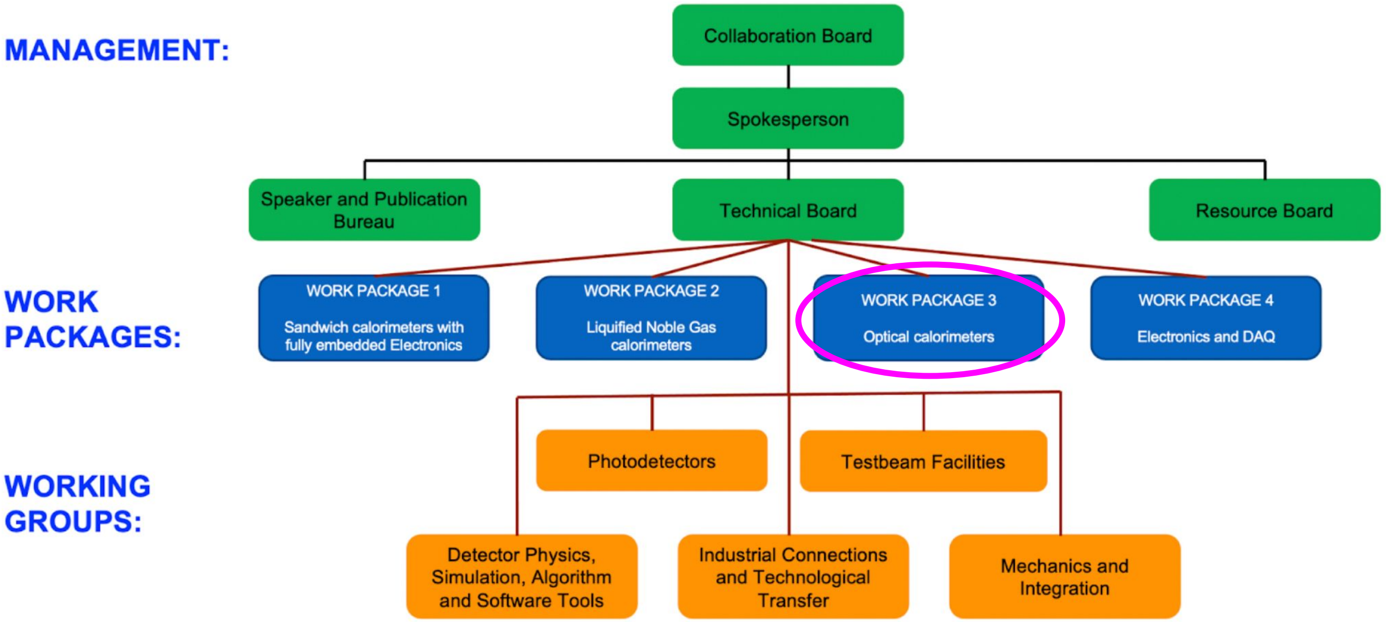
DRD6 WP3: Optical calorimeters

Michaela Mlynarikova (CERN)

The 2024 international workshop on the high energy Circular Electron Positron Collider, Oct 23-27, 2024

DRD6 WP3: Overview

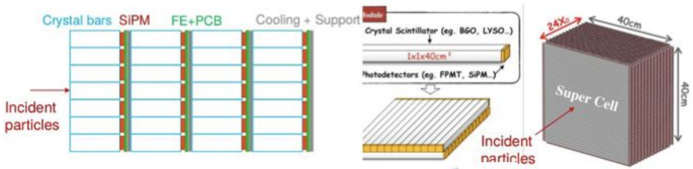
- Involvement from ~70 institutes working on 11 different projects
- **The goal**: explore, optimise and demonstrate with full shower-containment prototypes, new concepts of sampling and homogeneous calorimeters based on scintillating materials



