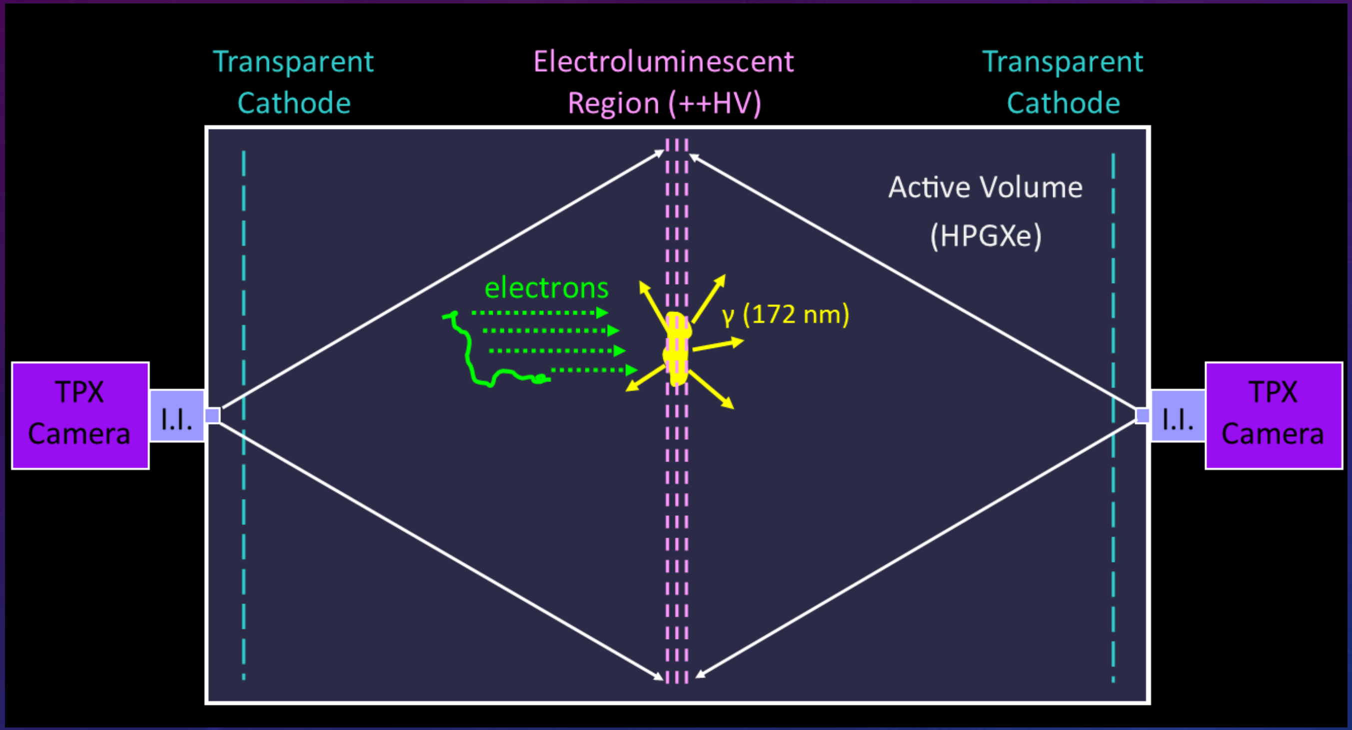
CAMERA READOUT IN GASEOUS XENON TPCS

LESLIE ROGERS
ARGONNE NATIONAL LABORATORY

COREY ADAMS, JONATHON ASAADI, JACKIE BAEZA-RUBIO, KEVIN BAILEY, NICK BYRNES, ERIC CHURCH, DIEGO GONZALEZ-DIAZ, ALEX HIGLEY, BEN JONES, KRISHAN MISTRY, IVANA MOYA, DAVID NYGREN, PHILIP OYEDELE, ILKER PARMAKSIZ, KARA STOGSDILL

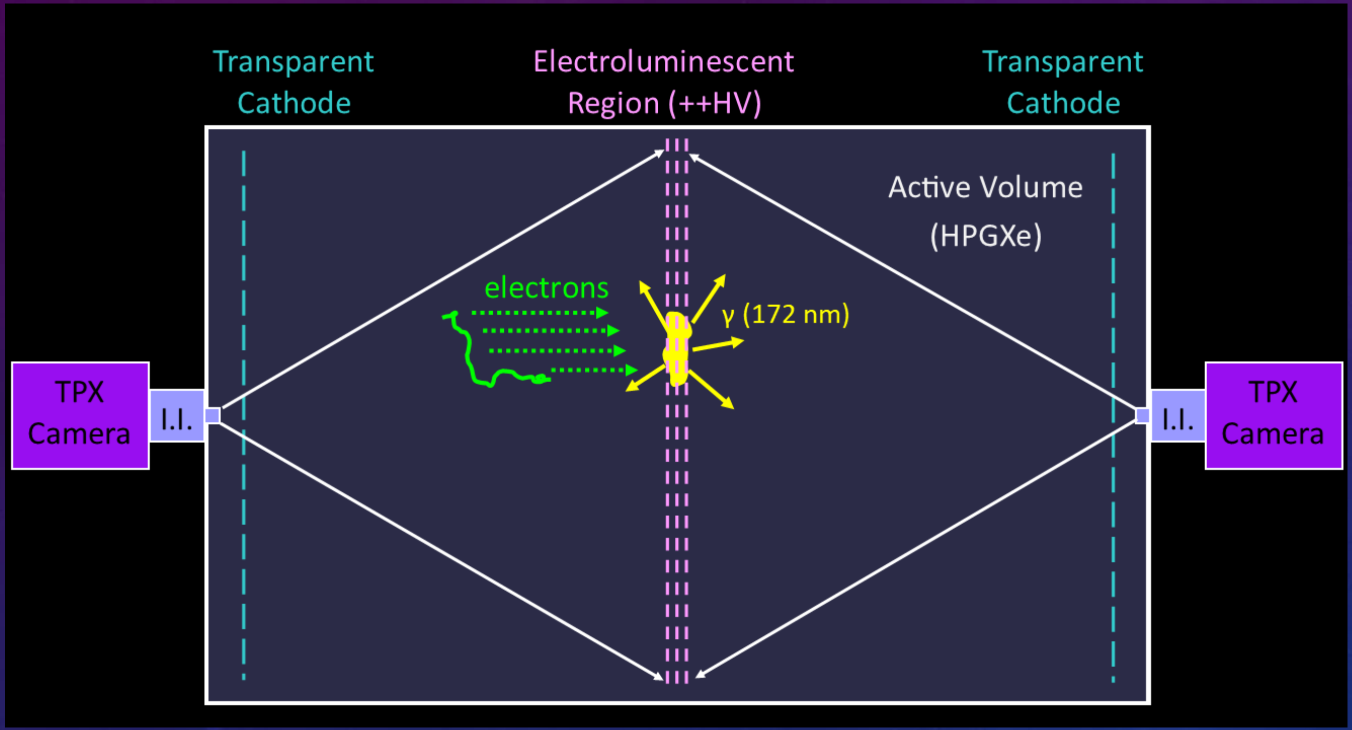
Camera Readout And Barium tagging

Motivation for using a Camera Readout in Place of a dense SiPM tracking plane for tonne scale



- Entire readout system can be outside the vessel, improving radiopurity and heat
- Simplifies electronics significantly
- Cheaper, 130k per camera system vs >1 million in SiPMs
- Each camera gives us 65k pixels
- Can focus from a distance rather than up close

Motivation for using a Camera Readout in Place of a dense SiPM tracking plane for tonne scale



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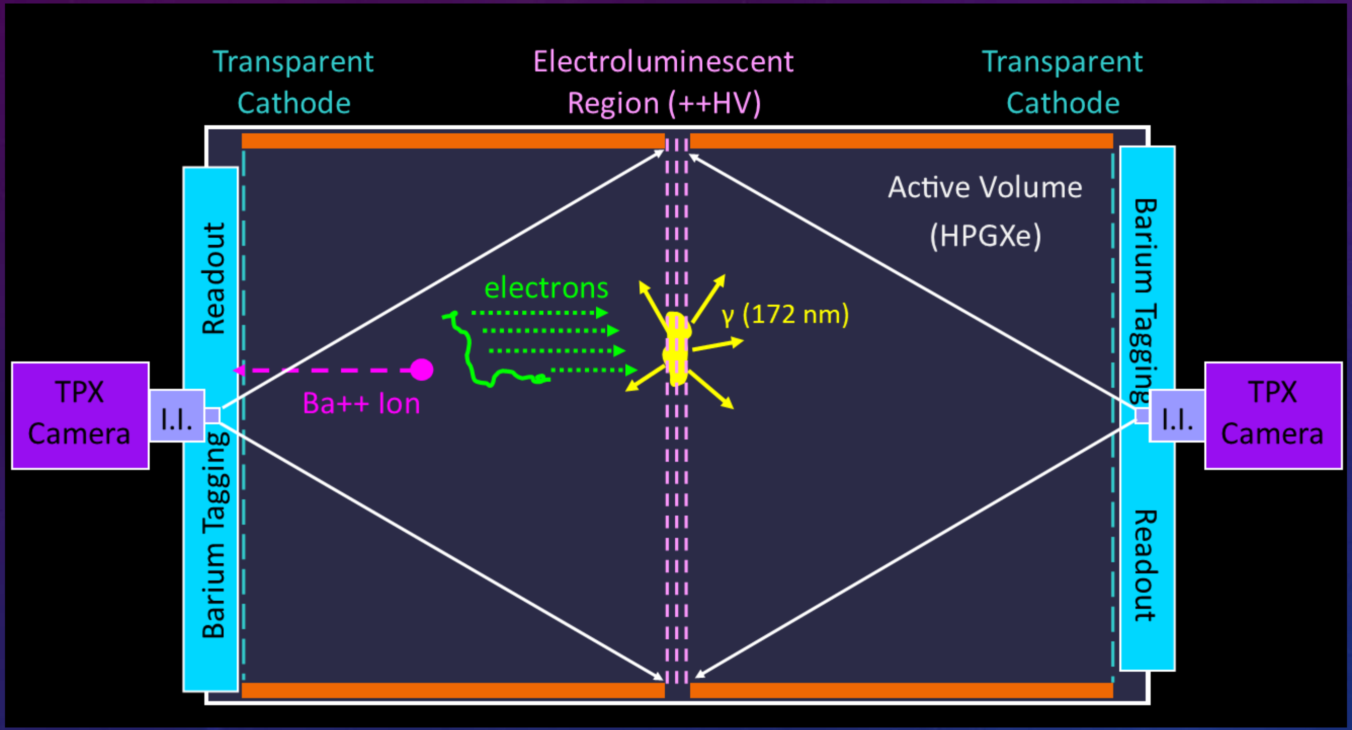
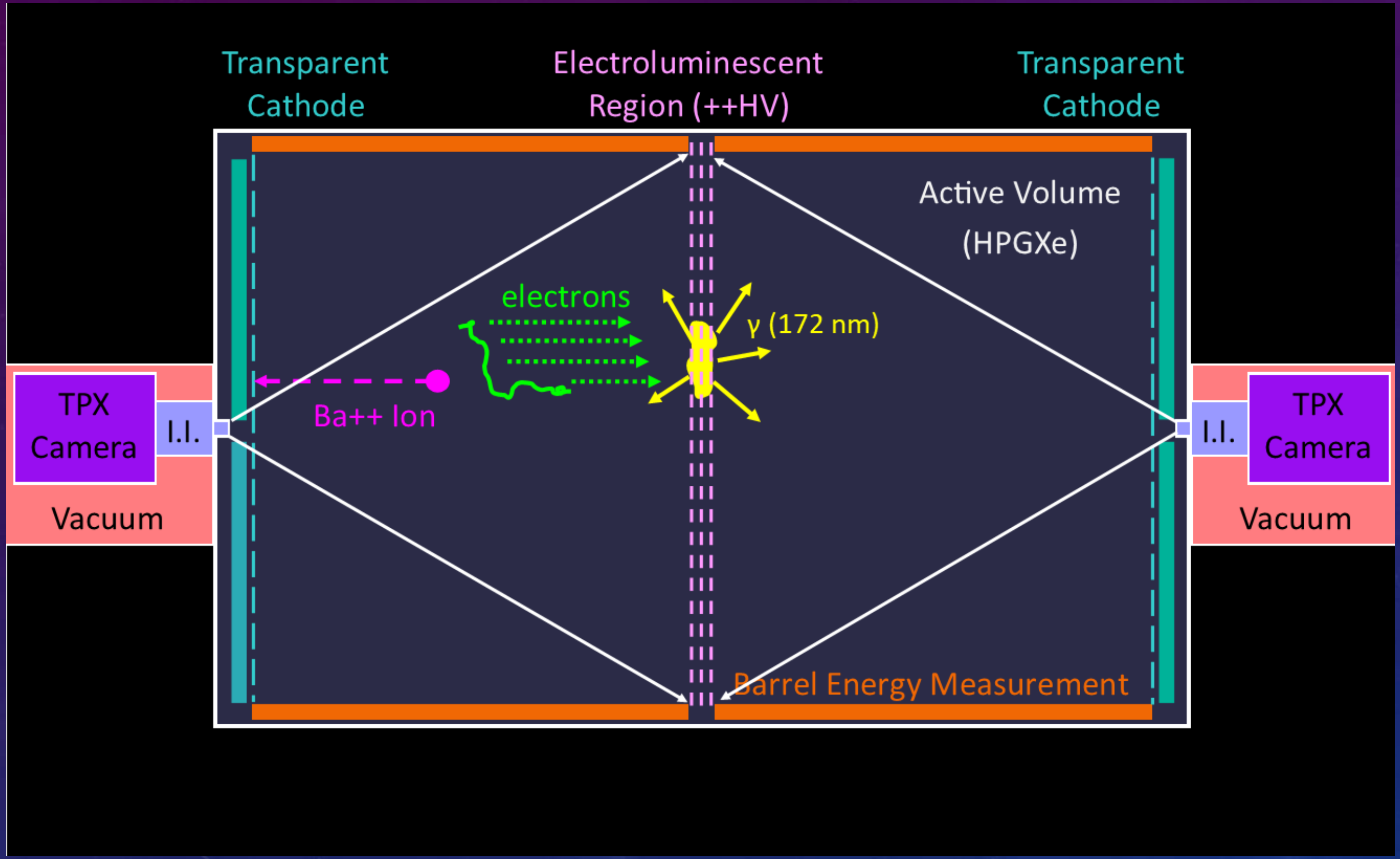
Opens up the Possibility of Barium Tagging



