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Intense
H2020 MSCA ITN
G.A. 858199

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

First Annual Workshop - INTENSE
Feb 2 - 4 , 2022

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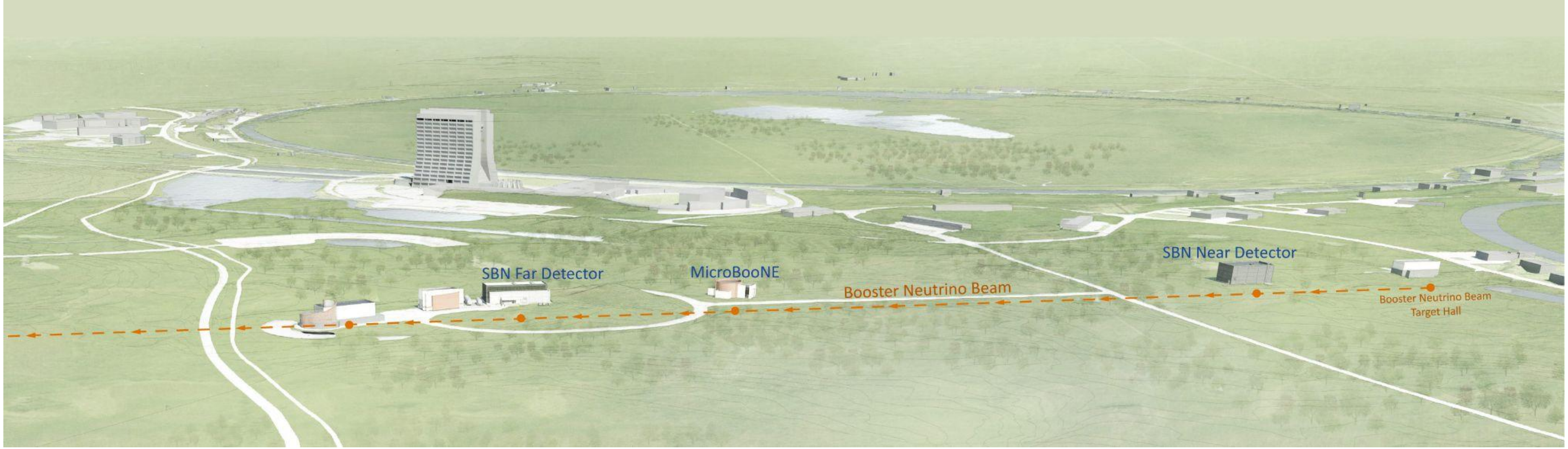
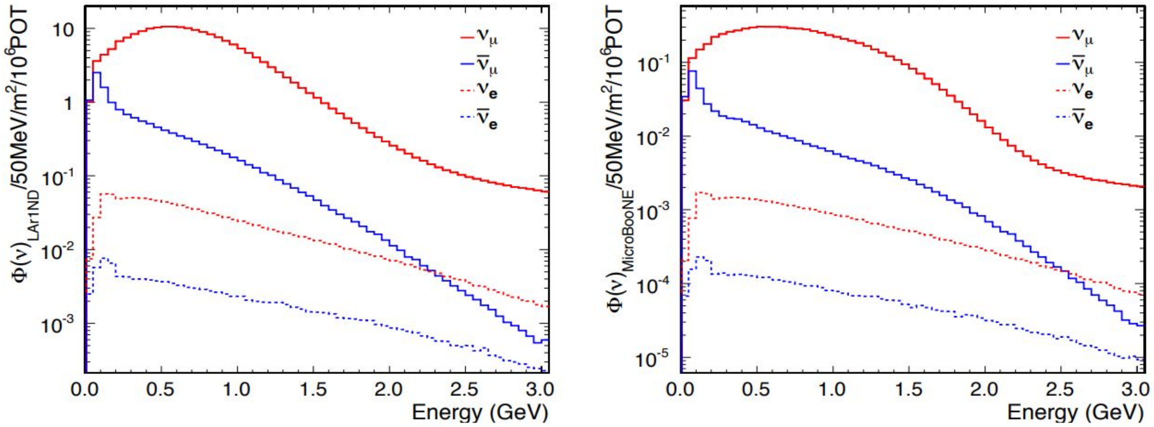
Short-Baseline Neutrino Program



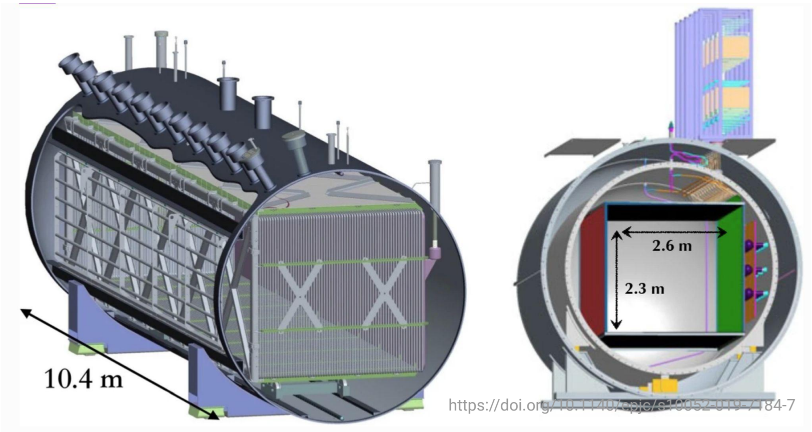
- To measure properties of neutrinos and study Neutrino Oscillation.
- Perform sensitive searches for ν_e appearance and ν_μ disappearance in the Booster Neutrino Beam.
- Development of LAr based particle detection technology for future experiments like DUNE

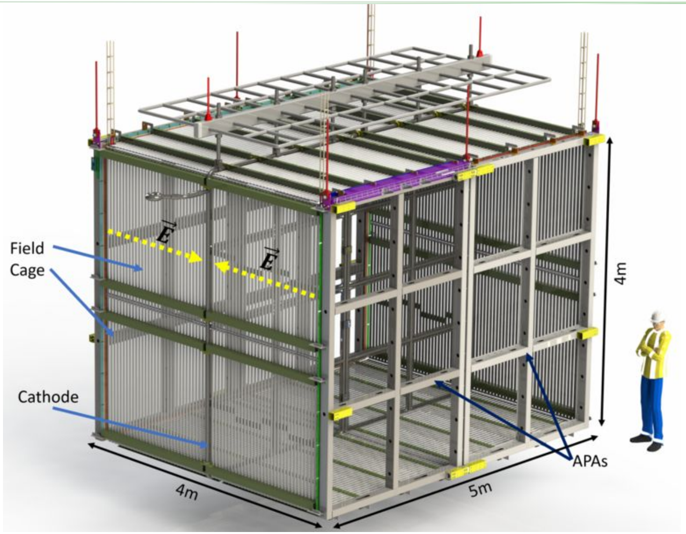
The Booster Neutrino Beam flux
at
SBND and **MicroBooNE**



