Smith Purcell Effect Emission Determination (SPEED) Final Presentation

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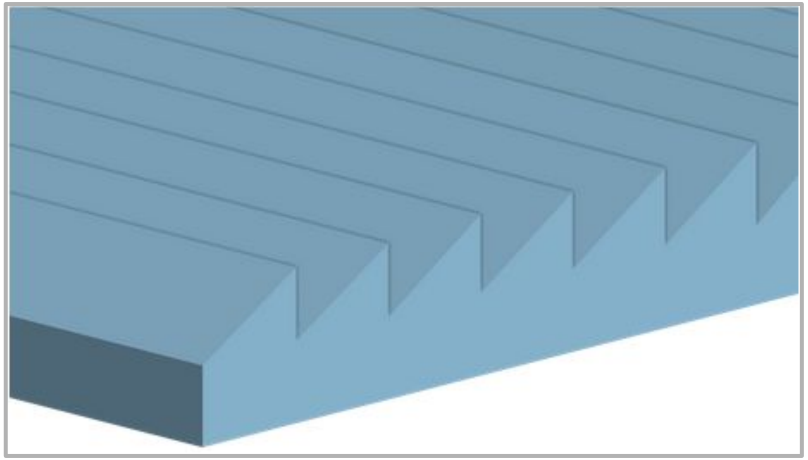
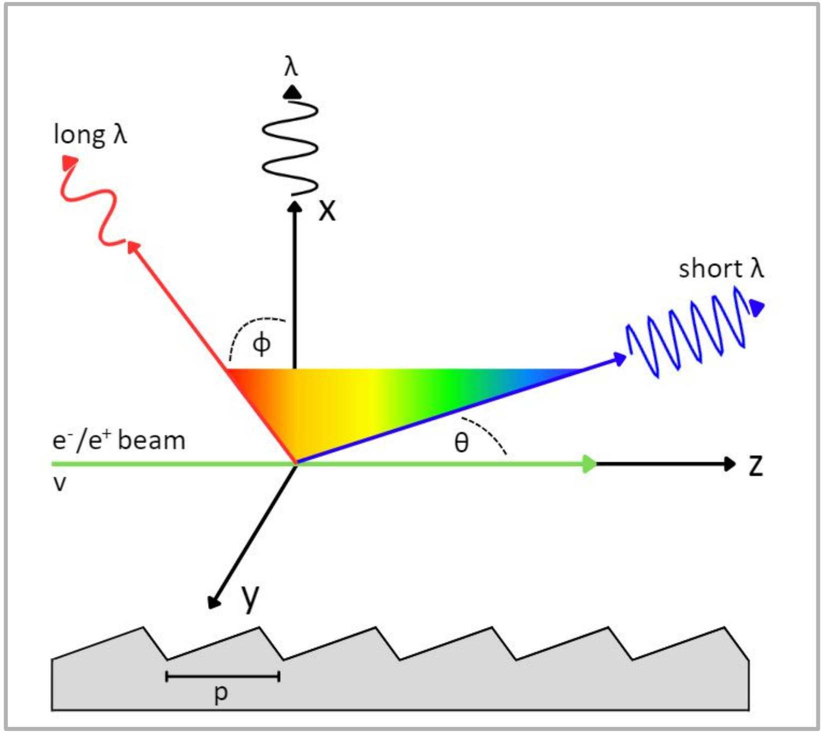
What is Smith-Purcell Radiation?

Smith-Purcell Radiation: Radiation that is generated from charged particles moving closely parallel to a conductive periodic grating



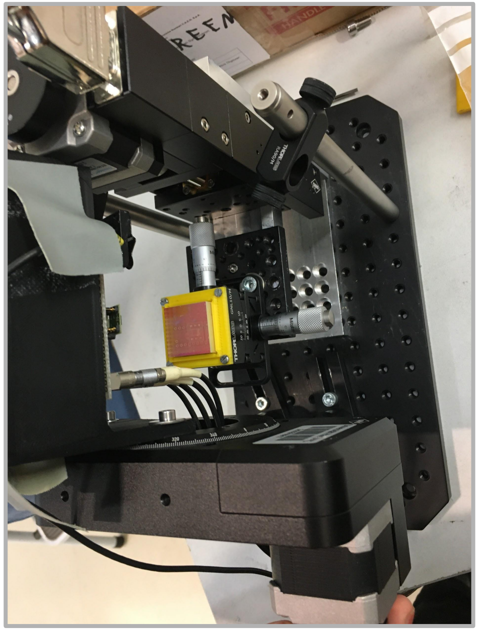


Overview of our Experiment and our Work Here

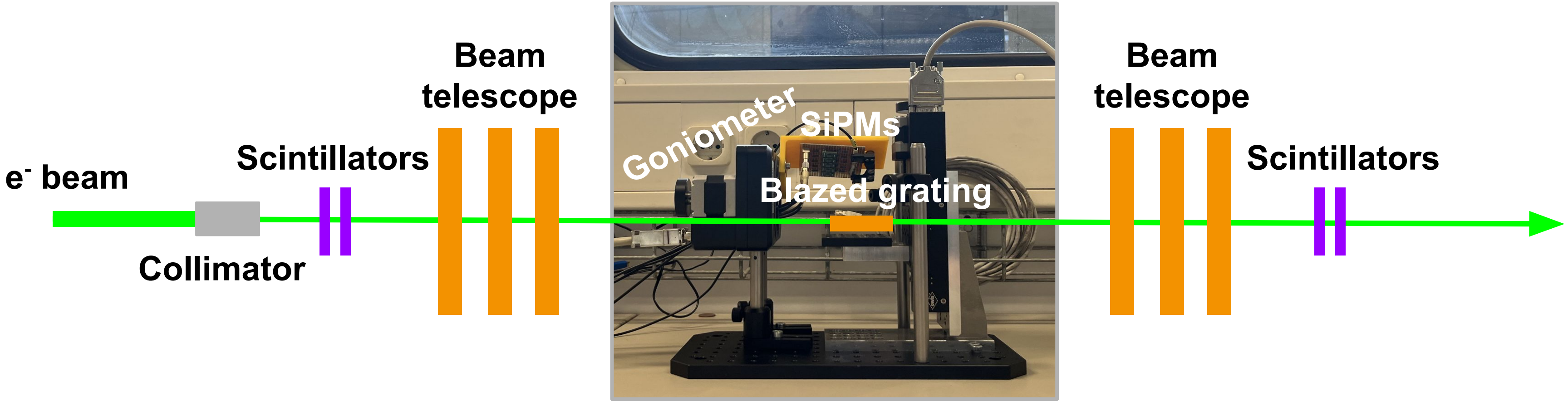
Original Goal: Measure intensity of Smith-Purcell radiation (SPR) with variable period gratings

- **We had to:**
  - Understand the detector
  - Analyze data to differentiate photons from noise
  - Optimize grating configuration
  - Correlate data from the beam telescope with the silicon Photomultipliers (SiPMs)

- **To do this, we learned:**
  - Organization, teamwork, and project management
  - Many bits and pieces of statistics
  - How to acquire and analyze data

