Search for Earth Skimming Ultra High Energy Neutrinos from Space

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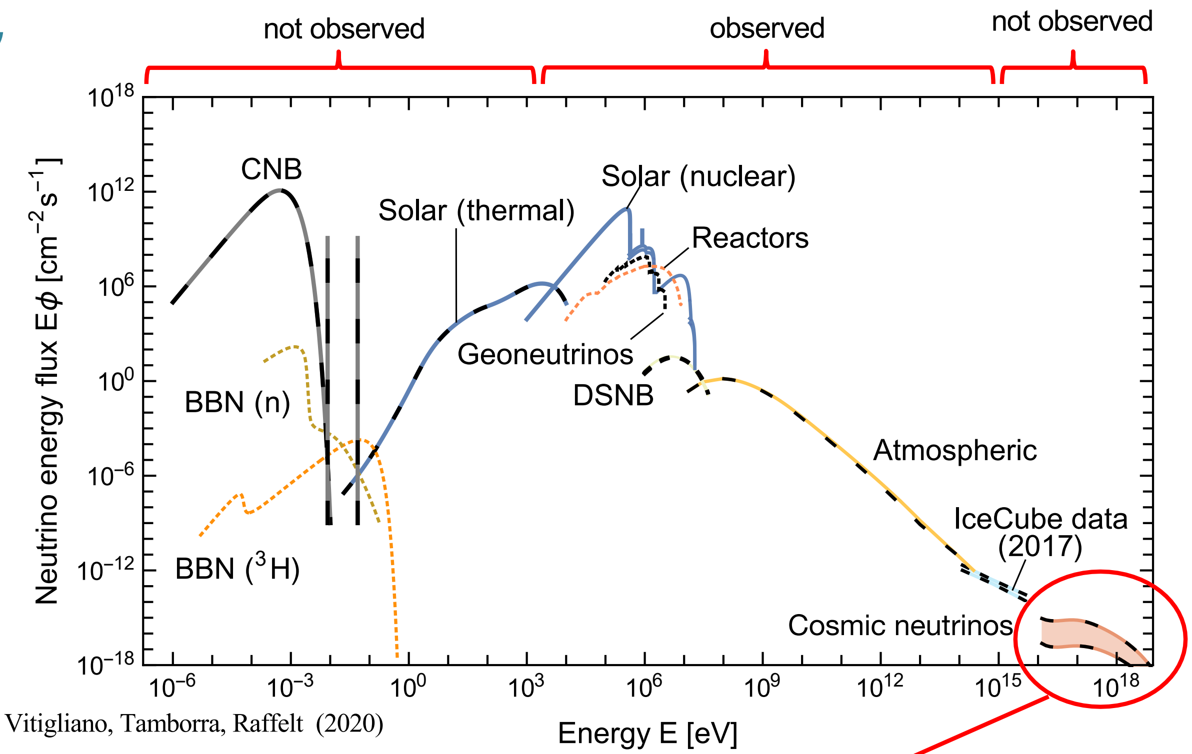
The highest energies ν

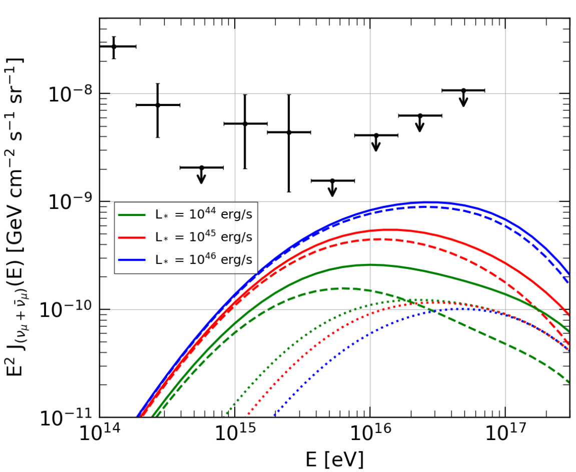
Neutrinos at energies larger then 1 PeV

- ✓ Hidden sources of CR "Berezinsky sources" (super-massive BH in a cocoon, NGC1068).
- ✓ Cosmogenic neutrinos and sources of UHECR
- ✓ New Physics BSM and Super Heavy Dark Matter

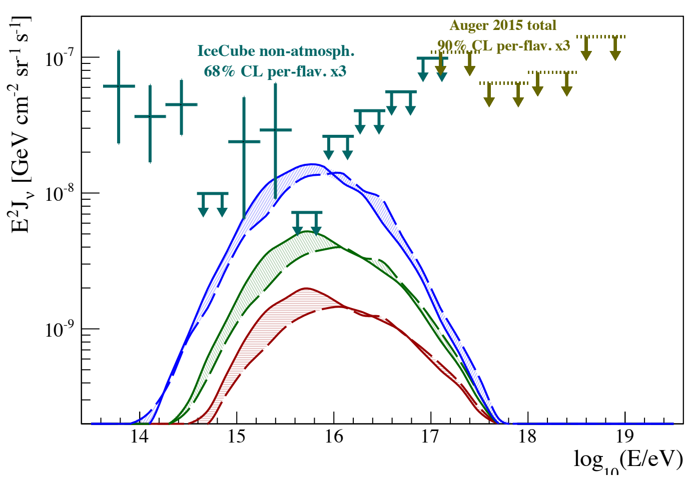


Vitigliano, Tamborra, Raffelt (2020)

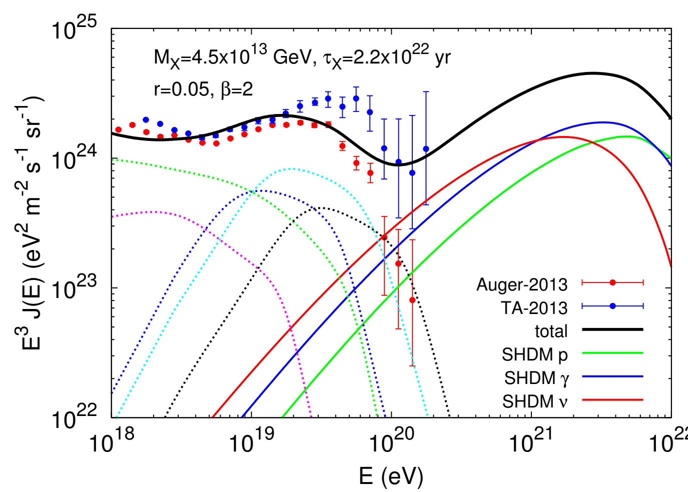
The High Energy ν "Flux Challenge"



Cermenati, RA, Blasi, Evoli (2024)

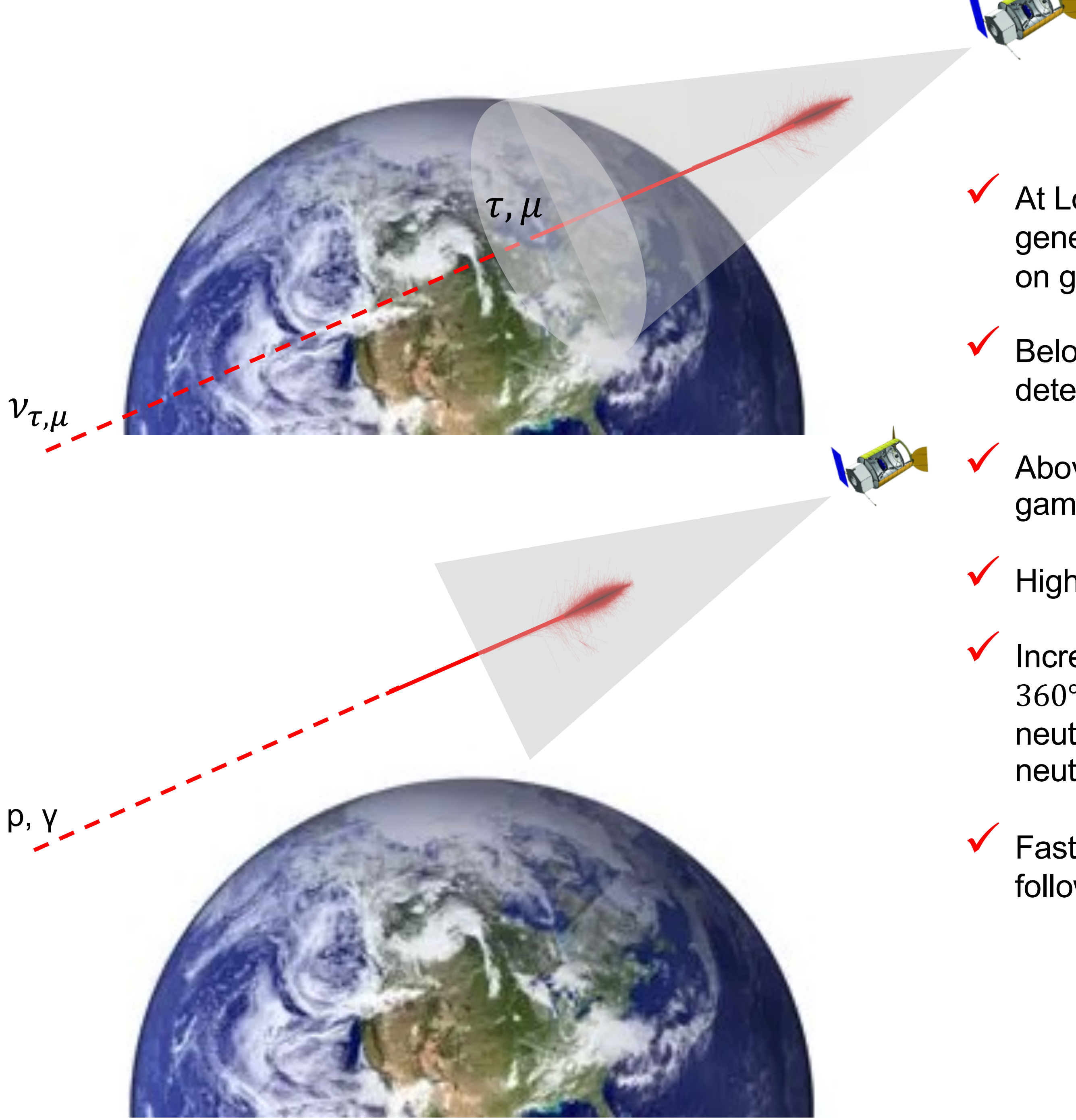


RA, Boncioli, di Matteo, Grillo, Petrera, Salamida (2015)



