HIGH-D

Bundesministerium
für Bildung
und Forschung

Overview: SiPM+WOM-based liquid-scintillator detector (WP 2.1)

4. High-D Consortium Meeting

Fairhurst Lyons
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20.02.2024

universität freiburg

JG|U

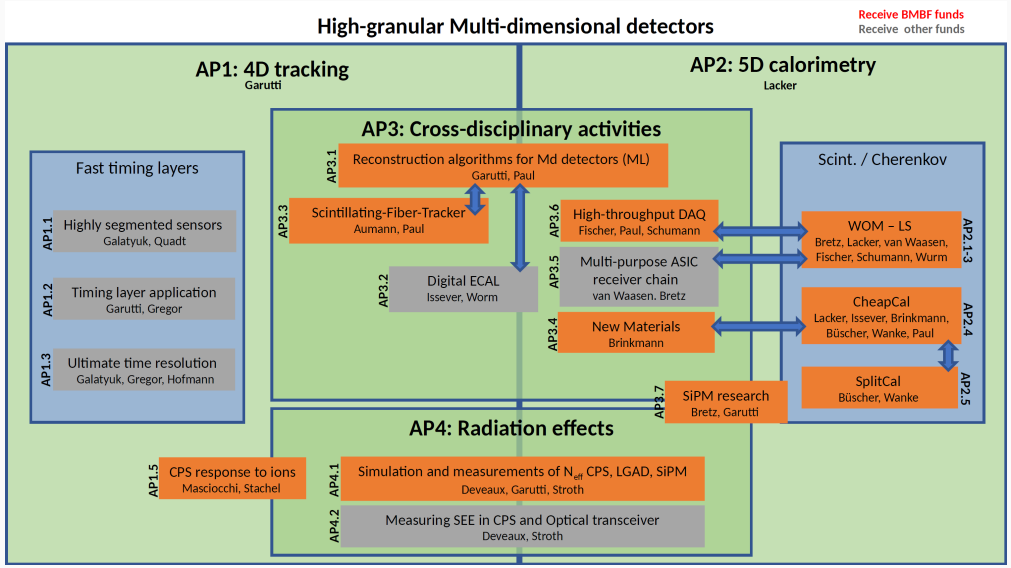
HUMBOLDT-UNIVERSITÄT ZU BERLIN

RWTH AACHEN UNIVERSITY

JÜLICH FORSCHUNGSZENTRUM

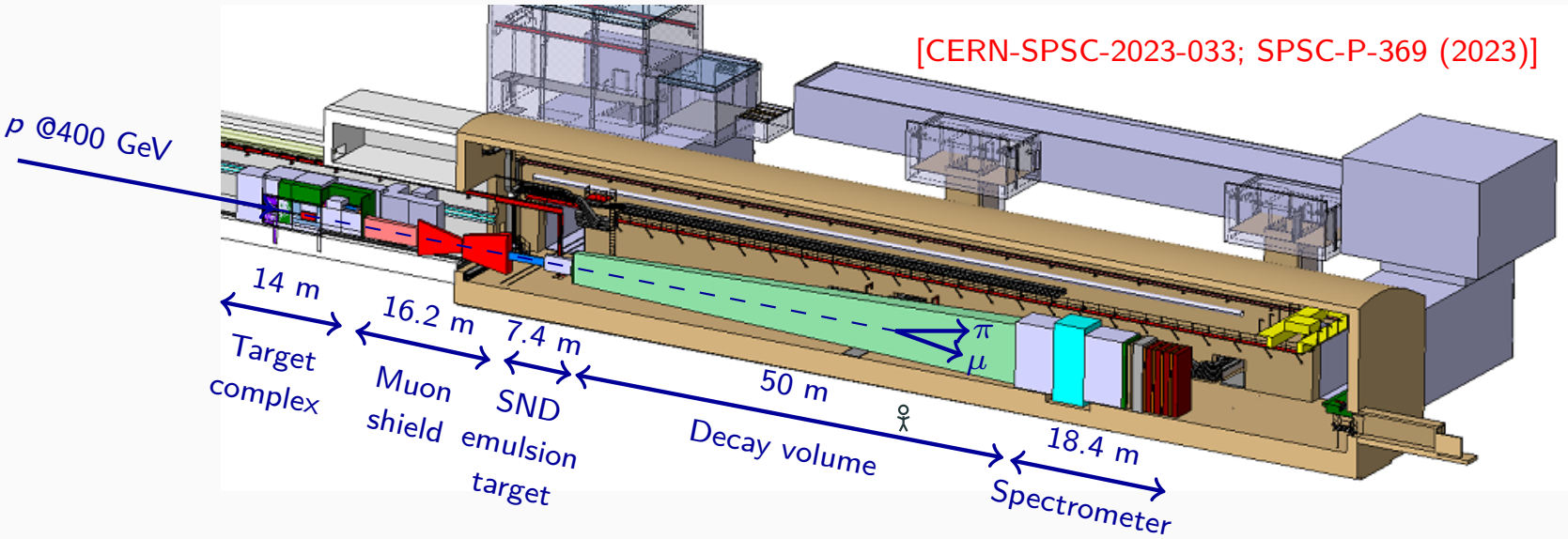
Work Package 2.1

- Particle identification + measurement
  - 3D information
  - Energy
  - Time
- Detector granularity
  - "High" segmentation
  - Electronic development
- Particle reconstruction
  - New algorithms
  - Incorporate detector segments



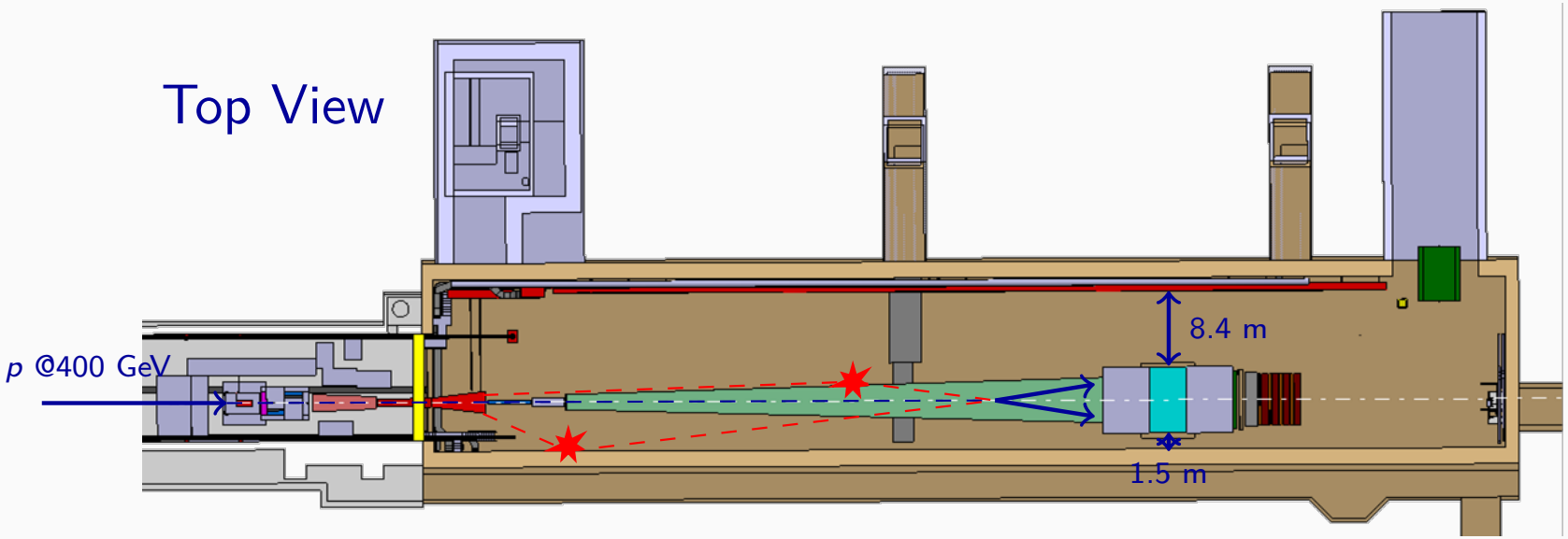
Motivation: Search for Hidden Particles (SHiP)

- Proposed Beam Dump Facility @ CERN SPS ECN3: SHiP
- Dedicated search for Feebly interacting particles (FIPs)
- 400 GeV p dumped in high-density target
- Magnets deflect μ out of beam line
- Scattering and Neutrino Detector (SND) light dark matter search and ν_τ physics
- Hidden sector decay volume = vacuum vessel
- Spectrometer reconstructs decay (tracker/calorimeter/timing)



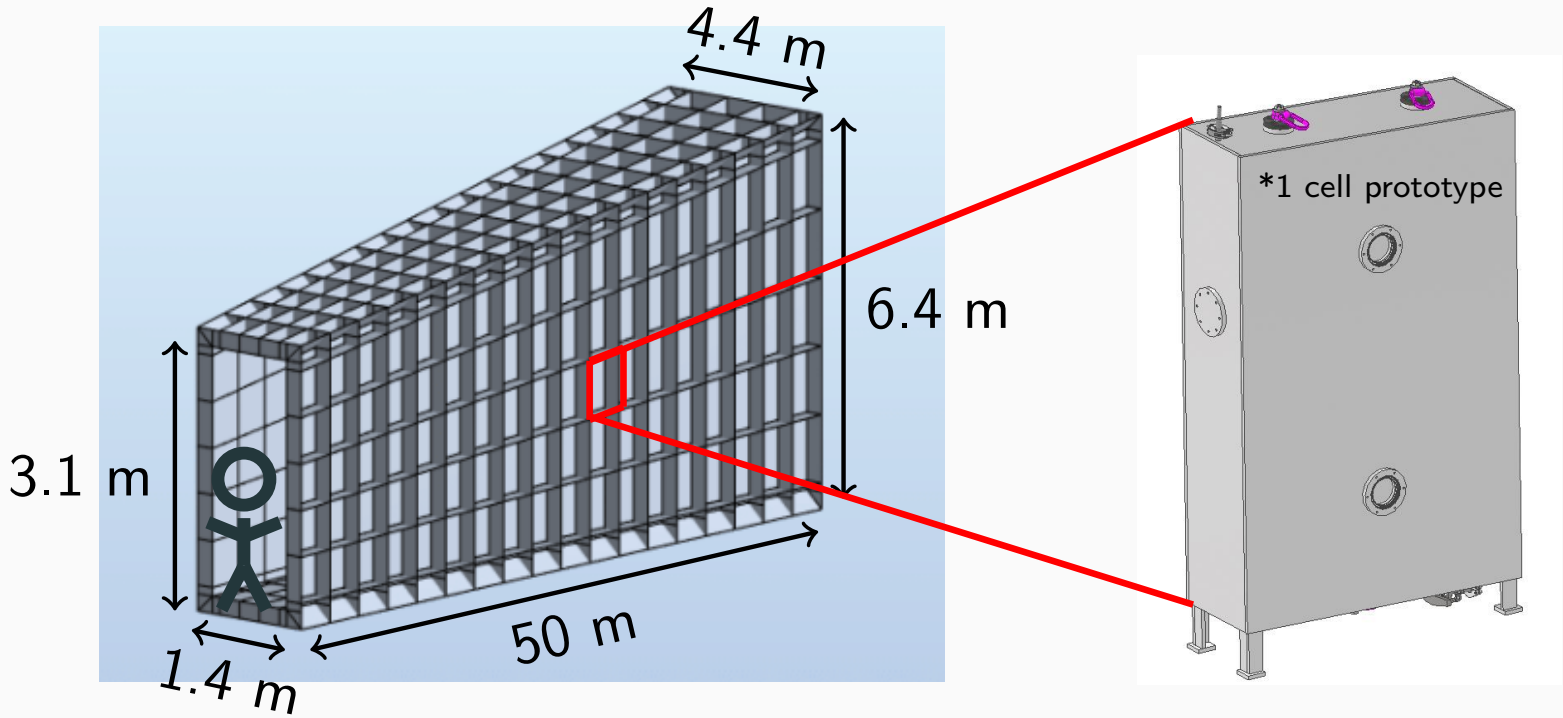
SHiP Background Sources

- Possible μ/ν scattering in material upstream of decay vessel or cavern/vessel walls
- Scattered particles in coincidence could mimic signal
- Aim: detect particles entering through decay volume walls
- Solution: instrument decay volume walls with Surrounding Background Tagger (SBT)
- Need $>$ 99% efficiency for tagging MIPs with $E_{dep} > 45$ MeV



