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

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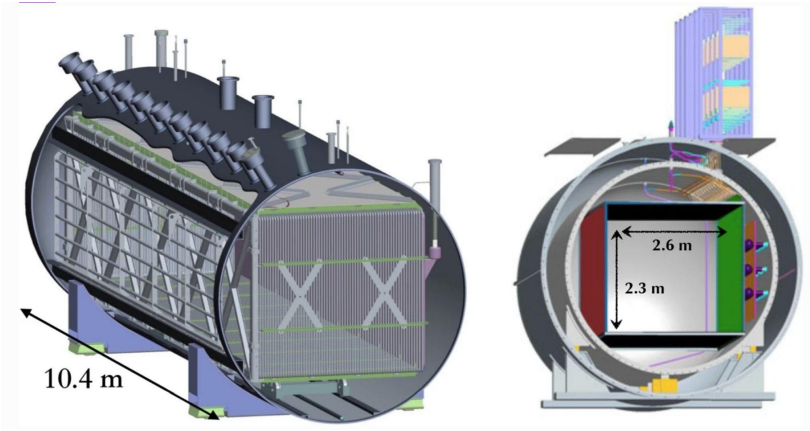
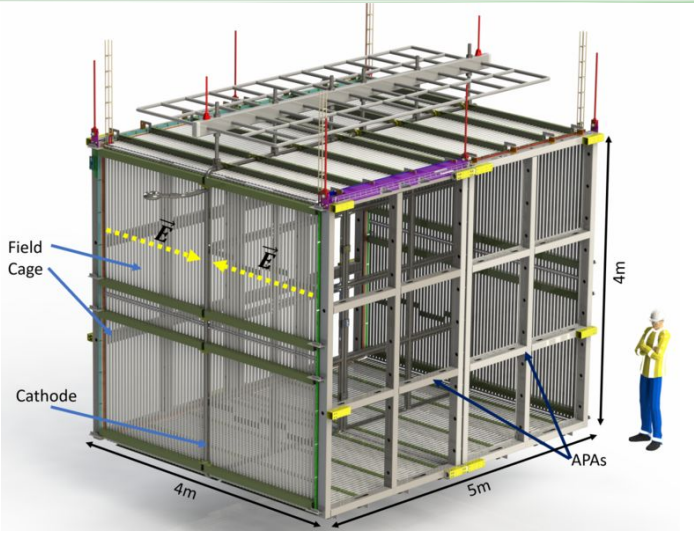


C. Adams *Eur. Phys. J. C* 79, 673 (2019)

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.

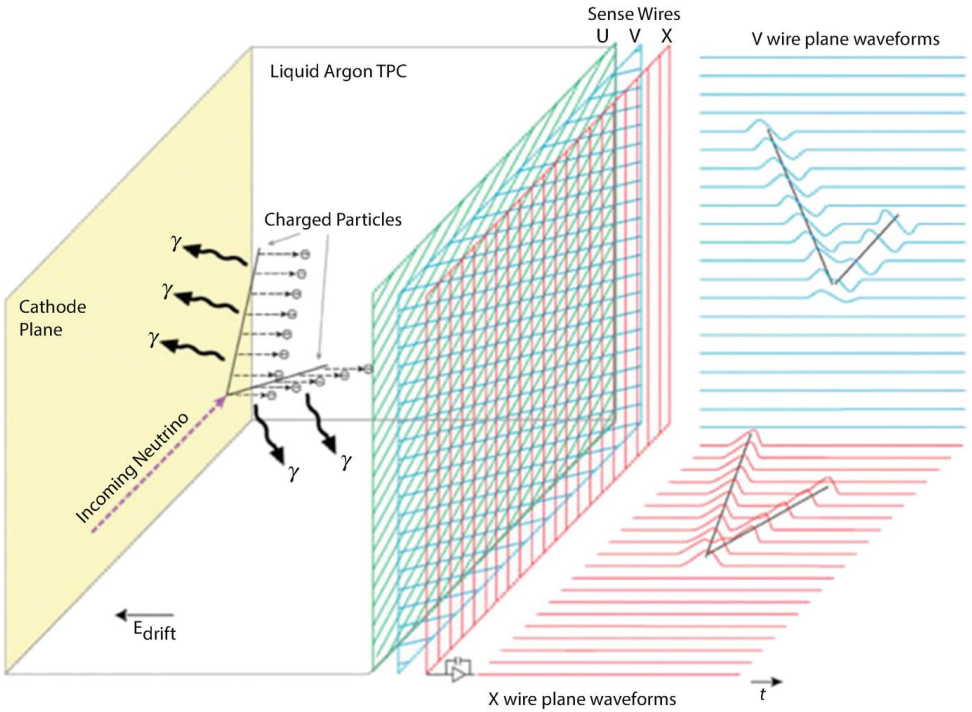


SBND:

- 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:

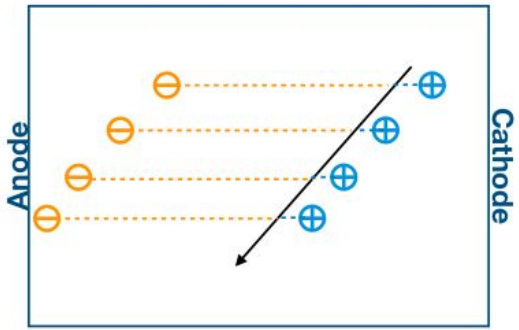
- Electric field is set up by cathode-anode plan
- Interaction in LAr produce scintillation light and ionization electrons.
- Scintillation light is detected by PMTs
- Due to Electric field $\mathbf{e}^-$ drift towards anode.
- At anode, the $\mathbf{e}^-$. Induce charge in induction planes and are collected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

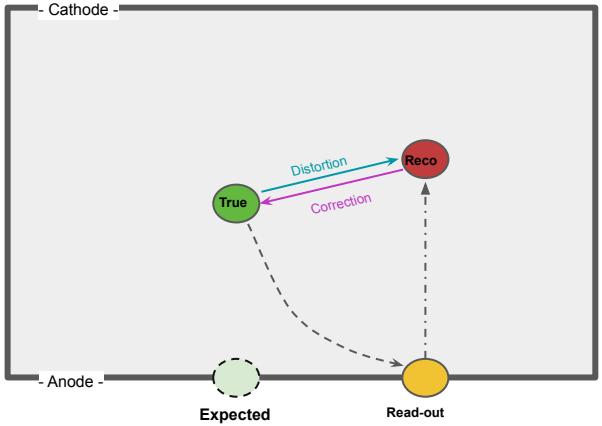
Why E-field Calibration ?

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

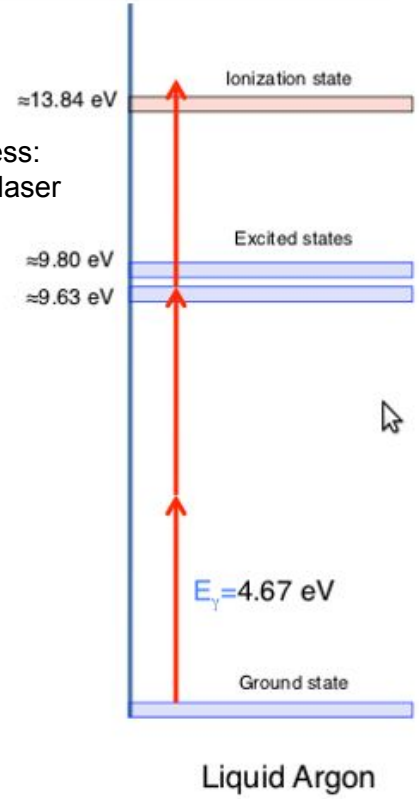
Why:

- 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.

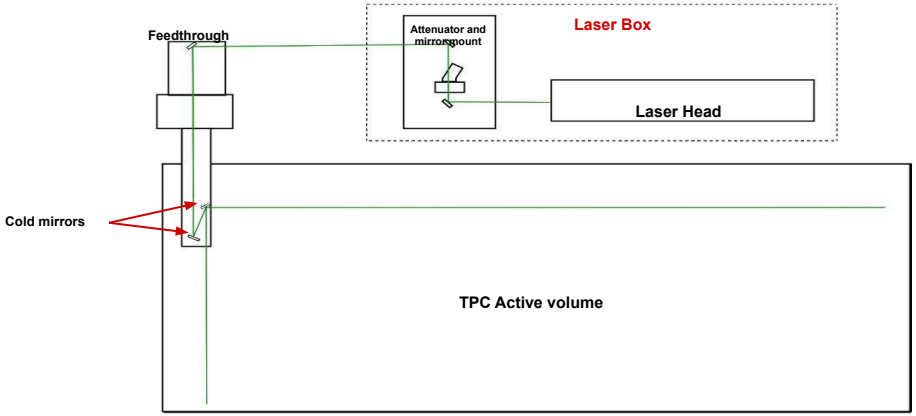
(2+1)-photon process:
Needs high power laser



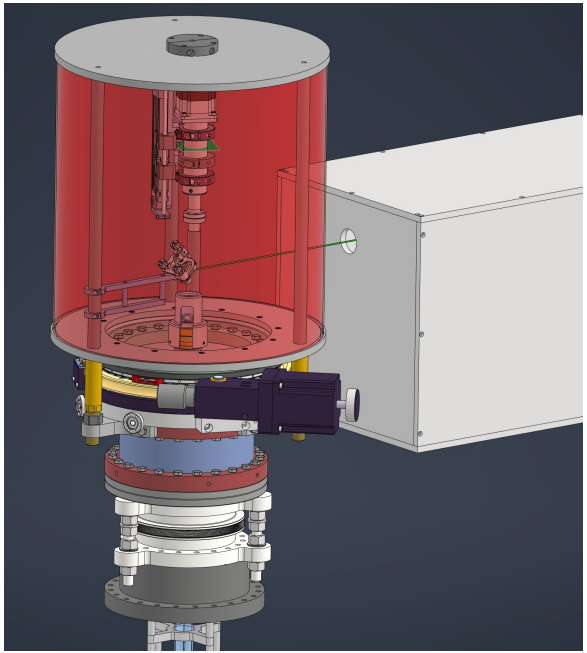
How:

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

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

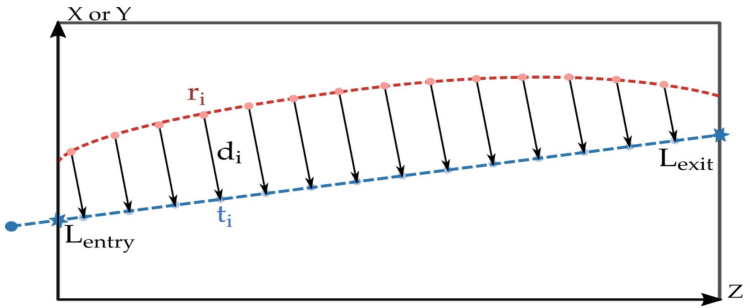


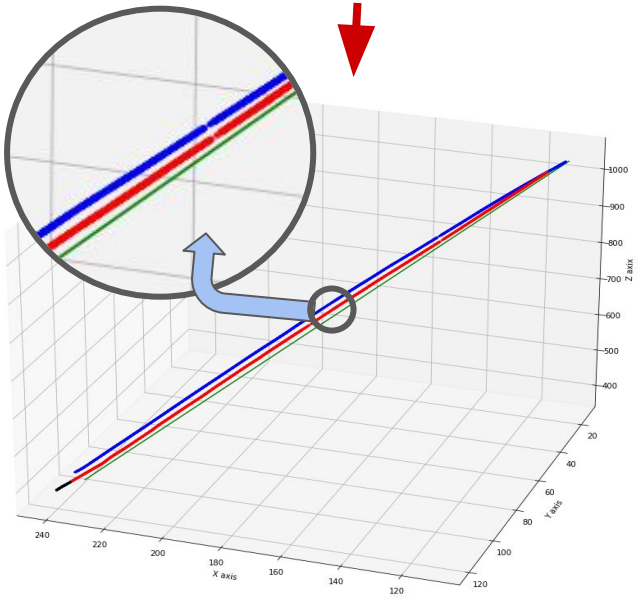
Schematic representation of SBND - UV laser calibration set up

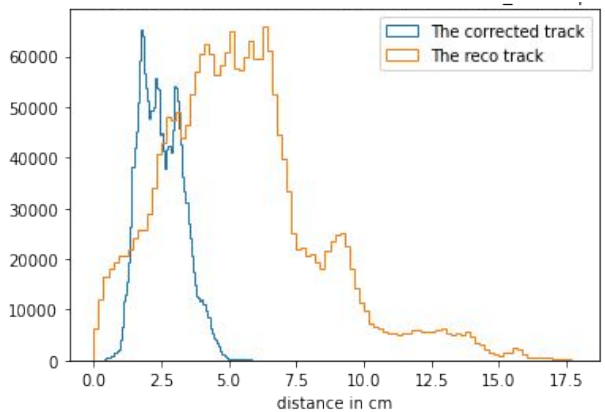


How:

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

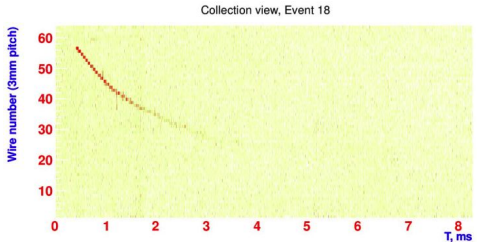




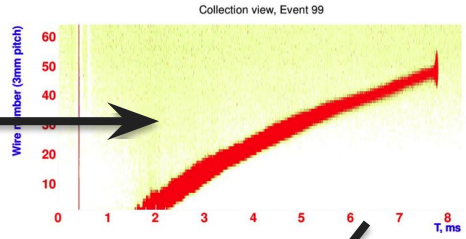


Shortest distance from true to reco points before and after correction.