RA, Matarrese, Olinto (2015)

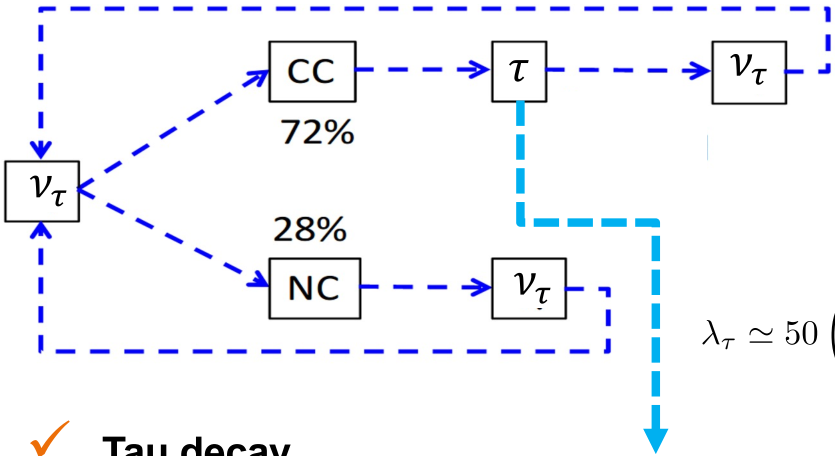
Space Cherenkov Telescopes



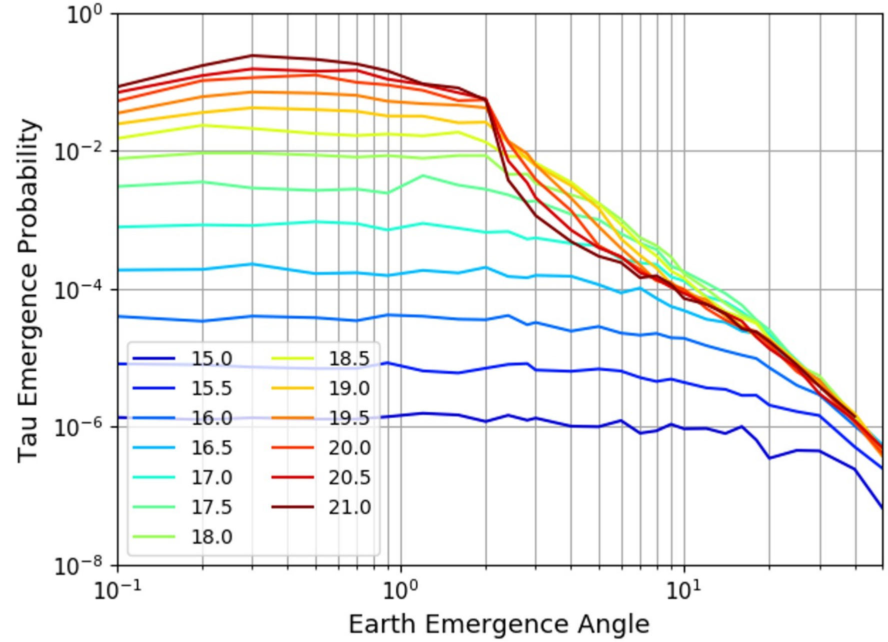
- At Low Earth Orbit (LEO, ~ 500 km) a generic FoV of $15° \times 7°$ corresponds to an on ground scanned area of 10^5 km^2.
- Belove the limb observations for neutrino detection.
- Above the limb observations for CR and gamma ray detection.
- High angular resolution (< 0.1 deg).
- Increasing the azimuth field of view up to $360°$ improved sensitivity to the diffuse neutrino emission and to detect transient neutrino sources.
- Fast re-pointing of specific sources for follow-up of GW events and ν, γ events.

Neutrino interactions in the Earth

✓ At energies around 1 PeV the Earth becomes opaque to neutrinos

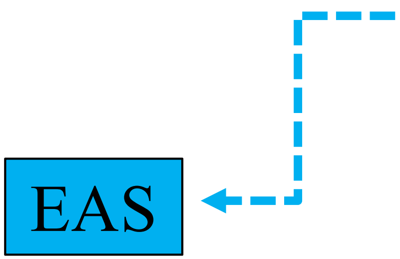


$$\lambda_\tau \simeq 50 \left(\frac{E_\tau}{1PeV}\right) \; m$$



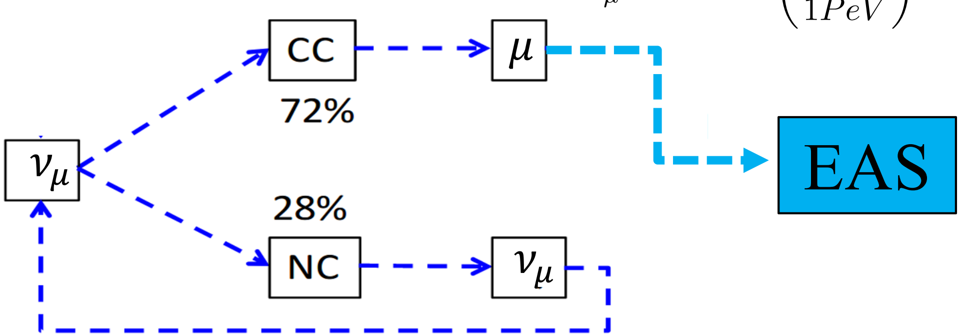
✓ **Tau decay**

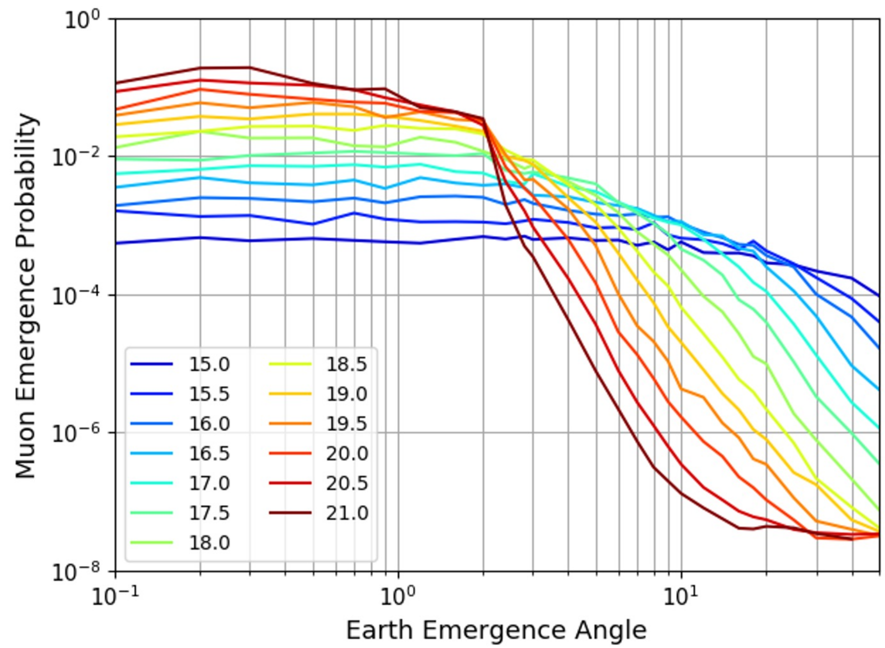
- $\tau^\mp \to \text{hadrons} + \nu_\tau(\bar{\nu}_\tau) \approx 64.79\%$
- $\tau^\mp \to e^\mp + \bar{\nu}_e(\nu_e) + \nu_\tau(\bar{\nu}_\tau) \approx 17.82\%$
- $\tau^\mp \to \mu^\mp + \bar{\nu}_\mu(\nu_\mu) + \nu_\tau(\bar{\nu}_\tau) \approx 17.39\%$



