THE IDEA DETECTOR

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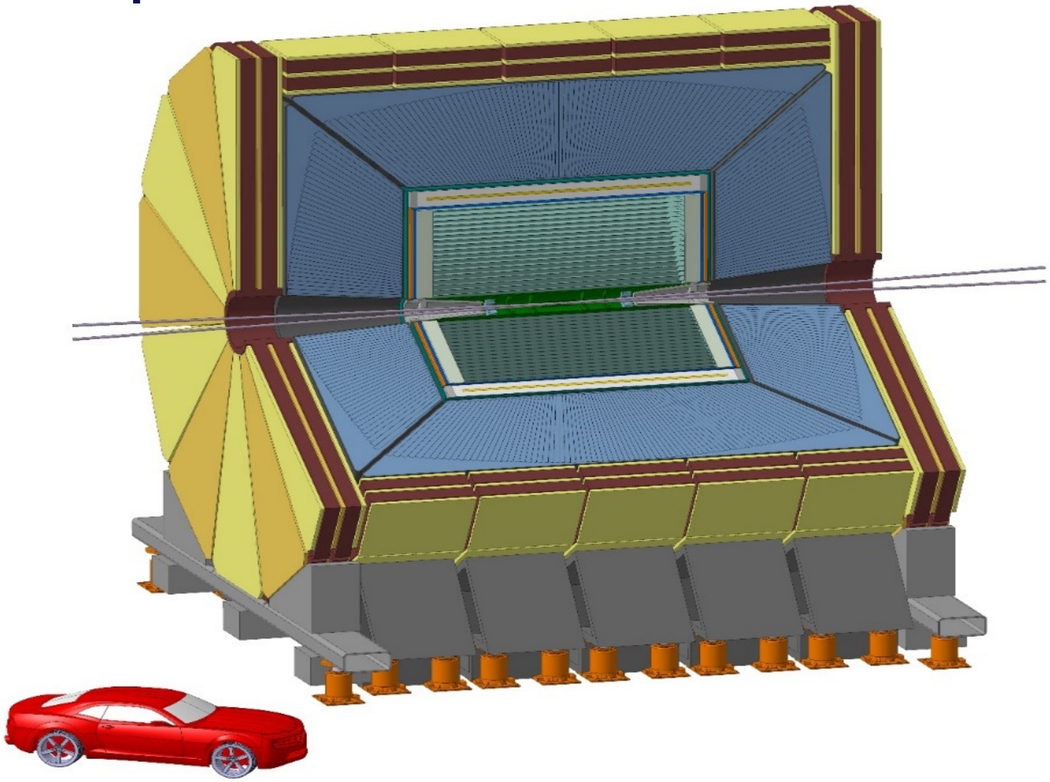
On behalf of the IDEA proto-collaboration

The IDEA detector concept

Innovative Detector for e^+e^- Accelerator

State-of-the-art detectors for exploiting the physics potential of the future circular e^+e^- collider

