Diffuse Neutrino Sensitivity

ICRC and Journal papers

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PROCEEDINGS OF SCIENCE

EUSO-SPB2 Cherenkov Telescope: Overview and First Neutrino Constraints

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Outline:

1. Introduction
2. Cherenkov Telescope, Data Selection and Simulation Criteria
3. Diffuse Neutrino Sensitivity Limits
4. Future Prospects
5. Acknowledgements

1. Introduction

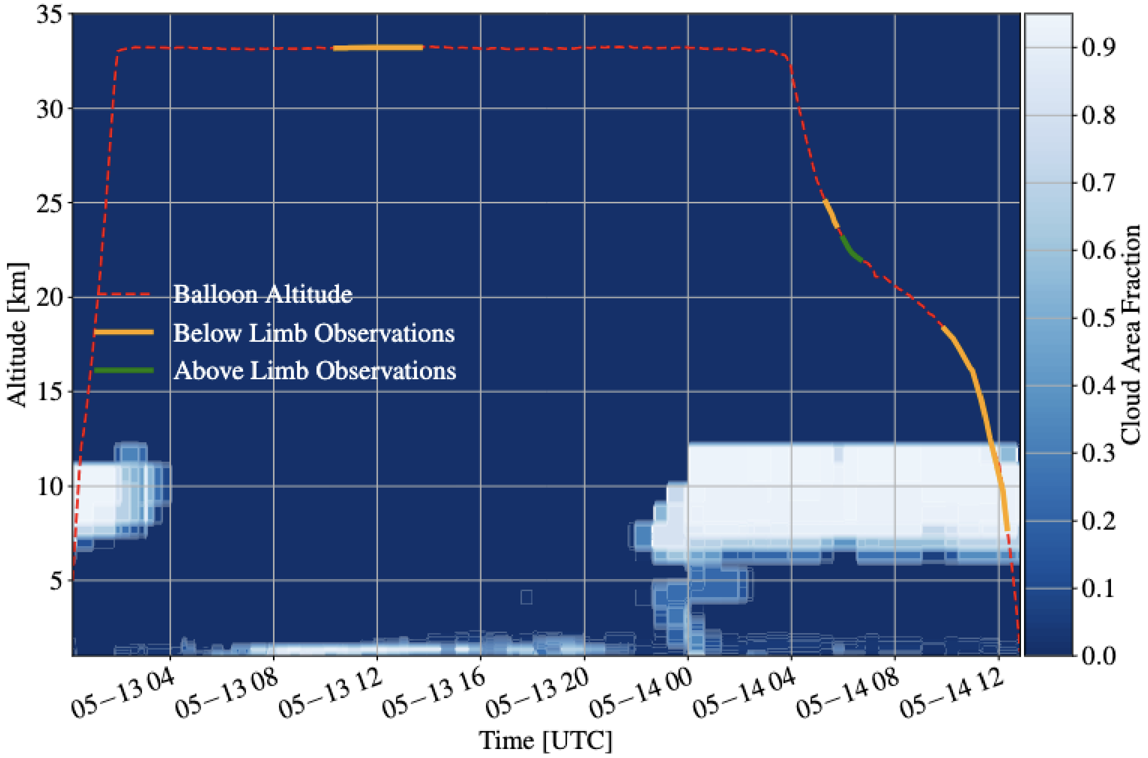
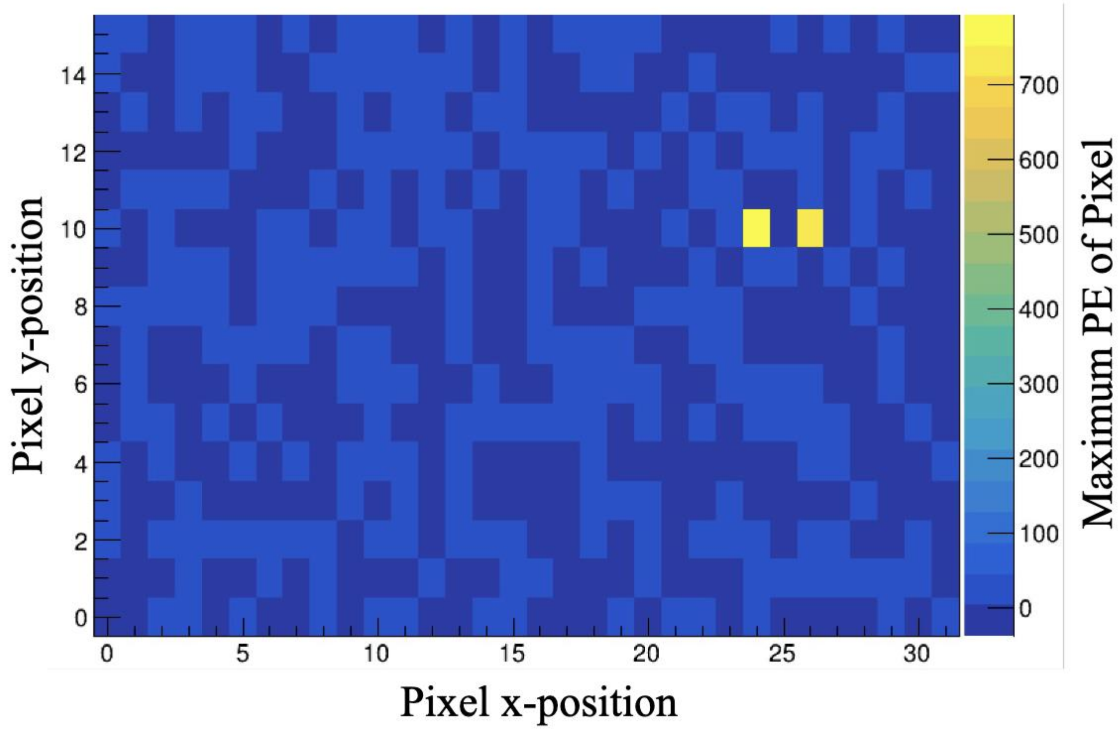


Figure 1: The red dashed line shows the balloon's altitude, while the green and orange lines shows the observation times above- and below-the-limb, respectively. The cloud area fraction below the EUSO-SPB2 flight path is shown as a function of altitude according to the color scale on the right.

- UHE neutrino detection requires large detection volumes.
- Cherenkov, radio, fluorescence methods used underground, ground, sub-altitudes.
- Earth skimming tau-neutrinos producing EASs in atmosphere.
- About EUSO-SPB2 flight.
- Diffuse limits are not competitive, but proof of principle demo for POEMMA.
- Also diffuse calculations a precursor to ToO sensitivity calculations.

2. Cherenkov Telescope, Data Selection and Simulation Criteria

5e9 GeV, 96° zenith EAS



Made using OffLine Simulation

- Description of Cherenkov Telescope (CT).
    - Entrance pupil, mirror orientation, optics.
    - Bifocal alignment for background filter.
    - SiPMs, MUSIC chips

- Data Selection and simulation criteria:
    - Background reduction by choosing astronomical nights with low or no moonlight.
    - Below the limb observation for neutrino events.
    - Over triggered pixels, Over triggered times (500 triggers/min).
    - Total observation time: **35 mins for Night 1**

2. Cherenkov Telescope, Data Selection and Simulation Criteria

- During observation windows of data:
  - Use the first 4 - 200 time bins to extract baseline to get a background behavior.
  - Not a Poissonian behavior.
  - **PE threshold = 67 PEs** in each bifocal pixel.
  - Background threshold rate = 10^{-7} Hz (1 background event in 116 days).

