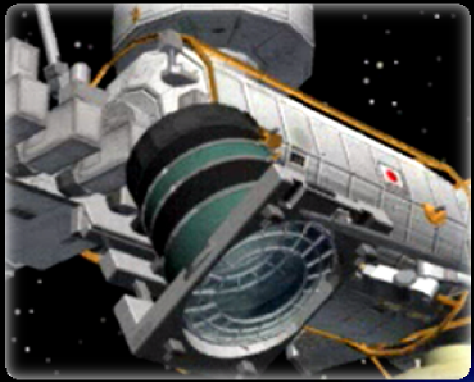


Extreme Universe Space Observatory

An overview of the JEM-EUSO Mission

Mario Bertaina

Torino University & INFN, Italy

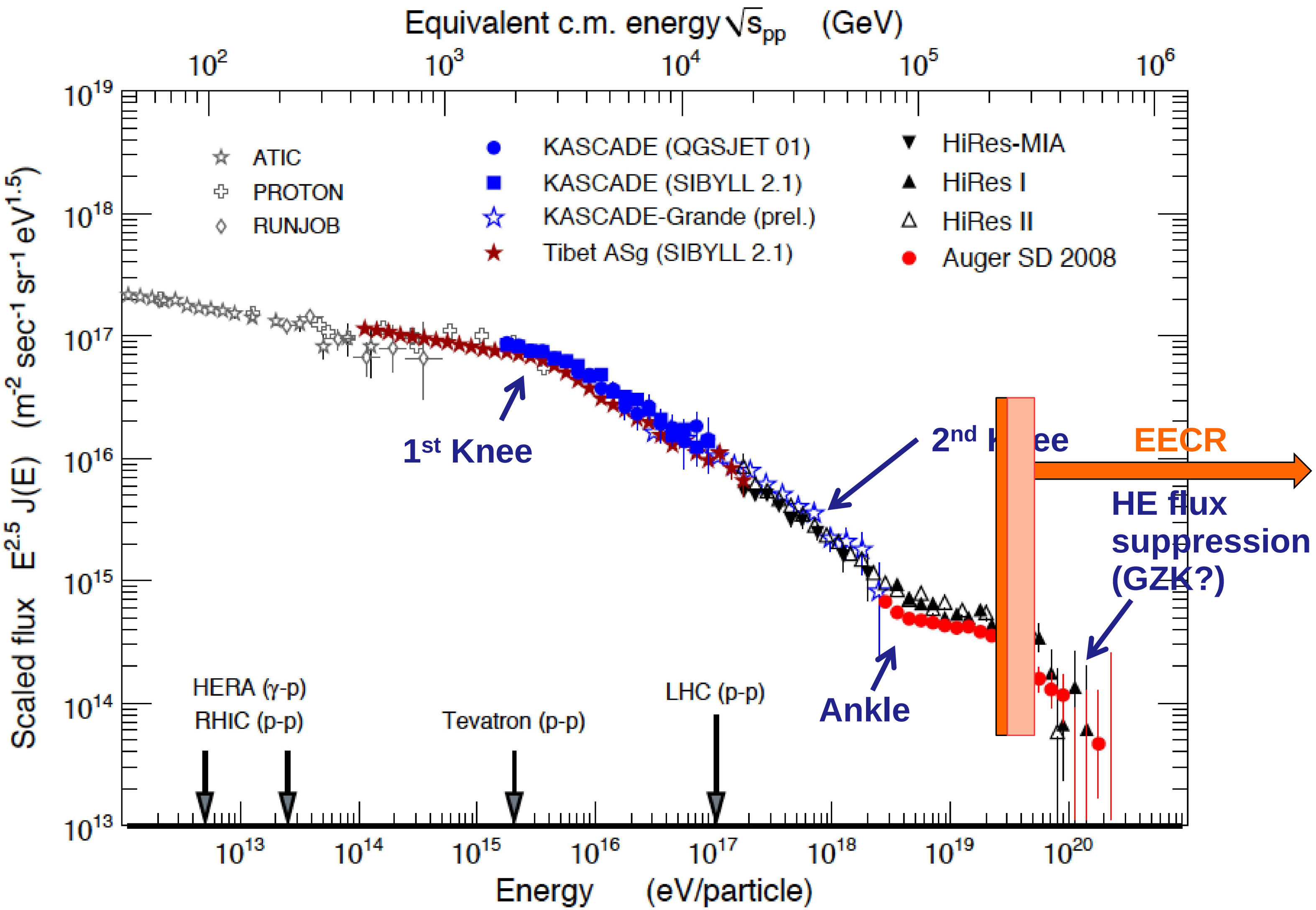
On behalf of the JEM-EUSO Collaboration

SciNeGHE 2012

Lecce, October 19-22, 2012

The Scientific Case

The Energy Spectrum



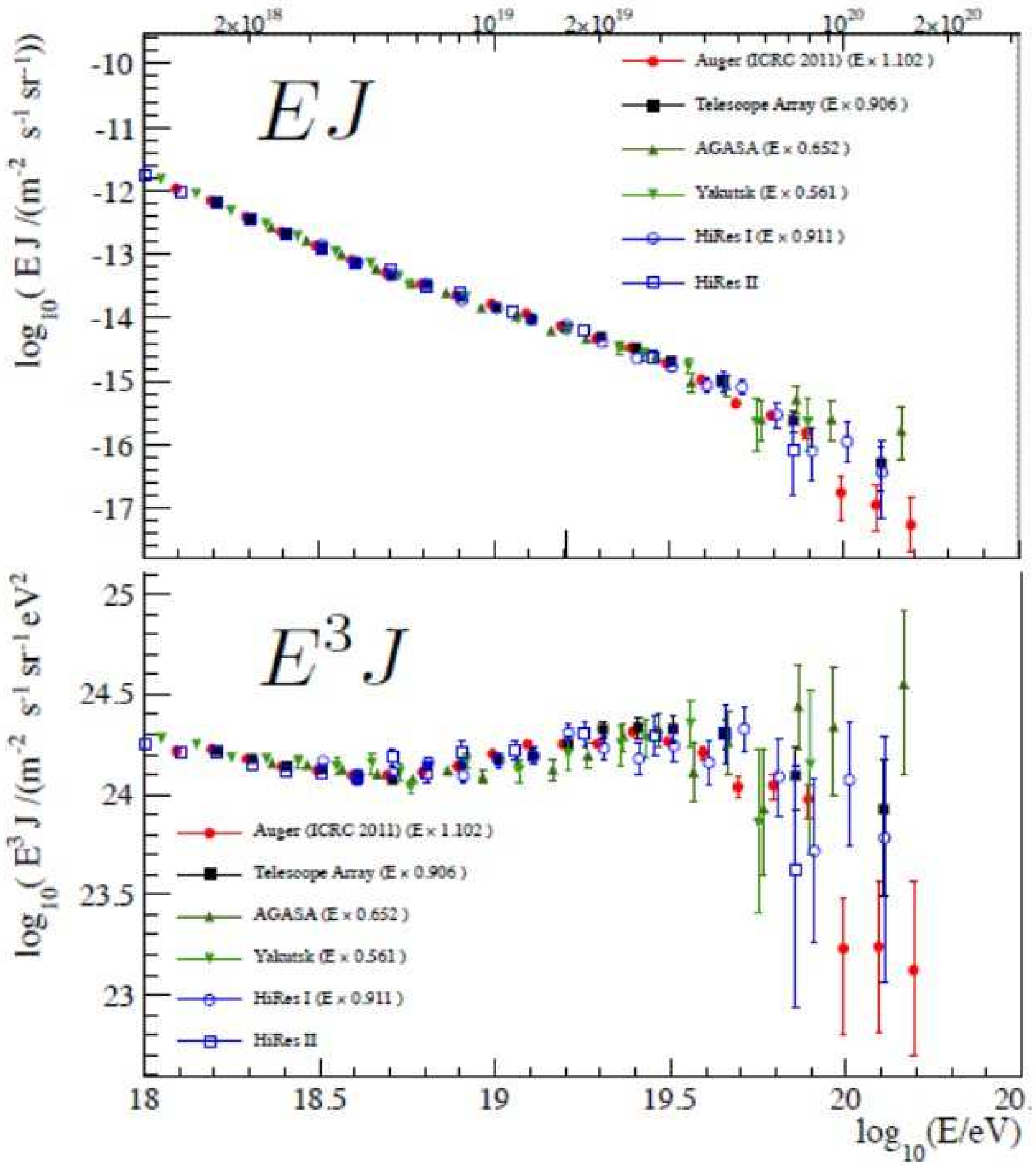
A key result of ground-based detectors

Energy Spectra

(after the scaling)

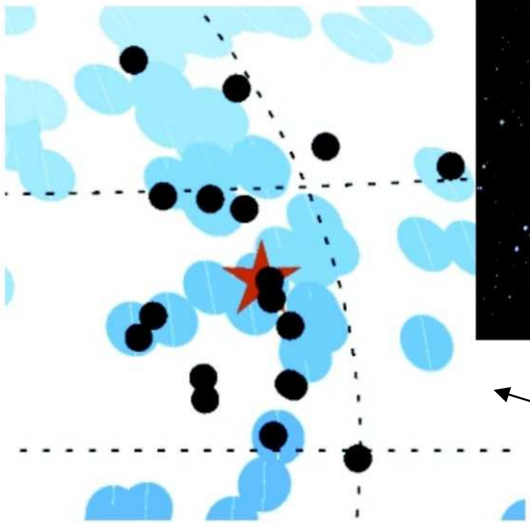
- We can find scaling factors to match the spectra: shape are similar (below log$E$=19.5)

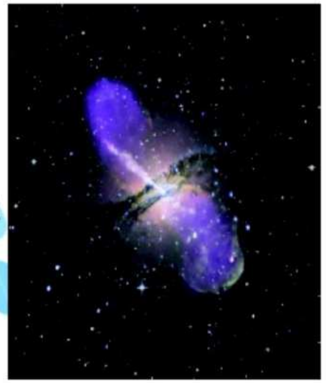
- Auger/HiRes/TA are in agreement well within the systematic uncertainties

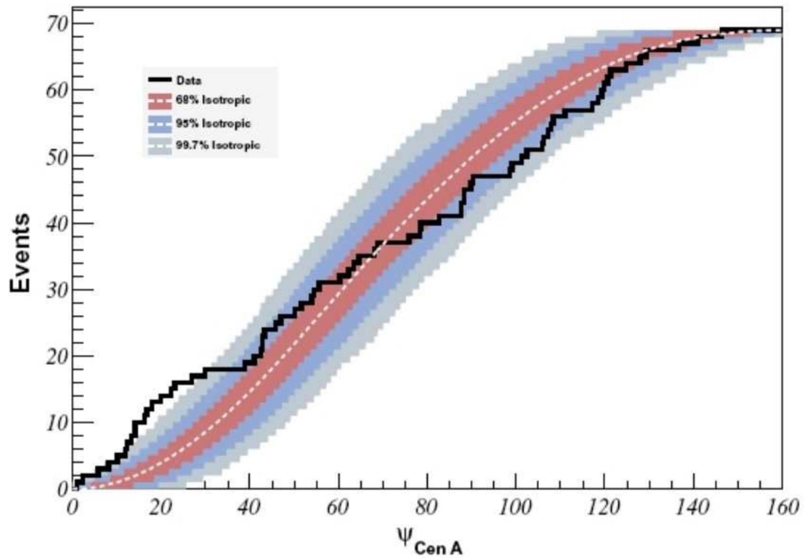


Tsunesada, UHECR 2012

UHERs from CenA?





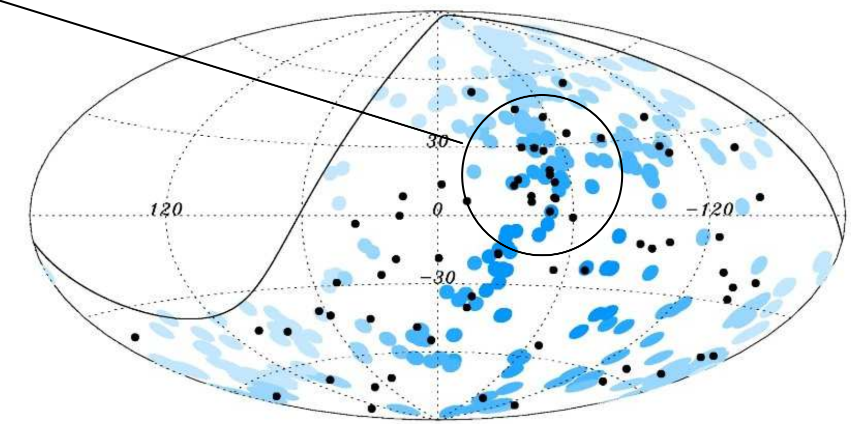


VCV Catalogue, E>57EeV, Z< 0.018, distance< 3.1°

13/62 within 18 deg., expect 3.2
limits on source composition?

E.M. Santos [Auger Coll.], icrc868

Auger



28 out of 84 correlate

Anisotropy

- No anisotropy established with certainty; however, various hints exist
- Expectations depend crucially on the actual mass composition of UHECR
- $O(10)$ increase in statistics, together with reasonable improvements in other parameters, is needed for definitive progress

... clarifying several aspects of the puzzle. Be patient.

