International Cosmic Ray Conference 2021

Overview of Cherenkov Telescope on-board EUSO-SPB2 for the Detection of Very-High-Energy Neutrinos

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On behalf of JEM-EUSO Collaborations

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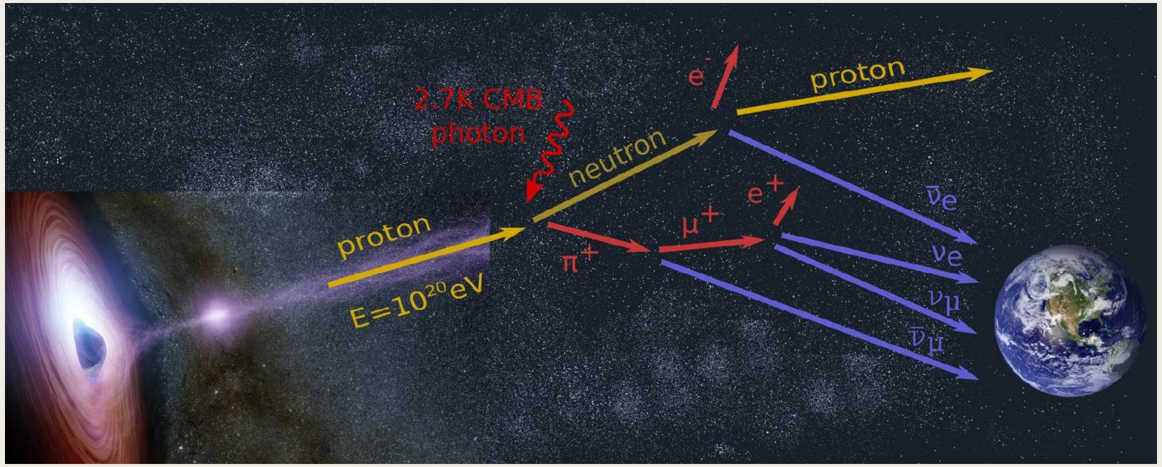
Scientific Motivation

VHE neutrinos (> 10 PeV) 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?*

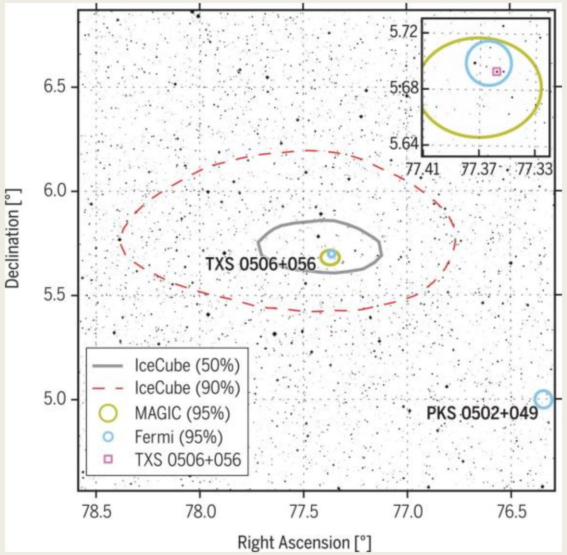
The composition of UHECR:

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

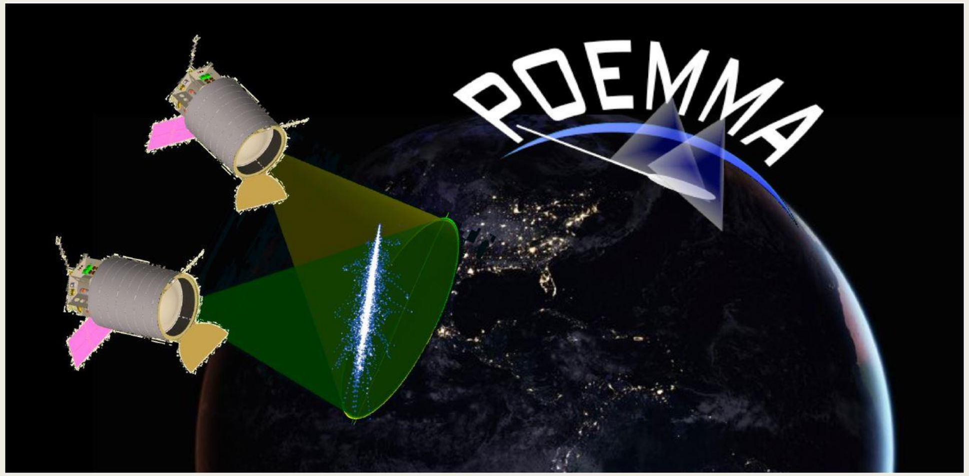
Probe Of Extreme Multi-Messenger Astrophysics (POEMMA)

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

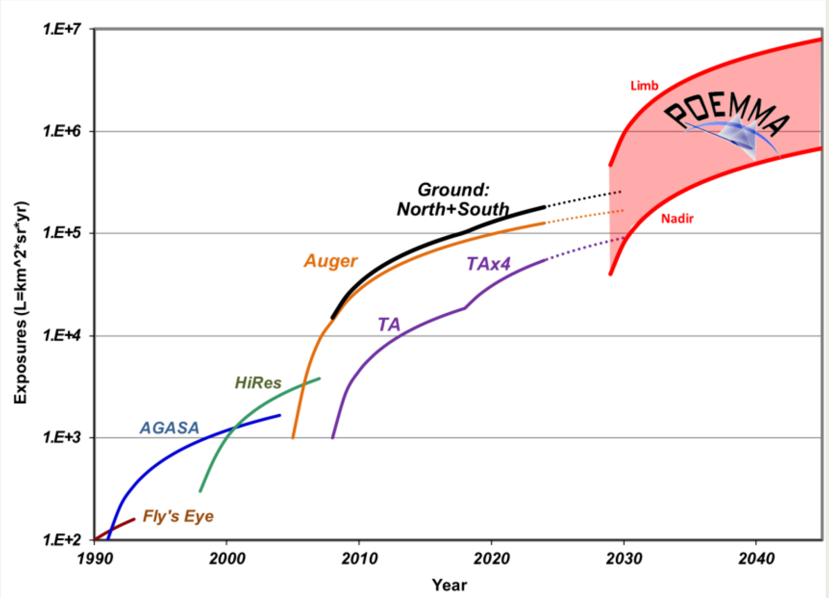
- **Science with POEMMA:**
  - Discover the nature and origin of **UHECR**
  - Discover **neutrino** emission from astrophysical transients
  - Probe particle interactions at extreme energies
  - Observe Transient Luminous Events (**TLEs**) and **Meteors**
  - Search for **Exotic** particles

- 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.