2. Cherenkov Telescope, Data Selection and Simulation Criteria

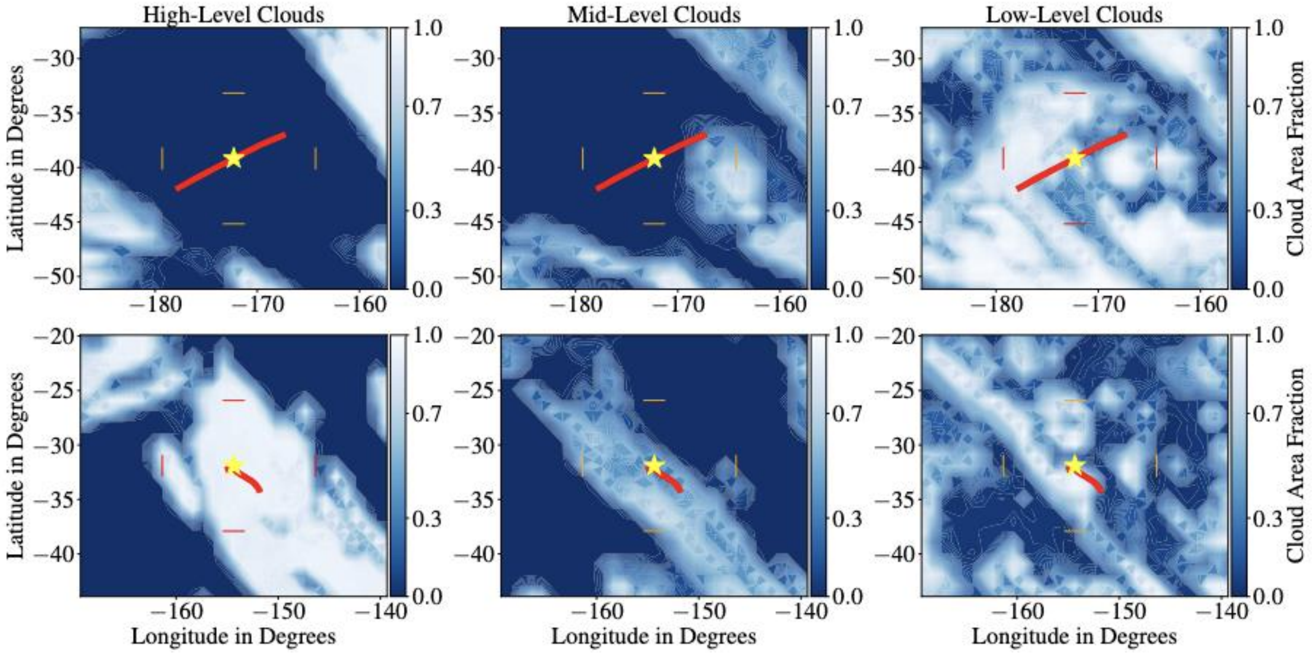


Figure 3: First, second and third column shows the high, mid, and low-level cloud area fraction for Night 1 (top panel) and Night 2 (bottom panel). The red line shows the balloon trajectory and the yellow star indicates the time stamp of the cloud snapshot. The orange lines shows the approximate FoV of the Cherenkov telescope.

- Clouds can obscure light from EASs.
- MERRA-2 database: global meteorological data from January 1980 to near-present.
- Takes weather data from both satellite and ground-based observations.
- Cloud coverage at low, mid, and high altitudes for the two nights of the flight.
- Night 1: significant amount of low-level cloud coverage.
- Night 2: significant high-level cloud cover.
- Assume homogeneous cloud coverage.
- Night 1, τ-leptons are required to decay above 2 km.
- Conservative estimate for neutrino detection as it neglects when EAS start within clouds and continue development beyond them.

3. Diffuse Neutrino Sensitivity Limits

- No neutrino candidate events observed.
- 67 PE threshold - no background events taken.

$$E_\nu^2 \phi_\nu(E_\nu) = \frac{2.44 \times N_\nu \times E_\nu}{\ln(10) \times \langle A\Omega \rangle (E_\nu) \times t_{\mathrm{obs}}} .$$

2.44: Feldman Cousins for 90% confidence interval of no events and no background
t_{obs}: Observation time
$\langle A\Omega \rangle$: Aperture

3. Diffuse Neutrino Sensitivity Limits

- 100,000 diffuse trajectories using nuSpaceSim software.
  - Each trajectory is weighted by neutrino-to-tau conversion and tau exit probability,
  - tau energy
  - trajectory is weighted by the chance of a decay in the atmosphere to create an EAS.

nuSpaceSim	**Simple Detector**	**OffLine**
• Photons at CC: Internal Cherenkov light model. • Detector: SiPM detection efficiency is uniform across wavelength (20%). • # of PE in the camera $2 \times 67 \geq 134$	• Wavelength dependence of the detection efficiency. • Gaps in detection surface. • Wavelength dependent losses in mirror reflectivity and transmittance in the aspheric corrector plate.	• EASCherSim used for photons at CC. • Full ray-tracing allowing asymmetric distribution of photons in bifocal pixels.

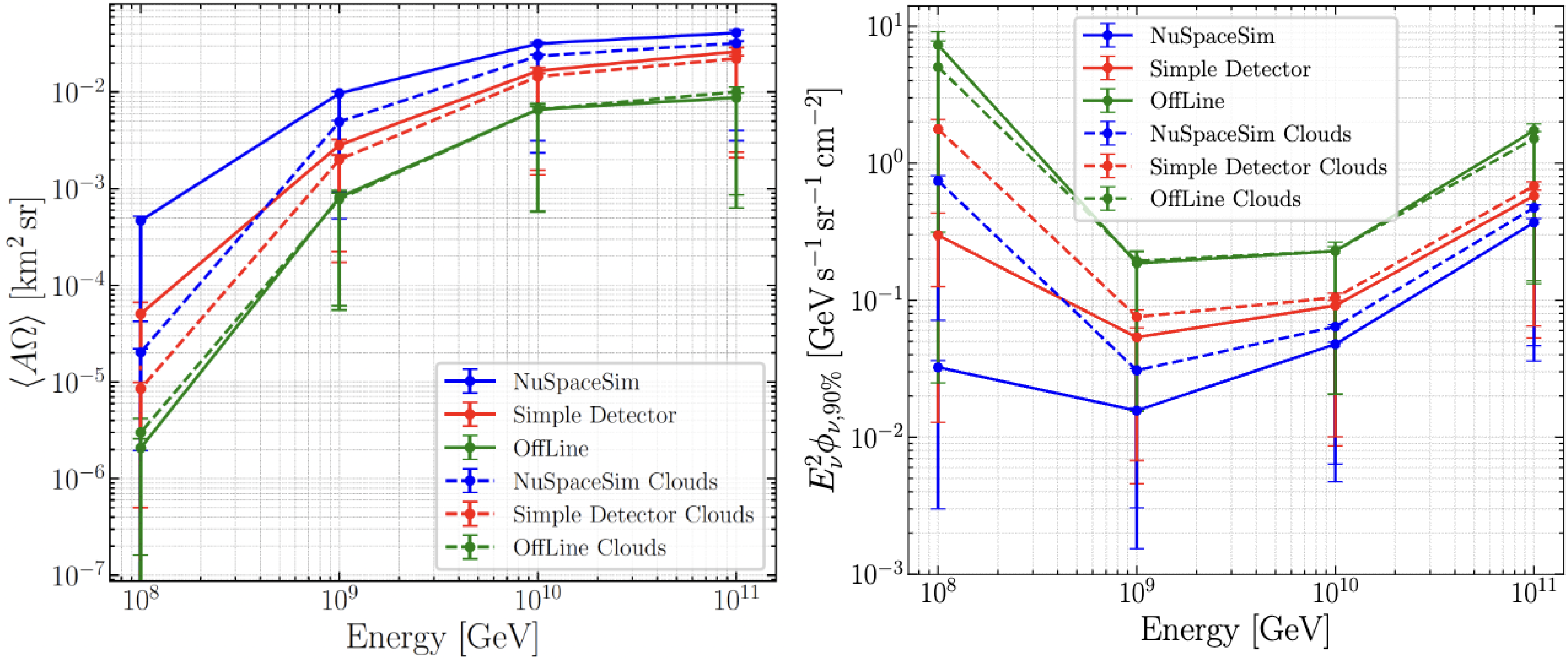


Figure 4: Left: Diffuse neutrino acceptance for 12.8° azimuth coverage as a function of energy calculated using NuSpaceSim (blue), the simple detector model (red), and the full detector model OffLine (green). The solid lines represent approximations without clouds, and the dashed lines represent approximations with clouds. Right: Resulting diffuse neutrino 90% confidence level per energy decade sensitivity as a function of energy.

