Scope Review:
Photoelectron Laser for ProtoDUNE-II and DUNE

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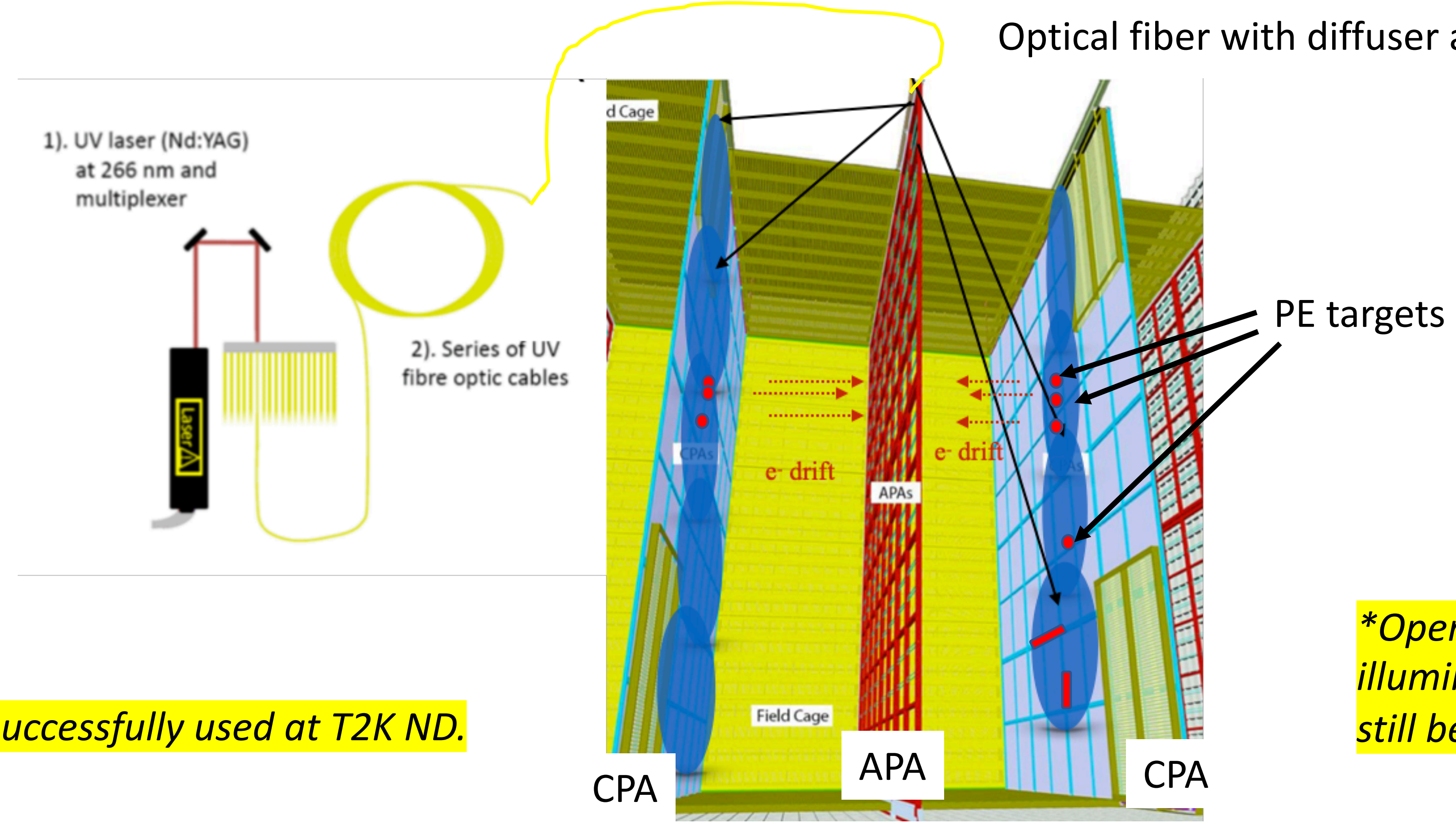
Motivation for the Photoelectron (PE) Laser I

- How does PE laser calibration system operate?
  - PE laser illuminates photoelectric targets attached to CPA → small **square-shape or strip-shape electron clouds** with **known amount of charge** generated on the CPA in **pre-determined locations** at **known times** (with 5 ns long laser pulses) **throughout the detector**.
  - Generated electron clouds drift **across the entire TPC drift distance** to be collected by APA.



Similar system successfully used at T2K ND.

**Opening angle of illumination from the fiber still being optimized.*

What does PE laser system offer for TPC calibration?

☐ **Complementary to IO laser as it provides efficient detector scan**

☐ **Measurement of electron drift time and velocity throughout detector volume**, at photoelectric target locations

☐ **CPA planarity throughout the detector**

☐ **Space charge effects and position reconstruction**

☐ **Measurement of diffusion effects** on the collection plane for simultaneously generated cluster

☐ **Charge collection efficiency -** ratio of generated to collected charge

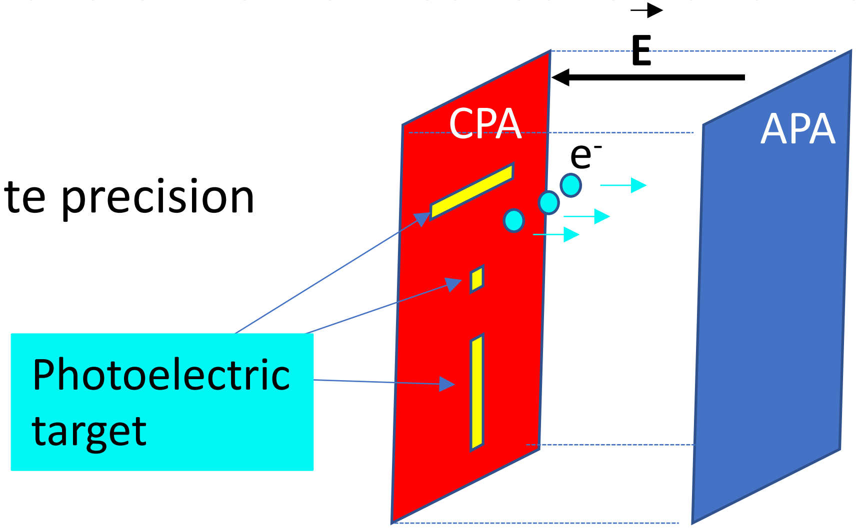
☐ **Linearity of the response for varying charge and charge triggering threshold**

$$\boxed{t_{electron\ drift} = t_{electron\ detection\ on\ APA} - t_{laser\ pulse\ trigger}}$$

- Electron clouds generated with 5 ns long laser pulses
- Force trigger issued by the laser to capture the anticipated cloud arrival time.
- Simultaneous measurement of the electron drift time across the detector at all YZ locations with PE targets
- Simultaneous measurement of the temporal spread on the collection plane at various locations

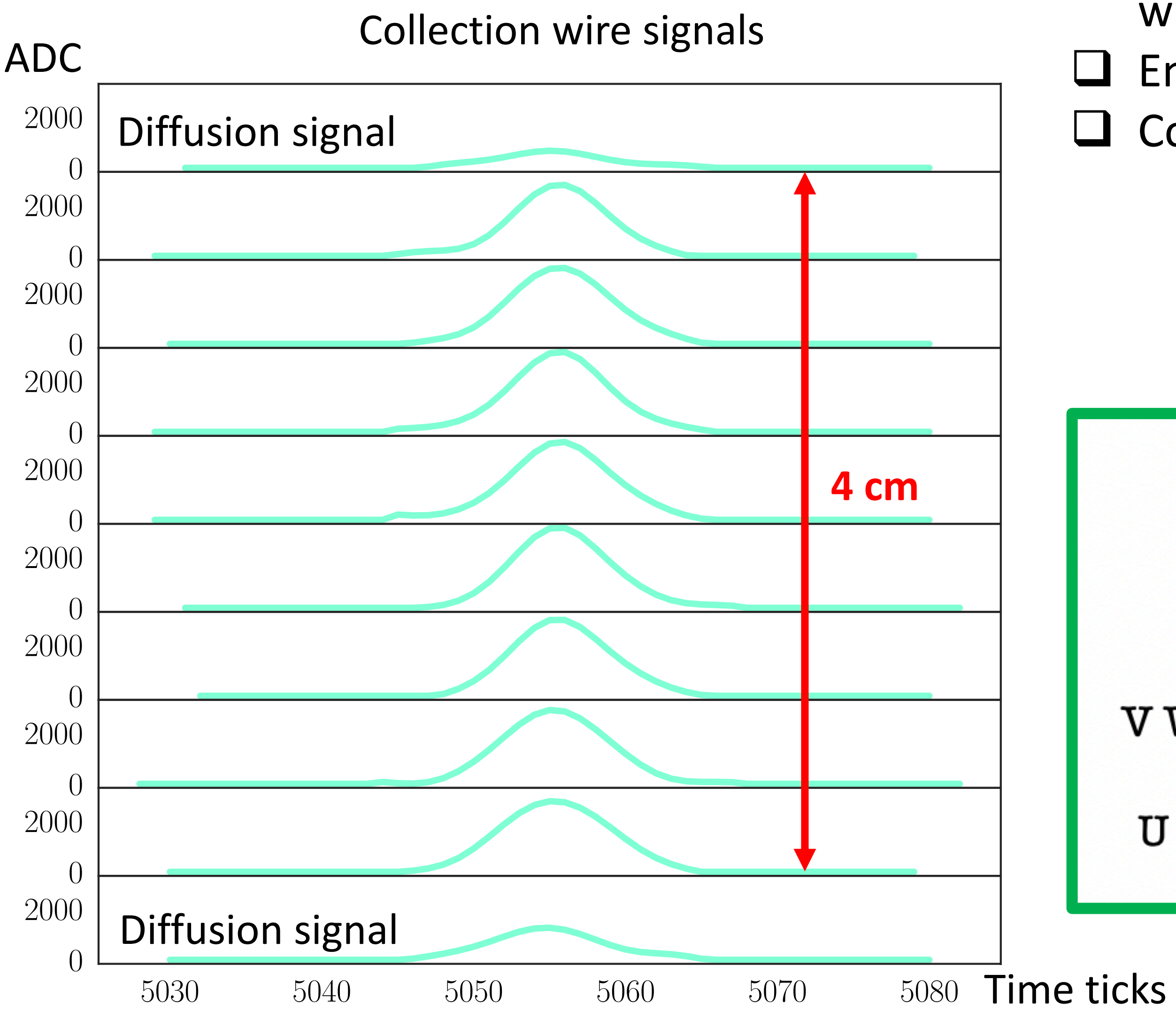
Simulations

- We have conducted a set of simulations to evaluate the potential of the PE laser for DUNE calibration with ProtoDUNE geometry.
- Planar electron clouds, parallel to the CPA, were simulated at the CPA (3 cm from the surface due to simulation limitations) and their signals were collected by APA and analyzed.
- Three different shapes were simulated with varying charge density: square patch (1cm x 1 cm and 2 cm x 2 cm), vertical and horizontal strip (1 cm x 4 cm and 2 cm x 8 cm)
- Instead of LArSoft reconstruction algorithms, waveforms from collection and induction wires were utilized to:
  - Measure drift velocity and estimate uncertainty
  - Reconstruct location of the strip (patch) and estimate precision
  - Observe diffusion effects
  - Measure shift due to space charge effects
  - Evaluate linearity of the response



Measurement of Electron Drift Time and Velocity

Simulated 4cm x 1cm horizontal Strip at the CPA


Collection wire signals

- ☐ Used peak times from collection and induction wires to find drift velocity
- ☐ Ends of the strip clearly noticeable
- ☐ Collection wires provide more precise velocity measure.

High precision measurement of drift velocity.

Drift velocity measurement is sensitive to offset among the three wire plains < 5 mm.

Velocity

Collection Wires: 1.5655 ± 0.0002 mm/μs
Expect: 1.565 mm/μs

V Wires (4.75 mm away): 1.5635 ± 0.0002 mm/μs

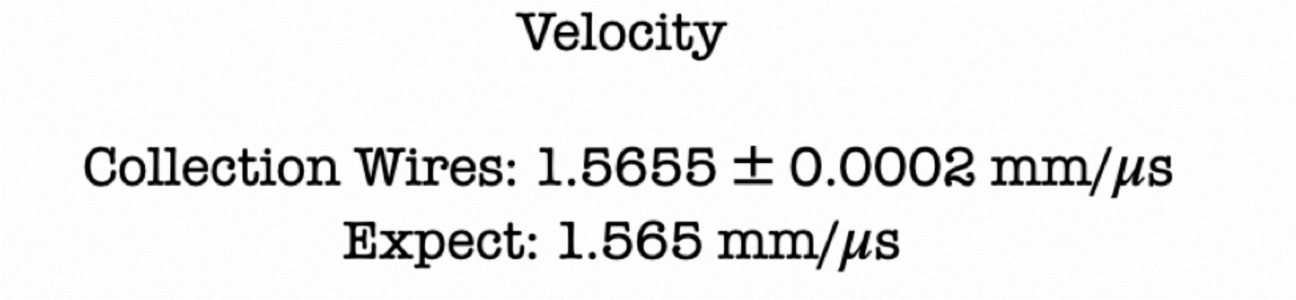
U Wires (9.5 mm away): 1.5612 ± 0.0003 mm/μs

Excellent charge reconstruction

Pixelation: 50 e's per 0.03 cm= 5.6e4 e's/(cm^2) → Charge Ratio = expected/collected = 1.06

CPA planarity

- High precision of the measured drift velocity and location of photoelectron targets on CPA → use it to verify CPA planarity



Velocity

Collection Wires: 1.5655 ± 0.0002 mm/μs

Expect: 1.565 mm/μs

- Velocity measurement uncertainty is well below mm level.
- 2 cm tilt corresponds to difference in arrival time:

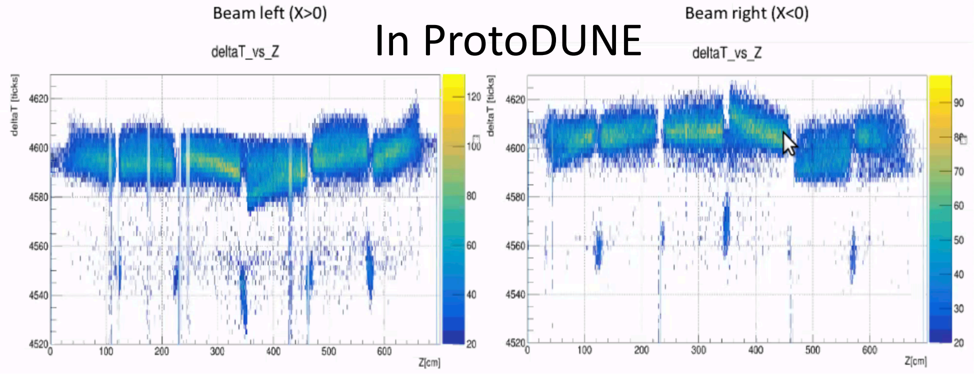
Δt = 12.776 ± 0.002 µs

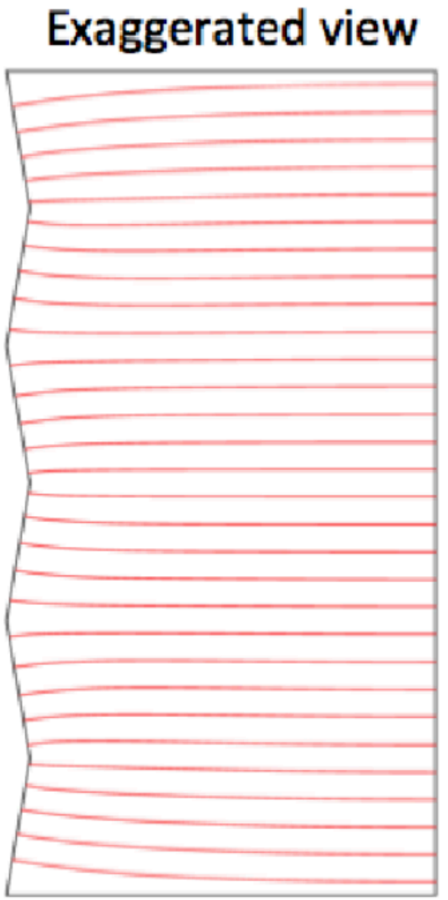
→ ***mm level shifts can be observed****

