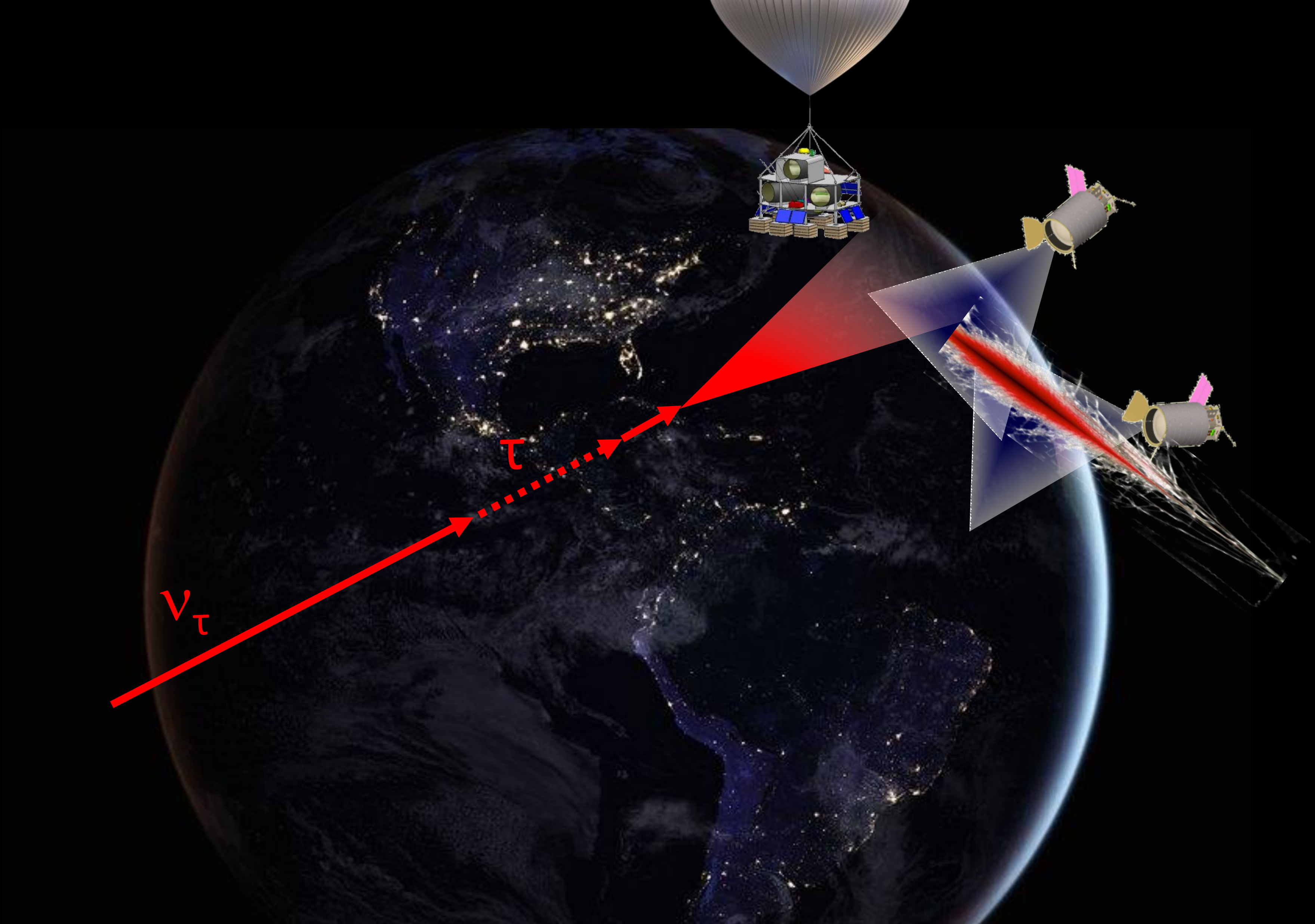


POEMMA, EUSO-SPB2

Francesca Bisconti

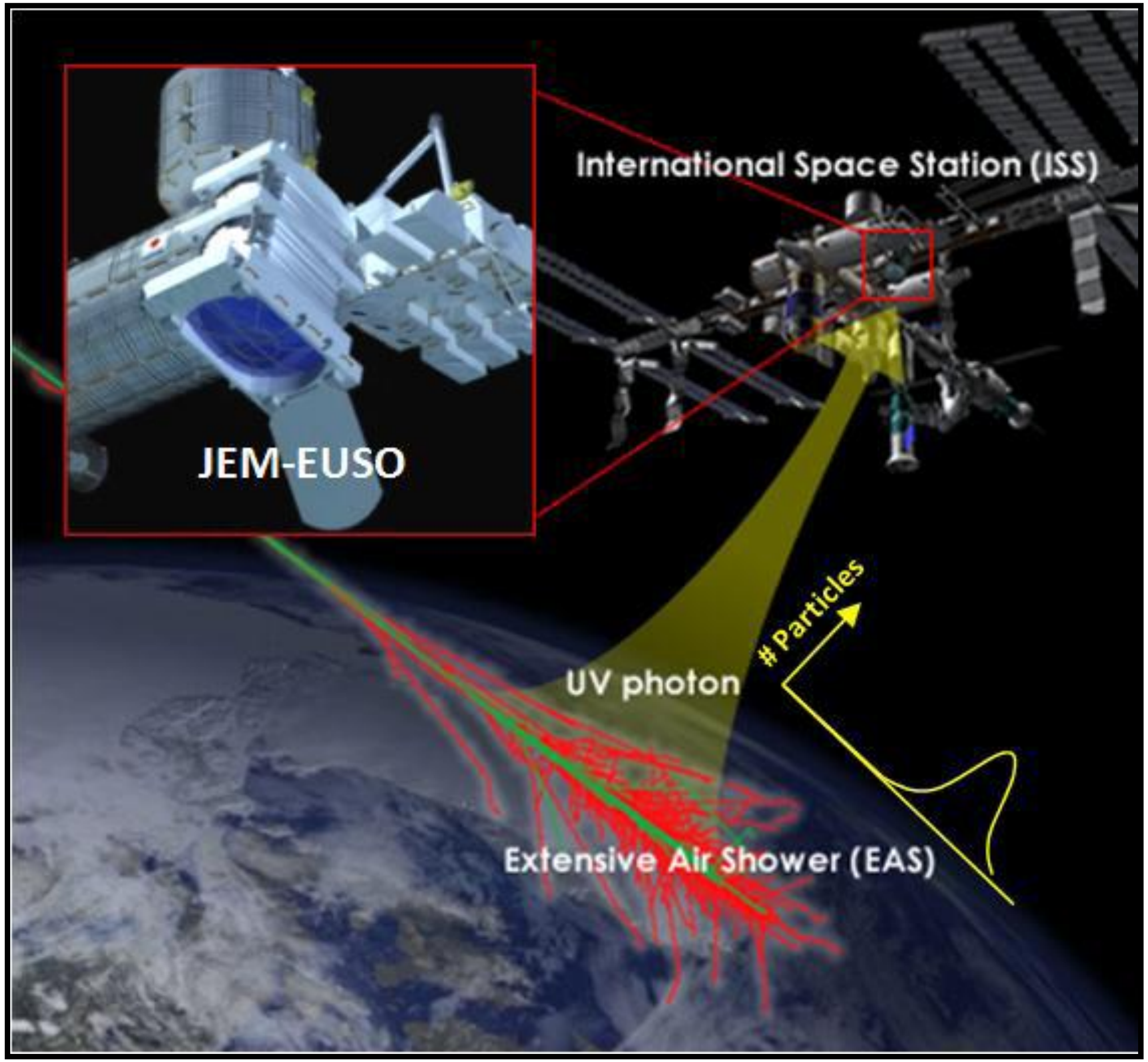
Next Generation CORSIKA Workshop
Karlsruhe, KIT, 25-26.06.2018

Overview

- Introduction to space based UHECR detectors with the JEM-EUSO mission
- Description of the POEMMA mission, a space based UHECR and neutrino detector
- Brief description of the EUSO-SPB2 and Terzina experiments
- Some tests made in Turin using a modified version of CORSIKA for simulations of upward going tau neutrino and consequent Cherenkov light emission
- Hints by The POEMMA Simulation Group for the next generation CORSIKA

JEM-EUSO Joint Experiment Missions for Extreme Universe Space Observatory

JEM-EUSO Collaboration: 16 Countries, 84 Institutes, 306 Researchers

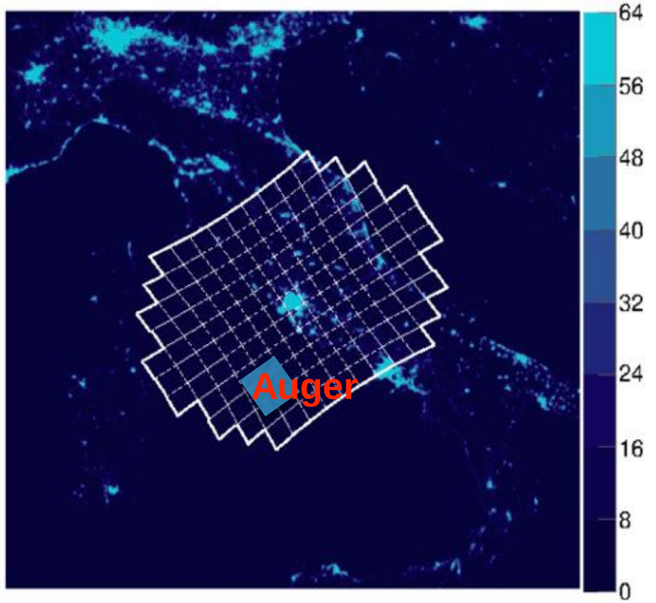


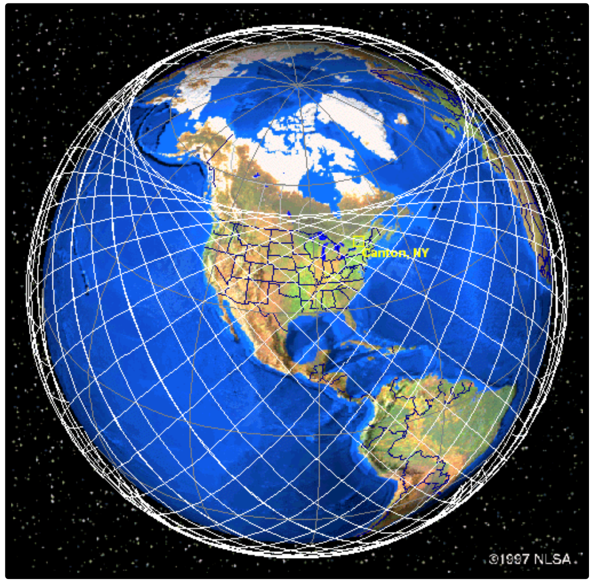
Mission to build a UHECR detector in space

Detection principle:
Fluorescence and Cherenkov light (UV band) at nighttime, observing from above the atmosphere as a calorimeter

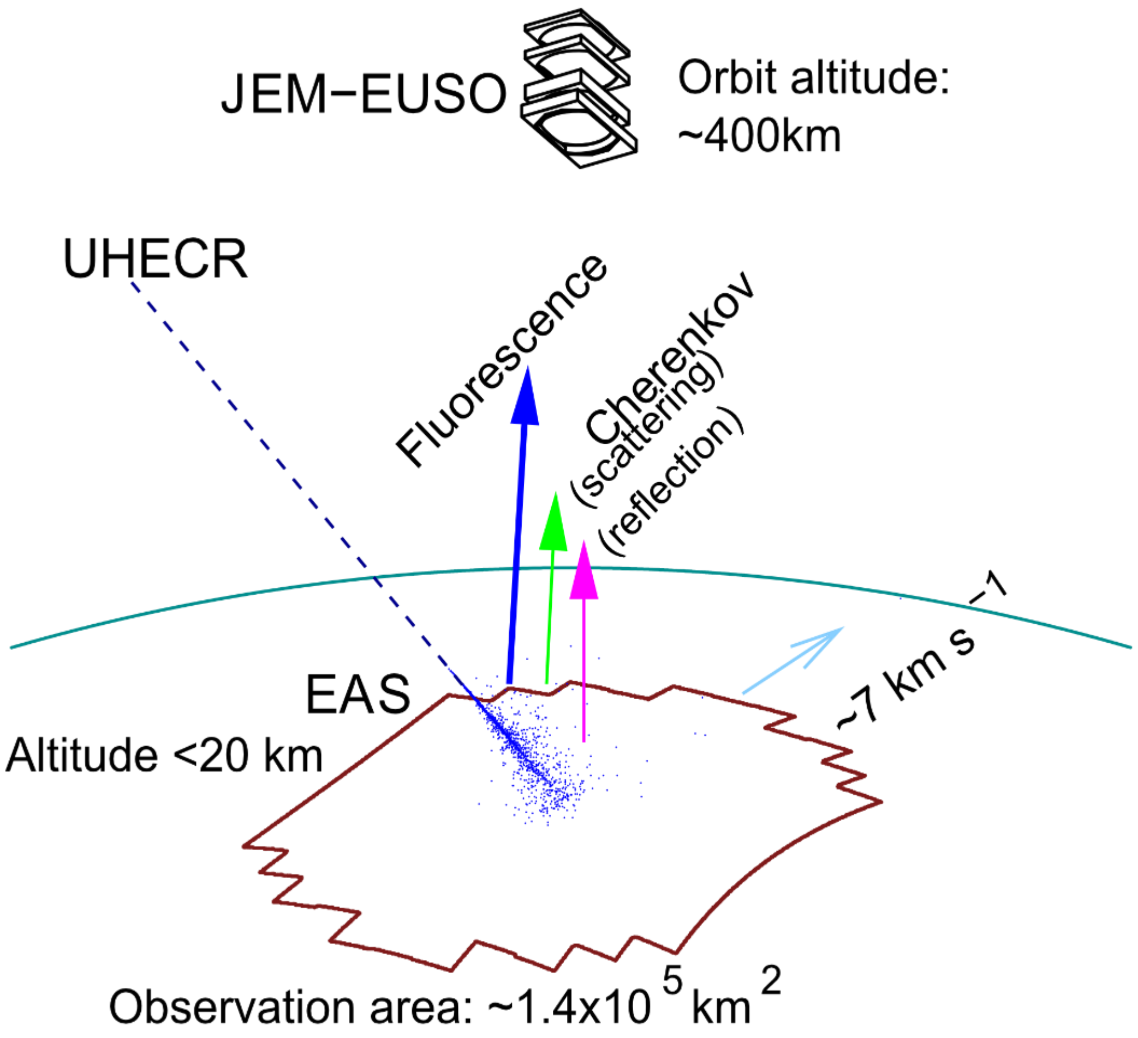
Wide field of view: ±30°
→ Observed area at 400 km: $2 \cdot 10^5$ km^2

