Projecto *PID2021-122134NB-C22* financiado por

FUTURE DETECTORS

M.C FOUZ - CIEMAT

9 SEPT 2024

LI - INTERNATIONAL MEETING ON FUNDAMENTAL PHYSICS

TALK OBJECTIVES

The talk is oriented towards the detectors for future e+e- Higgs factories

BUT

synergies with HL-HLC present and future upgrades and other experiments

The talk aim to present

- The most relevant requirements imposed to the detector to accomplish the expected physics program
- A fast overview of the different proposed detector concepts and the key differences
- A fast overview of the status of art and R&D on detectors
- A very,very, very, small touch on the Spanish groups activities (just few examples)

Even concentrating “only” on detectors for e+e- Higgs factories there is a large number of R&D ongoing all around the world
Some things will be described a bit, for others a brief comment or even I live them outside

My view, my interpretation, my knowledge… my ignorance too

SOME PHYSIC EXPECTATIONS FOR FUTURE e+e- COLLIDERS

Baseline FCC-ee operation model,

Working point	Z, years 1-2	Z, later	WW	HZ	$t\bar{t}$	
$\sqrt{s}$ (GeV)	88, 91, 94		157, 163	240	340-350	365
Lumi/IP (10^{34} cm^{-2}s^{-1})	115	230	28	8.5	0.95	1.55
Lumi/year (ab^{-1}, 2 IP)	24	48	6	1.7	0.2	0.34
Physics Goal (ab^{-1})	150		10	5	0.2	1.5
~~Run time (year)~~	2	2	2	3	1	4
Number of events	5×10^{12} Z		10^8 WW	10^6 HZ + 25k WW $\to$ H	$10^6 t\bar{t}$ +200k HZ +50k WW $\to$ H	

arXiv:2106.13885v2

Systematics are estimations

Observable	present 2021 value ± error	FCC-ee Stat.	FCC-ee Syst.	Comment and leading exp. error
m_Z (keV)	91186700 ± 2200	**4**	100	From Z line shape scan Beam energy calibration
Γ_Z (keV)	2495200 ± 2300	**4**	25	From Z line shape scan Beam energy calibration
τ lifetime (fs)	290.3 ± 0.5	**0.001**	0.04	radial alignment
τ mass (MeV)	1776.86 ± 0.12	**0.004**	0.04	momentum scale
τ leptonic ($\mu\nu_\mu\nu_\tau$) B.R. (%)	17.38 ± 0.04	**0.0001**	0.003	e/μ/hadron separation
m_W (MeV)	80350 ± 15	**0.25**	0.3	From WW threshold scan Beam energy calibration
Γ_W (MeV)	2085 ± 42	**1.2**	0.3	From WW threshold scan Beam energy calibration
$\alpha_s(m_W^2)(\times 10^4)$	1170 ± 420	**3**	small	from R_ℓ^W
$N_\nu(\times 10^3)$	2920 ± 50	**0.8**	small	ratio of invis. to leptonic in radiative Z returns
m_{top} (MeV/c^2)	172740 ± 500	**17**	small	From $t\bar{t}$ threshold scan QCD errors dominate
Γ_{top} (MeV/c^2)	1410 ± 190	**45**	small	From $t\bar{t}$ threshold scan QCD errors dominate
$\lambda_{top}/\lambda_{top}^{SM}$	1.2 ± 0.3	**0.10**	small	From $t\bar{t}$ threshold scan QCD errors dominate
ttZ couplings	± 30%	**0.5 – 1.5 %**	small	From $\sqrt{s}$ = 365 GeV run

Showmass

- Clearest environment than hadron colliders
  No pileup, no underlying event E and p constraints…
- **Huge number of events** (e.g. 5x10^{12} Z vs 18x10^6 at LEP
  108 WW pairs vs 8x103 W at LEP)

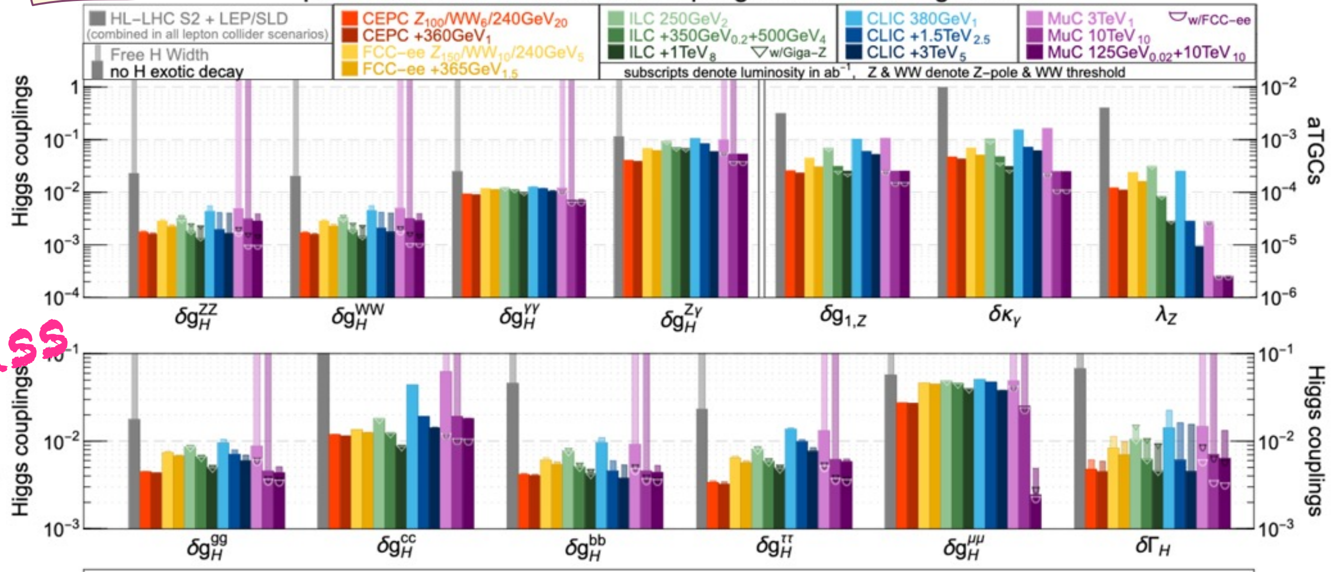
High precision can be achieved

To take full advantage of this conditions
DETECTORS WITH EXCELLENT PERFORMANCE ARE MANDATORY

Gain at least 1 order of magnitude

https://arxiv.org/pdf/2206.08326

precision reach on effective couplings from SMEFT global fit



(*) aTGCs =anomalous trilinear gauge couplings

DETECTOR CHALLENGES FOR FUTURE e+e- COLLIDERS

DETECTOR CHALLENGE

To achieve systematic uncertainties similar or smaller than the statistical

- Clearest environment than hadron colliders
  No pileup, no underlying event E and p constraints…
- **Huge number of events** (e.g. 5×10^{12} Z vs 18×10^{6} at LEP
  108 WW pairs vs 8x103 W at LEP)

High precision can be achieved

SOME PERFORMANCE REQUIREMENTS DRIVEN BY PHYSICS

Momentum	$\sigma_{Pt}/P^2_T \sim 3\text{-}4 \times 10^{-5}$ (~7 μm single hit resolution) (~1/10 of LEP)
Angular resolution	< 0.1 μrad for 45 GeV muons
Impact parameter	$\sigma_{do} = 5 \oplus 15\ (p \sin\theta^{3/2})^{-1}$ μm (~3 μm single hit resolution) (b and c tagging capability)
E.M resolution	$< 10 - 15\ \%\sqrt{E}$ (with low constant term)
Jet energy resolution	$\sim 30\%\sqrt{E}$ (~ a factor 2 better than present)
Particle Identification (PID)	Excellent lepton and photon ID (e/π, μ/π, γ/π^0) , π/K, K/p separation (heavy flavor studies)…. for a broader momentum range for e, μ and hadrons to improve tagging, jet energy…

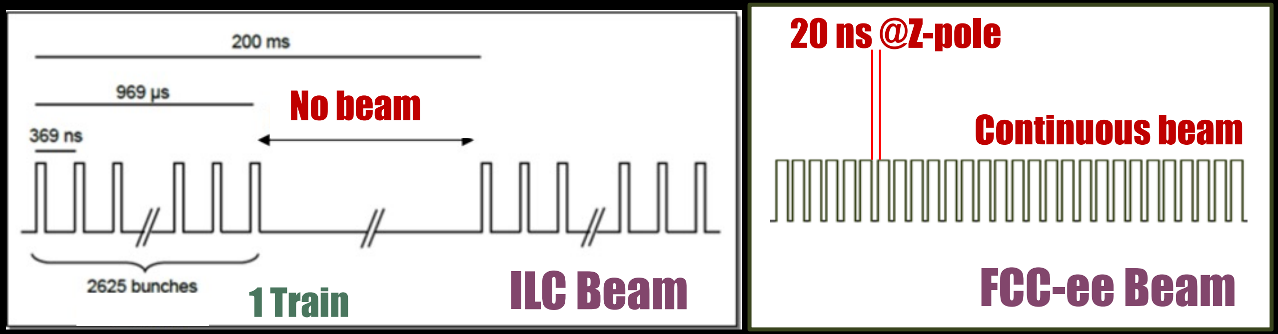
Hermetic coverage
Precise timing

will play an important role

Improve PID
Beam-induced background rejection
Pile-up rejection
Improve calorimeter/tracker reconstruction

MAIN DIFFERENCES BETWEEN CIRCULAR AND LINEAR e+e- COLLIDERS IMPACTING ON DETECTORS (I)

Beam structure



Continuous beam has implications on power, rates, readout…

ILC experiments uses power pulsing (electronics off between trains)
=> Reduction of power consumption a factor $\mathcal{O}(10)$

Luminosity. FCC-ee running at Z pole (Tera-Z vs Giga-Z)

@ Z-pole: L ~1.8 x 10^{36}/cm^{2} Z-pole, physic event rates up to 100 kHz. (pile up of 2x10^{-3})

Implication on detectors, electronics, DAQ: response time, time resolution, size of event, data handling….
Huge statistic → Systematic control down to $\sim 10^{-5}$ level
Excellent control of acceptances needed
Luminosity measurements $\sigma(L)/L = 10^{-4}$ (for low angle Bhabha events)

Constraints on design (including mechanics of Endcap Calorimeter and LumiCal)

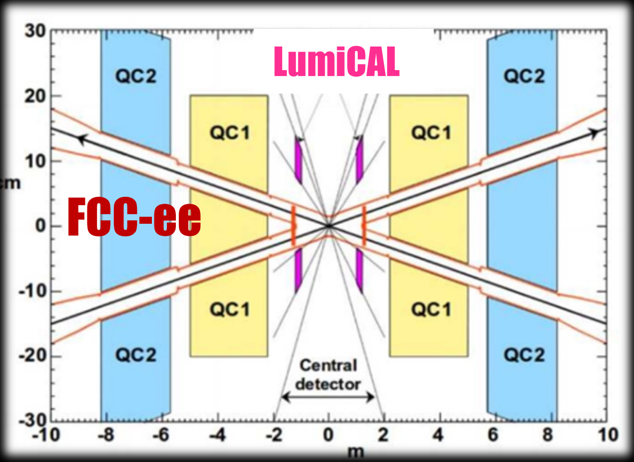
MAIN DIFFERENCES BETWEEN CIRCULAR AND LINEAR e+e- COLLIDERS IMPACTING ON DETECTORS (II)

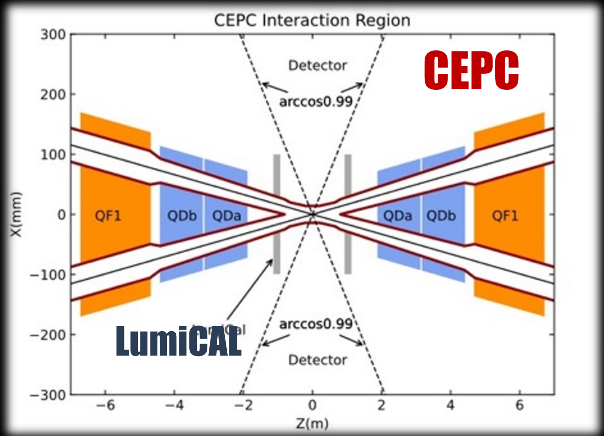
Daniel Jeans

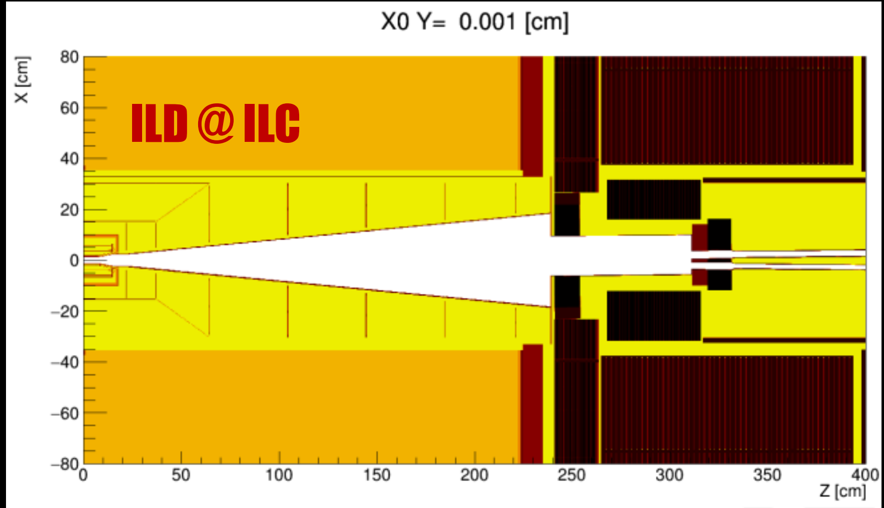
Machine Detector Interface (MDI)

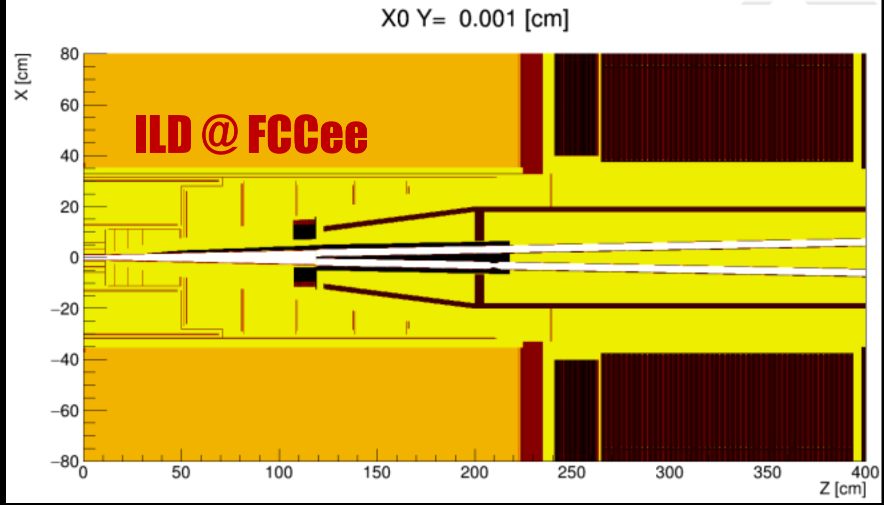
Crossing angles at interaction Point (mrad)	
ILC	14
CLIC	16.5 -20
FCC-ee	30
CEPC	33

L* (meters)	
ILC	4.1
CLIC	6
FCC-ee	2.2
CEPC	2.2









Circular machines:

- Last focusing magnet (at L*) INSIDE the detector volume (also the LumiCal at 1m from IP – vs 2.5m)
- B field limited to 2T at Z-pole operation (vs ~3.5T for linear) ➔ Larger tracker volume

Lower tracker acceptance for FCCee vs ILC

θ < 100 mrad reserved to magnets and instrumentation + Lumical (up to 150 mrad)
Forward tracker limitation > 10 deg.

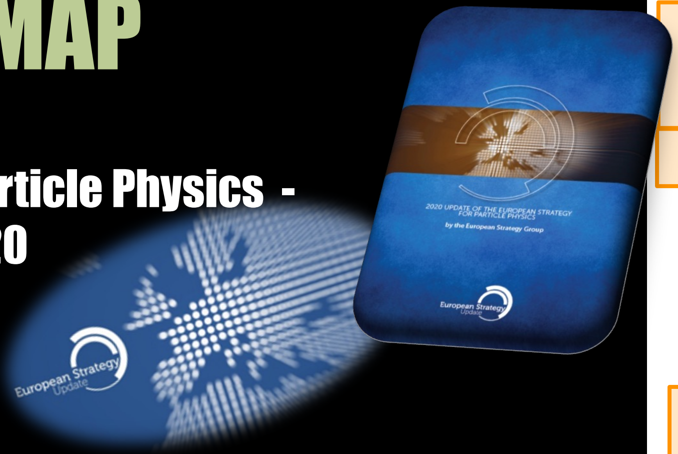
MAIN DIFFERENCES BETWEEN CIRCULAR AND LINEAR e+e- INTERACTION REGION SUMMARY

	FCC-ee	CEPC	ILC	CLIC
L* (Δz between IP and first	2.2 m	2.2 m	4.1 m	6 m
Position of final quadrupole	Inside detector	Inside detector	Outside detector	Outside detector
LumiCal position	z=1m, ~50-100 mrad (Constrained by compensating solenoid)	z~0.95~1.11m 26-105 mrad (fiducial volume 53-79 mrad)	z=2.5m, 33-80 mrad	z=2.5m, 39-134 mrad
Tracker acceptance	Down to ~9 degrees (defined by luminometer)	Down to ~8 degrees	Down to ~6° (defined by conical beam pipe)	Down to ~7° (defined by conical beam pipe)
Inner beam pipe radius	10 mm	10 mm	16 mm	29.4 mm
Crossing angle	30 mrad	33 mrad	14 mrad	20 mrad
Main solenoid B field	2T	3T (2T at Z pole)	3.5-5T	4T

Constraints from accelerators to future e^+e^--factory experiments - Giovanni Marchiori -

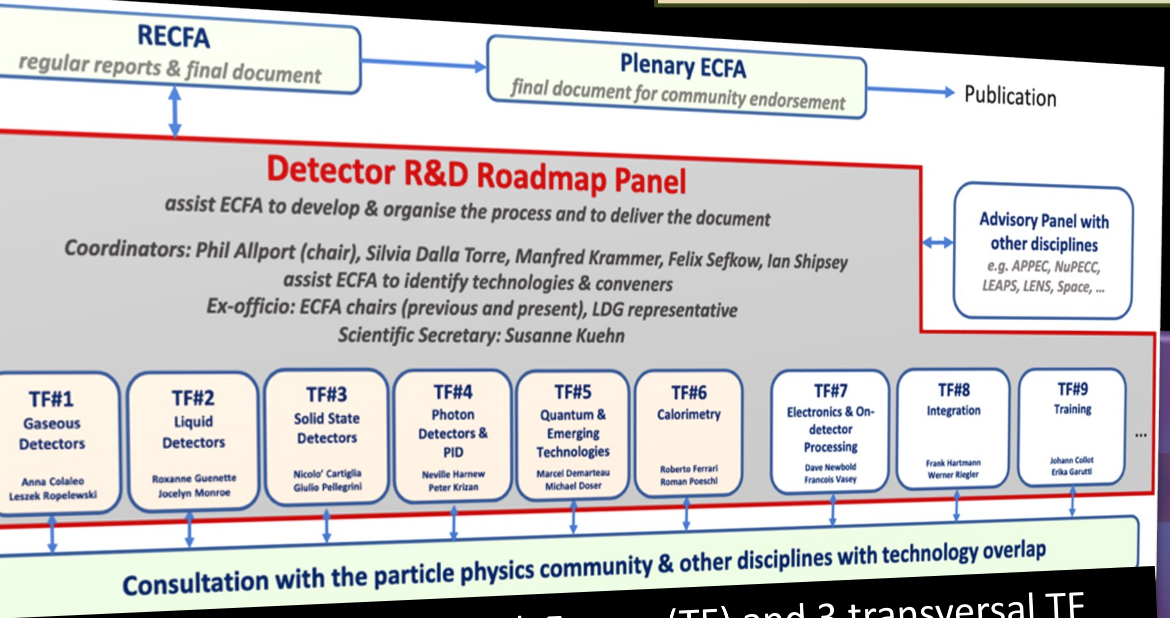
COORDINATED R&D DETECTOR EFFORTS WORLDWIDE - EUROPE VIEW - ROADMAP

European Strategy for Particle Physics - Update 2020



C. The success of particle physics experiments relies on innovative instrumentation and state-of-the-art infrastructures. To prepare and realise future experimental research programmes, the community must maintain a strong focus on instrumentation. ***Detector R&D programmes and associated infrastructures should be supported at CERN, national institutes, laboratories and universities. Synergies between the needs of different scientific fields and industry should be identified and exploited to boost efficiency in the development process and increase opportunities for more technology transfer benefiting society at large. Collaborative platforms and consortia must be adequately supported to provide coherence in these R&D activities. The community should define a global detector R&D roadmap that should be used to support proposals at the European and national levels.***

Detector Roadmap



6 technology-oriented Task Forces (TF) and 3 transversal TF across all technologies and facilities

Identification of R&D topics and Timeline

Approved by CERN Council **Dec 2021**

aim to establish the DRD collaborations which should start work in January 2024, with a ramp-up of resources through 2024/2025, reaching a steady state by 2026.

Detector Roadmap implementation Approved Sep. 2022

http://cds.cern.ch/record/2784893

SEP. 2024

COORDINATED R&D DETECTOR EFFORTS WORLDWIDE - EUROPE VIEW – DRD COLLABORATIONS

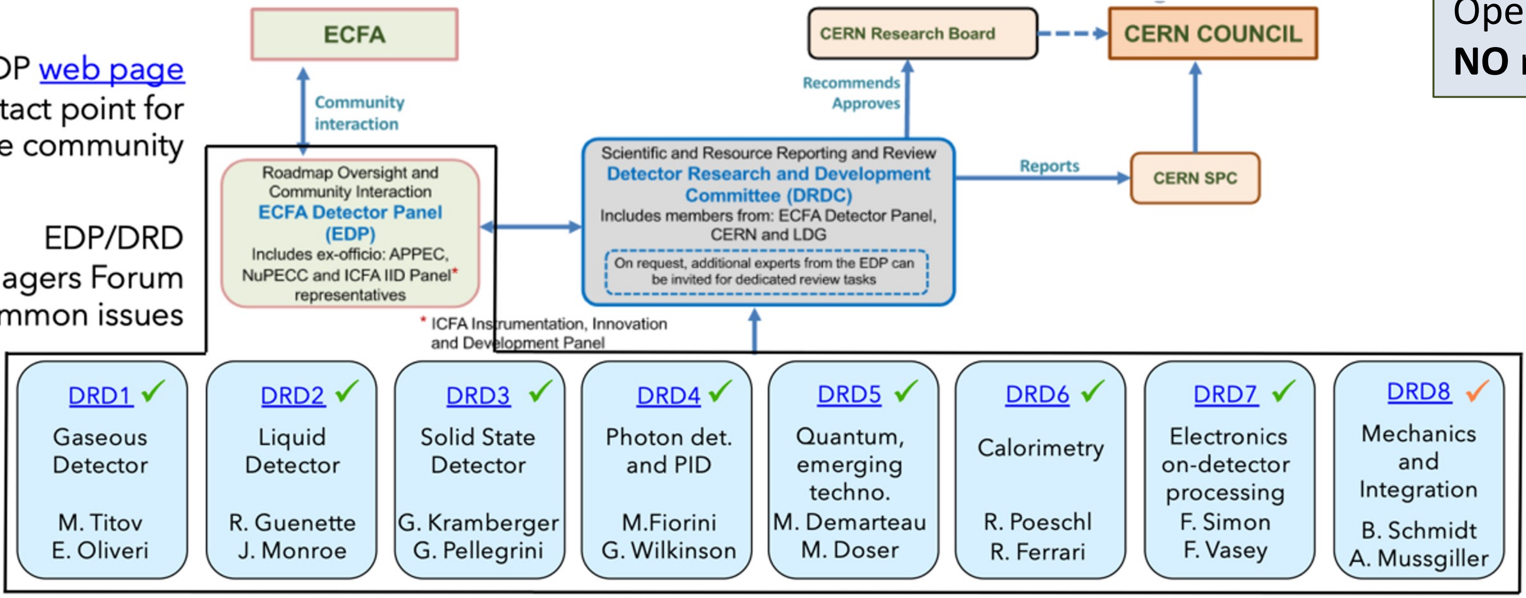
New DRD collaborations hosted at CERN (framework)

follows general conditions for execution of experiments at CERN

Open to collaborators all **over the world**
NO restricted to Europe

EDP web page
- contact point for the community

EDP/DRD Managers Forum
- common issues



✓ Approved by CERN RB*, ✓ DRD8 LoI submitted to DRDC, proposal aims end-2024

DRDC wep page and presentations of DRDs at open sessions

** approvals cover a period of three years – to be renewed*

From D. Contardo (IP2I)
ECFA highlights and DRD collaboration progress
FCCee week. San Francisco June 2024

COORDINATED R&D DETECTOR EFFORTS WORLDWIDE - US VIEW

Recommendation 4: Support a comprehensive effort to develop the resources—theoretical, computational, and technological—essential to our 20-year vision for the field. This includes an aggressive R&D program that, while technologically challenging, could yield revolutionary accelerator designs that chart a realistic path to a 10 TeV pCM collider.

Investing in the future of the field to fulfill this vision requires the following:

[redacted]

d. Invest in R&D in instrumentation to develop innovative scientific tools (section 6.3).