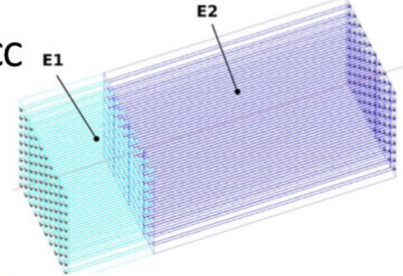
DRD6 WP3: Projects

Homogeneous EM

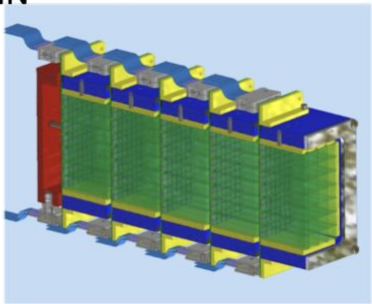
HGCCAL



MAXICC

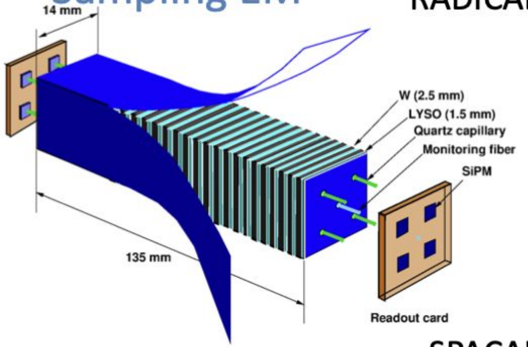


CRILIN

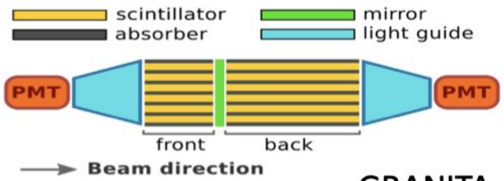


Sampling EM

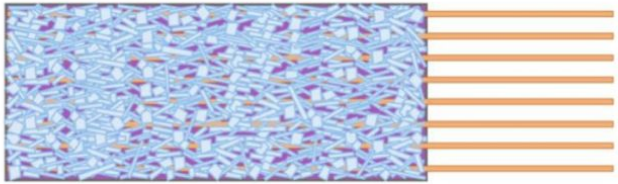
RADICAL



SPACAL

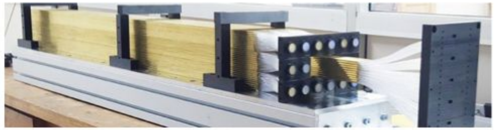


GRANITA

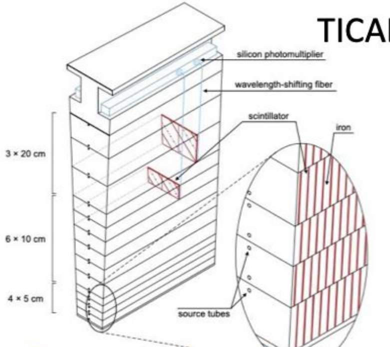


Sampling EM/HM

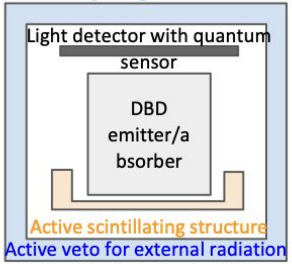
DRCAL



TICAL



Cryogenic calo



DRD6 WP3: Projects

Project	Scintillator/WLS	Photodetector	DRDTs	Target
Task 3.1: Homogeneous and quasi-homogeneous EM calorimeters				
HGCCAL	BGO, LYSO	SiPMs	6.1, 6.2	e^+e^-
MAXICC	PWO, BGO, BSO	SiPMs	6.1, 6.2	e^+e^-
Crilin	PbF_2, PWO-UF	SiPMs	6.2, 6.3	$\mu^+\mu^-$
Task 3.2: Innovative Sampling EM calorimeters				
GRAiNITA	$ZnWO_4$, BGO	SiPMs	6.1, 6.2	e^+e^-
SpaCal	GAGG, organic	MCD-PMTs,SiPMs	6.1, 6.3	e^+e^-/hh
RADiCAL	LYSO, LuAG	SiPMs	6.1, 6.2, 6.3	e^+e^-/hh
Task 3.3: (EM+)Hadronic sampling calorimeters				
DRCal	PMMA, plastic	SiPMs, MCP	6.2	e^+e^-
TileCal	PEN, PET	SiPMs	6.2, 6.3	e^+e^-/hh
Task 3.4: Materials				
ScintCal	-	-	6.1, 6.2, 6.3	$e^+e^-/\mu^+\mu^-$/hh
CryoDBD Cal	TeO, ZnSe, LiMoO NaMoO, ZnMoO	n.a.	-	DBD experiments