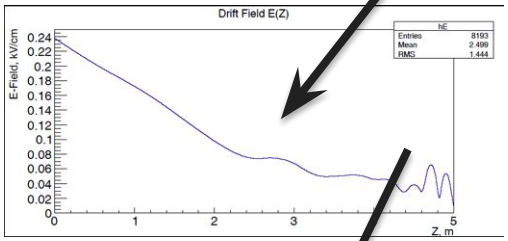
UV-laser method in actual scenario - measurement from ArgonTube (Bern, 2013)



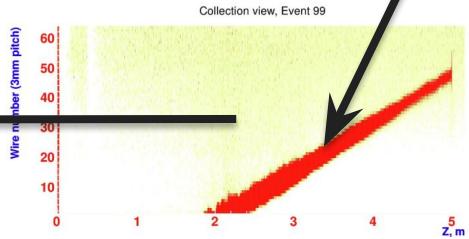
Distorted muon track, due to e-Field distortion



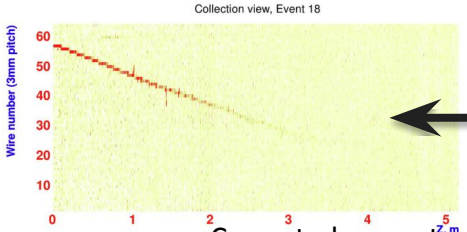
100 laser tracks



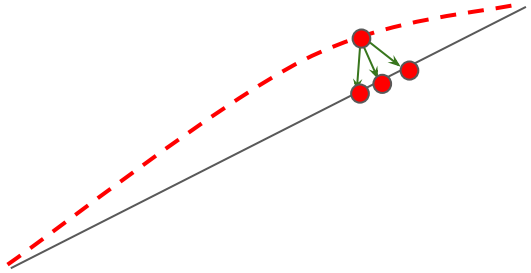
E-Field map



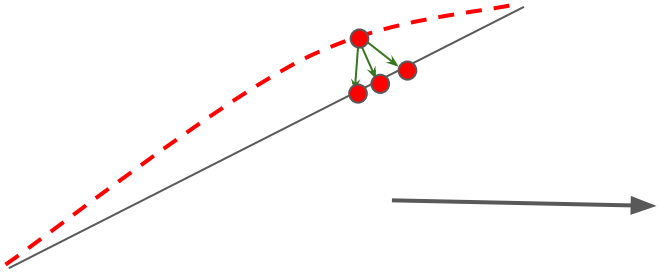
Corrected laser tracks



Corrected muon track

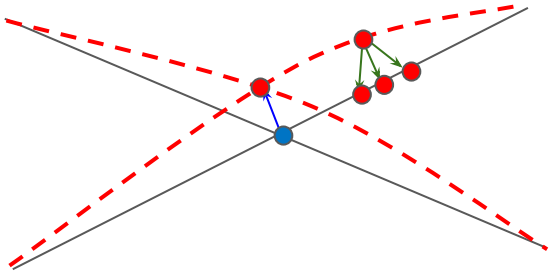


A reco points corresponds
to which point in true track?



A reco points corresponds to which point in true track?

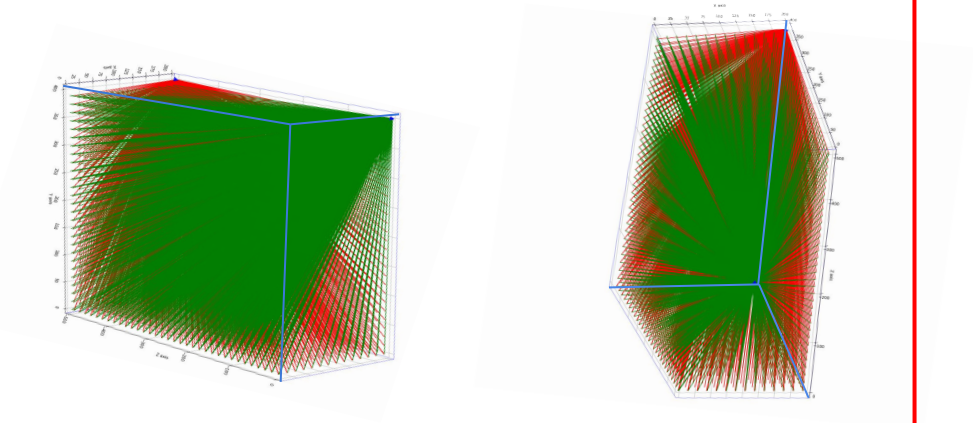
Crossing tracks!!!



Cold mirrors inside the TPC - No shadow effect by fieldcage

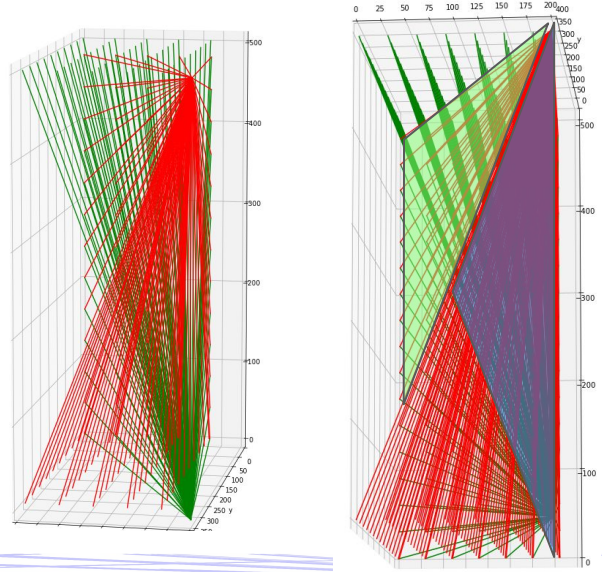
Full Laser Scanning:

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

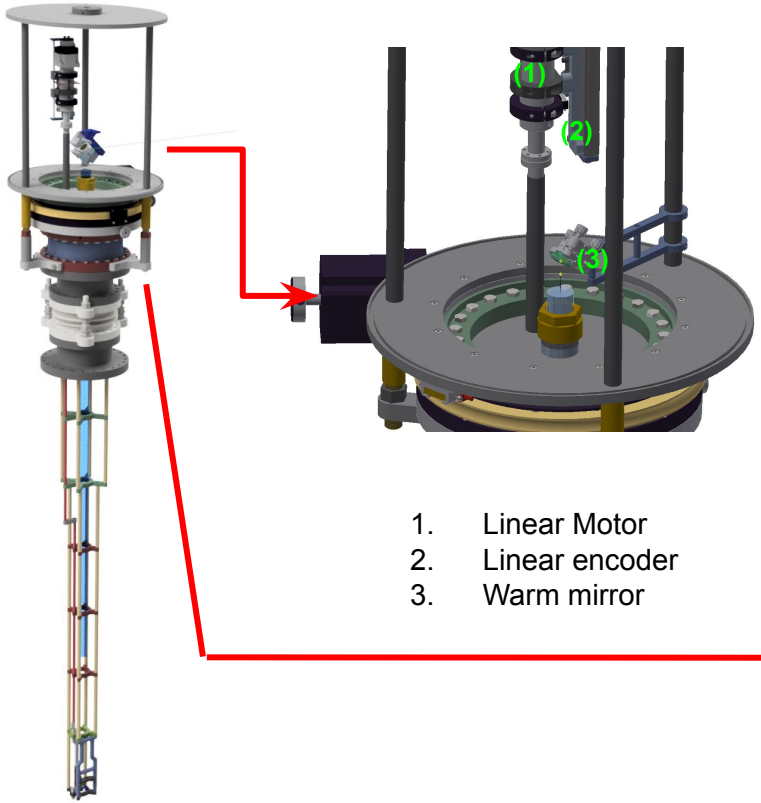


Partial Scanning:

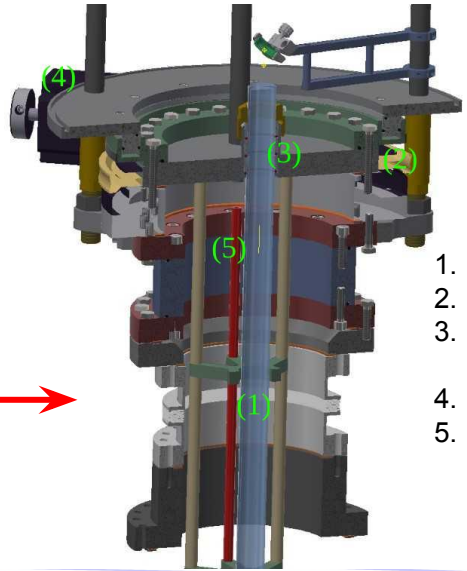
- Omit the laser tracks directed towards the cathode because of the presence of PTB-coated reflective sheets on the cathode.
- Partial coverage with crossing track points < 50% of total volume.
- Crossing tracks are close to anode.



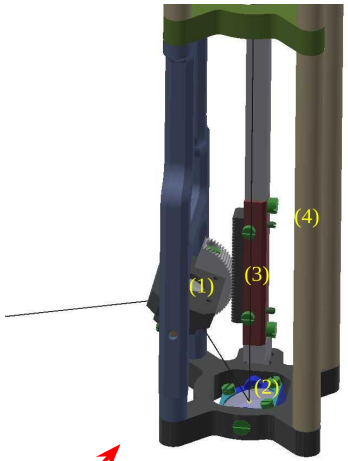
Hardware -Feedthrough: Cross Sectional view



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



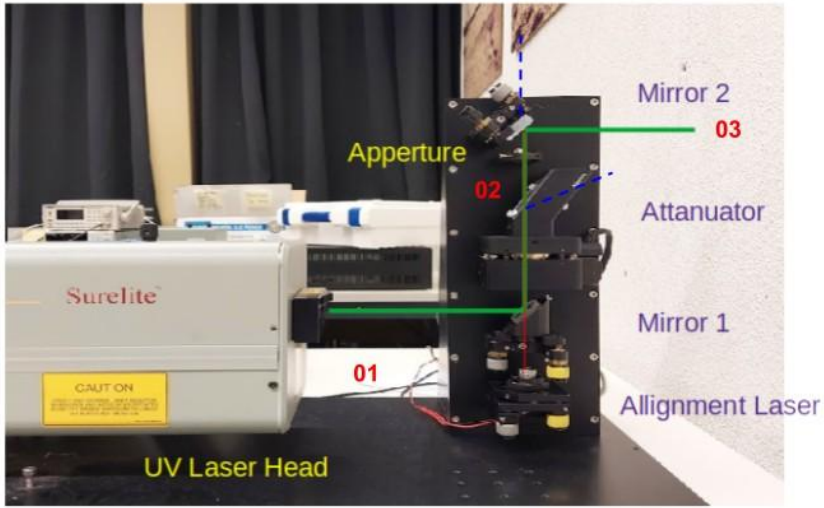
1. The evacuated glass tube.
2. Rotary encoder ring
3. Rubber seals for the glass feedthrough
4. Rotary motor.
5. Linear feedthrough piston from linear Motor for tilting mirror



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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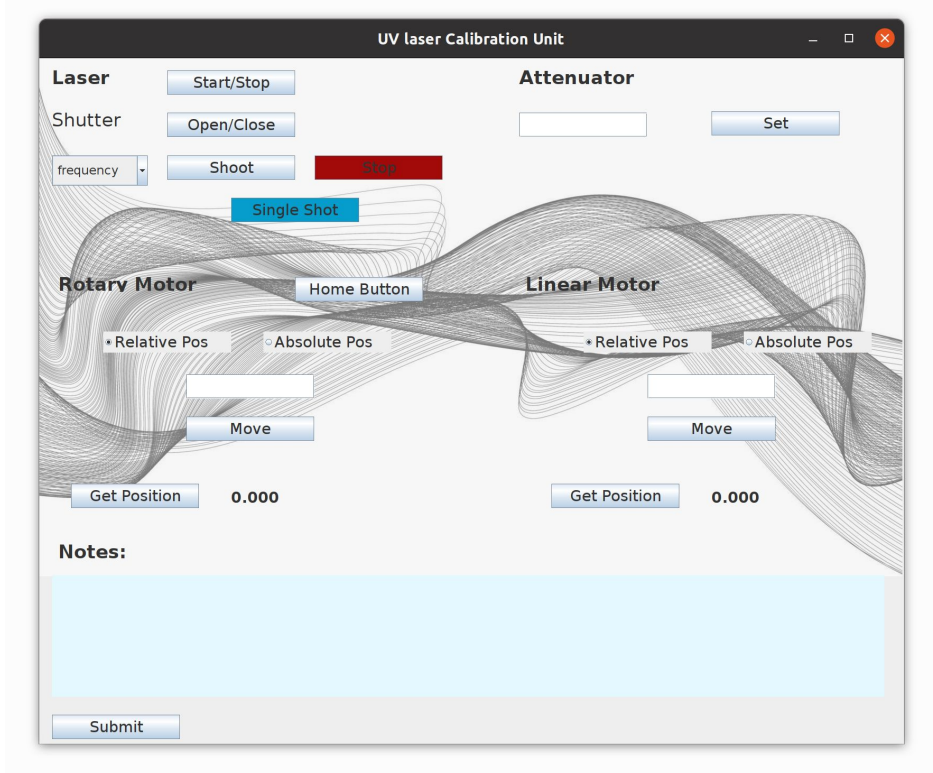
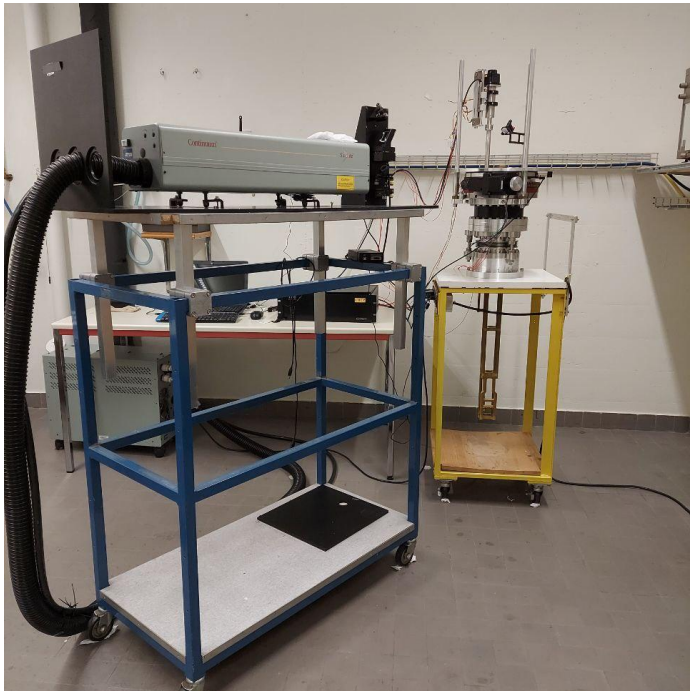
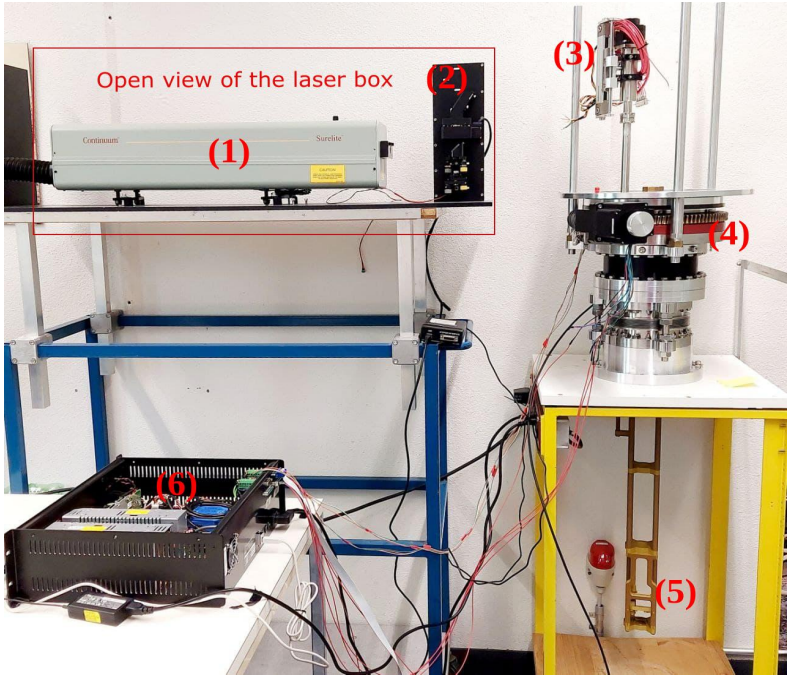