P5

(Particle Physics Project Prioritization Panel)

6.3

Detector Instrumentation

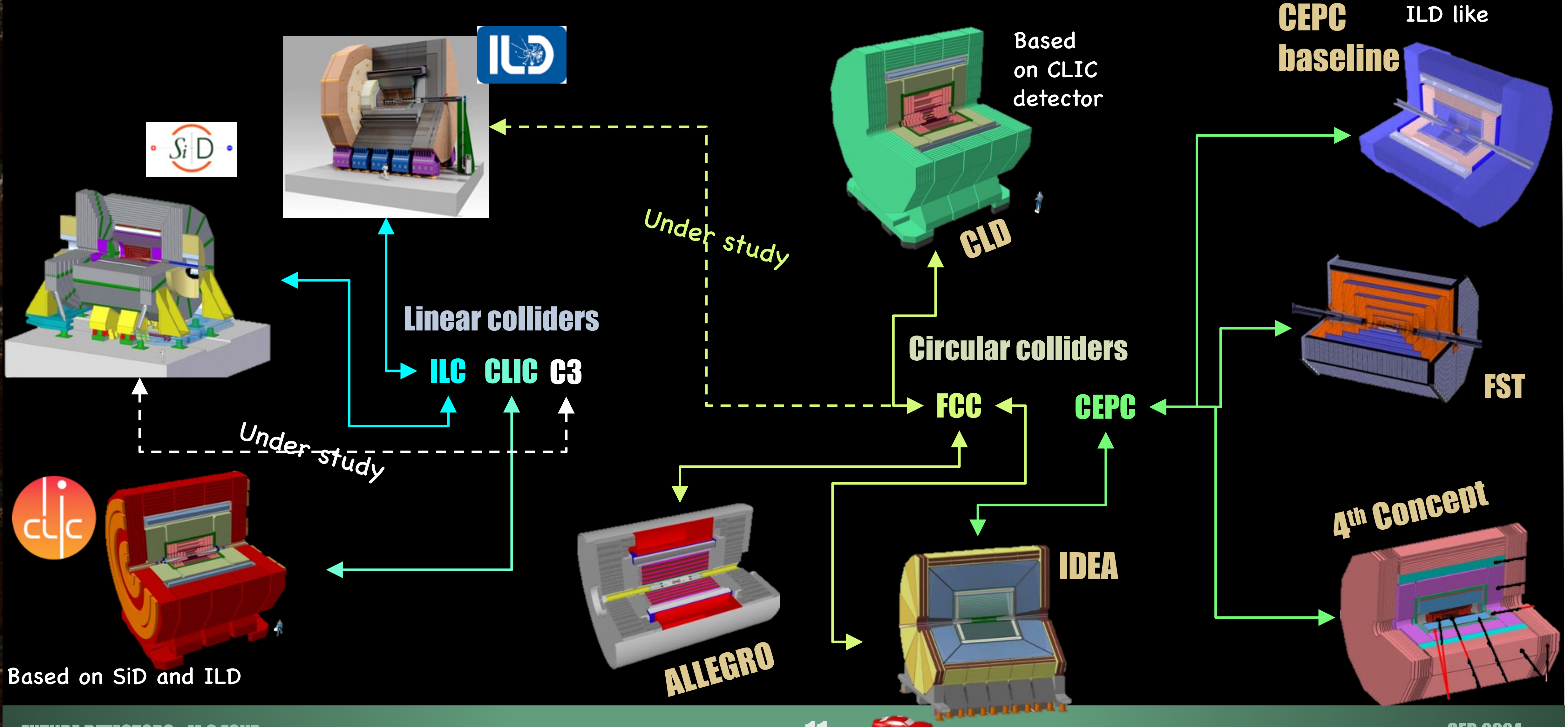
The field of particle physics is at an exciting juncture where current detector instrumentation technologies have pushed the boundaries of sensitivity and scalability. Whereas modest

[redacted]

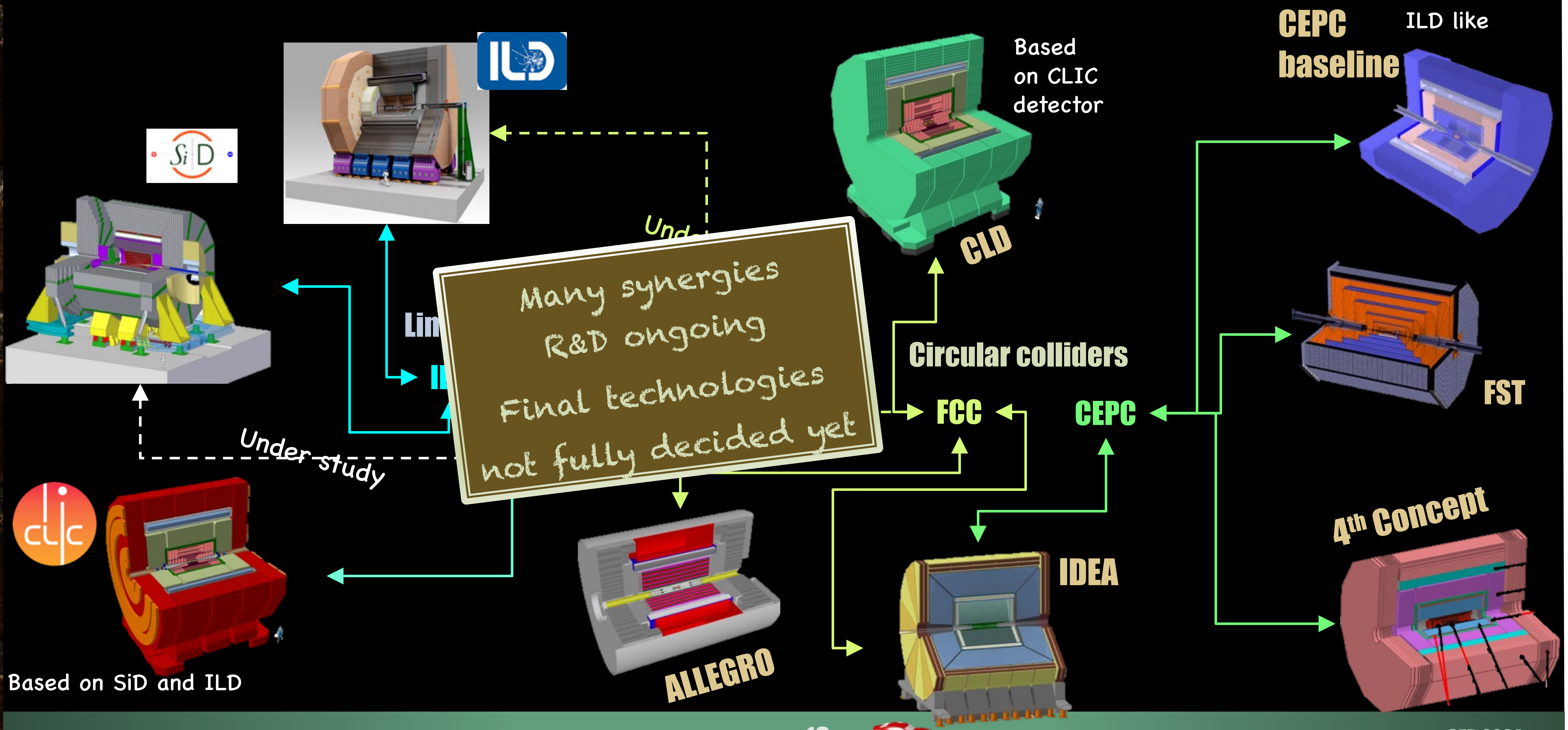
The particle physics community has identified the need for stronger coordination between the different groups carrying out detector R&D in the US. We strongly support the R&D collaborations (RDCs) that are being established and will be stewarded by the Coordinating Panel for Advanced Detectors, overseen by the APS Division of Particles and Fields. The RDCs are organized along specific technology directions or common challenges and aim to define and follow roadmaps to achieve specific R&D goals. This coordination will help to achieve a more coherent detector instrumentation program in the US and will help to avoid duplication while addressing common challenges. International collaboration is also crucial, especially in cases where we want to have technological leadership roles. Involvement in the newly established detector R&D groups at CERN is encouraged, as are contributions to the design and planning for the next generation of international or global projects. Targeted future collider detector R&D, such as for Higgs factories or a muon collider, is covered in section 6.5.

RDC#	TOPIC
1	Noble Element Detectors
2	Photodetectors
3	Solid State Tracking
4	Readout and ASICs
5	Trigger and DAQ
6	Gaseous Detectors
7	Low-Background Detectors
8	Quantum and Superconducting Sensors
9	Calorimetry
10	Detector Mechanics
11	Fast Timing

PROPOSED DETECTOR CONCEPTS



PROPOSED DETECTOR CONCEPTS



VERTEX AND TRACKER DETECTORS – SUMMARY REQUIREMENTS

- Excellent position resolution

  The most demanding is for primary and secondary vertex, as for b- and c-tagging capabilities (~3μm single layer),
  lifetime measurements (τ lifetime to sub-10^{-5}), B phisics

  First layer as closer to IP as possible

- Very low material budget

  To reduce the multiple scattering for Pt resolution & particle flow calorimeter measurements
  (limits photon conversions and hadronic interactions)

  Challenge for the detector technology itself and the associated mechanics (supports, services..)

- Low power consumption on-detector electronics to minimize/avoid the cooling needs

  More important for circular machines since power pulsing cannot be applied

  Requirements: 50 mW/cm² (vertex) / 150 mW/cm² (tracker)

- Time resolution $\mathcal{O}$(1 μs) [$\mathcal{O}$(ns) for CLIC]

  Benefits of precise timing <100 ps under study but not mandatory.
  Could be implemented on the tracker or in a dedicated layer.

  Enhanced background/backscatter rejection

  4D tracking

  particle ID by Time-of-Flight for heavy-flavour physics <30 ps / 2m for K/pi/p separation up to 3 GeV

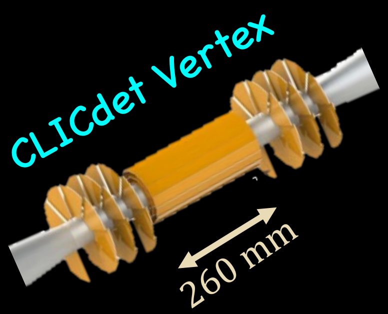
- High efficiency crucial for calorimeter measurements (Particle flow)

VERTEX AND TRACKER DETECTORS AT THE DIFFERENT CONCEPTS

VERTEX

All use pixel silicon detectors

~ 5-6 layers @Barrel and up to 6 @endcap.
single or double layer
Pixel size ≤ 25µm



TRACKER

Two different approaches

- Full silicon system

  Strips or large pixels

- Gaseous detector souronded by a layer of Silicon detector

  Several gaseous detectors options: TPC, Drift Chambers

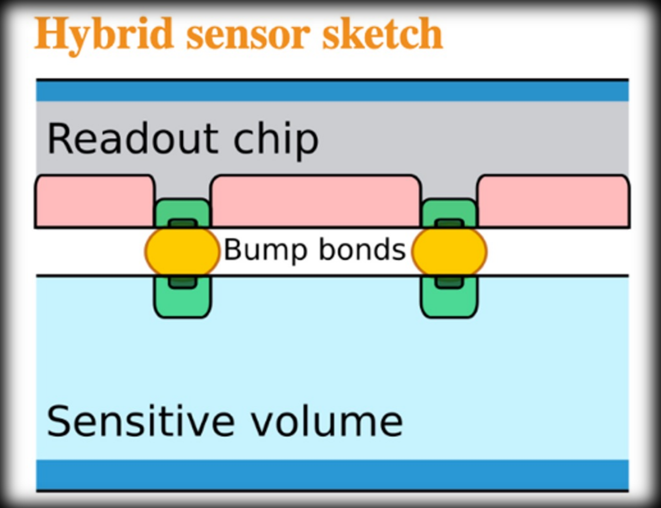
TRACKER OPTIONS	
SiD	Silicon Strips
CLICdet	Silicon Pixels
CLD	Silicon Pixels
ALLEGRO	Drift chambers + Silicon Strips or Silicon Pixels
CEPC baseline	TPC + Silicon Strips or Silicon Strips
ILD	TPC + Silicon Strips
IDEA	Drift Chamber + Silicon Strips
4th Concept	TPC + Silicon Strips or Drift Chamber + Silicon Strips

VERTEX AND TRACKING SILICON DETECTORS

Two main categories

HYBRID

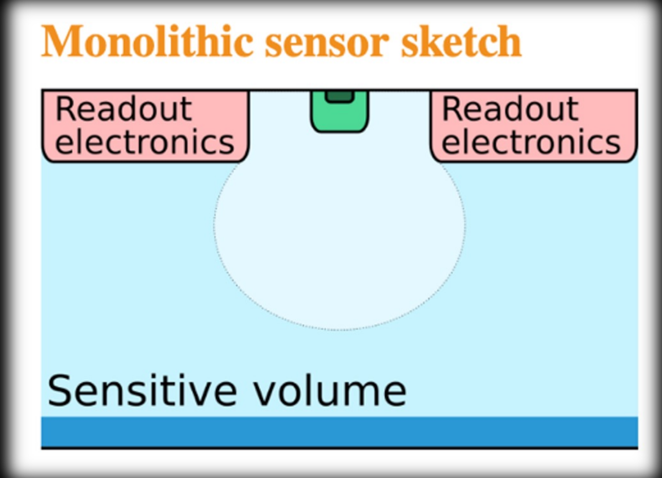
Sensor and readout electronics
in **two** separate chips
Connected by "bump bonding"



Separate optimization of sensor and readout
On-pixel functionality using mixed-mode CMOS circuits
(powerful processing – fast)

MONOLITHIC

Sensor and readout electronics
in **SAME** chip

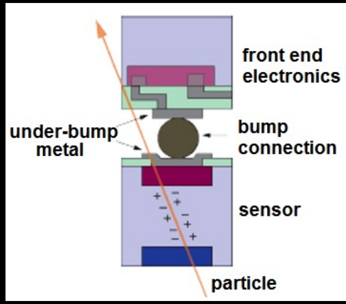


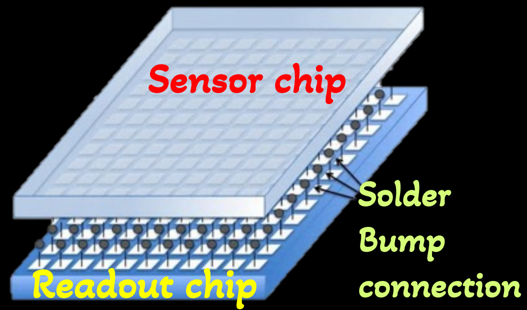
Lower material budget,
reduced complexity and production cost
No bump bounding ➔ Smaller pixel size (few μm^2)

Less sophisticated readout electronics

VERTEX AND TRACKING SILICON DETECTORS - HYBRID

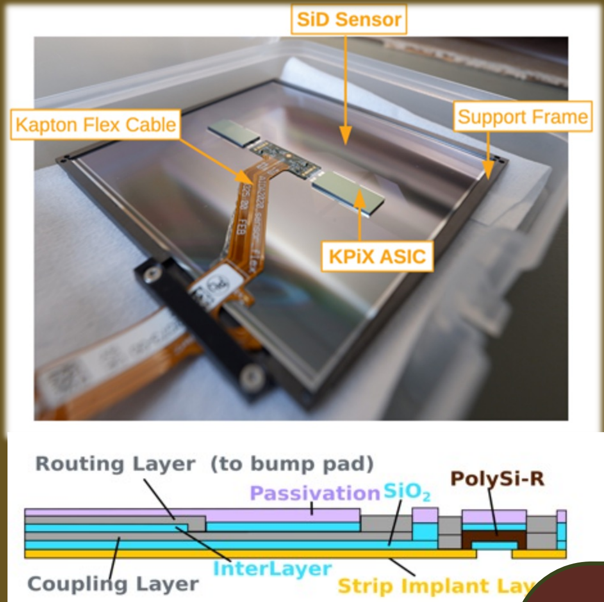
Some examples of options under development

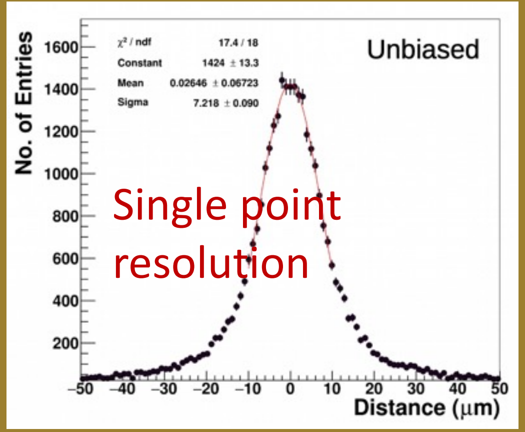




Sensor and readout electronics in **two** separate chips
Connected by "bump bonding"

Concerns: Material Budget, interconnection





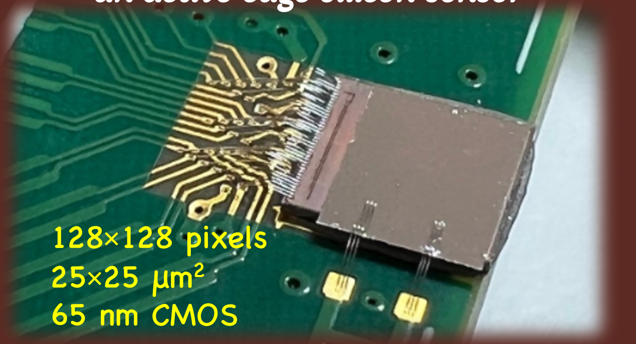
https://indico.cern.ch/event/995633/contributions/4259345/attachments/2210031/3740113/LCWS_2021.pdf

10 x 10 cm^2
320 μm Thickness → 0.3% X_0
Pitch 25 μm➔ hit resolution ~7.2 μm
92 mm strip length
An integrated (bump-bonding) pitch adapter and digital readout ASIC: KPiX

Different interconnect technologies are under study for future-collider detectors:
- Single-die bump-bonding process https://arxiv.org/abs/2210.02132
- Hybridization with Anisotropic Conductive Films (ACF) https://arxiv.org/abs/2210.13046

For picosecond timing ➔ LGAD
(Low Gain avalanche Photodiode)

CLICpix2 ASIC bump-bonded to an active edge silicon sensor



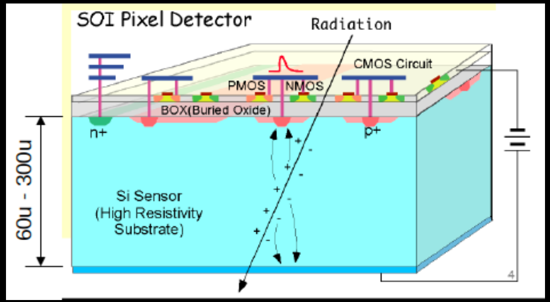
VERTEX AND TRACKING SILICON DETECTORS - MONOLITHIC

Different types are under development

MONOLITHIC

Sensor and readout electronic in the same chip

SOI (Silicon-on-Insulator)

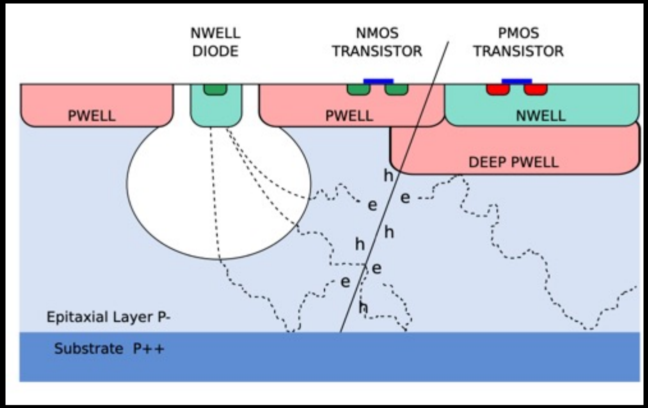


NIMA 623(2010)186

Layer structure: thin layer of silicon (SiO_2) placed on top of an insulating material

Thin and fast, can be fully depleted

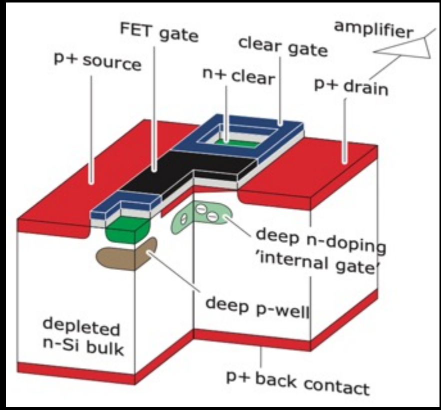
CMOS – MAPS & DMAPS (MAPS= Monolithic Active Pixel Sensor)



(CMOS=Complementary Metal-Oxide-Semiconductor) silicon pixel)

SEMI-MONOLITHIC

DEPFET - Depleted field-effect transistor



Amplification integrated but subsequent processing in an external ASIC
Large signal even for thin detectors
Fast signal rise time (ns)

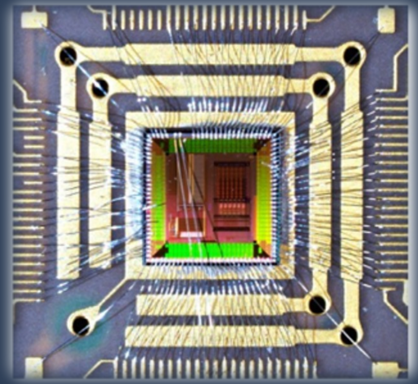
MONOLITHIC SILICON DETECTORS – FEW EXAMPLES OVERVIEW

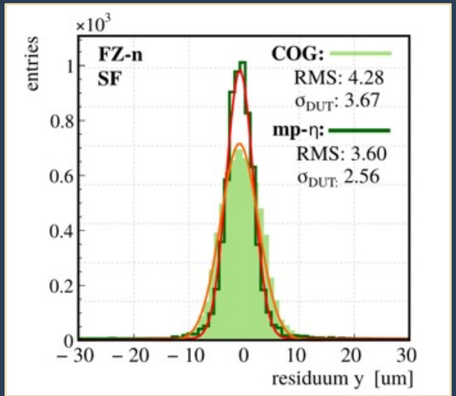
There are many developments on going, here some examples. Many advances last years but still R&D needed

SOI (Silicon-on-Insulator)

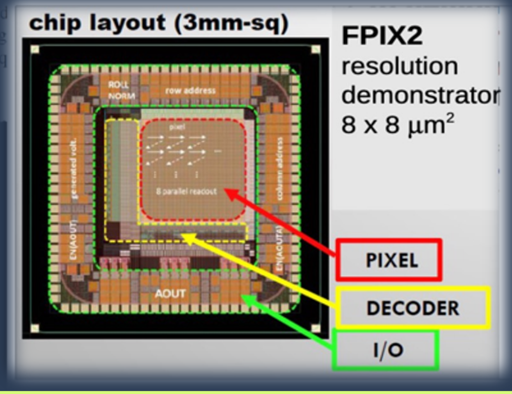
Cracow SOI Chips

(*) COG & mp-n are diff. algorithms





30x30 μm2 pixel size https://doi.org/10.1016/j.nima.2020.164897

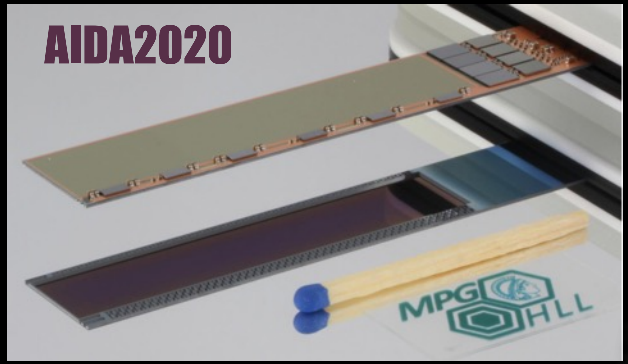


FPIX2
DSOI : Double silicon-on-insulator

DSOI = 2 layers of Si separated by insulator

DEPFET

BELLE II vertex detector and ILC central vertex



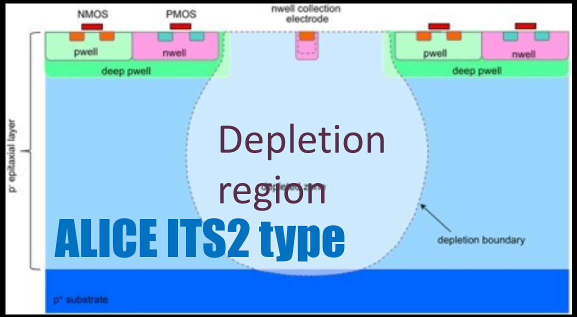
DEPTFET all-silicon ladder for Belle II
Metal layer on top of the sensor
Thinker area visible oin the mirrow image underneath the ladder

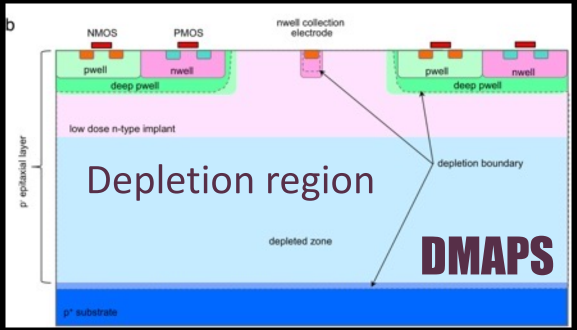
MONOLITHIC SILICON DETECTORS – FEW EXAMPLES OVERVIEW

There are many developments on going, here some examples. Many advances last years but still R&D needed

MAPS/DMAPS

DMAPS = Depleted MAPS





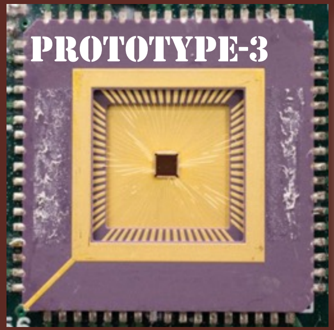
Depletion region increase when reverse bias is increased.
Difficult to expand laterally

DMAPS: Faster, higher charge collectionsharing, better S/N, better radiation tolerance, less cross-pixel charge

Chronopixel

Time-stamping capability
Hit accompanied by a time tag
(precision to assign BX of ILC)
occupancy reduction to $<10^{-4}$ per pixel

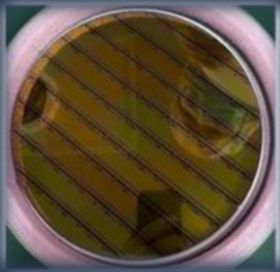
25x25 μm2 pixel size, 90 nm technology
Zero suppression
Digital readout → simplifies electronics

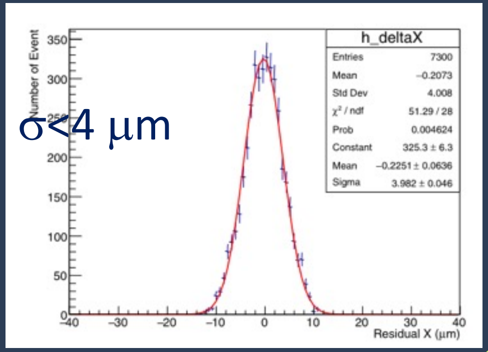


TaichuPix

For vertex at CEPC baseline

25 x 25 μm^2 pixel

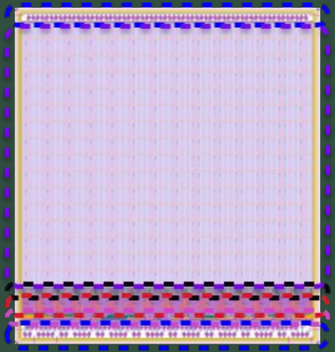


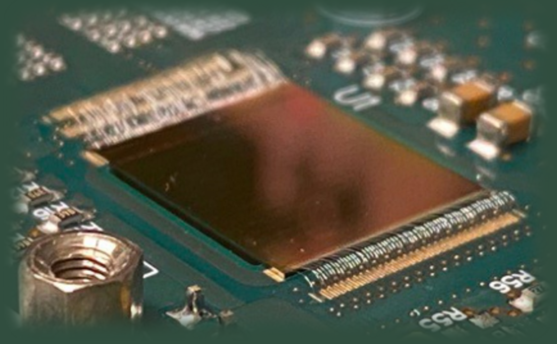


ARCADIA

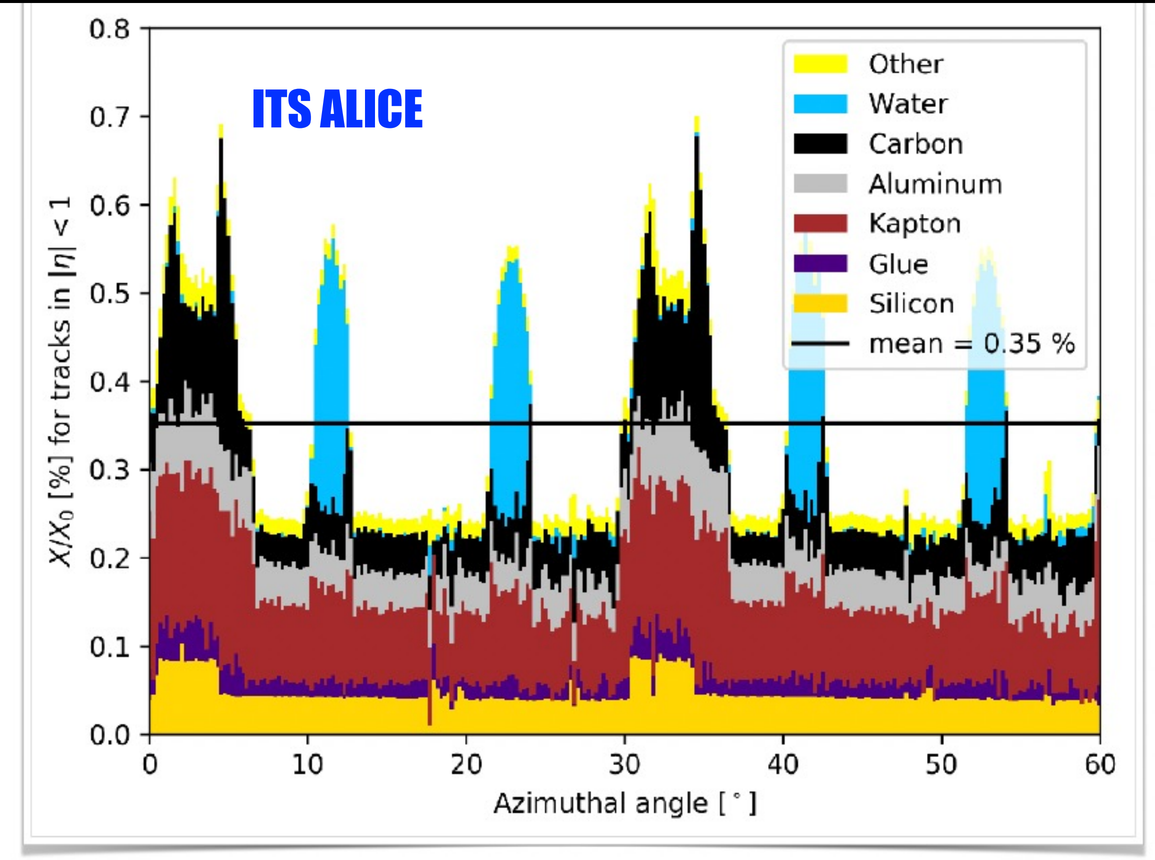
Fully depleted
Lfoundry 110nm CMOS
25x25 mm2 pixel size

