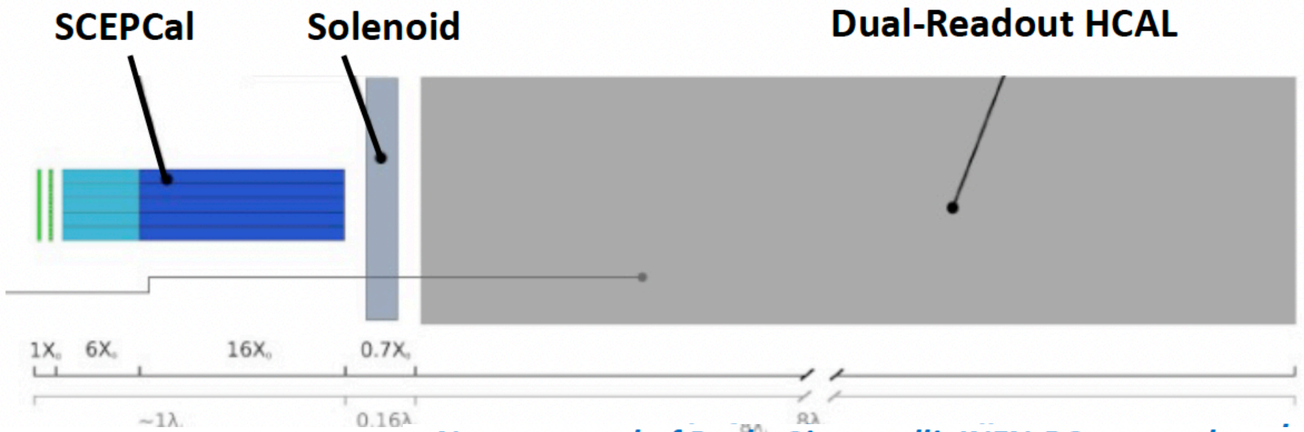
but:

NO Commercially available nowadays

- Need of re-establishing conductor technology in industry

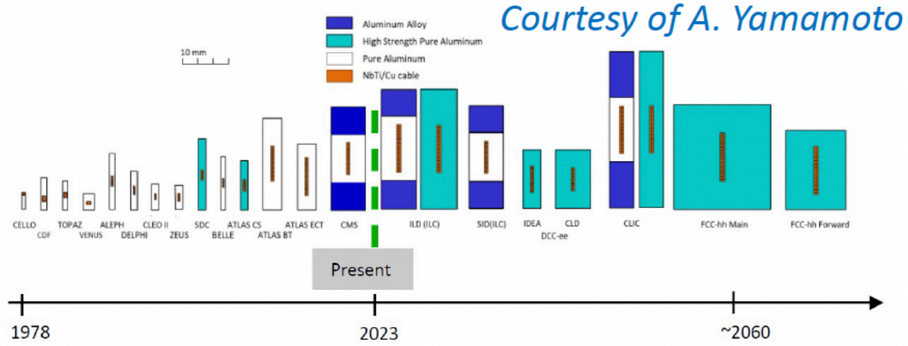
- **Required low temperature operation (< 5 K)**
  - Large energy consumption (cost and not sustainable)
  - Large inventory of LHe (scarcity of He and no sustainable)

"NEED OF NEW CONCEPTS OF DETECTOR MAGNETS"



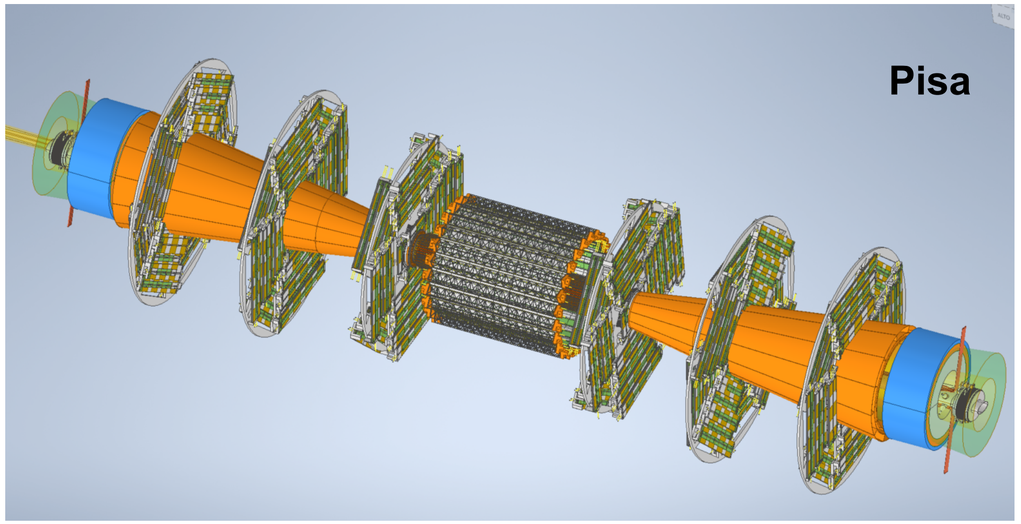
New proposal of Paolo Giacomelli, INFN-BO: move the em calo inside solenoid! → change of paradigm

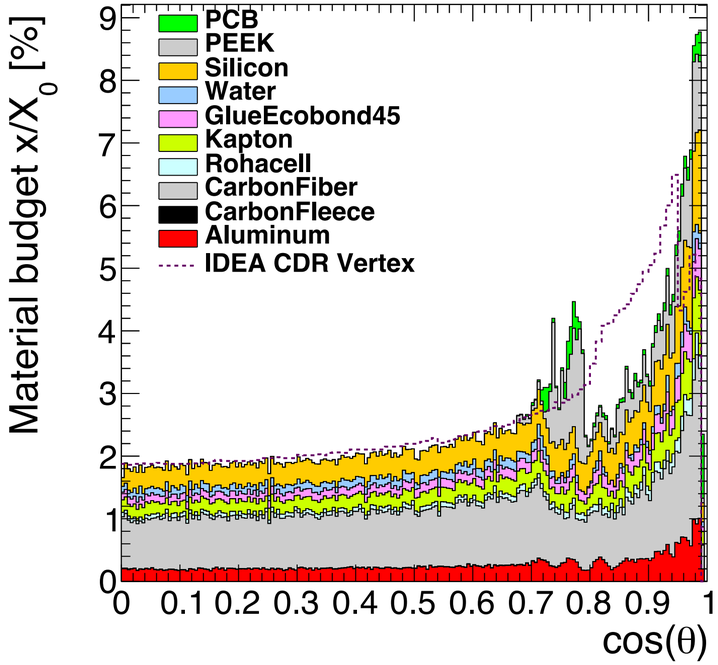
Aluminum-stabilized Nb-Ti conductors:
Courtesy of A. Yamamoto



Property	IDEA	CLD	Unit
Conductor			
Conductor material	Nb-Ti/Cu in Al/Ni cladding		
Conductor height	36	36	mm
Conductor width	10	22	mm
Turn-to-turn insulation	1	1	mm
Number of strands	30	26	
Strand diameter	1.1		mm
Cu:SC ratio	1: 1		
Operating current	20		kA
Operating temperature	4.5		K
Coil			
Inner radius	2.235	4.02	m
Length	5.8	7.2	m
Weight	12.5	49.5	t
Number of turns x layers	530 x 1	300 x 1	
Support cylinder thickness	12	25	mm
Total coil thickness	53	102	mm
Central field	2		T
Stored energy	170	600	MJ
Energy density	14	12	kJ/kg

Silicon tracker



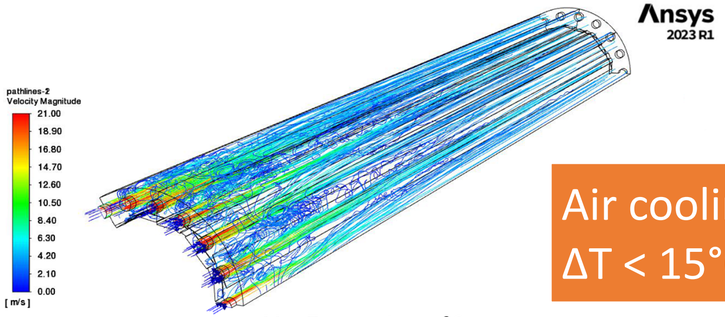


Outer vertex tracker:
ATLASPix3 based (Milano)

