Updated arguments for laser system

post special technical board meeting

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DUNE Calibration Task Force Meeting
Oct 5th, 2017

Big Picture

- This talk: State where the laser is strictly superior, complementary to information from cosmics
  - Assume enough cosmics for ~lifetime of experiment
  - Include current knowledge, motivations
  - *Mostly discussed on Tuesday meetings, so apologies to those who have heard this before. Comments welcome.*
- Today's goal: Identify studies to bolster the claims, for the TDR (or sooner, where possible)

Laser > ultimate cosmics

1. Stability of position dependent field effects
    - Space charge or space charge like effects (Ar39 combined with LAr convection can result in highly localized E-field distortions)
    - Failures which affect field: APA/CPA offsets, voltage variations in the cathode, resistive divider failure, field cage deformation, insulator charge up.
    - E field variations have not agreed in existing LAr TPCs
2. “Global” (multiple APA) alignment
3. Motion of the support structure
    - TPC is suspended from an array of pivoting hangers. Friction in the pivoting joints may produce unexpected shifts.

Laser > ultimate cosmics

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Any other cases?

Laser > ultimate cosmics

1. Stability of position dependent field effects - ***Crossing tracks?***
   - **Quantify: How big are these effects?** Space charge or space charge like effects (Ar39 combined with LAr convection can result in highly localized E-field distortions)

Qualify: why crossing tracks are needed for each?
Quantify: how well each measurement can be done (TDR)

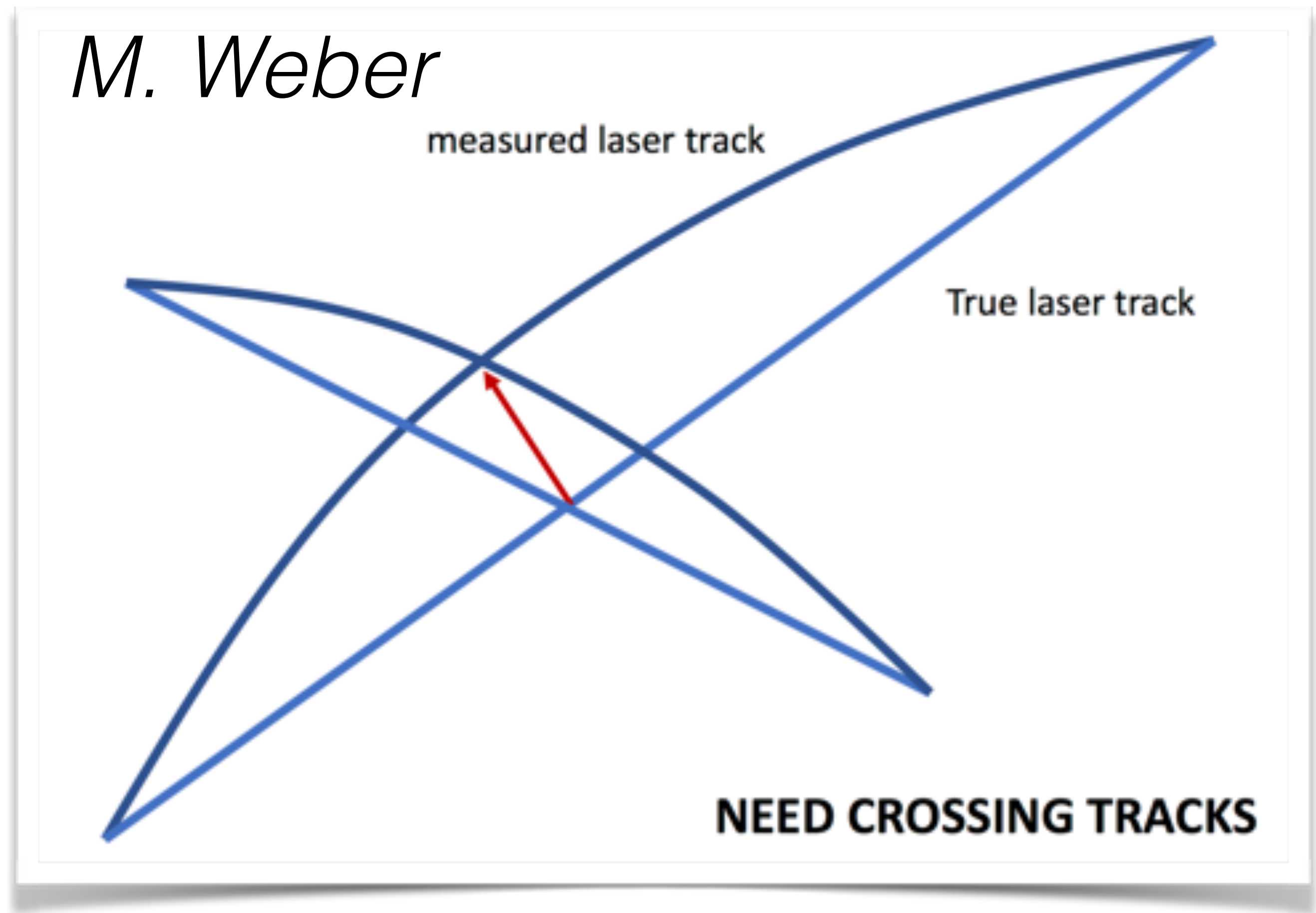
2. "Global" (multiple APA) alignment - ***Crossing tracks?***
3. Motion of the support structure - ***Crossing tracks?***
   - TPC is suspended from an array of pivoting hangers. Friction in the pivoting joints may produce unexpected shifts.

E-field: motivations from HV side

- Laser can map out E-field distortions from ***resistor failure across a field cage***
  - We will have a <u>large number of resistors</u> across the field cage
  - If a resistor fails, the local field distortions in that region can go from 3kV to 5 kV (docdb 1908, page 42-49)
  - Slow Controls will determine a resistor has failed but not its location (and where E field is distorted)
  - **Quantify:** with Cosmics, need to wait a long time for cosmics to go through the specific region where we have a failure
  - **Quantify:** How well do we expect laser can do this?

Independence (and dependance) of laser system E field measurement

- Know: measured track position and time, timing of laser pulse, position of laser intended track
- Unknown: distance or drift velocity
- Argument: Even if dependancies, independent of recombination; relative measurements beneficial



How do we clearly articulate the benefit and limit of laser E-field constraint?

Laser ~ ultimate cosmics

- APA local alignment - workable based on 35t experience
- Cathode flatness, APA flatness - takes time but possible?
  - APA frames can twist, modifying plane spacing which impacts transparency conditions between wire planes. Ionization electrons may only get partially collected by the collection plane wires.
  - Compensation in wire bias voltages may restore full collection when the wire plane position deviate less then 0.5mm from design values. beyond that, the bias voltages needed may be too close to the voltage rating of the components.
  - **Verify:** Can this be done with cosmics with arrival time differences? (TDR study?)
  - **Quantify:** How well can this be done with laser tracks (TDR study)
- Electronics testing - neither
  - Internal calibration circuit. External charge injection is useful to verify sense wires are connected to electronics. Can pulse cathode (Bo)

Iteration on Feedthroughs

Presented ideal request for laser system at special technical board meeting last Friday. Engineers have a an updated feedthrough default proposal (next page) and and (short term) questions:

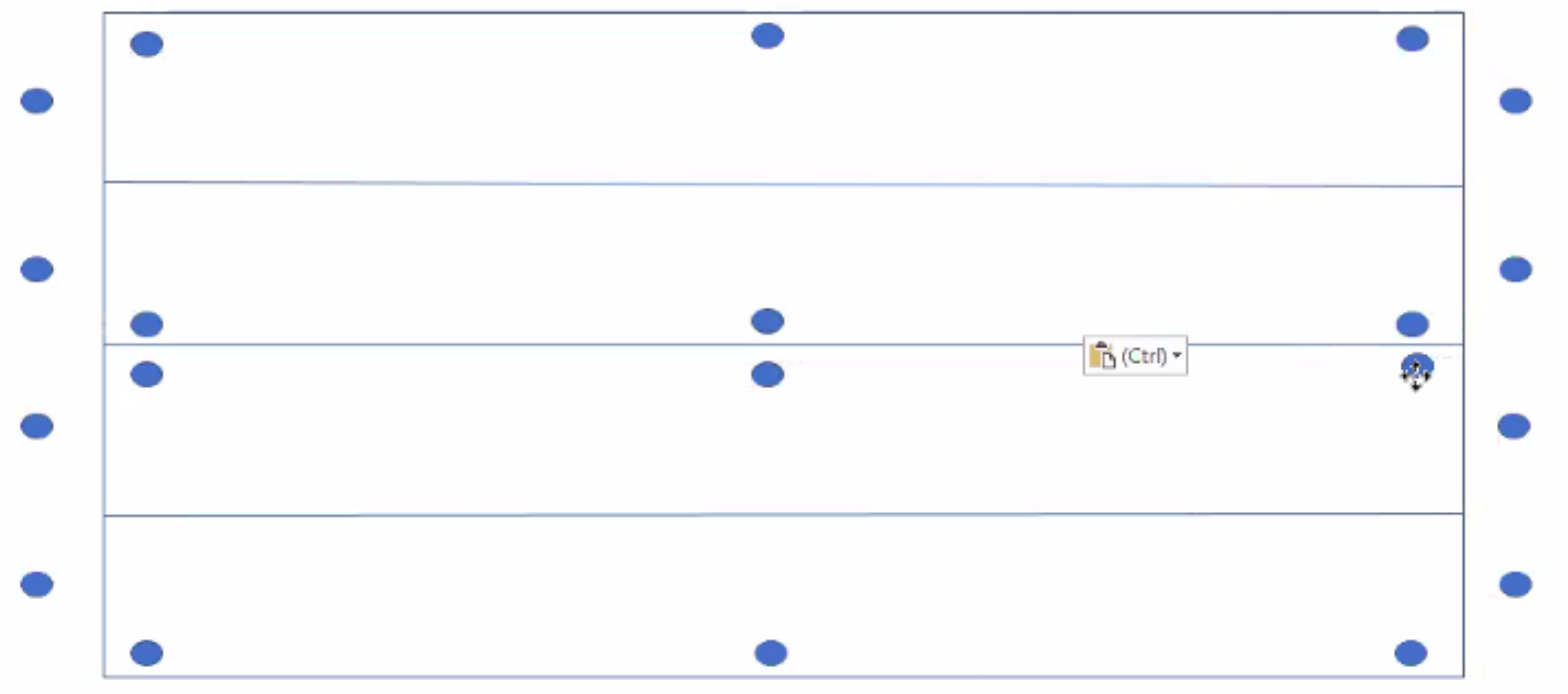
- Does not allow for crossing tracks. Will also have opportunity for an alternate proposal which does.
- For the current system, what is the optimal placement of the laser? Can we fire the laser from the end of the cryostat or must it only be mounted on top?
- Can we share (temporally) with other systems (steerable cameras + radioactive sources?)
- What is the cost of a laser system? (If it is 2M$, we won't have 20…)
- What happens if laser is outside the field cage? Do we need to have holes in the field cage for the laser system?

Option A: Artist's rendition of FT options

5->3 FT along N/S edge due to signal cable limitations

- Center ports as per radioactive sources mid-point of drift
- How far can the laser be moved away from the APA?

Option B: Artist's rendition of FT options



Moved FT toward old laser positions

- Does this work for radioactive sources?
- Easier to put ports in central area wherever we would like

Laser next steps

For the new nominal proposal, where are ideal laser points and related logistical concerns?

Prepare an alternate proposal which adds crossing tracks, refine why crossing track functionality is essential

What studies do we need for TDR?

Backup slides

Cosmics and other sources of muons

- *Overall cosmic rate:* 4000 per day per 10 kt module
  - https://indico.fnal.gov/getFile.py/access?contribId=3&resId=0&materialId=slides&confId=14909 (Vitaly)
  - Stopping muons: 30/d/10kt, APA-CPA crossing tracks 200-500/d/10kt
  - Limited angular coverage: No muons at zenith angles >75 degrees
  - Roughly, each collection plane wire is hit only every 2-3 days **at best** (assuming 100% efficiency and no geometry considerations)
- *Beam induced rock muons:* 1 - 3/d/10kt
- *Atmospheric neutrinos:* ICARUS saw 0.3 ν per day (476 ton active volume), implies 7/d/10kt for DUNE. Also muons from atm ν - rock interactions.
  - typically lower energy, multiple Coulomb scattering effects dominate

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Stability measurements from cosmics are not possible on a short timescale. Tests of spatial effects across whole detector are also (too) coarse.

- *Bea*
- *Atmospheric neutrinos:* ICARUS saw 0.3 ν per day (476 ton active volume), implies 7/d/10kt for DUNE. Also muons from atm ν - rock interactions.
  - typically lower energy, multiple Coulomb scattering effects dominate

More qualitatively…

- The TPC response model is a very convolved model and calibration parameters are strongly correlated!

<u>TPC response model</u>

Argon ionization energy
Electron drift velocity
t_0 offsets
Electron lifetime
Recombination parameters
Electric field
Longitudinal and transverse electron diffusion
Wire positions/geometry
Wire field response
Channel gain
Overall electronics analog transfer function
Electronic crosstalk
Electronics noise, including correlated noise
ADC linearity (differential and integral).

<u>Photon detector response model:</u>

<similar list here>

Correlations!!!

<u>High level quantities</u>

Position reconstruction biases
Direction reconstruction biases
Energy scale
Energy resolution
Particle ID efficiencies
Noise removal efficiencies
…
…

<u>Particle response</u>

Charged hadron propagation
Neutron response
…

More qualitatively…

- The TPC response model is a very convolved model and calibration parameters are strongly correlated!

TPC response model
Argon ionization energy
Electron drift velocity

High level quantities
Position reconstruction biases

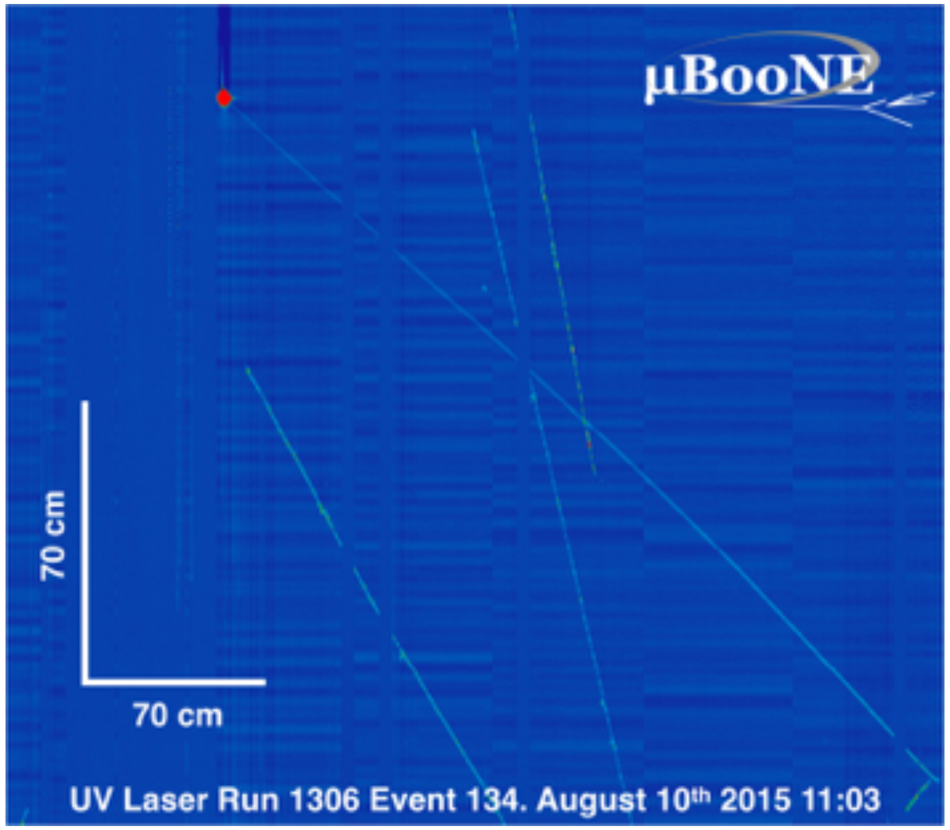
Currently, we have no system in the detector that can provide an independent probe for calibration.

A Laser system provides measurements with reduced or removed interdependencies. This mitigates risk in the face of unforeseen difficulties.

Photon detector response model:
<similar list here>

Laser System

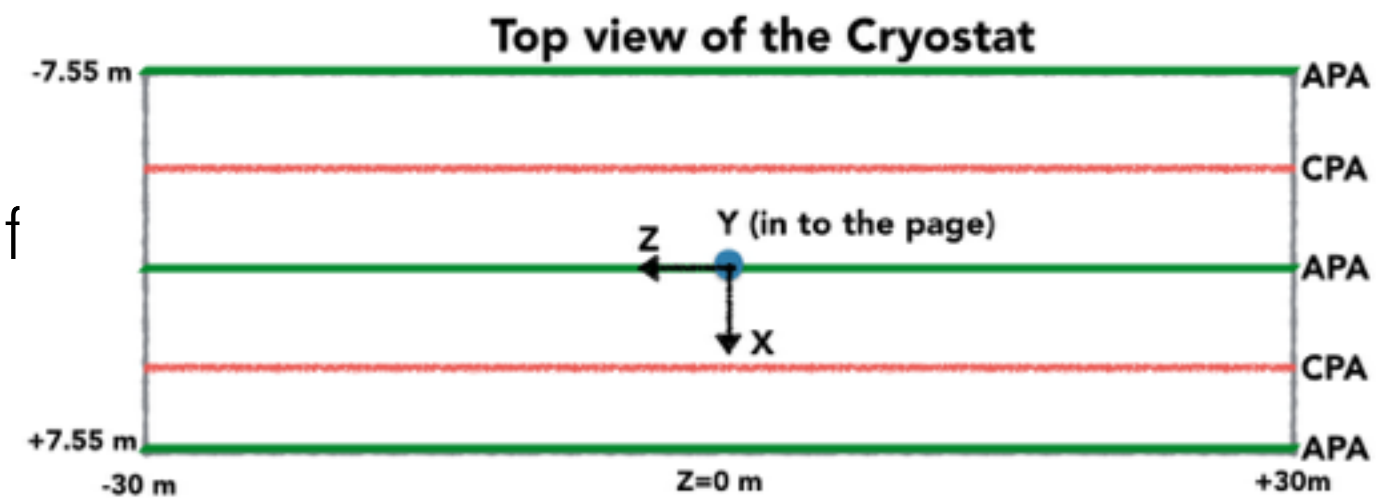
- For the purposes of argument here, the uB/SBND style Laser is considered as the default design choice. Details of this system in backup.
- *Laser is useful in many ways:*
  - Alignment, Stability Monitoring
  - Diagnosing failures *(need crossing tracks)*
  - E-field map *(need crossing tracks)*
  - ….