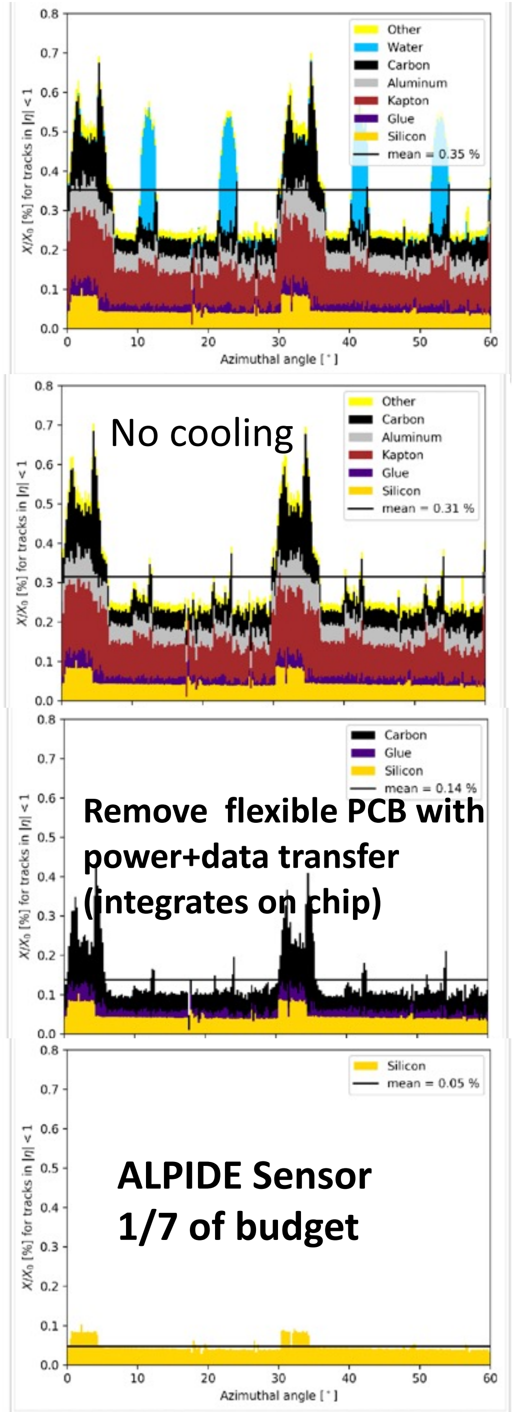
For IDEA





MATERIAL BUDGET OPTIMIZATION - COMPONENTS



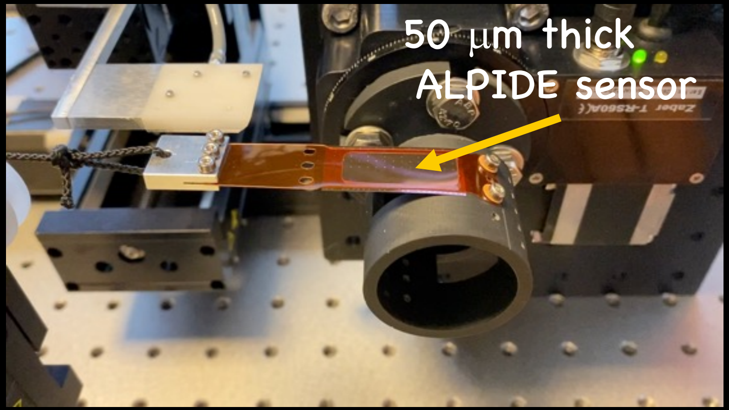


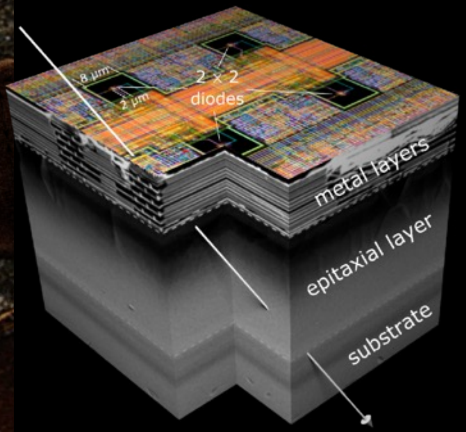
Material Budget is dominated by cooling, supports, and cabling

How to reduce it? Taking a look to the approach for the ALICE ITS3

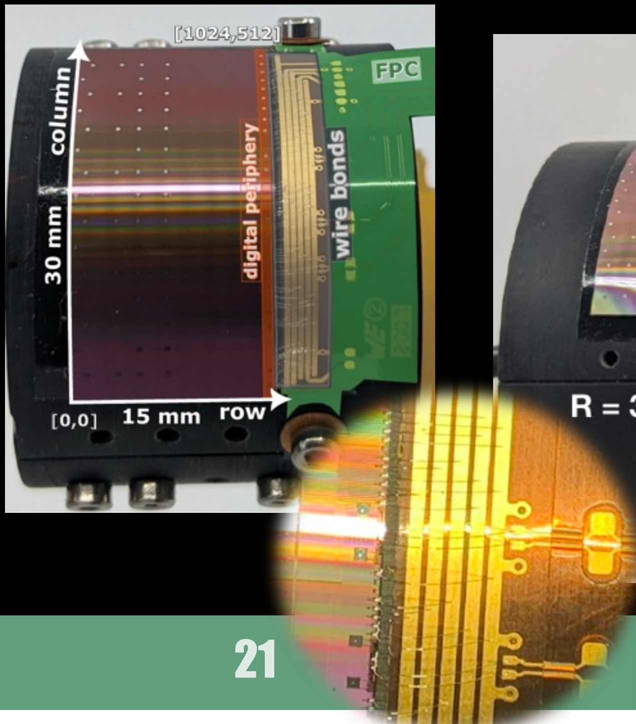
MATERIAL BUDGET OPTIMIZATION – BENT SENSORS – ALICE ITS 3

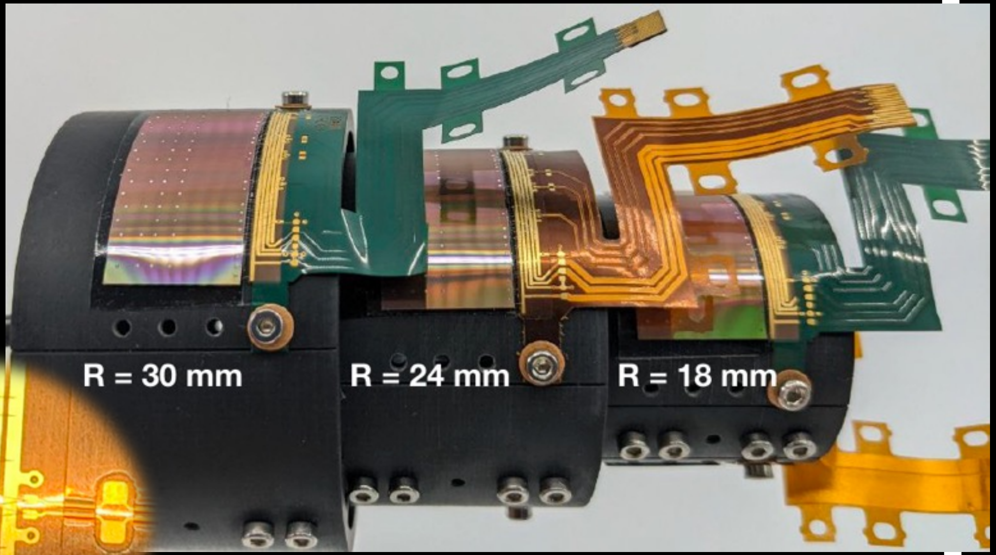
Silicon is flexible



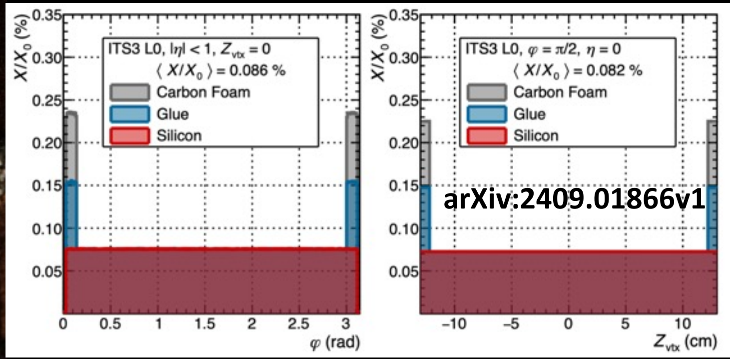


Flex embedded sensors





MATERIAL BUDGET OPTIMIZATION – BENT SENSORS & STITCHING – ALICE ITS 3



Reduction of the radiation length per layer
from 0.35% X_0 to 0.75%X_0 layer
More uniform distribution

Replace 3 innermost layers of the ITS2 with a new detector

Cooling and mechanical structures are minimized

Silicon sensors only component in the active area

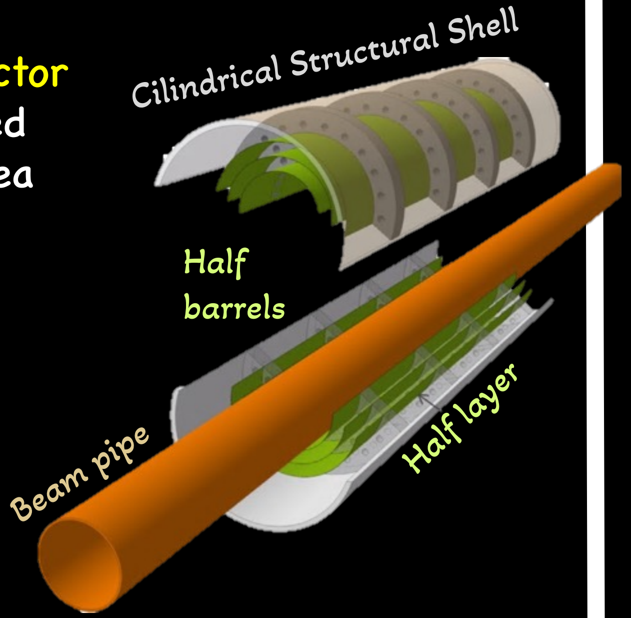
Radius innermost layer reduced from 22mm to 18mm

Cooling by air flow ➔ Power limit 20mW/cm2

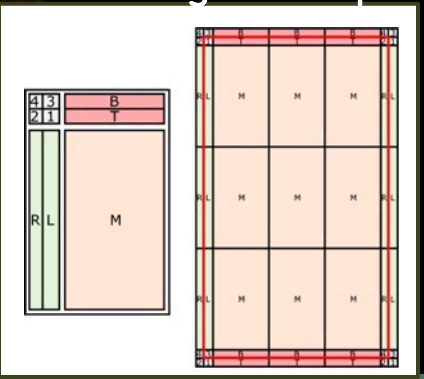
Power supply and transfer data cannot be on the chip

==> Circuits located at the short edges of the chip

Use Stitching!!



Stitching technique

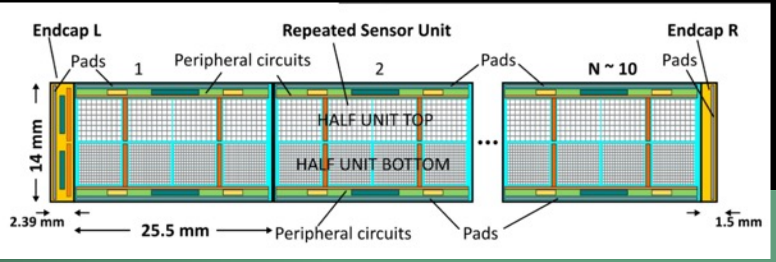


Stitched sensors

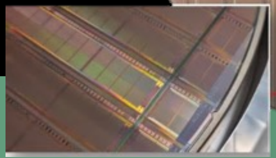
MOSS - Monolithic Stitched sensor chip

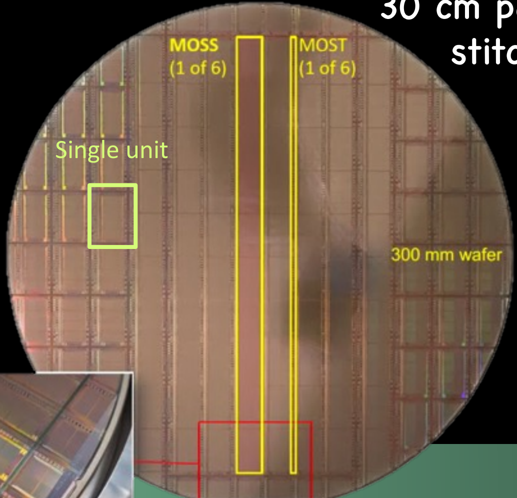
MOST - MOSS with Timing

MOSS design 65nm MAPS



Engineer run-1



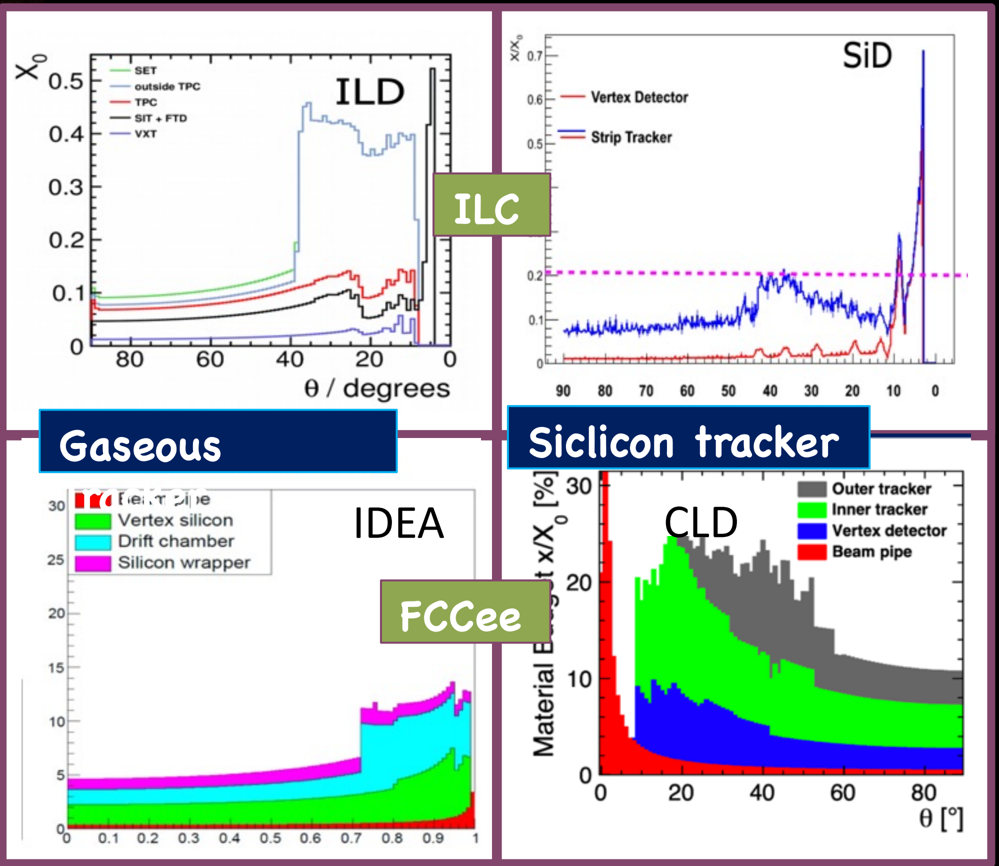


30 cm pad wafer using stitching on middle

MOSS
259×14 mm2
6.72 Mpixels

TRACKING – GASEOUS VS SILICON DETECTORS

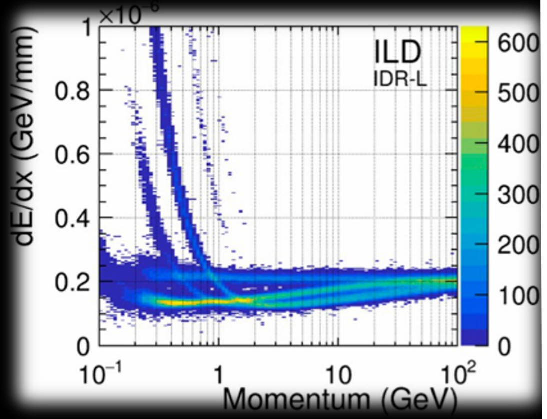
Gaseous detectors ➔ lower material budget
➔ less multiple scattering



Notice the different plot scales

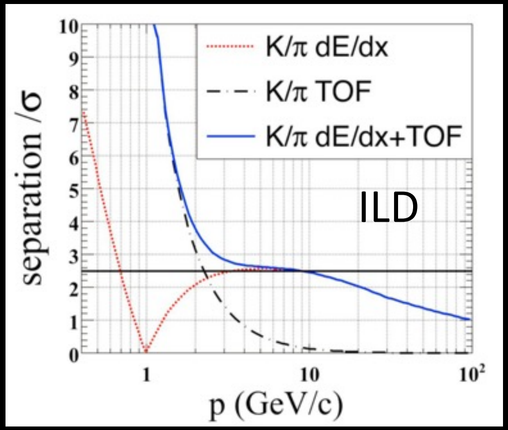
Gaseous detectors can provide dE/dx
==> TPC strength

Up to 220 points at ILD TPC

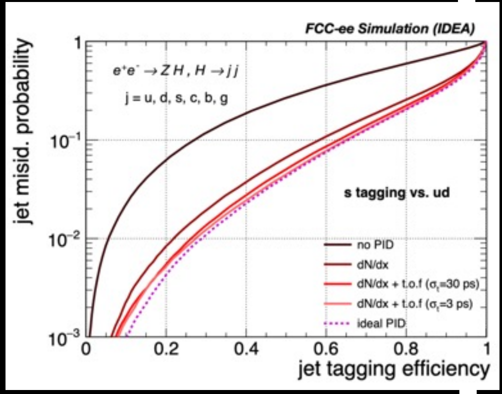


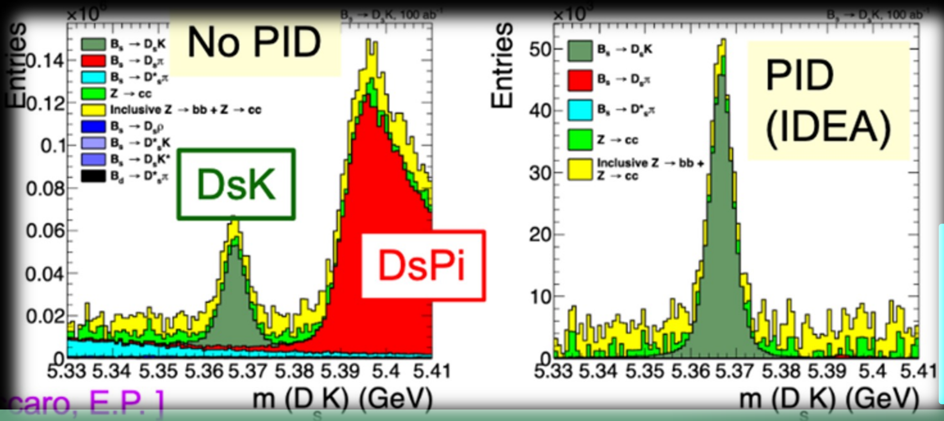
arXiv:2202.03285v1

PID capabilities



Kaon identification
Flavour physics (up to 40 GeV)
Key for strange tagging

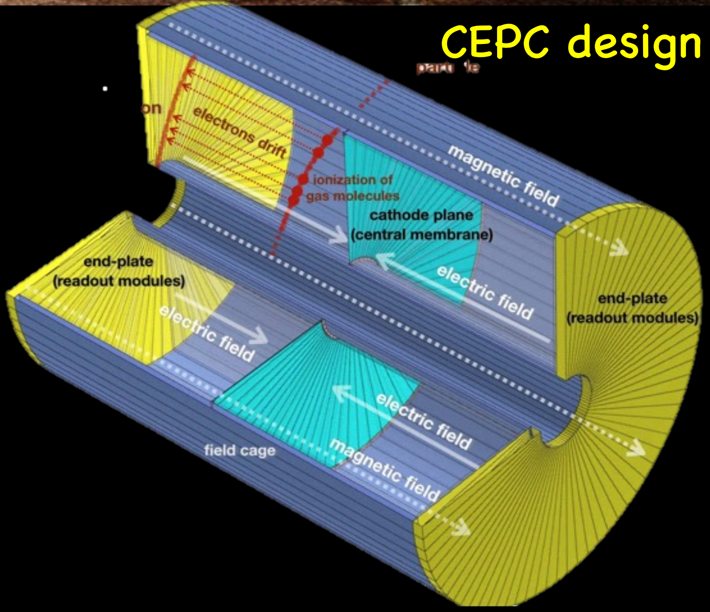




CP-violation studies distinguish
$B^0_s \to D_sK$ from $B^0_s \to D_sK\pi$

TRACKING - TPC

CEPC design

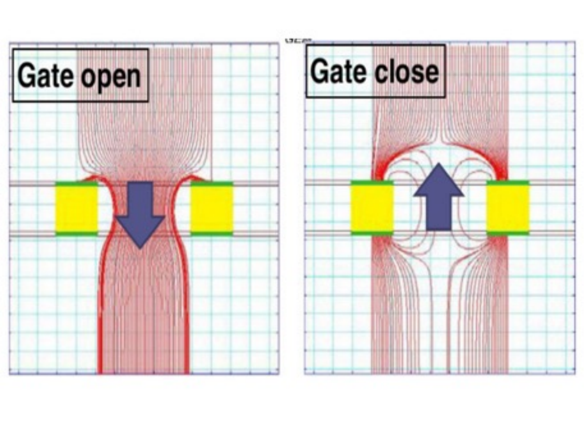


Proposed for ILD, CEPC Baseline and 4th Concept

No clear its capabilities to cope with the Z-pole conditions for circular colliders

Several studies ongoing at LC-TPC and ILD collaborations

The concern is the ion back flow that at Z pole could increases too much as for producing field distortions on the drift region ➔ more R&D needed



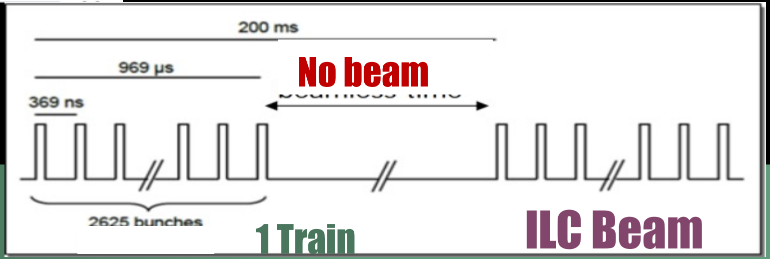
NIM A918 (2019) 41-53

Also happens in ALICE TPC with the GEM readout upgrade for Run 3

Expected 1% ions drifting back and $\mathcal{O}$(5-10 cm) distortions

Effects corrected by software with proper calibrations going down to $\mathcal{O}(100\mu m)$

ILC gating scheme using GEM
Gap opens 50 μs before the first bunch and closes 50μs after



Gating cannot be used at circular colliders due to the continuous beam

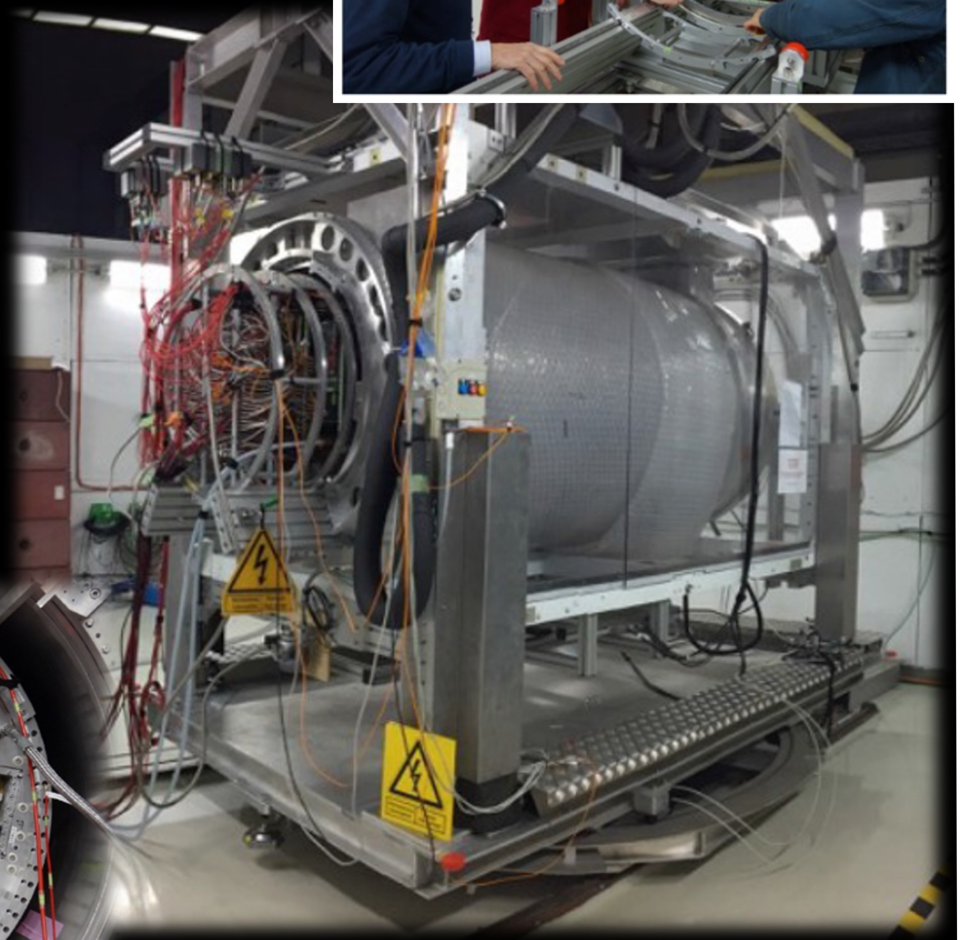
TRACKING - TPC SENSOR OPTIONS

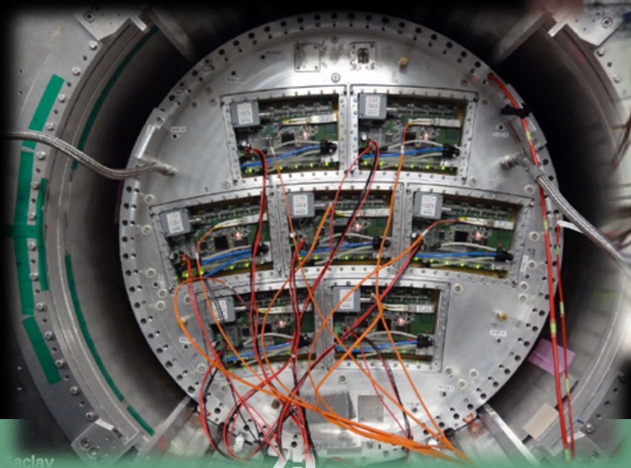
Different options for the readout have been studied along years