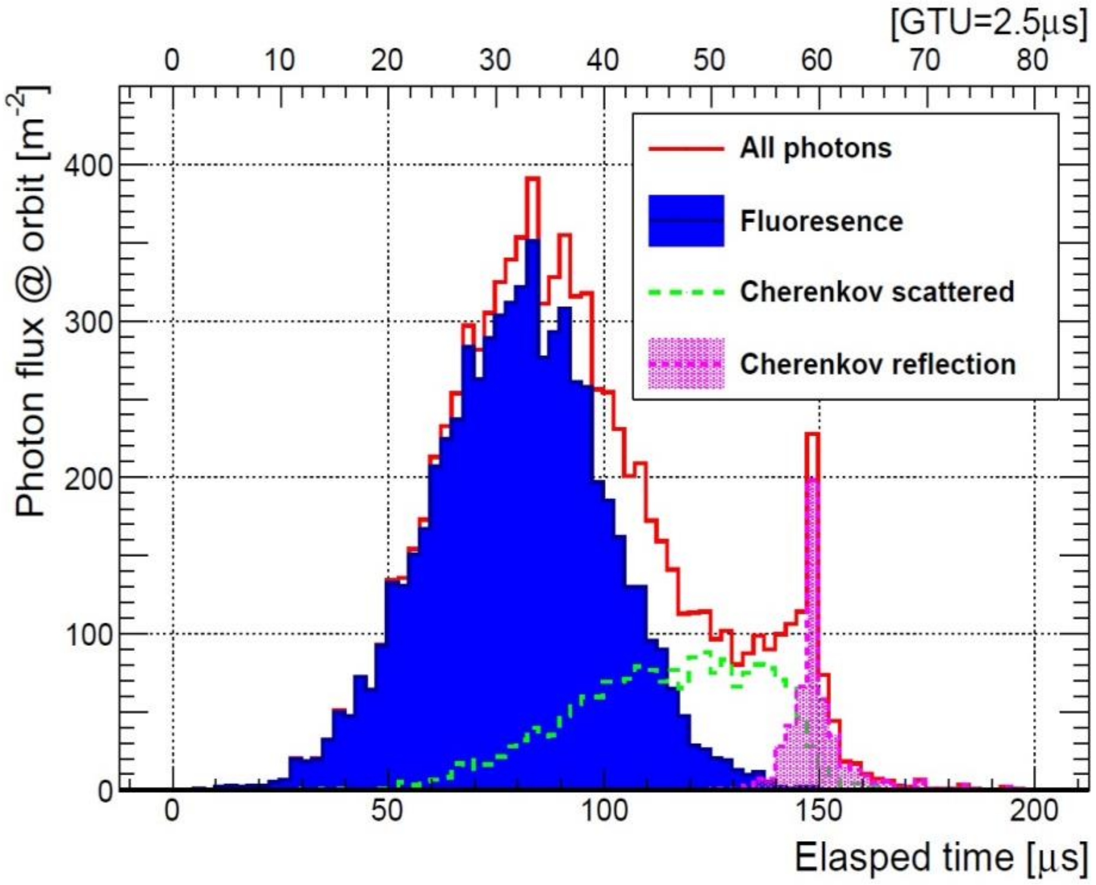
Observation of both the hemispheres





Observation principle

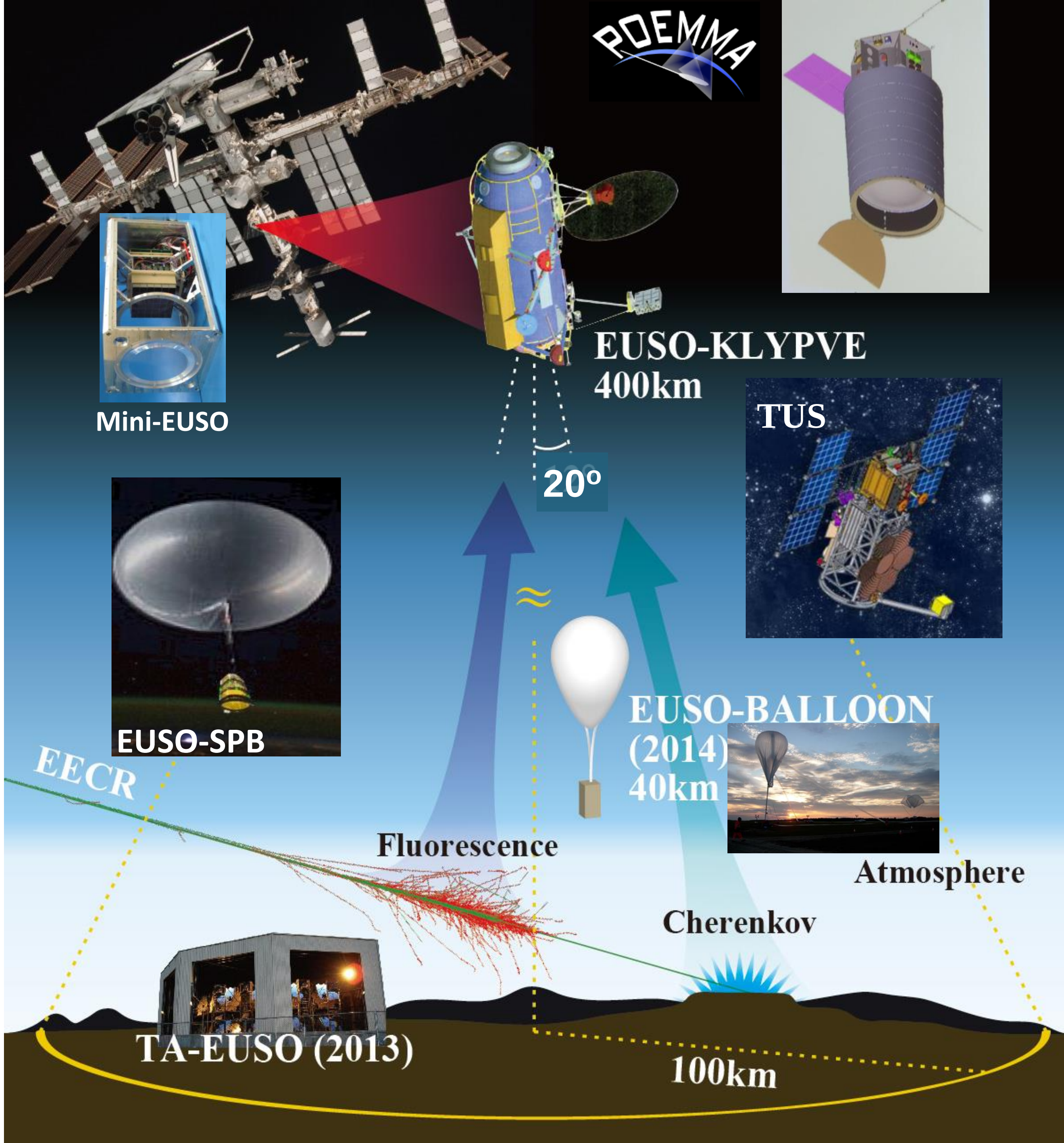




J.H. Adams Jr. et al. / Astroparticle Physics 44 (2013) 76–90

JEM-EUSO program

- EUSO-TA (2013-)
- EUSO-Balloon (2014)
- TUS (2016)
- EUSO-SPB1 (2017)
- Mini-EUSO (2018-19)
- EUSO-SPB2 (2020-22)
- K-EUSO (2023+)
- POEMMA (2028+)



POEMMA

Probe of Extreme Multi-Messenger Astrophysics
UHECRs and Neutrinos

Collaboration since 2017

Scientists from 16+ institutions from JEM-EUSO, OWL, Auger, TA, Veritas, CTA, Fermi

Leading Country: USA

POEMMA primary goals:

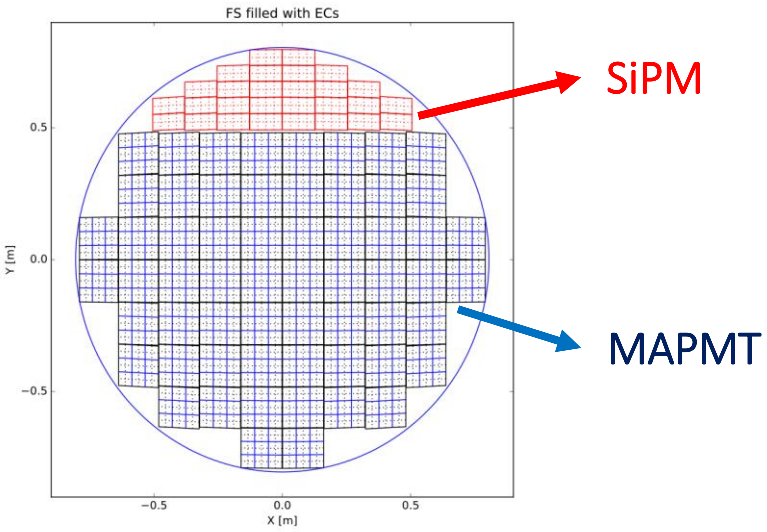
Study astrophysics and fundamental physics of the most energetic cosmic particles: UHECRs and neutrinos

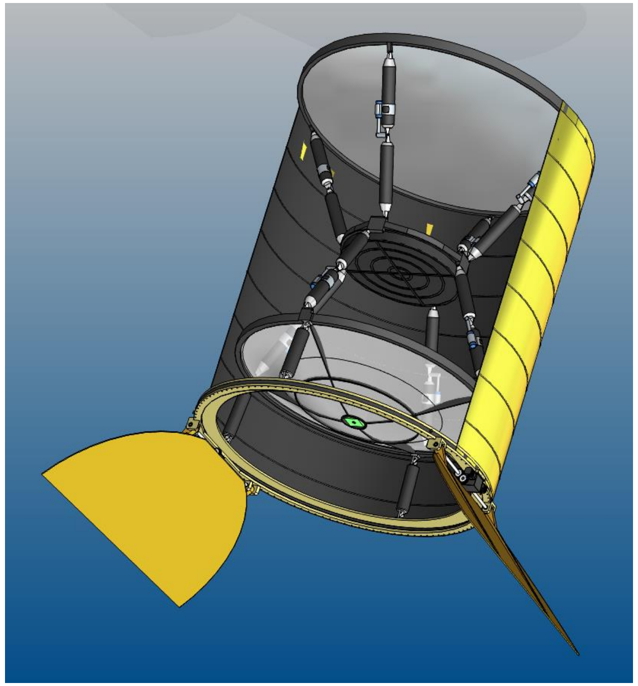
- Begin particle astronomy (identify the sources of UHECRs directly)
- Pioneer space observations of astrophysical neutrinos
- Discover cosmogenic neutrinos

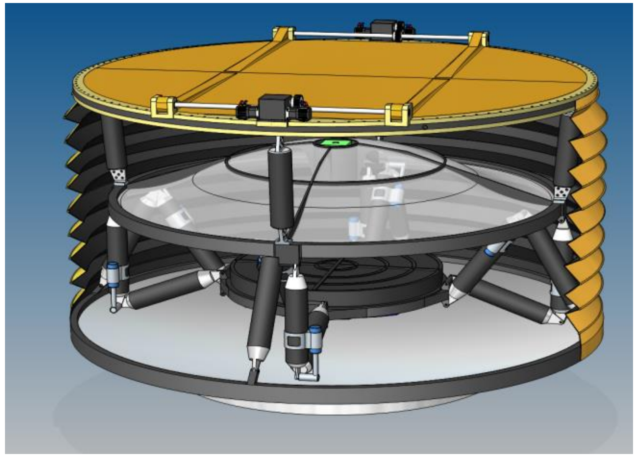
Status: Approved by NASA, launch foreseen in 2028

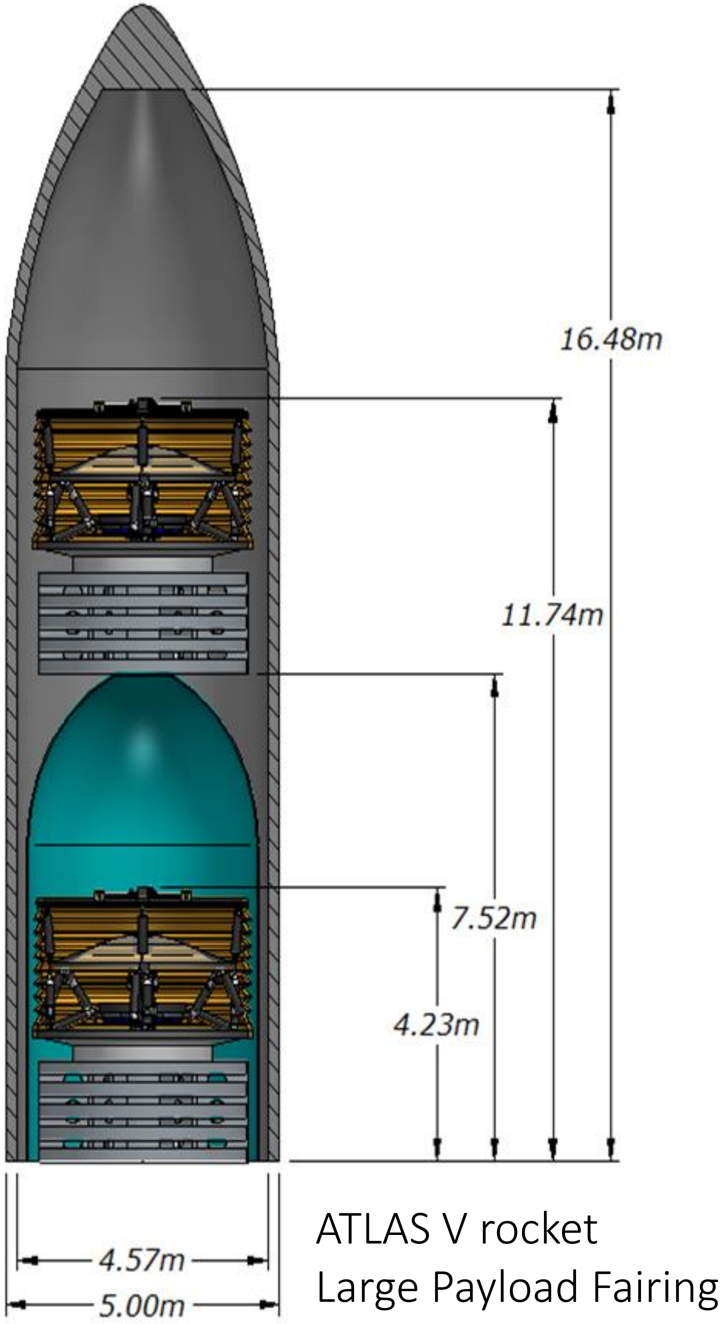
POEMMA detector details

- Two Schmidt telescopes with variable separation (300-25 km)
- Altitude: 525 km
- Instrument Mass: 1,547 kg
- Primary Mirror: 4 meter → FOV: 45 deg
- Corrector Lens: 3.3 meter
- Hybrid focal surface with MAPMTs and SiPM: 1.6 meter

