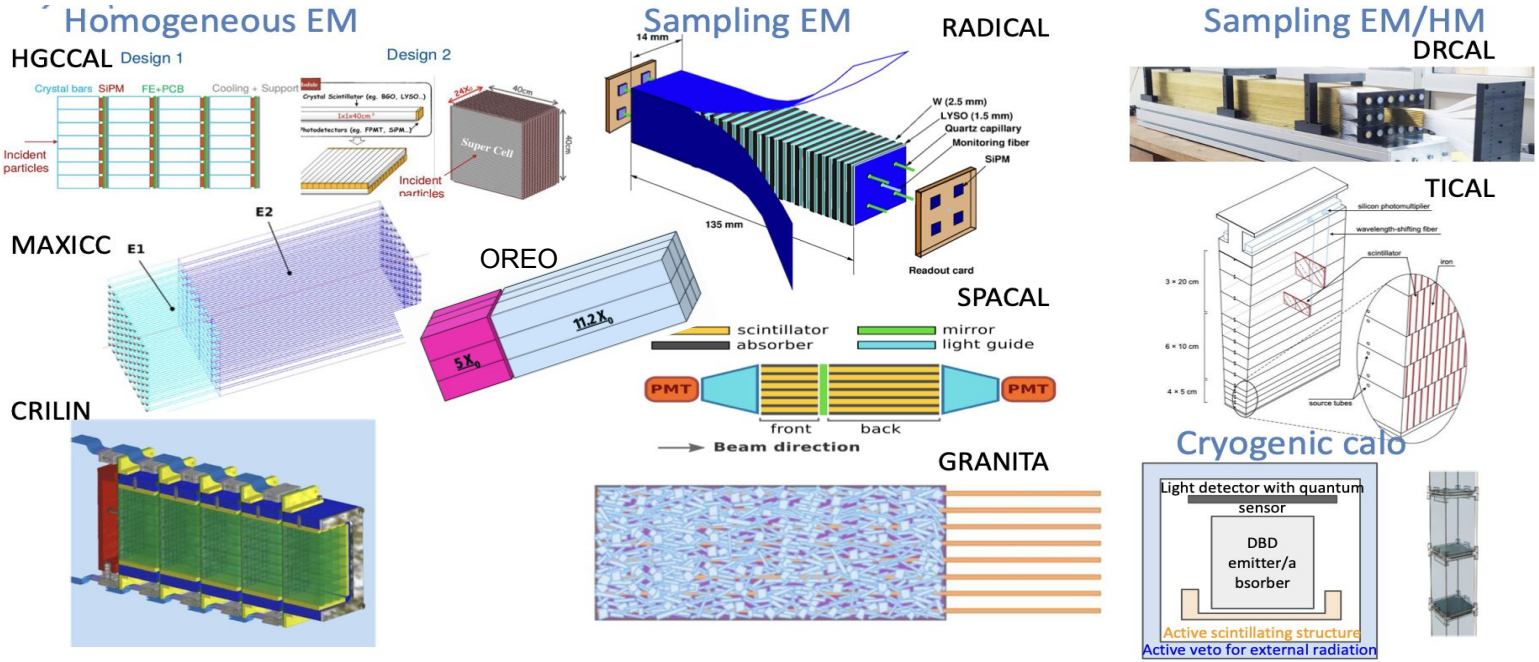
DRD6 WP3: Optical calorimeters

Michaela Mlynarikova (CERN)

1 November 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

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

WP3 milestones and deliverables in 2024

	Milestone	Deliverable	Description	Due date
HGCCAL	M3.1		Specifications of crystal, SiPM and electronics for highly granular EM crystal calorimeter prototype	2024
		D3.1	Development of 1-2 crystal EM modules to be exposed to beam tests	2024
	M3.2		Beam tests characterisation of a full containment highly granular EM crystal calorimeter prototype	2025
	M3.3		A first mechanical design for a final detector with crystal modules	2025
	M3.4		New reconstruction software for the long-bar design and updated PFA	2026
		D3.2	Large crystal module for hadronic performance, system integration studies and combined testbeam with HCAL	>2026
MAXICC	M3.5		Completion of qualification tests on components and selection of crystal, filter and SiPM candidates for prototype	2025
	M3.6		Report on the characterisation of crystal, SiPM and optical filter candidates and their combined performance for Cherenkov readout	2025
		D3.3	Full containment dual-readout crystal EM calorimeter prototype and testbeam characterisation	2026
	M3.7		Joint testbeam of EM module prototype with dual-readout fibre calorimeter prototype (DRCAL)	>2026
Crilin		D3.4	Acquisition and tests of crystals and SiPMs; design and production of electronics boards; design and production of the mechanical components	2024
		D3.5	Calorimeter fully assembled	2025
	M3.8		Beam test characterisation of a full containment EM calorimeter prototype	2025
	M3.9		Report on testbeam results	2026
GRAiNITA	M3.10		Characterisation of materials, wavelength shifters and SiPMs and identification of best technological choices	2024
		D3.6	Development of a GRAiNITA demonstrator as EM calorimeter prototype for e+/e- collider (full shower containment)	2026
SpaCal		D3.7	Tungsten and lead absorbers for module-size prototypes	2024
	M3.11		Design of optimised light guides	2025
		D3.8	Set of crystal samples, SPIDER ASIC prototype	2026
	M3.12		Specification of photon detector and improved simulation framework available	2026
		D3.9	Module-size prototypes (significantly larger than EM showers) built and validated in beam tests	>2026
RADiCAL		D3.10	Single module with prototype scintillating crystals, SiPMs and front-end electronics cards built and tested.	2024
		D3.11	3x3 array of RADiCAL modules built and tested	2026
	M3.13		Paper on beam-test results for EM shower position, timing and energy	2026
	M3.14		Continue beam testing with alternative scintillation and wavelength shifting materials - for improved cost/performance.	>2026
DRCal		D3.12	Construction of full-scale dual readout module with hadronic shower containment	2025
	M3.15		Testbeam campaign to assess module performance: result paper	2026
	M3.16		Continue beam testing with alternative readout elx	>2026
TileCal	M3.17		Characterisation of PEN- and PET-based scintillating tiles including optimisation of readout with WLS fibres and SiPMs	2025
		D3.13	Construction of up to 3 prototypes of a sampling tile calorimeter module with WLS fibres and SiPM readout (for beam tests after 2026)	2026
	M3.18		Paper on beam test results	>2026
		D3.14	Full hadron-shower containment prototype built and tested	>2026
ScintCal	M3.19		Dataset of scintillation and radiation hardness properties of various scintillation materials studied	2026
		D3.15	Samples of a set of scintillators produced and characterised	2026
		D3.16	Samples of most promising glasses produced and characterised	>2026
	M3.20		Material selected for future detectors	>2029
CryoDBDCal	M3.21		Report crystals in terms of optimisation of growing/doping procedures	2024
		D3.17	Scintillating polymer for 3D-printing, with optimal mechanical and light-production properties, produced and tested	2025

