MATHUSLA

MAssive Timing Hodoscope for detection of Ultra-Stable neutraL pArticles

https://mathusla-experiment.web.cern.ch/

The Search for Long-Lived Particles: Construction of MATHUSLA Test Stand

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Supervisor: Dr. Miriam Diamond

Introduction

(1) Motivation

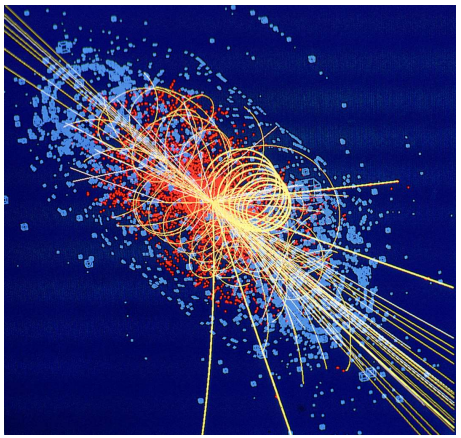
(2) MATHUSLA Proposal

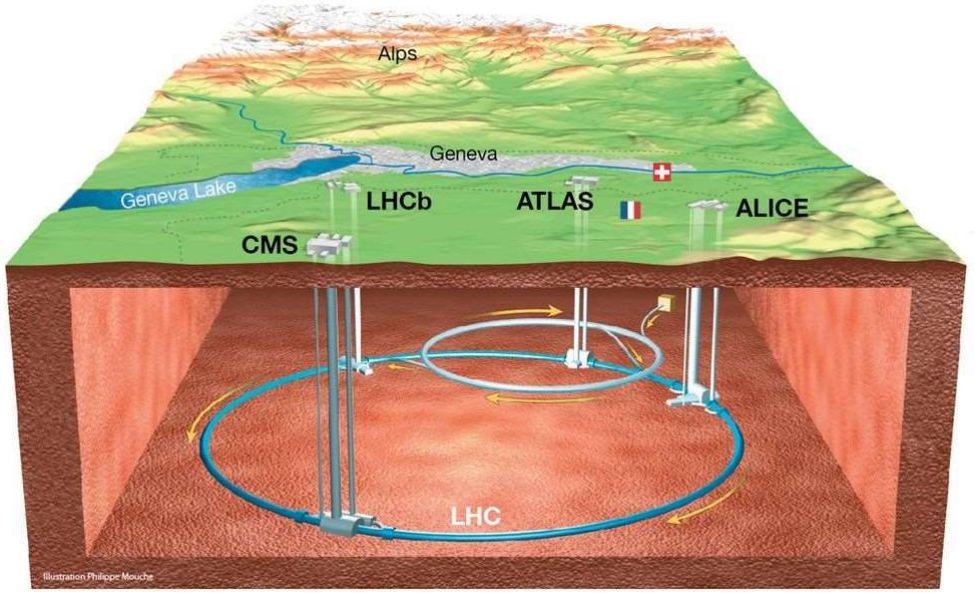
(3) Test Stand

(4) Next Steps

Large Hadron Collider (LHC)

- Operated by **CERN** (European Organization for Nuclear Research)
- World's **largest** particle collider
- Beams of **protons**
- **Higgs Boson** discovered here!