Δt = 0. 6388 ± 0.0001 µs

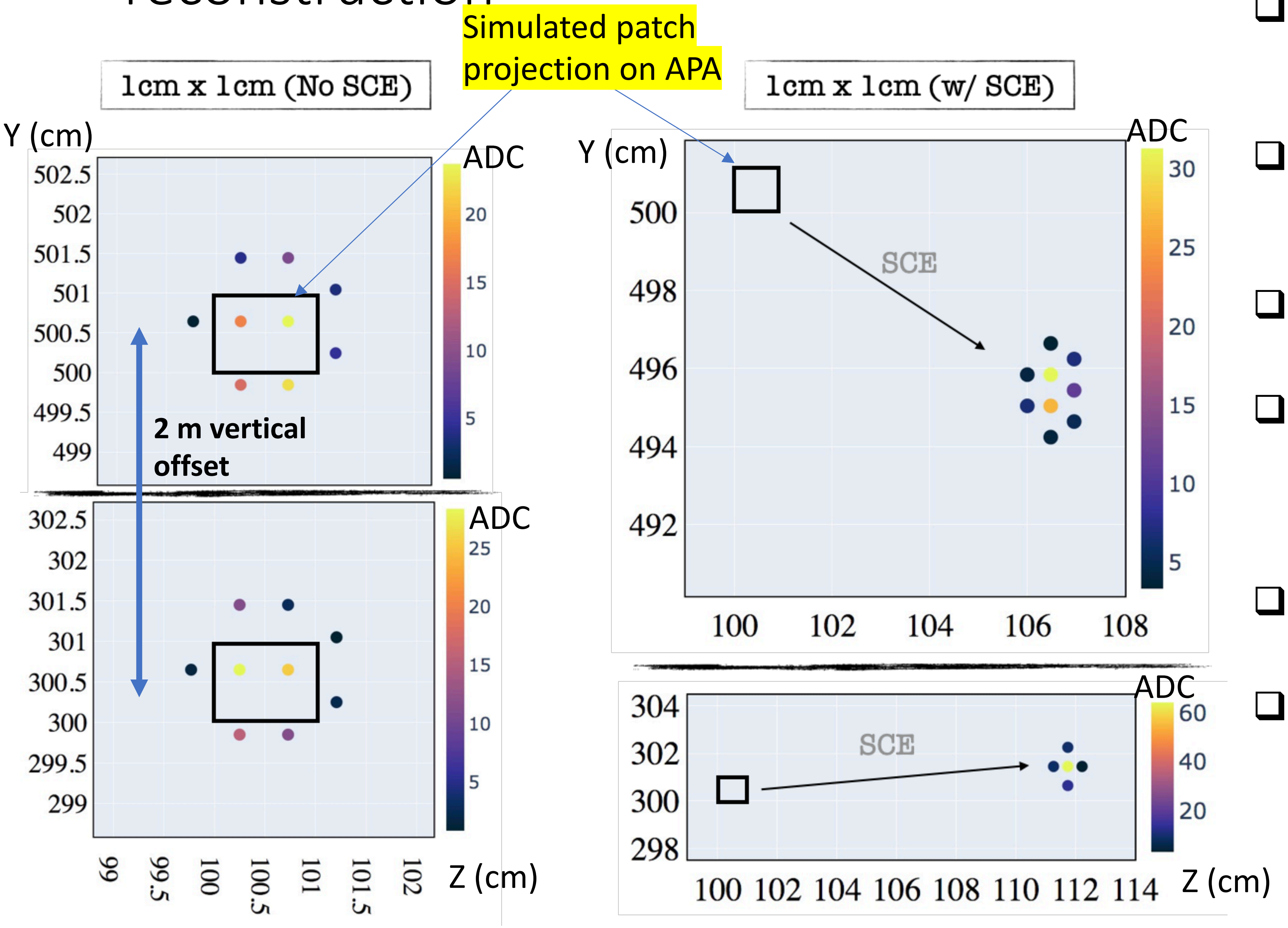
**Need IO laser to disentangle from APA shift*

CPA tilt
In ProtoDUNE





Measurement of Space Charge Effects (SCE) and position reconstruction


Simulated patch projection on APA

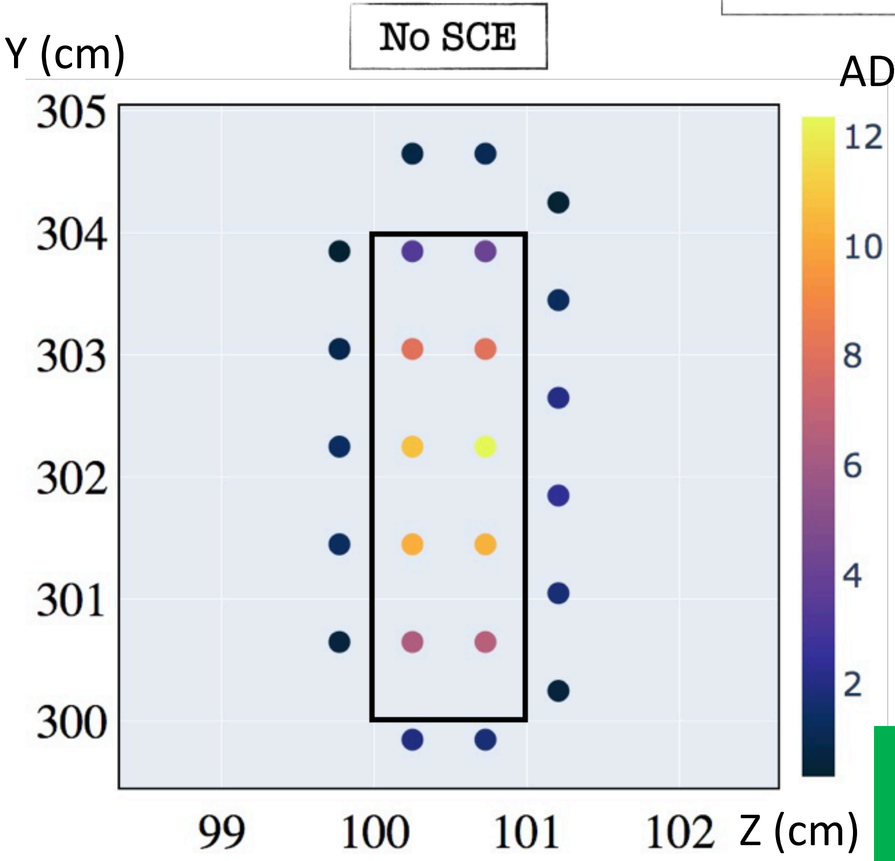
2 m vertical offset

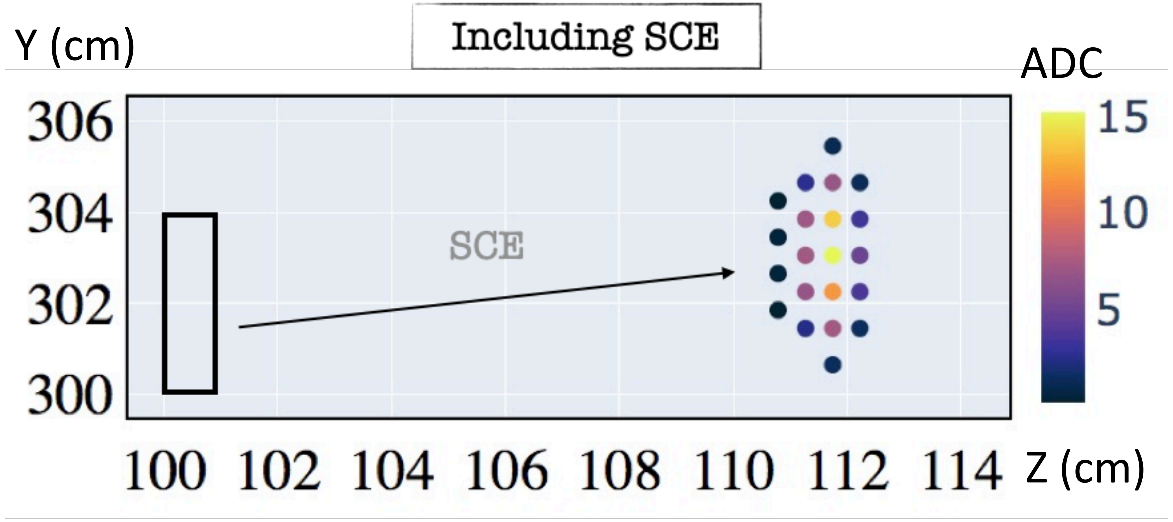
- ❑ Simulated two 1 cm x 1 cm patches – one above the other 2 m apart
- ❑ Used weighted signals from collection and induction wires to reconstruct position on APA
- ❑ Reconstructed patch represented with dots and heat map
- ❑ Distinguish between patches based on combination of the collection and induction wire signals.
- ❑ SCE turned on and off based on ProtoDUNE maps.
- ❑ **Shifts due to SCE clearly visible and can be measured with 5 mm precision → useful for small SCE shifts suitable for FD**

Measurement of Space Charge Effects and Position Reconstruction

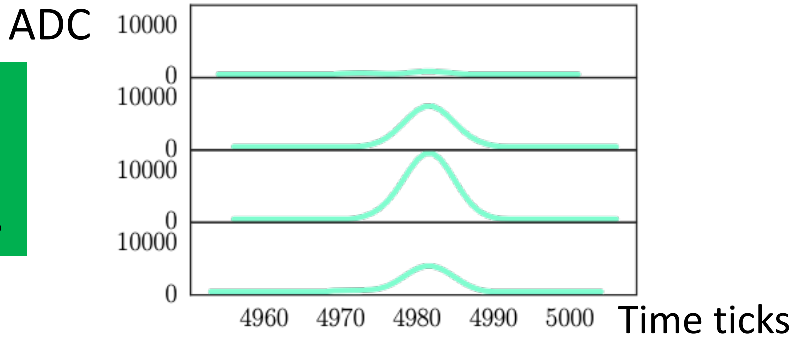
1 cm x 4 cm Vertical Strip w/ Weights

Pixelation: 50 e's per 0.03 cm
σ = 5.6e4 e's/(cm^2)





Collection Wires Charge Ratio: 1.1
Velocity: 1.560 ± 0.0002 mm/μs



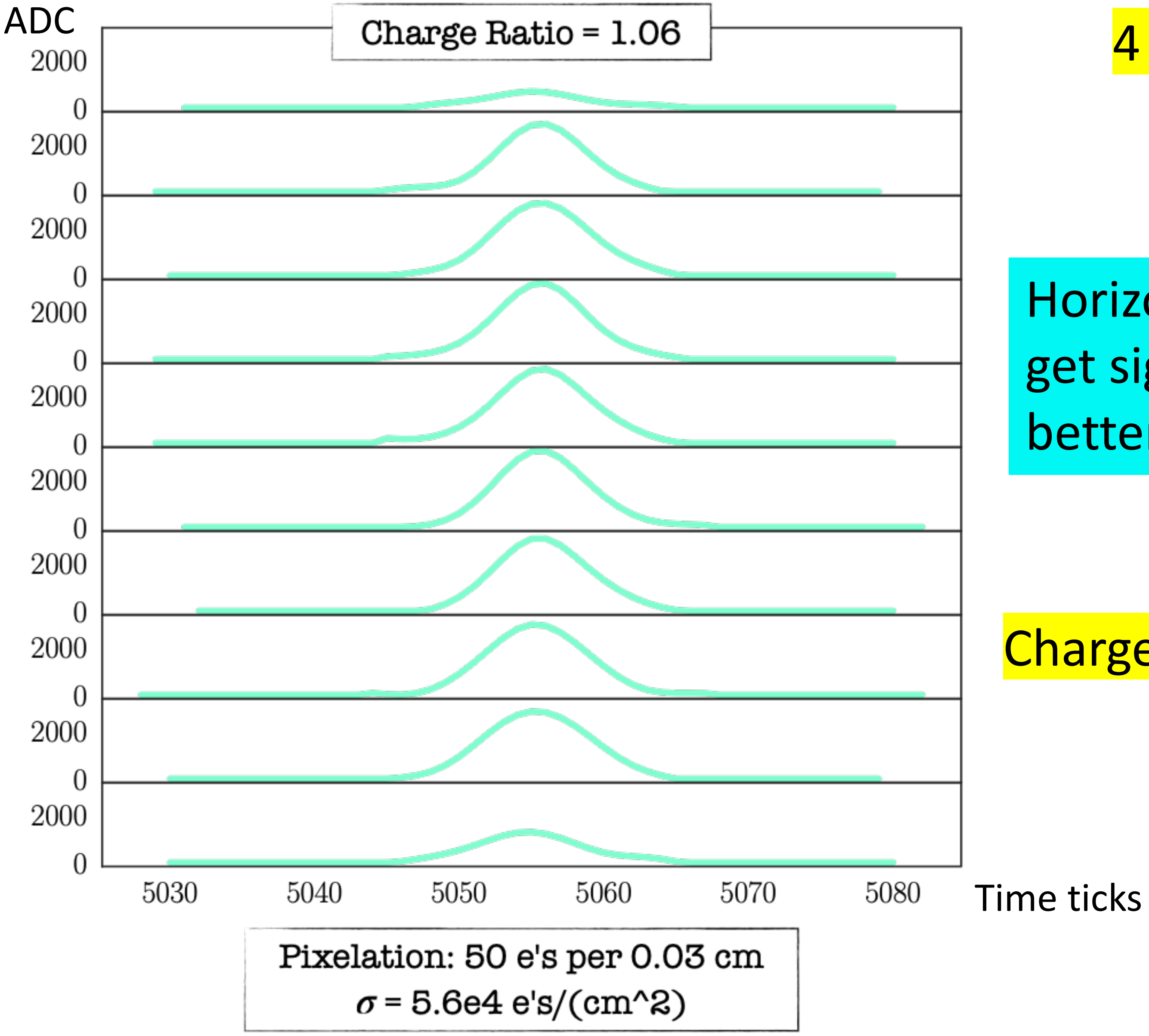
Charge Ratios:

Vertical strip	Horizontal strip
X: 1.15	X: 1.1
U: 0.83	U: 1.0
V: 0.90	V: 1.0

Precise position reconstruction; diffusion noticeable.

SCE changes the drift distance and the velocity is no longer 1.565 mm/ s (Can be greater or smaller depending on location)

Charge reconstruction



4 cm x 1 cm Horizontal Strip
Collection Wires

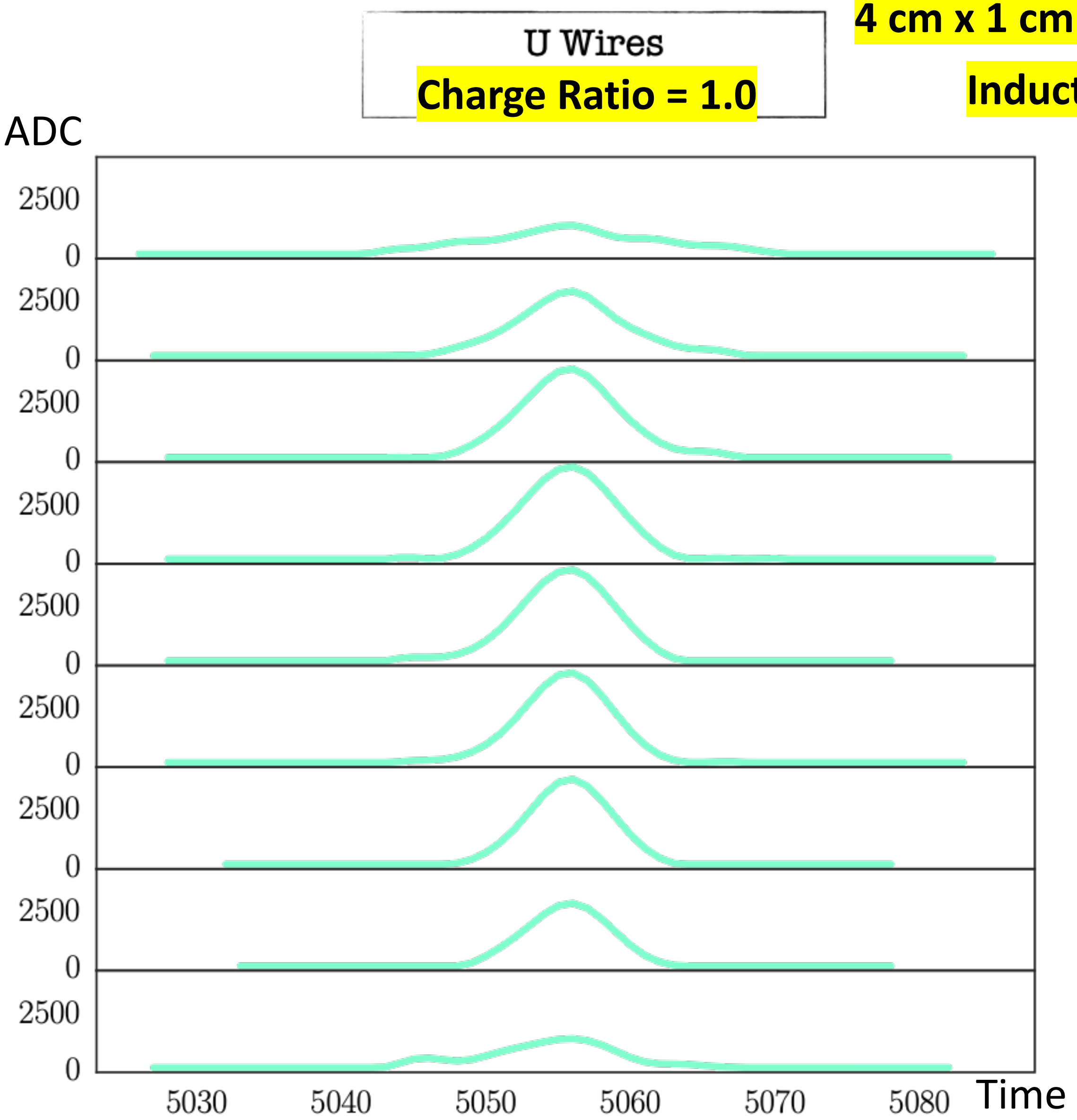
Horizontal strip more collection wires get signal→
better charge reconstruction