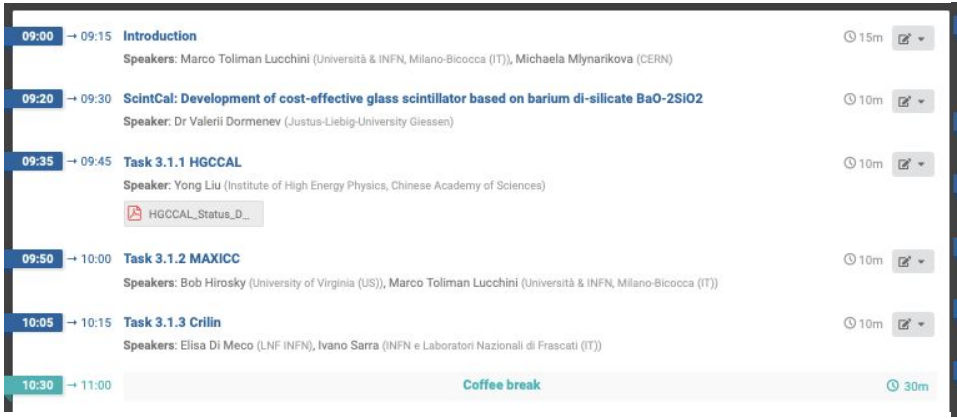
3 milestones in 2024:
HGCCAL: Specifications of crystal, SiPM and electronics for high granular EM crystal calorimeter prototype
GRAiNITA: Characterisation of materials, wavelength sifters and SiPMs and identification of best technological choices
CryoDBDCal: Report crystals in terms of optimisation of growing/doping procedures

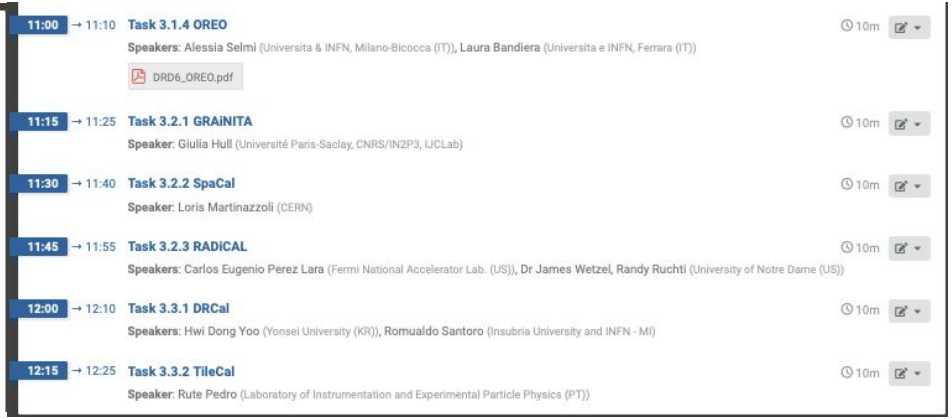
4 deliverables in 2024:
HGCCAL: Development of 1-2 crystal EM modules to be exposed to beam tests
Crilin: Acquisition and tests of crystals and SiPMs;
design and production of electronics boards;
design and production of mechanical components
SpaCal: Tungsten and lead absorbers for module-size prototypes
RADiCAL: Single module with prototype scintillating crystals, SiPMs and front-end electronics cards built and tested

WP3 parallel session

Last collaboration meeting of the year

- Report from each project → Collect information on achievement of deliverables and milestones with respect to what was the plan in the DRD6 document
- Agenda: https://indico.cern.ch/event/1470552/