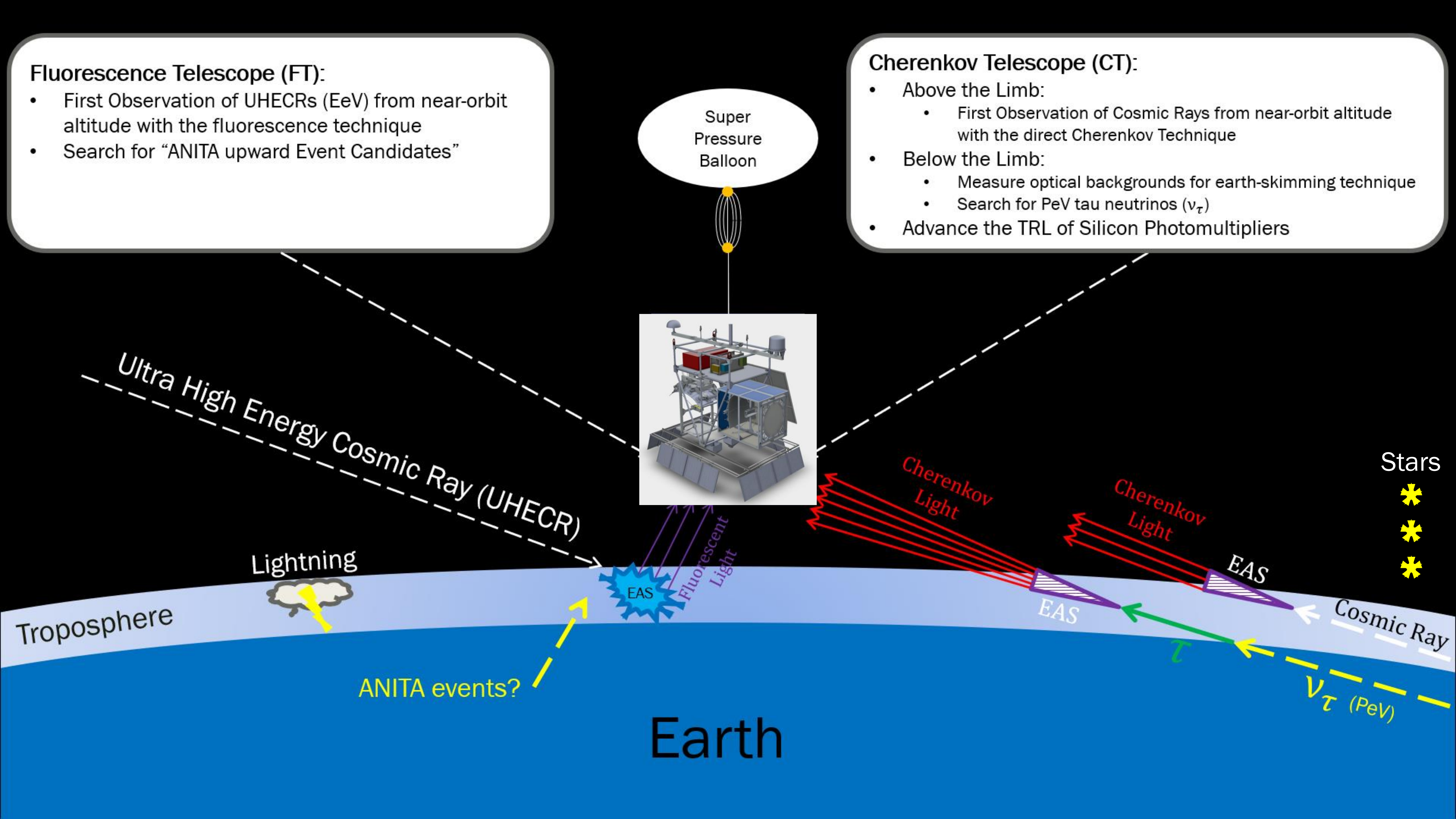
- **EUSO-SPB2 will be a precursor for POEMMA.**



A. Olinto et al. (2021)



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
Fluorescent Light
Lightning
EAS
EAS
EAS
Cosmic Ray
Troposphere
τ
ν_τ (PeV)
ANITA events?
Earth

