Connecting high-energy astroparticle physics for origins of cosmic rays and future perspectives

The UHE-Neutrino Cherenkov telescope onboard EUSO-SPB2

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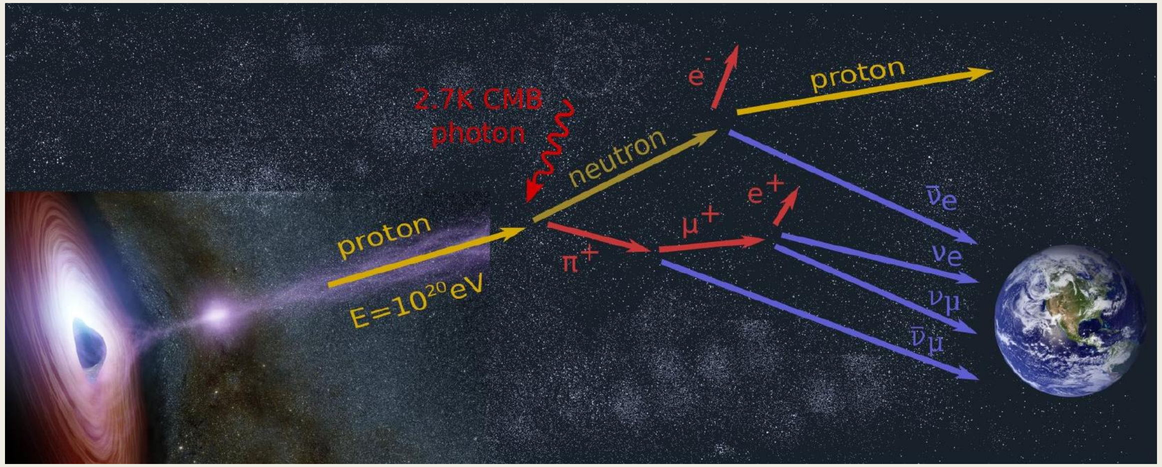
Scientific Motivation

UHE neutrinos address a broad range of major scientific drivers in astroparticle physics:

- *What are the most energetic particles in the Universe?*
- *Where and how do they gain their incredible energies?*
- *How did the universe evolve?*

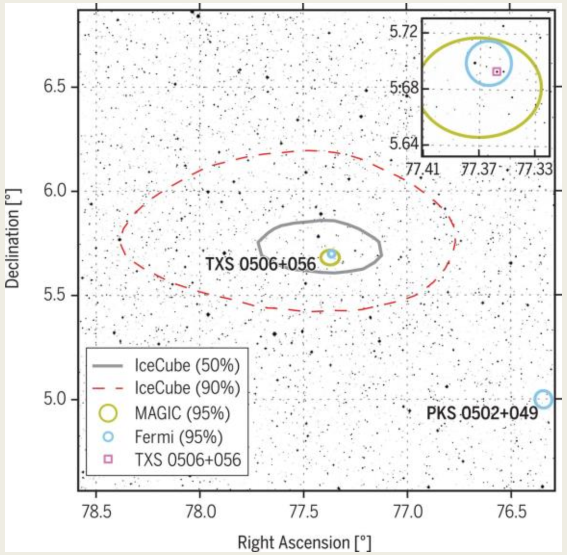
The composition of UHECR:

Cosmogenic neutrinos are the result of interactions between UHECR protons and CMB photons.
Due to neutrino oscillation, some will turn into tau neutrinos.



The sources of cosmic rays:

Astrophysical neutrinos are produced by decay of pions, kaons and secondary muons by hadronic interaction in astrophysical sources.



First evidence of a flaring blazar, TXS 0506+056, was provided by IceCube collaboration.

IceCube Collaboration et al., Science 361, eaat1378 (2018).

Other astrophysical sources:

- compact object mergers
- gamma-ray bursts
- pulsars and magnetars
- tidal disruption events

- New Physics beyond the Standard Model?

Probe Of Extreme Multi-Messenger Astrophysics (POEMMA)

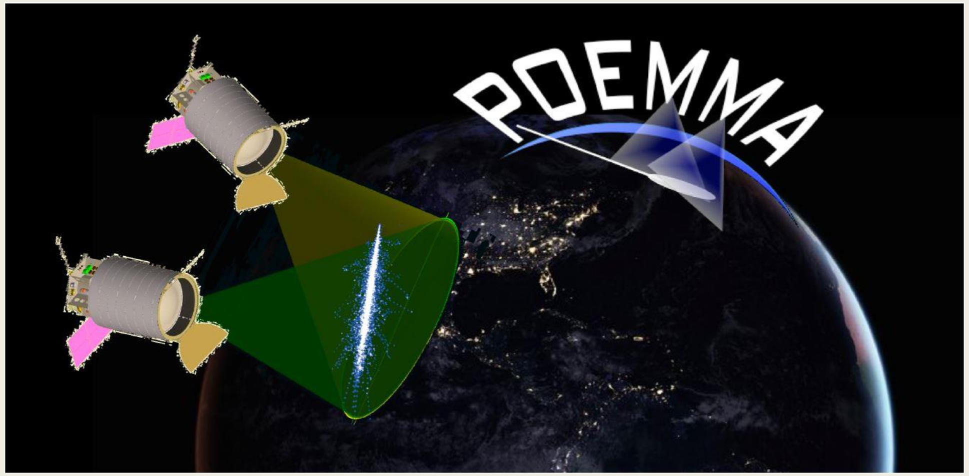
- POEMMA is a potential NASA astrophysics Probe class mission designed to precisely measure UHECRs and observe cosmic neutrinos using space-based measurements of EAS.