✓ **Muon bremsstrahlung**

$$\lambda_\mu \simeq 6 \times 10^9 \left(\frac{E_\mu}{1PeV}\right) \; m$$

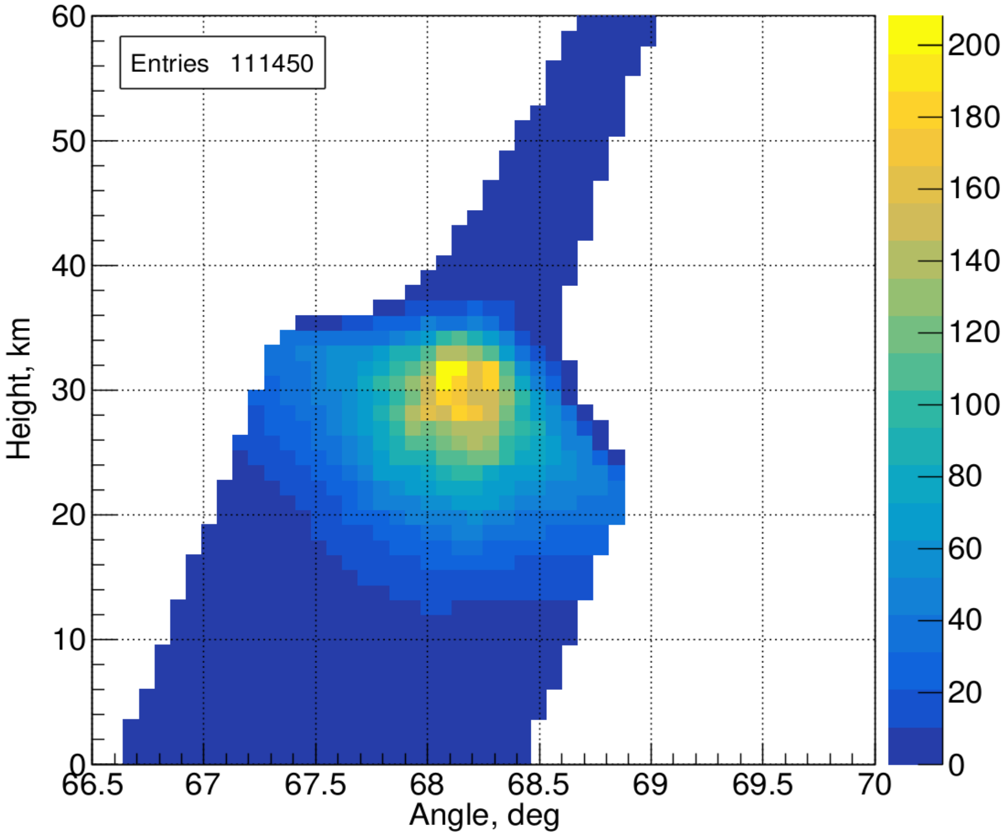




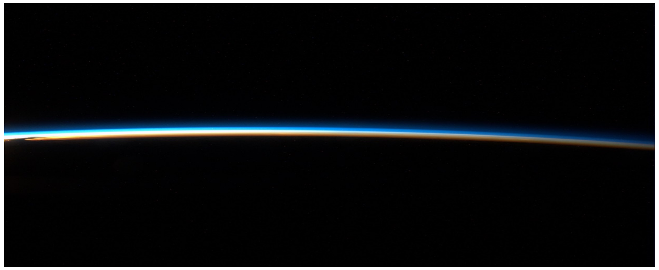
Cummings, RA, Krizmanik (2020)

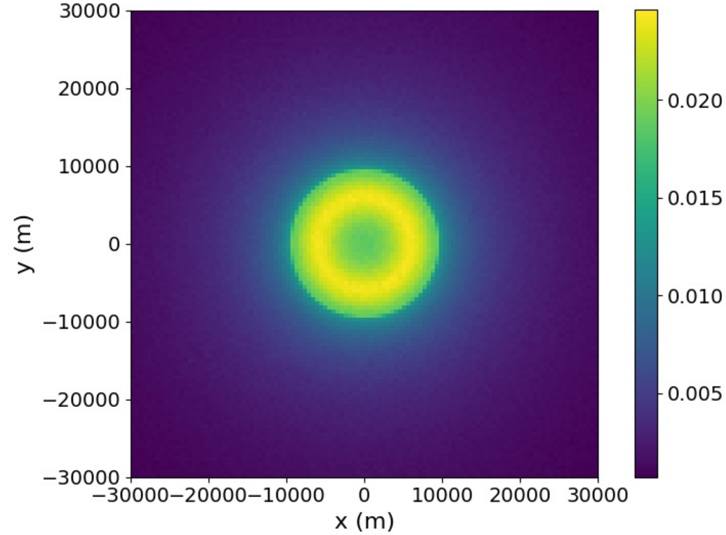
The EAS Cherenkov signal

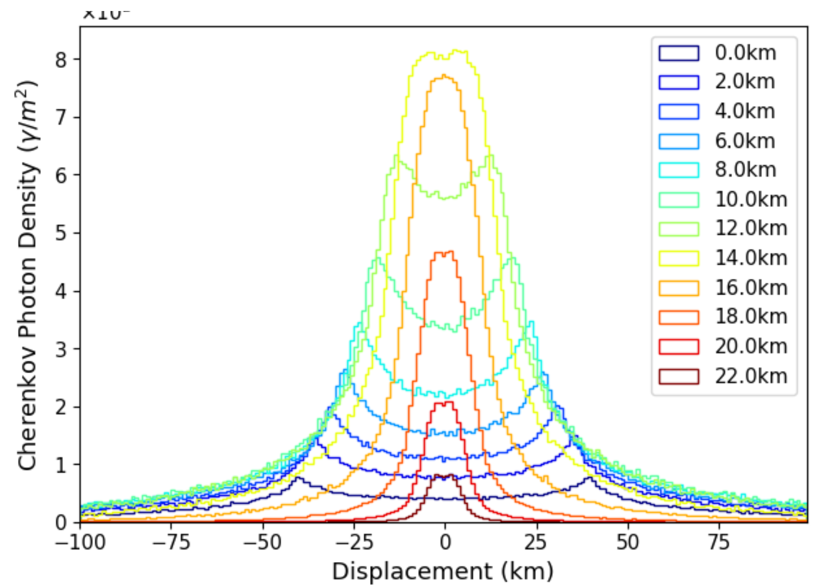
- ✓ Looking at the atmosphere limb (just below) for neutrinos detection and (just above) for CR, γ detection a tiny layer of the atmosphere shines in Cherenkov.
- ✓ Both orbital and high altitudes are suitable to detect the EAS Cherenkov emission.
- ✓ At orbits of ~ 500 km most contributing layers of the atmosphere around altitudes 20 – 40 km.



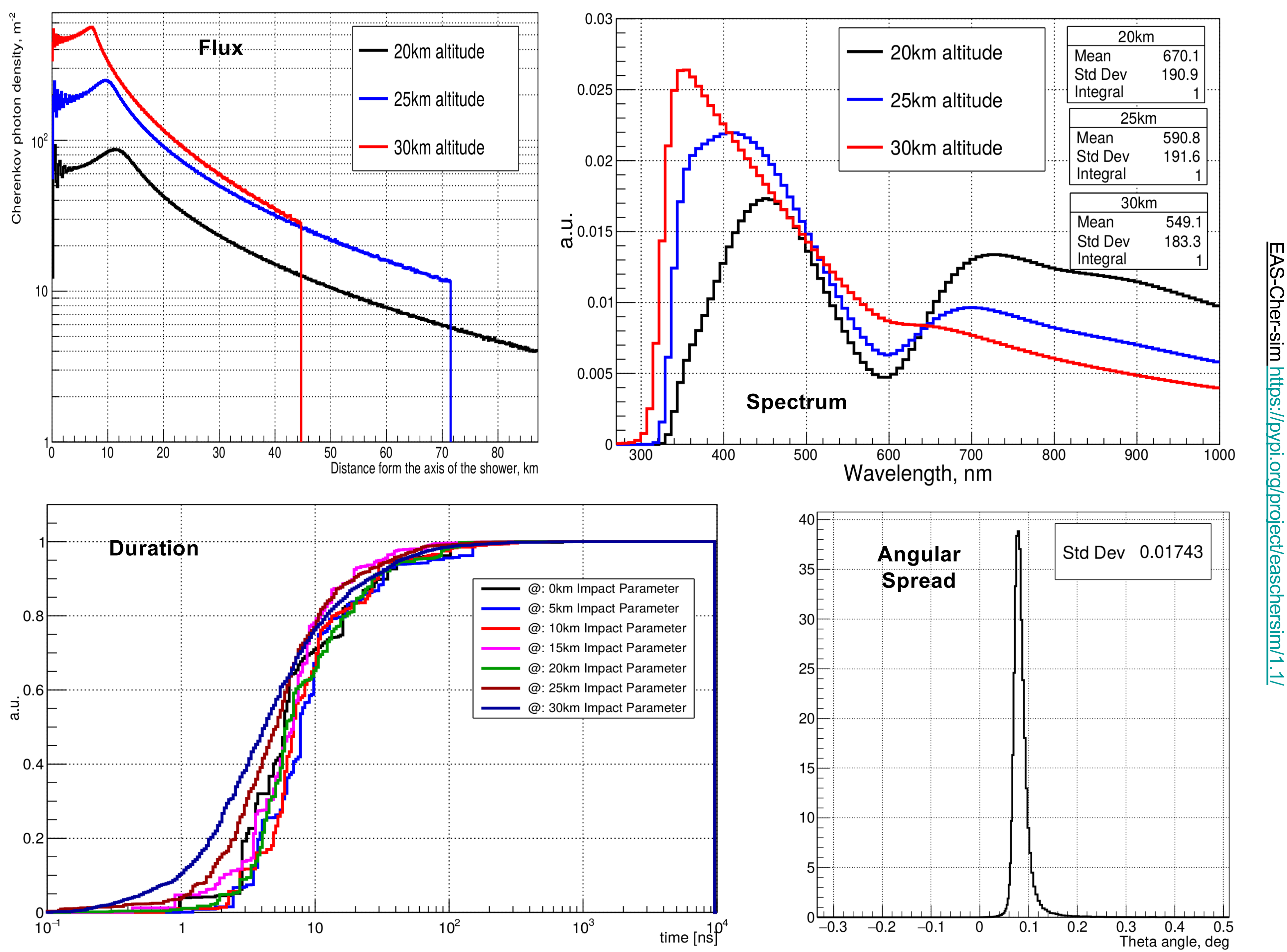
EAS-Cher-sim https://pypi.org/project/easchersim/1.1/





