THE DRD CALO AND THE FUTURE LEPTON COLLIDER AT CERN

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CIEMAT

Calorimeter Challenges for FCCee

COLLIDER CONDITIONS

> **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
> 10^8 WW pairs vs 8×10^3 W at LEP)
> At Z pole energy : L ~1.8 x 10^{36}/cm$^{2.}$
> physic event rates up to 100 kHz. (pile up of 2×10^{-3})

HIGH PRECISION COLLIDER

DETECTORS CHALLENGE

To achieve systematic uncertainties similar or smaller than the statistical

Systematic control down to ~10^{-5} level
Excellent control of acceptances needed
Luminosity measurements $\sigma(L)/L = 10^{-4}$
(for low angle Bhabha events)

CALORIMETER CHALLENGES

✓ **E.M calorimeter**
resolution < 10 – 15 %/$\sqrt{E}$ (with low constant term) (B physics could need to go down 5 %/$\sqrt{E}$)
Very good transversal **granularity** is required for τ **physics**

✓ **Jet energy resolution** ~30%/$\sqrt{E}$ (~ a factor 2 better than present)

✓ **Beam calorimeter. Precise dimensions:** O(1 μm) on the radial dimensions
O(100 μm) on the distance between the two calorimeters.

✓ **Hermetic coverage**

✓ **Precise Timing** will play an important role everywhere

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

Facing the calorimeter challenges: Jet energy resolution

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 needed (~a factor 2 with respect to the present experiments). 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
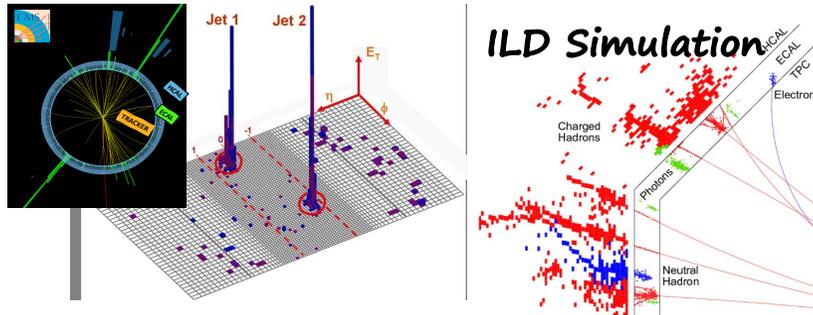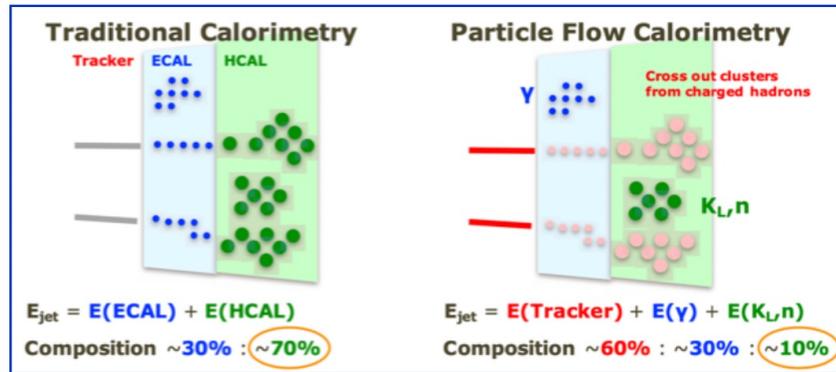