- **Science with POEMMA:**
    - Discover the nature and origin of **UHECR**
    - Discover **neutrino** emission from astrophysical transients
    - Probe particle interactions at extreme energies
    - Observe Transient Luminous Events (**TLEs**) and **Meteors**
    - Search for **Exotic** particles

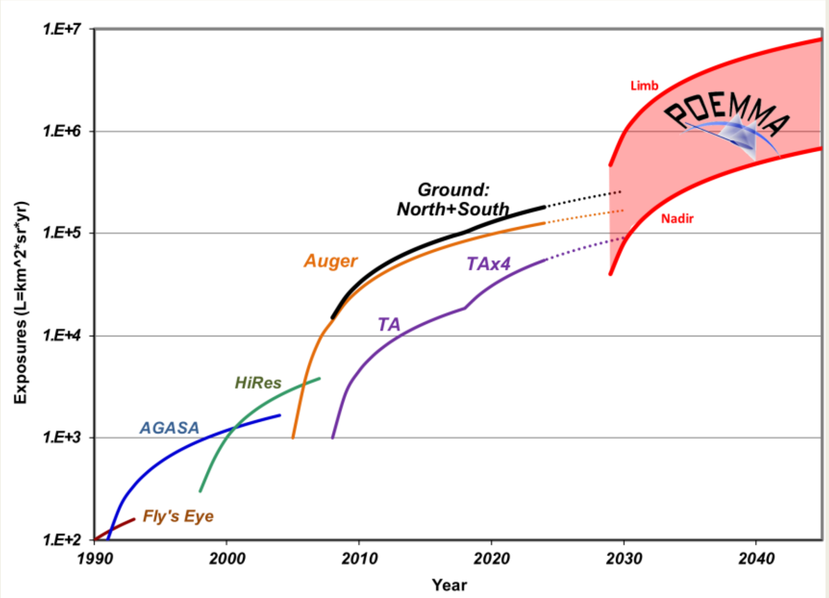
- POEMMA is comprised of **two identical observatories** separated no more than 300 km at an altitude of 525 km. PEOMMA **large acceptance** makes it a great candidate for catching a flaring source.

- Two observation mode:
    - Stereo (mono) mode:
        - UHECR fluorescence observations (E > 20 EeV)
    - Tilted mode:
        - Cherenkov emission of EASs from cosmic tau neutrinos (E > 20 PeV)
        - This configuration works based on the ToO alerts.

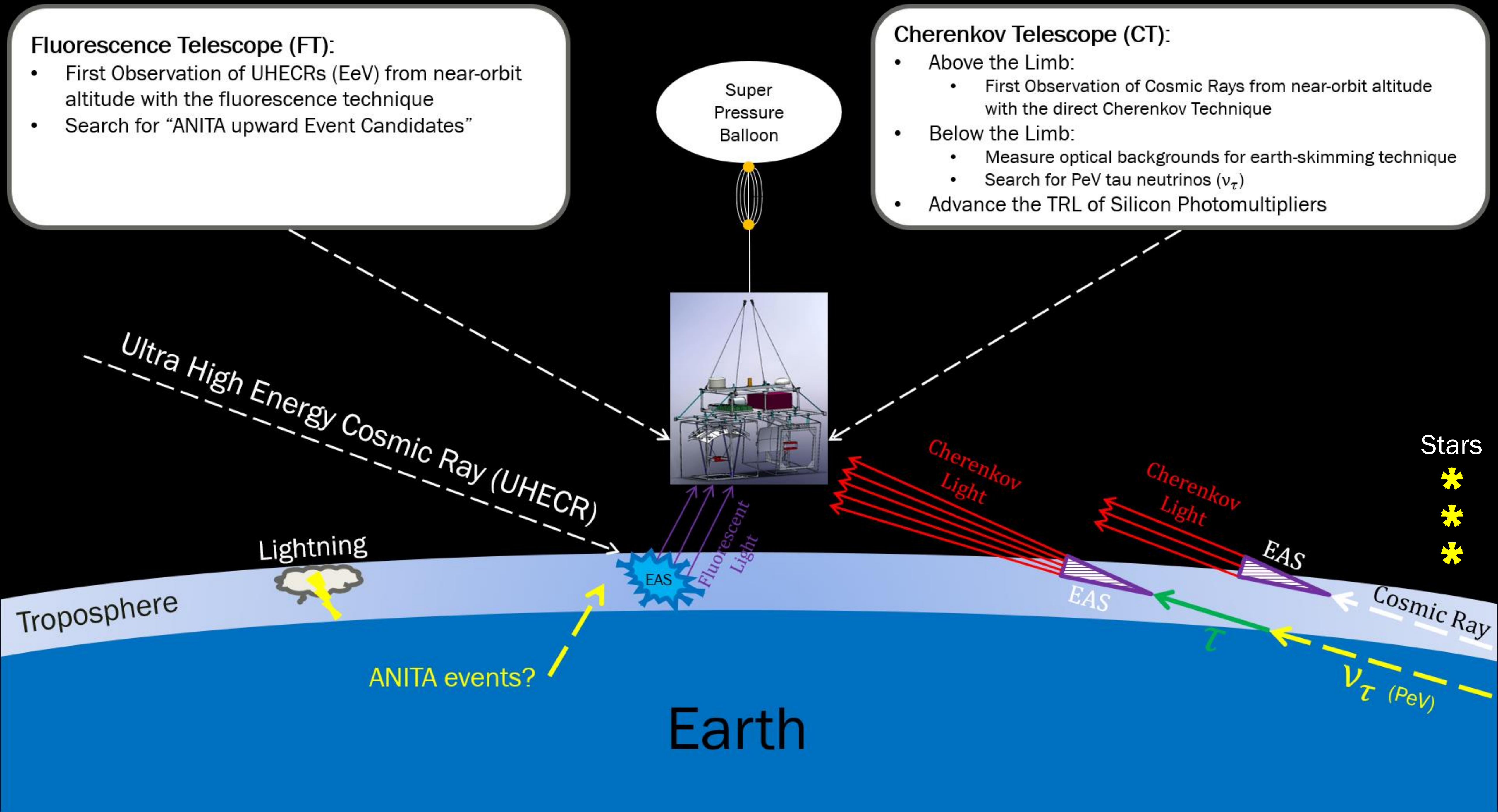
- **EUSO-SPB2 will be a precursor for POEMMA.**



A. Olinto et al. (2019) – submitted to JCAP



Comparison of POEMMA Exposure vs. time


Fluorescence Telescope (FT):
• First Observation of UHECRs (EeV) from near-orbit altitude with the fluorescence technique
• Search for "ANITA upward Event Candidates"
Super Pressure Balloon
Cherenkov Telescope (CT):
• Above the Limb:
• First Observation of Cosmic Rays from near-orbit altitude with the direct Cherenkov Technique
• Below the Limb:
• Measure optical backgrounds for earth-skimming technique
• Search for PeV tau neutrinos (ν_τ)
• Advance the TRL of Silicon Photomultipliers
Ultra High Energy Cosmic Ray (UHECR)
Cherenkov Light
Cherenkov Light
Stars
Lightning
EAS
Fluorescent Light
EAS
EAS
Cosmic Ray
Troposphere
τ
ANITA events?
ν_τ (PeV)
Earth