A setup available at DESY allows tests with beam with different detectors

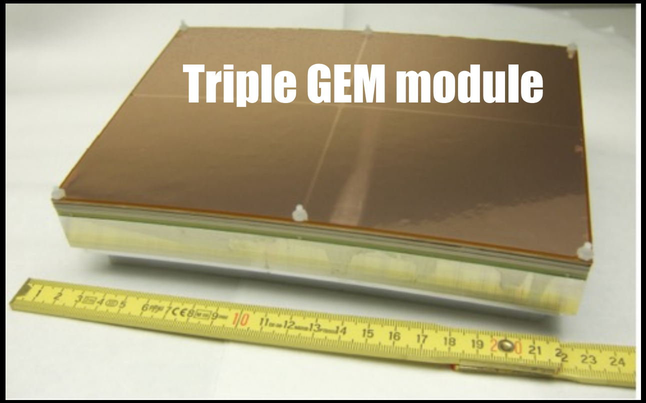
- GEM
- Resistive MICROMEGAS
- GRIDPIX

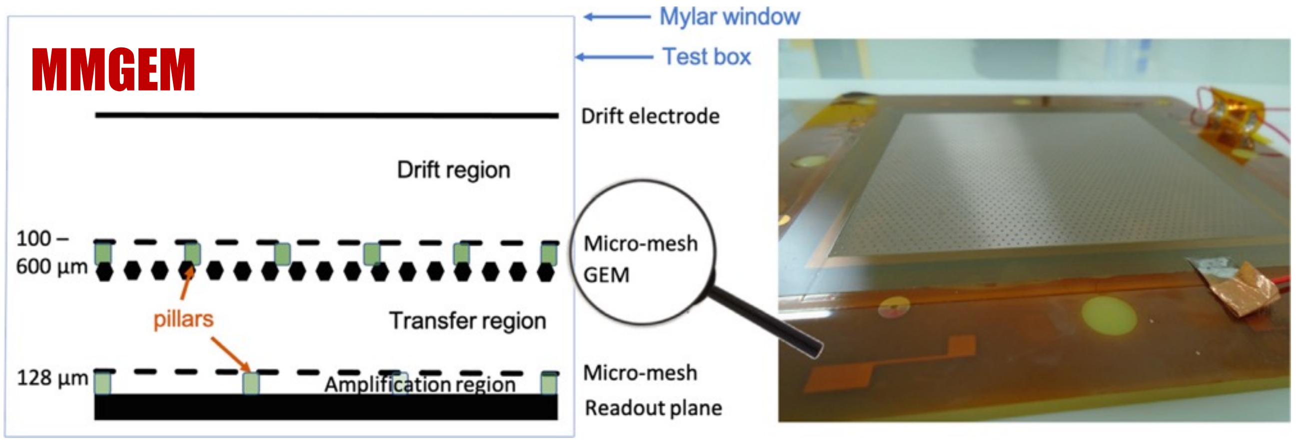
New devices combining GEM and Micromegas have been also designed to control the ion back flow





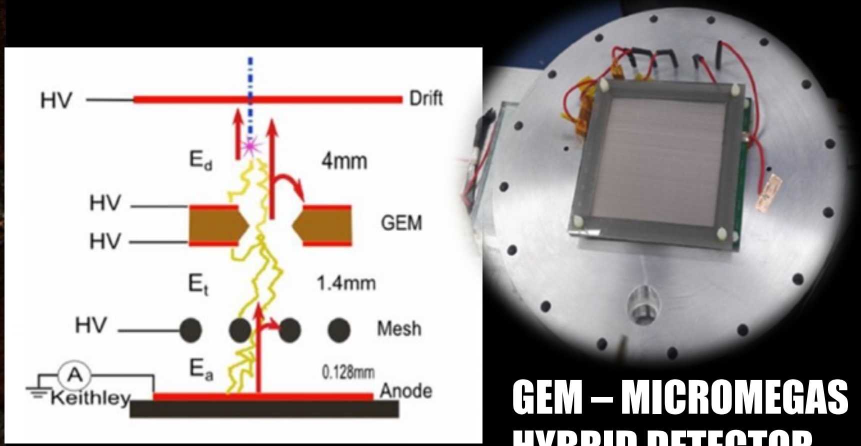
TRACKING - TPC SENSOR OPTIONS





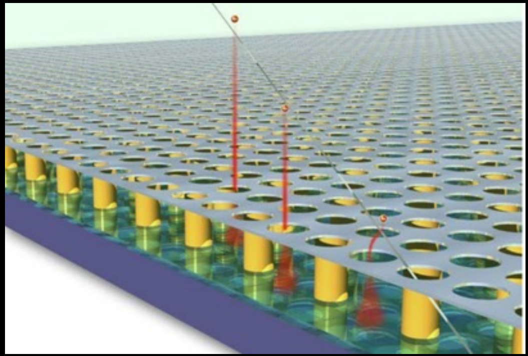
Reduces the ion back flow a factor 10 with respect to GEM, MICROMEGAS or GEM MICROMEGAS hybrid detector

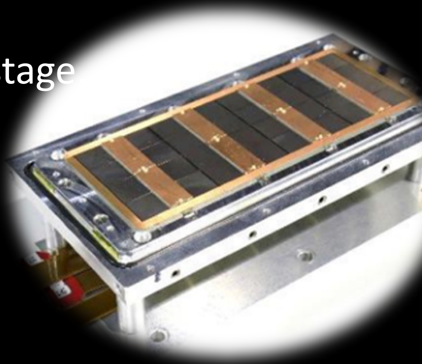
NIMA 1051 (2023) 168134



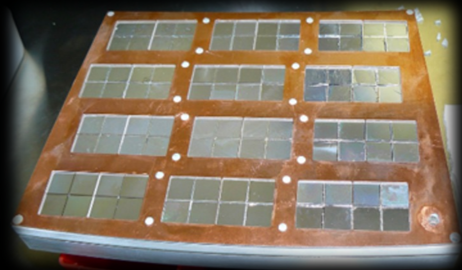
GEM – MICROMEGAS HYBRID DETECTOR

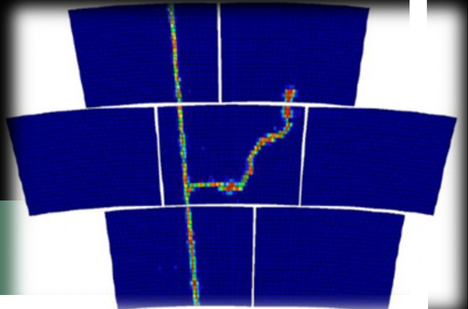
GRIDPIX combines a high density pixelized readout ASIC with a Micromegas gas amplification stage





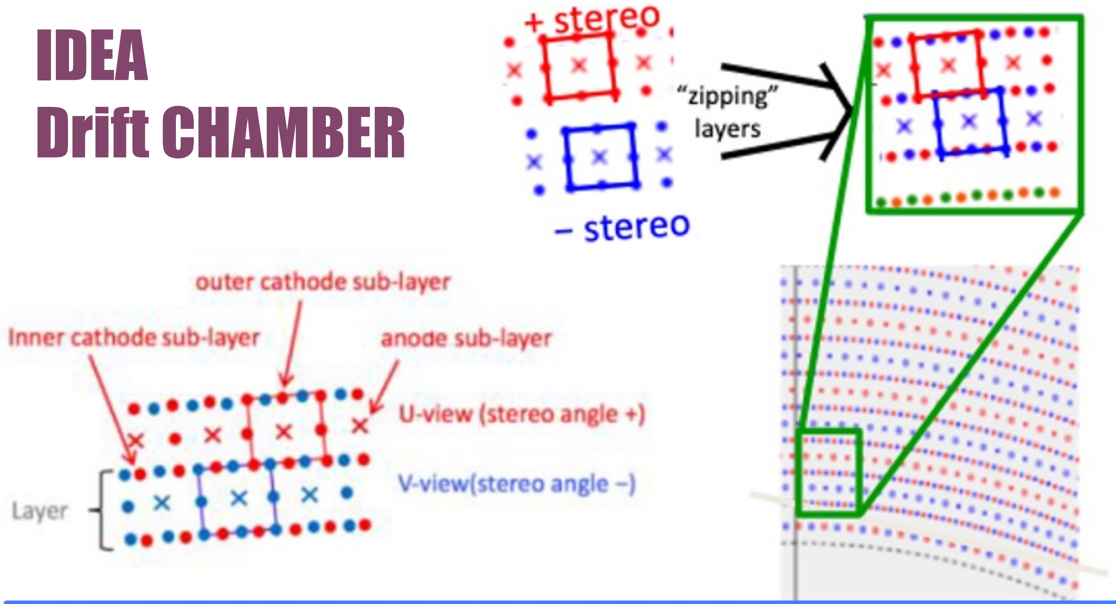
Timepix ASIC with a pixel pitch of 55 × 55 µm2



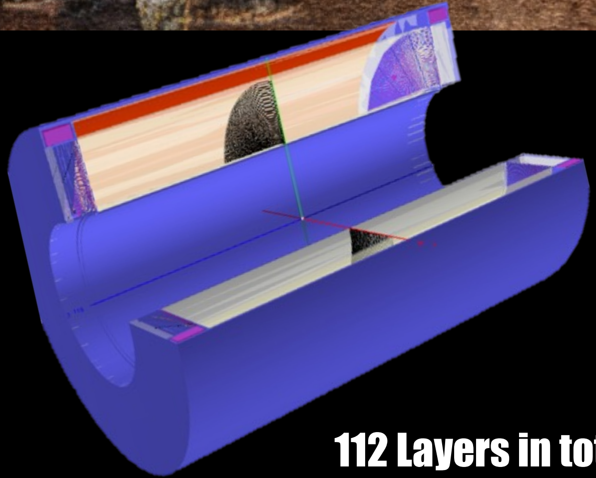


TRACKING - DRIFT CHAMBER

IDEA Drift CHAMBER



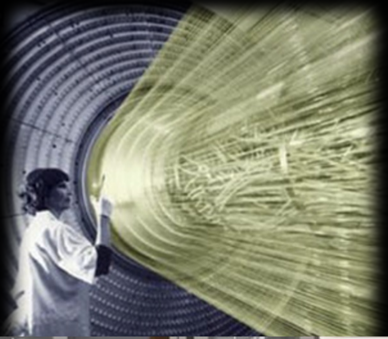
sense wires	20 μm diameter W(Au) =>	56448 wires
(**thin!!**) field wires	40 μm diameter Al(Ag) =>	229056 wires
Field between sense and guard wires	50 μm diameter Al(Ag) =>	58464 wires
	343968 wires in total	

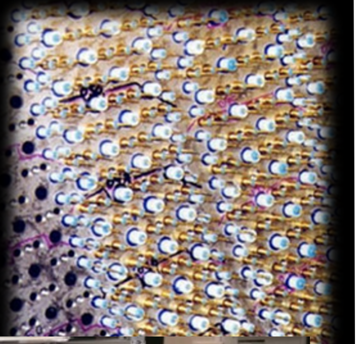


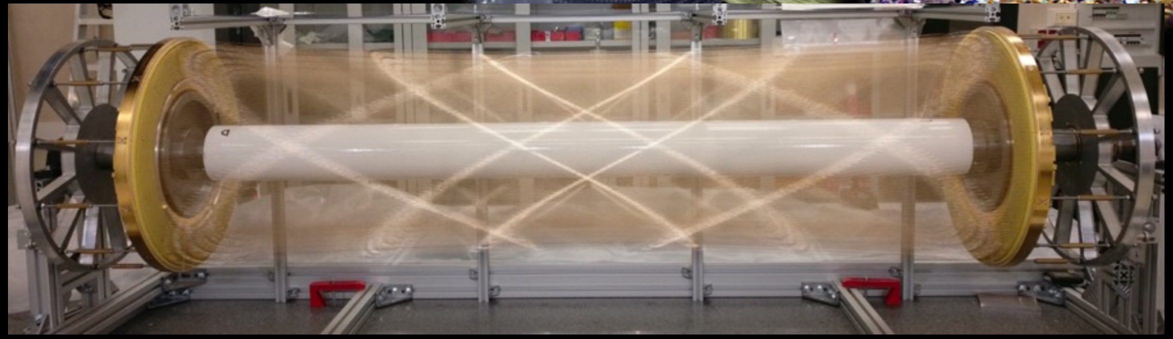
112 Layers in total:
14 co-axial super-layers (8 layers each)

Gas: He:iC4H10 (90/10)
Inner radius 0.35m
Outer radius 2m
Length 4m
Drift length ~1cm
Drift time ~150ms
σxy<100mm
σz < 1mm

Based on the MEG-II chamber

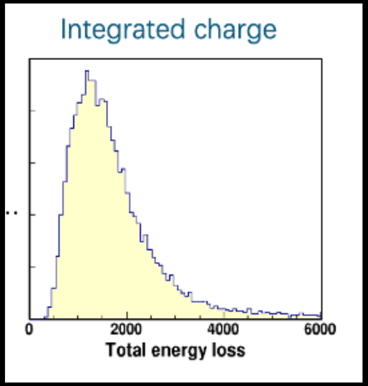






TRACKING - DRIFT CHAMBER: COUNTING CLUSTERS FOR PID

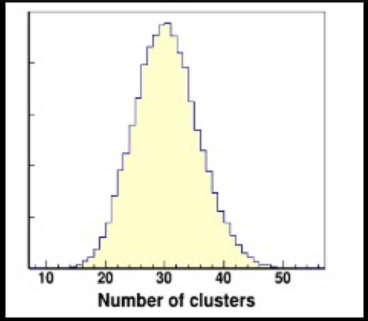
Using dE/dx



Many fluctuations

Driven by the "intrinsecal" Landau fluctuations

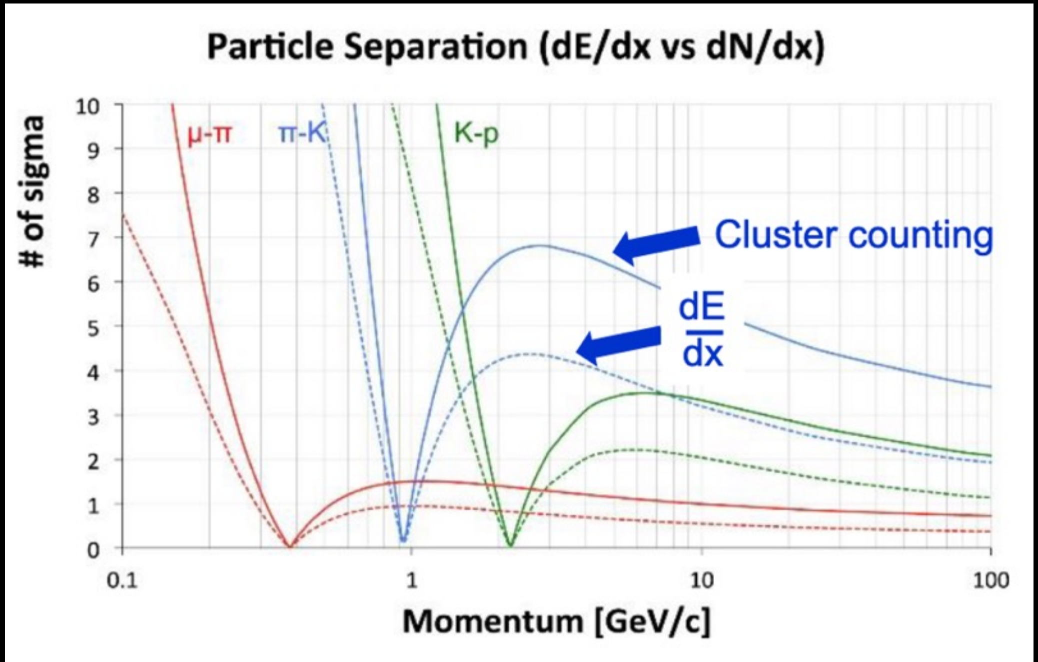
Counting primary clusters



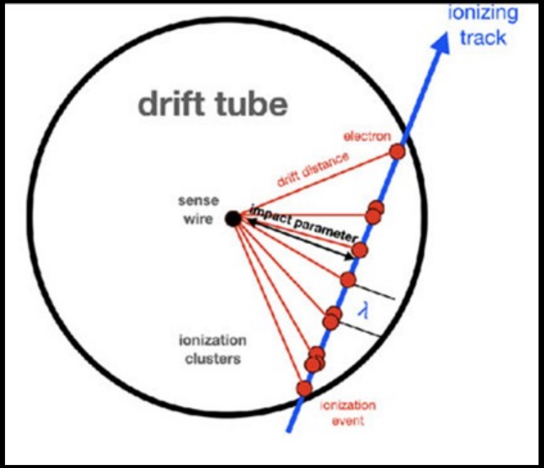
Poisson distribution

Small fluctuations

It is NOT full simulation



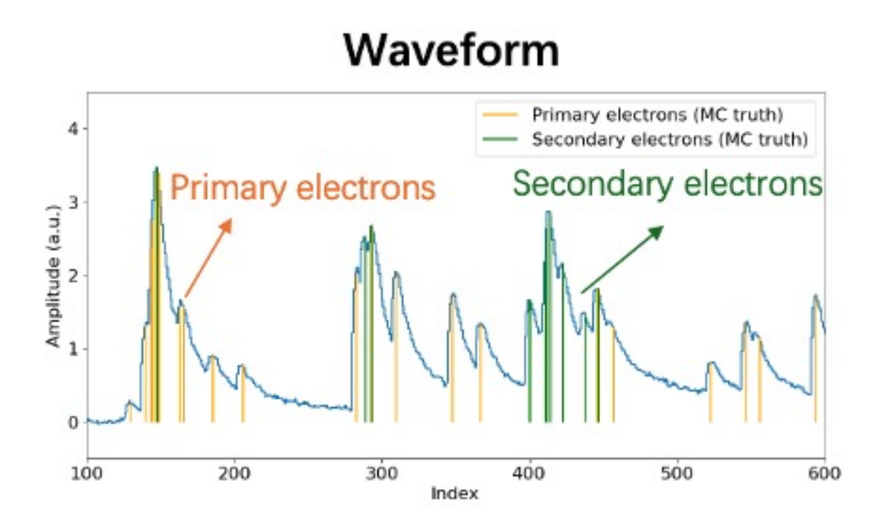
TRACKING - DRIFT CHAMBER: COUNTING CLUSTERS IMPLEMENTATION

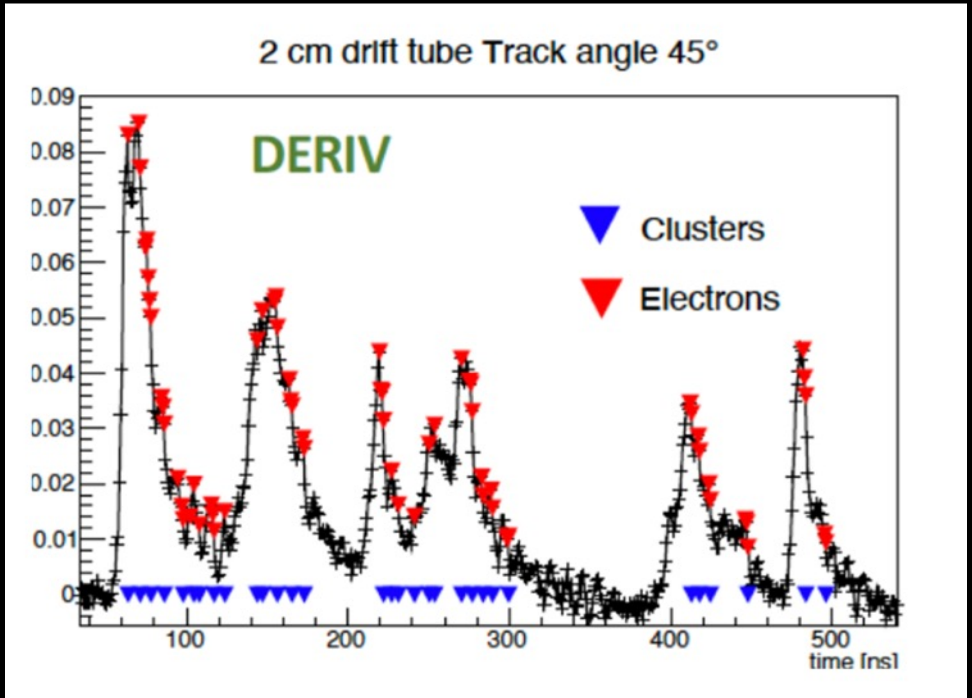


Record the arrival time of every cluster generated in every single ionization.
Reconstruct the most likely positions

Several algorithms developed

Test beam data from H8/CERN 2021
Using drift tubes





CALORIMETERS - REQUIREMENTS

Electromagnetic calorimeters:

Resolution:

10%/√E is probably enough for most of the physics studies

But B physics will probably need go down to at least 5%/√E

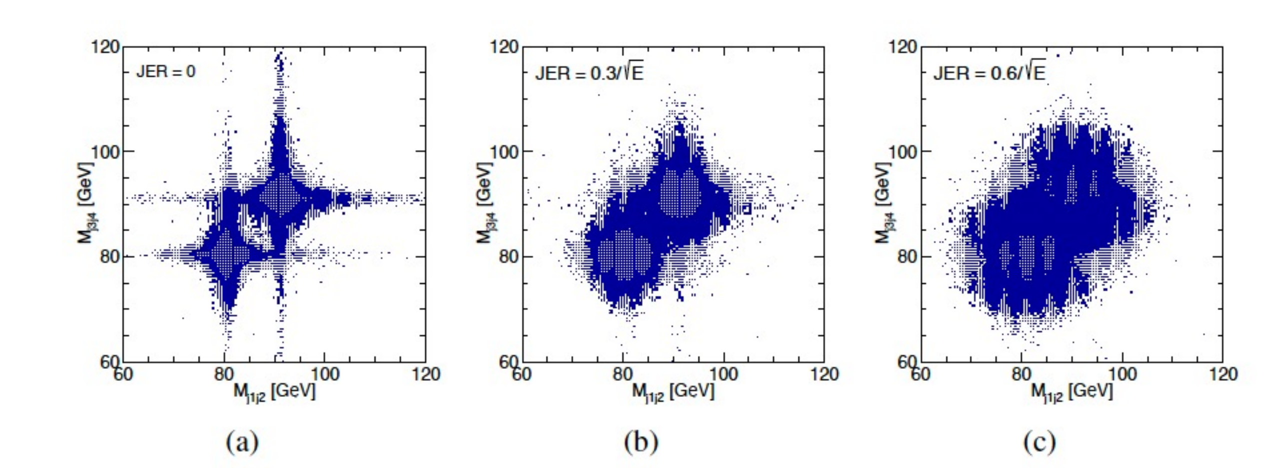
Very good transversal granularity is required for τ physics

Hadronic calorimeters

Hadronic final states are very relevant players, opening sometimes the access to rare process and helping on increasing statistics

Precision on the jet energy determination plays a very important role

30%/√E is needed, and this represents ~a factor 2 with respect to the present experiment. The value is driven by the precise separation of Z and W in their hadronic decays and it is comparable to the natural width of Z and W



The measurement of jets with the needed precision is the main challenge for the calorimeters

FACING THE CALORIMETER CHALLENGES – JET ENERGY RESOLUTION

Many R&D activities are ongoing, approaching the problems in different ways

Two main different methods to achieve the needed jet resolution for e+e- colliders:

- High granular calorimeters with embedded electronics to apply PFA (Particle Flow Algoritms). Developed by the CALICE Collaboration along more than 20 years (approach also used for the upgrade of the CMS endcap calorimeter for the HL-LHC). Several technologies as active medium under study: Silicon detectors, scintillators, gaseous detectors

  Concepts with PFA fully oriented calorimeters

  CEPC Baseline, CLD, CLIC, ILD, SiD, FST,

- Dual readout Calorimeter

  Concepts with Dual Readout

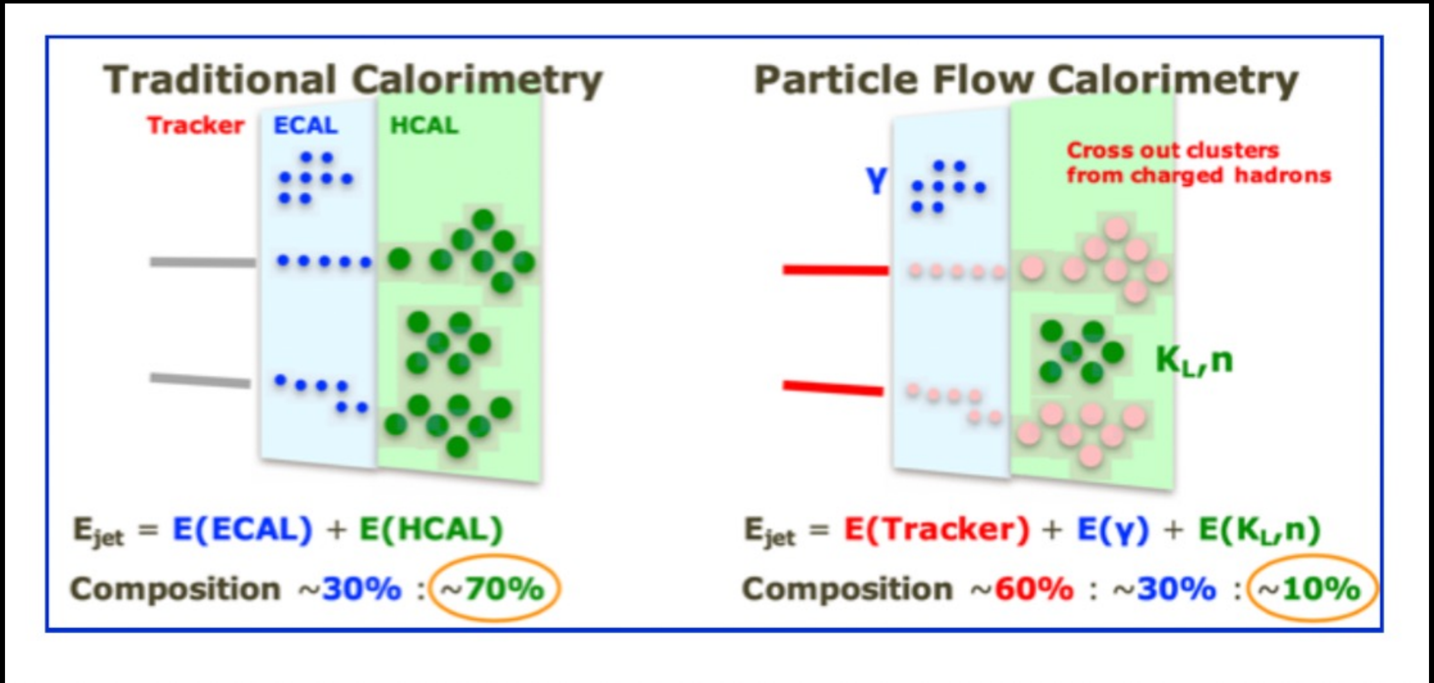
  IDEA

FACING THE CALORIMETER CHALLENGES – PFA

Average jet composition	PFA reconstruction
60% charged	Measured on the tracker, negligible resolution
30% photons (from π^0 decay)	Measured at ECAL ~10-20% /√(E)
10% neutral hadrons (n, K_L)	Measured at HCAL ~60-100% /√(E)

Particle Flow Algorithms – PFA

Reconstruct **every single particle** in the event and measure it **only** with the detector providing the best resolution



Very high granularity is needed

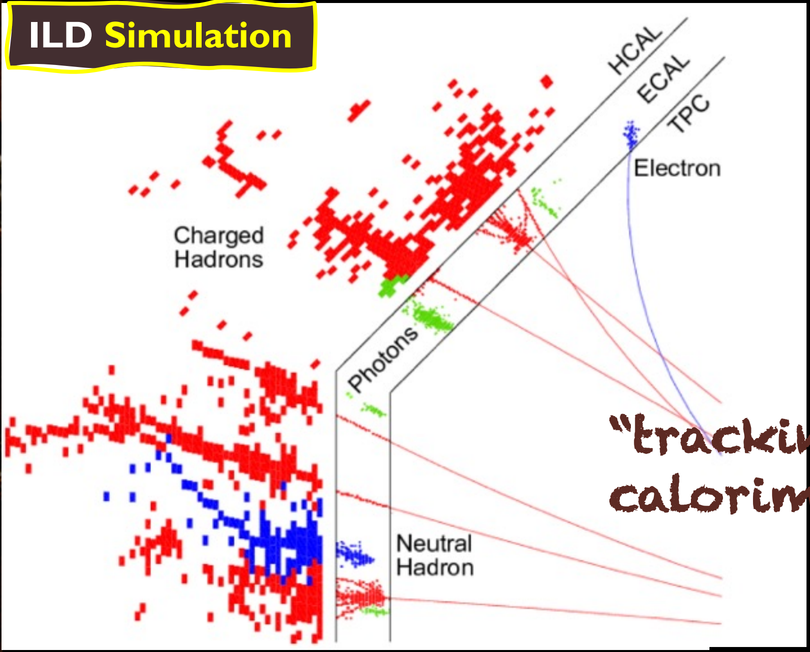
FACING THE CALORIMETER CHALLENGES – PFA

Average jet composition	PFA reconstruction
60% charged	Measured on the tracker, negligible resolution
30% photons (from π^0 decay)	Measured at ECAL ~10-20% /√(E)
10% neutral hadrons (n, K_L)	Measured at HCAL ~60-100% /√(E)

Particle Flow Algorithms – PFA

Reconstruct **every single particle** in the event and measure it **only** with the detector providing the best resolution