- *Big picture of Cosmics vs Laser - specific cases in following slides*
  - Generally, while cosmics can be used to map the entire TPC volume, it will take few months to a year *vs* Laser on the scale of days. Some measurements are not possible with cosmics, especially related to mapping spatial effects.

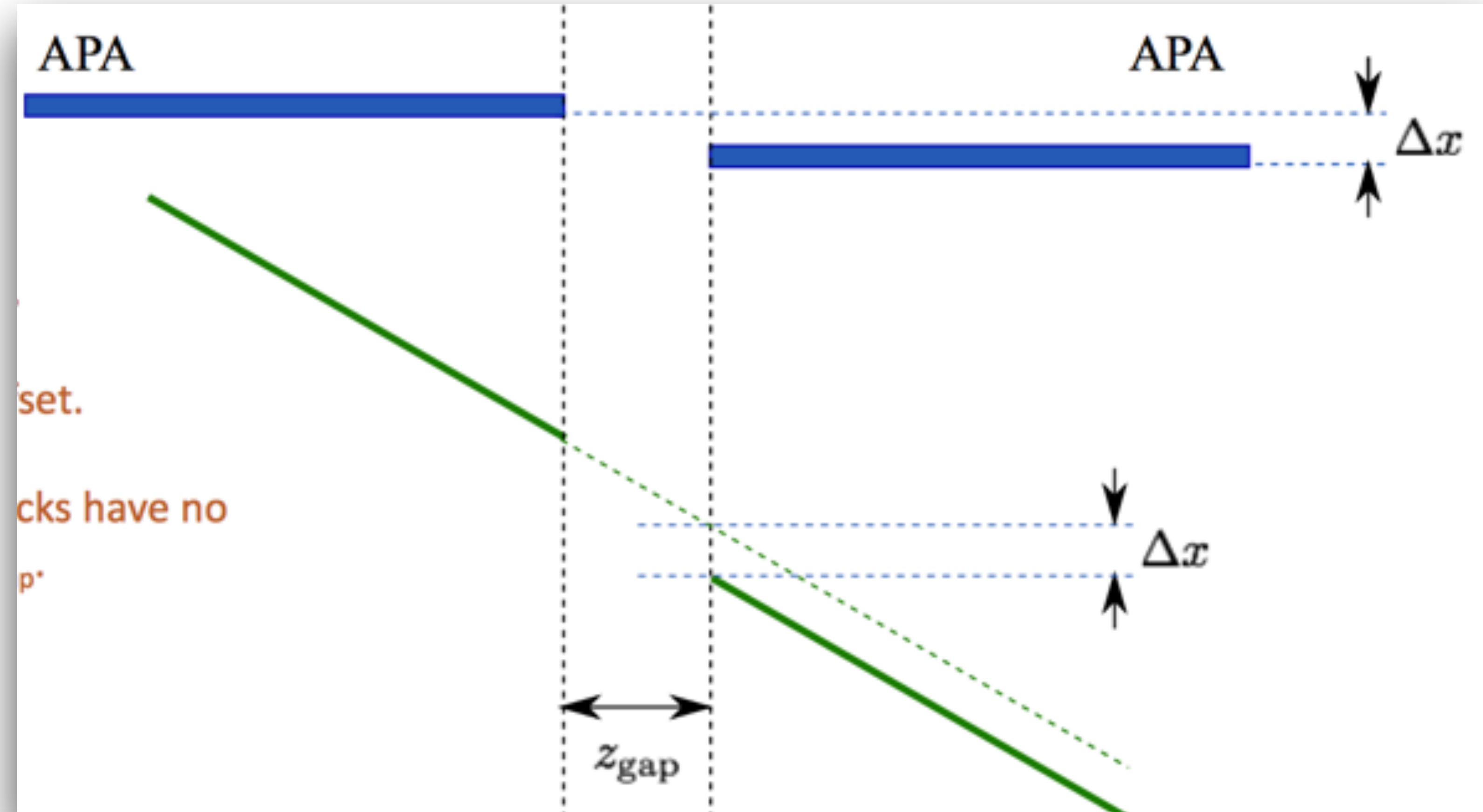
Alignment scale, issues

- Alignment affects measurement of muon momentum from multiple scattering
- *Mechanical changes during cool down: (V. Guarino, J. Fowler)*
  - Δx (drift): +/- 3mm before and after cool down; 7 mm due to bowing during cool down at half height of the CPA



  - Δy (vertical): 36 mm shrinkage
  - Δz (beam direction): about 180 mm shrinkage over the entire length (25 APAs results in 24 gaps with each gap around 2.32 m. Expect about 6.5 mm shrinkage in each gap. For 58 m length, results in about 180 mm)
- *This can also affect APA-CPA alignment; non-uniform gaps across APAs in the Z direction*

APA-APA "local" alignment: cosmics



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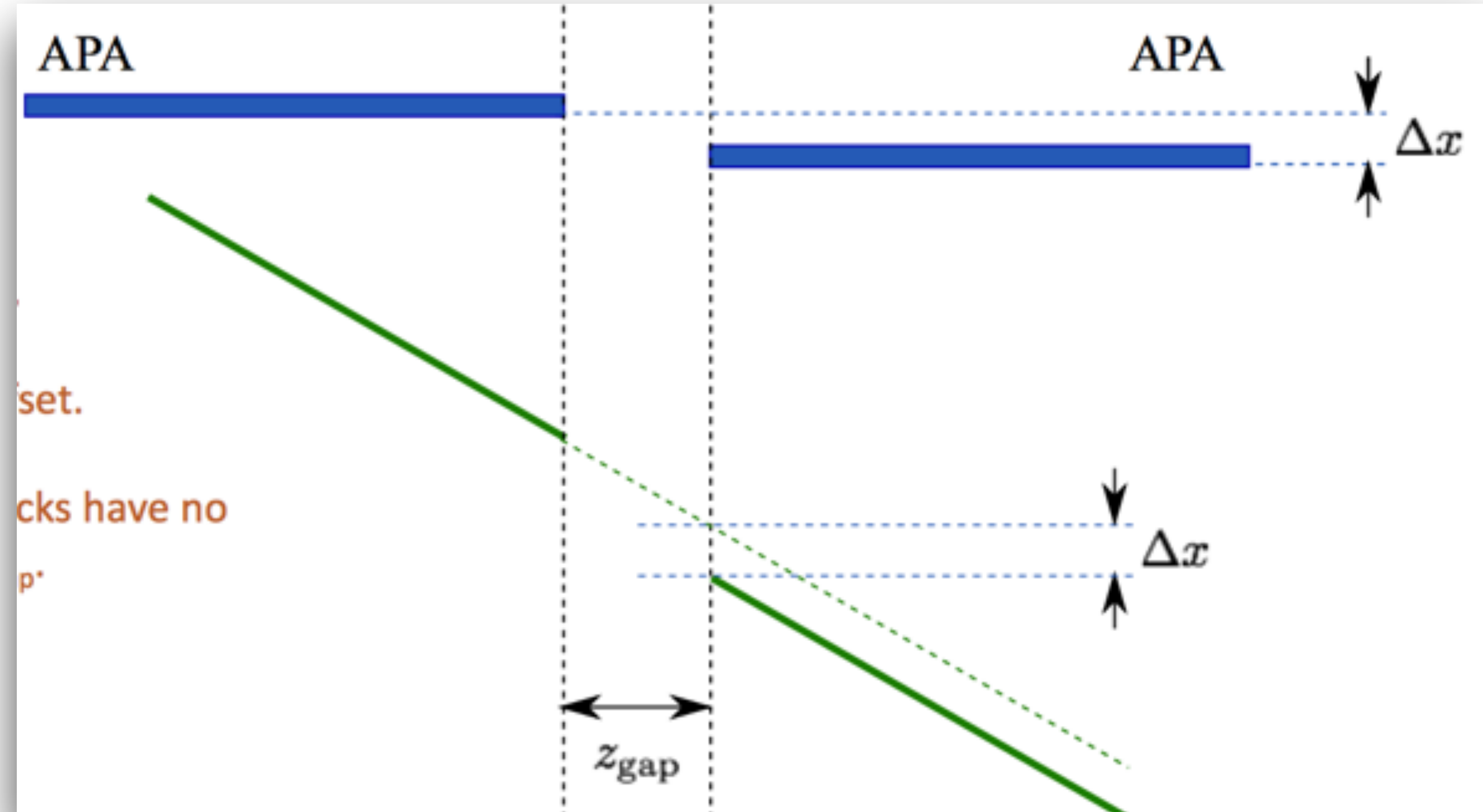
(Tom Junk)

- 35-ton saw Δx, Δz ~3mm at precision of 0.05mm

- Δy may depend on angular distribution of cosmics

APA-APA "local" alignment: laser



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(Tom Junk)

- 35-ton saw Δx, Δz ~3mm at precision of 0.05mm - Laser has comparable precision (sub-mm)
  - To achieve similar precision for DUNE, need ~1 year of cosmics vs. laser ~ days.
- Δy may depend on angular distribution of cosmics - laser provides range of angles

Other (mis) alignments

- *All-APA "global" alignment:* cosmics boot-strapped (only relative alignment), laser track can cross multiple APAs

- *Motion of support structure:* difficult/impossible with cosmics, laser location, reproducible position constrain scenarios.

