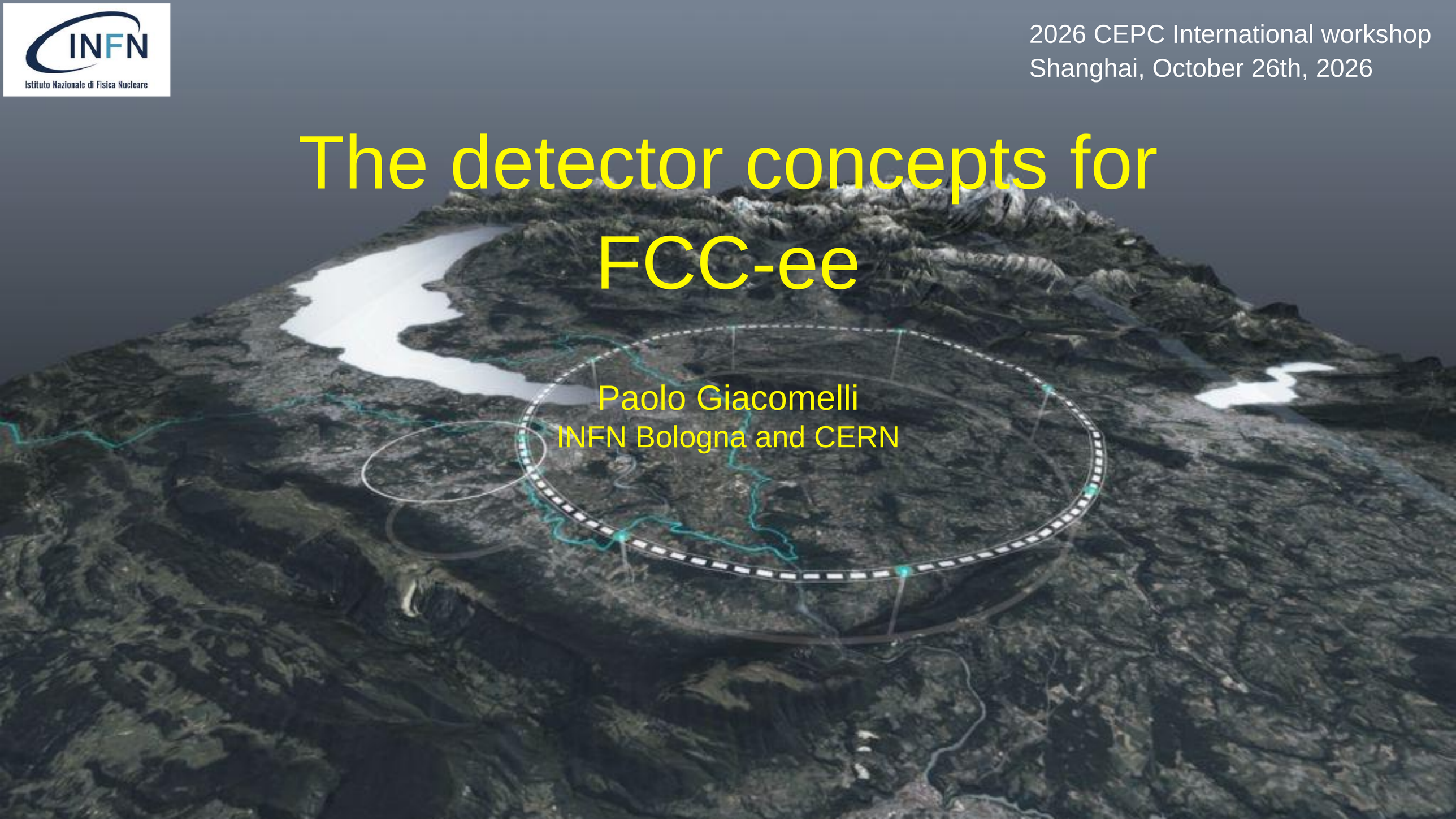
2026 CEPC International workshop
Shanghai, October 26th, 2026

The detector concepts for FCC-ee

Paolo Giacomelli
INFN Bologna and CERN



Outline

- FCC-ee layout
- FCC-ee physics requirements
- Detector requirements
  - Detector concepts for FCC-ee
    - Sub-detector technologies
- Conclusions

Disclaimer

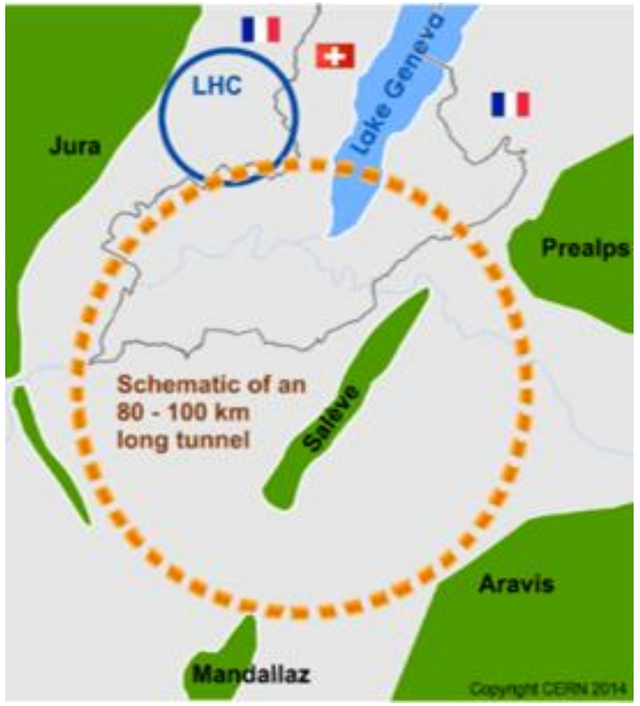
To prepare these slides I used content from many friends and colleagues, whom I wholeheartedly wish to thank. Any mistake or misinterpretation is entirely my fault!

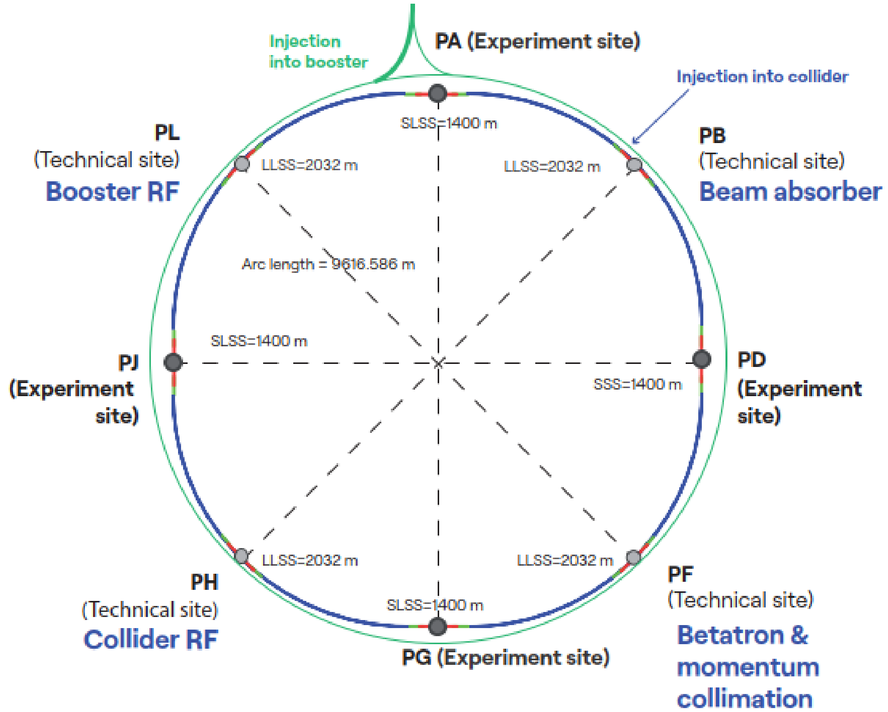
FCC Program

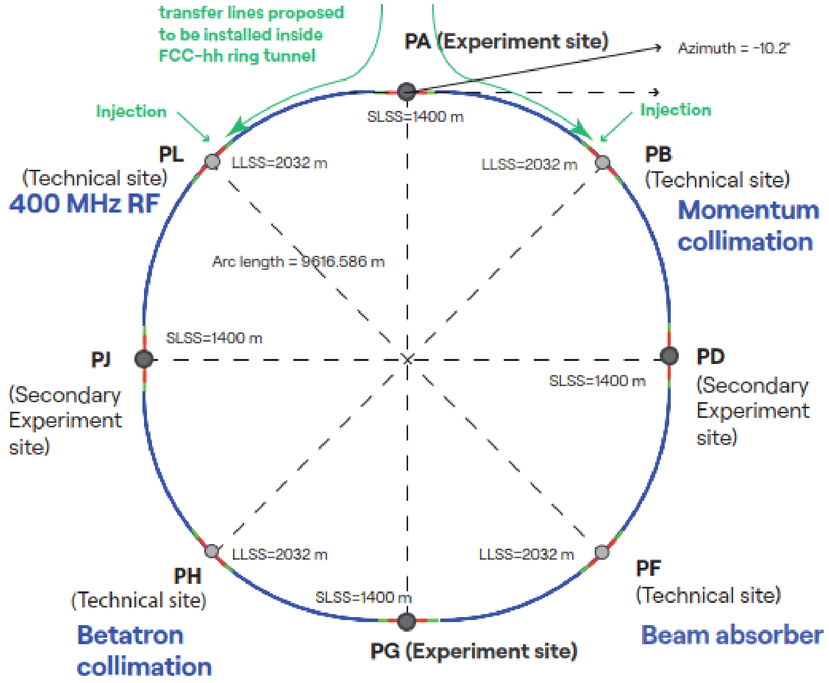
FCC-ee (Z, W, H, *tt*): Higgs factory, electroweak & top factory at highest luminosities

FCC-hh (~100 TeV) as potential second step: energy frontier, pp & AA collisions; e-h option

- focus on implementation of FCC-ee as first step; possible pathway to FCC-hh to be decided later
- Common civil engineering and technical infrastructures, building on and reusing CERN's existing infrastructure
- highly synergetic and complementary physics programme maximising the physics opportunities
- FCC-ee project would allow the start of a new, major facility at CERN within a few years of the end of HL-LHC







2020 - 2045 | **2048 - 2062** | **~2075 ?**

From Feasibility Study to Project Realisation



- Following the positive assessment of the Feasibility Study and Council approving the continuation, the FCC moves towards technical design.
- Expertise across CERN and from collaboration partners is required to be able to deliver an integrated technical design, with cost estimate and schedule, taking into account project authorisation processes, societal acceptance, procurement strategy.
- **2026-2028 Reference Design Phase**
- **2029-2032 Technical Design Phase**

Aiming for project decision by CERN Council after the Reference Design Phase

M. Benedikt

FCC-ee layout

4 experimental areas

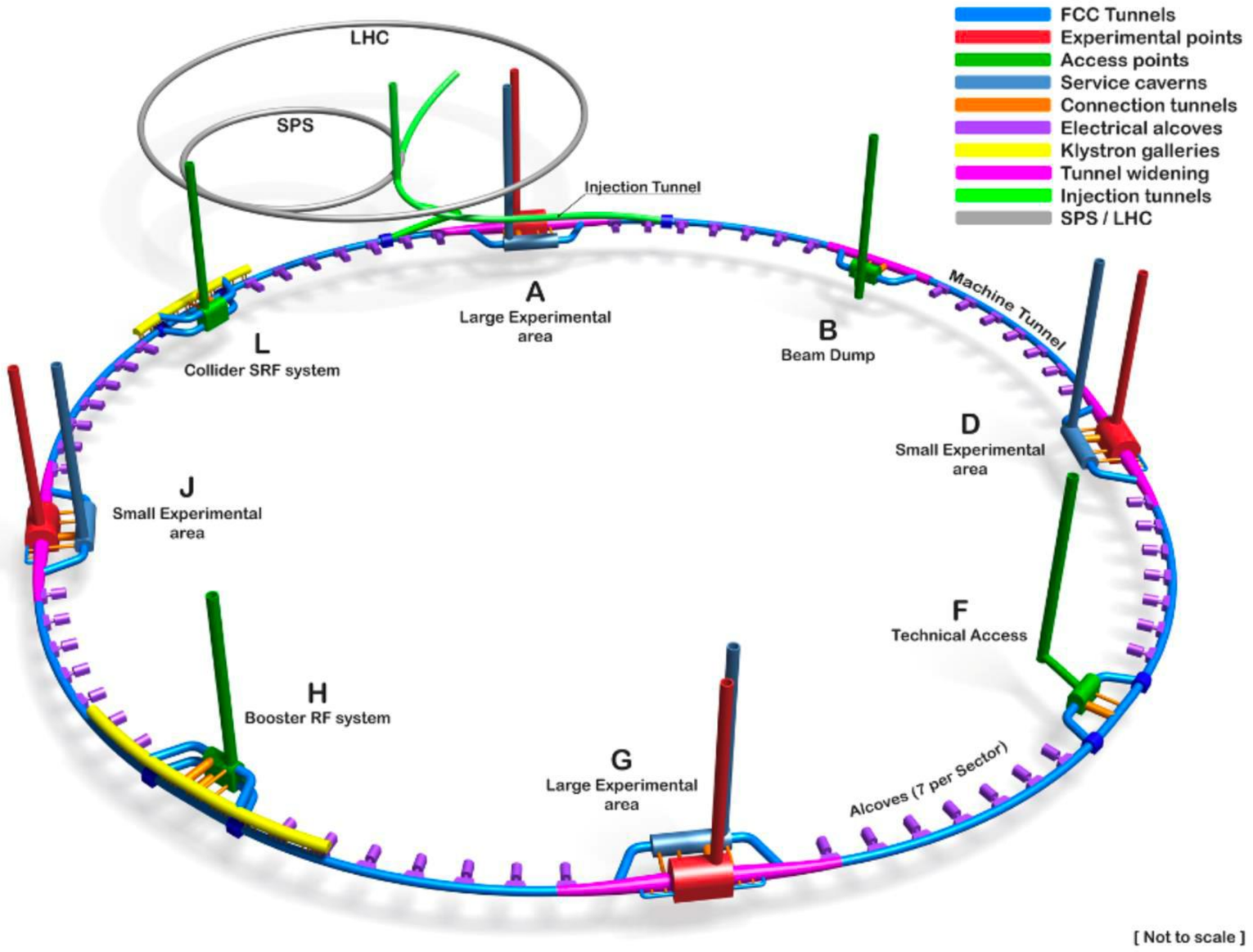
(4 experiments)

Point A

Point D

Point G

Point J



Stage 1: e^+e^- collider FCC-ee

Consolidated main parameters

parameter	Z	WW	H (ZH)	
beam energy [GeV]	45.6	80	120	182.5
synchrotron radiation/beam [MW]	50	50	50	50
beam current [mA]	1294	135	26.8	5.1
number bunches / beam	11200	1852	300	64
total RF voltage 400/800 MHz [GV]	0.08 / 0	1.0 / 0	2.09 / 0	2.1 / 9.2
luminosity / IP [10^{34} $cm^{-2}s^{-1}$]	145	20	7.5	1.4
total integrated luminosity / IP / year [ab^{-1} / yr]	17	2.4	0.9	0.17
electrical power operation [MW]	250	275	297	381
electrical energy per year [TWh]	1.17	1.32	1.41	1.85

