Karlsruhe Institute of Technology

Institute for Data Processing and Electronics

High-D-Calo Update

17th Terascale Detector Workshop
March 17-21, 2025 University of Bonn

Melike Akbiyik

Outline

- High-D-Calo Overview
- Recent results and future plans

No consortium meeting this week - report primarily based on consortium meeting at DESY in December 2024, plus updates on selected activites

The High-D Calo Consortium

BMBF ErUM-Pro Funding Period 2024 - 2027

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High-D-Calo consortium

WP1: Highly Granular Calorimeters
Simon

- WP1.1 Readout System — Krüger, Schultz-Coulon, Sefkow, Simon
- WP1.2 Mechanical and Thermal Integration — Büscher, Krüger, Masetti, Schultz-Coulon, Sefkow
- WP1.3 System Tests — Büscher, Garutti, Krüger, Lai, Masetti, Schultz-Coulon, Sefkow, Simon

WP2: Cost-effective Designs and Novel Materials
Lacker

- WP2.1 Optimisation — Brinkmann, Friedrich, Lacker, Märkisch
- WP2.2 Integrated Readout — Brinkmann, Lacker, Friedrich, Märkisch
- WP2.3 Multi-layer CheapCal prototype — Brinkmann, Friedrich, Lacker, Märkisch

WP3: Reconstruction and Simulation
Lai

- WP3.1 Reconstruction and calibration software — Gaede, Garutti, Lai, Sefkow
- WP3.2 Advanced Reconstruction Techniques — Gaede, Garutti, Heinrich, Kasieczka, Krüger, Lacker, Simon
- WP3.3 Simulation Studies — Lacker, Lai, List, Simon

WP4: Sensors and Scalability
Garutti

- WP4.1 SiPM characterization and radiation tolerance — Garutti
- WP4.2 Exploration of alternative Scintillator Materials — Brinkmann, Büscher

WP1 ✔ WP2 ✔ WP4 ✔

U Giessen
U Heidelberg
KIT
U Mainz
DESY (w/o application)

WP3 ✘

CALO5D

Not funded. Partially compensated via CALO5D.

Planned Activities: WP1

Overview

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WP1: Highly Granular Calorimeters - main R&D thrust: Further develop AHCAL technology to meet requirements of circular e^+e^- Higgs Factories

- WP1.1: Readout System Design and Optimisation (KIT, DESY, UHD)
  Develop front-end, detector interfaces and data concentration for continuous readout
- WP1.2 Mechanical and Thermal Integration (JGU, DESY, UHD)
  Develop technological solution to address increased cooling needs while meeting compactness requirements
- WP1.3 System Tests (DESY, KIT, JGU, UGoe, UHH, UHD)
  System tests with thermal layer demonstrator and small multi-layer stack

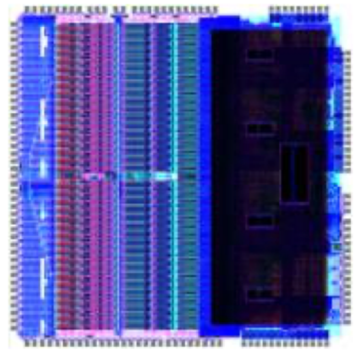
WP1 - Recent Results

WP1.1 Readout System Design and Optimisation

Development of the front-end:

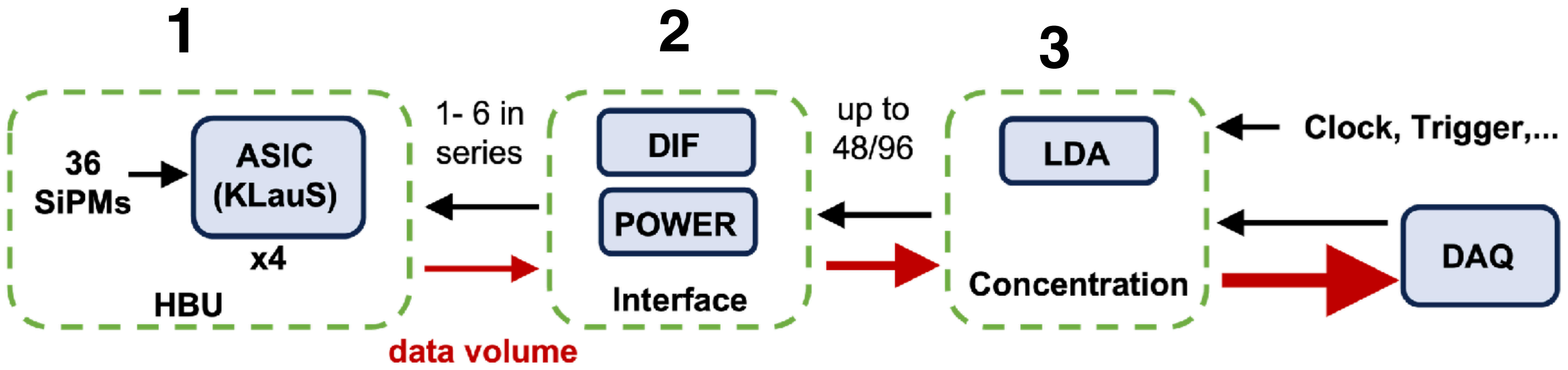
- The latest version(KLaus6b) provides full functionality. it supports both **power-pulsing** and **continuous readouts**.
- Low power, Power pulsing capable (~25uW @ 0.5% duty cycle)
- I²C (Slow) or LVDS (160 Mbit/s) readout. The data limit readout of ASICs 160 Mbit/s.

KLauS5



KLauS6 Layout (5x5 mm²)