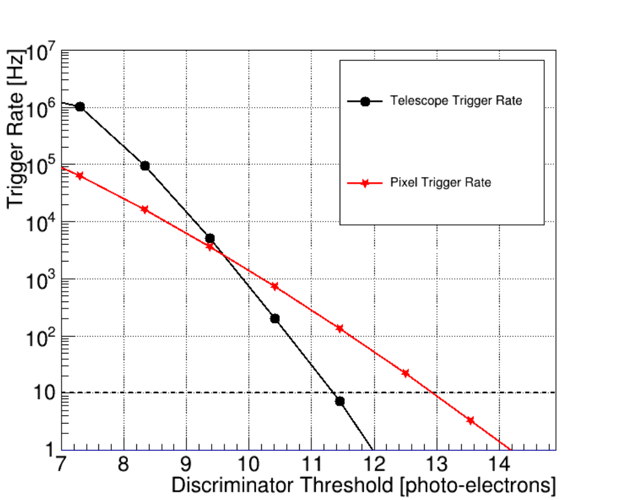
Studying Optical Background

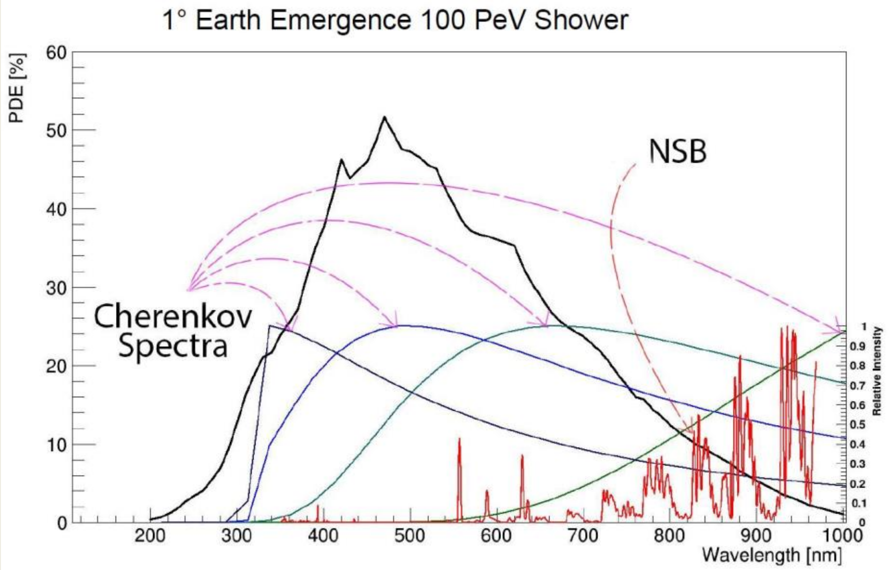
- We will be the **first** to operate a Cherenkov telescope from a **sub-orbital platform.**

❑ 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.





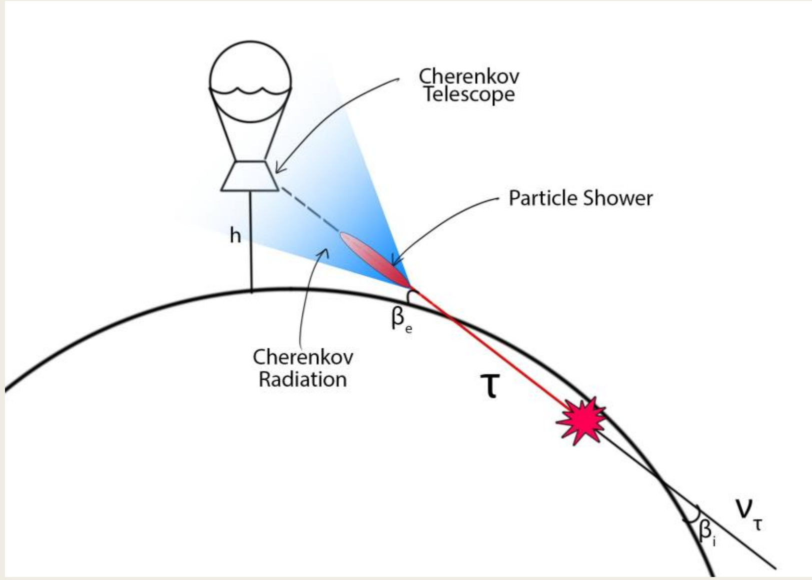
NSB spectra from: Benn and Ellison (2008)

Above and below the limb

- **Cherenkov telescope can observe up to 10° above and below the limb.**

❑ Below the limb:

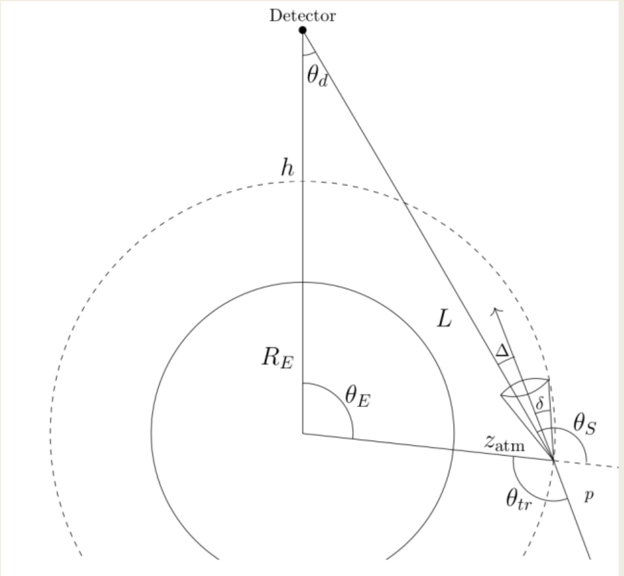
- Tau-neutrinos entering the earth can produce a **tau-lepton.**
- Tau can **emerge from ground** and generate an air shower.
- A significant amount of particle energy is converted into Cherenkov optical emission radiated in a **narrow cone** around **shower axis.**
- A Cherenkov telescope can collect a fraction of the light and **image the air shower.** The offline analysis reconstructs the **arrival direction** and the **energy of the neutrino** based on the recorded image.



❑ Above the Limb:

- Cosmic rays can deposit much of their primary energy into **Extensive Air Showers** (EAS).
- Cherenkov telescope **performance** could be well **evaluated** by measuring these events.
- Estimated measured rate: **100 events per hour**

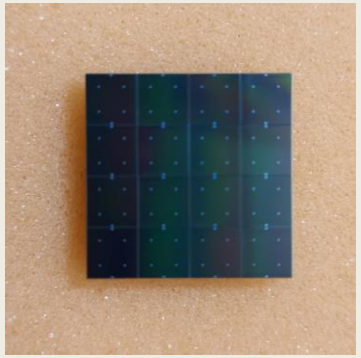
Cummings et al. (2021)

