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

Interim Review Meeting- INTENSE
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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
- AEC Graduate course - Monte Carlo Simulations for Particle Transport in Matter
  October - November 2022
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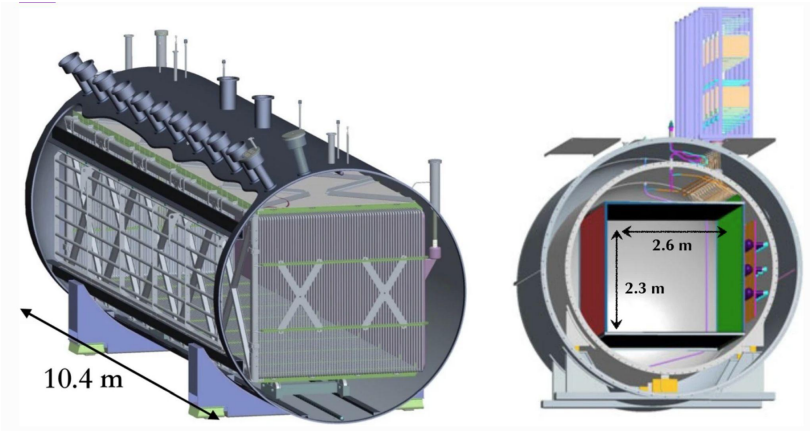
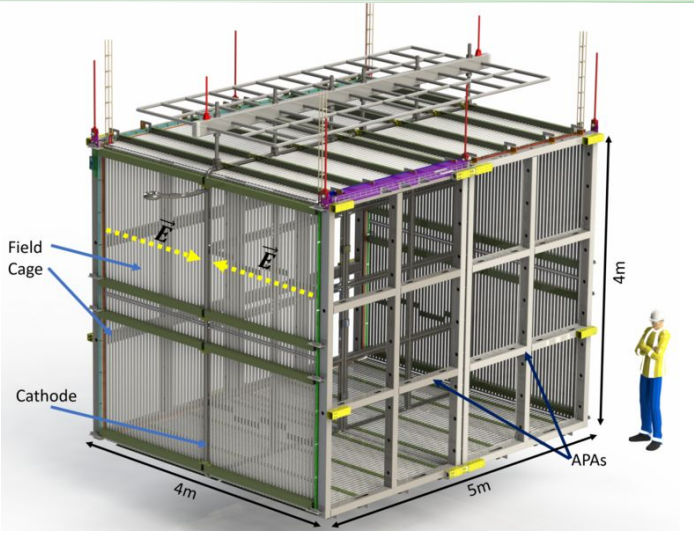


C. Adams *Eur. Phys. J. C* 79, 673 (2019)



MicroBooNE:

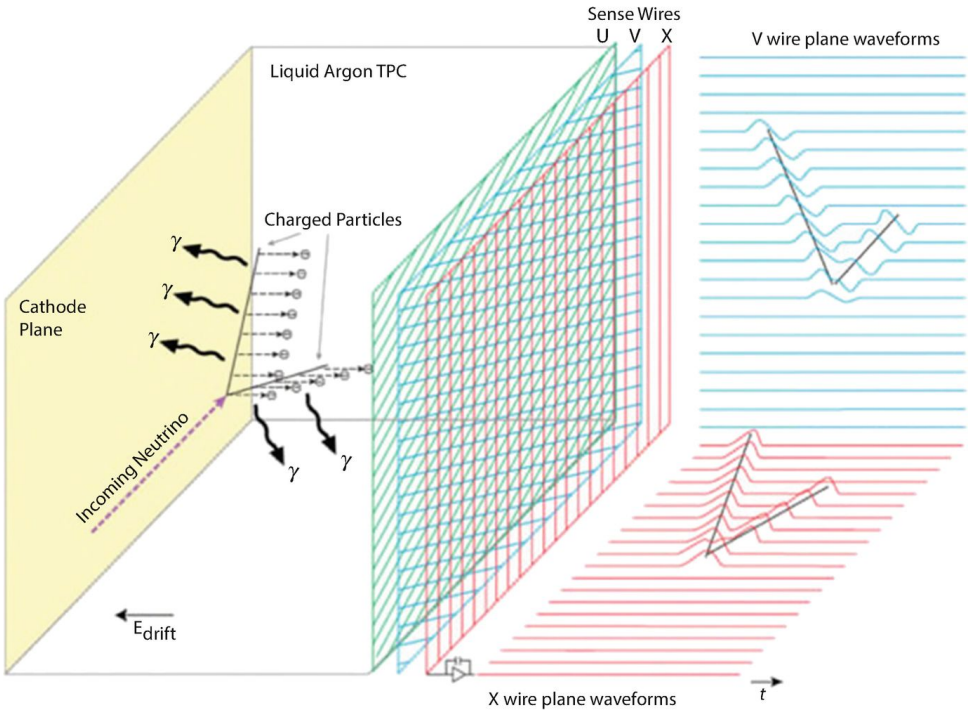
- 470 meters from the Booster Neutrino Beam target.
- 80 tons of liquid argon in the active volume.
- Single tpc (2.6 m x2.3 m x 10.4 m)
- Two UV laser system for E field calibration.