Laser test facility at LHEP:

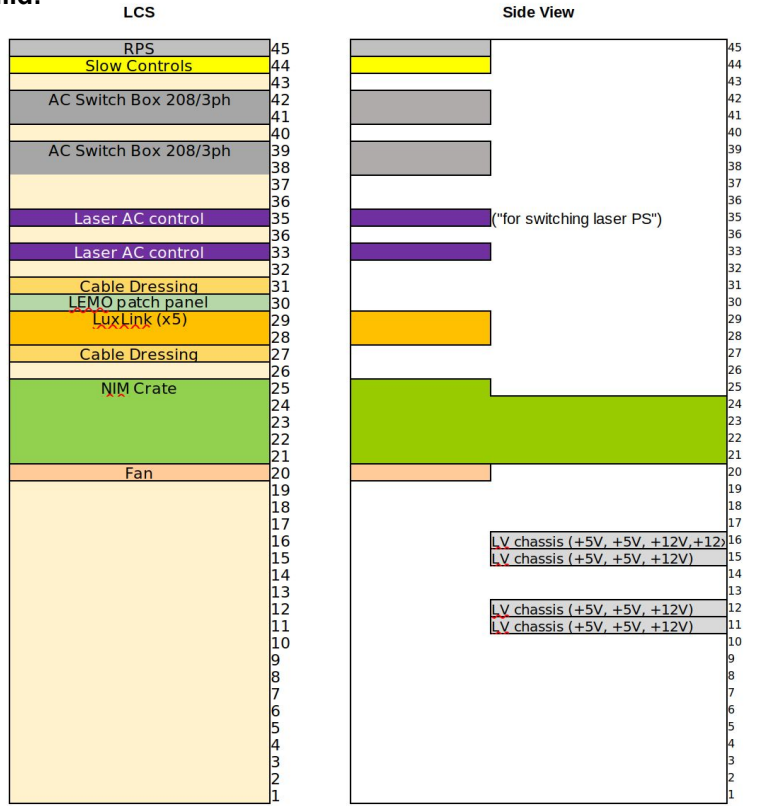


Thanks to Michele, Igor, Rogger, Silas, Lino and Andri

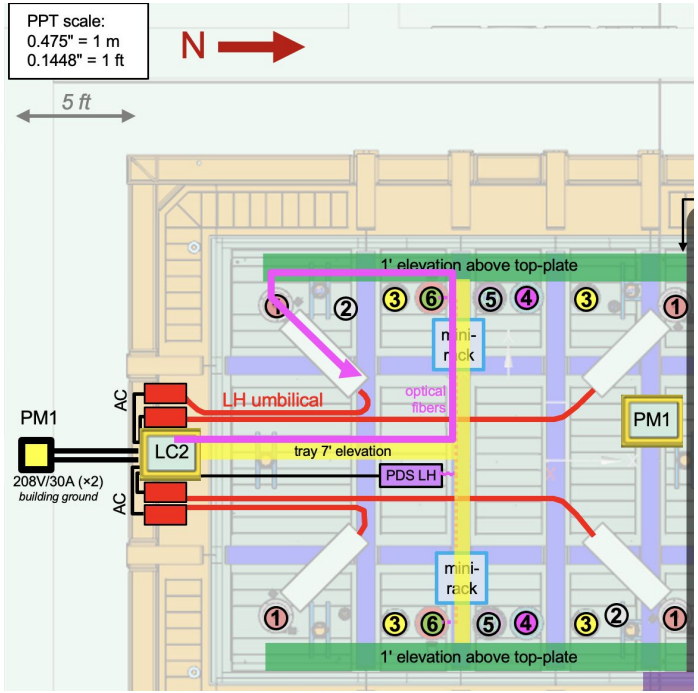


(1) Laser head, (2) Attenuator and mirror mount,
(3) Linear Motor to control the vertical movement of the cold mirrors,
(4) Rotary motor to control the horizontal movement of the mirror.
(5) Cold mirror mount and shafts, (6) Motor controller box

Rack Build:

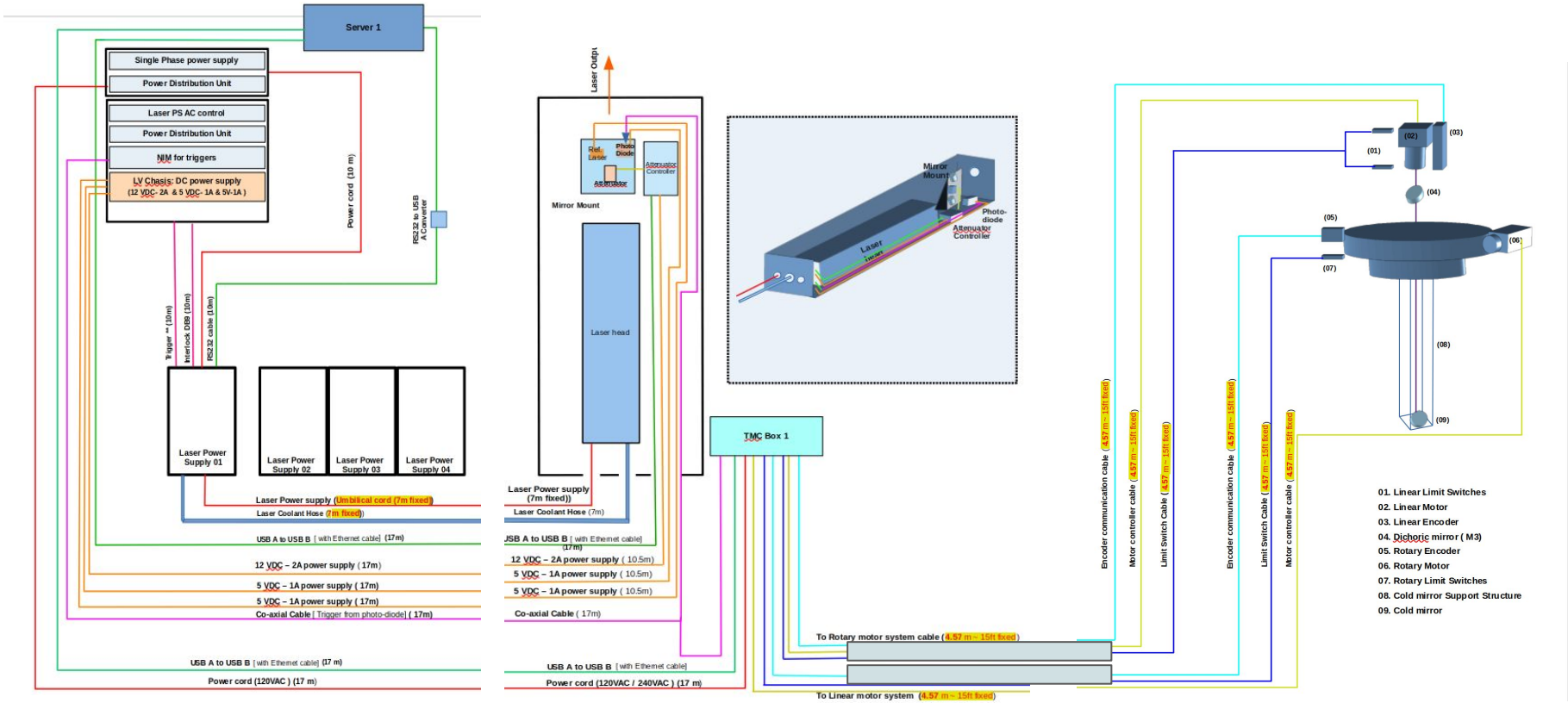


https://sbn-docdb.fnal.gov/cgi-bin/sso/ShowDocument?docid=1382



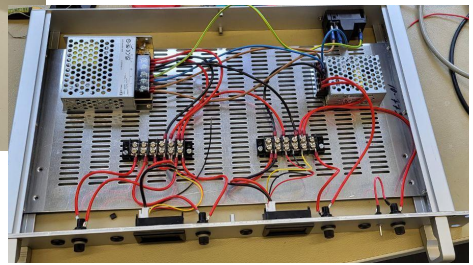
Thanks Will and Linda

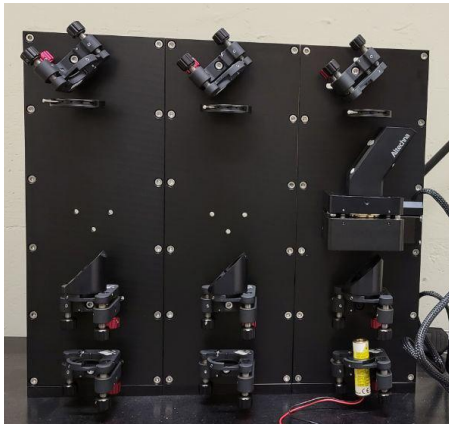
Wiring diagram:

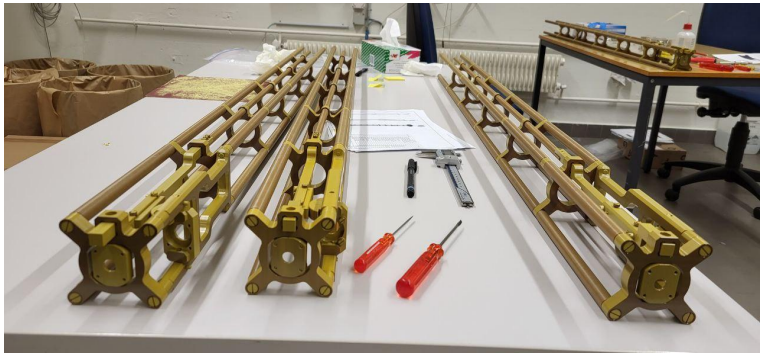


Parts assembly in Bern (April 2023)

Thanks.. Lori and Vasco







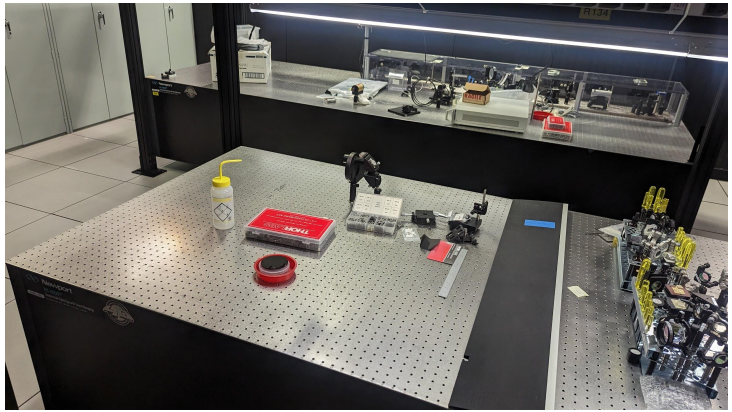
Mechanical installation of Feedthroughs at SBND:

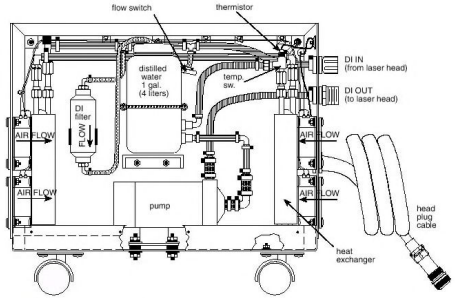
- Installation of feedthrough onto the cryostat was done last week (June 12 - 19)

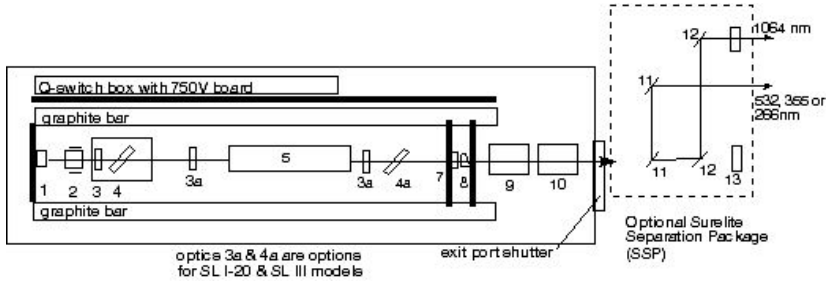
Thanks to Anne, Roberto, Lori, John, Luis

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)