(a)   (b)   (c)
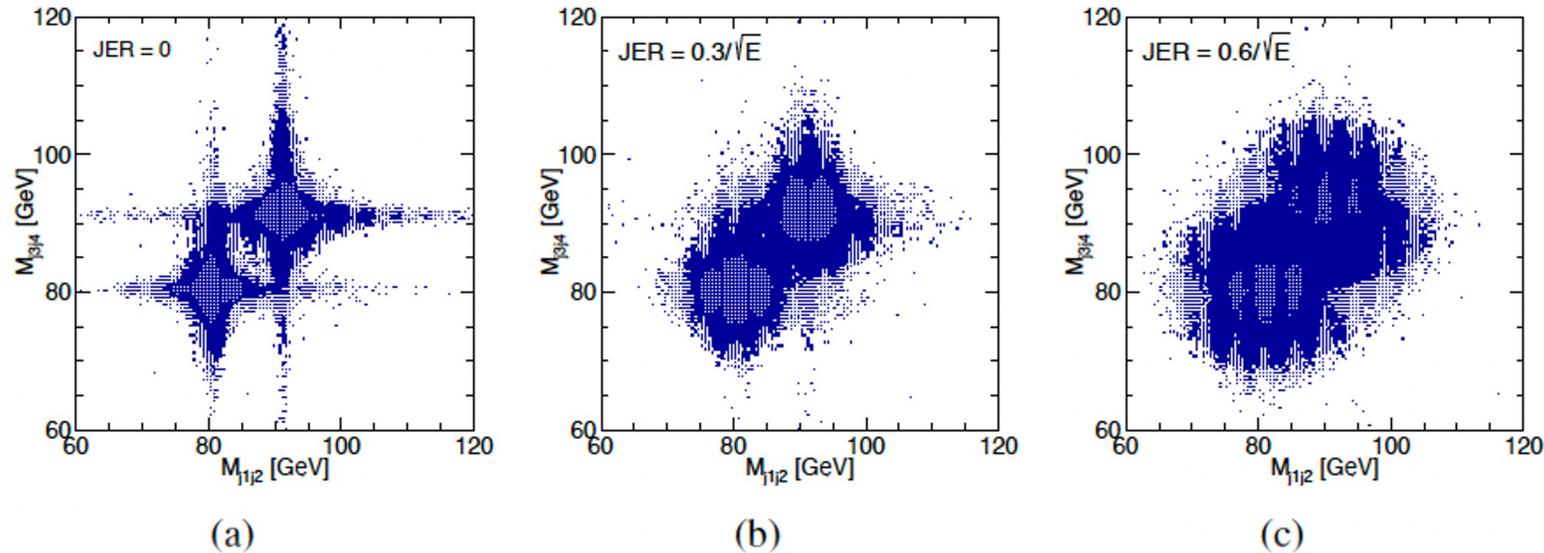
TWO MAIN APPROACHES:

➢ **High granular calorimeters with embedded electronics to apply PFA (Particle Flow Algorithms)**
➢ **Dual Readout Calorimeter**

High Granularity Calorimeters for PFA

PFA - PARTICLE FLOW ALGORITHMS

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

Traditional Calorimetry

Tracker | ECAL | HCAL

$E_{jet} = E(ECAL) + E(HCAL)$

Composition ~30% : ~70%

Particle Flow Calorimetry

γ

Cross out clusters from charged hadrons

K_L, n

$E_{jet} = E(Tracker) + E(\gamma) + E(K_L, n)$

Composition ~60% : ~30% : ~10%

ILD Simulation

Jet 1   Jet 2

HCAL
ECAL
TPC
Electron

Charged Hadrons

Photons

Neutral Hadron

"tracking" calorimeters

Real multi-particle RAW event @test beam

SDHCAL prototype (~1.3m^3)
Readout 1x1cm^2 pads
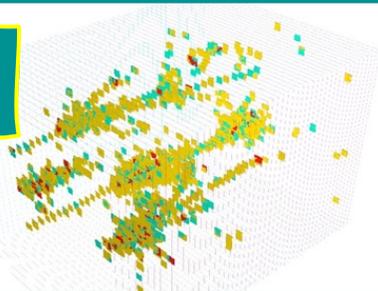
Sampling calorimeters

technologies as active medium under study:

Silicon detectors, scintillators, gaseous detectors

High granularity calorimeter technological challenges

High precision mechanics to minimize dead spaces.

Tolerances over 1x3x1m^3 of <1mm

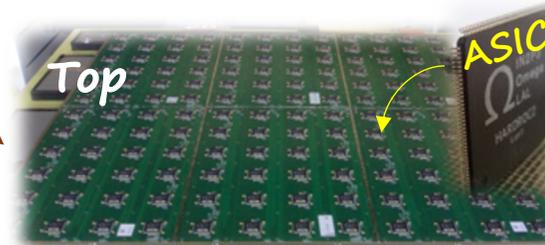**Compact electronics** despite the huge number of channels

Embedded in the calorimeter

Precise timing ~100-200 ps resolution

Low power consumption

5D -CALORIMETER
(E,x,y,z,t)

