Hadronic calorimetry for the ePIC detector

Daniel Brandenburg

Jeff Wilden, Xiaocheng Zhu, Sam Corey, Riley Reedy + OSU group

Design optimization, validation, and Performance

Discussion with the nHCal, BHCal, and LFHCal

Discussion purpose

- Global ePIC HCAL paper vs. subsystem specific
- Many advantages to a global paper
- Proposed title: "Hadronic Calorimetry for the ePIC Detector at the Electron-Ion Collider"
- This talk
  1. Propose starting point (very rough) paper outline
  2. Discuss nHCAL plans
  3. Discussion

The three ePIC hadronic calorimeters use related scintillator-based concepts, optimized for different particle-energy, occupancy, and containment regimes.

Discussion Questions
- Does a global paper add value?
- Do we have the buy-in + workforce needed from each subsystem
- Is there a logical and coherent way to combine the subsystems
- In contrast – are there advantage to subsystem independent papers

Hadronic Calorimetry for the ePIC Detector at the Electron–Ion Collider: Design Optimization, Validation, and Performance

The ePIC Collaboration

[TODO: Insert author list and affiliations]

Outline version: July 22, 2026

Abstract

Outline note: Write one paragraph in the following order: (1) the physics need for hadronic calorimetry across the backward, barrel, and forward regions; (2) the different particle-energy and occupancy regimes that motivate region-specific depth and segmentation; (3) the nHCal, BHCal, and LFHCal technologies; (4) their common scintillator, SiPM, electronics, calibration, simulation, and reconstruction framework; (5) the principal validation results—nHCal large-tile source scans and optical simulation, BHCal heritage and ePIC validation, and LFHCal prototypes and beam tests; and (6) expected single-particle, neutron, jet, particle-flow, and muon performance. Avoid detailed dimensions and exhaustive resolution values here.

Contents

https://www.overleaf.com/read/zrmtmvfctkqx#a8c0a4

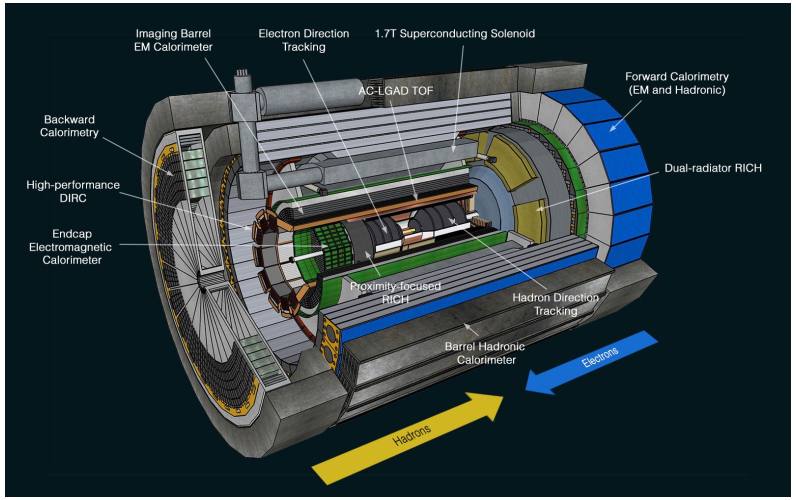
View only, but happy to share edit access

Global Paper outline

- Learning from the preTDR, a NIM article should not feel like 3 separate papers / chapters stuck together
- nHCAL and LFHCAL share a lot of synergy by design: technology, engineering, R&D, beam tests etc.
- Lots of shared physics and optimization strategies across all HCALs
- Overarching goal of paper: Demonstrated the holistic planning & implementation (across HCALs) for achieving maximal physics output of ePIC

Table 1: Comparison of the principal hadronic-calorimetry requirements by detector region. Numerical values should be added from the configuration-controlled requirements and geometry.

Requirement	Backward nHCal	Barrel BHCal	Forward LFHCal
Characteristic objects	Low-energy hadrons and neutrons	Neutral jet component and minimum-ionizing particles	High-energy hadrons and jets
Principal metric	Detection efficiency and low threshold	Neutral-energy constraint and muon identification	Energy resolution, containment, and shower separation
Depth strategy	Tail catcher with sampling optimized for low-energy response	Existing steel flux-return structure	Deep, longitudinally segmented calorimeter
Transverse segmentation	Approximately 10 cm tile scale; confirm baseline	Individual tile readout, fine in azimuth	Approximately 5 cm cells; finer insert
Longitudinal information	Sampling and threshold optimization	Multiple radial scintillator elements	Explicit shower-depth segmentation
Validation emphasis	Source scans and low-energy simulation	sPHENIX heritage and ePIC geometry/reconstruction	Engineering prototypes and beam tests



Please take a look at the overleaf (link on previous slide) and suggest changes

nHCAL update

Daniel Brandenburg

Jeff Wilden, Xiaocheng Zhu, Sam Corey, Riley Reedy + OSU group

THE OHIO STATE UNIVERSITY

nHCAL dedicated paper

- Up to now, we had indicated a dedicated nHCAL NIM-a paper
- We began working on a standalone paper (if global is no-go)

Design, Optical Validation, and Expected Performance of the Backward Hadronic Calorimeter for the ePIC Detector

The ePIC Collaboration

[TODO: Insert author list and affiliations]

Outline version: July 22, 2026

Abstract

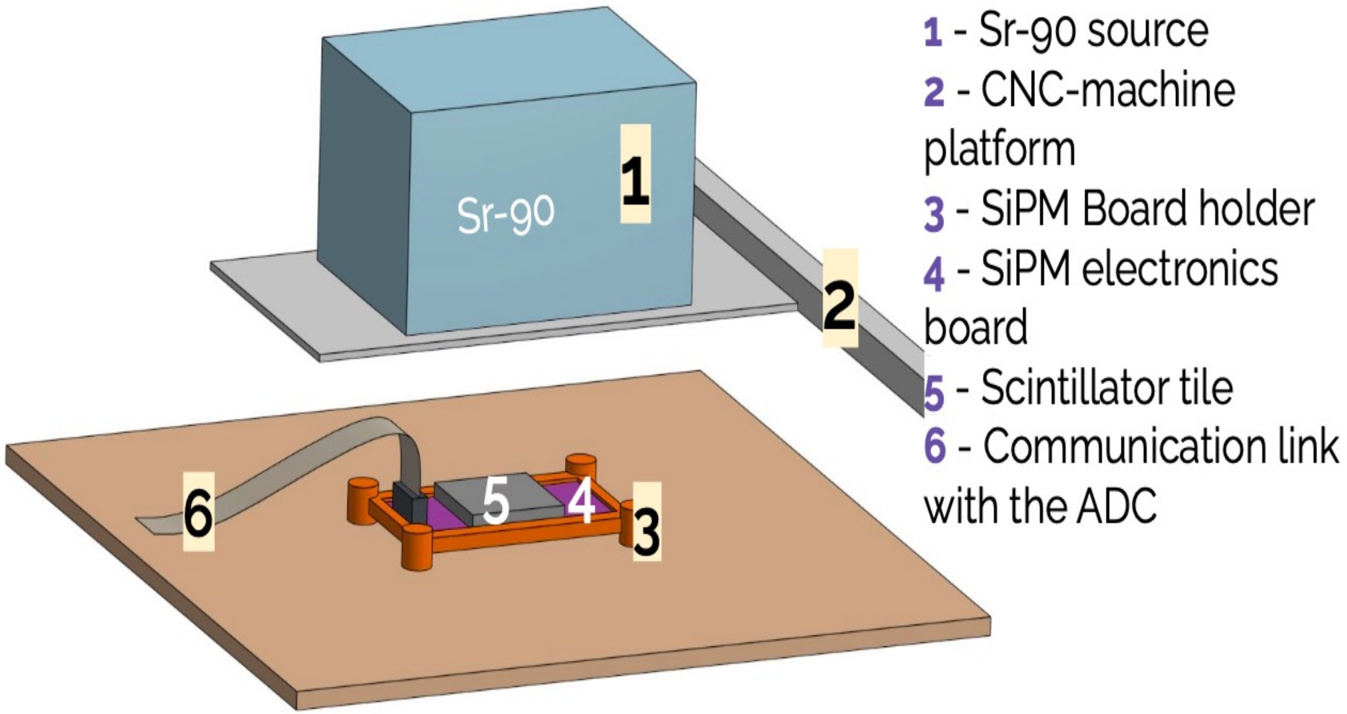
Outline note: Write one paragraph in this order: (1) the need for efficient detection of low-energy backward hadrons and neutrons in ePIC; (2) the principal nHCal functions and sampling-calorimeter concept; (3) the experimental program using collimated ^{90}Sr scans of $10 \times 10\,\mathrm{cm}^2$ scintillator tiles; (4) quantitative validation of an optical GEANT4 model; (5) propagation of the optical response into detector-level MIP, shower, and low-energy-hadron studies; and (6) the resulting design selection or constraints. State clearly which result is measured, which is simulation-based, and whether the construction baseline is frozen.

