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AEC
ALBERT EINSTEIN CENTER
FOR FUNDAMENTAL PHYSICS

UV Laser system

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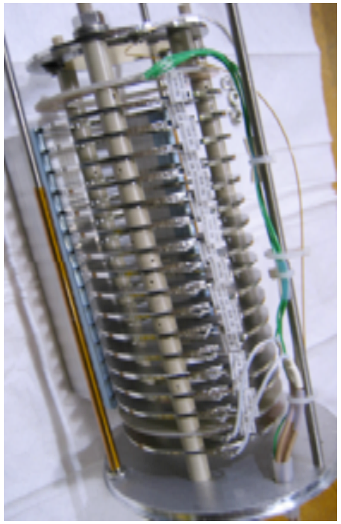
University of Bern

Calibration needs multiple tools… !

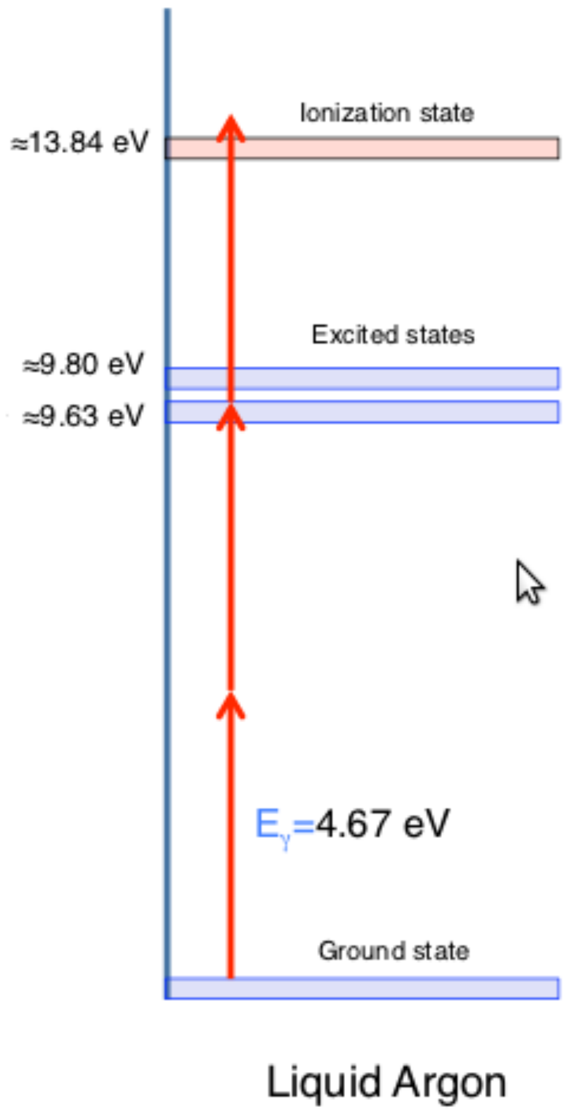
- Options (not exhaustive):
  - Purity monitors
  - Gas analyzers
  - Temperature monitors
  - Survey of TPC
  - Electric field (HV, resistor chain) measurement

  - Use cosmic muon tracks
  - Test beams
  - **Laser tracks -> straight tracks, reproducible, no delta rays, no MCS, no recombination**



- Make use of the specific characteristics and dependencies of all of the above in a combined way

How to ionize Argon with the UV laser



- 266nm <-> 4.7 eV
- For ionization, an energy of 13.4 eV (84 nm) wavelength laser is required
- Multi-photon transition via a quasi resonant state at 9.32eV
- Requires enough flux of photons, i.e. strong laser

UV laser calibration system
Primary beam generator

JINST 4 (2009) P07011
New J.Phys. 12 (2010) 113024

Primary Source: Nd:YAG laser, with frequency multiplication:
Output beam 266 nm , ~60 mJ/pulse, 5 ns.

Maximum repetition rate 10 Hz.

Beam divergence 0.5 mrad
Beam diameter about 5 mm

Effects contributing to the observable ionization

- Beam divergence: nominal 0.5 mrad (can change at the mirrors!)

- Beam absorption: does not seem to be an issue…
  λ_{att}> 100 m at 266 nm
  "Attenuation of vacuum ultraviolet light in liquid argon" , Eur. Phys. J. C (2012)

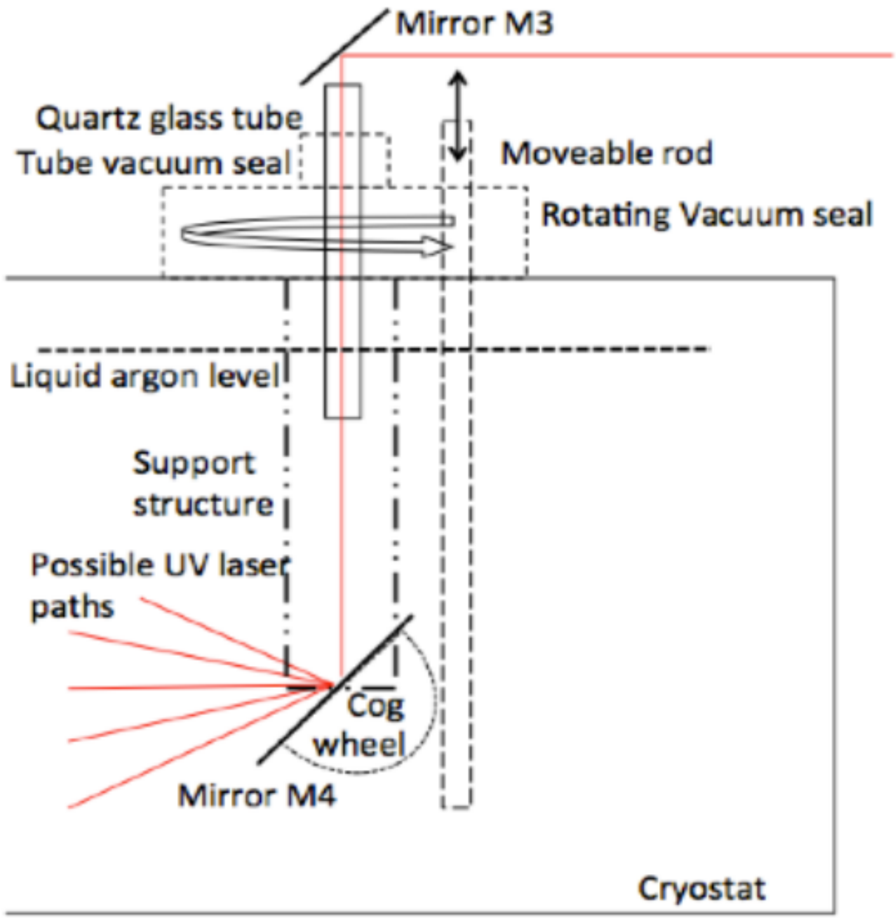
- Rayleigh scattering (40m at 266 nm)

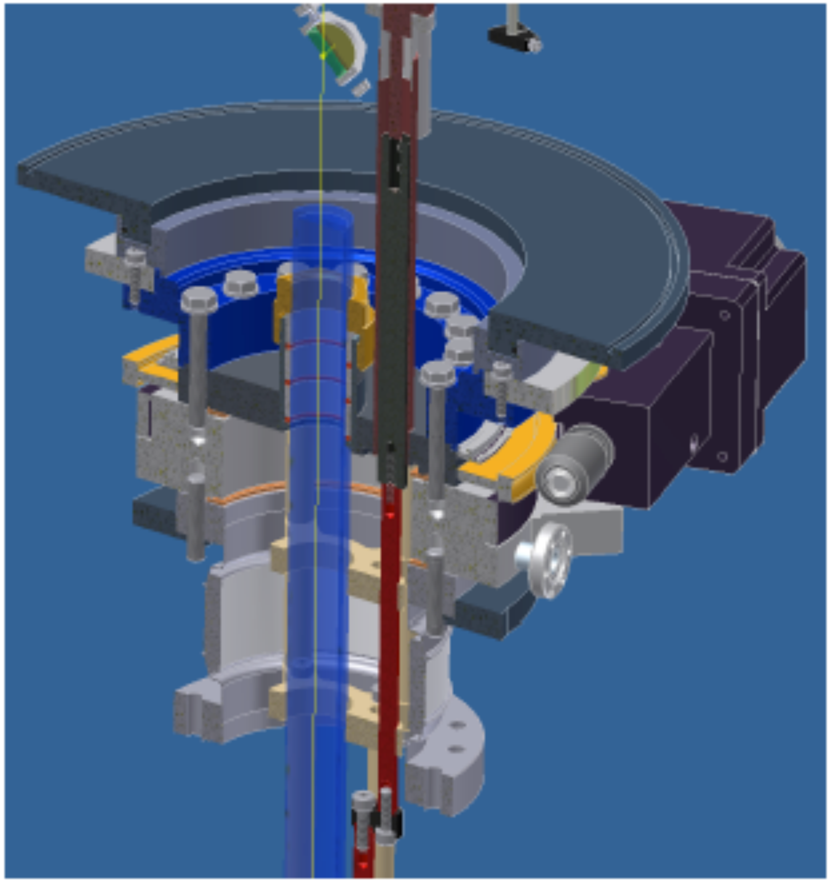
- Refraction on density gradients

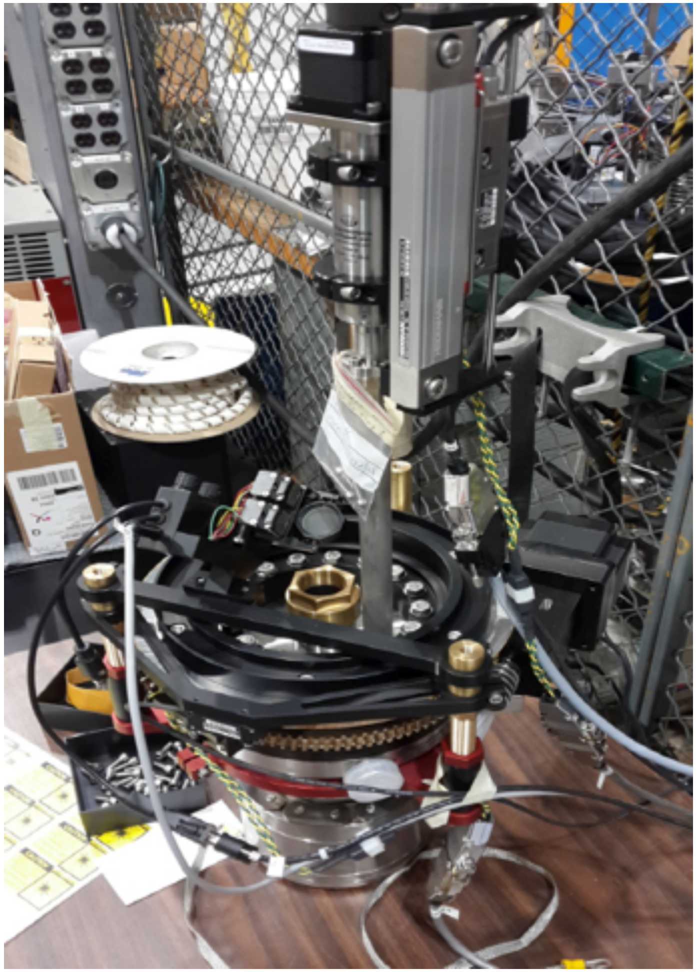
- Non-linear effects (Kerr-induced self-focusing)