FE electronics is embedded into the layer structure

Top

ASIC

PCB boards

Bottom

Bottom has the pads/strips
Top has ASIC chips

Dual readout calorimeter concept

REMEMBER

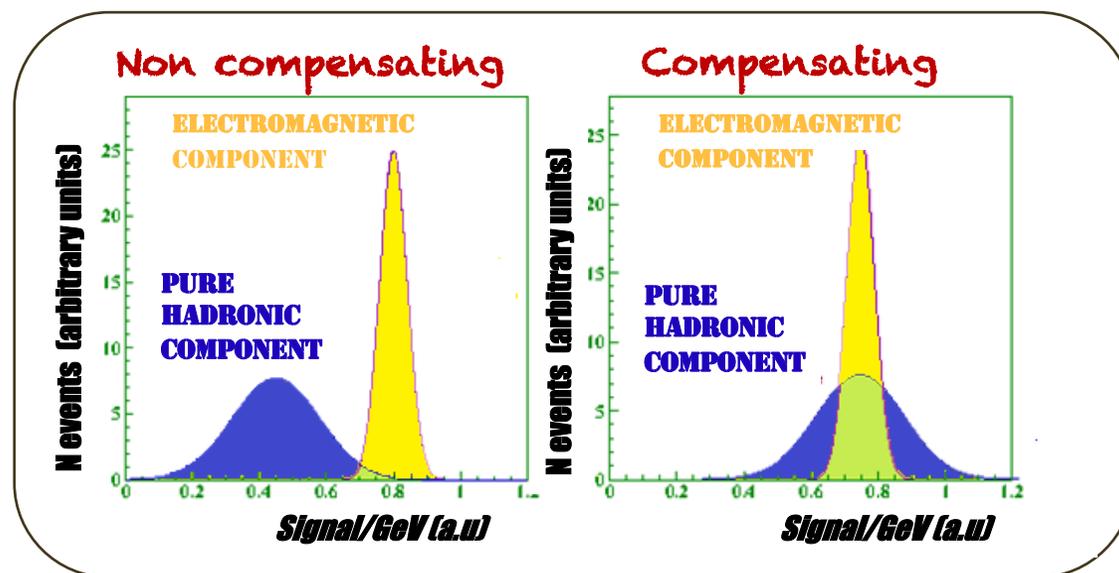in a **hadronic calorimeter** there are two components

$$Signal = S_{em} + S_{had} = e f_{em} E + h f_{had} E$$

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

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

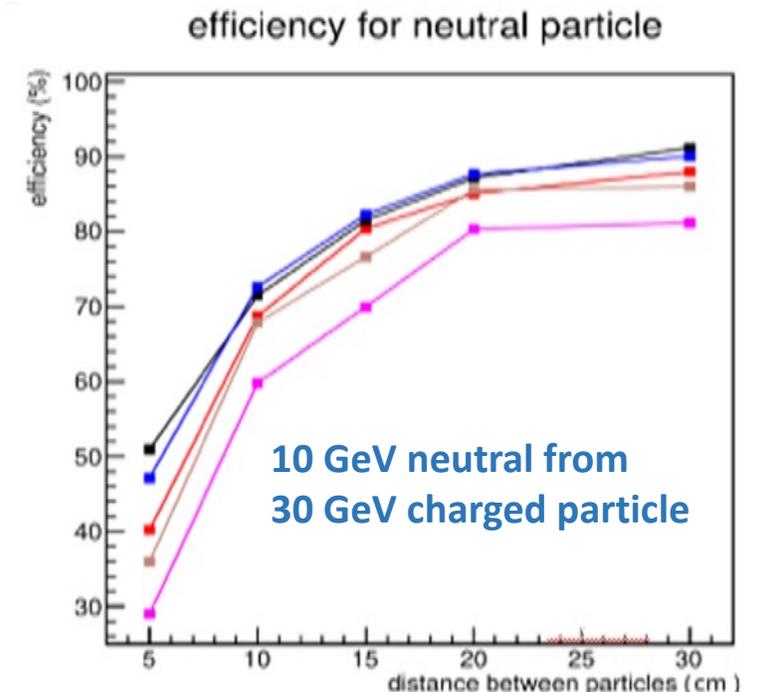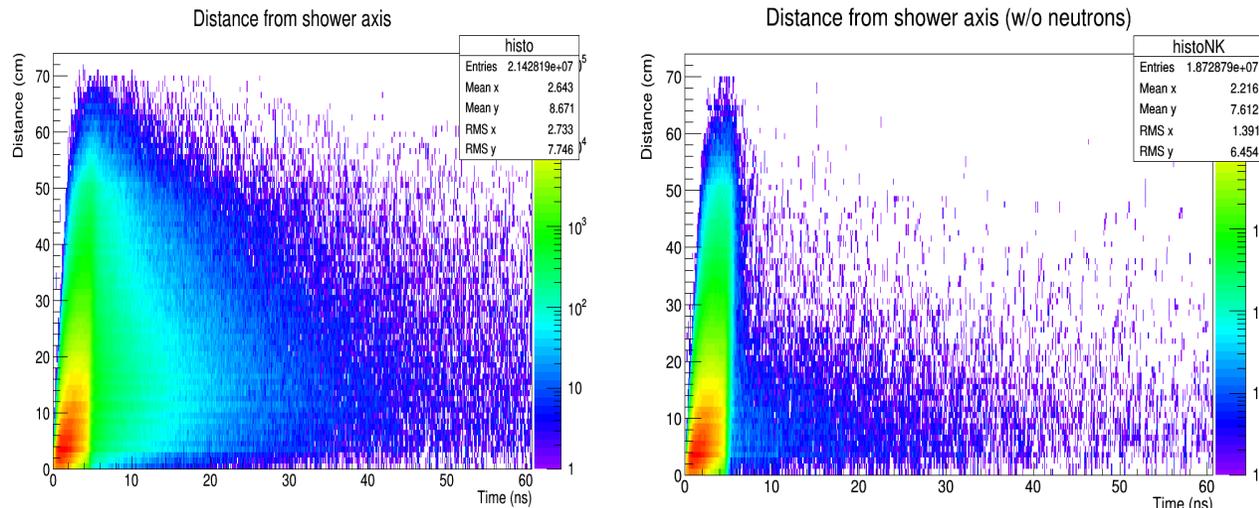A combination of dual-readout + PFA could also be envisaged