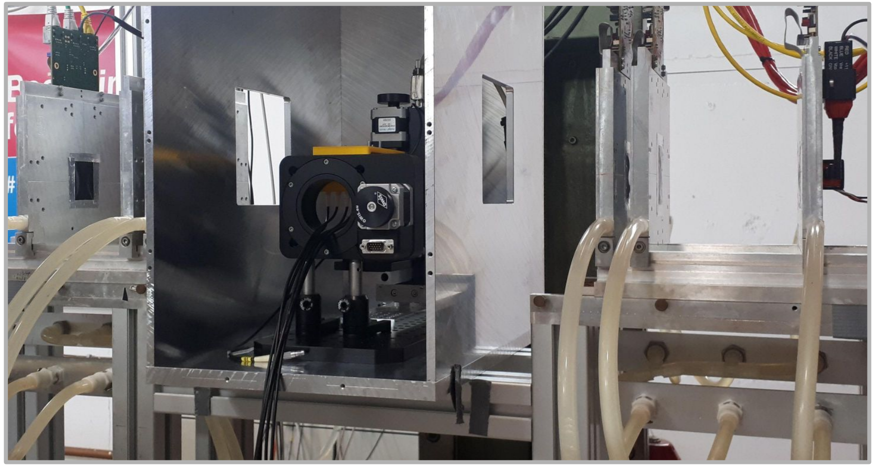


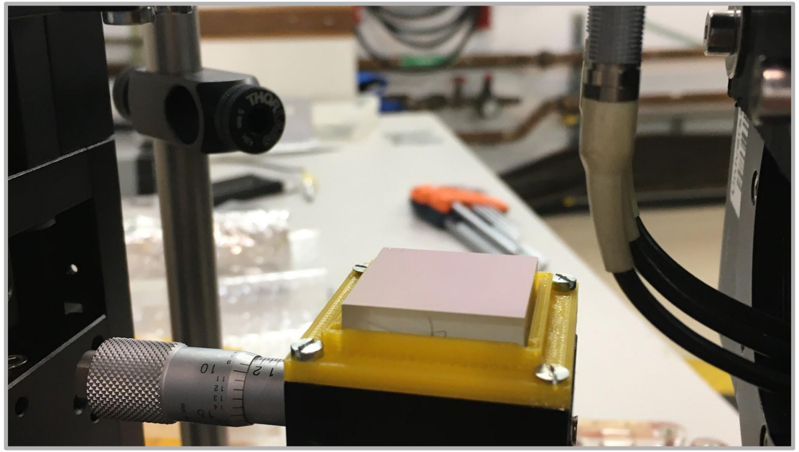
Final Experimental Setup



- **Collimator** to truncate beam size
- **Scintillators** to measure electron count and trigger events
- **Beam telescopes** to measure beam position and trajectory
- **Blazed gratings** positioned 100 microns from center of beam
  - To create and maximize radiation, the beam must pass closely parallel to the grating
- Four **SiPMs** to measure SPR intensity at multiple angles, angles measured via **goniometer**

Final Experimental Setup



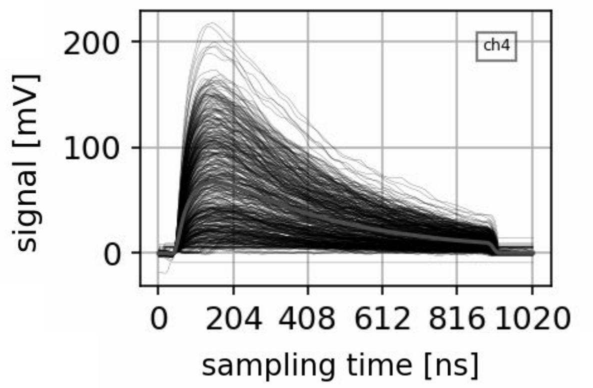


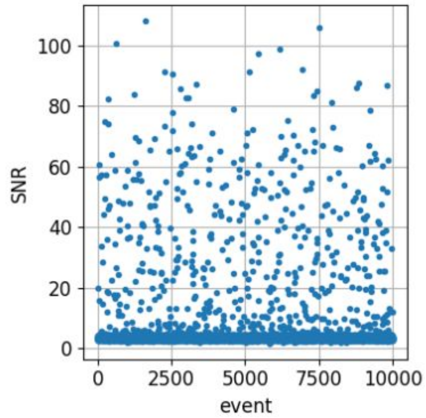
SiPMs: Introduction & Testing

- **Introduction:**
  - SiPMs convert photons to electric signals
  - 3x3 mm sensitive area of photon-detecting cells
  - Compared two types of SiPMs using a digitizer to measure waveforms

- **Aims**: Learn SiPM signal response, maximize Signal to Noise Ratio (SNR)

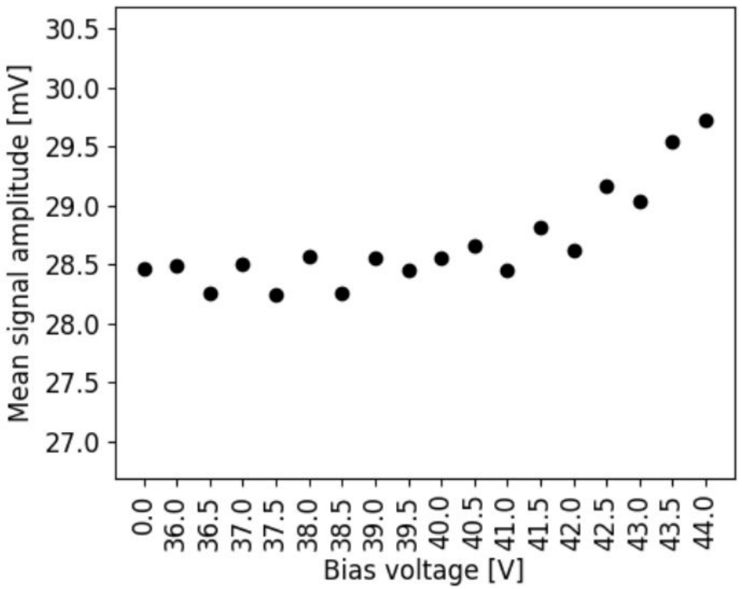
- **BGO scintillator and lead glass:**
  - Used BGO scintillator and lead glass to calibrate SiPMs
  - Signal observed by SiPMs with BGO scintillator produced large signal



