



ALLEGRO detector concept for FCC-ee



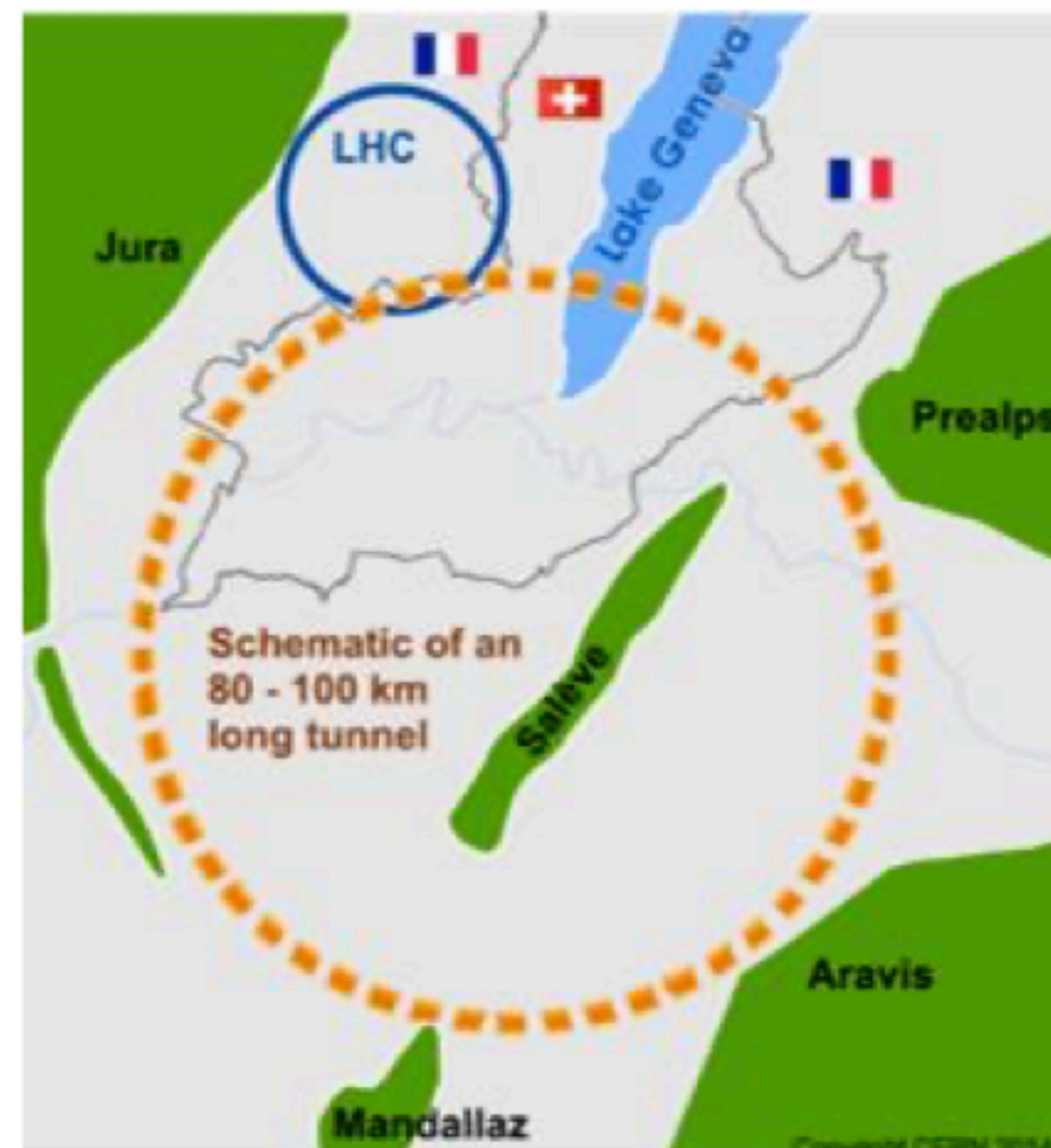
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CZ+SK HEP Workshop 2026

11.9.2026

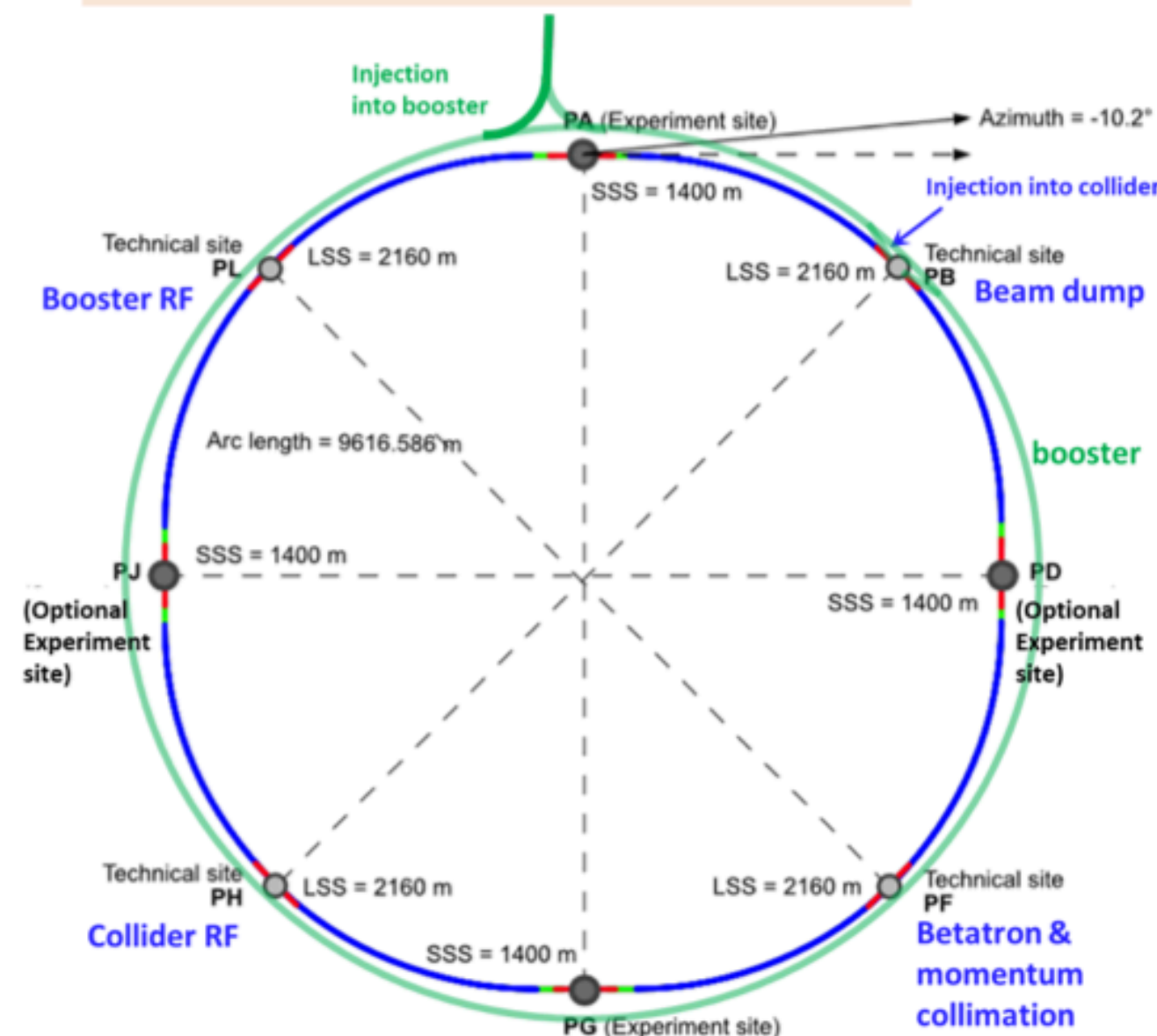
Future Circular Collider

- Ambitious two-stage accelerator programme, next flagship programme at CERN
- 91km ring, 300m below Geneva, under the lake and around Saleve mountain
- Two storage rings: collider and booster, LINAC as pre-accelerator
- FCC-ee project recommended by European Strategy for Particle Physics



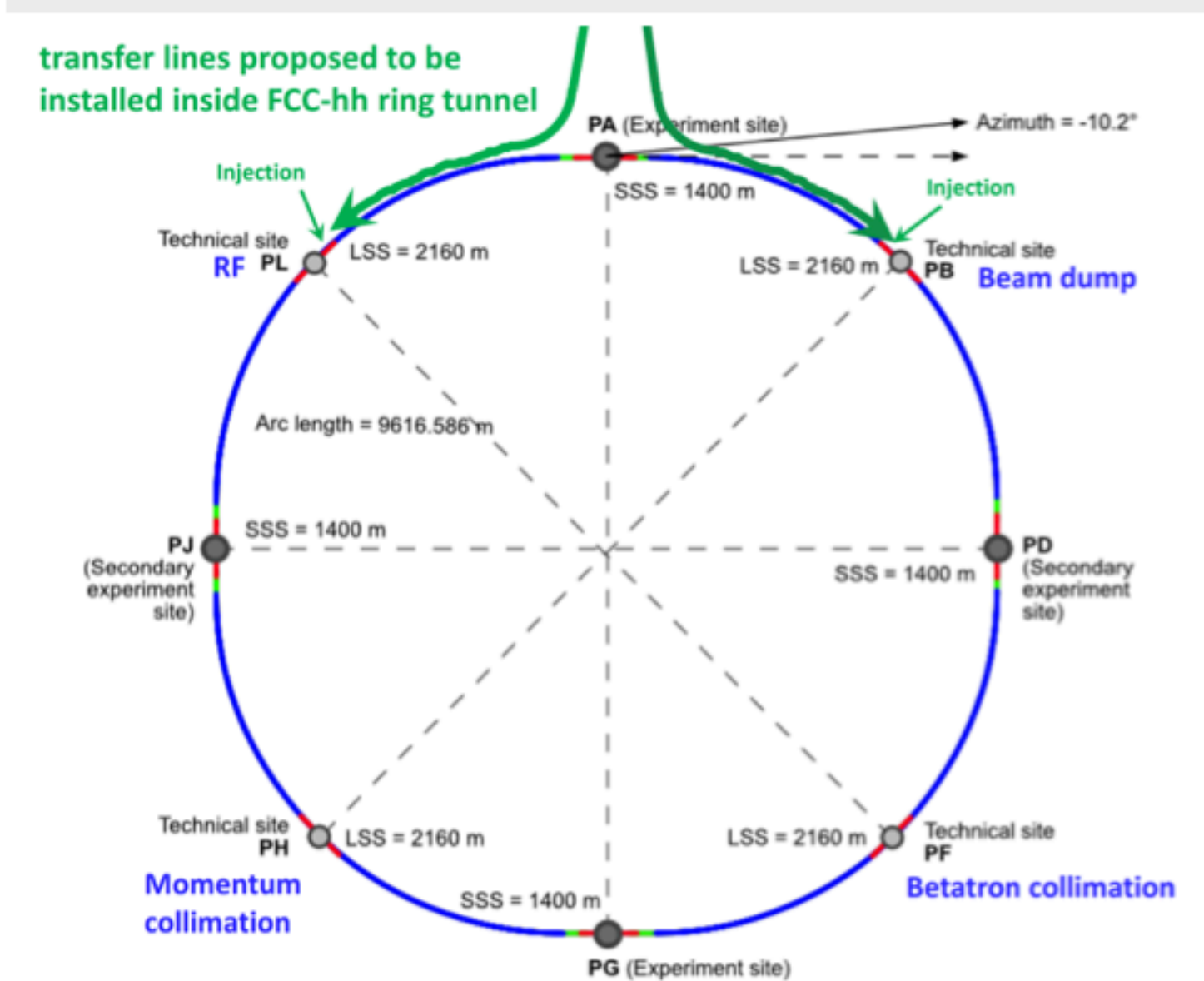
2020 - 2040

FCC-ee at Z, WW, ZH and tt



2045 - 2060

FCC-hh at 80-116 TeV, depending on magnet technology (Nb_3SN vs HTS)

