CT Cosmic-Ray Paper Status

Tobias Heibges

37th JemEUSO Collaboration meeting
06/05/2025 Paris

PHYSICS
COLORADO SCHOOL OF MINES

Paper status

- First draft by Eliza and Mahdi
  - Not complete and needs cross checks
- Analysis and simulation chain using OffLine complete
  - Different from simulation chain used by GT group
- Different data analysis strategy
  - Need to cross check cuts
- Main task: **Merging analysis that have been performed**

Observation of Cosmic Rays above the limb via Cherenkov Telescope on-board EUSO-SPB2 mission

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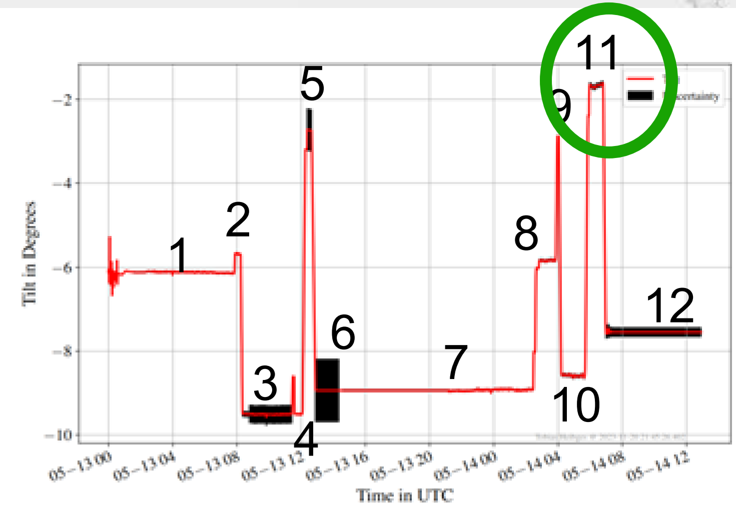
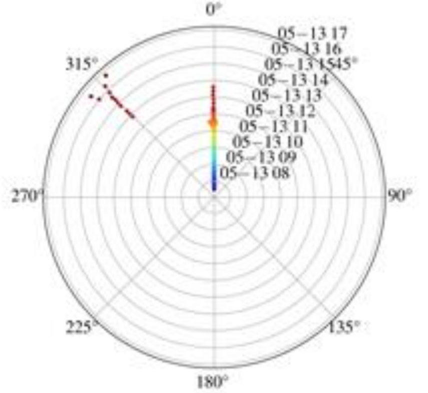
Abstract. The Extreme Universe Space Observatory on a Super Pressure Balloon 2 (EUSO-SPB2) was launched in May 13, 2023 from Wanaka, New Zealand as a pathfinder, carrying a Fluorescence Telescope (FT) and a Cherenkov Telescope (CT). The Cherenkov Telescope was able to slew and tilt towards neutrino transient targets and use the Earth-skimming technique to observe air-showers from cosmic rays above the limb and search for Very-High-Energy (VHE) tau neutrinos below the Earth's limb ($E > 10$ PeV). The 1 m^2 Cherenkov telescope was equipped with a 512-pixel silicon photomultiplier camera, covering 12.8° x 6.4° (Horizontal x Vertical) field of view, that utilized a novel stereo optical system. The camera signals were digitized with a 100 MS/s readout system. During its two nights of observation, the CT collected several hours of data from above and below the limb of the Earth. Eventually, the balloon flight was terminated after 36 hours due to an unexpected leak in the balloon. In this work, we report on the analysis of air showers from cosmic rays during above the limb observation.

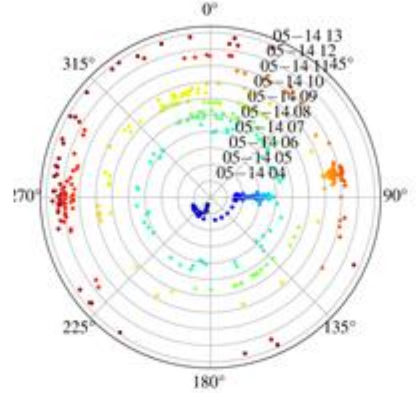
CT Flight Operations

Night 1				
Begin Time	**End Time**	**Telescope Status**	**Tilt**	**Pointing**
06:25:00	08:01:00	Commissioning	-	-
08:01:00	08:12:00	Observations	-5.8°	0.0°
08:12:00	08:23:00	Tilting/Observations	-5.8° to -9.62°	0.0°
08:15:00	08:35:00	Commissioning	-9.62°	0.0°
08:38:00	11:24:00	Observations	-9.62°	0.0°
11:25:00	12:02:00	Observations	-8.62°	0.0°
12:03:00	12:26:00	Tilting/Observations	-8.62° to -2.69°	0.0°
12:26:00	12:42:00	Observations	-2.69°	0.0°
12:43:00	12:55:00	Tilting/Observations	-2.69° to -9.69°	0.0°
12:55:00	13:39:00	Observations	-9.69°	0.0°
13:40:00	13:52:00	Observations	-9.69°	315.0°
13:52:00	-	Shutters Closed	-5.8°	315.0°
Night 2				
Begin Time	**End Time**	**Telescope Status**	**Tilt**	**Pointing**
05:37:00	05:40:00	Observations	-8.6°	0.0°
05:40:00	05:58:00	Tilting/Observations	-8.6° to -1.68°	0.0°
05:58:00	06:46:00	Observations	-1.68°	Spinning
06:47:00	07:02:00	Tilting/Observations	-1.68° to -7.6°	Spinning
07:02:00	07:10:00	Observations	-7.6°	Spinning
07:10:00	09:24:00	Troubleshooting	-7.6°	Spinning
09:10:00	12:40:00	Observations	-7.6°	Spinning
12:40:00	-	Shutters Closed	-7.6°	Spinning



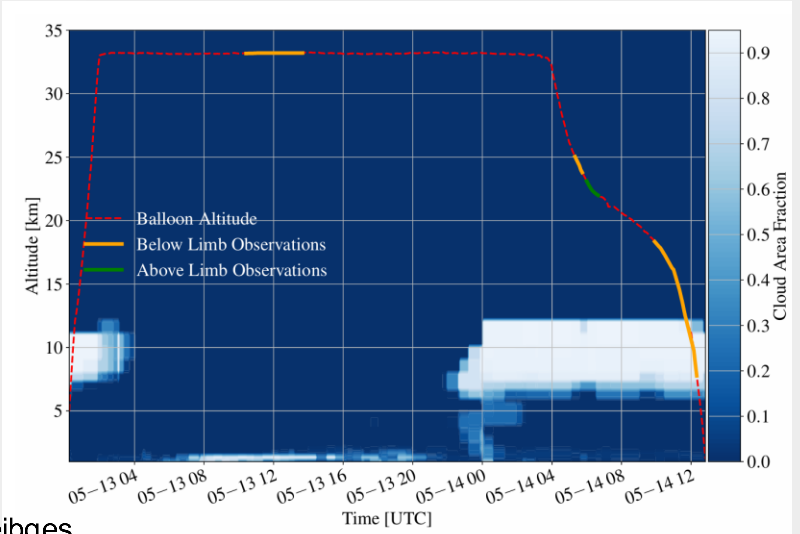
Mask	Uncertainty
Mask 1	0.7023°
Mask 2	0.0068°
Mask 3	0.1110°
Mask 4	0.3852°
Mask 5	1.4843°
Mask 6	1.3288°
Mask 7	0.0161°
Mask 8	0.0341°
Mask 9	0.0396°
Mask 10	0.0393°
Mask 11	0.1432°
Mask 12	2.2192°



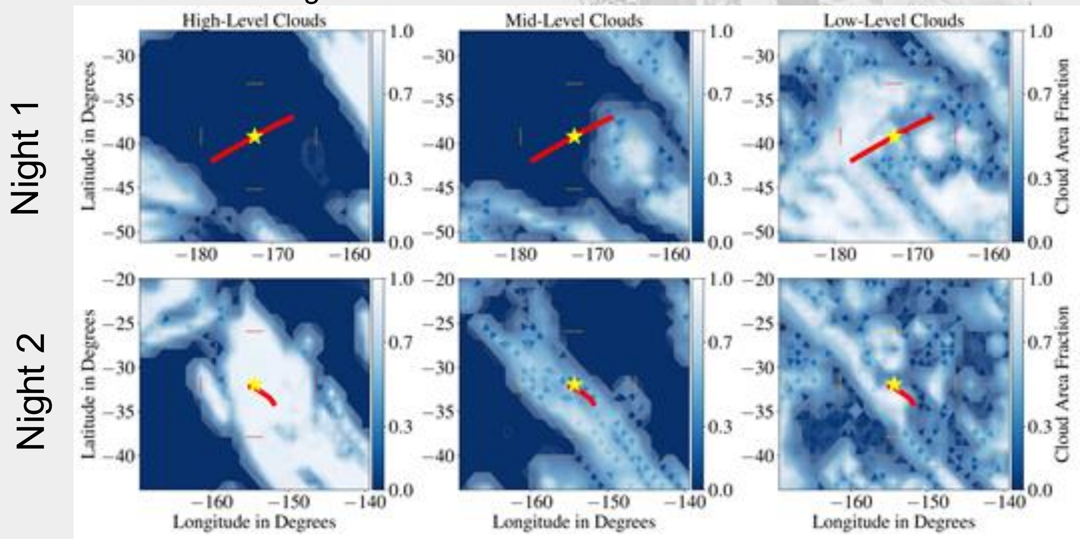


Flight Cloud Coverage

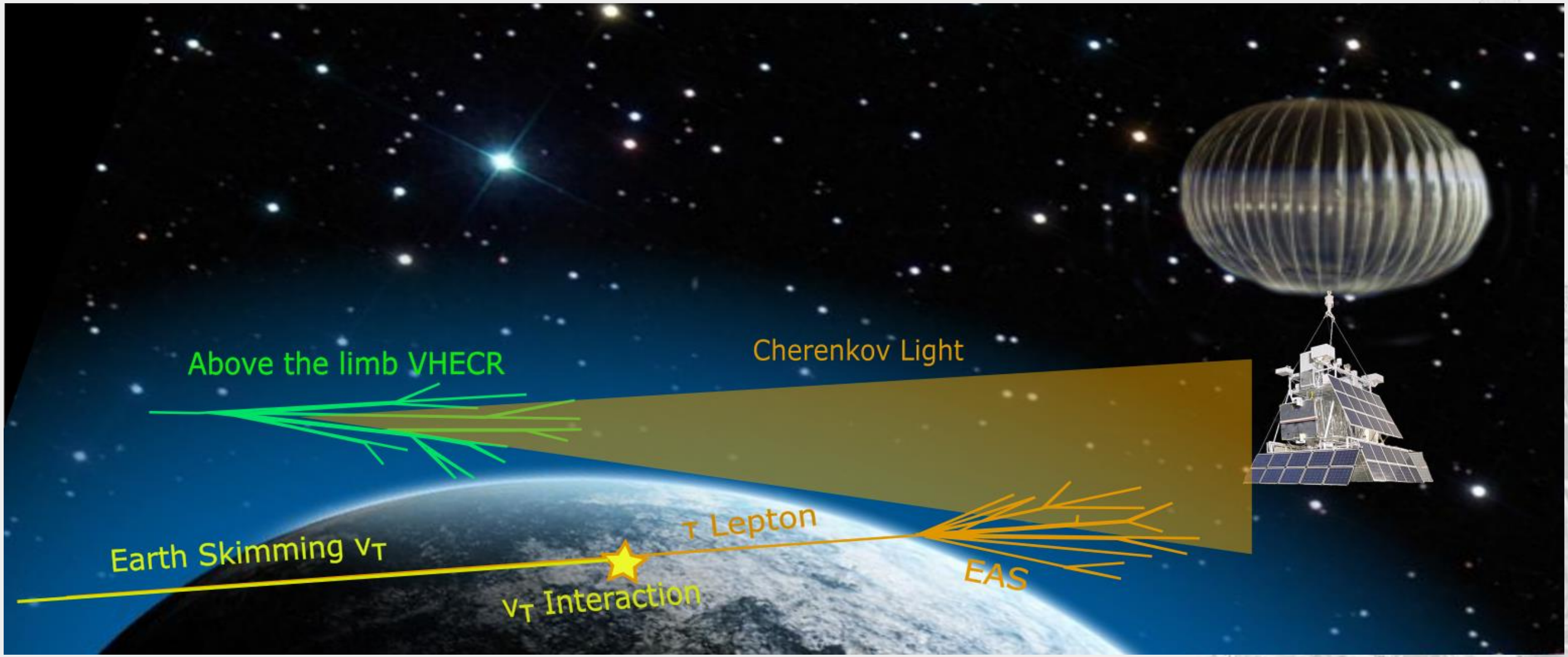
- Assumed homogenous cloud cover
  - Night 1: low-level (2km)
  - Night 2: high-level (12km)
- Clouds impact neutrino acceptance
  - Need light creation above clouds
  - Requirement on Energy and tau decay location



Julia Burton-Heibges

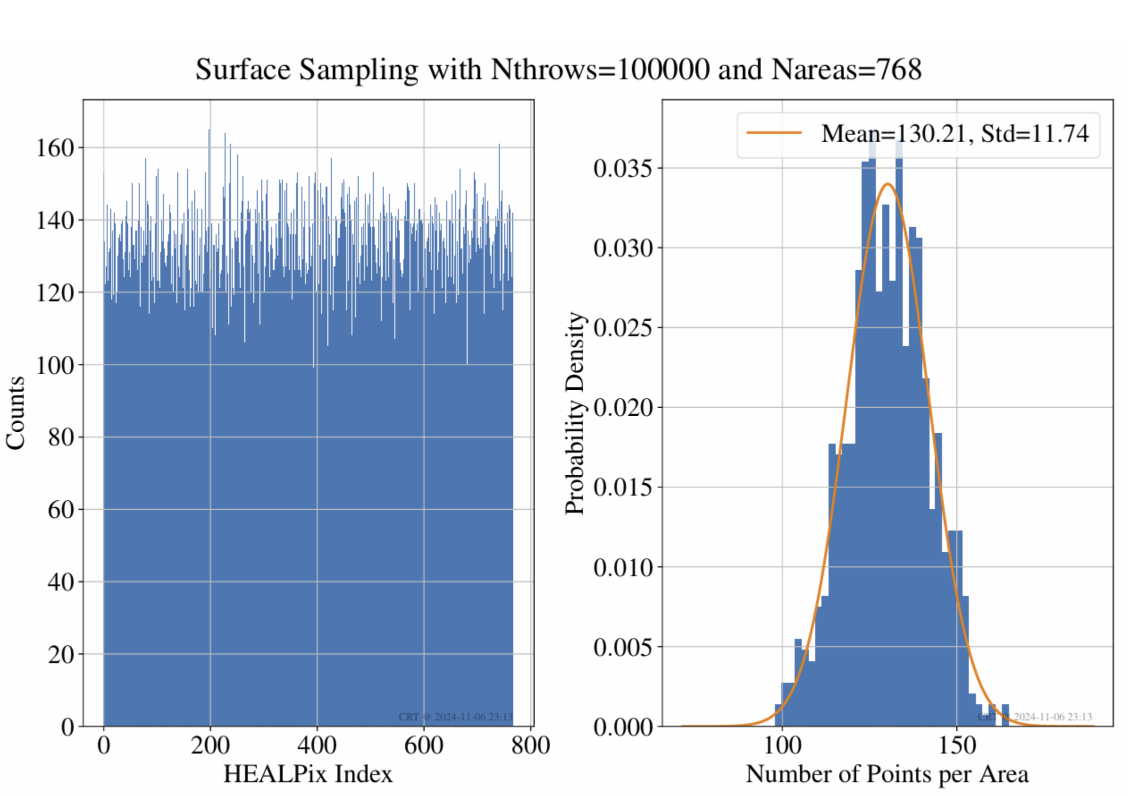


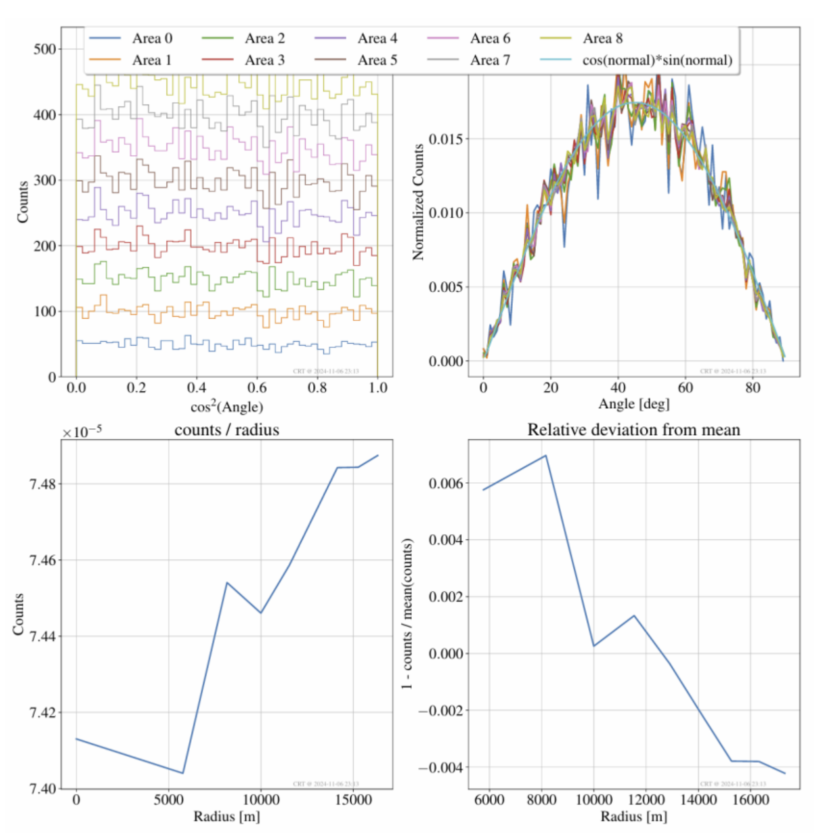
General CT Simulation Chain



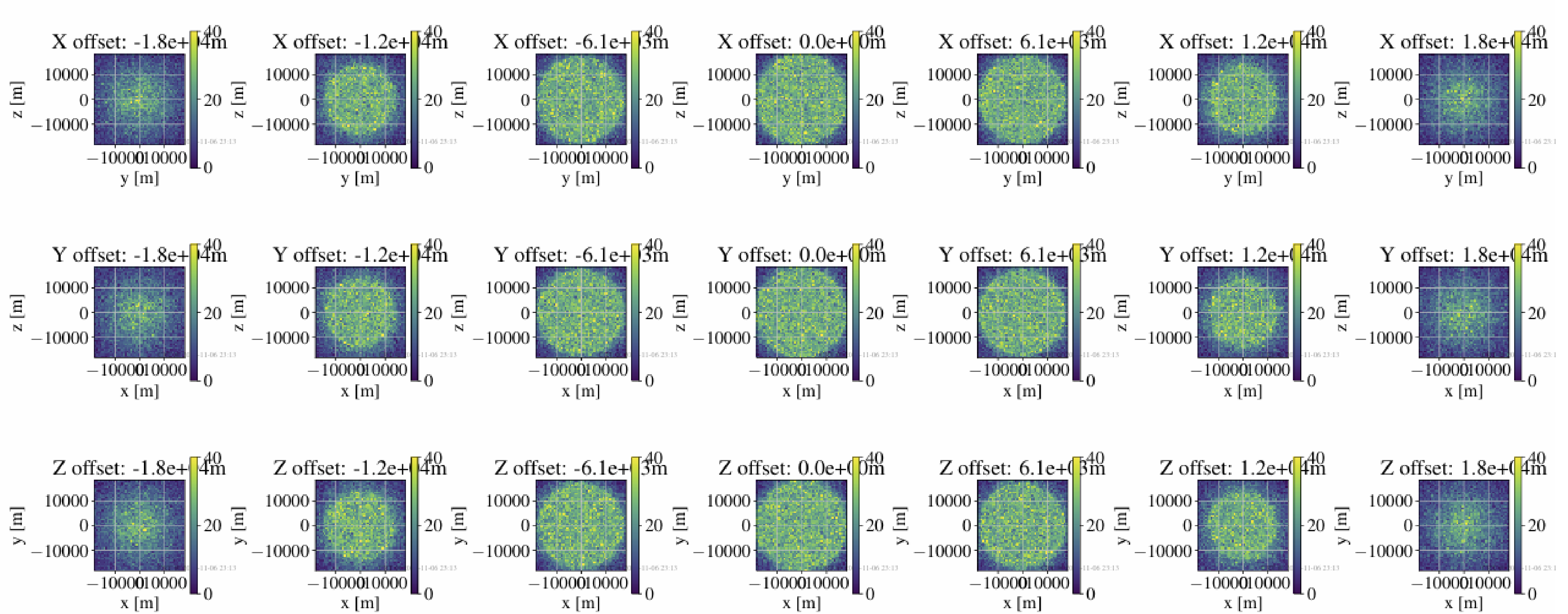
Cosmic Ray Sampling → EAS Profile Simulation (Conex) → EAS Cherenkov Light Simulation (EASCherSim) → Detector Simulation

Cosmic Ray / Neutrino Geometry Sampling → EAS Profile Simulation (Conex) → EAS Cherenkov Light Simulation (EASCherSim) → Detector Simulation





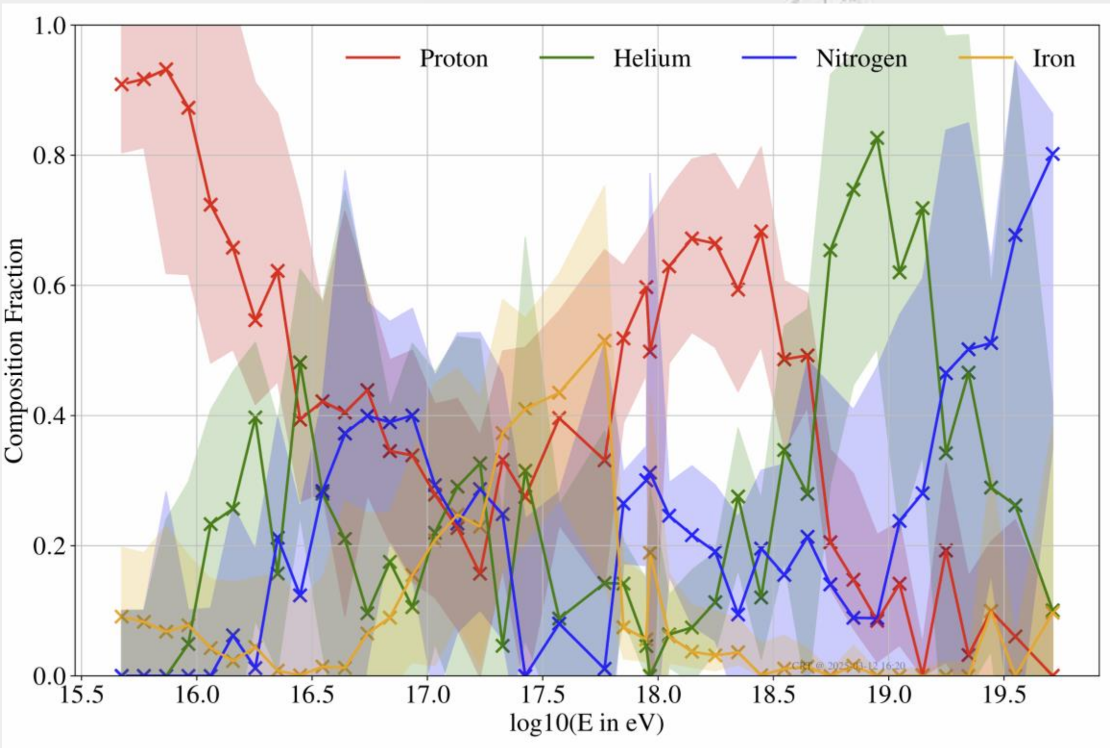
Cosmic Ray / Neutrino Geometry Sampling → EAS Profile Simulation (Conex) → EAS Cherenkov Light Simulation (EASCherSim) → Detector Simulation



Cosmic Ray / Neutrino Geometry Sampling → EAS Profile Simulation (Conex) → EAS Cherenkov Light Simulation (EASCherSim) → Detector Simulation

Cosmic Ray / EAS Simulations

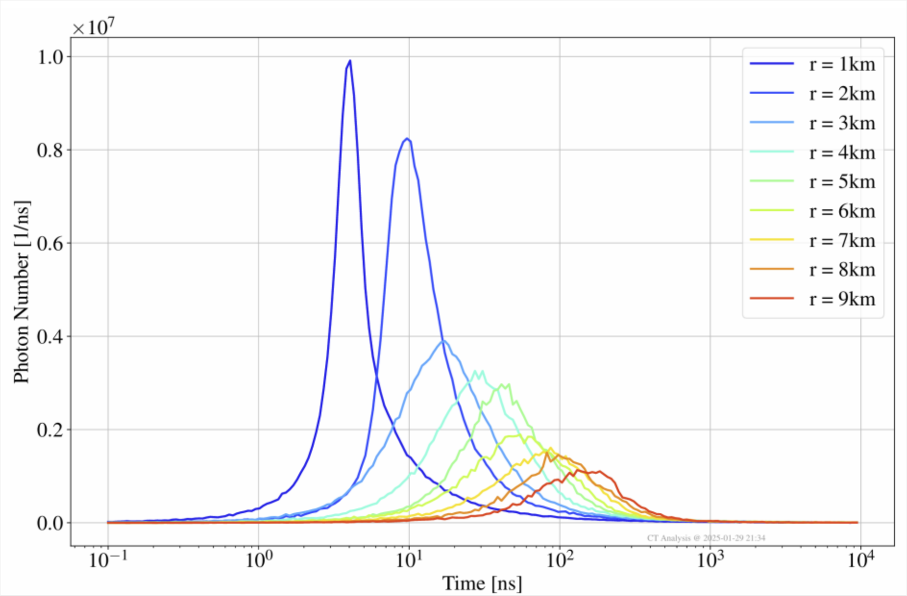
1. Sample CR composition from measurements by Auger and TALE
2. Inject trajectory into MC EAS Simulation Conex
3. Use EASCherSim to estimate Cherenkov light production and propagation to detector for each EAS



Cosmic Ray / Neutrino Geometry Sampling → EAS Profile Simulation (Conex) → EAS Cherenkov Light Simulation (EASCherSim) → Detector Simulation

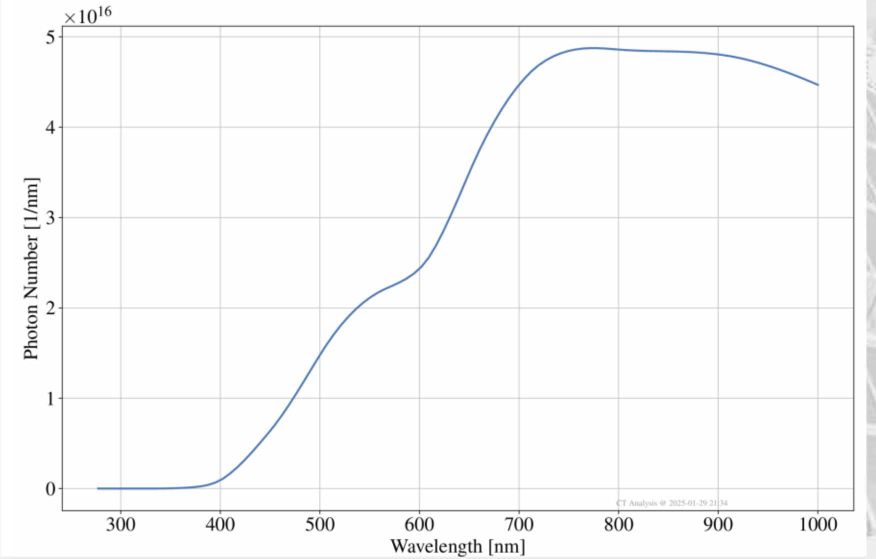
CONEX Longitudinal EAS profile simulation from MC Simulation

- Accounts for change in energy (beyond simple scaling)
- Changes in elongation rate based on primary particle



EASCherSim Cherenkov light simulation based on longitudinal EAS profile, which provides

- Radial photon profile
- Wavelength profile
- Photon timing profile
- Angular photon profile

