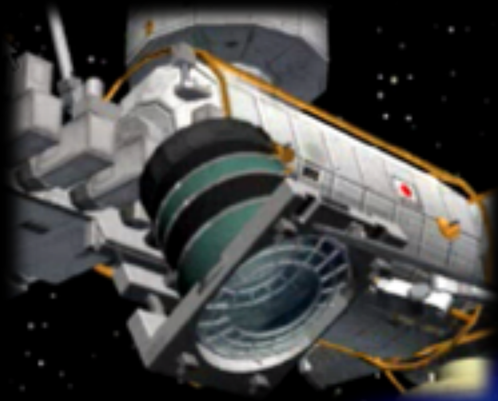


Extreme Universe Space Observatory

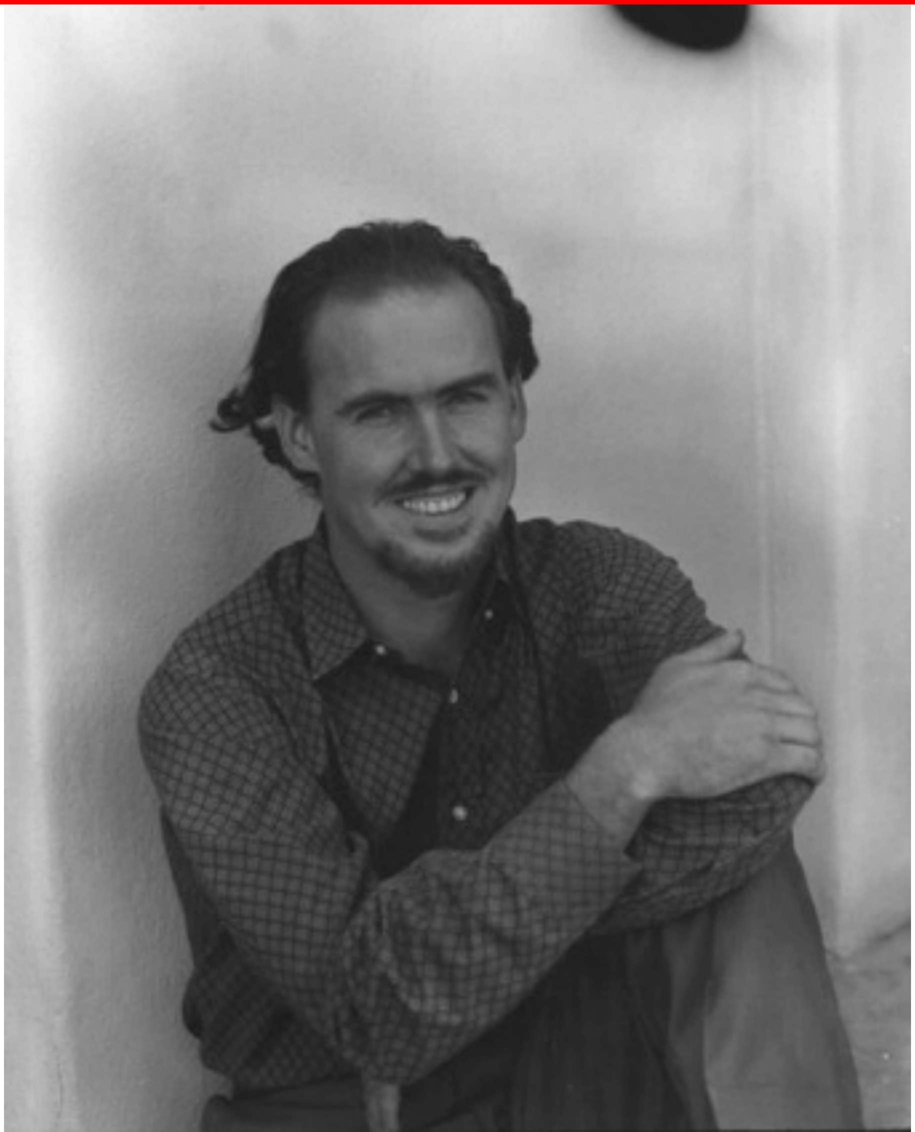
The JEM-EUSO mission: UHECRs observation from space

Mario Bertaina (bertaina@to.infn.it)
Torino University & INFN, Italy

What Next Padova, 3-4 December 2014

1979, An idea* of John Linsley

SOCRAS: Satellite Observatory of Cosmic Ray Showers



John Linsley in 1979 in the Field Committee Report of NASA "Call for Projects and Ideas in High Energy Astrophysics for the 1980s"

The concept to observe, by means of Space Based devices looking at Nadir during the night, the fluorescence light produced by an EAS proceeding in the atmosphere

In Early 1990s John had moved to Palermo to work on the PLASTEX experiment with his old friend Livio Scarsi, and Osvaldo Catalano

John Linsley, "search for the End of the Cosmic Ray Spectrum",
AIP CP433, 21, 1977.

FOURTH BREAKTHHROUGH?

On 15 May, 1995, my wife Paola te
was trying to get in touch with me
was, "I have written a paper ab
Satellite. The technology and neu
idea of 1979. I would like to send

MASS: Maximum Energy Auger (Air) Shower Satellite
Italian Mission

reduction that moves the proposal w
launch requirements. His order of
the same amount his counting rate.
if formidable technical problems are

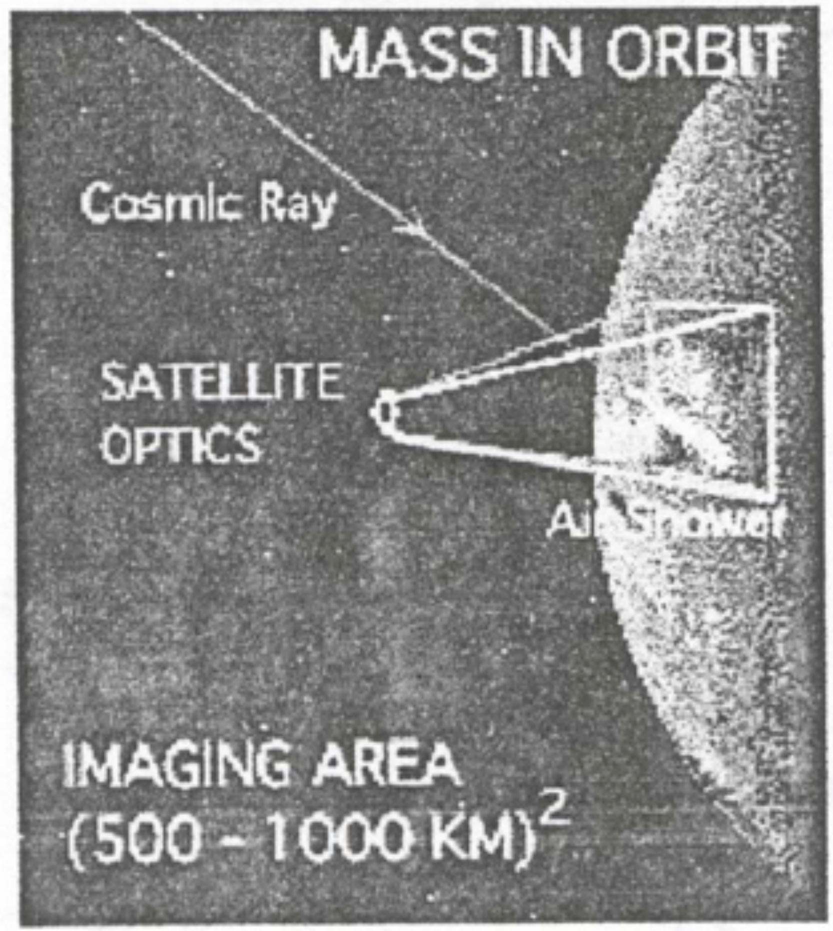
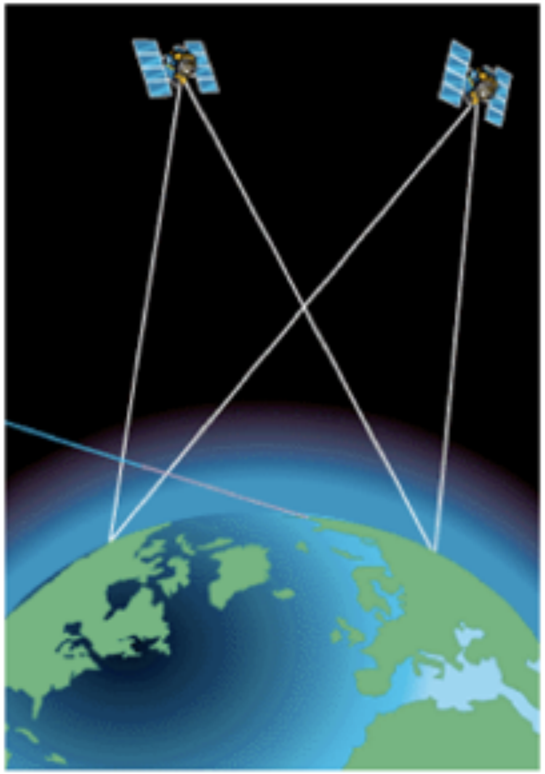


Fig. 3 Artist view of the MASS on orbit.



The OWL Concept

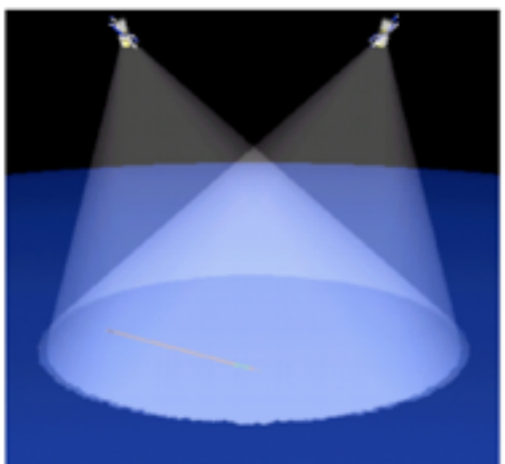
Use air fluorescence technique to image 300 ~ 400 nm photons in ~ 0.1^{O} pixels (with 10 ns ~ μs timing), from low Earth orbit, airshowers induced by E > 10^{19} eV cosmic rays

Wide angle (~ 60^{O} full, FOV) optics at a 600 - 1200 km orbit in a stereo configuration ≈ an asymptotic, *instantaneous* aperture ~ 3 x 10^{6} km^{2}-ster (640 km orbit, 60^{O} full, FOV, 'Original' Baseline)

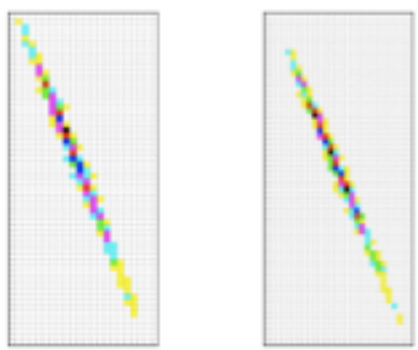
10% duty cycle ~ *effective* aperture ~ 3 x 10^{5} km^{2}-sr

Assuming F_{CR} (E) ~ $E^{-2.75}$, the asymptotic OWL stereo aperture leads to ~ 3000 events/year with E ≥ 10^{20} eV

Multi-OWL could evolve to viewing majority of night side atmosphere

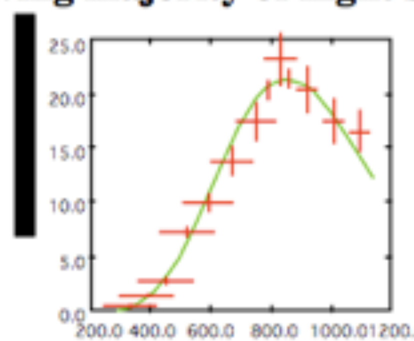


3/23/01, 3/14/04



Eye 1 Eye 2

Space Assembly & Deployment



*Y. Takahashi's presentation in Paris at College de France in 2004

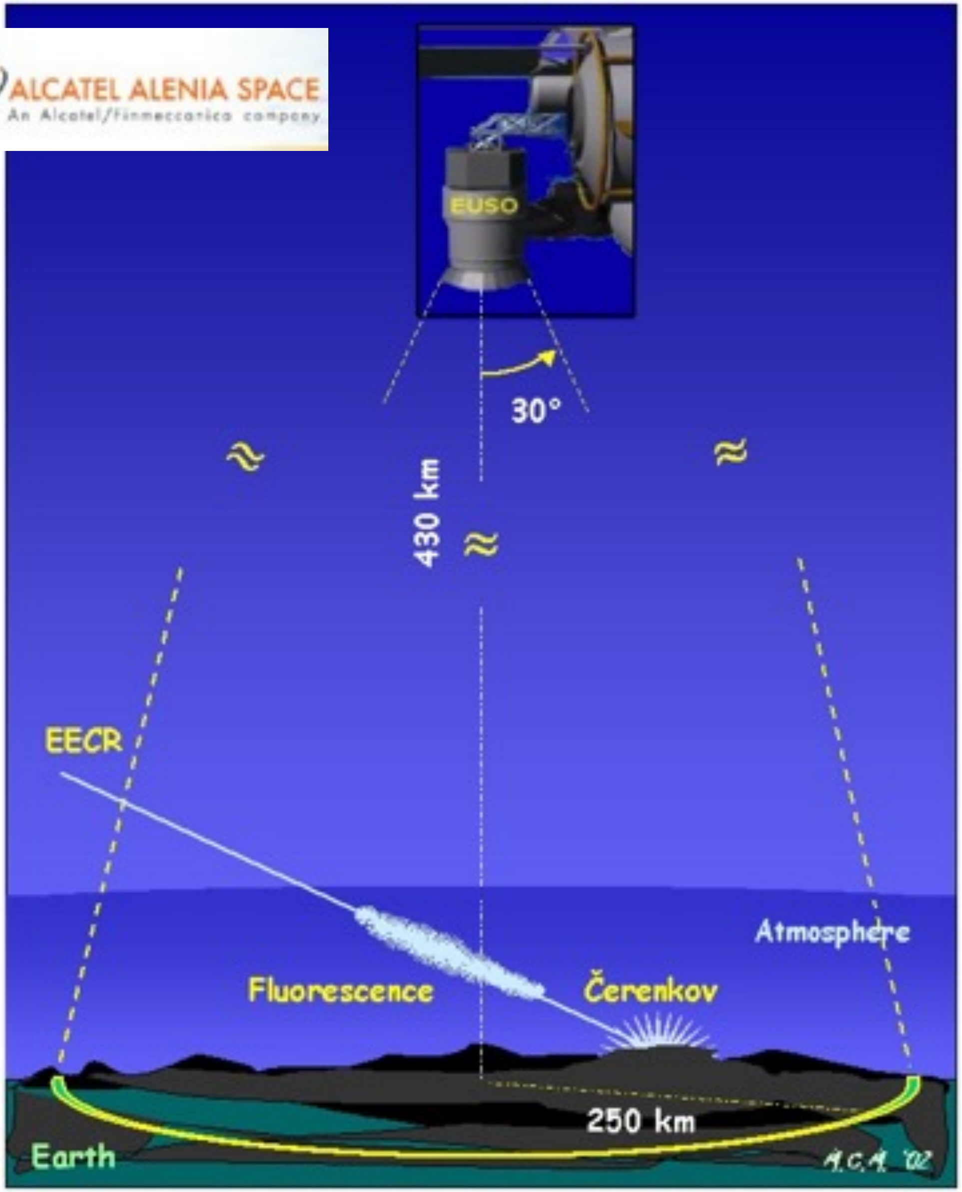
EUSO

- Large distance > 400 km
- Large FOV $\gamma \geq 30^\circ$
- $A^{geo} \approx 6 \times 10^5 \ km^2 \cdot sr$

$$\eta_{cycle} \approx 10 \div 25 \ \%$$

$$A_{Euso}^{eff} \approx (6 \div 9) \times 10^4 \ km^2 \cdot sr$$

$$\approx few \times 10^{12} \ tons$$

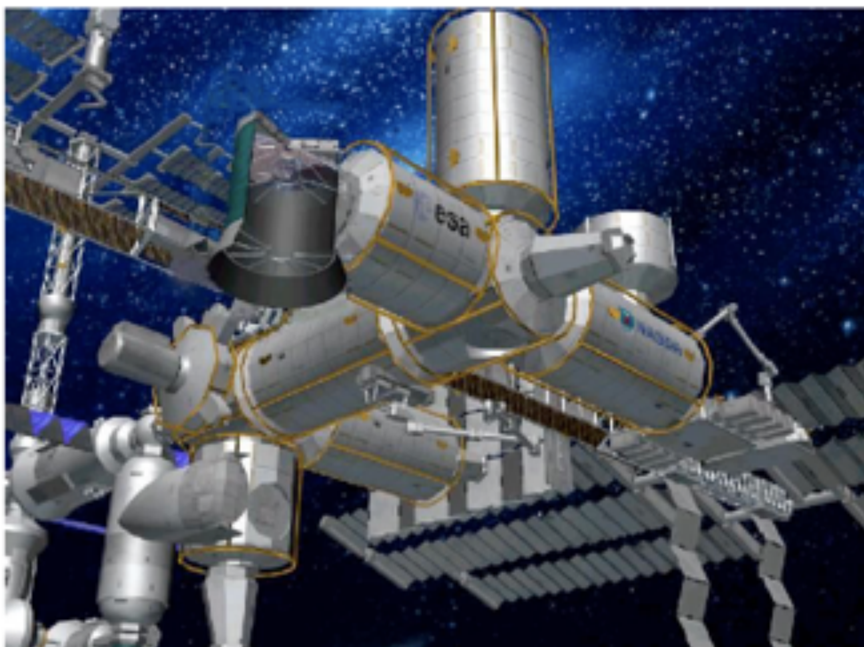


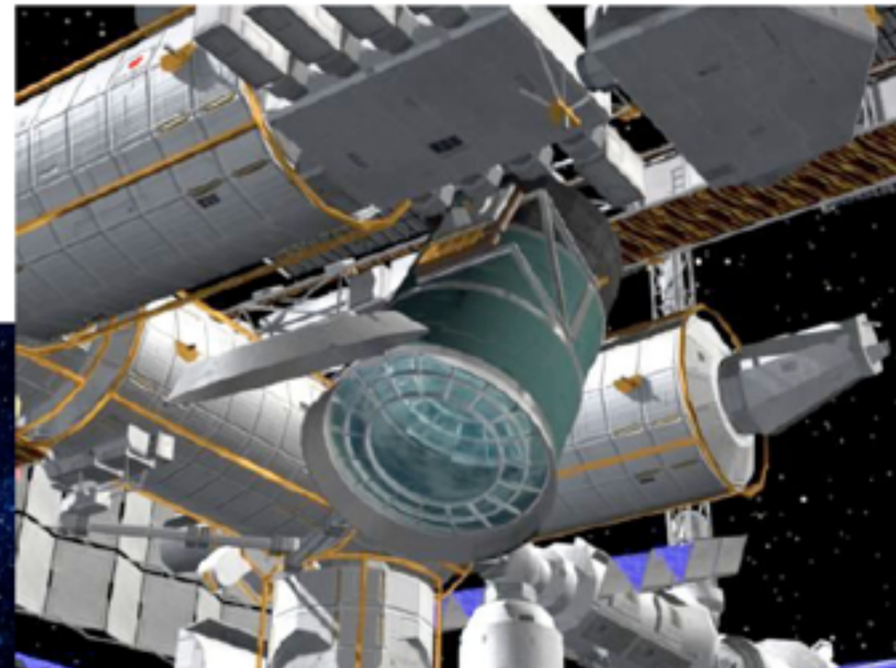
mass ($\lesssim 1.5$ ton), volume ($\lesssim 2.5 \times 2.5 \times 4.5$ m^3), power ($\lesssim 1$ kW) and telemetry ($\lesssim 180$ Mbit/orbit).

EUSO and JEM-EUSO: A Mission to Explore the Extremes of the Universe using the Highest Energy Cosmic Rays and Neutrinos by observing Earth

ESA CEPF case

Launch by STS (2000-4)



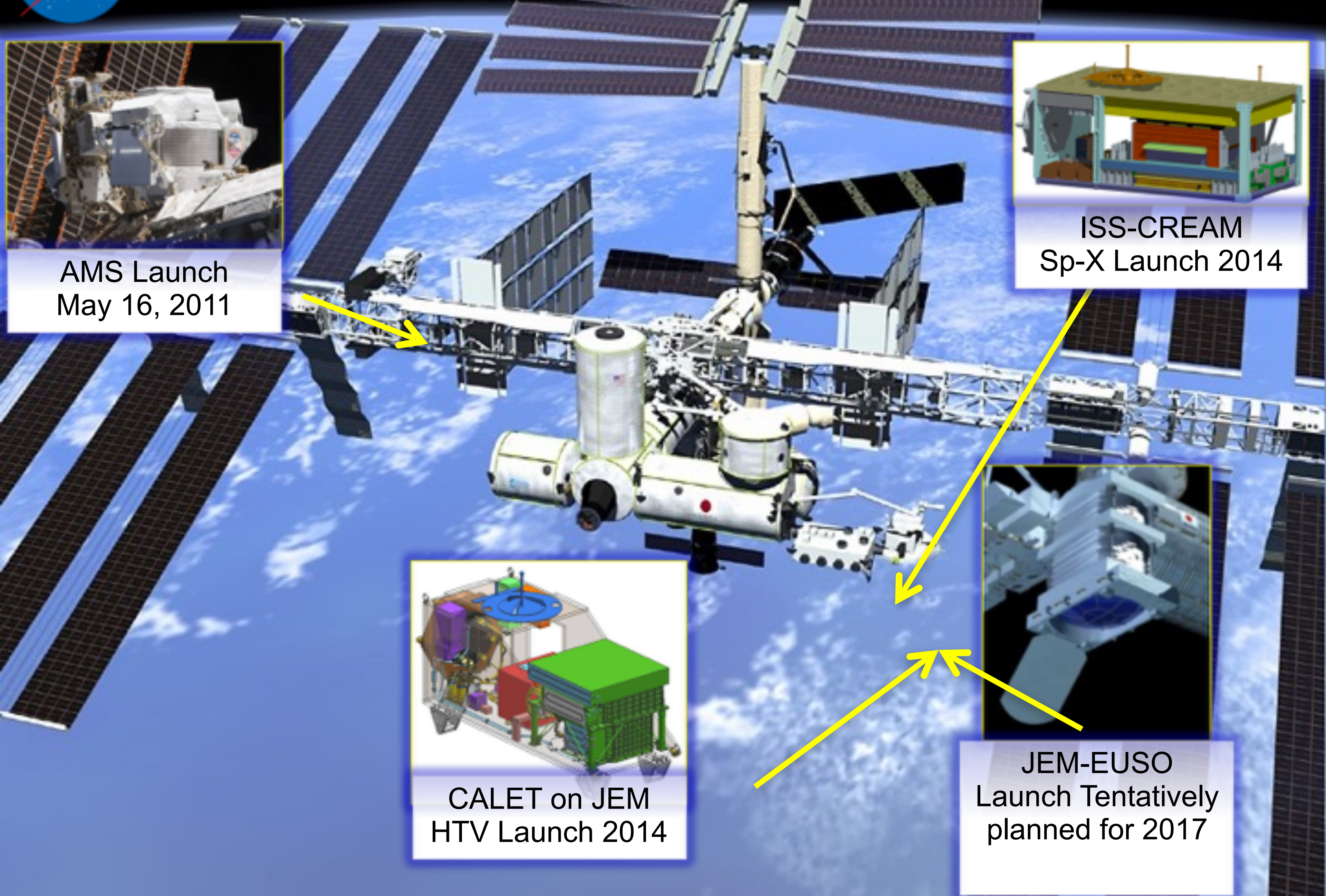


JEM EF case
JEM-EUSO launch by HTV

*Y. Takahashi’s presentation 2006

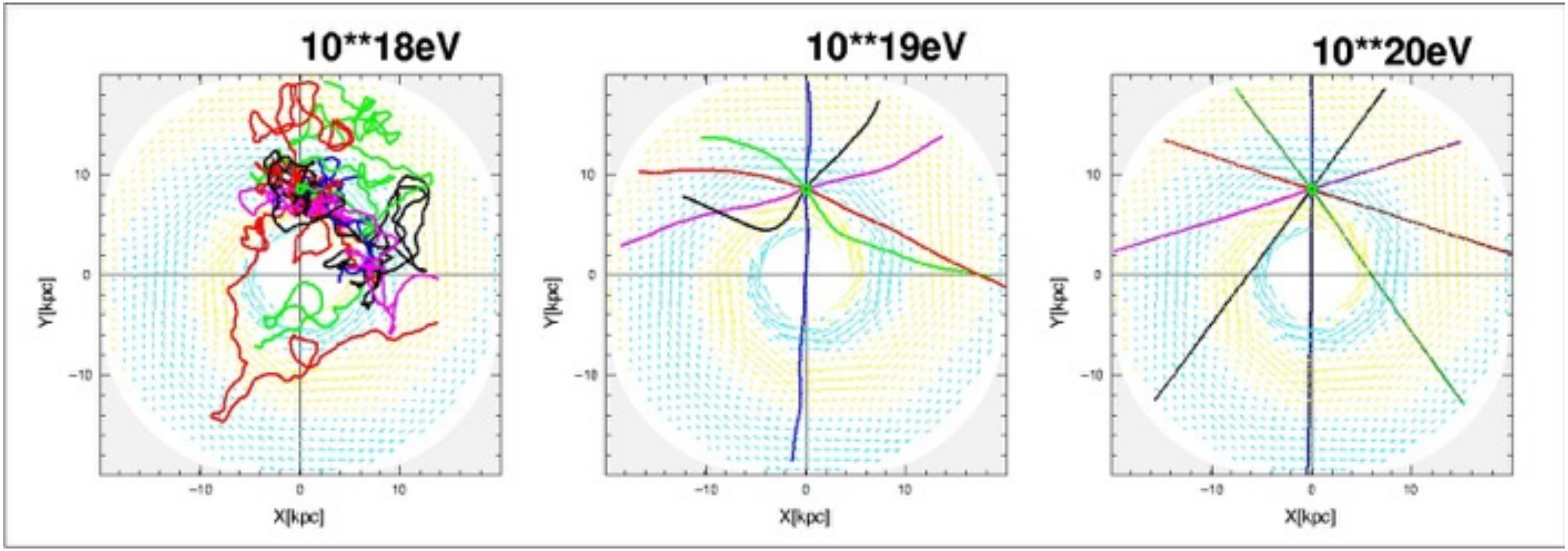
“Cosmic Ray Observatory on the ISS”

View from NASA: “Cosmic Ray Observatory on the ISS”



