Highlights of The Detector Technology and Computing at ICHEP 2022

Jianchun Wang

07/22/2022

General Impression

- ICHEP is one of the most prominent conference in HEP. It started more than 70 years ago. The CEPC2022 at Bologna is the number XLI.

- The program is packed with interesting presentations (3 days parallel, 3 days plenary).

- Parallel sessions (July 7-9), total 17 scientific topics:

  12) Operation, Performance and Upgrade (incl. HL-LHC) of Present Detectors

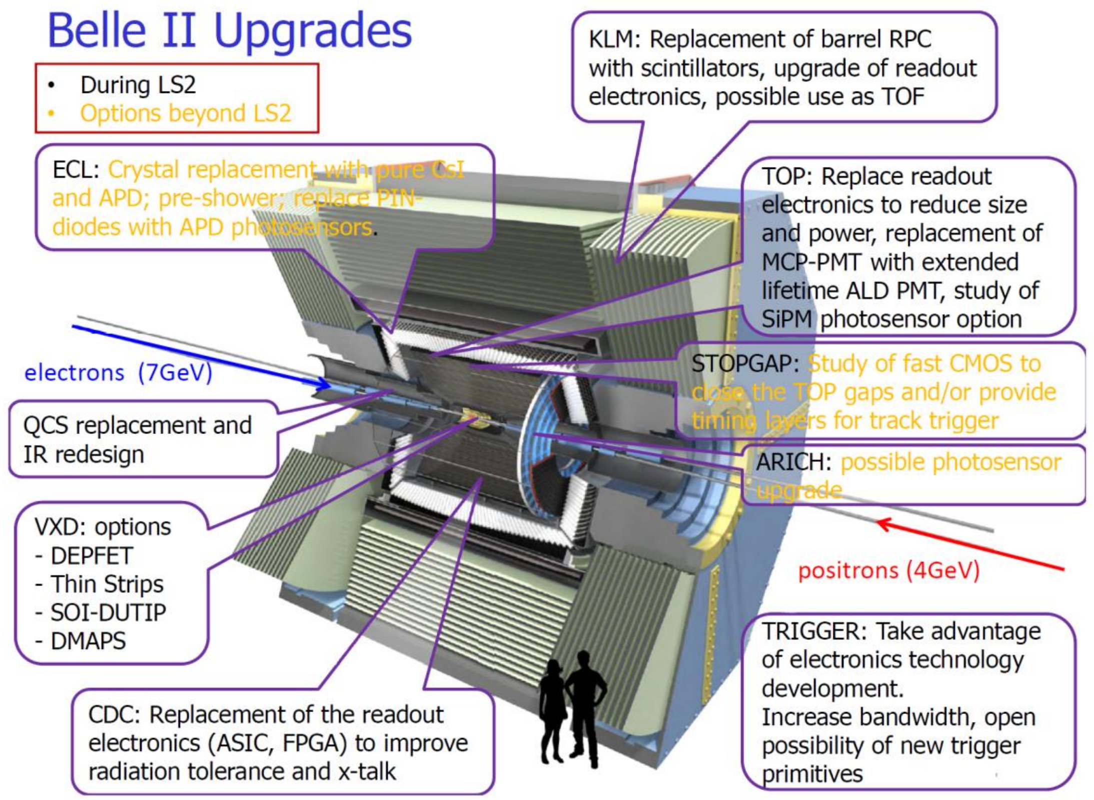
  13) Detectors for Future Facilities, R&D, Novel techniques.

  14) Computing and Data Handling (*Maybe Weidong could do it next time*).

- Plenary sessions (July 11-13)
  - Some detector design/construction/upgrade work or plans are included in more general talks of different experimental domains.
  - Computing session: computing infrastructure, and HEP software.

Many nice ideas from neutrino, DM experiments are not covered here.

Belle-II Upgrade

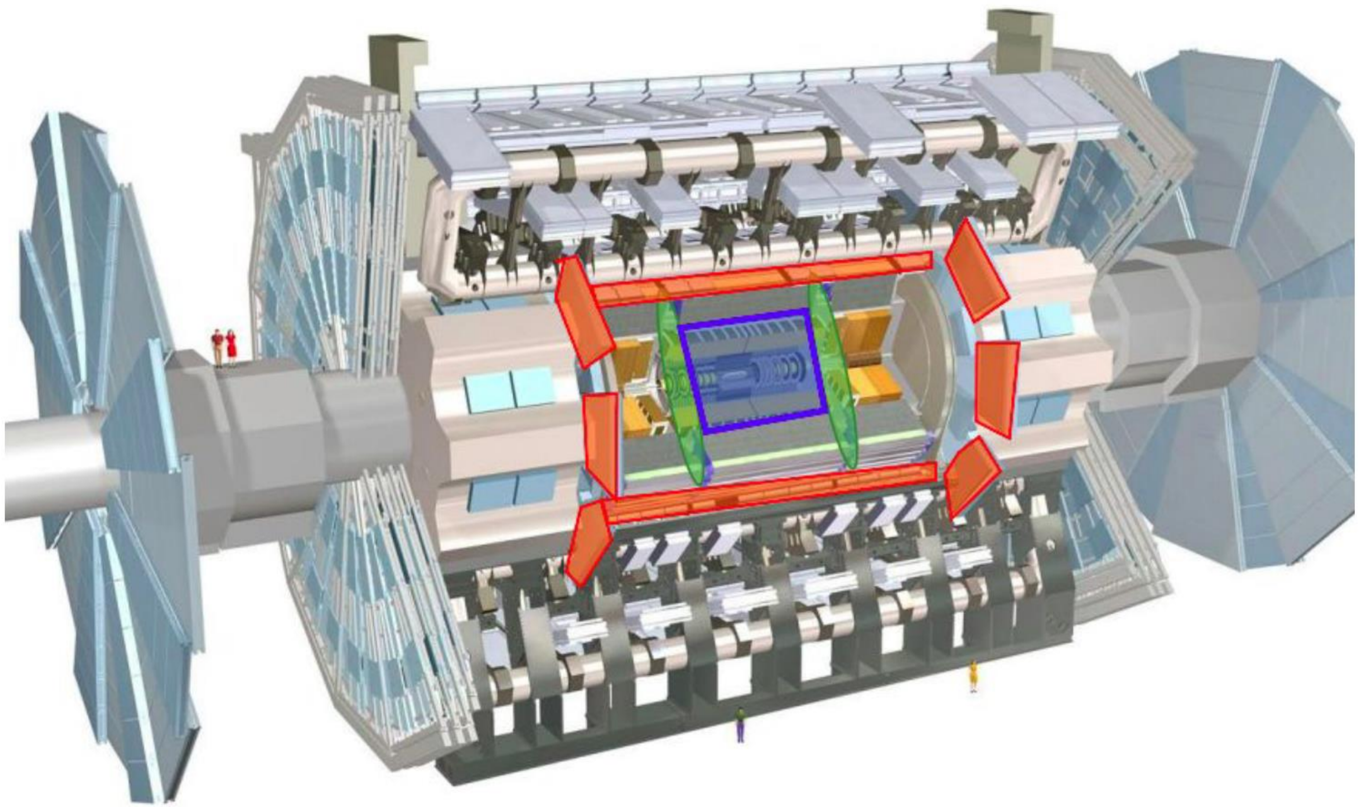


- Resumed physics in 2020.
- Target luminosity 6x10^{35} cm^{-2}s^{-1}, reached 4.7x10^{34}. + beam bkg issue. It needs machine consolidation.
- LS1 (2022-23) to complete PXD, and more robust TOP PMTs.
- Further upgrade in LS2(2026~27), and later > 2032

EOI	Upgrade ideas scope and technology	Time scale
DEPFETs	Adiabatically improved replacement of existing PXD system	LS2
DMAPS	Fully pixelated Depleted CMOS tracker, replacing the current VXD. Evolution from ALICE ITS developed for ATLAS ITK.	LS2
SOI-DUTIP	Fully pixelated system replacing the current VXD based on Dual Timer Pixel concept on SOI	LS2
Thin Strips	Thin and fine-pitch double-sided silicon strip detector system replacing the current SVD and potentially the inner part of the CDC	LS2
CDC	Replacement of the readout electronics (ASIC, FPGA) to improve radiation tolerance and x-talk	< LS2
TOP	Replace readout electronics to reduce size and power, replacement of MCP-PMT with extended lifetime ALD PMT, study of SiPM photosensor option	LS2 and later
ECL	Crystal replacement with pure CsI and APD; pre-shower; replace PIN-diodes with APD photosensors.	> LS2
KLM	Replacement of barrel RPC with scintillators, upgrade of readout electronics, possible use as TOF	LS2 and later
Trigger	Take advantage of electronics technology development. Increase bandwidth, open possibility of new trigger primitives	< LS2 and later
STOPGAP	Study of fast CMOS to close the TOP gaps and/or provide timing layers for track trigger	> LS2
TPC	TPC option under study for longer term upgrade	> LS2

Three presentations on general upgrade, SVD performance, and DAQ

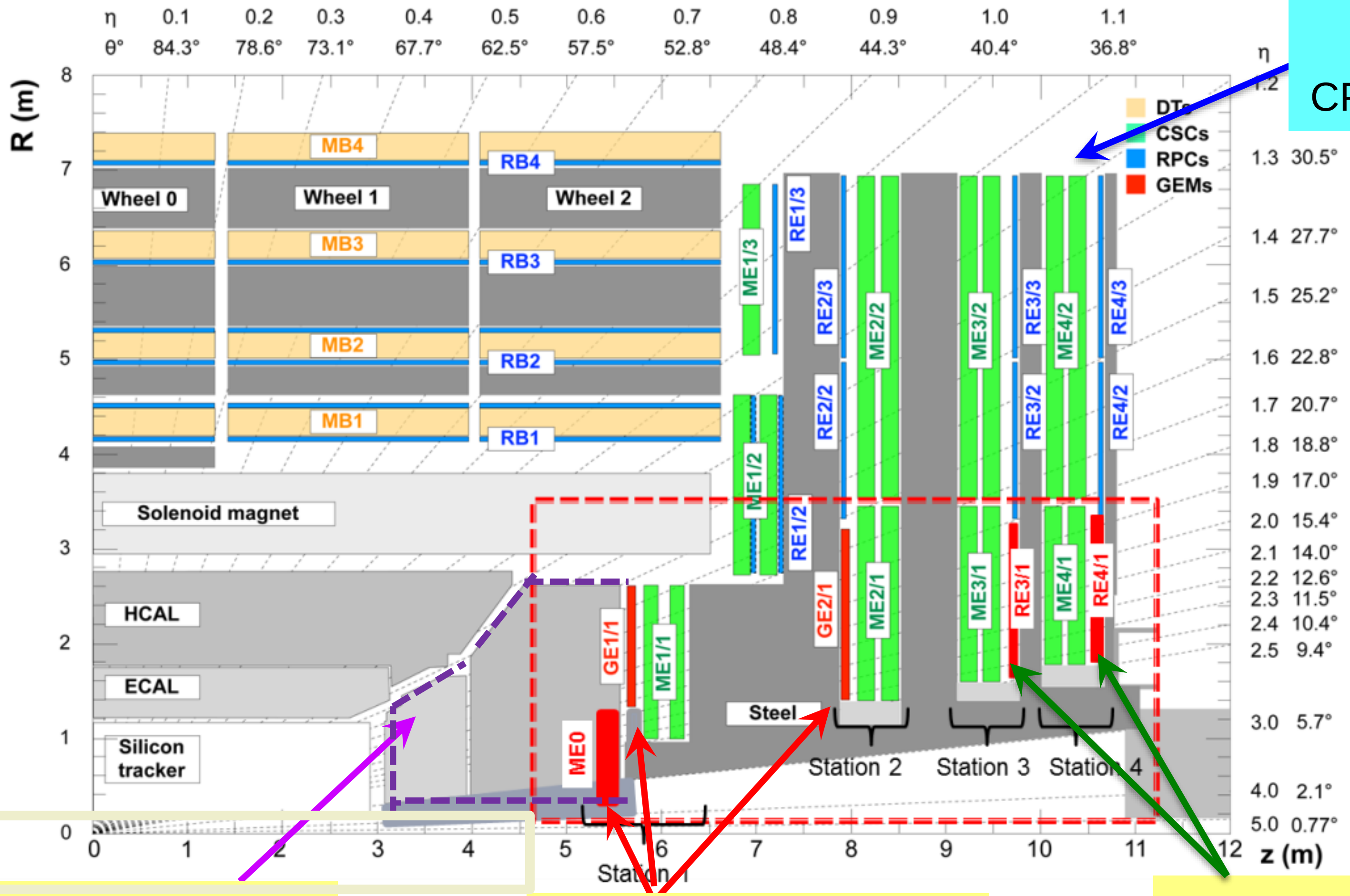
ATLAS Upgrade



- **New muon chambers**
  - Improved trigger efficiency/momentum resolution, reduced fake rate
- **New tracker (ITk)**
  - Less material & finer segmentation
- **High Granularity Timing Detector (HGTD)**
  - Improved pile-up separation and bunch-by-bunch luminosity
- **EM calorimeter (LAr), hadronic calorimeter (Tile), and Muon detectors** will have on- and off-detector electronics upgrade
- **Upgraded TDAQ system**
  - Single Level Trigger with 1 MHz output
- **Upgraded luminosity detectors**
  - 1% precision

❖ Many separate talks on subdetectors, performance, etc.