Fukushima, UHECR 2012

UHECR status in just one word

Previous to Auger / HiRes :

$$\frac{1 \text{ particle}}{100\ km^2\ yr\ sr}$$

Key Auger / HiRes result:

$$\frac{1 \text{ particle}}{\not{100}\ km^2\ yr\ sr}$$

1000

A quantitative jump in exposure

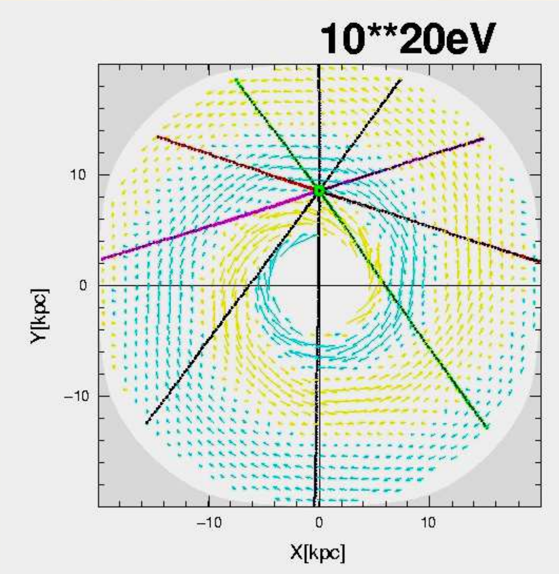
(orders of magnitude: e.g., $10^3 \rightarrow 10^5$ km^2 yr sr)

is needed to effectively open such an astronomical window @ E > 10^{20} eV

JEM EUSO:
AN OBSERVATORY
OF UHECRs FROM SPACE

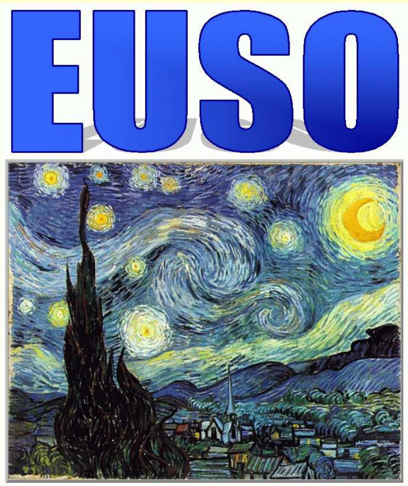
Instantaneous aperture: up to ~10^6 km^2 sr

Main Objective:
ASTRONOMY and ASTROPHYSICS THROUGH PARTICLE CHANNEL



An experimental pathfinder with outstanding scientific capability

The Extreme Universe Space Observatory on-board the Japan Experiment Module (JEM) of the ISS



2001- 2004

Heritage of the ESA EUSO study

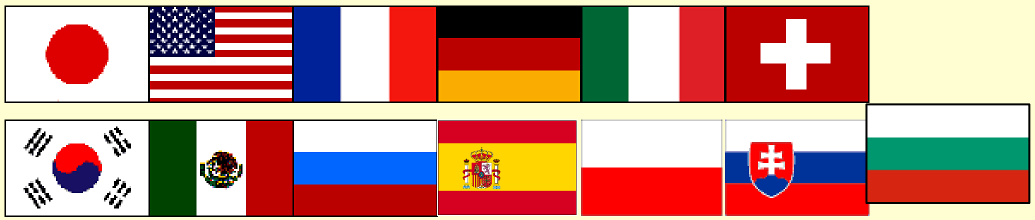
JEM EUSO Collaboration

•Japan, USA, Korea, Mexico, Russia

•Europe: Bulgaria, France, Germany, Italy, Poland, Slovakia, Spain, Switzerland

•13 Countries, 77 Institutions, more than 250 researchers

•RIKEN: Leading institution



Science Objectives

- **Main Objectives**：

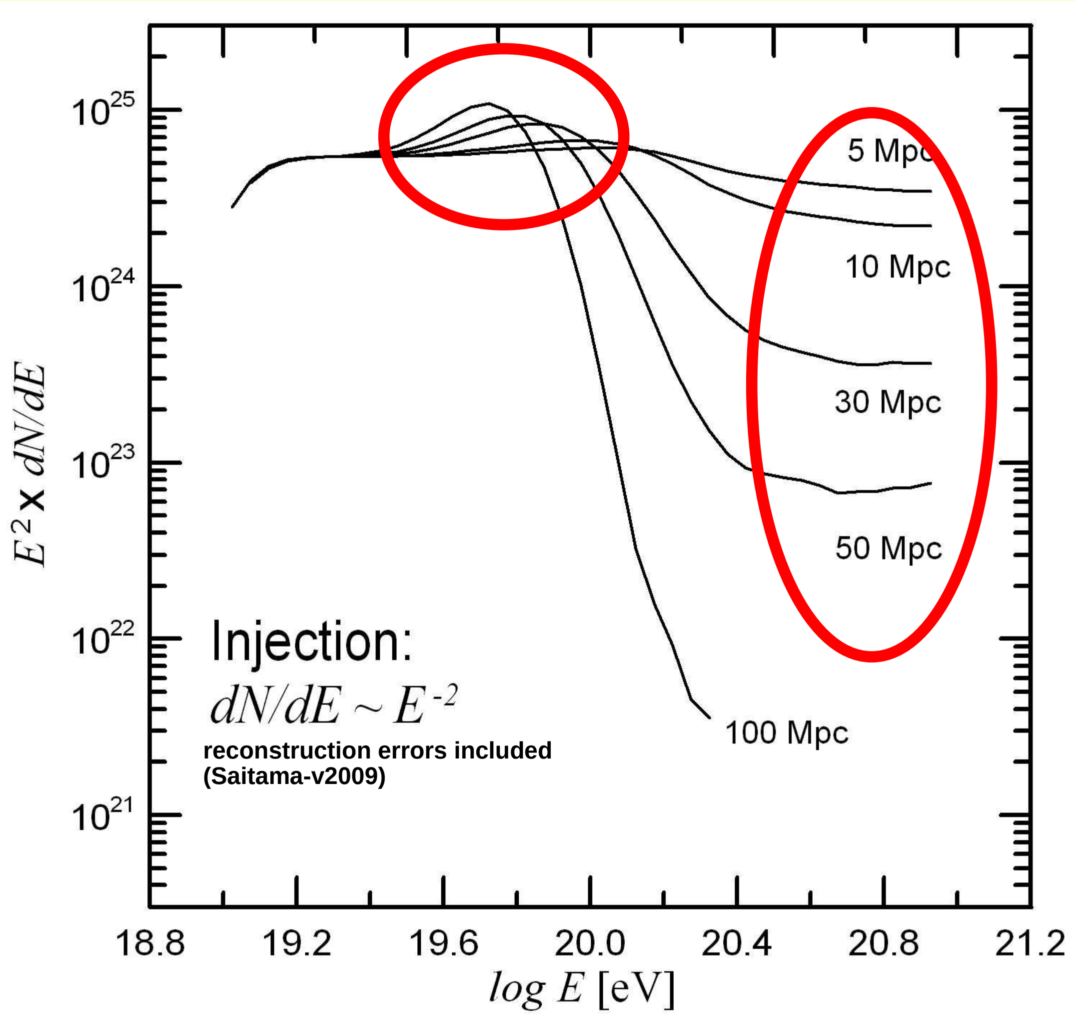
  Astronomy and astrophysics through particle channel with extreme energies > 5×10^{19} eV

  - Identification of individual **sources** with high statistics
  - Measurement of the **energy spectrum** of individual sources
  - Understanding of the acceleration processes and source dynamics

- **Exploratory objectives**：
  - Detection of extreme energy **neutrinos**
  - Measurement of extreme energy **gamma rays**
  - Study the intensity and topology of Galactic and extragalactic magnetic fields
  - Global observation of **atmospheric** phenomena: nightglows, lightning and plasma discharges

GZK flux-suppression – all sky spectrum

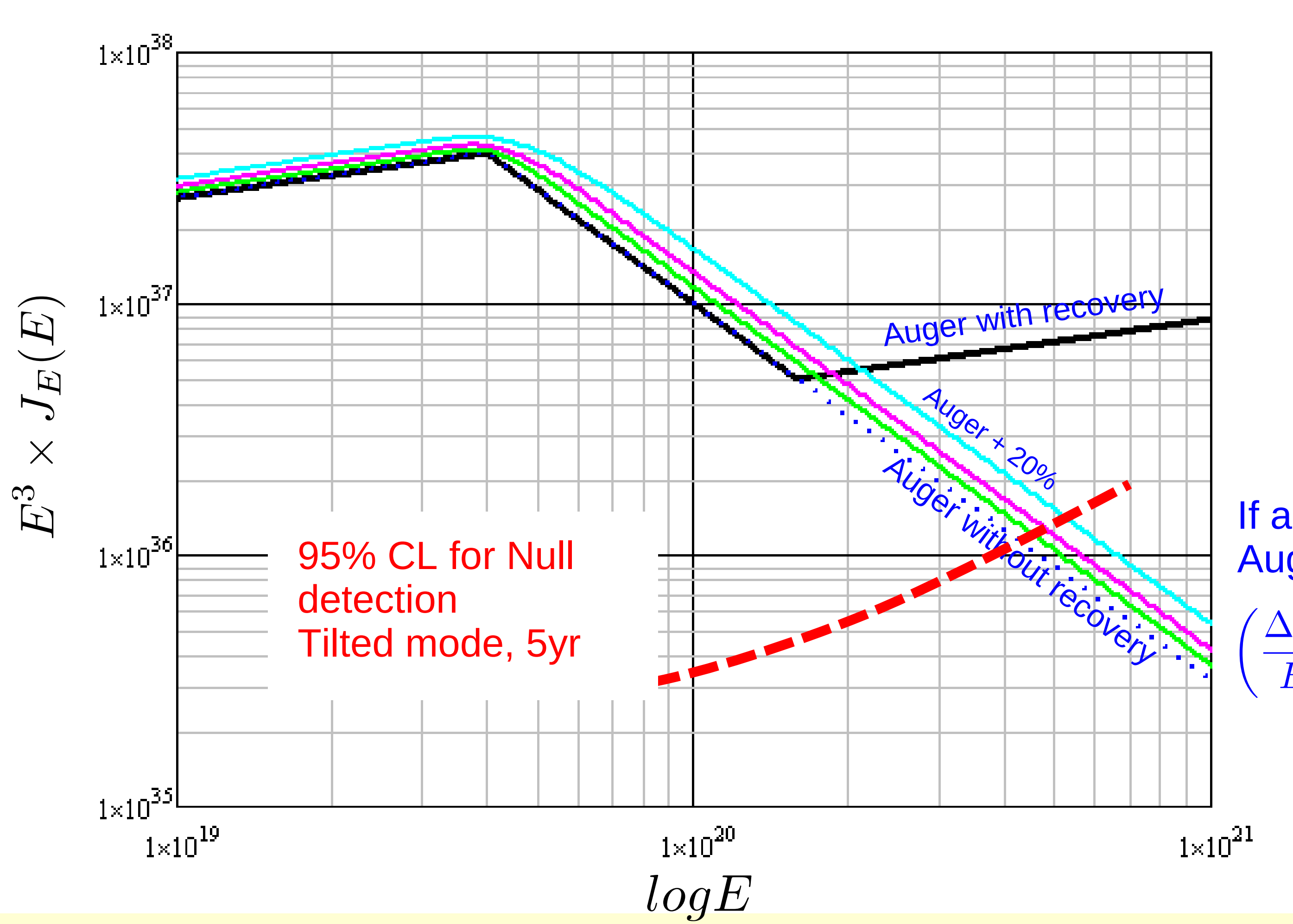
If there are UHECR **proton** sources at $D \leq D_{virgo}$ ➔ Recovery at $E_{rec} \sim 10^{20.2}$ eV



The flux-suppression may be a cut-off in acceleration rather than the result of propagation, either photo-pion production or photo-disintegration of heavy nuclei

In fact known astrophysical objects and bottom-up mechanisms apparently barely arrive at the maximum energies observed so far.

Recovery's detectability (exposure, ΔE/E & spillover)



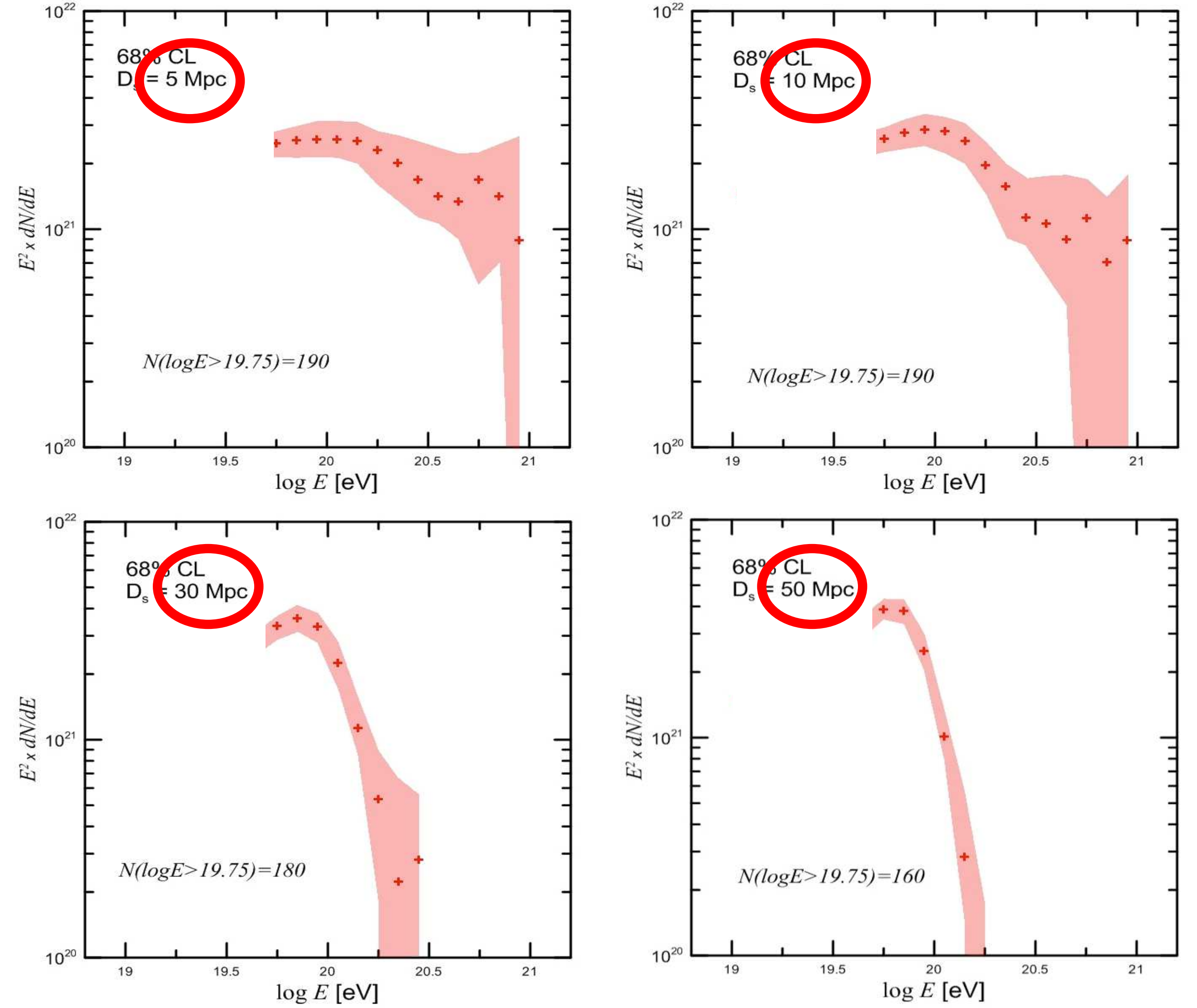
If actual spectrum were Auger without recovery

$$\left(\frac{\Delta E}{E}\right)_{EUSO} = 15, 20, 25\%$$

Spectra of individual sources (or unresolved source-regions)