Studying Optical Background

- We will be the **first** to operate a Cherenkov telescope from a **sub-orbital platform.**

❑ Studying the Night Sky Background (NSB)

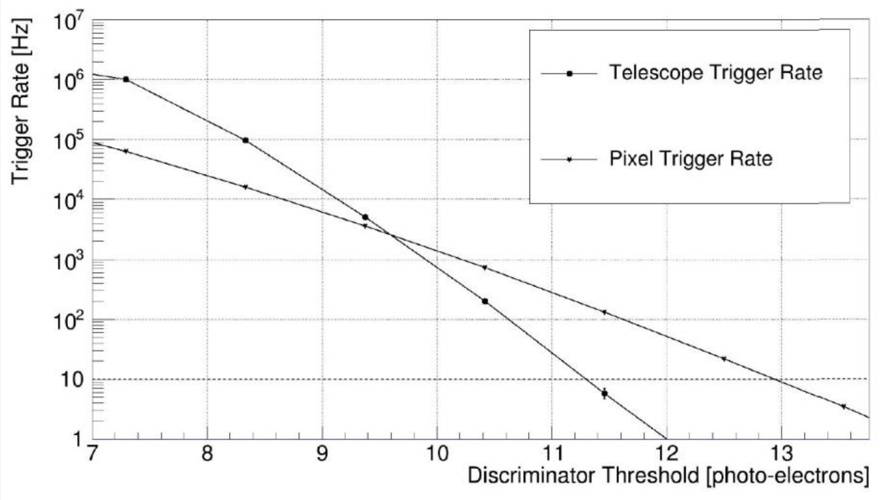
- The brightness of the sky has significant impact on the energy threshold of the Cherenkov telescope and the event reconstruction
- We will study how the **NSB** over the spectral response of the SiPMs which varies over **time** and **position** in the sky.

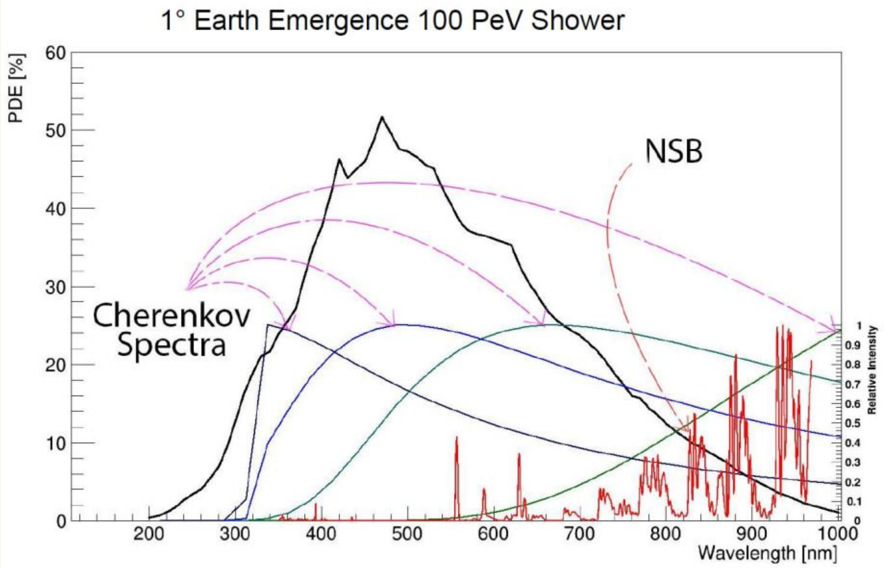
❑ Identifying known and unknown sources

- For ground measurements, background is mostly dominated by muon initiated sub-showers of primary cosmic-ray air showers.
- What about higher altitude measurements?

❑ Effect of charged particles traversing the telescope

- They show up as ring images for ground telescopes, if a muon passes nearby.



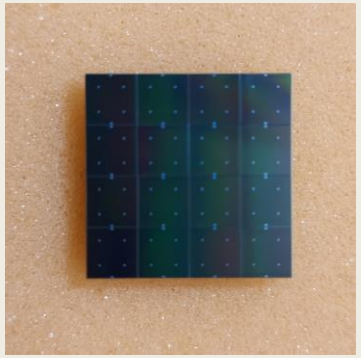


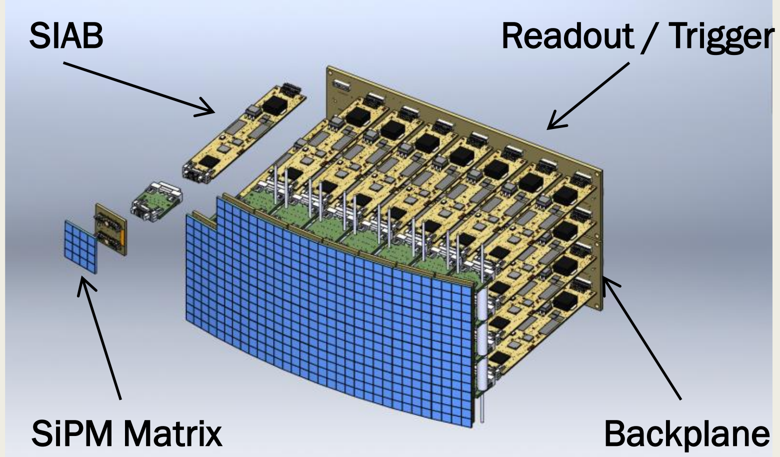
NSB spectra from: Benn and Ellison (2008)