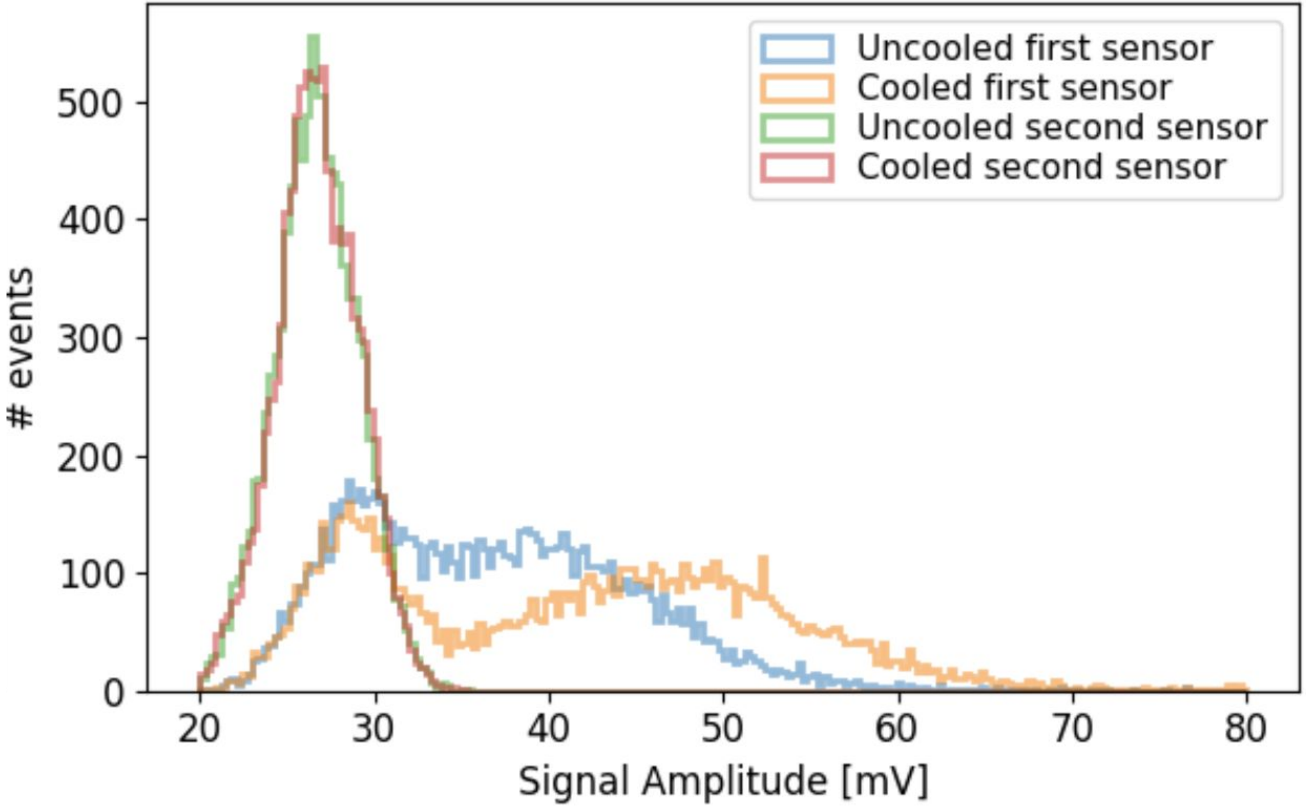


SiPMs: Noise Measurements

- **Noise sources:**
  - Dark count: random firings of SiPM pixels identical to single photons
  - Electrical equipment
- **Overvoltage scan:**
  - Overvoltage leads to more gain and dark count
  - Tested various voltages before determining 44 V
- **Dry ice:**
  - Dry ice had significant reduction (~50-75%) on first SiPMs
  - Had little effect on second SiPMs, less noisy overall

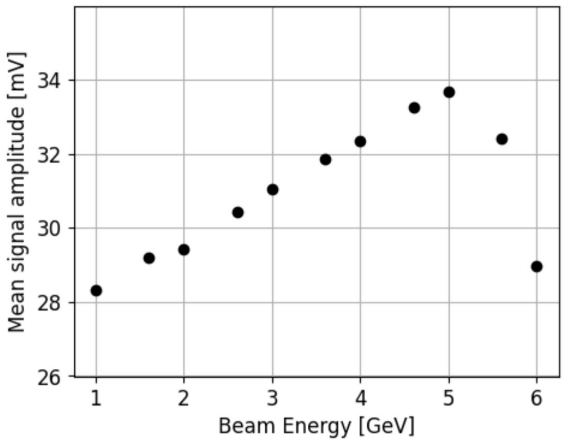


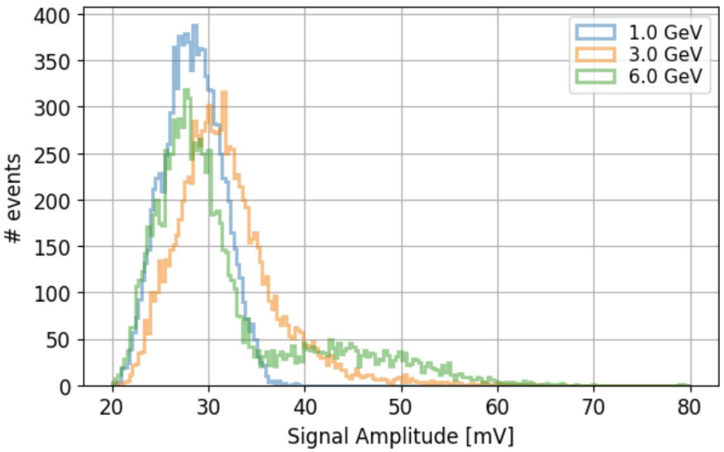
SiPM Dry Ice Noise Comparison



SiPMs: Single Photon Spectrum

- **Aim:** Detect single photons from other sources to identify SPR
- **Beam energy scan with lead glass:**
  - Lower beam energies produce less photons
  - Too many photons produced, could not see single photons
- **Single photon trials with LEDs:**
  - Used LED pulser to try to produce single photons
  - Same results as above



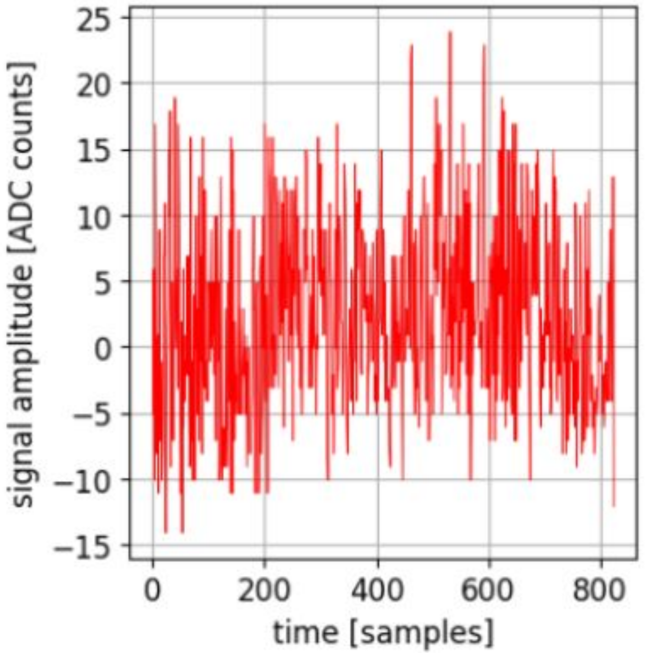


SiPMs: Addressing Challenges

- **High noise levels:**
  - Difficulty with single photon detection
  - Clouded potential SPR signal waveforms

