FERMILAB-SLIDES-24-0070-STUDENT

Fermilab U.S. DEPARTMENT OF ENERGY Office of Science

Characterization of Non-Science Grade DESI CCDs and Creating Additional ICARUS Monitoring Metrics for Data Quality

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SULI Spring 2024: Final Presentation

24 April 2024

a. This manuscript has been authored by Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the U.S. Department of Energy, Office of Science, Office of High Energy Physics.
b. This work was supported in part by the U.S. Department of Energy, Office of Science, Office of Workforce Development for Teachers and Scientists (WDTS) under the Science Undergraduate Laboratory Internships Program (SULI).

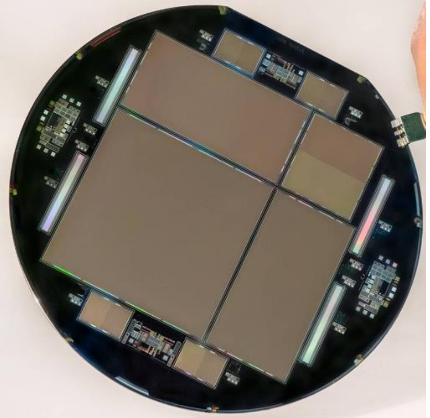
DESI: Dark Energy Spectroscopic Instrument

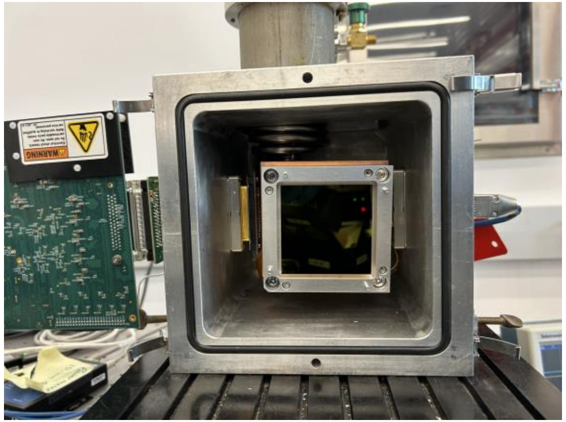
Introduction

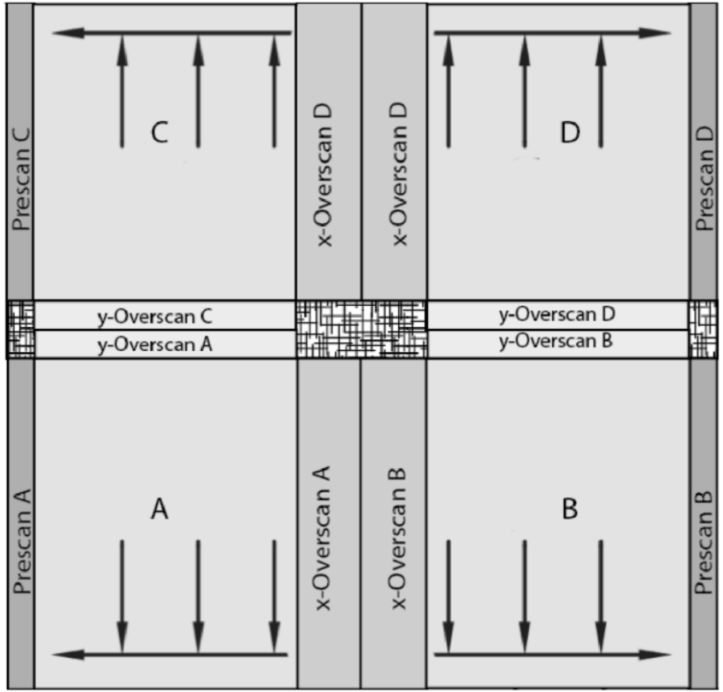
- Dark Energy Spectroscopic Instrument (DESI) main objective to is measure optical spectra of galaxies and large-scale structures to better constrain the effects of dark energy on the universe
  - DESI is stationed at the Nicholas U. Mayall 4-meter Telescope on Kitt Peak, Arizona
  - The project has been running for 3 years, and some sensors are failing and they need spares
- My focus was on building more robust data taking and analysis scripts to characterize current and future DESI CCDs
  - Photon Transfer Curve
  - Relative Quantum Efficiency
  - ETC.

DESI CCD

- Active Area: 4k x 4k pixels
  - Pixel size: $15\ \mu m^2$
- Single Readout
- Readout Noise (Expected): <5 e^-
- Wafer Thickness: $250\ \mu m$