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:

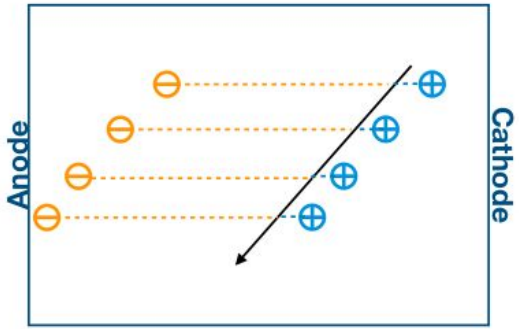
- Electric field is set up by cathode-anode plan
- Interaction in LAr produce scintillation light and ionization electrons.
- Scintillation light is detected by PMTs
- Due to Electric field $\mathbf{e}^-$ drift towards anode.
- At anode, the $\mathbf{e}^-$. Induce charge in induction planes and are collected 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

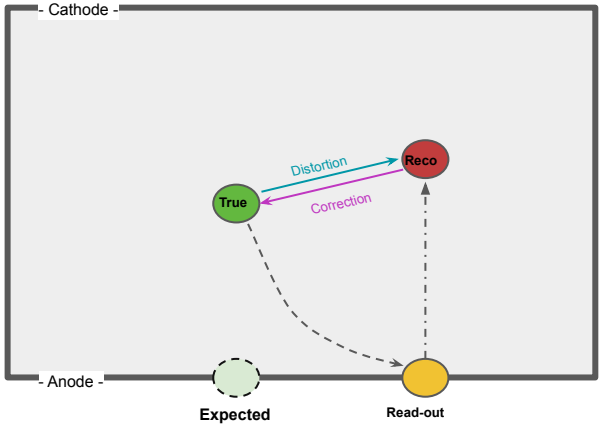
Why E-field Calibration ?

- $V_{e-} > V_{Ar+}$: 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 :

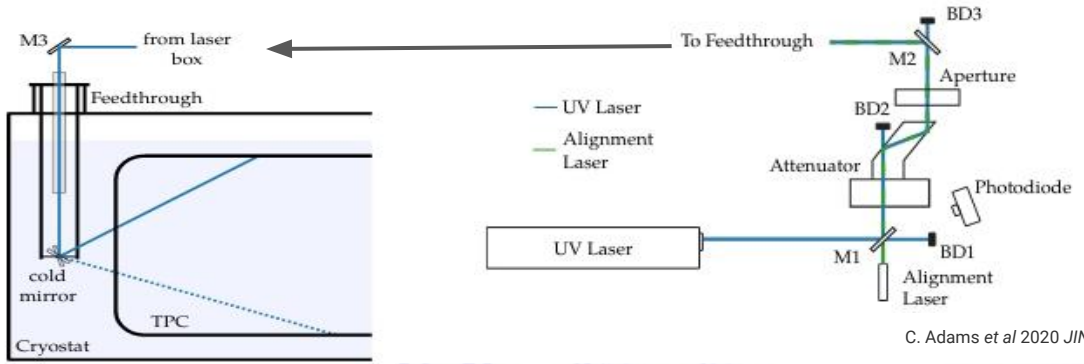
- Drive finely tuned energetic UV laser beam inside TPC, which ionises the Ar ion thus leaving a ionisation track.
- Compare expected (true) and reconstructed track points to calculate the E - filed distortion inside TPC.