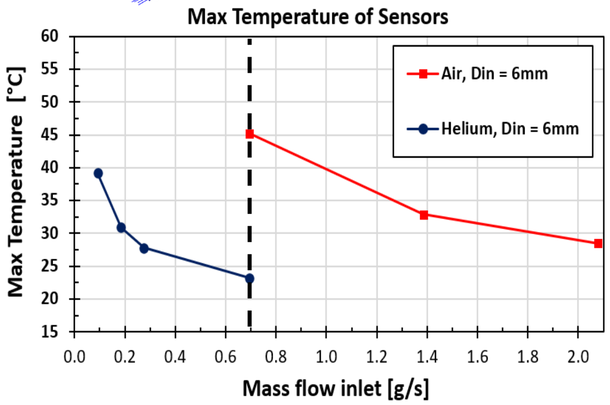
Modules of $50 \times 150\ \mu m^2$ pixel

Inner Vertex detector:
ARCADIA based (Torino, Milano, Padova, Pisa, Perugia)

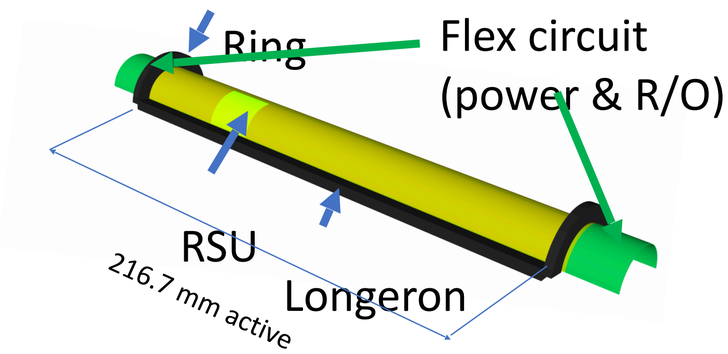
Modules of $25 \times 25\ \mu m^2$ pixel size



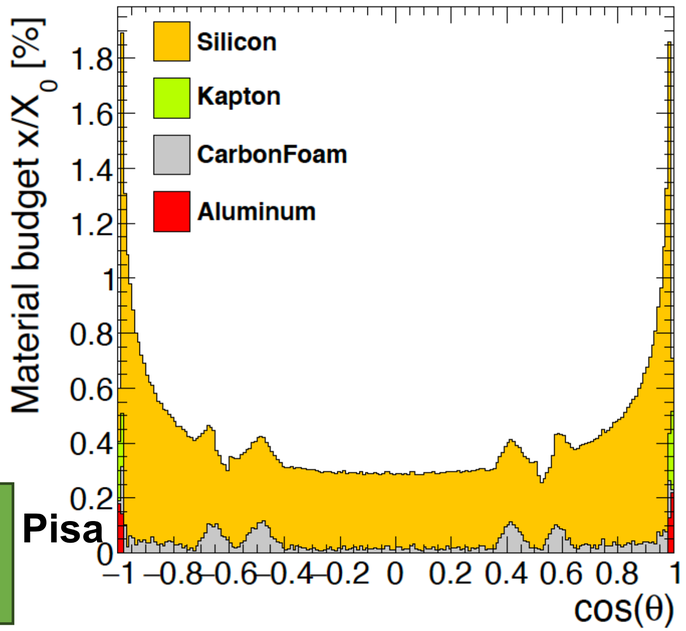
Air cooling studies:
ΔT < 15°C



Perugia



Also studying curved Silicon layout (ITS3 like)
~4 smaller material budget for inner vertex



Pisa

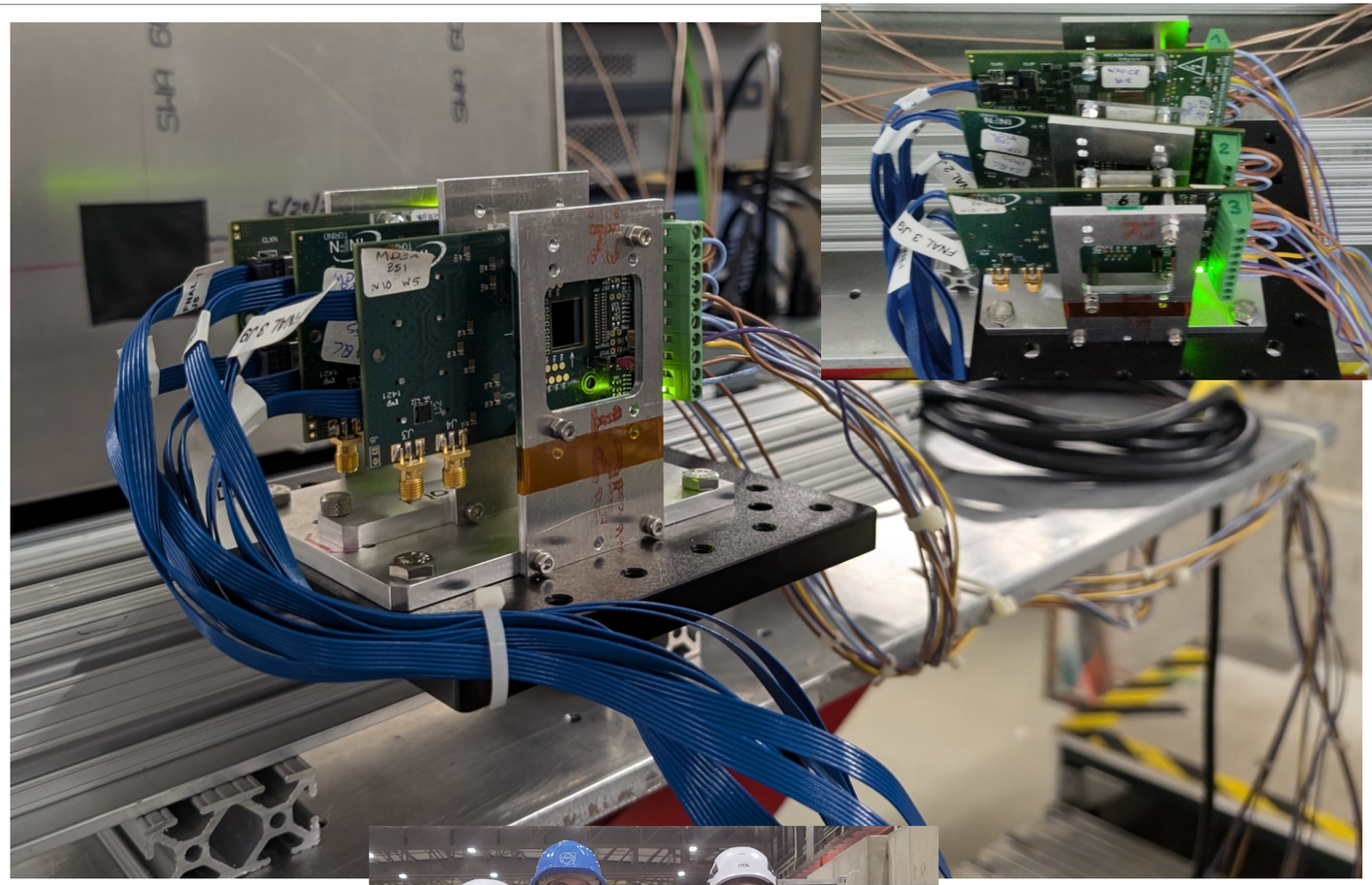
Silicon tracker: test beams

ARCADIA MD3 sensors test beam at FNAL
(PD, BO, TO)

- 120 GeV protons from June 26th to July 10th
- Telescope with 3 ARCADIA-MD3 sensors
- Threshold, sensor HV and incidence angle parametrization:
  - study of cluster size, collection efficiency, spatial resolution

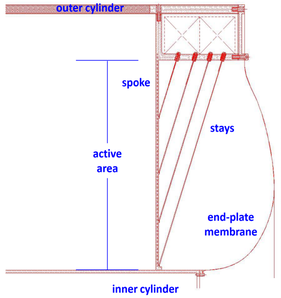
ATLASPIX3 Module at H8 beam line
(MI+Edinburgh+IHEP)

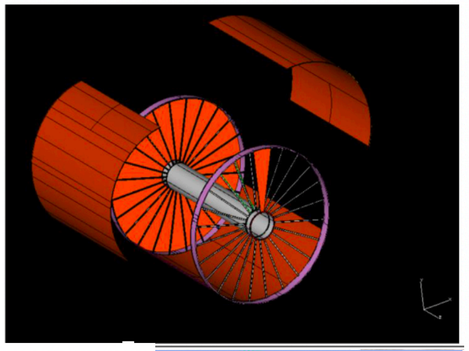
- Module inserted in the Hydra calorimeter test beam August 28th – September 4th
- Testing the integration in a readout chain with other detectors