Contents

Purpose		Requirements
Low x and Q², high y high gluon densities		Coverage in backwards direction
diffraction	vector mesons	Good μ/π separation via MIP signal
	dijets	High efficiency for low-energy neutron detection
Neutral jets / neutral veto		
Charged jets		Good spatial resolution to distinguish clusters (neutral vs. charged)
Scattered **electron ID** (h veto)		
Improved hermiticity (↗ kinematic resolution in CC)		Good timing resolution

1. Validation of nHCAL Tiles

- Laboratory testing to validate larger / thicker nHCAL tiles
- nHCAL Design: 4cm Steel + 2.4 cm scintillator
- SiPM placement light collection & impact on MIPS

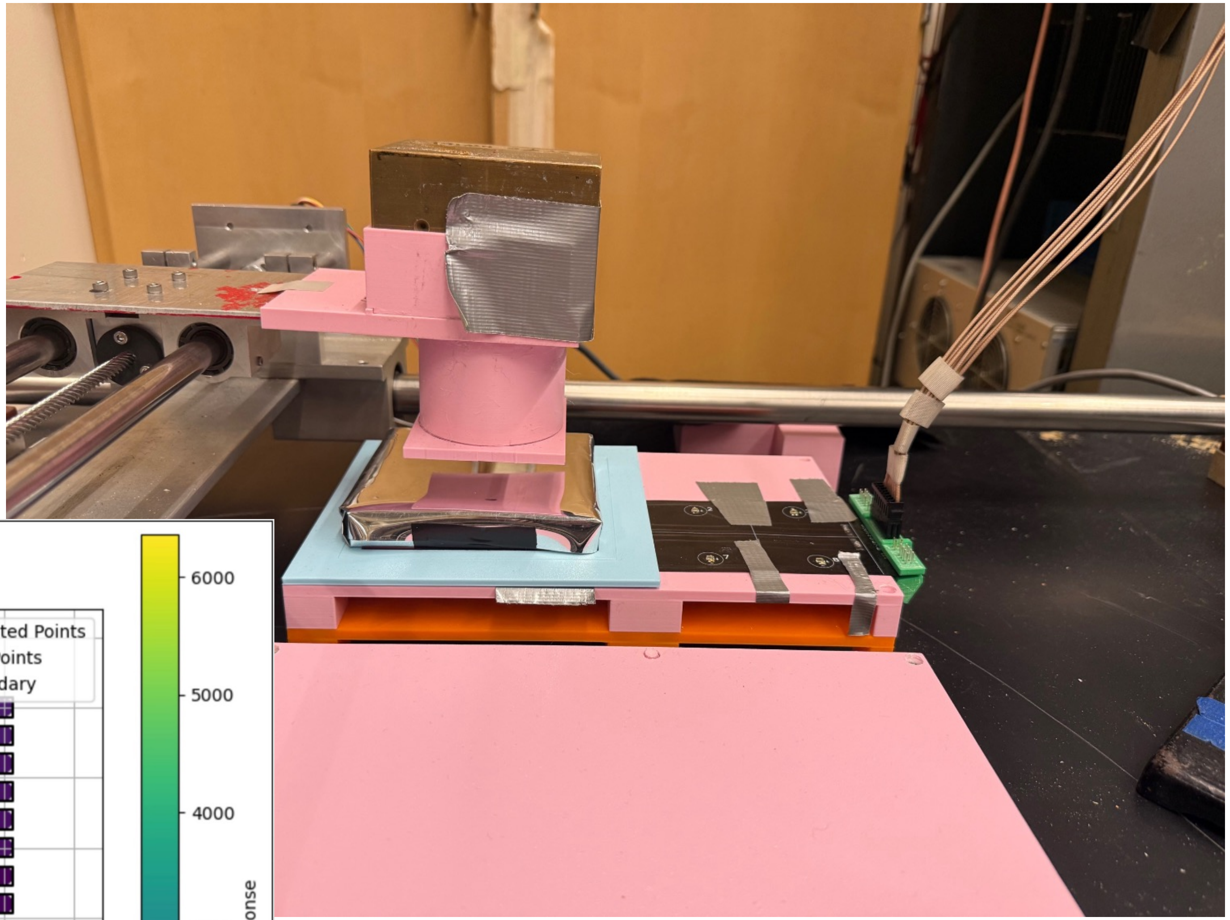


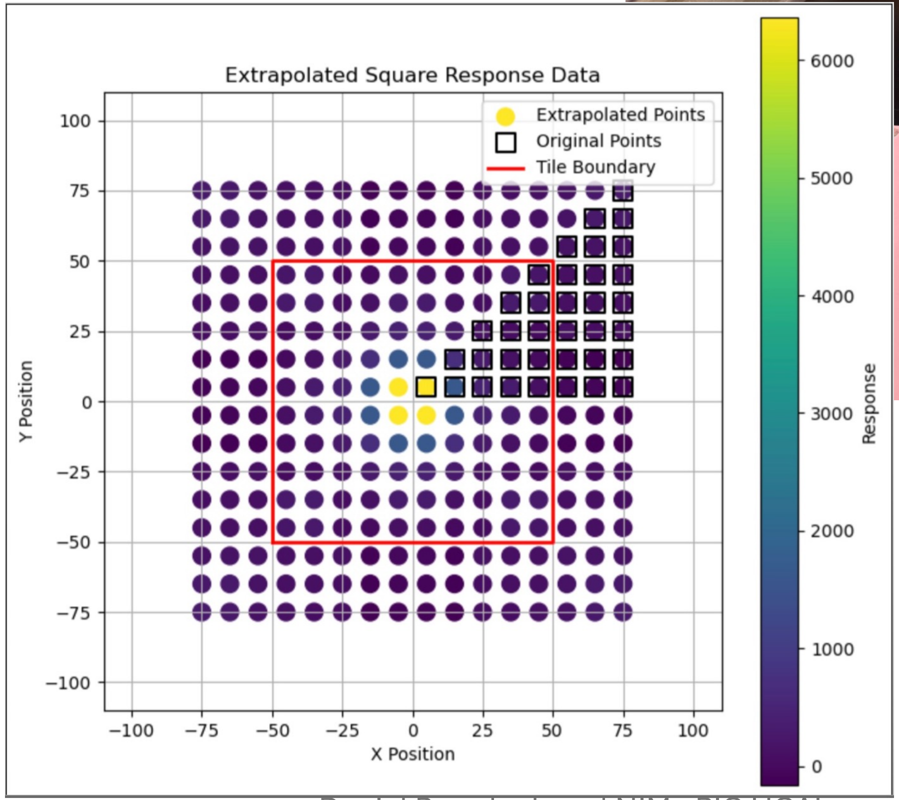
Tile testing in OSU Lab

Sr90 beta source

- Source moved through a list of positions via x-y table
- Tile centered over SiPM
- Readout through CAEN module

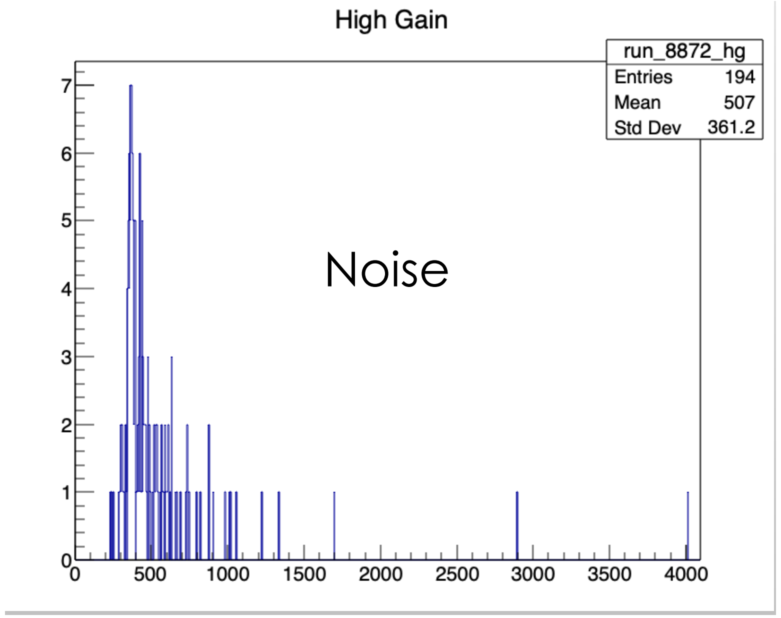
When running, lights are off and multiple layers of black felt is placed over the tile+PCB

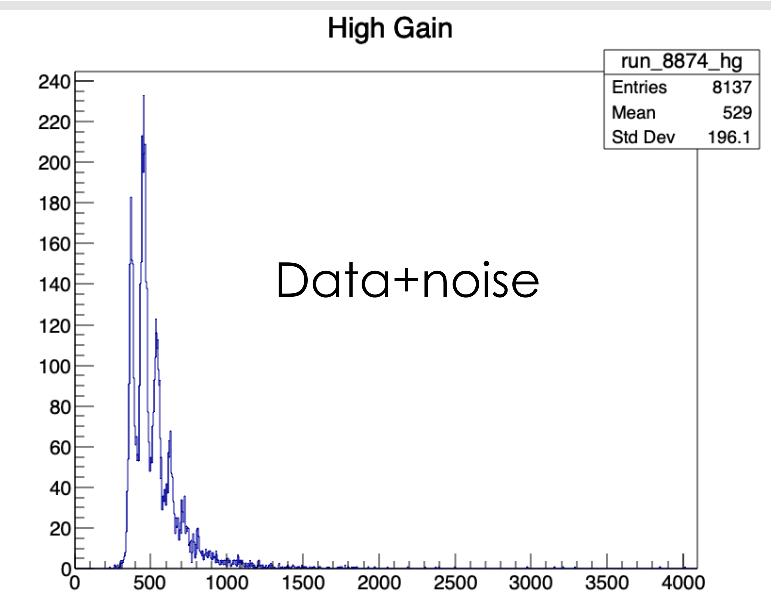


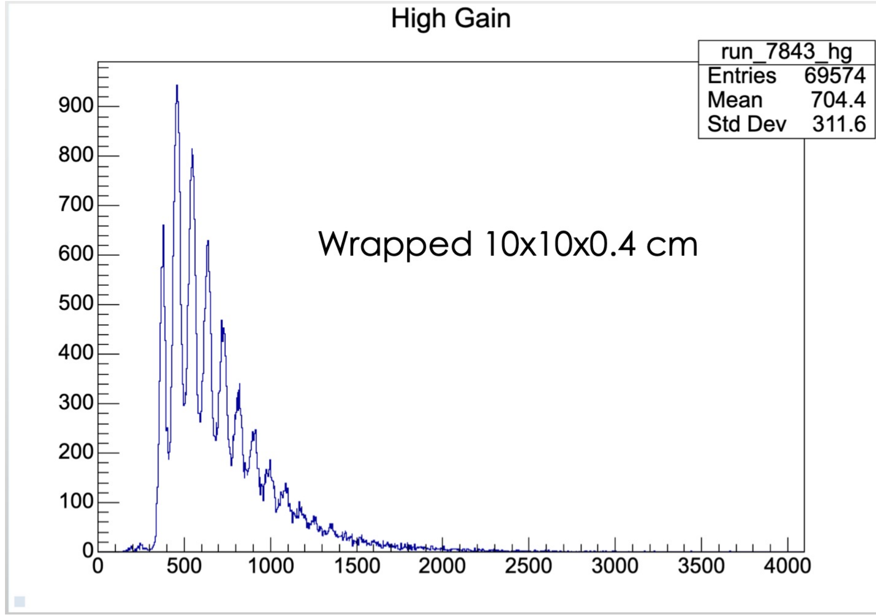


Nots on Data Collection

- The noise is sampled at the start and end at each run, and generally is < 5% of the total yield.