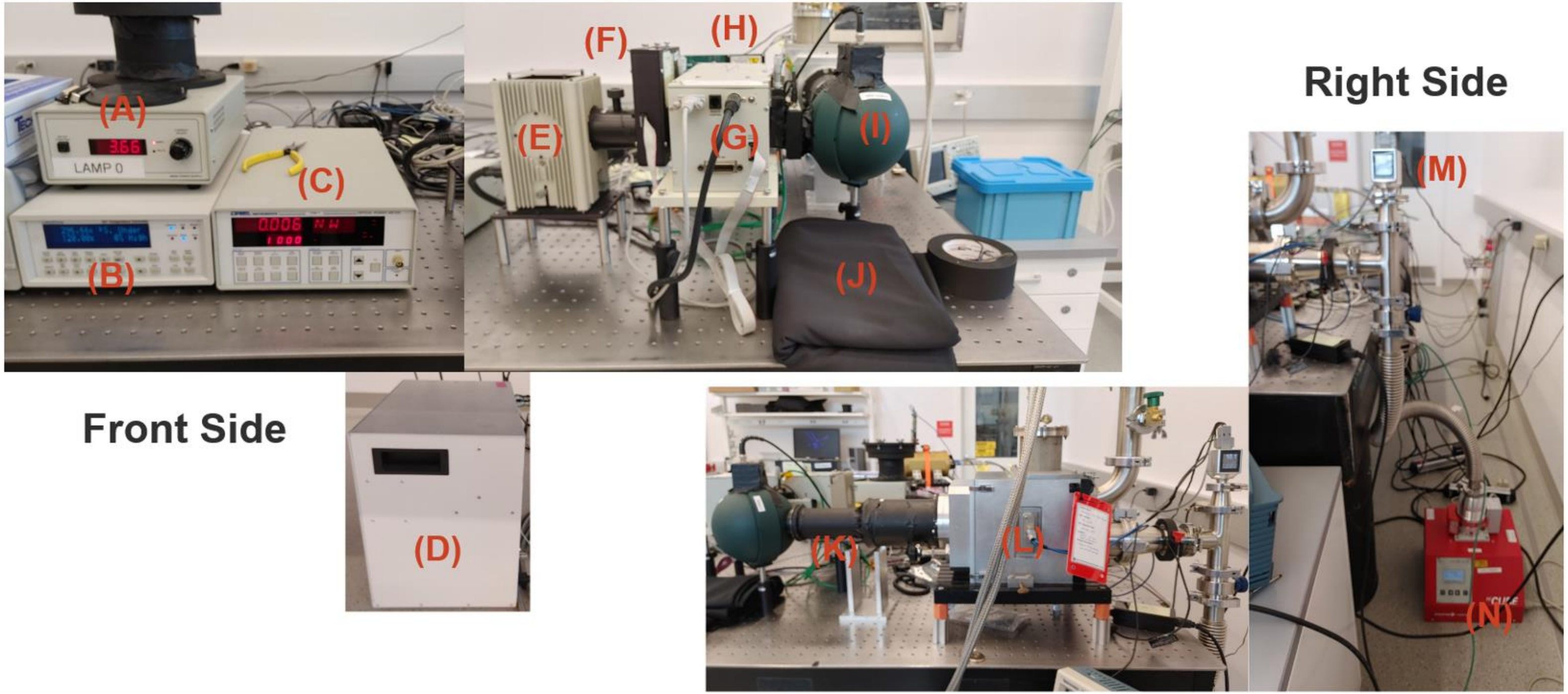






DESI CCD Readout
Amplifier Direction

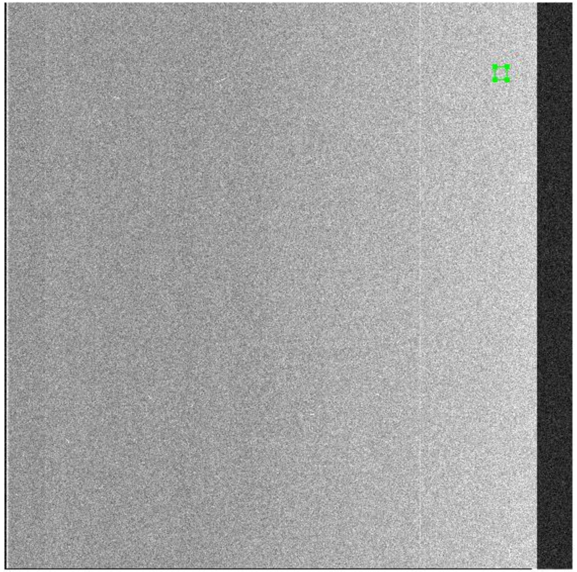
Setup



Front Side: (A) Halogen Lamp Power Supply, (B) Lakeshore Temperature Controller, (C) Optical Power Meter, (D) Cryocooler, (E) Halogen Lamp, (F) Filter/Grating, (G) Monochromator, (H) LTA, (I) Collimating Sphere, (J) Blackout Blanket.
Right Side: (K) Collimating Tube, (L) Vacuum Cube, (M) Pressure Gauge, (N) Vacuum Pump.

Data Analysis Region on DESI CCD

- Using nonscientific grade DESI CCDs, meaning silicon purity isn't the highest leading to charge traps and potentially broken readout channels
- **Data Taking Regions:**
  - **Active Scan Location:**
    - Rows: 1900 – 1950
    - Columns: 1900 – 1950
  - **Overscan Location:**
    - Rows: 1900 – 1950
    - Columns: 2100 – 2150



