Ionization Laser System

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May 26, 2020

CALCI Scope Review Workshop

Outline

- **Introduction**
  - Motivation
  - Measurements with Laser
  - Physics Requirements
  - Measurement Method
- **Baseline Laser System**
  - System Outline
  - Coverage
  - Design Progress
- **Endwall Laser System**
  - Motivation
  - System Outline
  - Design Progress
- **ProtoDUNE Plans**
- **Response to Charge questions**

Note:
Everything shown in this talk is for Single-Phase (SP) only

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Laser Systems for DUNE

- Two types of Laser Systems are planned for DUNE Calibration
  - **Direct Ionization Laser (IoLaser)**
    - e.g. MicroBooNE, SBND, ArgonTUBE
    - Two designs: Baseline and end-wall
    - **Laser Beam Location System (LBLS)**
      - Part of the IoLaser system
      - e.g. Mini-CAPTAIN
  - **Photoelectron Laser System (PE Laser)**
    - e.g. T2K

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  - **Direct Ionization Laser (IoLaser)**
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This talk will focus on this

  - **Laser Beam Location System (LBLS)**
    - Part of the IoLaser system
    - e.g. Mini-CAPTAIN

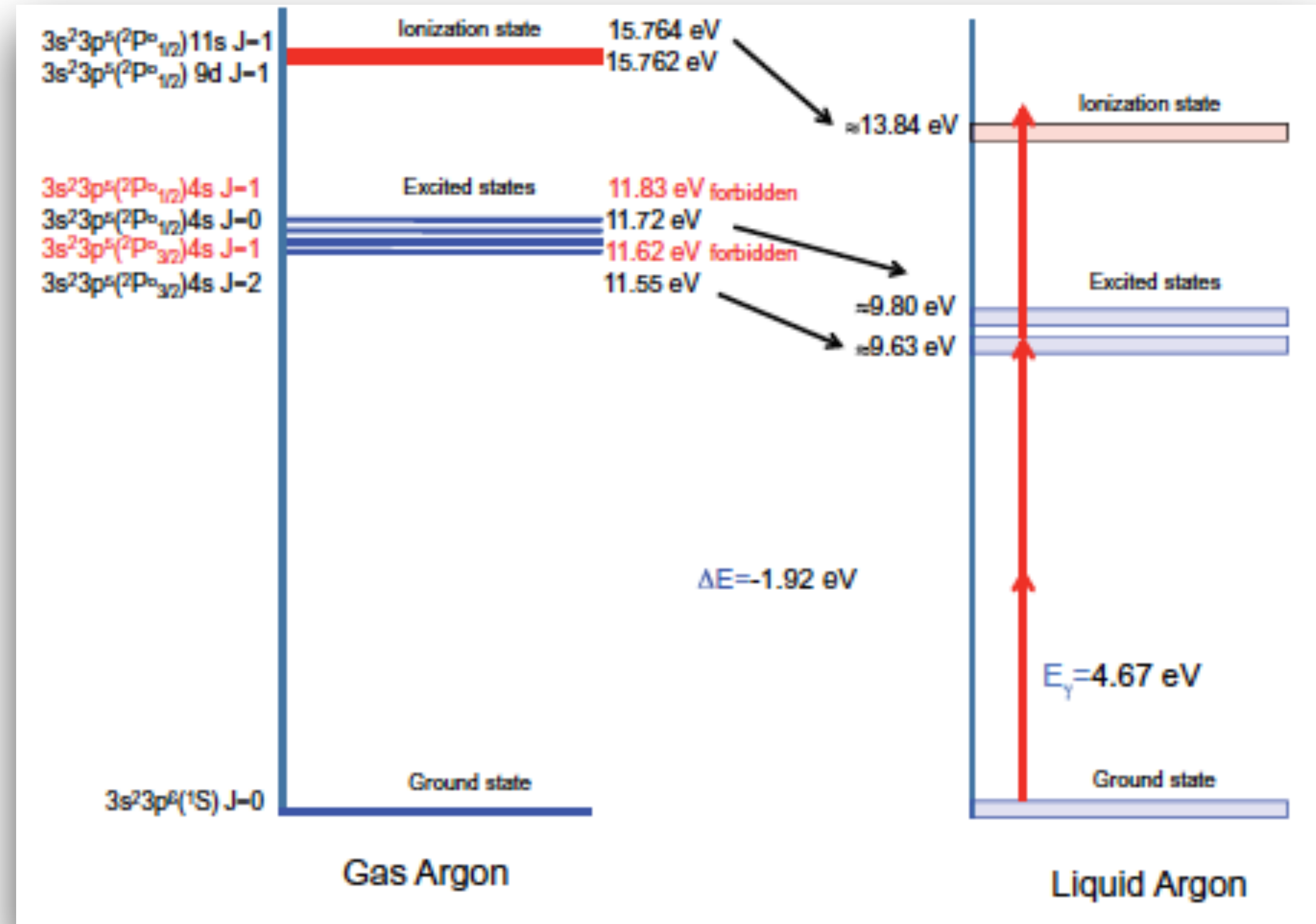
Dedicated talk by ***Jose Maneira*** on this

  - **Photoelectron Laser System (PE Laser)**
    - e.g. T2K

Dedicated talk by ***Jelena Maricic*** on this

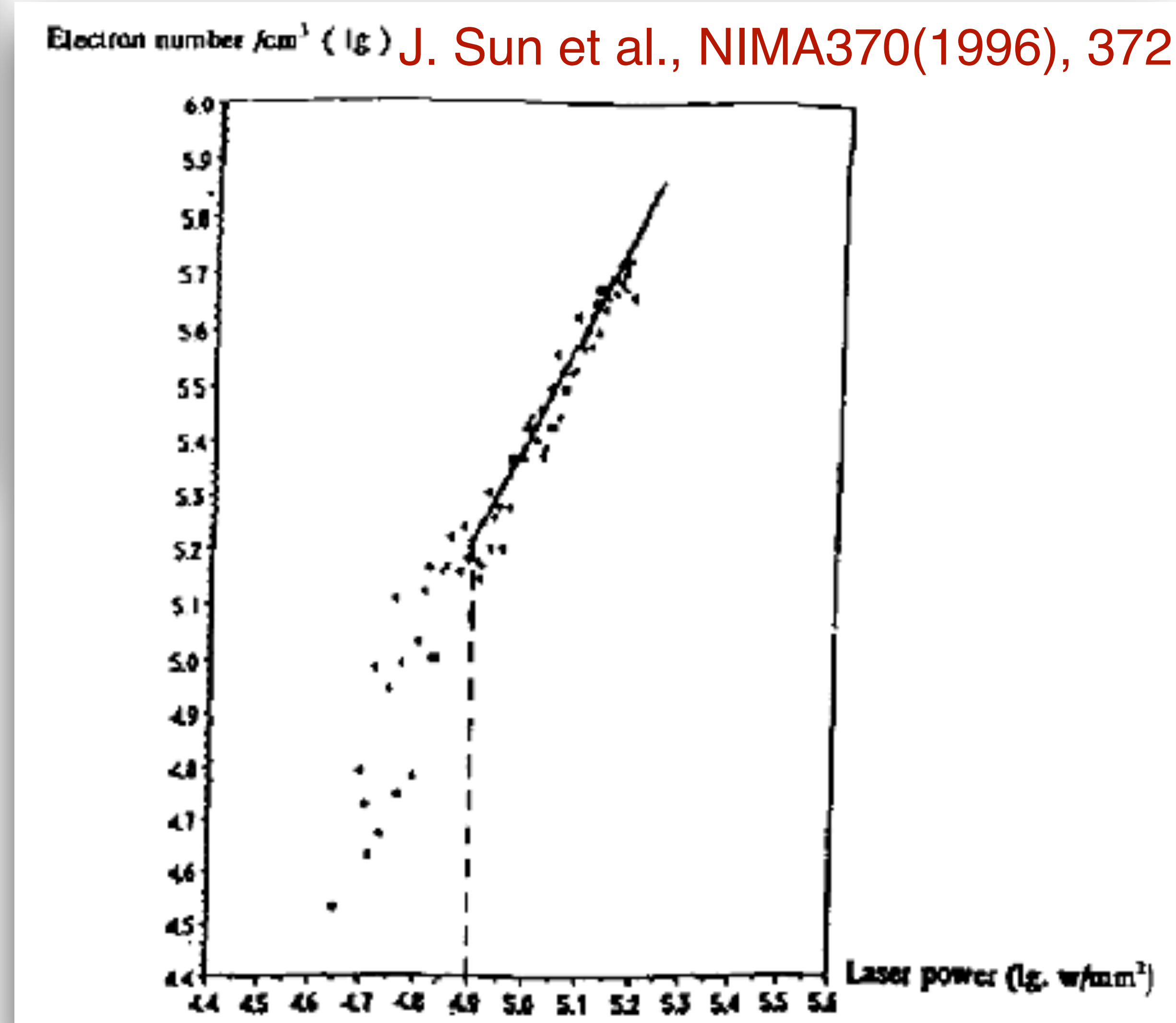
Laser Ionization of LAr

I. Badhrees et al., New J. Phys. 12 (2010) 113024



- 266 nm (4.67 eV) laser light can ionize argon through 2-photon excitation followed by single-photon ionization
- electron yield goes with the square of photon intensity (in typical regime)

J. Sun et al., NIMA370(1996), 372



- Possible to get a few x MIP signal with tens of mJ pulses

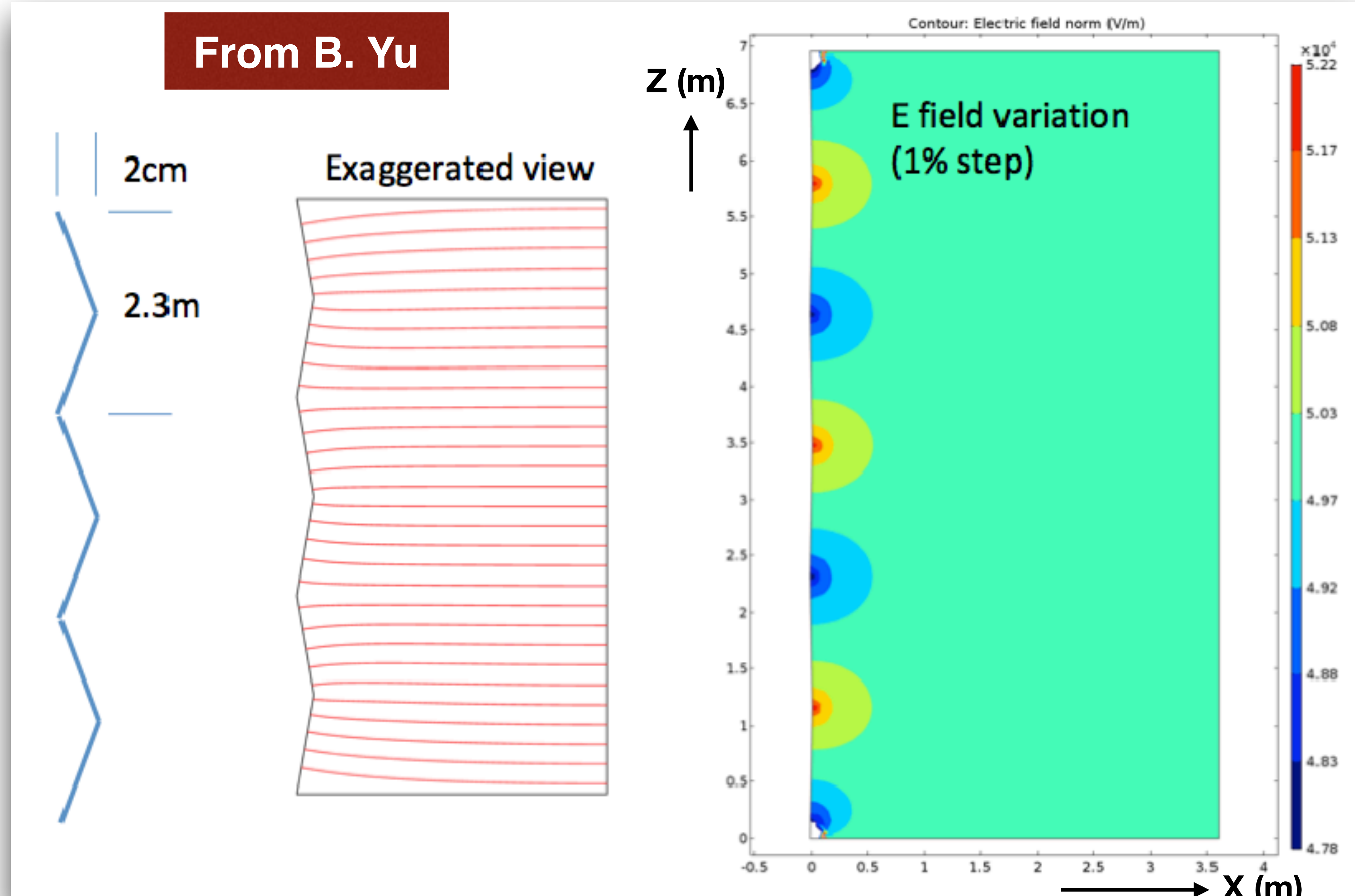
What can we use Laser for?

- Measure Drift velocity & E-field
- Locate and measure detector imperfections
  - Field cage resistor failures, CPA tilts/rotation etc.
- Measure Electron Lifetime
  - challenging but possible
- Recombination measurements
  - Angular dependence?
- Photon detector — timing, relative and absolute efficiency calibration?
- Mis-alignments
- Check APA wire response uniformity
- Electron diffusion

Sources of E-field Distortions

- **Ionization sources**
  - e.g. Cosmic rays, Ar39
  - Very small in SP
    - E-field distortions: 0.1%; Impact on dQ/dx: 0.03%
    - Spatial distortions: 1-1.5 mm; Impact on dQ/dx (including Recombination): <0.1%
  - *However, we don't know the behavior of fluid flow yet! — the fluid flow can potentially amplify these effects e.g. stable eddies*
- **Non-ionization sources**
  - Detector imperfections e.g. detector mis-alignment such as CPA tilts, FC resistor failures
  - These effects can be significant locally
- Also, important here in both cases is *to capture time dependent changes*

E-field distortions: CPA position tilts

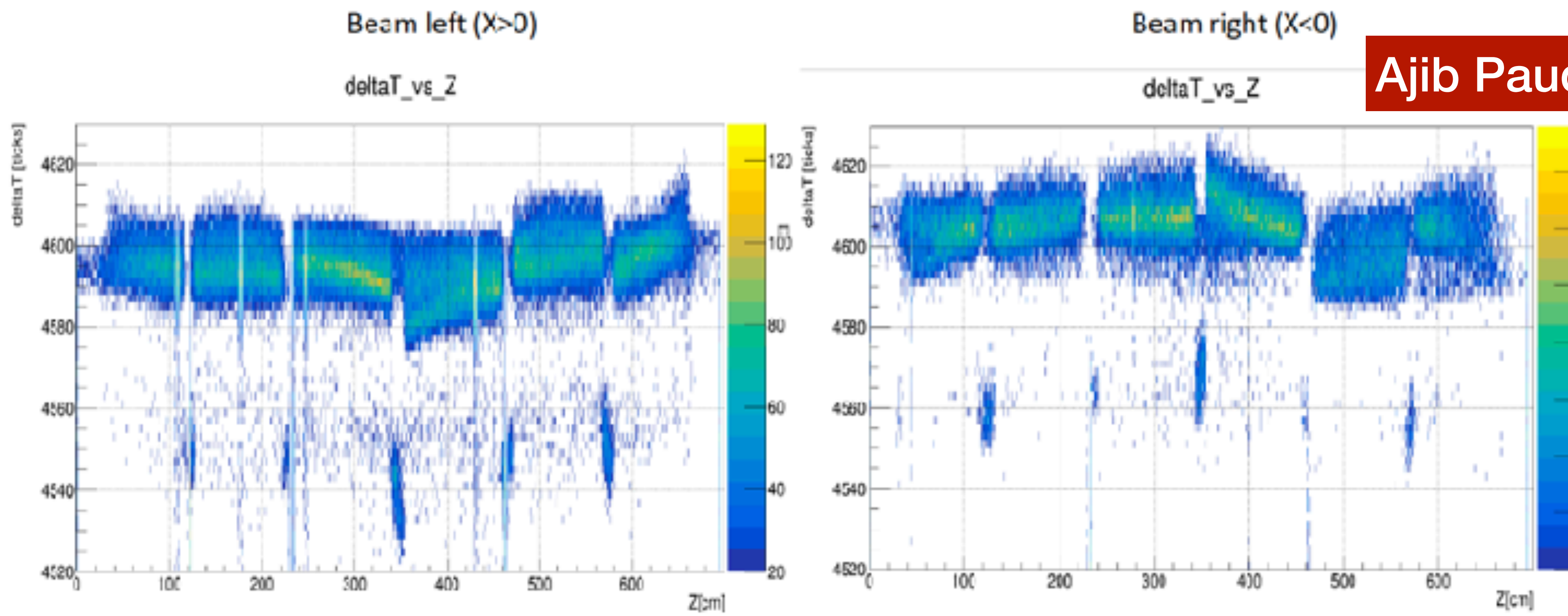


- Assuming 2 cm CPA position tilts results in few % effect on E-field

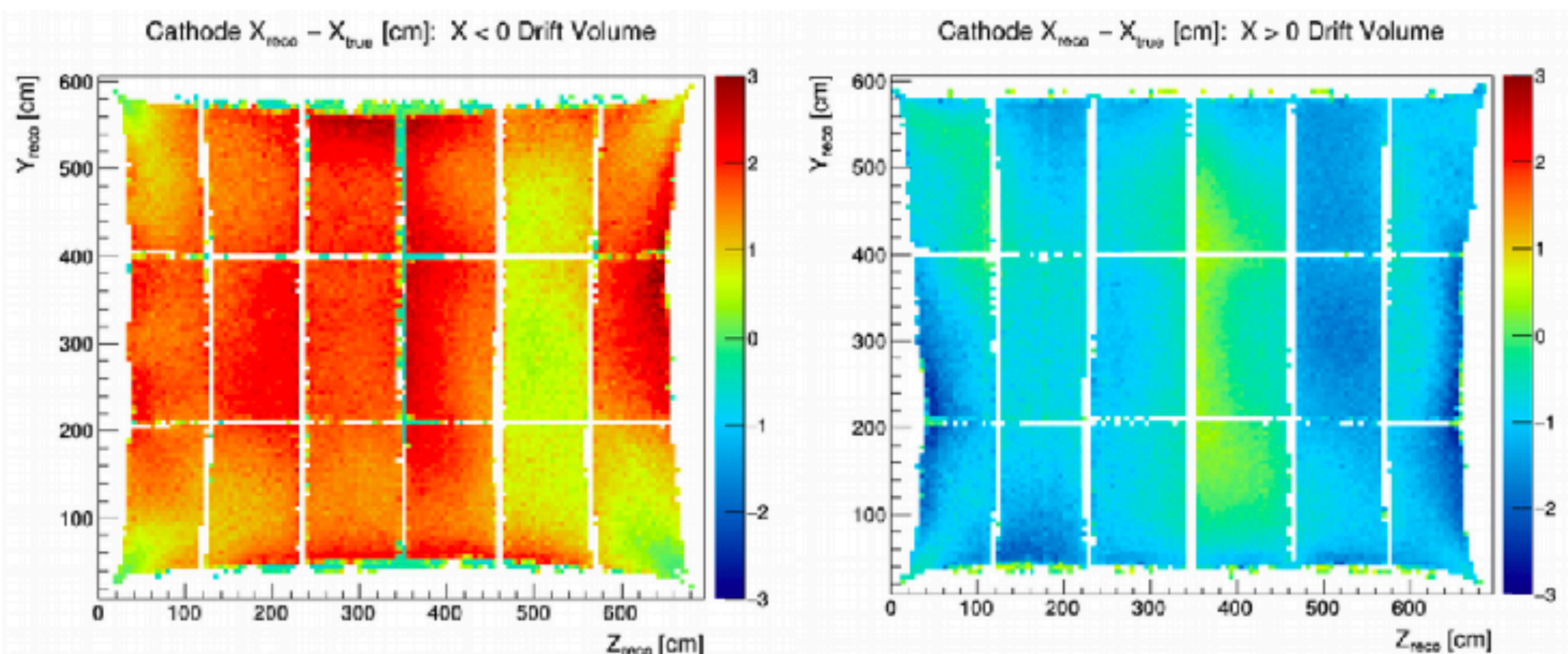
CPA Shifts/Rotations in ProtoDUNE-SP

Studying APA-CPA crossing tracks in ProtoDUNE-SP led to the discovery of CPA shifts/rotations

(see talk here)



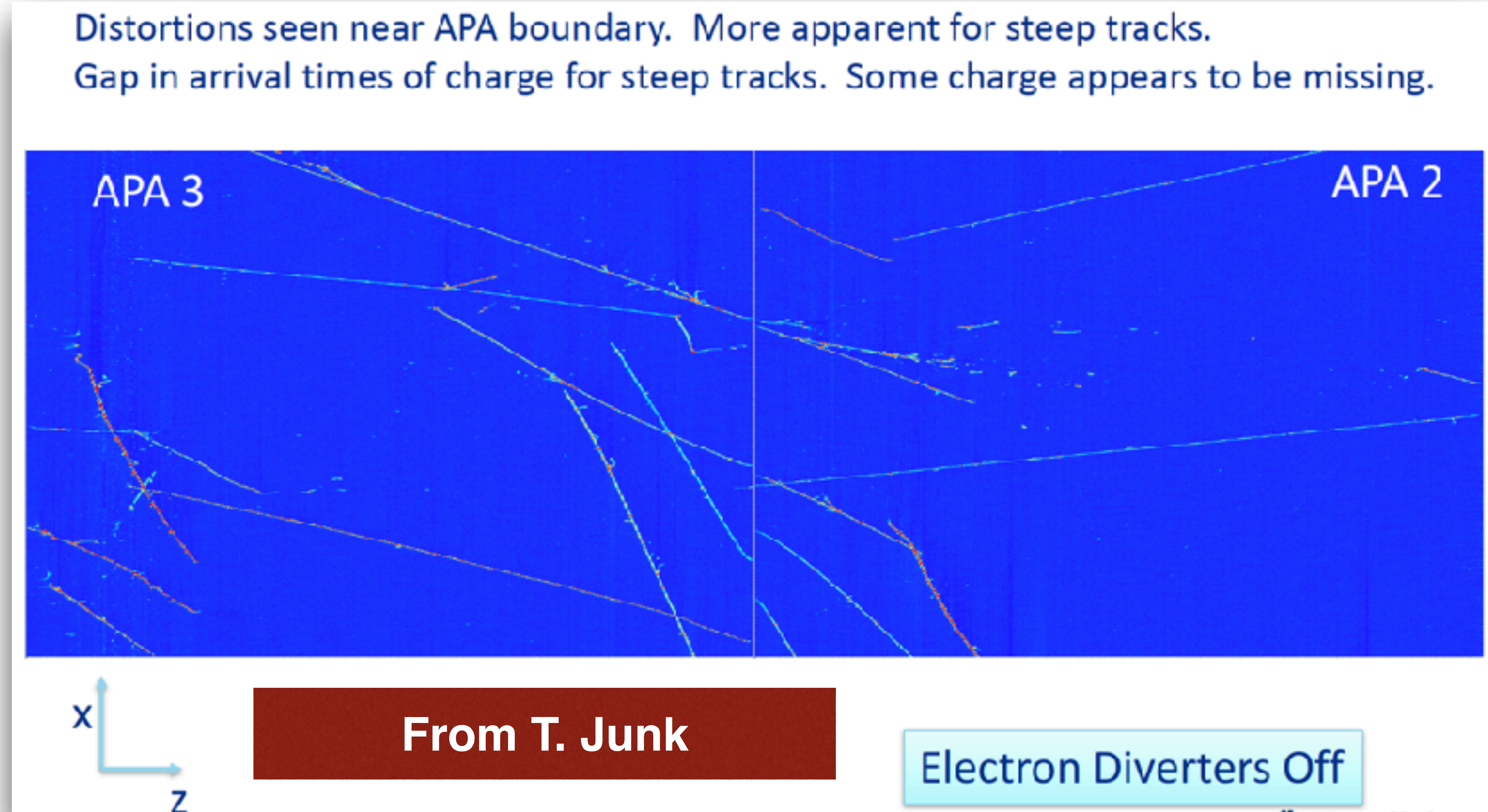
Ajib Paudel



Mike Mooney

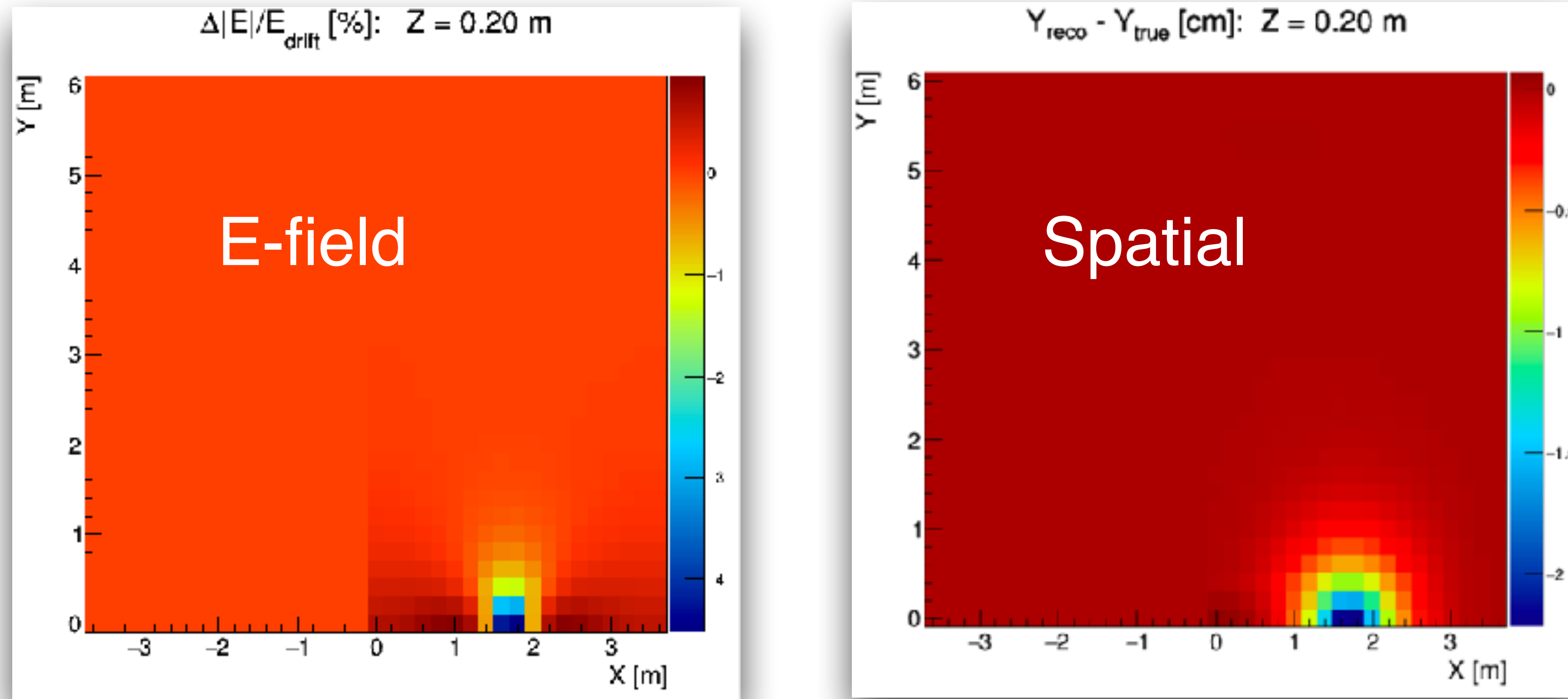
- Space charge offsets not quite zero at corners in data (see talk here)
- CPA shifts of ~15mm observed

E-field Distortions: APA boundaries



- Alignment of “straight” tracks still depend on E-field and in-situ effects. In ProtoDUNE, easy to see with copious amount of cosmics. What about in DUNE?
- What if this region is not small and we want to measure it? — Laser can measure distortions like this.

E-field distortions: Field Cage Resistor Failure (SP)

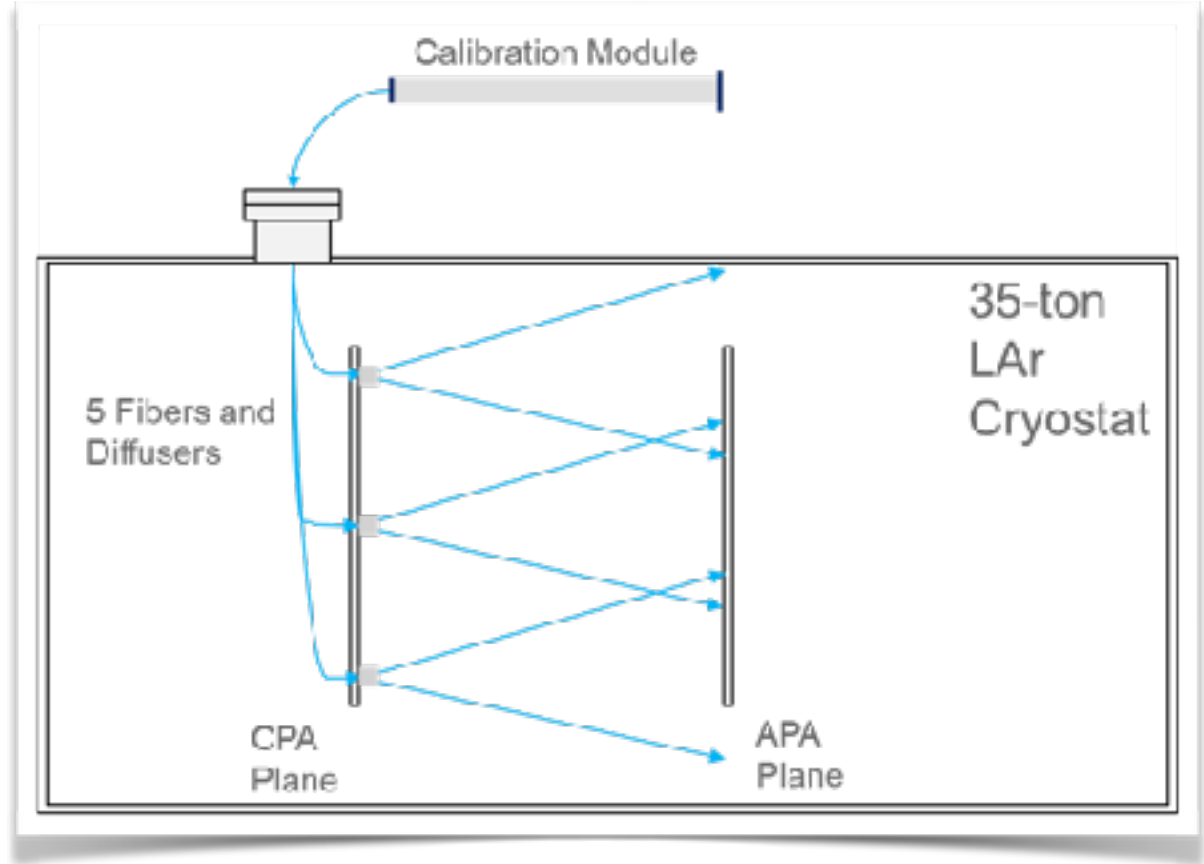


- Single FC resistor failure in ProtoDUNE-SP geometry
- Up to 4% effect on total E-field and up to 2 cm offset in the Y-direction
- Effect is not completely local, but strongest in the ~1 m^3 volume around the defect
- Impact on dQ/dx = 1-2%

From B. Yu, M. Mooney

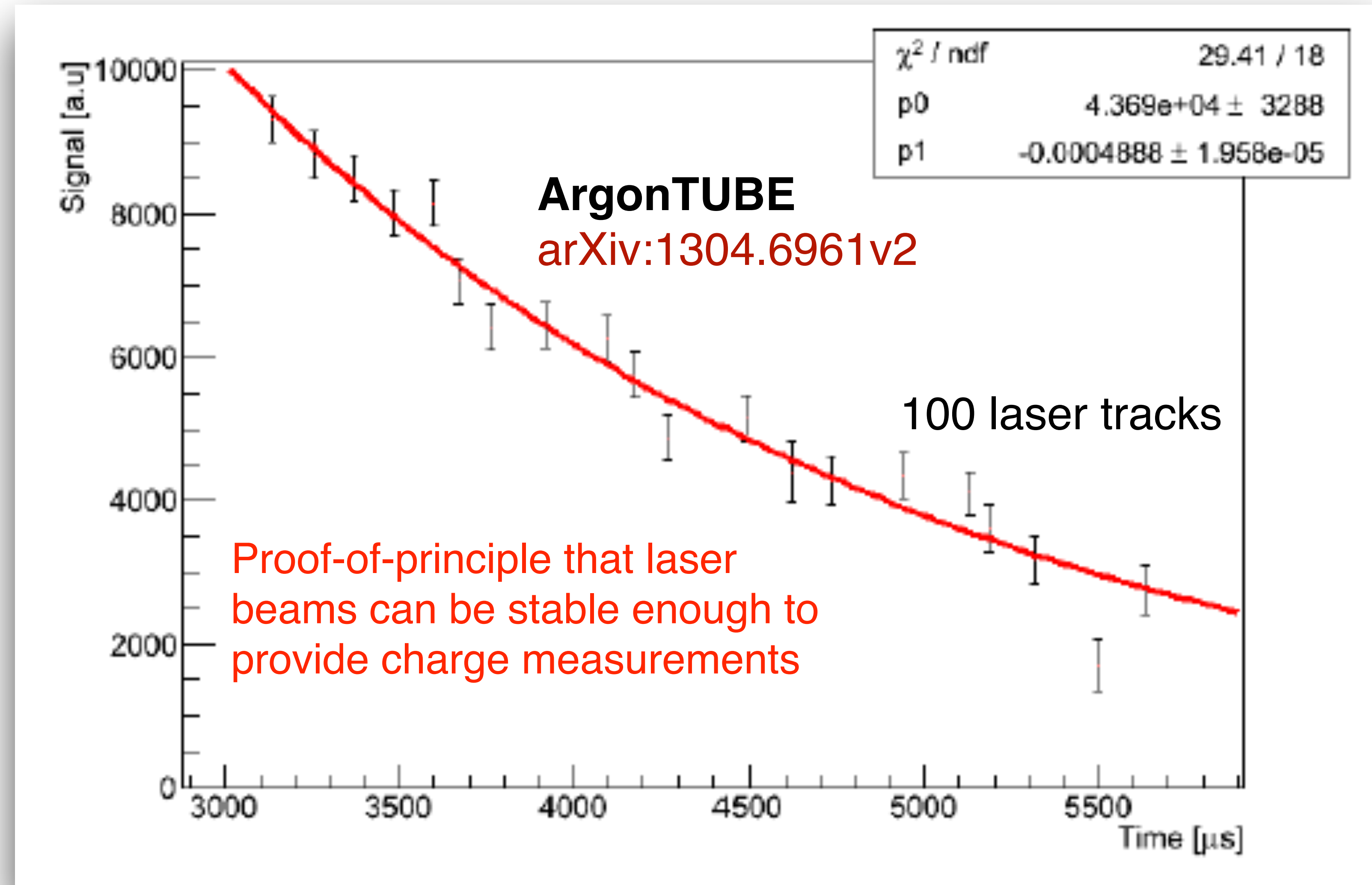
PDS Calibration with Laser

- PDS currently only includes a monitoring/verification system, sufficient for commissioning and operating PDS.
  - Measure the PDS gain, linearity, and timing resolution
  - Monitor stability and response over time
  - debug PDS issues (e.g. bias scans, time correlation runs)
- It doesn't provide PDS efficiency calibration



- Can laser bed used for PDS calibration? Laser can provide
  - *Synchronization and timing calibration*
  - *Absolute PDS efficiency calibration?*
    - Does the scattered/reflected from laser light dominate the scintillation light from laser tracks? Does this saturate the PDS?
      - Possible Mitigation: run laser at lower intensity for PDS calibration runs
    - Can one use timing cuts to separate prompt vs late light from laser?
      - Scintillation has prompt and late light; prompt will arrive at the same time as scattered light but late light can be useful

Lifetime Measurement with Laser



- Using attenuator and iris, find intensity and collimation parameters leading to the lowest self-focusing effects
- *Calibrate* intensity along track using laser tracks parallel to APA (keep the effects from drift constant)
- Use non-parallel tracks, corrected with the previous, to measure effects of drift
- Low-angle tracks may give indication of **recombination angular dependence** (see backup)

Laser System Motivation Summary

- Our primary source to measure or constrain parameters of the detector model
  - Check detector response — wire response uniformity, PDS timing (maybe efficiency too)
  - Look for detector imperfections — CPA tilts, APA gaps, FC resistor failures
  - Drift velocity and E-field
  - Quite possibly electron diffusion and lifetime
- Advantages w.r.t. natural sources
  - w/r cosmics — high statistics and steerability allow checking localized, time-dependent effects.
    - Space charge map in ProtoDUNE — once per hour; In DUNE, this takes O(1000) days ~ 3 years
  - w/r Ar39 lifetime measurement — does not need to assume uniformity in lifetime along x

Laser System Motivation Summary

- Do we need the laser since space charge is low?
  - How will we prove it is? What if there are unforeseen fluid flow effects?
- Do we need the laser since detector defects shouldn't change with time?
  - What if they do? And even if they don't, how long are we willing to wait until having the first localized E-field map from cosmics? 3 years?
- **Far detector energy response will be — by far — our largest systematic.**
  - How do we justify that detector effects such as E-field distortions do not contribute more than 1% to the systematics budget?
  - Even if no corrections are needed, the laser can demonstrate we reached that very stringent level.
- **In general, we need an insurance policy to verify and demonstrate that detector systematics are under control — laser system provides exactly that!**

Requirements: E-field Measurement Precision

- Measurement of E-field with 1% precision
  - Impact on dQ through recombination ~ 0.3%
  - Aiming to not dominate the overall 2% E scale uncertainty budget and possibly improve it!
    - Note: E-field is not the only source of Energy scale uncertainty
- 1% precision on E-field is quite ambitious but achievable with laser
  - We will have better coverage with lasers distributed across the detector
  - High statistics (MicroBooNE 2% statistical uncertainty, we can reduce that to 1%)

Requirements: E-field Measurement Coverage & Granularity

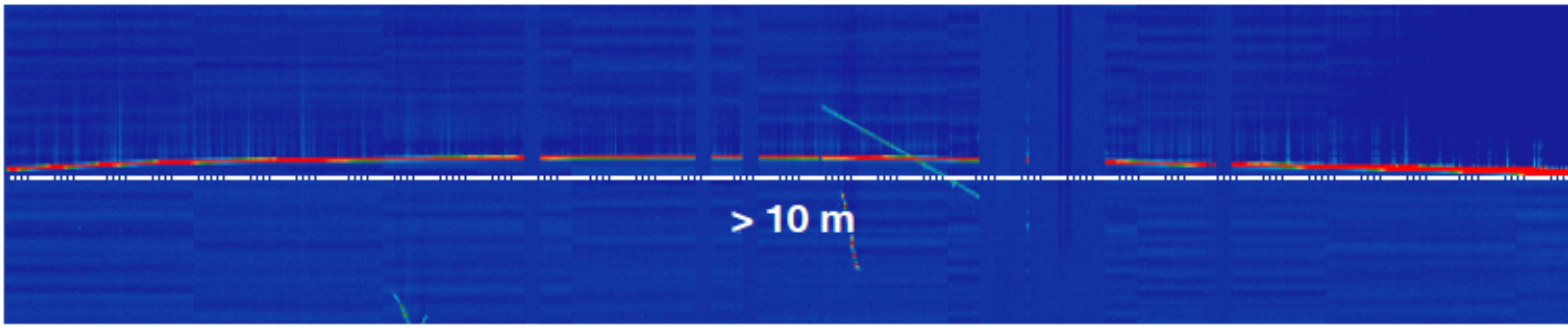
- Previously estimated coverage in terms of number of voxels
- Following comments at the 2019 review, coverage & granularity requirements shown here for detector elements/boundaries where distortions are expected
- **CPA Panels**
  - *Required Coverage:* All CPA panels
  - *Required Granularity* (*following ProtoDUNE example*)
    - Resistive Plate (RP) forms the lowest unit size for CPA (1.2m in Z x 2m in Y)
    - Minimum: require 4 points per RP unit
      - Statistics in FD: 90 crossing tracks/year (180 for the CPA panel)
    - Ideal: 9 points per RP unit