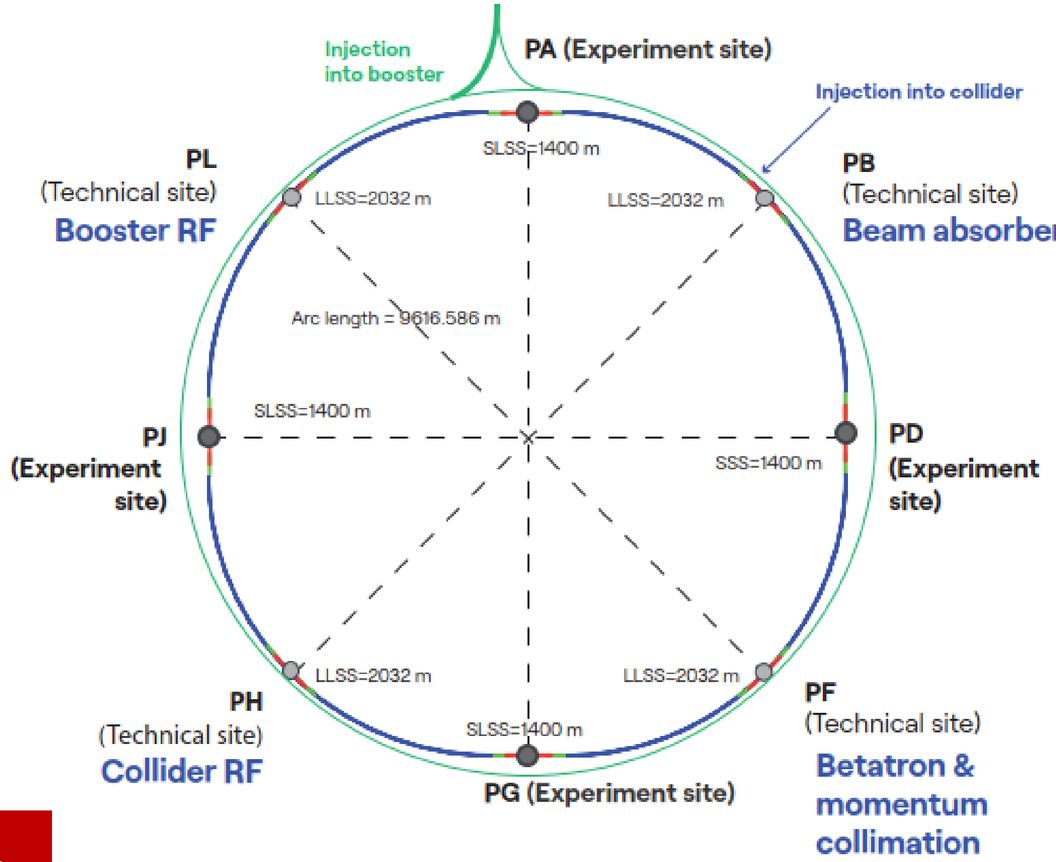
4 years
6 x 10^{12} Z
LEP x 10^5

2 years
> 10^8 WW
LEP x 10^4

3 years
> 2x10^6 H

5 years
2 x 10^6 tt pairs

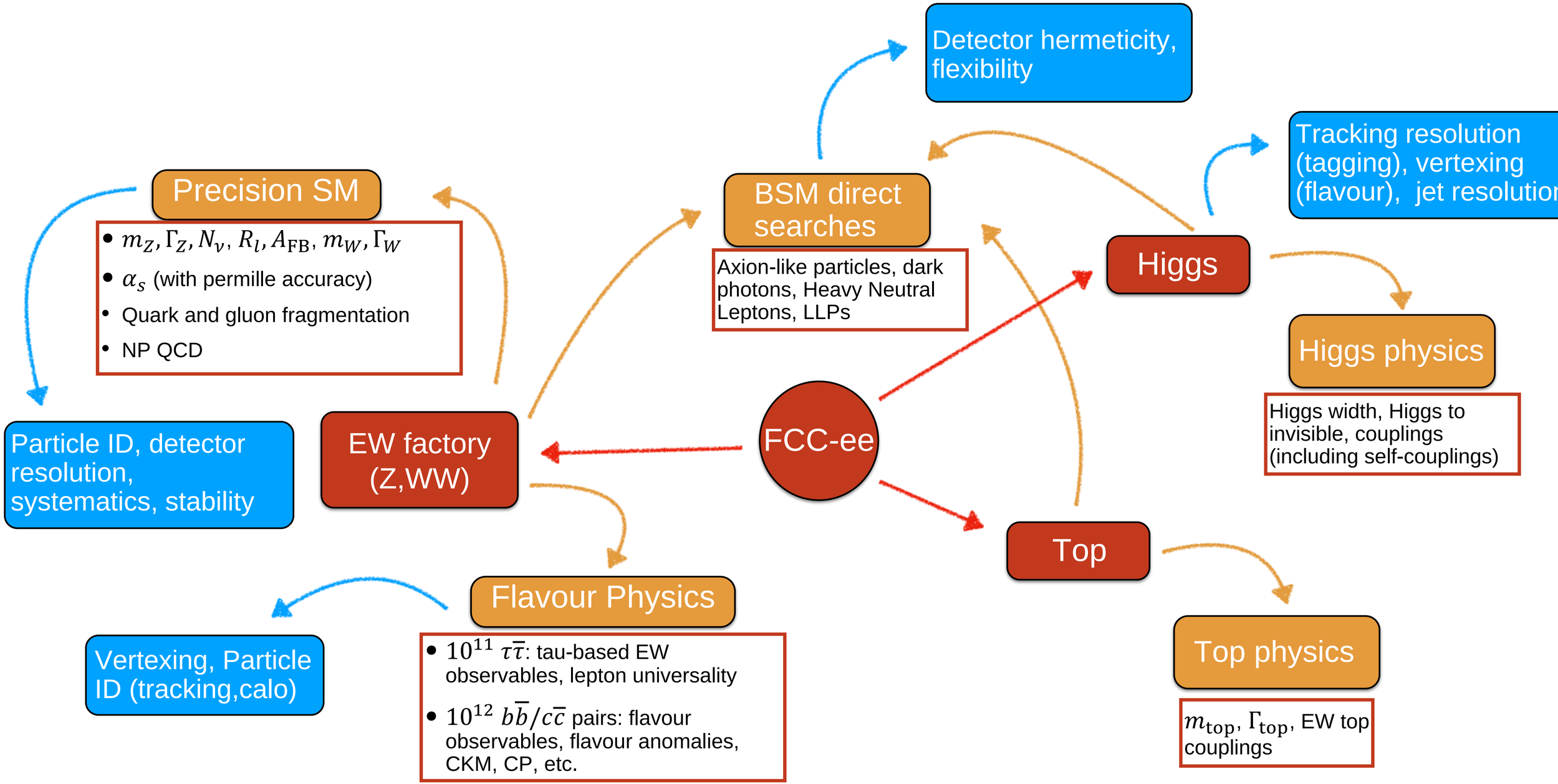
FCC-ee functional layout



10^4 (@WW) - 10^5 (@Z) x luminosity/energy of LEP ➔ sustainable physics

M. Benedikt - F. Zimmermann

The physics of FCC-ee



Physics requirements

Higgs Factory Programme

- At √s=240 and √s=365 GeV collect 2.6M HZ and 150k WW→ H events
- Higgs couplings to fermions and bosons
- Higgs self-coupling (~4 σ) via loop diagrams
- Unique possibility: s-channel $e^+e^- \rightarrow$ H at 125 GeV

→

- **Momentum resolution $\sigma(p_T)/p_T \simeq 10^{-3}$ @ $p_T \sim 50$ GeV**
  - σ(p)/p limited by multiple scattering → minimise material
- **Jet σ(E)/E ≃ 3-4% in multijet events for Z/W/H separation**
- **Superior impact parameter resolution for b, c tagging**
- **Hadron PID for s tagging**

Precision EW and QCD Programme

- 6×10^{12} Z and 2×10^8 WW events
- × 500 improvement of statistical precision on EWPO: m_Z, Γ_Z, Γ_{inv}, $\sin^2\theta_W$, R_b, m_W, Γ_W, …
- 2×10^8 tt events: m_{top}, Γ_{top}, EW couplings
- Indirect sensitivity to new physics up to tens of TeV

→

- **Absolute normalisation of luminosity to 10^{-4}**
- **Relative normalisation to $\lesssim 10^{-5}$ (e.g. Γ_{had}/Γ_ℓ)**
  - Acceptance definition to $\mathcal{O}$(10 μm)
- **Track angular resolution < 0.1 mrad**
- **Stability of B field to 10^{-6}**

Heavy Flavour Programme

- 10^{12} bb, cc, 2×10^{12} ττ (clean and boosted): 10 × Belle II
- CKM matrix, CP measurements
- rare decays, CLFV searches, lepton universality

→

- **Superior impact parameter resolution**
- **Precise identification and measurement of secondary vertices**
- **ECAL resolution at few %/√E**
- **Excellent π^0/γ separation for τ decay-mode identification**
- **PID: K/π separation over wide p range** → dN/dx, RICH, timing

Feebly coupled particles Beyond SM

- Opportunity to directly observe new feebly interacting particles with masses below m_Z
- Axion-like particles, dark photons, Heavy Neutral Leptons
- Long-lifetime LLPs

→

- **Sensitivity to (significantly) detached vertices (mm → m)**
  - tracking: more layers, ”continous” tracking
  - calorimetry: granularity, tracking capabilities
- **Precise timing**
- **Hermeticity**

M. Dam

Detector requirements

Table 13: Summary of detector requirements.

	Aggressive	Conservative	Comments
Beampipe	$X/X_0 < 0.5\%$	$X/X_0 < 1\%$	$B \to K^* \tau\tau$
Vertex	$\sigma(d_0) = 3 \oplus 15 \,/\, (p \sin^{3/2}\theta)\,\mu m$ $X/X_0 < 1\%$	–	$B \to K^* \tau\tau$ R_c
	$\delta L = 5$ ppm	–	$\delta\tau_\tau < 10$ ppm
Tracking	$\sigma_p/p < 0.1\%$ for $\mathcal{O}(50)$ GeV tracks	$\sigma_p/p < 0.2\%$ for $\mathcal{O}(50)$ GeV tracks	$\delta M_H = 4$ MeV $\delta\Gamma_Z = 15$ keV $Z \to \tau\mu$
	t.b.d.	$\sigma_\theta < 0.1$ mrad	$\delta\Gamma_Z(\text{BES}) < 10$ keV
ECAL	$\sigma_E/E = 3\%/\sqrt{E}$	$\sigma_E/E = 10\%/\sqrt{E}$	$Z \to \nu_e\bar{\nu}_e$ coupling, B physics, ALPs
	$\Delta x \times \Delta y =$ $2 \times 2\,\text{mm}^2$	$\Delta x \times \Delta y =$ $5 \times 5\,\text{mm}^2$	τ polarisation boosted π^0 decays bremsstrahlung recovery
	$\delta z = 100\,\mu$m, $\delta R_{\text{min}} = 10\,\mu\text{m}$ ($\theta = 20°$)	In-situ constraint with dilepton/diphoton events	alignment tolerance for $\delta\mathcal{L} = 10^{-5}$ with $\gamma\gamma$ events
HCAL	$\sigma_E/E = 30\%/\sqrt{E}$	$\sigma_E/E = 50\%/\sqrt{E}$	$H \to s\bar{s}$, $c\bar{c}$, gg, invisible HNLs
	$\Delta x \times \Delta y =$ $2 \times 2\,\text{mm}^2$	$\Delta x \times \Delta y =$ $20 \times 20\,\text{mm}^2$	$H \to s\bar{s}$, $c\bar{c}$, gg
Muons	low momentum ($p < 1$ GeV) ID	–	$B_s \to \nu\bar{\nu}$
Particle ID	$3\,\sigma$ K/π $p < 40$ GeV	$3\,\sigma$ K/π $p < 30$ GeV	$H \to s\bar{s}$ $b \to s\nu\bar{\nu}, \ldots$
LumiCal	tolerance $\delta z = 100\,\mu$m, $\delta R_{\text{min}} = 1\,\mu$m acceptance 50–100 mrad	–	$\delta\mathcal{L} = 10^{-4}$ target (Bhabha)

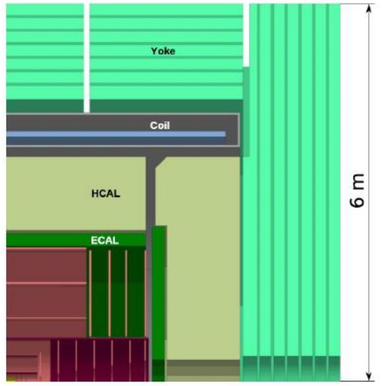
FCC-ee Detector concepts

You can find all the details in the 6 individual talks:

- AGORA (Yiming Li)
- ALFA (Duccio Abbaneo)
- ALLEGRO (Emmanuel Monnier)
- CLD (James Brau)
- IDEA (Franco Bedeschi)
- ILD (Mary-Cruz Fouz)

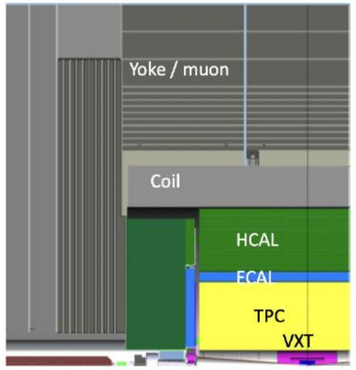
FCC-ee Detector concepts

Six detector concepts so far, probably more coming



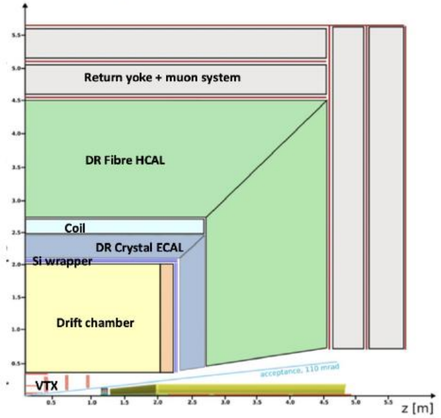
CLD
Full silicon tracking
High-granularity particle flow calorimetry

arXiV:1911.12230



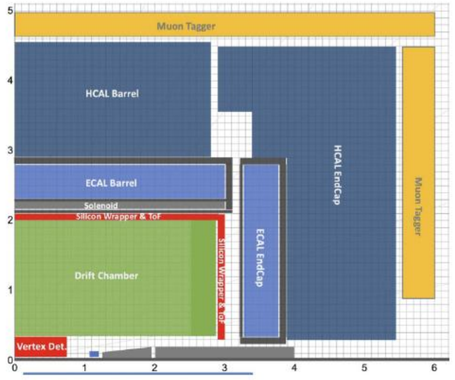
ILD
Silicon vertex tracker
TPC tracker
High-granularity particle flow calorimetry

arxiv:1306.6329



IDEA
Ultra-light drift chamber
Dual-readout calorimetry

arxiv:2502.21223

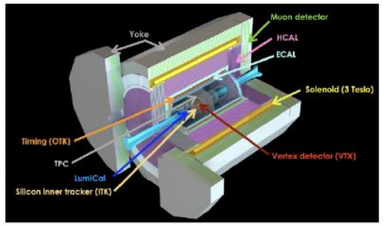


ALLEGRO
Noble liquid (LAr) electromagnetic calorimetry

arxiv:2109.00391



ALFA
All-MAPS silicon tracker
Novel crystal grain calorimetry



AGORA
TPC tracker
Heavy-glass scintillating tile technology

arxiv:2510.05260

Common Subsystems
Cross-cutting R&D shared across all concept proposals

Particle ID
RICH, Cherenkov ARC
Tracker d*N*/d*x* and TOF

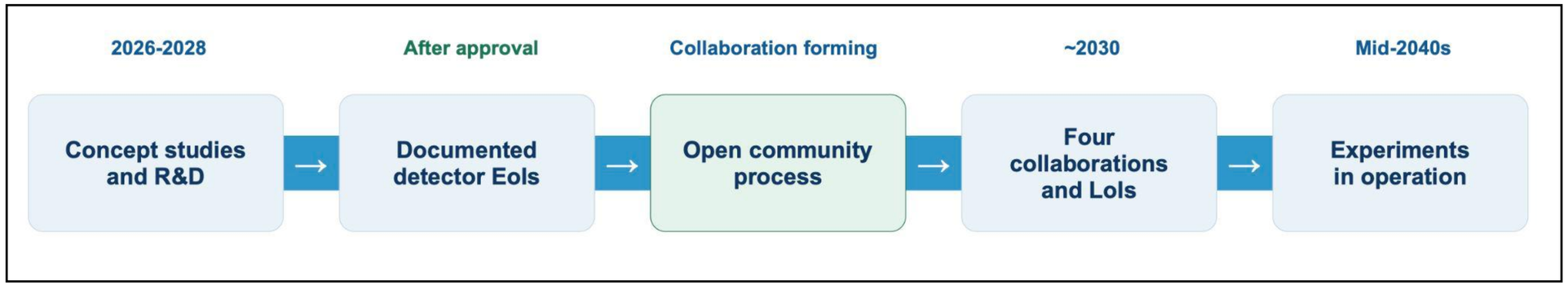
Magnetic fields
Up to 2 or 3 Tesla
Co-design with machine to avoid "emittance blow-up"

Aligning DRD Collaborations with FCC-ee Needs

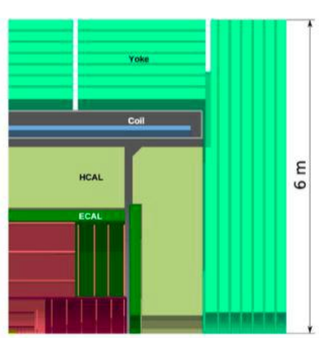
During the reference Design Phase cooperation across detector concepts and technologies is highly encouraged

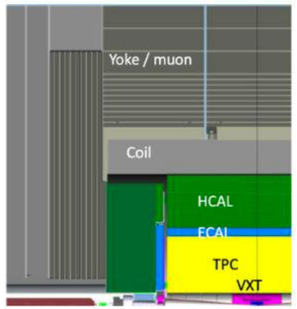
Reference Design Phase (RDP) seen from PED

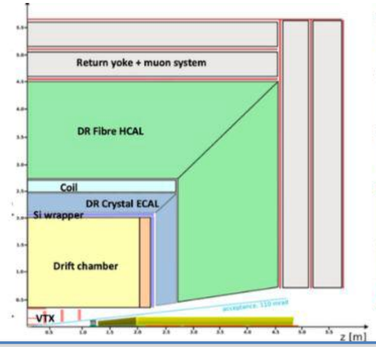
- The PED timeline is different from the rest of the study



- Six detector concepts are studied today — hopefully more coming!