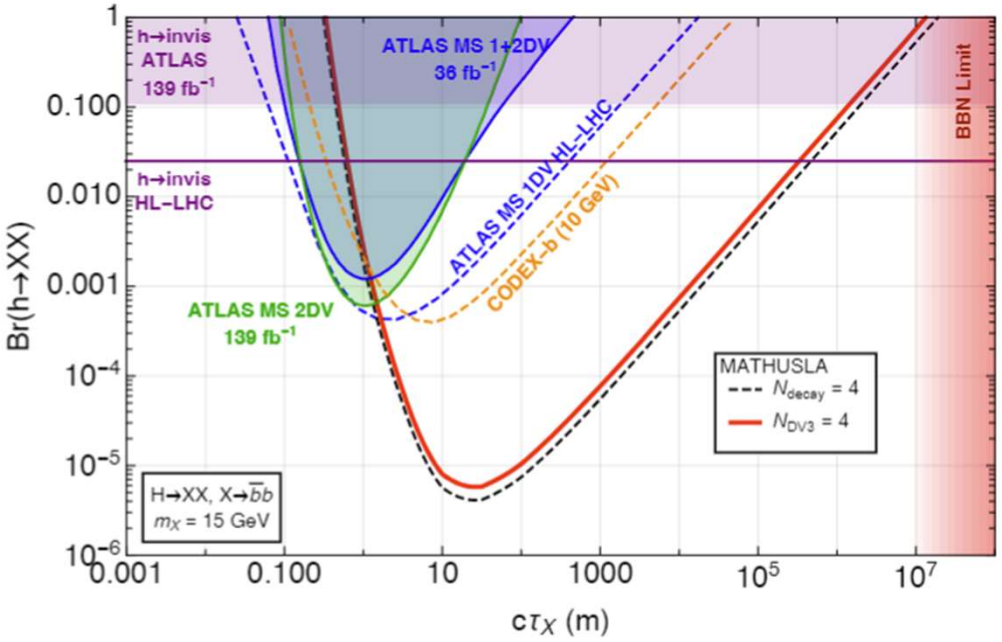




LHC

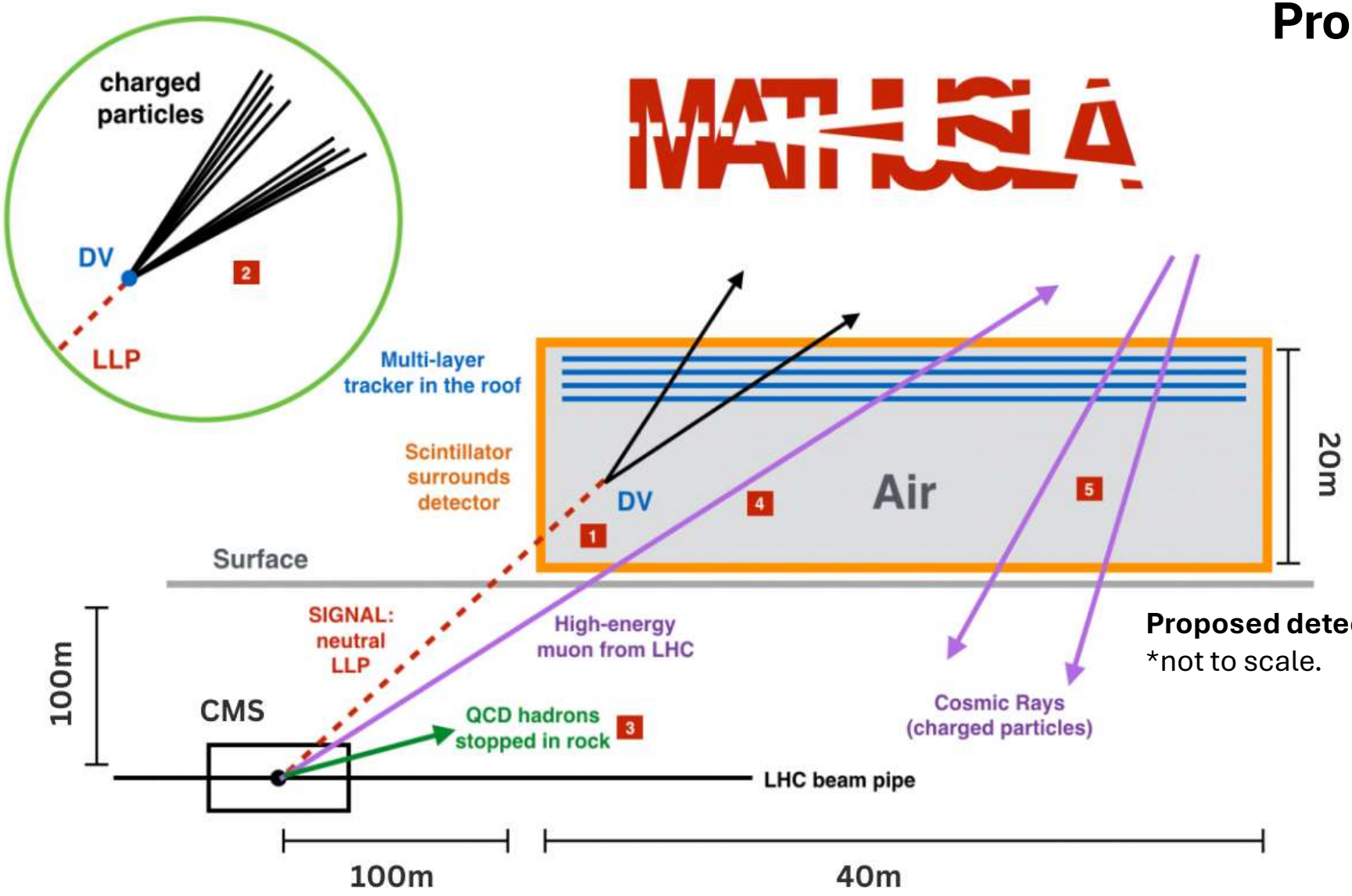
Long-Lived Particles (LLPs)

- Open problems: dark matter, hierarchy problem, baryogenesis
- Many **Beyond the Standard Model** (BSM) theories involve LLPs
- Weakly coupled → Long-lived
- May be produced in the LHC!
- MATHUSLA would be **orders of magnitude** more sensitive than the current ATLAS searches



Updated MATHUSLA Sensitivity Graph

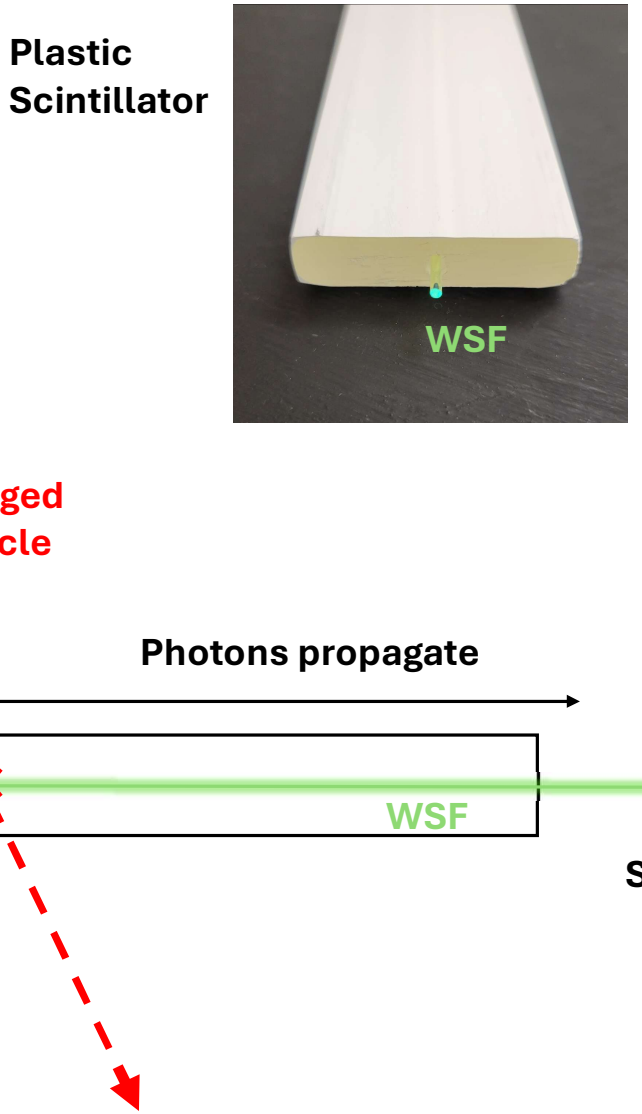
Proposal



Proposed detector
*not to scale.