Cosmic Ray Propagation in our Galaxy

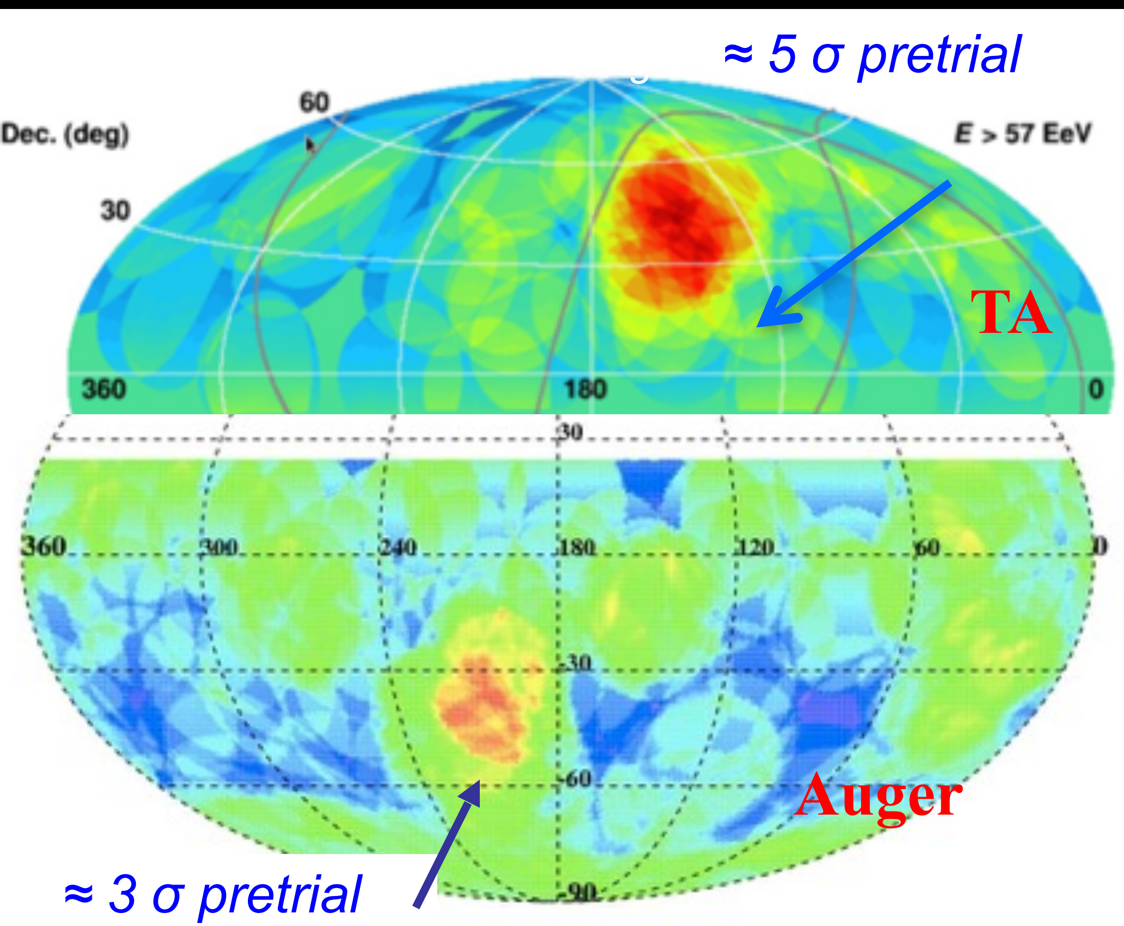
- Deflection angle < 1 degree at 10^{20}eV



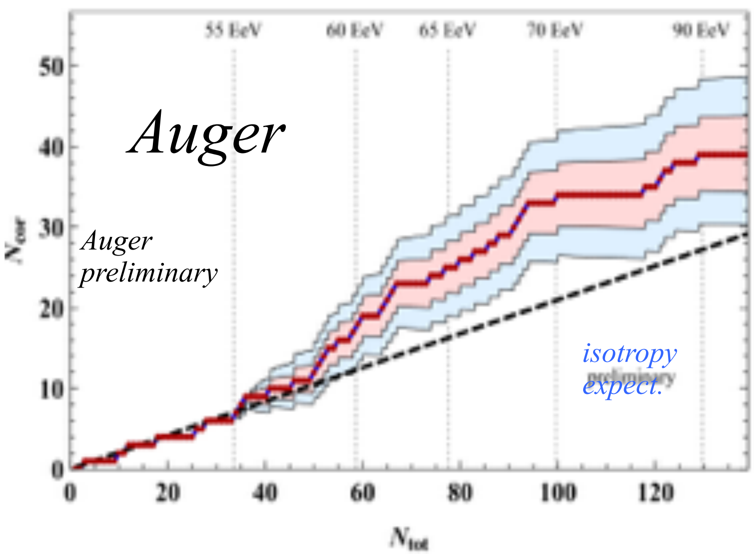
Proton simulations (Takeda, 2003)

Anisotropy Hints >60 EeV

Statistically limited evidence for Comic Ray Anisotropy above $5.7x\ 10^{19}$ eV in the North and South



# of events correlating with AGN,
ordered in energy (integral plot)



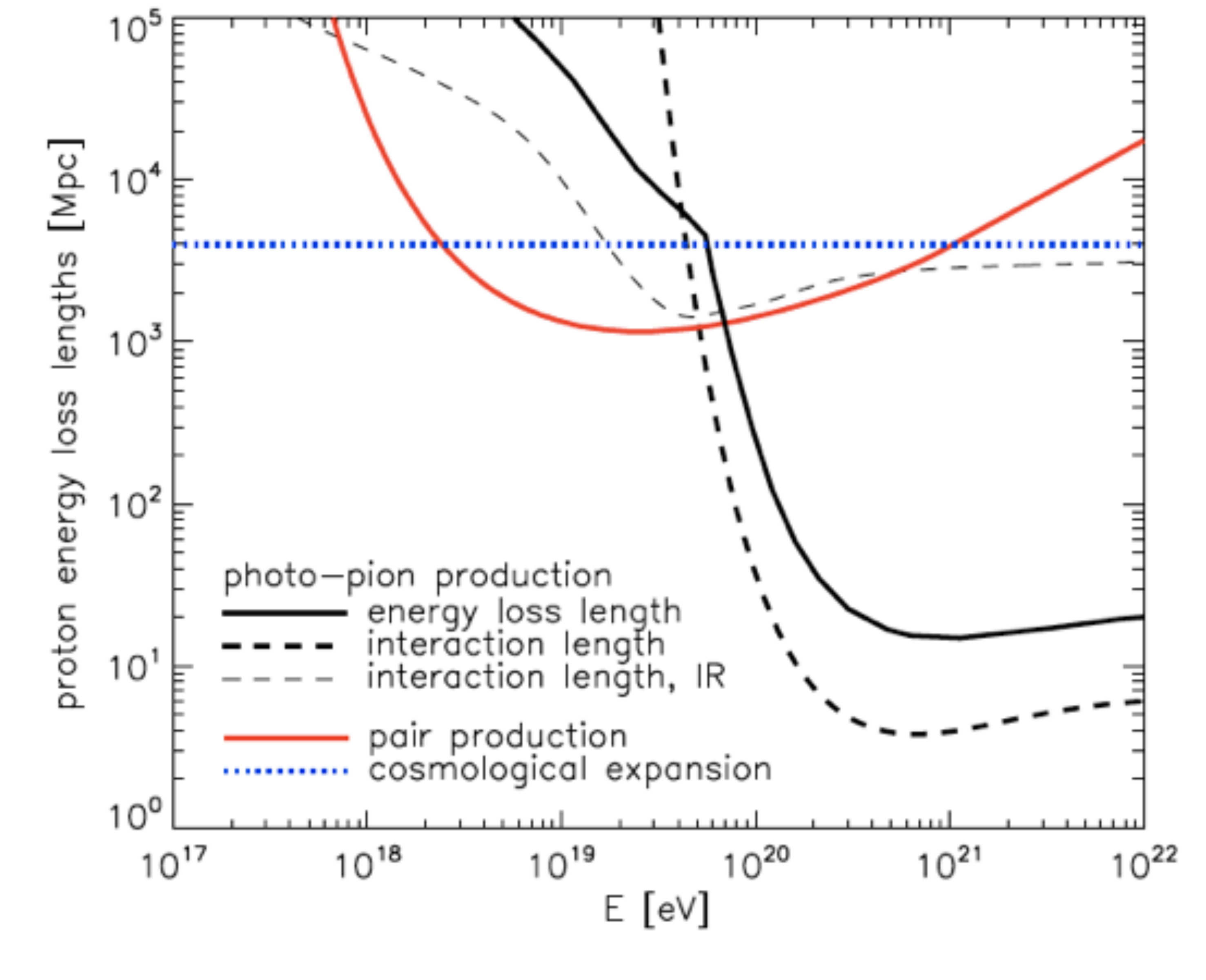
JEM-EUSO Main Science Goal

Increase Statistics of Extreme Energies Cosmic Rays (E > 60 EeV) by **one order of magnitude** compared to ground observatories to

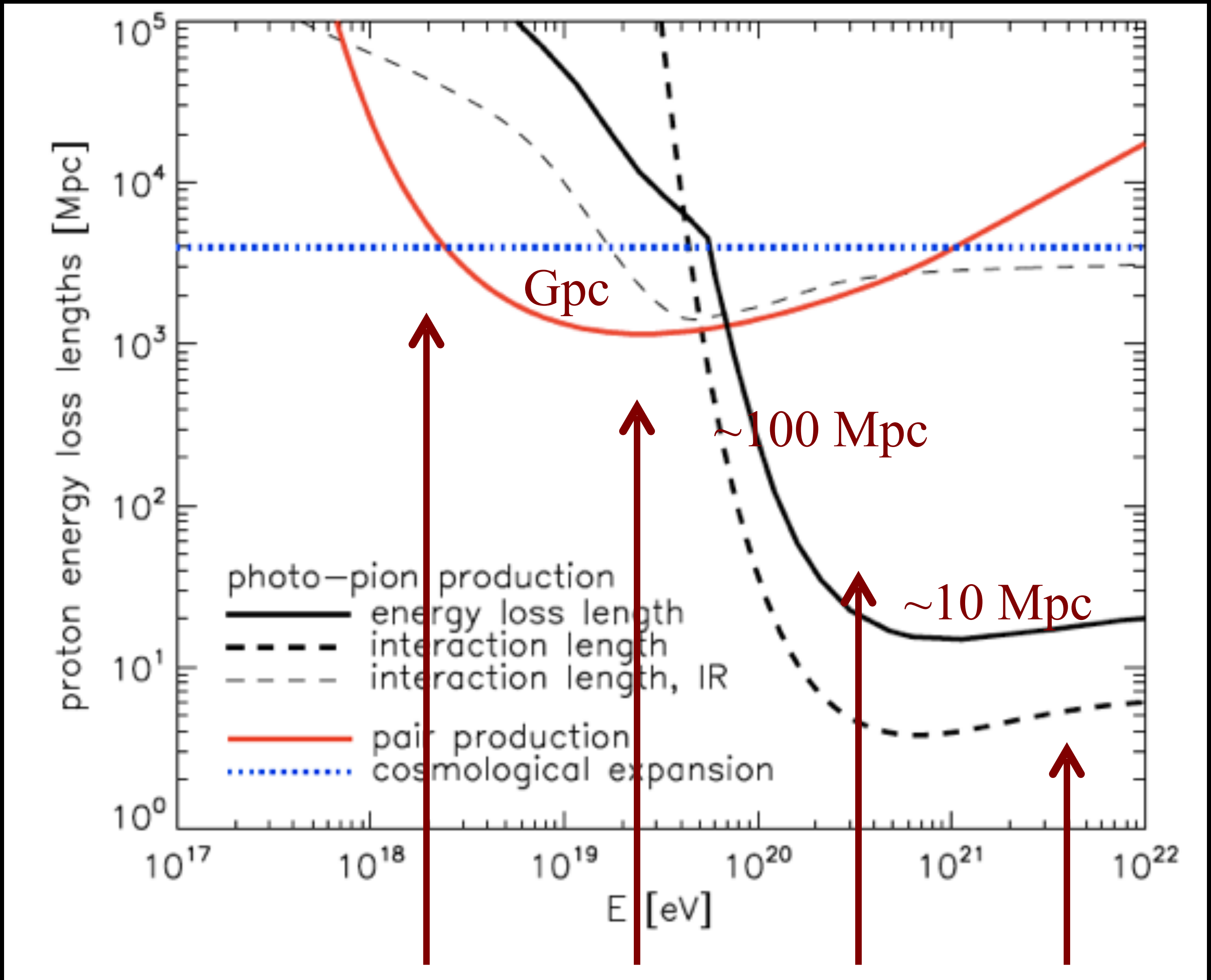
- **Identify EECR sources**

  discover source locations in the sky

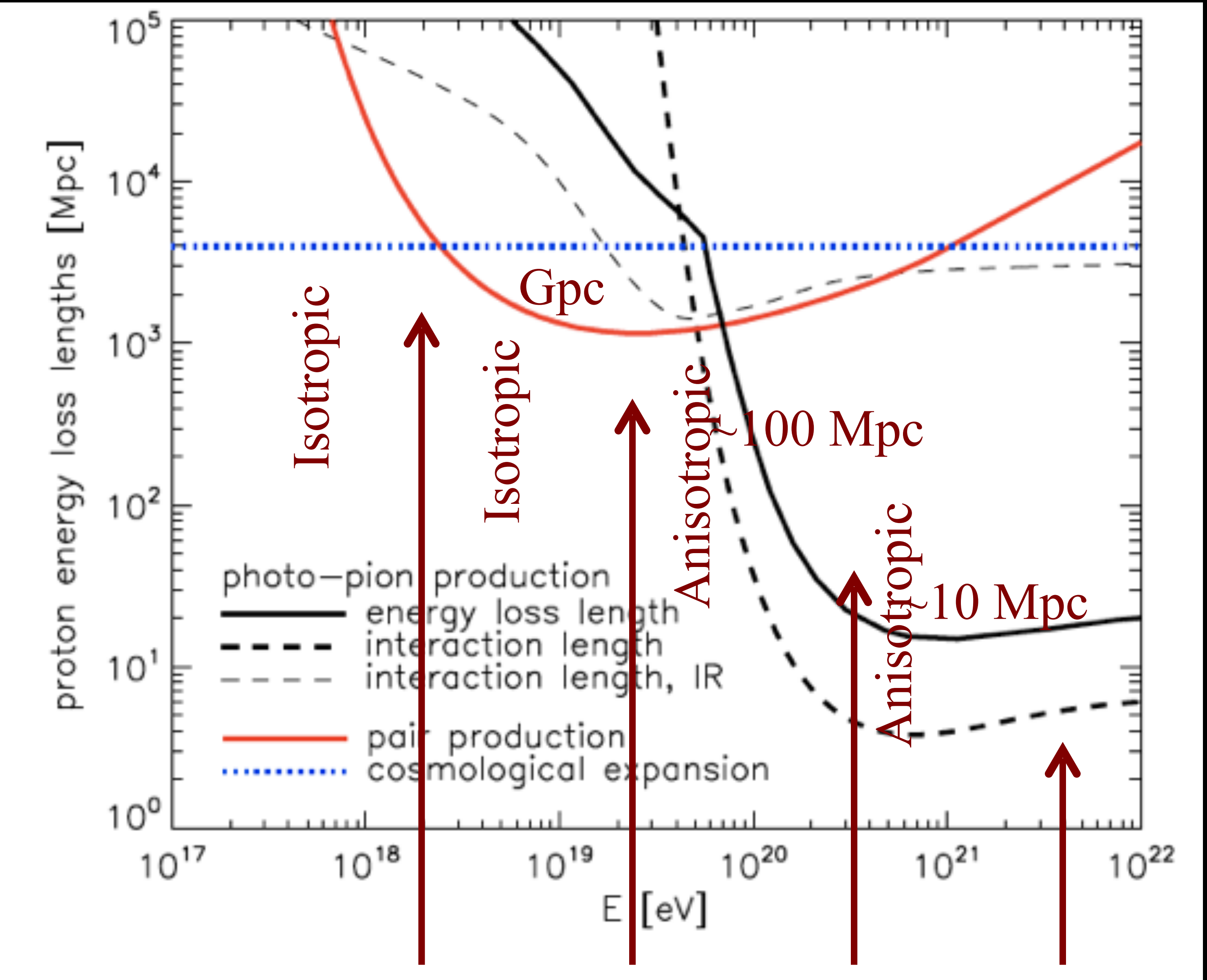
Greisen-Zatsepin-Kuzmin effect



Greisen-Zatsepin-Kuzmin effect

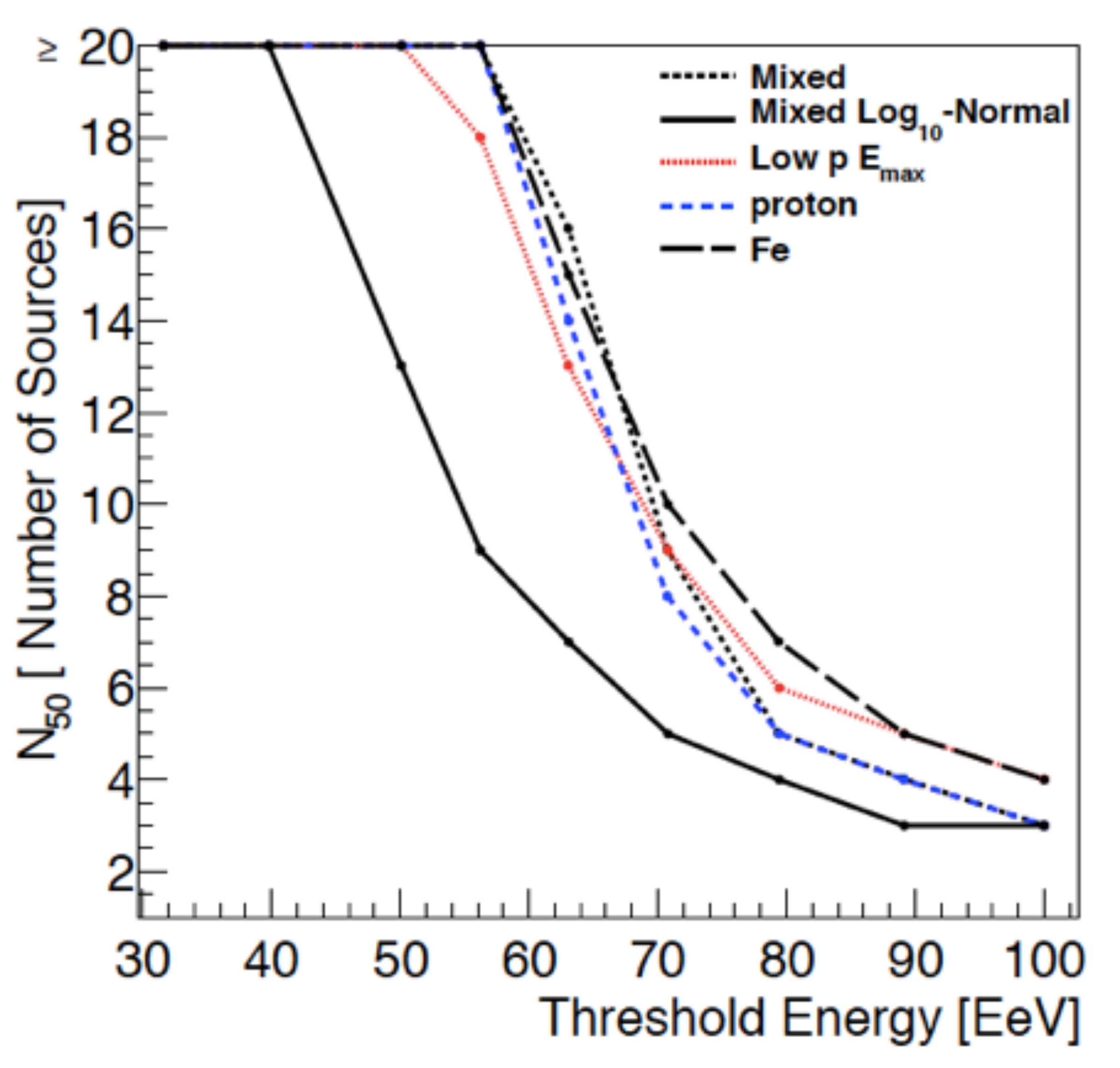


Greisen-Zatsepin-Kuzmin effect



To detect sources

- Observe at higher energies – fewer sources



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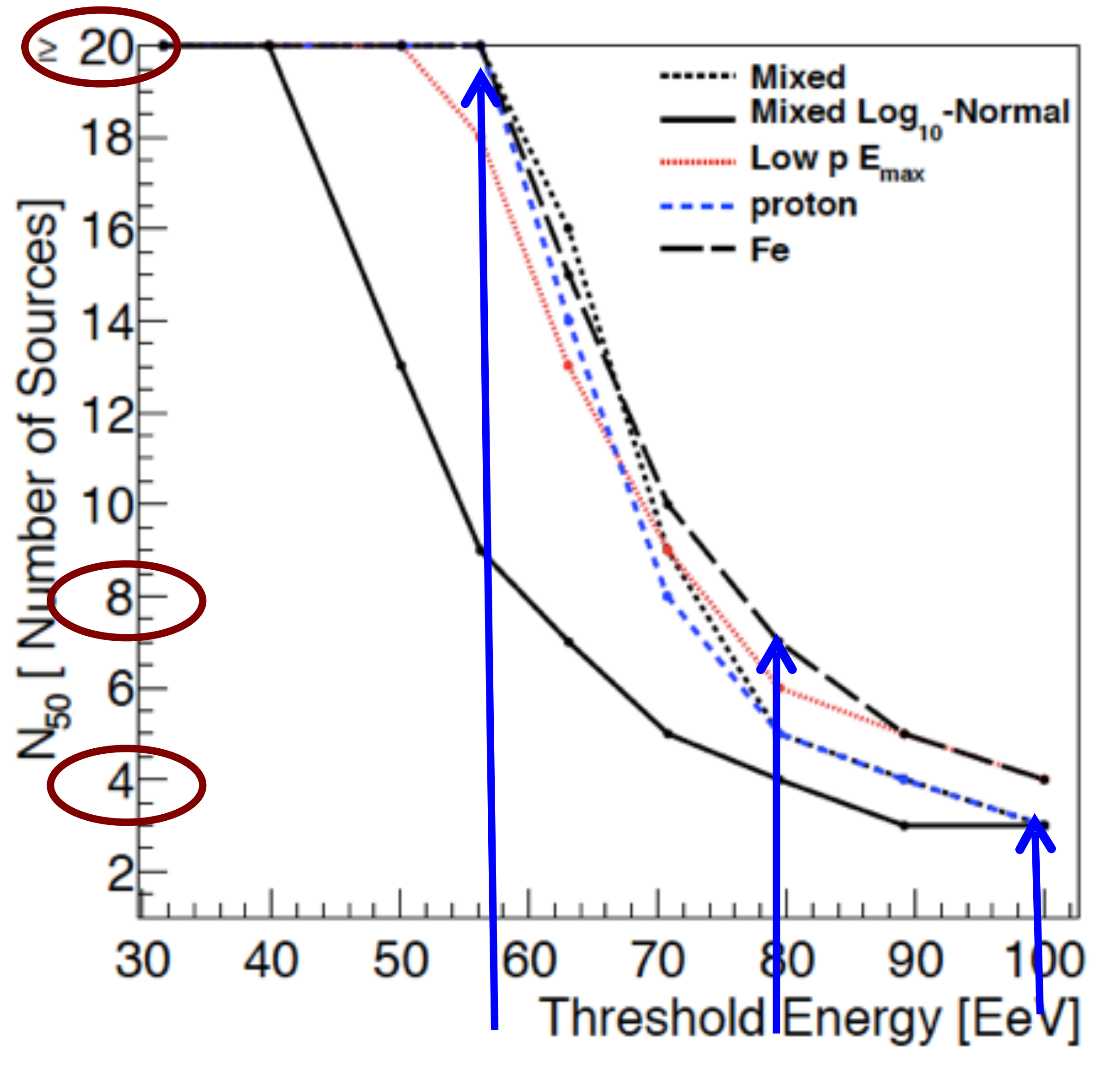

How to find the Sources?

- GET A LOT MORE DATA above 60 EeV!!!!
- GET ~ 1,000 events above 60 EeV!!!!
- OVER THE WHOLE SKY !!!!

How many EECRs > 60 EeV?

- Auger w/ 3,000 km^2
- ~20 events > 60 EeV/ yr
- Telescope Array w/ 700 km^2
- ~5 events > 60 EeV/ yr
- Auger + TA < 30 events/yr

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- Earth - surface ~ 5 10^8 km^2
- ~3.4 10^6 events/yr

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- ~5 events > 60 EeV/ yr
- Auger + TA < 30 events/yr

5 o.o.m to go!

- Earth - surface ~ 5 10^8 km^2

~3.4 10^6 events/yr

Go to SPACE!

To look down on the

Atmosphere!

How many UHECRs > 60 EeV?

- Auger + TA ~30 events/yr
- **JEM-EUSO**
- **~200 events/yr > 60 EeV**
- Earth - surface ~ 5 10^8 km^2

~3.4 10^6 events/yr

How many UHECRs > 60 EeV?

- Auger + TA ~30 events/yr

- **JEM-EUSO**
- **~200 events > 60 EeV!**

4 o.o.m to go!

- Earth - surface ~ 5 10^8 km^2

~3.4 10^6 events/yr

Why Looking Down?