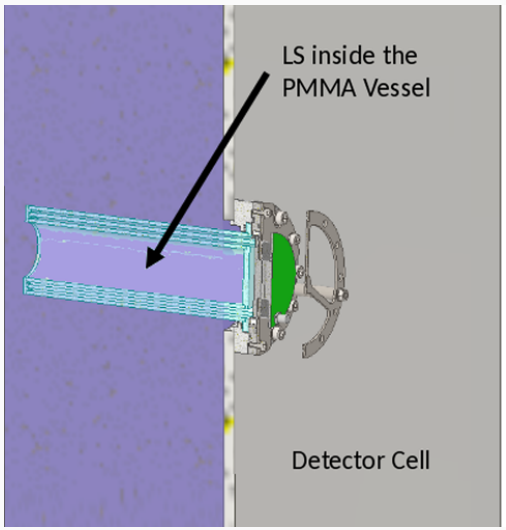
Surrounding Background Tagger (SBT)

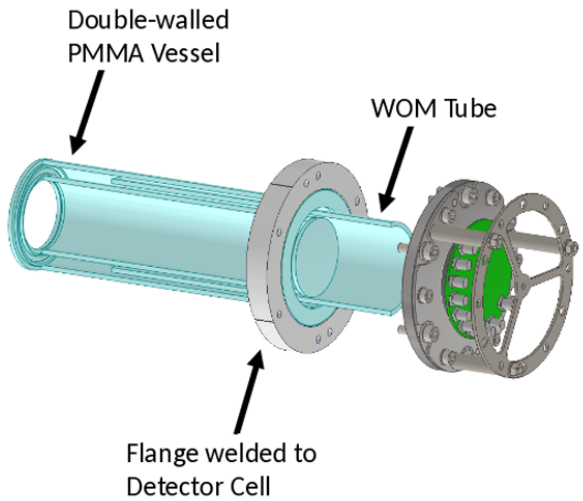
- Requirements:
  - Large-scale $\rightarrow \mathcal{O}(150)$ m^3 with $\sim$ 900 cells
  - Resolution $\rightarrow$ space + time + energy
  - Low cost (corten steel, sparse readout)
- Solution: Liquid Scintillator (LS) detector with Wavelength-shifting Optical Module (WOM) readout

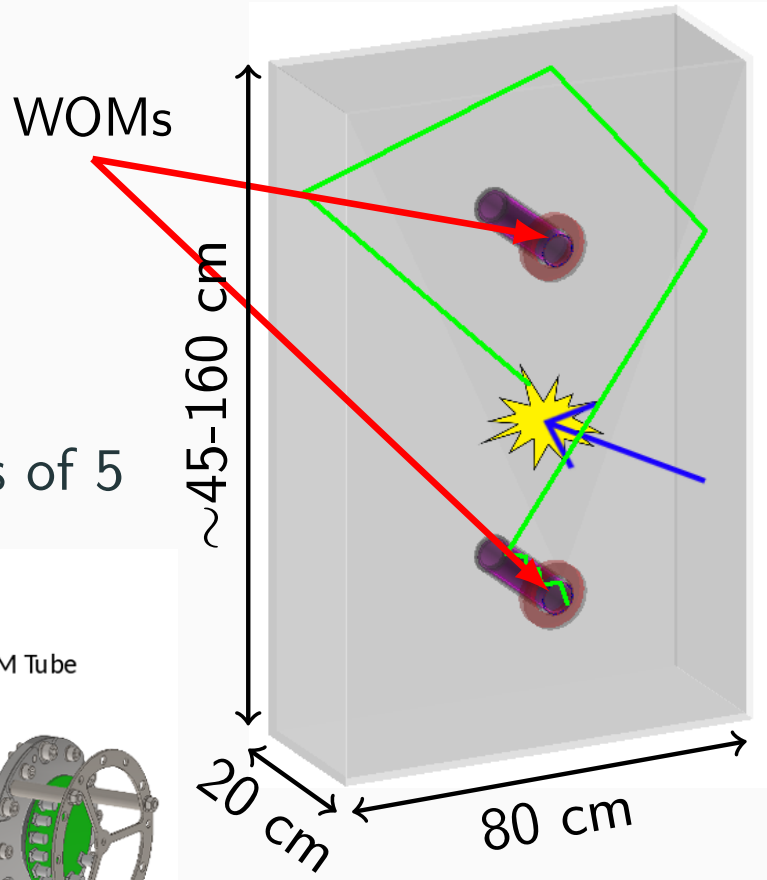


SBT Cell Principle

- Corten steel walls
- Filled with LS (LAB + 2 g/L PPO)
- WOMs catch and transmit light to Silicon Photomultipliers (SiPMs)
- 40 SiPMs per WOM, read in groups of 5

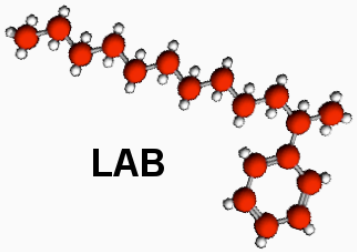


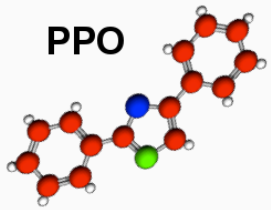


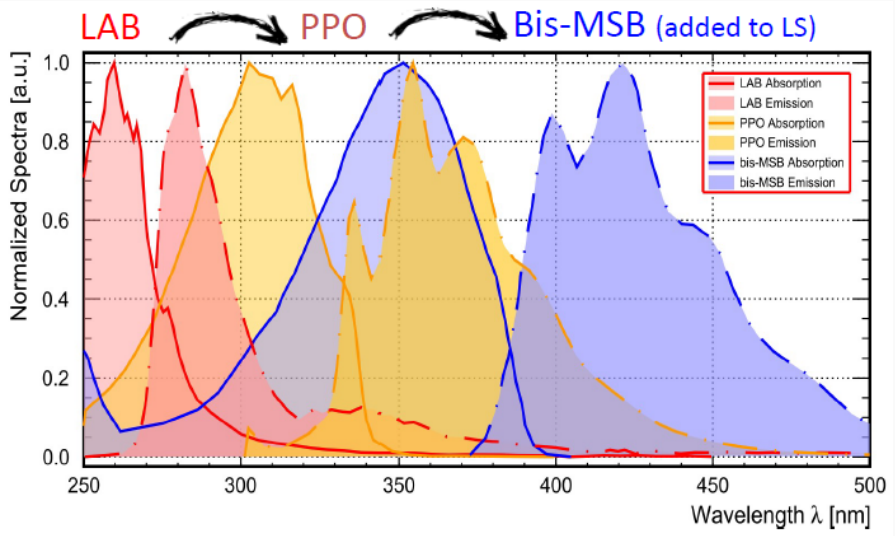


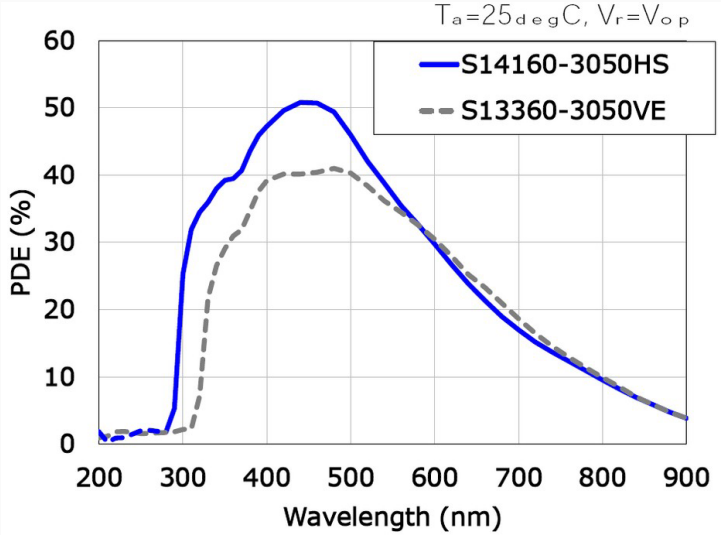
Liquid Scintillator

- Solvent: Linear alkylbenzene (LAB)
- Fluor: 2,5-diphenyl-oxazole (PPO)
- Spectra
  - LS (LAB + 2 g/L PPO) emission: 350-380 nm
  - WLS emission: 420 nm
  - SiPM max quantum efficiency: 400-520 nm



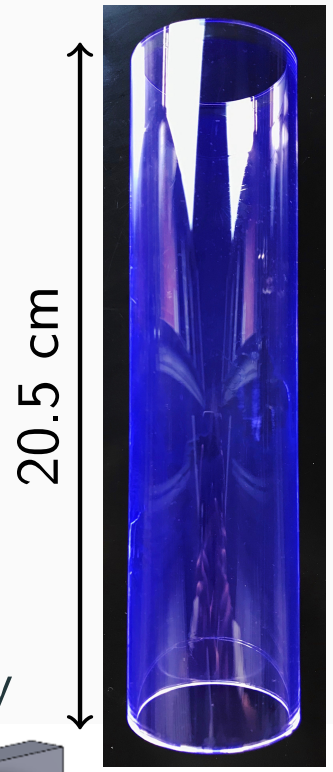


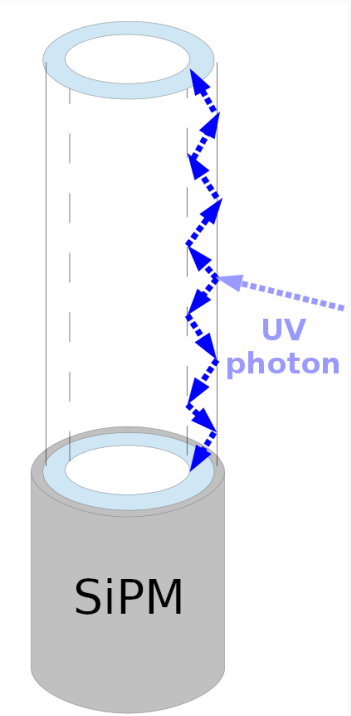


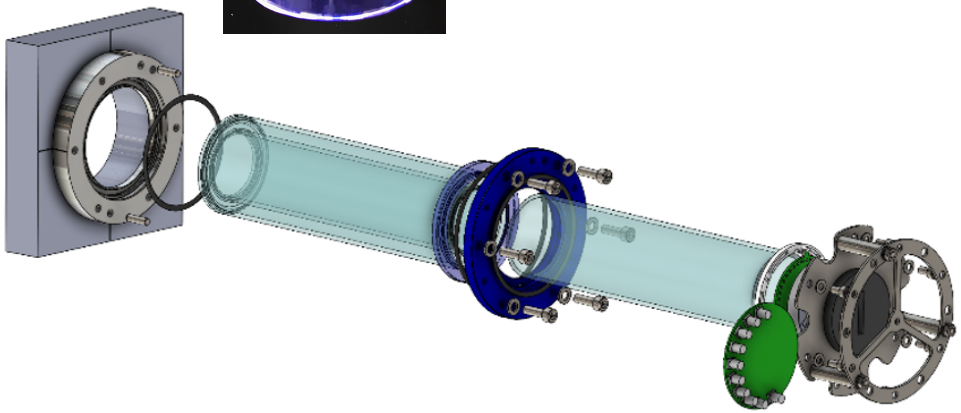


WOMs

- Cylinder of PMMA
- Wavelength-shifting coating
  - UV absorption
  - Isotropic blue light emission
- Transparent tube catches light
  - Total internal reflection
- Advantages:
  - Large surface area
  - Up to 75% collection efficiency
- IceCube:
  [10.3390/s22041385]