    - APAs hang from a support structure and frictions are involved; currently unpredictable as to how it impacts APA/CPA offsets

    - Mechanical support of APA/CPA not on the same pitch, can also result in unpredictable gaps.

    - Cooldown shifts the support structure and may not agree with models/expectation

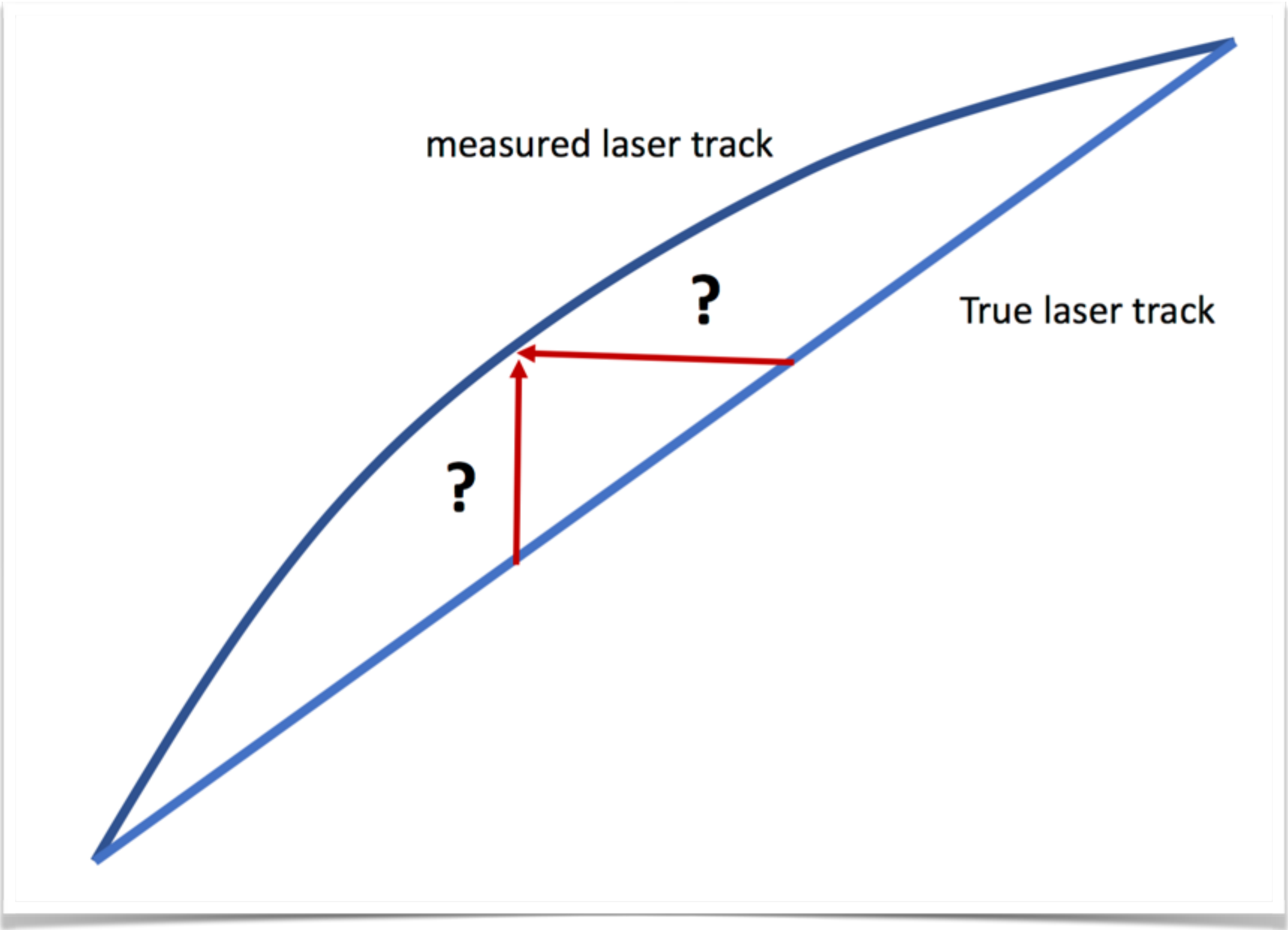
Diagnosing failures and stability monitoring

- *Cathode flatness*
    - ICARUS measured (empty, warm) cathode flatness, consistent with cosmics (~6 months). After refurbishment, residual distortions from simulation at ~2mm level.
    - For DUNE sized detector, cosmics measurement may take ~years. Laser rapid.
- *APA flatness*
    - APA frames can twist, modifying plane spacing which impacts transparency conditions between wire planes. Induction plane signals may only get partially to the collection planes
    - +/- 0.5 mm shift is correctable, but beyond that it is risky (Bo)
    - Not possible with cosmics, laser only option
- *Failure of electronics to readout:* Laser rapid, wait for cosmics to hit wire/region
- *Voltage variations across cathode:* unlikely event, but impossible with cosmics, laser only option

E-field distortions

- *Space charge presumed low, but no estimate yet for DUNE.*
    - Example of similar effects: Ar39 combined with fluid flow can result in highly localized E-field distortions. (Bo)
- *Other sources that can distort the E-field:*
    - APA/CPA offsets, voltage variations in cathode,…
    - Strong dependence of calibration parameters on E-field (e.g. Recombination, drift velocity, track distortions,…)
        - Stringent requirements from Physics on energy scale bias. According to experts, a 10% uncertainty in field can lead to about 1.5% bias in energy!
    - E-field variations from existing LArTPCs (MicroBooNE, ICARUS) has not agreed with expectations
- Laser measurement of the field have reduced or removed degeneracies, with good volume coverage and statistics. **If not Laser, what in-situ methods do we have to assess E-field distortions?**

How crossing track determines E field
(Michele Weber)



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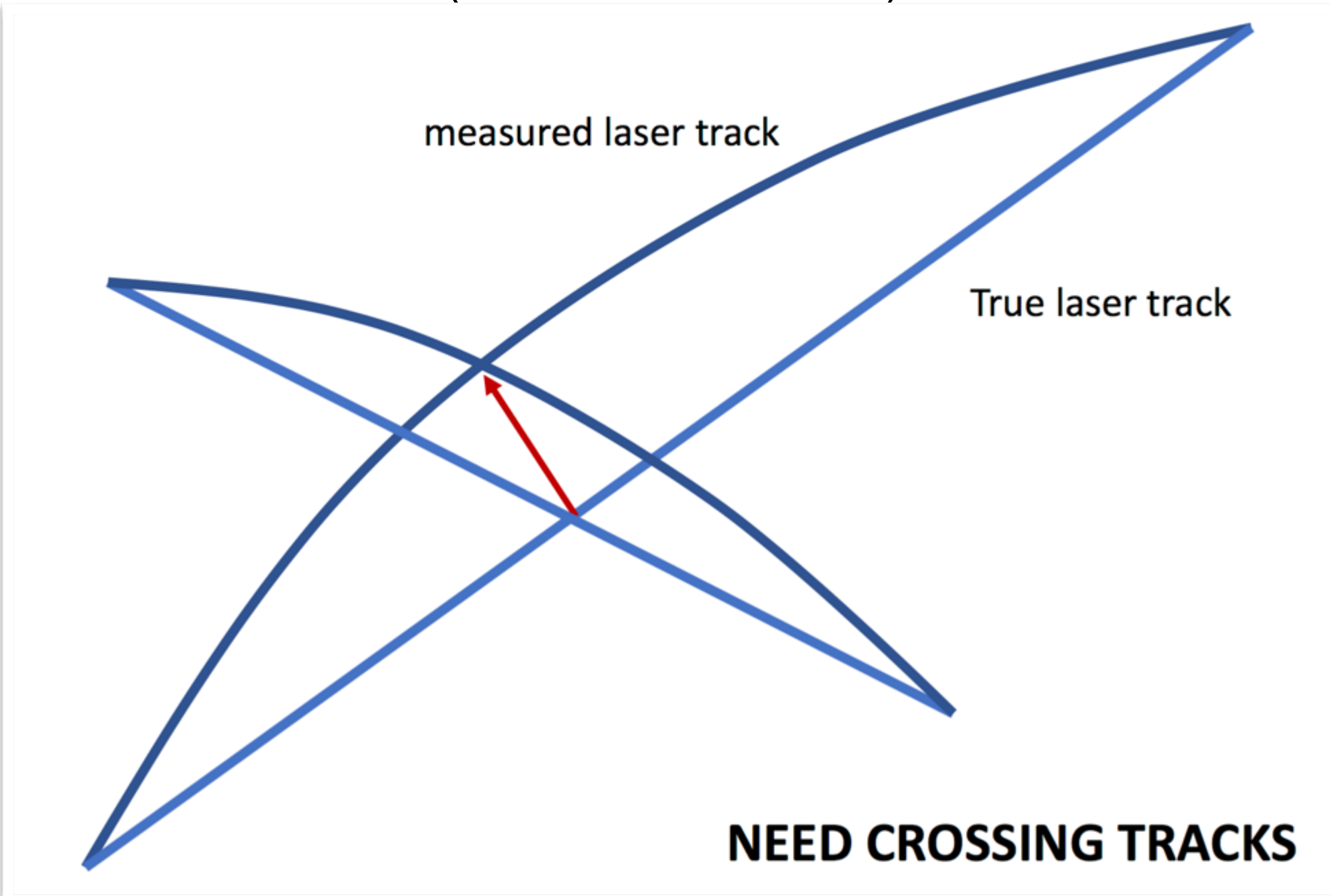