CMS Upgrade Plan



Upgrade I:

1/3 of CSC for ME4/2

CPPF for Muon L1-trigger

- CMS did not provide a general overview of the upgrade and detector program.
- I have one for what the Chinese teams are involved.
- Just like the ATLAS there are many presentations in “operation performance and upgrade” session

Upgrade II

HGCAL

IHEP/THU/ZJU/FDU

Upgrade II

GE1/1, GE2/1+ME0

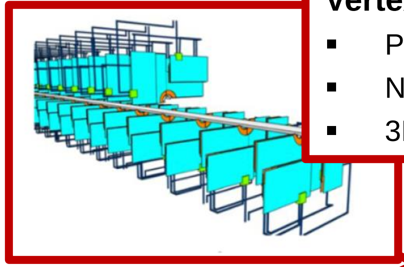
PKU/THU/SYSU/BUAA

Upgrade II

Muon trigger backend

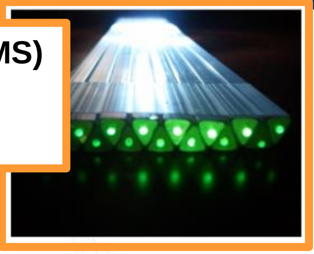
IHEP

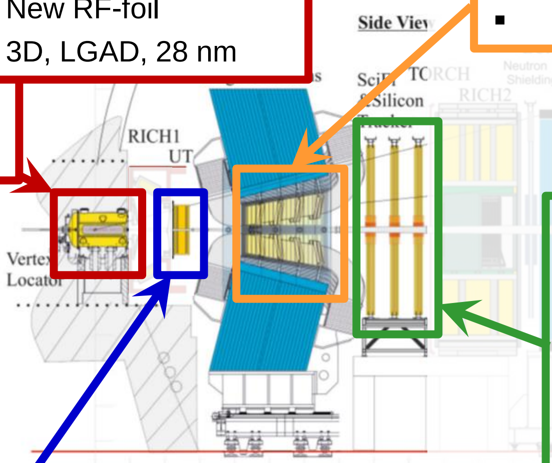
LHCb Upgrade Plan

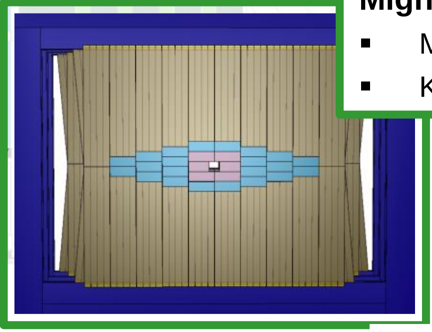


Vertex Locator (VELO)
- Pixel with timing
- New RF-foil
- 3D, LGAD, 28 nm

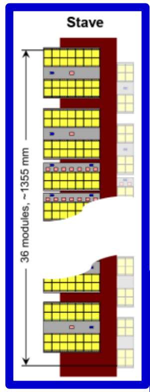
Magnet Stations (MS)
- Scintillating bar
- Low P particles





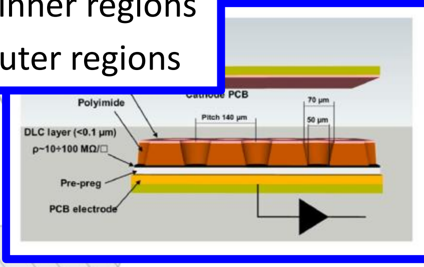


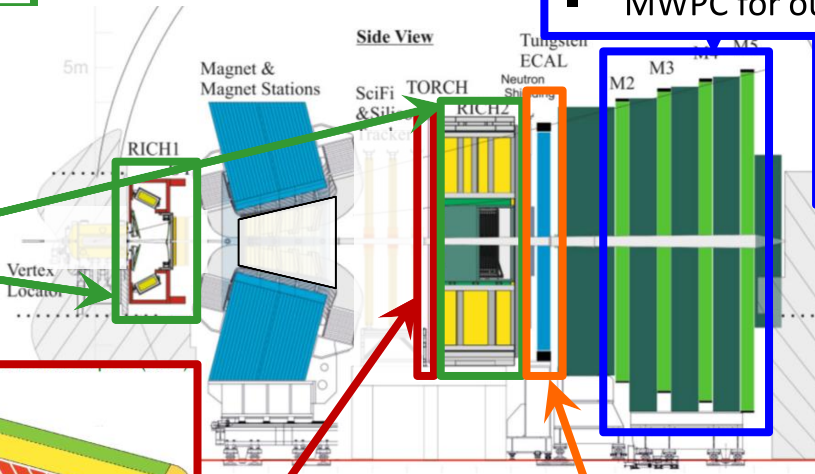
Mighty Tracker (MT)
- MAPS CMOS pixel (inner)
- Keep **SciFi** (outer)



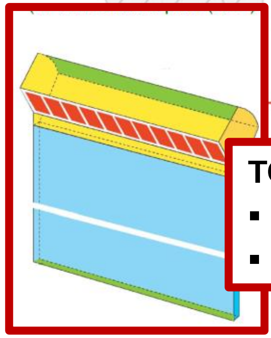
Upstream Tracker (UT)
- MAPS CMOS pixel
- Radiation tolerant

Muon
- µRWELL for inner regions
- MWPC for outer regions

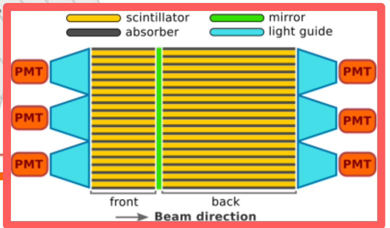




RICH1, RICH2
- Reduced pixel size
- Add timing information
- SiPM, MCP



TORCH
- TOF - quartz
- MCP



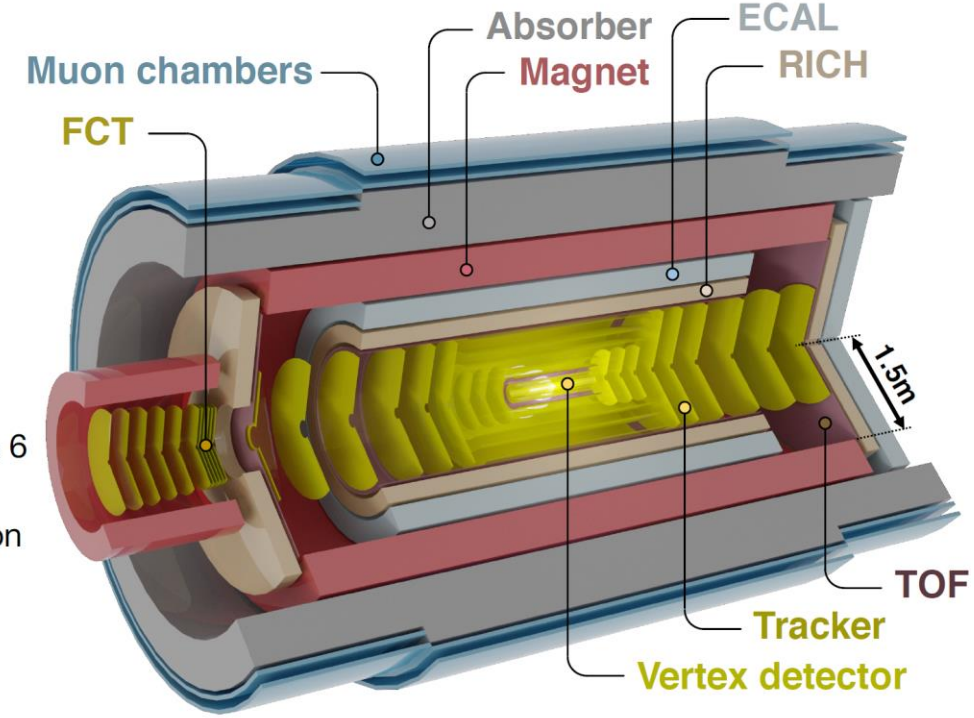
ECAL
- Space & time, longitudinal segmentation
- SPACAL with radiation hard crystals

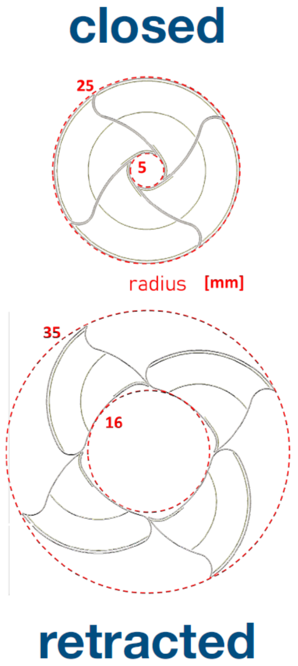
ALICE Upgrade

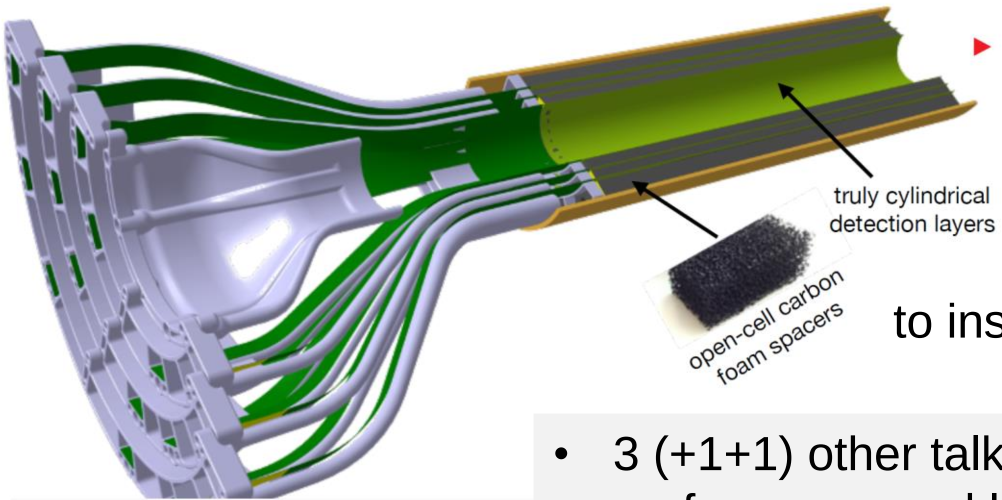
In few words:

Compact **all-silicon tracker**
with **high-resolution** vertex detector
Superconducting magnet system
Particle Identification over large acceptance:
muons, electrons, hadrons, photons
Fast read-out and online processing

For LHC Run 5 & 6
Improvement of
pointing resolution
and effective
statistics







ITS3
to install at LS3.

ALICE 3

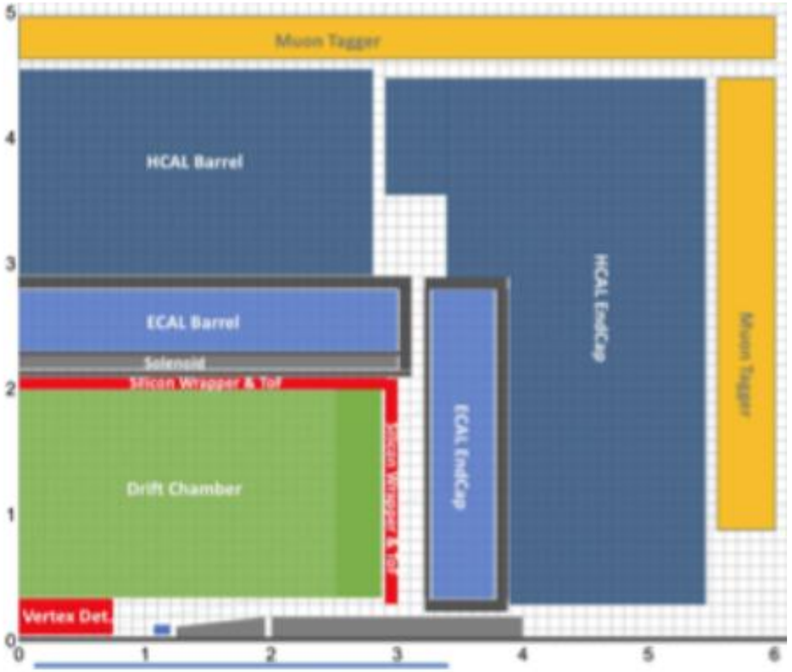
- To install at 2033-34
- R&D focuses on silicon technology
- Vertex detector retractable, and in the 2^{nd} vacuum

- 3 (+1+1) other talks on preparation, performance and lumin measurements

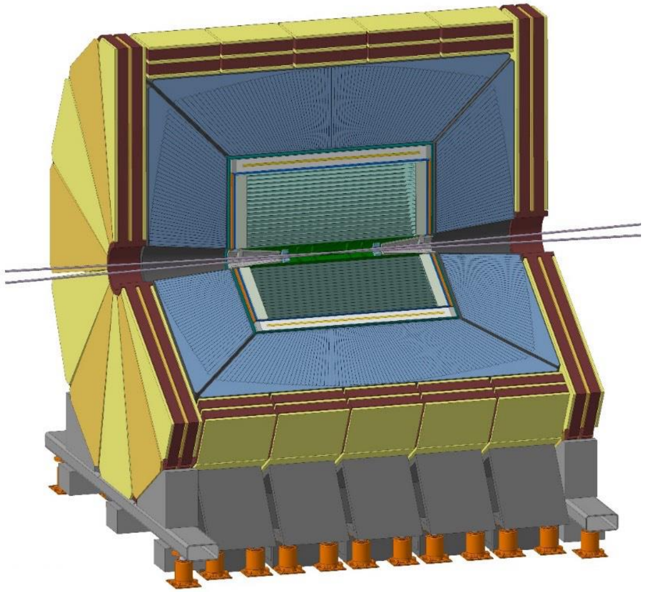
FCC-ee and CEPC

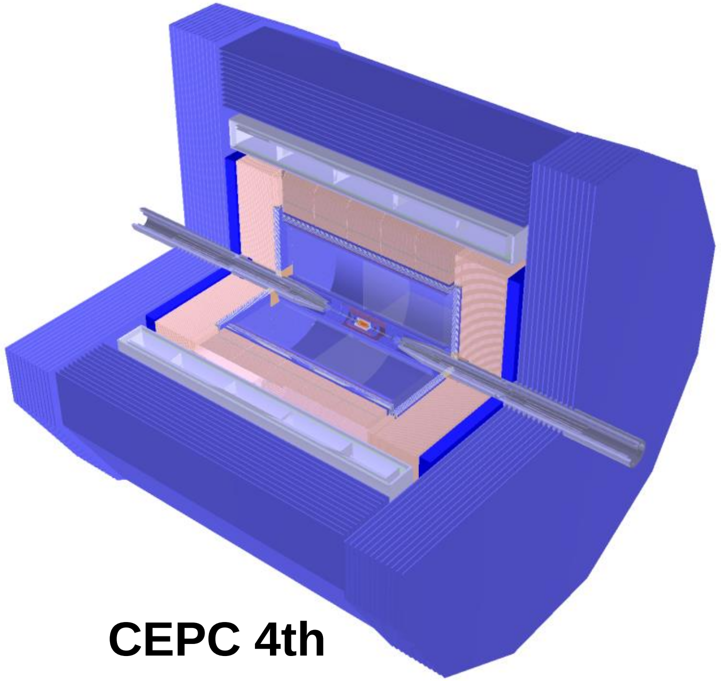
- ❑ One from each of Fcc-ee and CEPC on detector requirements, and IDEA detector concept.
- ❑ Not need to go to details here.