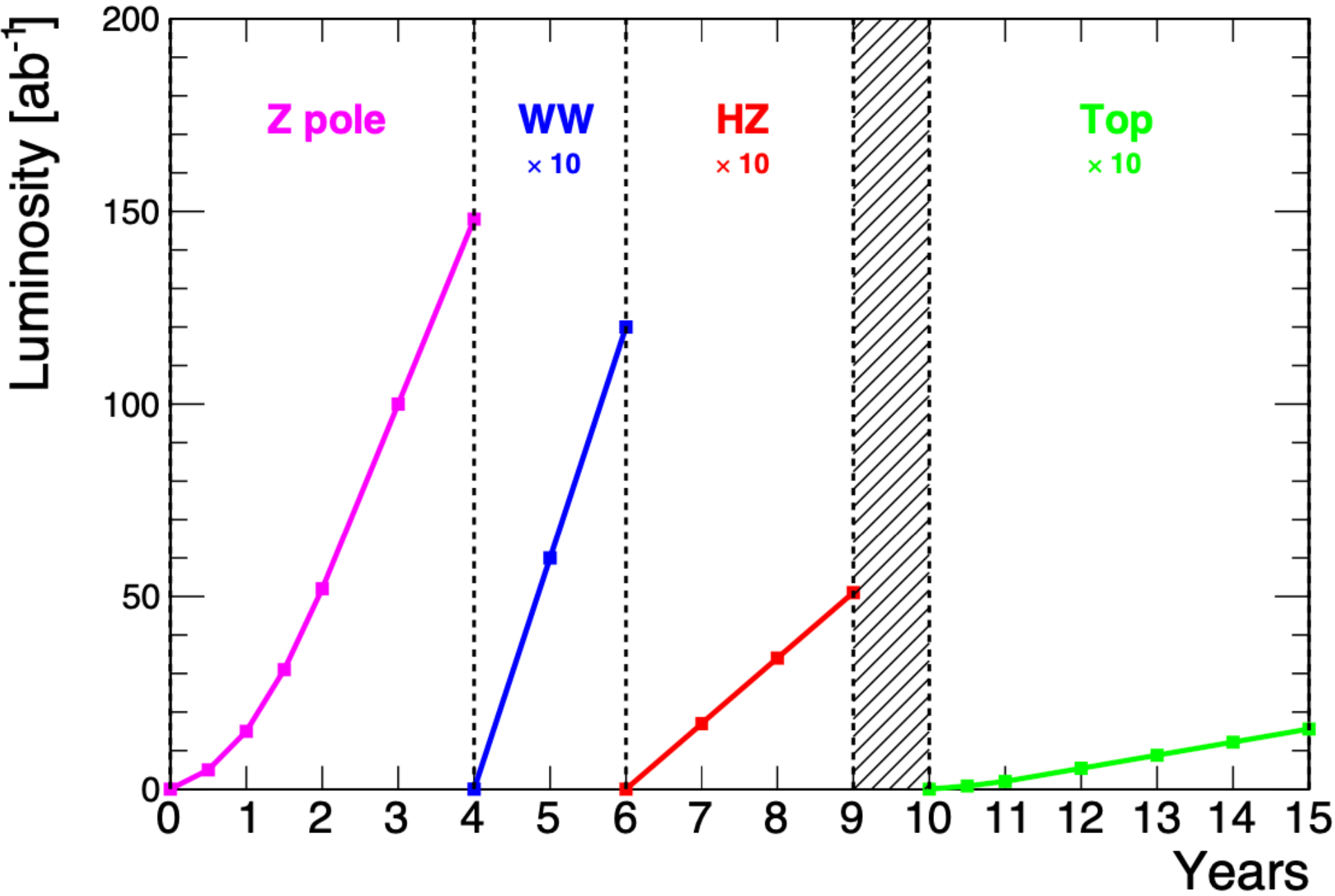


2065 - 2090

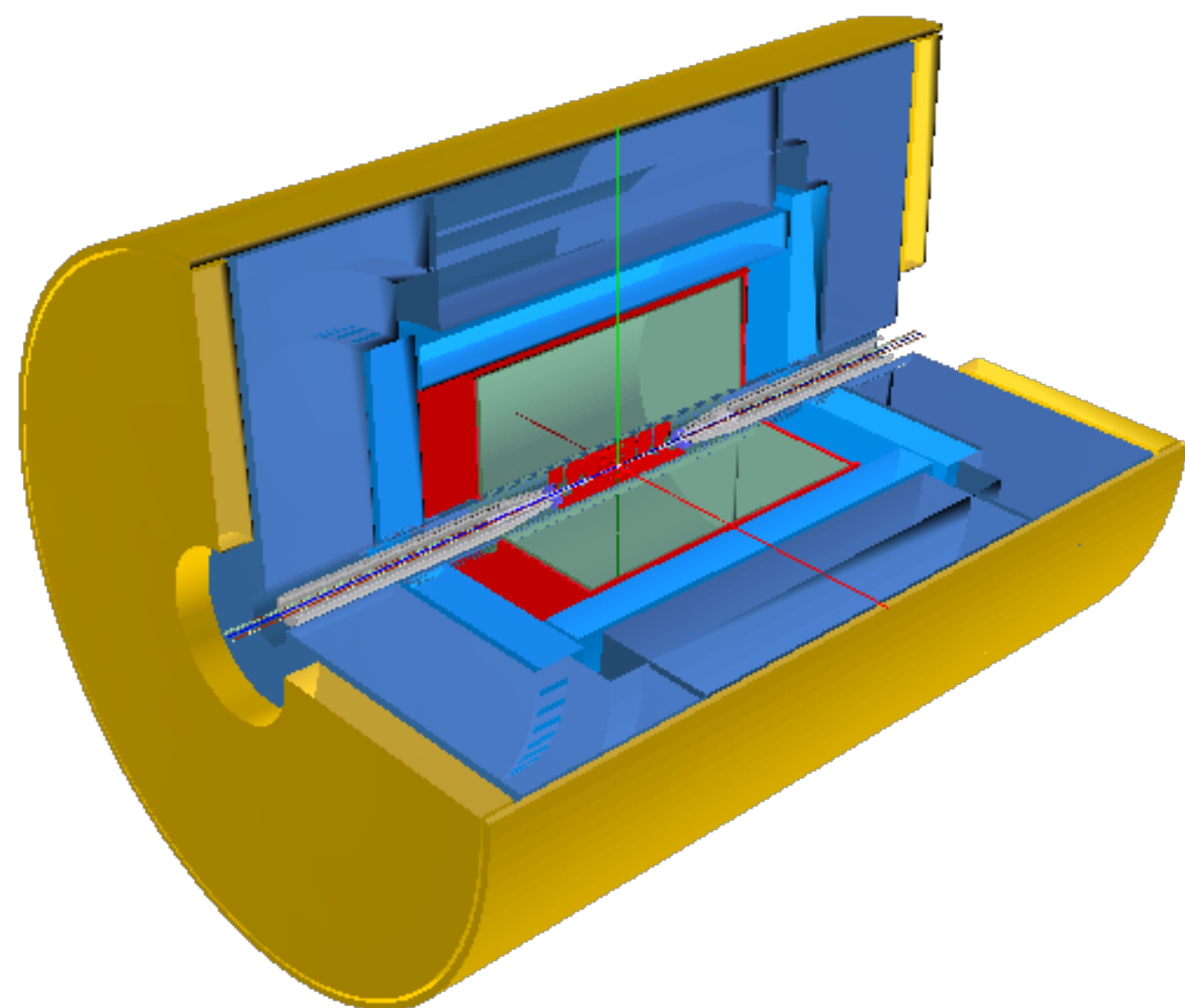
FCC as Higgs&EW&top factory at highest luminosity

Working point	Z pole	WW thresh.	ZH	t $\bar{t}$	
$\sqrt{s}$ (GeV)	88, 91, 94	157, 163	240	340–350	365
Lumi/IP ($10^{34} \text{ cm}^{-2} \text{ s}^{-1}$)	140	20	7.5	1.8	1.4
Lumi/year (ab^{-1})	68	9.6	3.6	0.83	0.67
Run time (year)	4	2	3	1	4
Integrated lumi. (ab^{-1})	205	19.2	10.8	0.42	2.70
Number of events	6×10^{12} Z	2.4×10^8 WW	2.2×10^6 ZH + 65k WW $\rightarrow$ H	2×10^6 t $\bar{t}$ + 370k ZH + 92k WW $\rightarrow$ H	

- ✓ 4 interaction points - possibility to specialised detectors to maximise physics output
- ✓ FCC integrated project allows seamless continuation of HEP after HL-LHC
- ✓ x10-50 improvements on all EW observables
- ✓ up to x10 improvement on Higgs coupling measurements over HL-LHC
- ✓ indirect discovery potential
- ✓ direct discovery potential for feebly-interacting particles over 5-100 GeV mass range