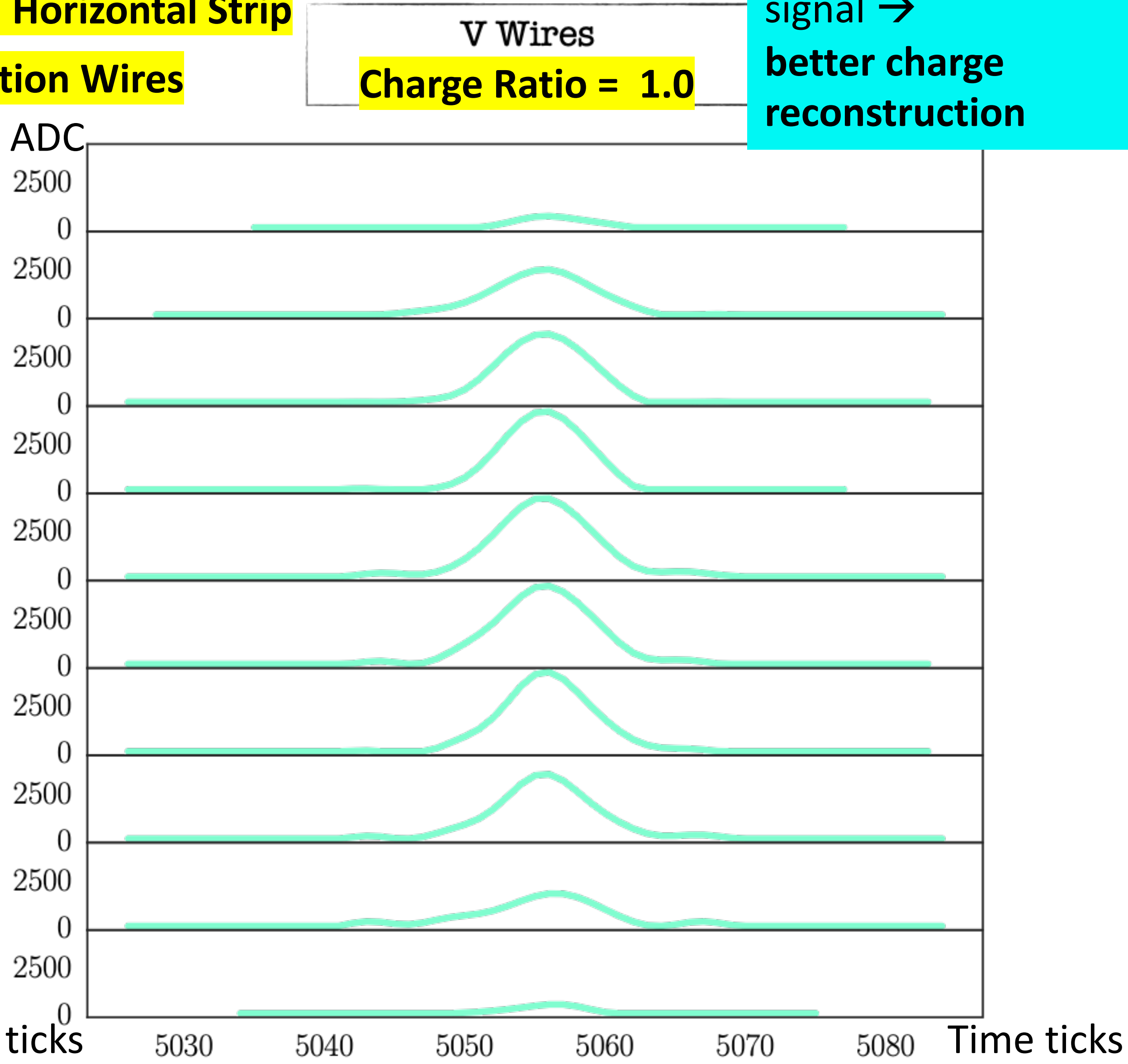
Charge Ratio = expected/collected = 1.06

Charge Reconstruction

4 cm x 1 cm Horizontal Strip

Induction Wires



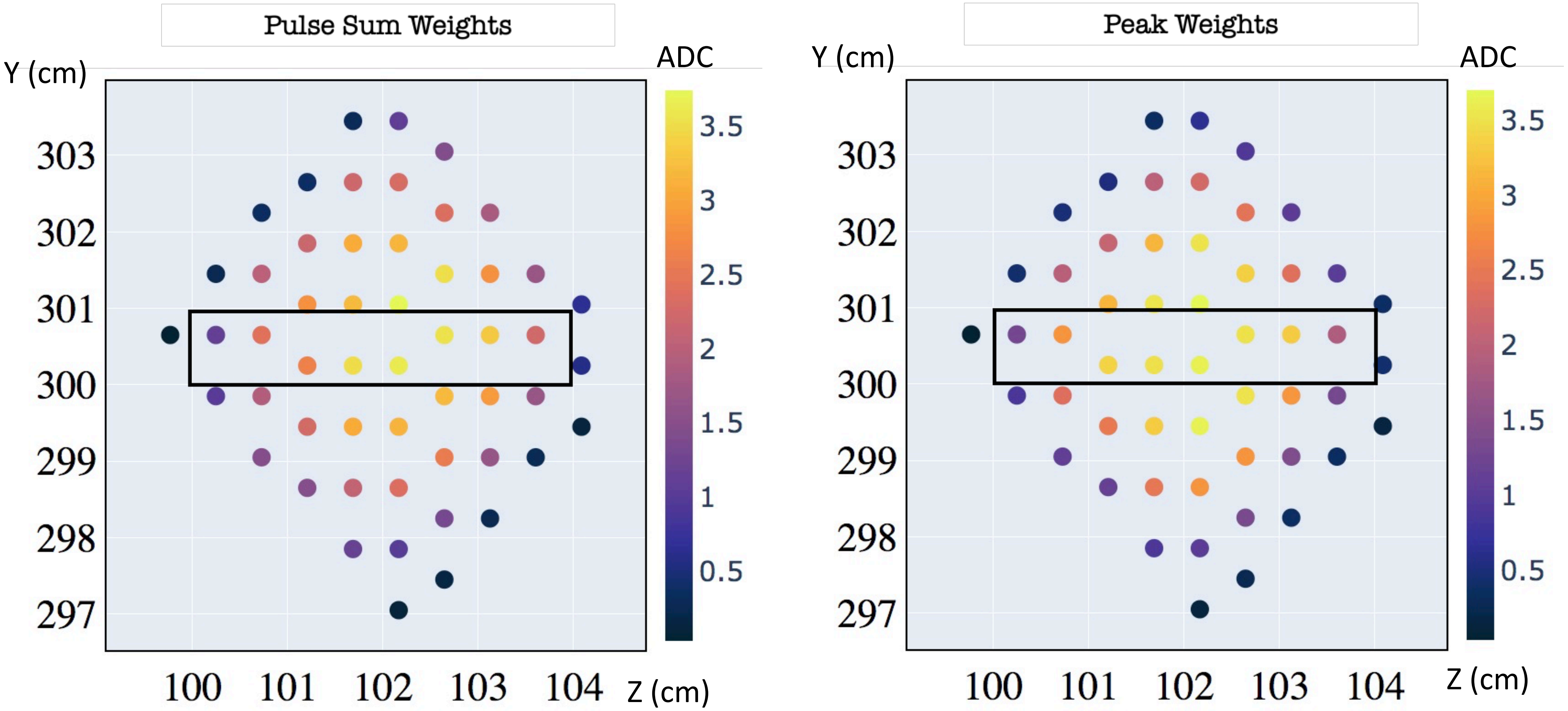


Horizontal strip - more collection wires with signal →
better charge reconstruction

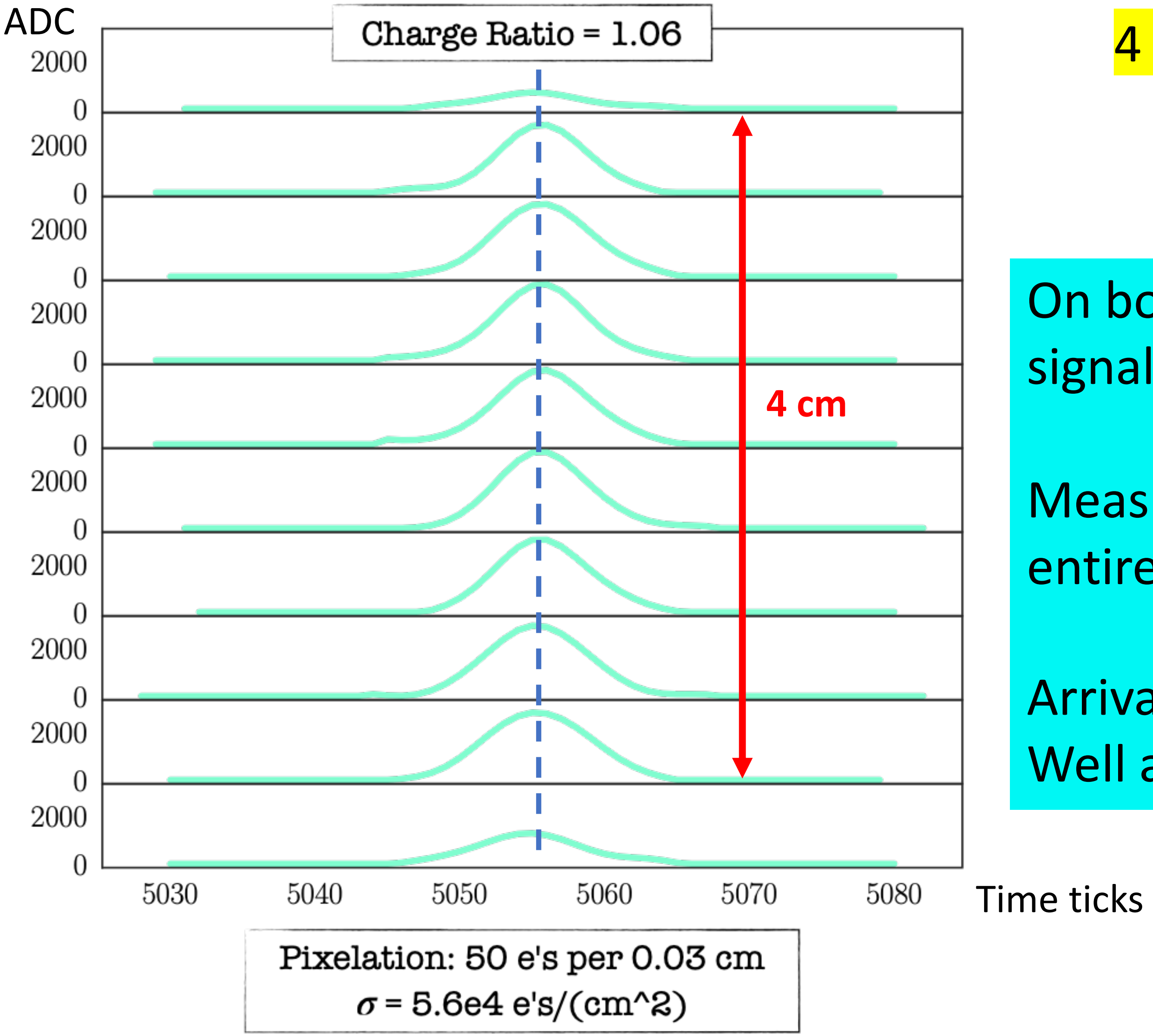
Position reconstruction

Horizontal strip crosses more collection wires and includes more induction wires → worse position reconstruction than vertical strip

4 cm x 1 cm Horizontal Strip



Diffusion effects



4 cm x 1 cm Horizontal Strip
Collection Wires

On both strip ends, additional weaker signals on the next collection wires.

Measures diffusion effects over entire volume.

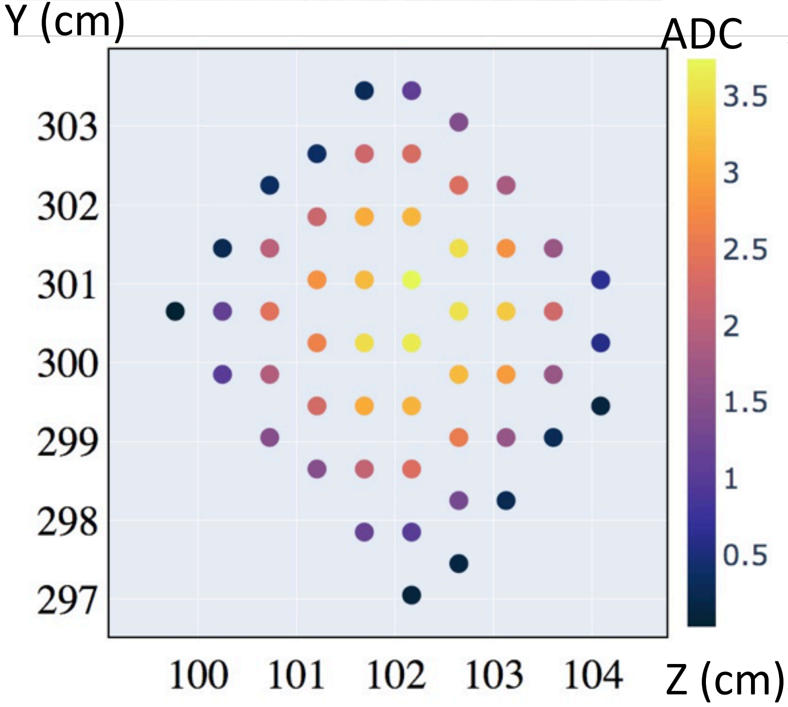
Arrival peaks on the collection wires Well aligned.

Charge density variation – linearity studies

4 cm x 1 cm Horizontal Strip

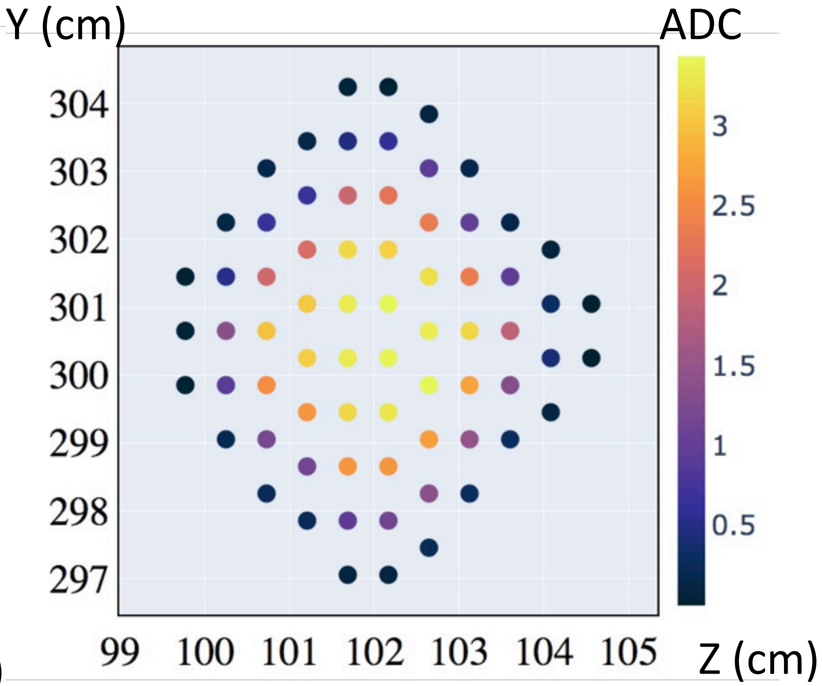
With increasing charge density → saturation effects become noticeable.