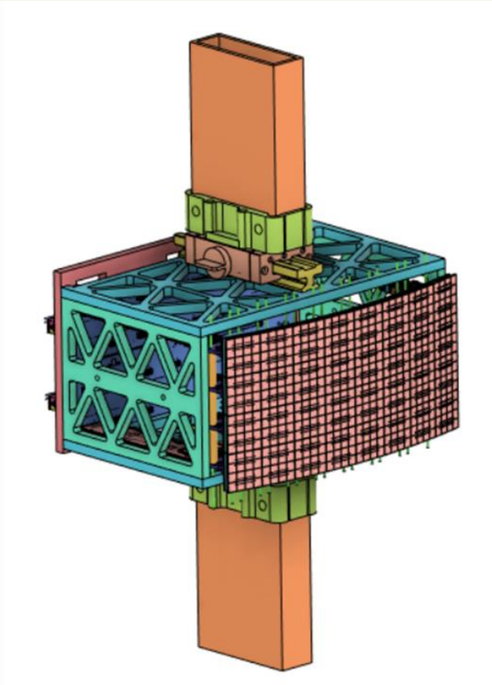
Cherenkov Camera Overview

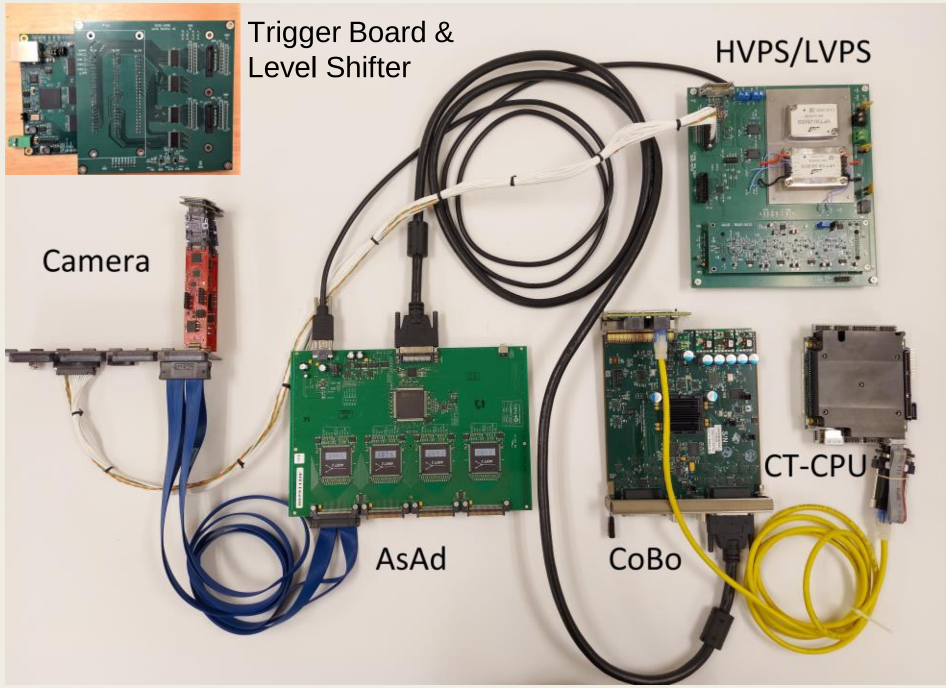
- SiPM: Hamamatsu S14521 (**6mm x 6mm**)
- Total Number of Pixels: **512** (array of 16x32)
- Overall Field of View: **13.6° x 6.8°** (H x V)
- Effective aperture area: **0.78** $\boldsymbol{m^2}$