Summary for ICRC Proceedings

- Nearly complete draft.
- To-do:
  - Work on uncertainties for main results.
  - 50-day ideal flight diffuse sensitivity curve will be plotted.
- Done by June 11, informal review starting now.
- Overleaf Link: https://www.overleaf.com/1483521449wgqvqgmtfydp#19bb37

Draft of Journal Paper

Written by Oscar Romero (Georgia Tech)

EUSO-SPB2: Below the Limb Observations

Author List

August 2023

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CT

PSF

Geometry and detector altitude and pointing time

NSB

Triggered event and traces

Acceptance

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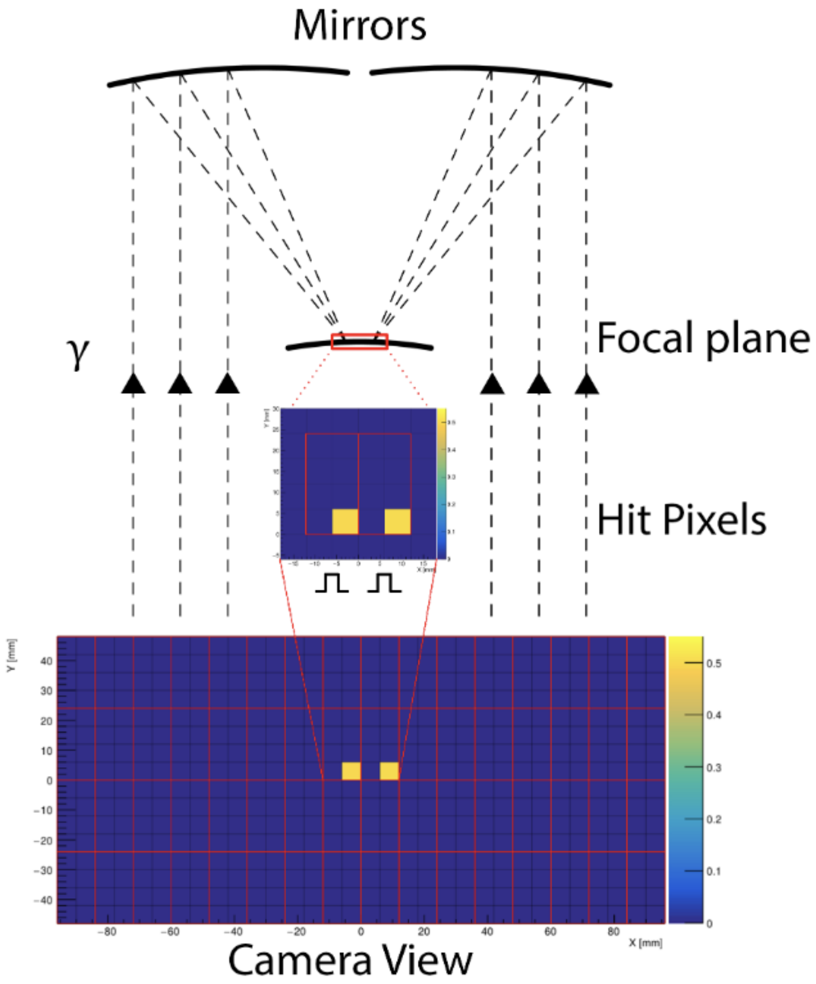
2. The EUSO-SPB2 Cherenkov Telescope

- Description of Cherenkov Telescope (CT).
  - Entrance pupil, mirror orientation, optics.
  - Bifocal alignment for background filter.
  - SiPMs, MUSIC chips

- Trigger:
  - Logic



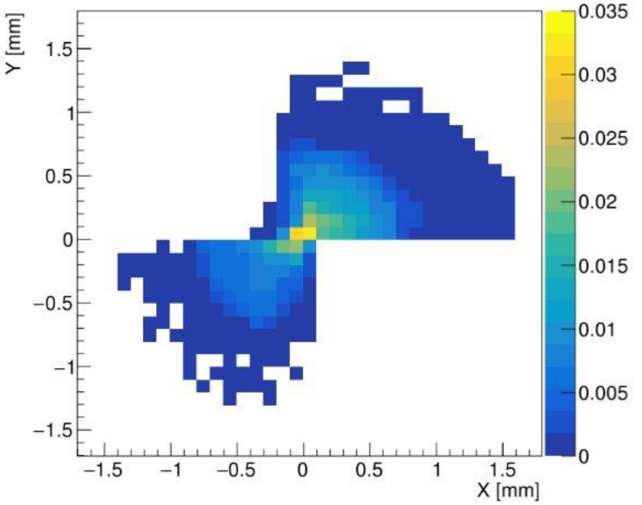
3. Simulation Chain

- nuPyProp --> CHASM --> GrOptics --> CARE

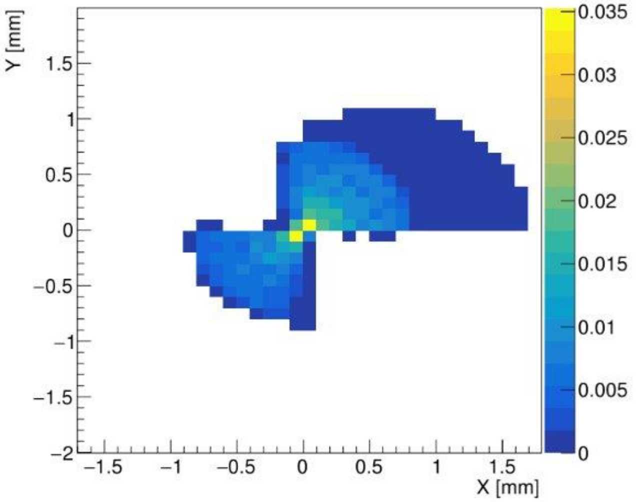
Nu to tau	EASs	Optics of photons in detector	Detector electronics

- The parameters energy, arrival direction, and impact point on the Earth of the simulated tau neutrinos are determined with I Fly Happy Balloons (IFHB) which organizes the Monte Carlo production for diffuse neutrino fluxes and neutrino point sources.