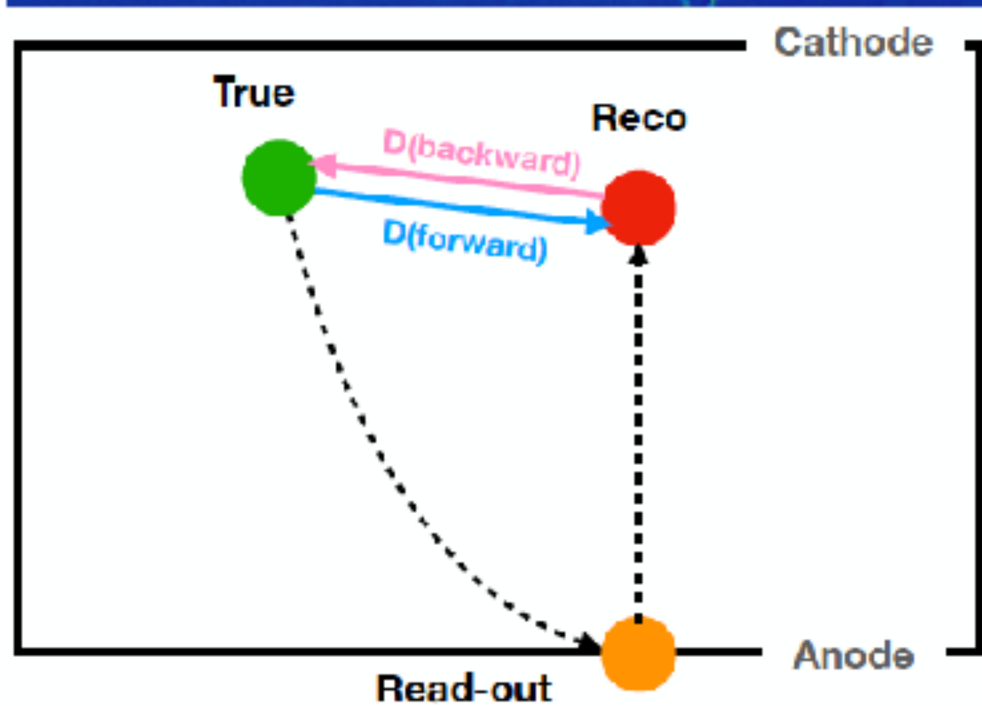
Requirements:
E-field Measurement Coverage & Granularity

- **APA Panels**
  - *Required Coverage*: All APA boundaries
  - Tracks have to be parallel to APA
  - Is 40 cm away from APA sensitive enough to measure this? If not, then do a very careful scan near the APA (to not directly hit the PDS).
  - *Required Granularity:* 0.5 m^3 volume
- **FC Models**
  - *Required Coverage:* All FC profiles; need to be sensitive to resistor failures in any module
  - *Required Granularity:*
    - Coarse scan: not less than 0.5m in drift direction — tells you if there is a failure; Each FC profile is 2.3m in Z and Y, so 0.5x2.3x2.3 m^3 volume
    - Finer scan: once known there is failure, do a finer scan within the 0.5x2.3x2.3 m^3 volume

E-field/drift velocity

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



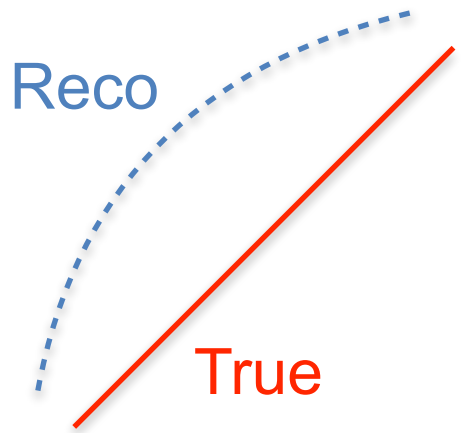


- Reconstruction assumes uniform, nominal field
- True is given by calibration hardware
- True - Reco displacement is the basic observable leading to E-field distortion measurement

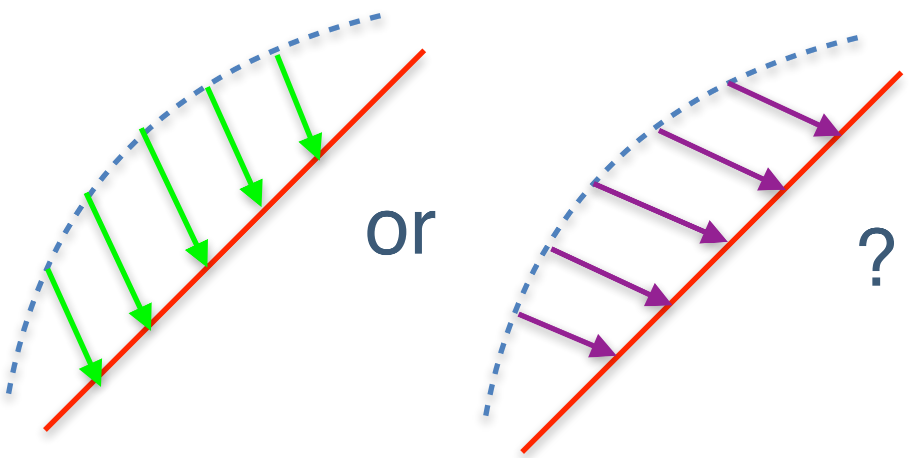
MicroBOONE paper

arXiv:1910.01430v2

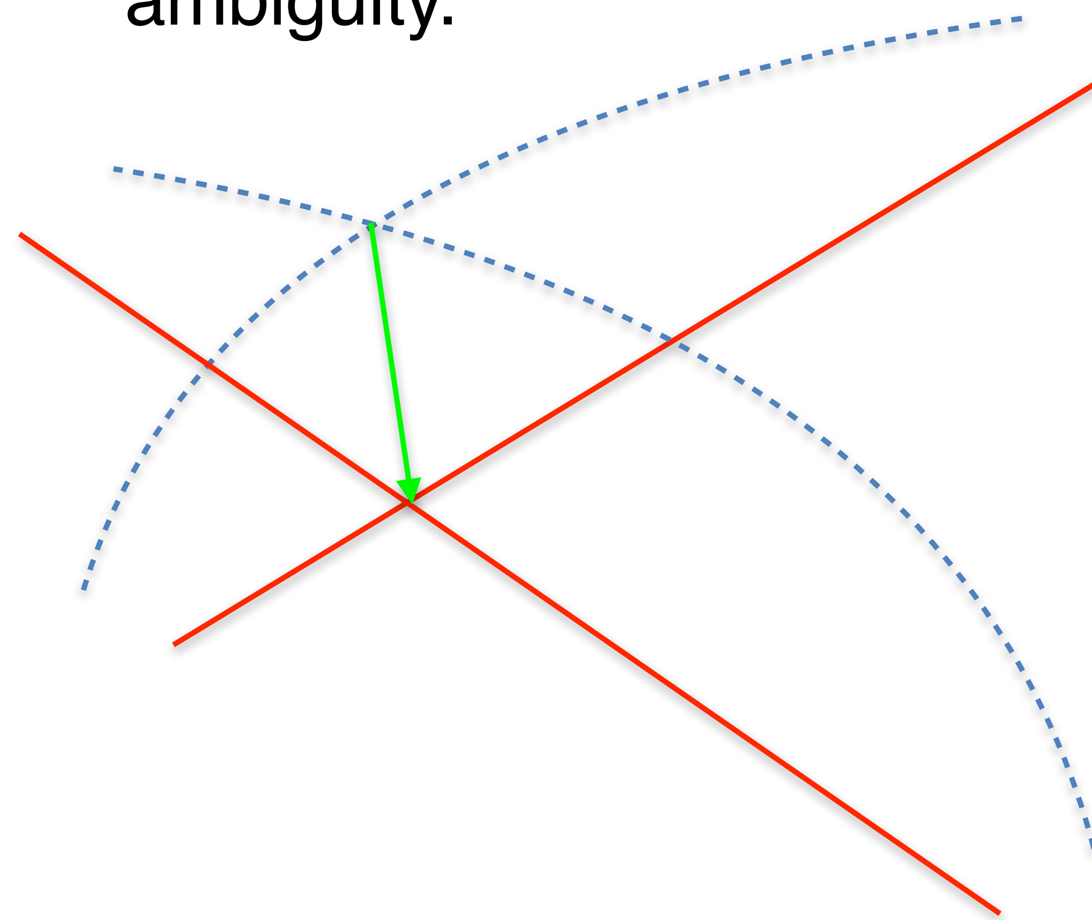
Why Need Crossing Tracks?



- What are the displacements if we see this?



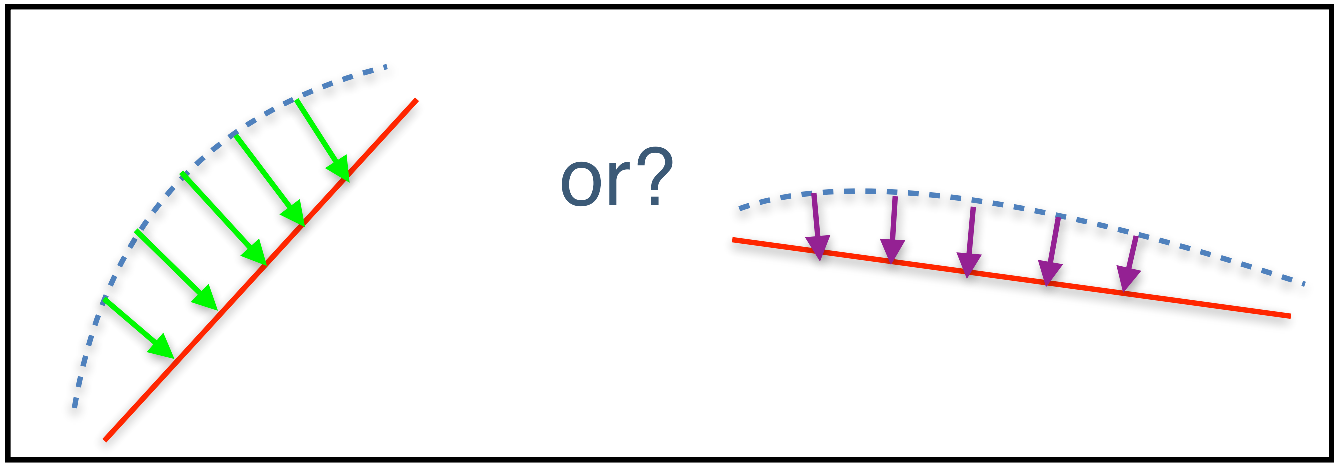
- With tracks from different lasers crossing in the same point, there is no ambiguity.

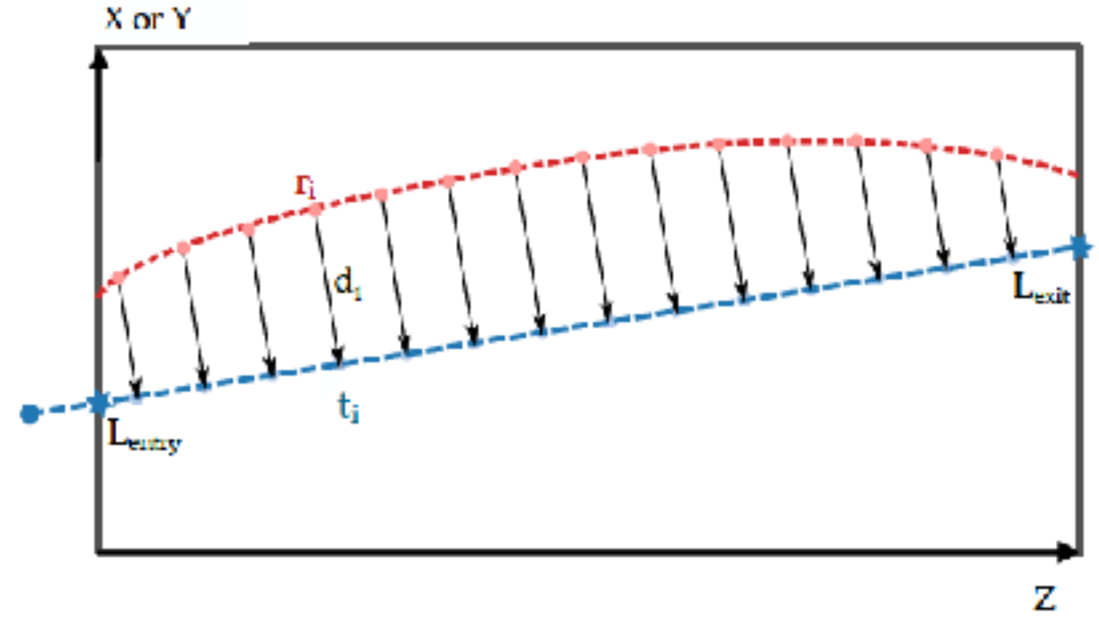


- Hard to get crossing tracks in all volumes, so we need other ways to get displacement
- MicroBooNE could not base full analysis on crossing tracks

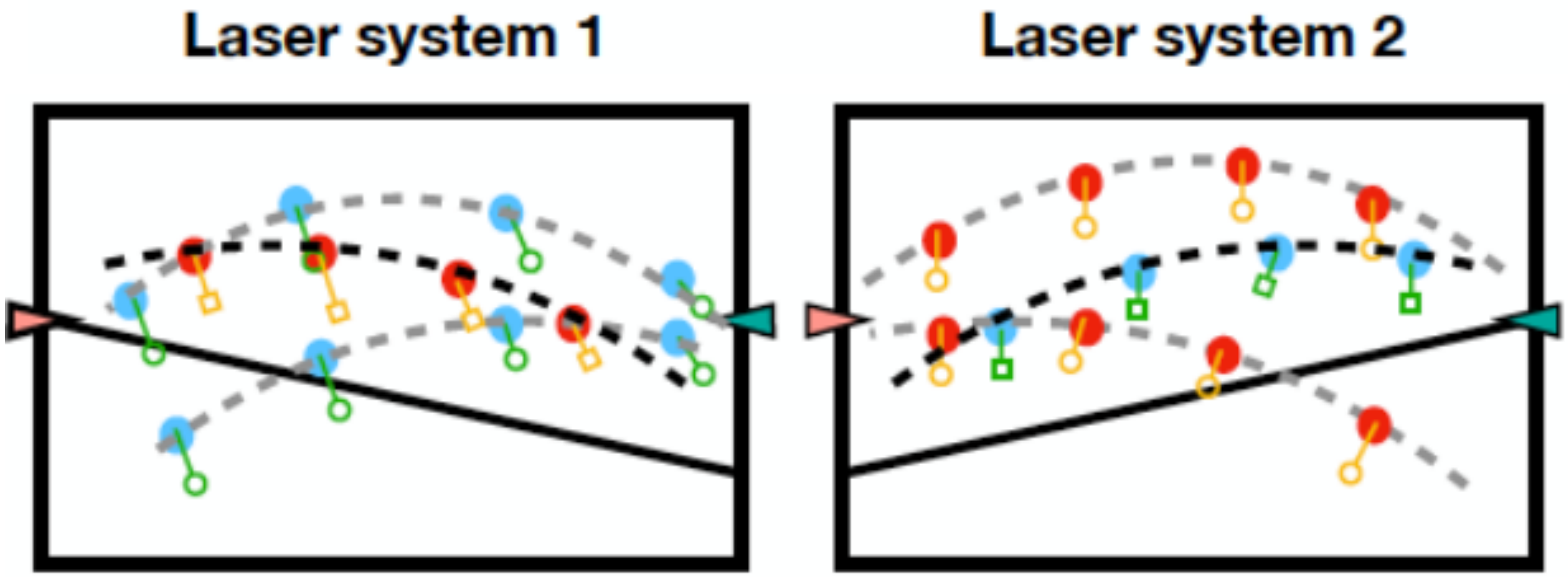
Closest point projection

- Assume that displacement is between point in reco and closest point in true track
- Leads to biases if used on a single track



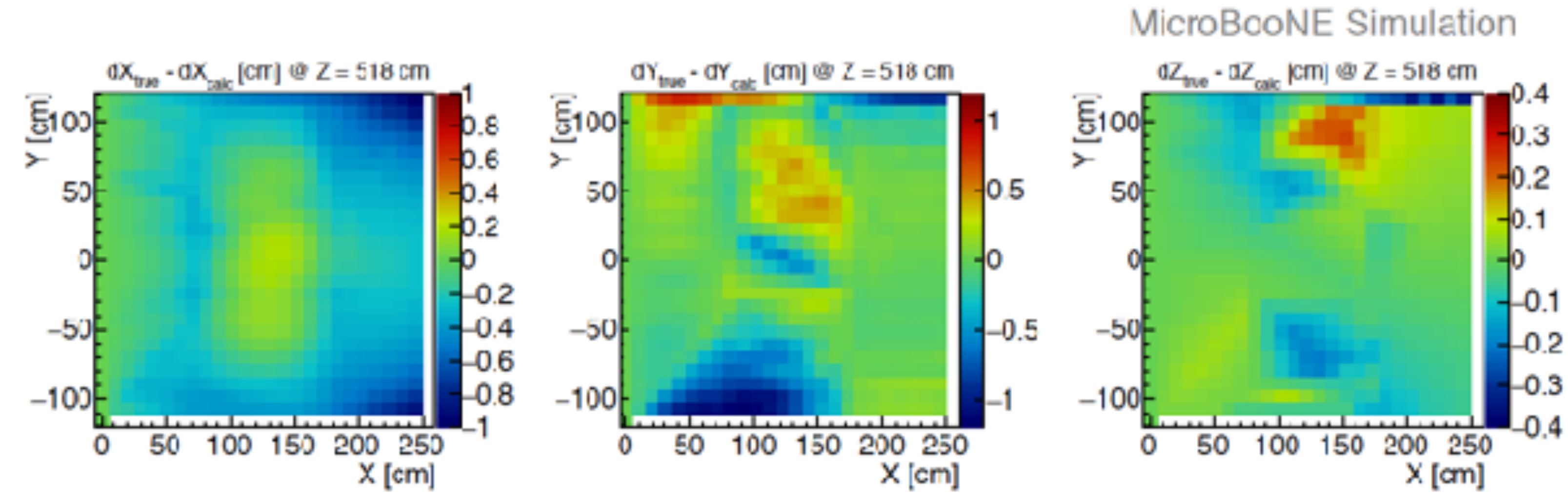


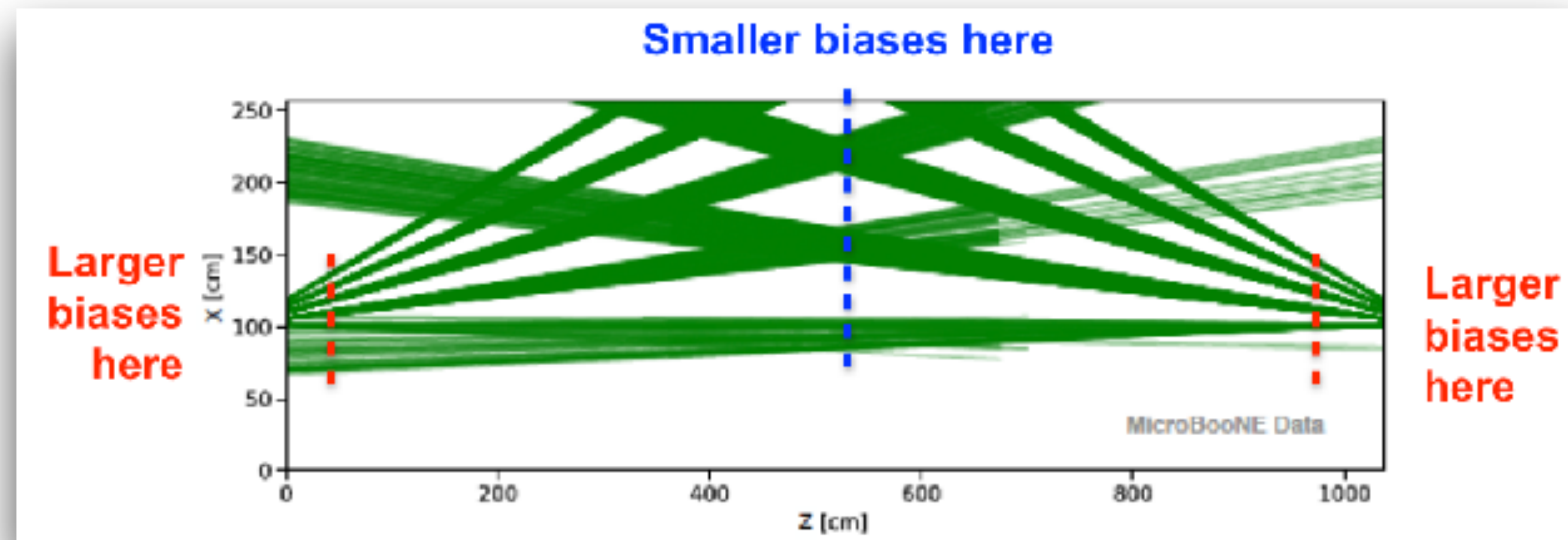
- MicroBooNE uses closest point, iterative method to reduce the bias from the initial laser beam angles (more in backup)
- But, requires two-origin tracks (or tracks from two laser systems)



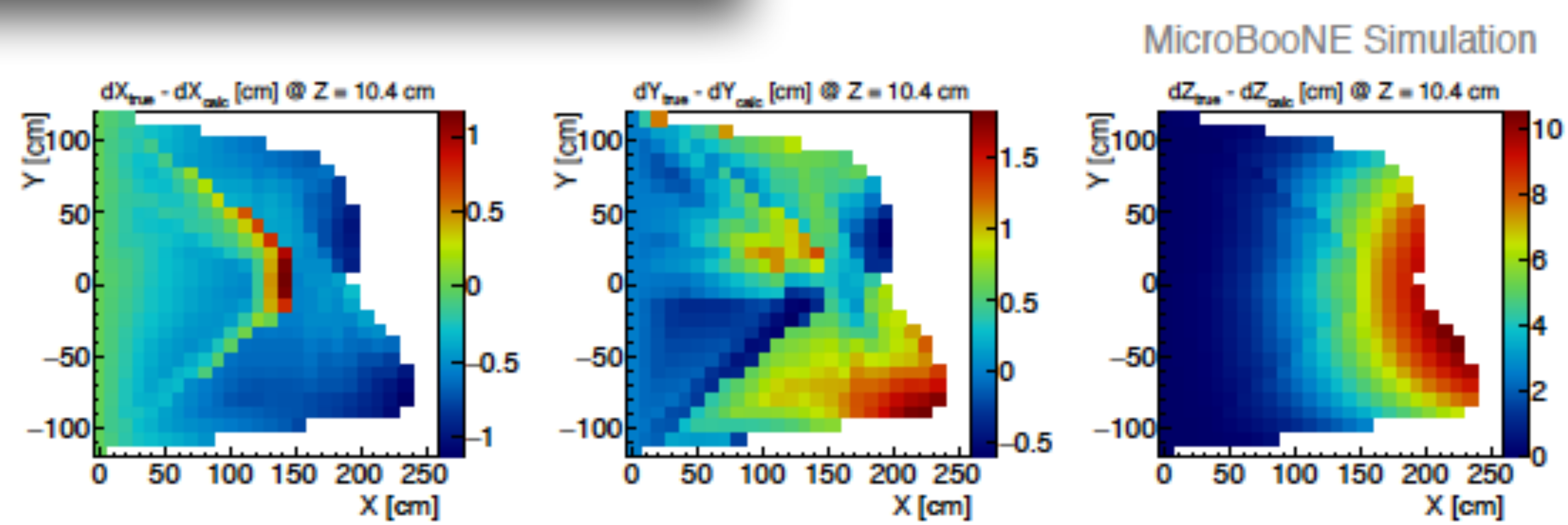
MicroBoone Full MC Bias Study

- Small position biases (< 1 cm) in well covered in central region



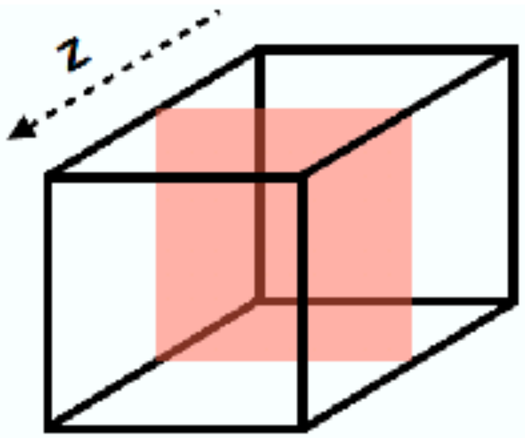


- Large biases in upstream/downstream regions, where **only tracks from one side** are available



MicroBooNE E-field measurement

arXiv:1910.01430v2



E-field map by laser data

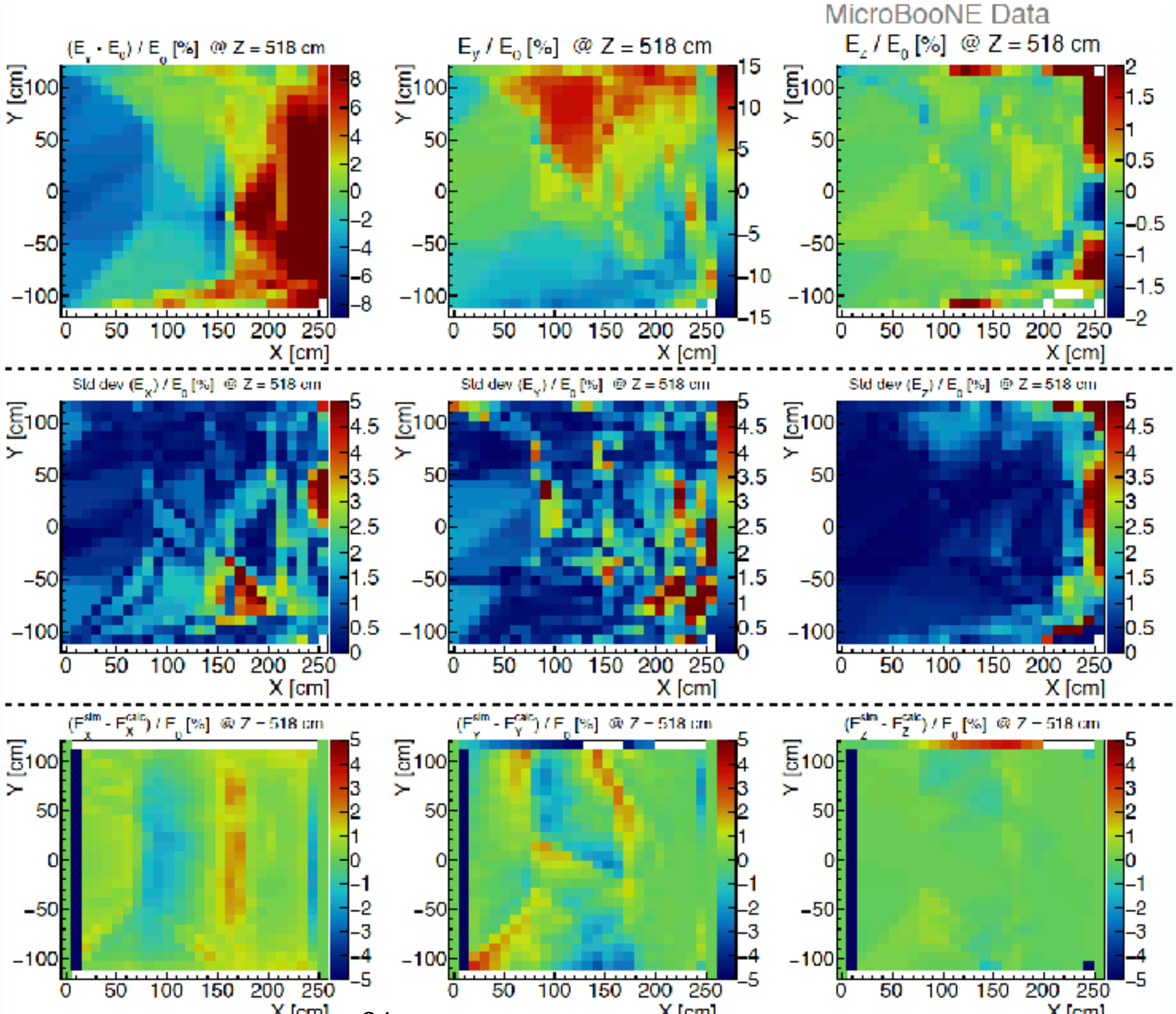
Up to 15% variations

(Mostly 2% except in certain regions)

Statistical Uncertainty

(mostly within 2%)

Systematic Uncertainty



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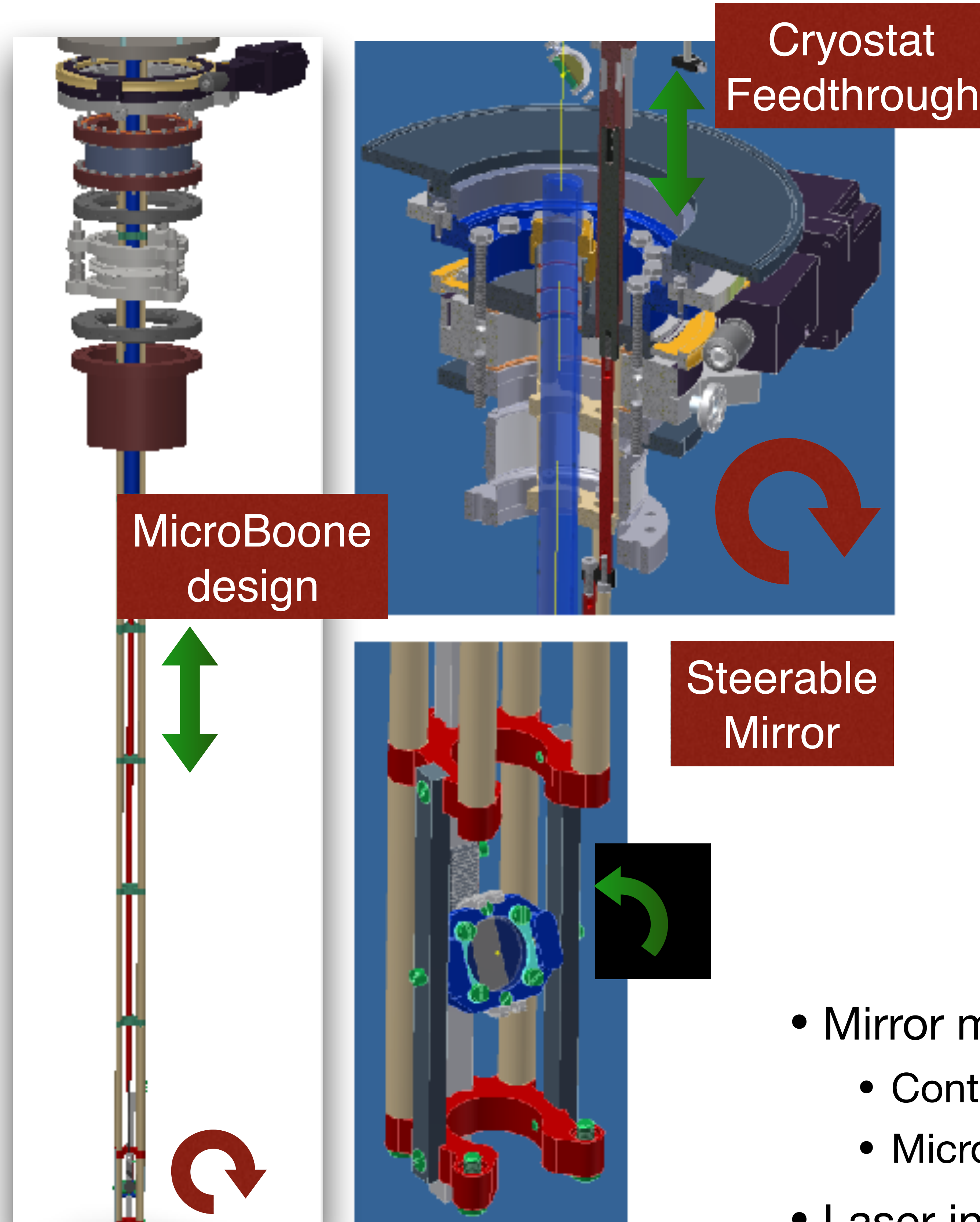
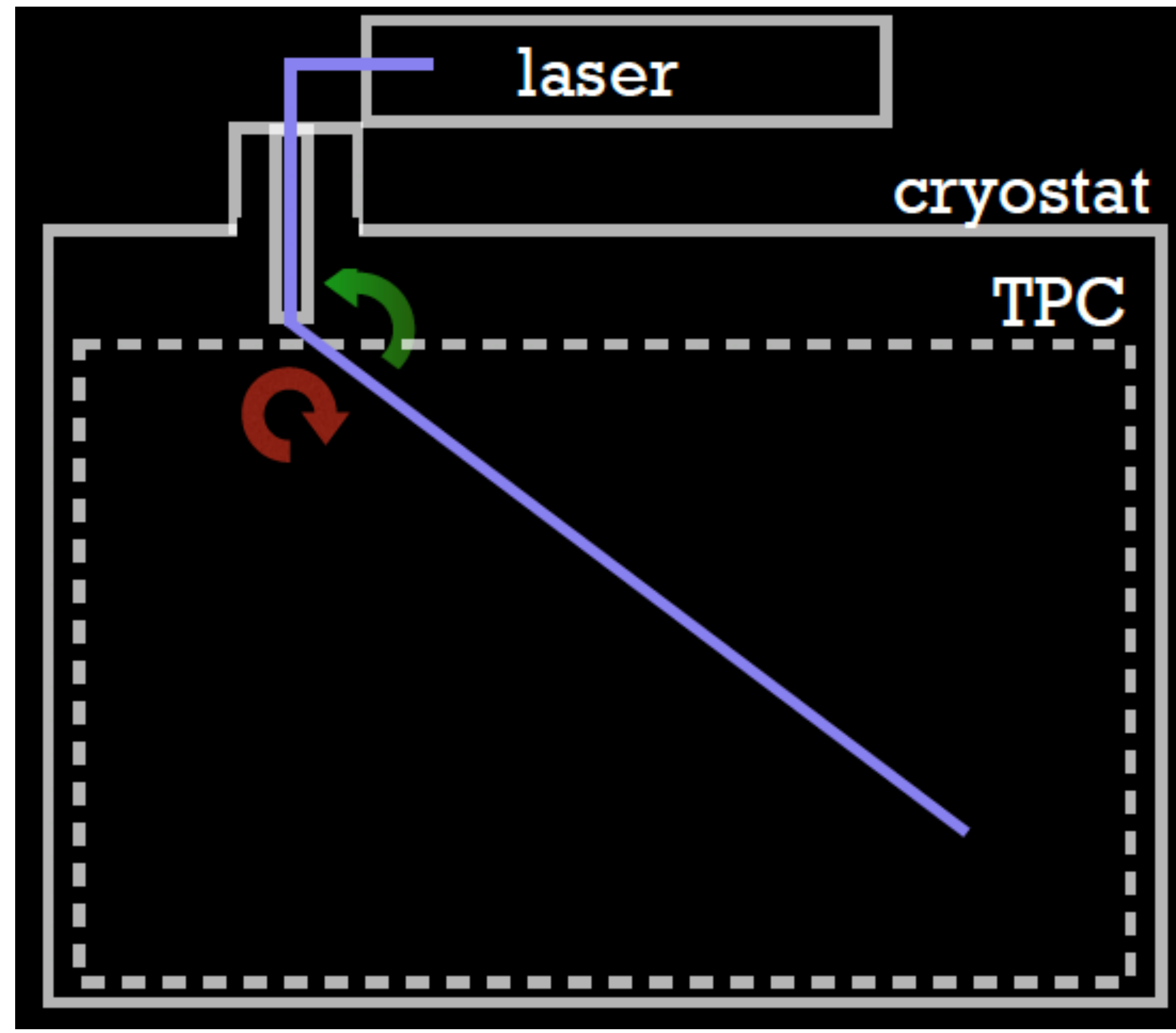
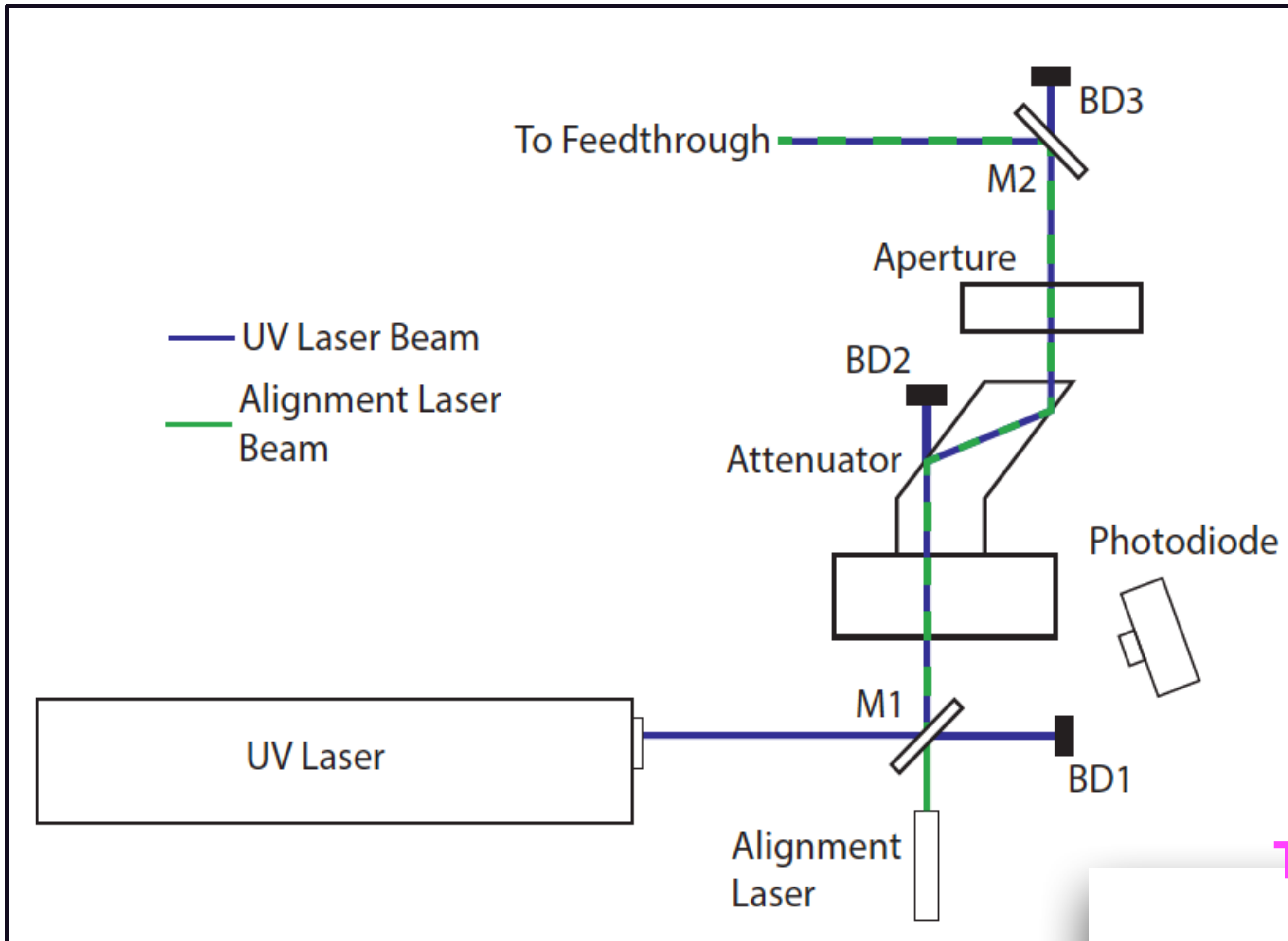
Ionization Laser System Outline





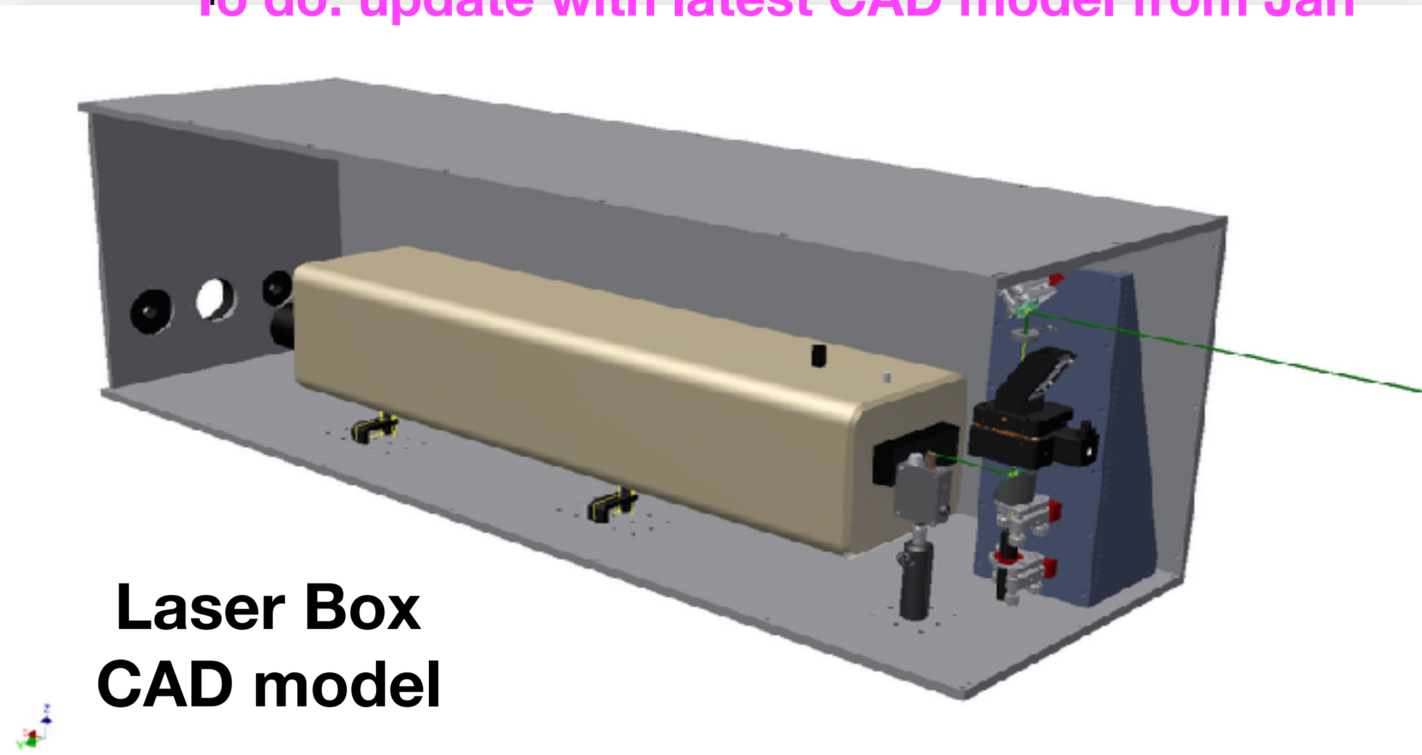
- Mirror movement with 2 degrees of freedom
  - Controlled by stepper motors and encoders
  - MicroBOONE precision: 0.05 mrad. Overall 2mm@10 m
- Laser intensity controlled by attenuator