DS9 Image
2k x 2k Readout

Data Analysis

- **Photon Transfer Curve:** This curve allows us to calculate gain and see when full well occurs
  - Gain ($^{ADU}/_{e^-}$): Useful in converting ADU to e^- such as readout noise
    - Linear region of PTC

$$Gain \propto \frac{[M_{Image}]}{\sigma^2}$$

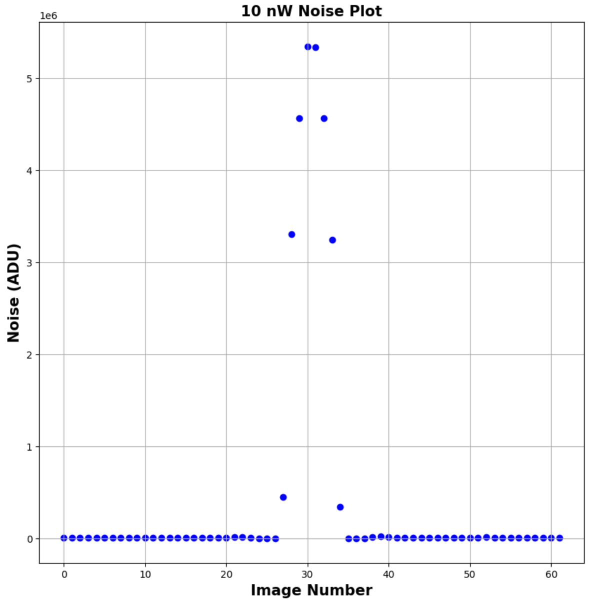
  - Full Well (e^-): When a pixel is filled with charge
    - Apex of linear region before drop-off

$$Full\ Well = \frac{[M_{Image}]}{Gain}$$

- **Relative Quantum Efficiency:** Useful in seeing how efficient the CCD is in a range of wavelengths (400 – 1000 nm)

$$RQE \propto \frac{[M_{Image}]}{WP}$$

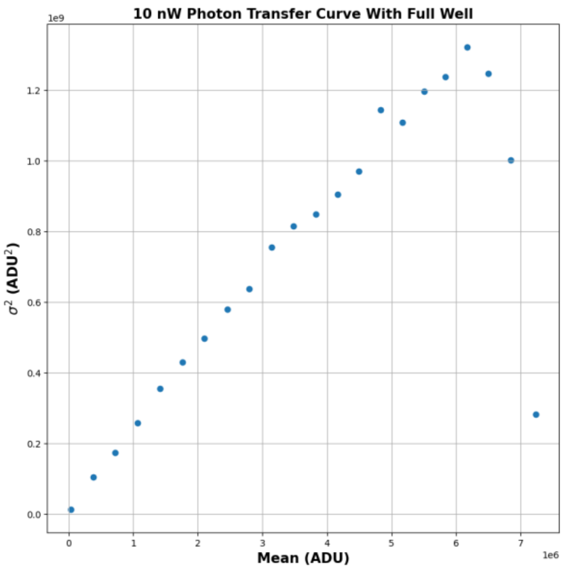
10 nW Readout Noise Plot



Can see an indication of the full well around 25 – 35 images
Using the first 20 images:

Readout Noise: 2,626 ADU

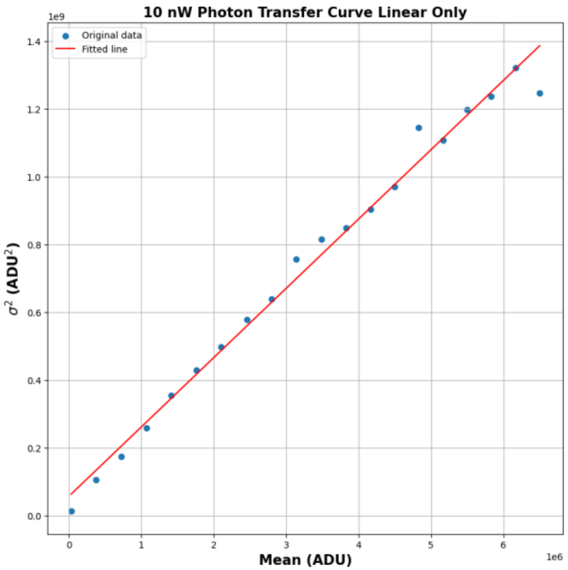
10 nW Photon Transfer Curve



First 22 Images: Full Well when linearity ends

Full Well: 40,074 $^{e^-}/_{pixel}$

Expect: 100,000 $^{e^-}/_{pixel}$



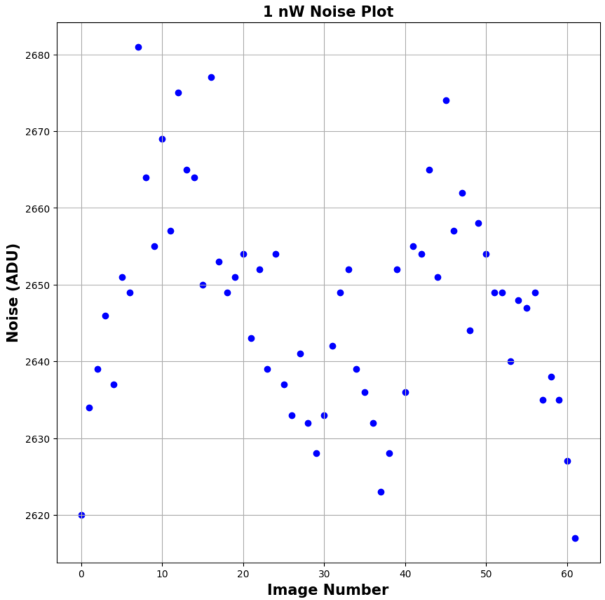
First 20 Images: Linear Section

Gain: 204.72 $^{ADU}/_{e^-}$

Average Readout Noise: 12.83 e^-

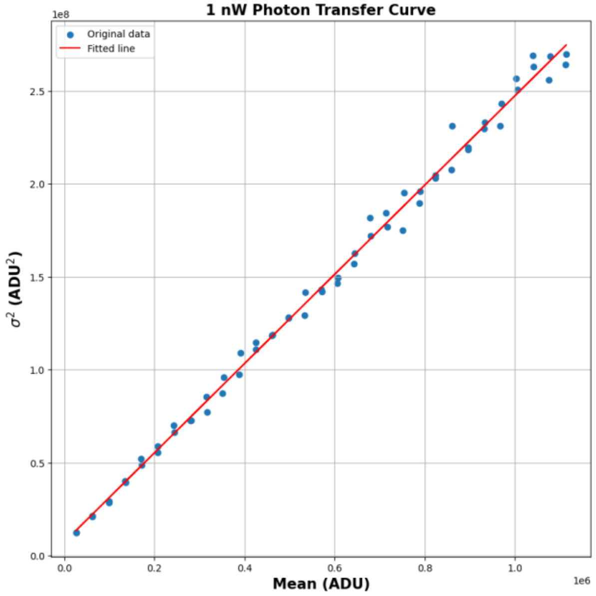
Expect: <5 e^-

1 nW Readout Noise Plot



Average Readout Noise: 2,647 ADU

1 nW Photon Transfer Curve



As this is 10x less power, the pixels will not be fully filled given the 50 second exposure time

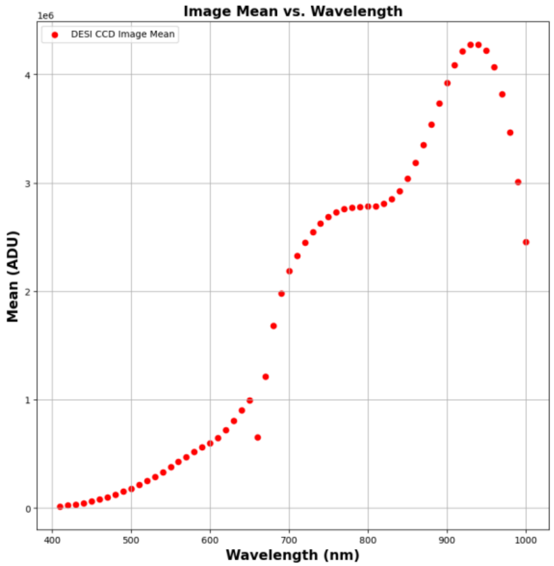
This plot tests for nonlinearity for the gain calculation

Gain: 239.88 $^{ADU}/_{e^-}$

Average Readout Noise: 11.04 e^-

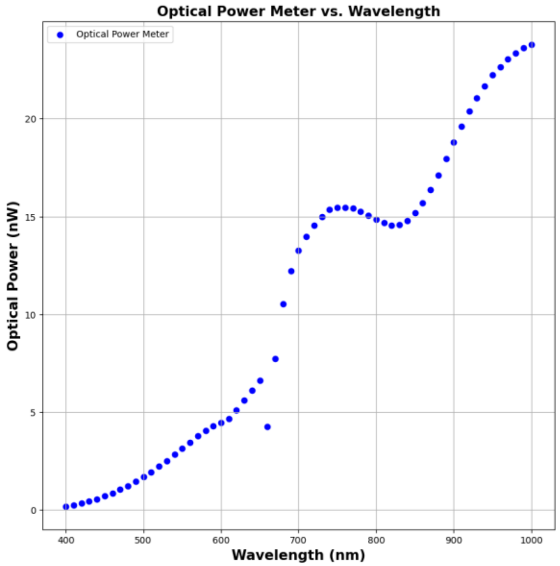
- **Averaging the Gain of the 1 – 10 nW data:**
  - Average Gain: 222.3 $^{ADU}/_{e^-}$
  - Average Readout Noise: 11.93 e^-
- The readout noise is higher than expected and may be attributed to the low purity of the CCD