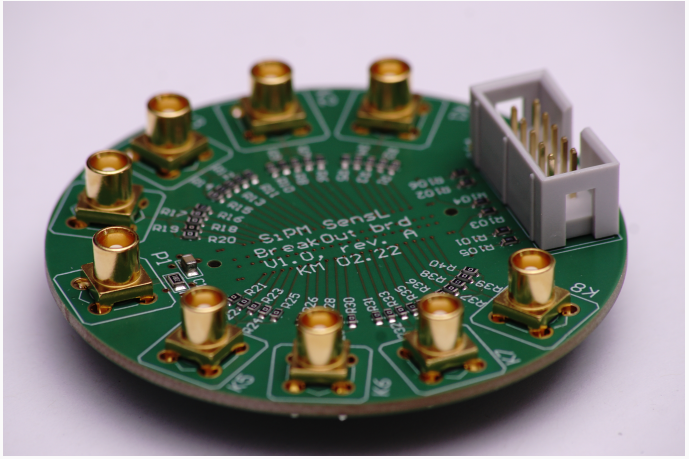


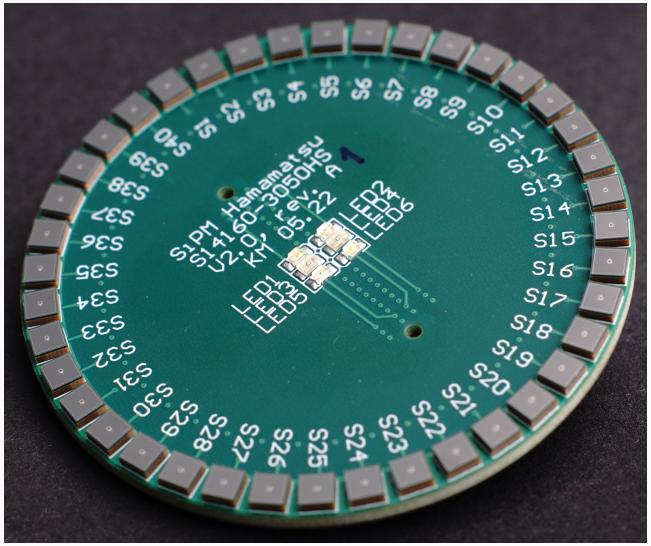


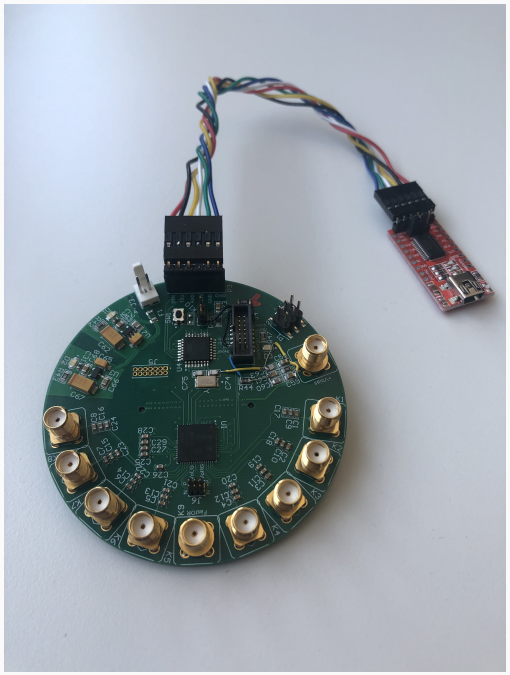


Electronics

- SiPMs (Hamamatsu S14160-3050HS)
  - 3×3 mm^2 area
  - Peak sensitivity in 400-500 nm range
- Testbeam readout + DAQ
  - PCBs developed in Freiburg
  - eMusic ASIC amplifies + shapes signal
  - WaveCatcher digitiser

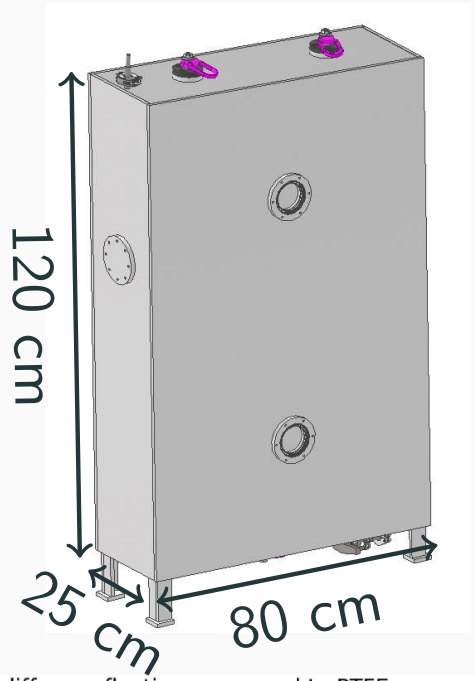


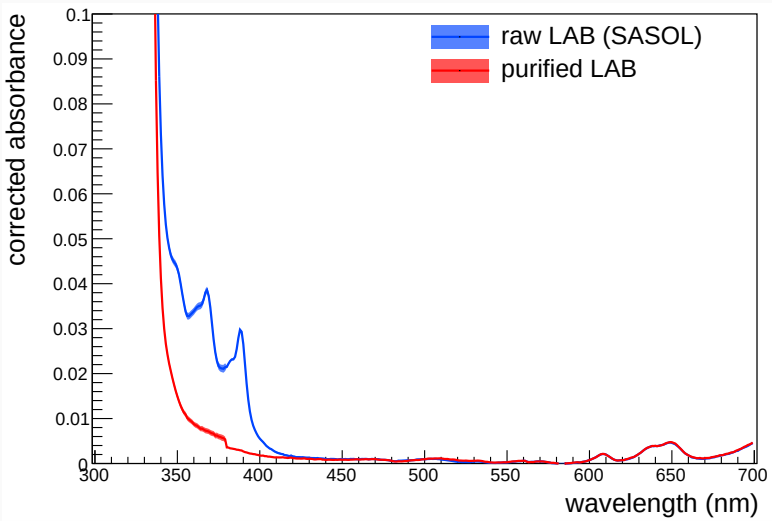


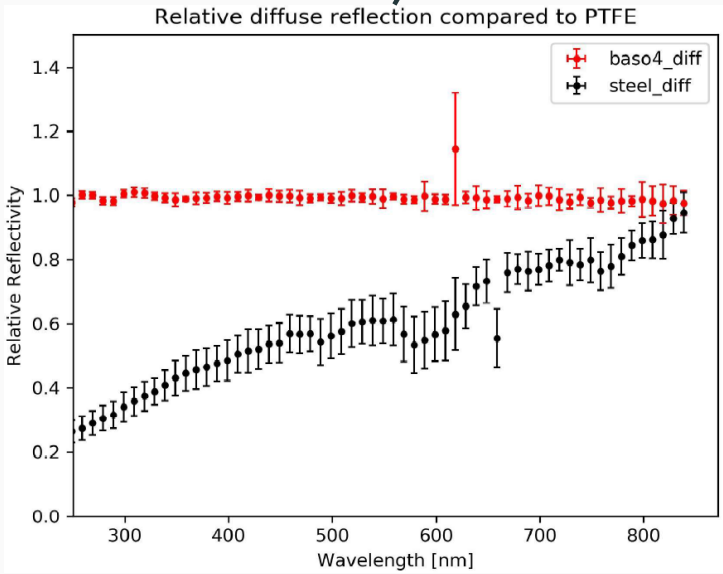


R&D Overview: 1 Cell Testbeam

- PCBs developed (Freiburg)
- WOM housing designed (Jülich)
- Purified LS (Mainz)
- Reflective coating on inner cell walls (Mainz)
- Objective: Test full-scale SBT cell
  - Identify required LS thickness
  - Evaluate efficiency, timing performance
  - Determine spatial resolution

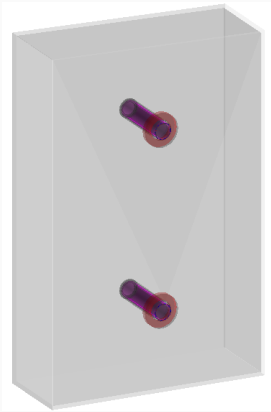




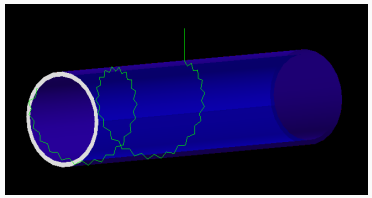


Full Geant4 Simulation of 1 Cell

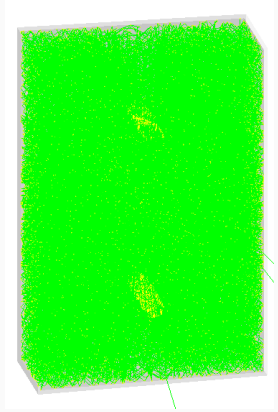
- Includes measurable material quantities
  - Absorption lengths
  - Emission spectra
  - Reflectivities
  - Indices of refraction



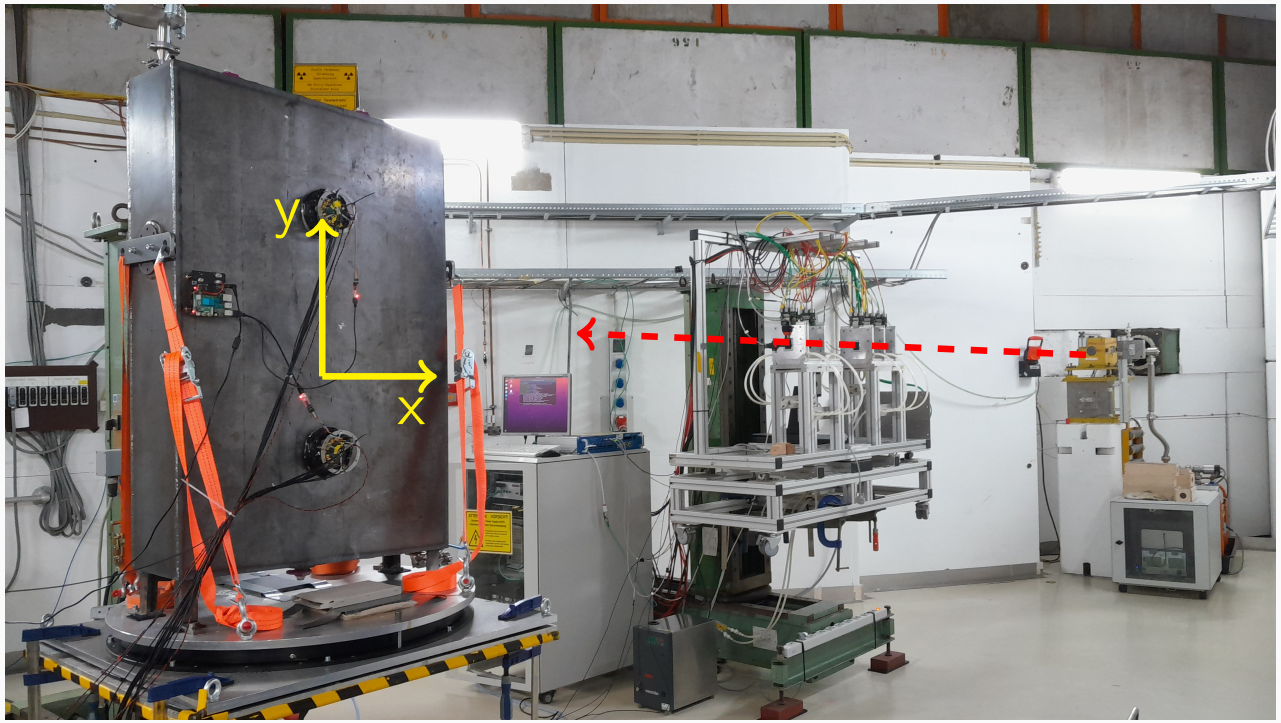
- Simulates full event from beam $\rightarrow$ SiPM detection
  - EM shower
  - Scintillation, Cerenkov processes
  - Optical photon transportation
  - No electronics



