# Demonstration of NEXT-CRAB-Optical TPC at High Pressure Xenon

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next

U.S. DEPARTMENT OF ENERGY

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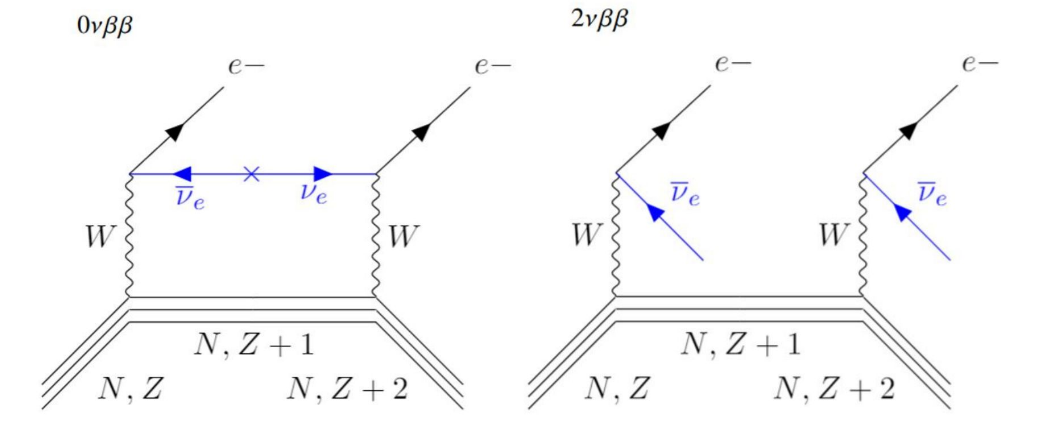
ADT UTA Center for Advanced Detector Technologies

# Overview

- Motivation
- Detector Layout
- S2 Light Yield Characterization.
- Direct Track Observation.
- Transverse Diffusion Measurement (Preliminary)
- Conclusion and Summary

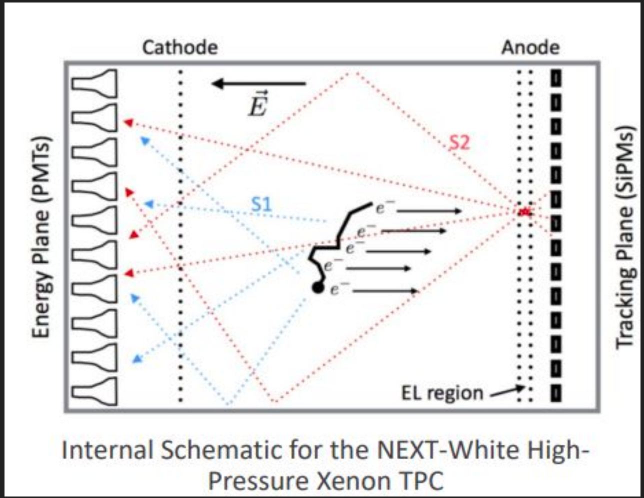
# Neutrinoless Double Beta Decay

- Observing this radioactive decay very crucial because
  - Proves Majorana nature of neutrinos
  - First violation of lepton number conservation.
    - Might Explain why there is more matter than antimatter (Leptogenesis)
  - Help to measure neutrino mass

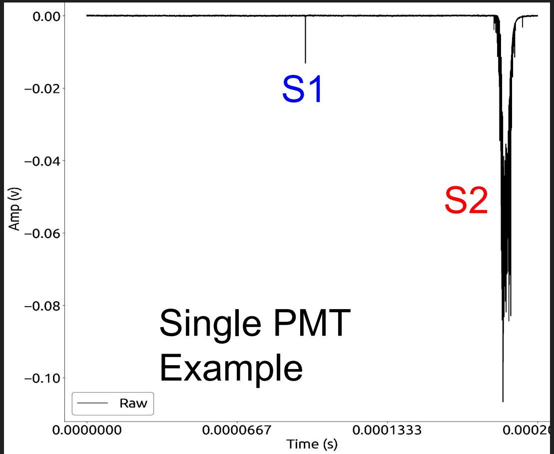


# The Concept of NexT

- High Pressure Xenon
  - 10 to 15 bar
  - Has good energy resolution.
- Optical TPC with an electroluminescent region that converts Ionization electrons into photons with wavelength of 172 nm
- Has energy reconstruction and tracking capabilities.



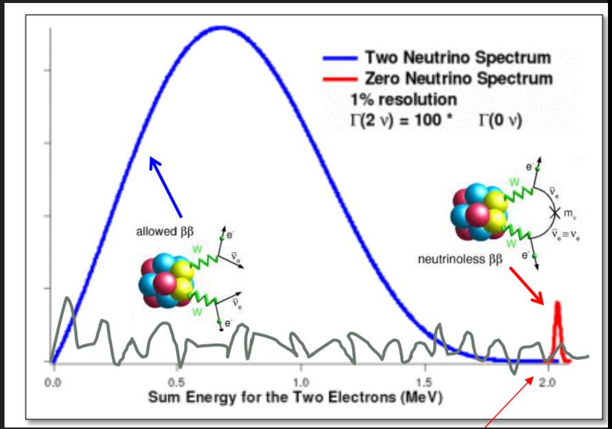

**Optical TPC**

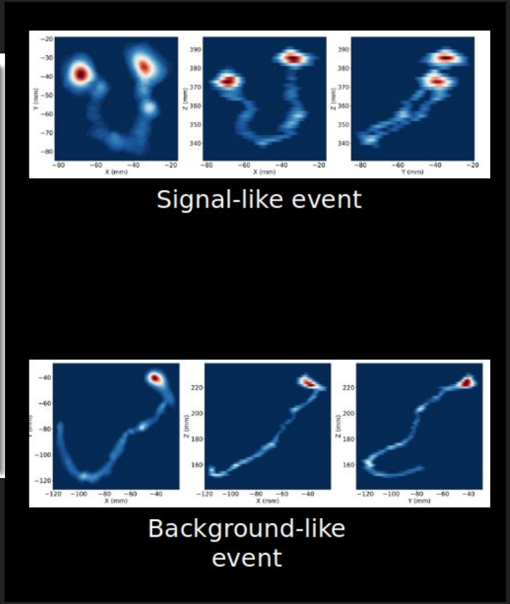


# Detection 0vBB

$$Xe^{136} -> Ba^{+2} + 2e + 2v(0v)$$

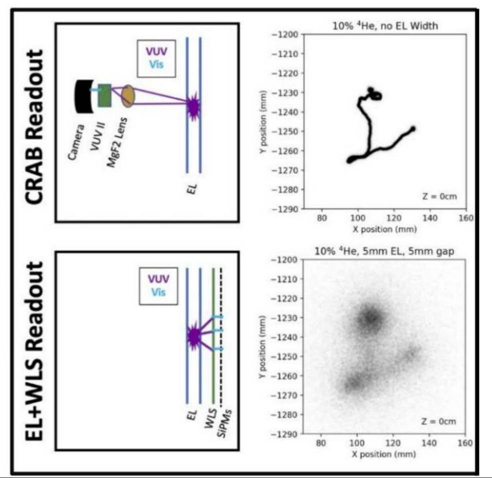
- Larger Volume
  - With Enriched Xe-136.
- Background Reduction
  - Removing Impurities
    - Gammas from Uranium and Thorium Chains.
  - Barium tagging  with RF Carpets (Karen’s Talk Plenary Session)
- Topological Identification
  - SIPMs
  - Camera Redout
    - NEXT-CRAB-0
      - EMCCD (UTA Group)
    - NEXT-CRAB-1
      - TimePix3 Camera (ANL)