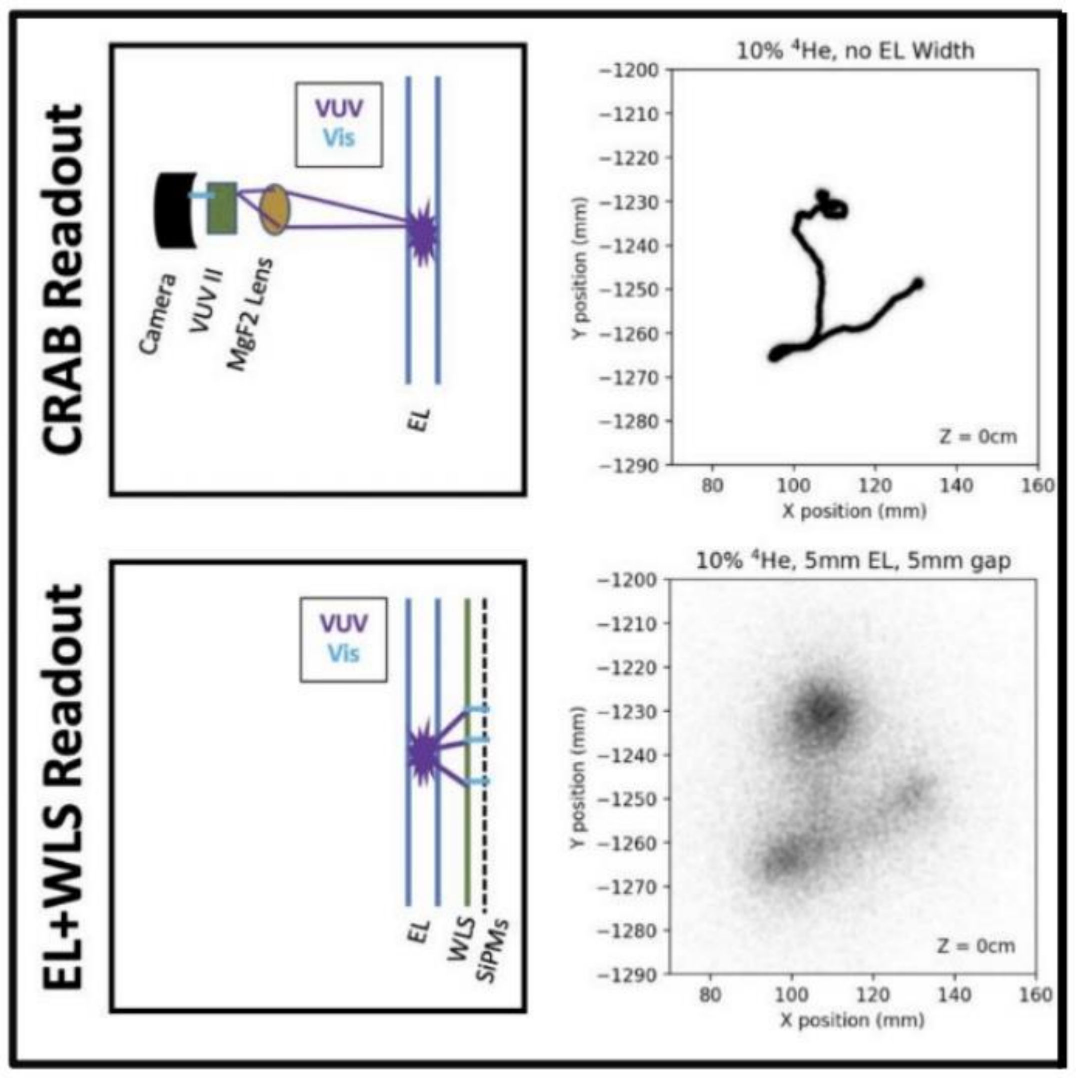
- To get barium to the chemosensors we need the Cathode to be at ground

(For barium tagging itself refer to yesterday's session)

Camera readout system

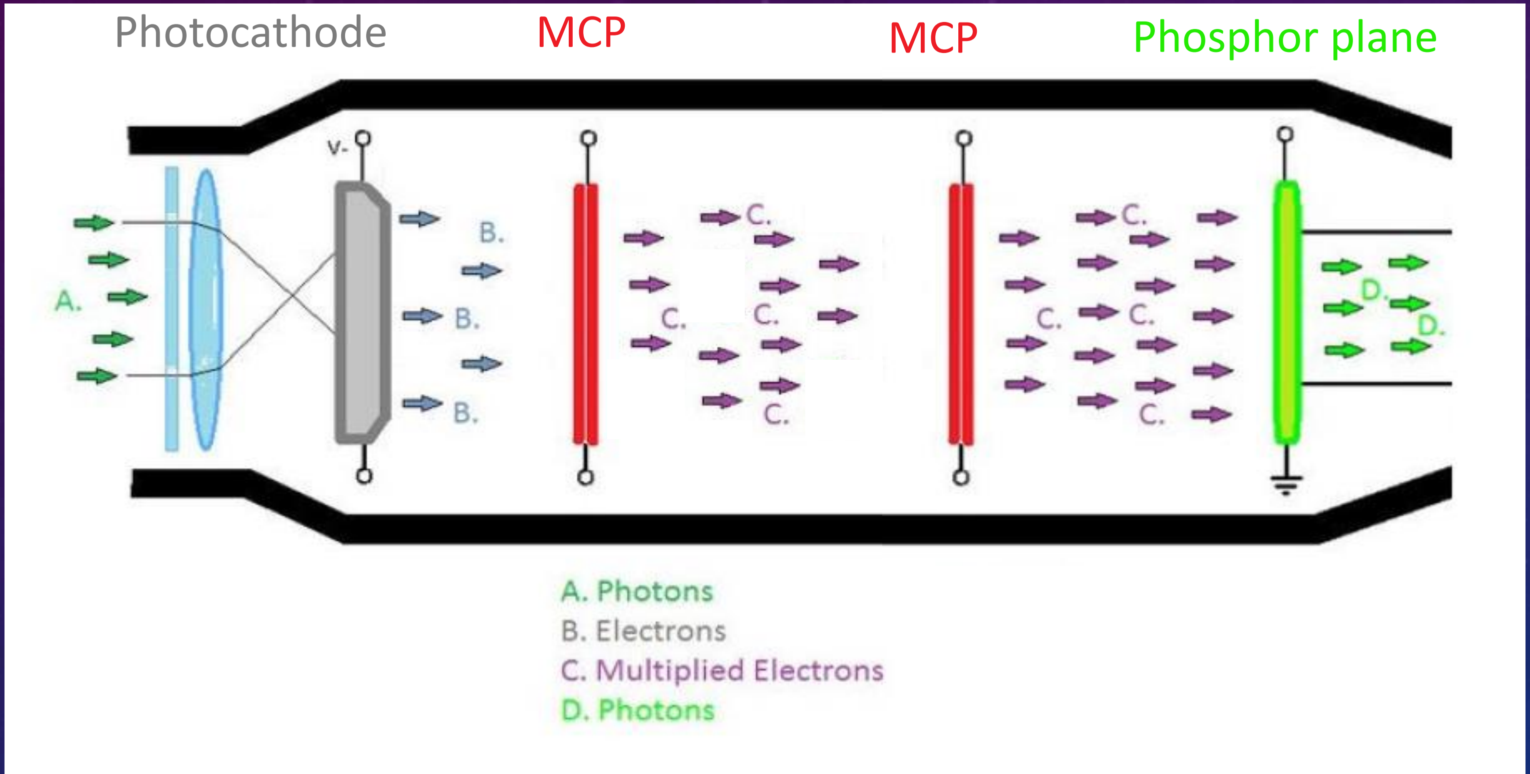


- The system includes a camera, an image intensifier, and optics to focus onto the region of interest
- Attaching an image intensifier enables single VUV photon sensitivity, amplifying the light as well as converting into the visible region



Replacing SiPMs + wavelength shifter with direct VUV camera tracking

Image Intensifier



CRAB-0 Paper

NEXT-CRAB-0: A High Pressure Gaseous Xenon Time Projection Chamber with a Direct VUV Camera Based Readout

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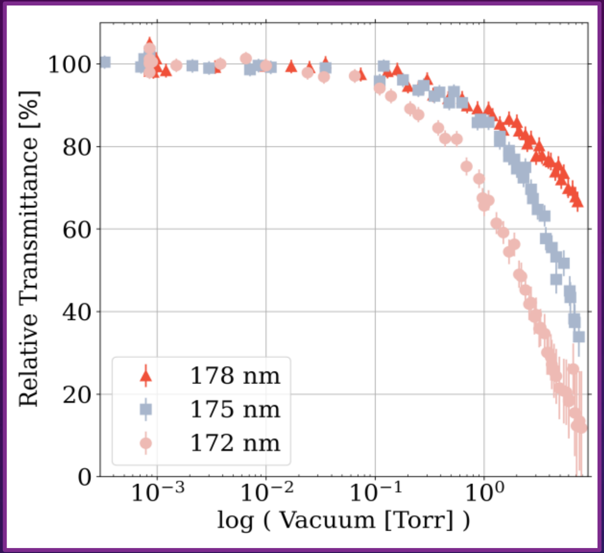
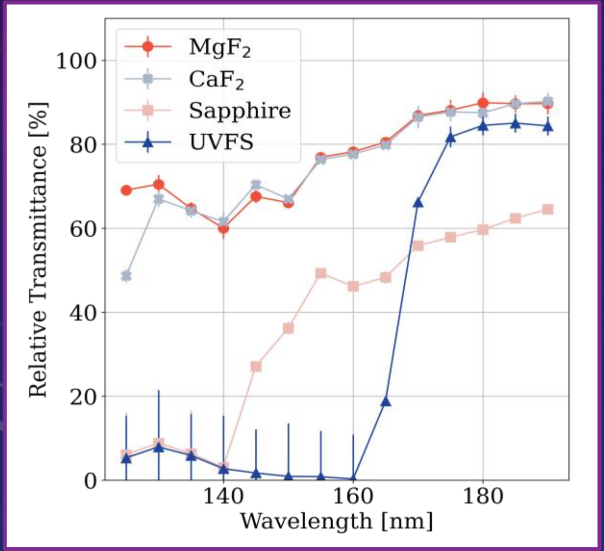
The NEXT Collaboration

N.K. Byrnes,[4,a] I. Parmaksiz,[4,a] C. Adams,[2] J. Asaadi,[4] J. Baeza-Rubio,[4] K. Bailey,[4] E. Church,[21] D. González-Díaz,[26] A. Higley,[2] B.J.P. Jones,[4] K. Mistry,[4] I.A. Moya,[4] D.R. Nygren,[4] P. Oyedele,[15] L. Rogers,[2] K. Stogsdill,[4] H. Almazán,[19] V. Álvarez,[27] B. Aparicio,[24] A.I. Aranburu,[23] L. Arazi,[7] I.J. Arnquist,[21] S. Ayet,[16] C.D.R. Azevedo,[5] K. Bailey,[2] F. Ballester,[27] J.M. Benlloch-Rodríguez,[22] F.I.G.M. Borges,[13] S. Bounasser,[19] S. Cárcel,[20] J.V. Carrión,[20] S. Cebrián,[28] C.A.N. Conde,[13] T. Contreras,[10] F.P. Cossío,[22,9] A.A. Denisenko,[3] E. Dey,[3] G. Díaz,[26] T. Dickel,[16] J. Escada,[13] R. Esteve,[27] A. Fahs,[19]