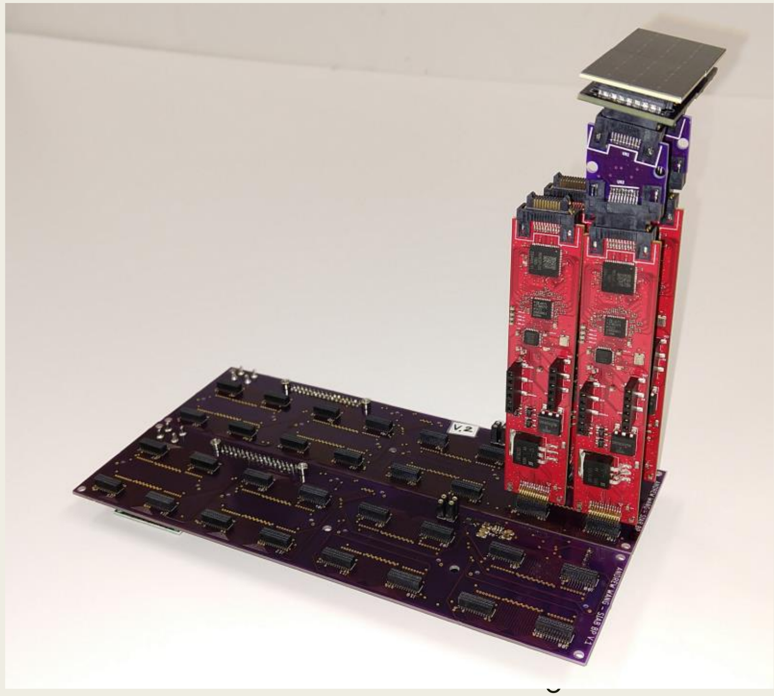
SiPM Matrix





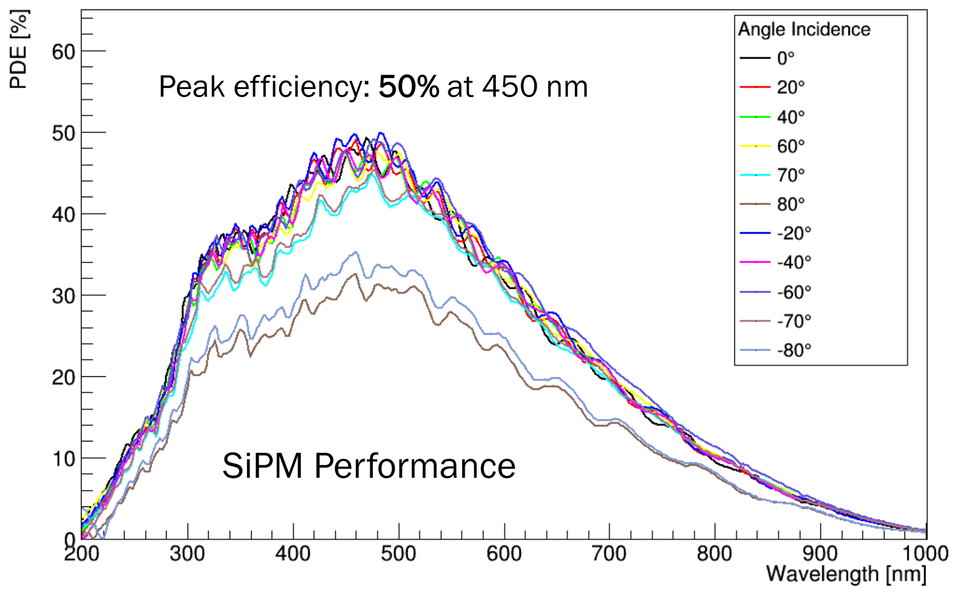




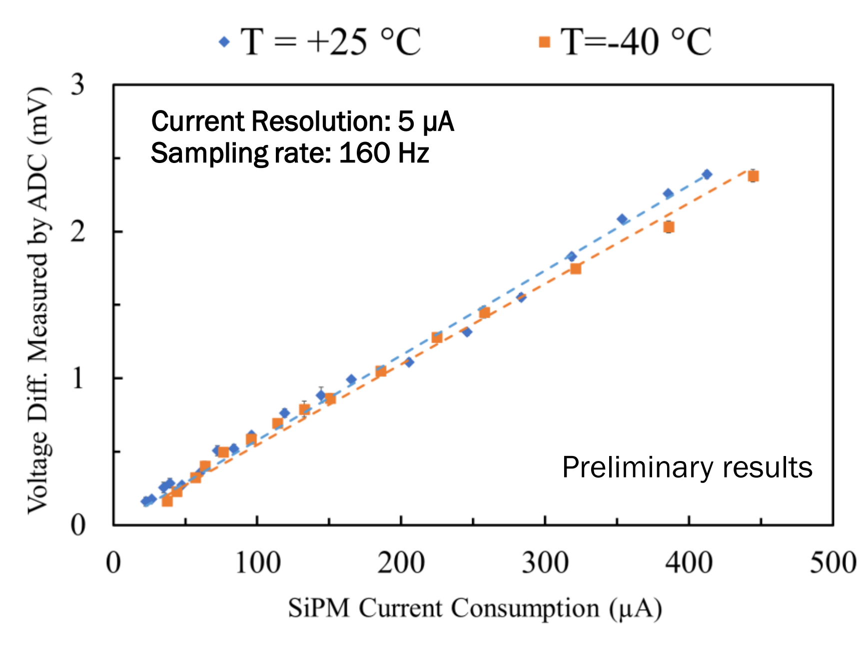


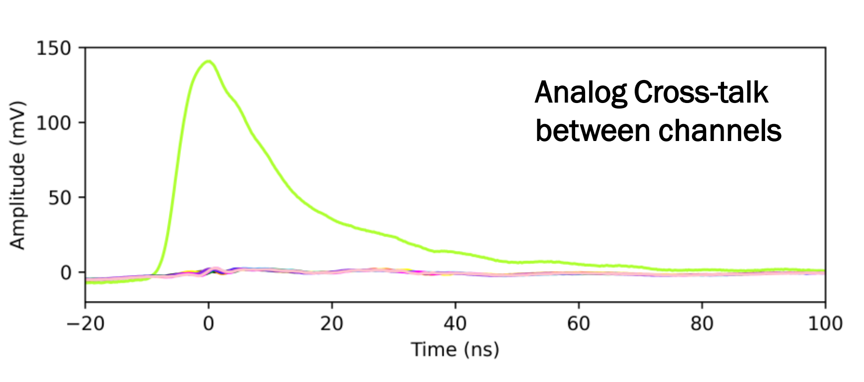
Front-end electronics Performance

- **Music Chip:** Shaping SiPM Signals, adjusting bias voltage and provide current per SiPM channel
- **24-bit ADC:** Sampling current consumption per pixel
- **Microcontroller:** slow-control of Music chip and ADC, controlling SiPM HV and power