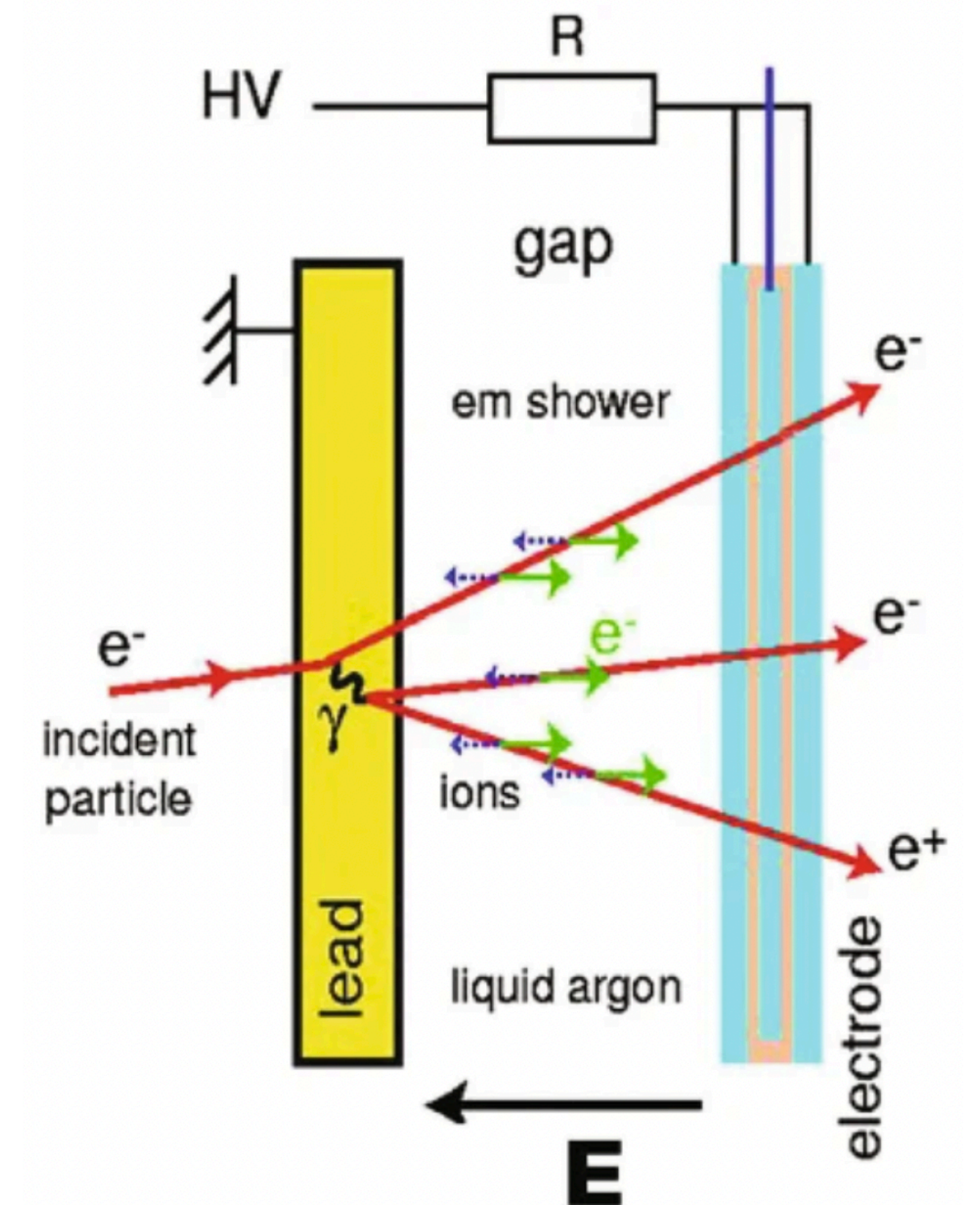
- **A**Lepton col**L**ider **E**xperiment with **G**ranular calorimetry **R**ead-**O**ut
- Highly-granular noble liquid EM calorimeter (ECal) inside solenoid
 - LAr/LKr with Pb/W
 - inside 2T solenoid sharing the cryostat
- Part of DRD CALO collaboration as Work Package 2 (WP2)



- General purpose detector concept for full FCC-ee programme
- Focus on particle identification with particle flow
- Other sub-detector systems
 - vertex detector, drift chamber, Tile-Cal hadronic calorimeter and muon tagger

Noble-liquid calorimetry

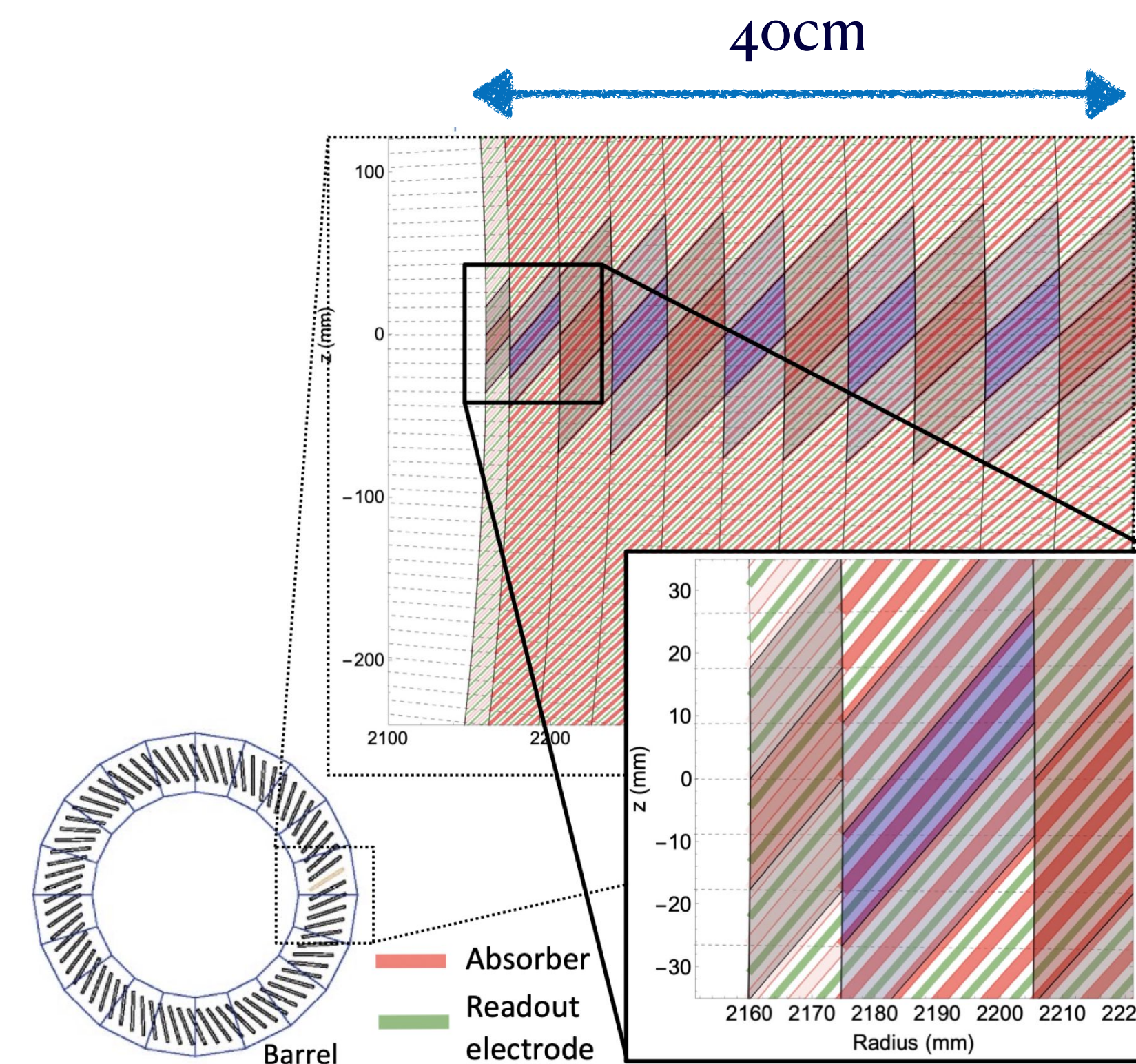
- Sampling calorimeter technology - alternating layers of absorber, noble liquid and read-out electrode
- EM showers start in absorber
- Electrons produced in the showers ionize the liquified noble gas and induce signal
- Decade of success at particle physics experiments: D0, H1, NA48/63, ATLAS,...
- Advantages
 - good energy resolution,
 - linearity, stability and uniformity of the response
 - easy to calibrate
- Challenges
 - signal extraction and complex mechanical structure inside the cryostat