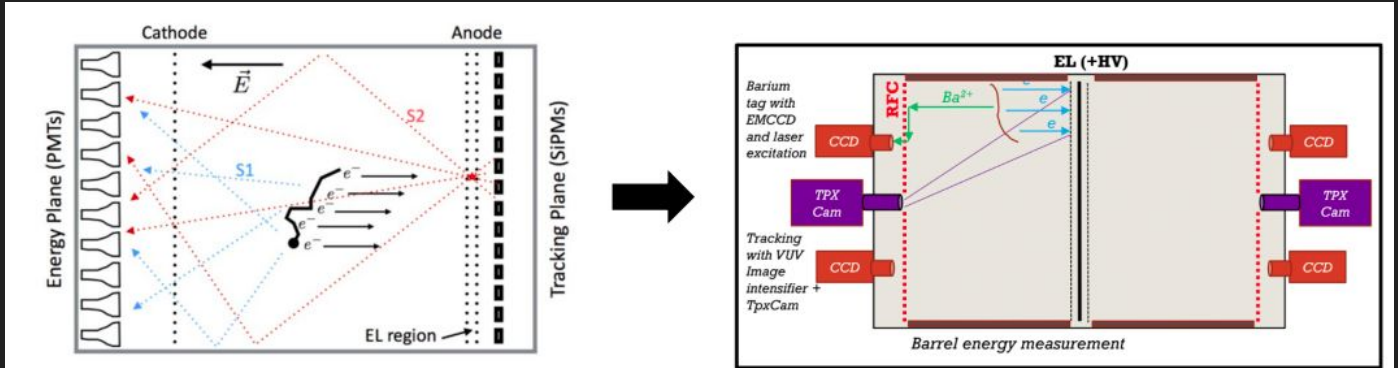


# Why coupling fast camera with UV Image Intensifier?

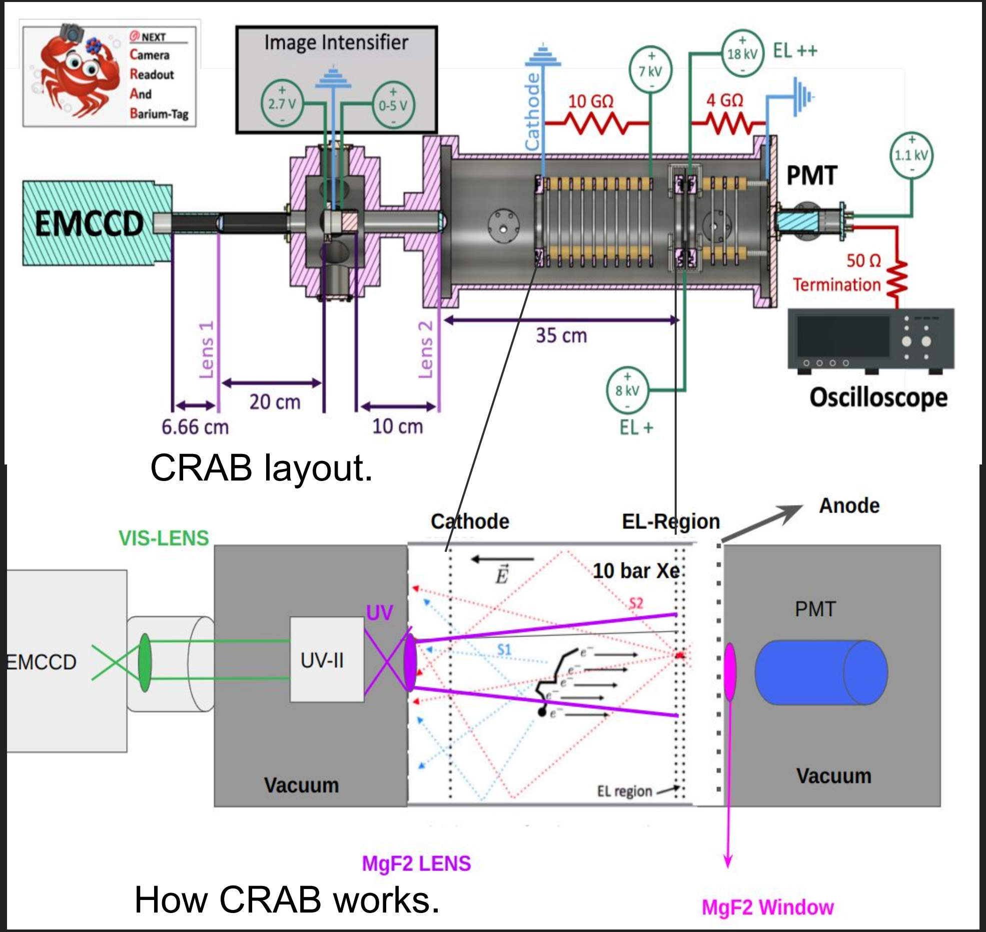
- Better track sharpness
  - SIPMs have good PE resolution and timing yet track resolution depends on how close they are to EL-Region.
- Direct UV detection
- Larger solid angle that could cover the most of the EL-region.



# CRAB0 Prototype

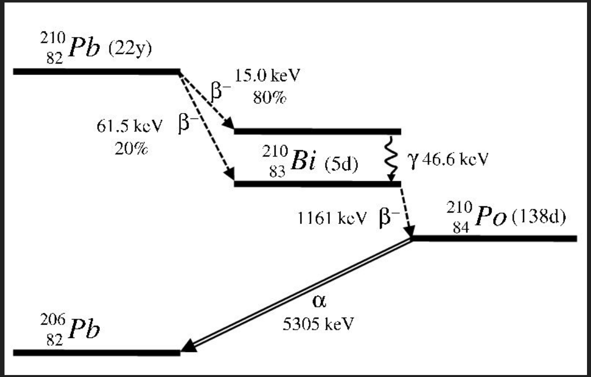
- Hamamatsu imagem X2 EMCCD
- Photonics VUV II
- Optical TPC
- Active Region
  - Length: 19.61 cm
  - Field Ring Diameter: 8.6 cm
  - Mesh diameter: 7.2 cm
  - 7 mm
- Hamamatsu UV Sensitive PMT
  - Position in front of MgF2 Window
- 2 Lens
  - Visible Lens (LENS 1)
  - MgF2 Lens (UV Sensitive) (LENS2)
- Constructed by
  - Nick Byrnes
  - Dr Leslie Rogers
  - Jackie Baezo
  - Ivana Moya



CRAB layout.
How CRAB works.

# S2 Light Yield Characterization

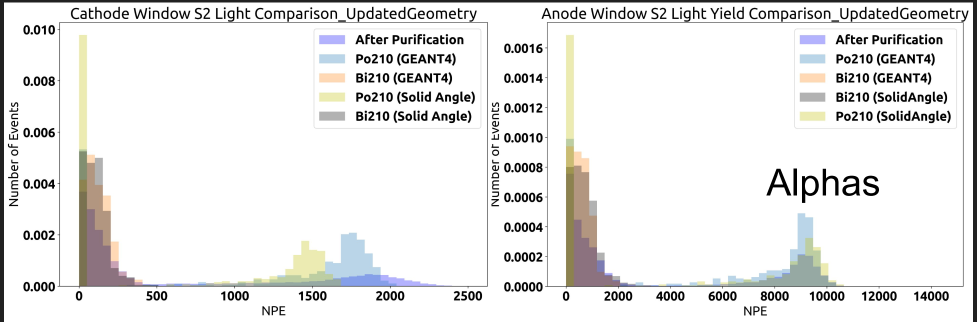
- Image Intensifier is replaced with a PMT
  - Calibrated by 430 nm LED insute
- Pb-210 needle source is placed at 5 cm away from EL-Region.
- Since alpha particles fully contained, we have focused on alpha particles in this study.
- 10 bar Xenon with a day of purification.