What about including also timing – 5D calorimeter

Precise time information has not been a requirement for calorimeters, but it could be very useful for the future.
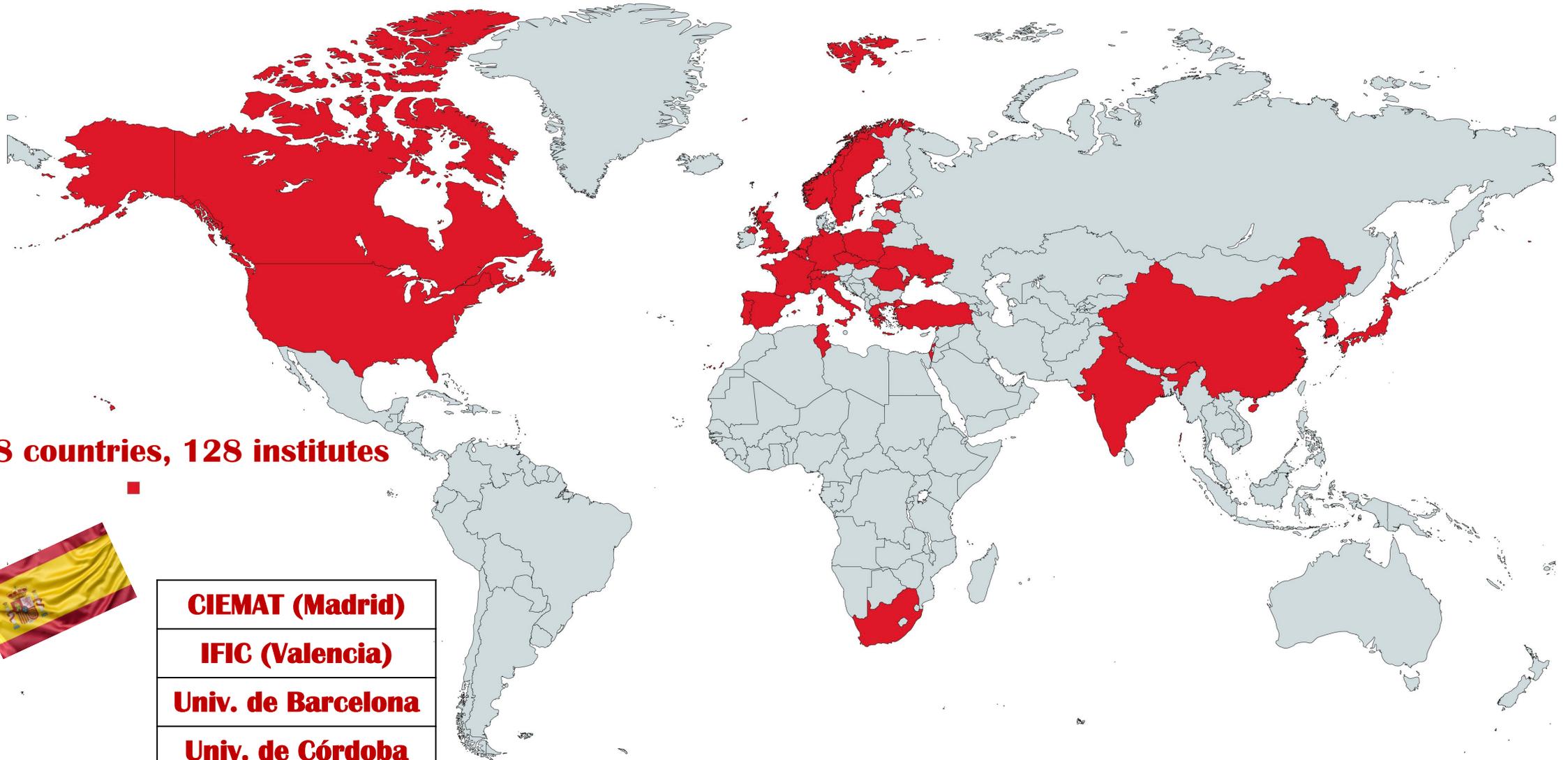
Timing in calorimeters could **mitigate backgrounds/pileup** , be used for **ToF** measurements, or eventually recognize **signatures for neutral long live particles.**