https://arxiv.org/abs/2304.06091

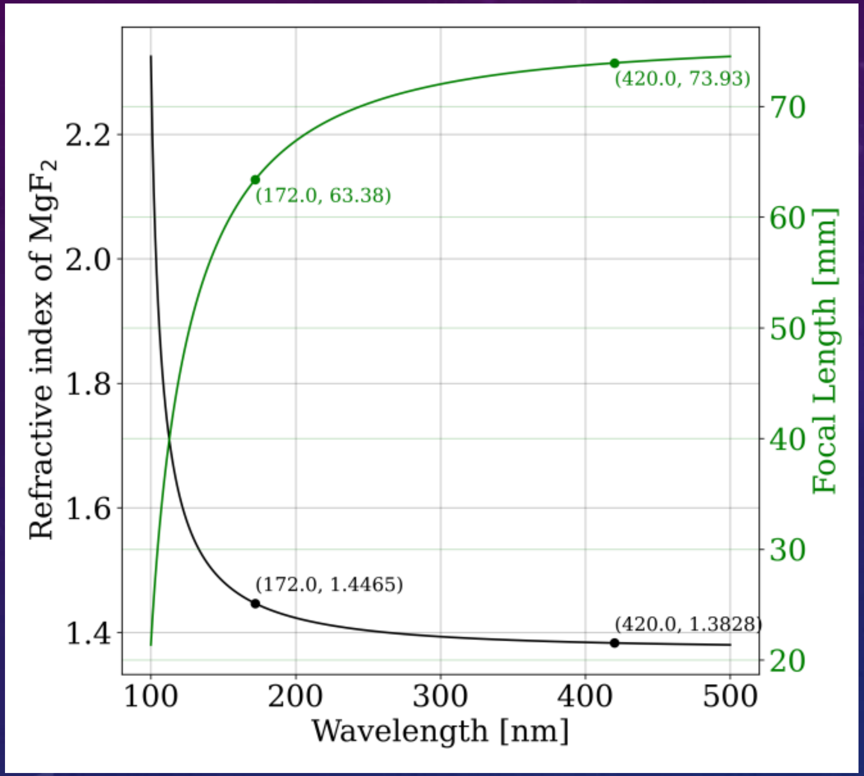
Transmissivities





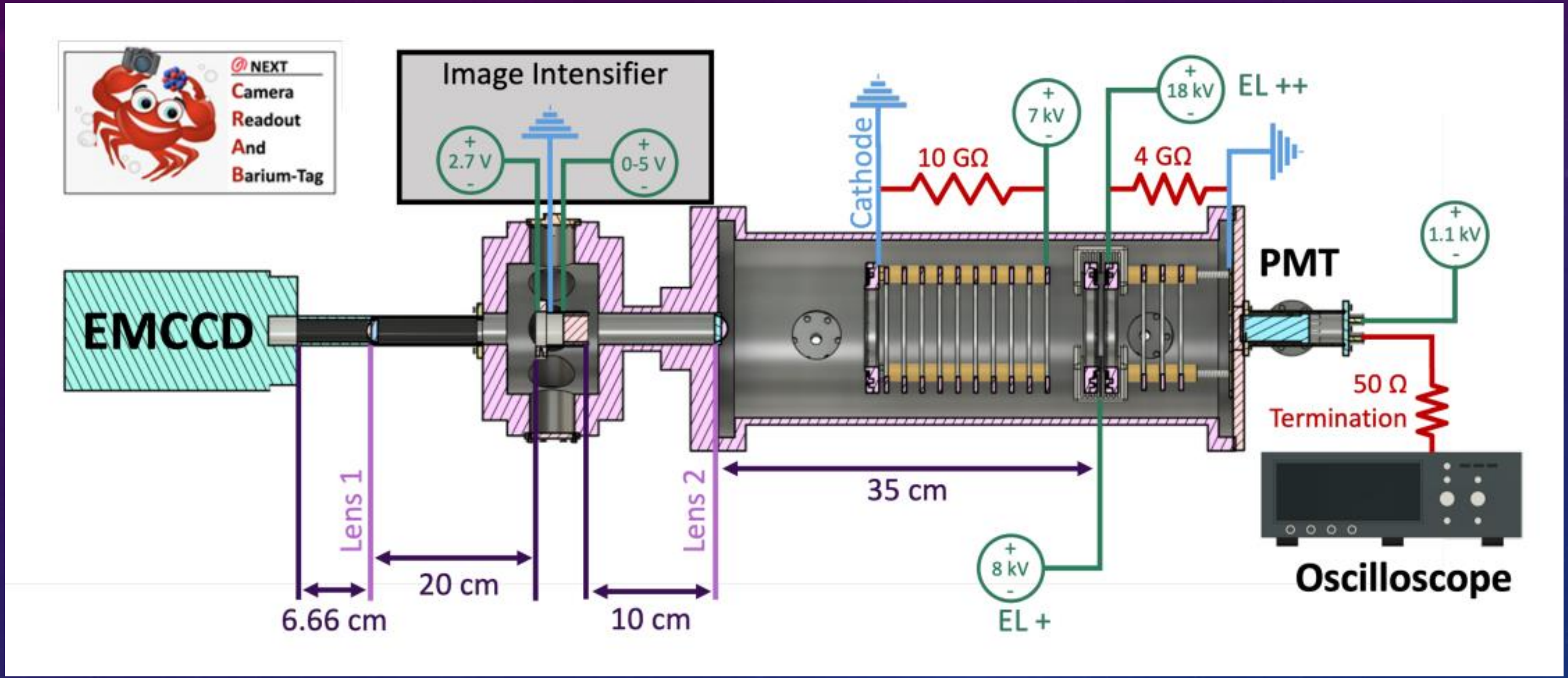
- We used a VUV monochromator to select appropriate lens material and establish necessary vacuum quality
- Until the light exits the image intensifier everything must be a vacuum <.1 Torr or clean gas to avoid attenuation
- All lenses and windows in the optics path should be made from MgF2 or CaF2
  - Once barium tagging is implemented we suspect the window should be MgF2 as Calcium is similar to Barium and may affect the chemosensors
  - This may affect how large lenses can be though we sourced a manufacturer capable of custom MgF2 lenses up to 6” diameter

Focal Lengths



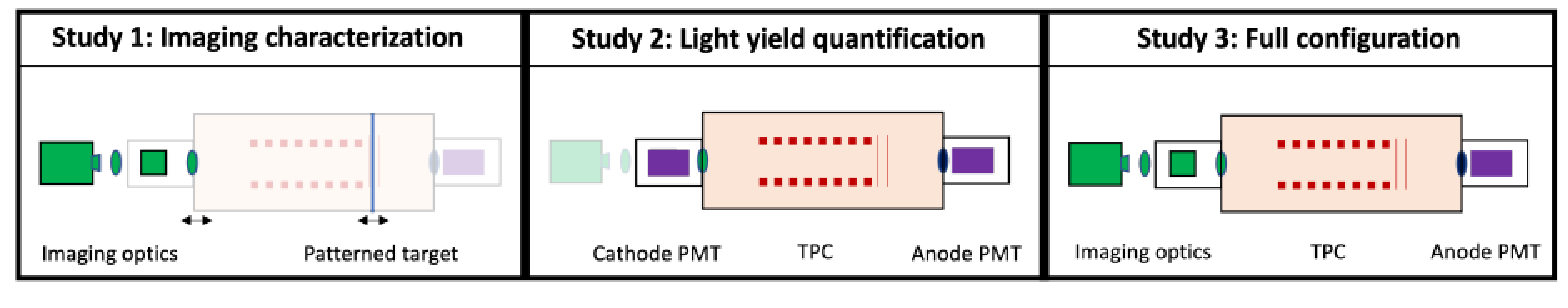
- The refractive index changes with wavelength which in turn changes the focal length
- Optics have to be focused using VUV light sources

NEXT Optical TPC at UTA

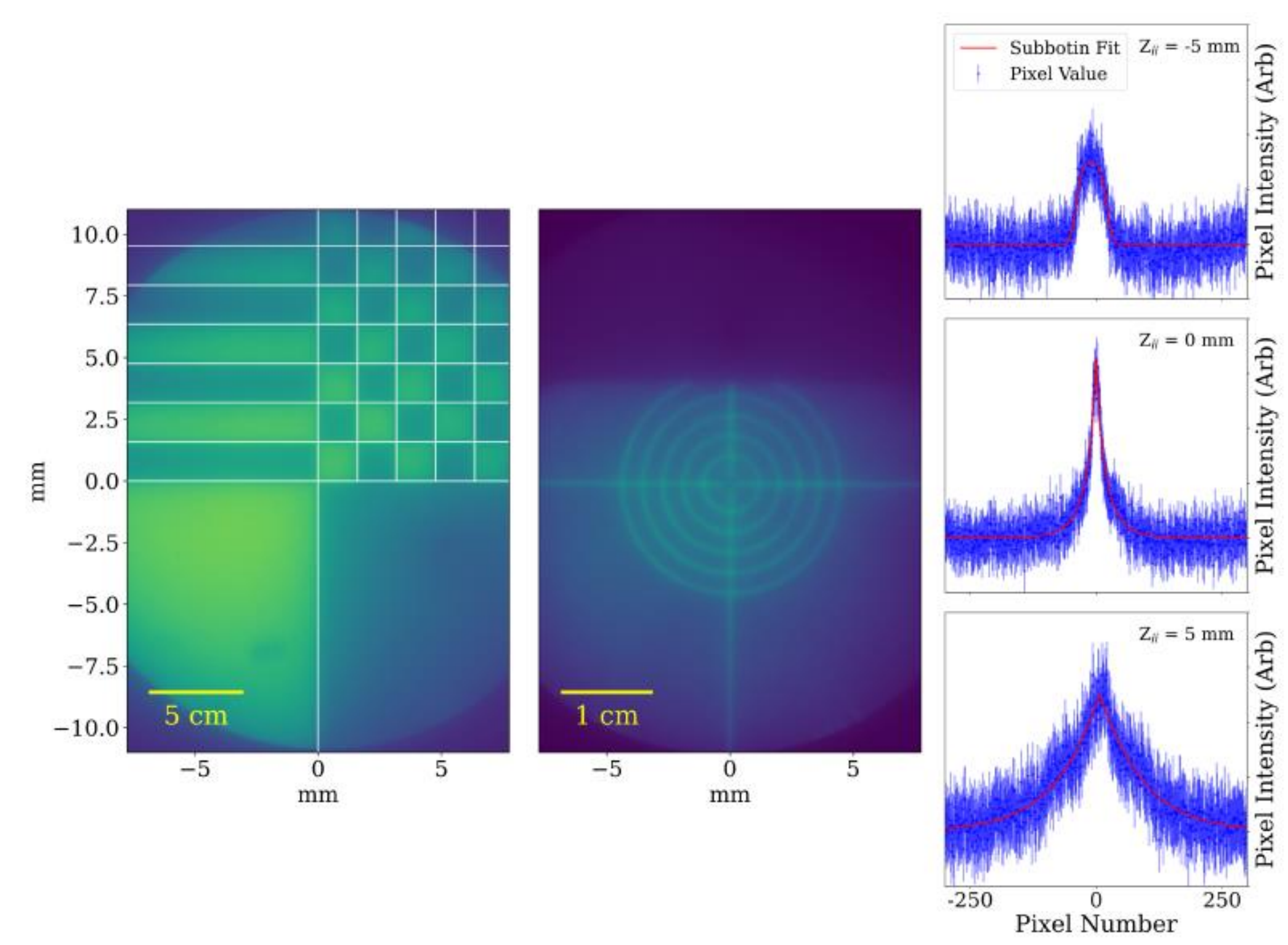


- Asymmetrical TPC but with Cathode still at ground
- MgF2 lens used to focus the EL light onto a Photonis single MCP Image Intensifier which is then read out onto Hamamatsu imagEMX2 camera
- PMT used on opposite side for energy reading

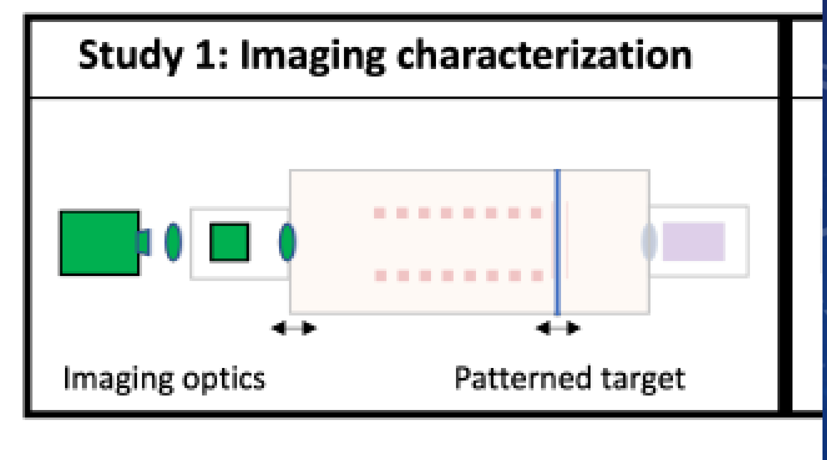
Running Configurations



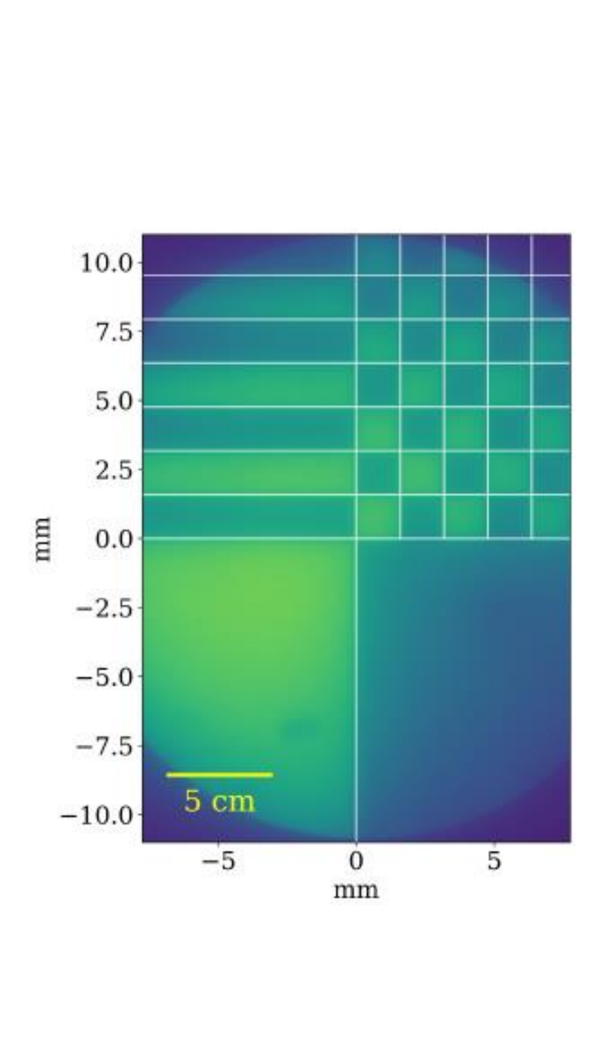
Imaging Characterization



- For this test a higher resolution FLIR Firefly 1.6 Mpixel CMOS camera was used
- Targets were illuminated with a low intensity 420 nm blue LED

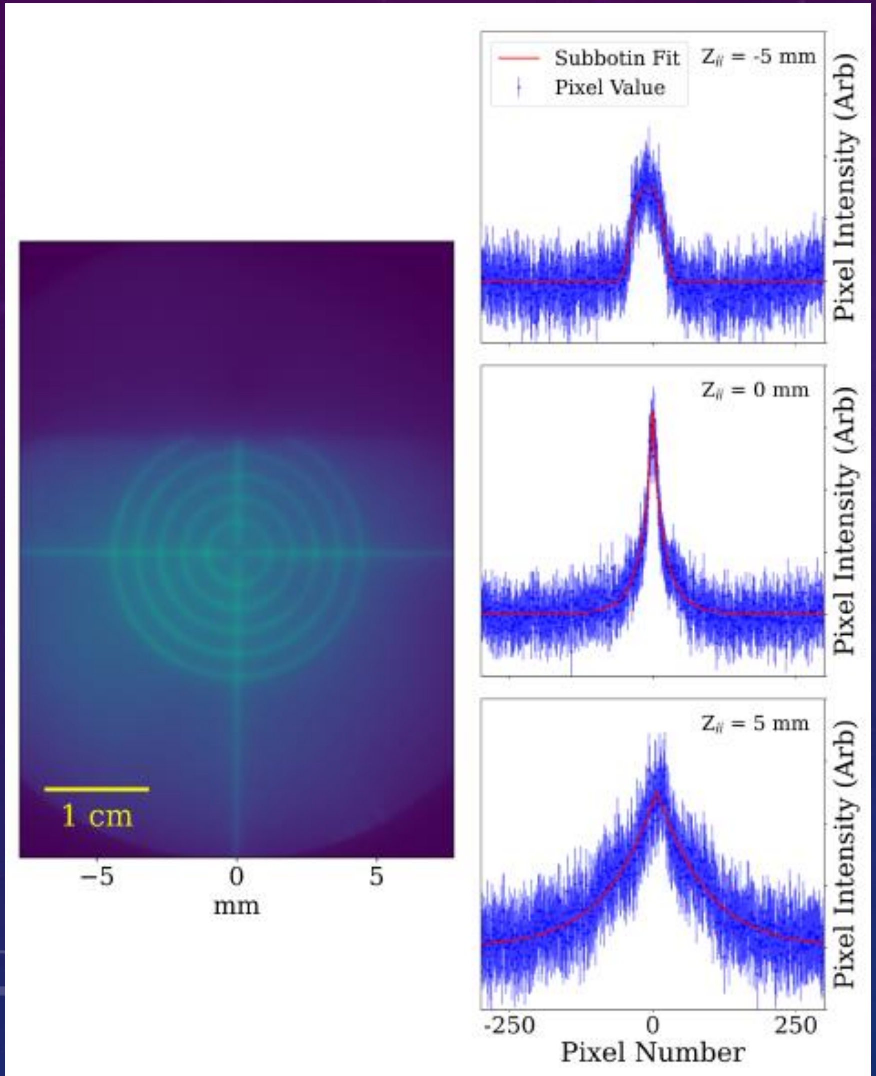


Larger Scale



- Left plot shows a larger scale target with clear distinctions between the white and black regions, indication there are not spherical distortions at larger scales that would be resolvable with the lower resolution hammamatsu camera