+ OREO in Task 3.1

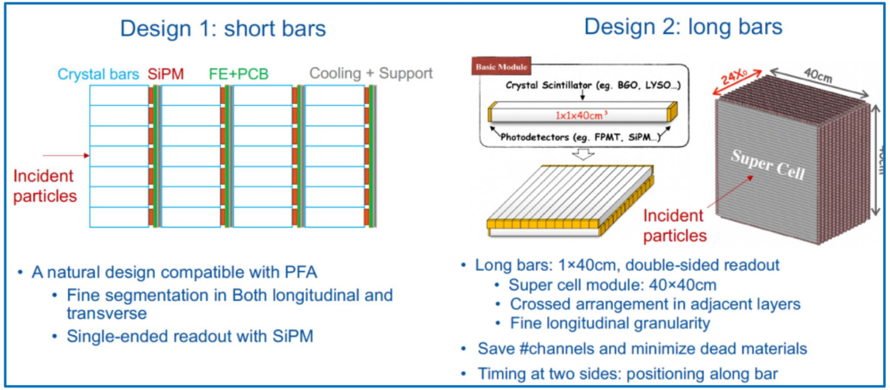
WP3: Task 3.1

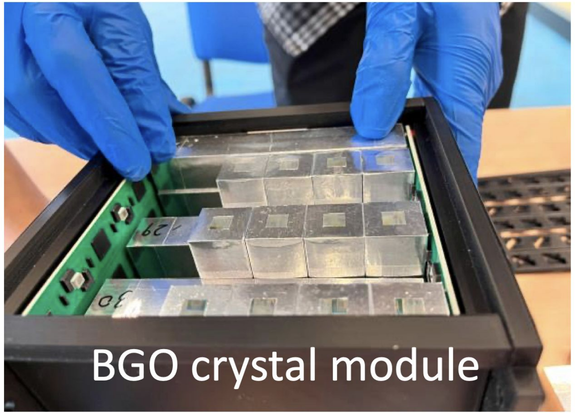
Project	Scintillator/WLS	Photodetector	DRDTs	Target
Task 3.1: Homogeneous and quasi-homogeneous EM calorimeters				
HGCCAL	BGO, LYSO	SiPMs	6.1, 6.2	e^+e^-
MAXICC	PWO, BGO, BSO	SiPMs	6.1, 6.2	e^+e^-
Crilin	PbF_2, PWO-UF	SiPMs	6.2, 6.3	$\mu^+\mu^-$

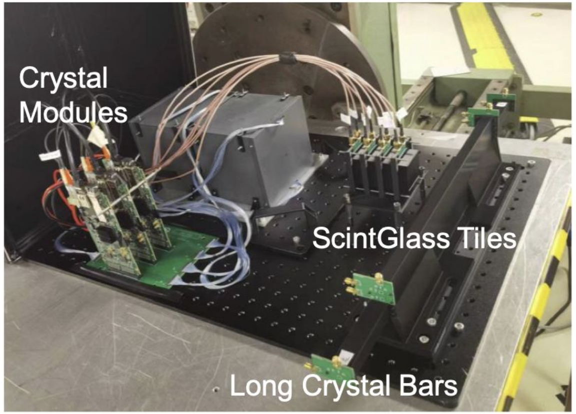
+ OREO project

High-granularity crystal calorimeter (HGCCAL)

- Crystal bars arranged in a grid structure
  - Optimal EM resolution: 2-3%/√E
  - Fine segmentation for particle flow algorithms
- Two designs: short and long crystals
- First prototypes tested in beam tests
- Main R&D Topics
  - Development an EM shower-scale prototype
  - Studies of SiPMs and ASICs with a large dynamic range



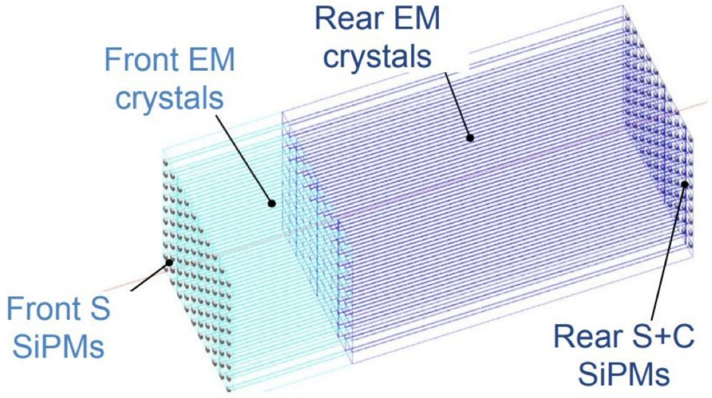


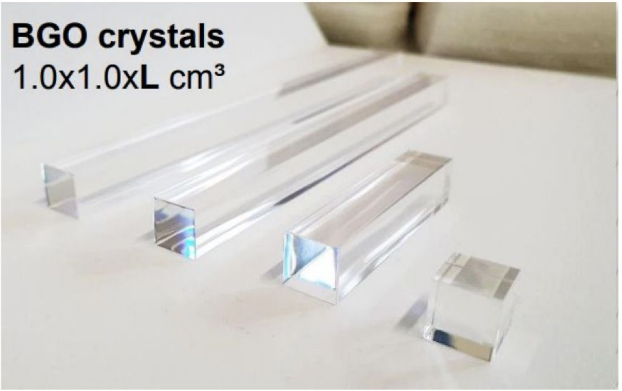


MAXICC

- Homogeneous EM calorimeter based on segmented crystals with dual-readout
  - High density scintillating crystals with good cherenkov yield
  - Dedicated optical filters and SiPMs to readout S and C from same active element
  - Promise 3%/√E + DR capability
  - Synergies within Calvision, IDEA and CERN Crystal Clear collaborations