1. Huge Exposure Area
2. Well Confined Distance toward showers
3. Dust (Cloud)-free atmosphere in the above half troposphere
4. Uniform Exposure across the both hemispheres

Full Sky Coverage

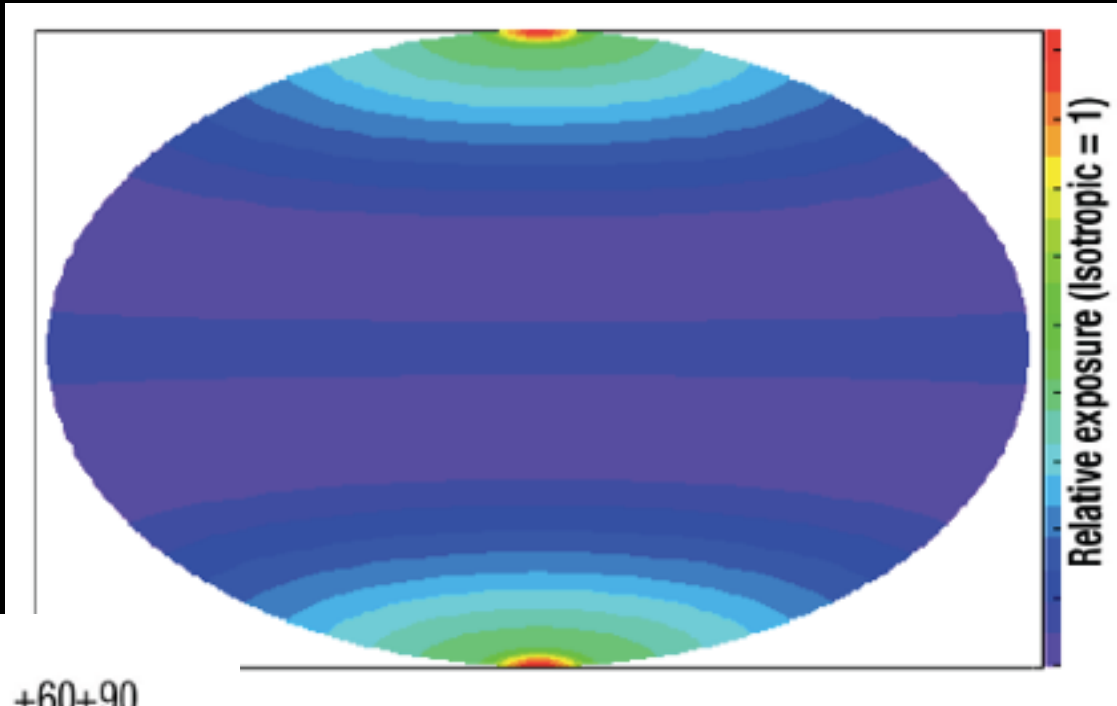
with nearly uniform exposure

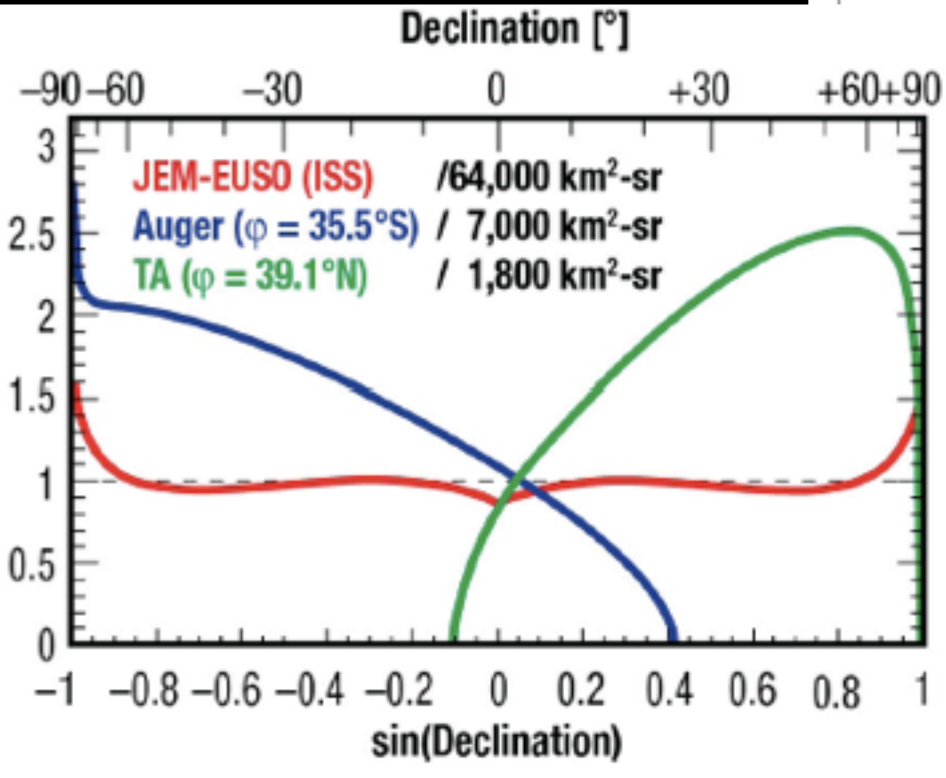
The ISS ORBIT

Inclination: 51.6°

Height: ~400km

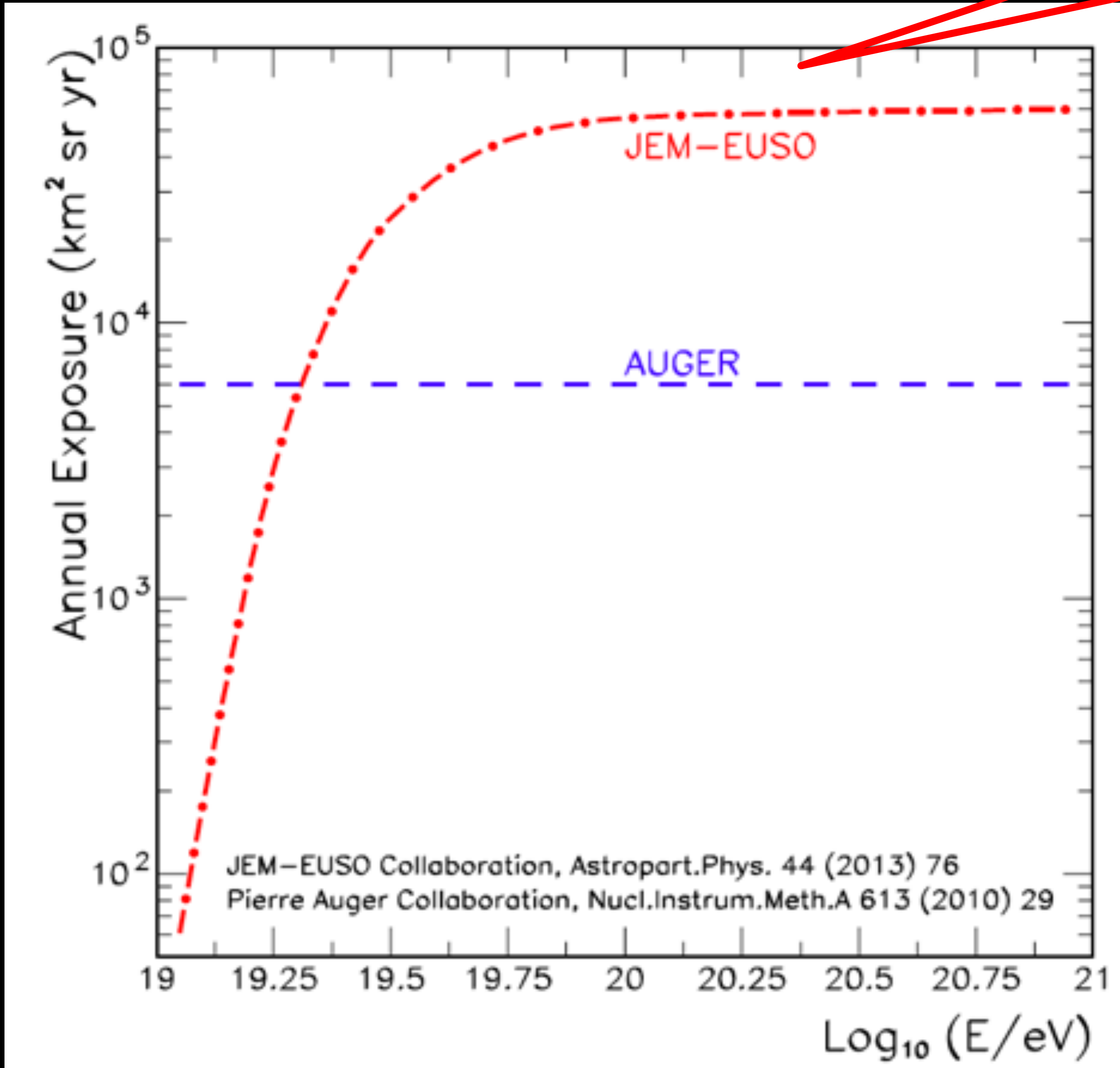
JEM-EUSO Sky Coverage





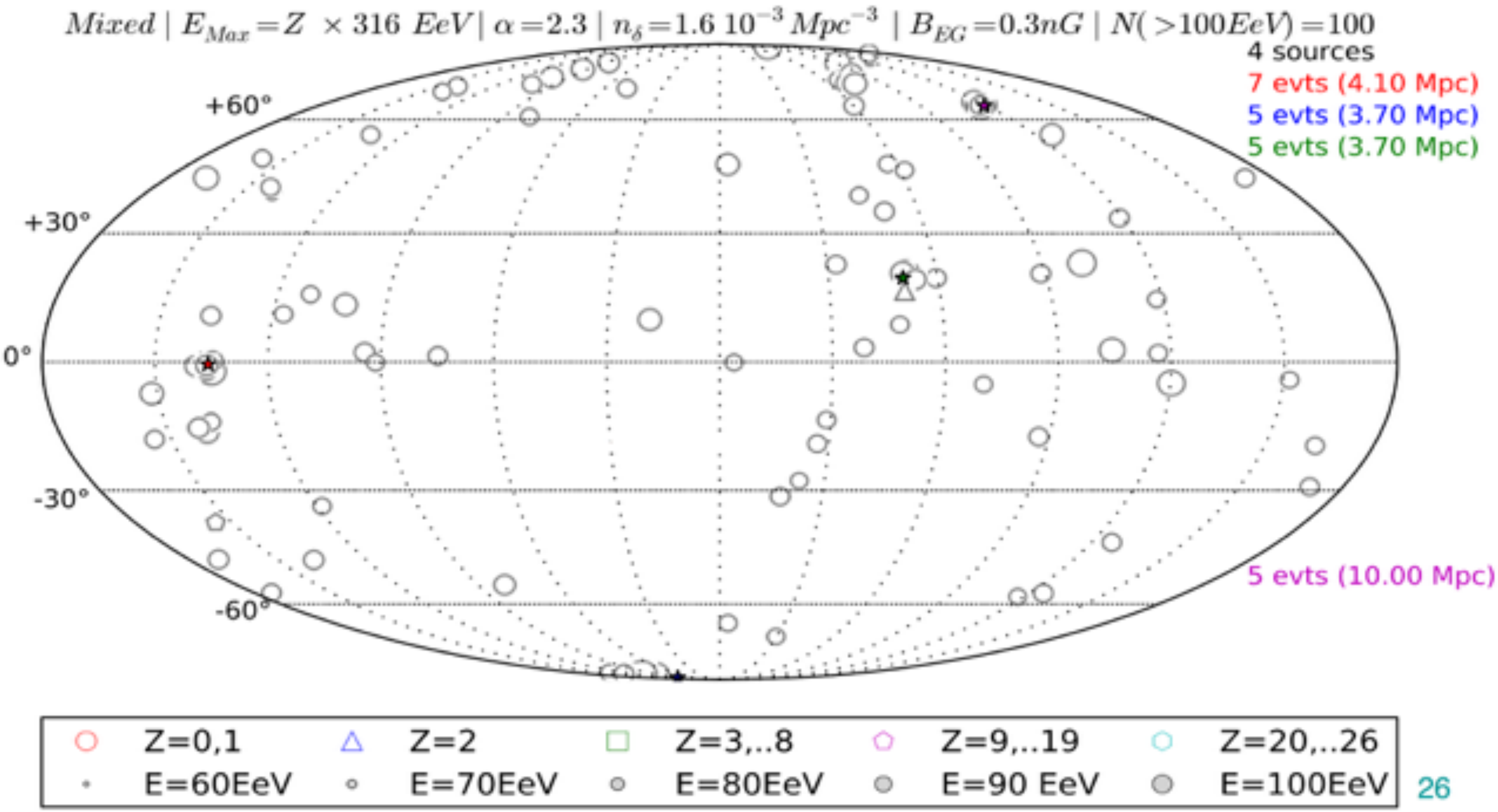
JEM-EUSO

annual exposure =
10 x Auger
6 10^4 km^2 sr yr



To detect sources

- Increase statistics: ~1,000 events > 60 EeV
- ~100 events > 100 EeV



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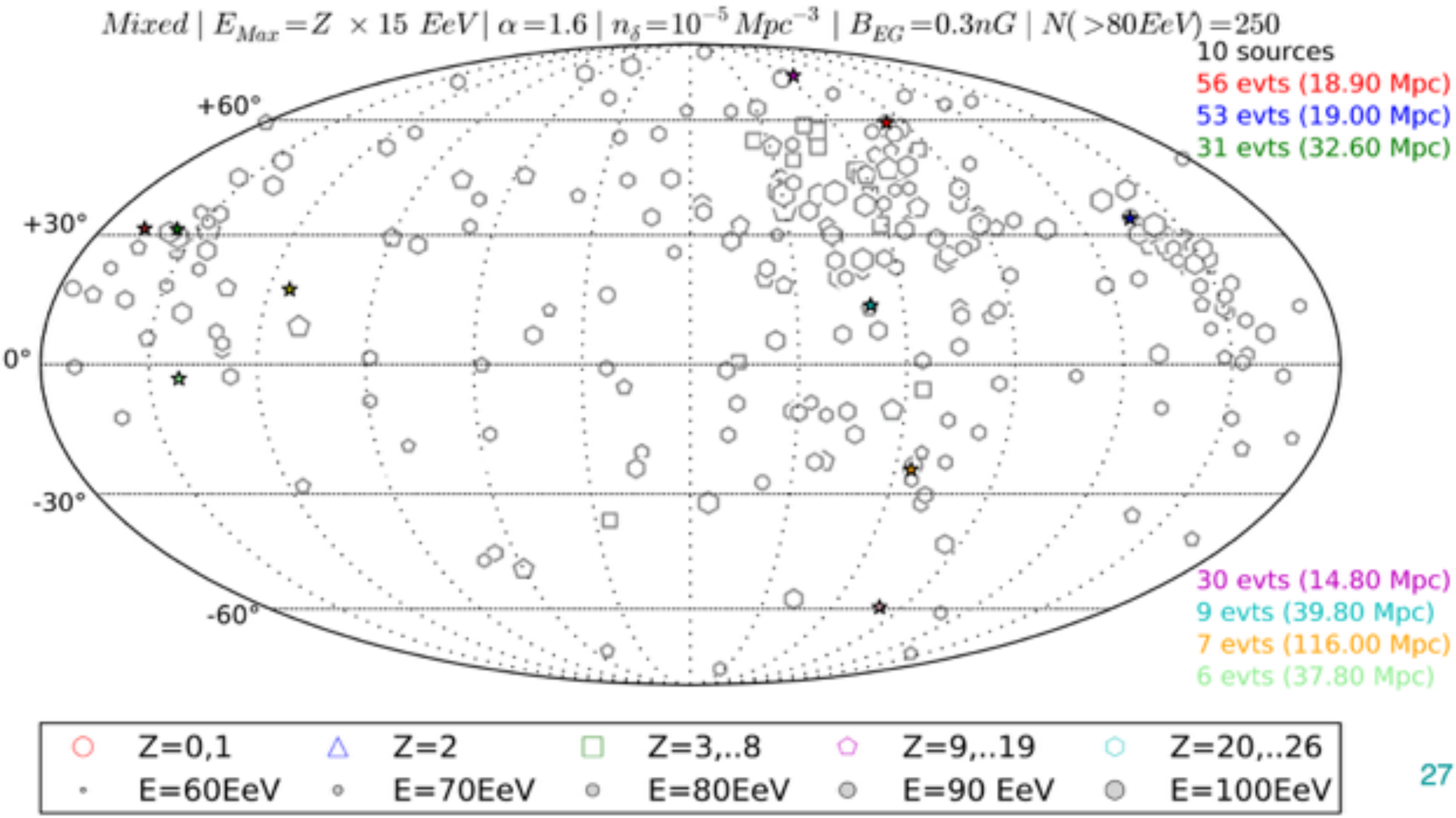
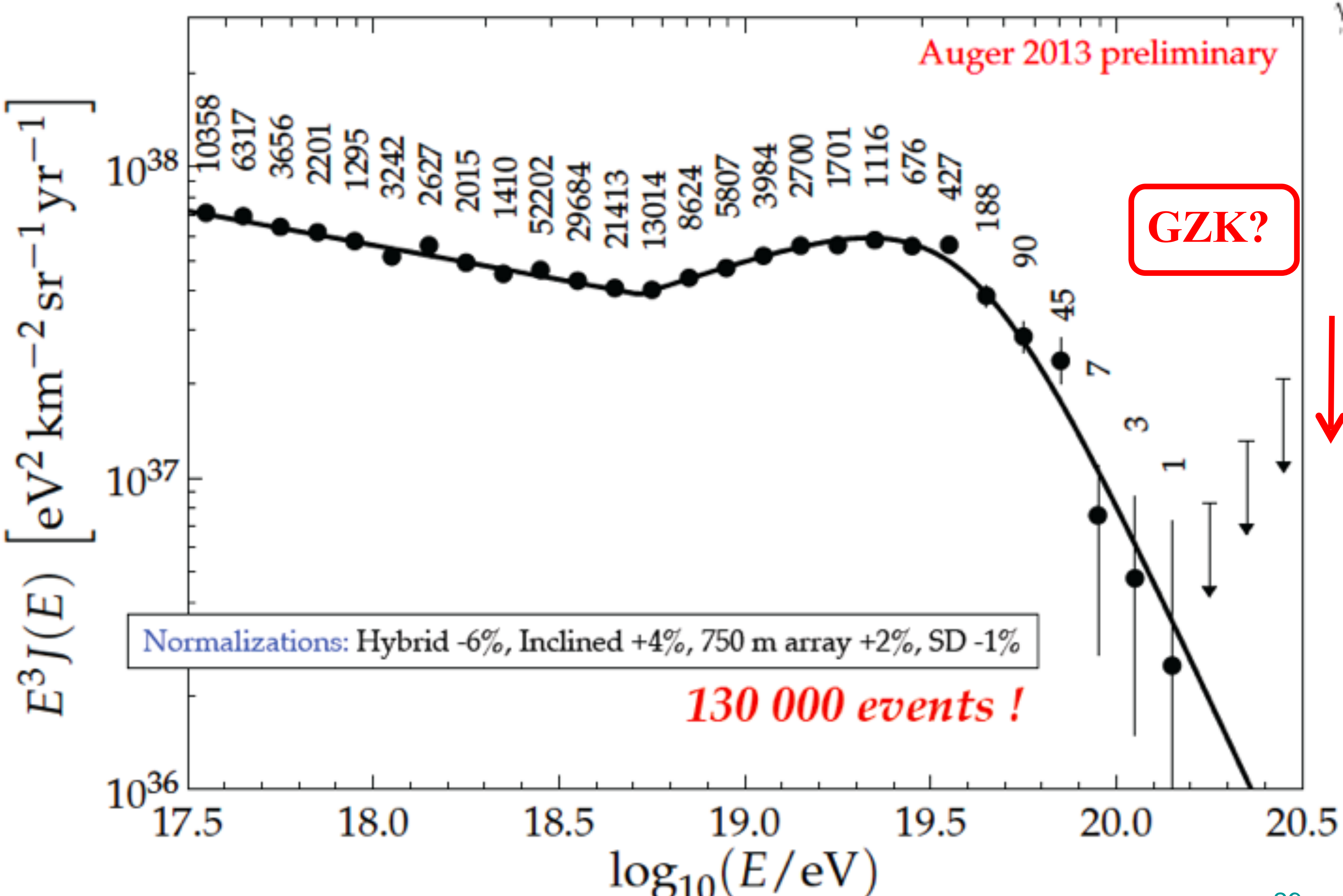


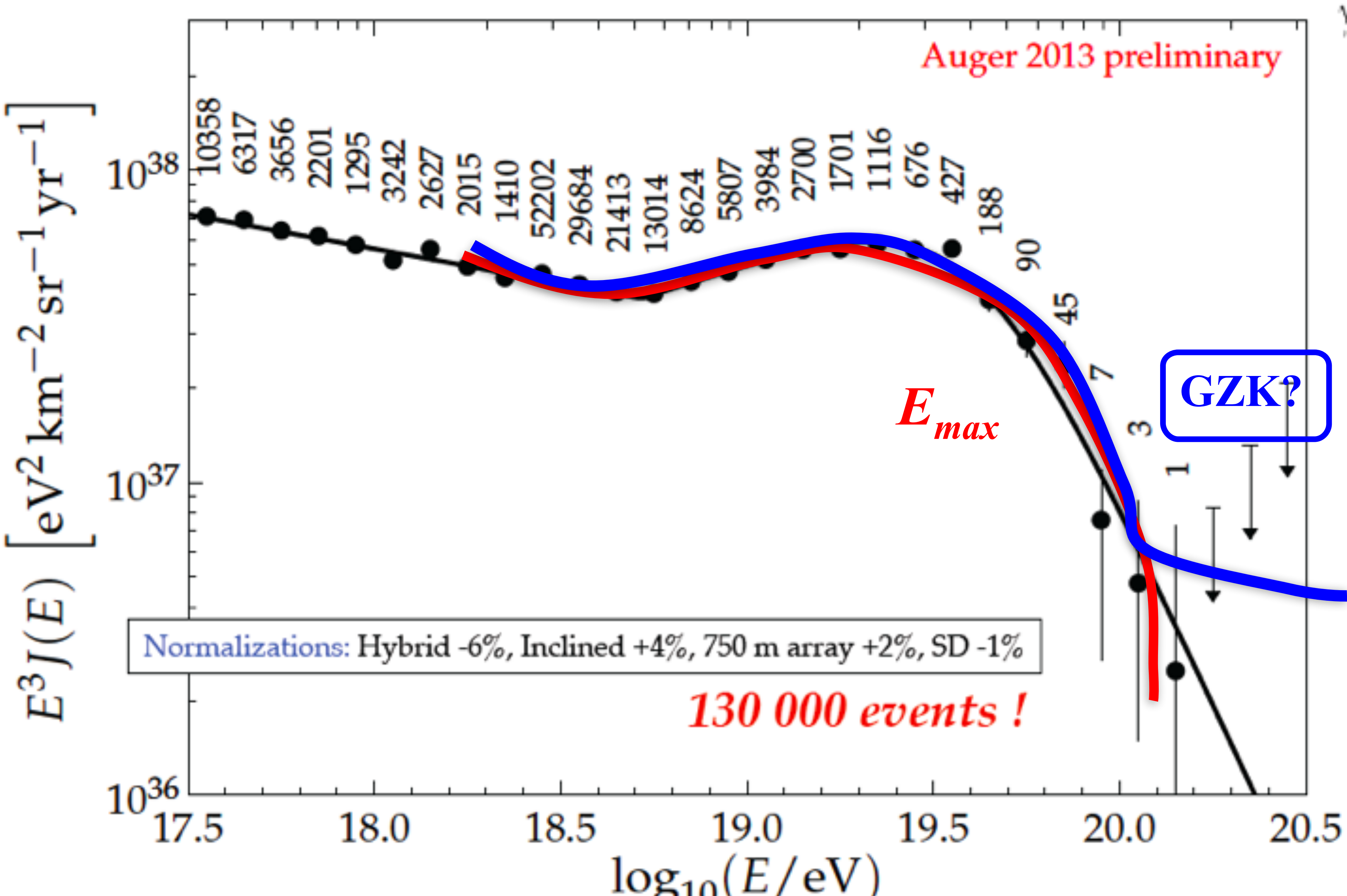
JEM-EUSO Science Goals

- Increase Statistics of Extreme Energies Cosmic Rays (E > 60 EeV) by one order of magnitude compared to ground observatories to
- **Identify EECR sources**

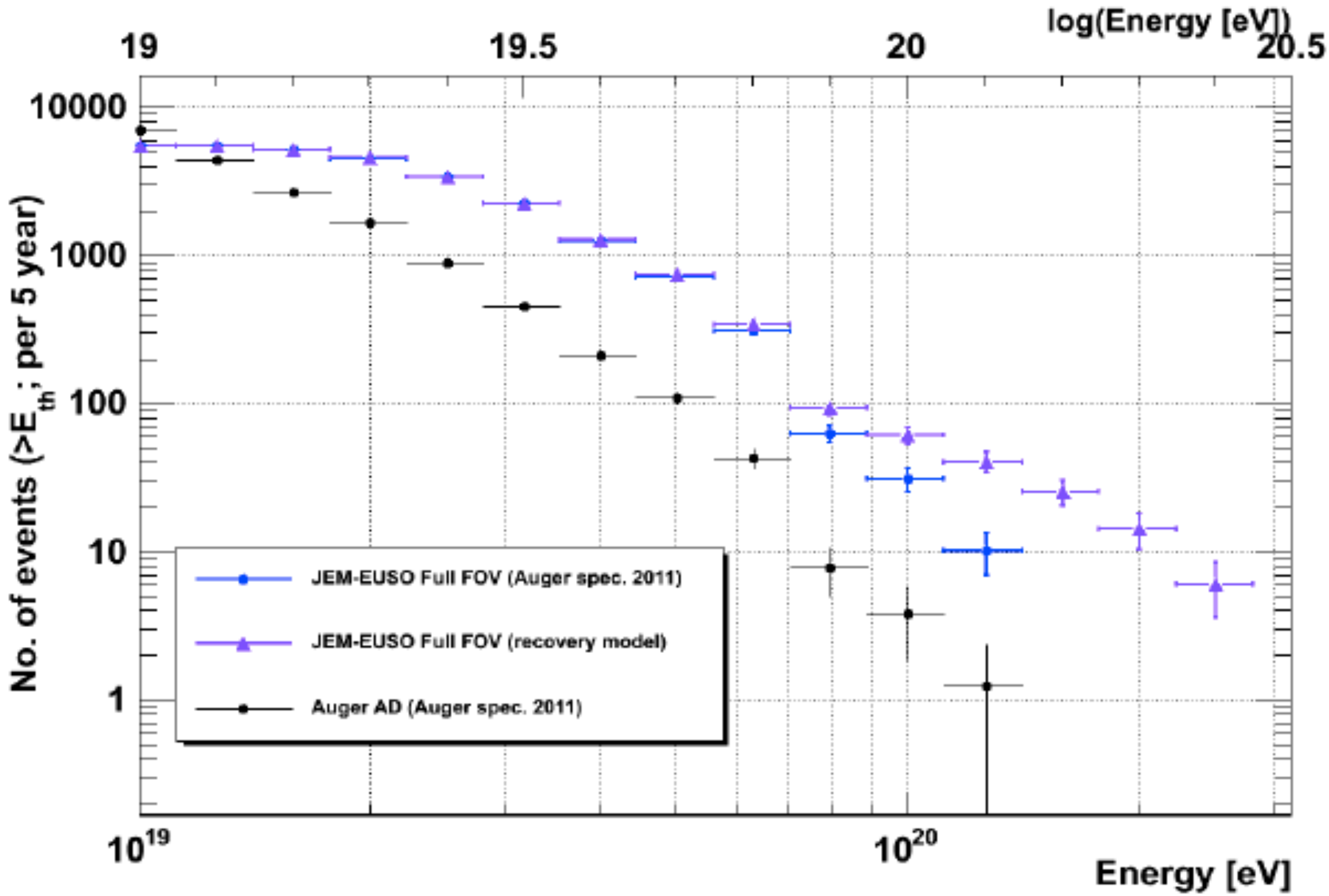
 - discover source locations in the sky

- - Anisotropy studies on small (sources), intermediate (composition multiplets or correlations with local galaxy distribution structures), and large scales (dipole, quadrupole)
- - test the spectral recovery if GZK is causing the decline and $E_{max} >> E_{GZK}$