Barrel design

Baseline geometry

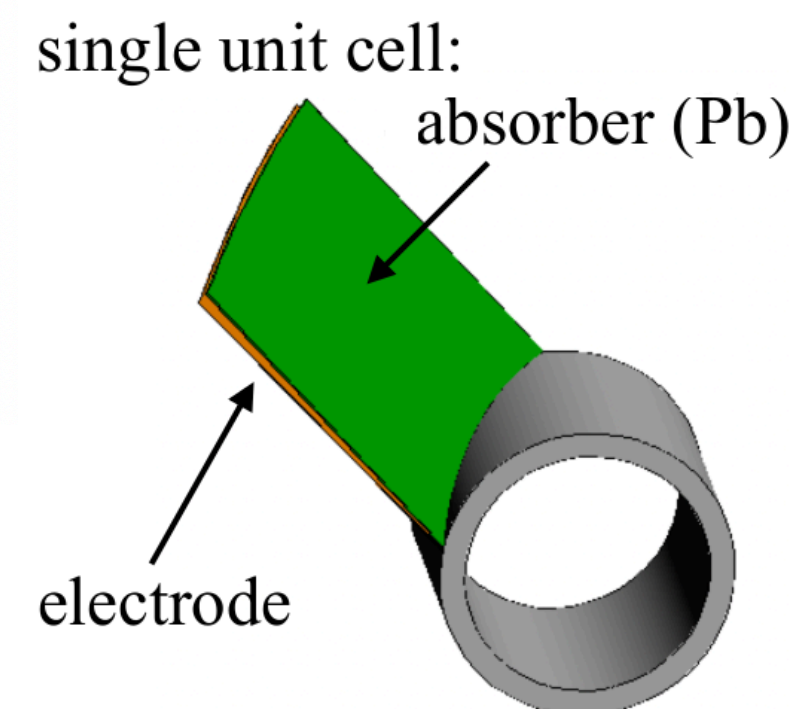
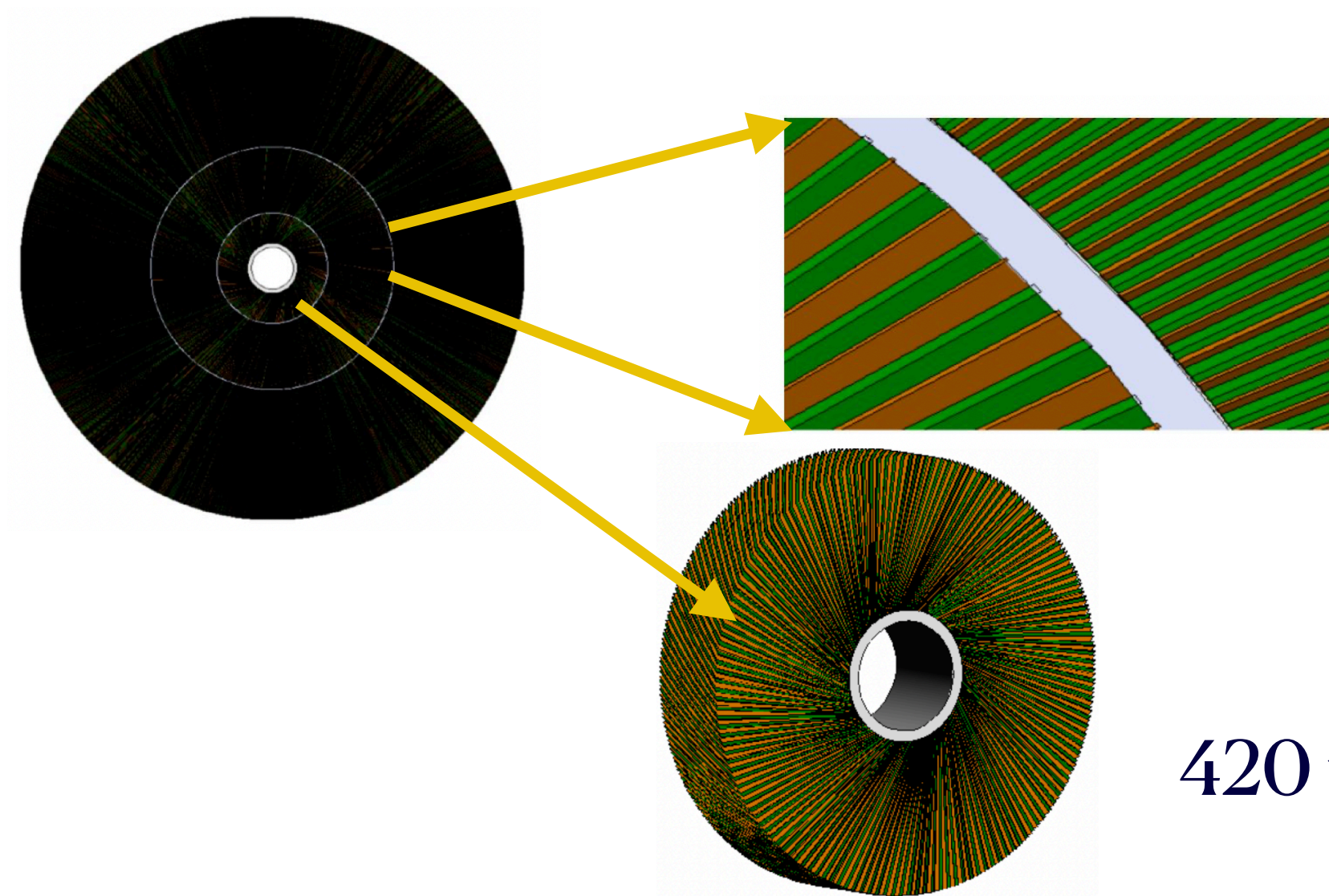
- 1536 straight inclined (50°) 1.8mm absorbers
- gaps between absorbers and electrode maintained by spacers
 - gaps from 1.2 to 2.4 mm
- 40cm in thickness, or $22 X_0$
- multi-layer PCBs as read-out electrodes
- segmentation
 - $\Delta\theta \sim 10$ mrad
 - $\Delta\phi \sim 8$ mrad
- 11 longitudinal layers
- the second layer with narrow strips segmented in θ for π^0 detection



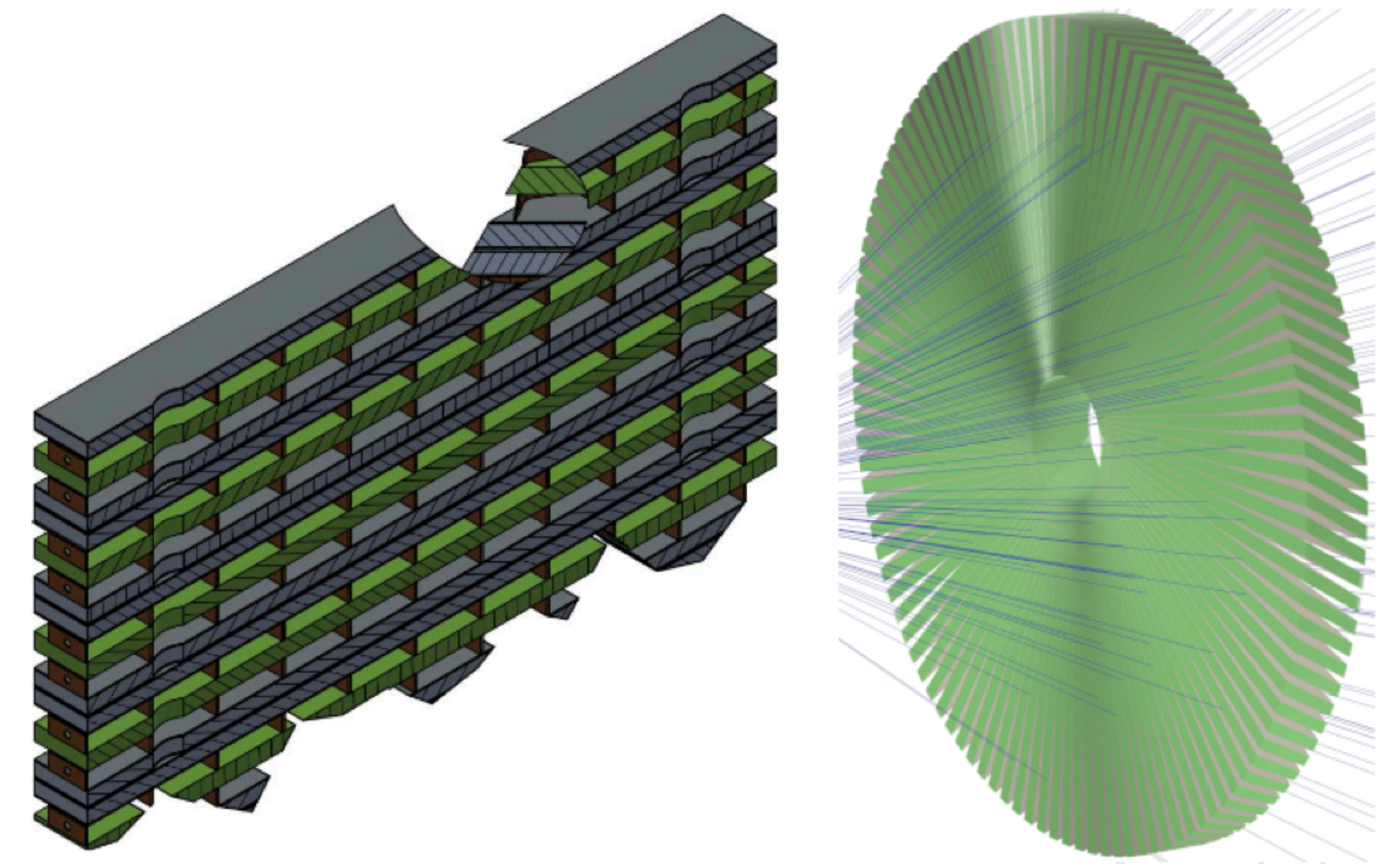
- LKr or LAr as active medium
- W or Pb as absorbers

Endcap design

- **Turbine geometry** : similar concept to the barrel
- Particles should traverse many thin absorber/sampler electrode unit cells
- 3 nested wheels with turbine-like layout
 - similar to barrel design with many thin absorbers
 - tapered absorber thickness
- **Parallel plate design** avoids gap widening
- Flat absorber easier to manufacture
- Prototype starting



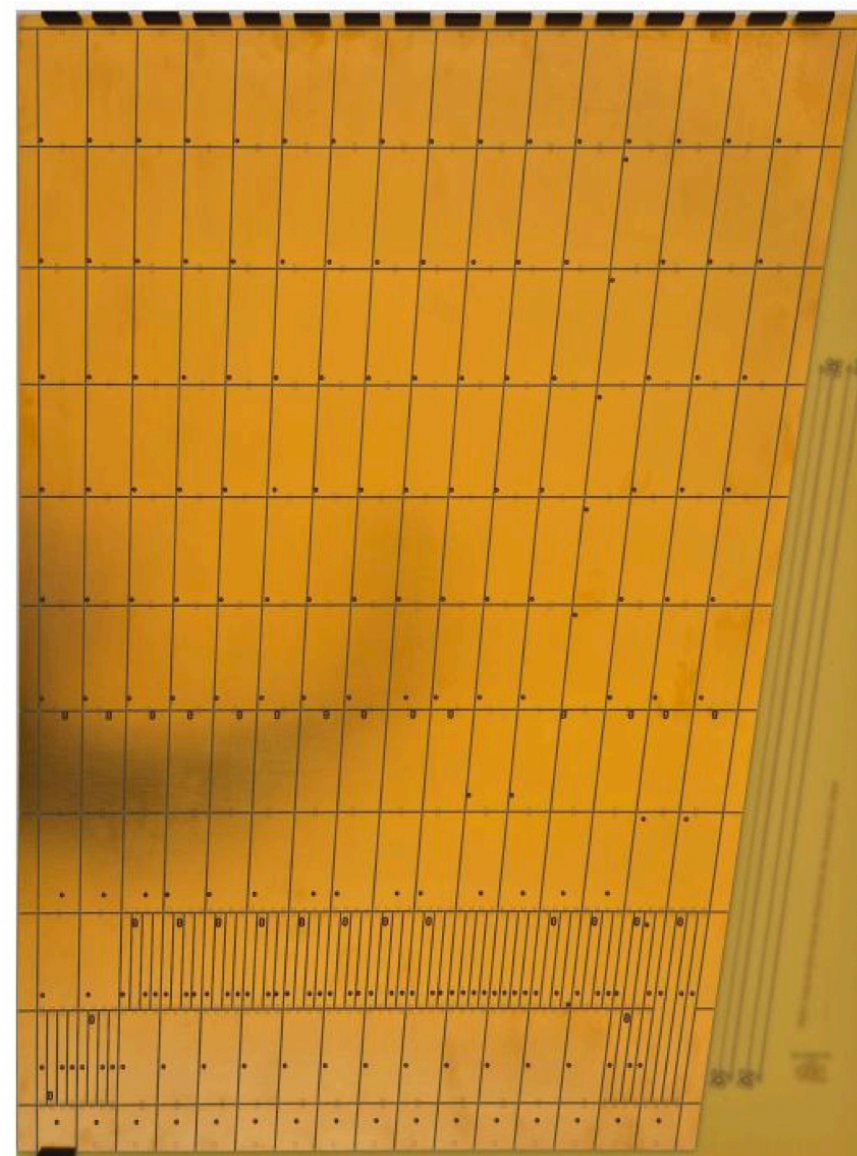
$420 \text{ mm} < R < 2750 \text{ mm}$ 7