ADC

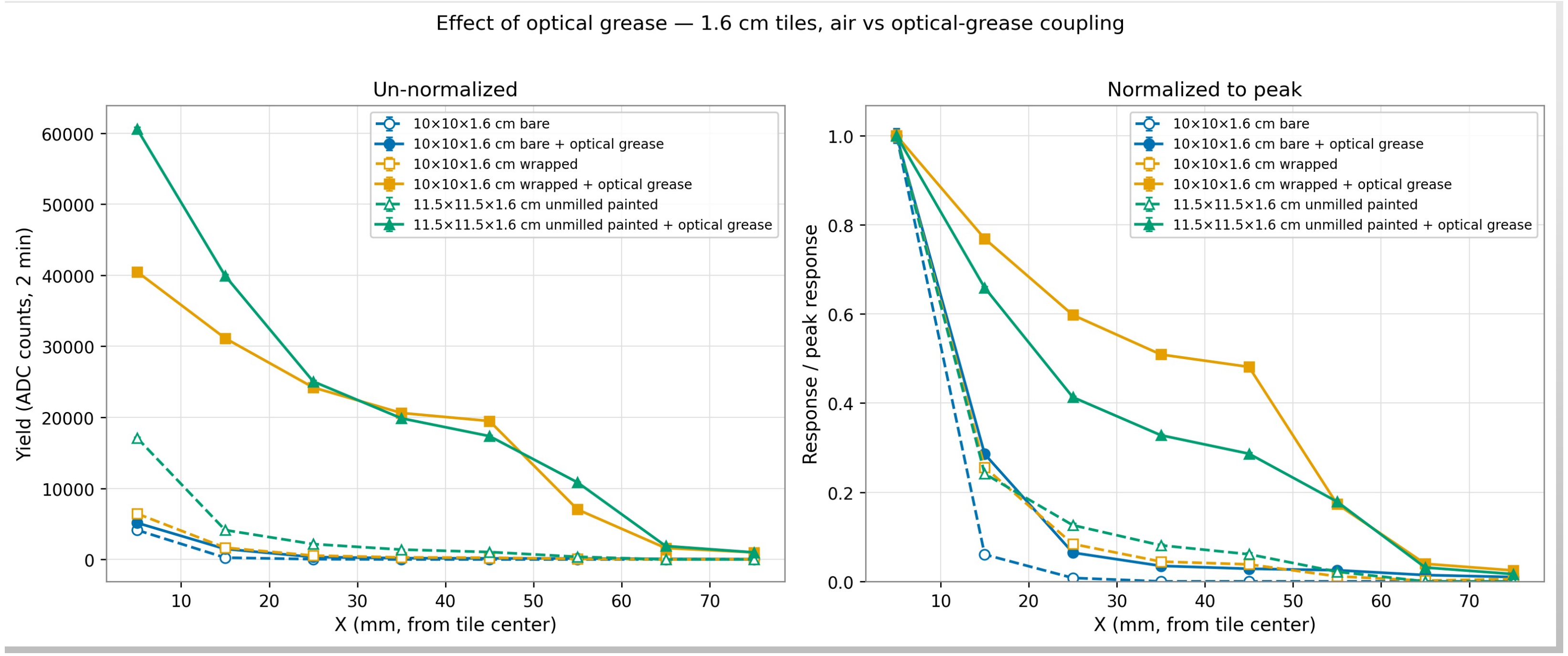
Example 2 min exposures

ADC

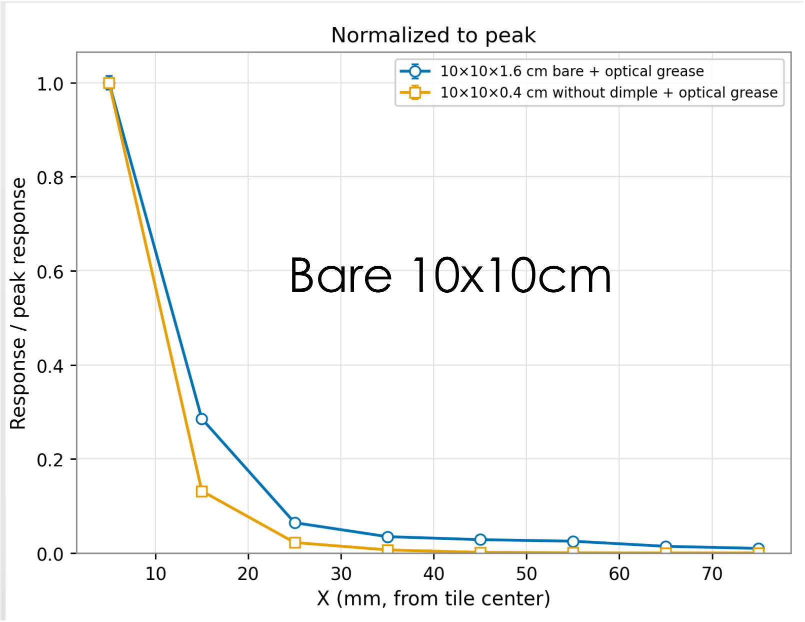
ADC

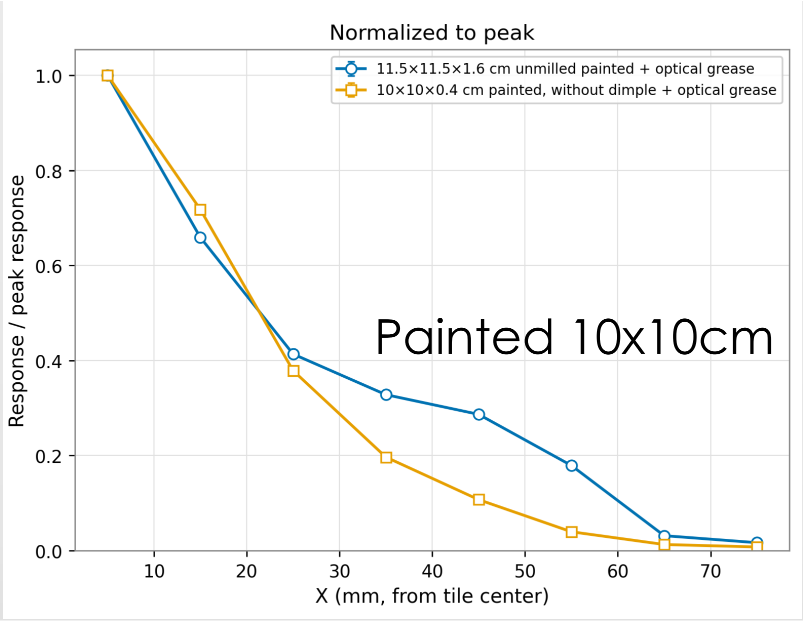
Effect of Optical Grease

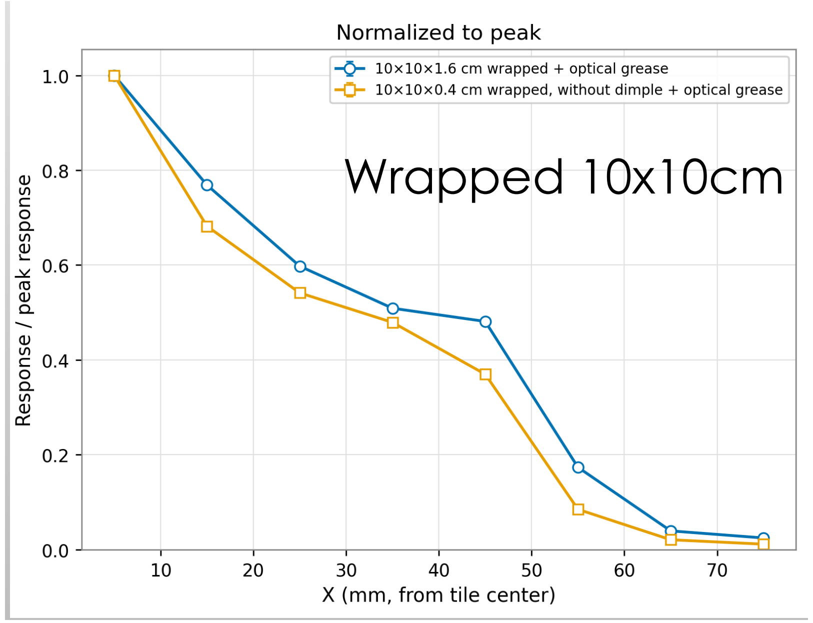
- Optical coupling has a very strong effect: a factor of up to ~3.5 increase in yield, and up-to 45% improvement in uniformity at tile edges