Illustration of the readout concept of the AHCAL, from front-end to DAQ



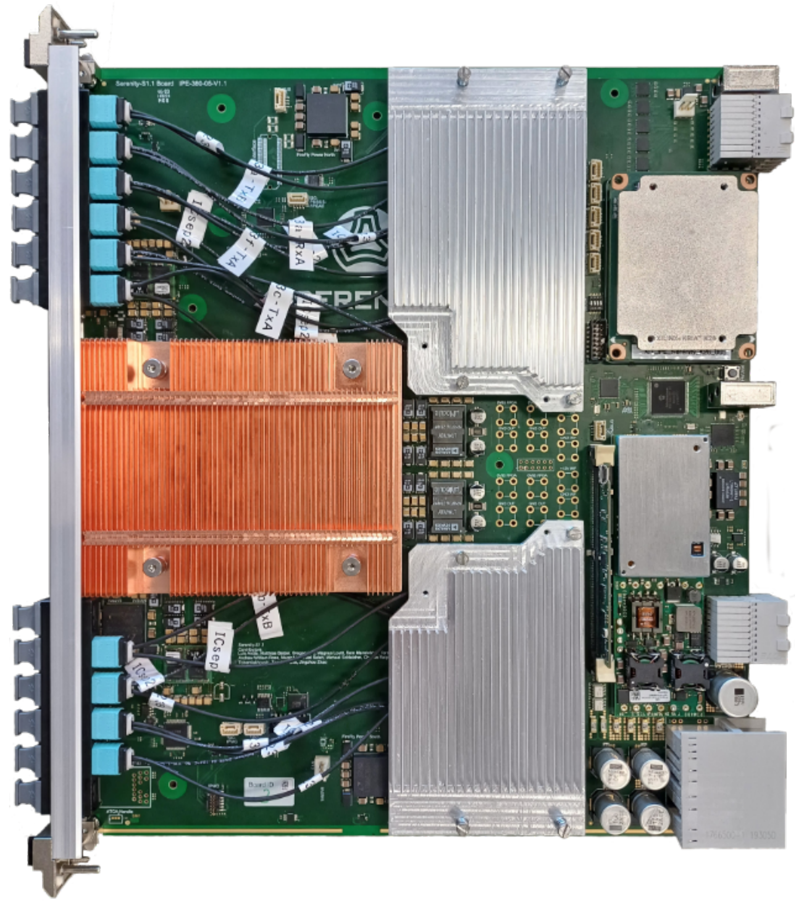
1 **HBU** electronic development

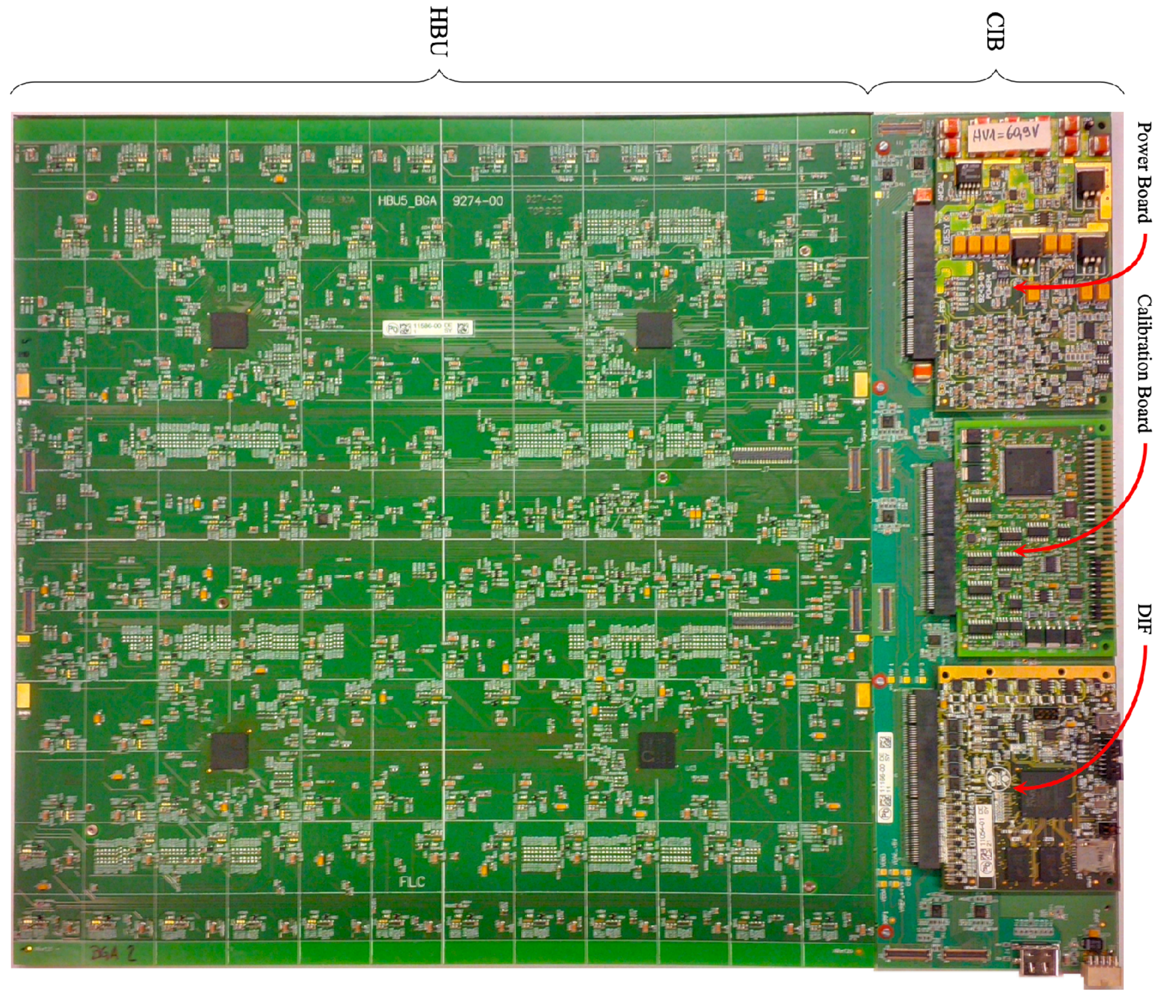
UHD DESY

2,3 Readout electronics for the **interface and concentration** stages

Development detector interfaces and data concentration for continuous readout:

- The latest DIF version contains a **Zynq-7020 SoC** (System-on-Chip),
- **FPGA with an embedded dual-core ARM processor.**
- **SERENITY** board for the data concentration:
  - A carrier card for the Phase-2 upgrade of the CMS experiment at the LHC at CERN. **High throughput data processing** (acting as a data engine) up to 3 Tbps/board.





Existing AHCAL HBU, SiPM, CIB, CALIB, DIF

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WP1 - Recent Results

WP1.2 Mechanical and Thermal Integration

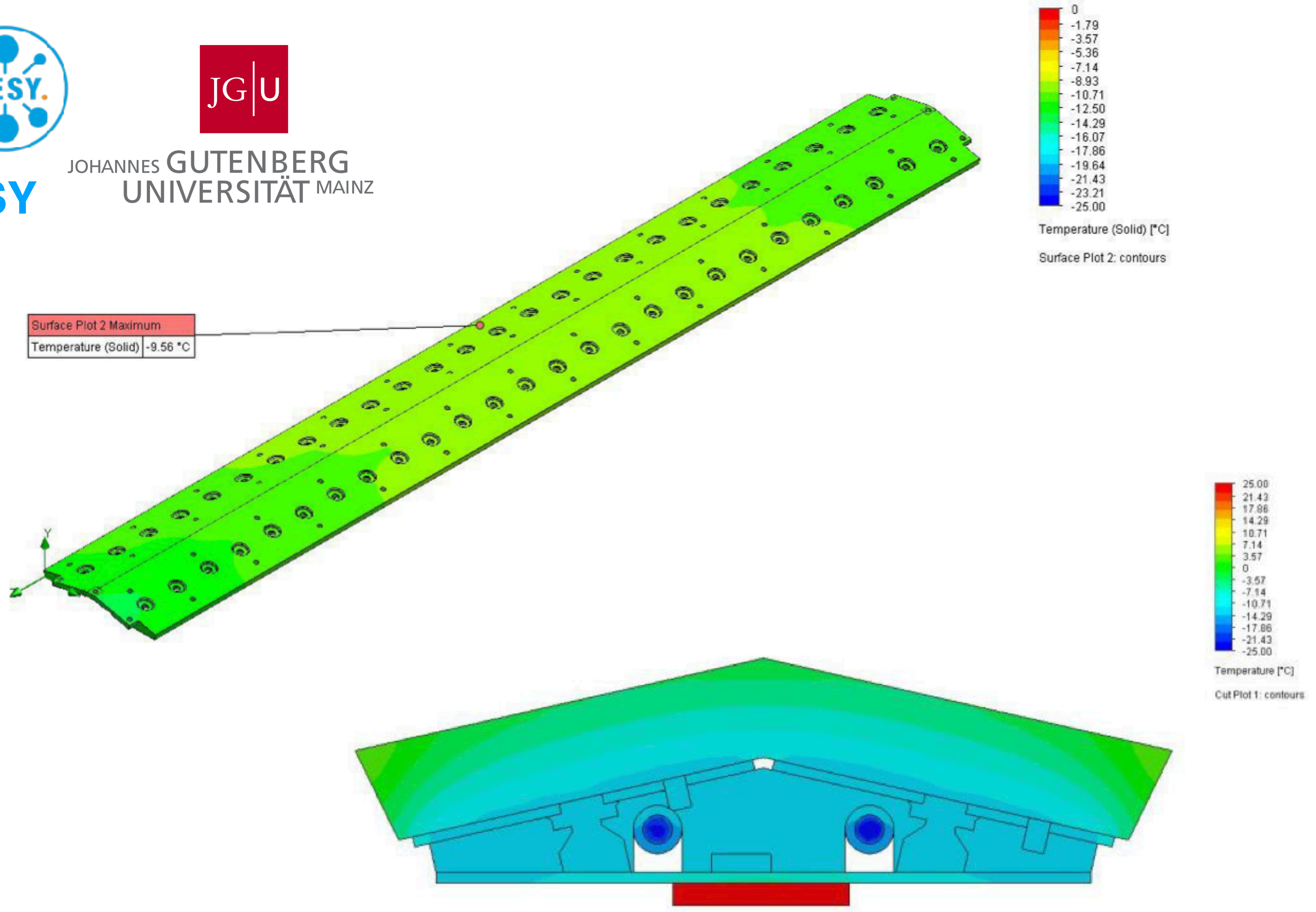
Development cooling material:

- ILC environment: power consumption managed through power pulsing (1 millisecond bunch trains at 5 Hz)
- FCC-ee requirement: higher interaction rate,electronics need to remain continuously powered

Need for integrated cooling.

