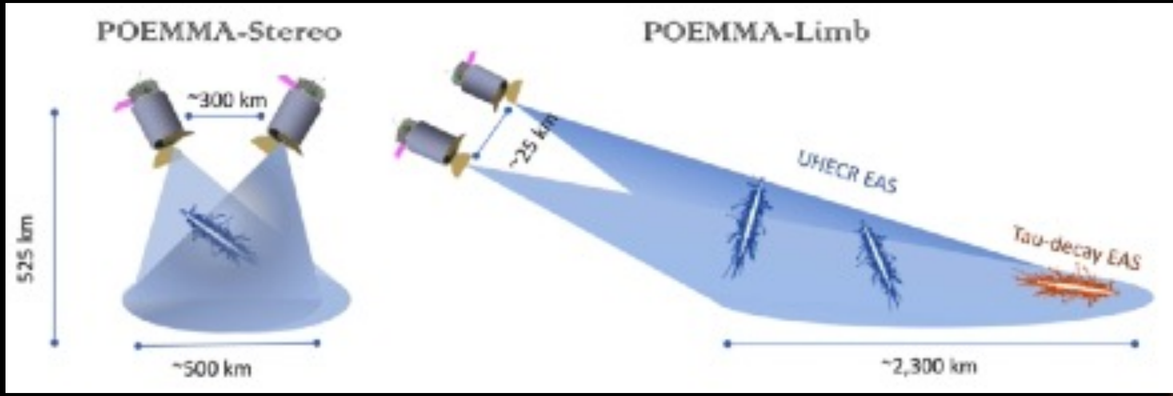
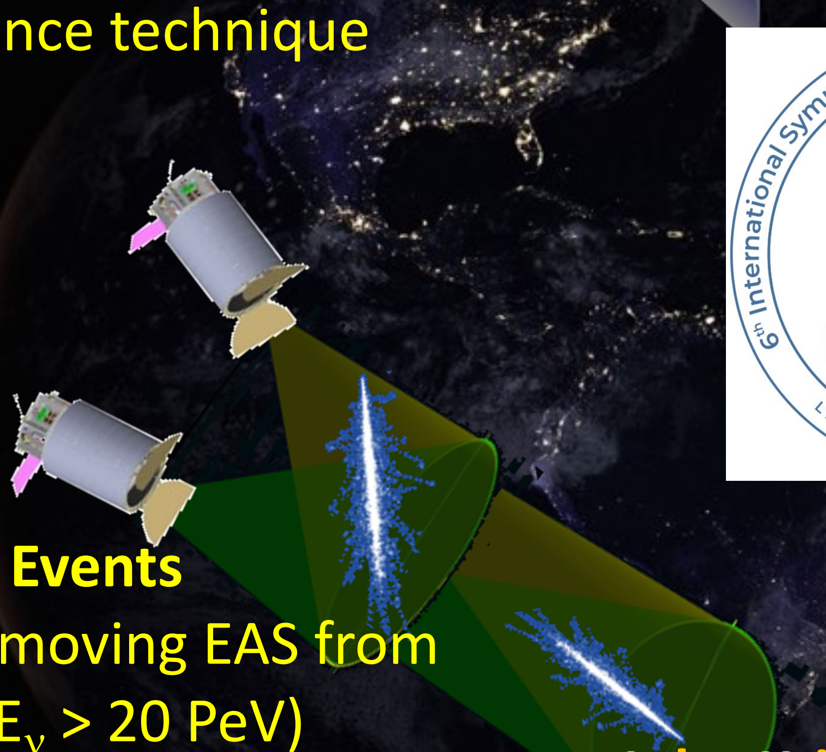
Poetry in Orbit: MultiMessenger Astrophysics with the Probe Of Extreme Multi-Messenger Astrophysics (POEMMA)

Science Goals:

- **Discover the origin of Ultra-High Energy Cosmic Rays**
  Measure Spectrum, composition, Sky Distribution at Highest Energies (E_{CR} > 20 EeV) using stereo air fluorescence technique



- **Observe Neutrinos from Transient Astrophysical Events**
  Measure beamed Cherenkov light from upward-moving EAS from τ-leptons source by ν_τ interactions in the Earth (E_ν > 20 PeV)



John Krizmanic
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for the POEMMA Collaboration

Poetry in Orbit: MultiMessenger Astrophysics with the Probe Of Extreme Multi-Messenger Astrophysics (POEMMA)

PERFORMANCE AND SCIENCE REACH OF THE PROBE OF ... PHYS. REV. D **101**, 023012 (2020)

UHECRs: E > 20 EeV

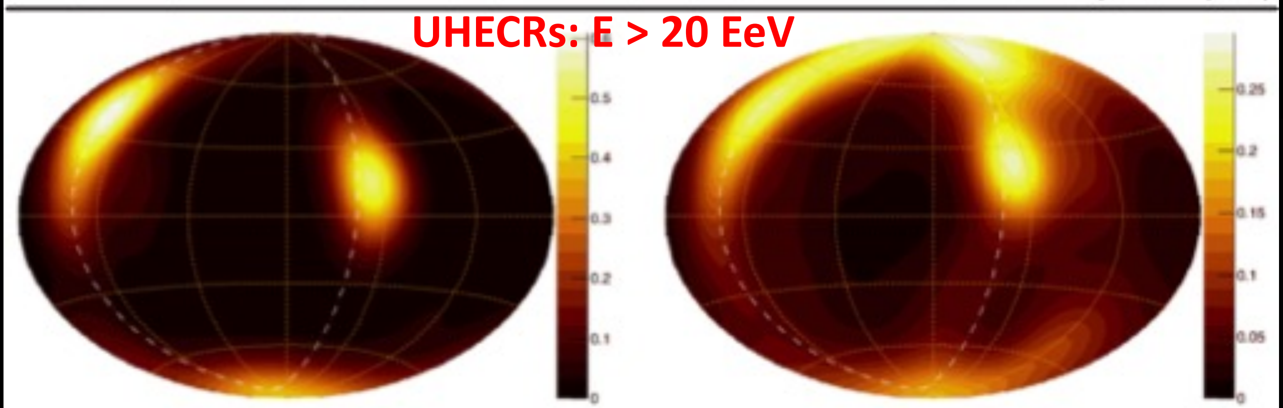
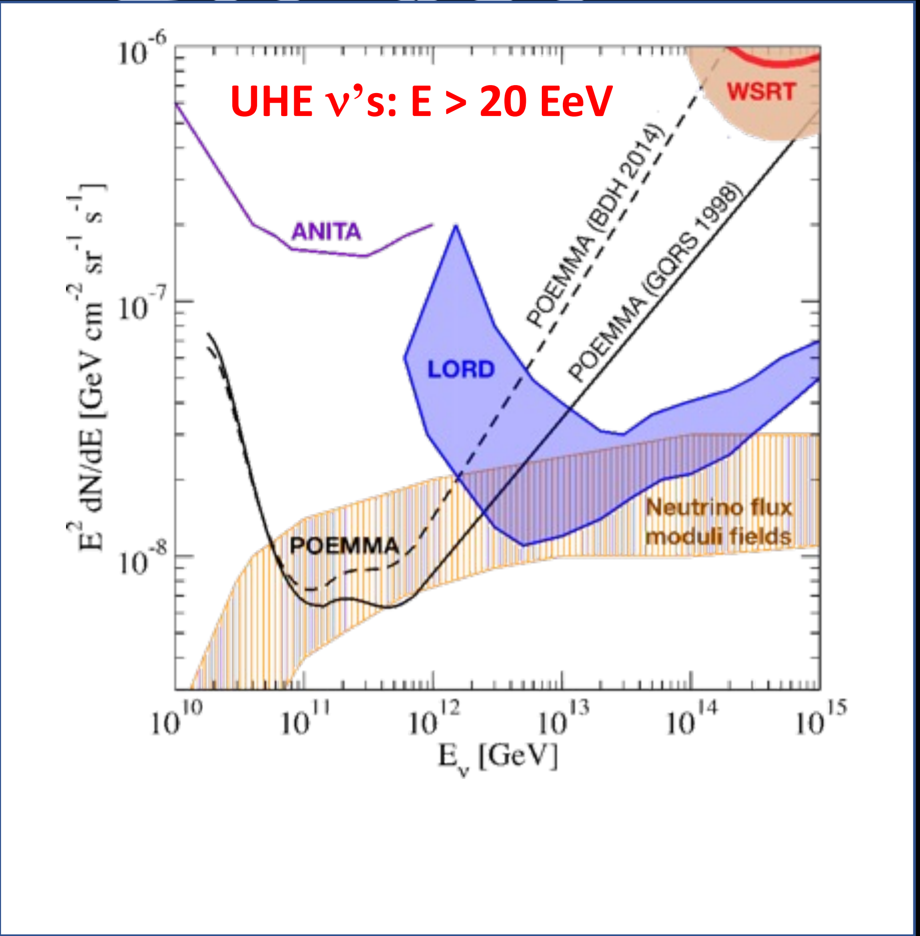
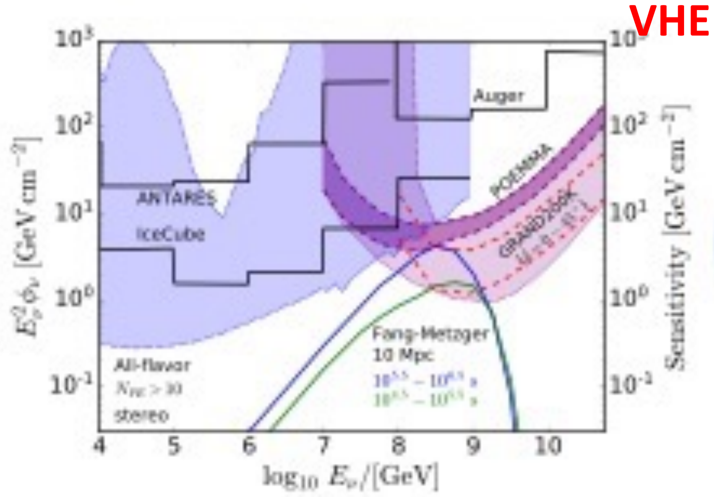
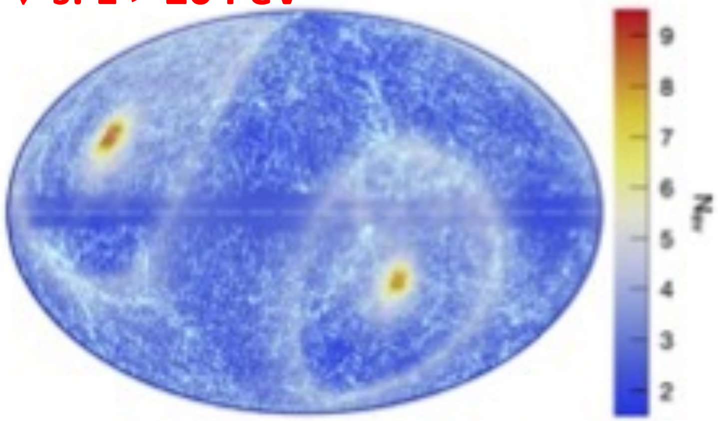


FIG. 23. Left: Skymap of nearby starburst galaxies from Refs. [35,103] weighted by radio flux at 1.4 GHz, the attenuation factor accounting for energy losses incurred by UHECRs through propagation, and the exposure of POEMMA. The map has been smoothed using a von Miser-Fisher distribution with concentration parameter corresponding to a search radius of 15.0° as found in Ref. [35]. The color scale indicates $\mathcal{F}_{src}$, the probability density of the source sky map, as a function of position on the sky. The white dot-dashed line indicates the supergalactic plane. Right: Same as at left for nearby galaxies from the 2MRS catalog [105] and weighting by K-band flux corrected for Galactic extinction.



VHE ν's: E > 20 PeV





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70+ scientists from 21+ institutions (US + 10+)
OWL, JEM-EUSO, Auger, TA, Veritas, CTA, Fermi, Theory

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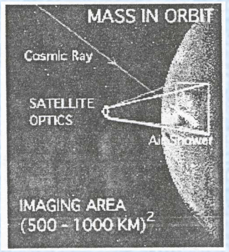
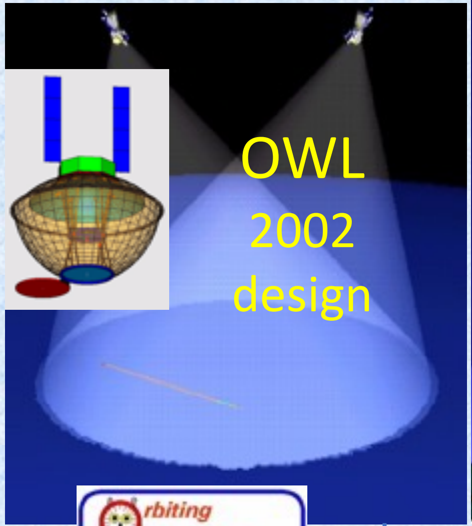
POEMMA Heritage and POEMMA-fueled developments

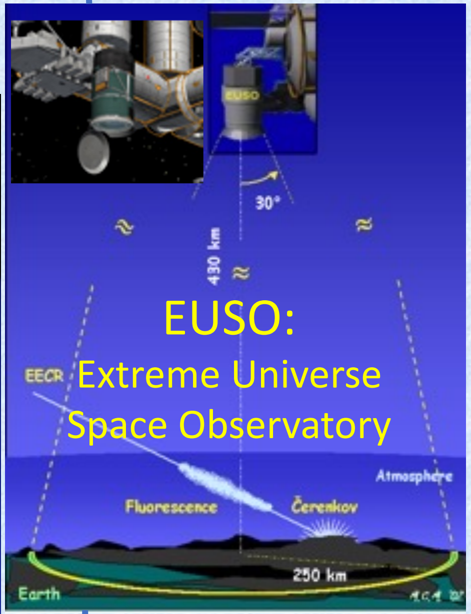
Based on OWL 2002 study, JEM-EUSO, EUSO balloon experience, CHANT & nueBACH concepts, TUS experience …