Pixelation: 50 e's per 0.03 cm
σ = 5.6e4 e's/(cm^2)



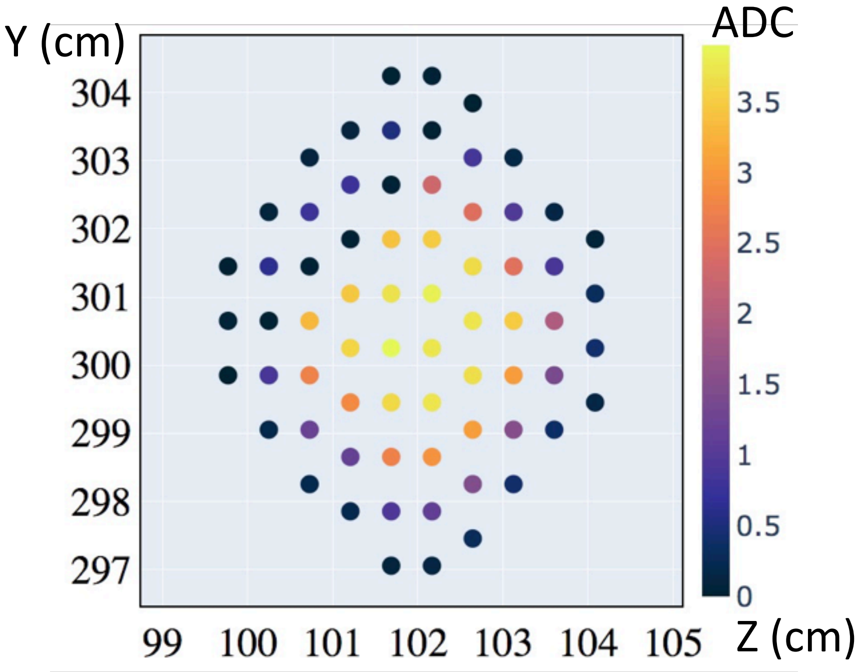
Charge Ratios
X: 1.1
U: 1.0
V: 1.0

Pixelation: 250 e's per 0.03 cm
σ = 2.8e5 e's/(cm^2)



Charge Ratios
X: 1.0
U: 0.8
V: 0.8

Pixelation: 500 e's per 0.03 cm
σ = 5.6e5 e's/(cm^2)



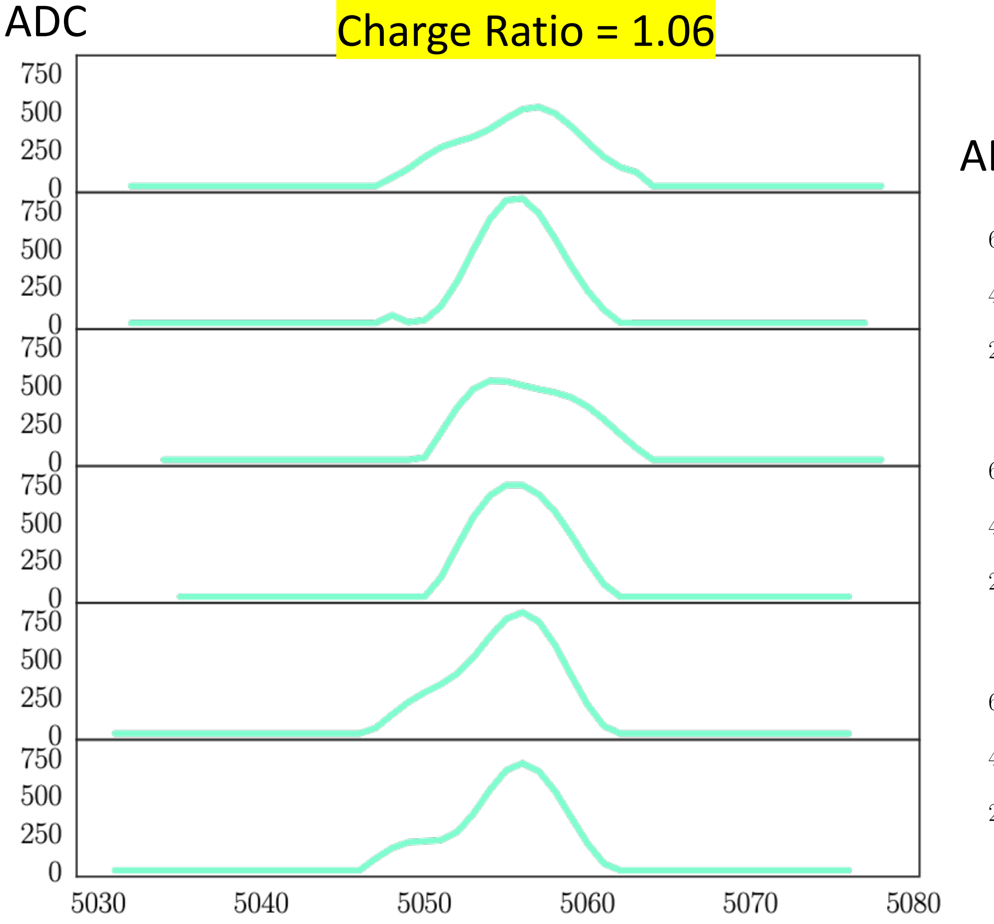
Charge Ratios
X: 0.95
U: 0.85
V: 0.7

Study of low charge signals

Charge density reduced 5 times – vary laser power.
Induction wires start loosing signals first.

Collection Wires

Charge Ratio = 1.06

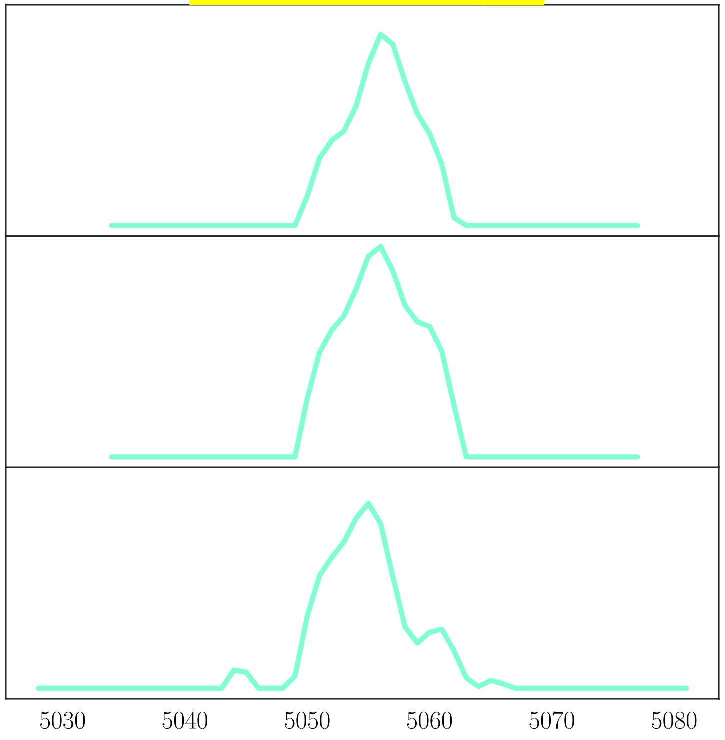


Time ticks

Pixelation: 10 e's per 0.03 cm
σ = 1.1e4 e's/(cm^2)

U Wires

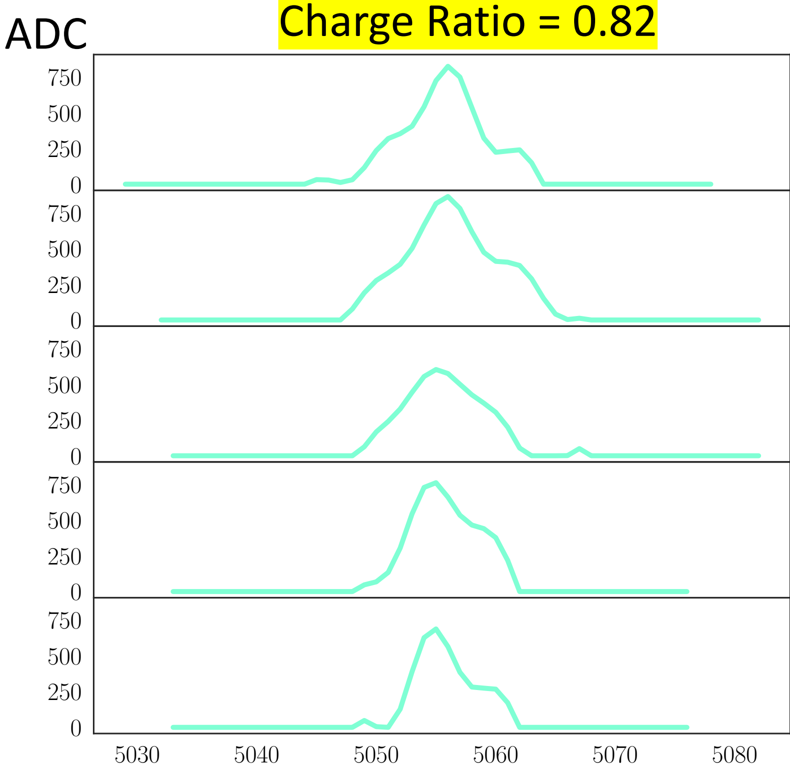
Charge Ratio = 0.5



Time ticks

V Wires

Charge Ratio = 0.82



Time ticks

Measurement of Charge Collection Efficiency

- ❑ **We can measure charge collection efficiency and scale linearity with PE laser, but it is challenging**

i. Laser pulse power will be monitored

ii. Diffusion of the light from the fiber characterized → know UV photon flux impinging on on PE target

iii. PE target quantum efficiency measured in the lab at UH

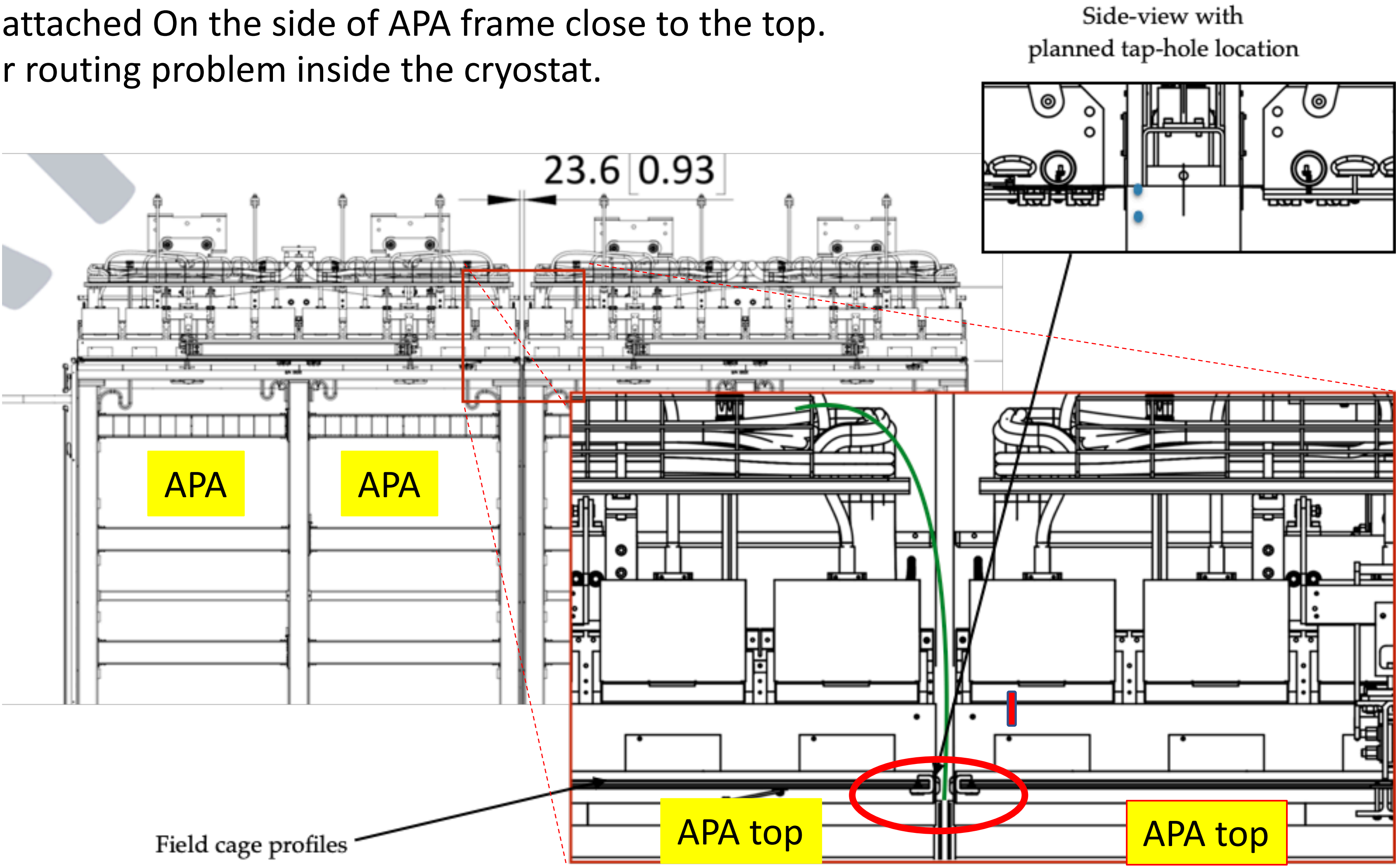
iv. Calculate amount of charge released from a PE target in a single pulse

v. Compare collected and induced charge on APA to measure charge collection efficiency

vi. Repeat the process for varying laser power level, i.e. different charge density to test linearity of the charge collection and charge triggering threshold

PE Laser – light injection location

Fiber holder attached On the side of APA frame close to the top.
Reduces fiber routing problem inside the cryostat.



Photoelectron targets

- Plan to use the same NdYag laser 266 nm with 4.66 eV photons --> no cost associated with buying lasers.
- Photoelectron candidates for targets based on experiences in the past

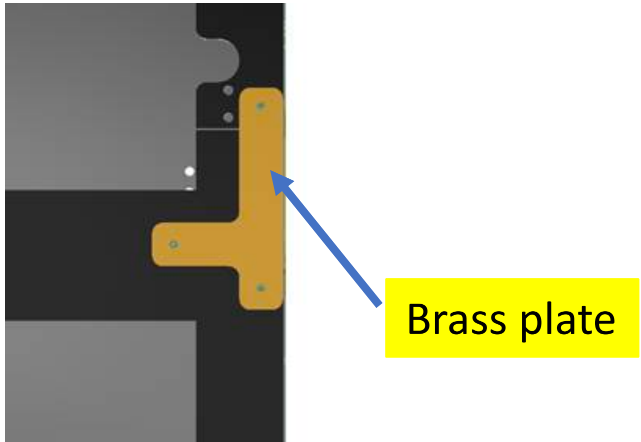
Target material	Work function (eV)	λ_{max} (nm)	Comparison to 266 nm NdYag	Oxidization in air	Type of oxidization
Gold	5.1 – 5.47	243 - 226	<	No	None
Nickel	5.04 – 5.35	246 - 232	<	Yes	Surface layer
Silver	4.26 – 4.74	291 - 262	>	Yes	Surface layer
Zinc (brass)	3.63 – 4.9	343 - 254	>	No	None
Copper (brass)	4.53 – 5.10	275 - 244	>	No	None
Aluminum	4.06 – 4.26	305 - 291	>	Yes	Surface layer

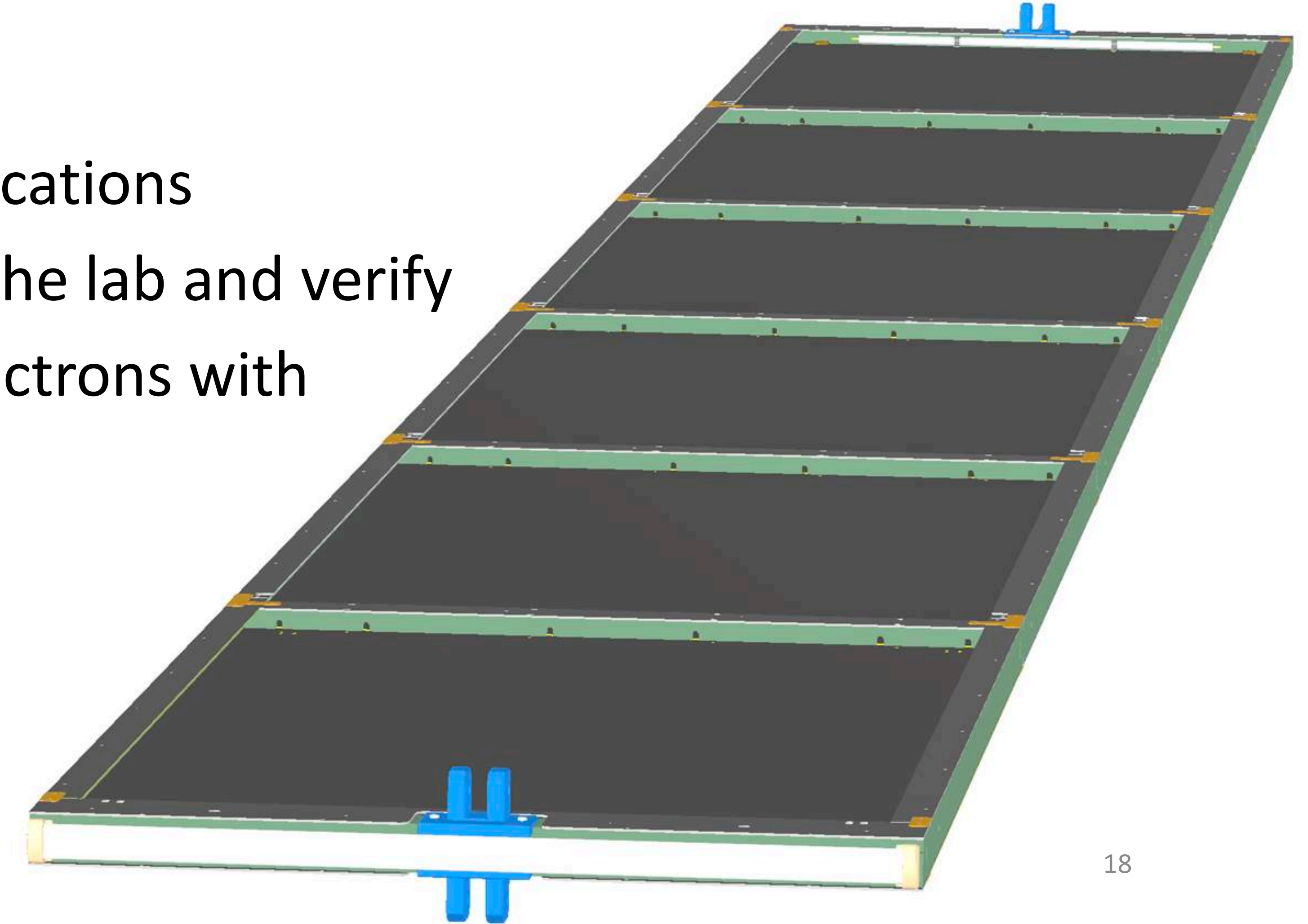
Note: aluminum develops surface layer (70 Angstroms), does not change over time (Al_2O_3 work function 3.9).