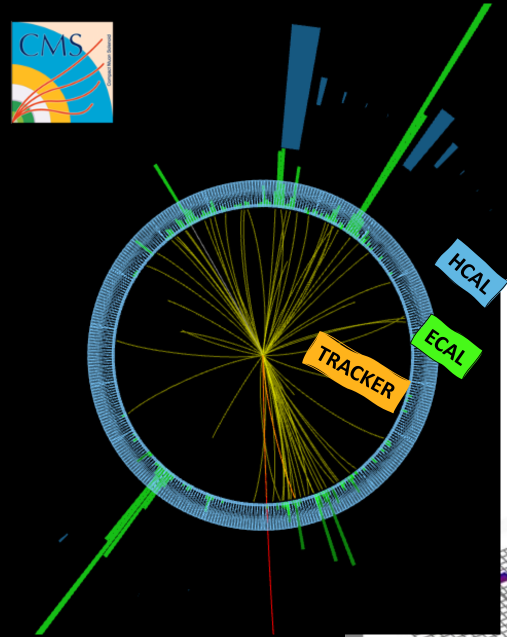
ILD Simulation



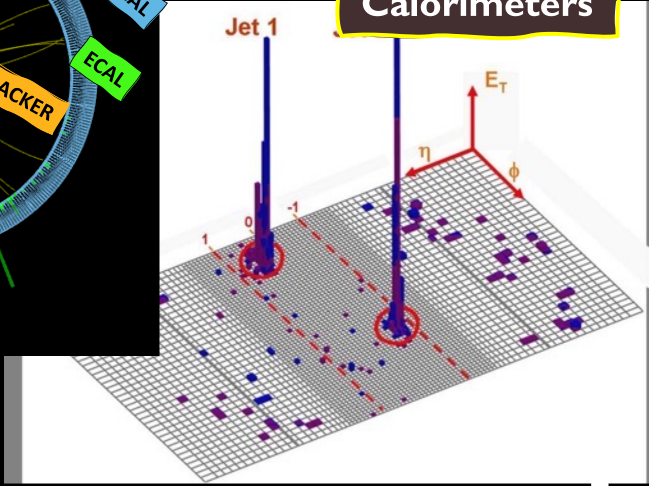
Real multi-particle event@ test beam

"tracking" calorimeters

SDHCAL prototype (~1.3m^3)
Readout 1x1cm^2 pads x 48 planes



Traditional Calorimeters



Main resolution challenge: **Confusion**

Bad assignment of energy between particles (**software**)
+ overlap in the same readout channel (**granularity**)

FACING THE CALORIMETER CHALLENGES –DUAL READOUT CONCEPT

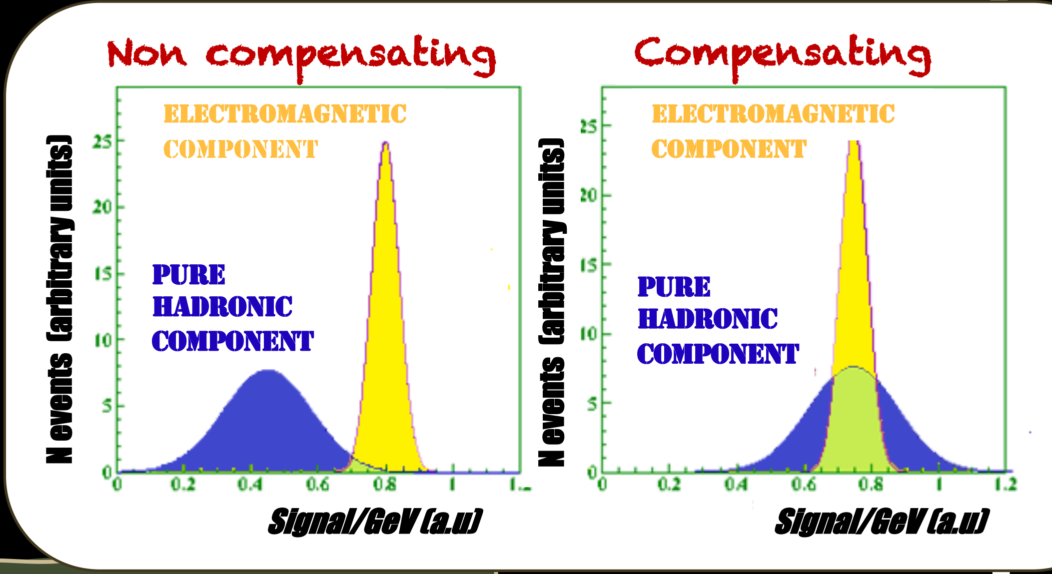
Remember that in a hadronic calorimeter there are two components

$$Signal = S_{em} + S_{had} = ef_{em}E + hf_{had}E$$

$$f_{had} = 1 - f_{em}$$

$\frac{e}{h} = 1$ Compensanting Calorimeter

If it could be possible to distinguish in the calorimeter the electromagnetic fraction , compensation is not needed



This can be achieved by using two different materials for producing different light type:

1. Cherenkov light, produced by relativistic particles dominated by electromagnetic components (80% of the hadronic component is not relativistic)

2. Scintillator light

It can be implemented for example using fibers embedded in the calorimeter absorber

A combination of dual-readout + PFA could also be envisaged

FACING THE CALORIMETER CHALLENGES – POWER CONSUMPTION

FACTS

- The huge number of channels, two orders of magnitude higher with respect actual calorimeters, implies a large power consumption.
- The need of compact devices with electronics embedded on the detector planes and large power consumption increase the heat.

Solutions

At e^+e^- linear colliders

Use of power pulsing electronics profiting from the duty cycle (1%)

ILC provides bunches with a rate of 3 – 5MHz for a period of 1ms, followed by an inactive gap of 199ms.

Switch off / stand-by the the front-end electronics during the gaps in between the bunch trains

Already implemented and successfully tested at some CALICE prototypes

At Circular colliders

Continuous rate of collisions

Active cooling could be needed if the electronics power consumption cannot be reduce

Challenging to maintain compactness and uniformity (important for high performance)

TOWARDS 5D CALORIMETERS?

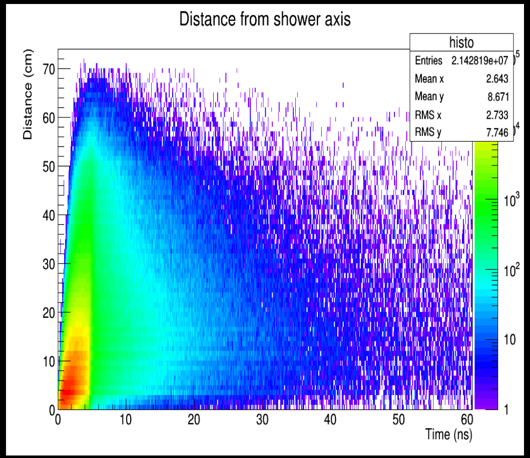
Precise time information was not a requirement for calorimeters, but it could be very useful for the future.

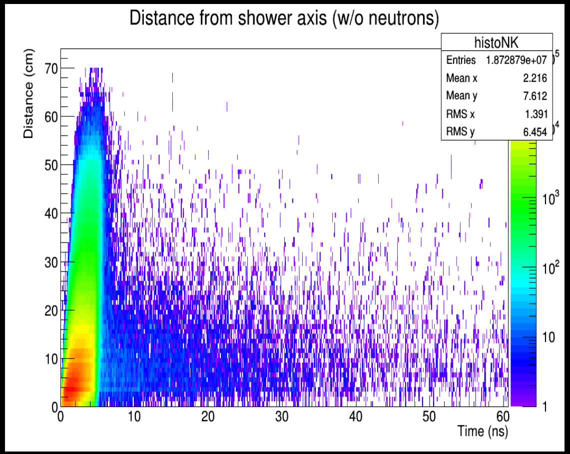
Timing in calorimeters could mitigate backgrounds/pileup , be used for ToF measurements, or eventually recognize signatures for neutral long live particles.

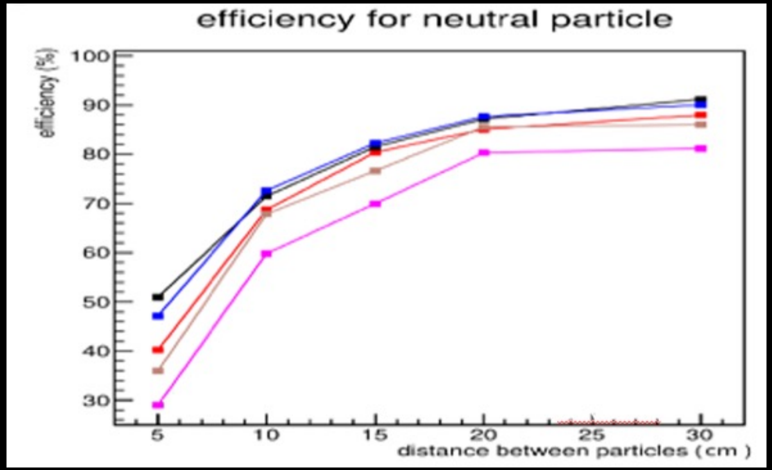
But it can be also useful at the calorimeter reconstruction level when having a highly segmented calorimeter which reconstruct individual hits and gives an image of the shower.

- Can be used for distinguish hits from different showers, improving the efficiency and resolution for reconstruction close by particles
- Can be used for improving the single particle resolution by taking into account the timing of the different particles in the shower

10 GeV neutral from 30 GeV charged particle





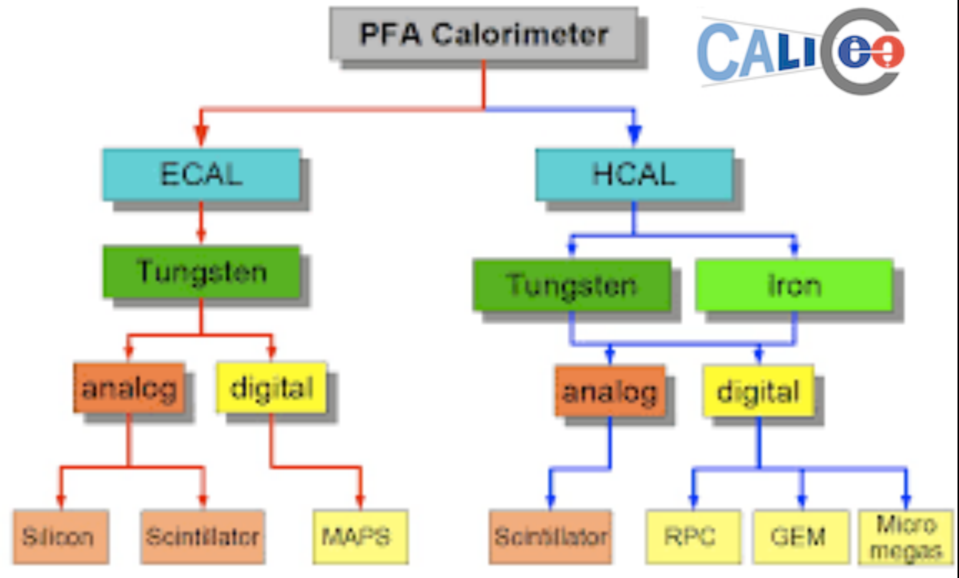


A lot of developments on going on calorimeters, detector concepts still open to different options or different implementations

CANNOT BE FULLY REVIEW IN THIS TALK

JUST AN OVERVIEW

HIGHLY SEGMENTED IMAGING CALORIMETERS OPTIMIZED FOR PFA



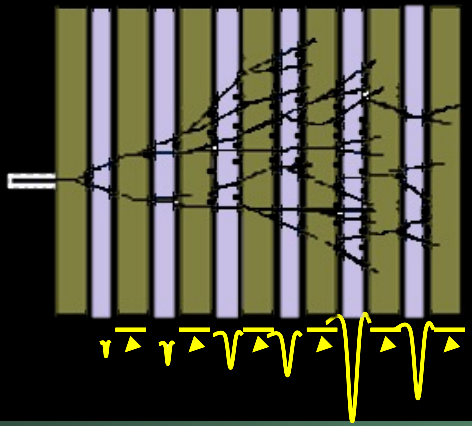
Tungsten absorber for ECAL.

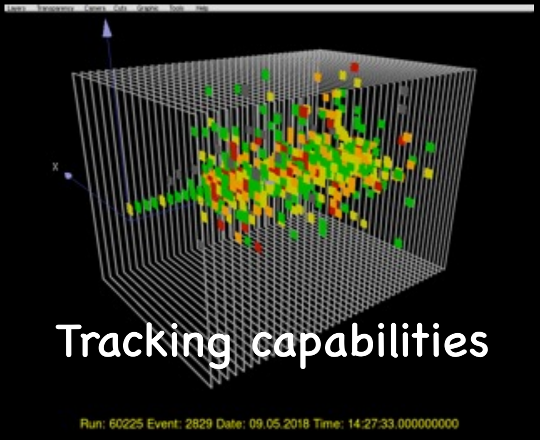
$\lambda_I/X_0 \sim 9$ ➔ excellent photon–hadron separation.
Important for PFA

$X_0 \sim 3.5$ mm (vs 1.76 cm in iron) ➔ Compact

Tungsten has been considered as HCAL absorber only for CLIC
Compact detector for very high energetic particles
(problem: very expensive)

Sandwich calorimeters





Tracking capabilities

SOME GENERAL CONCEPTS ON CALICE CALORIMETERS

CALICE calorimeters are oriented to be used with PFA. ➔ High granularity is a must

- Large segmentation, longitudinal and transversal

  What large means?

  The longitudinal segmentation is 1 layer sampling every ~0.1 X_0 for ECAL and ~0.1 λ_I for HCAL

  The transversal segmentation goes, from 25 μm x 100 μm Pixels in **DMAPS ECAL** till ~3x3cm^2 pads in **AHCAL**

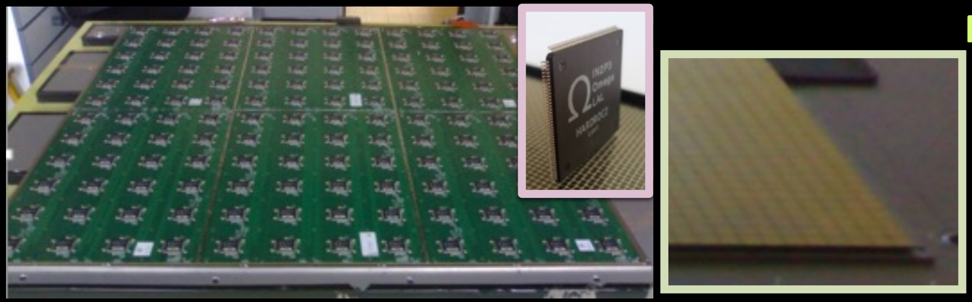
The number of channels is orders of magnitude bigger than the ones in the present experiments

SDHCAL 1x1cm^2 pads

500K Channels

More channels in this prototype than in the LHC calorimeters all together

- FE electronics is embedded into the layer structure (at least on final design, intermediate prototypes could be not fully optimized)



PCB boards

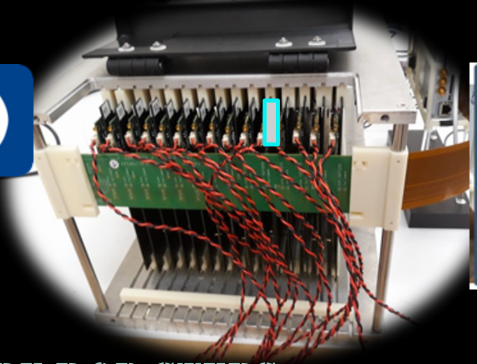
Bottom has the pads/strips

Top has ASIC chips

- Final electronics implements power pulsing mode, but now looking also to other options in view of circular colliders
- Dead spaces must be minimize, this includes tiny space between each detector and the absorber ➔ High precission mechanics needed

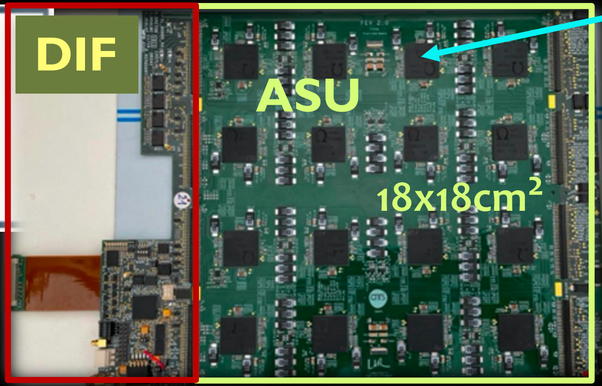
SILICON BASED SANDWICH CALORIMETERS
SI-W ECAL – PROTOTYPES UNDER DEVELOPMENT

Mature technology developed by CALICE since years
Adapted for the CMS HGCAL upgrade calorimeter



SiW-ECAL
- 15 layers 18×18 cm²
- 0.5×0.5 cm² Si cells
- 2.8+5.6 mm W (21 X_0)
- 100 kg, 0.4×0.4×80 cm³
- 15k channels

Embedded electronics

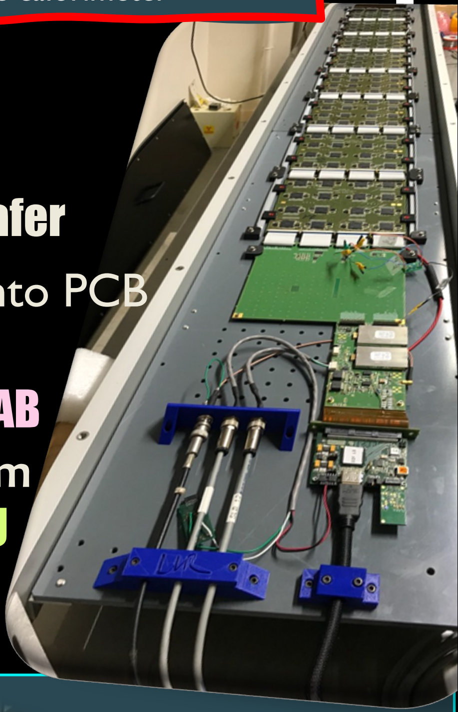


ASIC SKIROC2

ASU = ASIC+PCB+SiWafer

Silicon sensors glue onto PCB

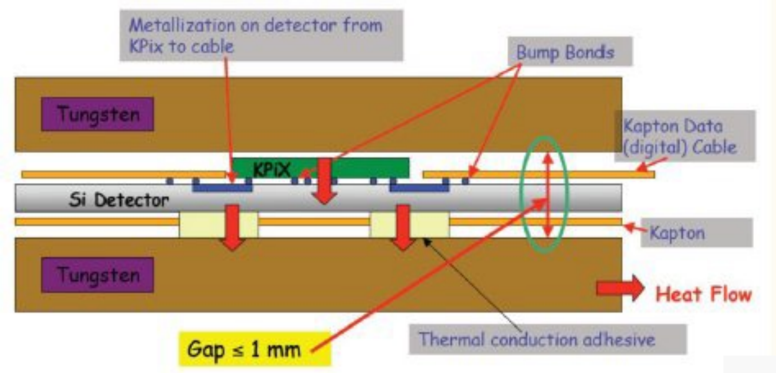
DIF = Detector InterFace: SL Board



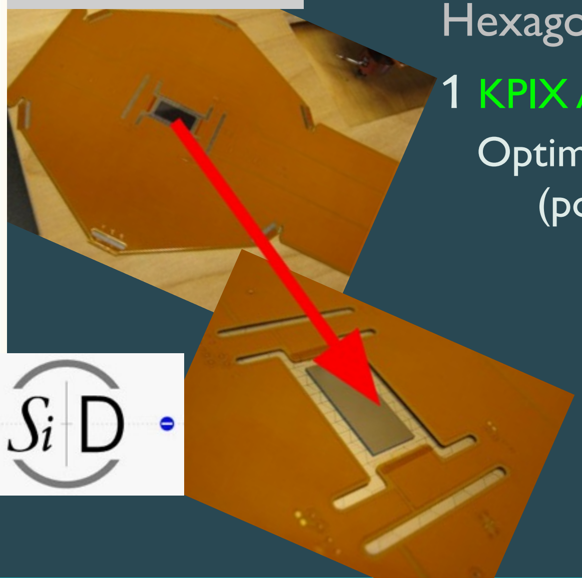
LONG SLAB
~150cm
7 ASU

FUTURE R&D STEPS

- Moving from power pulsing to continuous redout for circular colliders. Power consumption, cooling
- Addition of timing (dedicated layers or full device)

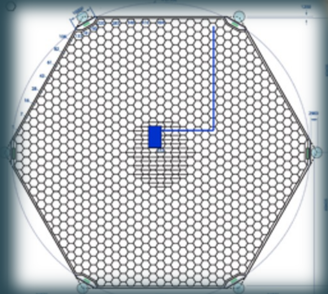


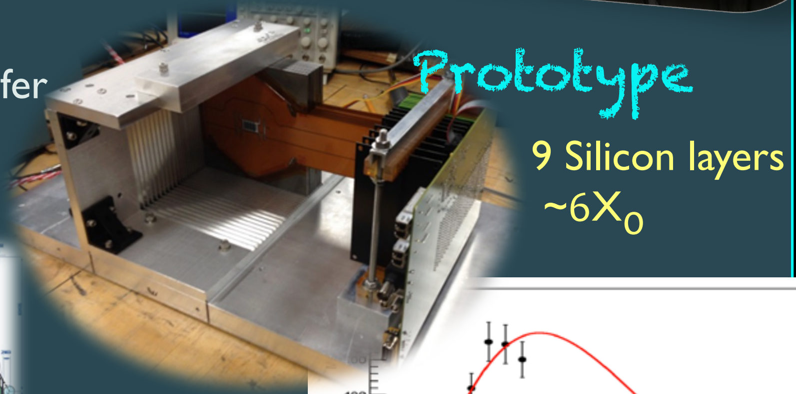
ASIC and cable bonded to sensor
Tungsten plates thermal bridge to edge cooling



Hexagonal sensor Wafers

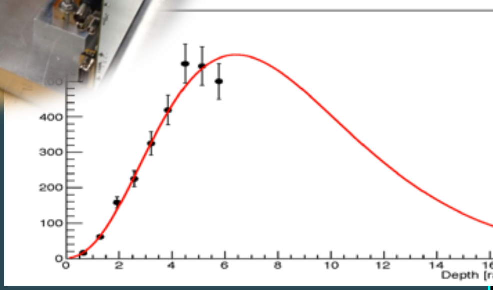
1 KPIX ASIC (1024 ch) per Wafer
Optimized for ILC
(power pulsing, multihit)





Prototype

9 Silicon layers
~6X_0

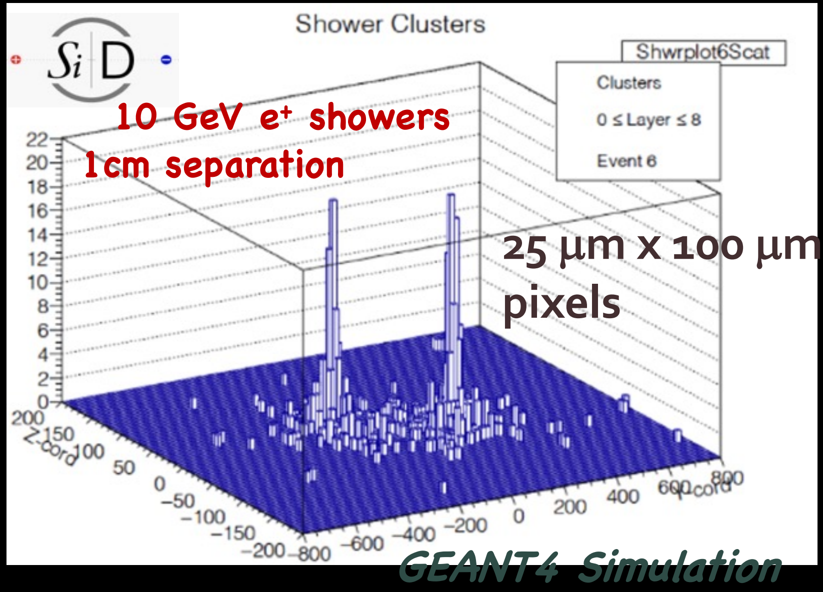


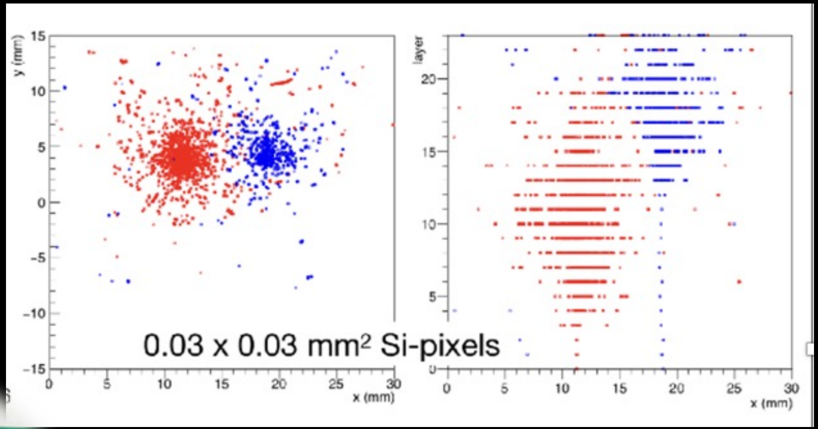
SILICON BASED SANDWICH CALORIMETERS
DMAPS ECAL

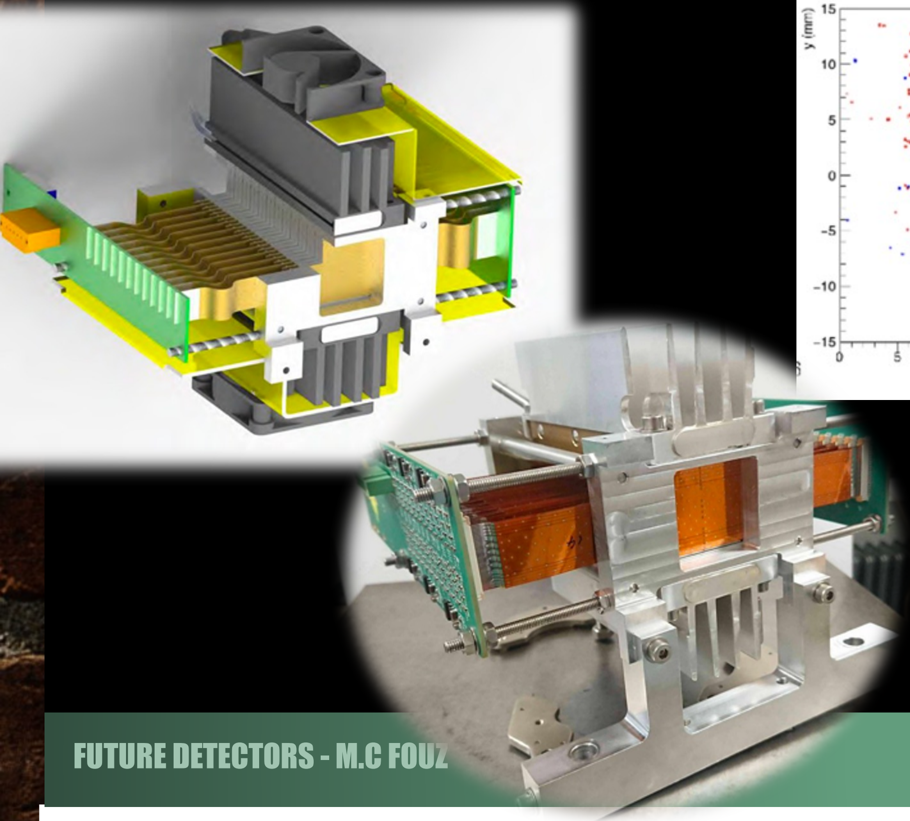
Monolithic Active Pixel Sensors (MAPS) as sensor with Digital Readut

Si diodes and readout combined in the pixel and build with standard CMOS process

- ➔ Bump-bonding not needed (easier, cheaper)
- ➔ Fine granularity of pixels (better separation of showers)





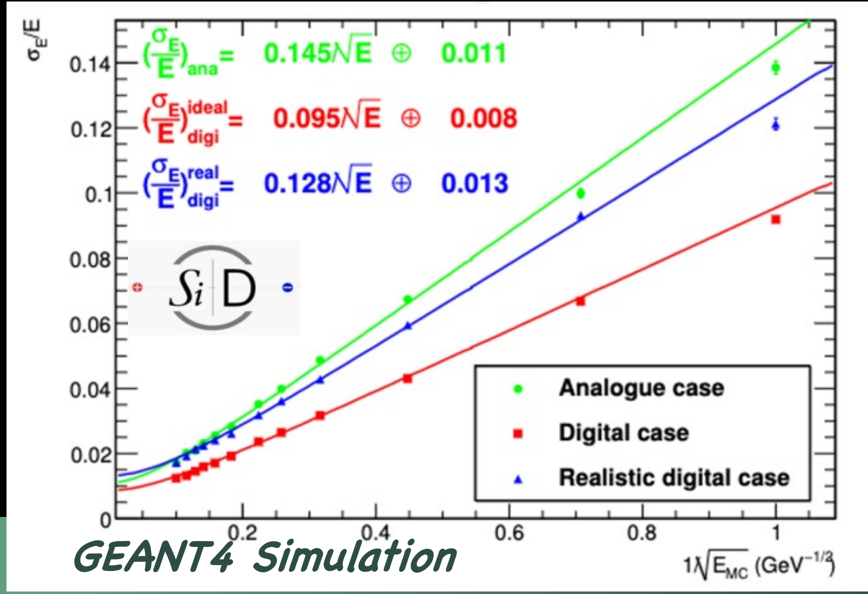


EPICAL-2 prototype

28 layers

ALPIDE CMOS sensors.