Auger 2013 preliminary
GZK?
10358
6317
3656
2201
1295
3242
2627
2015
1410
52202
29684
21413
13014
8624
5807
3984
2700
1701
1116
676
427
188
90
45
7
3
1
Normalizations: Hybrid -6%, Inclined +4%, 750 m array +2%, SD -1%
130 000 events !
10^{38}
10^{37}
10^{36}
17.5
18.0
18.5
19.0
19.5
20.0
20.5
$E^3 J(E)$ $[\mathrm{eV^2\,km^{-2}\,sr^{-1}\,yr^{-1}}]$
$\log_{10}(E/\mathrm{eV})$



Auger 2013 preliminary
10358 6317 3656 2201 1295 3242 2627 2015 1410 52202 29684 21413 13014 8624 5807 3984 2700 1701 1116 676 427 188 90 45 7 3 1
E_{max}
GZK?
Normalizations: Hybrid -6%, Inclined +4%, 750 m array +2%, SD -1%
130 000 events !
10^{38}
10^{37}
10^{36}
17.5
18.0
18.5
19.0
19.5
20.0
20.5
$\log_{10}(E/\mathrm{eV})$
$E^3 J(E)\ [\mathrm{eV^2\,km^{-2}\,sr^{-1}\,yr^{-1}}]$



log(Energy [eV])
19
19.5
20
20.5
10000
1000
100
10
1
No. of events (>E_th; per 5 year)
JEM-EUSO Full FOV (Auger spec. 2011)
JEM-EUSO Full FOV (recovery model)
Auger AD (Auger spec. 2011)
10^19
10^20
Energy [eV]

Science Objectives

Main Objective: Astronomy and astrophysics through particle channel with extreme energies ($E > 5 \times 10^{19} eV$)

- Identification of **sources** by the high statistics arrival direction analysis
- Measurement of the **energy spectra** from individual sources to constrain acceleration or emission mechanisms

Exploratory objectives:

- Detection of extreme energy **gamma-rays**
- Measurement of extreme energy **neutrinos**
- Study of the Galactic **magnetic field**
- Verification of the **relativity** and the **quantum gravity** effect in extreme energy & Dark Matter searches
- Global observation of **atmospheric** phenomena: nightglows, lightning (TLE), meteors

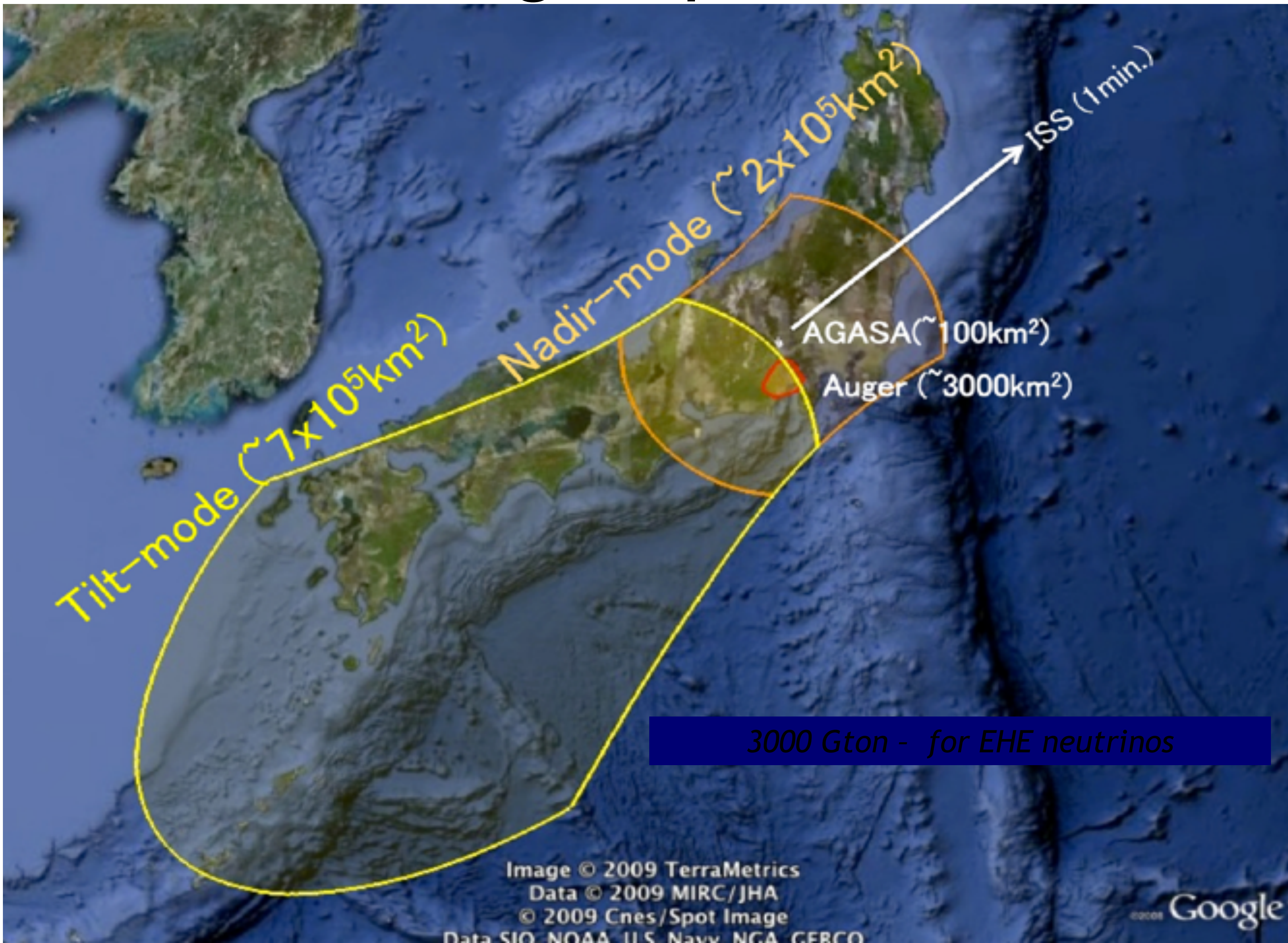
M. Bertaina & E. Parizot:

'The JEM-EUSO mission: a space observatory to study the origin of UHECRs'

Nuclear Physics B (Proc. Suppl.) NUPHBP15148
doi: 10.1016/j.nuclphysbps.2014.10.033

JEM-EUSO Mission

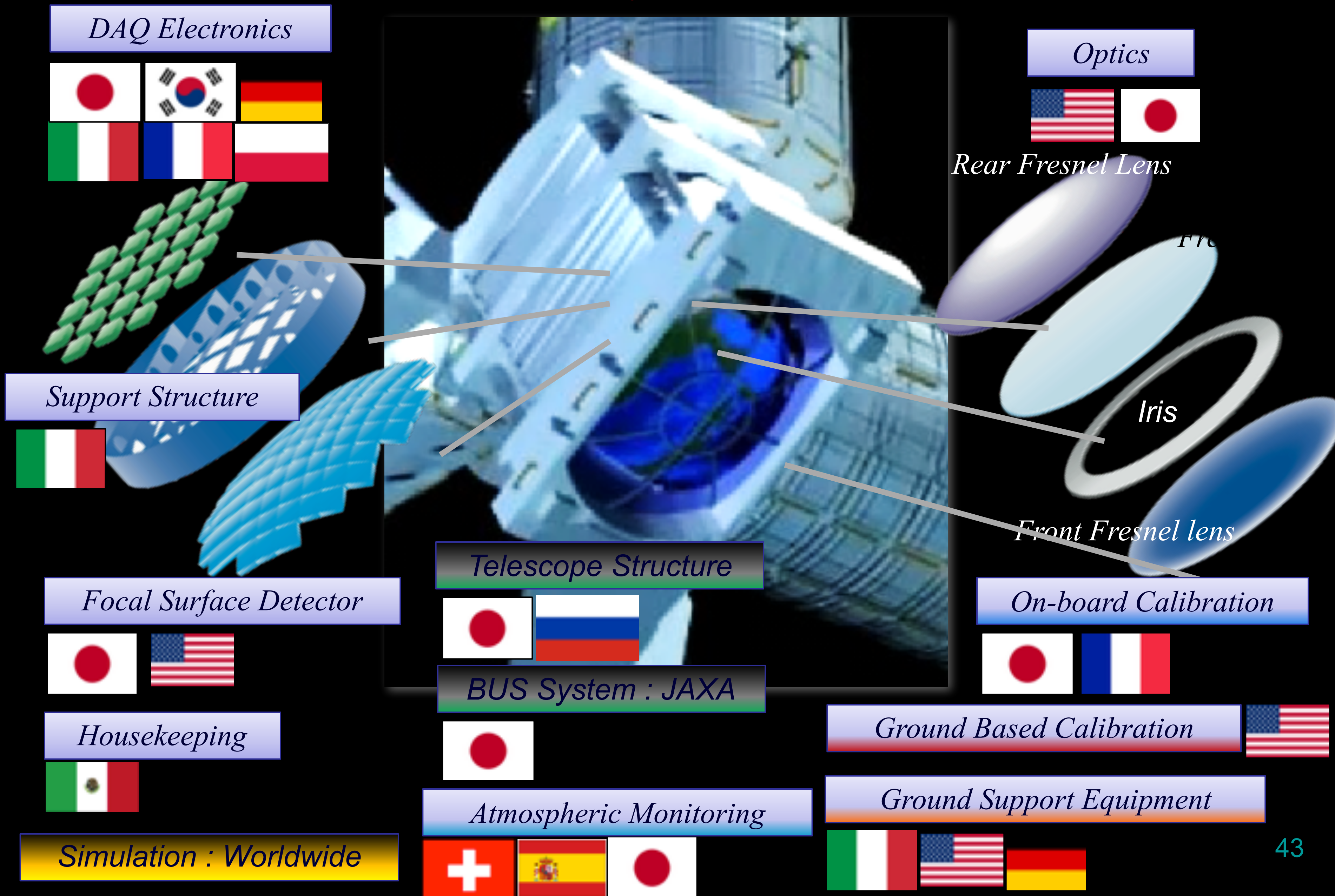
Huge Aperture



The UV Telescope Parameters

Parameter	Value
Field of View	±30°
Monitored Area	>1.3×10^5km^2
Telescope aperture	≥2.5 m
Operational wavelength	300-400 nm
Resolution in angle	0.075°
Focal Plane Area	4.5 m^2
Pixel Size	<3 mm
Number of Pixels	≈3×10^5
Pixel size on ground	≈560 m
Time Resolution	2.5 μs
Dead Time	<3%
Photo-detector Efficiency	≥20%

Payload

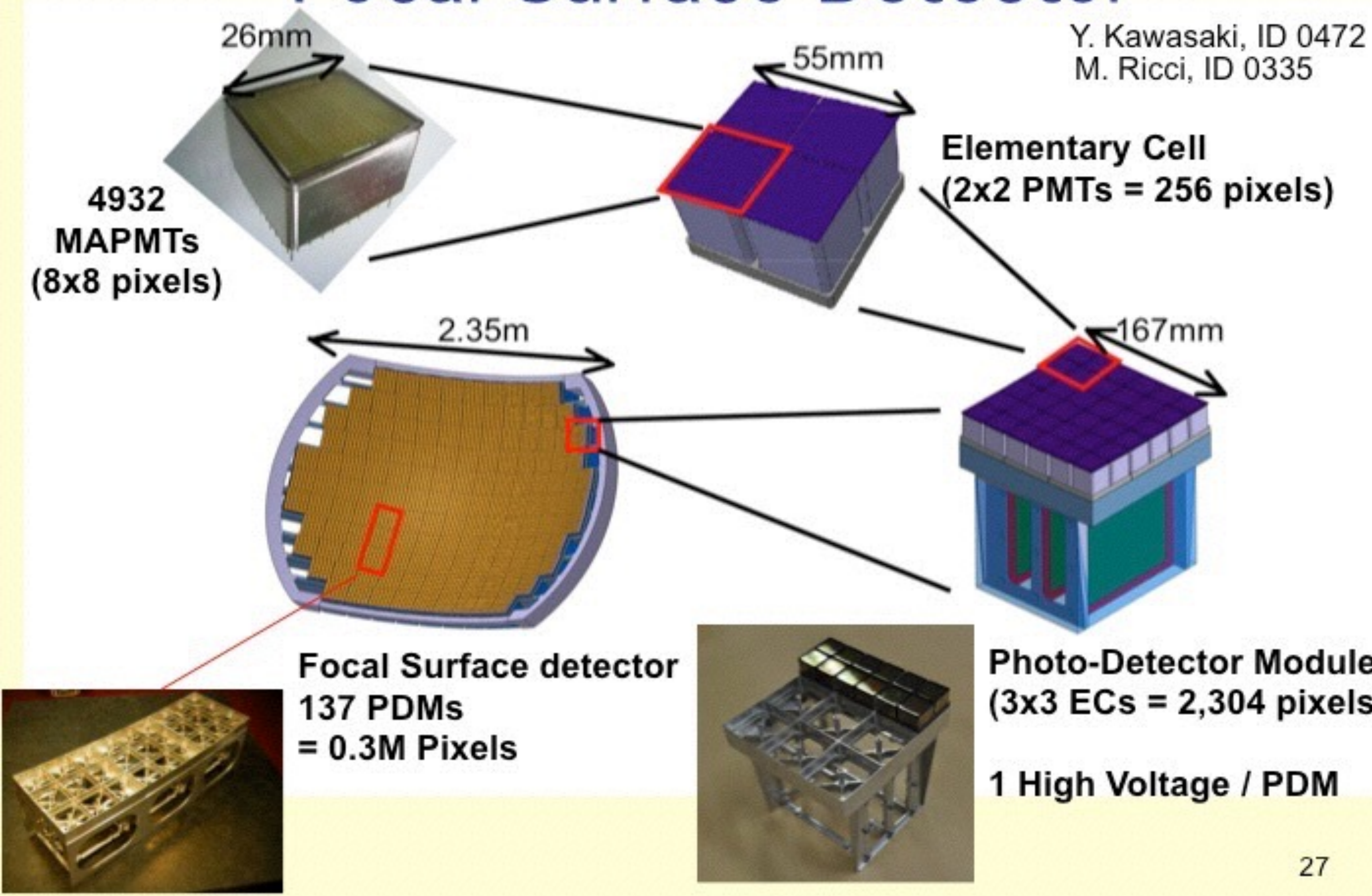


DAQ Electronics
Optics
Rear Fresnel Lens
Iris
Front Fresnel lens
Support Structure
Telescope Structure
Focal Surface Detector
On-board Calibration
BUS System : JAXA
Housekeeping
Ground Based Calibration
Atmospheric Monitoring
Ground Support Equipment
Simulation : Worldwide

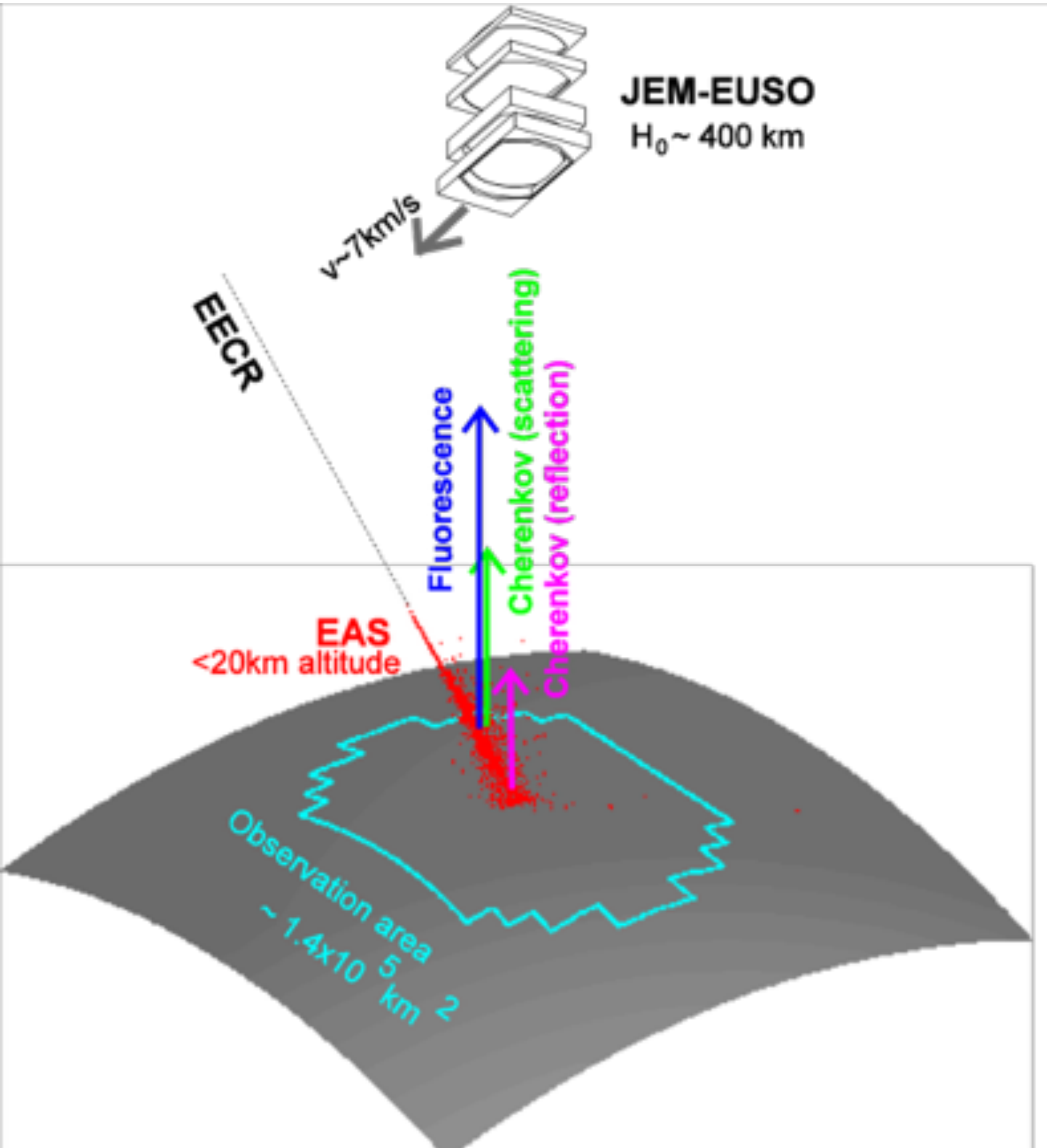
Science Instrument

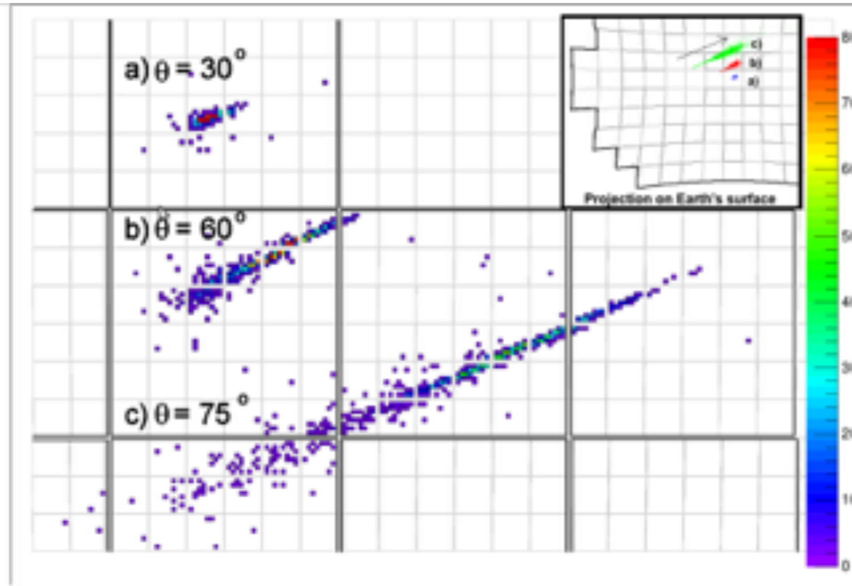
tics

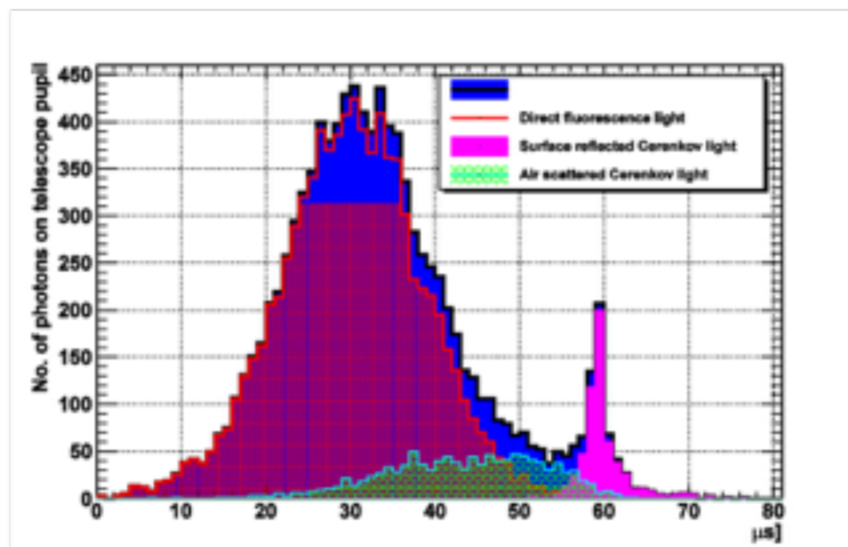
Focal Surface Detector



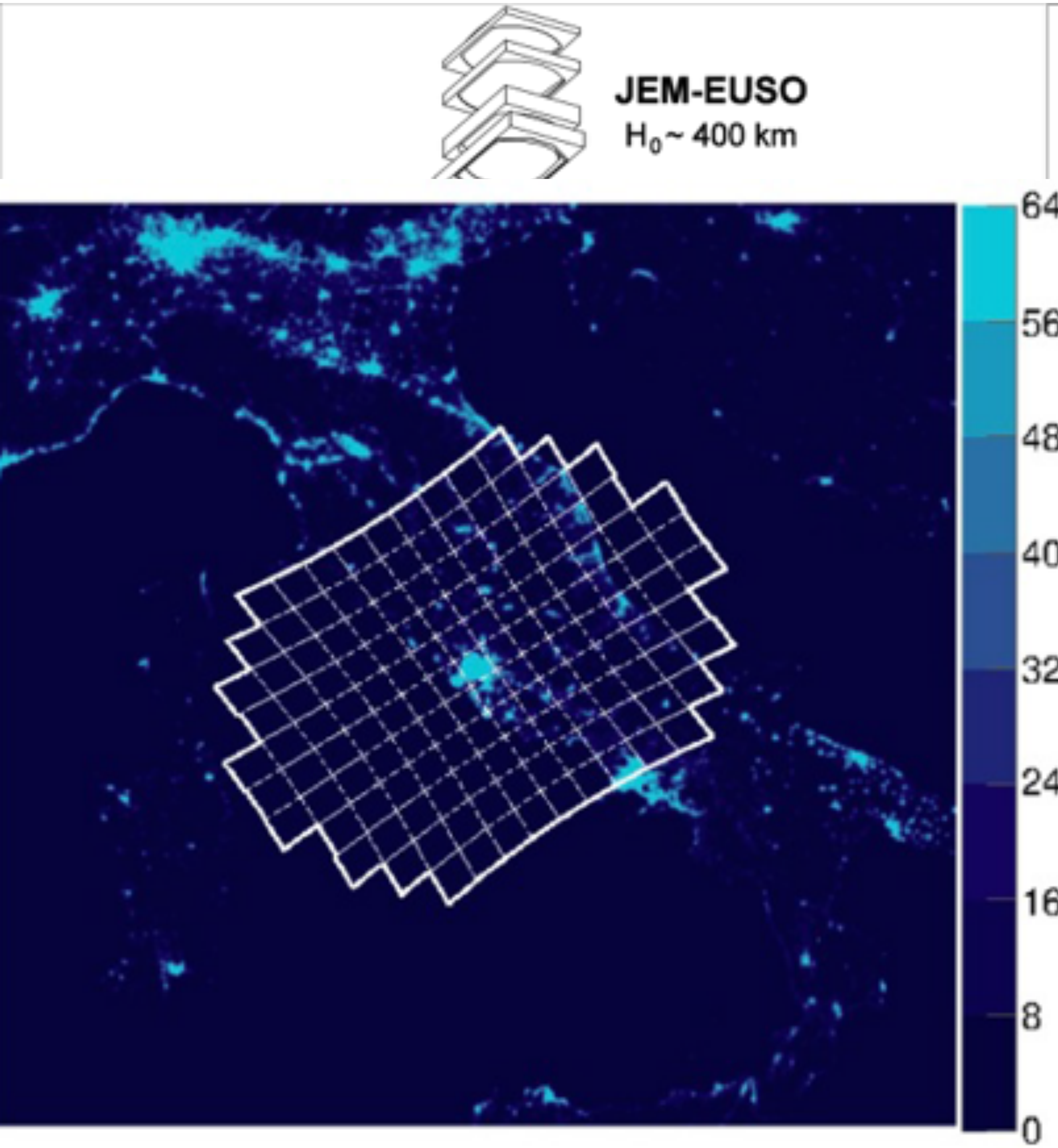
JEM-EUSO Observation Principle

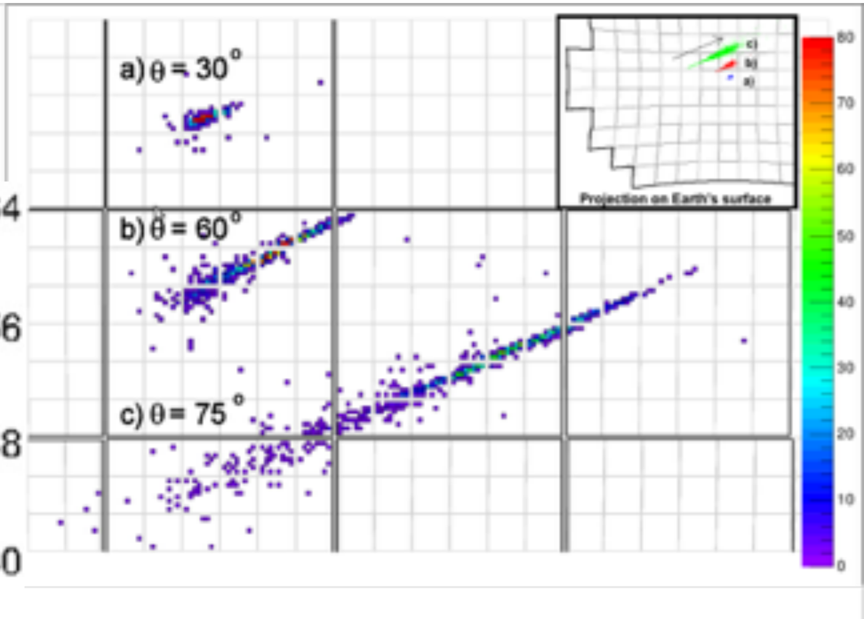


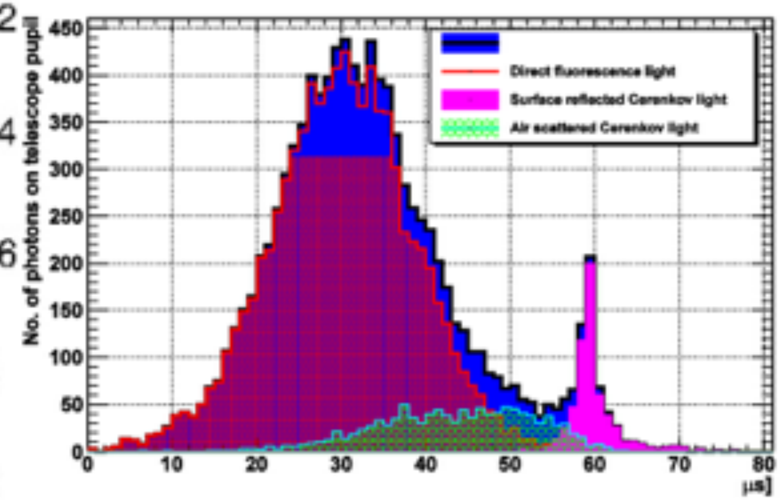




JEM-EUSO Observation Principle







Peculiarities from space

- *Far and almost constant distance* of the shower (no proximity effect)
- Shower is contained in the FOV: *observation of the entire profile*
- Possibility of *observing in cloudy conditions* (in most cases X_{max} above the cloud-top)
- *Less contamination* by Cherenkov
- *Efficient gamma/hadron separation* using different geographical areas
- Measurement of neutrino showers at high altitude *with less LPM effect*