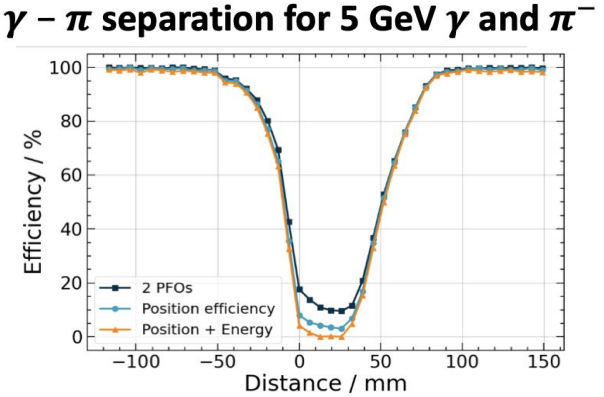


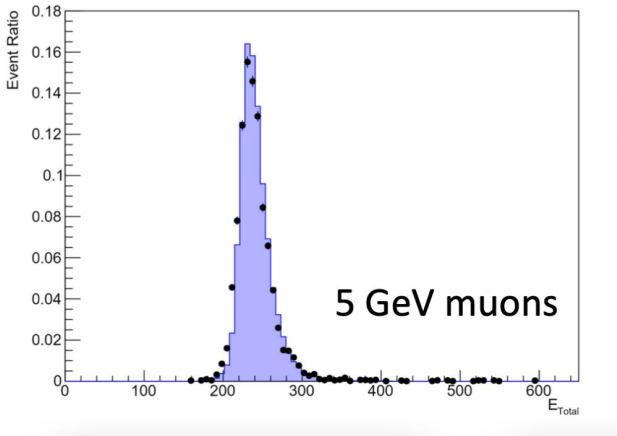


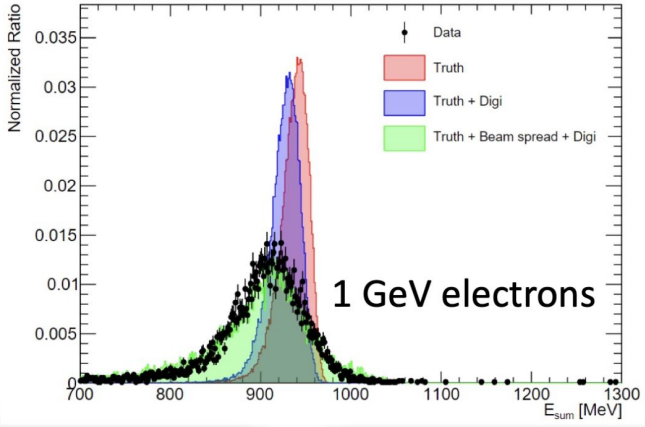
High-granularity crystal calorimeter (HGCCAL)

Yong Liu

- Crystal bars arranged in a grid structure
  - Optimal EM resolution: 2-3%/√E
  - Fine segmentation for particle flow algorithms
- Some of 2024 highlights
  - Well on track for (not only) 2024 milestones and deliverables
  - A full HGCCAL physics prototype developed and tested
  - New PFA reconstruction software for the long-bar design

