Particle Flow Oriented Detector for future Higgs factories: status & progresses

incomplete and biased: apologies

many talks from the real experts
later in this workshop

Daniel Jeans, KEK / IPNS

2022/5/23

Joint Workshop of the CEPC Physics, Software and New Detector Concept in 2022

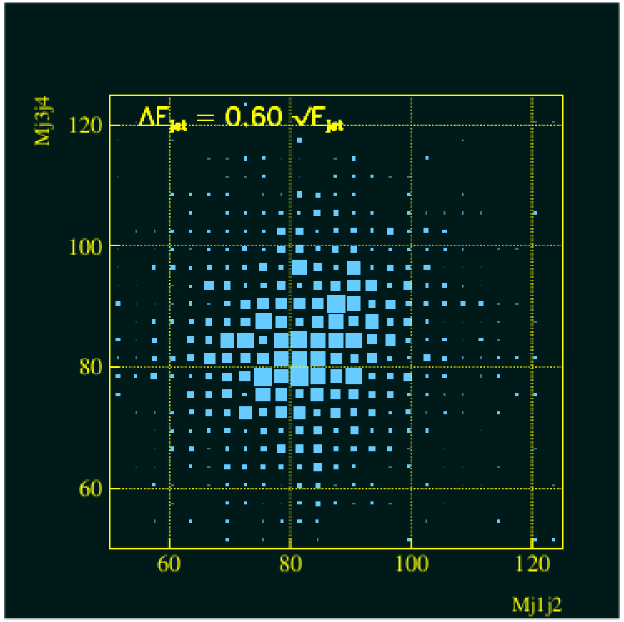
素粒子原子核研究所
Institute of Particle and Nuclear Studies

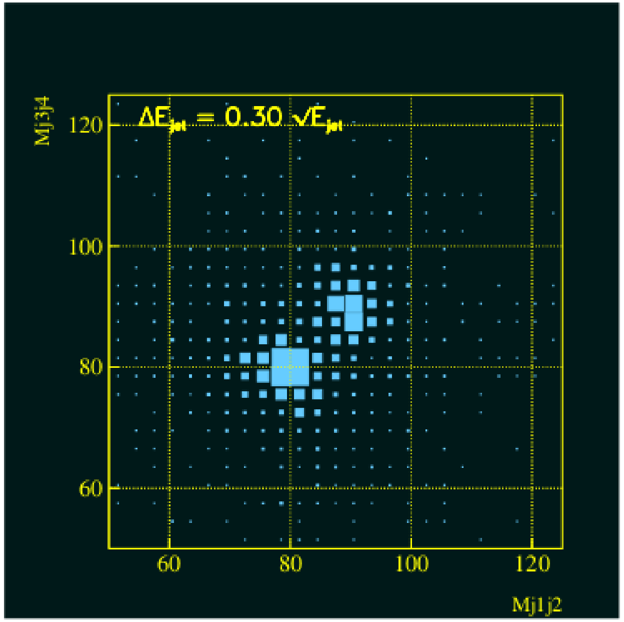
some history:

“Particle Flow” detectors developed mostly from LEP experiments

several discussions at Snowmass 2001

https://www.slac.stanford.edu/econf/C010630/proceedings.shtml



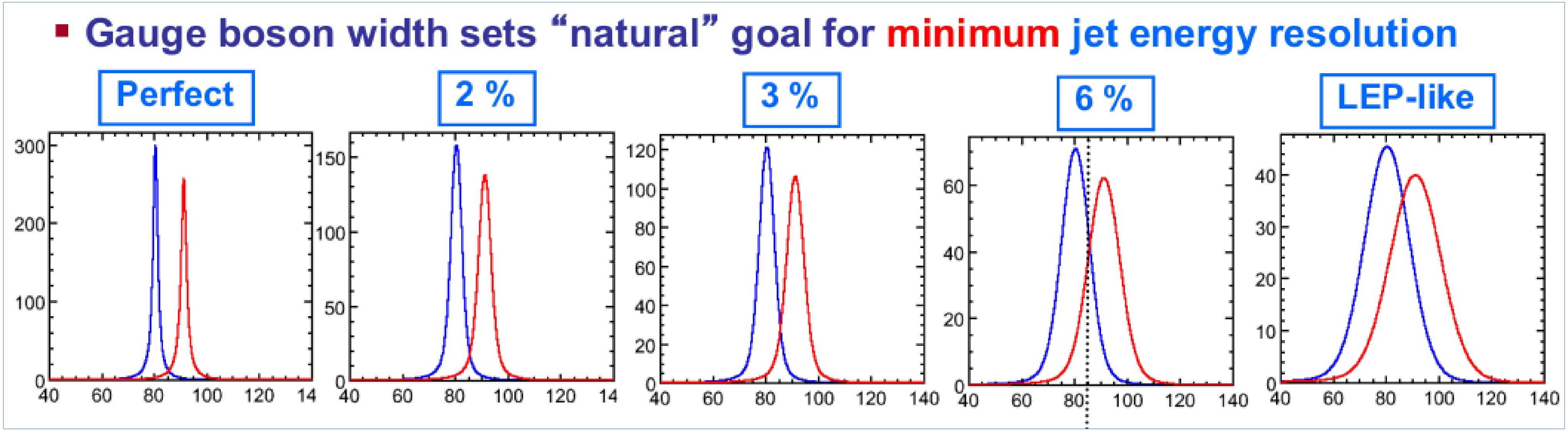


Jet Energy Resolution: “LEP-like” ~ 60%/sqrt(E) 30%/sqrt(E)

electron – positron collider

→ can and must make full use of QCD final states,
which dominate decays of W, Z, H

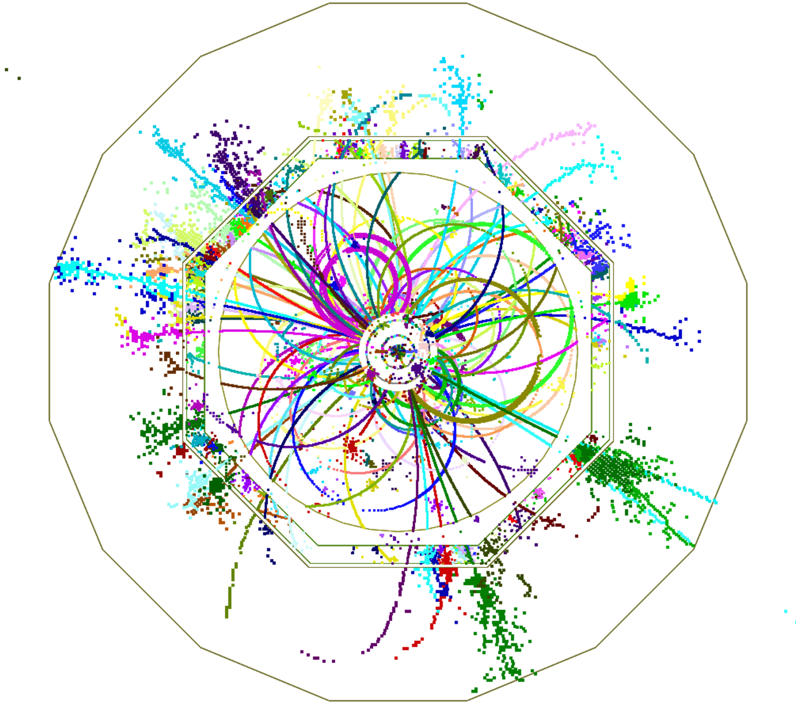
jet energy resolution is key



hadronic jets from fragmentation of quarks & gluons

energy carried on average by

charged hadrons	~65%
photons	~25%
neutral hadrons	~10%



charged hadrons

→ tracking detector

$dp_T/p_T \sim$ few x 10^{-5} p_T

photons

→ sampling ECAL

dE/E ~ 10-20% / sqrt(E)

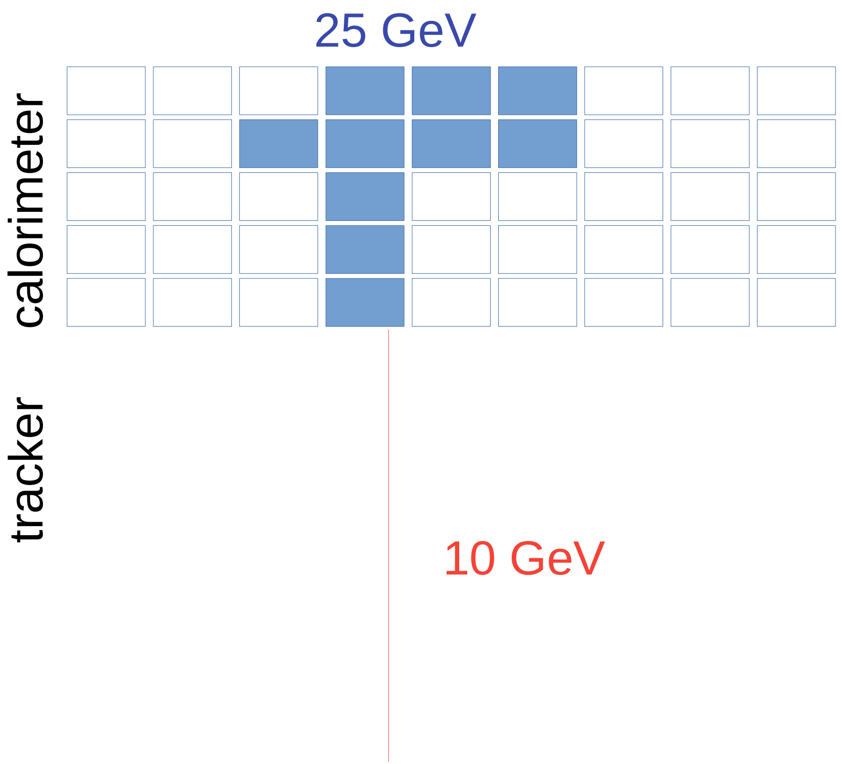
neutral hadrons

→ sampling HCAL

dE/E ~ 50% / sqrt(E)

- *individually* measure each particle in calorimeters
- if charged: replace calo with tracker measurement

“Energy Flow” vs. “Particle Flow”