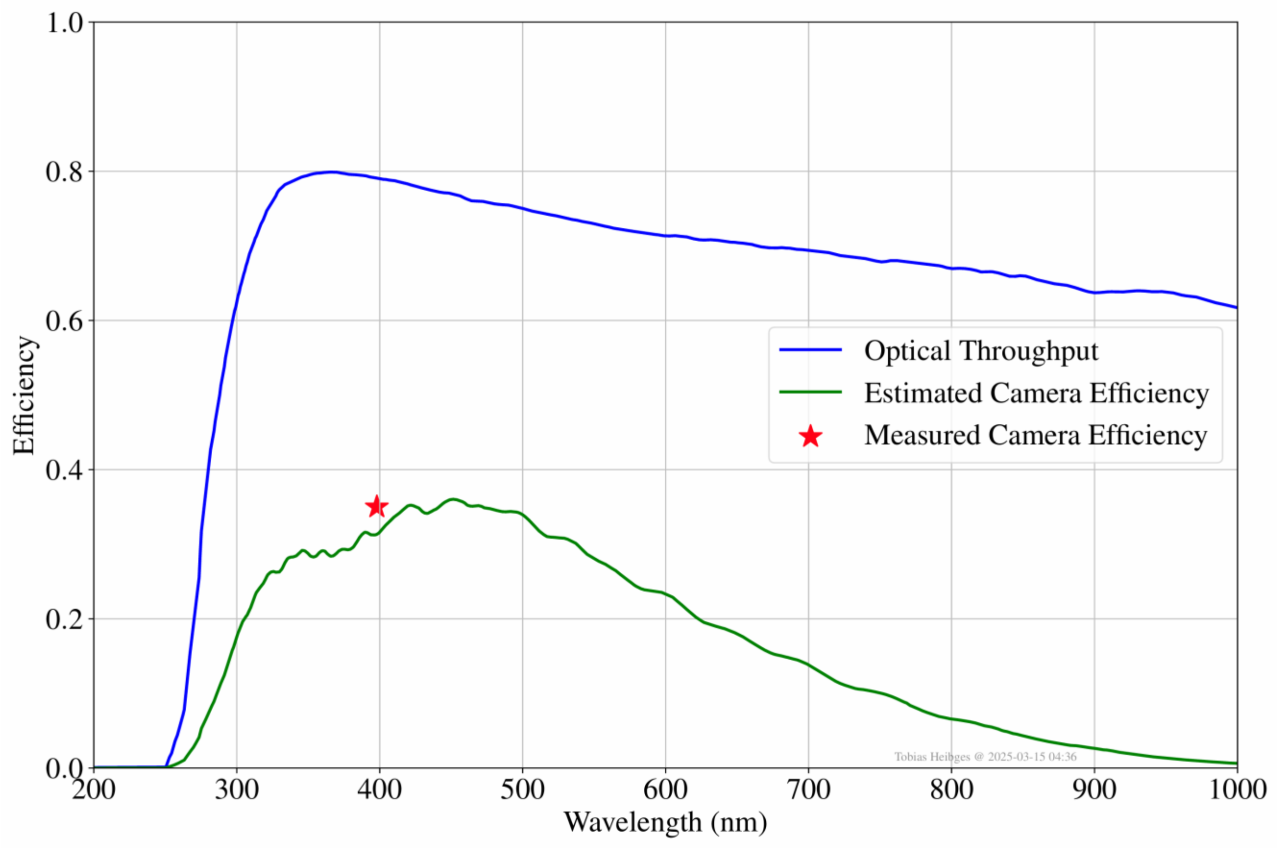


Cosmic Ray / Neutrino Geometry Sampling → EAS / Neutrino Simulation → EAS Cherenkov Light Simulation (EASCherSim) → Detector Simulation

Simplified model includes:

1. ACP throughput
2. Mirror reflectivity
3. SiPM efficiency
4. Gap estimation

Close to absolute calibration efficiency measured in the field



Cosmic Ray / Neutrino Geometry Sampling → EAS / Neutrino Simulation → EAS Cherenkov Light Simulation (EASCherSim) → Detector Simulation

In depth detector simulation OffLine:

1. Optics simulation (GEANT 4)
2. Photon PE conversion
3. Background simulation
4. Optical cross-talk
5. Bi-focal trigger
6. Signal pile up
7. Output pulse shaping
8. Digitization

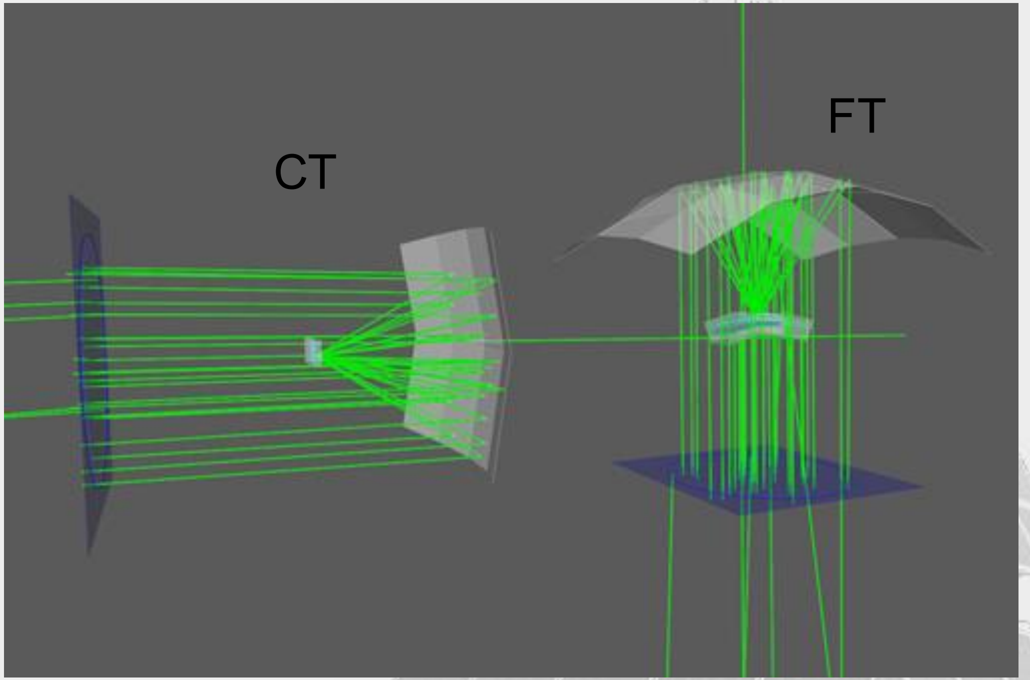
Result: Can not reproduce camera response accurately

- Event by event level
- Derived quantities like trigger rate

Lack of calibration data / understanding of instrument

Only use parts that can be verified: 1, 2

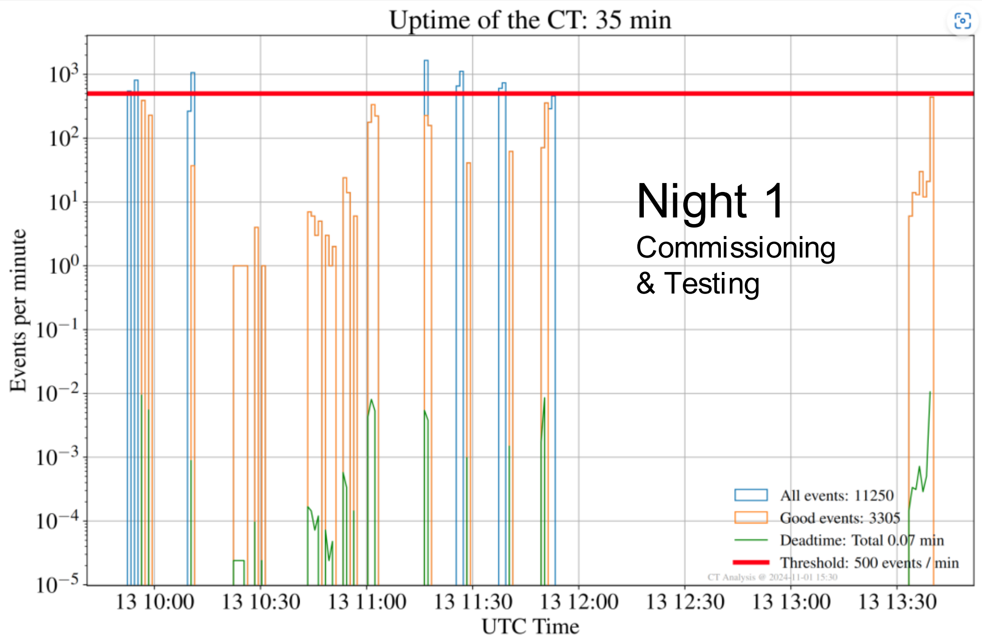
Need a different approach to estimate the camera response → Can we rely purely on data?

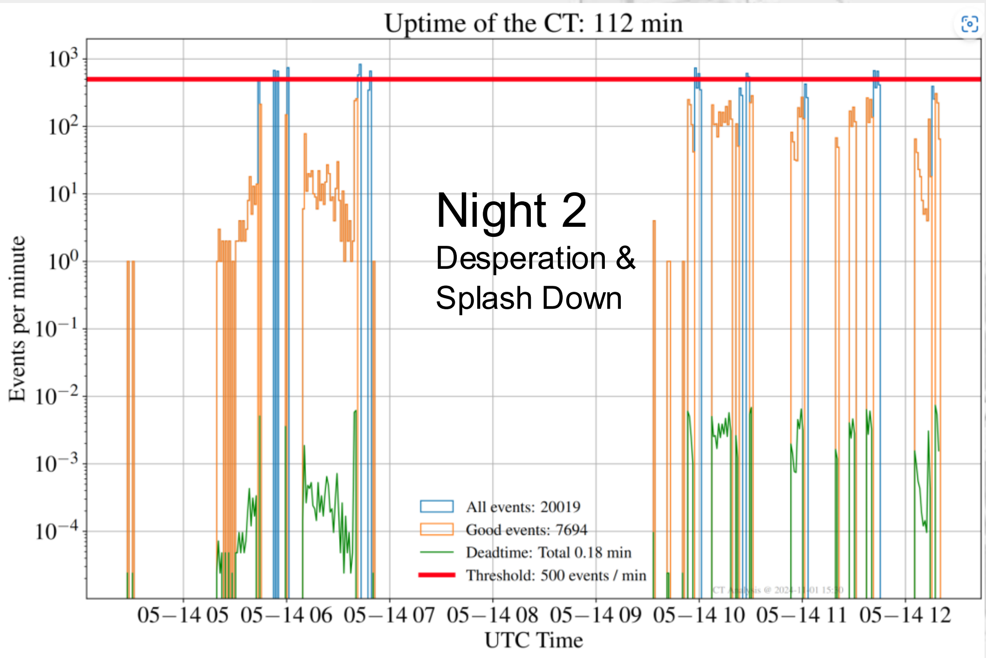


Observation time

As per recommendation from the GT group time periods with more than **500events/min** are considered over triggered and are remove

	Observation Time (min)	Events Recorded
Night 1	$50 \rightarrow 35$	$11250 \rightarrow 3305$
Night 2	$136 \rightarrow 112$	$20019 \rightarrow 7694$
Night 2 above limb	$41 \rightarrow 21$	$5537 \rightarrow 1043$
Night 2 below limb	$95 \rightarrow 78$	$14482 \rightarrow 6651$

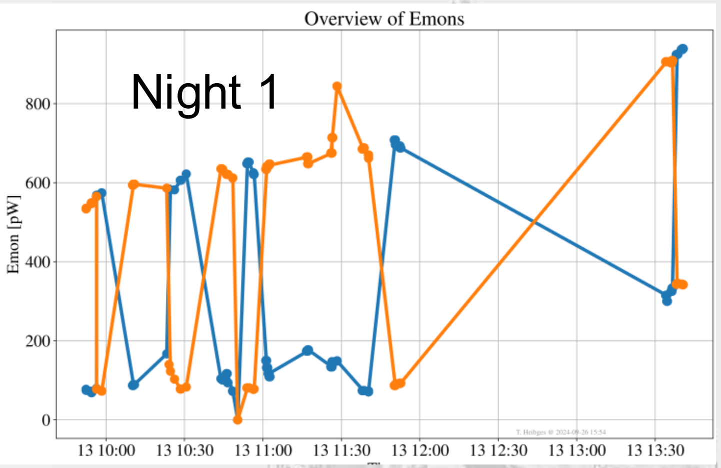


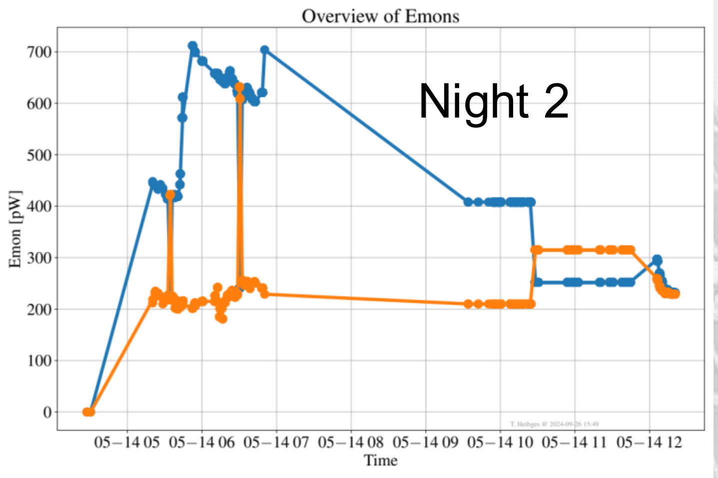


Observation Conditions

System	Acceptable range	Status during flight
HVPS	40-44V	✓
LVPS	24-26V	✓
CoBo Temp	<60C	✓
SiPM Temp	<30C (<25C preferred)	✓
EMONs	<300 pW (<100pW preferred)	X

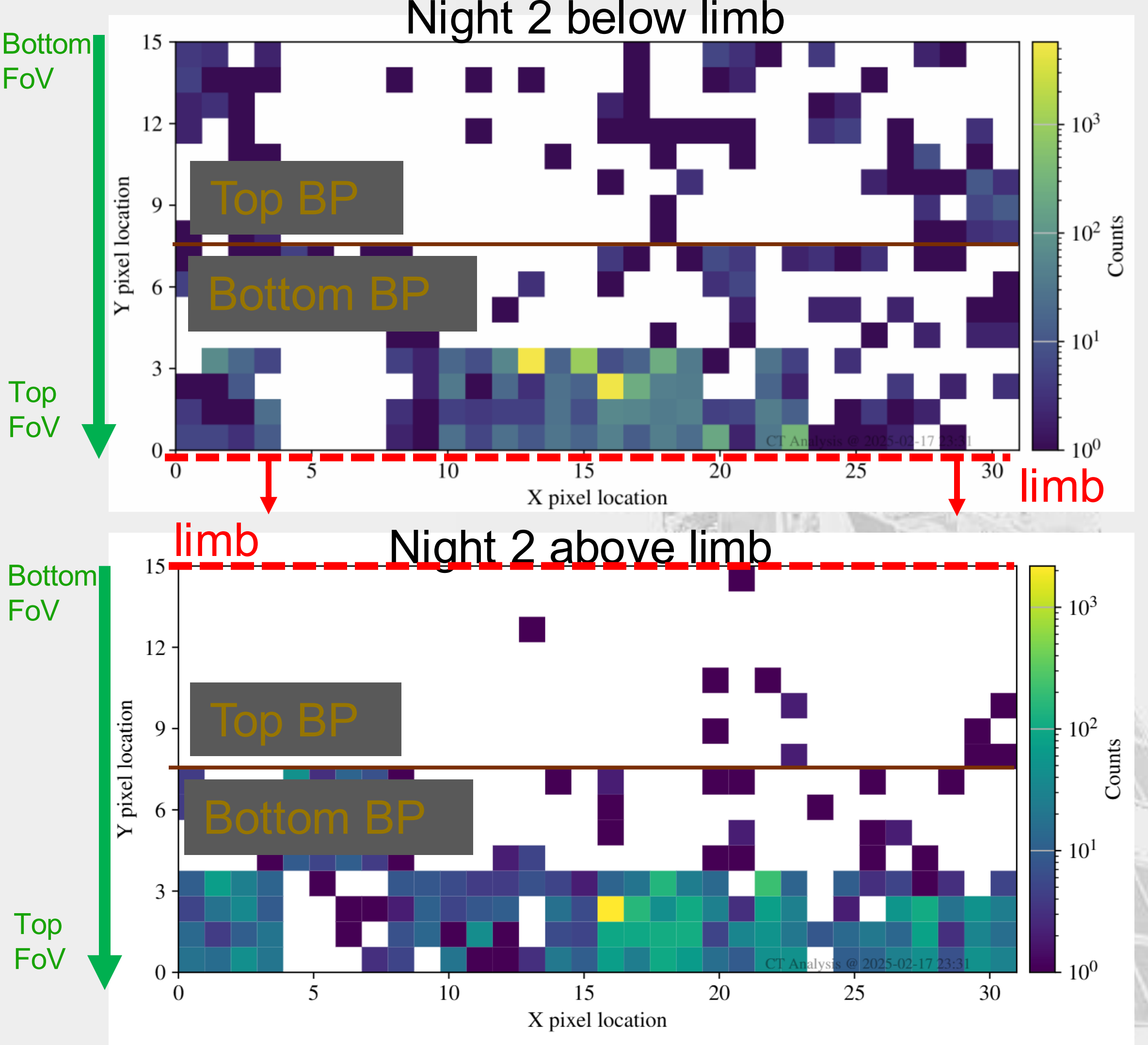
- Two EMONs mounted above and below the camera
- No clear labeling of EMON1 and EMON2
- 2 Scenarios:
  - One side of the camera sees significantly more light than the other
  - One of the EMONs is malfunctioning





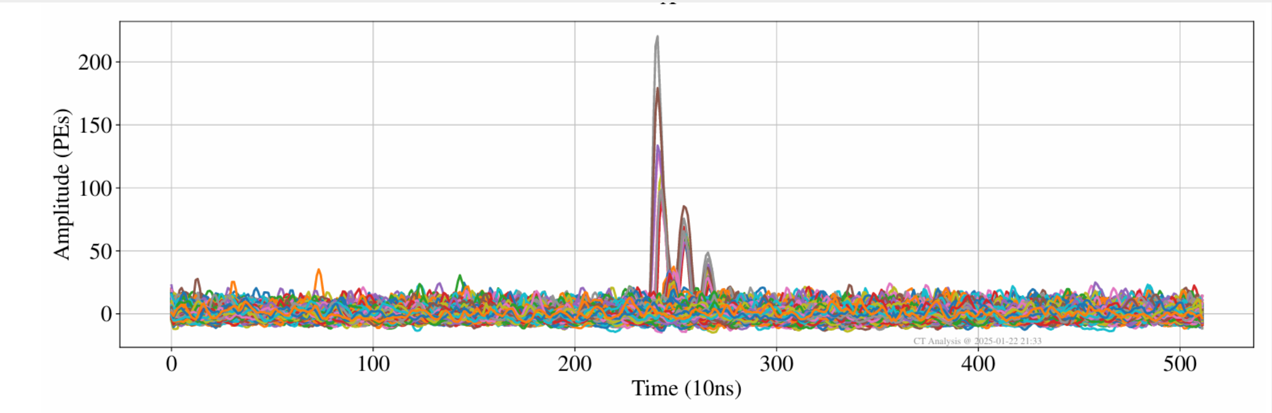
Trigger Overview

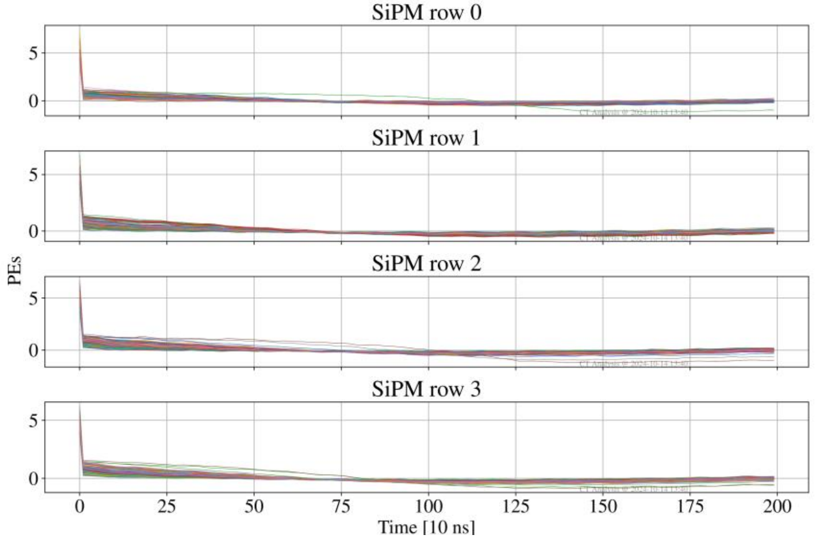
- Number of times a pixels contains the larges peak in the event
- Dominated by a few pixels
- Large discrepancy between top and bottom of camera
- Separate treatment of the backplanes
  - Expected number of counts:
    $$\mu = \frac{N_{events}}{N_{pixels}}$$
  - Pixels more than 5σ from expectation are flagged as overtriggering

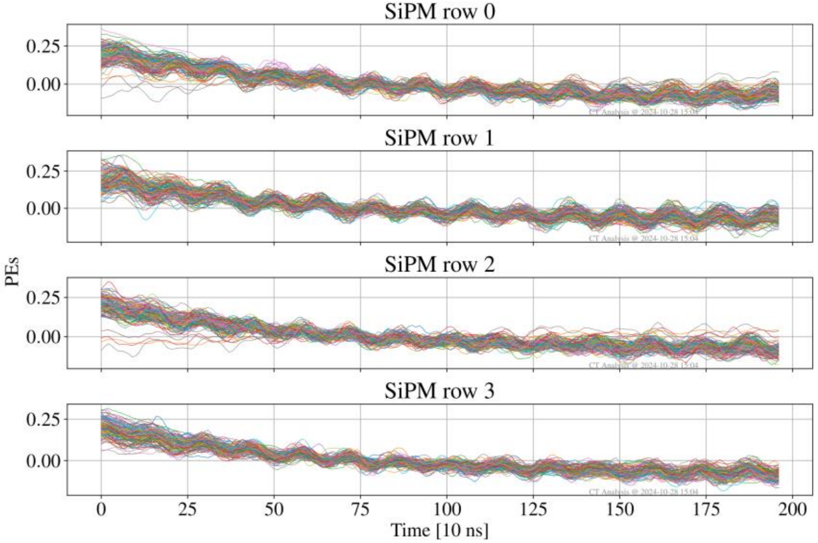


Baseline distribution

- Baseline defined as the 200 time bins before the main peak of the trace
- Should be free of ringing and other artifacts
- Unphysical peak in the first 4 time bins
- Ringing and general trend unexplained

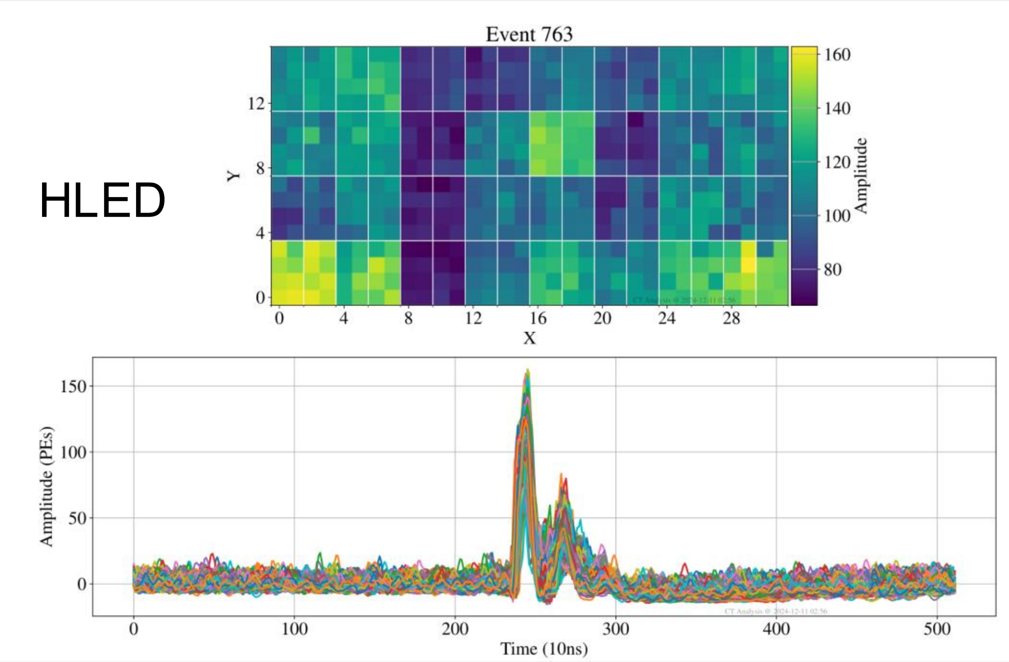




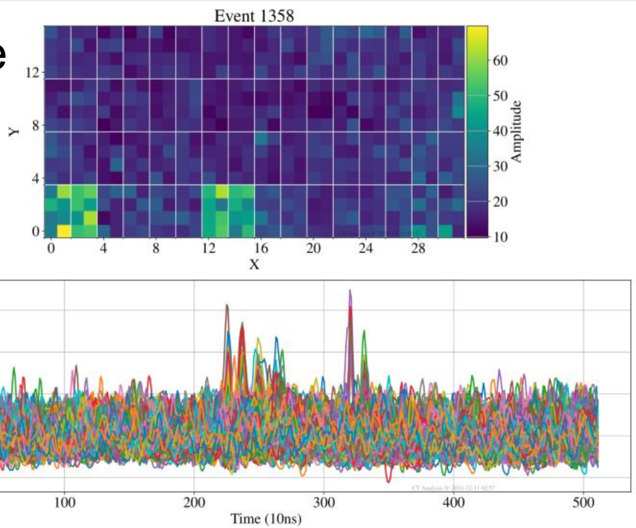


Unexpected Event Cuts

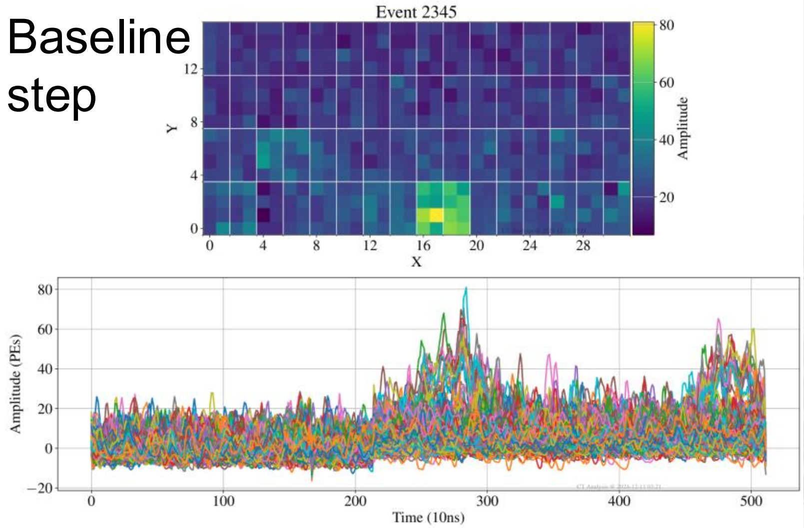
HLED



Double peak



Baseline step



	Bad Events	HLED Events	Multi-Peak Events	Pedestal shift Events
Night 1	1973	63	19	76
Night 2	1637	11	10	230
Night 2 above limb	1637	7	10	228
Night 2 below limb	0	4	0	2

Trigger Threshold Estimation

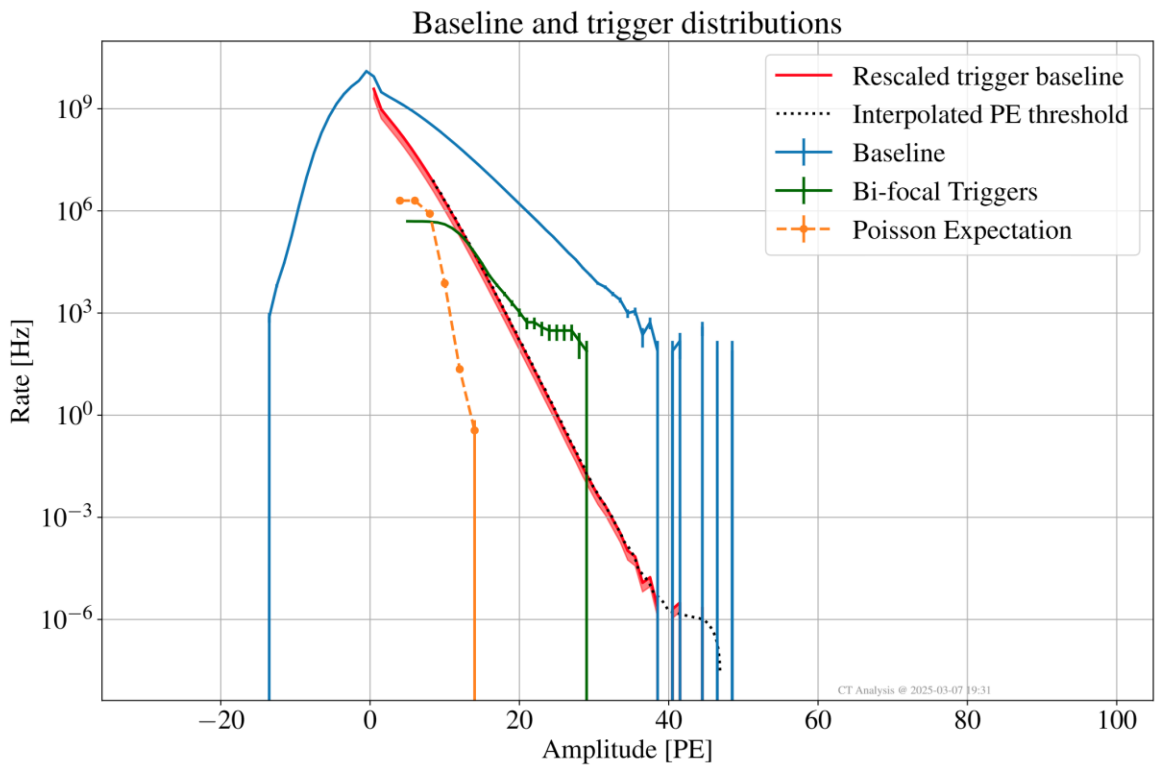
Baseline distribution can be used to estimate Bi-Focal trigger rate for a trigger threshold “a”

$$P_{\text{trigger}} = (2 \cdot n_{\text{timebins}} - 1) \cdot n_{\text{bifocal partners}} \cdot n_{\text{pixels}} \cdot P(x > a)^2$$