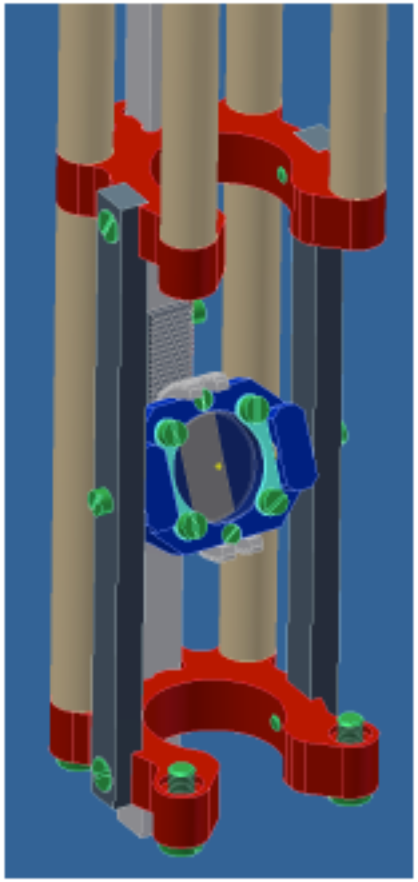
UV laser calibration system: Conceptual design

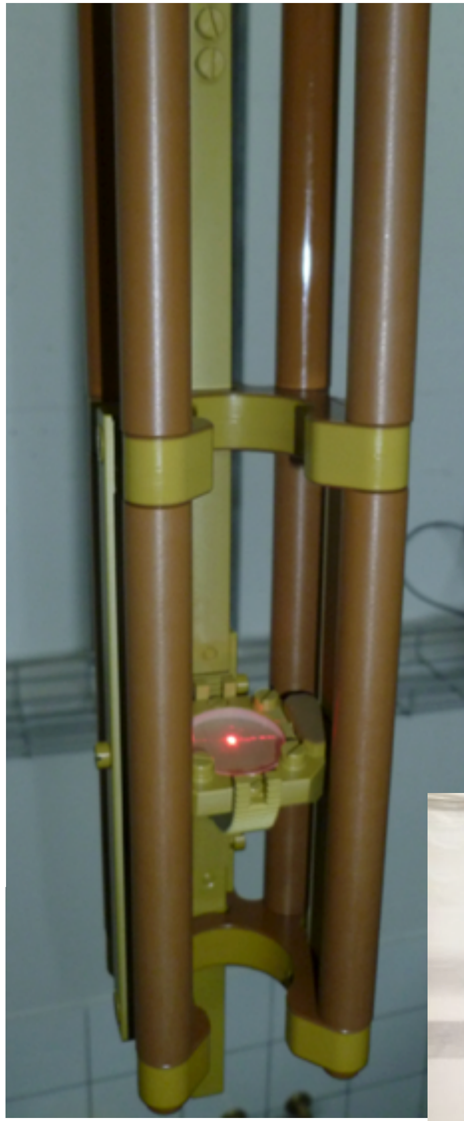
Goal: to provide straight ionisation tracks
Tool: multiple UV lasers, each with steerable mirror feed-through







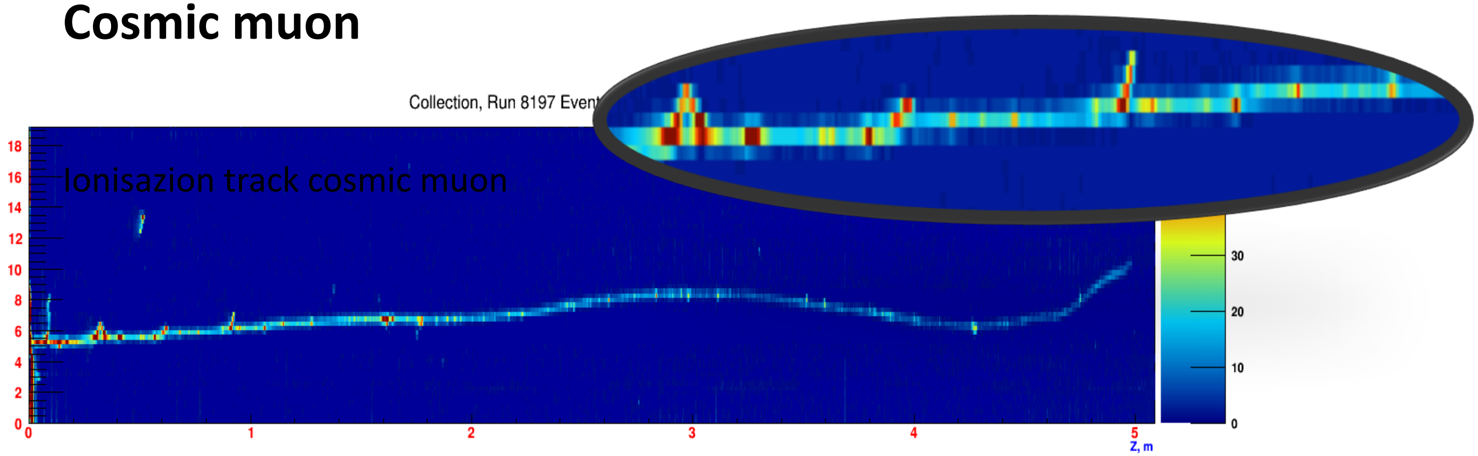




MicroBooNE setup
“Similar” will be used in SBND,
see later

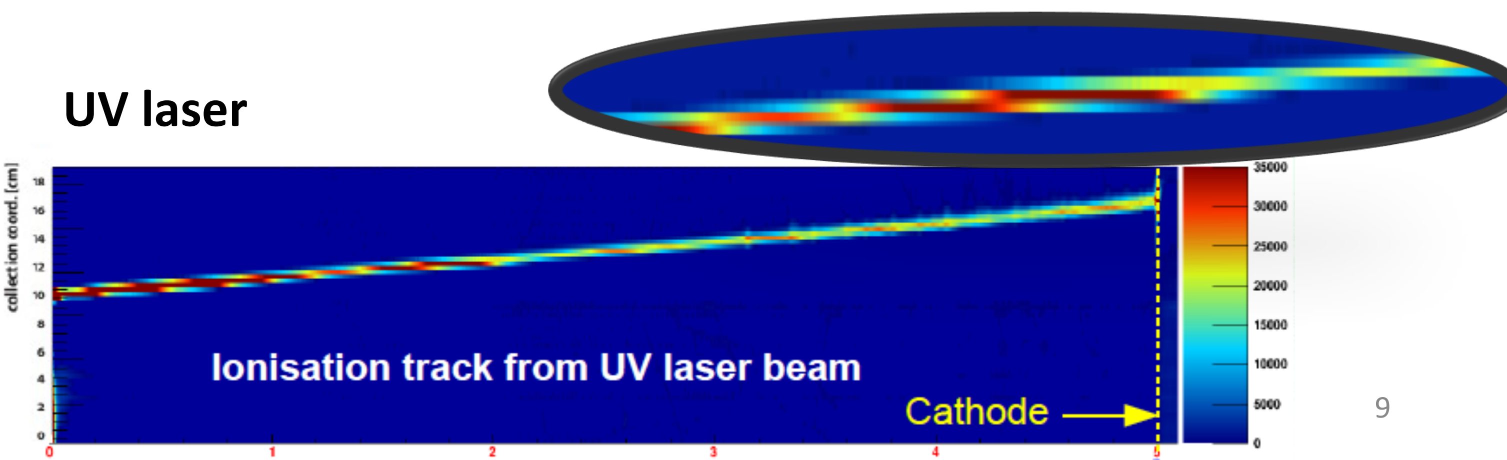
ArgonTube (Bern)