Aluminum or brass are the preferred candidate. Al - excellent experience from T2K TPC where photoelectron laser was implemented and successfully utilized.

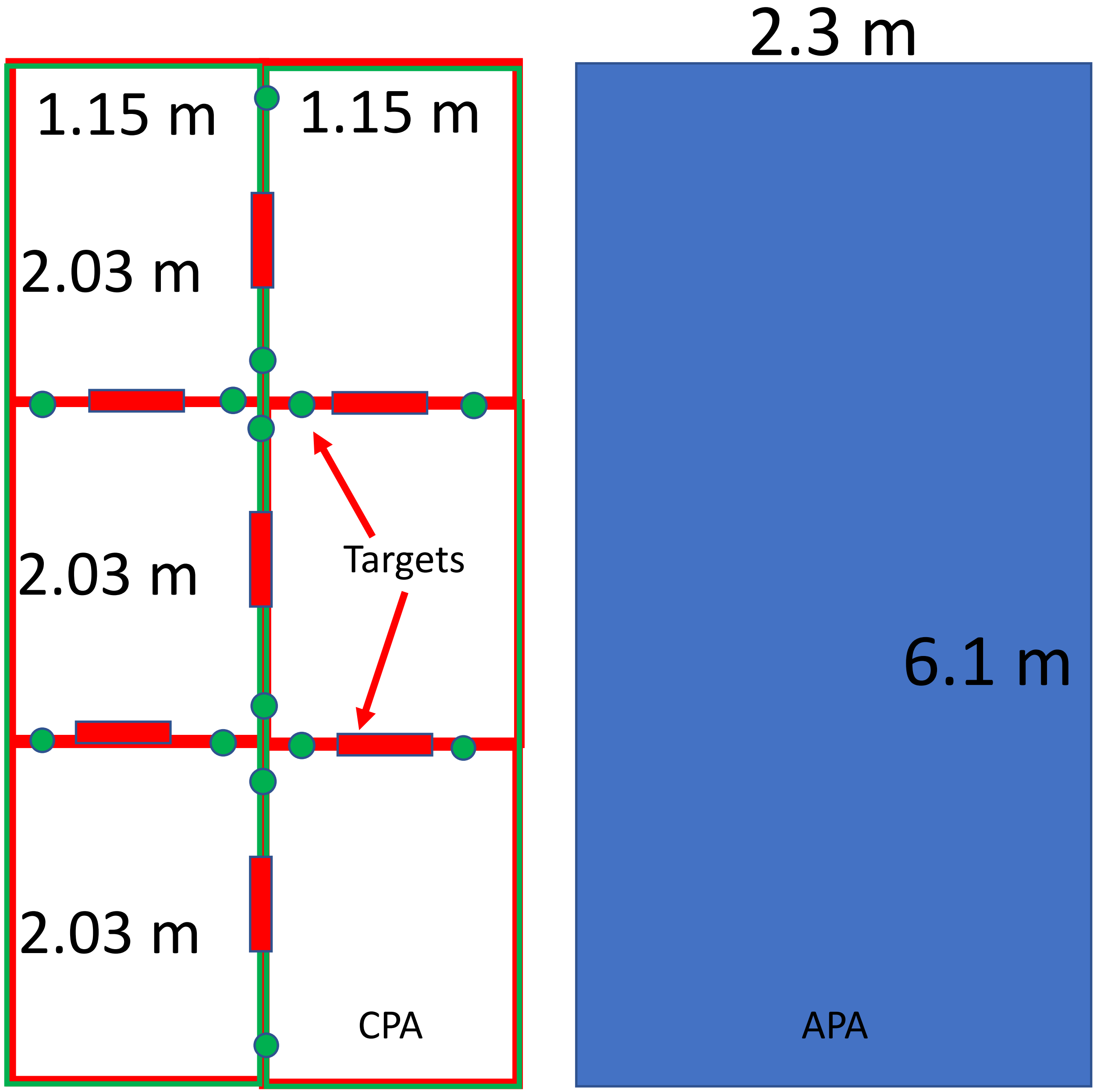
Locations of PE targets on CPA plane – option 1

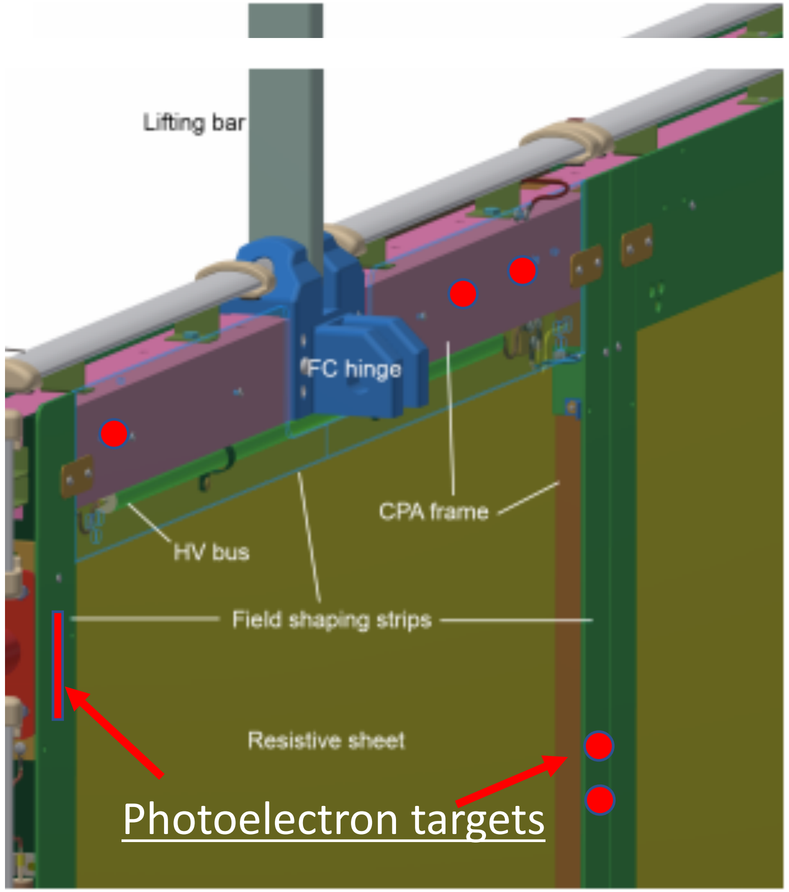
- There are already brass metal plates on the CPA to electrically connect CPA panels.
- They are 2.5 cm x 12.5 cm
- We need to simulate their locations
- We need to test samples in the lab and verify that we can release photoelectrons with 266 nm wavelength





Locations of PE targets on CPA and APA projection – option 2

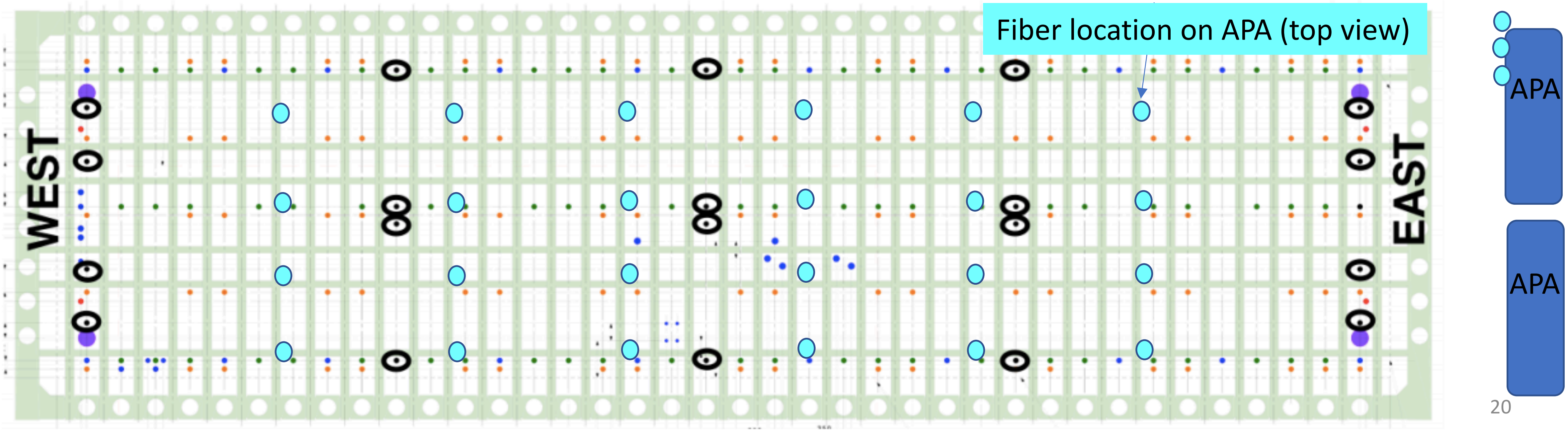




- Aluminum (or silver) targets planned
- Size optimization ongoing (1 cm x 4 cm or 2cm x 8 cm) strips and 1-2 cm targets – driven by wire spacing)
- Combine dots and strips
- Place targets on the CPA frame
- No targets placed across APA outer frame
- Place target approximately every 35 cm

Locations

- Utilize existing IO lasers for illumination of PE targets that are closer to the center (baseline).
- Two fiber bundles (six fibers) per laser . Along central axis – 4 bundles (12 fibers) per laser.
- 18 laser fibers along top aimed at 3 different heights in each volume.
- The total number of fibers is 18 x 4 = 72 (5 m illumination diameter anticipated).
- Fiber routing plan – tentatively plan to route the fibers on top of APA and then to CE flanges via CE cable trays.
- Assume average 20 m long optical fibers.
- Excellent TPC resolution allows for illumination of large number of targets in parallel.



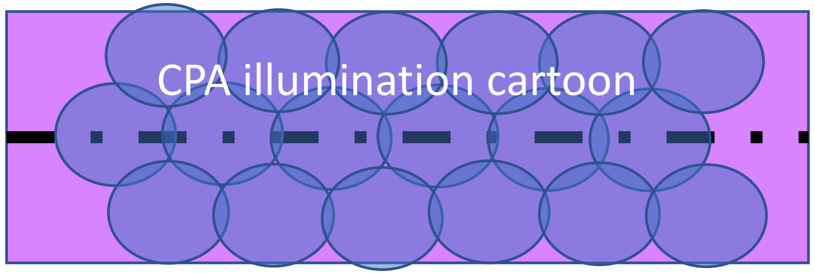
Review Charge questions

1. Does the system have a well-justified role in safeguarding the far detectors and facilitating their operation, and if so, what is the minimum amount of system scope needed to carry out this role? (Cryogenic Instrumentation only)

- Photoelectron laser can provide diagnostics efficiently **(if fibers are used in parallel**) of the detector condition including:
  - Trigger threshold
  - E-field distortions
  - Drift velocity
  - Cluster reconstruction
- This would be done comparing the collected charge from CPA wires with the expected template if detector performs as expected with <u>basic signal waveform processing.</u>
- Routine daily or weekly runs – 3000 pulses in 5 minutes would suffice, if used in parallel.
- Minimal scope would include 18 fibers in each of the four detector volumes.

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?

- Timely diagnostic survey of the detector performance by comparing calibration run with the template of good detector performance – drift velocity, SPE in the detector, cluster position reconstruction precision, charge collection efficiency
- Unique input to CPA planarity survey
- *Minimum configuration assumes reusing existing brass fixtures present on CPAs as PE targets that would provide full detector coverage equal to dimensions of the CPA frame.*

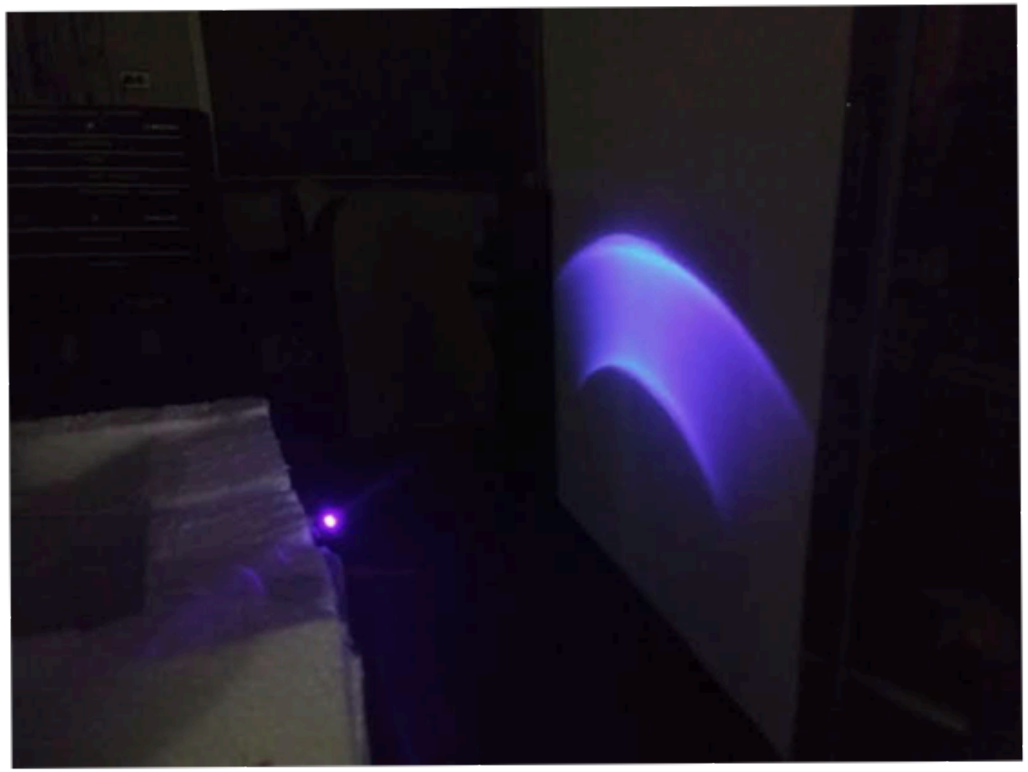


Have all technical issues related to the feasibility of the system (including those raised in the previous workshops) been resolved?

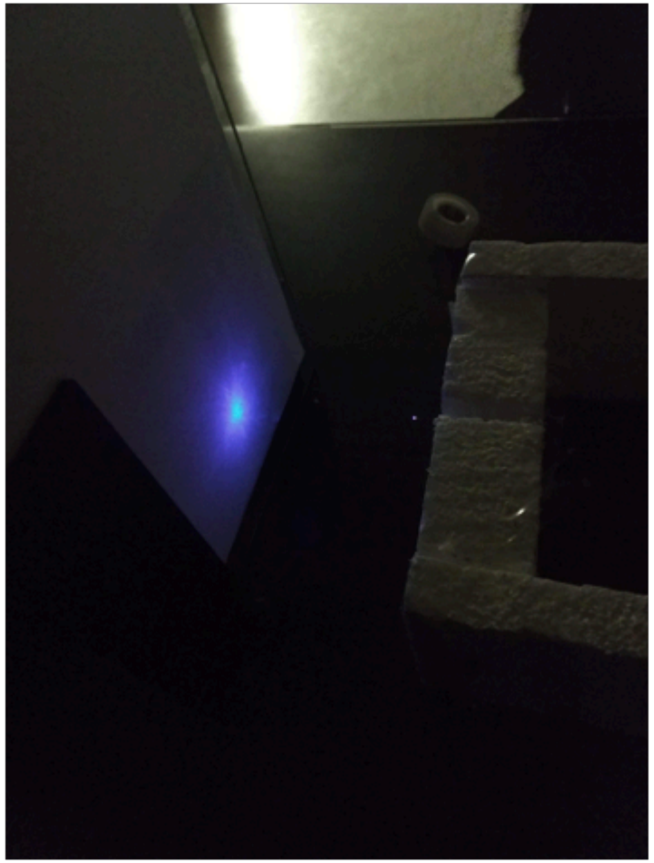
- This system requires high power NdYag laser → available
- Coupling efficiency of beam injection into fibers → needs test; high efficiency coupler under evaluation
- Coupling to the fibers and interface with ionization laser – feasible, but needs engineering
- Fiber attachment points on the APA planes identified
- Fiber holder being designed – prototype will be 3D printed at UH
- Angled diffusion from the fiber tips observed, but not fully characterized.
- Fiber routing and port allocation not finalized –feasible
- Measurement of photoelectric targets and Kapton quantum efficiency in liquid argon requires measurement – lab tests ongoing
- Choice of conductive cryogenic glue for attaching targets to CPA required

→All are feasible, but some items need to be directly demonstrated.