FCC-ee New
Noble Liquid Ecal based



IDEA



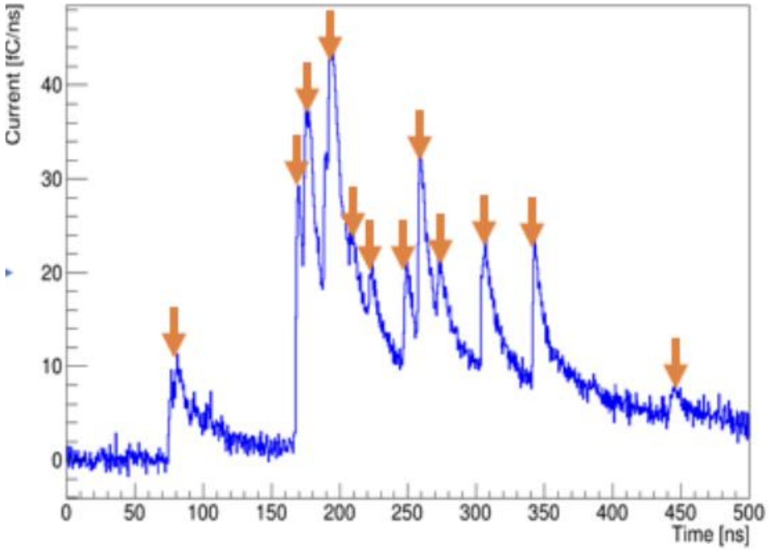


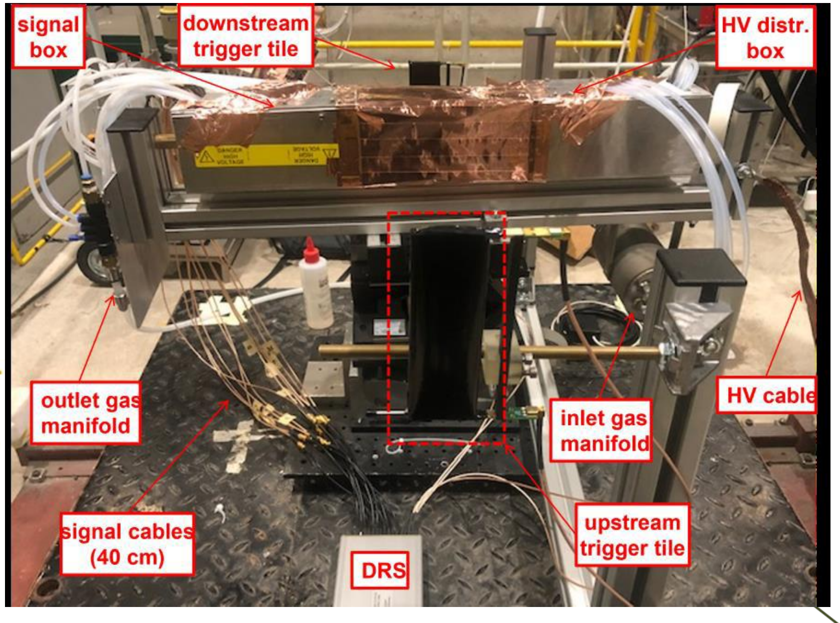
CEPC 4th

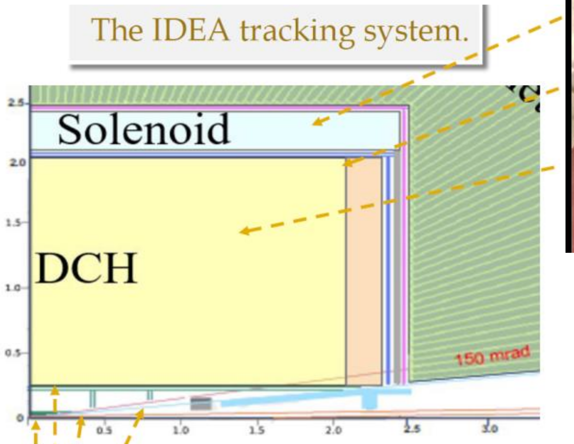
- HG ECAL: Pb+Lar, or W+LKr
- Drift chamber (or Si) tracker
- CALICE-like HCAL
- Coil in same cryostat as LAr

Drift Chamber

- Three talks on the drift chamber: PID for CEPC 4th and IDEA, R&D activities, and IDEA tracking performance.





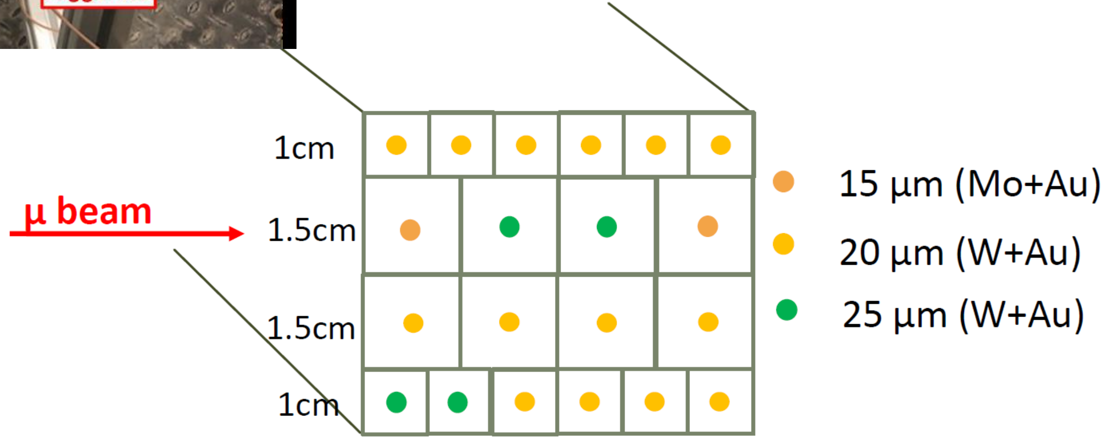


Vertex

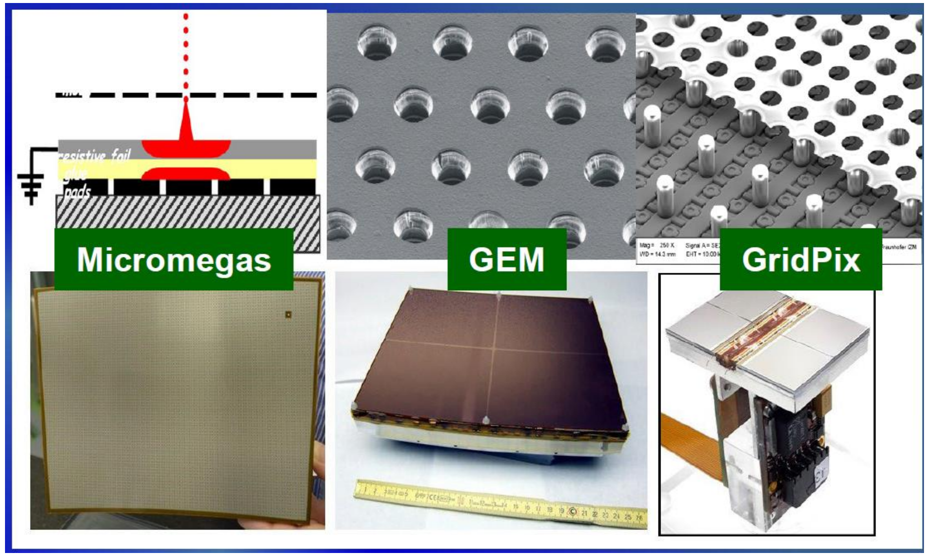
inner: 3 single Si pixel (20 μm x 20 μm) layers of 0.3% X_0

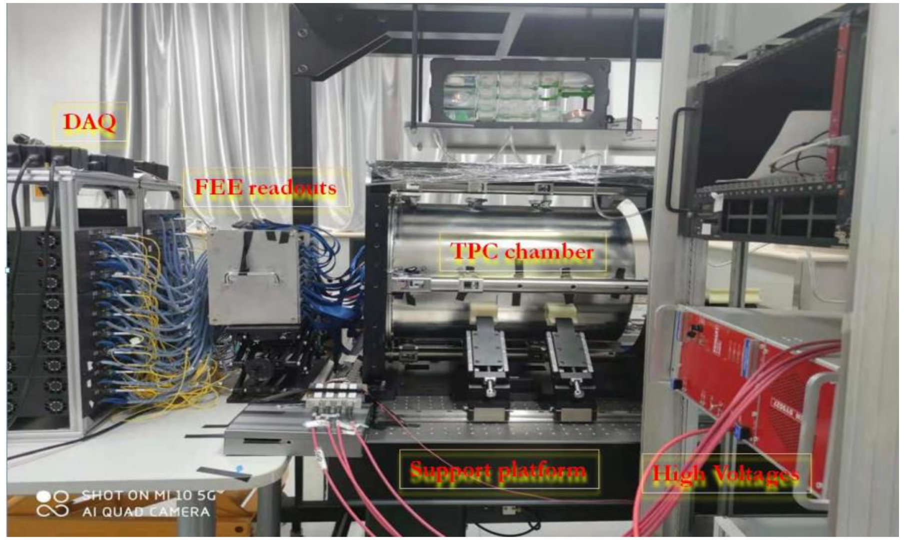
outer: 2 single Si pixel (50 μm x 50 μm) layers of 0.5% X_0

forward: 4 single Si pixel (50 μm x 50 μm) layers of 0.3% X_0



R&D of TPC within LCTPC Collaboration

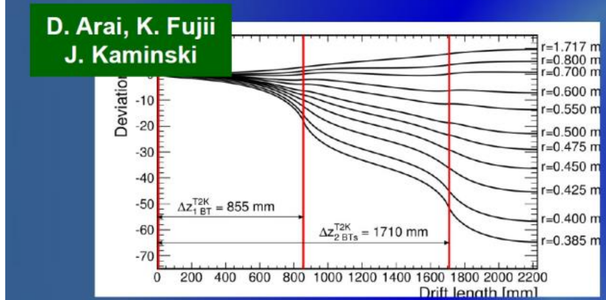




Pixel TPC for Z-Pole Running at CEPC and FCC-ee

Track Distortions in ILC TPC @ 250 GeV ($L \sim 10^{34}$ cm^{-2}):

- At ILC beam-beam effects are dominant: primary ion density 1-5 ions/cm^3 → track distortions < 5 μm
- Gas amplification 10^3 → ILC without gating leads to track distortions of 60 μm → gating device is needed



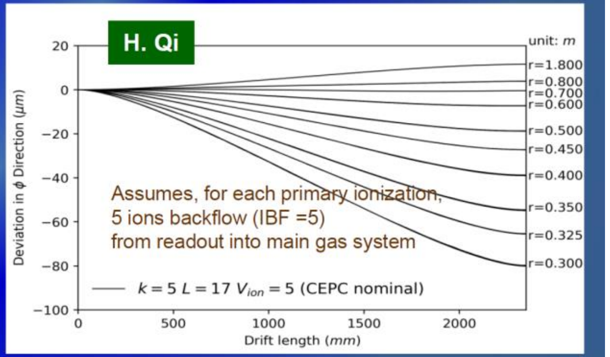
Track distortions @ CePC / FCC-ee:

- ✓ HZ-pole running → $\gamma\gamma$-background is very small → pad / pixels are OK – ion bkg. comparable to ILC @ 250 GeV
- ✓ Z-pole running (@10^{36})→ primary ion density 1000 ions/cm^3 → serious tracks distrotions O(mm); space charge effects could be calibrated (e.g. ALICE) ???
- ✓ Study pixel - TPC to replace pad - TPC for Z-pole running @ CEPC

Crucial considerations for FCC-ee / CEPC @ Z pole running:

- primary ionization of the gas;
- ions from the gas amplification stage;
- power consumption (no power pulsing possible;
- operation at 2 T during the Z-peak running;

- ✓ Ion backflow (IBF) can give a lot of additional charge → so IBF must be controlled (IBF = 5/1.5 → 80 / 14 um)
- ✓ Measuring IBF for Gridpix is a priority, expected $\mathcal{O}$(1‰)