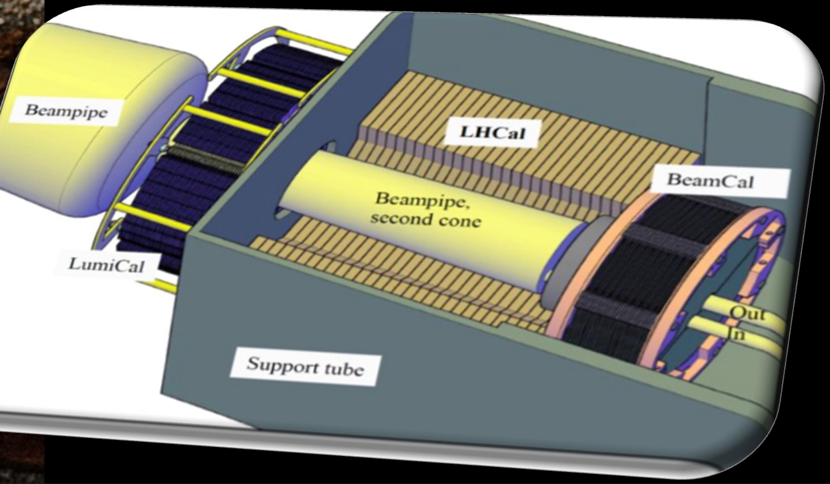
Active cross section 3x3cm^2



SILICON BASED SANDWICH CALORIMETERS FOR FORWARD CALORIMETERS

LC FORWARD CALORIMETERS

Similar still to be developed for FCCee



REQUIREMENTS

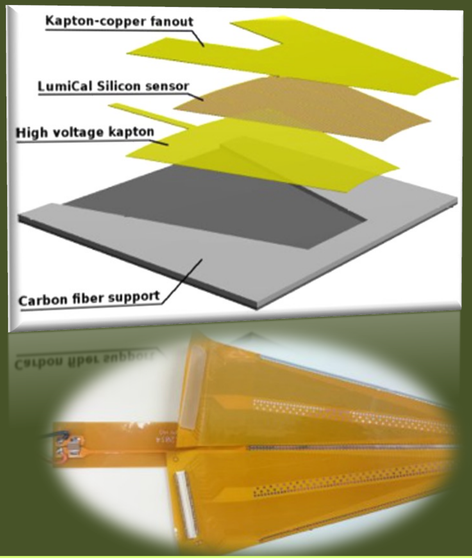
- Finely segmented and compact (Small Molière radius)
- Mechanical precision (polar angle measurement)
- Fast readout
- Radiation hard (BeamCal)

LumiCal: Precise luminosity measurement(Bhabha) (10^{-3}) at 500 GeV.
SiW ECAL

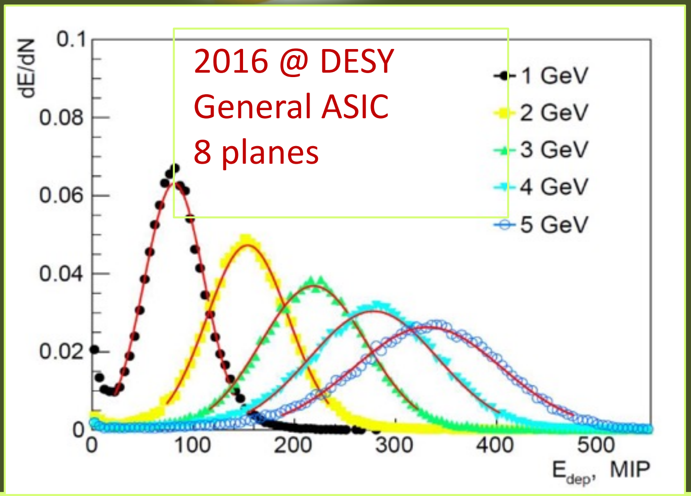
BeamCal : Instantaneous luminosity measurement, beam diagnostics
very high radiation load (up to 1MGy/ year)
W + radiation hard sensors (GaAs, CVD Diamon, Sapphire)

LHCaL: Extends the calorimeter measurements to small polar angles
SiW or Si+iron

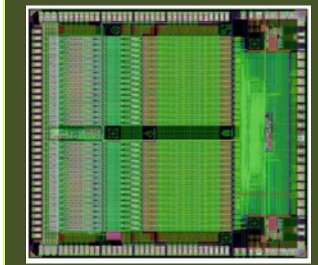
LumiCAL



15 Detector planes
FLAME ASIC



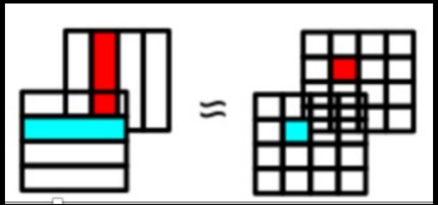
FLAME
FcaL Asic for Multiplane rEadout



3.7 x 4.3 mm²

OPTICAL BASED SANDWICH CALORIMETERS: SCW-ECAL

Sensor: Plastic scintillator
Readout: Strips (5×45 mm^2)
- SiPM



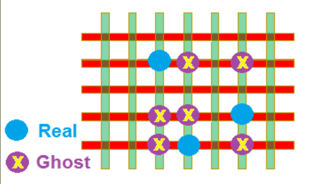
($5x45$ mm^2) ➔ ($5x5$ mm^2)

Less readout channels than SiW-ECAL

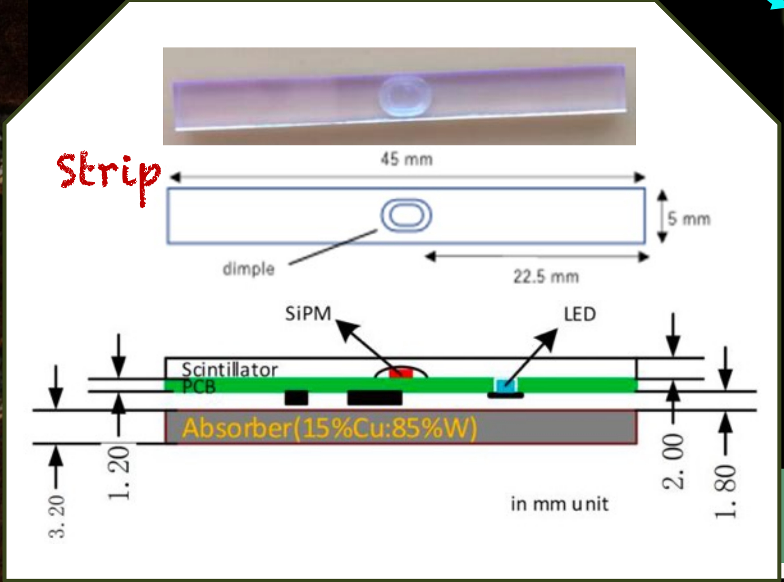
Possibility of introducing dedicated timing layer(s)

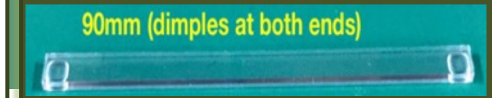
Cheaper 👍
(plastic and electronics)

Ghosts 👎

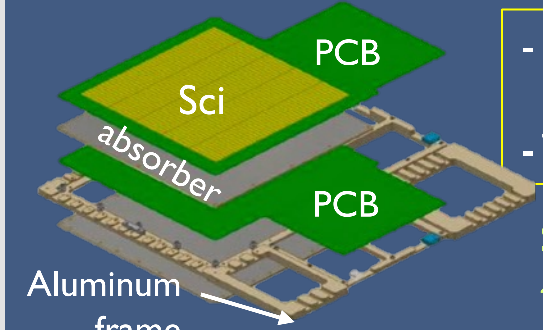


Should be eliminated by double SiPM readout





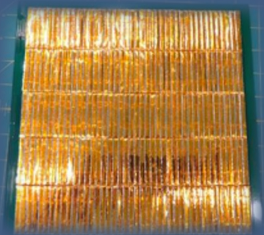
Prototype

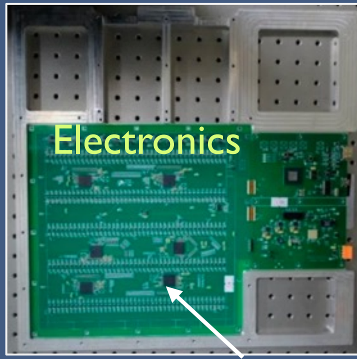


ECAL Basic Unit (EBU)

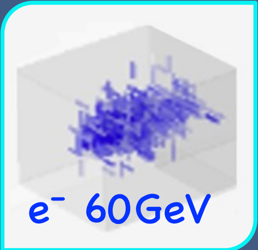
- Scintillator strips + Hamamatsu SiPMs + SPIROC2E chips
- Tungsten-copper alloy (85:15)

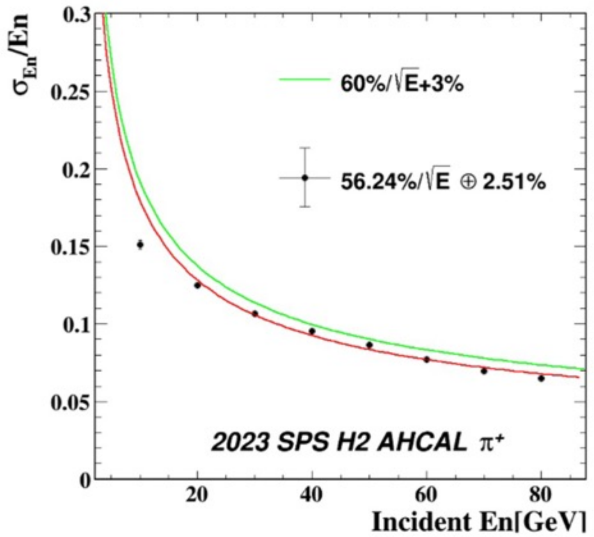
Scintillator plane
42 x 15 strips





32 EBU layers ~23 X_0
6720 readout channels
192 SPIROC2E chips



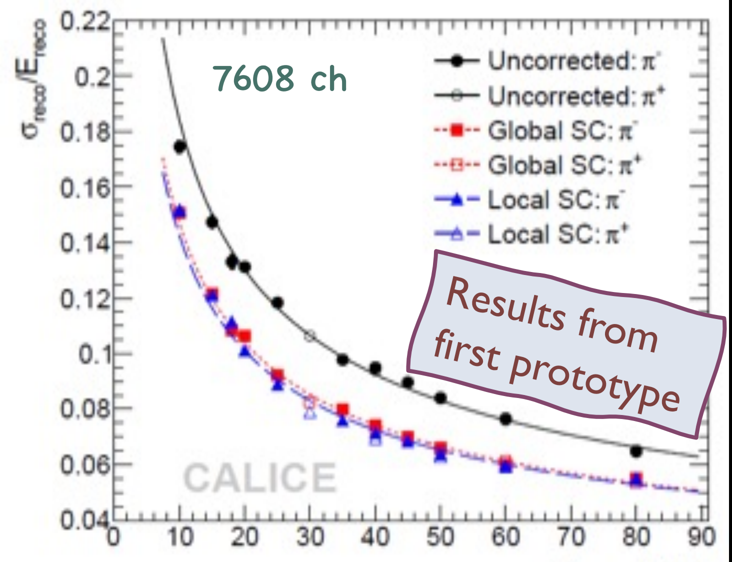


OPTICAL BASED SANDWICH CALORIMETERS: AHCAL

Mature technology developed by CALICE since years
Also adapted for the CMS HGCAL upgrade calorimeter

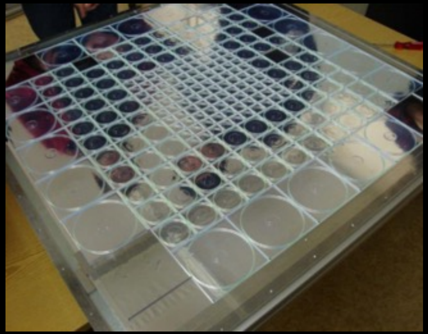
Absorber: Stainless steel (*)
Sensor: Plastic scintillator
Readout: Tiles (3×3 cm^2) - SiPM

(*) Tungsten also tested for CLIC



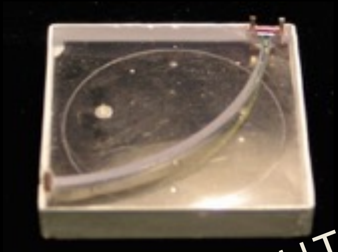
SC= Software Compensation

Many technical developments after the first prototype used as a probe of concept



First prototype

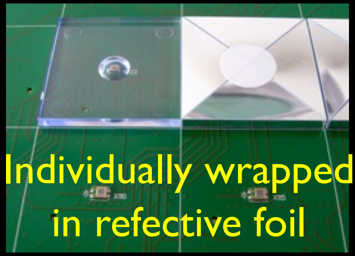
1 plane.
Diferent sizes:
- 3x3cm2 (30x30 cm2 core)
- 6x6cm2 12x12 cm2 (external)



Old Tile design

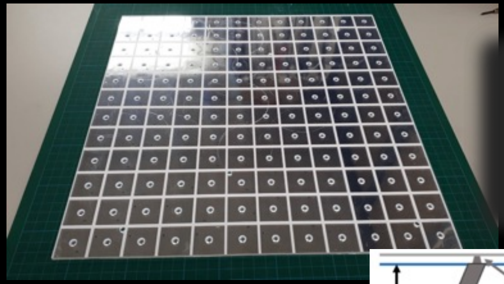
New Developments

Single Tile design



Glued one by one
Light Tightness 👍
Dead areas between tiles 👎

Megatile design



Large scintillator plate with optically separated trenches filled with reflective TiO2

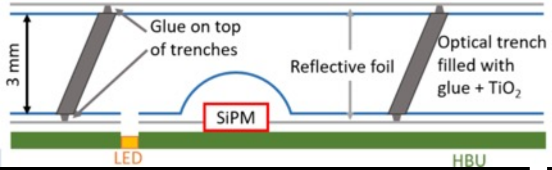


Plate wrapped in reflective foil

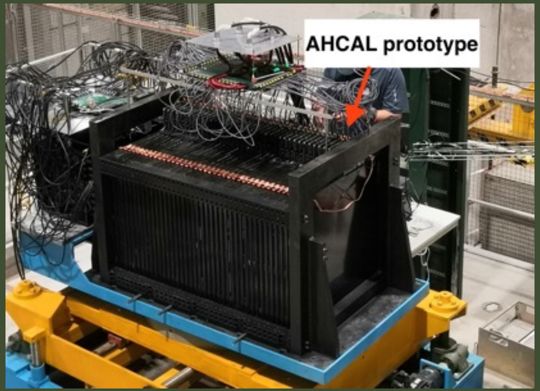
Easier assembly and no dead areas 👍
Not fully light tight 👎

OPTICAL BASED SANDWICH CALORIMETERS: AHCAL PROTOTYPES UNDER DEVELOPMENTS/TESTS

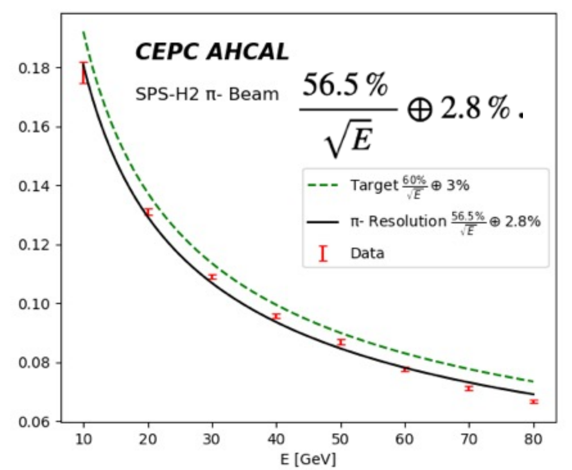
Two similar prototypes built. Several beam tests and data under analysis

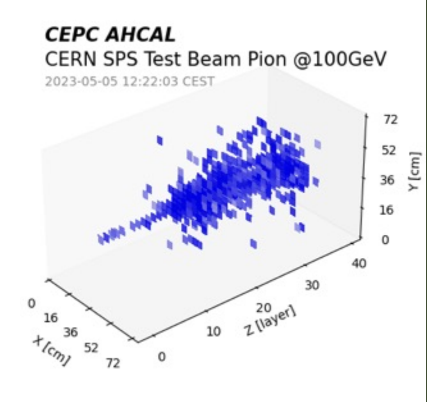
Both uses power pulsing electronics

Prototype for CEPC



Tiles **4x4**x0.3 cm^3
40 layers 0.72 x 0.72 m^2
~13.000 channels

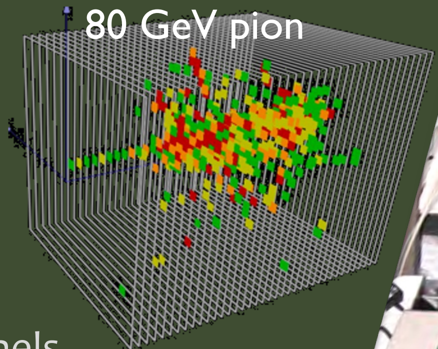




Prototype for ILC

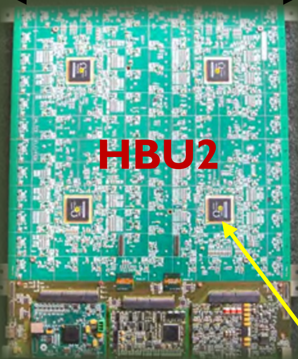
Tiles **3x3**x0.3 cm^3
38 layers 0.72 x 0.72 m^2
~22.000 channels

Full extension
1 slab = 6 HBU2

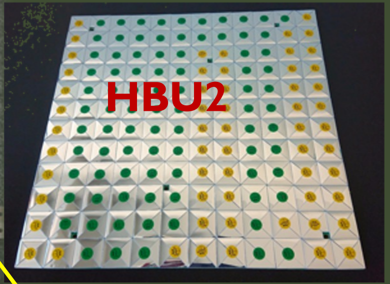


HBU: HCAL Base Unit

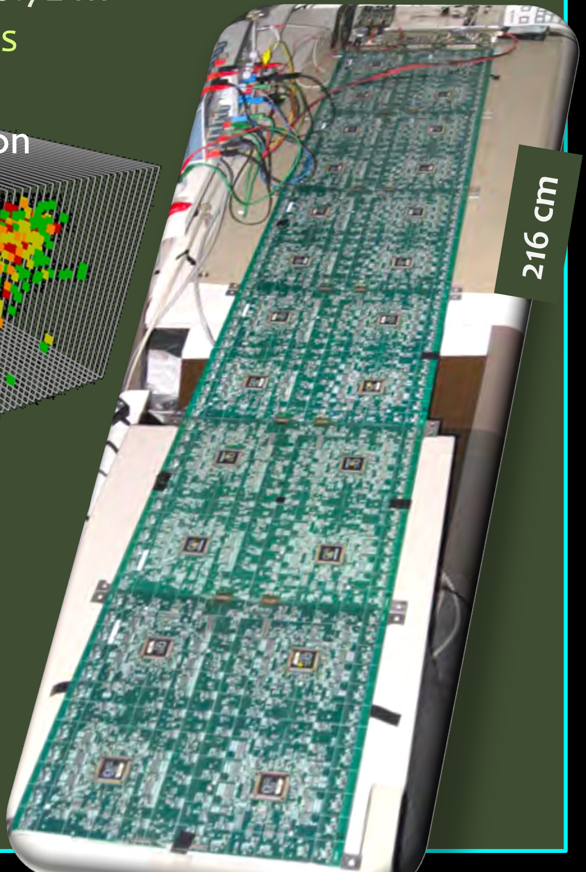
36 cm



144 channels



SPIROC2E ASIC

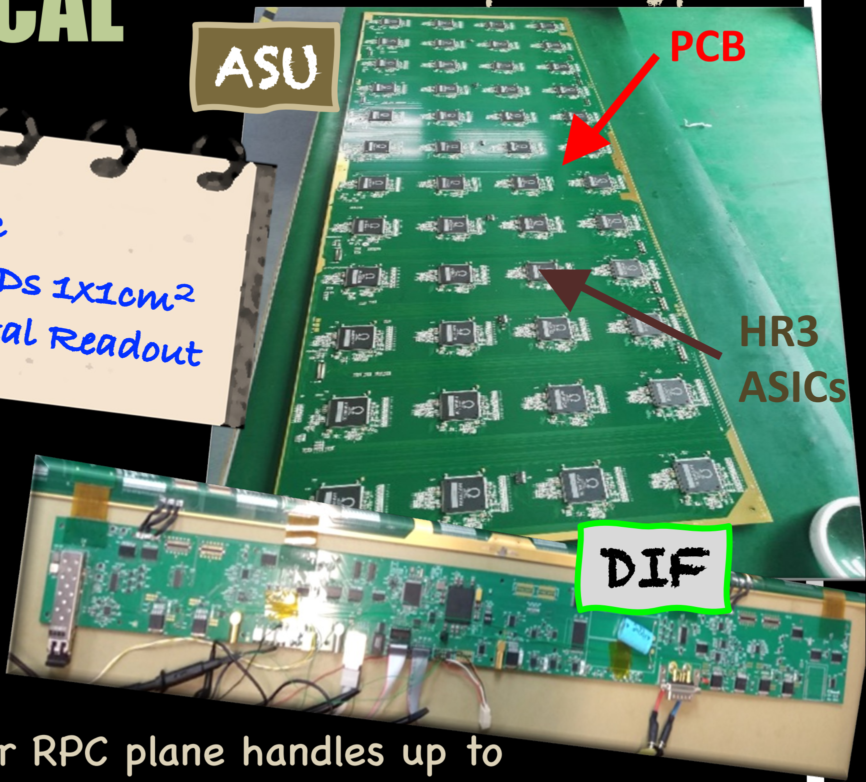


GAS BASED SANDWICH CALORIMETERS: SDHCAL

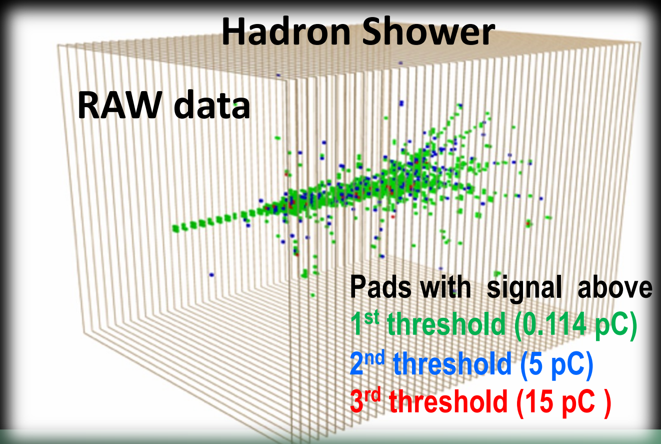
Large prototypes

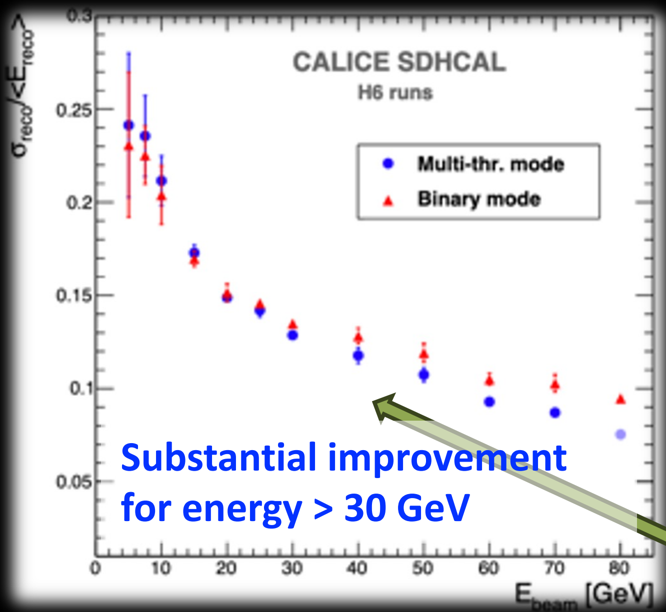
- 48 layers ($-6\lambda_I$)
- 1 cm x 1 cm granularity
  3-threshold, 500000 channels
  Semi-digital readout
- Power-Pulsed
- Triggerless DAQ system
- Self-supporting mechanical structure (<500 μm deformation)

Sensor: RPC
Readout: PADs 1x1cm²
Semi-digital Readout



SDHCAL ~1.3m³ prototype
At Test Beam @ CERN





1 DIF per RPC plane handles up to 432 HR3 chips. (1x3m2) chamber

Advantage of semi-digital vs digital
➔ Multi-threshold improves resolution

Technology under development by CALICE since more than 10 years

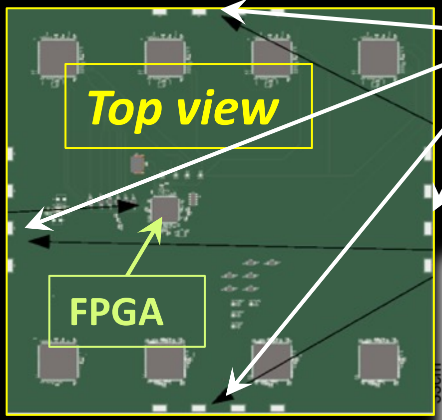
GAS BASED SANDWICH CALORIMETERS
TSDHCAL – TOWARDS A 5D-SDHCAL CALORIMETER

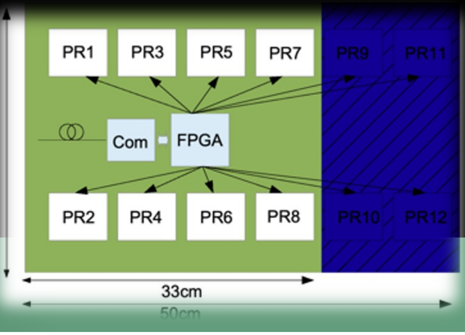
Goal: Time resolution better than 100 ps/mip

- RPC are replaced by MultiGap RPC -MRPC (faster)
- Semi-digital electronics (HARDROC) is replaced by low-time jitter PETIROC (> 20 ps @Q> 300 fC)