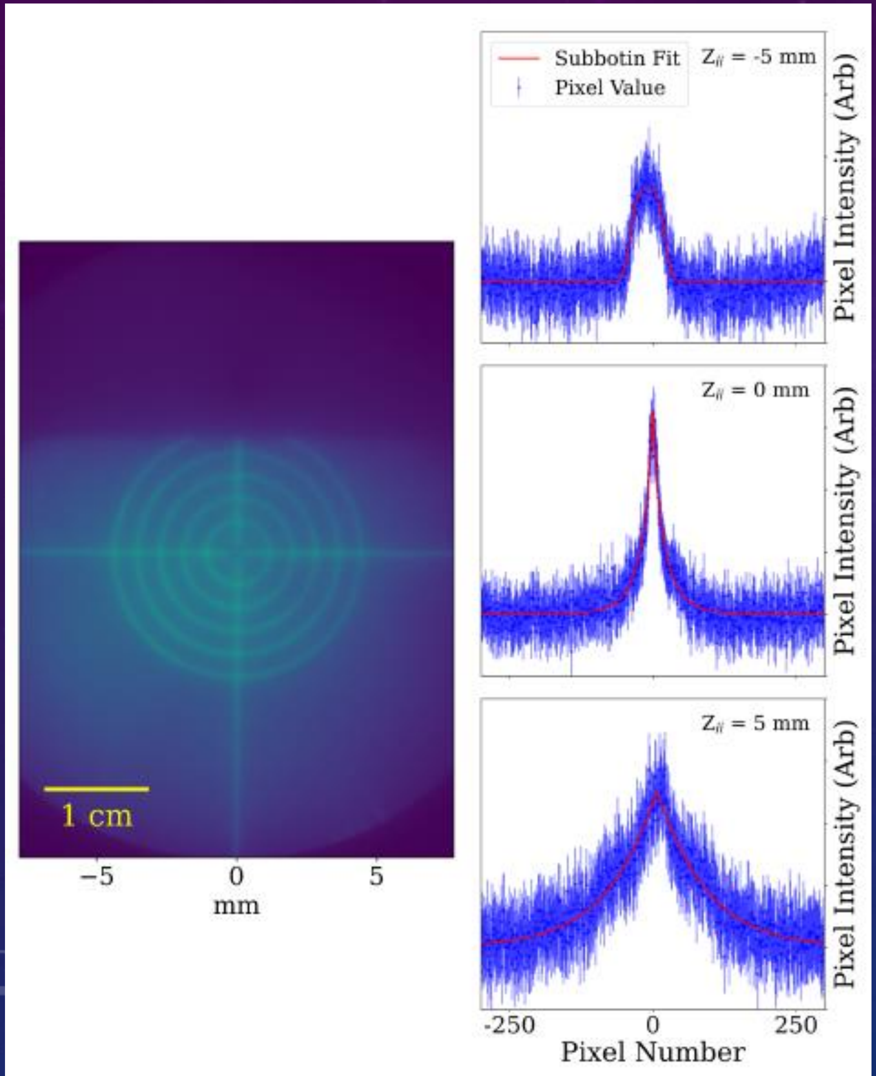
Quantifying Image Resolution



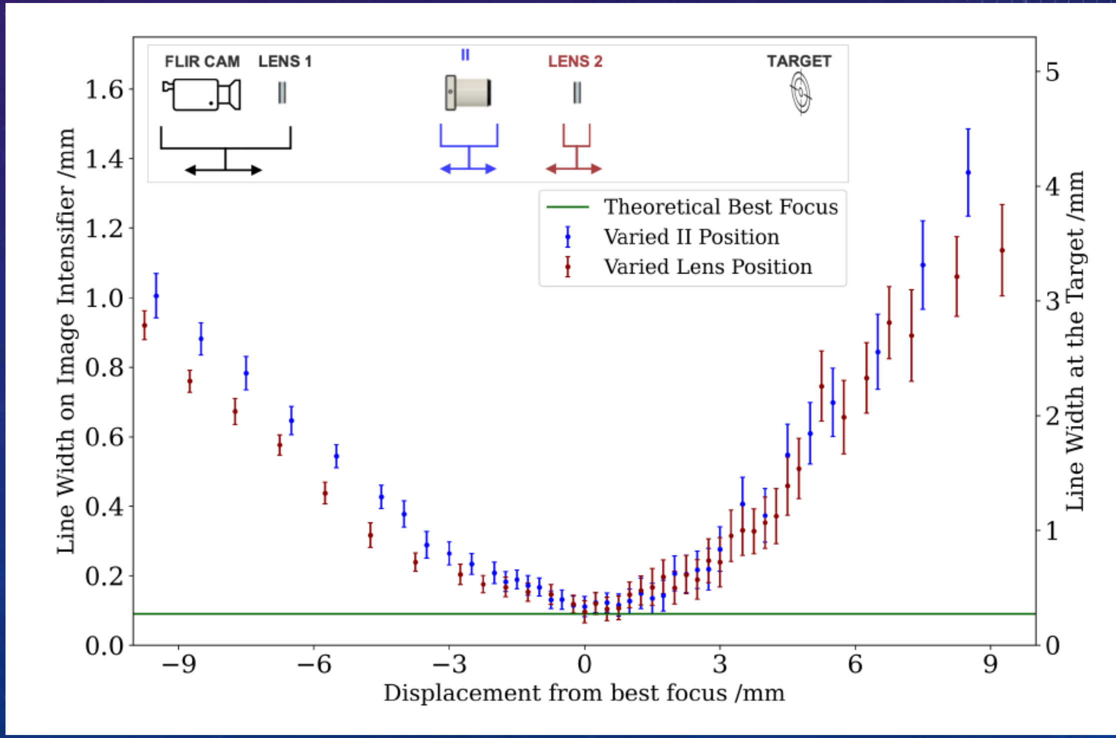
- A target with .25mm thick lines was imaged
- Each image was analyzed by measuring the intensities of 7 pixels along the horizontal and then averaged to assess the image point spread function.

$$I(x) = ax^3 + bx^2 + cx + d + \frac{\alpha\eta}{2\sigma\Gamma\left(\frac{1}{\eta}\right)} \exp\left[-0.5\left(\frac{|x-\mu|}{\sigma}\right)^\eta\right].$$

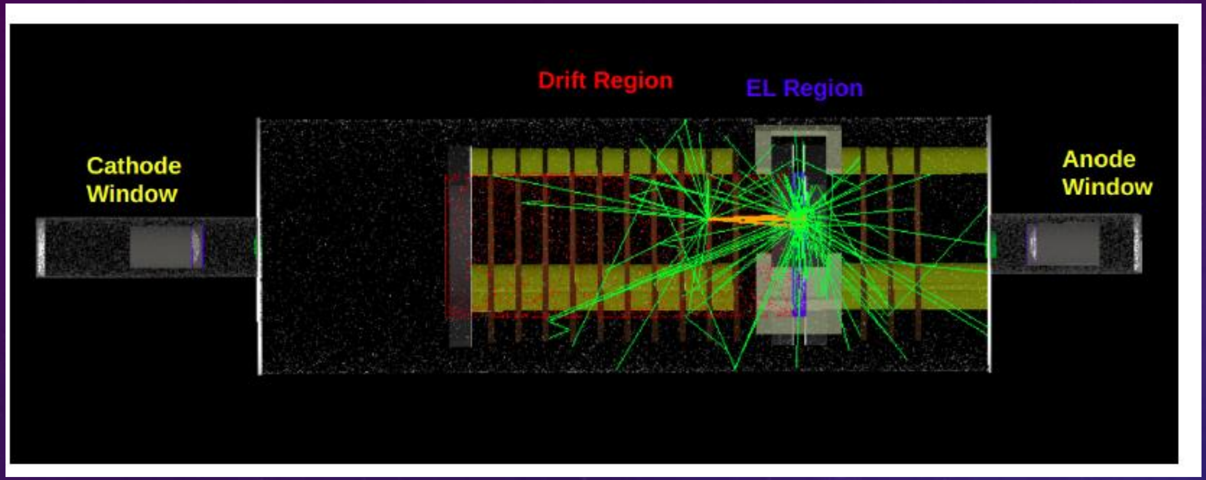
Quantifying Image Resolution



- A Positioning precision of around 1 mm is good enough for optimal image focusing