OWL AIRWATCH

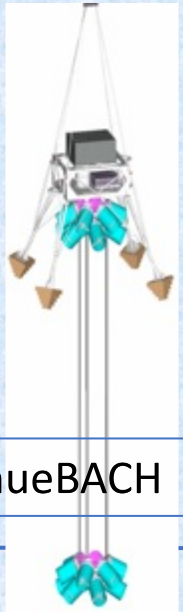


Orbiting Wide-angle Light-collectors



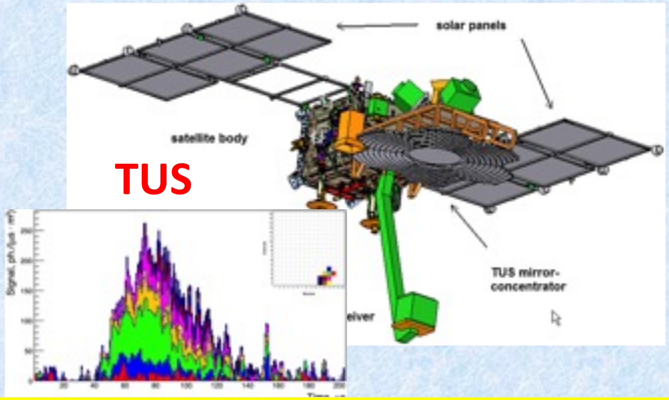
K-EUSO

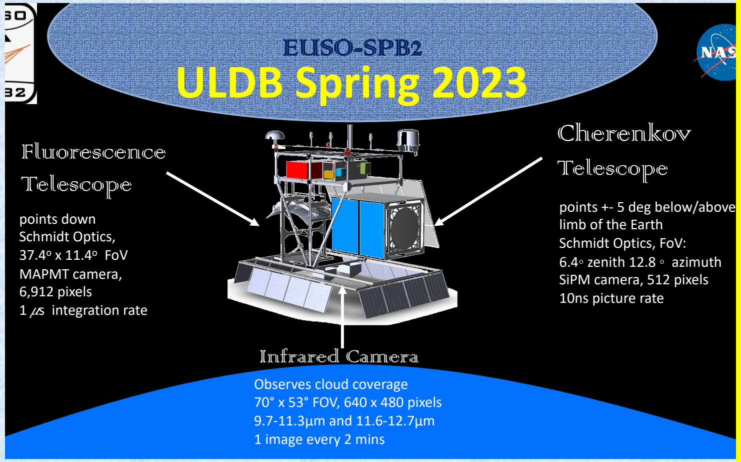
CHANT



nueBACH

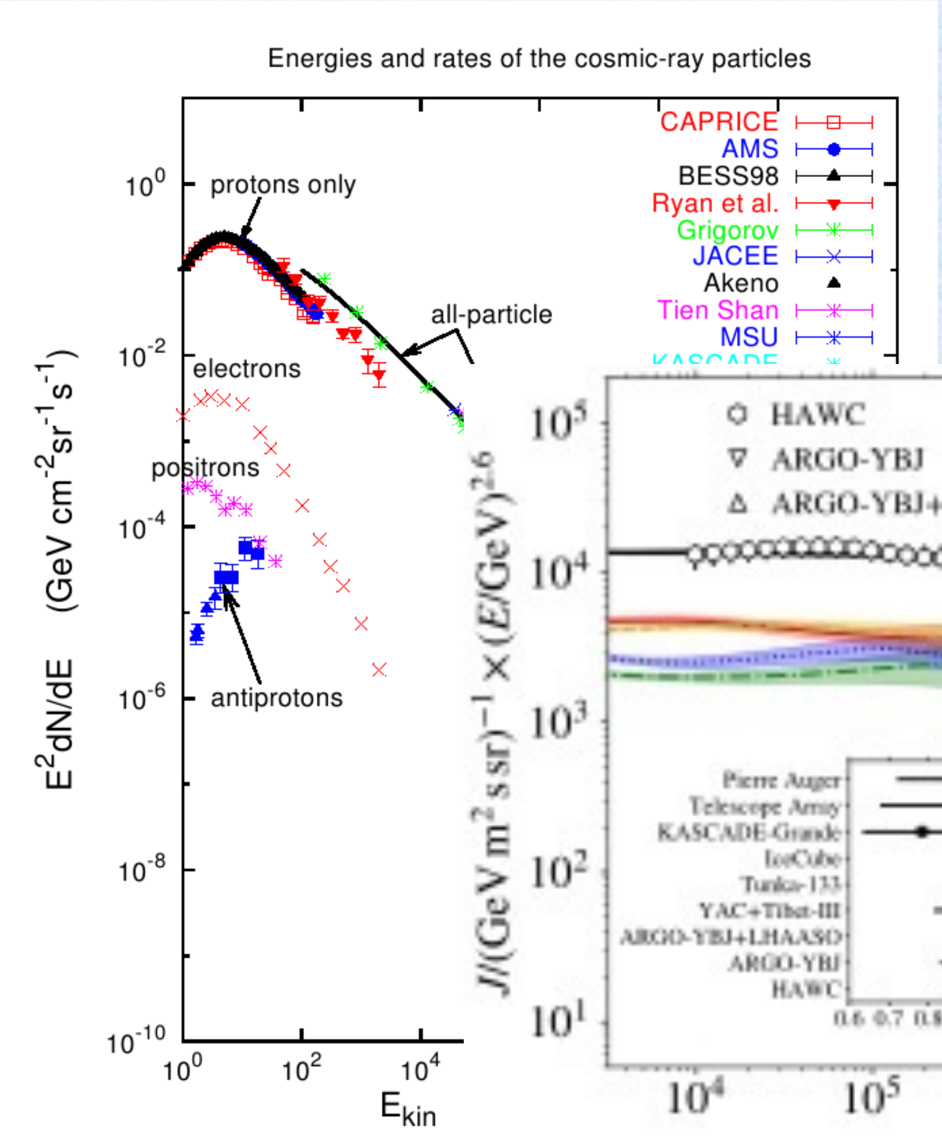
EUSO-Balloon
EUSO@TA
Mini-EUSO





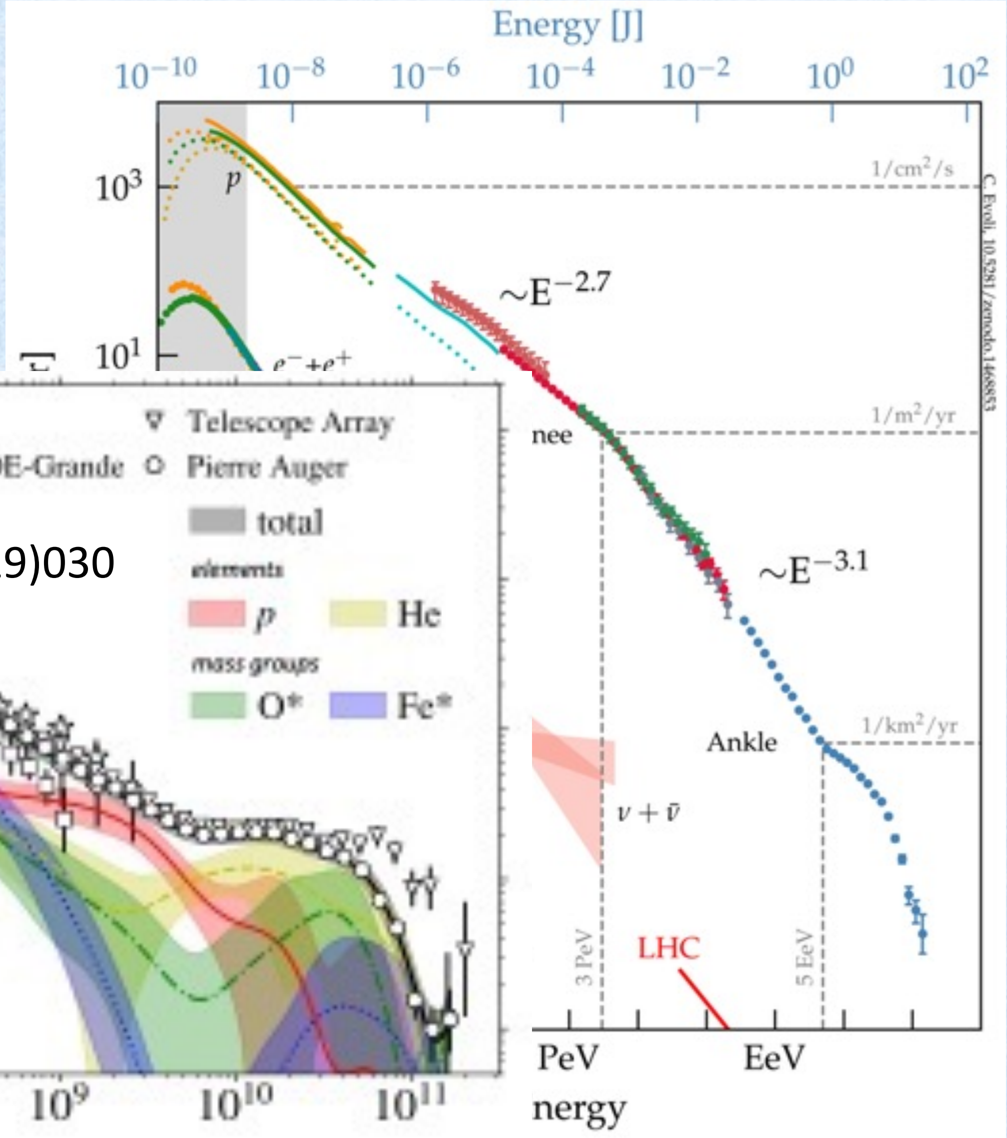
SpaceSim

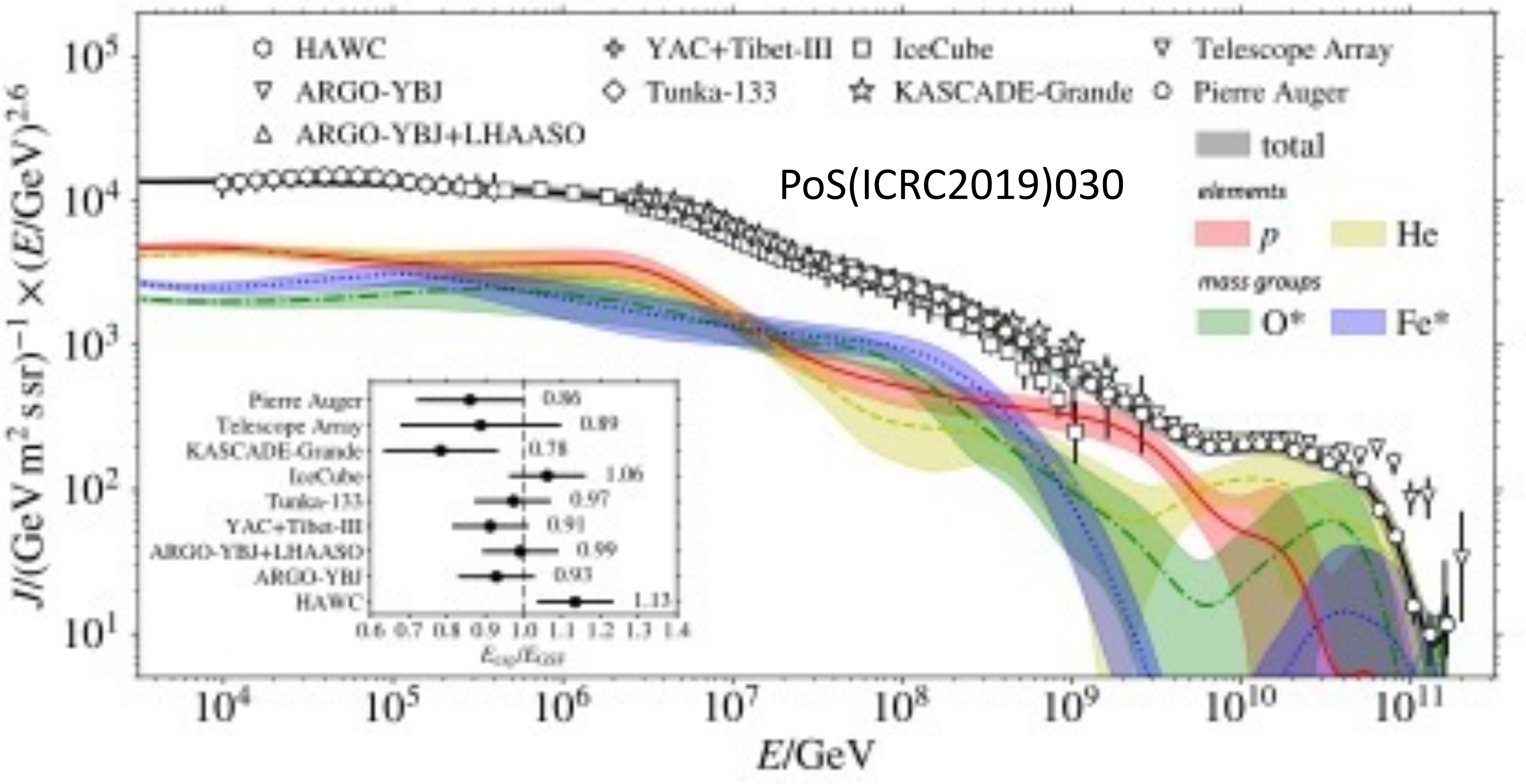
The Cosmic Ray Spectrum



End of the Cosmic Ray Spectrum?

What is the flux and composition at the highest energy scales?





PoS(ICRC2019)030

POEMMA: Science Goals

POEMMA Science goals:

primary

- **Discover the origin of Ultra-High Energy Cosmic Rays via high-statistics**

  Measure Spectrum, composition, Sky Distribution at Highest Energies (E_{CR} > 20 EeV)

  Requires very good angular, energy, and X_{max} resolutions: *stereo fluorescence*

  High sensitivity UHE neutrino measurements via stereo fluorescence measurements

- **Observe Neutrinos from Transient Astrophysical Events**

  Measure beamed Cherenkov light from upward-moving EAS from τ-leptons source by ν_τ interactions in the Earth (E_ν > 20 PeV)

  Requires tilted-mode of operation to view limb of the Earth & ~10 ns timing

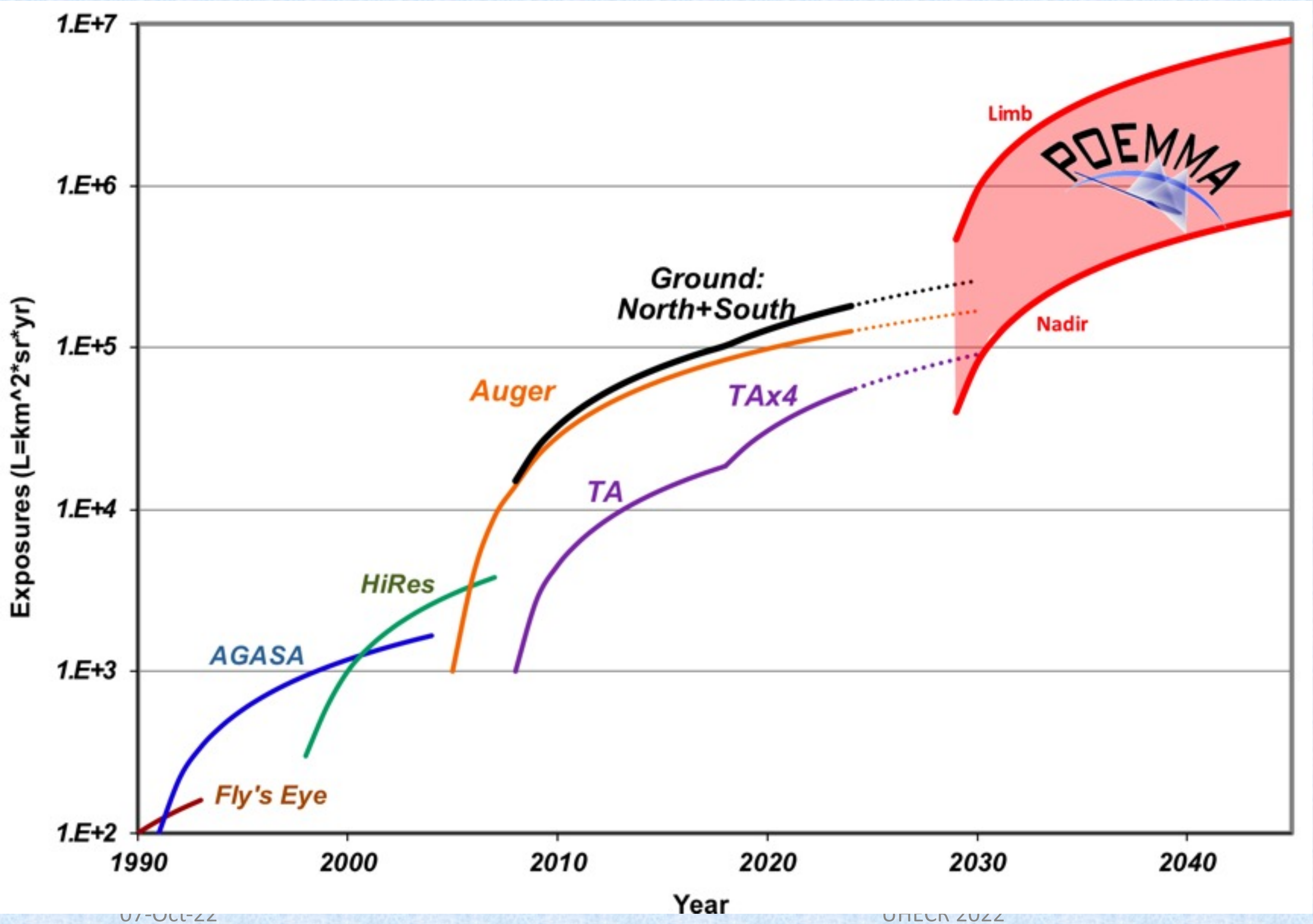
  Allows for tilted UHECR air fluorescence operation, higher GF but degraded resolutions

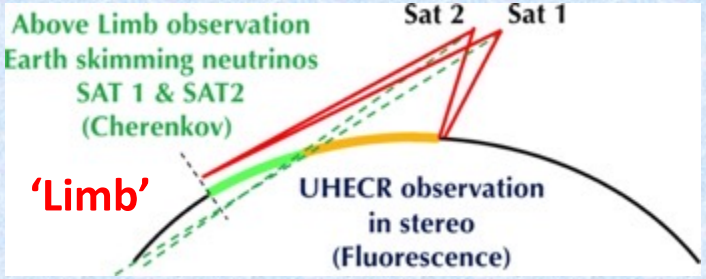
secondary

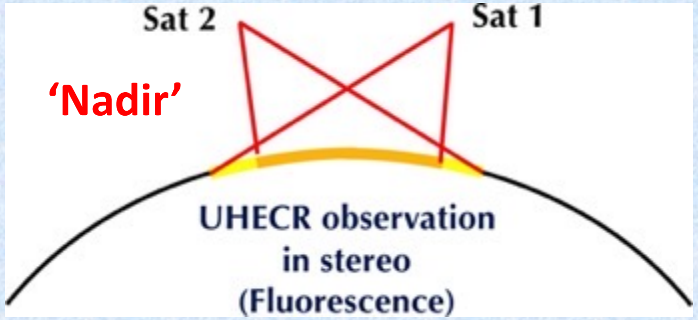
$\sqrt{s} \approx 450$ TeV @ 100 EeV

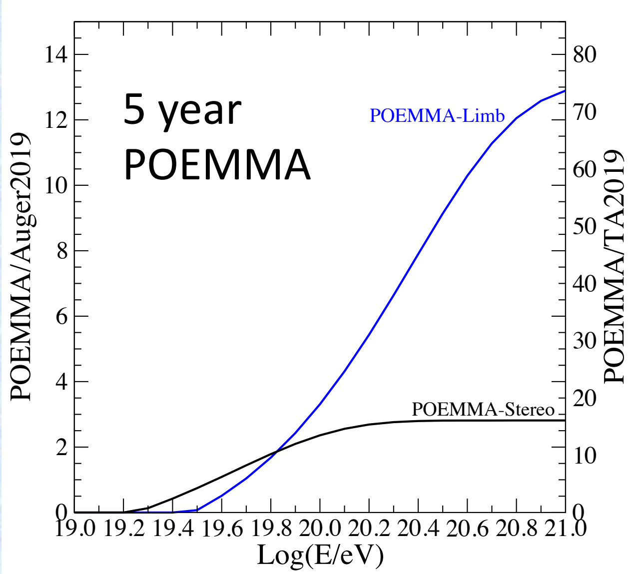
- study fundamental physics with the most energetic cosmic particles: CRs and Neutrinos
- search for super-Heavy Dark Matter: *photons and neutrinos :* **PhysRevD.101.023012 , PhysRevD.104.083002**
- study Atmospheric Transient Events, survey Meteor Population, …

POEMMA: UHECR Exposure History:

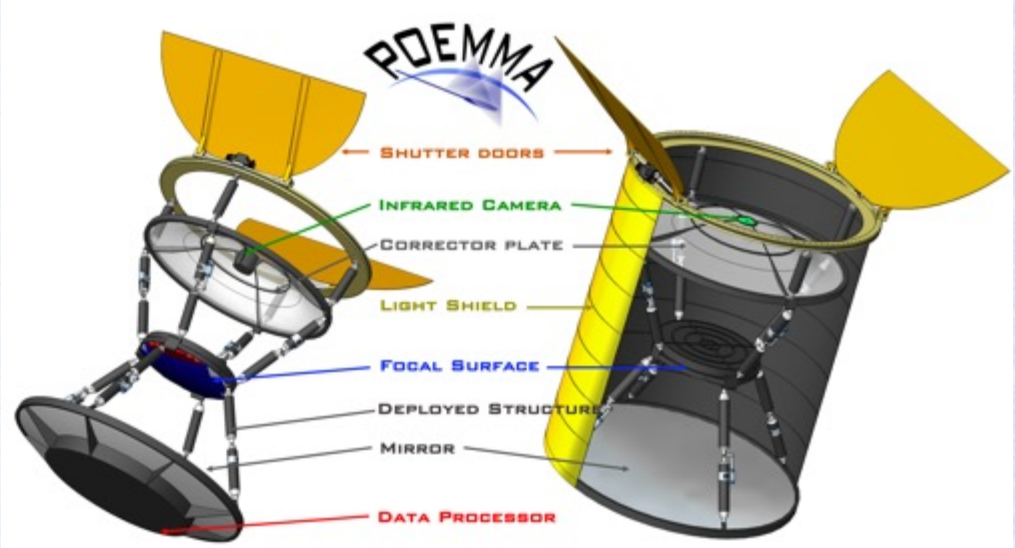








POEMMA: SpaceCraft and Telescope Specifications



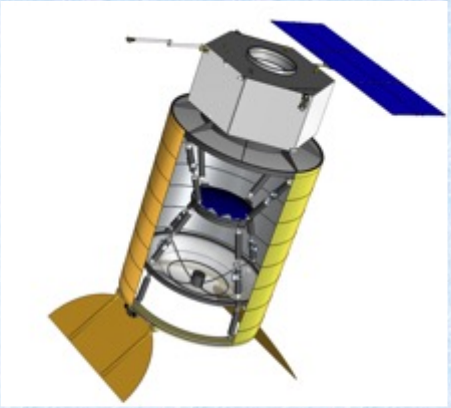
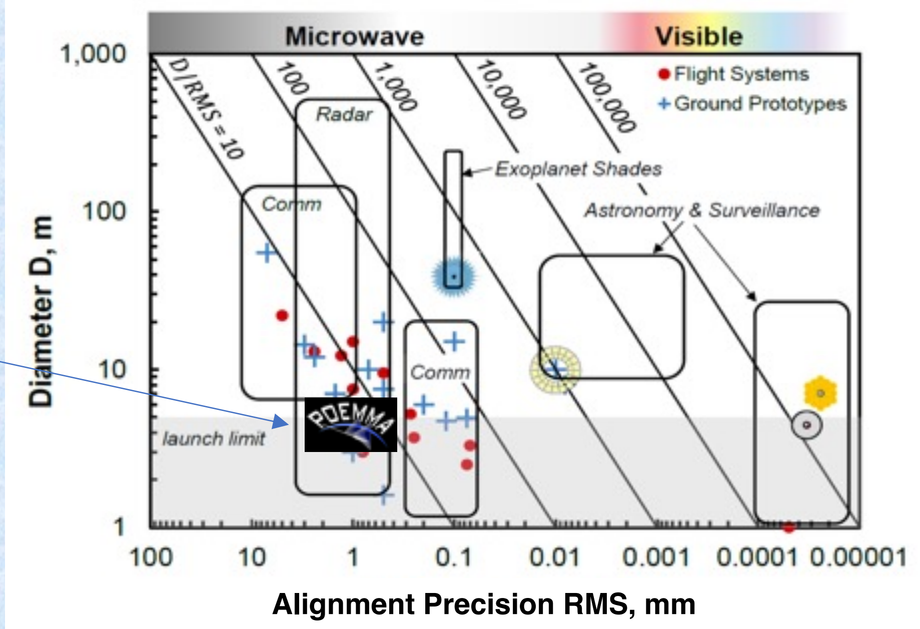


TABLE I: POEMMA Specifications:

Photometer	Components		Spacecraft	
Optics	Schmidt	45° full FoV	Slew rate	90° in 8 min
	Primary Mirror	4 m diam.	Pointing Res.	0.1°
	Corrector Lens	3.3 m diam.	Pointing Know.	0.01°
	Focal Surface	1.6 m diam.	Clock synch.	10 nsec
	Pixel Size	3×3 mm^2	Data Storage	7 days
	Pixel FoV	0.084°	Communication	S-band
PFC	MAPMT (1μs)	126,720 pixels	Wet Mass	3,450 kg
PCC	SiPM (20 ns)	15,360 pixels	Power (w/cont)	550 W
Photometer	(One)		Mission	(2 Observatories)
	Mass	1,550 kg	Lifetime	3 year (5 year goal)
	Power (w/cont)	700 W	Orbit	525 km, 28.5° Inc
	Data	< 1 GB/day	Orbit Period	95 min
			Observatory Sep.	~25 - 1000+ km

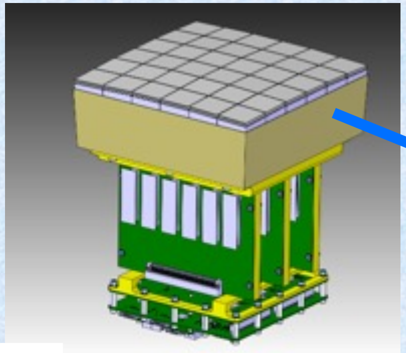
Each Observatory = Photometer + Spacecraft; POEMMA Mission = 2 Observatories

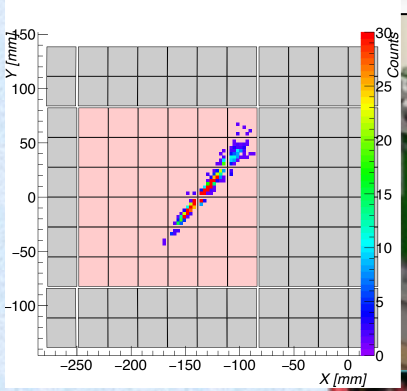


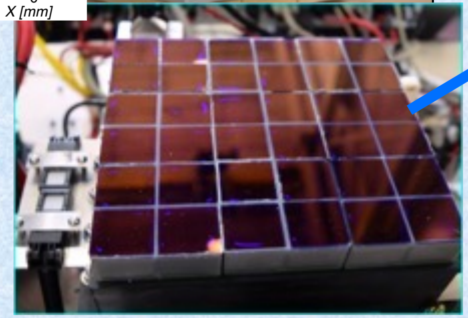
Imaging ~10^4 away from diffraction limit

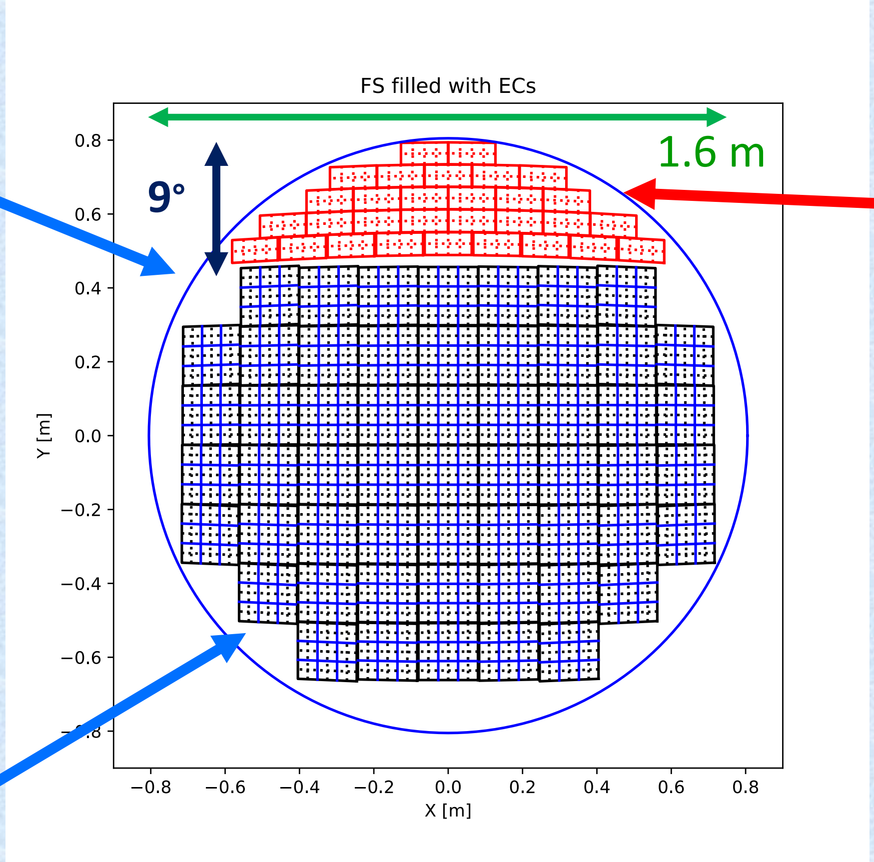
POEMMA: Hybrid Focal Plane

UV Fluorescence Detection using MAPMTs with BG3 filter (300 – 500 nm) developed by JEM-EUSO: 1 usec sampling





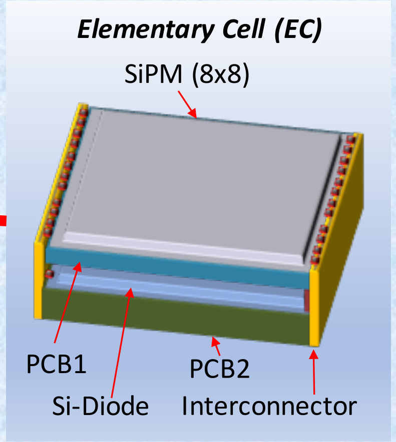




55 Photo Detector Modules (PDMs)= 126,720 pixels

1 PDM = 36 MAPMTs = 2,304 pixels

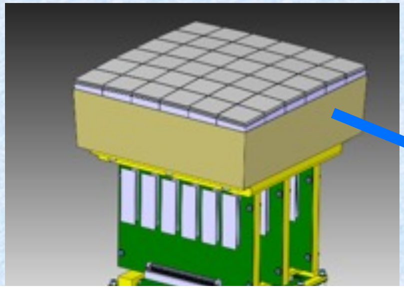
Cherenkov Detection with SiPMs (300 – 1000 nm): 10 nsec sampling

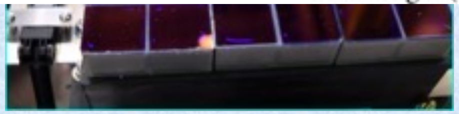


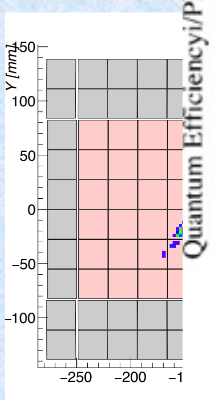
30 SiPM focal surface units
Total 15,360 pixels
512 pixels per FSU (64x4x2)
Si-Diode for LEO radiation backgrounds rejection