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 **distinguishing 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

Distance from shower axis

histo	
Entries	2.142819e+07
Mean x	2.643
Mean y	8.671
RMS x	2.733
RMS y	7.746

Distance from shower axis (w/o neutrons)

histoNK	
Entries	1.872879e+07
Mean x	2.216
Mean y	7.612
RMS x	1.391
RMS y	6.454

efficiency for neutral particle

10 GeV neutral from 30 GeV charged particle

DRD Calo Collaboration

28 countries, 128 institutes

CIEMAT (Madrid)
IFIC (Valencia)
Univ. de Barcelona
Univ. de Córdoba
Univ. de Oviedo

Created with mapchart.net

DRD Calo structure

MANAGEMENT:

Collaboration Board — Chair: R. Ferrari

Spokesperson — SP: R. Poeschl
Deputies: M.C Fouz & M.A. Pleier

Speaker and Publication Bureau — Chair: W. Ootani

Technical Board — Chair: G. Gaudio

Resource Board — Chair t.b.d

WORK PACKAGES:

WORK PACKAGE 1 — Sandwich calorimeters with fully embedded Electronics
Coordinators: L. Masetti & A. Irles

WORK PACKAGE 2 — Liquified Noble Gas calorimeters
N. Morange

WORK PACKAGE 3 — Optical calorimeters
Hwi Dong Yoo
Deputy: M. Lucchini

WORK PACKAGE 4 — Electronics and DAQ
C. de la Taille

WORKING GROUPS:

Photodetectors — Coordinator: M.Ruzarin

Testbeam Facilities

Detector Physics, Simulation, Algorithm and Software Tools
Coordinators: B. Francois & L. Pezzotti

Industrial Connections and Technological Transfer

Mechanics and Integration

DRD Calo technologies & FCC detector concepts

WORK PACKAGE 1

Sandwich calorimeters with fully embedded Electronics

WORK PACKAGE 2

Liquified Noble Gas calorimeters

WORK PACKAGE 3

Optical calorimeters

Different technologies of Imaging calorimeters optimized for PFA

Sampling ECAL
Noble-liquid calorimeter

Sampling and homogeneous calorimeters based on scintillating materials

11 different projects

Several of these technologies have already been considered for the FCC-ee conceptual detectors