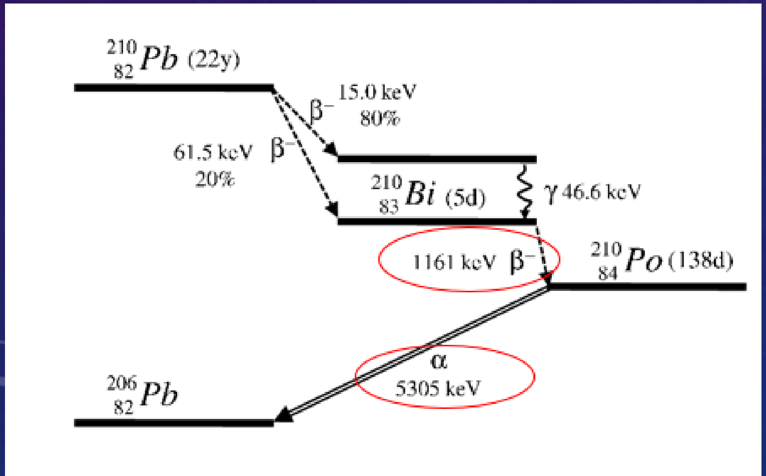


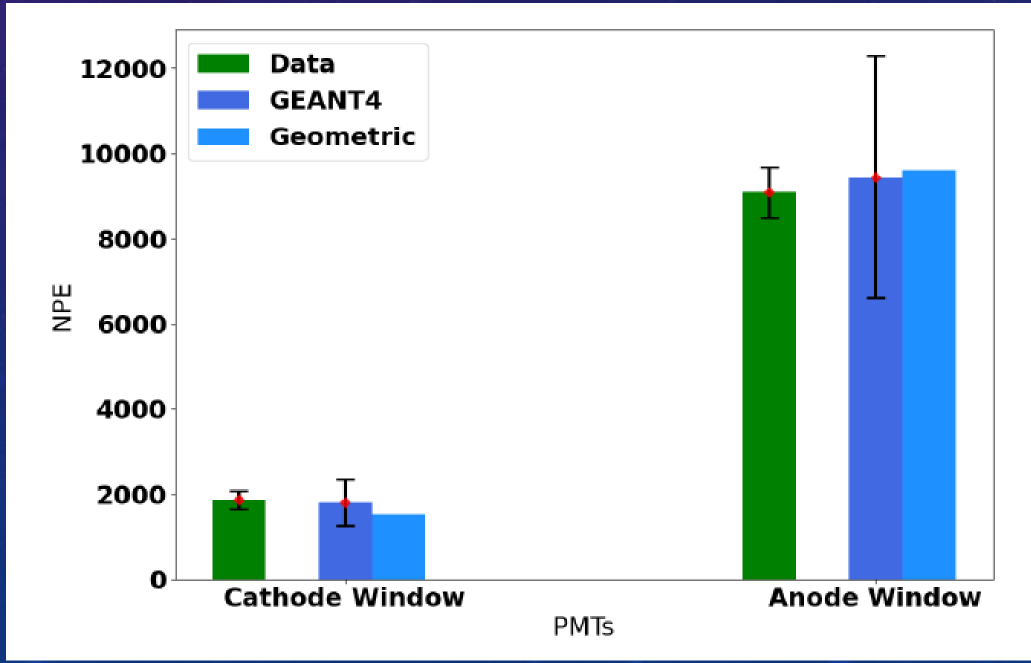
Light Yield Characterization



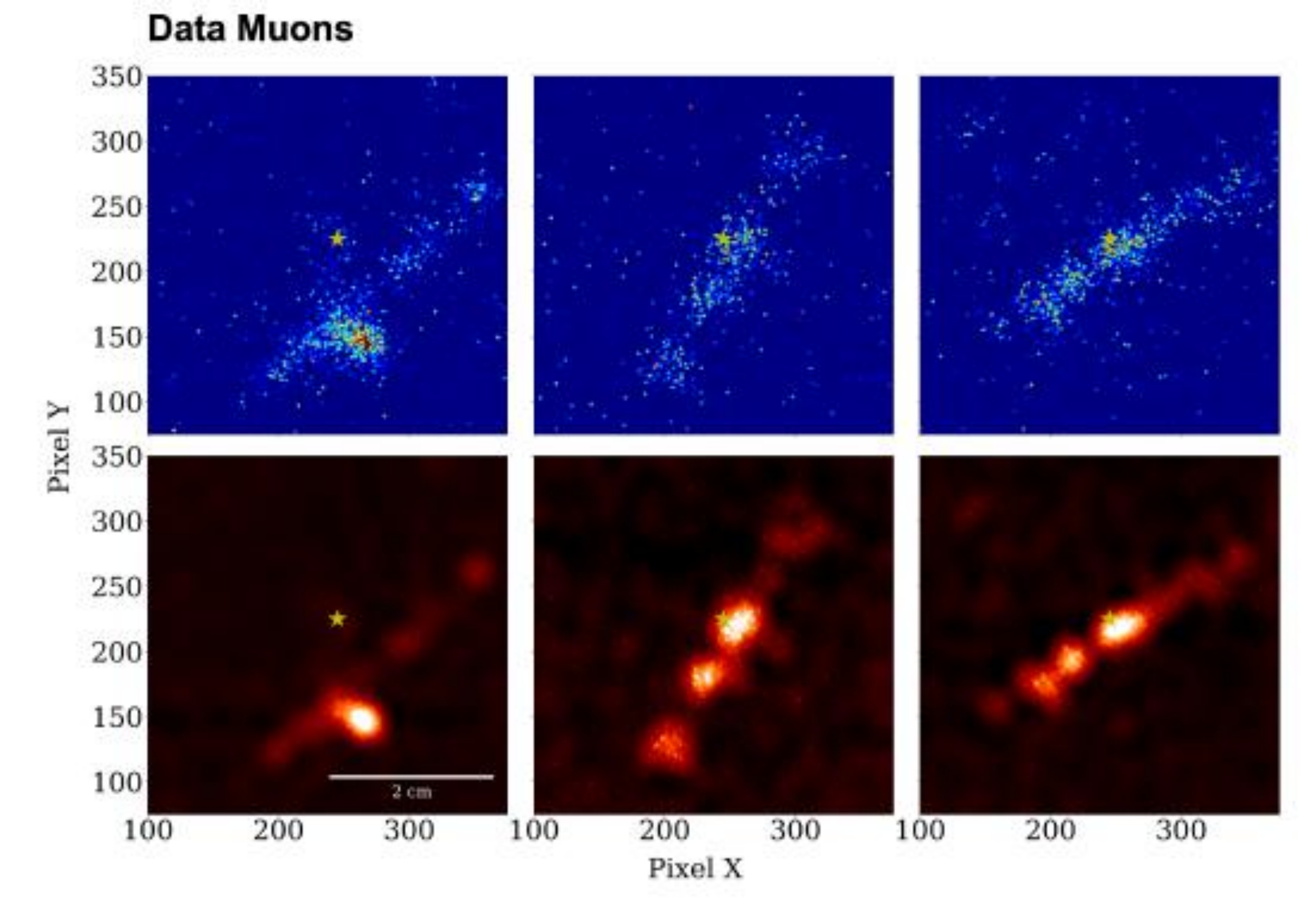
GEANT4 Geometry

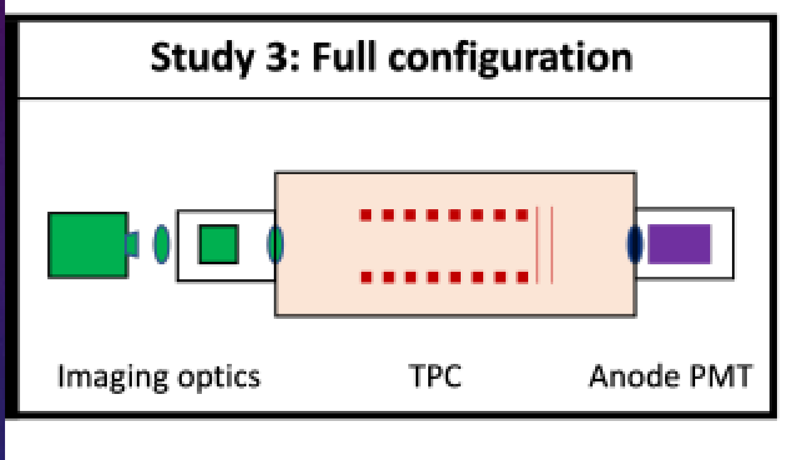
To characterize the light yield of the detector a 210Pb needle was inserted 5cm from the EL region with a PMT on either side of the detector