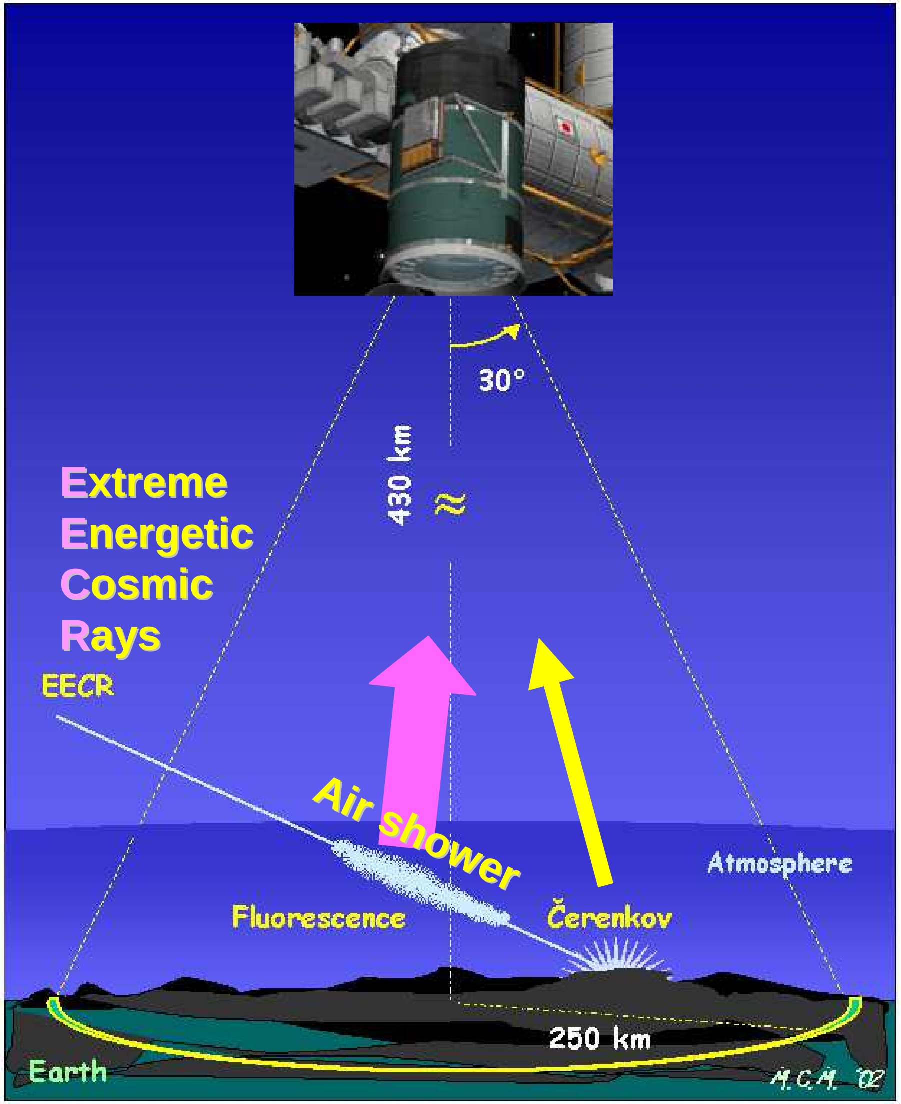
Simulated observed spectra of a point sources as a function of distance. The median and the upper and lower 68% CL are shown for each spectrum. All the hypothetical sources have approximately the same flux at Earth, which amounts to ***~ 160 to 190 events above 55 EeV****. If achieved in 5 yrs of operation of JEM-EUSO, such a flux would correspond to a collection rate at Auger of less than 4 events per year associated with each source. The injection spectrum at he source is* αE^{-2}*, an intergalactic magnetic field of 1 nG intensity and correlation length of ~1 Mpc is assumed, and the incoming events are selected with an appropriate trigger probability and their energies are convoluted with an energy and zenith dependent error. No reconstruction probability is applied, which would increasingly and considerably affect the lower energy portion (E<50 EeV) of all spectra.*

G. MEDINA-TANCO 2011



Based on Auger results, assume that correlation with source is traceable down to 55 EeV

JEM-EUSO Observational Principle



JEM-EUSO is a new type of observatory on board the International Space Station (ISS), which observes transient luminous phenomena occurring in the Earth's atmosphere.

The telescope has a super wide field-of-view (60°) and a large diameter (2.5m).

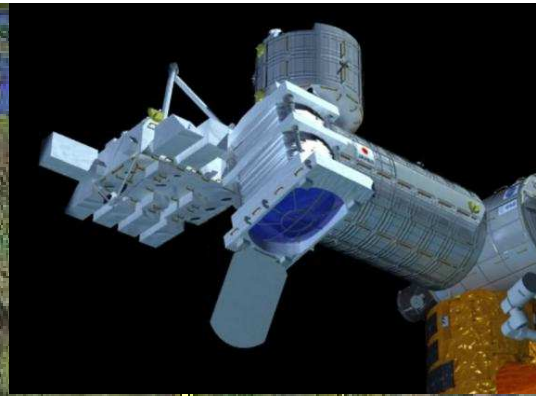
JEM-EUSO mission will initiate particle astronomy at ~10^{20}eV.

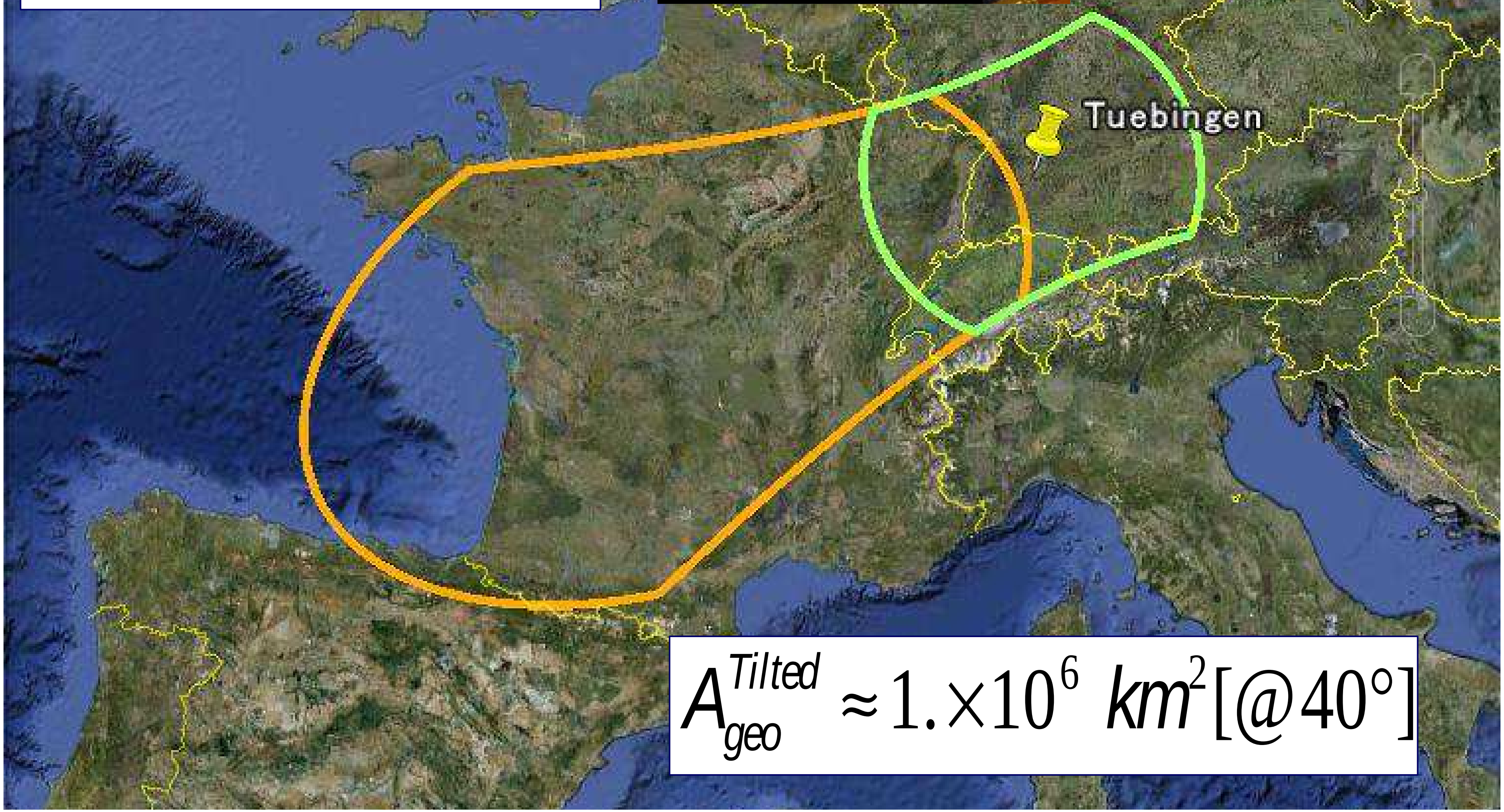
JEM-EUSO telescope observes fluorescence and Cherenkov photons generated by air showers created by extreme energetic cosmic rays

Two advantages:

1. Monitored area

$$A_{geo}^{Nadir} \approx 1.3 \times 10^{5}\ km^{2}$$

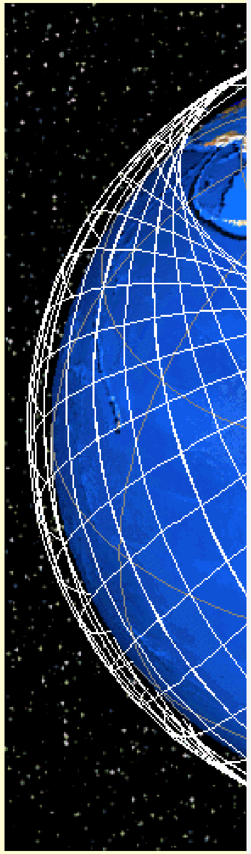


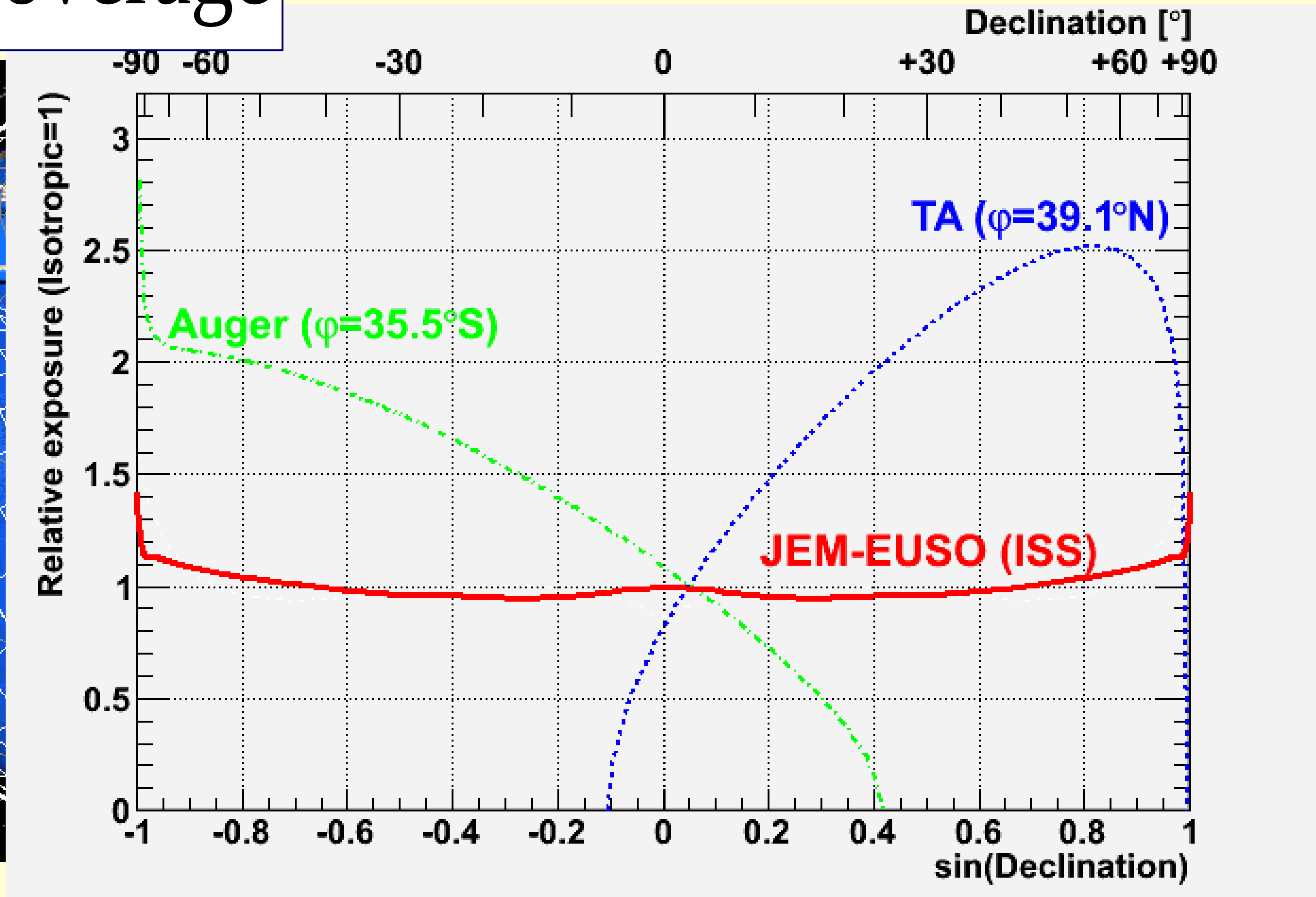


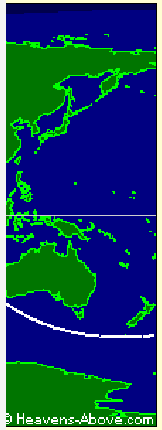
$$A_{geo}^{Tilted} \approx 1. \times 10^{6}\ km^{2} [@40°]$$