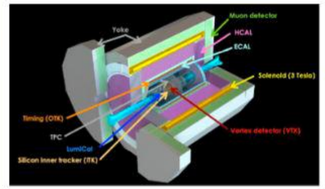












CLD	ILD	IDEA	ALLEGRO	ALFA	AGORA

- Expression of interests will be called AFTER the approval (but prepared now)
- Collaboration forming (merging, etc.): Evian-like series of workshop in 2029-30
  - ⊙ From 6+ detector concepts to four collaborations and four Letters of Intent in ~2030
- Detector CDRs in 2033-34; TDRs in 2036-37; Detectors ready in 2045-46.

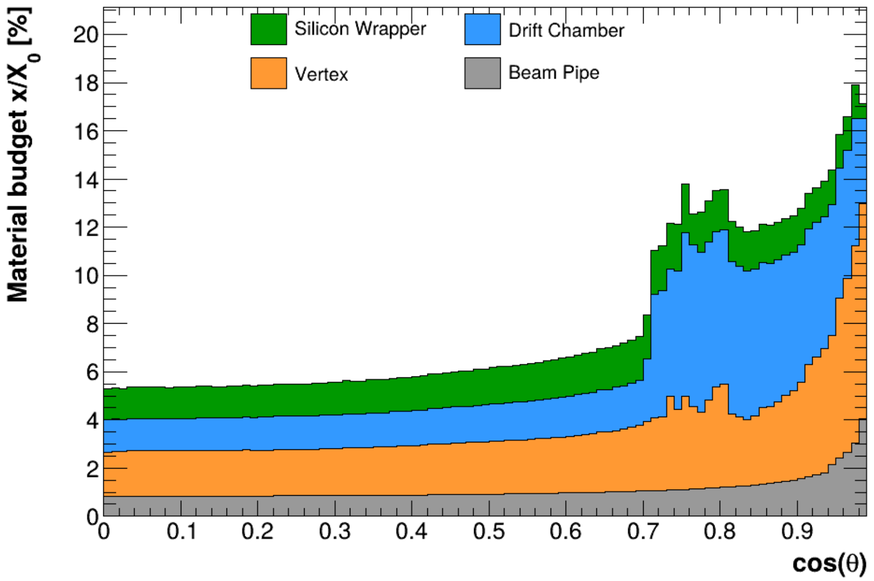
PED coordination

FCC-ee Detector concepts technologies

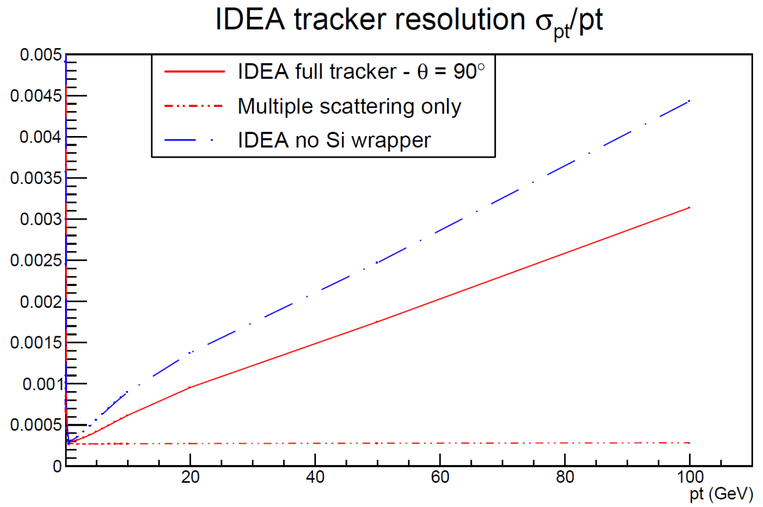
- **Vertex trackers** are very similar across the 6 detector concepts
  - MAPS (many different chips) with 3 μm position resolution (planar or curved geometry)
- **Central tracker**
  - Gaseous (Drift chamber, TPC) or silicon sensor based (MAPS or silicon-strip)
    - Straw tubes and Scintillating fiber tracker as other options
- **Wrapper**
  - Silicon-based (strips, MAPS, LGADs), ARC
- **Calorimeters**
  - **Ecal**
    - DR crystals, high-granularity particle flow, liquid Ar (or Xe), Grainita, heavy-glass scintillating tile
  - **Hcal**
    - DR fibers, high-granularity particle flow, liquid Ar
- **Muon detector**
  - MPGDs (μRWELL, Micromegas), RPCs, scintillators, DT, TGC

FCC-ee Detector concepts performances

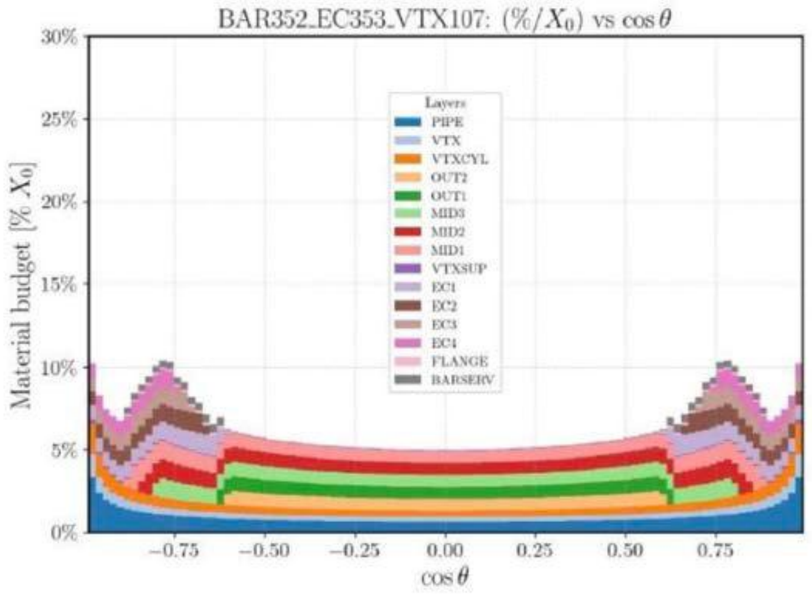
IDEA
Material budget

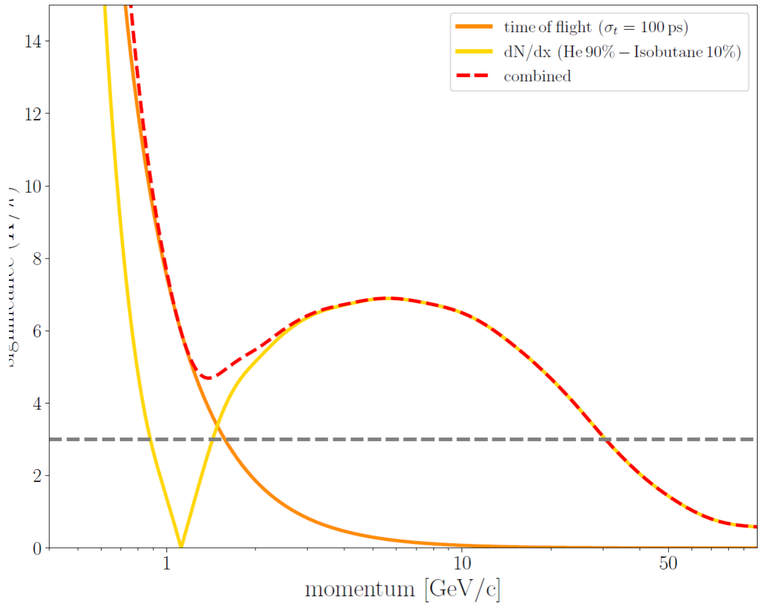


IDEA's pt resolution and PID
>3 σ K/π separation up up to 30 GeV



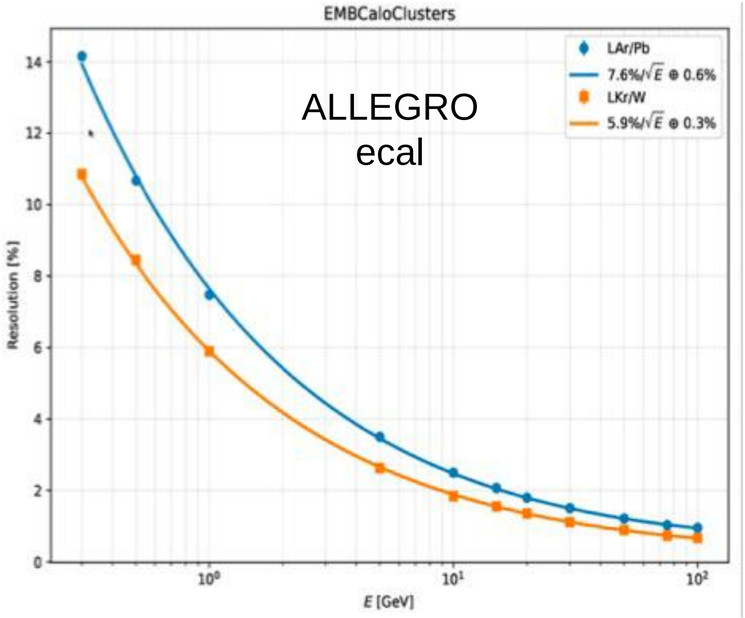
ALFA
Material budget

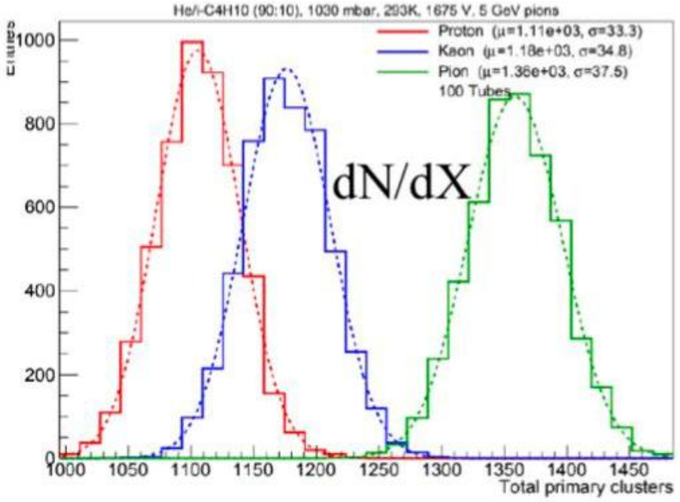




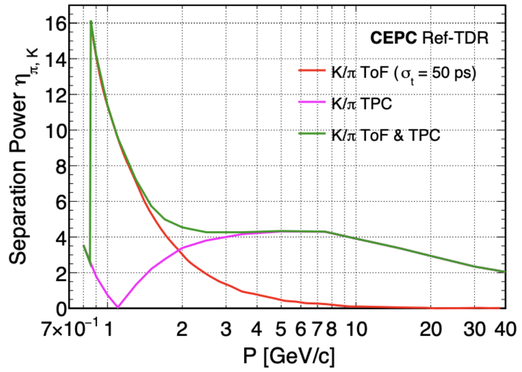
FCC-ee Detector concepts performances

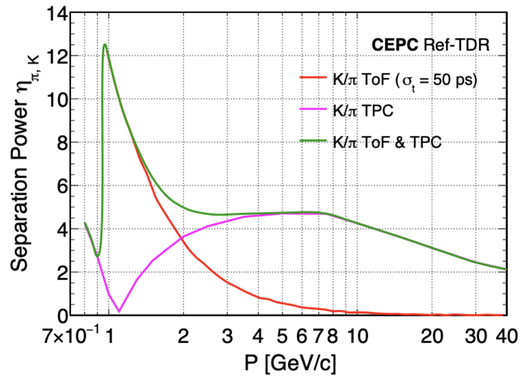
ALLEGRO
ecal

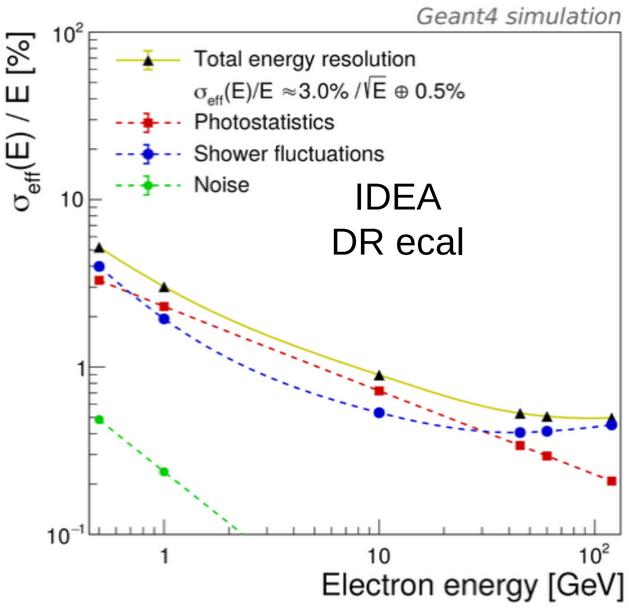


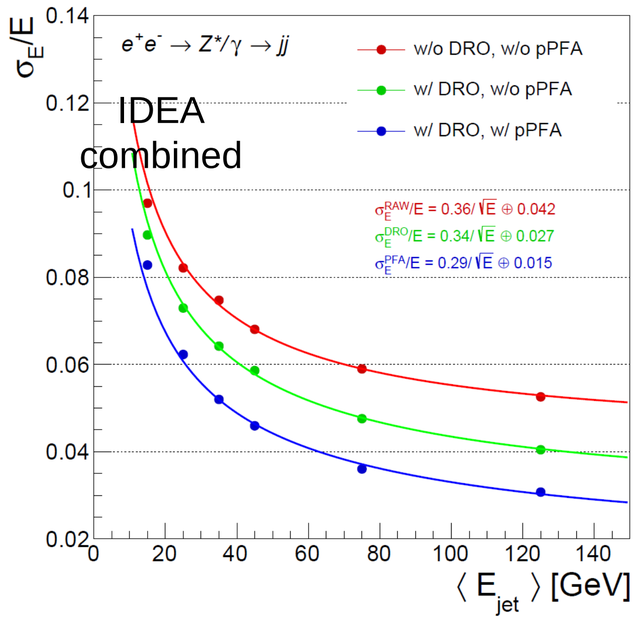


AGORA
PID





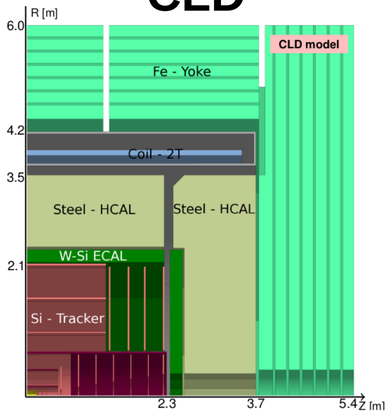




Detector concepts - Tracking systems

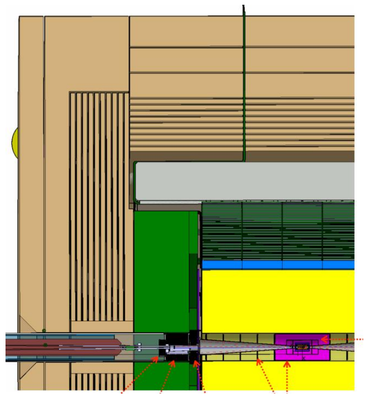
Legend: Inner Tracker, Outer Tracker, Wrappers