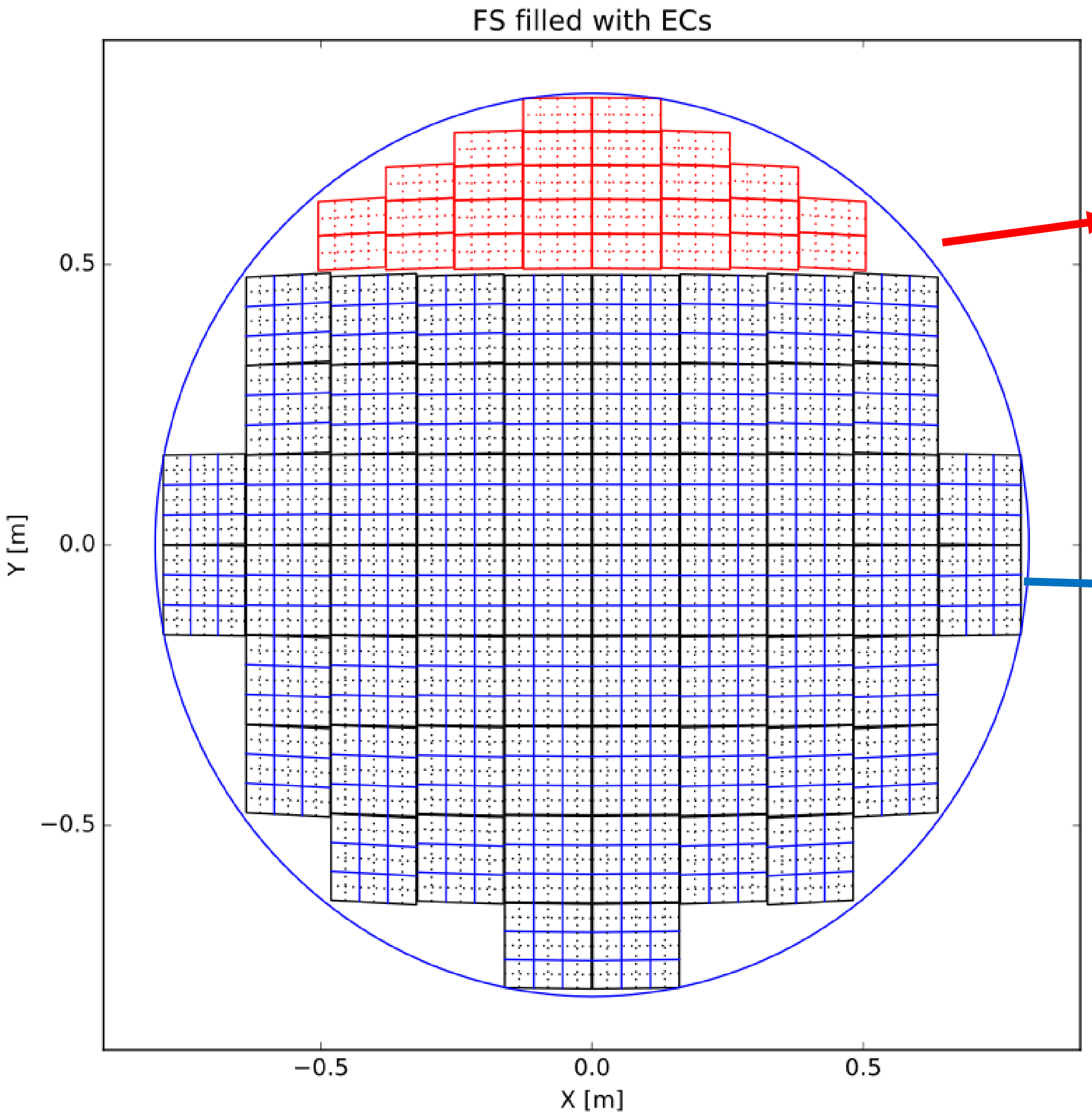




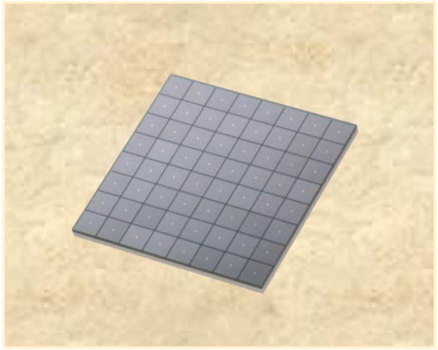




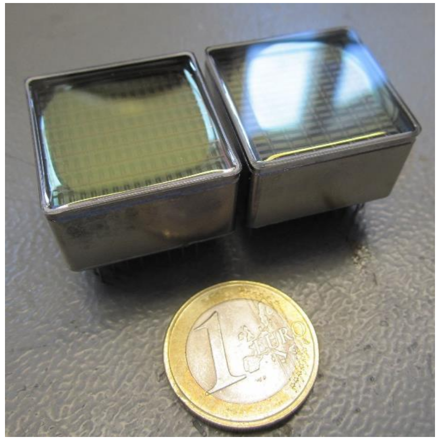
POEMMA focal surface



SiPM

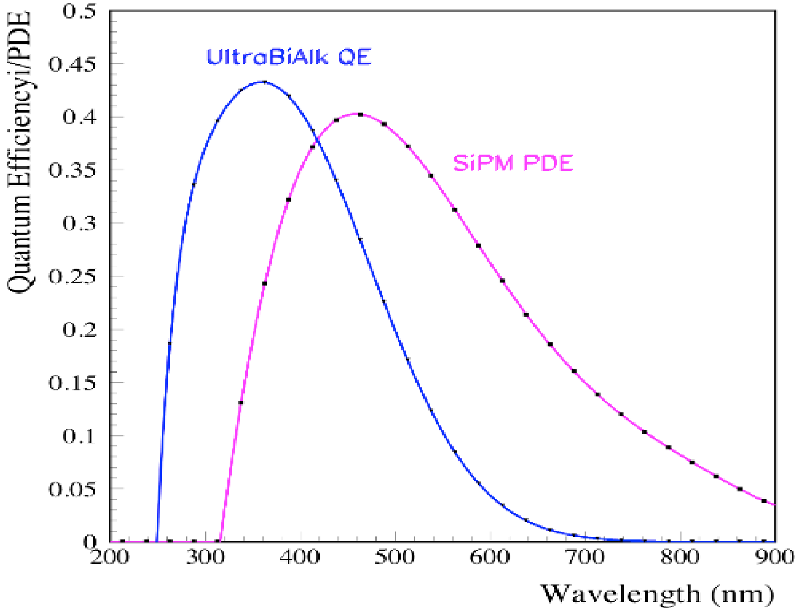


MAPMT



Cherenkov detection with SiPMs (300-900 nm, ~ns)
Edge of the focal surface which images the limb of the Earth

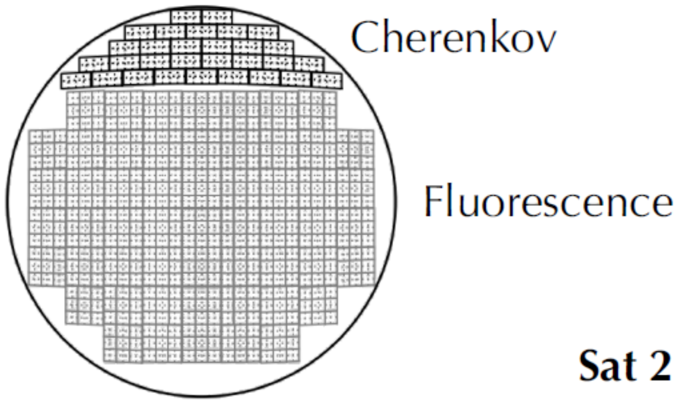
Fluorescence detection MAPMTs (300-400 nm, ~10 ns)
~90% of the focal surface

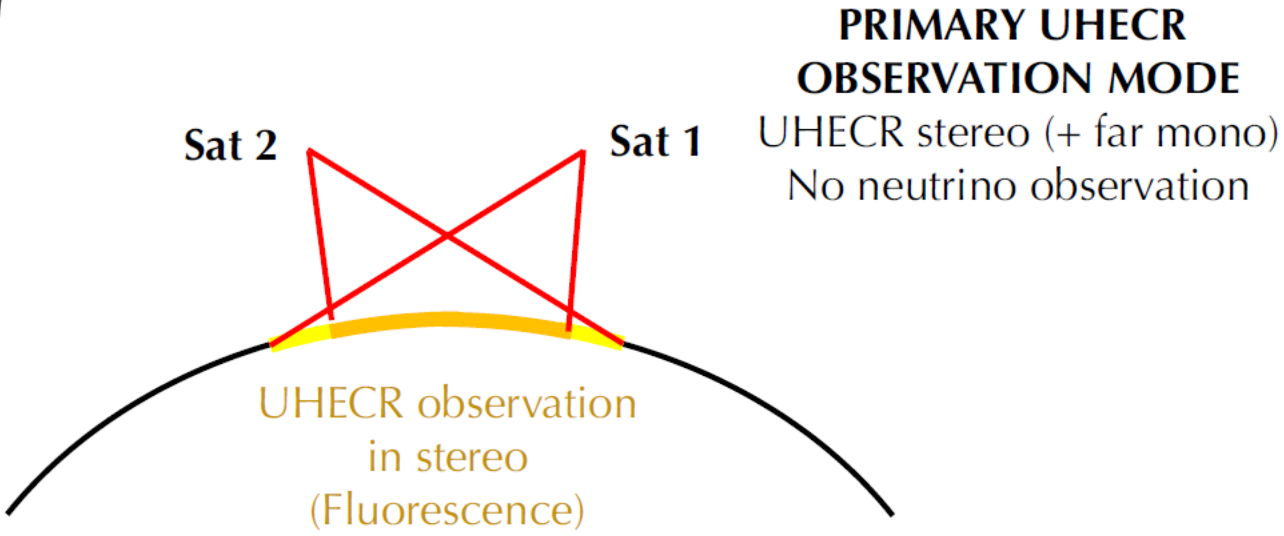


POEMMA

Primary UHECR observation mode

Cosmic rays through the atmosphere induce the emission of fluorescence light

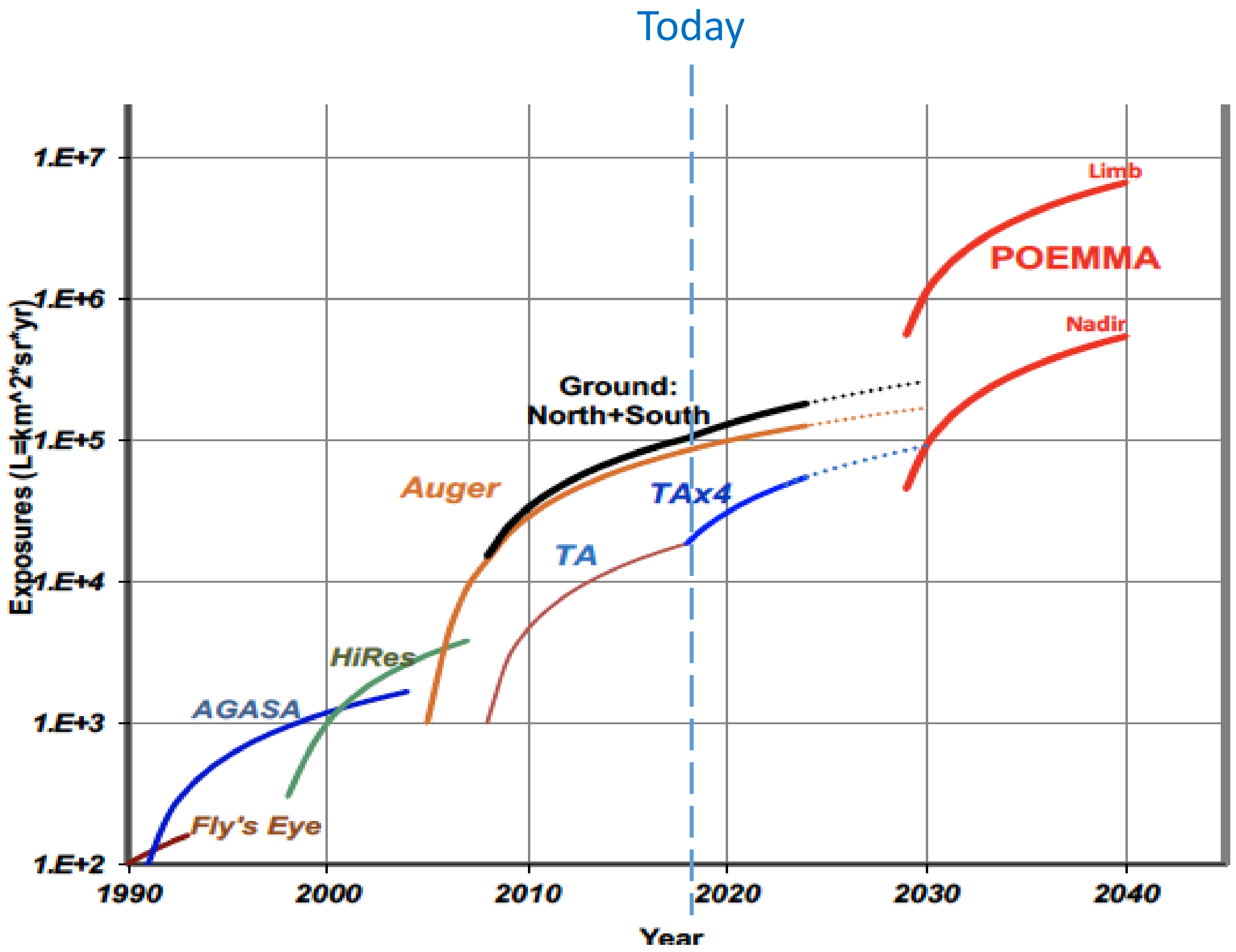




POEMMA

Primary UHECR observation mode

- POEMMA designed to observe cosmic rays with $E > 10^{18}$ eV
- Statistics of such events higher from space than on ground
- Significant increase in exposure (~10 x ground arrays, ~100 x fluorescence detectors)
- Good energy, angular, and shower maximum resolutions, to guarantee the discovery of UHECR sources

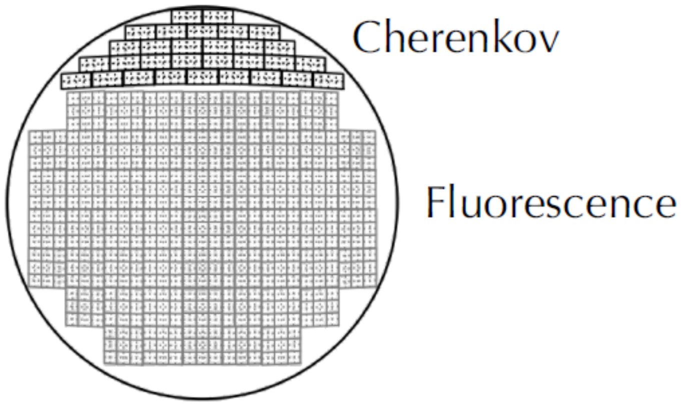


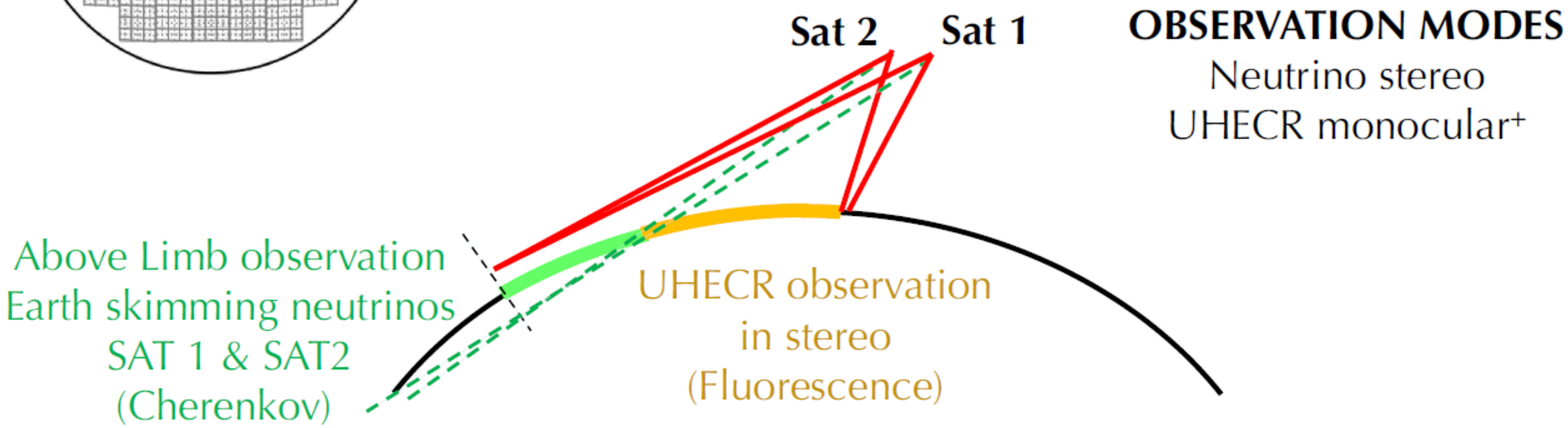
UHECR Exposure History

POEMMA

Primary neutrino observation mode

Tau neutrinos generate tau leptons on their way out of the Earth's surface which decay producing up-going showers