Cosmic muon

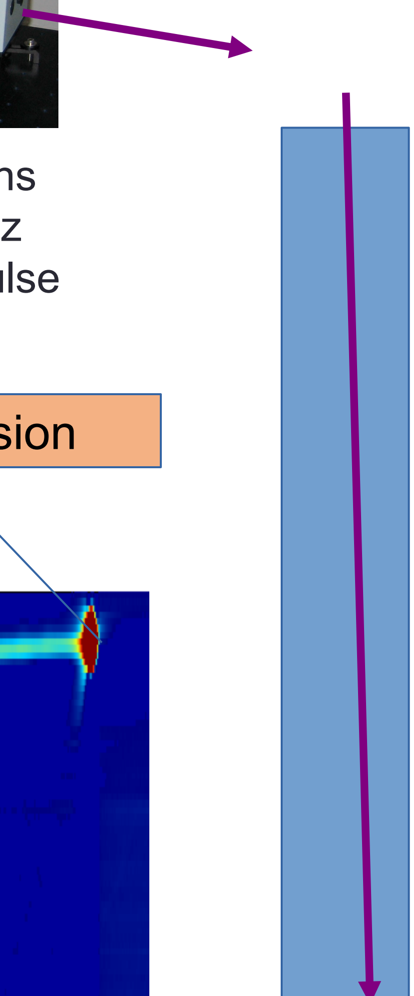


UV laser:
- No recombination
- No MCS
- No delta rays

UV laser



Use of Straight ionization tracks by a UV laser



Pulsed laser, t ~ 5 ns
F_{rep} from 0 to 10 Hz
266 nm, ~10 mJ/pulse

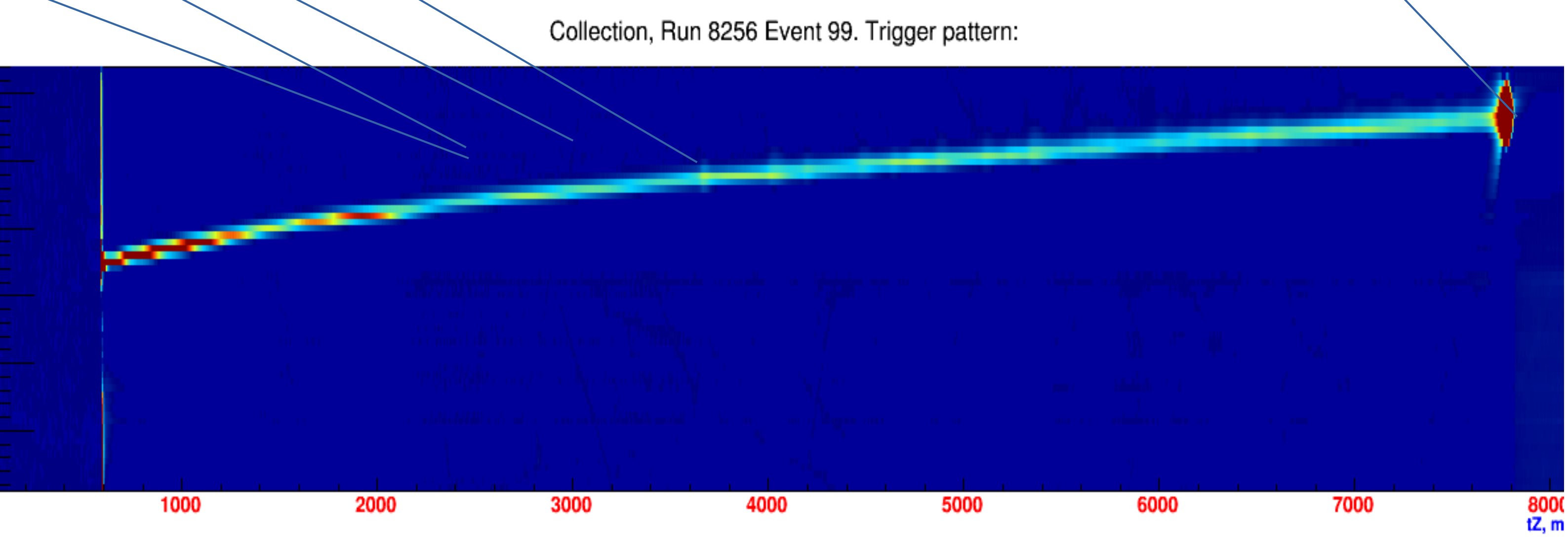
Charge density → dE/dX

Charge attenuation → LAr purity

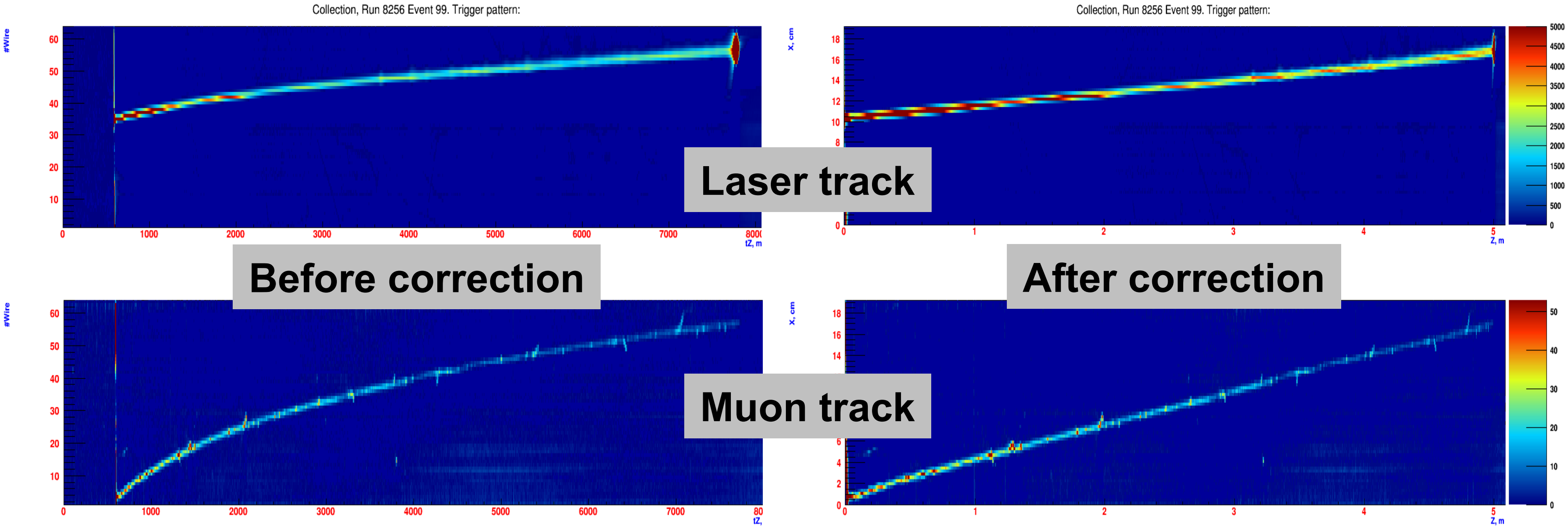
Track curvature → Drift field

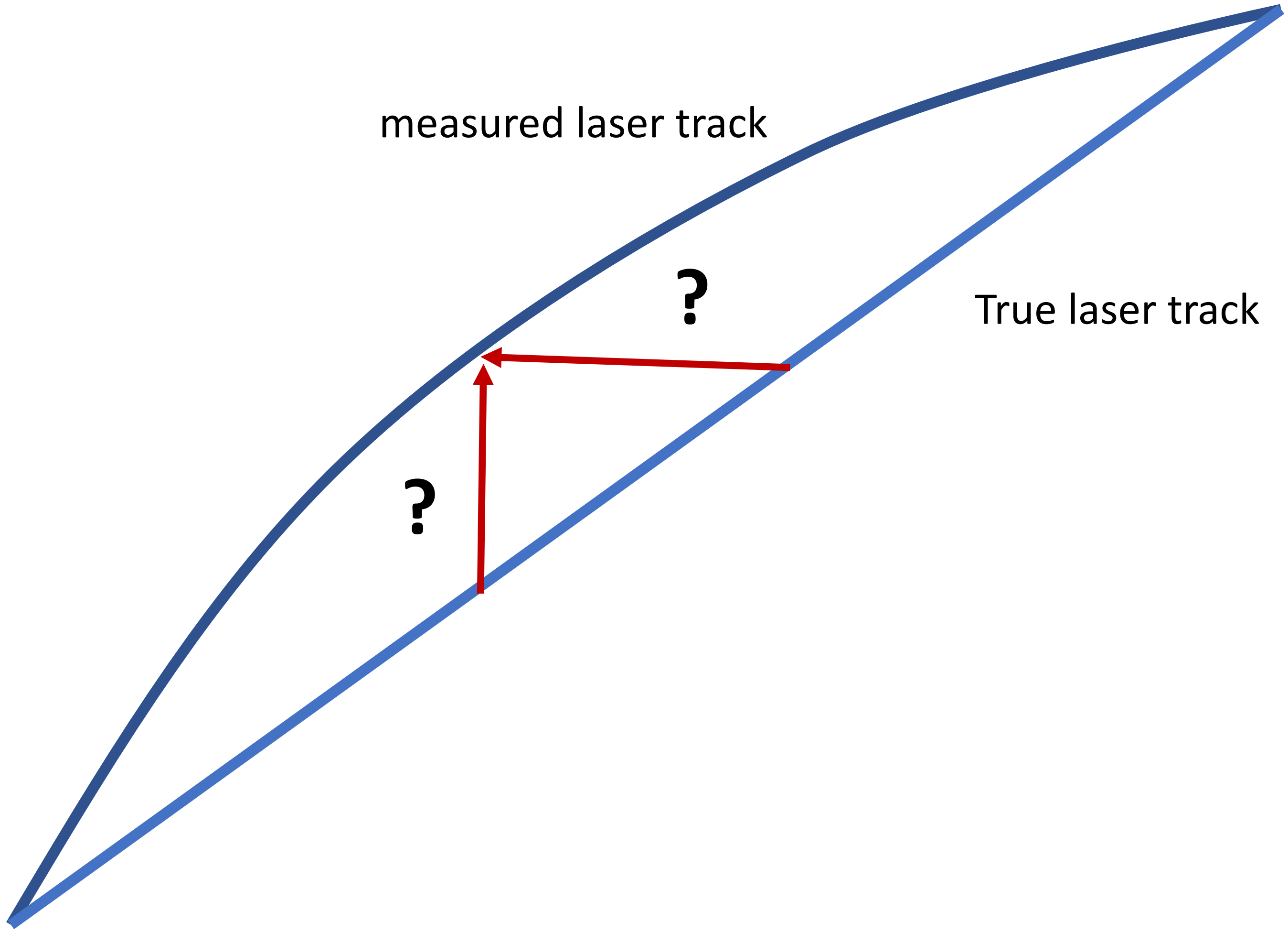
Track divergence → Tr. diffusion