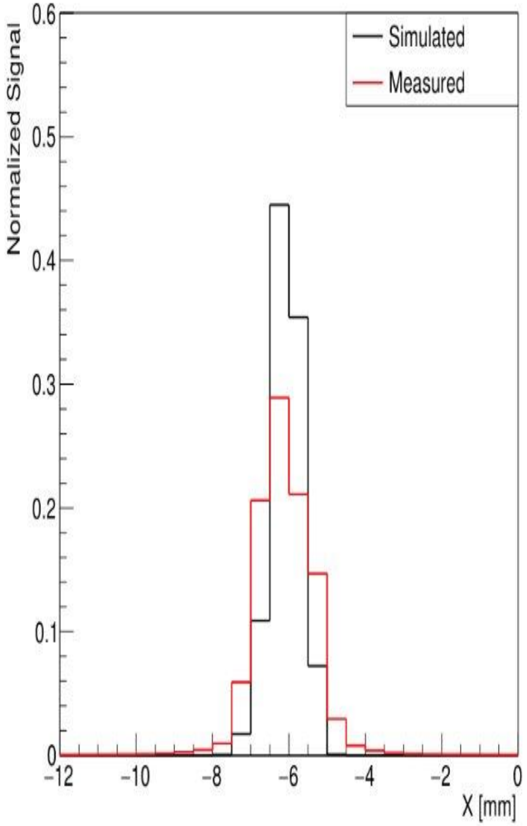
3. Simulation Chain



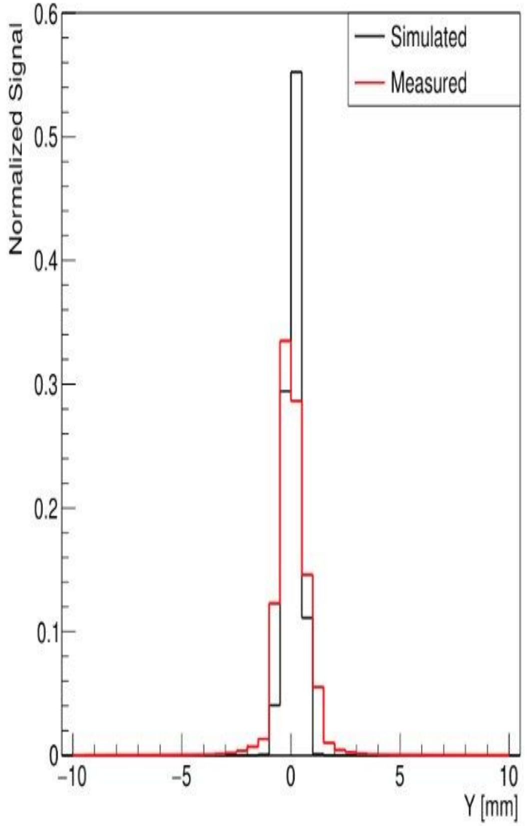
(a) GrOptics PSF



(b) ZeMax PSF



(a) X Projection of PSF



(b) Y Projection of PSF

Figure 4: Projections of PSF for comparison. Black: GrOptics. Red: Measured. 90% of the total signal is contained within 0.7 mm radius for the simulated PSF and 1 mm radius for the measured PSF. For comparison, the size of a camera pixel is 6.4 mm.

4. Observations

- Details on balloon launch and subsequent leak.
- 190 minutes below the limb; 53 minutes on 5/13 and 137 minutes on 5/14.
- Recorded 25,732 events while observing below the limb.

5. Night Sky Background Measurements

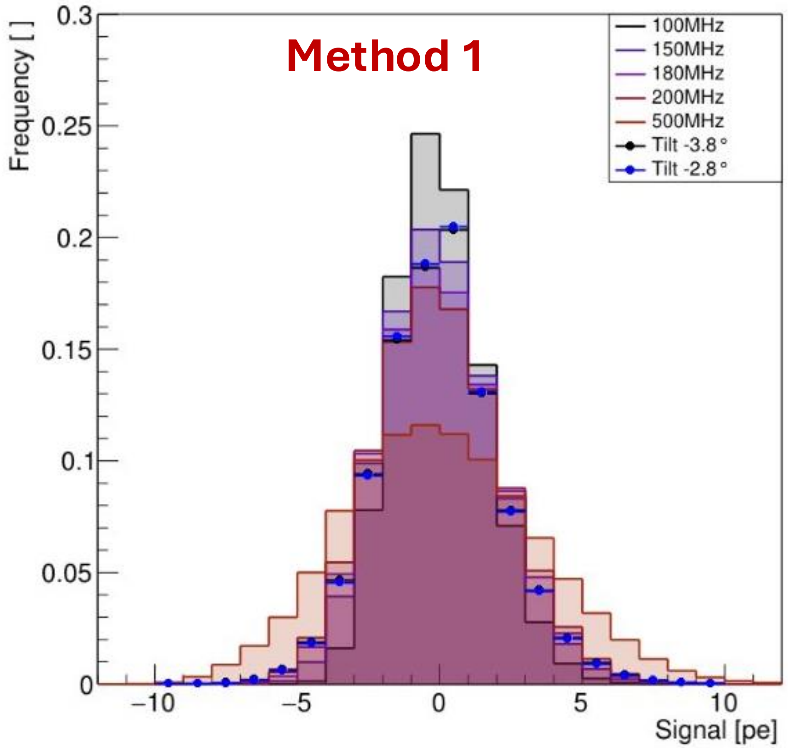


Figure 7: Pedestal distributions of camera signals at two different tilt angles from observations at 33 km altitude (data points), and simulated distributions for five NSB rates.

- Data distribution plotted for night 1.
- Using CARE simulation, 5 different NSB rate distributions are plotted.

Angle from Limb [°]	Altitude [km]	Method 1 Pedestal [MHz]	Method 2 Current [MHz]	Moon Elevation [°]
-2.8	33	184.1 ± 0.7	176.2 ± 0.2	
-3.8	33	179.3 ± 0.8	179.1 ± 0.1	
-4.0	18	N/A	342.6 ± 0.2	
-4.5	14	N/A	317.9 ± 0.4	
-5.0	8	N/A	312.8 ± 0.4	

Table 1: Night-Sky Background measured from the pedestal fluctuations of the recorded camera signals (Pedestal) and from the SiPM currents (Current). For tilt angles $-4.0, -4.5$, and -5.0 below the limb, the readout system did not work reliably and the NSB rate could only be measured from with the SiPM currents.