Effect of paint / wrapping

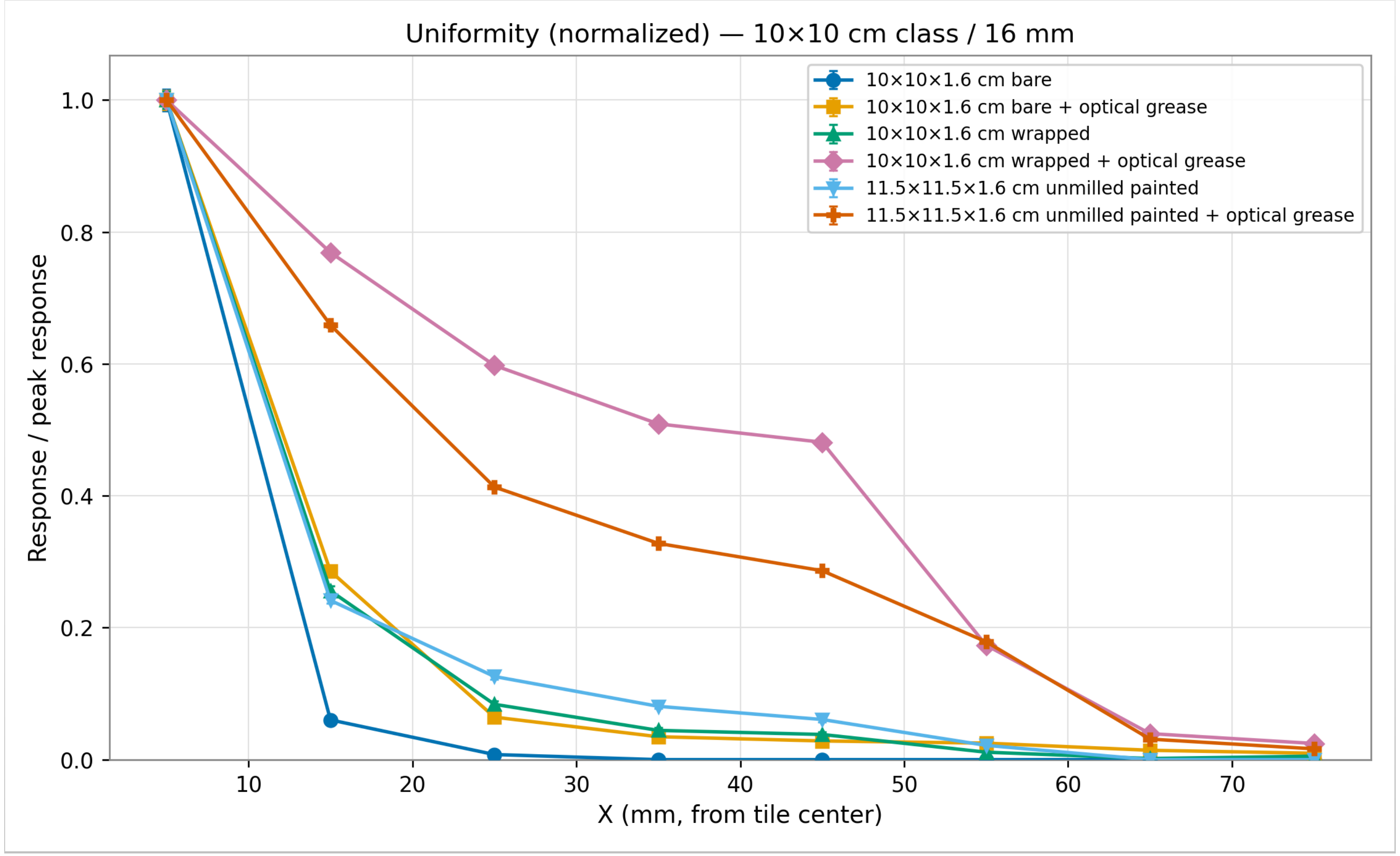






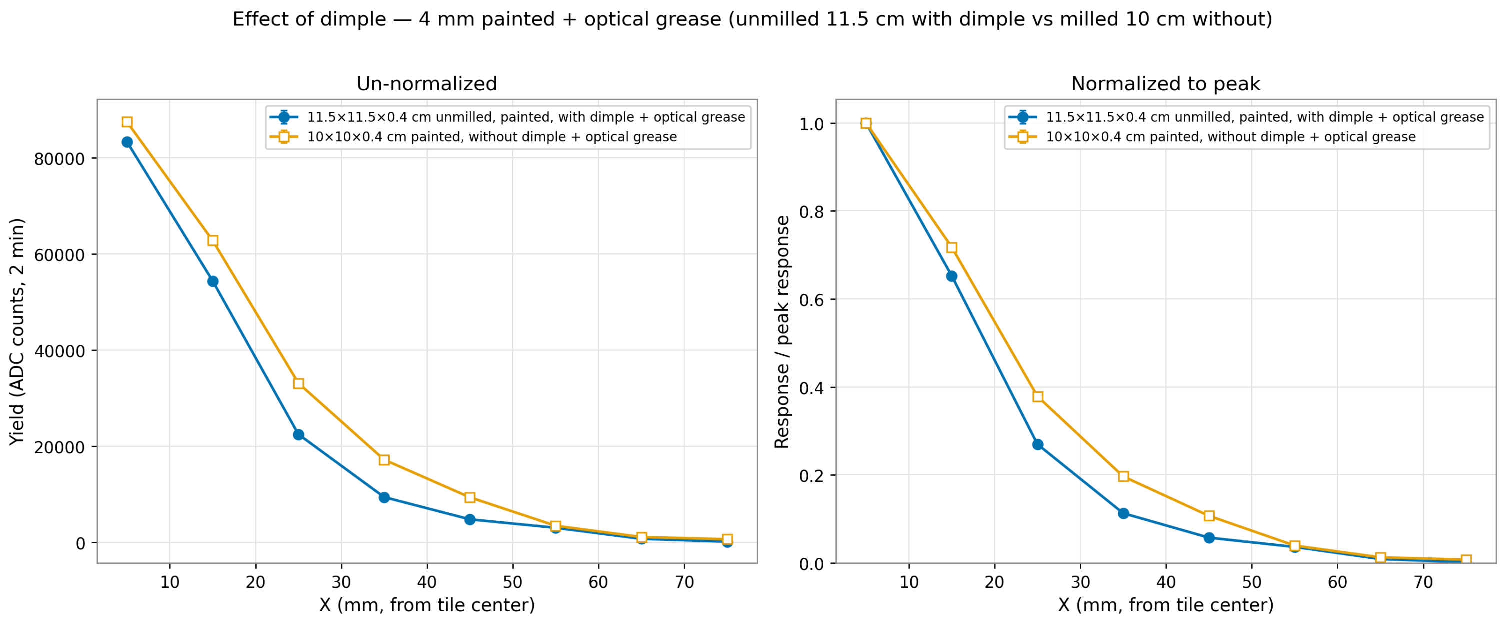
1) *properly* wrapped tiles perform the best: wrapped > painted > bare
2) Thicker tiles are marginally more uniform (at least no worse)