- Main R&D Topics
  - Identification of optimal crystals, optical filters and SiPM candidates
  - Proof-of-concept with lab measurements and prototypes
  - EM scale prototype for beam test

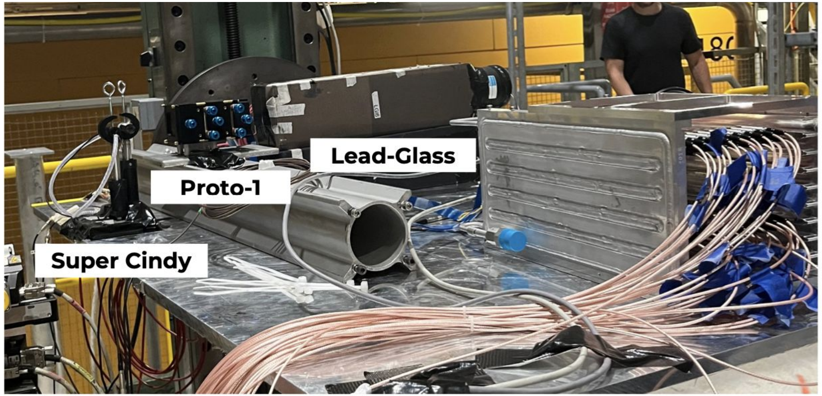


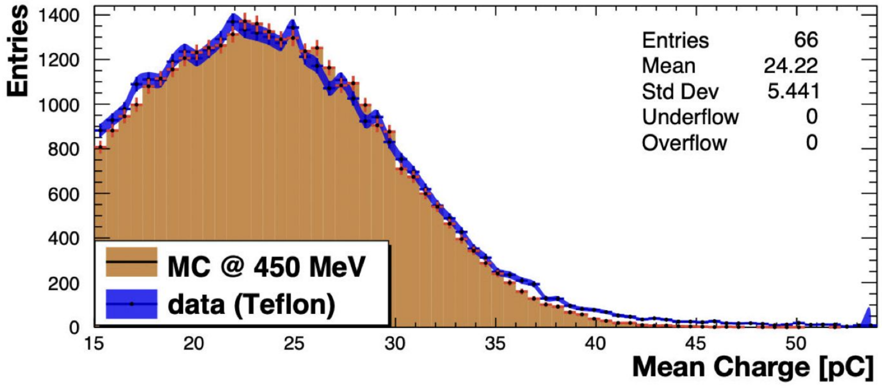


publication

CRILIN

- A CRystal calorimeter with Longitudinal InformatioN for the future Muon Collider
    - EM calorimeter: semi-homogeneous based on Lead-Fluorite (PbF2) crystals and SiPMs
- Targets EM resolution: 5-10%/√E
    - Limited by beam induced background (BIB) and SiPM noise (due to radiation damage)
- First prototypes tested in beam tests
- Main R&D Topics
    - Validation of the concept design
    - Simulations with EM-shower-scale prototype