This is not necessarily the final detector choice for the real experiment



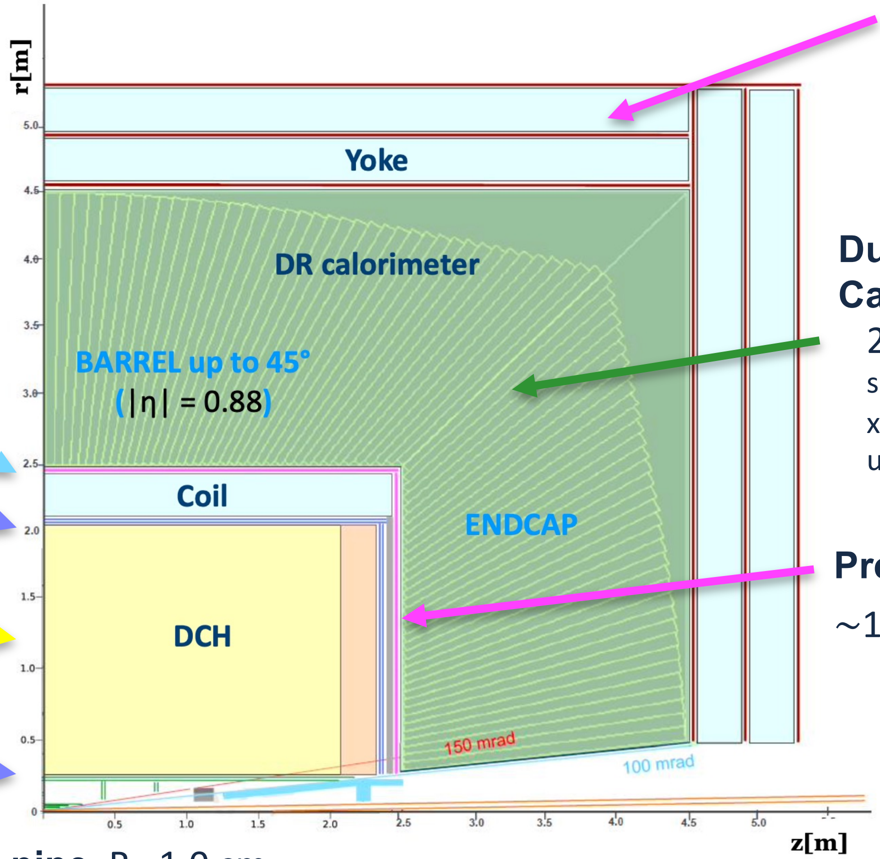
IDEA detector baseline layout

Superconducting solenoid coil:
2 T, R ~ 2.1-2.4 m
0.74 X_0, 0.16 λ @ 90°

Outer Silicon wrapper:
Si strips /LGAD options

Drift Chamber: 112 layers
4 m long, R = 35-200 cm

Vertex:
5 MAPS layers
R = 1.37-31.5 cm



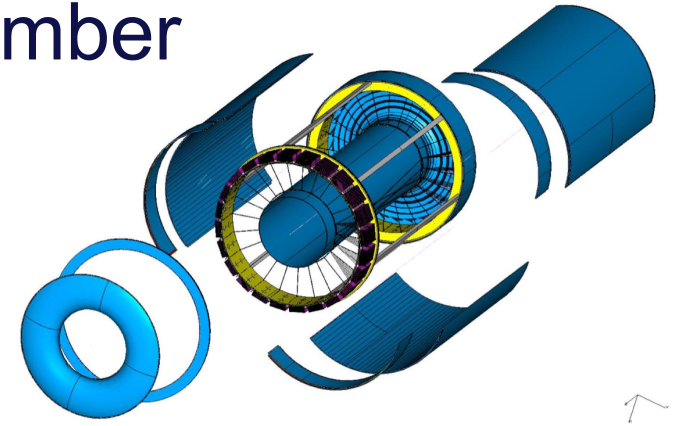
Yoke + Muon chambers

Dual-Readout Calorimeter:
2m / 7 λ_{int}
segmented option
xtal+fibres
under study

Preshower:
~1 X_0

Beam pipe: R~1.0 cm

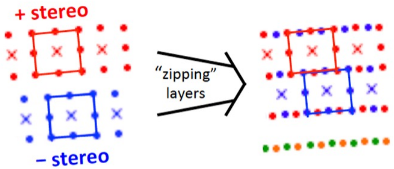
Extremely transparent Drift Chamber



Present design

All stereo wires (56448 cells, 343968 wires)
112 layers for each 15° azimuthal sector

Gas: 90% He – 10% iC4H10
Radius 0.35 – 2.00 m

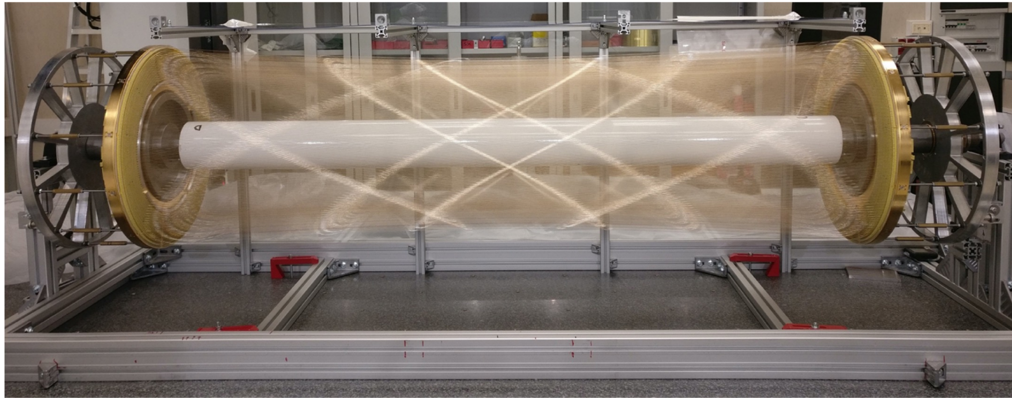


Total thickness: 1.6% of X_0 at 90°

- Tungsten wires dominant contribution

max drift time: 350 ns
σ_{xy} ~ 100 μm; σ_z < 1 mm

Based on MEG2 experience



Drift Chambers

Open challenges

Complete mapping of dN/dx data in all relevant background regions

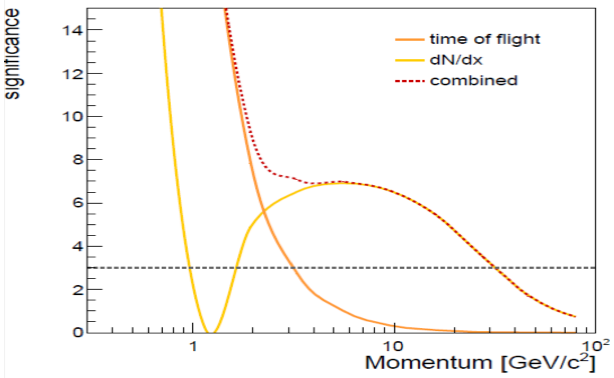
- Understand details of cluster counting performance

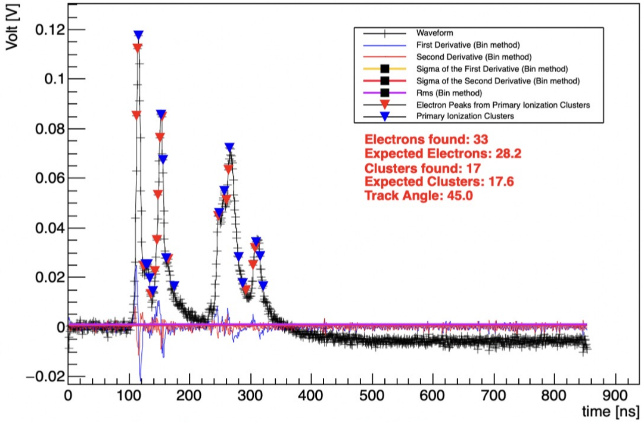
Build large mechanical prototype

- Inner radius R_{in} = 35 cm, outer radius R_{out} = 200 cm
- Mechanical deformation of the spokes (wire support) due to mechanical tension on wires

