UV Laser Calibration System: A probe to Determine Electric Field Distortion inside Liquid Argon Time Projection Chambers

ITN monthly Meeting
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Supervisor:

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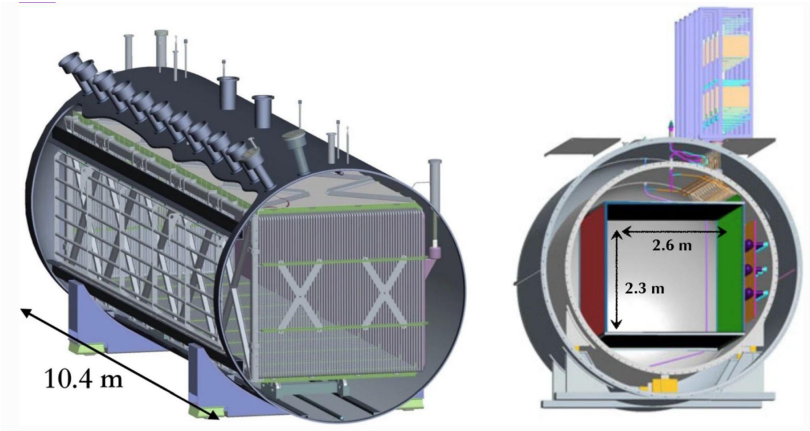
Self Introduction:

- From Kasaragod, Kerala, India.
- BSc in Physics (August 2014 - May 2017)
  Government College Kasaragod,Kannur University, India.
- MSc in Physics (August 2017 - May 2019)
  Central University of Karnataka, India

  Master's Thesis - " Study of Matter-antimatter asymmetry through leptogenesis"
  Indian Institute of Technology (IIT), Guwahati
- Started as Marie Curie Early stage researcher/ PhD Student
  University of Bern, Switzerland in March 2021.

Workshops, Schools and Courses:

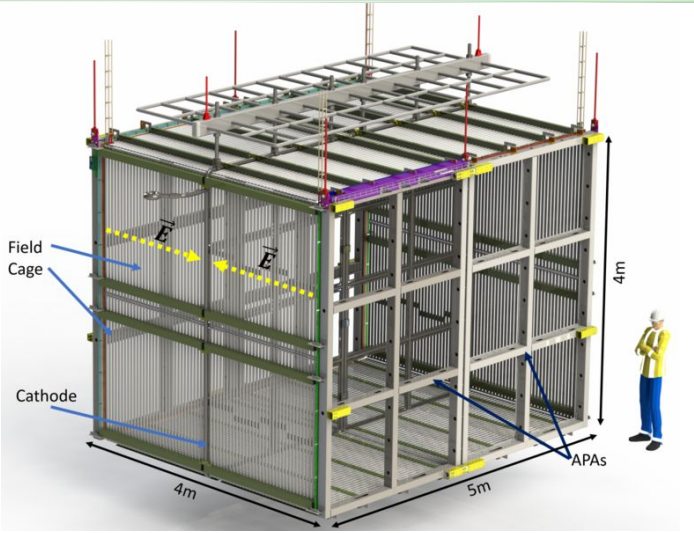
- PyHEP 2021 Workshop (virtual)
  05 July 2021- 09 July 2021.
- Fermilab - C++ / Standard Template Library course by Glenn Downing (virtual)
  17 August 2021 - 14 September 2021
- 2021 SBN Calibration Workshop (virtual)
  27 September 2021 - 01 October 2021.
- International Workshop on Cosmic-Ray Muography 2021 (virtual)
  24 November 2021 - 26 November 2022
- Bern Winter School on Machine Learning, Murren
  31 January 2022 - 04 February 2022
  Worked on a mini ML project named “ Finding Muons in LArTPC”
- KSETA Short Course : Introduction to Machine Learning and Deep Learning (Virtual)
  KSETA Short Course: Neutrino mass phenomenology
  05 October 2021 - 15 october 2021.
- Conference: Fermilab- New Perspective (Virtual)
  16 -22 June, 2022
- Conference: Fermilab- New Perspective (Virtual)
  26-27 June, 2023
- AEC Graduate course - Monte Carlo Simulations for Particle Transport in Matter
  October - November 2022
- Particle Physics / Detector technology
  2023*



C. Adams *Eur. Phys. J. C* 79, 673 (2019)

MicroBooNE:

- 470 meters from the Booster Neutrino Beam target.
- 80 tons of liquid argon in the active volume.
- Single tpc (2.6 m x2.3 m x 10.4 m)
- Two UV laser system for E field calibration.

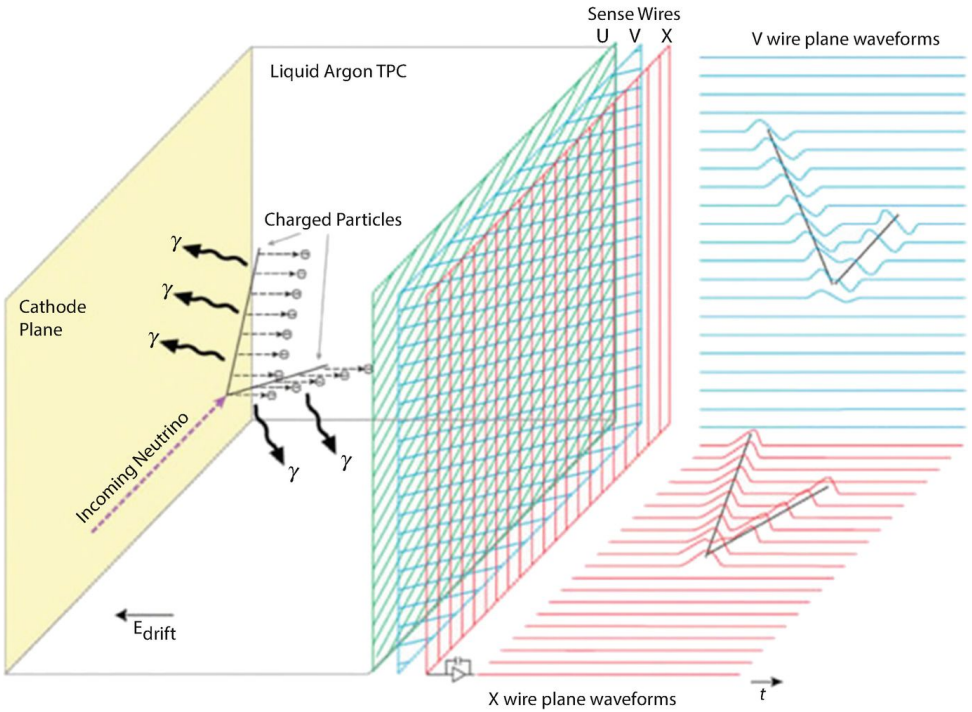


SBND:

- 110 meters from the Booster Neutrino Beam target.
- 112 tons of liquid argon within the active volume.
- 2 TPC system. (Each tpc is 2m x 4m x 5m)
- 4 UV laser system.

LArTPC:

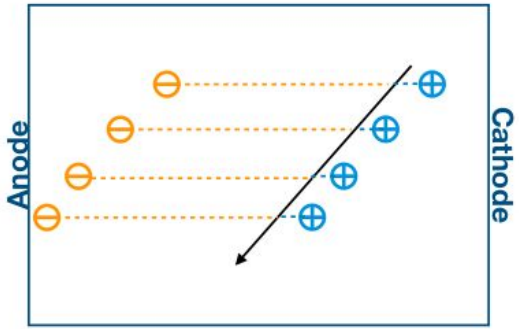
- Electric field is set up by cathode-anode plan
- Interaction in LAr produce scintillation light and ionization electrons.
- Scintillation light is detected by PMTs
- Due to Electric field $\mathbf{e}^-$ drift towards anode.
- At anode, the $\mathbf{e}^-$. Induce charge in induction planes and are collected on the collection plane.
- 2D spatial coordinates readouts from the collection plane along with time of flight is used to reconstruct 3D true position.



R. Acciarri *et al* 2017 *JINST* 12 P02017

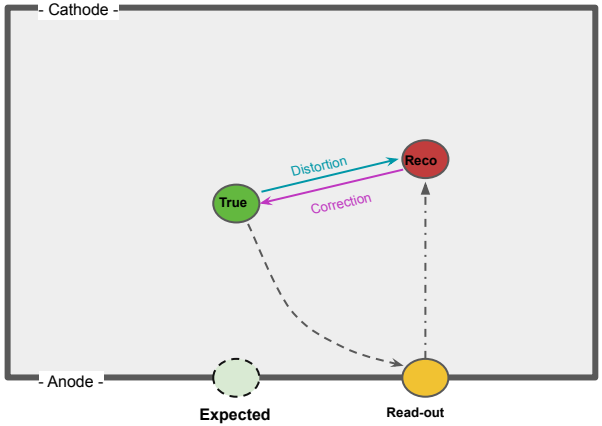
Why E-field Calibration ?