Ionization Laser: System Outline



- Based on MicroBooNE/SBND design
  - *Attenuator* to regulate intensity
  - *Aperture* to limit beam spot (5 mm)
  - *Photodiode* to monitor pulsing
  - *Visible laser* to align all downstream mirrors

To do: update with latest CAD model from Jan

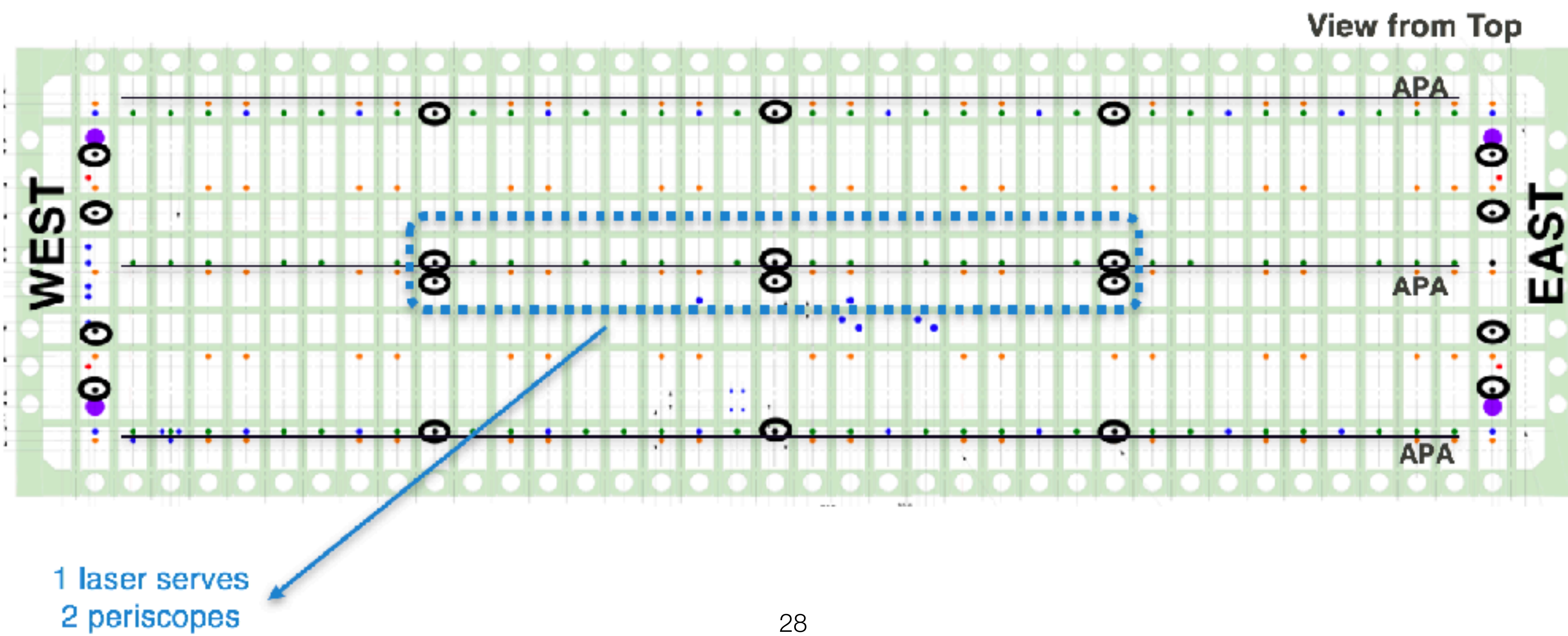


Laser Box CAD model

- Umbilical 7 m (max) for ~2.2 kW power and water cooling
- Rack for UPS, NIM, network, DAQ interface

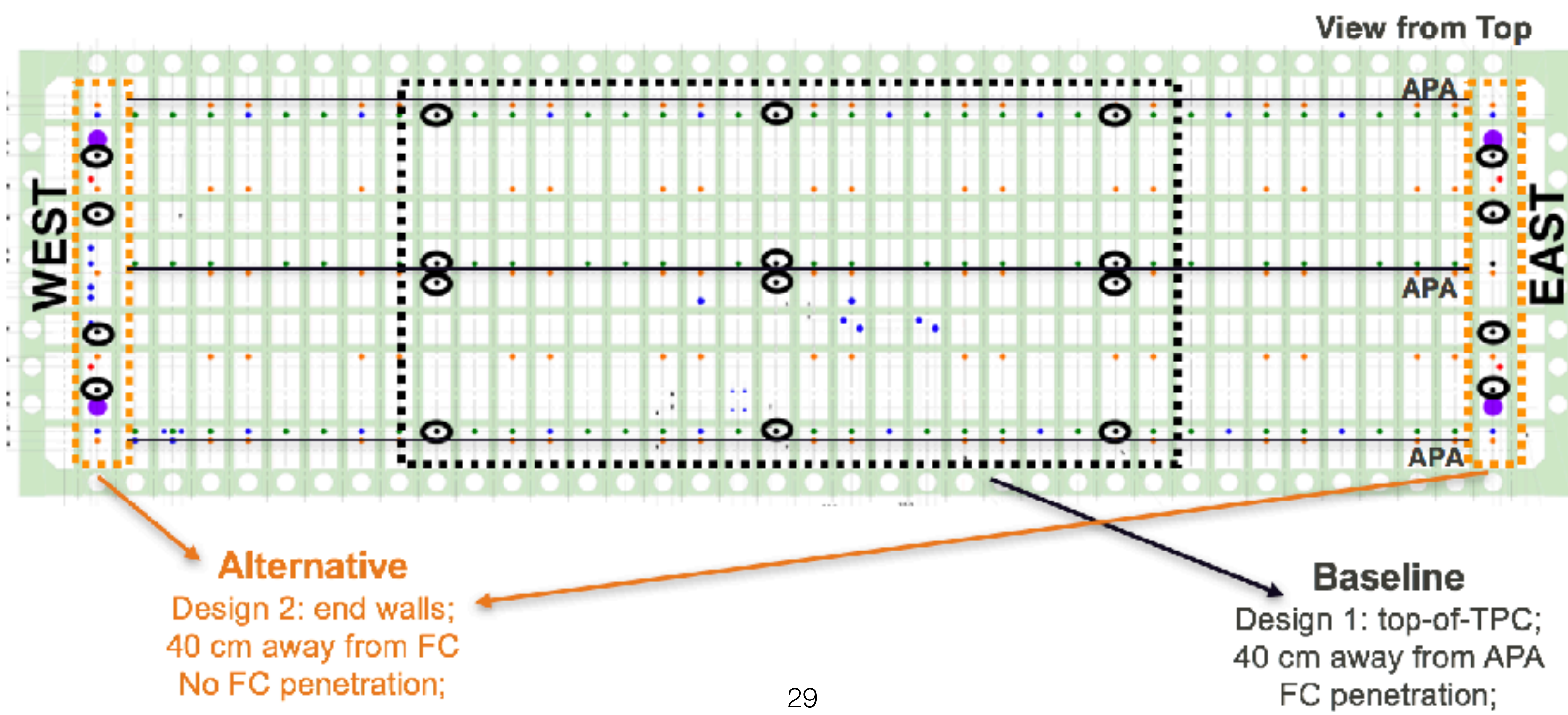
DUNE FD-SP module: Originally Proposed Laser System Distribution

- 17 lasers, 20 periscopes
  - Single laser beam can't reach full length of drift volume, so, split into 4 regions at a max. length = 20 m
  - Crossing tracks in each of 16 regions needs to be seen by 2 periscopes implies 5 per drift = 20 in total



DUNE FD-SP module:
New Baseline, June 2019 workshop

- **New baseline** recommendation following June 2019 workshop
  - 9 lasers, 12 periscopes
  - FC penetration needed; implement periscope retraction
- **Alternative** (End-wall)
  - Design 2; no FC penetration needed



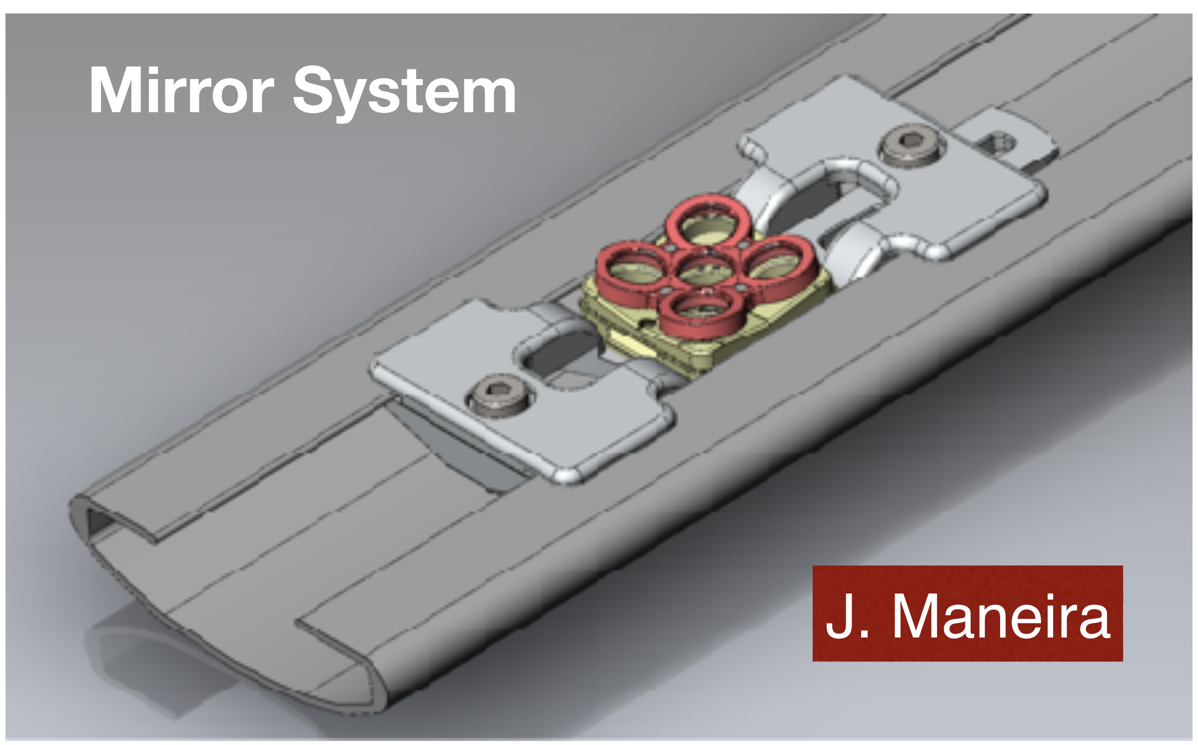
Impact of Requirements on System Design

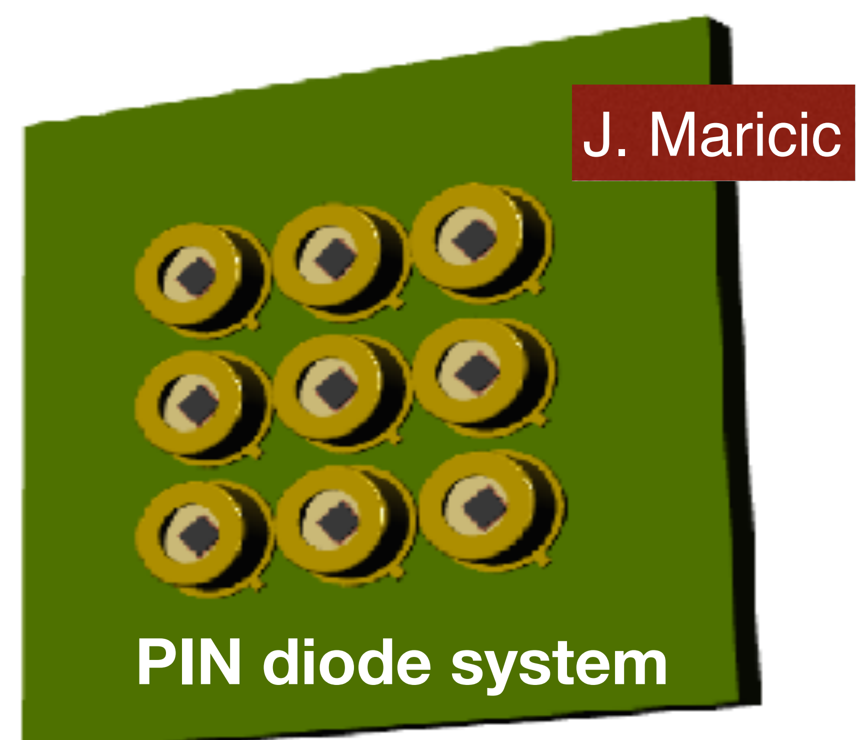
- **Precision of E-field: 1—2%**
  - leads to need for Laser Beam Location system (LBLS)
  - *See next slide*
- **Coverage**
  - *Top-of-the-TPC ports:* requires FC penetration
  - Need lasers in the end wall and different design for the periscope
  - *Discussion in next slides*
- **Granularity**
  - determines data volume and time needed for calibration campaign

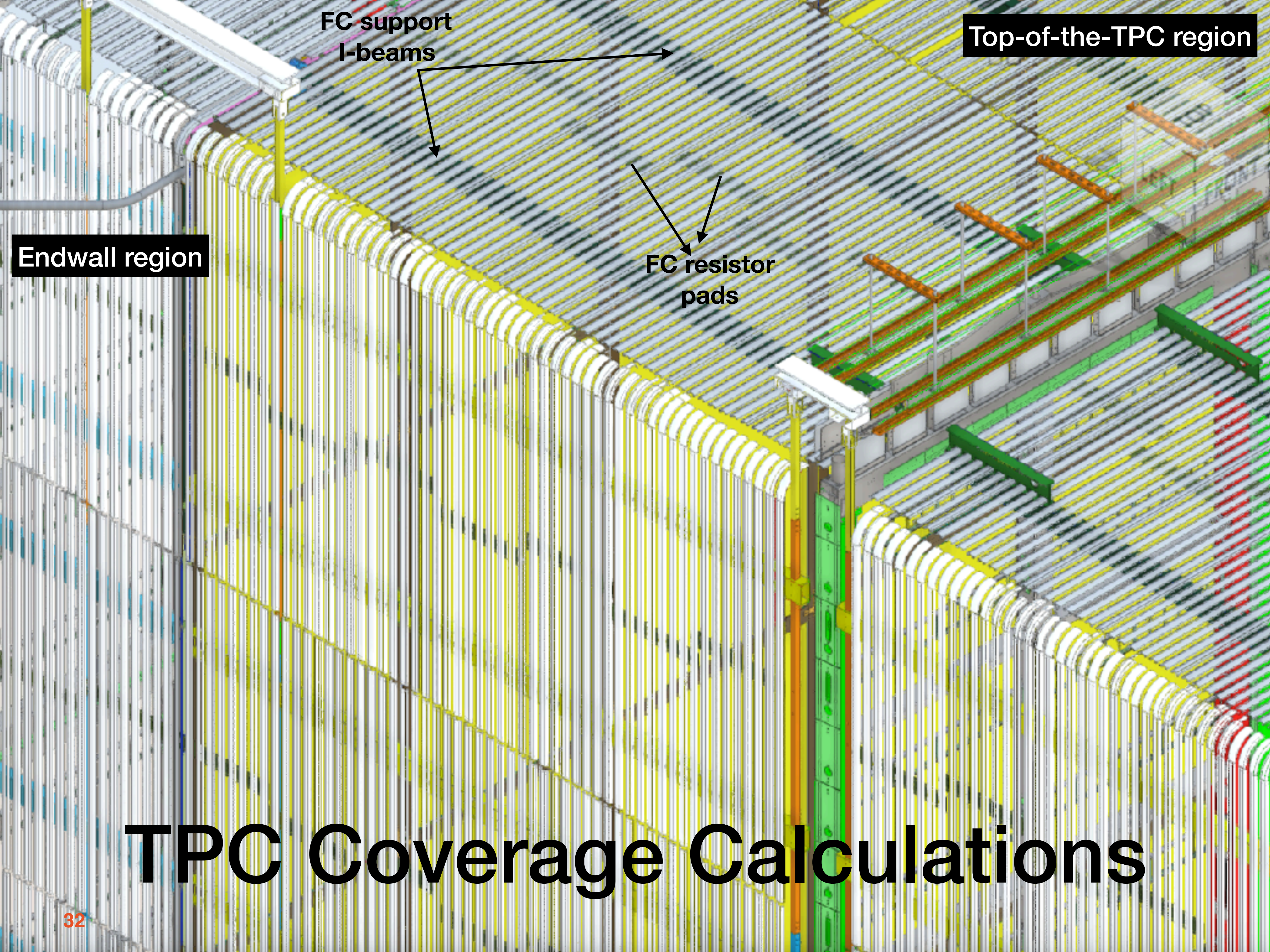
Laser Beam Location system

(see dedicated talk by J. Maneira)

- E-field measurement is based on measuring deviations from straightness of laser tracks
- Requirement of beam position uncertainty: **5 mm** (driven by TPC wire spacing)
  - Laser encoders pretty accurate: 2mm @ 10 m (MicroBooNE)
  - **But, need to have position relative to TPC also accurate and verifiable**
- Two independent in-situ systems planned:
  - PIN diode System
  - Mirror pad System

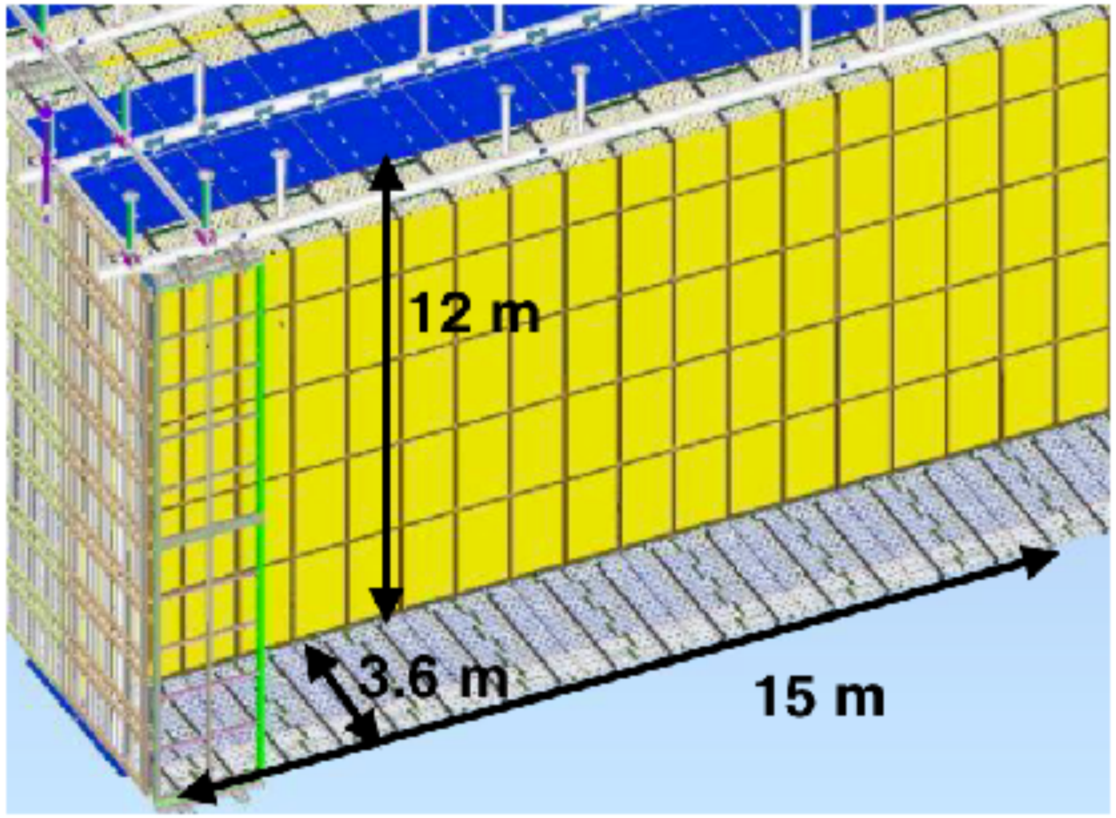






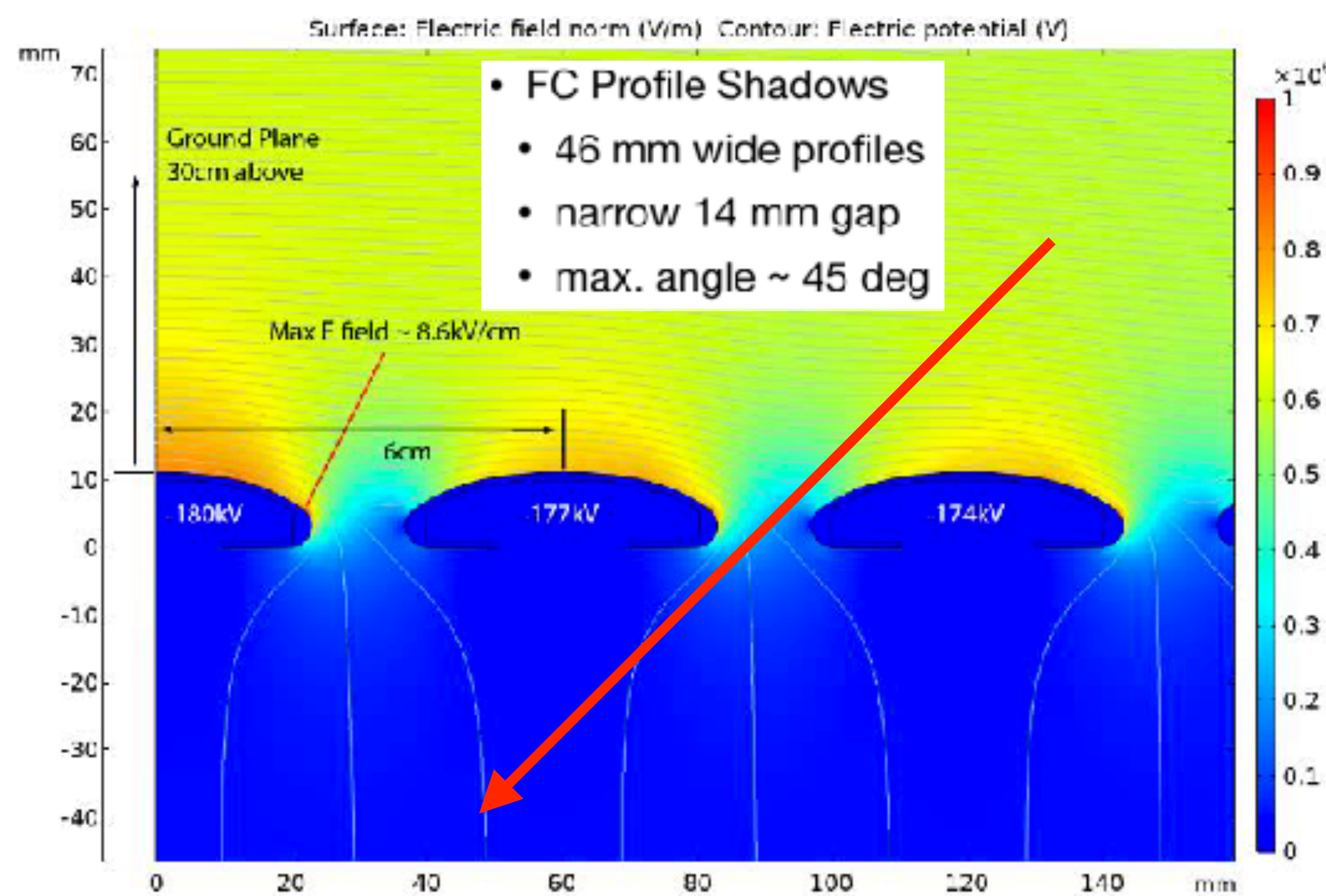
TPC Coverage Calculations

Coverage Calculations



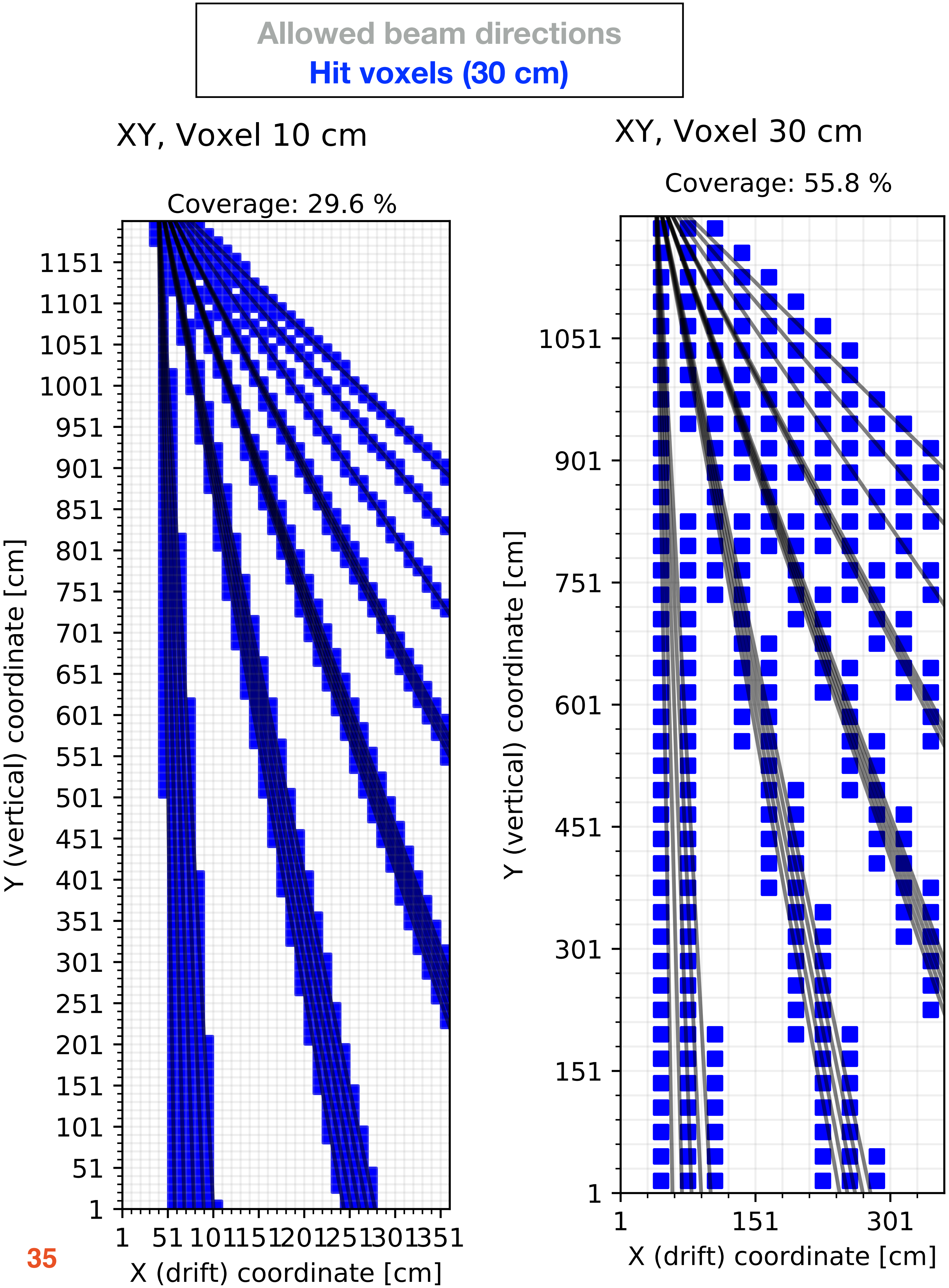
- Focus on a single "region", split in 30 cm or 10 cm voxels
- Consider starting points outside FC
- Allow/not allow beams aiming at APA
- Count fraction of hit voxels
- 2D or 3D; Projections XY, XZ, YZ

- 2D calculation on vertical plane only
- For the baseline system (top-of-the-TPC locations, true coverage ***overestimated***
  - FC support I-beams & Resistor strips shadowing not taken into account



Top-of-the-TPC Region (Baseline System)

Coverage Results

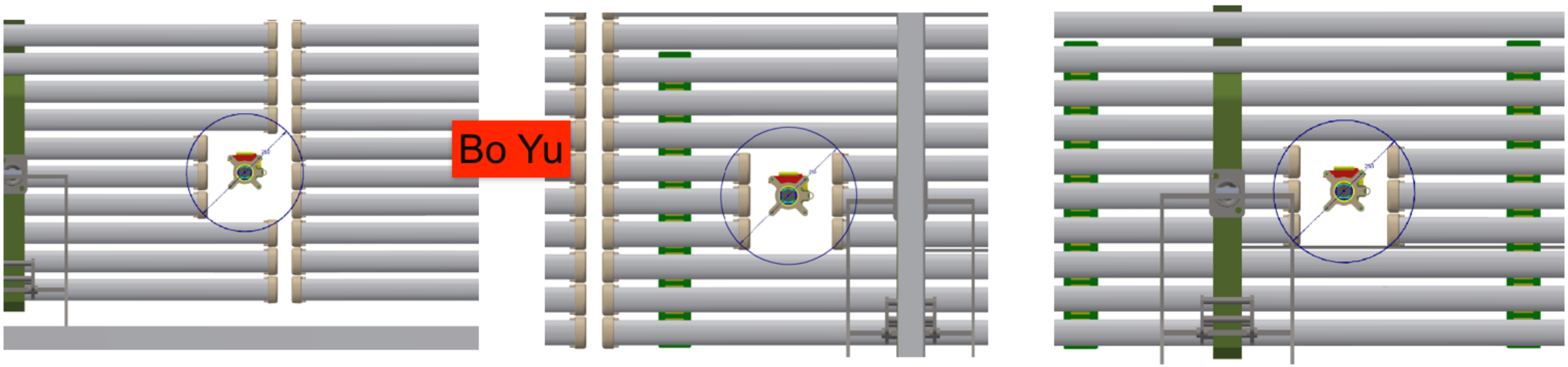


	30 cm Voxels	10 cm Voxels
APA	58%	31%
no APA	56%	30%

- “no APA” results are more realistic
- Only ~50% coverage in the central cryostat region *without FC penetration*
- Considering shadowing from FC support beams & resistive panels will reduce the coverage further (at least by about ~10%)
- ***FC penetration needed in order to meet coverage requirements***

Top FC Penetration

- Coverage not calculated yet, but surely well above 75%
- Agreement with HV experts that FC modules can be adapted for this and is low risk to penetrate (from HV simulations)

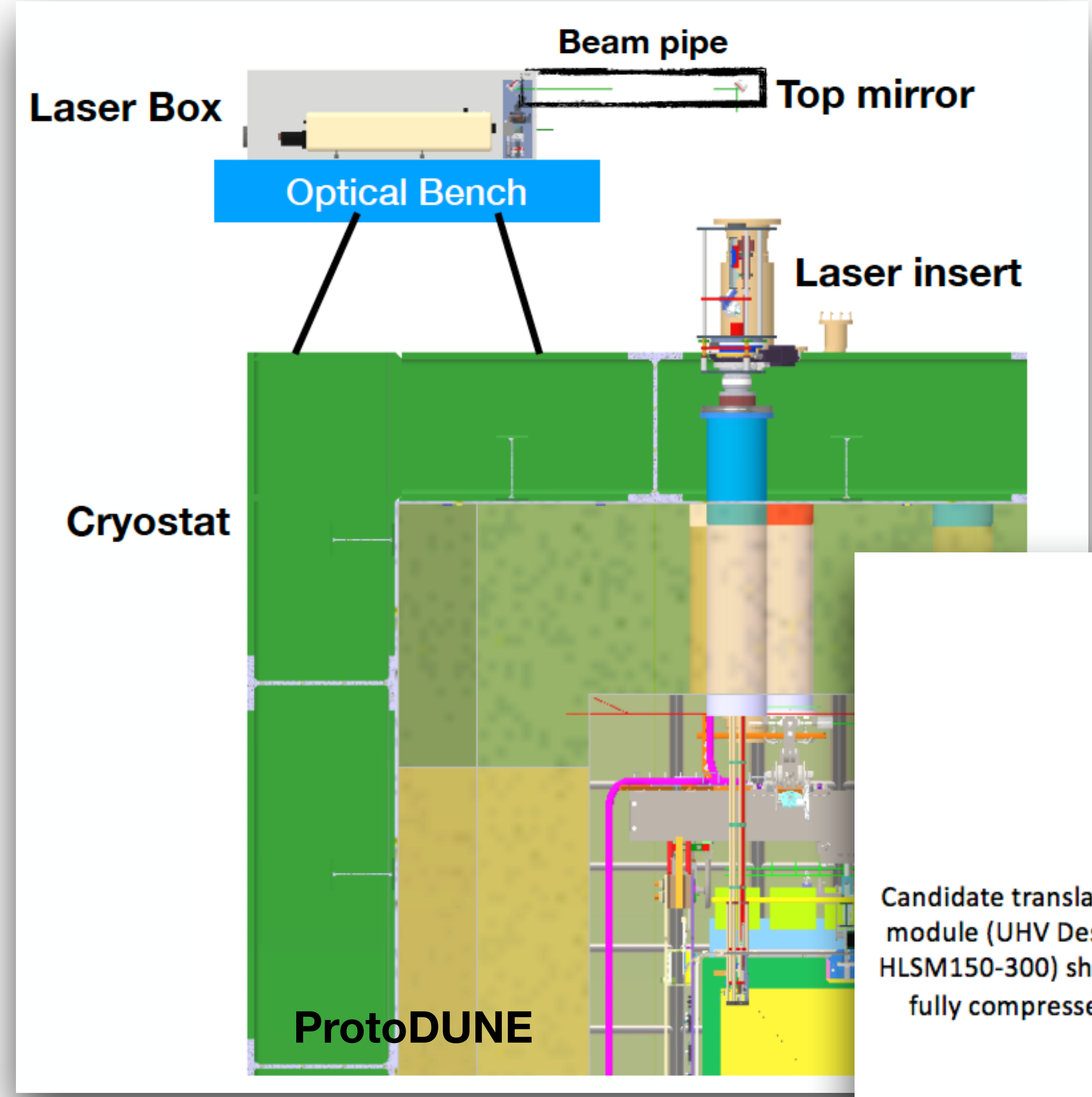


- Three types of FC penetrations needed (small increase in cost for last two)
- Production & Assembly
  - Plan is to assemble all FC modules underground.
  - A special set of FC profiles with non-standard lengths will fabricated by the “factory” and shipped to SURF. These special modules will be clearly marked in storage.