Summary of Results on Exposure:

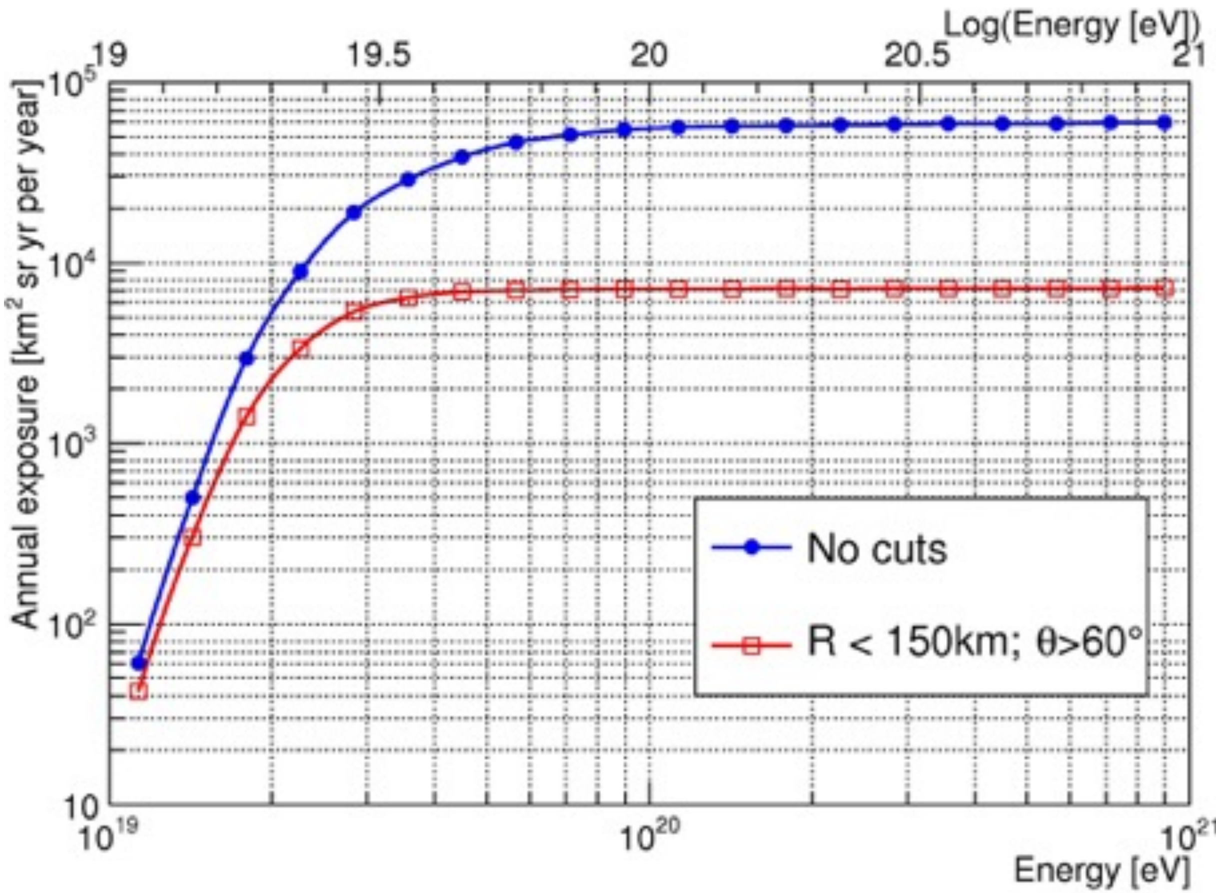
- Observational duty cycle (brightness of the sky does not hamper UHECR measurements): ~20%
- Role of clouds: ~72%
- City lights inefficiency: ~7%
- Lightning ineff.: ~ 2%
- Aurorae ineff.: ~1%

↓

- Conversion factor between Aperture and Exposure: ~13%

JEM-EUSO Coll.: Astrop. Phys. 2013 ; Adv. in Space Res. (2014); Experim. Astronomy (2014)

Annual Exposure nadir mode

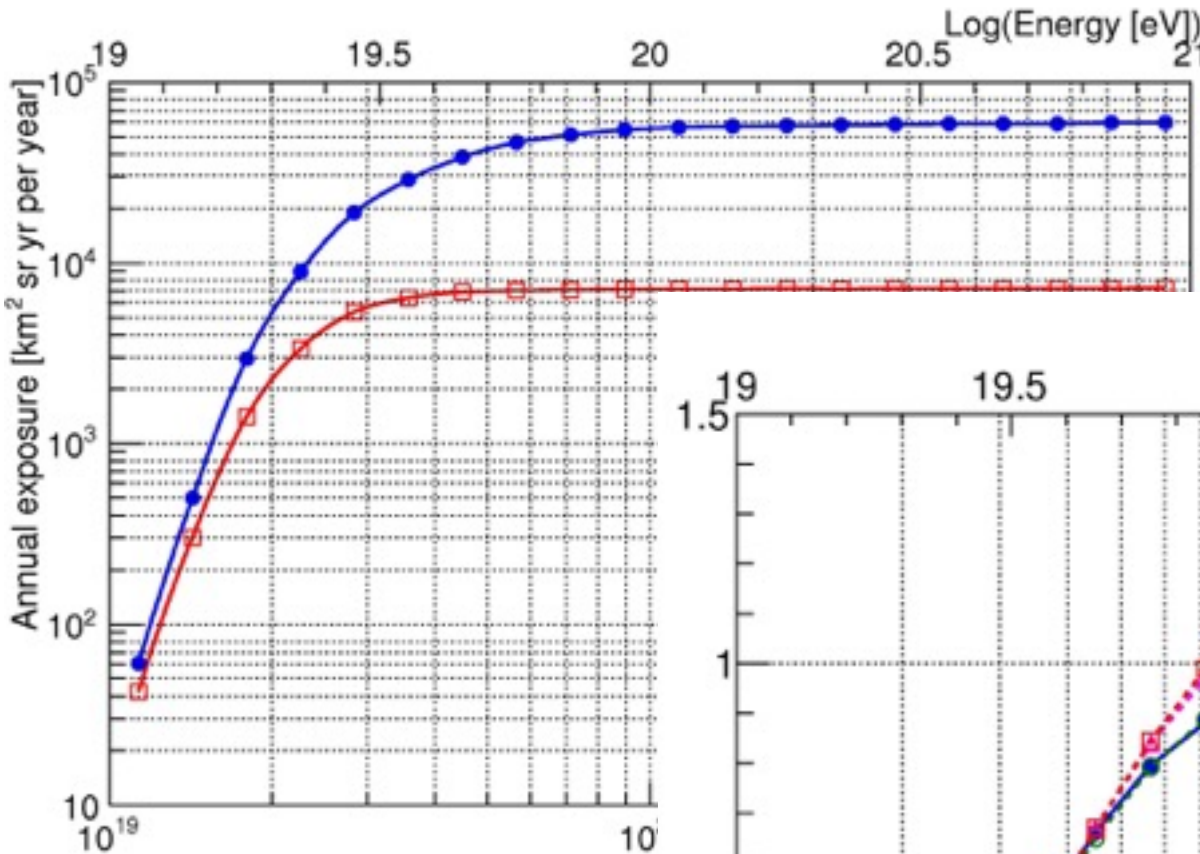


~60,000 km² sr yr

~7,000 km² sr yr

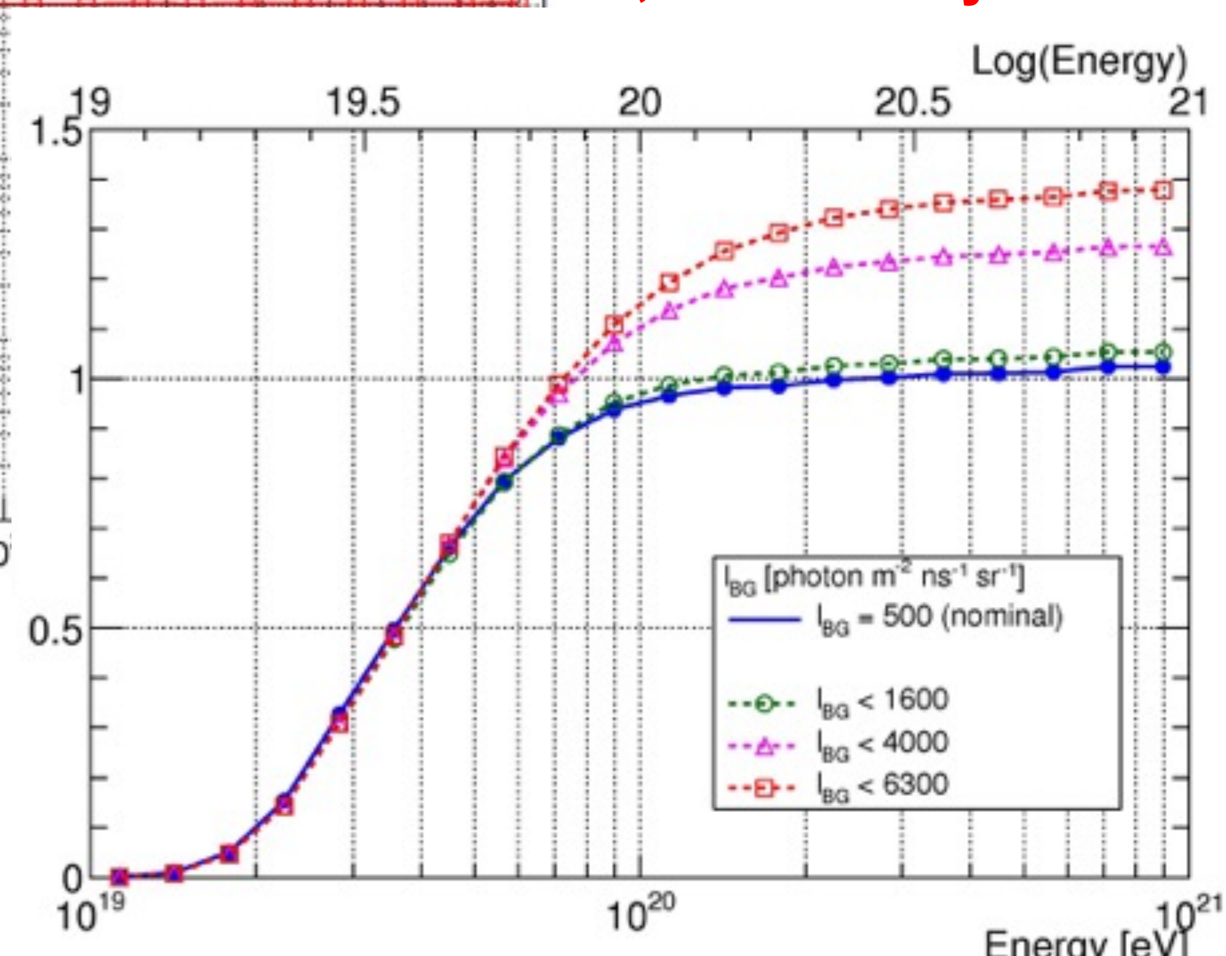
~9 times Auger
~50 times TA

Annual Exposure nadir mode



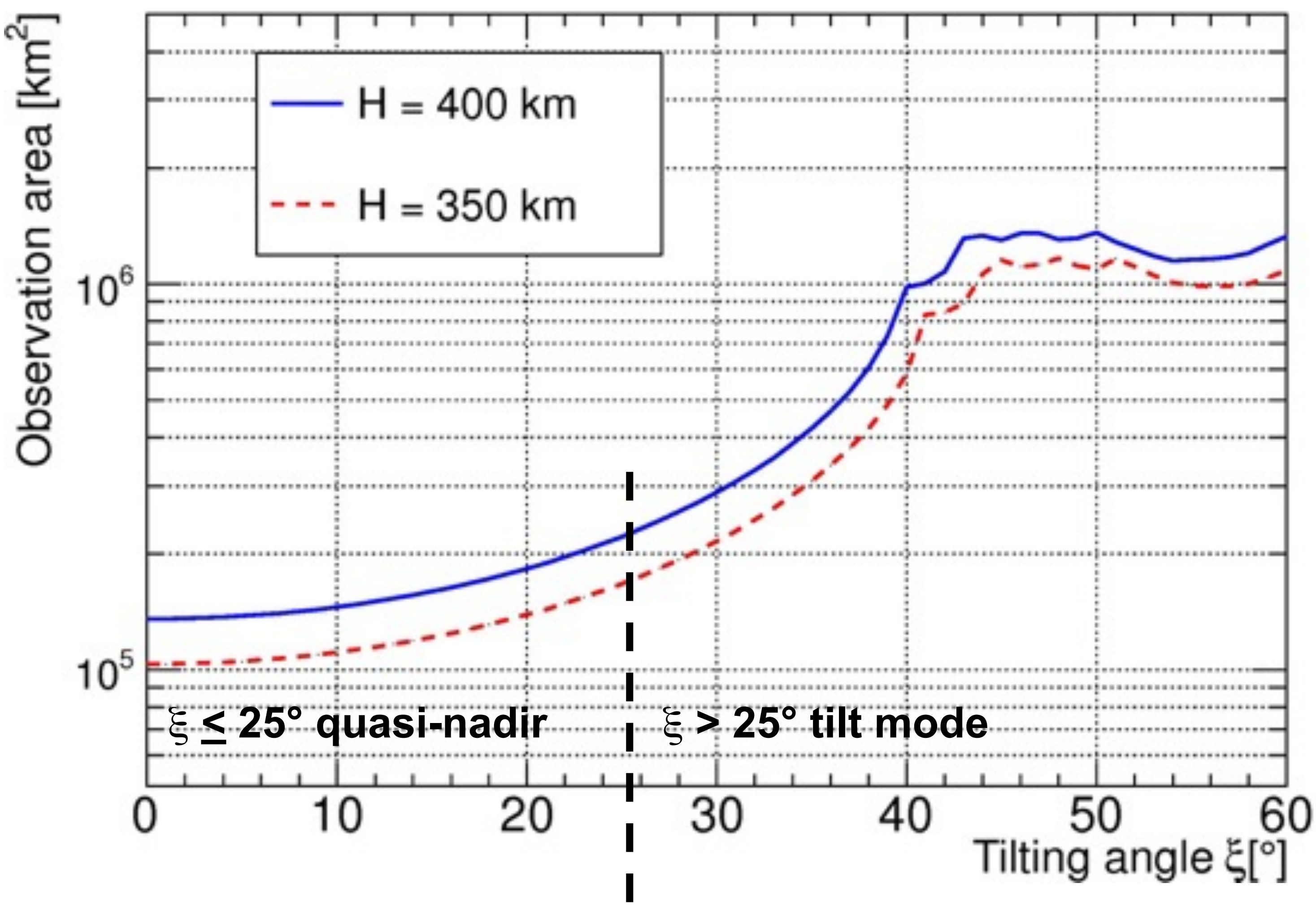
~60,000 km² sr yr

~7,000 km² sr yr



~9 times Auger
~50 times TA

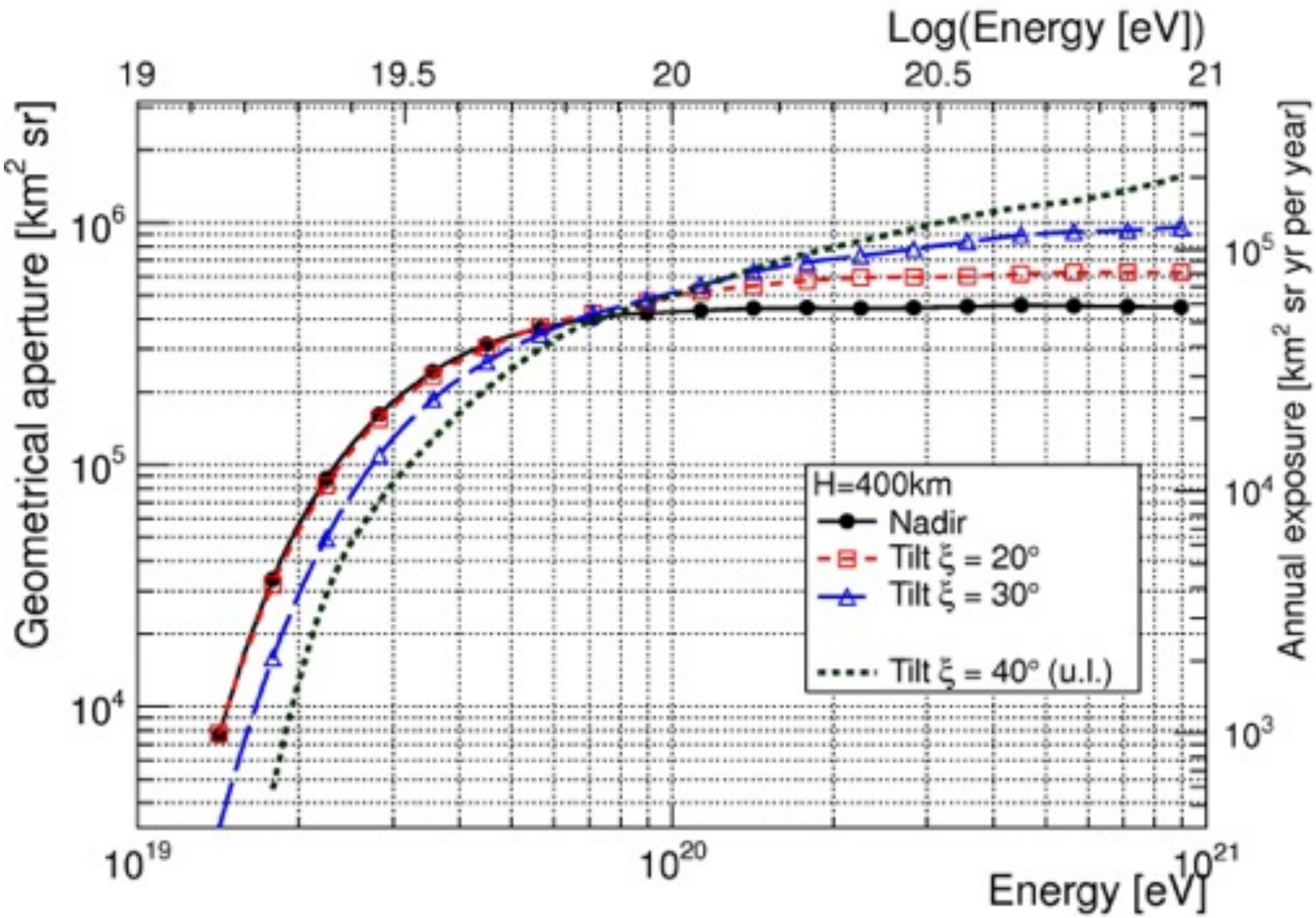
Observation area



$$A = k\,(\cos\xi\ )^{-3}$$

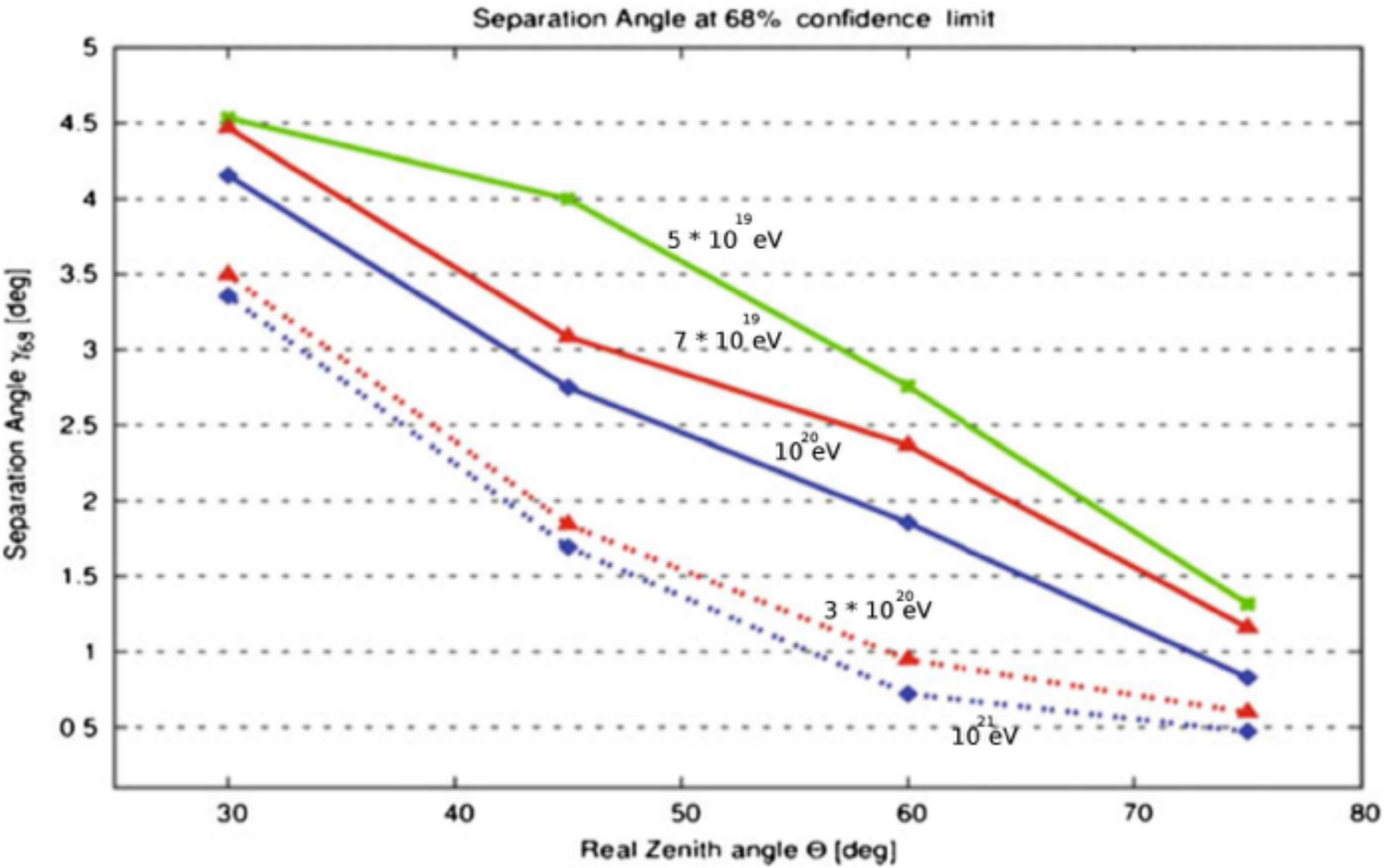
PERFORMANCE: $\xi \leq 30°$ easy to extrapolate from nadir
$\xi > 30°$ special simulation needed

Aperture & Exposure for tilt modes



ξ = 20° : exposure 10-20% higher than nadir mode at E~10^{20}eV
ξ = 30°: exposure ~1.8 higher than nadir mode at E > $5x10^{20}$eV