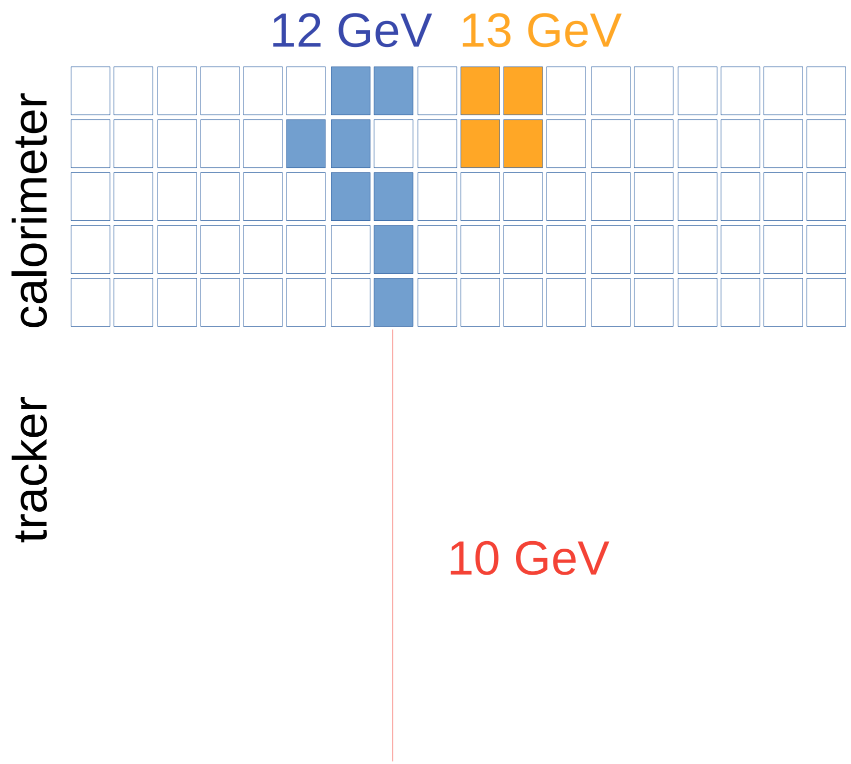
10 GeV charged

+

(25-10=)15 GeV neutral

subtract tracker measurement from calo

“Energy Flow” vs. “Particle Flow”



10 GeV charged

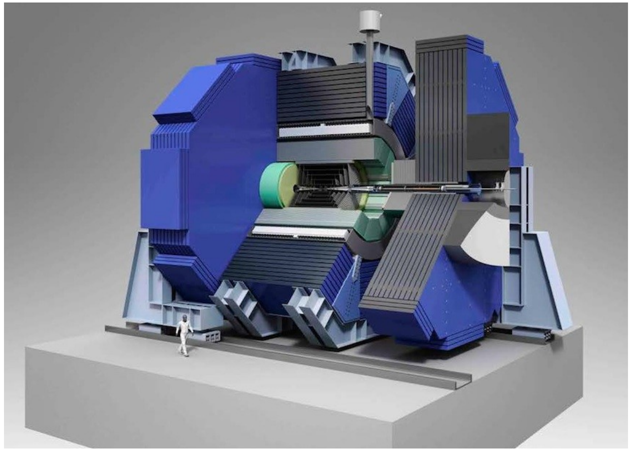
+

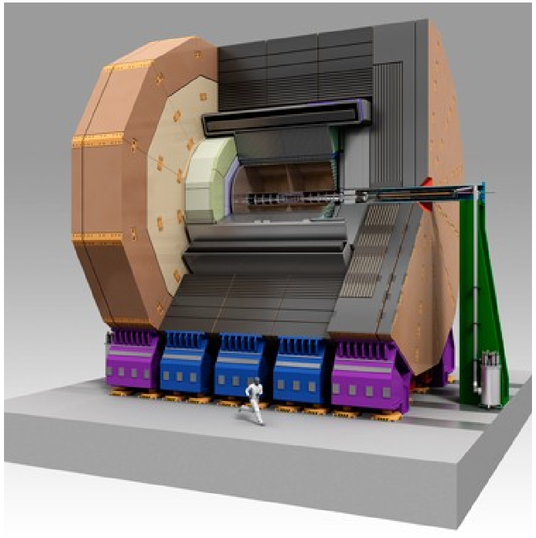
13 GeV neutral

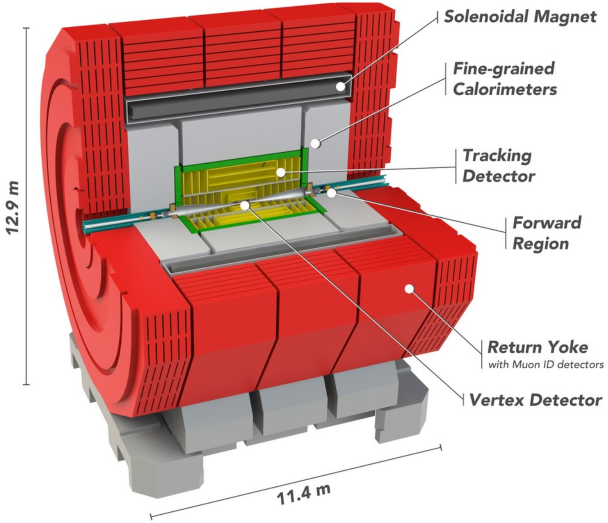
replace calo measurement with tracker

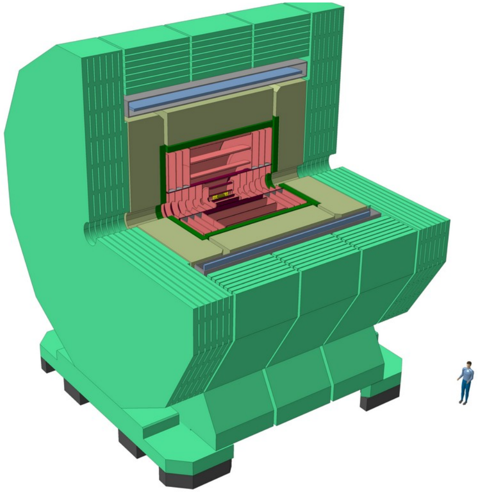
Key Points for Particle Flow:
* calorimeter granularity
* little material before CAL

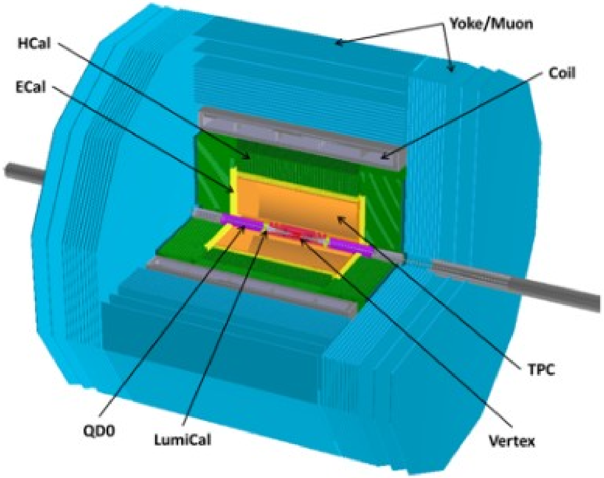
(virtual) implementations of Particle Flow detectors