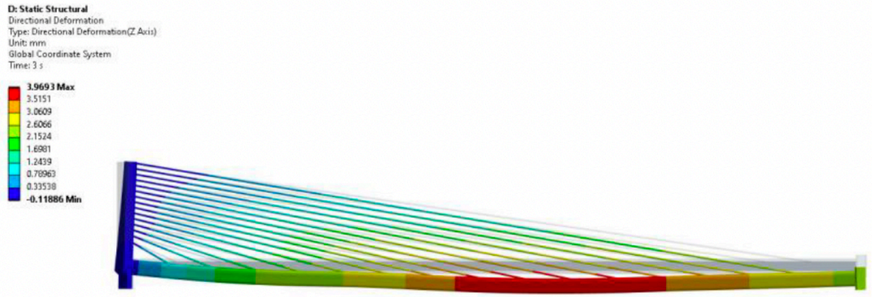


Drift chamber

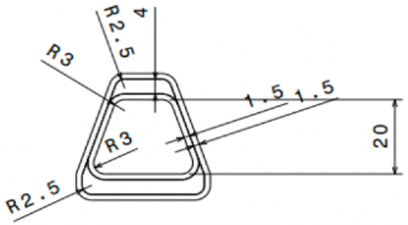
Simulation studies: progress about the final design of the cross section of the spoke

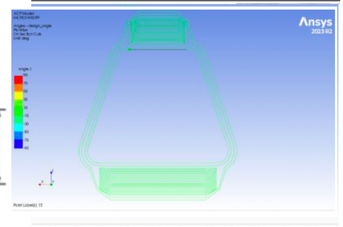






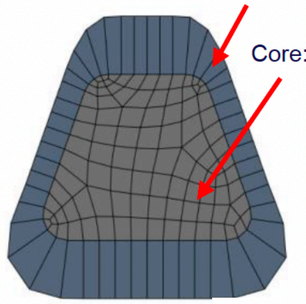
Statical structural simulation: deformation along z

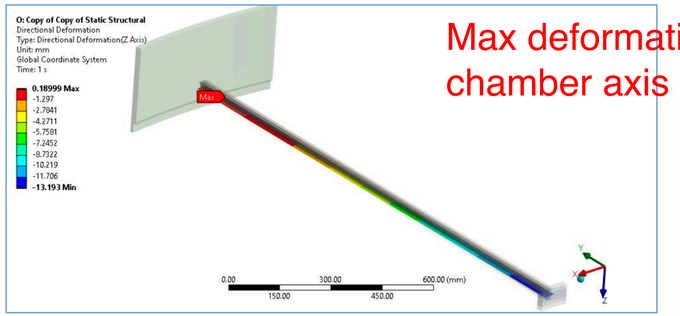




Skin: Layered Shell Elements SHELL181

Core: Brick Elements SOLID185





Max deformation along the chamber axis ~ 190 μm

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

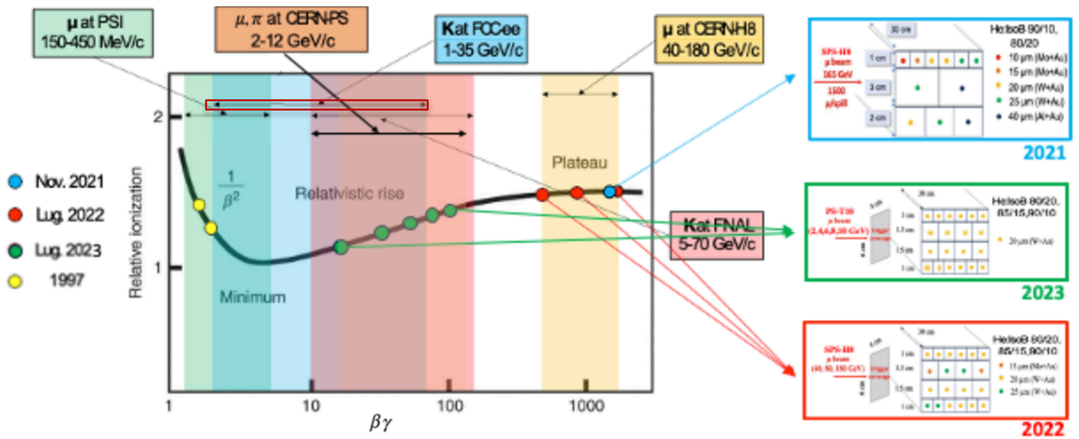
- Including **prestressing of spokes**
- Investigate more **composite structures** (different layer orientation)
- **Buckling** analysis on outer cylinder

Improving endcap simulations

The mechanical simulation project will be ready in next few months

Drift chamber

- New results from the 2021/2022 beam tests at CERN H8 ($\beta\gamma$ > 400) [ICHEP 2024]



- Landau distribution for the charge along a track
- Selected the distribution with 80% of the charges for the dE/dx truncation to be compared with dN/dx. There is still margin for improvements in CC efficiency!

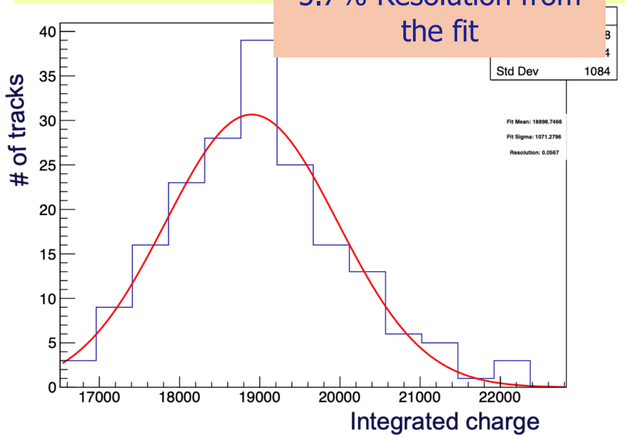
- Data analysis of the two test beams at CERN T10 performed in July 2023 and July 2024 with muons (1-12 GeV) ongoing

Study done using same tracks (2 m track length) made of the same hits.

180 GeV/c muons

dE/dx Resolution (re

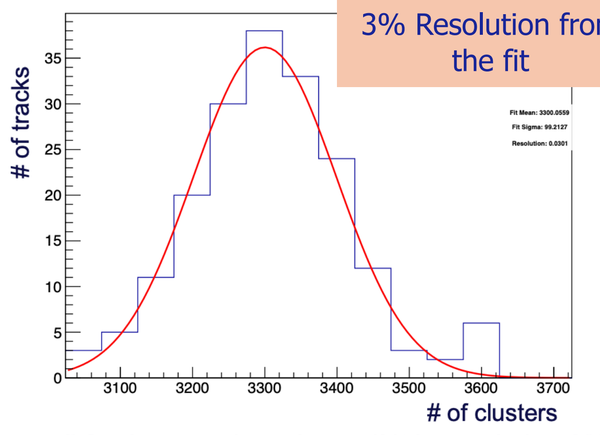
5.7% Resolution from the fit



@2m long track we have dE/dx resolution 5.7%

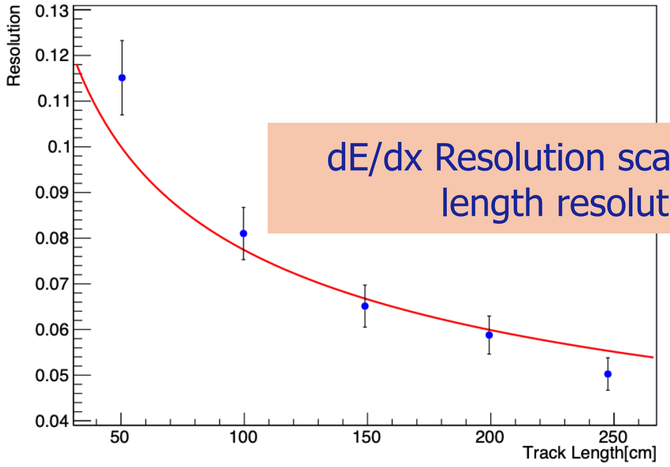
dN/dx Resolution

3% Resolution from the fit



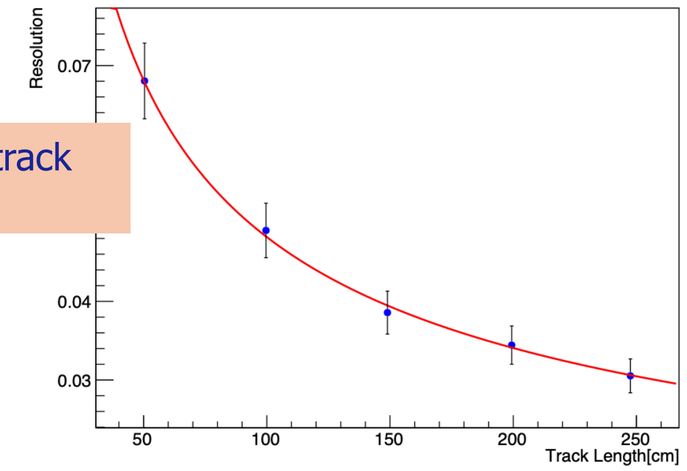
@2m long track we have dN/dx resolution 3%

dE/dx Resolution



dE/dx Resolution scan vs track length resolution

dN/dx Resolution



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

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

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

Drift chamber

(Additional wrt RD_FCC) Funding

➢ Eurizon (closed in January 2024), FEST to allow collaboration with IHEP

Effort to build a **international collaboration** enforced

➢ well established collaboration with **IHEP** for NN-based cluster counting algorithms

➢ started to collaborate with US colleagues from **BNL** (relevant contribution from them in July 2024 test beam!)