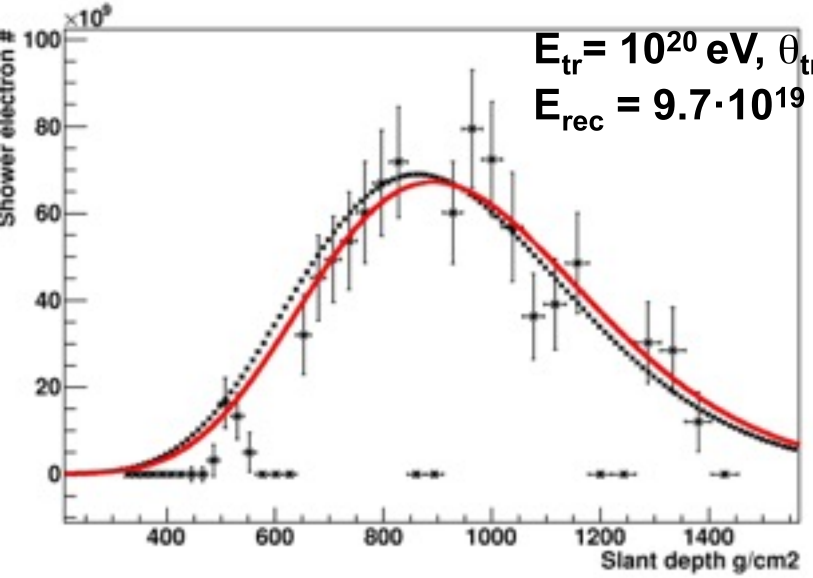
Angular resolution



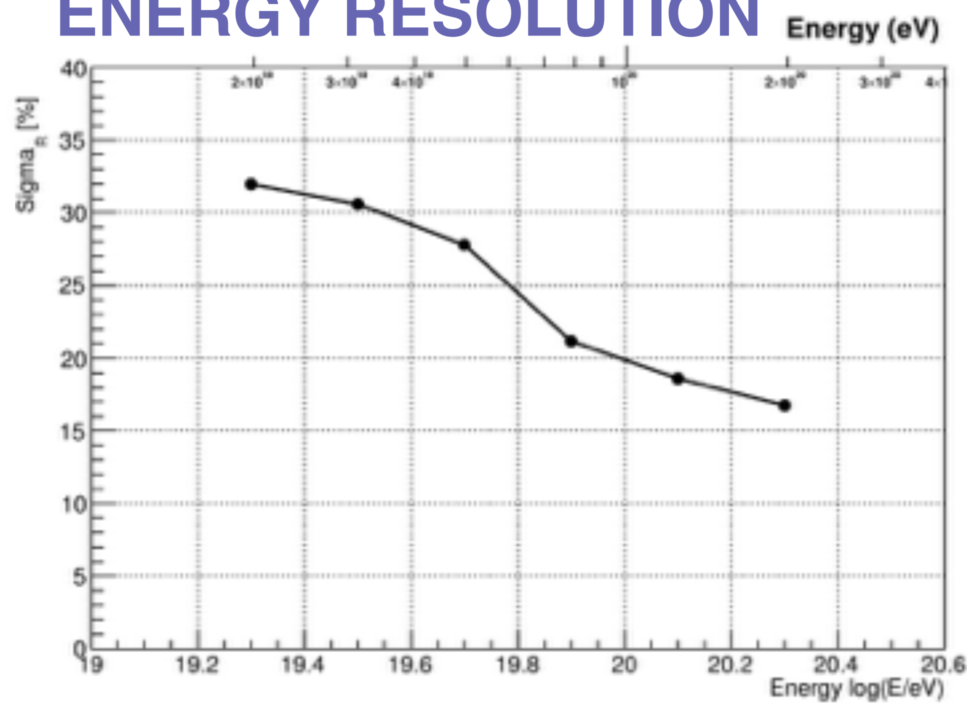
S. Biktemerova, T. Mernik, A. Guzman, Exp. Astron., JEM–EUSO special issue (2014)

Energy Reconstruction

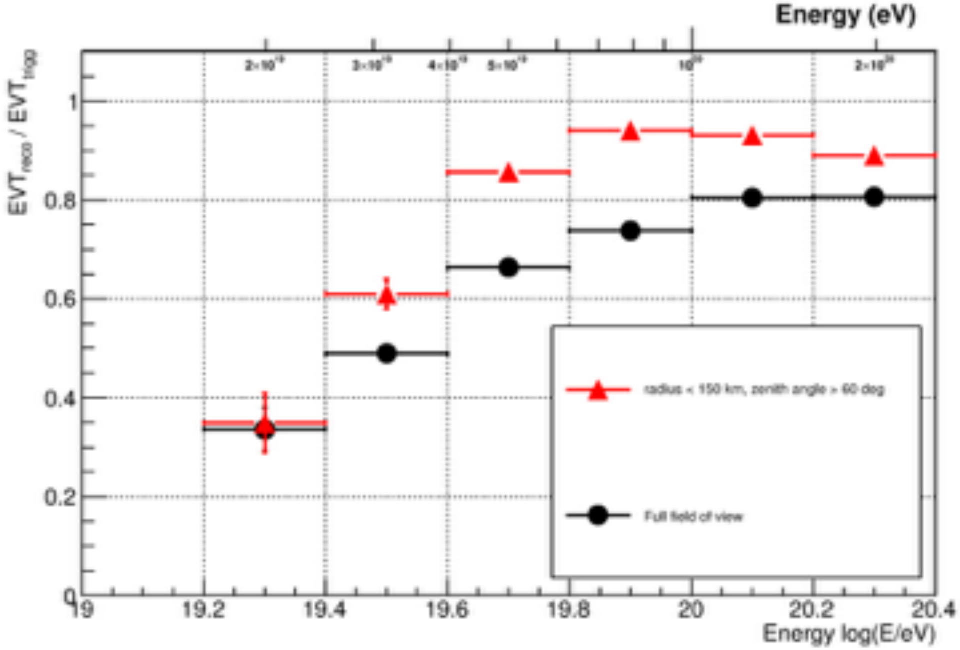
$E_{tr}= 10^{20}$ eV, θ_{tr} = 60.2°
E_{rec} = 9.7·10^{19} eV, θ_{rec} = 61.2°



ENERGY RESOLUTION

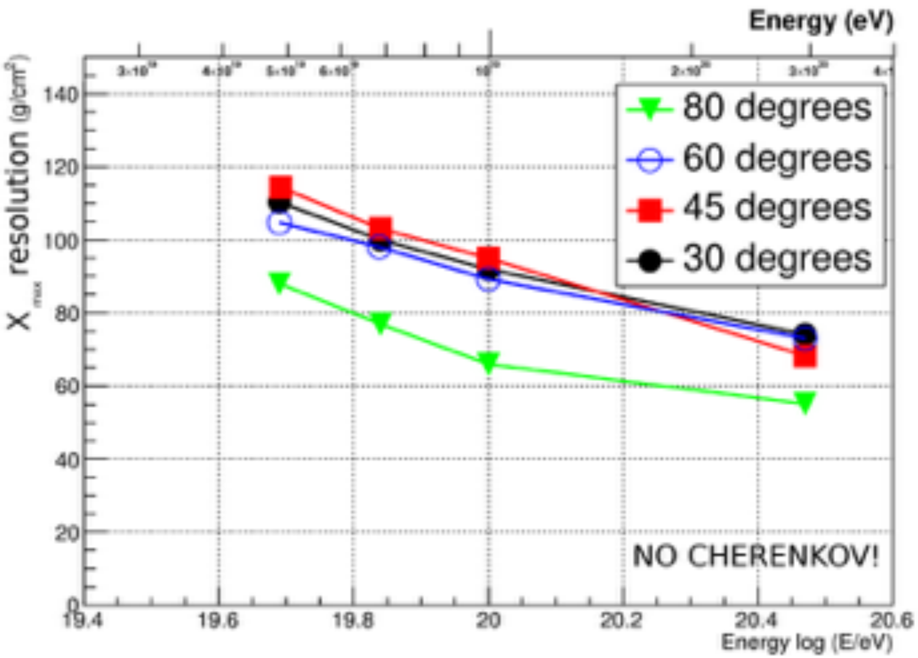


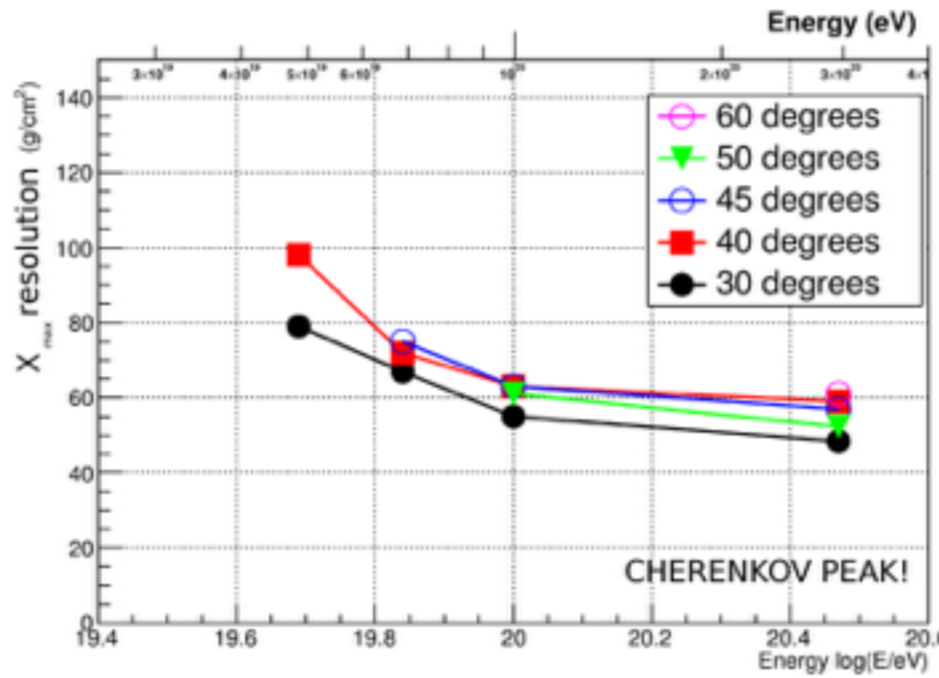
RECONSTRUCTION EFFICIENCY



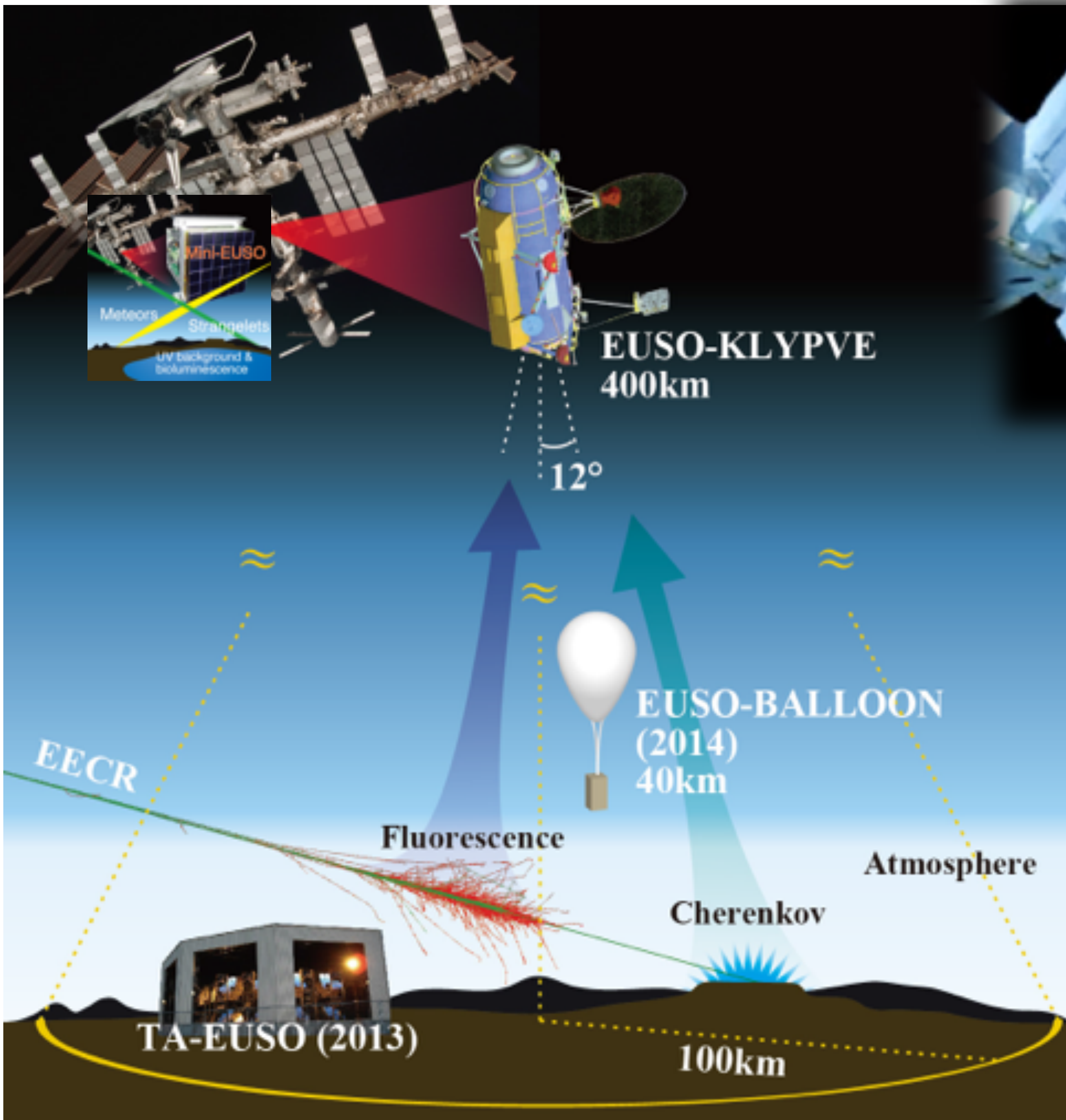
F. Fenu, A. Santangelo, D. Naumov, Exp. Astron., JEM–EUSO special issue (2014)

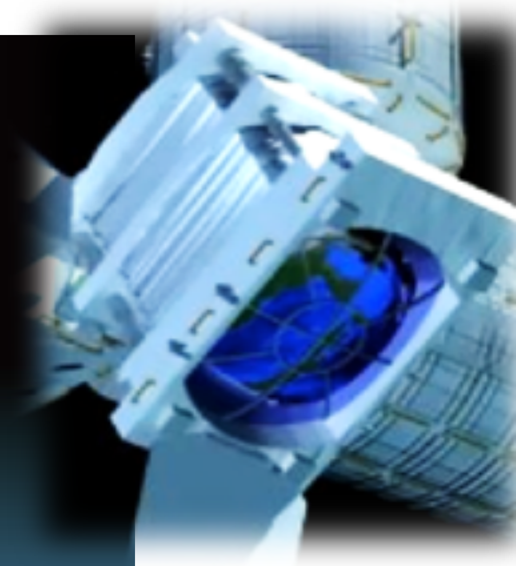
X_{max} reconstruction (center FoV)





F. Fenu, A. Santangelo, D. Naumov, Exp. Astron., JEM–EUSO special issue (2014)


Mini-EUSO
Meteors
Strangelets
UV background &
bioluminescence
EUSO-KLYPVE
400km
12°
EUSO-BALLOON
(2014)
40km
EECR
Fluorescence
Atmosphere
Cherenkov
TA-EUSO (2013)
100km



JEM-EUSO

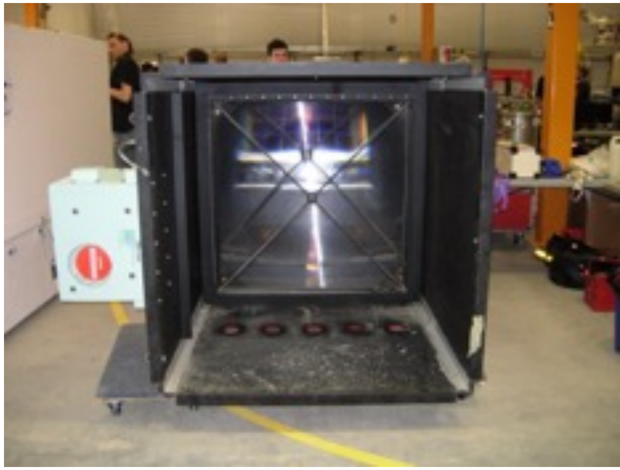
The path to JEM-EUSO ……

- EUSO Balloon Flights to test the technique in space and increase the TRL
- TA-EUSO at Telescope Array in Utah (US) ‘Endurance’ Test & cross-checks with standard EAS experiments
- MINI-EUSO to understand precisely the duty cycle, night glow background level, energy threshold
- KLYPVE/K-EUSO to prove the EAS observation from space (annual exposure per hemisphere comparable to Auger/TA)

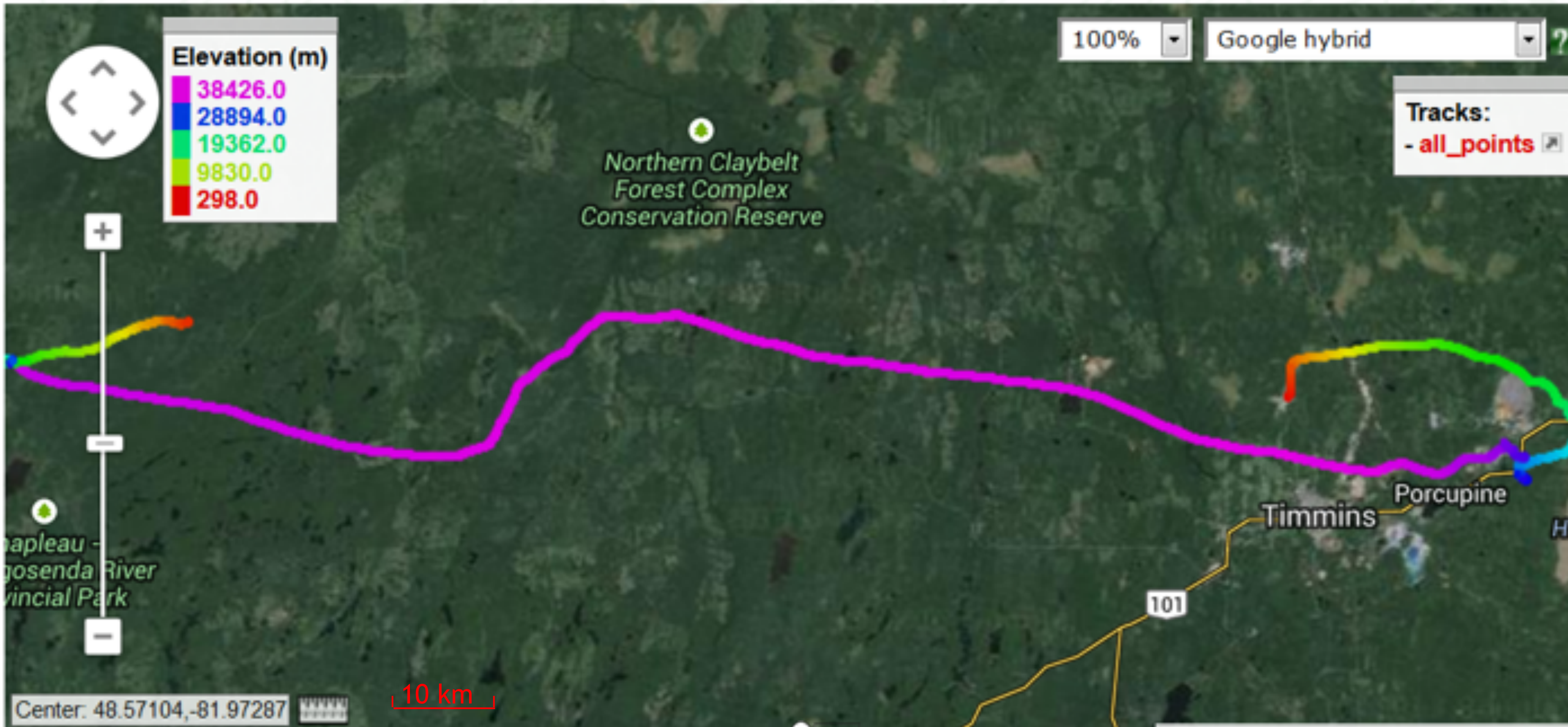

Euso Ballon flight
(Timmins, Ontario 2014)

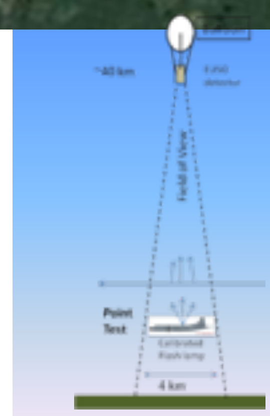
Integration
@Timmins
11-24 Aug 2014

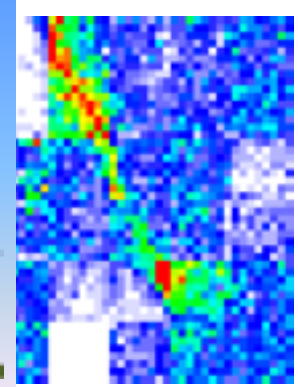


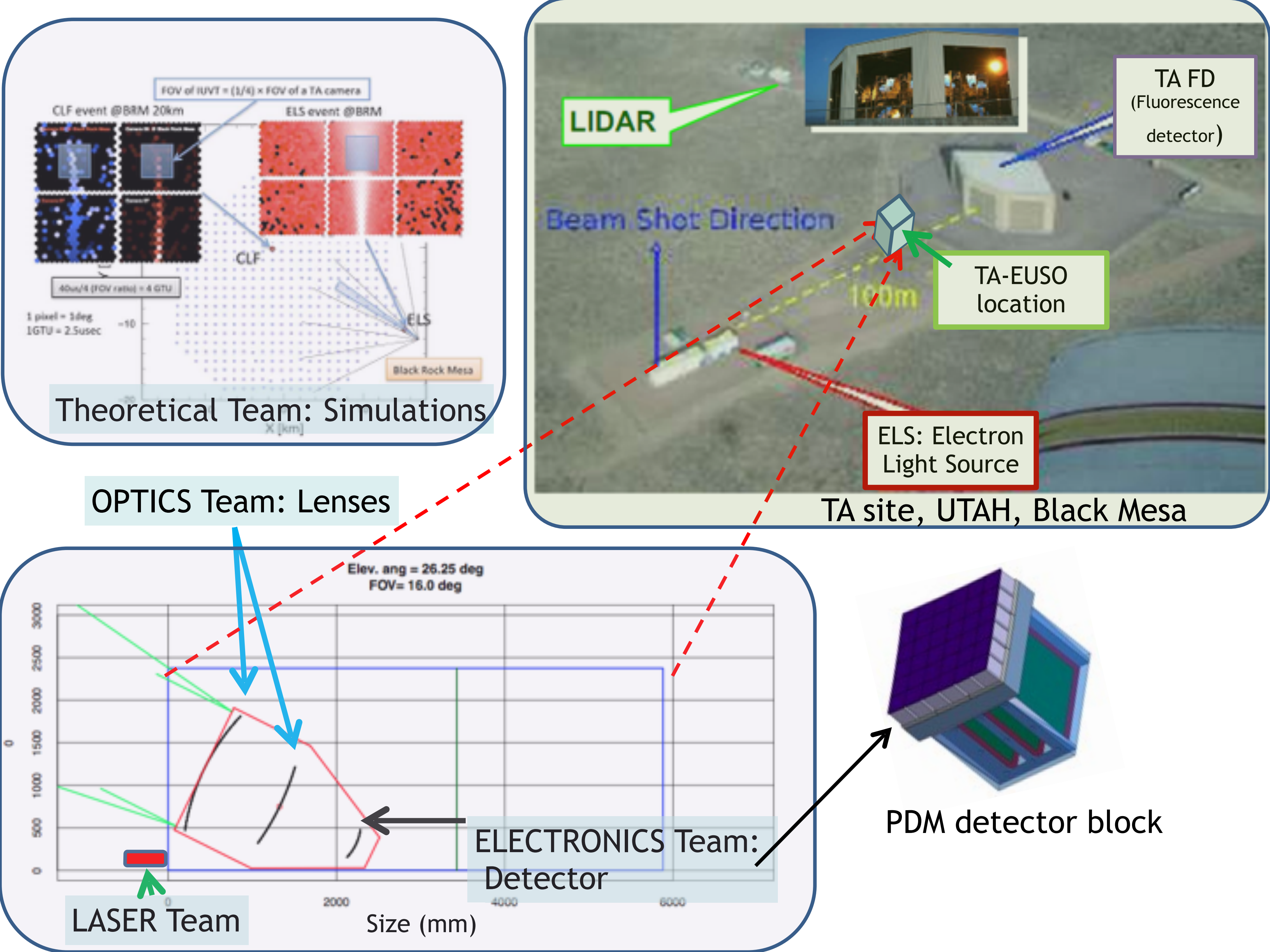



Balloon trajectory



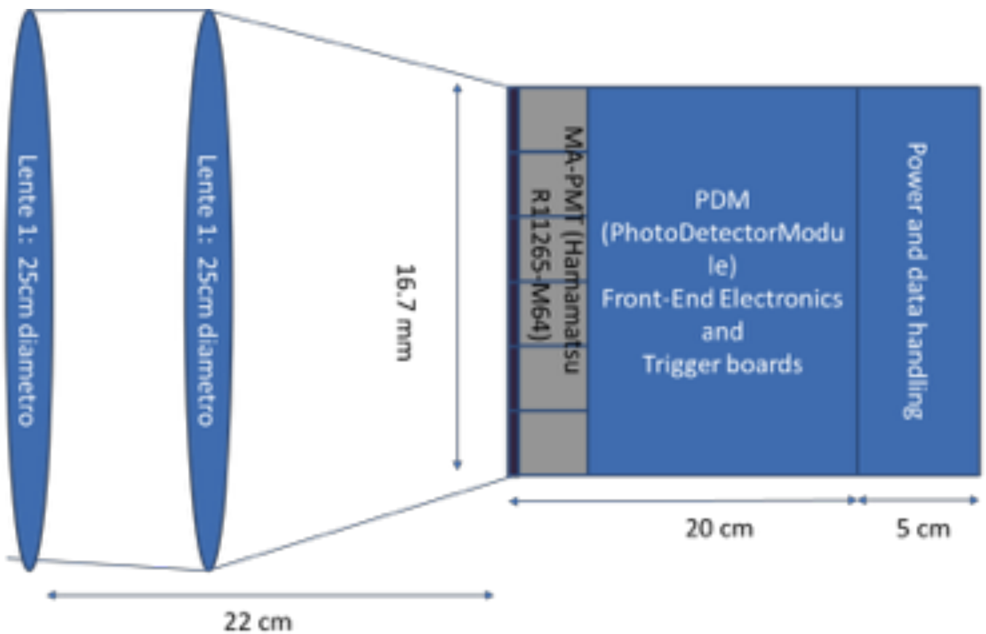


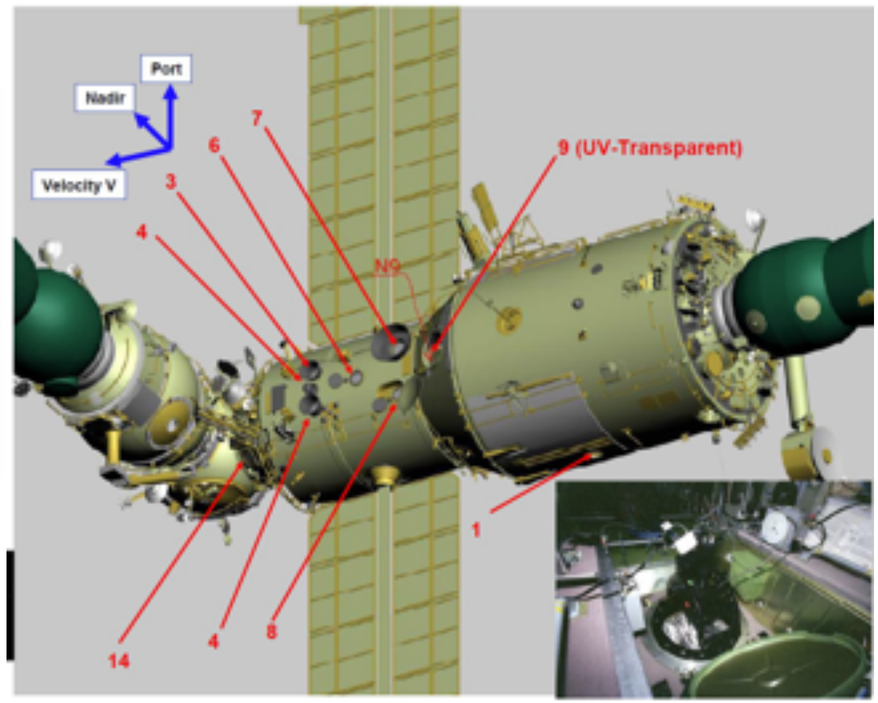



FOV of IUVT = (1/4) × FOV of a TA camera
CLF event @BRM 20km
ELS event @BRM
CLF
ELS
1 pixel = 1deg
1GTU = 2.5usec
Black Rock Mesa
Theoretical Team: Simulations
LIDAR
TA FD
(Fluorescence
detector)
Beam Shot Direction
100m
TA-EUSO
location
ELS: Electron
Light Source
TA site, UTAH, Black Mesa
OPTICS Team: Lenses
Elev. ang = 26.25 deg
FOV= 16.0 deg
0
500
1000
1500
2000
2500
3000
2000
4000
6000
ELECTRONICS Team:
Detector
LASER Team
Size (mm)
PDM detector block