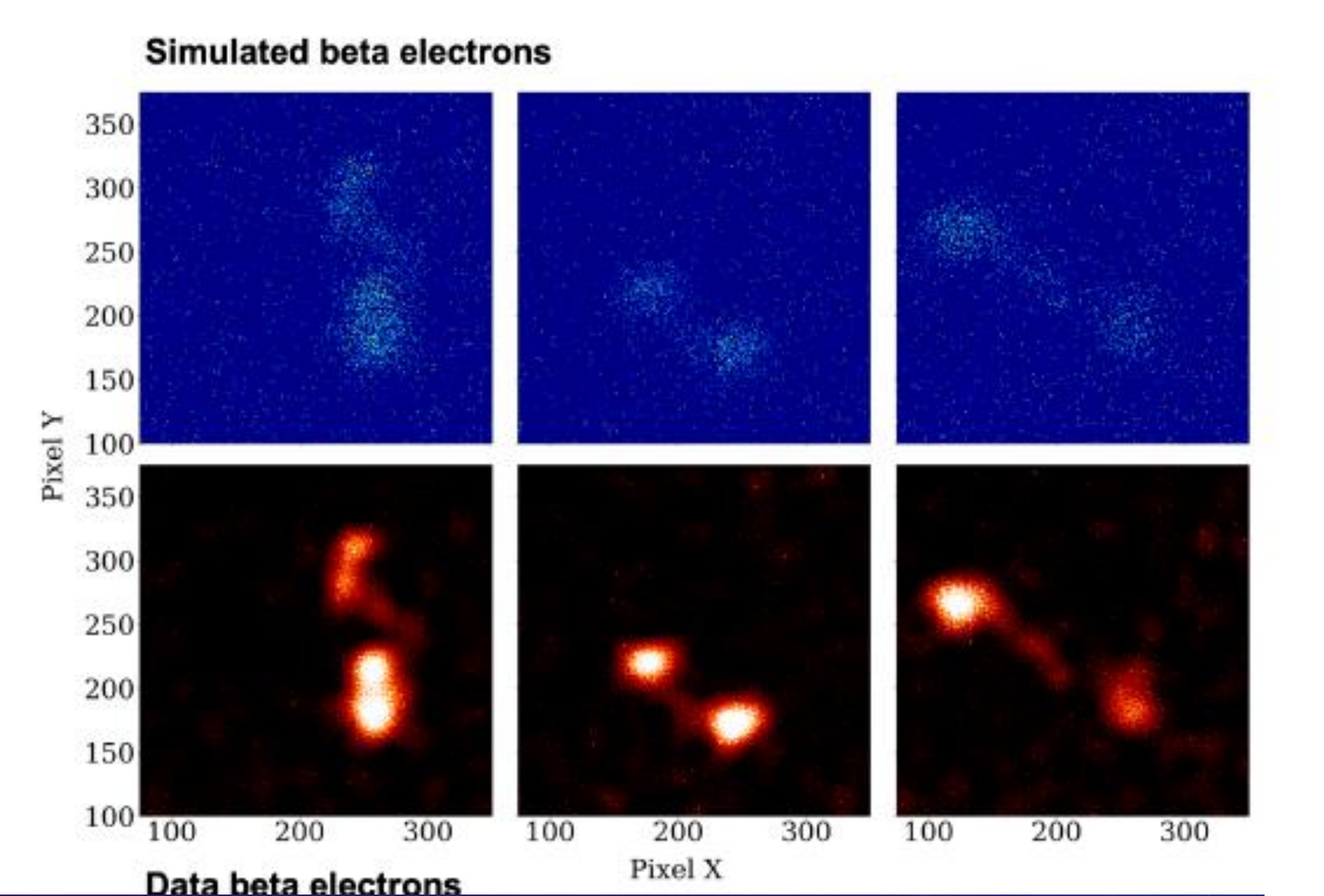


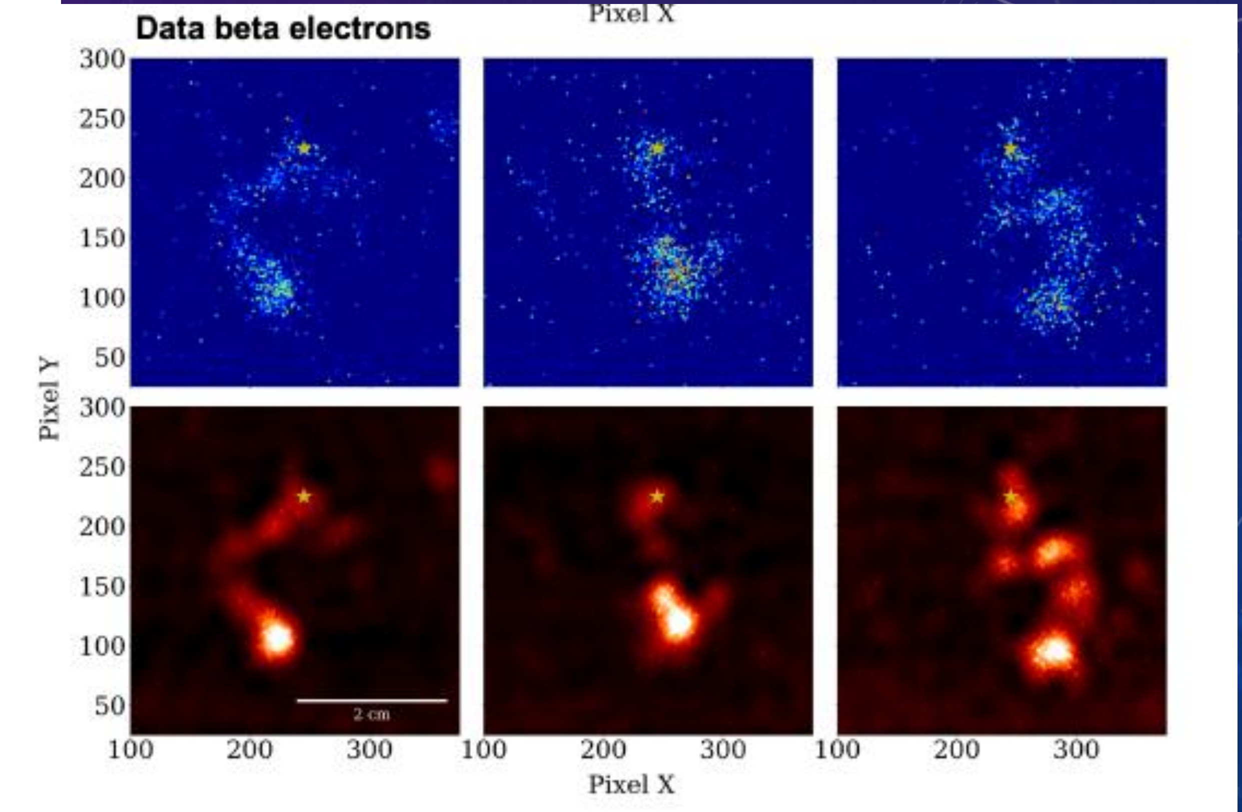
Full Configuration

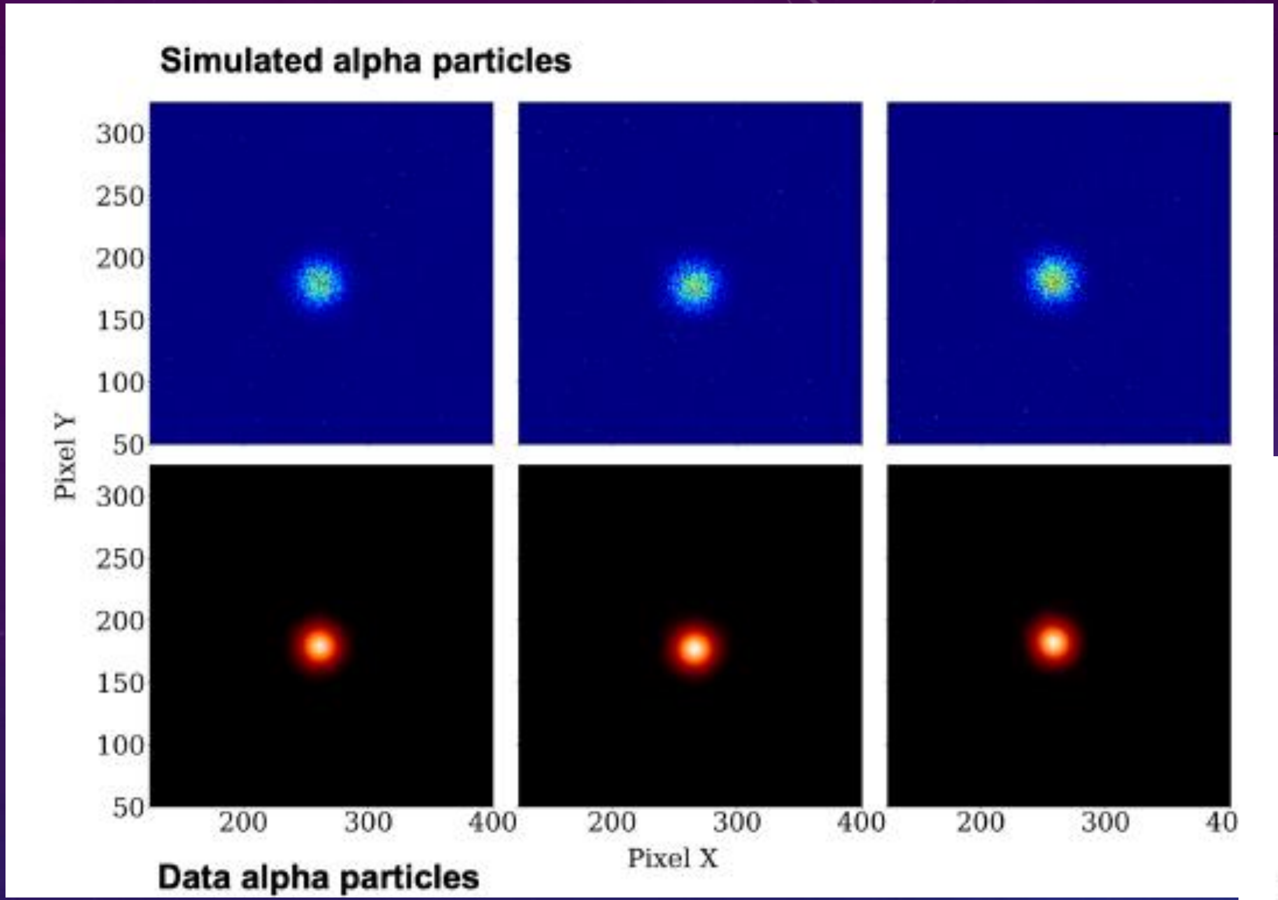


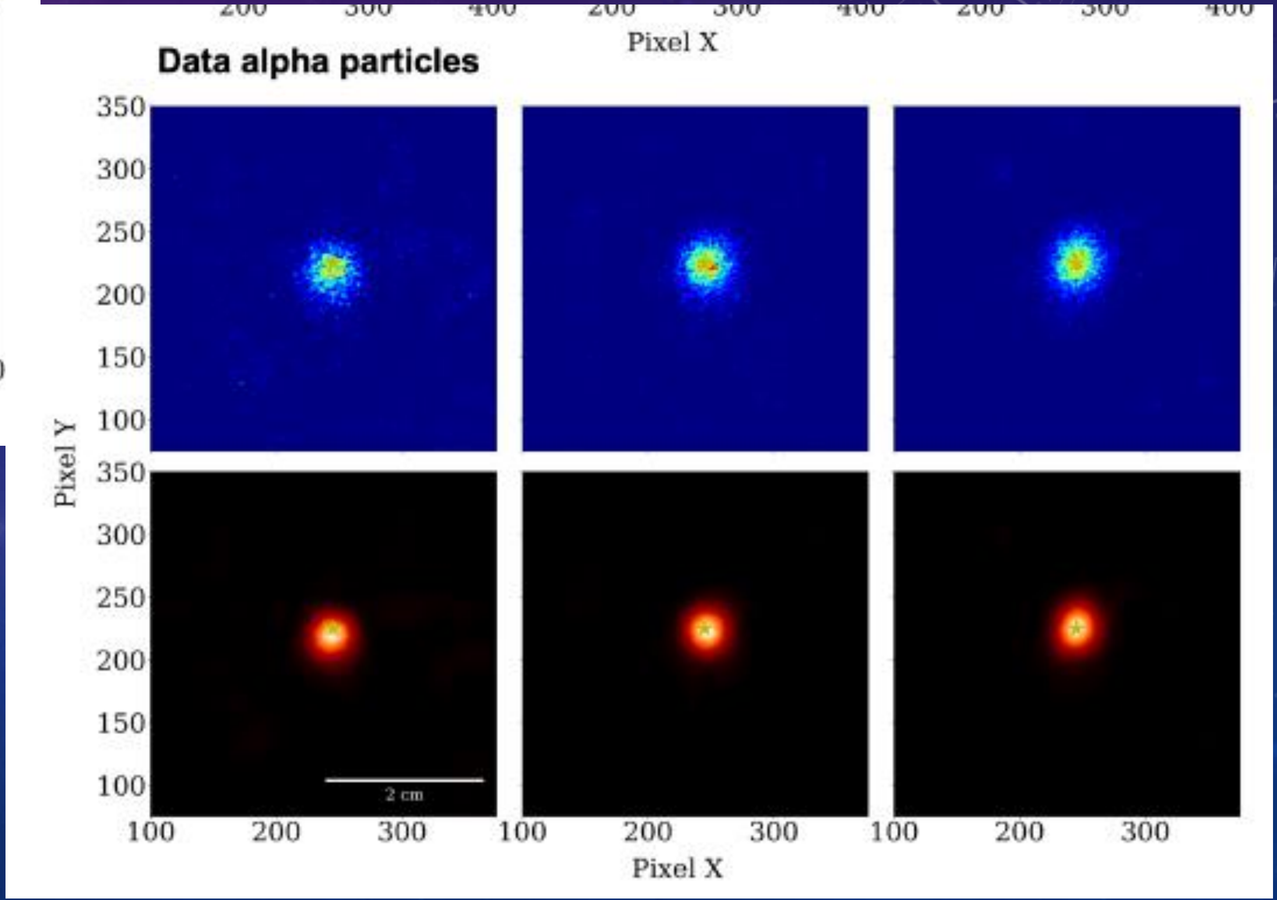


Having the optics system on one end and the PMT on the other we could then obtain relatively clear data (top) which could then have a filter applied for cleaner tracks (bottom)


Simulated beta electrons
Pixel Y
Pixel X
Data beta electrons


Data beta electrons
Pixel X
Pixel Y
2 cm
Pixel X


Simulated alpha particles
Pixel Y
Pixel X
Data alpha particles

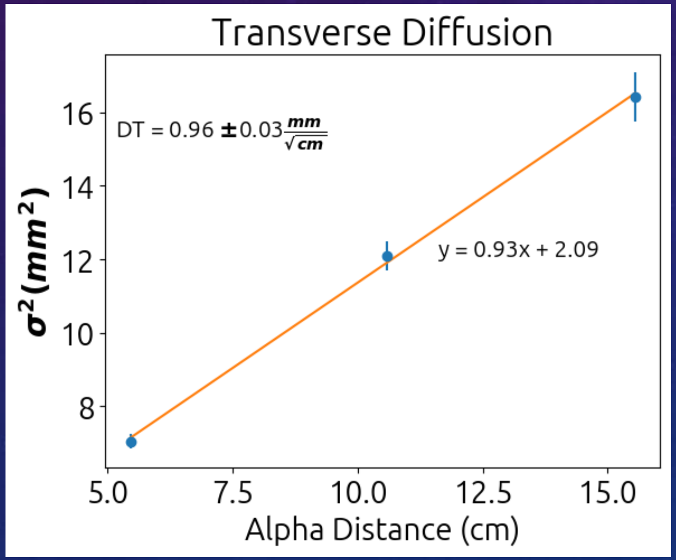

Pixel X
Data alpha particles
Pixel Y
2 cm
Pixel X

Conclusions of NEXT-CRAB-0 Paper

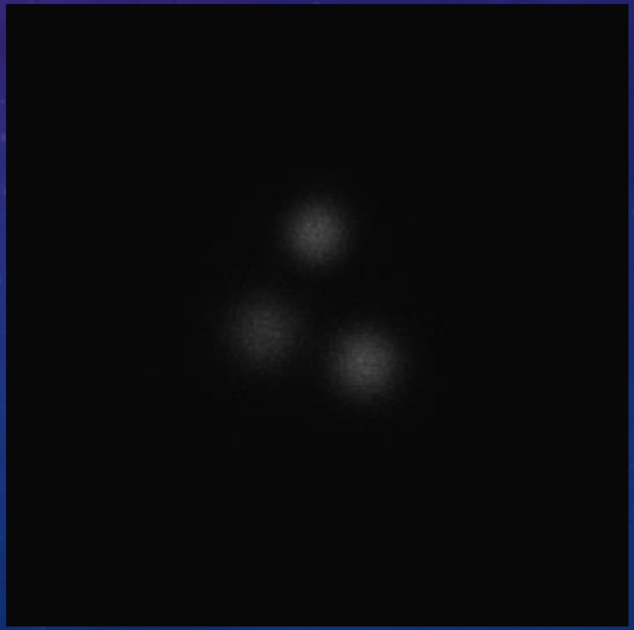
- NEXT-CRAB-0 imaged directly in the VUV, achieving high-resolution camera readout images of particle tracks.
- The detector performance has been tested and verified against simulations, showing good agreement in light-yield comparisons.

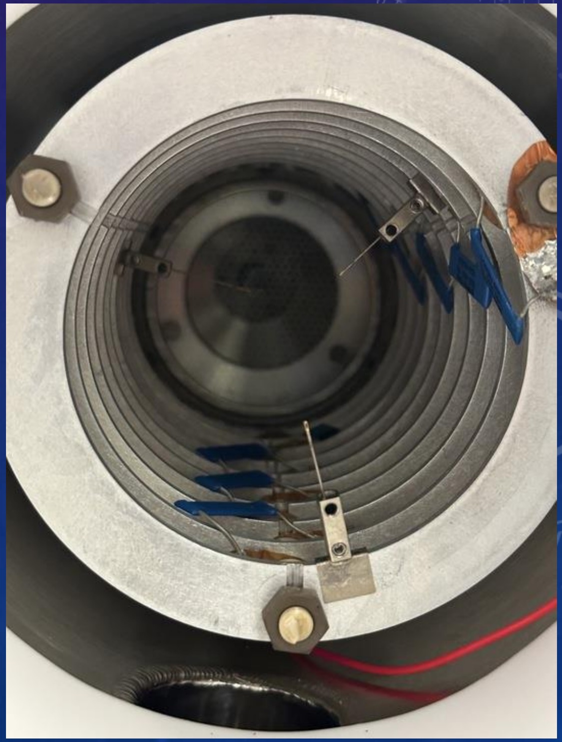
Measuring Transverse Diffusion with CRAB-0

- 3 Pb-210 sources placed in the field cage at 5, 10, and 15 cm from the EL
- Collect pictures at various EL-Fields and Drift Fields
- Mean spread of averaged images for each location then determines how much transverse diffusion occurs