Build full length functioning prototype with few cells

Develop on-detector cluster counting electronics

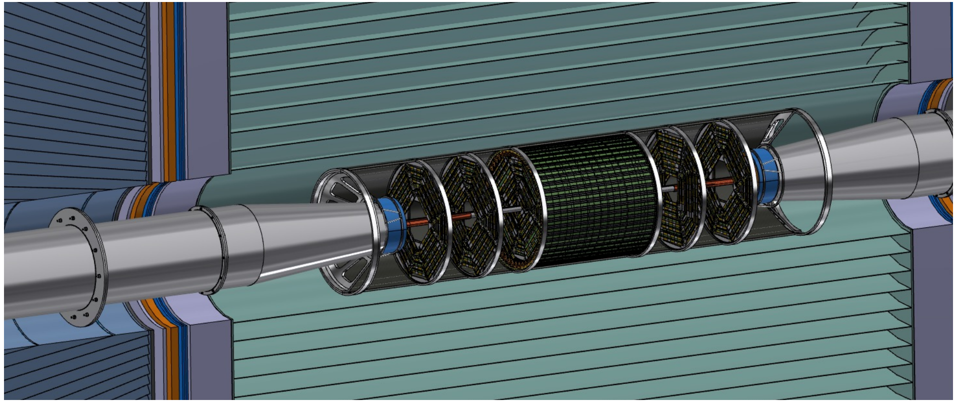




Sense Wire Diameter 10 um – Cell Size 1.0 cm – Track Angle 45° – 1.2 GSa/s – Gas Mixture He:IsoB 90/10 – 165 GeV

Vertex

The challenges



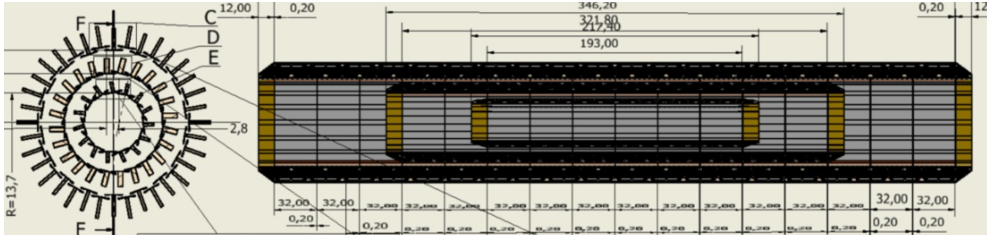
Keywords:

- lightweight
- low power consumption
  - cope with a 400 MHz/cm^2 estimated rate

Efforts ongoing at different levels

- Technology selection
  - Baseline option DMAPS
  - Alternative design:
    - based on curved MAPS for vertex
    - LGAD for timing information in the wrapper
- Vertex mechanical integration in the MDI (Machine Detector Interface)

Vertex technologies



Depleted Monolithic Active Pixel Detectors

3 Inner Vertex (ARCADIA based):

- Lfoundry 110 nm process
- *50 μm thick*
- Dimensions: $8.4 \times 32\ mm^2$
- Power density 30 mW/cm^2
- **100 MHz/cm^2**

Target high granularity
Low power consumption required
- compromise with time-resolution

Middle and Outer Vertex plus disks (ATLASPIX3 based):

- TSI 180 nm process
- *50 μm thick*
- Module dimensions: $42.2 \times 40.6\ mm^2$
- Power density 150 mW/cm^2
- **Up to 1.28 Gb/s downlink**

Precision points connecting vertex with Drift Chamber
Low-p_T tracking
Bunch-crossing ID

Vertex technologies: alternative

Curved and stitched MAPS

Proposed layout using an ALICE ITS3 inspired design

~0.05%X/X_0 material budget per layer

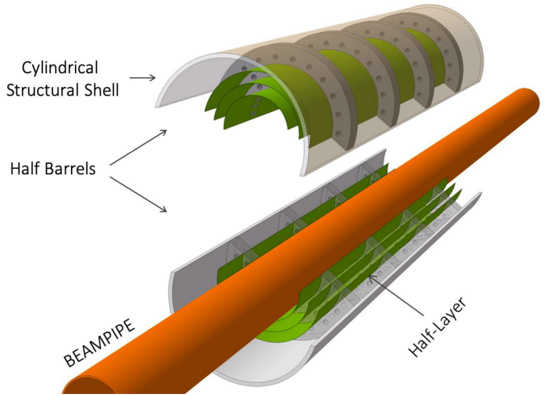
- 5 times less than the baseline option

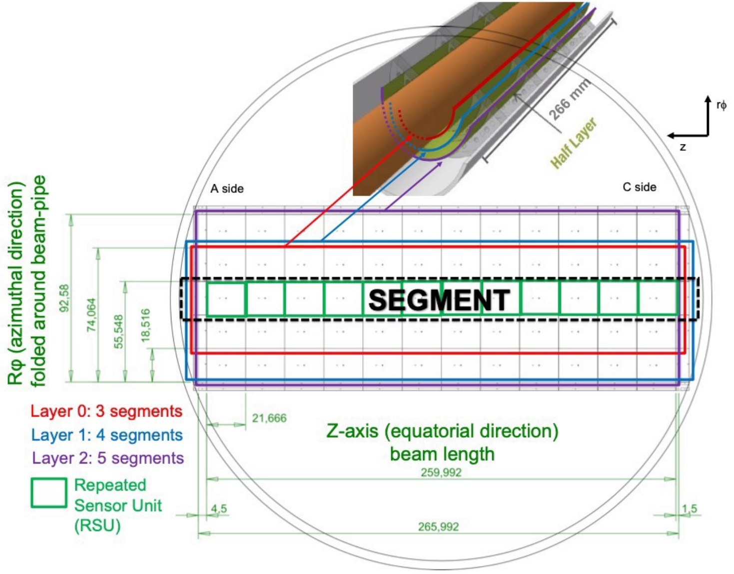
ALICE smaller radius will be 18 mm (beam pipe 16 mm)

- To demonstrate bent MAPS 13.7 mm radius works electrically – mechanically is OK

Active pixels <95% of covered area (chip service zones)

- Which impact has on physics?

