DRD6 Track 3 Proposals

ECFA Detector R&D Roadmap DRD6:
2nd Community Meeting

20/04/2023

Marco Lucchini [1,2], Philipp Roloff [3]
On behalf of the DRD6 input proposal team

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[3] CERN

First comments

- A variety of target experiments with **different physics goals**
- A variety of design flavors with many **common R&D interests**
- Almost **each proposal has some uniqueness**
  - Homogeneous-ness typically chosen to achieve the highest precision
  - Sampling-ness allows to tune the Molière radius and is generally more affordable than homogenous crystals (e.g. for large volumes)
- There are no sharp borders between track 1 and track 3

Apologies for imprecisions and misunderstandings: this is the occasion to fix them!

DRD6 Track 3 proposals

Scintillator based sampling calorimeters

Dual Readout Fiber Calorimeter for Higgs Factories

R&D on Spaghetti (EM) Calorimeter technologies for LHCb Upgrade II, Higgs factories, FCC-hh

Fast-timing, ultracompact, radiation hard, EM calorimetry (*RADiCAL*) for FCC-hh

High sampling fraction EM calorimeter with crystal grains (*GRAiNITA*) for FCC-ee

Scintillating Tile HCAL for FCC-hh, FCC-ee

Homogeneous EM crystal calorimeters

Maximum Information Crystal Calorimeter for Higgs Factories

High Granularity Crystal Calorimeter for Higgs Factories

Fast, segmented Crystal calorimeter for Muon Collider (*CRILIN*)

Homogeneous (EM+HAD) calorimeters

Triple-readout sandwich calorimeter for DM and BSM low energy physics (*ADRIANO3*)

Dual-readout Sandwich Calorimeter for future colliders

Large mass cryogenic calorimeters

Large mass cryogenic calorimeters for neutrinoless double beta decay

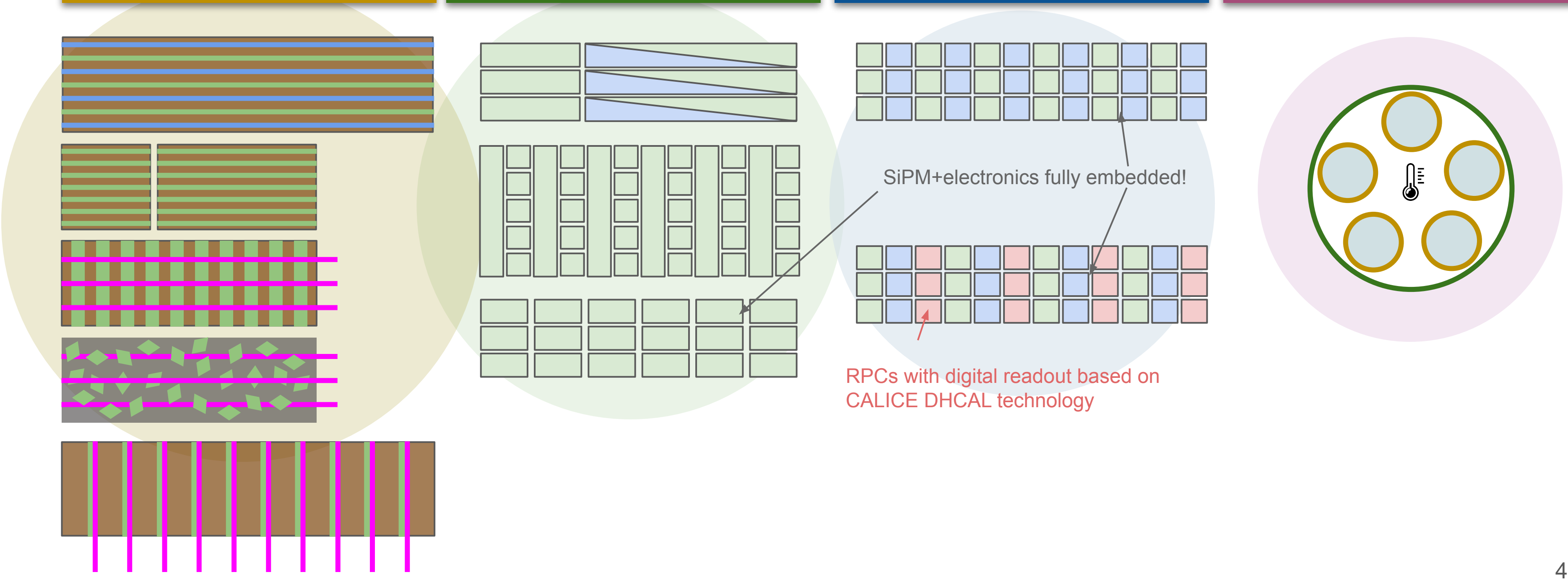
ScintCal: **Scintillator** material for future calorimeters

Common Readout **ASICs** for DRD6 calorimeter prototypes

Spot the differences

Legend
- Scintillation
- Cherenkov
- RPC
- Heat + Light
- WLS fiber

Scintillator based sampling calorimeters	Homogeneous EM crystal calorimeters	Homogeneous (EM+HAD) calorimeters	Large mass cryogenic calorimeters



Which active light emitters?

Scintillator based sampling calorimeters
- GAGG:Ce
- YAG:Ce
- LuAG:Ce
- $ZnWO_4$
- LYSO:Ce
- Plastic scintillators

Homogeneous EM crystal calorimeters
- PWO
- BGO
- BSO
- PbF_2

Homogeneous (EM+HAD) calorimeters
- Heavy glasses
- Plastic scintillator
- PWO

Large mass cryogenic calorimeters
- TeO_2
- ZnSe
- LiMoO
- NaMoO

LuAG:Ce, LYSO:Ce, GAGG:Ce, BGSO, BGO, BSO, PWO, BaF_2:Y, heavy glasses, plastic scintillators

Optimization and customization of active materials, light collection and readout is **common to all proposals**

Who is planning to use **SiPMs?**

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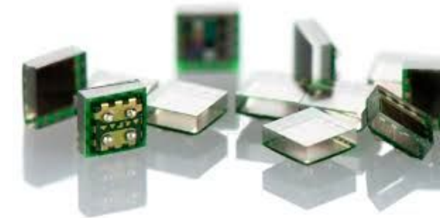
Large mass cryogenic calorimeters for neutrinoless double beta decay

Use cases with moderate radiation environment (e.g. Higgs factories)

Expected radiation levels rather challenging for SiPMs

Who is planning to use **SiPMs?**



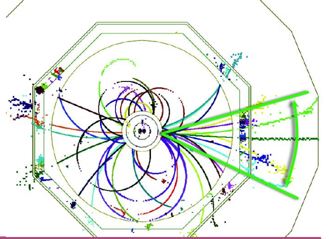
Scintillator based sampling calorimeters	**Homogeneous EM crystal calorimeters**	**Homogeneous (EM+HAD) calorimeters**	**Large mass cryogenic calorimeters**
Dual Readout Fiber Calorimeter for Higgs Factories	Maximum Information Crystal Calorimeter for Higgs Factories	Triple-readout sandwich calorimeter for DM and B low energy physics (*ADRIANO3*)	Large mass cryogenic calorimeters for neutrinoless double beta decay
R&D on Spaghetti (EM) Calorimeter technologies for LHCb Upgrade II, Higgs factories, FCC-hh	High Granularity Crystal Calorimeter for Higgs Factori	Dual-readout Sandwich Calorimeter for future colliders	
Fast-timing, ultracompact, radiation hard, EM calorimetry (*RADiCAL*) for FCC-hh	Fast, segmented Crystal calorimeter for Muon Colli (*CRILIN*)		
High sampling fraction EM calorimeter with crystal grains (*GRAiNITA*) for FCC-ee			

