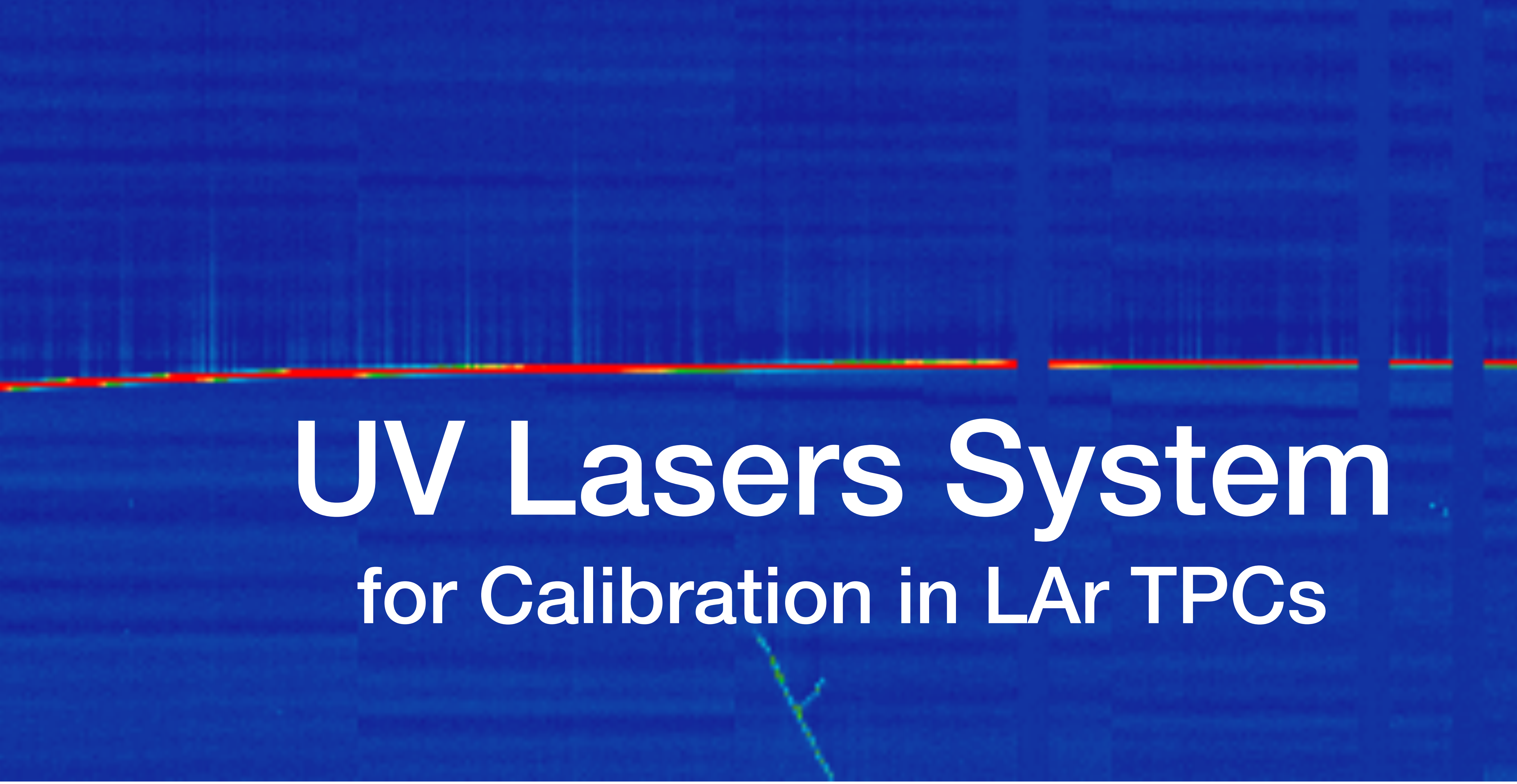

UV Lasers System

for Calibration in LAr TPCs

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University of Bern

Workshop on Calibration and Reconstruction for LArTPC Detectors
December, 2018

LABORATORIUM FÜR HOCHENERGIEPHYSIK LHEP UNIVERSITÄT BERN

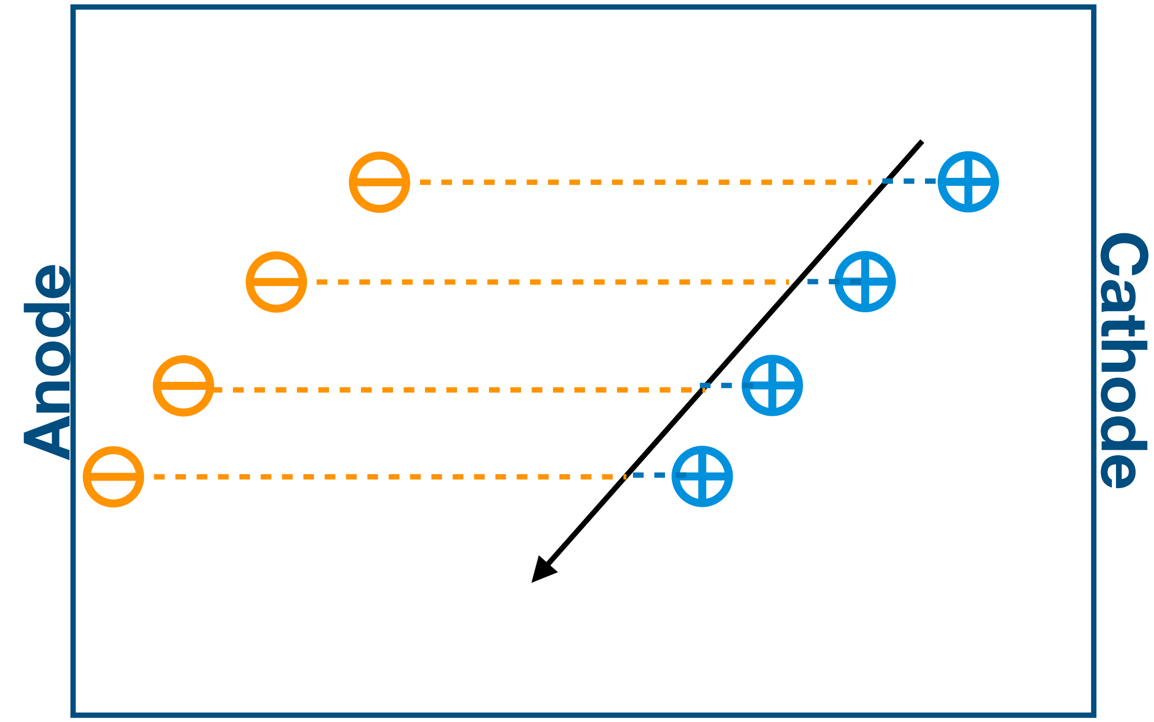
UNIVERSITÄT BERN

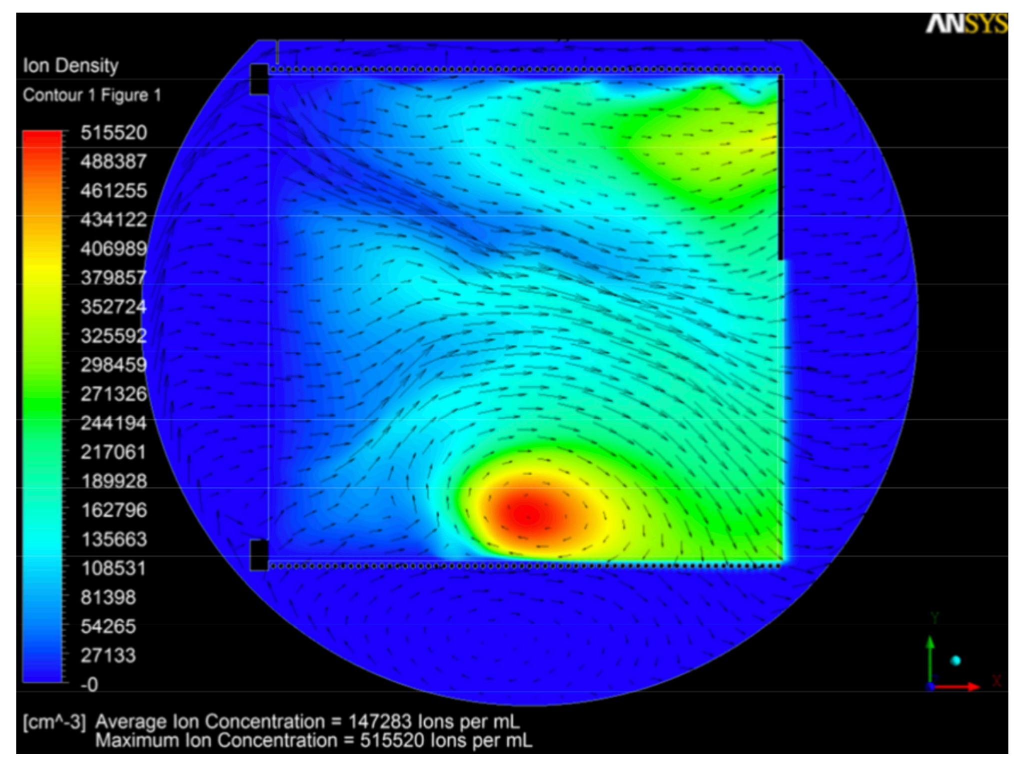
AEC ALBERT EINSTEIN CENTER FOR FUNDAMENTAL PHYSICS

LAr TPCs and nominal E-field

- **Space Charge Effect**
  - **Argon ions drift ~10^5 times slower than electrons**
  - **LAr convection moves the ions**
  - **Cosmic rays, radioactive sources and other constant high rate ionisation**
- **Detector Design**

E-field affects:
- **Spatial coordinates**
- **Drift velocity**
- **Charge recombination**
- **Charge diffusion**
- **Light Production**





Acciarri, R., et al. "Design and construction of the MicroBooNE detector." *Journal of instrumentation* 12.02 (2017): P02017.

UV Laser: Solution to E-field and more

A compact solution
to improve spatial resolution and energy response in LAr TPCs

1. **Measure E-field**
2. **Measure drift velocity**
3. **Measure spatial distortion**
4. **Calibrate charge recombination and light production**
5. **Measure electron lifetime**
6. **Examine readout response**

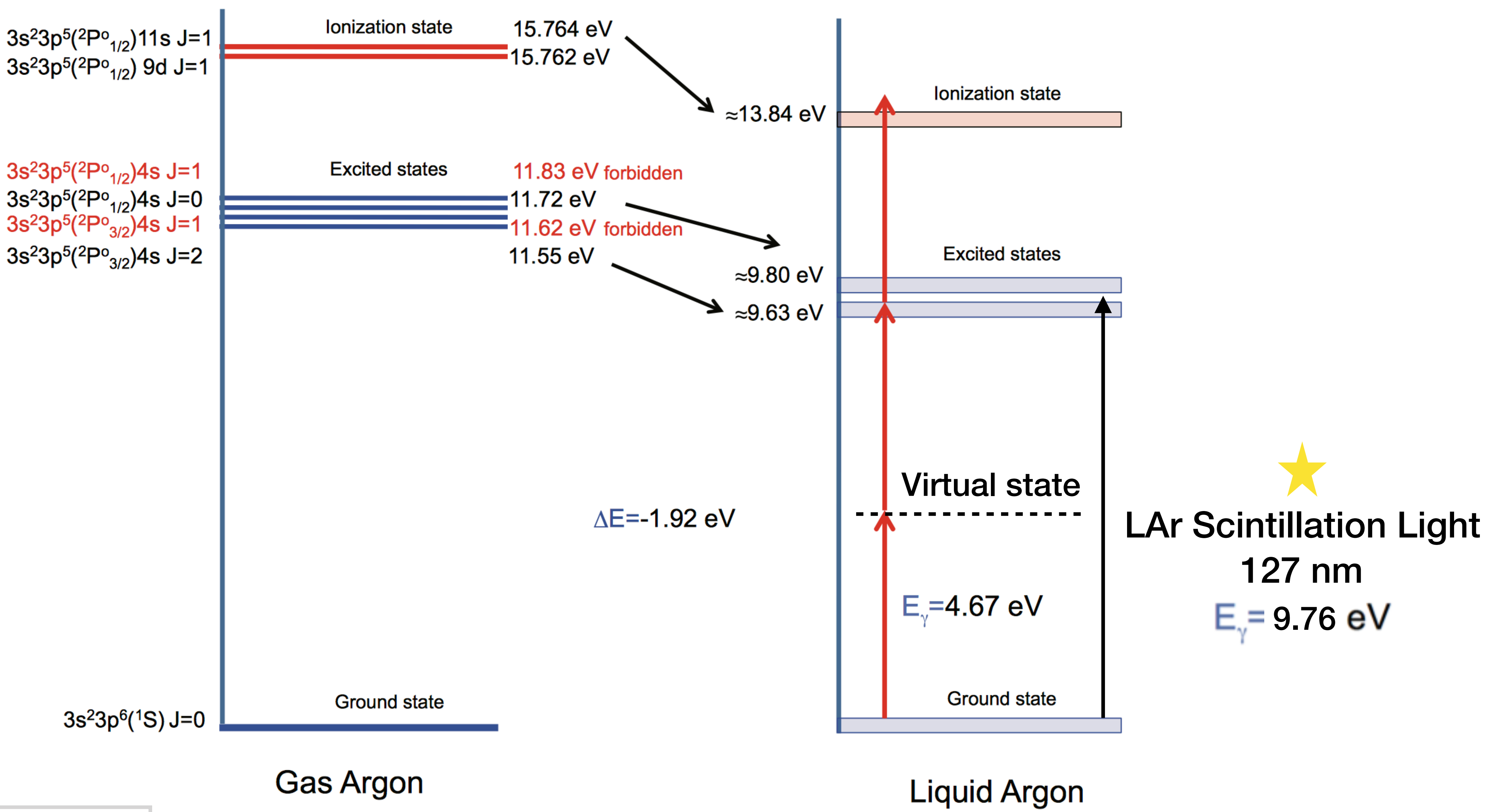
UV Laser can produce
reproducible
straight beam
with no delta rays
with no Multiple Coulomb Scattering
in LAr TPC