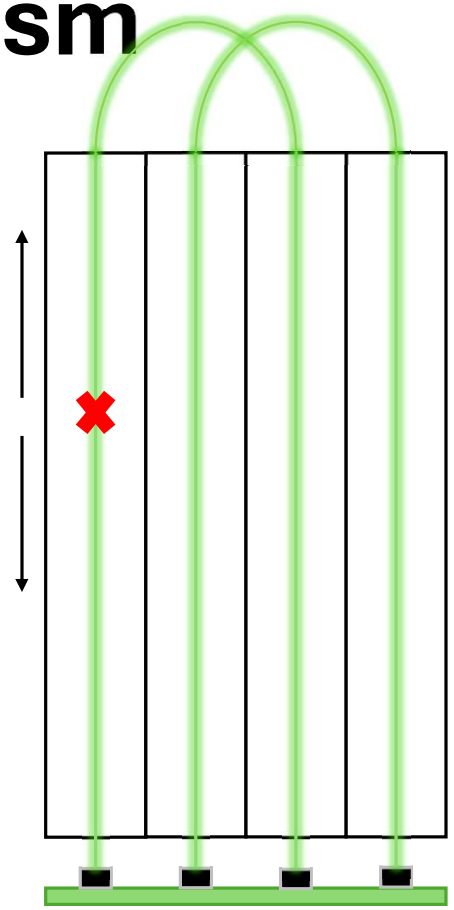
Detection Mechanism

- **Ionizing radiation** passing through plastic scintillator bars deposit energy
- **Fluor** molecules (PPO and POPOP) emit light
- **Wavelength-shifting fibre** (WSF) collects and shifts light
- **Silicon photomultipliers** (SiPMs) produce signal

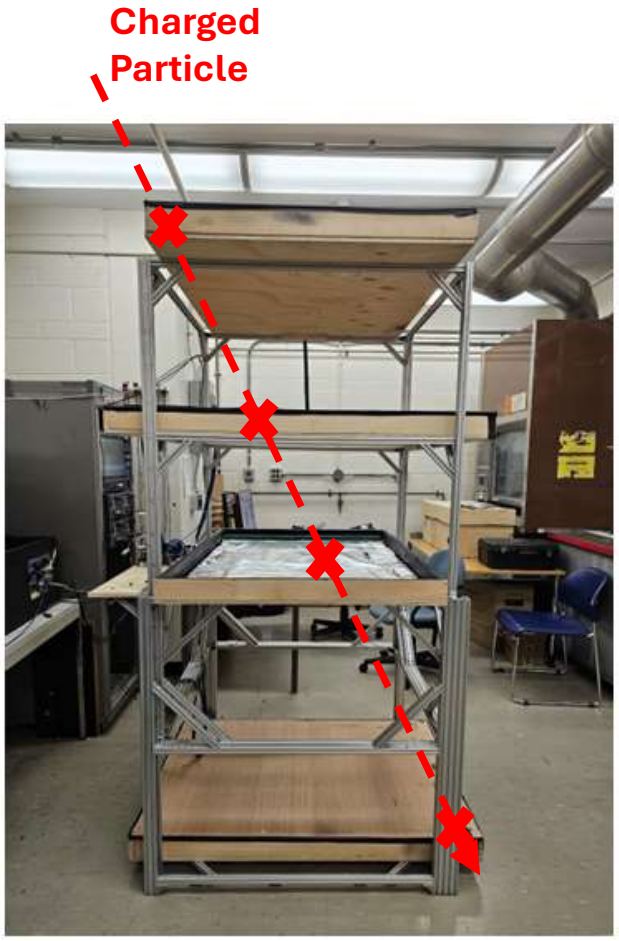


Detection Mechanism

- **Timing resolution** is crucial!
- Distinguish **upward** and **downward** going tracks
- Identifying **location** of hits in detector
- **Alternating** layer orientations
- **Nanosecond** precision