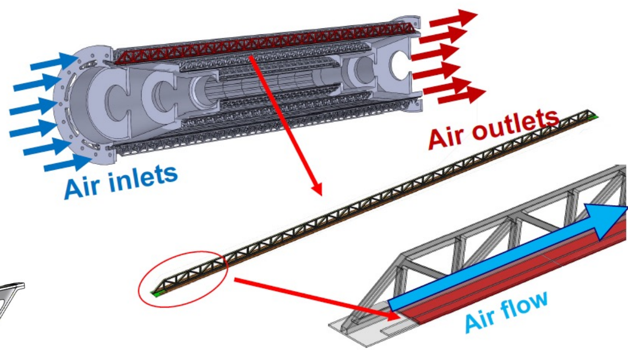


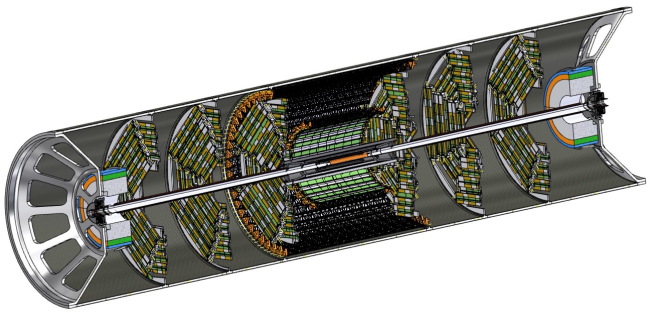


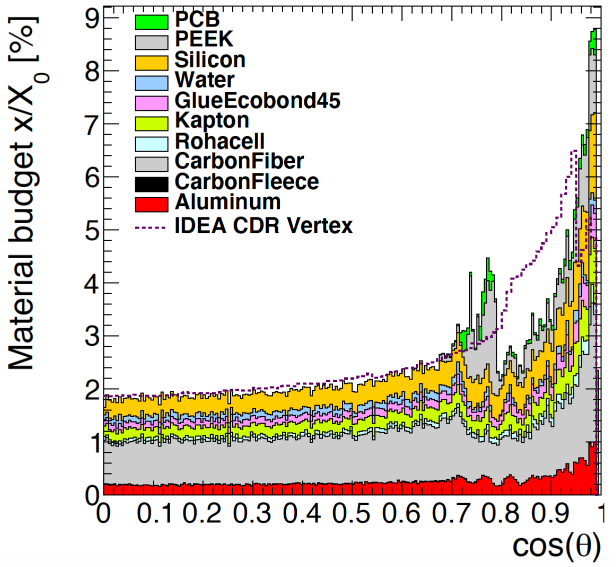
Vertex detector integration

- Interaction region detectors must be integrated with the beam pipe
- Must not interfere with the Luminosity Calorimeter
- Minimize power dissipation

Air cooling (simulations)







Minimize the radiation length

Smaller X/X_0 wrt IDEA CDR estimates even including power and readout cables in the sensitive region

Silicon only ~15% of the total

Silicon Wrapper

Baseline: DMAPS or Silicon Strip

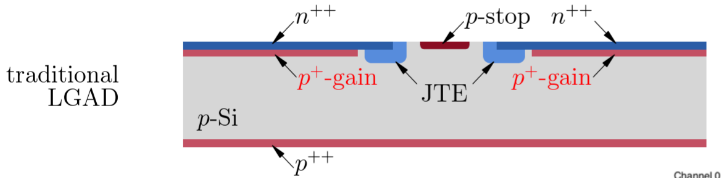
Alternative Options:
Resistive LGAD, which could provide optimal timing information in the wrapper outside the Drift Chamber

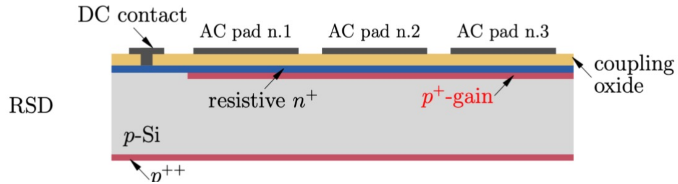
Working on cost reduction
Some "fast" prototypes already developed in Arcadia

Barrel Timing Layer with crystals also under evaluation (see later)

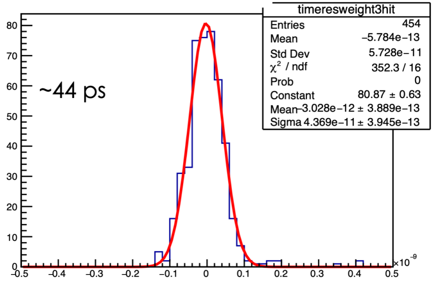
Improve momentum resolution
Extend tracking coverage
It may provide TOF measurements for PID

- Complementary to the dN/dx Drift Chamber measurement
- LLP measurements





100 - 200



Vertex and Detector R&D

Synergies with ongoing experiment development: Belle2, ALICE, FCC-ee, EIC

Recent Mini-Workshop of the Italian community https://agenda.infn.it/event/40905/

Challenges focused on system implementation more than on sensor development

- power supply distribution, cooling, data flow, readout architecture, ...
- relevant international framework DRD7 (electronics) and DRD8 (mechanics and integration) more than DRD3 (solid state detectors)