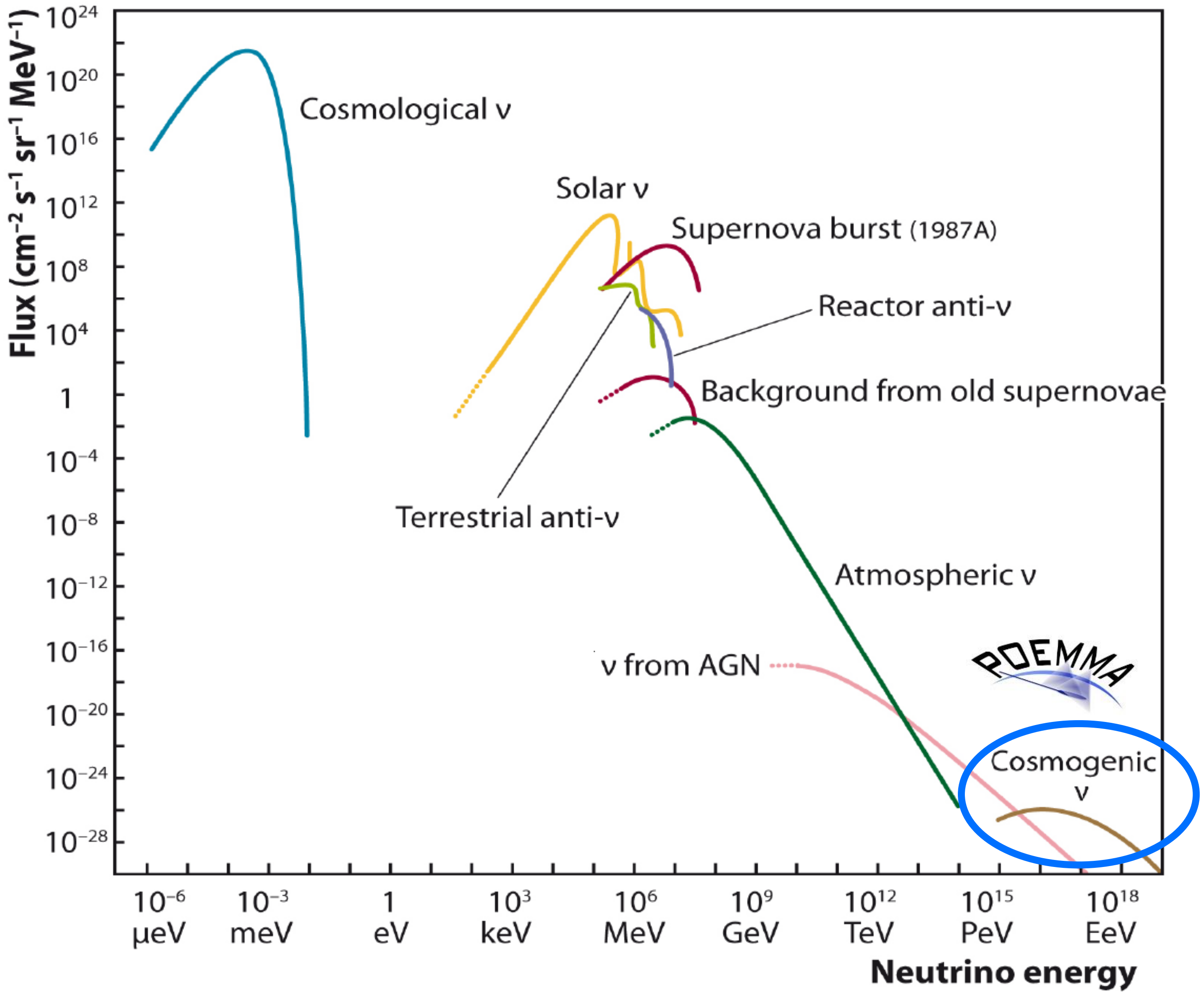




POEMMA

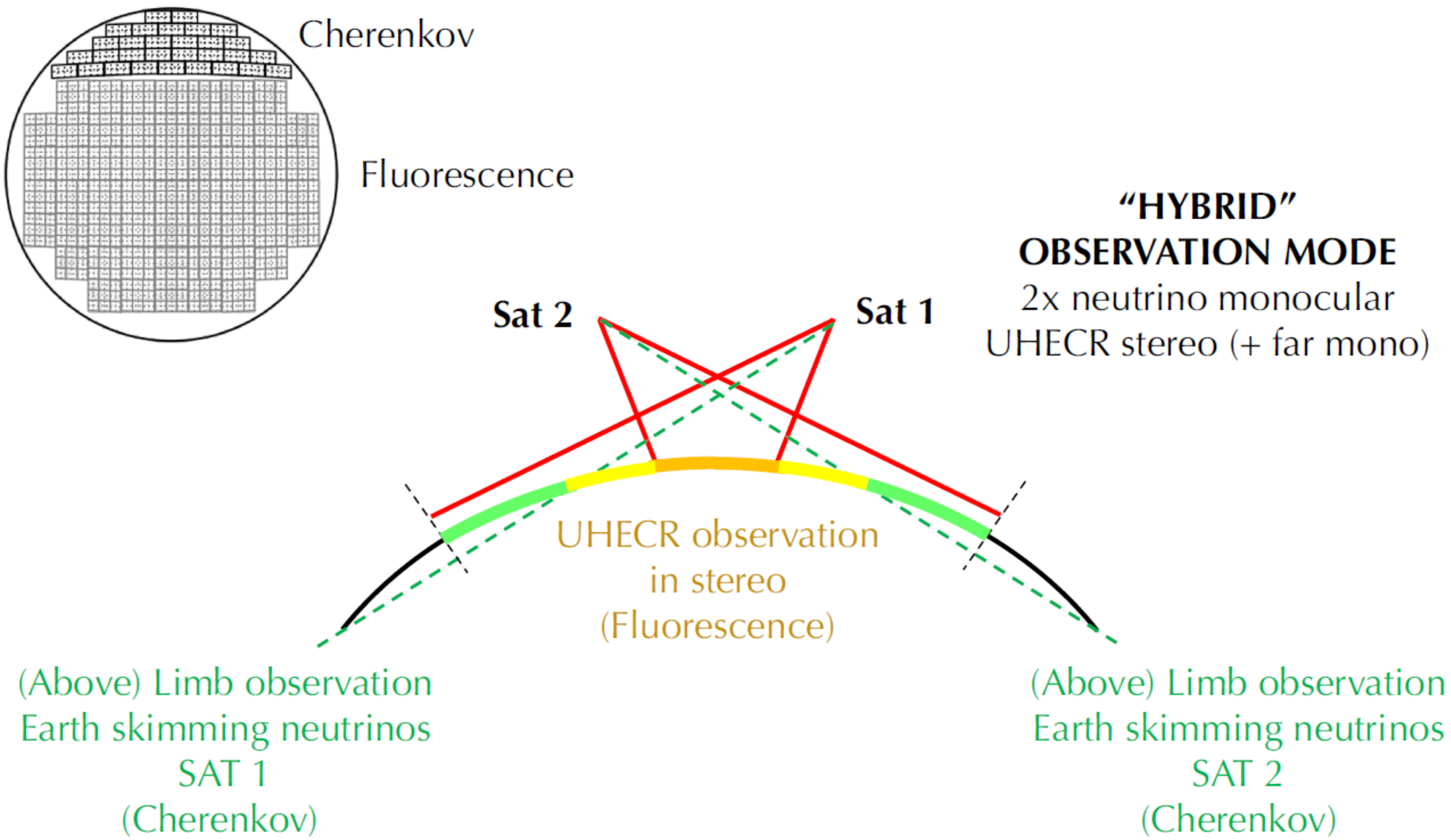
Primary neutrino observation mode

- POEMMA designed to observe neutrinos with $E > 10^{16}$ eV through Cherenkov signal of tau decays.
- The UHE neutrinos are expected to be born as ν_μ or ν_e.
  Due to vacuum oscillations, however, the astrophysical and cosmogenic neutrino flux at the Earth is expected to be almost equally distributed among the three neutrino flavours ν_μ, ν_e, ν_τ
- Some experiments search for ν_τ (ANITA, IceCube-Gen2, MAGIC…)
  → POEMMA will join the research!

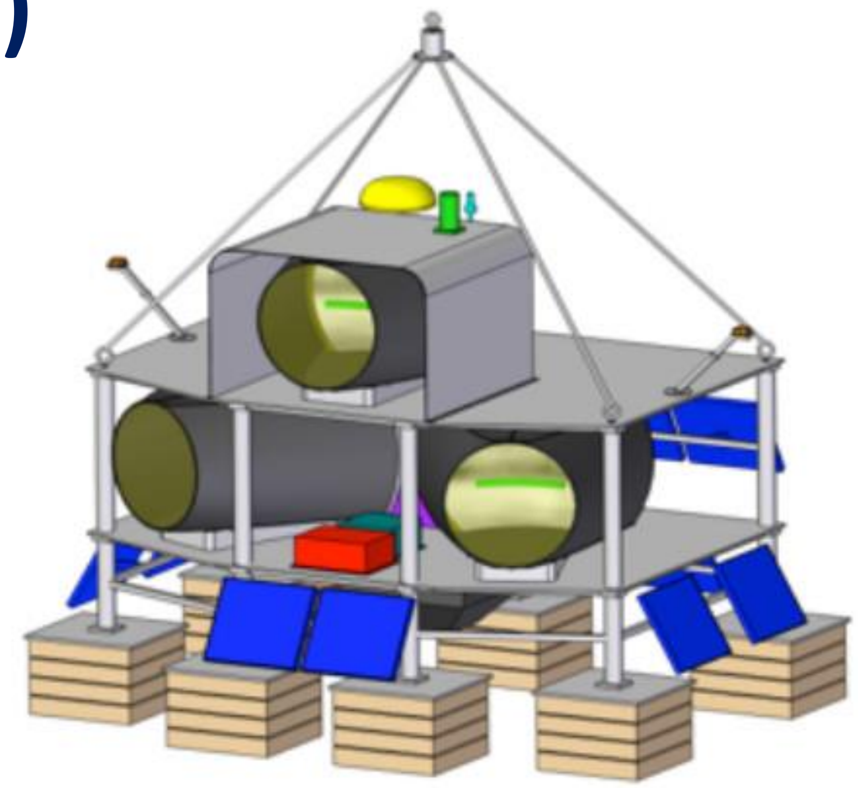


POEMMA

“Hybrid” observation modes



EUSO-Super Pressure Balloon 2 (EUSO-SPB2)



Goals:

- Measurements of background for upward going cosmogenic tau neutrinos
- Observation of Cherenkov light from EAS produced by CRs with E ~ 10^{16}-10^{17} eV
- Observation of fluorescence light from nearly horizontal EAS at high altitude in a nearly constant density atmosphere
  → check hadronic interactions at ultrahigh energies (on ground more muons than expected from existing hadronic interaction models)

Status:

Launch foreseen in 2022

Characteristics:

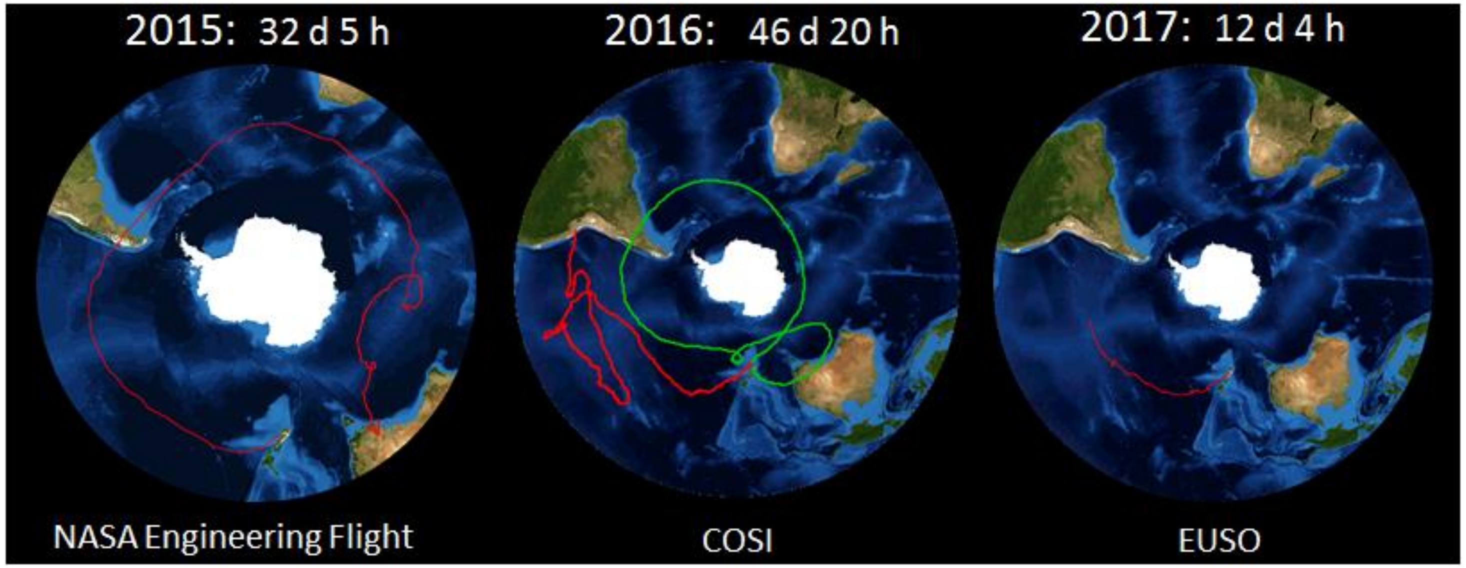
- 2 tel. for Cherenkov light (SiPMs), 1 tel. for fluorescence light (MAPMTs)
- Optics: Schmidt mirrors
- Tilting mechanism from nadir to 10° above the horizon

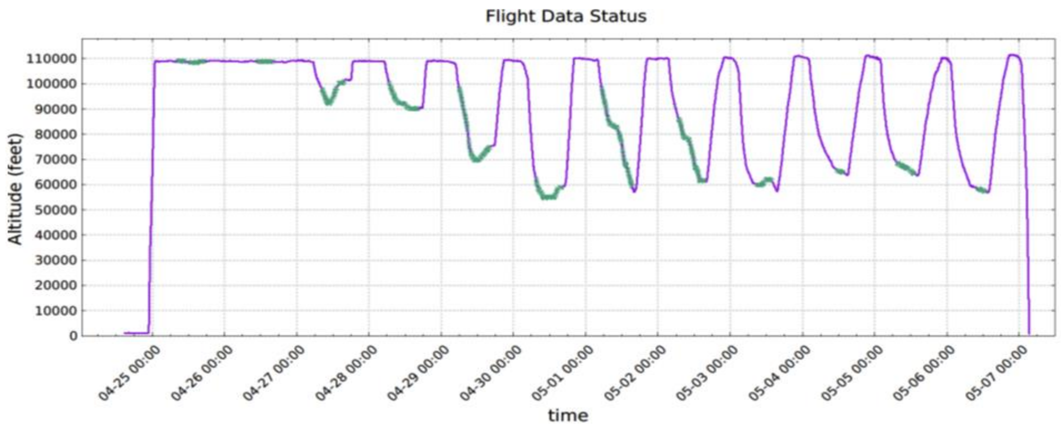
Experience from EUSO-Super Pressure Balloon (EUSO-SPB)

Goals:
- Detect UHECRs for the first time from high altitude
- Test the detector at high altitude
- Measurement of the UV background of the atmosphere from above