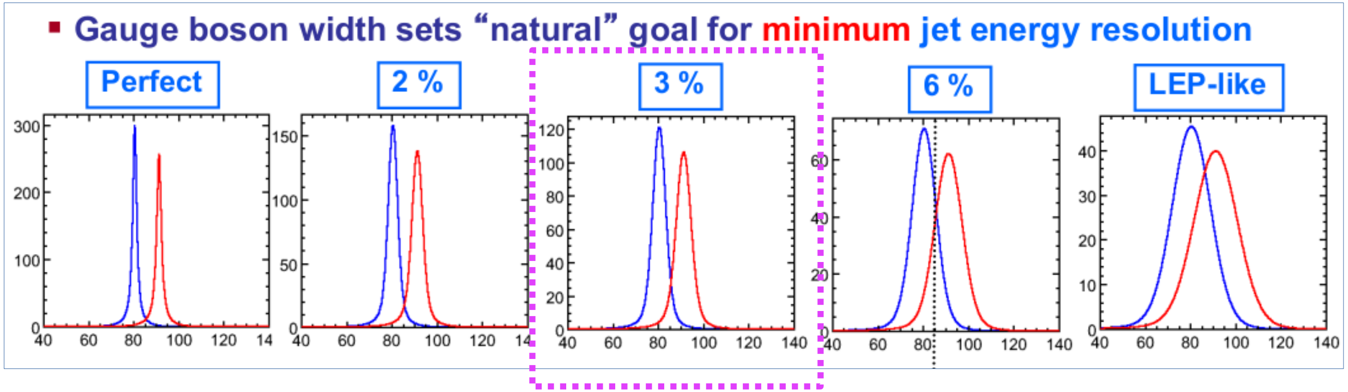




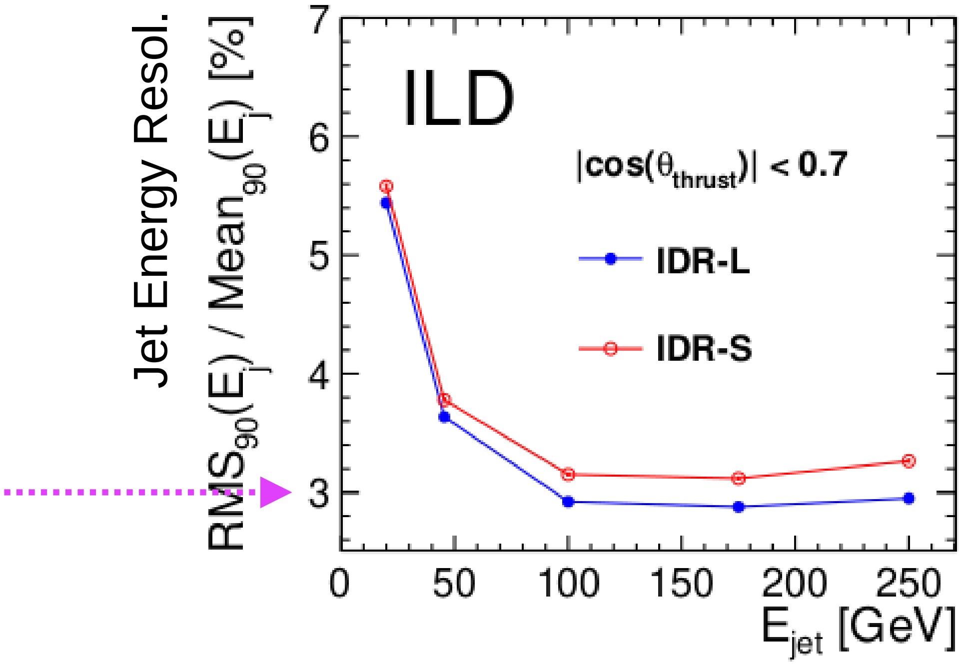




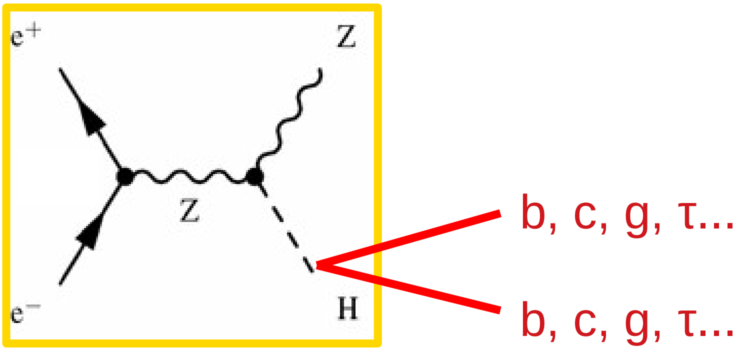
the most striking difference may be the colour of the paint used for the solenoid yoke



Particle Flow **detector**
+
Particle Flow Reconstruction **algorithm**
can achieve requested
Jet Energy Resolution



Vertex Detector

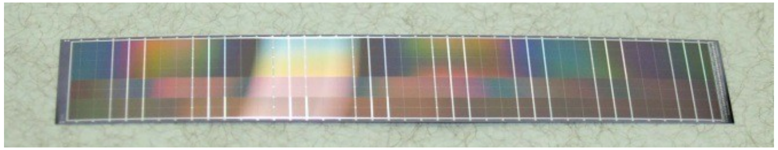


identification of medium lifetime particles B/D/tau

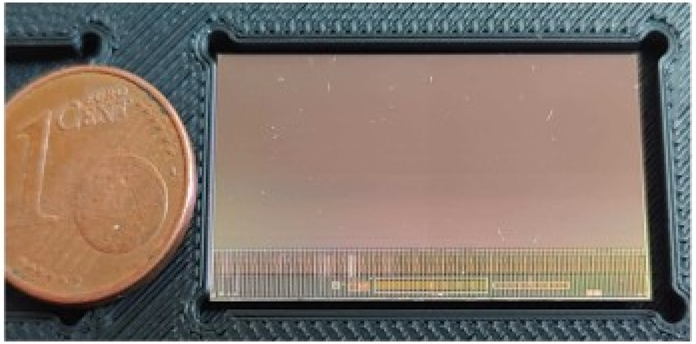
a few few-micron-precision points
starting as close to IP as possible
→ detector backgrounds, eg beamstrahlung

transparency to minimize multiple scattering
→ low-power ; support ; interfaces

many potential technologies: CMOS, SoI, FPCCD, DEPFET

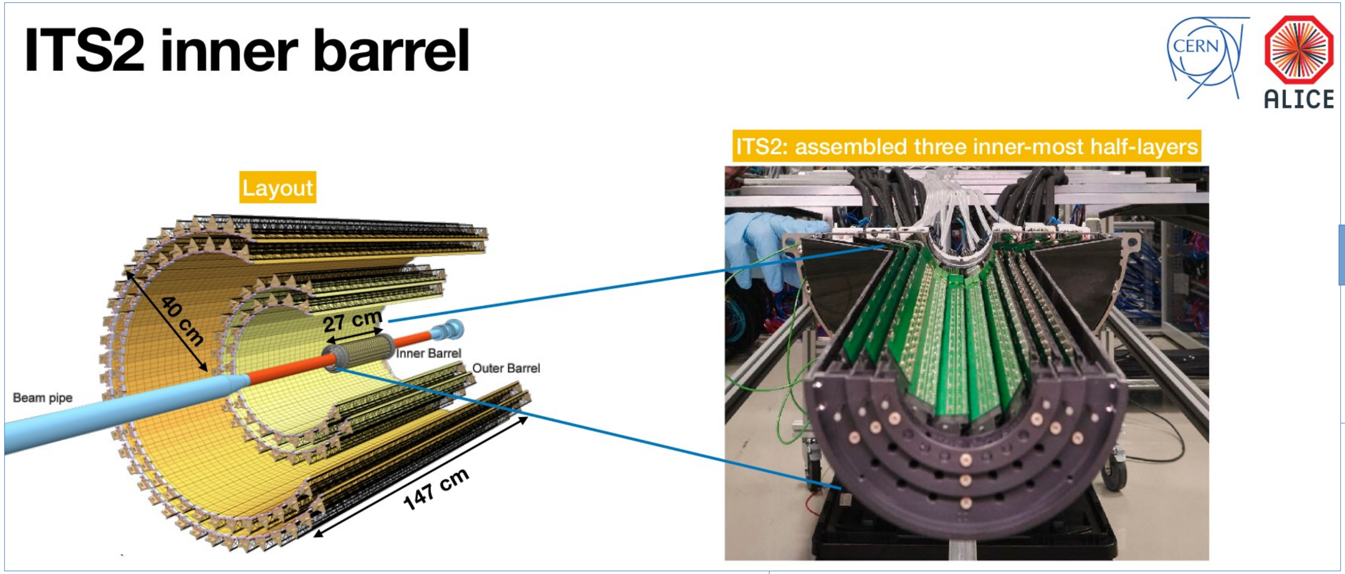


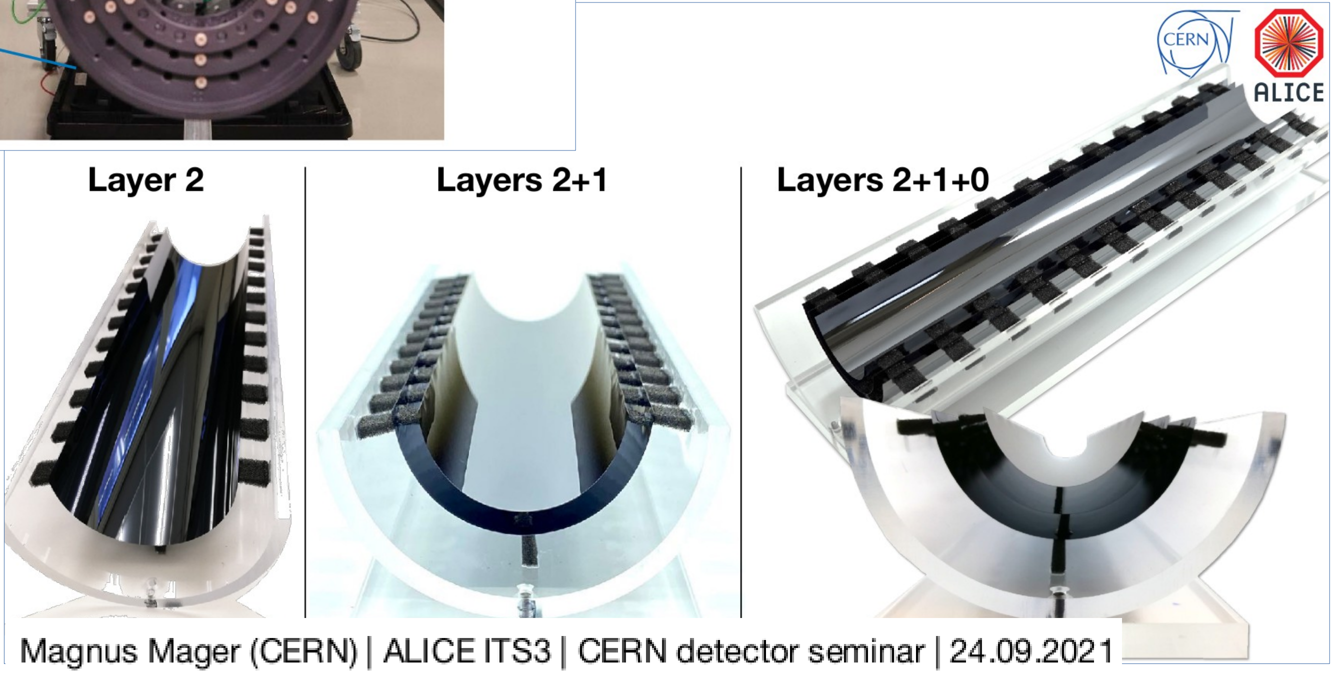
Fine Pixel CCD



MIMOSIS CMOS

Inspiration from “outside”