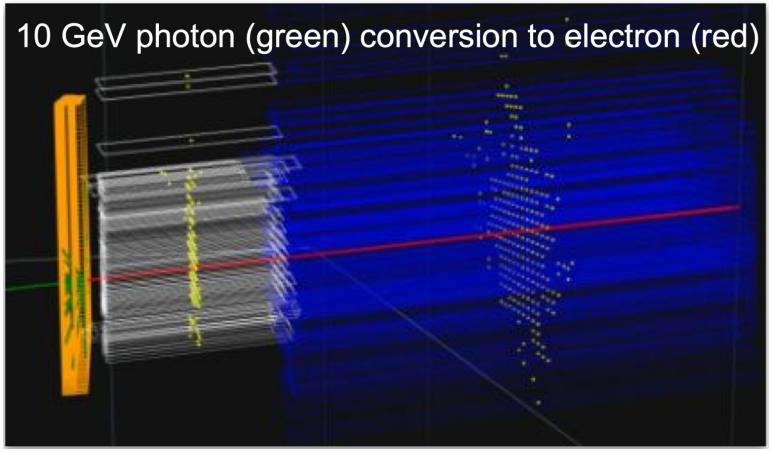


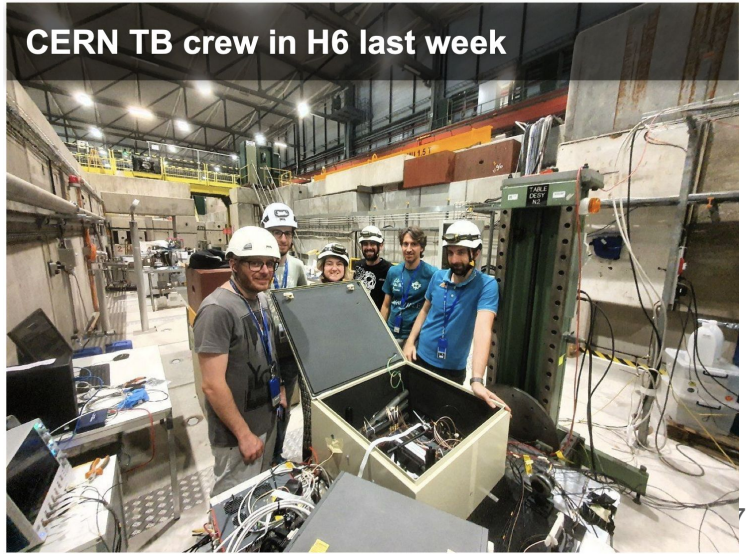


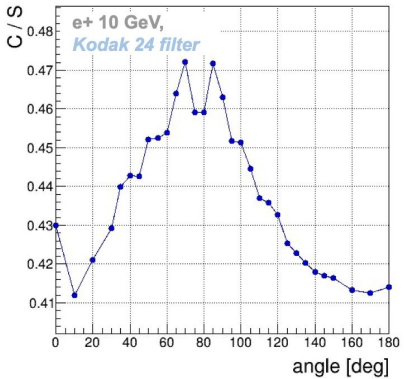


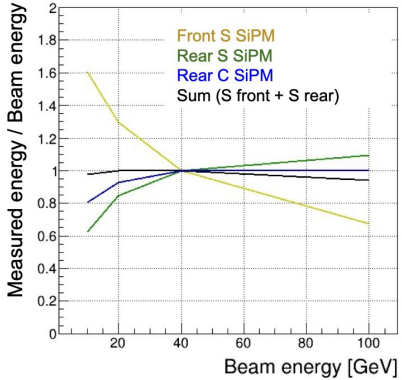
MAXICC

- Homogeneous EM calorimeter based on segmented crystals with dual-readout
  - High density scintillating crystals with good cherenkov yield, use
  - Promise 3%/√E + DR capability
- Some of 2024 highlights
  - Implementation in key4hep gearing up
  - **R&D to optimize dual-readout** in scintillating crystals using optical filters and SiPM **progressing well** thanks to successful beam tests in 2024





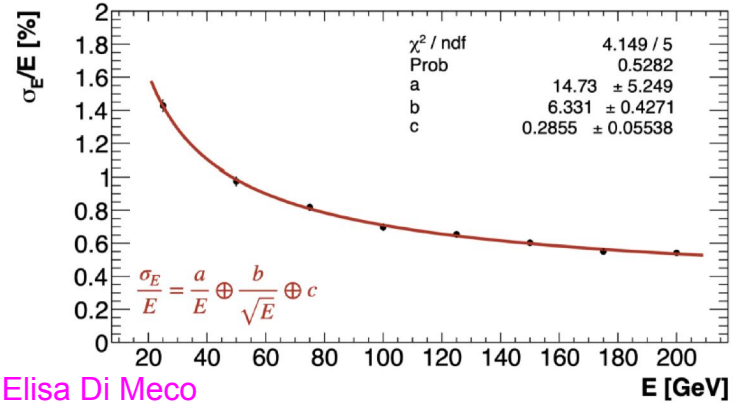




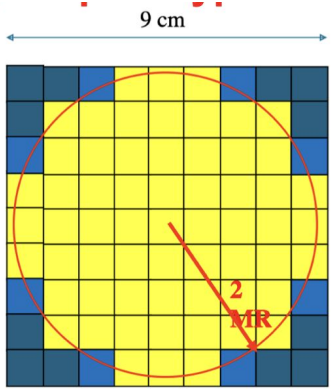
publication

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
- Some of 2024 highlights
  - Optimized number of crystals and layers using Geant4 simulations
  - Work ongoing towards a large scale prototype
    - Completion may be delayed due to delays in the funding



1 x 1 x 4 cm3
→ 4 cc x 25eur ~ 100eur



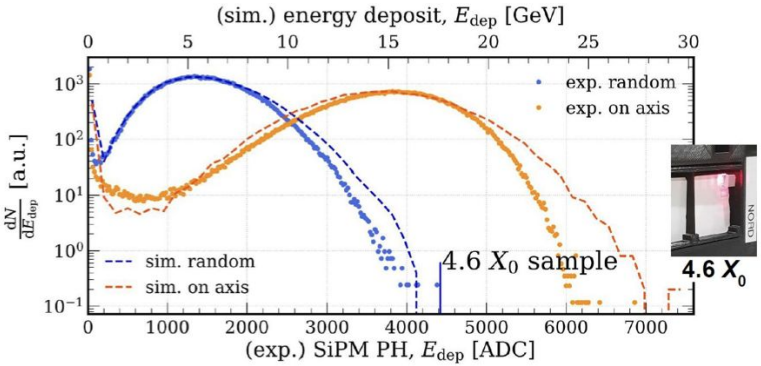
X6 Layer
--> 25 X0

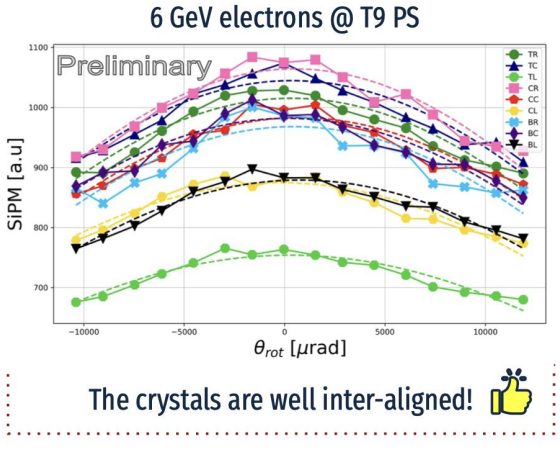
61 cry x 6 layers
= 366 crystals (120 eur/each+VAT)
~ 50keuro