2025-2026 **plans**

➢ Test beams: **2023-2024 test beam data analysis**, 2025 test beam at **FNAL-MT6** with **π** and **K (βγ = 10–140)** → important to fully exploit the relativitic rise.

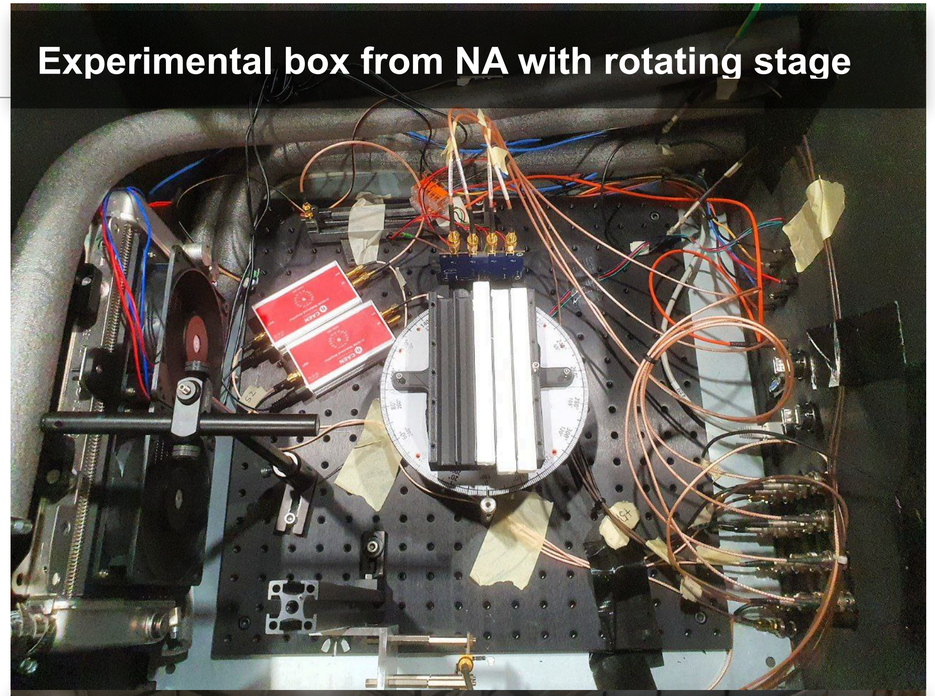
➢ DCH prototypes: activities to start the construction of a **full-scale prototype** → to test the chamber mechanical and electrostatic stability (a clean room is needed for wiring!), and a **small prototype** → to study the tracking performance

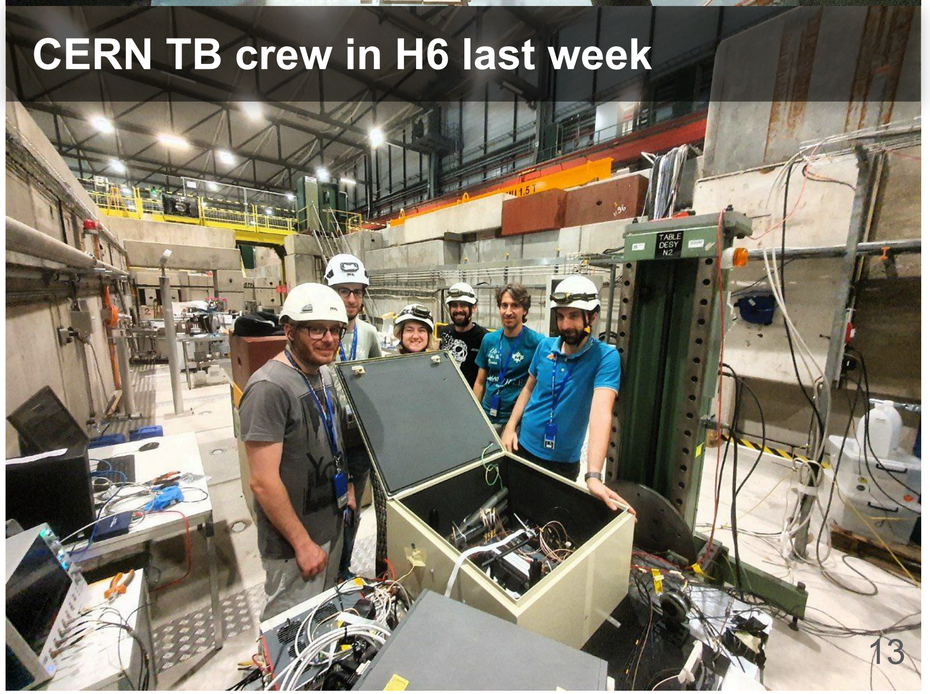
➢ **full simulation** (digi+ tracking algorithms) of the chamber

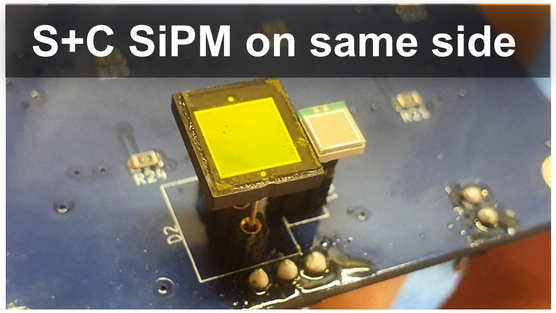
ECAL crystal calorimeter

Test beam at CERN (July 2024)

- Prepared and coordinated by Napoli (2 tecnici, 2 ricercatori, 3 PhD, 2 studenti) and MIB groups with participation from Perugia, US and CERN
- Tests with electrons (10-100 GeV), muons, hadrons
- Tested a variety of filters and crystals to assess Cherenkov yield as a function of beam angle
- **Plenty of useful data to steer the next R&D steps** and technological choices for the prototype construction → analysis is in progress!