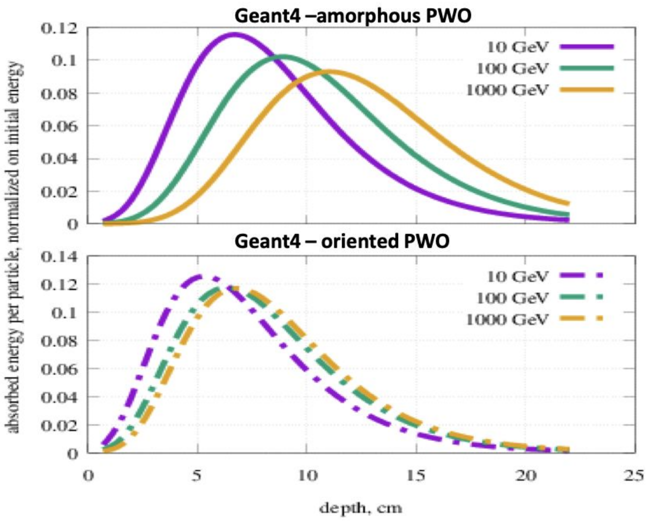


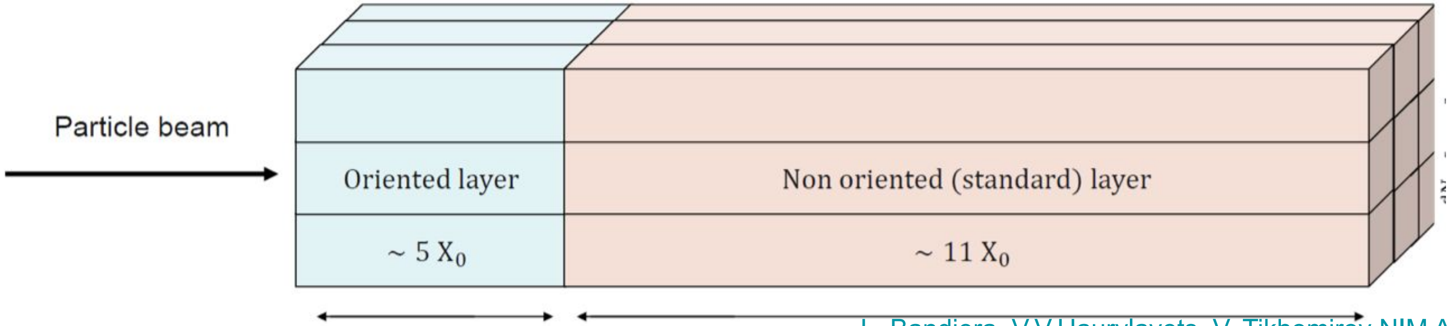


OREO

- Idea: Use oriented crystals
  - The input photon or electron/positron showers can fully develop in a much lower thickness with respect to the current state-of-the-art detectors, with the same light yield
- Advantages
  - Enhanced compactness
  - Cost reduction
  - Better n/γ discrimination
- Challenge
  - Construction of an oriented layer of many crystals

Simulation of the e.m. shower of HE electrons in a PWO crystal





L. Bandiera, V.V.Haurylavets, V. Tikhomirov NIM A 936 (2019) p.124-126
L. Bandiera et al., Front. Phys. 2023 11:1254020. doi: 10.3389/fphy.2023.1254020
M. Soldani et al., arXiv:2404.12016v1

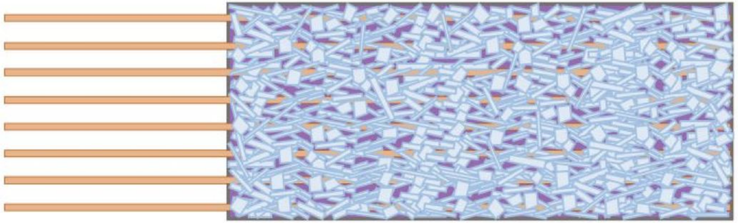
WP3: Task 3.2

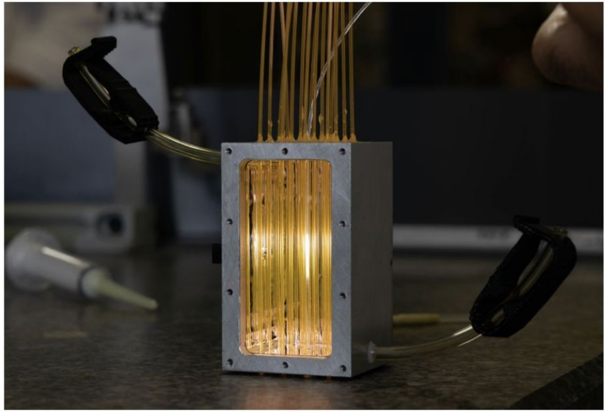
Project	Scintillator/WLS	Photodetector	DRDTs	Target
Task 3.2: Innovative Sampling EM calorimeters				
GRAiNITA	$ZnWO_4$, BGO	SiPMs	6.1, 6.2	e^+e^-
SpaCal	GAGG, organic	MCD-PMTs,SiPMs	6.1, 6.3	e^+e^-/hh
RADiCAL	LYSO, LuAG	SiPMs	6.1, 6.2, 6.3	e^+e^-/hh

arXiv:2312.07365

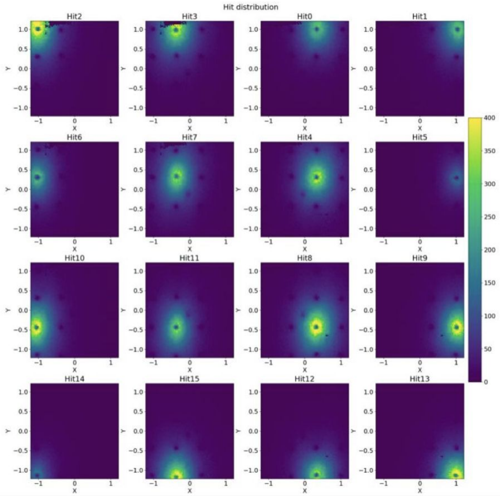
GRANiTA

- A novel type of calorimeter ~next generation shashlik
- Use grains of inorganic scintillating crystal readout by wavelength shifting fibers
  - Light spatially confined by refraction/reflections