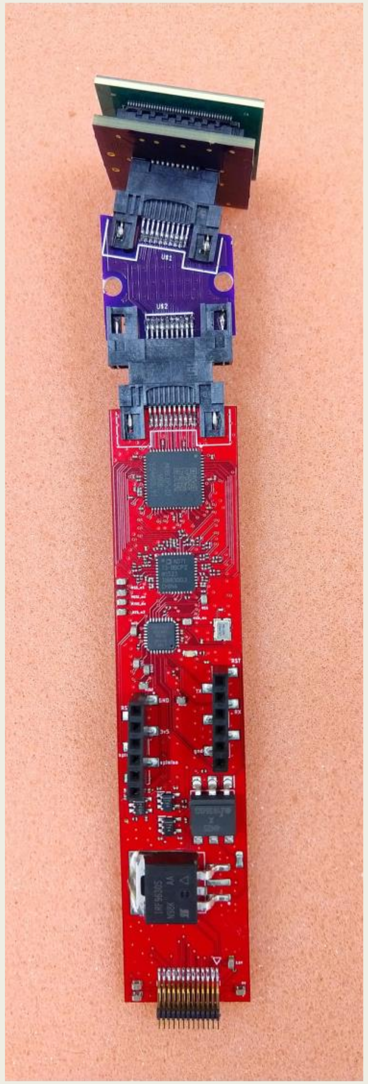


Pixels Current Monitoring

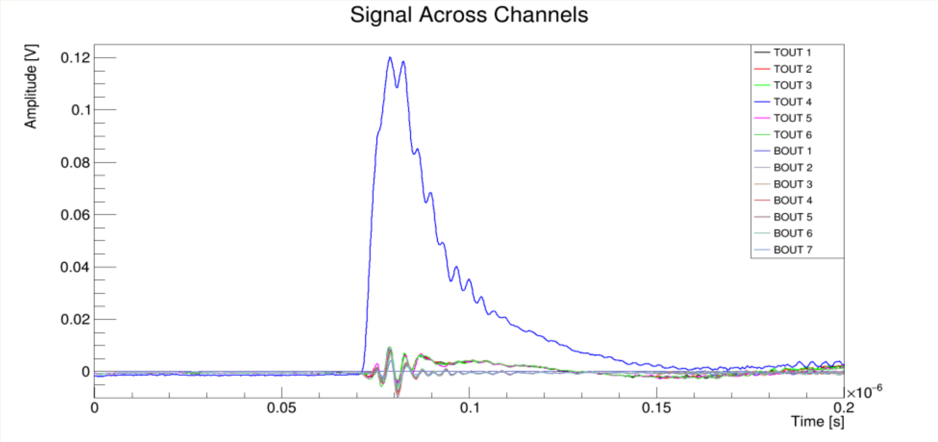




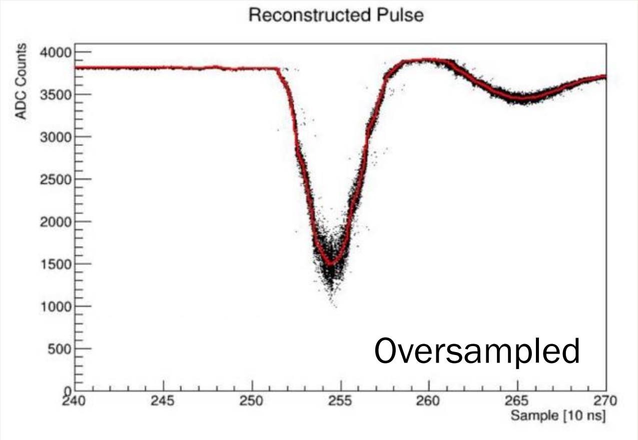
SIAB



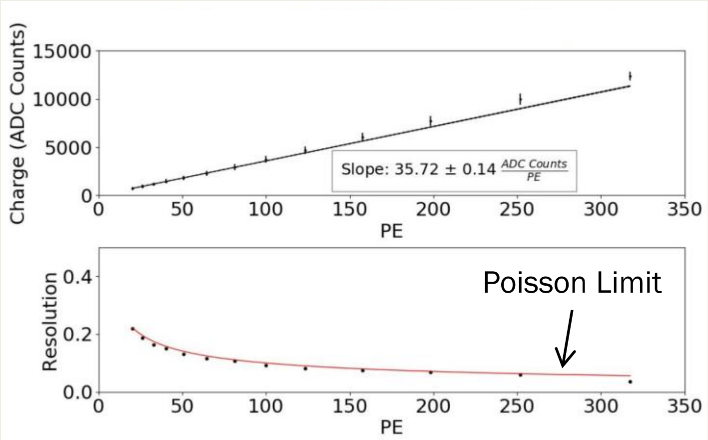
Readout Performance



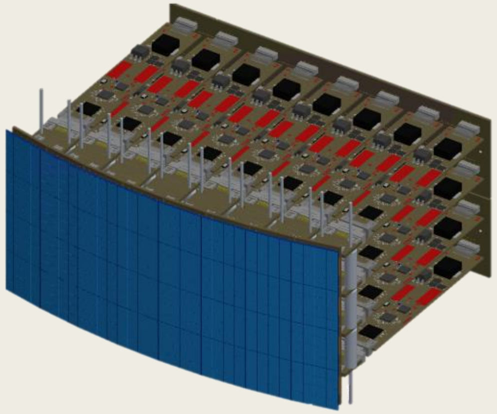
Analog Signal

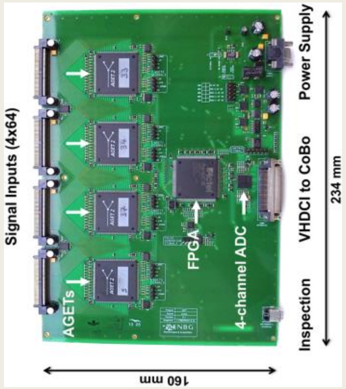


Digitized Signal



Linearity Response and Resolution





AsAd

CoBo

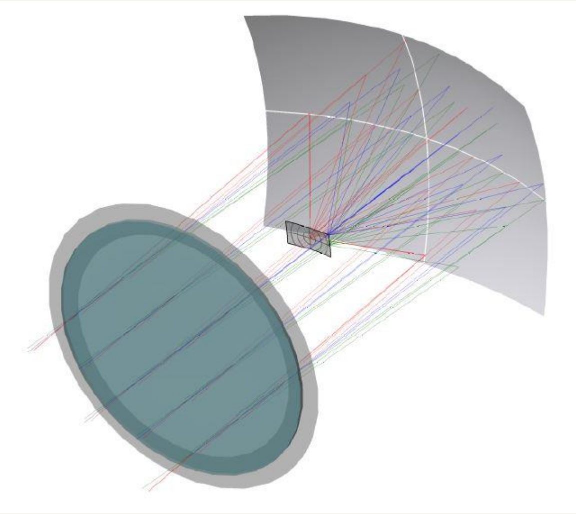
CPU

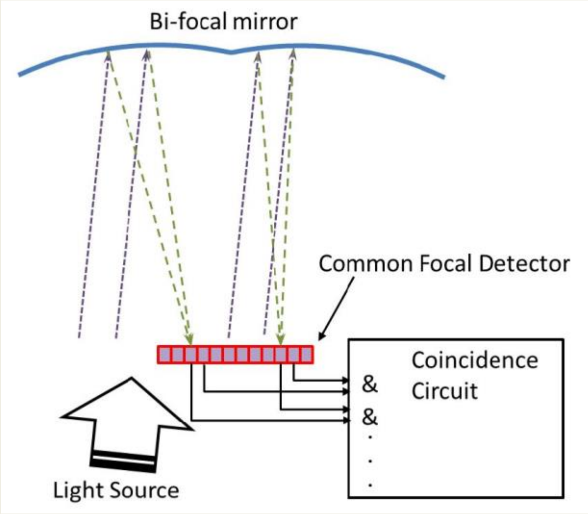
One full readout dead time: **1.44 ms**