drdcalo

ILD/CLD, DRD Calo WP1, CALICE Examples

Silicon-W ECAL

SiW-ECAL
- **15 layers 18×18 cm²**
- 0.5×0.5 cm² Si cells
- 2.8+5.6 mm W (21 X₀)
- 100 kg, 0.4×0.4×80 cm³
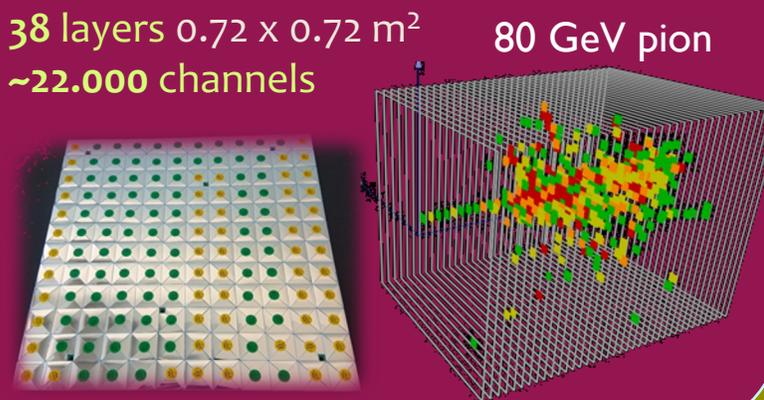- **15k channels**

Embedded electronics

DIF   ASU

18x18cm²

ASIC SKIROC2

Pads on bottom

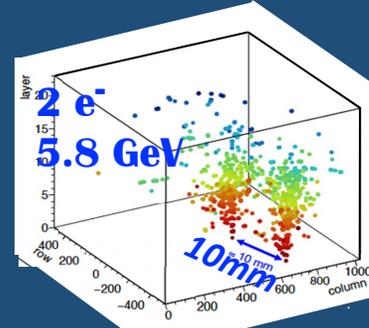**LONG SLAB** ~150cm
7 ASU

ASU = ASIC+PCB+SiWafer
DIF = Detector InterFace:

EPICAL-2 prototype

Active cross section
3×3cm²
0.03×0.03mm² Si–pixels
28 layers
ALPIDE CMOS sensors

2 e-
5.8 GeV
10mm

Scintillator HCAL - AHCAL

Tiles **3x3**x0.3 cm³
38 layers 0.72 x 0.72 m²
~22.000 channels

80 GeV pion

144 channels

SDHCAL – Semidigital HCAL

from SDHCAL to T-SDHCAL

500K Channels

1m³
48-50 GRPC

1m² M-GRPC

Starting to implement precise timing (tens ps) using Multigap Glass RPCs instead of single gap & new electronics with better timing capabilities
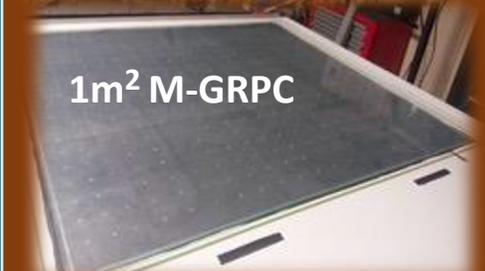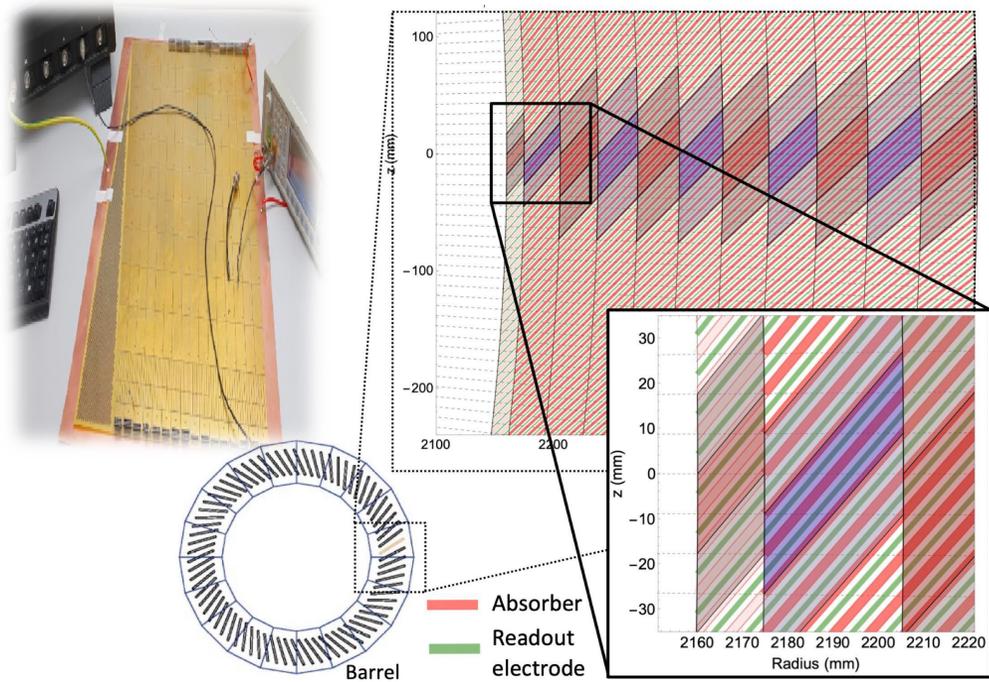
ALLEGRO, DRD Calo WP2 & WP3