Experimental box from NA with rotating stage


CERN TB crew in H6 last week

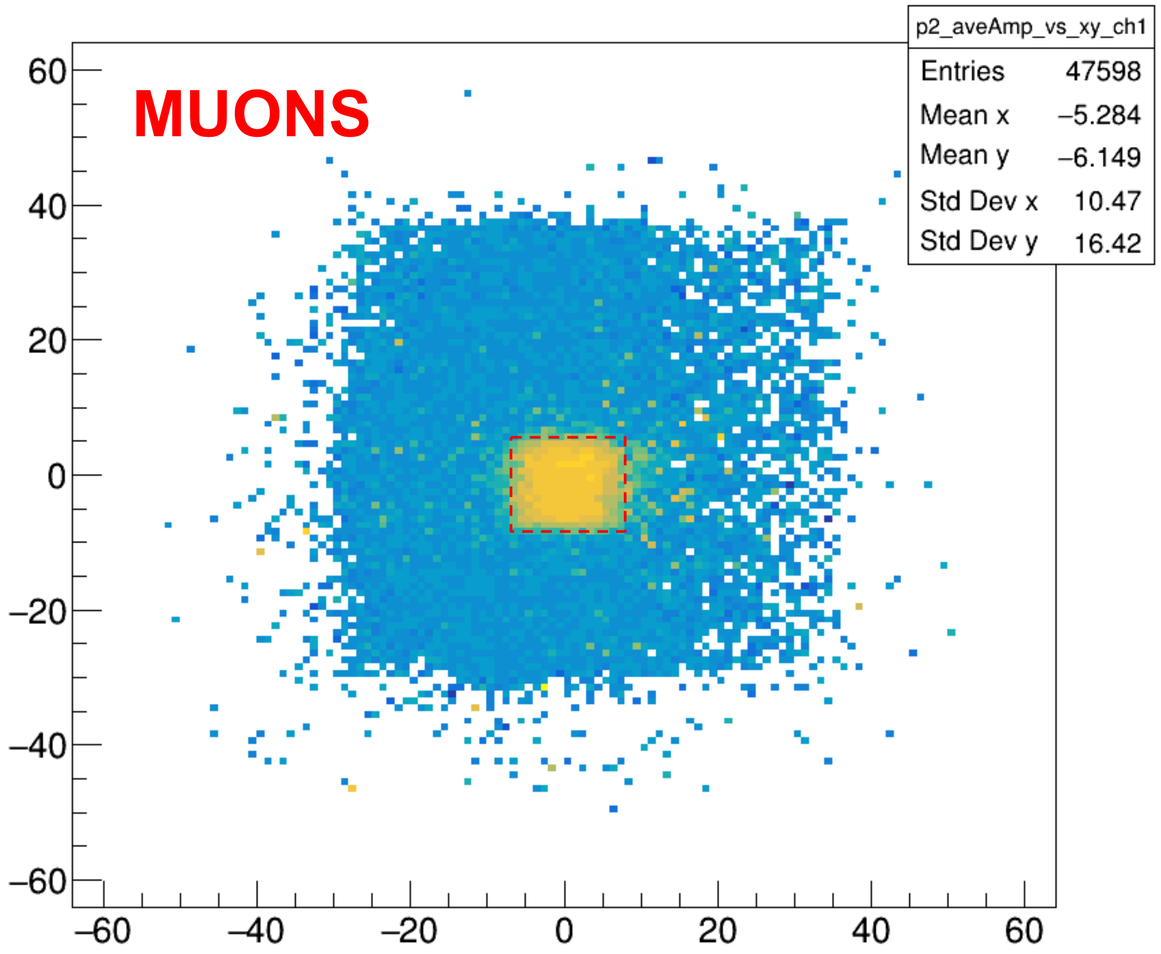

S+C SiPM on same side

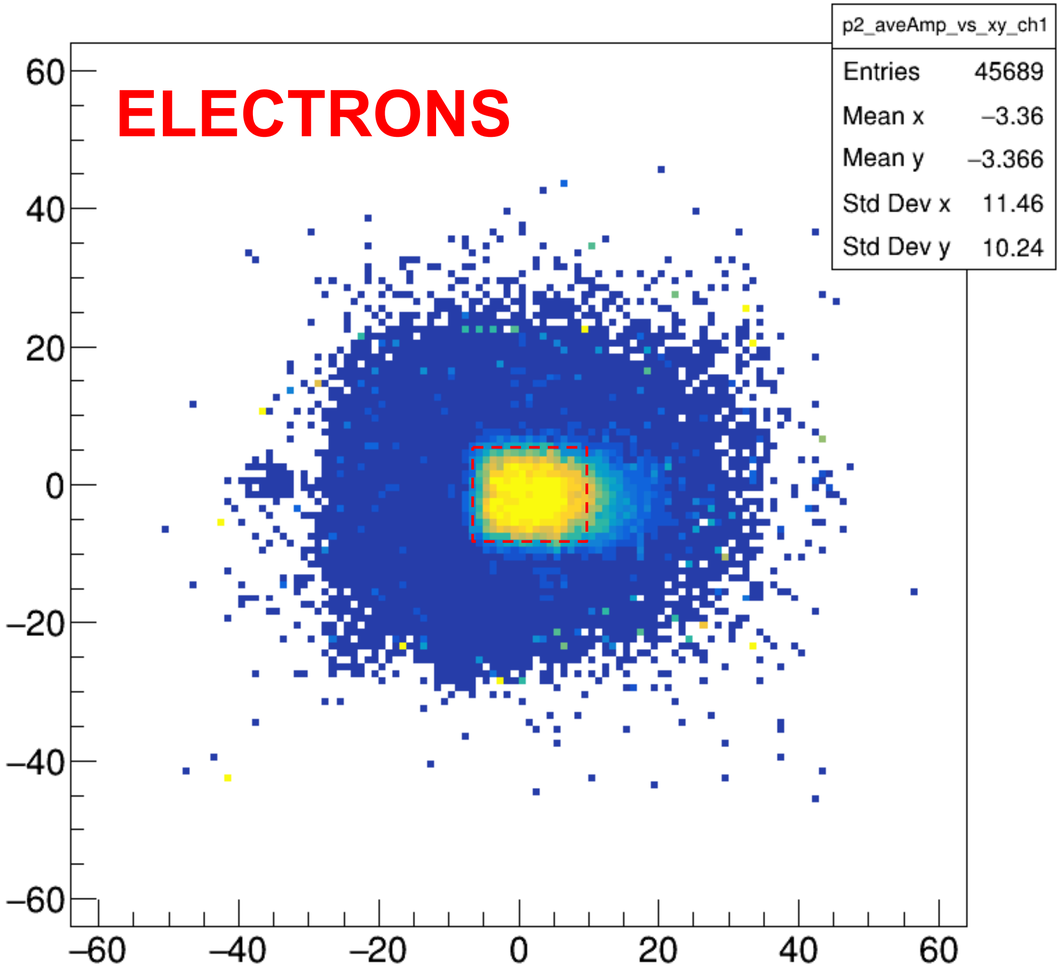

Ultrathin filters on Hamamatsu SiPMs

ECAL crystal calorimeter

Preliminary results from test beam

13x13x150 mm³ PWO with dual SiPM readout on rear side



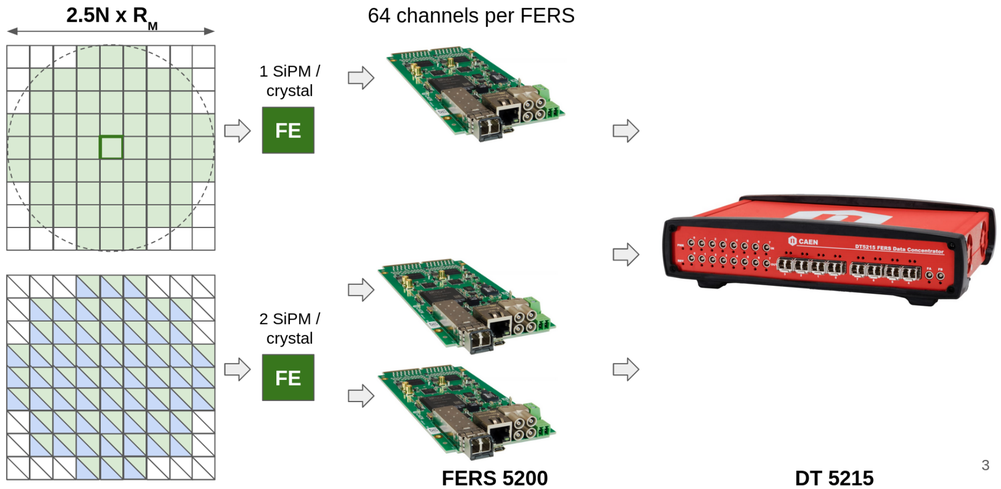


ECAL crystal calorimeter

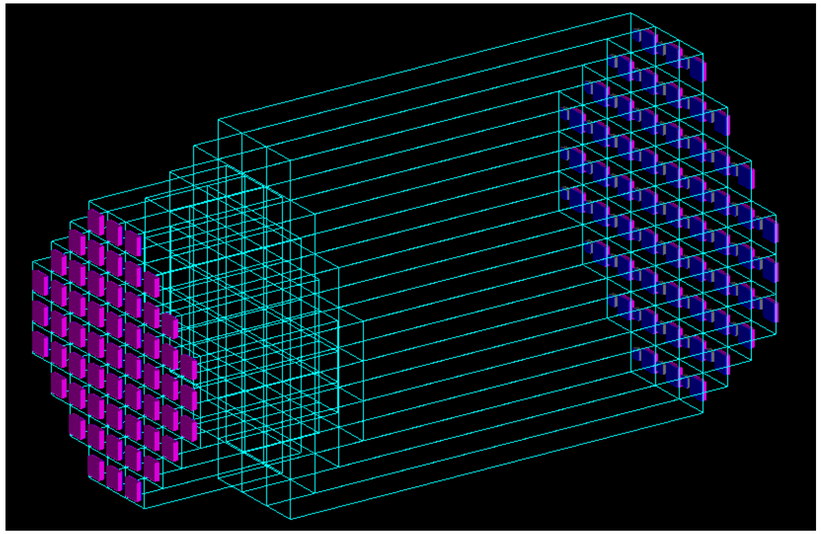
Towards a **multi-channel prototype** (2025-2026)