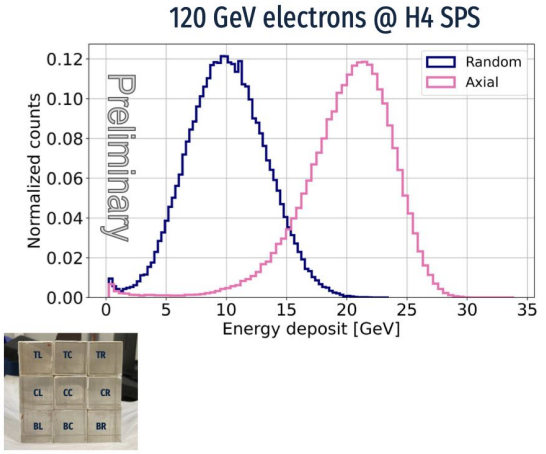
L. Bandiera, V.V.Haurylavets, V. Tikhomirov NIM A 936 (2019) p.124-126
L. Bandiera et al., Front. Phys. 2023 11:1254020. doi: 10.3389/fphy.2023.1254020
M. Soldani et al., arXiv:2404.12016v1

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
- Some of 2024 highlights
  - Two layer PWO-UF prototype fully assembled
  - First experimental tests at CERN and data analysis





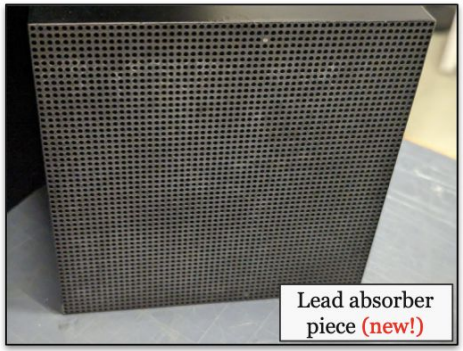


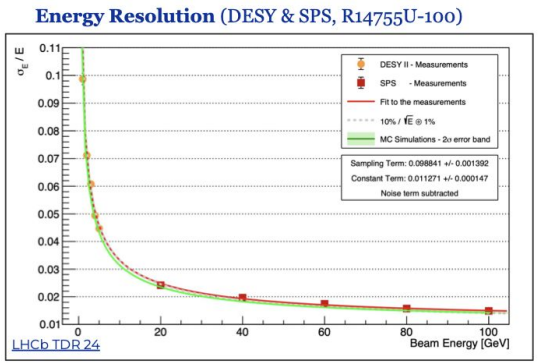
Alessia Selmi

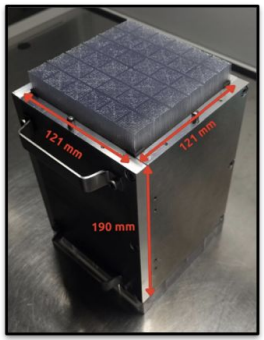
arxiv:2205.02500

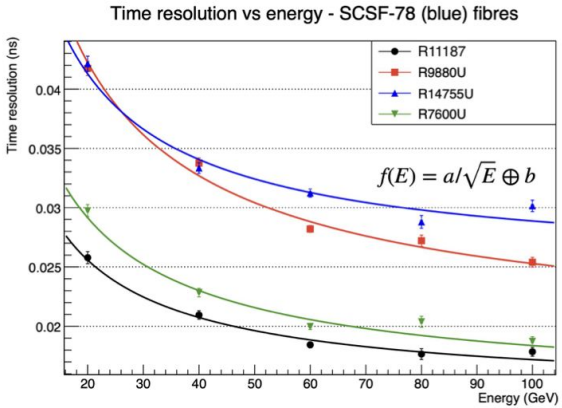
SpaCal

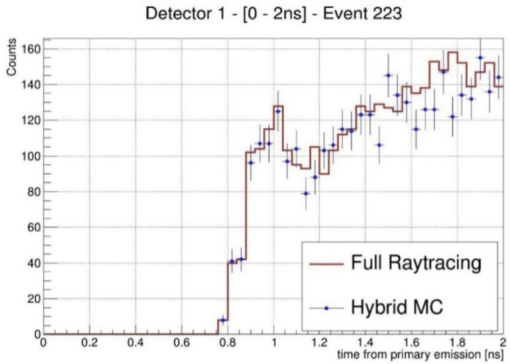
- Sampling EM calorimeter: scintillating fibres inserted in a high-density absorber material
  - Tunable energy resolution and time resolution of O(10-20) picoseconds
- Some of 2024 highlights
  - Tested prototypes with tungsten and lead absorbers
    - Deliverable D3.7 achieved!
  - **Time resolution** better than 20 ps for high-energy electron beams







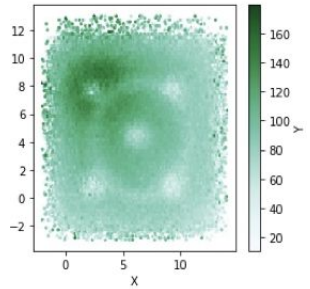


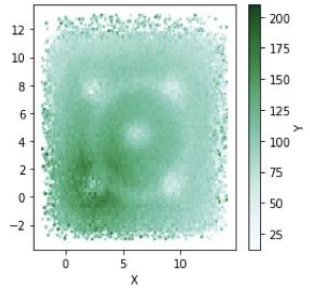


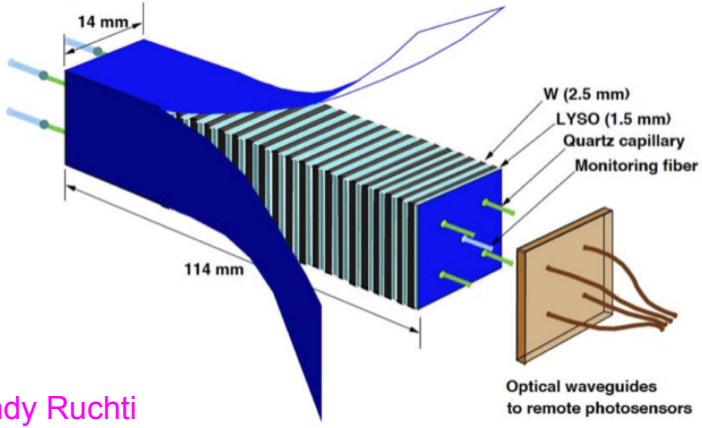
https://doi.org/10.1016/j.nima.2024.169737