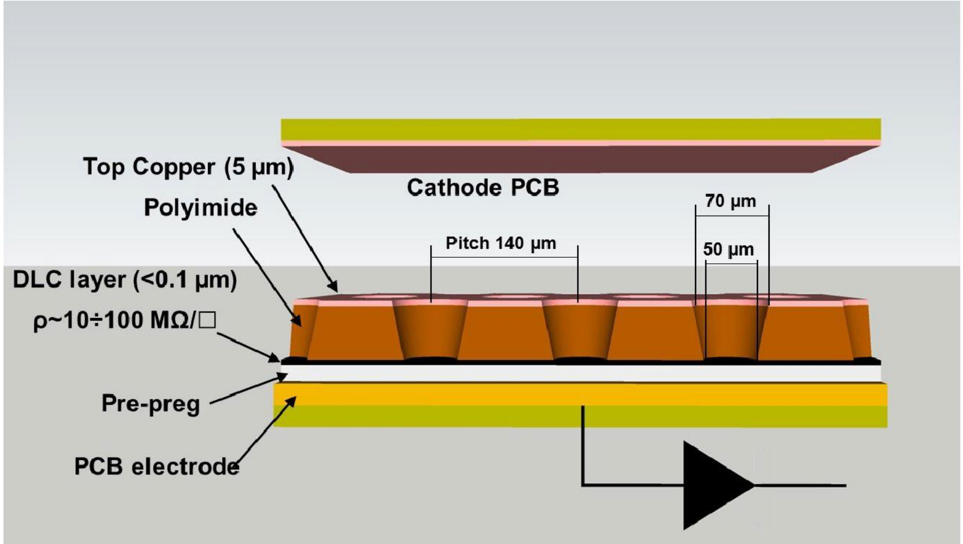


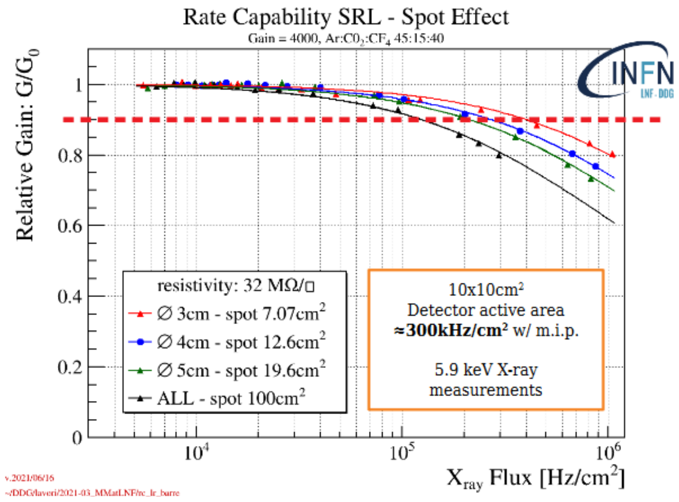
Future R&D needed:

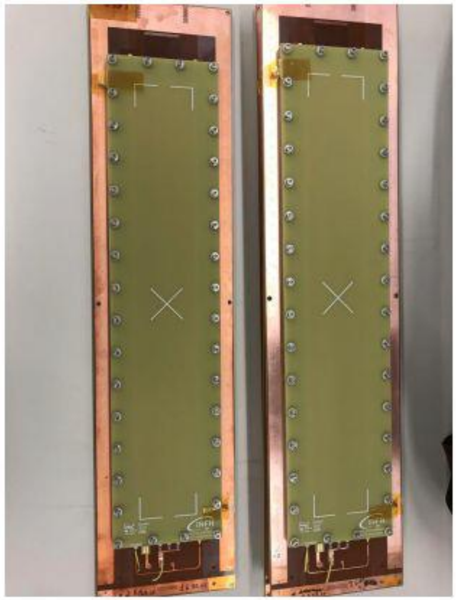
- Optimal pad size to improve track resolution;
- Pixel size > 200 um or large → cost reduction

Very healthy collaboration

R&D and Implementation of μ-RWELL







Developed in collaboration with CERN-EP-DT-MPT workshop

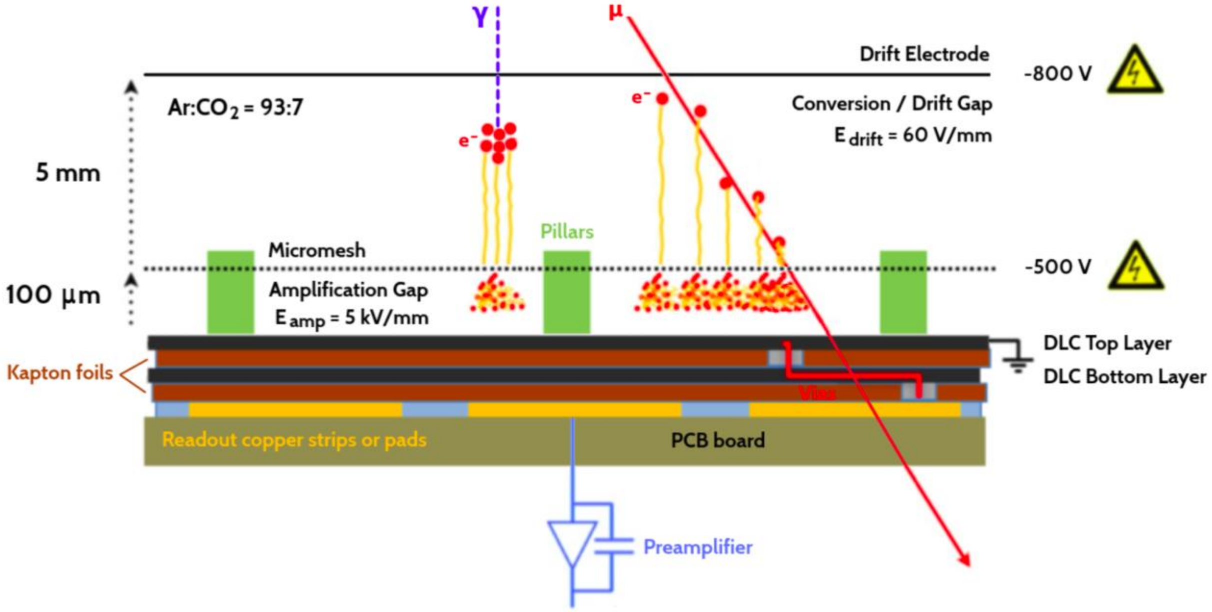
The features can be summarized:

- **Spark suppression**: presence of a resistive layer (Diamond-like Carbon) to quench sparks amplitude (like MM)
- **Compactness**: amplification stage (geometry like WELL and GEM) embedded in the PCB readout → multi-layer PCB std. industrial technology →mass production

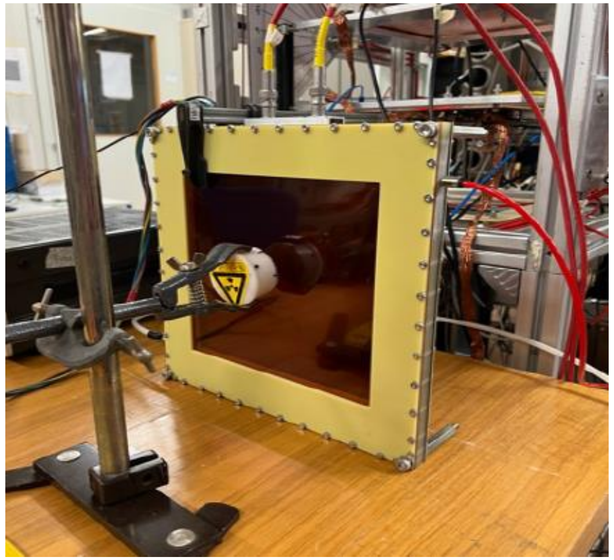
But the resistive layer introduces a local gain drop as the rate increases

For the **LHCb upgrade 2** muon system, the **IDEA** preshower and muon, several other experiments that did not present.

Resistive MicroMeGas Detectors



20x20 cm^2 prototype



- Resistive MicroMeGas: cover readout copper strip/pad with a resistive insulator to suppress discharges
- Drift region of ~5 mm width (E~60 V/mm) & amplification region of ~100 μm (E~5 kV/mm) separated by a metallic micro-mesh, supported by 0.8 mm diameter pillars
- Geometrical & electrical configuration to guarantee a fast ion evacuation – fundamental for high rate applications
- Demonstrated to be a solid detector technology for HEP.

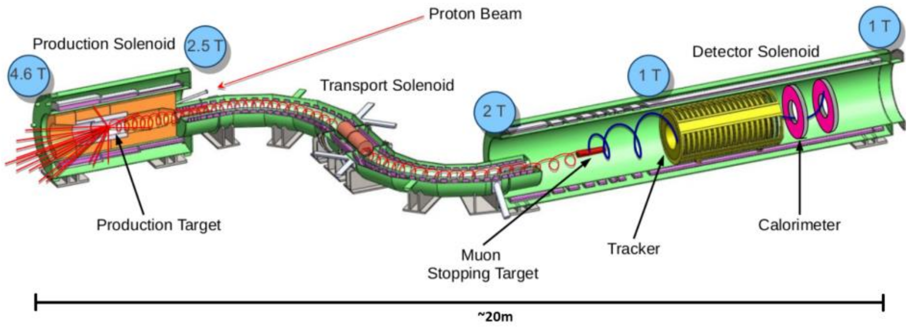
Two talks from the same group

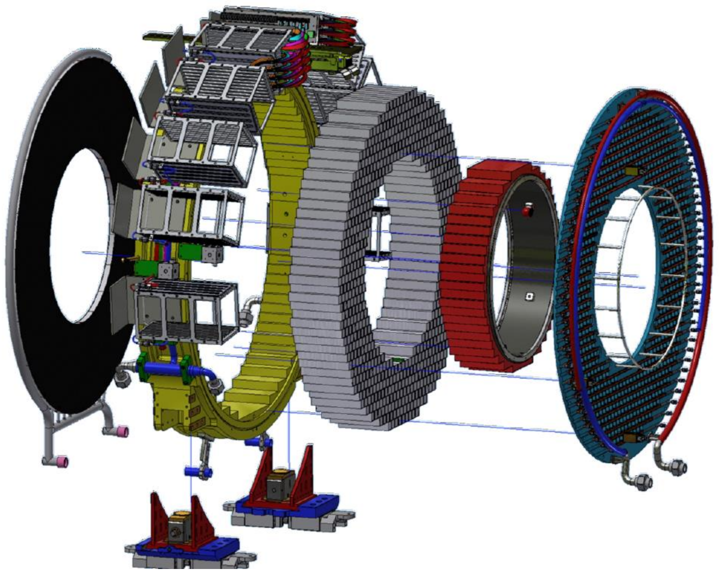
- Small-pad resistive MMG prototypes were tested in high-rate environment (X-ray, Fe55 source, π/μ beam)
- Irradiation and longevity test of Resistive Micromegas detector did not show sign of aging using both Ar:CO2 93:7 and Ar:CO2:iC4H10 93:5:2

Crystal Ecal (I)

Mu2e ECAL (CsI + SiPM)

QC ready, detector assembling started



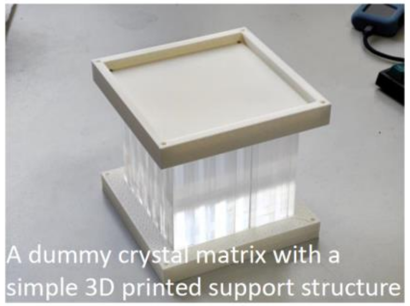


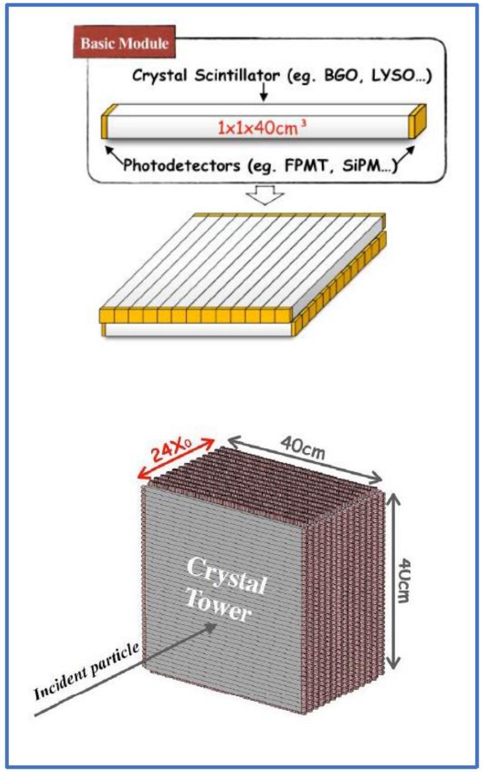
CEPC ECAL

vers

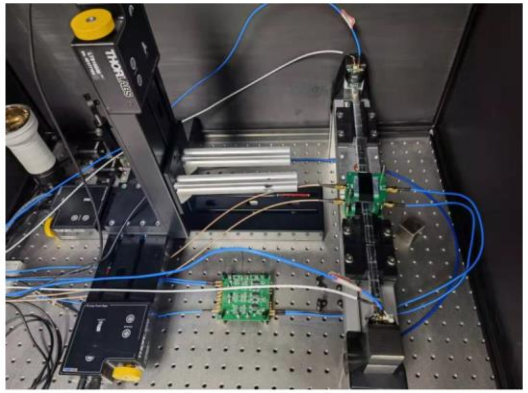
Diagonal Crystal bars + SiPM

Combine excellent energy resolution with superior imaging capabilities through fine 3D segmentation