Read-out electrodes

Barrel

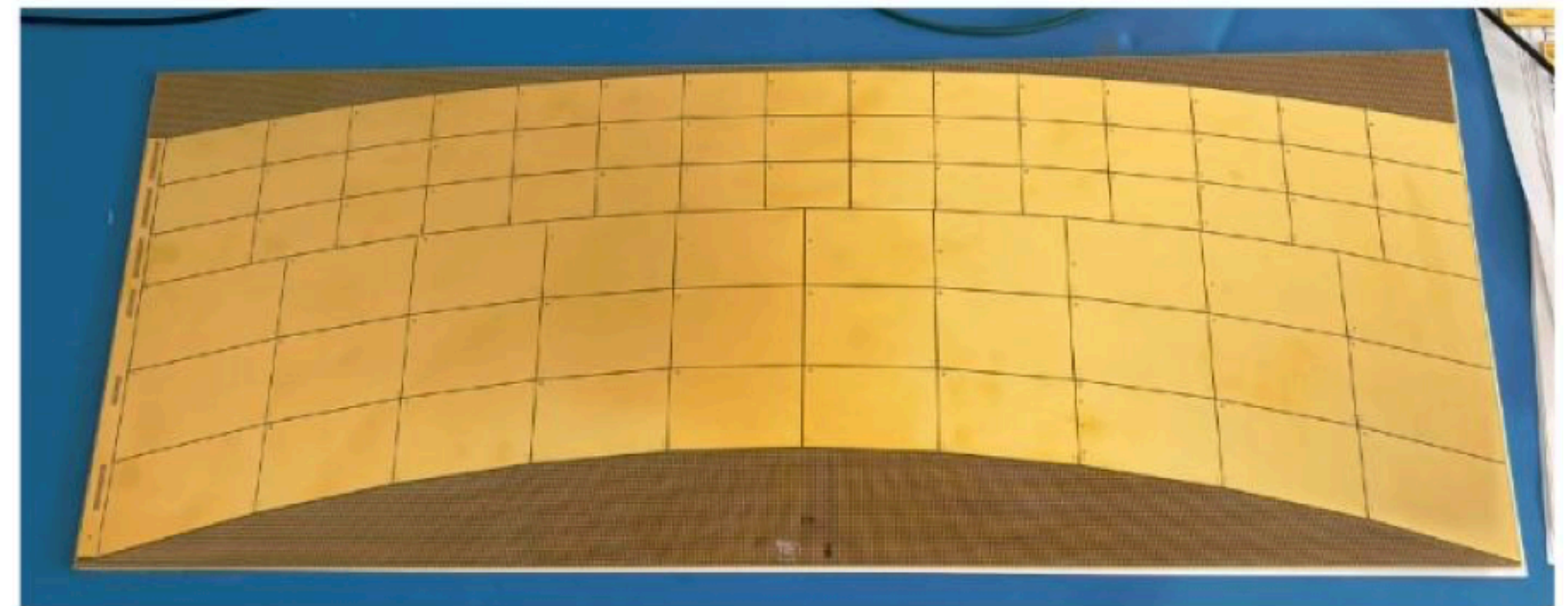
- Printed circuit board (PCB) technology allows high granularity
 - 11 longitudinal compartments, 16 θ -towers with unique configurations
 - signal traces inside the electrode
 - allows for $\sim 10\times$ ATLAS granularity
 - first versions of prototype were tested
 - CERN, IJCLab, BNL



barrel readout board

End-caps

- Dedicated PCB design in Arizona
 - flat PCB with shape adapted to the turbine-like design
 - signal read-out from high- $|z|$ edge
 - study of transfer line characteristic impedance
- Prototype design in progress



turbine inner wheel readout board

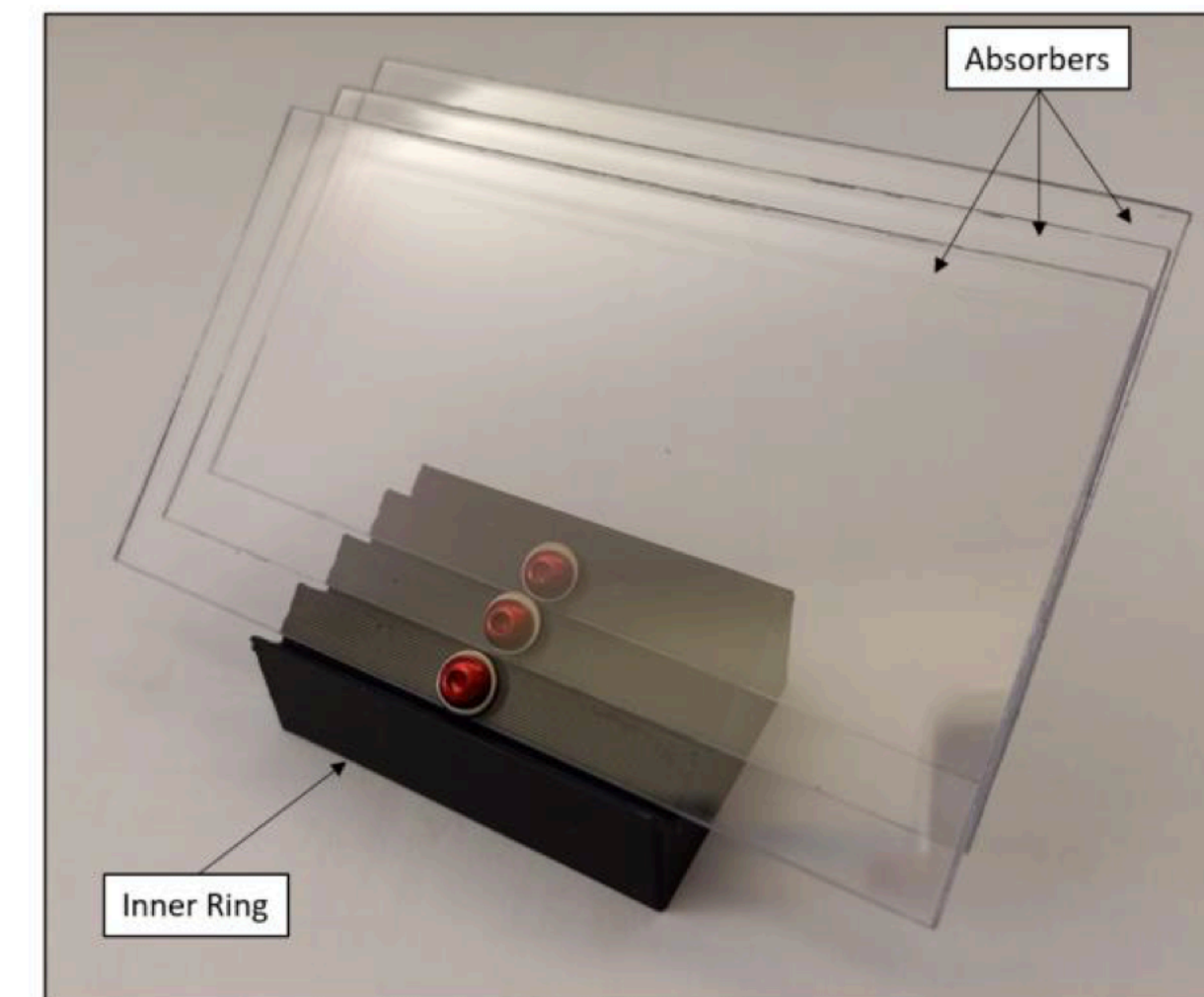
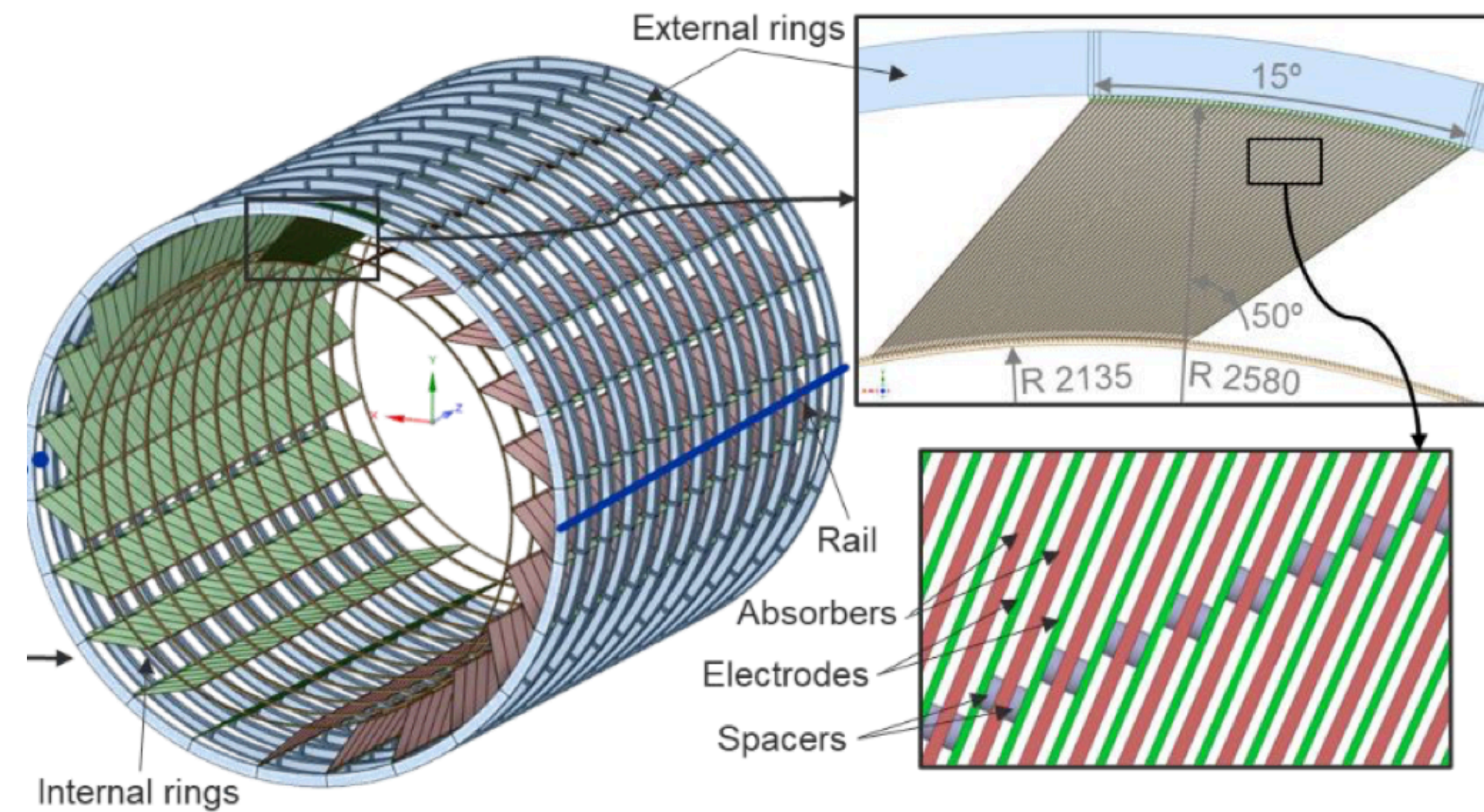
PCB prototypes for the barrel and the endcaps manufactured