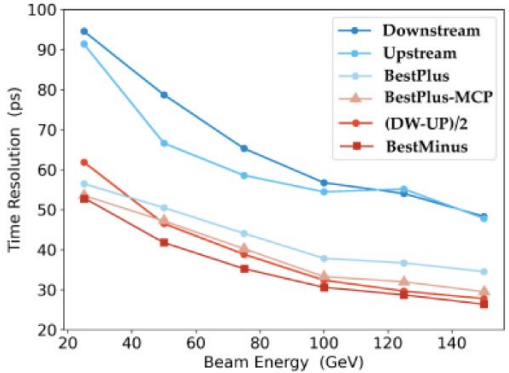
RadiCal

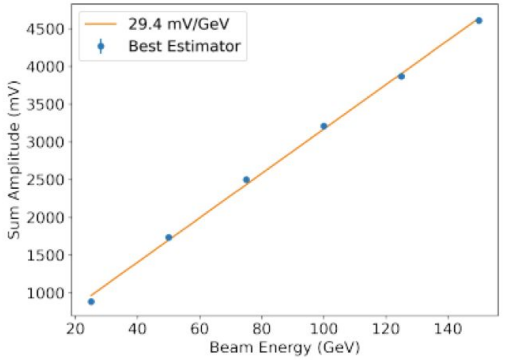
- Shashlik-type: crystal plates, tungsten plates, quartz capillaries with WLS filament
  - Uses the scintillation and cherenkov light
  - Compact EM calorimeter with fast-timing
- Some of 2024 highlights
  - Prototypes successfully measured at beam tests
  - Tested different wavelength shifters for timing measurements at shower max





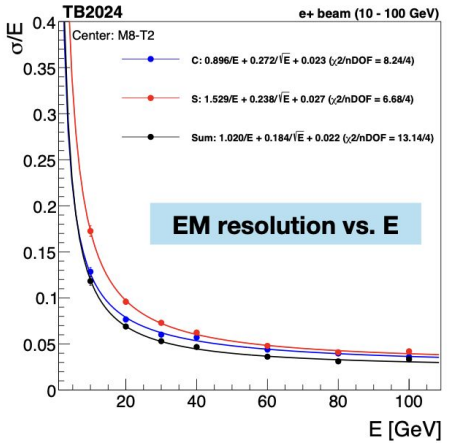


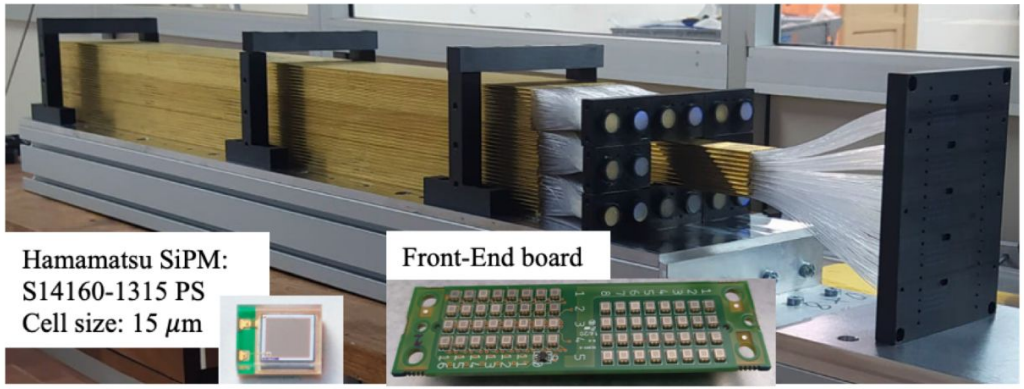


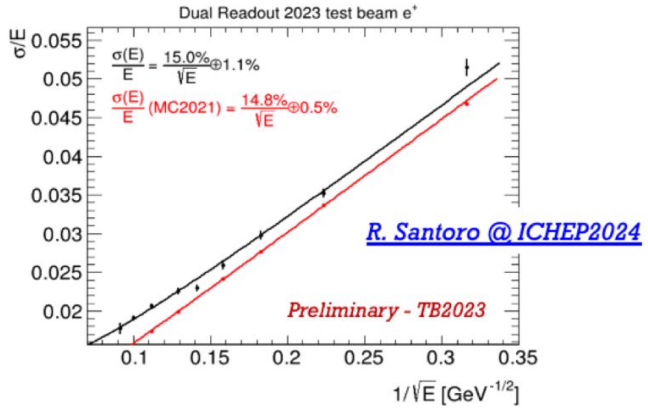


Dual Readout Calorimeter

- Longitudinally unsegmented dual-readout sampling calorimeter
  - Scintillation and Cherenkov fibres inside an absorber groove
  - Reaches 30%/√E for single hadrons
- Some of 2024 highlights
  - Lots of R&D activities are ongoing as well as successful beam tests