E-field: motivations from HV side

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  - We will have a large number of resistors across the field cage
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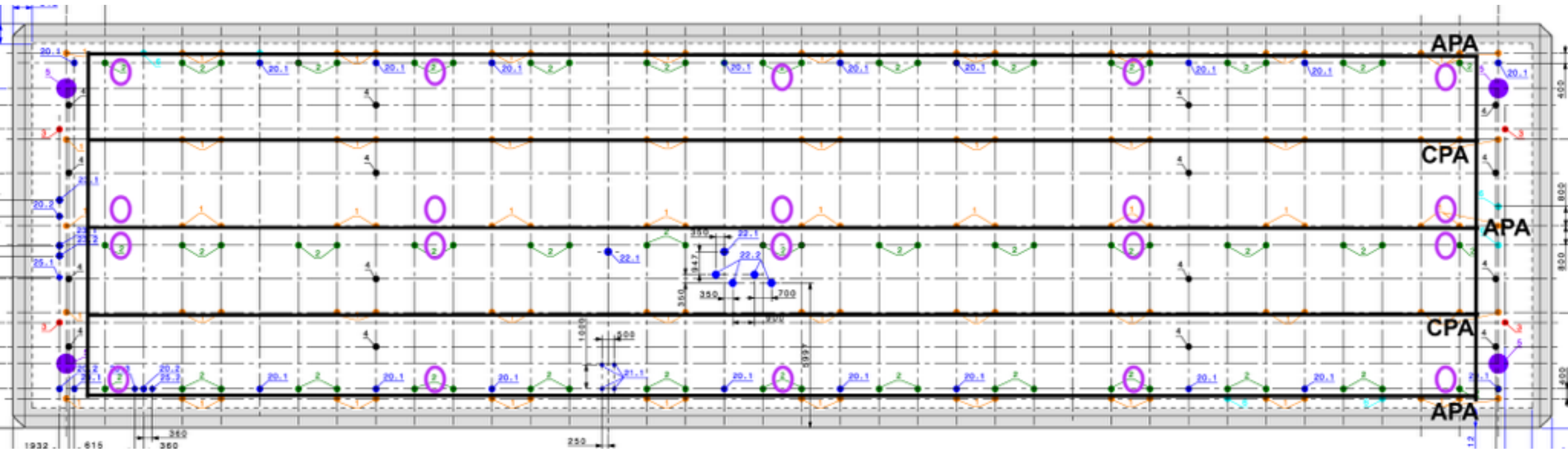
Laser Feedthrough request (assuming 15 m achievable range; 10 m demonstrated by MicroBooNE)



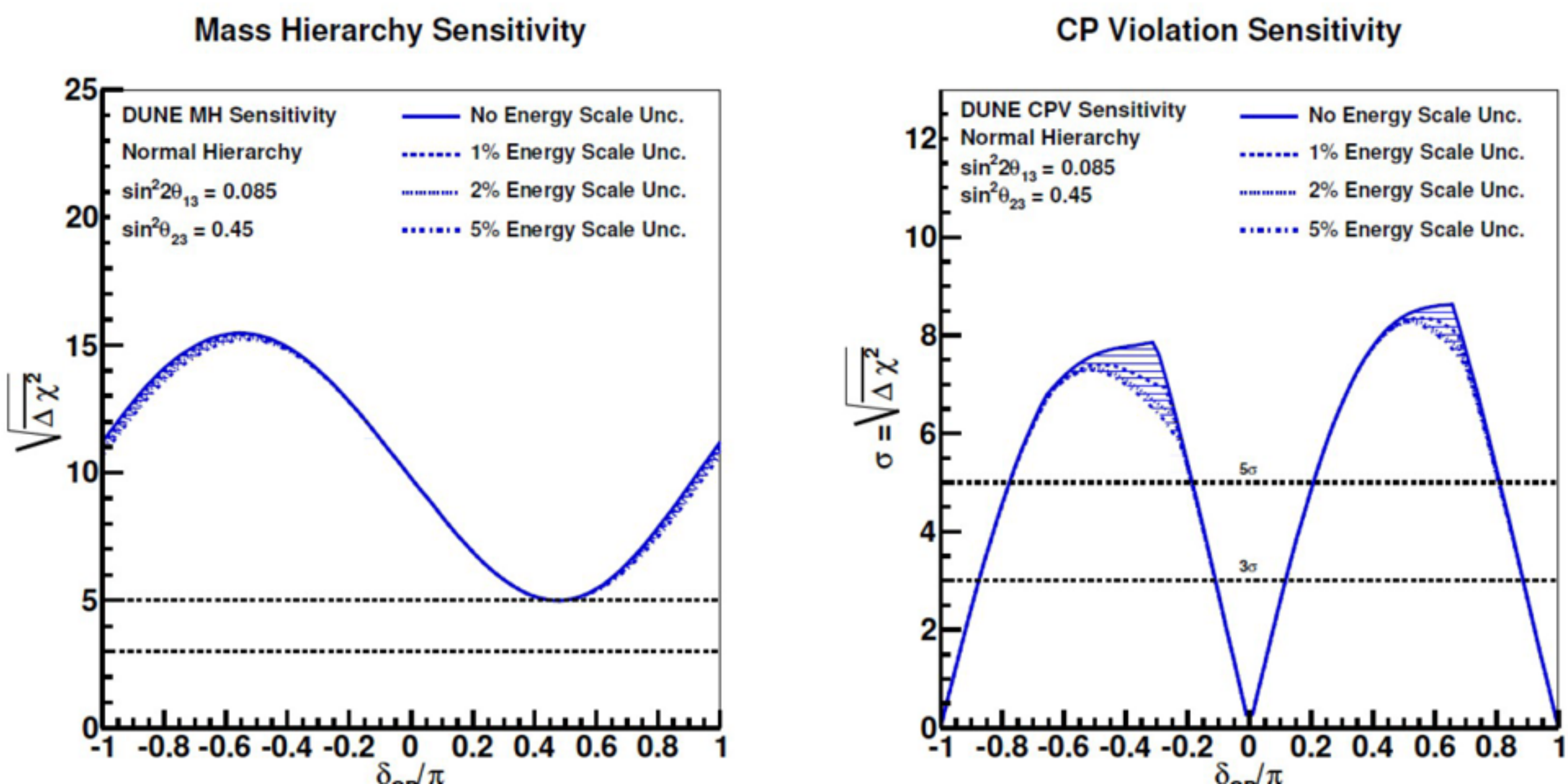
- Full volume calibration of E-field map and associated diagnostics (e.g. HV) requires crossing tracks
- Laser FTs every 14 to 15 m or so. 10m is demonstrated range in MicroBooNE.
- Total 20 FTs requested (see magenta open ovals in the image)
- Port size would be ‘standard’ (250mm)

Closing thoughts

- *Laser is motivated as a stability monitor, system for diagnosis, and E-field map along with many other possible measurements*
    - Cosmics are an important tool, but cannot provide rapid measurements or sufficient spatial information.
    - Certain stability measurements are only possible with a laser system
    - We currently have NO system in the detector which gives us any direct measure of the E field, which the laser would provide. We need to be able to include such a system for risk mitigation.
- *Cost perspective:*
    - Per Marzio: highly uncertain to predict cost now but expect it to go (very) high if requested later