large area CMOS sensors
”stitched” design

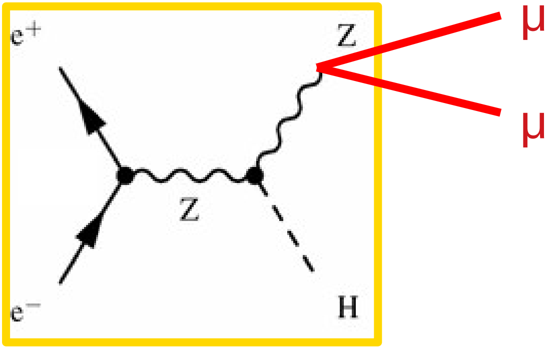
thinned → flexible

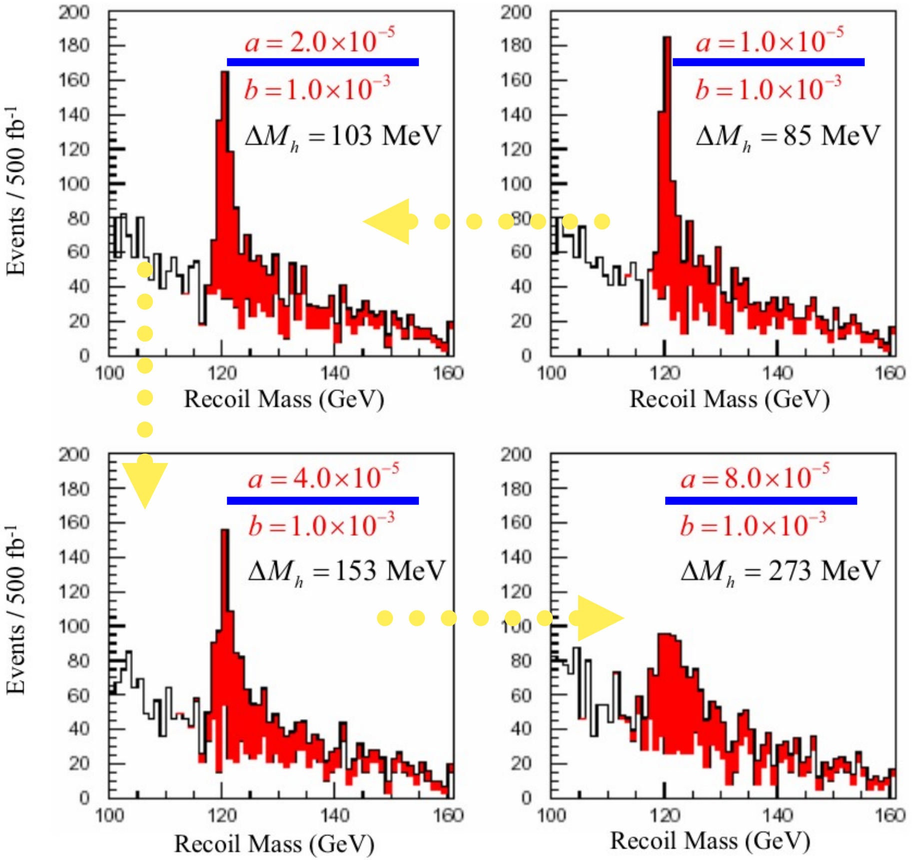
curved silicon
stiffness, ...

Tracking detector

→ Higgs-strahlung defines upper useful limit for momentum resolution

→ accelerator & detector contributions to recoil mass resolution





tracking detector typical layout

magnetic spectrometer with relatively strong B-field

low mass tracker → resolution @ low momentum

silicon detector layers: provide some very precise points

possibly complemented by a gaseous detector

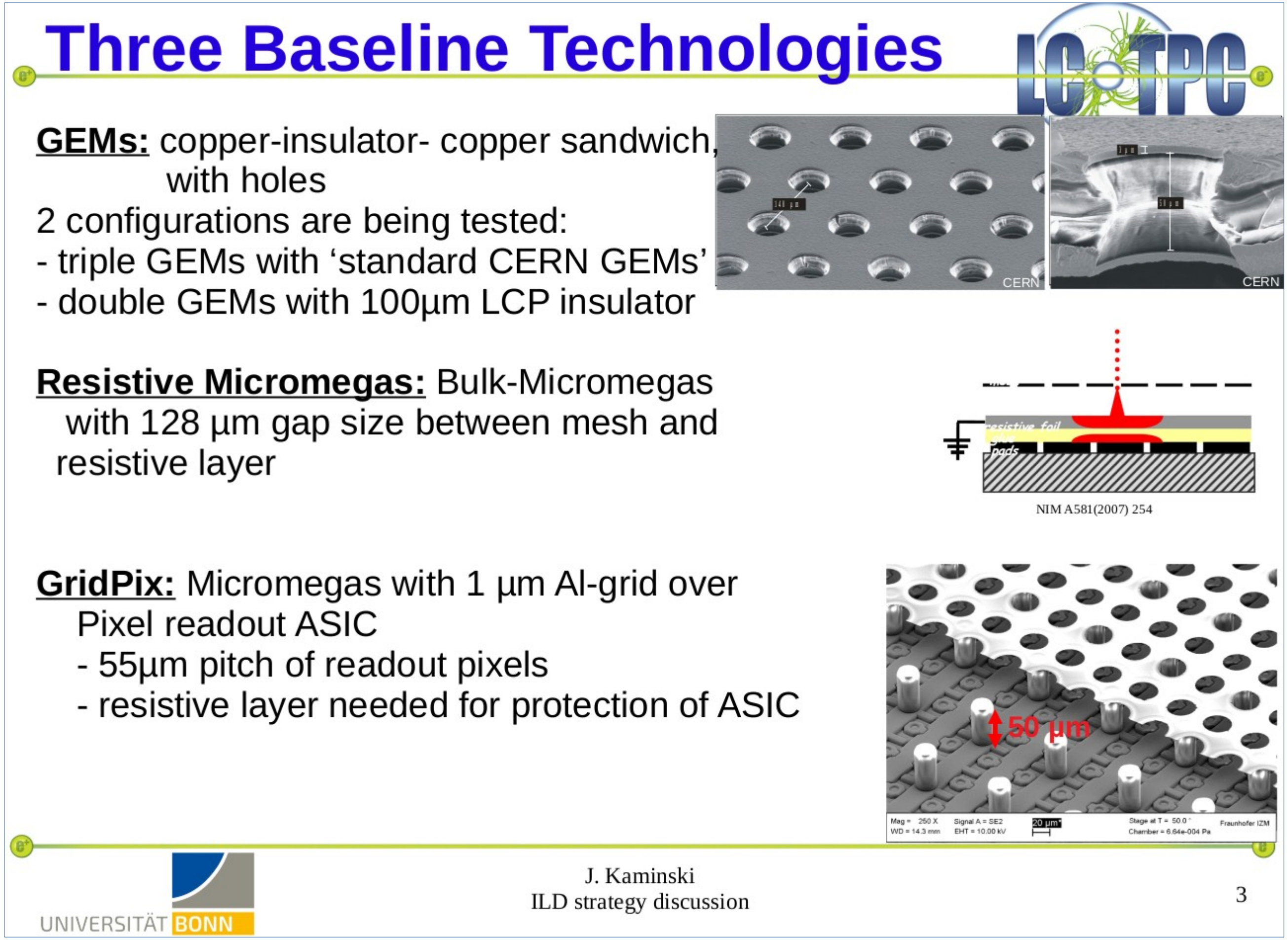
→ pattern recognition

→ particle ID (dE/dx, dN/dx)

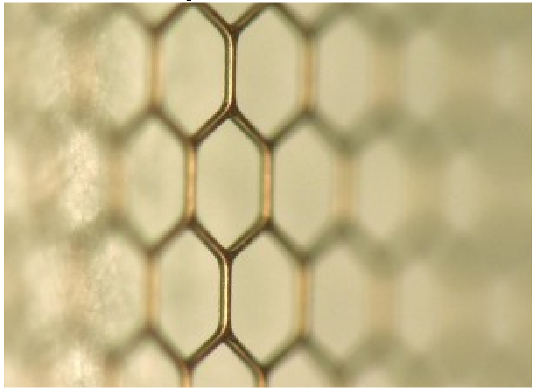
Time Projection Chamber

e.g. for ILD concept @ ILC

three main readout technologies under study in LC-TPC collaboration



gating GEM to block amplification ions



applicable at high rate colliders, e.g. Z-pole running ?

charged particle identification
~ distinguishing charged hadrons

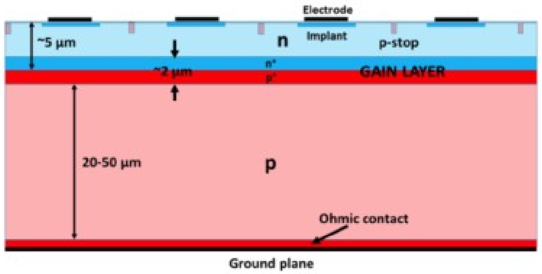
ionization → dE/dx or dN/dx

in a gaseous tracker: cover momenta up to ~10s of GeV

timing layer(s) before or in calorimeter

e.g. Low Gain Avalanche Diodes

→ very active development → 10 ps



large flight distance → outside tracker volume

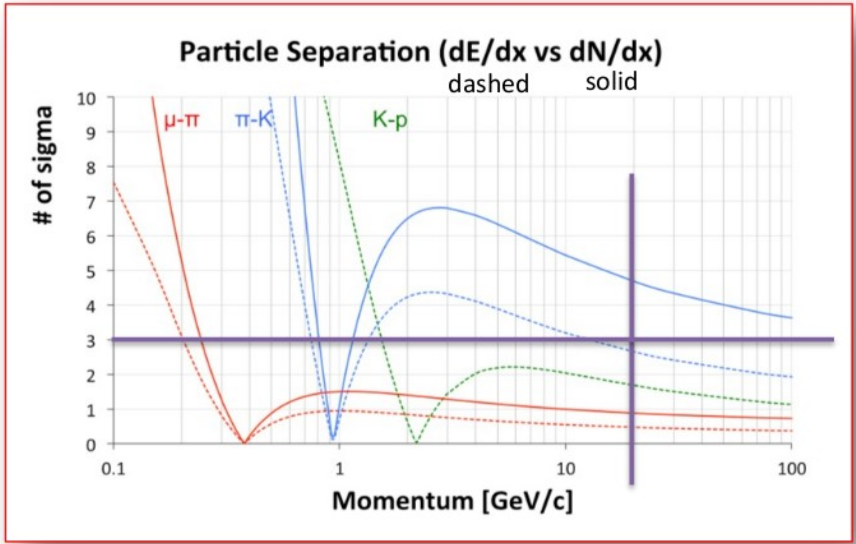
typically power-hungry readout → reduce granularity ?

cables, cooling → keep outside “transparent” tracker

→ incorporate into ECAL readout ?