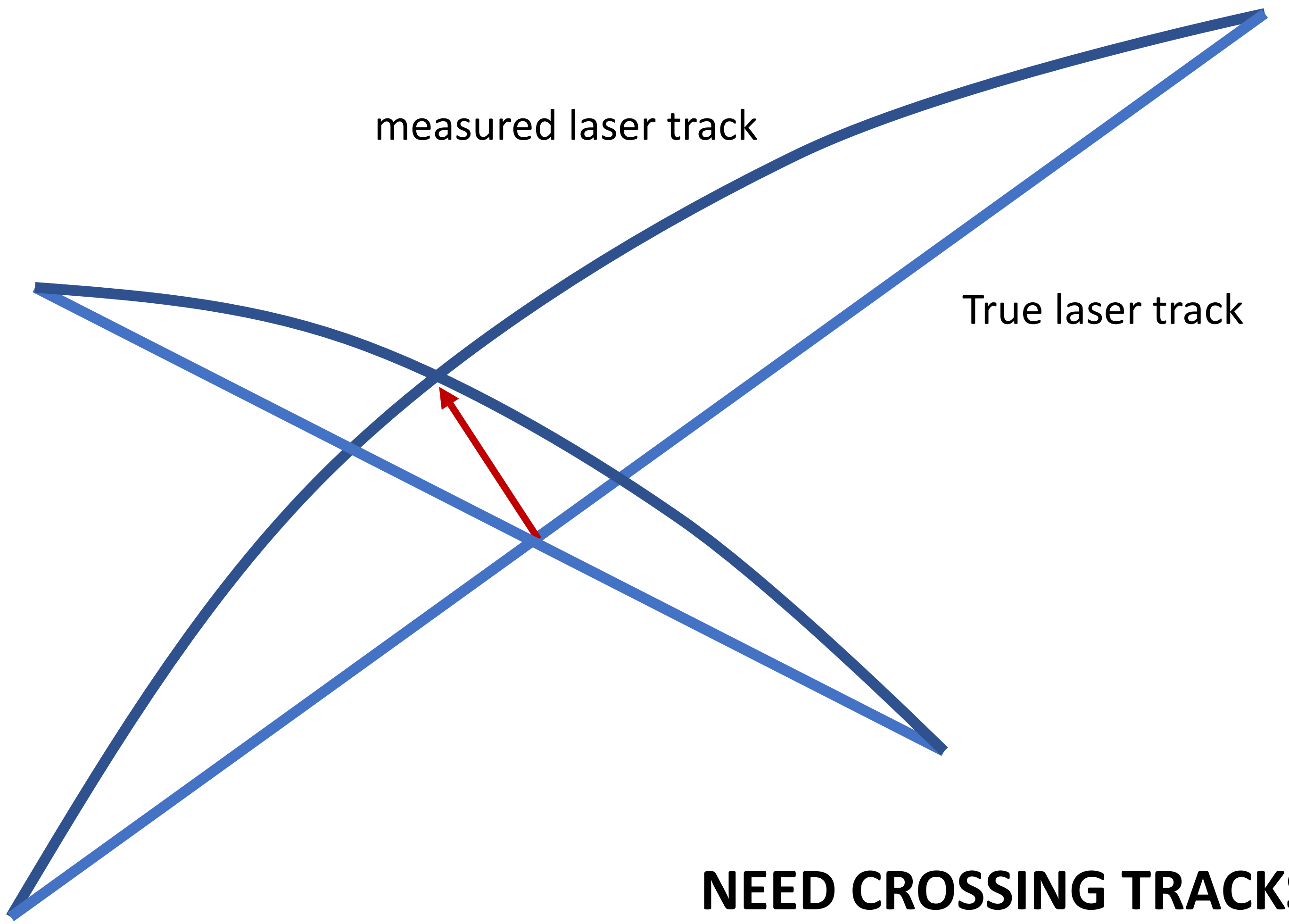
End peak → Lon. diffusion



ARGONTUBE geometry/field calibration with laser



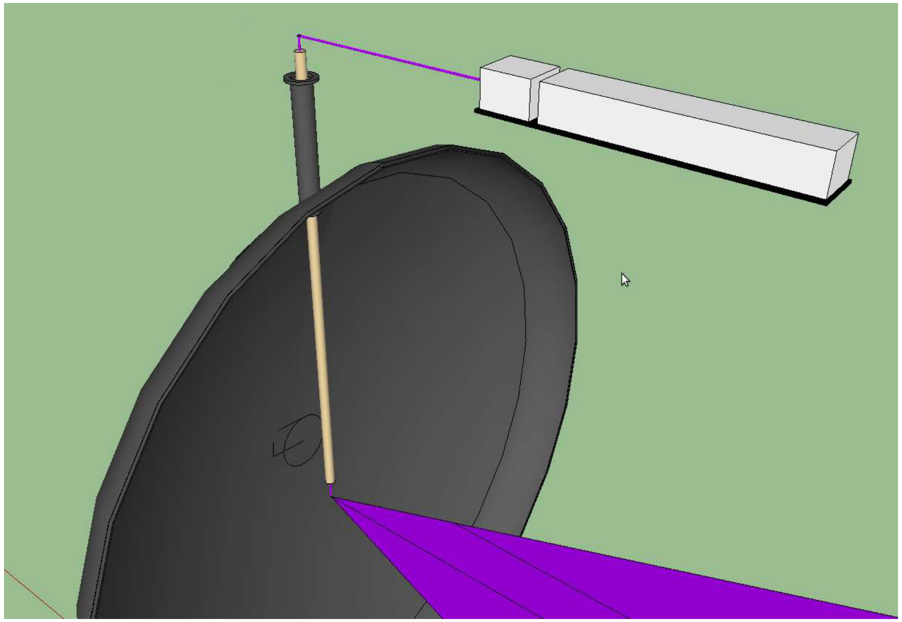

measured laser track
?
True laser track
?

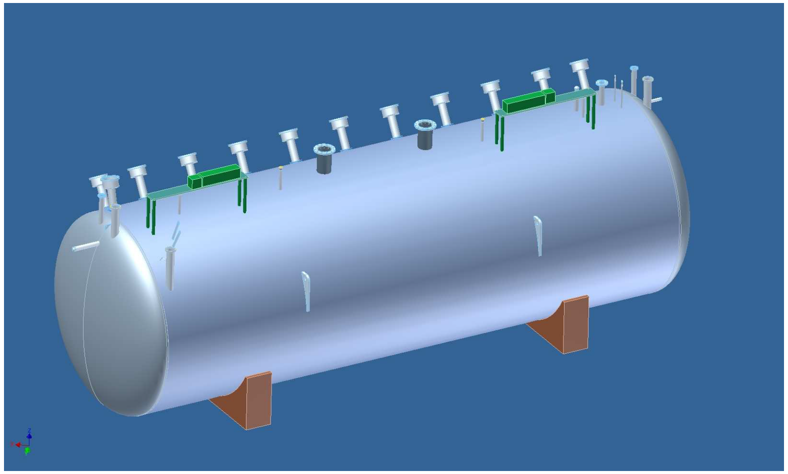


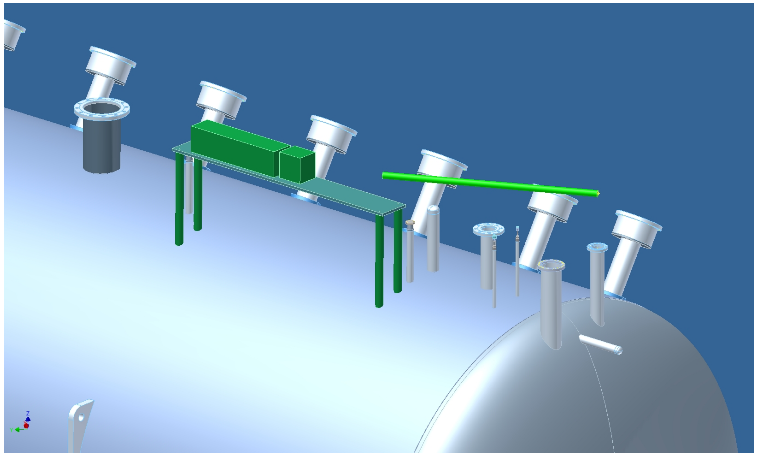
NEED CROSSING TRACKS

MicroBooNE

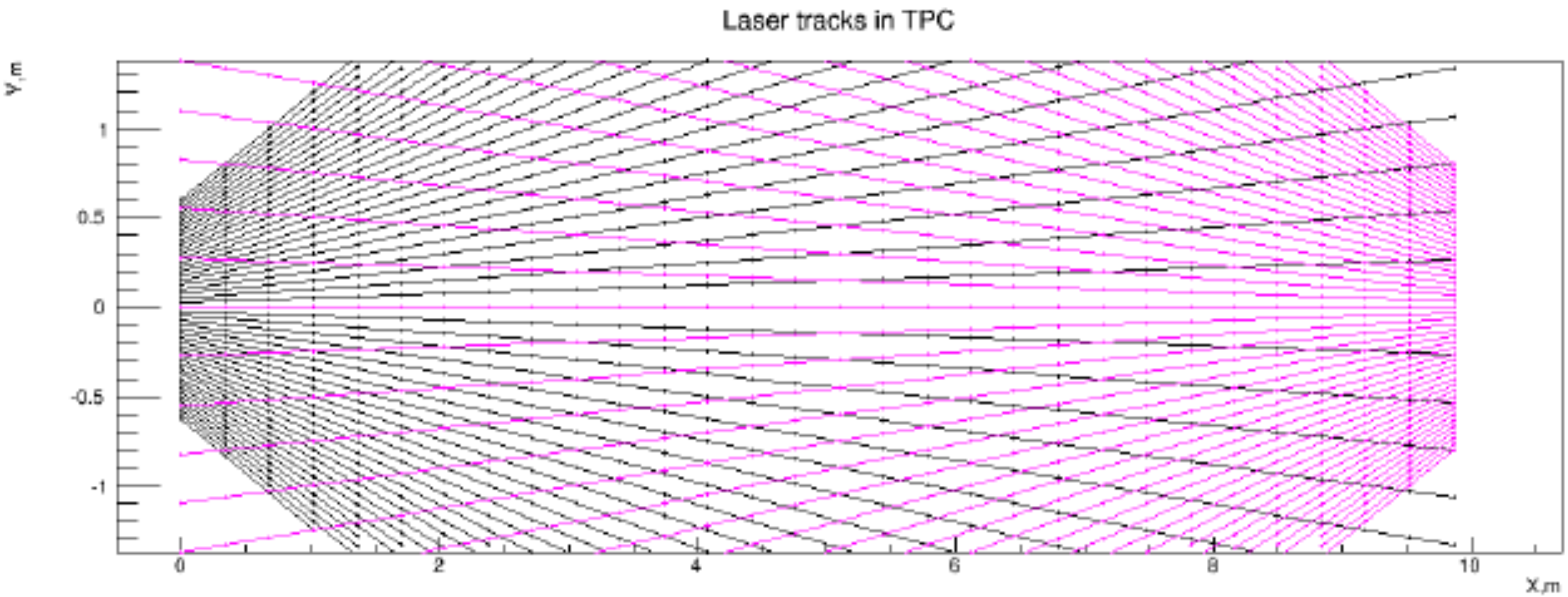
- Coverage of the TPC by using a moveable mirror
- TPC Volume scan in ~ 1h
- Two lasers to cover the full volume