Why:

- 3 UV photons provide the correct energy to ionize the argon atom in liquid phase.
- 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

How:

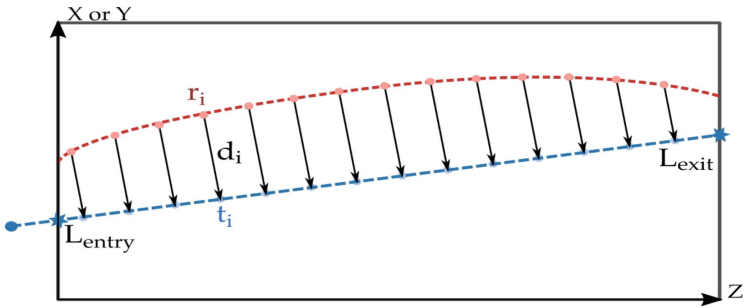
Schematic representation of MicroBooNE UV laser calibration set up

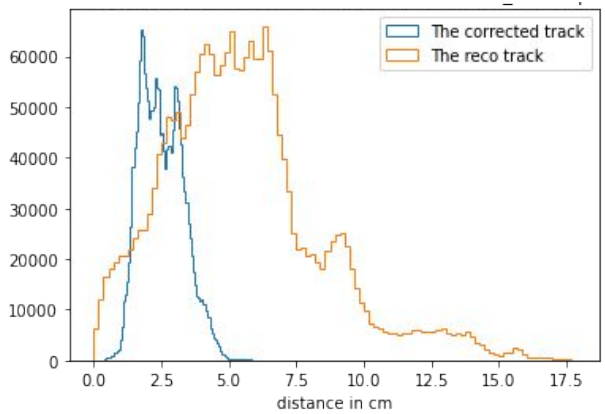


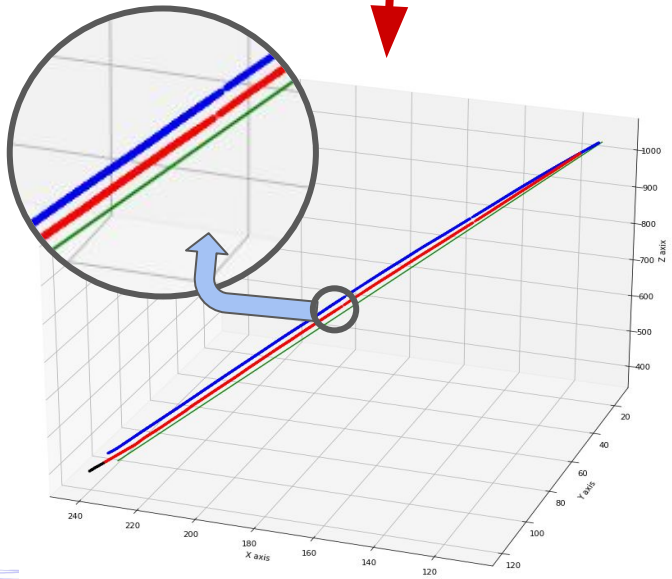
C. Adams *et al* 2020 *JINST* 15 P07010

How:

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

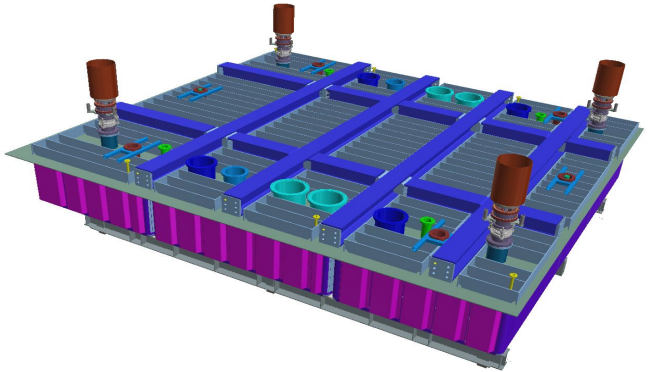


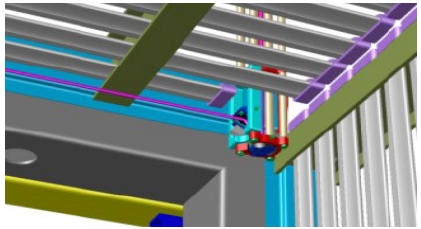


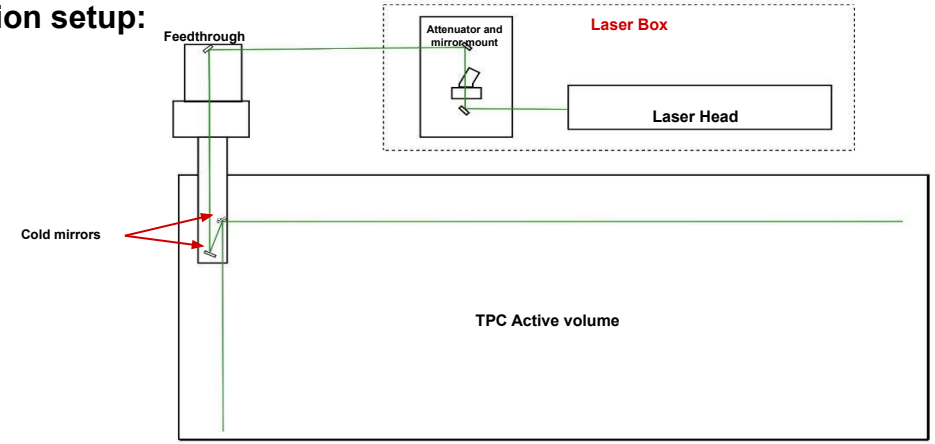


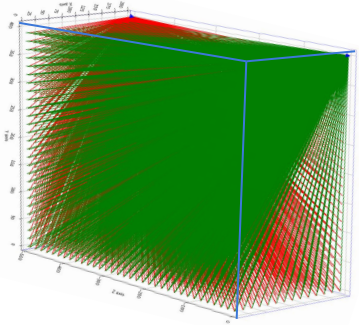
Shortest distance from true to reco points before and after correction.

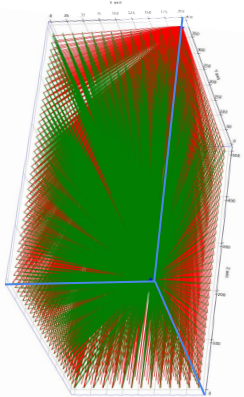
Schematic representation of SBND UV laser calibration setup:



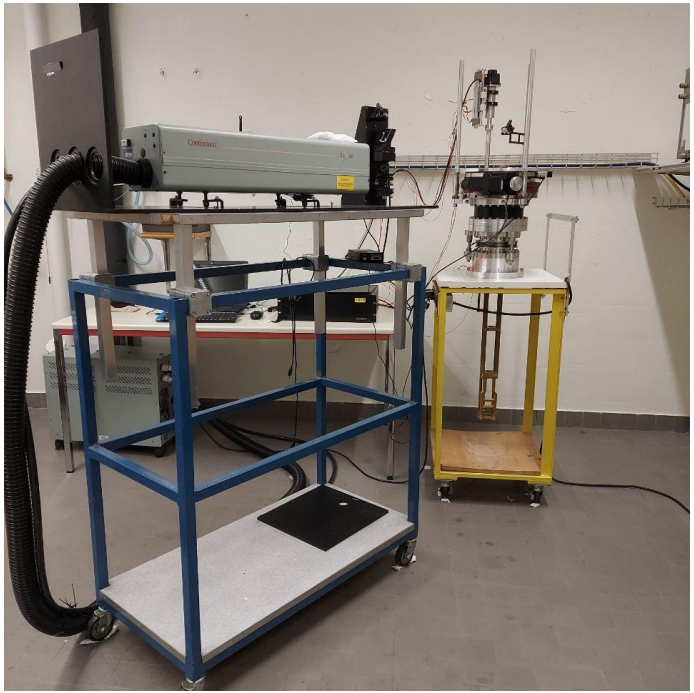




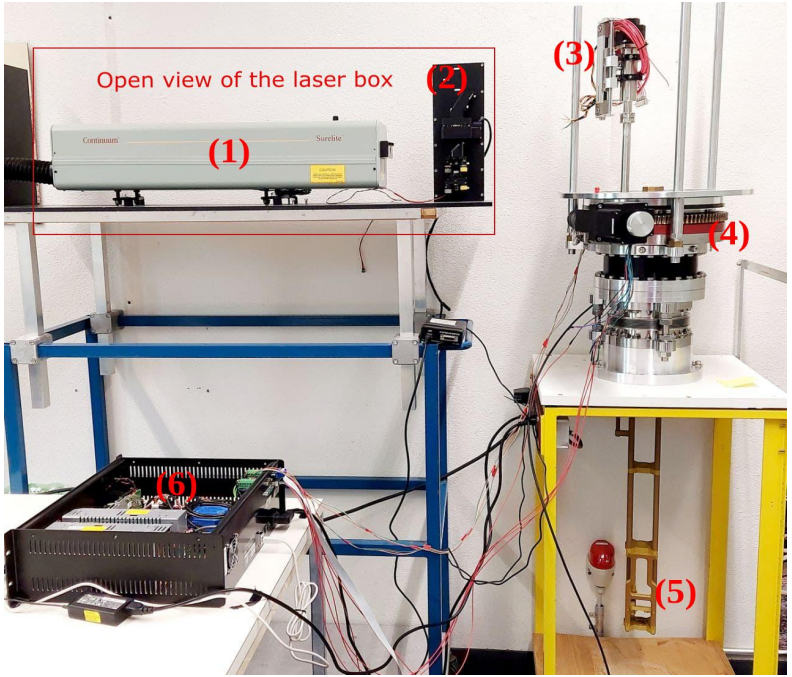




Laser test facility at LHEP:



Thanks to Michele, Igor, Rogger, Silas and Andri



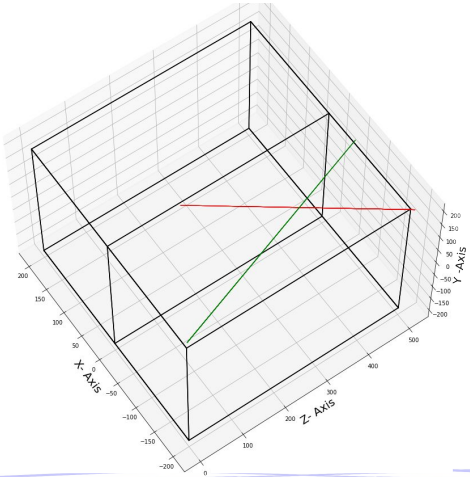
(1) Laser head, (2) Attenuator and mirror mount,
(3) Linear Motor to control the vertical movement of the cold mirrors,
(4) Rotary motor to control the horizontal movement of the mirror.
(5) Cold mirror mount and shafts, (6) Motor controller box

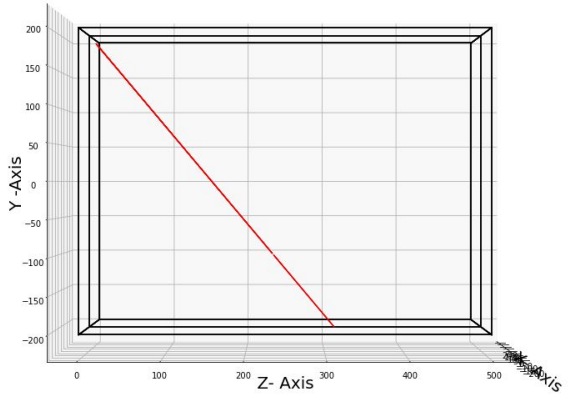
Finished works:

- Construction 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:

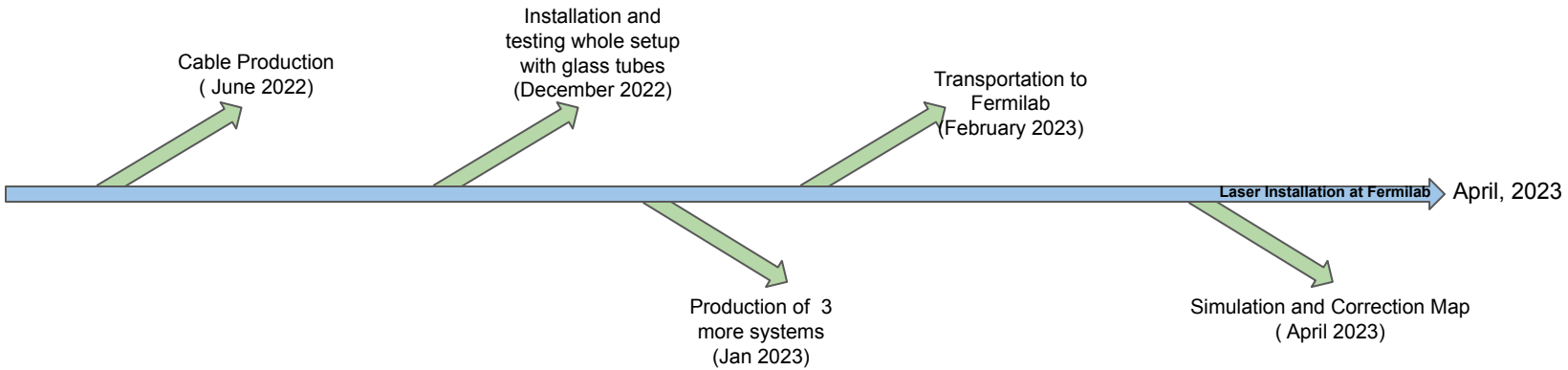
- Software for controlling the components remotely- Debugging
- Simulation - LArSoft





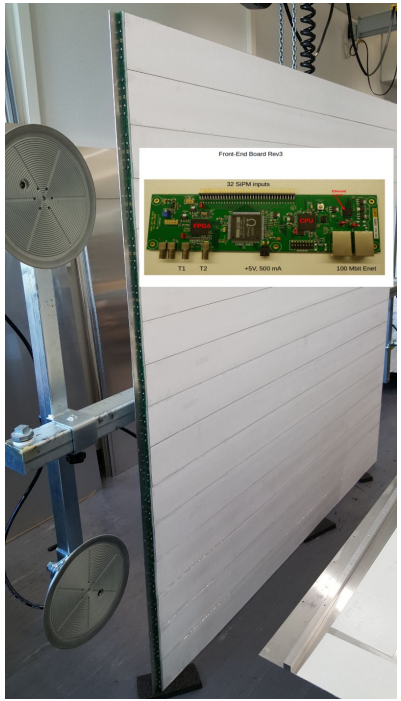
Future:

- Reconstruction and correction maps
- Cable production (1 tested, 3 Left) , Transportation.
- Laser System Installation at Fermilab.



SBND - Cosmic Ray Tagger (CRT):

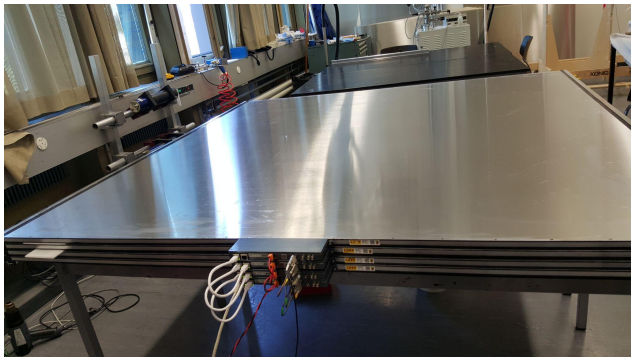
- Background interactions can occur in the active volume of the LArTPC detector.
- Main Background are cosmic rays- mostly muons from pion and kaon decay in the atmosphere.
- SBND consist of 220 modules, each made up of 16 mechanically joined strips of scintillating plastic in a protective aluminum case.



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

Characteristics:

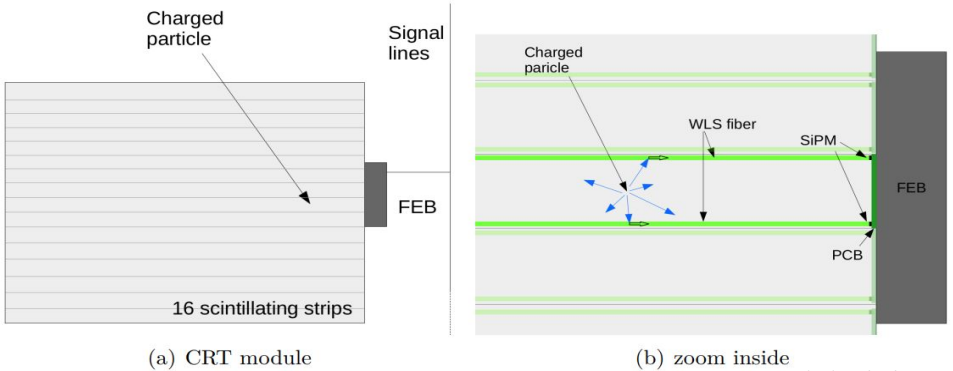
- Each strip 10.8cm wide, 1cm thick,
- High light yield (20 -30 photo e^-)
- Time resolution - 2ns RMS
- Spatial resolution 1.8 cm RMS
- Geometry efficiency > 95%