There is no proposal targeting **SiPM R&D specifically for calorimeters!** ← Only in **DRD4**

ScintCal: **Scintillator** material for future calorimeters ← Partly in **DRD4/5**

Common Readout **ASICs** for DRD6 calorimeter prototypes ← Also in **DRD7**

Who envisions a **particle flow approach?**



Scintillator based sampling calorimeters

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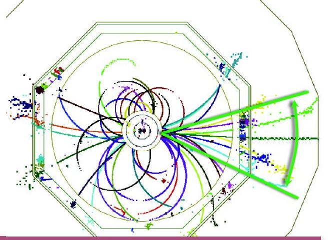

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Large mass cryogenic calorimeters for neutrinoless double beta decay

Need a dedicated activity within a *transversal working group* on simulation tools?

Who aims at **precision timing** (10-100 ps)?

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Large mass cryogenic
calorimeters
for neutrinoless double
beta decay

Improving timing by at least a order of magnitude appears as a transversal trend

Peculiarities of each proposal

Prototypes of dual readout calorimeter

Detector concept: Dual-readout calorimetry

Target application: Future Higgs factory (needs excellent hadronic energy resolution, good electromagnetic energy resolution)

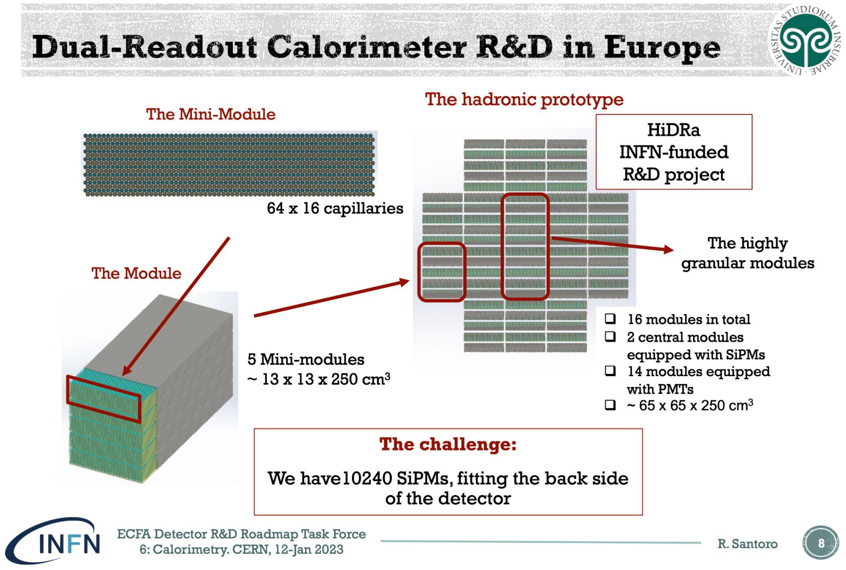
Unique challenges: separation of scintillation and Cherenkov signals, integration of a large number of SiPMs

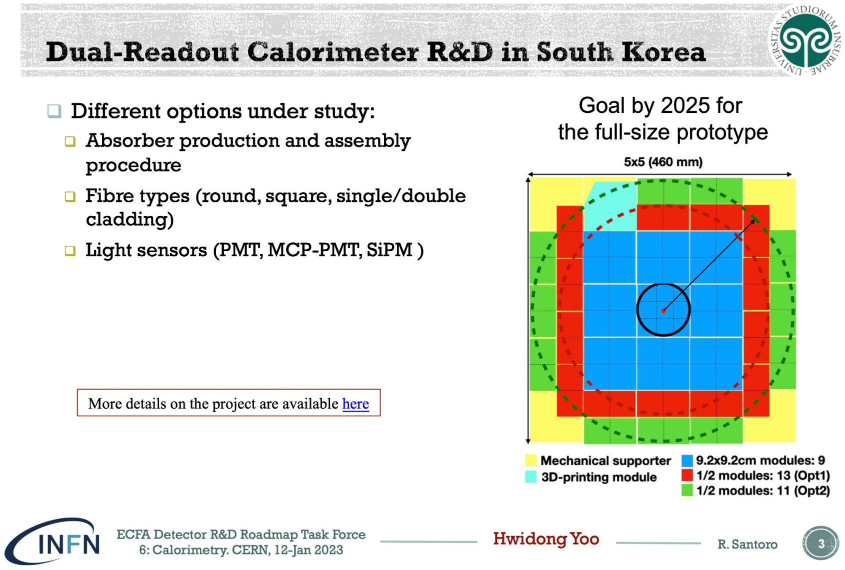
Technology: Organic scintillating fibres in brass or steel absorber, SiPM or MCP-PMT photon detectors

Next 3+ year goals: test beam with full containment prototype modules, development of readout system

*University of Bologna and INFN Bologna (**Italy**)*
*University of Insubria and INFN Milano (**Italy**)*
*INFN Pavia (**Italy**)*
*INFN Pisa (**Italy**)*
*Sapienza University and INFN Roma (**Italy**)*
*University of Sussex (**UK**)*
*Texas Tech University (**US**)*
*Korea Consortium: Yonsei University, Kyungpook National University, University of Seoul, Gangneung-Wonju National University, Pusan University, Sungkyunkwan University, Korea University, Hanyang University (**Korea**)*

Prototypes of dual readout calorimeter





R&D on picosecond SpaCal technology

Detector concept: SpaCal (ECAL made of scintillating fibres in dense absorbers) with O(10-20) ps time resolution

Target application: EM calorimetry for LHCb Upgrade II, Higgs factories, FCC-hh, fixed-target experiments at the intensity frontier

Unique challenges: Radiation-hard (and radiation-tolerant) scintillating fibres

Technology: Crystal or organic fibres in lead or tungsten absorber, hollow light guides, PMT/SiPM photon detectors, SPIDER ASIC for timing

Next 3+ year goals: provide all individual components (e.g. absorbers, light guides, scintillating fibres, photon detectors, electronics) for module-size prototypes with lead and tungsten absorber, refinement and validation of simulation software

*CERN (**Switzerland**)*

*Institute of Physics of the Czech Academy of Sciences (**Czech Republic**)*

*University of Barcelona - IFIC Valencia (**Spain**)*

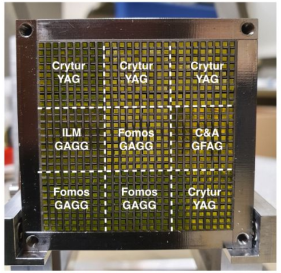
*University of Milano-Bicocca (**Italy**)*