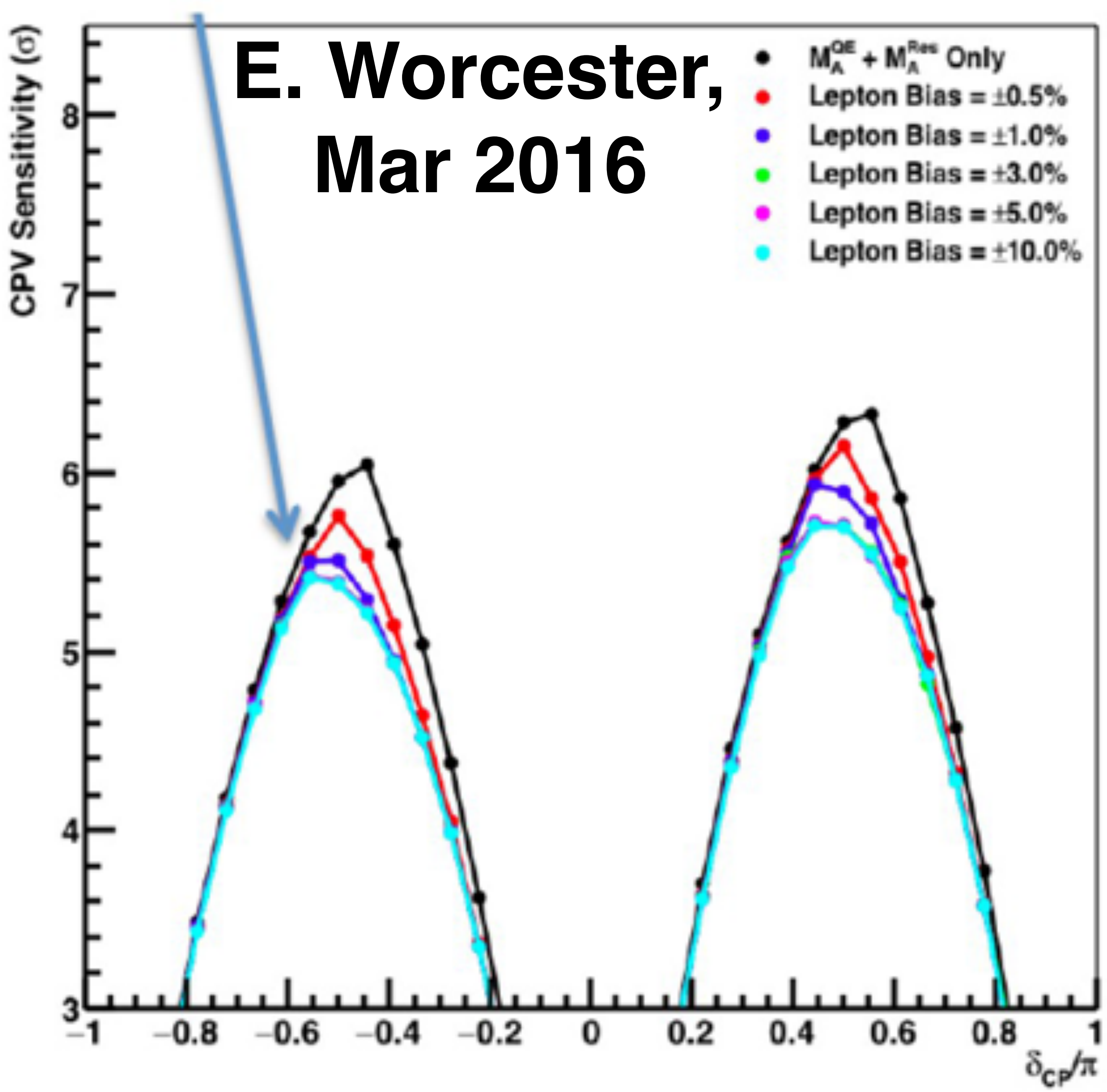
Issue: Unprecedented Physics Requirements of DUNE

CDR: Uncertainty of 2% on energy scale is already important to physics goals; calibration must be <2%



Issue: Unprecedented Physics Requirements of DUNE

1% Lepton energy bias is already important to physics goals; calibration must be <1%



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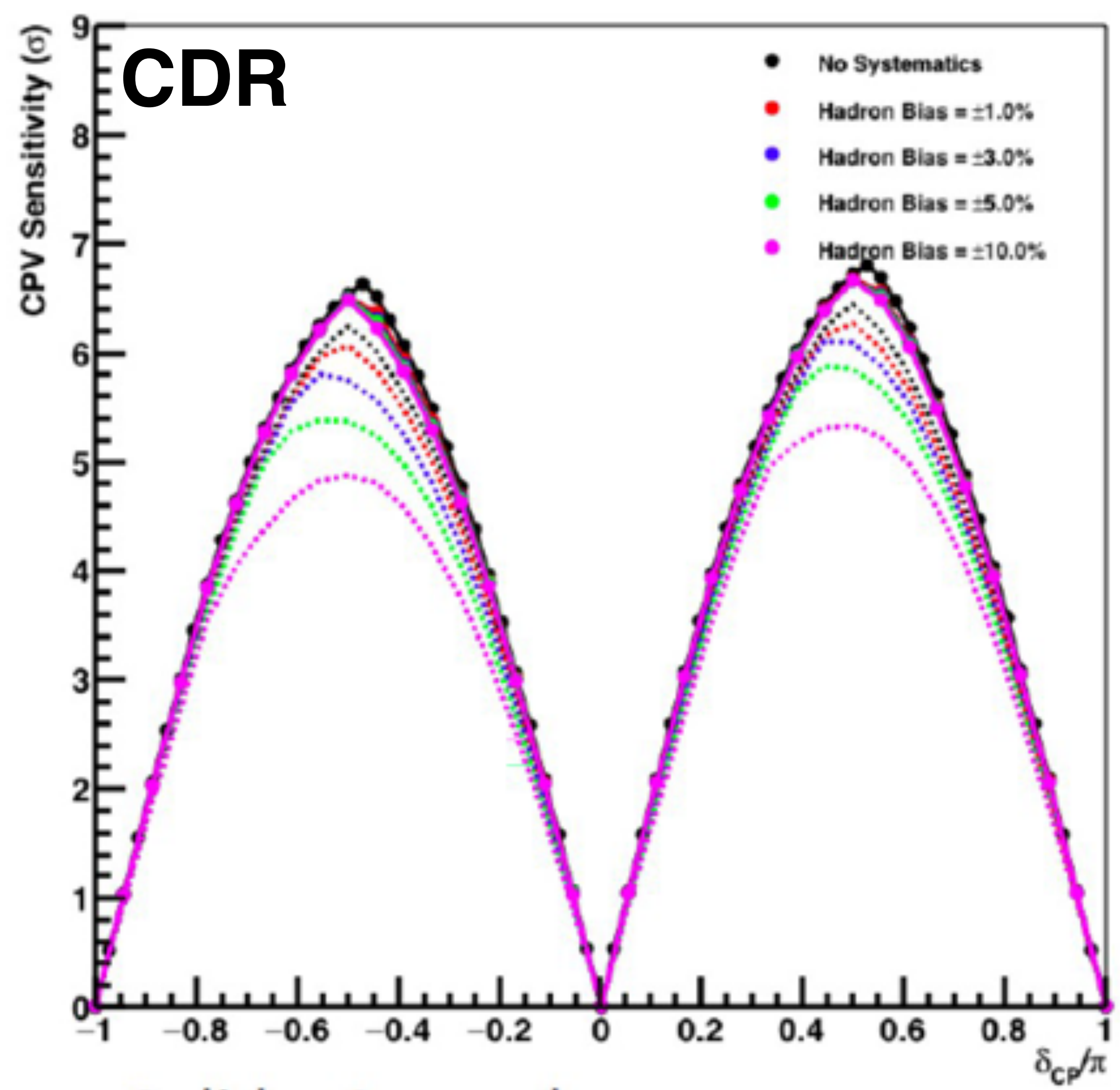
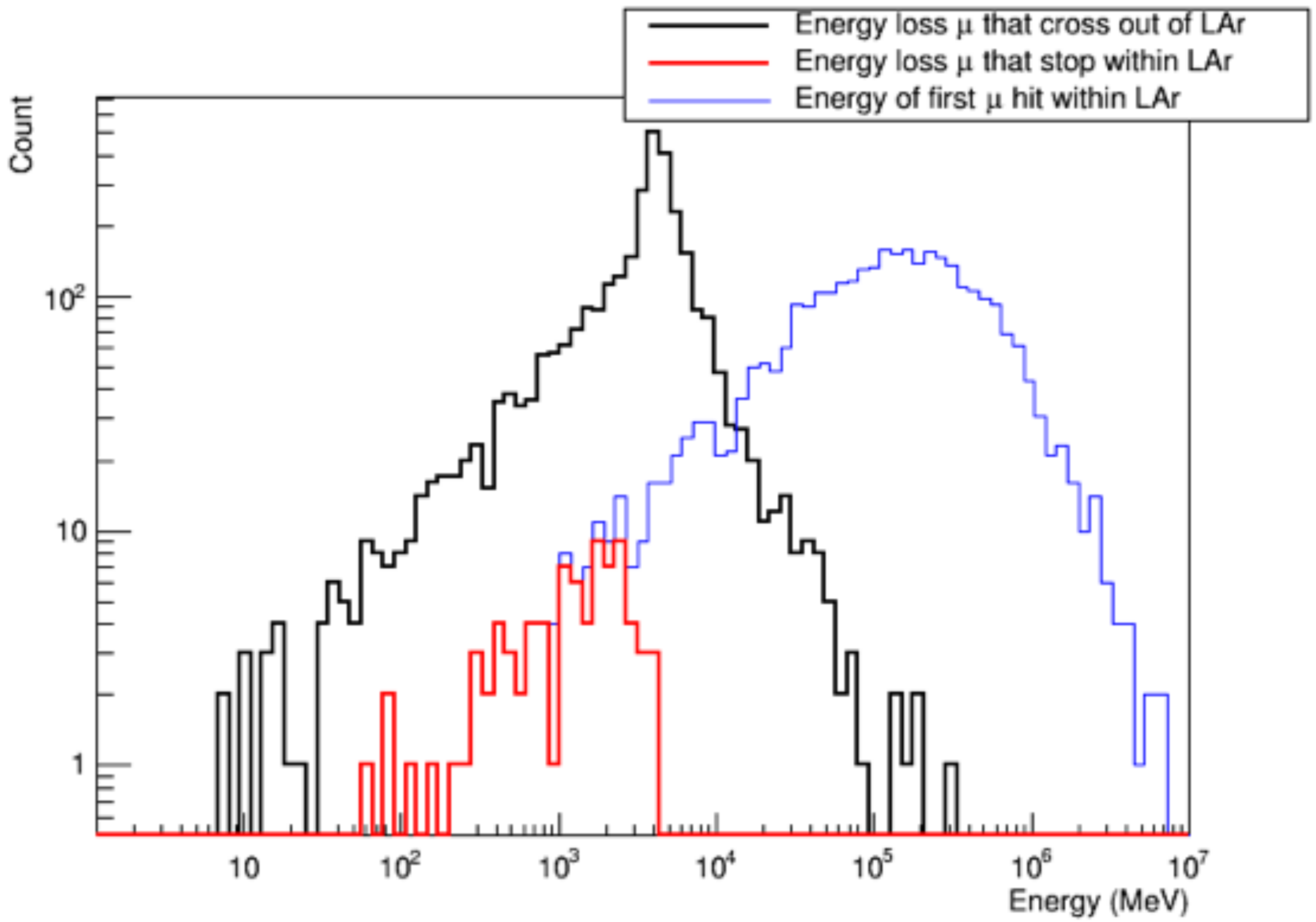