Comparison with triggers found in baseline shown

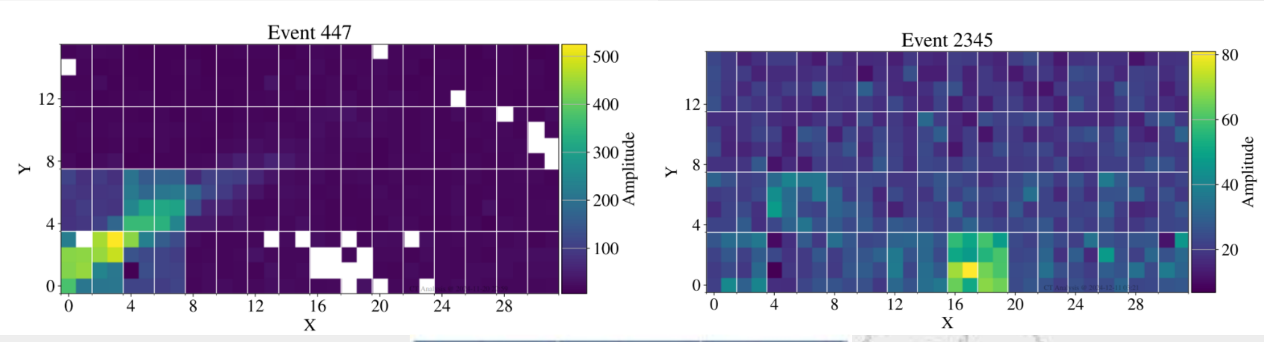
- Saturation at low PE values because only one trigger can be found in 2us
- Most high PE baseline triggers can be identified as ‘bad’-events by eye but the algorithm does not catch them

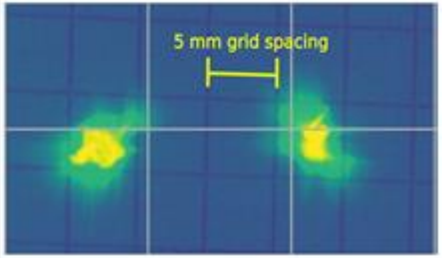
Background rate threshold of 1E-7 Hz



Observation Period	PE threshold	Top BP threshold	Bottom BP threshold
Night 1	67	64	66
Night 2 above the limb	53	34	53
Night 2 below the limb	47	47	44

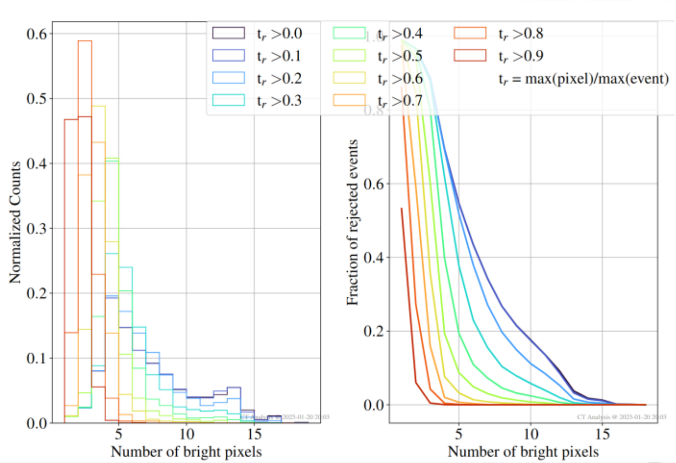
Event Criteria

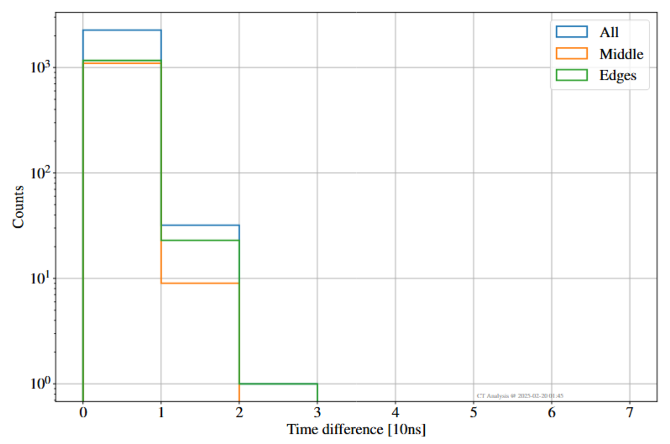




To select signatures that look like EAS signatures

1. The event has to have **two bifocal spots each above the PE-threshold**
2. The triggering pixels are **not overtriggering**
3. The peak occurs in the **same 10ns timebin**





Signal classification

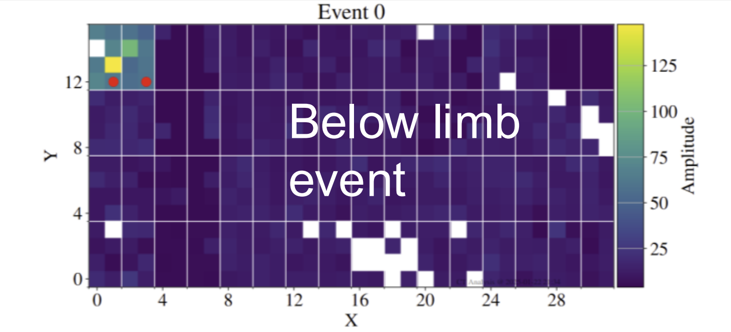
C0: Event triggered off cross-talk

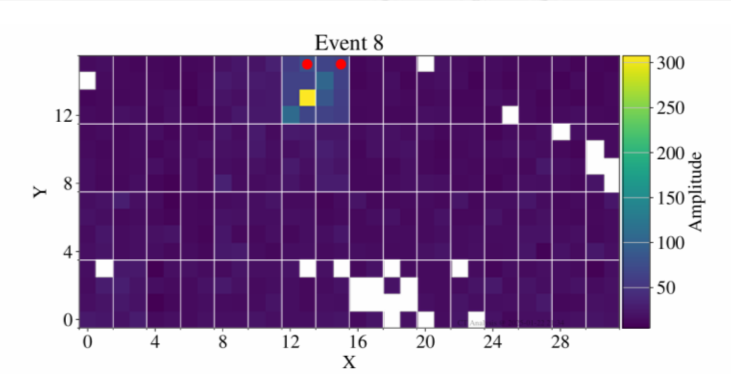
C1: Event is within 2 pixels of an over-triggered pixel or in a separate SiPM matrix

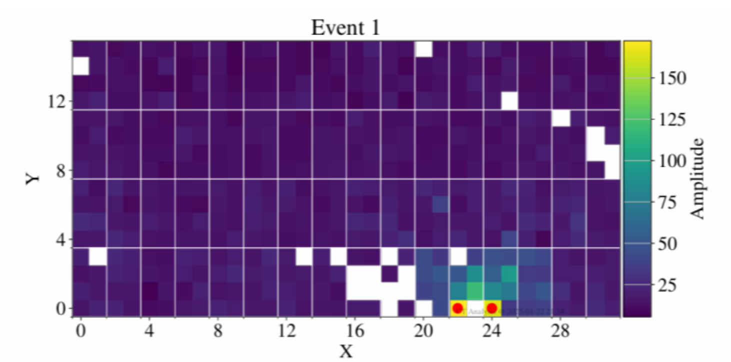
C2: Event is on the edge row of pixels

P: Passing event. The event is by itself, with the camera fully operational.

Observation period	Total number of passing events	C0	C1	C2	P
Night 1 below the limb	0	0	0	0	0
Night 2 above the limb	8	2	1	3	2
Night 2 below the limb	1	0	1	0	0







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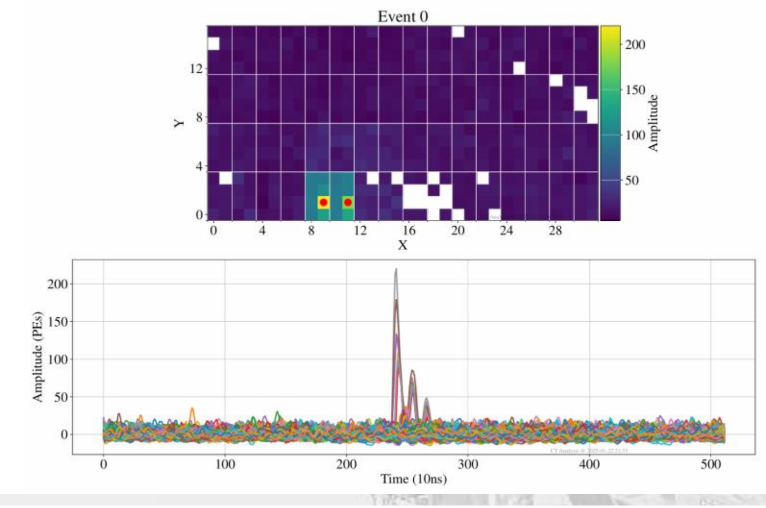
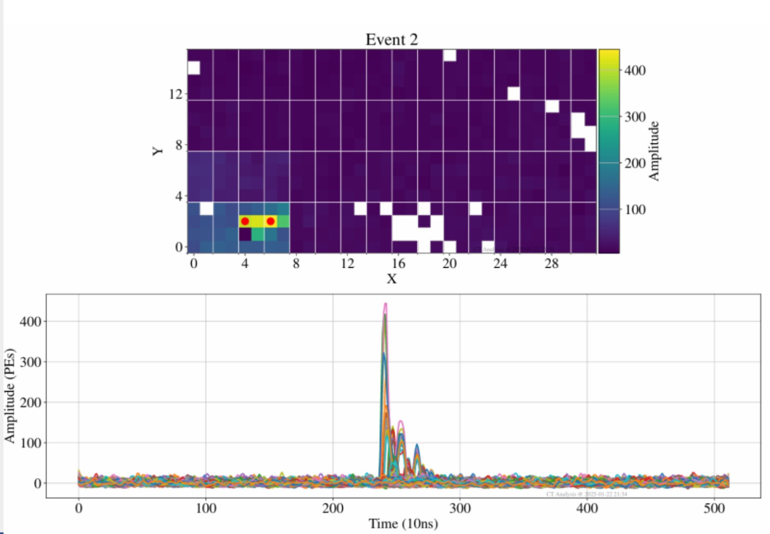
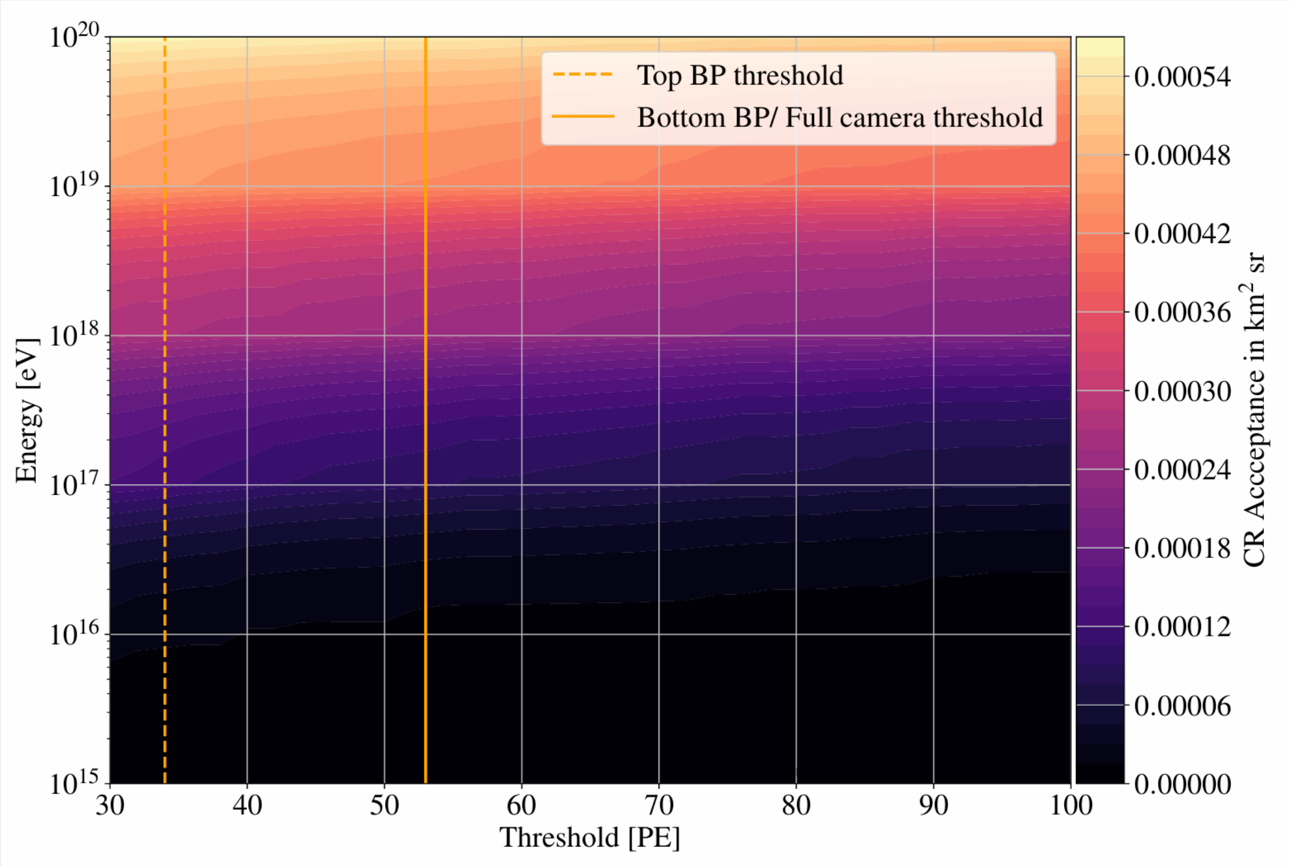




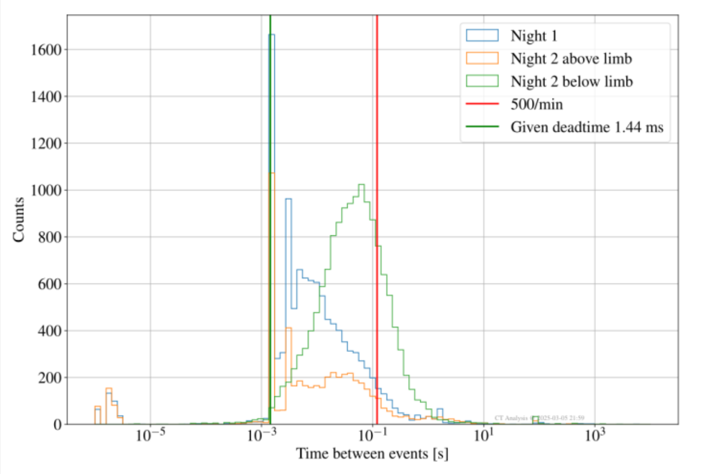
Cosmic Ray Acceptance - OffLine



Uncertainty Estimation

- Many effect contributing in different ways
- Very conservative estimates

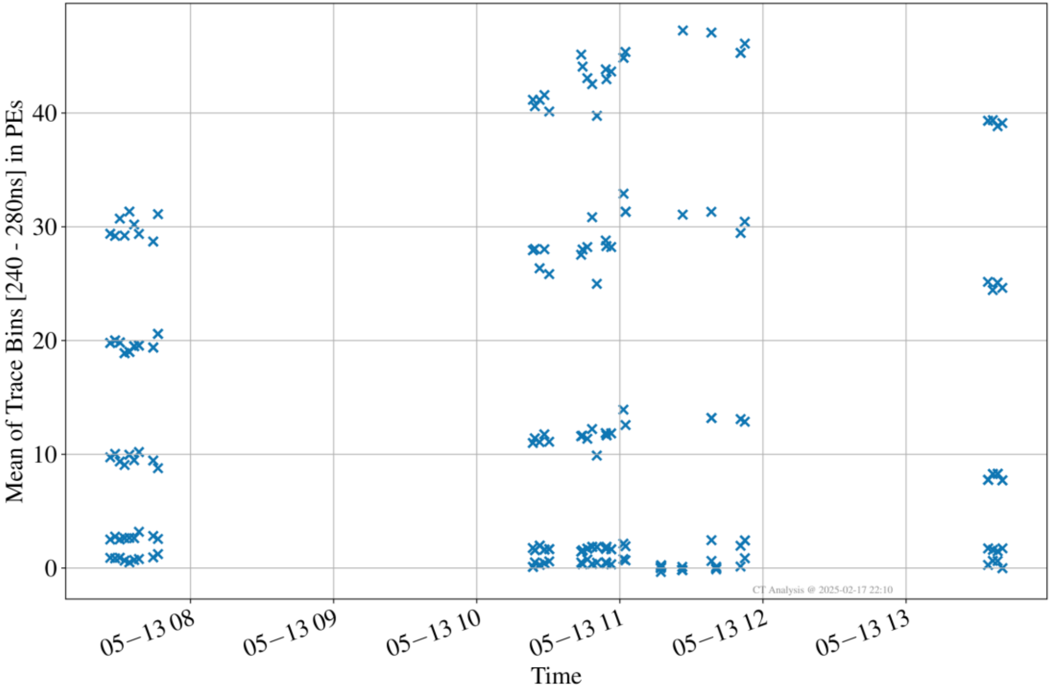
	Average trigger rate in [Hz]	Deadtime percentage
Night 1	1.57	0.20% - 16.7%
Night 2	1.14	0.16% - 13.7%
Night 2 above-the-limb	0.83	0.11% - 9.9%
Night 2 below-the-limb	1.42	0.20% - 16.9%

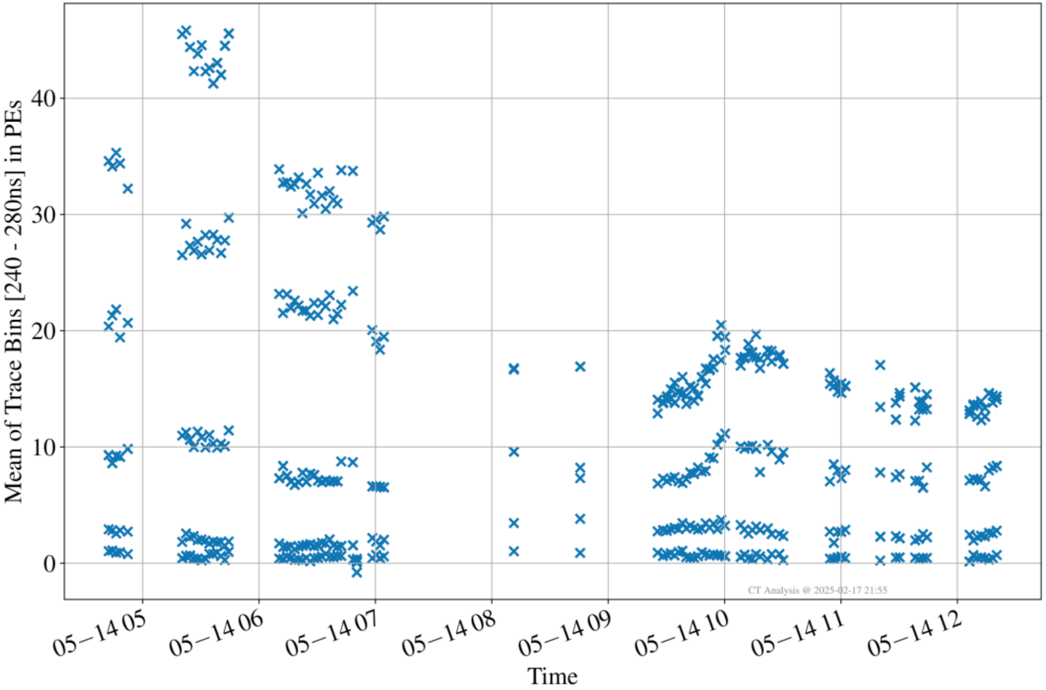


Observation Period	Effect	Uncertainty
Night 1	Baseline trend	0.3 PE
Night 2	Baseline trend	0.4 PE
Night 2 above-the-limb	Baseline trend	0.4 PE
Night 2 below-the-limb	Baseline trend	0.4 PE
Night 1	Baseline oscillation	0.2 PE
Night 2	Baseline oscillation	0.2 PE
Night 2 above-the-limb	Baseline oscillation	0.3 PE
Night 2 below-the-limb	Baseline oscillation	0.2 PE
Night 1	Extrapolation	(+0.0067 / -0.0935) PE
Night 2	Extrapolation	(0.0047 / -0.0653) PE
Night 2 above-the-limb	Extrapolation	(0.00008 / - 0.0012) PE
Night 2 below-the-limb	Extrapolation	(0.0140 /- 0.1959) PE
Night 1	Extrapolation Top BP	(0.0016 / - 0.0228) PE
Night 2	Extrapolation Top BP	(0.0189 /-0.2648) PE
Night 2 above-the-limb	Extrapolation Top BP	(0.00004 / -0.0005) PE
Night 2 below-the-limb	Extrapolation Top BP	(0.0142 /-0.1987) PE
Night 1	Extrapolation Bottom BP	(0.0171 / - 0.2392) PE
Night 2	Extrapolation Bottom BP	(0.0023 /-0.0322) PE
Night 2 above-the-limb	Extrapolation Bottom BP	(0.00004 / - 0.0006) PE
Night 2 below-the-limb	Extrapolation Bottom BP	(0.0276 /- 0.3862) PE
Night 1	ADC to PE conversion	16.7%
Night 2	ADC to PE conversion	33.3%
Night 2 above-the-limb	ADC to PE conversion	33.3%
Night 2 below-the-limb	ADC to PE conversion	33.3%
Night 1	Total	±11.20 PE
Night 2	Total	±17.50 PE
Night 2 above-the-limb	Total	±17.50 PE
Night 2 below-the-limb	Total	±17.50 PE

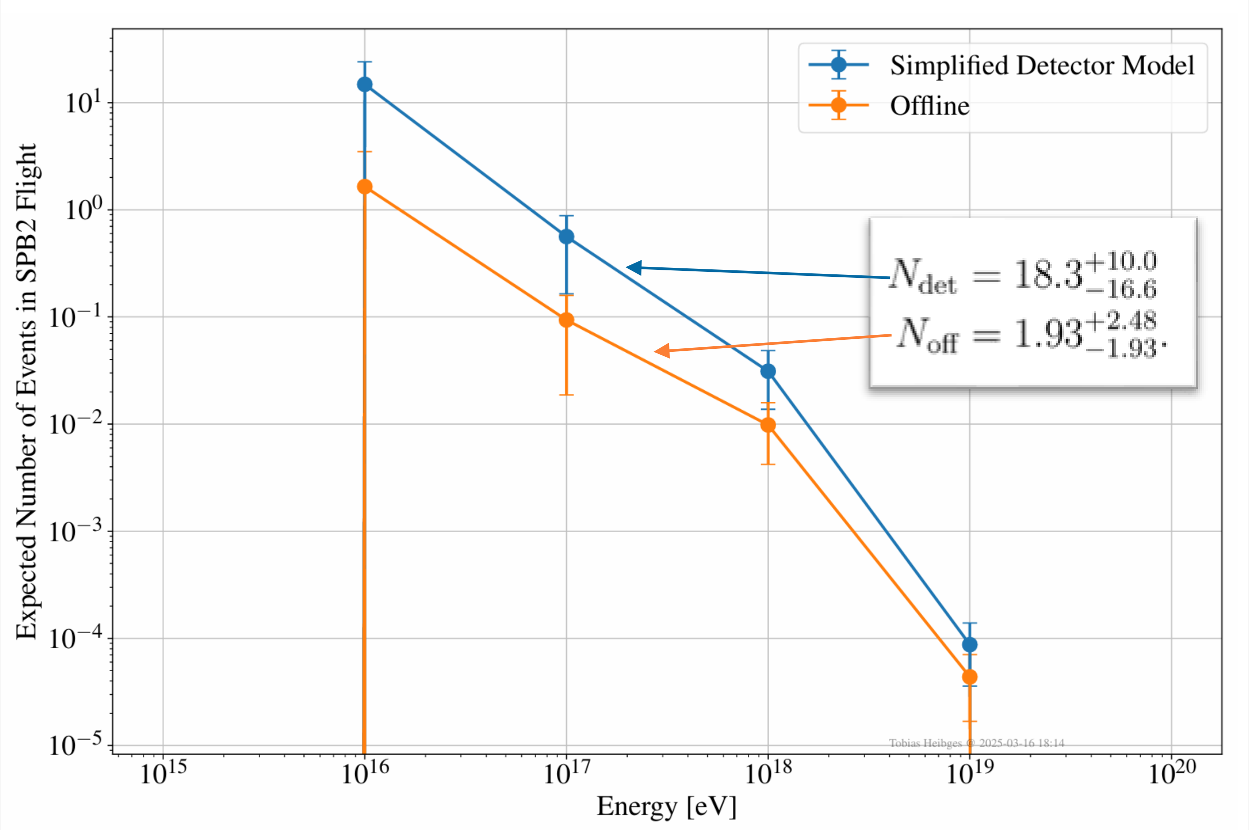
System Monitoring

- Calibrated Health-LED
  - Flashes at 5 different intensities
- Average values around the central peak



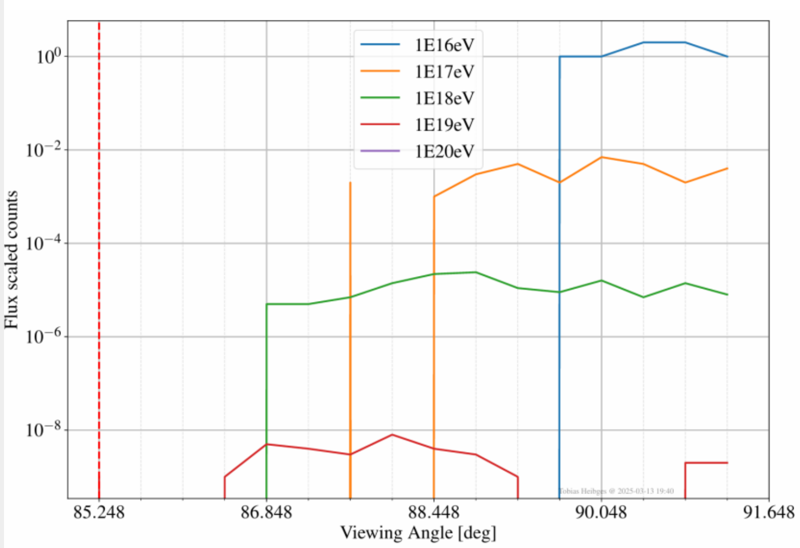


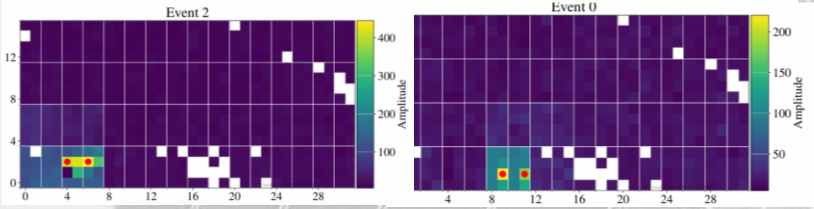
Expected number of CR



Where in the camera do simulated passing events occur?

Distribution in the camera matches location of events





Paper status

- First draft by Eliza and Mahdi
  - Not complete and needs cross checks
- Analysis and simulation chain using OffLine complete
  - Different from simulation chain used by GT group
- Different data analysis strategy
  - Need to cross check cuts
- Main task: **Merging analysis that have been performed**
- **Remaining Items:**
  - **Simulating finer grain energy bins**
  - **Simulating more statistics**
  - **Merging analysis**
  - **Finish writing remaining sections**

Observation of Cosmic Rays above the limb via Cherenkov Telescope on-board EUSO-SPB2 mission

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Abstract. The Extreme Universe Space Observatory on a Super Pressure Balloon 2 (EUSO-SPB2) was launched in May 13, 2023 from Wanaka, New Zealand as a pathfinder, carrying a Fluorescence Telescope (FT) and a Cherenkov Telescope (CT). The Cherenkov Telescope was able to slew and tilt towards neutrino transient targets and use the Earth-skimming technique to observe air-showers from cosmic rays above the limb and search for Very-High-Energy (VHE) tau neutrinos below the Earth's limb ($E > 10$ PeV). The 1 m^2 Cherenkov telescope was equipped with a 512-pixel silicon photomultiplier camera, covering 12.8° x 6.4° (Horizontal x Vertical) field of view, that utilized a novel stereo optical system. The camera signals were digitized with a 100 MS/s readout system. During its two nights of observation, the CT collected several hours of data from above and below the limb of the Earth. Eventually, the balloon flight was terminated after 36 hours due to an unexpected leak in the balloon. In this work, we report on the analysis of air showers from cosmic rays during above the limb observation.

Thank you!

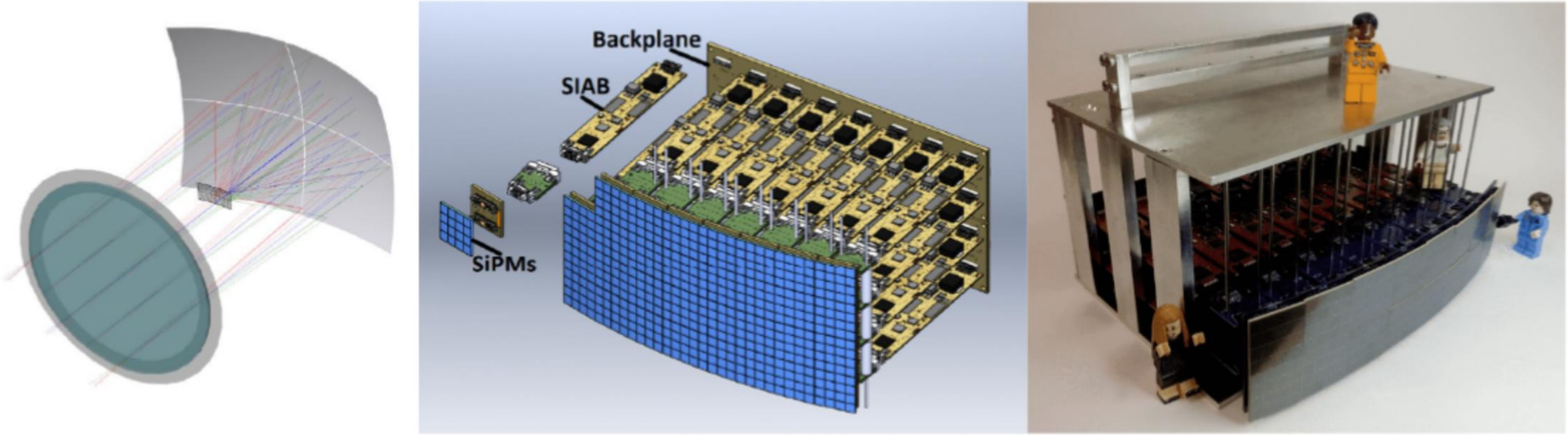


Fig 1 Left: Schmidt catadioptric optics of the Cherenkov telescope. The mirrors focus the light onto the curved focal plane located between the corrector plate and the mirror. Middle: CAD drawing of the camera without housing. Right: Half assembled camera (Lego figures for scale).