- The flux at the near detector is 20-30 times higher than at the MicroBooNE.
- The majority of the v_μ flux originates from **pion decay** ($\pi^+ \rightarrow \mu^+ + v_\mu$) in flight and charged kaon decay (above ~2 GeV)
- Majority of v_e flux from the pion -muon decay chain
  ($\pi^+ \rightarrow \mu^+ \rightarrow e^+ + v_e + v_\mu$)

arXiv:1503.01520v1





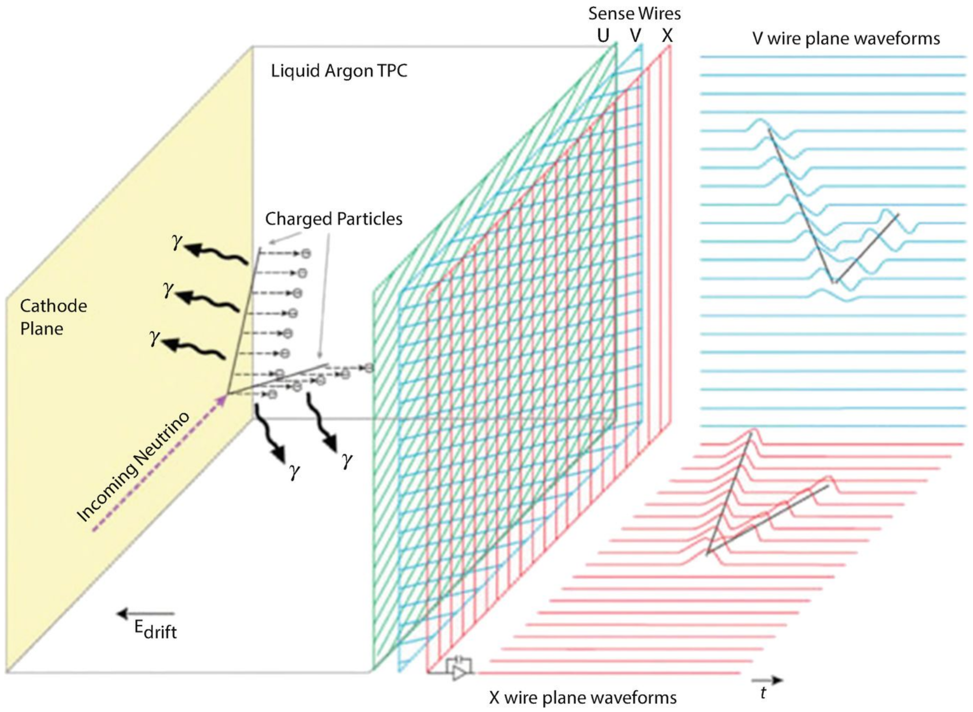
MicroBooNE:

- 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.

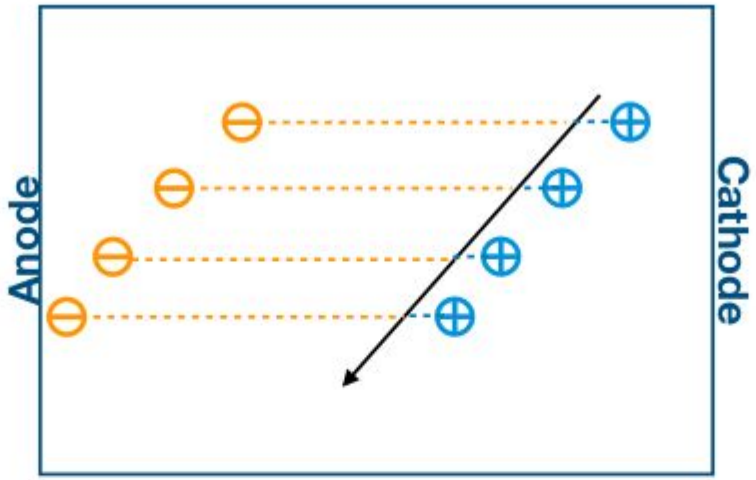
SBND:

- 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.

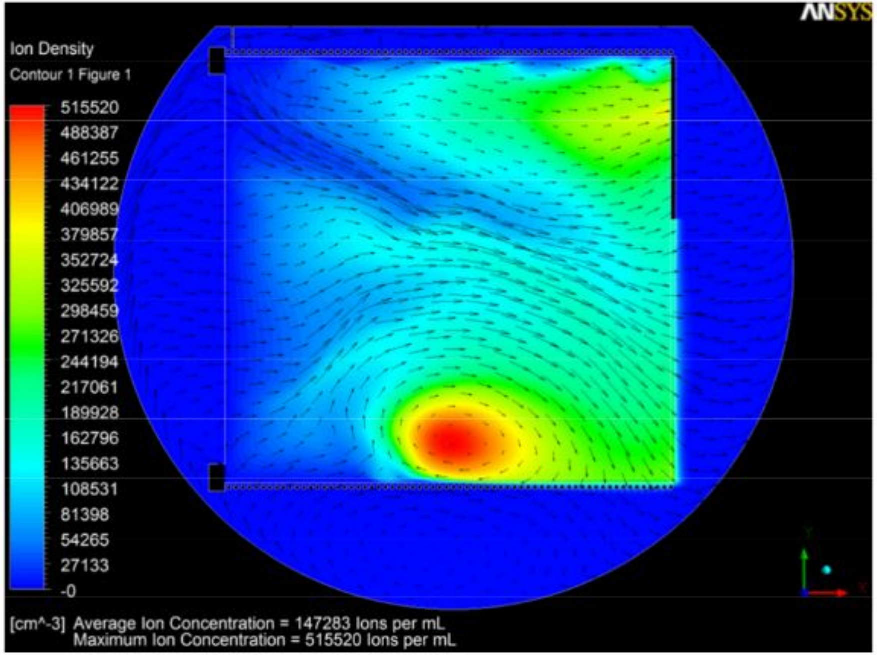
- Electric field is set up by cathode-anode plan
- Interaction in LAr produce scintillation light and ionization electrons.
- Scintillation light is detected by PMTs
- Due to Electric field **e**$^-$ drift towards anode.
- At anode, the **e**$^-$. Induce charge in induction planes and are collected on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



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



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

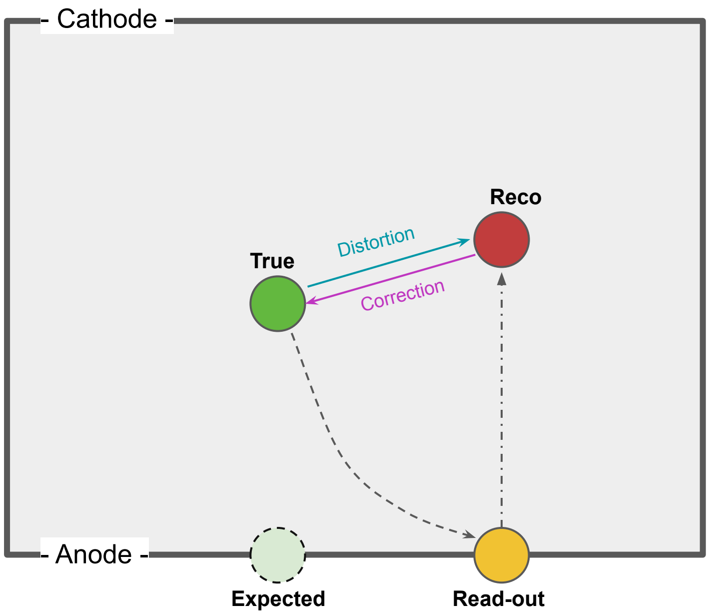


Eric Voirin: MicroBooNE-doc-1895-v4

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

Need a method to reduce such uncertainties:

Ultra Violet (UV) Laser Calibration method.



UV Calibration method :

What :