Fibers with diffusing end



Side fire

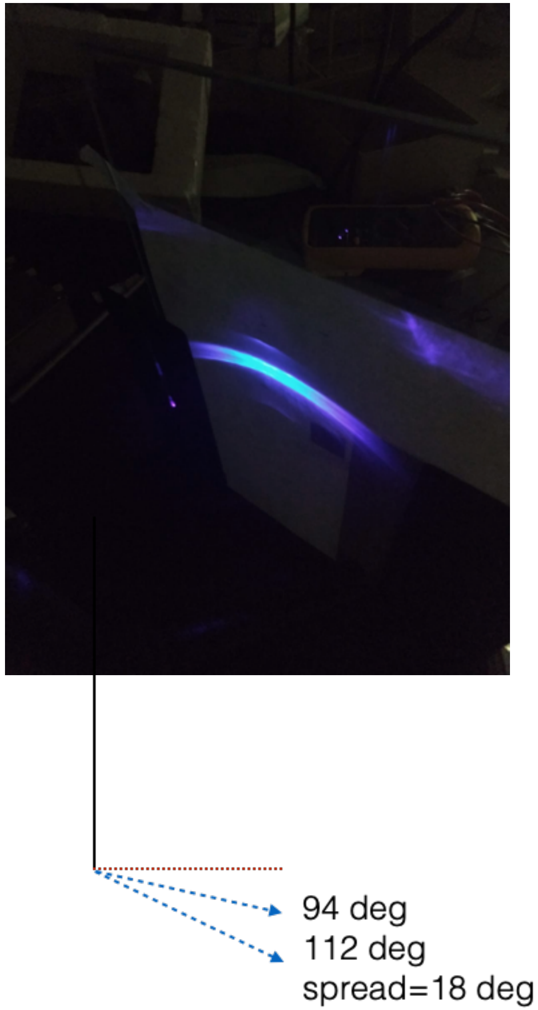


Regular fiber

Polymicro company can produce quartz fibers that let the light on the side with predetermined opening angle, rather than straight, which allows illumination of the parts of the detector.
In the lab, we have been running tests to verify opening angles of the diffused light coming out of the fiber.
This measurement determines illumination area on the CPA – being optimized.

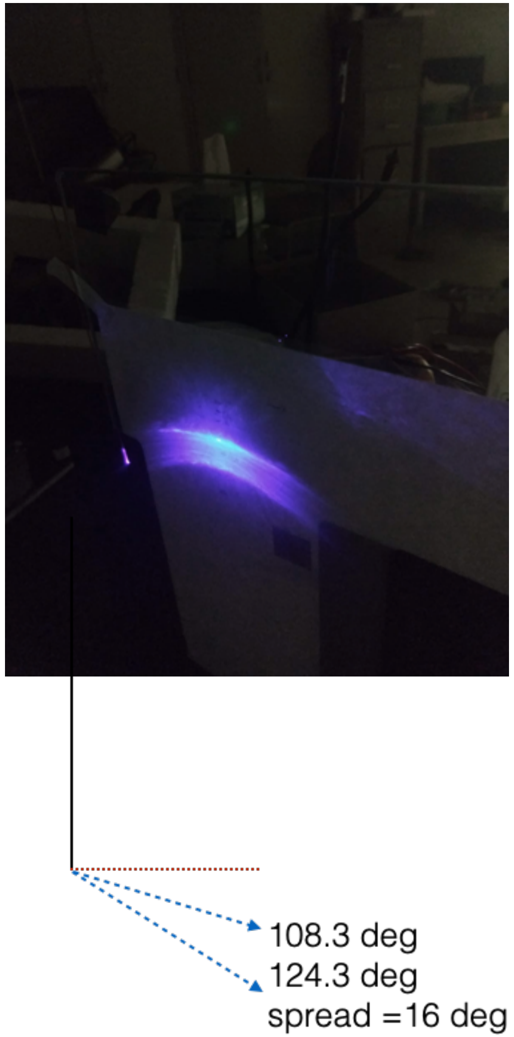
Angled fiber tests

Sidefire 100 deg



Opening angle from spec. =22 deg

Sidefire 110 deg



Opening angle from spec. =22 deg

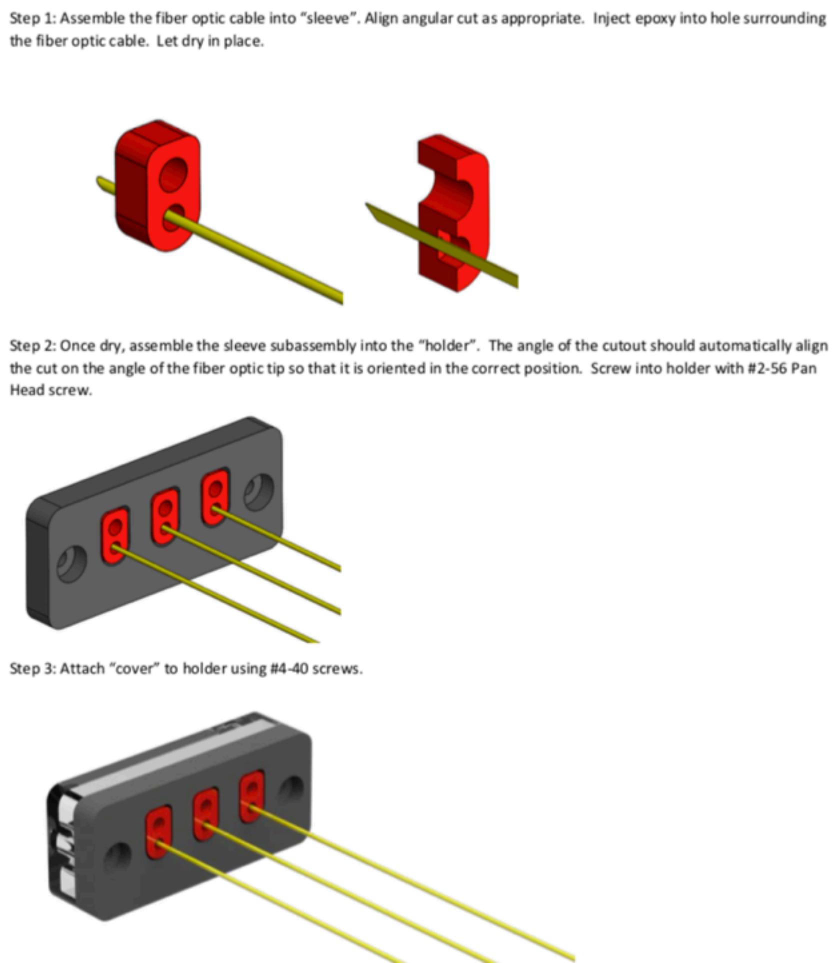
Sidefire 120 deg

Opening angle from spec. =22 deg

Will talk to Polimicro
To understand the source
of variation

Fiber holder

- Fibers with exact orientation have to be attached to APA frame on the side



Step 1: Assemble the fiber optic cable into “sleeve”. Align angular cut as appropriate. Inject epoxy into hole surrounding the fiber optic cable. Let dry in place.

Step 2: Once dry, assemble the sleeve subassembly into the “holder”. The angle of the cutout should automatically align the cut on the angle of the fiber optic tip so that it is oriented in the correct position. Screw into holder with #2-56 Pan Head screw.

Step 3: Attach “cover” to holder using #4-40 screws.

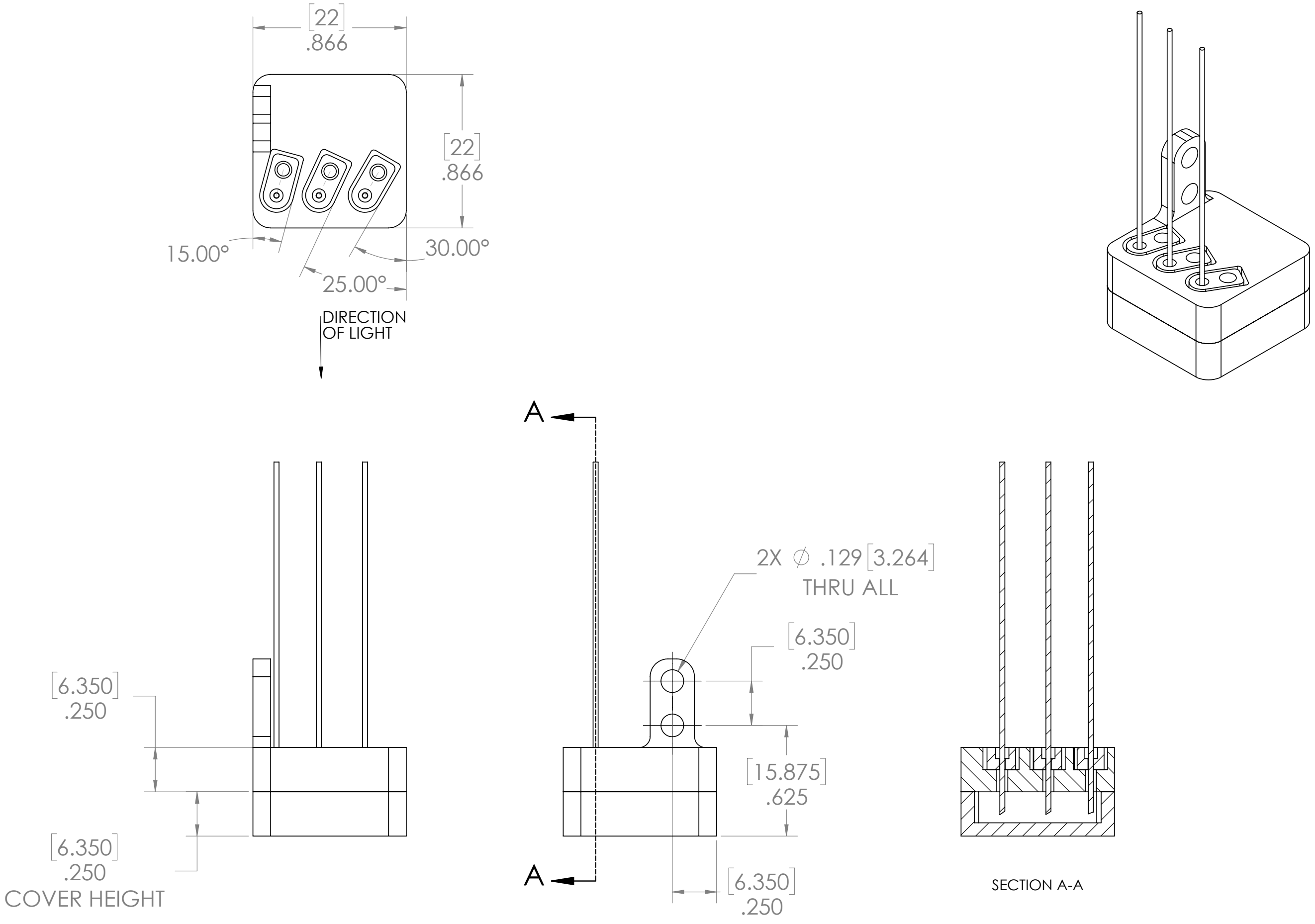


Photo-Electron Laser System:The photocathode targets

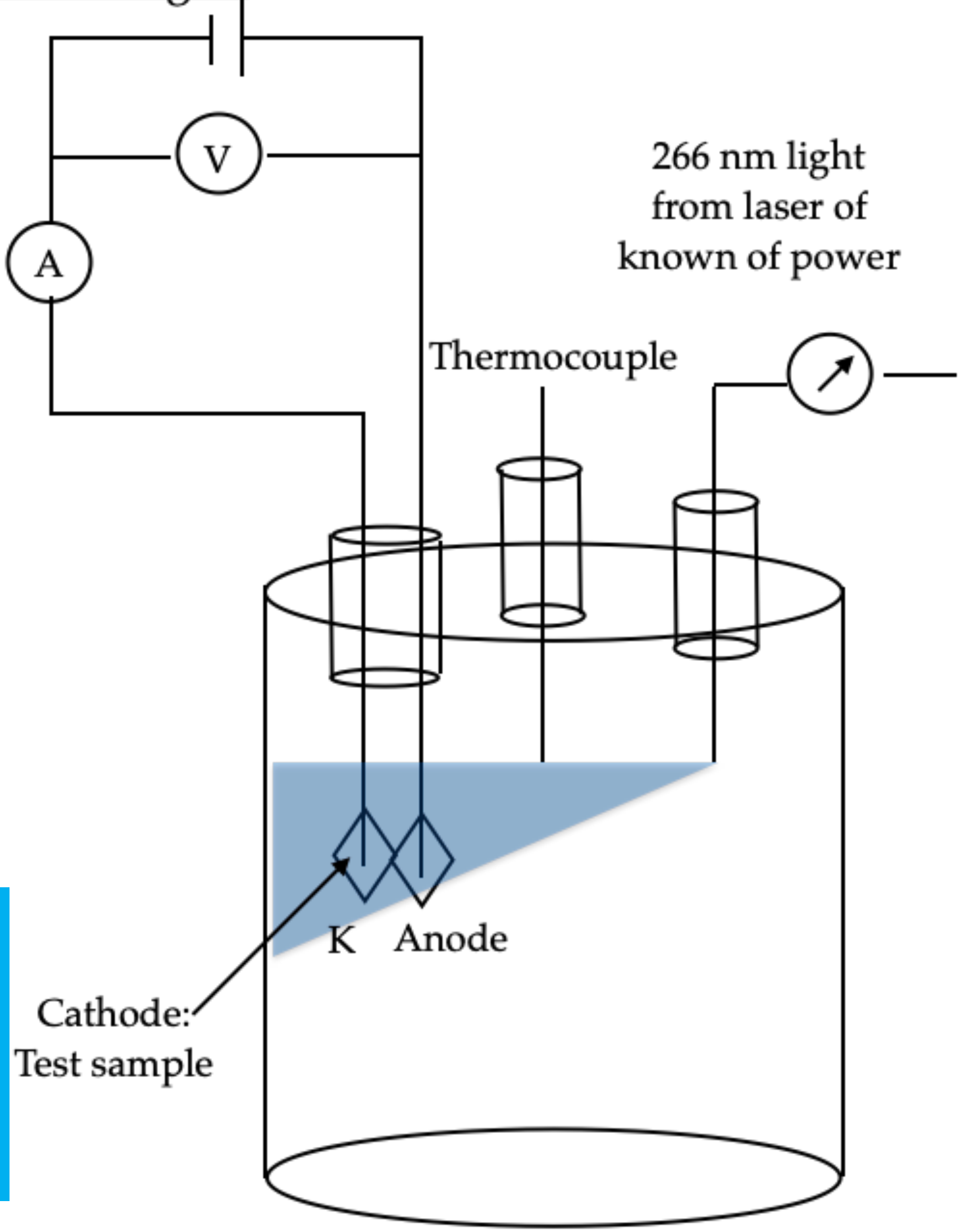
Work function of materials known, but need to investigate surface effects.