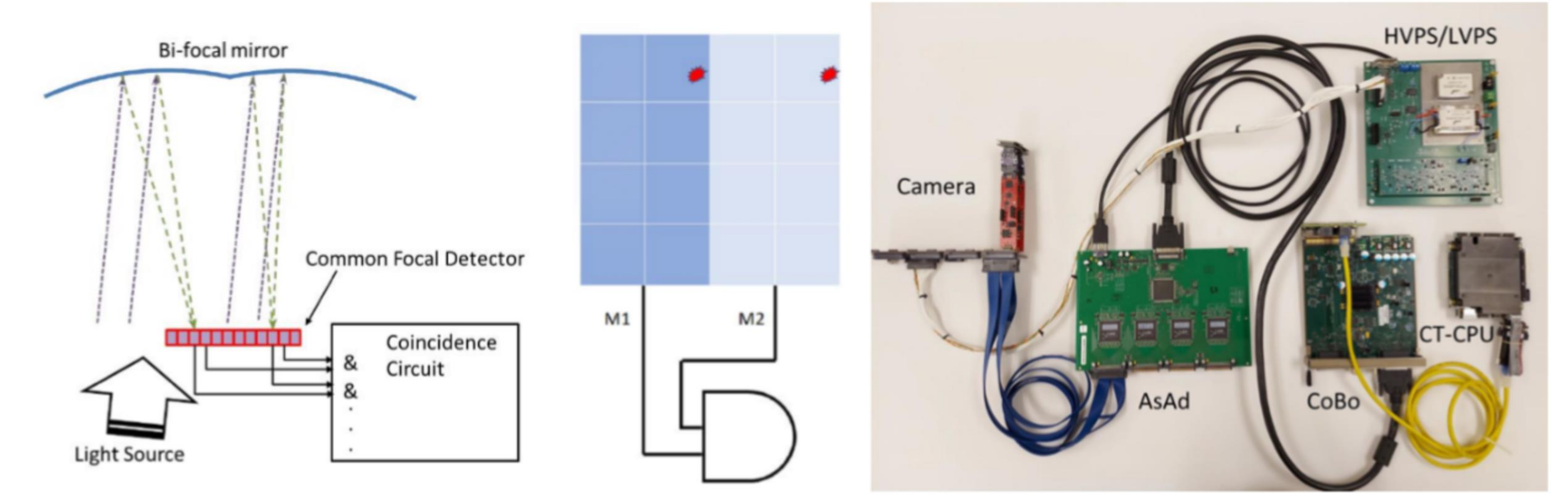


Fig 2 Left and Middle: The bi-focal optics duplicates the image and projects it to two separate locations in the camera. The telescope readout is triggered if two pixels separated by the bi-focal split record a signal within 100 ns. Right: Partially assembled camera and the readout electronics.

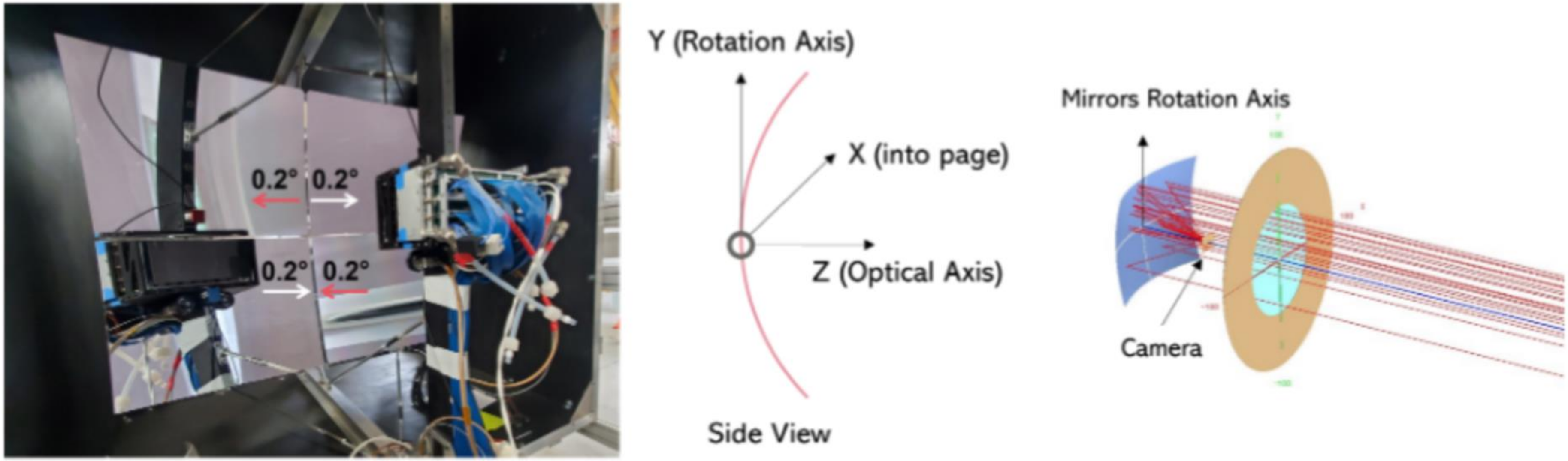
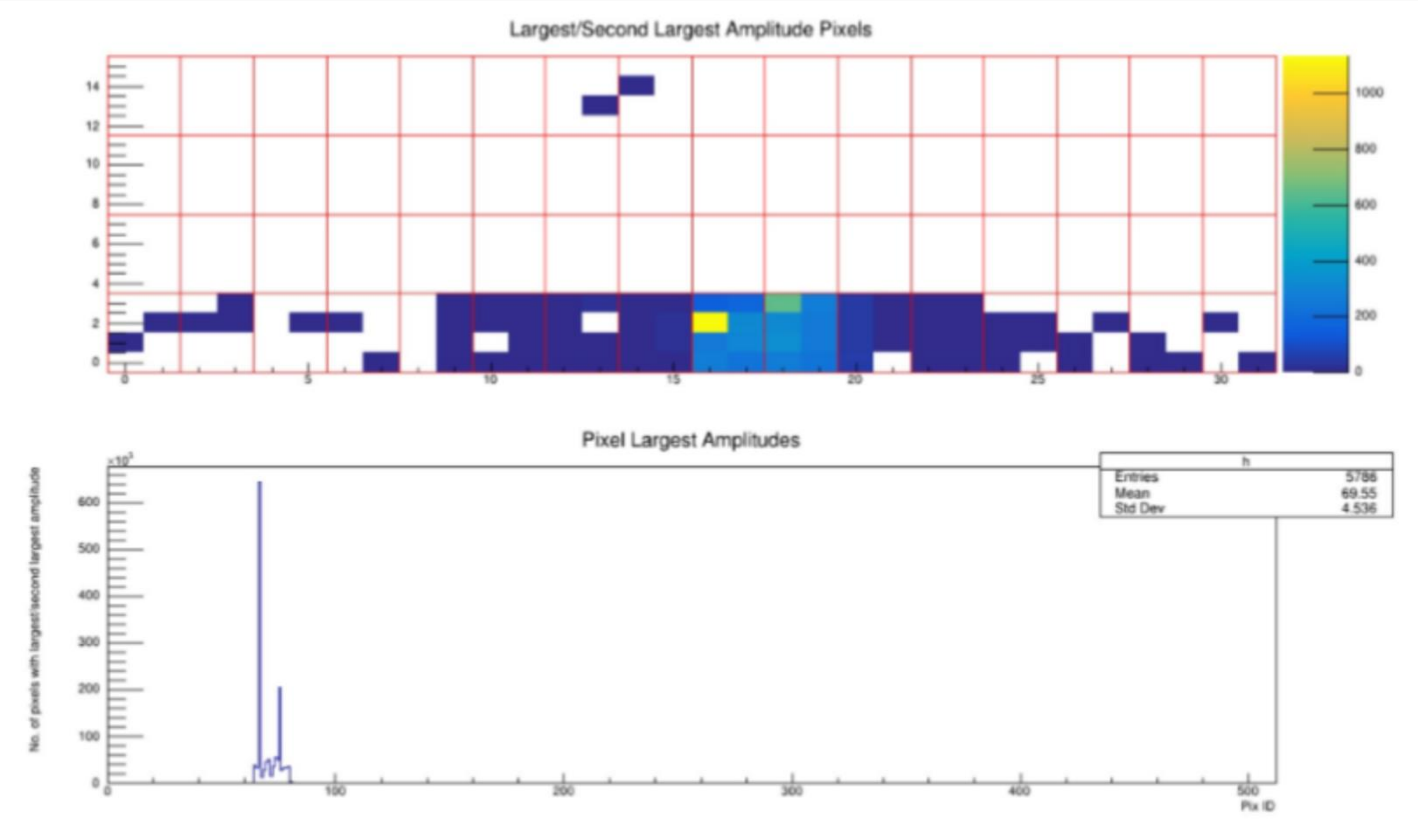
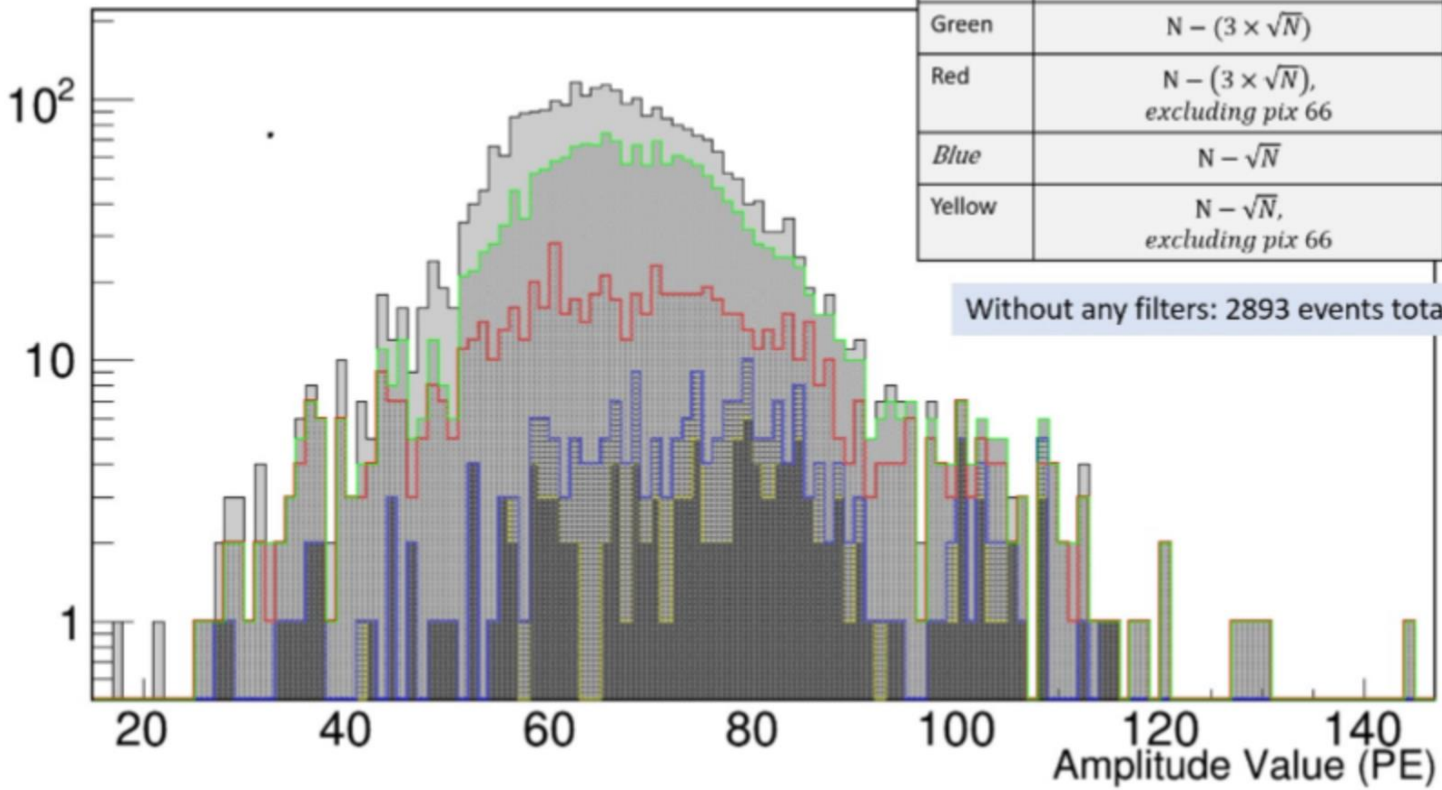


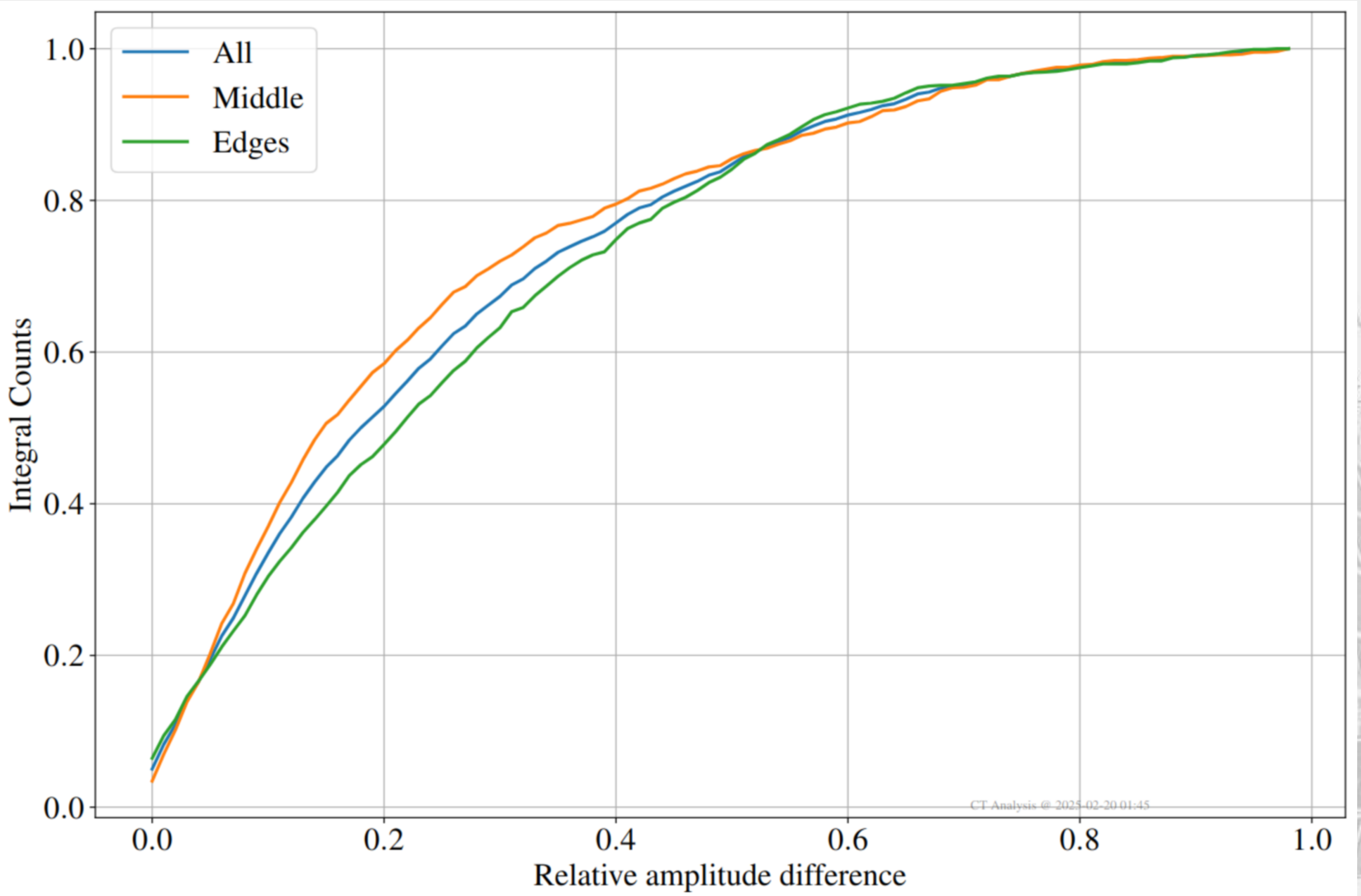
Fig 3 Left: SPB2 Cherenkov telescope mirrors and camera. Right: Simulated snapshot of the SPB2 bifocal optics in GrOptics.


Largest/Second Largest Amplitude Pixels
Pixel Largest Amplitudes
No. of pixels with largest/second largest amplitude
Pix ID
Entries 5786
Mean 69.55
Std Dev 4.536



	Filter Applied	# of Events	# of Event > 140 PEs
Green	$N-(3\times\sqrt{N})$	1913	11
Red	$N-(3\times\sqrt{N})$, *excluding pix 66*	780	11
Blue	$N-\sqrt{N}$	235	2
Yellow	$N-\sqrt{N}$, *excluding pix 66*	148	2

Without any filters: 2893 events total, ~ 16 > 140PEs


All
Middle
Edges
Integral Counts
Relative amplitude difference
0.0
0.2
0.4
0.6
0.8
1.0
CT Analysis @ 2025-02-20 01:45

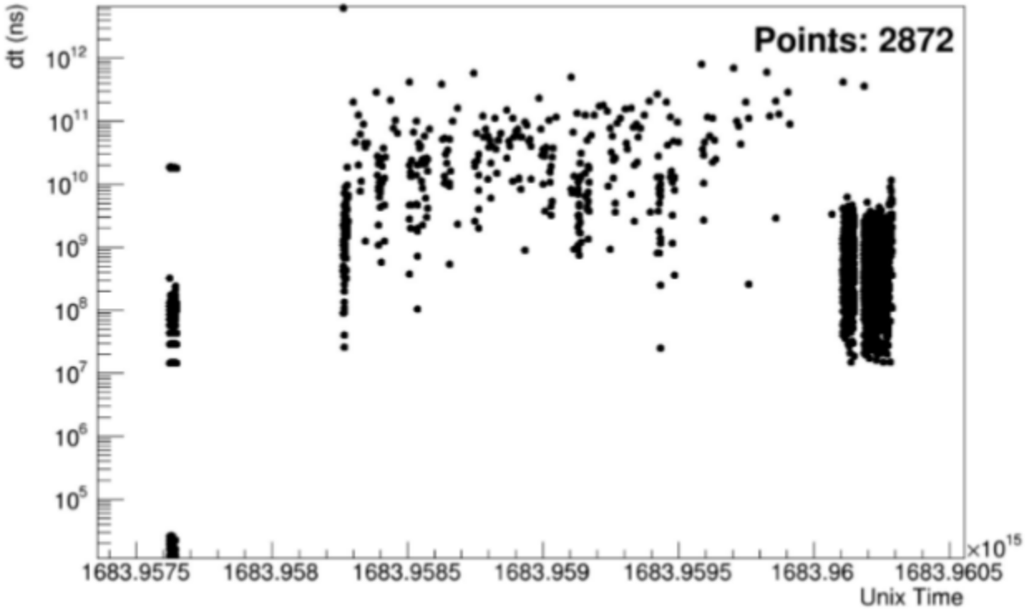
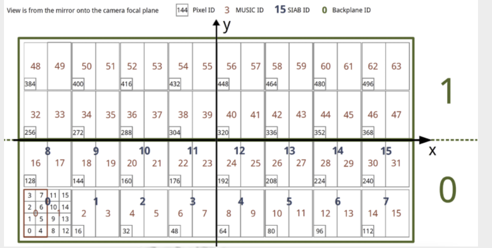


Fig 9 Label sections on the plot (first and last overtriggered runs, gap for threshold adjustment, events faster then the dead time, etc). Change x-axis to hrs in UTC, should I make this plot with a trigger time on y axis as well or dt? total time observed is 45min, however at the beginning there and end of the run there are over-triggered data runs. also there was a 10min gap in data taking after the first run to adjust the trigger threshold. Therefore he total observation time with all the dead time subtracted is: ???? calculate this.

Camera Characterization

Backplane discrepancy

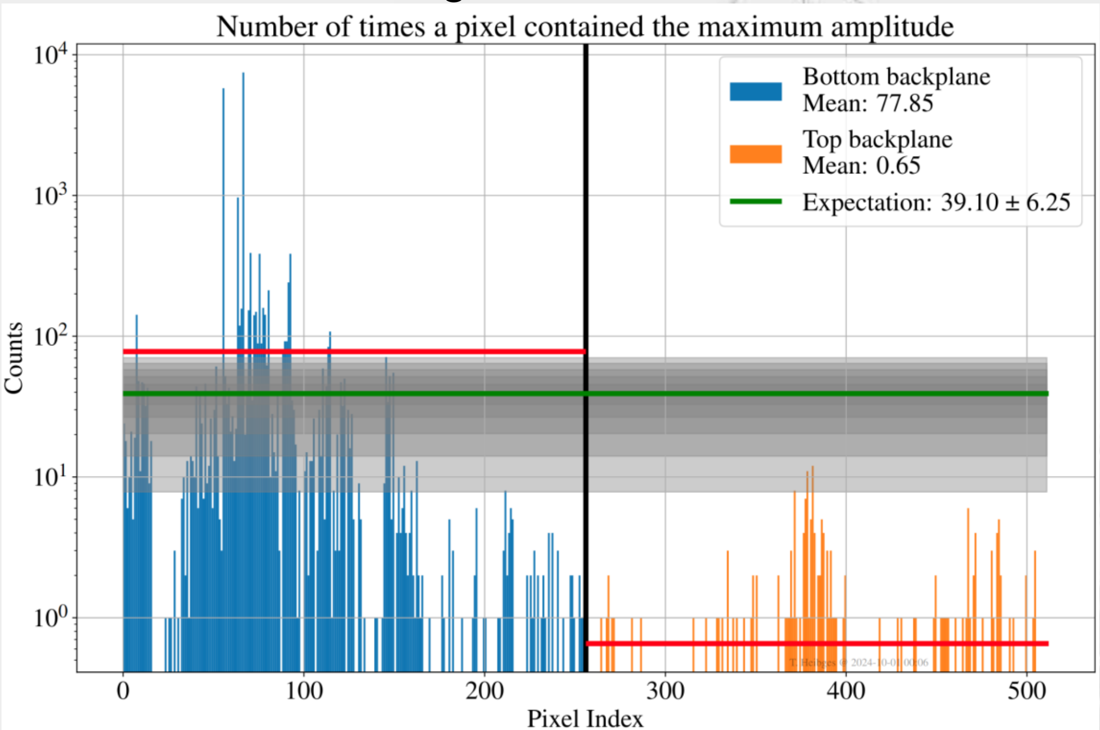


- Number of times a pixels contains the larges peak in the event
- Dominated by a few pixels
- Large discrepancy between top and bottom of camera
  - Expectation Poissonian distribution with mean:

$$\mu = \frac{N_{events}}{N_{pixels}}$$

  - Difference between top and bottom >5σ
- Separate treatment of the backplanes
  - Pixels that contain more triggers than 5σ from expectation are flagged as overtriggering

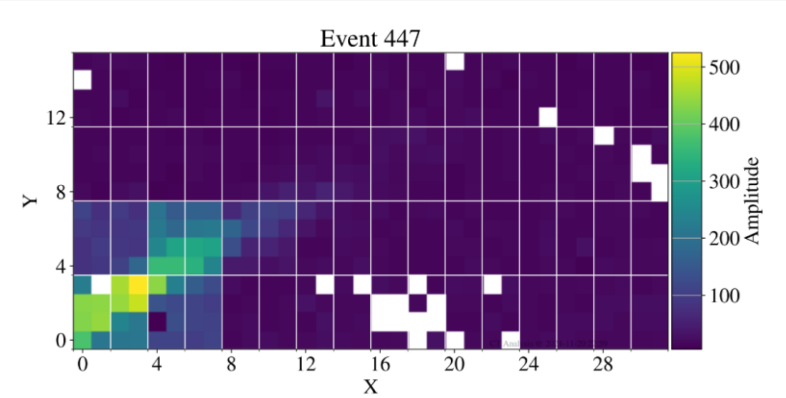
Night 2 above limb

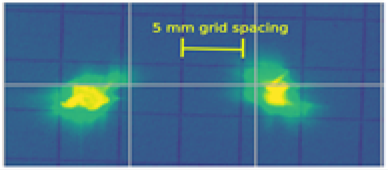


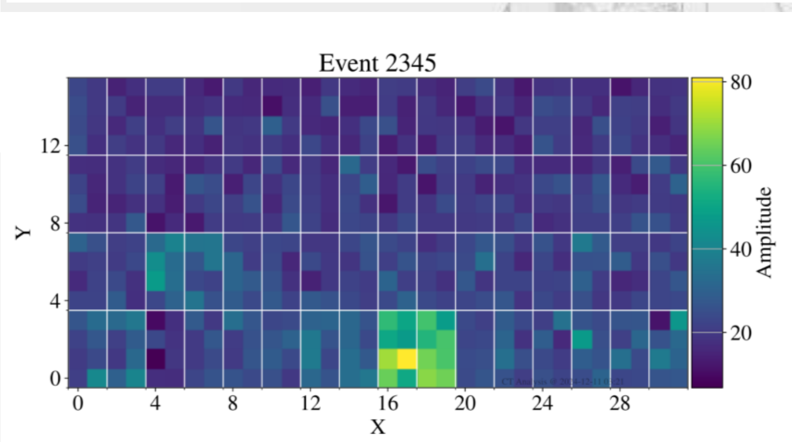
Event Criteria

To select signatures that look like EAS signatures

1. The event has to have **two bifocal spots each above the PE-threshold**
2. The triggering pixels are **not overtriggering**
3. The peak occurs in the **same 10ns timebin**





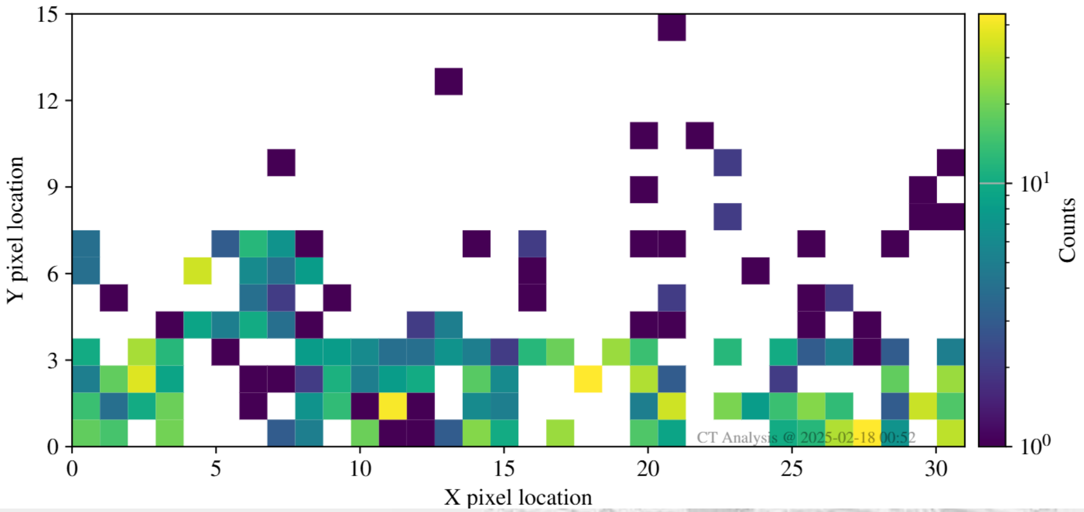


Observation Period	Number of events before	Number of events cut	Number of events after
Night 1	3305	2148	66
Night 2	7694	4135	66
Night 2 above the limb	1043	568	53
Night 2 below the limb	6651	3567	44

Overtriggering pixels

- Dominated by a few pixels
- Large discrepancy between top and bottom of camera
  - Expectation Poissonian distribution with mean: Nevents/Npixels
  - Difference between top and bottom >5sigma
- Separate treatment of the backplanes
  - Pixels that contain more triggers than 5sigma from expectation are flagged as overtriggering

Night 2 above limb



	Number of masked pixels	Top BP	Bottom BP	Camera fraction
Night 1	37	24	13	7.2%
Night 2	23	8	15	4.5%