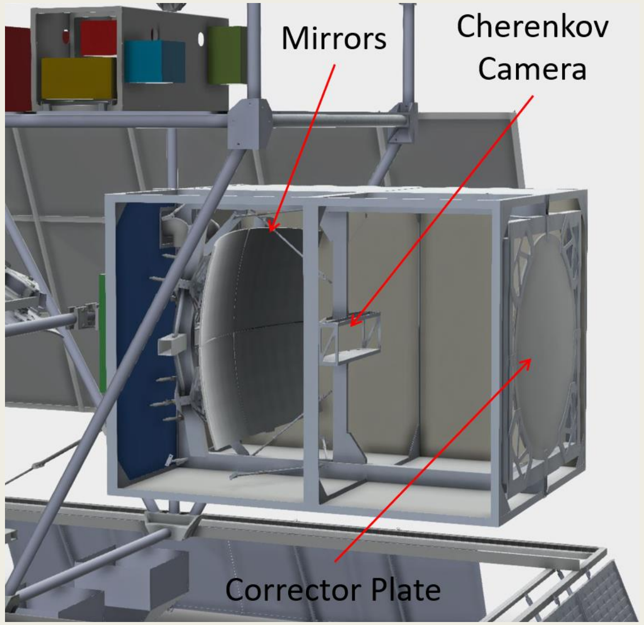


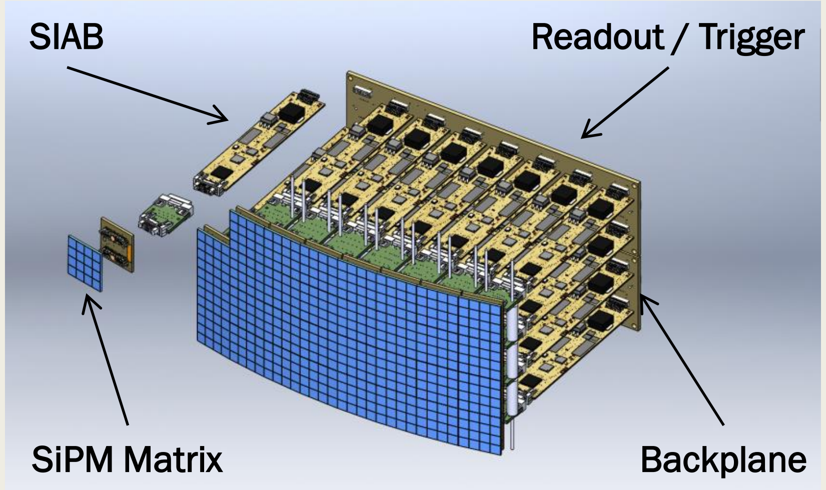
Cherenkov Camera Overview

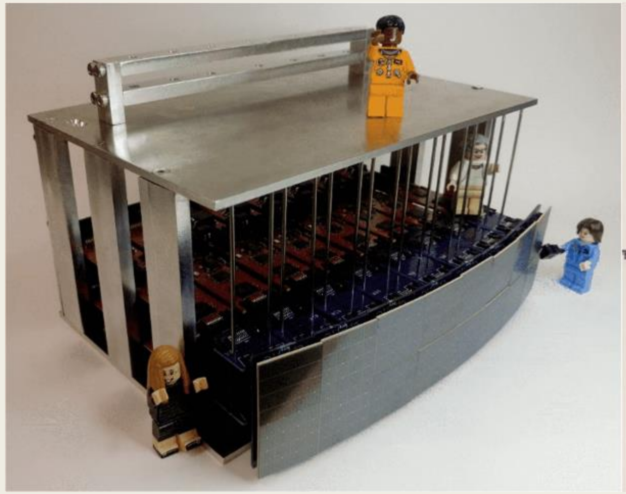
- SiPM: Hamamatsu S14521 (**6mm x 6mm**)
- Total Number of Pixels: **512** (array of 16x32)
- Overall Field of View: **12.8° x 6.4°** (H x V)
- Effective aperture area: **0.785** $\boldsymbol{m^2}$
- Readout: **100 MS/s** digitization