Mechanical structure design

Precise positioning of the absorbers

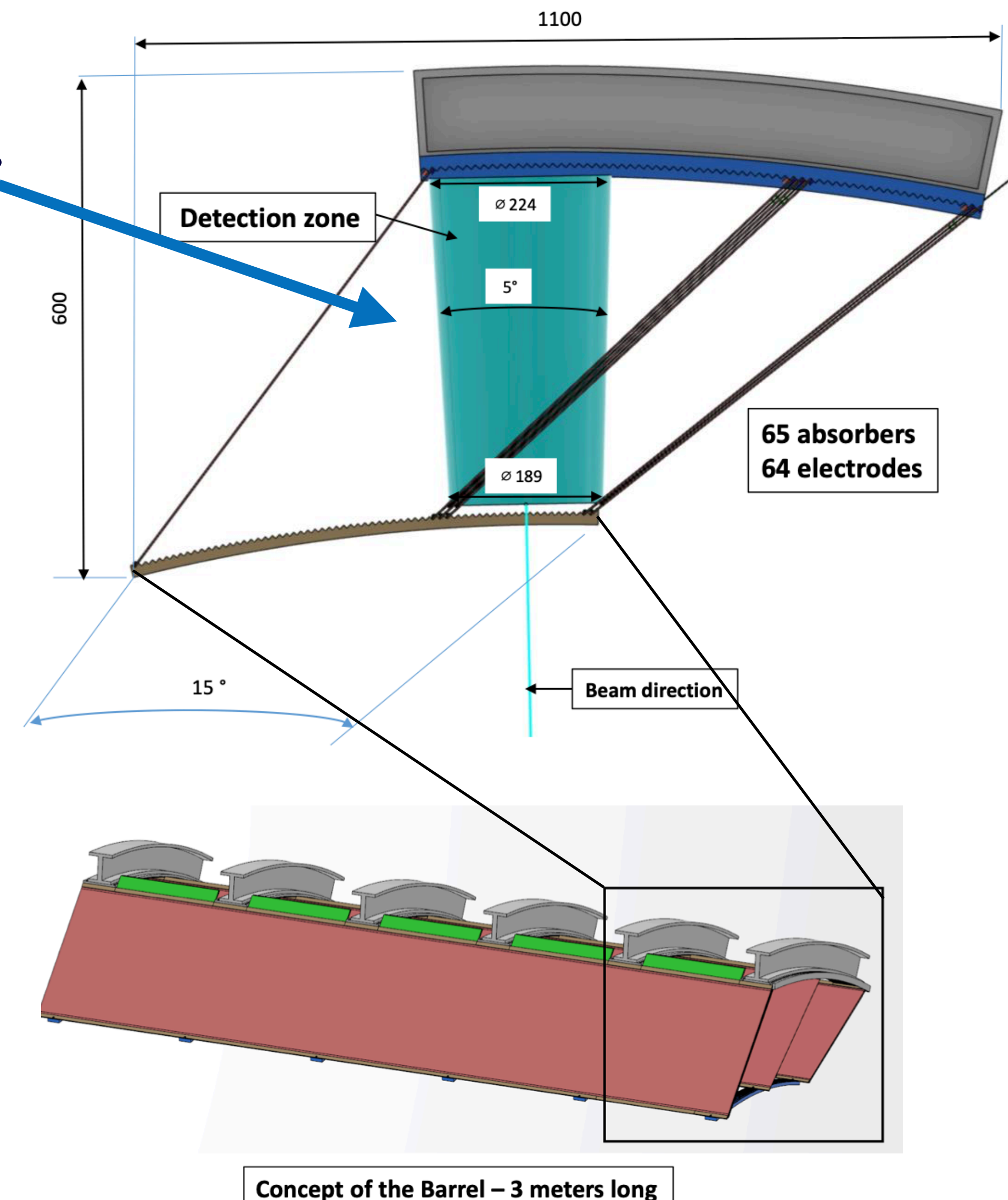
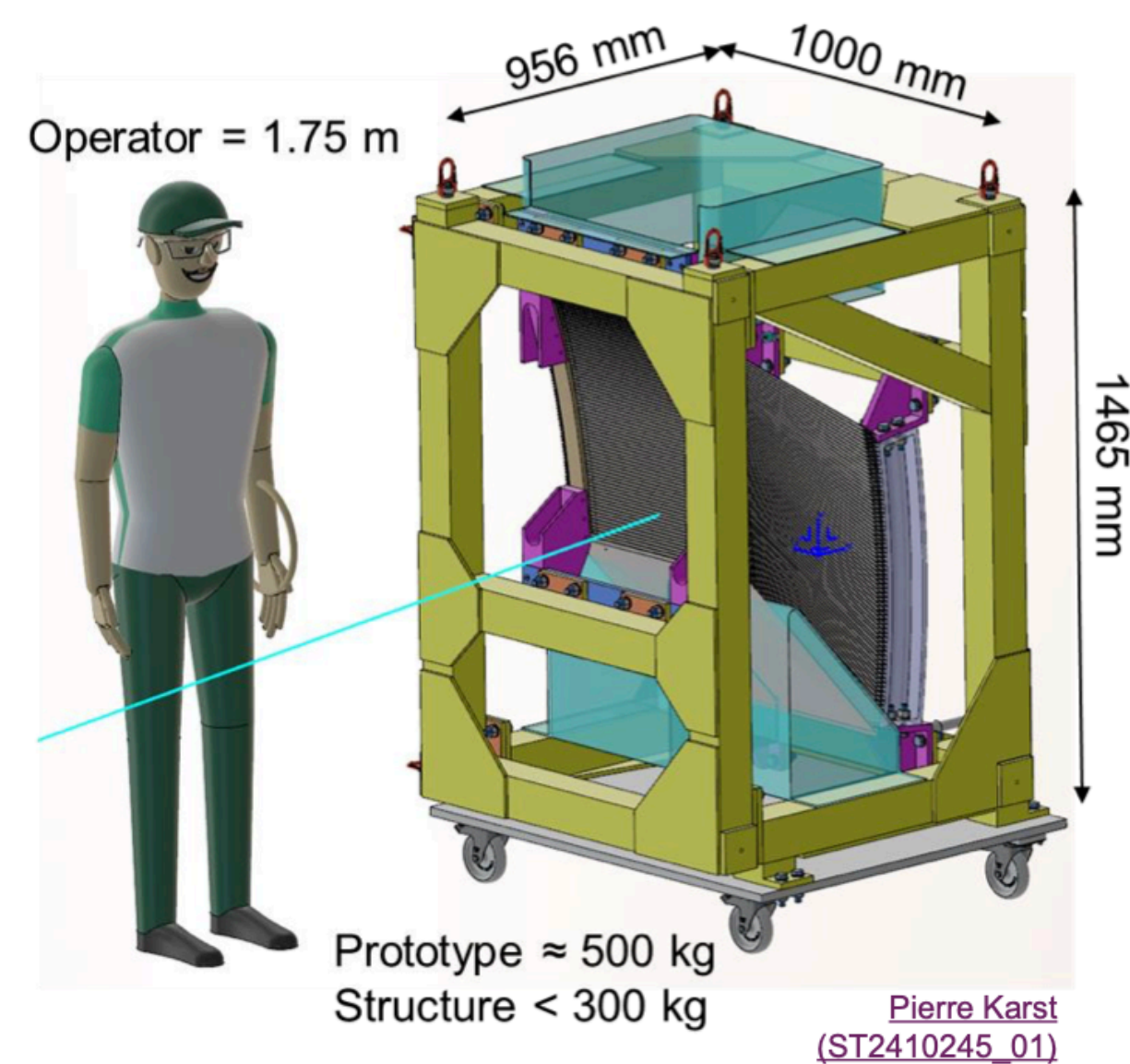
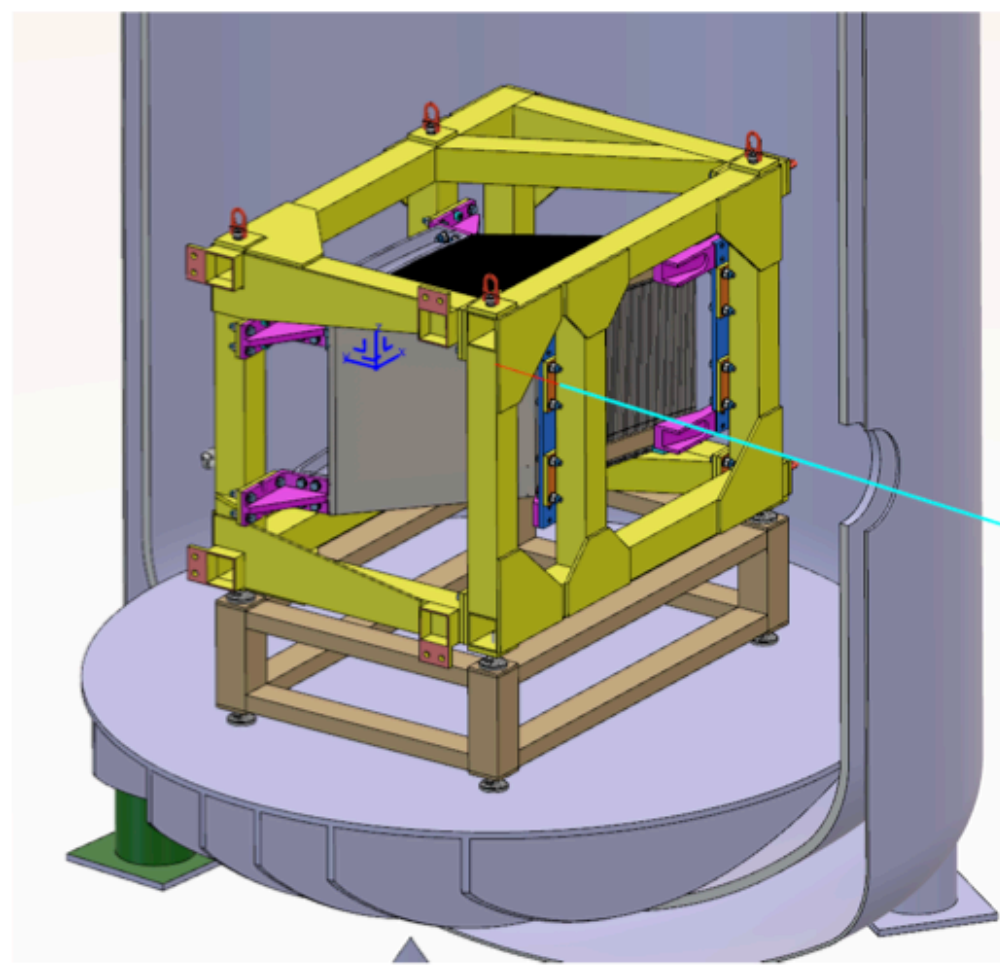
Main components of barrel support structure