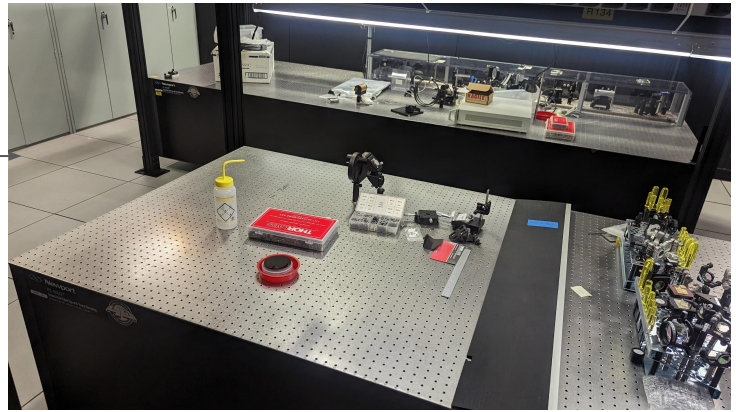


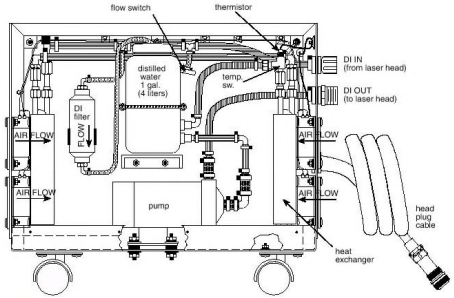


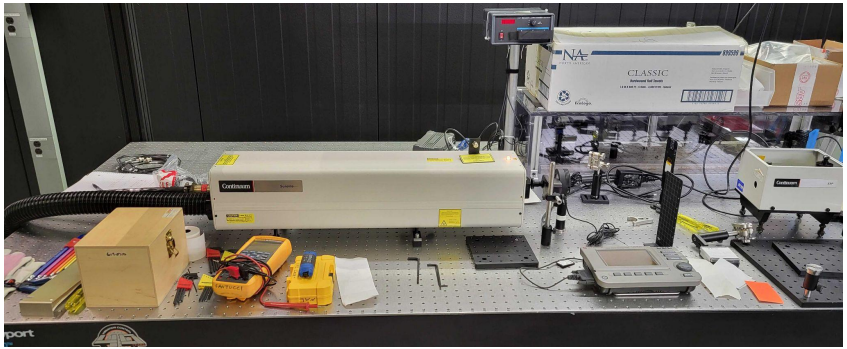


Laser unpacking, assembly and tuning

- Procedure to uncrate, unpack and first setup (October 2-8)
- Tuning procedure at NML (laser lab)
  Thanks to Michele, Jamie, Jinhuao and Abhishek and Matthew Spaw
- Attached umbilical, fill cooling DI water,
  Connect flashlamp, tune settings an measure power IR,
  mount second and fourth harmonic and tune power
- 3 laser with ~90-100 mJ and 1 with ~14 mJ
- One laser crystal needs to be replaced, the crystal was retrieved
  From MicroBooNE laser system (Nov 20)



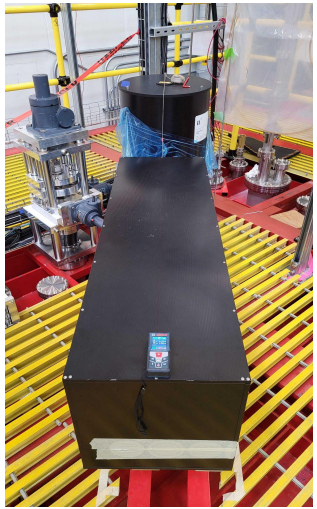


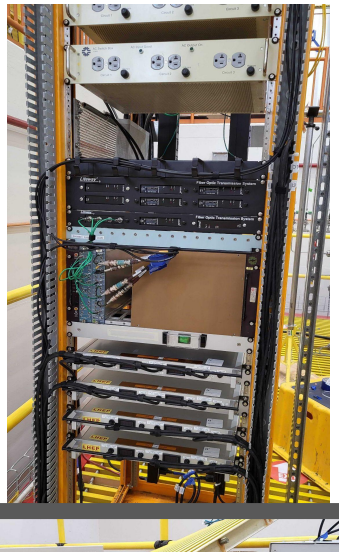


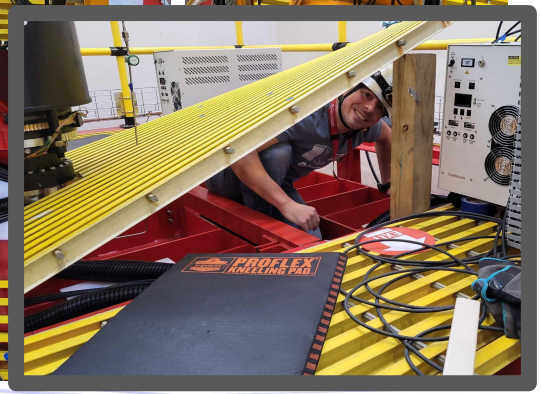
Current Status:

- Laser box Installed on top of cryostat.
- Laser is installed inside the box along with attenuator, photodiode module, reference laser and communication cables.
- Laser Calibration system (LCS) has been installed and all the equipments are installed.
- Cabling is done (except ethernet, ofc and Interlock)
- Power supply cables to all equipments from the LCU Rack is connected and labelled.
- Laser connectors are routed beneath the grating To avoid trip hazard. (Thanks to Roberto)

As of 17 May 2024 - All hardware works are done, waiting for ORC review and operation



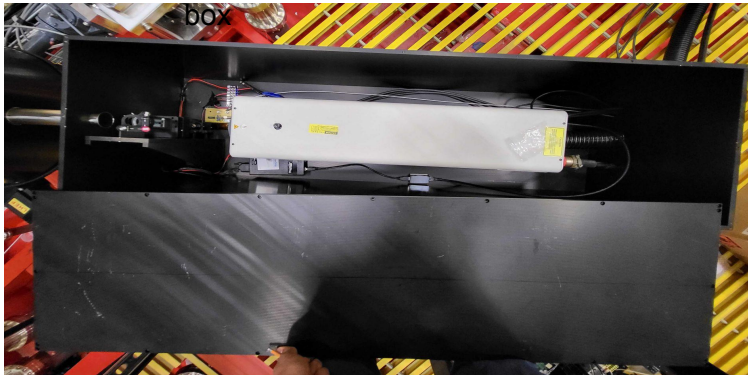


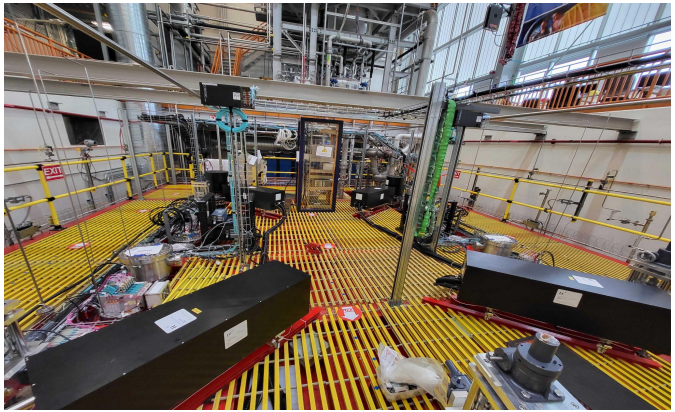


Pending/Upcoming Work:

- Final ORC and operation.(March 2024*)
  two operation modes = two documents:
  standard operation and maintenance
  - Standard operation: laser light fully contained
    (no photon gets in SBND for PMT, no laser gets out)
  - Maintenance needs building and street closure (class 4 laser)

Equipments inside the laser box





Cryostat top as of 22nd Nov.

Differential cross sections in longitudinal and transverse muon & proton momenta

(MicroBooNE BNB Data)

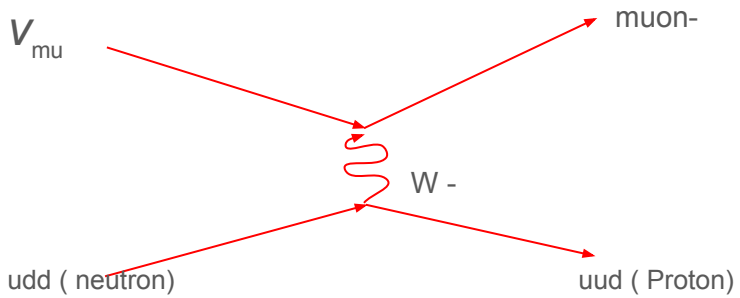
Objective:

Will be using the already published **CC1p0π** selection to add the longitudinal and perpendicular components and extract the cross sections.

Phys. Rev. D 108, 053002 (2023)
Phys. Rev. D.101.112007

Using Afro's infrastructure for preliminary steps.

Flat root files using:
bnb.ub.num.genie_v2_12_10.mec.flat.root
bnb.ub.num.genie_v3_00_06.flat.root
bnb.ub.num.neut_5_4_0_1.flat.root
bnb.ub.num.nuwro_19_02_1.flat.root



Events Selection criteria:

1. final-state muon with momentum $0.1 < p_\mu < 1.2$ GeV/c

2. exactly one proton with $0.3 < p_p < 1$ GeV/c.

3. Events with final-state neutral pions and heavy mesons at any momentum are excluded.

4. Signal events may contain any number of protons below 300 MeV/c or above 1 GeV/c, but only one of them should satisfy condition 2.

5. neutrons at any momentum are included

6. Events with charged pions with momentum lower than 70 MeV/c are included

7. No events with particles other than the charged pion, proton, neutron and muon in final state are allowed.

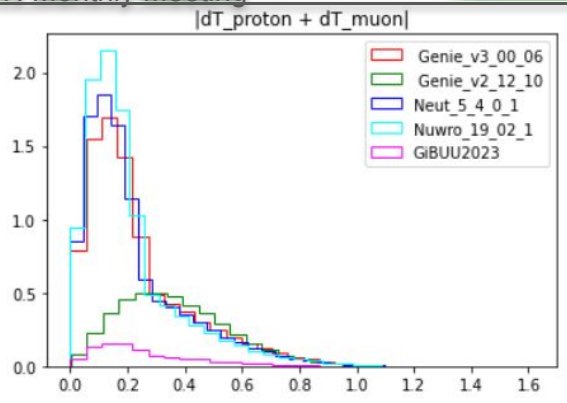
Events that passed the selection:

Genie_V2	2M	183779	9.2%
Genie_V3	2M	474848	23.74%
Neut	1M	245005	12.3
Nuwro	1M	270272	13.5%
Gibuu	2.04M	701957	35.1%

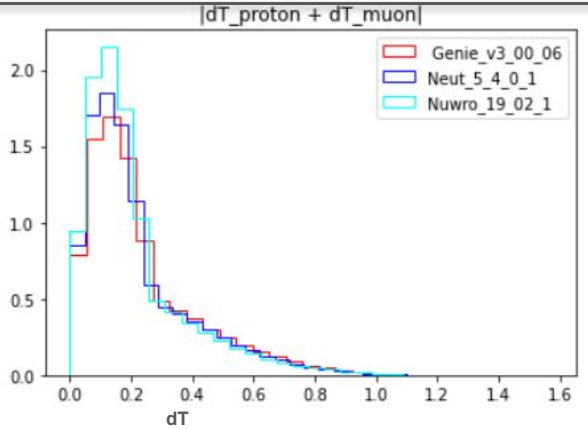
NB: Using Python with Uproot3 and Pandas

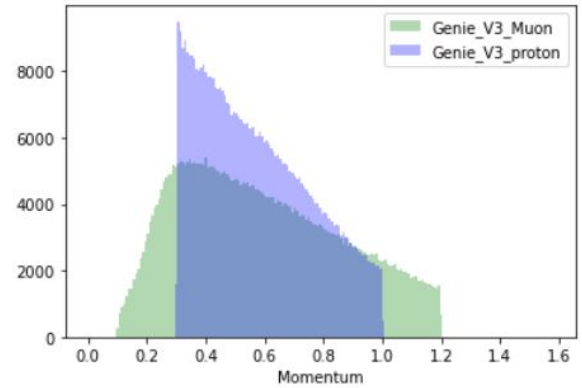
entry	Mode	cc	PDGnu	Enu_true	tgt	tgta	tgtz	PDGLep	ELep	CosLep	...	flagNCcoh	flagCC1pip	flagNC1pip	flagCC1pim	flagNC1pim	f
0	1	1	14	1.111011	1000180400	40	18	13	1.021066	0.900990	...	False	False	False	False	False	
1	21	1	14	1.346048	1000180400	40	18	13	0.506649	0.639489	...	False	False	False	False	False	
2	32	0	14	0.443595	1000180400	40	18	14	0.150372	-0.648304	...	False	False	False	False	False	
3	1	1	14	0.652729	1000180400	40	18	13	0.448851	0.225985	...	False	False	False	False	False	
4	2	1	14	1.349738	1000180400	40	18	13	1.310274	0.903796	...	False	False	False	False	False	
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	
1999995	1	1	14	1.014459	1000180400	40	18	13	0.933192	0.995647	...	False	False	False	False	False	
1999996	12	1	14	1.876403	1000180400	40	18	13	0.471340	0.565452	...	False	False	False	False	False	
1999997	31	0	14	0.579869	1000180400	40	18	14	0.198307	0.281334	...	False	False	False	False	True	
1999998	41	0	14	1.308710	1000180400	40	18	14	0.747612	0.935924	...	False	False	False	False	True	
1999999	31	0	14	0.976227	1000180400	40	18	14	0.204486	0.694217	...	False	False	False	False	False	