A5202 unit (FERS-5200)

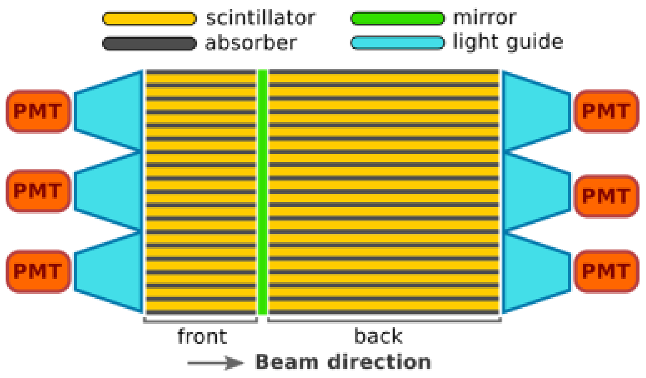


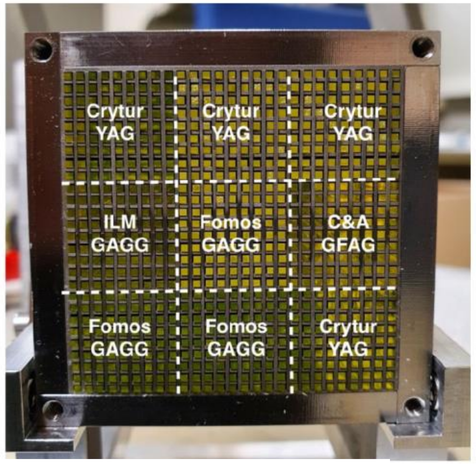
Calorimters (II)

LHCb ECAL Upgrade

GAGG / PS + W / Pb, PMT

Emphasize on timing





Time resolution above 5 GeV

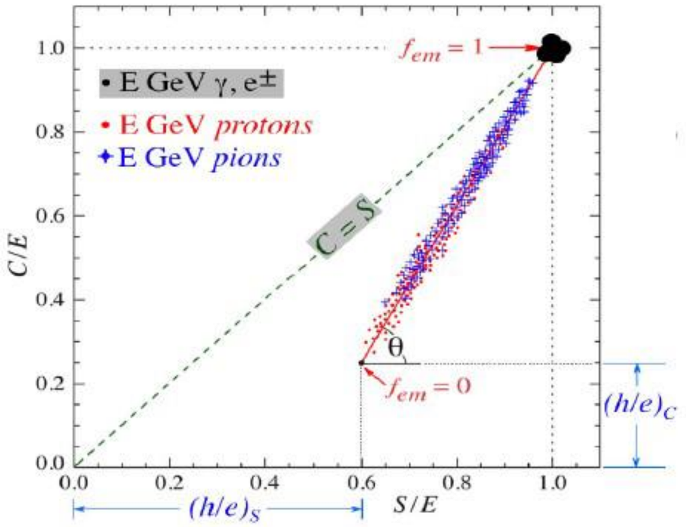
- ✓ SPACAL W+GAGG < 20 ps (1.5x1.5 cm^2 cell size)
- ✓ SPACAL W+Polystyrene < 20 ps (2x2 cm^2 cell size)
- ✓ SPACAL Pb+Polystyrene < 25 ps (3x3 cm^2 cell size)
- ✓ SHASHLIK < 40 ps (4x4 / 6x6 / 12x12 cm^2

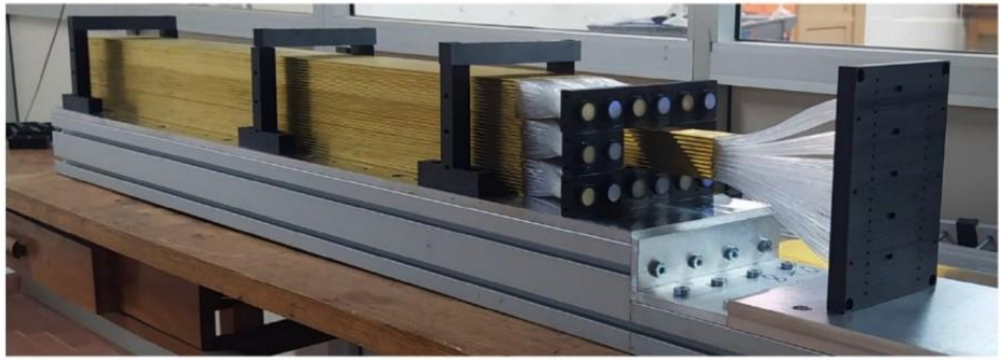
Energy resolution of order $\sigma(E) / E \approx 10\% / \sqrt{E} \oplus 1\%$ can be reach

IDEA DR Calorimeter

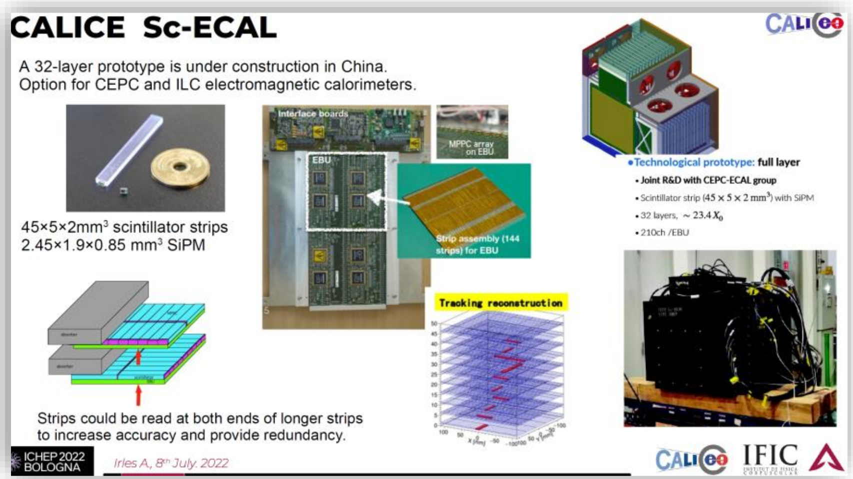
(Cu, Sc/C fiber, SiPM/PMT)

Beam test of a prototype (EM) detecter at DESY and CERN



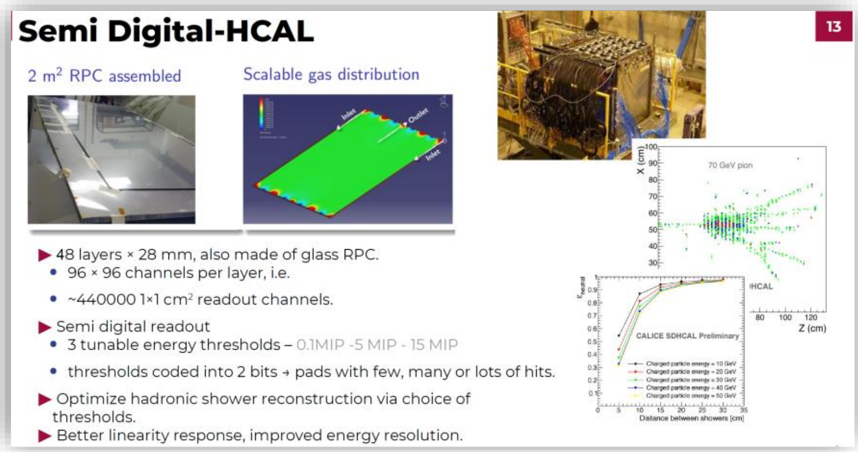


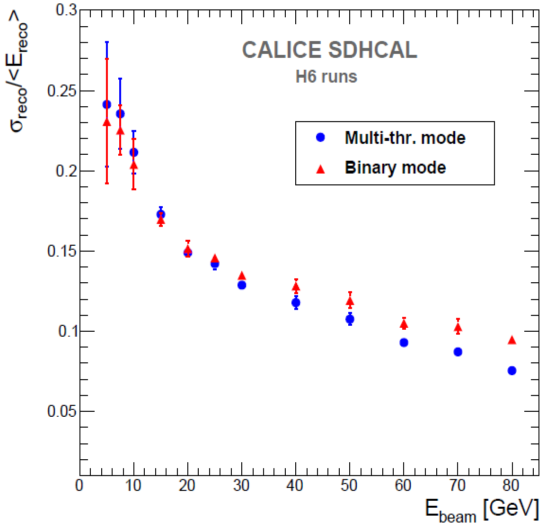
CALICE Calorimter Studies



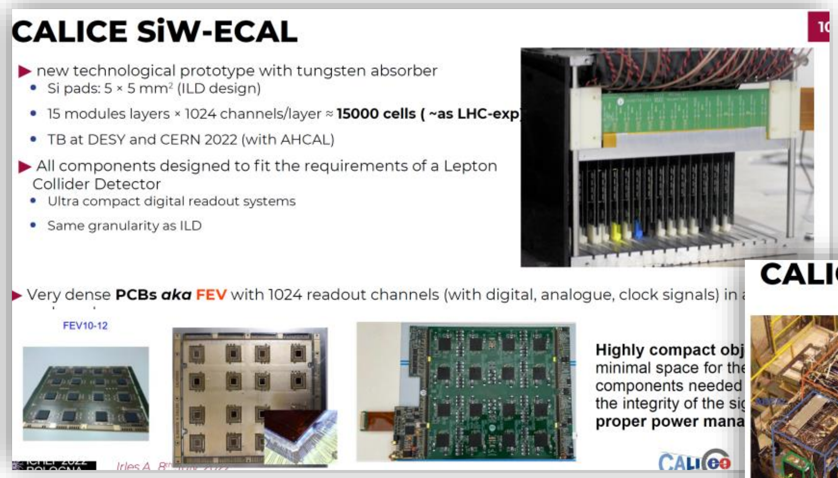
CALICE Imaging Calorimeters: A Review and New Results

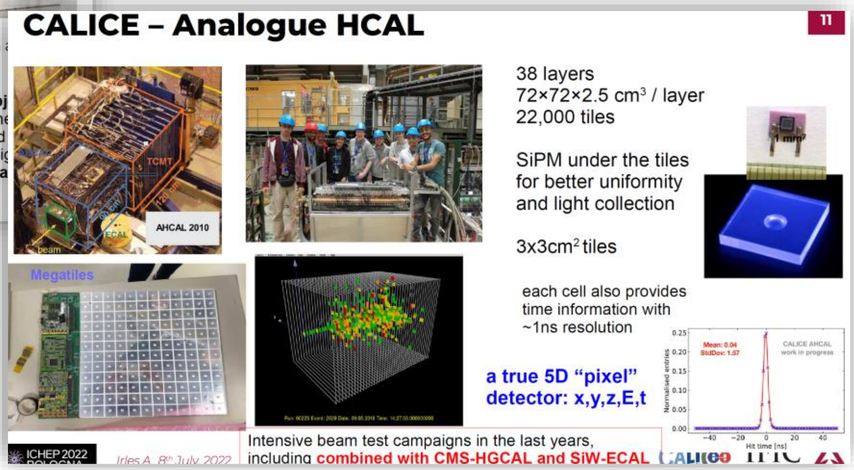
By Adrian Irles





Hadronic energy reconstruction in highly granular calorimeters

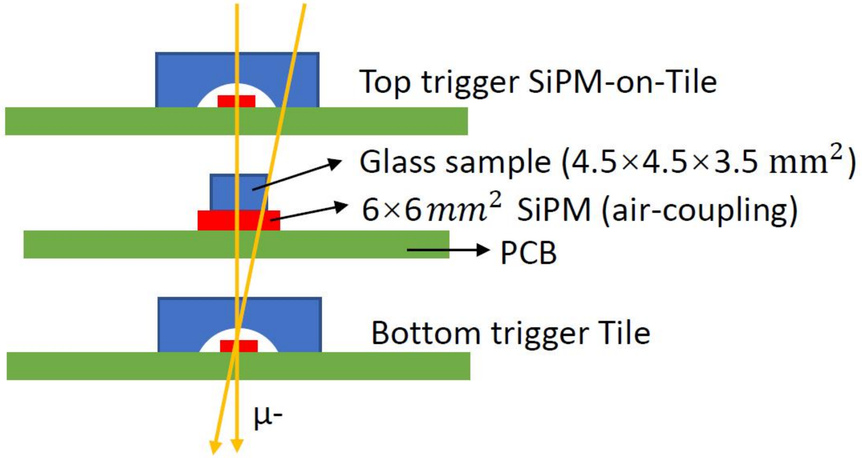


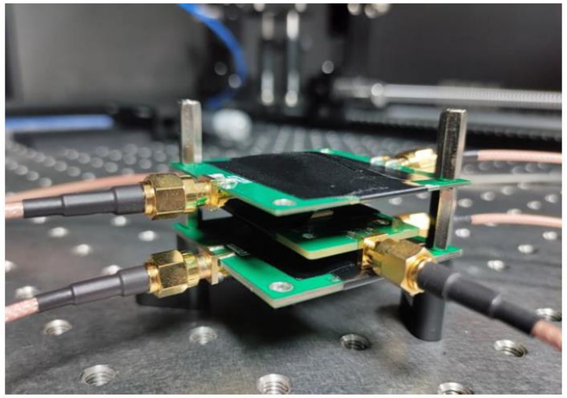


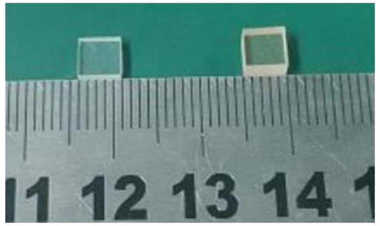
Also "Advanced reconstruction and simulation techniques for highly granular calorimeters"