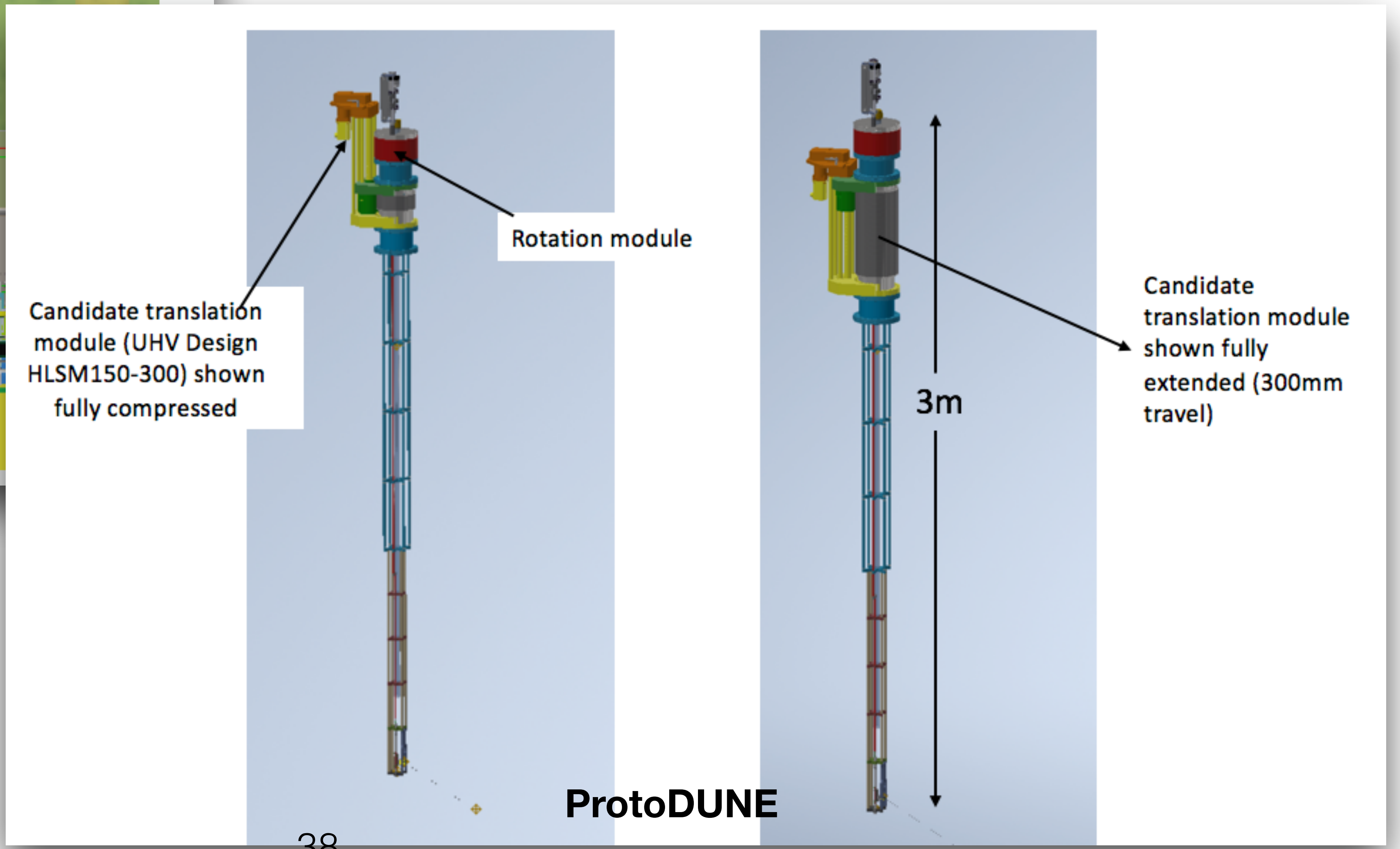
Latest E-field simulations from Bo

- These were done only this week so hot off the press; uses the latest baseline periscope model from Jan
- Full slides here: https://drive.google.com/file/d/1YSEn1keogLM1GREDz2ZQyiIM2bWJn59t/view?usp=sharing
- Conclusions
  - "For the periscope up configuration, I simply disabled the periscope model inside the FC. Once the periscope is beyond ~ 10 cm above the FC opening, it would not have any noticeable influence to the inside of the field cage.
  - Since the new opening is closer to the APA than what I had simulated in the earlier study, the distortion is expected to be smaller.
  - The distortion caused by the periscope goes deeper into the TPC, but *nowhere near the fiducial volume."*
- Bo's last year slides: https://indico.fnal.gov/event/20996/contributions/60353/

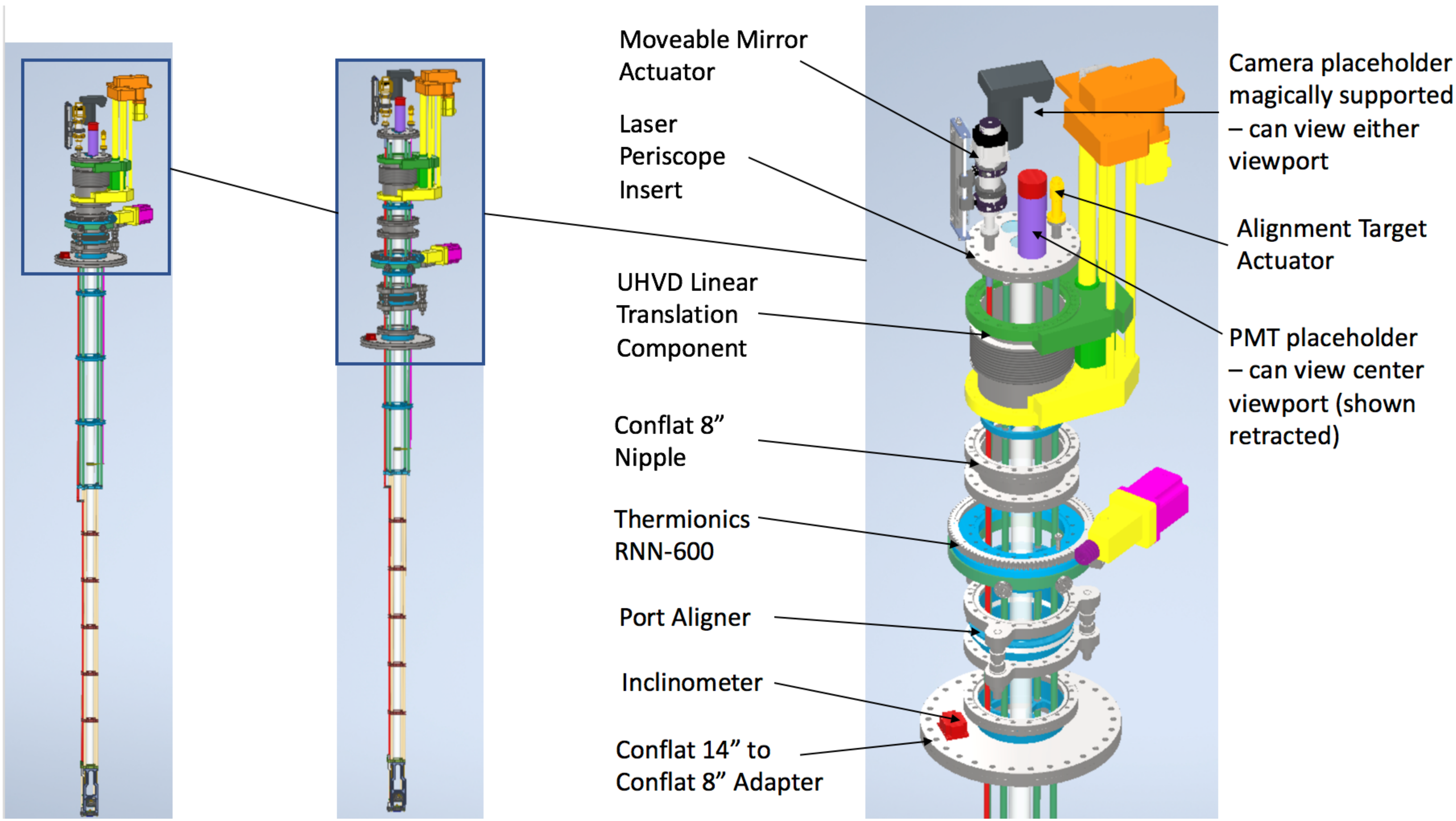
Laser Periscope Retraction



- The top mirror is connected to the laser beam pipe (coming from the laser box) to keep the beam vertically down irrespective of periscope motion
- Jan introduced a translation and rotation stage into the design that allows **300 mm** of travel at full extension



Laser Periscope Exploded View



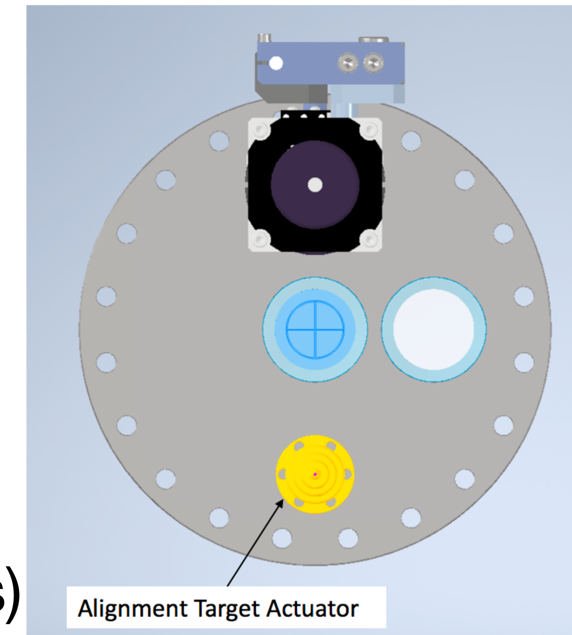
- Camera system on the periscope will help with alignment along with visual confirmation of periscope clearance from FC edges ***(dedicated talk by G. Horton-Smith on Cameras)***
- The TPB coated PMT can serve as a UV detector

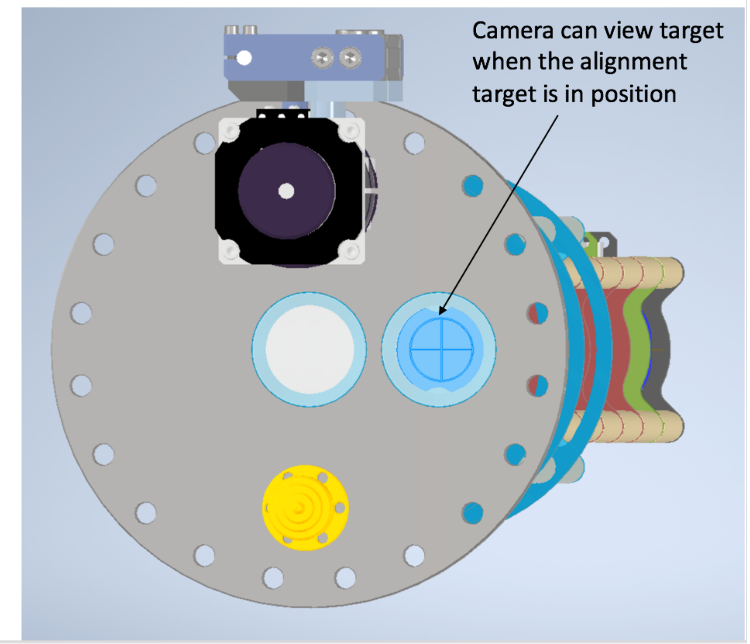
J. Boissevain (LANL)

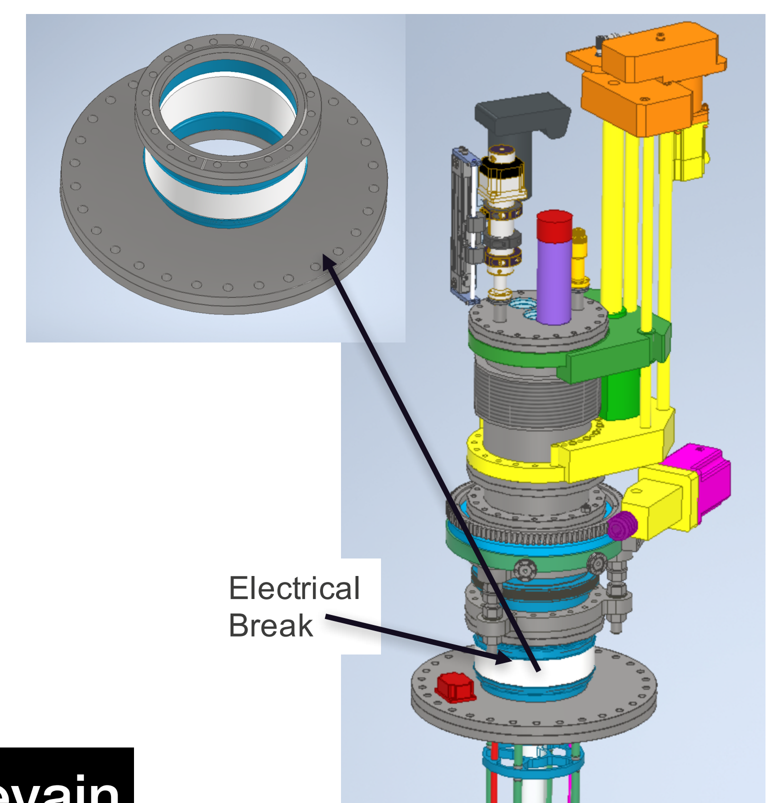
Laser Design Progress Summary

(more details in backup)

- ✓ Electrical break for the periscope
- ✓ Use large bottom mirrors for increased coverage and viewing
- ✓ Laser alignment features
  - Movable alignment target
  - Two view ports (for camera, PMT)
- ✓ Periscope split design (two 1.5 m sections)
  - Mitigates the installation issue for the FD
- ✓ Value Engineering
  - Replace chimney side from Torlon to Steel
  - Replace Torlon with Peek for the periscope support structure on the cold side
- ✓ One Laser beam to two periscopes design
- ✓ Component selection
  - Vendors identified for most parts, quotes in hand
- ✓ Laser arrangement on the cryostat
- ✓ Laser Rack, Electrical and Grounding

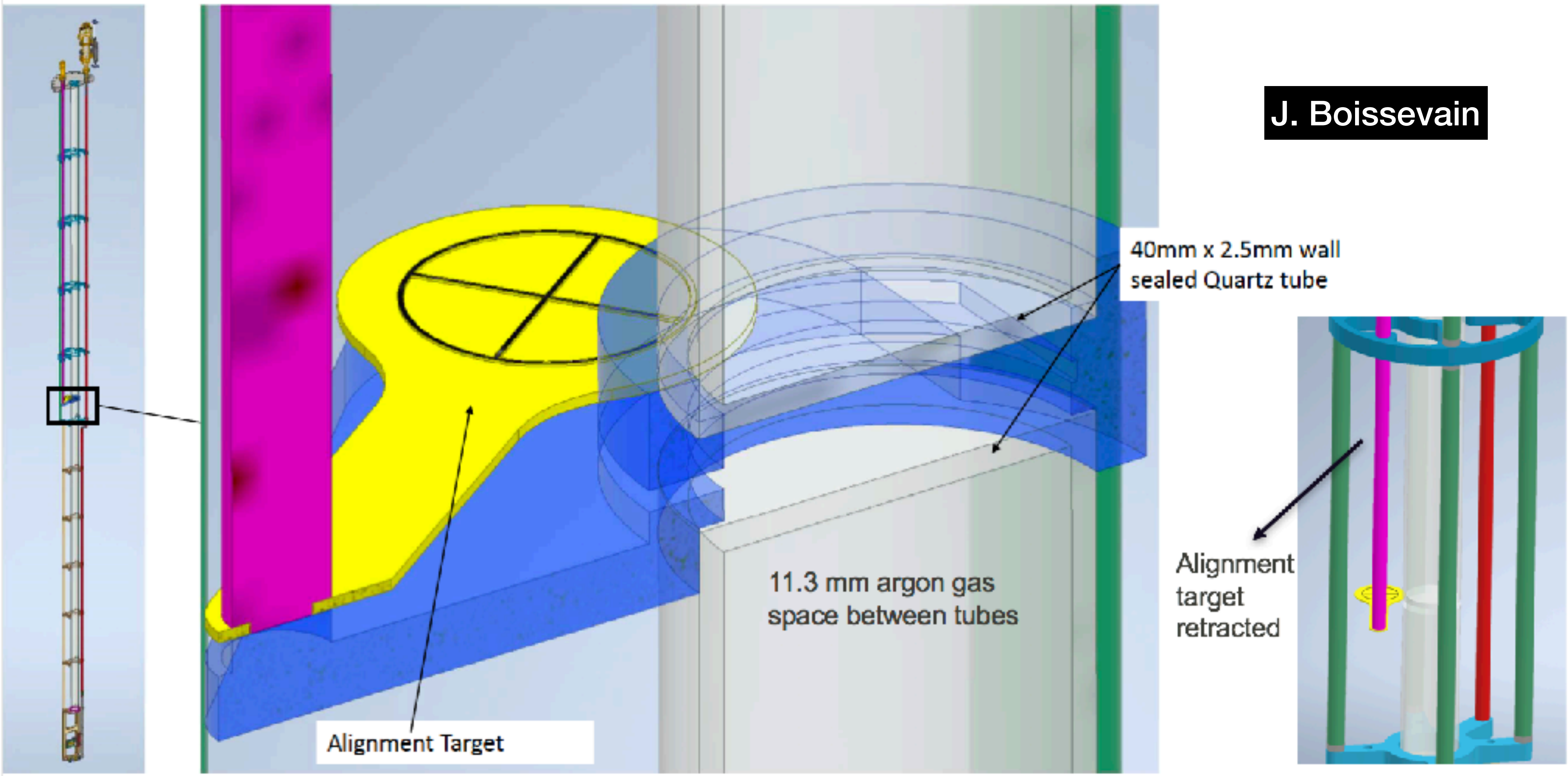




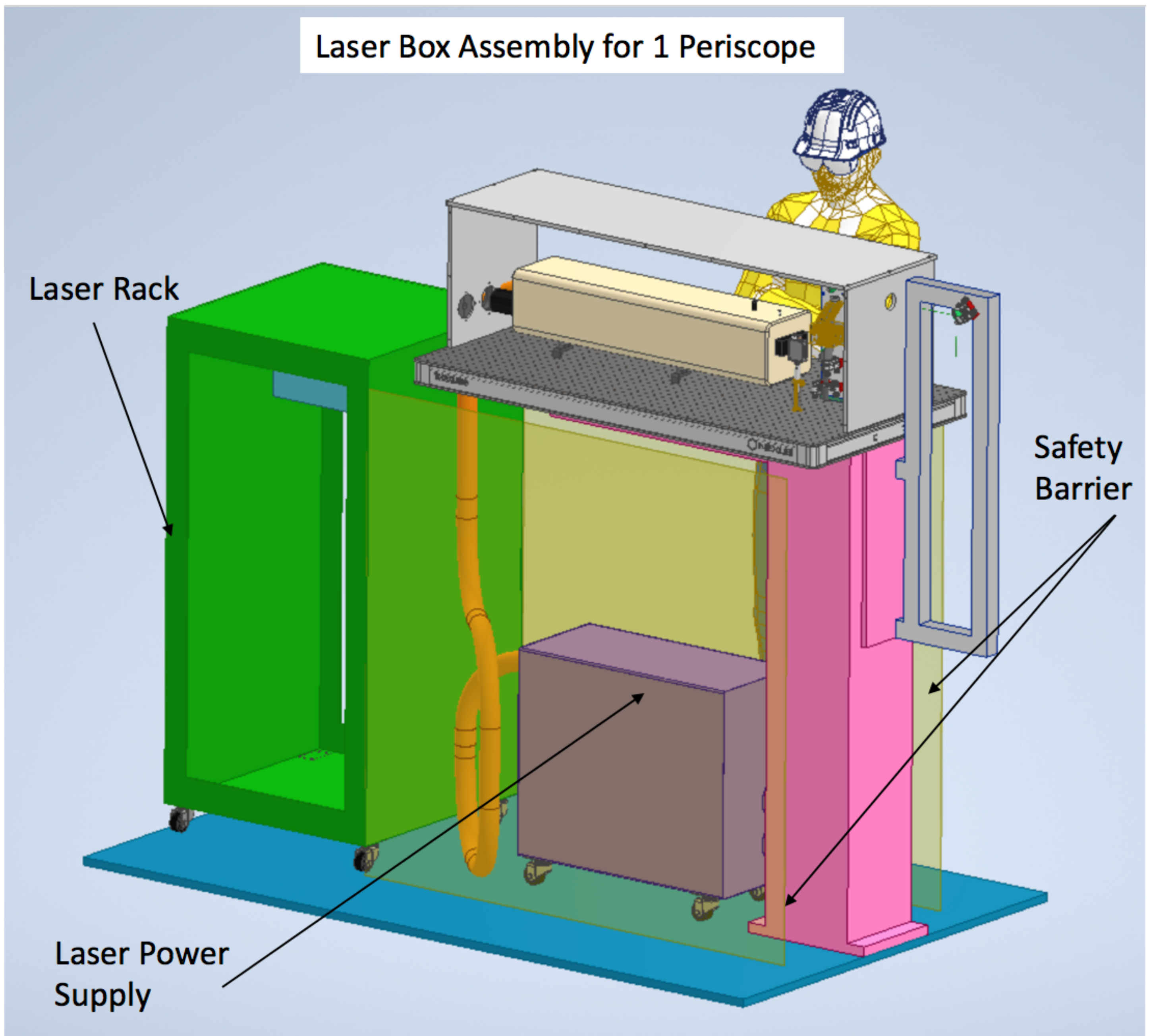


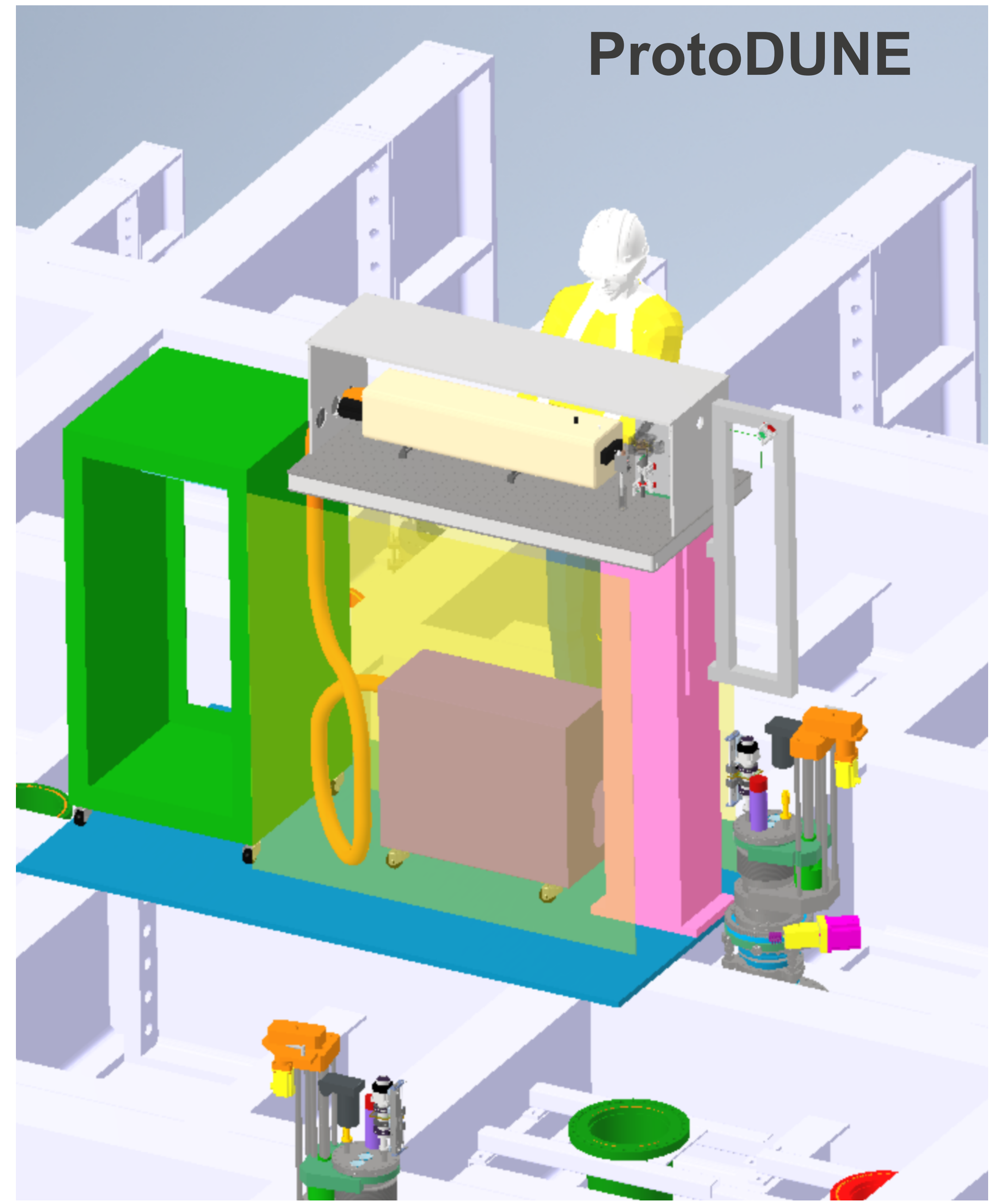
J. Boissevain

Split Periscope Design & Laser Alignment Target



Proposed Laser System Assembly: One Periscope





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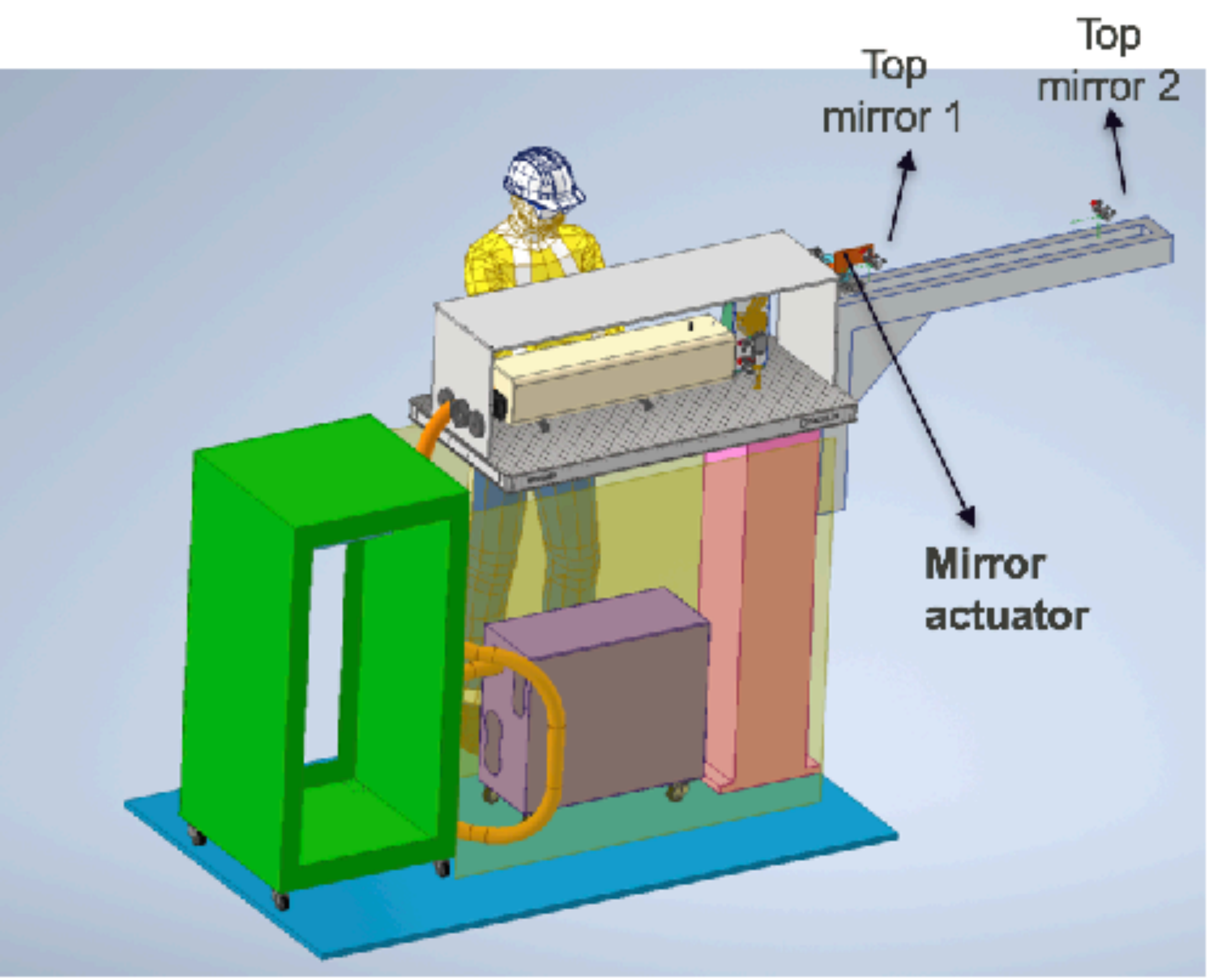
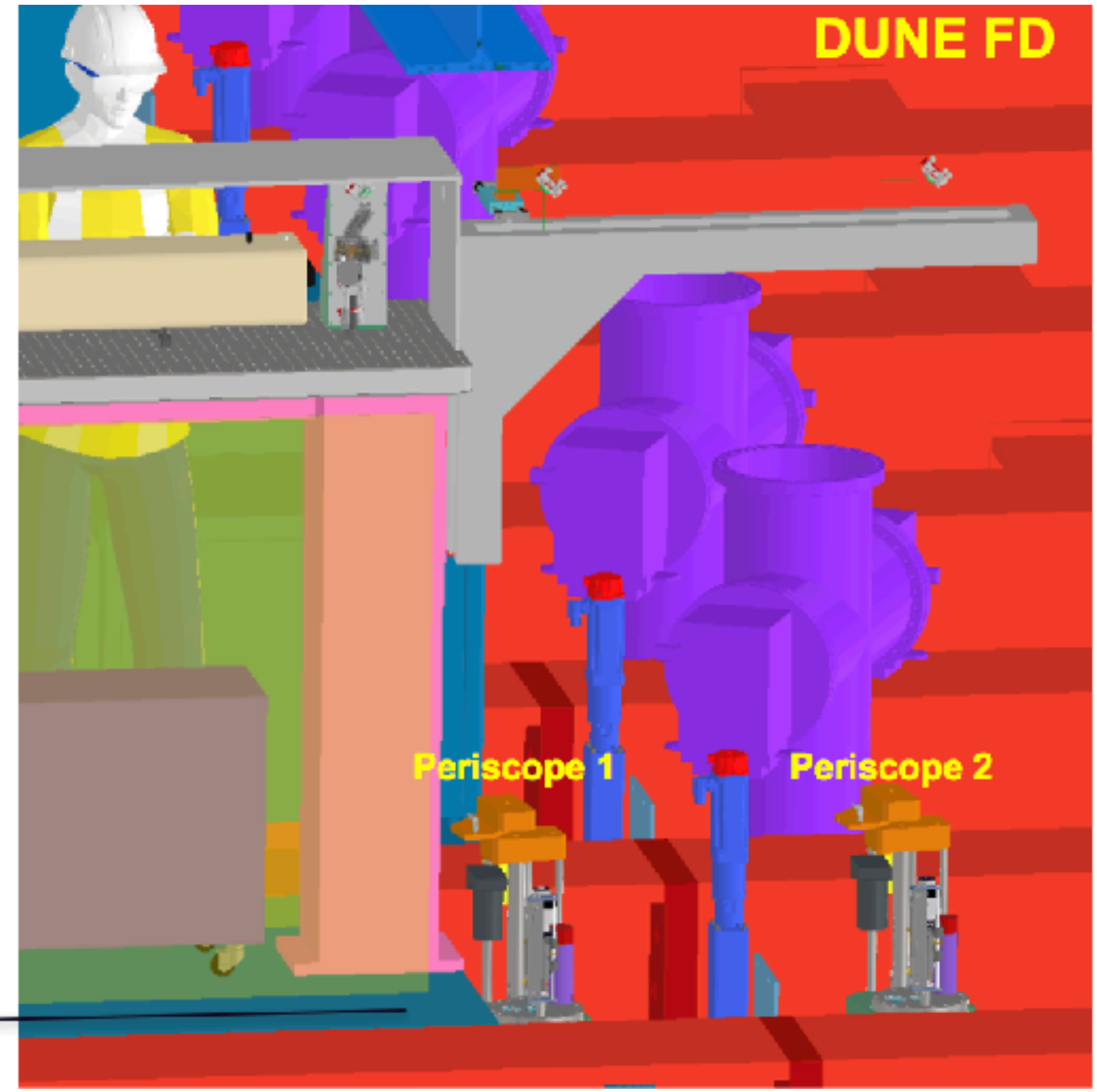
move to backup?

One Laser for Two Periscopes





Laser system base at the same
level as the I-beam

J. Boissevain

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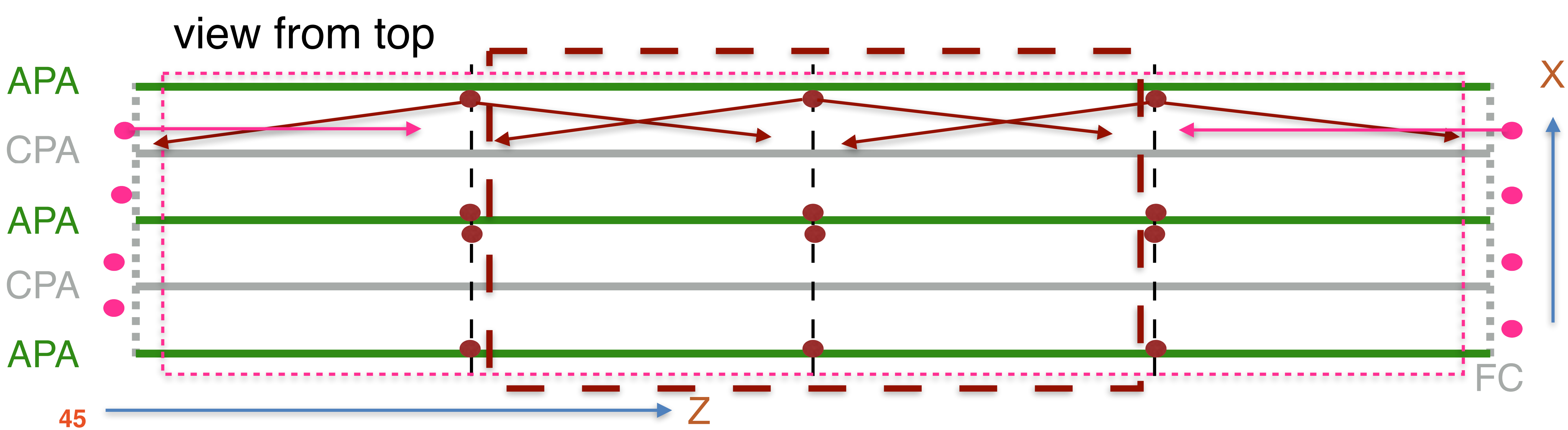
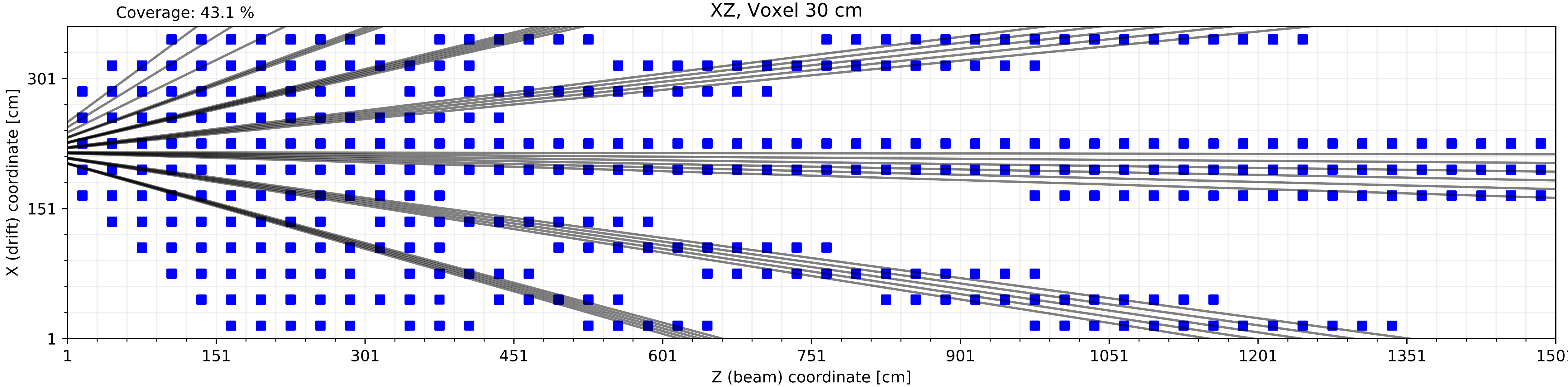
Motivation for End-Wall Lasers

- As noted before (slides 22—27), Iterative method needs two-origin tracks
- Can they be from the same laser?
  - No. For distant regions, tracks from same laser are close to parallel, iterative method would not reduce bias over single track
- Baseline system only: two-origin track coverage in only 50% of volume
- Need second origin close to end-wall to increase that to ~90%



End-Wall Coverage

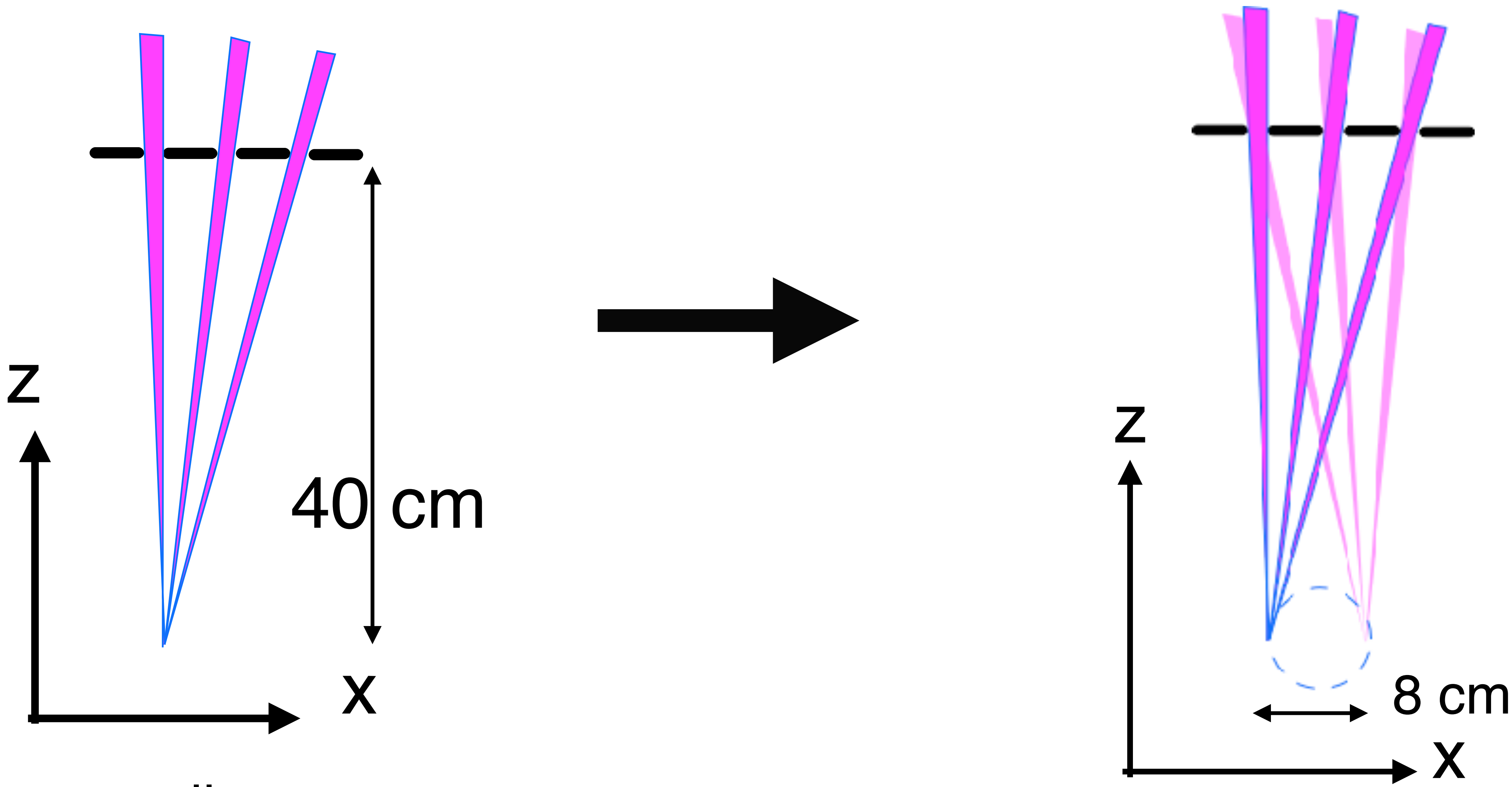


- Main effect is FC profile shadowing
- Avoiding APA ("no APA" case) implies bigger reduction (origin farther from APA)
- With 10 cm voxels, coverage lower
- Should be an overestimate
- In no case above 75%

	30 cm Voxels	**10 cm Voxels**
APA	55%	29%
no APA	46%	22%

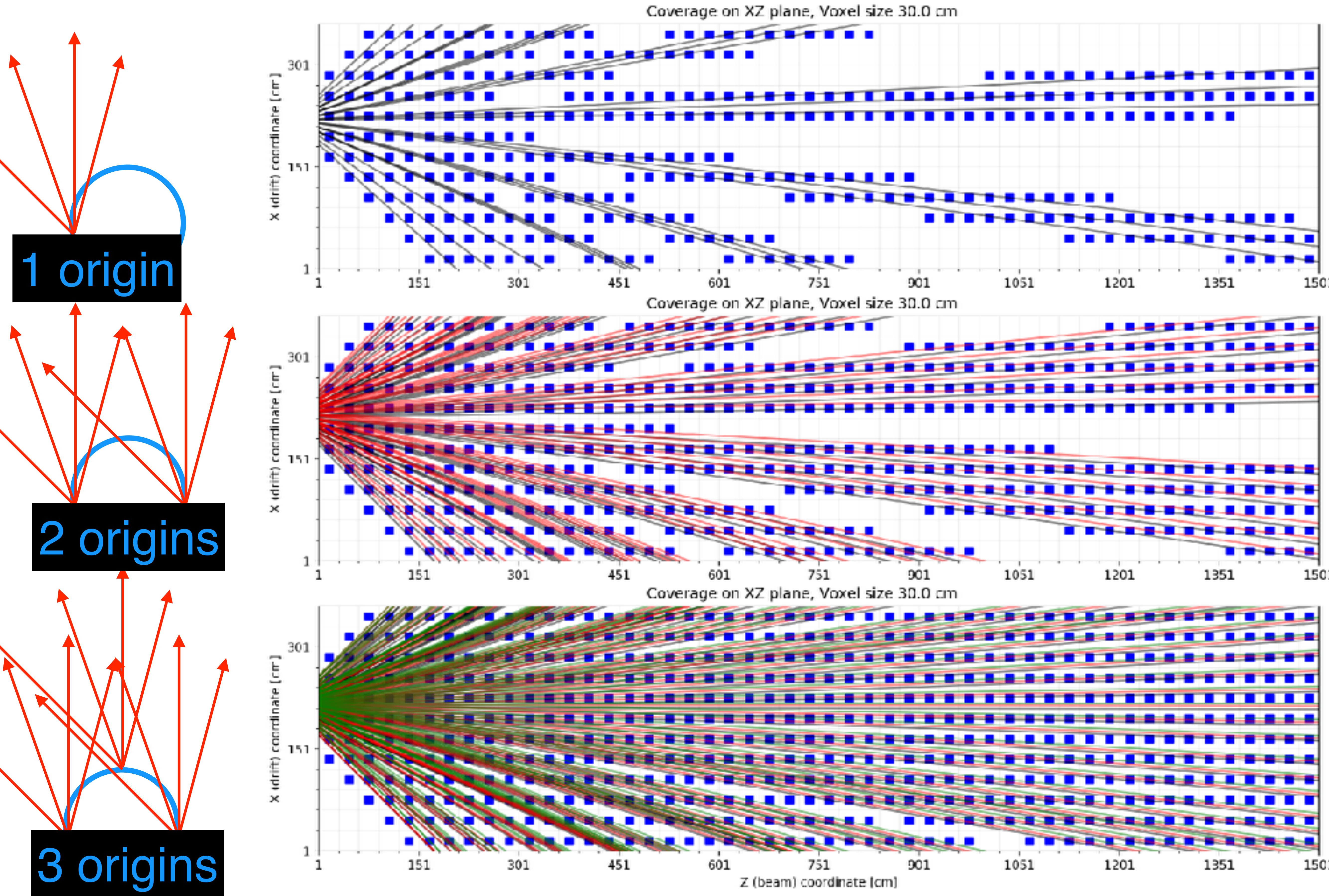
Baseline design for end-walls not really adequate for SP.

How to avoid FC shadowing?