Both calorimeters are projects in DRD6 and supported by an international collaborations

Dual-readout calorimeter(s)

Measure simultaneously:
- Scintillation signal (S)
- Cherenkov signal (C)

Calibrate both signals with e^-
Unfold event-by-event f_{em} to obtain corrected energy

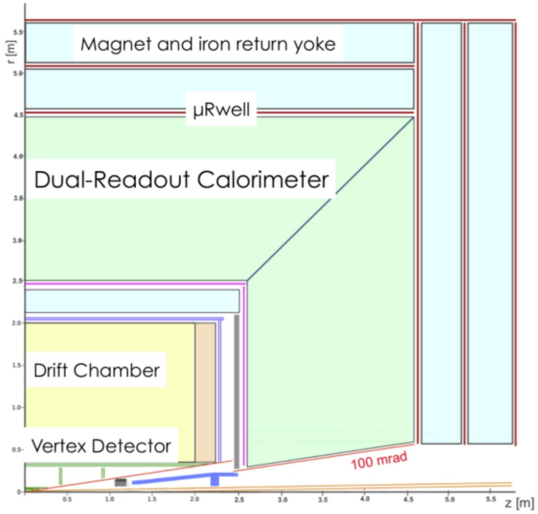
$$S = E[f_{em} + (h/e)_S(1 - f_{em})]$$

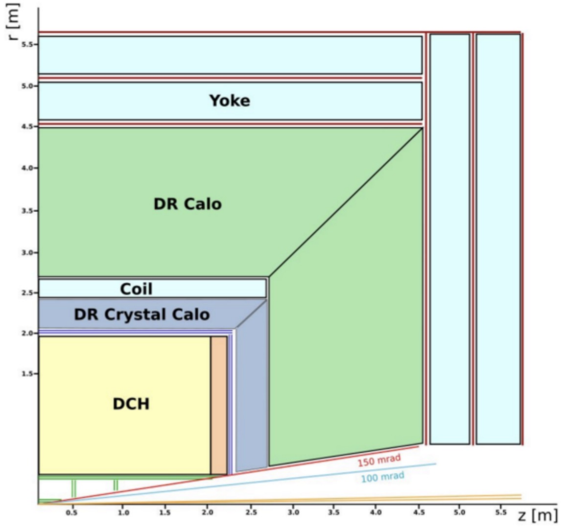
$$C = E[f_{em} + (h/e)_C(1 - f_{em})]$$

$$E = \frac{S - \chi C}{1 - \chi} \quad \text{with:} \quad \chi = \frac{1 - (h/e)_S}{1 - (h/e)_C}$$

Currently 2 options under study:

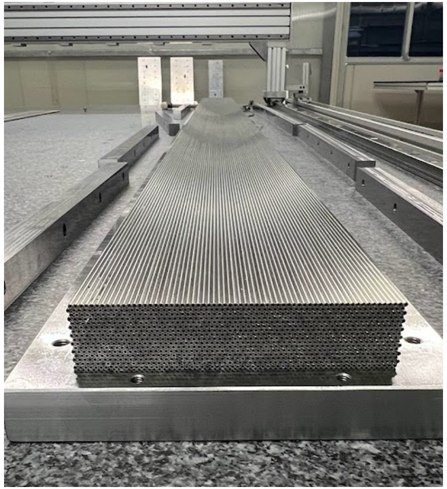
- Longitudinal unsegmented dual-readout fibre calorimeter (combined EM+HAD)
- Dual-readout crystal (EM calo) + dual-readout fibre calorimeter (HAD calo)



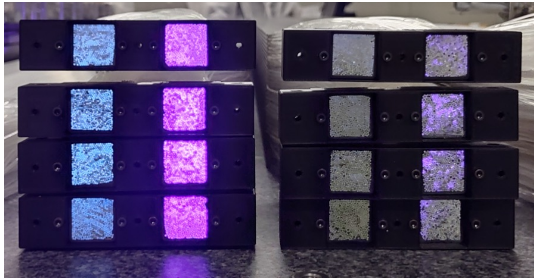


Dual-Readout Fibre Calorimeter

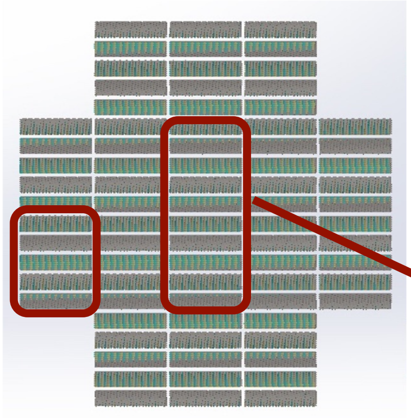
Full containment unsegmented fibre prototype under construction (Call CSN5 HiDRa)



New construction technique base on capillary stainless-steel tubes, arranged in modules.
Full containment prototype, 60x60x250 cm^3
High granular core + PMT surrounding readout