How does UV laser generate tracks in LAr?

Multiphoton ionisation: strong intensity dependence

Resonance-enhanced multiphoton ionisation (2 + 1)

266nm UV laser in 60mJ pulse have ~8E16 photons



I Badhrees et al 2010 New J. Phys. **12** 113024

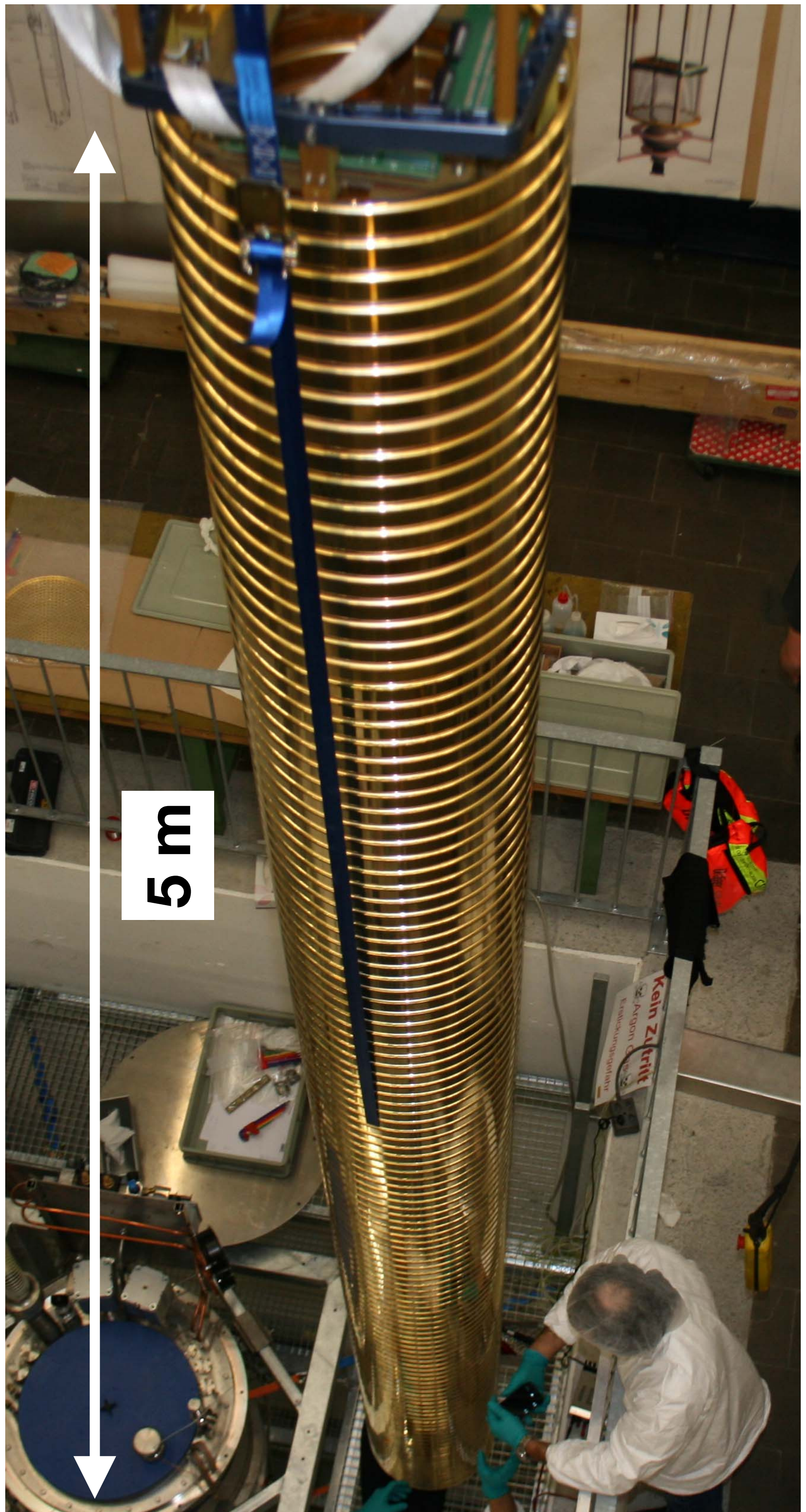
Choice of Primary Laser

Continuum Surelite I-10

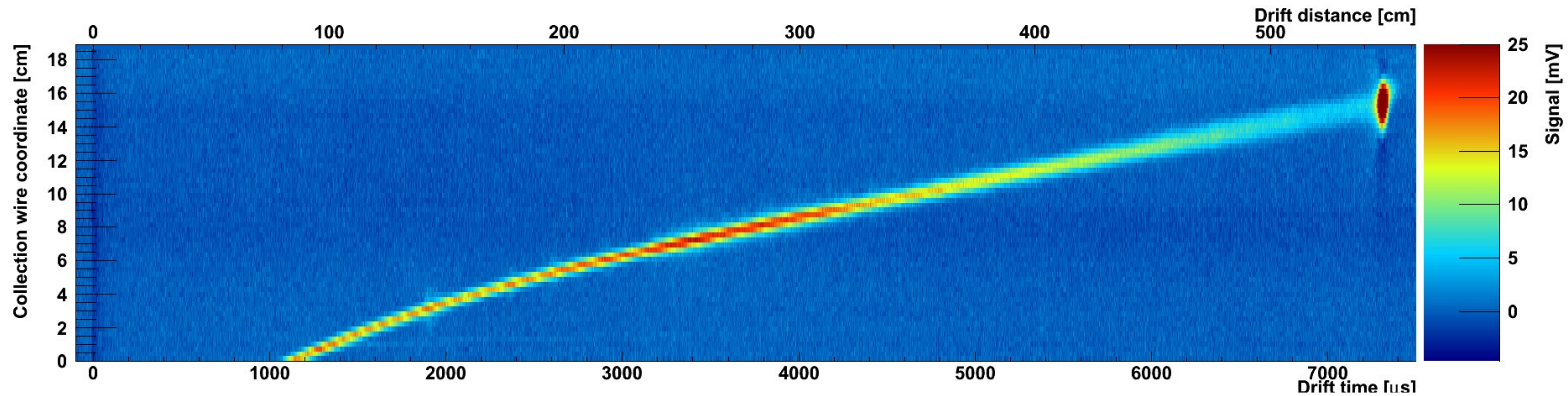
ARGONTUBE
MicroBooNE
SBND

Beam Characters	
Wavelength	266 nm (dominate), 532 nm, 1064 nm
Repetition Rate	Up to 10Hz
Energy (266nm)	60 mJ (adjustable by attenuator and aperture)
Pulsewidth	4-6ns
Beam Diameter	5 mm (adjustable by aperture)
Beam Divergence	0.5 mrad

ARGONTUBE: reproducible, long Laser Tracks

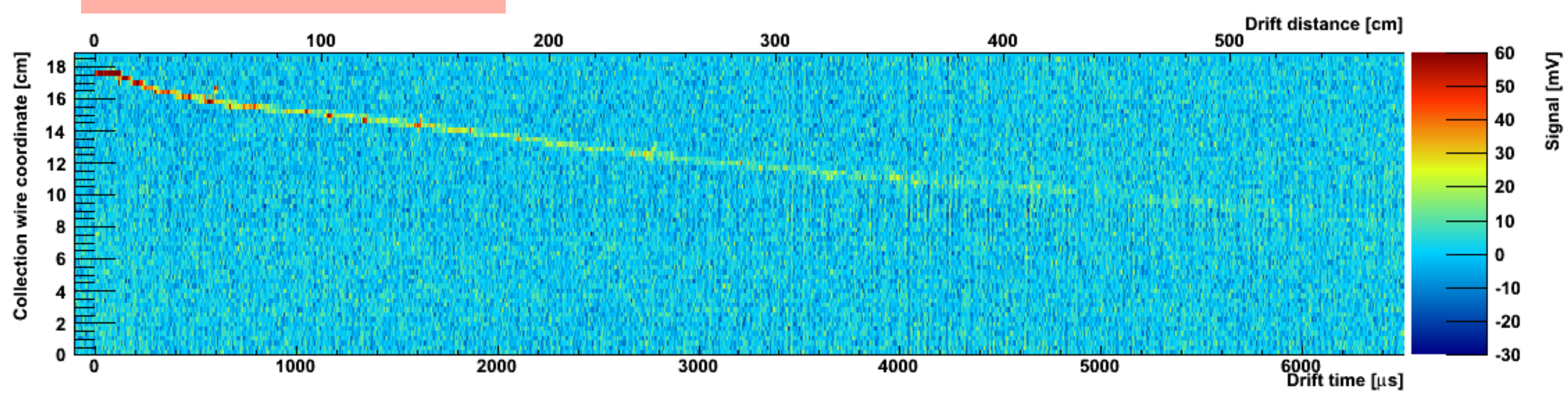


100 UV laser pulse (average)



- Reproducible
- Can generate long tracks (~ 5 m)