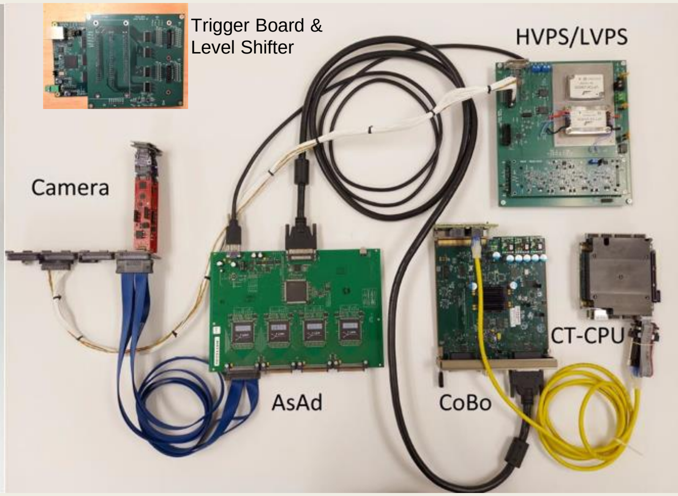
SiPM Matrix



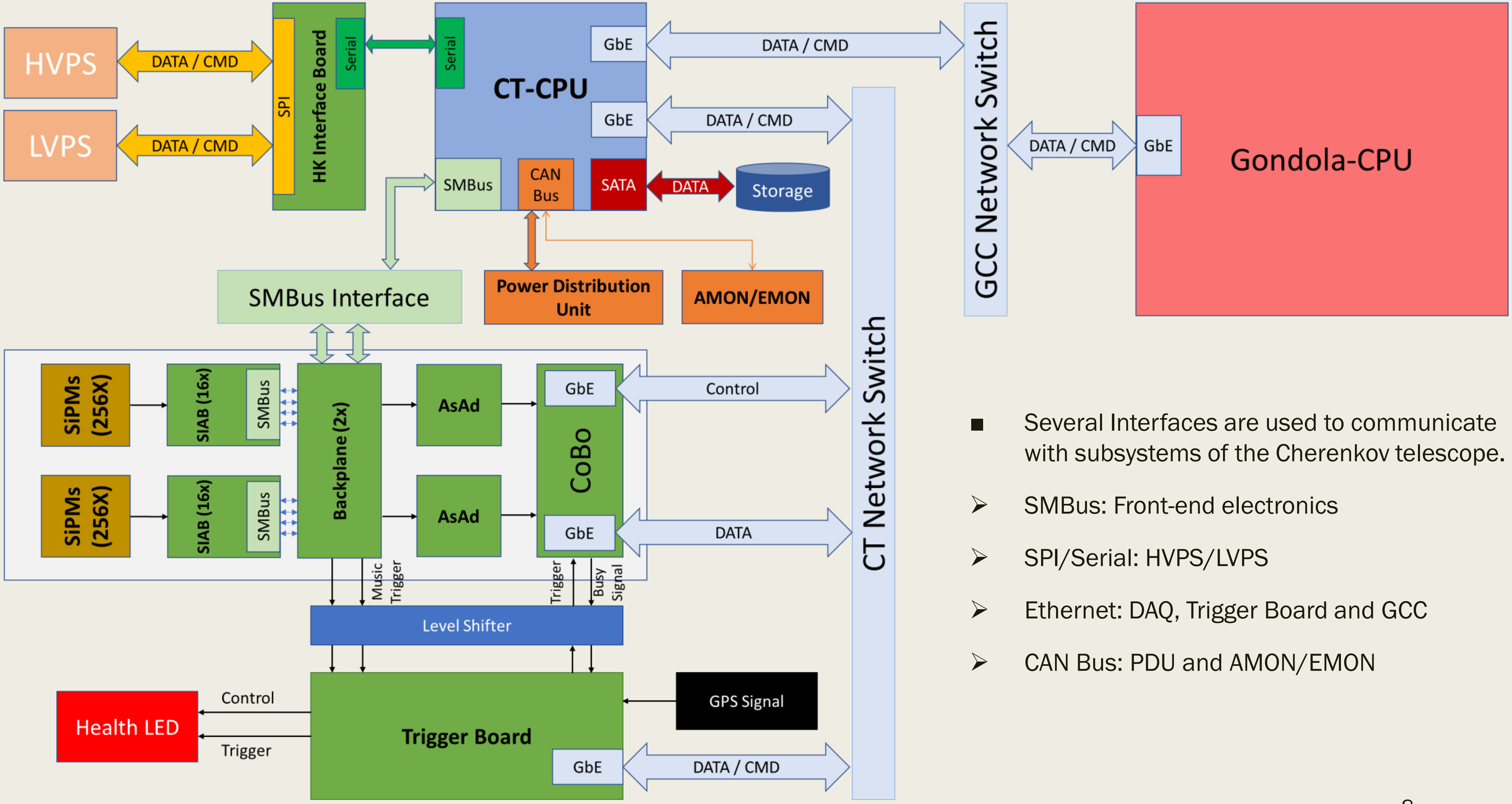








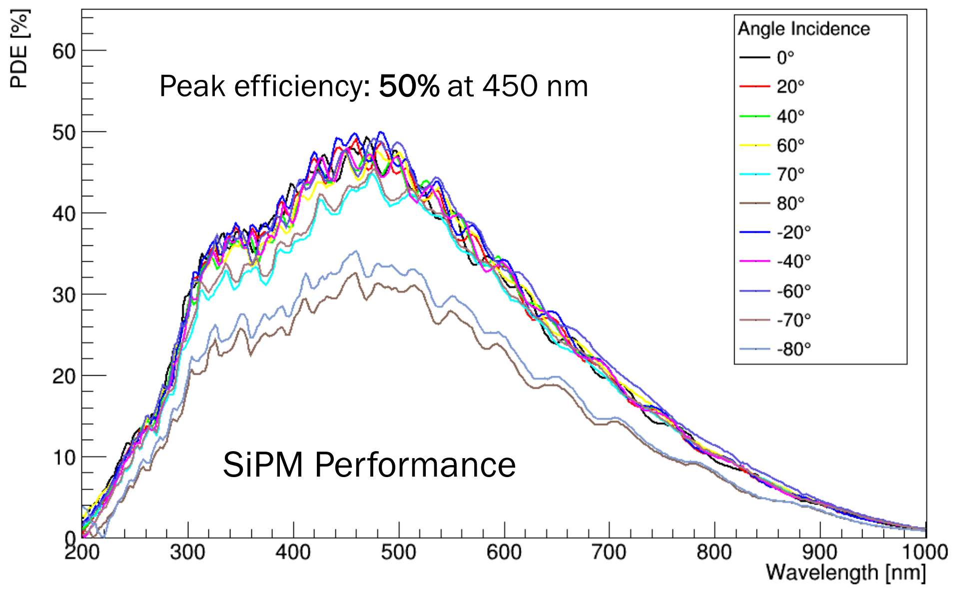
Network Architecture



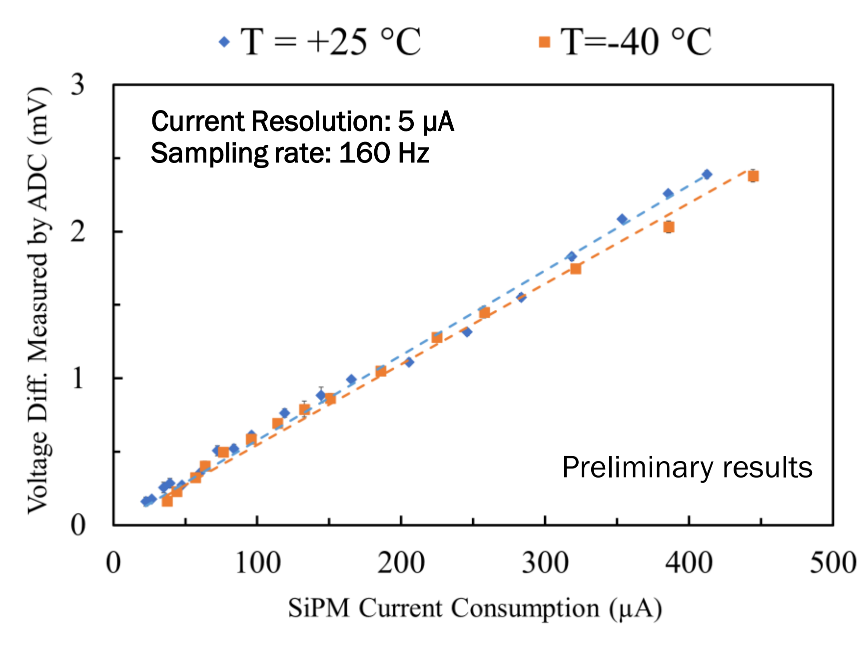
- Several Interfaces are used to communicate with subsystems of the Cherenkov telescope.
  - SMBus: Front-end electronics
  - SPI/Serial: HVPS/LVPS
  - Ethernet: DAQ, Trigger Board and GCC
  - CAN Bus: PDU and AMON/EMON