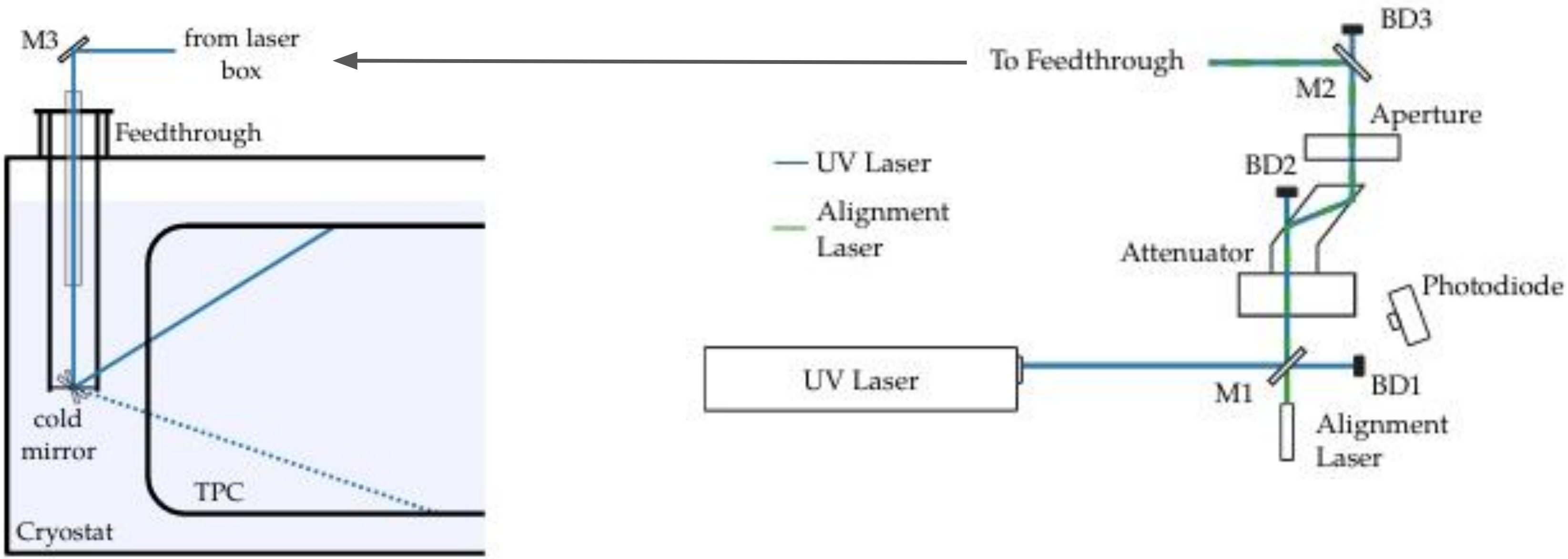
- Drive finely tuned energetic UV laser inside TPC, which ionises the Ar ion thus leaving a ionisation track.
- Compare expected (true) and reconstructed track points to calculate the E - filed distortion inside TPC.

Why:

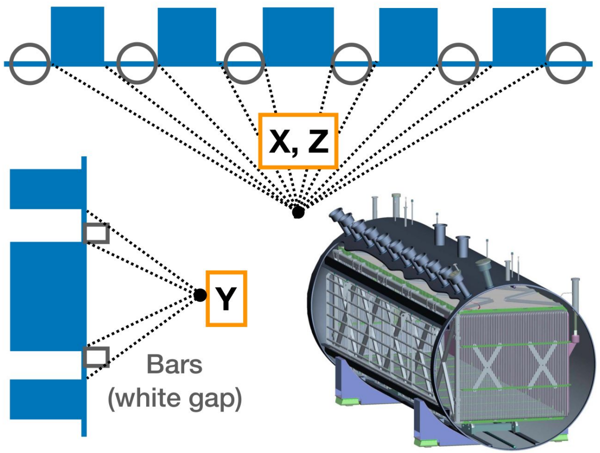
- UV photon provides the correct energy to ionize the argon atom in liquid phase.
- laser beams do not experience delta ray emission in LAr.
- No multiple Coulomb scattering in LAr.
- Laser beams can also be repetitively pulsed in controllable directions
- UV laser system can be used to investigate detector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

How:

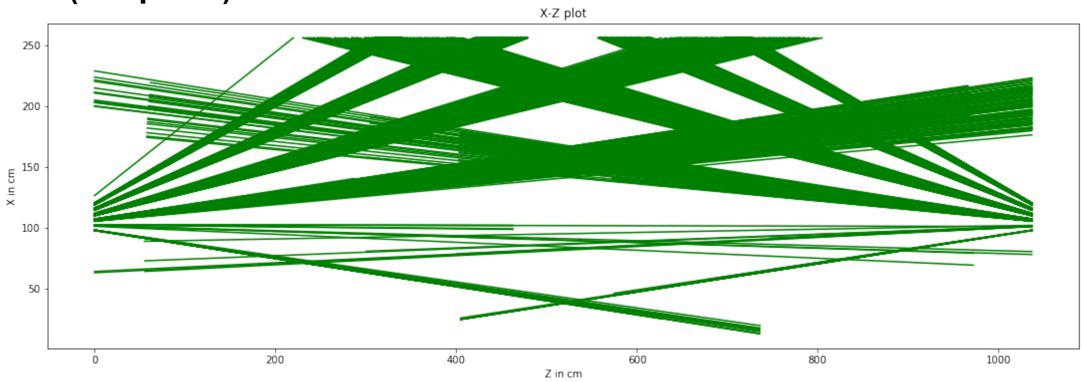
Schematic representation of MicroBooNE UV laser calibration set up



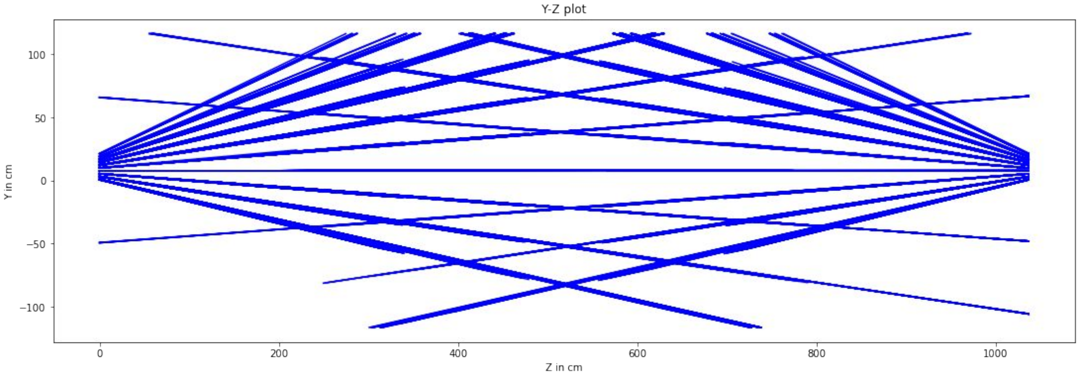
Laser coverage is limited due to field cage rings.



Top view (X-Z plane):



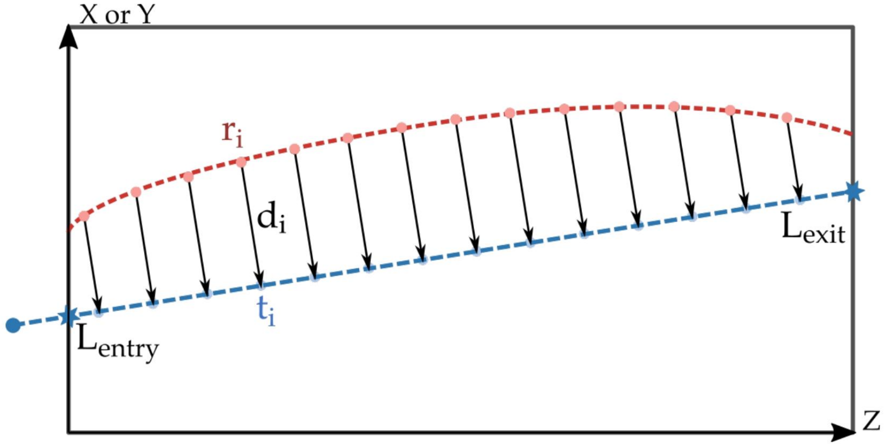
Side view (Y-Z plane):



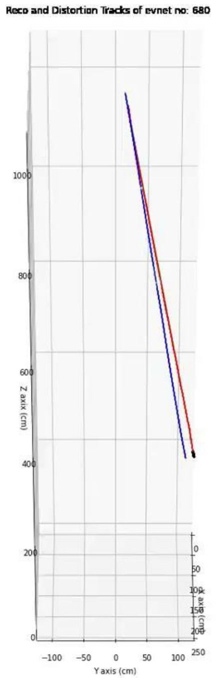
Spatial displacement maps:

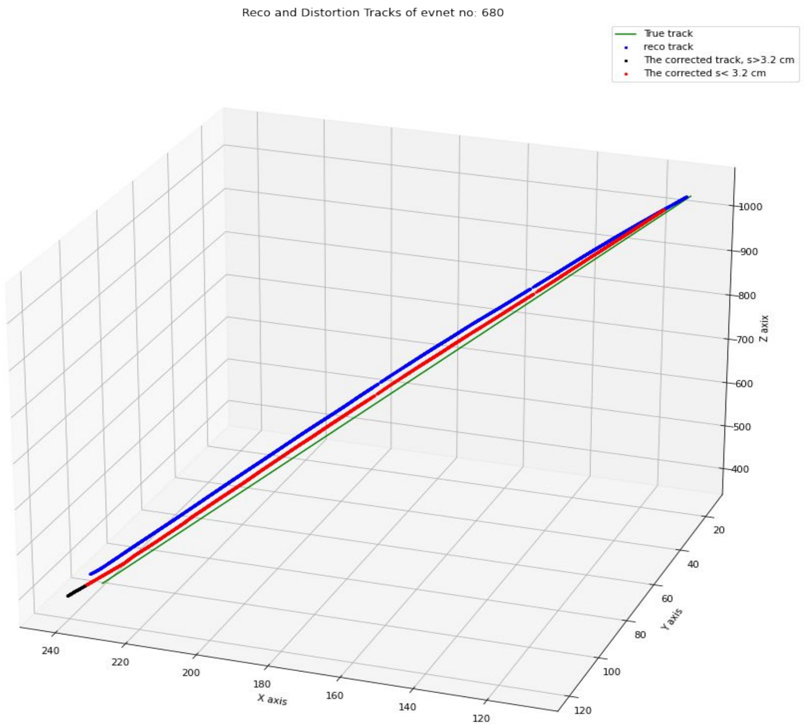
- Correction Map: Based on reco spatial coordinates
  Gives expected true points, given by the reco points.

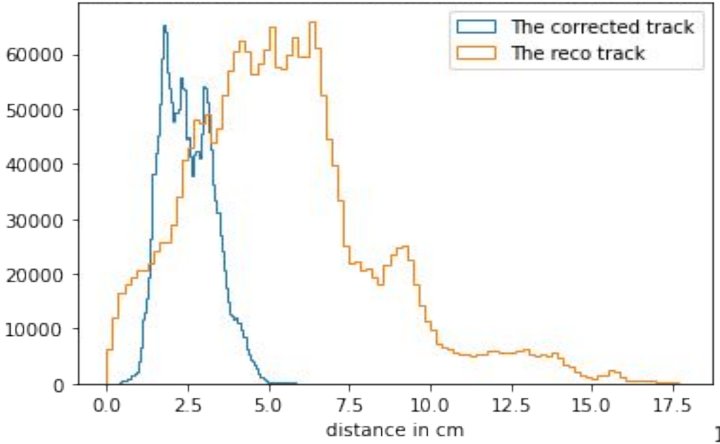
- Distortion map: Based on True spatial coordinates.
  Gives expected reco points, given true points.



- 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.

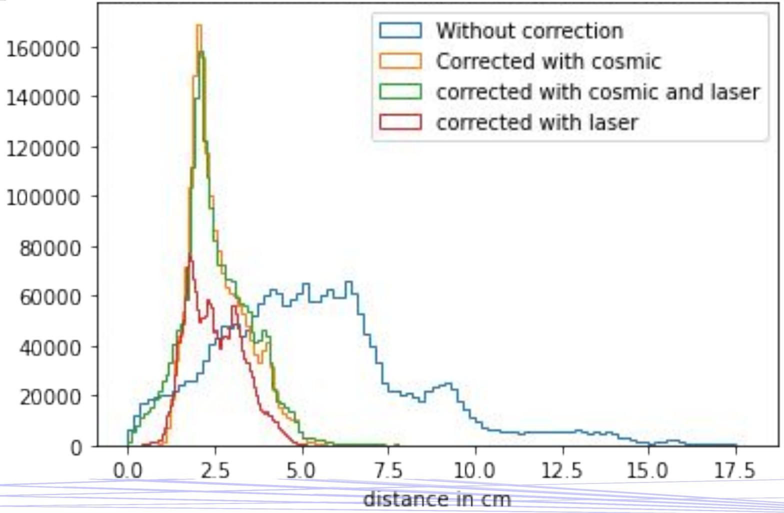

Reco and Distortion Tracks of evnet no: 680
1000
800
600
400
200
0
Z axix (cm)
−100
−50
0
50
100
Y axis (cm)
0
50
100
150
200
250


Reco and Distortion Tracks of evnet no: 680
True track
reco track
The corrected track, s>3.2 cm
The corrected s< 3.2 cm
1000
900
800
700
600
500
400
Z axix
240
220
200
180
160
140
120
X axis
20
40
60
80
100
120
Y axis

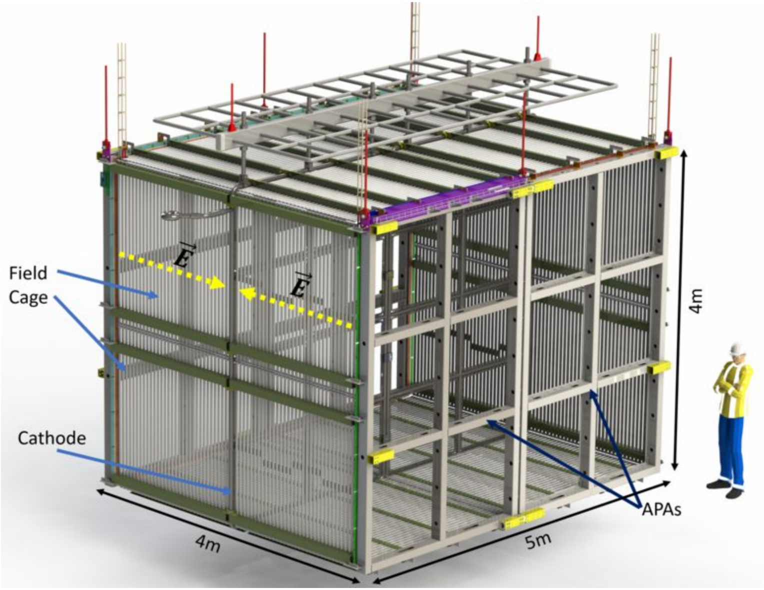


Shortest distance from true to reco points before and after correction (Laser only)

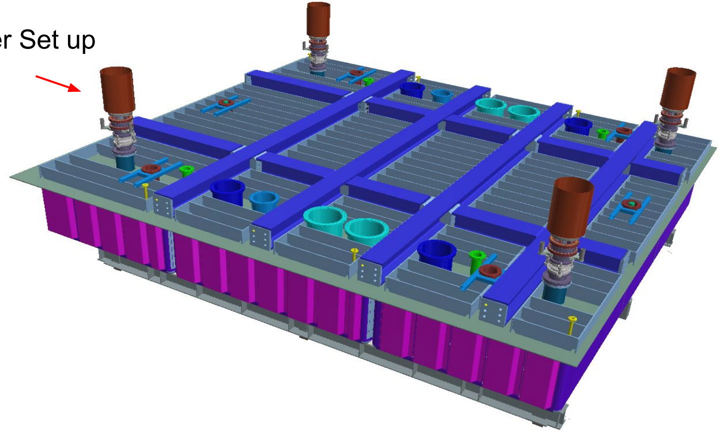
Shortest distance from true track before and after correction (All maps)

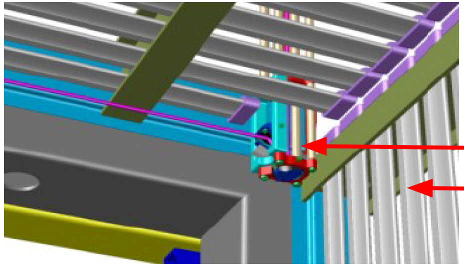


SBND:



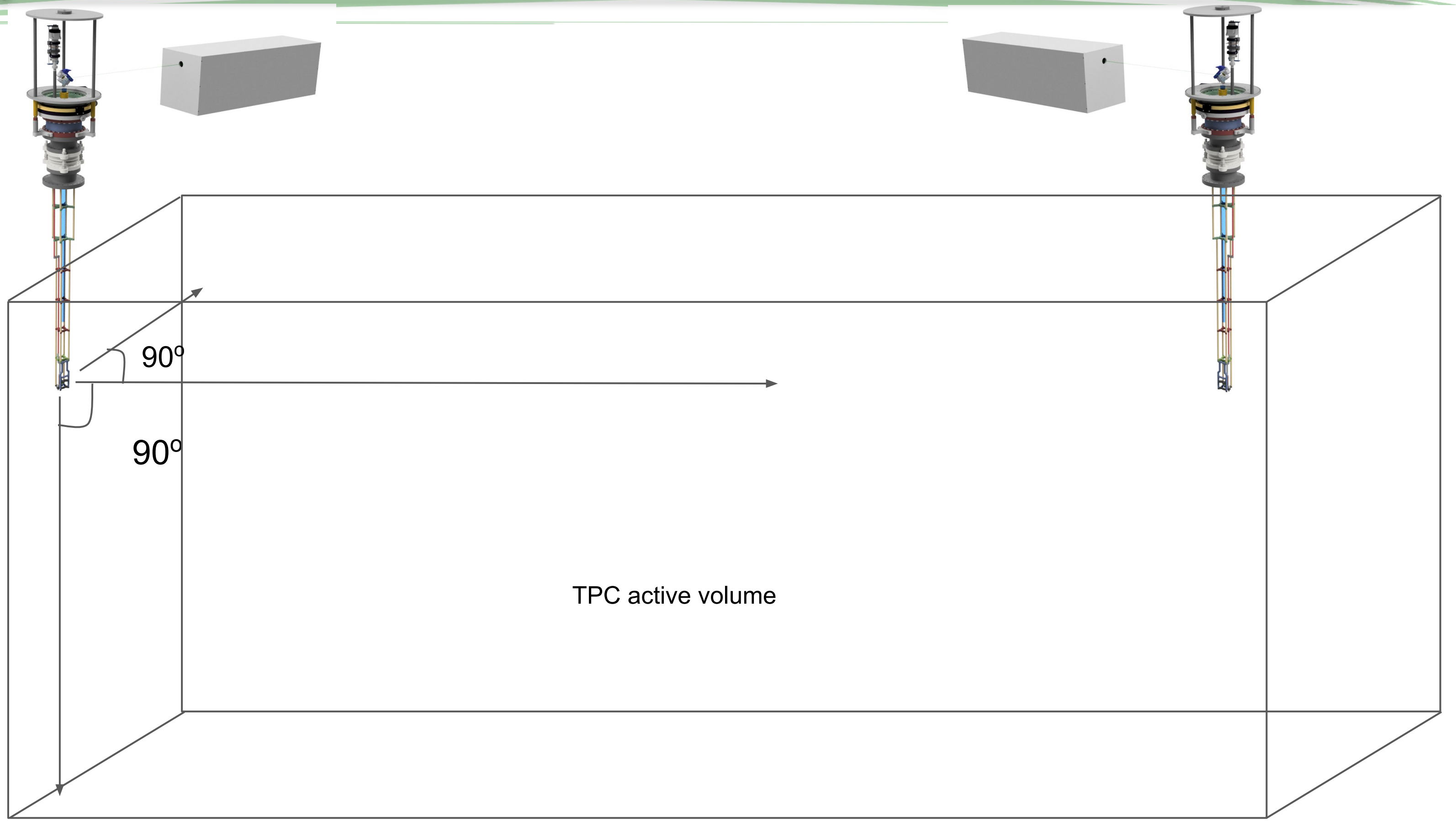
Laser Set up



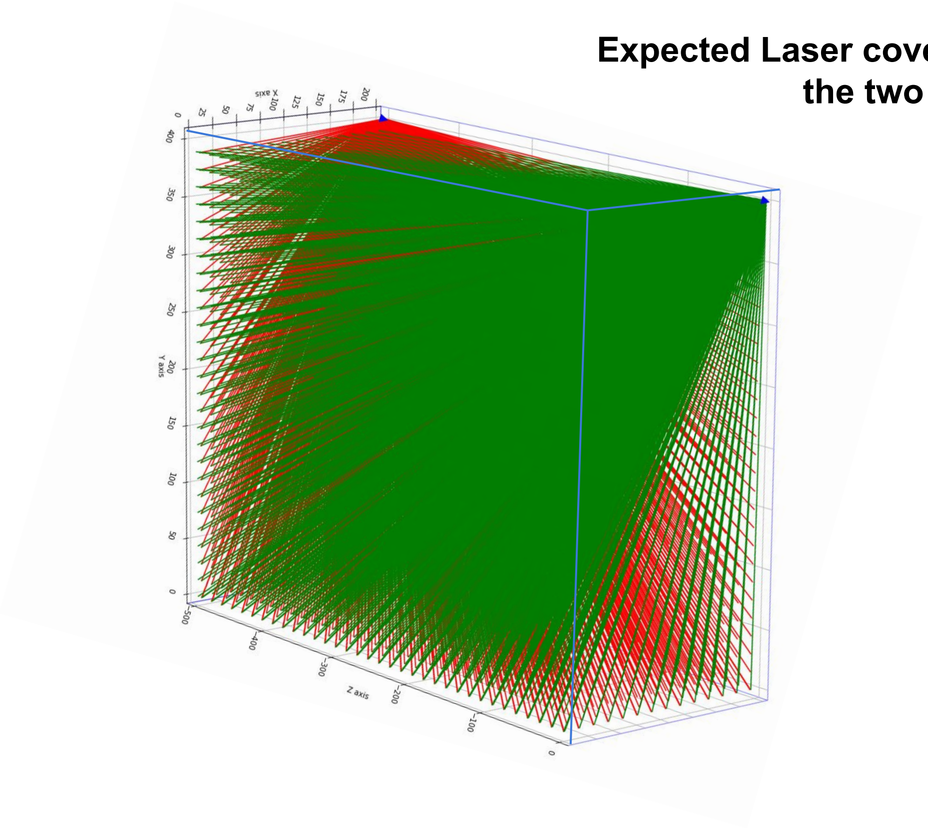


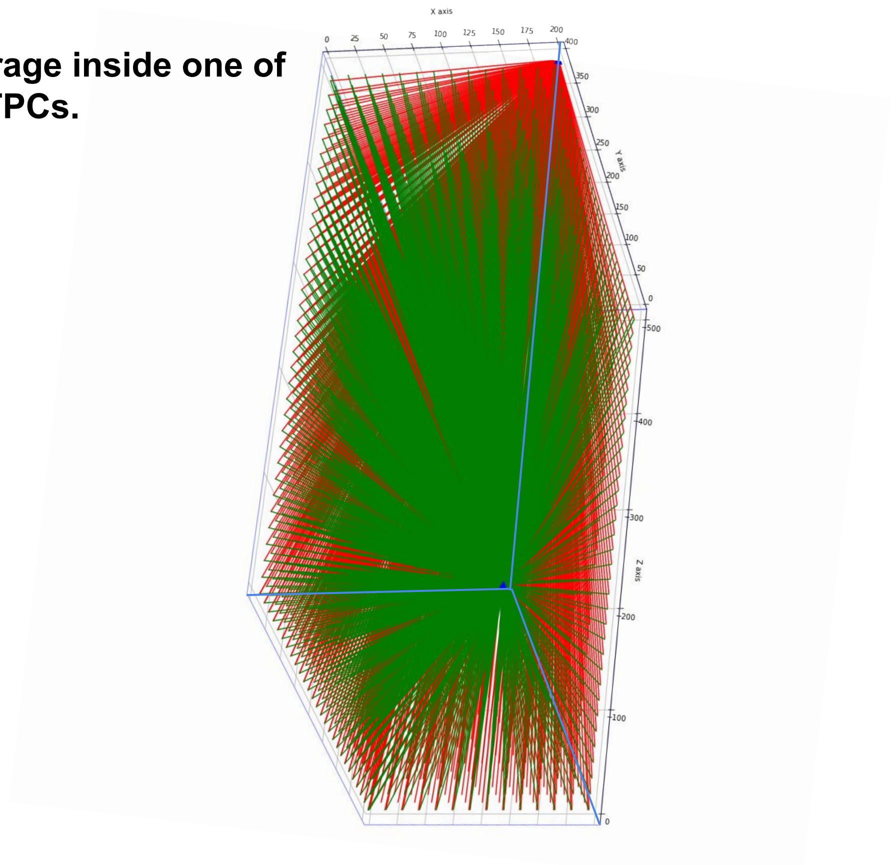
Cold mirror

Field cage


90º
90º
TPC active volume

Expected Laser coverage inside one of the two TPCs.