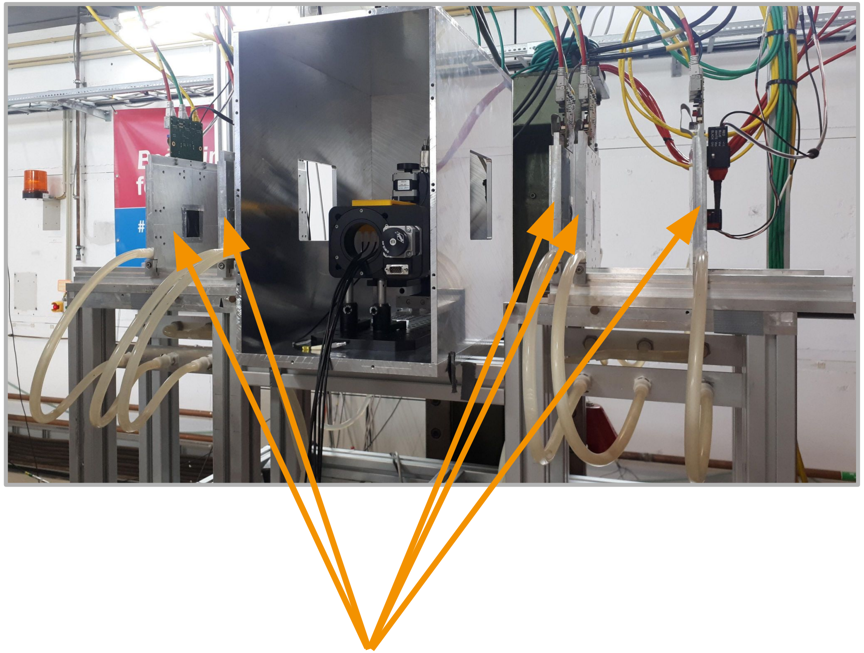
- **Noise filtering:**
  - Trigger logic with beam telescopes
  - SNR cutoff, low pass filters

Run 371 Event 1818 - Closely parallel



Beam Telescopes: Introduction & Alignment

- **Aim:** Select electrons passing closely parallel to grating, align grating with beam center
  - Beam telescopes record electron tracks with high precision
- **Alignment:**
  - Proper alignment required for all analysis
  - Alignment in 2 translations and 3 orientations
  - Took initial measurement of telescope Z positions



Beam telescopes

Beam Telescopes: Alignment

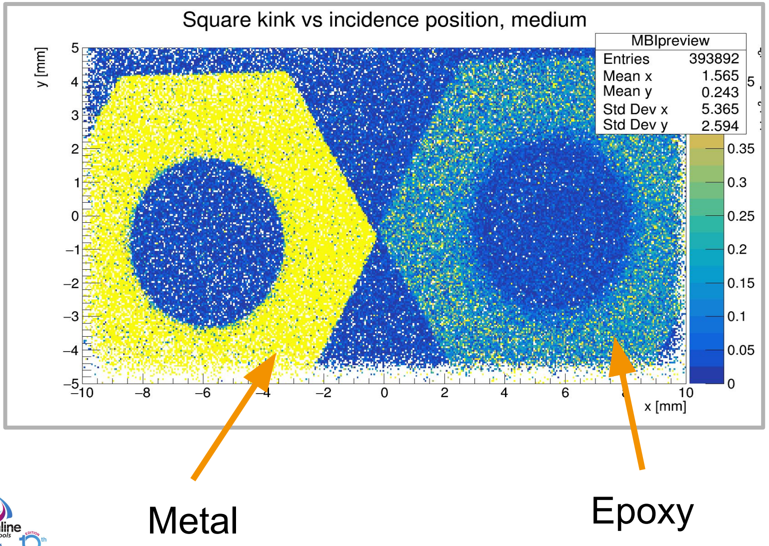
Alignment procedure:

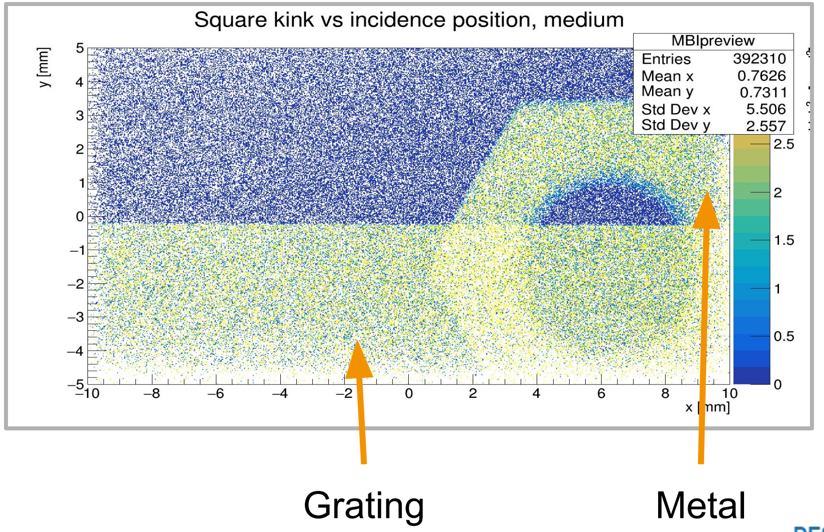
1. Take beam data with nothing in between planes
2. Straight line track reconstruction
3. Check global residuals and χ^2

Repeated over 200 iterations with same data

Beam Telescopes: Electron Tomography

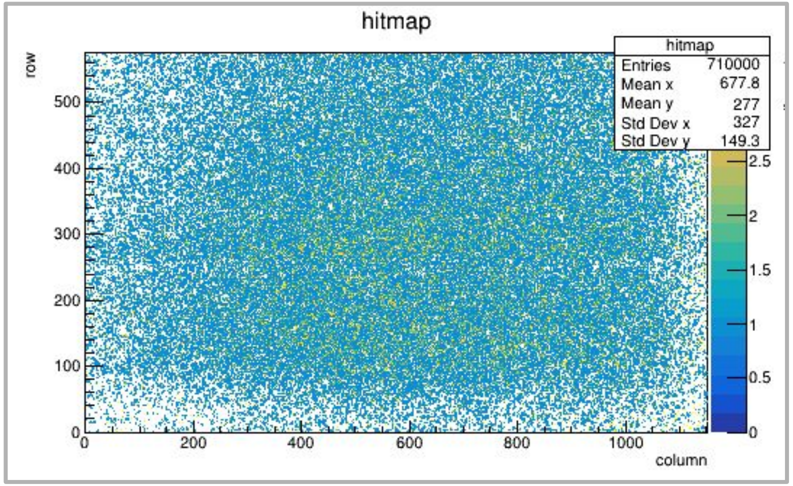
- **Aim:** Tomography tests and grating alignment
  - Tomography shows roll and placement of grating → more accurate than stage adjustments
  - Orientation of grating successfully aligned





Beam Telescopes: Beam Spread & Center of Distribution

- **Aim**: Orient grating in beam center & calculate beam spread with different collimators
- **Hitmaps**: spatial distribution of electrons detected by each sensor
- **Beam center** → Mean of hit distributions in x and y
- **Beam spread** → Standard deviation of the hits
- Aligned grating 0.4mm under beam center