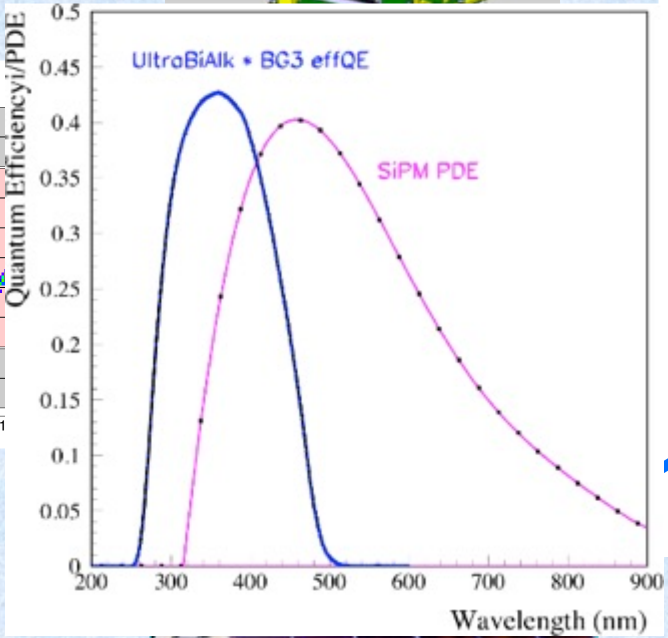
POEMMA: Hybrid Focal Plane: see NIMA 985 id.164614 (2021)

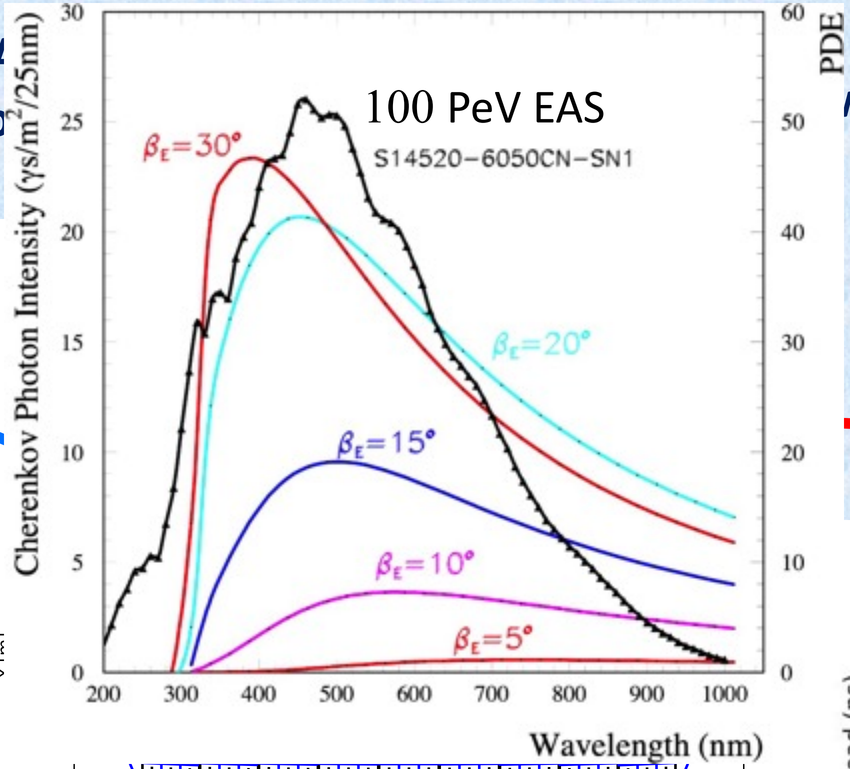
UV Fluorescence Detection using MA
with BG3 filter (300 – 500 nm) develo
JEM-EUSO: 1 usec sampling

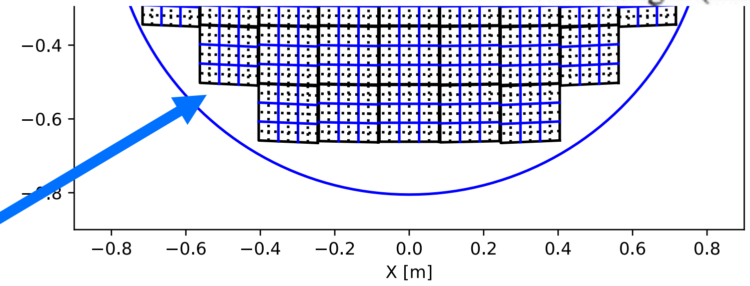












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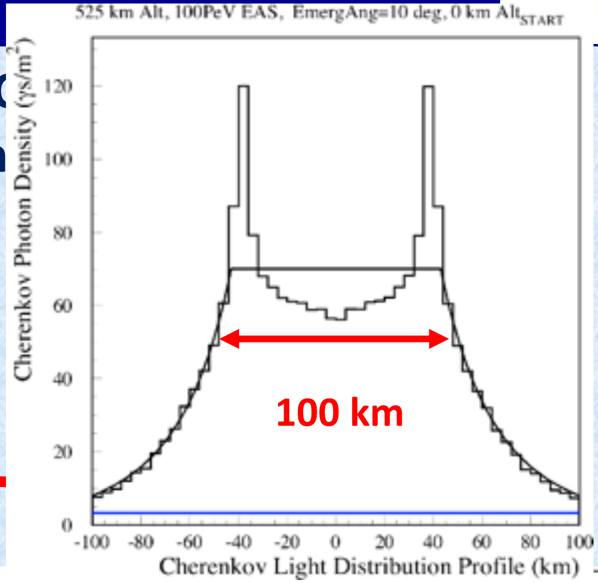
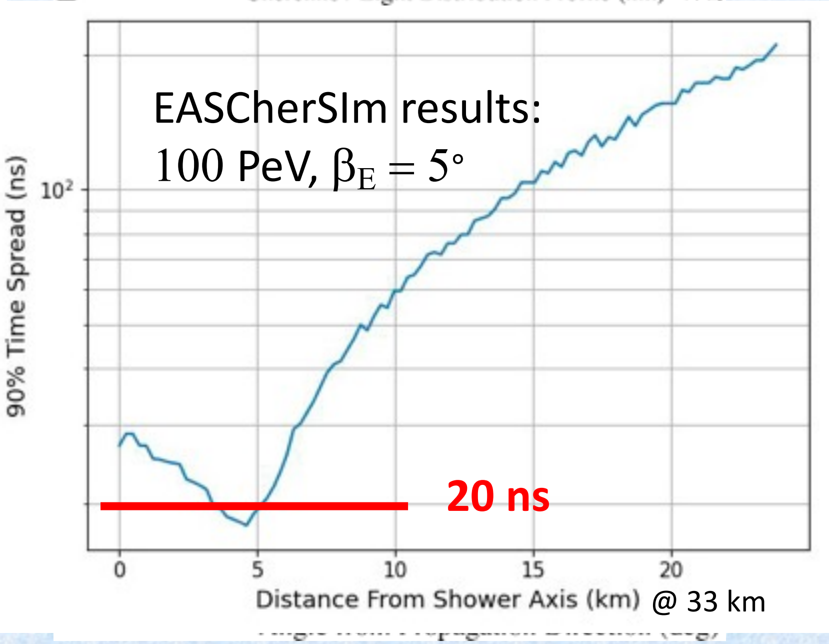
1 PDM = 36 MAPMTs = 2,304 pixels

with



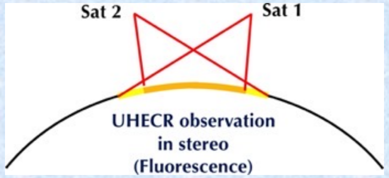


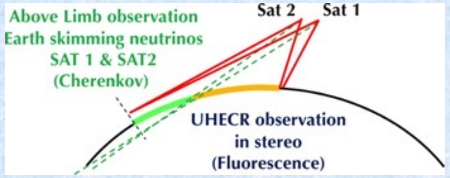
https://c4341.gitlab.io/easchersim/

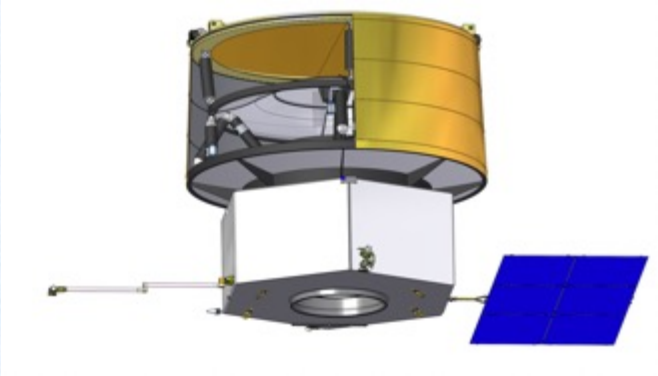
POEMMA: Mission (Class B) defined by weeklong MDL run at GSFC

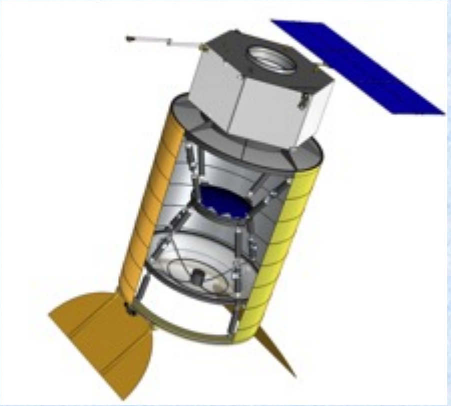
Mission Lifetime: 3 years (5 year goal)
Orbits: 525 km, 28.5° Inc
Orbit Period: 95 min
Satellite Separation: ~25 km – 1000+ km
Satellite Position: 1 m (knowledge)
Pointing Resolution: 0.1°
Pointing Knowledge: 0.01°
Slew Rate: 8 min for 90°
Satellite Wet Mass: 3860 kg
Power: 1250 W (w/contig)
Data: < 1 GB/day
Data Storage: 7 days
Communication: S-band
Clock synch (timing): 10 nsec

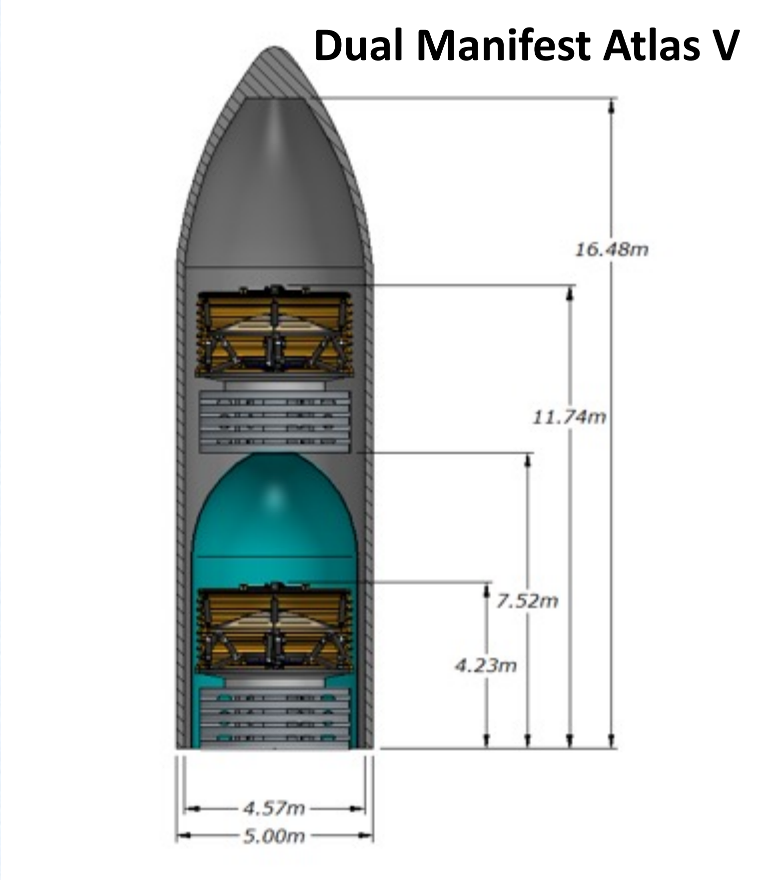
Flight Dynamics/Propulsion:
- 300 km ⟹ 25 km SatSep
  - Puts both in CherLight Pool
- Δt = 3 hr: 8 – 15 times
- Δt = 24 hr: 90 times





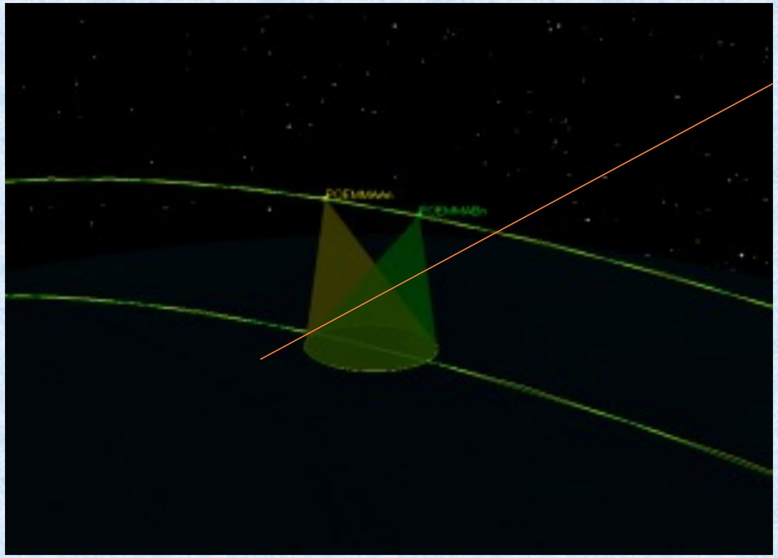




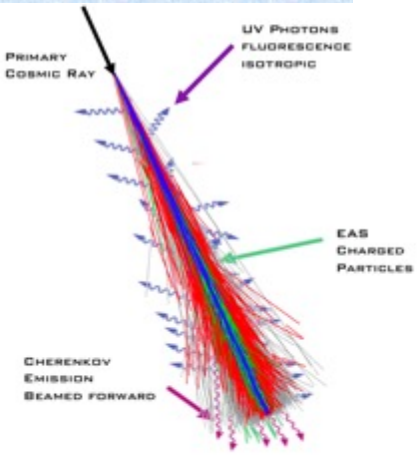


Operations:
- Each satellite collects data autonomously
- Coincidences analyzed on the ground
- View the Earth at near-moonless nights, charge in day and telemeter data to ground
- ToO Mode: dedicated com uplink to re-orient satellites if desired

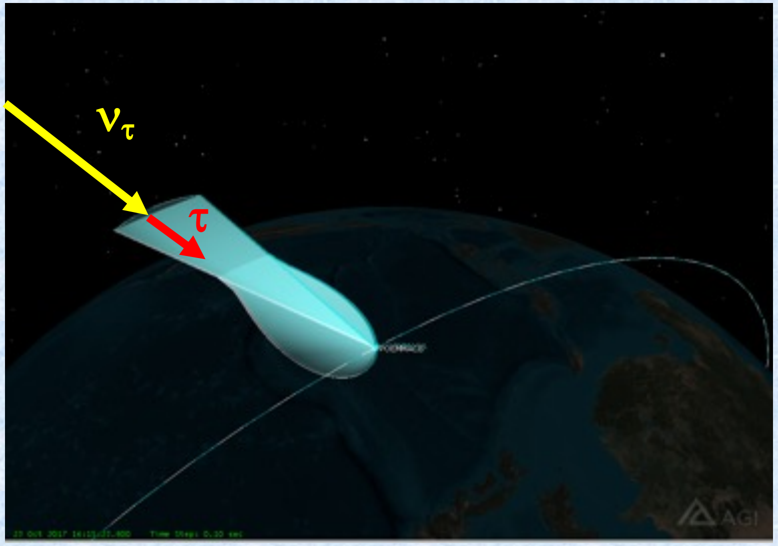
POEMMA Operational Modes: UHECR Stereo versus Limb-viewing Neutrino



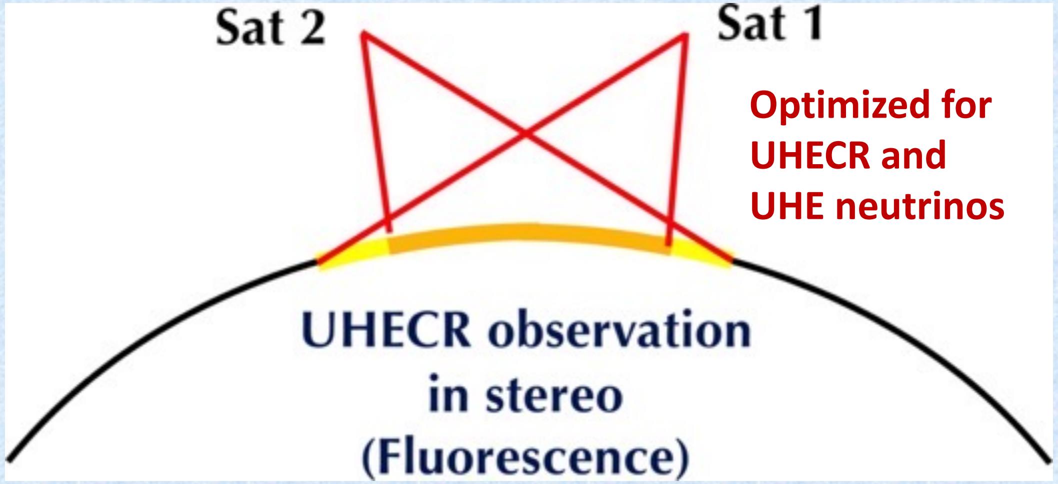
Stereo Viewing of UHECRs E ≳ 20 EeV
via Fluoresence: 10's of μsec timescale

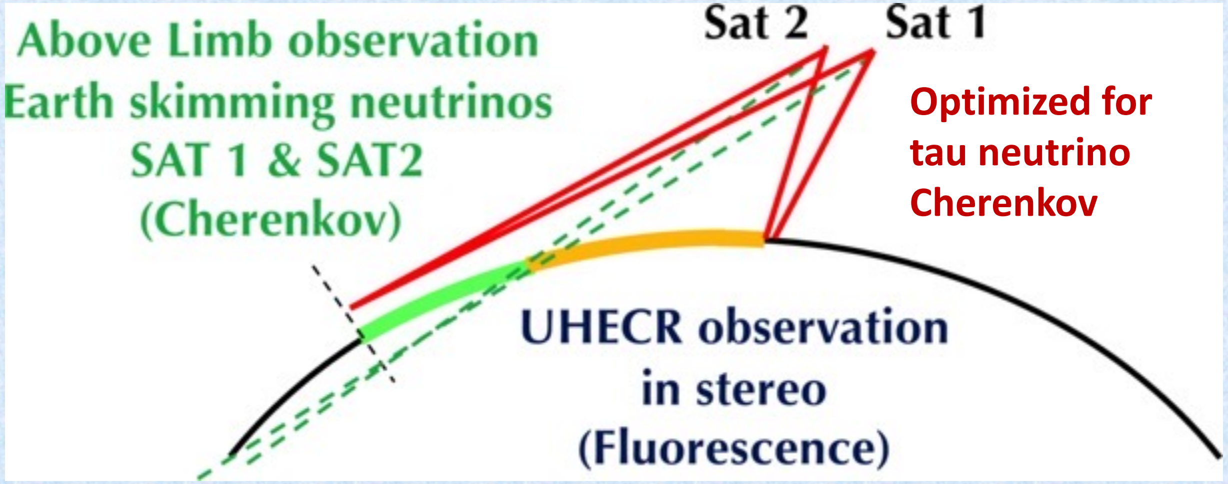


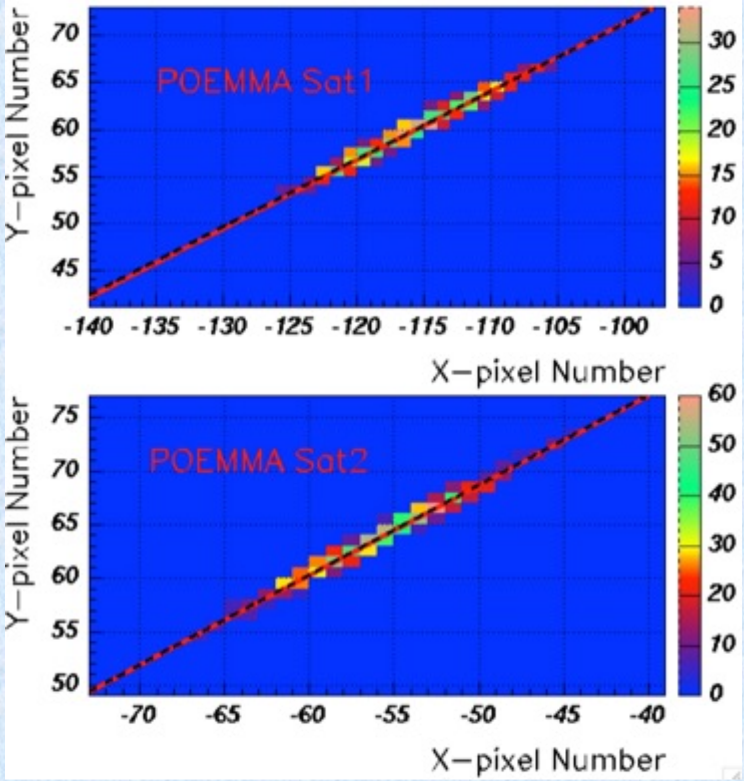
Dark, quasi-moon less nights:
Fluorescence Duty Cycle: 11%
Cherenkov Duty Cycle: 20%