Trigger Overview

- Number of times a pixels contains the larges peak in the event
- Dominated by a few pixels
- Large discrepancy between top and bottom of camera
  - Expectation Poissonian distribution with mean:
    $$\mu = \frac{N_{events}}{N_{pixels}}$$
  - Difference between top and bottom >5σ
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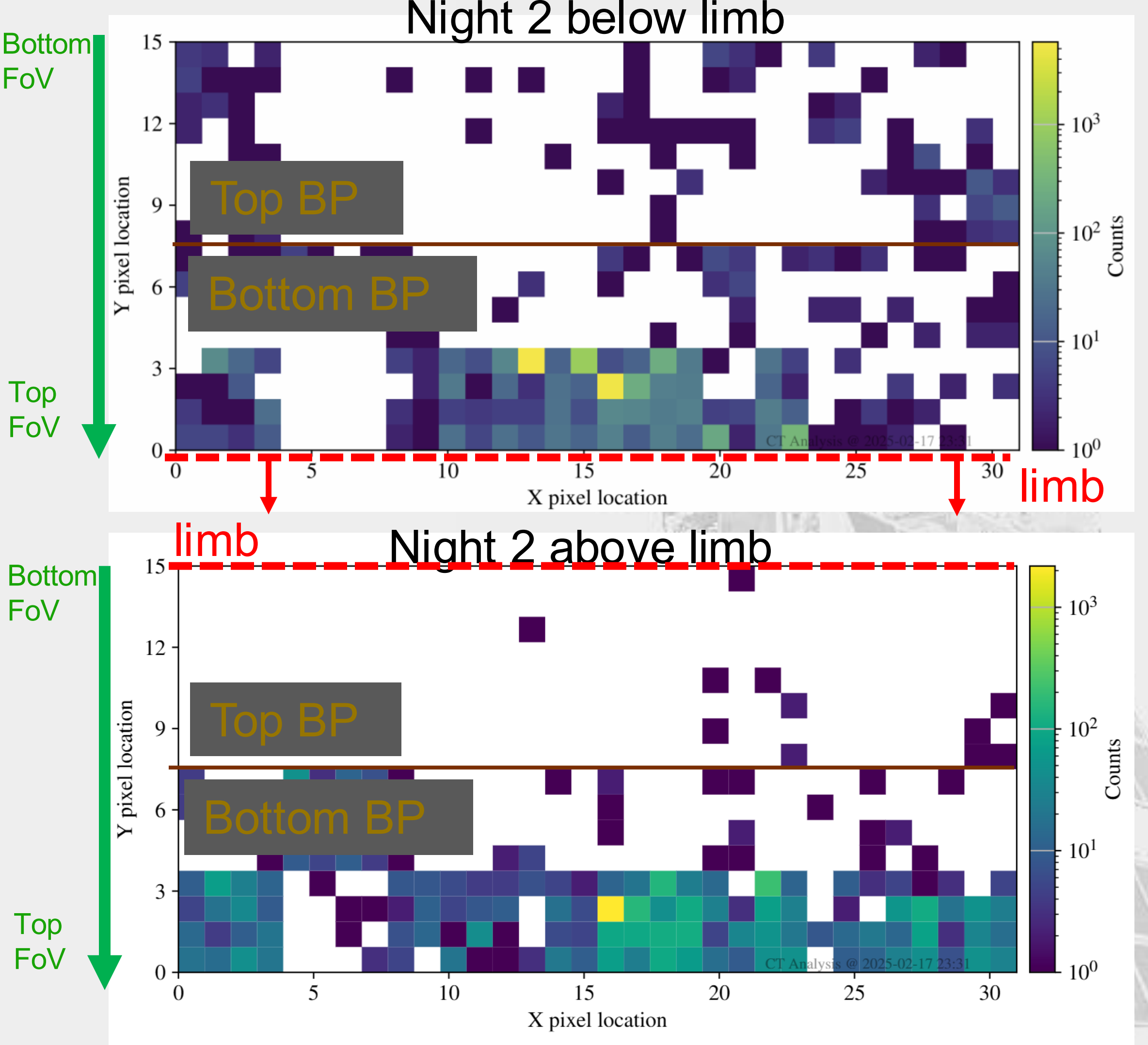
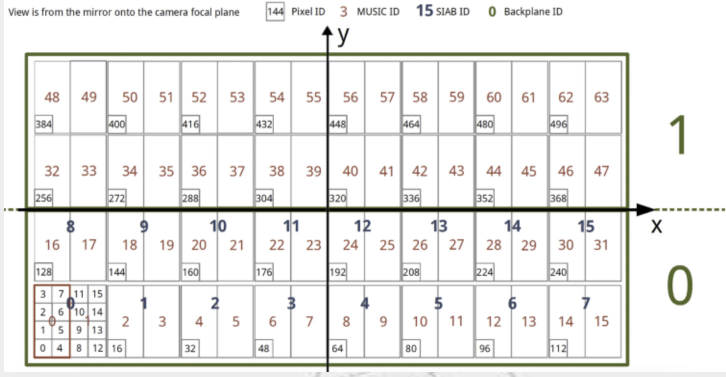


Overtriggering pixels

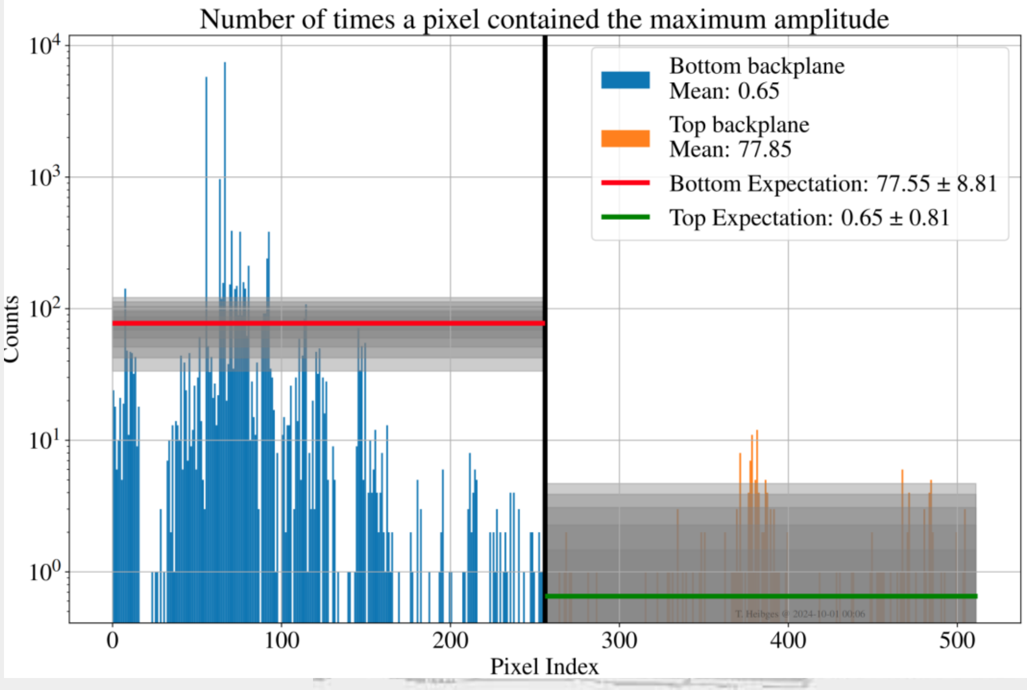
- Number of times a pixels contains the larges peak in the event
- Dominated by a few pixels
- Large discrepancy between top and bottom of camera
- Separate treatment of the backplanes
  - Expected number of counts:

$$\mu = \frac{N_{events}}{N_{pixels}}$$

  - Pixels more than 5σ from expectation are flagged as overtriggering



Night 2 above limb



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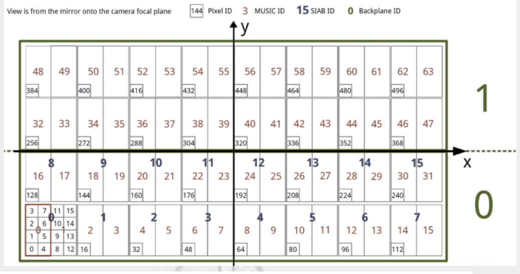
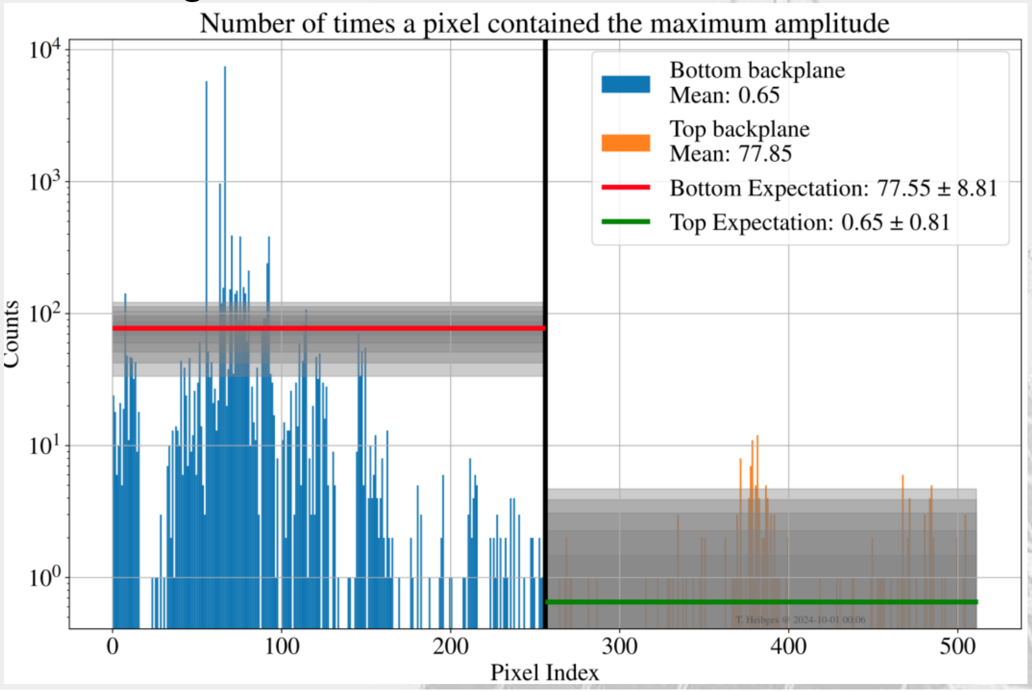


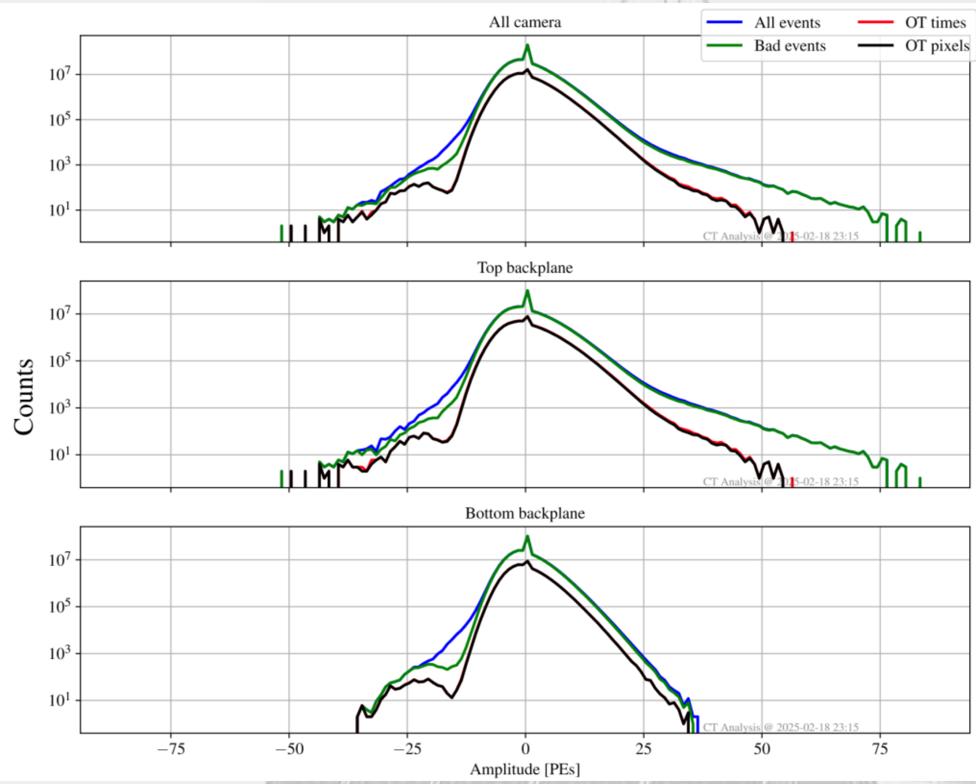
Night 2 above limb



	Number of masked pixels	Top BP	Bottom BP	Camera fraction
Night 1	37	24	13	7.2%
Night 2	23	8	15	4.5%

Baseline distribution

- Baseline defined as the 200 time bins before the main peak of the trace
- Should be free of ringing and other artifacts
- Unphysical peak in the first 4 time bins
- Ringing and general trend unexplained



CR-Simulation

Cosmic Ray Simulations

Cosmic Ray Sampling → EAS Profile Simulation (Conex) → EAS Cherenkov Light Simulation (EASCherSim) → Detector Simulation

Expected CR Number

The expected number of CRs for the EUSO-SPB2 flight

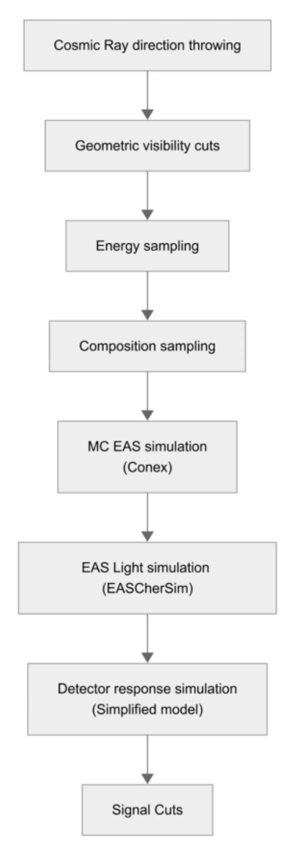
$$N = \int \mathcal{A}(E) N_{\text{injected}}(E)\, dE$$

where

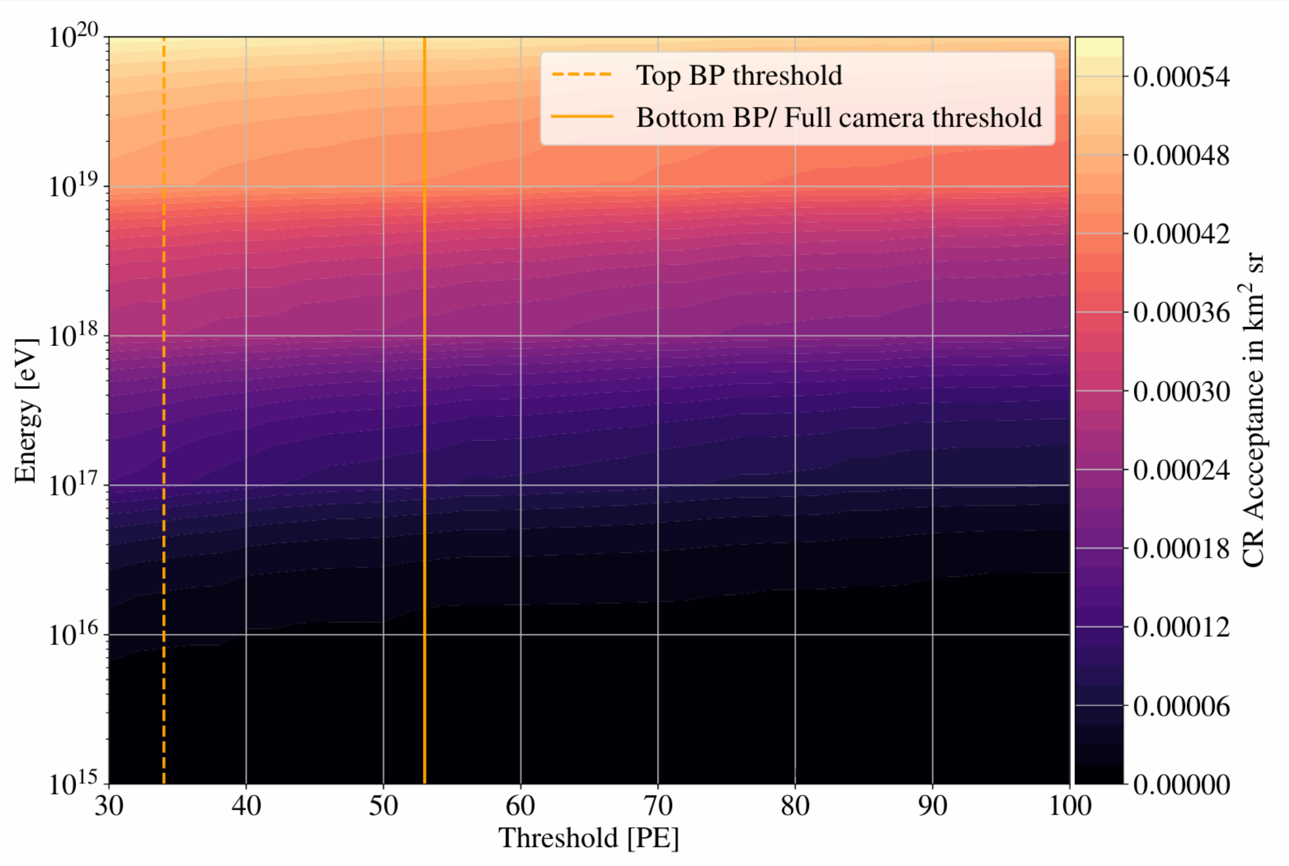
$$N_{\text{injected}} = A_{\text{throw}} \Omega_{\text{throw}} T_{\text{obs}} E \; \Phi_e(E)$$

Calculating Expected CR rate

1. Mimic the distribution of VHECRs
    1. Inject CR trajectories homogenously and isotropically
    2. Sample the CR type composition
    3. Build first visibility cuts
2. EAS shower simulation
    1. Longitudinal shower simulation using MC framework Conex
    2. Cherenkov light simulation and propagation through the Atmosphere using EASCherSim
3. Estimate the detector response
    1. Simplified detector response model on all showers
    2. More in depth simulation on passing showers
4. Apply signal search cuts to events
5. Calculate the acceptance of the detector as a function of energy
6. Numerically integrate the product of expected flux and acceptance



Cosmic Ray Acceptance - OffLine

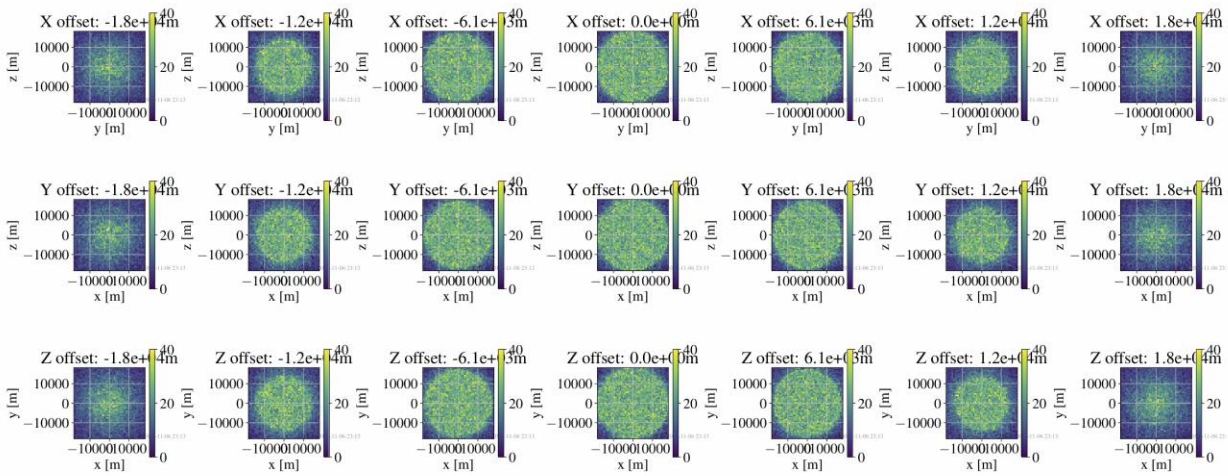


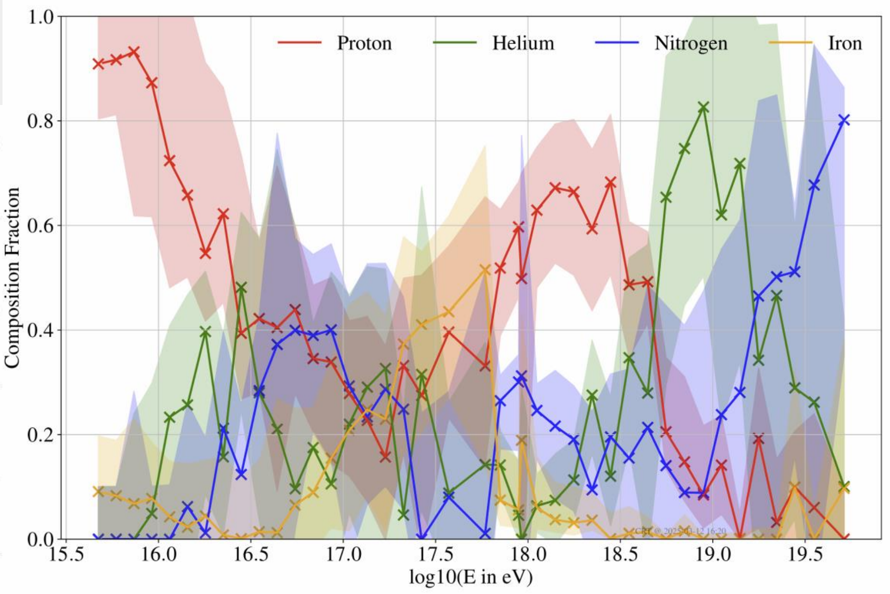
Cosmic Ray Simulations

Cosmic Ray Sampling → EAS Profile Simulation (Conex) → EAS Cherenkov Light Simulation (EASCherSim) → Detector Simulation

Properties:

- **Homogenous and isotropic direction distribution**
- **Follow measured CR composition**



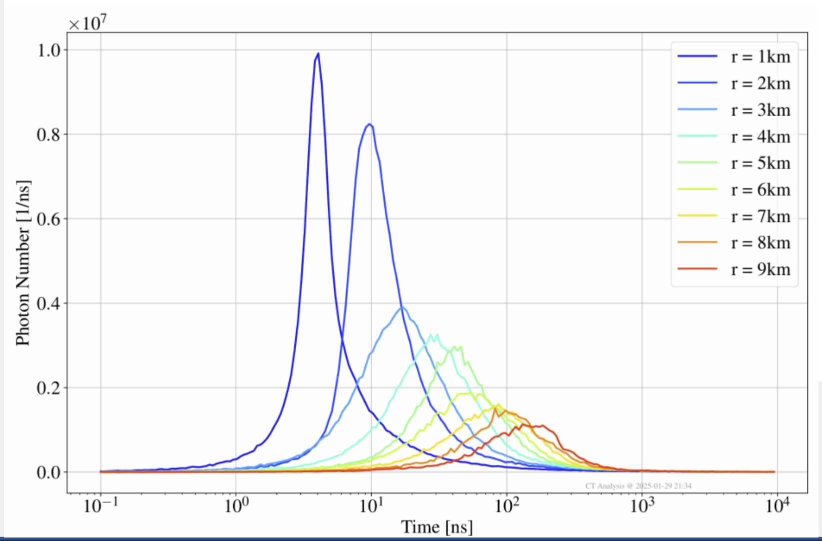


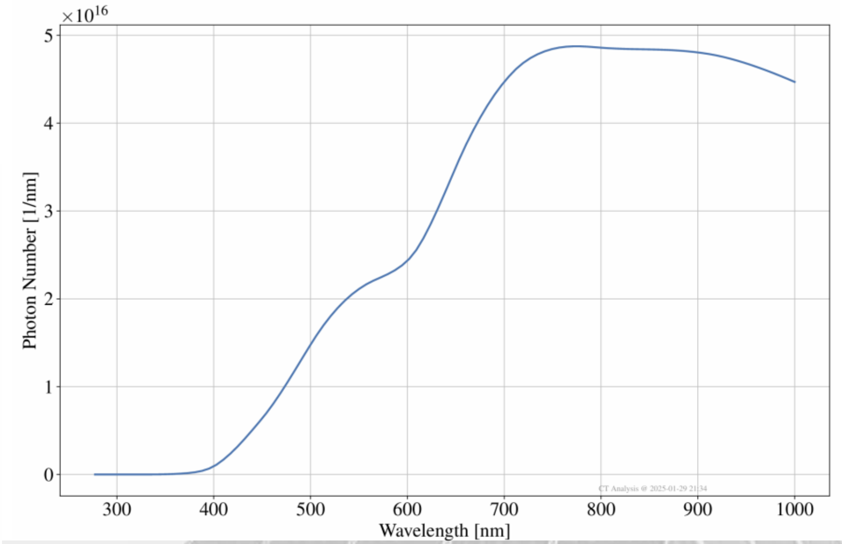
Cosmic Ray Simulations

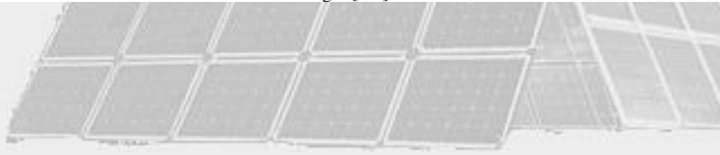
Cosmic Ray Sampling → EAS Profile Simulation (Conex) → EAS Cherenkov Light Simulation (EASCherSim) → Detector Simulation

Conex Longitudinal EAS profile simulation from MC Simulation
- Accounts for change in energy (beyond simple scaling)
- Changes in elongation rate based on primary particle

EASCherSim Cherenkov light simulation based on longitudinal EAS profile, which provides
- Radial photon profile
- Wavelength profile
- Photon timing profile
- Angular photon profile







Calculating Expected CR rate

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    1. Inject CR trajectories homogenously and isotropically
    2. Sample the CR type composition
    3. Build first visibility cuts
2. EAS shower simulation
    1. Longitudinal shower simulation using MC framework Conex
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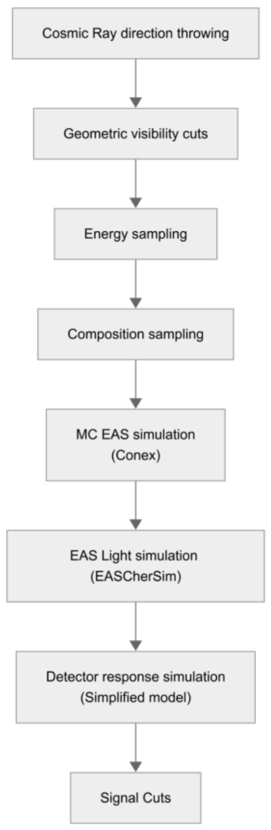
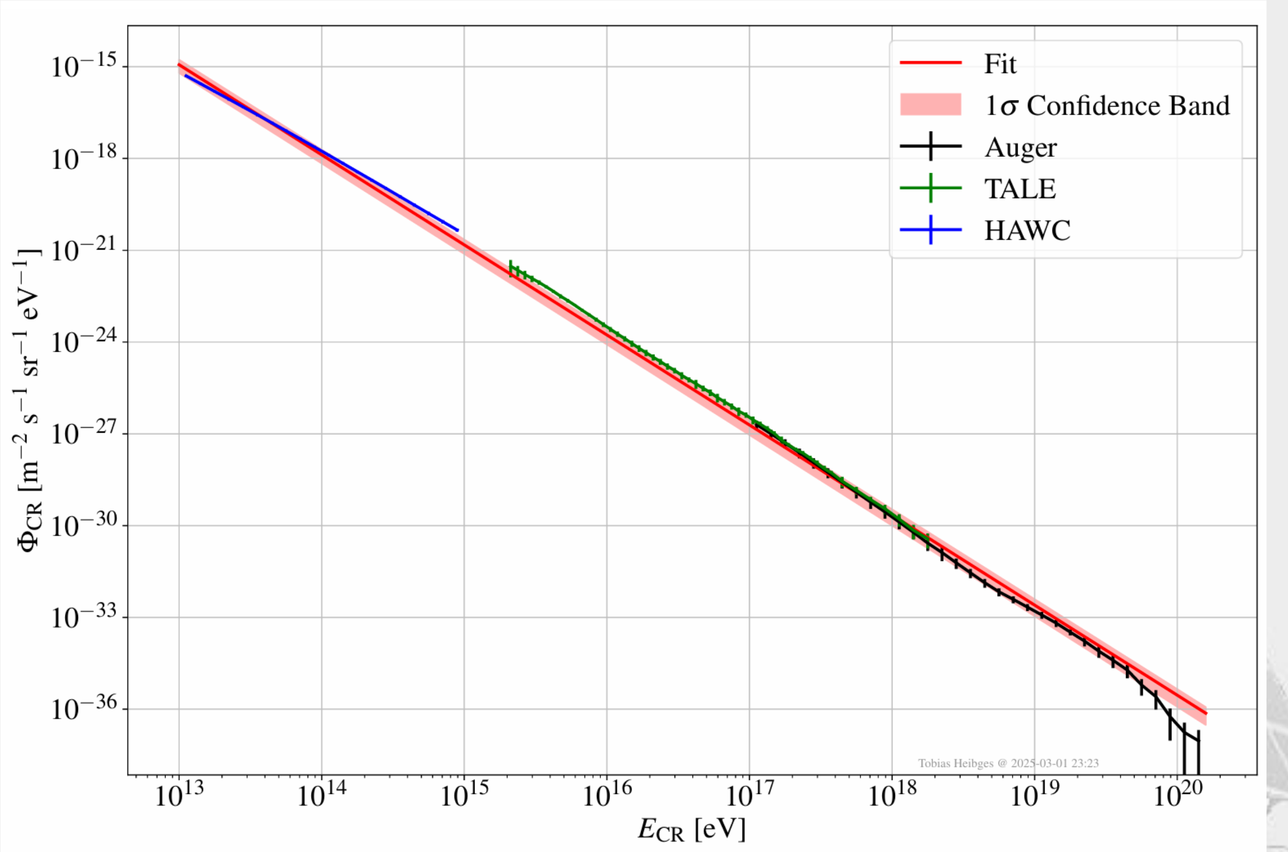