- $V_{e-} > V_{Ar+}$: by 5 orders of magnitude
- Accumulation of Ar^+ ions inside TPC :
- Average density of positive ions is much larger than that of electrons results in **Space Charge effect.**
- E- field distortion



Acciarri, R., et al. Journal of instrumentation 12.02 (2017): P02017

- Discrepancies between true and reconstructed points.
- Reduces track and energy reconstruction efficiencies of the detector and introduces additional systematic uncertainties



UV Calibration method :

What :

- Drive finely tuned energetic UV laser beam inside TPC, which ionises the Ar ion thus leaving a ionisation track.
- Compare expected (true) and reconstructed track points to calculate the E - filed distortion inside TPC.

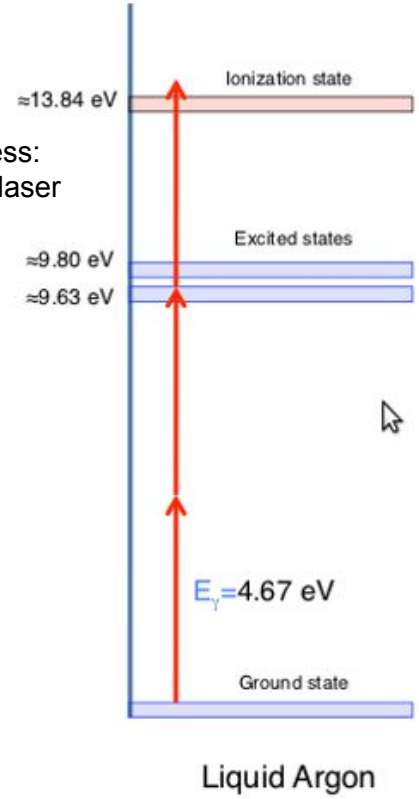
Why:

- laser beams do not experience delta ray emission in LAr.
- No multiple Coulomb scattering in LAr.
- Laser beams can also be repetitively pulsed in controllable directions
- UV laser system can be used to investigate detector failures, such as unresponsive or mis-configured wires in the read-out planes

Laser to ionize Ar:

- Nd:YAG laser from Continuum Surelite.
- Up to 10 Hz repetition rate.
- 5 mm beam diameter.
- Energy of 60 mJ (at 266 nm) per 5 ns pulse.
- The Surelite I-10 initially generates infrared (IR) light (1064 nm), which is shifted to green (532 nm) first, and then UV (266 nm) through second and fourth harmonic generators.

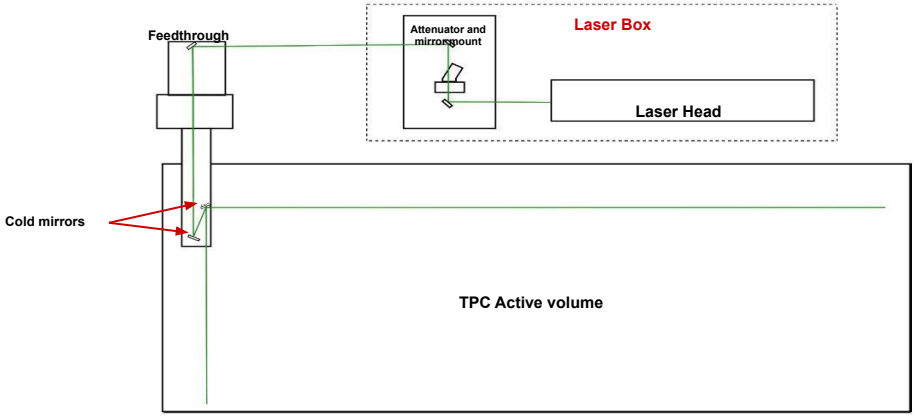
(2+1)-photon process:
Needs high power laser



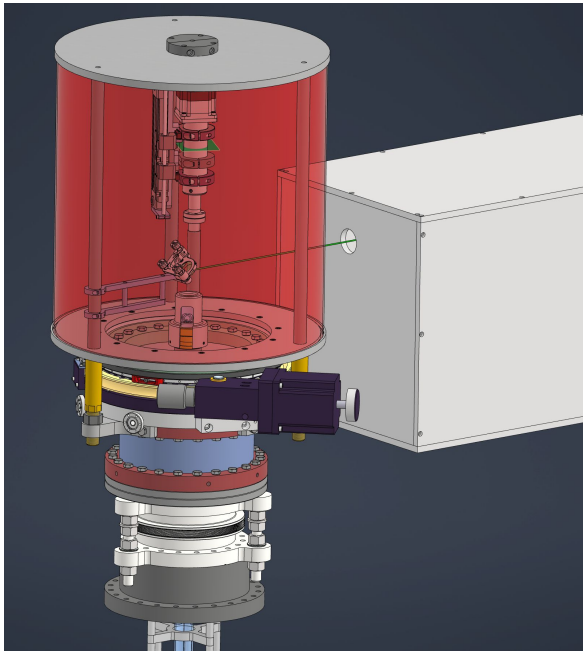
How:

Laser Head -> Mirror -> Attenuator -> 3 Mirrors -> 2 Cold Mirrors

- Each Dichroic Mirror eliminates 532, 1064 nm and reflects 266 nm.

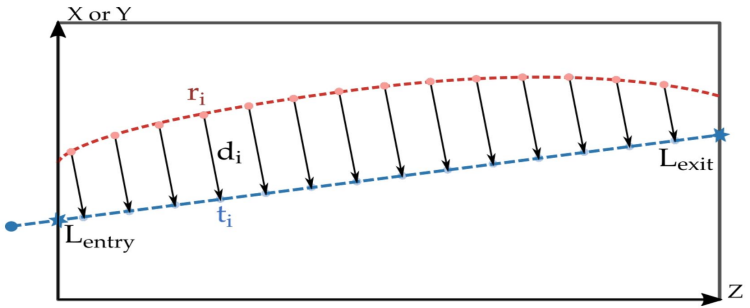


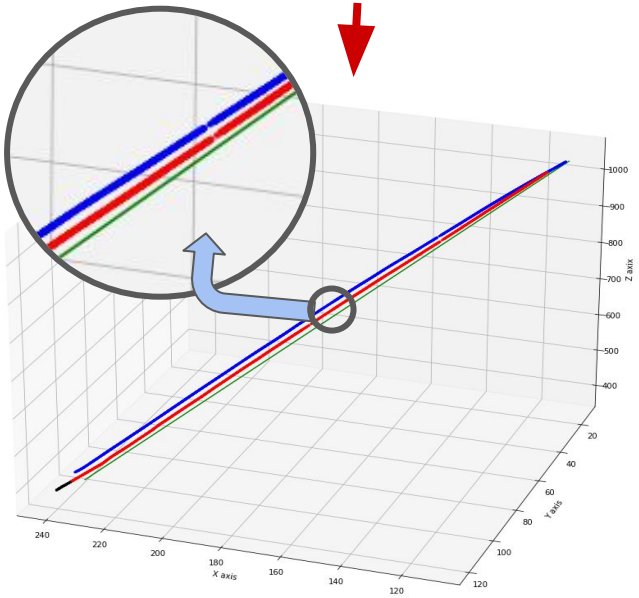
Schematic representation of SBND - UV laser calibration set up

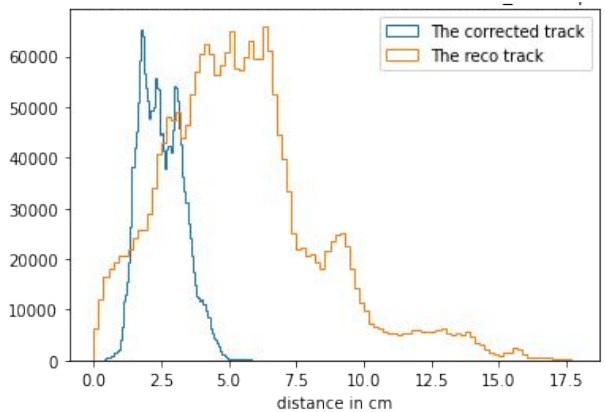


How:

- Correction Map: Based on reco spatial coordinates
  Gives expected true points, given by the reco points.

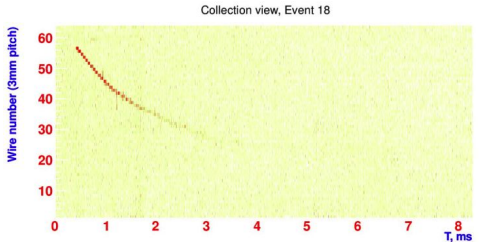




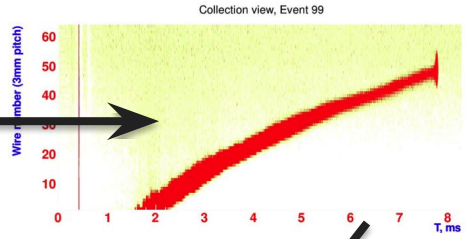


Shortest distance from true to reco points before and after correction.