TA-EUSO

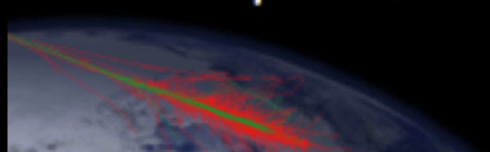
MINI-EUSO on ISS Russian module Zvesda





Scientific Objectives approved by ROSCOSMOS & ASI

- ***a) Scientific objectives***
- a.1) UV emissions from night-Earth
  - *6.5 km resolution, from 2.5mus and above +-51°*
  - *Noise from different lightning conditions, moon phase*
  - *Noise from different inclinations*
- *a.2) Map of the Earth in UV*
- *a.3) Study of atmospheric phenomena*
- a.4) Bioluminescence of Animal and vegetal organisms
- *a.4) Study of meteors*
  - *Search for Strange quark matter*
  - *Space Debris assessment*



JEM-EUSO collaboration 13 Countries, 80 Institutes as of March, 2013

K-Euso

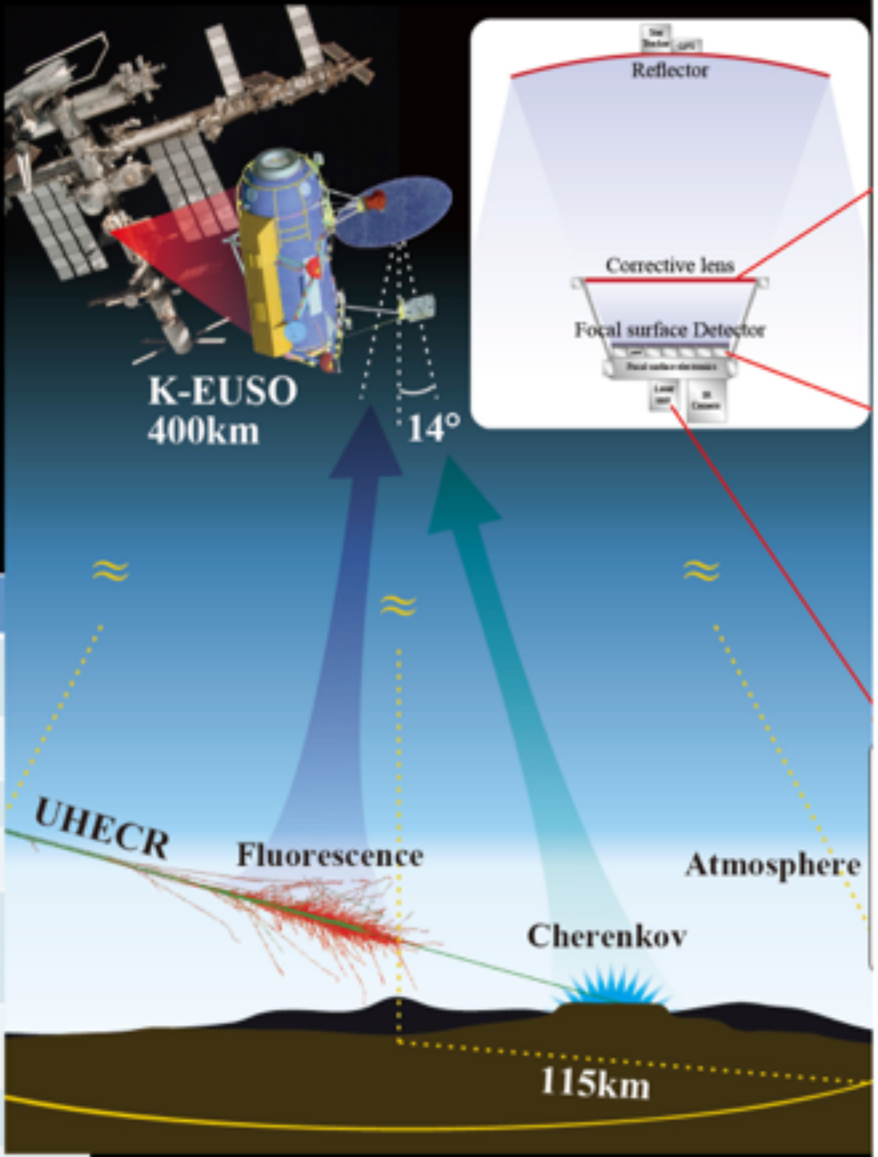
Mirror based design

Collaboration with Russia

Upgrade of KLYPVE

Russian detector on ISS

Total mass	< 650 kg (delivery requirement)
Total power consumption	< 600 W (RS ISS limit)
Mirror diameter	3600 mm (< 4000 mm)
Focal distance	4000 mm
Parts size (mirror segments, photo detector clusters)	1200×700 mm (airlock requirement)
Scientific information	>4 TB/year hard disk to ground
Telemetry information	50 Mbytes per day
Focal Surface	1200 mm diameter



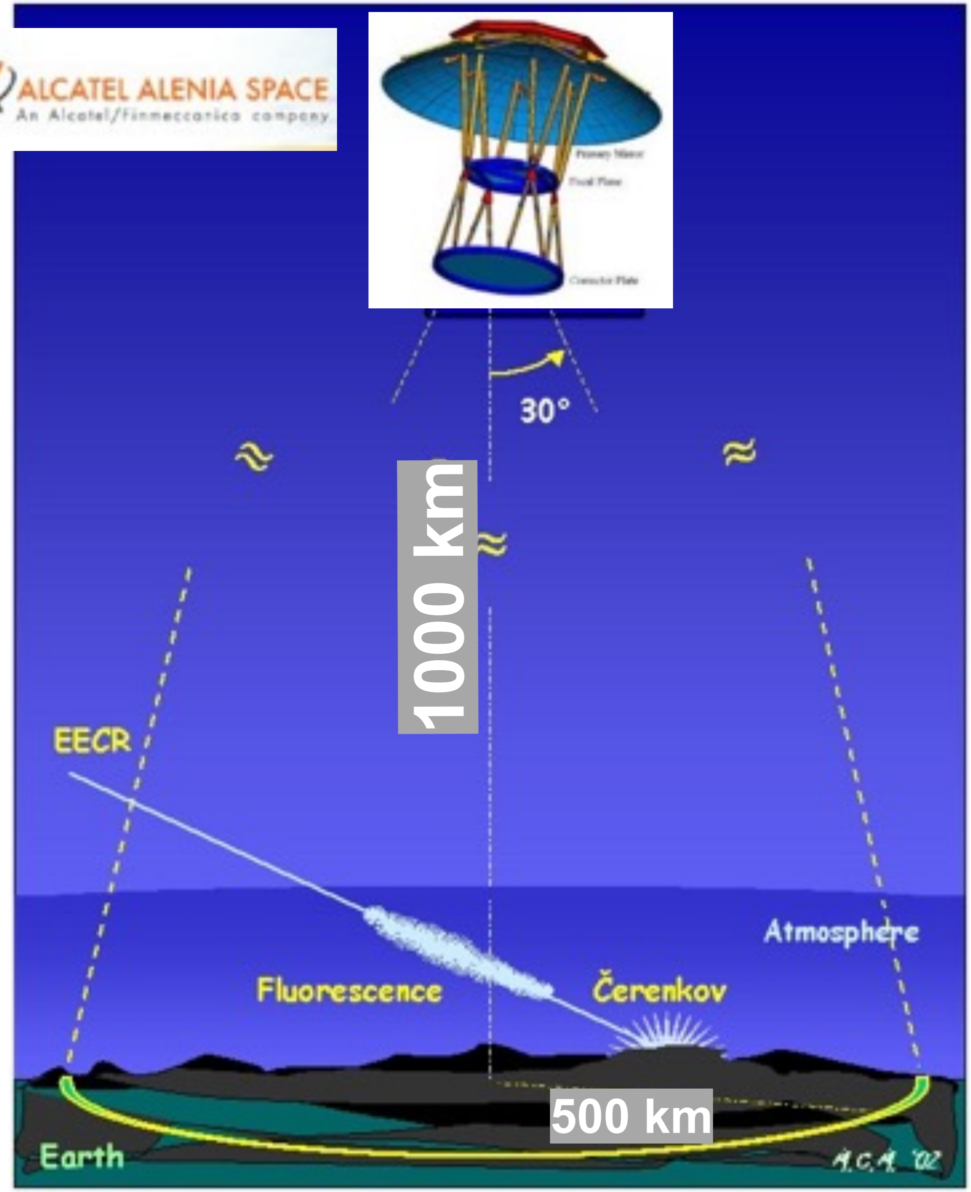
…. and then ….

S-EUSO

- Variable orbit 1000 km
- Large FOV $\gamma \geq 30°$
-

A_{exp} ~ (1.2 - 2.4) x10^6 km^{2}sr

$\eta_{cycle} \approx 10 \div 25\ \%$

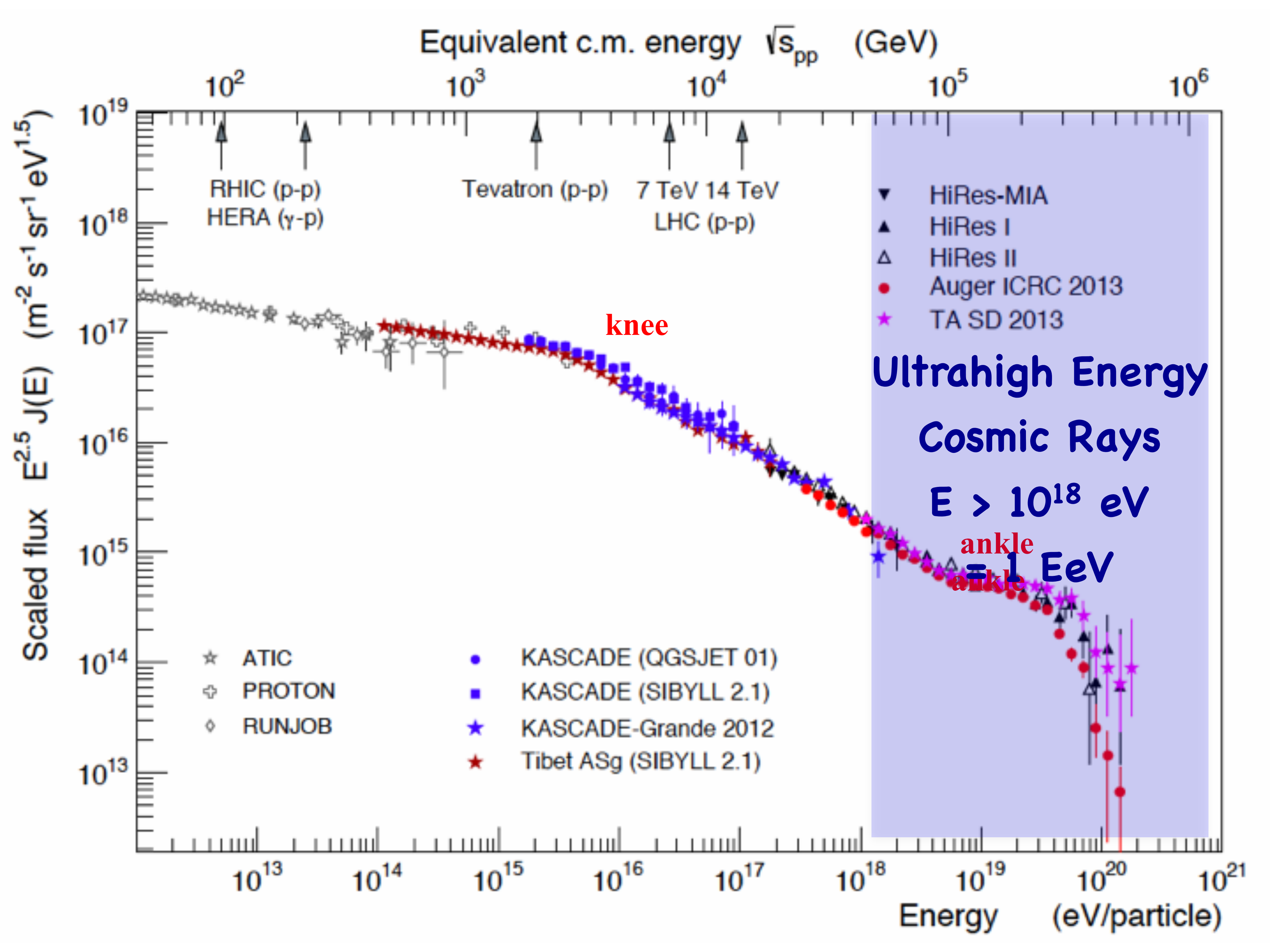


mass ($\lesssim 1.5$ ton), volume ($\lesssim 2.5 \times 2.5 \times 4.5\ \mathrm{m}^3$), power ($\lesssim 1$ kW) and telemetry ($\lesssim 180$ Mbit/orbit).

S-EUSO requirements

- Effective Aperture: **$A_{eff} > 5 \times 10^6$ km sr yr**
- Low Energy Threshold: **~100% @ $1\text{-}2 \times 10^{19}$eV**
- Average Angular Resolution: **1-2° @ 10^{20}eV**
- Energy Resolution: **~10% @ $1\text{-}2 \times 10^{19}$eV**
- EAS Xmax determination: **ΔX_{max}: 20-50 gr/cm^2**
- Orbit height: variable, **500 - 1000 km**
- Operational Life: **5 - 10 yr on orbit**

THANK YOU



Equivalent c.m. energy $\sqrt{s}_{pp}$ (GeV)
10^2
10^3
10^4
10^5
10^6
RHIC (p-p)
HERA (γ-p)
Tevatron (p-p)
7 TeV 14 TeV
LHC (p-p)
HiRes-MIA
HiRes I
HiRes II
Auger ICRC 2013
TA SD 2013
knee
Ultrahigh Energy
Cosmic Rays
E > 10^{18} eV
ankle
= 1 EeV
Scaled flux $E^{2.5}$ J(E) ($m^{-2} s^{-1} sr^{-1} eV^{1.5}$)
ATIC
PROTON
RUNJOB
KASCADE (QGSJET 01)
KASCADE (SIBYLL 2.1)
KASCADE-Grande 2012
Tibet ASg (SIBYLL 2.1)
Energy (eV/particle)

Current Observatories of Ultrahigh Energy Cosmic Rays

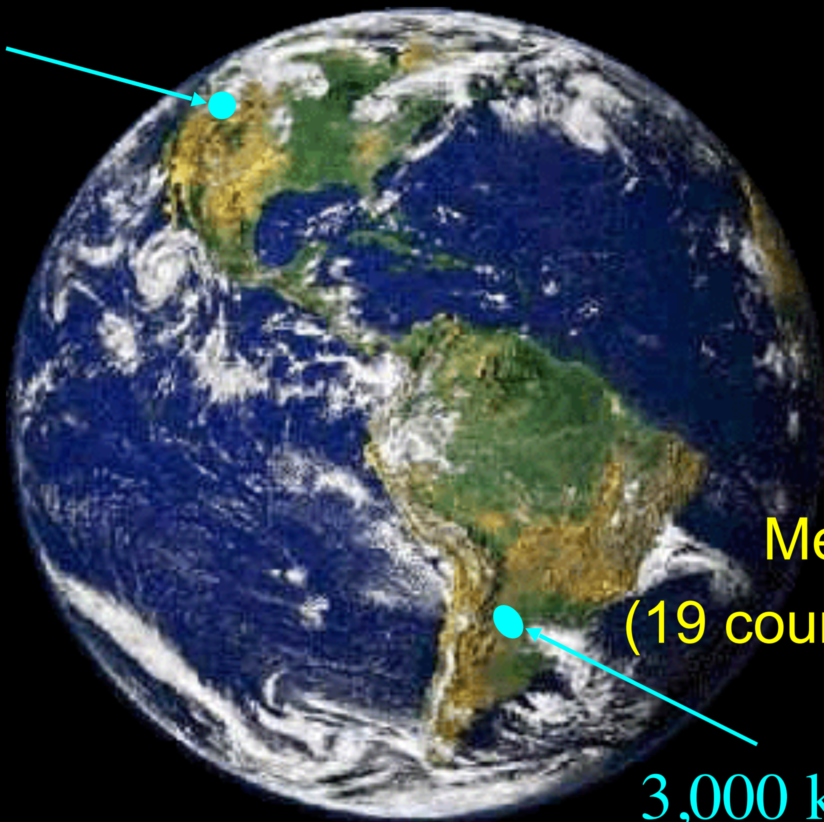
Telescope Array

Utah, USA

(5 country collaboration)

700 km^2 array

3 fluorescence telescopes



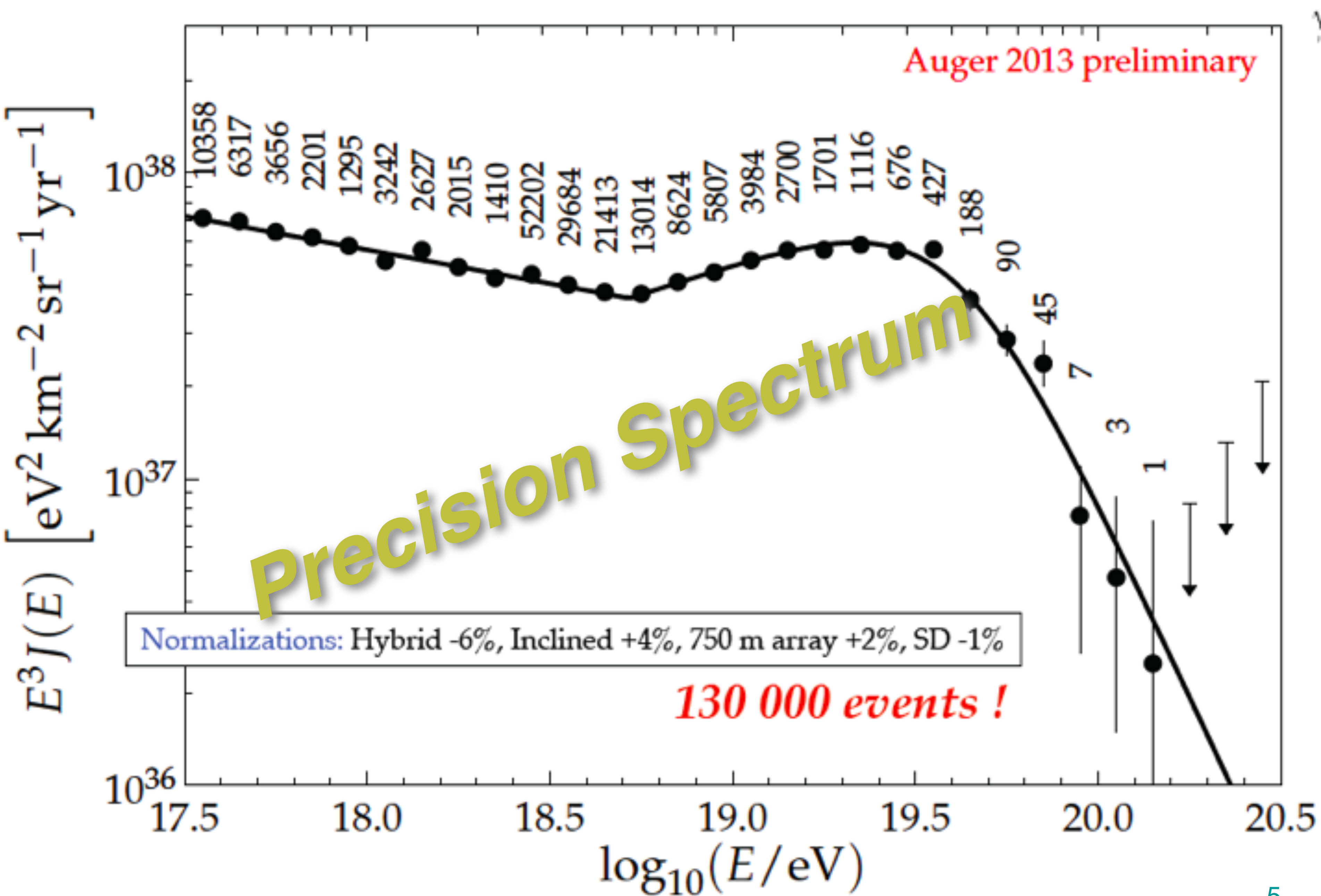
Pierre Auger Observatory

Mendoza, Argentina

(19 country collaboration)

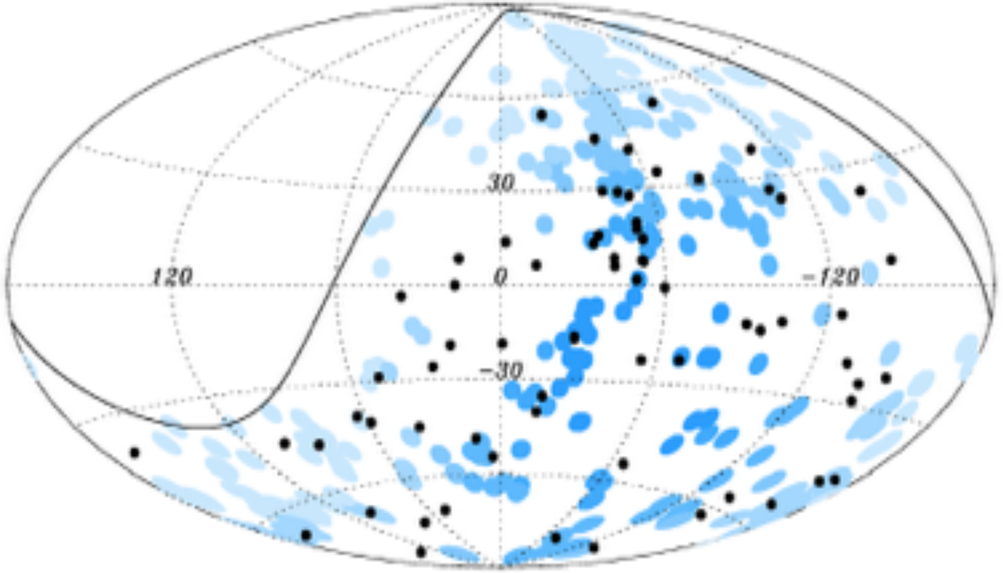
3,000 km^2 array

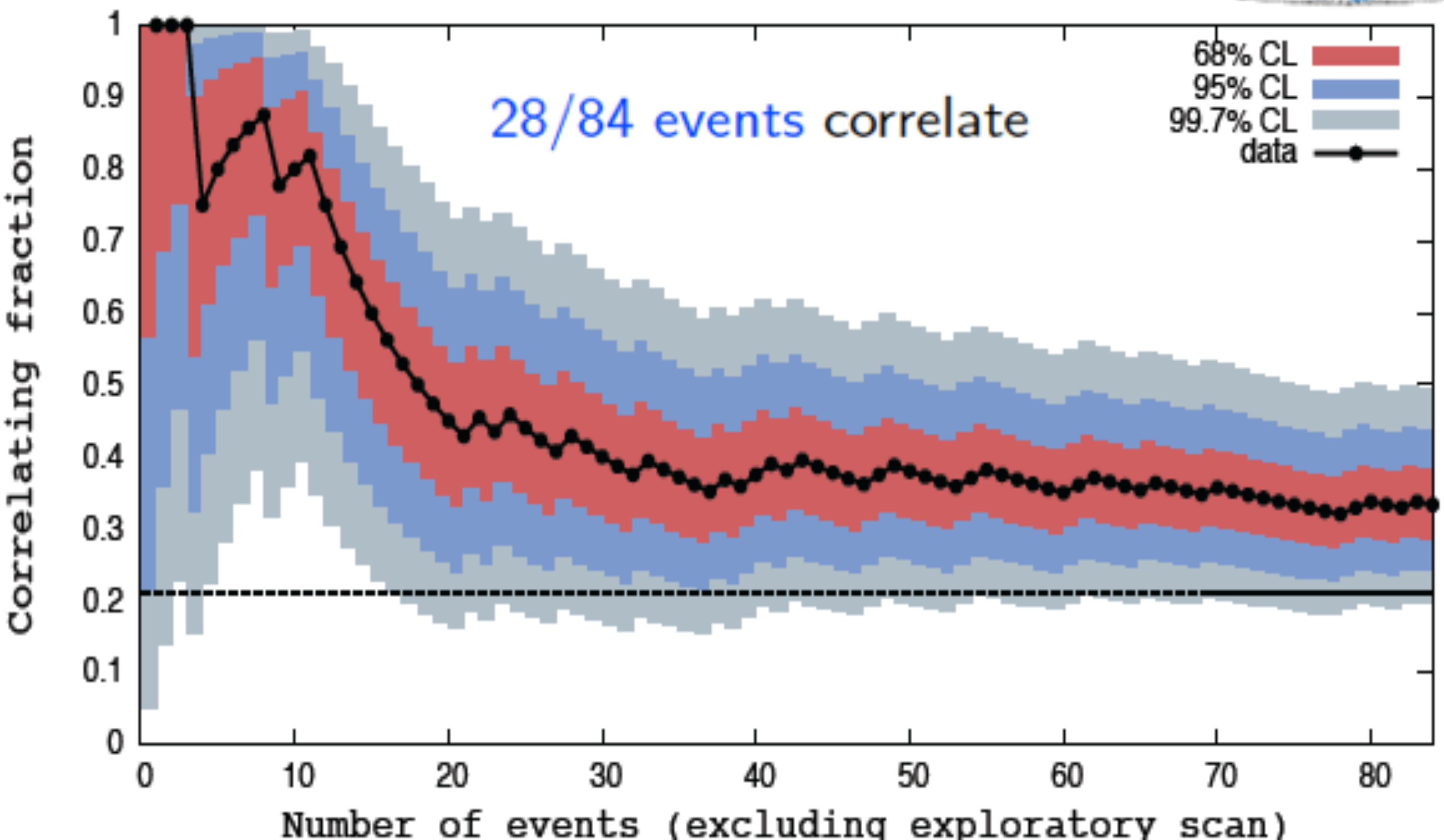
4 fluorescence telescopes


Auger 2013 preliminary
Precision Spectrum
Normalizations: Hybrid -6%, Inclined +4%, 750 m array +2%, SD -1%
130 000 events !
$E^3 J(E)$ [$eV^2 km^{-2} sr^{-1} yr^{-1}$]
$\log_{10}(E/eV)$
10^{38}
10^{37}
10^{36}
17.5
18.0
18.5
19.0
19.5
20.0
20.5
10358
6317
3656
2201
1295
3242
2627
2015
1410
52202
29684
21413
13014
8624
5807
3984
2700
1701
1116
676
427
188
90
45
7
3
1