ECAL

Based on **LAr** ATLAS **Calorimeter** with
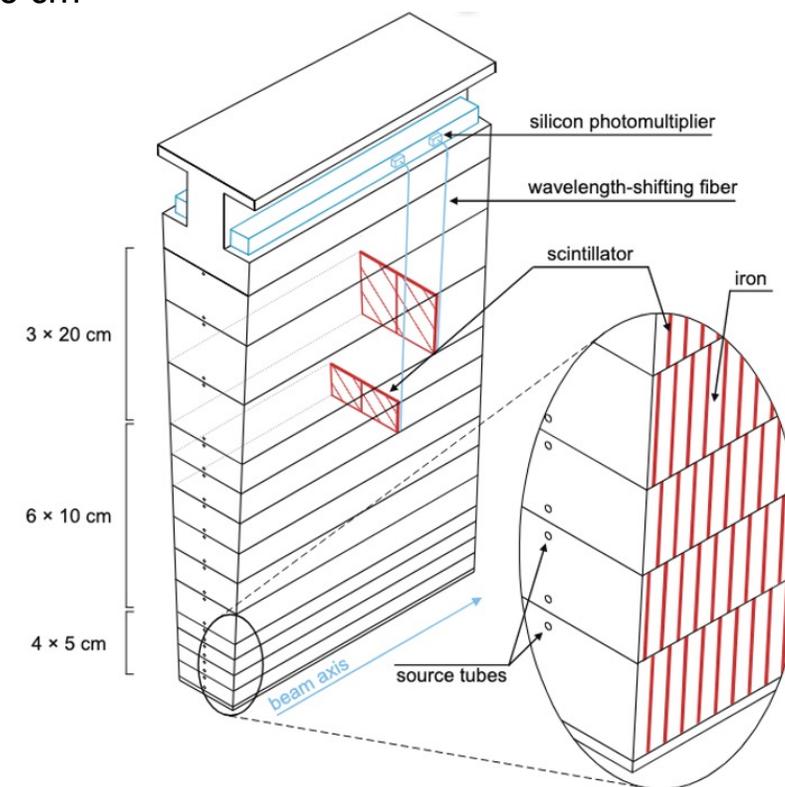10-15 times higher granularity for PFA

Barrel design:
- 1536 straight inclined (50°) absorber plates
- 11 longitudinal layers, 22 X0
- Lightweight carbon fiber cryostat
- Typical cell size: $\theta \times \phi \times r$ ~ $2 \times 1.8 \times 3$ cm3

Absorber
Readout electrode

Barrel

HCAL - TileCAL

Low-carbon steel absorber plates interleaved with plastic scintillating tiles.
The barrel is segmented into 128 modules in φ and 13 radial layers (of different depths: four of 5 cm, six of 10 cm, and three of 20 cm