- Extractable quantities
  - # of detected photons in each SiPM (group)
  - Energy deposit in cell
  - Photon arrival time at SiPM

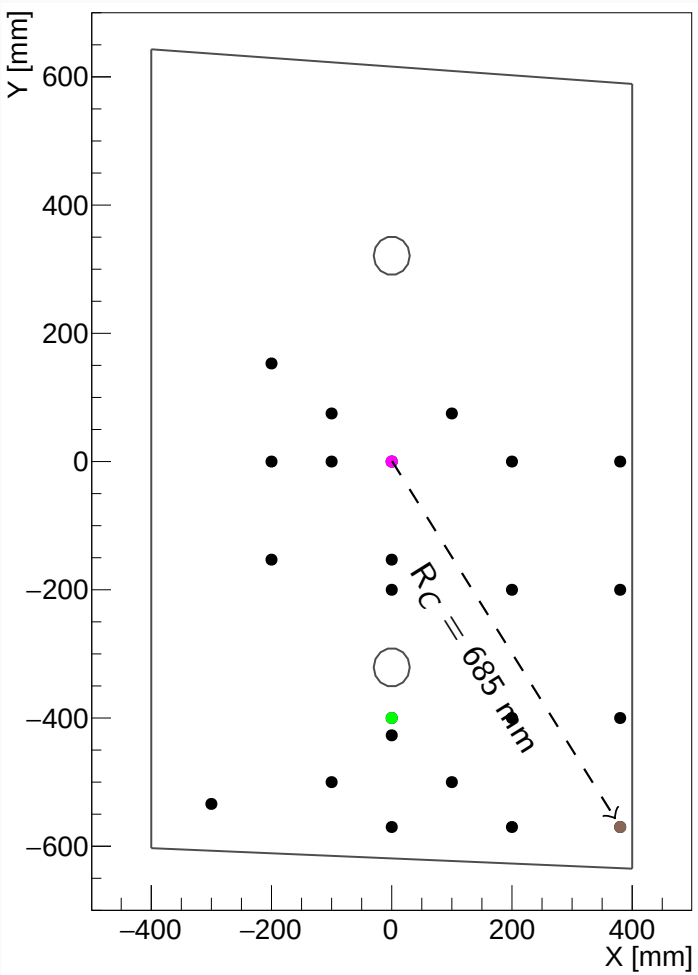


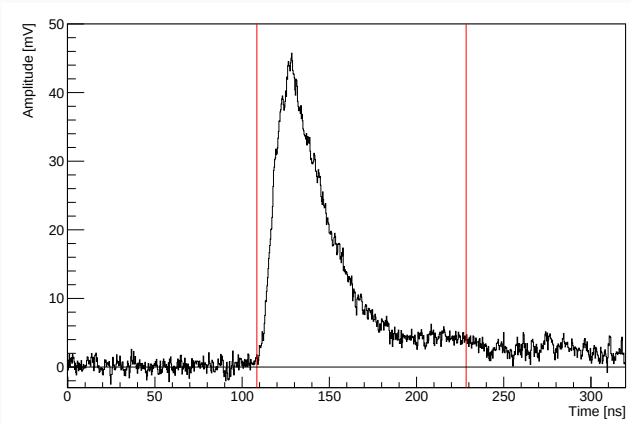
1 Cell at DESY e^+ Testbeam: October 2022

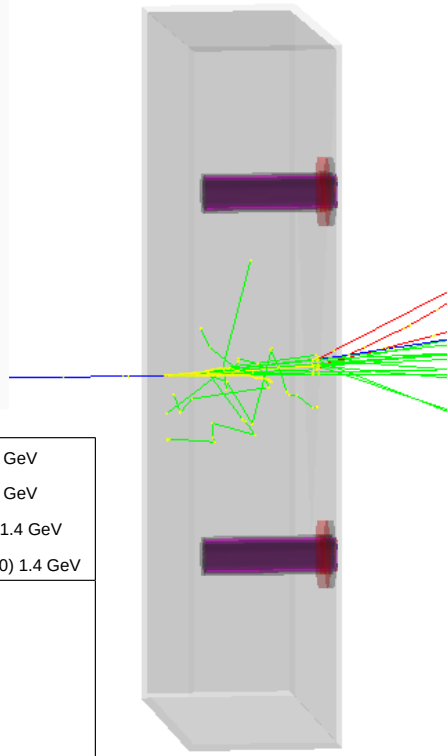


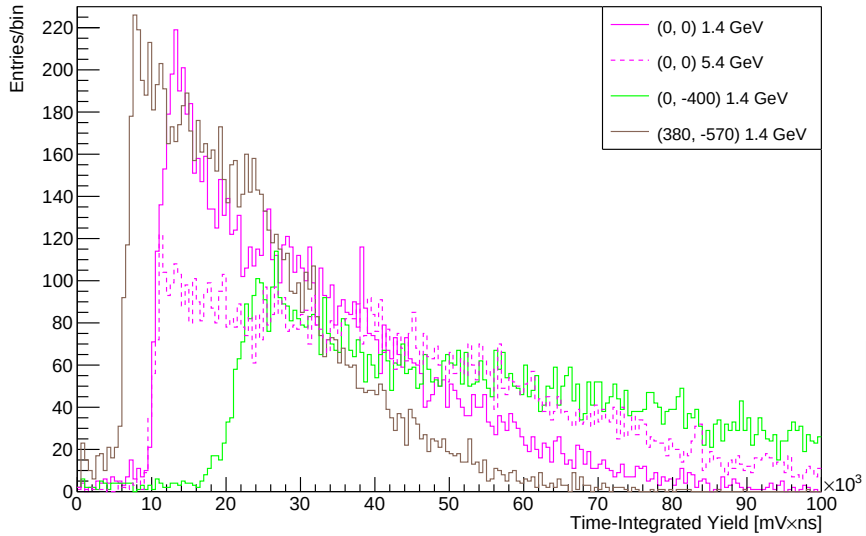
- e^+ beam (2 mm diameter)
- Energy = 1.4 - 5.4 GeV
- 10000 events/run
- Beam telescope: 4 plastic scintillators with PMTs
- Trigger $\rightarrow$ beam telescope coincidence
- LS cell on $x-y$ movable stand, rotating platform around y