2. ISS Orbit → Full sky Coverage…

4π coverage



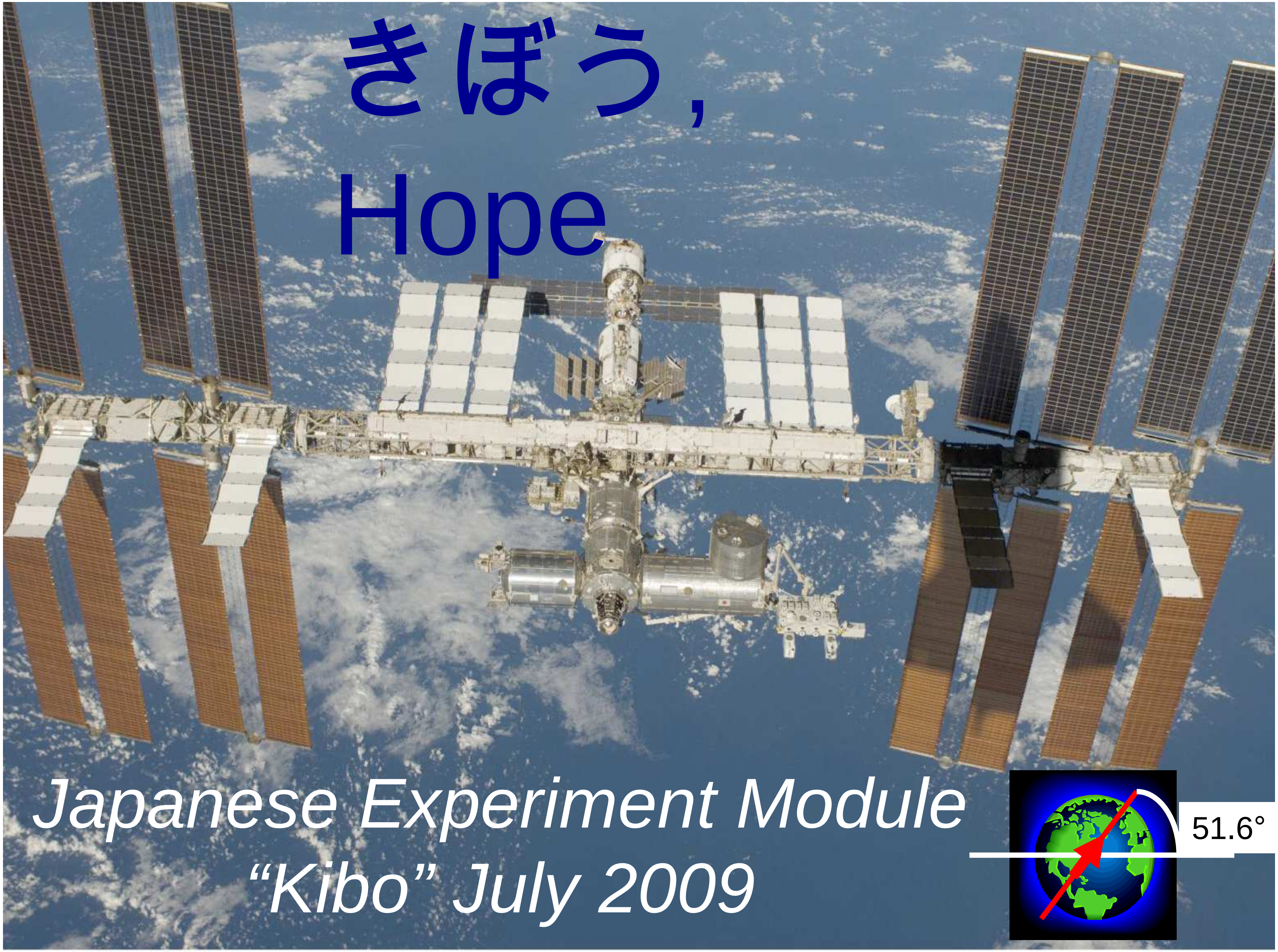




… and uniform exposure

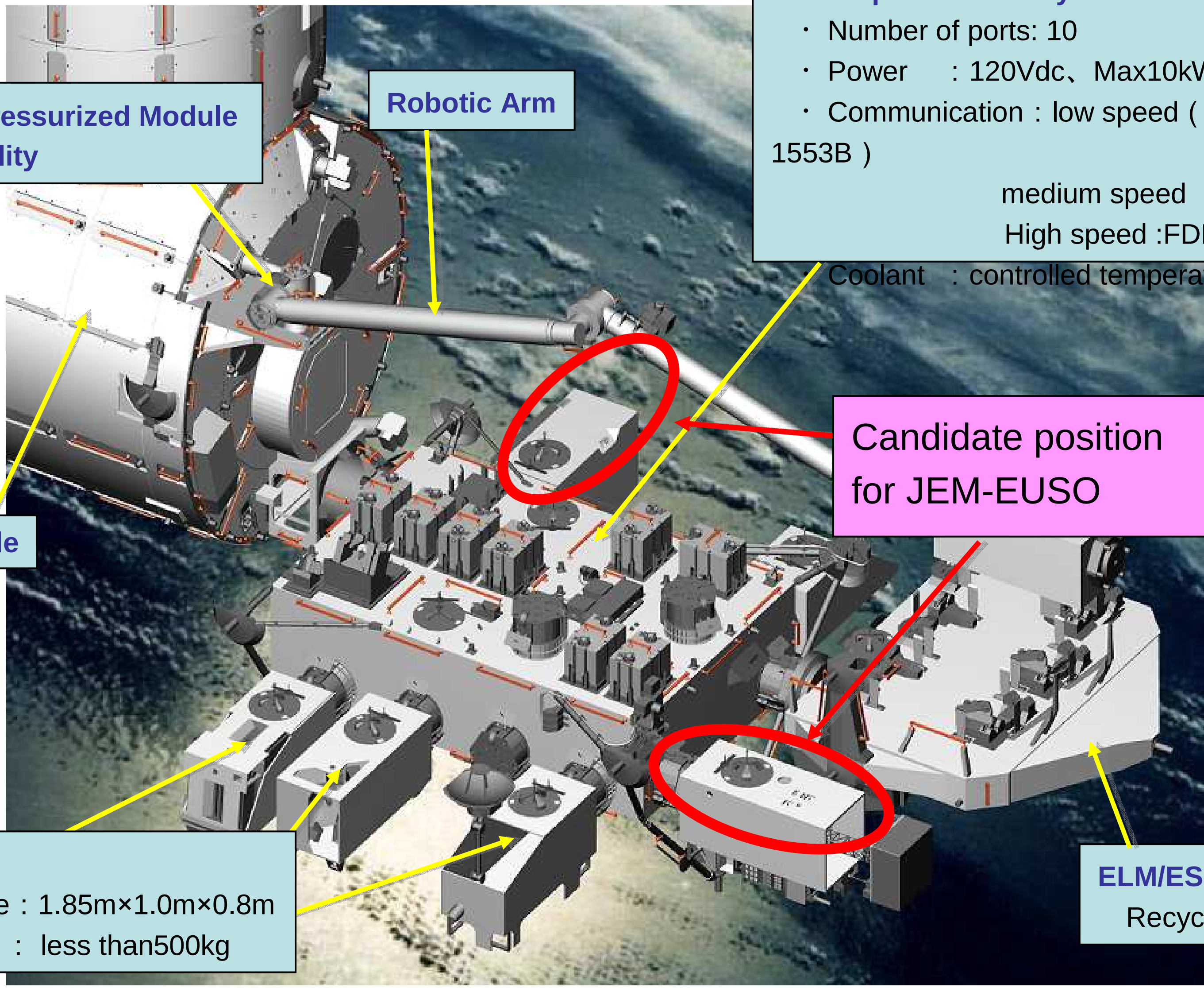
The Mission

きぼう, Hope



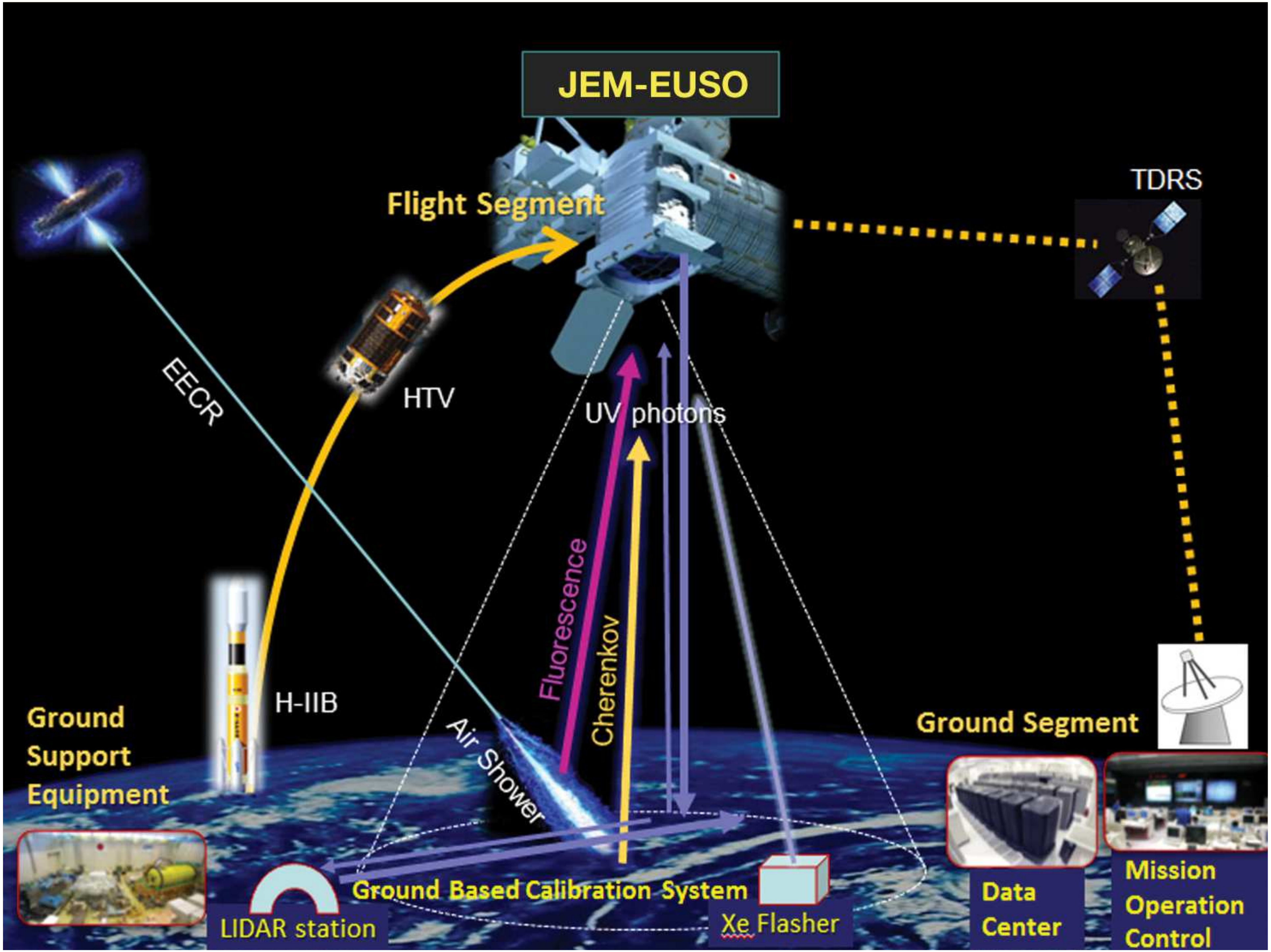
Japanese Experiment Module
“Kibo” July 2009

Outline of JEM Exposure Facility
Japanese Experiment Module “KIBO”



Mission aspects have been successfully studied by JAXA and RIKEN

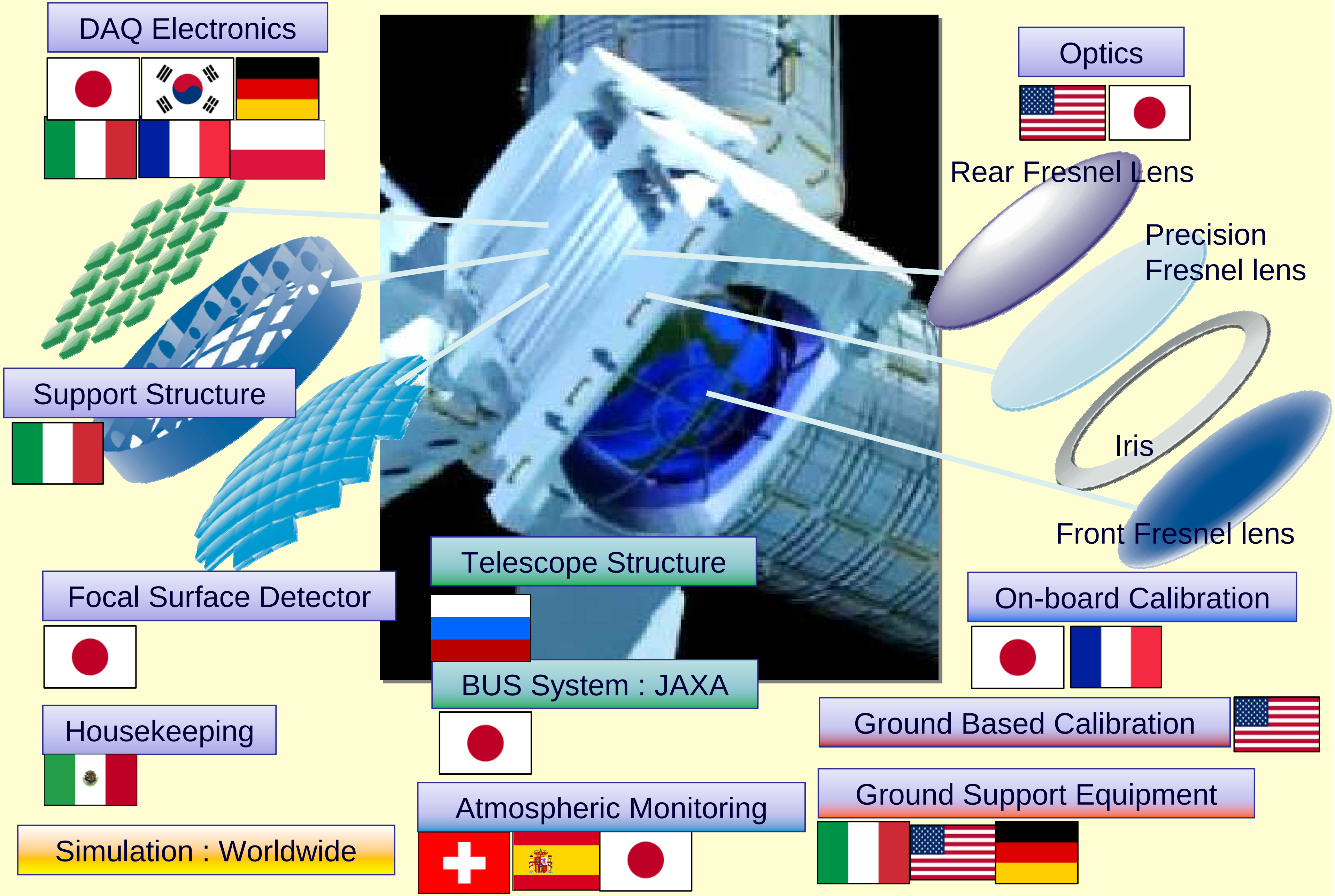
Parameter	Value
Launch date	JFY 2016
Mission Lifetime	3+2 years
Rocket	H2B
Transport Vehicle	HTV
Accommodation on JEM	EF#2
Mass	1938 kg
Power	926 W (op.) 352 W (non op.)
Data rate	285 kbps (+ on board storage)
Orbit	400 km
Inclination of the Orbit	51.6°
Operation Temperature	-10° to +50°



JEM-EUSO
Flight Segment
TDRS
EECR
HTV
UV photons
Fluorescence
Cherenkov
H-IIB
Air Shower
Ground Support Equipment
Ground Segment
Ground Based Calibration System
LIDAR station
Xe Flasher
Data Center
Mission Operation Control