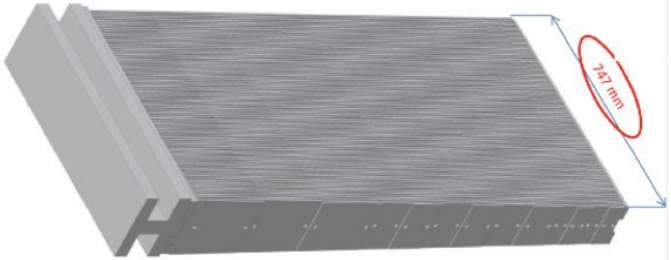


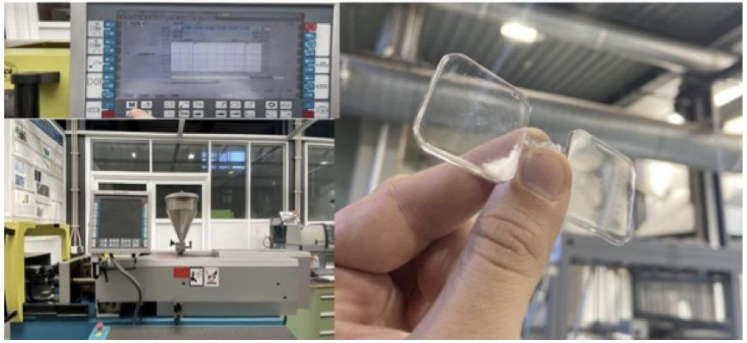


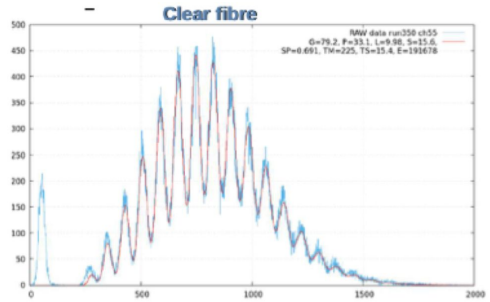
Henric Wilkens

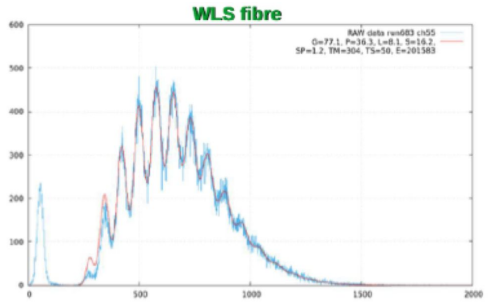
TileCal

- High-granularity version of ATLAS TileCal hadronic calorimeter
  - 5mm steel absorber plates alternating with 3mm scintillators
  - SiPM readout through WLS
  - Part of ALLEGRO → close collaboration with WP2
- Some of 2024 highlights
  - Exploration of new scintillator materials
  - Optimisation of WLS and SiPMs for readout efficiency
  - Mechanical studies of the testbeam module
    - First period of master and filler plate produced



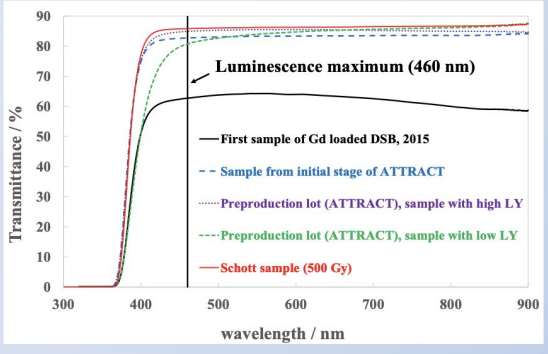


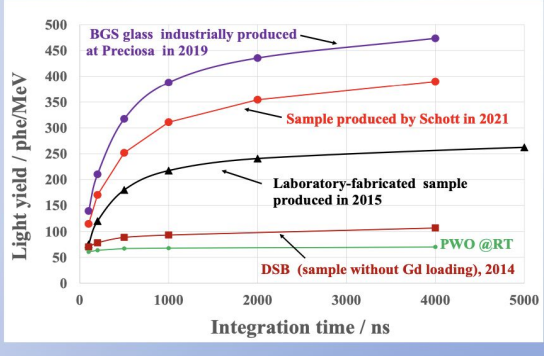


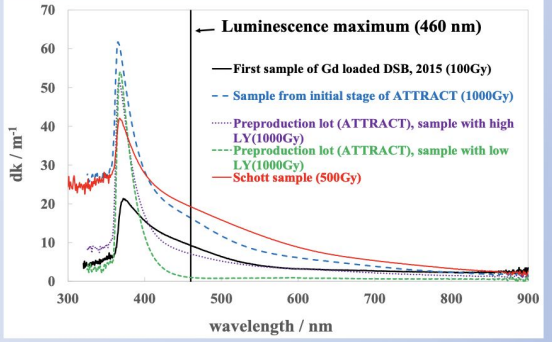


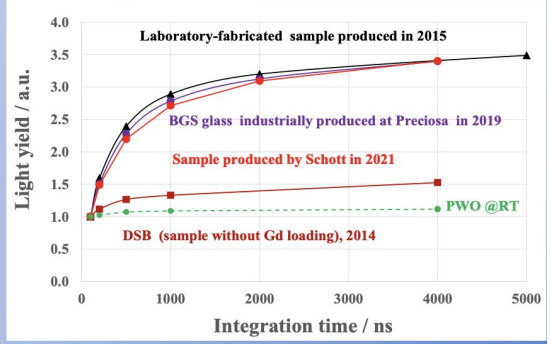
Development of cost-effective glass scintillators