Working Principle:

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

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

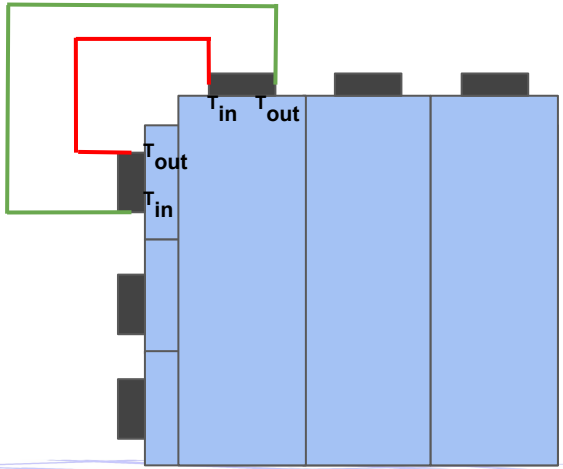


(a) CRT module (b) zoom inside

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)



Thank You….

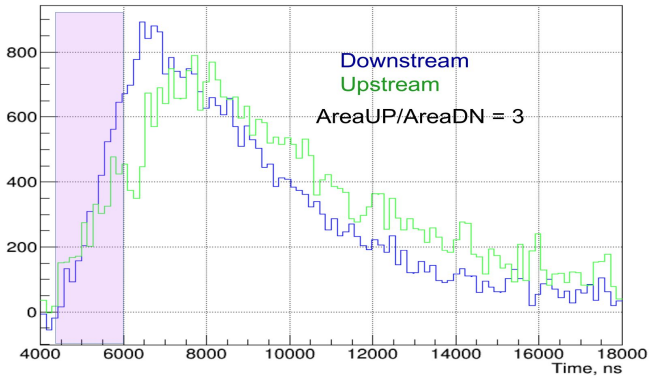
Analysis Plan:

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

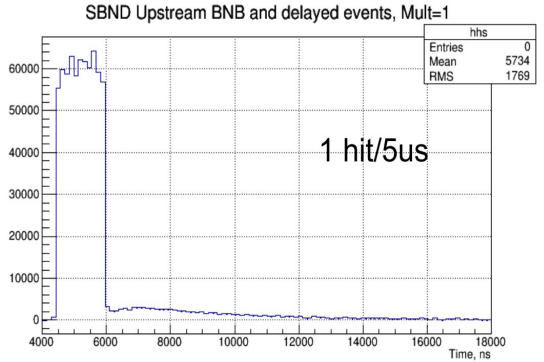
- Timing measurements and Heavy Neutral lepton search using CRT data and MC efforts.
  1. CRT Beam telescope measurements at Fermilab. Beam data from 2017 -2019 run
  2. Test setup at Bern with 3 modules of CRT.

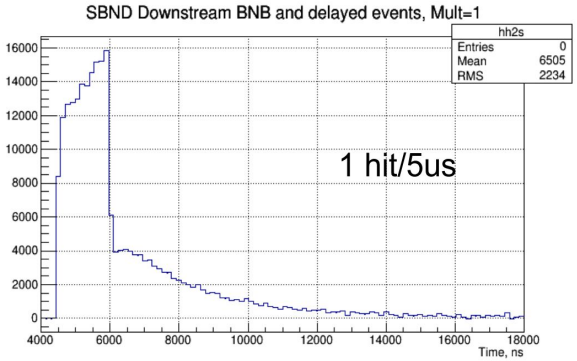
- Cross Section measurements with SBND tpc data (end of 2023 - beginning of 2024)

- CRT in SBND produces very interesting data: delayed event excess
- Reasons are unknown.. Possible explanation: Muon decay, Something going backward, Nuclear de-excitation with gamma etc.
- MC effort is needed