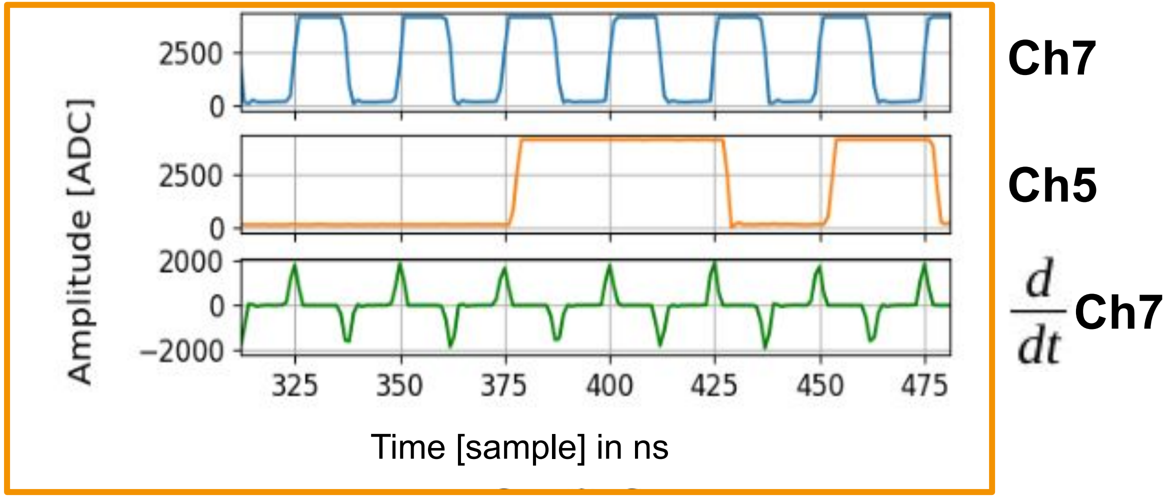
Trigger IDs: Introduction

Event IDs:

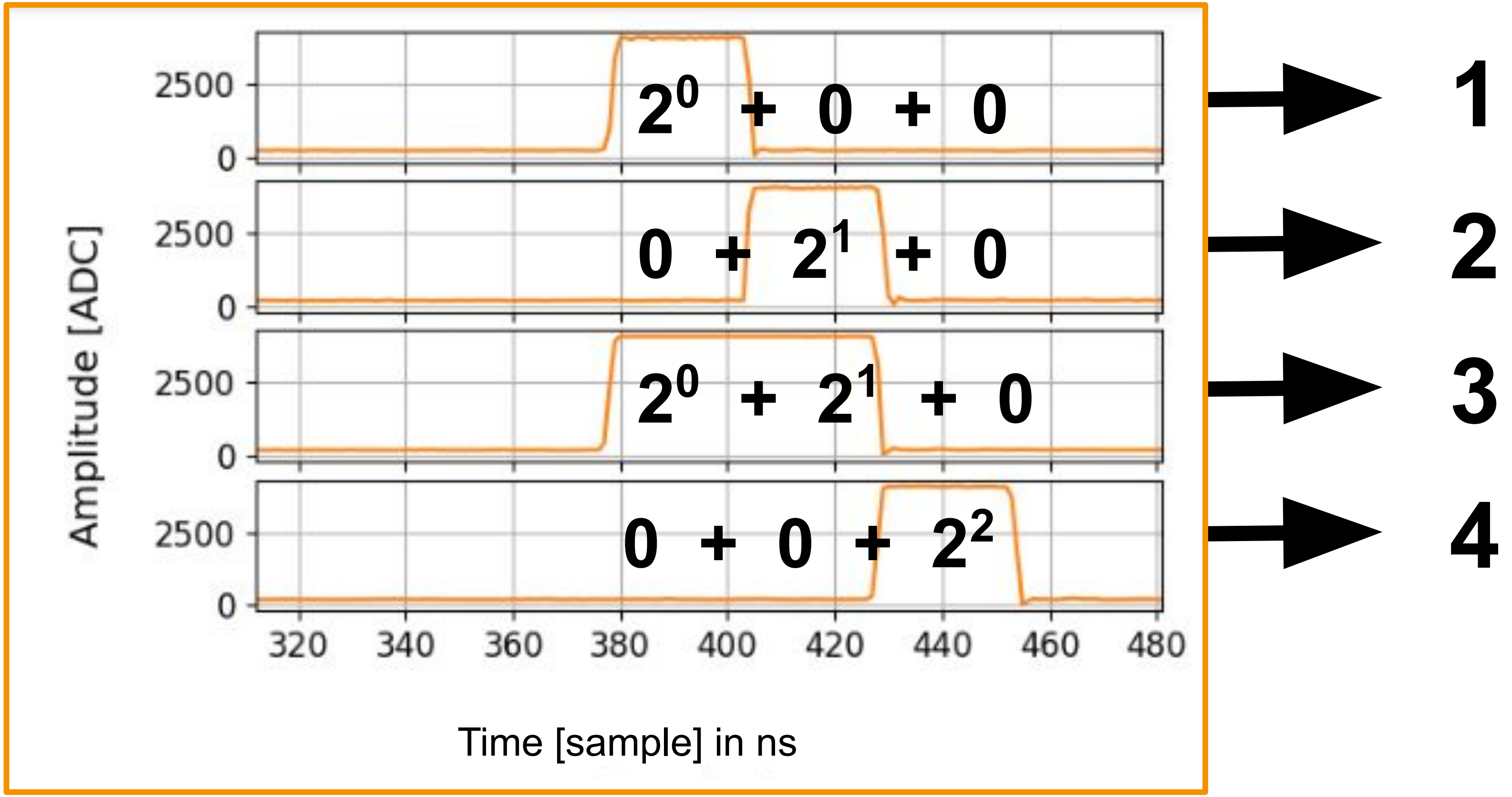
- The beam telescope and digitizer are not synchronized
- The digitizer doesn't record every event (longer dead time)
- **Aim:** match the events between the two detectors

Trigger Logic Unit (TLU):

- **Problem:** communicates the trigger ID with the telescope but not the digitizer
- **Solution:** send the digitizer an analog bitstream and a clock encoding the trigger IDs