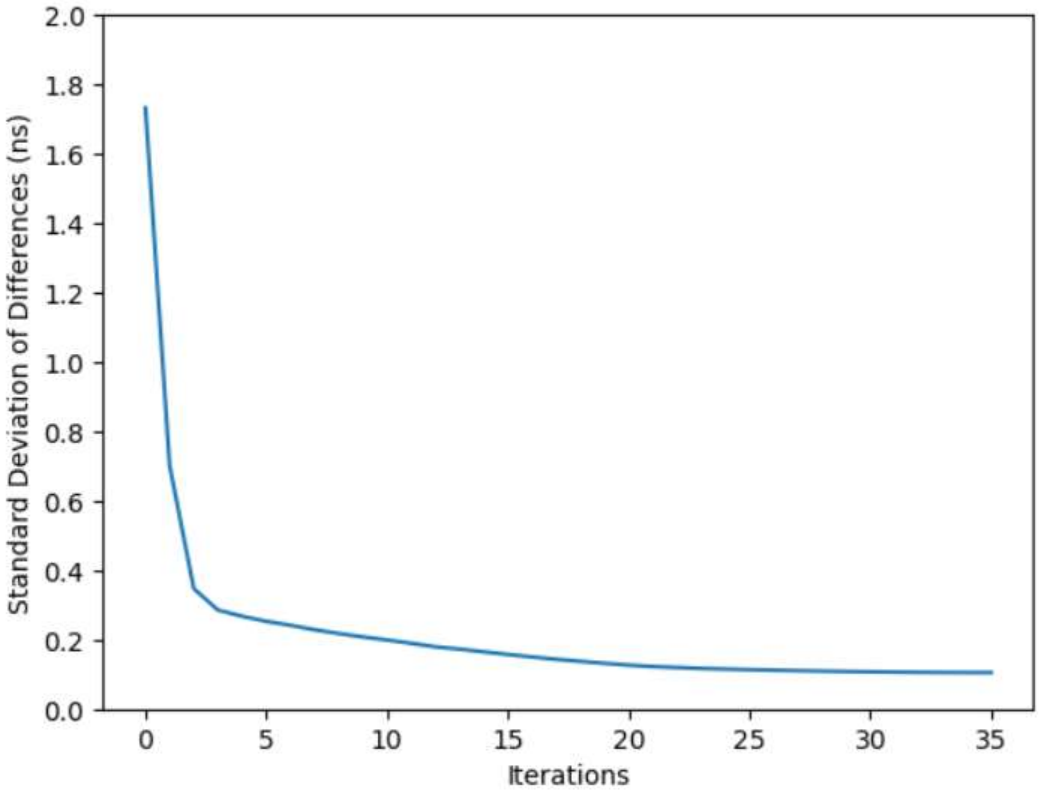
Layer of Test stand



UofT Test stand

Time Synchronization with Cosmic Rays

- Entire detector (**~100,000 bars**) can be synchronized at once
- Fits coordinates of hits to a **track reconstruction**, then fits the **times** of the hits to the distances of the hit along track reconstruction
- **150 seconds** of data-taking, synchronization uncertainty down to **±0.10ns**



Time Resolution

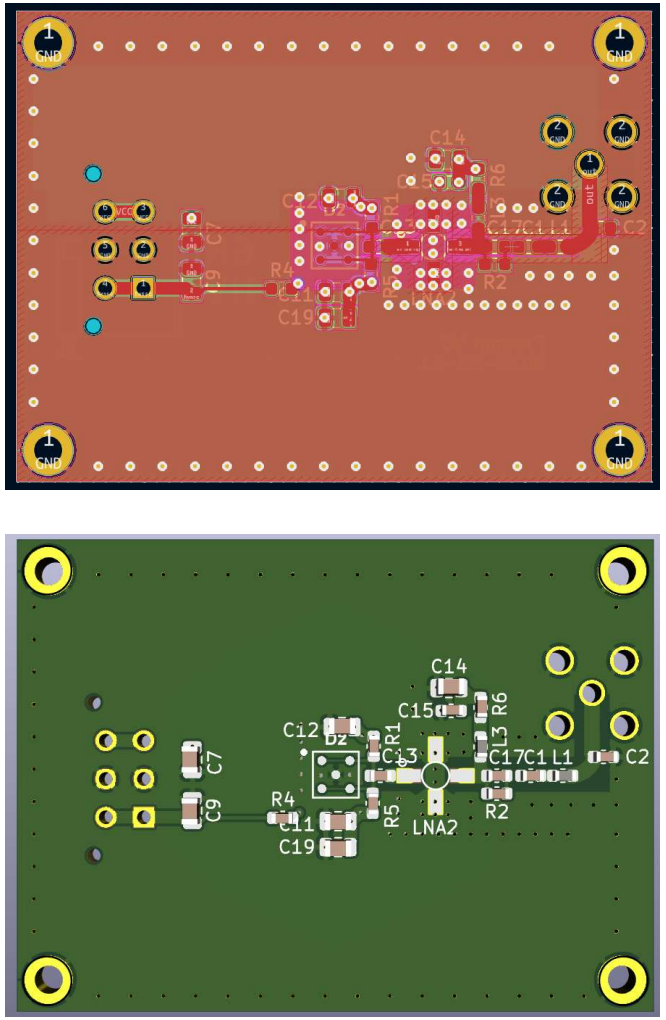
Factors that affect our time resolution:

1. **SiPM Signal & Trigger Threshold**
2. **SiPM Dark Counts**
3. **Light Output / Scintillator Quality**
4. **DAQ (Data Acquisition System) Board & Cabling**

Component	Model & Dimensions
SiPM	Hamamatsu S14160-3050HS 3.0mm x 3.0mm
Wavelength Shifting Fibers	Saint-Gobain BCF-92XL Attenuation length: 530 cm, 1.5mm diameter
Scintillator Bars	Fermilab Extruded polystyrene 1cm x 4cm x 100cm
DAQ Board	PETsys TOFPET2

SiPM Signal

- **Rise time** should be as fast as possible
- **Fall time** should not be too long. Otherwise dark counts will pile up!
- Minimize **noise** and distortion:
  - Shield signal layer
  - Decoupling capacitors
  - Make sure components are close together
  - Minimize trace lengths