Solid = 4 sample
Dashed = ν_e only

Cosmics

https://indico.fnal.gov/conferenceDisplay.py?confId=14909

V. Kudryavtsev



- Stopping: 30 per day
- APA-CPA module crossing tracks: 200-500 per day
- No muons at zenith angles >75 degrees

Back of the envelope calculations showing collection wires are hit only 2-3 per day

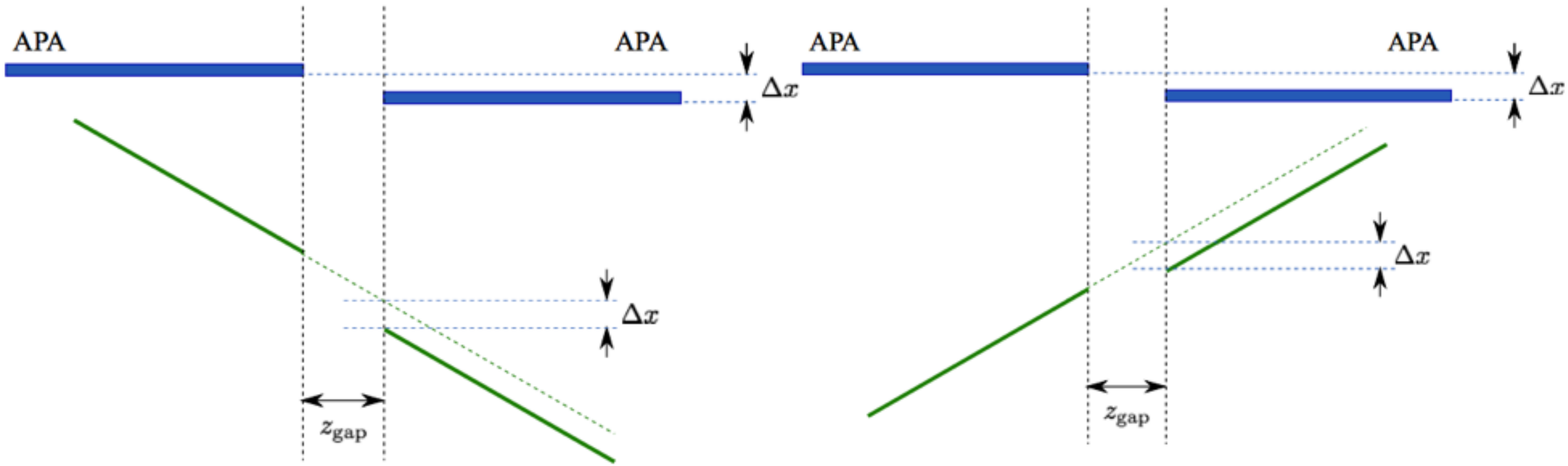
- Assume 200 crossing tracks/d/10kt,
- Assume 1000 wires hit per cosmic.
- CDR: 384,000 wires/10kt cryostat => 380k/1000/200=2
- Roughly implies 2 days to hit all wires.

Back of the envelope calculations of extrapolation of atmospheric neutron rate from ICARUS to DUNE

Atmospheric neutrino rate, scale up from ICARUS:

ICARUS saw 1 neutrino per 3 days => 0.33333 nu per day
ICARUS has 476 tons of active volume
DUNE active volume for a 10kt detector is 10 kt which results in about 7 muons per day per 10 kt volume