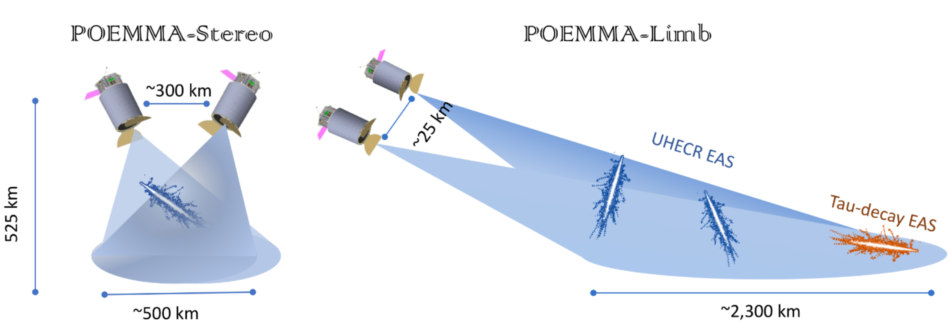


Cummings, RA, Krizmanik (2020)



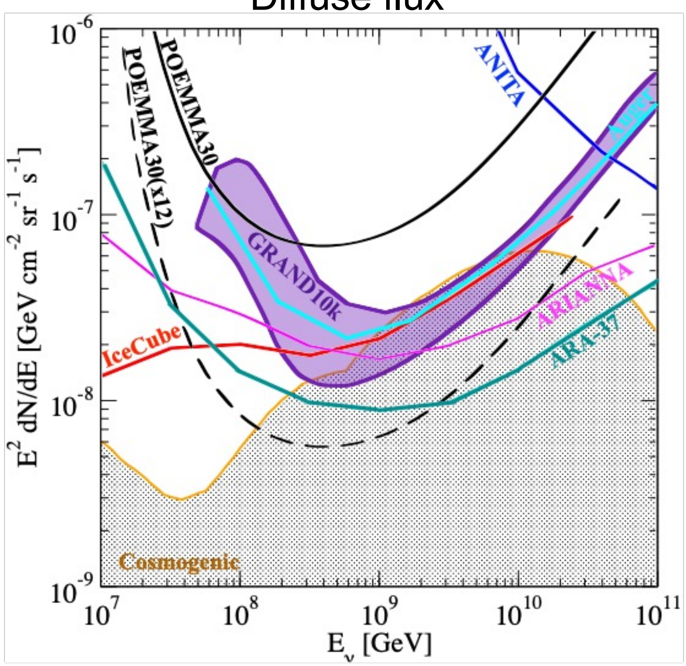
Flux
Cherenkov photon density, m⁻²
Distance form the axis of the shower, km
20km altitude
25km altitude
30km altitude
Spectrum
a.u.
Wavelength, nm
20km altitude
25km altitude
30km altitude
20km
Mean 670.1
Std Dev 190.9
Integral 1
25km
Mean 590.8
Std Dev 191.6
Integral 1
30km
Mean 549.1
Std Dev 183.3
Integral 1
Duration
a.u.
time [ns]
@: 0km Impact Parameter
@: 5km Impact Parameter
@: 10km Impact Parameter
@: 15km Impact Parameter
@: 20km Impact Parameter
@: 25km Impact Parameter
@: 30km Impact Parameter
Angular Spread
Std Dev 0.01743
Theta angle, deg
EAS-Cher-sim https://pypi.org/project/easchersim/1.1/

Probe Of Extreme Multi Messenger Astrophysics – POEMMA



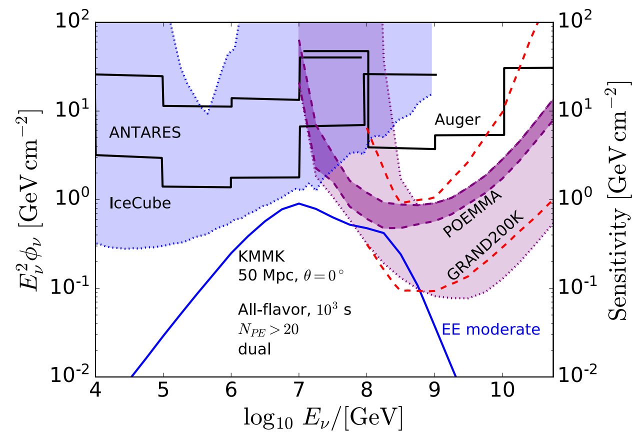
- ✓ Fluorescence camera to detect of ultra-high energy cosmic rays through EAS fluorescence emission (E>10 EeV).
- ✓ Cherenkov camera to detect Earth skimming neutrino events, and above the limb CR events (E>10 PeV)

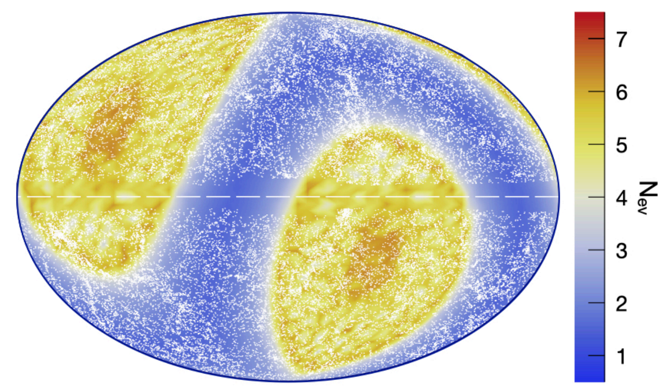
Diffuse flux



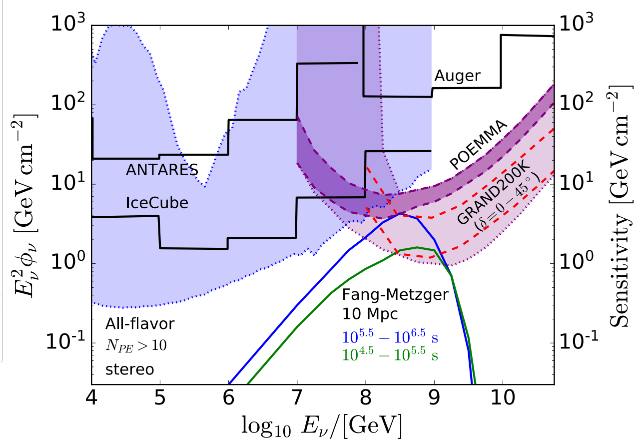
POEMMA Coll. (2021)