Mission start:
25 Aprile 2017 from New Zealand

Mission end:
7 Maggio 2017 Pacific Ocean

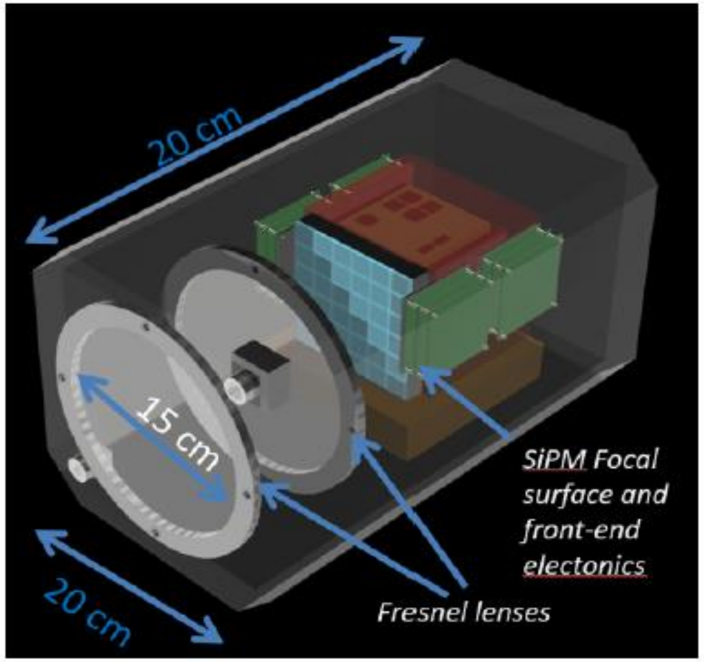


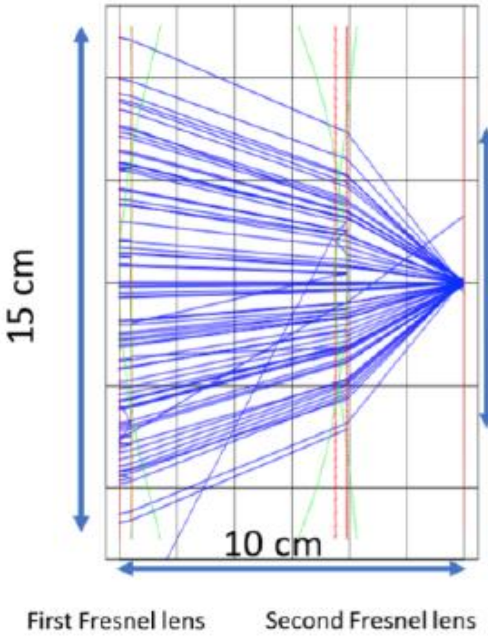


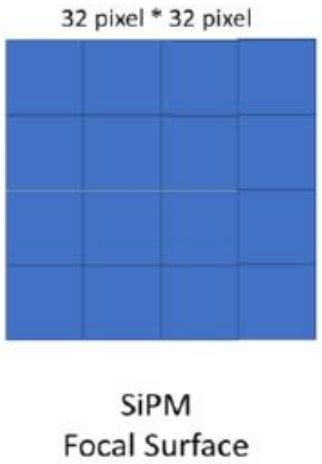
Terzina

Goals:

- Pathfinder experiment in development by Thales Alenia Space to detect high energy astrophysical and cosmogenic neutrino looking to the Cherenkov emission from upward going neutrino induced air showers
- Hosted by the NUSES project, together with other scientific experiments onboard a satellite







Status:

Launch foreseen in 2020

Characteristics:

- Size 20x20 cm^2
- 2 Fresnel lenses with diameter 15 cm
- Focal surface of SiPMs 10x10 cm^2

CORSIKA (modified version) simulations for upward going Cherenkov light

Applications
Considerations
Questions

(by Turin group)

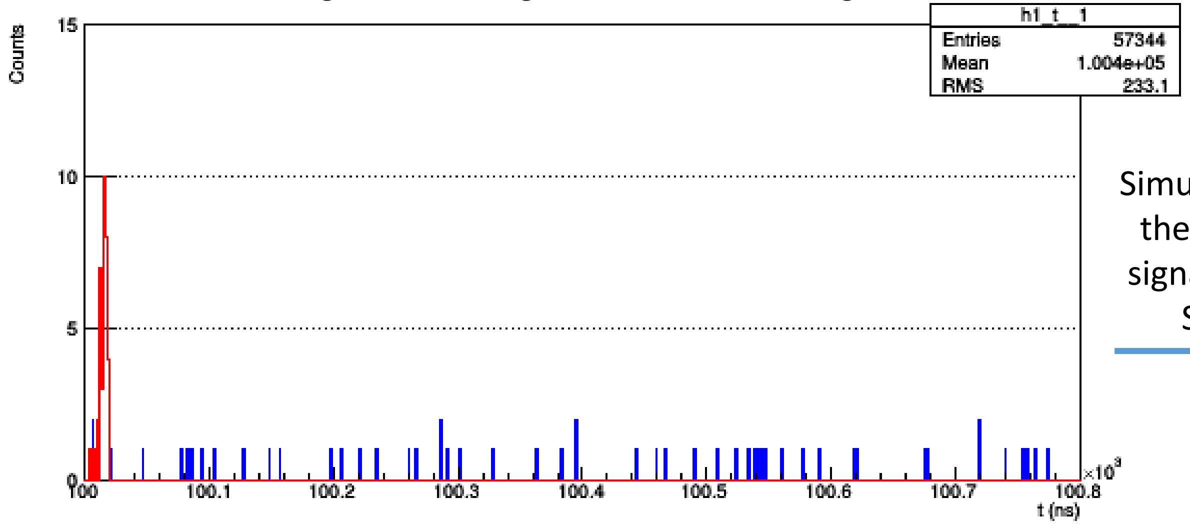
Simulation Cherenkov signal and background

- Work done to design an ASIC board for Terzina for the detection of Cherenkov photons from upward going showers induced by τ (presumably from ν_τ)
  → Main interest in the time information of the signal (not yet in the energy information)
- Exercise done for one pixel of Terzina but can be applied also for POEMMA and EUSO-SPB2
- Generation of **background photons** with different background rates: example reported for **0.057 ph. ns^{-1} $pixel^{-1}$**
- Addition of **Cherenkov photons** from **upward going tau** simulated with CORSIKA (with modified software version provided by Dieter Heck):
  - Zenith 179.9° (almost vertical)
  - Azimuth 45°
  - Energy 10^{13} eV → rescaled to 10^{17} eV changing the area on which the photon flux was generated (some problems with the thinning simulating directly a τ with energy 10^{17} eV)
- Simulation of a **SiPM response** (electronics engineers) → Analog signal
- **Sampling** and **digitization** of the analog signal

Simulation Cherenkov signal and background

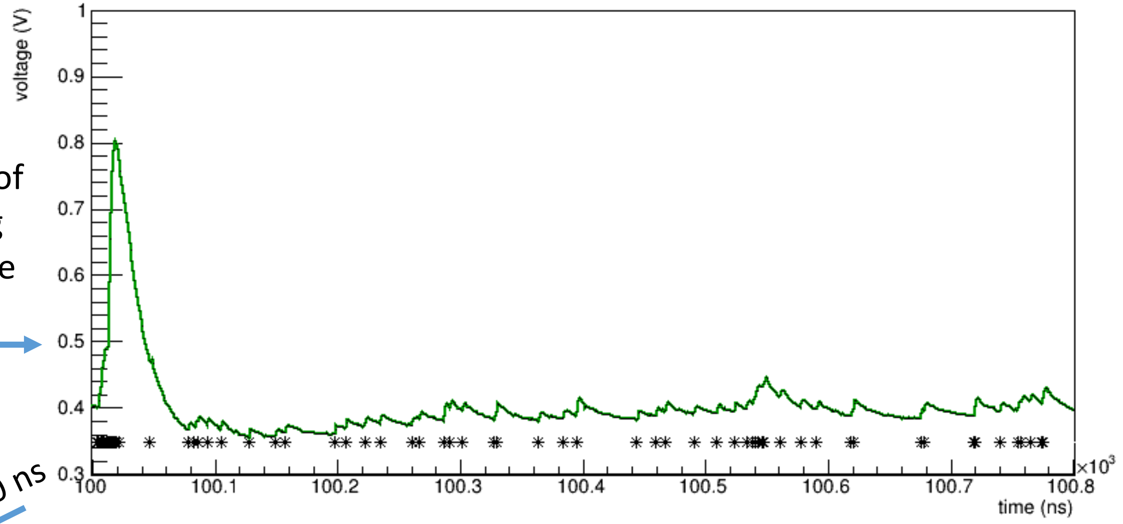
Mean background 0.057 photons ns^{-1} pixel^{-1}

Random generated background and Cherenkov signal



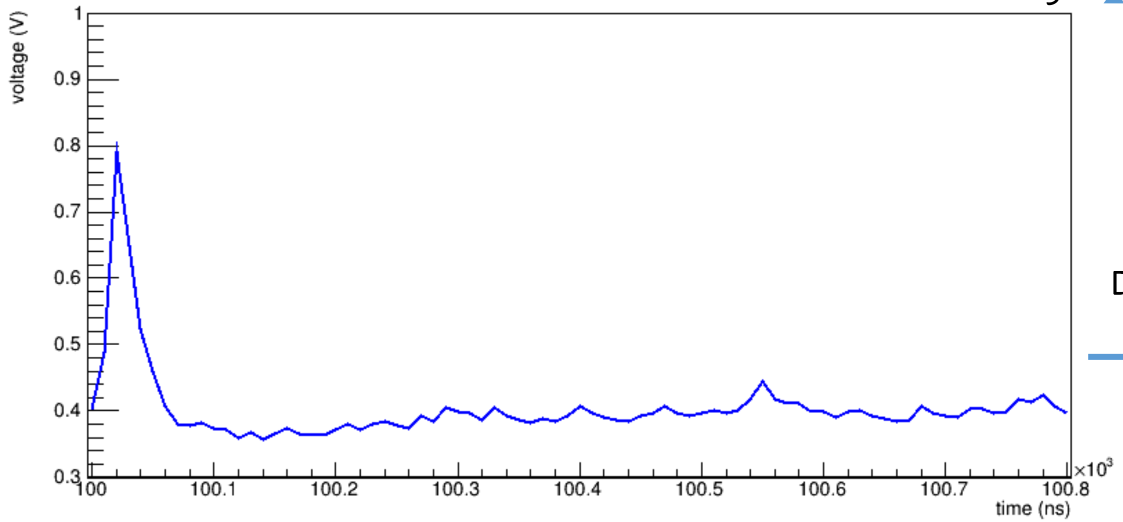
Simulation of the analog signal of the SiPM

Simulated analog signal and incoming photons



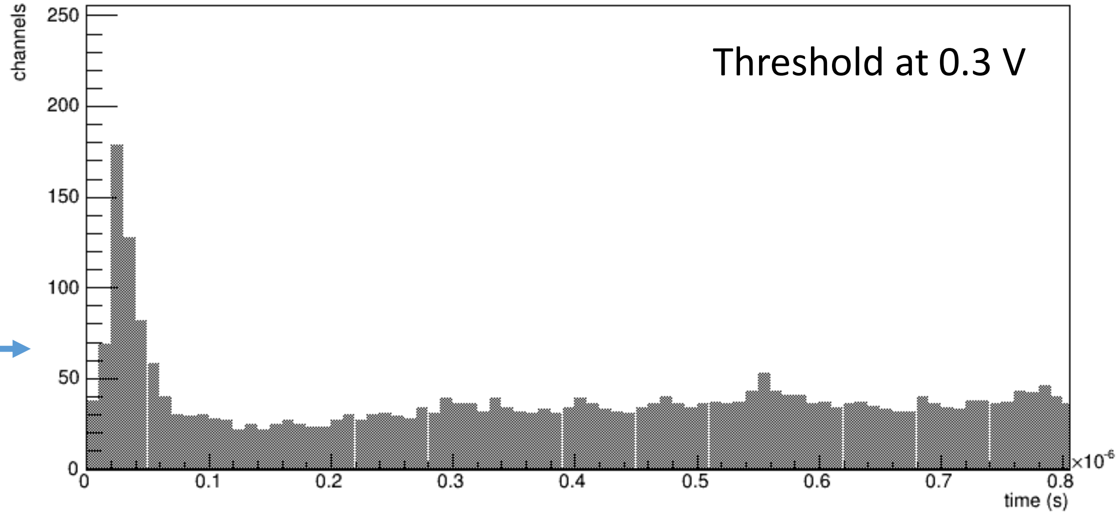
Sampling each 10 ns

Analog signal sampled each 10 ns



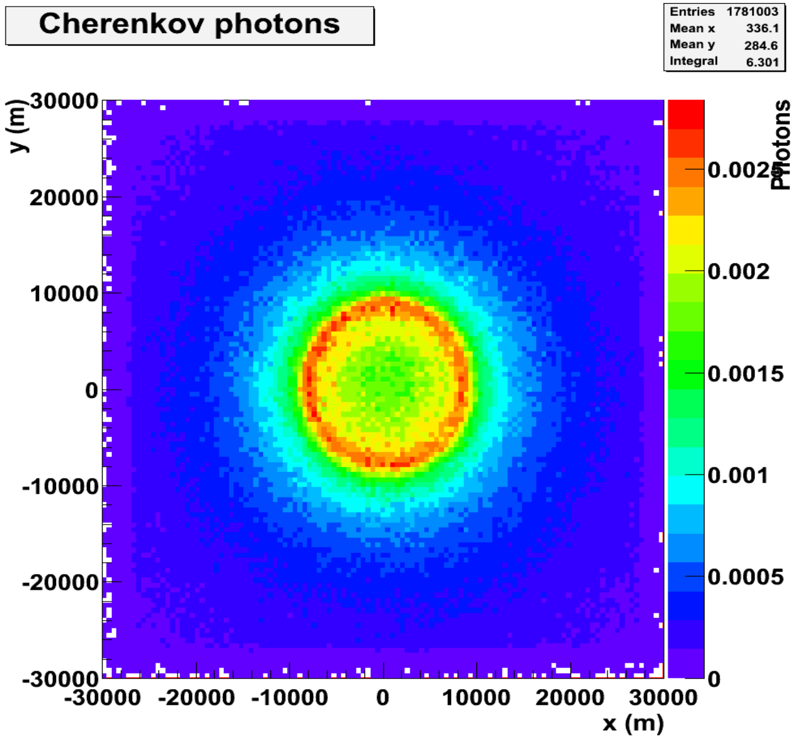
Digitization 8 bit

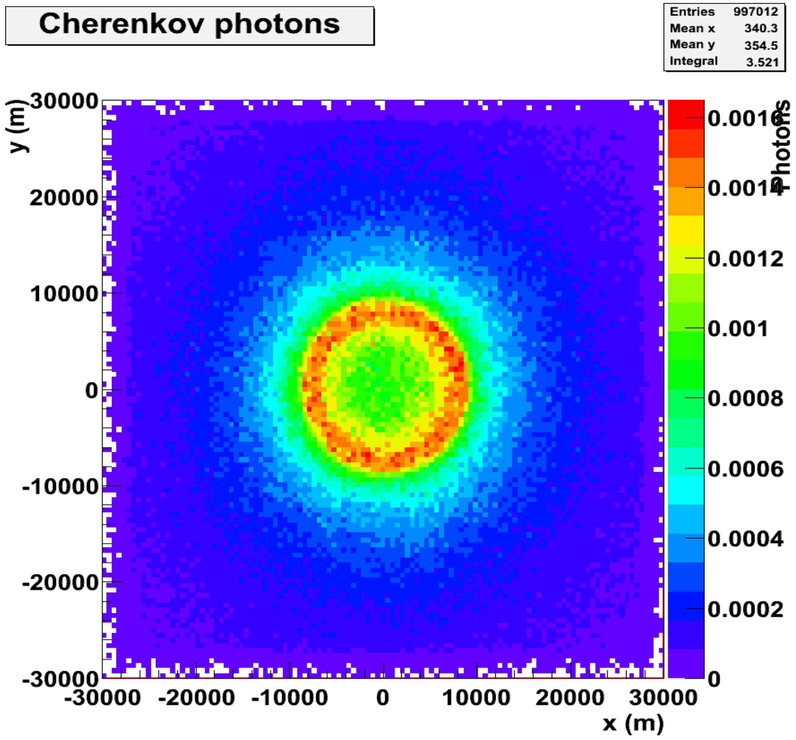
Dynamic range 0.3-1 V → 2.75 mV/ch.