1 cosmic muon



- Delta rays
- Multiple Coulomb Scattering

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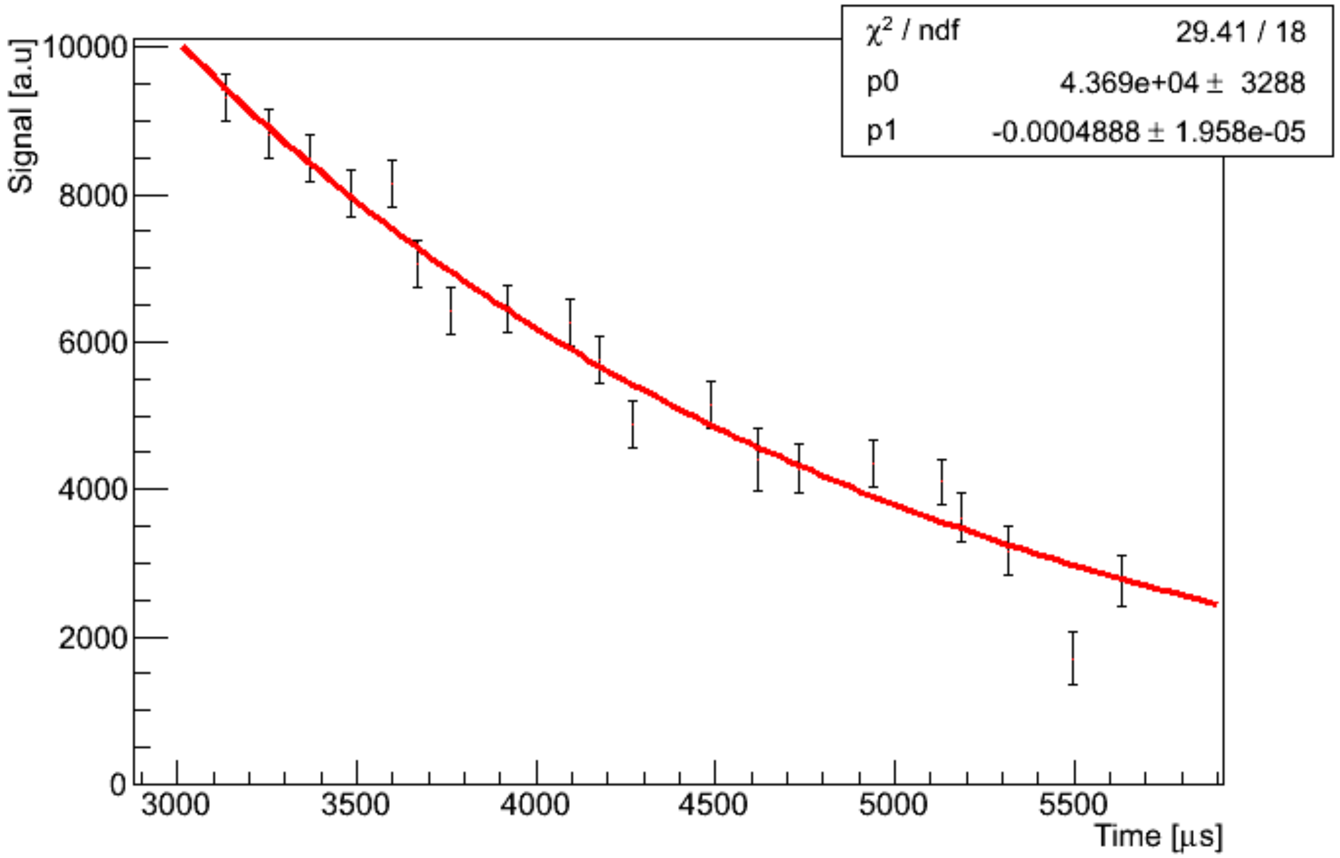
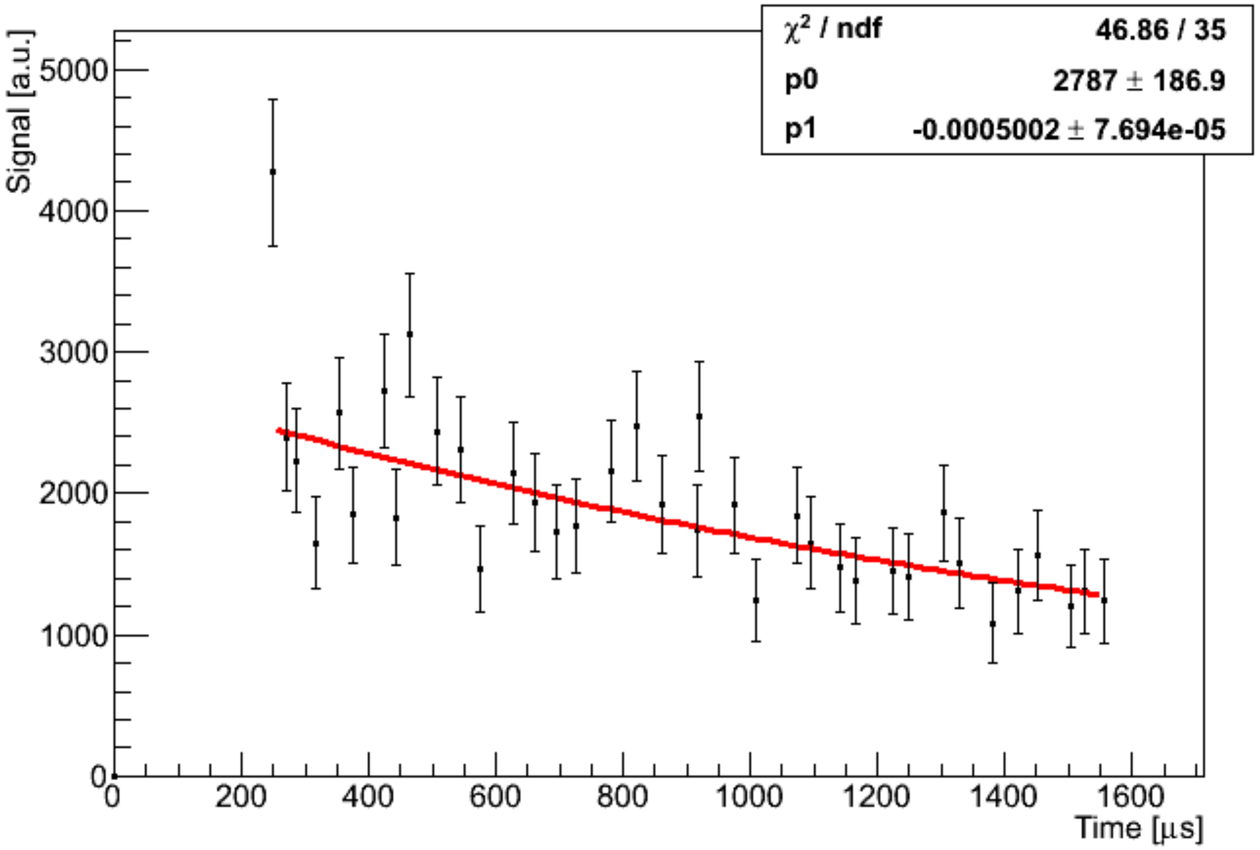
ARGONTUBE: Electron Lifetime Measurement

Laser



τ = 2.05±0.08 ms

Cosmic



τ = 2.00±0.31 ms

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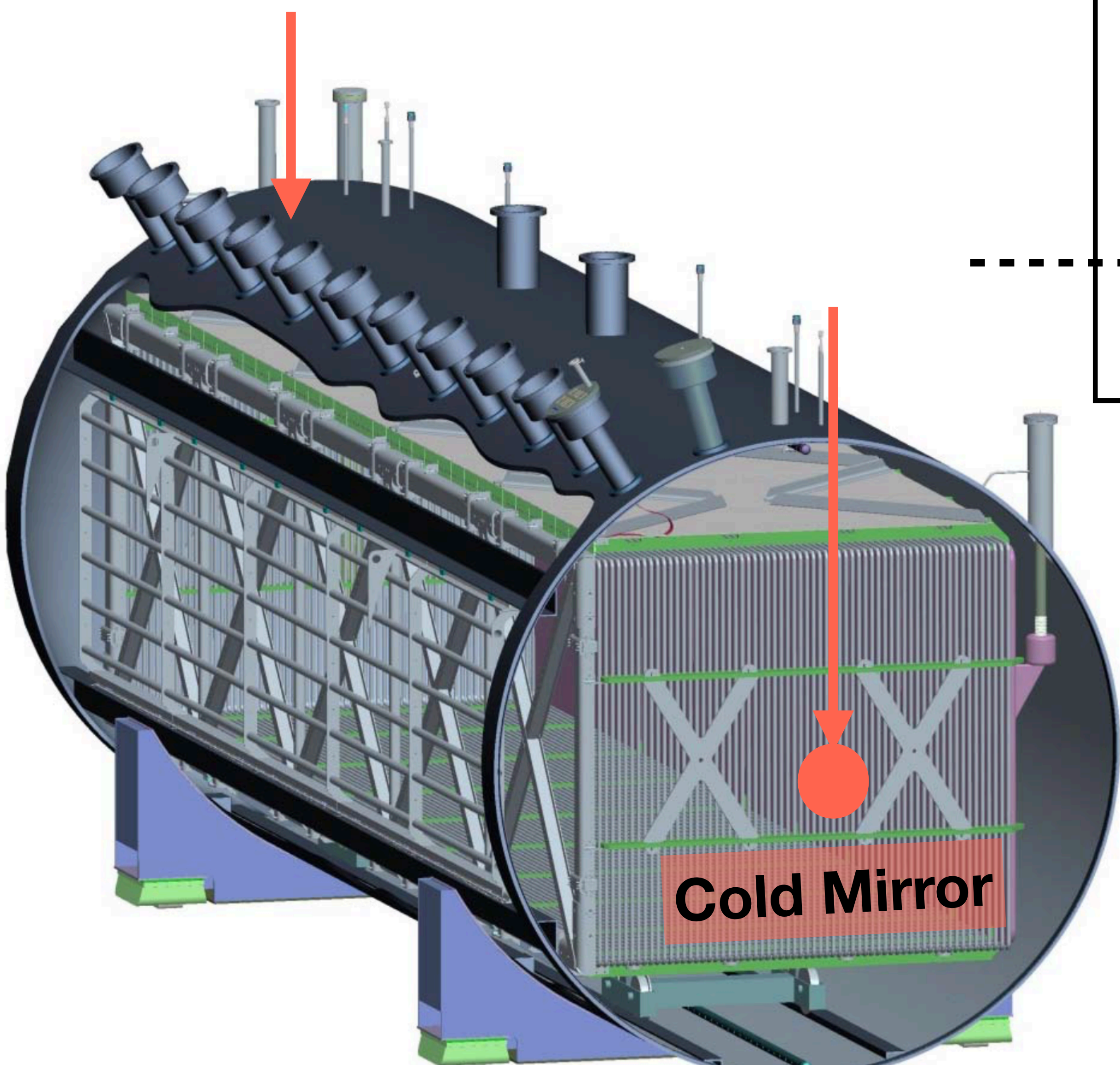
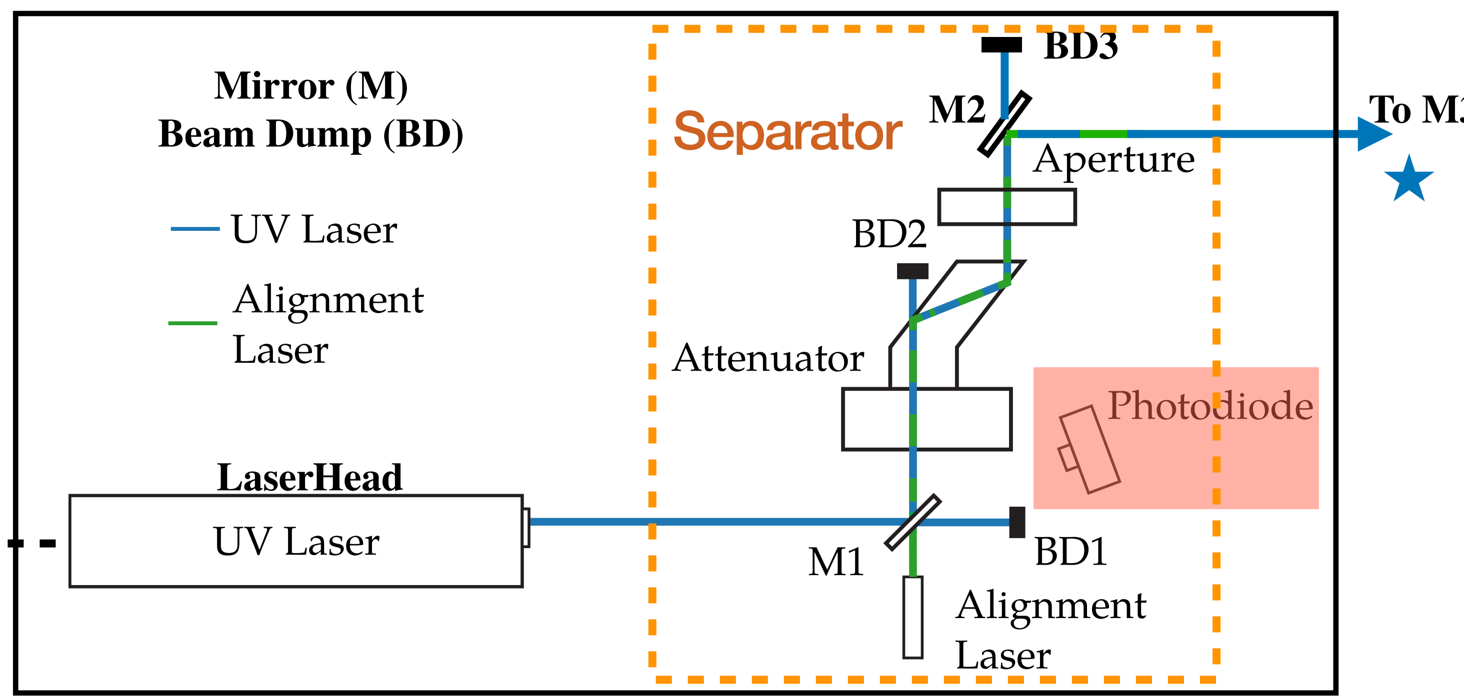
MicroBooNE: UV Laser Setup in a comprehensive LAr TPC