2000000 rows × 76 columns

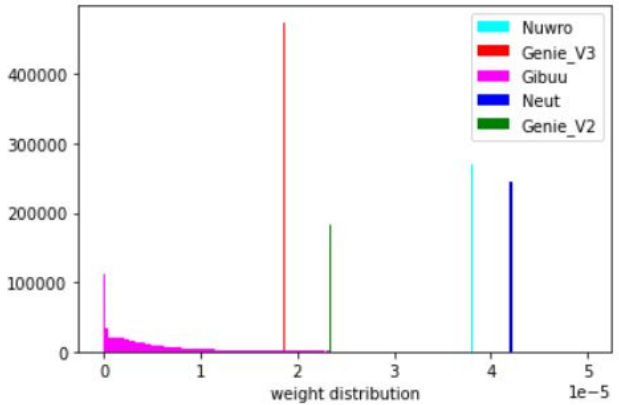


dT All generators

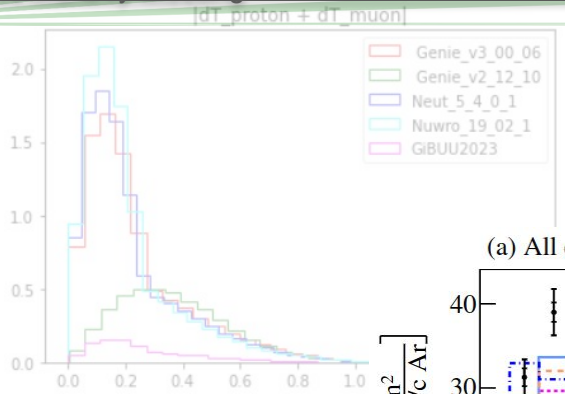


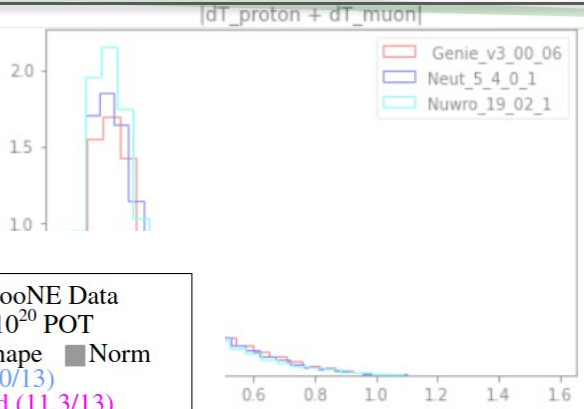


Momentum of proton and muon

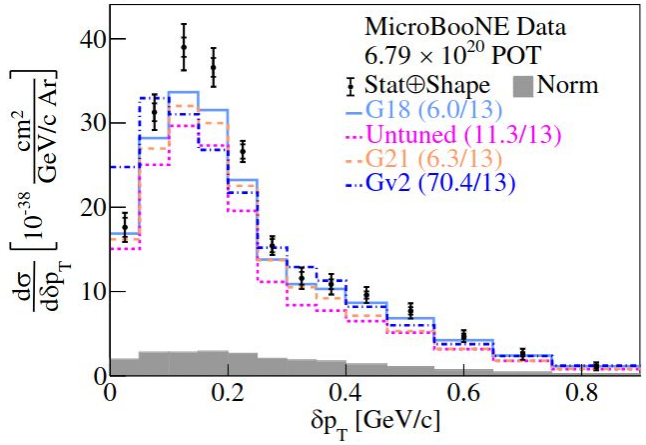


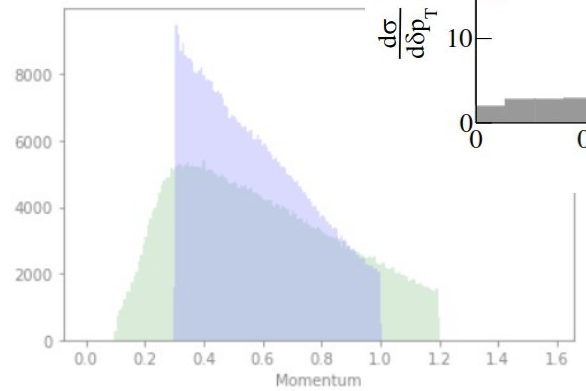
For Gibuu: (scaleFactor*40*10**38*weight)/500
Rest: scaleFactor*40*10**38*weight

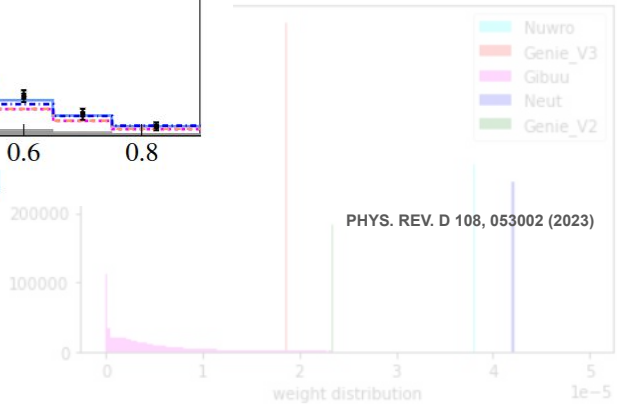




(a) All events





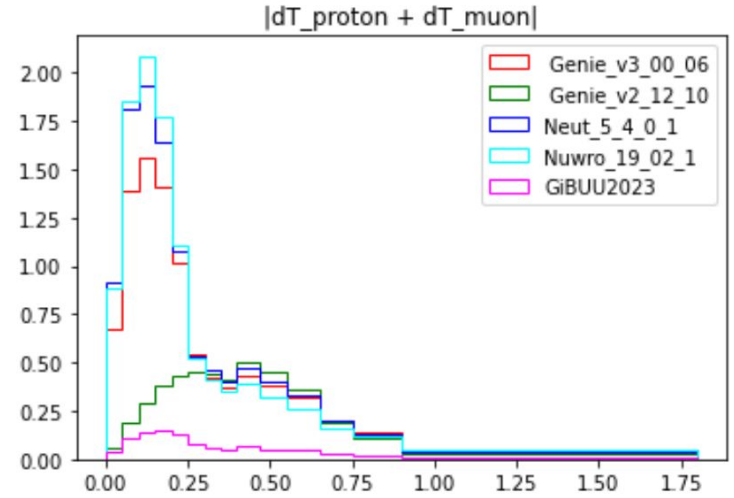


For Gibuu: (scaleFactor*40*10**38*weight)/500
Rest: scaleFactor*40*10**38*weight

Genie_V3:
Bin Heights: [2.32129806e+01 2.42285137e+01 8.50505353e+00 5.69510704e+00
3.40350853e+00 1.80613882e+00 7.59862379e-01 2.29074056e-01
5.04763681e-02 7.14962720e-03 1.71591053e-03 1.42992544e-04]

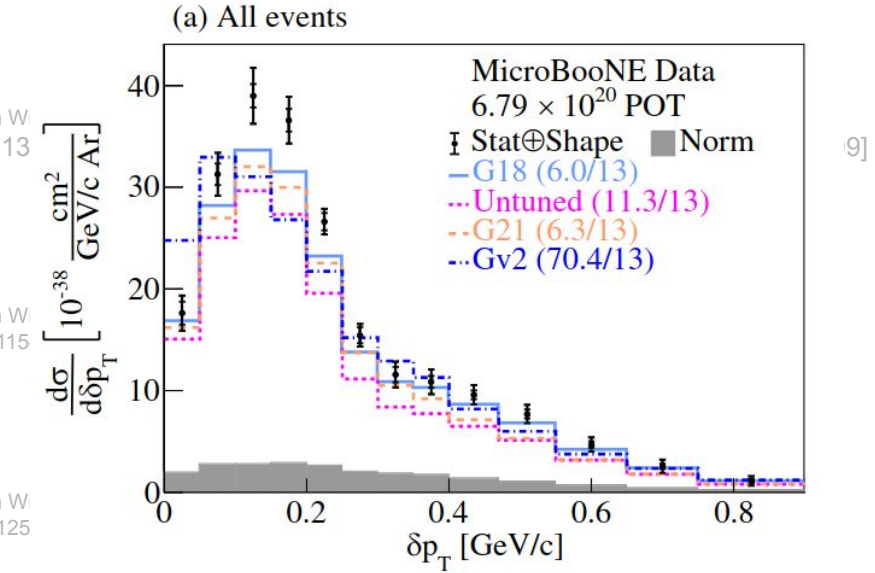
Bin Widths: [0.13119072 0.13119072 0.13119072 0.13119072 0.13119072 0.13119072
0.13119072 0.13119072 0.13119072 0.13119072 0.13119072 0.13119072]

Geni
Bin He
3.519
2.752



Neut
Bin He
4.825
2.075

Nuwr
Bin He
3.159
1.012



in W
).13

in W
.115

in W
u.125

9]

GiBUU:
Bin Heights: [1.90189669e+00 2.65357969e+00 1.24051964e+00 8.20565728e-01
4.51237957e-01 2.14782619e-01 7.16544399e-02 1.99030637e-02
5.07346132e-03 7.88985577e-04 1.12838213e-04 6.12960451e-05]

Bin Widths: [0.13134332 0.13134332 0.13134332 0.13134332 0.13134332 0.13134332
0.13134332 0.13134332 0.13134332 0.13134332 0.13134332 0.13134332]

Thank You….

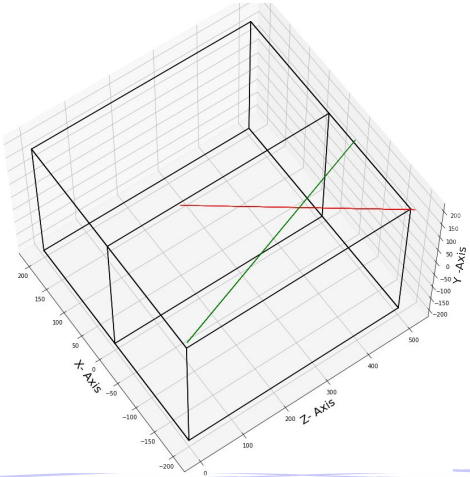
Backup slides.

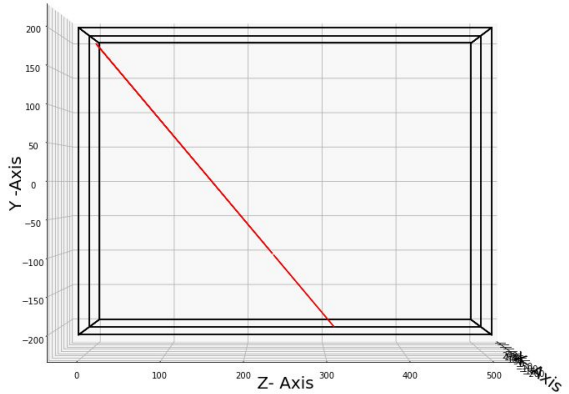
Finished works:

- 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)
- Feedthrough installation at SBND

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. ✓

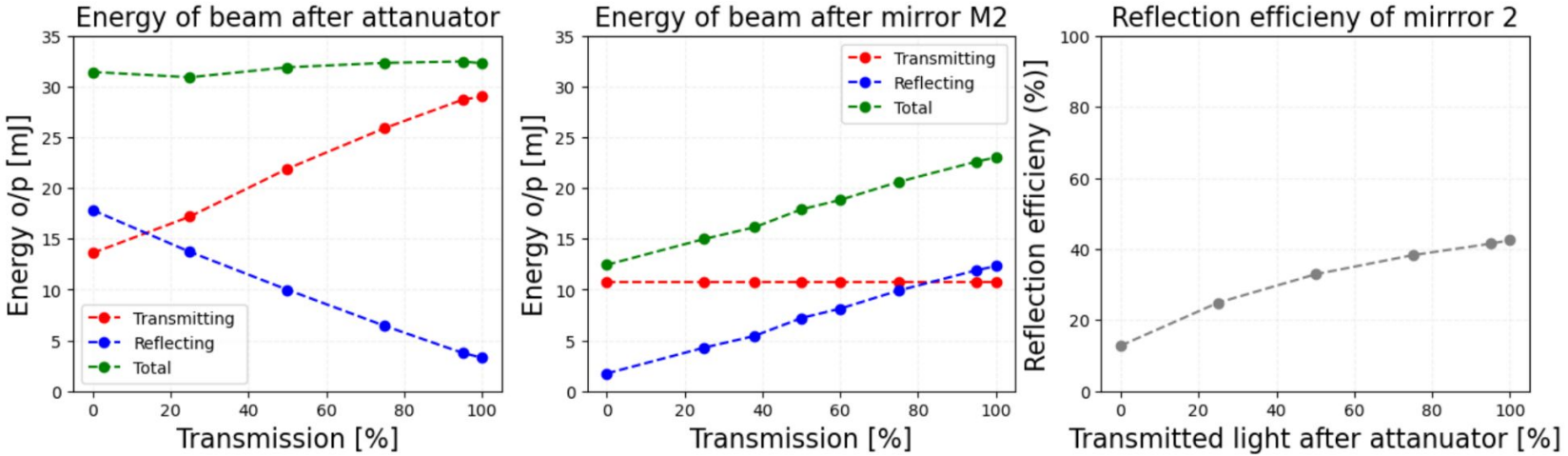
All Points with same encoder position reading

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.

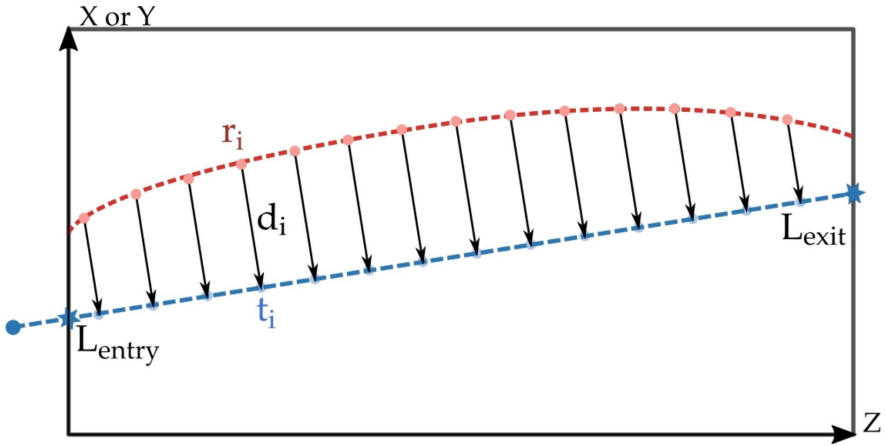
Unwanted light components in the infrared and green (base wavelength and 2nd harmonic) are transmitted through the mirror and ultimately absorbed on a beam dump.