PMT-based readout for surrounding modules



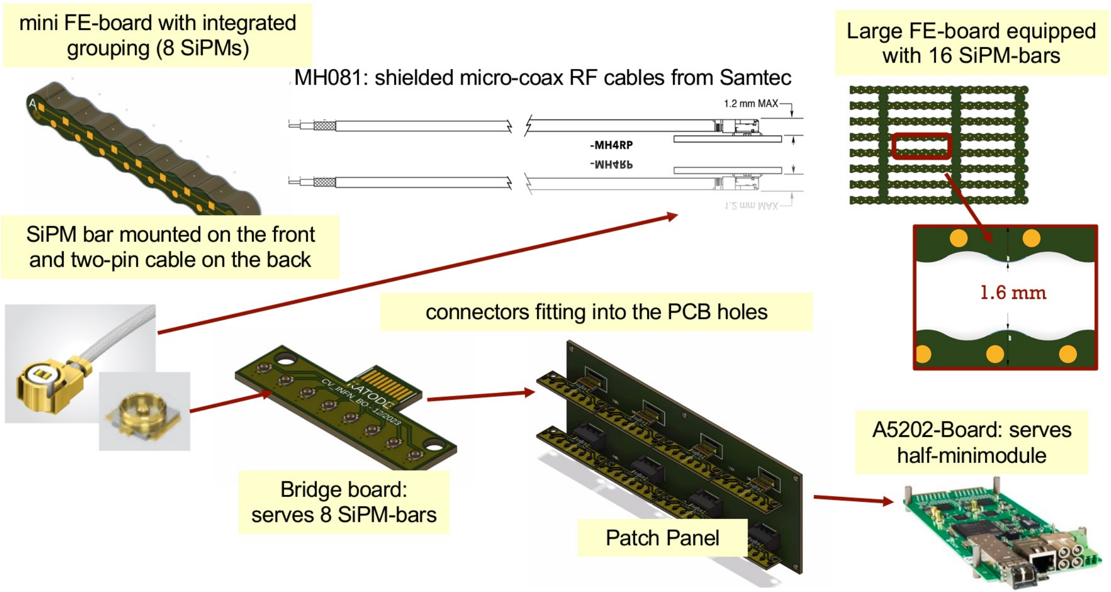
10 µm SiPM for Scintillation (optimise dynamic range)

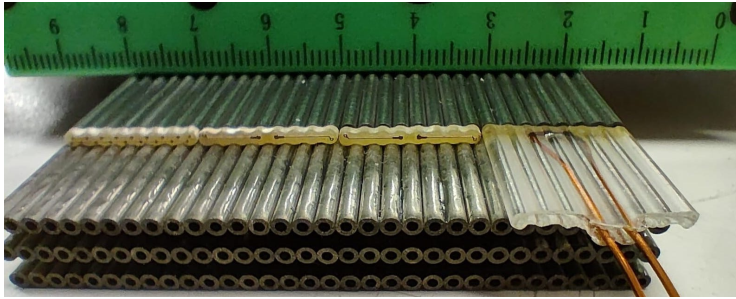
15 µm SiPM for Cherenkov (optimise PDE)

The highly granular modules: 1 fiber-1 SiPM

Dual-Readout Fibre Calorimeter

Scalable SiPM readout





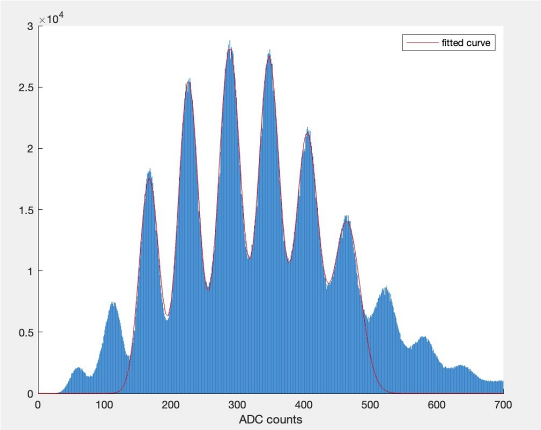
Hamamatsu SIPM already mounted on custom 8-SiPM board

Grouping board, cabling connection, interface to readout boards: all custom designed

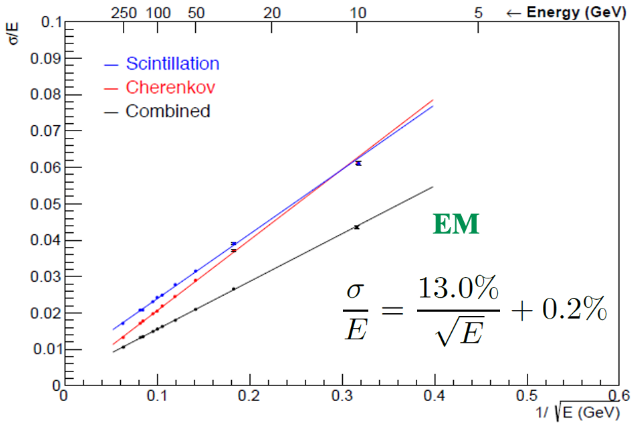
High density channels

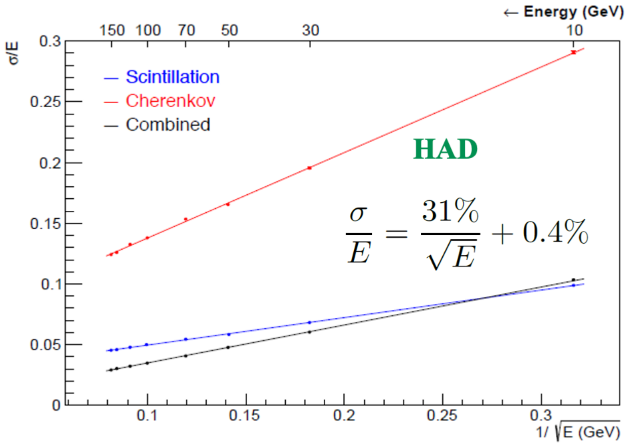
Dual-Readout Fibre Calorimeter

Detector Performance



Full simulation in Geant4 to study all the HW and readout effects (e.g. grouping)
SiPM calibration is a delicate item, due to analogic sum of the channels
ML approach to extract as much information as possible