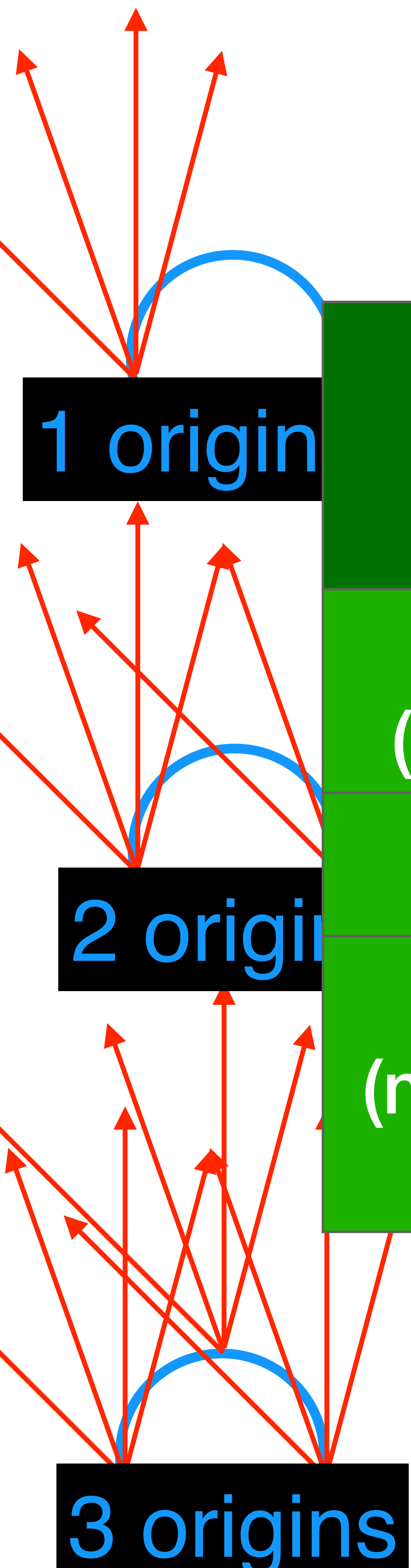


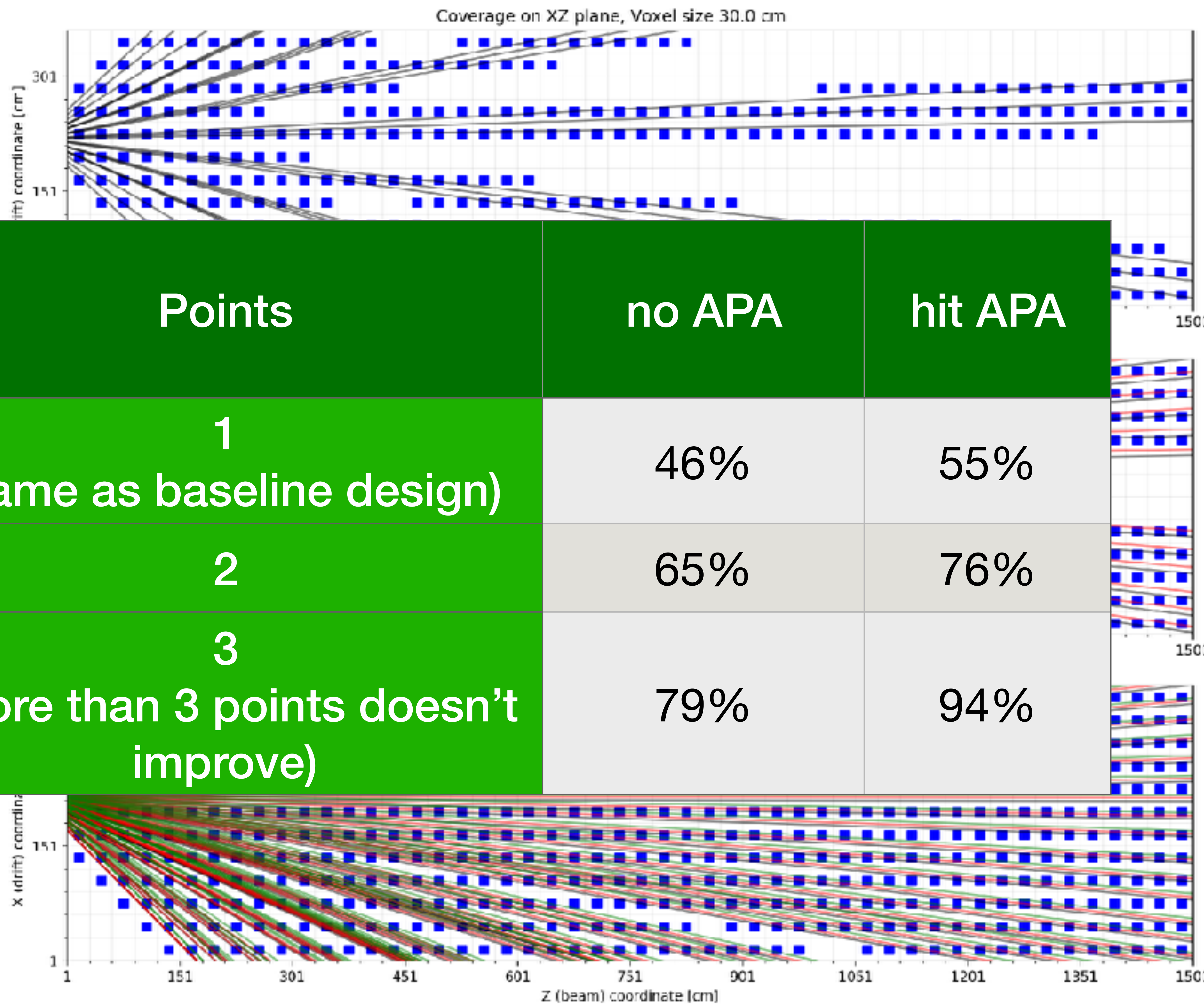
- Use parallax
- Move cold mirror to different positions (not just angles)
- FC will project different shadows in each position
- 3 positions within a maximum shift of 8 cm is enough

End-wall Laser Coverage



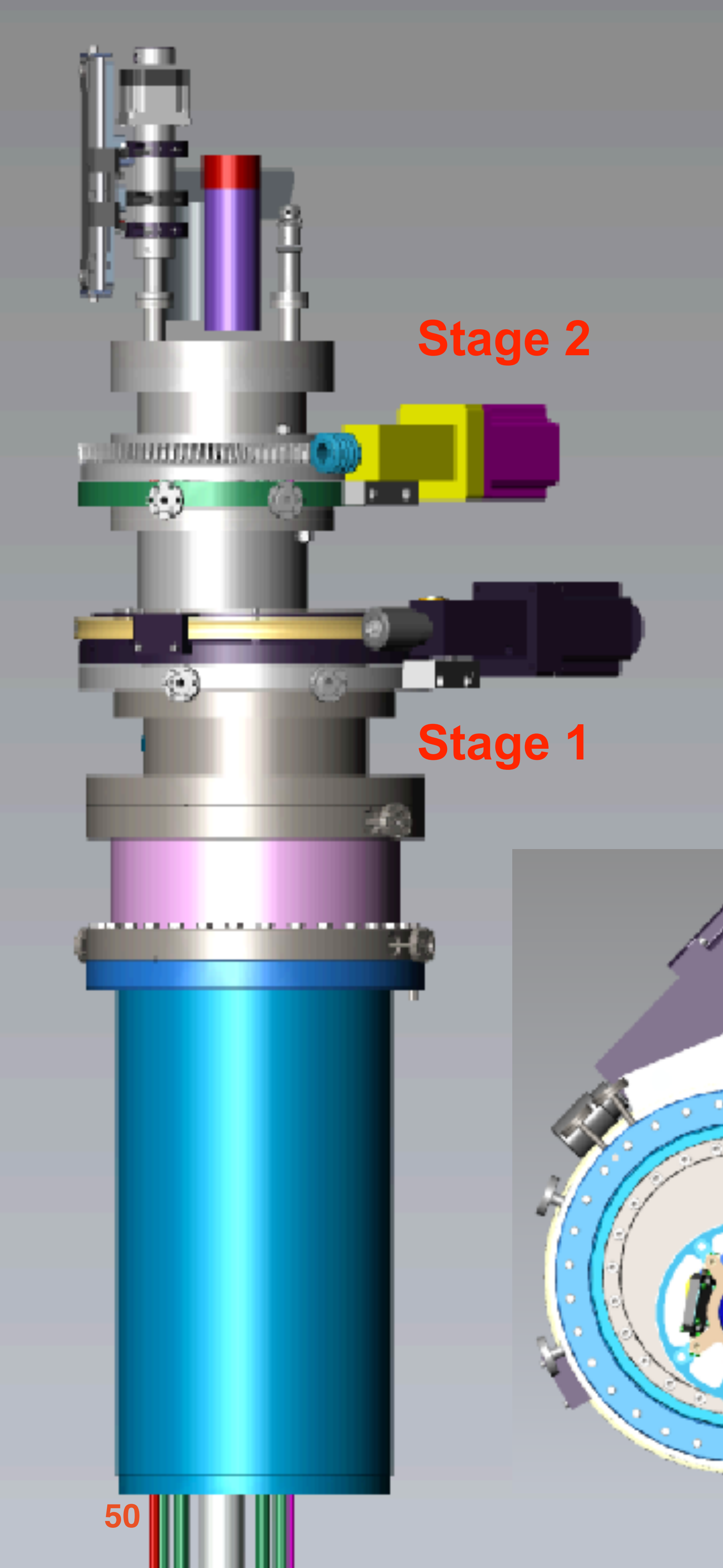
End-wall Laser Coverage



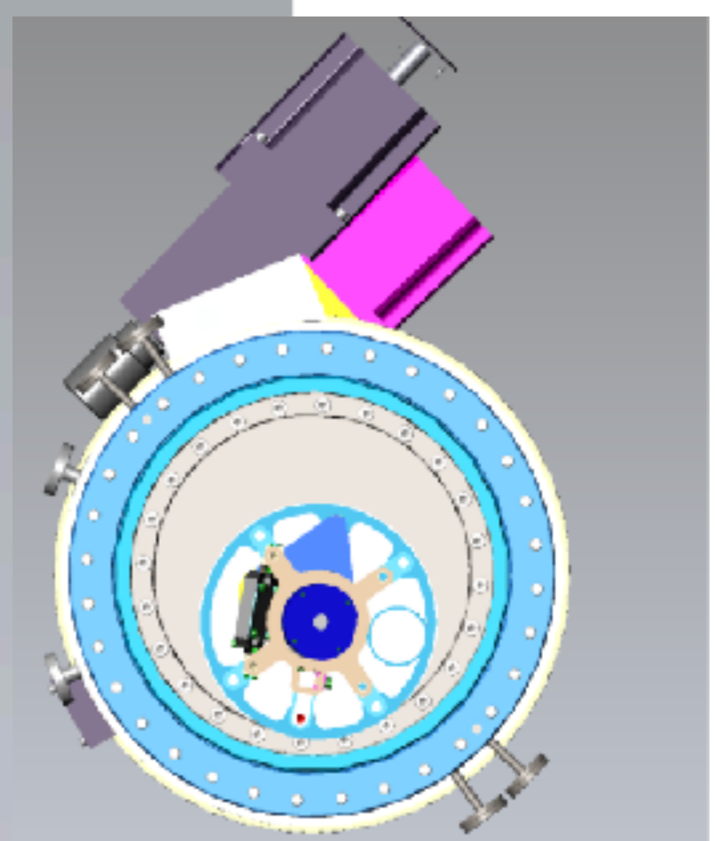


Points	no APA	hit APA
1 (same as baseline design)	46%	55%
2	65%	76%
3 (more than 3 points doesn't improve)	79%	94%

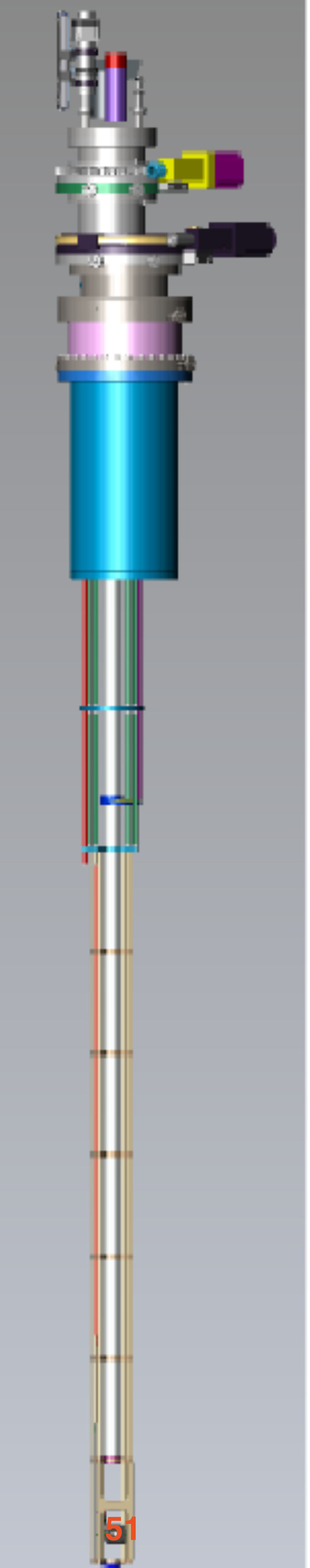
How to get multiple positions ?



- Dual rotation flange:
  - Rotary stage 1: centered on port
  - Rotary stage 2: axis offset by 40 mm from central axis
  - periscope mounted on stage 2

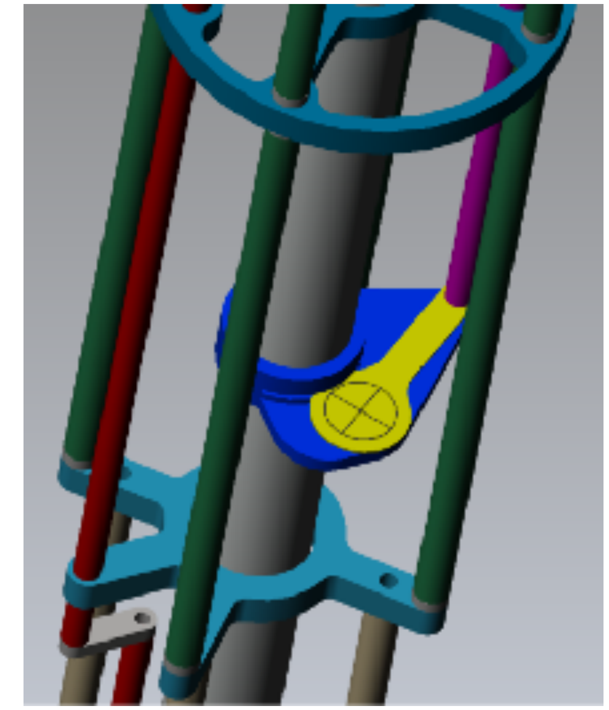


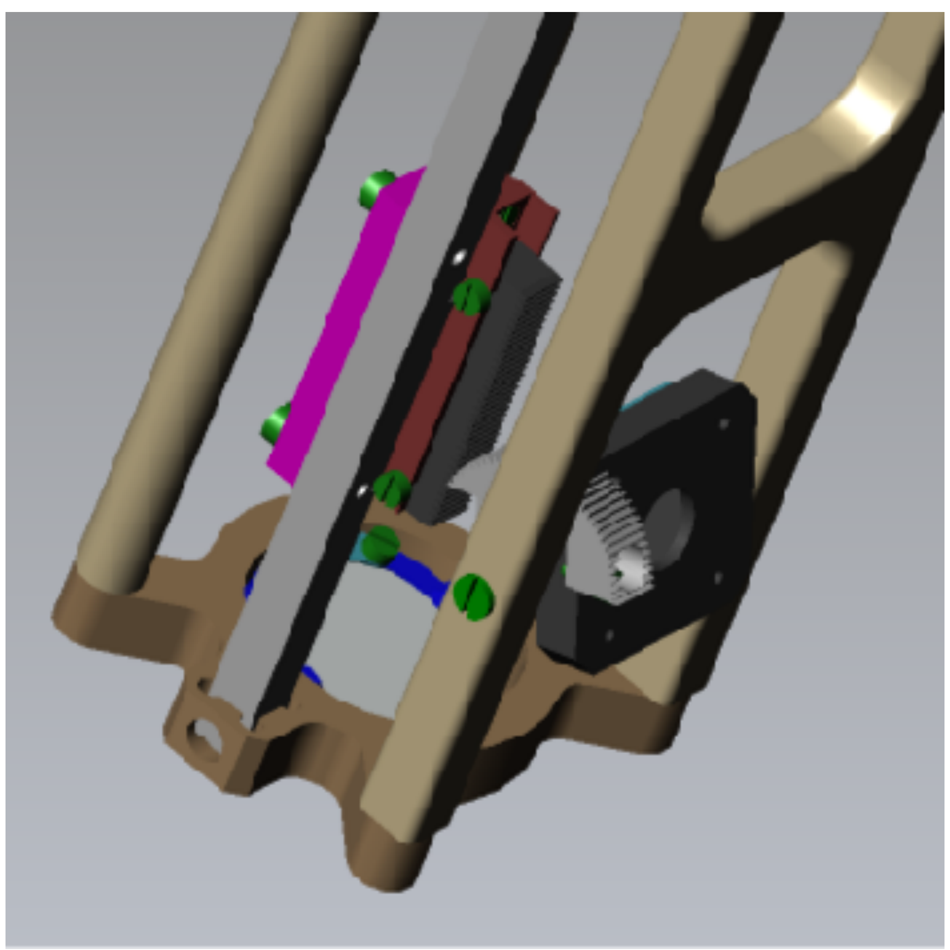
- Example:
  - Stage 2 rotates 180 deg —> mirror rotates (phi) by 180 deg
  - Stage 1 rotates 180 deg —> mirror rotates (phi) by 180 deg **and is shifted by 80 mm**

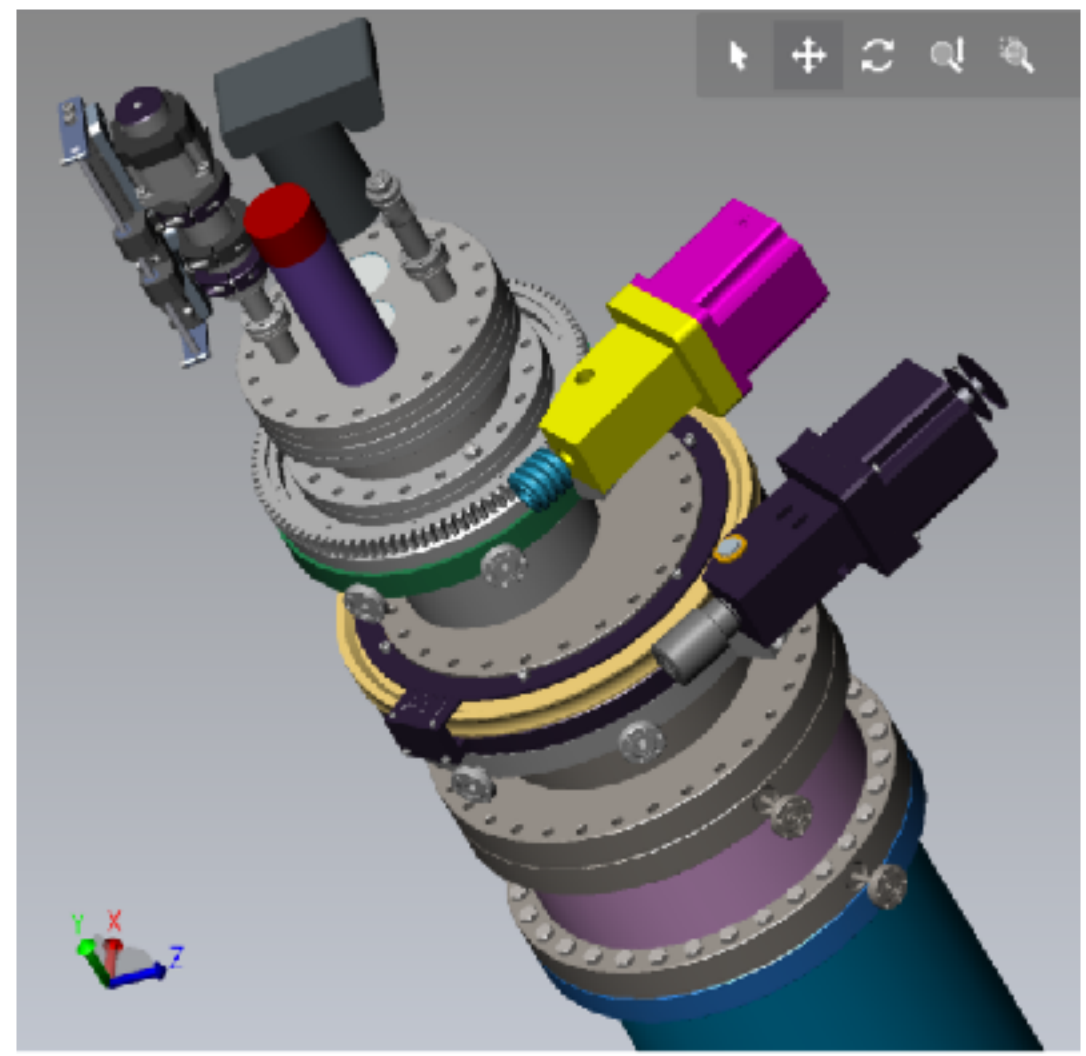


Mechanical design

- Main idea developed in May 2019 at LIP
- Recently re-worked to keep up-to-date with developments in baseline system
- Jan Boissevain (LANL) and Rui Alves (LIP) sharing their CAD designs







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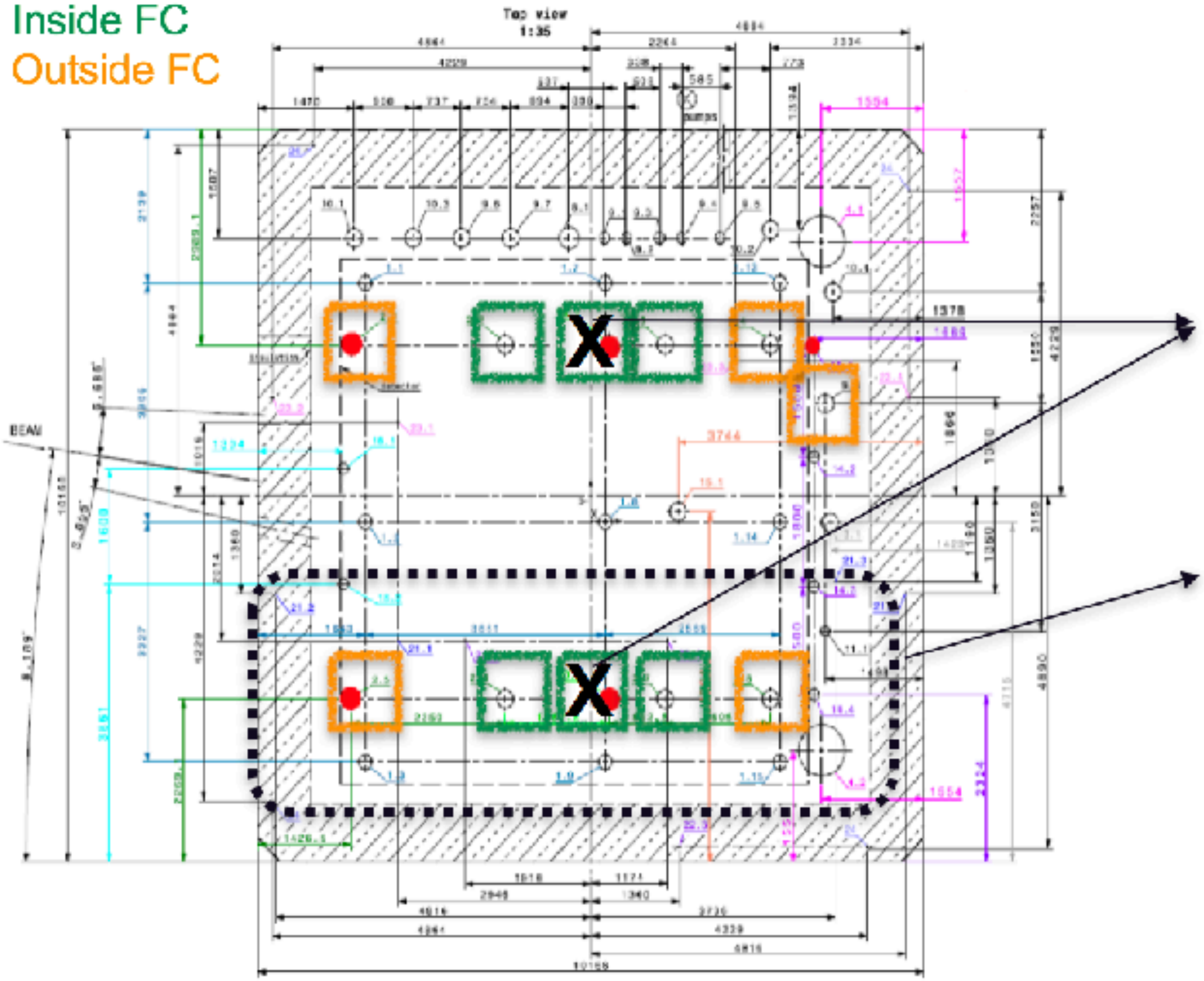
ProtoDUNE-II Plans

- **Essential to test Laser systems in ProtoDUNE-II to install in DUNE**
- Crossing tracks essential for E-field measurement
  - *At a minimum, test one baseline and one end-wall system*
  - End-wall system: new idea, never used in other experiments
- Desirable ports identified for laser in ProtoDUNE-II (next slide)
- Enormous progress in laser design over the last few months
  - Design close to final!
  - Design already being integrated into the new ProtoDUNE-II TPC model
  - Vendors identified for most parts, quotes in hand
  - A laser being procured at LANL; testing facilities being setup
- Currently working on electrical, grounding and space needs
- Need to work out a detailed production and testing plan
- Institutional Interest:
  - LANL, LIP, KSU; possible interest from York

ProtoDUNE-II: Desirable Ports for Laser

Inside FC
Outside FC



These two currently have collisions with FC I-beams

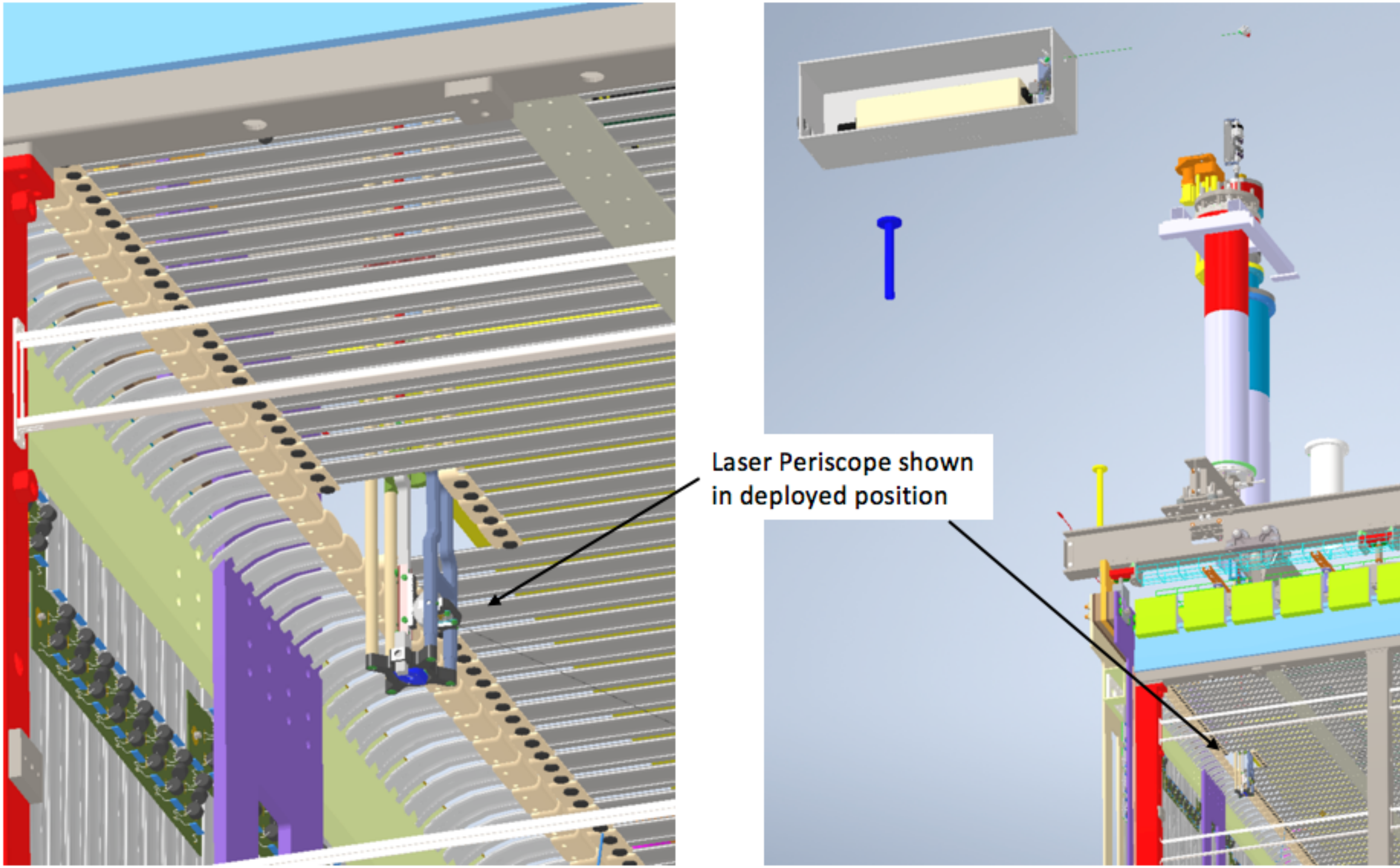
This drift volume preferred since beam is in this volume

- Baseline laser in either internal port
- Endwall laser in either external port

Working with HV consortium on FC penetrations for these locations — no issues foreseen; need to make a detailed plan

- **Plan to install 4 inclinometers in ProtoDUNE-I** to understand port tilts due to pressure changes (LANL+KSU)
- Interface boards currently being developed at KSU; system will be shipped to CERN this month

Laser Periscope in ProtoDUNE-II



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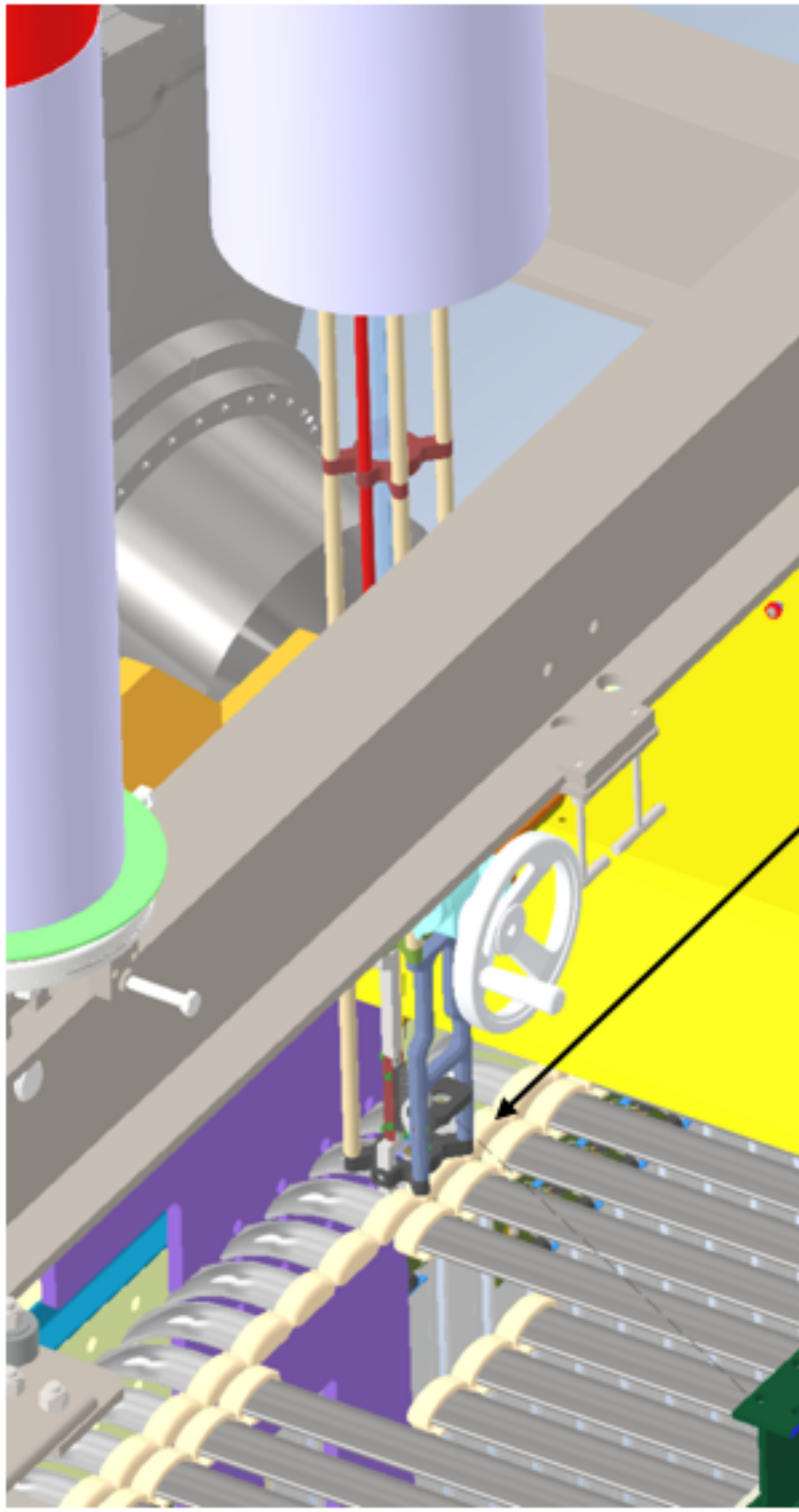
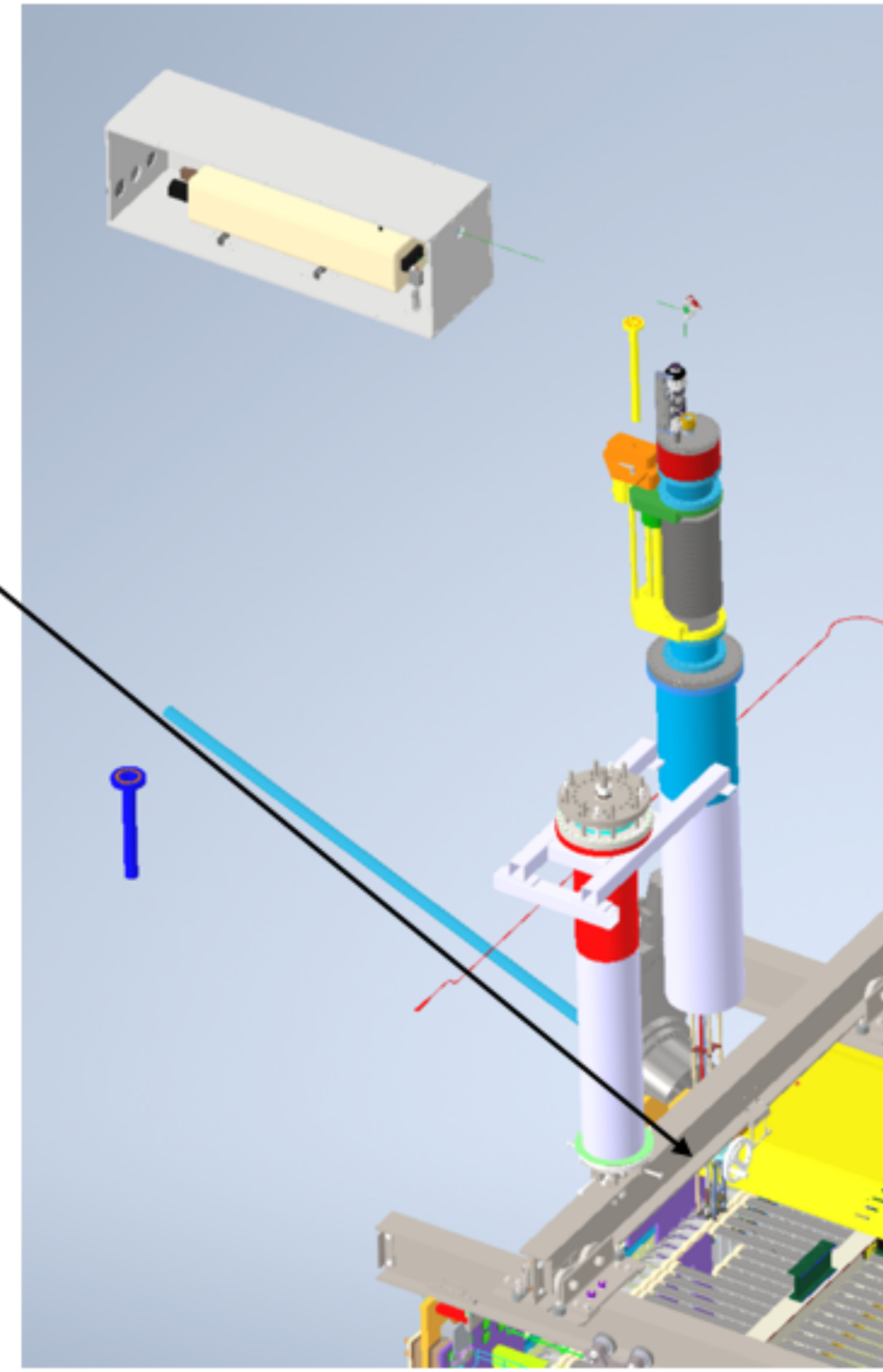
Laser Periscope in ProtoDUNE-II



Laser Periscope in retracted position



J. Boissevain

ProtoDUNE-II

Activities & Milestones

S. No.	Activity	Start Date	End Date
1	Engineer at LANL on laser design & integration	11/15/20	8/31/22
2	Setup Laser Lab at LANL	11/21/19	5/30/20
3	Postdoc at LANL to work on laser system	4/20/20	4/19/23
4	Purchase Class-IV UV laser	3/1/20	5/30/20
5	Purchase laser box optics	3/1/20	6/30/20
6	Calibration Scope review workshop	5/7/20	5/8/20
7	Setup Warm and Cold testing station at LANL	7/1/20	12/31/20
8	Develop first full design of laser system	8/30/20	8/30/20
9	Laser Design Review by DUNE (review 1)	9/15/20	9/15/20
S1	Disassembly TCO drift volume	10/1/20	11/30/20
S2	Open TCO	11/1/20	12/31/20
10	Laser Design Production-ready review by DUNE (review 2)	11/30/20	11/30/20
11	Procure laser system components	12/120	3/31/21
12	Technician(s) at LANL for fabrication	1/1/21	12/31/21
13	Start fabrication of the laser system	1/1/21	7/31/21
S3	Remove ProtoDUNE-SP TPC	1/1/21	3/31/21
14	Test Mechnanical aspects of the system in warm/cold	7/1/21	9/30/21
15	Laser Box unit(s) arrive at CERN	7/31/21	7/31/21
S4	ProtoDUNE-SP Cryostat accessible	4/1/21	8/31/21
16	install laser boxes on Cryostat and test alignment	8/1/21	8/15/21
17	Laser periscope units arrive at CERN	10/15/21	10/15/21
18	Document safety, access and alignment procedures	10/1/21	10/31/21
S5	Install ProtoDUNE-SP-2 Detector	8/1/21	12/31/21
19	Install Laser periscopes into the detector & test alignment	11/1/21	11/20/21
S6	Close ProtoDUNE-SP cryostat TCO	1/1/22	1/31/22
S7	Fill ProtoDUNE-SP-II Detector	2/1/22	4/30/22

- The goal is to start fabrication as soon as design is approved to be production-ready
- First design review is tentatively scheduled for Sept. 2020

Calibration milestones
PD-SP-II global schedule

Laser Boxes arrive at CERN end of July 2021 and will be installed first

Laser periscope units arrive at CERN in Oct. 2021 – can only be installed after relevant TPC components are installed e.g. FC modules

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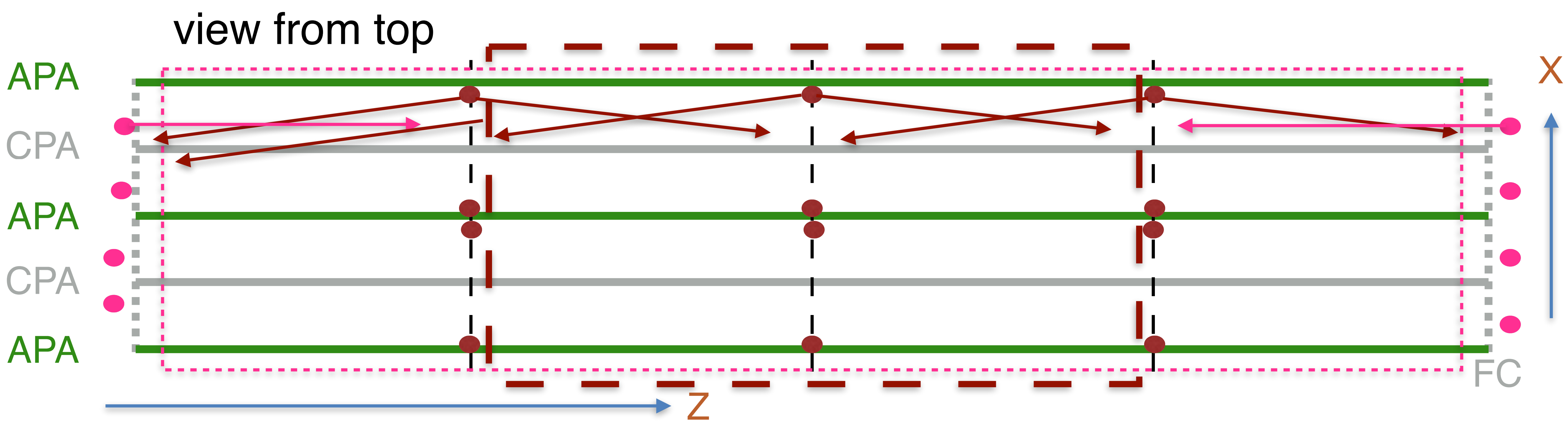
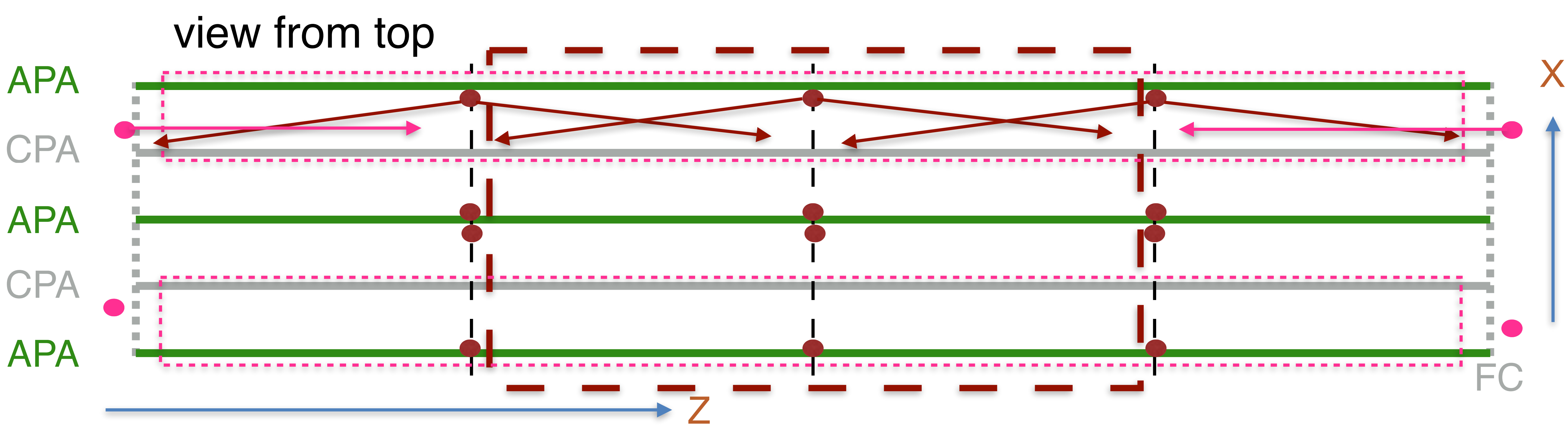
Scope Scenario 1 (Full scope): 12 Baseline + 8 End-wall Periscopes

- Iterative method needs two tracks from different laser
- The only way to have two-laser coverage in the whole volume is to have all 8 end-wall periscopes in addition to the 12 baseline



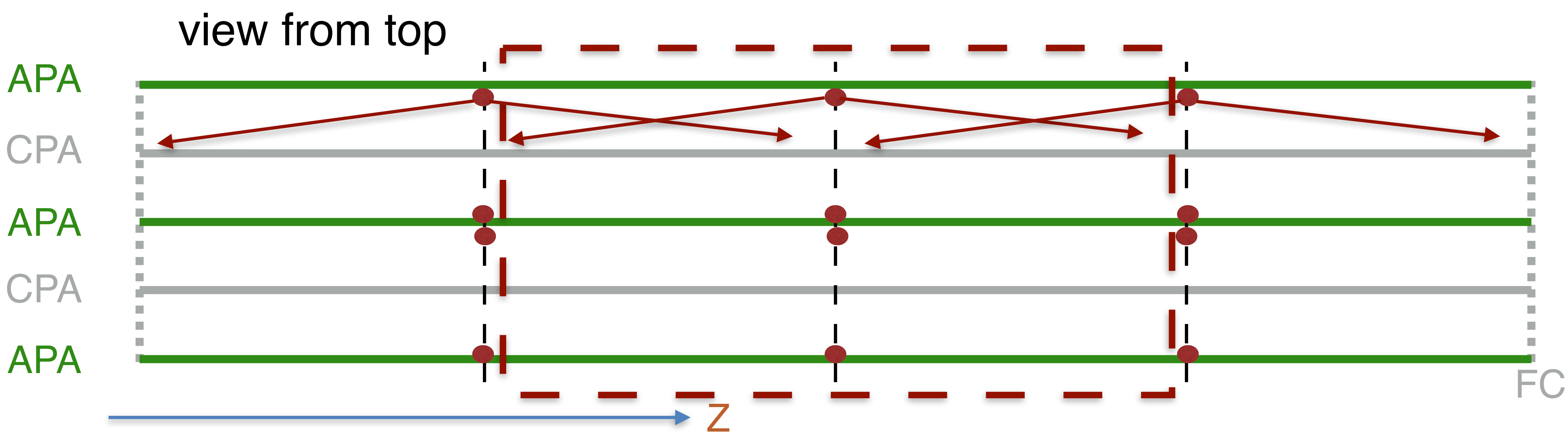
Scope Scenario 2 (Reduced scope): 12 Baseline + 4 End-wall Periscopes

- Only 4 end-wall periscopes in corner regions
- Two-laser coverage in 12 of 16 “laser regions” (75%)
- Measure CPA distortions from one side and use that information on the other side



Scope Scenario 3: 12 Baseline + 0 End-wall Periscopes

- Iterative method needs two tracks from different laser
- Having no end-wall periscopes means large biases and no (or very poor) measurement of drift velocity and E-field in 50% of the detector
- We think this should not really be an option



Review Charge — Part 1

1.1) Does the system have a well-justified role in facilitating the analysis of far detector data, and if so, what is the minimum amount of system scope required to fulfill this role?