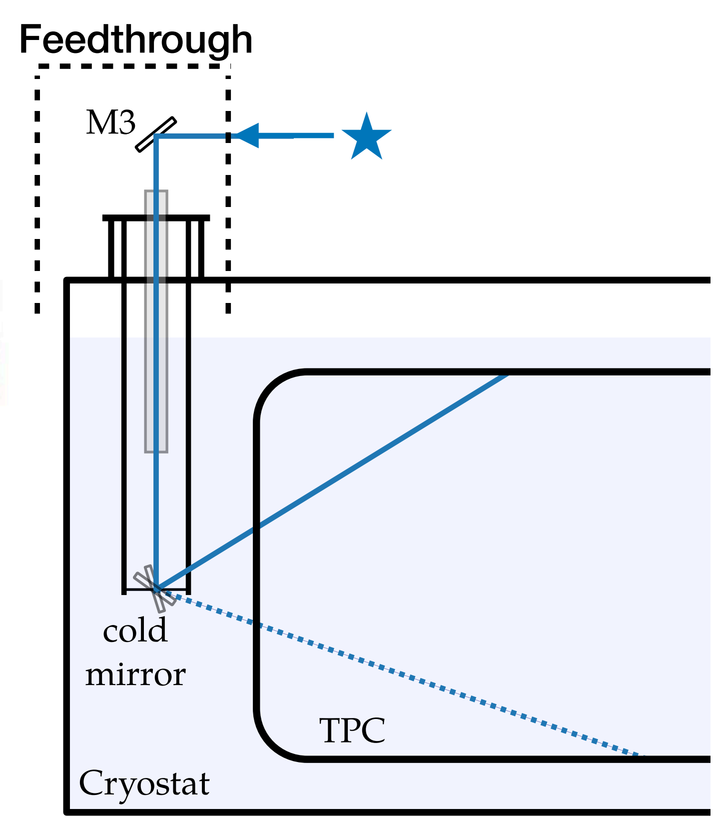
2 similar laser systems



Acciarri, R., et al. "Design and construction of the MicroBooNE detector." *Journal of instrumentation* 12.02 (2017): P02017.

Laser Box



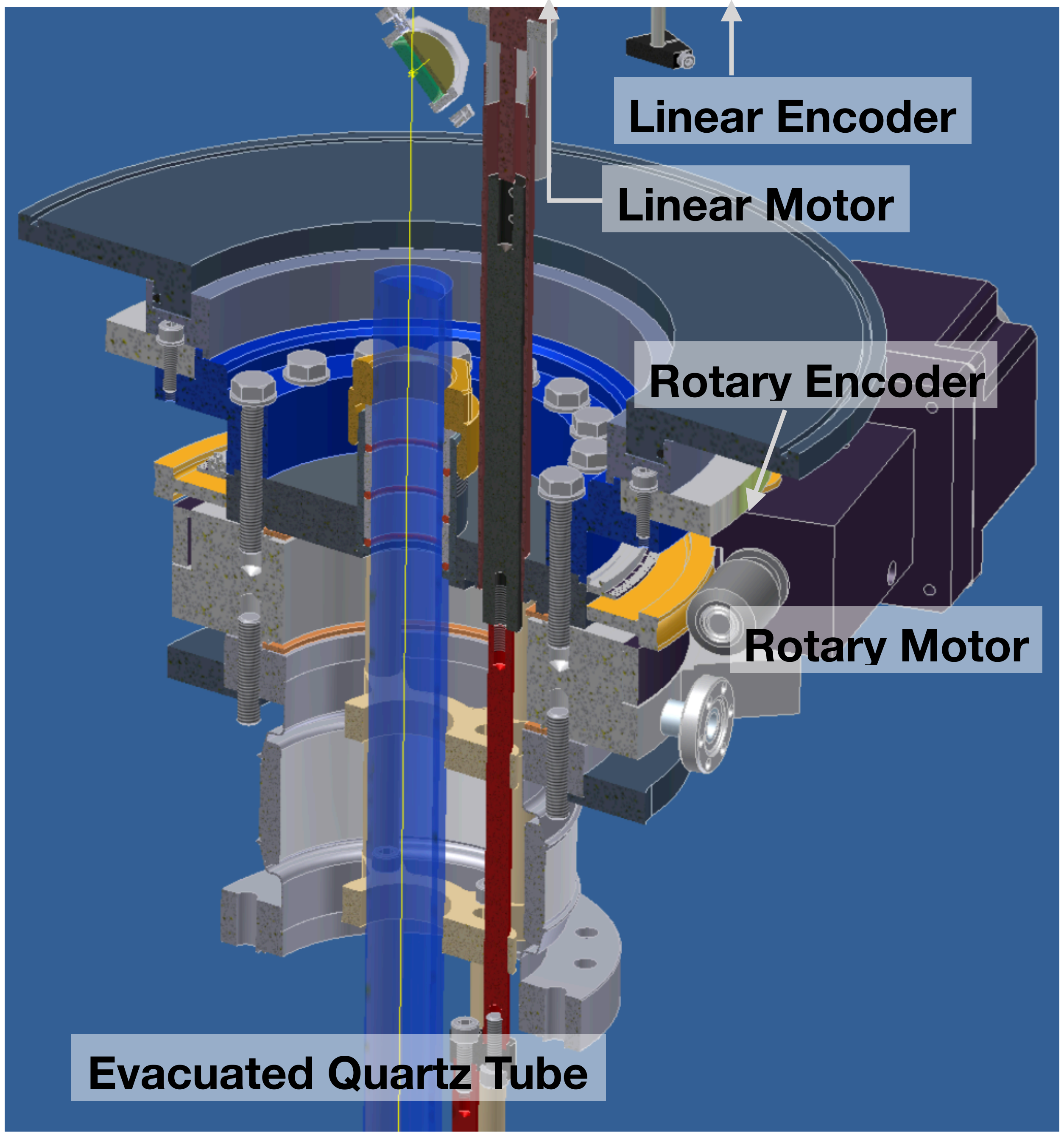


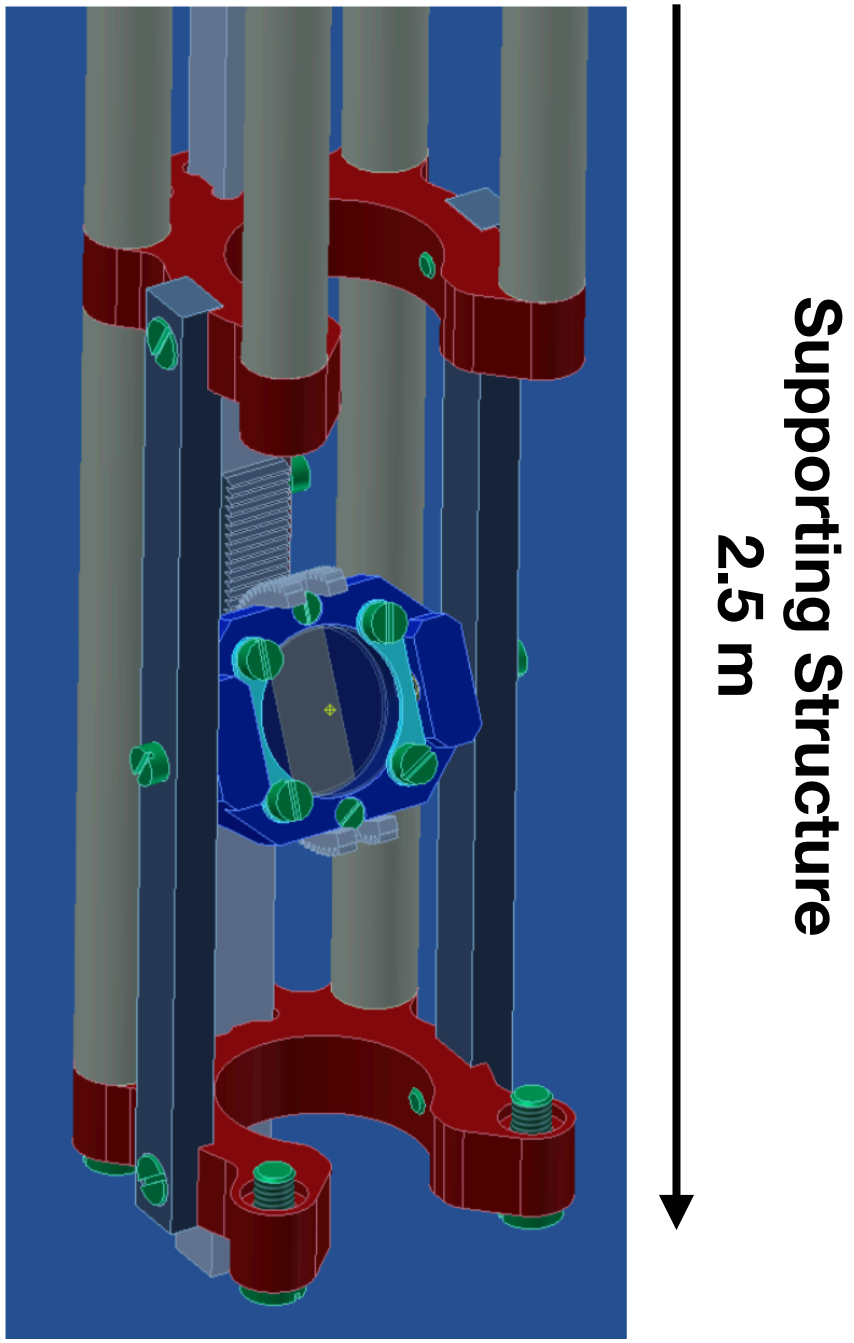
Plot by Matthias Lüthi

- Filter out 532 nm and 1064 nm laser and select 266 nm UV laser
- Photodiode for triggering
- Attenuator, Aperture, M2, M3 and cold mirror can be remote controlled

MicroBooNE: Steerable Laser System with Feedthrough

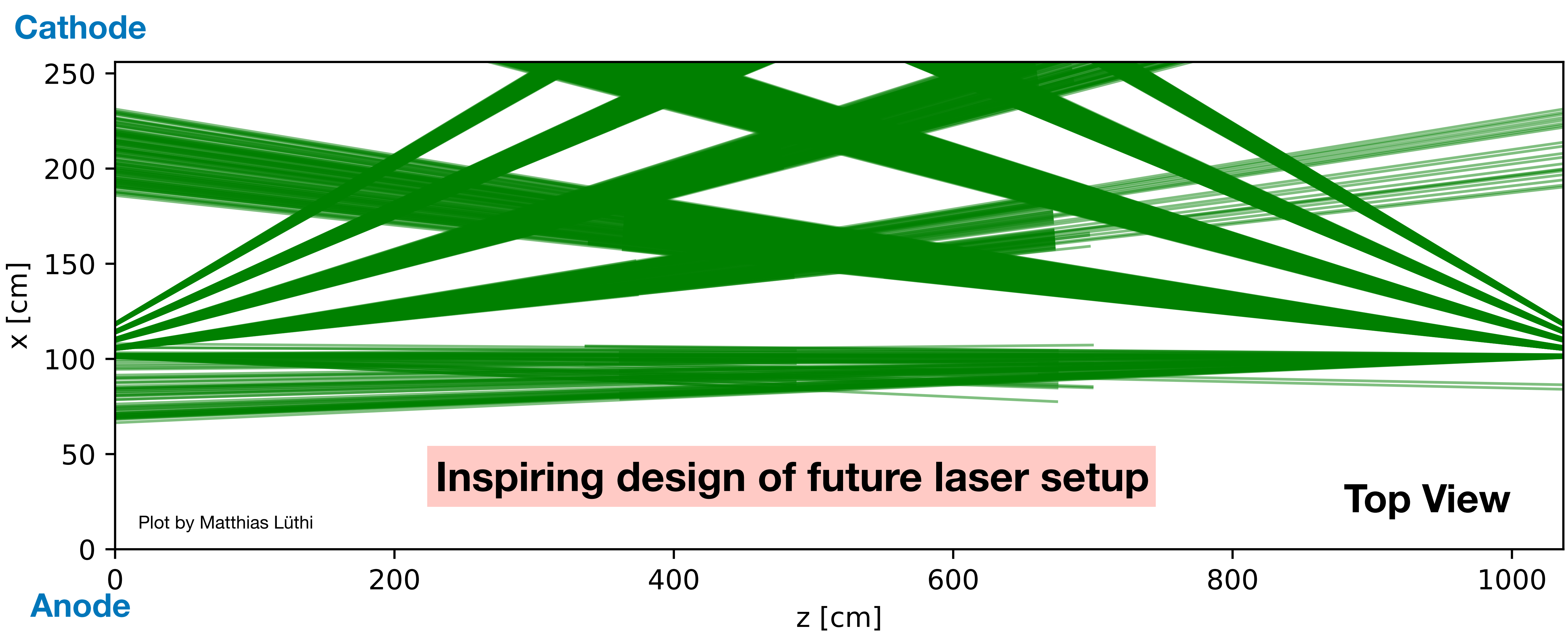
Cold mirror can rotate vertically (linear) and horizontally (rotary).
Mirror position is read by two encoders.
Evacuated quartz tube guides UV laser entering LAr.