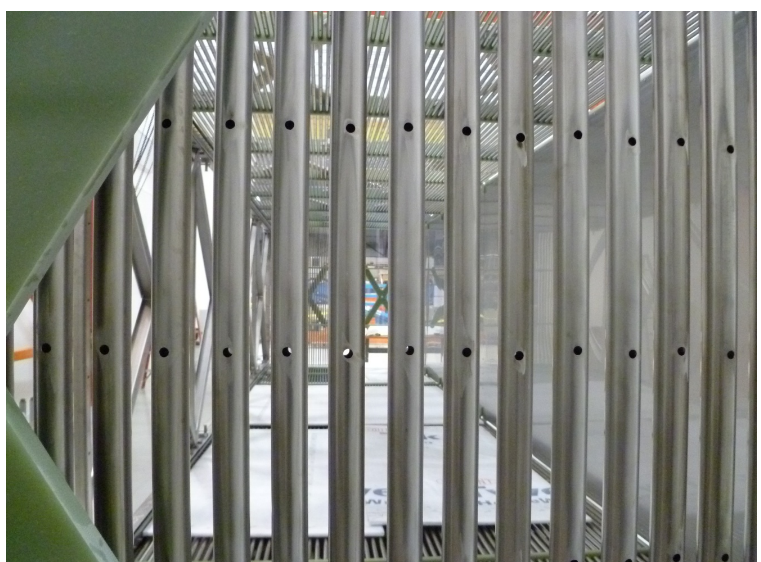




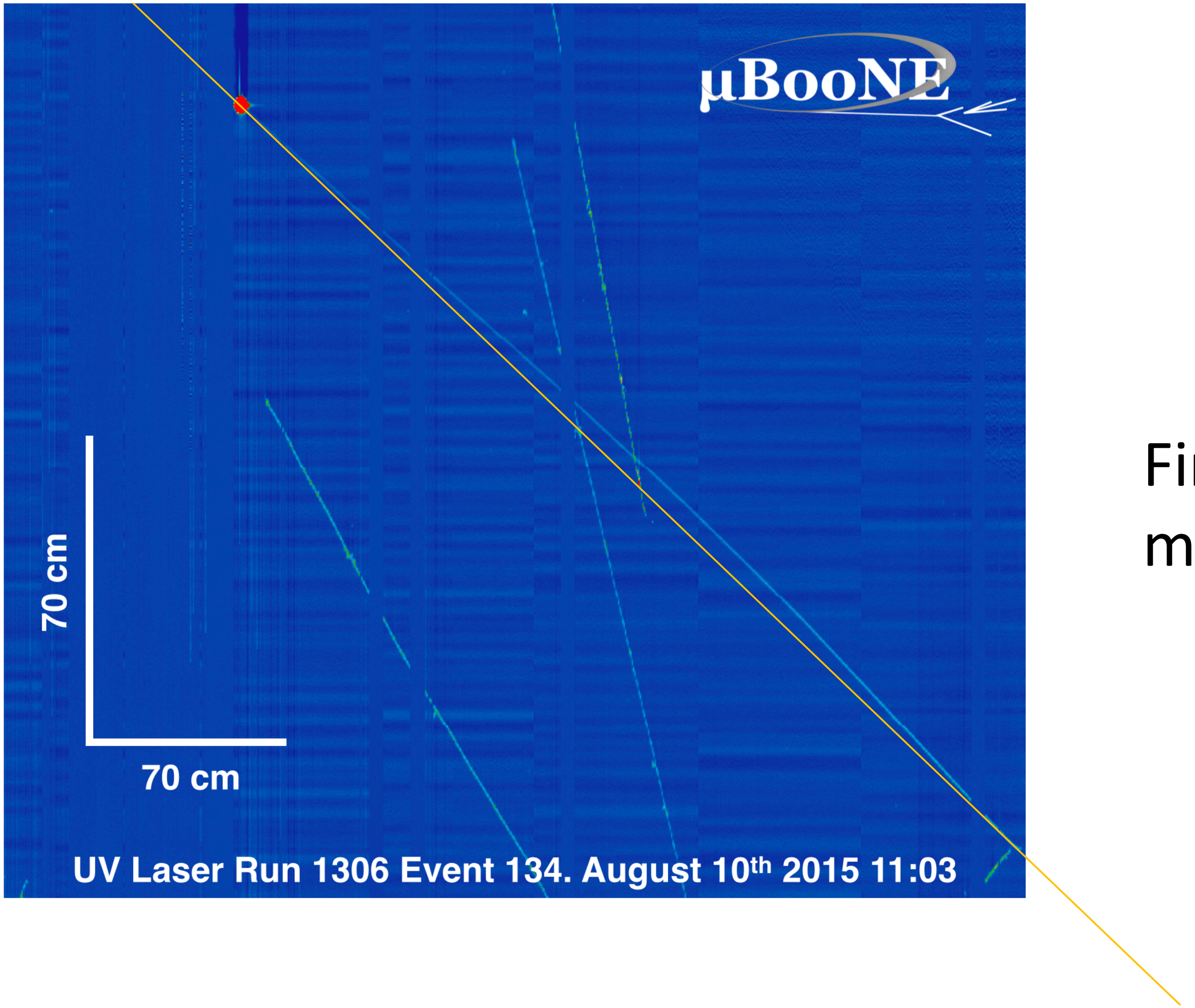


MicroBooNE geometry example



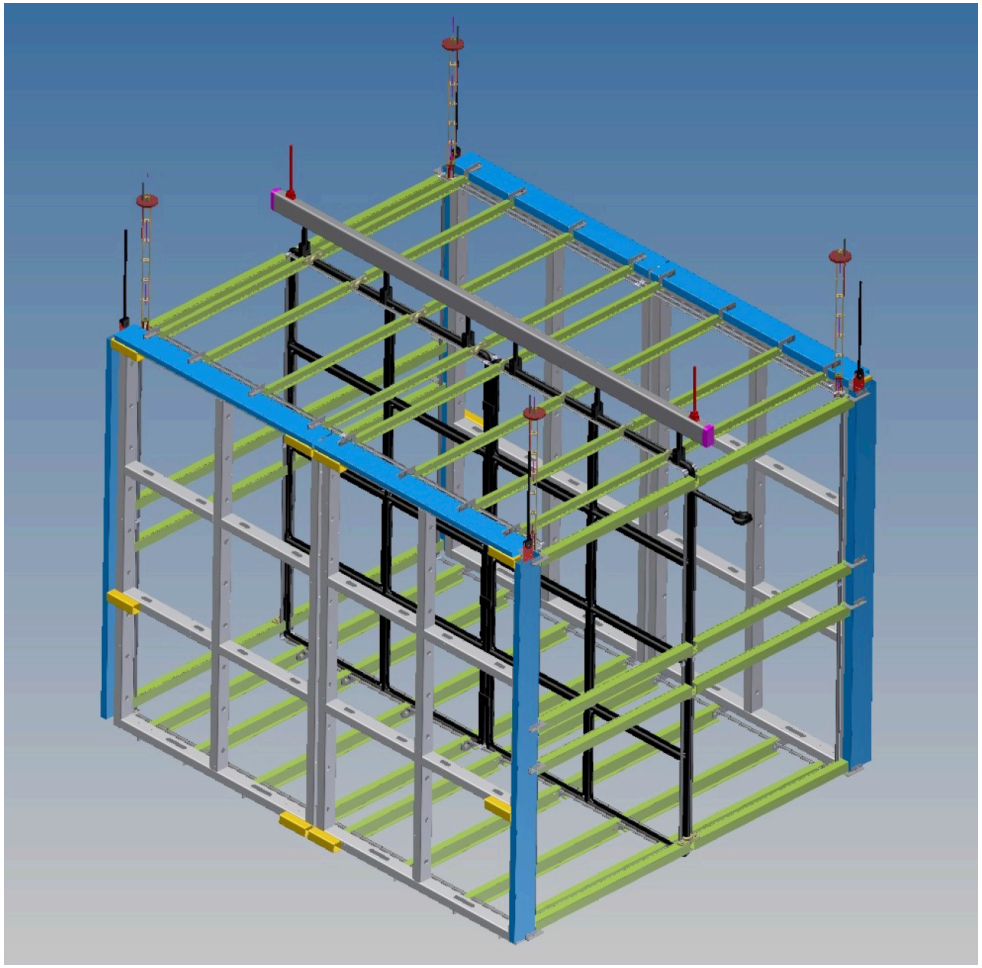


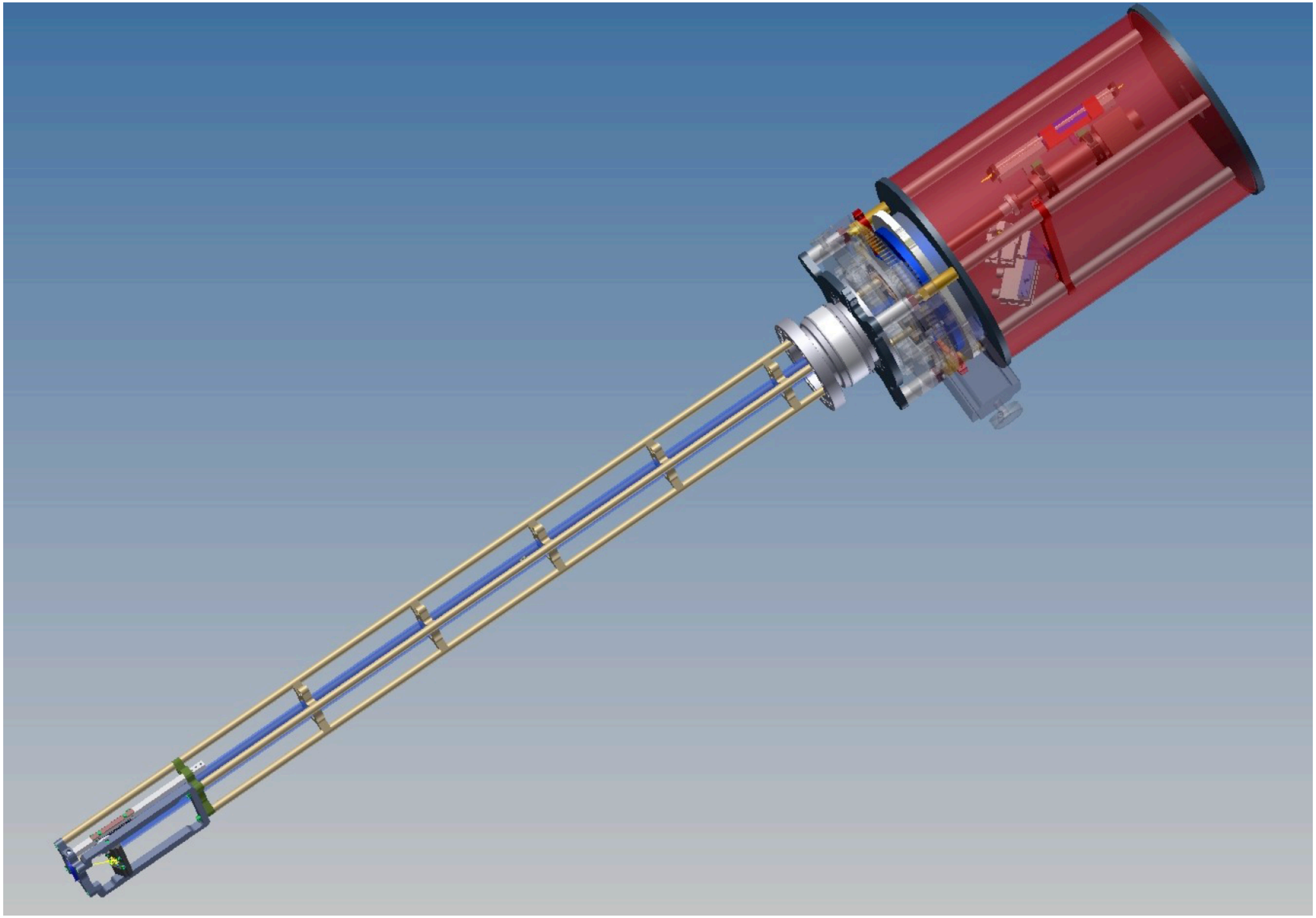
MicroBooNE geometry/field calibration

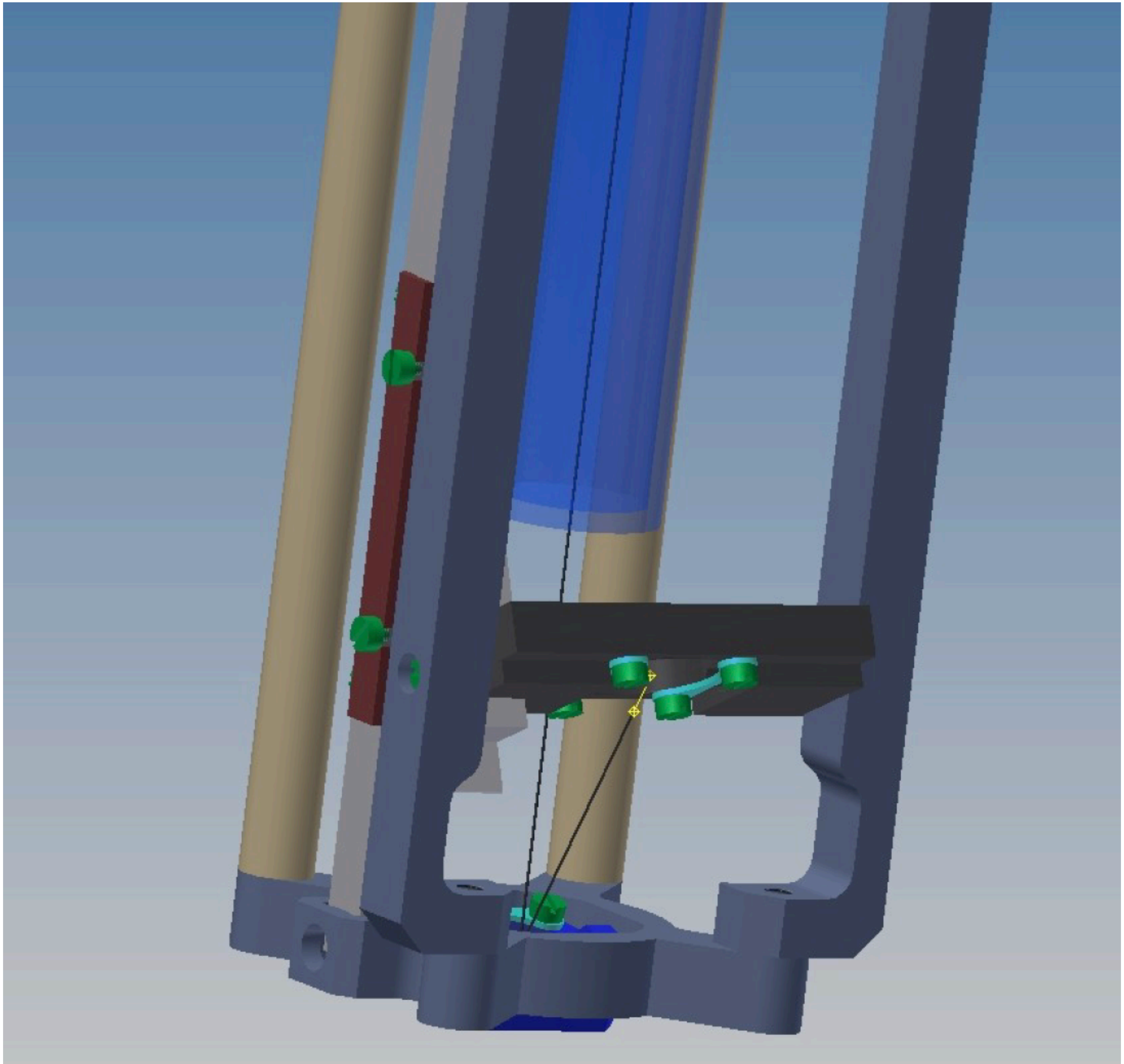


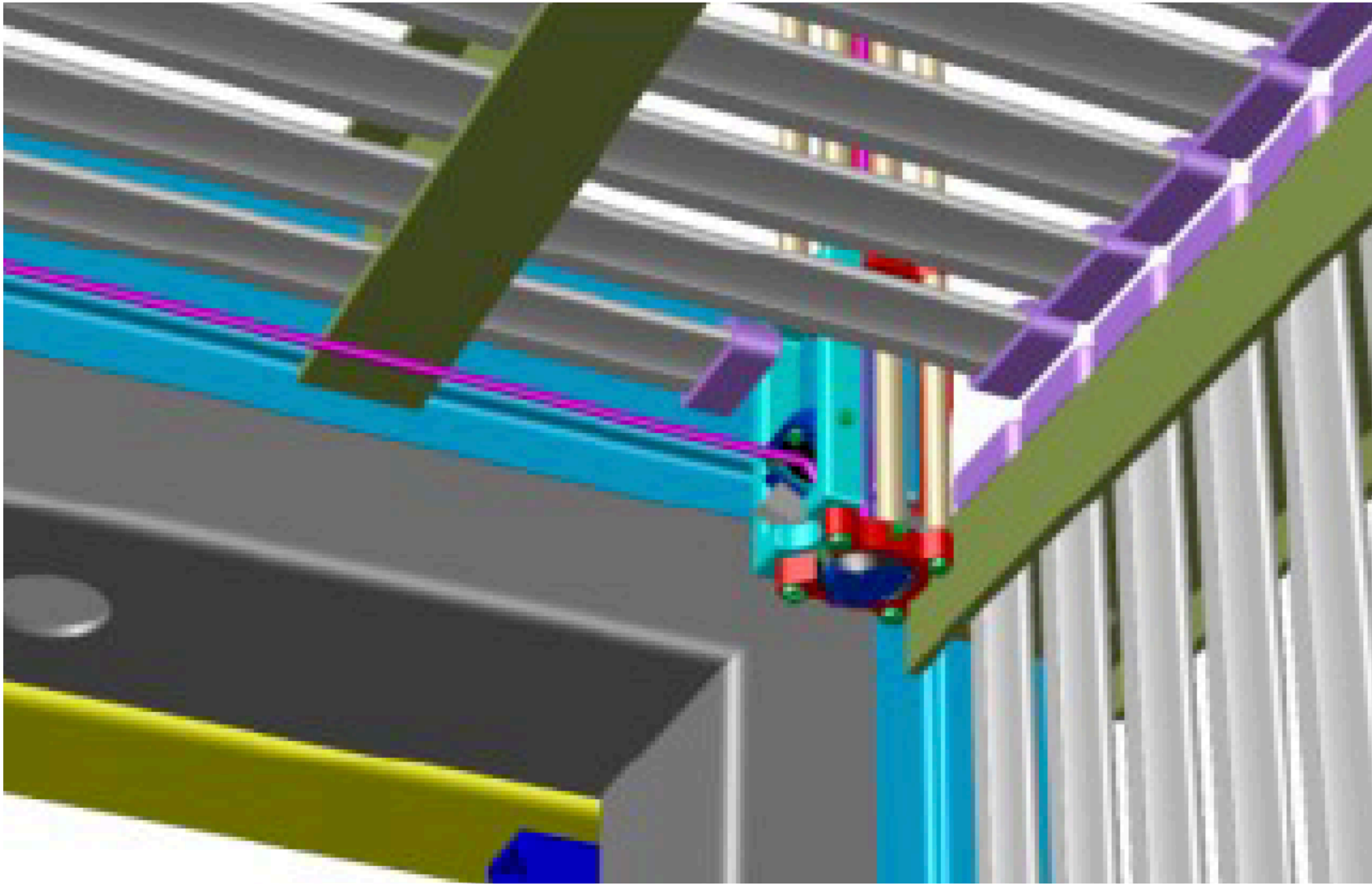
First field maps soon

SBND design



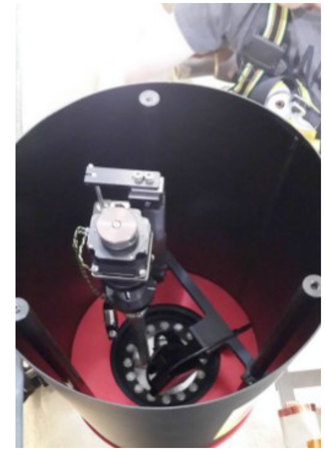


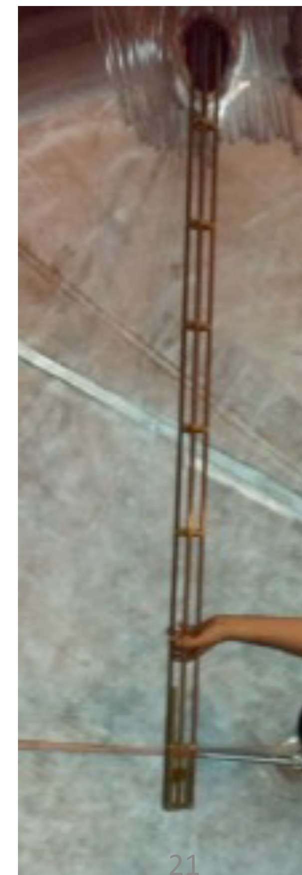




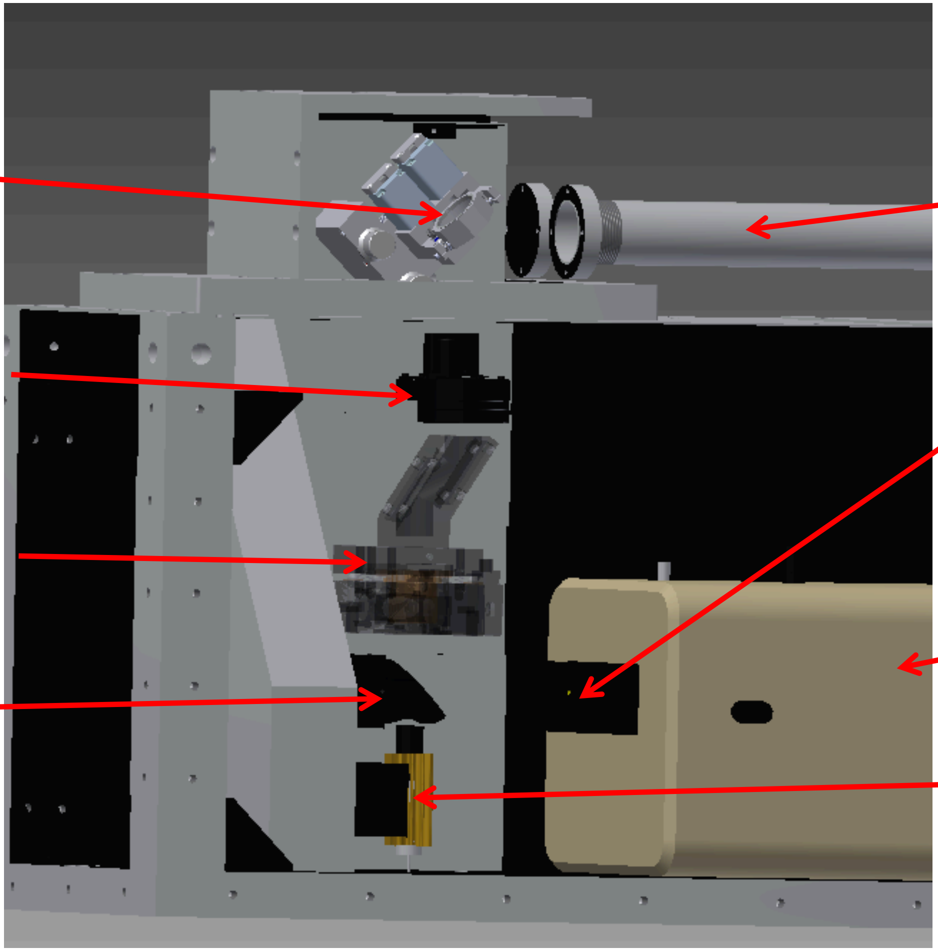
Requirements

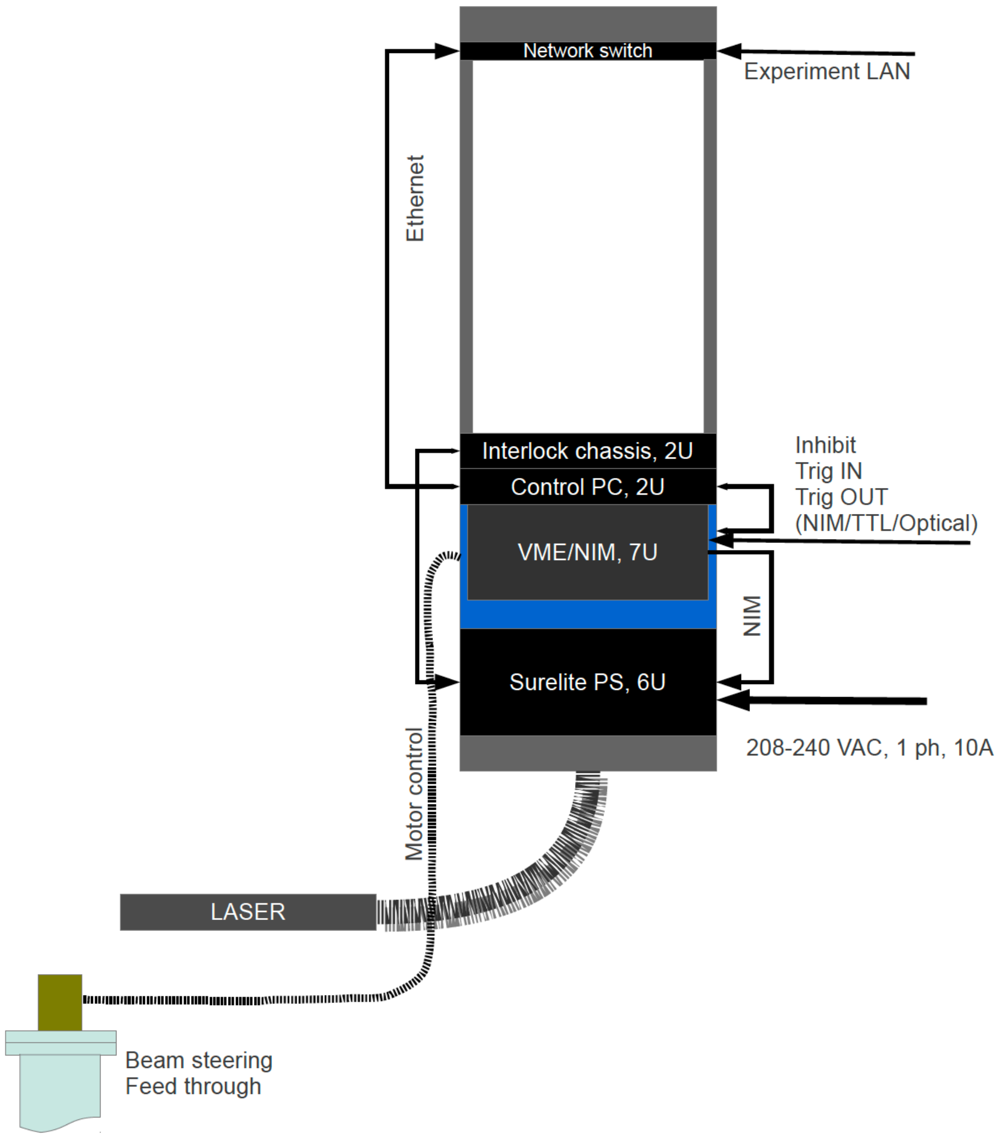
- Crossing tracks
- At least CF160, better CF200 flanges
- Space on top to insert feed-through