CLD



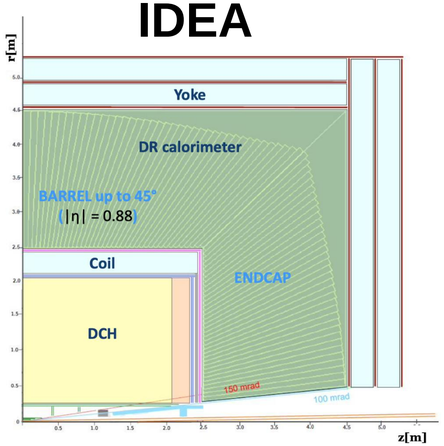
- Evolved from CLIC detector
- Silicon vertex with 25μm pixels
  - Geometry with ALICE ITS approximation → FCC-SEED
- Silicon tracker with 50μm strips
  - Sensors plus ASICs or monolithic structure or MAPS
- ARC (Array of RICH Cells) Lightweight with 20cm radial depth
  - Two radiators (gas + aerogel)

ILD



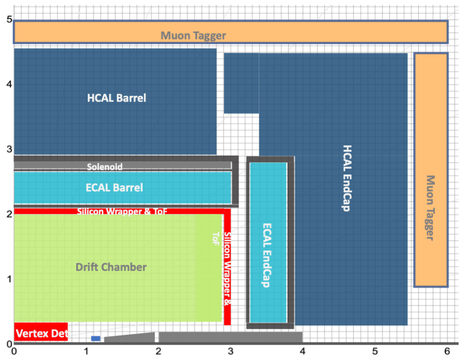
- Initial design for ILC
  - Significant changes for FCC-ee
- Silicon Vertex
  - Currently borrowed from CLD for simulations
- TPC as outer tracker
  - Studying different layouts varying the inner Radii
  - Pad or pixel electrode, GEM or Micromegas
- Silicon External Tracker for ToF + momentum resolution

IDEA



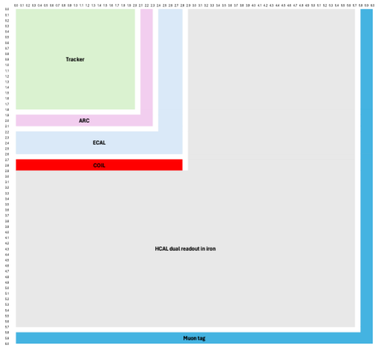
- Conceived for FCC-ee
- Silicon vertex tracker
  - Outer based on ATLASPix3 with 50x150μm² pixels
  - Inner ARCADIA based 25x25 μm² pixels
- Central tracker based on low mass Drift Chamber
  - 112 layers
  - 4m Long
  - R = 35-200cm
- Silicon wrapper
  - either with MAPS with ~10^{11} channels!
  - or CMOS-LGADs ~40ps

ALLEGRO



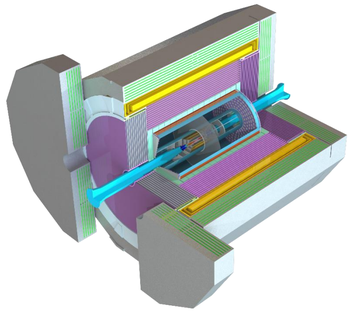
- Conceived for FCC-ee, started with a noble-liquid calorimeter
- Tracking system taken from IDEA
- Silicon Vertex with curved or straight sensors
- Outer tracker with
  - Extended Drift Chamber
  - Straw tubes
  - Scintillating Fiber Tracker (SciFi)
    - 5m Long
    - R = 35-200cm
- Silicon wrapper
  - Monolithic pixel or AC-LGADs

ALFA



- Newly Conceived project for FCC-ee
- MAPS tracker following ALICE ITS3 developments
  - Vertex curved MAPS 65 nm CMOS TPSCo 10x10 μm² pixels
  - Outer tracker Reticle-size MAPS,
    - 25x32 mm² to 50x128 mm² module
- ARC (Array of RICH Cells) Lightweight with 20cm radial depth
  - Two radiators (gas + aerogel)

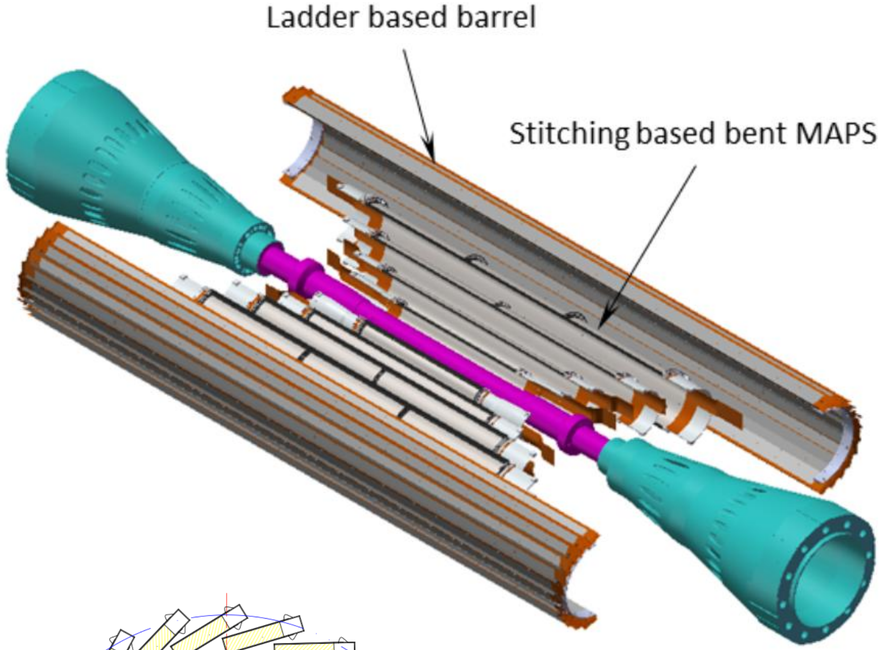
AGORA

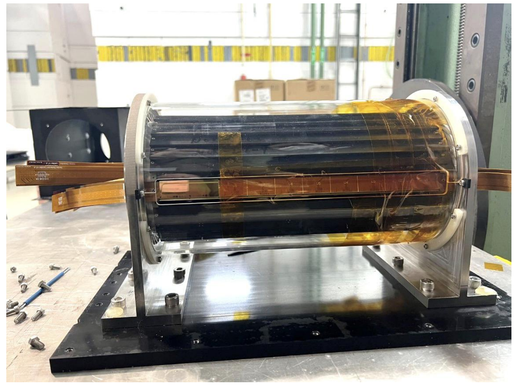


- Newly Conceived project for CEPC
- MAPS tracker
  - Vertex curved MAPS 55 nm CMOS COFFEE3 pixels+stitching (4 single layers)
  - Inner tracker Si pixels CMOS MAPS 55 nm (2 double-sided conventional layers)
- Central tracker TPC with high granularity readout
  - 5.8 m long
  - 600 mm inner radius
- AC-LGAD ~40 ps

Detector concepts - Tracking systems

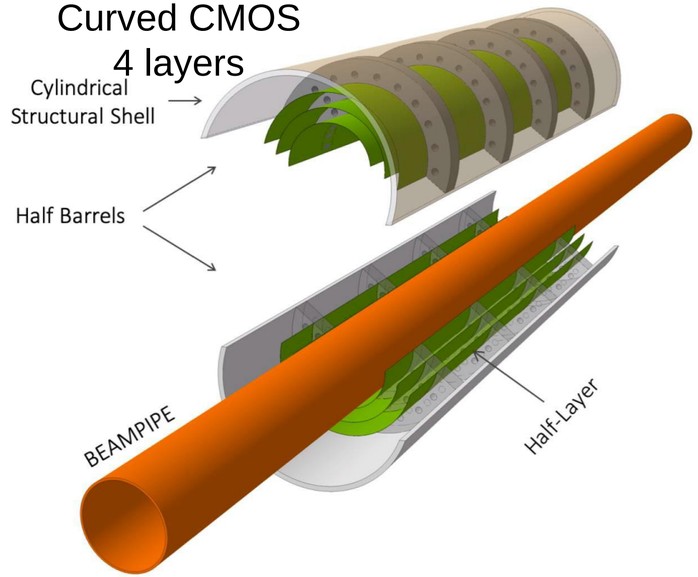
AGORA
Curved MAPS stitched
4 layers

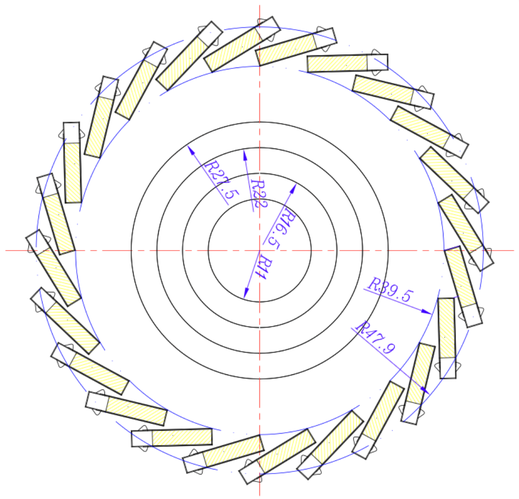




TaichuPix-based ladder prototype
@ DESY, spatial res. <5 μm

IDEA
Curved CMOS
4 layers





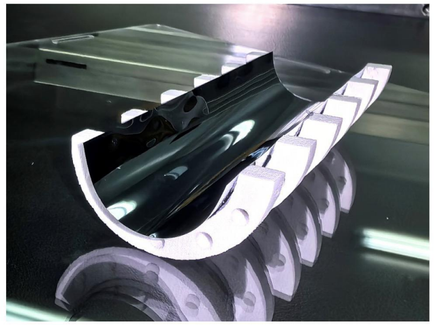
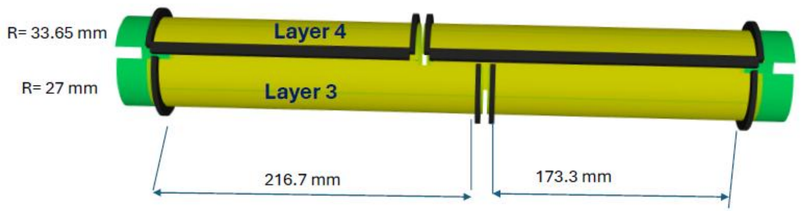
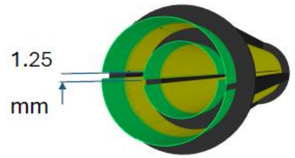
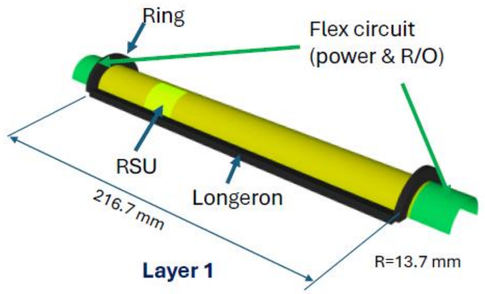


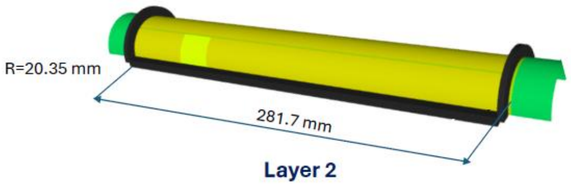
Figure 4.26: 12 mm bending radius.

Sensor bending demo'd for 12mm radius







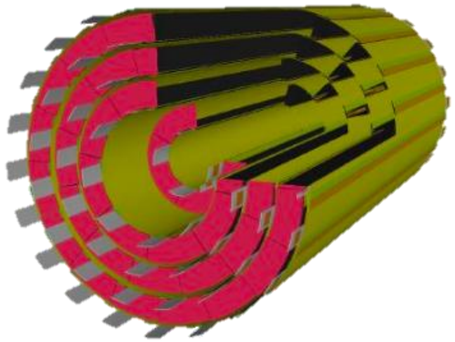


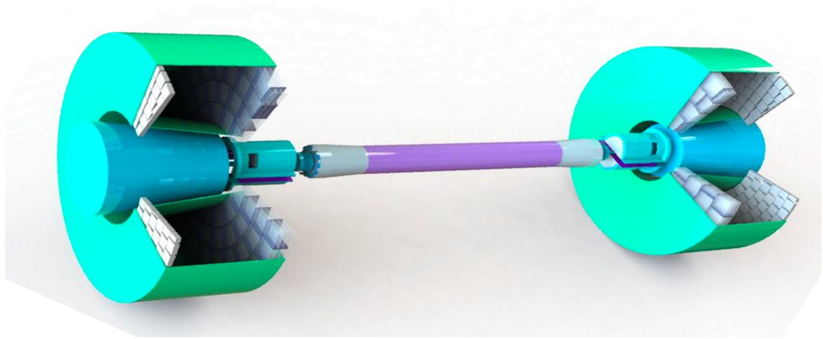
Detector concepts - Tracking systems

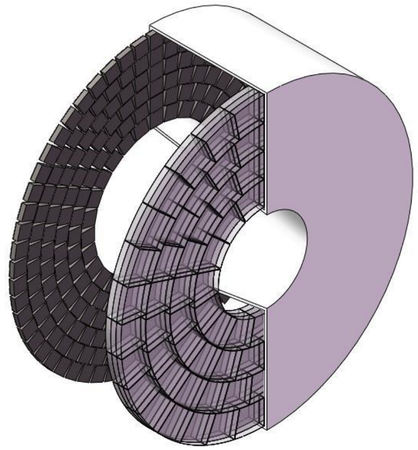
ILD and CLD
FCC-SEED

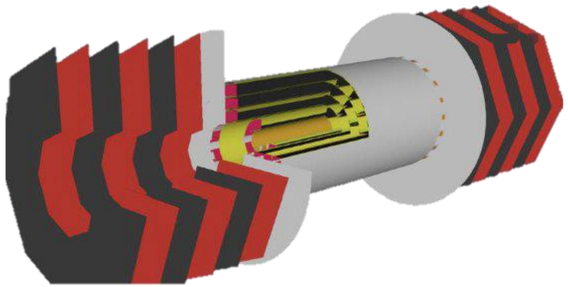
AGORA
RICH

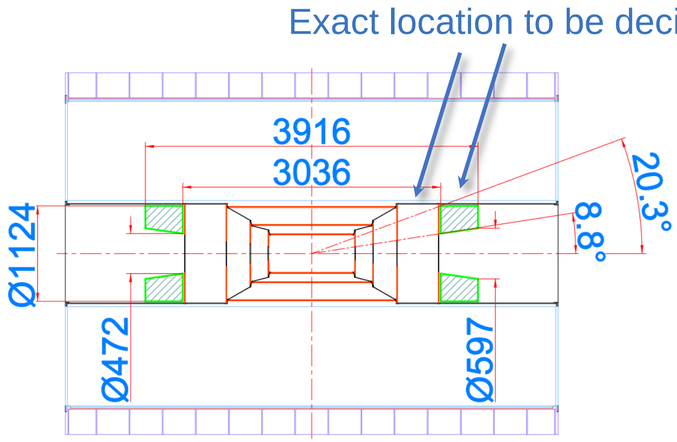
[FCC Snail-shape vErtEx Detector (FCC – SEED)]