- internal ring - positioning
 - external ring - support
 - absorbers are positioned and fixed on the rings
- **Absorbers** are 1.8mm lead plates sandwiched between stainless steel sheets
 - Absorber with 0.1mm stainless steel sheets is now default
 - **Spacers** need to control LAr gap between absorbers and electrode
 - different options being explored : honeycomb paper, glue-in plastic button or “waffle” like



Test beam prototype

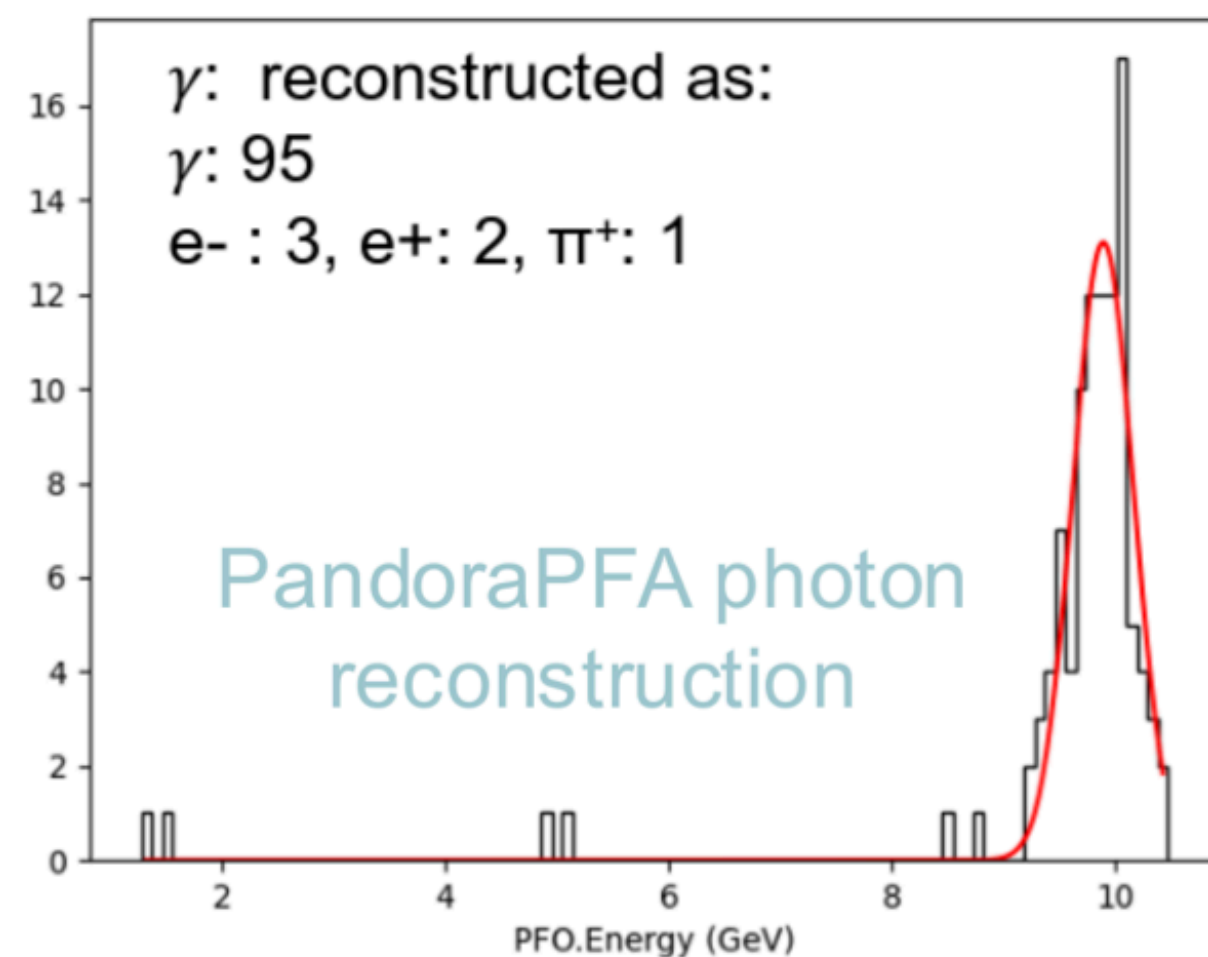
- Preparation of the ECal barrel test beam prototype
- Dimension is a sector of 15° and it corresponds to a detection zone of 5°
- Design with 65 absorbers and 64 electrodes with ~ 5000 channels
 - capable of containing the development of a typical shower



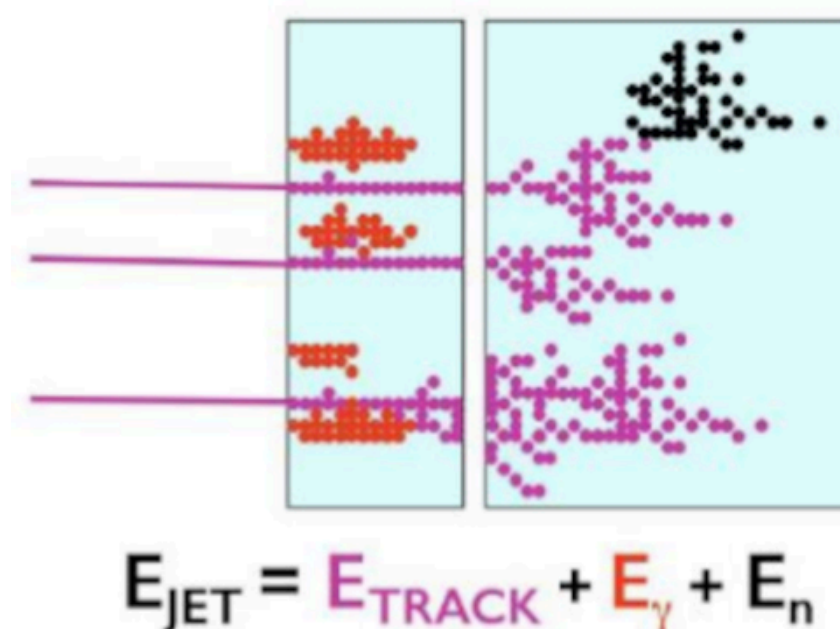
- Prototype to be ready for **test beam** in **2029-2030** (after LS3)