The Instrument

International Role Sharing

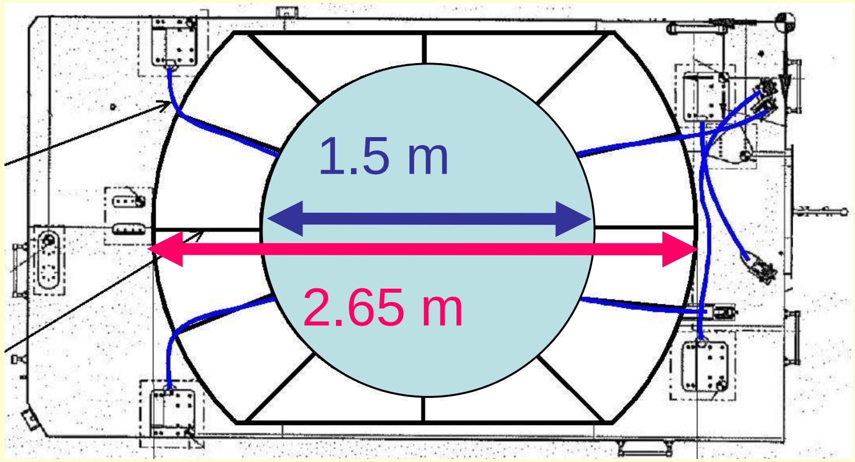


The UV Telescope Parameters

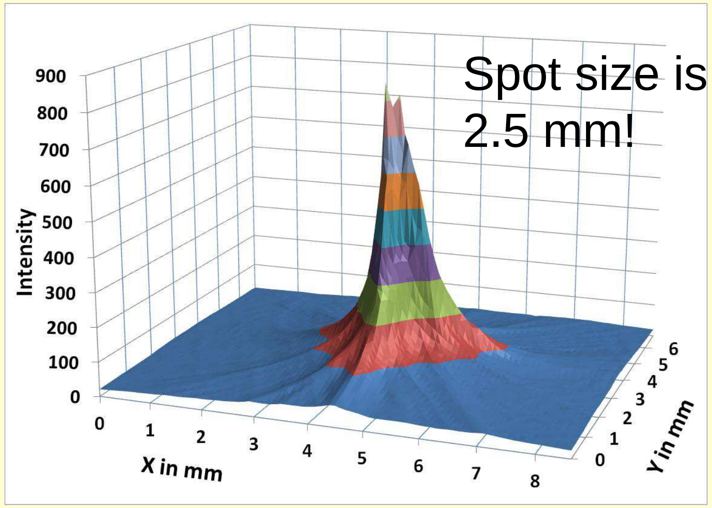
Parameter	Value
Field of View	±30°
Monitored Area	>1.3×10^{5}km^2
Telescope aperture	≥2.5 m
Operational wavelength	300-400 nm
Resolution in angle	0.075°
Focal Plane Area	4.5 m^2 +
Pixel Size	<3 mm
Number of Pixels	≈3×10^5
Pixel size on ground	≈560 m
Time Resolution	2.5 μs
Dead Time	<3% +
Detection Efficiency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

+ Optics Throughput

BBM of the Optics (Prototypes)

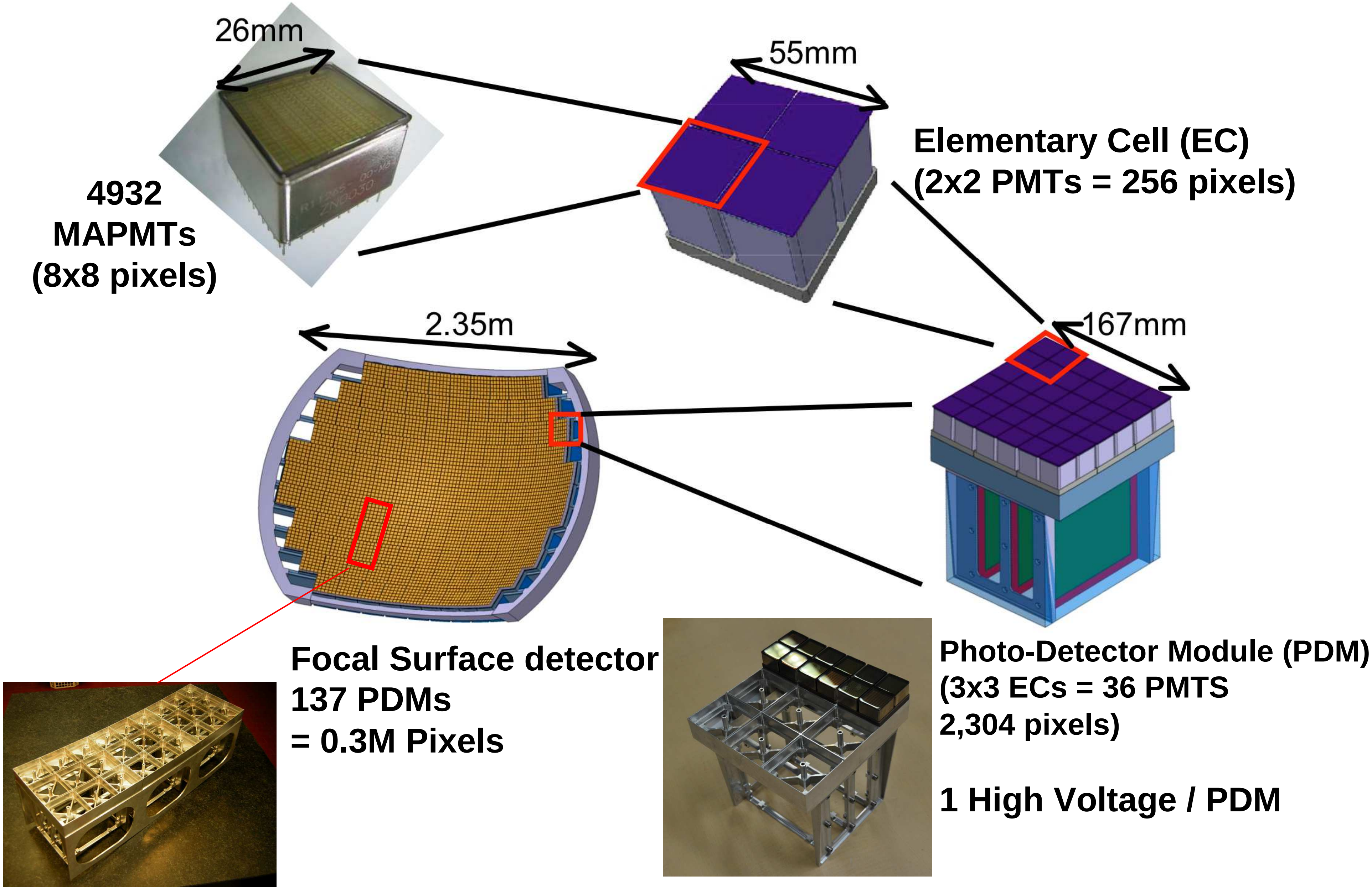


large diameter Fresnel lenses manufactured in Japan and tested in the US at the University of Alabama (Huntsville) and at MSFC (NASA)



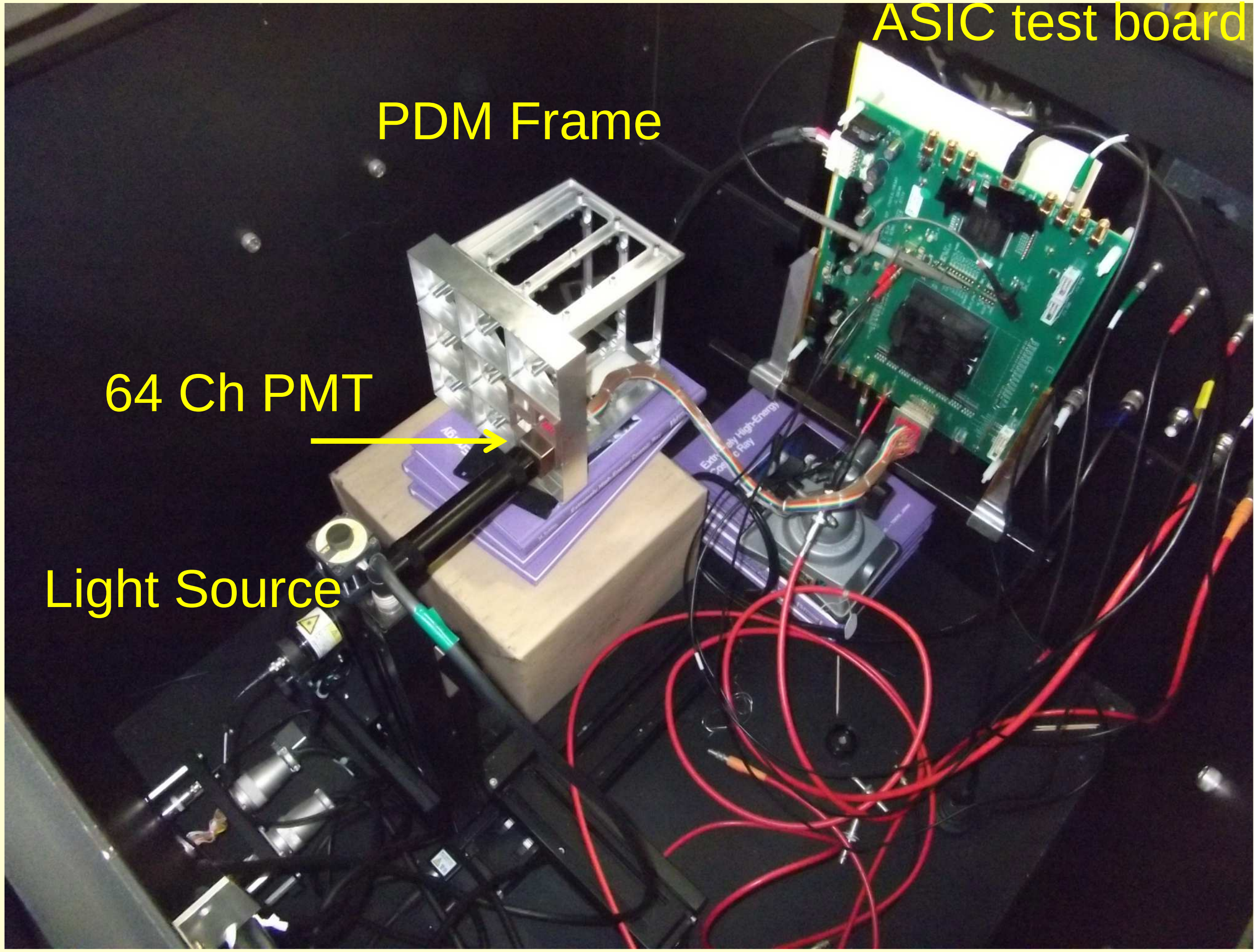
Tested performances meet already the requirements (or are close to it)

Focal Surface Detector



Detector and electronics

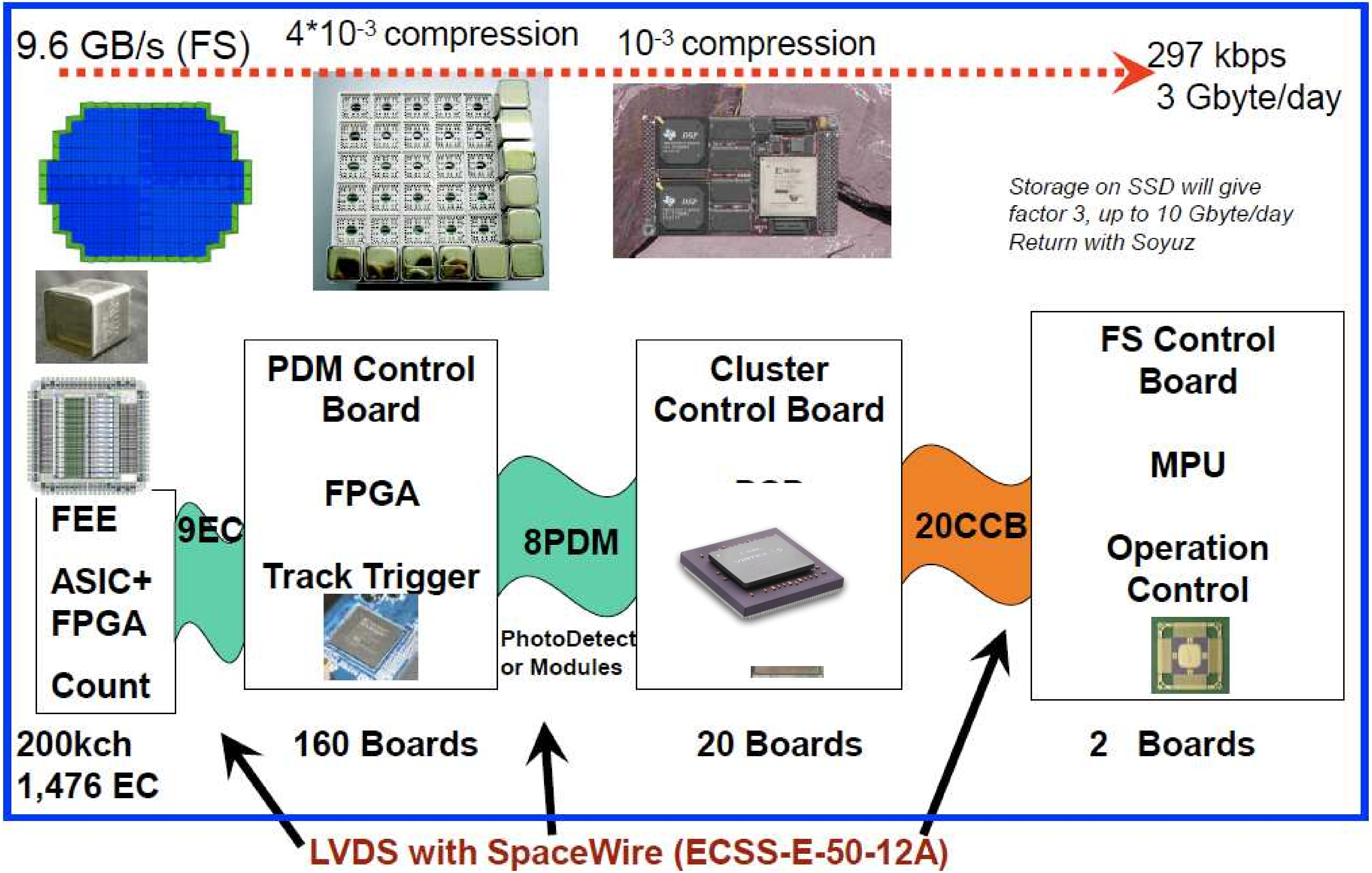
- MAPMT-64
- ASIC *Spaciroc*
- *Electronic Cell* Board
- 137 PDM *1st trigger and readout*
- CCB *2nd trigger*