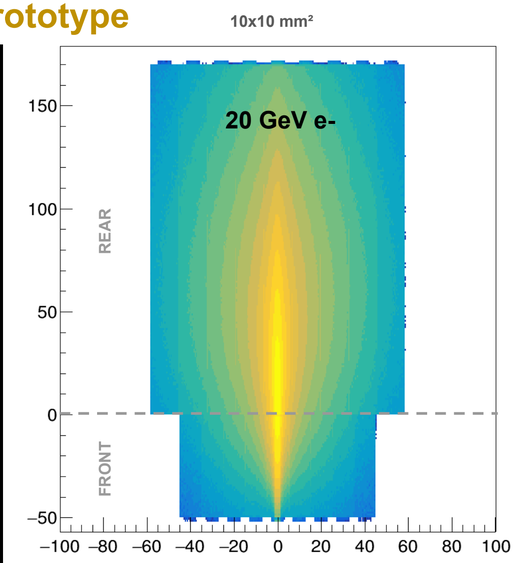
- 2024 lab and beam test results will inform the choice of a baseline technology to **build a full containment EM calorimeter prototype (~200 channels)**
- Procurement of electronics for readout started, procurement of crystals and SiPMs in early 2025 (informed by test beam results in 2024)
- **Test of the prototype on beam** at DESY or CERN in the second half of 2025 (possibly joint test with HIDRA fiber calorimeter prototype to anticipate beam shortage from 2026)

Prototype readout schematics



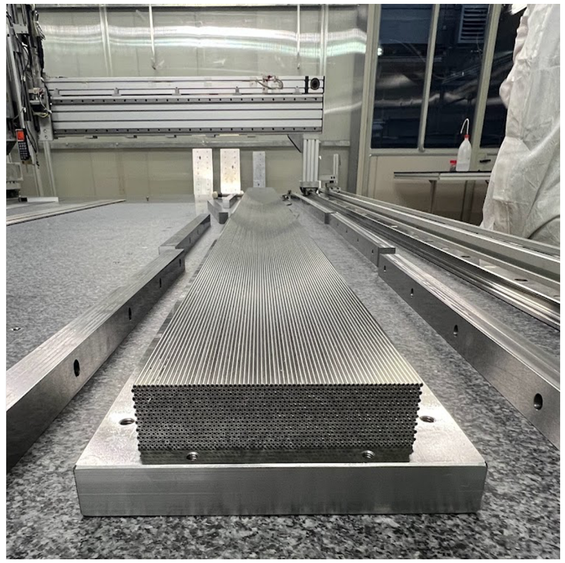
Geant4 simulation of prototype

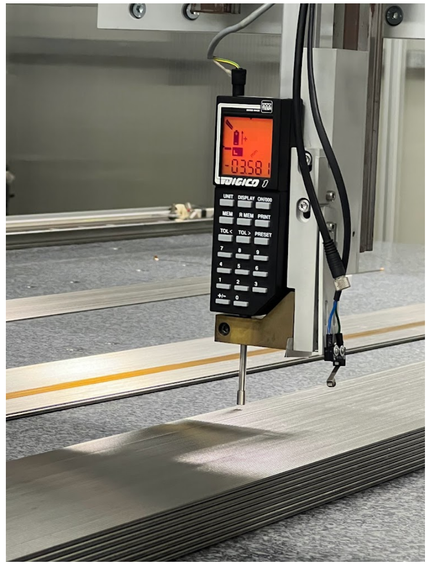




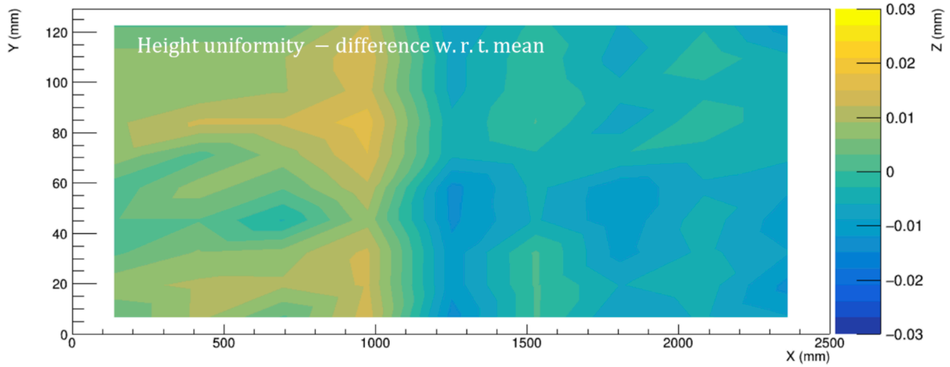
DR calorimeter

HiDRa construction on its way (~50%)





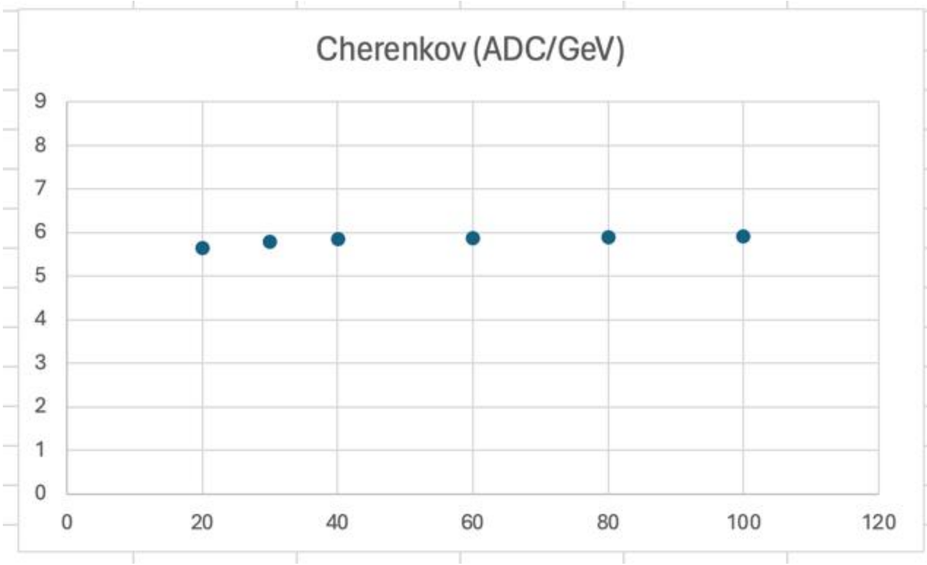
O(10 μm) precision on minimodule height (calor2024)

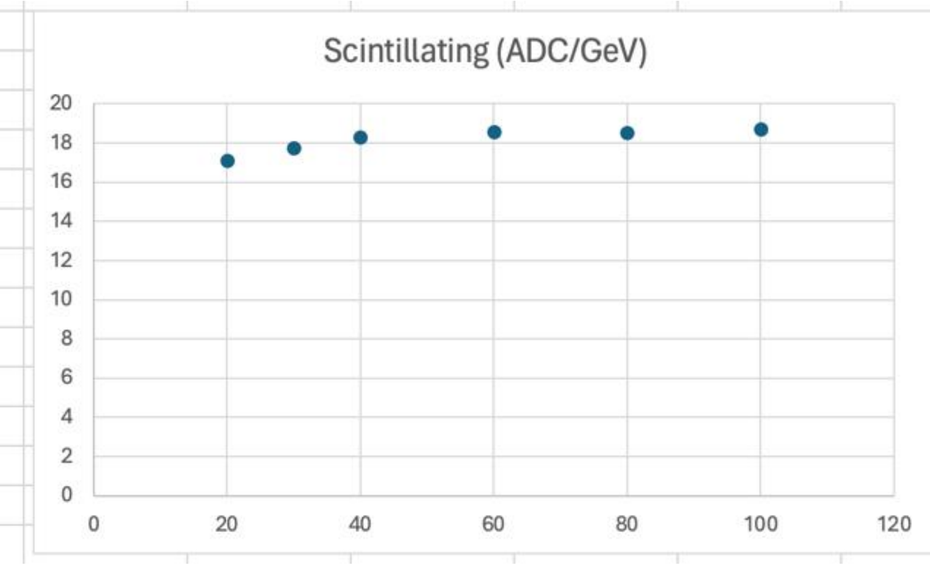


Excellent mechanical precision

Testbeam 2024 - done

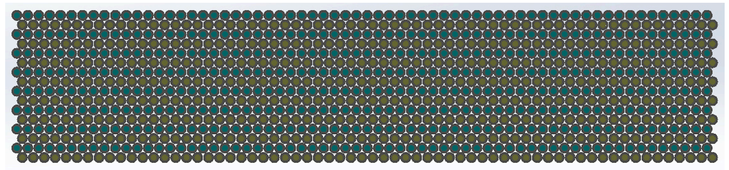
Very preliminary linearity (after quite some troubles):