Data Spectra at Different Cell Locations



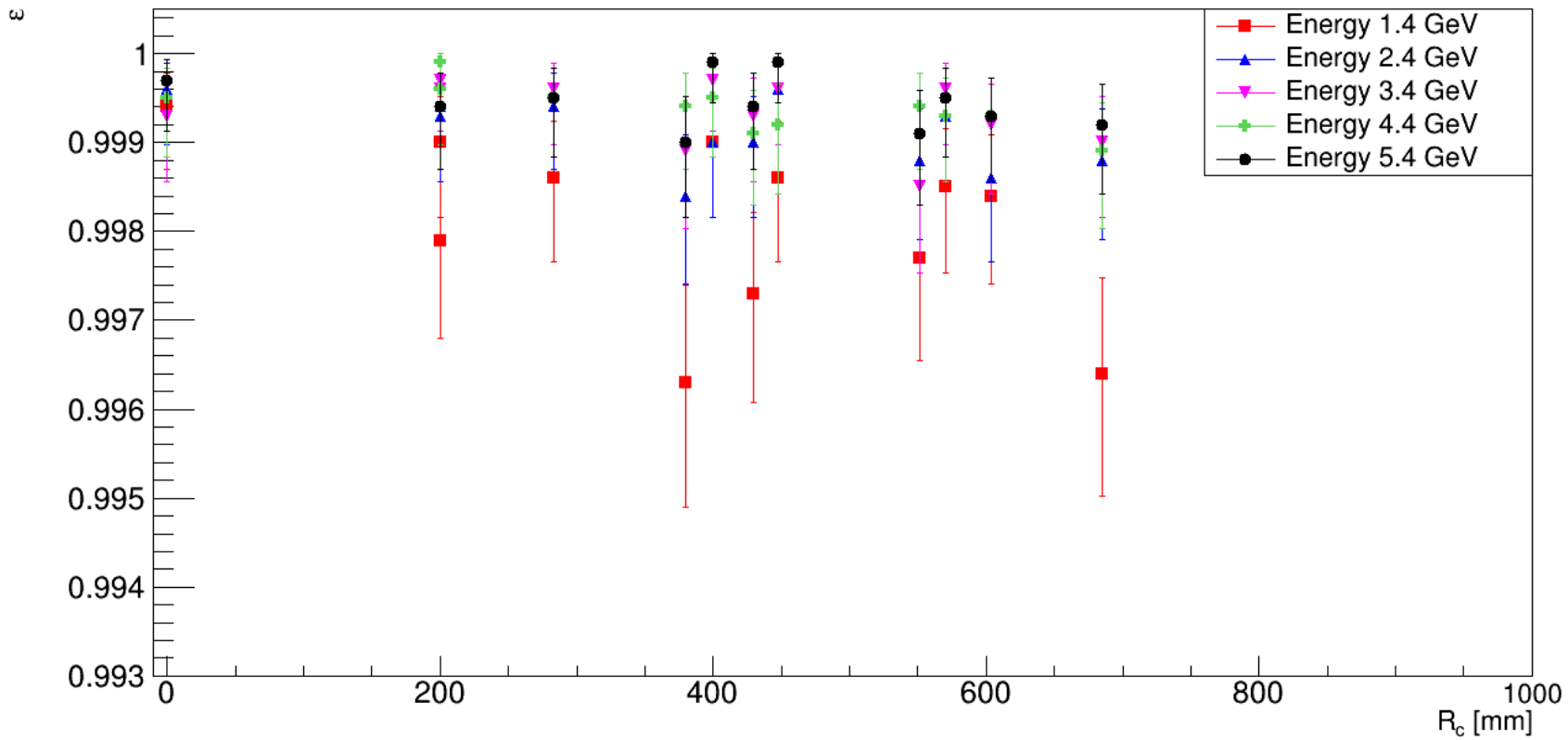






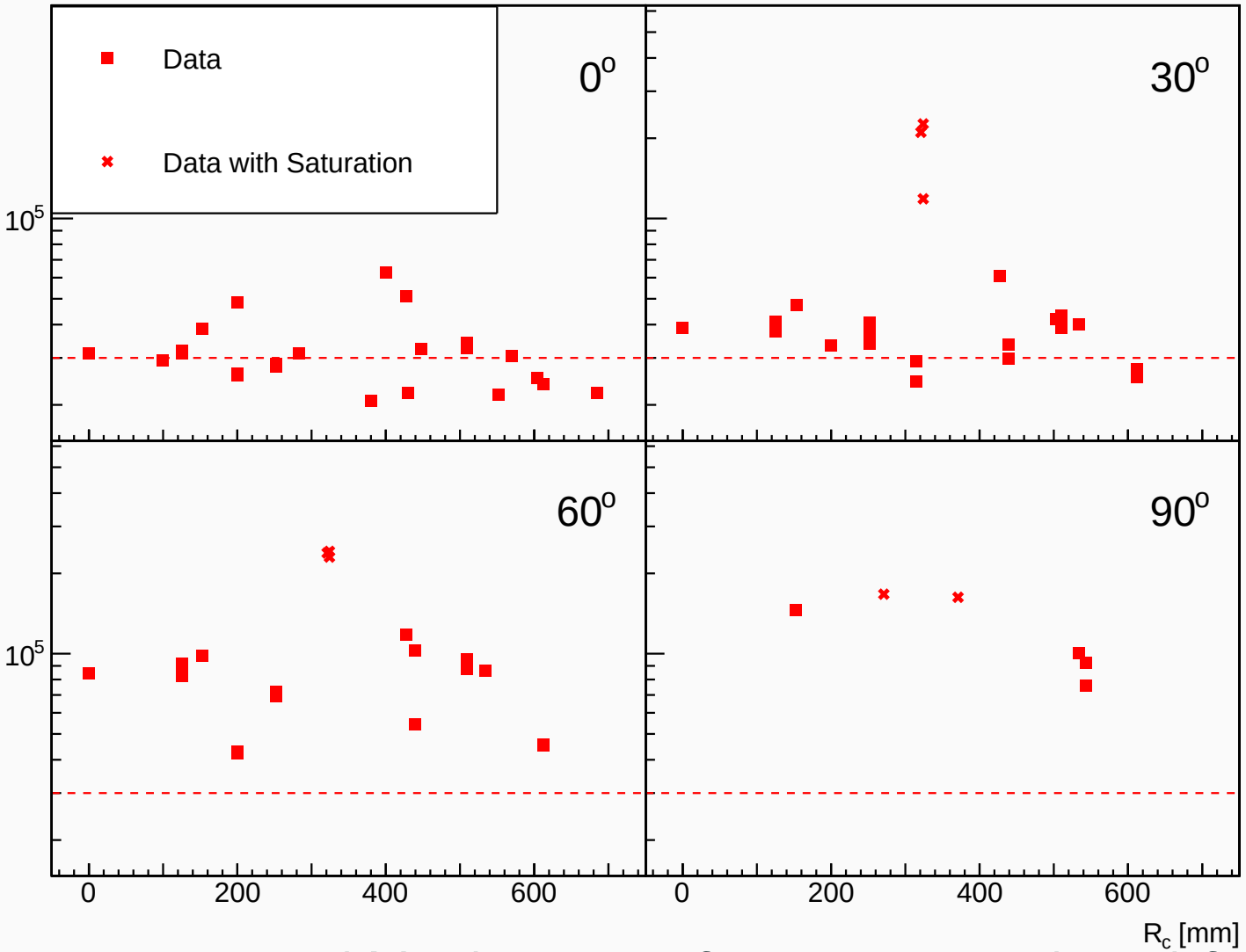
- Signals visible for all positions - including corners
- ∼30% variation in mean charge from centre point to corner
- Expected behaviour wrt beam energy and position

Efficiency

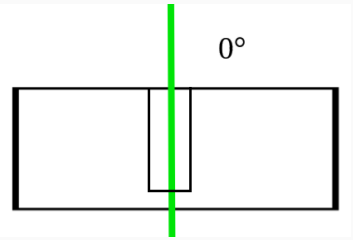


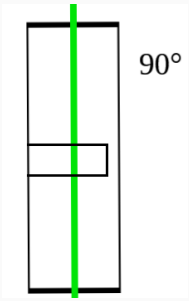
- Efficiency = accepted events/total events $> 99.5\%$
- Goal achieved
- Mean (most probable) $E_{dep} = 113$ (50) MeV from simulation

Integrated Yield Dependence on Beam Angle



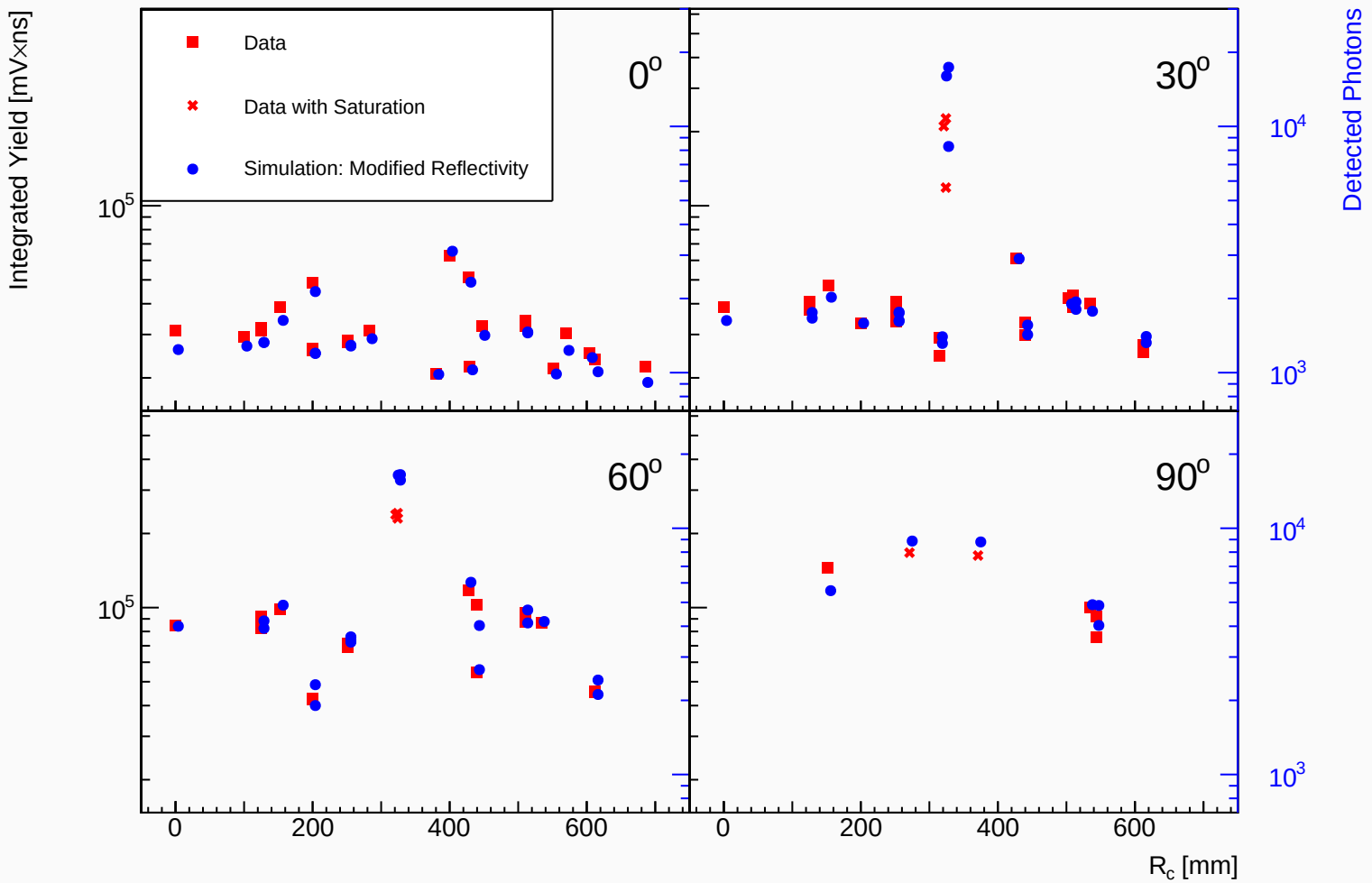
Top View





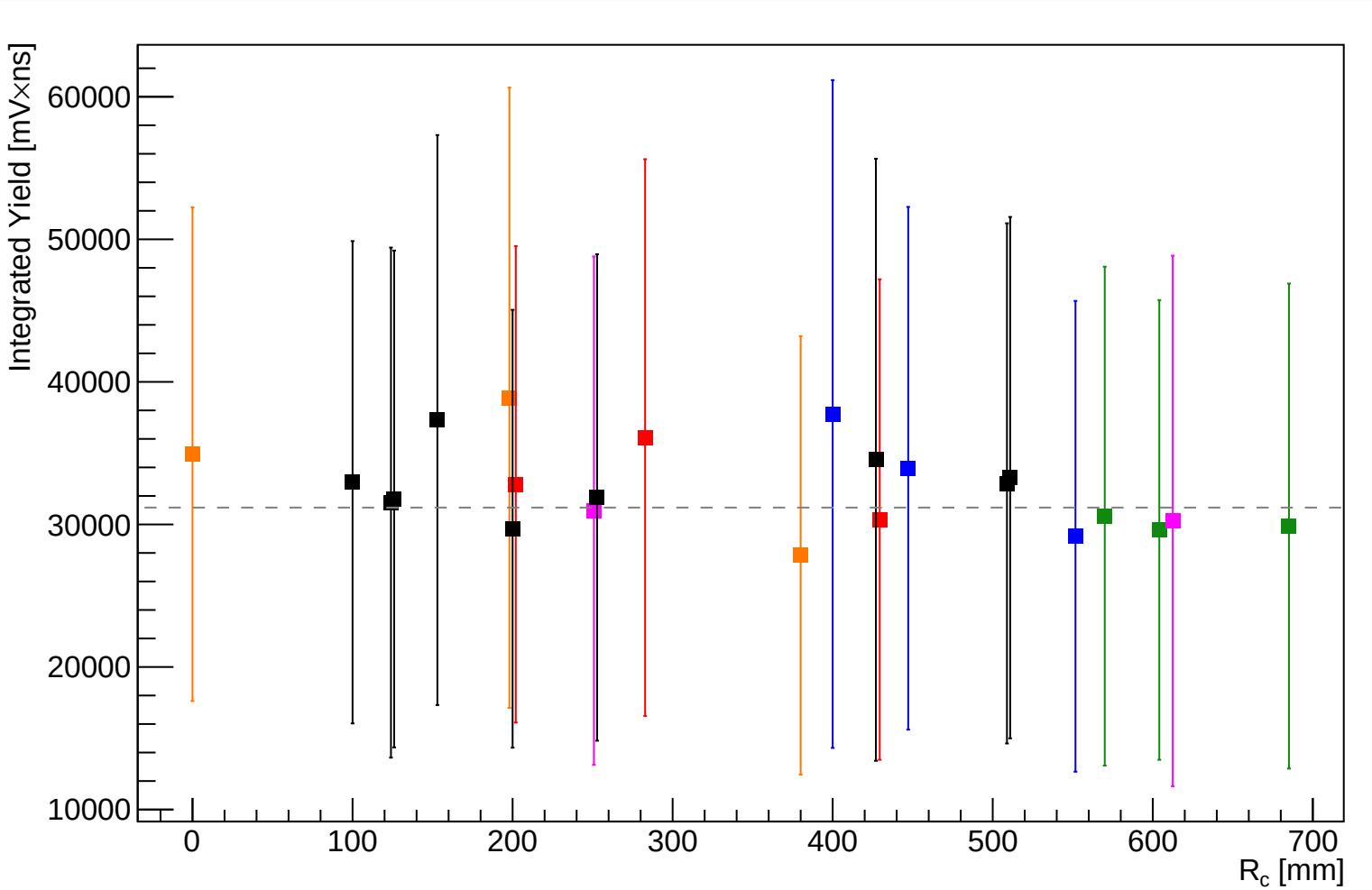
- Integrated Yield = sum of time-integrated yield for all SiPM groups in both WOMs