Upward τ-lepton EAS E ≳ 20 PeV
via Cherenkov: ~10 nsec timescale

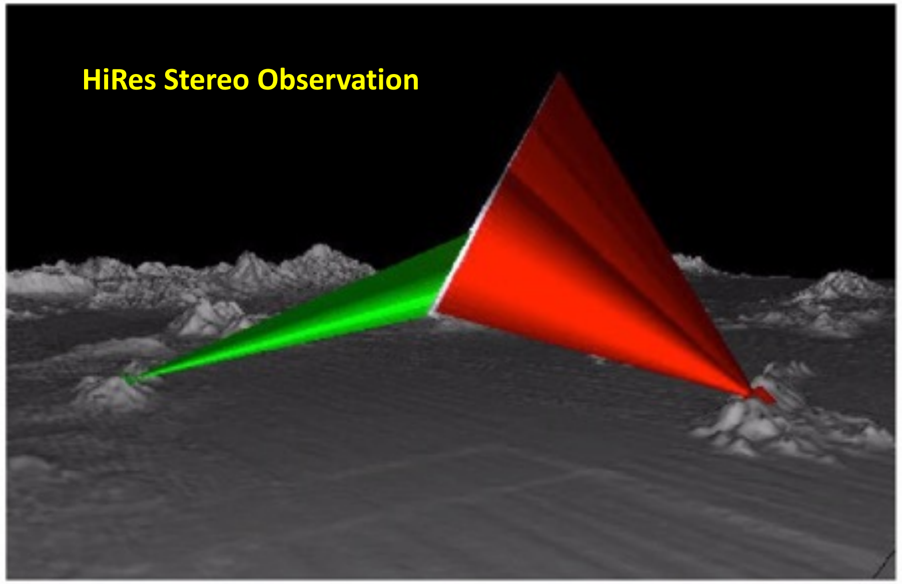






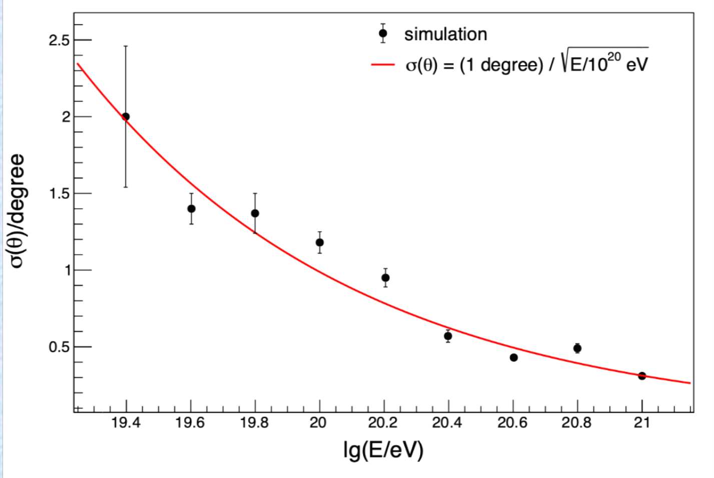
50 EeV simulated event

see PhysRevD.101.023012

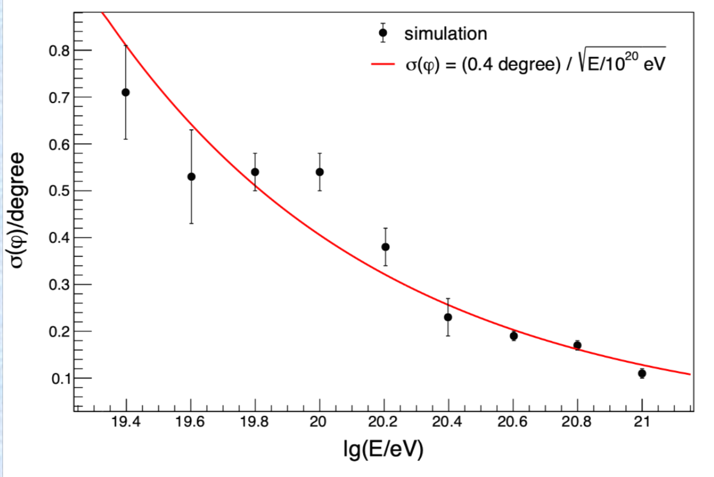


Stereo Geometric Reconstruction

- Intersection of EAS-detector planes defines the EAS trajectory
- Requires minimum opening angle between planes $\gtrsim 5^\circ$
- With track selection → 80% reconstruction efficiency
- $FoV_{PIX} = 0.084^\circ$ coupled with small RMS spot size allows for precise determination



Stereo Reconstructed Zenith Angle Resolution



Stereo Reconstructed Azimuth Angle Resolution

POEMMA: UHECR Performance: *see PhysRevD.101.023012*

Significant increase in exposure with all-sky coverage

Uniform sky coverage to *guarantee the discovery of UHECR sources*

Spectrum, Composition, Anisotropy: **E_{CR} > 20 EeV**

Very good energy (< 20%), angular ($\lesssim$ 1.2°), and composition ($\sigma_{Xmax} \lesssim$ 30 g/cm²) resolutions

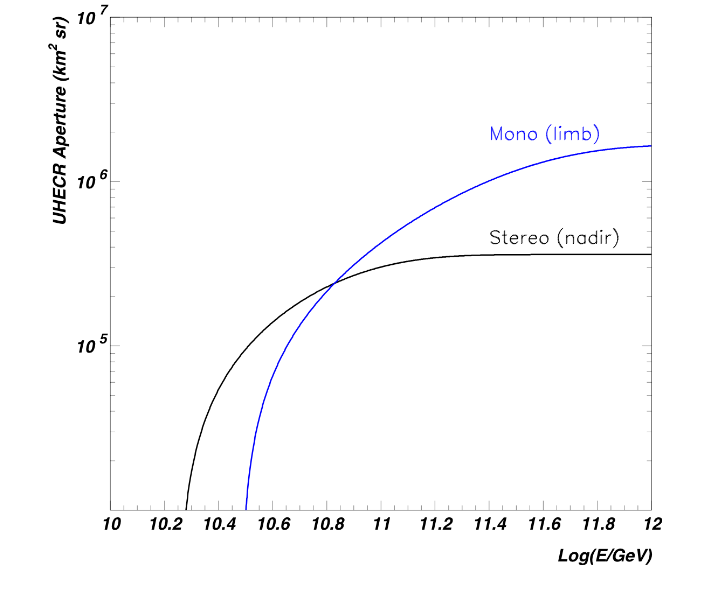
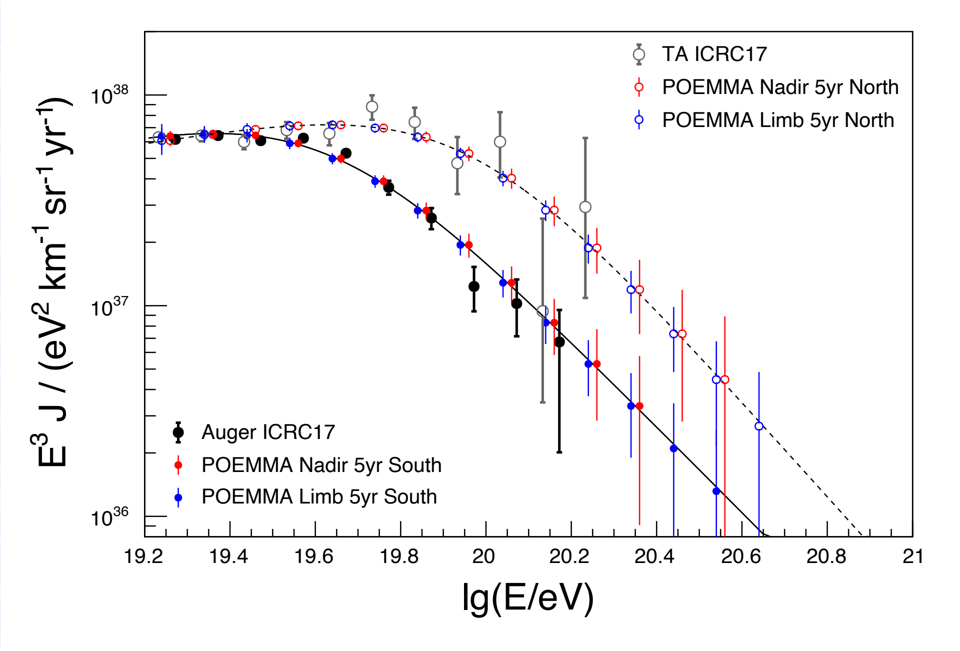
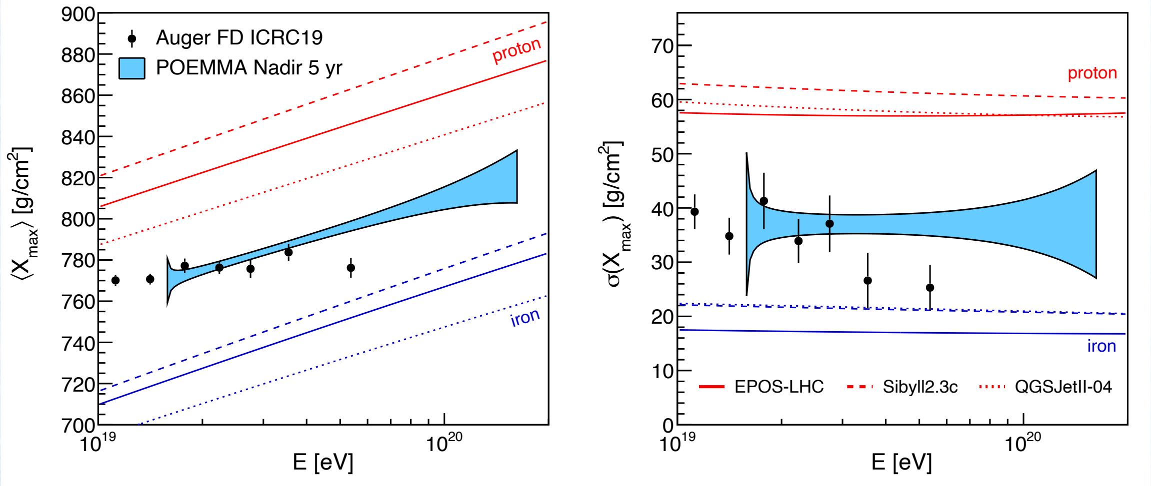


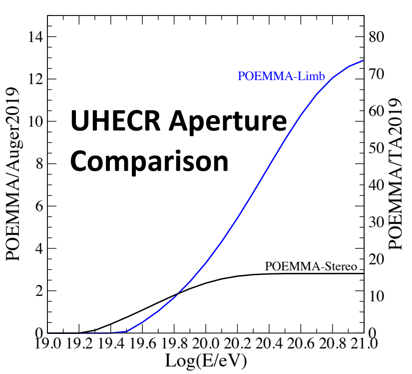
FIG. 10: The simulated UHECR aperture after event reconstruction for POEMMA for stereo mode and tilted mode.





Auger-inspired Composition Evolution Model

POEMMA: UHECR Sky Coverage (isotropic UHECR flux)



Significant increase in exposure with all-sky coverage

Uniform sky coverage to *guarantee the discovery of UHECR sources*

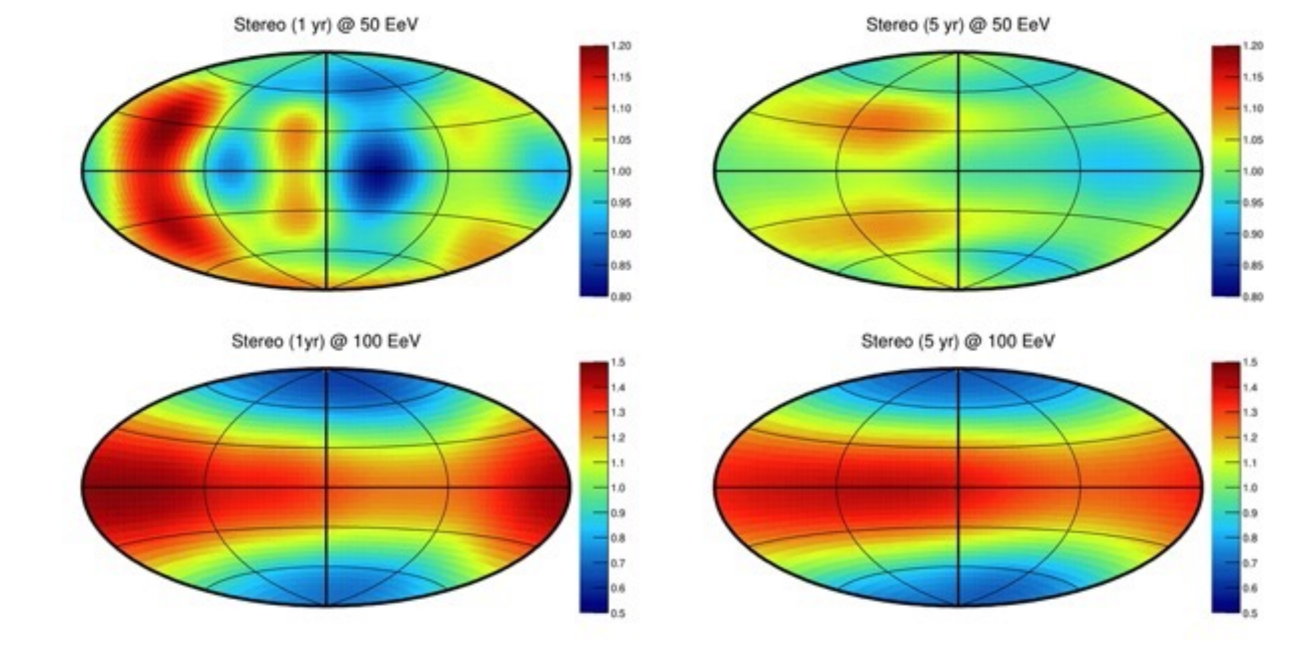
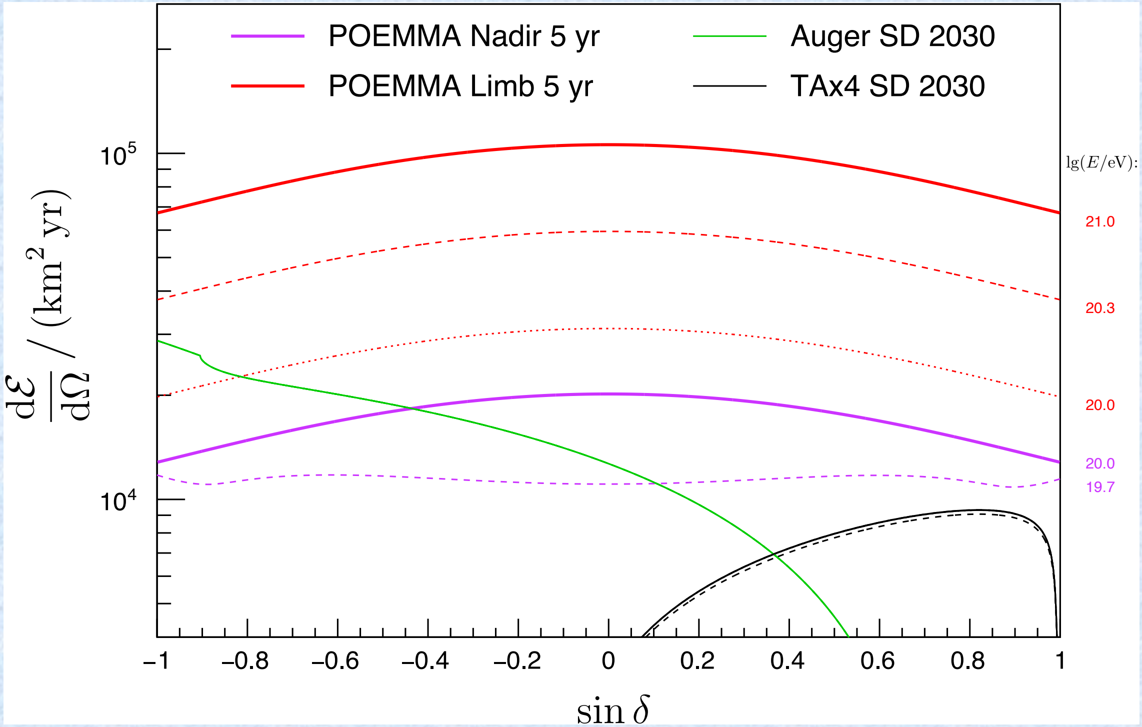


FIG. 13: POEMMA's UHECR sky exposures in declination versus right ascension. The color scale denoting the exposure variations in terms of the mean response taking into account the positions of the sun and the moon during the observation cycle.



POEMMA: UHECR Anisotropy Analysis *see PhysRevD.101.023012*

15° Angular Spread, 10% StarBurst Fraction

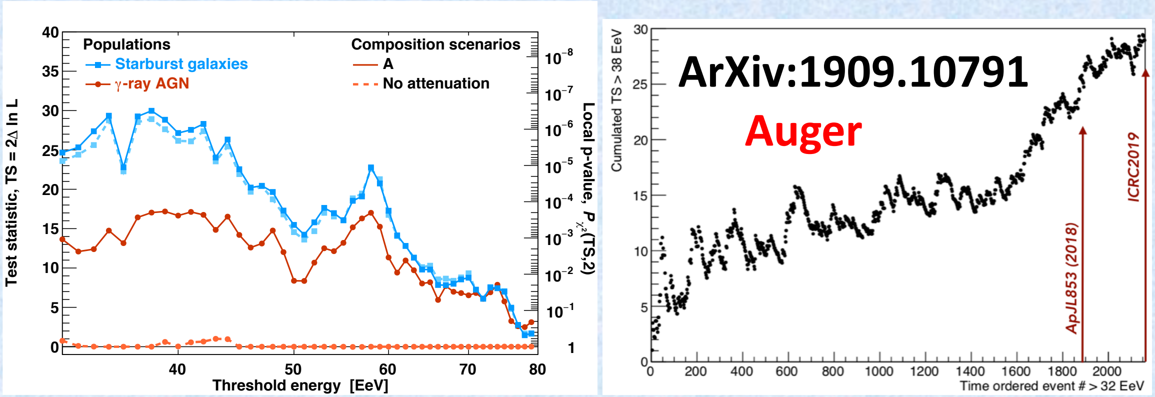


Figure 11: Left: Maximum likelihood-ratio as a function of energy threshold for the models based on SBGs and γAGNs. The results are shown in the attenuation (full line) and no-attenuation (dashed line) scenarios. Right: Cumulated test statistics for $E_{\rm thr} = 38$ EeV as a function of the time ordered number of events (for the SBG-only model). The number of events at the time of [39] and of this conference are indicated by the red arrows.

TABLE II. TS values for scenarios with $\Theta = 15°$.

Catalog	$f_{\rm sig}$	TS	σ
SBG	5%	6.2	2.0
	10%	24.7	4.6
	15%	54.2	7.1
	20%	92.9	9.4
2MRS	5%	2.4	1.0
	10%	8.7	2.5
	15%	20.0	4.1
	20%	35.2	5.6
Swift-BAT AGN	5%	10.4	2.8
	10%	39.6	6.0
	15%	82.4	8.8
	20%	139.3	11.6

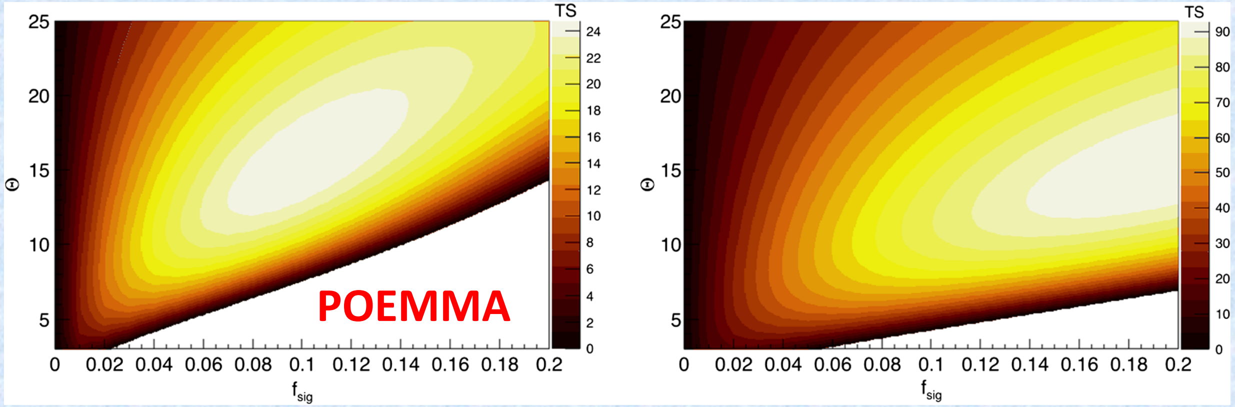


FIG. 24. TS profile for 1400 events for a particular scenario using the starburst source sky map in Fig. 23. In the scenario pictured here, the fraction of events drawn from the source sky map is $f = 10\%$ (left) and 20% (right), and the angular spread is $\Theta = 15°$.

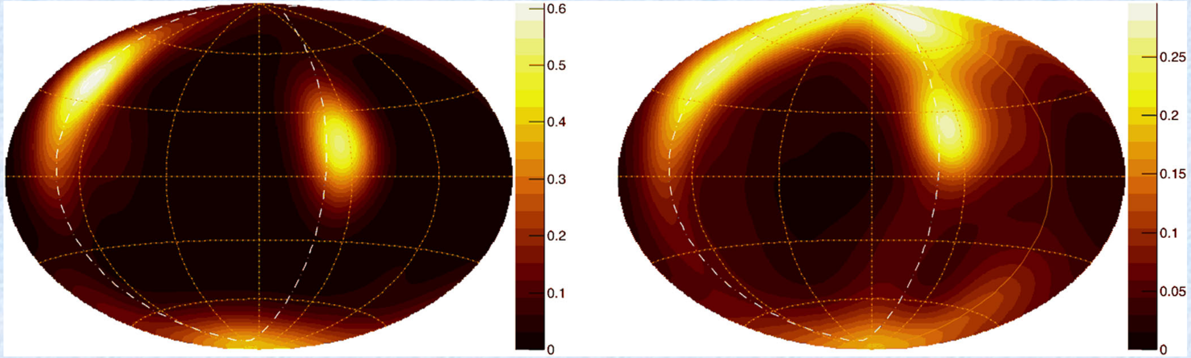


FIG. 23. Left: Skymap of nearby starburst galaxies from Refs. [35,103] weighted by radio flux at 1.4 GHz, the attenuation factor accounting for energy losses incurred by UHECRs through propagation, and the exposure of POEMMA. The map has been smoothed using a von Miser-Fisher distribution with concentration parameter corresponding to a search radius of 15.0° as found in Ref. [35]. The color scale indicates $\mathcal{F}_{\rm src}$, the probability density of the source sky map, as a function of position on the sky. The white dot-dashed line indicates the supergalactic plane. Right: Same as at left for nearby galaxies from the 2MRS catalog [105] and weighting by K-band flux corrected for Galactic extinction.