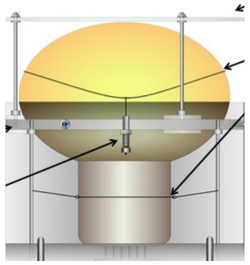




MicroBooNE: Laser Scan and the Coverage

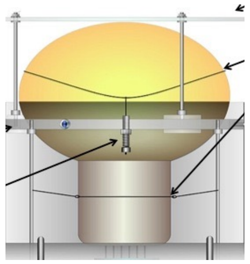
~ 80% of TPC active area is covered by **either** laser (with interpolation)
~ 60% of TPC active area is covered by **both** lasers (with interpolation)





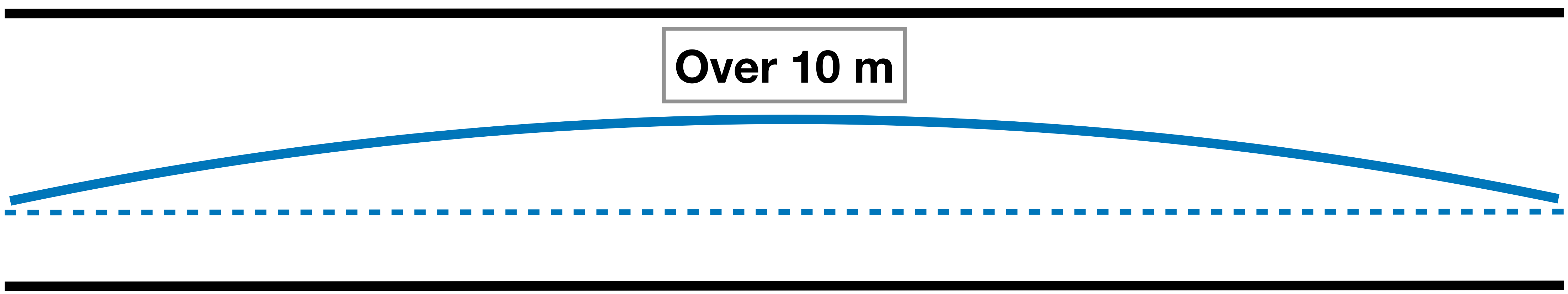
The Coverage is limited by

- Field cage rings in front of the cold mirror
- PMTs behind the anode

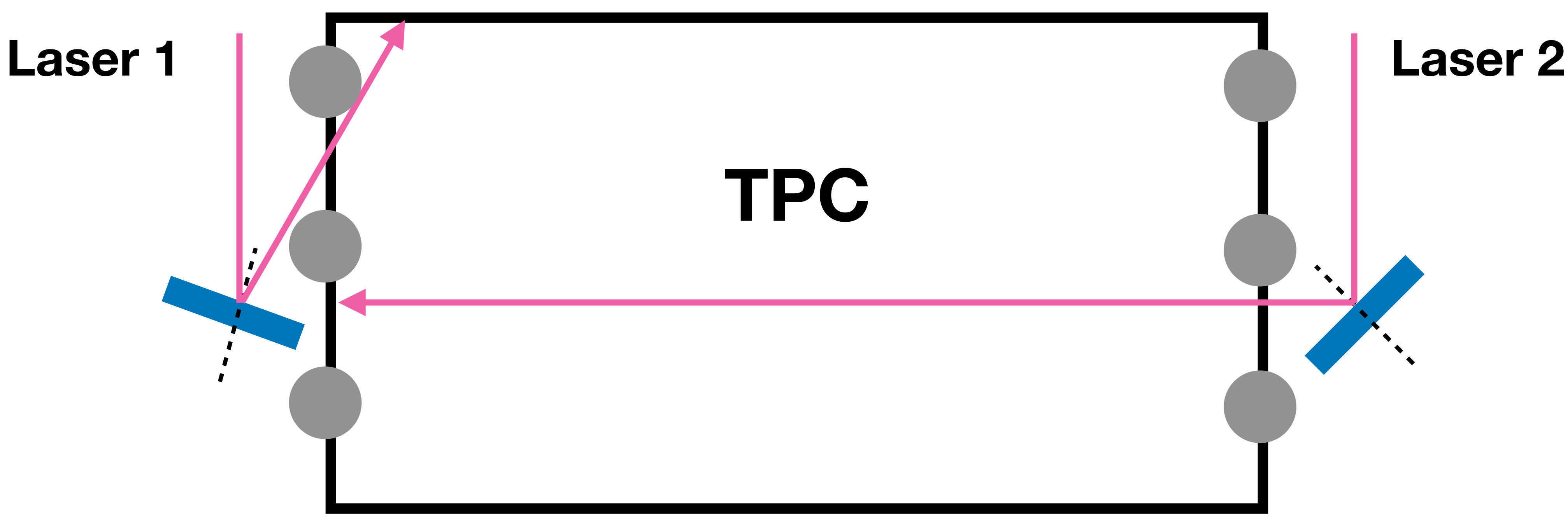


MicroBooNE: Laser Tracks

Reconstructed laser tracks are bent if E-field is non-uniform.
are shifted if nominal E-field is off.



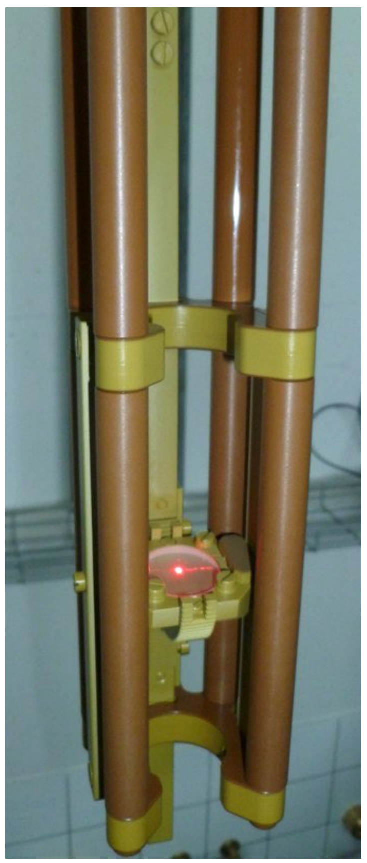
True laser tracks are straight lines.



MicroBooNE: Determine Positions of True Laser Tracks

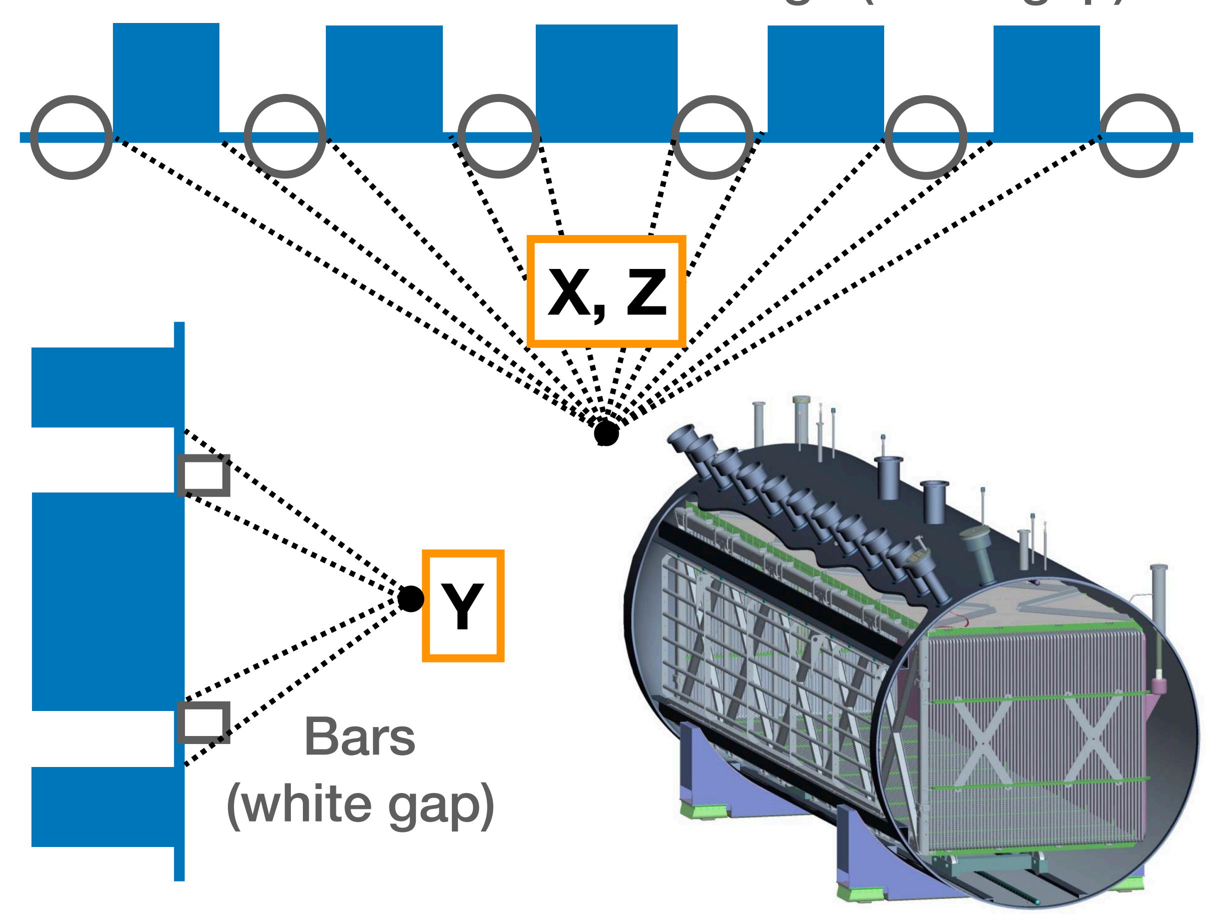
To determine a true laser track, an angle and a point are enough.