Pre-Amplifier V.5

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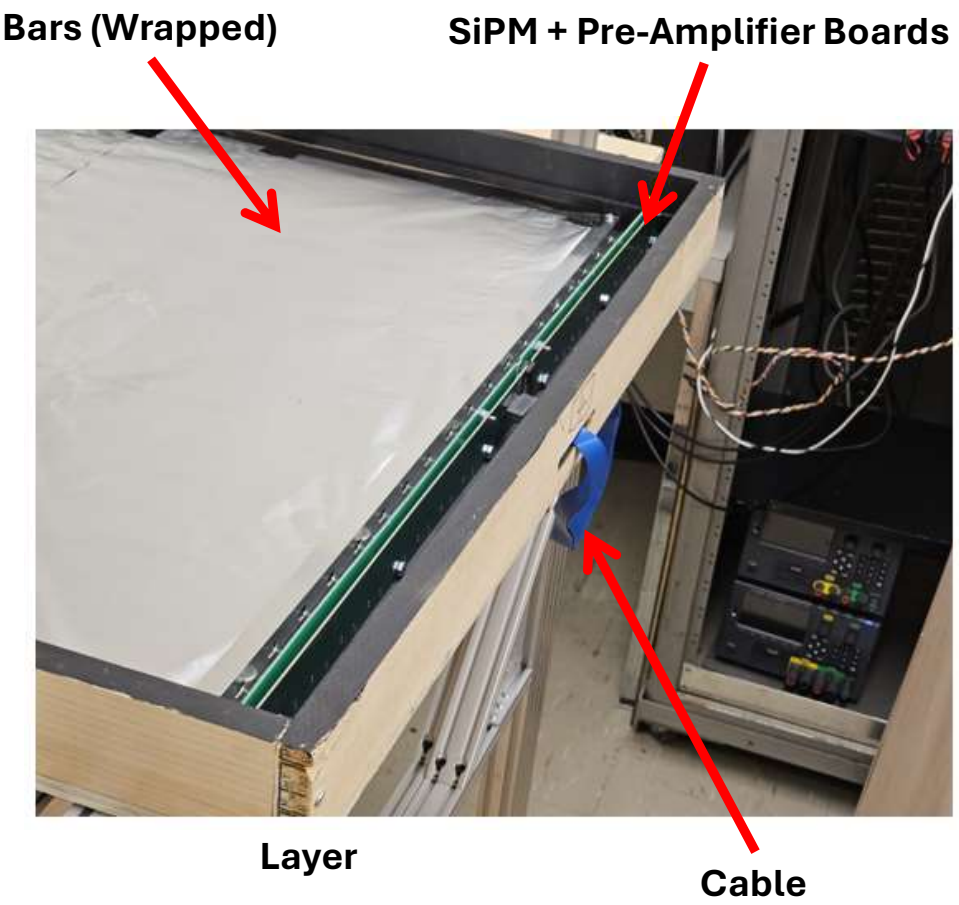
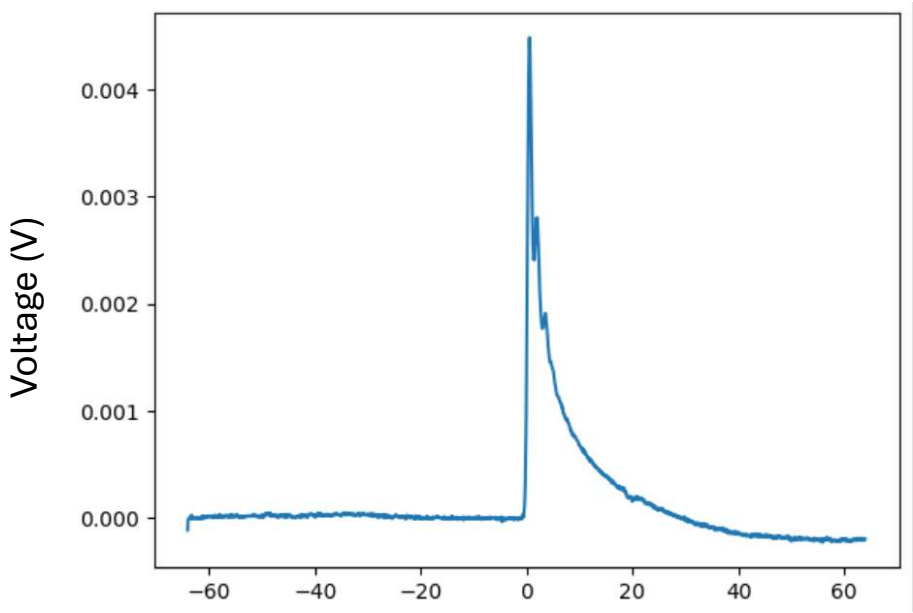


Trigger Threshold

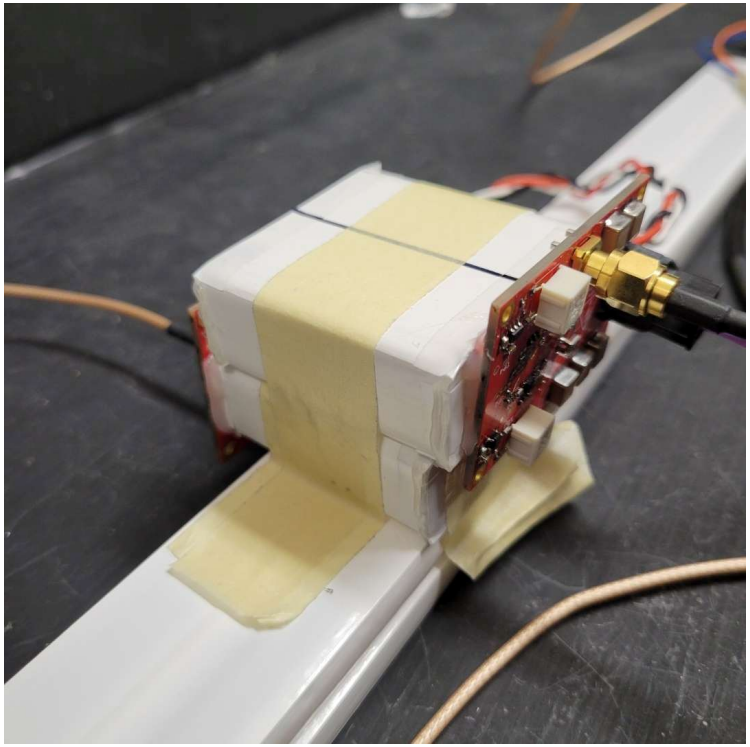
- Trigger: **1.5 photoelectrons**



Single Photon Pulse

Scintillator Quality

- Bar quality **differed** between batches!
- How do we prove this?
- Built a **cosmic ray trigger** to isolate signals from cosmic rays
- Issue with the **TiO_2** coating process and **polystyrene** source