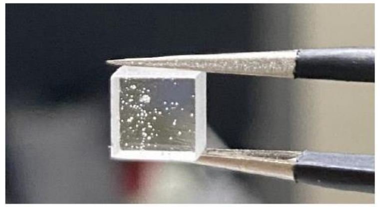
Other New Ideas On Calorimters

CEPC ScintGlass HCAL



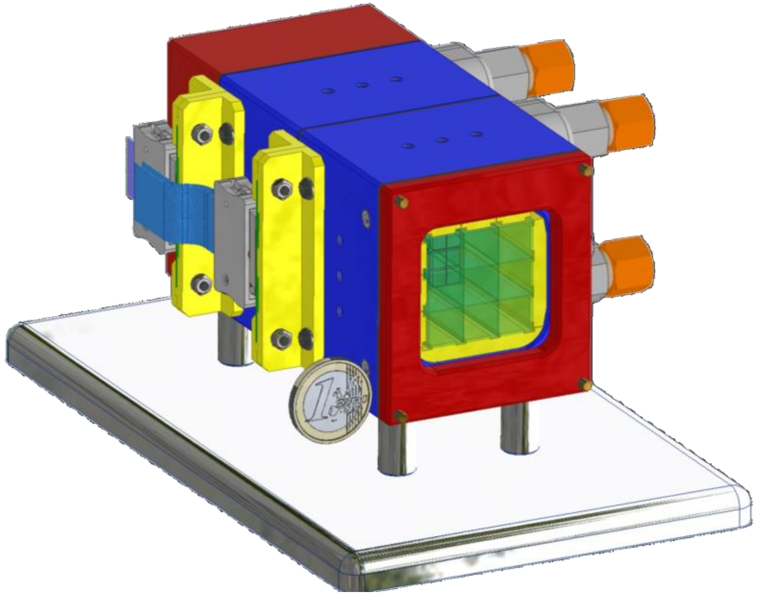






Crilin Prototype

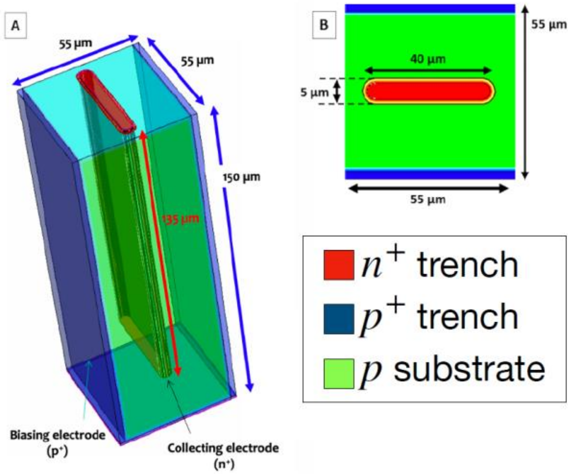
- Crystal calorimeter with longitudinal information, for muon collider barrel.
- Lead Fluoride (PbF_2) crystals readout by 2 series of two UV-extended 15μm pixel SiPMs each.
- Longitudinal segmentation and excellent timing resolution
- Timing information can be used to suppress beam induced background.

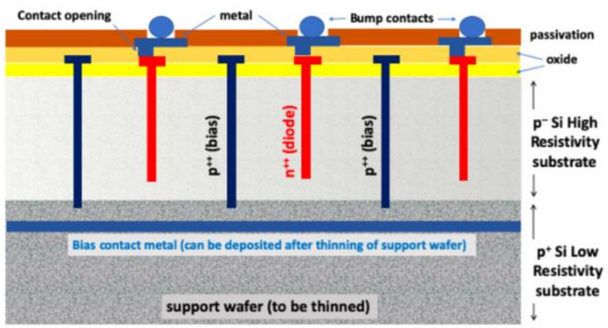


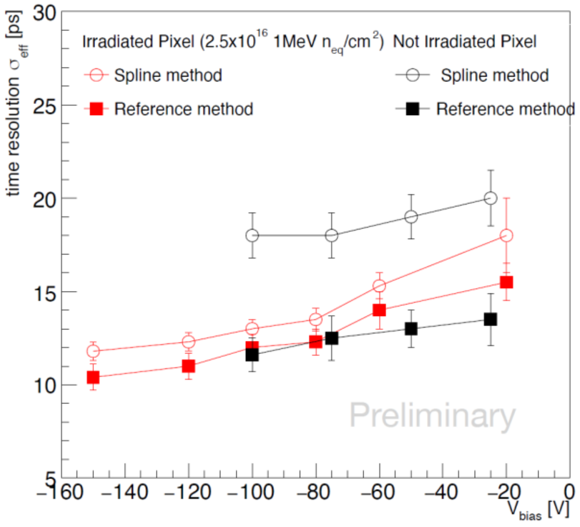
Silicon Pixel Detectors

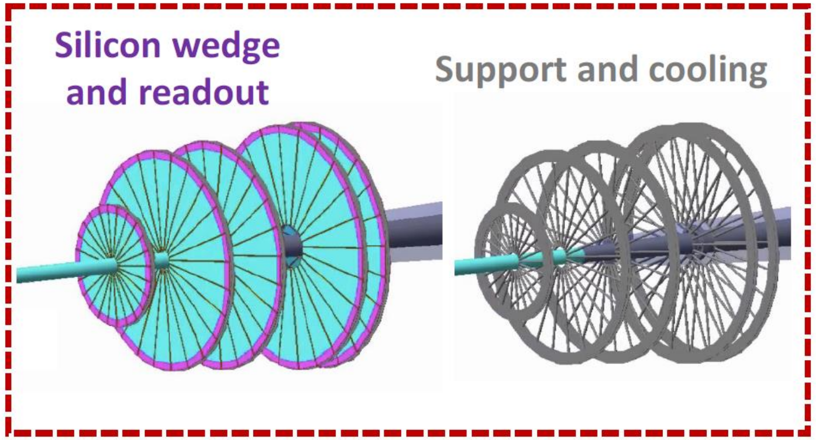
TimeSpot:

- Picosecond timing resolution with 3D trench Si sensor.
- 55x55 μm^2 pixel, potentially can be reduced to 28x28 μm^2
- Rad-hard as a candidate for LHCb upgrade 2 VELO.





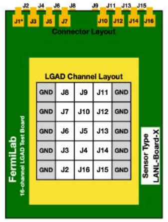




Forward silicon tracker for EIC

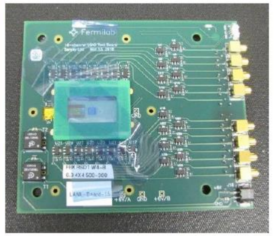
total ~2.2m², look into different technologies

LGAD pixel map 3X5 Matrix

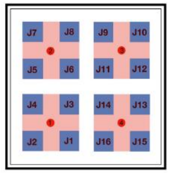


LGAD Carrier Board

AC-LGAD Carrier Board

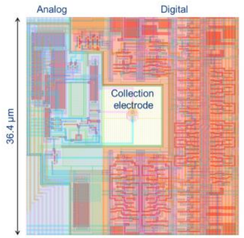


AC-LGAD pixel map 4X4 Matrix

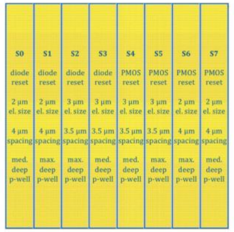


MALTA Carrier Board

MALTA Pixel diagram

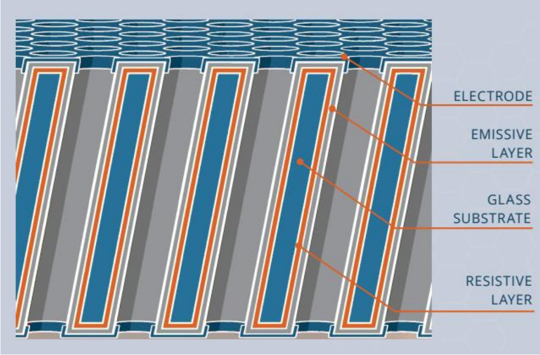


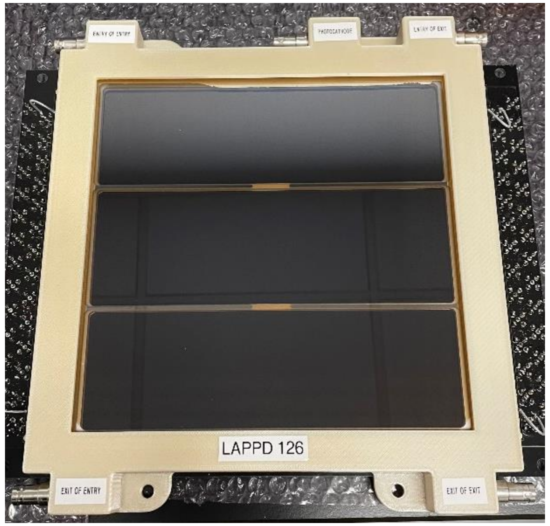
MALTA sensor diagram 512X512 Matrix



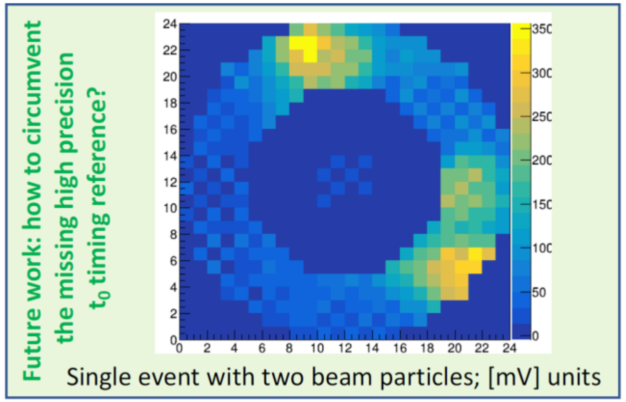
Large Area Picosecond Photodetectors – LAPPD

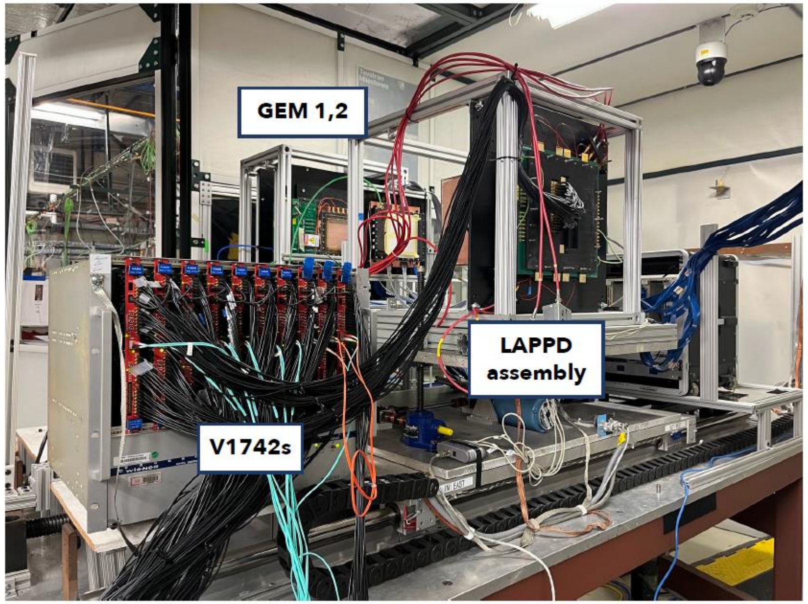
- ***Features***
  - **10 µm/20 µm** MCPs
  - Glass/Ceramic body
  - New internal support design → **373 cm²** (97% active area)
  - Gen-II → flexible **pickup pattern modification**
- ***Performance***
  - **High QE** blue-sensitive photocathode **(>30%)**
  - **~1E7** Gain
  - Low Dark Rates
  - **~50 ps** SPE, **~10 ps** MPE
  - ***O*(mm)** position resolution depending on readout board
- ***Availability***
  - Gen I Direct readout & Gen II Capacitively Coupled readout
  - High Rate Picosecond Photodetector (**HRPPD** 10 cm) in development