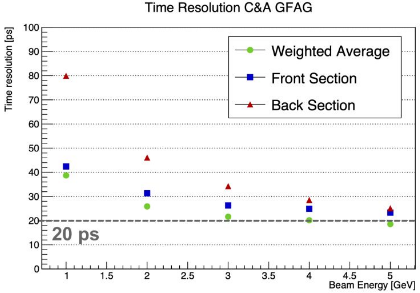
*IN2P3: IJCLab Orsay, LPC Clermont-Ferrand, LPC Caen, IP2I Lyon (**France**)*

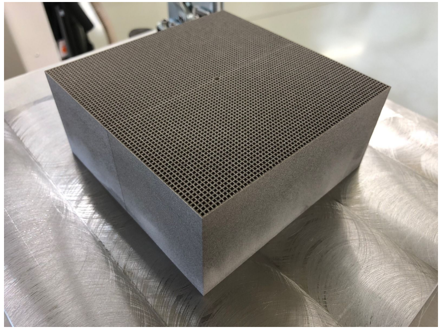
R&D on picosecond SpaCal technology

Better than 20 ps time resolution achieved with 3x3 cell prototypes

Example: SpaCal with crystal fibres and tungsten absorber



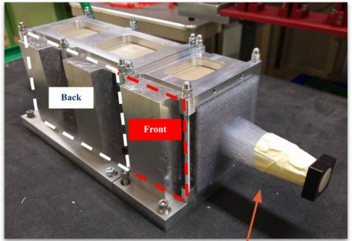




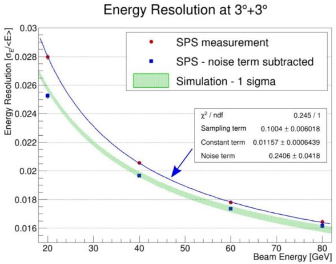
3D-printed tungsten

NIM A 1045, 167629 (2022)

Example: SpaCal with polystyrene fibres and lead absorber

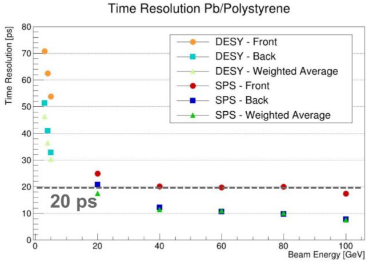


Fibres bundle (1 cell)

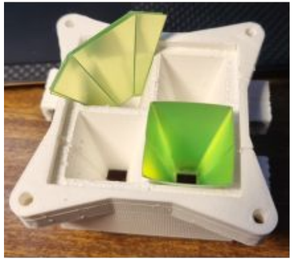


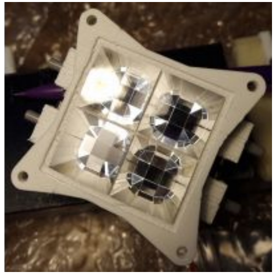
Sampling term: (10.0 ± 0.6)%

Constant term: (1.2 ± 0.1)%



Time resolution below 30 ps for energies above 10 GeV





Hollow light guides

Fast-timing, ultracompact, radiation hard, EM calorimetry (RADiCAL)

Detector concept: Radiation-hard EM calorimeter with 10%/√E energy resolution and 25 ps timing resolution

Target application: FCC-hh

Unique challenges: Radiation-hard WLS filament and SiPM

Technology: Shashlik/type ECAL modules with tungsten absorber and LYSO:Ce tiles, WLS (full-length or in shower maximum), SiPM readout

Next 3+ year goals: Test beams with a 3x3 array for energy, timing and position resolution, design to serve as test bed for new materials

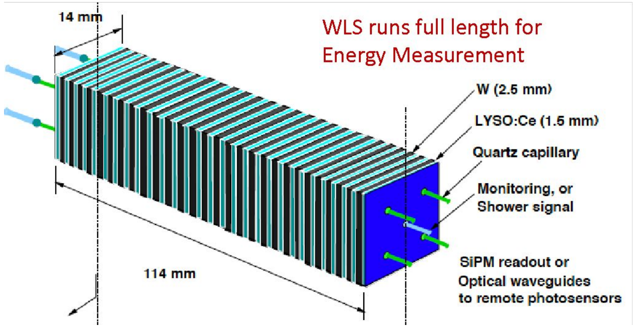
*University of Notre Dame (**USA**)*

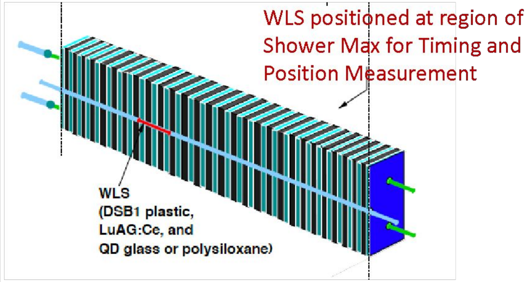
*University of Iowa (**USA**)*

*University of Virginia (**USA**)*

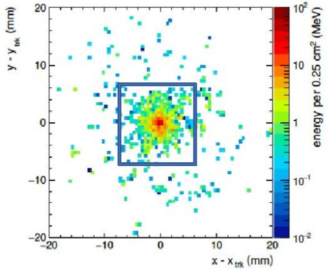
*Caltech (**USA**)*

Fast-timing, ultracompact, radiation hard, EM calorimetry (RADiCAL)

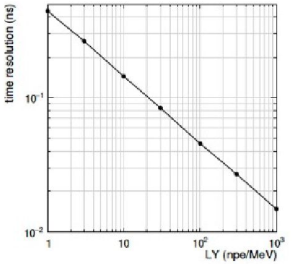




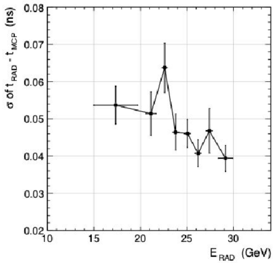
Prototype RADiCAL modules



GEANT4 simulation of an EM Shower Profile for a 50 GeV electron at Shower Max. Module cross section of 14 x 14 mm^2 is indicated.



GEANT4 simulation of time resolution vs detected light yield



Time resolution of a RADiCAL Module compared to a trigger MCP tube as a function of detected energy in the RADiCAL module - 28 GeV electron beam.