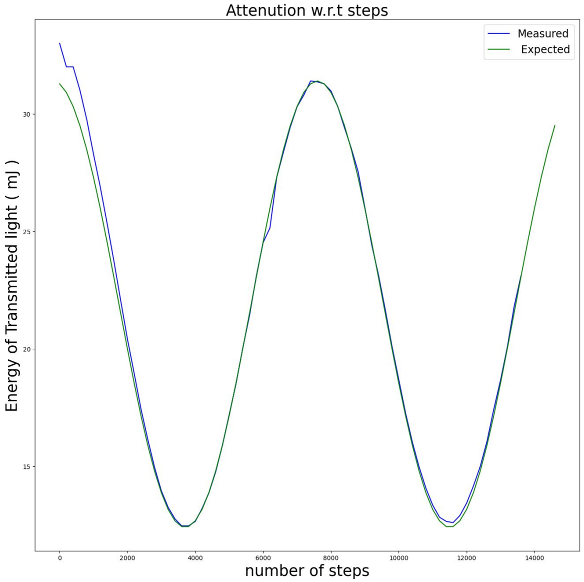
Hardware:

Laser:

- Nd:YAG laser from Continuum Surelite.
- Class **iv** laser.
- Up to 10 Hz repetition rate.
- 5 mm beam diameter.
- 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.
- Energy o/p of 60 *mJ*.

Attenuator:

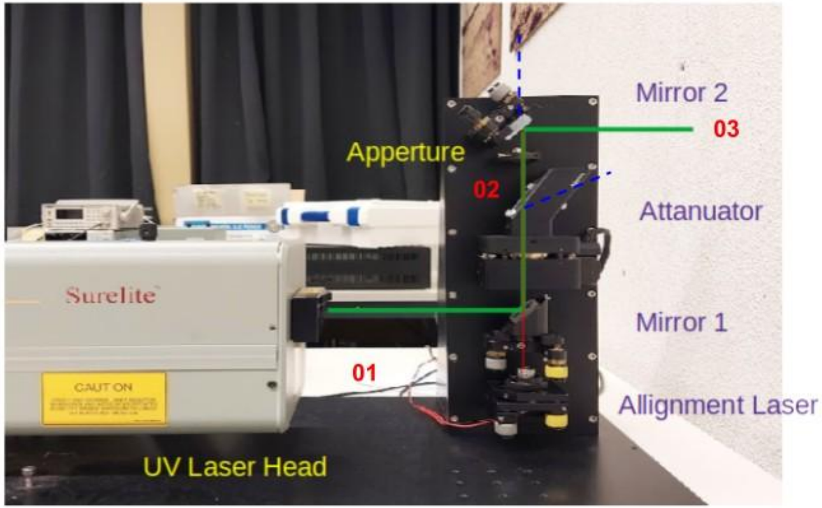
- Altechna half wave plate attenuator.



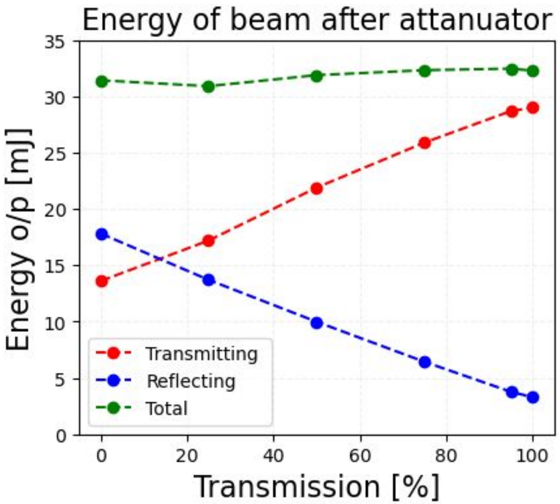
First task: To obtain optimal working range

Inside the laser box:

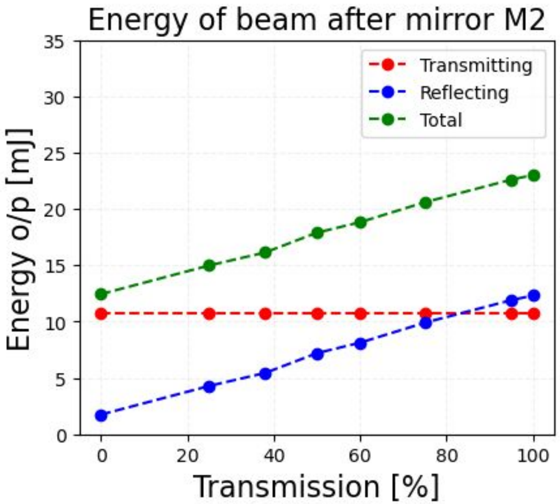
1. U-V laser head
2. Two dichroic mirrors (wavelength separator)
3. Attenuator
4. Aperture
5. Photo Diode for DAQ trigger.



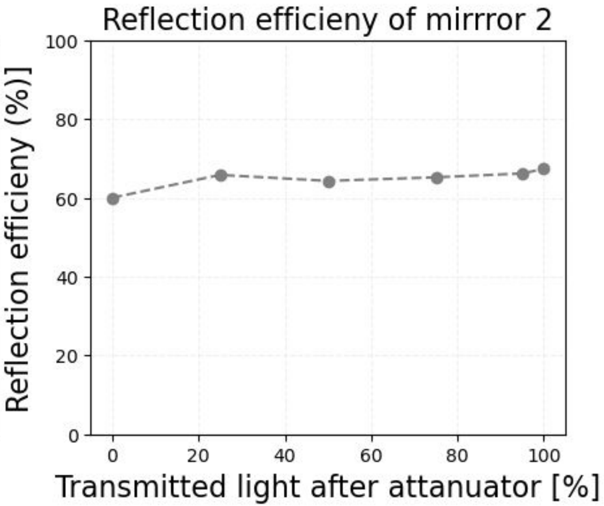
Laser Energy and mirror reflection efficiency measurements:



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.

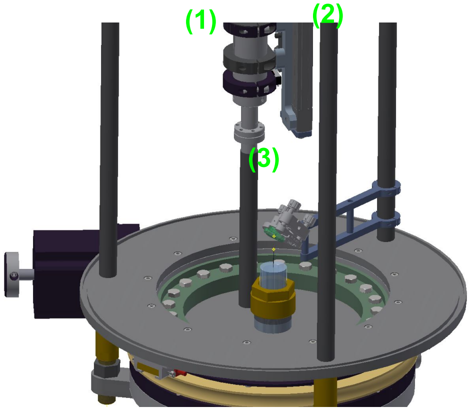


Unwanted light components in the infrared and green (base wavelength and 2nd harmonic) are transmitted through the mirror and ultimately absorbed on a beam dump.



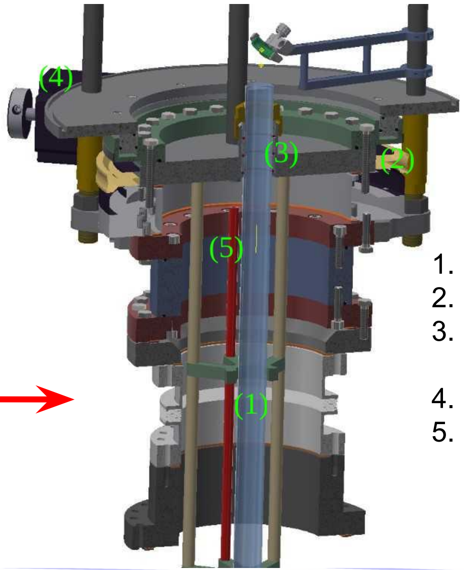
The reflection efficiency of the mirror 2 is defined as the ratio between the energy of reflected UV light with respect to the total energy of incoming light.