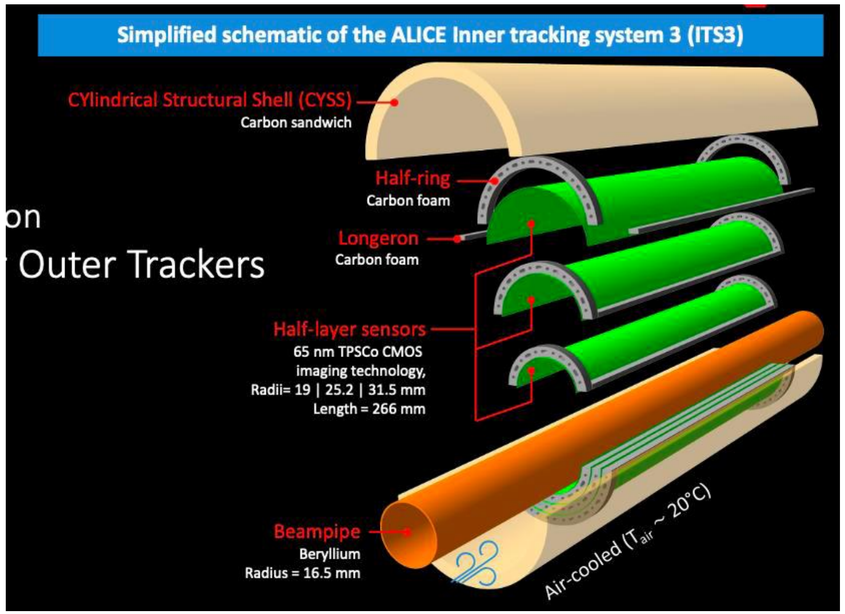




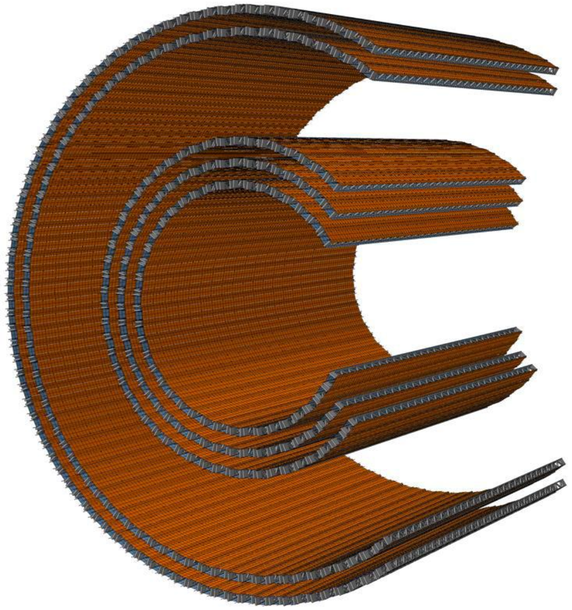


Detector concepts - Tracking systems

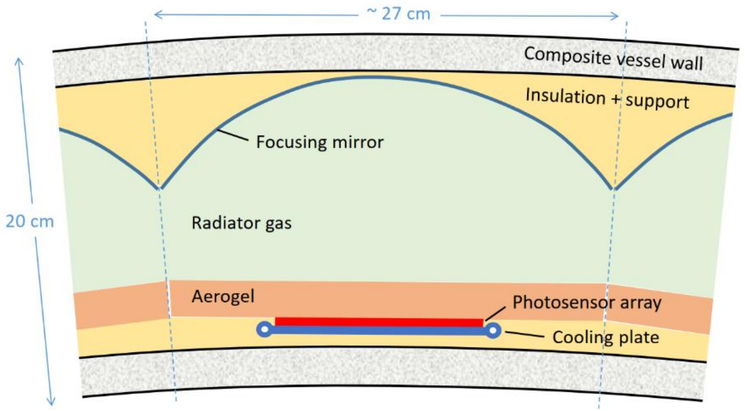
ALFA
Curved MAPS
4 layers

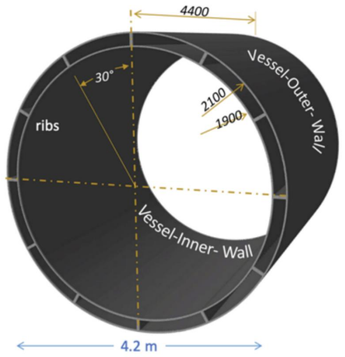


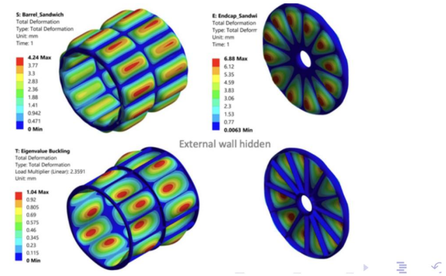
ALFA
Outer tracker

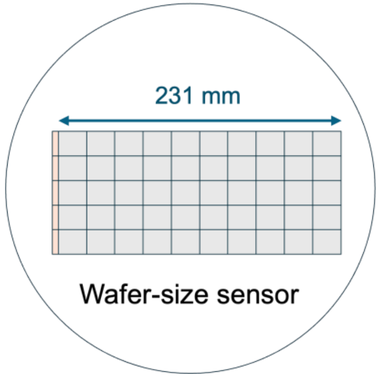


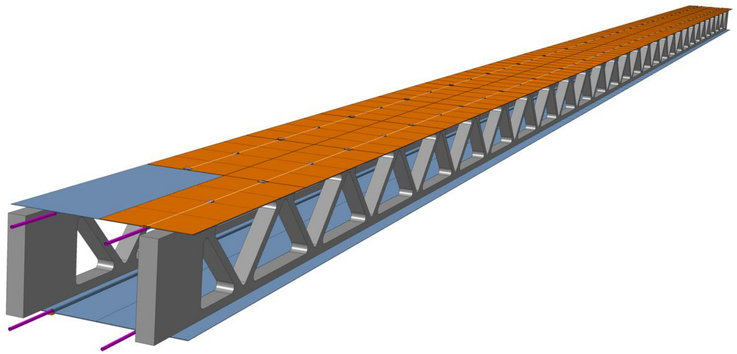
ALFA
ARC





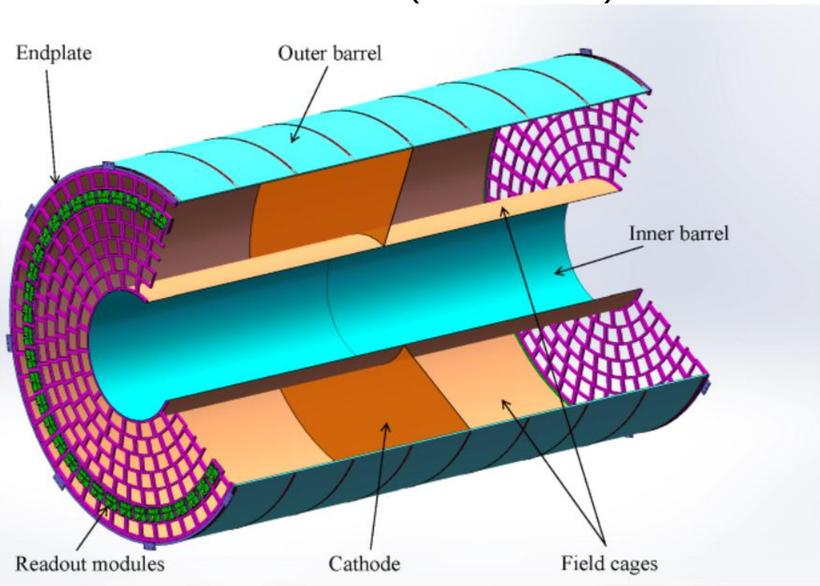




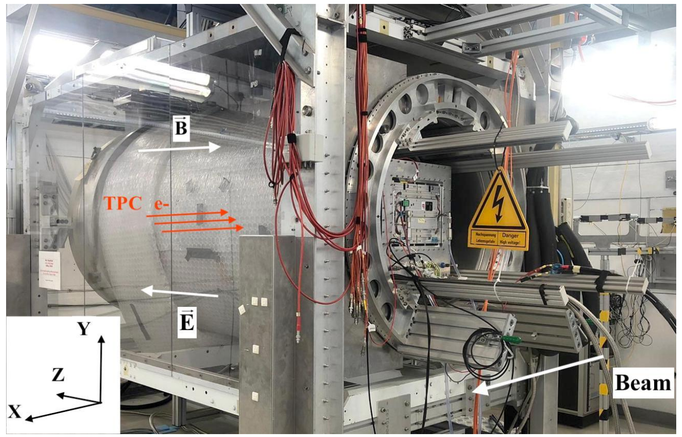


Detector concepts - Tracking systems

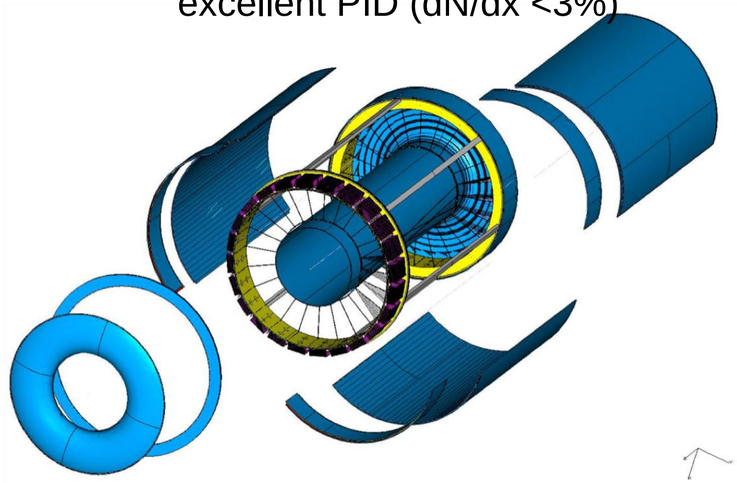
AGORA
TPC
Good tracking (σ~100 μm),
excellent PID (dN/dx ~3%)

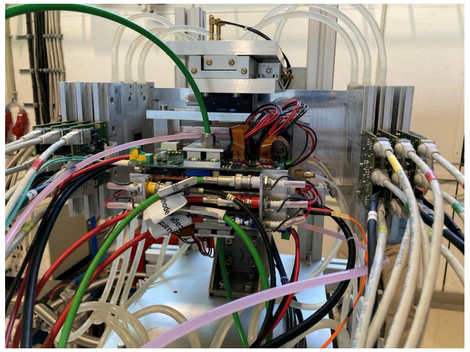


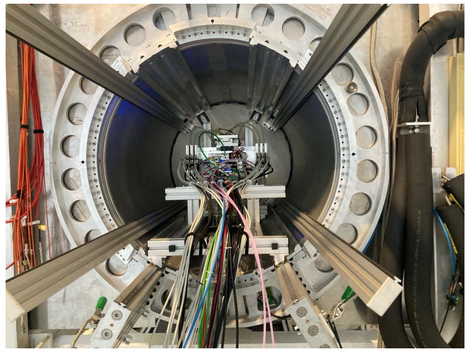
ILD
TPC
Good tracking (σ~100 μm)

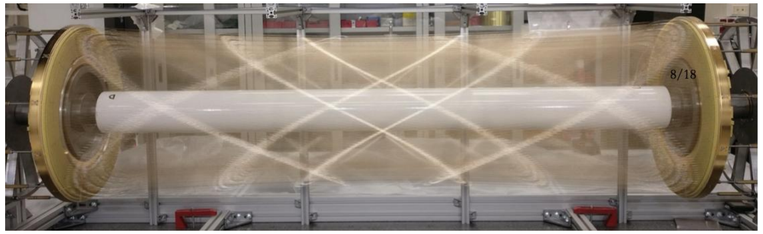


IDEA
Drift chamber
Good tracking (σ~100 μm),
excellent PID (dN/dx <3%)