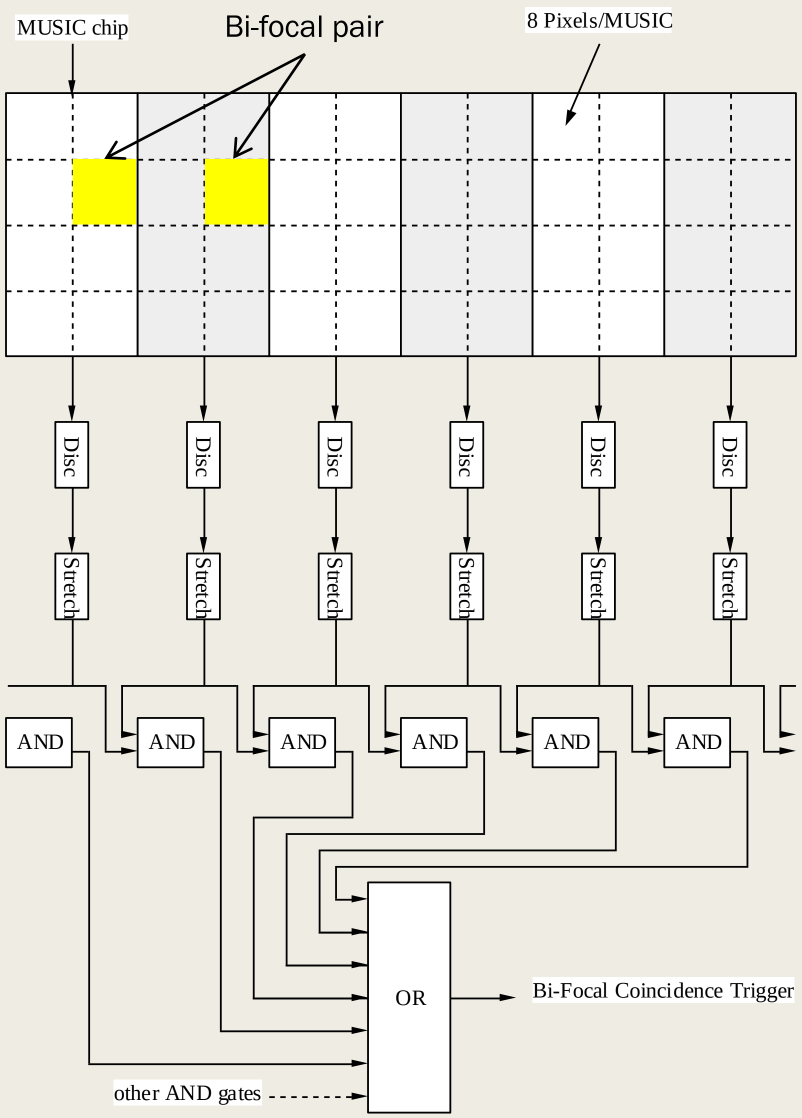
Average live time: **98%** with 10 Hz NSB accidental trigger

Trigger Logic

- 1 discriminator output per MUSIC chip
- **Bi-focal spots** are in **adjacent MUSIC chips** within each row.
- **Discriminator** signals will be spread out over **10's of ns** when they reach the Trigger Board.
- **Edge-sensitive** logic used to register signals.
- Each stretched signal will be AND'ed with its neighbors in the row.
- The results will be OR'ed together to make the bi-focal coincidence trigger.