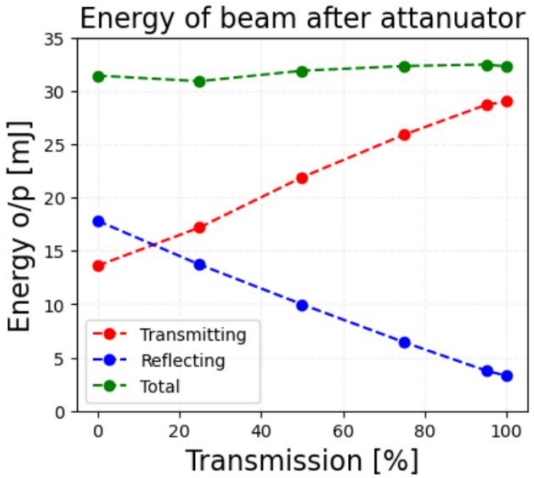
Beam direction

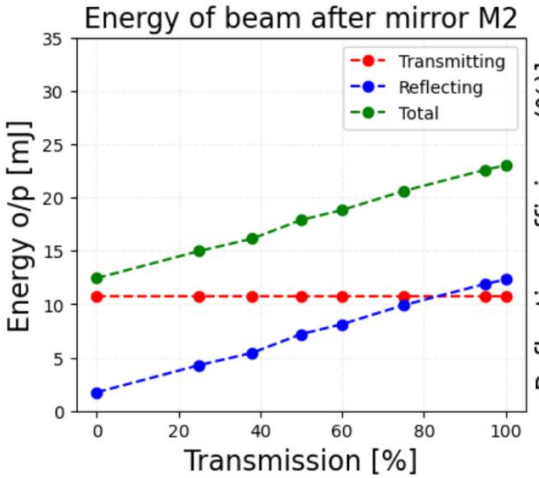


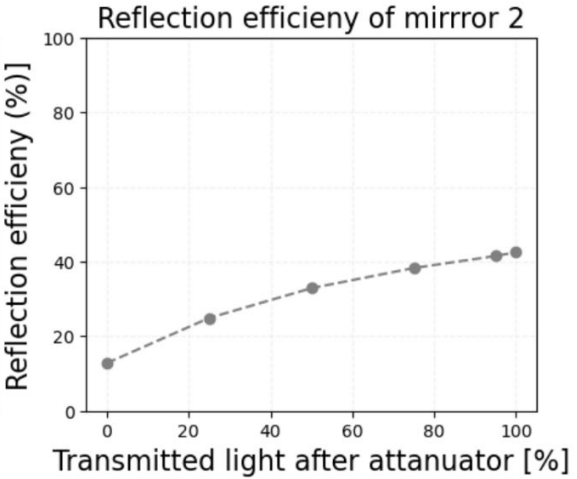


Plots are from Igor kreslo, from his talk on 'CRT Measurements in the SBND Hall'

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.

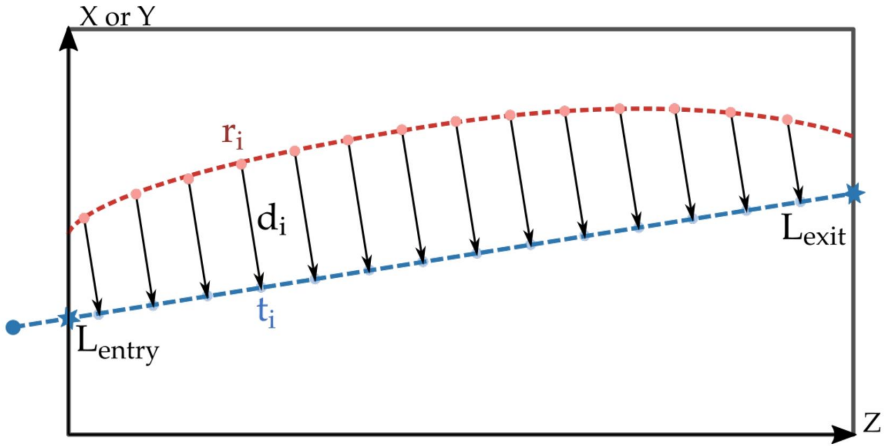
Unwanted light components in the infrared and green (base wavelength and 2nd harmonic) are transmitted through the mirror and ultimately absorbed on a beam dump.

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.