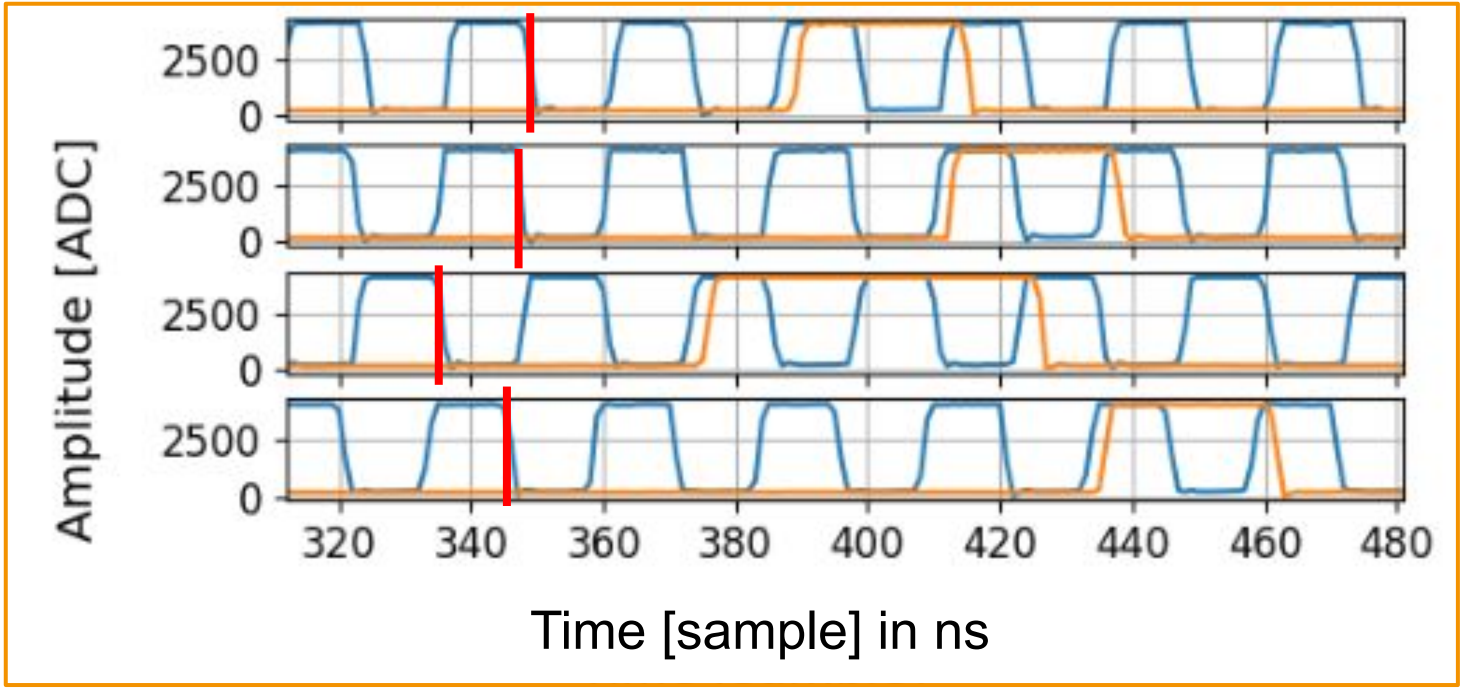


Trigger IDs: Converting to Binary



Trigger IDs: TLU (Clock and Analog Bitstream)

- **Problem:** The clocks are not aligned from event to event

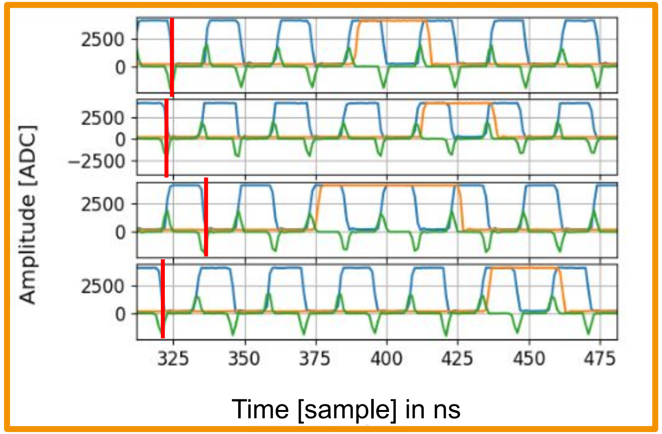


Trigger IDs: Aligning the Clocks

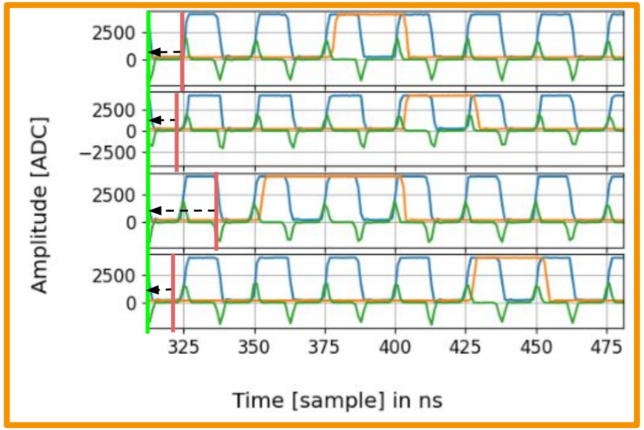
Solution: Aligned all of the clocks to the first falling edge

```
def get_falling_edges(
        clk_wf: np.ndarray,
        threshold: float = 0.15
        ) -> List[np.ndarray]:
    """Get the time indices of the falling edges of a clock-like waveform.

    See `get_rising edges` for a detailed explanation

    Args:
        clk_wf (1D np.ndarray): array of the clock waveform.
        threshold (float, optional): fraction of the maximum gradient used to
            determine where the rising edges are.

    Returns:
        List[np.ndarray]: each element of the list is an array containing the
            time points corresponding to one rising edge.
    """
    grad = np.gradient(clk_wf)
    # print("grad min/max amplitude:", grad.min(), grad.max())

    edges = grad < grad.min() * threshold
    splits = np.nonzero(edges[1:] != edges[:-1])[0] + 1
    time_points = np.arange(clk_wf.shape[-1])
    sections = np.split(time_points, splits)

    return [time_points[s] for s in sections
            if grad[s].mean() < grad.min() * threshold]
```

Before

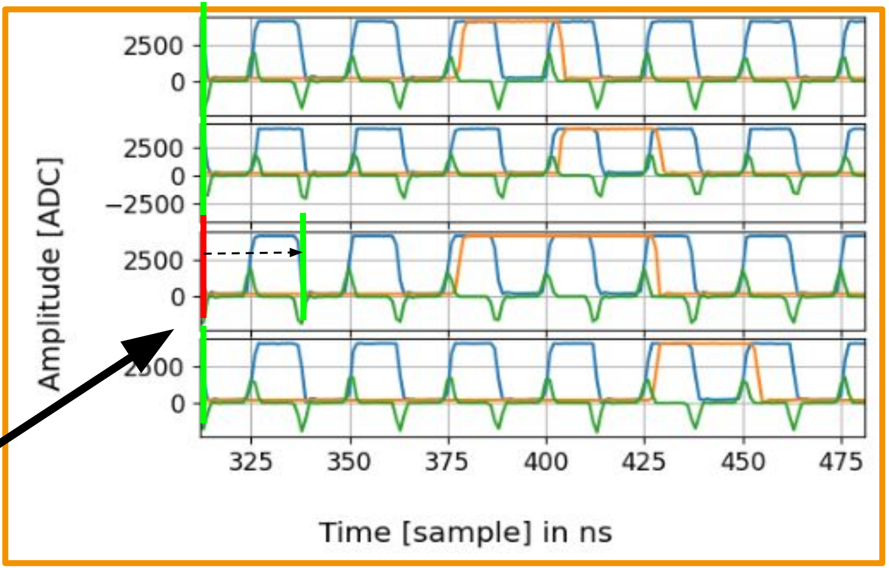


After



Trigger IDs: Bit Shifts

- **Problem:** Bit Shifts occur when the clock is shifted enough that we align it to the wrong falling edge.
- **Solution:**
  - If current ID > 2 × previous ID, we shift it to the left (*half it*)
  - If current ID < previous ID, we shift it to the right (*double it, unless it is odd*)