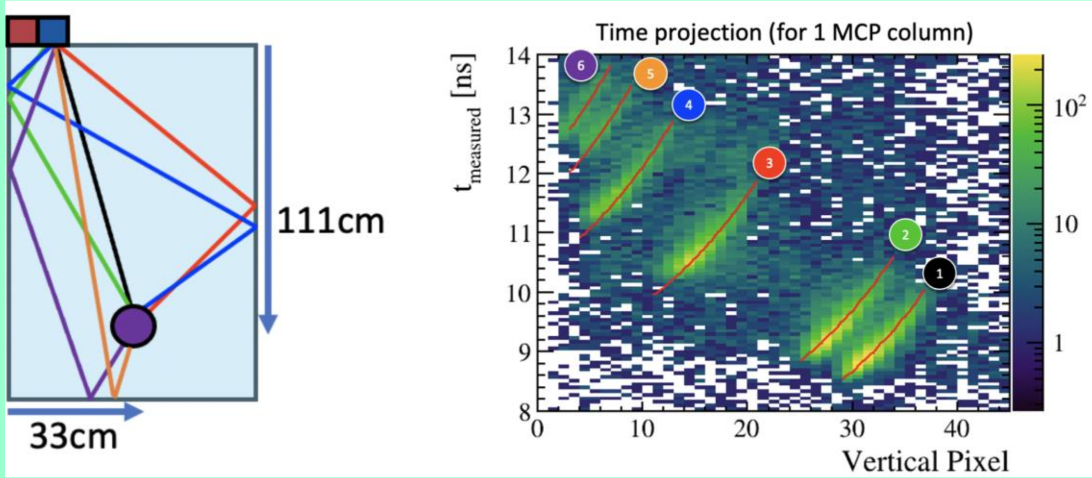
Applied on a RICH detector

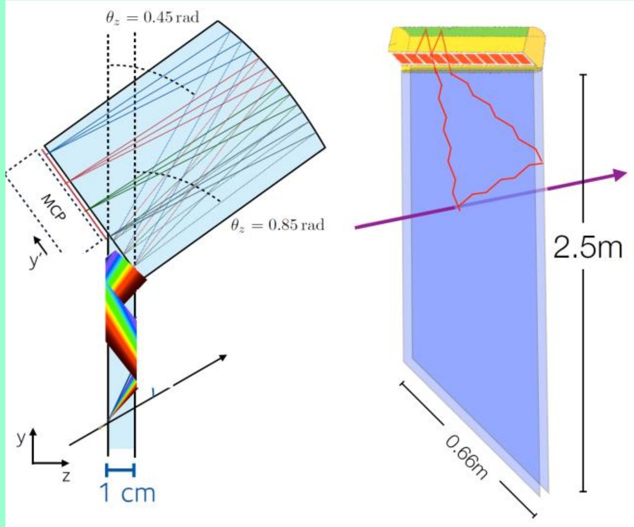




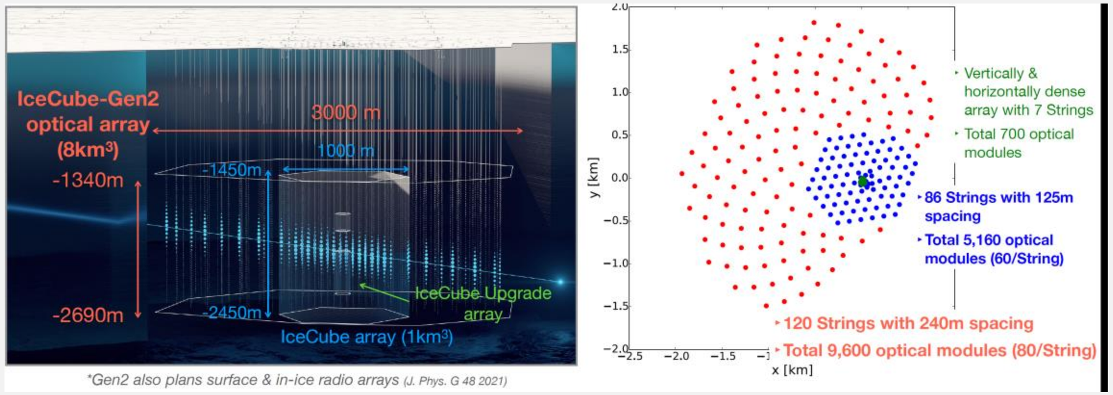
Photon Detection

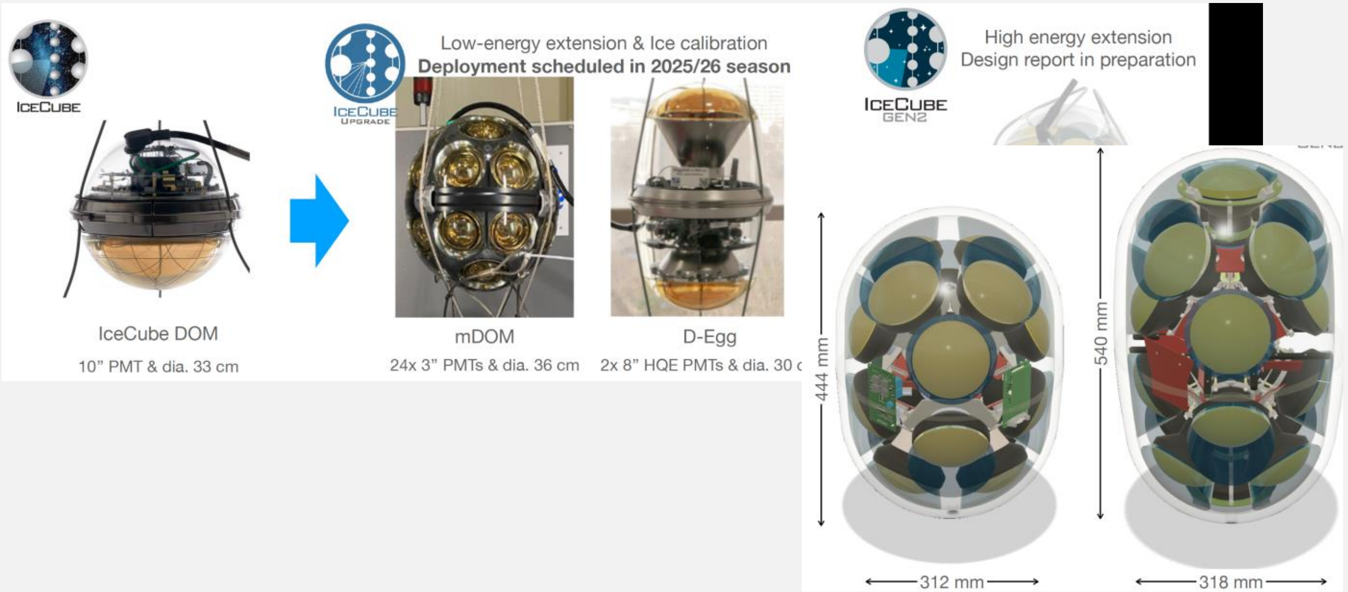
TORCH for low P PID





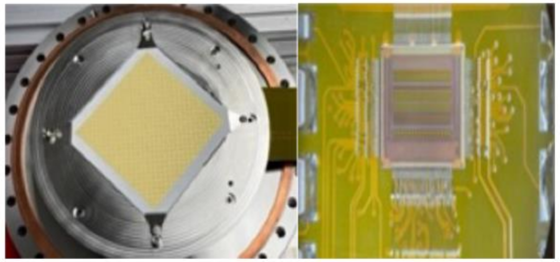
Optical Modules for IceCube-Gen2



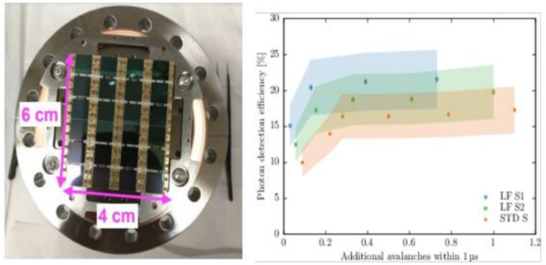


nEXO – search for 0νββ with a 5-ton liquid xenon TPC

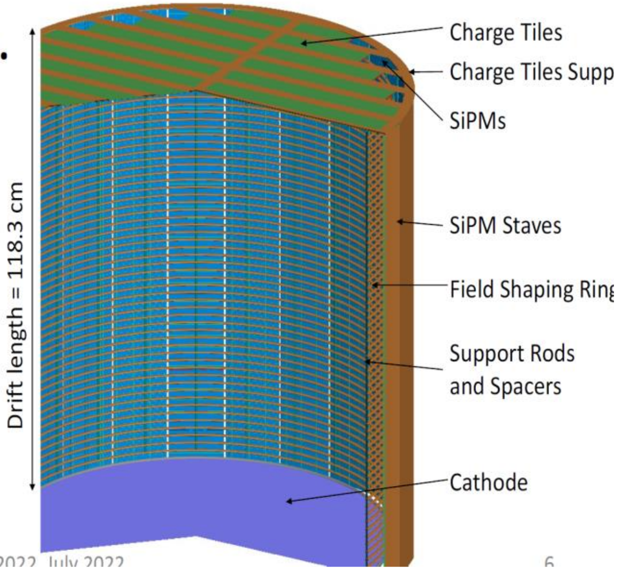
Charge sensing tile and in-LXe cold electronics

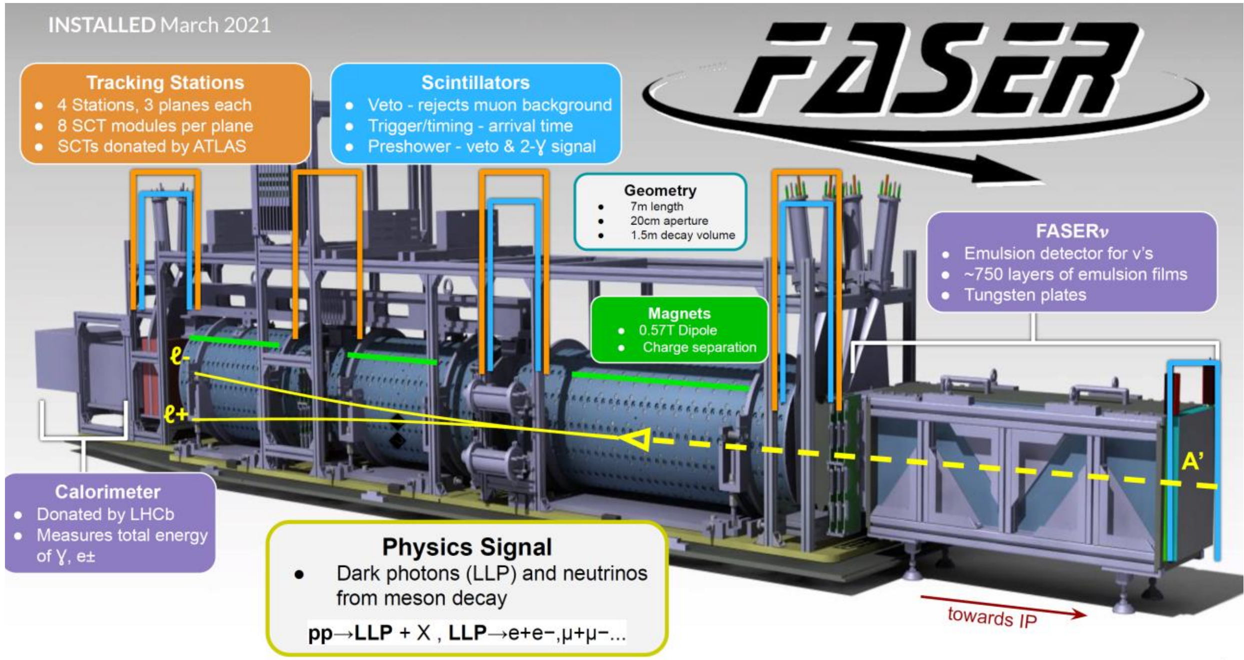


- Charge detection: anode plane of modular charge tiles (10 cm long and 6 mm pitch), readout with ASIC in LXe.
- Light detection: 4.5 m^2 of VUV SiPMs with ASIC readout in LXe.
- Electron lifetime: 10 ms
- Electric field: 400 V/cm



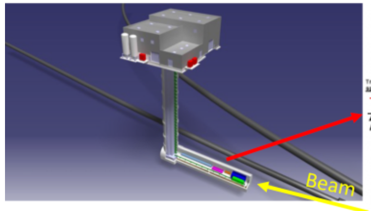
VUV silicon photomultipliers (SiPMs)

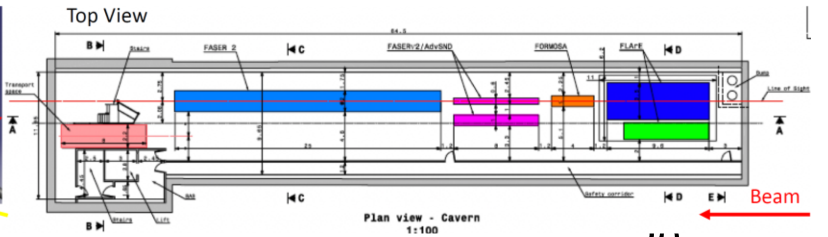


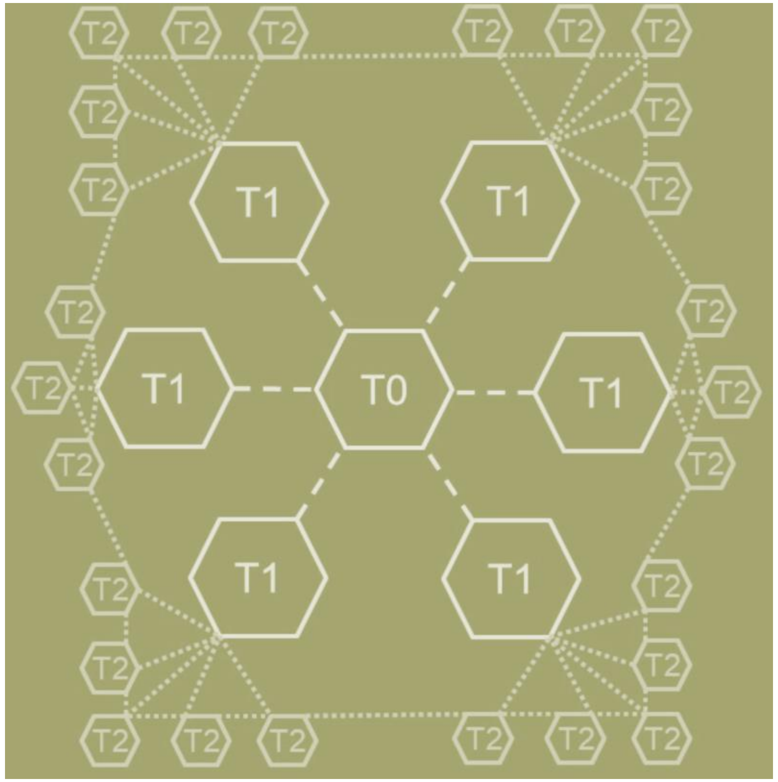


Other proposed detectors for FPF

Experiment	Science Priority	Technology
Faser 2	Long-live neutral particles decay	Large decay volume (super-conducting) magnetic spectrometer
FASERnu2	Neutrino Interactions	Tungsten/Emulsion 20 tons. Veto and interface tracker for muons
AdvSND	Neutrino Interactions on/off axis	Hybrid electronic and tungsten/emulsion detector with had. cal.
FORMOSA	Milicharged particles	Scintillation bars with photomultiplier readout.
FLArE	DM scattering and neutrino interactions	Liquid Argon TPC 10-20 tons