Data Comparison to Geant4 Simulation: 65% Reflectivity



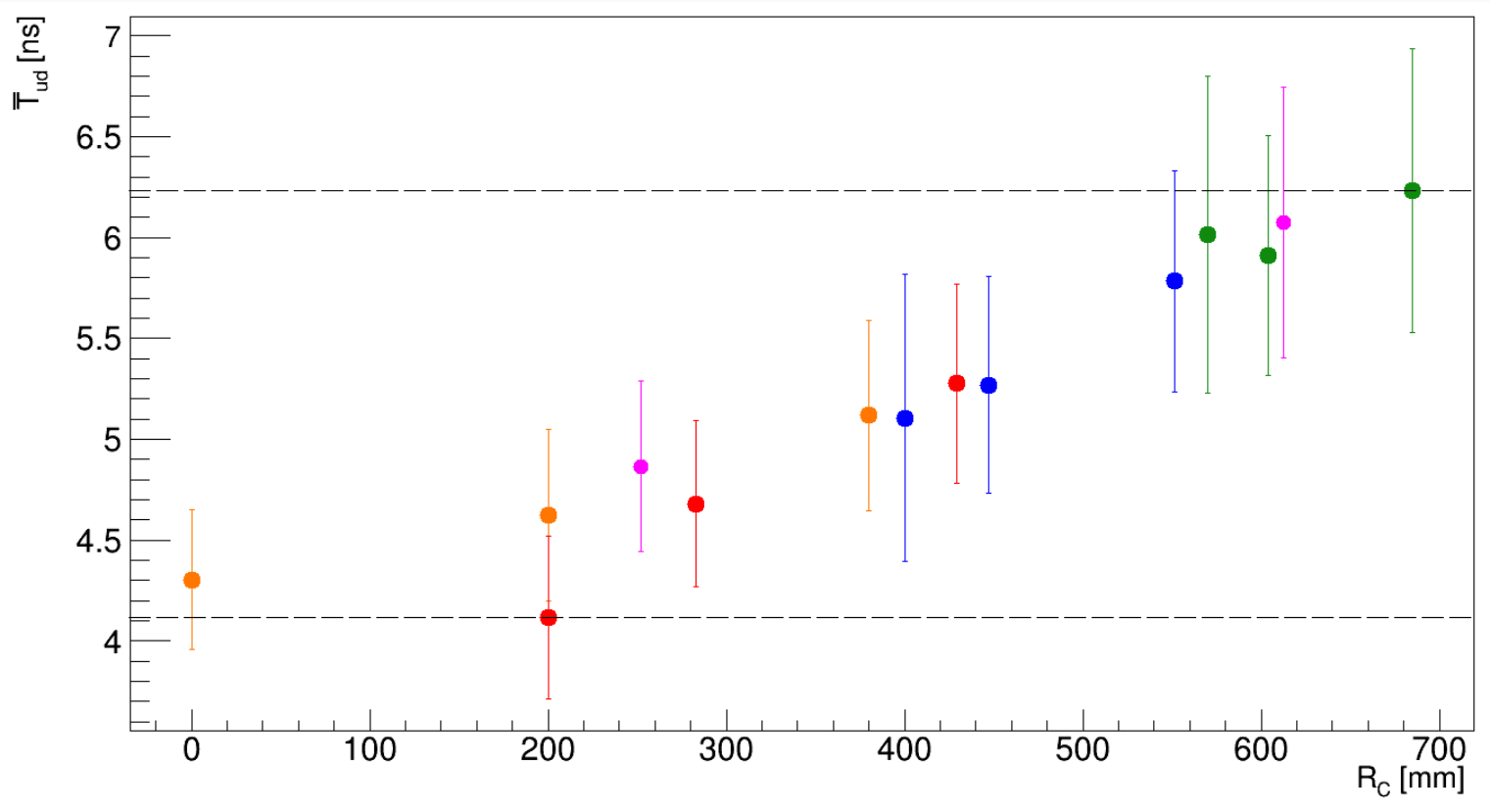
- No gain measurement, can scale simulation - nice agreement
- 65% of measured reflectivity used for training reconstruction

Data Uniformity Correction



- Yield fraction per WOM and channel used for likelihood-based particle crossing point reconstruction
- Signal nonuniformities corrected to reference yield at (0, 0)

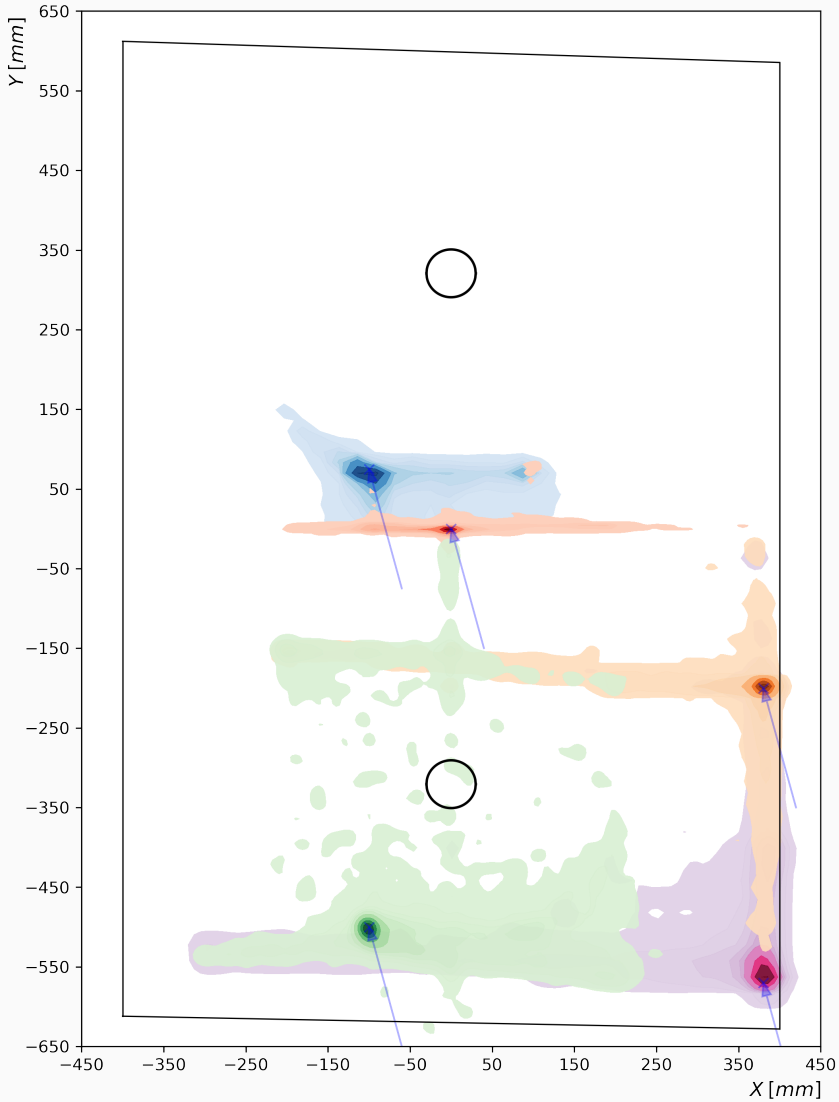
Timing Resolution



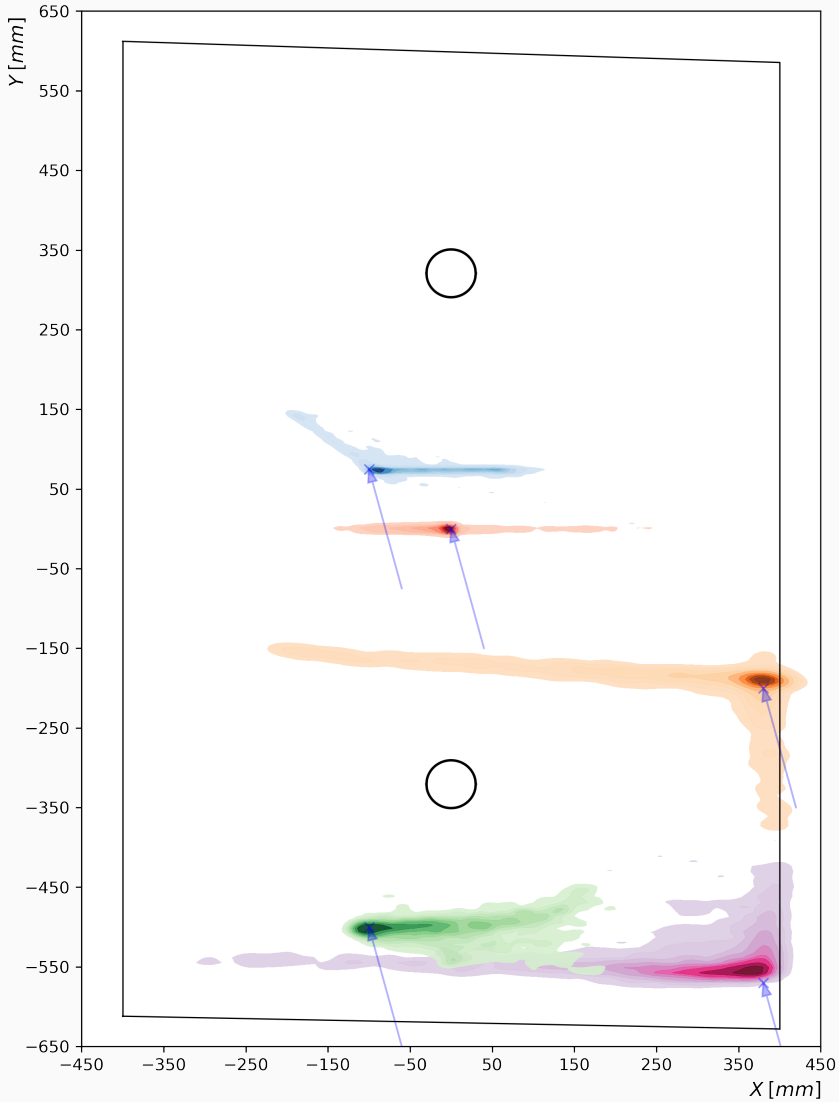
- Particle arrival time at the detector $\bar{T}_{ud} = (T_u^{corr} + T_d^{corr})/2$ where $T_{u,d}^{corr}$ are obtained by subtracting the trigger time
- Timing resolution of ± 1 ns