- Excellent expected EM resolution: 2-3%/√E
  - Using BGO or ZnWO4 crystals
  - 16-channel prototype tested with cosmics
  - First test beam of small proto at CERN
- Main R&D topics
  - R&D on crystal grains
  - Aim for larger prototype to validate on testbeam

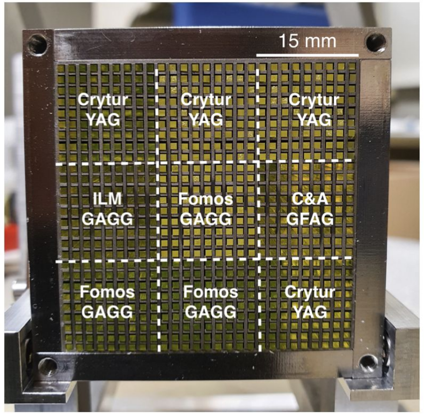


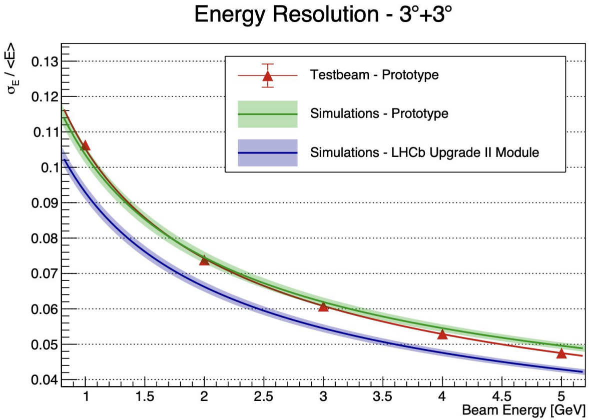
Confirmation of light confinement

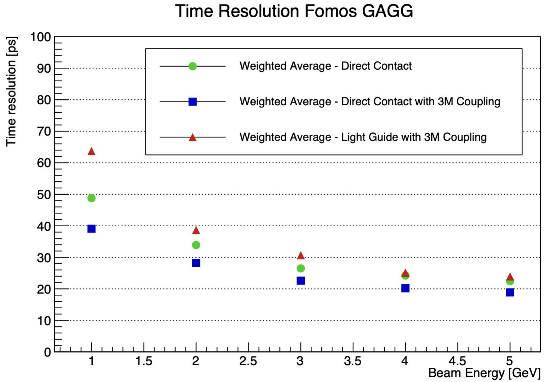
arxiv:2205.02500

SpaCal

- Sampling EM calorimeter: scintillating fibres inserted in a high-density absorber material
  - Tunable energy resolution and time resolution of O(10-20) picoseconds
- Use radiation-hard crystal fibres as active elements → viable technology for hadron colliders
  - Possible optimisation for for e+e− collider
- EM-shower-scale prototypes with tungsten and lead absorbers were successfully tested
- Main R&D topics
  - Optimisation of absorbers, light guides, photon detectors, scintillating fibres and simulation
  - Development of ASIC optimised for waveform sampling with 15 ps time resolution