Auger: consistent with Anisotropy above 60 EeV

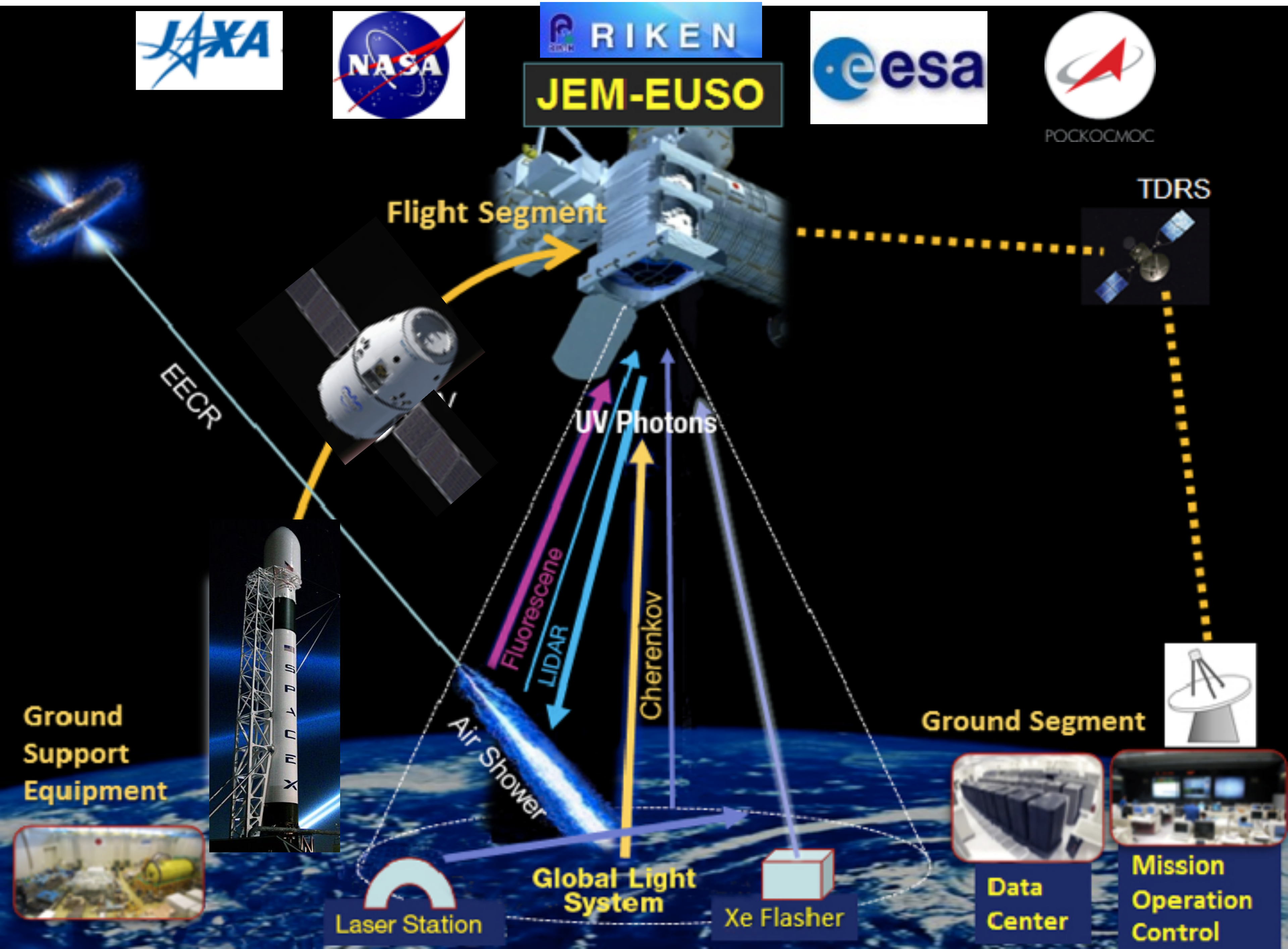
AGN catalog test





JEM-EUSO Mission

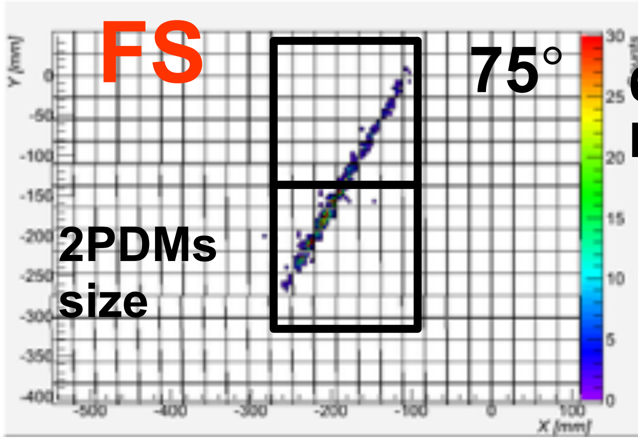
Parameter	Value
Launch date	2017
Mission Lifetime	3+2 years
Rocket	H2B (or Falcon9)
Transport Vehicle	HTV (or Dragon)
Accommodation on JEM	EF#9
Mass	1938 kg
Power	926 W (op.) 352 W (non op.)
Data rate	285 kbps (+ on board storage)
Orbit	400 km
Inclination of the Orbit	51.6°
Operation Temperature	-10° to +50°

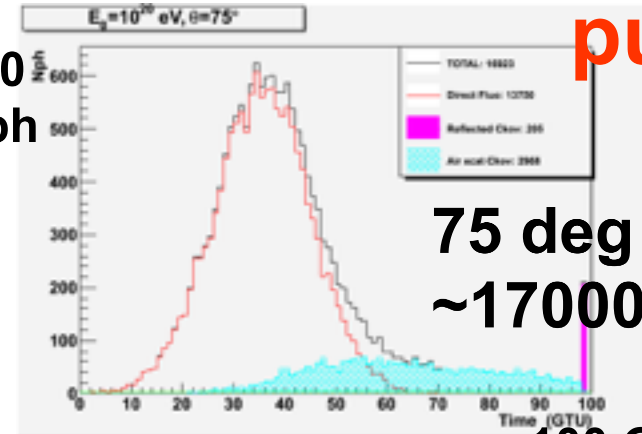


RIKEN
JEM-EUSO
esa
РОСКОСМОС
TDRS
Flight Segment
EECR
UV Photons
Fluorescene
LIDAR
Cherenkov
Air Shower
Ground Support Equipment
Ground Segment
Laser Station
Global Light System
Xe Flasher
Data Center
Mission Operation Control

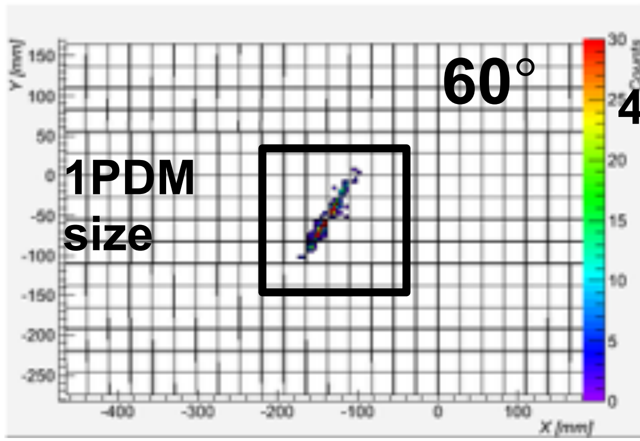

SpaceX
Dragon

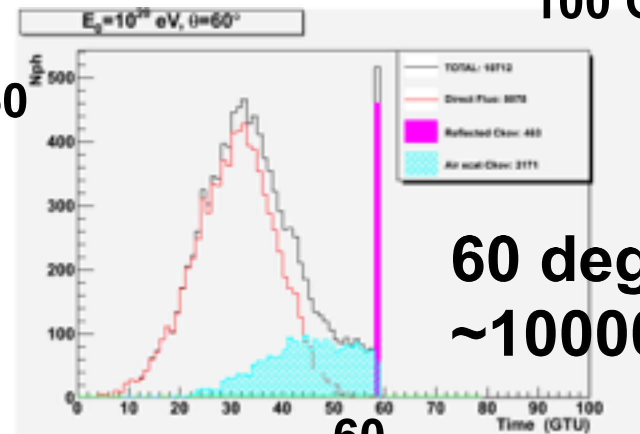
Proton
E=10^{20}eV



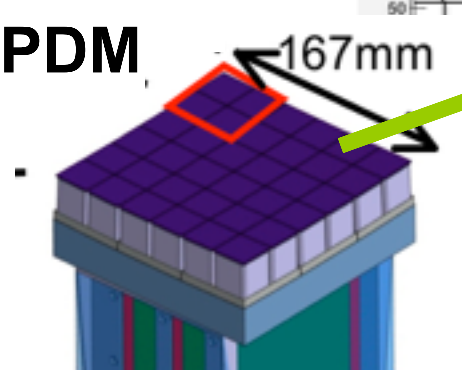


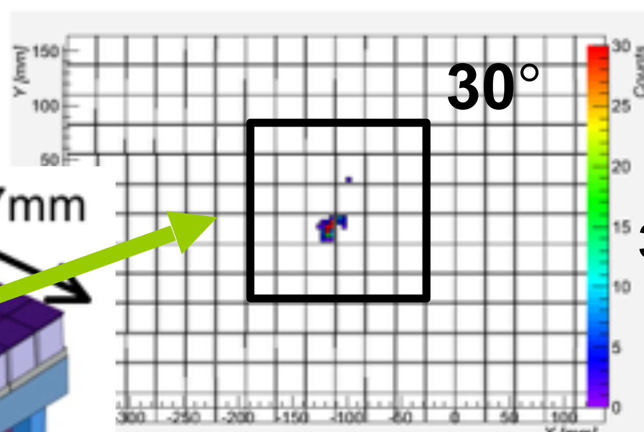
1 PDM FoV:
~ 27 km x 27 km
~1/4 Auger
~ 1 TA

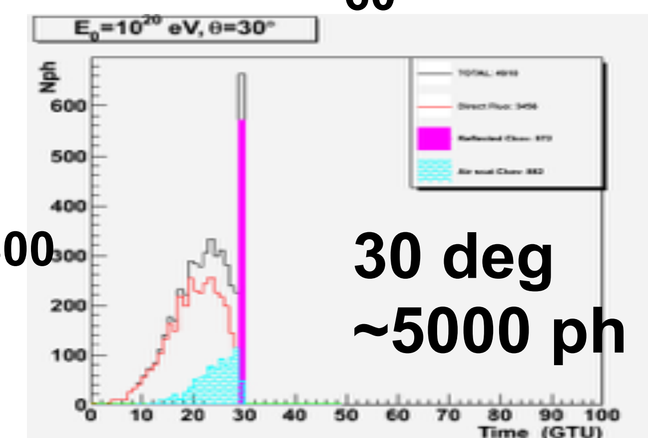




137 PDMs on FS







1GTU = 2.5 μs

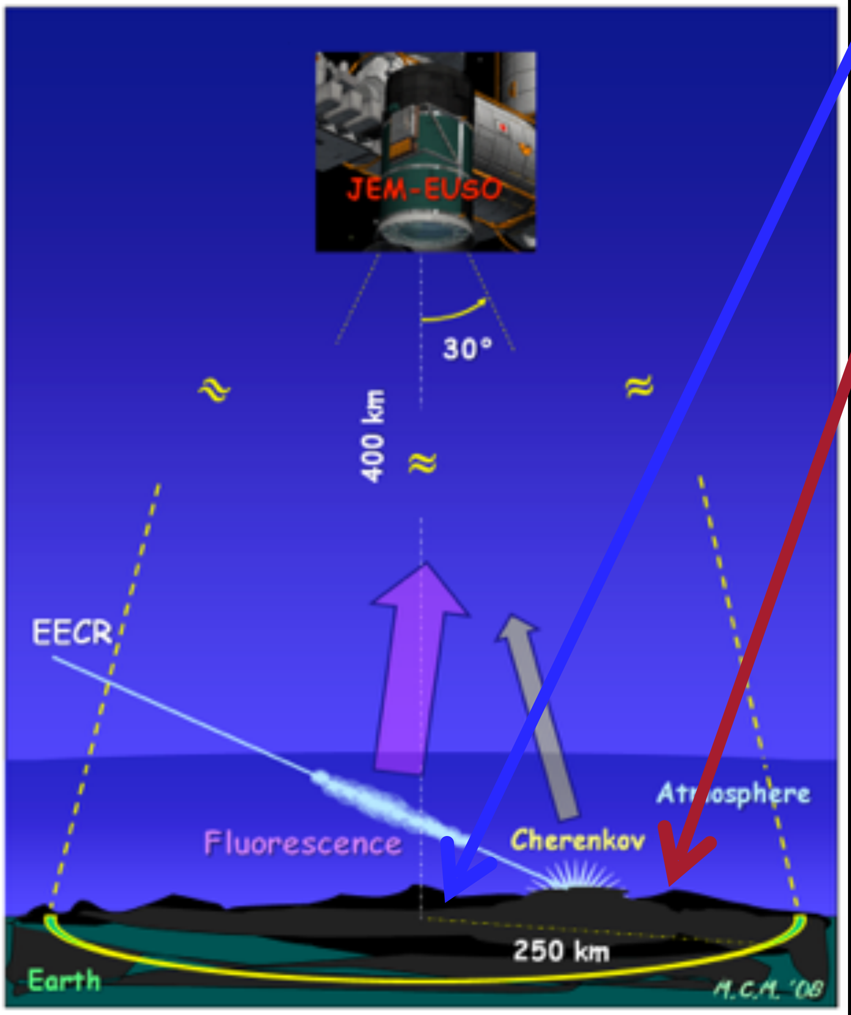
FAST SIGNAL

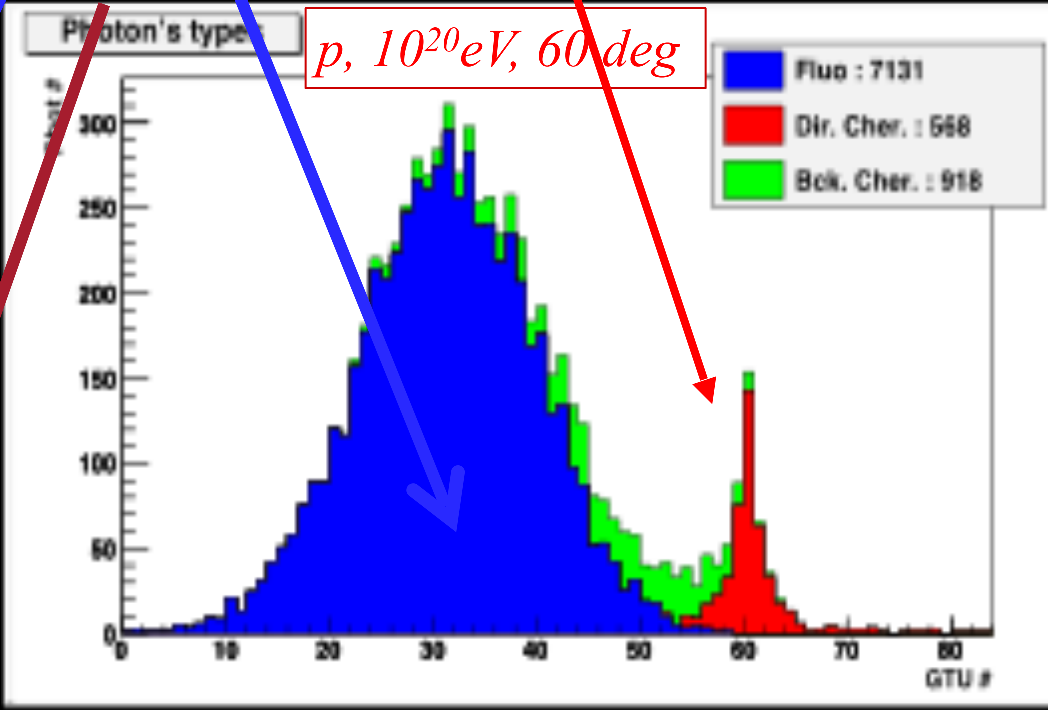
duration 50 -150 μs

a) Fluorescence

b) Scattered Cherenkov

c) Direct (diffusively reflected Cherenkov)

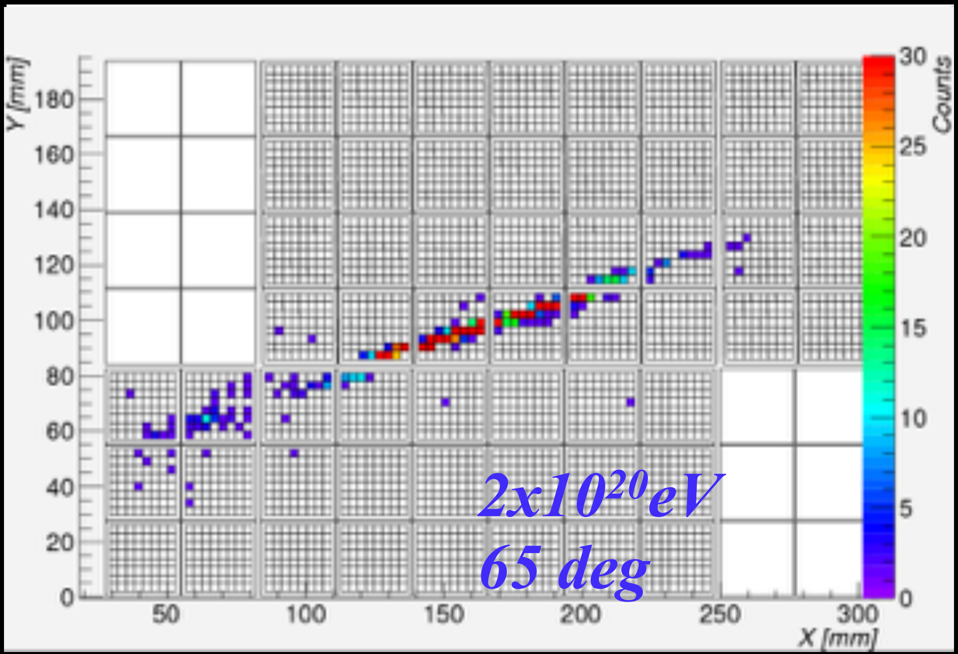




1 GTU gate time units = 2.5 μs

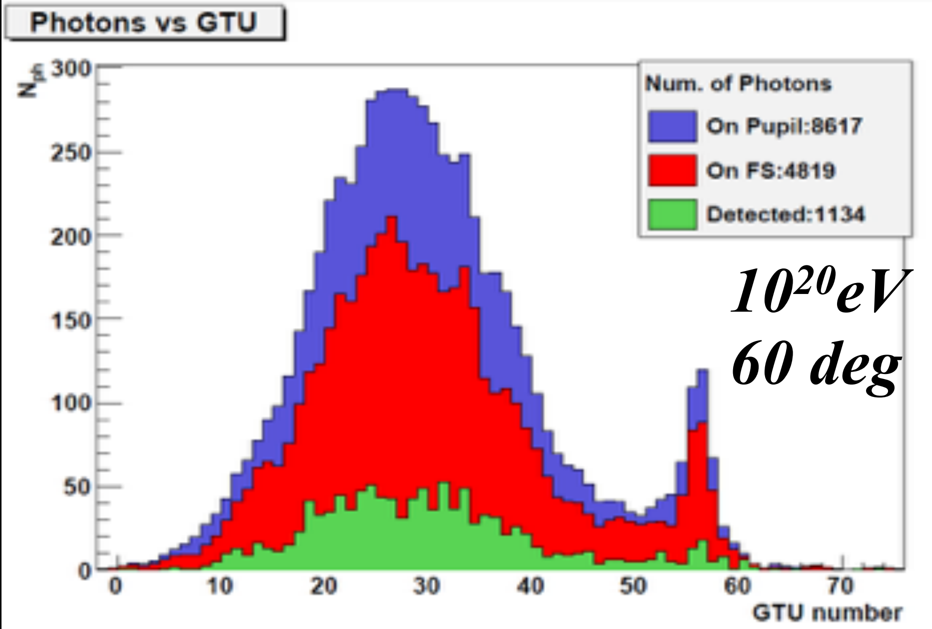
Background: 500 /m^2 sr ns

Result of end-to-end simulation



Simulated air shower image on the focal surface detector.

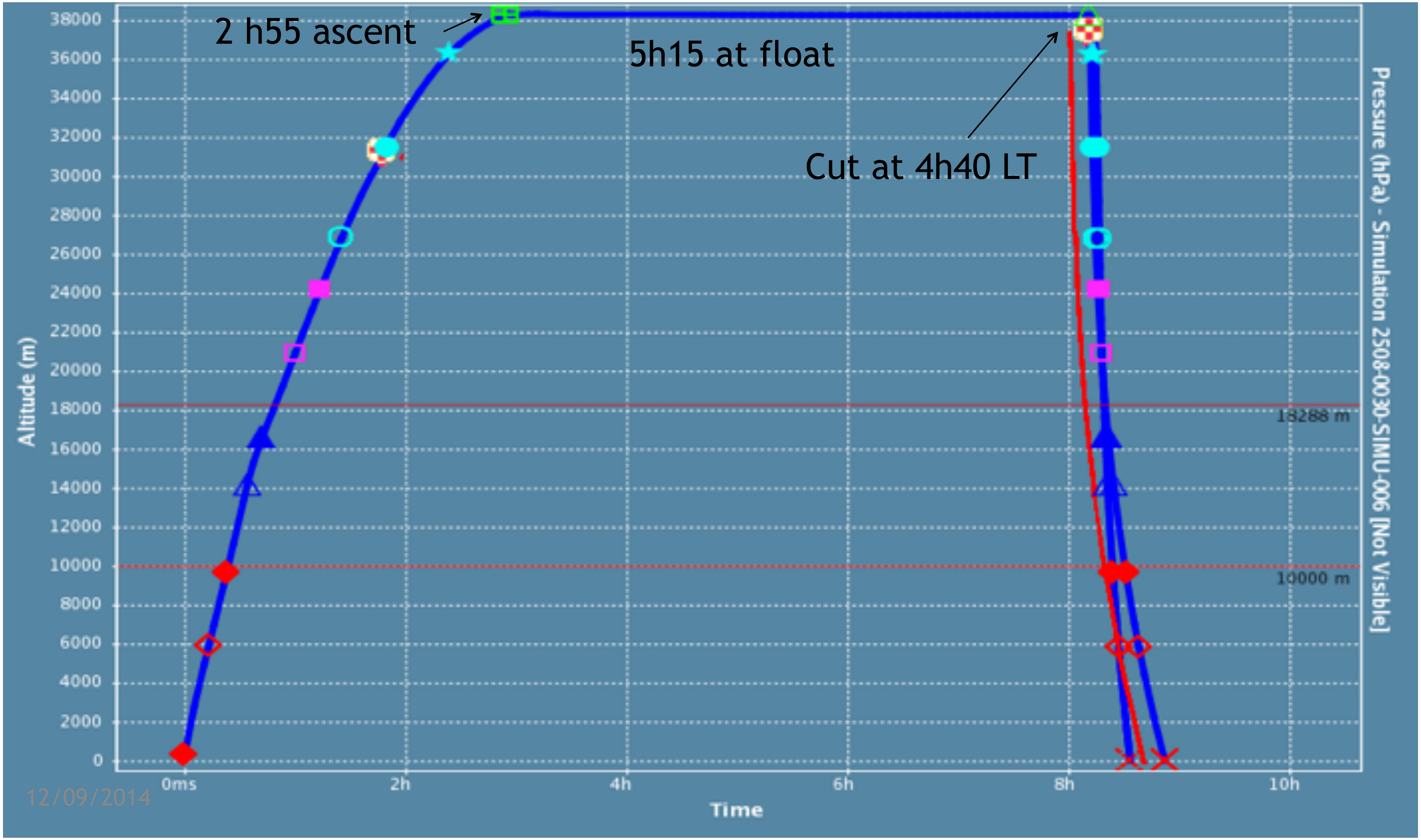
3 x 10^5 pixels



Detected photoelectrons are recorded every Gate Time Unit (GTU) of 2.5μs continuously.

Large tilting case (eg 45 deg)
Range: 450—2150 km; Area ~$9x10^5 km^2$
Duty cycle reduced
(both FOV & ISS should be in umbra)

Euso flight profile



Current Status

- Leading Observatories:
  - Pierre Auger Observatory: 3,000 km^2 Argentina
  - Telescope Array: 700 km^2 Utah, USA
- Agreement on the shape of the spectrum
- Energy scale: 10% difference bet. Auger and TA
- Composition: controversial(?)
- Anisotropies: hints above 60 EeV – no >5σ signal

- Need significant INCREASE in STATISTICS E > 60 EeV = EECR (extreme energy cosmic rays)

JEM-EUSO Aperture in nadir mode (standard configuration)