CR Flux

- Power-law fit to HAWC, TALE and Auger data

$$\Phi(E) = A \cdot E^B$$

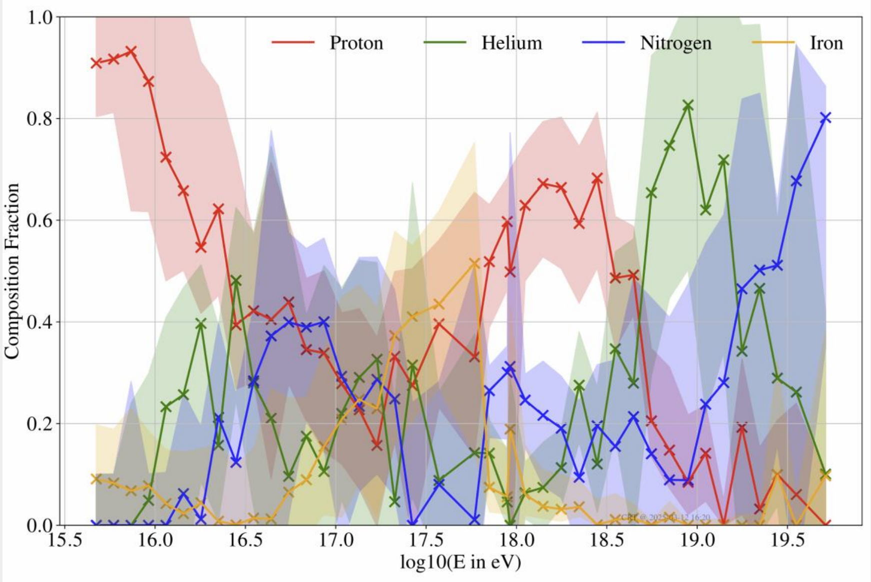


Parameter	Value	Uncertainty
A	$2.16 \cdot 10^{23}$ eV^{-1}m^{-2}s^{-1}sr^{-1}	$\pm$ $0.76 \cdot 10^{23}$ eV^{-1}m^{-2}s^{-1}sr^{-1}
B	-2.94	$\pm$ 0.01

Cosmic Ray / Neutrino Geometry Sampling → EAS / Neutrino Simulation → EAS Cherenkov Light Simulation (EASCherSim) → Detector Simulation

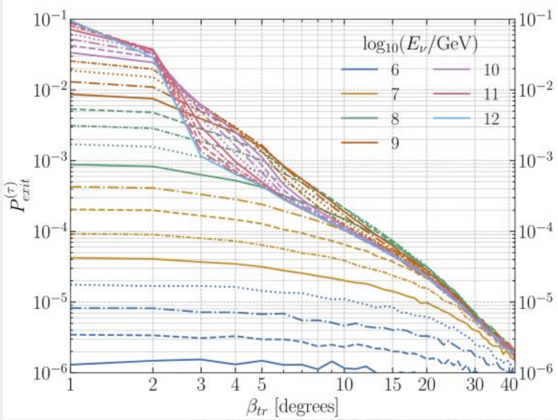
Cosmic Ray / EAS Simulations

1. Sample CR composition from measurements
2. Inject trajectory into MC EAS Simulation Conex
3. Use EASCherSim to estimate Cherenkov light production and propagation to detector for each EAS



Neutrino Simulation (NuSpaceSim)

2. Samples ν_τ interaction and τ propagations in the Earth to estimate P_{exit} based on NuPyProp/NuLeptonSim tables

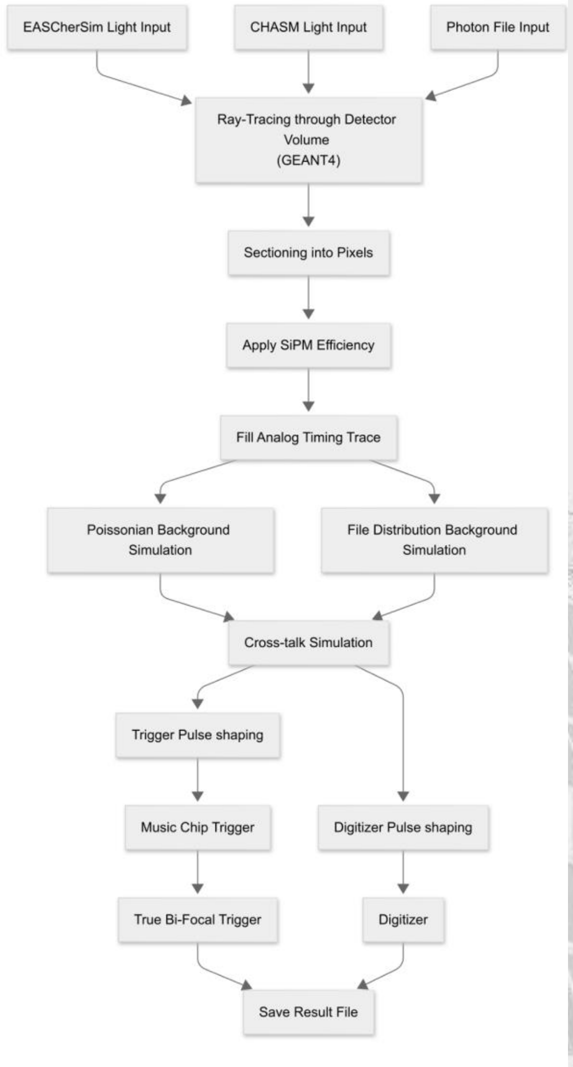


3. Samples τ probability based on exponential decay and produces EAS
4. Uses NuSpaceSim internal EAS model or samples EASCherSim shower library

Detector Simulation

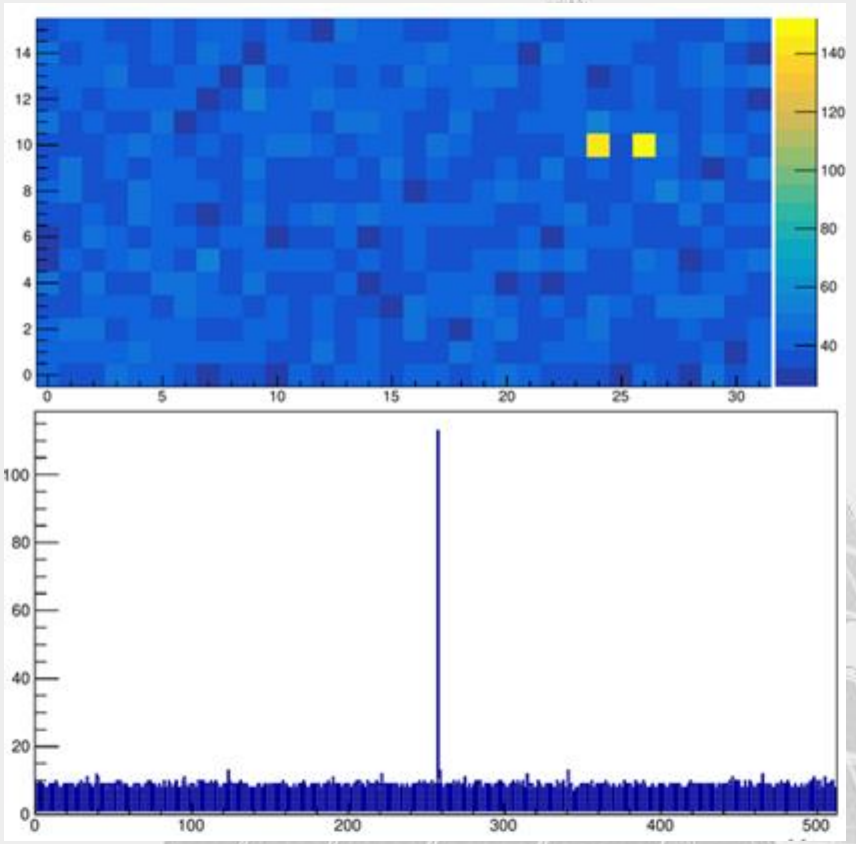
Detector Response - OffLine

- Optics simulation (GEANT 4)
- Photon to photoelectron conversion
- Background simulation
- Optical cross-talk
- Bi-focal trigger logic with 50ns coincidence window
  - Hardware and Software trigger to detect true bi-focal events
- Signal pile up
  - Minimum resolvable signal 30ns
- Output pulse shaping
  - Based on delta function input combined with cross-talk
  - Does not fully recover edge cases
- Digitization saturation
- To be cross checked against
  - Data, GT Simulation chain, Lab tests



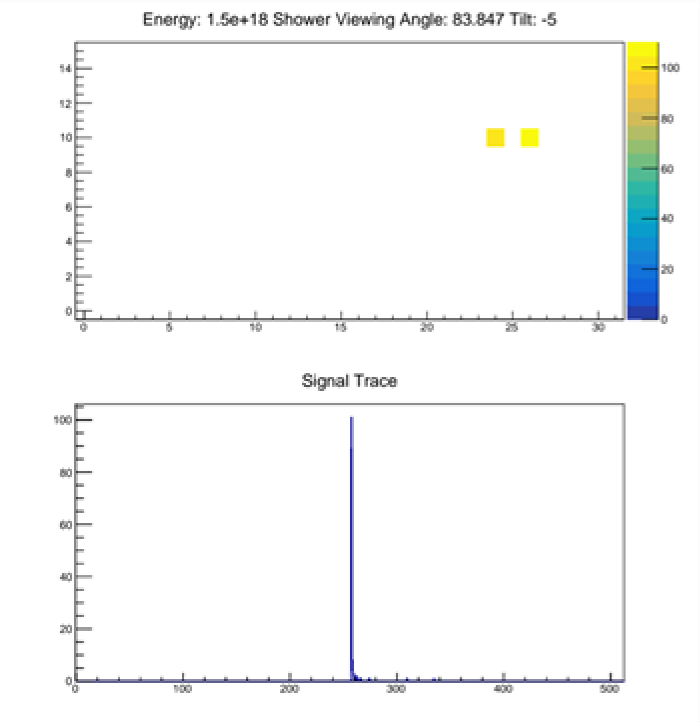
Detector Response - Background simulation

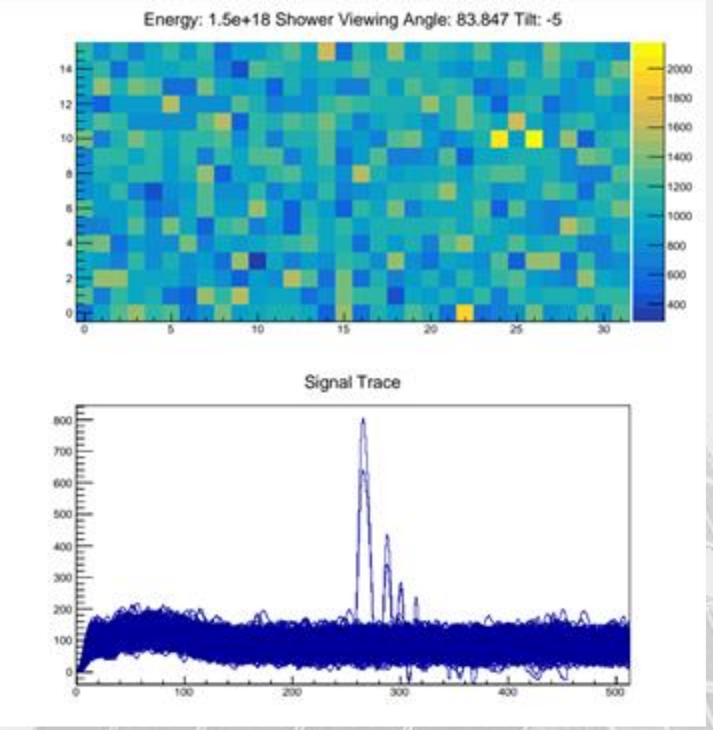
- Based on estimated night sky background measurements from SPB2
- PE rate of ~180MHz
- Implemented in OffLine by sampling from Poisson distribution with a mean of 1.8PE per digitization bin



Detector Response - Pile Up and Pulse Shaping

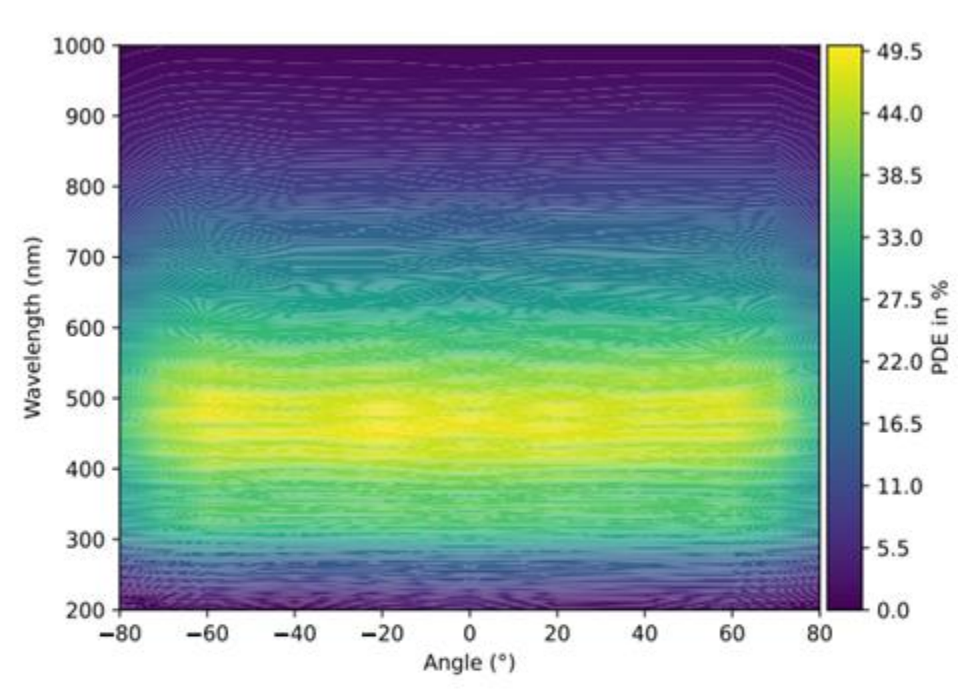
- Pile up:
  - Minimum pulse shape resolution of 30ns
  - 30ns sliding window
- Pulse shaping:
  - 1ps laser response curves for different input PEs
  - Pick closest trace in PEs

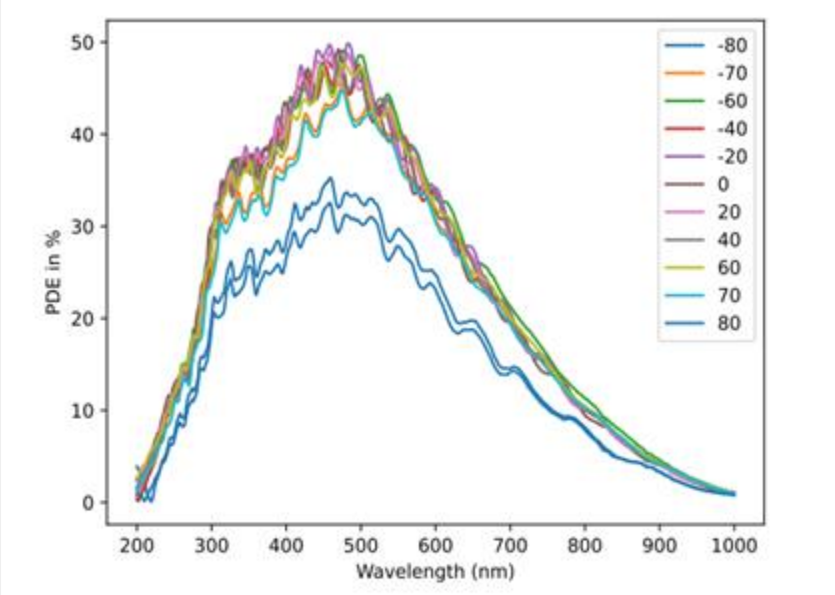




Detector Response - Photons to Photoelectrons

- Photon detection efficiency (PDE):
  - Peak around 480 nm
  - Range 200nm to 1000nm
  - Constant with incoming angles of -60° to 60°
  - PDE was applied to the incoming photons in OffLine



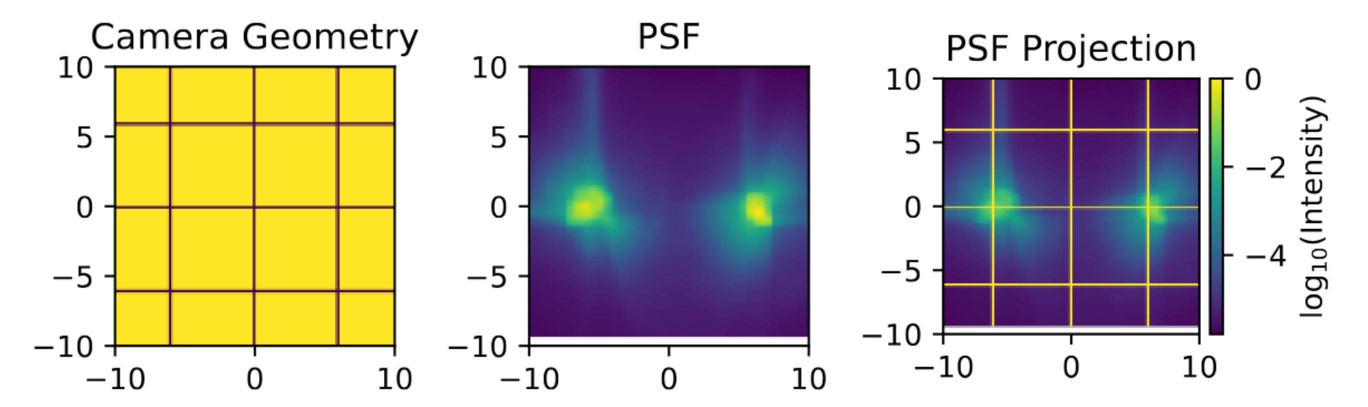


Detector Response – Simplified model

Wavelength dependent PE-threshold

Includes:

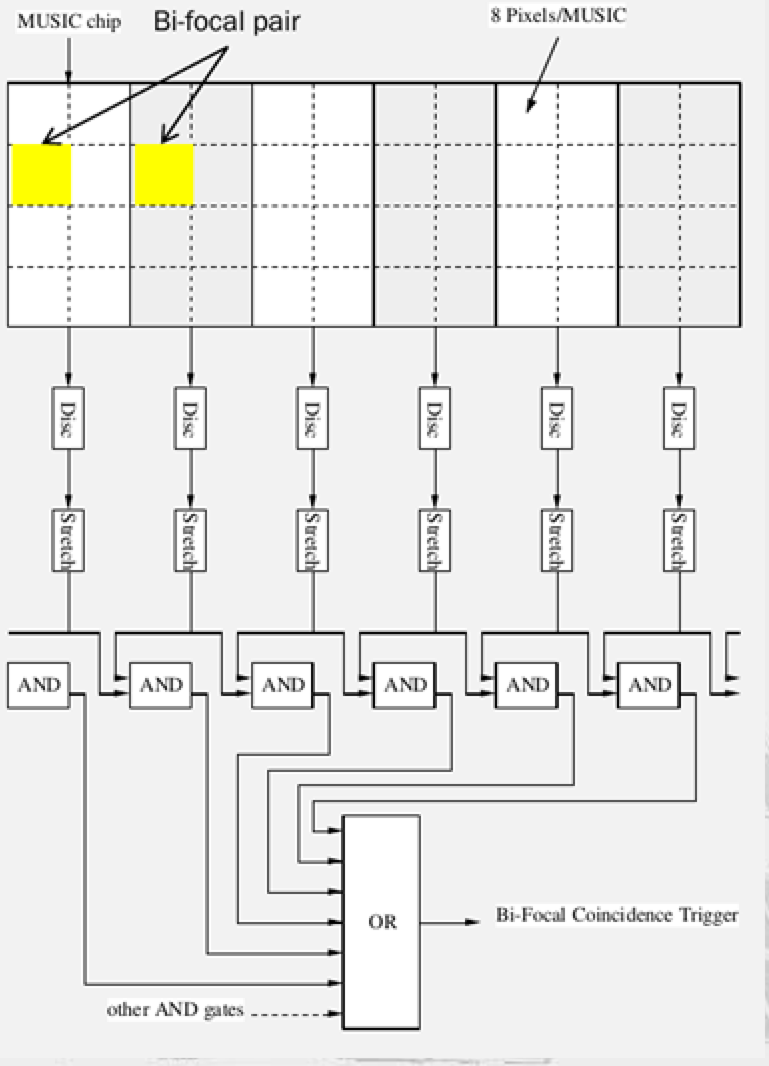
- ACP through put
- Mirror reflectivity
- SiPM efficiency
- Gap estimation



Close to absolute calibration efficiency measured in the field

Detector Response - Trigger

- Hardware Trigger
  - Coincident signal between two neighboring music chips within 50ns.
  - Does not mean a bifocal pair...
- Software Trigger
  - Requires that two triggering pixels are a bifocal pair.
- Implemented by Diksha Garg

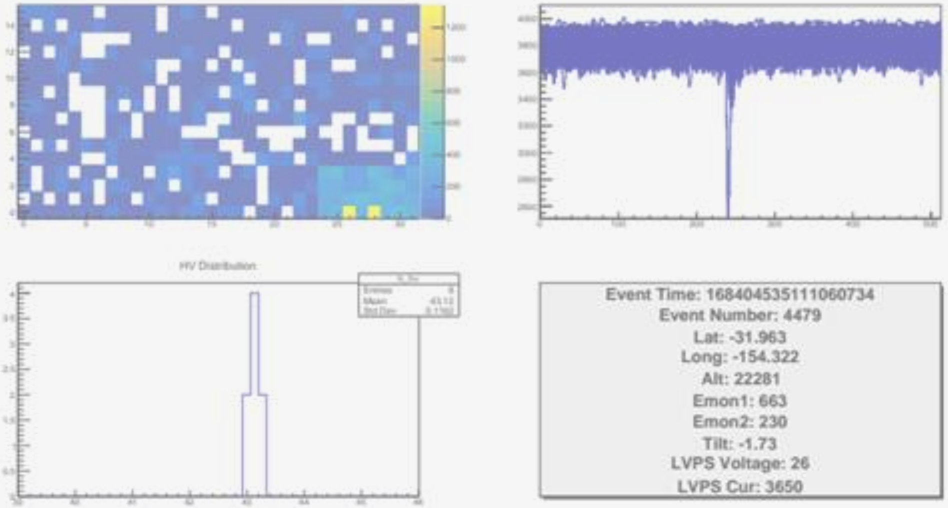


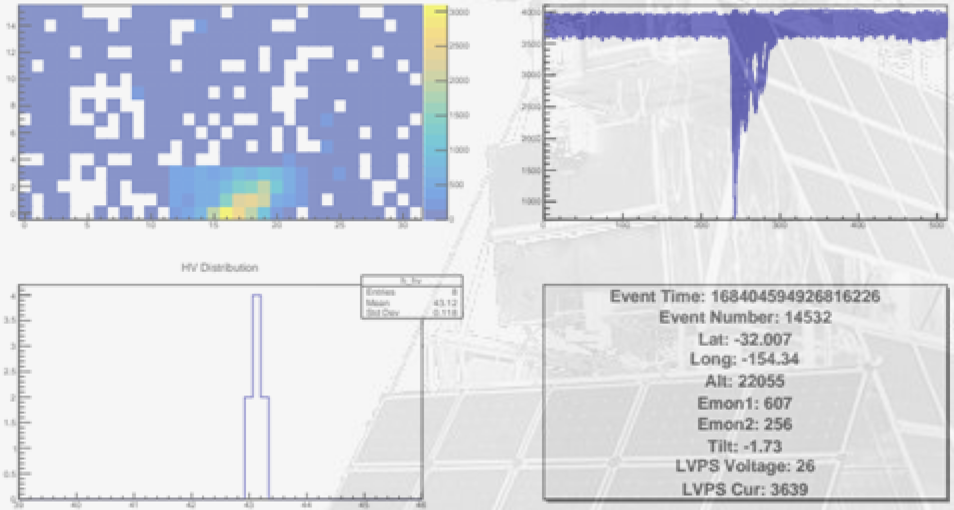
Above the limb Cosmic Rays

First pass at signal searches:

- Only high amplitude events (>800 ADC counts)
- Several CR candidates while looking above the limb
- Some unidentified signals

	Night 1	Night 2
Event type	**Number**	**Number**
Cosmic Ray Candidates	15	19
Extended events	20	5
Up-going extended events	1	0
Health LED or Bad Events	170	16
Total	205	57

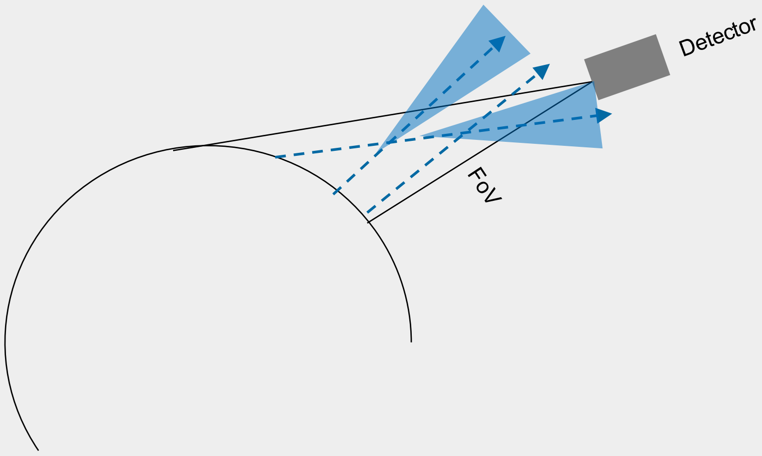


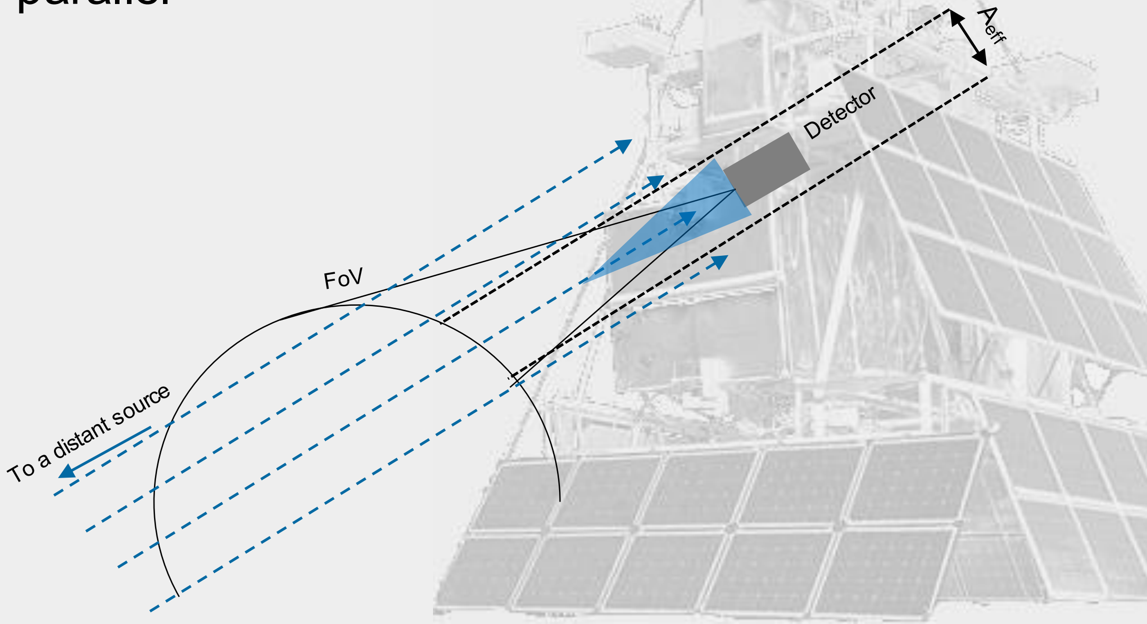


Cosmic Ray / Neutrino Geometry Sampling → EAS / Neutrino Simulation → EAS Cherenkov Light Simulation (EASCherSim) → Detector Simulation

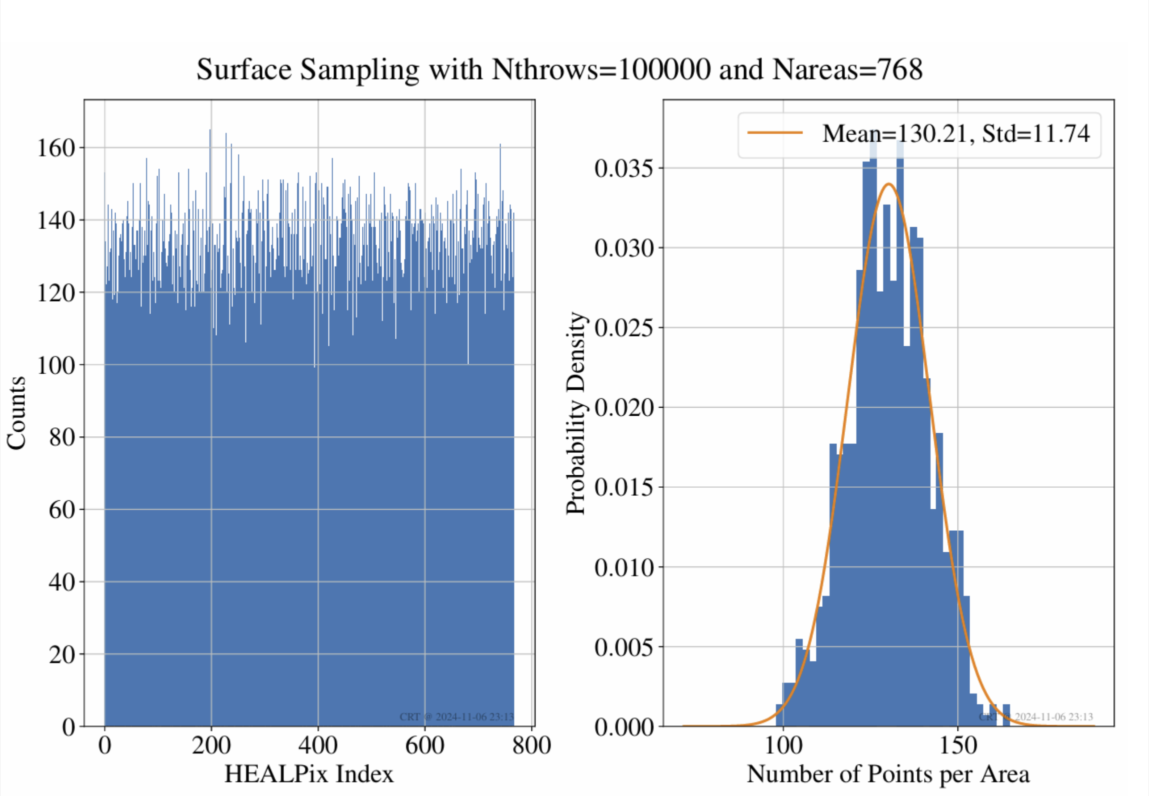
Geometries:

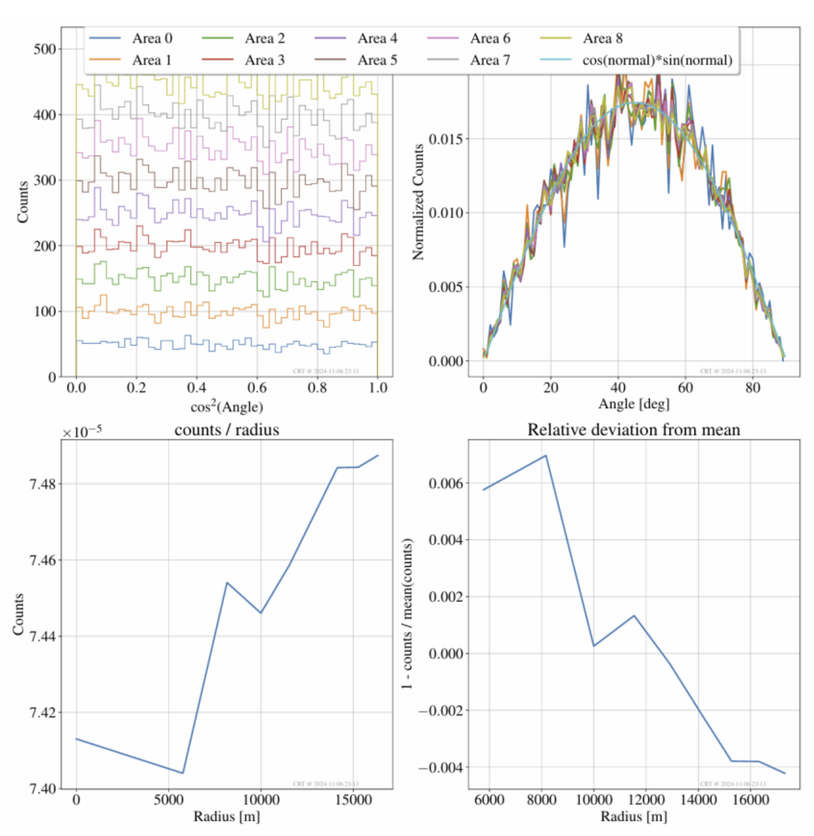
- **CRs:** Isotropic and homogenous
- **Diffuse neutrinos:** Isotropic and homogenous
- **ToO neutrinos:** Quasi parallel



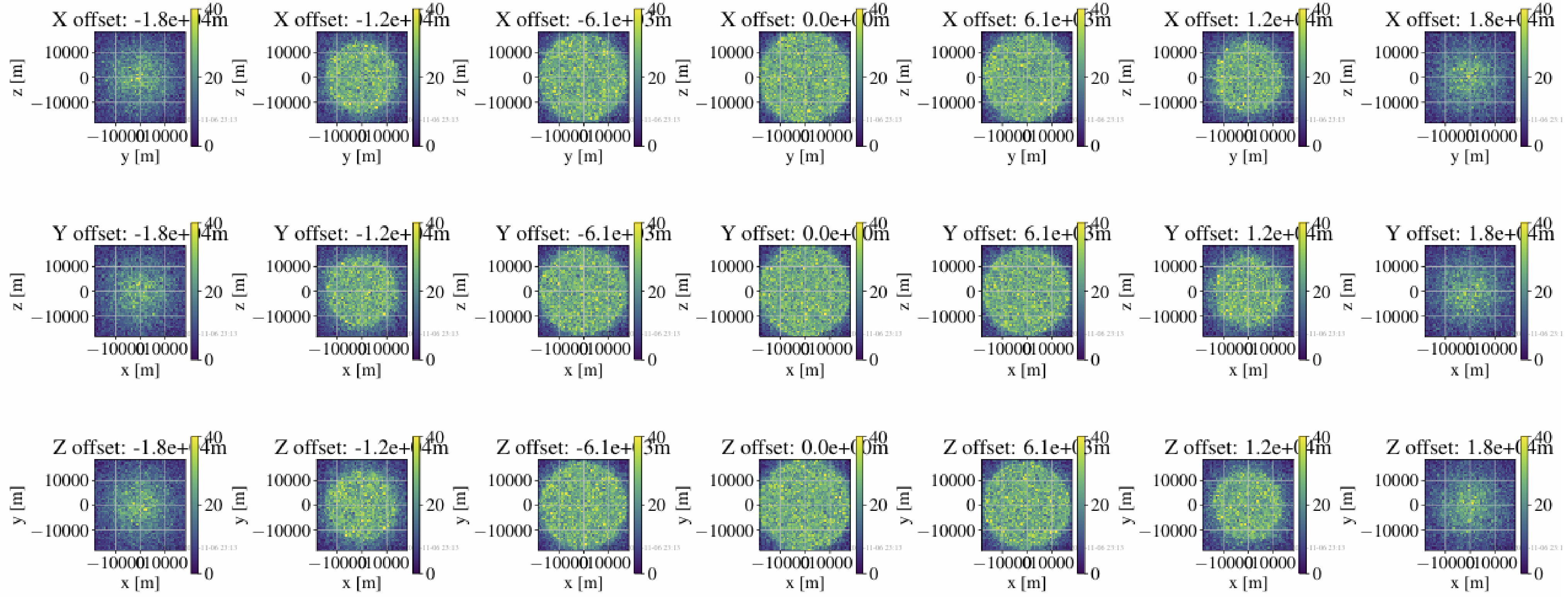


Cosmic Ray / Neutrino Geometry Sampling → EAS / Neutrino Simulation → EAS Cherenkov Light Simulation (EASCherSim) → Detector Simulation

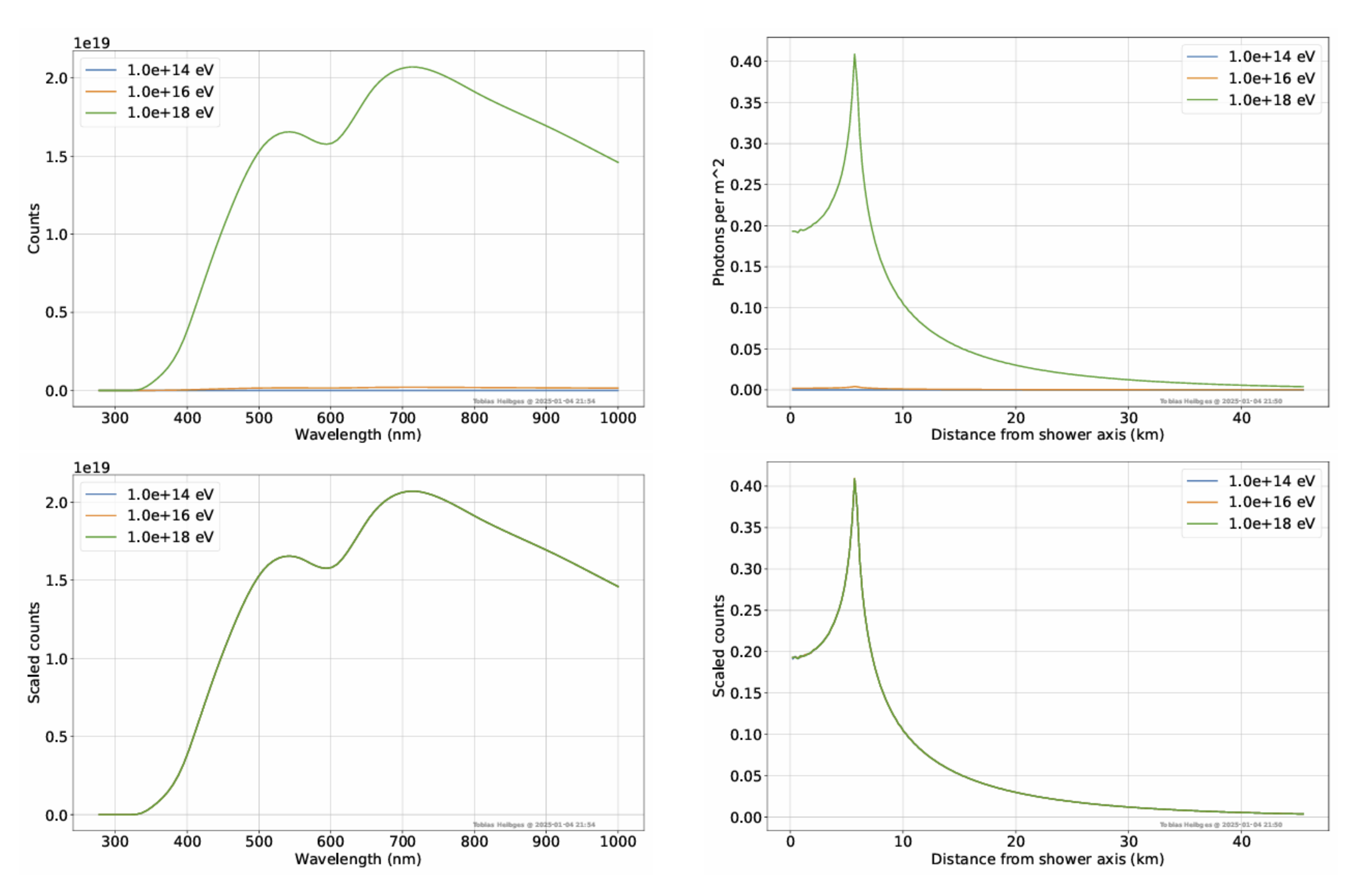


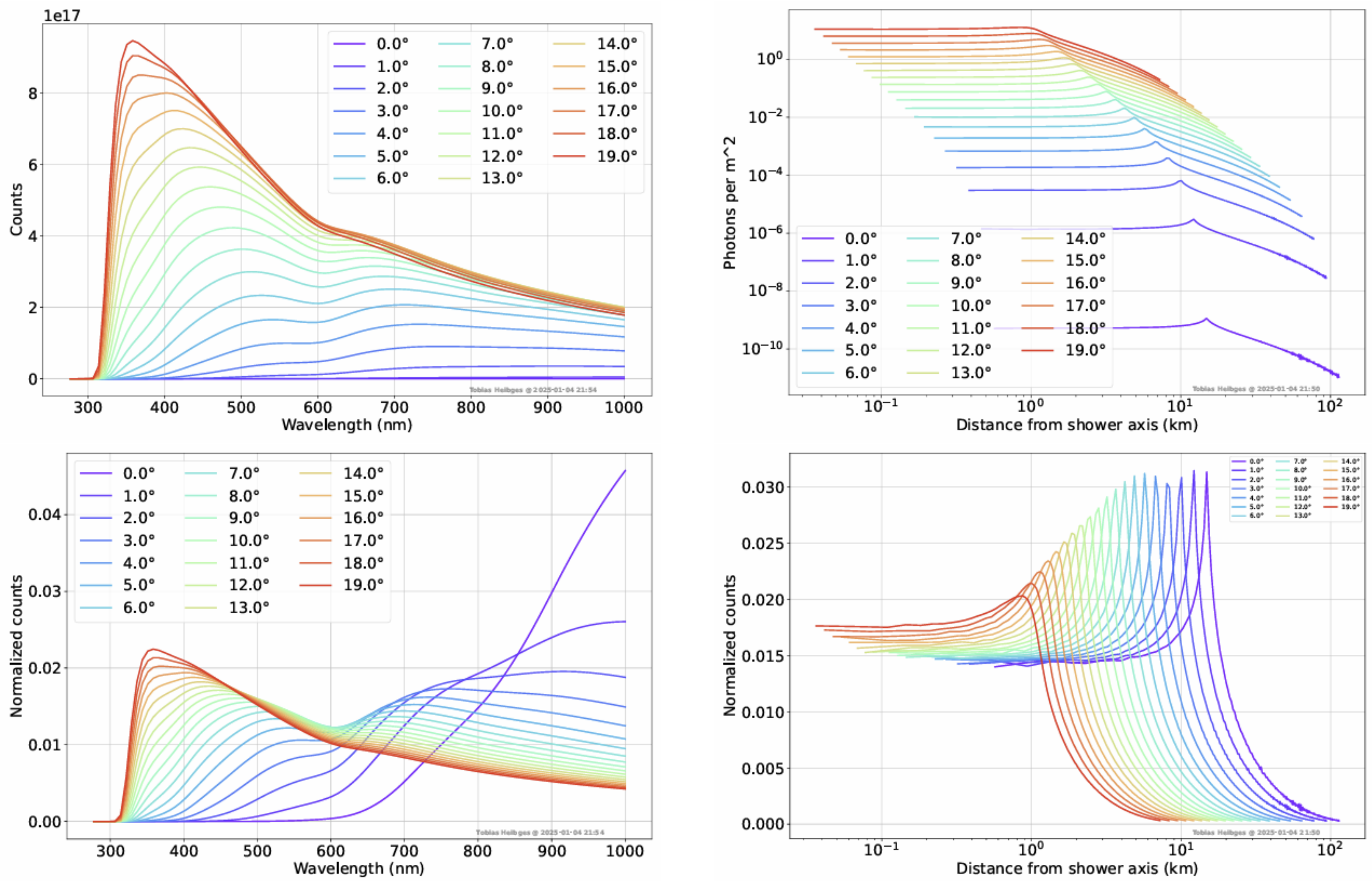


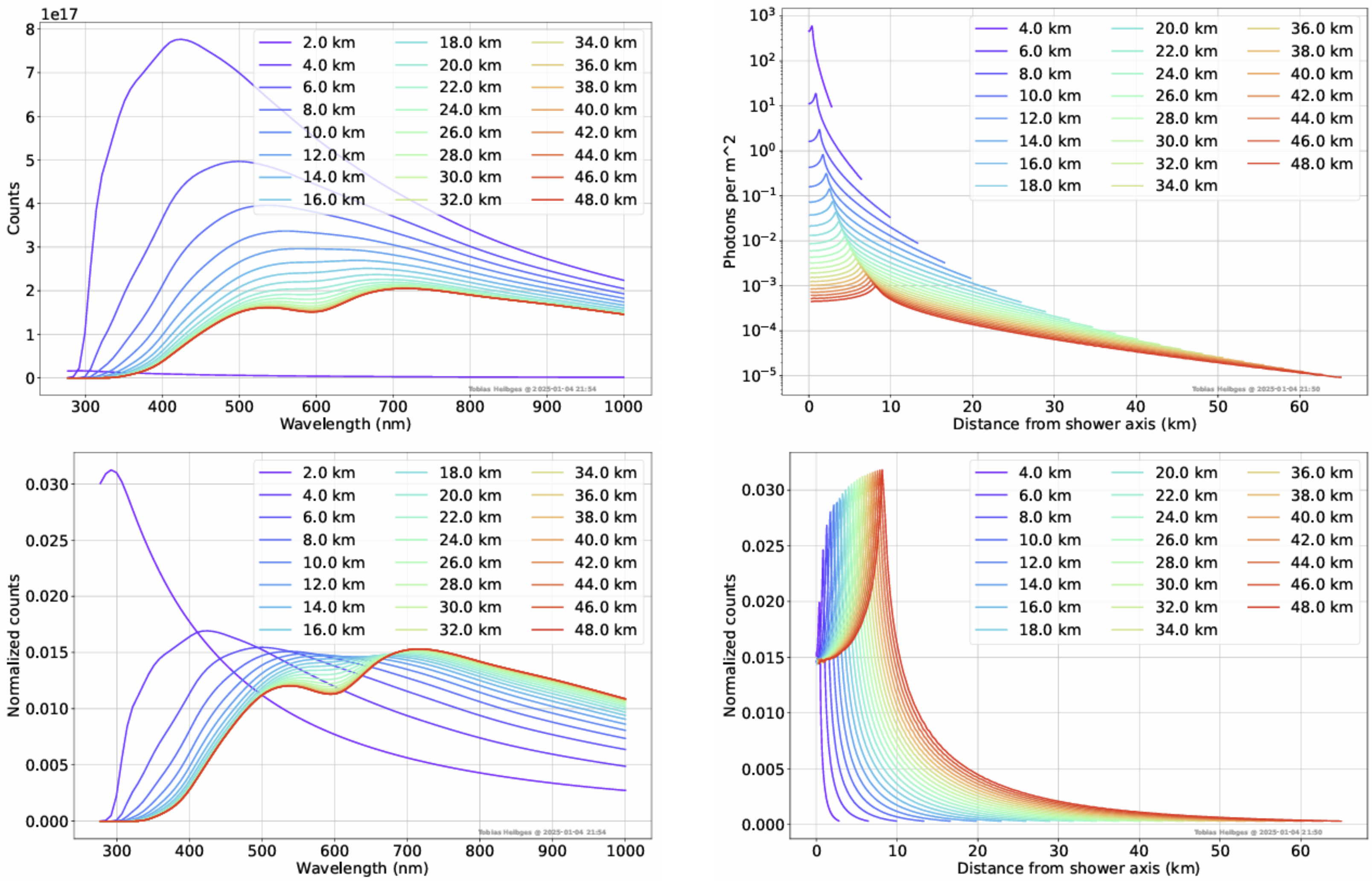
Cosmic Ray / Neutrino Geometry Sampling → EAS / Neutrino Simulation → EAS Cherenkov Light Simulation (EASCherSim) → Detector Simulation

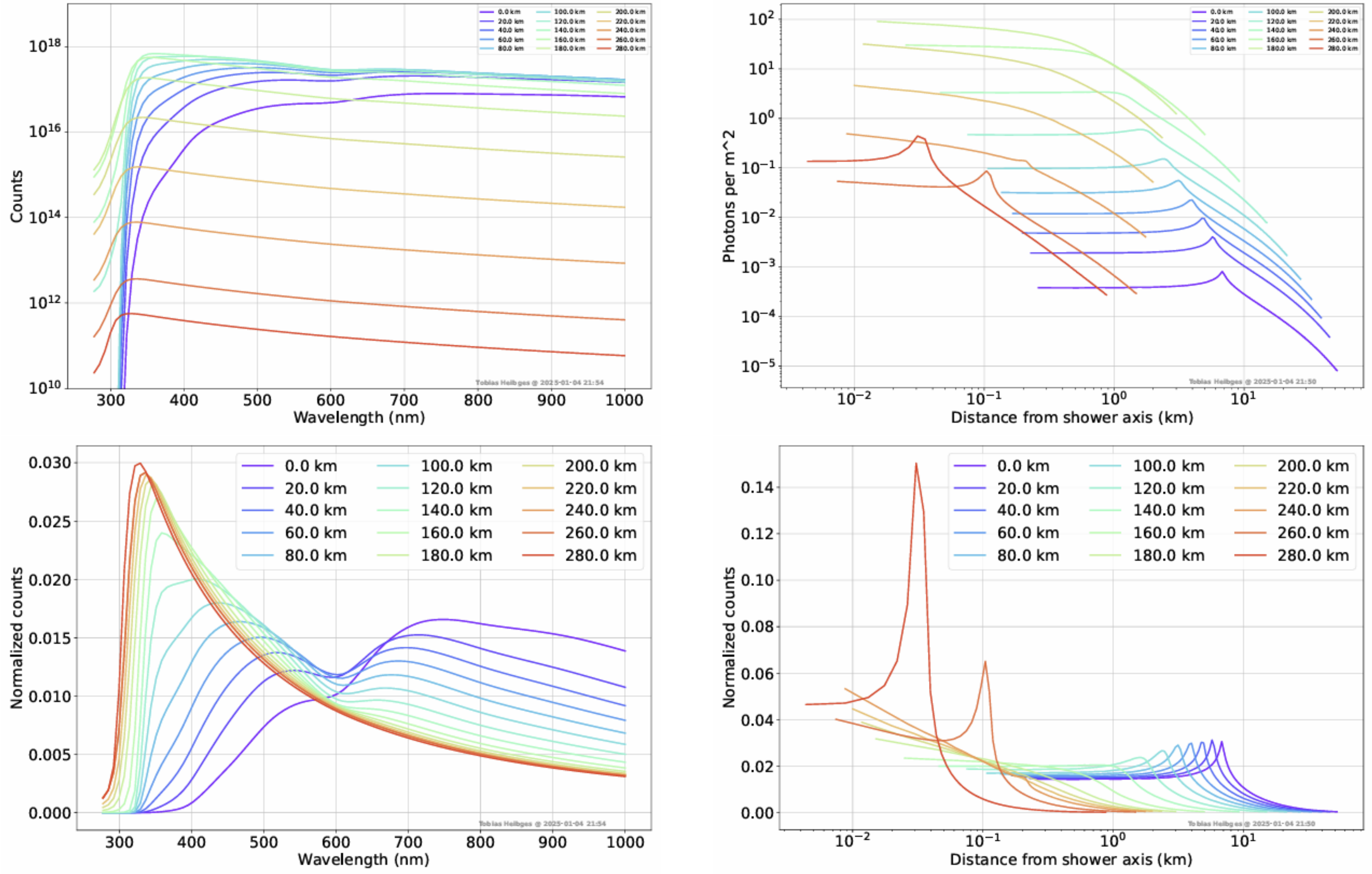


Shower Library


1e19
2.0
1.5
1.0
0.5
0.0
Counts
1.0e+14 eV
1.0e+16 eV
1.0e+18 eV
300
400
500
600
700
800
900
1000
Wavelength (nm)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Photons per m^2
0
10
20
30
40
Distance from shower axis (km)
Scaled counts
Scaled counts

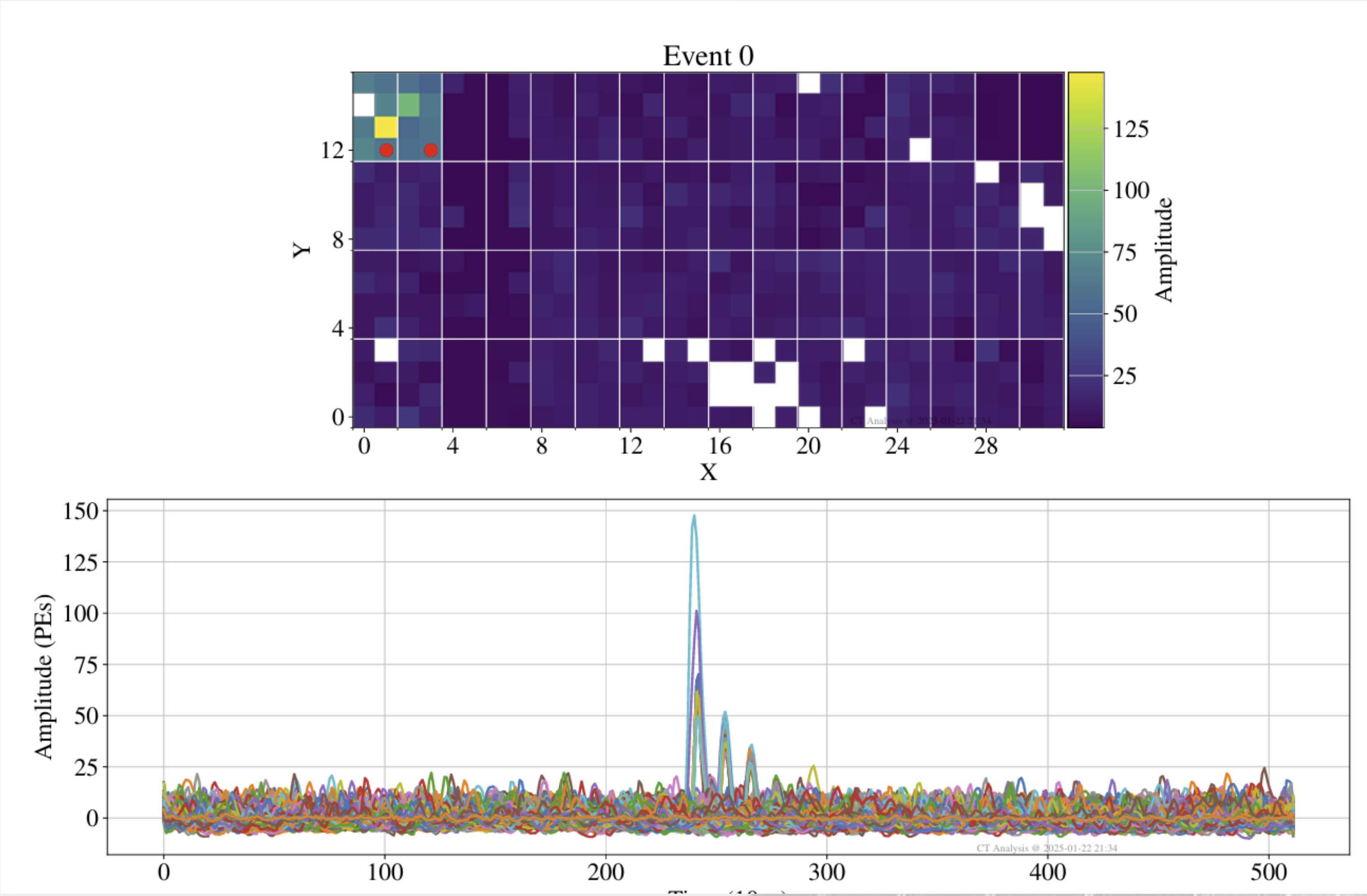

1e17
Counts
Wavelength (nm)
Photons per m^2
Distance from shower axis (km)
Normalized counts
Wavelength (nm)
Normalized counts
Distance from shower axis (km)
0.0° 1.0° 2.0° 3.0° 4.0° 5.0° 6.0° 7.0° 8.0° 9.0° 10.0° 11.0° 12.0° 13.0° 14.0° 15.0° 16.0° 17.0° 18.0° 19.0°


1e17
Counts
Wavelength (nm)
2.0 km 4.0 km 6.0 km 8.0 km 10.0 km 12.0 km 14.0 km 16.0 km 18.0 km 20.0 km 22.0 km 24.0 km 26.0 km 28.0 km 30.0 km 32.0 km 34.0 km 36.0 km 38.0 km 40.0 km 42.0 km 44.0 km 46.0 km 48.0 km
Photons per m^2
Distance from shower axis (km)
4.0 km 6.0 km 8.0 km 10.0 km 12.0 km 14.0 km 16.0 km 18.0 km 20.0 km 22.0 km 24.0 km 26.0 km 28.0 km 30.0 km 32.0 km 34.0 km 36.0 km 38.0 km 40.0 km 42.0 km 44.0 km 46.0 km 48.0 km
Normalized counts
Wavelength (nm)
2.0 km 4.0 km 6.0 km 8.0 km 10.0 km 12.0 km 14.0 km 16.0 km 18.0 km 20.0 km 22.0 km 24.0 km 26.0 km 28.0 km 30.0 km 32.0 km 34.0 km 36.0 km 38.0 km 40.0 km 42.0 km 44.0 km 46.0 km 48.0 km
Normalized counts
Distance from shower axis (km)
4.0 km 6.0 km 8.0 km 10.0 km 12.0 km 14.0 km 16.0 km 18.0 km 20.0 km 22.0 km 24.0 km 26.0 km 28.0 km 30.0 km 32.0 km 34.0 km 36.0 km 38.0 km 40.0 km 42.0 km 44.0 km 46.0 km 48.0 km