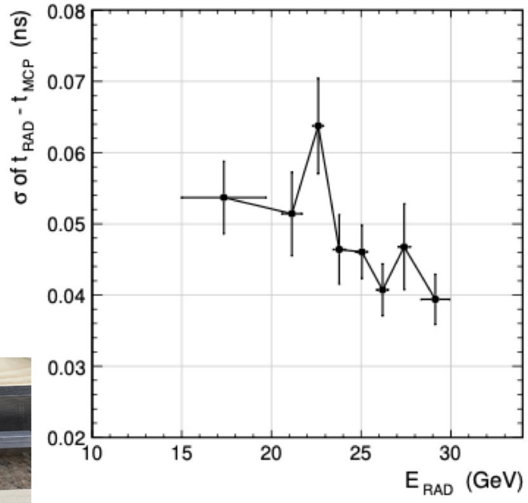


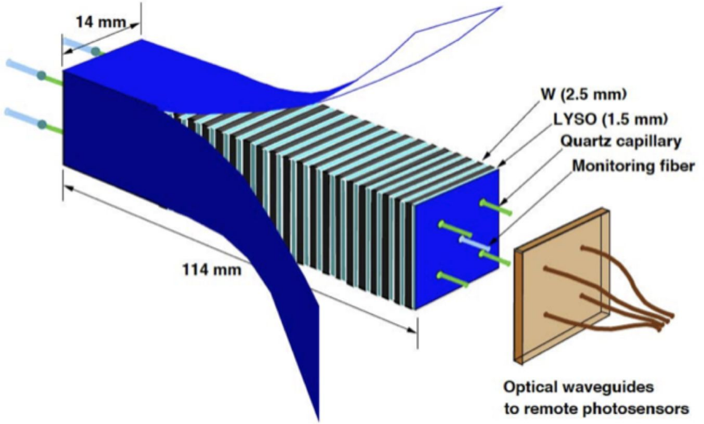


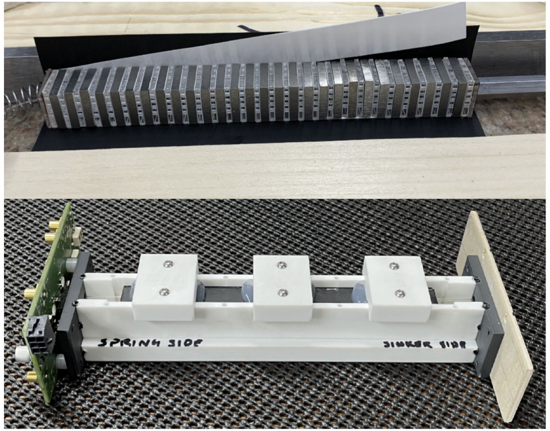
arXiv:2303.05580

RadiCal

- Shashlik-type: crystal plates, tungsten plates, quartz capillaries with WLS filament
  - Uses the scintillation and cherenkov light
  - Compact EM calorimeter with fast-timing
  - Designed for high radiation tolerance in extreme environments
- Prototypes measured at beam tests
- Main R&D topics:
  - Development of radiation-hard wavelength shifters
  - Construction of EM-shower-size prototype







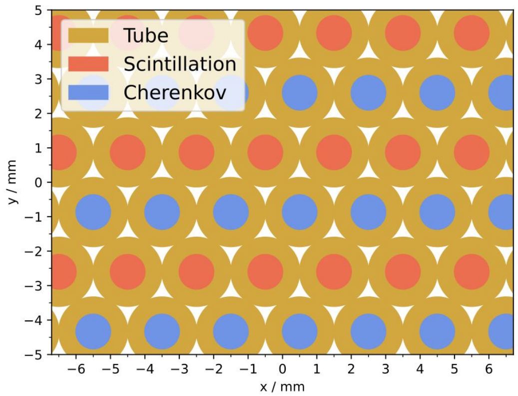
WP3: Task 3.3

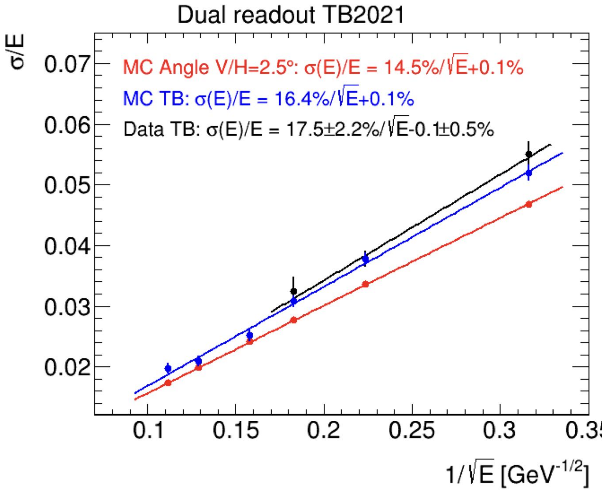
Project	Scintillator/WLS	Photodetector	DRDTs	Target
Task 3.3: (EM+)Hadronic sampling calorimeters				
DRCal	PMMA, plastic	SiPMs, MCP	6.2	e^+e^-
TileCal	PEN, PET	SiPMs	6.2, 6.3	e^+e^-/hh