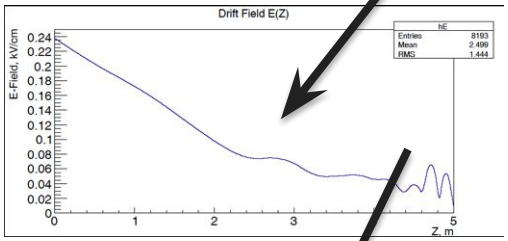
UV-laser method in actual scenario - measurement from ArgonTube (Bern, 2013)



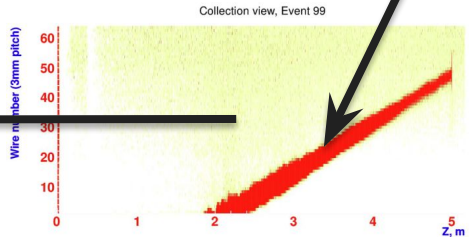
Distorted muon track, due to e-Field distortion



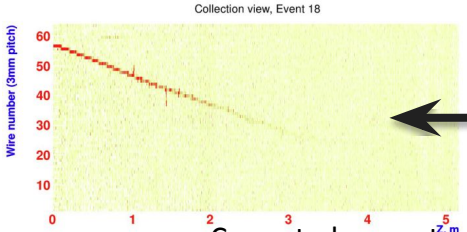
100 laser tracks



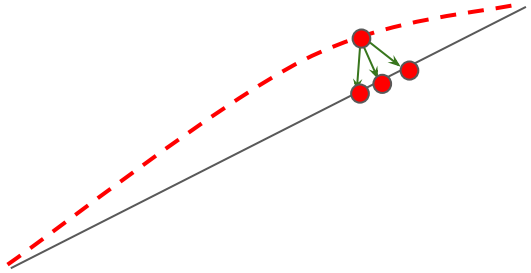
E-Field map



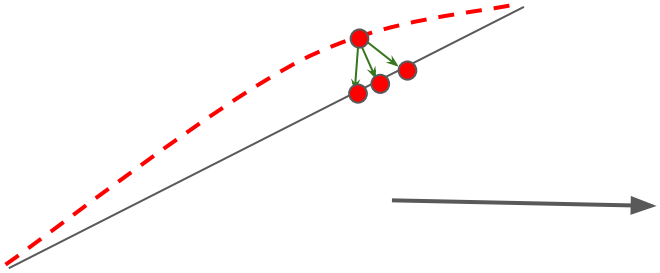
Corrected laser tracks



Corrected muon track

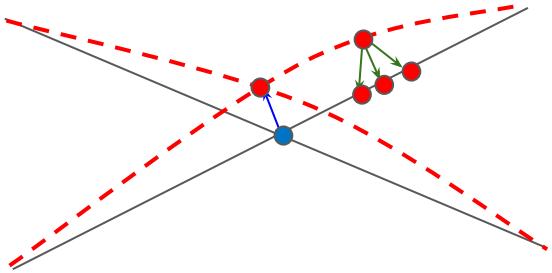


A reco points corresponds
to which point in true track?



A reco points corresponds to which point in true track?

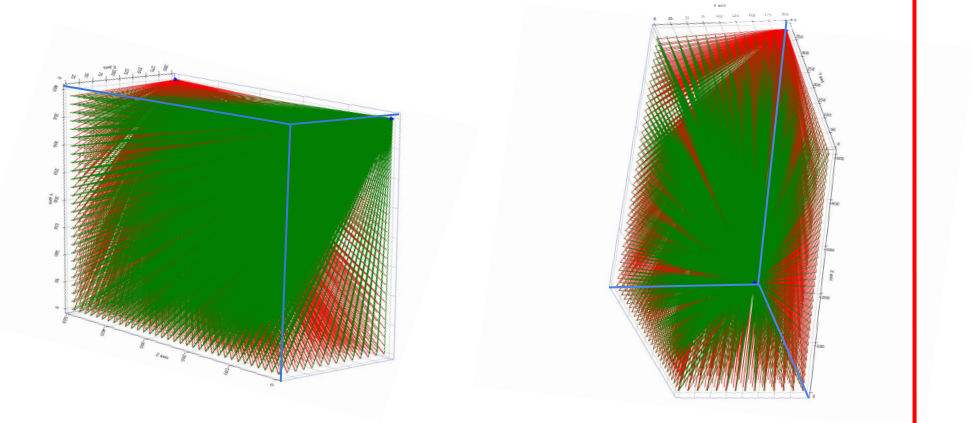
Crossing tracks!!!



Cold mirrors inside the TPC - No shadow effect by fieldcage

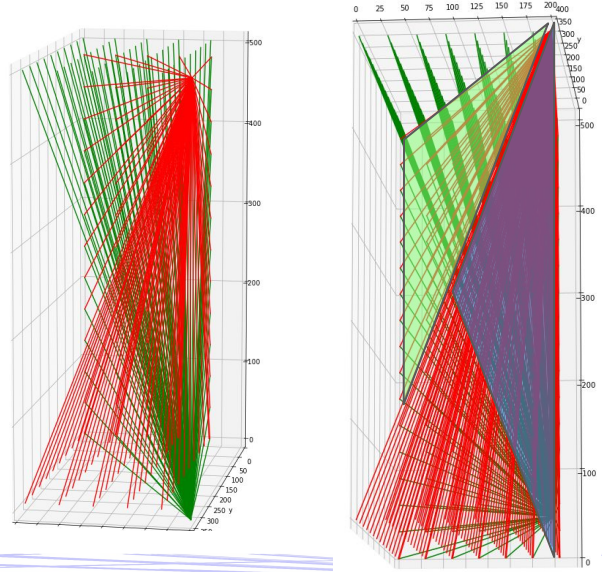
Full Laser Scanning:

- Full coverage with crossing tracks
- More precise and effective informations from crossing tracks

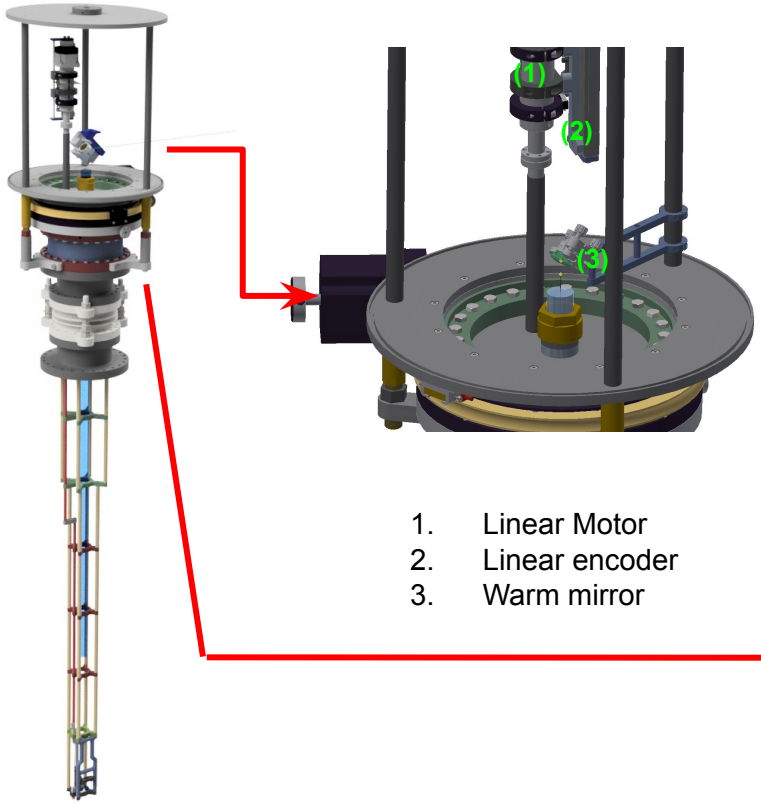


Partial Scanning:

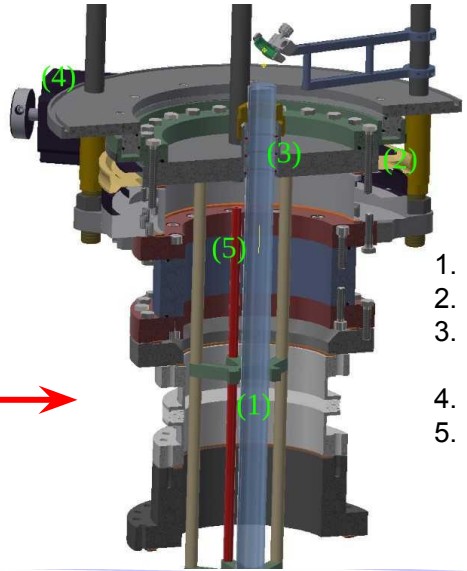
- Omit the laser tracks directed towards the cathode because of the presence of PTB-coated reflective sheets on the cathode.
- Partial coverage with crossing track points < 50% of total volume.
- Crossing tracks are close to anode.