POEMMA: Air fluorescence Neutrino Sensitivity: *see PhysRevD.101.023012*

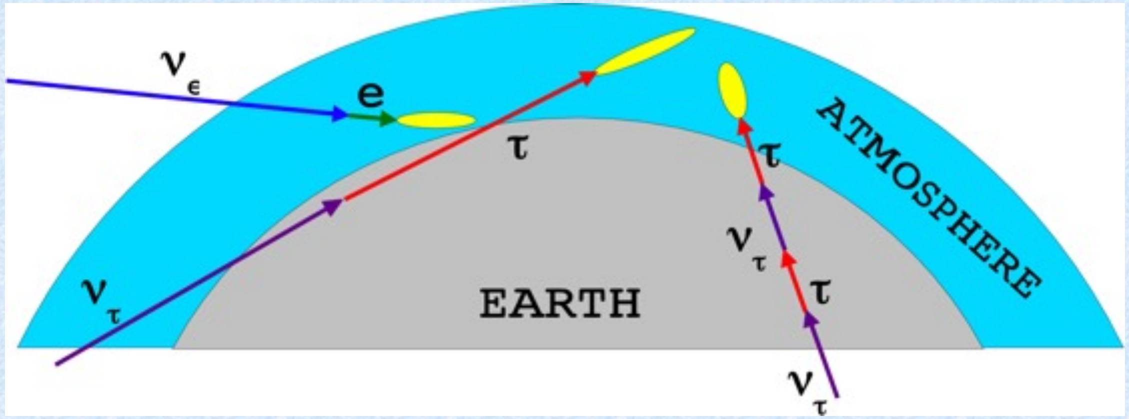
Effectively comes for free in stereo UHECR mode

Assumptions:

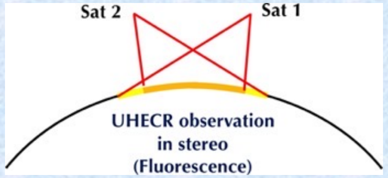
- CC ν_e : 100% E_ν in EAS
- CC ν_μ & ν_τ : 20% E_ν in EAS ($\gamma c \tau_\tau \approx 5000$ km)
- NC ν_e & ν_μ & ν_τ : 20% E_ν in EAS

UHECR Background Probabilities (1 event in 5 years):

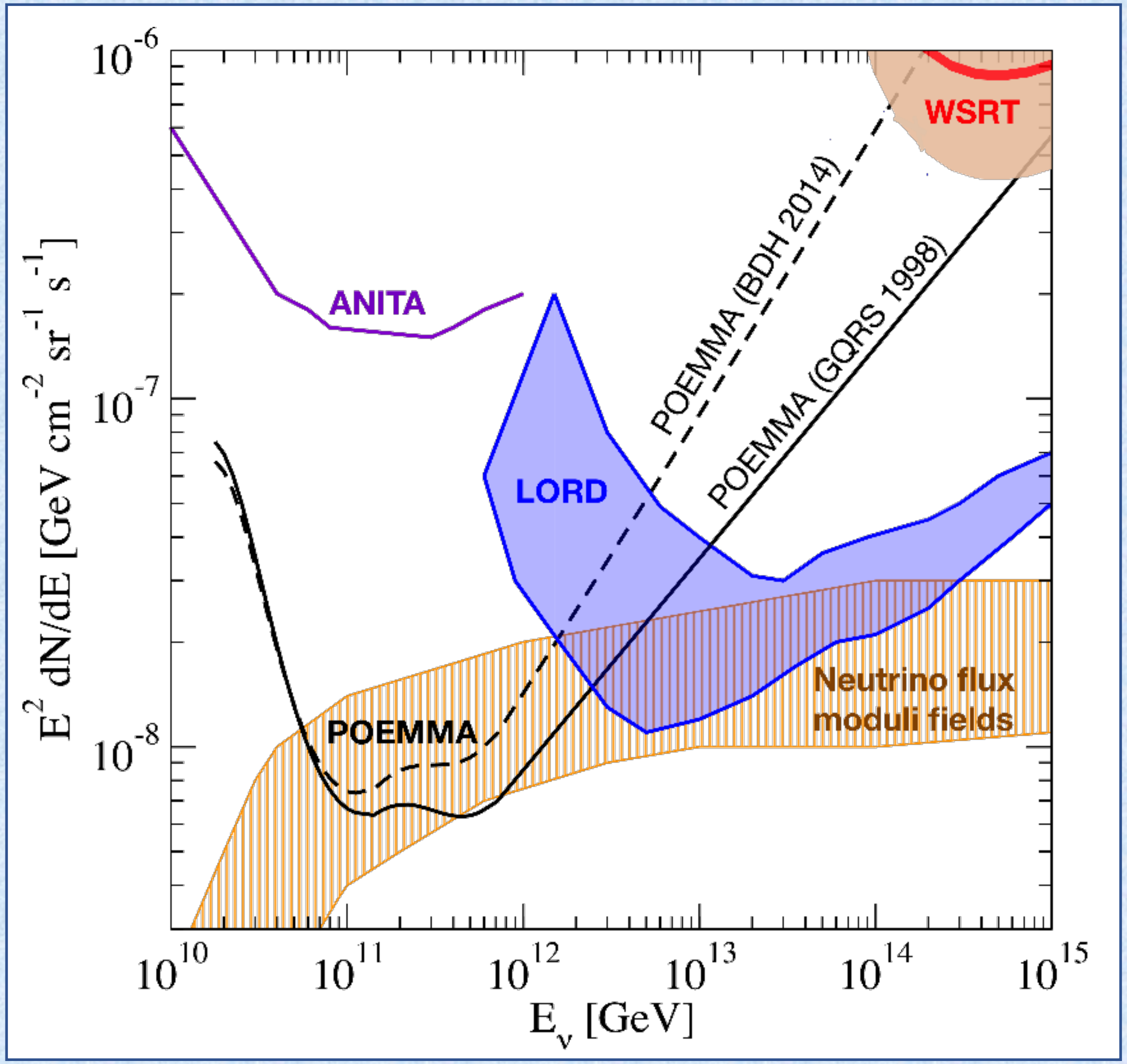
- Auger Spectrum (100% H): < 1%
- TA Spectrum (100% H): ≈ 4%



S. Bottai and S. Giurgola, UHE and EHE neutrino induced taus inside the Earth, Astroparticle Physics. 18(6), 539-549 (Mar., 2003).



For $E_\nu \gtrsim$ 1 PeV, σ_{CC} & σ_{NC} virtually identical for ν & νbar



POEMMA: Air fluorescence Neutrino Sensitivity: *see PhysRevD.101.023012*

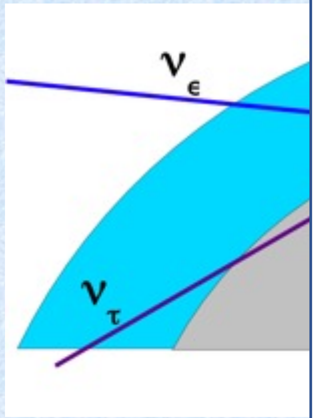
Effectively

Assumptions

- CC
- CC
- NC

UHECR Back

- Aug
- TA S



S. Bottai and S. G
Earth, Astroparti

Indirect dark matter searches at ultrahigh energy neutrino detectors

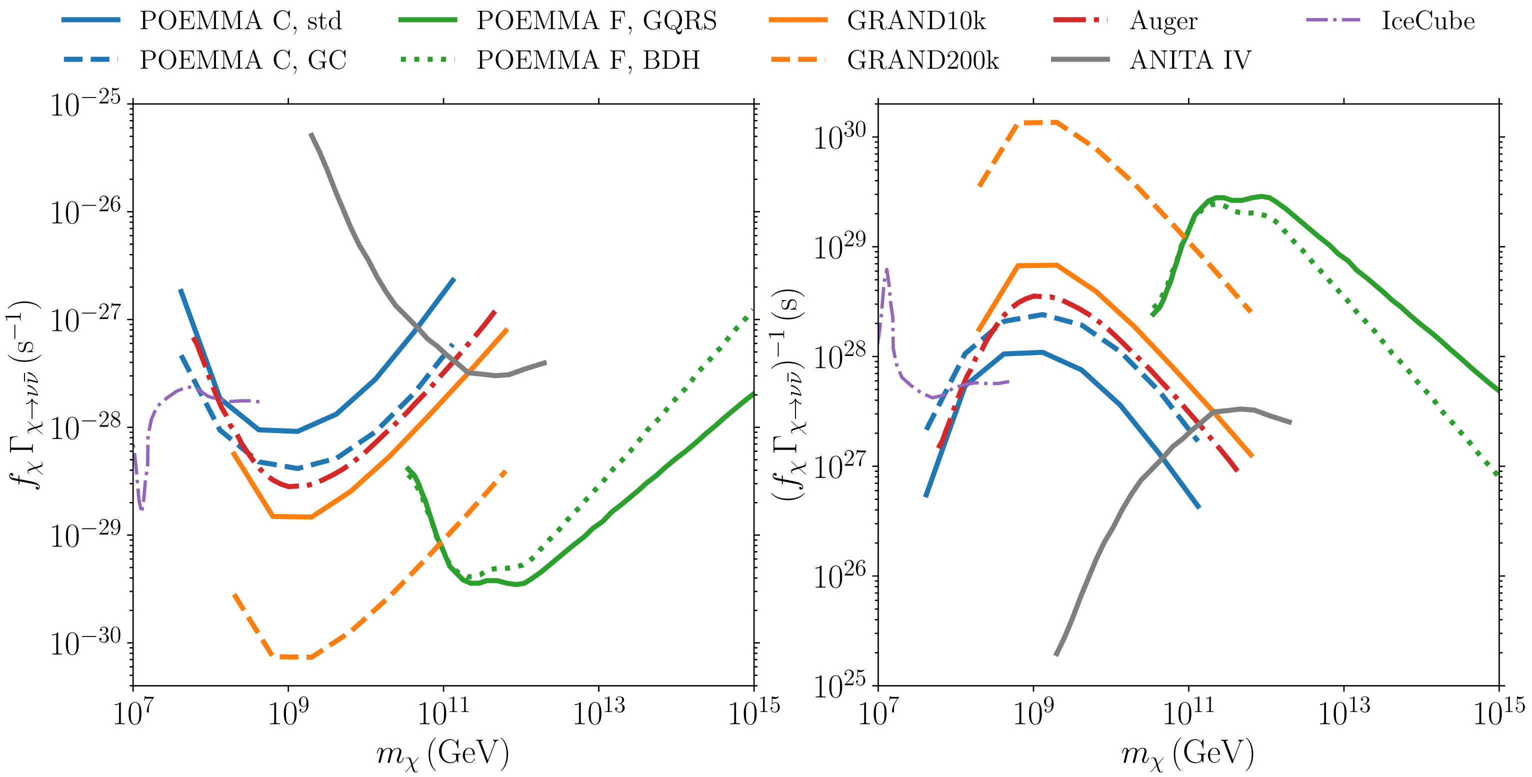
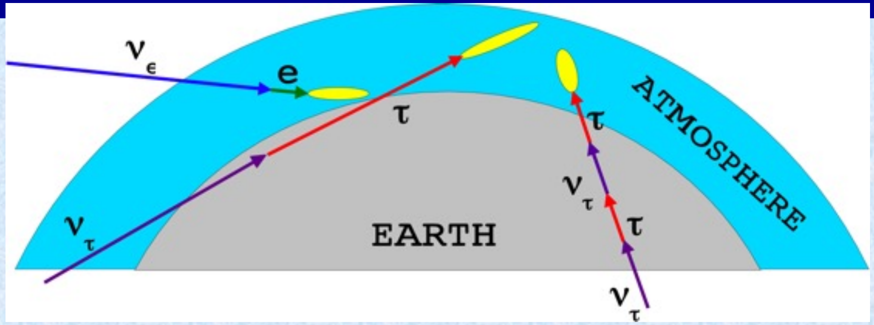
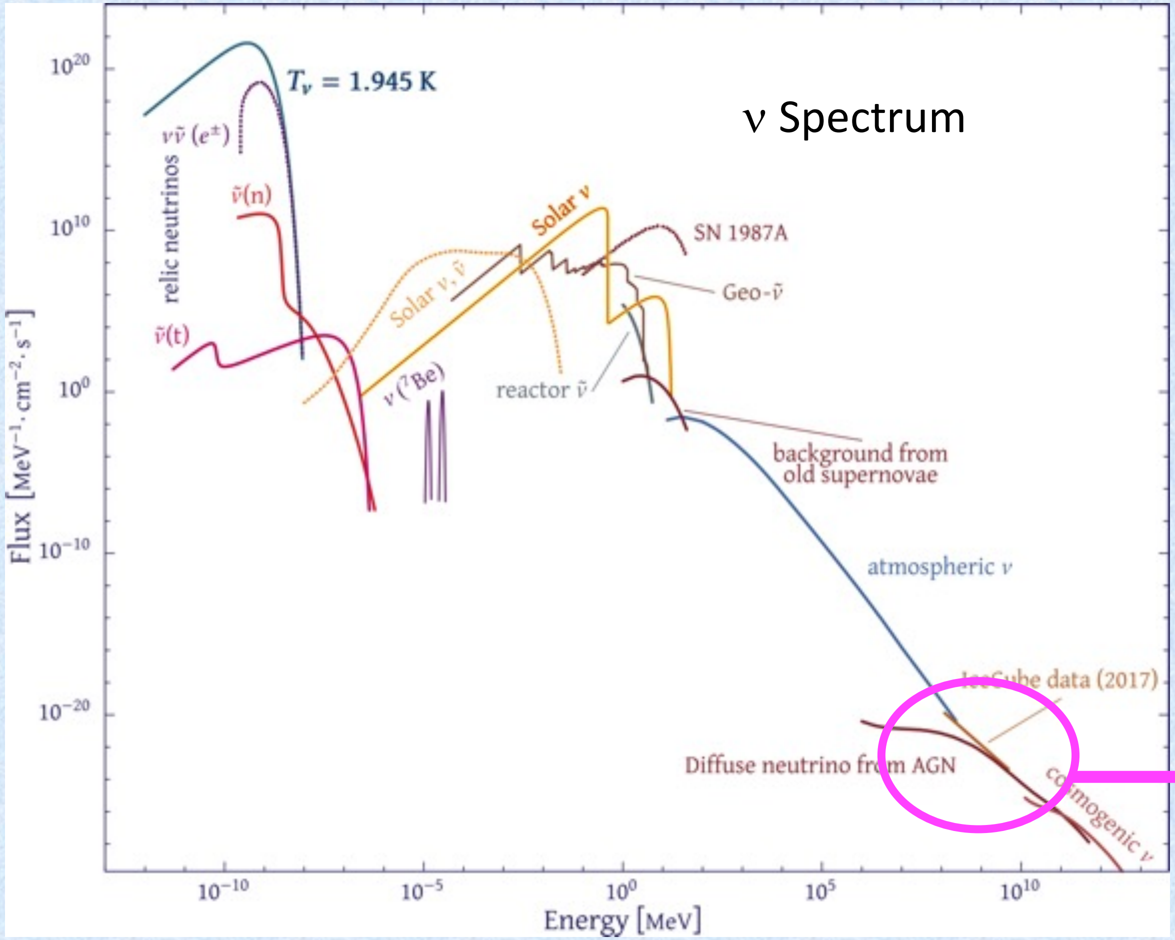


FIG. 4. Sensitivities to dark matter decay width (left) and inverse of the decay width (right), $\nu\bar{\nu}$ channel. Five-year sensitivities of POEMMA for the Cherenkov standard [(std), solid blue] and Galactic Center [(GC), dashed blue], and the fluorescence (green) observation modes, GRAND10k (solid orange), and GRAND200k (dashed orange). Sensitivities of ANITA IV (gray), Auger (dot-dashed red), and the IceCube [84] (dot-dashed purple). Allowed regions are below (above) the curves in the left (right) figure.

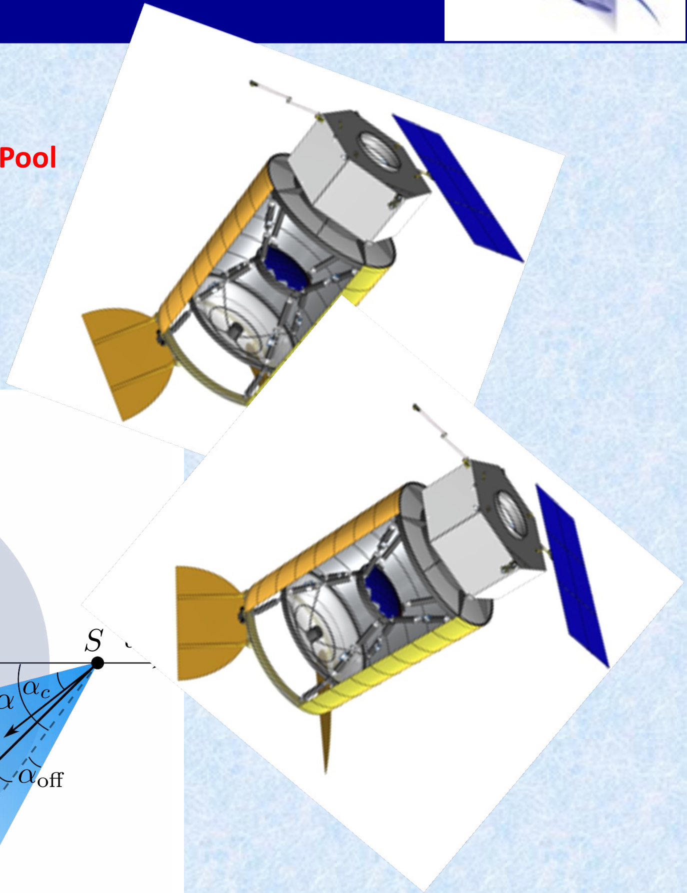
Cosmic Neutrino Sources and Optical Cherenkov EAS Detection

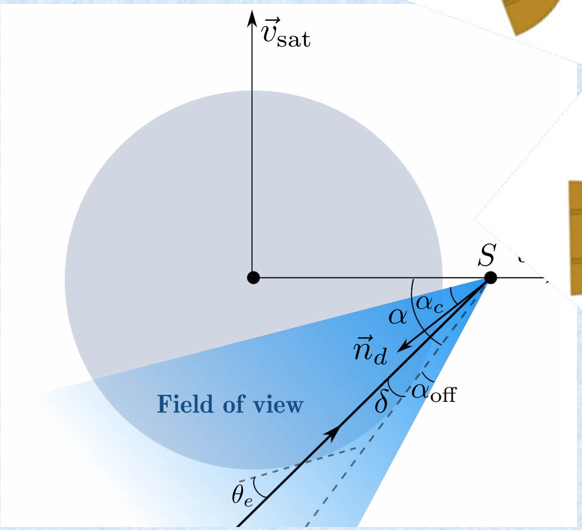




Flight Dynamics/Propulsion:

- 300 km ⟹ 25 km SatSep
  - Puts both in CherLight Pool
- Δt = 3 hr: 8 – 15 times
- Δt = 24 hr: 90 times





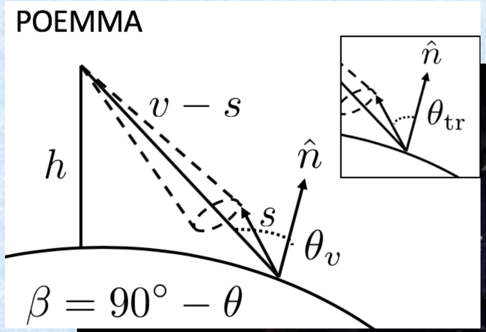
Avionics on each POEMMA satellite allow for slewing : 90° in 500 sec

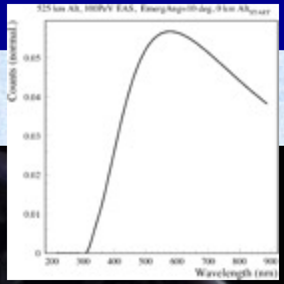
Cosmic ν flux dominates over ATM background ~100 TeV
Note: ATM ν flux has a minimal ν_τ component at high energies.

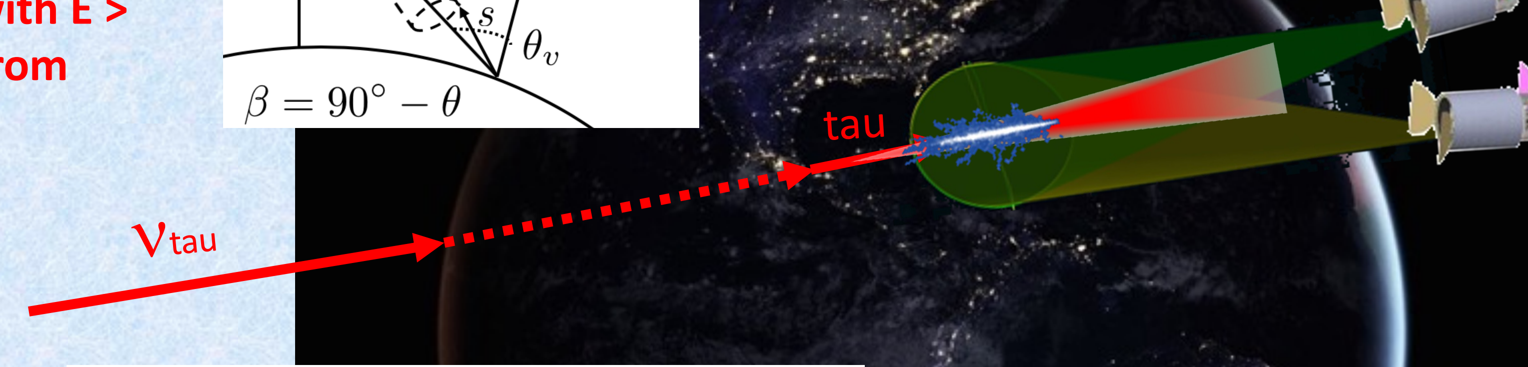
POEMMA Tau Neutrino Detection: *see PhysRevD.100.063010*

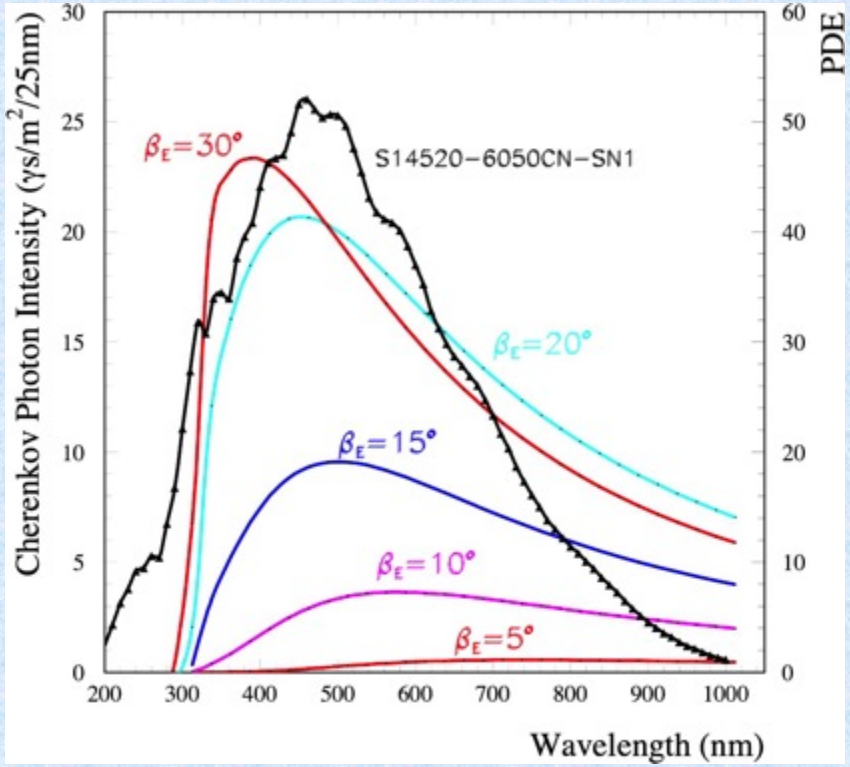
High-Energy Astrophysical Events generates neutrinos (ν_e,ν_μ) and 3 neutrino flavors reach Earth via neutrino oscillations.