Particle Crossing Point Reconstruction (0°, 1.4 GeV) with NN

Data



Simulation

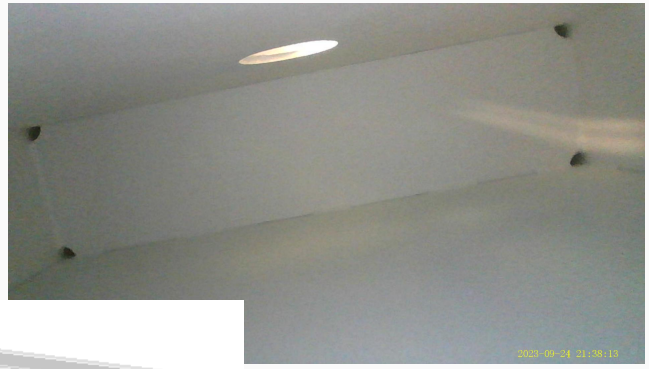


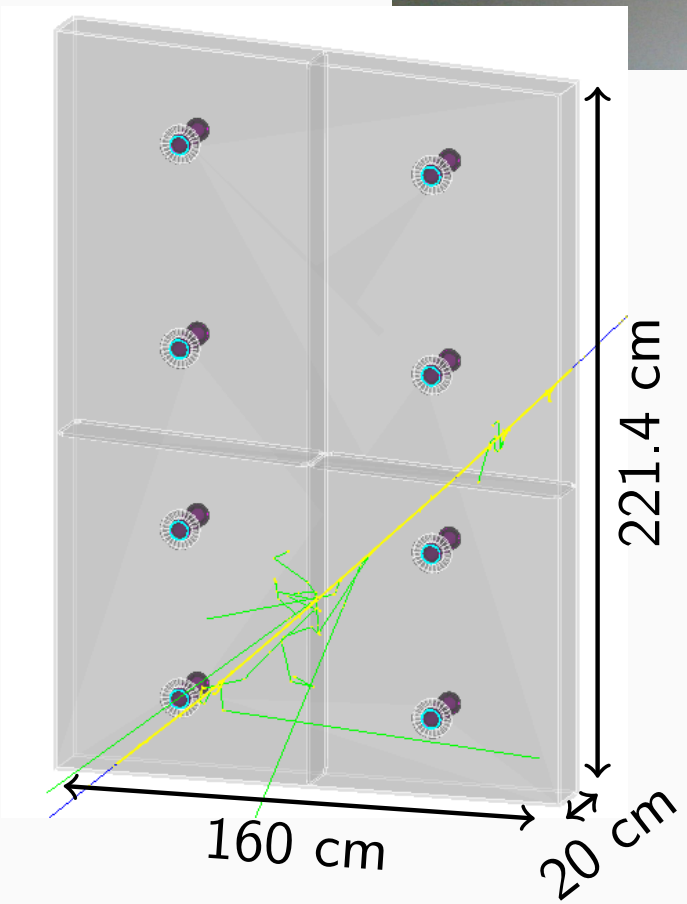
1 Cell Testbeam Summary

- Successful DESY e^- testbeam
- $>$ 99.5% efficiency achieved
- Detector response as expected wrt beam energy/position/angle
- Timing resolution ± 1 ns
- NN-based spatial reconstruction with RMS $<$ 14 cm
- **Reflective coating sub-optimal, rust spots on corten steel $\rightarrow$ Patrick Deucher**
- LS thickness can be reduced to 20 cm
- [arXiv:2311.07340]
- Cell in Freiburg for long-term stability (cosmic) measurements

R&D Overview: 4 Cell Prototype

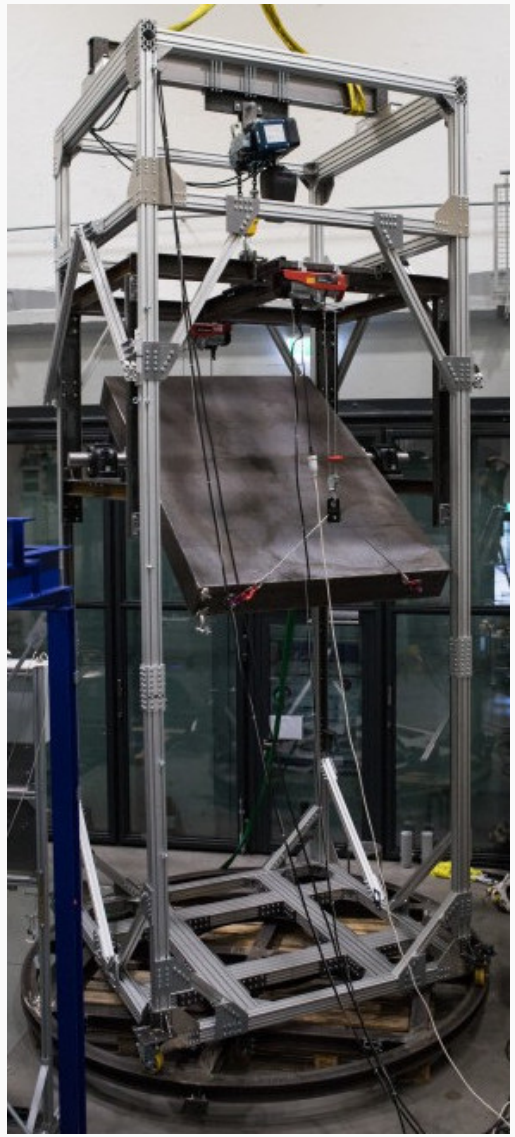
- Test full-scale multi-cell configuration
- 20 cm of LS
- New WOMs produced
- Slow control
  - Pressure sensor for LS
  - Tilt sensor
  - Thermometer
  - 2x laser rangefinder
- Reflective coating better
- MC Simulation
- Liquid handling
  to be tested





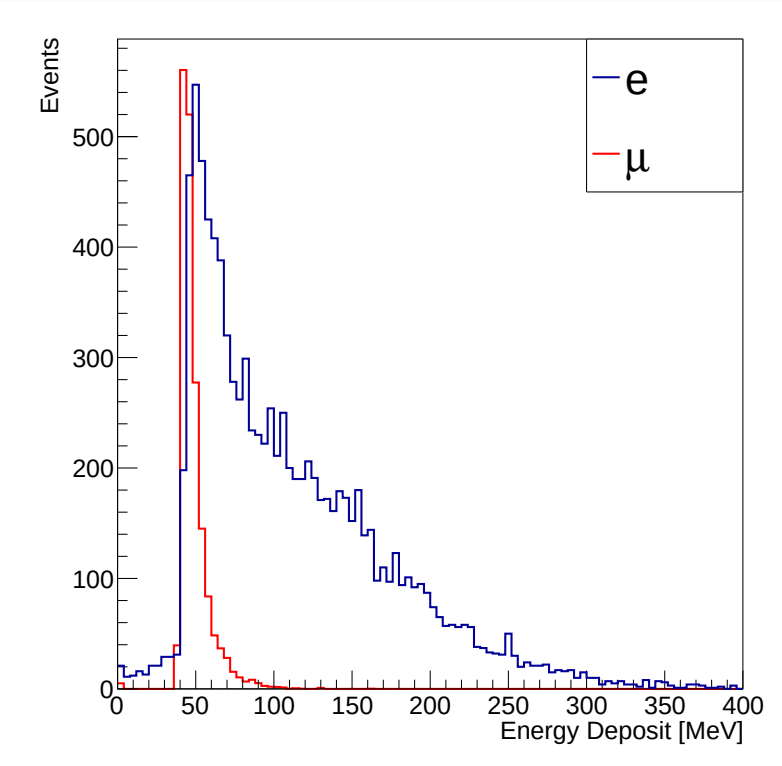
Support Structure

- 6 m x 2.4 m
- 7t filled
- Translation in x and y
- Rotation around x and y

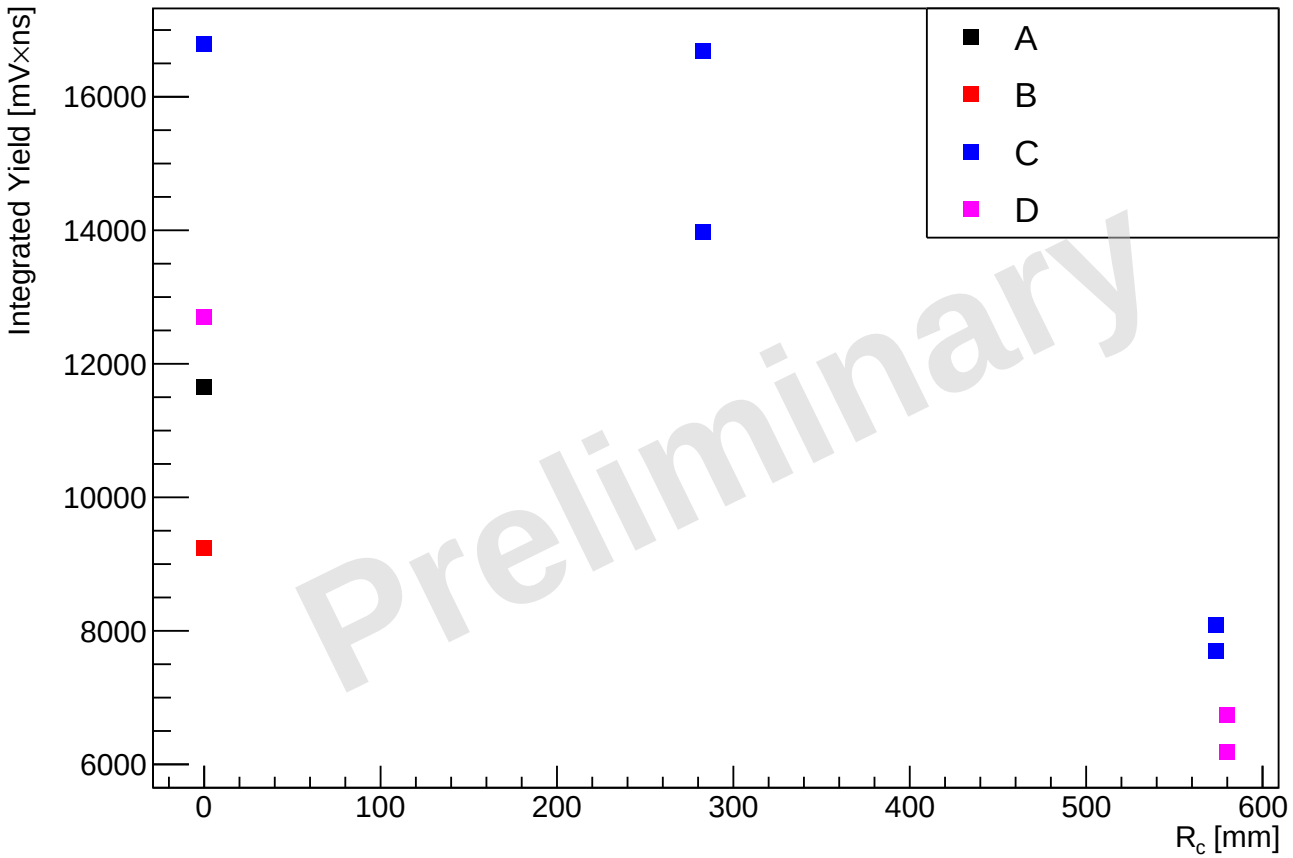


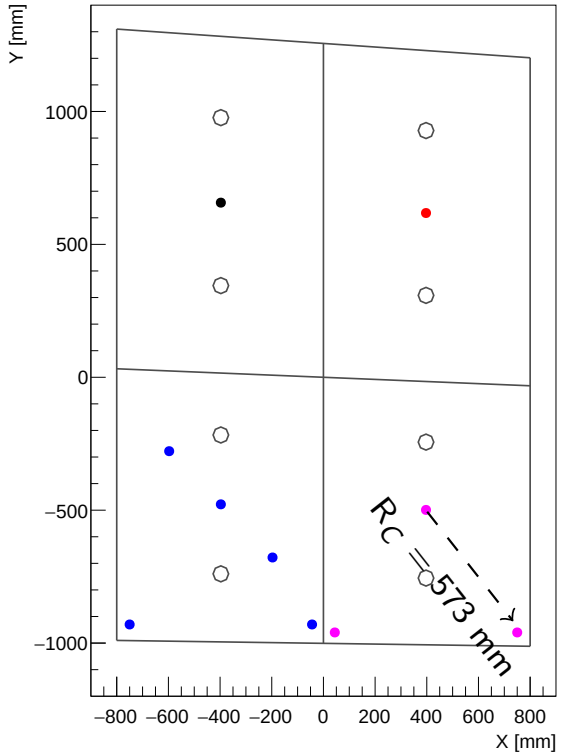
4 Cells at CERN μ^- Testbeam: October 2023

- μ^- beam ($\sigma_{beam} = 13$ mm)
- Energy ≈ 5 GeV
- Trigger on beam telescope
  + scintillator behind detector