Cosmic Ray Trigger

Scintillator Quality

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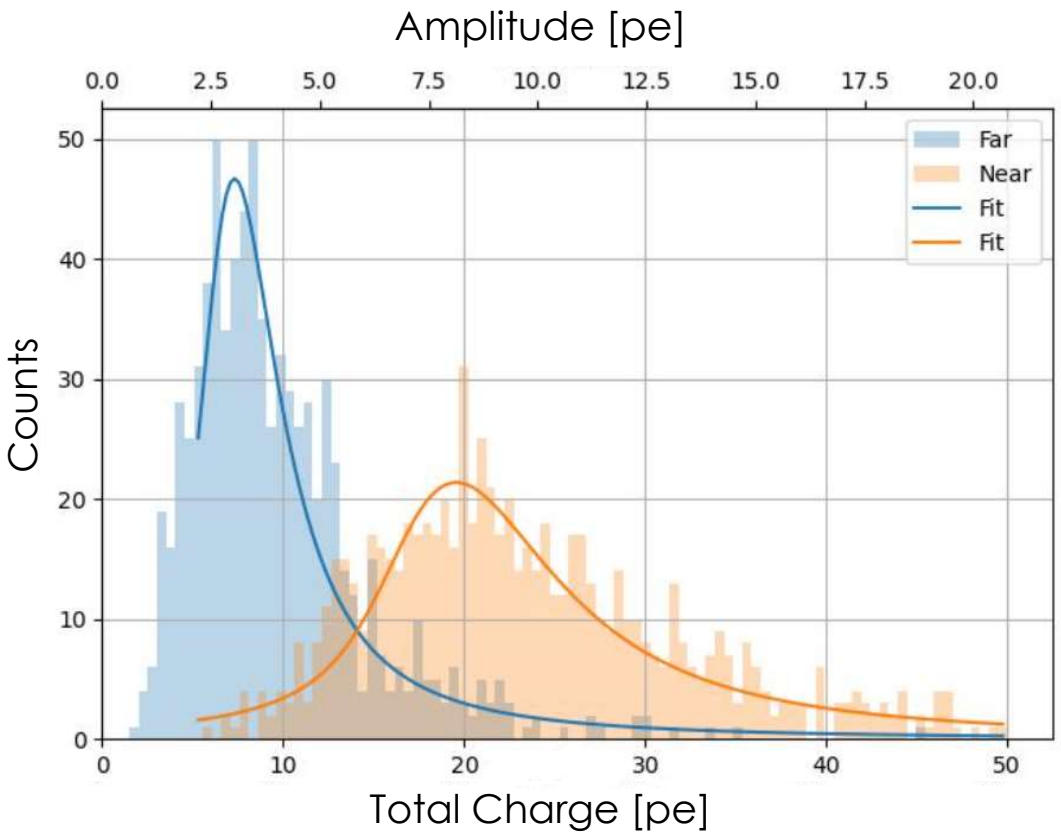

New Bar

Scintillator Quality

- Bar quality **differed** between batches!
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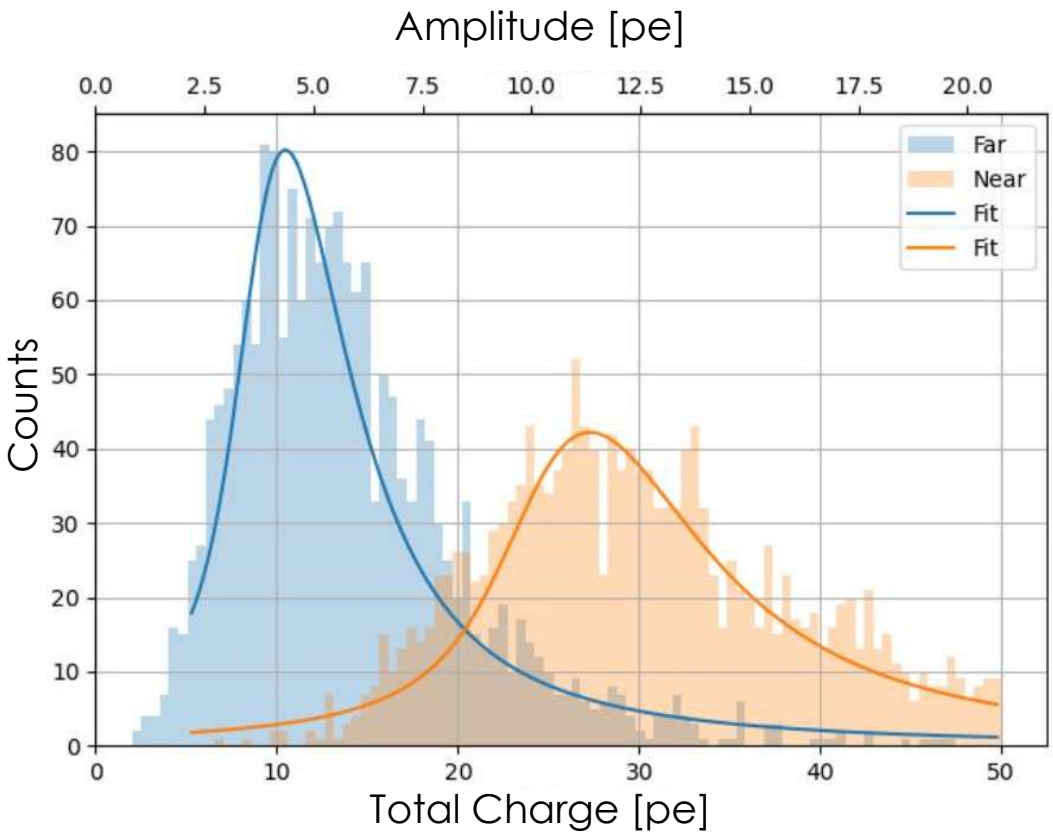
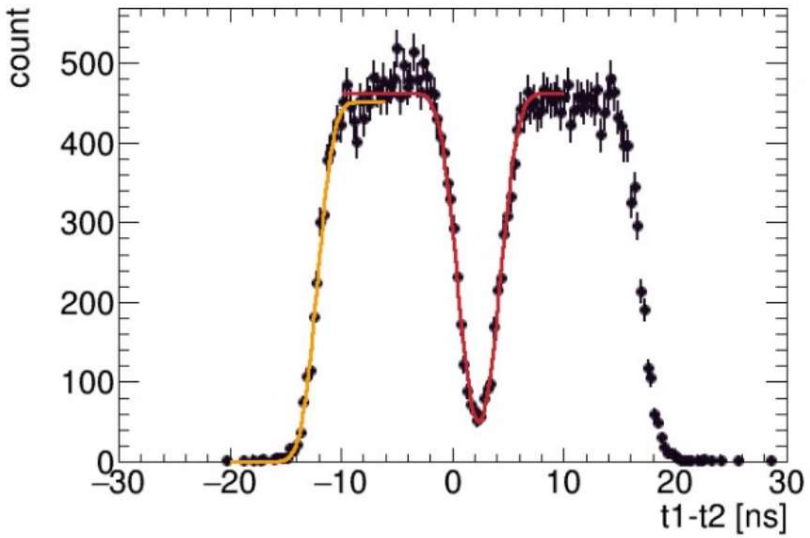
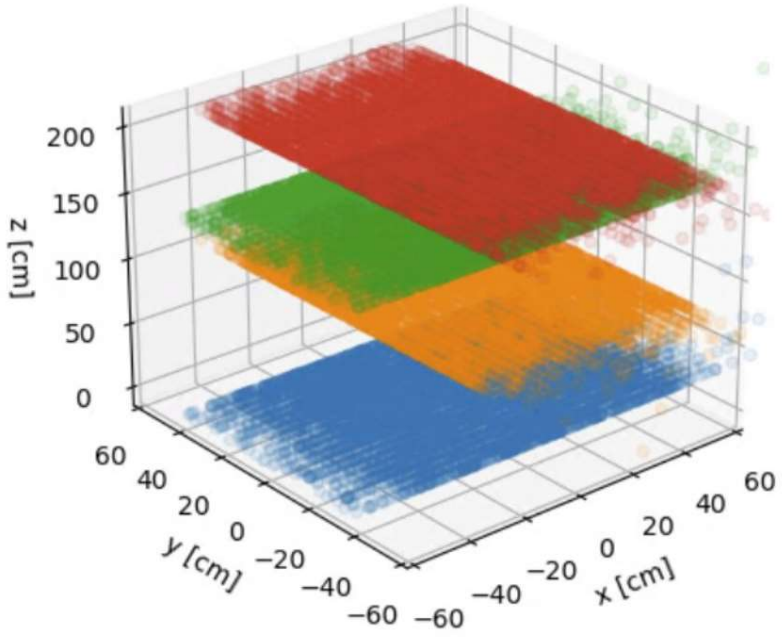