Full simulation

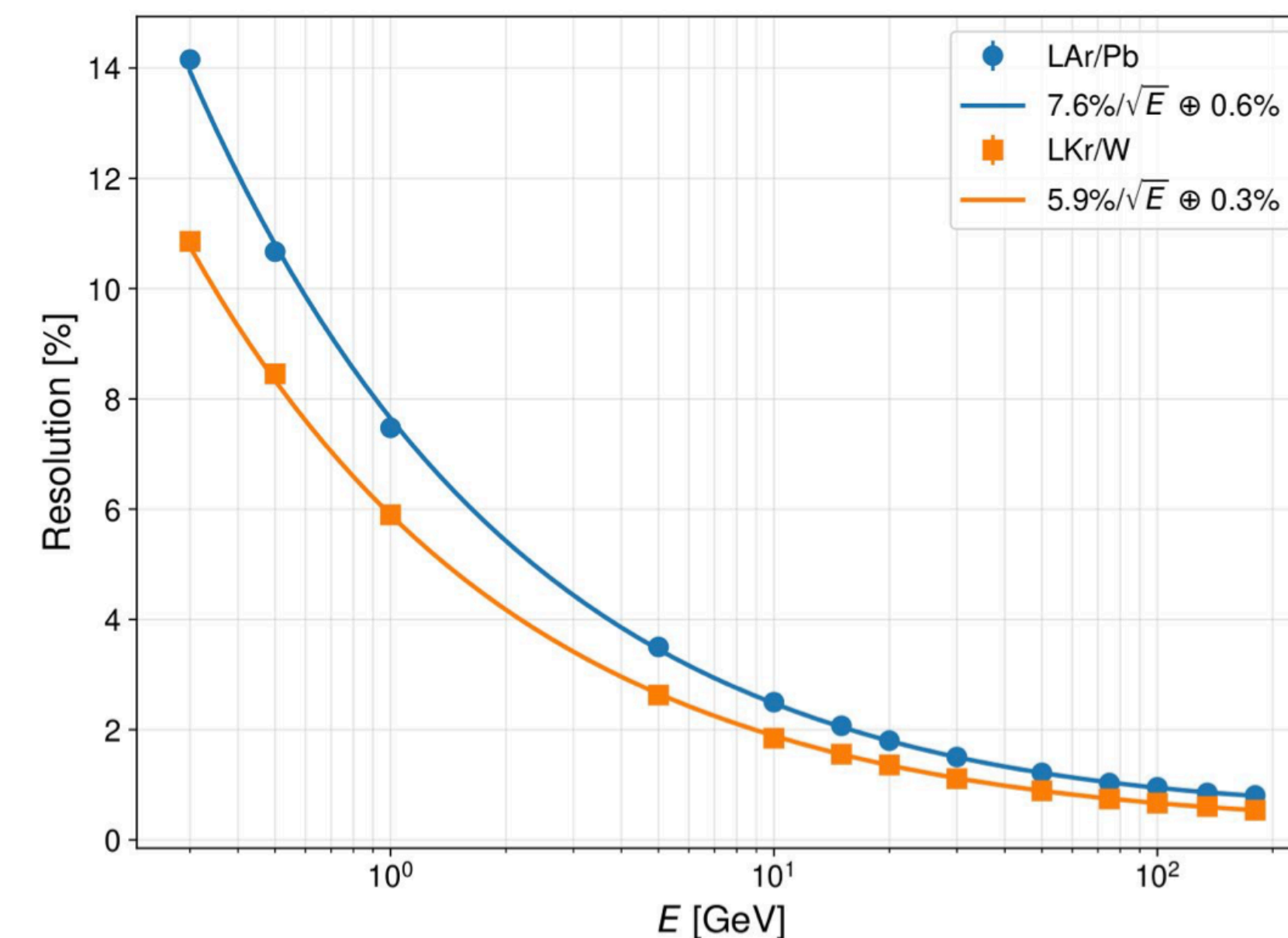
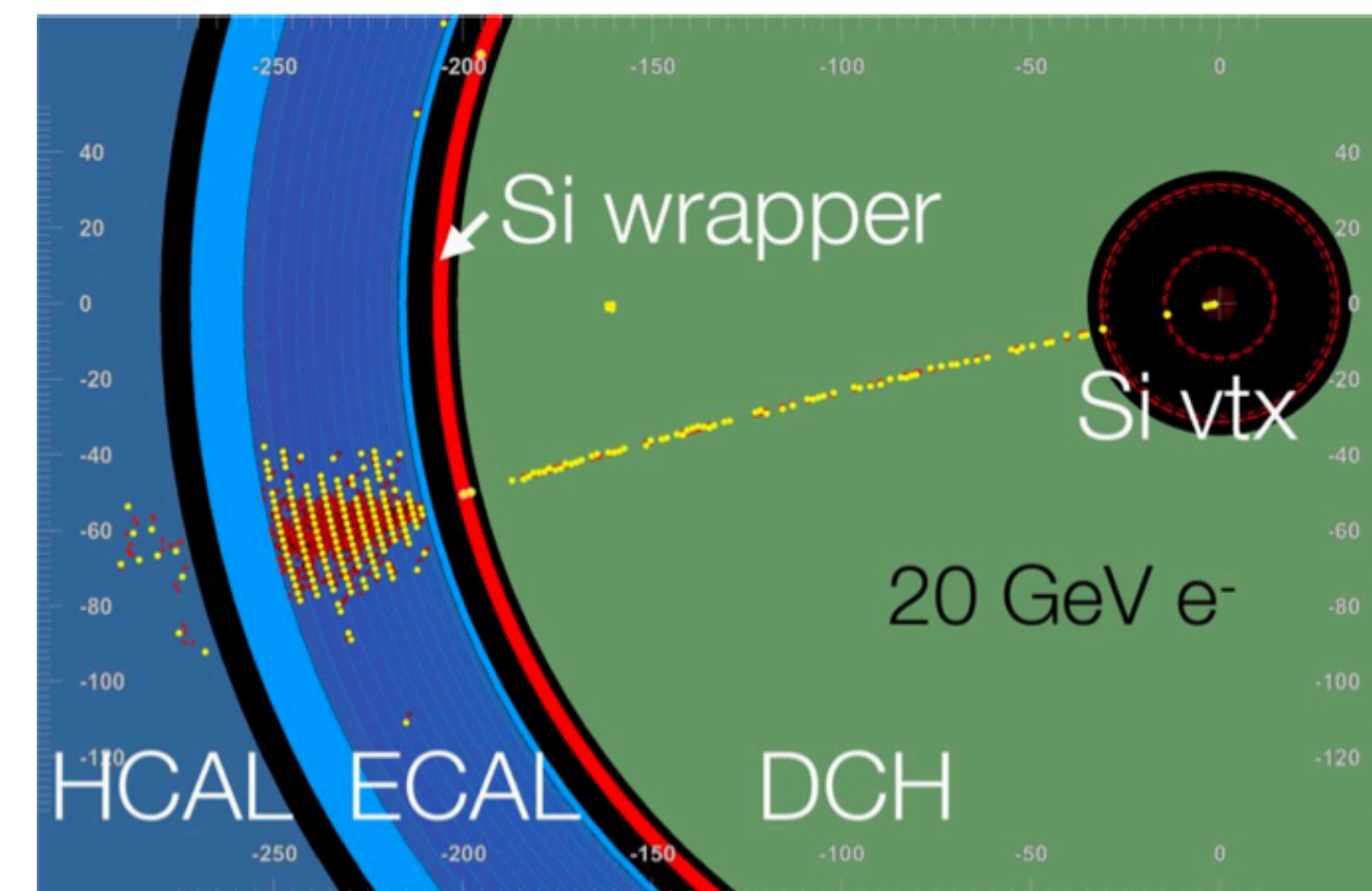
- Geometry description of ALLEGRO detector concept & ECal full-sim implemented in FCCSW,
- Simple digitization as a sum of Geant4 energy deposit, corrected by pre-calculated sampling fraction for each layer, also handle noise addition and cross-talk emulation
 - realistic digitization on-going
- Clustering is available for fixed-size sliding window cluster and topocluster
- ParticleFlow event reconstruction implementations in progress
- Simulation on different absorber/noble liquid setups
- γ/π^0 identification



Particle Flow approach



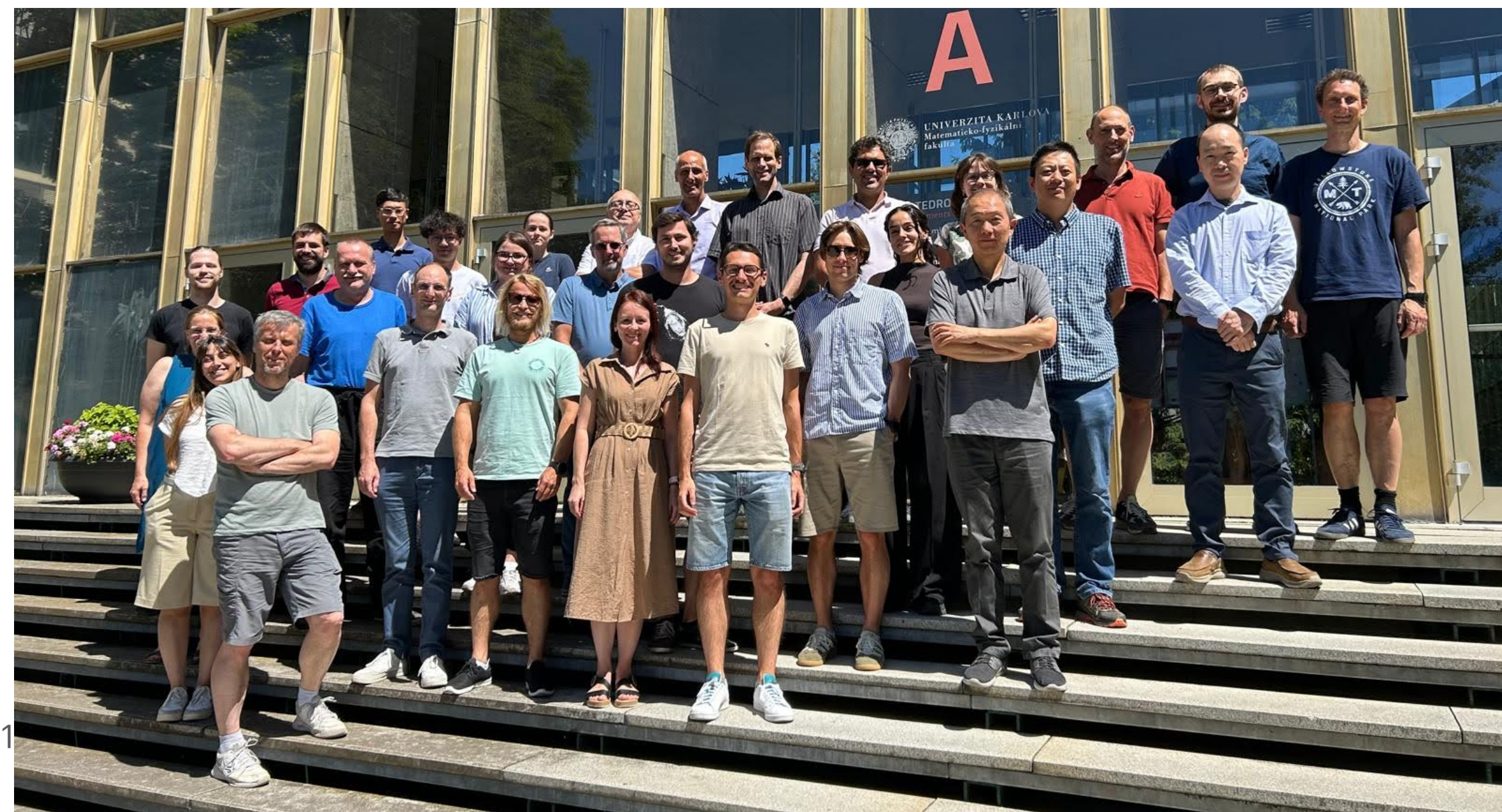
$$E_{\text{JET}} = E_{\text{TRACK}} + E_{\gamma} + E_n$$



Conclusions

- **ALLEGRO** is realistic **general-purpose** detector concept for Higgs factory build around noble liquid ECal
- High granularity with multi-layer PCBs
- The technology seems to be very promising for FCC-ee
- Working on mechanics for our **test beam prototype**
- **Progress** in almost all aspects of ECal calorimetry
- Very active collaboration in DRDCalo

Join us !



Absorbers & Spacers

- **Absorbers** are 1.8mm lead plates sandwiched between stainless steel sheets
 - two designs - 0.1mm and 0.05mm stainless steel sheets
 - tests performed with liquid nitrogen bath of 77K
 - deformation appear in tests with 0.05mm steel
 - differences in thermal expansions
- Absorber with 0.1mm stainless steel sheets is now default
- Need to control LAr gap between absorbers and electrode
- First studies on **cylindrical spacers**
 - at least $\varnothing 6\text{mm}$
 - placed in the edges of readout cells
 - at most 200 mm between spacers
 - total volume occupied is 0.15% of the total LAr gap
- Other studied options
 - 3D printed mesh
 - Honeycomb paper