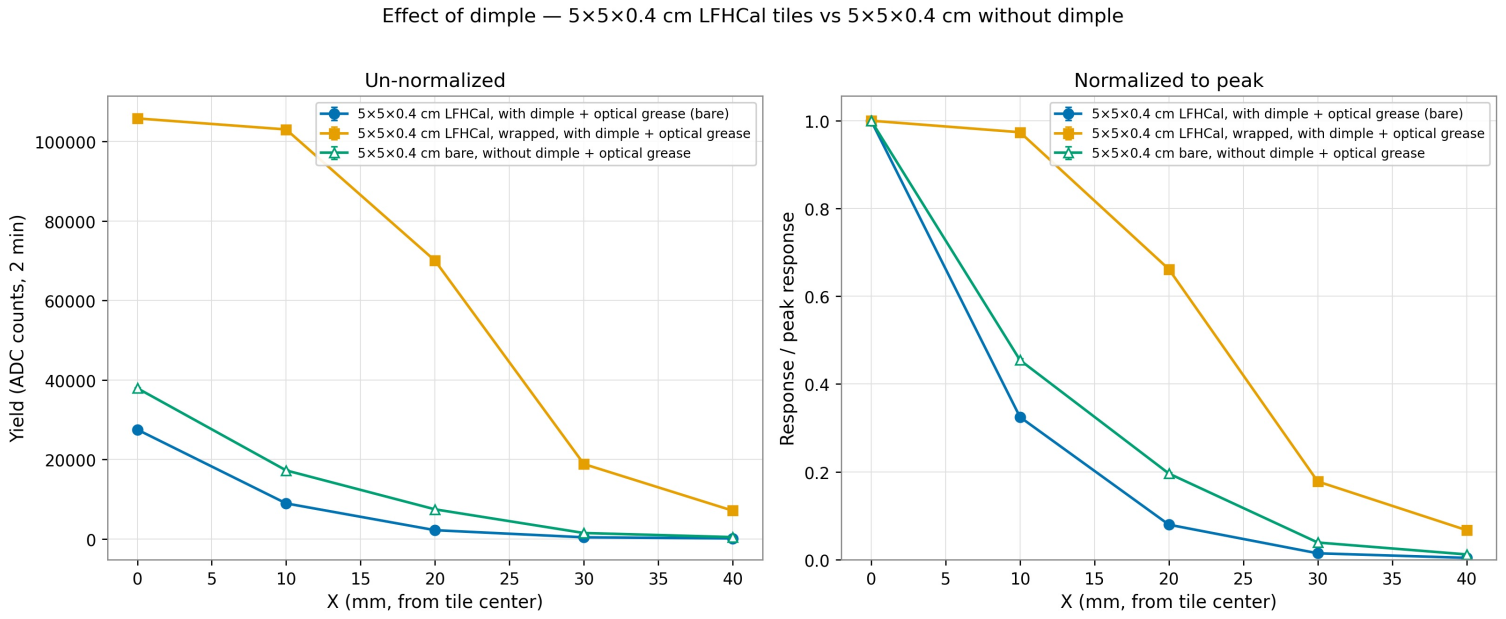
Wrapped > Painted > bare tiles



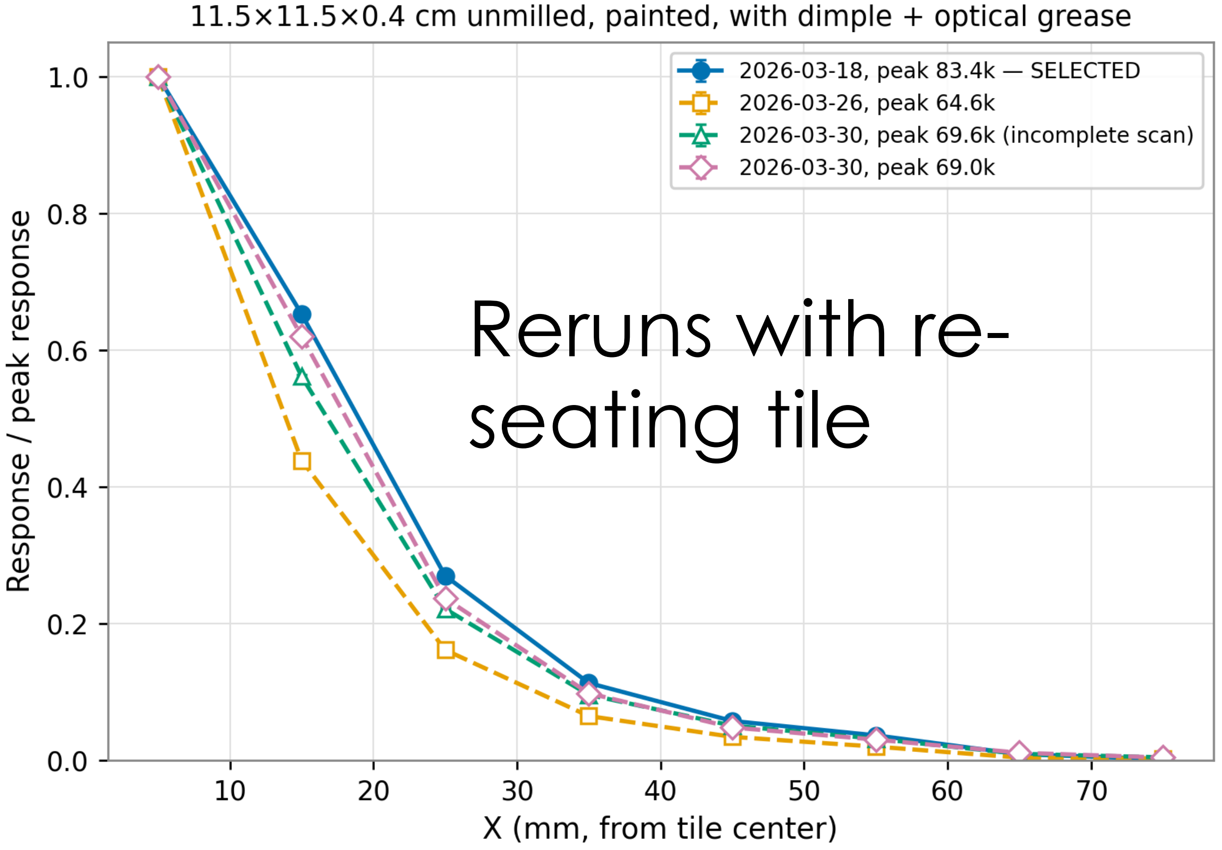
Dimple effect

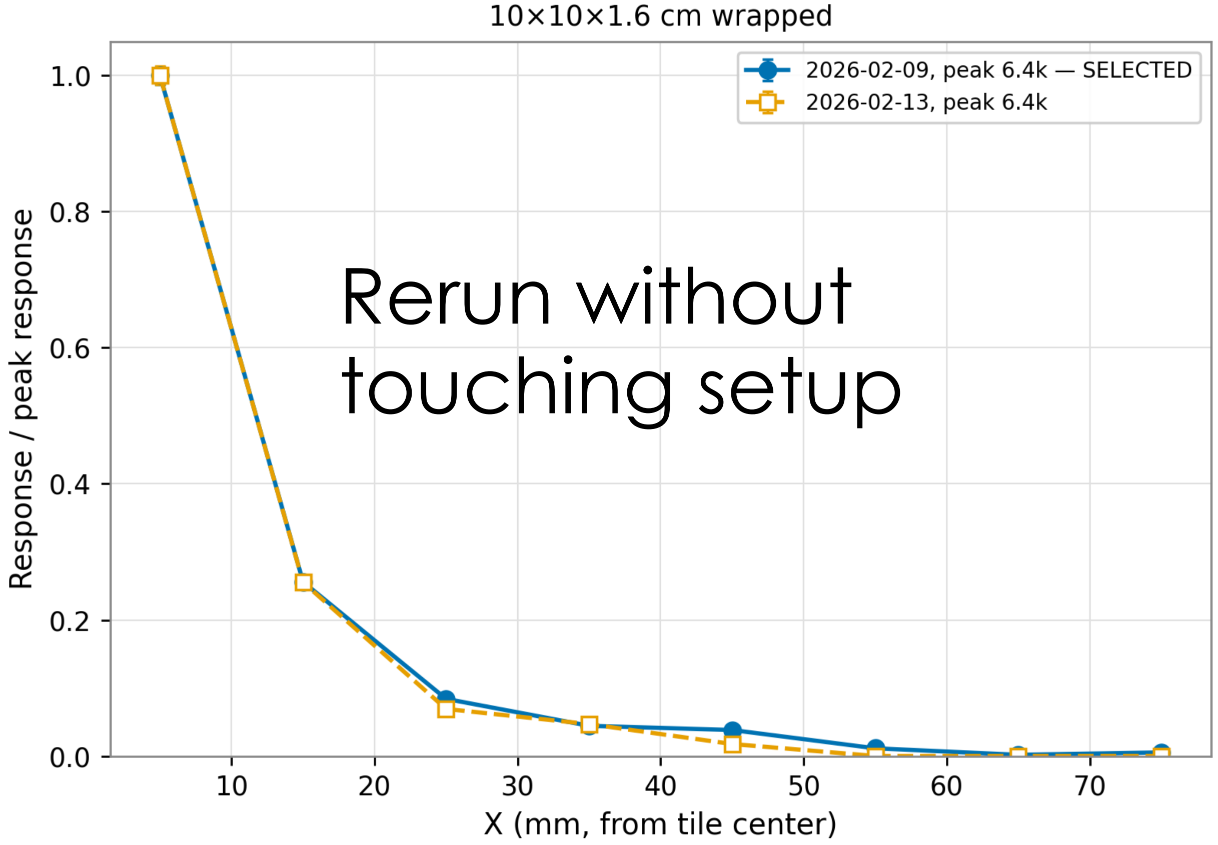
- Dimple in tile improves uniformity primarily by decreasing collection of light from particles hitting directly above SiPM





Lab setup reproducibility

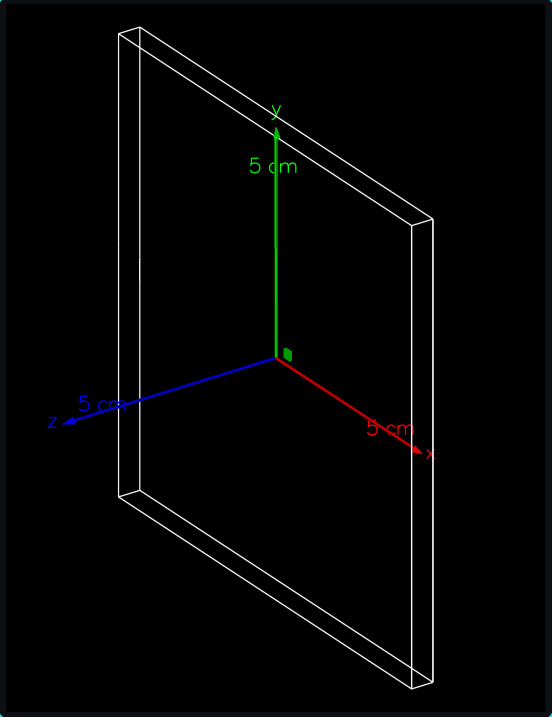




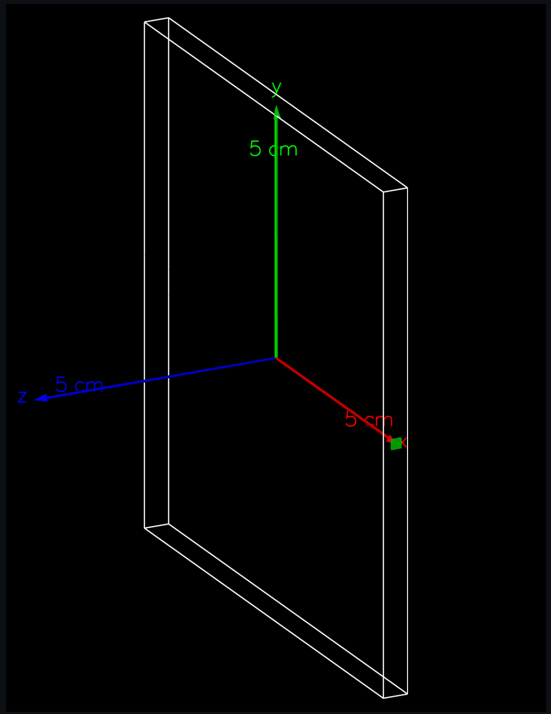
GEANT4 OPTICAL MODEL

Back, side, and dimple isolate geometry effects

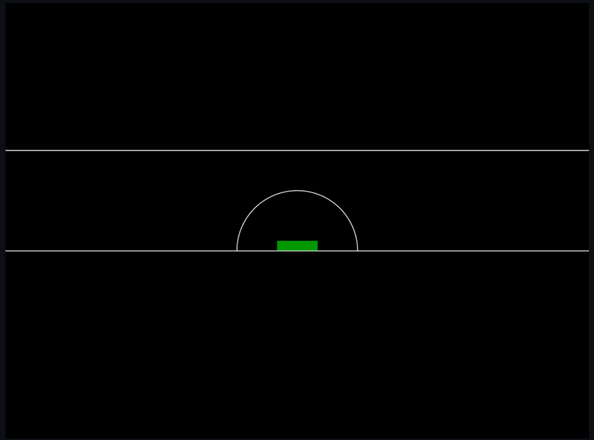
A Back-center



B Side-center (+X)