Old Bar

Results

- 3D visualization of the hits within our detector!

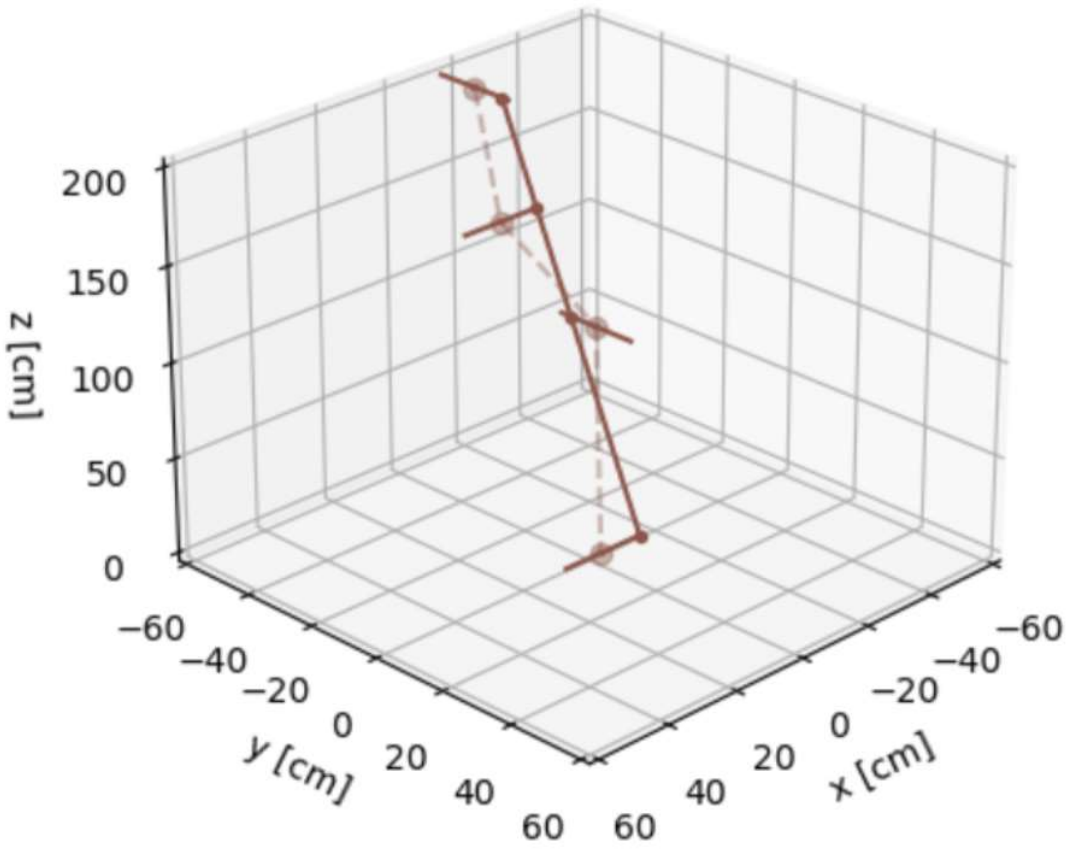




Position uncertainty of 9.5cm.
Credit: Tom Ren

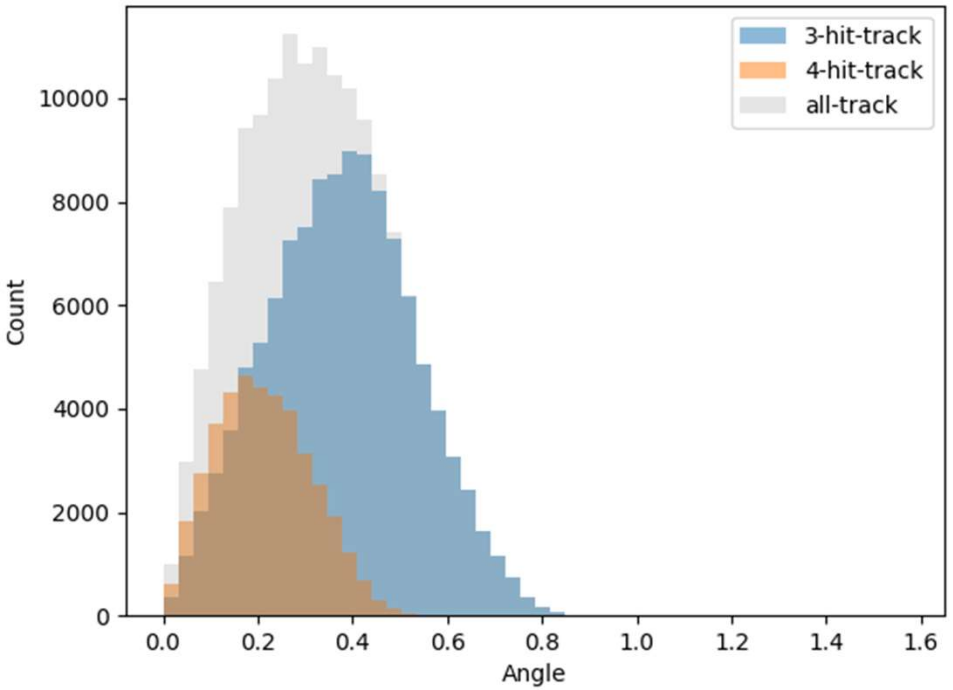
Results

- Hits in our detector with uncertainties, plotted with the results of track reconstruction algorithm



Results

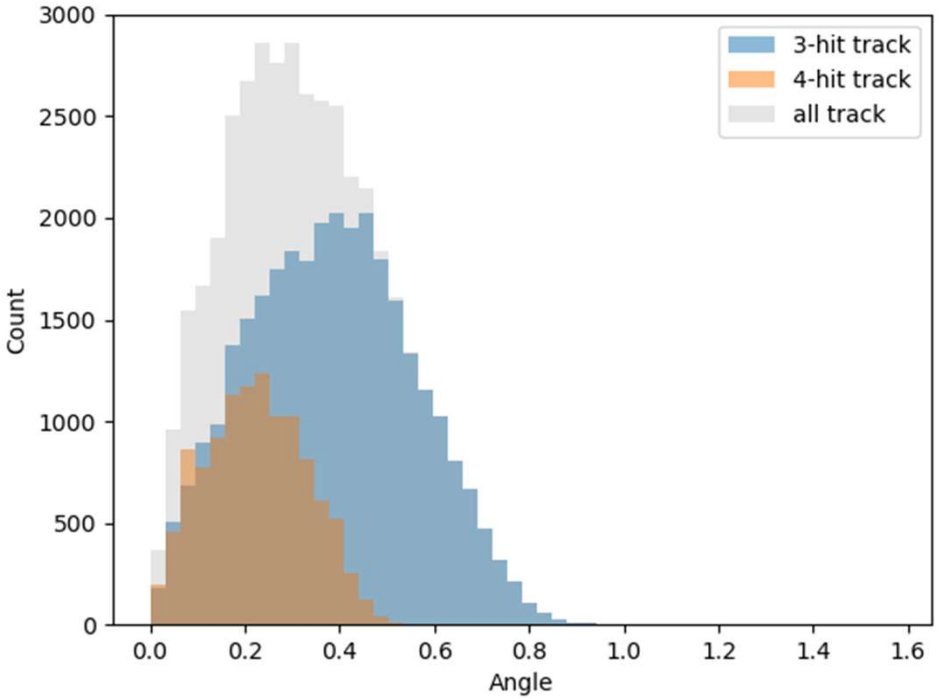
- Hits in our detector with uncertainties, plotted with the results of track reconstruction algorithm
- Preliminary results suggest **88%** efficiency



Simulated Track Angular Distribution

Results

- Hits in our detector with uncertainties, plotted with the results of track reconstruction algorithm
- Preliminary results suggest **88%** efficiency



Test Stand Track Angular Distribution

Next Steps?

- Preparing technical design report
- Seeking funding for **10m x 10m** first module at CERN
- Aim to run during High Luminosity LHC in a few years

Superconducting Magnet for HL-LHC

Collaboration

Canadian Groups:

PIs: David Curtin (UofT), Miriam Diamond (UofT), Heather Russell (UVic), Steven Robertson (McGill)

Postdocs: Caleb Miller, Tom Ren

Students: Gabriel Owh, Alex Lau, Caleb Gemmell, Andrija Rasovic, Zhihan Yuan, ...

References & Readings

- *The lifetime frontier*. EP News. (n.d.). https://ep-news.web.cern.ch/content/lifetime-frontier