- Work on current cooling system for AHCAL:
  - Only cooling of Power board
  - Does not allow for continous running (… with larger slabs)..
- Study of Cooling solutions for next generation prototypes:
  - Production of a cooling mock-up
  - Commisioning of a AHCAL cooling system.
  - Fluid and Thermal Simulation
  - Verification of simulation results
- Simulation frameworks:
  - Licences for Fluid and Thermal simulations in Solidworks CAD available
  - Experience in setup and verification of Simulation ; Commisioning andintegration of such a system (Mu3e Tile detector)

UHD DESY JOHANNES GUTENBERG UNIVERSITÄT MAINZ



Simulation of Mu3e Tile detector Cooling system

Planned Activities: WP2

Overview

WP2: Cost-effective Designs and Novel Materials - main R&D thrust: Further develop CheapCal project.

- WP2.1: Study of possible optimizations of the concept (HUB, JLU, TUM)
  Optimisation in terms of photon sensors, scintillator materials, design of optical coupling to fibers
- WP2.2: Towards a fully-integrated front-end readout (HUB, JLU, TUM)
  Develop readout system for CheapCal modules, starting from multi-channel sampling ADC, and exploring solutions with higher integration, such as CALICE ASICs
- WP2.3: Design, construction, and test of the first multi-layer CheapCal prototype (HUB, JLU, TUM)
  Construction of a multi-layer prototype, beam tests with muons and possibly pions

Due to reduction of funding not all activities will take place.

WP2 - Recent Results

Cost-effective Designs and Novel Materials

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WP2.1:

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

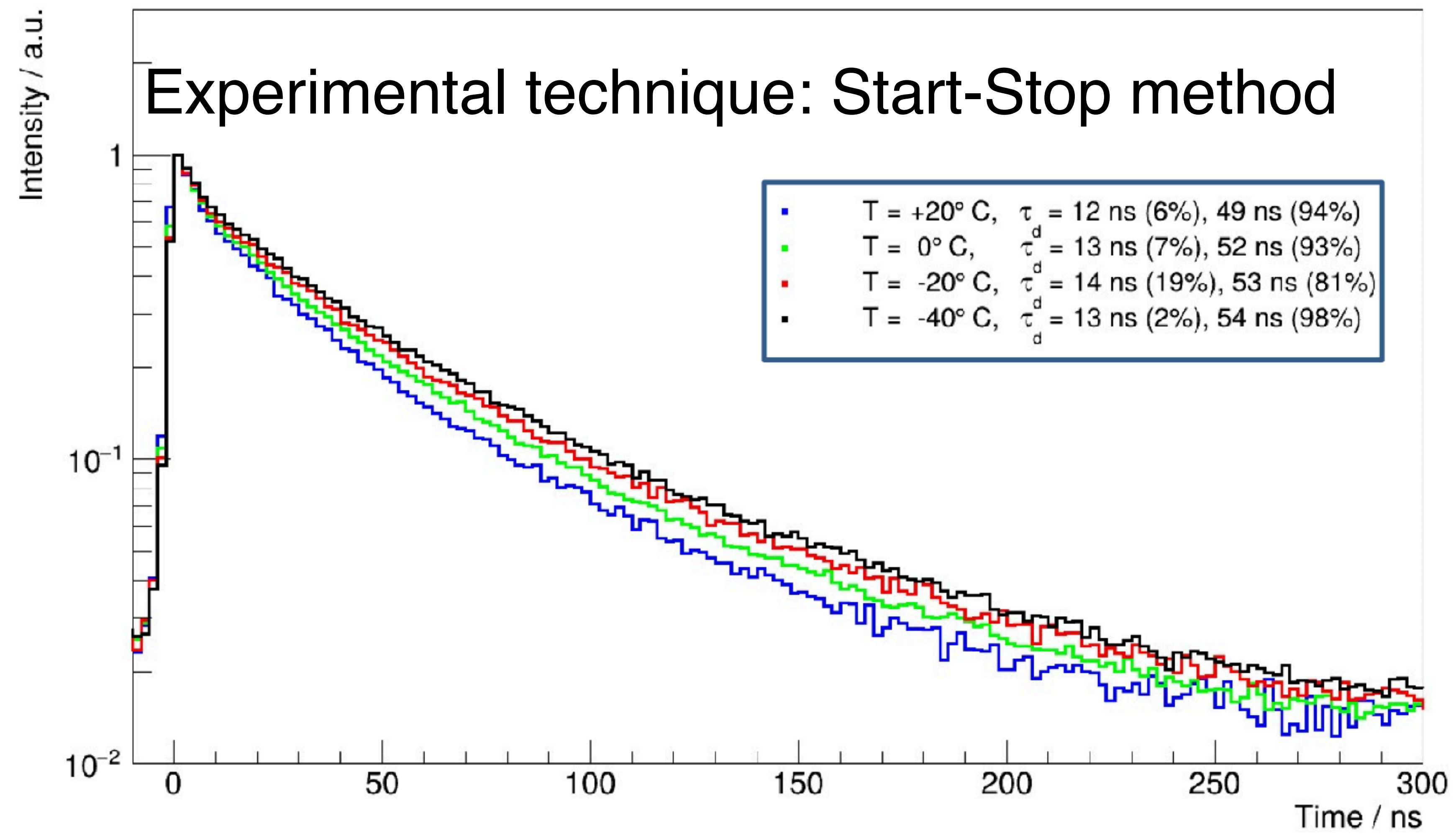
- The activity with different scintillation materials:
  - Ceramics scintillation material **$(Gd_2Y_{0.5}Lu_{0.5})Al_2Ga_3O_{12}$: Ce, Mg**
  - $BaO*2SiO_2$: Ce (DSB) glass scintillation material
- **Goals**:
  - Increase of density. Best combination of cations to optimize Zeff, LY, CTR. Reduction of slow component based on implementation of Lutetium(Lu) in the matrix.