Simulated and measured time resolutions

GRAiNITA

Detector concept: Scintillating grains in transparent liquid to reach better energy resolution than in traditional Shashlik approach

Target application: EM calorimetry for Higgs factories with excellent energy resolution (2%/√E)

Unique challenges: Production of scintillator grains

Technology: Sub-millimetric (0.5 - 1 mm) inorganic scintillator crystals in bath of high-density liquid, light collection by WLS fibres

Next 3+ year goals: scintillator characterisation, MC simulation, cosmic test bench, development of a medium-size prototype (2.8 x 2.8 x 6 cm^3), full-size prototype beyond 2024 if concept proves effective

*IJCLab (**France**)*

*Laboratoire de Physique Clermont - LPC (**France**)*

*Institute of Scintillation Materials of the National Academy of Sciences of Ukraine - ISMA (**Ukraine**)*

GRAiNITA

The overall idea (in a nutshell)

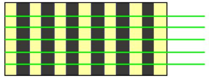
Inspired by LiquidO technique for neutrino detector
(A. Cabrera et al. LiquidO Commun Phys 4, 273 (2021))

Typical sampling calorimeters:
$\frac{\sigma_E}{E} \sim \frac{10\%-15\%}{\sqrt{E}}$

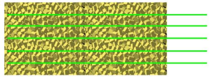
Crystal calorimeters :
$\frac{\sigma_E}{E} \sim \frac{1\%-2\%}{\sqrt{E}}$

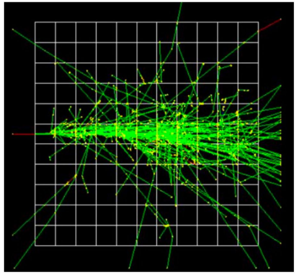
Requirements:
- fine sampling
- scintillation light locally contained

Shashlyk-type calorimeter



GRAiNITA





GEANT4 simulation
ZnWO4 + CH2I2 cubes
(random position)

1mm cubes $\frac{\sigma_E}{E} \sim \frac{2\%}{\sqrt{E}}$

2

Towards a 16 fibers test bench

- Active volume = 2.8 x 2.8 x 6 cm^3 (~200 g of $ZnWO_4$)
- Fibers spacing: 7 mm
- 16 fibers read-out by SiPM
- Possibility to repeat the study with the well known BGO

- Blue/Green LED injected in the middle (& UV LED with a quartz fiber ?)
- Cosmic rays triggering

time

What will we learn ?
- Number of photo-electrons by MeV on the SiPM (need 2.5k to 10k per GeV to reach 1 to 2 % energy resolution)
- Study the uniformity of response (μ close to a fiber or half-way)
- Study the angular dependence of response

4

M.-H. Schune, FCC Detector Concepts meeting, 04/04/2023

Scintillating Tile HCAL for future colliders with TileCal like geometry and SiPM photodetectors

Detector concept: Hadron calorimeter with scintillating tiles and WLS fibre readout

Target application: FCC-hh and FCC-ee

Unique challenges: Cost-effective production of tiles, radiation hardness for FCC-hh

Technology: Organic scintillating tiles, Steel (+Pb for FCC-hh) absorber, readout by WLS fibres and SiPMs

Next 3+ year goals: Performance studies using simulations, R&D on PEN and PET scintillator, mechanical design and construction of test-beam modules

*CERN (**Switzerland**)*

*LIP (**Portugal**)*

*FZU (**Czech Republic**)*

*Universitetet I Bergen (**Norway**)*

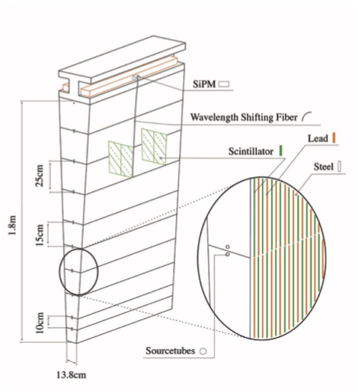
*IFIC - Valencia University (**Spain**)*

*INCDTIM (**Romania**)*

*Charles University (**Czech Republic**)*

Scintillating Tile HCAL for future colliders with TileCal like geometry and SiPM photodetectors

A design for FCC-hh central calorimeter system



Specs:
5mm steel absorber plates,
alternating with 3mm Scint. and 4mm Pb tiles
128 modules in Φ, 2 tile/module
10 layers
$\Delta\eta=0.025$ (grouping 3-4 tiles), $\Delta\Phi=0.025$

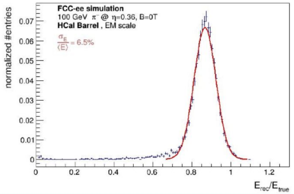
- 4 times the tile density of ATLAS, 1 tile 1 channel.
- SiPM readout at outer radius (~10^{11} neq)
- Ongoing R&D on scintillator material and SiPMs (8kGy requirement).

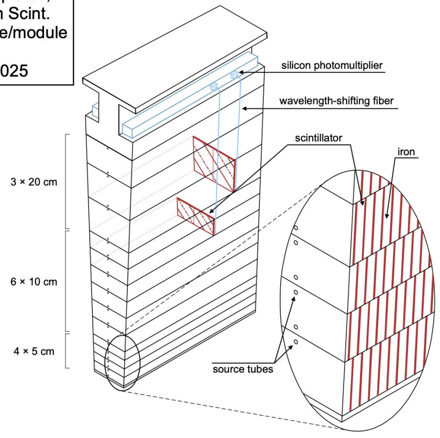
Mechanical structure feasible.
Started testing Sci tile+WLS fibre+SiPM

A design for FCC-ee central calorimeter system

Specs:
5mm steel absorber plates,
alternating with 3mm Scint.
128 modules in Φ, 2 tile/module
13 layers
$\Delta\eta=0.025$, $\Delta\Phi=0.025$

- Removed the Pb plates compared to FCC-hh design (HCAL acts as return yoke for the central solenoid)
- 13 layer in depth.
- work on optimisation of segmentation and reconstruction starting.





Maximum information homogeneous calorimetry for lepton colliders using moderately-segmented crystals with dual-readout

Detector concept: Homogeneous EM calorimeter based on segmented crystals with dual-readout for cost-effective integration with dual-readout HCAL

Target application: Future Higgs factories (mainly e^+e^- colliders)

Unique challenges: Simultaneous readout of scintillation and cherenkov light signals from the same active element (heavy inorganic scintillator)

Technology: High density scintillating crystals with good cherenkov yield instrumented with dedicated optical filters and SiPMs

Next 3+ year goals: Identification of optimal crystal, optical filters and SiPM candidates and development of EM scale prototype for beam test

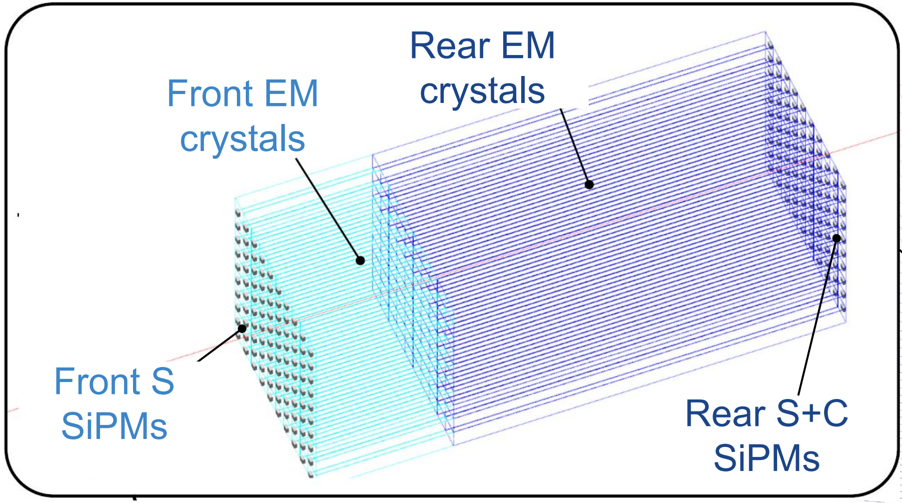
*University of Maryland (**USA**), University of Michigan (**USA**), University of Virginia (**USA**), Princeton University (**USA**), Caltech (**USA**), FNAL (**USA**), Argonne National Lab (**USA**), MIT (**USA**), Purdue University (**USA**), Texas Tech University (**USA**)*