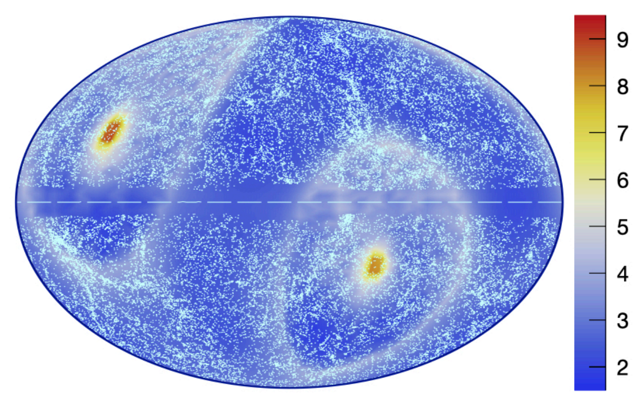
Transient sources





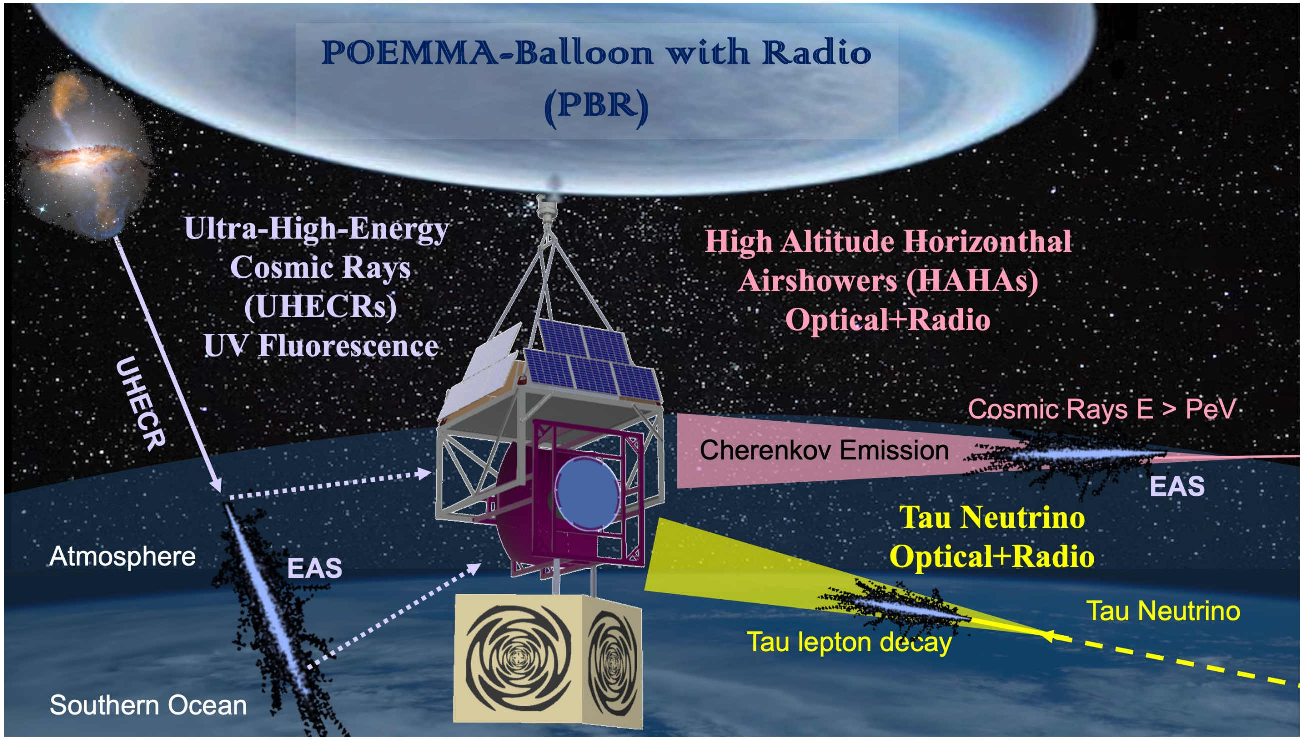
POEMMA Coll. (2021)





Pathfinders

- **POEMMA-Balloon with Radio (PBR)** – A super-pressure balloon (altitude ~ 30 km) with a Cherenkov Telescope onboard to observe Earth skimming ν and above the limb CR (poster by Julia Burton Heibges).



- **Terzina** (the building block of a poem!) – A space-based LEO (BoL 535 km) Cherenkov telescope onboard the **NUSES mission**.

The **NUSES mission** (talk by Pierpaolo Savina) is a joint project of GSSI and Thales Alenia Space, participated by INFN, U. of Geneva (CH) and U. of Chicago (USA), funded by the Italian Government and the Italian Space Agency. NUSES satellite launch by ASI foreseen by 2nd half of 2026.

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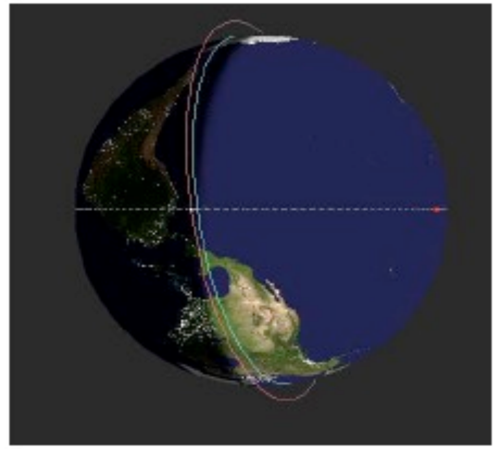
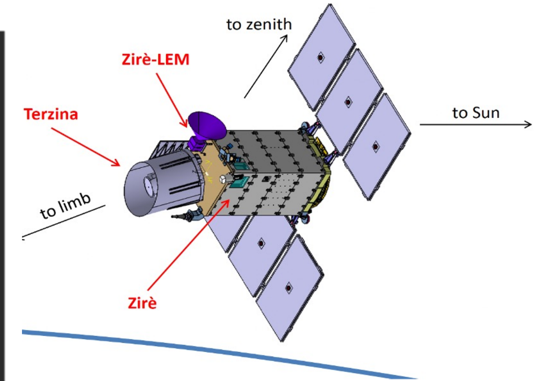
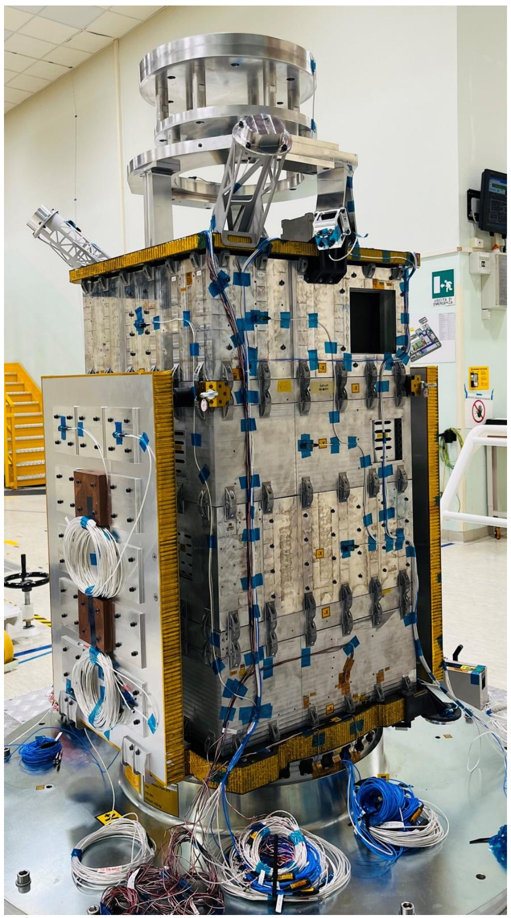
Istituto Nazionale di Fisica Nucleare
UNIVERSITÉ DE GENÈVE
THE UNIVERSITY OF CHICAGO

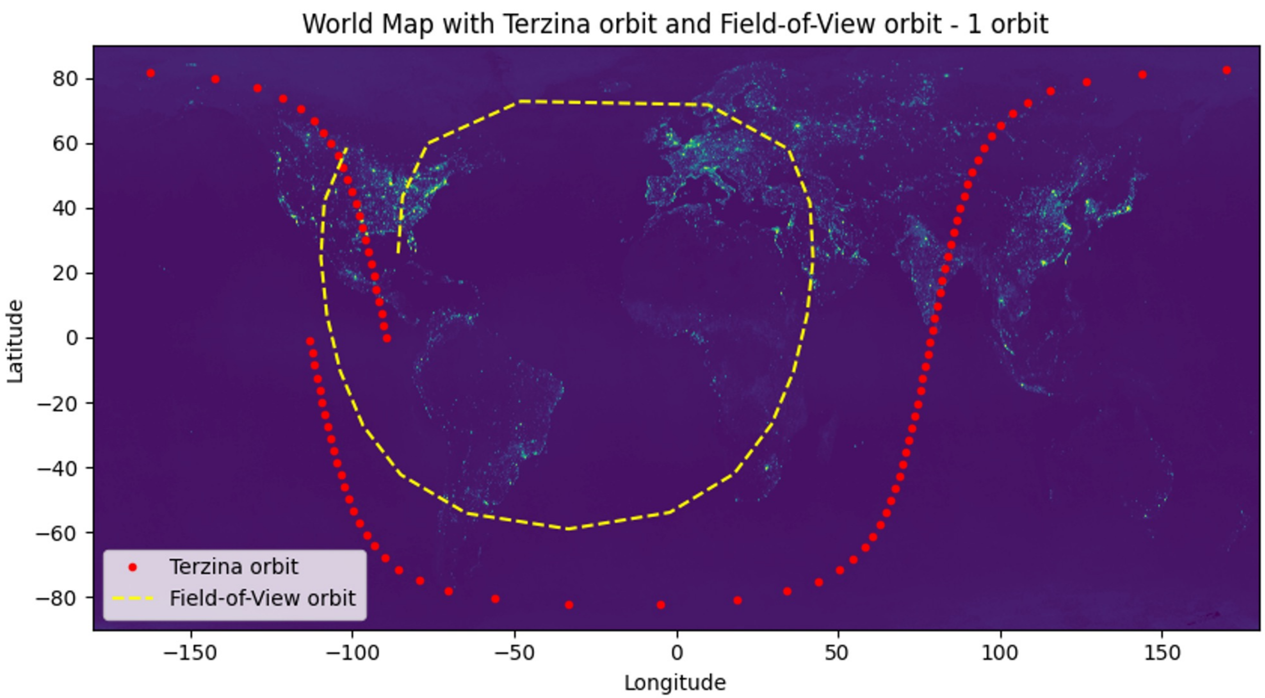
NUSES Satellite

- The NUSES satellite hosts two payloads: Terzina and Zirè (more in the P. Savina talk).
- Low Earth Orbit (LEO) with high inclination, sun-synchronous orbit on the day-night border (BoL altitude 535 Km, LTAN = 18:00, inclination = 97.8°).
- Orbit optimized for Cherenkov photons detection.
- Ballistic mission (no orbital control).