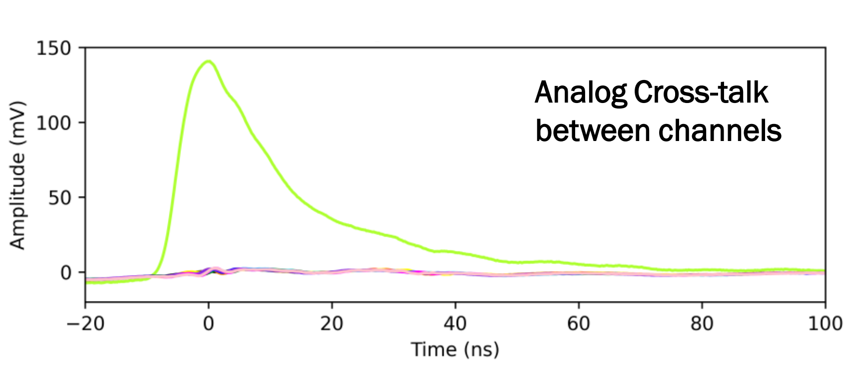
Front-end electronics Performance

- **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

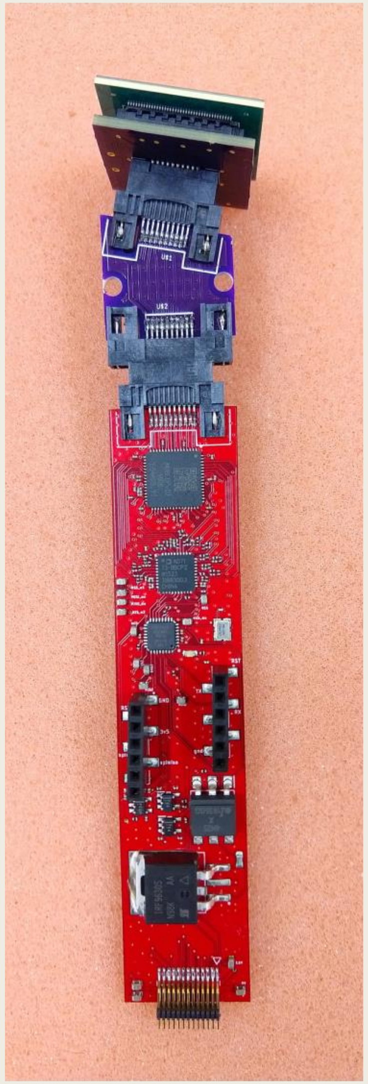


Pixels Current Monitoring



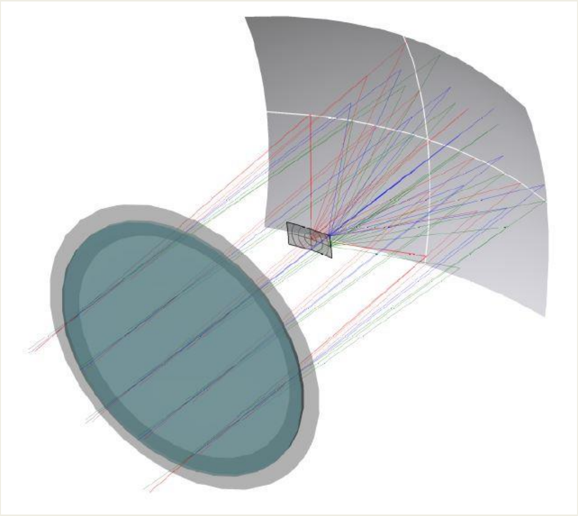


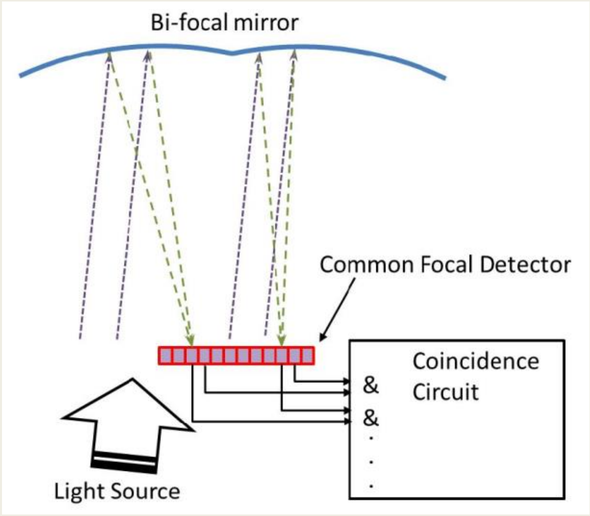
SIAB

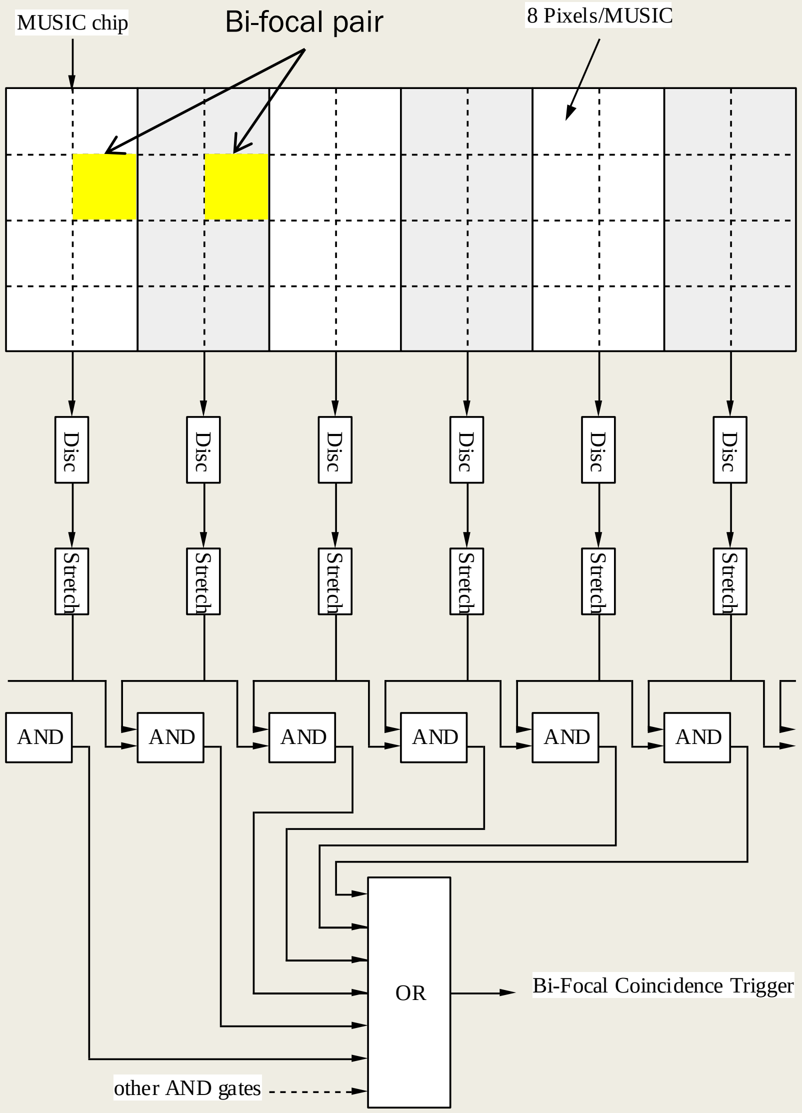


Optics and Trigger Logic