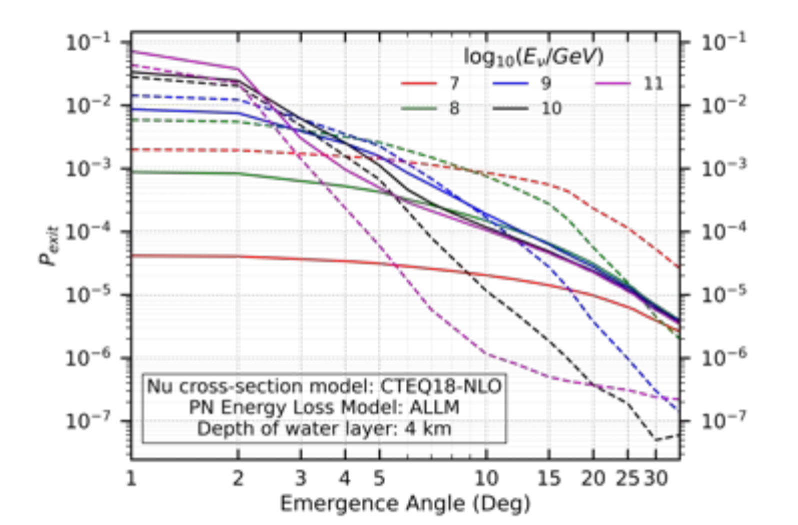
POEMMA designed to observe neutrinos with E > 20 PeV through Cherenkov signal of EASs from Earth-emerging tau decays.



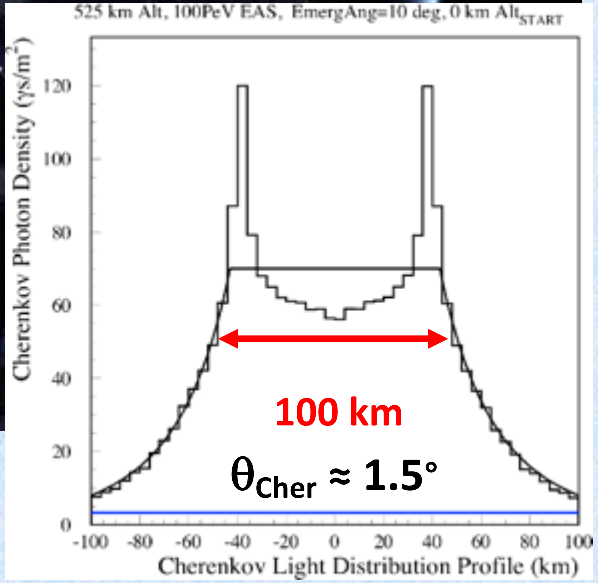






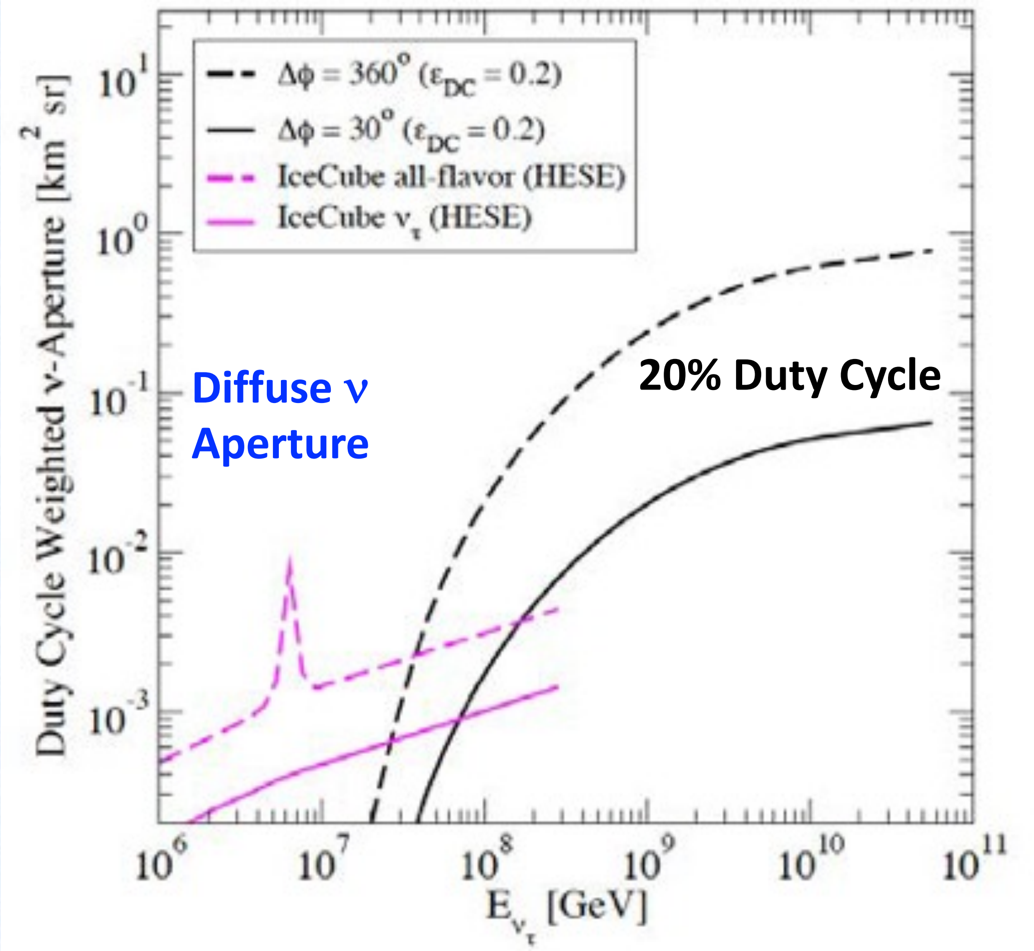


nuPyProp: arXiv:2209.15581



POEMMA VHE Diffuse Neutrino Sensitivity: see PhysRevD.103.043017

High-Energy Astrophysical Events generates neutrinos (ν_e,ν_μ) and 3 neutrino flavors reach Earth via neutrino oscillations.



EAS from Earth-emergent muons dominant below 10 PeV

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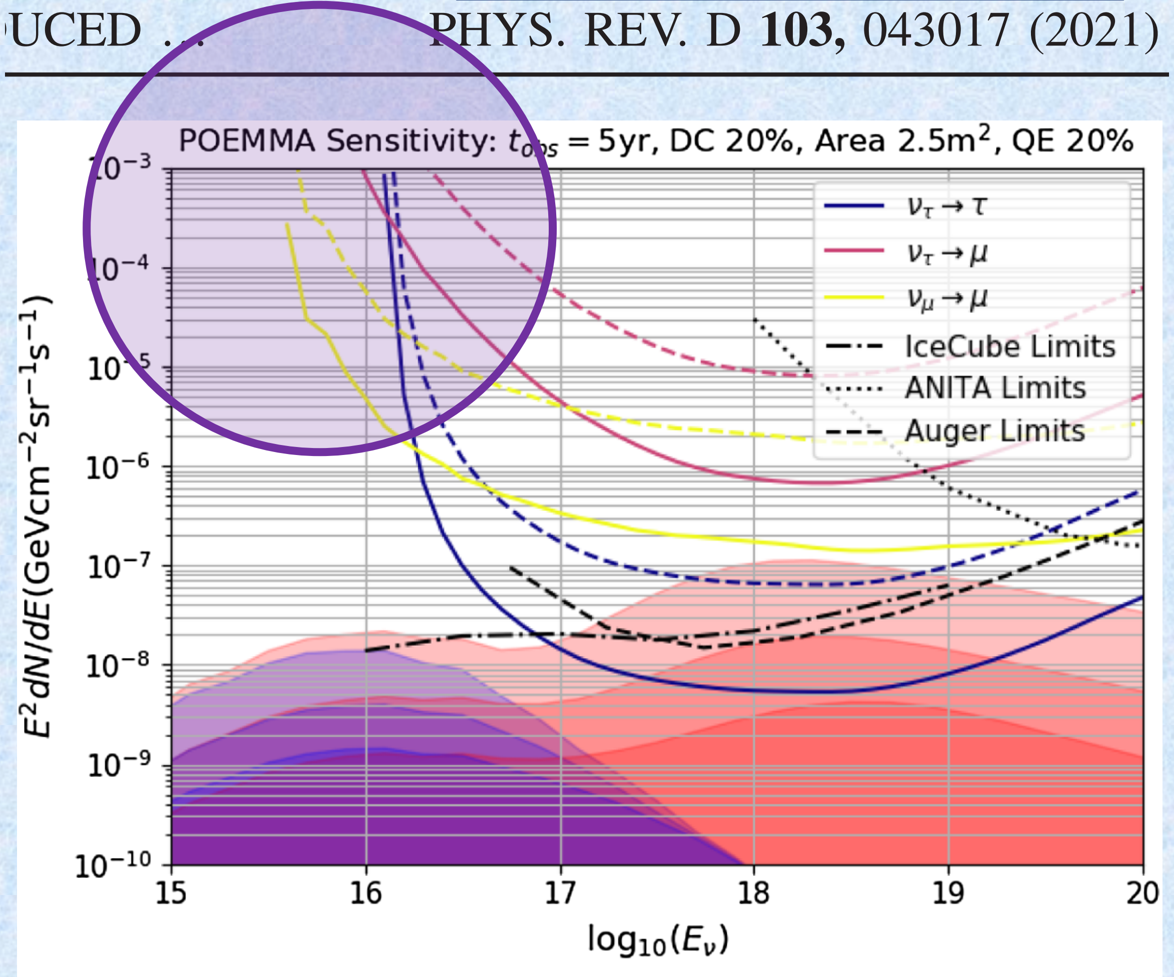
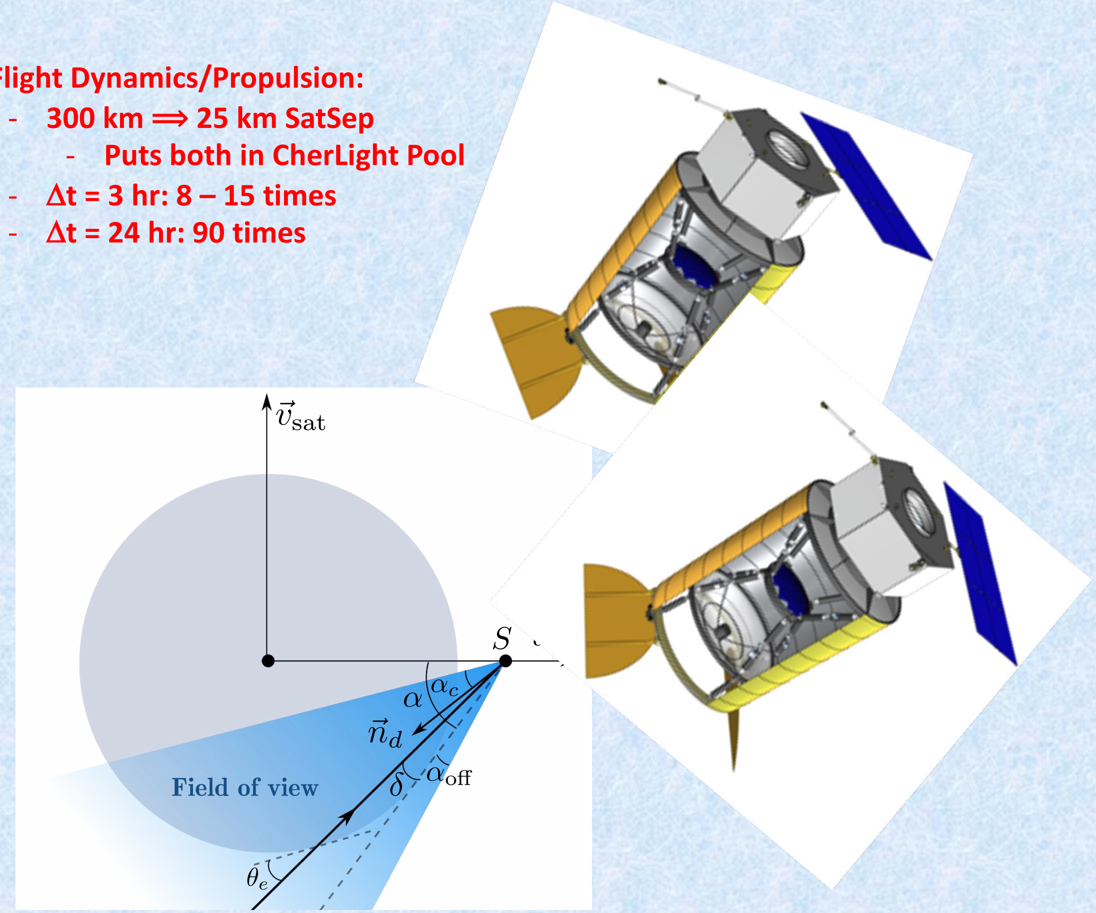


POEMMA Transient Neutrino Detection via external alert

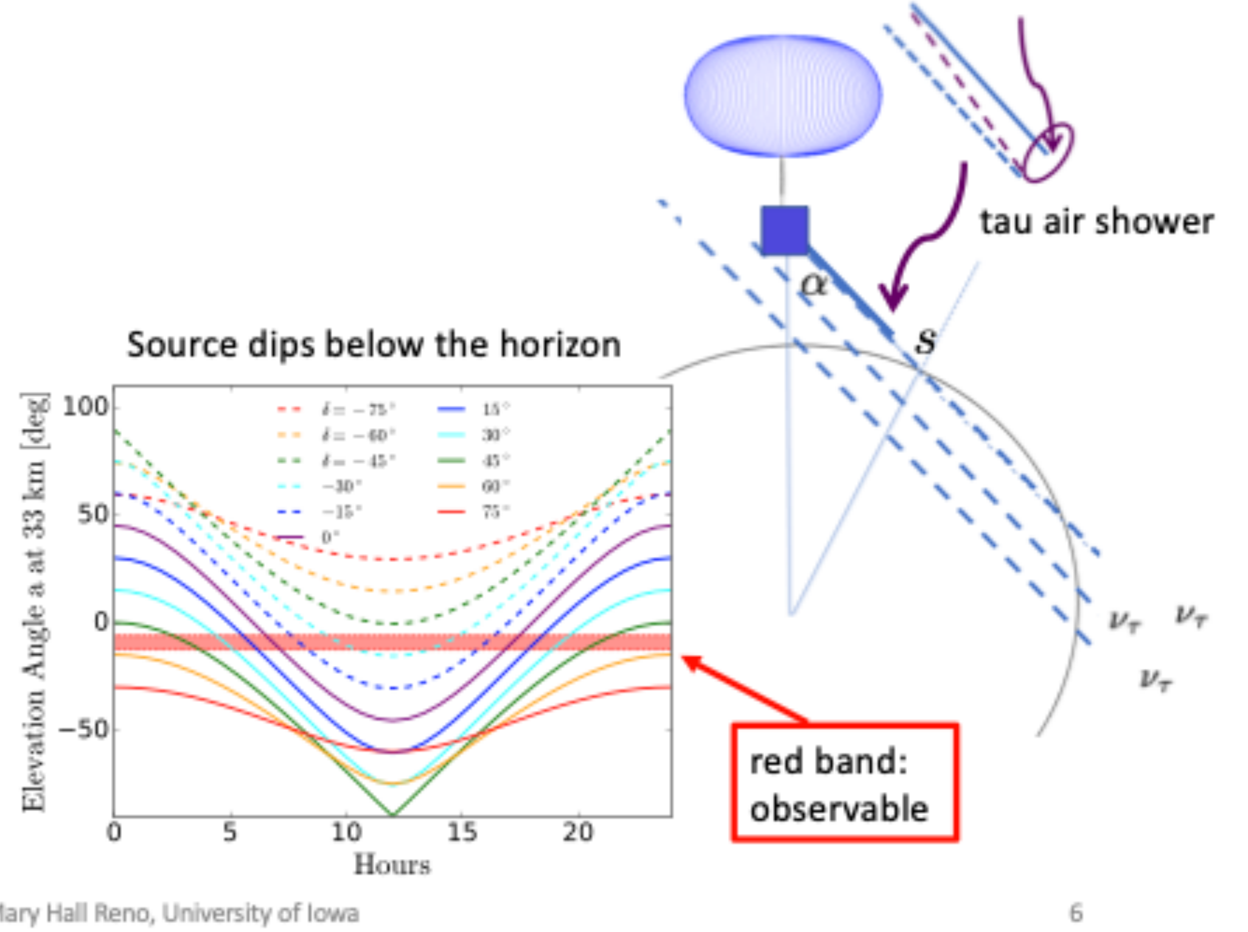
Flight Dynamics/Propulsion:
- 300 km ⟹ 25 km SatSep
  - Puts both in CherLight Pool
- Δt = 3 hr: 8 – 15 times
- Δt = 24 hr: 90 times



Avionics on each POEMMA satellite allow for slewing : 90° in 500 sec

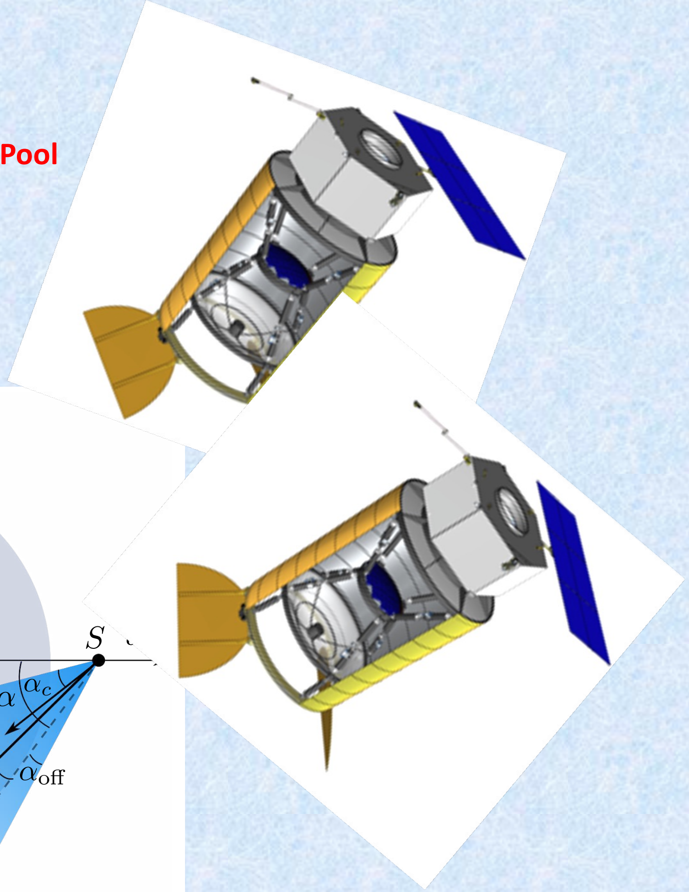
EUSO-SPB2 Work by M.H Reno, T. Venters, and JFK (

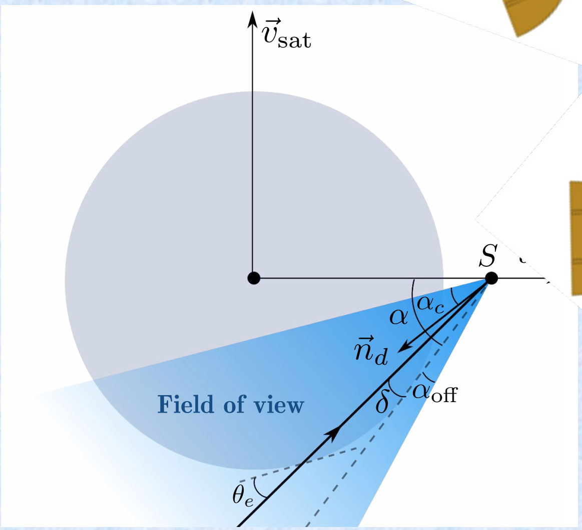
$$A_{\rm Ch} = \pi\theta_{\rm Ch}^2(v-s)^2$$
$$v - s$$

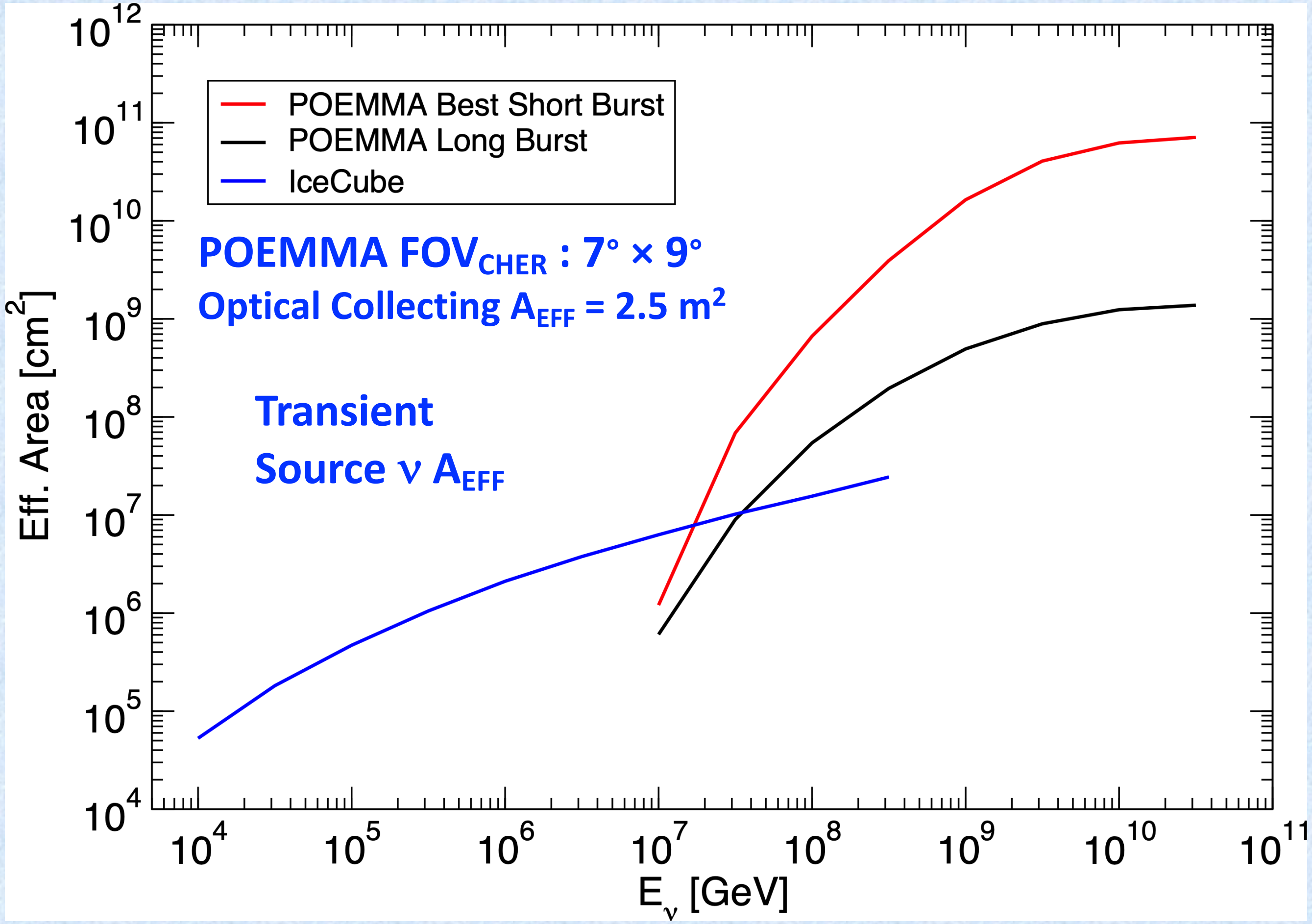


POEMMA Transient Neutrino Aperture and Diffuse Sensitivity

Flight Dynamics/Propulsion:
- 300 km ⟹ 25 km SatSep
    - Puts both in CherLight Pool
- Δt = 3 hr: 8 – 15 times
- Δt = 24 hr: 90 times