- yes, the laser system plays an well-justified role to allow DUNE to reach and/or demonstrate systematics goals for physics
  - Verify space charge is low with fluid flow
  - Capture detector imperfections and demonstrate small uncertainties on drift velocity and E-field overall thus reducing uncertainties on energy scale
  - Provide ability to capture time dependent effects
- Minimum Scope
  - Scenario 2 (12 baseline + 4 end-wall) is the minimum amount of system scope required to have crossing tracks in ~75% volume of the detector to perform E-field and drift velocity measurements

Review Charge — Part 1

1.2) Have all technical issues related to the feasibility of the system (including those raised in the previous workshops) been resolved?

- FC penetration & periscope retraction
  - Identified a FC penetration plan with HV consortium
  - Periscope retraction implemented in the design
- Amount of Engineering effort needed and if it is achievable on the timescale of ProtoDUNE-II
  - As demonstrated, both baseline and end-wall designs are very mature!
  - Enormous progress both at LANL and LIP in this direction

1.3) Are there any risks to overall detector performance associated with the implementation of the system, and if so, is there a plan in place for mitigating these risks?

- *Baseline:* FC penetration a risk, mitigation implemented in design with periscope retraction
- *End-wall:* no FC penetration needed; System is 40 cm away from FC
- *Does laser impact PDS?*
  - *PDS says no need to turn off PDS during laser runs*
  - *We will* avoid direct hits to PDS; lab tests planned for PDS with laser

Review Charge — Part 1

1.4) Is there a credible plan in place for demonstrating system performance in ProtoDUNE-II?

- yes, the plan is to deploy at least one baseline and one end-wall system
- Good progress for both designs in the last months towards ProtoDUNE-II
  - Designs close to final
  - Already started addressing ProtoDUNE-II detector interfaces
  - Vendors selected for most parts, quotes in hand
  - Identified desirable ports for laser
  - Need to work on ProtoDUNE interfaces for electrical, grounding, DAQ and slow controls

Review Charge — Part 1

1.5) Does the functionality of the system justify its overall cost?

- The per unit cost of baseline and end-wall laser system is very similar

Laser System one unit cost

Laser Box+optics	$55,000
Periscope+feedthrough	$95,000
Rack+control	$25,000
Total	$175,000

- ProtoDUNE
  - One baseline + one end-wall: $350,000 total
- FD-SP
  - Scenario 1 (12 baseline+8 end-wall): $2,017,000+$1,400,000 (=$3,417,000)
  - Scenario 2 (12 baseline+4 end-wall): $2,017,000+$700,000 (=$2,717,000)
  - Scenario 3 (12 baseline +0 end-wall): $2,017,000

Review Charge — Part II

- ***Is the system essential or highly desirable or not essential?***

- Essential:
  - *FD-SP:* The Reduced scope 12 port baseline + 4 end-wall system (scenario 2)
  - *ProtoDUNE-II:* At least one baseline and one end-wall system need to be tested in ProtoDUNE 2
- Highly desirable
  - *FD-SP:* Full scope 12 port baseline + 8 end-walls (Scenario 1)

BACKUP

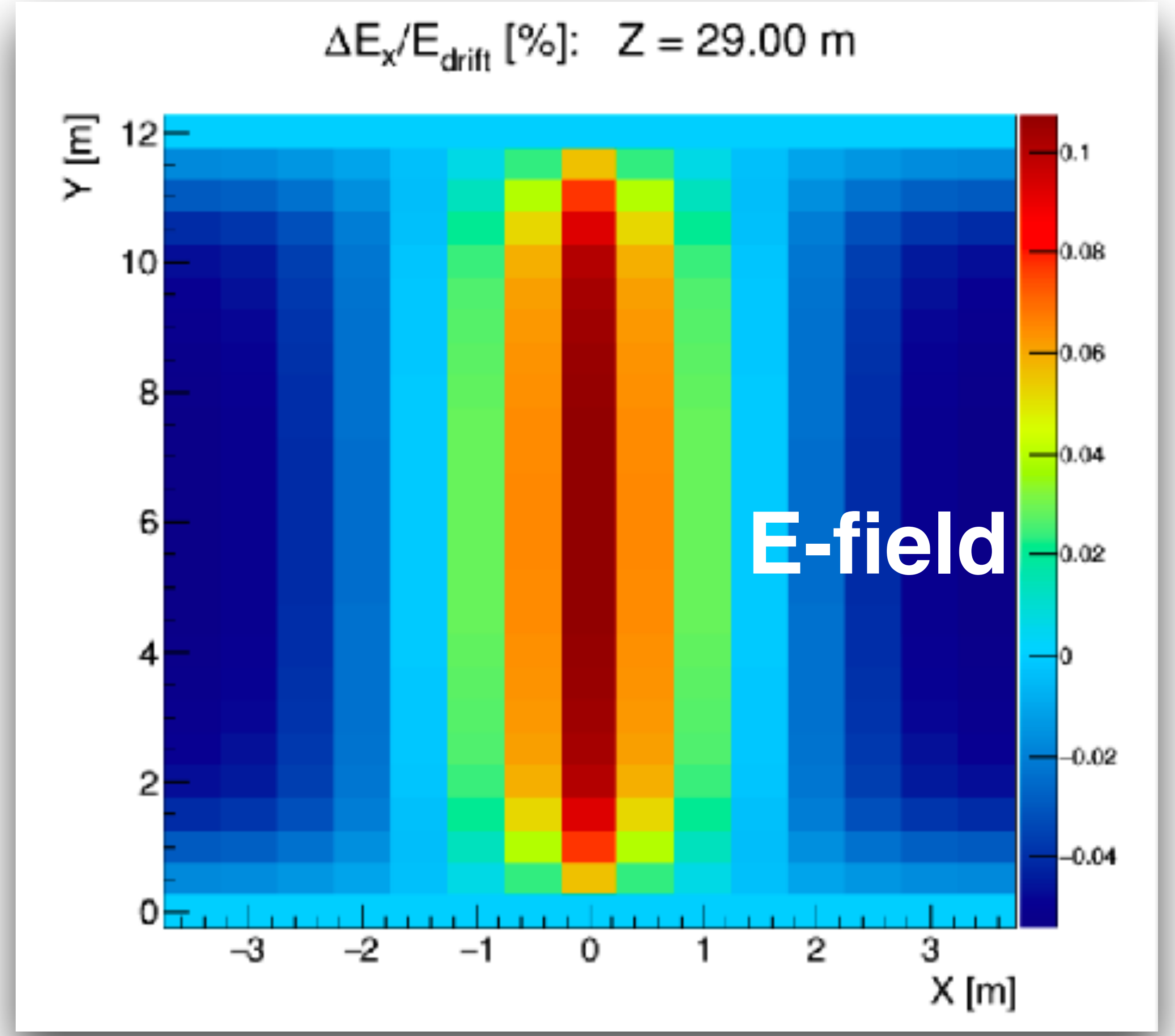
How does E-field impact detector response?

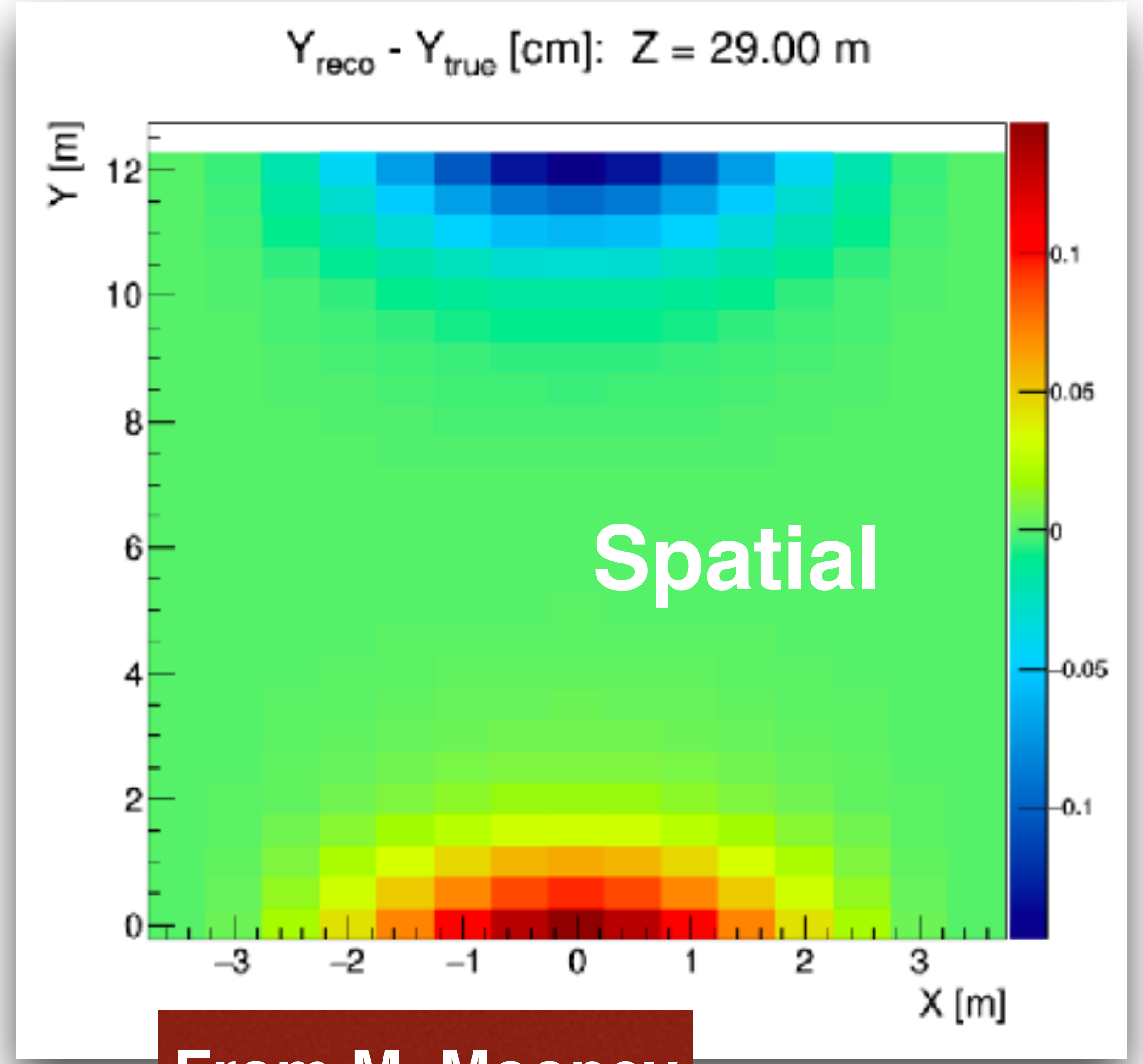
- Converting “detected charge per unit length *(dQ/dx)*” to “deposited charge per unit length *(dE/dx)*”

$$\frac{dQ}{dx}(ADC/cm) \xrightarrow[\text{calibration}]{\text{Electronics}} \frac{dQ_e}{dx}(e/cm) \xrightarrow[\text{correction}]{\text{Lifetime}} \frac{dQ_e'}{dx}(e/cm) \xrightarrow[\text{correction}]{\text{Recombination}} \frac{dE}{dx}(MeV/cm)$$

- Recombination depends on E-field
  - Smaller E-field results in higher recombination and thus lower detected charge *“dQ”*
  - E field distortions also induce spatial distortions which impact *“dx”* through charge squeezing/stretching resulting in an overall impact on *dQ/dx.*
- Additionally, The FV and vertex resolution also depend on the E field, via the drift velocity

E-field distortions: Ionization Sources

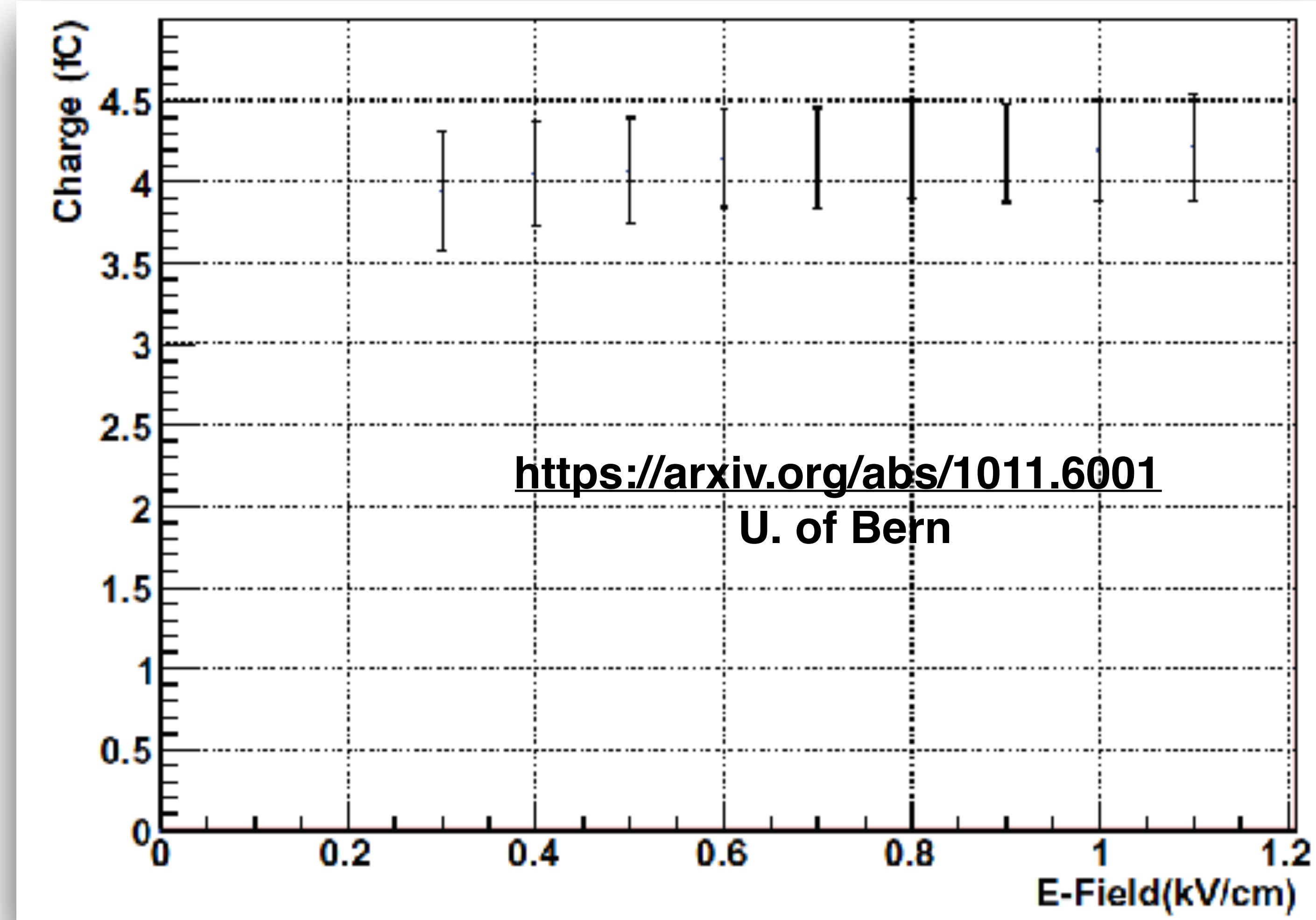




From M. Mooney

- Very small
  - E-field distortions: 0.1%; Impact on dQ/dx: 0.03%
  - Spatial distortions: 1-1.5 mm; Impact on dQ/dx (including Recombination): <0.1%
- Time dependence
  - < 5% SCE time dependence in MicroBooNE (over 3 years)
  - ~10-15% effects in ProtoDUNE over 1 year; could be fluid flow

Recombination Measurements with Laser

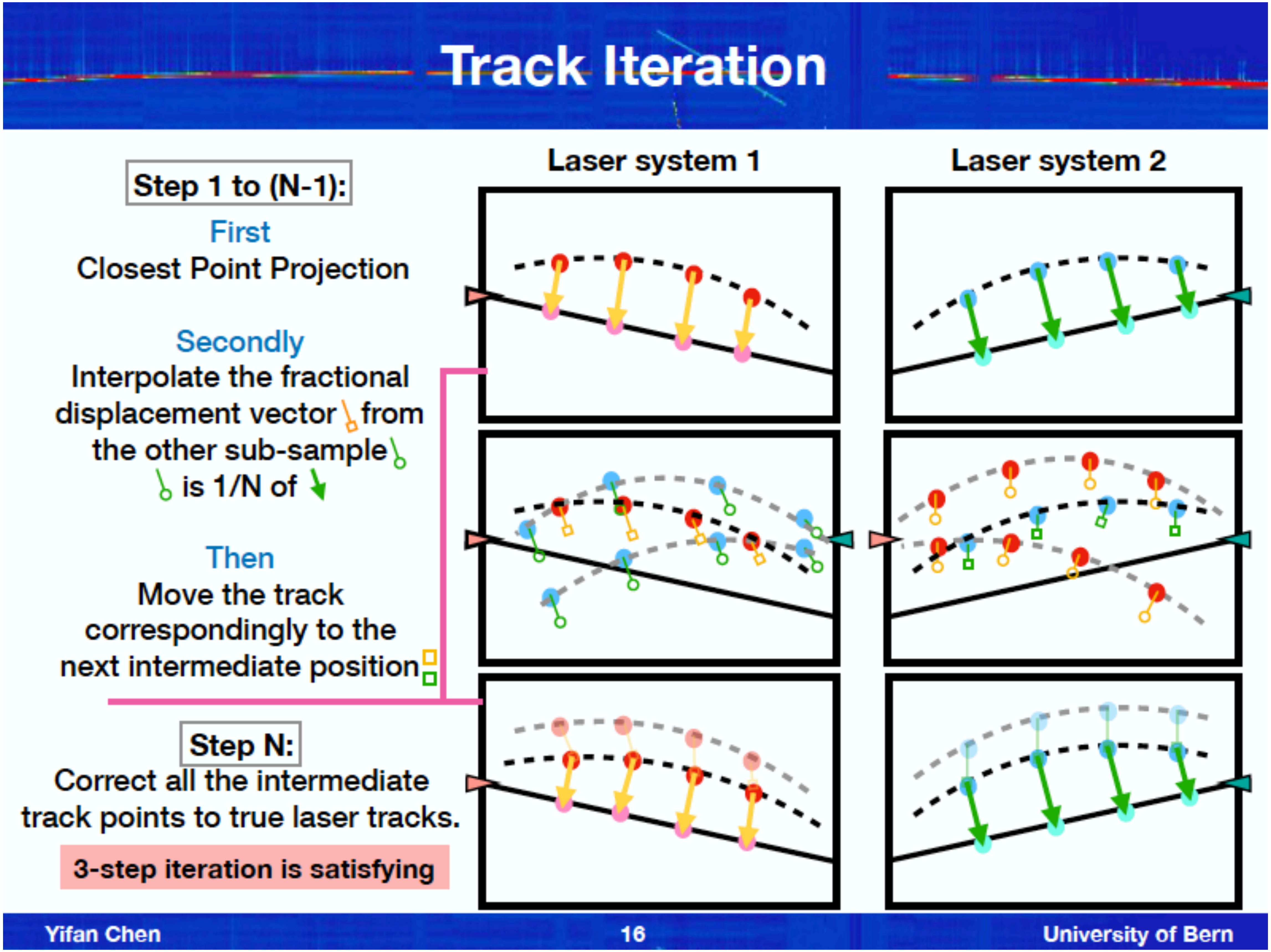


$$dE/dx = \frac{dQ'_e/dx}{A_B/W_{ion} - k_B \frac{dQ'_e/dx}{\epsilon \times \sin\phi}}$$

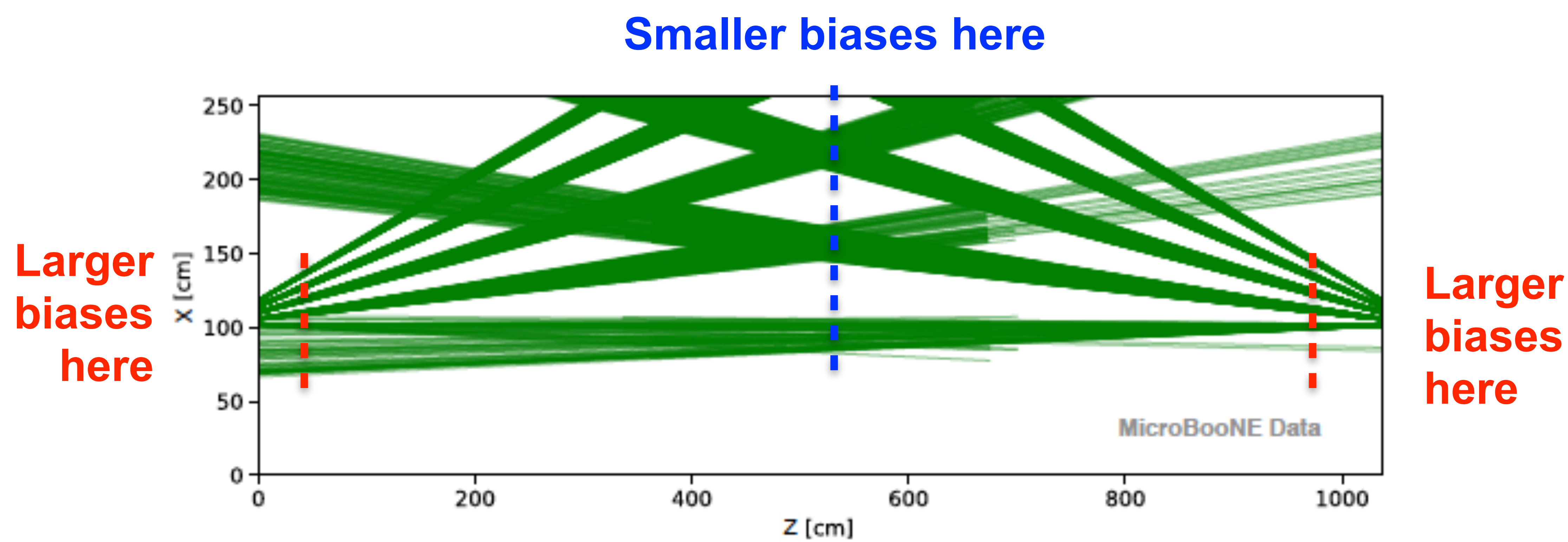
- ϕ: angle between track and electric field
- Angular dependence (ϕ) of recombination unclear

- The recombination observed with lasers is small compared to e.g. from muons
- But, one can enhance the effect
  - Using higher laser intensity
  - Using laser tracks at low angles w.r.t. E-field to enhance the 1/sinϕ term
  - At lower E-fields
- This could be the only way we get low angle tracks underground

Closest-point, iterative method



MicroBoone Full MC Bias Study

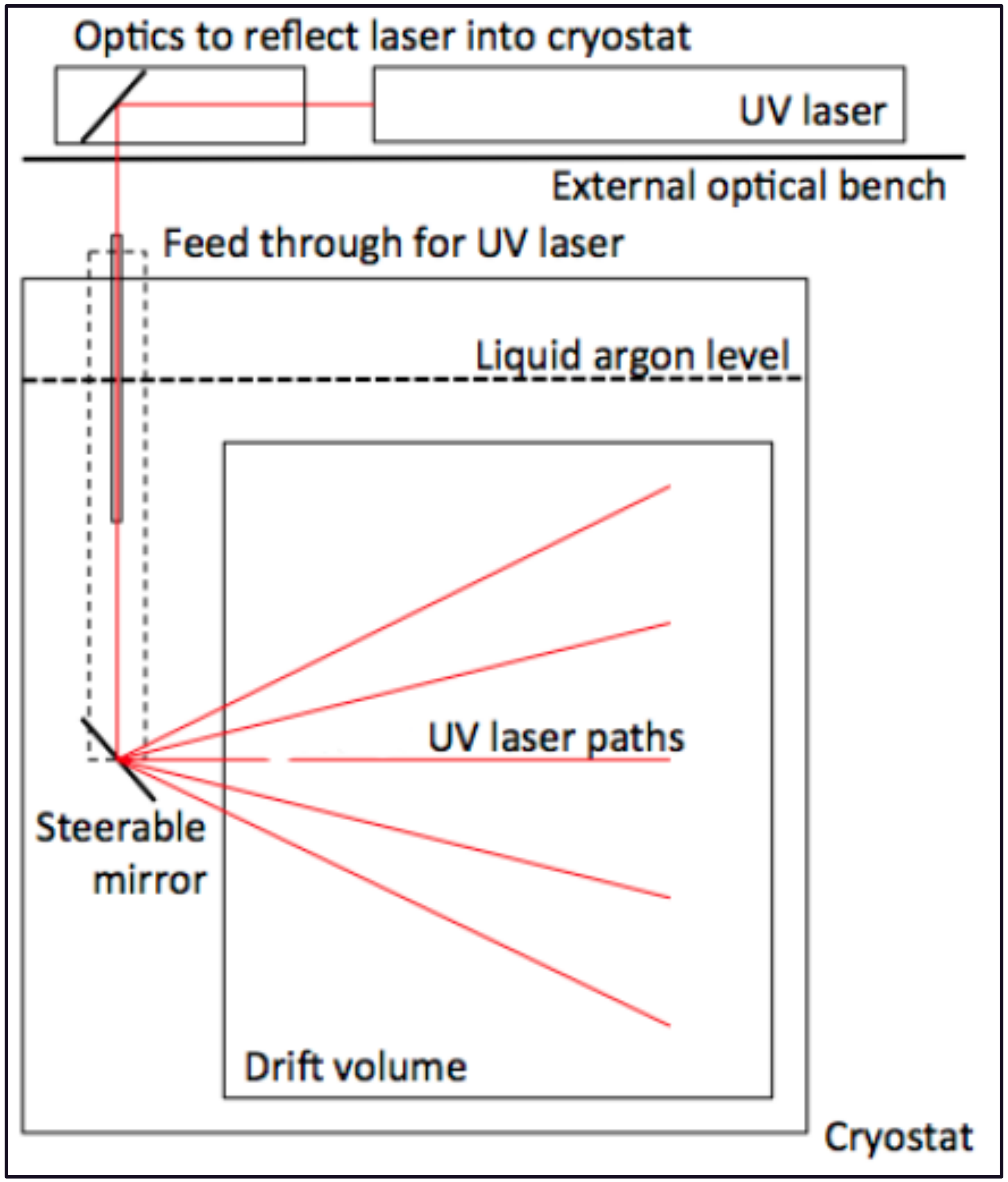


The track iteration does reduce this bias, but is less effective at the upstream and downstream edges, which is due to the placement of the mirrors and thus the start points of the laser tracks. Where these enter the TPC, **they are close to collinear** and point to the same spot on the mirror. In figure 2 we show that the starting points of the laser tracks are mostly located in **an area not accessible by tracks from the other side**. Also, tracks which reach the other end in Z **usually have small angle differences compared to all tracks.**

From MicroBOONE paper

Ionization Laser: System Outline

- High intensity UV laser (266 nm, 60 mJ/pulse), to ionize argon
- Two main parts:
  - Optical cryostat **feedthrough and a periscope** with steerable mirrors to aim laser tracks
  - A "**laser box**" housing the laser
- Based on existing designs
  - MicroBooNE, outside field cage
  - SBND, inside field cage



Data/time needed

- **~800 k tracks** needed for goal granularity (10×10×10 cm^3)
    - from corners, cover 3 walls of each region
    - × 16 regions, × 2 for crossing tracks
- **3 days** for full scan
    - 800k × 4Hz rate × 80% efficiency
    - assuming motors moving, laser shooting continuously, but not in parallel (could save time)
- **92 TB/scan**, 2 scans/year
    - assumes data reduction to 100 µs window

Effect on PDS (old tests from Bern)

- Direct beam exposure to 266 nm beam leads to measurable light yield loss.
- Loss of 20% is reached after the exposure dose of 14000 pulses with brightness of 10 mJ/ 20 cm^2. Total exposure is 7 J/cm^2.
- uBooNE TPC calibration:
  - beam energy twice lower
  - Total area larger (One WLS plate of a PMT has diameter 30 cm)
  - typical calibration run N = 2000 pulses
- Pessimistic scenario:

  30 cm diameter WLS plate
  - 20% loss at > 1 million pulses
  - 2% loss at > 100 K pulses – more than enough for calibration.
- In reality:

  reflected diffused light => much larger area => negligible effect.

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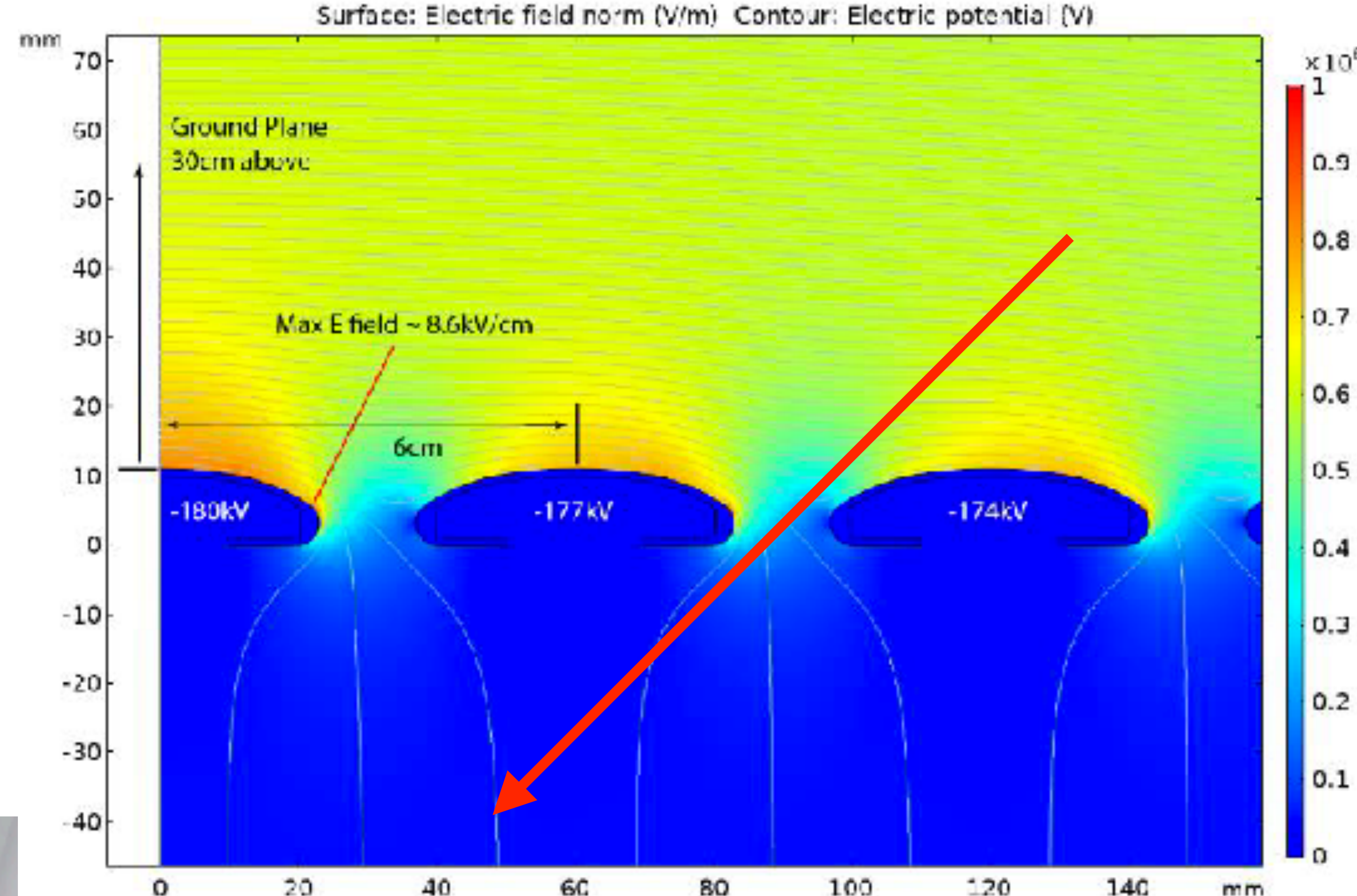
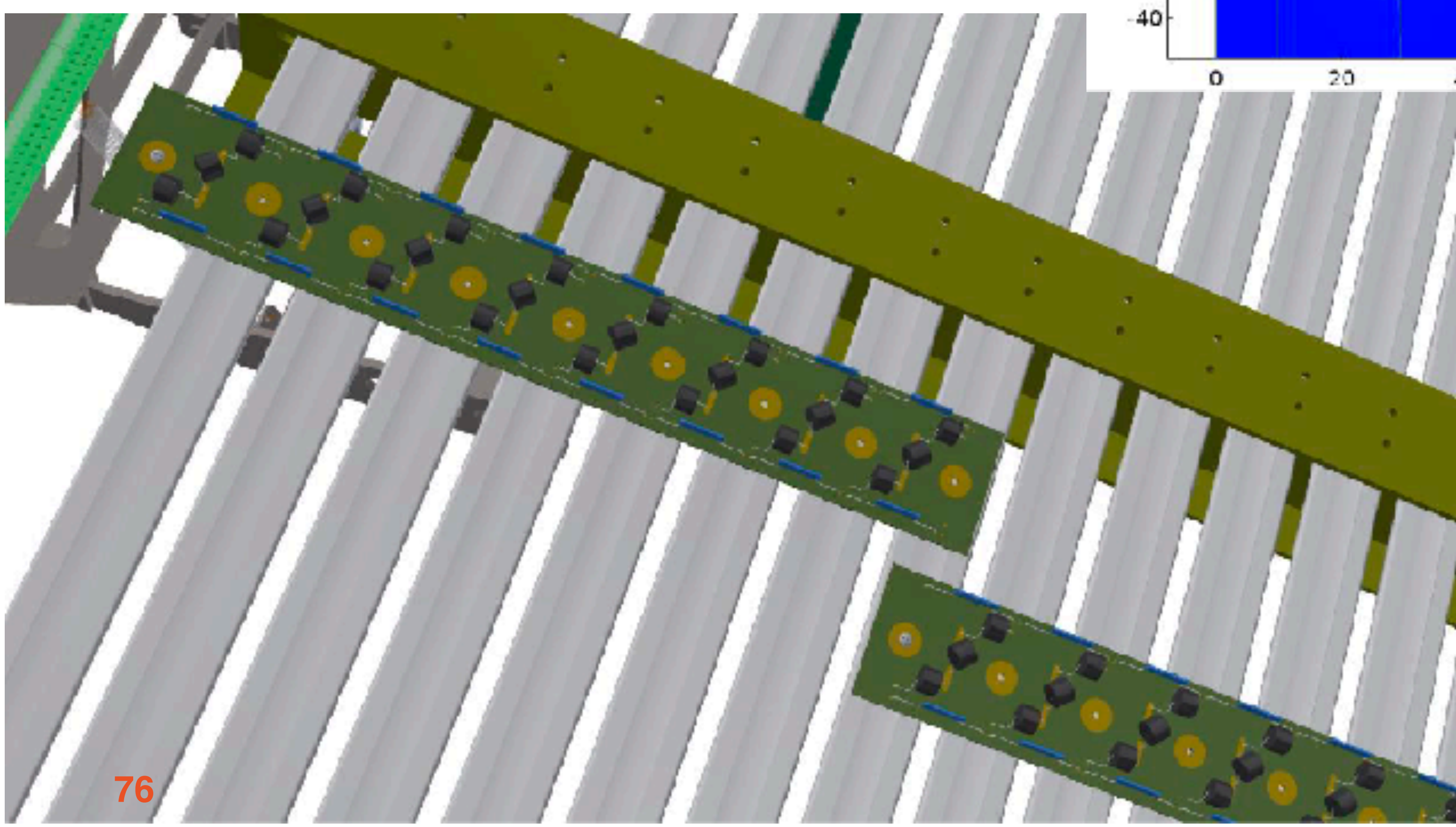
Igor Kreslo