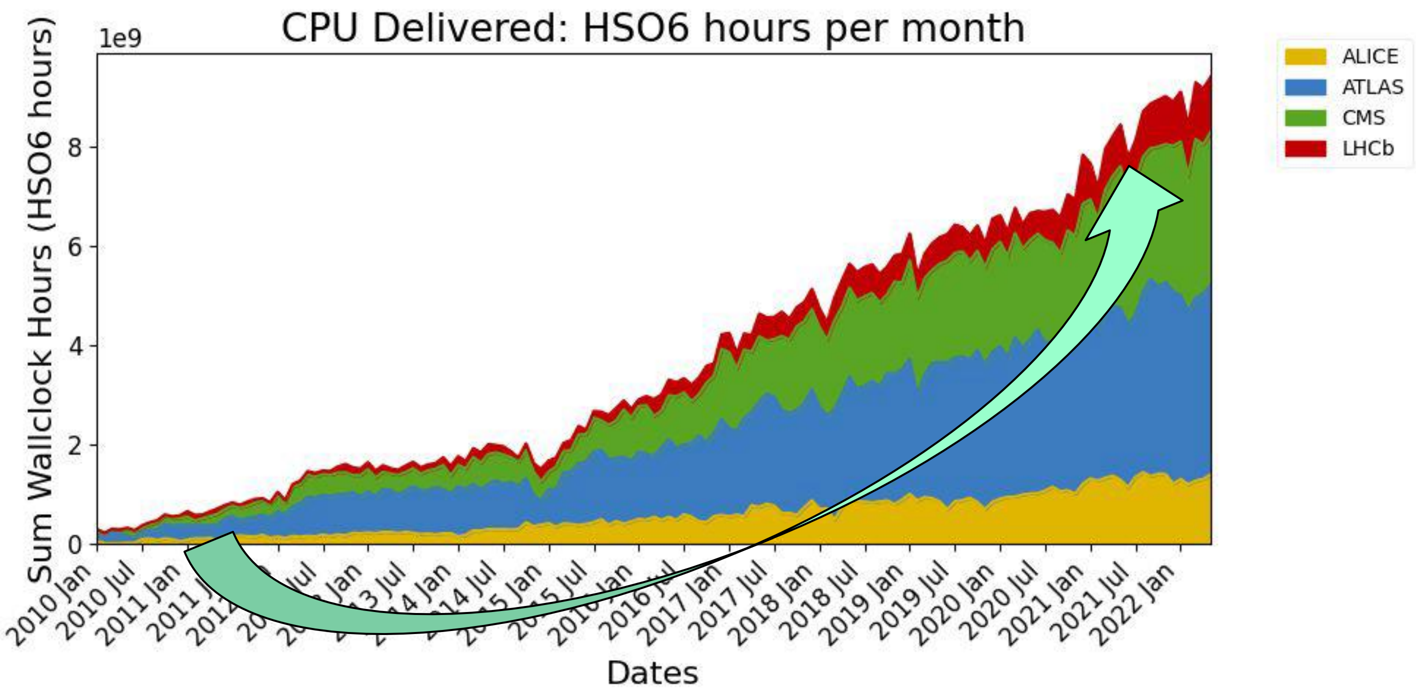




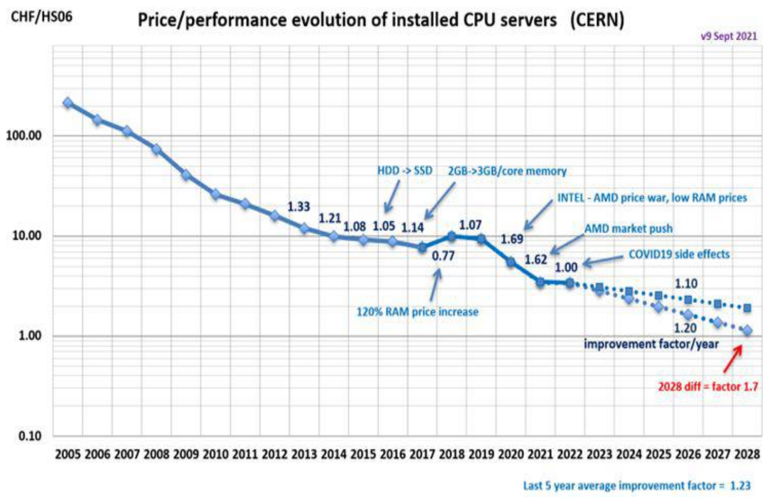
- Globally distr. system of computing centers
- WLCG: Tier0 + 14 Tier1's + >150 Tier2's in >40 countries

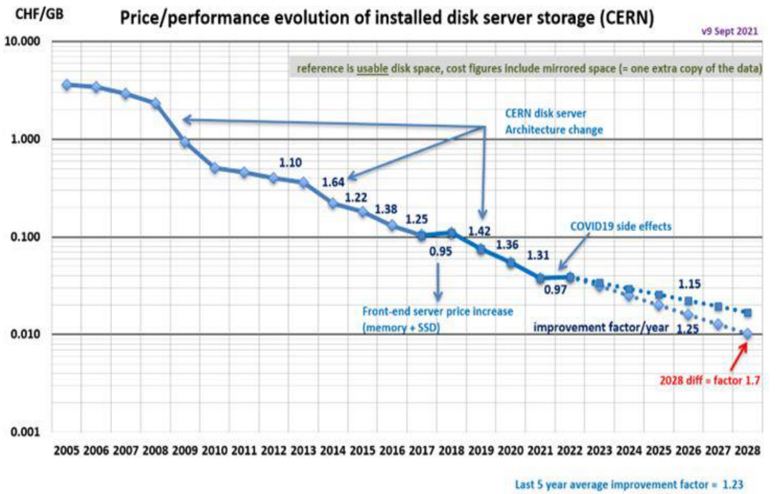
Robust resource growth of pledged resources:

- Average +20% CPU and disk yearly growth
- Consistent with a 'flat budget' funding for computing centers
  – A de-facto adopted model across all Funding Agencies for the past 10 years
- CPU: > 1 million cores fully occupied today, Data ingestion tens of EB/year

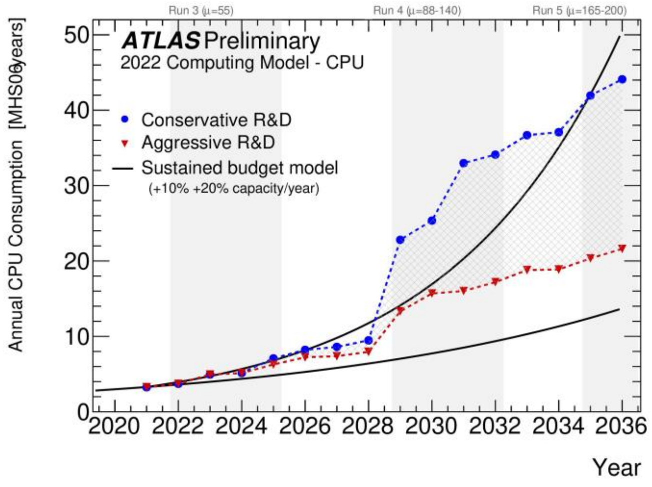


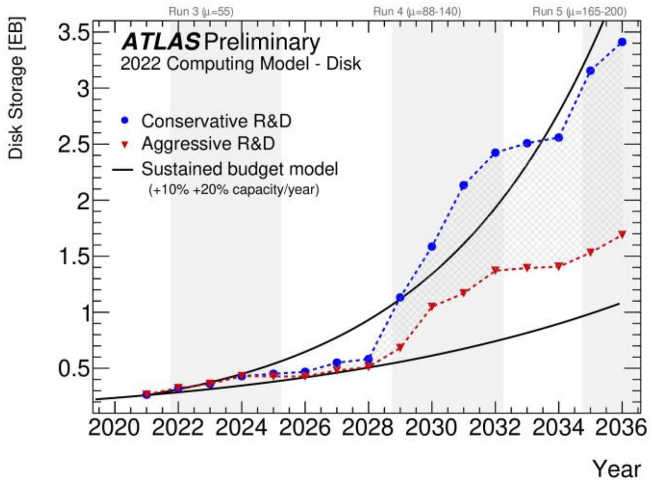
Projections of Hardware Prices and Needs





Cost Projection





Similar for other LHC experiments

LHCb has a sharp increase due to trigger less readout for Run3

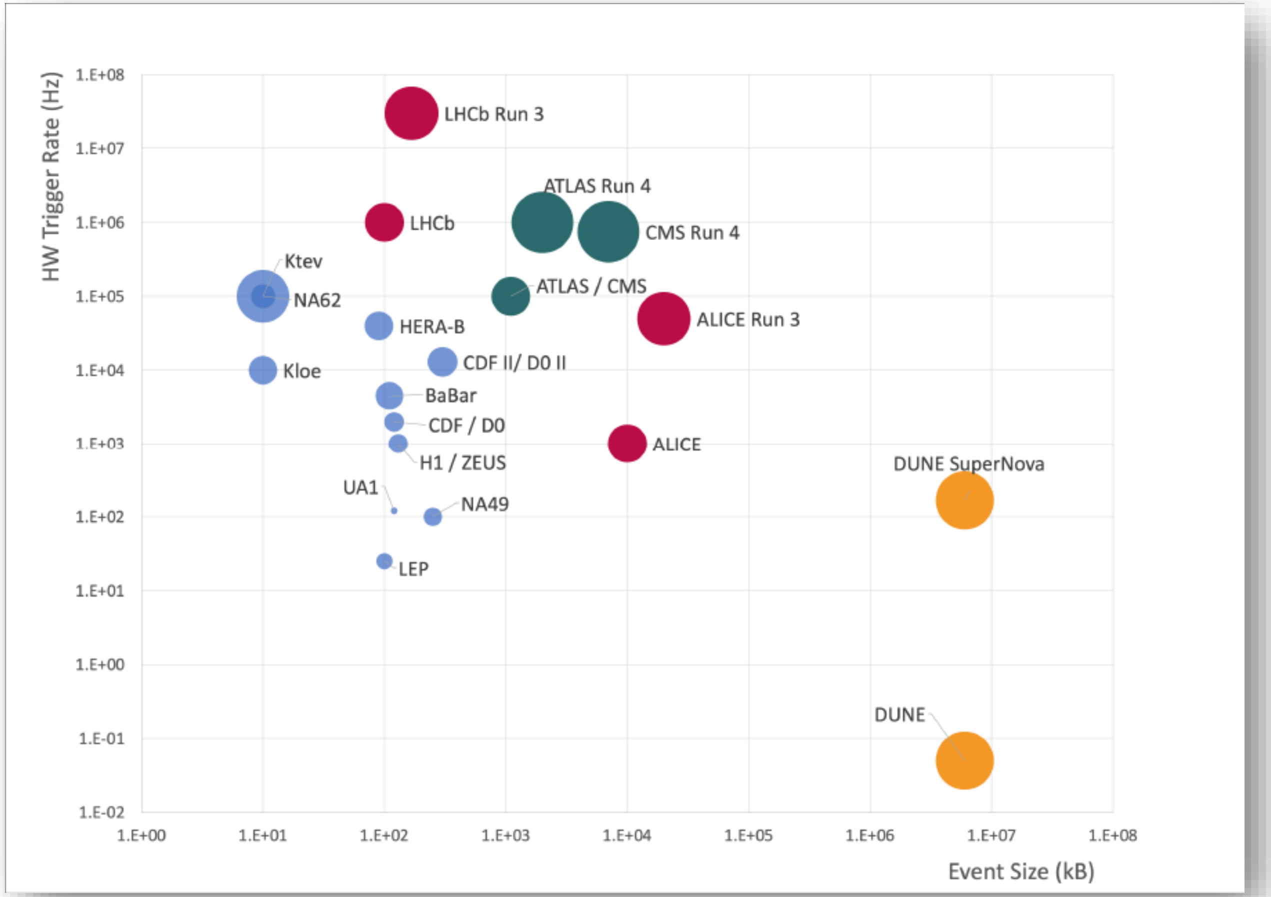
How can these challenges be overcome?

- Fully exploit the features offered by modern HW architectures
- Towards a more flexible and sustainable infrastructure
- Synergies and collaborations across scientific disciplines and with Industry partners
- Getting performant software and computing infrastructure requires significant investment in programming and computing skills

- **Characteristics** of HEP experiments over the next decade
  - Increasingly sophisticated detectors, increased event data volume
  - Higher data rates
  - Increasing demands in physics precision
  - Need to explore unconventional signatures

- **Challenges/Opportunities**
  - Technology evolution: Increased concurrency, Increasingly diverse architectures
  - Machine learning
  - Data science, including python for scientific computing
  - Open Source Software
  - Funding constraints

HEP event rates and sizes



Conclusion by Heather

- Software plays a key role in essentially **every component** of modern HEP experiments
- Within HEP, software been going through a period of **rapid evolution** due to more demanding **experimental requirements** and changing **hardware environment**
- Key features include
  - **Optimization** and **modernization**
  - Movement towards **common software**
  - Increasing diversity of **hardware architectures**
  - Impact of **machine learning**
- This rapid development will need to continue in preparation for **future upgrades** such as the HL-LHC
- For further details, I encourage you to consult the excellent talks from the **parallel sessions**