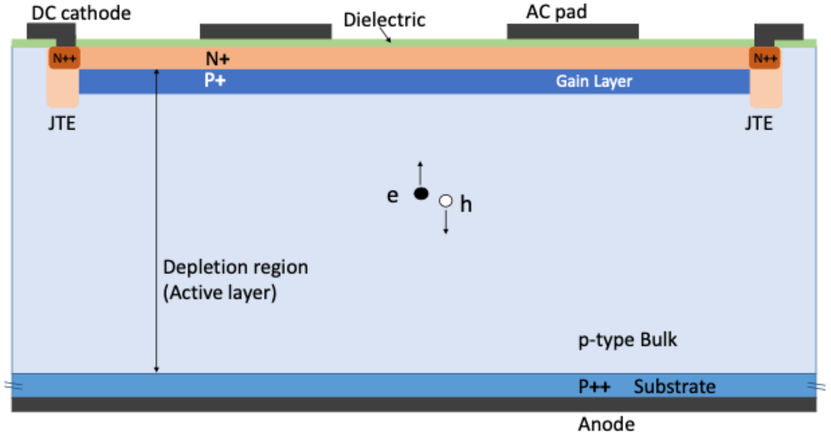


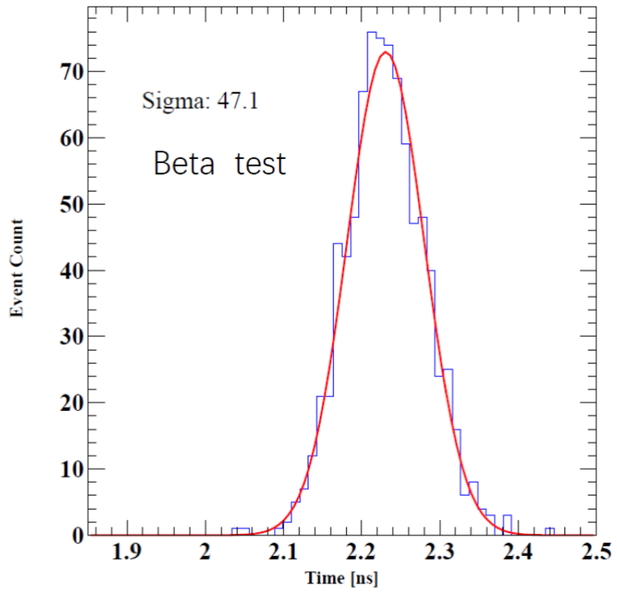


2021 TB: 32 GridPi Nucl. Instrum. Meth. A 1075 (2025) 345

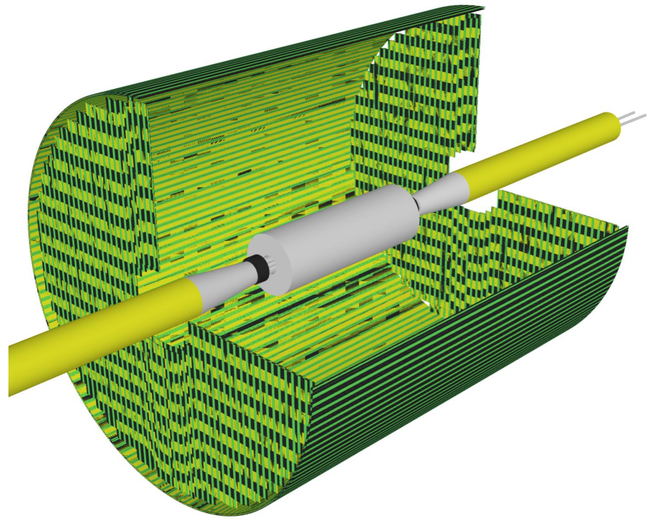
Detector concepts - Tracking systems

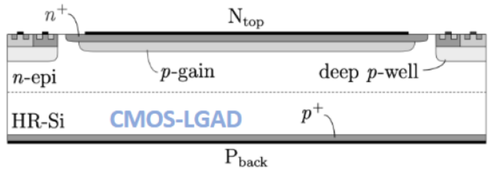
AGORA
Outer tracker

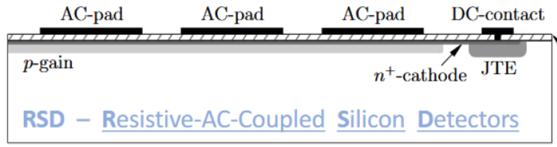




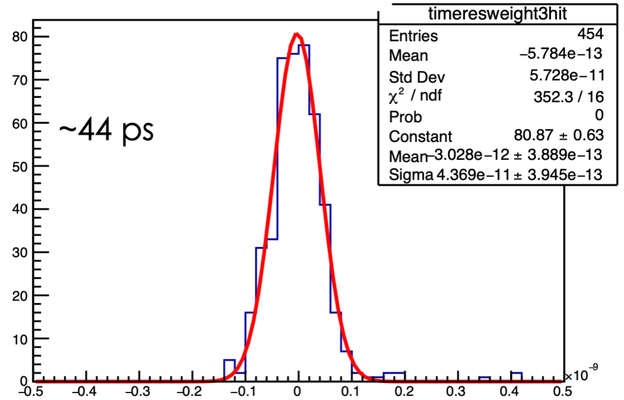
IDEA
Silicon wrapper





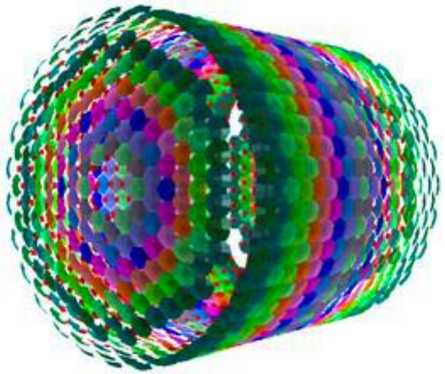


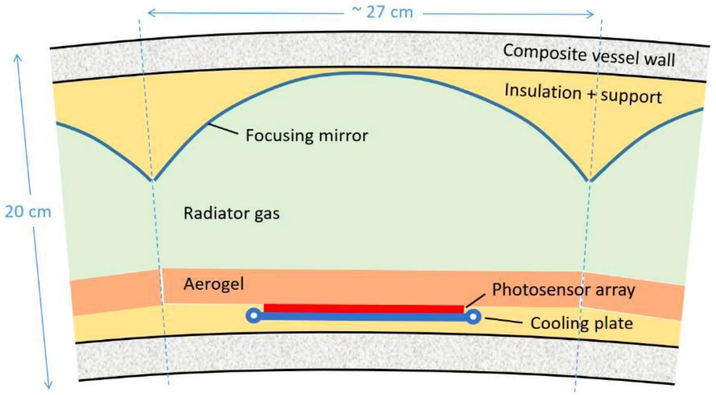
100 - 200

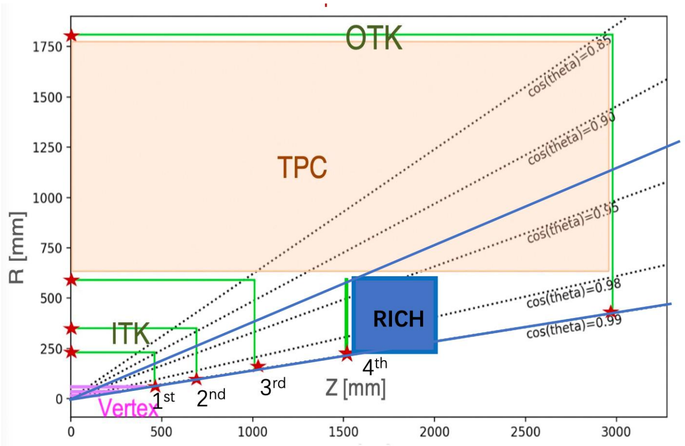


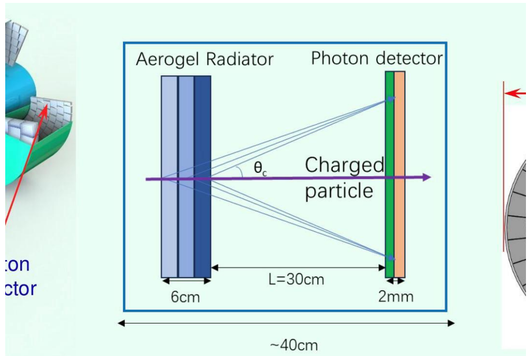
Detector concepts - Tracking systems

ALFA
ARC
dual radiator RICH

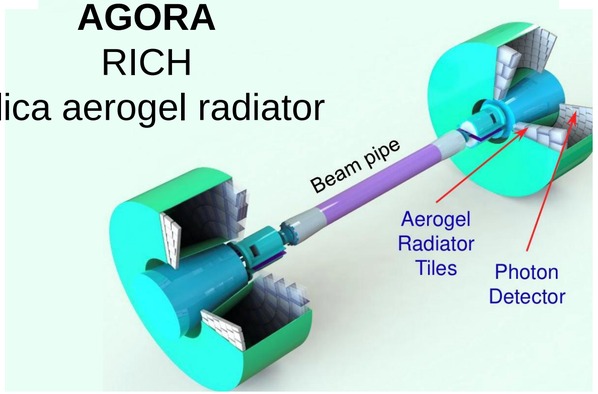






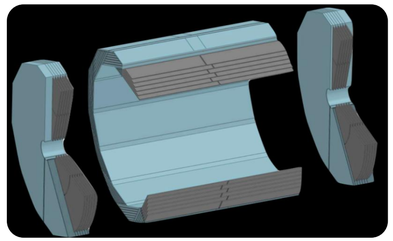


AGORA
RICH
silica aerogel radiator



Detector concepts - Calorimetry

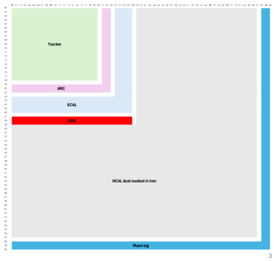
AGORA



ECAL: 4D transverse BGO crystal bars

HCAL: Heavy-glass (GFO) scintillating tile technology

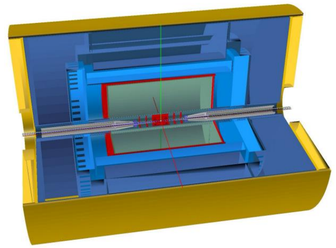
ALFA



ECAL: Grainita, crystal grains ($ZnWO_4$) immersed in a sodium-tungstate water solution

HCAL: DR fibres with Iron

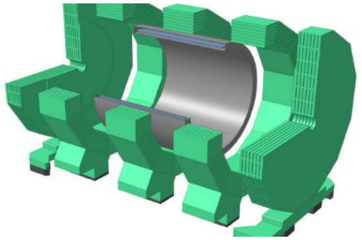
ALLEGRO



ECAL: High-granularity LAr (or LXe)

HCAL: High-granularity LAr

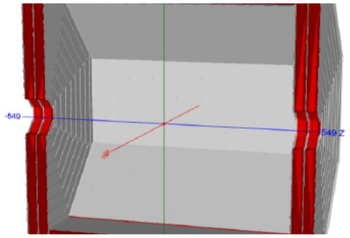
CLD



ECAL: High-granularity Si-W

HCAL: High-granularity Scintillator-steel

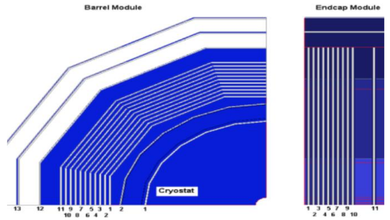
IDEA



ECAL: PWO or BS(G)O DR crystals (possible LYSO timing layer)

HCAL: DR fibres-steel

ILD



ECAL: High-granularity Si-W or Sci-W

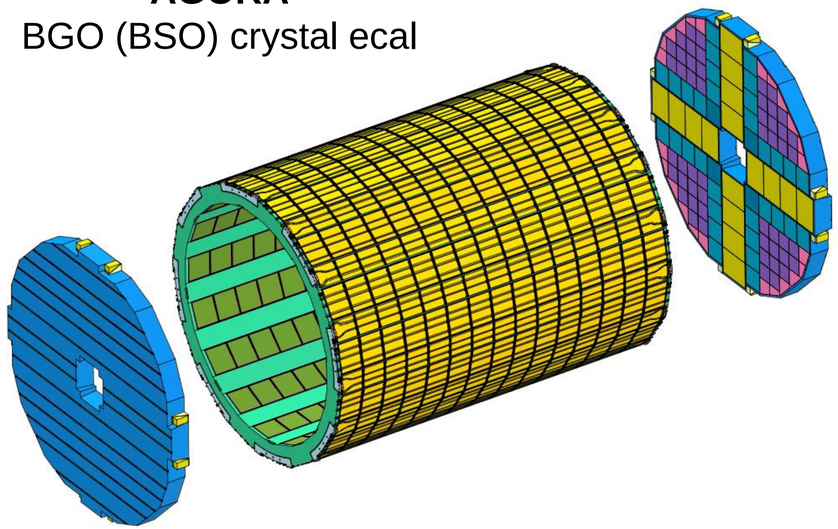
HCAL: High-granularity Scintillator-steel (analog) or RPC-steel (semi-digital)

Energy resolution ECAL: 2-3%/√E

Energy resolution HCAL: 30%/√E

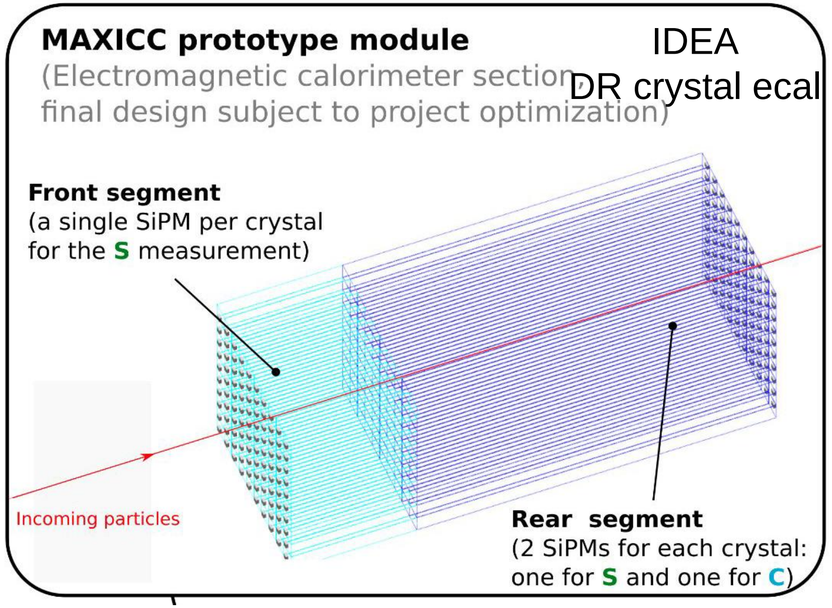
Detector concepts - Calorimetry

AGORA
BGO (BSO) crystal ecal



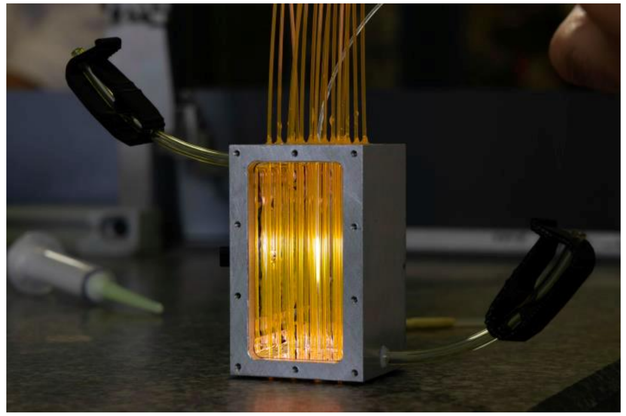
MAXICC prototype module
(Electromagnetic calorimeter section, final design subject to project optimization)

IDEA
DR crystal ecal



ALFA
Grainita ecal

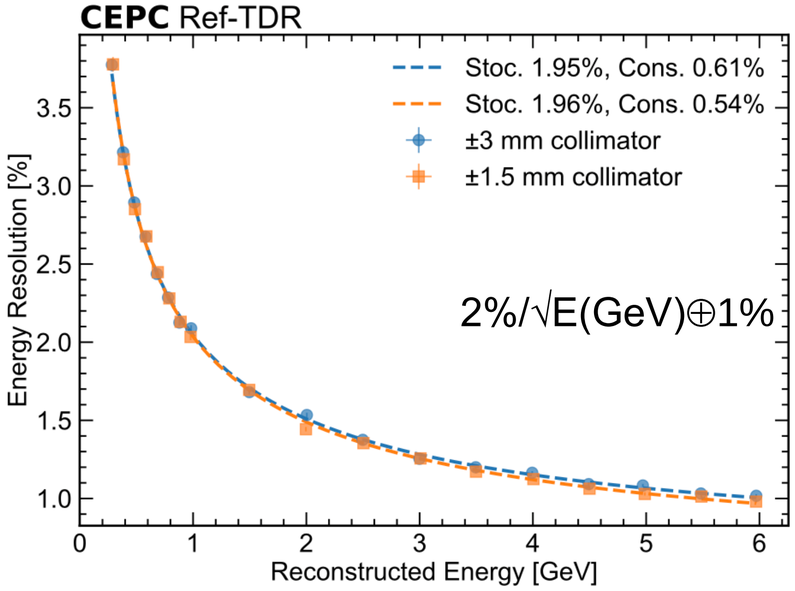
without grains



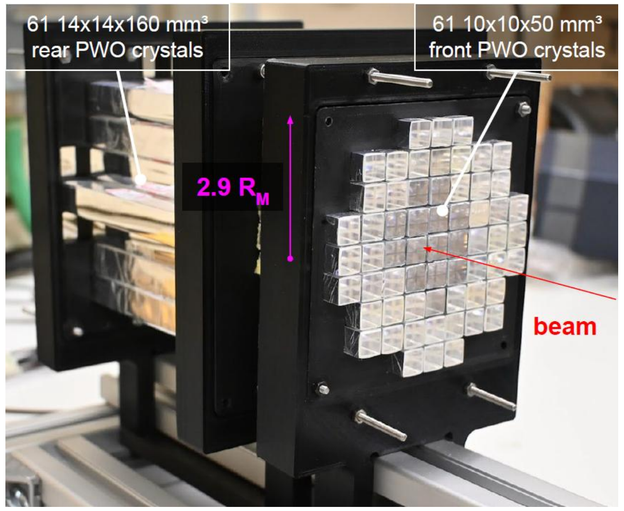
with grains



CEPC Ref-TDR

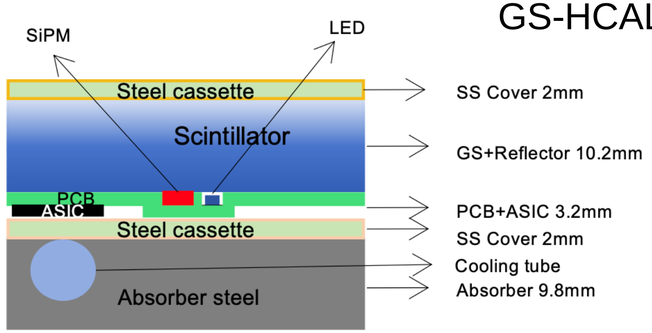


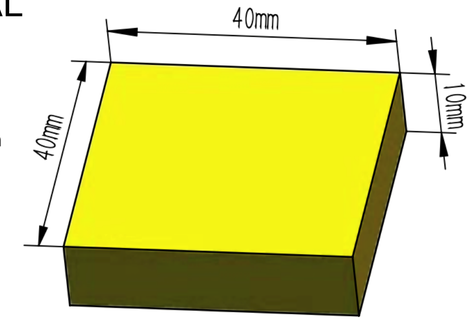
Test beam at SPS H8
with HiDRa in 2026



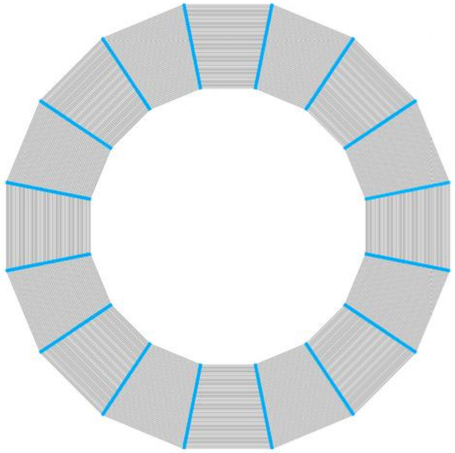
Detector concepts - Calorimetry

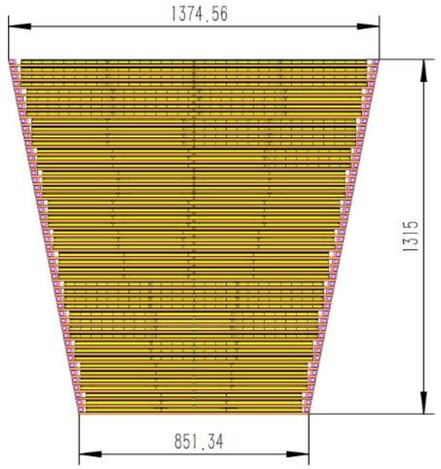
AGORA
GS-HCAL



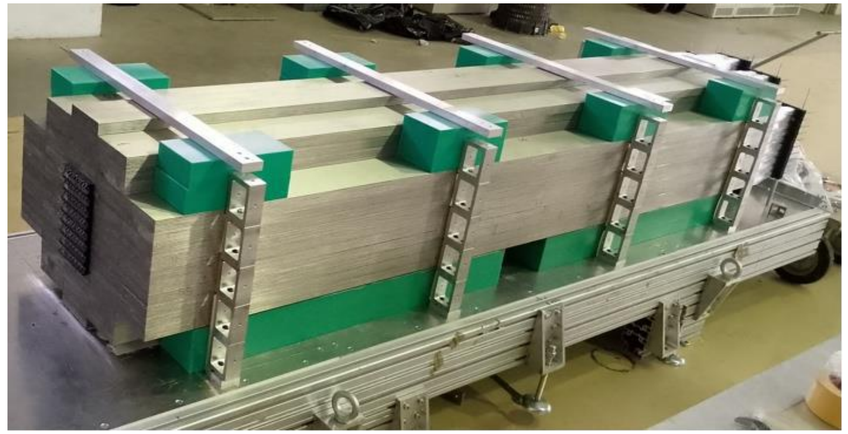


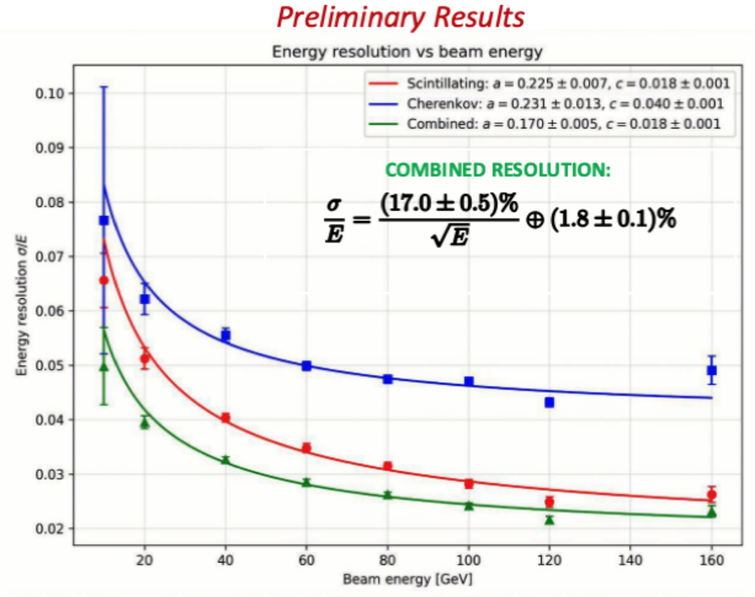
Sampling ratio (~30%)
energy resolution 30%/√E