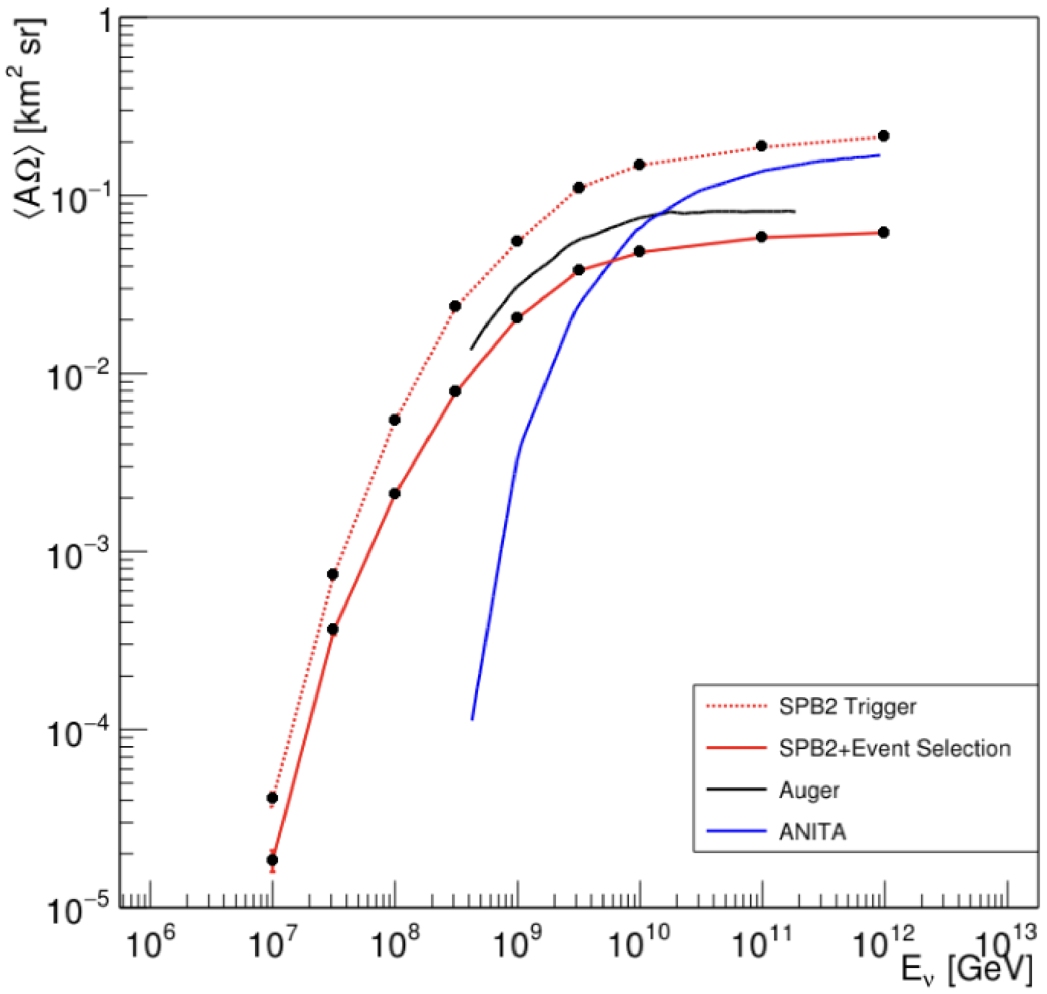
Method 2: not enough information written in draft.

6. Search for neutrino like events

- Event selection:
  - Baseline subtraction
  - ADC to PE conversion
- NSB triggered events:
  - Bifocal requirement with coincidence window
  - Photons to be equally distributed between bifocal pixels
- 6 bifocal events recognized by Oscar as potential background events.

7. Upper flux limits on diffuse neutrinos

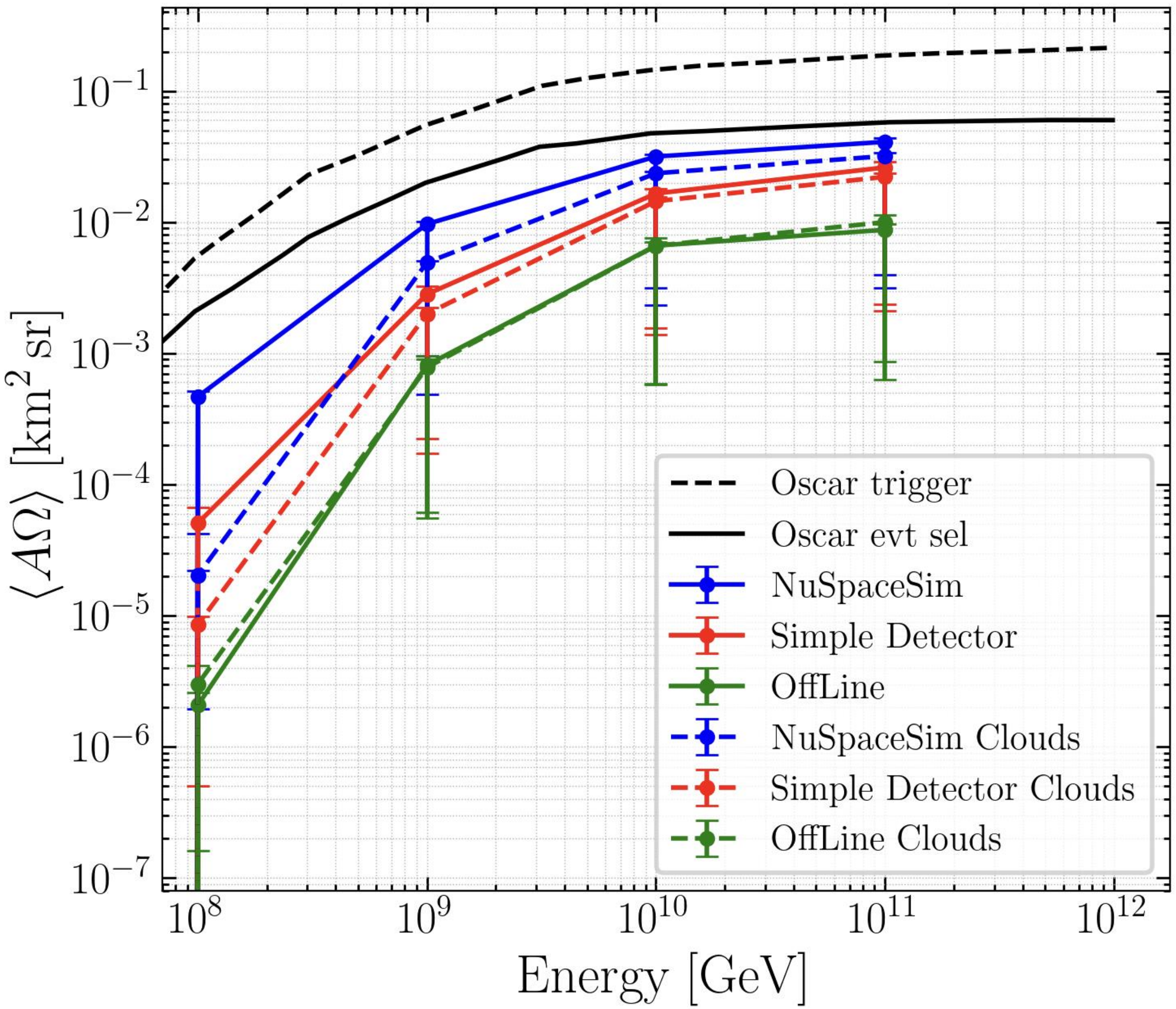
- Acceptance calculation is explained.
- Solid red curve: acceptance with end-to-end simulation.
- Red dotted: acceptance without the bifocal requirement.