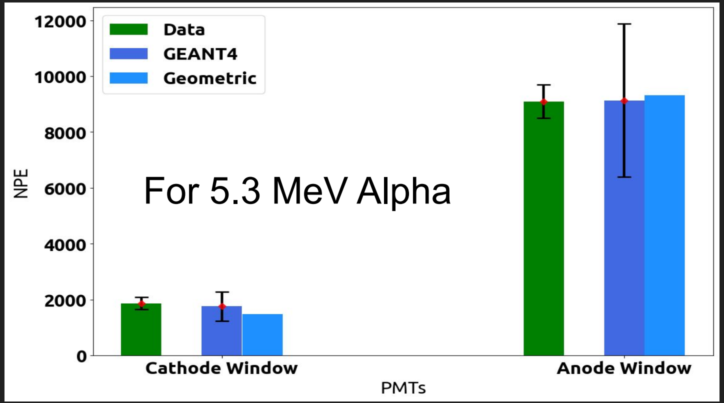

Pb-210 Decay Chain

# S2 Characterization Results

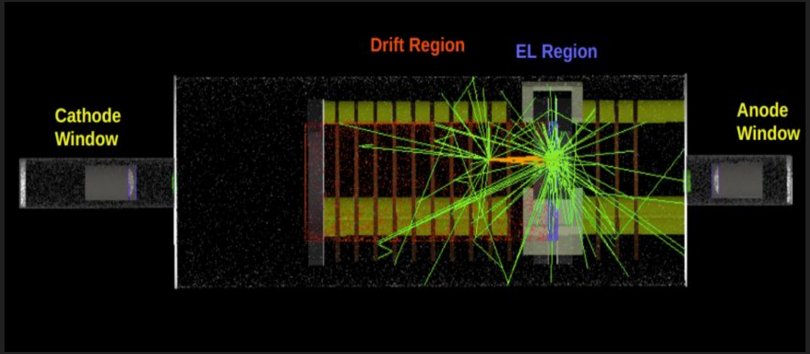
- Waveforms are collected for each PMT and NPE extracted from the area of the S2 Pulses.
- Amount of NPEs in each PMT is also simulated with GEANT4.




**GEANT4 and Data Comparison**



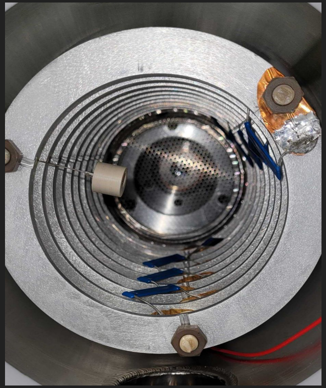

**Light yield estimation for Alphas**




**GEANT4**

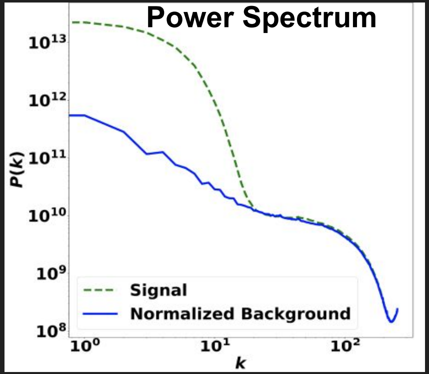
# Direct Track Observation

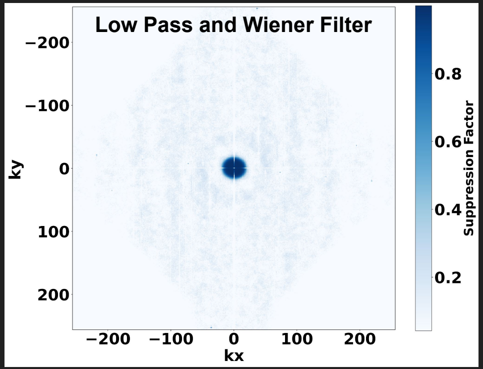
- Collimated Pb-210 Needle Source.
- Placed Backed the Image Intensifier.
- Images collected for tracks and background after purification.
- Data Driven Filter is constructed from the Signal and Background.