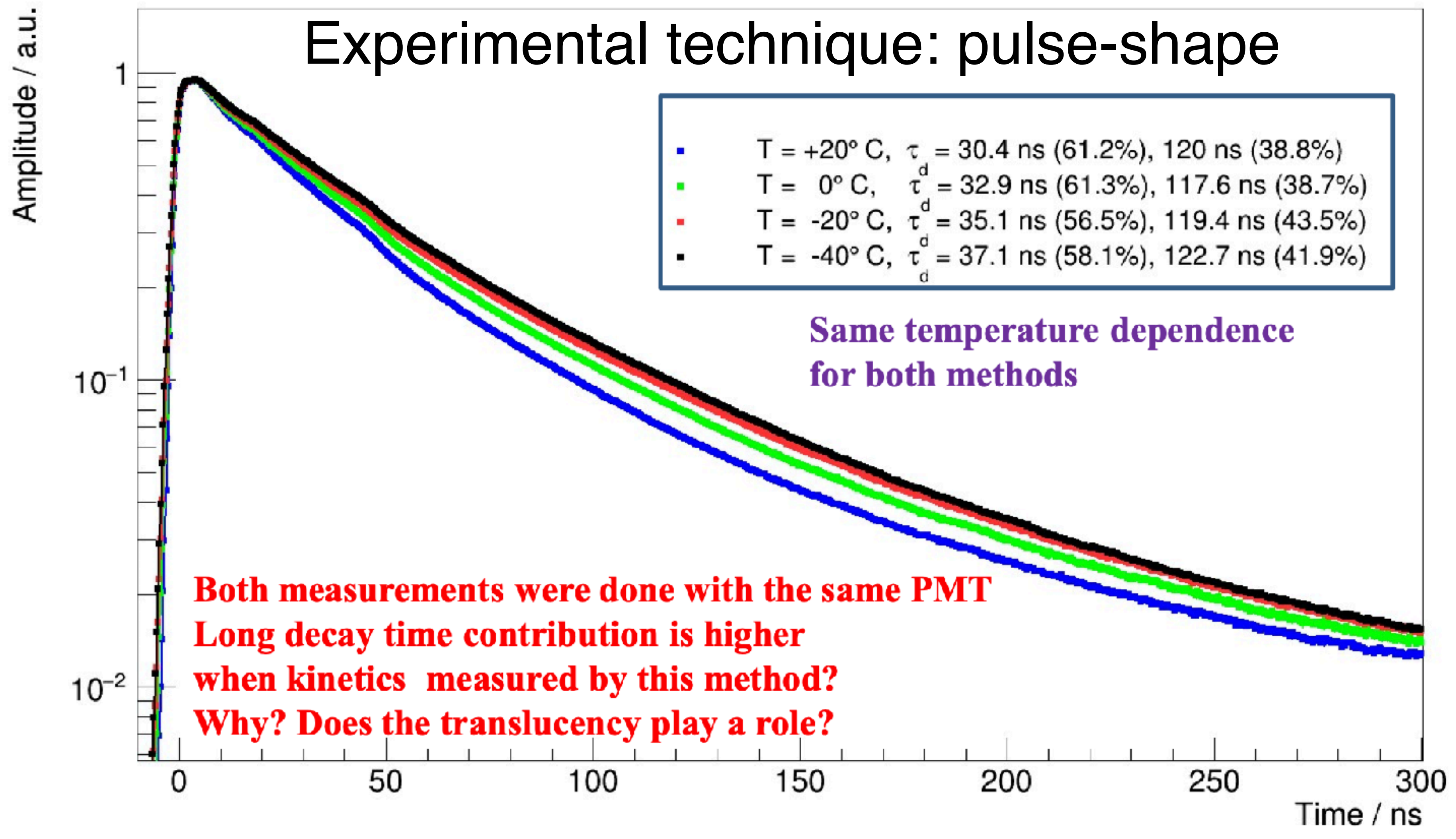
Material	Density, g/cm^3	Light Yield, ph/MeV	τ_{sc}, ns	λ_{max}, nm
$Bi_3Ge_4O_{12}$ (BGO)	7.1	9 000	300	505
Lu_2SiO_5:Ce (LSO)	7.4	26 000	40	420
$(Lu_{0.8}-Y_{0.2})_2SiO_5$:Ce (LYSO)	7.0	30 000	36	420
$Gd_3Al_2Ga_3O_{12}$:Ce , Mg (GAGG)	6.6	46 000	80	530
$(Gd,Y)_3Al_2Ga_3O_{12}$:Ce , Mg (GYAGG)[1]	5.8	52 000	50	520
$(Gd,Lu)_3Al_2Ga_3O_{12}$:Ce (GLAGG)[2]	6.8	50 000	75, 190, 1300	545

Properties of heavy and bright scintillators in comparison to members of the GAGG family.

- GYAGG is too light
- GLAGG has an additional very slow component that can be critical for CTR.

Kinetics of scintillation:





WP2 - Recent Results

Cost-effective Designs and Novel Materials

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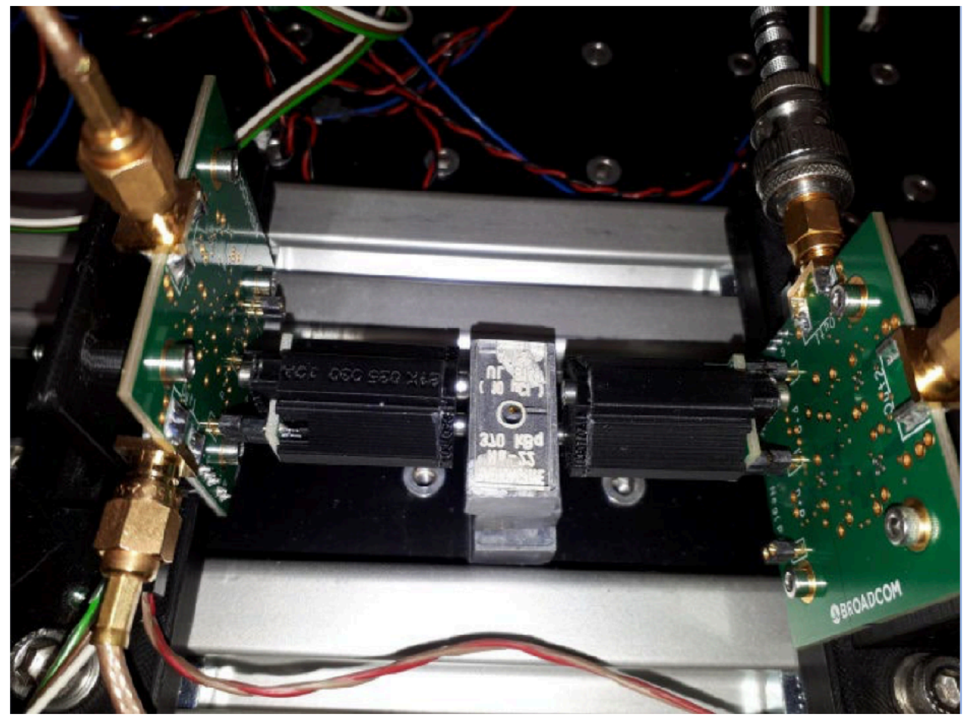
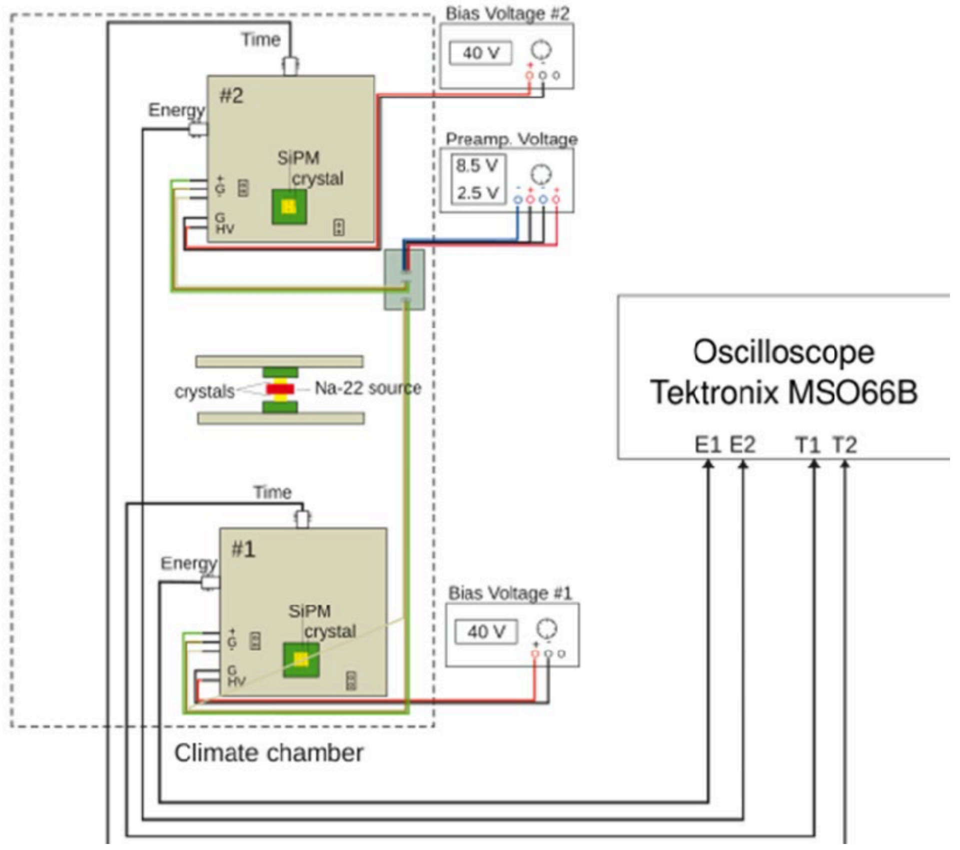
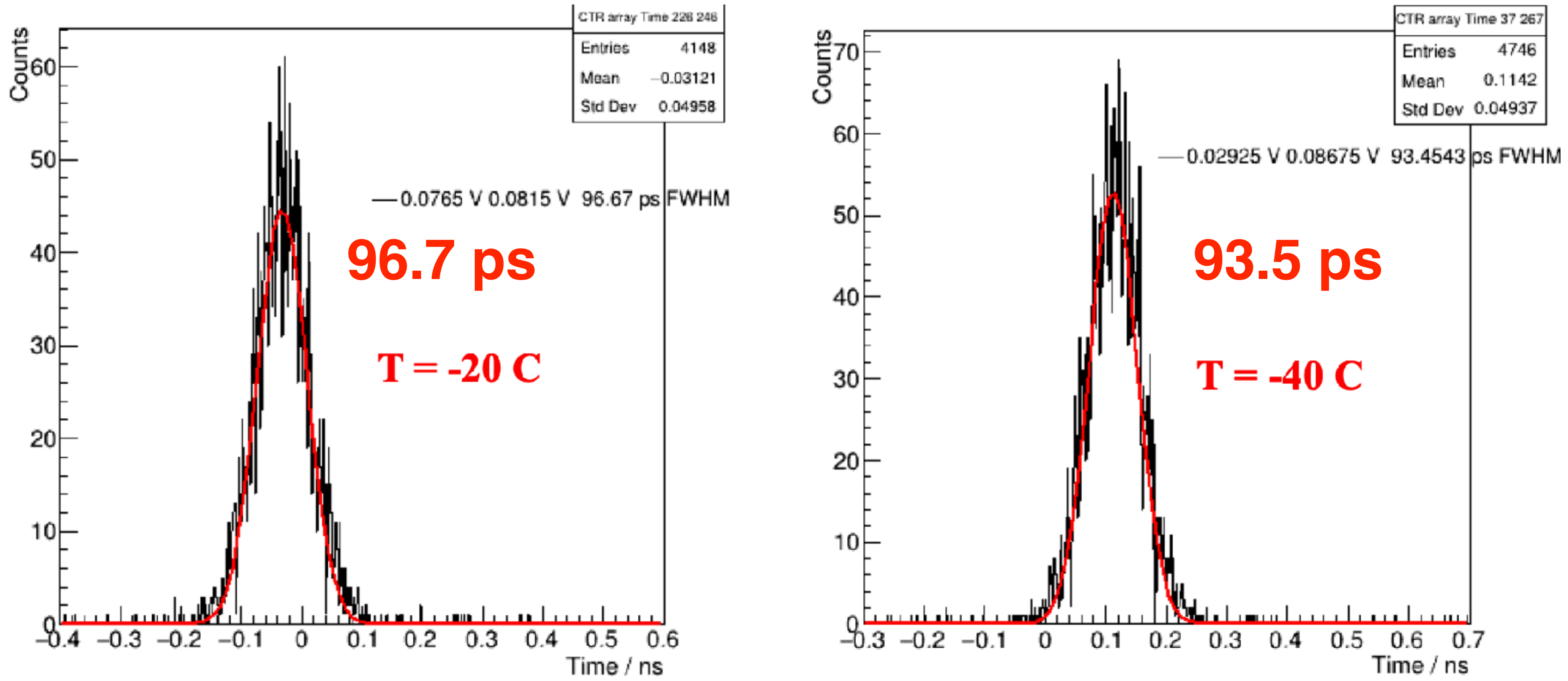
Coincidence Time Resolution (CTR) :

- Experimental set-up:

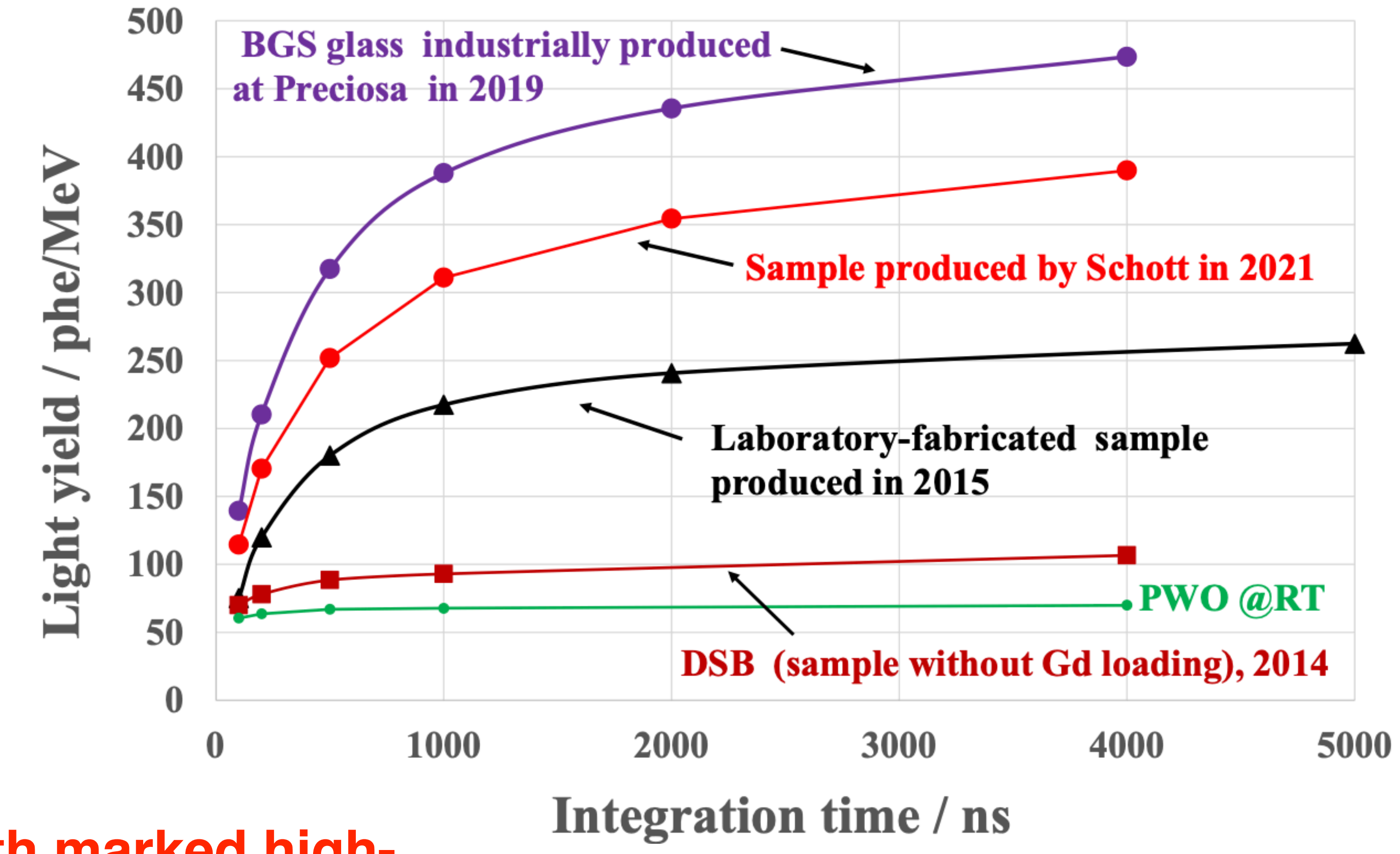






For the first time CTR (FWHM) values below 100 ps!