C r = 3 mm opening-mode dimple



y = 0 cutaway · visualization only

White wireframe: EJ-200 tile · Green: simplified silicon photon-entry volume

GEOMETRY
EJ-200
100 × 100 × 5 mm^3

SiPM PROXY
2.0 × 2.0 × 0.5 mm^3
historical epoch

SOURCE
n/a
geometry-only render

BEAM
n/a
0 events

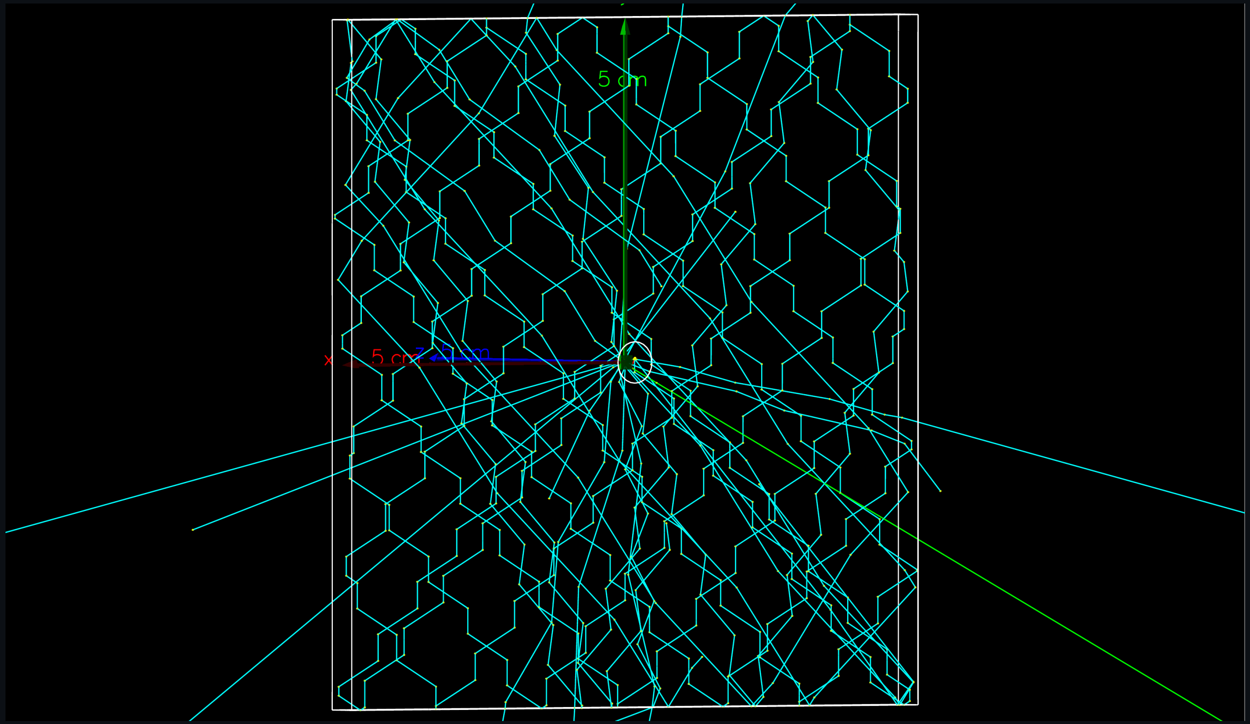
OPTICS
production-derived
true-scale geometry

READOUT
none
visualization only

RED-01 · accepted / frozen

GEANT4 OPTICAL TRANSPORT

One event makes optical transport through the tile visible



20 photons

generated in this event

30 / MeV

display-only scintillation yield

Scintillation yield reduced to 30 photons/MeV for visualization only; 20 optical photons were generated in this representative event.

Representative single-event display — illustrative, not statistical.

GEOMETRY

$100 \times 100 \times 5$ mm^3

r=3 mm surface-mode dimple

SiPM PROXY

$2.0 \times 2.0 \times 0.5$ mm^3

-Z · against dimple surface

SOURCE

point-like 1 MeV e^-

z=4 mm · direction -Z

BEAM

transverse σ=0 mm

angular σ=0 mrad

DISPLAY

1 event · 30 photons/MeV

20 photons generated

INTERPRETATION

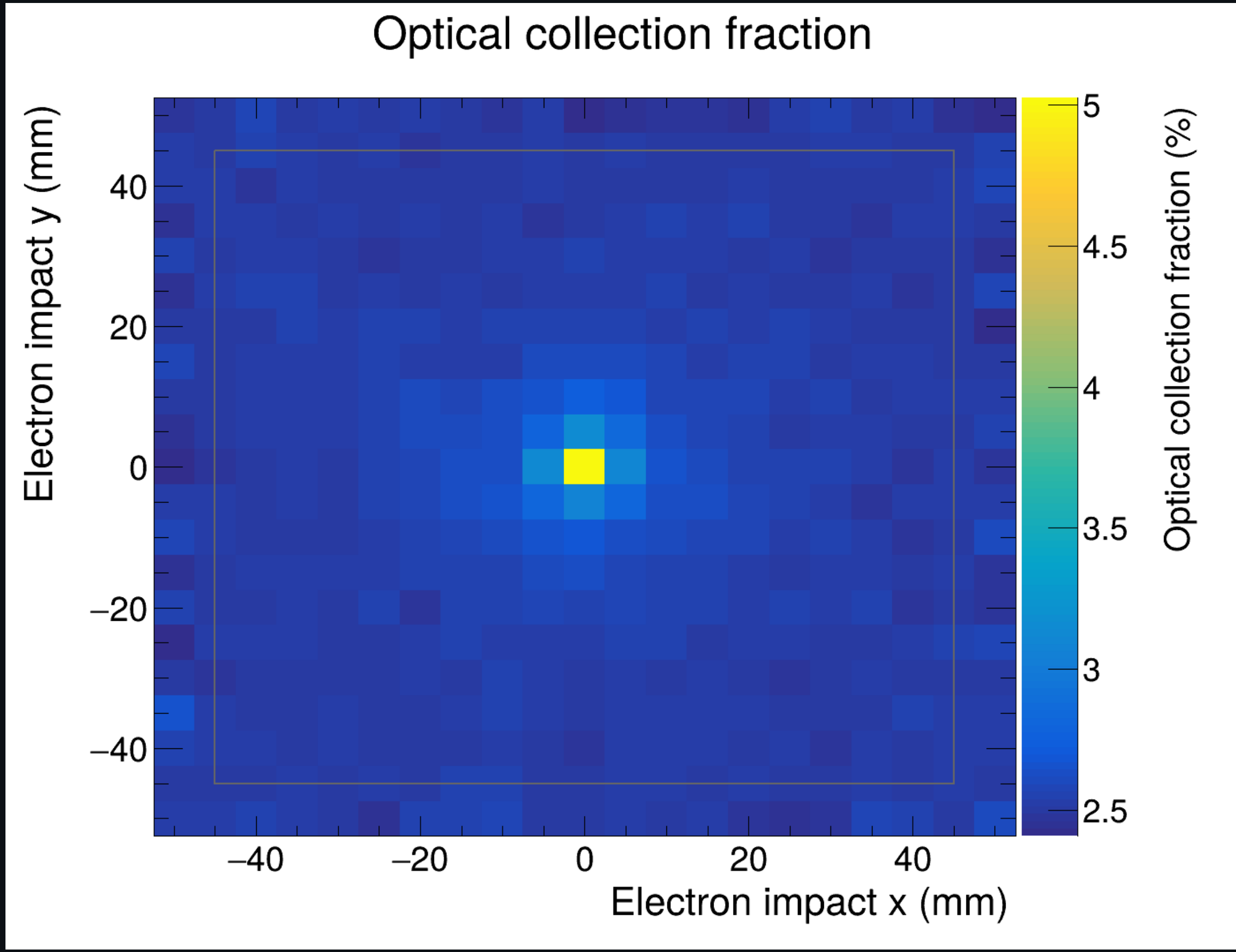
trajectory illustration only

not PDE or efficiency

RED-01D · historical / qualitative

POINT-SOURCE RESPONSE

Optical collection peaks directly above the back-center SiPM



5.03%

center / maximum

2.54%

full-grid mean

The sensor produces a localized peak; away from it, most of the tile stays near a common background.