Two examples:
IDEA @ FCC-ee & ILD @ ILC

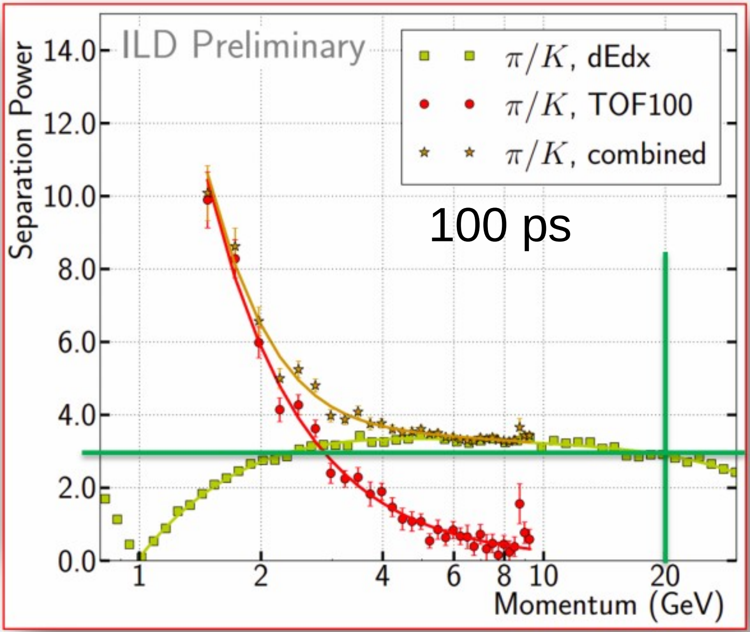
IDEA @ FCC-ee



Analitical calculations

e2019-900045-4

ILD @ ILC



1912.04601

Comparable dE/dx performance at e.g. 20 GeV, boost from dN/dx

Extending PID capabilities

2203.07535

- TOF or dE/dX have great PID capabilities, but cover only the low momentum regime (unless very large tracker volumes are used)
- **Ring Imaging Cherenkov Detectors (RICH)** are a favourable option at higher momentum

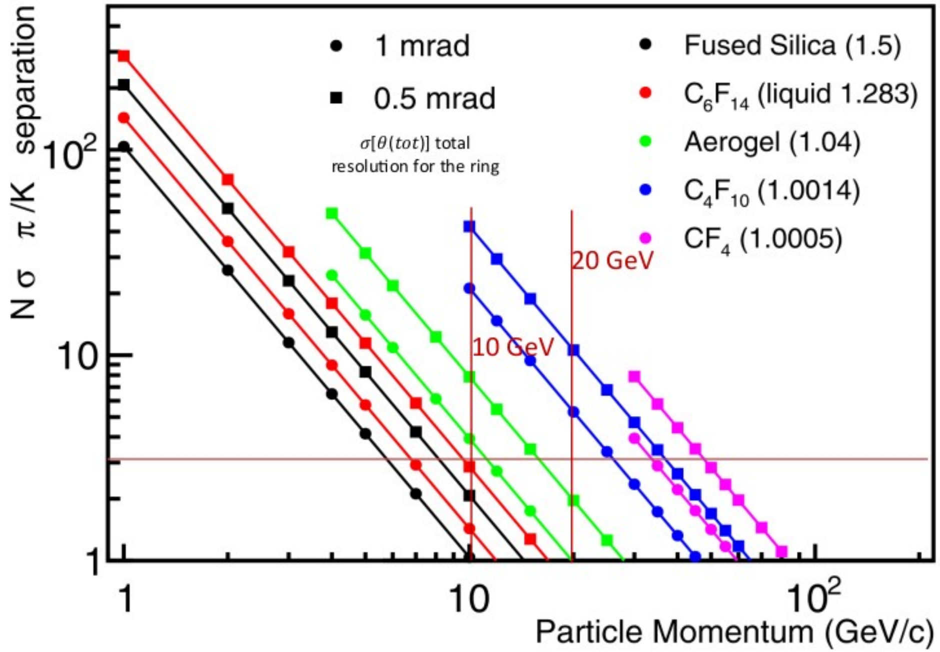


Fig. 2. The number standard deviations in $\pi - K$ separation versus momentum for different radiators and two different Cherenkov angle resolutions.

NIM,A 952 (2020) 162004

sizable volume between tracker and calorimeters ?

trk – calo linking essential for PFA

can PFA perfomance be preserved ?

https://indico.fnal.gov/event/54189/

V. Cairo

Silicon-W ECAL

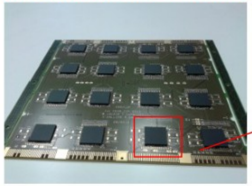
20~30 layer sampling
calorimeter

Moliere radius <2 cm

segmentation ~ 5 mm

power-pulsing at linear colliders
turn off front-end
between collisions
→ reduce power/cooling

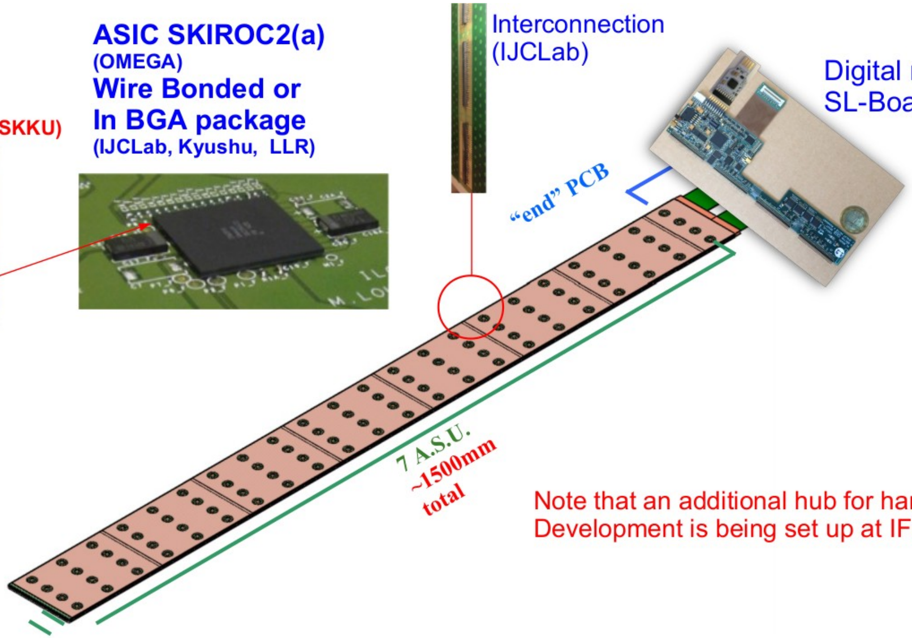
ASIC+PCB+SiWafer
=ASU
Size 18x18 cm²
(IJCLab, Kyushu, OMEGA, LLR, SKKU)



ASIC SKIROC2(a)
(OMEGA)
Wire Bonded or
In BGA package
(IJCLab, Kyushu, LLR)

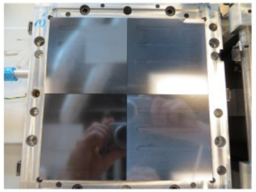
Interconnection
(IJCLab)

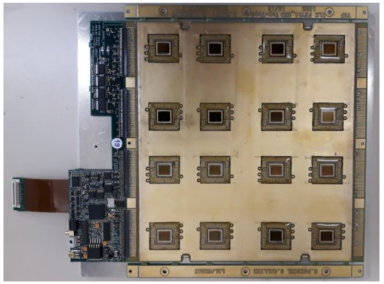
Digital readout
SL-Board (IJCLab)

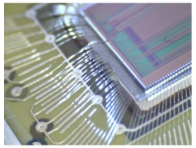


Note that an additional hub for hardware
Development is being set up at IFIC/Valencia

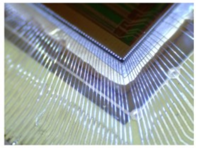
SiWafers
glued
onto PCB
Pixel size
5.5x5.5 mm²
(LPNHE)



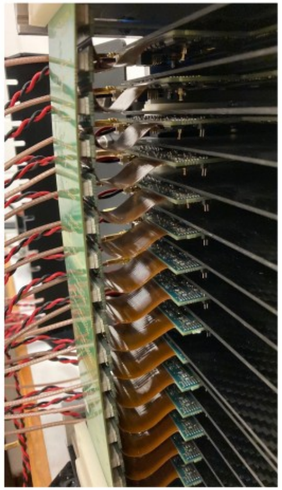


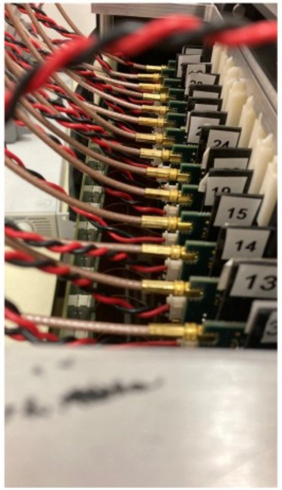


Before application of epoxy



After application of epoxy





compact
electronics
& cabling

Future Colliders Workshop: Cool Copper Collider R&D

https://indico.fnal.gov/event/54189/

May 17, 2022

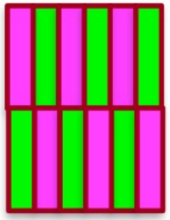
The SiD Digital ECal based on Monolithic Active Pixel Sensors

Jim Brau,
University of Oregon

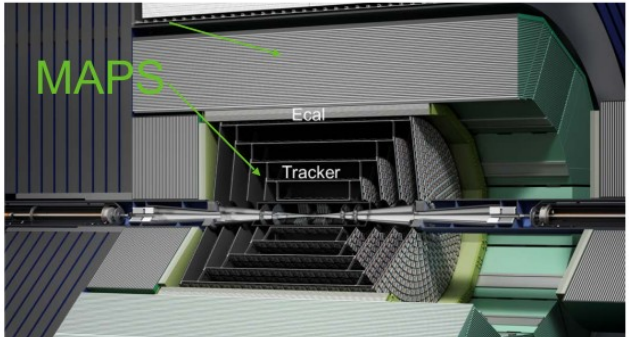
Main specifications for Large Area MAPS development

TID-AIR SLAC

Parameter	Value	Notes
Min Threshold	140 e^-	0.25*MIP with 10 µm thick epi layer
Spatial resolution	7 µm	In bend plane, based on SiD tracker specs
Pixel size	25 x 100 μm^2	Optimized for tracking
Chip size	10 x 10 cm^2	Requires stitching on 4 sides
Chip thickness	300 µm	<200 µm for tracker. Could be 300 µm for EMCal to improve yield.
Timing resolution (pixel)	~ ns	Bunch spacing: C^3 strictest with 5.3->3.5 ns; ILC is 554 ns
Total Ionizing Dose	100 kRads	Total lifetime dose, not a concern
Hit density / train	1000 hits / cm^2	