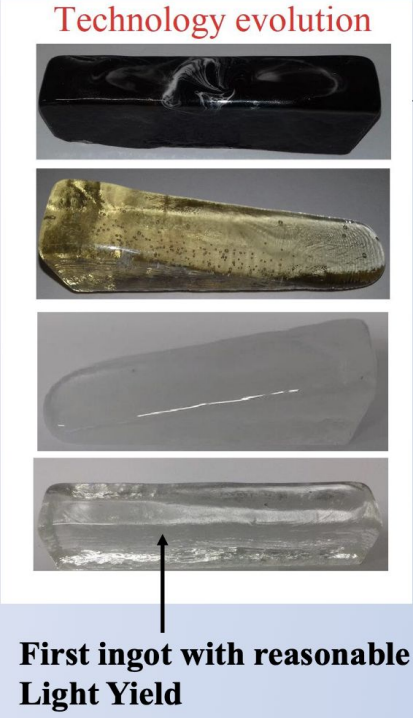
- Glass scintillators based on barium disilicate BaO-2SiO2
  - Low-cost material, light yield was increased thanks to optimization of the manufacturing process, but macro-defects are still a limiting factor particularly for blocks of large volume











WP3 projects plans for 2025 beam tests

Seven WP3 projects submitted requests for beam tests at CERN

- **HGCCAL**
- **MAXICC -** 2 weeks at SPS (H6) has been placed for late September
- **OREO -** 2 weeks at SPS
- **RadiCal** - one-week at SPS in 2025 during the late summer
- **DRCal** - 4 weeks
- **Crilin** - 2 x 7 days
- **ScintCal** - 1 week of test beam for CERN R&D

WP3 organization update

- Marco Lucchini is a deputy WP3 coordinator
- Work package contact persons represent the community
  - No institute body in place
  - To ensure diverse community representation, I proposed having two contact persons per project, ideally from different institutes (optional)
  - Voting procedure unchanged: 1 vote per project

WP3 projects and current contact persons
3.1.1 (HGCCAL): Yong Liu
3.1.2 (MAXICC): Marco Lucchini, Bob Hirosky
3.1.3 (Crilin): Ivano Sarra
3.1.4 (OREO): Laura Bandiera
3.2.1 (GRAiNITA): Giulia Hull
3.2.2 (SpaCal): Philipp Roloff, Marco Pizzichemi
3.2.3 (RADiCAL): Randy Ruchti, James Wetzel, Carlos Perez Lara
3.3.1 (DRCal): Hwi Dong Yoo, Romualdo Santoro
3.3.2 (TileCal): Henric Wilkens, Rute Pedro
3.4.1 (ScintCal): Etiennette Auffray
3.4.2 (CryoDBDCal): Matteo Biassoni

Conclusions

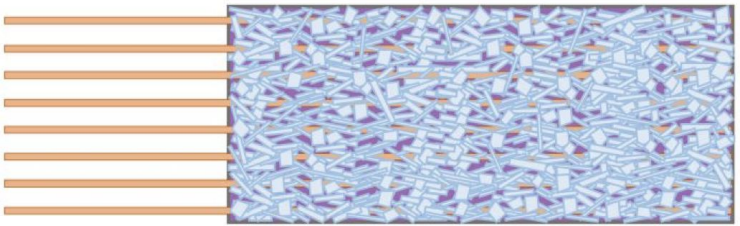
- WP3 community is very active, making progress in collaborative spirit
- Large diversity of calorimeter technologies, all making steady progress towards meeting their milestones and deliverables
- In parallel, R&D on new scintillating materials ongoing and progressing well
  - Wasn't presented in this meeting, we keep it for the next time
- Several talks in the WP3 parallel session given by ECR
  - Great to see such passion and dedication from these young scientists
- Huge thanks to everyone who participated in WP3 parallel session
  - Looking forward to our next meeting!

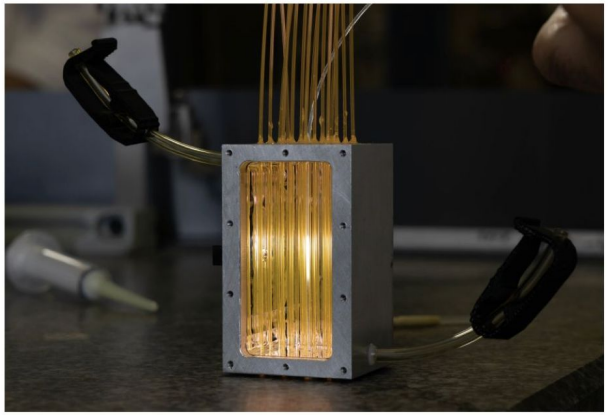
BONUS SLIDES

arXiv:2312.07365

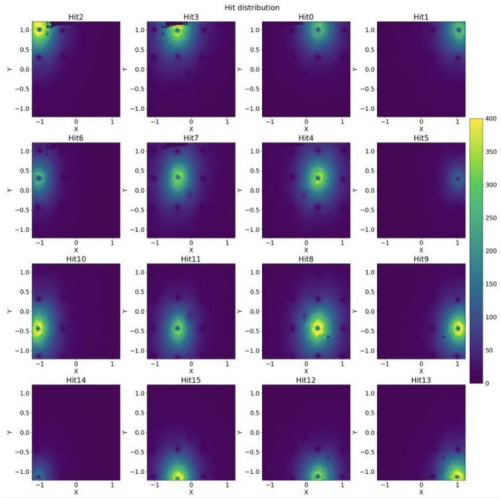
GRANiTA

- 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