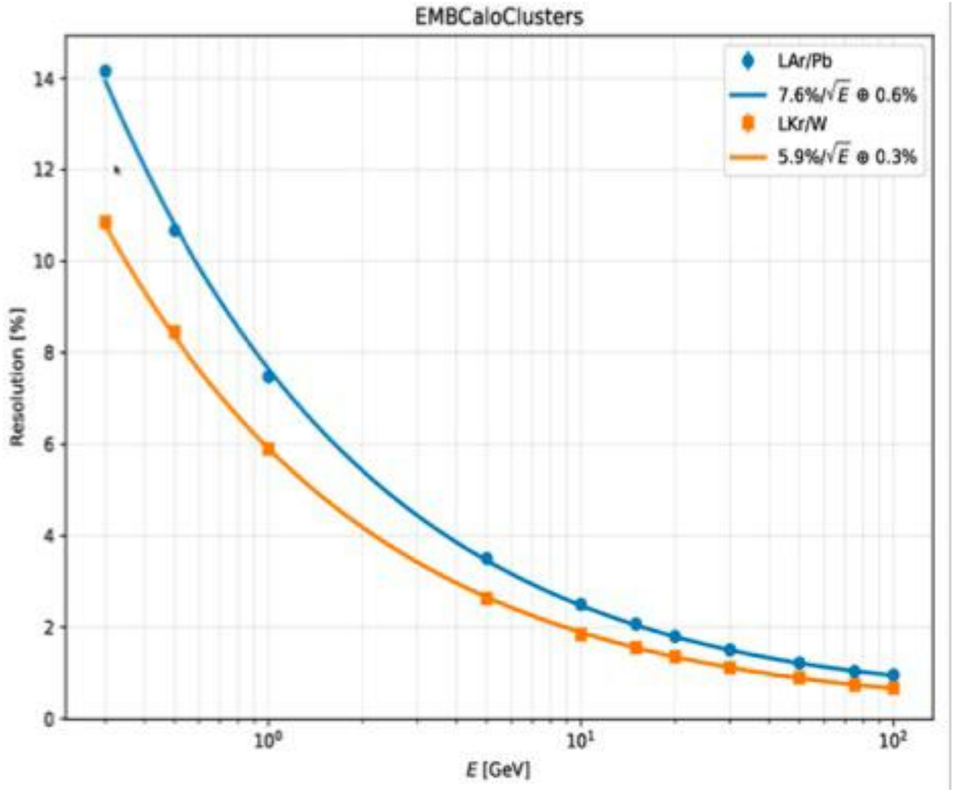
IDEA
DR fiber hcal



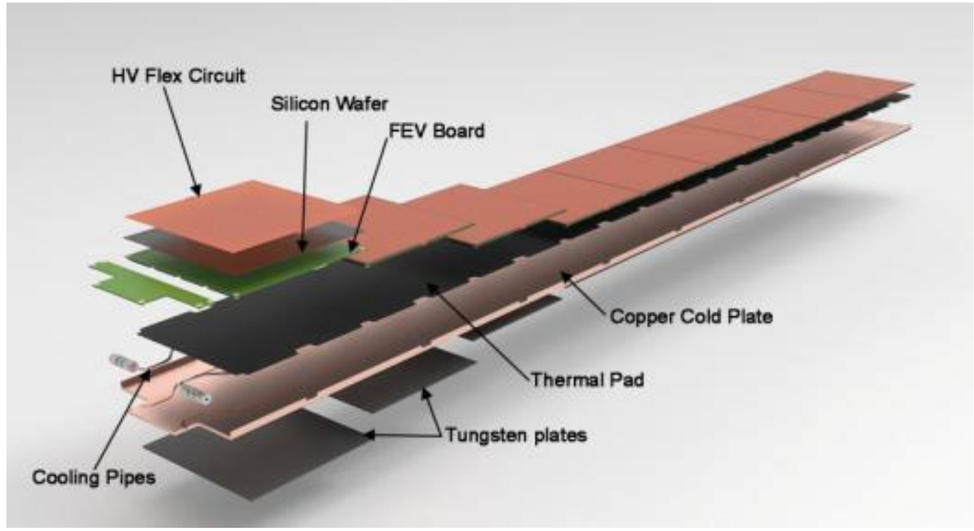


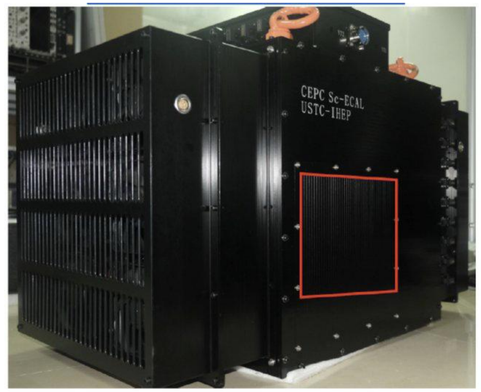
Detector concepts - Calorimetry

ALLEGRO
ecal



CLD and ILD
Si-W ecal

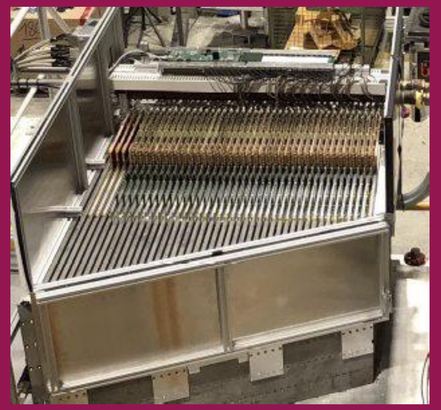


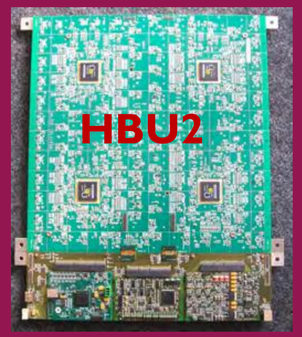


Detector concepts - Calorimetry

ILD
Scintillator HCAL-AHCAL

Scintillator HCAL - AHCAL

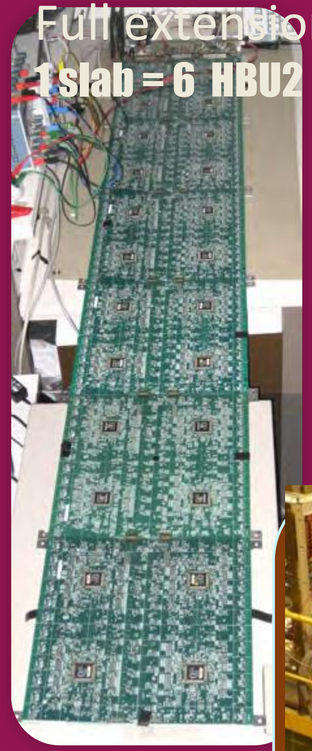






144 channels

Tiles **3x3**x0.3 cm^3
38 layers 0.72 x 0.72 m^2
~22.000 channels

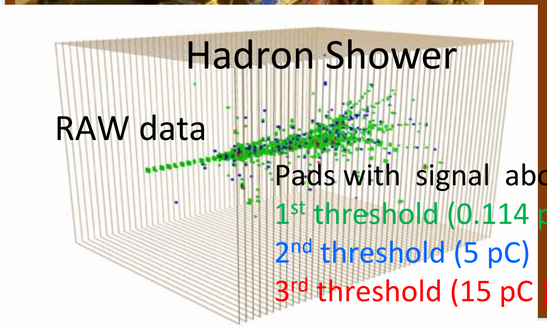


ILD
GRPC HCAL-SDHCAL



Semidigital HCAL – SDHCAL

- 48 GRPC layers (-6λ_I)
- 1 cm^2 pads - 3-threshold –Semi-digital Readout
- Self-supporting mechanical structure (<500 µm deformation)

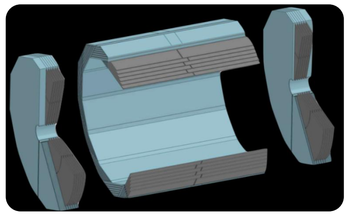






Overview of Muon detection systems

AGORA



Tech: plastic scintillator strips

Layout: 6 layers in iron yoke

Purpose: tagging muon system

ALFA

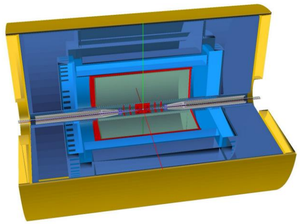


Tech: RPC or Scint. under discussion, possibly same HCAL

Layout: under discussion

Purpose: tagging muon system

ALLEGRO

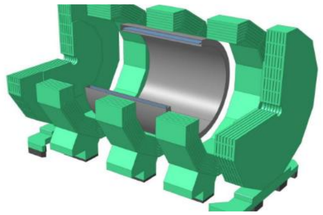


Tech: Squared drift tubes and Scintillator strips or Micromegas or Bigap RPCs

Layout: under discussion

Purpose: both tagging muon system and tracking muon system are considered

CLD

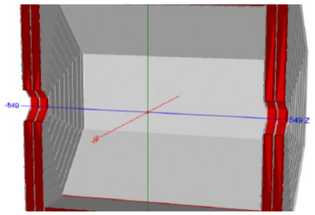


Tech: RPCs with 30x30 mm² cells.

Layout: 6 equidistant layers embedded in yoke slots. and 1 extra layer behind solenoid as tail-catcher.

Purpose: high granularity tagging and calorimetry support.

IDEA

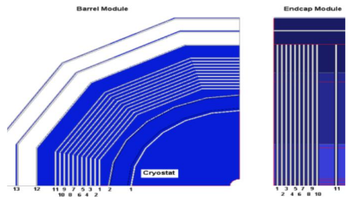


Tech: 50x50 cm^2 μ-RWELL chambers with 1.2 mm strip pitch

Layout: 4 stations interleaved with 30/50 cm iron yoke

Purpose: standalone tracking muon system for LLP

ILD



Tech: Scintillators (SiPM/WLS) or X-Y RPCs, possibly same HCAL

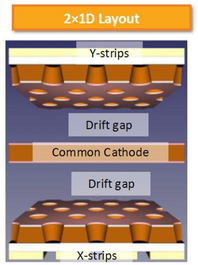
Layout: 14 active layers in barrel, 12 layers in endcap in iron yoke

Purpose: Robust tagging and 2D reconstruction

Performance: over 95% efficiency, under 1%→μ fake rate
Coverage: over 98% solid angle
Resolution: 1 ns time resolution and 1 cm spatial for tagging muon system or 200 μm spatial for tracking muon system
Rate: 50 Hz/cm^2 in the barrel and 10 kHz/cm^2 in the endcap

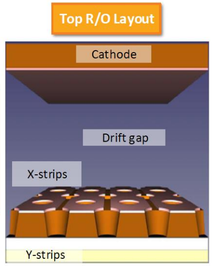
Overview of Muon detection systems

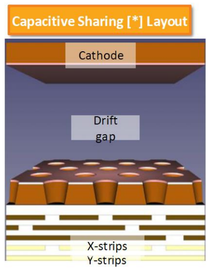
IDEA
4 layers
μRWELL-based



Lower gas gain w.r.t. the "COMPASS R/O" (X / Y are not sharing any charge)
Pitch strip: 0.8 mm

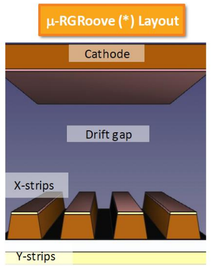
Lower gas gain w.r.t. the "COMPASS R/O" (X / Y are not sharing any charge)
The "Top" coordinate introduces dead zone in the active area
Pitch strip: 0.4 mm

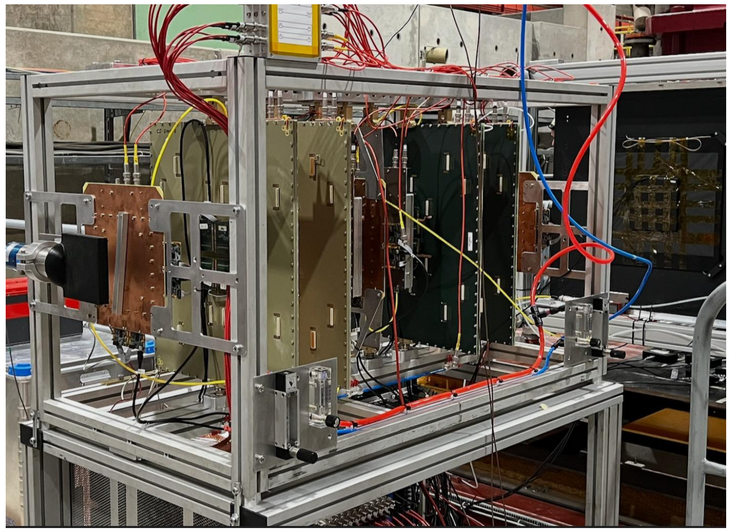




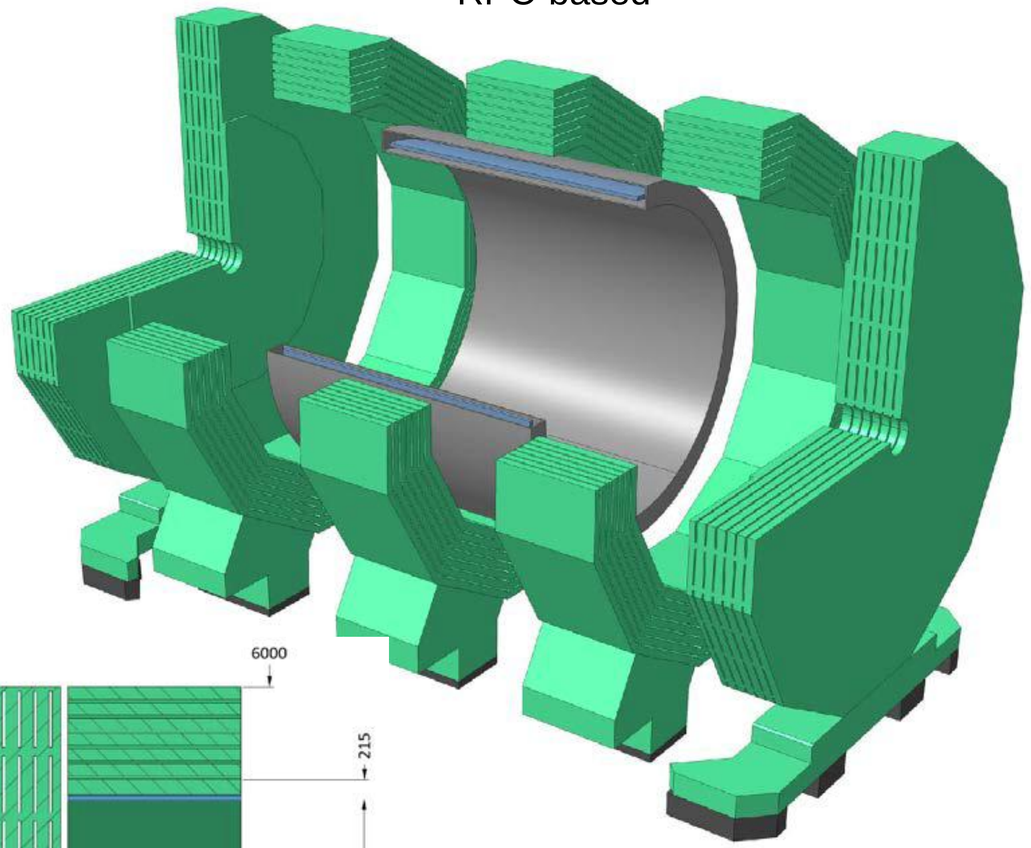
Reduce the FEE channels
The charge is divided between X and Y → Higher gas gain required w.r.t. 1D
Pitch strip: 1.2 mm