*CERN (**Switzerland**)*

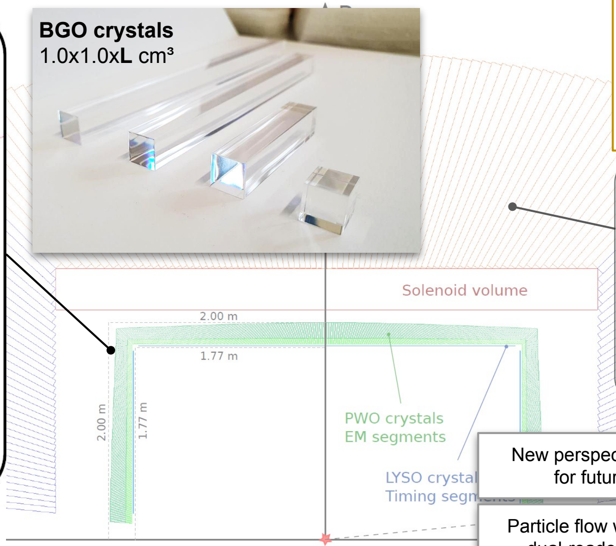
*INFN and University of Milano-Bicocca (**Italy**), University of Napoli (**Italy**)*

Maximum information homogeneous calorimetry for lepton colliders using moderately-segmented crystals with dual-readout

- Moderate longitudinal segmentation for **cost-effectiveness and easy integration**
- Synergies within **Calvision**, **IDEA** and CERN **Crystal Clear** collaborations
  - Proof-of-concept with lab measurements and prototypes (PWO, BGO, BSO, … with SiPMs)
  - Ongoing simulation effort in DD4HEP and FCC software + DR-PFA developments



Scintillating crystal candidates (PWO/BGO/BSO/PbF2)

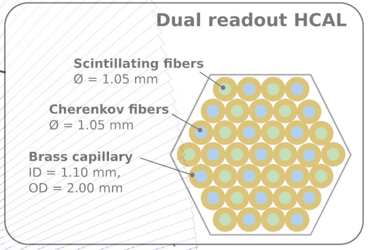


Hybrid DRO crystal calorimeter

σ_E/E (**EM**) ~ **3%/√E**

σ_E/E (**HAD**) ~ 30%/√E

Jet resolution ~ 30%/√E



New perspectives on segmented crystal calorimeters for future colliders, 2020 *JINST* **15** P11005

Particle flow with a hybrid segmented crystal and fiber dual-readout calorimeter, 2022 *JINST* **17** P06008

Highly Granular Crystal Calorimeter

Detector concept: Highly granular EM crystal based calorimeter to exploit maximum potential of PFA algorithms

Target application: Future Higgs factories (mainly e^+e^- colliders)

Unique challenges: Integration (readout, minimize gaps, material budget), reconstruction driven by grid layout

Technology: High density scintillating crystals with double-ended SiPM readout

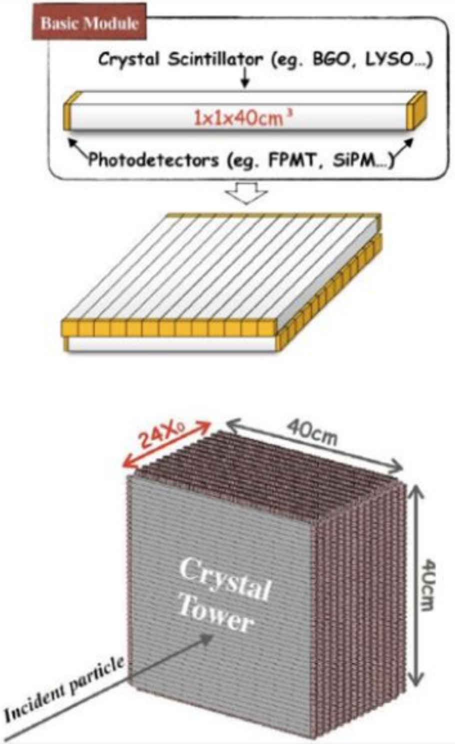
Next 3+ year goals: Comprehensive feasibility study: single particle and jet performance with PFA, **mechanical** designs and integration, crystal-SiPM readout and front-end electronics optimization, EM prototype and beam tests

*Institute of High Energy Physics (IHEP) (**China**)*

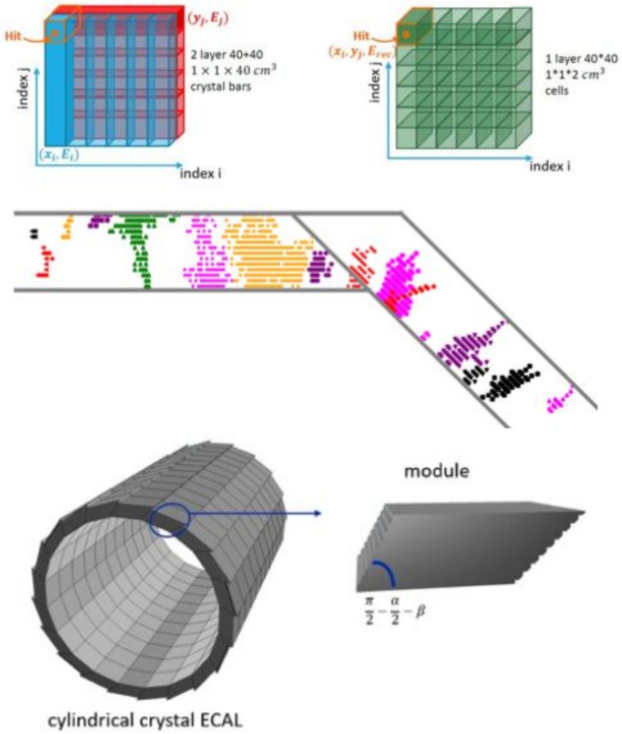
*Shanghai Jiao Tong University (SJTU) and Tsung-Dao Lee Institute (TDLI) (**China**)*

*The Shanghai Institute of Ceramics of the Chinese Academy of Sciences (SICCAS) **(China)***