Feedthrough:

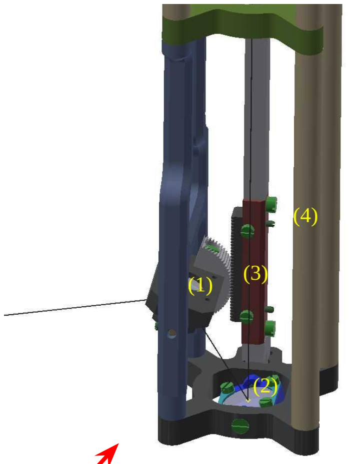


1. Linear Motor
2. Linear encoder
3. Dichroic mirror

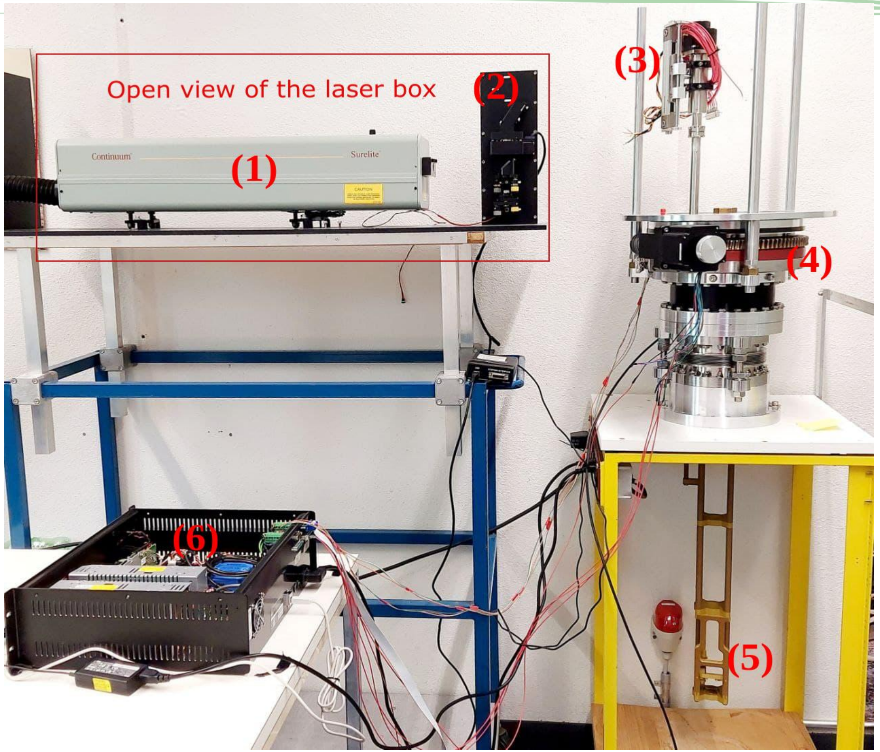
Cross Sectional view



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



(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

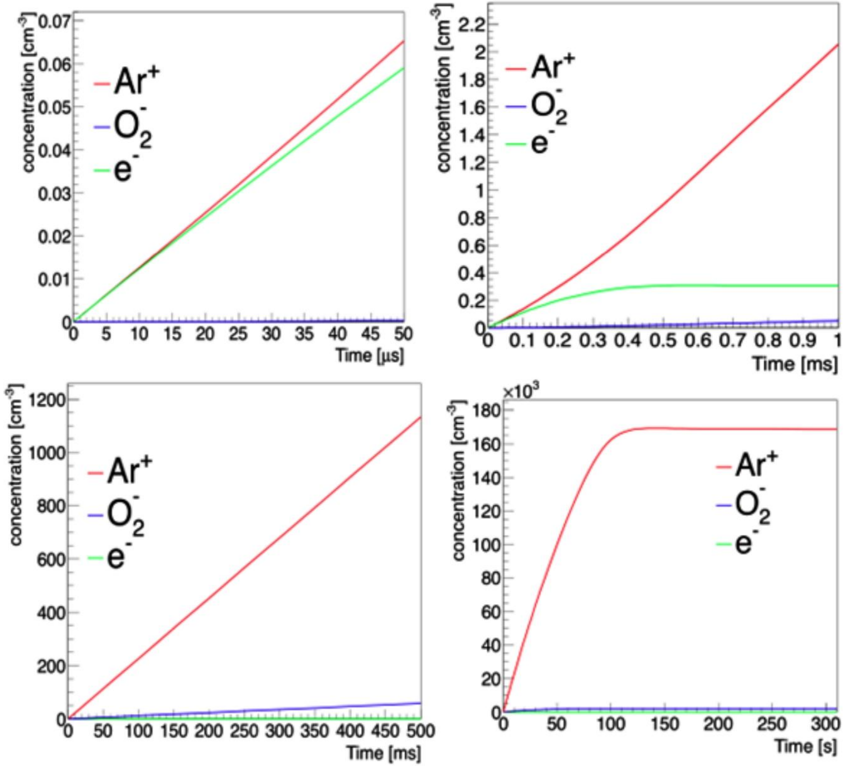
Conclusion:

- Controlling script has been developed for the system in python.
- Calibration of motors and encoders are underway.
- Track simulation of laser beams and reconstruction needs to be done.

Thank You…

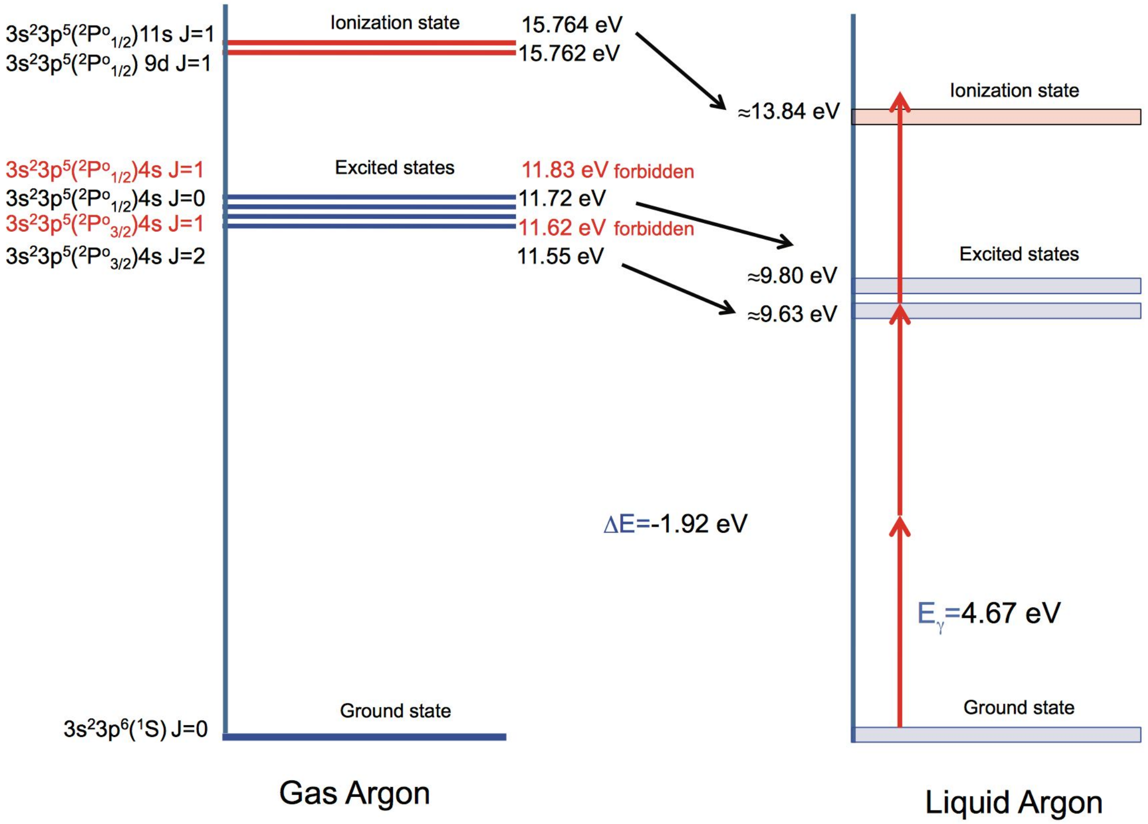
Backup Slides.