- Space to put the laser head, at level with the feed-through top, direct line of sight, optical stability
- Laser rack at <5m from the heads





Beam line-up

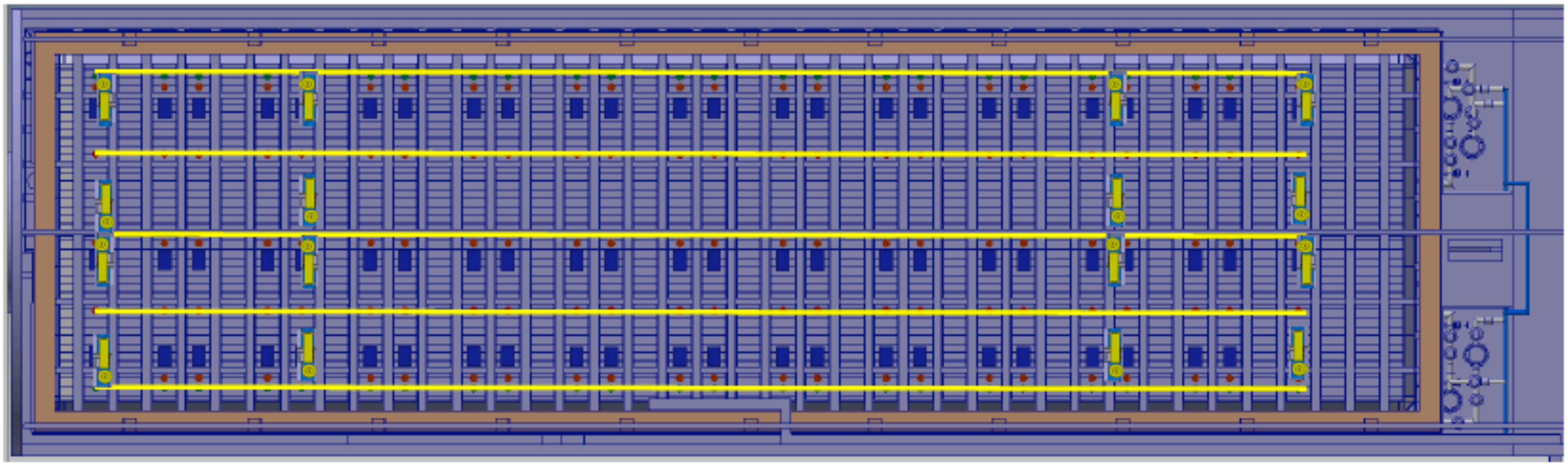

Steerable mirror
Motorized aperture
Motorized attenuator
First 266nm mirror
Beam tube
Laser shutter
Laser head
Optical laser



Network switch
Experiment LAN
Ethernet
Interlock chassis, 2U
Control PC, 2U
Inhibit
Trig IN
Trig OUT
(NIM/TTL/Optical)
VME/NIM, 7U
NIM
Surelite PS, 6U
208-240 VAC, 1 ph, 10A
Motor control
LASER
Beam steering
Feed through

From J. Stewart

Possible Laser configuration



- Assume a 16m laser path is possible as MicroBooNE has seen 10m.
- Place lasers near the anode planes so the field is low.
- Assume the corners are the most sensitive to effects of alignment/geometry and E-field distortions. Assume measurements will over the ends of the detector can be extending to the whole volume using cosmic rays.
- Assume that either the penetrations for the other calibration systems will have cameras that can see the laser feedthrus or the laser feedthrus will have the capacity to have a camera for alignment.
- Total of penetrations
  - 16 laser penetrations in the cryostat

+++ BACKUP +++

Rayleigh scattering at 266 nm

Index of refraction, Rayleigh scattering length, and Sellmeier coefficients in solid and liquid argon and xenon
arxiv:1502.04213