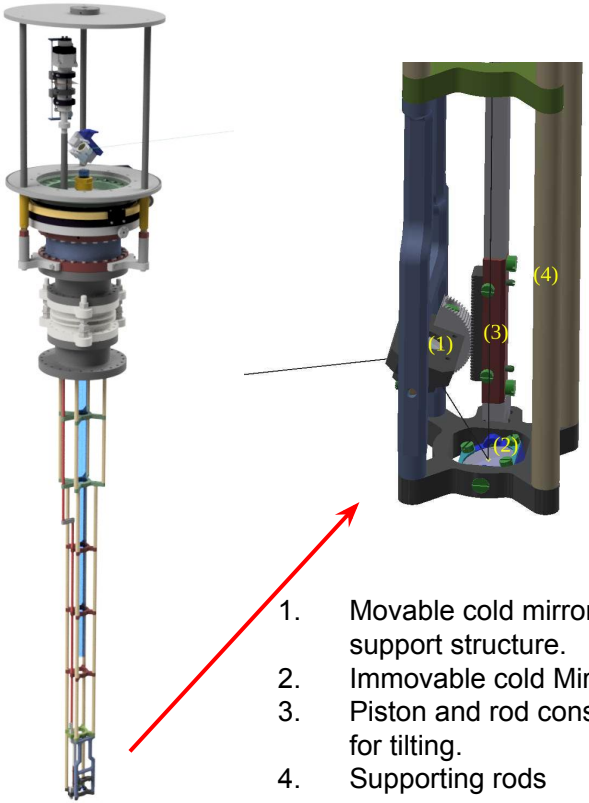
Hardware -Feedthrough: Cross Sectional view



1. Linear Motor
2. Linear encoder
3. Warm mirror



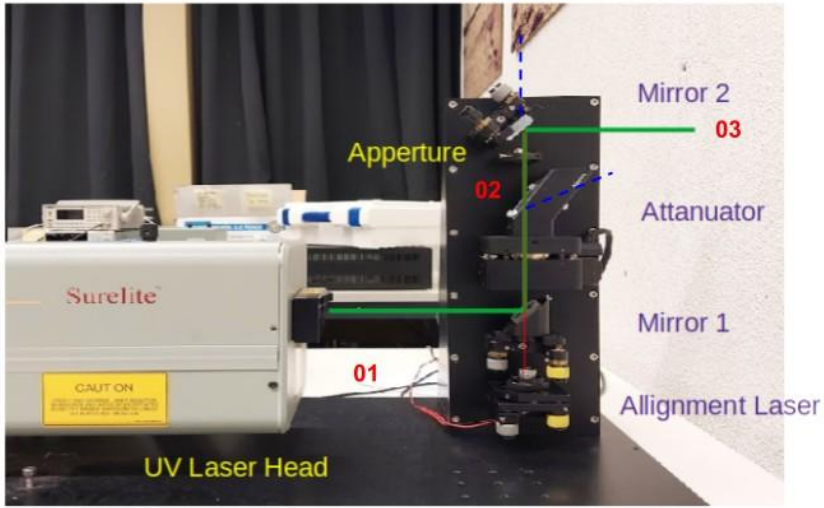
1. The evacuated glass tube.
2. Rotary encoder ring
3. Rubber seals for the glass feedthrough
4. Rotary motor.
5. Linear feedthrough piston from linear Motor for tilting mirror



1. Movable cold mirror and support structure.
2. Immovable cold Mirror.
3. Piston and rod construction for tilting.
4. Supporting rods

Inside the laser box:

1. U-V laser head
2. Two dichroic mirrors (wavelength separator)
3. Attenuator
4. Aperture
5. Photo Diode for DAQ trigger.



Controlling Script and User Interface:

- Controlling script ready.
- Script available in python2 and python3 (interactive Python shell).
- Currently using the interactive Python session to perform all the functions.
- Trying to make **User Interface**. (Incomplete)
  - helps are highly appreciated.

```
10:55:18 linear_actuator: matching_______start_____
////////////////////////////____ 1 __/////////////////////////__
___comserial___ 76 PR P
____comserial.py _____________80 b'1PR P\n'
___comserial.py_____ 108 b'1PR P\r\n1982\r\n?'
_____feedthrough 157 b'1PR P\r\n1982\r\n?'
_____feedthrough___ 159 1PR P
1982
?
_____feedthrough __163
1982
___feedthrough.py 193__
1982
////////////////////////////____ 1982 __/////////////////////////__
10:55:18 linear_actuator: matching_______end_____
10:55:18 linear_actuator: --- 0.20385003089904785 seconds ---
____comserial___ 76 PR MV
____comserial.py _____________80 b'1PR MV\n'
___comserial.py_____ 108 b'1PR MV\r\n1\r\n?'
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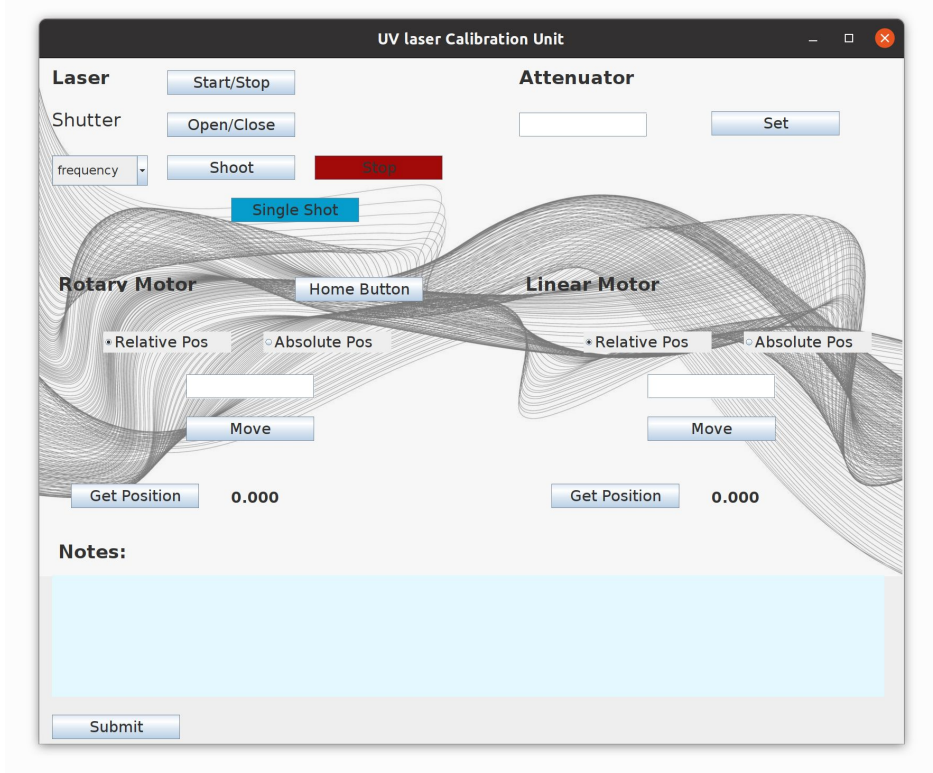
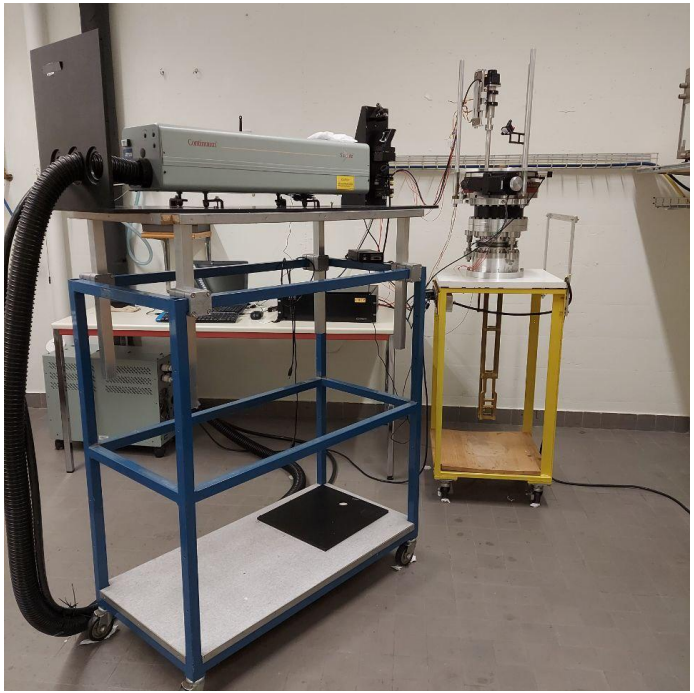
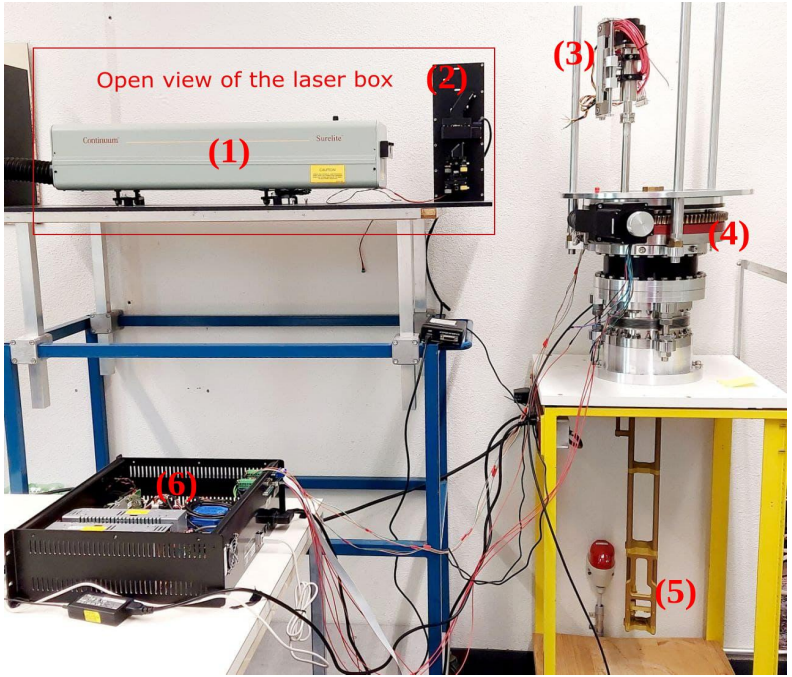


Laser test facility at LHEP:

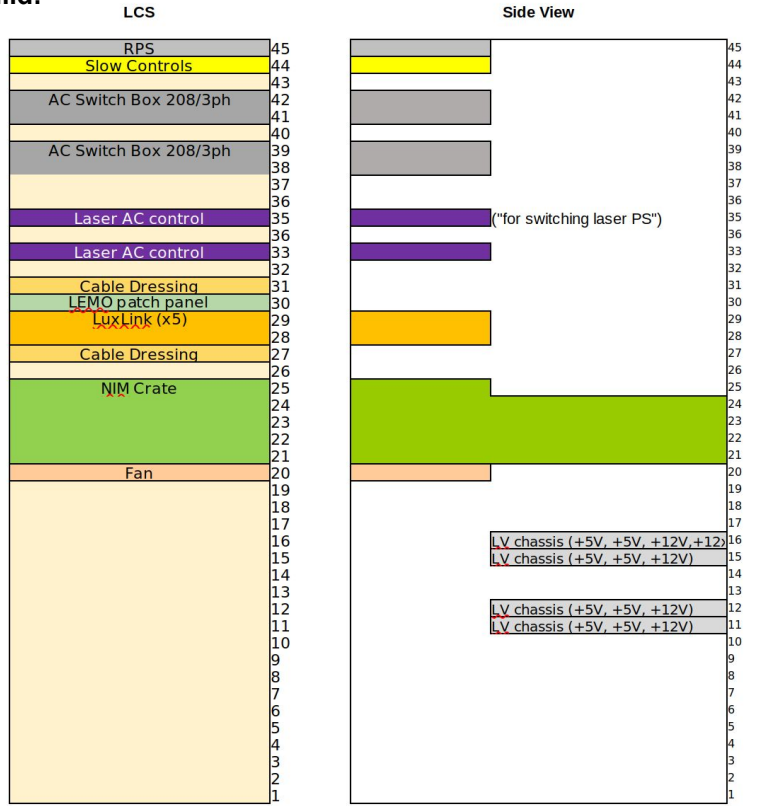


Thanks to Michele, Igor, Rogger, Silas, Lino and Andri

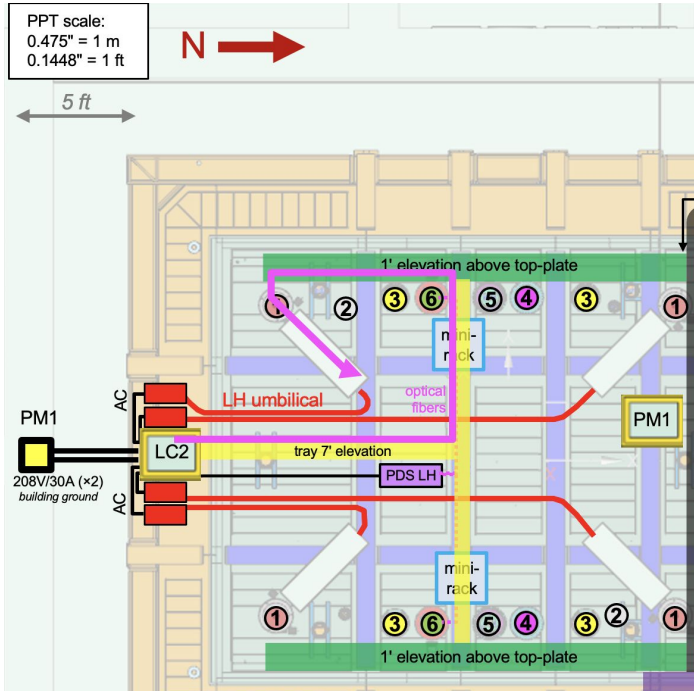


(1) Laser head, (2) Attenuator and mirror mount,
(3) Linear Motor to control the vertical movement of the cold mirrors,
(4) Rotary motor to control the horizontal movement of the mirror.
(5) Cold mirror mount and shafts, (6) Motor controller box

Rack Build:

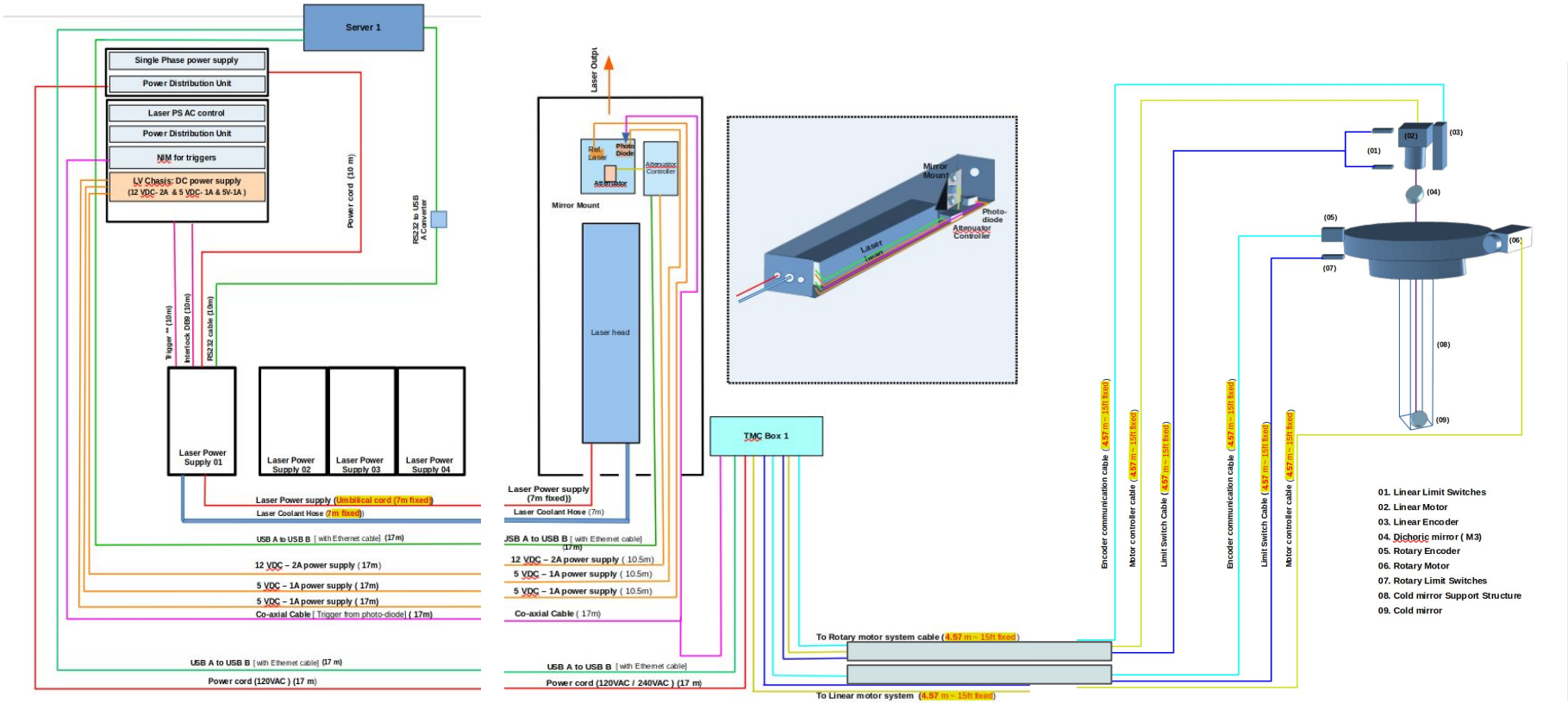


https://sbn-docdb.fnal.gov/cgi-bin/sso/ShowDocument?docid=1382



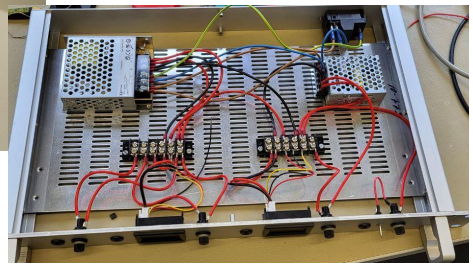
Thanks Will and Linda

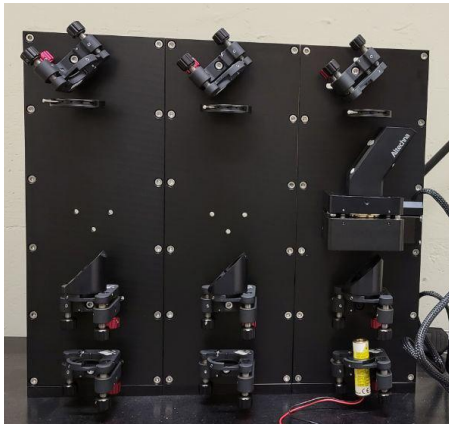
Wiring diagram:

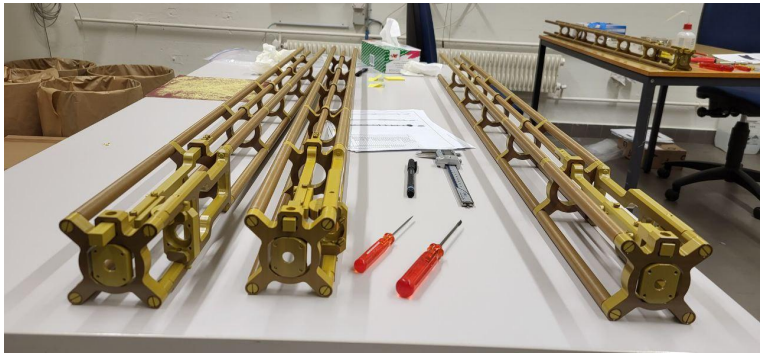