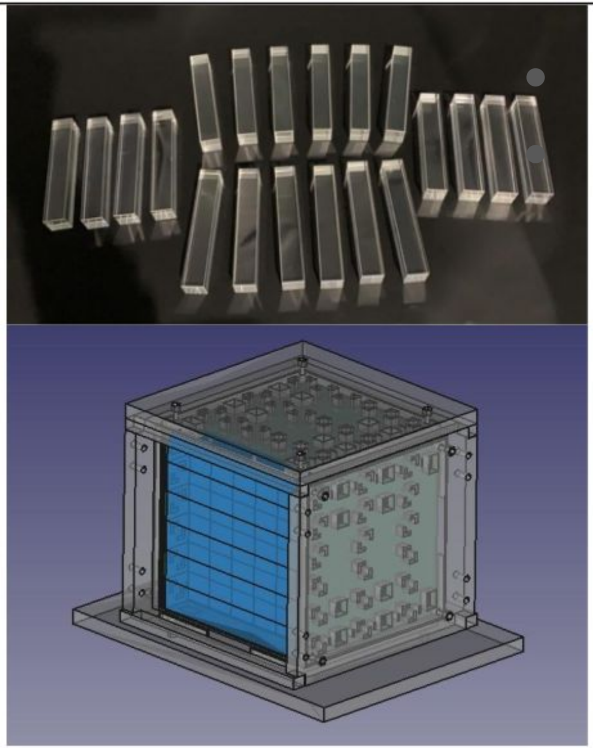
Highly Granular Crystal Calorimeter



EM calorimeter module: a grid of ~1x1x40cm³ crystal bars



Advanced simulation and reconstruction studies with PFA



Hardware developments on crystals, SiPMs, prototypes

Baselineco

Development and test of an innovative semi-homogeneous calorimeter for a future Muon Collider

Detector concept: Cost effective and radiation tolerant design of a longitudinally segmented crystal EM calorimeter (10%/√E) for mitigation of beam induced background at muon colliders.

Target application: Muon collider.

Unique challenges: Very harsh radiation environment for SiPMs, high rate of operation, large beam induced background (BIB)

Technology: Lead fluoride (PbF_2) crystals, each readout with 2 channels consisting of a pairs of SiPMs connected in series

Next 3+ year goals: Construction of EM prototype and operational test (with cooling, etc.), detailed validation of simulation with beam tests

*INFN - Sezione di Trieste (**Italy**)*

*Helmholtz-Zentrum Dresden-Rossendorf (**Germany**)*

*INFN - Sezione di Torino (**Italy**)*

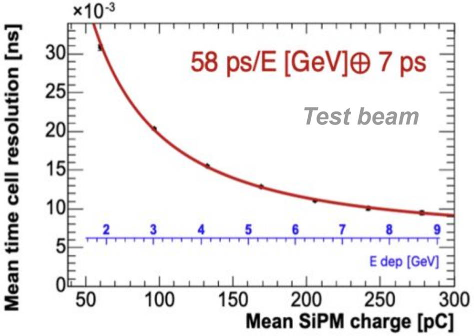
*INFN - Laboratori Nazionali di Frascati (**Italy**)*

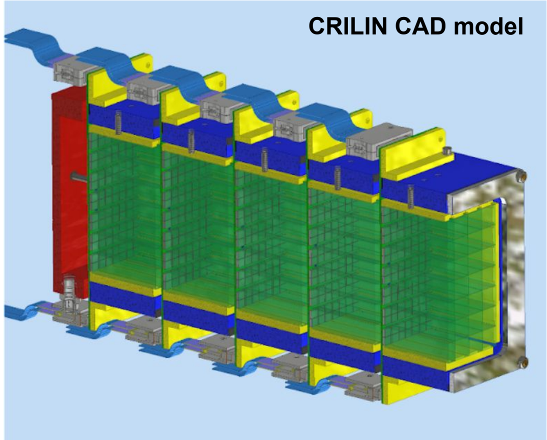
*INFN - Sezione di Padova (**Italy**)*

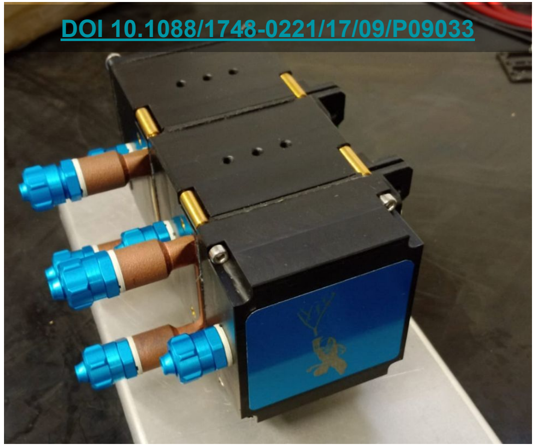
*Donostia International Physics Center (**Spain**)*

Development and test of an innovative semi-homogeneous calorimeter for a future Muon Collider

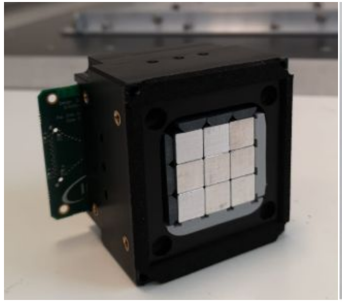
- **Timing and longitudinal segmentation** to tackle the beam induced background (BIB)
- **Advanced** R&D and **prototyping**
    - 5 layers: 1x1x4 cm³ **PbF_2** crystals with 3x3 mm² UV extended 10µm SiPMs
- Synergies with other collaborations (AIDAinnova, HIKE, …)

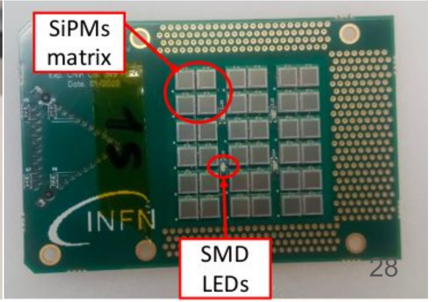






Modular architecture based on stackable modules





Development of a New type of sandwich calorimeter named Double read out Sandwich Calorimeter (DSC)

Detector concept: Sandwich homogeneous EM+HAD calorimeter with dual-readout

Target application: Higher-energy physics experiments in the future…

Unique challenges: Targeting instrumentation of large volumes with embedded electronics and many channels

Technology: Lead glass and PWO crystals for cherenkov and scintillation signals respectively, SiPM readout, embedded electronics

Next 3+ year goals: Optimization of Cherenkov signal readout and construction of few layers prototypes

*Shinshu University (**Japan**)*

ADRIANO3: a highly granular, triple-readout calorimetric technique

Detector concept: Triple-readout (S,C, neutral component) fully active calorimeter for MeV-GeV energy physics (smaller than HEP calorimeters)

Target application: REDTOP: η-meson factory for Dark Matter and Beyond the Standard Model (BSM) physics in the MeV-GeV energy range

Unique challenges: Integration of 3 different active materials with fully embedded electronics, high precision at low energy

Technology: Heavy glass tiles, plastic scintillator tiles and Resistive Plate Chambers (RPCs, insensitive to neutrons)

Next 3+ year goals: Small scale test layers, small scale prototypes, large scale prototype validated with beam test

*FNAL (**USA**), Argonne National Lab (**USA**), University of Iowa (**USA**), Fairfield University (**USA**), Northern Illinois University (**USA**)*

*Beykent University (**Turkey**)*

*International Center for Elementary Particle Physics (ICEPP), The University of Tokyo (**Japan**)*

*Shinshu University (**Japan**)*

Cryogenic DBD Calorimeters

Detector concept: Large mass cryogenic calorimeters operated in a double read-out configuration (heat+light)

Target application: search for Neutrinoless Double Beta Decay (0ν-DBD) in a multi-isotope approach and zero background condition

Unique challenges: whole system operated in vacuum at 10 mK, radiopurity of materials, quantum detectors (**synergies with DRD5?**)