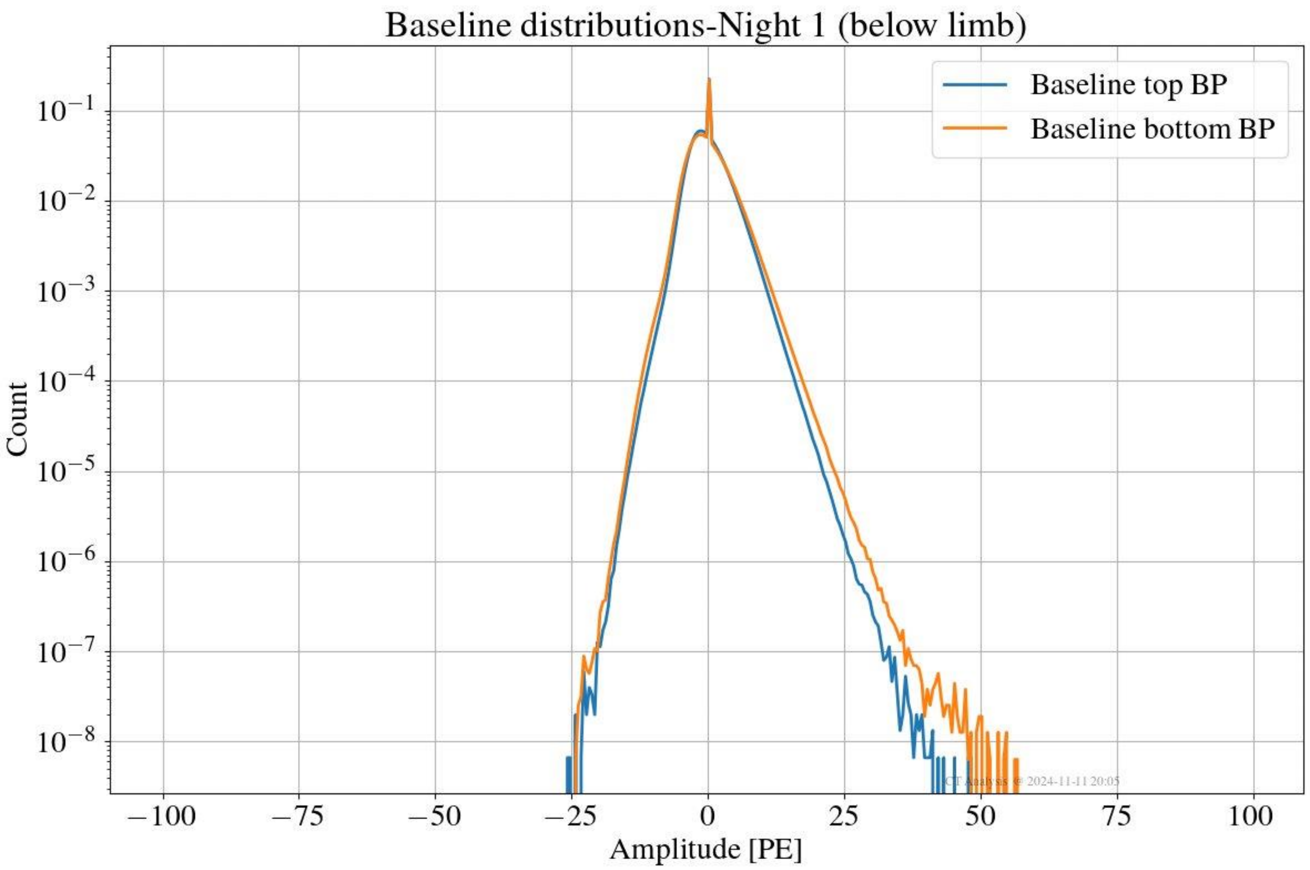
Summary of Journal paper

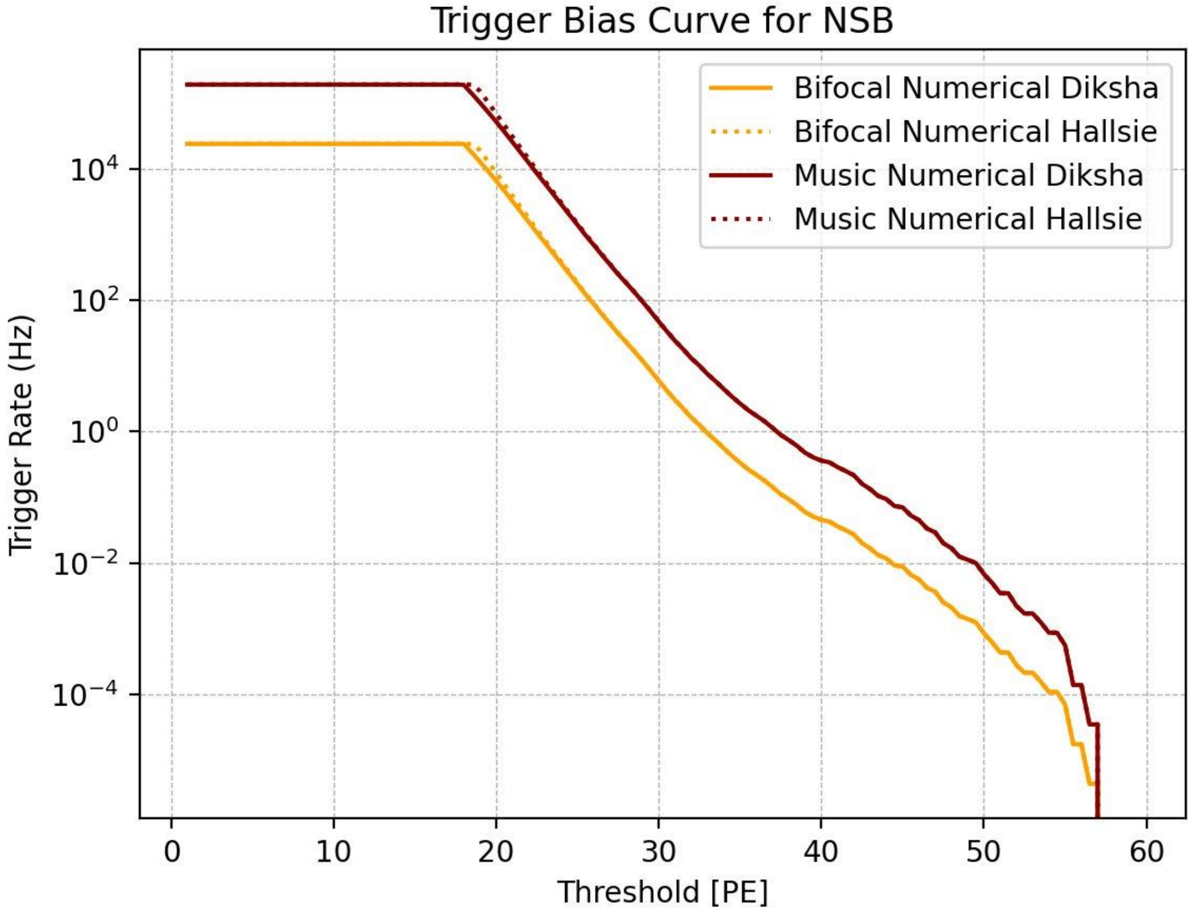
- Difficulty in repeating NSB analysis by us.
- Oscar takes: Poissonian bkg distribution with PE threshold lower than us.
- Can't run GT simulation chain.
- Can't reproduce only 6 bifocal events using Oscar's selection criteria.
- **Approach 1**: In current draft, explain 2 simulation chains. GT for bkg NSB. CSM/UI for diffuse neutrino sensitivity.
- **Approach 2**: 2 separate papers. GT on NSB. CSM/UI for diffuse neutrinos limits.
- Advice welcome.

Comparison of Acceptance (not in paper)