Properties evolution



$BaO*2SiO_2$: Ce (DSB) glass scintillation material:

- Two types of the glass materials have been delivered by Schott Company: 5 samples with 20x20x5 mm^3 , 5 samples with 20x20x50 mm^3.
- Physical properties of different heavy silica glasses:

Material	ρ g/cm3	Z_{eff}	X_0 cm	λ_{max} nm
$BaO*2SiO_2$	3.7	51	3.6	-
DSB: Ce	3.8	51	3.5	440-460
$BaO*2SiO_2$:Ce glass heavy loaded with Gd	4.3-5(?)	56.9	2.6	440-460

Beam test results with marked high-energy photons @ MAMI June 2023

Planned Activities

Brief Summary

- ***WP4: Sensors and Scalability*** - main R&D thrust: Develop and characterize basic elements of optical calorimeters: SiPMs, scintillator materials
- WP4.1 SiPM characterization and radiation tolerance (UHH)
  Characterize SiPMs for calorimeter prototype, explore performance in areas relevant for other applications such as LIDARs
- WP4.2 Scintillator materials and production techniques (JGU, JLU)
  Explore and develop alternative scintillator materials and geometries

WP4 - Recent Results

WP4.1 SiPM characterization and radiation tolerance

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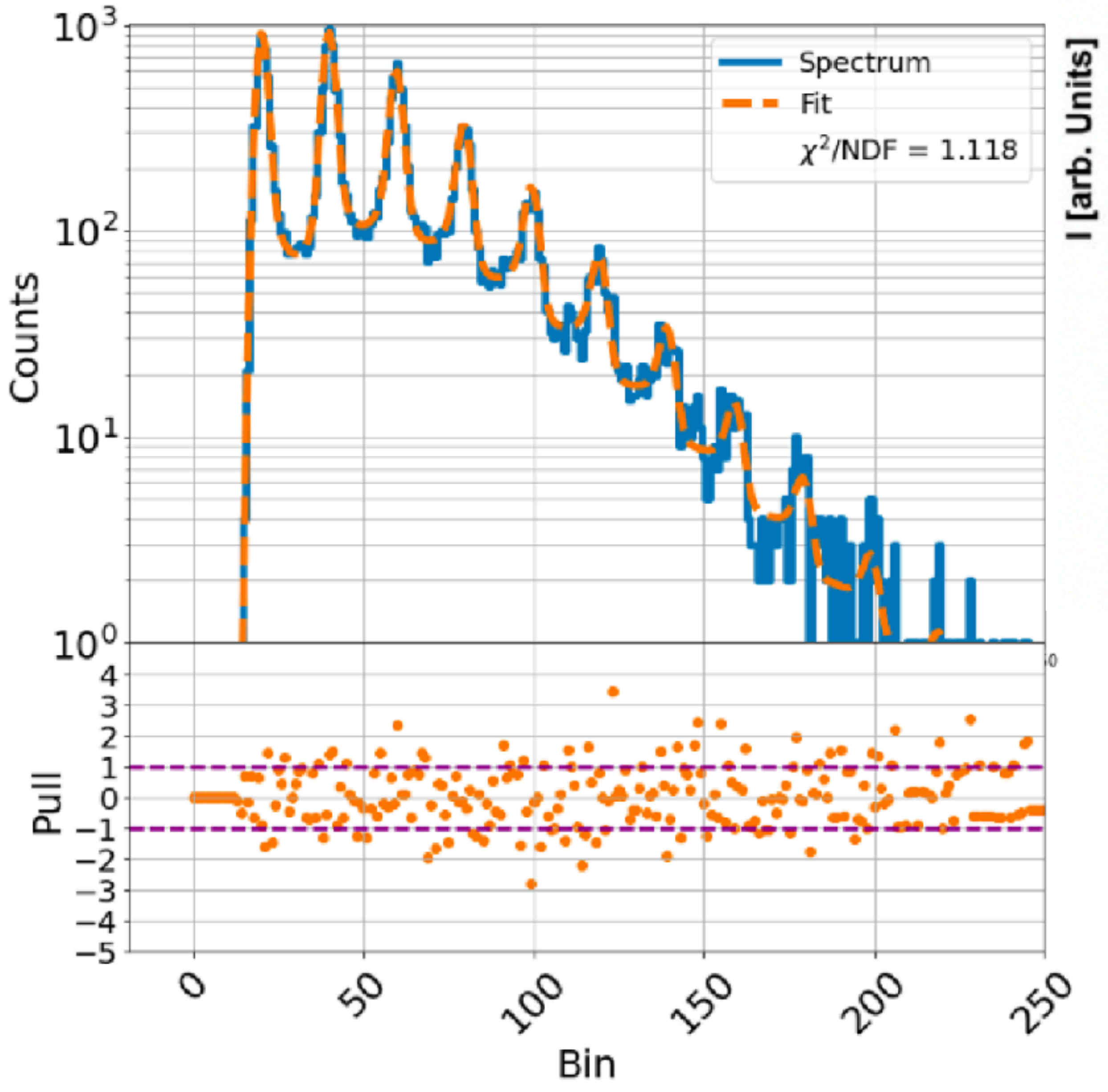
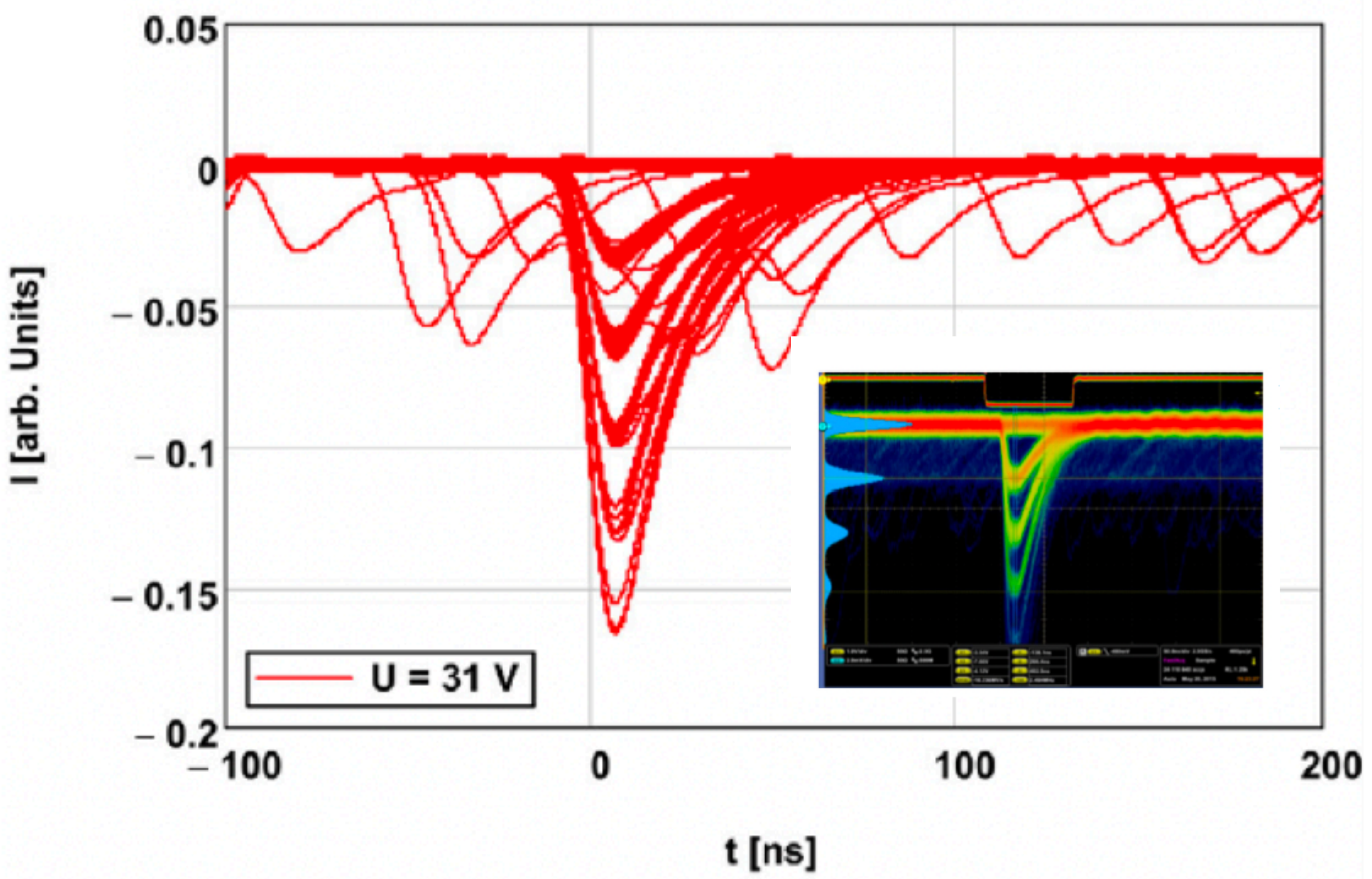
The SiPM non-linear response:

- The detailed studies of the response of SiPMs, including after irradiation, have been and are being performed.
- Develop a tool to enable **fast simulation of SiPM response** based on knowledge of basic SiPM parameters.

SUM Model:

- A comprehensive model that describes SiPM operational physics while bridging the gap between low and high light response regimes
- A modular and extensible framework for SiPM simulation, optimization, and characterization.





1. Single cell signal
2. SiPM key parameters
3. Light source

SUM
SiPM Unified Model

SiPM response:

- For every event and Geiger discharge:
  - Time of arrival.
  - Cell ID.
  - Signal amplitude.
  - Type (light, DCR, OCT, AP).
- Transient for every event (from GA).

- **Step 1:** Extract the SiPM key parameters: Light spectrum.Fit with PeakOTron and Extract the SiPM parameters
- **Step 2:** Verify the model for low light intensity: Simulate low light intensity spectrum using the key parameters extracted in step 1. Validation: Compare measured and simulated spectra.
- **Step 3:** Validate the full SiPM response function on measurements:Simulation (SUM): Simulate the SiPM response function and the high light intensity spectrum with SUM.

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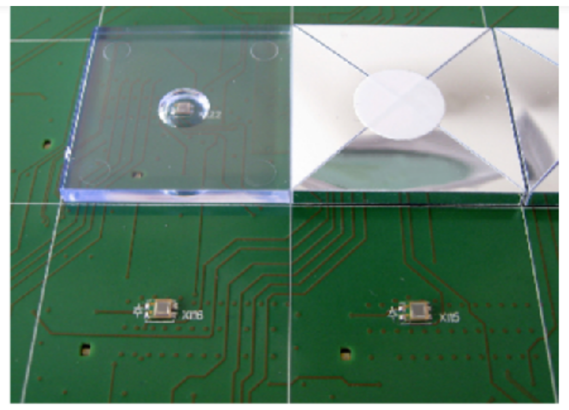
WP4 - Recent Results

WP4.2: Sensors and Scalability

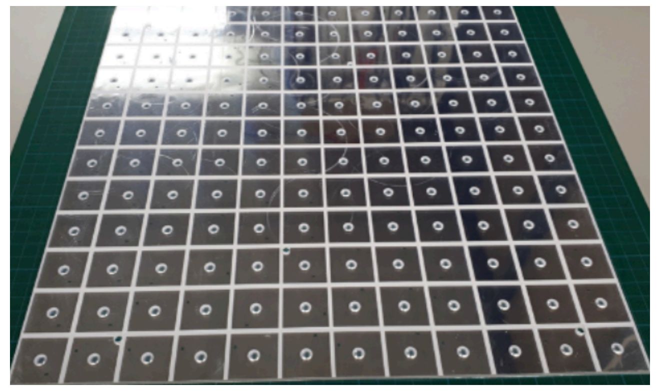
Megatiles and 3D printed scintillators.

Detector designs:

- **Single Design**: Scintillator tile individually wrapped in reflective foil. Glued to board one by one. **Light tightness.**



- **Megative design:** Large scintillator plate optically separated with **trenches**.



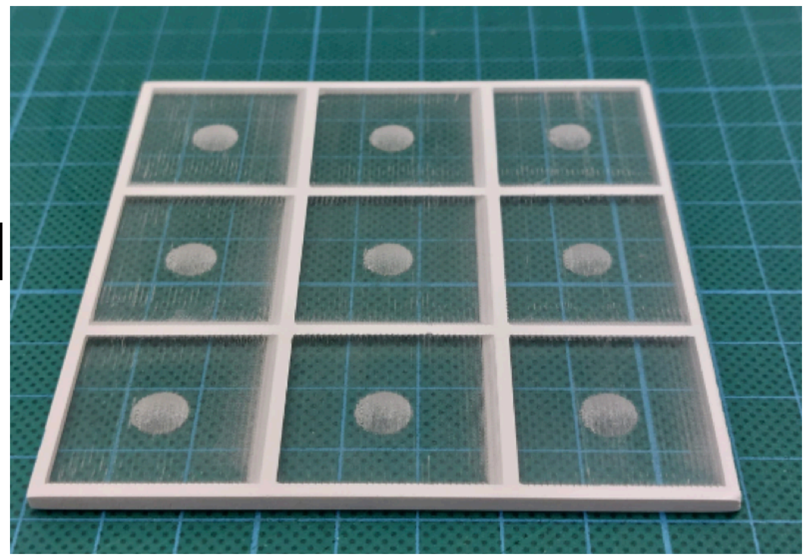
Megatile tests:

Beam test at DESY with 5GeV electrons:

- MIMOSA beam telescope with 6 planes. 1Megatile layer(latest prototype) right after telescope, 3 single tile layers behind.