- How many photo-electrons emitted (per area^2) per laser pulse?
- Surface oxidation layer effects

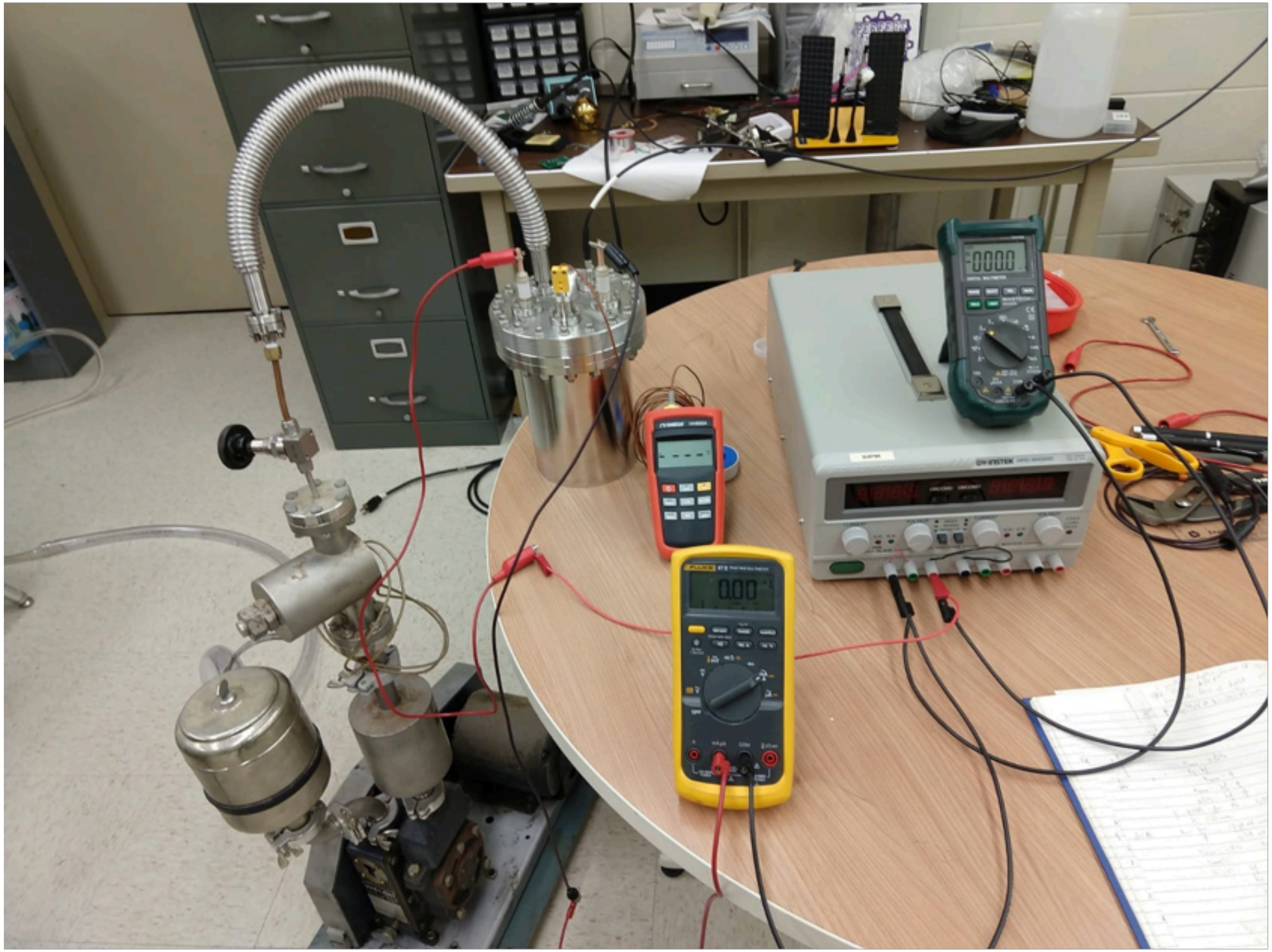
- A small (~10 in) vacuum vessel with electrodes, thermometer and fiber.
- Calculations show we need ~10^-5 K Pa vacuum.
- Vessel to be dunked in LN2 for cold test.

Test aluminum and silver as the first choice.

Test the couplers between the laser output And optical fiber.



Test work function/QE of Photocathodes



X

UH Lab tests status

- Vacuum chamber to measure quantum efficiency of different target photoelectric materials has been built and is currently being commissioned. The setup will allow testing in liquid nitrogen and will include testing Kapton for potential background noise.
- Five fibers with side cut have arrived from Polymicro.Their opening angles and tolerance still need to be verified.
- Holder for the fibers is being fabricated at UH Manoa Innovation center and will be 3D printed for the first prototype. Preliminary design under review.

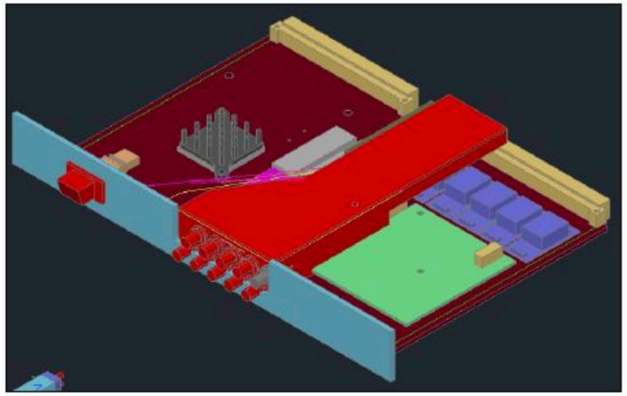
- *Tests have been slowed down by the COVID-19 pandemic.*

University of Iowa → coupling to IO laser

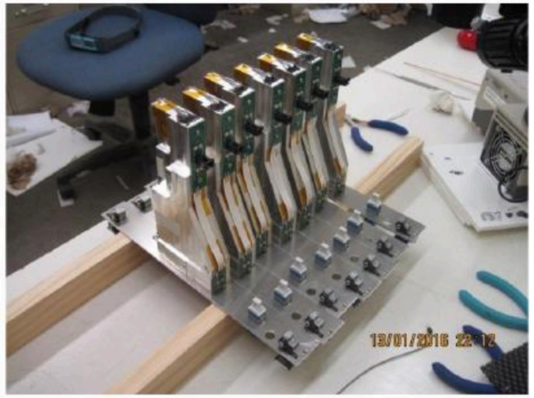
- University of Iowa group will be in charge of coupling fibers to IO laser output
- Monitoring the signal injected in the fiber
- Fiber splitter

- Previous experience with CMS HCAL calibration system – included laser, LED pulser, calibration module and optical mixer

Calibration Unit



Calibration Unit



Light Mixer / Fiber Housing

New fiber housing design

- Expand housing to enclose fibers
    - Minimum stress on fibers
    - Easier to produce fiber bundle assembly.
    - Easier to light tight
    - More robust
- Better fiber PIN diode integration.

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?

- During use, there will be laser operation associated electronic noise that should be mitigated by proper grounding.
- There is no direct illumination of PDS
- Kapton also exhibits photoelectric effect with 2 orders of magnitude lower quantum efficiency – simulations indicate that it is not an issue and Kapton signal is practically negligible. Even at high intensity illumination, it can easily be distinguished from the phototarget signal by simple ADC cut as can be seen in the simulation studies.

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

- Plan includes routing 3 fibers from the laser location to the top of the APA, placed in the holder that is attached to the APA frame.
- Either use brass strips or dedicated 21 targets (14 dots and 7 strips on one CPA) attached to CPA inner rims
- Requires:
  - Dedicated locations on the CPA planes to glue the targets (should be OK)
  - Attachment holes for fiber holders to APA planes – is part of the design
  - Routing of fibers – share CE cable trays
  - Allocating (sharing) exit port for the fibers – discussed sharing of CE flange or using dedicated port
  - Coupling to the laser system – University of Iowa

Does the functionality of the system justify its overall cost?

- The cost of the system is modest – less than $50k per SP DUNE module. Will be further optimized (*laser-fiber interface & power monitoring system not included – University of Iowa

Item	Cost ($)
Optical fibers (72)	21,000
Target production, diffusers, connectors	15,000
Multiplexers(3)	9,000 (if needed)
Contingency (10%)	5,000
Total	**50,000 (with multiplexers)**

- **Cost of the system in ProtoDUNE-II $5k that relates to fibers and targets and a simple coupling system.**

Review Charge – Part II

- Is the system essential or highly desirable or not essential?
- *The system is considered essential.*

✓ PE laser is a simple, low cost system that complements the IO laser well.

✓ PE laser will address CPA planarity in unique way.

✓ PE laser is uniquely suited to provide simple, efficient calibration throughout the volume, since the rate of cosmic rays is low underground.

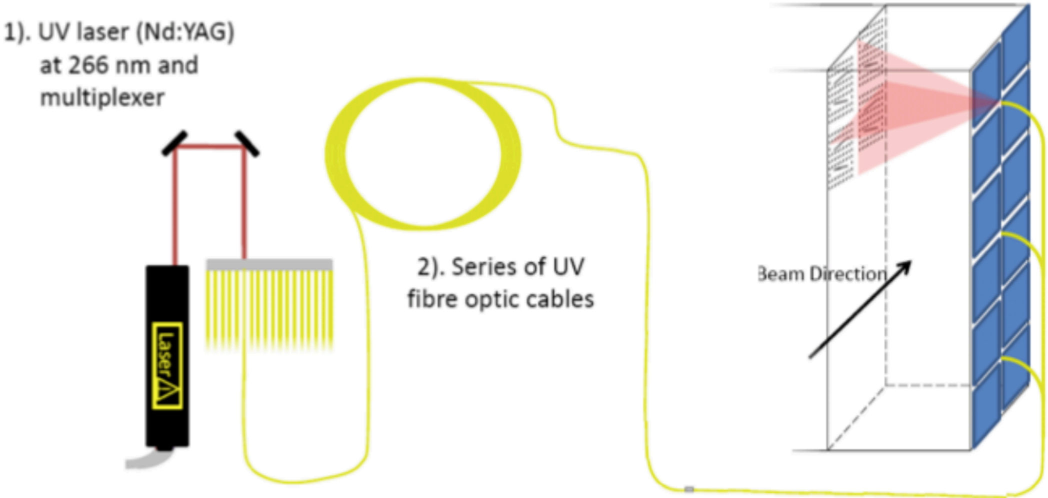
✓ Exact knowledge of the timing and position of the generated electron clouds provides uniquely defined input to vertex reconstruction.

✓ PE laser is an effective diagnostic and calibration tool, that can quickly and accurately sample the electron drift velocity in the entire detector

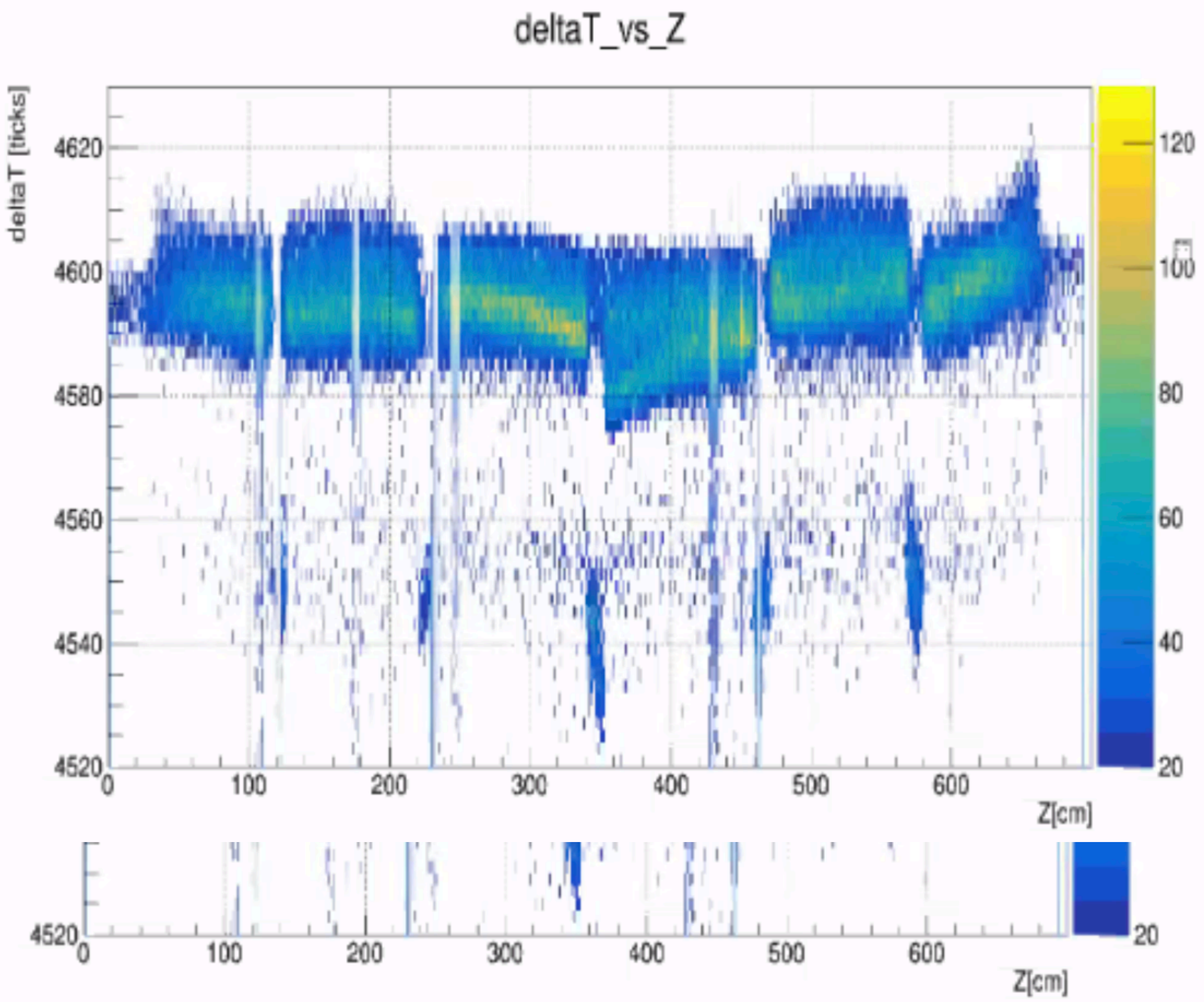
✓PE laser will identify electric field distortions due to space charge effects near CPA.

Photoelectron Laser (PhEL) Benefits

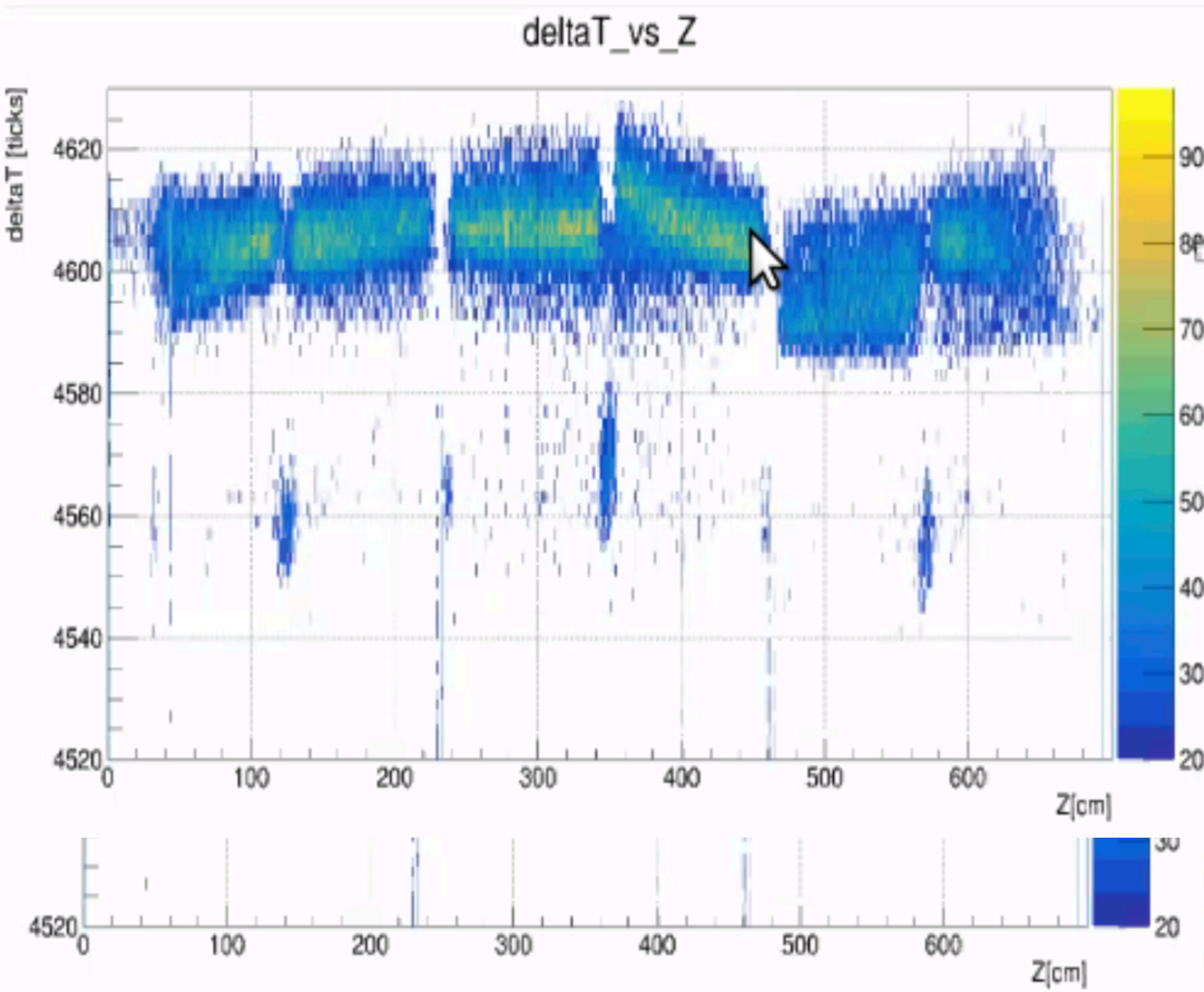
- Cost-effective system – main cost are optical fibers used to deliver UV light to TPC and illuminate targets (below ~$50k for the system per SP FD module).
- PhEL generates well localized electron clouds on the CPA at predetermined locations released after every laser trigger. Clouds can vary in charge density.
- Thus, ***PE Laser provides electron sources of <u>varying charge density</u> with well know position and time of release*****.**
- Generated electron clouds drift in the TPC electric field until they are collected on the APA.