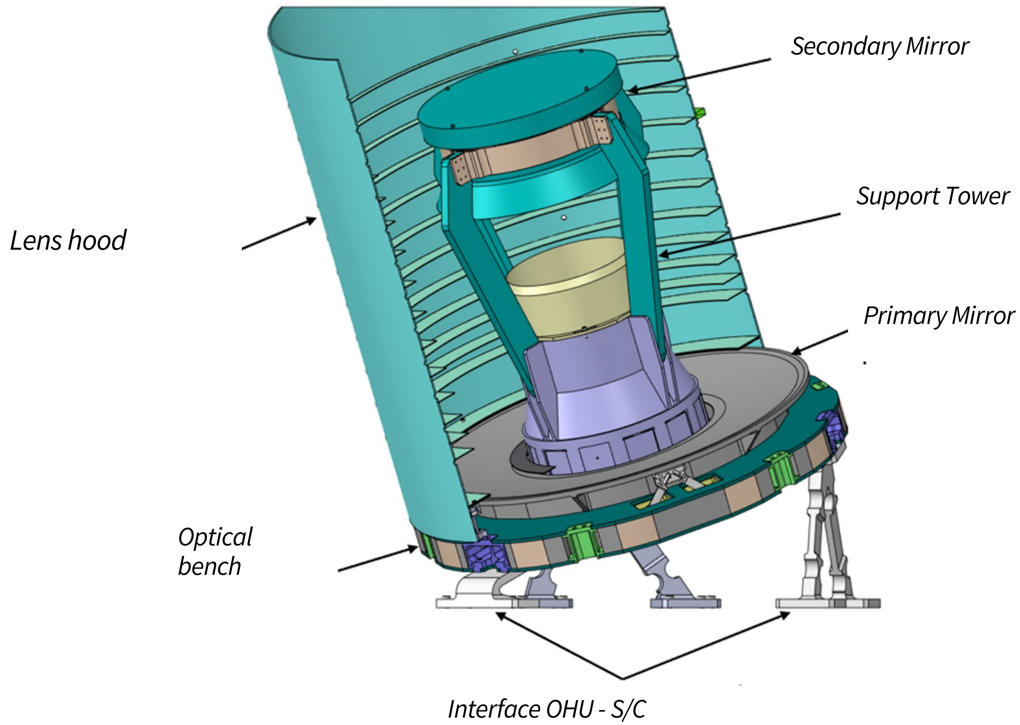


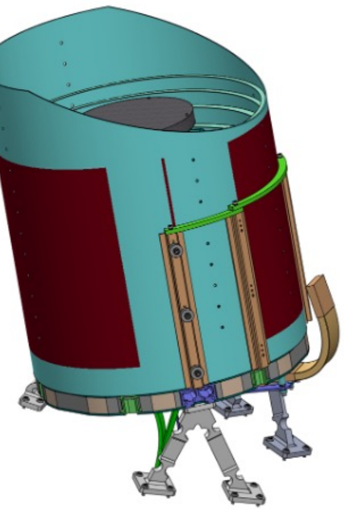


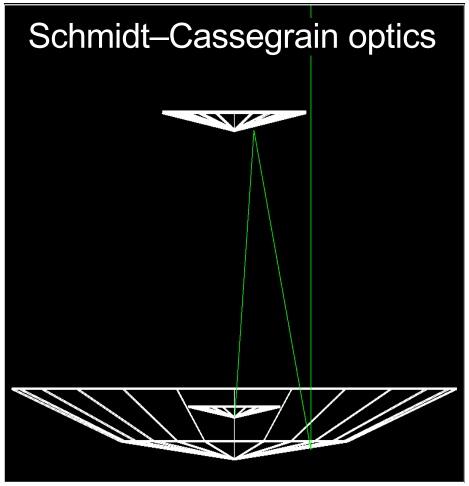




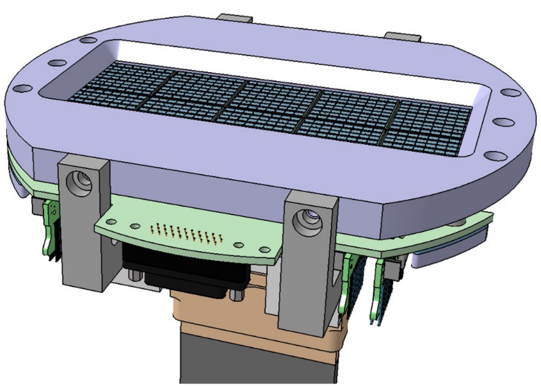
Terzina telescope

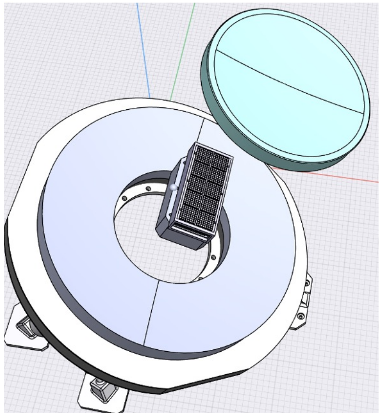






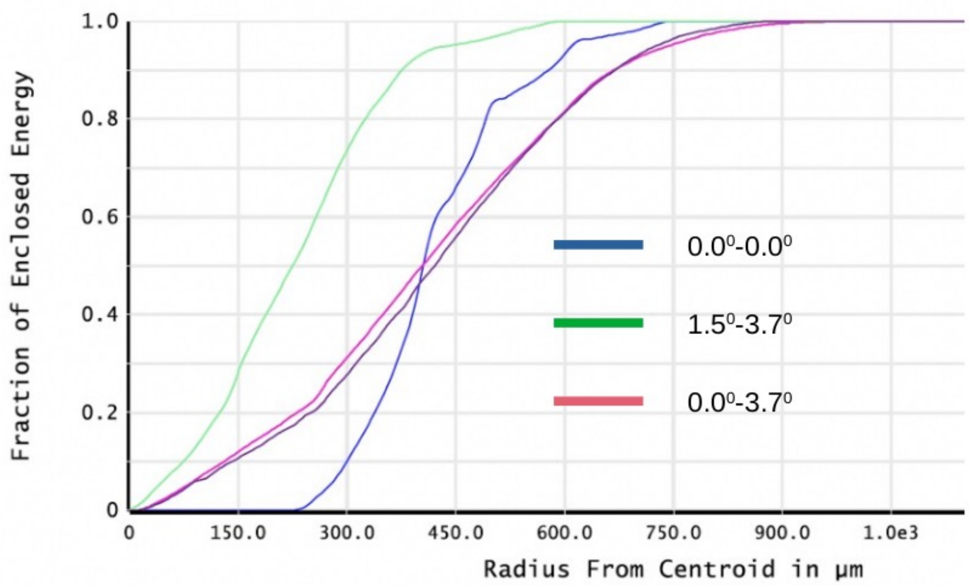
- ✓ Equivalent focal length F_L= 925 mm
- ✓ FP Field of View (FoV) : 7.2º x 2.88º
- ✓ Point spread function (PSF) : <1.0 mm
- ✓ Effective area of the primary mirror: 0.1 m²
- ✓ M1 paraboloid, M2 hyperbole





Terzina total weight ~45 kg

Point spread function for different inclination angles



Telescope FP & DAQ

SiPM arrays: **8 x 8 channels**

Pixel: **3 x 3 mm^2 (eff. area 6.58 mm^2)**

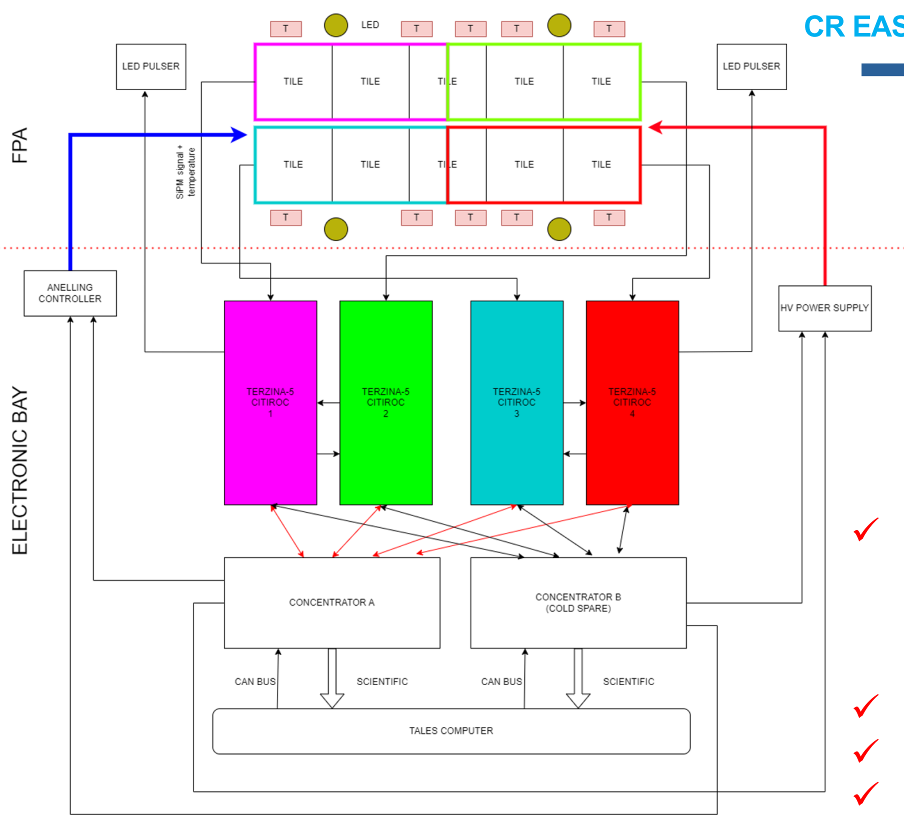
Pixel FoV: atan(r_{pix}/F_L) ~ **0.18°**