Parts assembly in Bern (April 2023)

Thanks.. Lori and Vasco







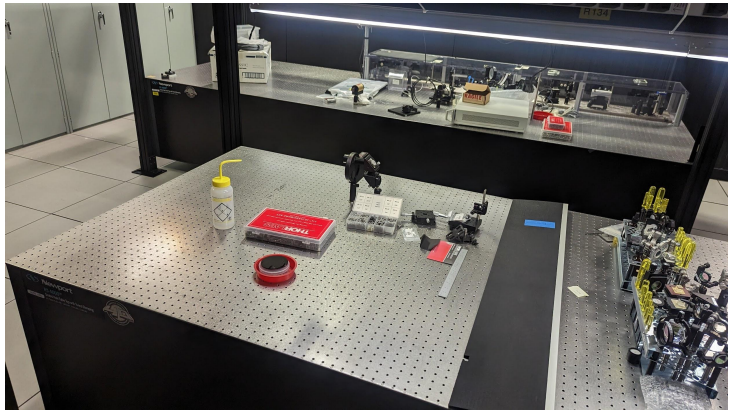
Mechanical installation of Feedthroughs at SBND:

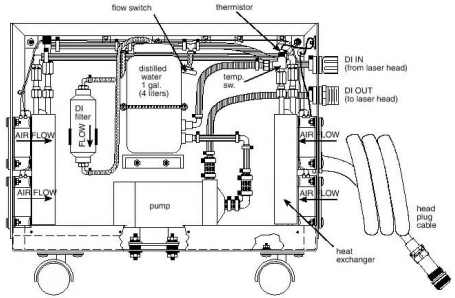
- Installation of feedthrough onto the cryostat was done last week (June 12 - 19)

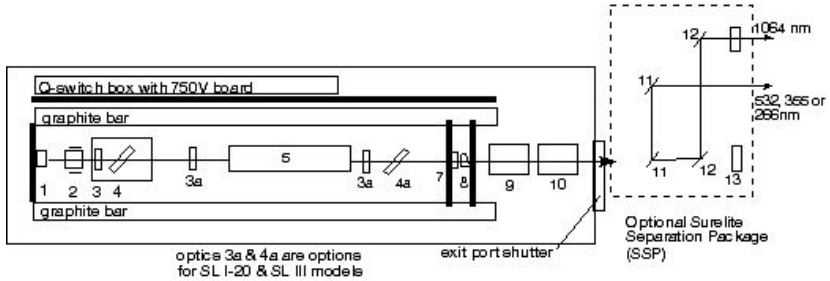
Thanks to Anne, Roberto, Lori, John, Luis

Laser unpacking and first setup

- Procedure to uncrate, unpack and first setup
- Identified location at NML (laser lab)
  Very comfortable setup (thank you!)
- Need to attach umbilical, fill cooling DI water,
  Connect flashlamp, tune settings an measure power IR,
  mount second and fourth harmonic and tune power
- ½-day to 1 day per laser
- Writing TSW
- Planned for May (when Shivaraj @FNAL)

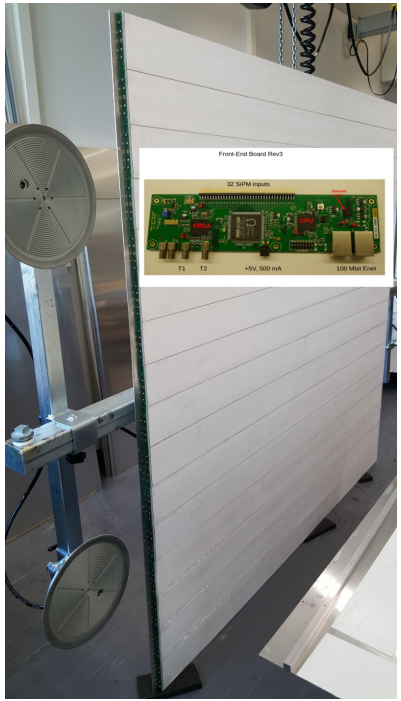






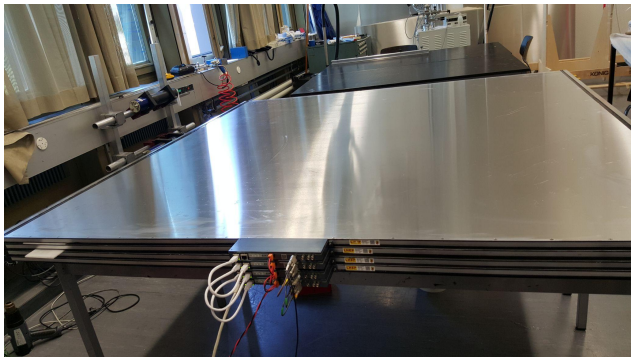
SBND - Cosmic Ray Tagger (CRT):

- Background interactions can occur in the active volume of the LArTPC detector.
- Main Background are cosmic rays- mostly muons from pion and kaon decay in the atmosphere.
- SBND consist of 220 modules, each made up of 16 mechanically joined strips of scintillating plastic in a protective aluminum case.



Characteristics:

- Each strip 10.8cm wide, 1cm thick,
- High light yield (20 -30 photo e^-)
- Time resolution - 2ns RMS
- Spatial resolution 1.8 cm RMS
- Geometry efficiency > 95%

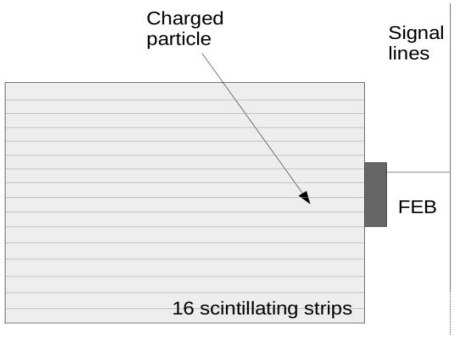


https://www.lhep.unibe.ch/research/detector_development/scintillating_detectors/index_eng.html

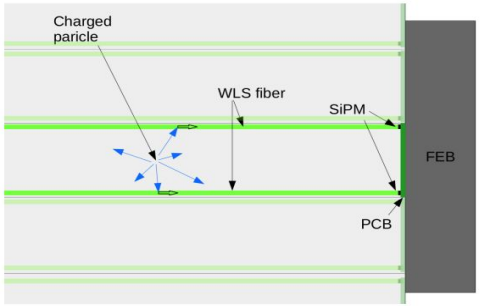
Working Principle:

- CRT system can only measure particles interacting electromagnetically inside the modules.

Scintillation → **WLS** → **SiPM** → **FEB** → **Server**



(a) CRT module

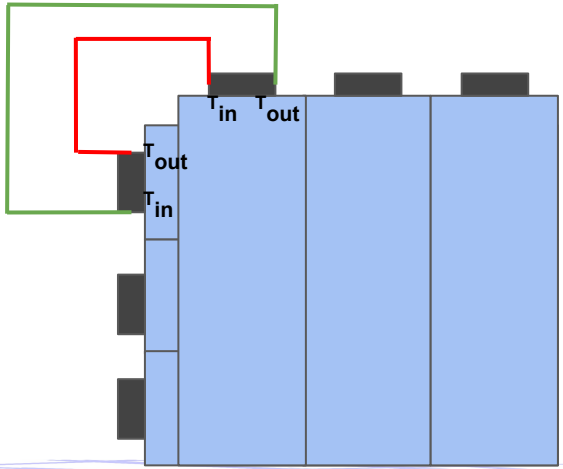