Beam left (X>0)



Beam right (X<0)



Small clusters below the gaps corresponds to lower drift distance owing to CPA frames.

Considering nominal drift velocity, a shift of 10ticks corresponds to around 8mm in length.

Weighted Crossings

Channel Lists (3 Planes)

$$C = \{\{c_1\}, \{c_2\}, \{c_3\}\}$$

Single collection channel of ADCs:

$$X_c = \{x_1, .\,., x_i\}$$

Same channel, weighted by all collection channels

$$W_{x_c} = \frac{\sum_i \; x_c}{\sum_{i,c} \; x_c}$$

Doublet Weights (X x U)

$$W_{xu}(c1,c2) = \frac{W_{x_{c_1}} \times W_{u_{c_2}}}{\sum_{c_1,c_2} W_{x_{c_1}} \times W_{u_{c_2}}}$$

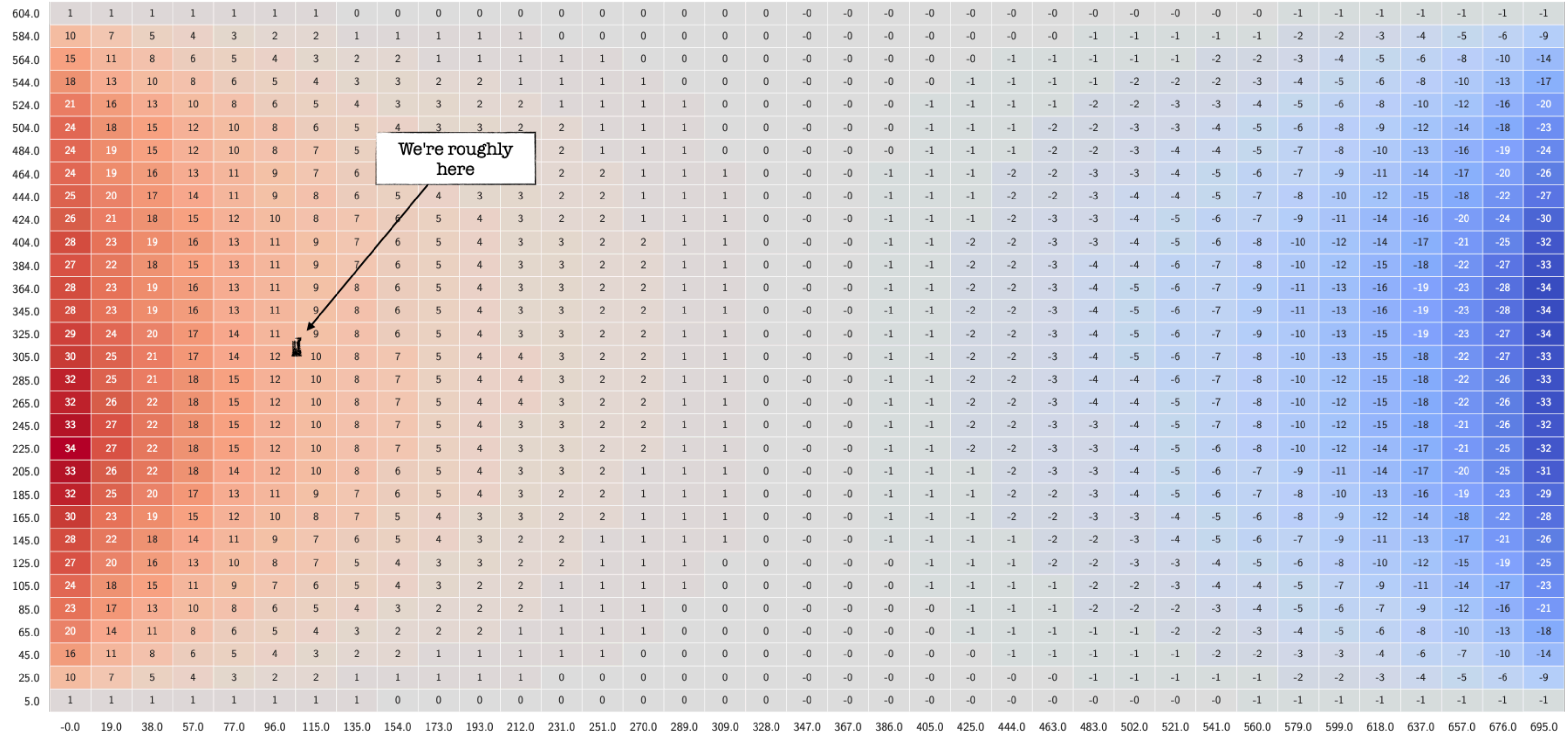
X x V is analogous

Triplet Weights

$$W_{xuv}(c1,c2,c3) = \frac{W_{x_{c_1}} \times W_{u_{c_2}} \times W_{v_{c_3}}}{\sum_{c_1,c_2,c_3} W_{x_{c_1}} \times W_{u_{c_2}} \times W_{v_{c_3}}}$$

More on Triplets on the following slide

Sanity Check: Z Distortions at the CPA



We're roughly here

	-0.0	19.0	38.0	57.0	77.0	96.0	115.0	135.0	154.0	173.0	193.0	212.0	231.0	251.0	270.0	289.0	309.0	328.0	347.0	367.0	386.0	405.0	425.0	444.0	463.0	483.0	502.0	521.0	541.0	560.0	579.0	599.0	618.0	637.0	657.0	676.0	695.0
604.0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-1	-1	-1	-1	-1	-1	-1
584.0	10	7	5	4	3	2	2	1	1	1	1	1	0	0	0	0	0	0	-0	-0	-0	-0	-0	-0	-0	-1	-1	-1	-1	-1	-2	-2	-3	-4	-5	-6	-9
564.0	15	11	8	6	5	4	3	2	2	1	1	1	1	1	0	0	0	0	-0	-0	-0	-0	-0	-1	-1	-1	-1	-1	-2	-2	-3	-4	-5	-6	-8	-10	-14
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484.0	24	19	15	12	10	8	7	5	[illegible]	[illegible]	[illegible]	[illegible]	2	1	1	1	0	0	-0	-0	-0	-1	-1	-1	-2	-2	-3	-4	-4	-5	-7	-8	-10	-13	-16	-19	-24
464.0	24	19	16	13	11	9	7	6	[illegible]	[illegible]	[illegible]	[illegible]	2	2	1	1	1	0	-0	-0	-1	-1	-1	-2	-2	-3	-3	-4	-5	-6	-7	-9	-11	-14	-17	-20	-26
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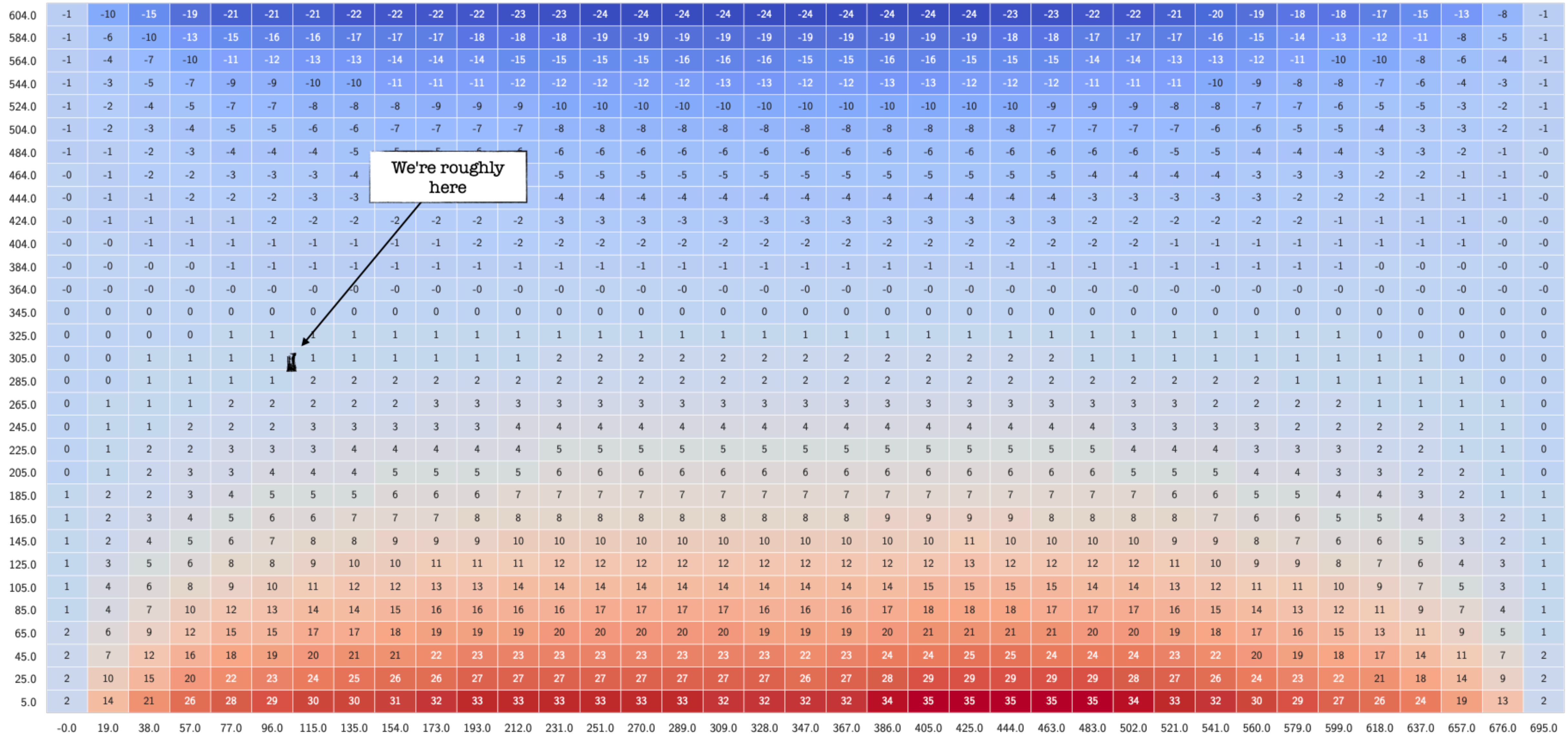
5.0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-1	-1	-1	-1	-1	-1	-1	-1

X

Y and X Distortions on following slides

Sanity Check: Y Distortions at the CPA



We're roughly here

	-0.0	19.0	38.0	57.0	77.0	96.0	115.0	135.0	154.0	173.0	193.0	212.0	231.0	251.0	270.0	289.0	309.0	328.0	347.0	367.0	386.0	405.0	425.0	444.0	463.0	483.0	502.0	521.0	541.0	560.0	579.0	599.0	618.0	637.0	657.0	676.0	695.0
604.0	-1	-10	-15	-19	-21	-21	-21	-22	-22	-22	-22	-23	-23	-24	-24	-24	-24	-24	-24	-24	-24	-24	-24	-23	-23	-22	-22	-21	-20	-19	-18	-18	-17	-15	-13	-8	-1
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564.0	-1	-4	-7	-10	-11	-12	-13	-13	-14	-14	-14	-15	-15	-15	-15	-16	-16	-16	-15	-15	-16	-16	-15	-15	-15	-14	-14	-13	-13	-12	-11	-10	-10	-8	-6	-4	-1
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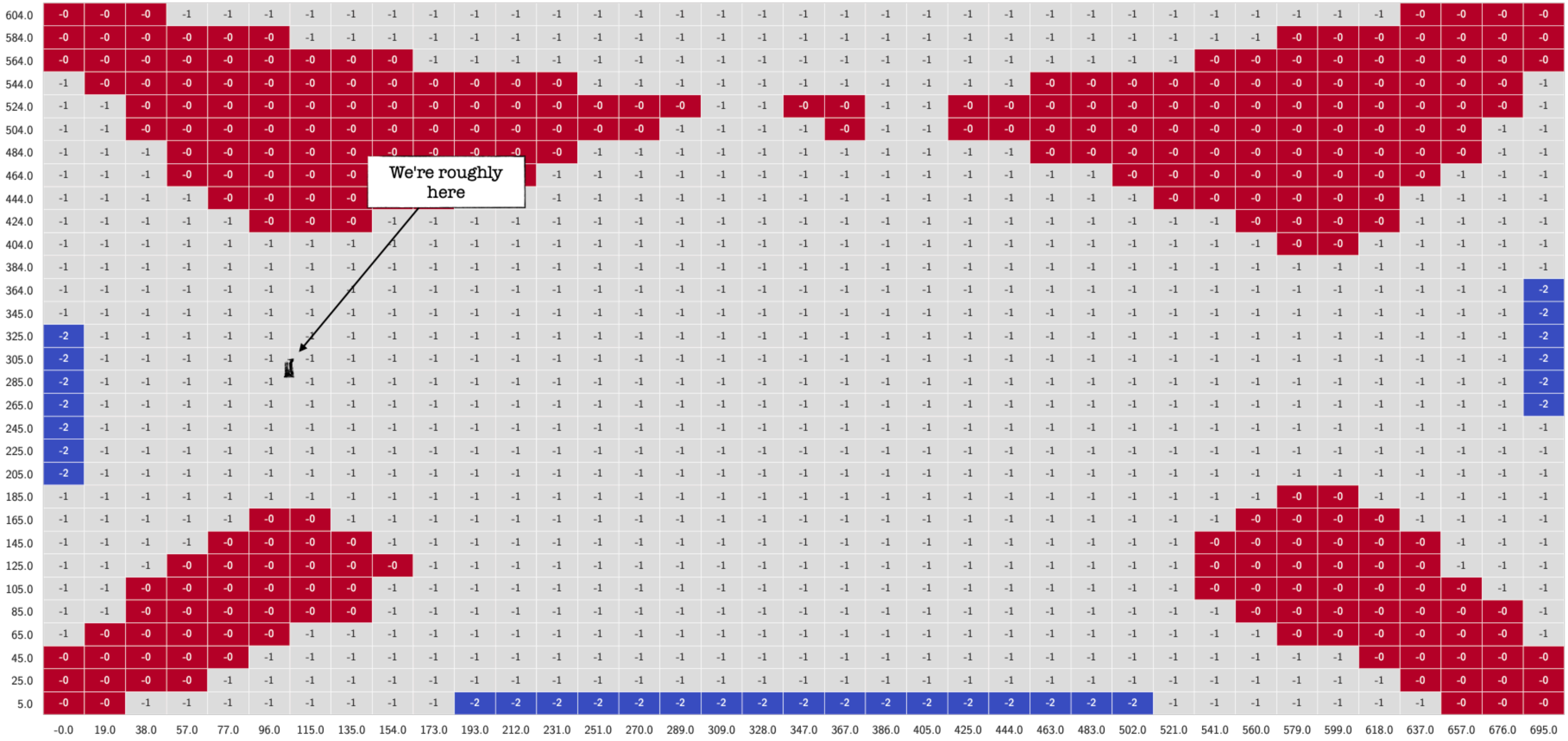
Sanity Check: X Distortions at the CPA



	-0.0	19.0	38.0	57.0	77.0	96.0	115.0	135.0	154.0	173.0	193.0	212.0	231.0	251.0	270.0	289.0	309.0	328.0	347.0	367.0	386.0	405.0	425.0	444.0	463.0	483.0	502.0	521.0	541.0	560.0	579.0	599.0	618.0	637.0	657.0	676.0	695.0
604.0	-0	-0	-0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-0	-0	-0	-0
584.0	-0	-0	-0	-0	-0	-0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-0	-0	-0	-0	-0	-0	-0
564.0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-0	-0	-0	-0	-0	-0	-0	-0	-0
544.0	-1	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-1
524.0	-1	-1	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-1	-1	-0	-0	-1	-1	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-1
504.0	-1	-1	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-1	-1	-1	-1	-0	-1	-1	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-1	-1
484.0	-1	-1	-1	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-1	-1
464.0	-1	-1	-1	-0	-0	-0	-0	-0	[illegible]	[illegible]	[illegible]	[illegible]	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-0	-0	-0	-0	-0	-0	-0	-0	-1	-1	-1
444.0	-1	-1	-1	-1	-0	-0	-0	-0	[illegible]	[illegible]	[illegible]	[illegible]	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-0	-0	-0	-0	-0	-0	-1	-1	-1	-1
424.0	-1	-1	-1	-1	-1	-0	-0	-0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-0	-0	-0	-0	-1	-1	-1	-1
404.0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-0	-0	-1	-1	-1	-1	-1
384.0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
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345.0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-2
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165.0	-1	-1	-1	-1	-1	-0	-0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-0	-0	-0	-0	-1	-1	-1	-1
145.0	-1	-1	-1	-1	-0	-0	-0	-0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-0	-0	-0	-0	-0	-0	-1	-1	-1
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105.0	-1	-1	-0	-0	-0	-0	-0	-0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-0	-0	-0	-0	-0	-0	-0	-1	-1
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5.0	-0	-0	-1	-1	-1	-1	-1	-1	-1	-1	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-1	-1	-1	-1	-1	-1	-1	-0	-0	-0

We're roughly here

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