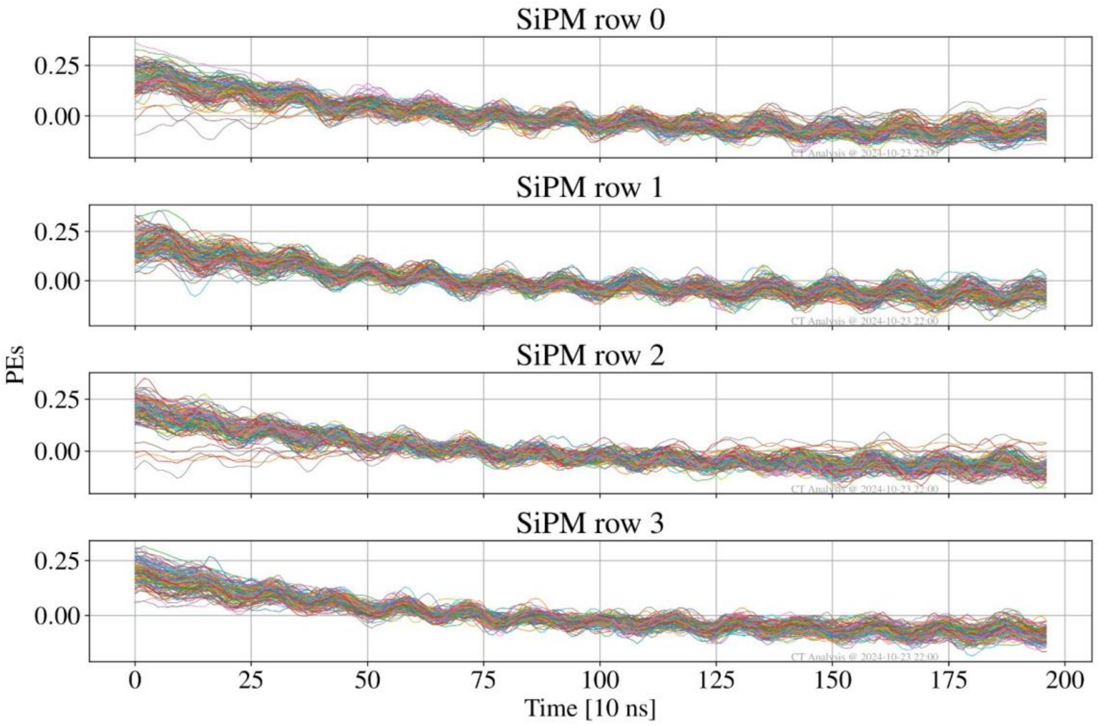


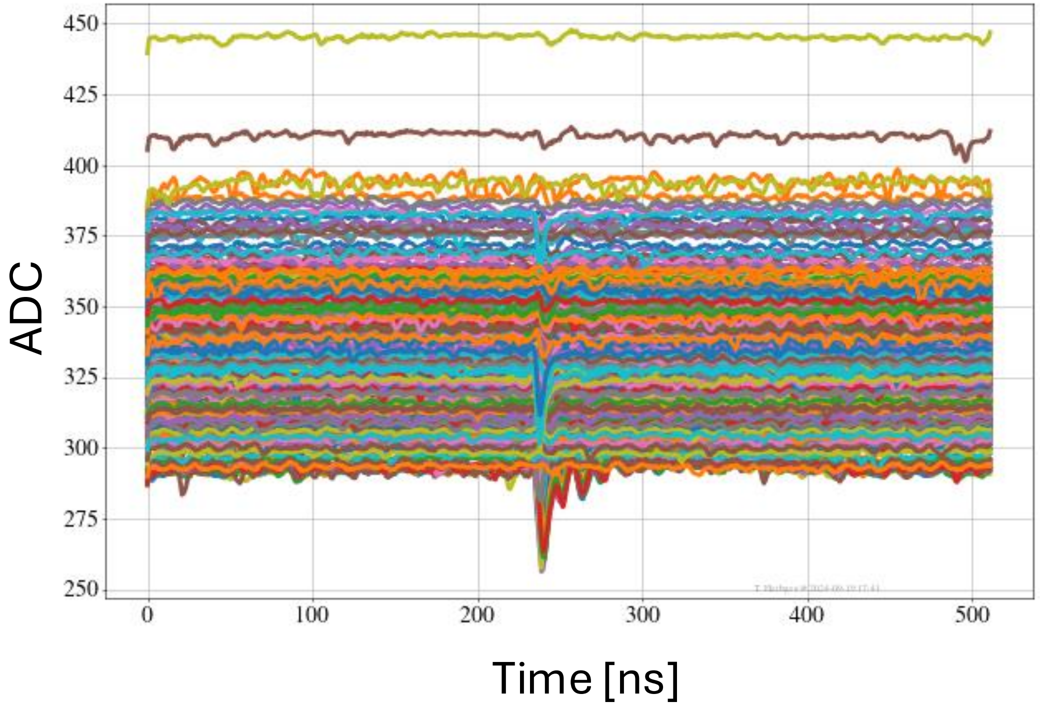
Backup Slides

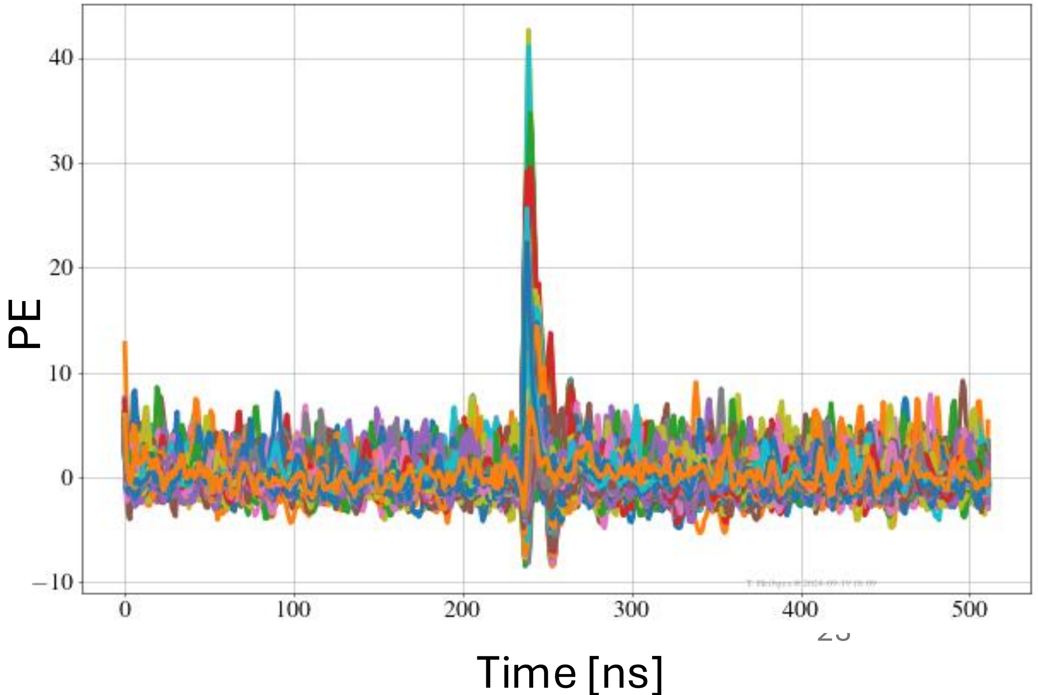




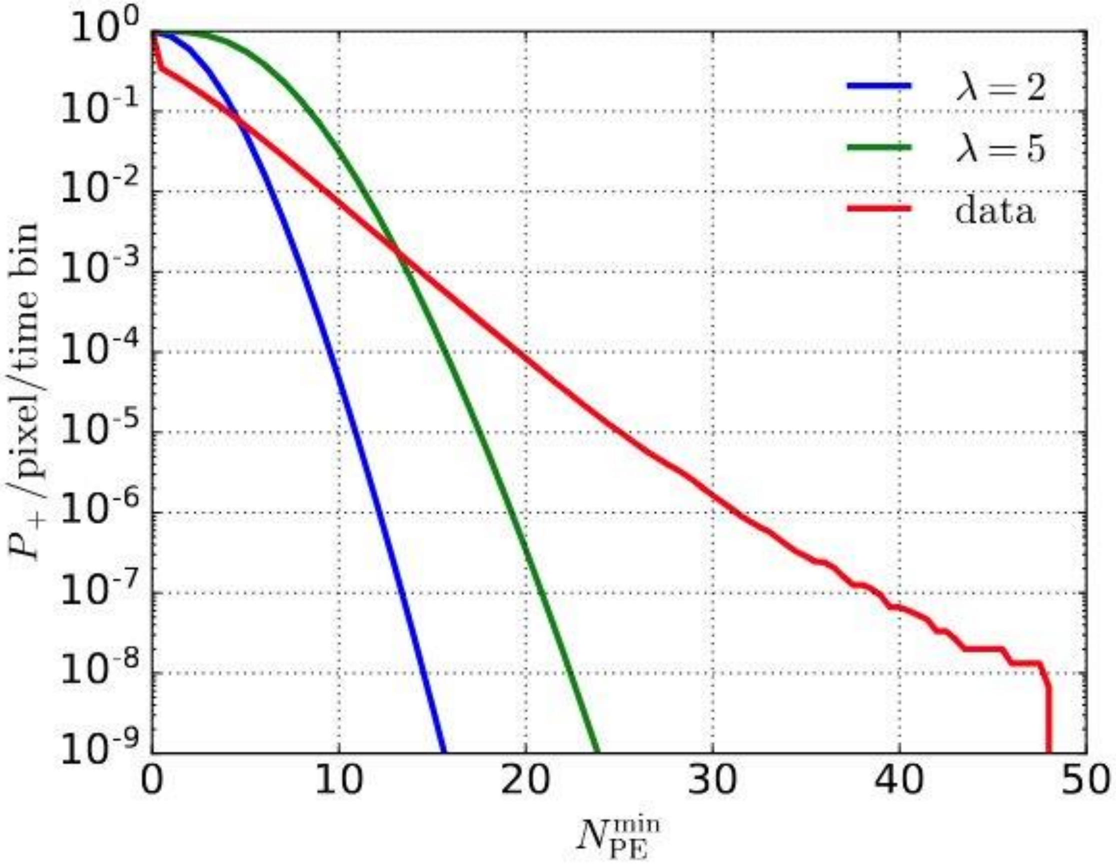
Data Characteristics



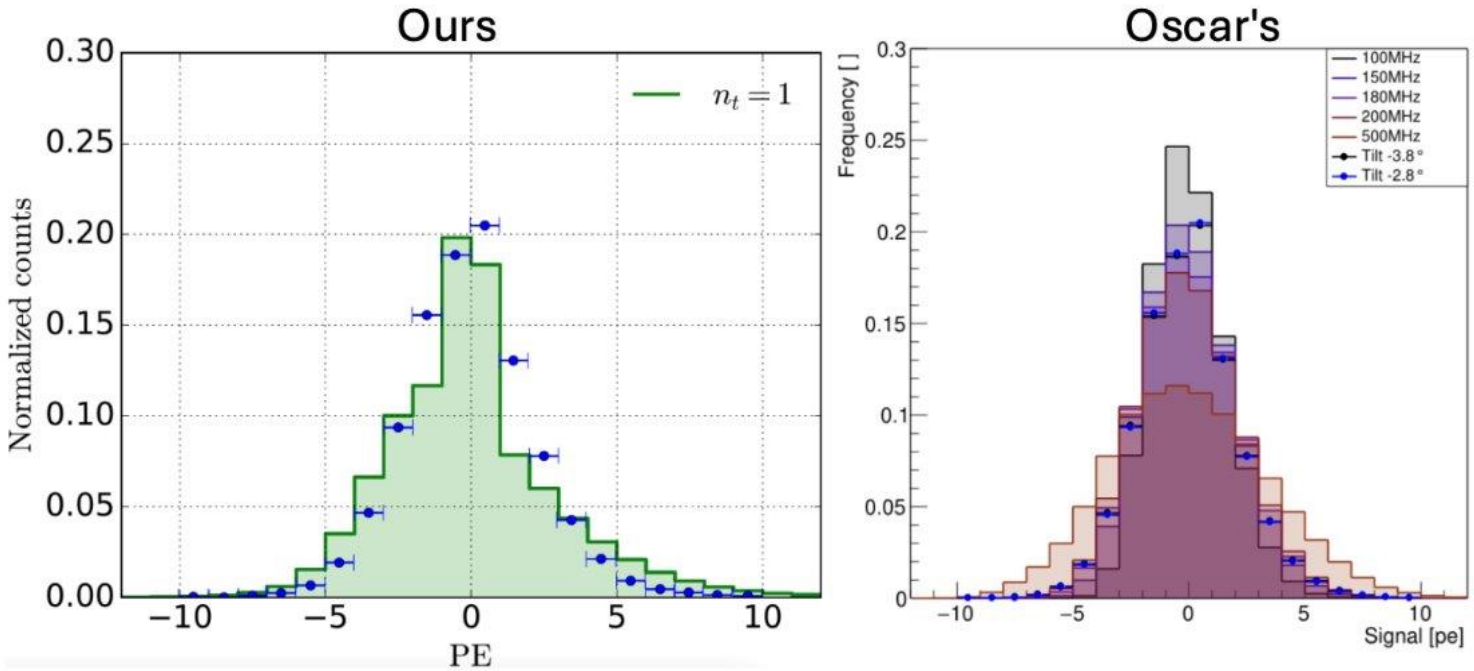




Comparing with Poissonian distribution



Comparison with Oscar's



Not sure if we have the same thing plotted as Oscar's

Distribution of flight data is shown in blue

Figure 13. Single pixel fluctuations compared to Oscar's results. Left: Using the single pixel probability per time bin probabiliities (fig. 8 plus excess at $N_{\mathrm{PE}} = 0$), plotted is the frequency of N_{PE} averaged over n_t 10 ns time bins. Data points copied from figure on the right. Right: From Oscar's manuscript: "Pedestal distributions of camera signals at two different tilt angles from observations at 33 km altitude (data points), and simulated distributions for five NSB rates." Title angles are below Earth's limb.