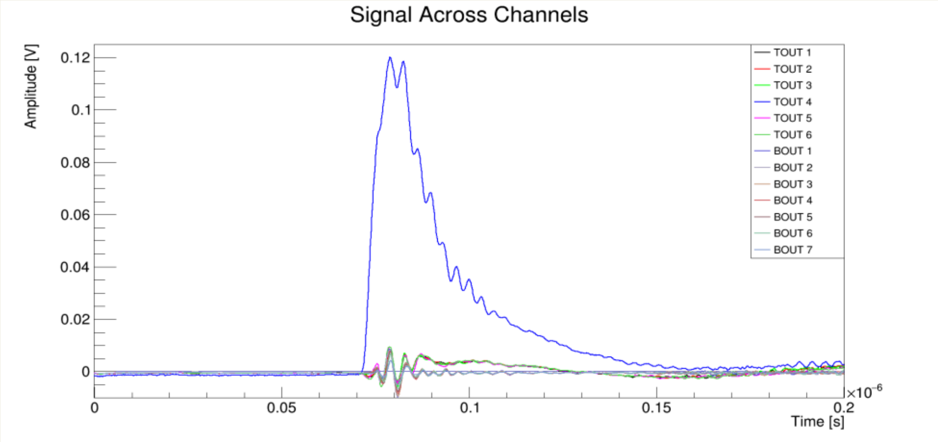
- 1 discriminator output per MUSIC chip
- **Bi-focal spots** are in **adjacent MUSIC chips** within each row.
- **Discriminator** signals will be spread out over **10's of ns** when they reach the Trigger Board.
- **Edge-sensitive** logic used to register signals.
- Each stretched signal will be AND'ed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