Relative Quantum Efficiency



Subtracted Image Mean vs Wavelength of the DESI CCD

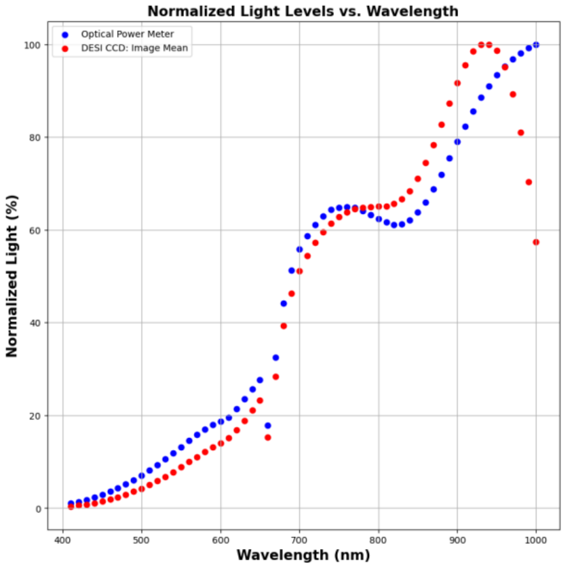
Decrease in efficiency after 950 nm



Optical Power Meter vs. Wavelength

Measured from the collimating sphere

Has a similar shape to the CCD, except at the higher wavelengths



Normalized Light Levels vs. Wavelength

A decent method to compare where the CCD's efficiency changes

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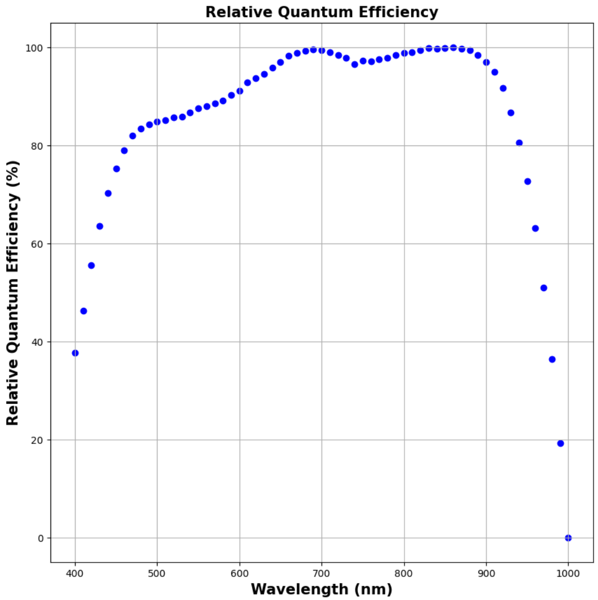
Relative Quantum Efficiency



This shows what we would expect from this CCD

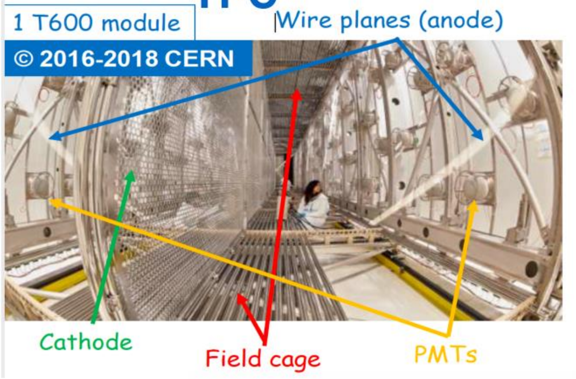
They are built to have high efficiency in the optical red to near-infrared

ICARUS: Imaging Cosmic And Rare Underground Signals

Introduction

- ICARUS (Imaging Cosmic And Rare Underground Signals) is a neutrino detector that utilizes LAr-TPCs, CRTs, and PMTs for data collection
  - My work focuses on creating additional monitoring metrics for data quality
    - **TPC:** Track Start in X, Y, Z – etc.
    - **CRT:** Hit Positions in X, Y, Z – etc.
    - **PMT:** Flash in X, Z, Sum Photoelectrons – etc.