Acceptance calculation formula

Diffuse flux all-flavor sensitivity assuming no observed events (and no background):

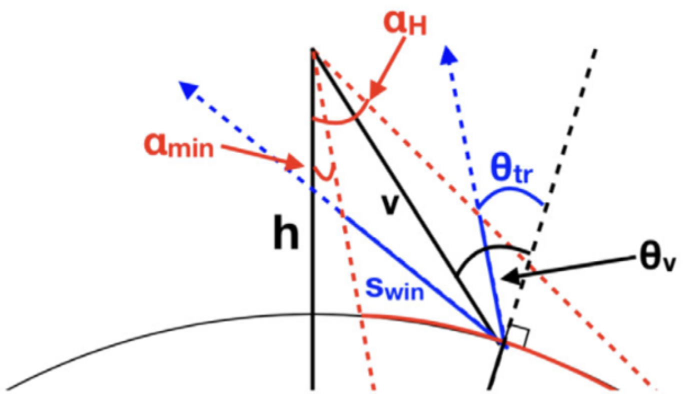
$$F_{\rm sens} = \frac{2.44 \times N_\nu}{\ln(10) \times E_{\nu_\tau} \times \langle A\Omega\rangle(E_{\nu_\tau}) \times t_{\rm obs}}$$

$$N_\nu = 3$$

plot $E^2_{\nu_\tau} F_{\rm sens}$

Detector aperture:

$$\langle A\Omega\rangle(E_{\nu_\tau}) = \int_S \int_{\Delta\Omega_{tr}} P_{\rm obs}\, \vec{r}\cdot\hat{n}\, dS\, d\Omega_{tr}$$



Observation and detection probability

$$dP_{\rm obs}(E_{\nu_\tau}, \beta_{\rm tr}, s) = ds\, P_{\rm exit}(E_{\nu_\tau}, \beta_{\rm tr}) \times p_{\rm dec}(s) \times P_{\rm det}(E_{\nu_\tau}, \beta_{\rm tr}, s)$$

$$P_{\rm det} = H[\theta_{\rm Ch} - \theta] H[s_{\rm win} - s] H[N_{\rm PE} - N_{\rm PE}^{\rm min}]$$