Technology: 1-2 kg crystals with embedded DBD isotopes, Single-Photon Light Detector (LD) + heat quantum sensor (TES,KID) +veto system with plastic scintillators

Next 3+ year goals: proof-of-principle, material selection, optimization

*INFN and University of Milano-Bicocca (**Italy**)*

*Università la Sapienza, Roma (**Italy**)*

*Laboratori del Gran Sasso, LNGS (**Italy**)*

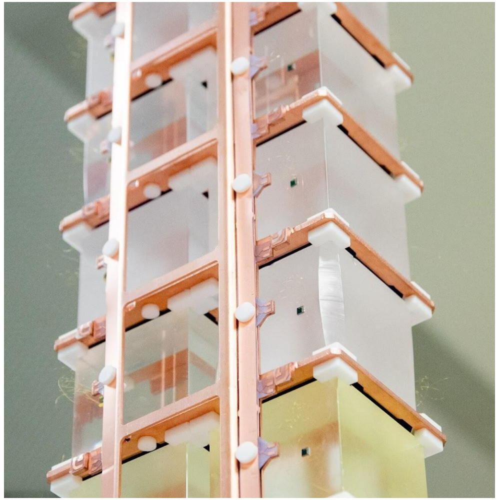
*Laboratori Nazionali di Legnaro, LNL (**Italy**)*

*IRFU, CEA, Université Paris-Saclay (**France**)*

*Université Paris-Saclay, CNRS/IN2P3, IJCLab (**France**)*

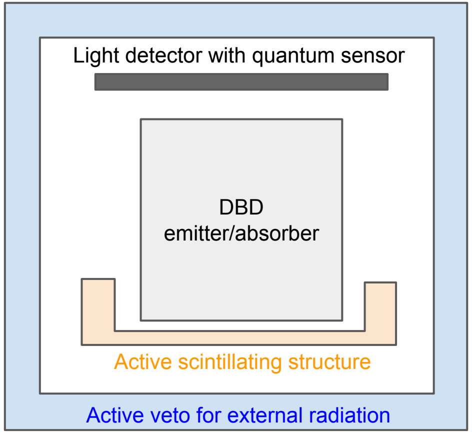
Cryogenic DBD Calorimeters

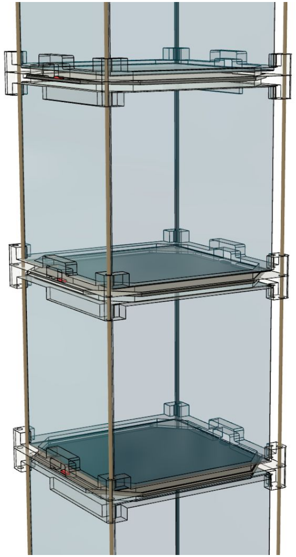
Next generation (CUPID):



- Reduced passive materials in the structure (copper)
- Heat readout with conventional thermal sensors
- Light readout with improved conventional thermal sensors
- Isotope choice based on high Q-value to reduce gamma background from environment

Next-to-next generation (beyond CUPID):





- Replace passive materials with scintillating structures (plastic scintillators)
- Heat readout with quantum sensors
- Improved light collection with crystal coating
- Light readout with quantum sensors and discrimination between crystal and structure scintillation (scintillation time and/or wavelength)
- New cryogenic infrastructure with active veto for multi-isotope setup

*Scintillator material for future calorimeter (**ScintCal**)*

Detector concept: R&D on various scintillators and wavelength shifters

Target application: Homogenous and sampling calorimeters for HL-LHC, FCC-hh, Higgs factories

Unique challenges: Optimisation of materials (e.g. for radiation hardness, decay time, collection of Cherenkov light, mass production)

Technology: Inorganic and organic scintillators, glasses, ceramics, quantum materials

Next 3+ year goals: Clear overview of the state-of-the-art materials and propose scintillators with mass scale production capability for future collider experiments

*CERN (**Switzerland**)*
*Vilnius University (**Lithuania**)*
*Centre for Particle Physics of Marseille (imXgam) (**France**)*
*University of Maryland (**USA**)*
*Institute of Physics of the Czech Academy of Sciences (**Czech Republic**), ILM- CNRS & University Claude Bernard Lyon1 (**France**), Institute for Scintillation Materials NAS of Ukraine (**Ukraine**), Università Politecnica delle Marche, Ancona (**Italy**), Institute of Physics, University of Tartu (IPUT), (**Estonia**), FH Aachen (Germany), Giessen University (**Germany**), ORNL (**USA**), University of Notre Dame (**USA**), University of Iowa (**USA**), University of Virginia (**USA**), Caltech (**USA**), Istanbul University (**Turkey**), CEA Saclay / IRFU (**France**) University of Milano-Bicocca (**Italy**)*

Summary

- All proposals **aim to demonstrate the feasibility of a calorimeter concept**, although starting from different level of maturity and with different timescales
- **Many common R&D and potential synergies** on several fronts and **with other DRDs** (#4 photon detectors, #5 quantum sensors, #7 electronics)
- There are **no sharp borders** between some proposals within the same track nor between track 1 and track 3
- Need to think of the best way to **organize** them **into work packages** and **working groups** (e.g. by target application, by major challenges, by active material technology, else…?)

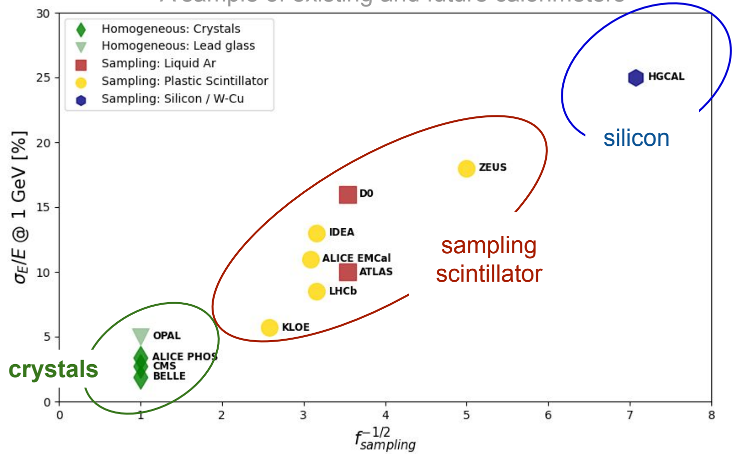
Additional material

Motivations for homogeneous calorimetry at FCCee

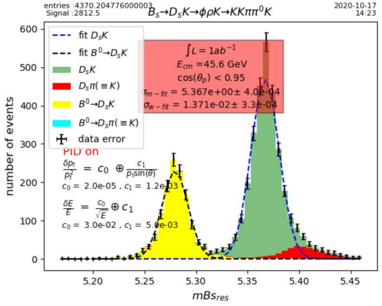
- Homogeneous calorimetry remains the **only way to get a 1-3%/√(E)** energy resolution for photons (but also a good option for shower imaging and time resolution)

- Potential to improve event reconstruction and **expand the landscape of physics studies**