TPC

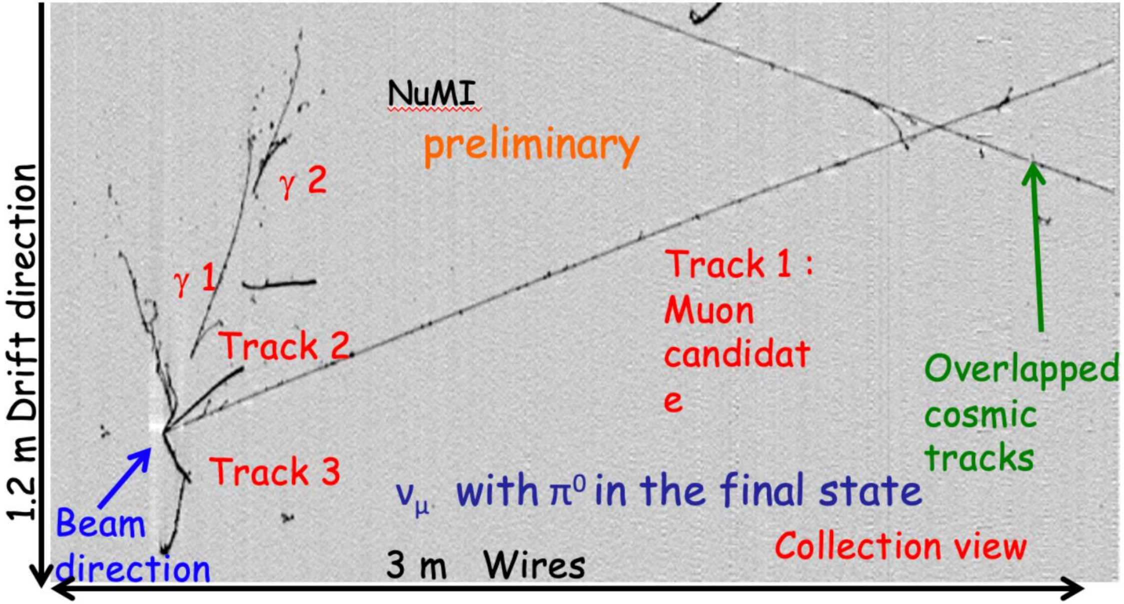


PMT

side CRT

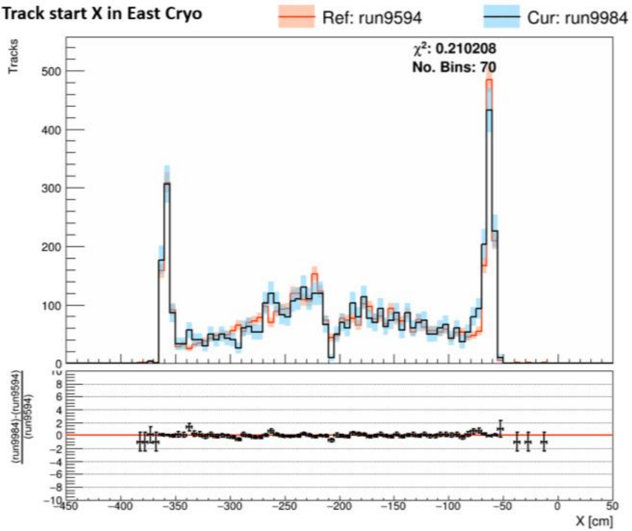
CI Validation Framework

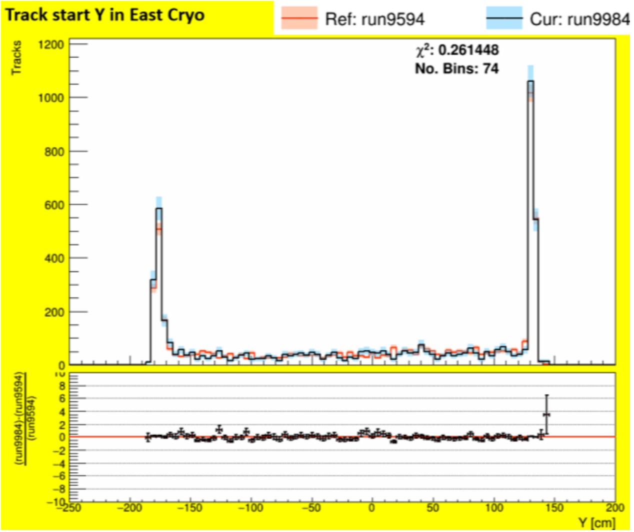
- An automated framework that compares reference data with different data sets of the different detection systems:
  - TPC
  - CRT
  - PMT
- The version of the CI I'm using is for the data distributions of calib tuples via ROOT