From 9.6 GB/s to 3 GB/day on the entire FS

PDM Bread board model integrated at RIKEN

JEM-EUSO DAQ – Data reduction block scheme



Atmospheric Monitoring System

- IR Camera

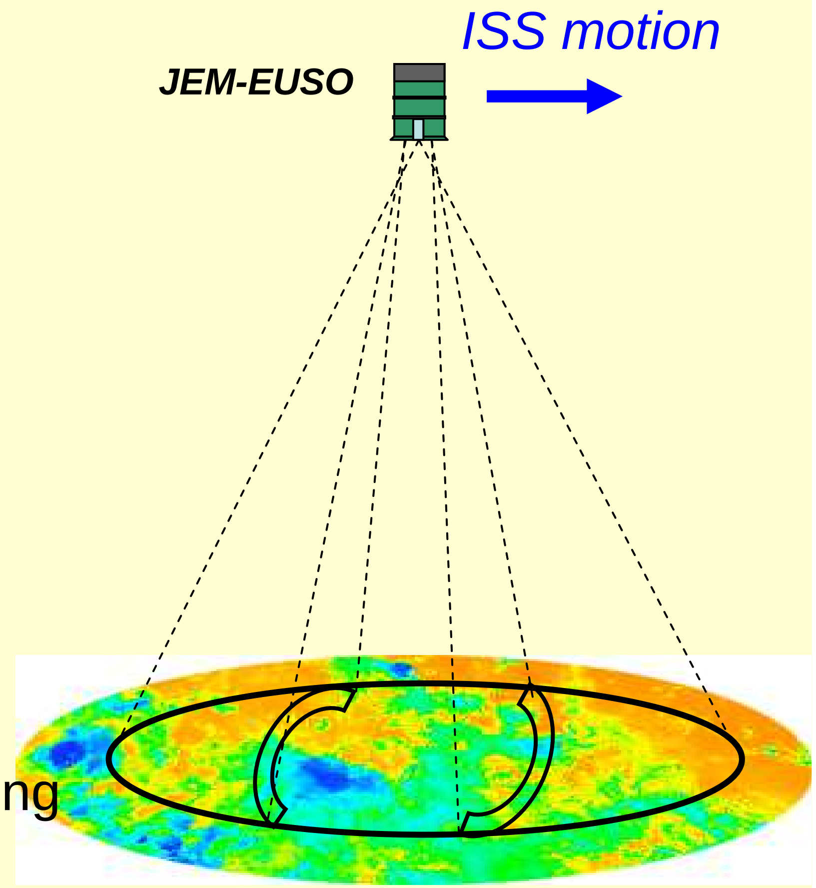
  Imaging observation of cloud temperature inside FOV of JEM-EUSO

- Lidar

  Ranging observation using UV laser

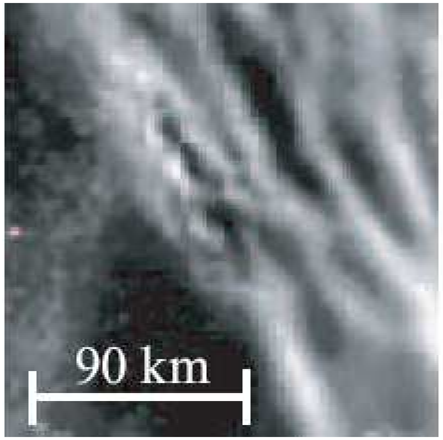
- JEM-EUSO "slow-data"

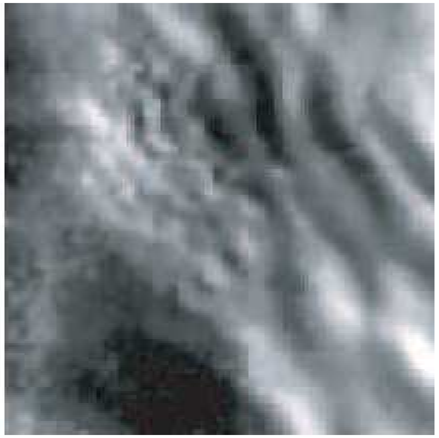
  Continuous background photon counting



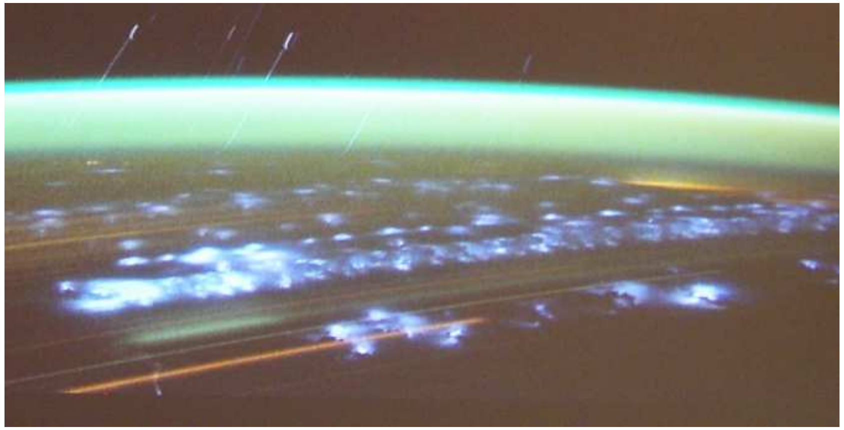
- *Cloud amount, cloud top altitude*: (IR cam., Lidar, slow-data)
- *Airglow* : (slow-data)
- *Calibration of telescope* : (Lidar)

Atmospheric Luminous Phenomena



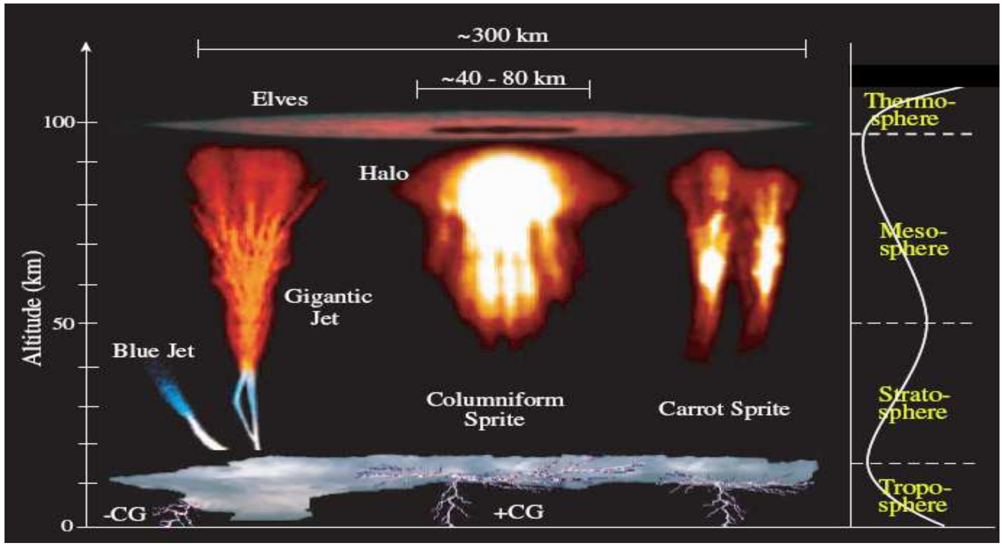


OH airglow observed from ground



Lightning picture observed from ISS

Leonid meteor swarm in 2001 taken by Hivison



Various transient airglows

The Performance

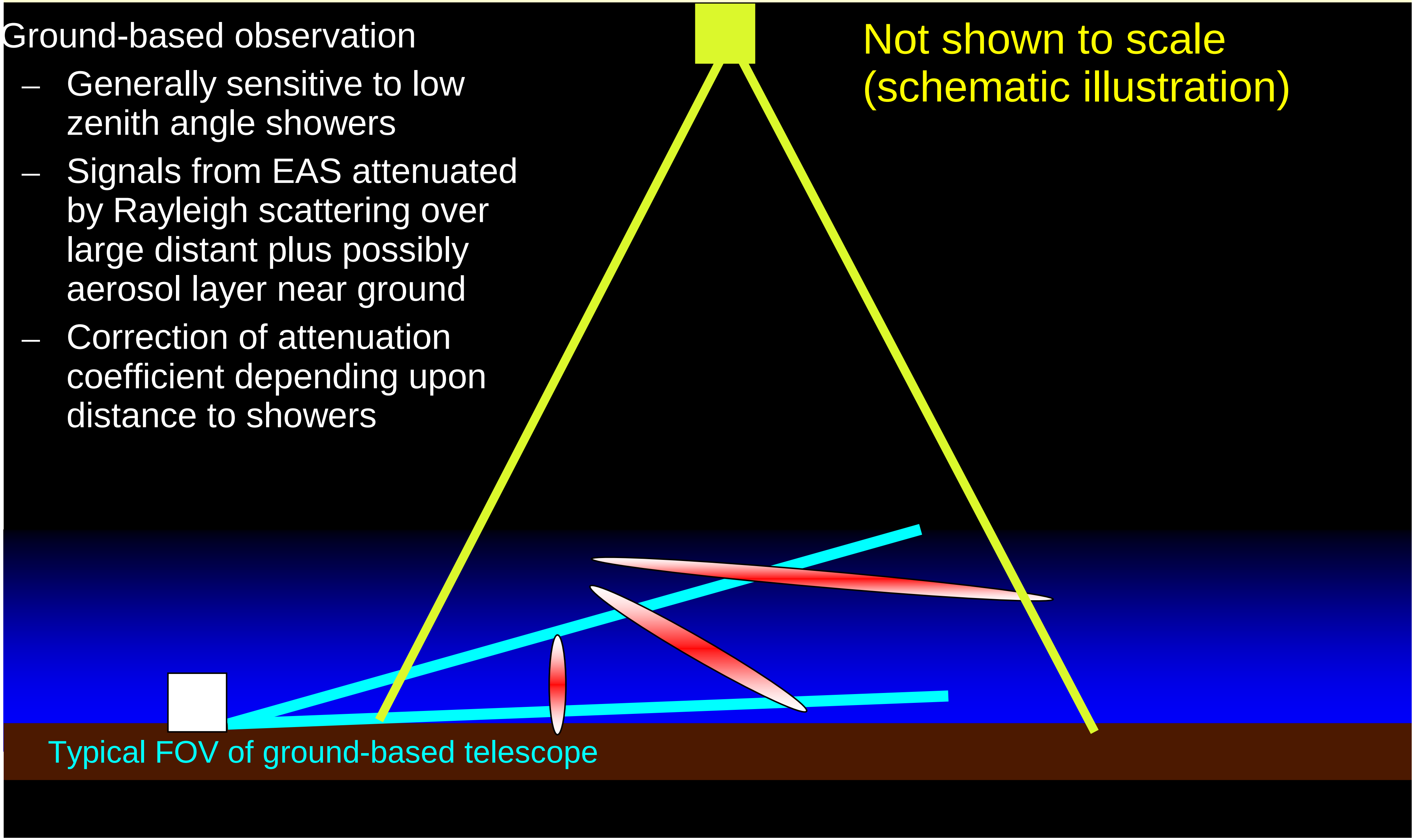
Peculiarities from space

- *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

Comparison to ground-based observation

Ground-based observation

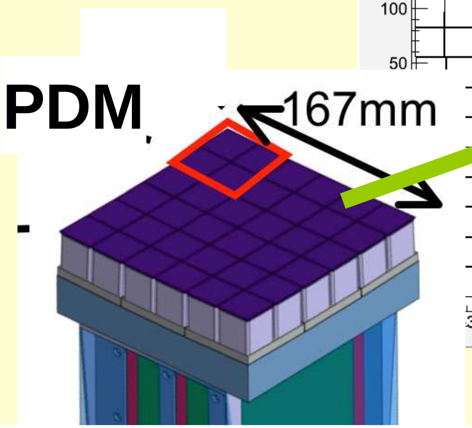
- Generally sensitive to low zenith angle showers
- Signals from EAS attenuated by Rayleigh scattering over large distant plus possibly aerosol layer near ground
- Correction of attenuation coefficient depending upon distance to showers

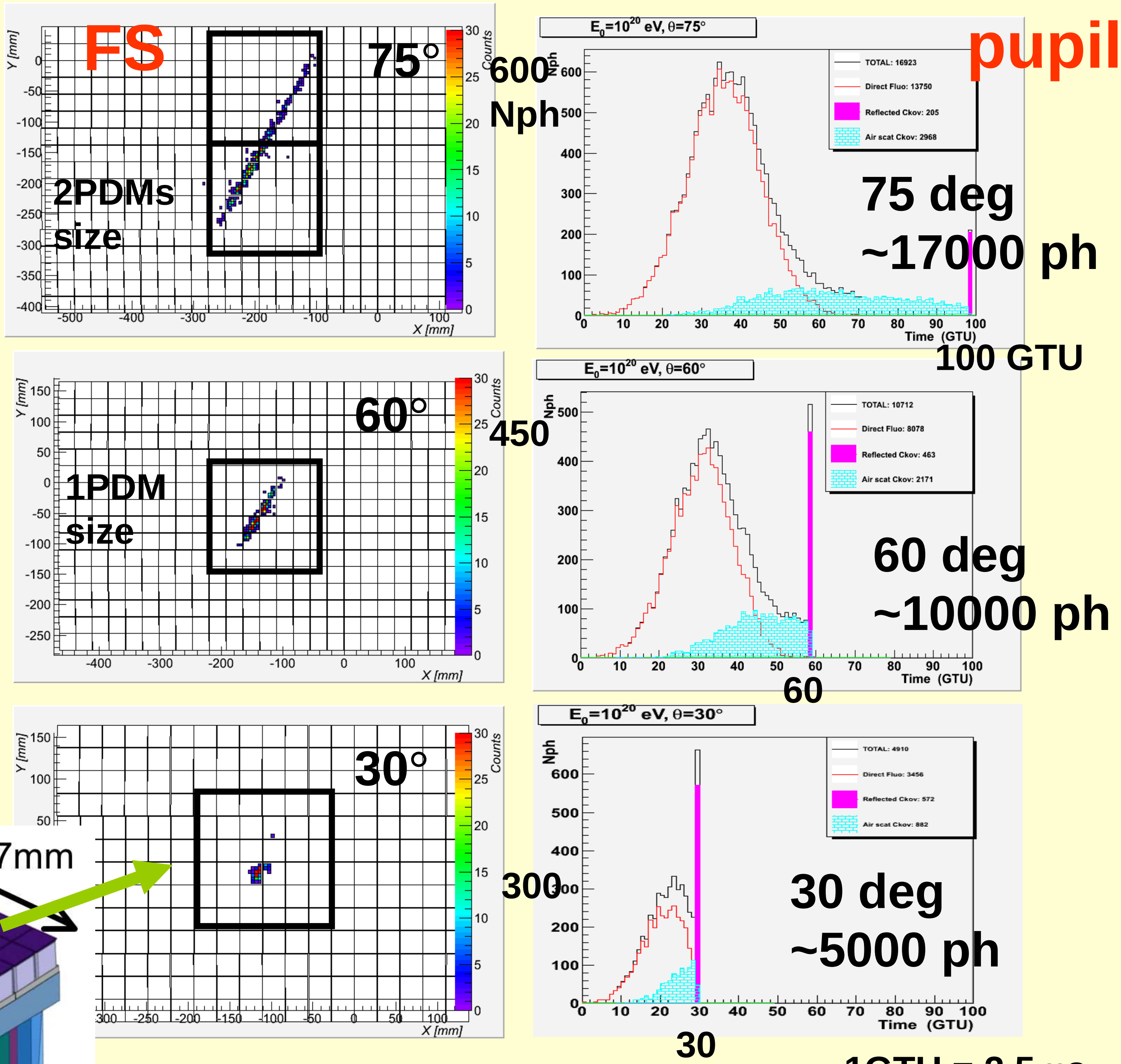


Proton
E=10^{20}eV

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

137 PDMs on FS





1GTU = 2.5 μs

Which is the annual exposure?