(b) zoom inside

Mettler, Thomas (2021). *Detection and Measurement of Neutrino Interaction in a Cosmic Contaminated Environment.* (Thesis). Universität Bern, Bern

Triggering between X and Y modules:

- When the signal in the two SiPMs in one strip crosses the threshold, the FEB digitizes the signal of all 32 SiPMs and sends a signal out through the TOUT line
- TOUT is plugged into the TIN connection of the FEBs in the perpendicular module. (time window of 150ns)



Analysis Plan:

- Detector Physics analysis: E- field distortion measurements and Calibration using UV laser, e^- drift measurements. (Nov 2023)

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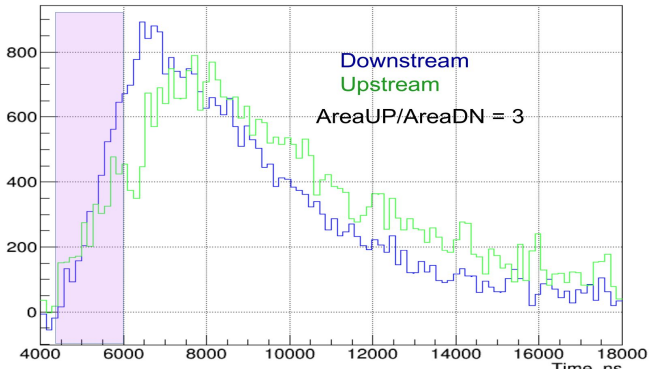
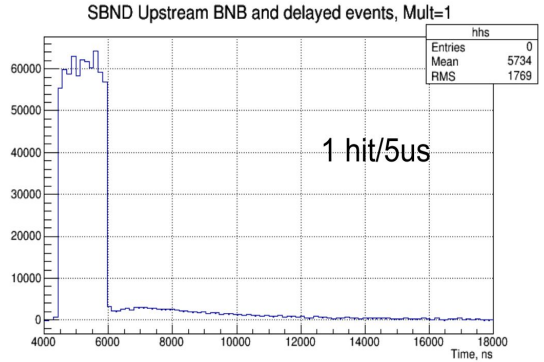
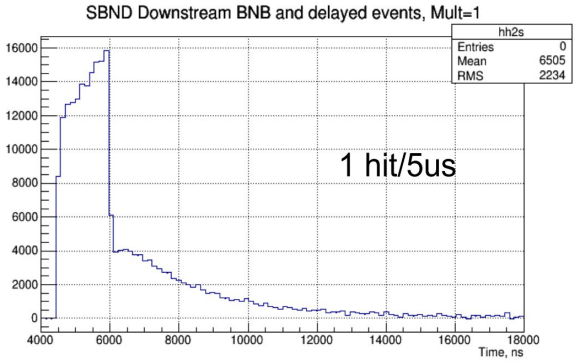


Signal after beam spill in SBND

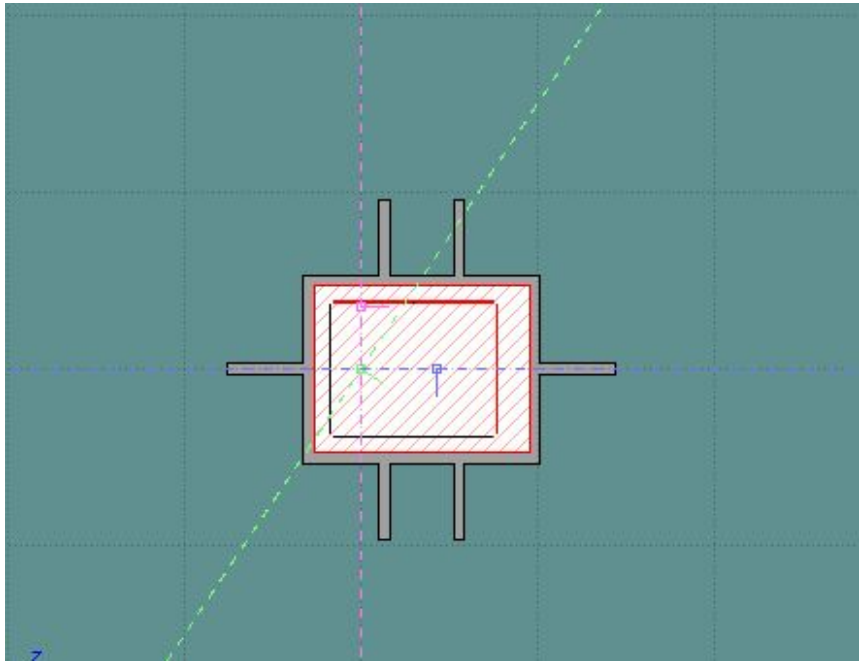
Beam direction

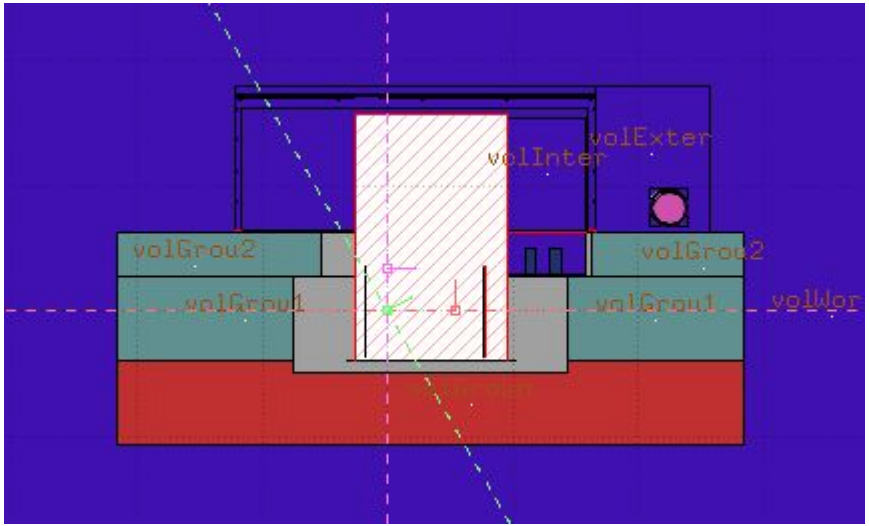




Plots are from Igor kreslo, from his talk on 'CRT Measurements in the SBND Hall'

First Step: Simulation





Thank You….

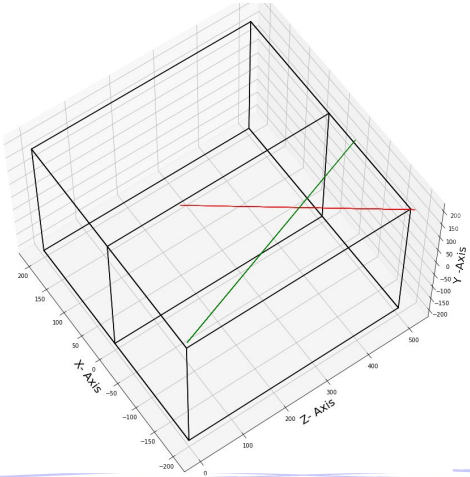
Backup slides.

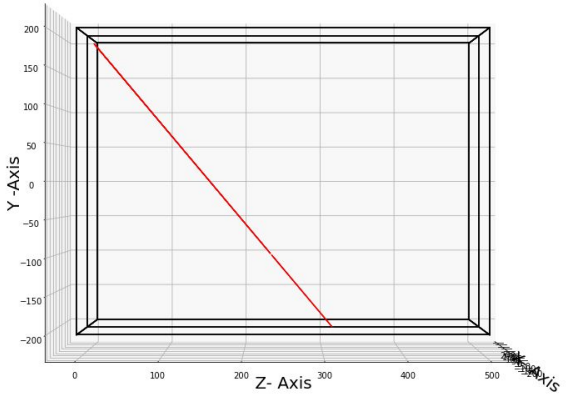
Finished works:

- Assembly of first feedthrough setup and testing at LHEP- Bern.
- Laser energy and reflection efficiency measurement.
- To check the repeatability of laser points and Positional error.
- Directionality Influence. (Mechanical freedom)

Ongoing works:

- Software for controlling the components remotely- Debugging
- Simulation - LArSoft





Laser Accuracy test:

Aim:

- To check the repeatability of laser points and Positional error. ✓
- Directionality Influence. (Mechanical freedom) ✓
- Software issues. ✓

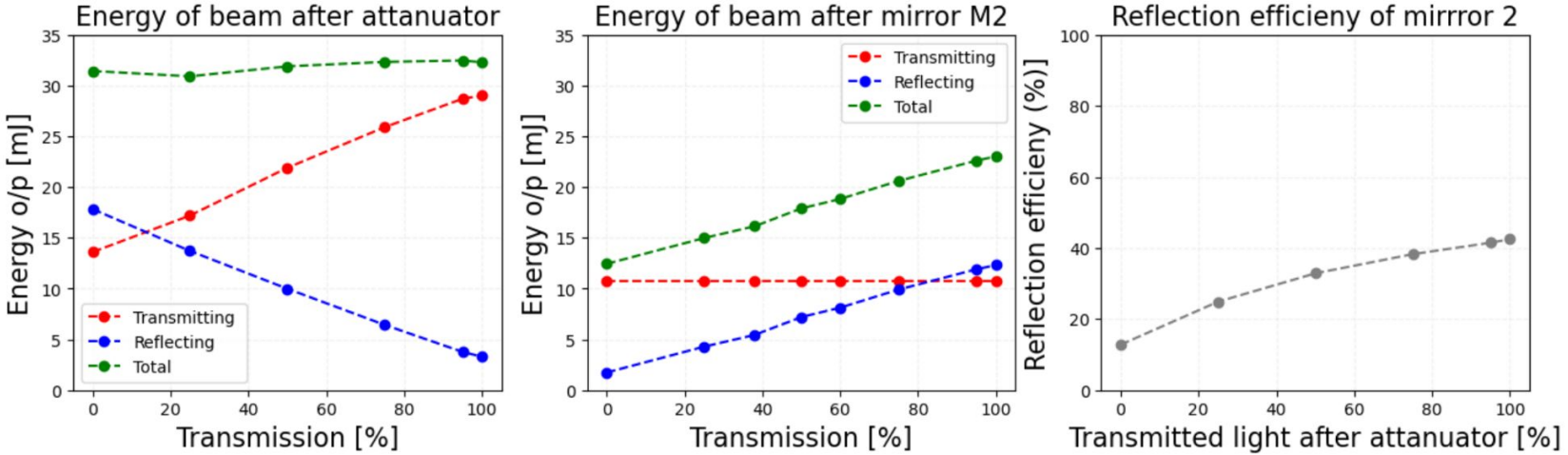
All Points with same encoder position reading

Vertical Movement:

Horizontal movement:

Sorry for messy representation of laser marks…

Laser Energy and mirror reflection efficiency measurements:



The total energy of the laser beam remains the same but the energy of p-polarised and s-polarised light varies with respect to the transmission through the attenuator.

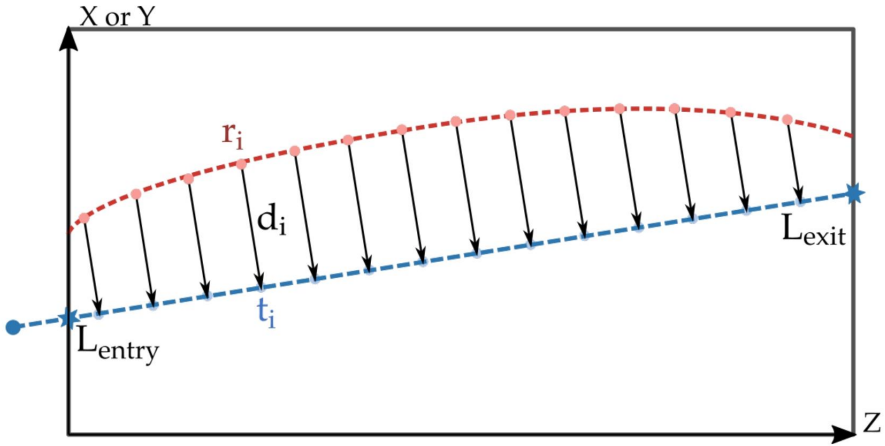
Unwanted light components in the infrared and green (base wavelength and 2nd harmonic) are transmitted through the mirror and ultimately absorbed on a beam dump.

The reflection efficiency of the mirror 2 is defined as the ratio between the energy of reflected UV light with respect to the total energy of incoming light.

Spatial displacement maps:

- Correction Map: Based on reco spatial coordinates
  Gives expected true points, given by the reco points.

- Distortion map: Based on True spatial coordinates.
  Gives expected reco points, given true points.



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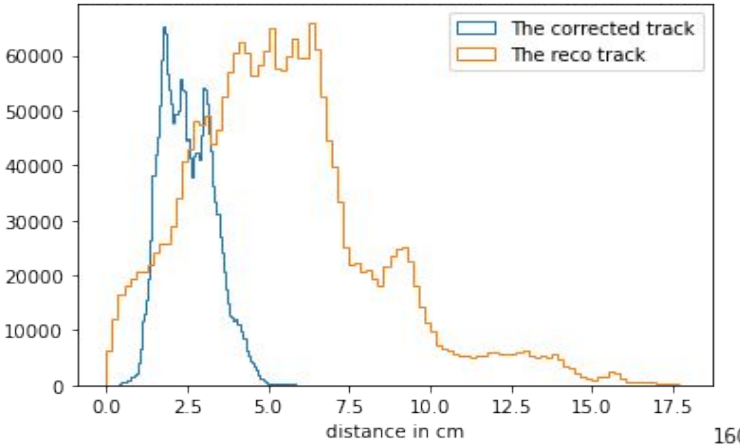
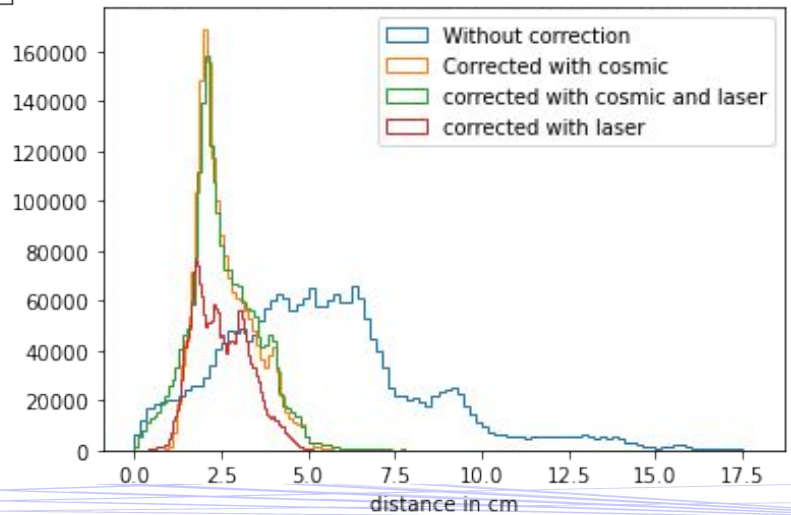
- The vectors from the reconstructed track points (red) to their closest point on the true track (blue) are the **correction vectors**.
- The vectors starting from the true track (blue) to the reconstructed track points (red) are the **distortion vectors**
- This forces the displacement vectors to be perpendicular to the corresponding true laser tracks.



Shortest distance from true to reco points before and after correction (Laser only)

Shortest distance from true track before and after correction (All maps)



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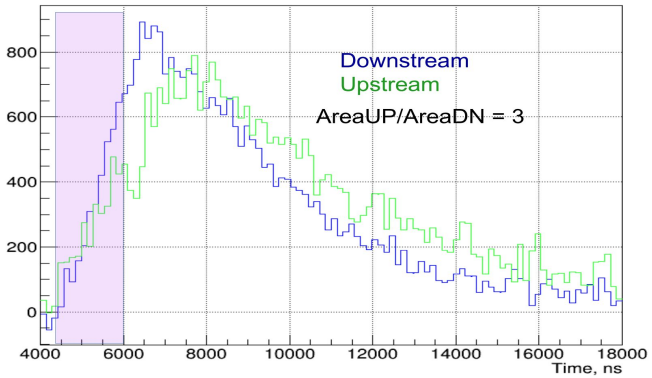
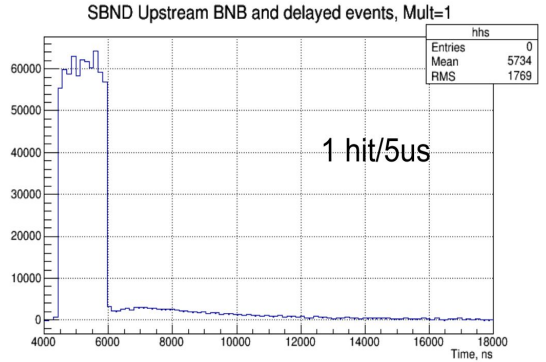
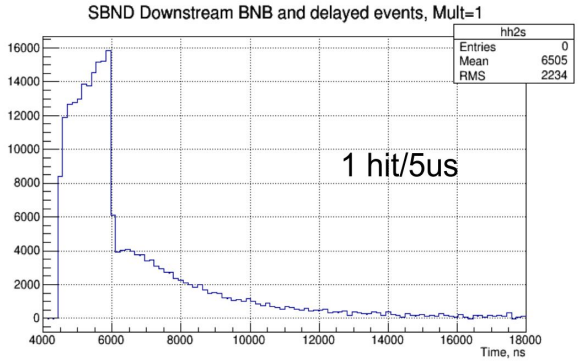


Beam direction





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