This is an example of a backwards bit shift

Trigger IDs: Bit Overflow

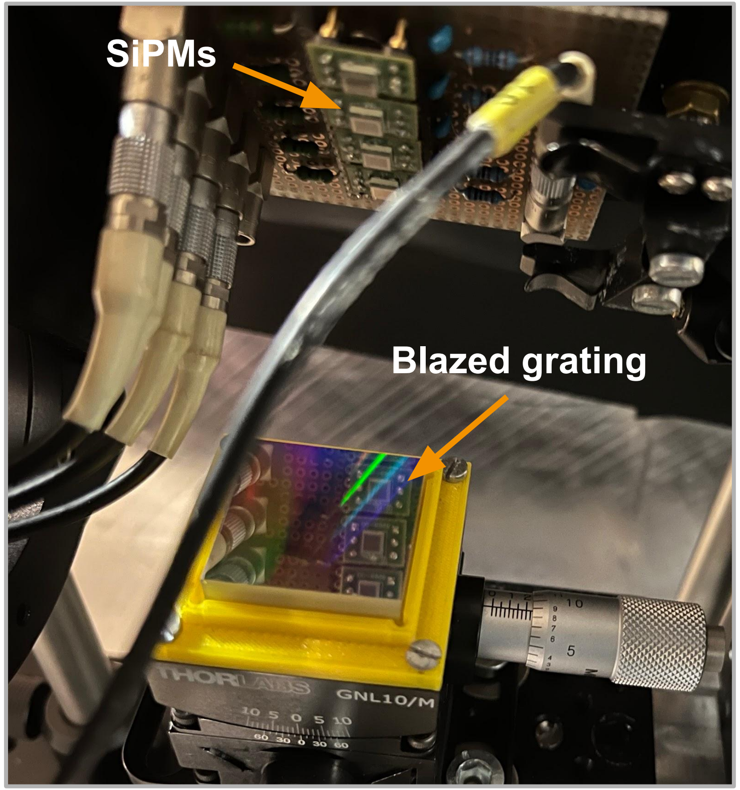
- **Problem:** TLU can only send up to $2^{16} - 1 = 65535$
- Our data sets contain hundreds of thousands of events
- **Solution:** Afterwards, 65536 is added to each entry once for each time it has looped before that point

Trigger IDs: Filtering Trigger IDs from beam telescope data

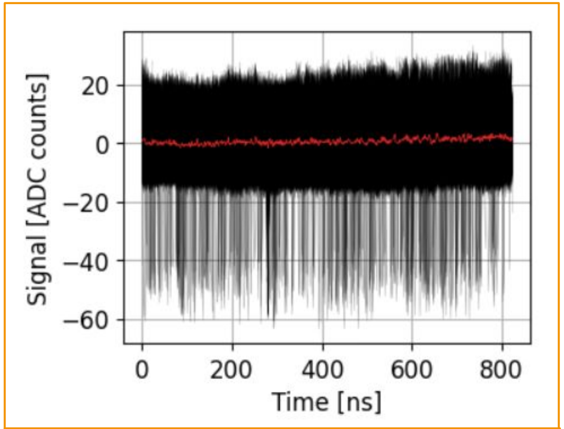
- Converting between Trigger IDs and Event IDs
  - Necessary to match telescope and SiPM data
- Event Selection for SPR detection:
  - Identifying events with high signal amplitude from SiPM data was inefficient
  - Filtering for electrons that pass closely parallel to grating on telescope → checking event on SiPM data

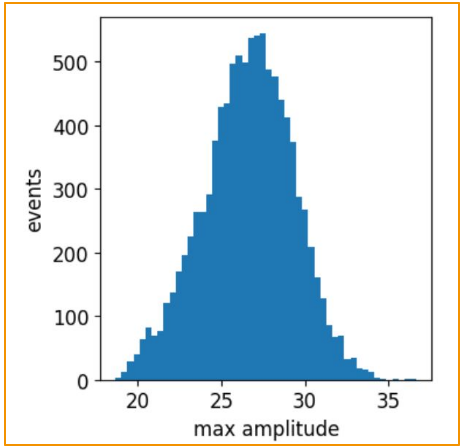
Final Setup Planning

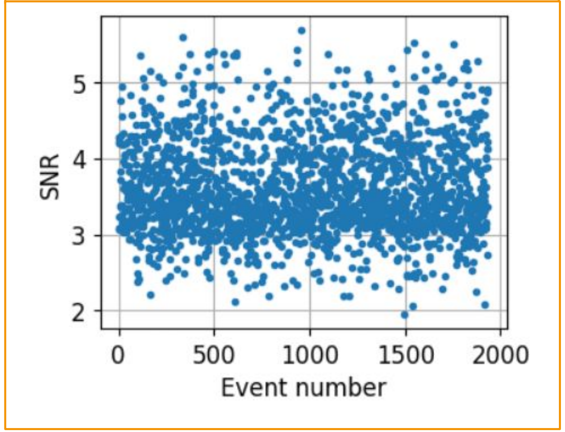
- **Parameters:**
  - Collimator: 2x2 mm
  - Beam energy: 1.0 GeV
  - Dry ice: initially tested, decided to not use
  - Color filter: not used, deemed unnecessary
  - Goniometer angle: varied between -22° and -34°
  - Grating groove density: varied between 1200 g/mm, 1800 g/mm, and 2400 g/mm