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:

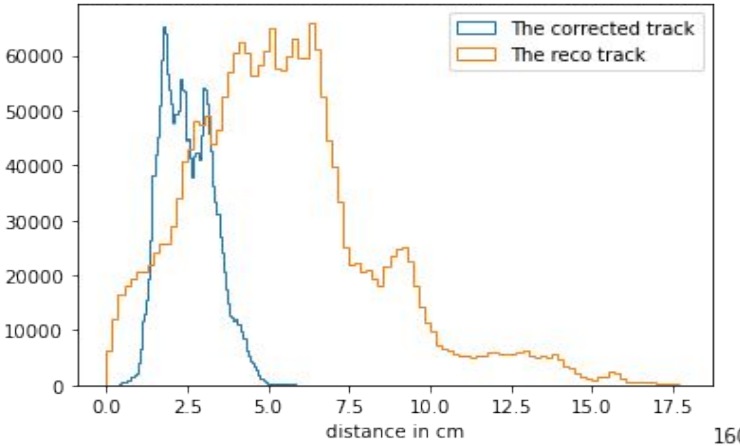
- Correction Map: Based on reco spatial coordinates
  Gives expected true points, given by the reco points.

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



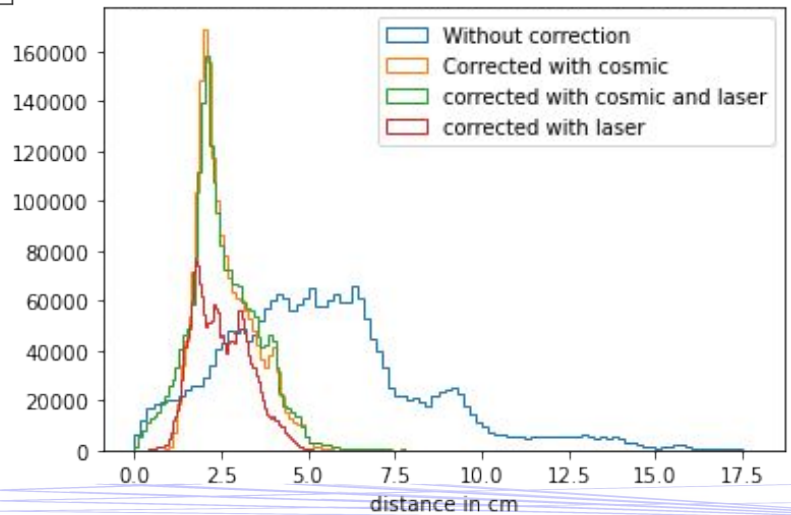
C. Adams *et al* 2020 *JINST* 15 P07010

- 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)



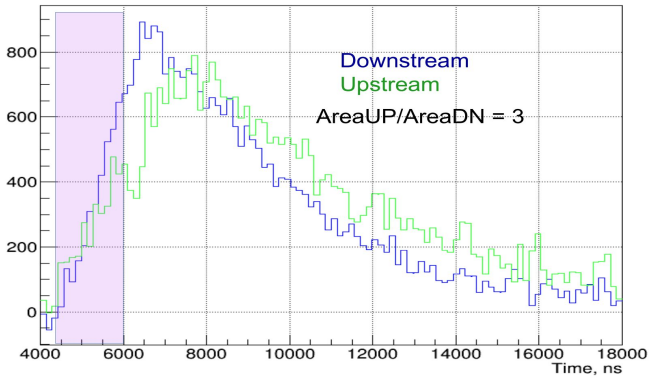
Analysis Plan:

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

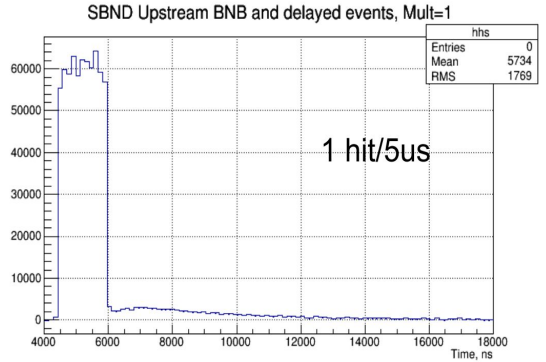
- Timing measurements and Heavy Neutral lepton search using CRT data and MC efforts.
  1. CRT Beam telescope measurements at Fermilab. Beam data from 2017 -2019 run
  2. Test setup at Bern with 3 modules of CRT.

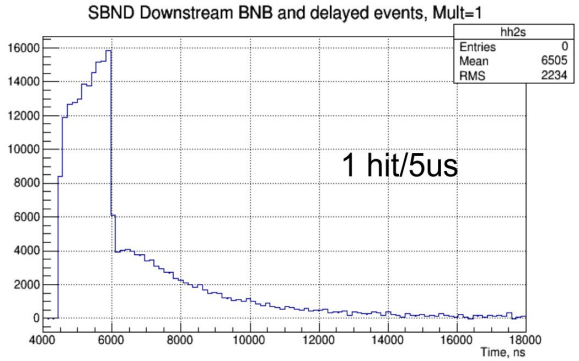
- Cross Section measurements with SBND tpc data (end of 2023 - beginning of 2024)

- 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

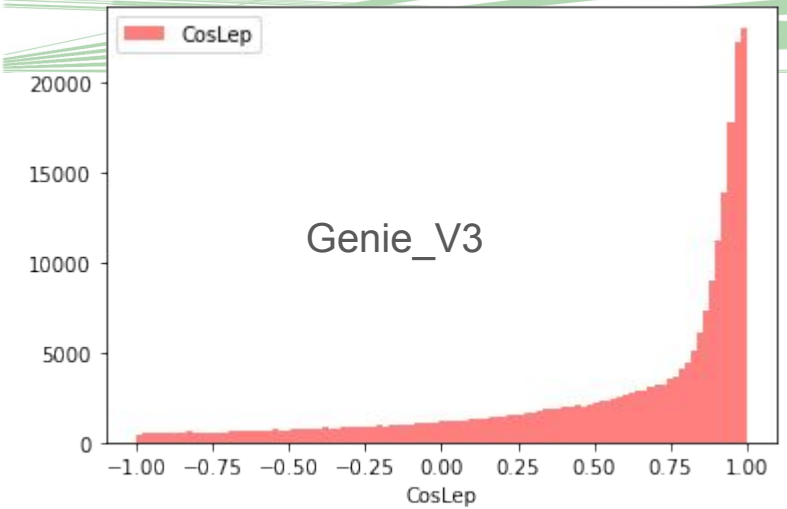


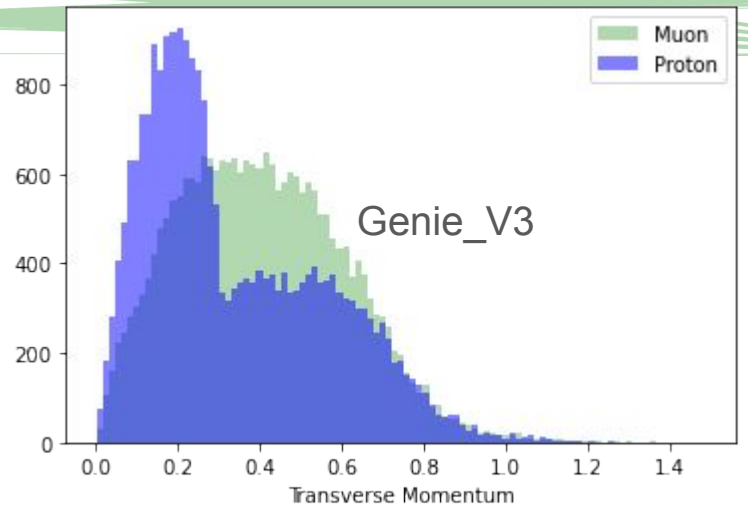
Beam direction

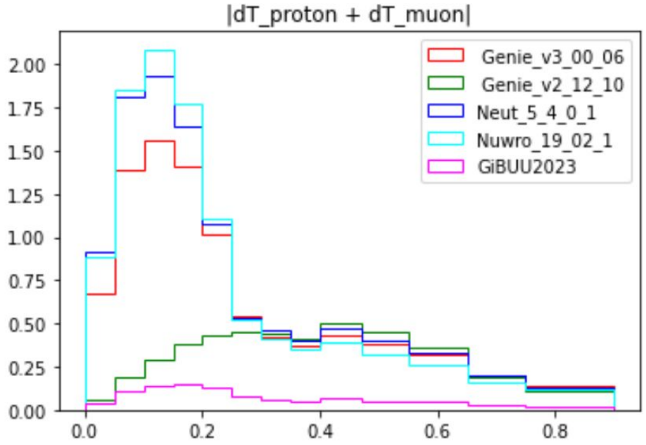




Plots are from Igor kreslo, from his talk on 'CRT Measurements in the SBND Hall'


CosLep
Genie_V3
20000
15000
10000
5000
0
−1.00
−0.75
−0.50
−0.25
0.00
0.25
0.50
0.75
1.00
CosLep


Muon
Proton
Genie_V3
800
600
400
200
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
Transverse Momentum


|dT_proton + dT_muon|
Genie_v3_00_06
Genie_v2_12_10
Neut_5_4_0_1
Nuwro_19_02_1
GiBUU2023
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
0.0
0.2
0.4
0.6
0.8

Reference Genie v3

```
Proton P = 0.426111, Px = -0.0341188, Py = 0.0426671, Pz = 0.422595

Event = 105
DeltaAlpha3Dq = 47.1732, DeltaPn = 0.179285, DeltaPL = 0.121497
DeltaAlphaT = 75.8663, DeltaPT = 0.131839, ECal = 0.416889
Muon P = 0.208861, Px = 0.00643097, Py = -0.202247, Pz = 0.0517469
Proton P = 0.555134, Px = 0.120329, Py = 0.238487, Pz = 0.48664

Event = 112
DeltaAlpha3Dq = 130.617, DeltaPn = 0.401717, DeltaPL = 0.0940951
DeltaAlphaT = 156.419, DeltaPT = 0.390542, ECal = 0.674556
Muon P = 0.582367, Px = -0.118094, Py = 0.272856, Pz = 0.500754
Proton P = 0.315993, Px = 0.119305, Py = 0.117683, Pz = 0.267897

Event = 113
DeltaAlpha3Dq = 149.169, DeltaPn = 0.230367, DeltaPL = -0.223642
DeltaAlphaT = 59.4136, DeltaPT = 0.055254, ECal = 0.885705
Muon P = 0.449322, Px = -0.158015, Py = 0.384471, Pz = -0.170598
Proton P = 0.944741, Px = 0.124707, Py = -0.428557, Pz = 0.83266

Event = 114
DeltaAlpha3Dq = 106.682, DeltaPn = 0.234574, DeltaPL = 0.0316878
DeltaAlphaT = 131.236, DeltaPT = 0.232424, ECal = 1.12438
Muon P = 0.586437, Px = -0.55188, Py = 0.236072, Pz = 0.333008
Proton P = 0.952797, Px = 0.479763, Py = -0.0151191, Pz = 0.823056
```

Reference

```
Event = 329
DeltaAlpha3Dq = 106.159, DeltaPn = 0.331942, DeltaPL = -0.289482
DeltaAlphaT = 51.7426, DeltaPT = 0.162436, ECal = 1.26613
Muon P = 1.01837, Px = -0.513471, Py = -0.171526, Pz = 0.862553
Proton P = 0.664362, Px = 0.649282, Py = 0.0824145, Pz = 0.114092

Event = 335
DeltaAlpha3Dq = 11.1463, DeltaPn = 0.195864, DeltaPL = 0.195753
DeltaAlphaT = 112.444, DeltaPT = 0.00659169, ECal = 0.641062
Muon P = 0.177405, Px = 0.103864, Py = -0.0887705, Pz = -0.113157
Proton P = 0.959411, Px = -0.10591, Py = 0.0825041, Pz = 0.949972

Event = 337
DeltaAlpha3Dq = 148.028, DeltaPn = 0.312926, DeltaPL = -0.238331
DeltaAlphaT = 140.79, DeltaPT = 0.202782, ECal = 0.729805
Muon P = 0.621683, Px = -0.122516, Py = 0.46744, Pz = 0.391126
Proton P = 0.364482, Px = -0.0413227, Py = -0.347951, Pz = 0.100348
```

```
Event = 1756
DeltaAlpha3Dq = 133.5, DeltaPn = 0.398855, DeltaPL = -0.120128
DeltaAlphaT = 130.482, DeltaPT = 0.380335, ECal = 1.25434
Muon P = 1.13662, Px = 0.43188, Py = -0.251371, Pz = 1.02088
Proton P = 0.40054, Px = -0.0729558, Py = 0.377182, Pz = 0.113329

Event = 1757
DeltaAlpha3Dq = 102.59, DeltaPn = 0.0999176, DeltaPL = -0.0770096
DeltaAlphaT = 6.51914, DeltaPT = 0.0636635, ECal = 1.05626
Muon P = 0.655328, Px = -0.0796672, Py = -0.558054, Pz = 0.334191
Proton P = 0.89958, Px = 0.0957618, Py = 0.61965, Pz = 0.645064

Event = 1766
DeltaAlpha3Dq = 68.0124, DeltaPn = 0.256049, DeltaPL = 0.0862736
DeltaAlphaT = 79.4438, DeltaPT = 0.241077, ECal = 0.593682
Muon P = 0.229862, Px = -0.141018, Py = 0.170561, Pz = -0.0621244
Proton P = 0.822998, Px = -0.0134914, Py = -0.355614, Pz = 0.74208
```

Myselection Genie v3

```
Event = 105
Muon  : P = 0.2088607998145122, Px = 0.006430971436202526,Py = -0.20224672555923462, Pz = 0.051746867597103l2
Proton: P = 0.5551335708410 99, Px = 0.120328895747666159,Py = 0.238486722111701 97, Pz = 0.4866398274898529

Event = 113
Muon  : P = 0.44932181015059736, Px = -0.15801450610160828,Py = 0.38447099924087524, Pz = -0.1705976426601 41
Proton: P = 0.944741107628611, Px = 0.124706894159317 02,Py = -0.4285573959350586, Pz = 0.832659900188446

Event = 114
Muon  : P = 0.6864366889408914, Px = -0.5518798232078552,Py = 0.23607198894023895, Pz = 0.3330075144767761
Proton: P = 0.9527973717546698, Px = 0.4797627627849579,Py = -0.015119115822017193, Pz = 0.8230564594268799

Event = 116
Muon  : P = 0.9657318894491657, Px = -0.20479485392570496,Py = 0.4861128628253937, Pz = 0.8089446425437927
Proton: P = 0.5473620706718272, Px = 0.1107766404747963,Py = 0.43743082880973816, Pz = 0.30981937050819397

Event = 122
Muon  : P = 0.6367376288881 22, Px = 0.23178043510322 57,Py = 0.14015077054500 58, Pz = 0.5762540102005005
Proton: P = 0.3979335624239724 3, Px = -0.30166001873016357 4,Py = -0.13849475979804993, Pz = 0.2096097469329834

Event = 124
Muon  : P = 0.6646700661791307, Px = 0.15040336549282074,Py = 0.5798422694206238, Pz = 0.28800705075263977
Proton: P = 0.8018748936117183, Px = 0.08519036322832108,Py = -0.677806556224823, Pz = 0.4199097752571106

Event = 126
```