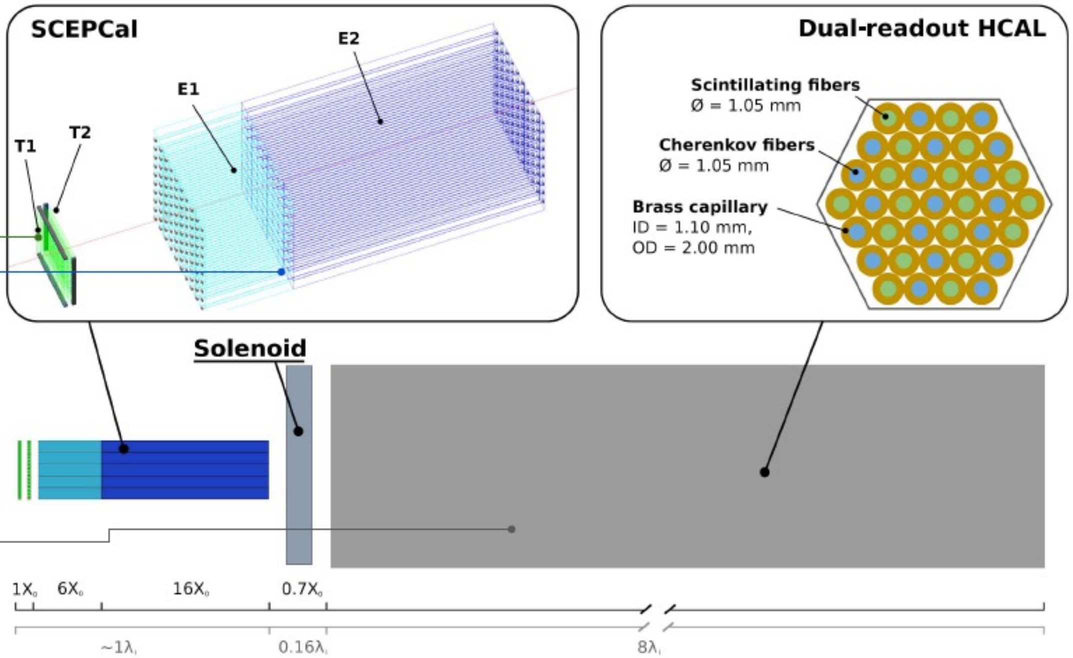


Crystal ECAL with DR calorimeter

Layout overview

- **Transverse and longitudinal segmentations** optimized for particle identification and particle flow algorithms
- Exploiting **SiPM readout** for contained cost and power budget

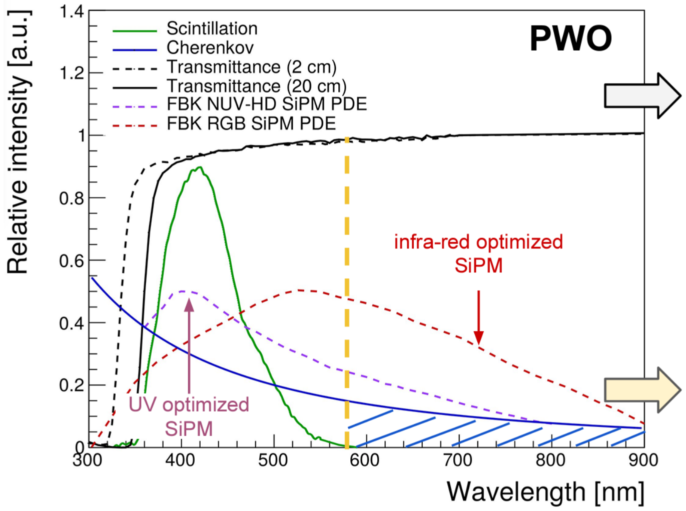
- **Timing layers** — $\sigma_t \sim 20$ ps
  - LYSO:Ce crystals (~$1X_0$)
  - 3x3x60 mm³ active cell
  - 3x3 mm² SiPMs (15-20 um)
- **ECAL layers** — $\sigma^{EM}_E/E \sim 3\%/\sqrt{E}$
  - PWO crystals
  - Front segment (~$6X_0$)
  - Rear segment (~$16X_0$)
  - 10x10x200 mm³ crystal
  - 5x5 mm² SiPMs (10-15 um)
- **Ultra-thin IDEA solenoid**
  - ~$0.7X_0$
- **HCAL layer** — $\sigma^{HAD}_E/E \sim 26\%/\sqrt{E}$
  - Scintillating and "clear" PMMA fibers (for Cherenkov signal) inserted inside brass capillaries



Crystal ECAL with DR calorimeter

Challenges:

Need to separate scintillation and Cherenkov signals from the same media



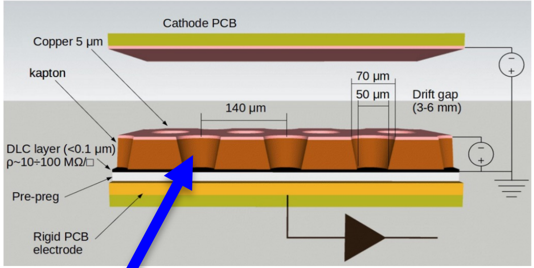
Estimated:
- >2000 phe/GeV for scintillation photons [dyn. range: 100-120,000 phe]
- >100 phe/GeV for Cherenkov photons [dyn. range: 10-10,000 phe]

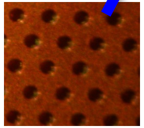
Cherenkov photons above scintillation peak are much less affected by elf-absorption