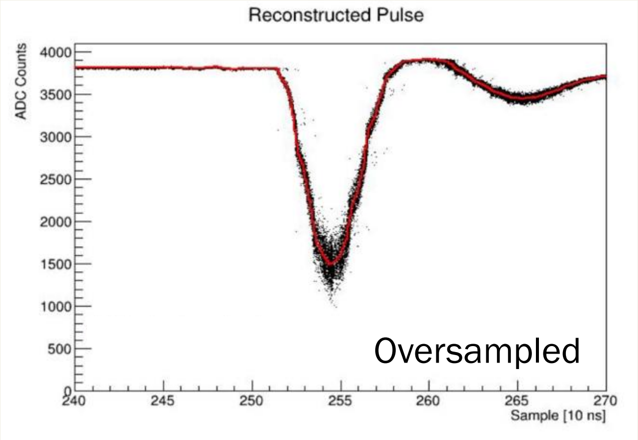




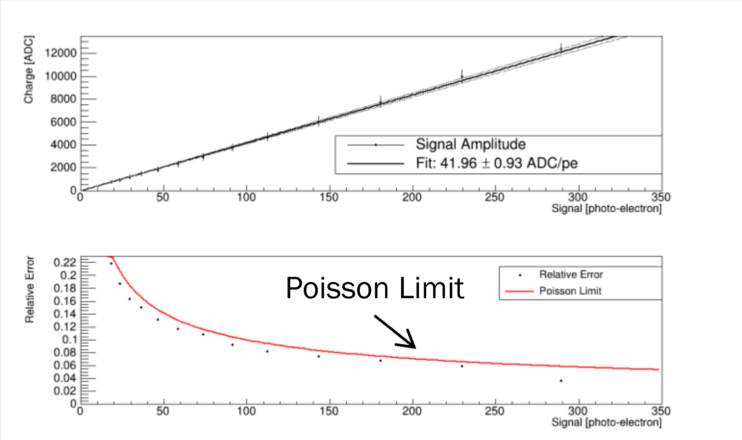
Readout Performance



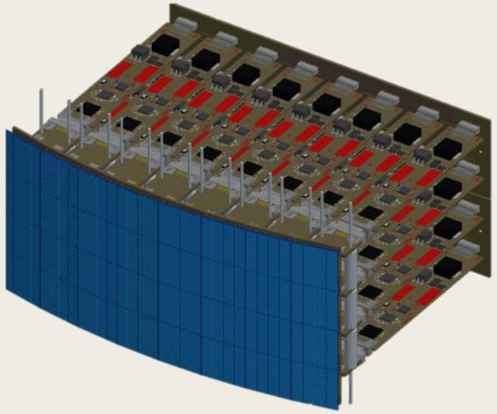
Analog Signal

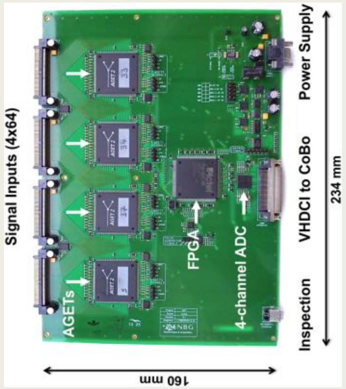


Digitized Signal



Linearity Response and Resolution





AsAd

CoBo

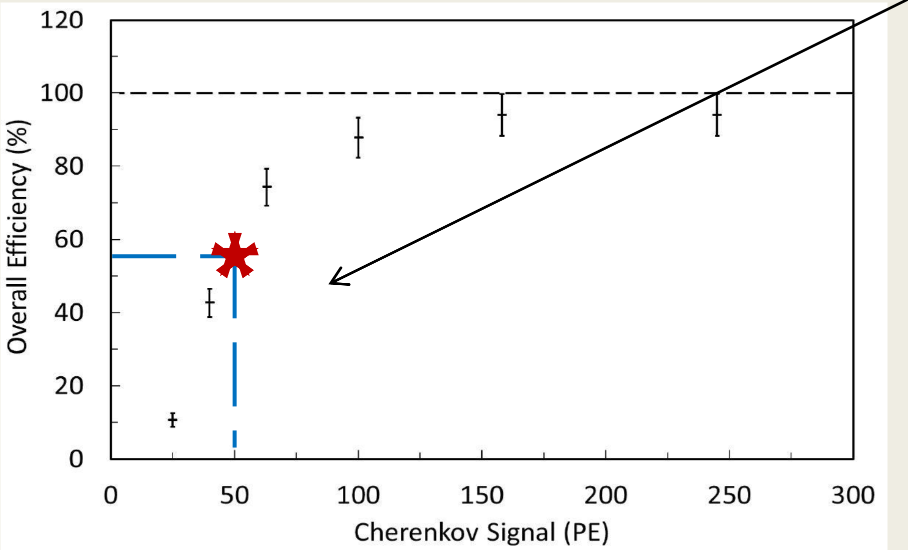
CPU

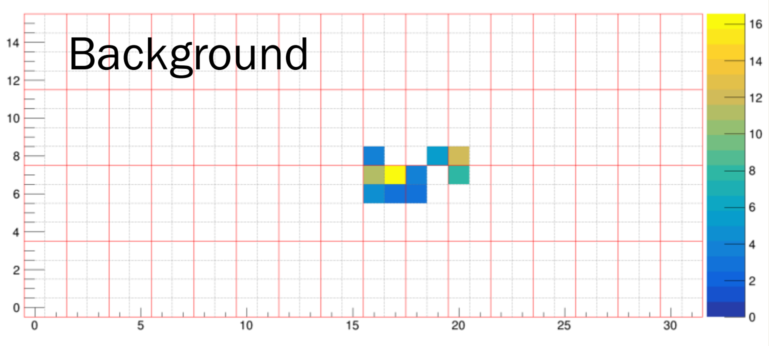
One full readout dead time: **1.44 ms**

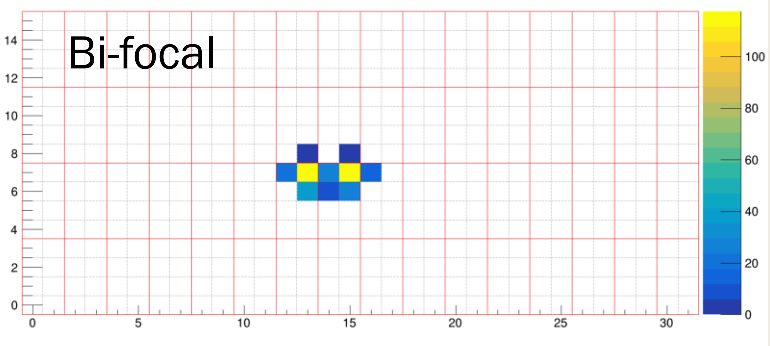
Average live time: **98%** with 10 Hz NSB accidental trigger

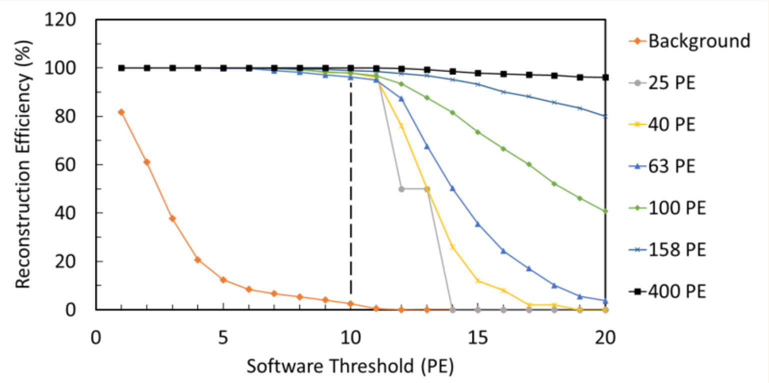
Event Reconstruction

- 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.









Summary

- The **Cherenkov telescope** onboard **EUSO-SPB2** lays the groundwork for the future detection of VHE neutrinos (E > 10^7 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.**

- We will be able to detect EAS from **Cosmic rays above the limb** at a rate of **100 events per hour.**

- Cherenkov Camera electronics development is in final stages and will be **integrated** into telescope in **late 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.