dashed box: ±45 mm fiducial

GEOMETRY

EJ-200
100 × 100 × 5 mm^3

SiPM PROXY

2.0 × 2.0 × 0.5 mm^3
back-center · -Z · W05

SOURCE

point-like 1 MeV e^-
z=4 mm · direction -Z

BEAM

transverse σ=0 mm
angular σ=0 mrad

OPTICS

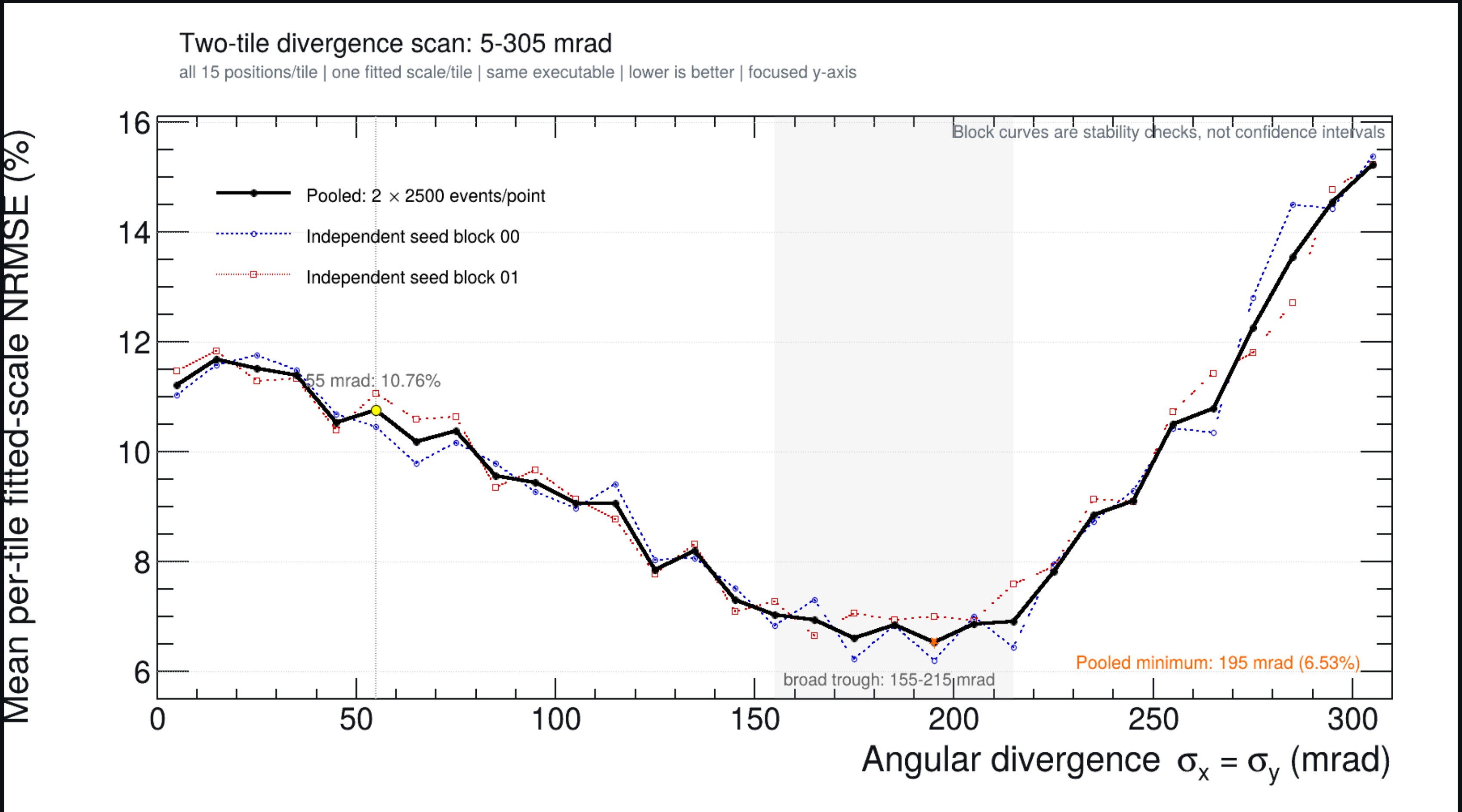
UNIFIED polished
no explicit coupling

SCAN / READOUT

21 × 21 · 5 mm step
100/point · optical fraction

W05 · historical factor study

The extended scan brackets a broad minimum near 155–215 mrad



CALIBRATION TILES

EJ-200 · 50 × 50 mm^2
4 / 16 mm thickness

SiPM PROXY

2.4 × 2.4 × 0.5 mm^3
back-center · -Z · LABV2

SOURCE

bare Sr-90/Y-90 β
sampled spectrum

BEAM

transverse σ=5 mm
angular σx=σy=5–305 mrad

OPTICS

polishedfrontpainted
EJ-510 · zero-gap proxy

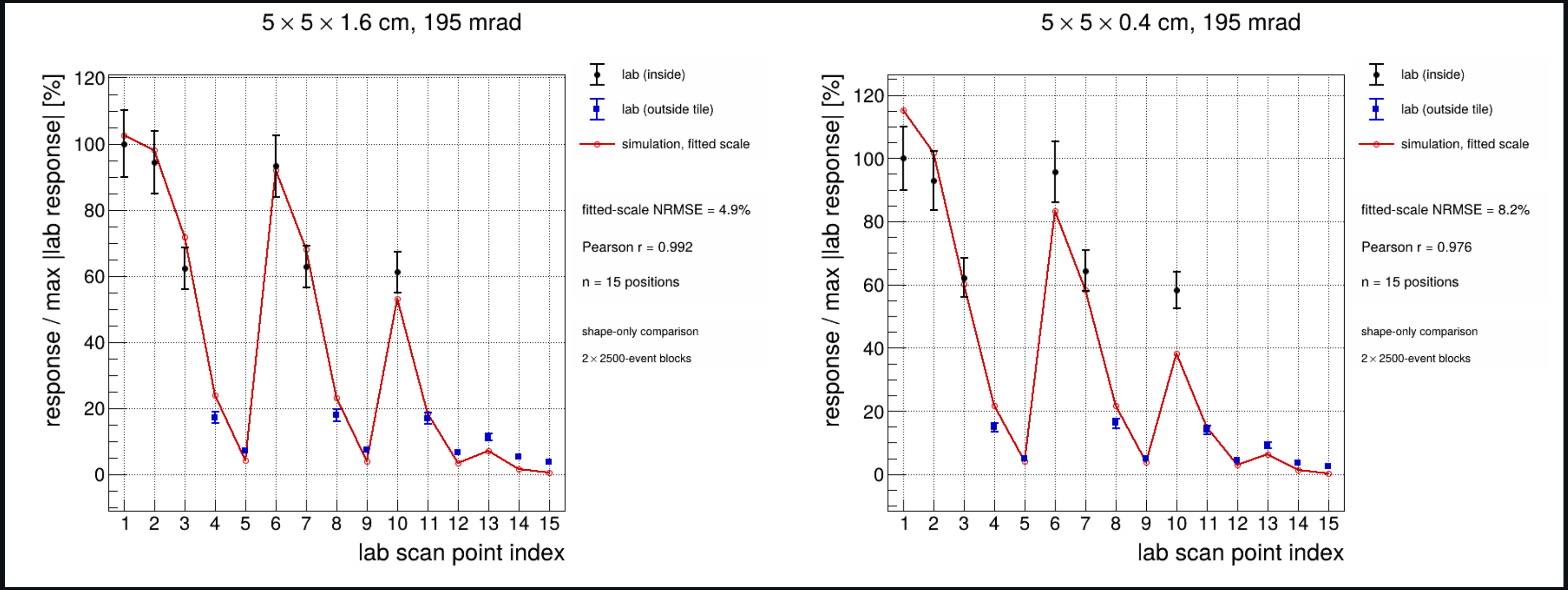
MATCH / SCORE

fitted-scale NRMSE
2 production seed blocks

LABV2 · 4.65M primaries
wide trough, not unique fit

SIMULATION–LABORATORY COMPARISON

At 195 mrad, simulation follows both 5 × 5 cm spatial profiles



TILE SET
EJ-200 · 50 × 50 mm
4 / 16 mm thickness

SiPM PROXY
2.4 × 2.4 × 0.5 mm^3
back-center · -Z · LABV2

SOURCE
bare Sr-90/Y-90 β
sampled spectrum

BEAM
transverse σ=5 mm