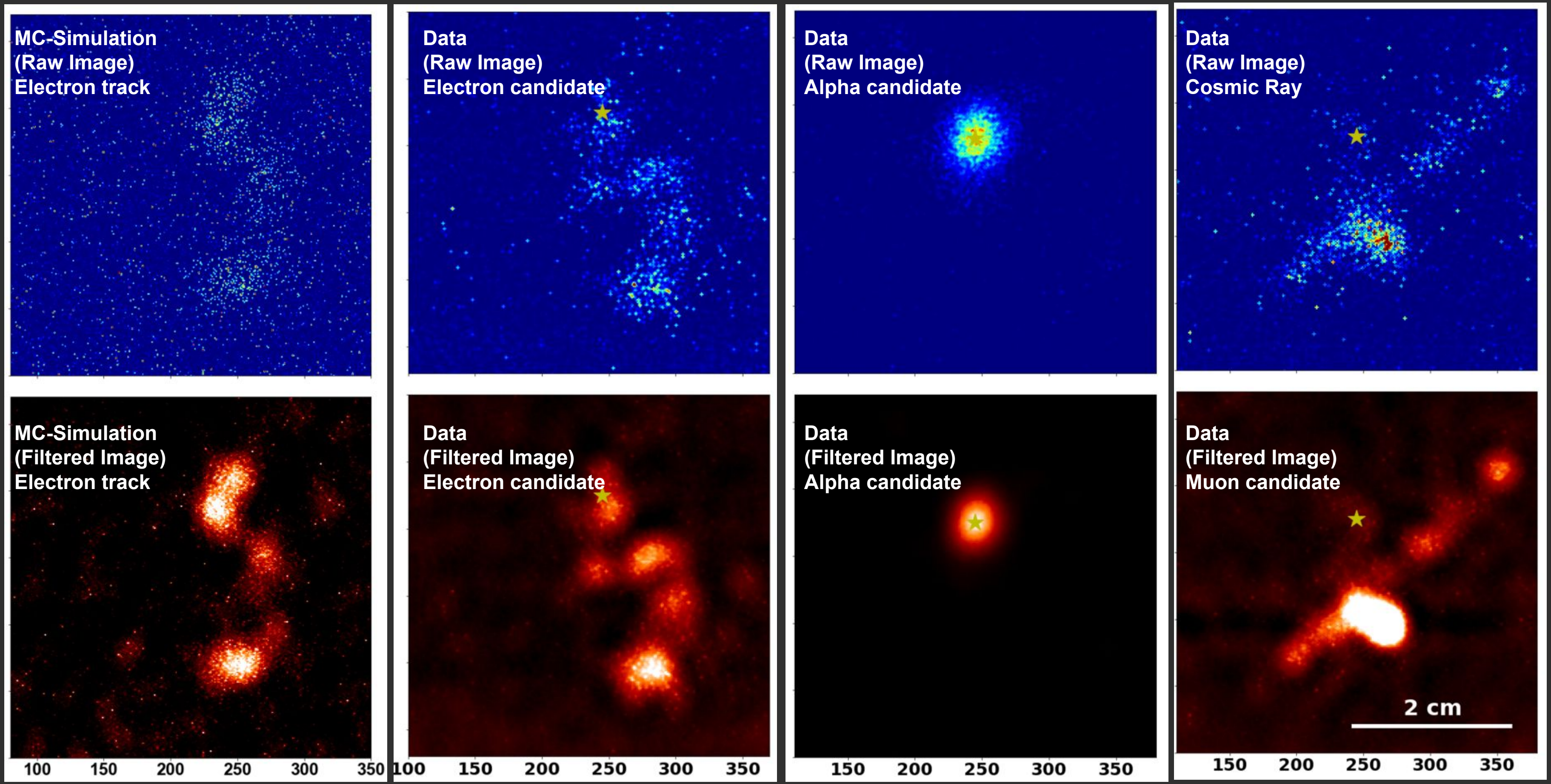
Collimated Needle


First Images



# Direct Track Observation Results

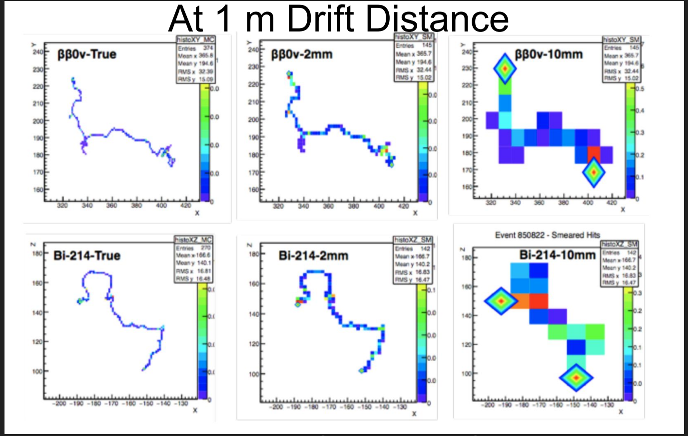



https://iopscience.iop.org/article/10.1088/1748-0221/18/08/P08006

Nick Byrnes and Ilker Parmaksiz

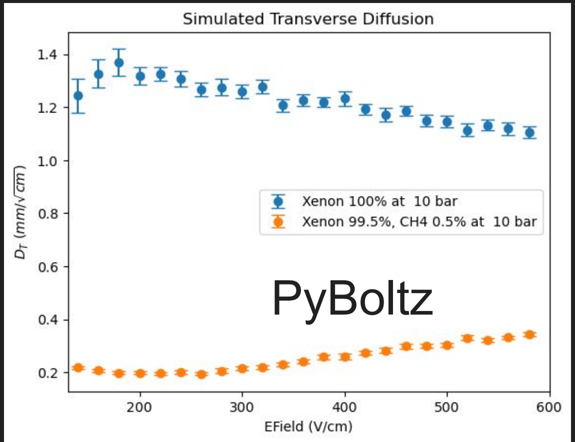
# Electron Diffusion

- Transverse Diffusion
  - Spread of Ionization electrons perpendicular to e-field
- Longitudinal Diffusion
  - Spread of Ionization electrons parallel to e-field.
- Expected Transverse Diffusion in pure Xenon at 10 bar is close to 1.2 mm/sqrt(cm) and 0.4 mm/sqrt(cm) with a typical drift fields.
- It is clear that diffusion in pure xenon will be detrimental to the topological identification of the two electrons.
- There are some gas additives can improve the transverse diffusion such as CH4,CO2,He,and CF4.




https://arxiv.org/pdf/1511.07189.pdf

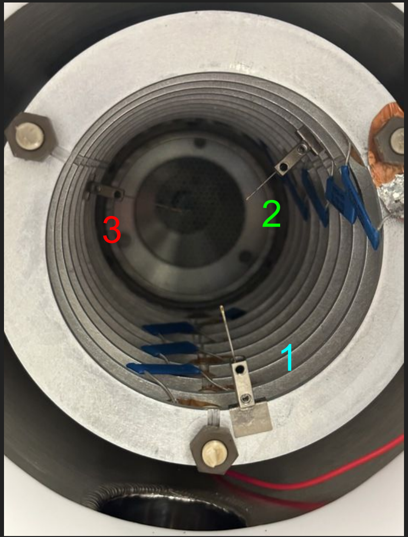
**Increasing Diffusion**



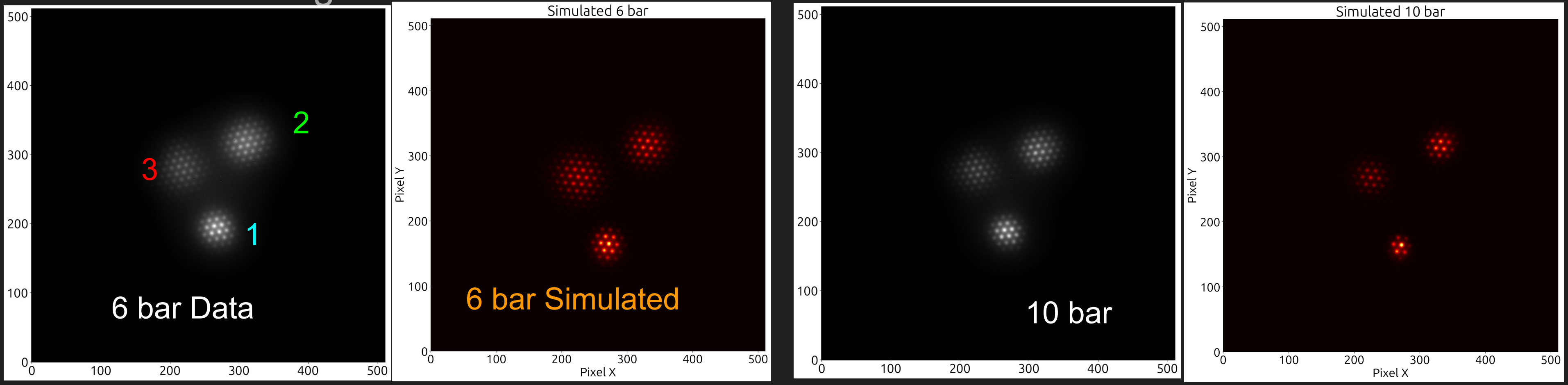

https://github.com/UTA-REST/PyBoltz

# CRAB-0 Diffusion Setup

- 3 Pb-210 sources placed in the field cage at varying distances from the EL-region
  - 4cm , 10cm , and 14cm
- After a day of purification
  - 440 V/cm drift field
- Images are collected for alpha particles at 6 bar and 10 bar High Pressure Xenon.