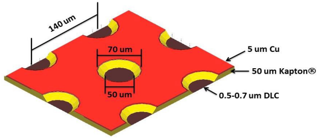
- **Light yield**: demonstrate that enough scintillation and Cherenkov photons can be read-out from the same (rear) crystal
- **Signal purity**: demonstrate contamination of scintillation light to Cherenkov signal < 20%
- **Dynamic range**: demonstrate sufficient linearity and dynamic range with SiPM

Preshower and Muon detectors

Based on μ-RWELL technology







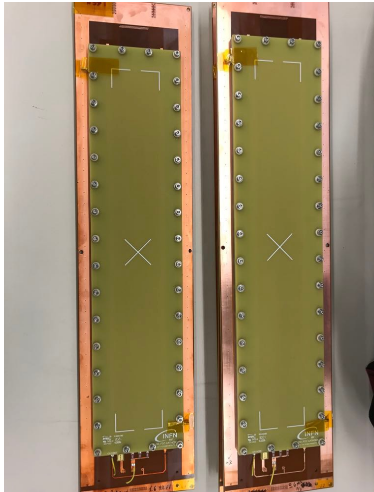
Preshower:

- High resolution after the magnet to improve $\pi^{\pm}/e^{\pm}$ and 2γ separation
- Space Resolution < 100 μm
- pitch = 0.4 mm
- 1.3 million channels

Muon detector:

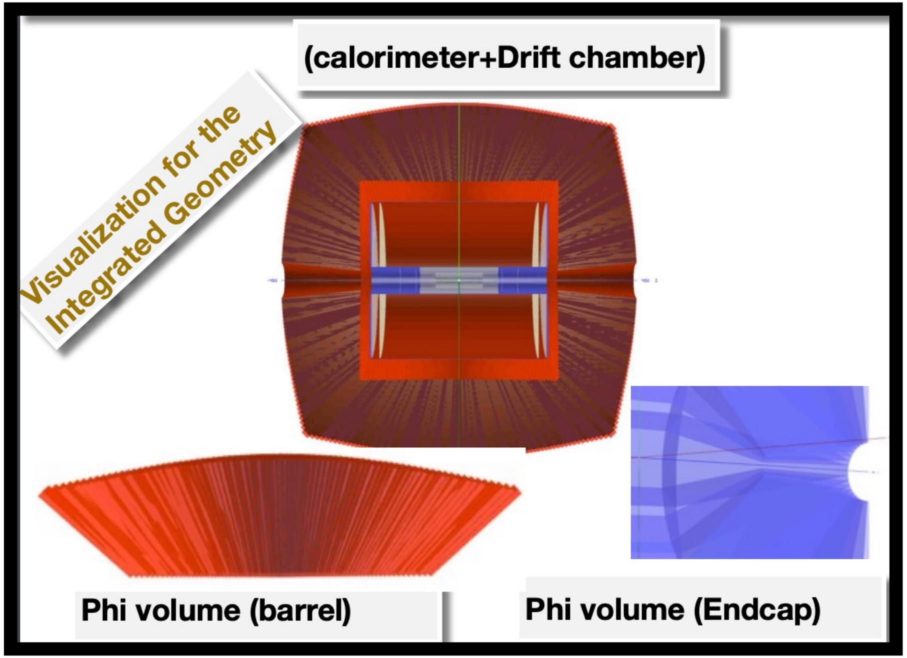
- Identify muons and search for LLPs
- Space resolution < 400 μm
- pitch = 1.2 mm
- 5 million channels

Ongoing development
- Mass production
- Optimization of FEE channels/cost
- 50x50 cm² 2D tiles to cover more than 1650 m²



New μ-RWELL prototypes with 40 cm long strips

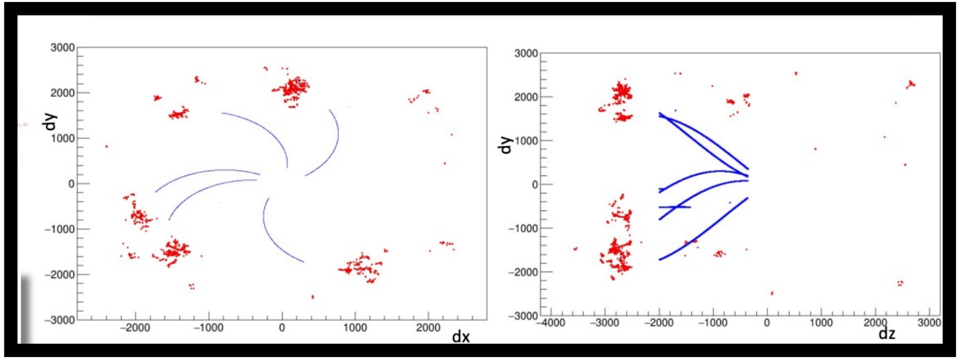
Status of Simulation of IDEA concept



FASTSIM Delphes IDEA card used for performance studies FCCSW

Very sophisticated compared to default.

Latest additions: Vertexing, LLP, PID, dN/dx, dE/dx



FULLSIM: standalone GEANT4 description

- **Fully integrated geometry**
- **Output hits and reco tracks converted to EDM4HEP**
- **Ready for PFlow development and other reconstruction frameworks/algorithms (ACTS, Pandora etc) in FCCSW**

Outlook

Large effort, especially in Italian community
International collaborations on different detectors development already in place

Impressive progress on both detector and software studies shown at Mid-Term feasibility study ....

These projects have received funding from the European Union's Horizon Europe Research and Innovation programme under Grant Agreements No. 101004761 (AIDAinnova), 101057511 (EURO-LABS).

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Impressive progress on both detector and software studies shown at Mid-Term feasibility study ....

... but a lot of work still ahead to be accomplished

New groups ...
...new ideas...
... more expertise ...
are more than welcome

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