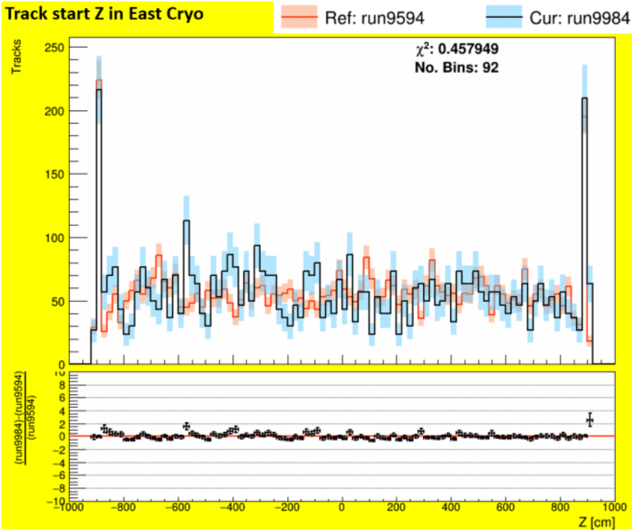


CI Validation Reconstruction of NuMI beam data run

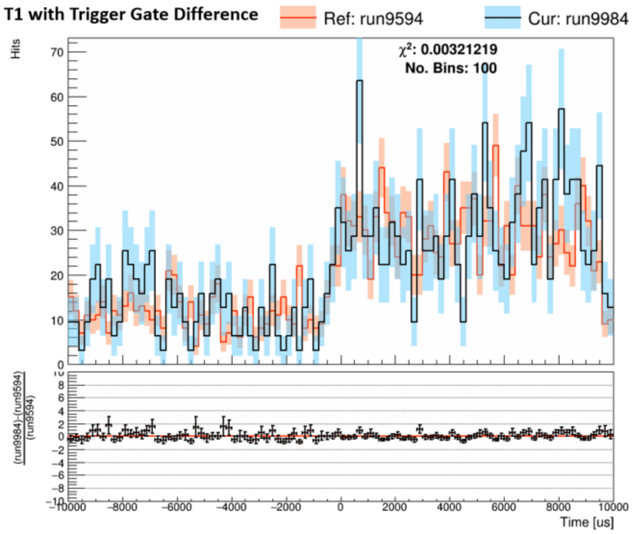
Data Quality: East TPC

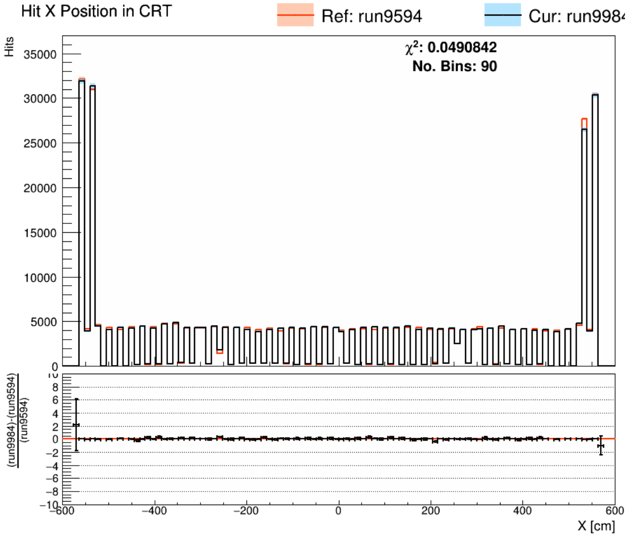


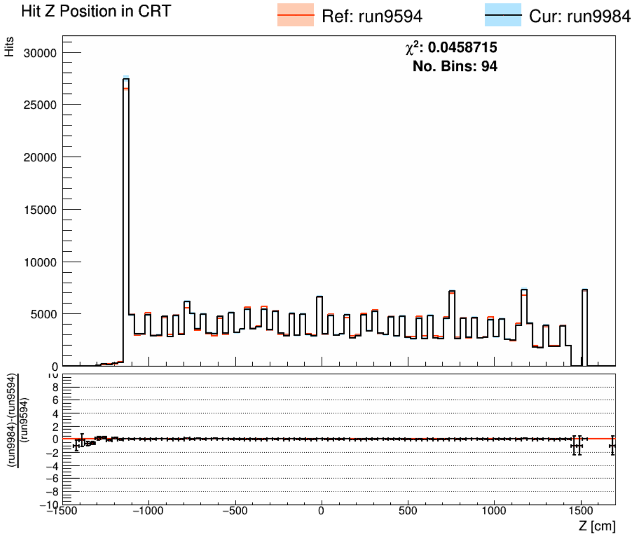




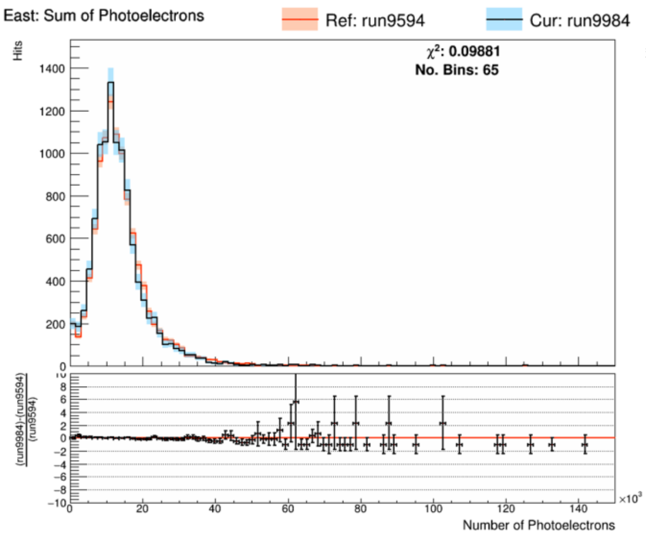
Data Quality: CRT

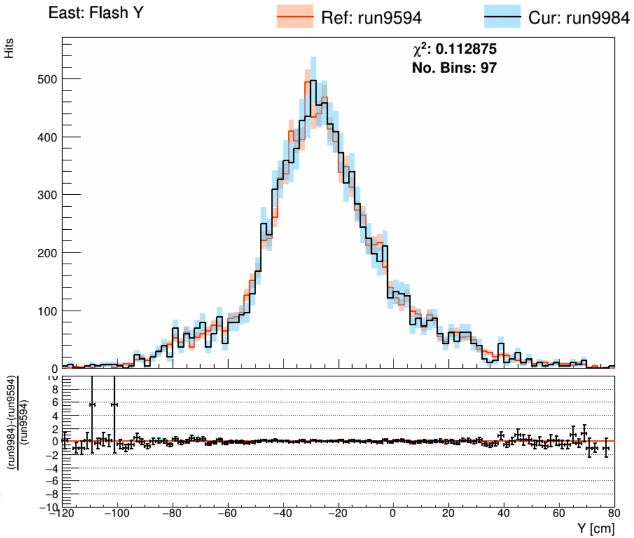


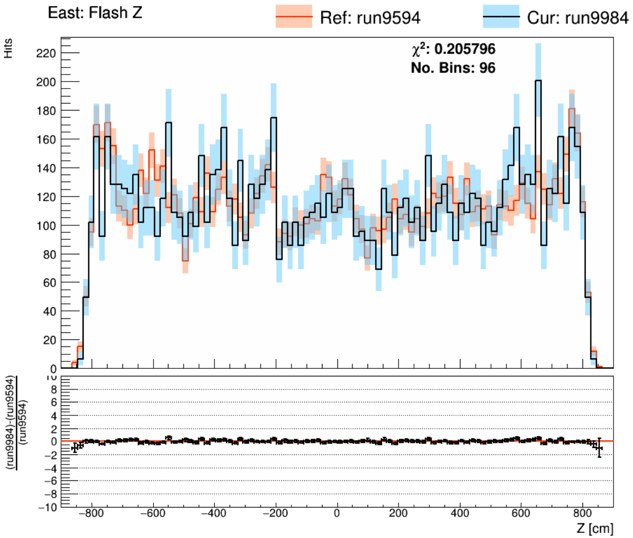




Data Quality: PMT







Conclusion

Conclusion

- There is still work to be done on the data taking/analysis of DESI
  - The RQE still needs to be fixed and currently more data is being taken
  - A few other types of runs need to be run (data taking scripts are functional as of writing):
    - **Flat Exposures:** Tests how consistent the CCDs are under a constant source for a constant exposure time
    - **Dark Exposures:** Used to measure dark current (electronic noise) in the DESI CCD

- The additional ICARUS metrics for data quality is still an ongoing effort
  - Currently can only compare 2 runs at a time, but in the future will be able to compare multiple
  - A summer student will work on automating the comparisons

Acknowledgements

Big Thanks To:

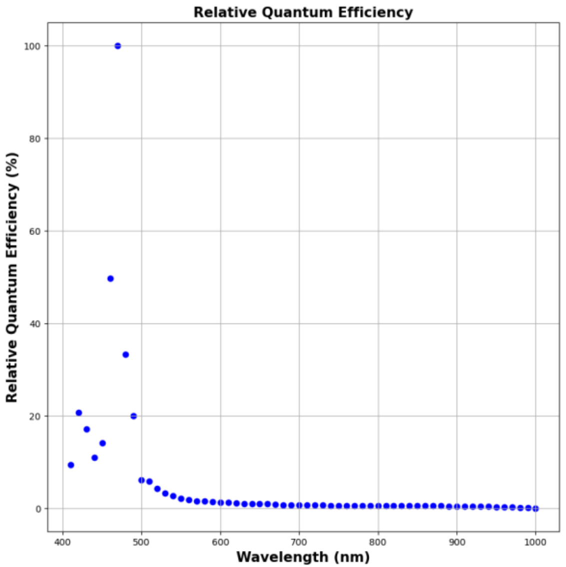
Juan Estrada

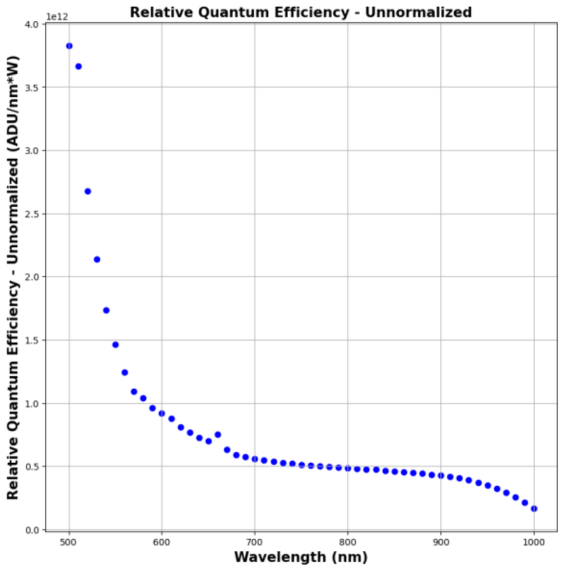
Minerba Betancourt

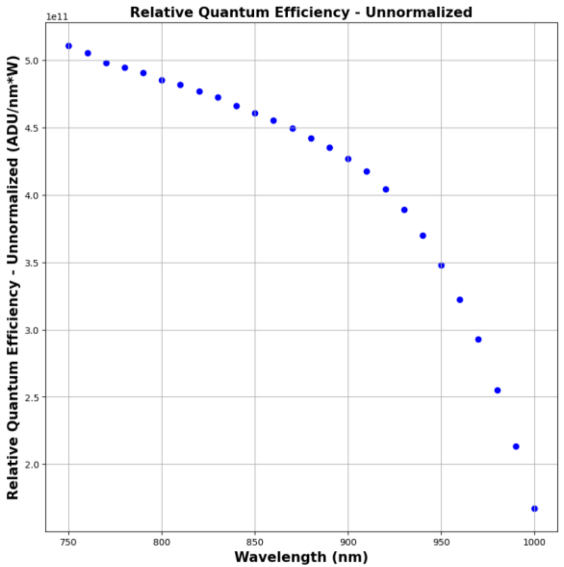
Fermilab

Additional Slides

Relative Quantum Efficiency [M1-73 Bad Run]







Relative Quantum Efficiency Plot

400 – 500 nm: Lack of light reaching the CCD, resulting in random-like behavior

Increasing the Halogen Lamp PSU may fix this

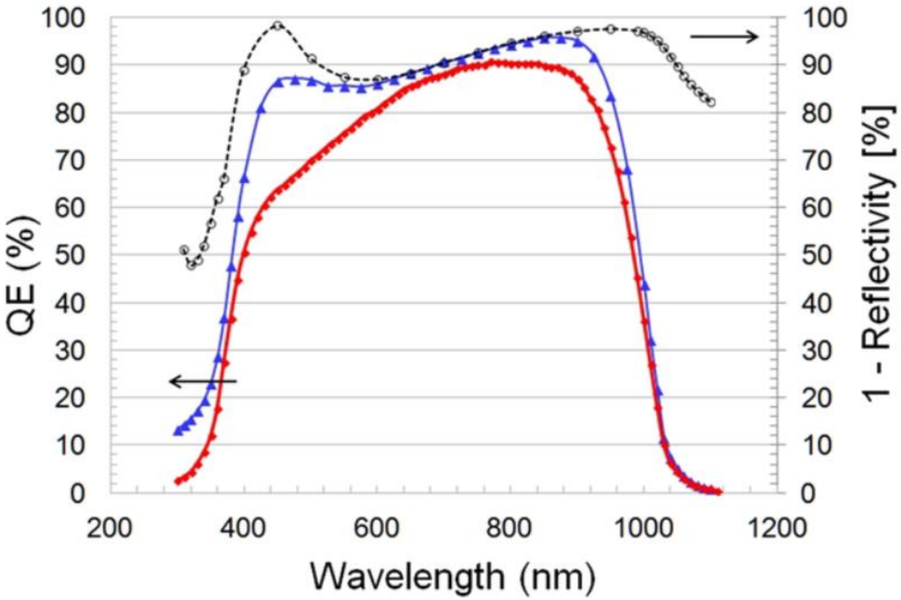
Unnormalized Version: 500 – 1000 nm

Unsure why there is an exponential decay, this is not the expected RQE shape

Unnormalized Version: 750 – 1000 nm

This shows a better resemblance of the RQE for these wavelengths

Expected Shape for an RQE/QE



Taken From A DESI Paper (2017)

Red Line: This shows the increased efficiency in the red region, which is what DESI is designed for