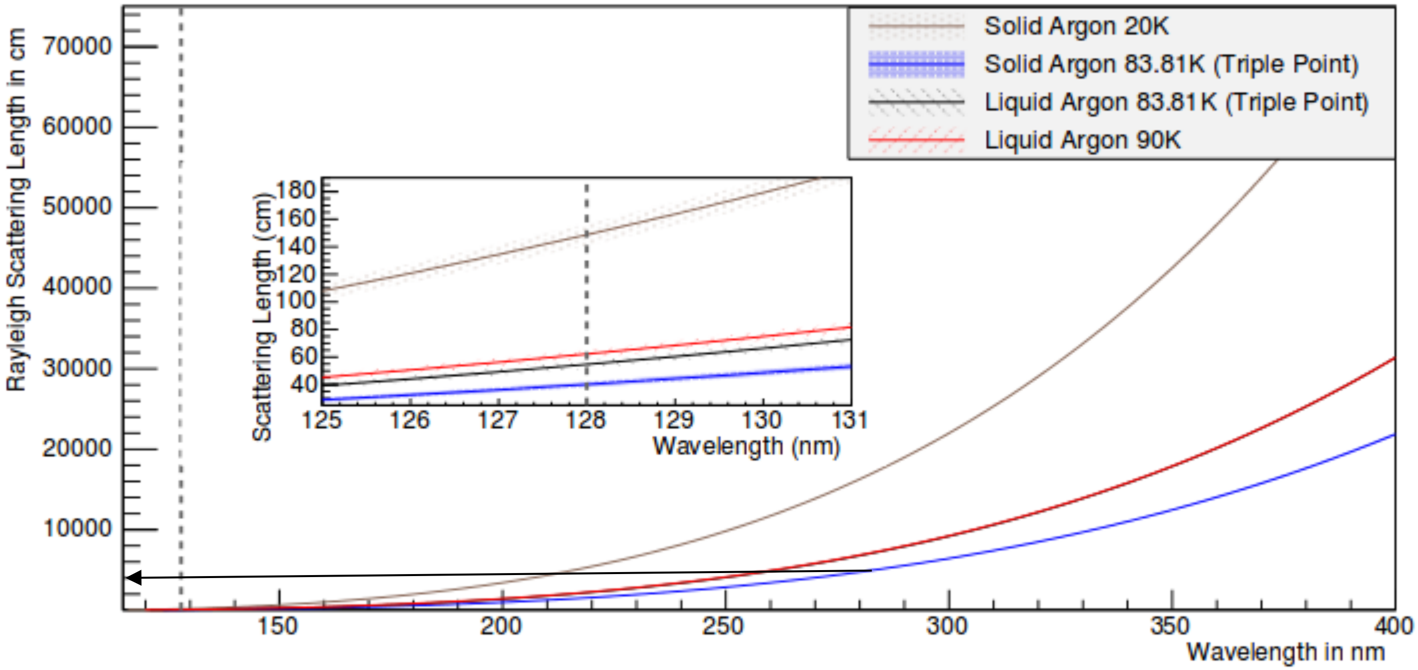
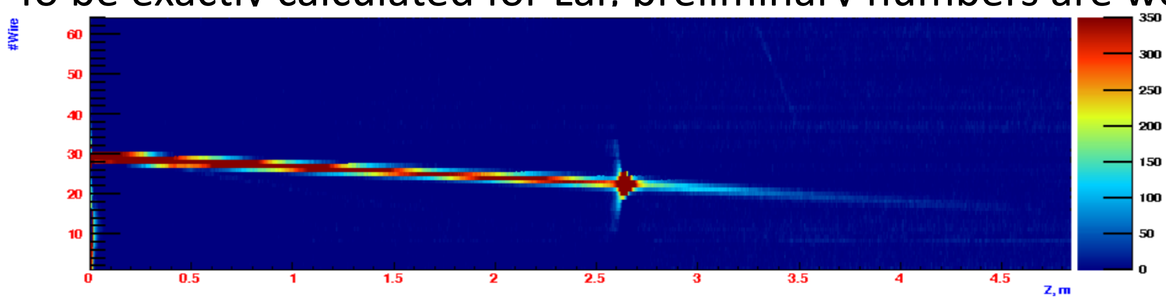


Figure 3: The Rayleigh scattering length of argon extrapolation. A dashed line is placed at 128 *nm*, the scintillation wavelength of Argon.

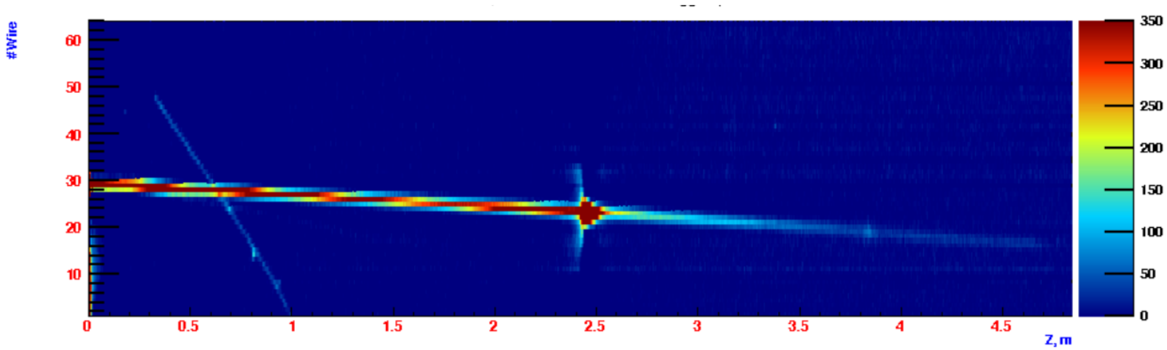
($\lambda_R \approx$40m at 266 nm)

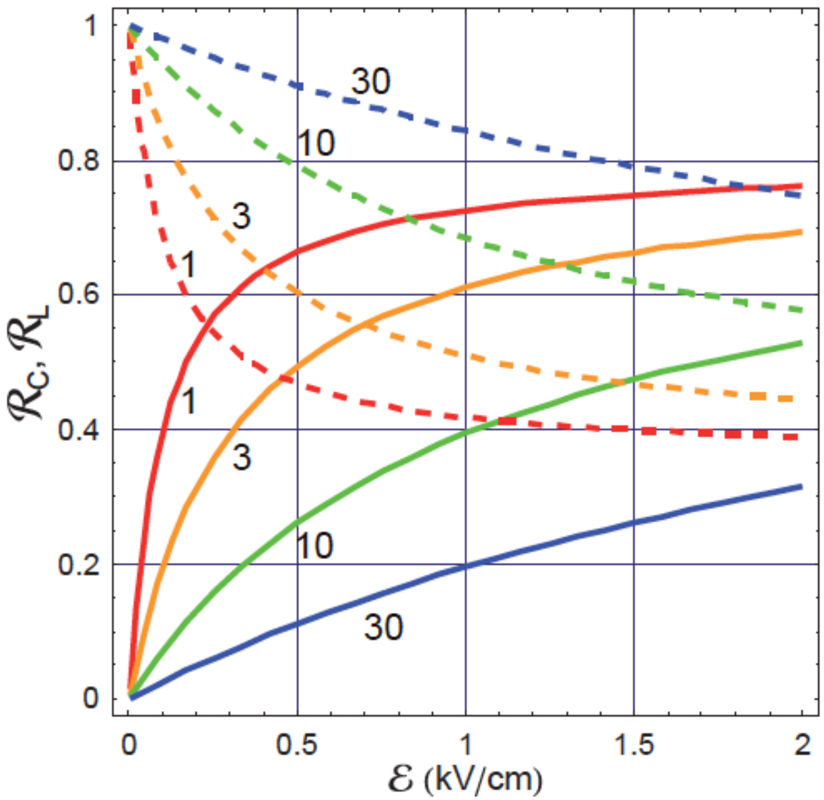
Non-linear effects (Kerr-induced self-focusing)

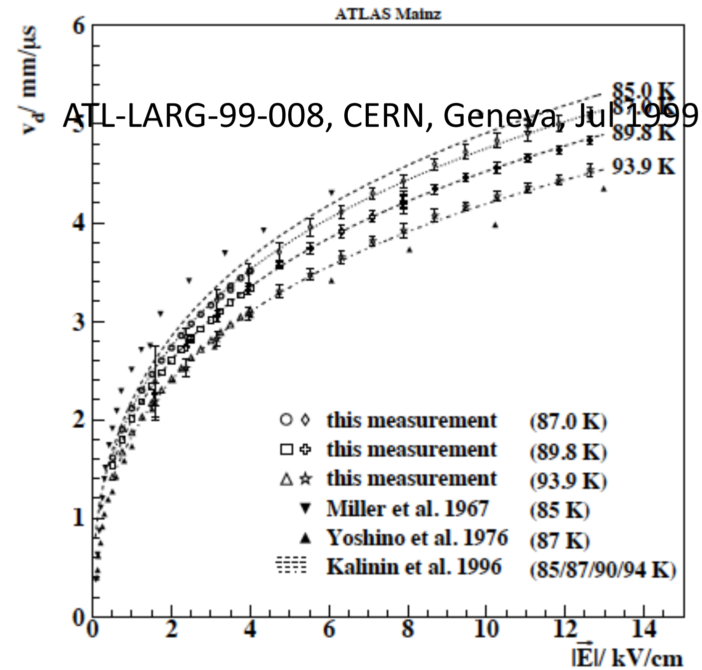
- AC Kerr effect: $$n = n_0 + n_2 I$$
  - Threshold: self-focusing appear at a beam power P > Pcr
- For silica, $n_0 \approx 1.453$, $n_2 \approx 2.4\times10^{-20}$ m^2/W, Pcr ≈ 2.8 MW.
- @10 mJ per 5 ns pulse we are at P=2 MW !
- To be exactly calculated for Lar, preliminary numbers are well below MW



Is it really self-focusing?







ATL-LARG-99-008, CERN, Geneva, Jul 1999

Recombination and light output (ratio for light and charge shown in the plot) depends on applied **drift field**

$$\frac{Q}{Q_0} = \frac{1}{\xi}\ln(1+\xi), \quad \xi = \frac{N_0 K_r}{4a^2 u\_E}$$

Phys. Rev. A, 36:614-616, Jul 1987

drift speed depends on the applied **drift field** and **Temperature**

And the drift time relates to charge loss due to **impurity**:

$$N(t) = N_0 e^{-t/\tau_e}$$

$$\tau_e[\mu s] = \frac{300}{P_{O_2 equiv}[ppb]}$$