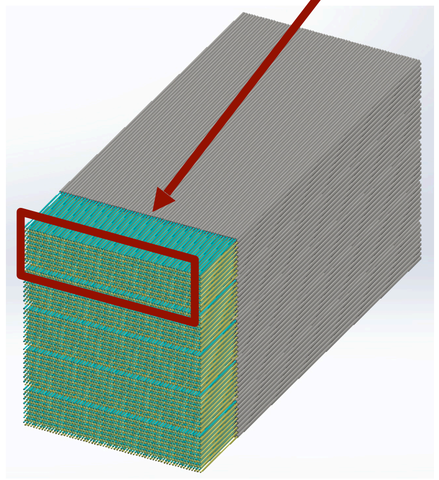
DR calorimeter: HiDRa layout

Minimodule



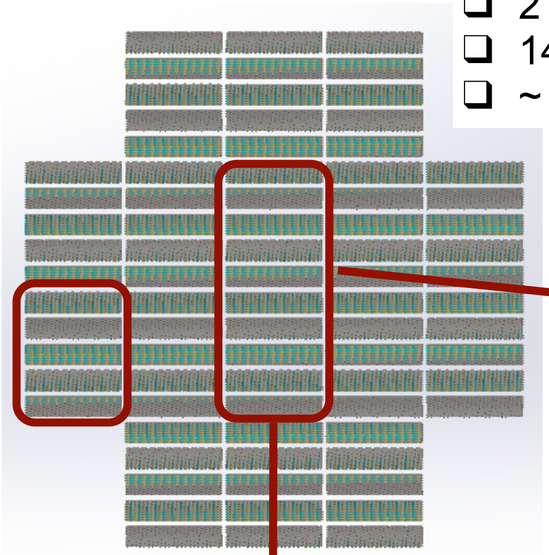
64 × 16 capillaries

Module



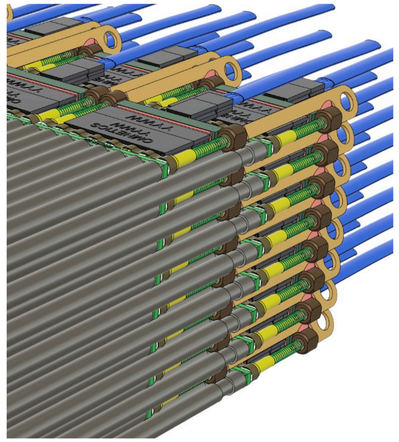
5 minimodules
~ 13 × 13 × 250 cm^3

HiDRa



- 16 modules in total
- 2 central modules w/ SiPMs
- 14 modules w/ PMTs
- ~ 65 × 65 × 250 cm^3

Highly granular modules



10240 SiPMs fitting detector back side

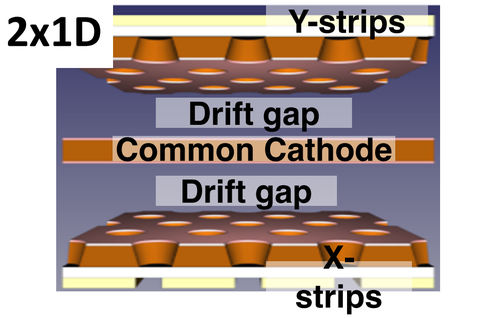
µRWell

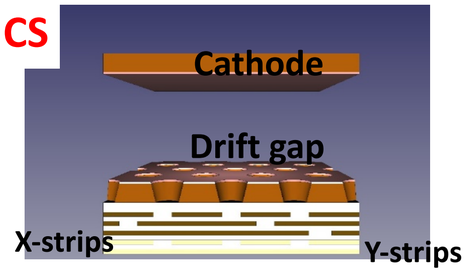
The results of TB-22-23, where the 2D layouts have been compared, giving the following results:

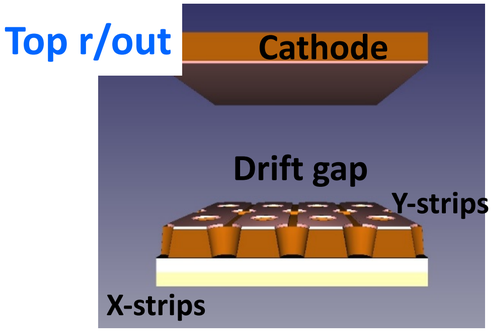
2x1D layout: spatial resolution < 200 µm (pitch 0.8 mm), low voltage operating point ~520V, efficiency ≥ 98% (large eff. plateau)

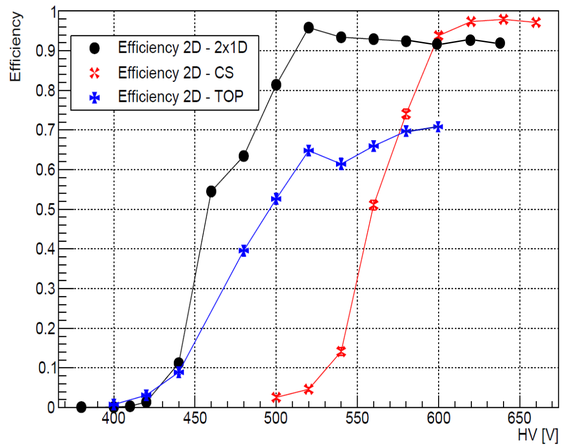
CS layout: spatial resolution < 200 µm (with pitch 1.2 mm), very high voltage operating point, ≥ 600V, efficiency ≥ 98%

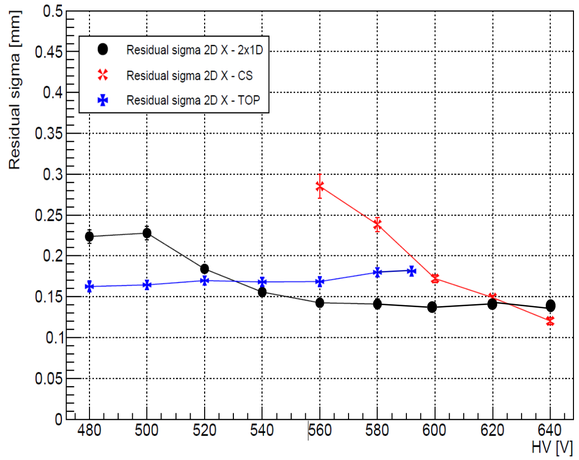
Top layout: spatial resolution < 200 µm (pitch 0.8 mm), low voltage operating point ~520V, efficiency ~ 70% (dead-zone)





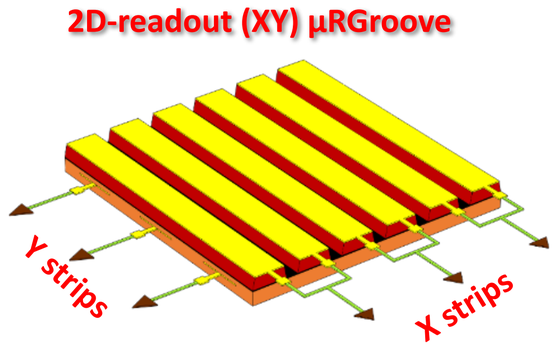


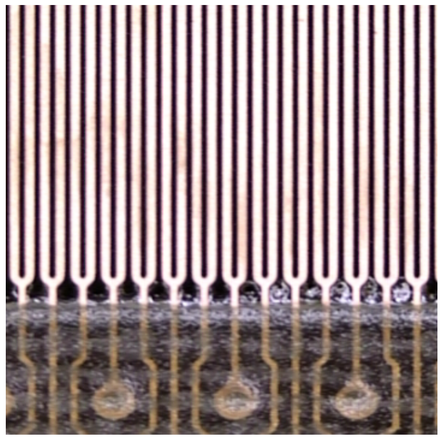




Detector solution & **program 2025**:

- **Hybrid CS with strip readout**→ CS + GEM pre-amplification stage, to lower the operating point, greatly improving the RWELL stability and maintaining high spatial performance with millimetric pitches
- **Micro-RGroove** → new layout, where the amplification stage is not based on the **«wells» but on the «grooves».** This facilitates the realization of the strip readout on the top, without introducing dead-zones (introduced by Z. Yi in RD51).