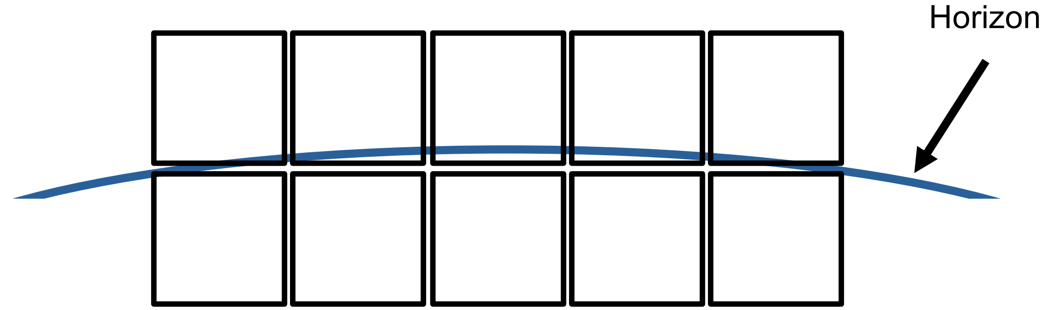
5 x 2 = 10 SiPM tile arrays total

(8 x 8) x 10 = 640 pixels (channels)

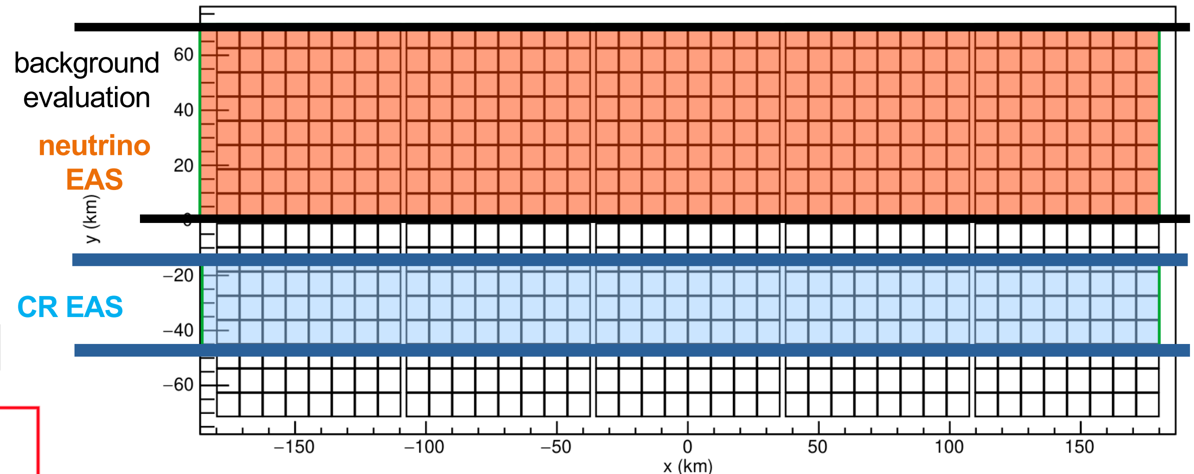
Array dim. : 25.3 x 25.3 mm^2

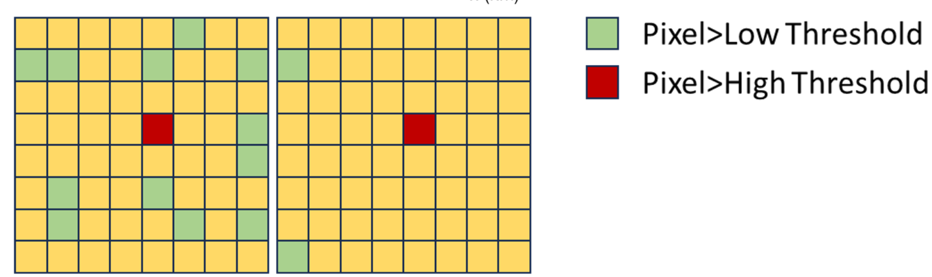
Array Eff. area : 24 x 24 mm^2





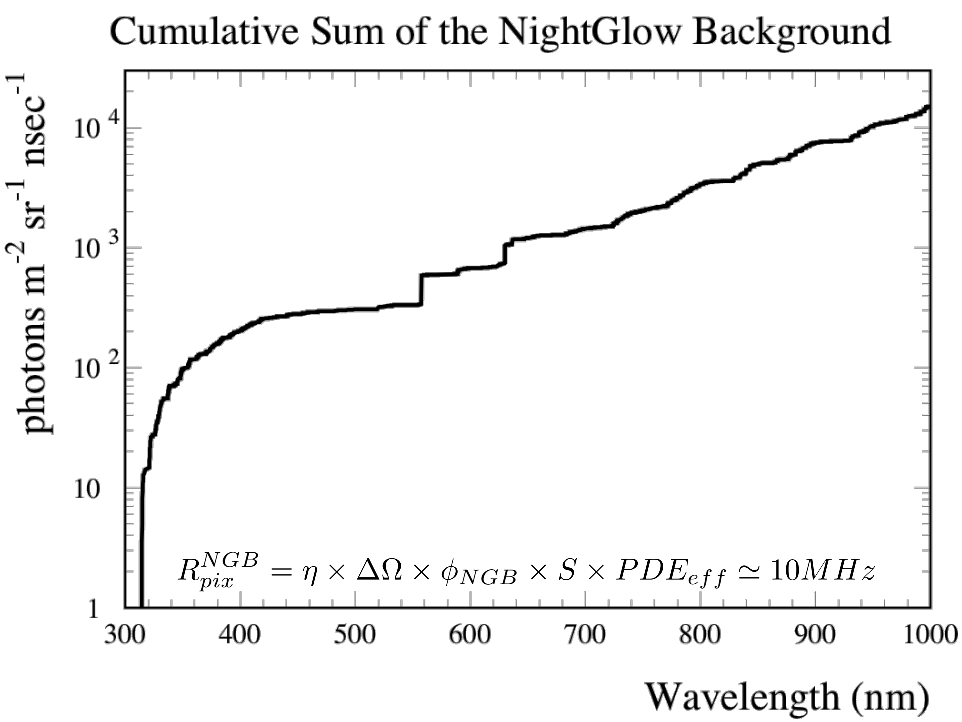
Camera plane with Earth projection of total area 360x140 km^2

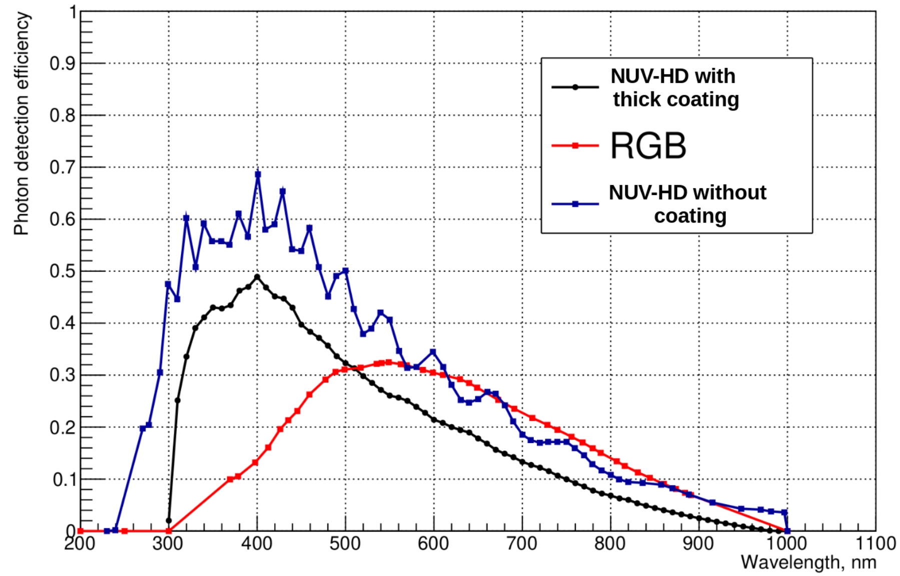




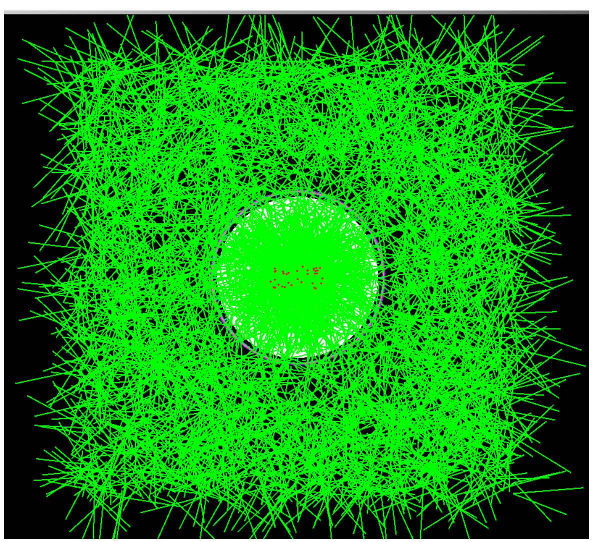
- ✓ High Threshold Trigger (HTT) and Low Threshold Trigger (LTT) for tile readout
  - HTT: 1 pixel above HT
  - LTT: 2 adjacent pixels above LT within Δt=10 ns.
- ✓ Negligible delay between second pixel above LT and readout.
- ✓ Onboard analysis of the hit-map topologies for event recording.
- ✓ For each trigger: dead time between events of 15 μs.