Position of the Sources



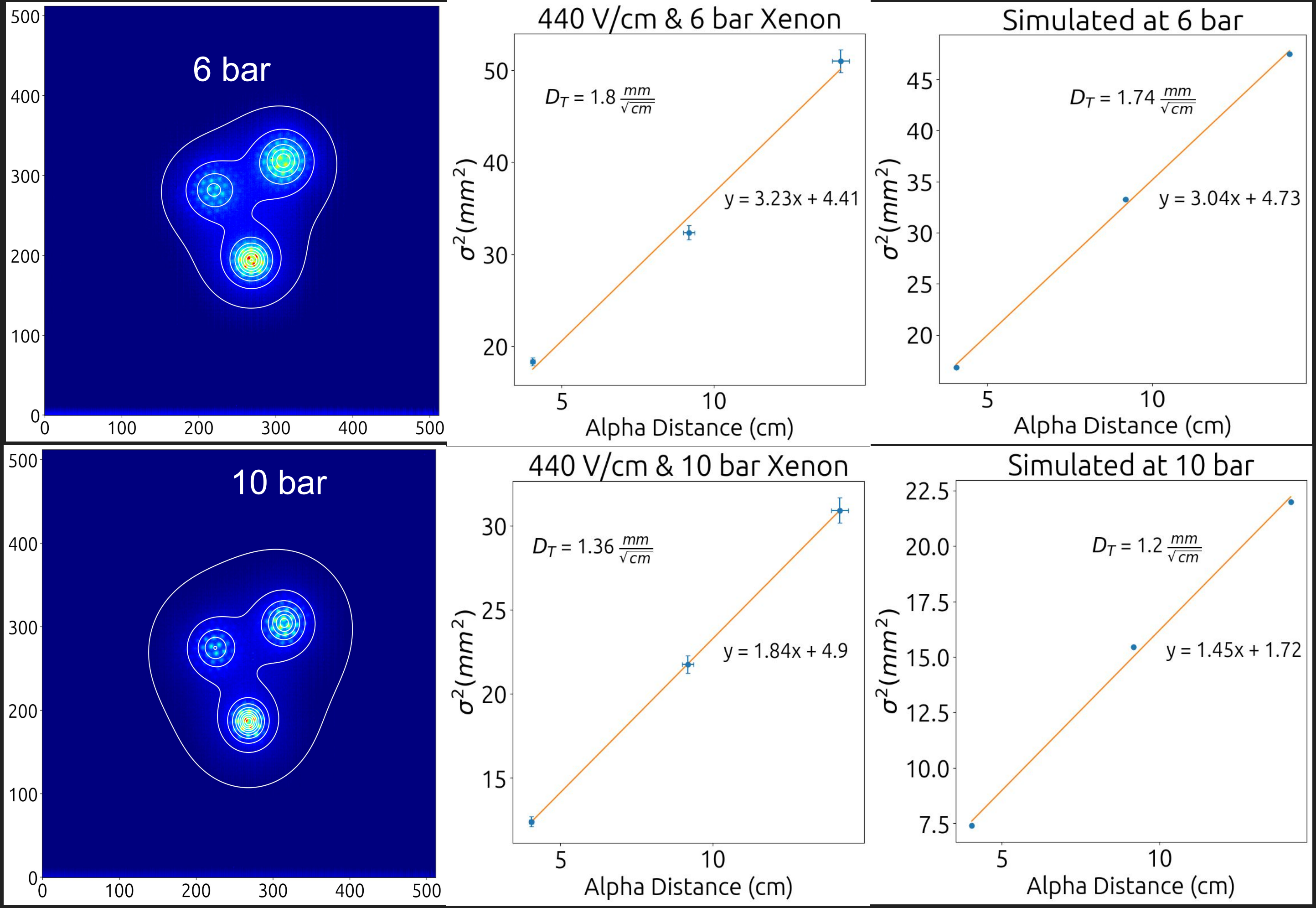
# Preliminary

- 440 V/cm

$$\sigma^2 = \sigma_T^2 + \sigma_{EL}^2$$

$$\sigma^2 = (2Dz) + \sigma_{EL}^2$$

$$D_T = \sqrt{2D}$$



# Conclusion and Summary

- CRAB is one of the prototypes that has potential to improve topological identification of electrons from Neutrinoless double beta decay events.
- We have successfully imaged xenon scintillation light is possible with UV sensitive imaging Intensifier in High Pressure Xenon.
    - Published and accepted.
- We are also working on measuring Diffusion in Xe-CH4 Mixtures.

PAPER

**NEXT-CRAB-0: a high pressure gaseous xenon time projection chamber with a direct VUV camera based readout**

N.K. Byrnes[1], I. Parmaksiz[1], C. Adams[2], J. Asaadi[1], J. Baeza-Rubio[1], K. Bailey[2], E. Church[3], D. González-Díaz[4], A. Higley[2], B.J.P. Jones[1] + Show full author list

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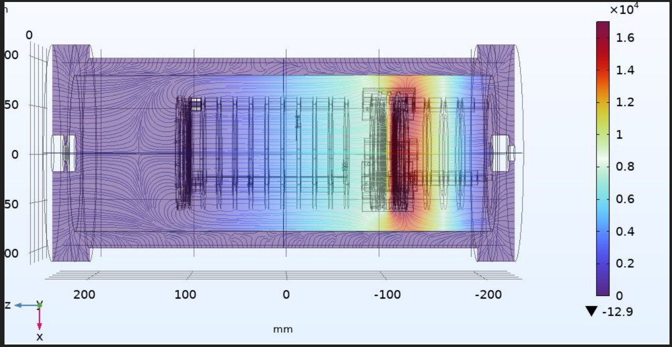
# Thank you for your attention!

Any Questions?

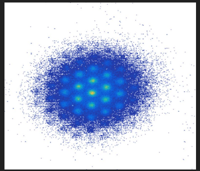
# Backup Slides

# Simulations Tools

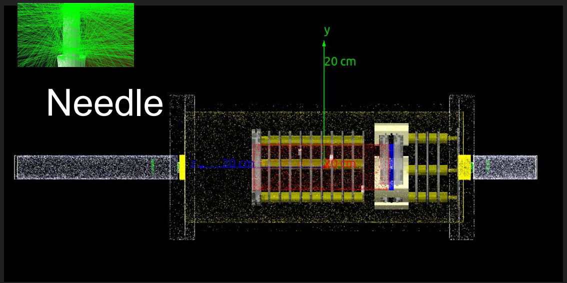
- COMSOL
  - E-Field Simulations
    - Potential field map
    - Mesh information
- Degrad
  - Handles Photon Medium Interactions
    - Ex: photoelectric effect.
- NEST
  - Scintillation and Ionization Yields
  - Produce ionization-electrons and Scintillation photons hands it to GEANT4
- GARFIELD++
  - Computes the transverse diffusion,longitudinal diffusion,and drift velocities. according to potential field map and mesh information from comsol.
  - Drifts Ionization electrons.
- GEANT4
  - Communicates with NEST and Garfield++, and Degrad
    - Credits to **Dr Eric Church** and **Dr Krishan Mistry**
  - Photon Propagation and Position and Momentum Information.
  - Hybrid of CSG and STL
  - Alpha Sampling from the surfaces of 3 needles.
- Opticks Integration
  - Photon Propagation using GPUs
  - Work in Progress.




COMSOL, Francisco UTEP



Simulated Alpha event




Needle

GEANT4

# Generalized Wiener Filter

- Data Driven Filter
- Reduces the common background noise.
- Power Spectrum is obtained by taking the FFT, then taking absolute value of the FFT and squaring it.
- S_ij is signal background power spectrum
- B_ij is the background power spectrum
- Constructed two wiener filters
  - 2D Wiener filter
  - 1D Wiener filter

$$W(ij) = \frac{S_{ij}}{S_{ij} + B_{ij}}$$

**Wiener Filter**

$$S_{mp} = S_{ij} + B_{ij}$$

**Observed Track  Power Spectrum**

$$W_{mp;ij} = \frac{S_{mp} - B_{ij}}{S_{mp}}$$

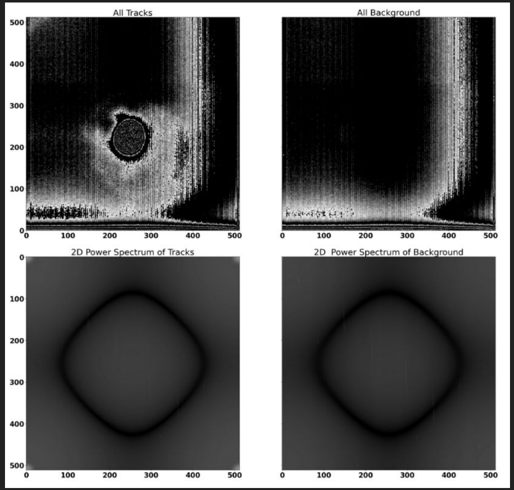
**For one image each**

$$W_{mp;ij} = \frac{N}{N} \times \frac{\sum_{a=1}^{N} S_{mp}^{a} - \sum_{a=1}^{N} B_{ij}^{a}}{\sum_{a=1}^{N} S_{mp}^{a}}$$

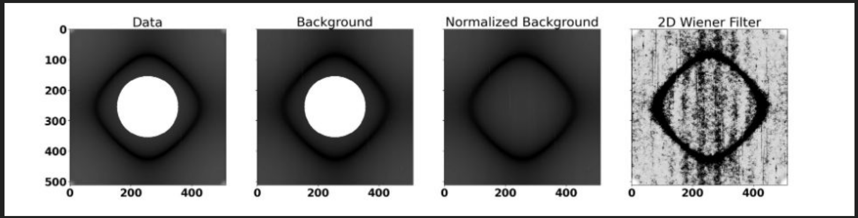
**For All the Images**

# Constructing 2D Wiener Filter

- Average Power Spectrum  for track and background images computed.
- Due to offset between background and signal. We normalized the background by taking the mean of the circular regions in the data and background, and obtaining ratio of them. Then multiply it with background.
- Using the equation from previous background. We constructed wiener filter.
- In 2D illustration of the wiener filter , darker regions are suppressed.
- Apply filter by
    - Taking the FFT of observed image
    - Perform element wise multiplication with Wiener filter.
    - Take the inverse FFT of the result.
    - Keep the real values, and image it.