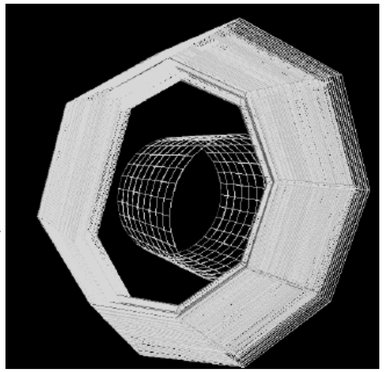


μRWell

Simulation

FULL IDEA DD4HEP IMPLEMENTATION

- The simple Muon System and Pre-shower have been included in the full IDEA DD4hep implementation.
- Current DR Calorimeter is still missed. A simple version has been implemented in order to study the **multiple scattering of muons.**



- The full implementation now is available on **k4geo**

READOUT SYSTEM

- Description of the readout is made for every single layer represents the system (segmentation in ϕ and θ direction).
- Chamber represents the 50 * 50 cm^2 the μRWELL
- The sensitive layer is the gas layer.

DIGITIZATION (ONGOING)

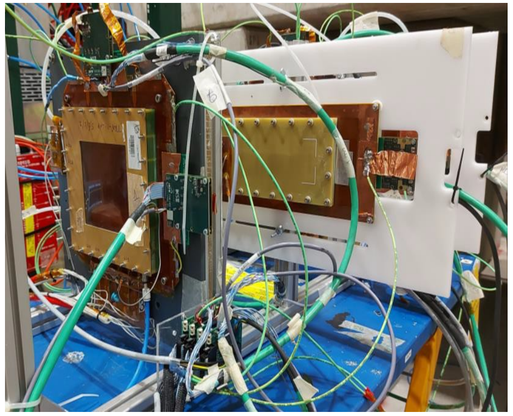
In order to convert the **SimHits** into **DigiHits**, some parameters have been implemented from the μRWELL test beam results:

- μRWELL efficiency: >95%., pre-shower candidate space resolution: ~ 100 μm, muon system candidate space resolution: ~ 400 μm

Front-end Electronics

TIGER/GEMROC Front-end electronics

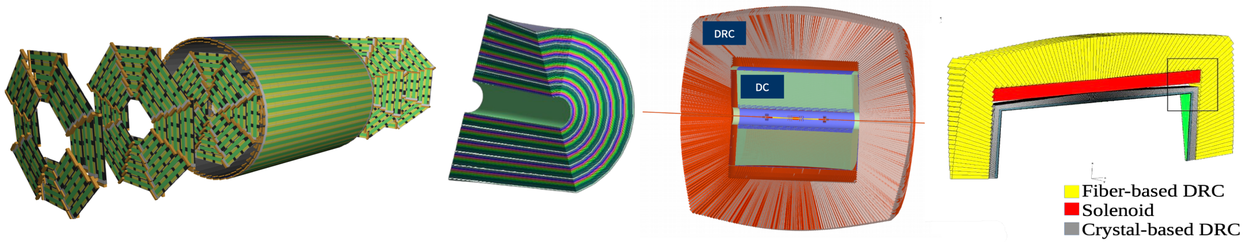
- Noise level very low (~1 fC)
- Input capacitance up to 100 pF
- TDC resolution < 50 ps
- Average gain ~ 10.75 mV/fc
- Maximum power consumption ~ 12 mW/ch



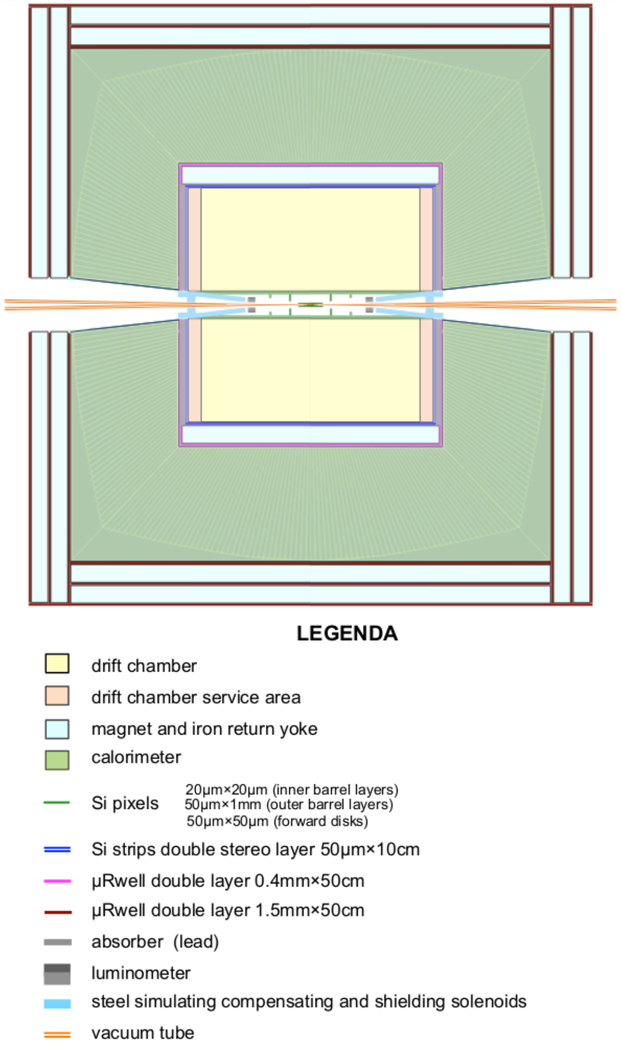
A TB has been performed @ SPS in July 2024. The data analysis of HV scan, Drift scan and Thr. scan, with Ar:CO_2:CF_4 is ongoing and will be finalized in the next month

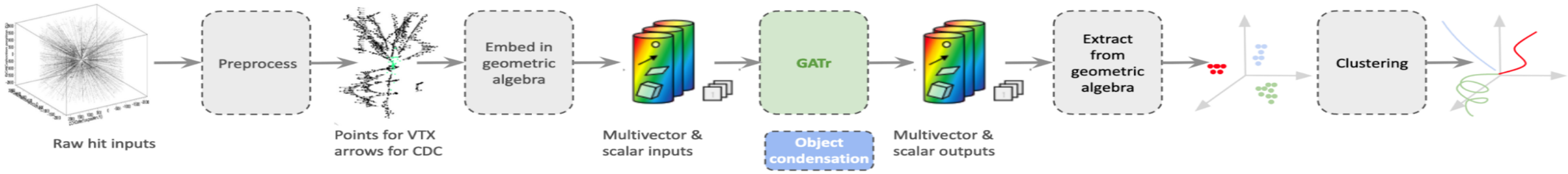
Software & Computing

- **Software** [BA, BO, PI, MIB, PD, PV, UD]
  - Realization of the description of IDEA concept sub-detectors': silicon (vertex+wrapper), drift chamber, calorimeters (ECAL crystal + DR Calo), muon detector (and pre-shower) in DD4HEP
    - Geometry
    - Simulation & Beam background studies



  - Initial development of Local & global Reconstruction & Performance studies → new track reconstruction effort is based on TFGG, a generalised geometric track finding approach to allow for more complex tracking detectors which involve multiple tracking technologies.





IDEA study group meetings

- IDEA has many activities as well as an extensive list of future plans
  - It becomes indispensable to have some regular meetings
  - Even more IMPORTANT to keep international colleagues informed
    - Propose to have monthly IDEA Study group meetings
      - Start in October
      - Invite
        - People who already collaborate with IDEA activities
        - People who expressed interest in collaborating with IDEA
        - Anybody who wants to be informed about IDEA activities and news
    - These meetings will be complementary to detector concepts meetings
      - Will regularly report to detector concepts meetings and PED
      - Are not proto-collaboration meetings

FCC Expression of Interests

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- **IDEA plans to prepare an EoI for each sub-detector:**

FCC Expression of Interests

- **IDEA plans to prepare an EoI for each sub-detector:**
  - **Vertex tracker**

FCC Expression of Interests

- **IDEA plans to prepare an EoI for each sub-detector:**
  - **Vertex tracker**
  - **Drift chamber**

FCC Expression of Interests

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  - **Vertex tracker**
  - **Drift chamber**
  - **Outer wrapper**

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  - **Superconducting Solenoid**

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  - **Muon detection system**

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- **An EoI of the IDEA detector concept**

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  - **Superconducting Solenoid**
  - **DR fibre calorimeter**
  - **Muon detection system**
- **An EoI of the IDEA detector concept**
  - **Strongly encourage international collaborators to participate and sign the EoI(s) of their interest**

Backup