Field Cage Constraints

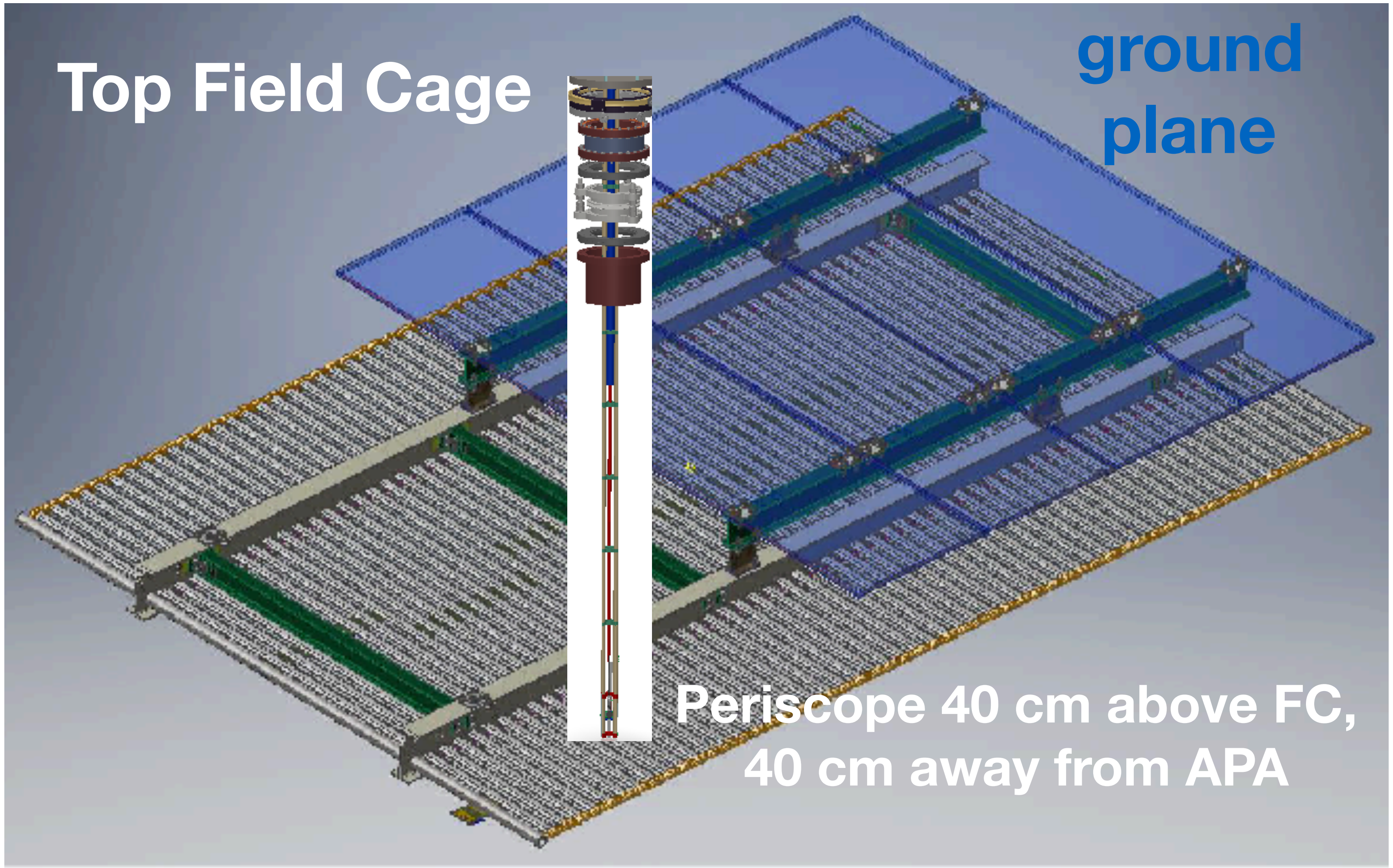
- FC Profile Shadows
  - 46 mm wide profiles
  - narrow 14 mm gap
  - max. angle ~ 45 deg



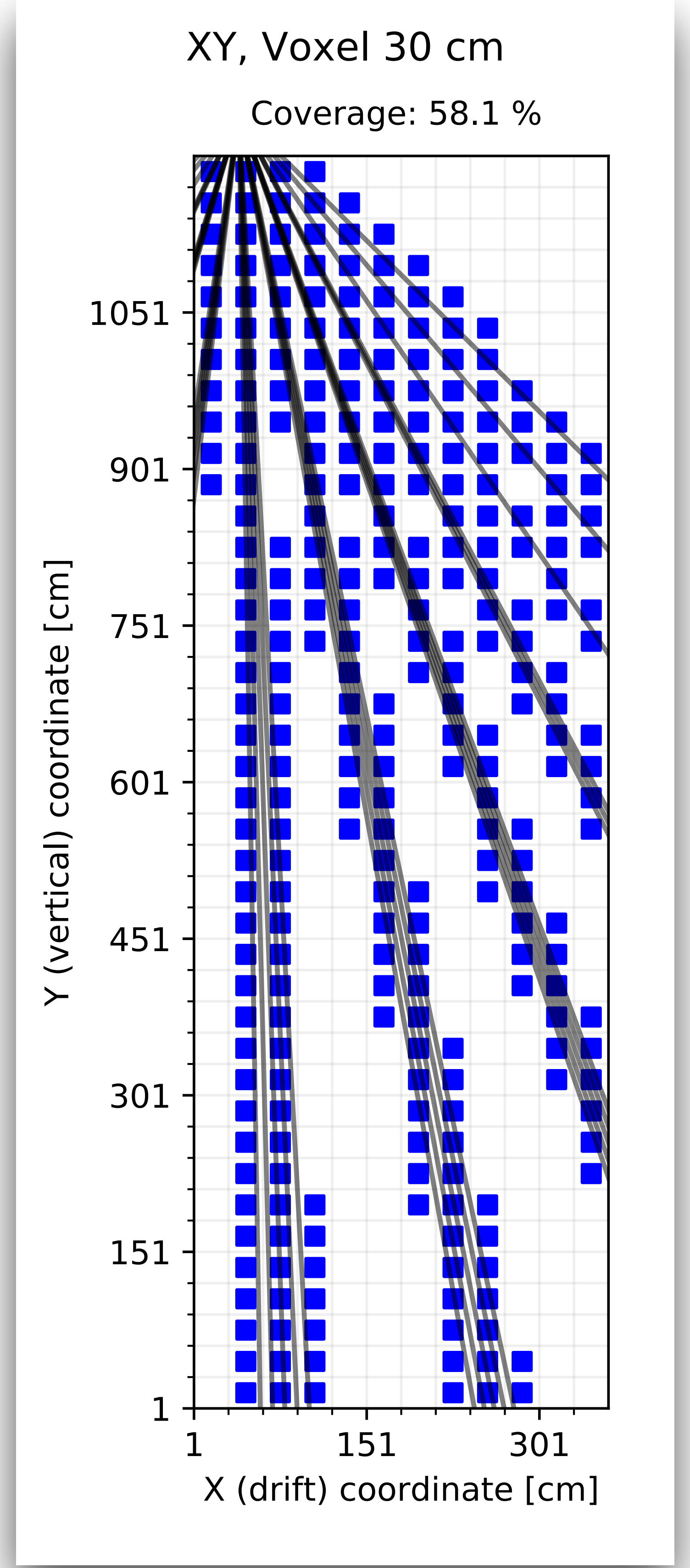


- Ground Plane
  - Can't be too far up
- Shadows from FC support I-beams and FC resistor strips

Coverage



- 2D calculation on vertical plane only
- True coverage _overestimated_
  - FC support I-beams & Resistor strips shadowing not taken into account



Allowed beam directions
Hit voxels (30 cm)

Updated Result on TPC Coverage (Baseline)

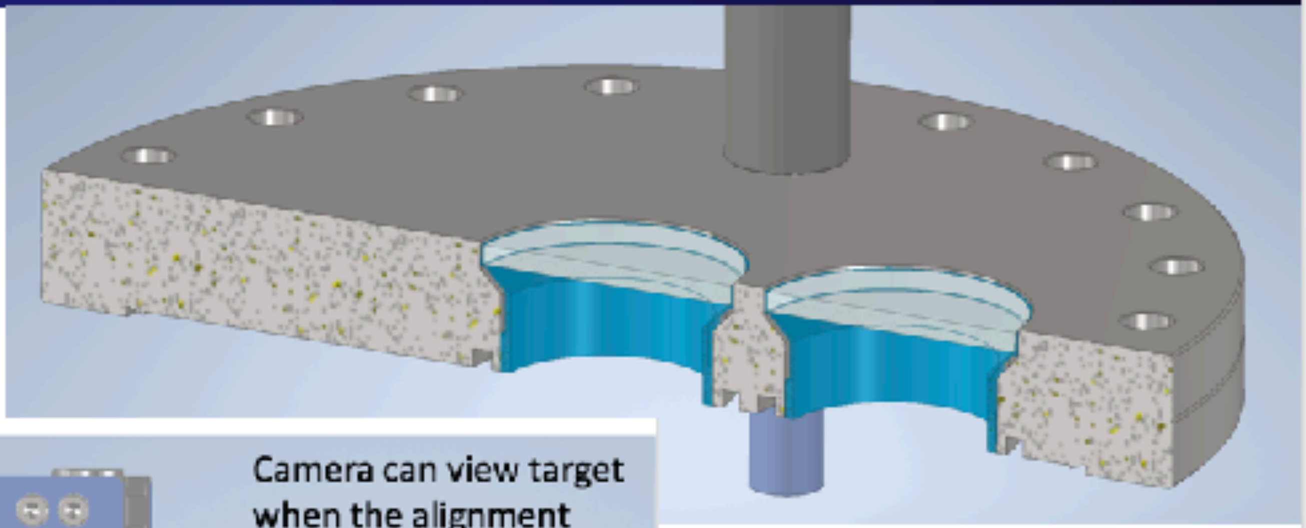
Mattia Fani

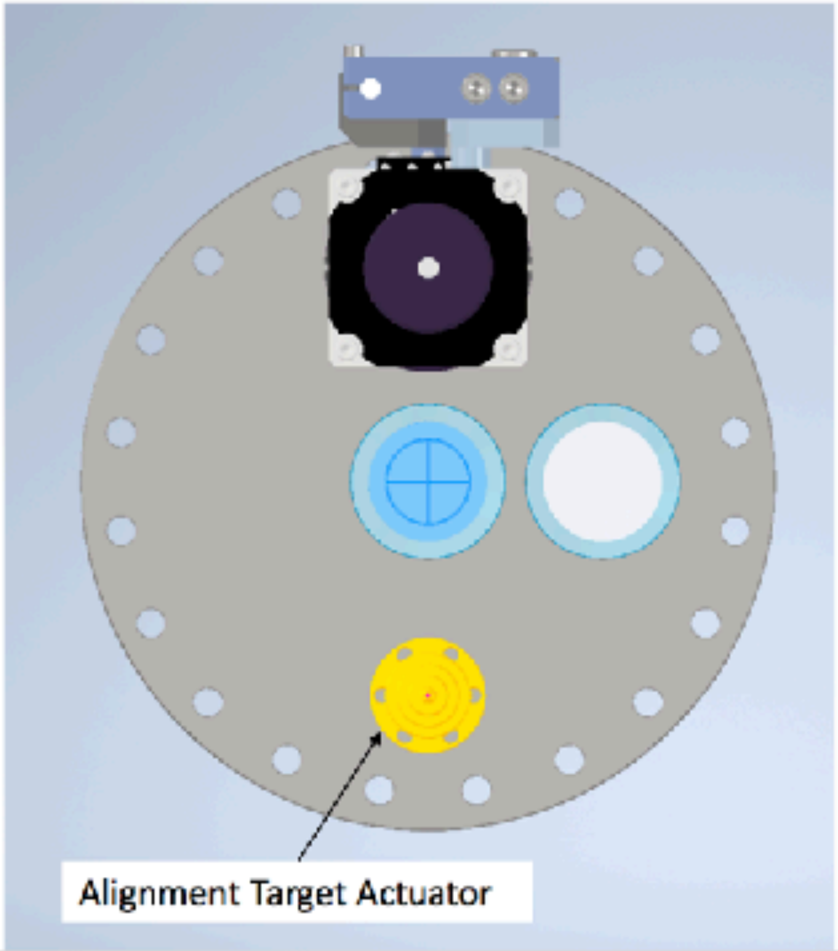
- More accurate compared to previous results
- Here “all shadowing” includes shadowing from top FC profiles, endwall FC profiles, endwall supports, top I-beams, top resistor plates
- Results obtained only this week, to be confirmed
- The numbers correspond to SW port, but for other locations, the impact from shadowing from I-beams will be greater.

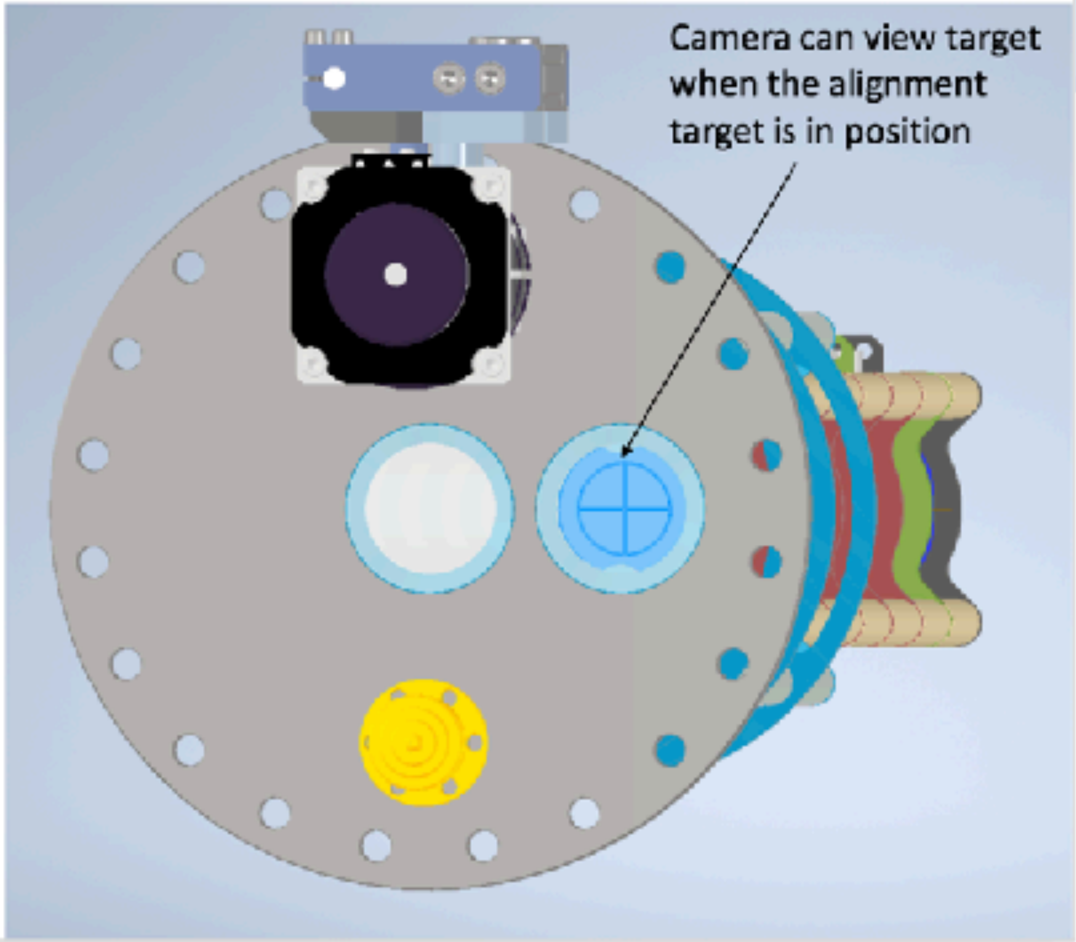
	30 cm Voxels (only top FC profile shadowing)	**30 cm Voxels (include all shadowing)**
APA	64.3%	54.5%
no APA	61.9%	52.4%

View Ports

Insulator Seal 107330 View Ports welded to top flange (Ø34.6mm) – one port centered, one port offset by 2"

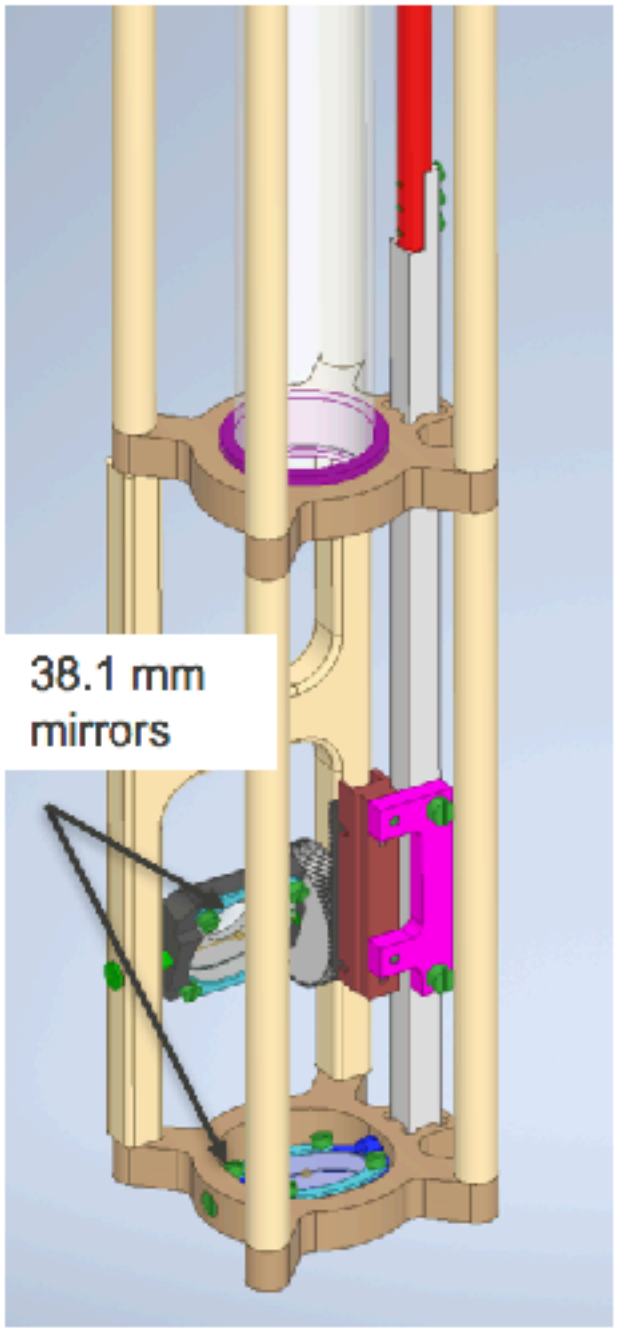






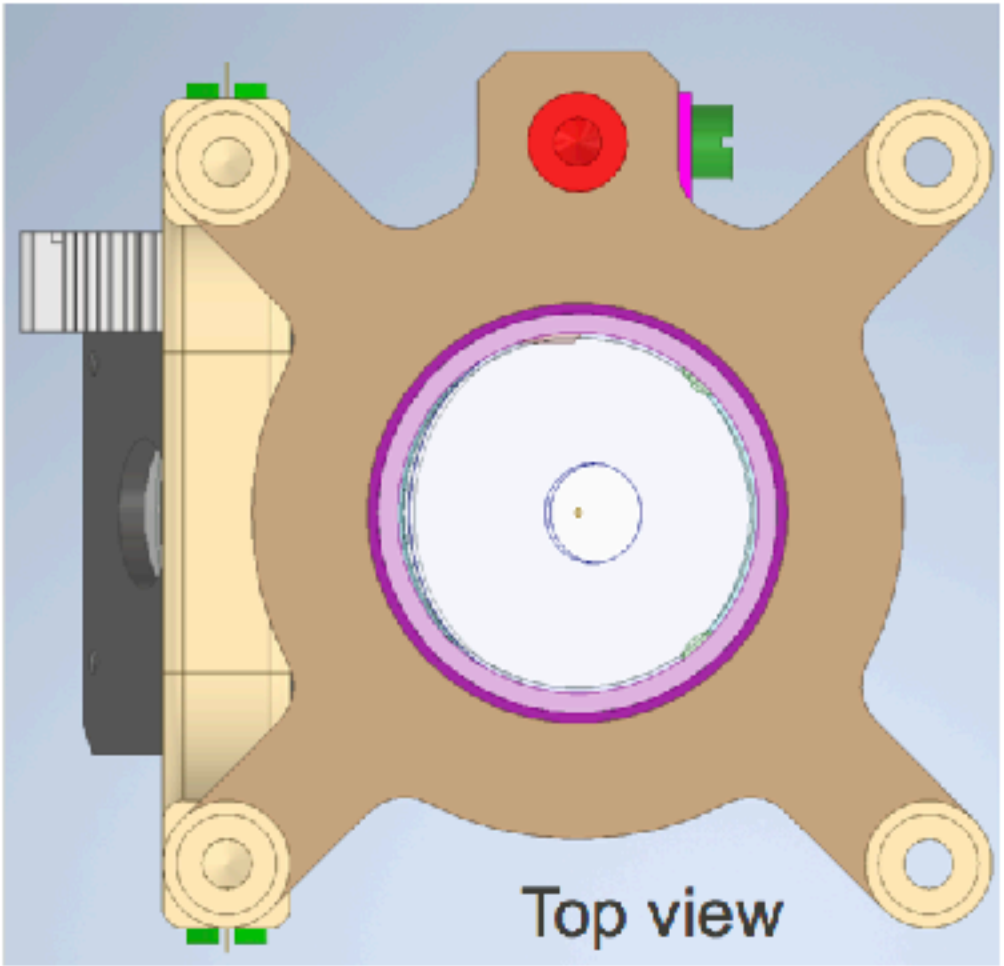
Periscope top view

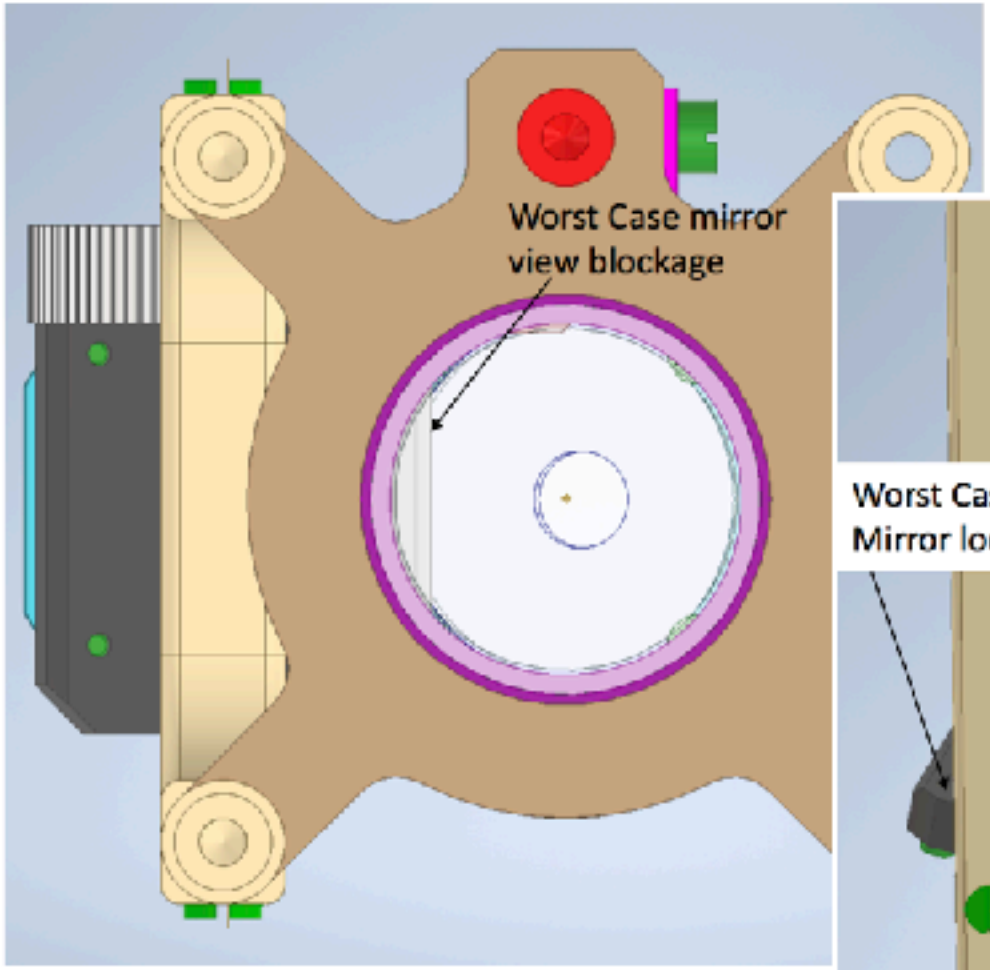
Larger Periscope Mirrors

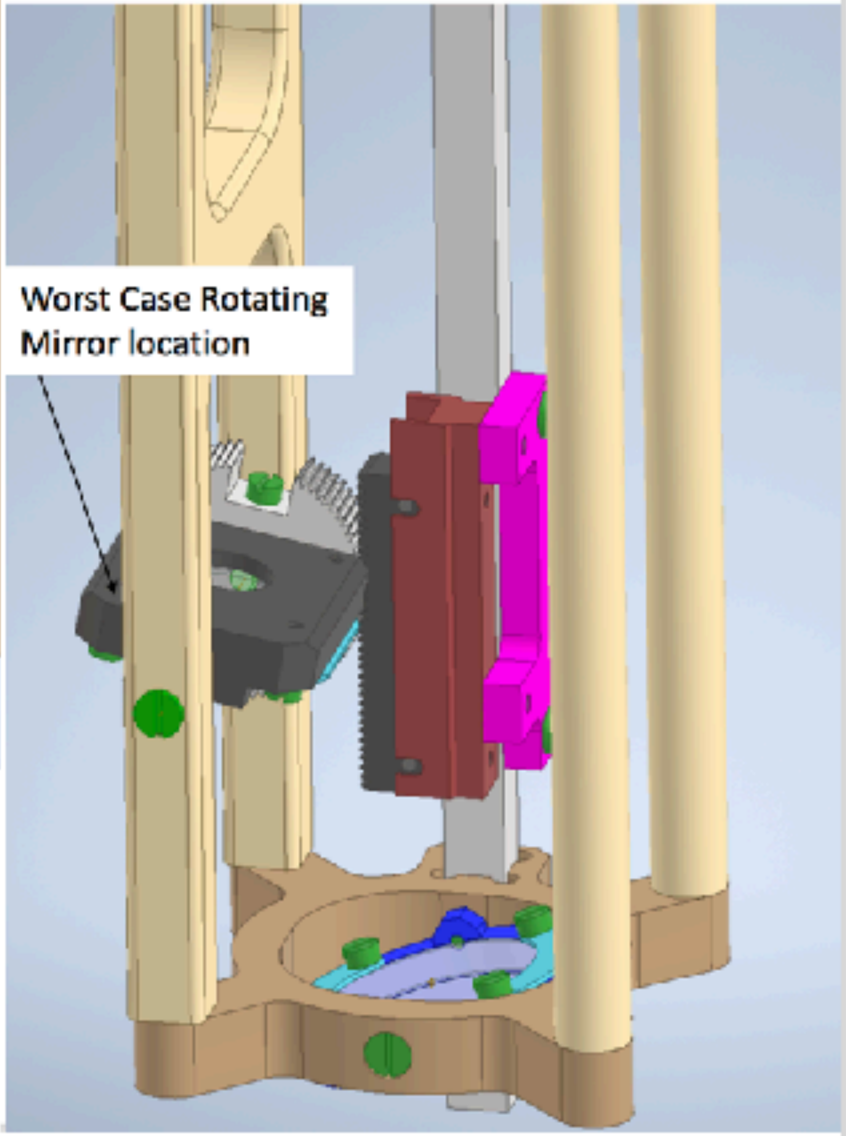


- Design study to understand the viability of increasing the mirror size from 25.4 mm diameter to 38.1 mm diameter: increases the coverage for cameras
- Still need to understand and quantify the overall gain due to this change – Glenn is working on this
- Camera integration into the periscope done in collaboration with KSU (Glenn)

Larger Mirrors for the Periscope



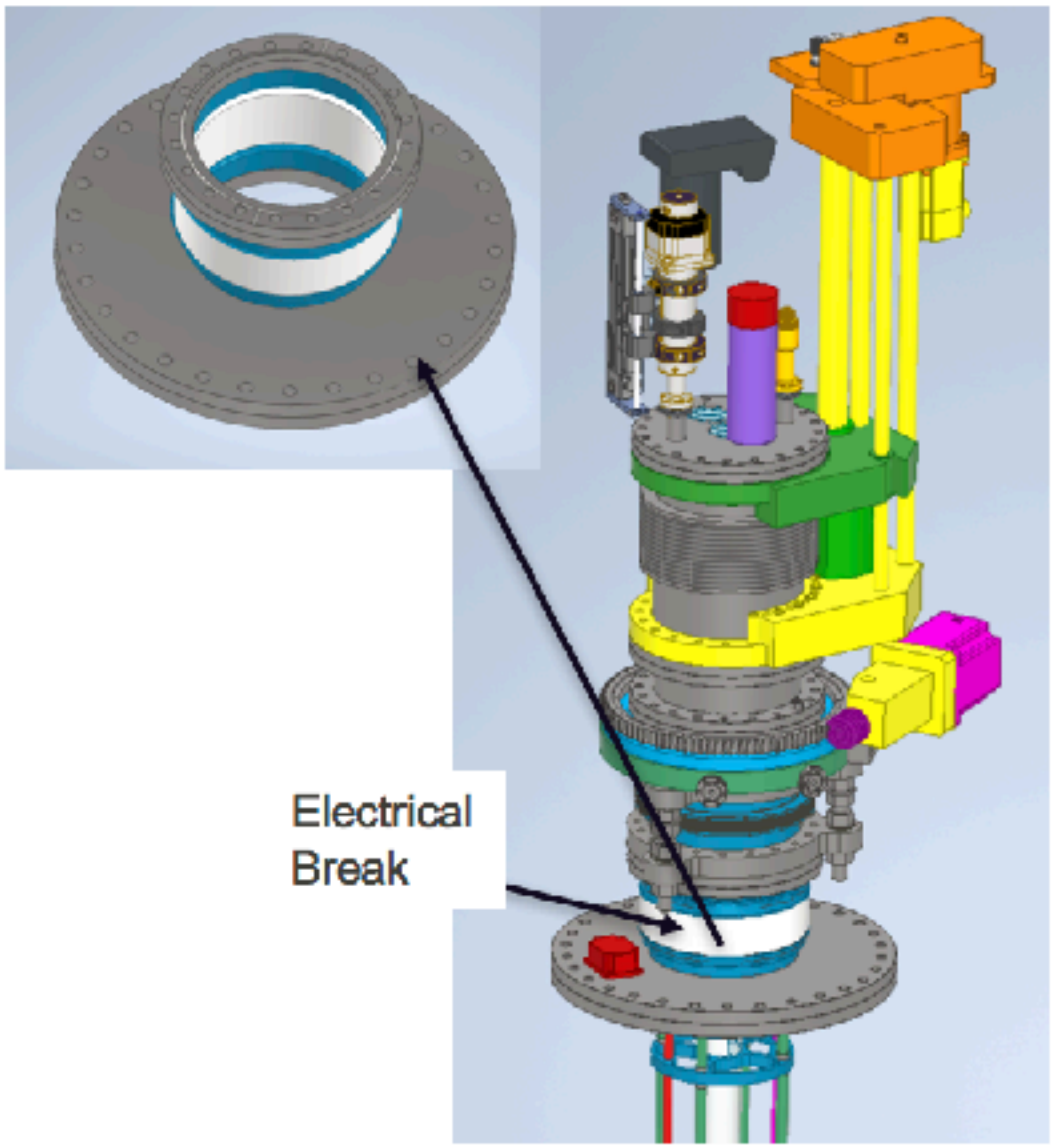


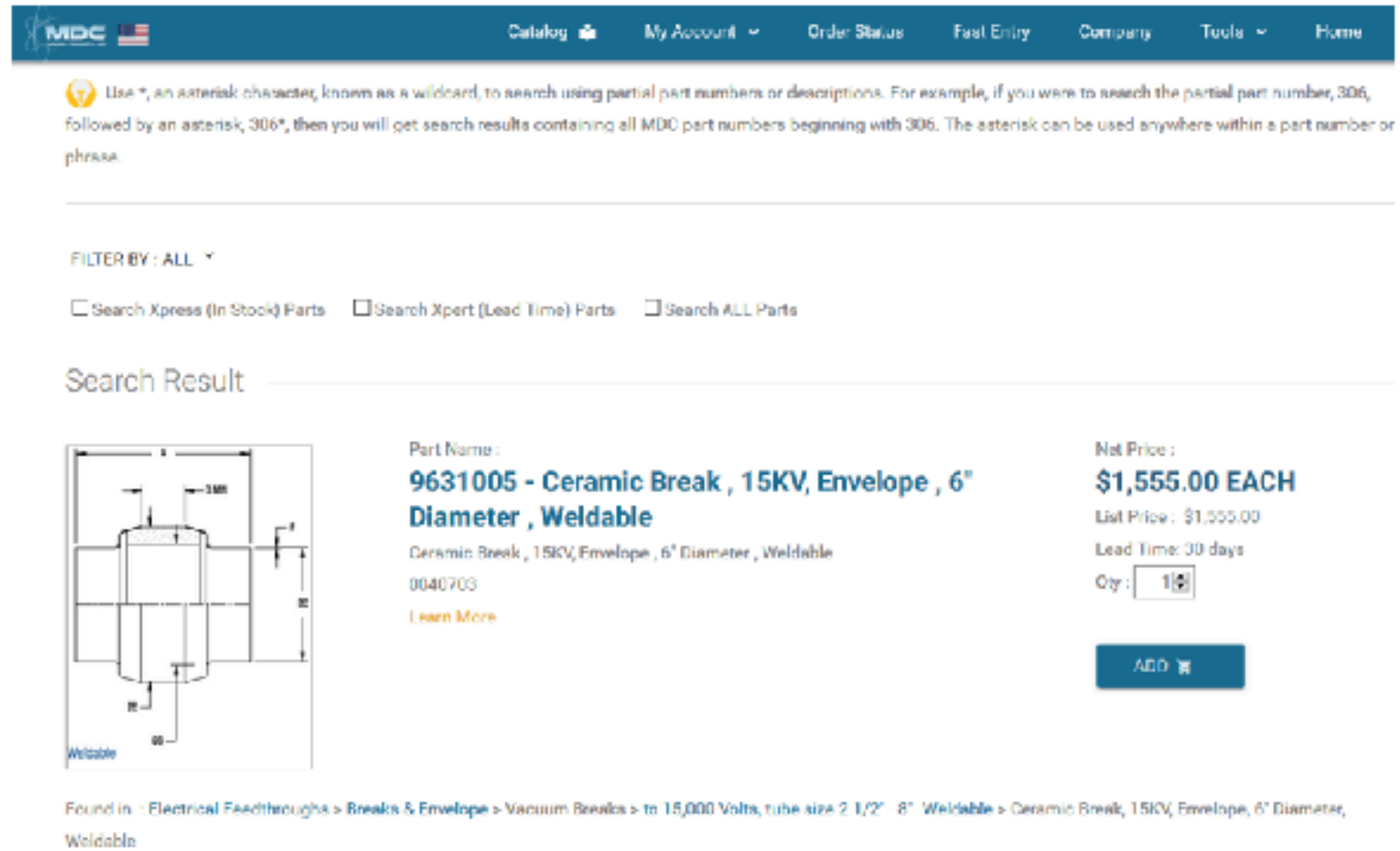


Can slightly increase the overall periscope envelope to accommodate larger mirrors and stay within the planned spacing between the periscope and the FC edges

Electrical Insulation for the periscope

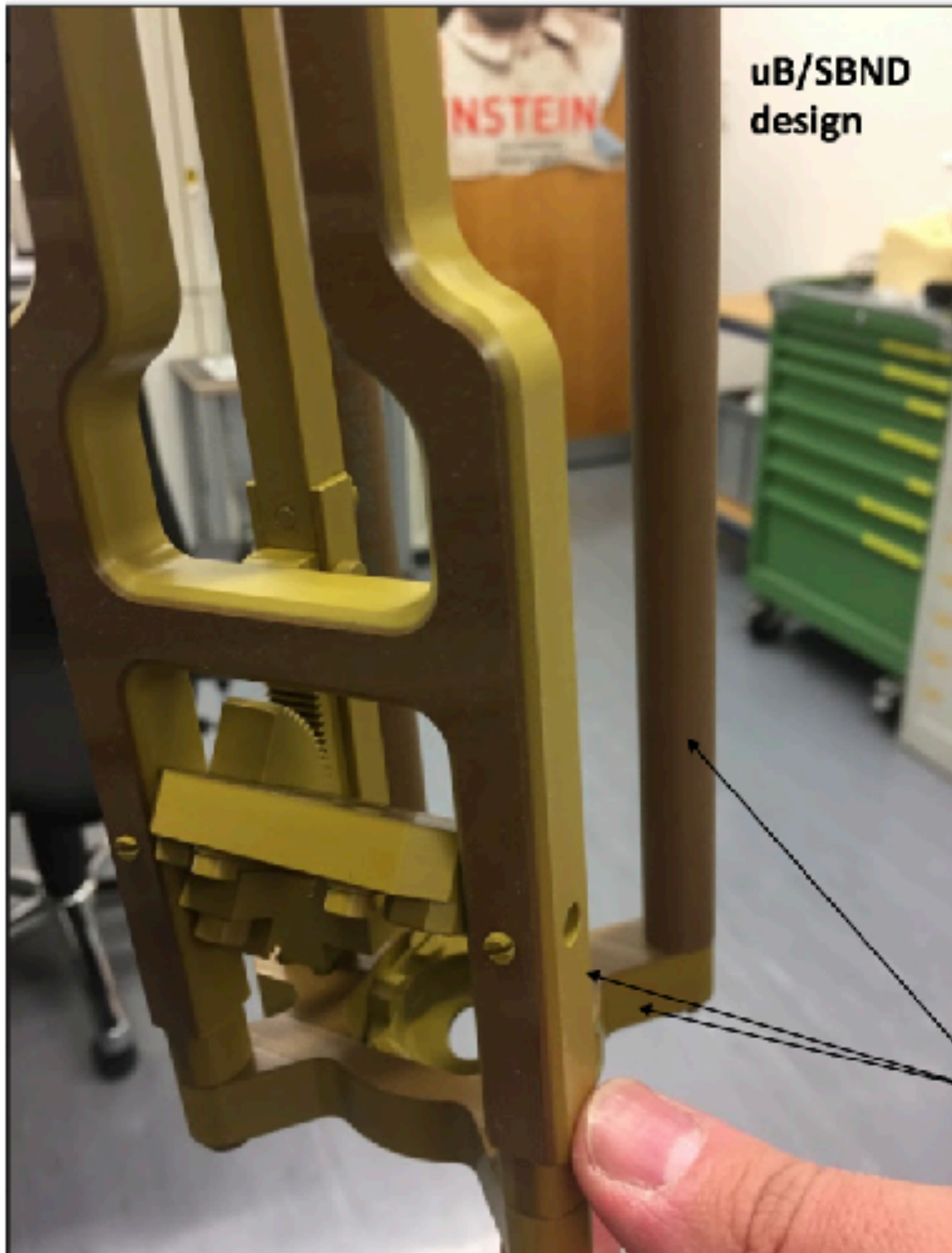
- Need to ensure good electrical insulation for the periscope





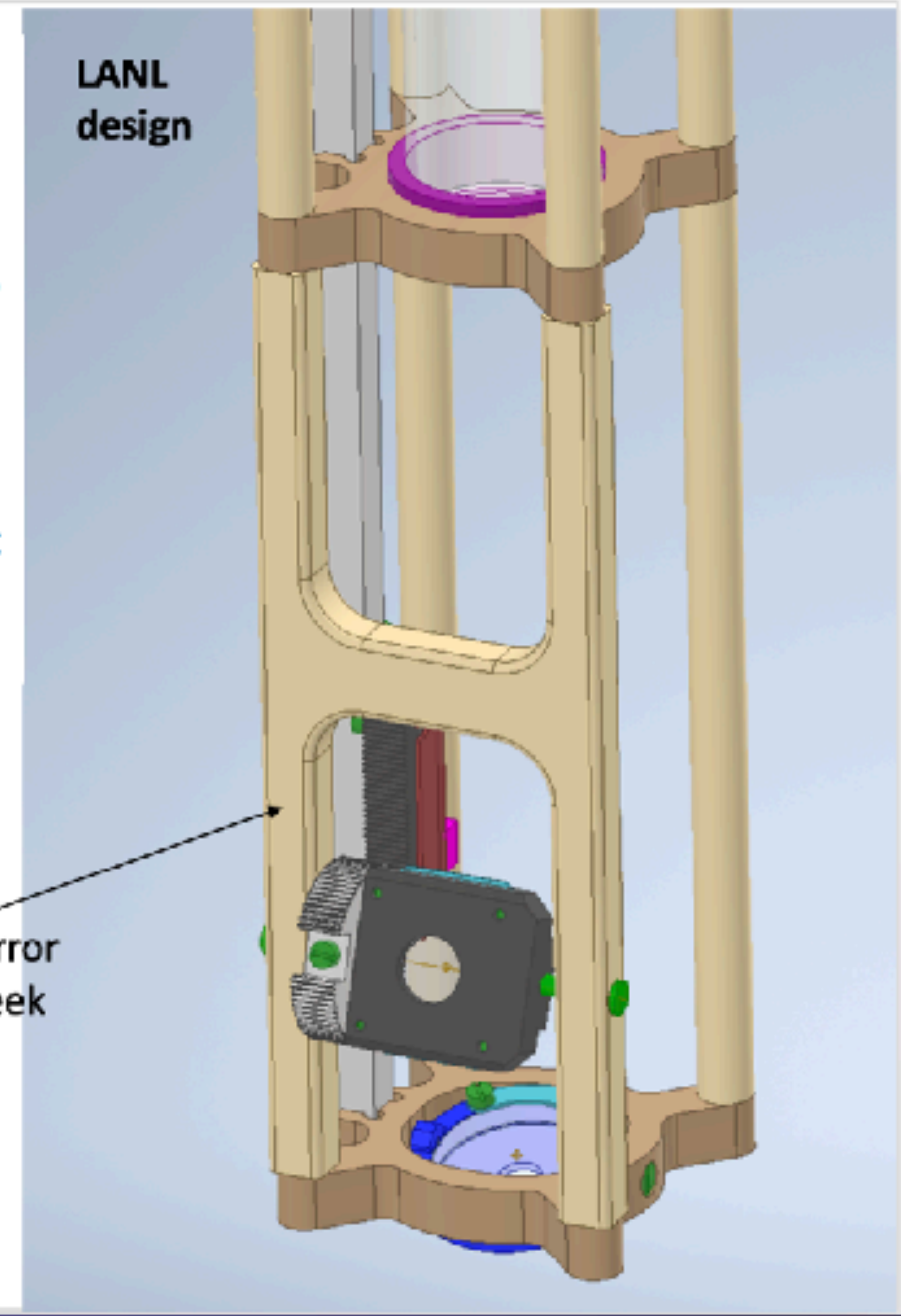
Ceramic break with Conflat flanges welded in place by MDC, total cost estimated ~$5000 with welding