- Fermilab. (n.d.). https://www.fnal.gov/
- *The MATHUSLA experiment*. Home | mathusla.web.cern.ch. (n.d.). https://mathusla-experiment.web.cern.ch/
- MATHUSLA LHCC letter of intent: arXiv:1811.00927, 2009.01693
- MATHUSLA Physics Case: arXiv:1806.07396
- LLP decays in MATHUSLA: arXiv:2308.05860
- Analysis of Long Lived Particle Decays with the MATHUSLA Detector: https://arxiv.org/abs/1705.06327
- On the Origin of Long-Lived Particles: https://arxiv.org/abs/2007.05538
- Recent Progress and Next Steps for the MATHUSLA LLP Detector: https://arxiv.org/abs/2203.08126

Supplementary Slides

SiPM Dark Count

- **Thermal noise** in SiPMs
- Layers should be **light-tight**
  - **Spray-painted** insides black
  - Lined edges with **black foam**
  - **Taped** edges of the box
- **Calibrated** our data acquisition board trigger to ignore dark counts

Picture of Layers

Scintillator Quality

- Issue with the **TiO_2** coating process and **polystyrene** source
- Tried **wrapping** the bars in different materials

	Old Bar	New Bar	Mylar, Adhesive Side In	Mylar, Adhesive Side Out	Teflon	Tyvek	Mylar and Teflon	Printer Paper	Aluminum Foil
Near End	**34.6**	24.7	24.4	29.3	28.9	25.2	28.8	28.2	**28.2**
Far End	**14.2**	9.7	7.5	8.7	8.9	8.2	8.6	8.2	**7.7**