- Of course it depends on the zenith angle and energy…
- It is determined by three factors:

$$TA \times \eta \times \kappa$$

$TA \rightarrow Trigger\ Aperture$ *Determined by the trigger efficiency*

$\eta \rightarrow duty\ cycle$ *Determined by the background (and operation)*

$\kappa \rightarrow cloud\ impact$ *Determined by the cloud coverage*

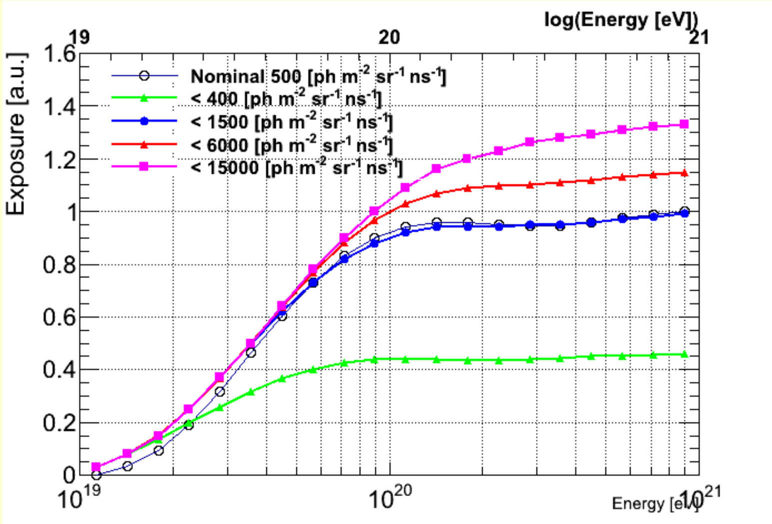
P.Bobik et al., ID886

Solar zenith angle (deg.)	Duty cycle (%)
108	22.2
109	22.1
110	21.9
111	21.7
112	21.5
113	21.3
114	21.0
115	20.6
116	20.3
117	19.9
118	19.5
119	19.0
120	18.4

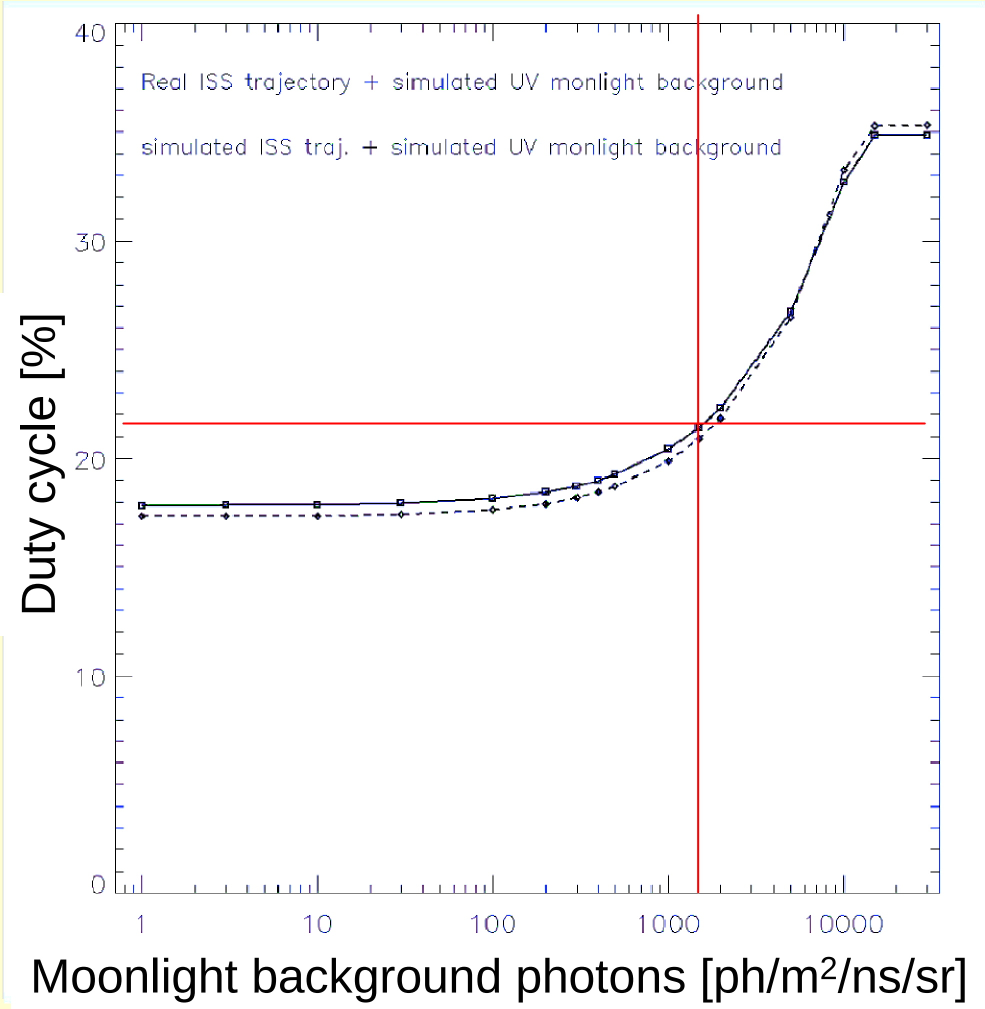
Based on Tatiana data

Duty cycle (2)

Note that: Selecting bckg < 1500 photons/(m^2 ns sr) with its relative occurrence gives a trigger efficiency curve equivalent to an average bckg of 500 photons/(m^2 ns sr)



Duty cycle: EUSO old estimate

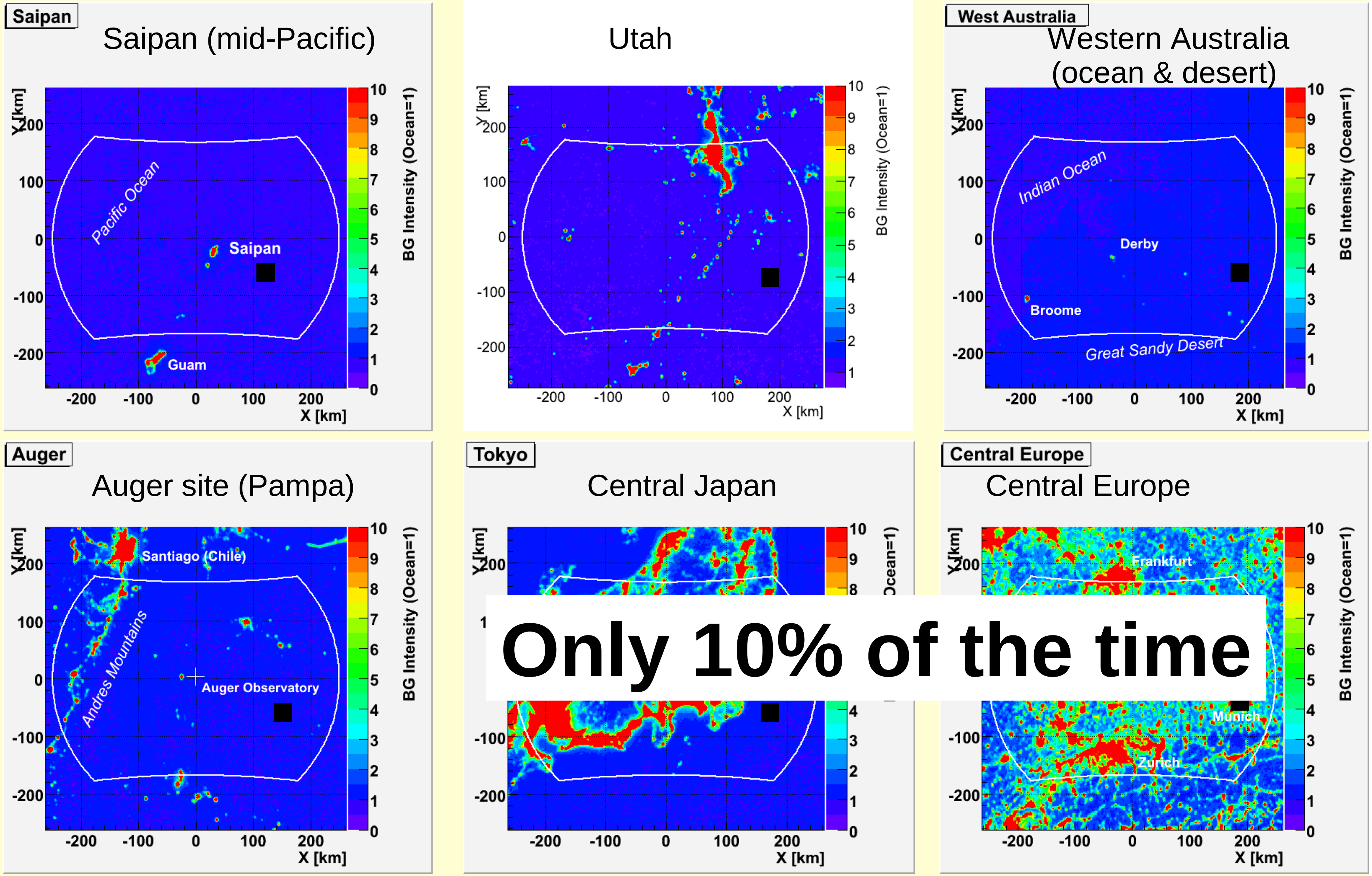


C. Berat et al. 2003

F. Montanet et al. 2004

Independent estimate

All these results are in very good agreement with and actually better than *the conservative value* assumed by the JEM-EUSO consortium: *20%*

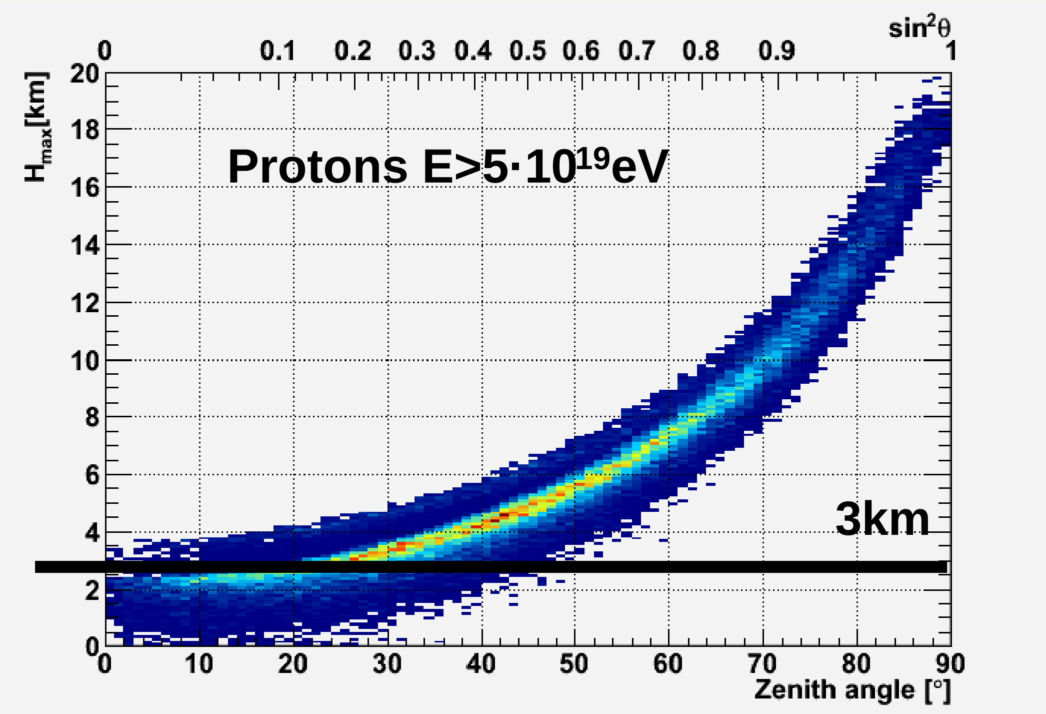


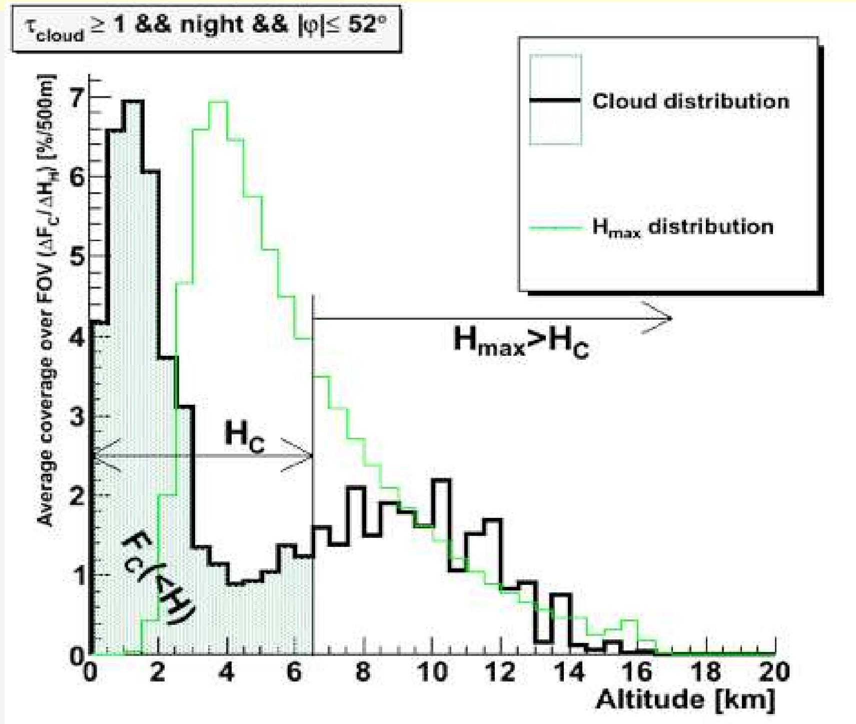
FoV of 1 PDM (27km x 27 km) ■

BG Ocean = 1 = 500 ph/m²/ns/sr

In the city impact we assumed that 1 PDM is blind if 1 km x 1km area sees $I > I_o$