My file

```
Event = 329
Muon  : P = 0.8940043931915803, Px = -0.4620562195777893,Py = 0.05908254534006119, Pz = 0.7630577683448792
Proton: P = 0.6642839229855309, Px = 0.5115193128585815,Py = -0.16925492882728577, Pz = 0.38855358958244324

Event = 329
Muon  : P = 1.0183673299935883, Px = -0.5134713649749756,Py = -0.17152605950832367, Pz = 0.8625531792640686
Proton: P = 0.6643620257985549, Px = 0.6492824554443359,Py = 0.082414545118808 75, Pz = 0.11409223079681396

Event = 337
Muon  : P = 0.6216833115530426, Px = -0.12251591682434082,Py = 0.4674401283264 16, Pz = 0.39112621545791626
Proton: P = 0.3644822993518 4256, Px = -0.041322726756334305,Py = -0.34795135259628296, Pz = 0.10034757107496262

Event = 339
Muon  : P = 0.2364918026 11899, Px = -0.22539162635803223,Py = -0.07091796398162842, Pz = 0.009880782105028 63
Proton: P = 0.8222184515355833, Px = 0.21563467383384705,Py = 0.0726591944694519, Pz = 0.7901047468185425

Event = 345
Muon  : P = 0.6143341633665195, Px = -0.5360747575759888,Py = 0.22957131266593933, Pz = 0.19320282340049744
Proton: P = 0.3435588996908109. Px = -0.15580973029136658.Pv = 0.29936695098876953. Pz = 0.064307652413845 06
```

```
Proton: P = 0.31924687796355755, Px = 0.23002351820468903,Py = 0.11780394613742828, Pz = 0.18742993474006653

Event = 1756
Muon  : P = 1.1366183059200423, Px = 0.4318796992301941,Py = -0.25137093663215637, Pz = 1.0208789110183716
Proton: P = 0.4005403893829231, Px = -0.07295576483011246,Py = 0.3771823048591614, Pz = 0.11332947015762329

Event = 1757
Muon  : P = 0.6553279942348367, Px = -0.07966717332601547,Py = -0.5580542087554932, Pz = 0.334190696477 89
Proton: P = 0.8995797031503944, Px = 0.09576179832220078,Py = 0.6196497082710266, Pz = 0.6450639963150024

Event = 1759
Muon  : P = 0.489481817788787 47, Px = -0.2116502821445465,Py = -0.3392716050148 01, Pz = 0.28229662775993347
Proton: P = 0.5388056426247686, Px = -0.17286576330661774,Py = -0.17503757774829865, Pz = 0.4793649911880493

Event = 1766
Muon  : P = 0.2298624629094 1023, Px = -0.14101849496364594,Py = 0.17056113481521606, Pz = -0.062124352902173996
Proton: P = 0.8229980377537005, Px = -0.013491370715200901,Py = -0.3556143939495086 7, Pz = 0.74207961559295 65
```

Reasons

Reference Genie v3

```
Proton P = 0.426111, Px = -0.0341188, Py = 0.0426671, Pz = 0.422595

Event = 105
DeltaAlpha3Dq = 47.1732, DeltaPn = 0.179285, DeltaPL = 0.121497
DeltaAlphaT = 75.8663, DeltaPT = 0.131839, ECal = 0.416889
Muon P = 0.208861, Px = 0.00643097, Py = -0.202247, Pz = 0.0517469
Proton P = 0.555134, Px = 0.120329, Py = 0.238487, Pz = 0.48664

Event = 112
DeltaAlpha3Dq = 130.617, DeltaPn = 0.401717, DeltaPL = 0.0940951
DeltaAlphaT = 156.419, DeltaPT = 0.390542, ECal = 0.674556
Muon P = 0.582367, Px = -0.118094, Py = 0.272856, Pz = 0.500754
Proton P = 0.315993, Px = 0.119305, Py = 0.117683, Pz = 0.267897

Event = 113
DeltaAlpha3Dq = 149.169, DeltaPn = 0.230367, DeltaPL = -0.223642
DeltaAlphaT = 59.4136, DeltaPT = 0.055254, ECal = 0.885705
Muon P = 0.449322, Px = -0.158015, Py = 0.384471, Pz = -0.170598
Proton P = 0.944741, Px = 0.124707, Py = -0.428557, Pz = 0.83266

Event = 114
DeltaAlpha3Dq = 106.682, DeltaPn = 0.234574, DeltaPL = 0.0316878
DeltaAlphaT = 131.236, DeltaPT = 0.232424, ECal = 1.12438
Muon P = 0.686437, Px = -0.55188, Py = 0.236072, Pz = 0.333008
Proton P = 0.952797, Px = 0.479763, Py = -0.0151191, Pz = 0.823056
```

Reference

```
Event = 329
DeltaAlpha3Dq = 106.159, DeltaPn = 0.331942, DeltaPL = -0.289482
DeltaAlphaT = 51.7426, DeltaPT = 0.162436, ECal = 1.26613
Muon P = 1.01837, Px = -0.513471, Py = -0.171526, Pz = 0.862553
Proton P = 0.664362, Px = 0.649282, Py = 0.0824145, Pz = 0.114092

Event = 335
DeltaAlpha3Dq = 11.1463, DeltaPn = 0.195864, DeltaPL = 0.195753
DeltaAlphaT = 112.444, DeltaPT = 0.00659169, ECal = 0.641062
Muon P = 0.177405, Px = 0.103864, Py = -0.0887705, Pz = -0.113157
Proton P = 0.959411, Px = -0.10591, Py = 0.0825041, Pz = 0.949972

Event = 337
DeltaAlpha3Dq = 148.028, DeltaPn = 0.312926, DeltaPL = -0.238331
DeltaAlphaT = 140.79, DeltaPT = 0.202782, ECal = 0.729805
Muon P = 0.621683, Px = -0.122516, Py = 0.46744, Pz = 0.391126
Proton P = 0.364482, Px = -0.0413227, Py = -0.347951, Pz = 0.100348
```

```
Event = 1756
DeltaAlpha3Dq = 133.5, DeltaPn = 0.398855, DeltaPL = -0.120128
DeltaAlphaT = 130.482, DeltaPT = 0.380335, ECal = 1.25434
Muon P = 1.13662, Px = 0.43188, Py = -0.251371, Pz = 1.02088
Proton P = 0.40054, Px = -0.0729558, Py = 0.377182, Pz = 0.113329

Event = 1757
DeltaAlpha3Dq = 102.59, DeltaPn = 0.0999176, DeltaPL = -0.0770096
DeltaAlphaT = 6.51914, DeltaPT = 0.0636635, ECal = 1.05626
Muon P = 0.655328, Px = -0.0796672, Py = -0.558054, Pz = 0.334191
Proton P = 0.89958, Px = 0.0957618, Py = 0.61965, Pz = 0.645064

Event = 1766
DeltaAlpha3Dq = 68.0124, DeltaPn = 0.256049, DeltaPL = 0.0862736
DeltaAlphaT = 79.4438, DeltaPT = 0.241077, ECal = 0.593682
Muon P = 0.229862, Px = -0.141018, Py = 0.170561, Pz = -0.0621244
Proton P = 0.822998, Px = -0.0134914, Py = -0.355614, Pz = 0.74208
```

Myselection Genie v3

```
Event = 105
Muon  : P = 0.2088607998145122, Px = 0.006430971436202526,Py = -0.20224672555923462, Pz = 0.051746867597103l2
Proton: P = 0.5551335708410 99, Px = 0.120328895747666159,Py = 0.238486722111701 97, Pz = 0.4866398274898529

Event = 113
Muon  : P = 0.44932181015059736, Px = -0.15801450601606828,Py = 0.38447099924087
Proton: P = 0.944741107628611, Px = 0.124706894159317 02,Py = -0.42855739593505 86

Event = 114
Muon  : P = 0.6864366889408914, Px = -0.5518798232078552,Py = 0.23607198894023 89
Proton: P = 0.9527973717546698, Px = 0.4797627627849579,Py = -0.01511911582201 71

Event = 116
Muon  : P = 0.9657318894491657, Px = -0.20479485392570496,Py = 0.48611286282539 3
Proton: P = 0.5473620706718272, Px = 0.1107766404747963,Py = 0.43743082880973 81

Event = 122
Muon  : P = 0.6367376288888122, Px = 0.23178433032257,Py = 0.14815907705450658, Pz = 0.5762540102005005
Proton: P = 0.3979335624239724 3, Px = 0.30660018730163574,Py = -0.13849475979804993, Pz = 0.2096097469329834

Event = 124
Muon  : P = 0.6646700611791307, Px = 0.15040336549282074,Py = 0.5798422694206238, Pz = 0.28800705075263977
Proton: P = 0.8018748936117183, Px = 0.08519036322832108,Py = -0.6778065562248 23, Pz = 0.4199097752571106

Event = 126
```

```
Event = 329
Muon  : P = 0.8940043931915803, Px = -0.4620562195777893,Py = 0.05908254534
Proton: P = 0.6642839229855309, Px = 0.5115193128585815,Py = -0.16925492881

Event = 329
Muon  : P = 1.0183673299935883, Px = -0.5134713649749756,Py = -0.17152605 9
Proton: P = 0.6643620257985549, Px = 0.6492824554443359,Py = 0.08241454511

Event = 337
Muon  : P = 0.6216833115530426, Px = -0.12251591682434082,Py = 0.46744012 8
Proton: P = 0.3644822993518425 6, Px = -0.041322726756334305,Py = -0.347951

Event = 339
Muon  : P = 0.2364918026111899, Px = -0.22539162635803223,Py = -0.07091796398162842, Pz = 0.009880782105028 63
Proton: P = 0.8222184515355833, Px = 0.21563467383384705,Py = 0.0726591944694519, Pz = 0.7901047468185425

Event = 345
Muon  : P = 0.6143341633665195, Px = -0.5360747575759888,Py = 0.22957131266593933, Pz = 0.19320282340049744
Proton: P = 0.3435588996908109. Px = -0.15580973029136658.Pv = 0.29936695098876953. Pz = 0.064307652413845 06
```

```
Event = 1756
Muon  : P = 1.1366183059200423, Px = 0.4318796992301941,Py = -0.25137093663215637, Pz = 1.0208789110183716
Proton: P = 0.4005403893829231, Px = -0.07295576483011246,Py = 0.3771823048591614, Pz = 0.11332947015762329

Event = 1757
Muon  : P = 0.6553279942348367, Px = -0.07966717332601547,Py = -0.5580542087554932, Pz = 0.334190696477 89
Proton: P = 0.8995797031503944, Px = 0.09576179832220078,Py = 0.6196497082710266, Pz = 0.6450639963150024

Event = 1759
Muon  : P = 0.48948181778878747, Px = -0.2116502821445465,Py = -0.3392716050148 01, Pz = 0.28229662775993347
Proton: P = 0.5388056426247686, Px = -0.17286576330661774,Py = -0.17503757774829865, Pz = 0.47936499118804 93

Event = 1766
Muon  : P = 0.2298624629094023, Px = -0.14101849496364594,Py = 0.17056113481521606, Pz = -0.062124352902173996
Proton: P = 0.8229980377537005, Px = -0.013491370715200901,Py = -0.35561439394950867, Pz = 0.74207961559295665
```

Reasons

```
Total selected protons :  1
PDG:  [  13 2212 2212 2212 2112 2112 2212 2212 2212 2212 2112 2112 2212 2212 2212
 2112 2112 2212 2212 2212 2112 2112 2112 2212 2212 2112 2112  111]
>>> Muon Selection:  True Momentum:  0.5823672698921473
>>> Prot Selection:  True Momentum:  0.31599346054927197
>>> Pi - Selection:  True
>>> pi + Selection:  True
>>> Extr Selection:  False
----------------------------------------,  113  ,----------------------------------------
Muon momentum:  0.44932181015059736
```

```
 2112 2112 2112 2112  111]
not satisfied skiipping to next ,  27
Total selected protons :  0
No proton selection passed:
PDG:  [  13 2212 2212 2212 2112 2112 2112 2112 2212 2212 2212 2212 2112 2112 2112
 2212 2212 2212 2212 2112 2112 2112 2212 2212 2212 2112 2112 2212 2212
 2112 2112 2112 2112  111]
>>> Muon Selection:  True Momentum:  0.1774051652406625
>>> Prot Selection:  False Momentum:  0
>>> Pi - Selection:  True
>>> pi + Selection:  True
>>> Extr Selection:  False
```

```
----------------------------------------,  1759  ,----------------------------------------
Muon momentum:  0.48948181778878747
Momentum check:  0.04216107135569617  Position of proton in code :  1
Px:  -0.0010186335  Py:  0.011402185  Pz:  -0.04057719
Momentum check:  0.05249461614795788  Position of proton in code :  2
Px:  -0.0248414  Py:  0.04173545  Pz:  0.019918375
Momentum check:  0.07776680805234924  Position of proton in code :  3
Px:  0.013956916  Py:  -0.07626442  Pz:  0.0060513956
Momentum check:  0.040362163738126934  Position of proton in code :  8
Px:  0.0080521277  Py:  -0.0187846668  Pz:  -0.034848273
Momentum check:  0.09686912593116961  Position of proton in code :  9
Px:  -0.06041887  Py:  0.07467781  Pz:  -0.012506492
Momentum check:  0.06149906073963245  Position of proton in code :  10
Px:  0.0056567225  Py:  0.04190615  Pz:  0.044654347
Momentum check:  0.09921758896543  Position of proton in code :  15
Px:  0.08360555  Py:  -0.038084235  Pz:  0.03746776
Momentum check:  0.06706373034418242  Position of proton in code :  16
Px:  -0.089912926  Py:  0.066245794  Pz:  0.003282159
Momentum check:  0.08382540927682023  Position of proton in code :  17
Px:  -0.08105518  Py:  -0.006565585  Pz:  -0.016738664
Momentum check:  0.04881254750366968  Position of proton in code :  22
Px:  -0.026420722  Py:  -0.03364267  Pz:  0.023511354
Momentum check:  0.05038083235872804  Position of proton in code :  23
Px:  0.019509688  Py:  0.029678812  Pz:  0.035731897
Momentum check:  0.08808124636803395  Position of proton in code :  24
Px:  -0.031164404  Py:  0.07443507  Pz:  0.035305895
Momentum check:  0.05482265386476414  Position of proton in code :  28
Px:  0.0024876986  Py:  -0.008099625  Pz:  0.054163925
Momentum check:  0.04925158023528943  Position of proton in code :  29
Px:  -0.023774667  Py:  -0.040744208  Pz:  0.01415602
Momentum check:  0.11758423330218044  Position of proton in code :  30
Px:  0.001768643  Py:  0.027755205  Pz:  -0.11424795
Momentum check:  0.5388056426247686  Position of proton in code :  34
Px:  -0.17286576  Py:  -0.17503758  Pz:  0.479365
Total selected protons :  1
PDG:  [  13 2212 2212 2212 2112 2112 2212 2212 2212 2212 2112 2112 2112
 2112 2212 2212 2212 2212 2112 2112 2212 2212 2212 2112 2112 2112 2212
 2212 2212 2212 2112 2112 2212]
>>> Muon Selection:  True Momentum:  0.48948181778878747
>>> Prot Selection:  True Momentum:  0.5388056426247686
>>> Pi - Selection:  True
>>> pi + Selection:  True
>>> Extr Selection:  True
--->>>>> PASS
Proton_Index ==> Proton at:  34  & Muon at:  0
Total Momentum ==> Proton:  0.5388056426247686  & Muon:  0.48948181778878747
```