Avionics on each POEMMA satellite allow for slewing : 90° in 500 sec

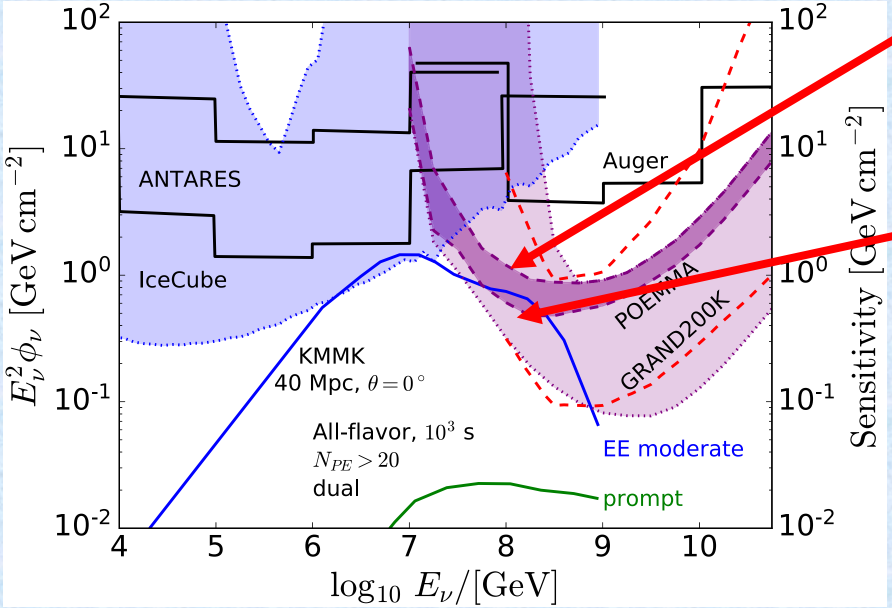
POEMMA ToO Neutrino Sensitivity: *see PhysRevD.102.123013*

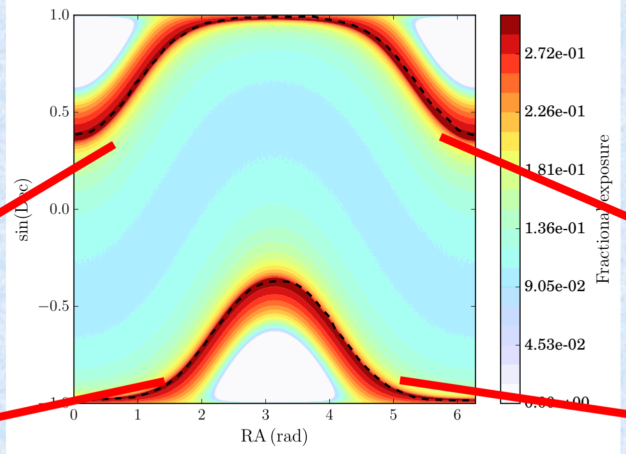
17% hit for ignoring τ → μ channel

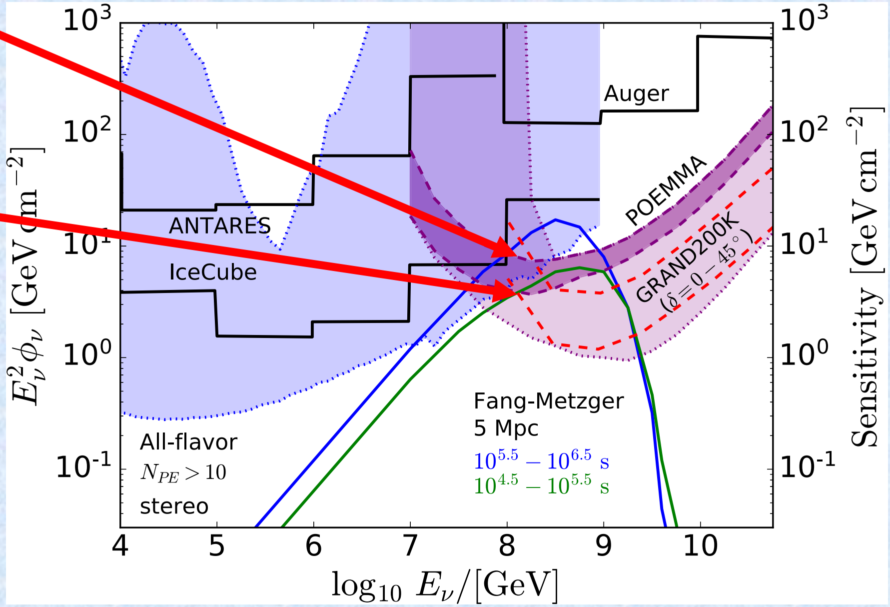
Short Bursts:
- 500 s to slew to source after alert
- 1000 s burst duration
- Source celestial location optimal
- Two independent Cher measurements
  - 300 km SatSep
- 20 PE threshold:
  - AirGlowBack < 10^{-3}/year

One orbit sky exposure assuming slewing to source position

Long Bursts:
- **3 to 24+hr to move SatSep to 50 km**
- Burst duration ≳ 10^5 s (models in plot)
- Average Sun and moon effects
- Simultaneous Cher measurements
  - 50 km SatSep
- **10 PE threshold (time coincidence):**
  - AirGlowBack < 10^{-3}/year







IceCube, ANTARES, Auger Limits for NS-NS merger GW170817

POEMMA ToO Neutrino Sensitivity: *see PhysRevD.102.123013*

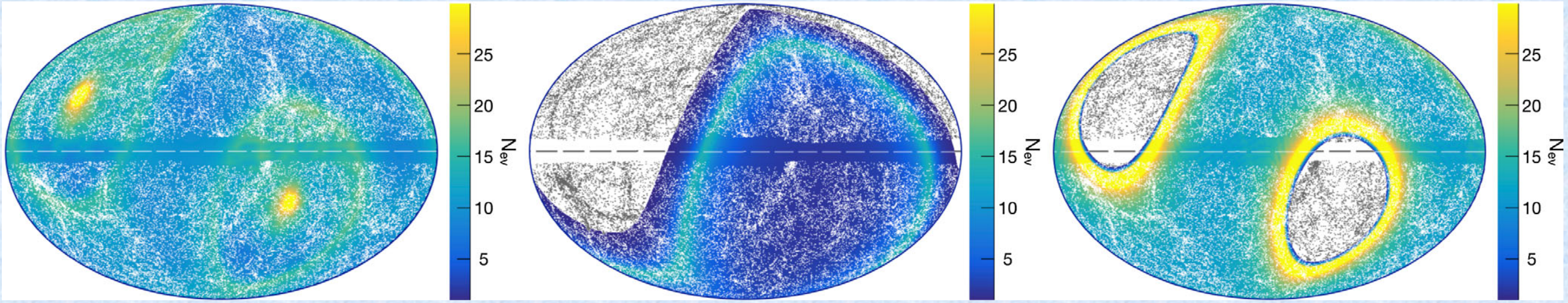


FIG. 7. Left: sky plot of the expected number of neutrino events as a function of galactic coordinates for POEMMA in the long-burst scenario of a BNS merger, as in the Fang and Metzger model [22], and placing the source at 5 Mpc. Point sources are galaxies from the 2MRS catalog [78]. Middle: same as at left for IceCube for muon neutrinos. Right: same as at left for GRAND200k. Areas with gray point sources are regions for which the experiment is expected to detect less than one neutrino.

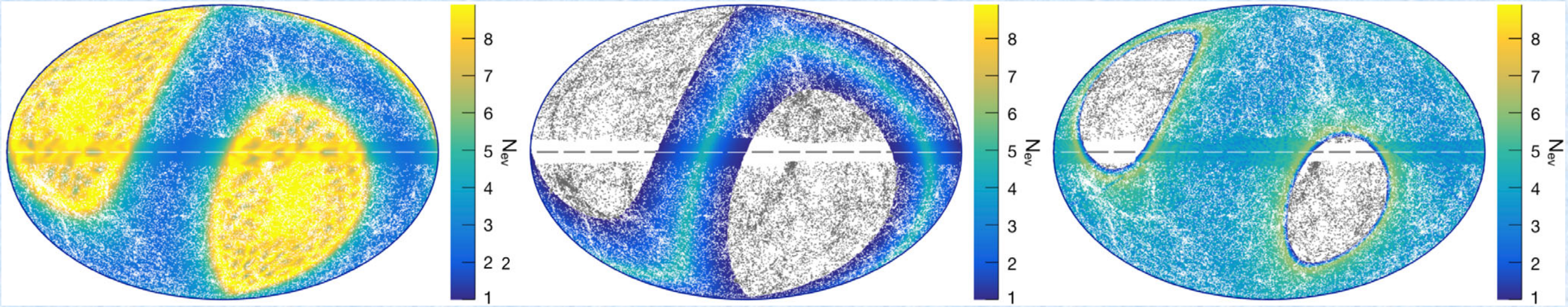


FIG. 8. Left: sky plot of the expected number of neutrino events as a function of galactic coordinates for POEMMA in the best-case short-burst scenario of an sGRB with moderate EE, as in the KMMK model [17], and placing the source at 40 Mpc. Point sources are galaxies from the 2MRS catalog [78]. Middle: same as at left for IceCube for muon neutrinos. Right: same as at left for GRAND200k. Areas with gray point sources are regions for which the experiment is expected to detect less than one neutrino.

POEMMA ToO Rate of Detection: *see PhysRevD.102.123013*

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TABLE IV. Average expected numbers of neutrino events above $E_\nu > 10^7$ GeV detectable by POEMMA for several models of transient source classes assuming source locations at the GC and at 3 Mpc. The horizon distance for detecting 1.0 neutrino per ToO event is also provided. Source classes with observed durations $>10^3$ s are classified as long bursts. Those with observed durations $\lesssim 10^3$ s are classified as short bursts. Models in boldface type are those models for which POEMMA has $\gtrsim 10\%$ chance of observing a ToO during the proposed mission lifetime of 3–5 years. Models in italics are the same but for a mission lifetime of 10 years.

Long bursts

Source class	No. of ν's at GC	No. of ν's at 3 Mpc	Largest distance for 1.0ν per event	Model reference
TDEs	1.4×10^5	0.9	3 Mpc	Dai and Fang [18] average
TDEs	6.8×10^5	4.7	7 Mpc	Dai and Fang [18] bright
TDEs	$\mathbf{2.7 \times 10^8}$	$\mathbf{1.7 \times 10^3}$	**128 Mpc**	**Lunardini and Winter** [19] $M_{SMBH} = 5 \times 10^6 M_\odot$ **Lumi scaling model**
TDEs	7.7×10^7	*489*	*69 Mpc*	*Lunardini and Winter* [19] *Base scenario*
Blazar flares	NA[a]	NA[a]	47 Mpc	RFGBW [20]—FSRQ proton-dominated advective escape model
lGRB reverse shock (ISM)	1.2×10^5	0.8	3 Mpc	Murase [16]
lGRB reverse shock (wind)	2.5×10^7	174	41 Mpc	Murase [16]
BBH merger	$\mathbf{2.8 \times 10^7}$	**195**	**43 Mpc**	**Kotera and Silk** [21] **(rescaled) Low fluence**
BBH merger	$\mathbf{2.9 \times 10^8}$	$\mathbf{2.0 \times 10^3}$	**137 Mpc**	**Kotera and Silk** [21] **(rescaled) High fluence**
BNS merger	$\mathbf{4.3 \times 10^6}$	**30**	**16 Mpc**	**Fang and Metzger** [22]
BWD merger	25	0	38 kpc	XMMD [23]
Newly born Crablike pulsars (p)	190	0	109 kpc	Fang [24]
Newly born magnetars (p)	2.5×10^4	0.2	1 Mpc	Fang [24]
Newly born magnetars (Fe)	5.0×10^4	0.3	2 Mpc	Fang [24]

Short bursts

Source class	No. of ν's at GC	No. of ν's at 3 Mpc	Largest distance for 1.0ν per event	Model reference
sGRB extended emission (moderate)	1.1×10^8	800	90 Mpc	KMMK [17]

[a]Not applicable due to a lack of known blazars within 100 Mpc.

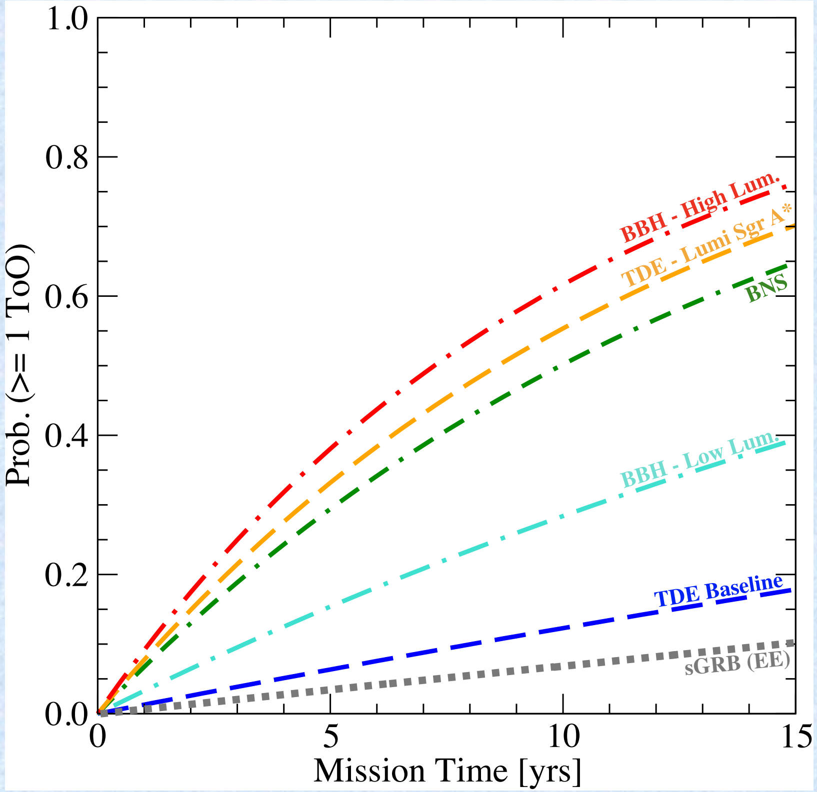
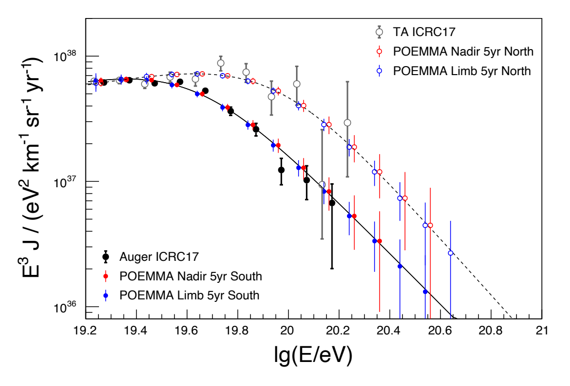


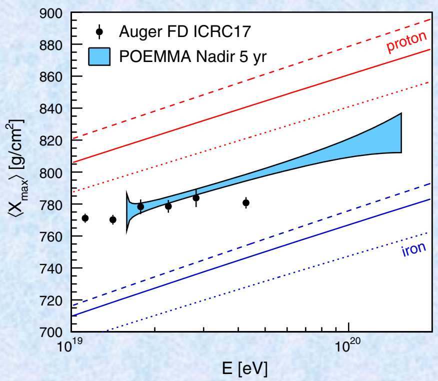
FIG. 9. The Poisson probability of POEMMA observing at least one ToO versus mission operation time for several modeled source classes. Featured source models are TDEs from Lunardini and Winter [19], BNS mergers from Fang and Metzger [22], BBH mergers from Kotera and Silk [21], and sGRBs with moderate EE from KMMK [17].

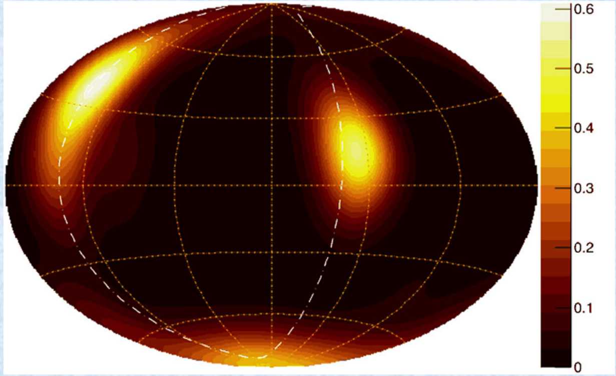
Summary

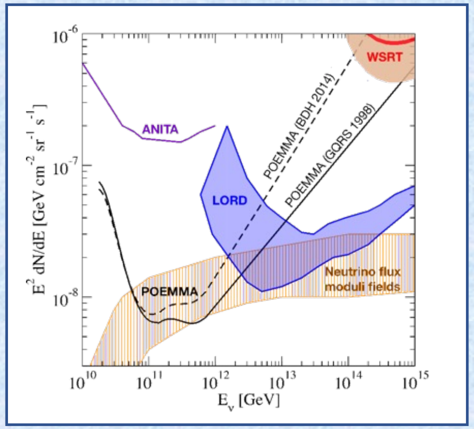
POEMMA will make high-statistics UHECRs above 20 EeV with the goal of discovering the source(s) of UHECRs

- **POEMMA stereo fluorescence measurements provides excellent Angular, Energy, and Composition (x_{Max}) resolutions over the full sky.**
- **Ability to tilt POEMMA telescopes increases UHECR aperture at the highest energies, albeit with reduced EAS measurement performance.**
- **POEMMA Stereo fluorescence also provides exceptional UHE all-flavor UHE neutrino sensitivity**



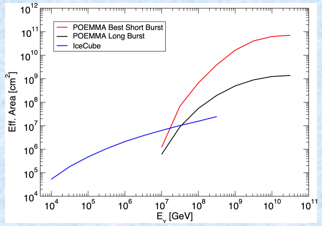


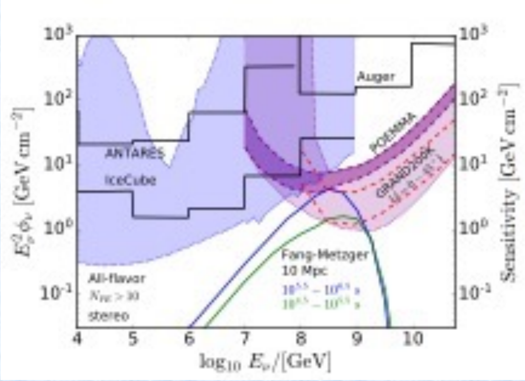


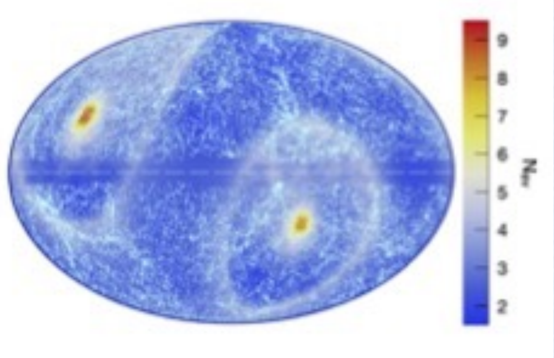


POEMMA will have unique VHE tau-neutrino sensitivity above 20 PeV to transient neutrino sources using EAS optical Cherenkov:

- **The ability to quickly slew to a neutrino ToO provides remarkable sensitivity above 20 PeV**



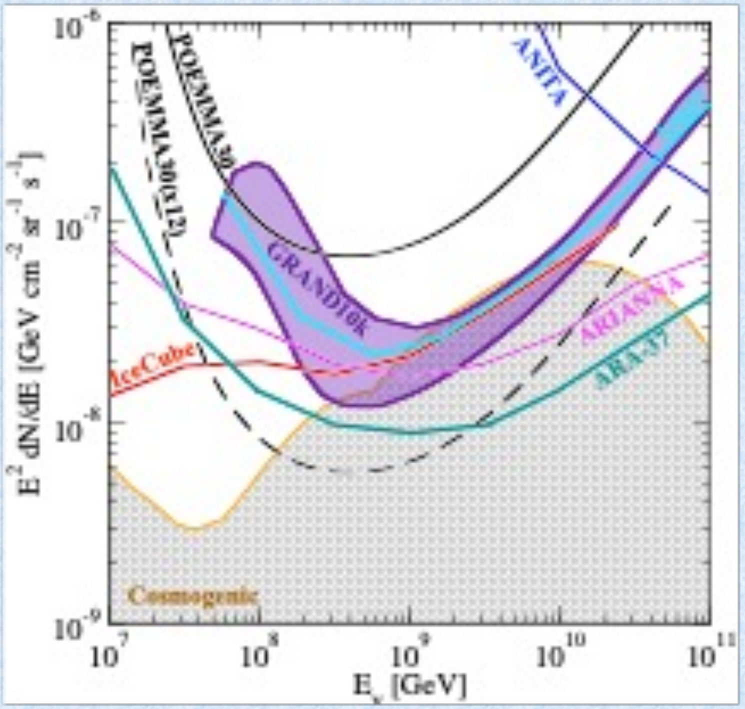




Conclusion and future …

POEMMA Benefited from being a NASA POEMMA Probe study:

- review determined *No new technology needed*, could benefit from technology developments.
- **NASA Probe implementation *may* allow POEMMA proposal in 2nd NASA Probe AO (2025+)**
- SnowMass CF7 UHECR whitepaper (arXiv:2205.05845) recommends proceeding with the development of POEMMA as one of the next generation UHECR experiments (along with GCOS and GRAND).
- Rich portfolio of POEMMA science papers helped perception (at least within NASA community) that a mission like POEMMA, using UHECR, UHE & VHE neutrinos, probes unique and interesting high-energy astrophysics phenomena.



nuSpaceSim https://heasarc.gsfc.nasa.gov/docs/nuSpaceSim/ end-to-end space-based neutrino detection simulation of optical and radio EAS signals *allows for the development of **combined radio and optical Cherenkov** neutrino instruments that leverage the advantage of each method*

- *Optical Cherenkov is sensitive to neutrinos 2 – 3 orders of magnitude lower in energy than the radio*
- *Radio has 100% duty cycle*
- *Two combined would allow for lower background events*

Tool to develop the space-based cosmic neutrino missions:

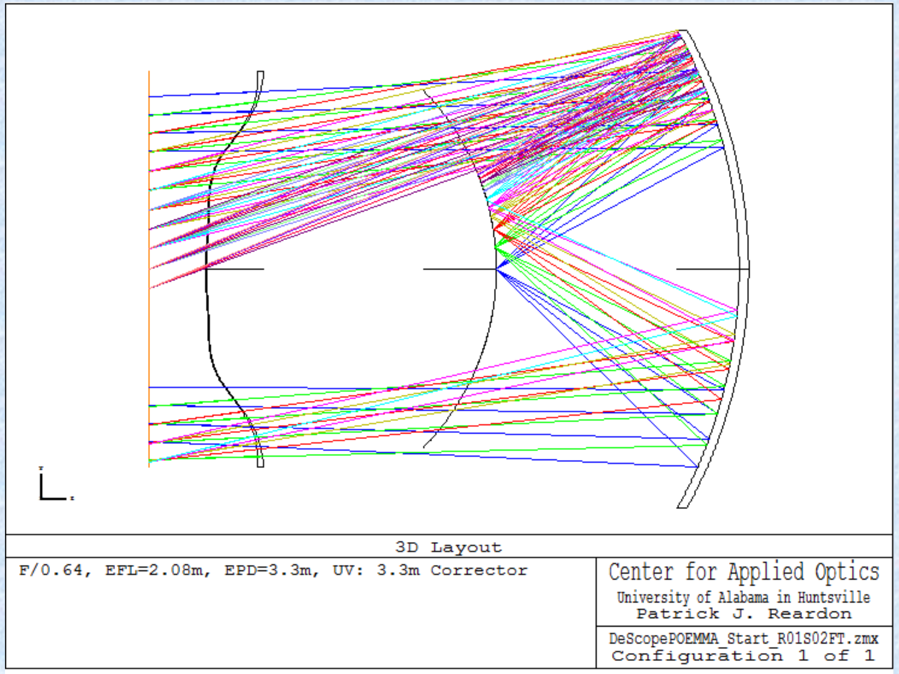
- ***Space-based Neutrino Surveyor (POEMMA360) using near limb-viewing Cherenkov telescope with $\Delta\phi = 360°$, and would be self-triggering for neutrino transients events while having significant sky coverage to follow-up external ToO alerts.***
- ***Space-based ToO Cherenkov Telescope(s) with modest, few degree FoV, $A_{Eff} \gtrsim 1$ m, and ability to quickly slew to follow-up external ToO alerts, could be a SmallSat format.***

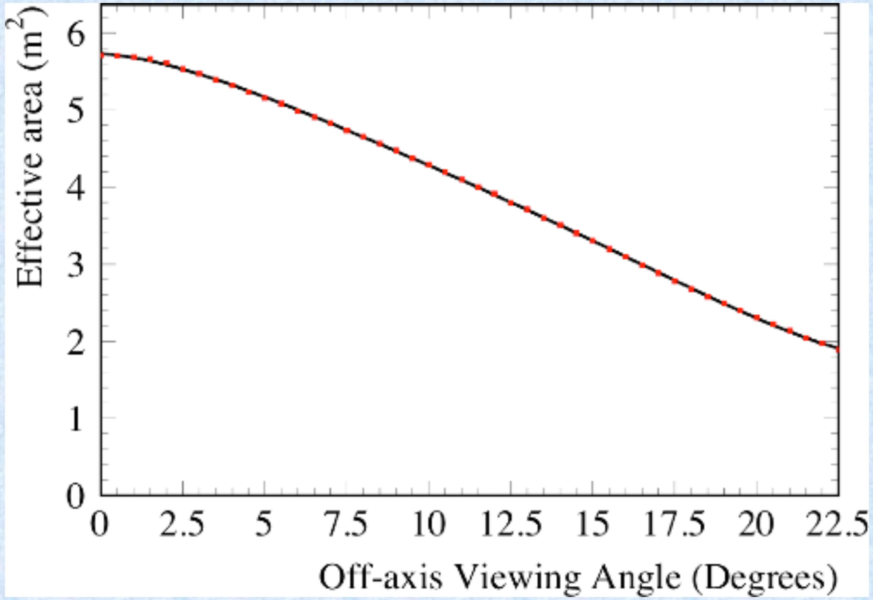
POEMMA Mission and Science Performance Publications

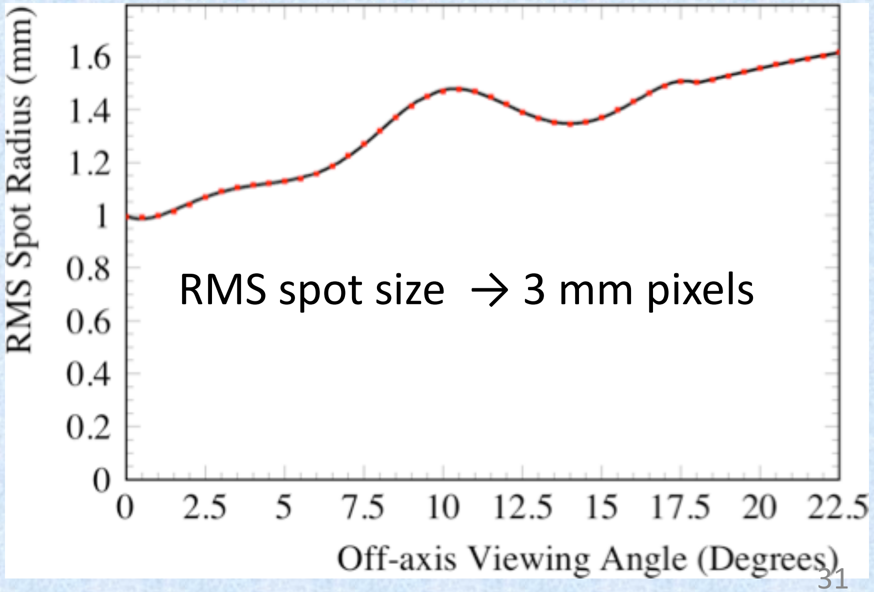
1. C. Guepin, F. Sarazin, J. Krizmanic, J. Loerincs, A. Olinto, and A. Piccone, ***Geometrical Constraints of Observing Very High Energy Earth-Skimming Neutrinos from Space***, JCAP 2019, 03, 021, arXiv:1812.07596
2. M. H. Reno, J. F. Krizmanic, and T. M. Venters, ***Cosmic tau neutrino detection via Cherenkov signals from air showers from Earth-emerging taus***, PhysRevD 100, 063010, (2019), arXiv:1902.1128
3. L. A. Anchordoqui, D. R. Bergman, M. E. Bertaina, F. Fenu, J. F. Krizmanic, A. Liberatore, A. V. Olinto, M. Hall Reno, F. Sarazin, K. Shinozaki, J. F. Soriano, R. Ulrich, M. Unger, T. M. Venters, and L. Wiencke, ***Performance and science reach of POEMMA for ultrahigh-energy particles,*** *PhysRevD.101.023012, arXiv:1907.03694*T.
4. M. Venters, M. Hall Reno, J. F. Krizmanic, L. A. Anchordoqui, C. Guépin, and A. V. Olinto, ***POEMMA's target of opportunity sensitivity to cosmic neutrino transient sources***, *PhysRevD.102.123013, arXiv:1906.07209*
5. *A.L. Cummings, R. Aloisio, R., J.F. Krizmanic,* ***Modeling of the Tau and Muon Neutrino-induced Optical Cherenkov Signals from Upward-moving Extensive Air Showers,*** PhysRevD.103.043017, arXiv:2011.09869
6. A.V Olinto, J.F. Krizmanic, and the POEMMA Collaboration***, The POEMMA (Probe of Extreme Multi-Messenger Astrophysics) Observatory,*** *JCAP 2021, 06, 007*
7. A.L. Cummings, R. Aloisio, R., J.Eser, J.F. Krizmanic, ***Modeling the optical Cherenkov signals by cosmic ray extensive air showers directly observed from suborbital and orbital altitudes***, PhysRevD.104.063029, arXiv:2105.03255
8. C. Guépin, A. Aloisio, L.A. Anchordoqui, A. Cummings, J. Krizmanic, A.V. Olinto, M.H. Reno, T.M. Venters, ***Indirect dark matter searches at ultrahigh energy neutrino detectors***, PhysRevD.104.083002, arXiv:04446
9. L. A. Anchordoqui, M. E. Bertaina, M. Casolino, J. Eser, J.F. Krizmanic, A.V. Olinto, A.N. Otte, T.C. Paul, L.W. Piotrowski, M.H. Reno, F. Sarazin, K. Shinozaki, J.F. Soriano, T.M. Venters, L. Wiencke, **Prospects for macroscopic dark matter detection at space-based and suborbital experiments,** Europhysics Letters 135, id.51001, arXiv: 2104.05131
10. M.H. Reno, L. A. Anchordoqui, A. Bhattacharya, A. Cummings, J. Eser, C. Guépin, J.F. Krizmanic, A.V. Olinto, T. Paul, I. Sarcevic, T. M. Venters, ***Neutrino constraints on long-lived heavy dark sector particle decays in the Earth***, PhysRevD.105.055013

Backup

POEMMA: Schmidt Telescope details







Two 4 meter F/0.64 Schmidt telescopes: 45° FoV

Primary Mirror: **4 meter diameter**

Corrector Lens: **3.3 meter diameter**

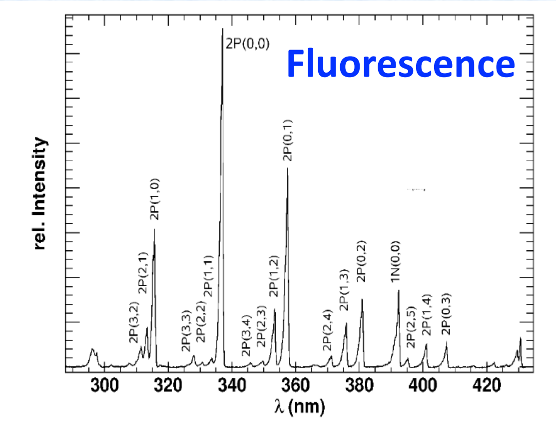
Focal Surface: **1.6 meter diameter**

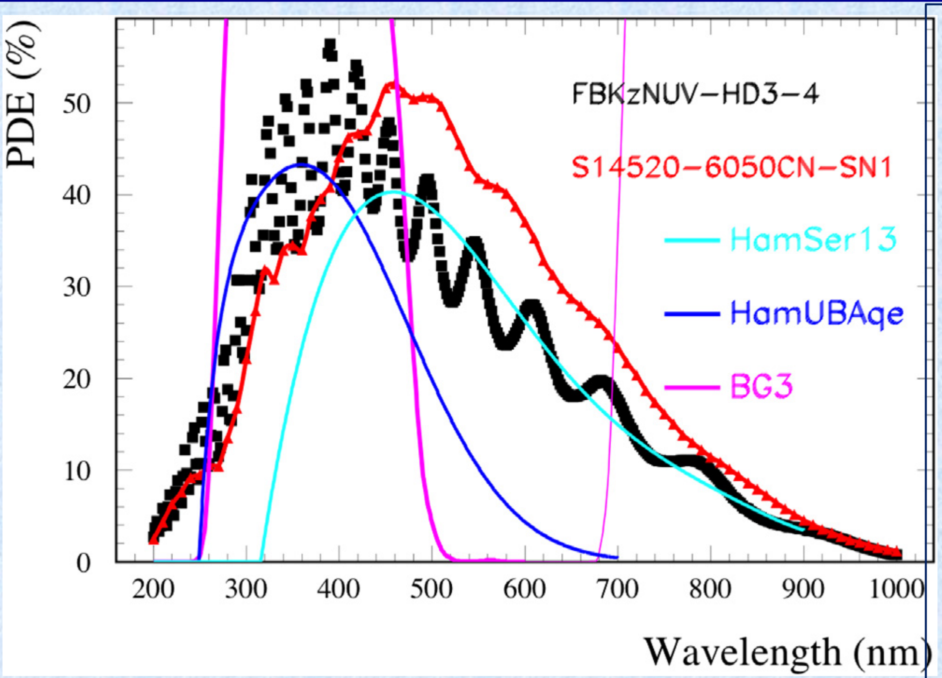
Optical Area$_{EFF}$: **~6 to 2 m^2**

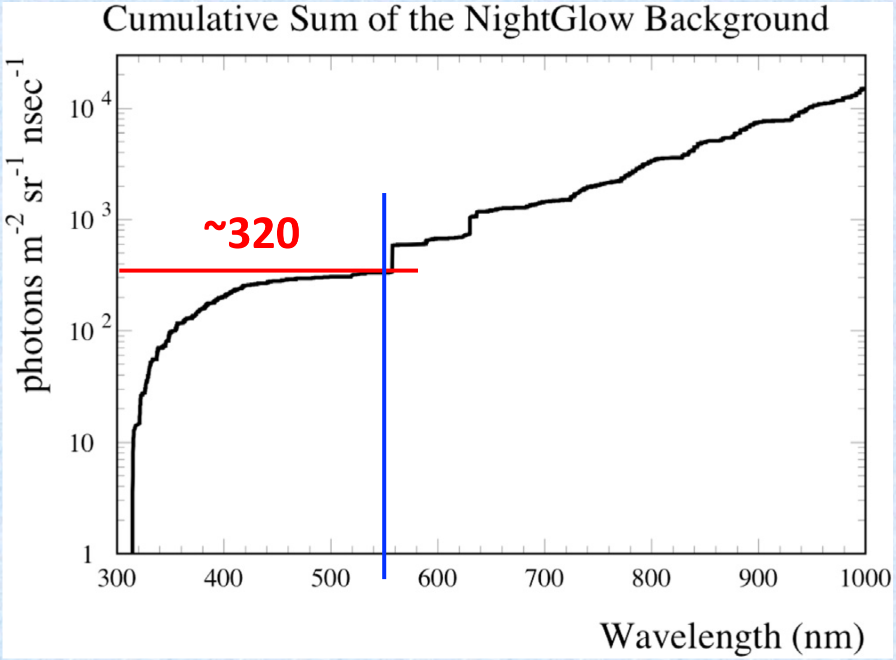
Hybrid focal surface (MAPMTs and SiPM)

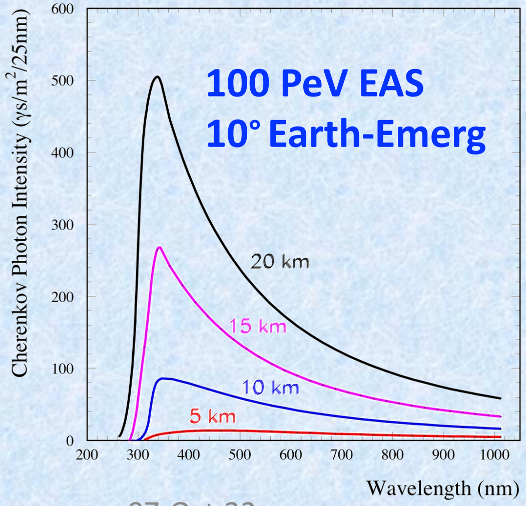
3 mm linear pixel size: 0.084 ° FoV

DarkSky Airglow Background NIMA 985 id.164614 (2021)









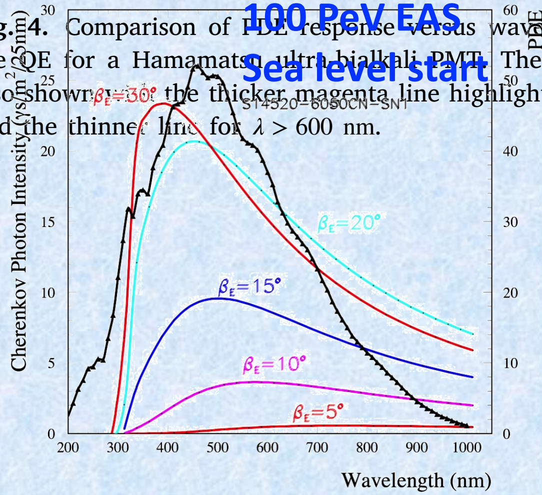
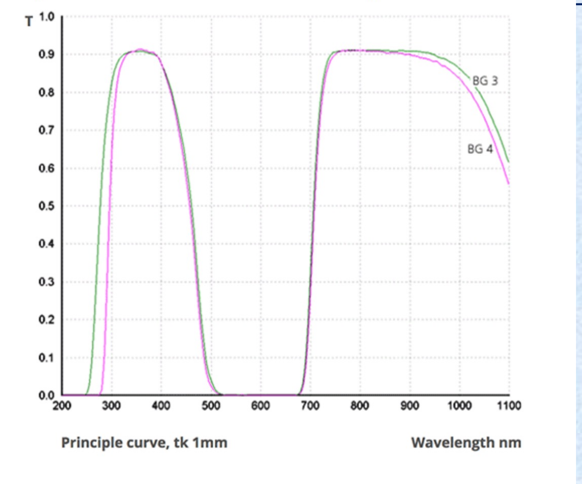


Fig. 4. Comparison of PDE response versus wavelength for various devices included the QE for a Hamamatsu ultra-bialkali PMT. The bandpass of a Schott BG3 filter is also shown with the thicker magenta line highlighting the transmission for $\lambda \leq 600$ nm and the thinner line for $\lambda > 600$ nm.

Fig. 8. The cumulative sum of the NightGlow Background (NGB) using the measurements of Hanu

Recovery of transmission above 700 nm for BG3 is problematic for use with SiPMs for fluorescence light detection



POEMMA Stereo Fluorescence X_{max} Resolution, *see PhysRevD.101.023012*

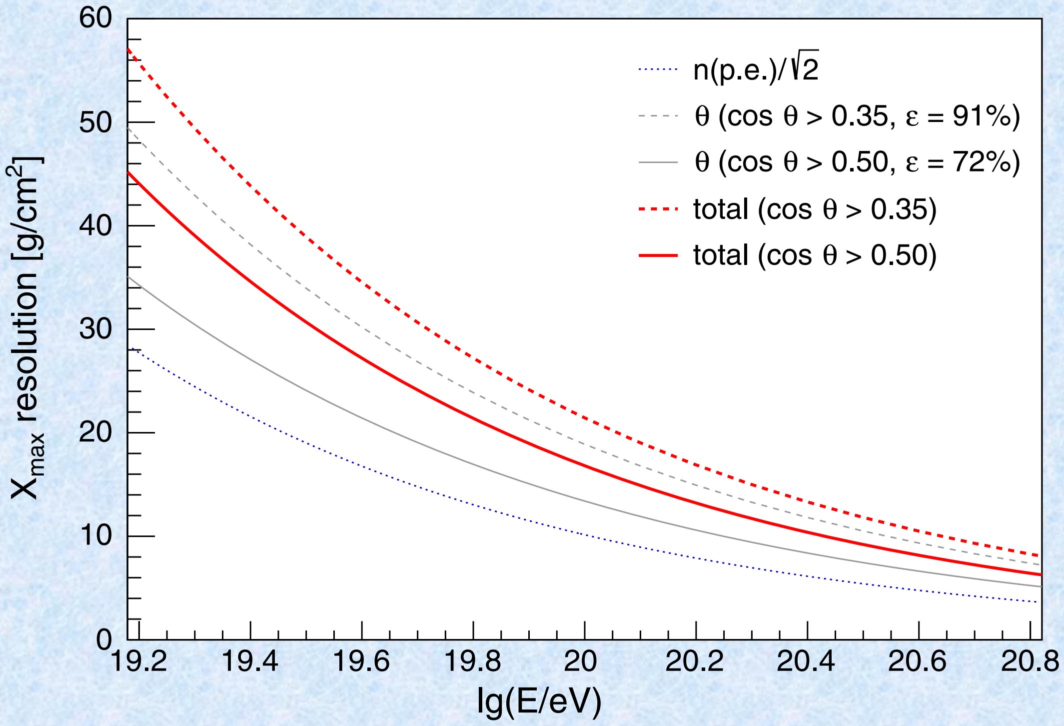


FIG. 17. Preliminary estimate of the X_{max} resolution of POEMMA in stereo mode. The contributions from the photoelectron statistics and angular resolution are shown in blue and gray, respectively. The total resolution, obtained by adding both contributions in quadrature, is shown in red for two cuts on the maximum zenith angle.

Proton-Air Cross Section Measurements

LUIS A. ANCHORDOQUI *et al.* PHYS. REV. D **101,** 023012 (2020)

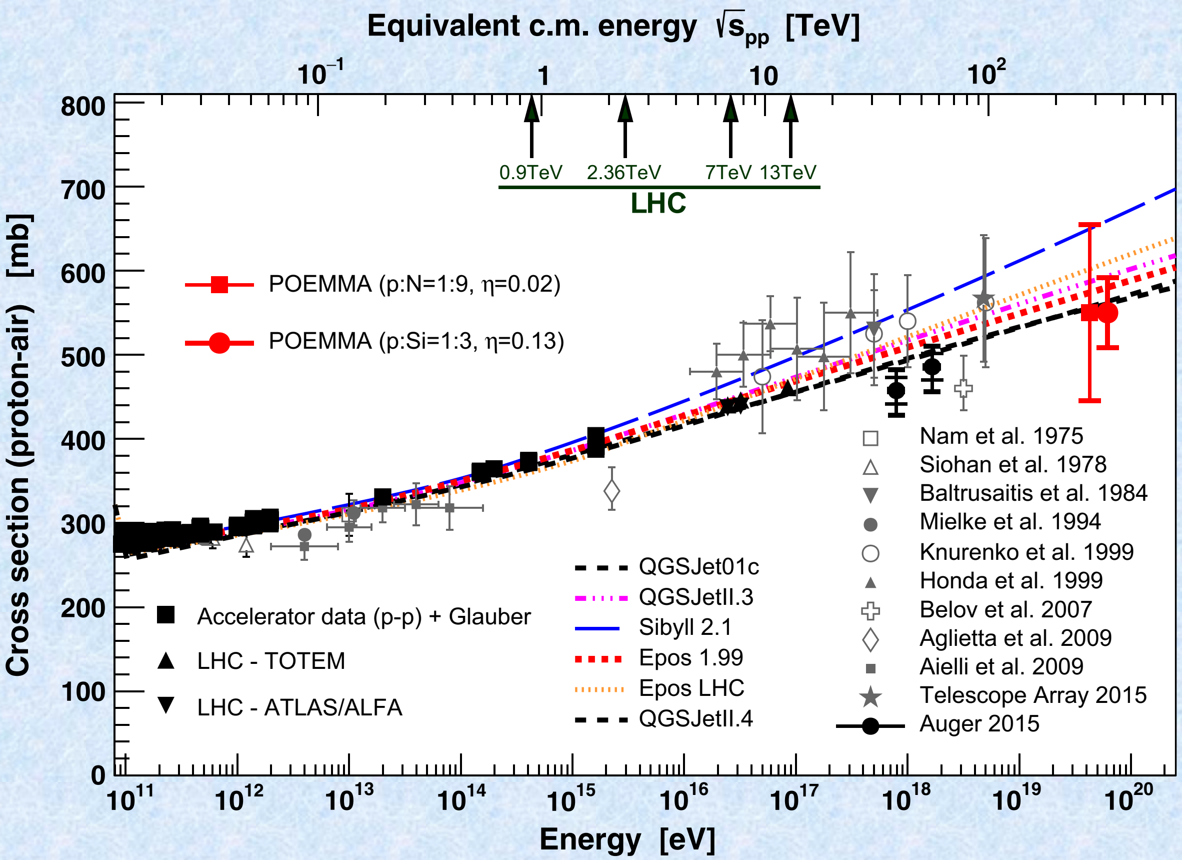


FIG. 26. Potential of a measurement of the UHE proton-air cross section with POEMMA. Shown are also current model predictions and a complete compilation of accelerator data converted to a proton-air cross section using the Glauber formalism. The expected uncertainties for two composition scenarios (left, $p:N = 1:9$; right, $p:Si = 1:3$) are shown as red markers with error bars. The two points are slightly displaced in energy for better visibility.