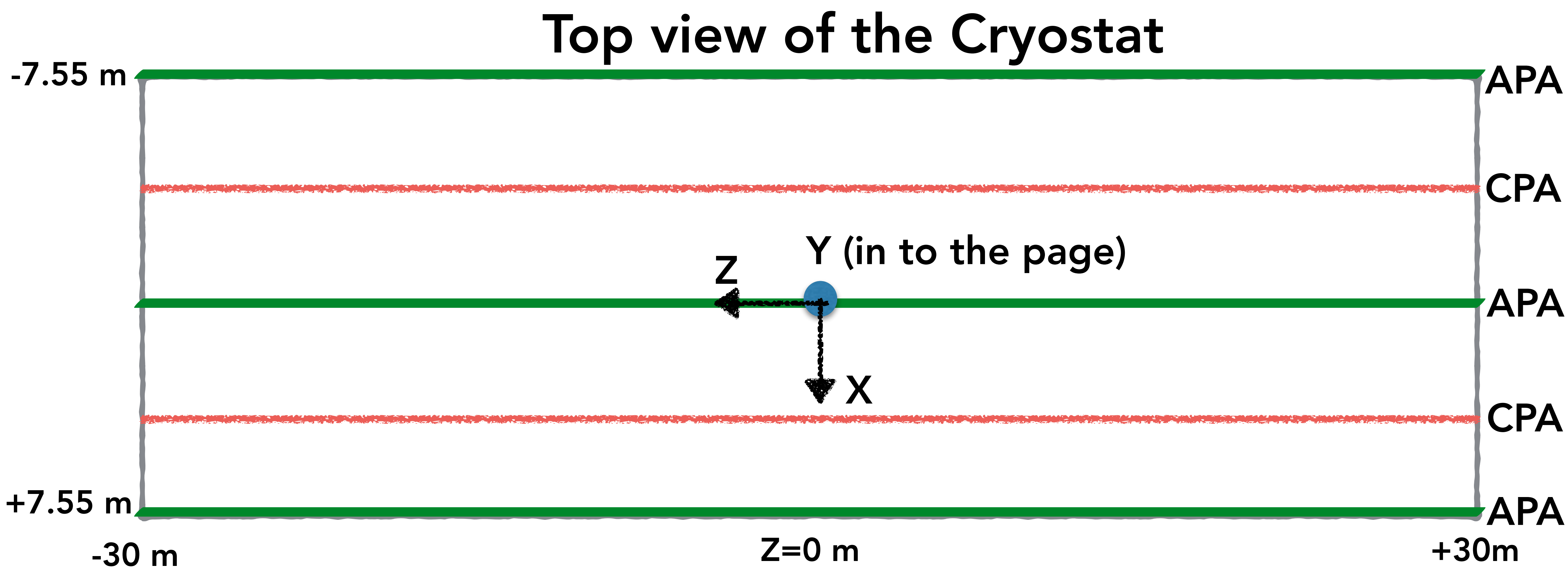
Need Tracks With + and - Angles



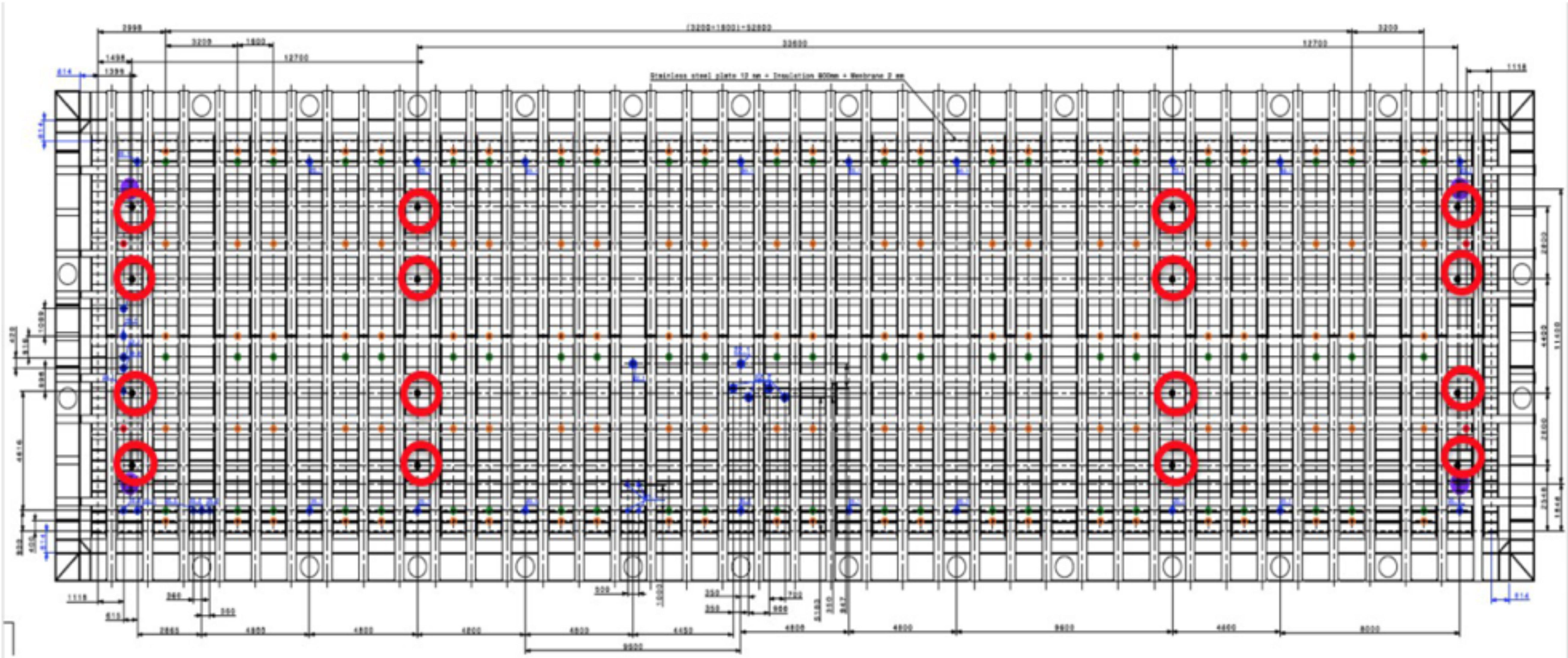
Need positive *Δ*x or positive *Δ*z
to fix this track (really a combination)

Need positive *Δ*x or negative *Δ*z
to fix this track (really a combination)

DUNE Coordinate System



Current design for cryostat penetrations
(only showing the instrumentation ports)



Pos.	Diameter [mm]	Quantity	Description
1	Ø250	120	Support
2	Ø250	72	Cable
3	Ø250	4	High voltage
4	Ø250	16	Instrumentation
5	Ø800	4	Manholes

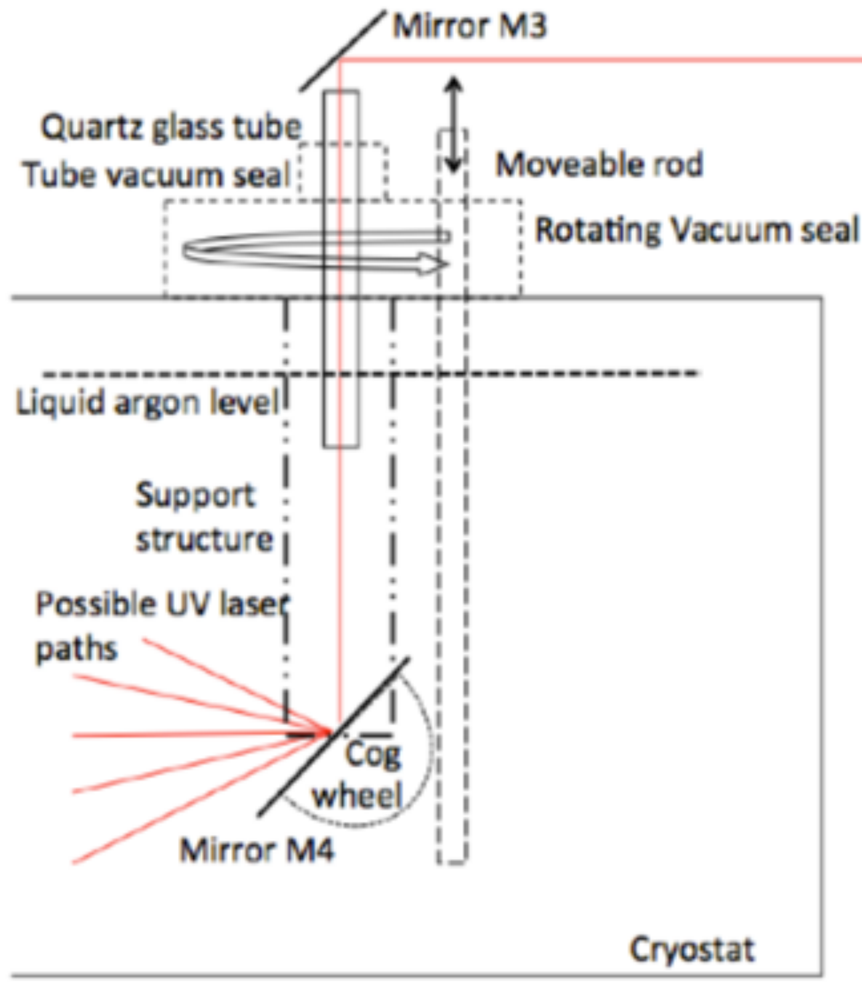
- 16 instrumentation ports
- 250 mm diameter (current design)

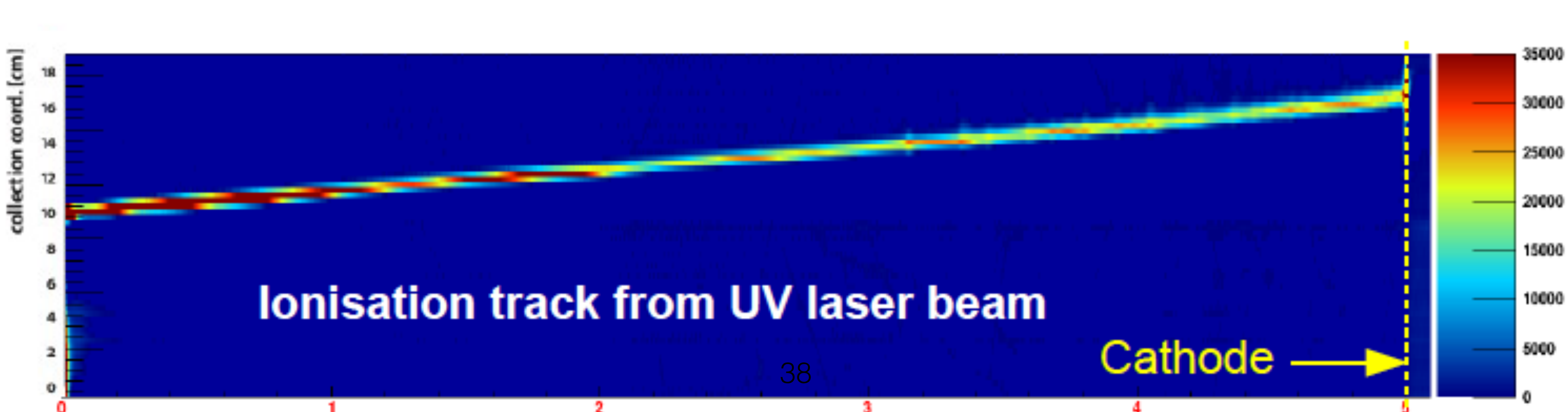
- About 0.5 m clearance on the sides
- About 0.7 m clearance on top from the surface of liquid argon

MicroBooNE, SBND laser system

Ionize the liquid Ar using 266nm laser

- Steerable mirror to alter path, crossing tracks for field map:
    - Is the field linear as expected? What about deformations or changes with time?
- Straight tracks (no MCS, no delta rays), no recombination





Track distance depends on:

M. Weber, mini-workshop: https://indico.fnal.gov/getFile.py/access?contribId=9&resId=0&materialId=slides&confId=14909

- 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)

Achieved 10m in uB

Summary of (possible) laser measurements

- **Alignment, Stability/Diagnosis, E Field map**
- Source of tracks at wide angle
- Diffusion (track divergence), end track peak (longitudinal)
- Charge attenuation for purity measurement
- Energy scale (under development)
- Cross calib of light for photon systems? (under development)
- Creation of localized charge for model testing (under development)