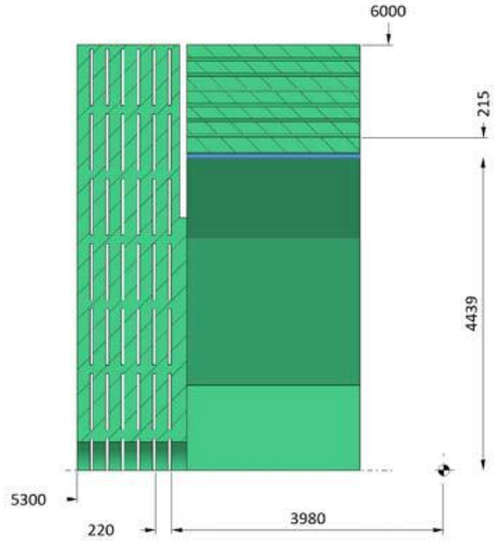
Lower gas gain w.r.t. the "COMPASS R/O" (X / Y are not sharing any charge)
No dead zone w.r.t the Top R/O lauout
Pitch strip: 0.4 mm





ILD
RPC-based

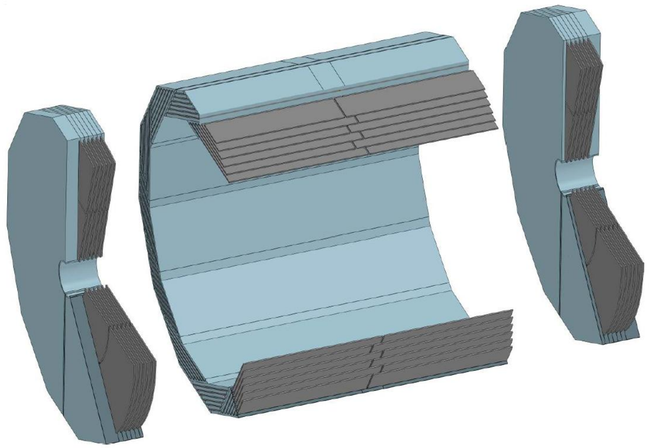


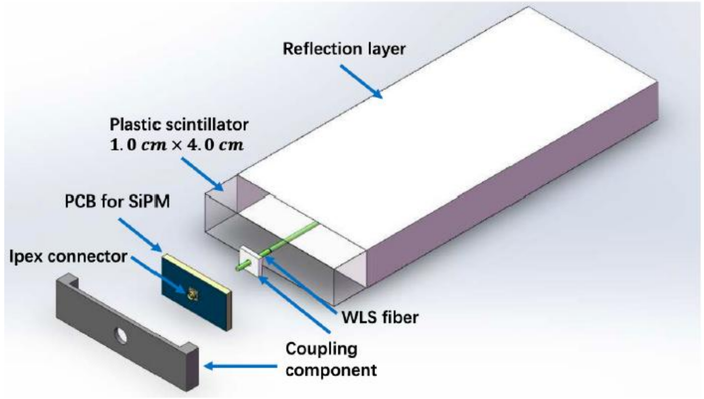


Overview of Muon detection systems

AGORA
scintillator-based

- 6 layers of plastic scintillator strips embedded in the iron Yoke
  - μ identification efficiency: > 95%
  - Spatial resolution: ~1 cm
  - Time resolution: ~1 ns





A 5-m plastic scintillator strip

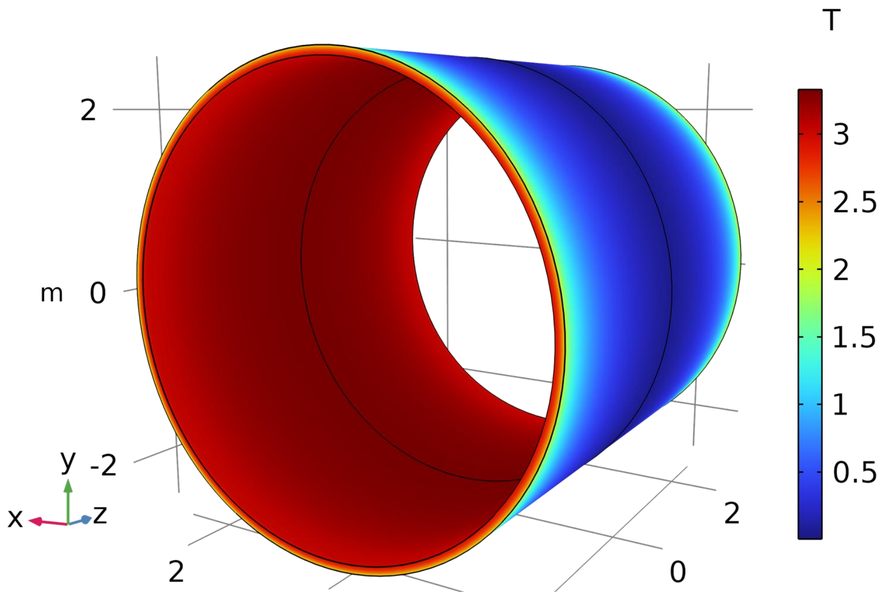


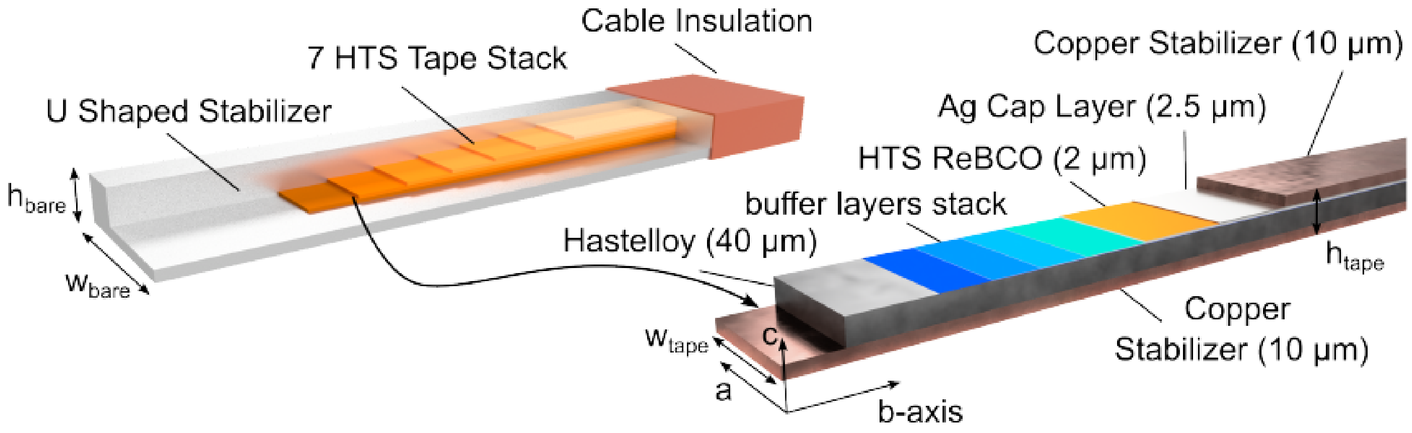
Solenoids

Using IDEA as an example

Max. field 3 T, maybe have to use 2 T at the Z peak

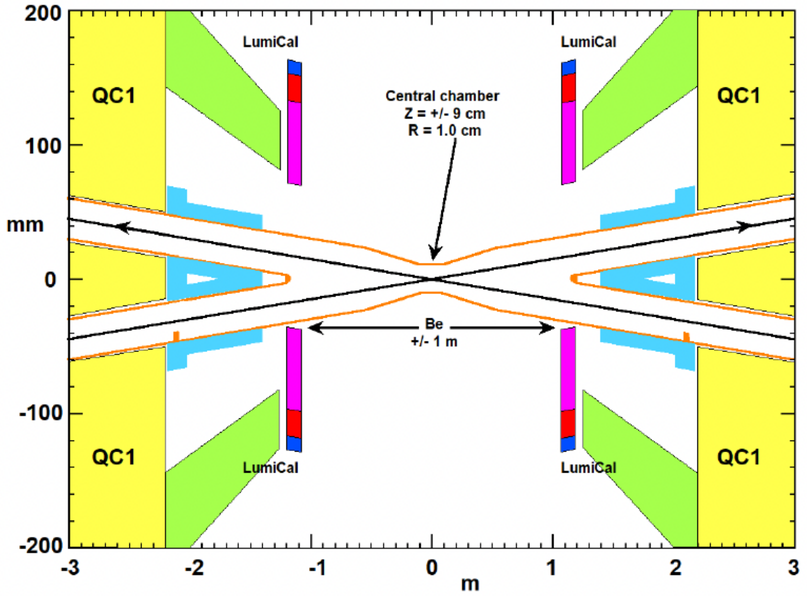
- Two options: standard SC or HTS
  - Light NbTi 2T field - Rin = 2.5 m
    - Total thickness ~30 cm
    - Total mass = 0.74 X_0 (0.16 λ) at $\theta = 90^o$
- Current HTS baseline
  - HTS 2-3T field @20 K - Rin = 2.5 m
    - Total thickness ~30 cm
    - Total mass = 1.74 X_0 (0.38 λ) at $\theta = 90^o$
    - Studying impact of additional material

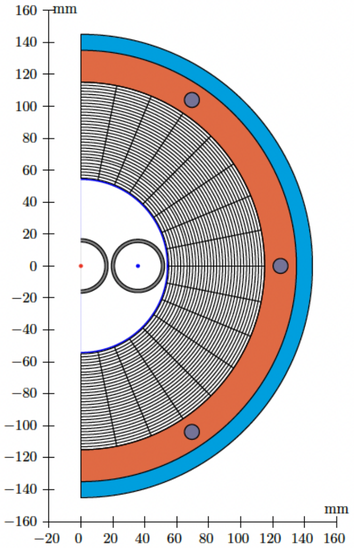


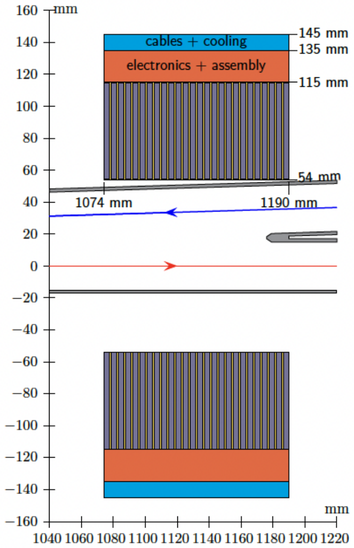


Luminometers

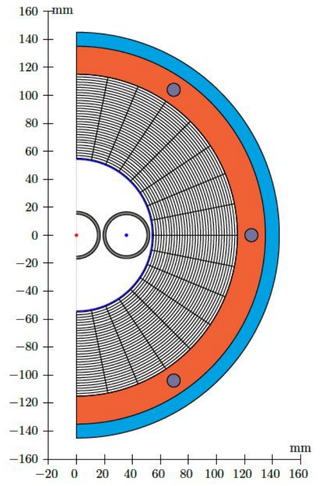
- One existing concept made of W and Si-strip layers
  - Inspired by the OPAL luminosity calorimeter

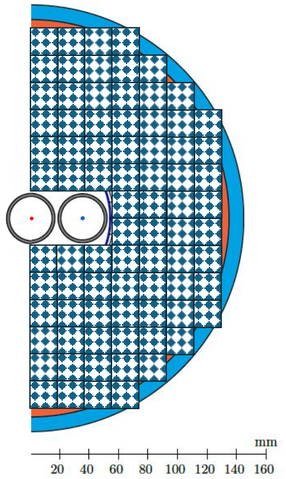






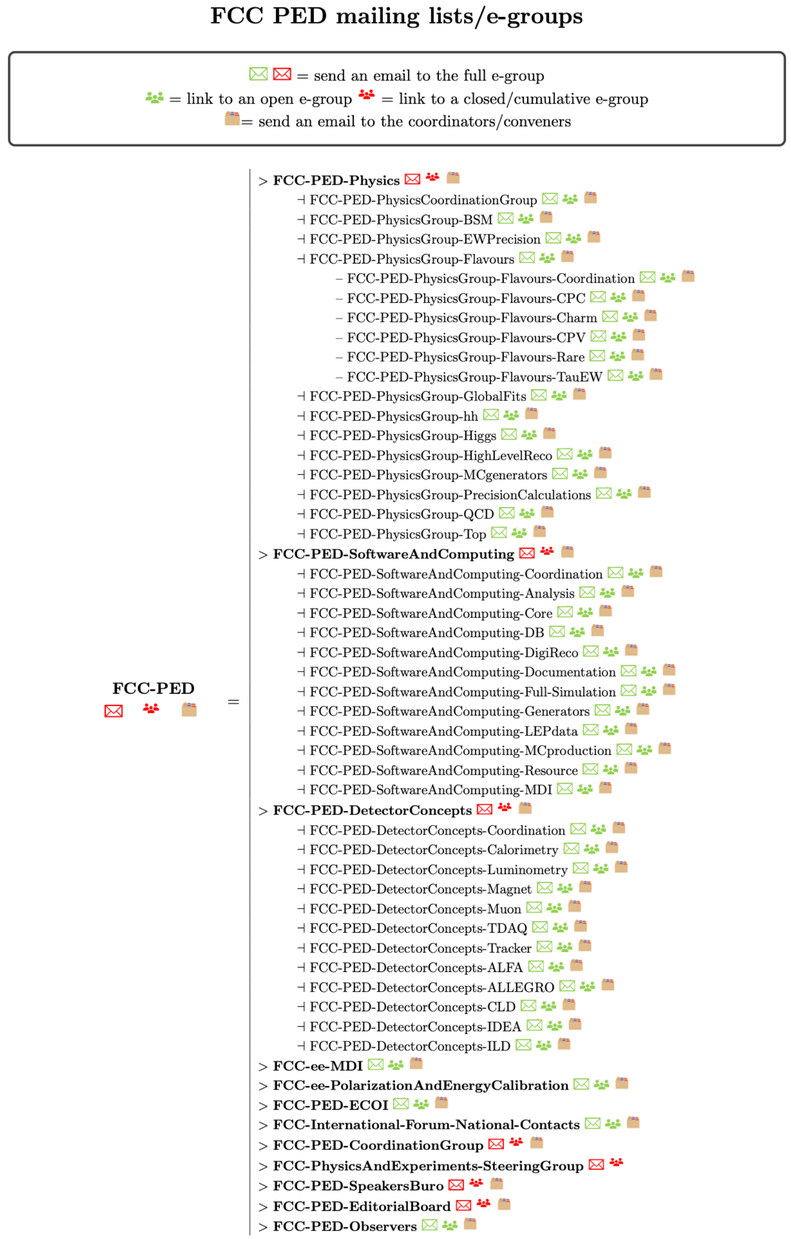
ALFA's proposal
MAPS-based





Still a lot of work to do!

FCC PED mailing lists and links



https://fcc-ped.web.cern.ch/organisation

Conclusions

- The FCC integrated program provides a fantastic future scientific program for particle physics for the next 60-70 years
  - In the first phase, FCC-ee, electron-positron collisions will be studied
    - Six detector concepts have been proposed so far
      - In the RDP there is cooperation across detector concepts and technologies
      - EOIs will be sent by all detector concepts after FCC's approval
        - Chinese physicists are now fully integrated in the FCC PED structure
          - AGORA is one of the FCC-ee detector concepts
        - 4 detectors and collaborations will be selected and they will send their LoI
  - We are living in very interesting times, especially for our young collaborators
- We are open to cooperation and collaboration, there are plenty of opportunities

Backup