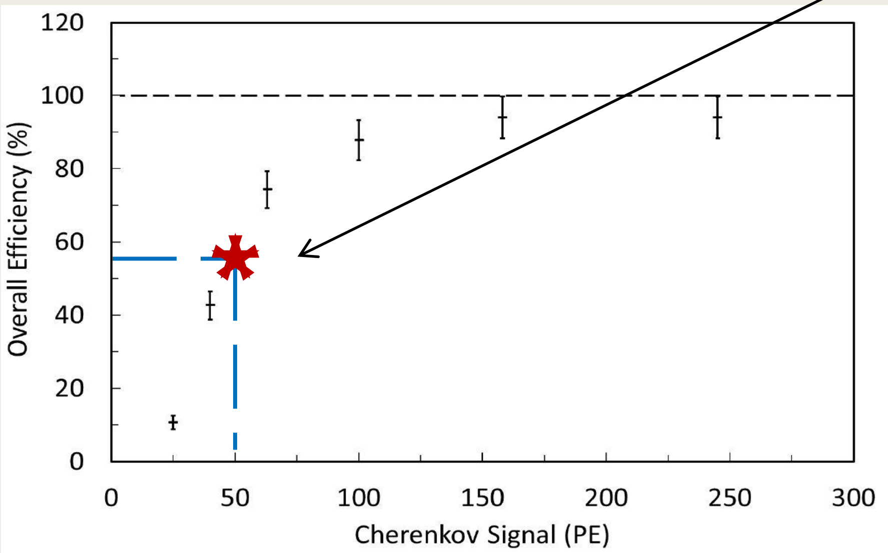


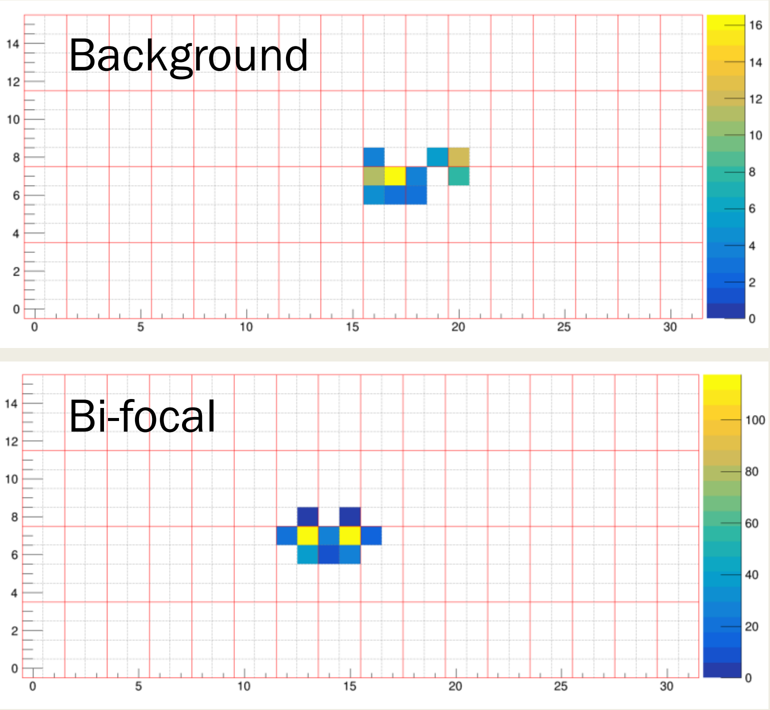


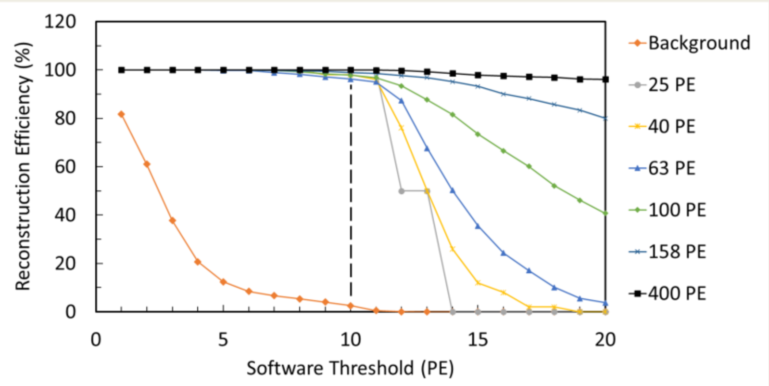


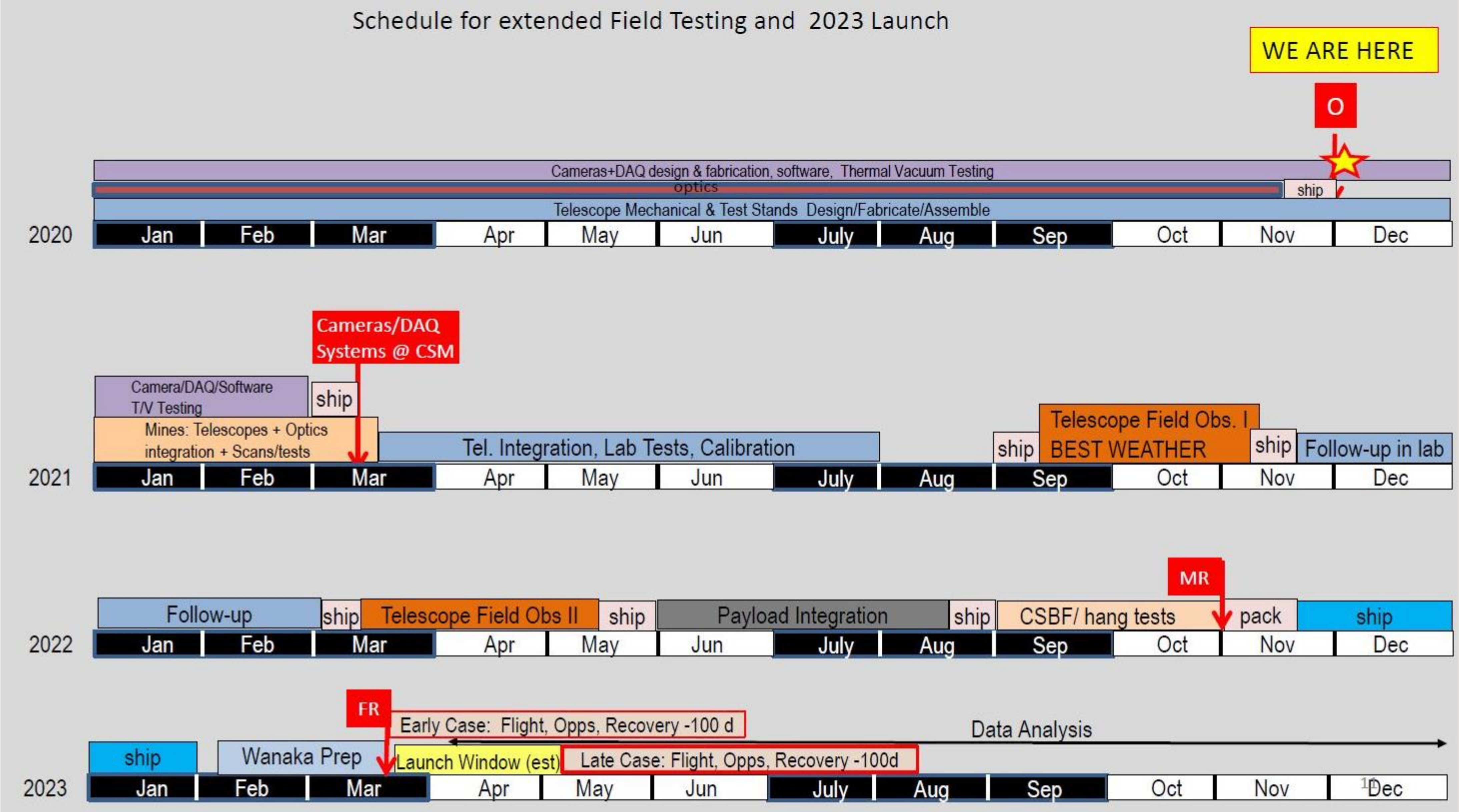
Event Reconstruction

- Cherenkov Telescope will be operating at a **trigger threshold** close to noise level, so it is vital to reject accidental triggers due to Night Sky Background (NSB).
- Cherenkov Camera response has been well studied using **CARE** simulation.
- Event reconstruction analysis has been done to **retain more than 95%** of **true bi-focal** Cherenkov events and **reject more than 97% of background** events.
- Overall efficiency = (Trigger efficiency) x (reconstruction efficiency)
- For a Cherenkov signal of **50 Photoelectron**, more than **55% overall efficiency** is achieved.








Schedule for extended Field Testing and 2023 Launch
WE ARE HERE
O
Cameras+DAQ design & fabrication, software, Thermal Vacuum Testing
optics
ship
Telescope Mechanical & Test Stands Design/Fabricate/Assemble
2020
Jan Feb Mar Apr May Jun July Aug Sep Oct Nov Dec
Cameras/DAQ Systems @ CSM
Camera/DAQ/Software T/V Testing
ship
Mines: Telescopes + Optics integration + Scans/tests
Tel. Integration, Lab Tests, Calibration
ship
Telescope Field Obs. I BEST WEATHER
ship
Follow-up in lab
2021
Jan Feb Mar Apr May Jun July Aug Sep Oct Nov Dec
MR
Follow-up
ship
Telescope Field Obs II
ship
Payload Integration
ship
CSBF/ hang tests
pack
ship
2022
Jan Feb Mar Apr May Jun July Aug Sep Oct Nov Dec
FR
Early Case: Flight, Opps, Recovery -100 d
Data Analysis
ship
Wanaka Prep
Launch Window (est)
Late Case: Flight, Opps, Recovery -100d
2023
Jan Feb Mar Apr May Jun July Aug Sep Oct Nov Dec

Summary

- The **Cherenkov telescope** onboard the Extreme-Universe Space Observatory Super-Pressure Balloon 2 (**EUSO-SPB2**) lays the groundwork for the future detection of ultrahigh-energy neutrinos (E > 10^8 GeV) from high-altitudes and space.
- The **ambient photon fields** will be investigated for both below and above the limb observations.
- **Earth-skimming technique** will be used to search for the air showers caused by **PeV tau neutrinos** and **cosmic rays above the limb.**
- Cherenkov Camera electronics development is in final stages and will be **integrated** into telescope in **early 2021**.
- Field tests will be performed in late 2021 and 2022 with a planned **launch** in **2023 from Wanaka, New Zealand.**

Thanks for your attention.