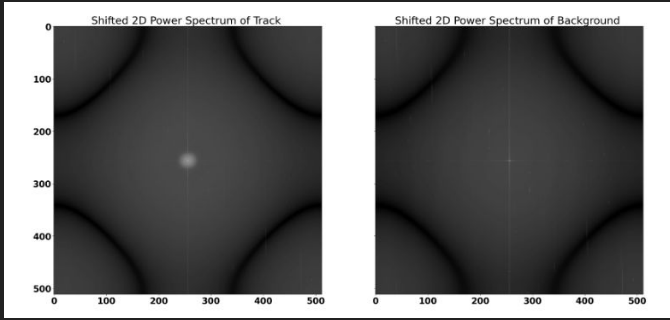

Average Signal and Background Images

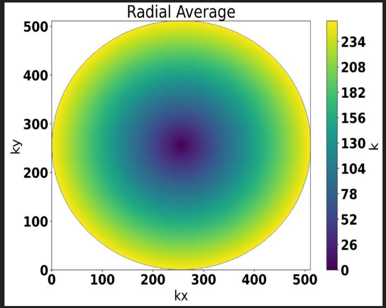


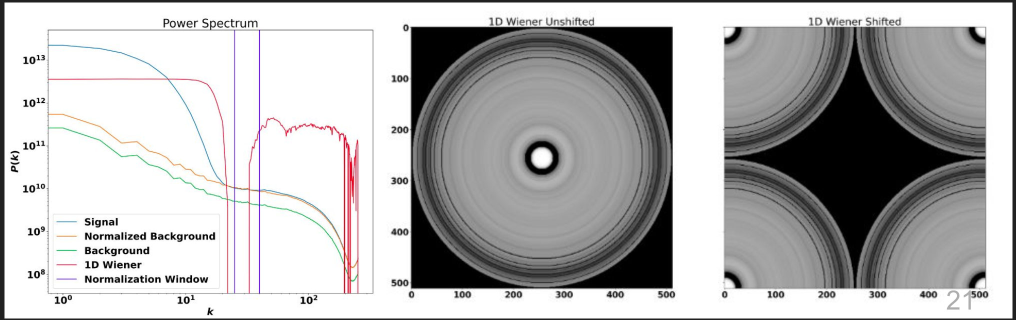

**Demonstration of 2D Wiener filter.**

# 1D Wiener Filter

- Using the 2D background and signal power spectrum , 1D power spectrum is computed by a method called radial averaging
  - By obtaining the mean of the data points between, two concentric circles with radius k, and k+1
  - Then k incremented by 1 until N/2
  - Results in 1D array.
- Radially distribute the filter in to a similar layout of the observed images.
  - This results in multidimensional array With wiener 1D wiener filter information.
- Apply the filter the same way of 2D Wiener filter.