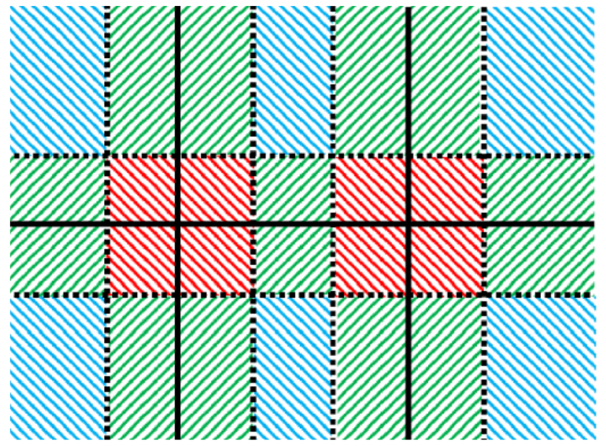
3D printed tiles :

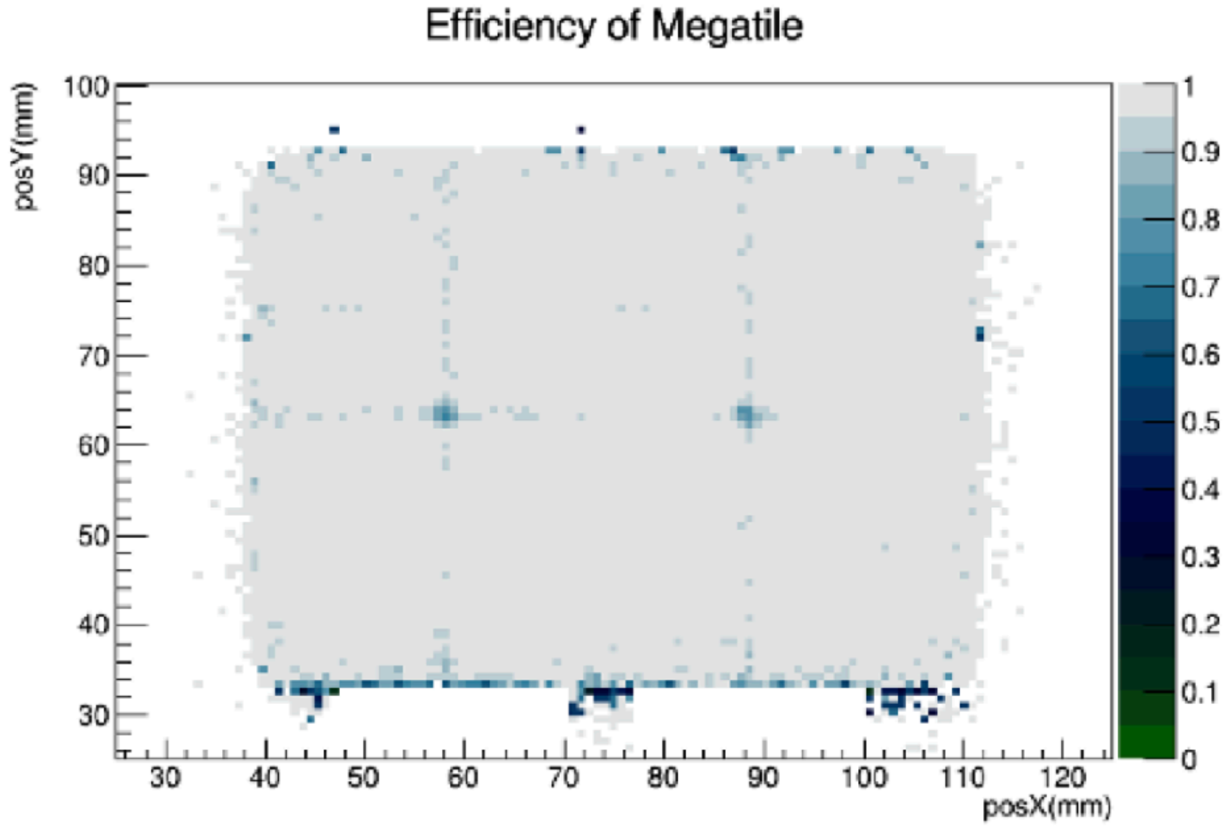
- First **3x3 tile prototype already printed**, but not tested, yet.
- Developing test stand to test and characterize printed megatiles.
- Test stand has 4 SiPMs to also measure cross talk.

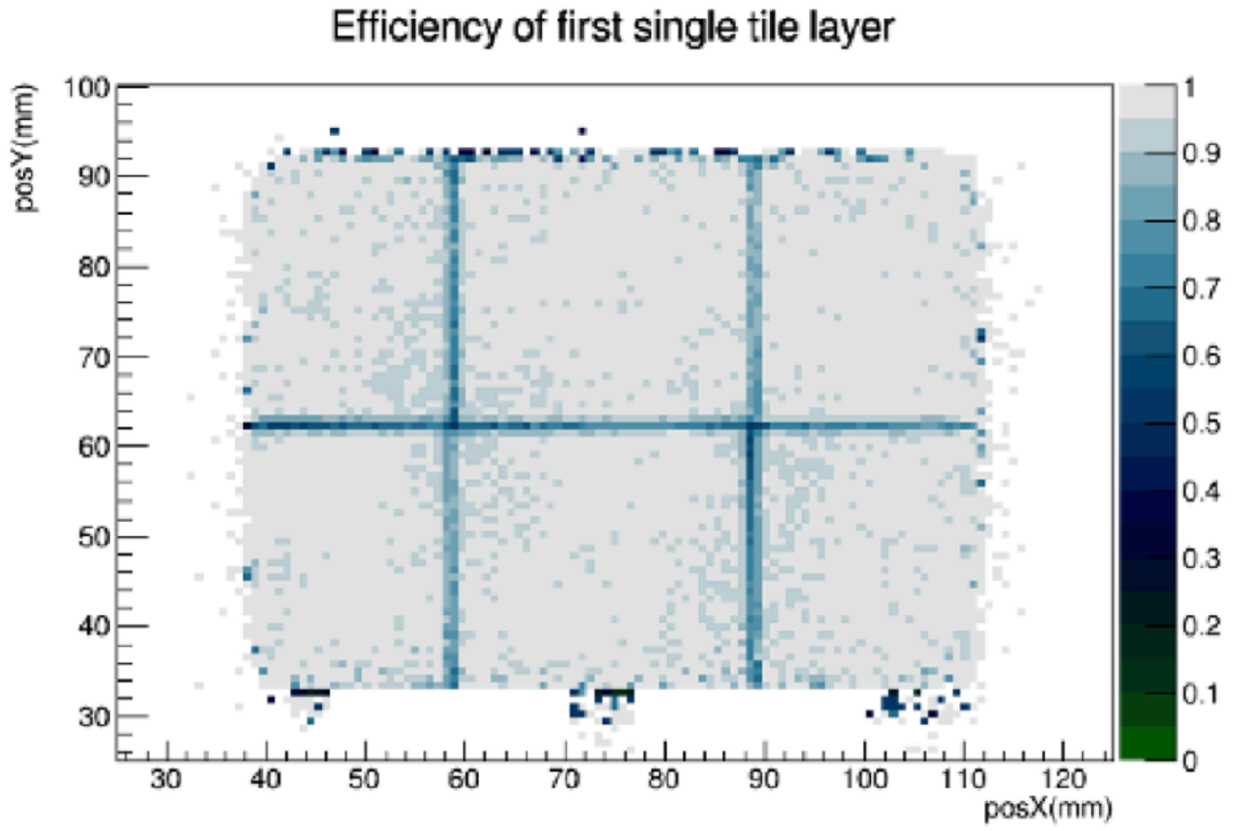


Efficiency results:

- If a particle hits a tile, how often is there signal? Each layer considered individually.
- Denominator: Events with single telescope track.
- Numerator: Energy deposit>0.5 MIP in a square with 2cm side around extrapolated position of track.







	Megatile	L2	L3
Total	0.983	0.956	0.957
Middle	0.983	0.965	0.964
Trench	0.962	0.705	0.720

- Simplifies mass production.
- No dead area in trench region
- Cross talk within acceptable level.

Summary & Outlook

- The High-D-Calo consortium is well under way
  - Activities in all funded workpackages
  - Lively exchange in collaborative subtasks
- Activities closely aligned with DRD6 collaboration, and ECFA Detector R&D Roadmap

- Consortium meeting with broad participation in December 2024
- More discussions at upcoming DRD6 collaboration meeting.