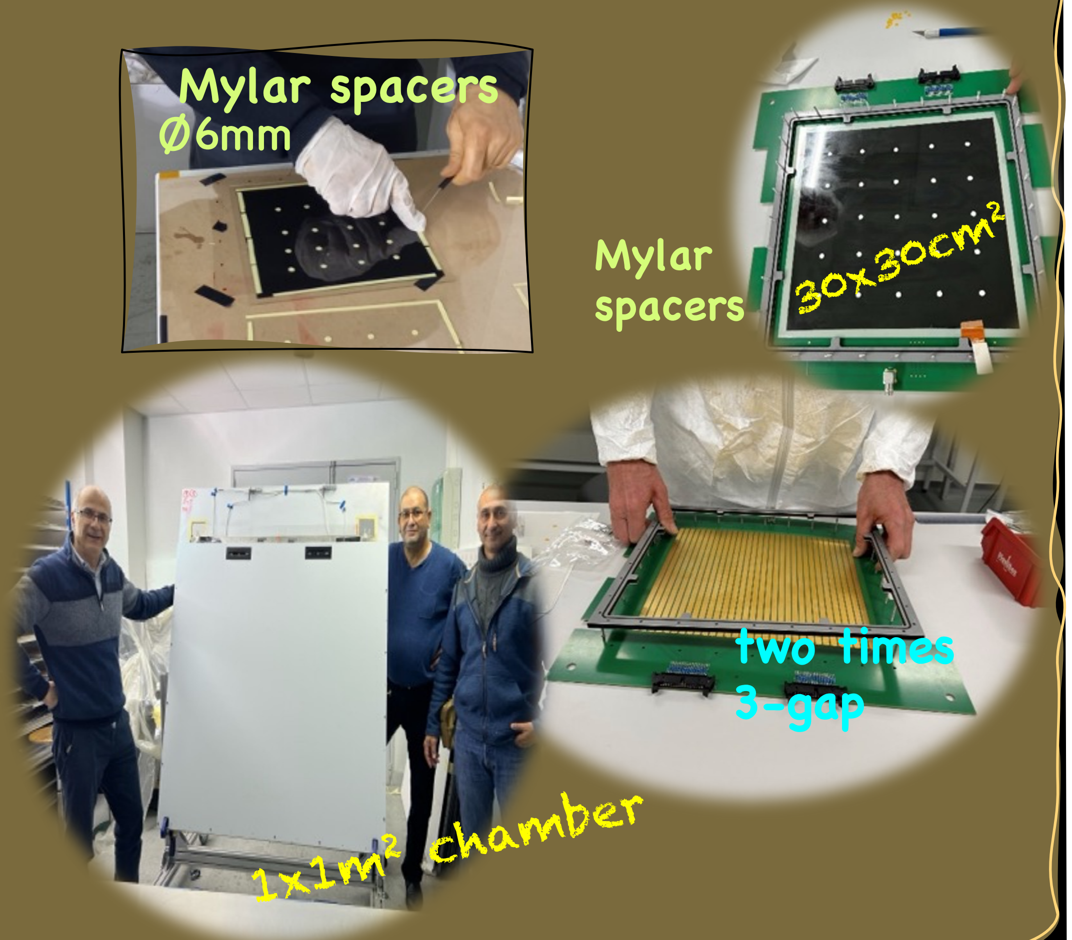
New Boards designed

Power Supply connections





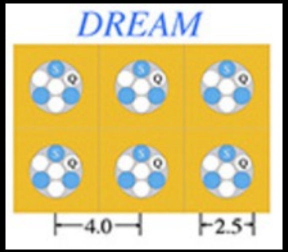
Several MPRC developments

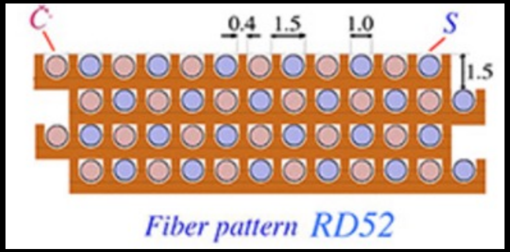


DOUBLE READOUT FIBER CALORIMETER

Absorber: brass or steel
Sensor: Scintillator + cherenkov Fibers
Readout: SiPM/MCP-PMT
Dual readout

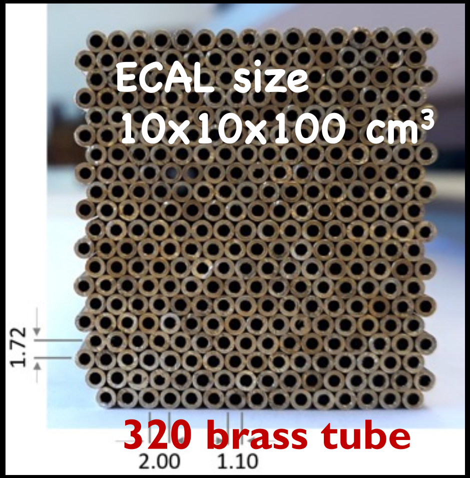
Geometry based on metal capillaries acting as absorber with inserted fibers

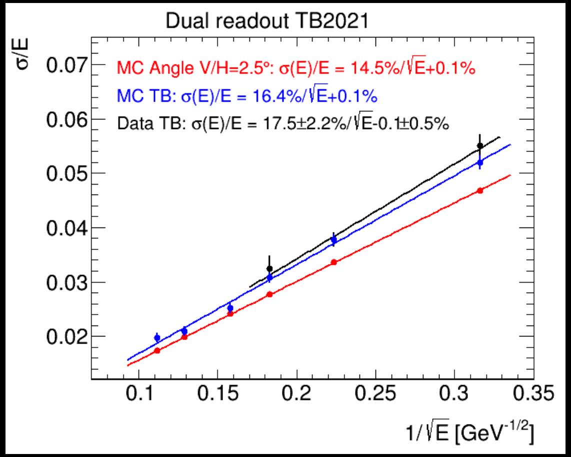




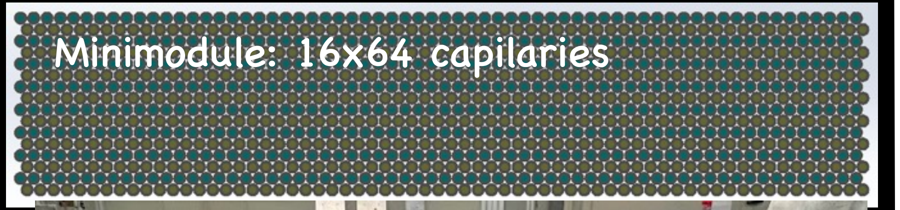
Readout with a SiPM or PMT

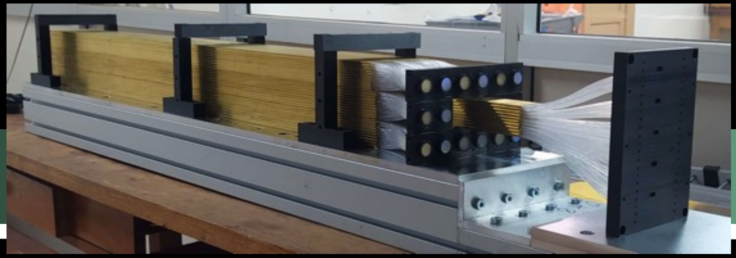
Several prototypes under development

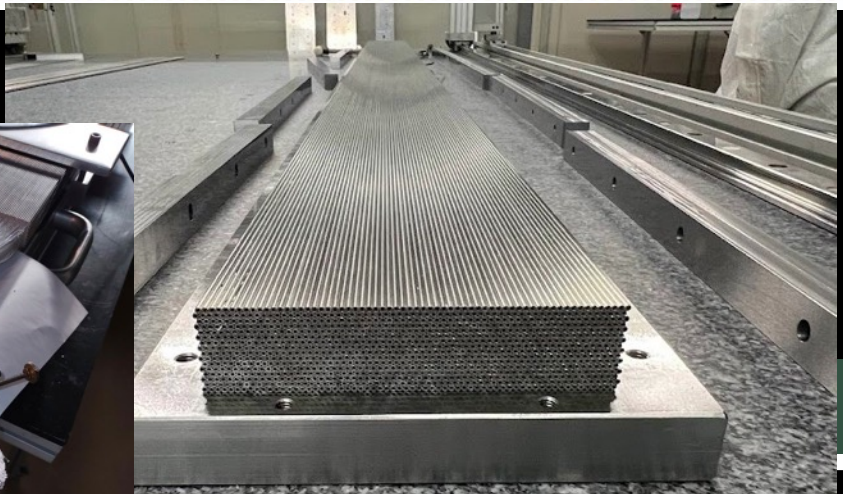




HCAL size 65x65x250 cm³. → 80 minimodules.





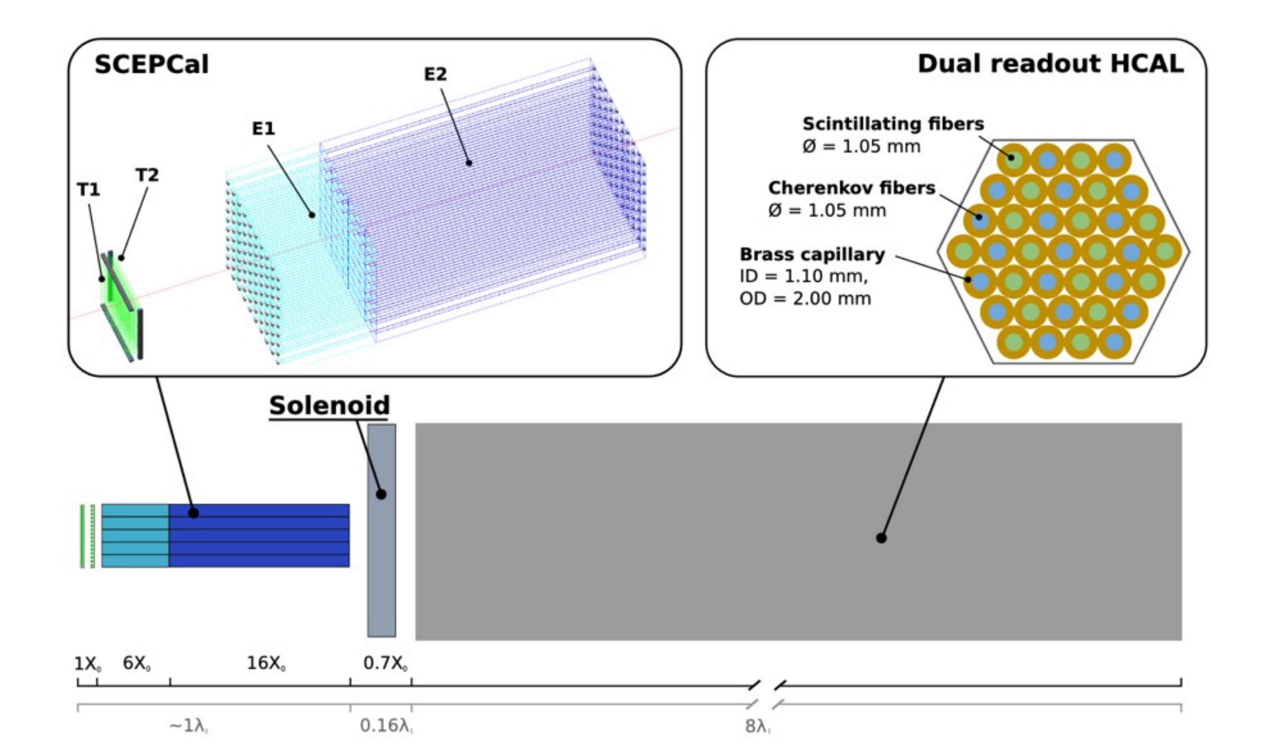


DOUBLE READOUT CRYSTAL CALORIMETER: SCEPCAL

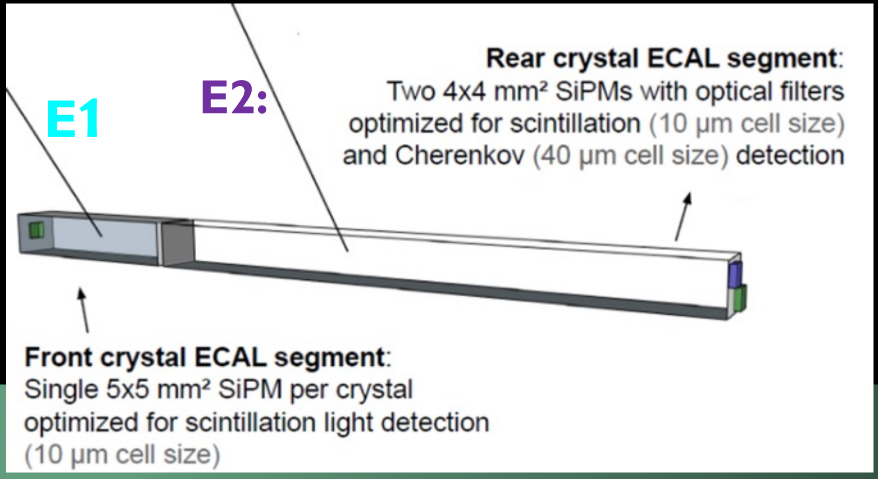
SCEPCAL: Segmented Electromagnetic Precision CALorimeter

FT1,T2 Fast and bright Scintillator
(e.g LYSON:Ce Crystals)
MIP tagging 20 ps

E1,E2: Dense crystal with dual-readout capabillitites (PBWO4, BFP, BSO)
Precise measurement EM showers



Scintillator and Cherenkov from the same active medium, disentangle using optical filters



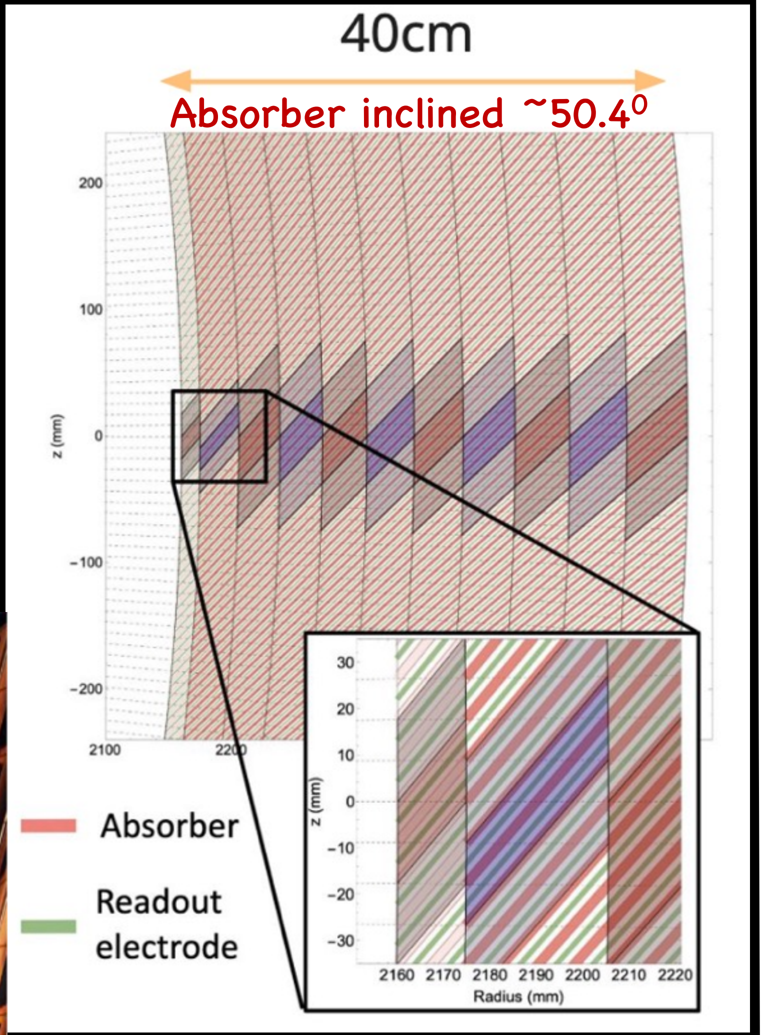
NOBLE LIQUID CALORIMETER

Absorber: Lead/Tungsten (2mm)
Sensor: LiAr (LiKr) (1.2-2.4mm)
Readout: Strips PCB
FCC-hh, FCC-ee

Based o LiAr ATLAS Calorimeter

Good energy resolution
(sampling term ~10%)
Low systematics
PID Capabilities
Radiation hardness

Target 10-15 times higher granularity than ATLAS for PFA in high pile-up environment. (ATLAS Cu/Kapton electrode but PCB allows high granularity)



Multilayer PCB developments

Low mass cryostats needed
CERN R&D: CFRP/Metal interfaces

CFRP: Carbon Fibre Reinforced Plastic

OPTICAL BASED HOMOGENEOUS HIGH GRANULARITY EM CRYSTAL CALORIMETER - HGCCAL

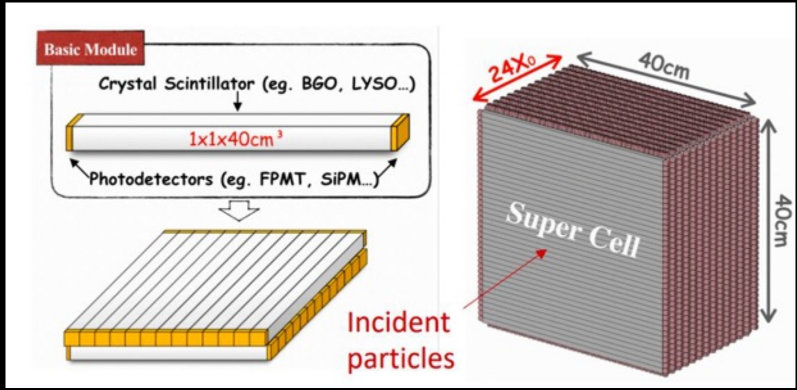
High density Scintillating Crystal (BGO/PWO)
Readout: SiPM
Higgs Factories

Design 1: Short bars

Small crystal cubes: fine segmentation longitudinal & transversal. → PFA

Single-ended readout SiPM

Design 2: Long bars

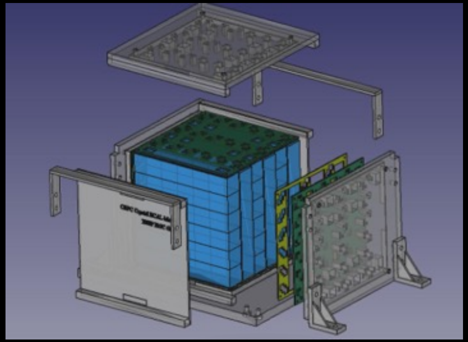


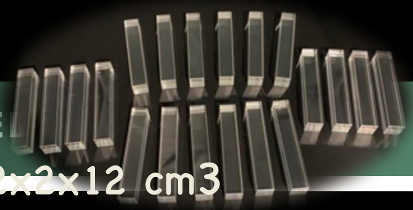
double-side readout SiPM with time
=> position along the bar

Less channels
reduce dead space

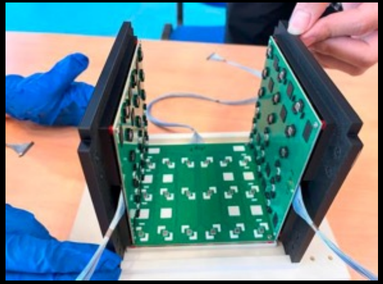
Ambiguities

First Module
72 channels, 10.7 X_0

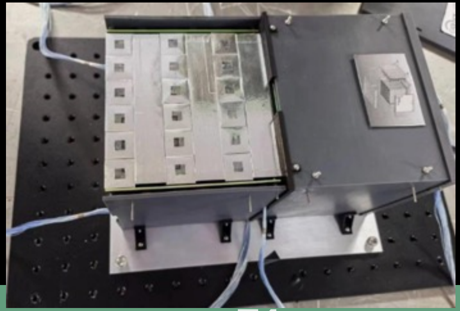




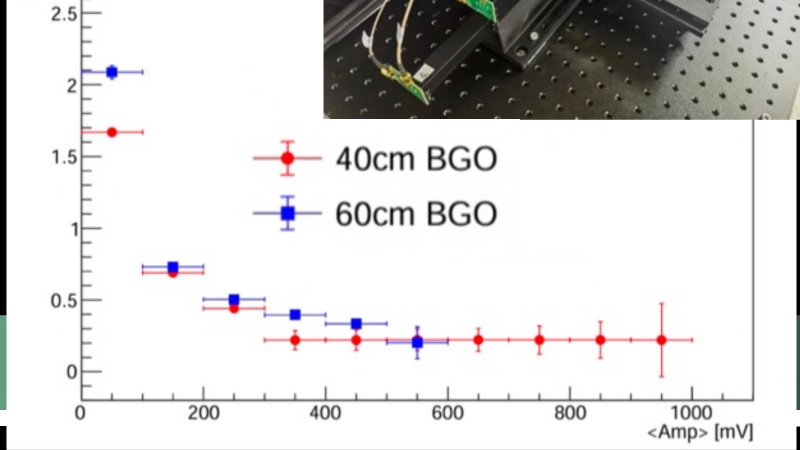
2x2x12 cm3

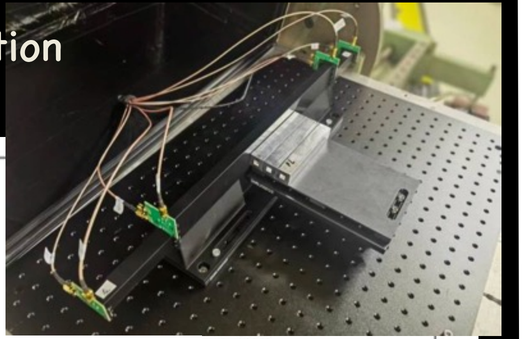


Second Module
144 channels, 21.4 X_0



Bars Time resolution test set-up

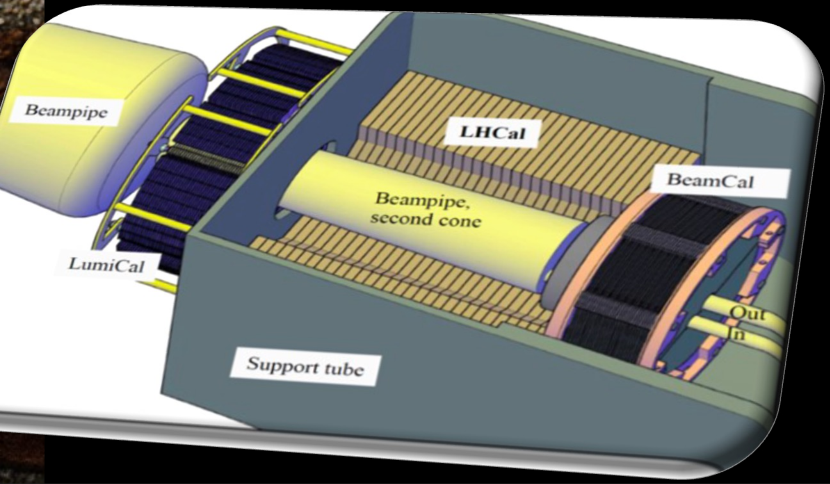




SILICON BASED SANDWICH CALORIMETERS FOR FORWARD CALORIMETERS

LC FORWARD CALORIMETERS

Similar still to be developed for FCCee



REQUIREMENTS

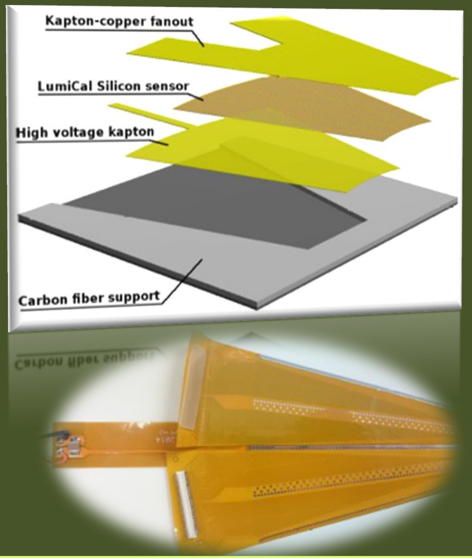
- Finely segmented and compact (Small Molière radius)
- Mechanical precision (polar angle measurement)
- Fast readout
- Radiation hard (BeamCal)

LumiCal: Precise luminosity measurement(Bhabha) (10^{-3}) at 500 GeV.
SiW ECAL

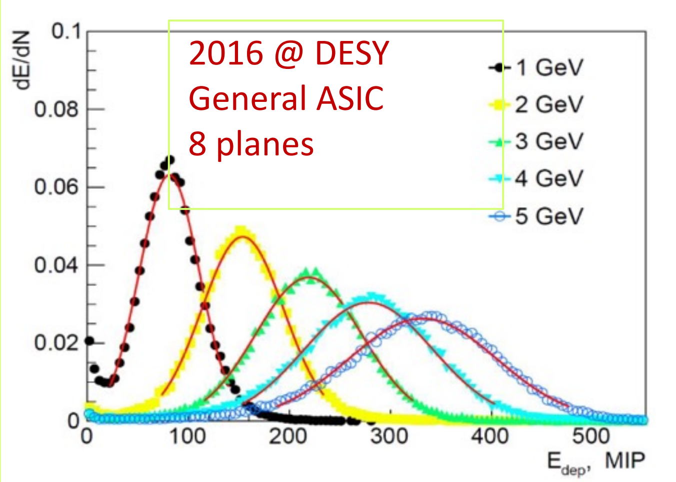
BeamCal : Instantaneous luminosity measurement, beam diagnostics
very high radiation load (up to 1MGy/ year)
W + radiation hard sensors (GaAs, CVD Diamon, Sapphire)

LHCaL: Extends the calorimeter measurements to small polar angles
SiW or Si+iron

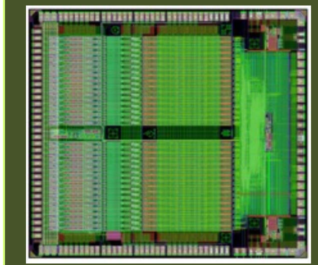
LumiCAL



15 Detector planes
FLAME ASIC



FLAME
FcaL Asic for Multiplane rEadout



3.7 x 4.3 mm²

A FAST SNAPSHOT ABOUT THE TYPE OF DETECTOR DEVELOPMENTS GOING ON IN SPAIN FOR FUTURE COLLIDERS

THE SPANISH COMMUNITY OF DETECTOR R&D FOR COLLIDERS HAS BEEN INVOLVED ON DETECTOR DEVELOPMENTS FOR FUTURE e+e- SINCE AROUND 18 YEARS

MAIN CONTRIBUTIONS TO ILD DETECTOR (ILC AND NOW LOOKING ALSO FCCee) - LOI, DBD, TOP LEVEL COORDINATORS… BUT ALSO AT CLIC

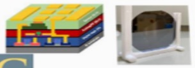
AND SOME GROUPS HAVE ALSO COLLABORATION WITH CEPC DIRECTLY ON INDIRECTLY

CNM CSIC — G. Pellegrini

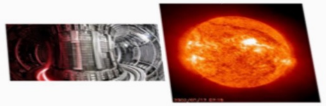
Collaborations

All CERN projects are coordinated with the main HEP institutes in Spain.


Soft X-ray imaging


IFIC — 3D system integration

Interconnection


Fusion


Brachytherapy

IFAE
- DMAPS simulation
- Timing and 3D
- 2D materials

CNM

CNA
- WBG materials (SiC, GaN, Diamond)
- Irradiation studies


Single Photon Detectors for Quantum Imaging

IFCA
- Innovative LGAD technologies
- Ultra radiation hard silicon
- SiC testing.

IGFAE
- Medipix 4 (LGADs and 3D)

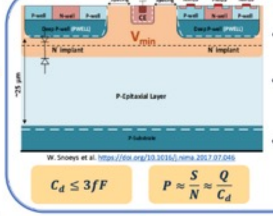

Radiotherapy

9

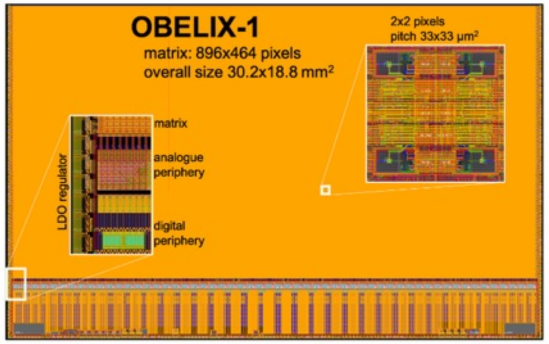
OBELIX – Layout

IFIC Institut de Física Corpuscular

- Matrix inherited from TJ-Monopix2 developed for ATLAS (Tower 180 nm CIS)
- Dimensions adjusted to VTX geometry
  464 rows and 896 columns, 29.60 x 15.33 mm^2 active area
- Low dropout regulators (LDOs) to allow a wide input supply voltage range 2-3 V
- Clock frequency for the timestamp and trigger unit is 21.2 MHz (timestamp length 47.2 ns)
- Trigger unit with 2-stage trigger memory (data loss < 0.02% at design trigger latency of 10 μs and hit rate of 120 MHz/cm^2
- 320 Mbit/s output



DMAPS in TJ 180 nm: Concept
- Small sensor capacitance (Cd)
  - Key for low power/low noise
- Radiation tolerance challenges
  - Modified process
  - Small pixel size
- Design challenges
  - Compact, low power FE
  - Compact, efficient R/O



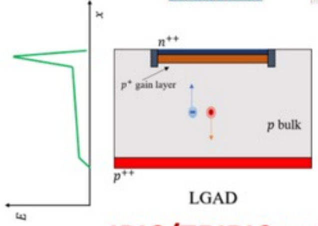
cmarinas@ific.uv.es 4

Participation of the Centro Nacional de Aceleradores (CNA) in CERN R&D collaborations on Semiconductor Detectors

RD50: "RADIATION HARD SEMICONDUCTOR DEVICES FOR VERY HIGH LUMINOSITY COLLIDERS"
- RD50: 65 *institutes and 440 members*

RD50 Project: "Thin Low Gain Avalanche Detectors (LGAD) characterization using Ion Beam Induced Charge (**IBIC**) and Time-resolved IBIC (**TRIBIC**) at the Centro Nacional de Aceleradores."