Night Glow Background

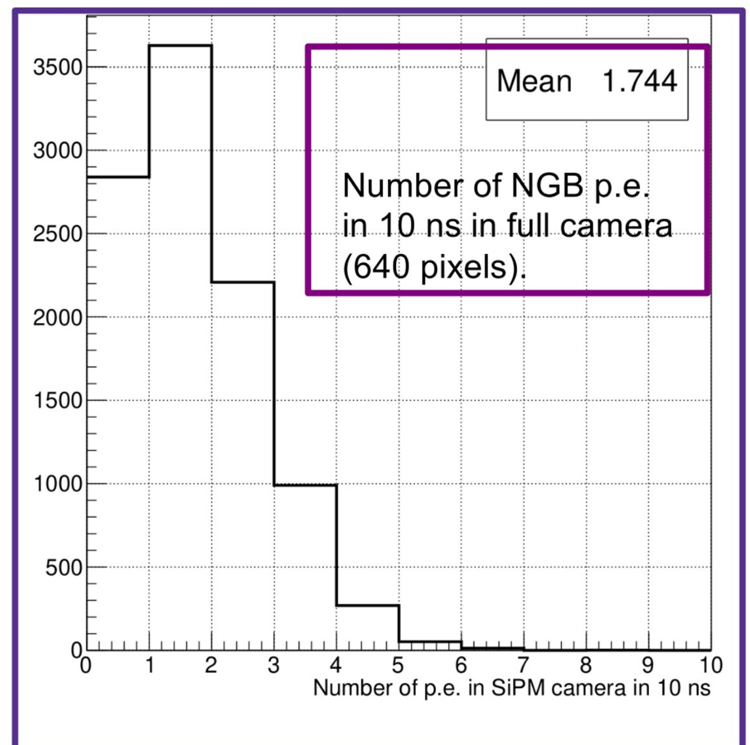




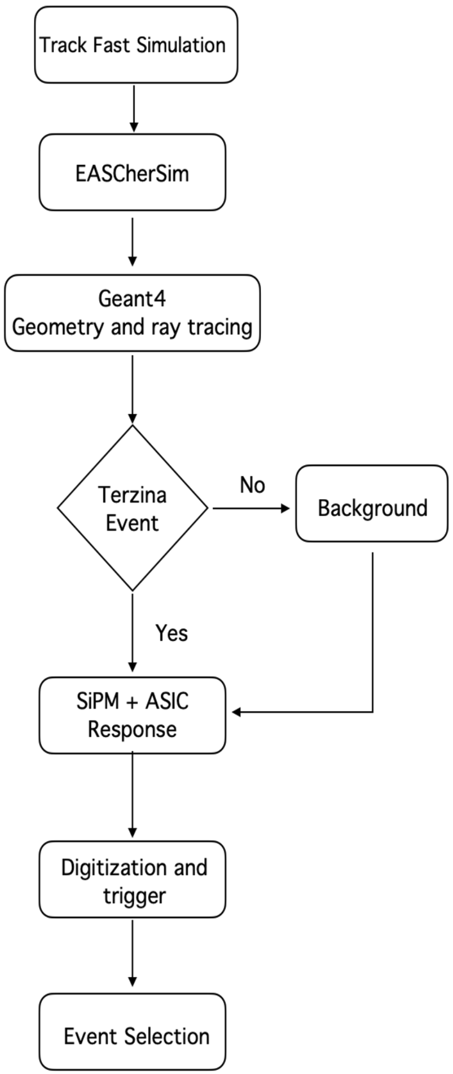
- ✓ SiPM NUV-HD-MT (FBK): 35 µm cell-size, DCR ~ 50 kHz/mm^2, afterpulsing AP ~ 5%, crosstalk CT ~ 5%–20%, detection efficiency peak PDE ~ 50%–60%. Safety factor: $\eta = 10$.

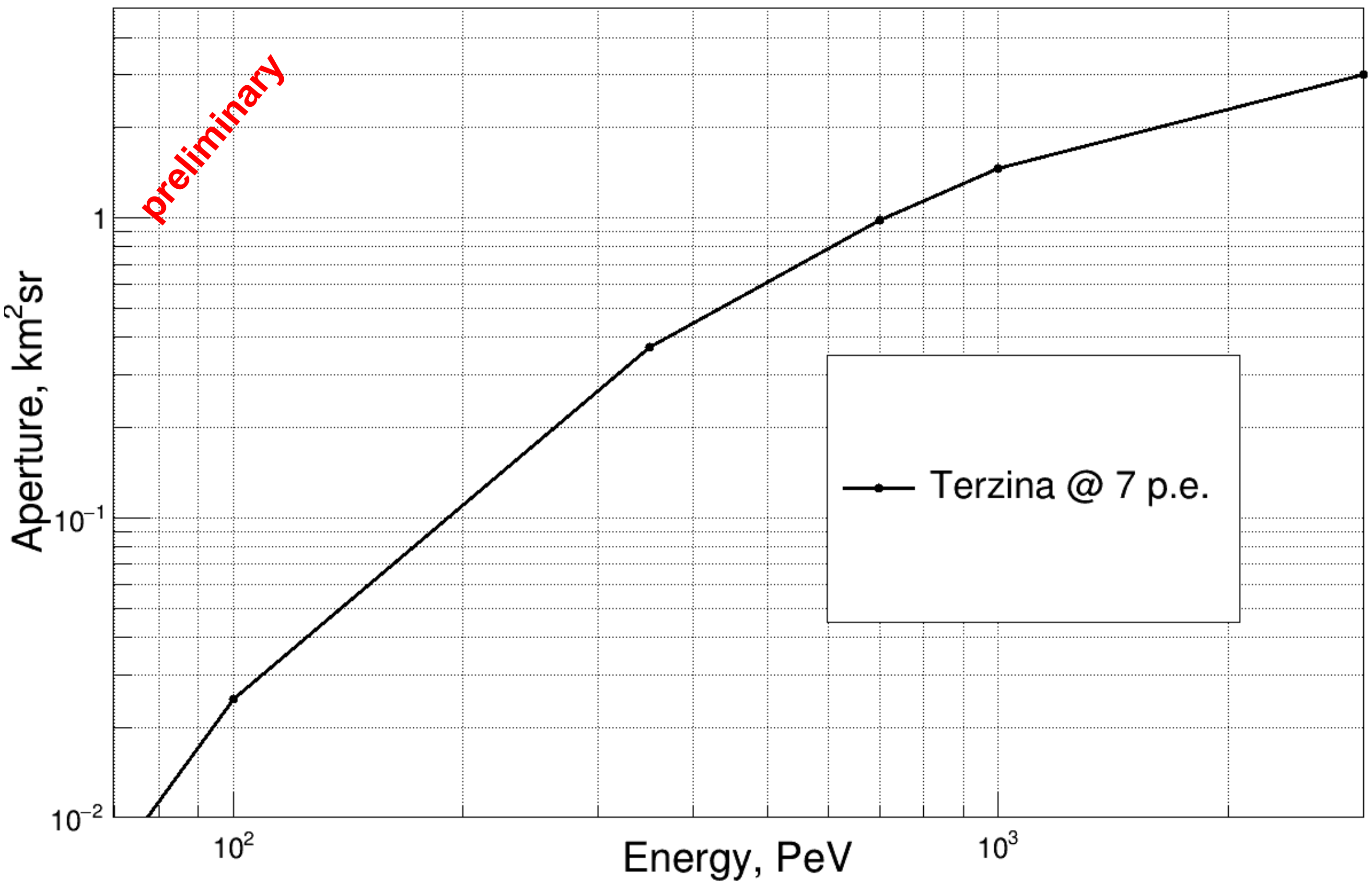


- ✓ For a discussion of the Terzina SiPM radiation damage in space see the poster by Shideh Davarpanah



Terzina aperture





✓ Not less than 20 events per year of CR with E>100 PeV will be detected by Terzina

Conclusions

- ✓ The detection technique of high energy EAS from space through Cherenkov emission is beginning its validation phase.

The results expected by the NUSES (Terzina) and PBR missions will provide:

- ✓ The first robust observation of high energy EAS from orbital and high altitudes through Cherenkov emission.
- ✓ A test of HE neutrino detection in the Earth skimming geometry.
- ✓ A complete characterization of the UV - near visible background from the Earth limb at different altitudes.

In the forthcoming 3 years new eyes for the observation of high energy neutrinos from space will be opened, paving the way for more ambitious missions.

Thank you