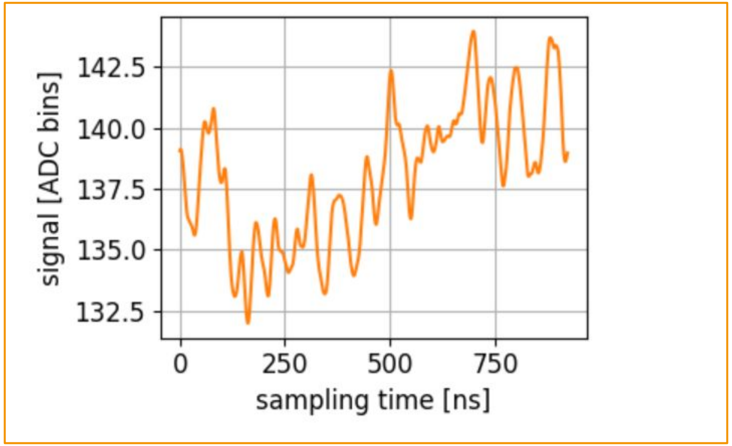


Data Analysis





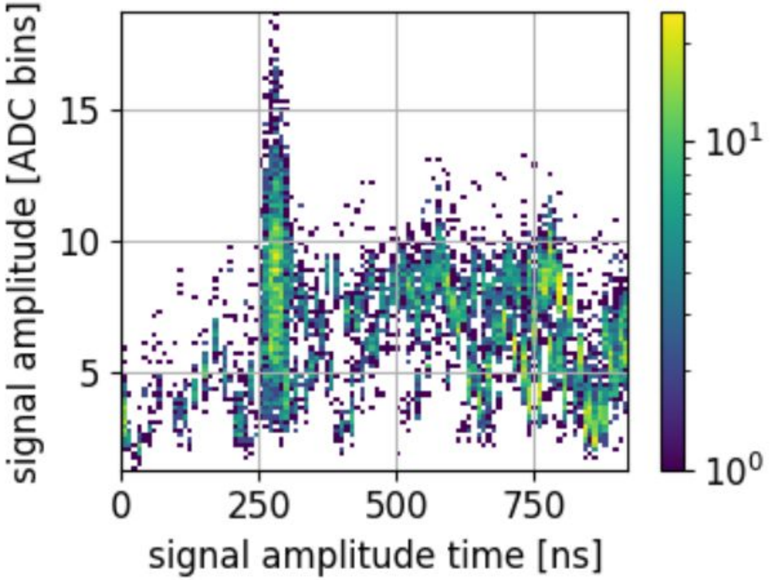




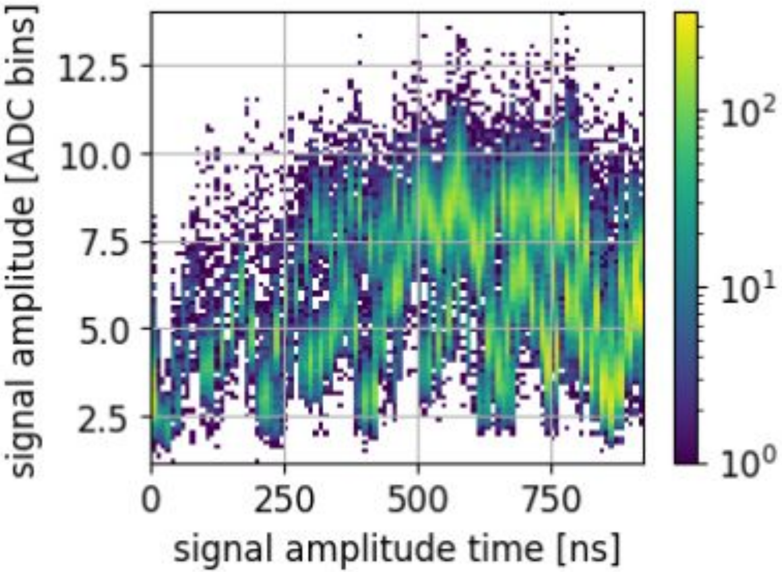
Data Analysis and Results

Amplitude vs. Time Histogram: Scintillator vs. Grating

Scintillator



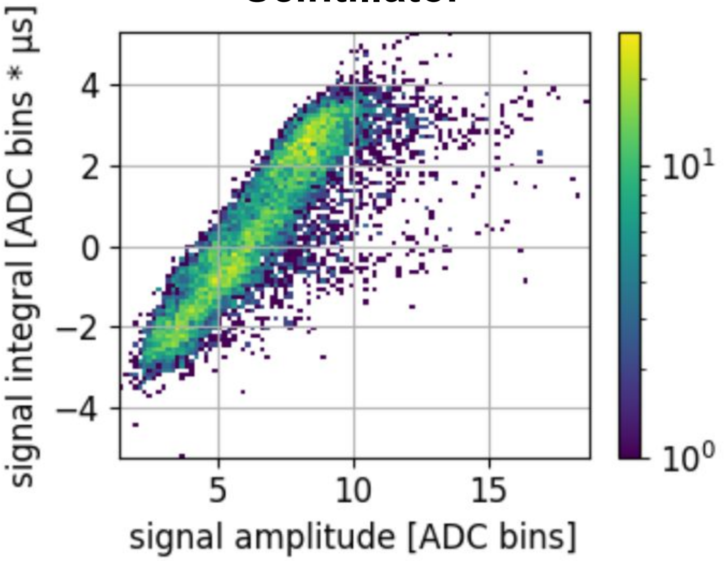
Grating



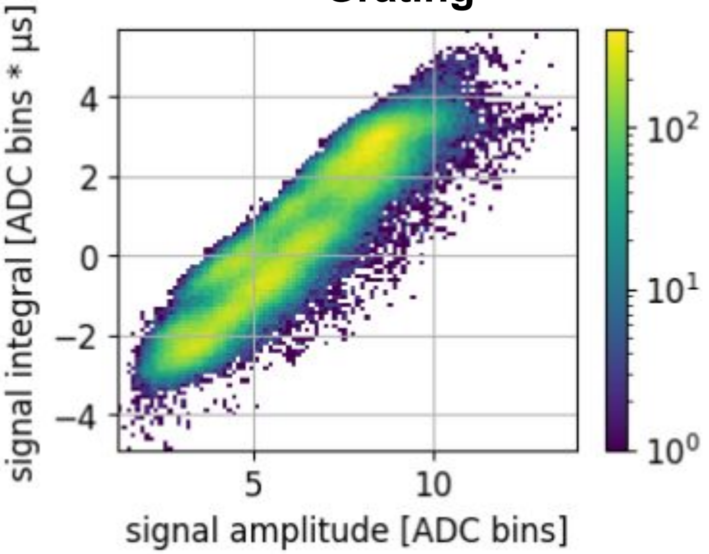
Data Analysis and Results

Integral of Signal Amplitude vs. Signal Amplitude: Scintillator vs. Grating

Scintillator



Grating



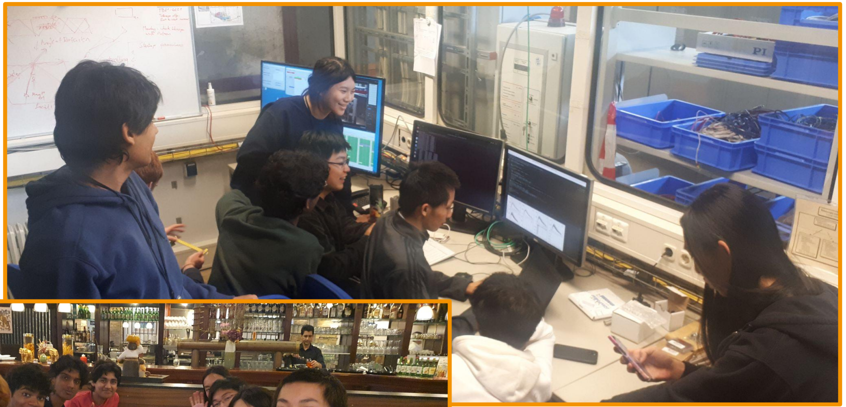
Conclusions and Future Research

- Identified noise and attempted to identify single photons of SPR in SiPMs
- Aligned grating and found beam center/spread using beam telescopes
- Created trigger ID reconstruction system with TLU in order to correlate SiPM events and beam telescope paths
- Tested different grating groove densities and goniometer angles in 1.0 GeV beam
- Data analysis finds high noise in SiPM data, difficult to identify single photons of SPR
- Future data analysis: look at difference in closest events to grating vs. furthest events

Ending Notes

- Outreach
  - Documenting our experience to inspire other students
  - Instagram, Website, Blog
  - Improving science curriculum

- Cool things we've seen
  - XFEL
  - HERA
  - ARGUS
  - ALPS
  - Hamburg City Center
  - Miniatur Wunderland



- **Thank you to everyone at BL4S, DESY, and CERN!**