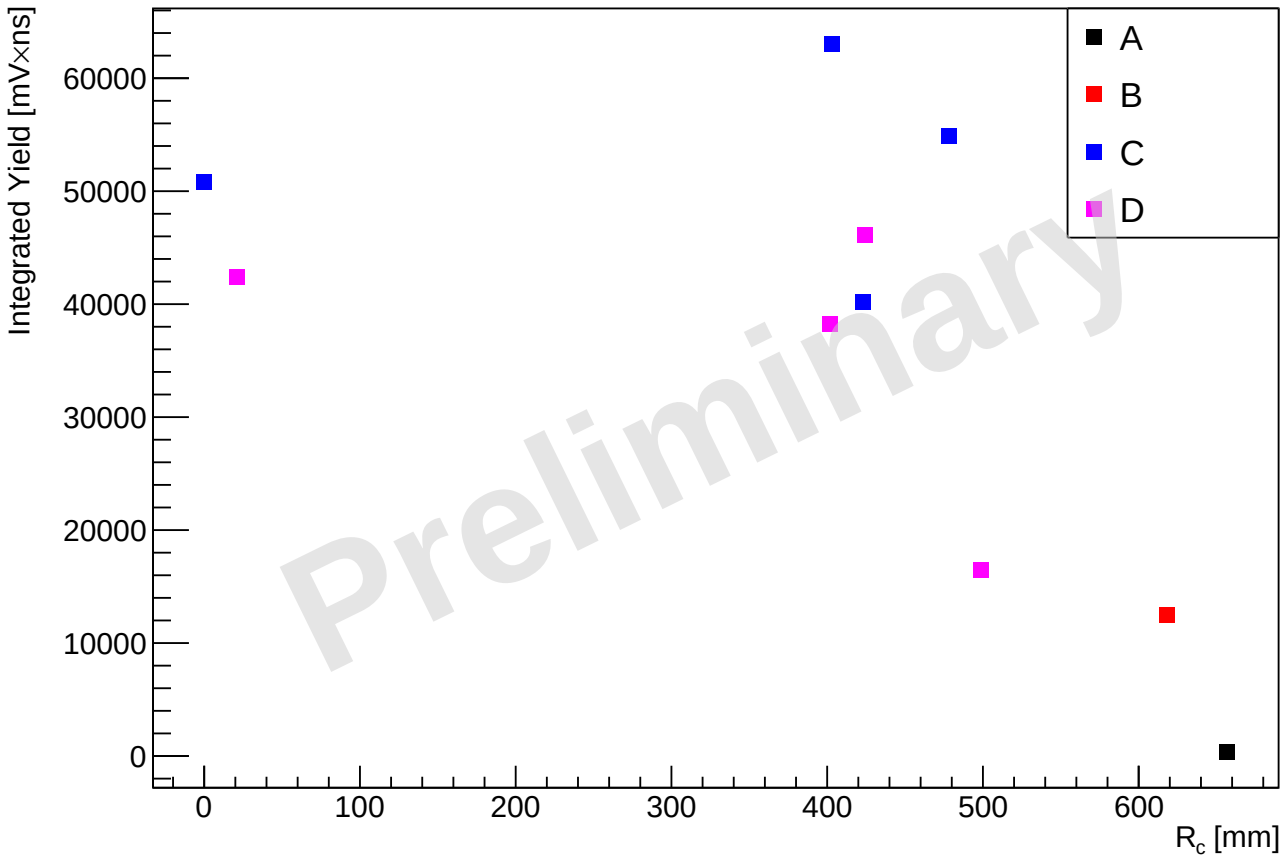
Preliminary: Integrated Yield at $\theta_x = 0°$, $\theta_y = 0°$

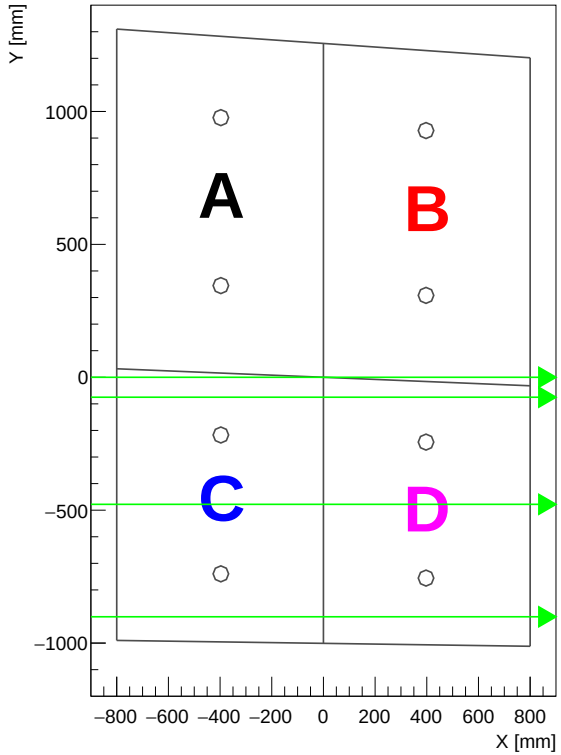




- Possible sources of variations:
  different dimensions, electronics, optical coupling per cell
- 1/3 - 1/2 of e^+ yields (no shower, less LS)

Preliminary: Integrated Yield at $\theta_x = 0°$, $\theta_y = 90°$





- Signals higher in C than D for similar tracks
- Further study required
- Results similar to previous testbeam, as expected

Ongoing R&D

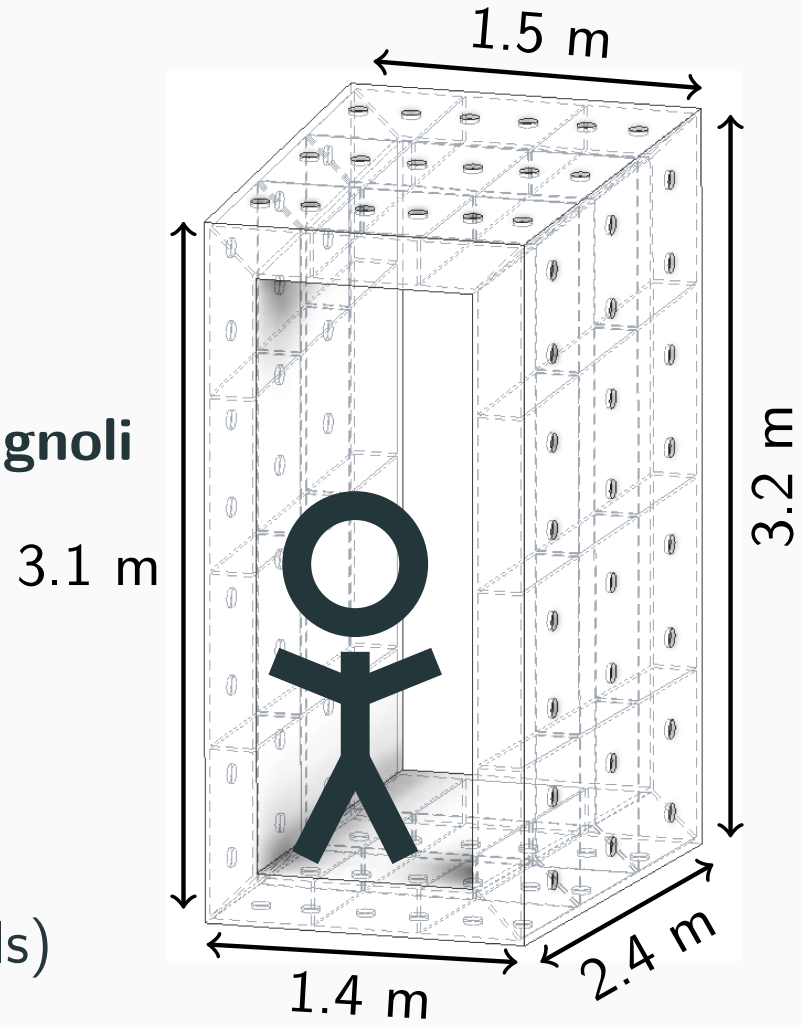
- Testbeam data analysis
- WOM production
- Readout PCBs
- Material compatibility, optimisation
- **Simulation, timing → Alessia Brignoli**

Next Testbeam

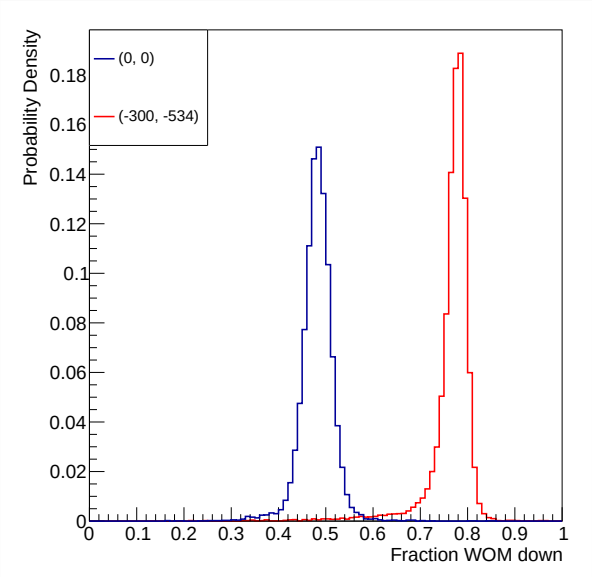
- March/April 2024 @ CERN

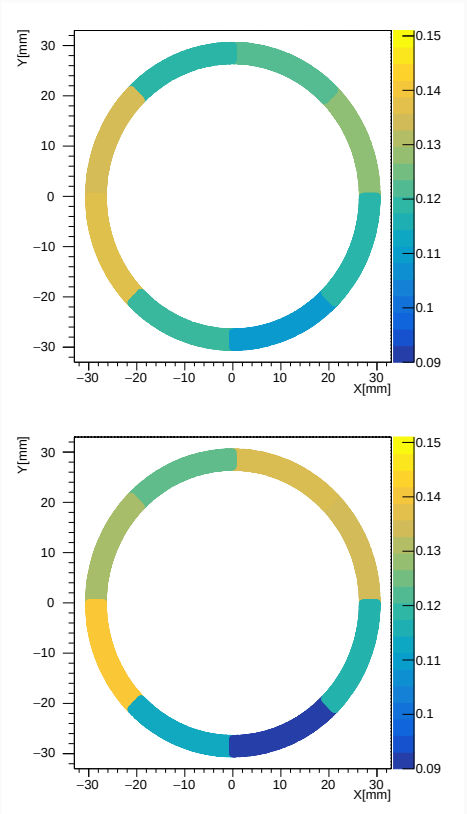
Next Prototype

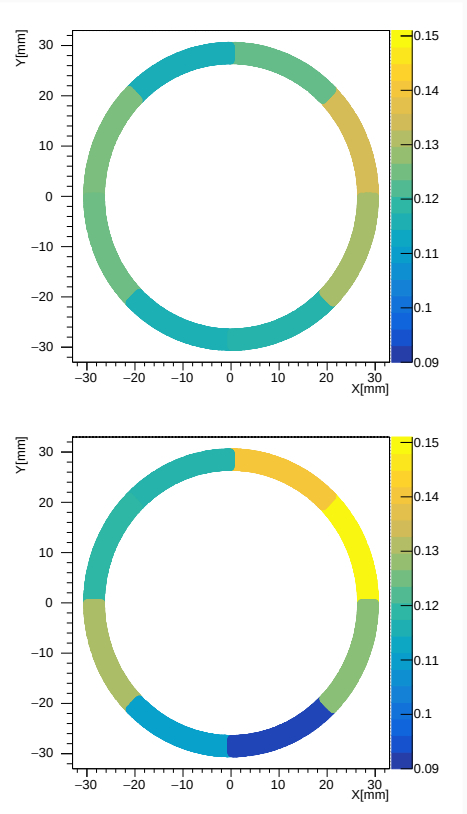
- First 3 ring sections of SBT (42 cells)



Data Uniformity Correction: Probability Density Distributions







- Yield fraction per WOM and channel determined for each particle crossing point
- Probability density distributions used for reconstruction and correction of each event