Value Engineering: Replace Some Torlon with Peek



Substitute Peek for Torlon for periscope support structure

- Cheaper
- More vendor choices for material
- Easier to machine
- Demonstration of usage of Peek in other experiments at cryogenic temperatures

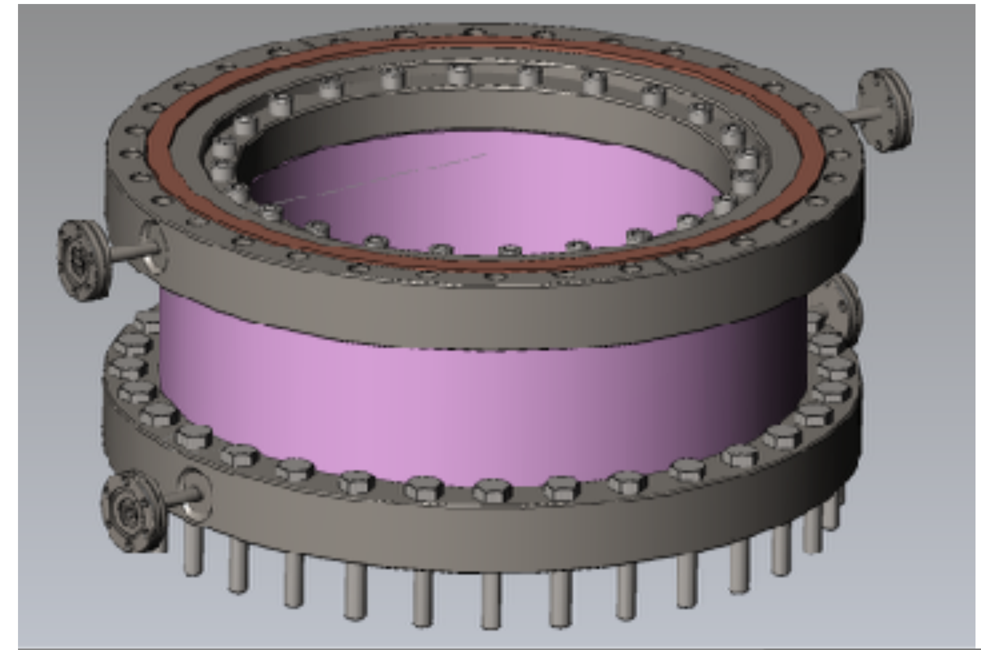


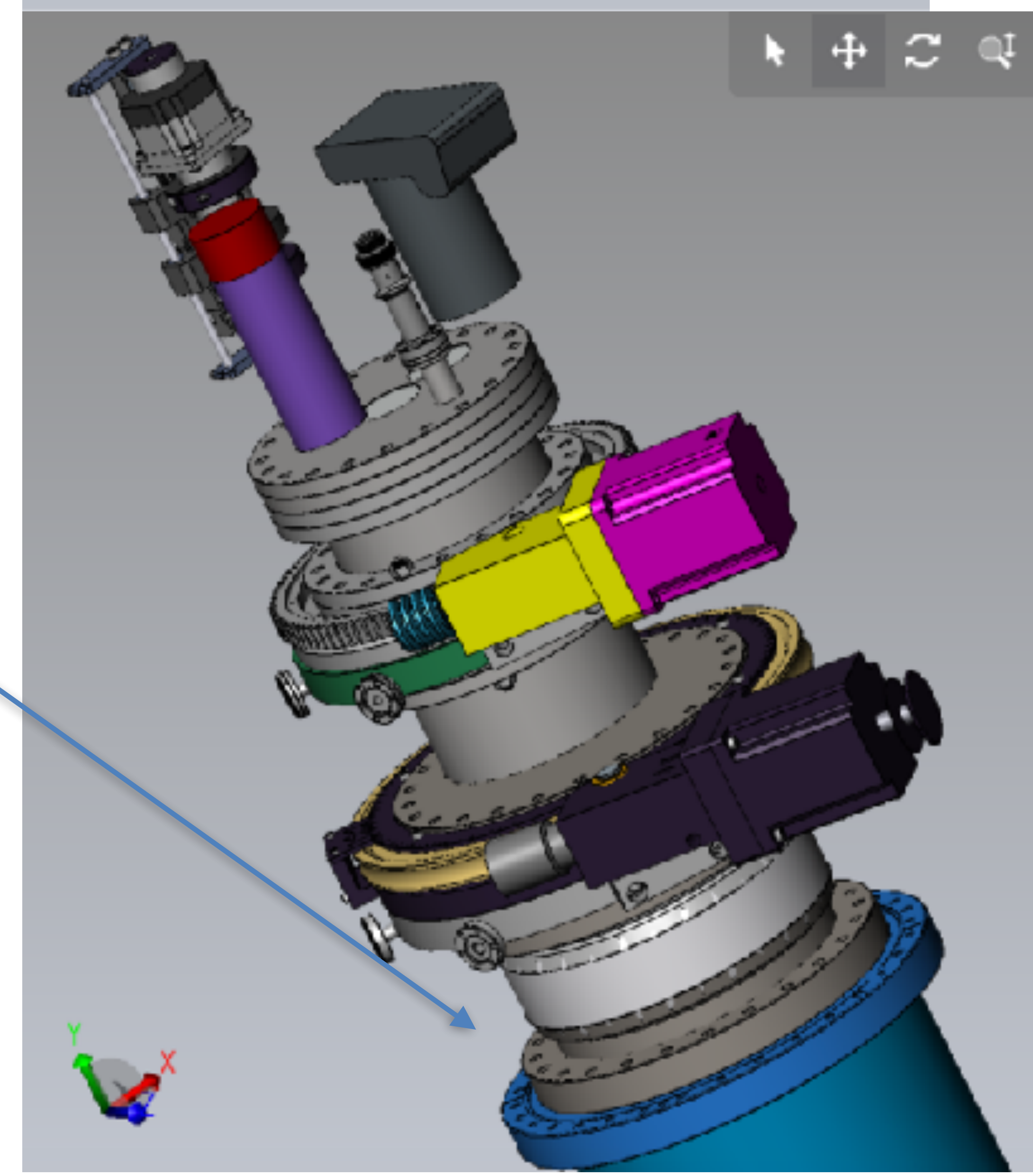
Simplified Rotating Mirror Support - Peek

Torlon

Electrical break (End-wall)

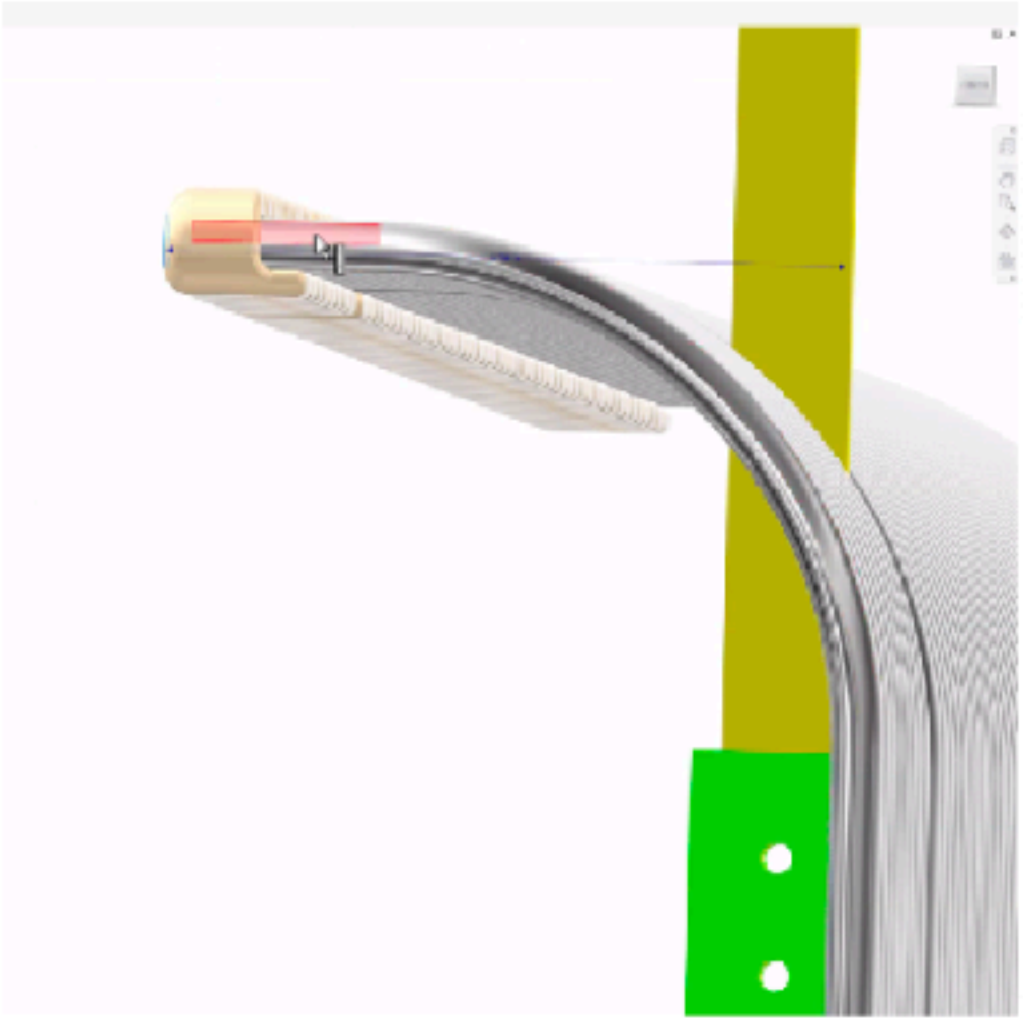
- “Homemade” electrical break designed at LIP with steel flanges and plastic middle, in case large commercial ones too expensive
- Affordable commercial solution apparently exists even at large size
- Ceramic break welded into steel (2135 € for 197 mm inner diameter)
- Waiting for quote with full welded flanges





ProtoDUNE-SP-II Changes

- ProtoDUNE-SP II will have changes that impact the laser system
  1. *Ground planes will be shortened*
  2. *Vertical FC profiles will be curved*
  3. *Shorter TPC* impacts ports and locations
  4. *FC sits deeper compared to ProtoDUNE-I –* increases periscope length

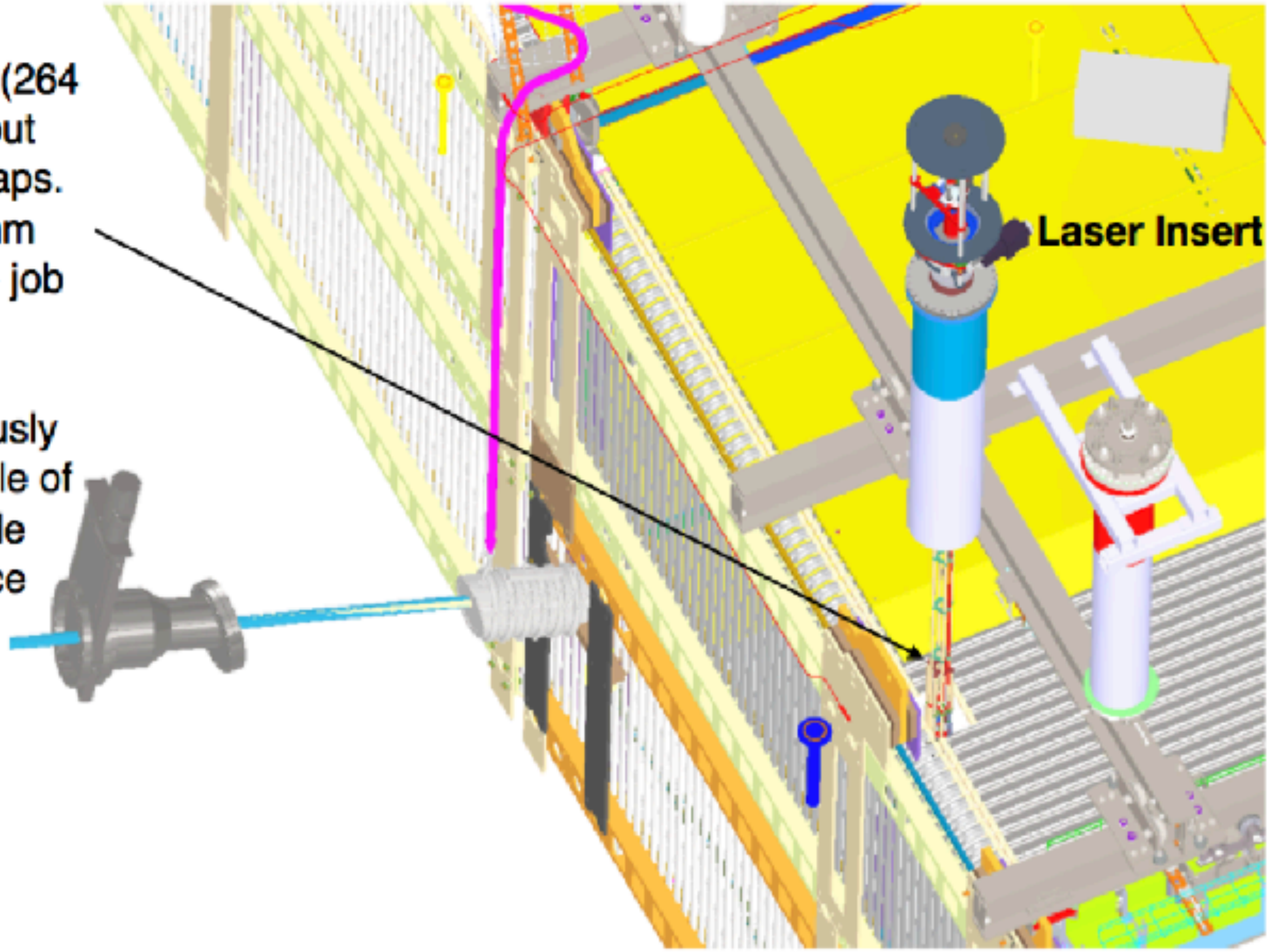


- All of these changes have been implemented (thanks to Bo!)
- Periscope design will be optimized once ProtoDUNE-II final model is available

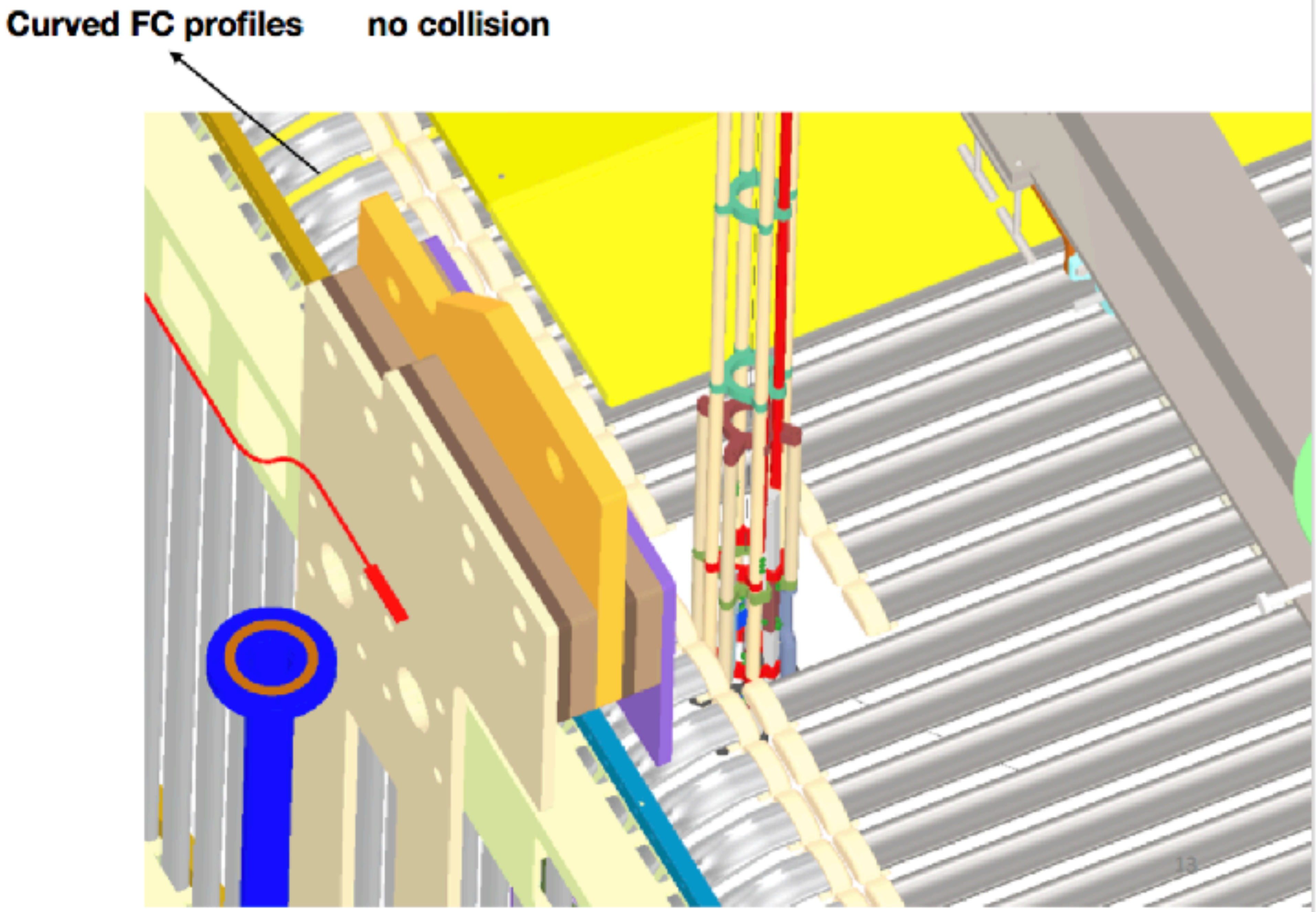
ProtoDUNE-SP-II Changes: Shortened ground planes

- Width of each ground plane is 528 mm, shortening it by half (264 mm) only clears about 2.75 FC bars with gaps.
- Shortening to 291 mm seems to just do the job (3 FC bars + gaps cleared)
- Note that we previously agreed that a FC hole of 3 FC bars will provide the needed clearance for us

Yellow structure = ground planes

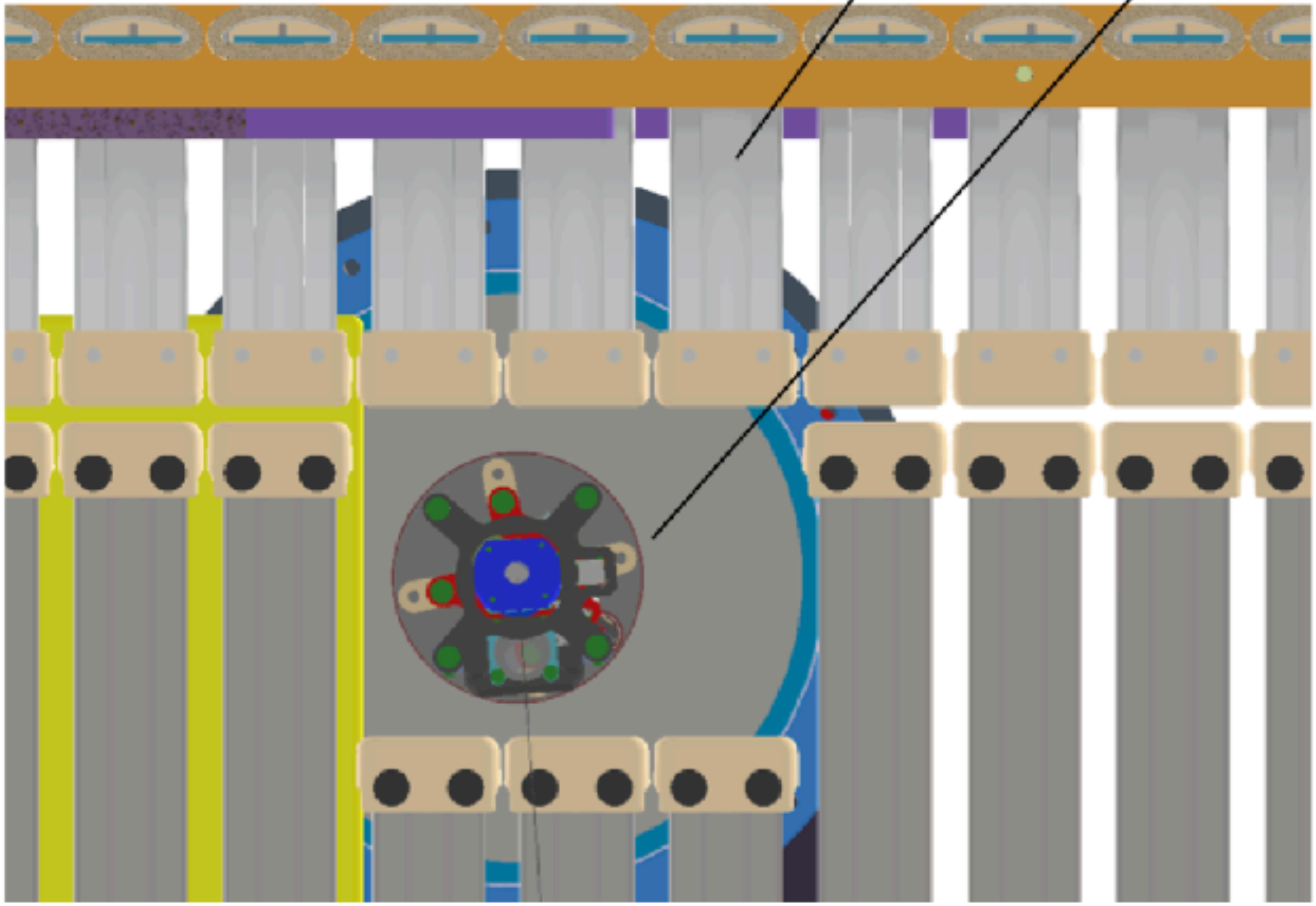


ProtoDUNE-SP-II Changes: Curved FC profiles

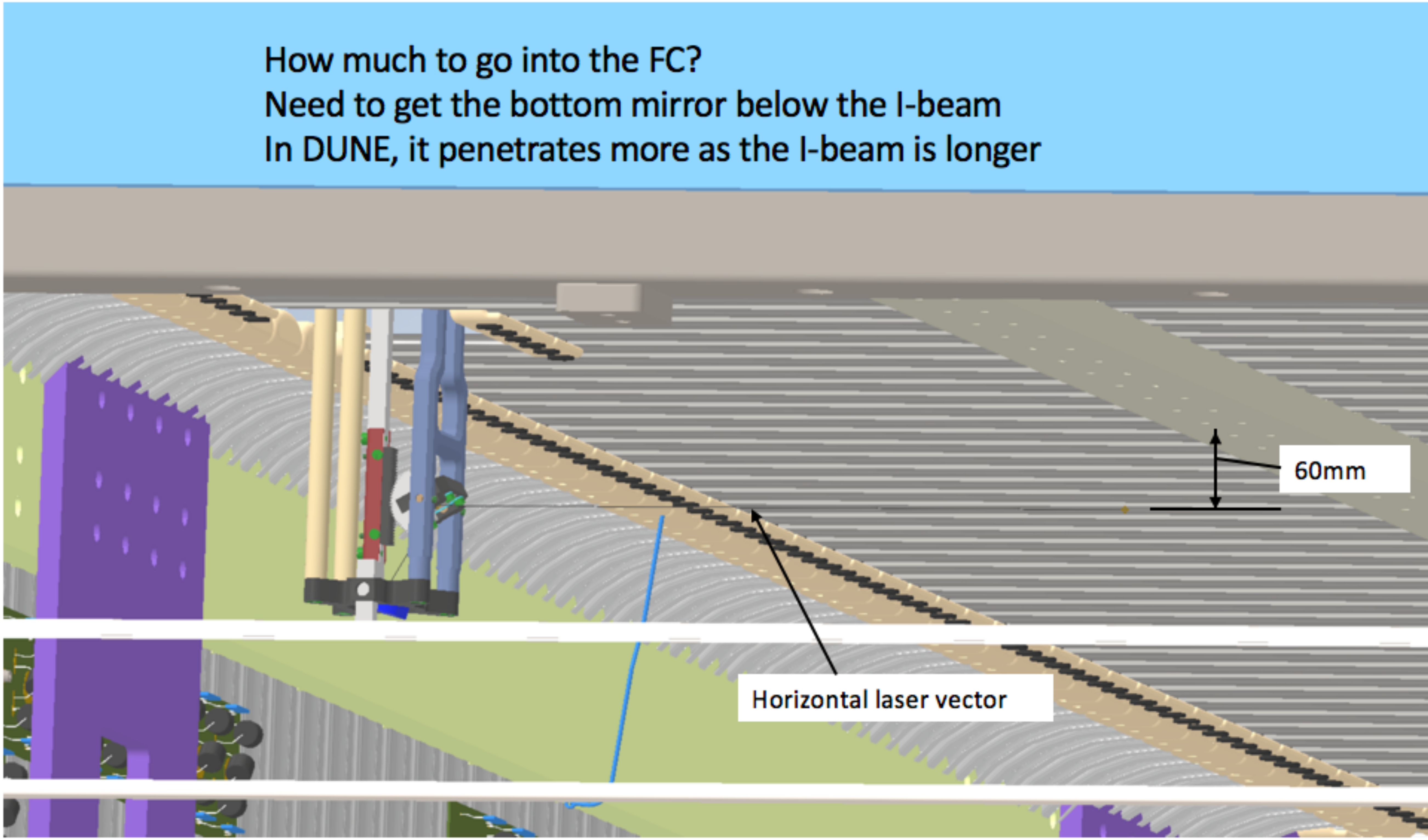


ProtoDUNE-SP-II Changes: Curved FC profiles

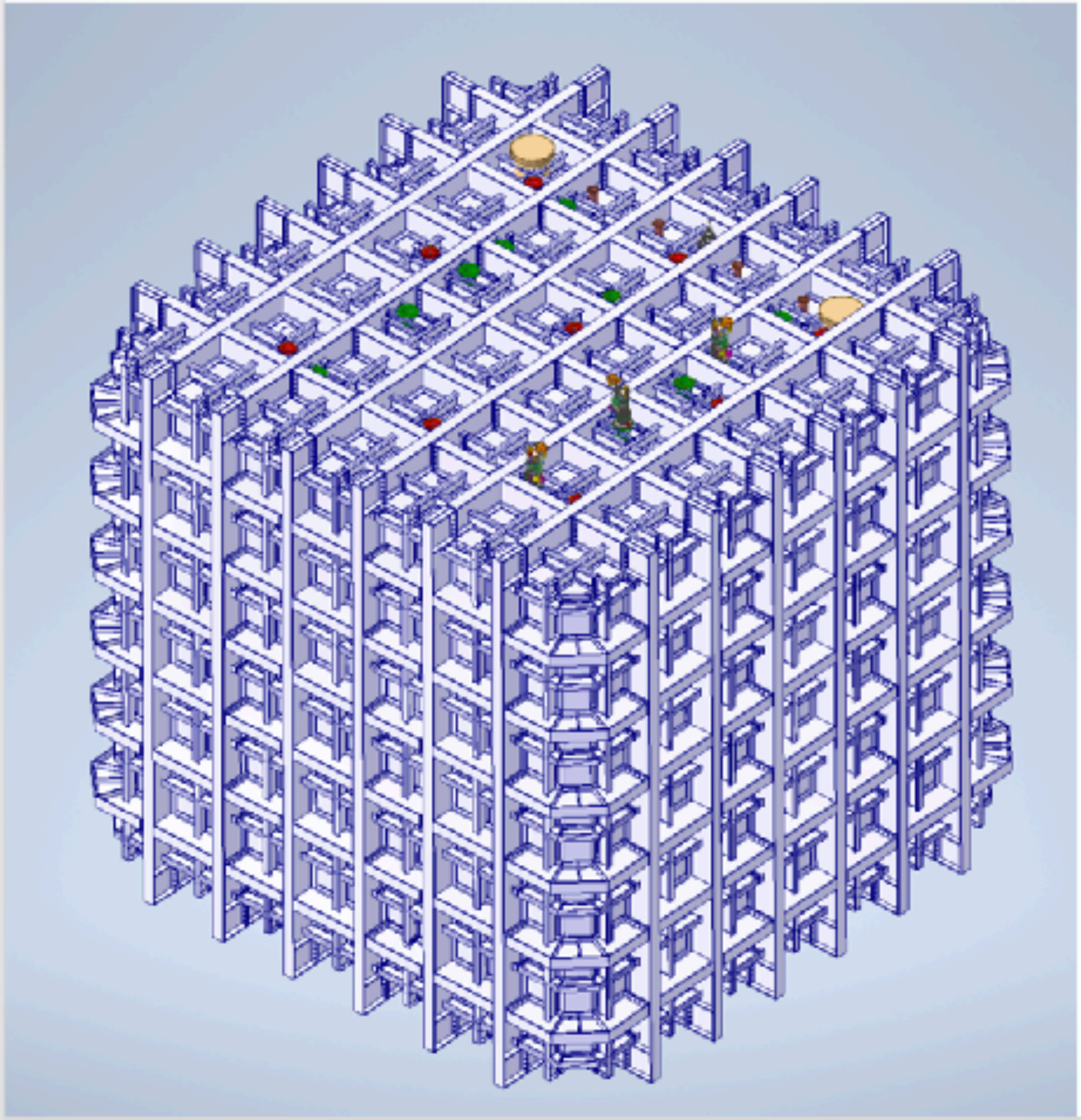
While clearance is not symmetric on all sides around the insert, there is clearance all around

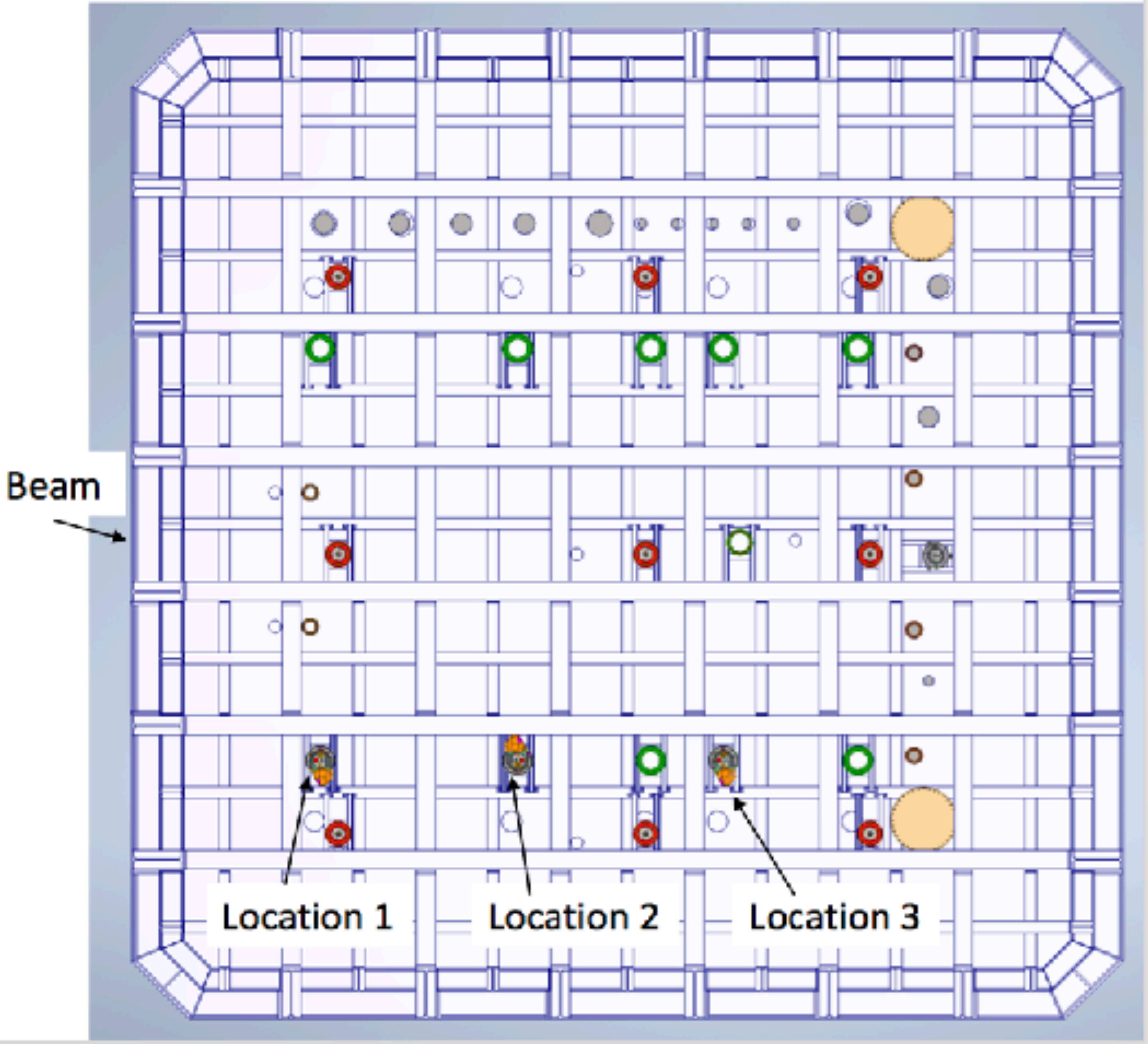


Laser Periscope in ProtoDUNE-SP-II

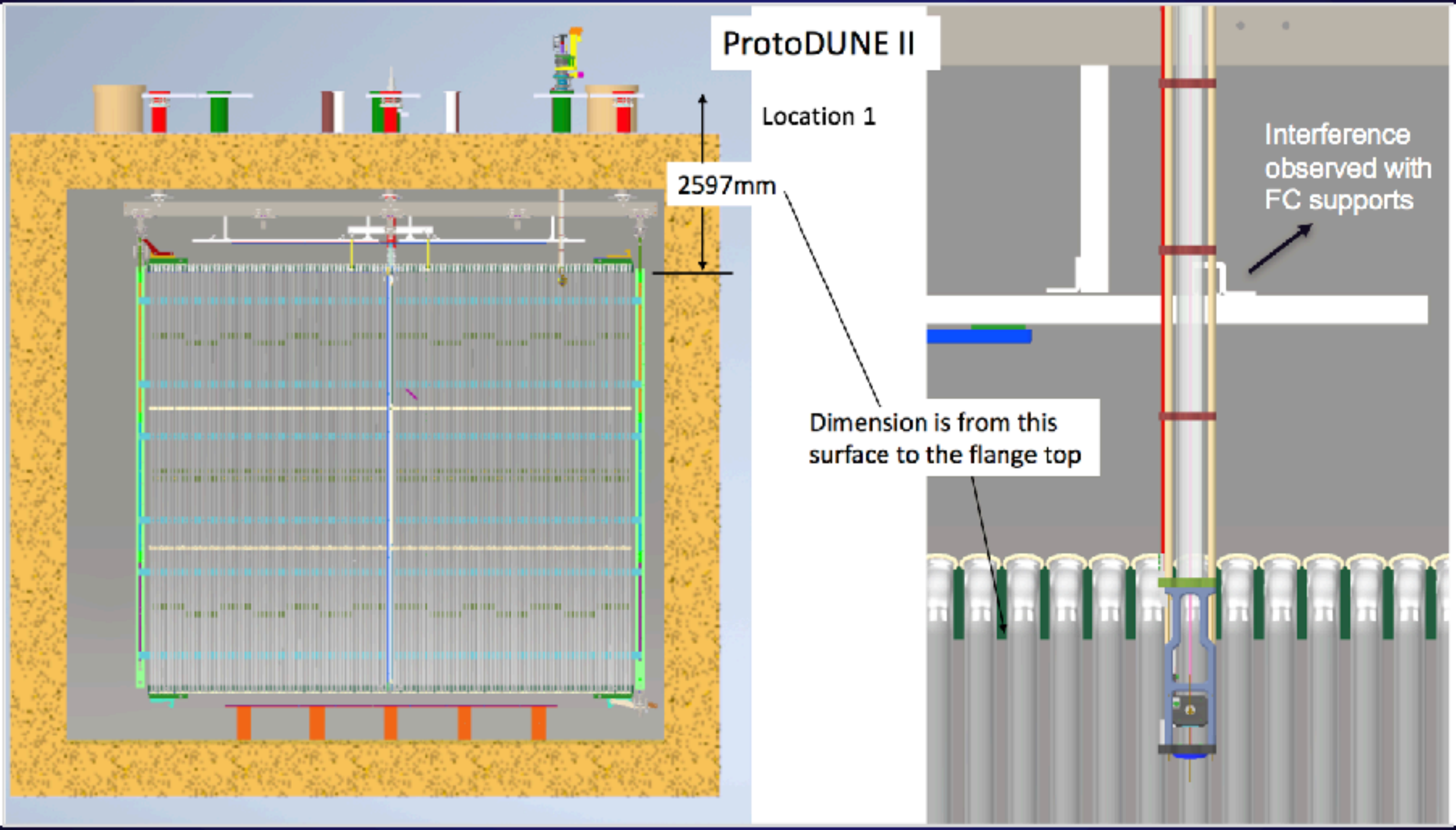


ProtoDUNE II Desirable ports for Laser

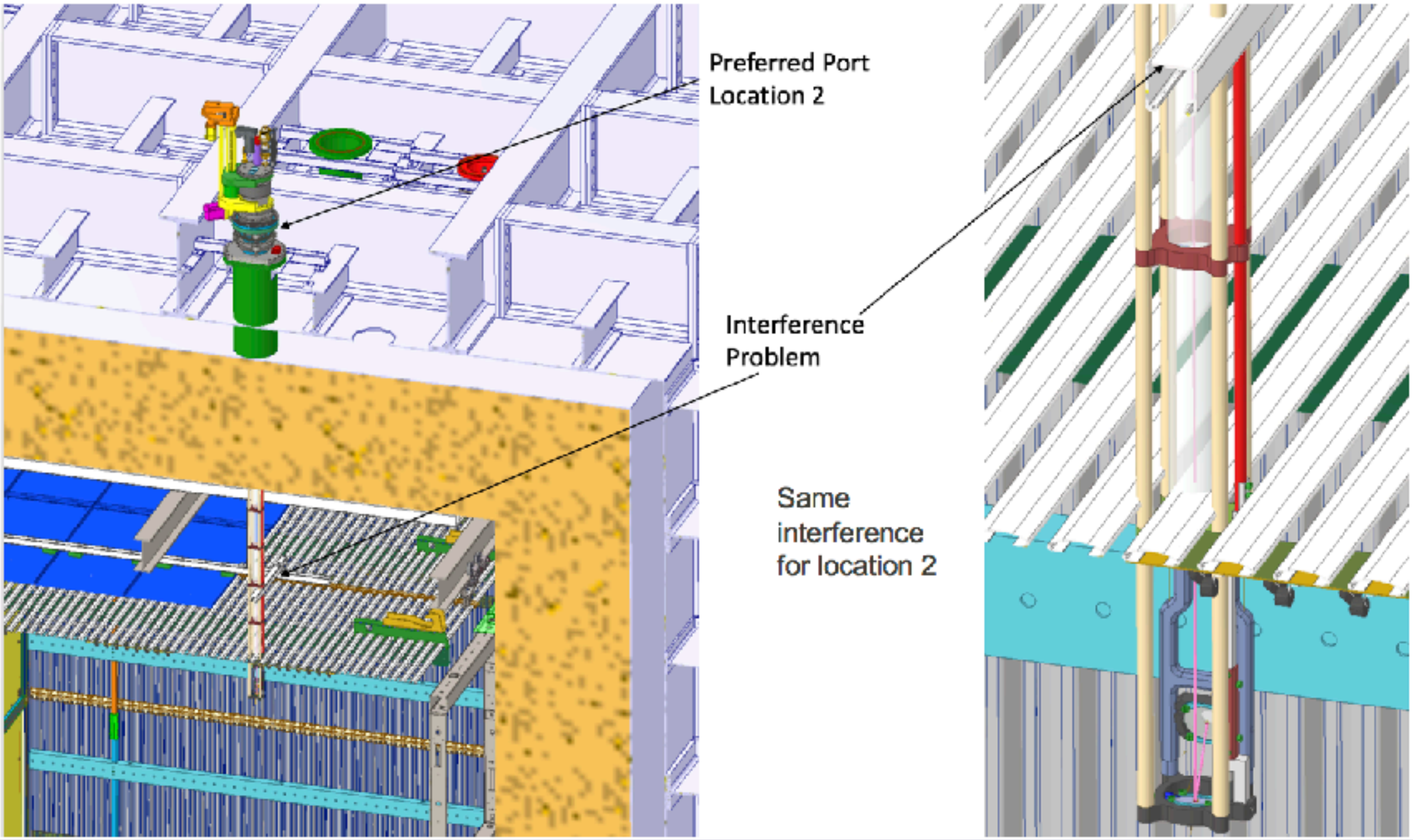




ProtoDUNE II Laser port location 1



ProtoDUNE II Laser port Location 2



ProtoDUNE II Laser port Location 3

Same interference for location 3

Bo confirmed that those can be moved away and that DSS is redesigning the ground plane structure so this design will evolve.