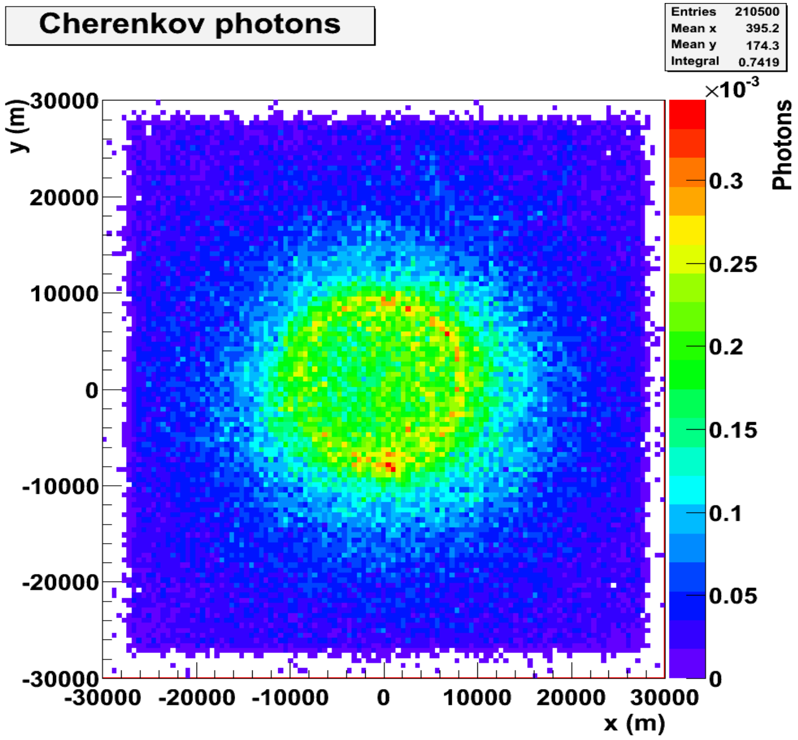


Some test simulations (1)

3 events simulated in the same run







Entries	1781003	997012	210500

Some test simulations (2)

Main tau lepton decay channels

Decay channel	Secondaries	Branching ratio [%]
$\tau^- \to \pi^- \ \nu_\tau$	π^-	11.8
$\tau^- \to \pi^- \ \pi^0 \nu_\tau$	π^-, $\pi^0 \to 2\gamma$	25.8
$\tau^- \to \pi^- \ 2\pi^0 \nu_\tau$	π^-, $2\pi^0 \to 4\gamma$	10.79
$\tau^- \to \pi^- \ \pi^- \pi^+ \nu_\tau$	$2\pi^-$, π^+	10.0
$\tau^- \to \pi^- \ \pi^- \pi^+ \pi^0 \nu_\tau$	$2\pi^-$, π^+, $\pi^0 \to 2\gamma$	5.18
$\tau^- \to \pi^- \ \pi^0 \pi^0 \pi^0 \nu_\tau$	$2\pi^-$, $3\pi^0 \to 6\gamma$	1.23
Total hadronic		64.8
$\tau^- \to e^- \bar{\nu}_e \nu_\tau$	e^-	17.8
$\tau^- \to \mu^- \bar{\nu}_e \nu_\tau$	μ^-	17.4
Total leptonic		35.2

Some test simulations (3)

Portion of DAT000XXX.long file

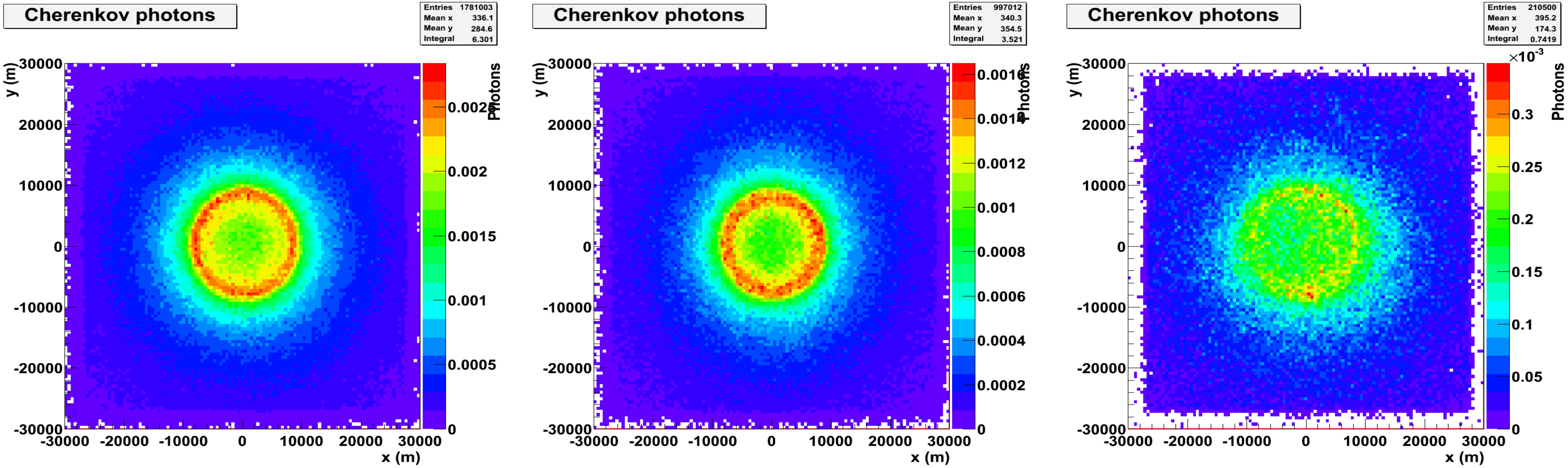
LONGITUDINAL ENERGY DEPOSIT IN 104 VERTICAL STEPS OF 10. G/CM**2 FOR SHOWER 1

DEPTH	GAMMA	EM IONIZ	EM CUT	MU IONIZ	MU CUT	HADR IONIZ	HADR CUT	NEUTRINO	SUM
5.	6.67290E-01	1.36054E+01	2.96637E+00	2.46244E+00	2.71317E-01	8.79934E-02	6.63577E-01	1.25857E+01	3.33100E+01
15.	6.61956E-01	1.40712E+01	3.07874E+00	2.54470E+00	0.00000E+00	1.07969E-01	2.82835E-01	3.10508E-01	2.10579E+01
25.	7.39703E-01	1.54624E+01	3.37604E+00	2.56152E+00	0.00000E+00	1.07969E-01	0.00000E+00	0.00000E+00	2.22476E+01
35.	8.42619E-01	1.69930E+01	3.61885E+00	2.56287E+00	0.00000E+00	1.21694E-01	5.01924E-01	0.00000E+00	2.46410E+01
45.	8.23727E-01	1.87396E+01	3.84854E+00	2.56984E+00	1.35658E-01	1.35854E-01	8.32624E-02	0.00000E+00	2.63365E+01
55.	8.57989E-01	1.91272E+01	3.94443E+00	2.59640E+00	0.00000E+00	1.49817E-01	8.82094E-01	3.94399E-01	2.79523E+01
65.	9.54255E-01	2.08233E+01	4.28625E+00	2.62319E+00	0.00000E+00	2.36015E-01	3.00001E-02	4.27151E-01	2.93802E+01
…									
…									
955.	1.13855E-01	7.87880E+00	6.00699E-01	6.32178E-01	0.00000E+00	6.44264E-01	1.17170E+00	2.63985E+00	1.36813E+01
965.	4.58378E-02	5.28093E+00	3.53135E-01	4.58520E-01	3.57774E-01	6.49599E-01	1.99607E+00	8.64655E+00	1.77884E+01
975.	3.62203E-02	3.11777E+00	1.63031E-01	2.95564E-01	0.00000E+00	6.35000E-01	1.17456E+00	2.39415E+00	7.81628E+00
985.	1.60234E-02	1.58428E+00	1.05972E-01	1.51593E-01	3.52018E-01	6.21126E-01	1.17278E+00	5.92786E+00	9.93166E+00
995.	1.17423E-02	7.79642E-01	6.08307E-02	5.85302E-02	3.06593E-01	4.91114E-01	2.89727E-01	1.59053E+01	1.79035E+01
1005.	4.39748E-03	2.48603E-01	2.40000E-02	1.12109E-02	3.57199E-01	1.91393E-01	1.02504E-01	5.48092E-01	1.48740E+00
1015.	1.20316E-03	1.15233E-01	6.00000E-03	0.00000E+00	0.00000E+00	4.16366E-02	0.00000E+00	0.00000E+00	1.64073E-01
1025.	0.00000E+00	4.15000E-02	3.00000E-03	0.00000E+00	0.00000E+00	4.16366E-02	0.00000E+00	0.00000E+00	8.61366E-02
1035.	0.00000E+00	1.38039E-02	3.00000E-03	0.00000E+00	0.00000E+00	1.91450E-02	1.33515E-01	6.49671E+02	6.49840E+02

- Is the grammage of the vertical steps considering that the air shower goes upward? i.e. Is the max neutrino energy reported in the table relative to ground or top level?

Some test simulations (4)

3 events simulated in the same run



Entries	1781003	997012	210500
ν energy loss (GeV)	6.49671E+02	4.69887E+03	8.31172E+03

- Is it reasonable to think that the energy transported by the neutrino is the cause of less photons?
- Is it possible to know/set the τ decay channel in the simulation? (not found in the manual, yet…)

Comments on EAS Simulation Requirements for Space-based Measurements

(*The POEMMA Simulation Group*)

Comments on EAS Simulation Requirements for Space-based Measurements

The POEMMA Simulation Group

John Krizmanic (CRESST/NASA/GSFC/UMBC)
Toni Venters (NASA/GSFC)
Angela Olinto (Chicago)
Mary Hall Reno (Iowa)
Johannes Ester (CSM)
Fred Sarazin (CSM)
Lawrence Wiencke (CSM)
Doug Bergman (Utah)
Luis Anchordoqui (Lehman)
James Adams (UAH)
A. Nepomuk Otte (GeorgiaTech)
Mario Bertaina (Torino)
Francesco Fenu (Torino)
Kenji Shinozaki (Torino)
Francesca Bisconti (Torino)
Andrii Neronov (Geneva)
Simon Mackovjak (IEP SAS)

Abstract: We provide some commentary on the simulation requirements for extensive air showers (EAS) in view of suborbital- and space-based observations for downward moving, upward moving, and over the Earth limb EAS.

Downward-moving EAS:

1. *Accurate generation of fluorescence and Cherenkov light (200 nm -> 900 nm)*. The large wavelength bandpass for Cherenkov generation is imposed by considering both PMT and SiPM photodetector responses. While the Earth's ozone layer will attenuate the Cherenkov signal below ~300 nm, there is phase space for a suborbital instrument to observe the Cherenkov signal with only slight attenuation.
2. *Reflection of the Cherenkov (and fluorescence signal) off the ground (& clouds see below).* This requires modeling of the reflection and propagating the photons to higher altitudes. Baseline model and ability to include user defined model.
3. *Accurate baseline atmospheric propagation & attenuating/scattering model* including model of effects due to aerosol and ozone layers. Baseline model and ability to include user defined model.
4. *Ability to model variable atmospheric conditions*: space-based observations inherently view different volumes of the atmosphere. Baseline model and ability to include user defined model.
5. *Ability to model the attenuation and reflection of the EAS Cherenkov (and fluorescence signal) due to cloud cover*. Baseline model and ability to include user defined model.

Upward-moving EAS:

1. ***Accurate generation of fluorescence and Cherenkov light (200 nm -> 900 nm)***.
2. ***Accurate baseline atmospheric propagation & attenuating/scattering model*** including aerosol layer and ozone layer. Aerosol attenuation of the Cherenkov signal from EAS due to t-lepton induced EAS can strongly affect the signal, especially at small Earth-emergence angles. Baseline model and ability to include user defined model.
3. ***Ability to model variable atmospheric conditions***: space-based observations inherently view different volumes of the atmosphere. Baseline model and ability to include user defined model.
4. ***Ability to model the attenuation and reflection of the EAS Cherenkov (and fluorescence signal) due to cloud cover***. Baseline model and ability to include user defined model.

… continues

…

5. ***Propagation of photons and particles in the upward-direction*** with the ability to start the upward EAS at arbitrary altitude and angle. Upward t-lepton induced EAS can occur at higher altitudes; if the atmosphere is thin enough, EAS longitudinal develop extends over long distances and can have significant EAS charged particle flux at suborbital altitudes; if EAS begins at an altitude above ~20 km, charged particle content gets 'frozen' due to developing in a rarified atmosphere, thus there is potential for charged particle flux at Low Earth Orbit (LEO); since suborbital (and maybe space-based) observations can sample charged-particle flux from EAS, hadronic modeling is also important for upward-moving EAS.
6. ***Ability to accurately model the t-lepton decay and form the resultant composite EAS*** from the t-lepton decay particles, including modeling of muonic EAS.

Cherenkov signal from EAS above the Earth's Limb:

1. Upward-moving items 1-5 above.
2. Modeling of the refractive nature of the atmosphere when viewing Cherenkov signals very near the Earth's horizon.

Thanks for your attention!

Backup slides

Cutoff at $E > 5 \cdot 10^{19}$ eV

Interaction of the protons and nuclei with the photons of the Cosmic Microwave Background (CMB). This effect is called Greisen-Zatsepin-Kuzmin (GZK) effect. Protons can interact via the process of photo-pion production, where the mass of the resonance Δ+ is $m_{\Delta+}$ = 1232 MeV. The kinetic energy of protons is reduced by the energy needed to form the pion.

$$\begin{aligned} p + \gamma_{\text{CMB}} \rightarrow \Delta^{+} \quad & \rightarrow \quad p + \pi^{0} \rightarrow p + \gamma\gamma \\ & \rightarrow \quad n + \pi^{+} \rightarrow n + \mu^{+} + \nu_{\mu} \end{aligned}$$

Heavier nuclei with atomic mass number A are fragmented into lighter nuclei (with n nucleons N) due to its excitation for giant dipole resonances at similar energies. This effect is named photo-disintegration and can occur both with the CMB and the Extragalactic Background Light (EBL). This effect can produce secondary protons that may lose energy with the GZK effect.

$$A + \gamma_{\text{CMB,EBL}} \rightarrow (A - nN) + nN.$$

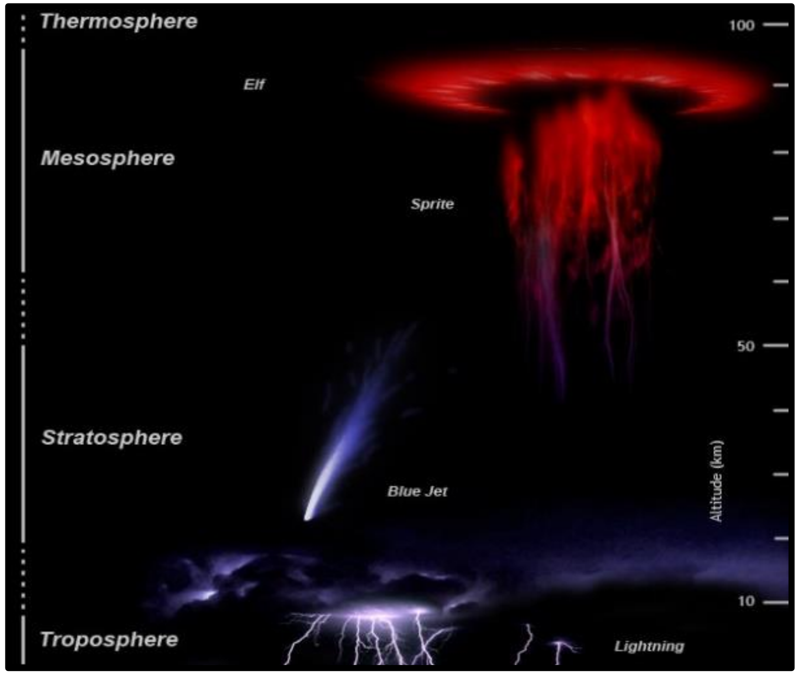
JEM-EUSO Scientific goals

Astrophysics and Cosmology

- Detection of UHECRs and high energy neutrino
  → End of the CR spectrum at E>10^{20} eV
- Identification of the UHECRs sources