silicon photomultiplier

wavelength-shifting fiber

scintillator

iron

3×20 cm

6×10 cm

4×5 cm

beam axis

source tubes

# IDEA, DRD Calo WP3

Dual-readout Crystal ECAL

E1, E2: Dense crystals under consideration: PWO, BGO and BSO due to their high density and high Cherenkov yield
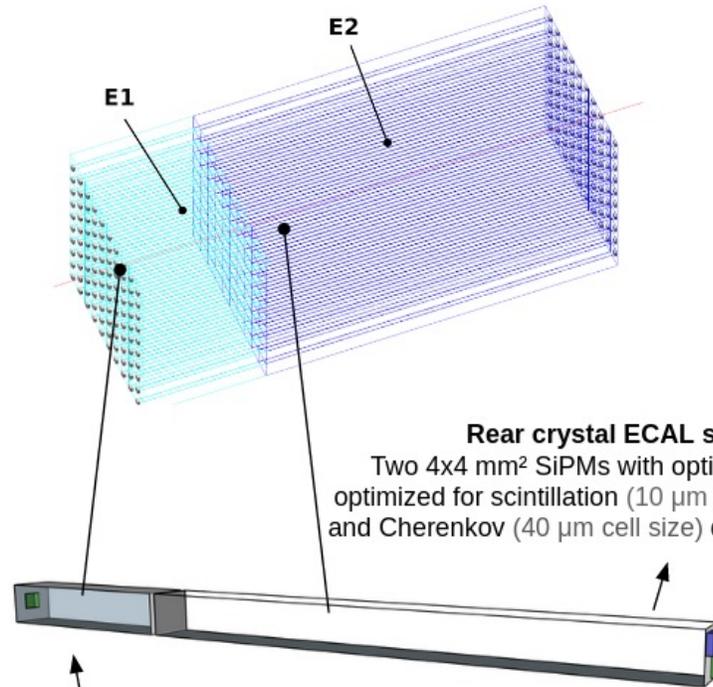
Rear crystal ECAL segment:
Two 4x4 mm² SiPMs with optical filters optimized for scintillation (10 µm cell size) and Cherenkov (40 µm cell size) detection

Front crystal ECAL segment:
Single 5x5 mm² SiPM per crystal optimized for scintillation light detection (10 µm cell size)

Dual-readout Fiber HCAL

ECAL size 10x10x100 cm³
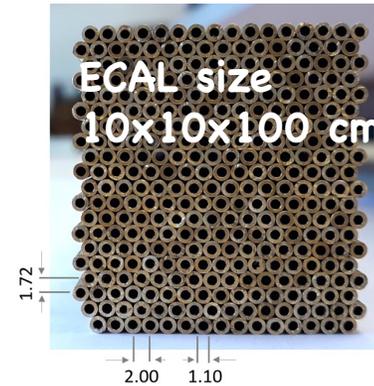
320 brass tubes

ECAL – size Prototype

HCAL minimodule

DRD Calo technologies & FCC detector concepts

WORK PACKAGE 1

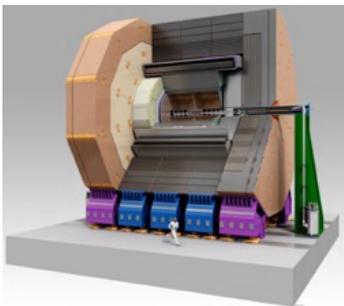Sandwich calorimeters with fully embedded Electronics

WORK PACKAGE 2

Liquified Noble Gas calorimeters

WORK PACKAGE 3

Optical calorimeters

ECAL – W absorber

Silicon pads (**ILD**/**CLD**)
MAPS (**ILD**)
Scintillator strips (**ILD**)

HCAL – Steel absorber

Scintillator tiles (**ILD**/**CLD**)
Gas pads: GRPC/MPGD) (**ILD**)

Full PFA optimization
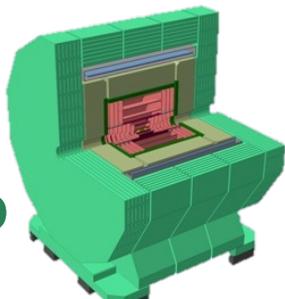
ECAL

Pb (or W) absorber + LAr (**ALLEGRO**)
or, W absorber + LKr (**ALLEGRO**)
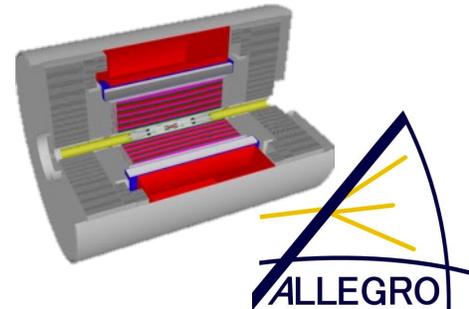
ECAL

MAXICC : Homogeneous crystal calorimeter longitudinally segmented with embedded dual-readout and precise timing capabilities (**IDEA**)

Dual – Readout: (ECAL + HCAL) or HCAL

Brass or Fe absorber + Alternate rows of scintillating and Cherenkov (clear) fibers (**IDEA**)

HCAL – Steel absorber

Plastic scintillating tiles (**ALLEGRO**)

Double readout

IDEA

ILD

ALLEGRO

CLD

drdcalo

Thank you
for your attention

In the road towards new calorimeters for a future Collider