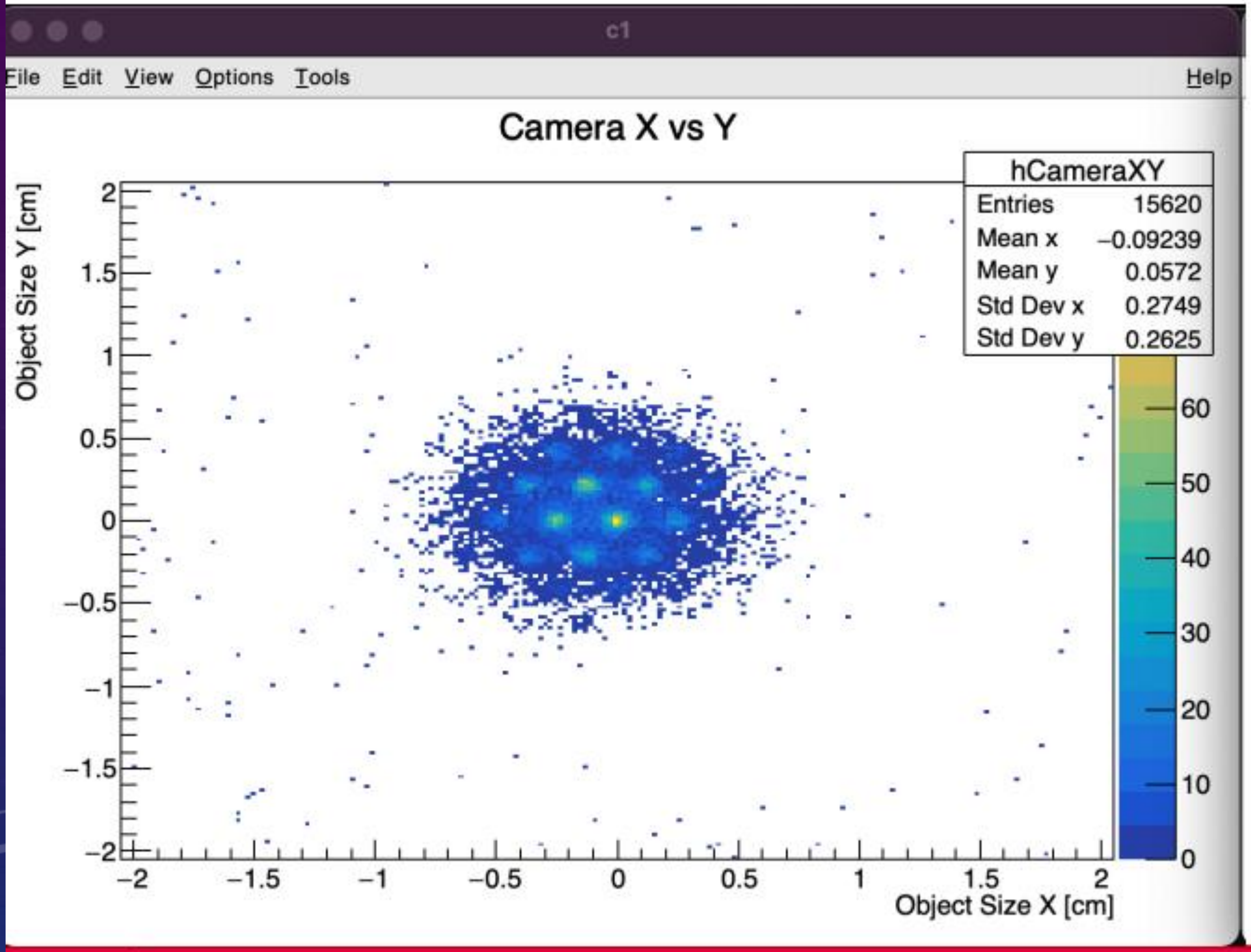


Field of 440 V/cm, EL Field at 10k/cm

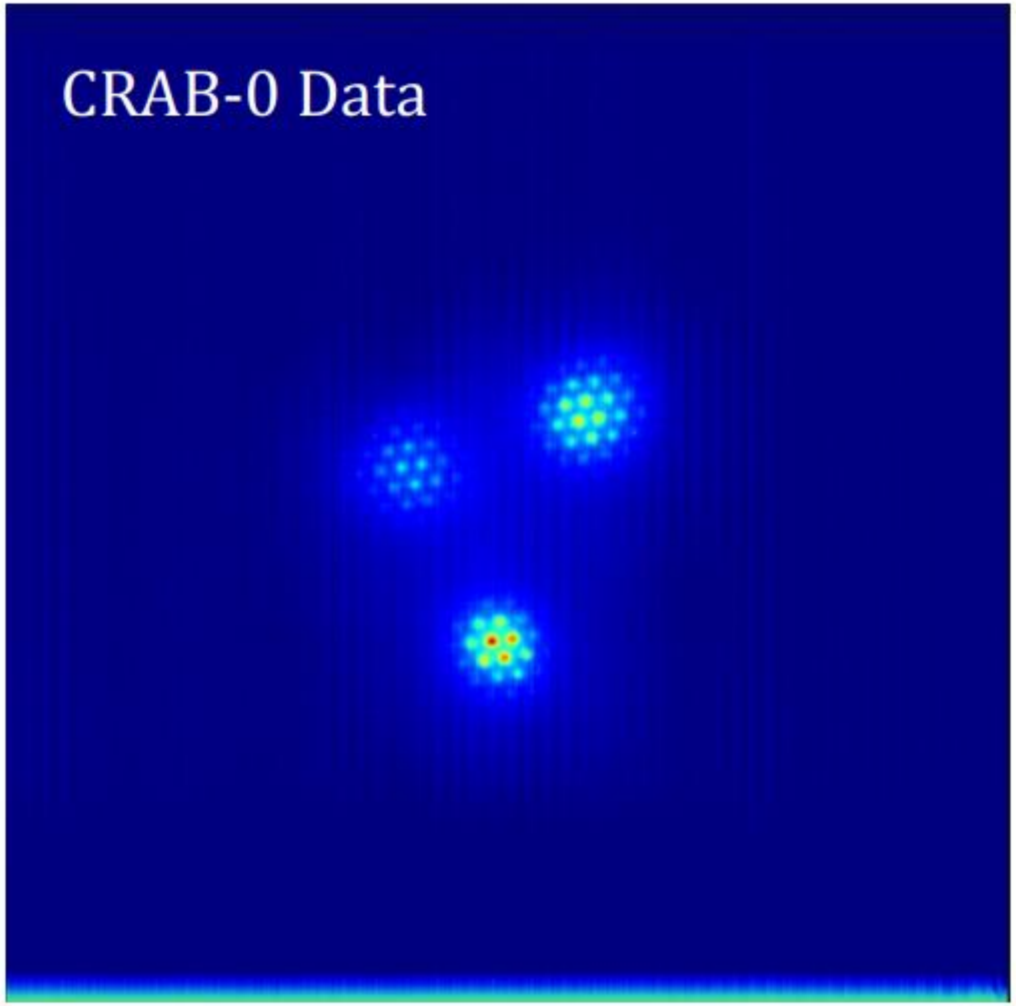




Fun Extra

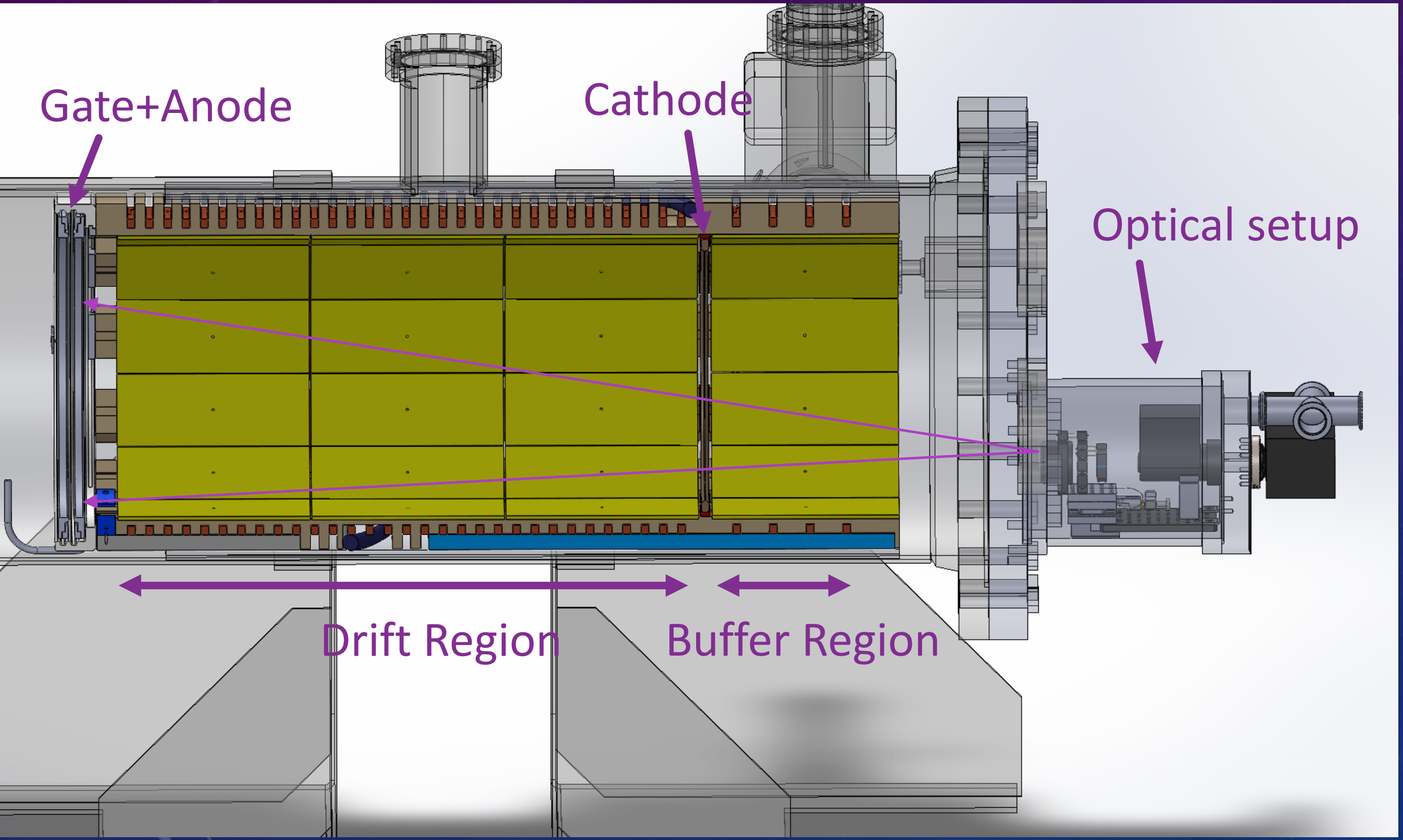


c1
File Edit View Options Tools Help
Camera X vs Y
hCameraXY
Entries 15620
Mean x −0.09239
Mean y 0.0572
Std Dev x 0.2749
Std Dev y 0.2625
Object Size Y [cm]
Object Size X [cm]



CRAB-0 Data

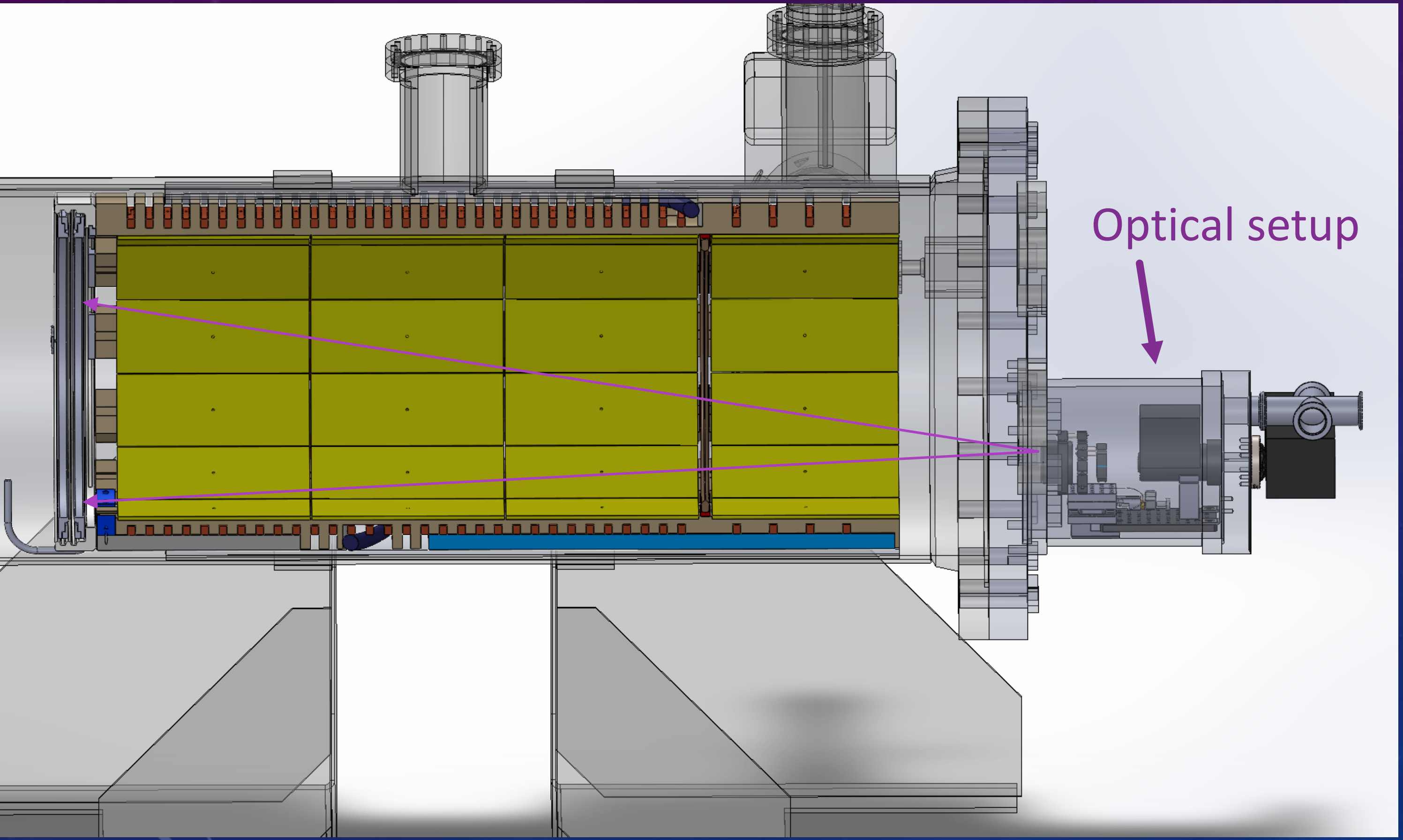
NEXT Optical TPC at Argonne



- We turned the NEXT-100 prototype into an optical TPC capable of 3D imaging

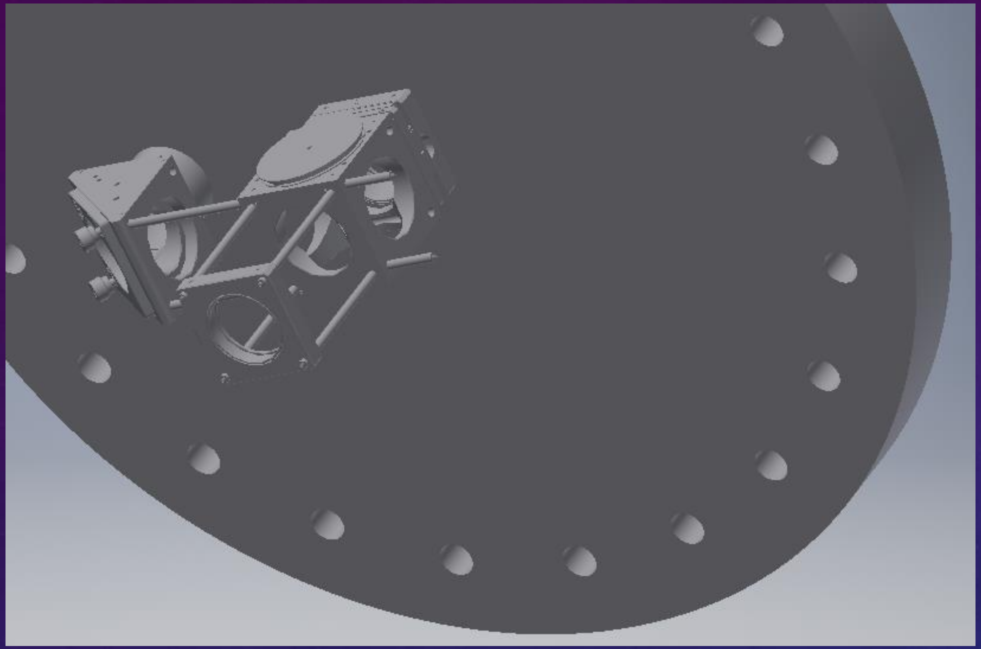
	NEXT-White	CRAB
Tracking Plane Diameter [cm]	45.4	34.3
Tracking Plane Area [cm^2]	1620	924
Number of Pixels	1792	65,536
Pixel Spacing [cm]	1	0.13
Feedthrough Channels	3600	0
Time Resolution	1us	1.6ns

NEXT Optical TPC at Argonne



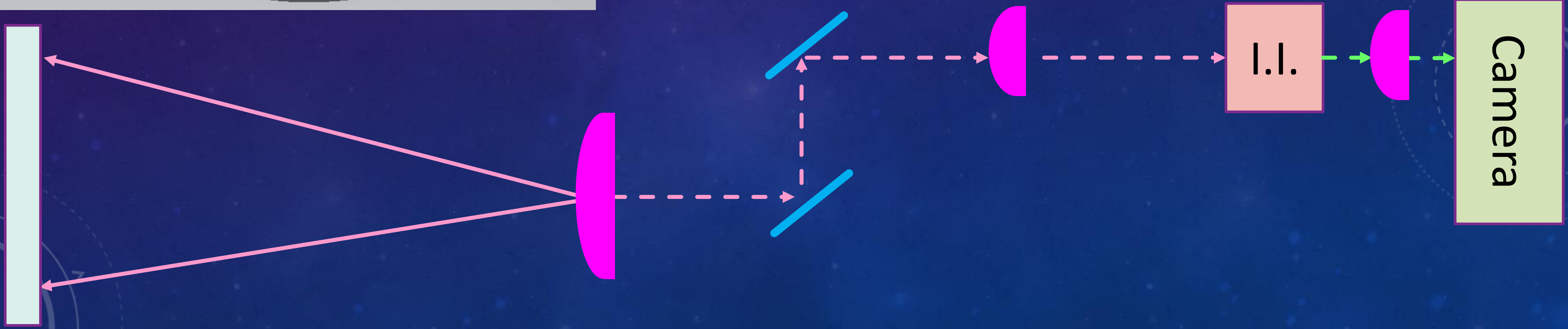
- While this is asymmetrical and does not have cathode at ground, the camera cannot tell the difference and is still modeling looking at the EL from a distance

Focusing the Image Intensifier and Camera

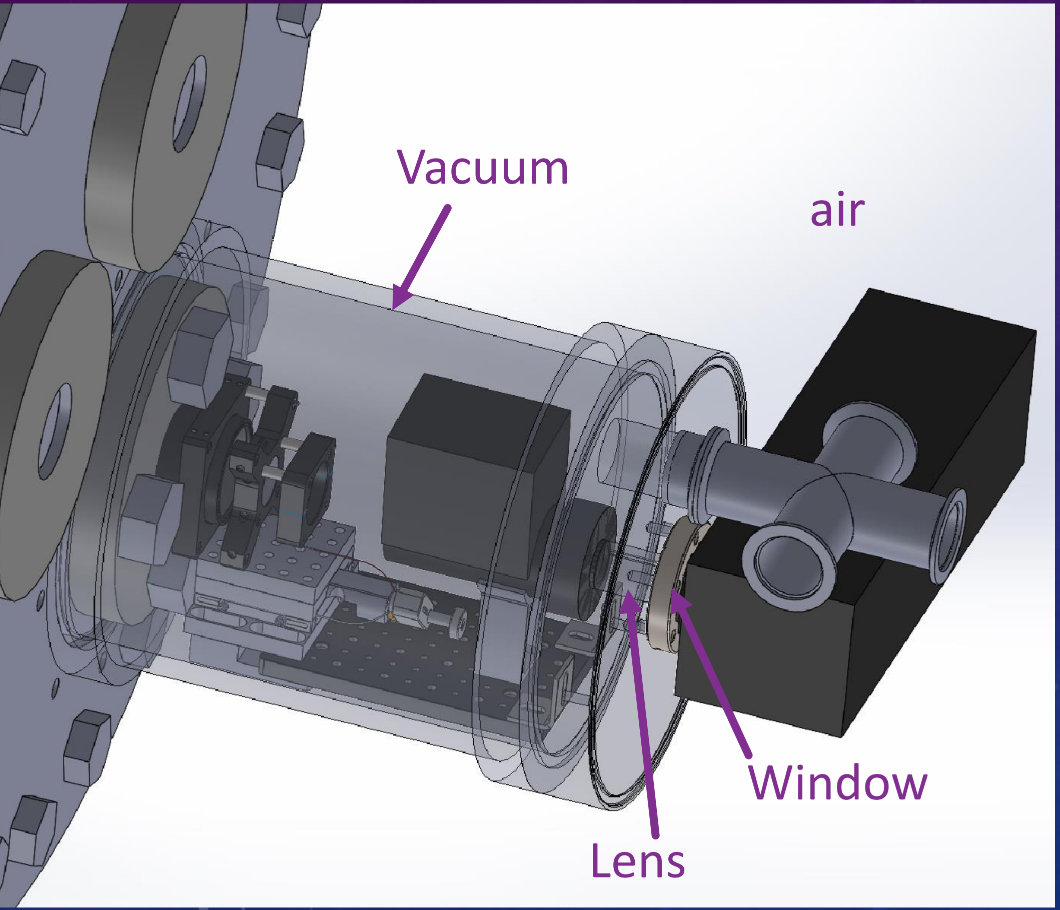


The end cap has the windows at different radii that are not centered

Rather than just focusing a single convex lens directly on the EL plane we use a system of mirrors and lenses