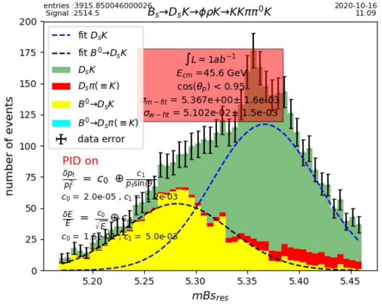
A sample of existing and future calorimeters



3%/√E

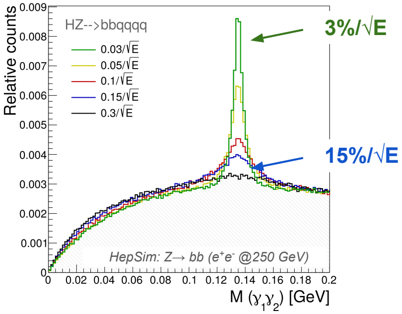


15%/√E



CP violation studies with B_s decay to final states with low energy photons

[R.Aleksan et al., *Study of CP violation in $B^{\pm}$ decays to D0(D0)$K^{\pm}$ at FCCee*, arXiv:2107.05311]



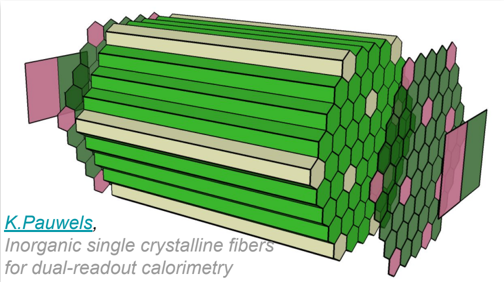
Clustering of π^0's photons to improve performance of jet clustering algorithms

[M.Lucchini et al., New perspectives on segmented crystal calorimeters for future colliders, 2020 *JINST* **15** P11005]

Homogeneous **H**adron **Cal**orimeters

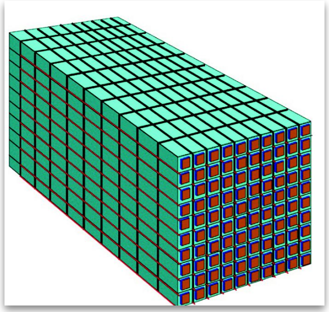
- Full absorption dual-readout hadron calorimetry concepts aiming at further boosting the energy resolution for hadronic showers→~15%/√E
- **Major challenges**: **requires breakthrough in mass production** (quality/uniformity) and cost reduction for high density scintillators (crystals/heavy glasses)
    - Various options under investigation by the international community (DSB:Ce, AFO:Ce, …)
    - Recent R&D collaboration and progress on Gd-rich heavy glasses for a HHCAL for CEPC

Exploiting bundles of meta-crystal **fibers** *[P.Lecoq, J PHYS 160 (2009) p12016 & G.Mavromanolakis et al.]*

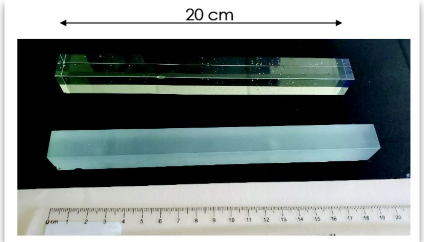


K.Pauwels, Inorganic single crystalline fibers for dual-readout calorimetry

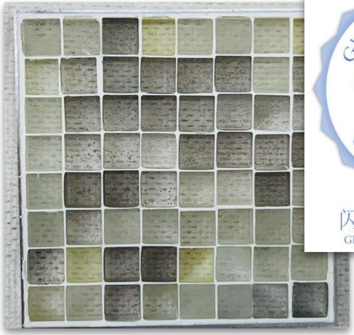
Exploiting **bulk** cost-effective dense scintillators *[CPAD2021, M.Demarteau et al.]*



Bulk scintillating glass production as part of EIC R&D

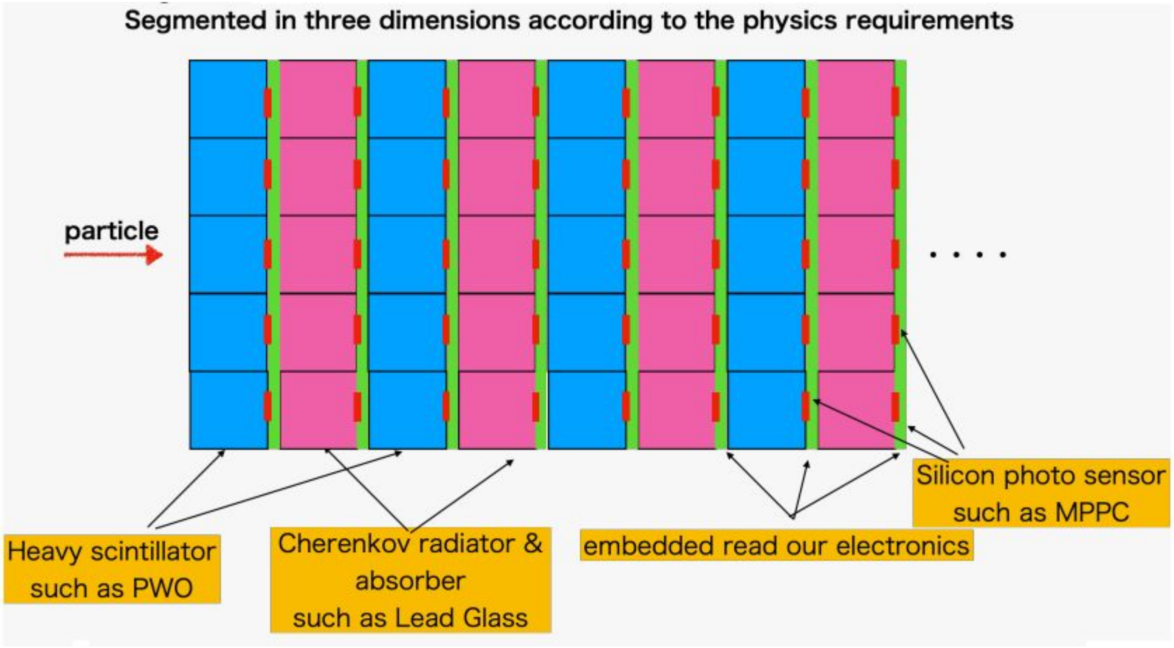


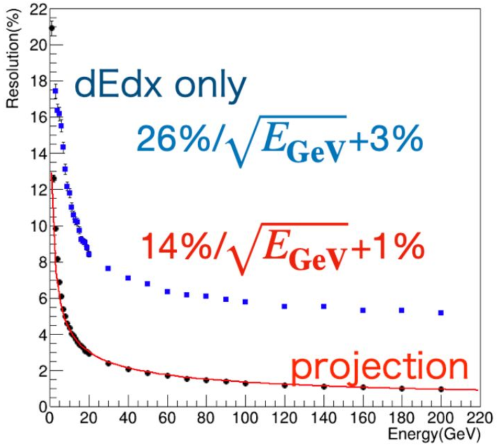
Sen.QIAN, R&D for high density, high light yield glass scintillator for CEPC



Development of a New type of sandwich calorimeter named Double read out Sandwich Calorimeter (DSC)

- Focused on prototype





ADRIANO3: a highly granular, triple-readout calorimetric technique