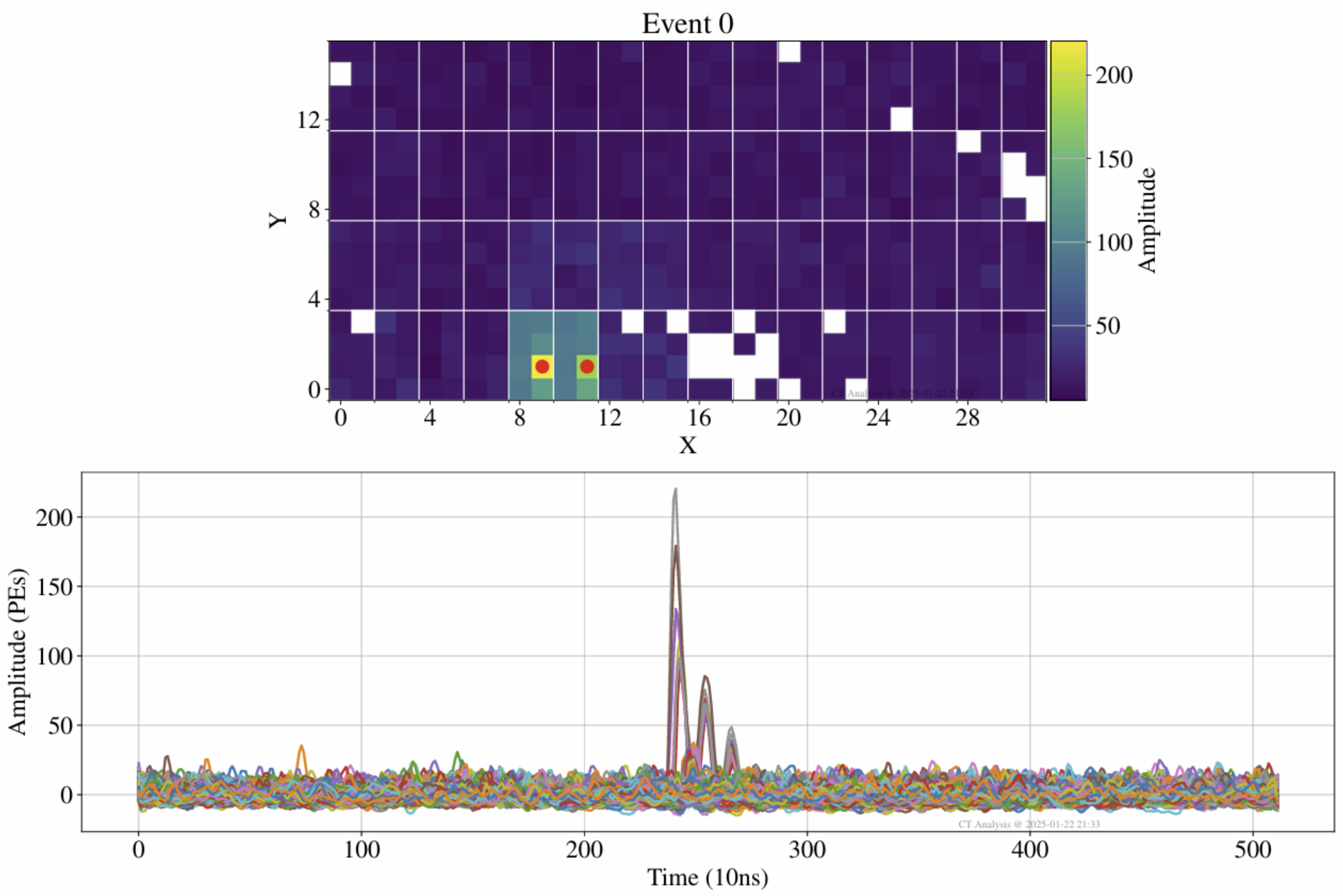

Counts
Wavelength (nm)
Photons per m^2
Distance from shower axis (km)
Normalized counts
Wavelength (nm)
Normalized counts
Distance from shower axis (km)
0.0 km
20.0 km
40.0 km
60.0 km
80.0 km
100.0 km
120.0 km
140.0 km
160.0 km
180.0 km
200.0 km
220.0 km
240.0 km
260.0 km
280.0 km

Passing Events

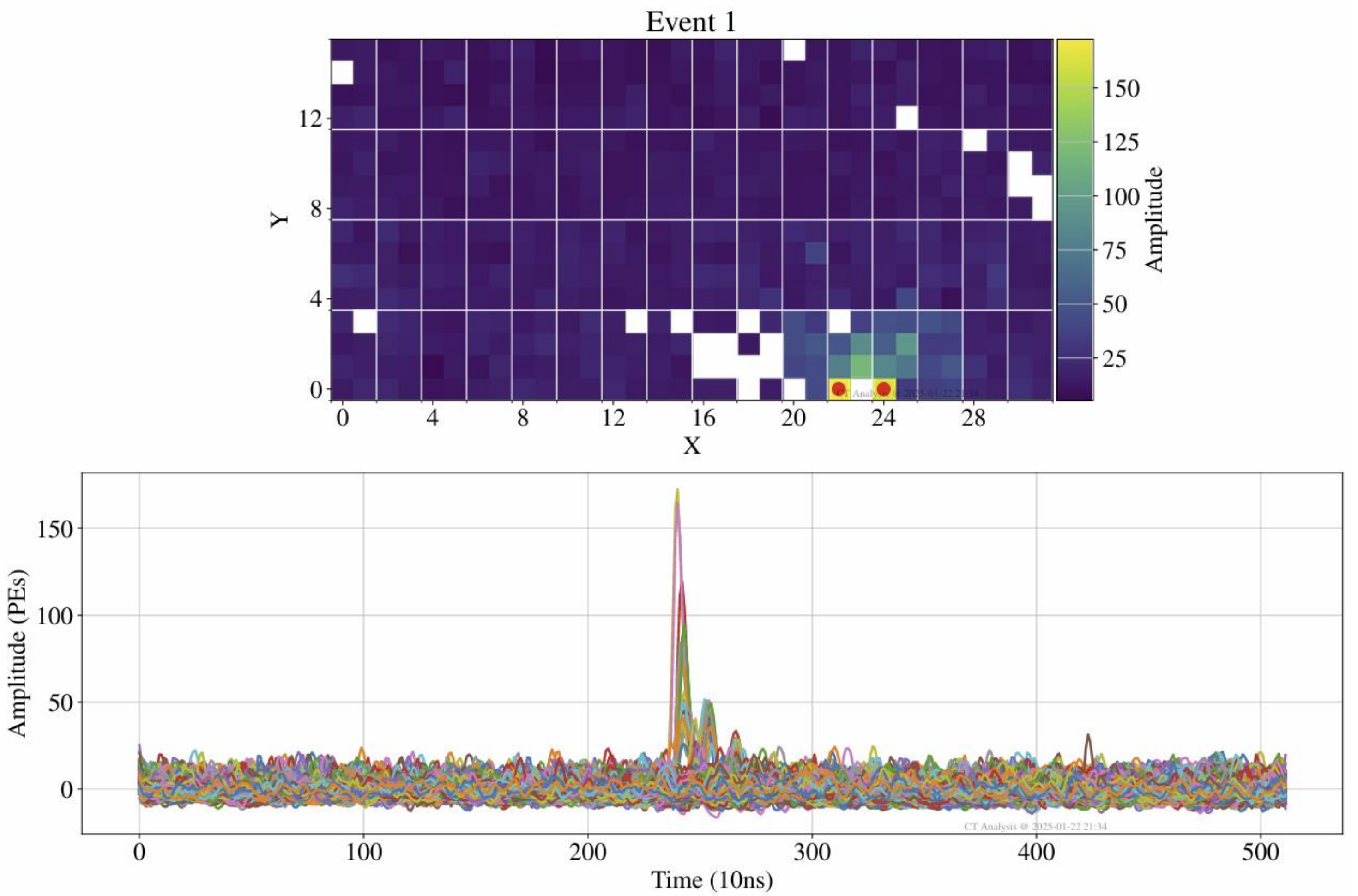
Below limb



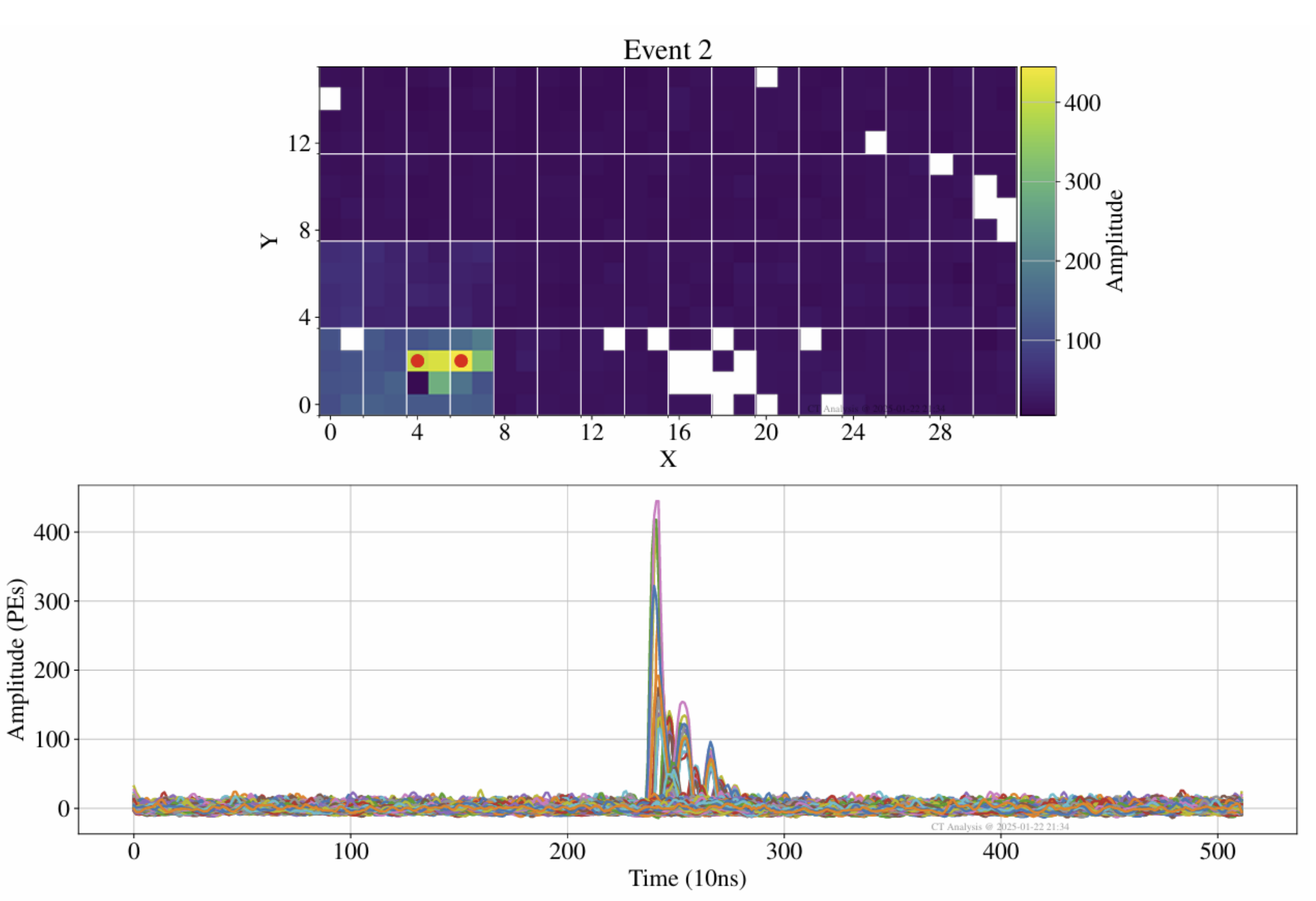
Above limb



Above limb

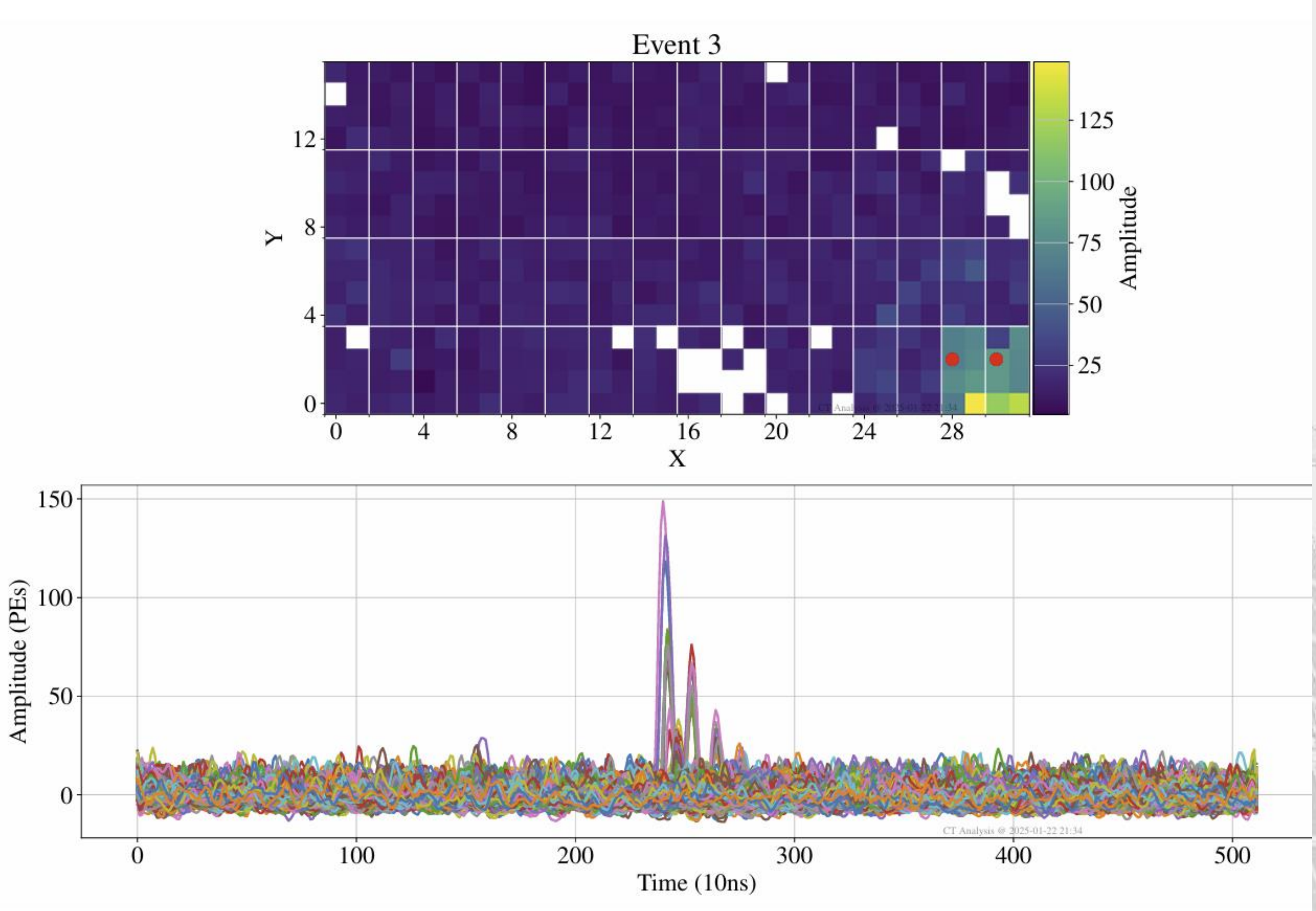

Event 1
Y
X
Amplitude
0
4
8
12
16
20
24
28
25
50
75
100
125
150
Amplitude (PEs)
Time (10ns)
0
100
200
300
400
500
CT Analysis @ 2025-01-22 21:34

Above limb



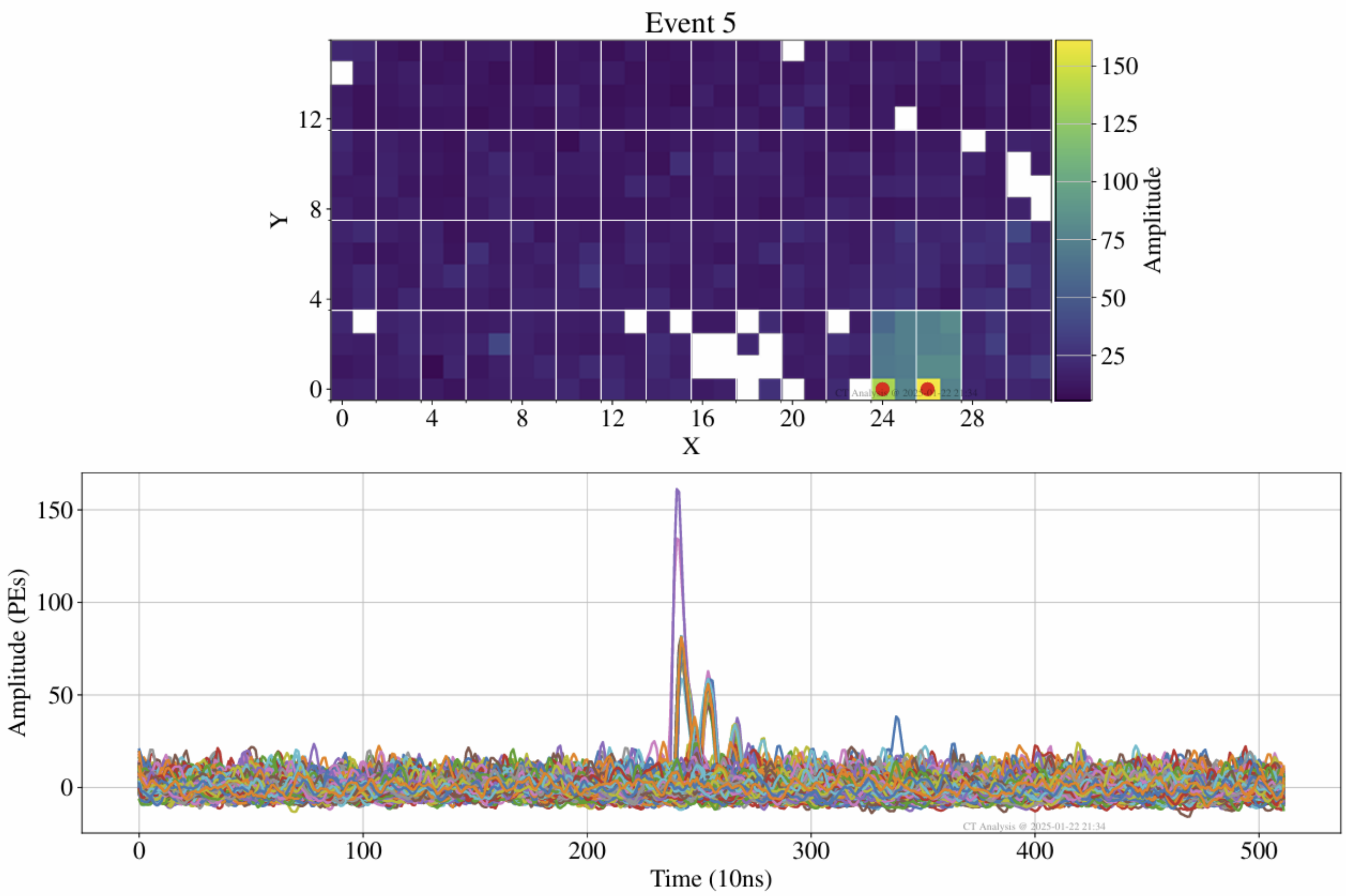
Event 2
Y
X
Amplitude
0
4
8
12
16
20
24
28
100
200
300
400
Amplitude (PEs)
Time (10ns)
0
100
200
300
400
500
CT Analysis @ 2025-01-22 21:34

Above limb



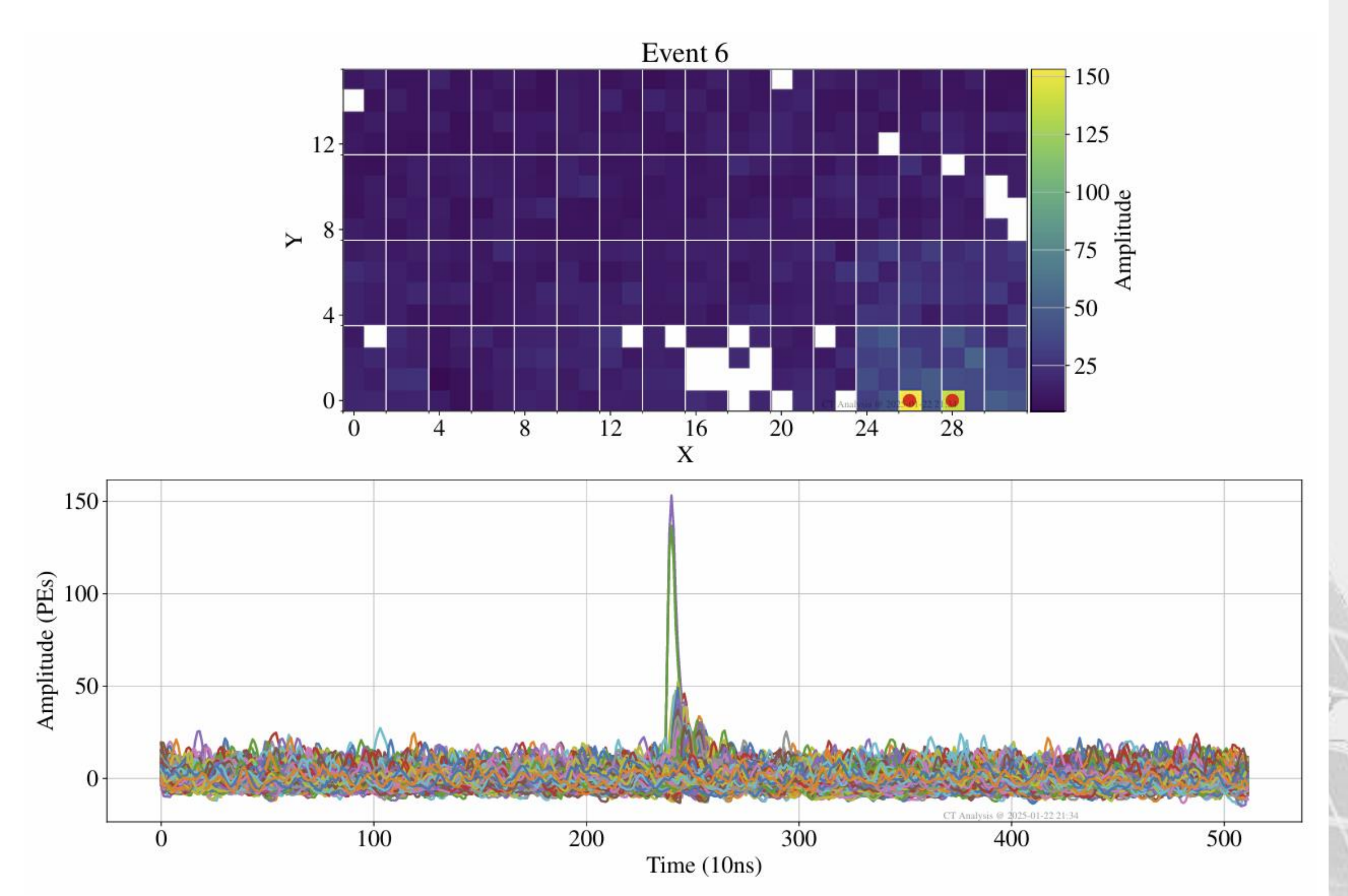
Event 3
Y
X
Amplitude
0
4
8
12
16
20
24
28
125
100
75
50
25
Amplitude (PEs)
Time (10ns)
150
0
100
200
300
400
500
CT Analysis @ 2025-01-22 21:34

Above limb



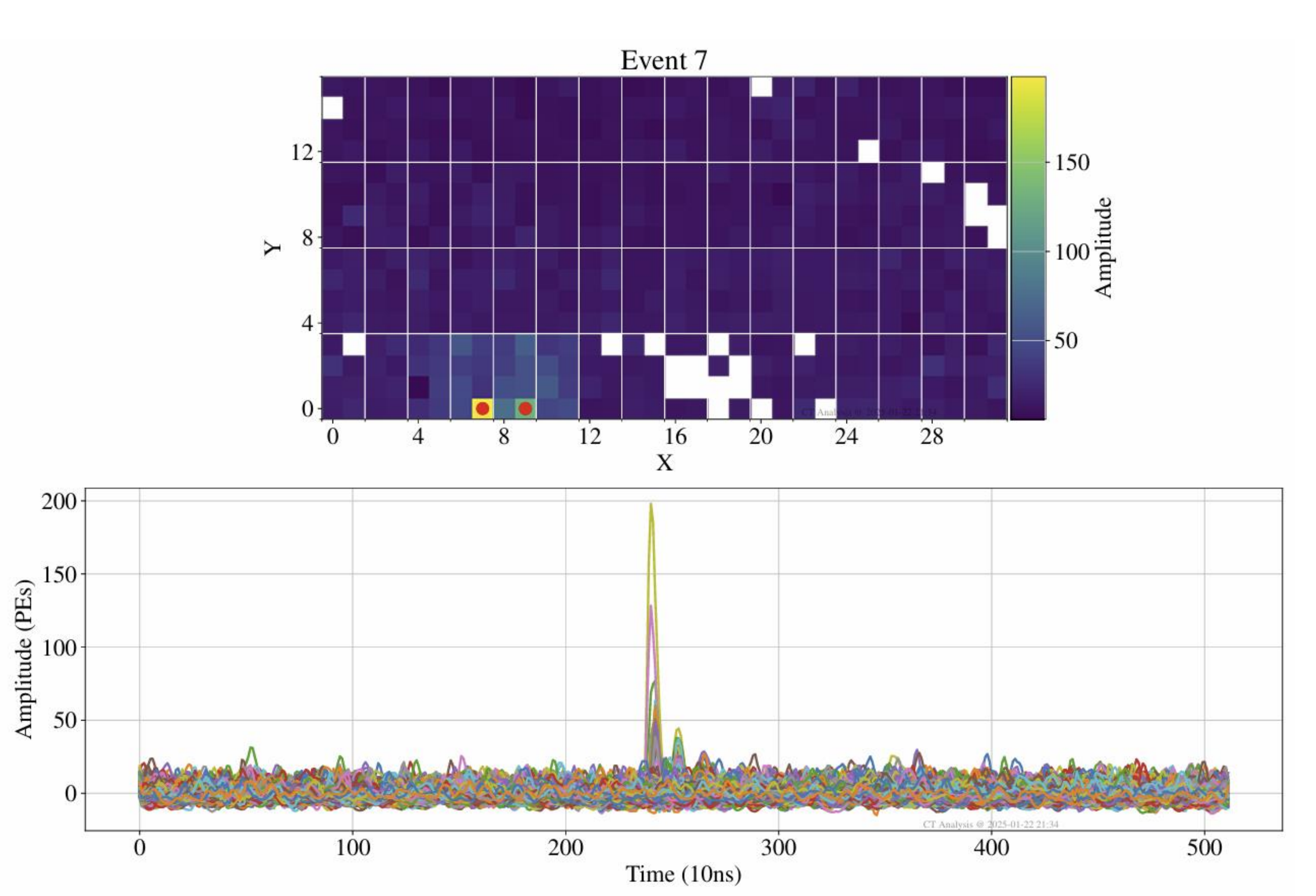
Event 5
Y
X
Amplitude
0
4
8
12
16
20
24
28
25
50
75
100
125
150
Amplitude (PEs)
Time (10ns)
0
100
200
300
400
500

Above limb

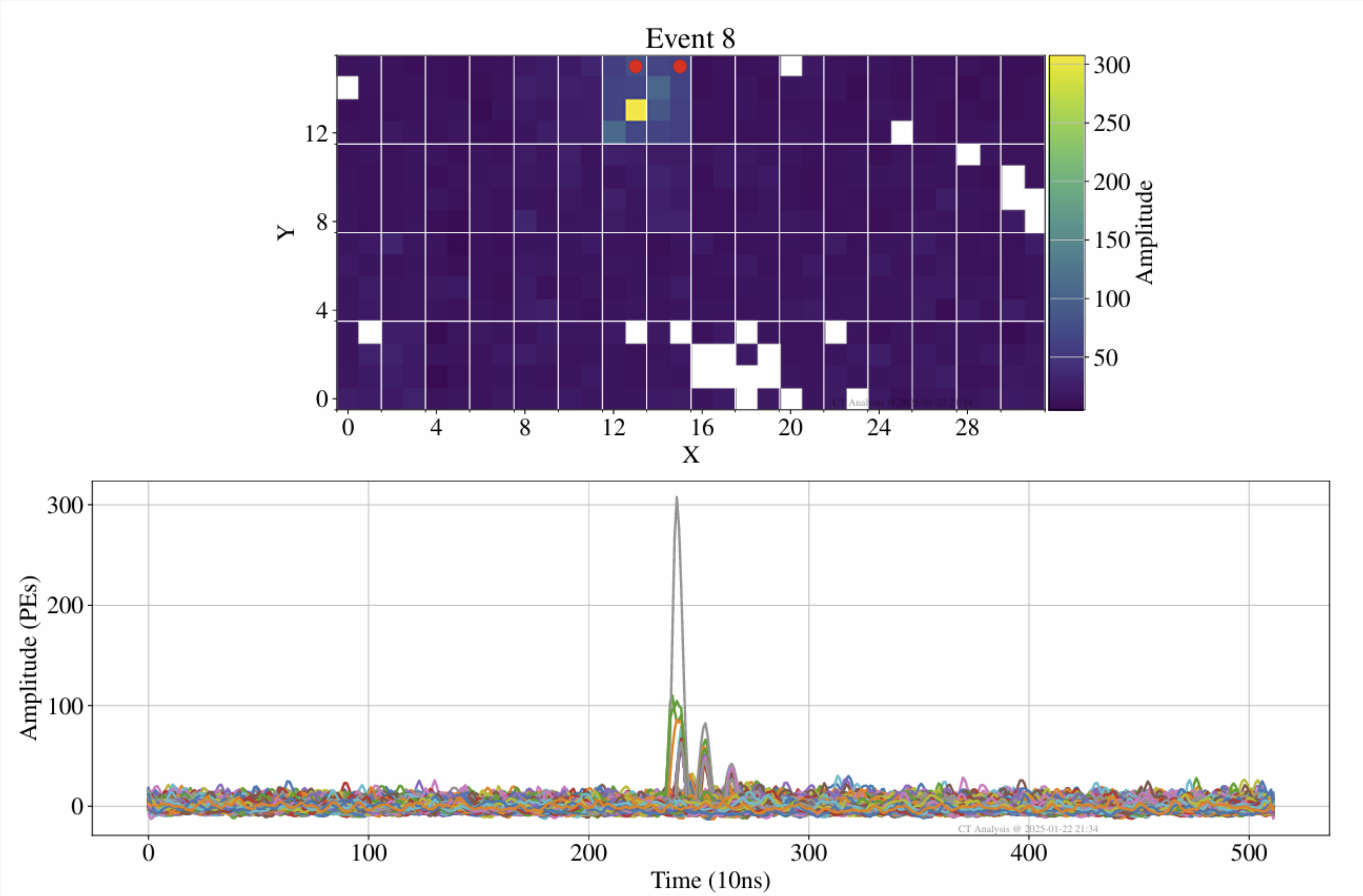


Event 6
Y
X
Amplitude
150
125
100
75
50
25
Amplitude (PEs)
Time (10ns)
CT Analysis @ 2025-01-22 21:34

Above limb



Above limb


Event 8
Y
X
Amplitude
0
4
8
12
16
20
24
28
50
100
150
200
250
300
Amplitude (PEs)
Time (10ns)
0
100
200
300
400
500