Reference Genie v3

```
Proton P = 0.426111, Px = -0.0341188, Py = 0.0426671, Pz = 0.422595

Event = 105
DeltaAlpha3Dq = 47.1732, DeltaPn = 0.179285, DeltaPL = 0.121497
DeltaAlphaT = 75.8663, DeltaPT = 0.131839, ECal = 0.416889
Muon P = 0.208861, Px = 0.00643097, Py = -0.202247, Pz = 0.0517469
Proton P = 0.555134, Px = 0.120329, Py = 0.238487, Pz = 0.48664

Event = 112
DeltaAlpha3Dq = 130.617, DeltaPn = 0.401717, DeltaPL = 0.0940951
DeltaAlphaT = 156.419, DeltaPT = 0.390542, ECal = 0.674556
Muon P = 0.582367, Px = -0.118094, Py = 0.272856, Pz = 0.500754
Proton P = 0.315993, Px = 0.119305, Py = 0.117683, Pz = 0.267897

Event = 113
DeltaAlpha3Dq = 149.169, DeltaPn = 0.230367, DeltaPL = -0.223642
DeltaAlphaT = 59.4136, DeltaPT = 0.055254, ECal = 0.885705
Muon P = 0.449322, Px = -0.158015, Py = 0.384471, Pz = -0.170598
Proton P = 0.944741, Px = 0.124707, Py = -0.428557, Pz = 0.83266

Event = 114
DeltaAlpha3Dq = 106.682, DeltaPn = 0.234574, DeltaPL = 0.0316878
DeltaAlphaT = 131.236, DeltaPT = 0.232424, ECal = 1.12438
Muon P = 0.686437, Px = -0.55188, Py = 0.236072, Pz = 0.333008
Proton P = 0.952797, Px = 0.479763, Py = -0.0151191, Pz = 0.823056
```

Reference

```
Event = 329
DeltaAlpha3Dq = 106.159, DeltaPn = 0.331942, DeltaPL = -0.28948
DeltaAlphaT = 51.7426, DeltaPT = 0.162436, ECal = 1.26613
Muon P = 1.01837, Px = -0.513471, Py = -0.171526, Pz = 0.862553
Proton P = 0.664362, Px = 0.649282, Py = 0.0824145, Pz = 0.114092

Event = 335
DeltaAlpha3Dq = 11.1463, DeltaPn = 0.195864, DeltaPL = 0.195753
DeltaAlphaT = 112.444, DeltaPT = 0.00659169, ECal = 0.641062
Muon P = 0.177405, Px = 0.103864, Py = -0.0887705, Pz = -0.113157
Proton P = 0.959411, Px = -0.10591, Py = 0.0825041, Pz = 0.949972

Event = 337
DeltaAlpha3Dq = 148.028, DeltaPn = 0.312926, DeltaPL = -0.238331
DeltaAlphaT = 140.79, DeltaPT = 0.202782, ECal = 0.729805
Muon P = 0.621683, Px = -0.122516, Py = 0.46744, Pz = 0.391126
Proton P = 0.364482, Px = -0.0413227, Py = -0.347951, Pz = 0.100348
```

```
Event = 1756
DeltaAlpha3Dq = 133.5, DeltaPn = 0.398855, DeltaPL = -0.120128
DeltaAlphaT = 130.482, DeltaPT = 0.380335, ECal = 1.25434
Muon P = 1.13662, Px = 0.43188, Py = -0.251371, Pz = 1.02088
Proton P = 0.40054, Px = -0.0729558, Py = 0.377182, Pz = 0.113329

Event = 1757
DeltaAlpha3Dq = 102.59, DeltaPn = 0.0999176, DeltaPL = -0.0770096
DeltaAlphaT = 6.51914, DeltaPT = 0.0636635, ECal = 1.05626
Muon P = 0.655328, Px = -0.0796672, Py = -0.558054, Pz = 0.334191
Proton P = 0.89958, Px = 0.0957618, Py = 0.61965, Pz = 0.645064

Event = 1766
DeltaAlpha3Dq = 68.0124, DeltaPn = 0.256049, DeltaPL = 0.0862736
DeltaAlphaT = 79.4438, DeltaPT = 0.241077, ECal = 0.593682
Muon P = 0.229862, Px = -0.141018, Py = 0.170561, Pz = -0.0621244
Proton P = 0.822998, Px = -0.0134914, Py = -0.355614, Pz = 0.74208
```

Myselection Genie v3

```
Event = 105
Muon  : P = 0.2088607998145122, Px = 0.006430971436202526,Py = -0.20224672555923462, Pz = 0.051746867597103l2
Proton: P = 0.5551335708410 99, Px = 0.120328895747666159,Py = 0.238486722111701 97, Pz = 0.4866398274898529

Event = 113
Muon  : P = 0.44932181015059736, Px = -0.15801450601606828,Py = 0.38447099924087
Proton: P = 0.944741107628611, Px = 0.12470689415931702,Py = -0.4285573959350586

Event = 114
Muon  : P = 0.6864366889408914, Px = -0.5518798232078552,Py = 0.2360719889402389
Proton: P = 0.9527973717546698, Px = 0.4797627627849579,Py = -0.0151191158220171

Event = 116
Muon  : P = 0.9657318894491657, Px = -0.20479485392570496,Py = 0.4861128628253957
Proton: P = 0.5473620706718272, Px = 0.1107766404747963,Py = 0.4374308288097387

Event = 122
Muon  : P = 0.6367376288888122, Px = 0.23178443532257,Py = 0.1481507705450658, Pz = 0.5762540102005005
Proton: P = 0.3979335624239724 3, Px = 0.30660018730163574,Py = -0.13849475979804993, Pz = 0.2096097469329834

Event = 124
Muon  : P = 0.6646700617913 07, Px = 0.15040336549282074,Py = 0.5798422694206238, Pz = 0.28800705075263977
Proton: P = 0.8018748936117183, Px = 0.08519036322832108,Py = -0.6778065562248 23, Pz = 0.4199097752571106

Event = 126

Event = 329
Muon  : P = 1.0183673299935883, Px = -0.5134713649749756,Py = -0.1715260595
Proton: P = 0.6643620257985549, Px = 0.6492824554443359,Py = 0.0824145451119

Event = 337
Muon  : P = 0.6216833115530426, Px = -0.12251591682434082,Py = 0.4674401283
Proton: P = 0.3644822993518425 6, Px = -0.04132272675633430 5,Py = -0.3479511

Event = 339
Muon  : P = 0.2364918026111899, Px = -0.22539162635803223,Py = -0.07091796398162842, Pz = 0.009880782105028 63
Proton: P = 0.8222184515355833, Px = 0.21563467383384705,Py = 0.0726591944694519, Pz = 0.7901047468185425

Event = 345
Muon  : P = 0.6143341633665195, Px = -0.5360747575759888,Py = 0.22957131266593933, Pz = 0.19320282340049744
Proton: P = 0.3435588996908109. Px = -0.15580973029136658.Pv = 0.29936695098876953. Pz = 0.064307652413845 06

Event = 1756
Muon  : P = 1.1366183059200423, Px = 0.4318796992301941,Py = -0.25137093663215637, Pz = 1.0208789110183716
Proton: P = 0.4005403893829231, Px = -0.07295576483011246,Py = 0.3771823048591614, Pz = 0.11332947015762329

Event = 1757
Muon  : P = 0.6553279942348367, Px = -0.07966717332601547,Py = -0.5580542087554932, Pz = 0.334190696477 89
Proton: P = 0.8995797031503944, Px = 0.09576179832220078,Py = 0.6196497082710266, Pz = 0.6450639963150024

Event = 1759
Muon  : P = 0.48948181778878747, Px = -0.2116502821445465,Py = -0.3392716050148 01, Pz = 0.28229662775993347
Proton: P = 0.5388056426247686, Px = -0.17286576330661774,Py = -0.17503757774829865, Pz = 0.4793649911880493

Event = 1766
Muon  : P = 0.22986246290941023, Px = -0.14101849496364594,Py = 0.17056113481521606, Pz = -0.06212435290217399 6
Proton: P = 0.8229980377537005, Px = -0.013491370715200901,Py = -0.35561439394950867, Pz = 0.74207961559295665
```

Reasons

```
Total selected protons :  1
PDG:  [  13 2212 2212 2212 2112 2112 2212 2212 2212 2212 2112 2112 2212 2212 2212
 2112 2112 2212 2212 2212 2112 2112 2112 2212 2212 2212 2112 2112  111]
>>> Muon Selection:  True Momentum:  0.5823672698921473
>>> Prot Selection:  True Momentum:  0.31599346054927197
>>> Pi - Selection:  True
>>> pi + Selection:  True
>>> Extr Selection:  False
----------------------------------------,  113  ,----------------------------------------
Muon momentum:  0.44932181015059736
```

```
 2112 2112 2112 2112  111]
not satisfied skiipping to next ,  27
Total selected protons :  0
PDG:  [  13 2212 2212 2212 2112 2112 2112 2112 2212 2212 2212 2212 2112 2112 2112
 2212 2212 2212 2212 2112 2112 2212 2212 2212 2112 2112 2212 2212 2212
 2112 2112 2112 2112  111]
>>> Muon Selection:  True Momentum:  0.1774051652406625
>>> Prot Selection:  False Momentum:  0
>>> Pi - Selection:  True
>>> pi + Selection:  True
>>> Extr Selection:  False
```

```
----------------------------------------,  1759  ,----------------------------------------
Muon momentum:  0.48948181778878747
Momentum check:  0.04216107135569617  Position of proton in code :  1
Px:  -0.0010186335  Py:  0.011402185  Pz:  -0.04057719
Momentum check:  0.05249461614795788  Position of proton in code :  2
Px:  -0.0248414  Py:  0.04173545  Pz:  0.019918375
Momentum check:  0.07776680805234924  Position of proton in code :  3
Px:  0.013956916  Py:  -0.07626442  Pz:  0.0060513956
Momentum check:  0.040362163738126934  Position of proton in code :  8
Px:  0.0080521277  Py:  -0.0187846668  Pz:  -0.034848273
Momentum check:  0.09686912593116961  Position of proton in code :  9
Px:  -0.06041887  Py:  0.07467781  Pz:  -0.012506492
Momentum check:  0.06149906073963245  Position of proton in code :  10
Px:  0.0056567225  Py:  0.04190615  Pz:  0.044654347
Momentum check:  0.09921758896543848  Position of proton in code :  15
Px:  0.08360555  Py:  -0.038084235  Pz:  0.03746776
Momentum check:  0.06706373034418242  Position of proton in code :  16
Px:  -0.089912926  Py:  0.066245794  Pz:  0.003282159
Momentum check:  0.08382540927682023  Position of proton in code :  17
Px:  -0.08105518  Py:  -0.006565585  Pz:  -0.016738664
Momentum check:  0.04881254750366968  Position of proton in code :  22
Px:  -0.026420722  Py:  -0.03364267  Pz:  0.023511354
Momentum check:  0.05038083235872804  Position of proton in code :  23
Px:  0.019509688  Py:  0.029678812  Pz:  0.035731897
Momentum check:  0.08808124636800395  Position of proton in code :  24
Px:  -0.031164404  Py:  0.07443507  Pz:  0.035305895
Momentum check:  0.05482265386476414  Position of proton in code :  28
Px:  0.0024876986  Py:  -0.008099625  Pz:  0.054163925
Momentum check:  0.04925158023528943  Position of proton in code :  29
Px:  -0.023774667  Py:  -0.040744208  Pz:  0.01415602
Momentum check:  0.11758423330218044  Position of proton in code :  30
Px:  0.001768643  Py:  0.027755205  Pz:  -0.11424795
Momentum check:  0.5388056426247686  Position of proton in code :  34
Px:  -0.17286576  Py:  -0.17503758  Pz:  0.479365
Total selected protons :  1
PDG:  [  13 2212 2212 2212 2112 2112 2212 2212 2212 2212 2112 2112 2112
 2212 2212 2212 2212 2112 2112 2212 2212 2212 2212 2212 2112 2112 2212]
>>> Muon Selection:  True Momentum:  0.48948181778878747
>>> Prot Selection:  True Momentum:  0.5388056426247686
>>> Pi - Selection:  True
>>> pi + Selection:  True
>>> Extr Selection:  True
--->>>>> PASS
Proton_Index ==> Proton at:  34  & Muon at:  0
Total Momentum ==> Proton:  0.5388056426247686  & Muon:  0.48948181778878747
```

More than 5500 such discrepances