COLLABORATION: CNA, IFCA, CNM



LGAD:
- Moderate intrinsic gain.
- Higher bias → Higher gain.
- Ultrafast signal.

IBIC/TRIBIC powerful tool for semiconductors characterization

MC Jiménez-Ramos et al. Sensors, 22-3,1080, 2022

From 2024:
ECFA Roadmap →
New 'Detector R&D' collaborations→
- DRD3: Solid-State detectors
- 143 institutions / 600++ people
- WG5: Characterization techniques, facilities

CNA FACILITIES


3 MV Tandem
Ions: H-Au
600 keV-few MeV


Cyclotron
18 MeV H⁺/ 9 MeV D⁺

CNA contact: Carmen Jiménez-Ramos (mcyjr@us.es)

Belle II **Upgrade**

CMOS & LGADS

SEP. 2024

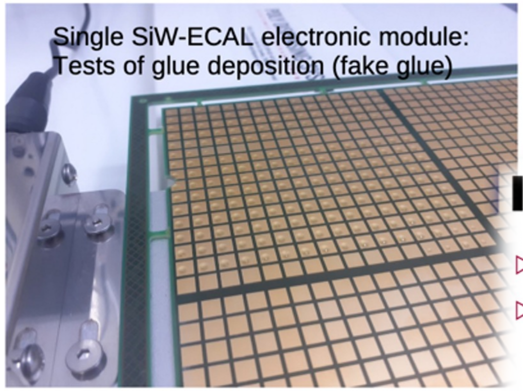
Si ECAL hybridization / integration

IFIC
INSTITUT DE FÍSICA CORPUSCULAR

Common R&D Short term

▷ Current technological prototype solution for sensor-PCB connection is based on epoxy-silver glue.

- Mechanical strength, industrialization, durability, aging studies,...
- Silver → may be an issue on high radiation environments



SILICON DETECTORS FOR CALORIMETRY

IFIC-Lab for ECAL hybridization

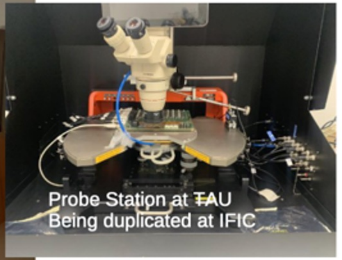
IFIC
INSTITUT DE FÍSICA CORPUSCULAR

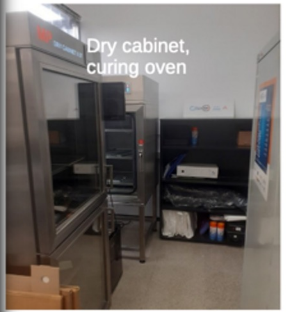
DRD6
ILD LUXE

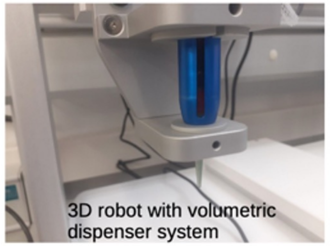
▷ **New facility and capabilities at IFIC**

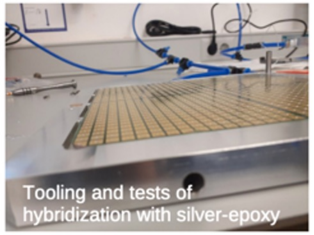
▷ **Funding: CIDEGENT/ASFAE/CNS** → In line with ECFA – R&D roadmap, DRD6, Future Colliders

▷ **IFIC will become** the hub for module hybridization R&D / production / commissioning for DRD6 Si-ECALs and for the LUXE experiment

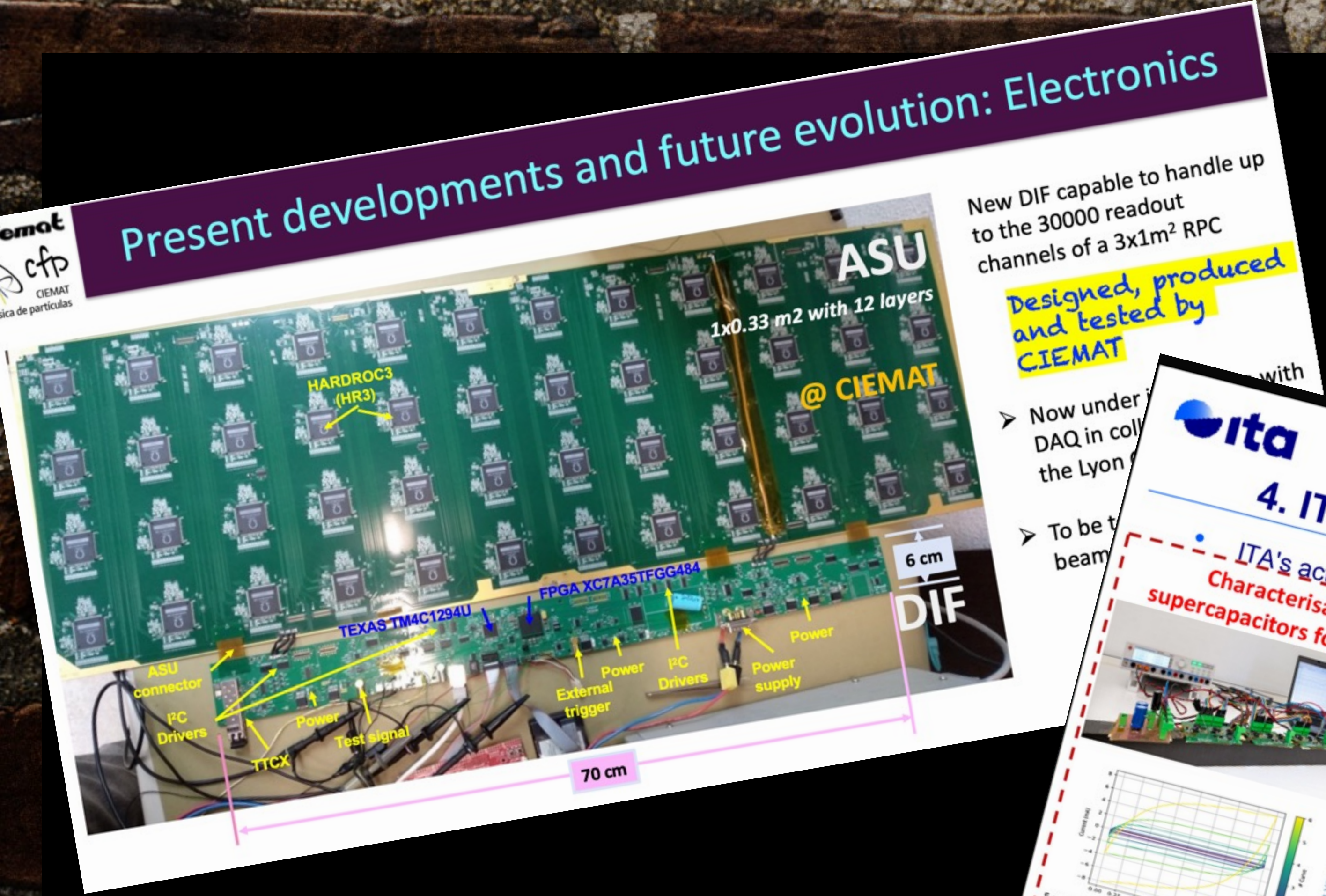








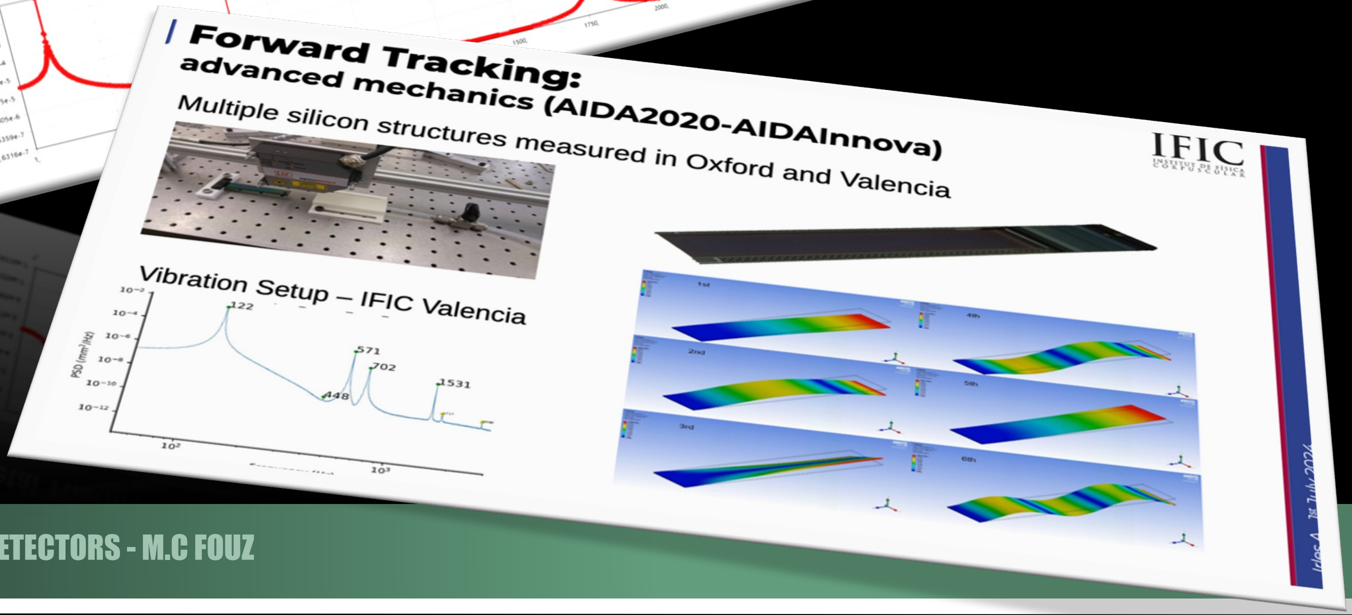
ELECTRONICS



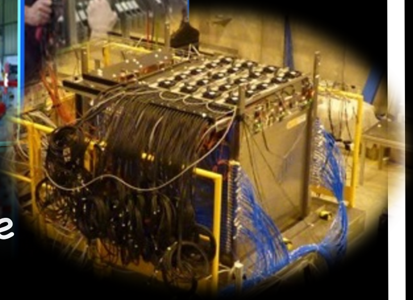
CALORIMETRY

ADVANCED MECHANICS

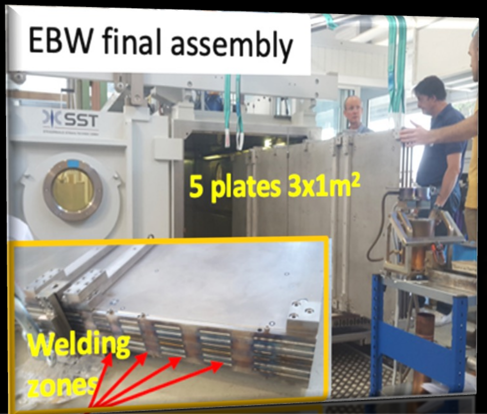
Forward tracker



Calorimetry



1m3 SDHCAL mechanical structure



Development of Electron Beam Welding assembly protocols to reduce deformations introduced by welding procedures below mm level (600 microns in this test with 5 plates 3x1 m^2)

IN SUMMARY....

IN SUMMARY....

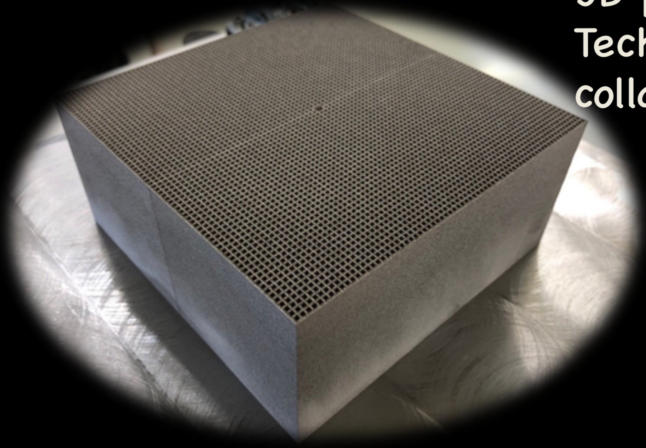
BUT THERE IS PLENTY OF WORK AND FUN IN FRONT !!

BACKUP

OPTICAL BASED SPACAL CALORIMETER: PicoCAL

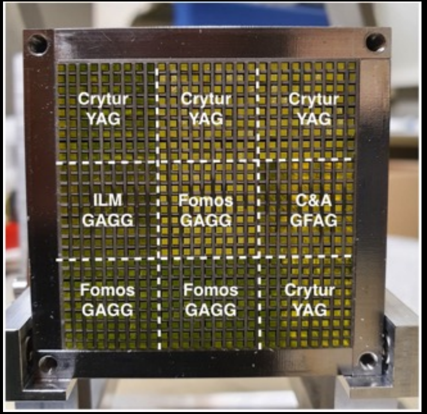
PicoSecond SPACAL

Absorber: Lead or Tungsten
Sensor: Radiation hard Scintillator Fibers
Readout: Light guides
Fast photo detectors: MCD PMTs/SiPM
LHCb, Higgs Factories FCC-hh

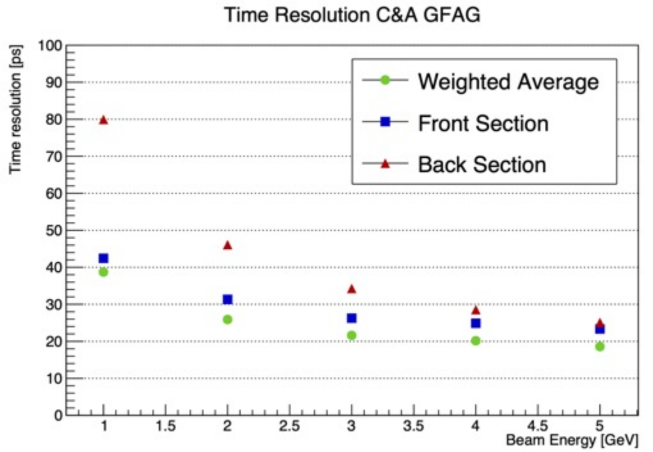


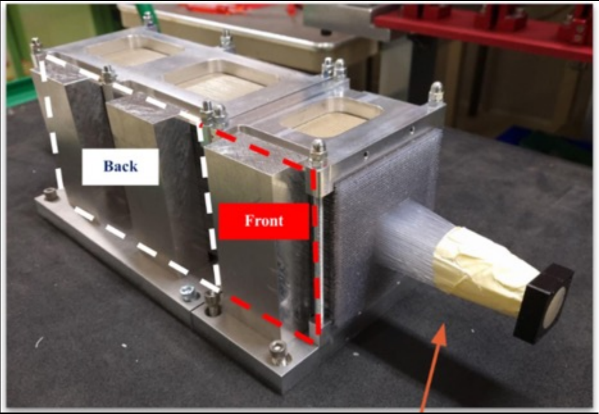
3D printed tungsten absorber
Technical development in collaboration with industry

12x12 cm2

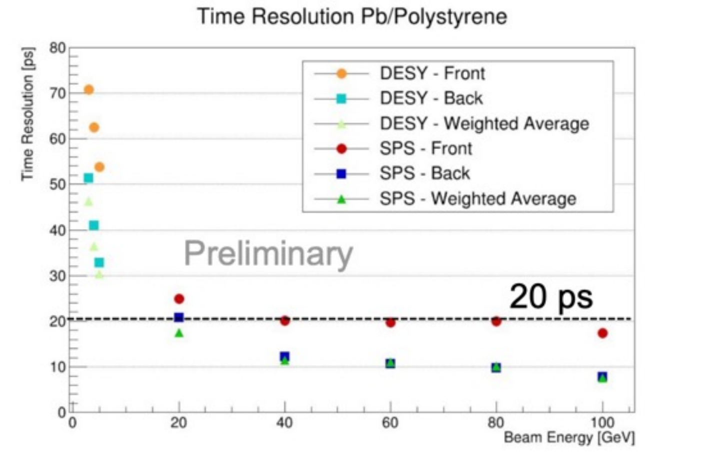


Garnet Crystal fibers + Tungsten





Polystyrene fibers + lead



OPTICAL BASED SHASLIK-LIKE CALORIMETER GRAiNITA

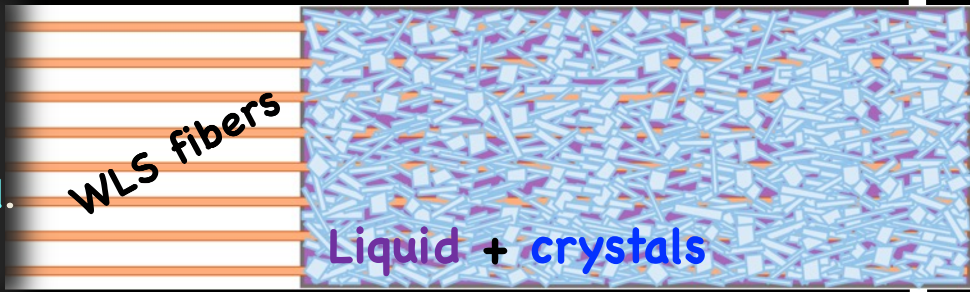
Inorganic crystals have excellent energy resolution but expensive, limited granularity
Sampling calorimeters worst resolution due sampling fraction

Scintillator grains in transparent liquid
Readout: WLS fibers - SiPM
Higgs Factories

GRAiNITA:

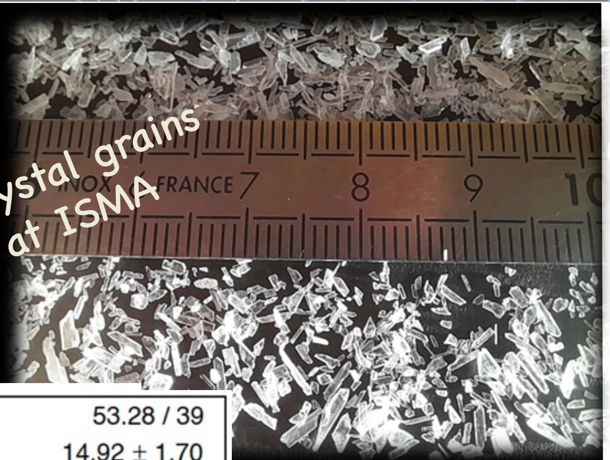
High Z scintillator sub-millimetric inorganic scintillator crystals in a bath of high-density liquid.

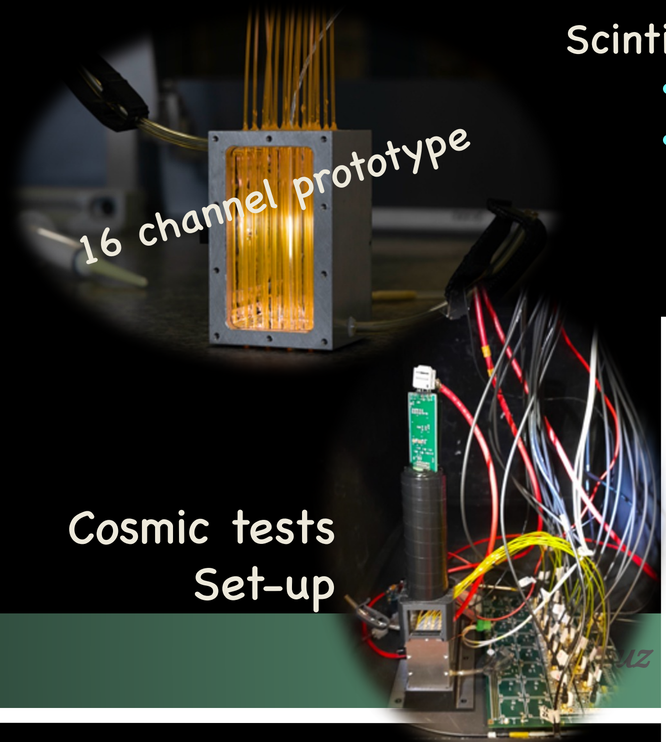
Light collection by WLS fibers, as shaslik



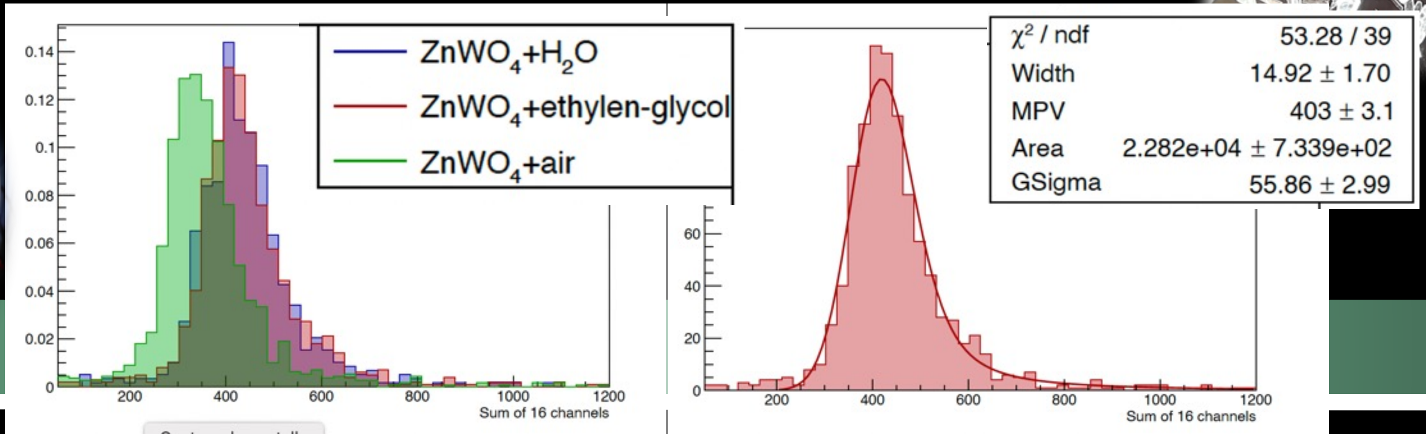
Scintillator candidates:

- ZnW04 grains (spontaneous crystallization method)
- BGO crushed crystals





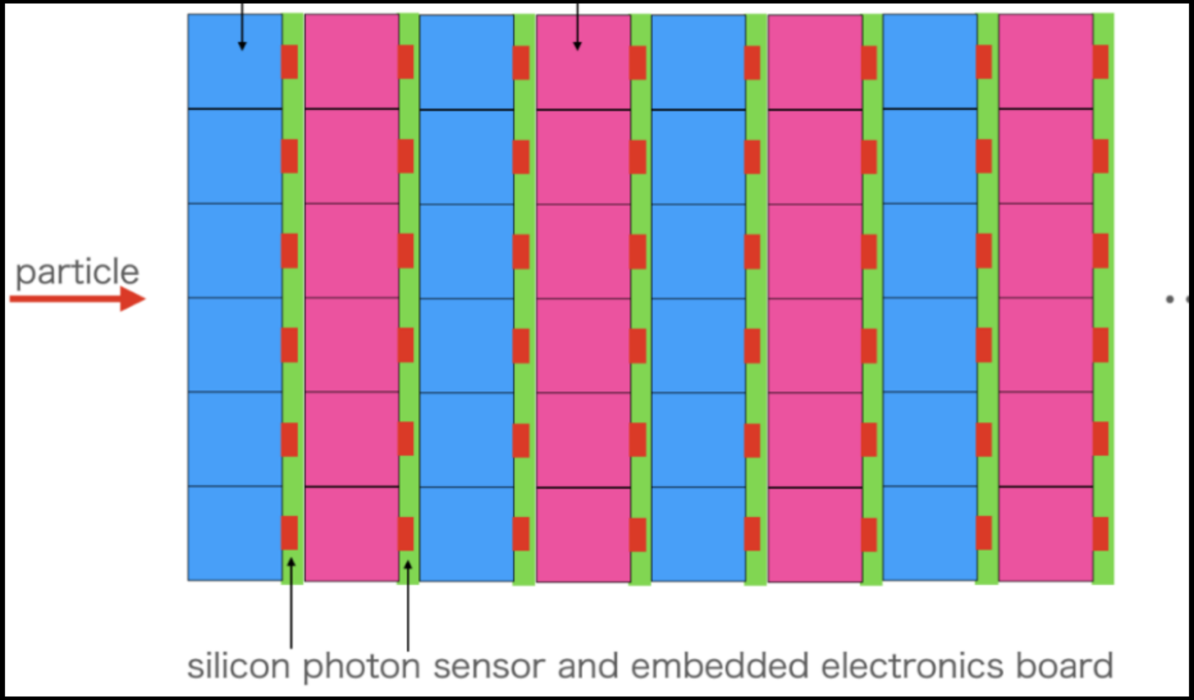
Cosmic tests results – ZnW04 + different liquid



DOUBLE READOUT SANDWICH CALORIMETER

Higgs Factories

Alternating layers of heavy scintillator (e.g. PWO) and Cherekov medium (lead glass)
Readout buy embedded electronic board with SiPMs



Status

Simulations & individual crystal material R&D

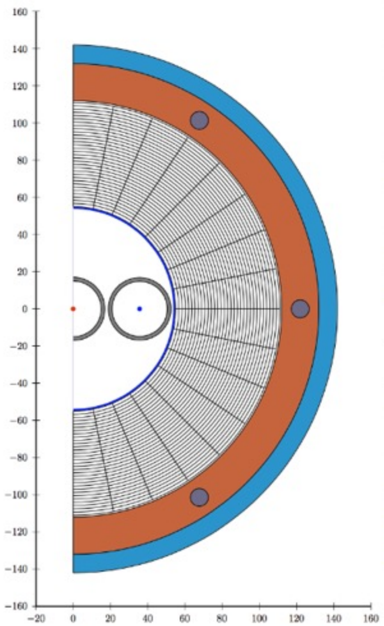
The luminosity monitor

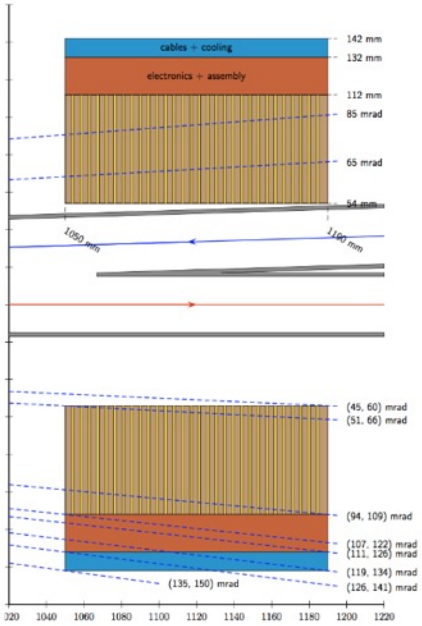
- **Design largely inspired from FCAL study for linear colliders**
  - Same geometry works: "just" make it smaller and closer to the IP
    - Centred around the outgoing beam (measures the outgoing particle deviation)

- Length 10 cm (1.05 to 1.15m)
- Radius from 5.4 to 14.2 cm
- 30 layers ($1X_0$) of 3.5mm W + 1mm Si
- 32 × 32 Si pads in (r,ϕ): 3×10^4 channels
- Mechanical support on FF system

- Total Acceptance: 45-95 mrad
- Loose acceptance: 63-83 mrad
- Tight acceptance: 68-78 mrad
- $\sigma(e^+e^- \rightarrow e^+e^-)$ = 6-13 nb

- **Statistical precision on luminosity:**
  - Few 10^{-5} at the Z pole
  - Few 10^{-4} at the $t\bar{t}$ threshold
- **Positioning of the two front faces with 1μm precision (fixed to the BP)**





Patrick Janot

Séminaire au CPPM
26 Feb 2018

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