The ions and electrons in a 1 × 1 × 1 m3 box filled with liquid argon, considering the ionization produced mainly by cosmic muons and a 1 kV/cm drift field. Diffusion of the charges and recombination is taken into account.



arxive.org/pdf/1712.07971

- Multiphoton ionisation: strong intensity dependence
- Resonance-enhanced multiphoton ionisation (2 + 1)
- 266nm UV laser in 60*mJ* pulse have ~8×10^{16} photons



Correction Maps:

- Calculate the correction vectors of track samples A and B using closest-point projection
- 1/n of the calculated correction vectors of track sample A are assigned to the corresponding reconstructed track points.
- Interpolate the partial correction vectors of track sample B with the mesh of all the reconstructed track points in sample A and their partial correction vectors.

Interpolation:

- The regular grid points are located at the center of each bin in the spatial displacement maps. Each bin has the same size of approximately 10 cm × 10 cm × 10 cm.
- First a mesh of all the track points by using Delaunay triangulation. Then barycentric coordinates of the grid points in the corresponding Delaunay triangulation unit are computed, and they are further applied to achieve the spatial displacement vectors on the grid points.

Step 1:

Closest Point projection.

Step 2:

Interpolate the fractional displacement vector from the other sub sample (where is fractional vector of)

Move the track correspondingly to the next intermediate position.

.

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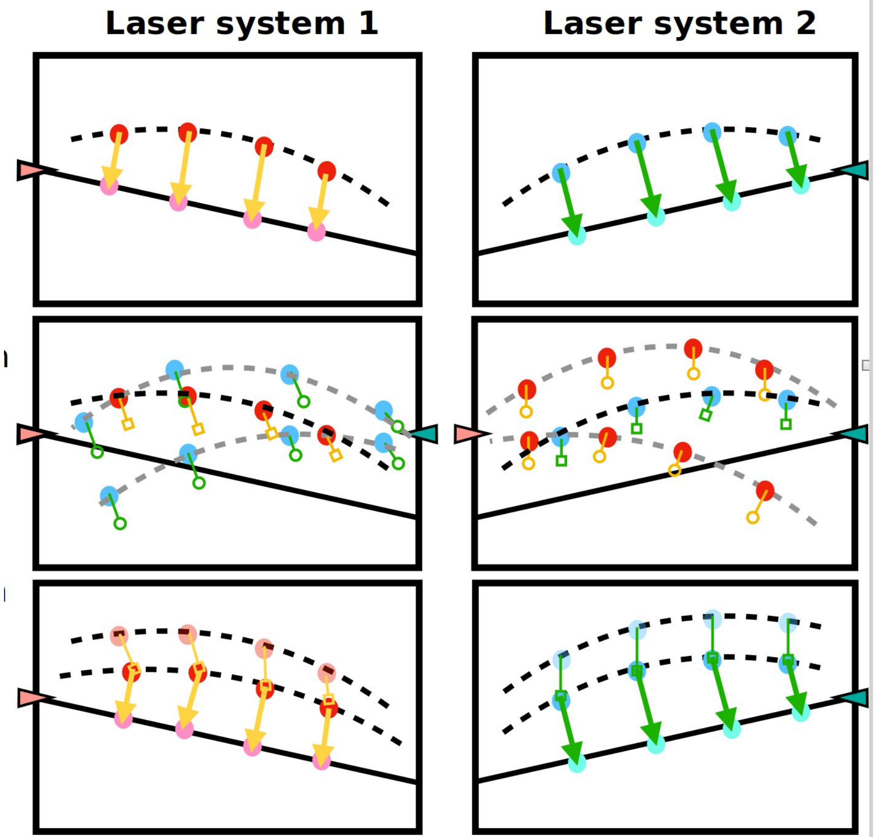
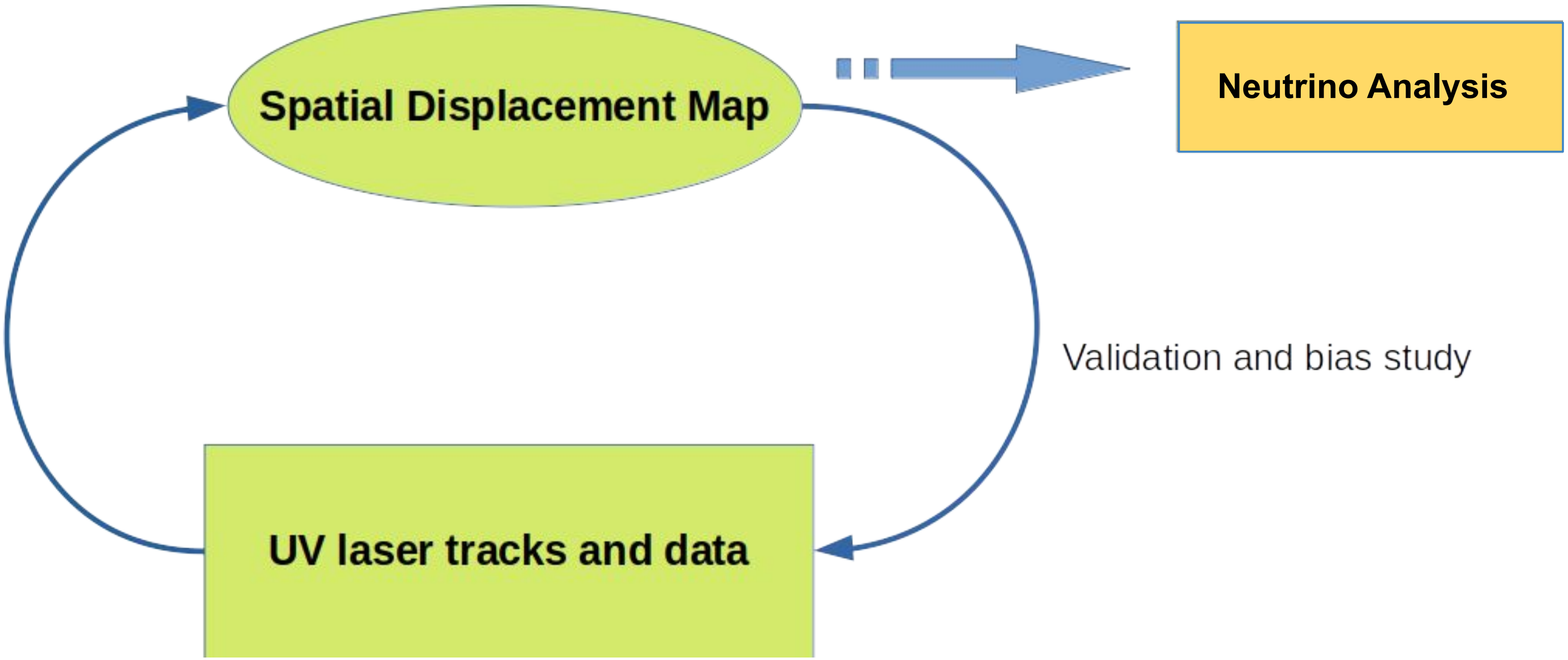
Step N:

Correct all the intermediate track points to the laser track .




Spatial Displacement Map
Neutrino Analysis
Validation and bias study
UV laser tracks and data

Set 2:

1. 1892 (moved 1500)
2. 1893 (500)
3. 1895 (1000)
4. 1895 (700)
5. 1895 (1000)
6. 1895
7. 1892
8. 1889
9. 1886

Set 1:

1. 1887 (moved 1500 steps)
2. 1888 (1500)
3. 1889 (500)
4. 1889 (500)
5. 1892 (700)
6. 1892

Set 3:

1. 161 (moved 1500)
2. 161 (1000)
3. 161 (150)
4. 161
5. 160
6. 161
7. 161
8. 161
9. 161

The SBN program makes use of the Booster Neutrino Beam (BNB) at Fermilab. The neu- trino beam is created by **extracting 8 GeV kinetic energy protons from the** Booster acceler- ator and impacting them on a beryllium target to produce a secondary beam of hadrons, mainly pions.