angular σx=σy=195 mrad

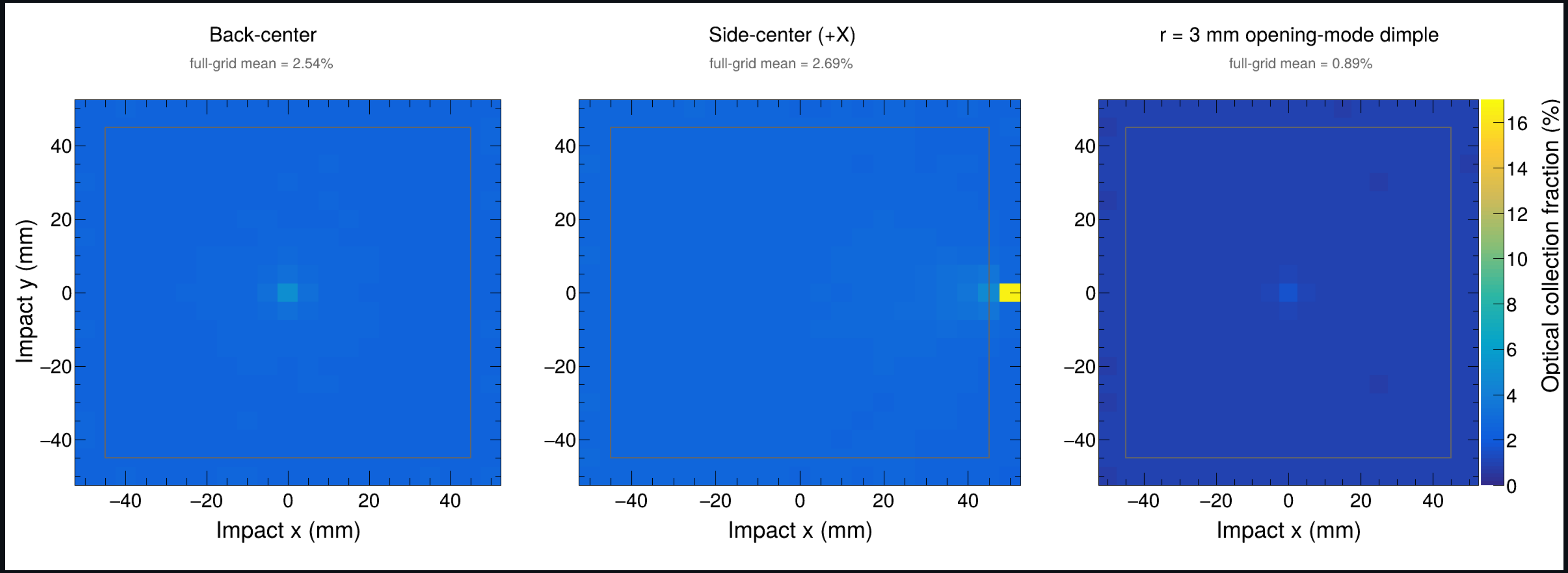
OPTICS
polishedfrontpainted
EJ-510 · zero-gap proxy

MATCH / SCORE
30 positions · per-tile scale
fitted-scale NRMSE

2 × 2500 events/point
shape only, not yield

SiPM PLACEMENT STUDY

Placement changes both collection strength and spatial response



TILE
EJ-200
$100 \times 100 \times 5\ mm^3$

SiPM PROXY
$2.0 \times 2.0 \times 0.5\ mm^3$
back / side +X / dimple

SOURCE
point-like 1 MeV e-
fixed energy

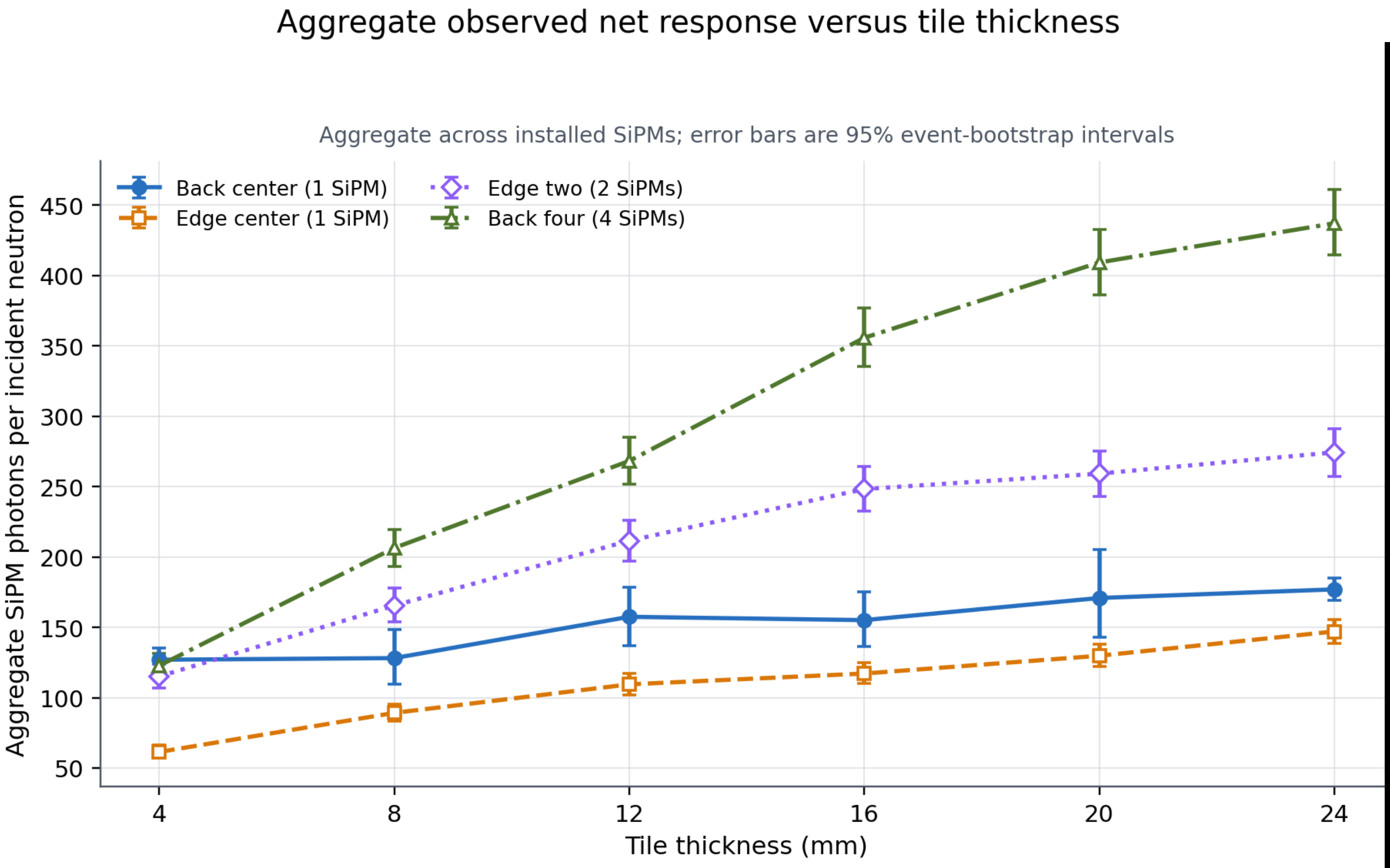
BEAM
transverse σ=0 mm
angular σx=σy=0 mrad

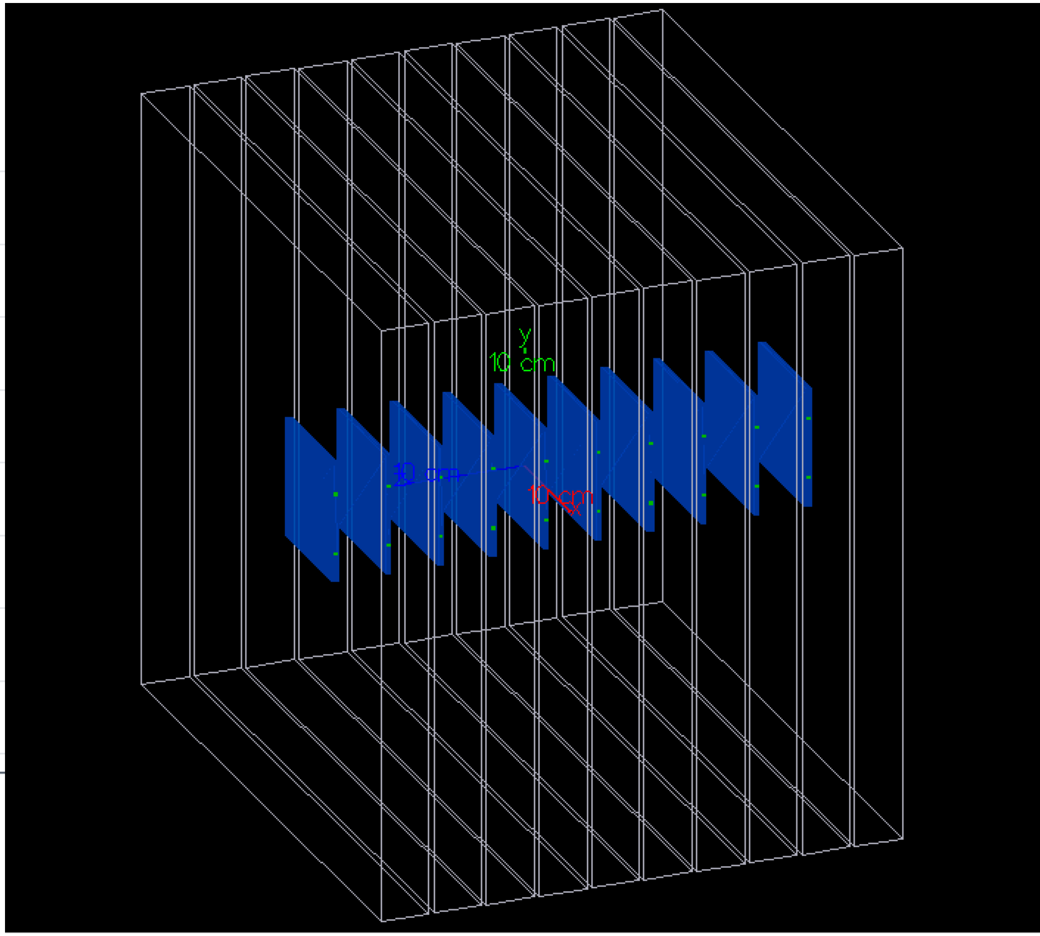
OPTICS
UNIFIED polished
no explicit coupling

SCAN / READOUT
21 × 21 · 100/point
optical collection fraction

mean 2.54 / 2.69 / 0.89%
exact dimple geometry only

Light collection & tile thickness





Summary

- nHCAL design verification
- nHCAL paper contributions (standalone or global):
  - Laboratory tile testing with SR90
  - GEANT4 simulation and validation
  - Impact of light uniformity and SiPM response on MIP analysis, jet reconstruction (not shown)

- Discussion of standalone vs. global papers + outline

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