1D Power Spectrum 1D Wiener Filter

# Alpha Track

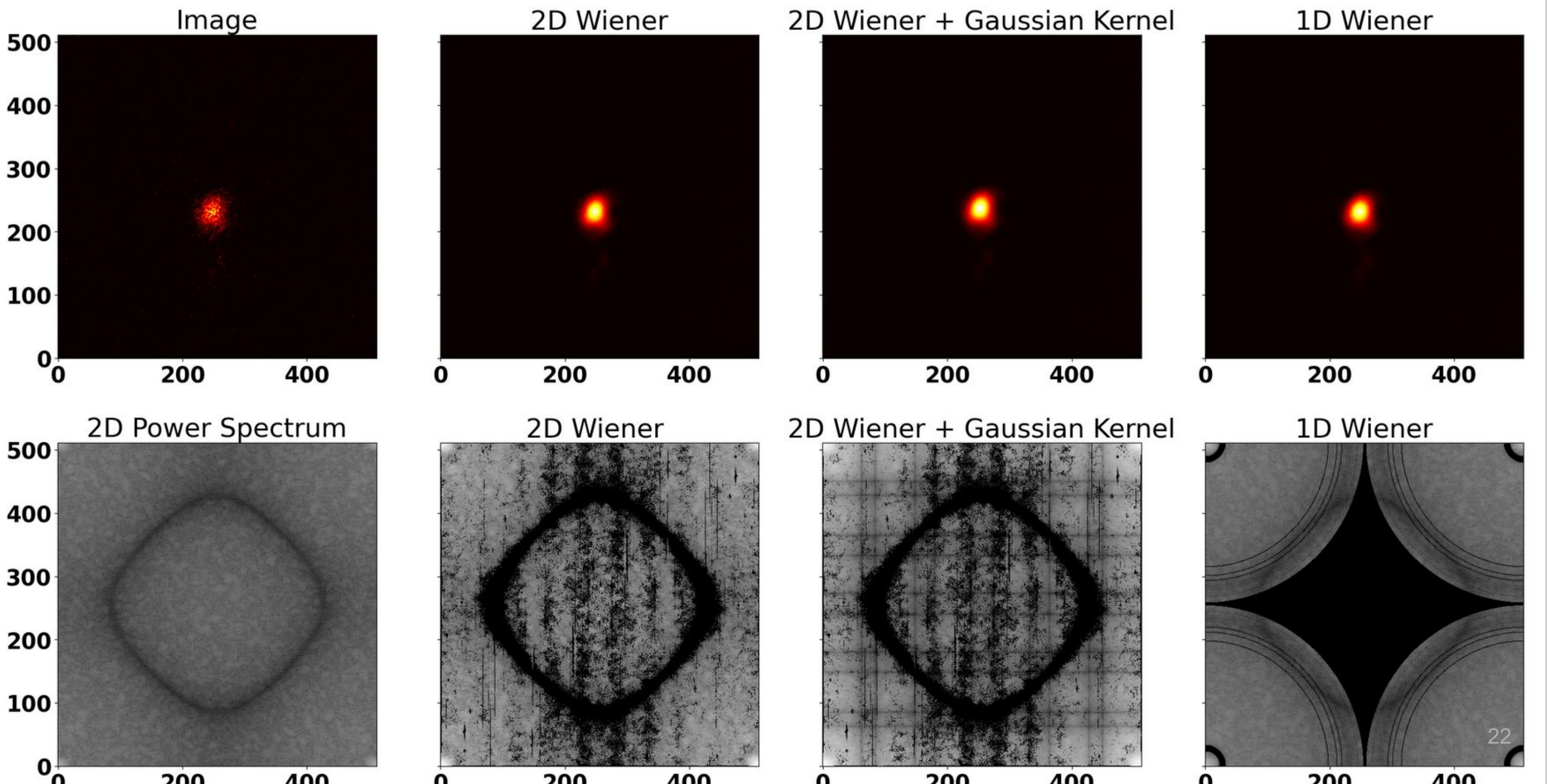
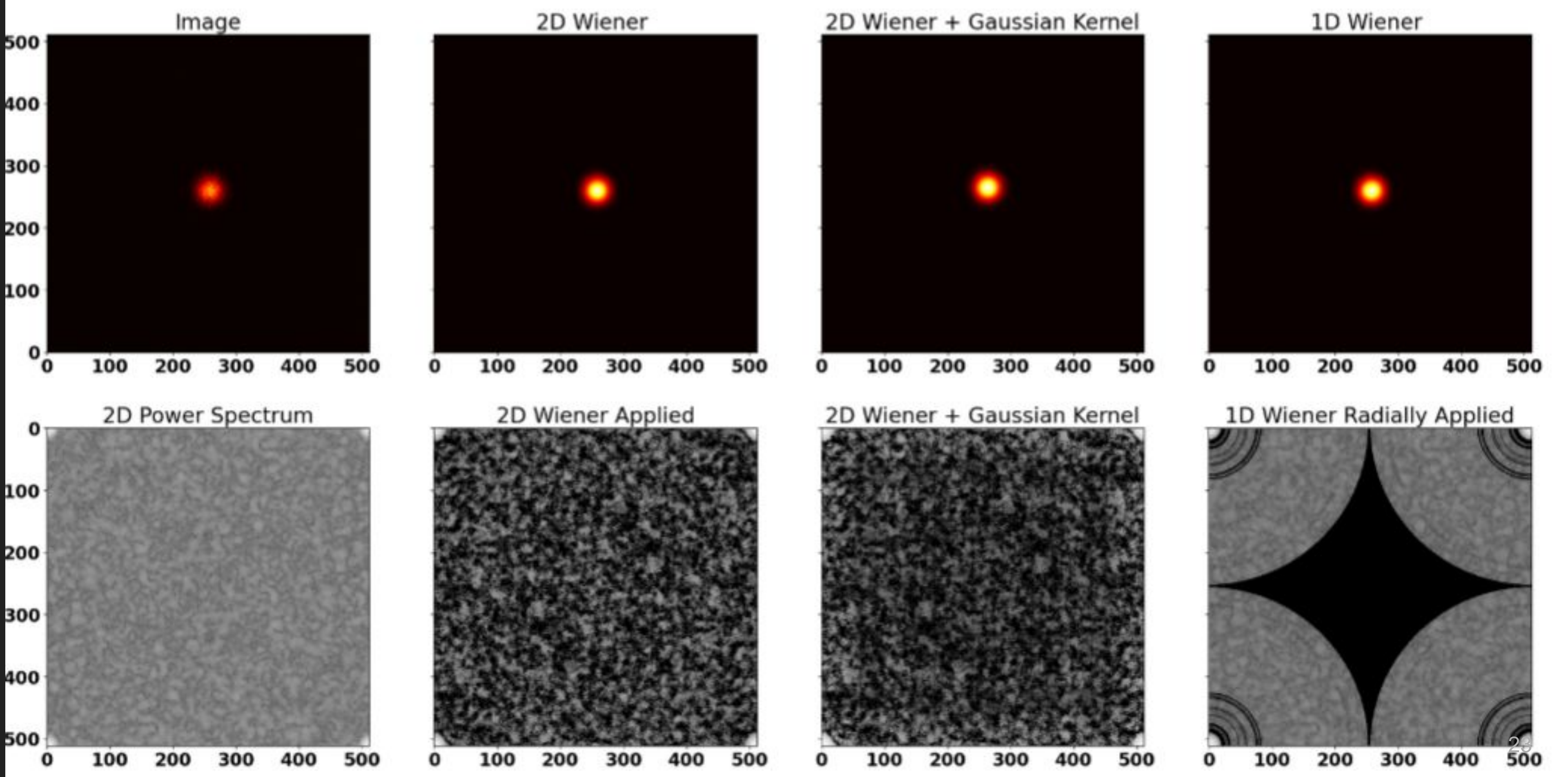
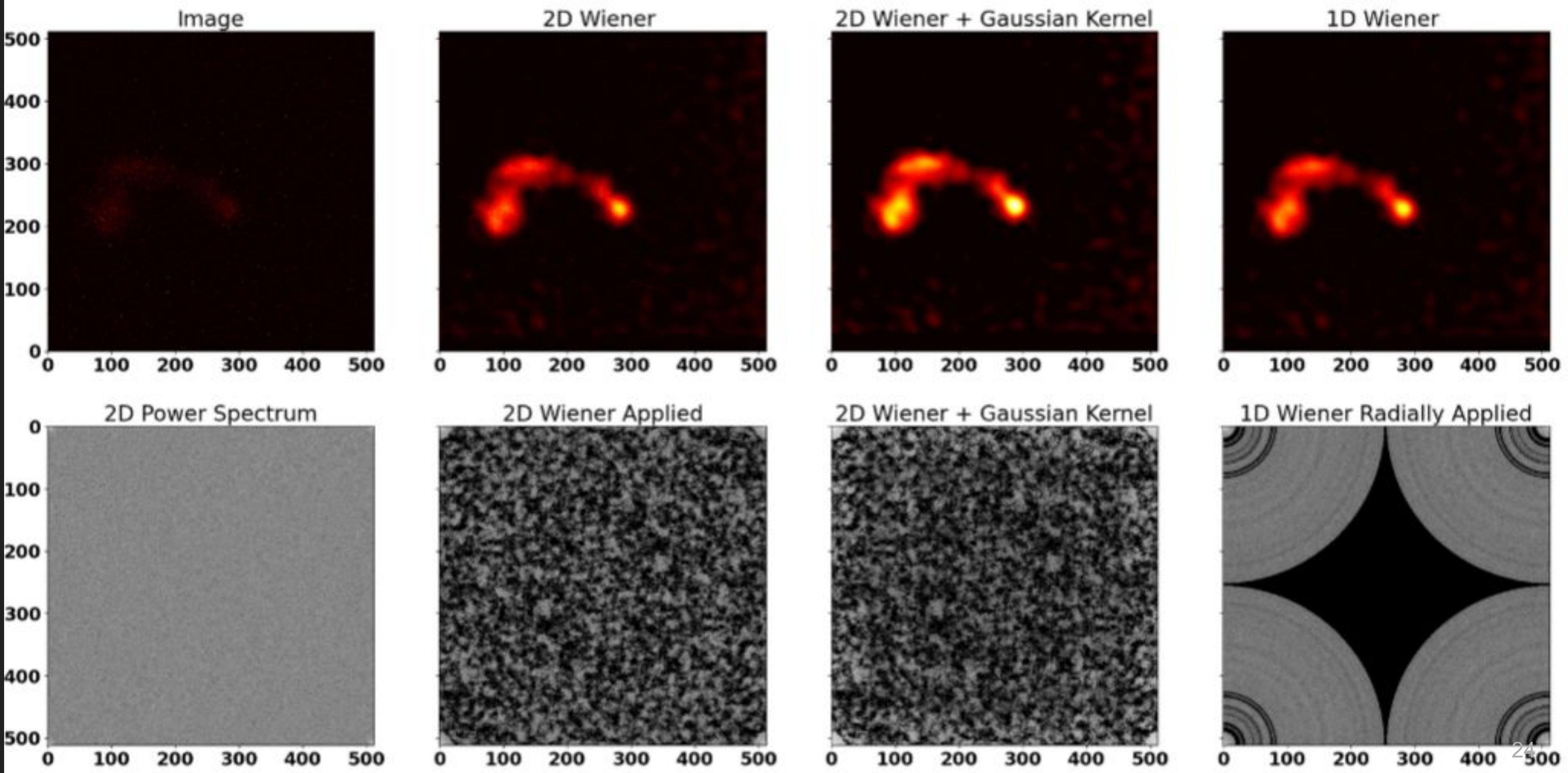


Image
2D Wiener
2D Wiener + Gaussian Kernel
1D Wiener
2D Power Spectrum
2D Wiener
2D Wiener + Gaussian Kernel
1D Wiener
0
100
200
300
400
500
0
200
400