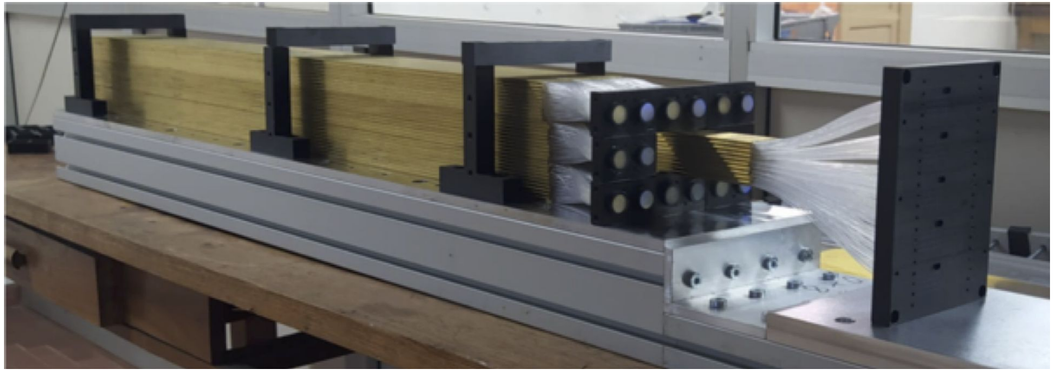
publication

DRCal

- Longitudinally unsegmented dual-readout sampling calorimeter
  - Scintillation and Cherenkov fibres inside an absorber groove
  - Reaches 30%/√E for single hadrons ⇒ ultimate resolution for jets
- Main R&D Topics
  - Develop scalable readout electronics
  - Optimize metal matrix mechanics for large production
  - Develop mechanical model of full system with services

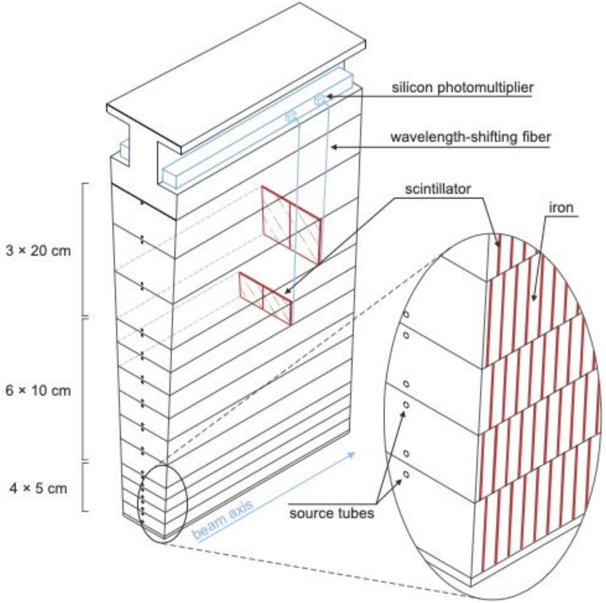




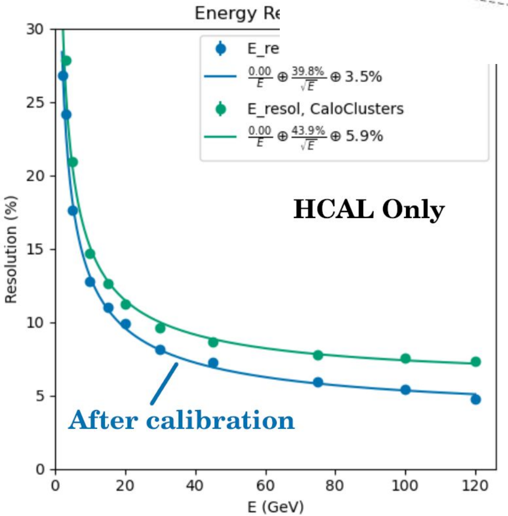


TileCal

- High-granularity version of ATLAS TileCal hadronic calorimeter
  - 5mm steel absorber plates alternating with 3mm scintillators
  - 8 - 9.5λ
  - SiPM readout through WLS
  - Cost-effective solution



- Main R&D topics
  - Exploration of new scintillator materials
  - Optimisation of WLS and SiPMs for readout efficiency
  - Build testbeam module



WP3: Task 3.4

Project	Scintillator/WLS	Photodetector	DRDTs	Target
Task 3.4: Materials				
ScintCal	-	-	6.1, 6.2, 6.3	$e^+e^-/\mu^+\mu^-/hh$
CryoDBD Cal	TeO, ZnSe, LiMoO NaMoO, ZnMoO	n.a.	-	DBD experiments

Materials

- A lot of development on new scintillating materials are ongoing
- Main R&D topics of **ScintCal** project:
    - Fast and radiation-hard organic and inorganic scintillators
    - Ultrafast inorganic scintillators for ultrafast calorimetry
    - Cost-effective inorganic scintillators
- Main R&D topics of **Cryogenic DBD-calorimeters** project:
    - Goal: Future generations of double beta decay experiments based on cryogenic calorimeters
    - Interested in development of of new scintillating materials
    - Radiopurity and compatibility with a cryogenic environment are of paramount importance

Conclusions

- WP3 community is very active, making great progress in collaborative spirit
- Large diversity of calorimeter technologies
  - Some building on proven technologies
    - Pushing those technologies to their limits
  - Some coming to fruition after years of R&D
  - Some brand new ideas

- In all cases:
  - Long road ahead to get to large scale prototypes
  - System-level concerns and engineering challenges are numerous

- In parallel, R&D on new scintillating materials ongoing and progressing well