Laser beam angle from cold mirror angle



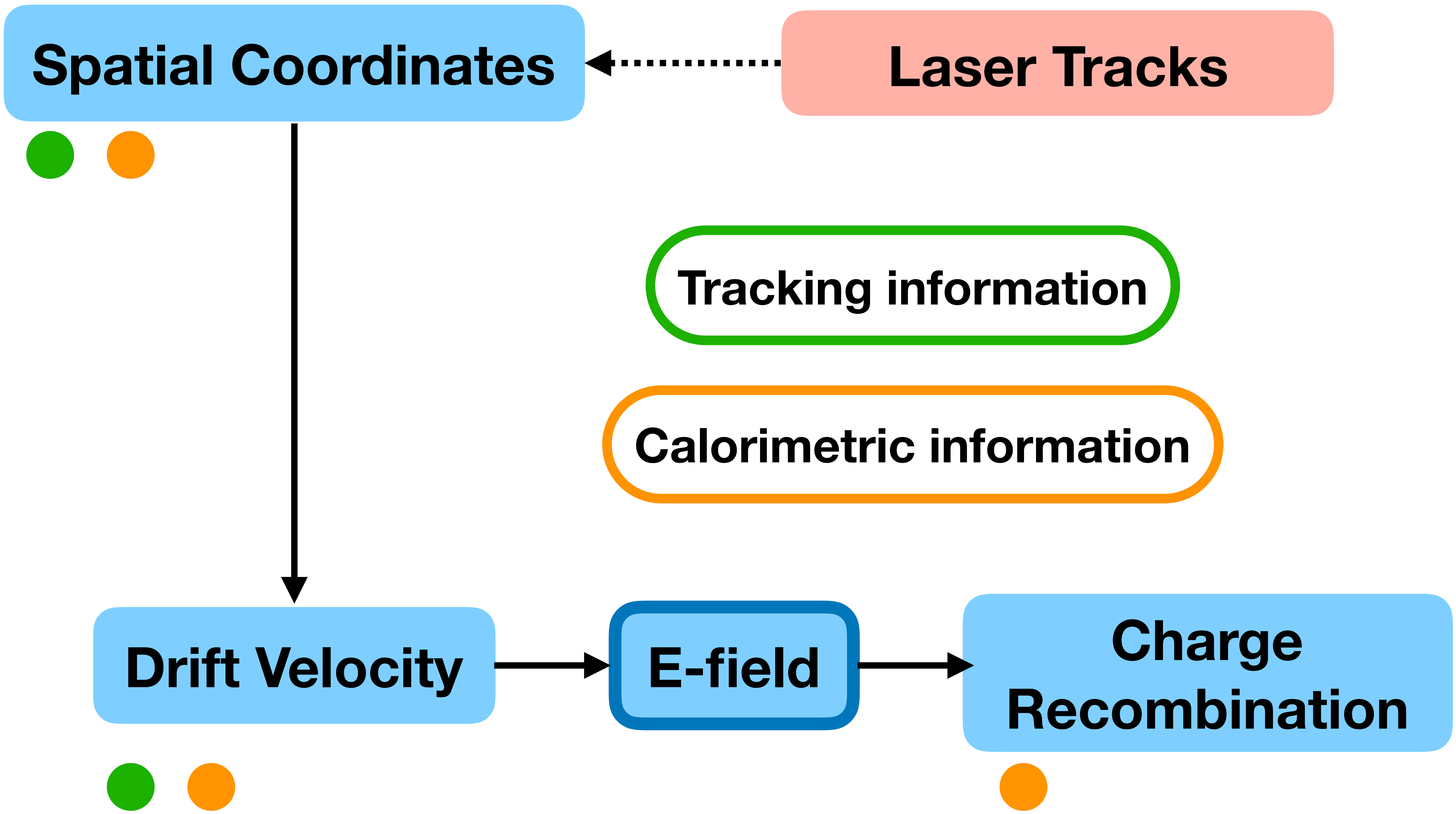
- The angle of cold mirror is measured by linear encoder and rotary encoder on the top of feedthrough
- σ (vertical/horizontal) = 0.05 mrad
  σ (encoder) = 0.5 mm @ 10 m
- Laser beam angle can be converted from cold mirror angle

Reflection point on cold mirror



True laser tracks only depend on mechanical information (independent of TPC readout)
2 mm position accuracy is achieved at 10 m from cold mirror

MicroBooNE: Calibration Flow



Concepts of D Map

The displacement map (D map) shows the offsets of spatial coordinates in TPC range due to E-field variations.

Dictionary:

True spatial coordinates:

- Represent actual position of ionisation
- Regular TPC boundary

Reconstructed spatial coordinates:

- Ionised electrons drifted by a different E-field but reconstructed by a nominal E-field
- Potentially irregular TPC boundary

Distortion Map (True -> Reconstructed):

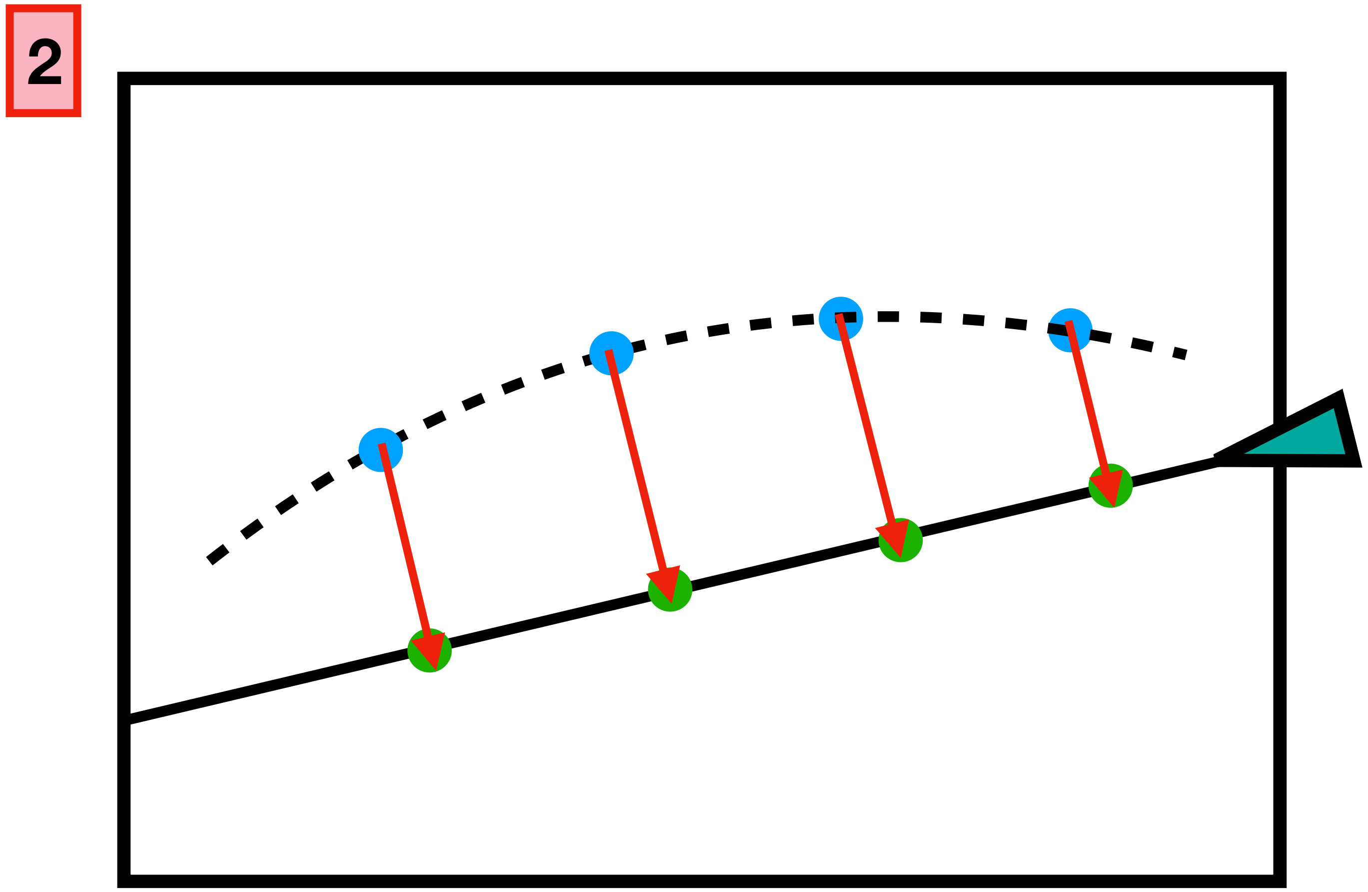
- Regular grid in true spatial coordinates
- Used for simulation

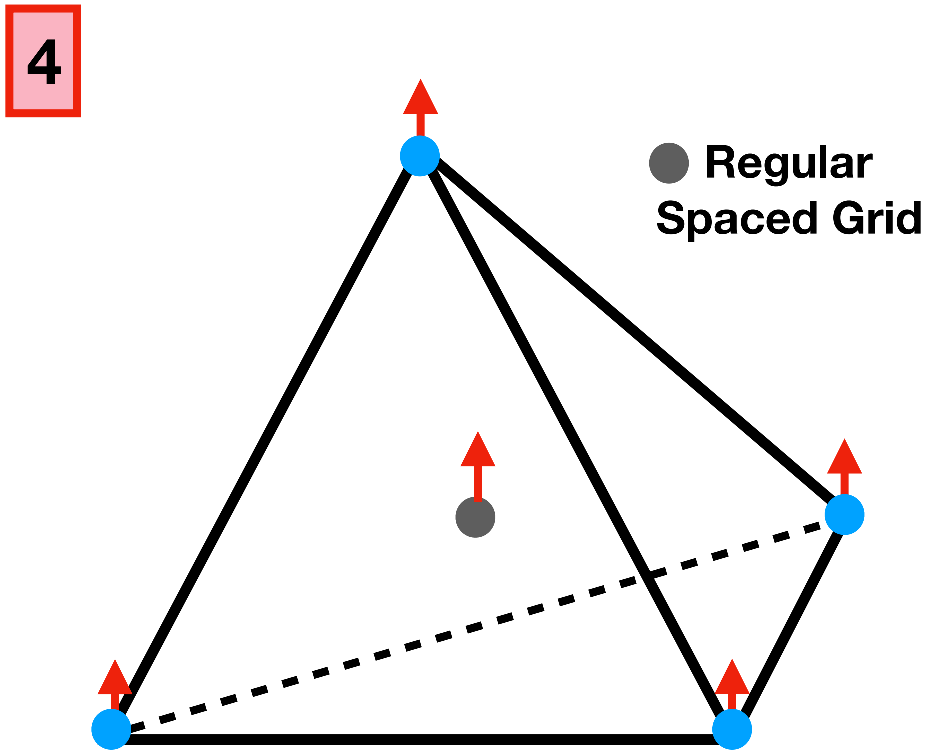
Correction Map (Reconstructed -> True):

- Regular grid in the reconstructed spatial coordinates
- Used for spatial calibration and E-field calculation

MicroBooNE: Calculation of D Map

1. Reconstruction: laserhit + Pandora
2. Track Iteration: map the reconstructed tracks to true tracks
3. Boundary Condition: no spatial distortion at the anode
4. Interpolation the spatial distortion to form regular grid





Using barycentric parameters

MicroBooNE: Track Iteration

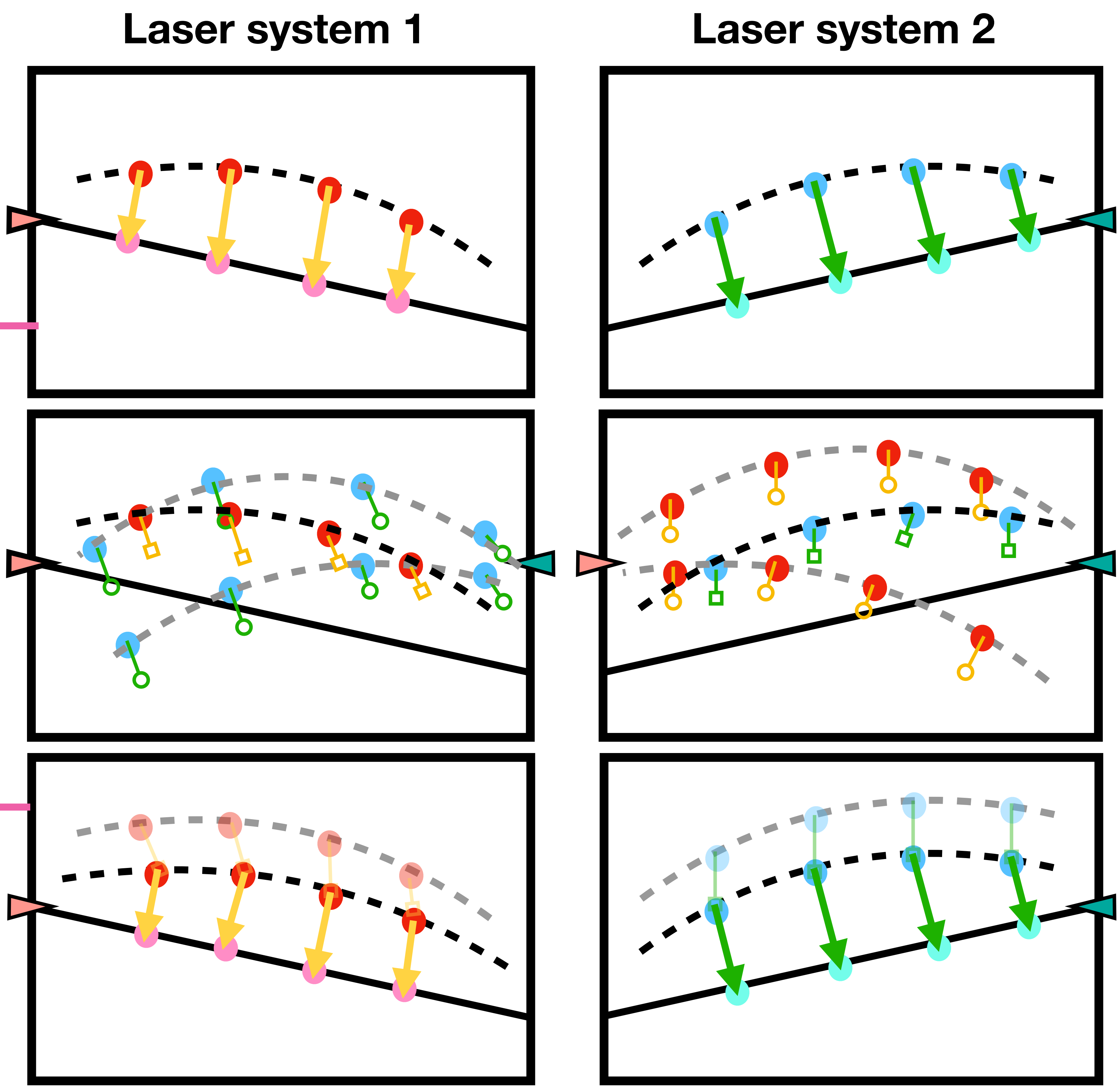
Projection by Closest Point has angle dependence and may not be precise enough.