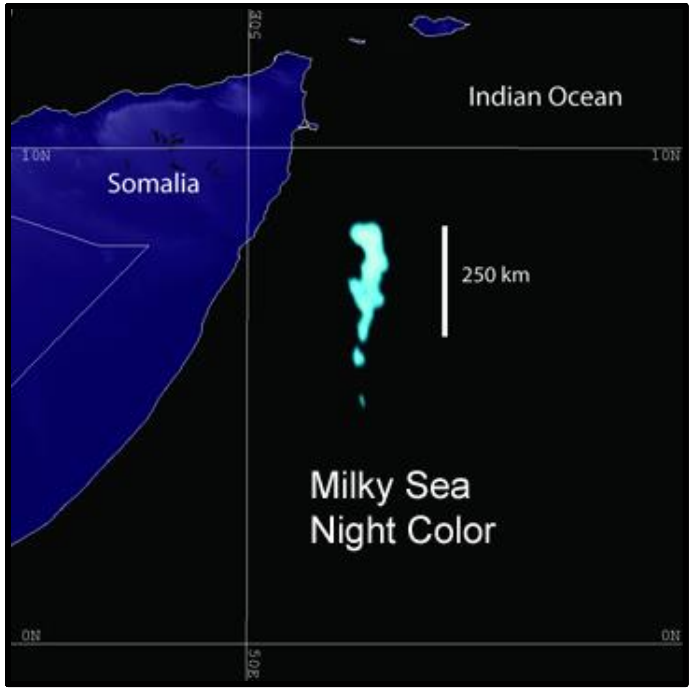
Atmospheric Science

- Nightglow
- Transient luminous events (red sprites, elves, blue jets)
- Slow events (meteors)



Natural Science

- Animal and plant bioluminescence



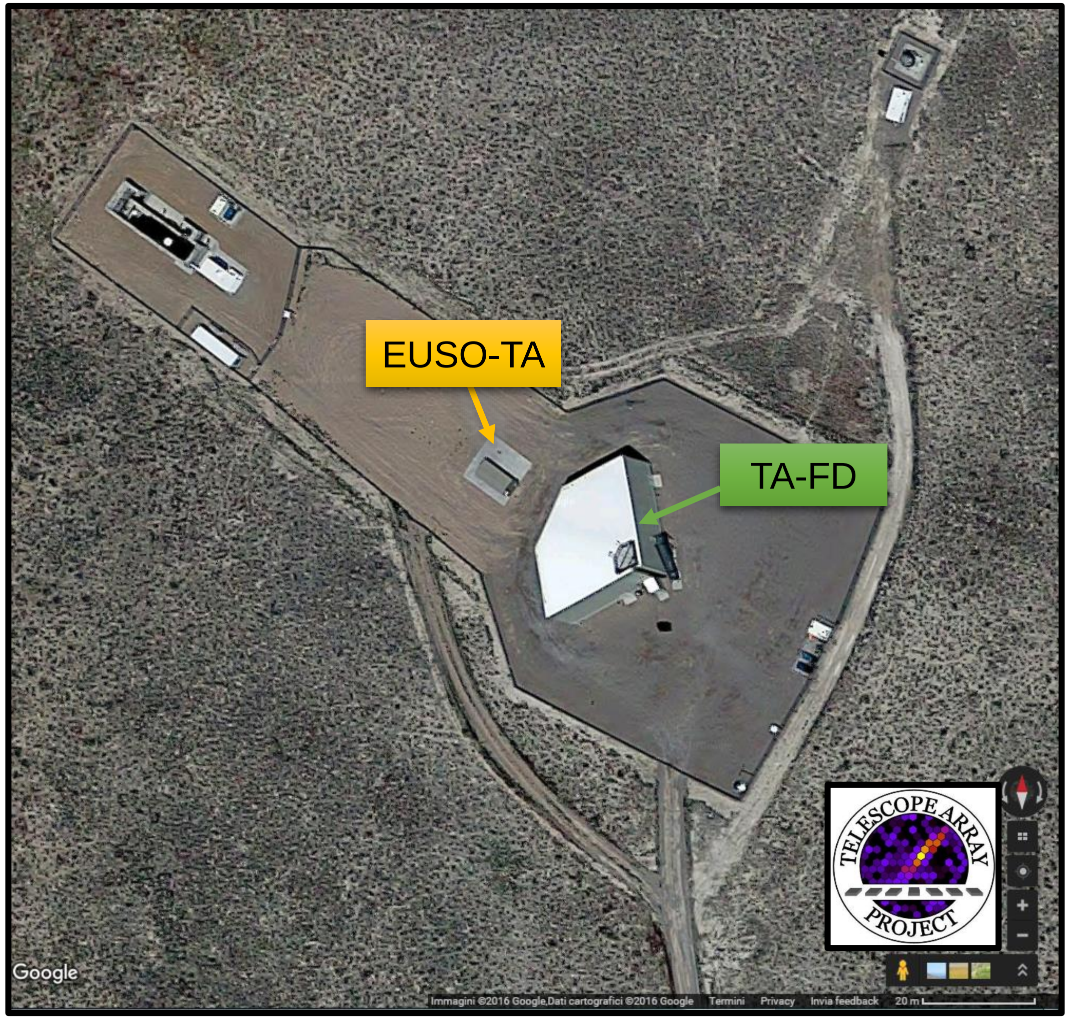
A new window on the unknown…

- Search for nuclearites made of Strange Quark Matter (SQM), the dark matter could be made of

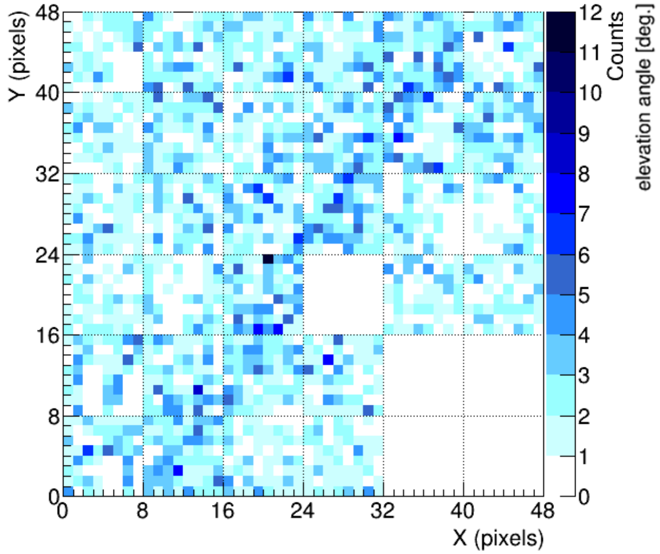
EUSO-TA at the Telescope Array site (Utah, USA)

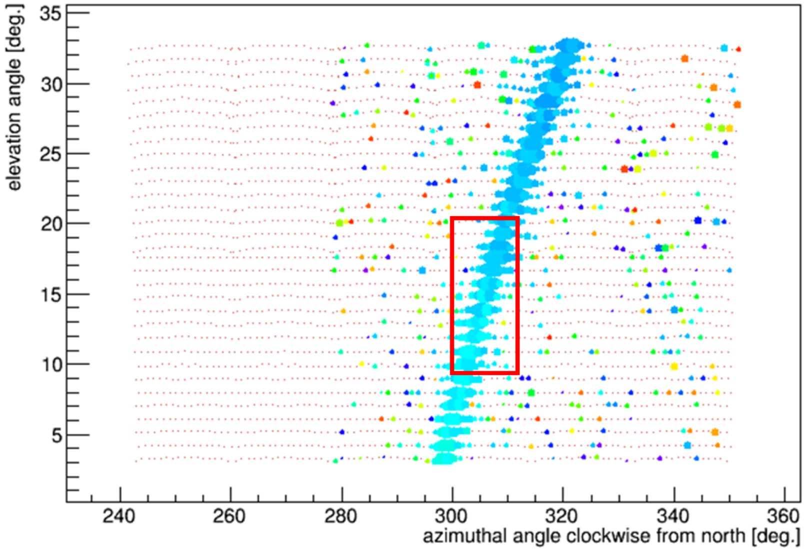
Goals:
Test the detector design and the detection principle

Missions: 2015-2016 → Upgrade by end 2018

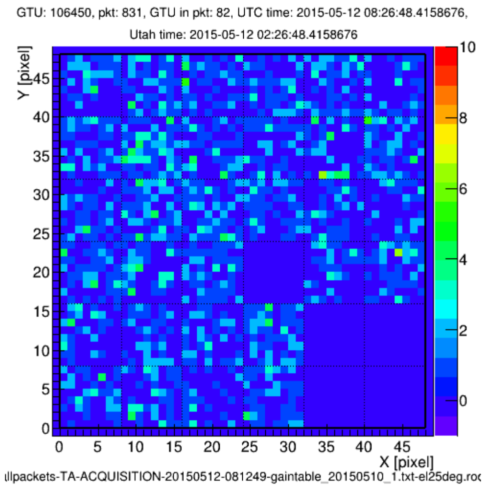


Same CR event seen by EUSO-TA and Telescope Array (13 May 2015)