25 x 100 μm^2
ECal performance same as
50 x 50 μm^2



Future Colliders Workshop: Cool Copper Collider R&D

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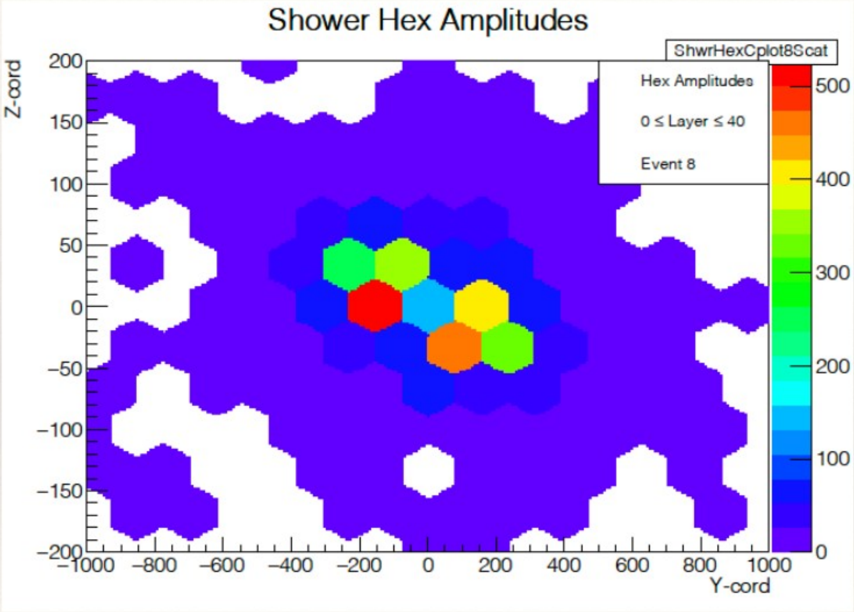
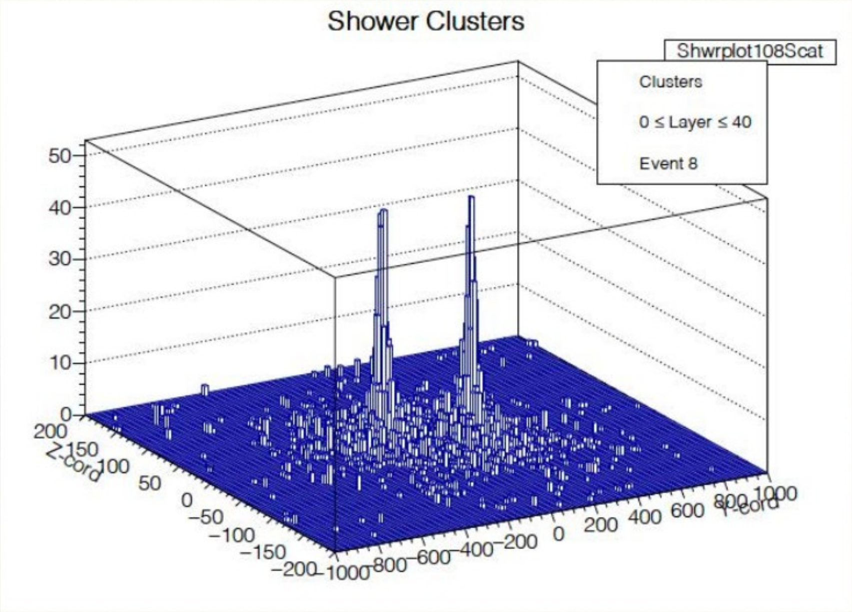
SiD Digital ECal based on Silicon MAPS J. Brau - 17 May 2022

Multi-shower of SiD MAPS compared to SiD TDR

40 GeV $\pi^0 \rightarrow$ two 20 GeV γ's



SiD TDR hexagonal sensors
13 mm^2 pixels



New SiD fine pixel sensors
25 µm x 100 µm pixels

13

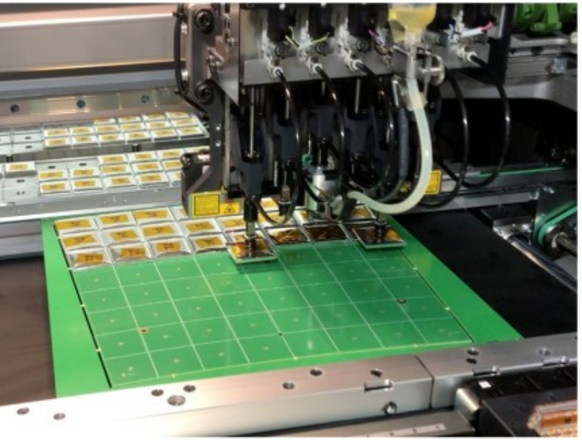
J. Brau

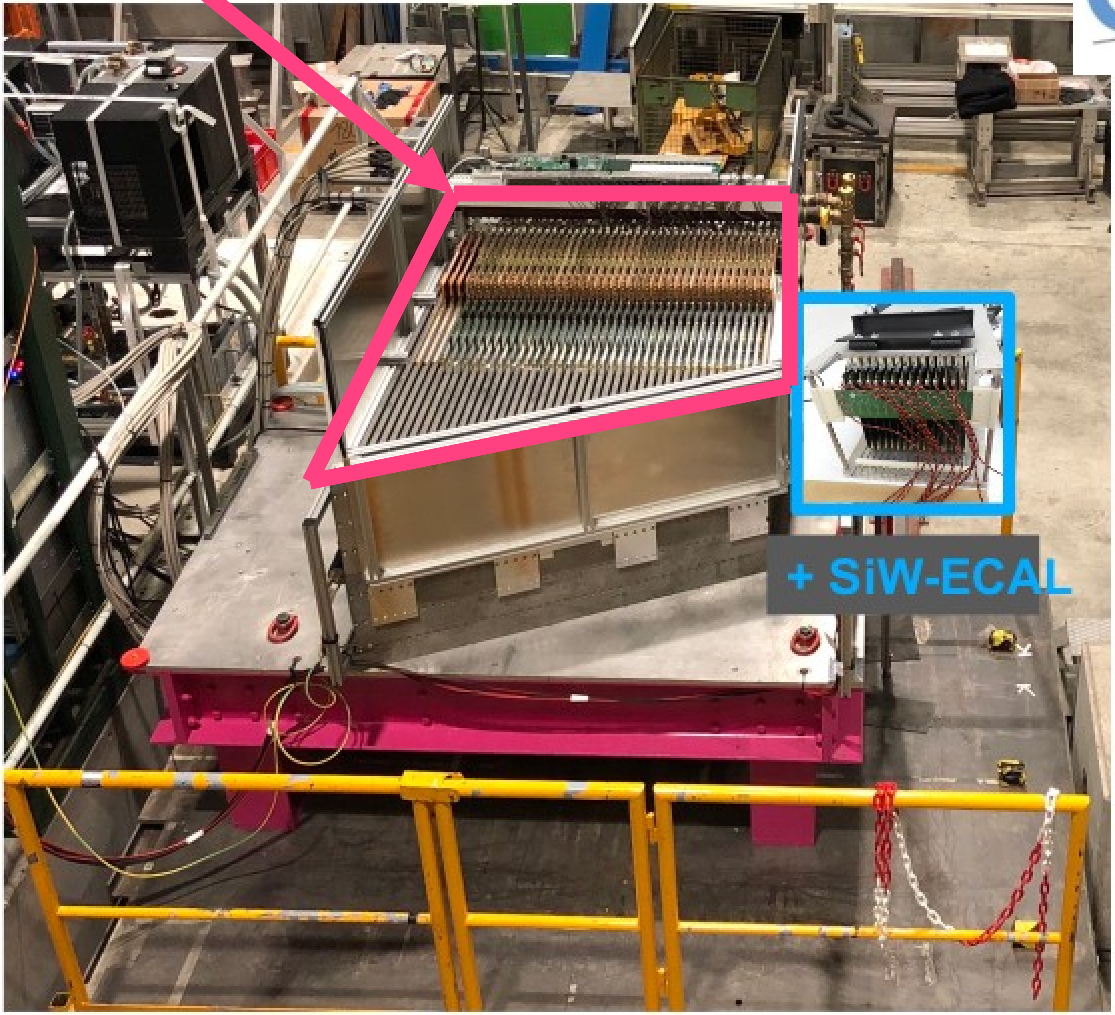
large AHCAL prototype

scintillator tile + SiPM well-established technology

extensive beam tests in 2018

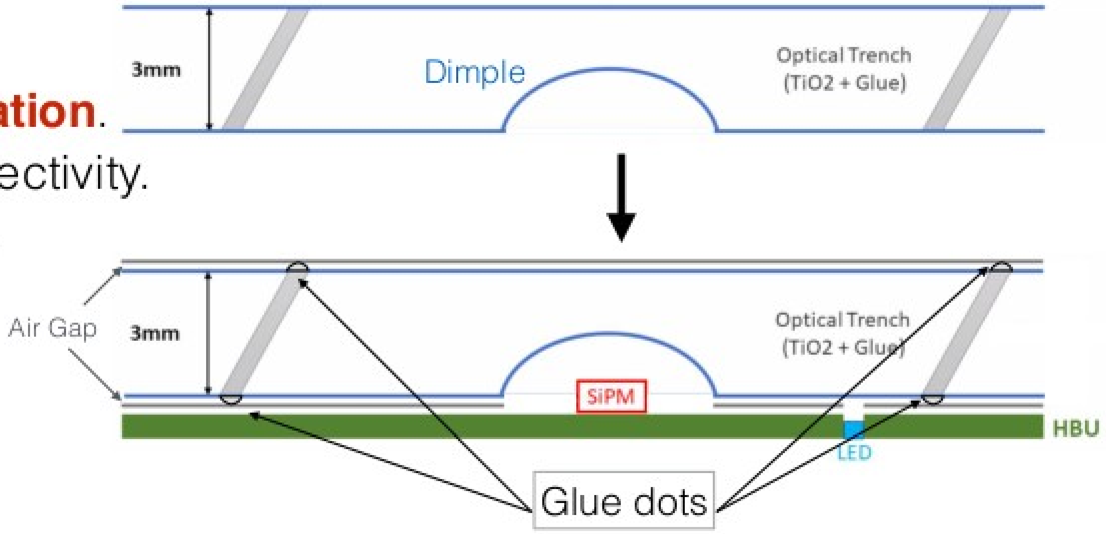
combined ECAL+HCAL test beams next month





Megatile concept

- Build **one single** 36x36 cm^2 **tile**.
- **Cut trenches** and fill with **optical insulation**.
- Pour flowing **glue + TiO_2 mixture** → reflectivity.
- Optimal angle: 30°, minimise dead area.