Step 1 to (N-1):

First
Closest Point Projection
Secondly
Interpolate the fractional displacement vector from the other sub-sample is 1/N of
Then
Move the track correspondingly to the next intermediate position

Step N:
Correct all the intermediate track points to true laser tracks.

3-step iteration is satisfying

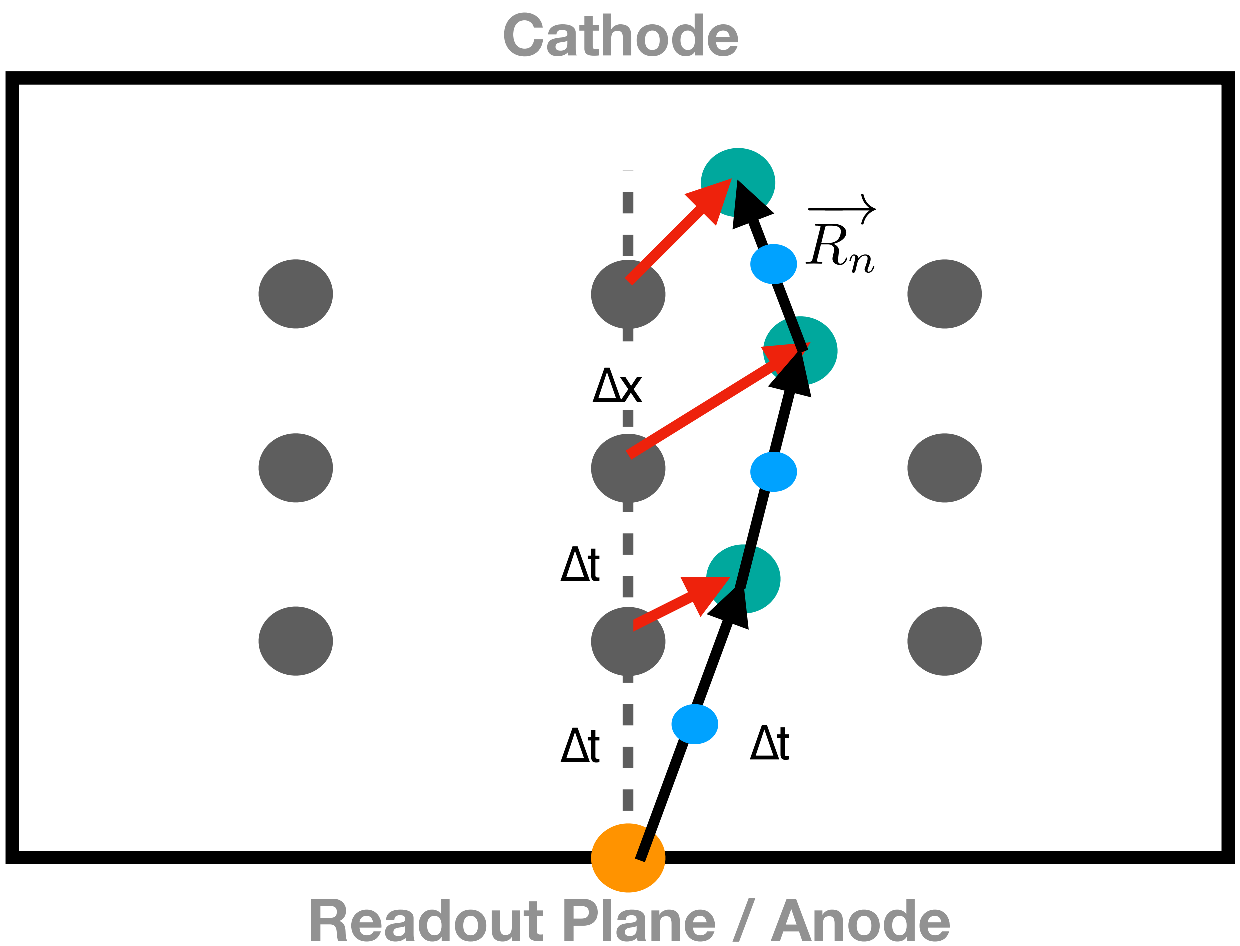


MicroBooNE: Calculation of Drift Velocity and E-field

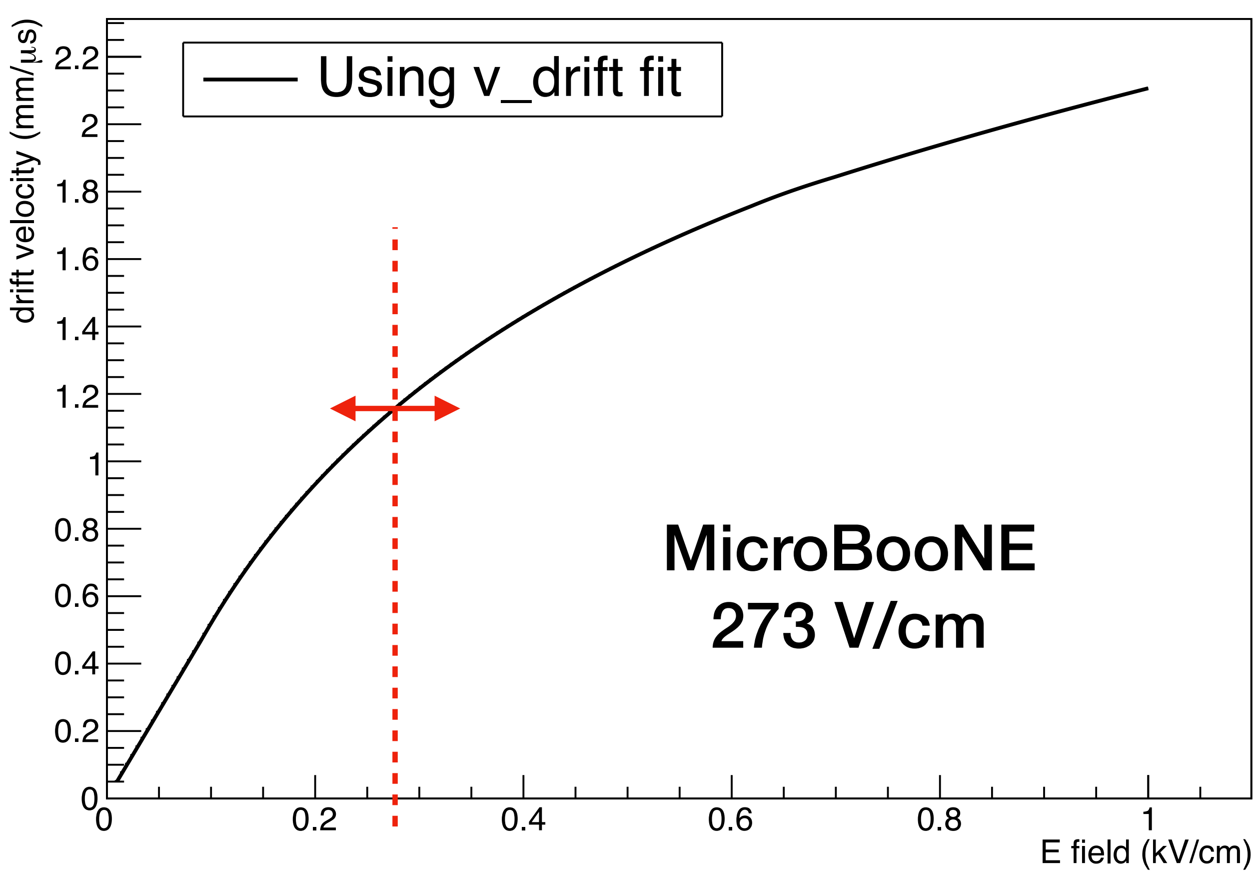
$$|\overrightarrow{v_n}| = \frac{|\overrightarrow{R_n}|}{\Delta x} |\overrightarrow{v_0}|$$

$$|\overrightarrow{v_0}| = 1.114 mm/\mu s$$

$$\boxed{|\vec{v_n}|(|\vec{E}|, T) \rightarrow |\vec{E}|(|\vec{v_n}|)}$$



Drift velocity as a fit function of E field and Temperature



MicroBooNE: Lesson and Homework 1

Long laser track:

- Over 10 m

Do we need better laser?

- Minimise the number of dichroic mirrors
- More powerful and stable laser?

Laser Alignment:

- Easy accessible environment

Laser coverage:

- Put the cold mirror in TPC active volume (at corner)
- Test WLS efficiency change in LAr with UV laser running
- Test reflection efficiency of dichroic coating with different incident angles
- Optimise the placement of light detection system and UV laser

True laser position calibration:

- Anode is the best calibration source with respect to TPC position
- Otherwise using photoelectrons on at least one item with well know position

MicroBooNE: Lesson and Homework 2

Crossing track:

- Move from track-track correction to point-point correction

Laser Scan Pattern:

- How to increase number of crossing tracks?
- Lower the TPC running time without light detection

Laser Pulse Rate:

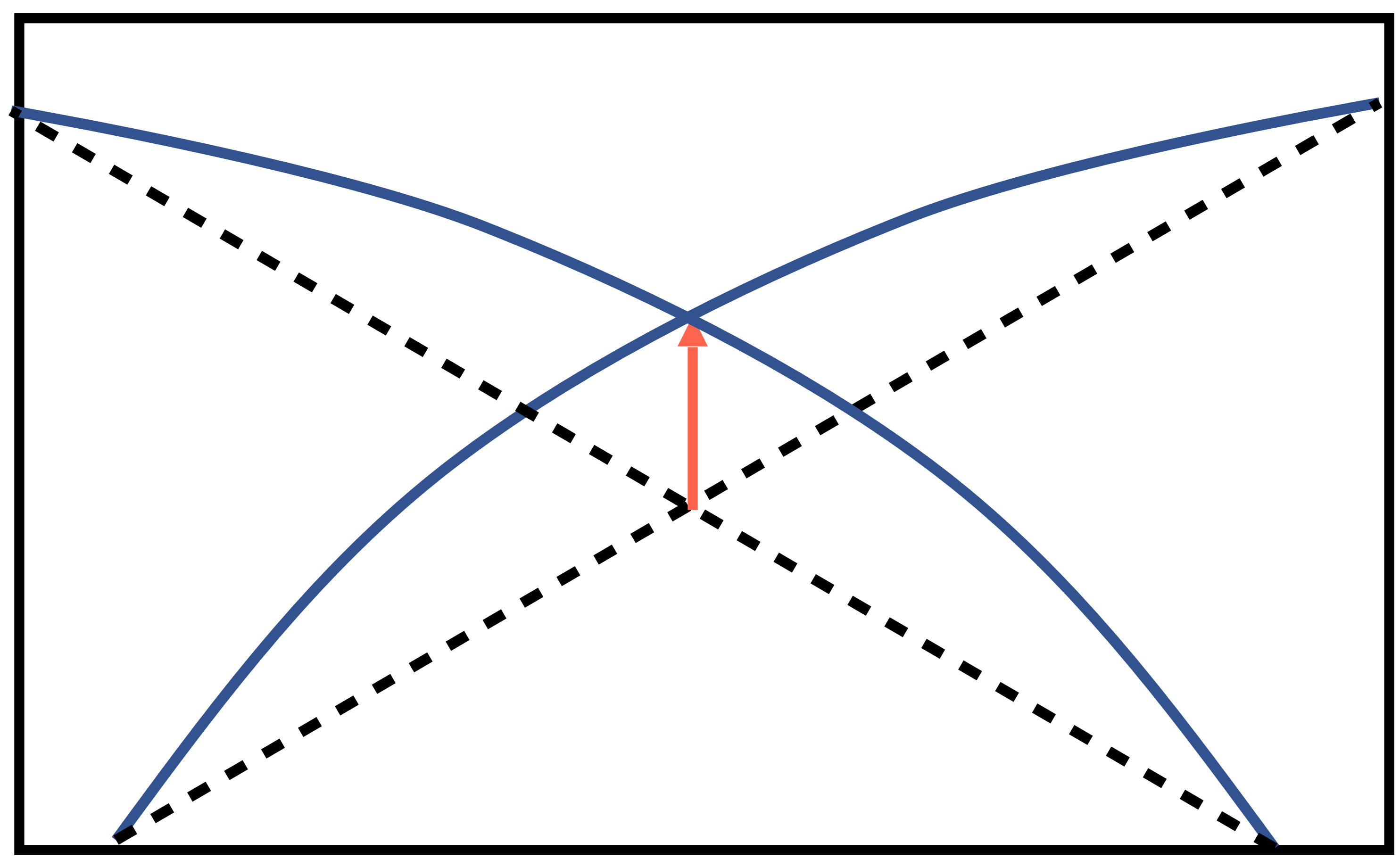
- No more than 4 Hz

Regular Calibration Run:

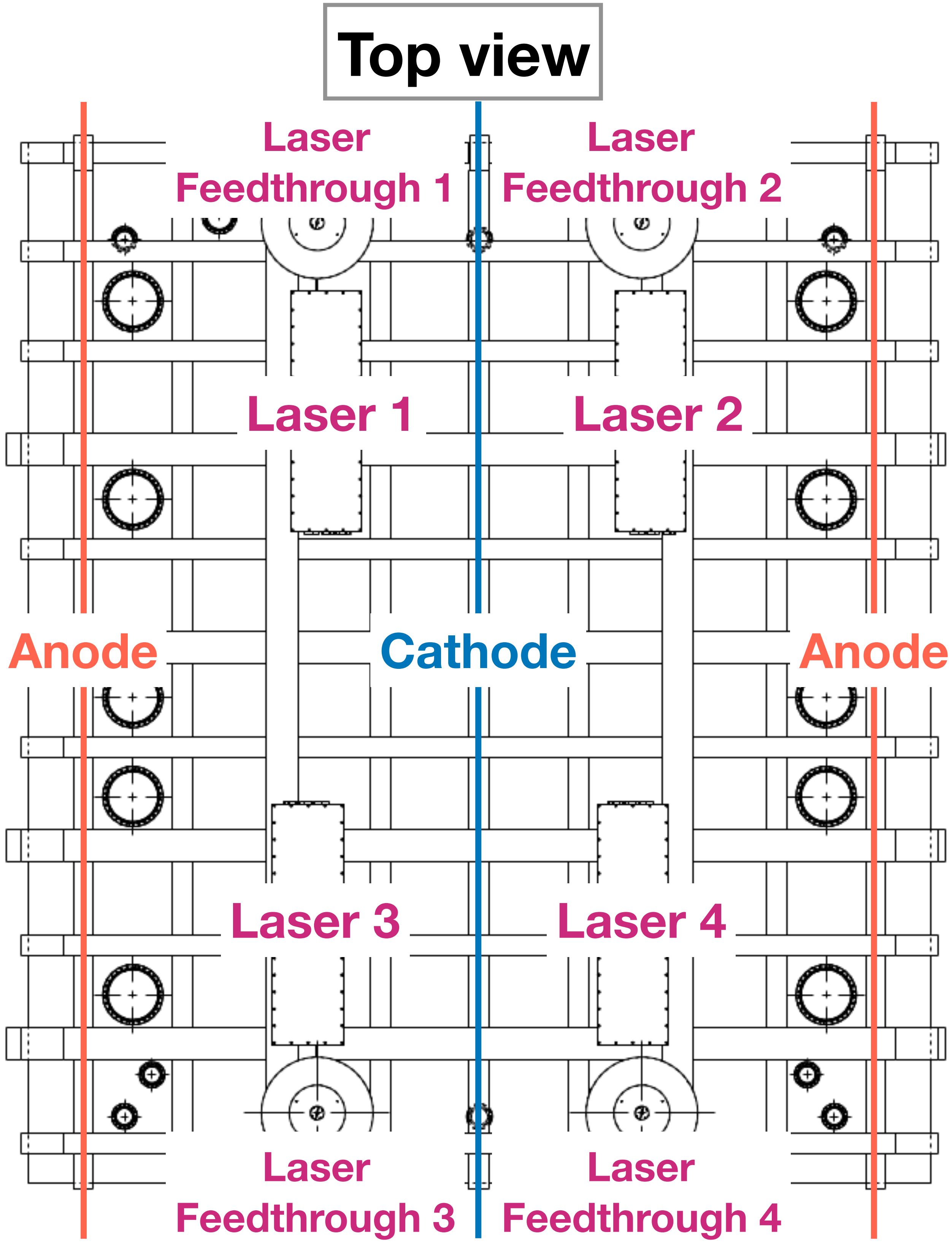
- How often?

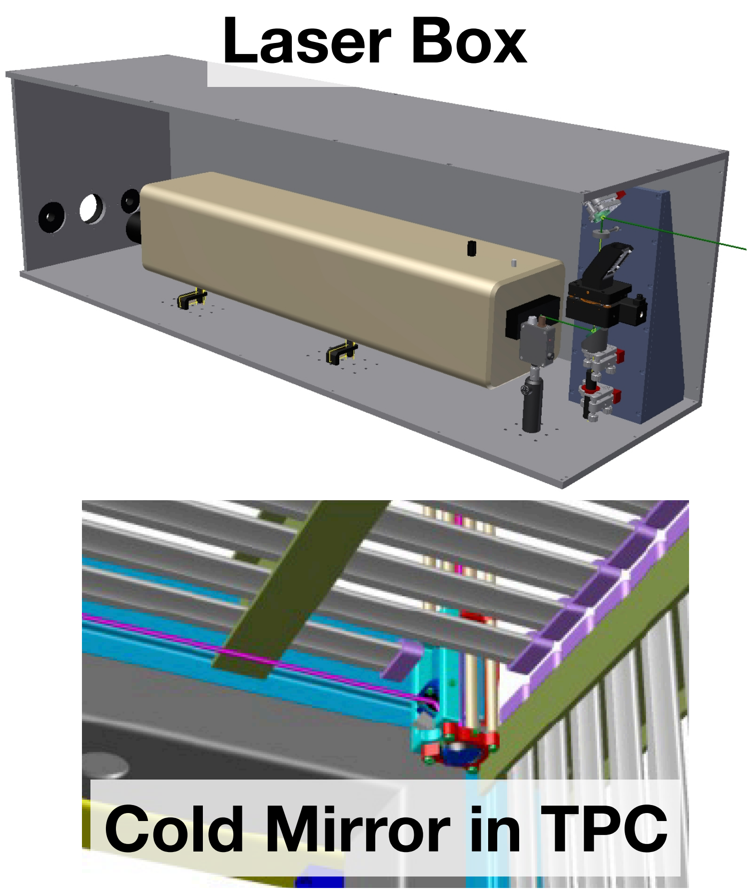
TPC Geometry Survey:

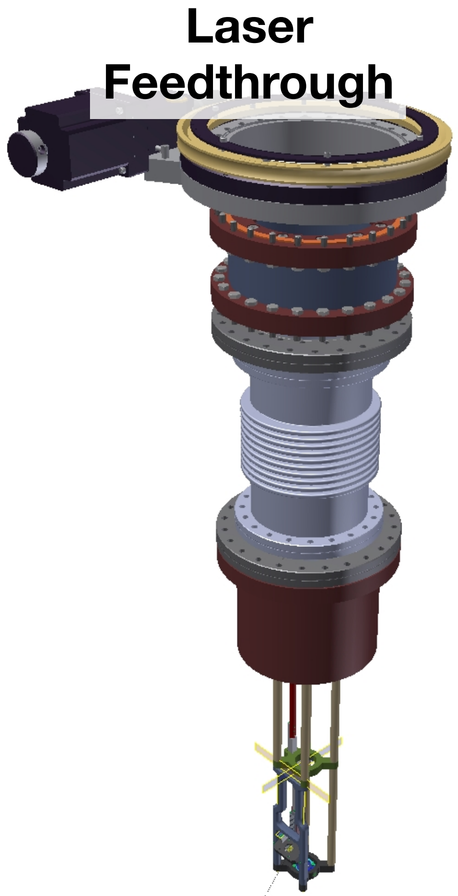
- Necessary



SBND: Design of Laser Setup



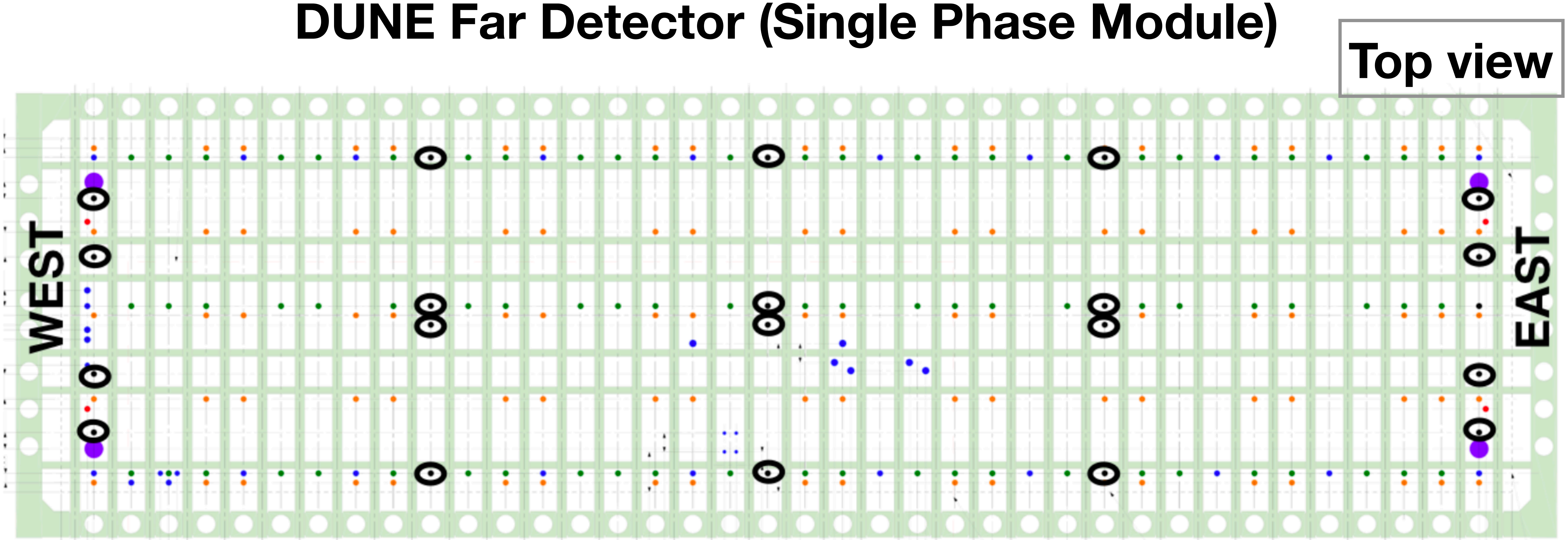




Plots by Roger Hänni

- 4 laser heads are delivered to Fermilab
  1 laser head is used for tests in Bern
- Full coverage allows plenty crossing tracks
- Incident angle on dichroic mirror 0 - 45°

DUNE Far Detector (Single Phase Module)



- UV laser system design based on MicroBooNE and SBND laser
- Cryostat design with calibration ports
- Calibration Consortium is formed and it supports laser calibration system design in view of the Technical Design Report

arXiv:1807.10334 arXiv:1807.10327