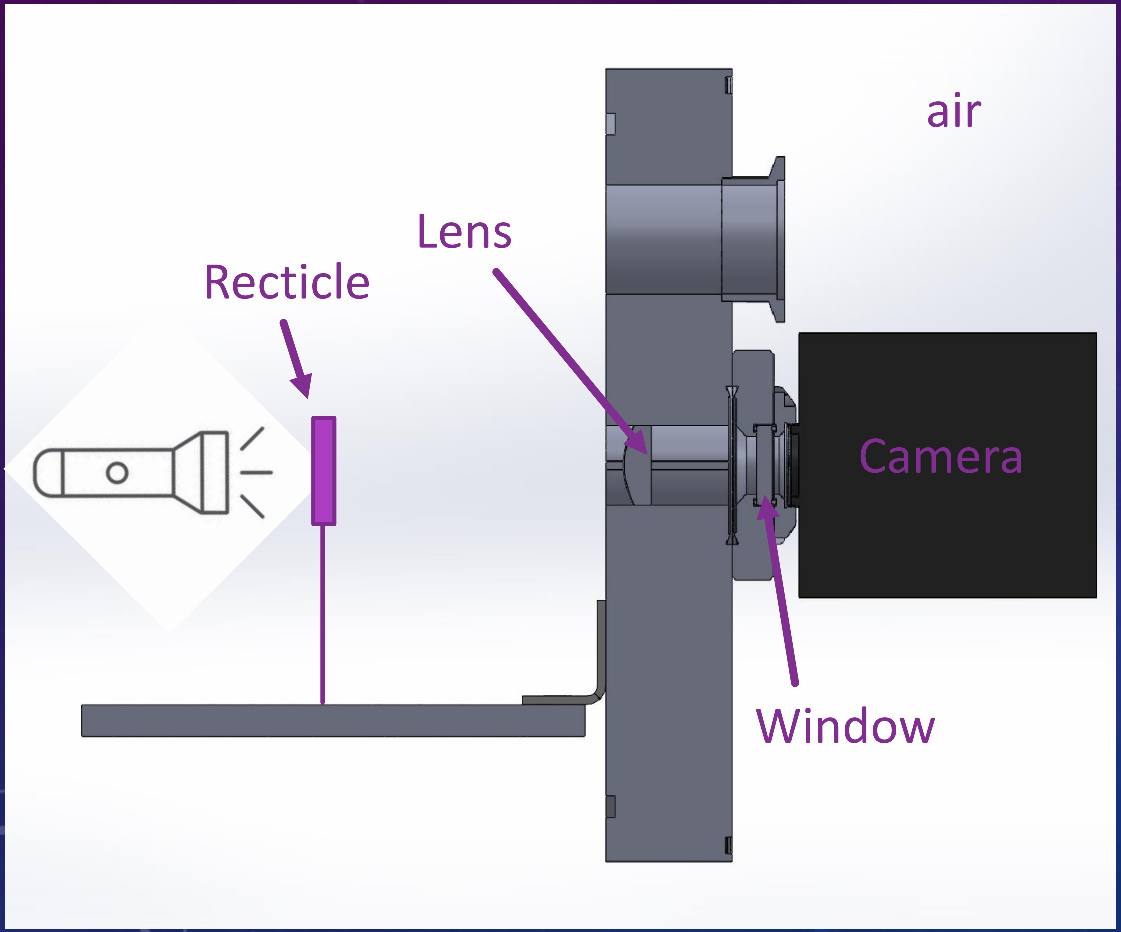


Attaching the TimePix Camera



- Once the light leaves the image intensifier it is in the visible range
- The camera has a cooling fan and therefore must be outside the vacuum chamber
- We use a lens between the image intensifier and camera to focus the virtual image onto the camera readout due to the compact space we are working in

Attaching the TimePix Camera



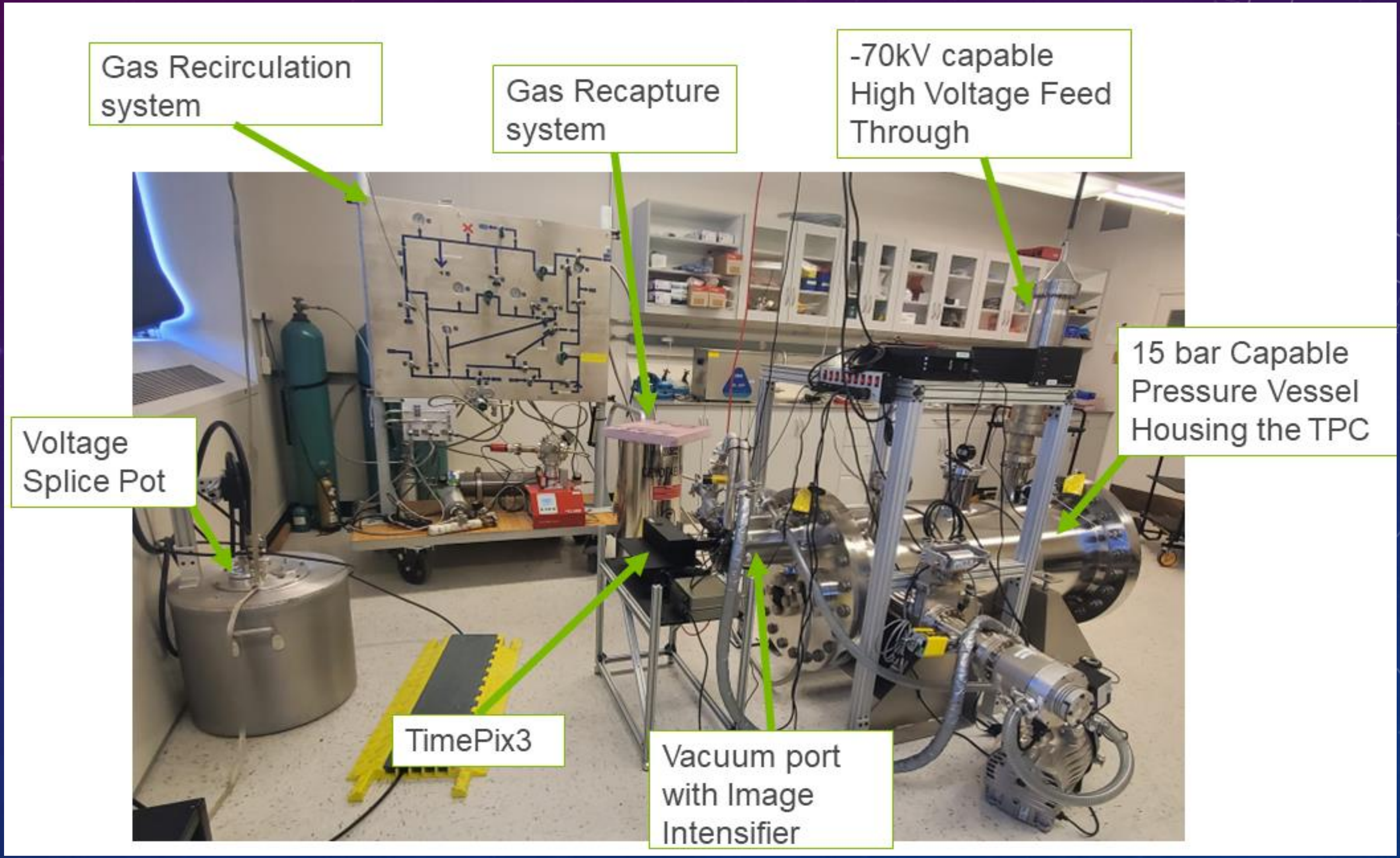
- By putting a reticle where the image intensifier's virtual image will be we were able to adjust the lens position within the end cap

Focusing the optical system in VUV

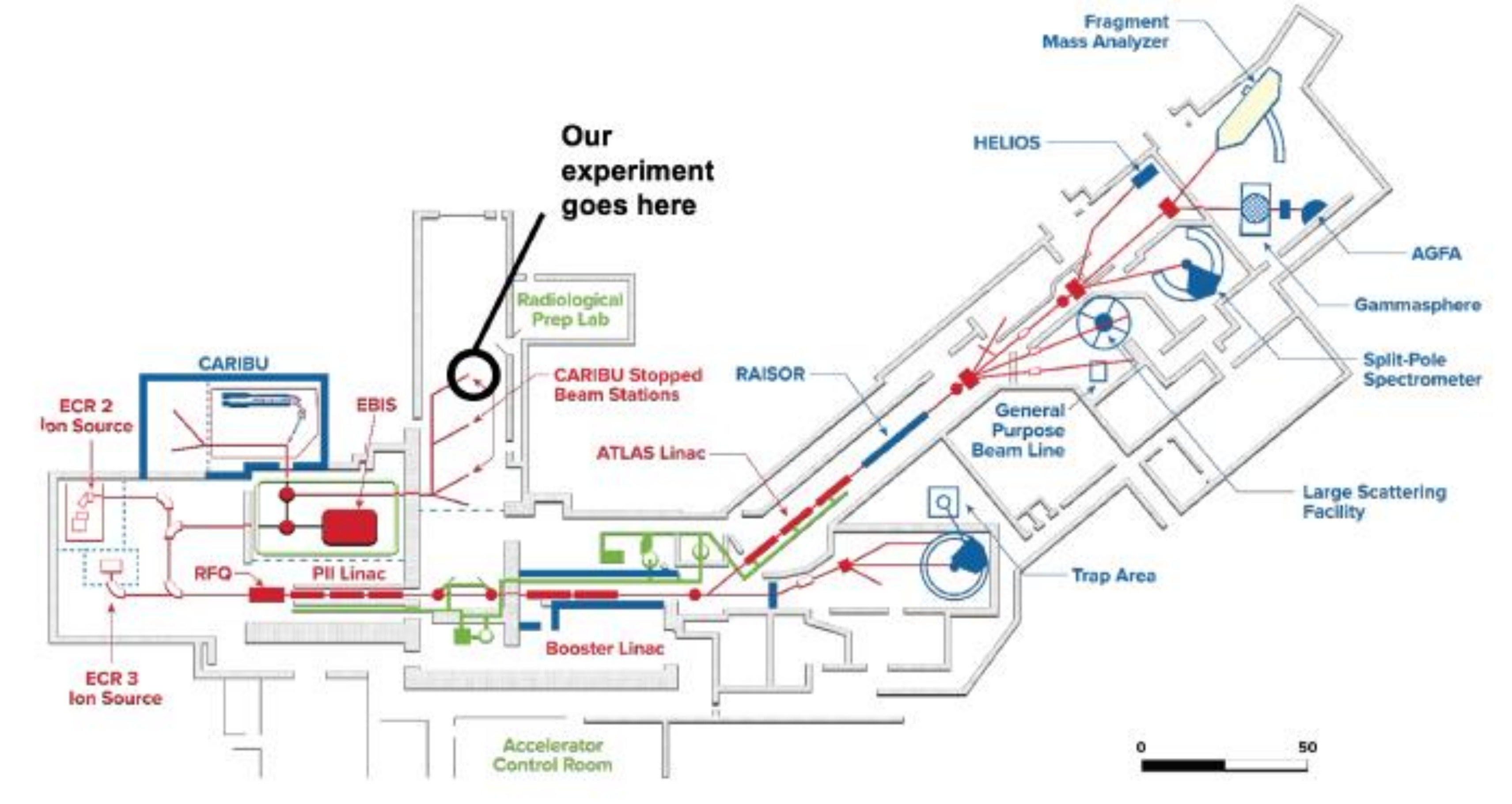
$$(1)\ Ar_2^* \rightarrow 2Ar + h\nu_1,$$
$$(2)\ h\nu_1 + Xe \rightarrow Xe^*,$$
$$(3)\ Xe^* + Xe \rightarrow Xe_2^*,$$
$$(4)\ Xe_2^* \rightarrow 2Xe + h\nu_2.$$

- We have a small amount of xenon in hand but not enough to fill the vessel at a suitable pressure
- We run using a mixture of 3% Xe, 97% Ar which turns all excitations into 175nm

CRAB lab at Argonne

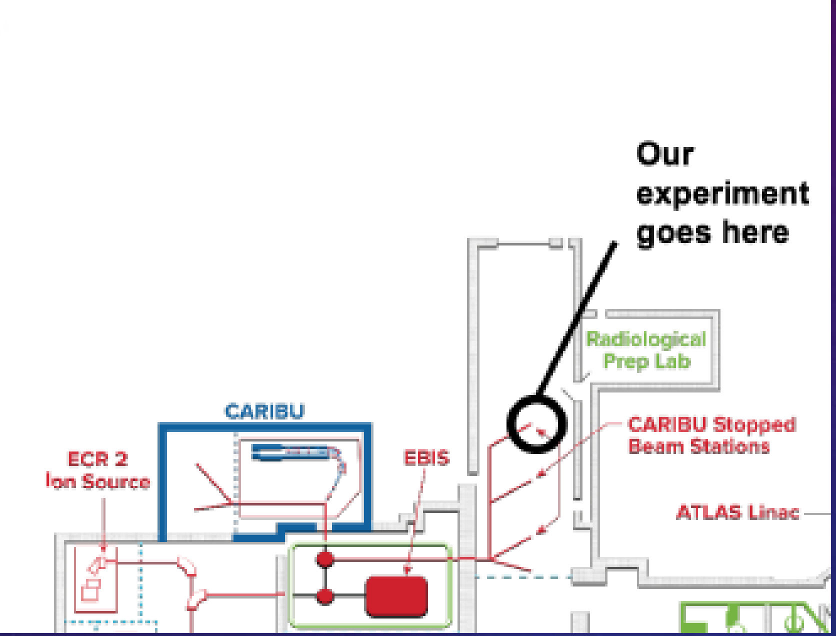


Measuring Efficiencies of Components



Use CARIBU to extract Ba^{144} and get key insight into barium tagging R&D

Measuring Efficiencies of Components



First stages of testing can be done in low pressures up to 500 mbar

Only need this portion of ATLAS for a 200keV acceleration energy

Need to find a reliable way to get the barium from vacuum into gas

Lower Background Run?

Conclusions

A TimePix Camera plus Image Intensifier could provide a more radiopure option for tracking than SiPMs

Argonne will demonstrate 3d tracks with a fast optical camera

Argonne has the ability to provide a barium beam to test barium tagging components in situ

Colorado School of Mines has just joined the CRAB effort!