# GEANT4 Simulated Alpa Track



# GEANT4 Simulated Beta Track



# Beta Track

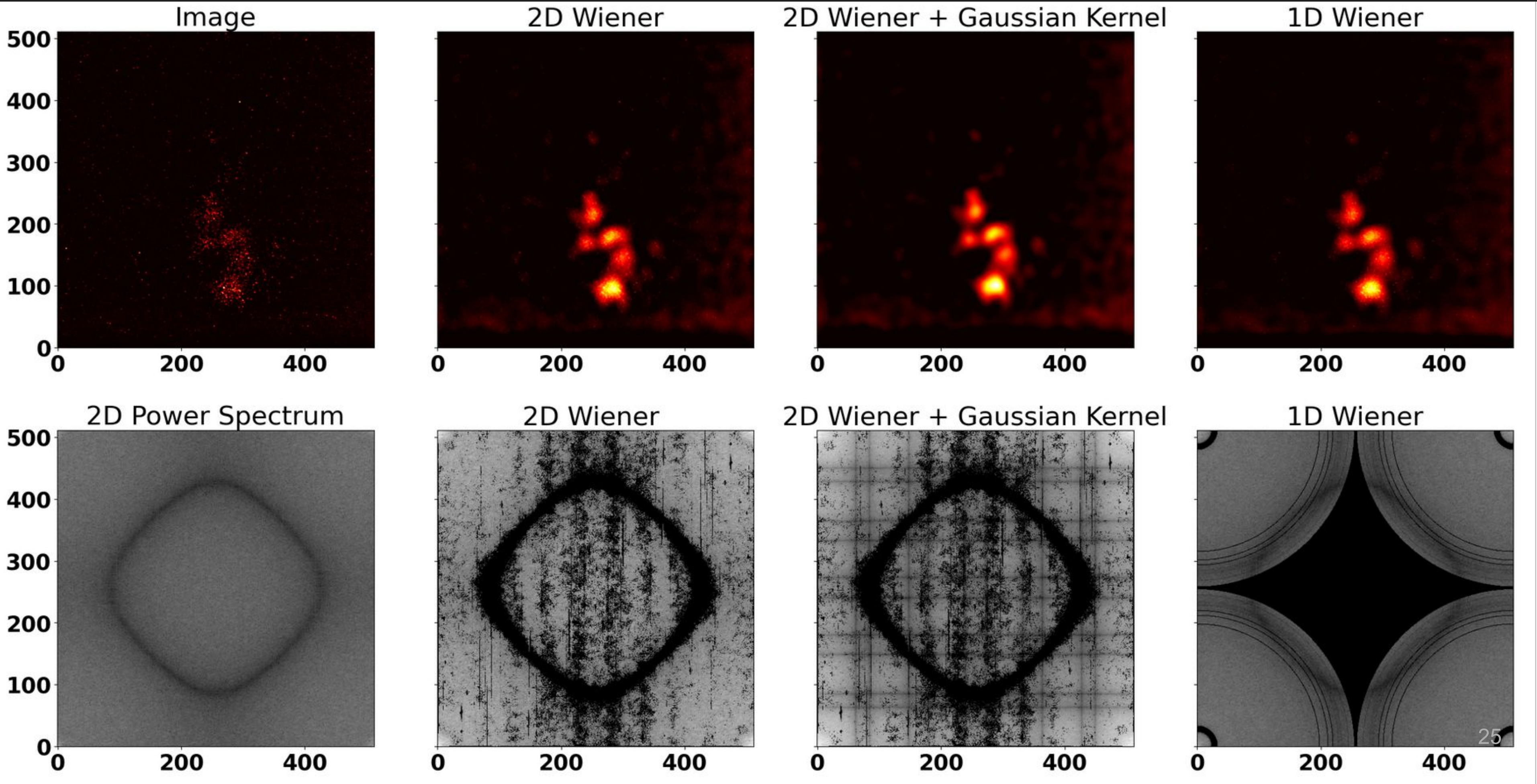
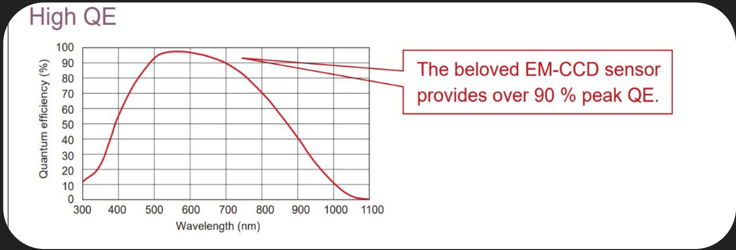


Image
2D Wiener
2D Wiener + Gaussian Kernel
1D Wiener
2D Power Spectrum
2D Wiener
2D Wiener + Gaussian Kernel
1D Wiener
0
100
200
300
400
500
0
200
400

# Hamamatsu imagem X2 EMCCD Camera

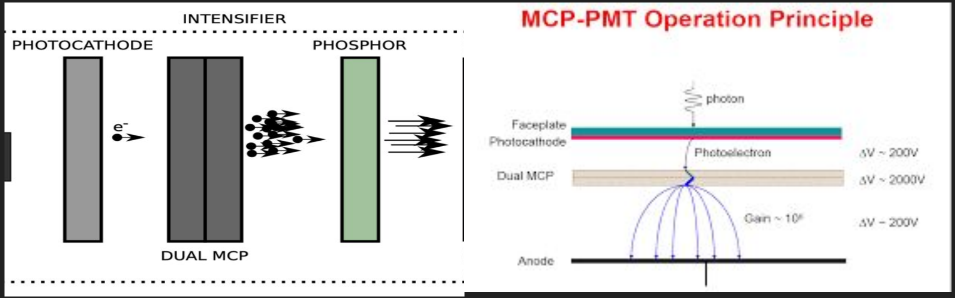
- Electron-Multiplying CCDs
  - Photoelectric effect
  - Silicon Pixel Arrays
  - Charge Accumulated in each pixel
  - This charge further amplified by Impact Ionization
- Single Photon Sensitivity
- 1076 frames/s (max)
- 90% QE
- 2D Tracking



# Photonics Image Intensifier

- Photoelectric effect
- Electron drifts to Dual-MCP and collides with chevron shaped dynodes result in secondary electrons.
- Multiplied Photo electrons strikes the phosphor screen and emits light at 520 nm.
- Gain of 10^6
  - Vis-Photons / UV-Photons
- 25% to 30 % QE

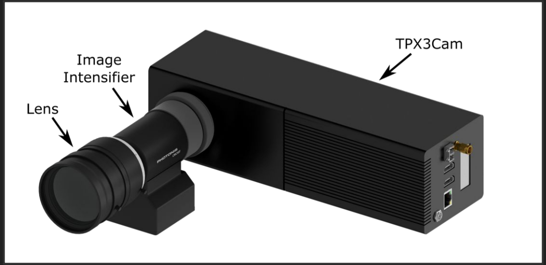

Photonics UV- Sensitive II




Working Principle Of Image Intensifier

# TimePix3 Camera

- An optical sensor bump bonded to a TimePix3 ASIC with a SPIDR readout Board.
  - 256x256 pixels
  - 55umx55um pixel size
  - 90 % QE at 420 nm
  - Single Photon Sensitivity
- Asynchronous hit based data driven readout
  - Adjustable threshold
  - 80 MHits/s
  - External Time Stamps with 200ps resolution.
  - 3D Raw Data
    - X and Y position of pixels
    - Time of Arrival (TOA)
      - 1.6 ns time resolution
  - Time Over Threshold (TOT) (Calorimetry)
    - 10 bit resolution
      - 2^10=1024 ADU (Max)
    - The length of time for which the charge remained over threshold.



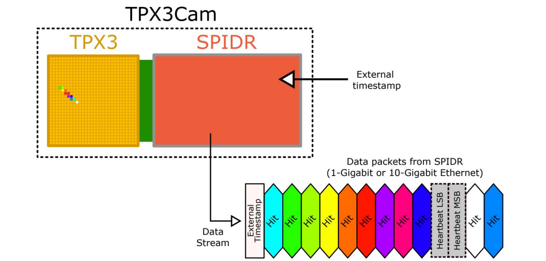




**Figure 5.** General overview of the operation of the SPIDR readout board. A continuous stream of data packets is generated by the SPIDR readout board, encoding all of the information taken during operation, including the external timestamps. The packets are transferred to storage via a 1 Gigabit Ethernet connection, and are then parsed and analysed offline. A more detailed description can be found in [28].