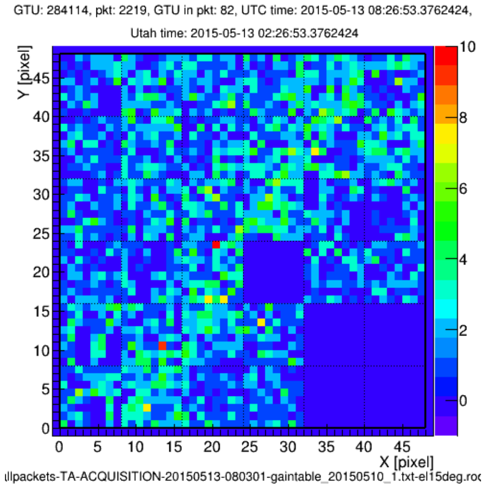




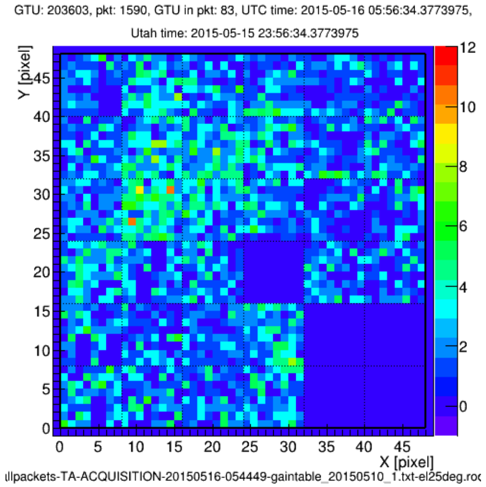
Events detected by EUSO-TA



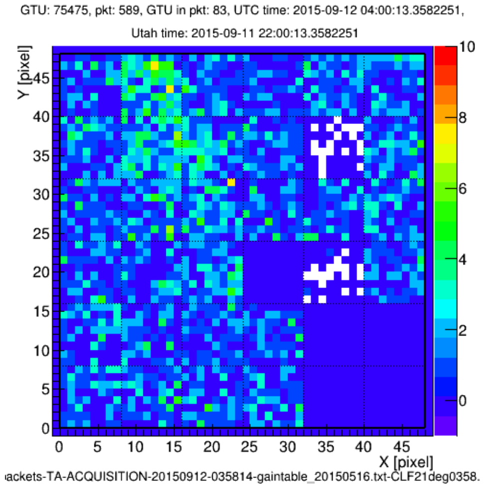
1. logErec=18.69
   Rp=8.3



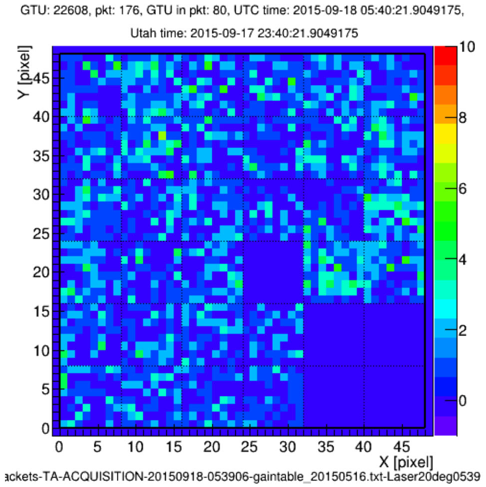
2. logErec=18.06
   Rp=2.5



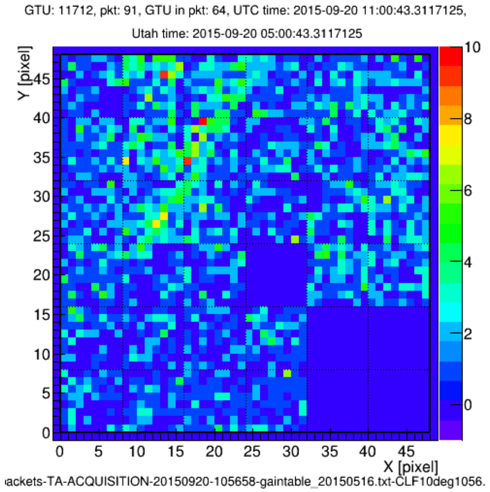
3. logErec=18.20
   Rp=0.8



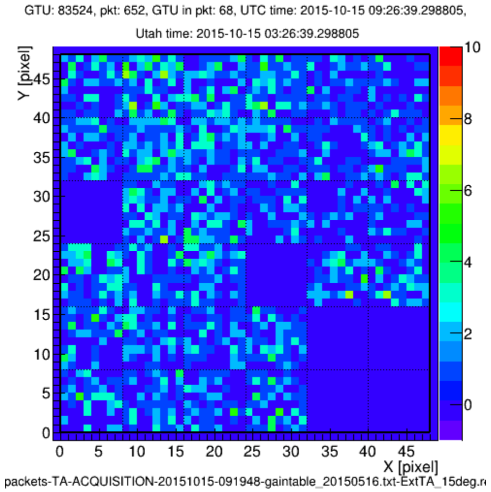
4. logErec=18.05
   Rp=5.0



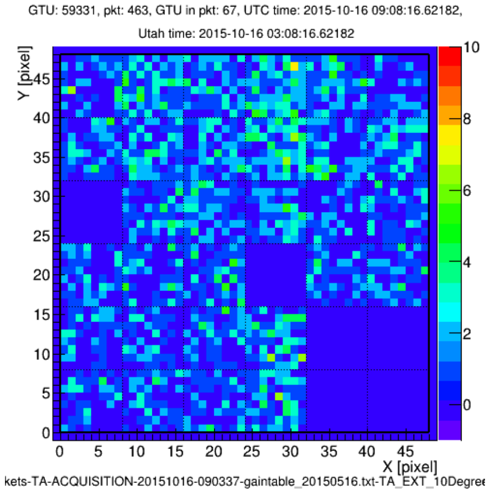
5. logErec=18.51
   Rp=9.1



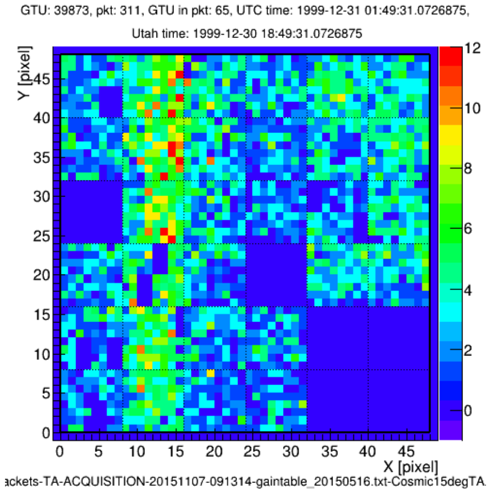
6. logErec=18.38
   Rp=6.7



7. logErec=18.52
   Rp=9.0



8. logErec=17.71
   Rp=1.7



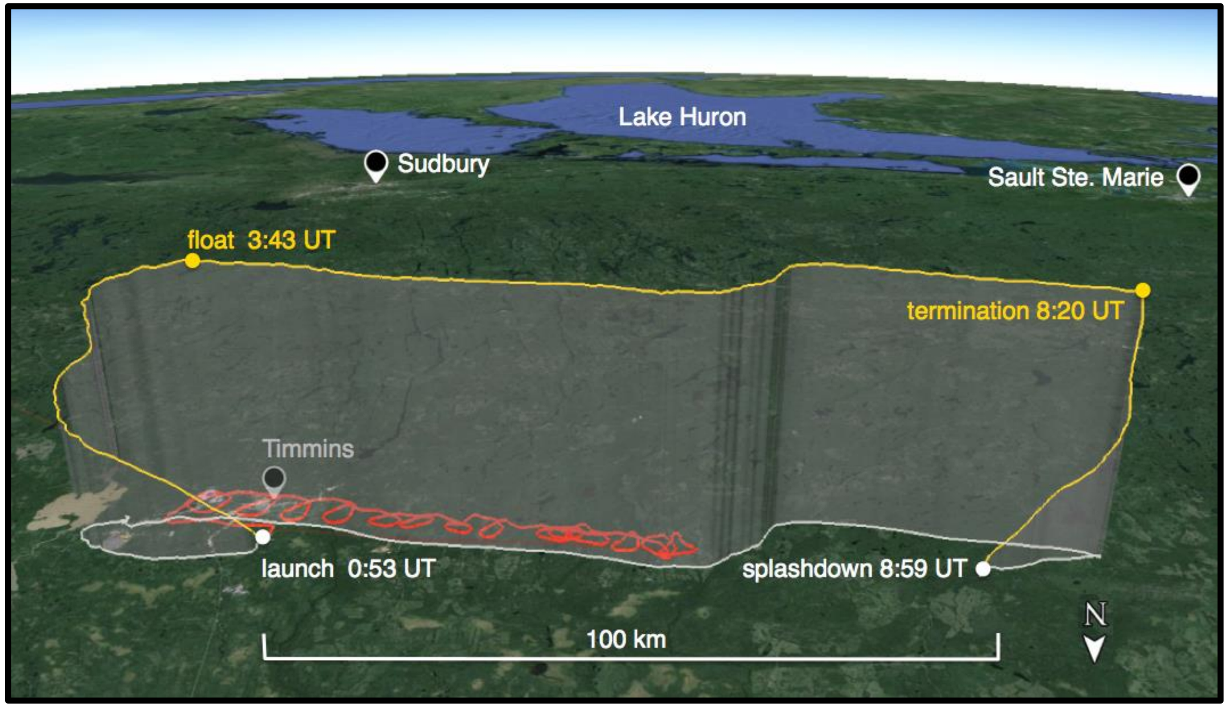
9. logErec=18.42
   Rp=2.6

EUSO-Balloon

Goals:

- Test the detector with UV lasers and flashers from an helicopter
- Measurement of the UV background of the atmosphere

Mission: 25 August 2014 from Timmins, Canada, 1 night

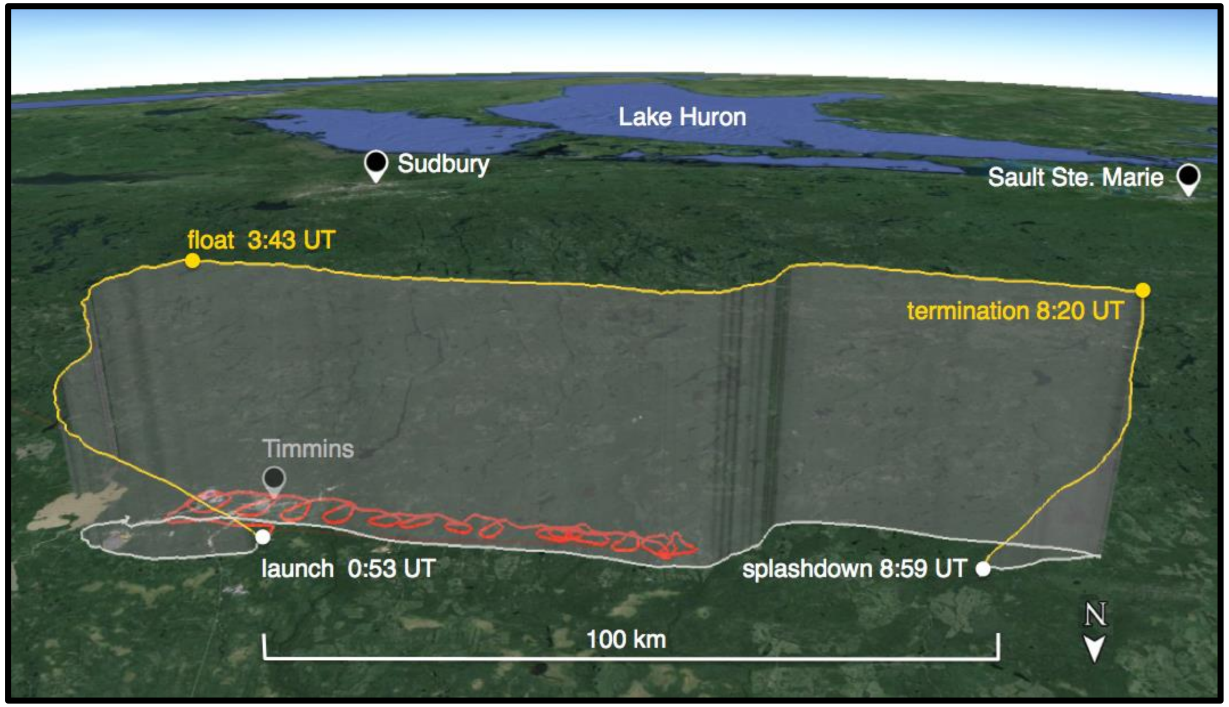


EUSO-Balloon

Goals:

- Test the detector with UV lasers and flashers from an helicopter
- Measurement of the UV background of the atmosphere

Mission: 25 August 2014 from Timmins, Canada, 1 night

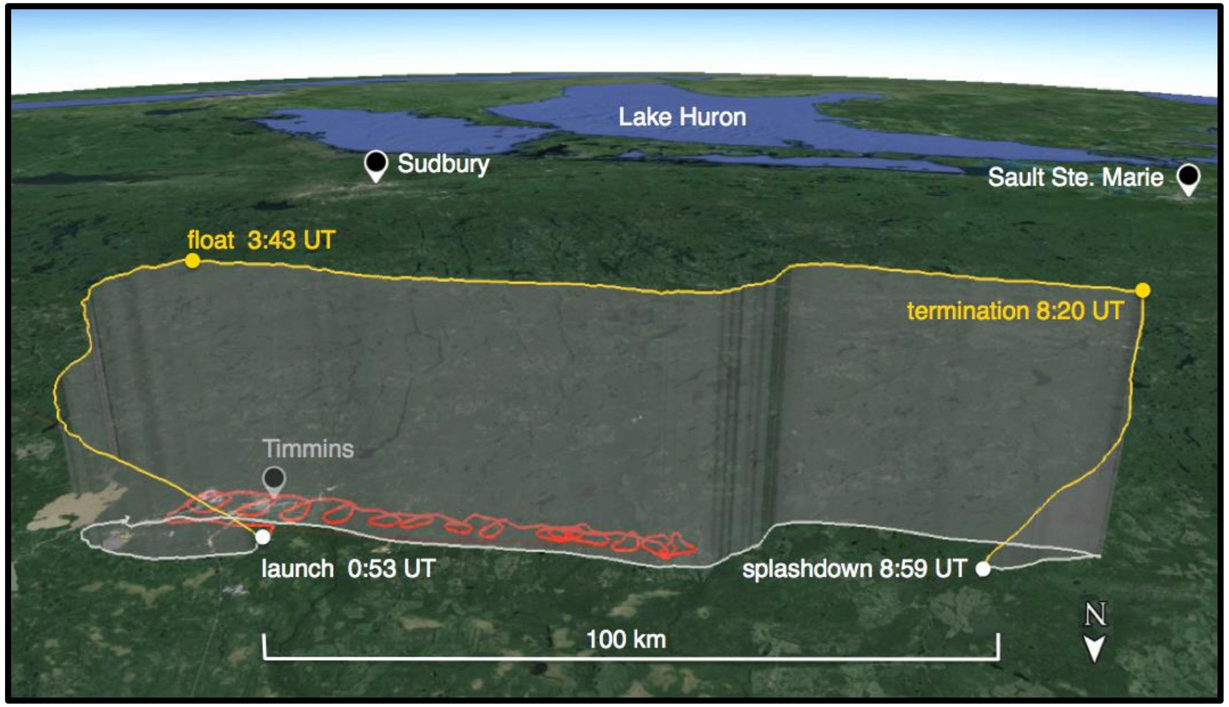


EUSO-Balloon

Goals:

- Test the detector with UV lasers and flashers from an helicopter
- Measurement of the UV background of the atmosphere

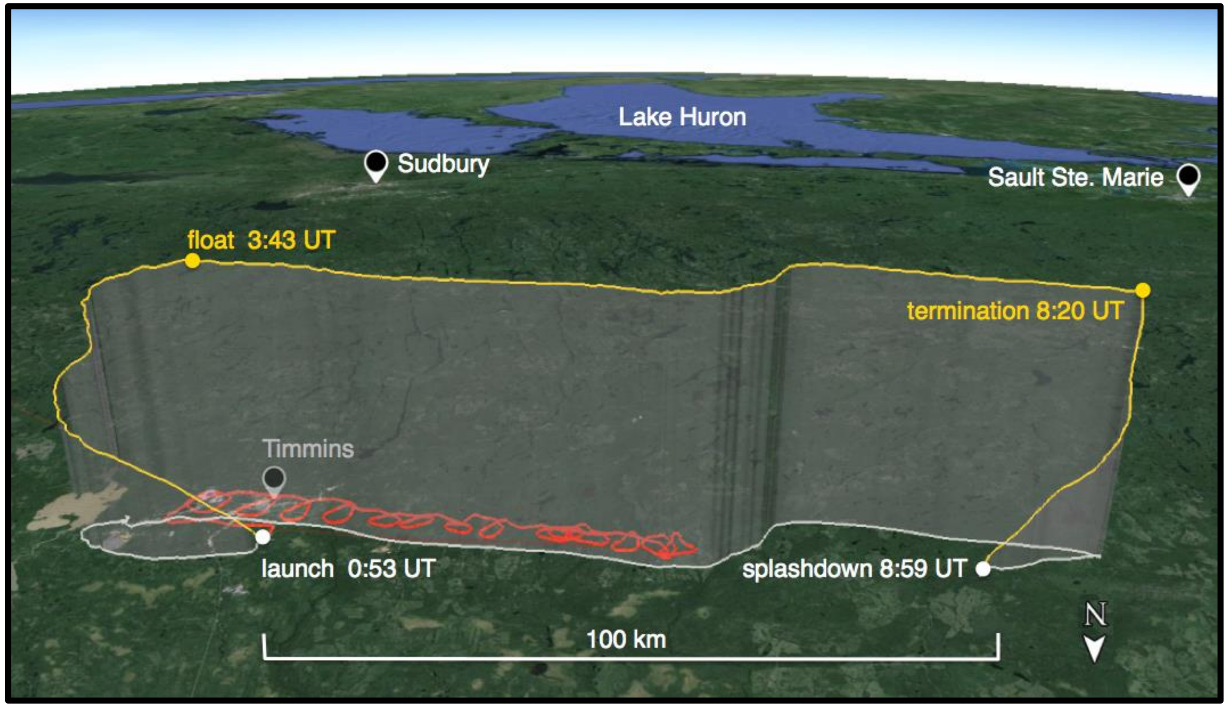
Mission: 25 August 2014 from Timmins, Canada, 1 night



EUSO-Balloon

Goals:
- Test the detector with UV lasers and flashers from an helicopter
- Measurement of the UV background of the atmosphere

Mission: 25 August 2014 from Timmins, Canada, 1 night

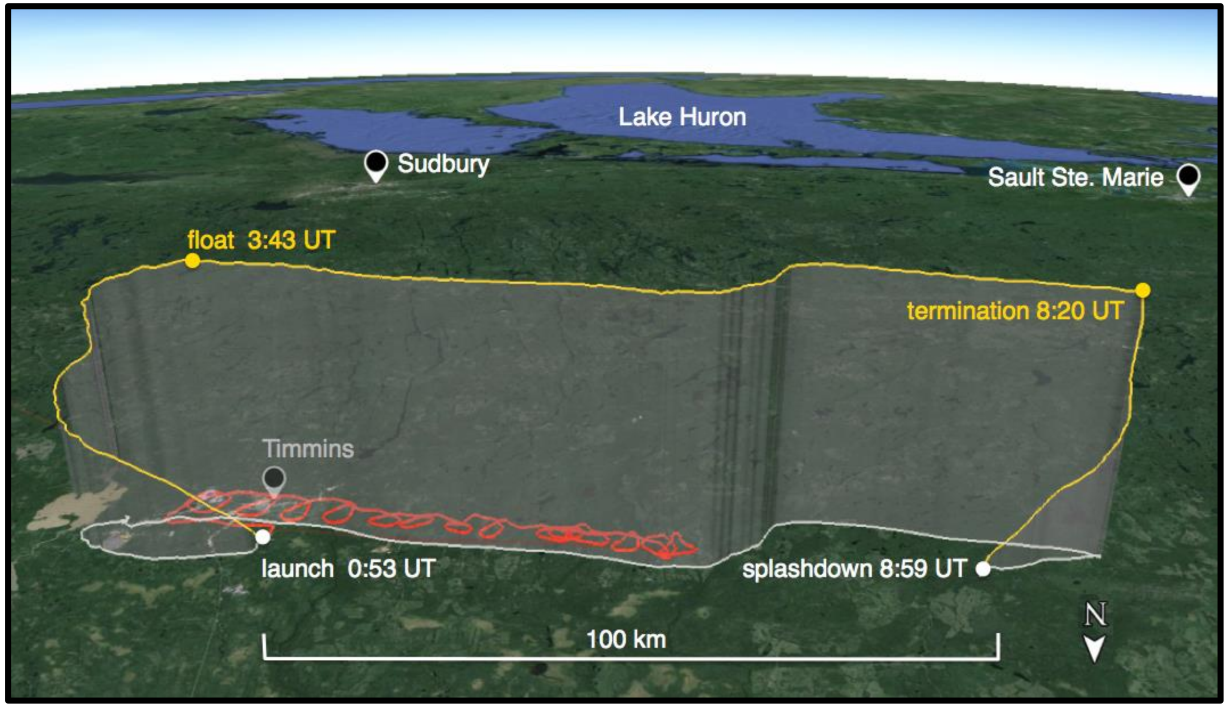


EUSO-Balloon

Goals:

- Test the detector with UV lasers and flashers from an helicopter
- Measurement of the UV background of the atmosphere

Mission: 25 August 2014 from Timmins, Canada, 1 night



Mini-EUSO inside the ISS

Goals:

- Test the design of the detector in space
- First nighttime UV map of the Earth
- Study of atmospheric phenomena and bioluminescence
- Study of meteores

Mission start: Foreseen in 2018/19