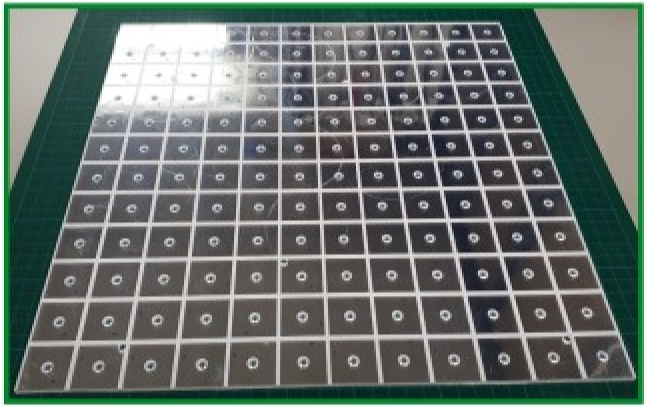


- Glue **reflective foil sheet** directly on the megatile (with laser-cut holes for SiPM)

- **Air gap** (<100 μm) to ensure total reflection.

> - 👍 ~ **No dead area**!
> - 👍 **Easier assembly**.

In real life:

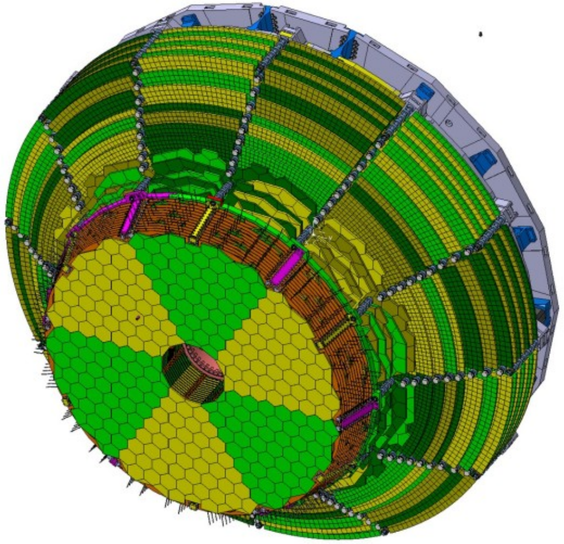


ÖAW AUSTRIAN ACADEMY OF SCIENCES

Layout of the HGCAL

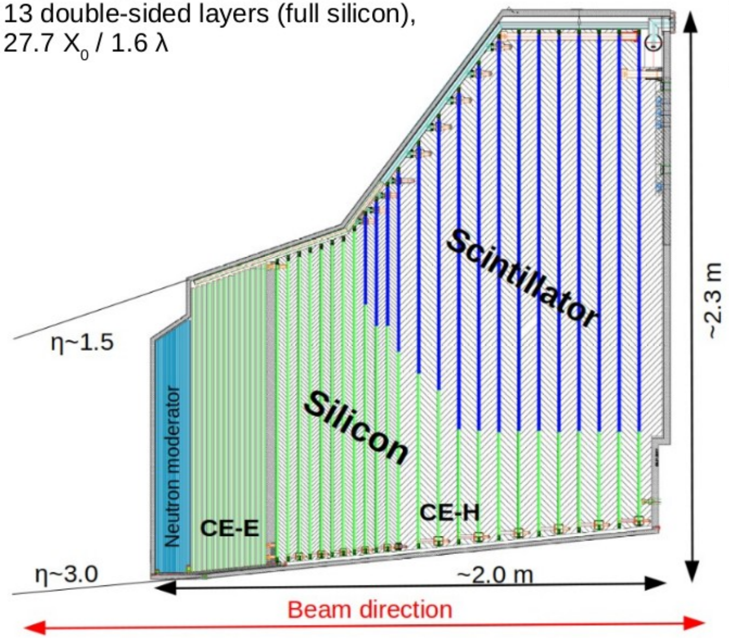
HEPHY INSTITUTE OF HIGH ENERGY PHYSICS

Calorimeter endcaps:
- Coverage 1.5< | η | <3.0
- radiation tolerant
- high granularity
- precise hit/cluster timing
- Enhanced capability for particle flow reconstruction
- Operation at -30°C



Philippe Bloch, On-detector integration, 2022

CE-E (Electro-magnetic)
Active: Silicon
Passive: Cu, CuW, Pb absorbers
13 double-sided layers (full silicon),
27.7 X_0 / 1.6 λ



CE-H (Hadronic)
Active: Silicon + Scintillator / Silicon-photomultiplier
Passive: Steel absorbers
7 all-Si layers
21 layers, 9.4 λ (total)

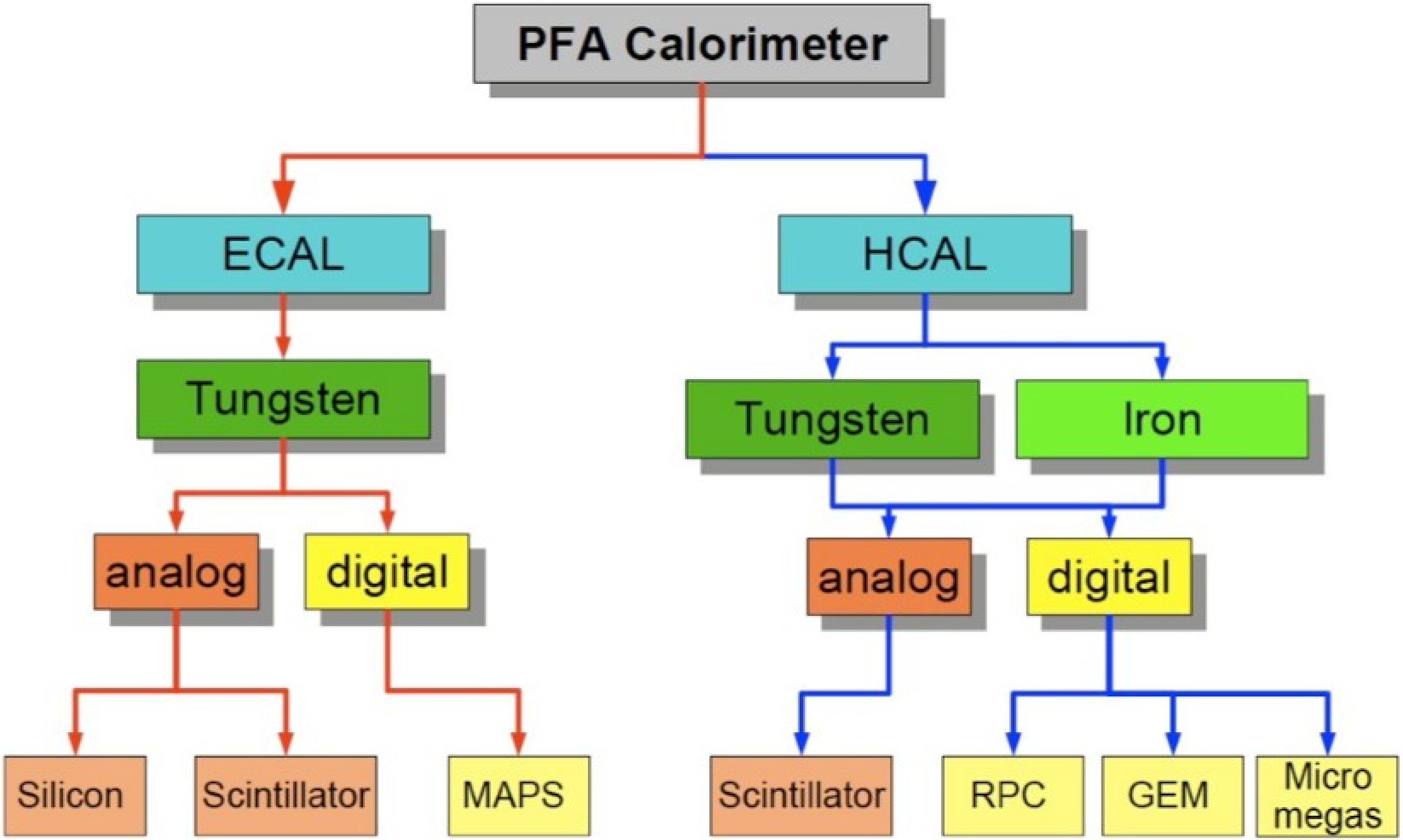
Values for both endcaps:

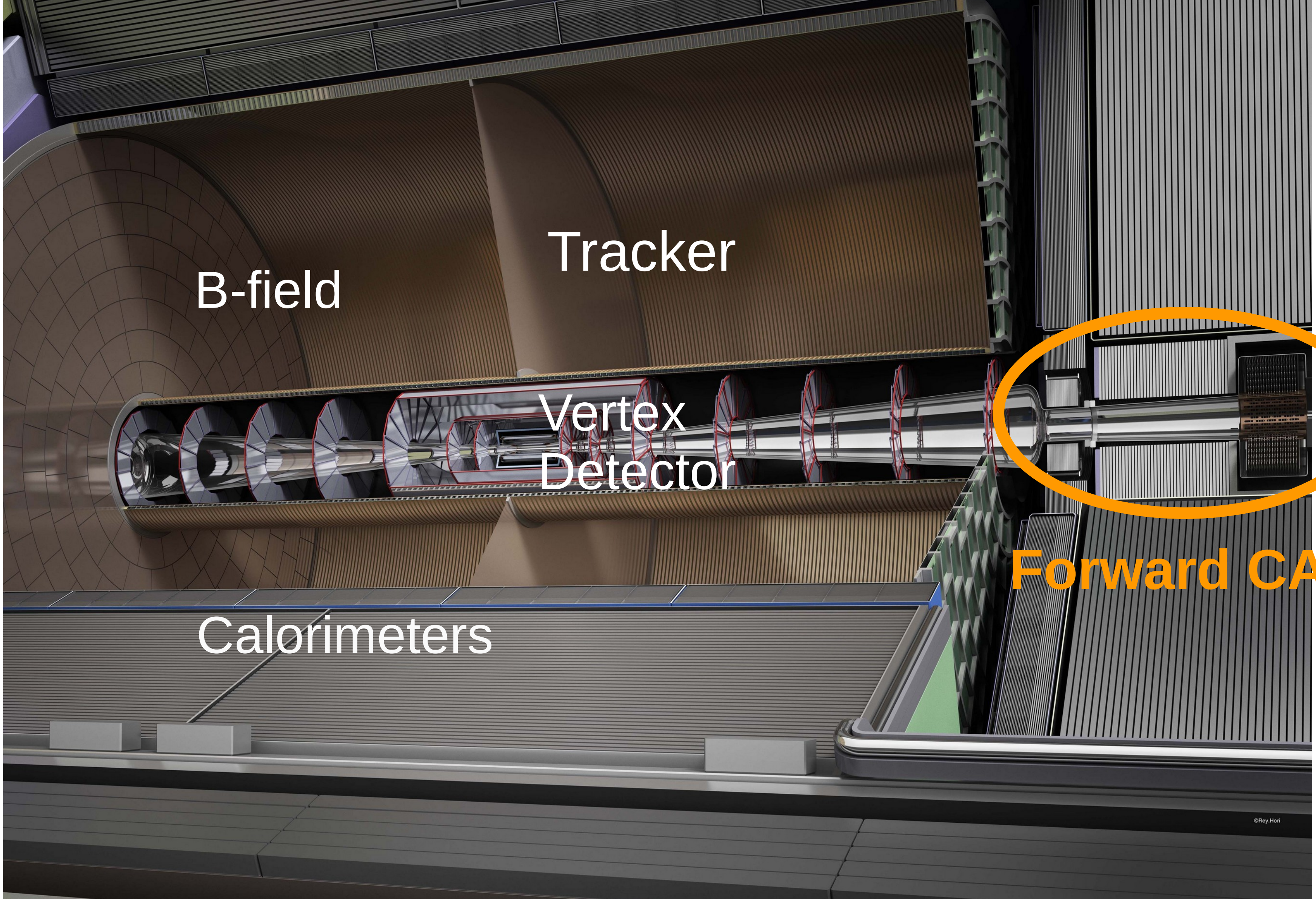
Silicon
- 620m² of silicon
- 6M channels
- 30k modules
- 0.5 – 1.1cm² per cell

Scintillator + SiPM
- 400m² of scintillator
- 240k tiles + SiPM
- 4000 boards
- 4 - 30cm² per tile

HGCAL design inspired by CALICE studies, e.g. C Adloff et al 2013 JINST 8 P09001

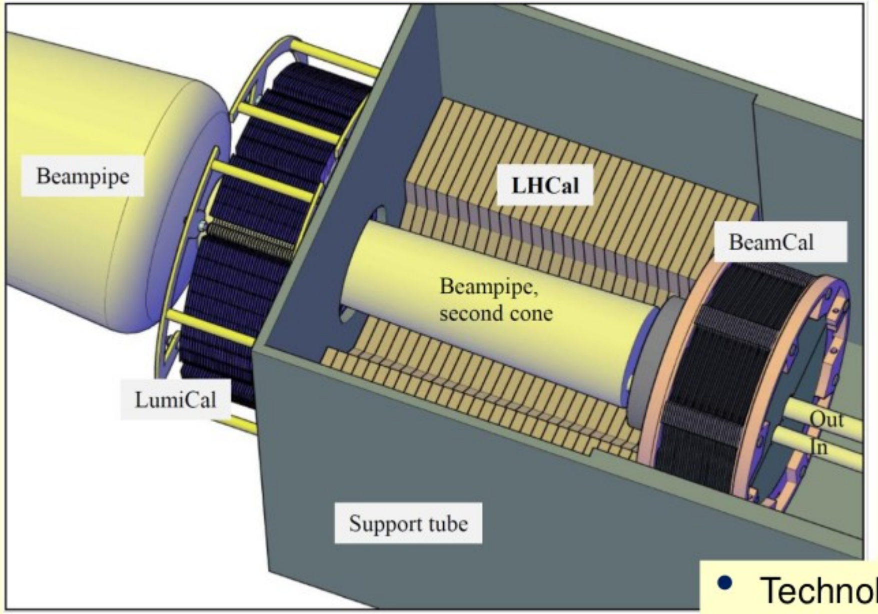
CALICE → CMS HGCAL → e+e- collider detector “technology tree”




Tracker
B-field
Vertex
Detector
Forward CAL
Calorimeters

Design of the very forward region

Forward region of an e^+e^- collider detector



- LumiCal for precise luminosity measurement (Counting Bhabhas)
- BeamCal for fast luminosity Measurement (using beamstrahlung)
- Both for large polar angle coverage (important for new particle searches)

- Technology choice: Si or GaAs/W sandwich calorimeters
- 1 X_0 absorber thickness, 20 (30) layers in ILC (CLIC)

- Small Moliere radius
- High granularity

layout depends on accelerator's MDI; final focus system

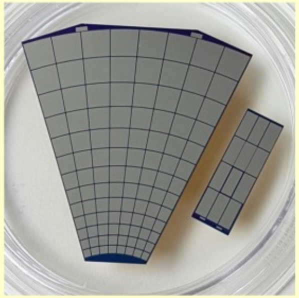
LumiCal

Outer active radius R = 195.2 mm

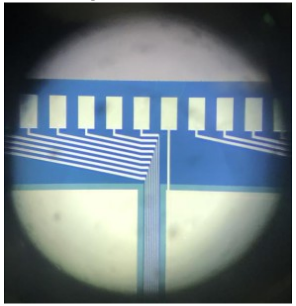
Inner active radius R = 80.0 mm

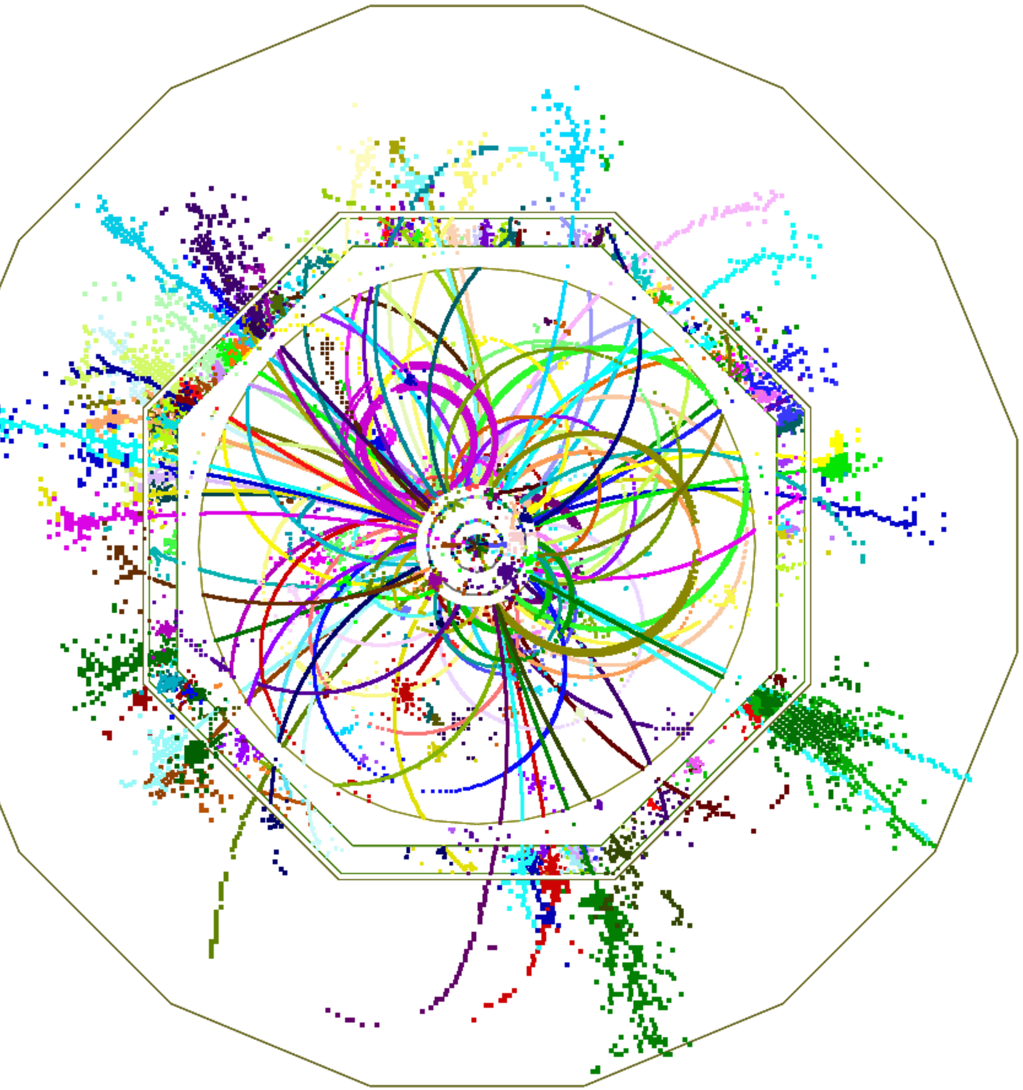
BeamCal

high resistivity GaAs sensors



now with integrated signal traces





Summary

Particle Flow approach can provide
the performance needed at an
e+ e- Higgs (+top+Z+W+...) Factory collider

high granularity calorimetry is the most
distinctive feature: R&D is very well advanced,
being implemented in CMS HGCAL

many technologies are being developed,
both within and outside our e+e- communities,
which will be of use for such a detector
and its subsystems