Cloud impact & shower maximum





- Large ZA EAS has limited cloud impact

Cloud Coverage

Clear sky ~ 29%
Green band ~ 60%

Cloud top

F.Garino et al., ID398

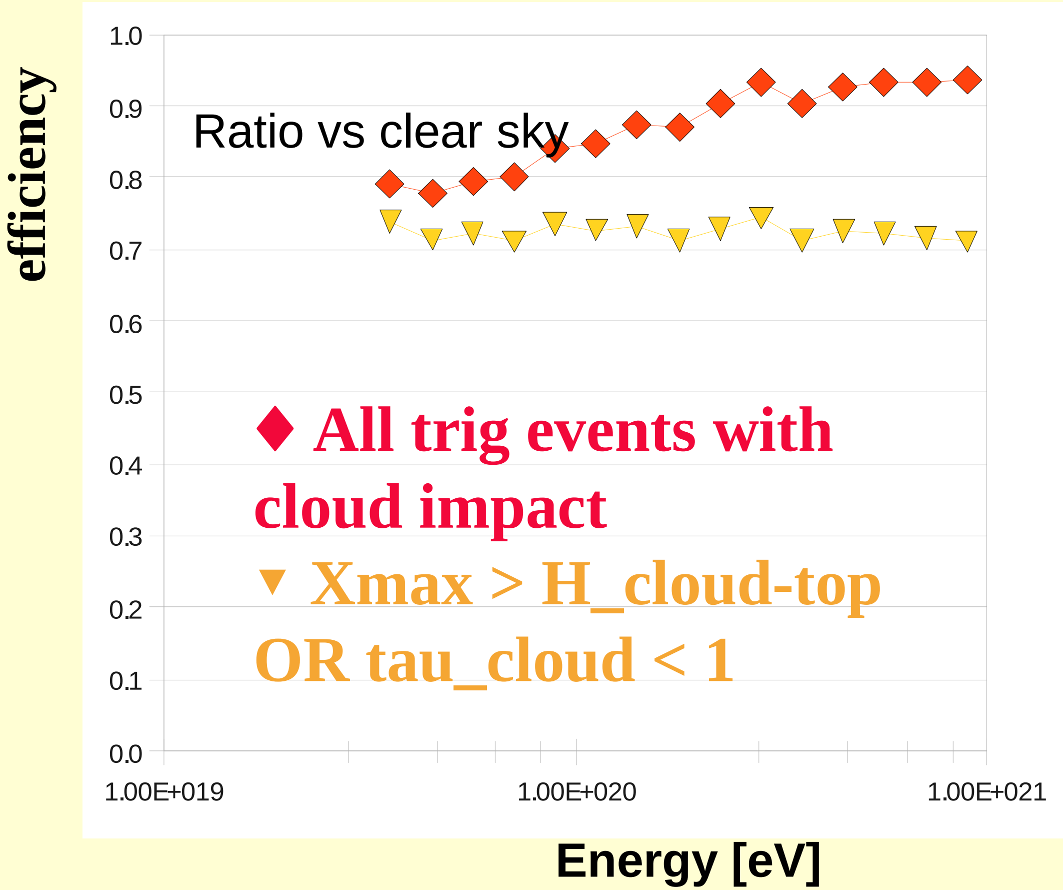
Optical Depth	<3 km	3-7 km	7-10 km	>10 km
OD>2	17.2	5.2	6.4	6.1
OD:1-2	5.9	2.9	3.5	3.1
OD:0.1-1	6.4	2.4	3.7	6.8
OD<0.1	29.2	<0.1	<0.1	1.2

Occurence of clouds (in %) between 50° N and 50° S on TOVS database. The matrix Optical depth vs. Cloud-top altitude is shown.

Confirmed by ISCCP,CACOLO & MERIS database

L.Saez et al., ID1034,

K.Shinozaki et al. ID979

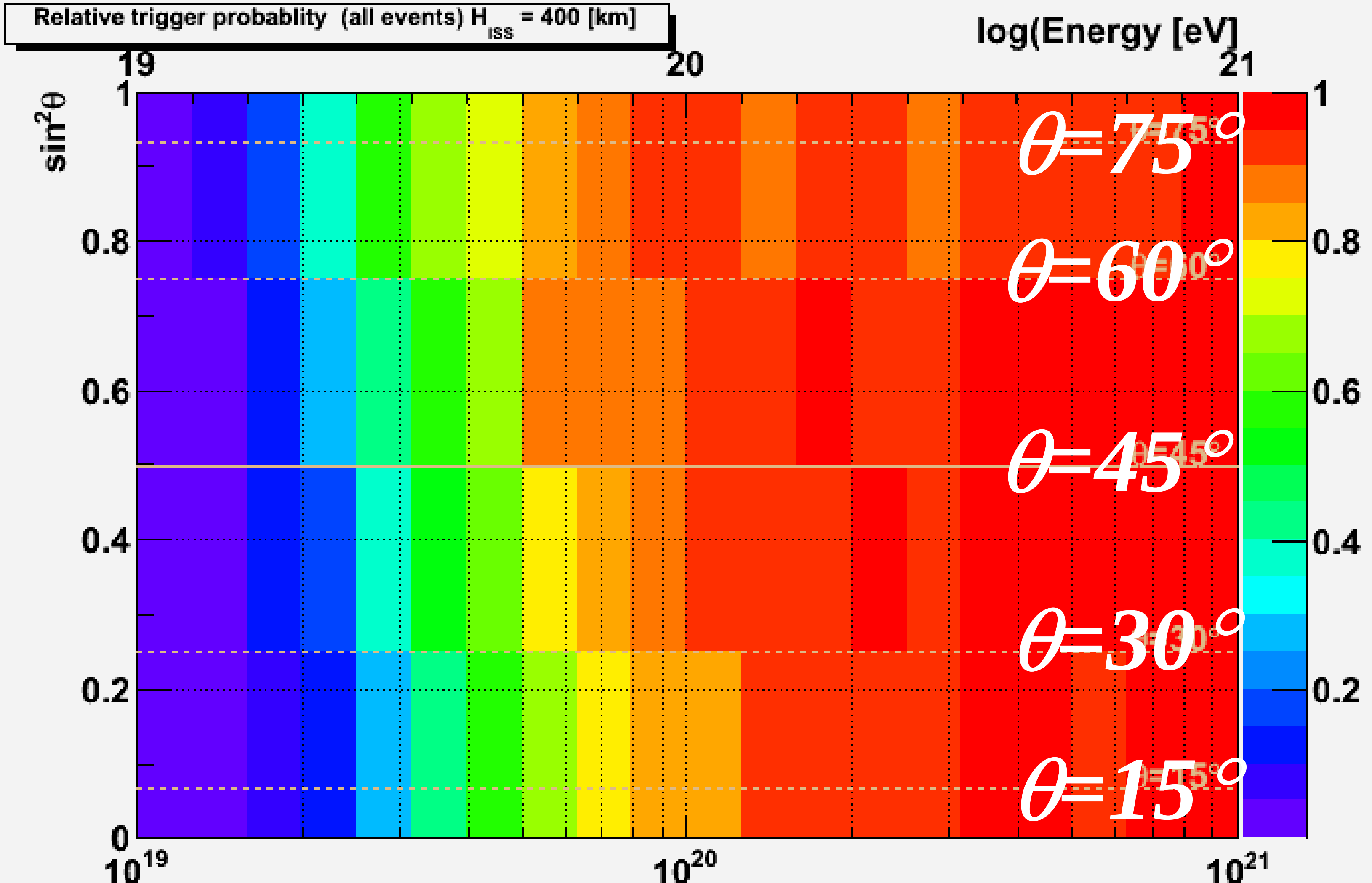


Basic conclusion:

In more than 70% of the cases the UV track including Xmax is observable

**Different geometrical conditions for optically thick or optically thin clouds*

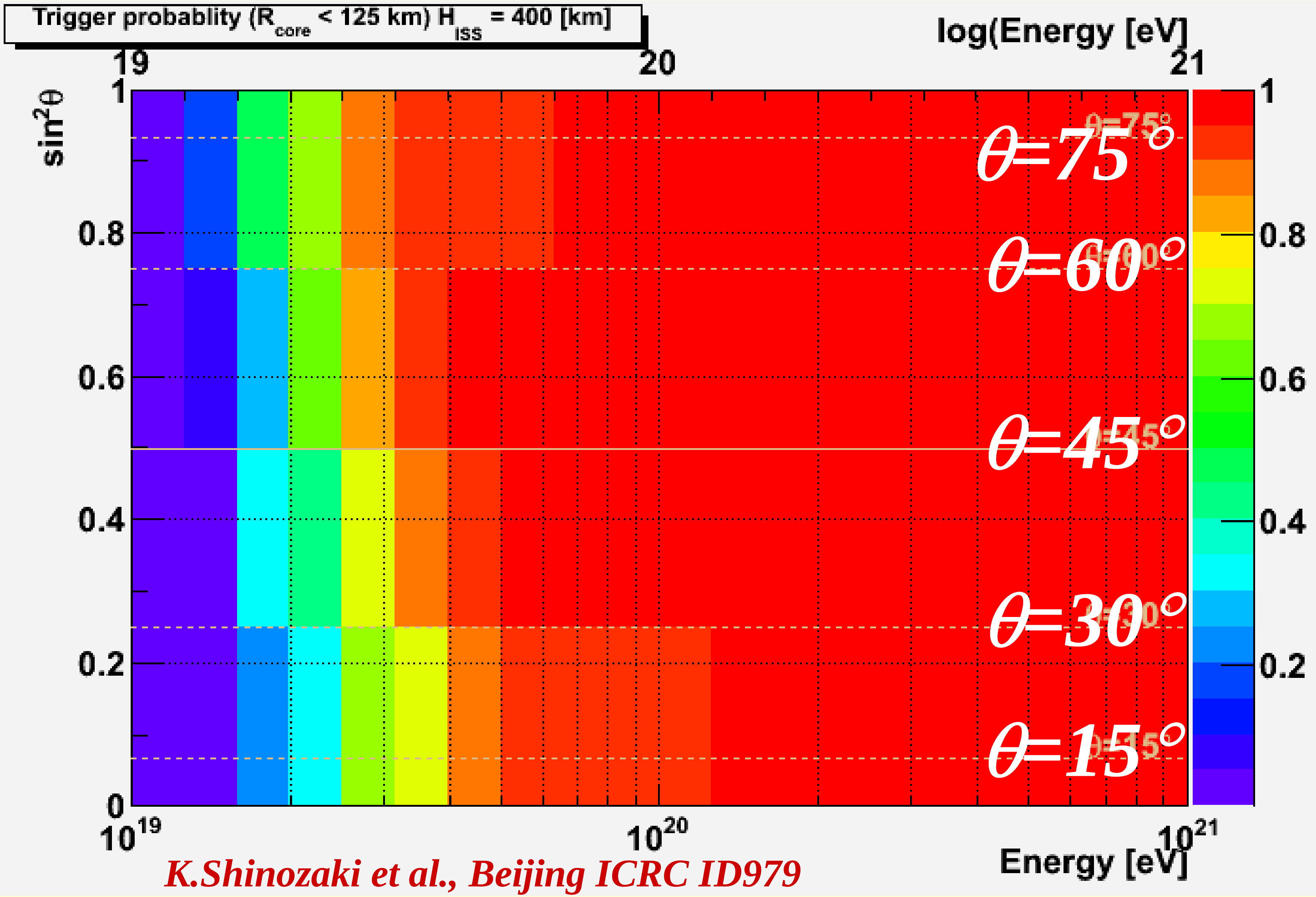
Trigger Probability (Zenith angle vs. Energy)



K.Shinozaki et al., ID979

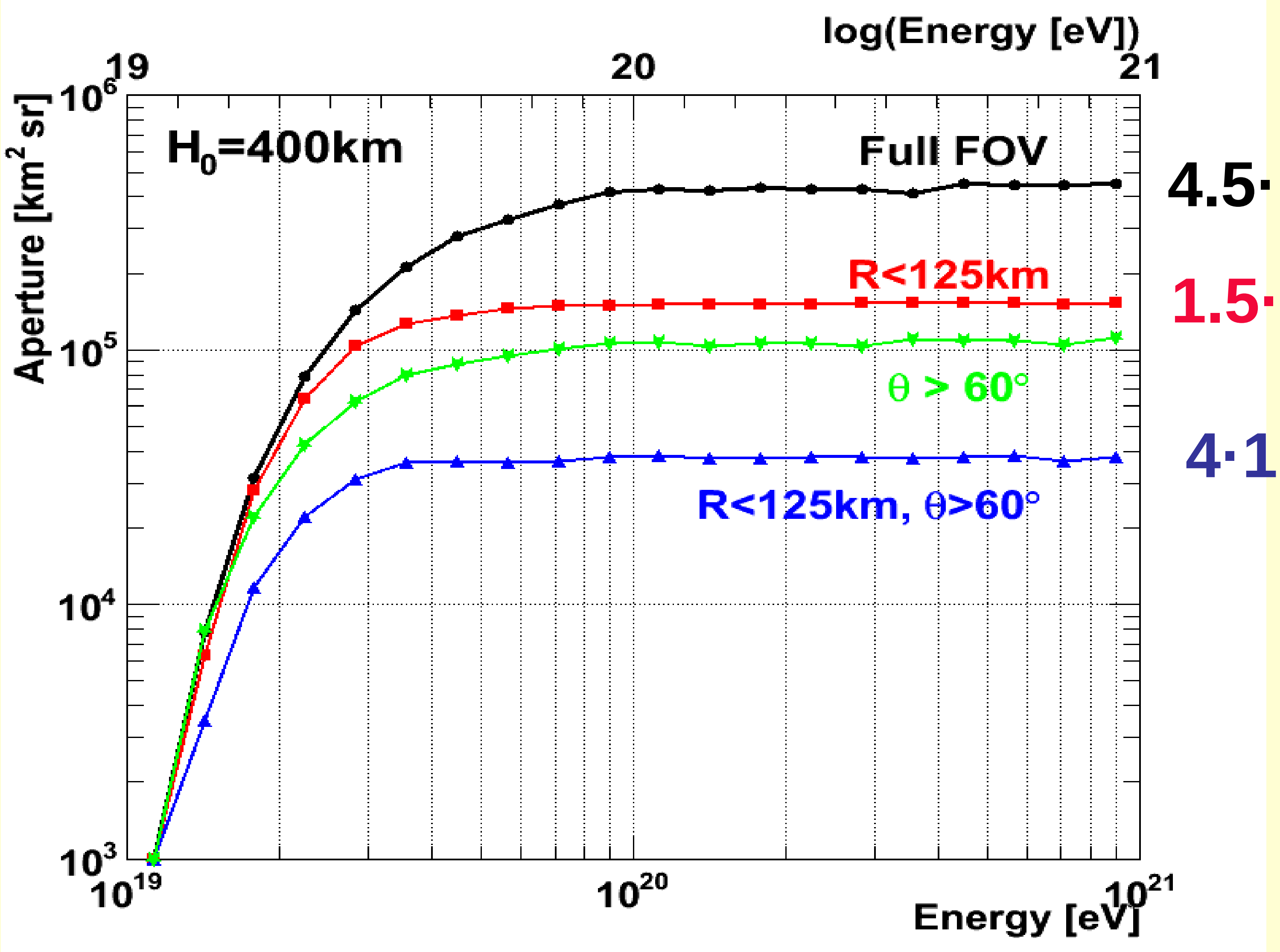
Full FoV, *bckg = 500 ph/m²/ns/sr*

Trigger Probability for Central FoV (R<125 km)



K.Shinozaki et al., Beijing ICRC ID979

Instantaneous Geometric Aperture



$4.5 \cdot 10^5$ km^{2}sr

$1.5 \cdot 10^5$ km^{2}sr

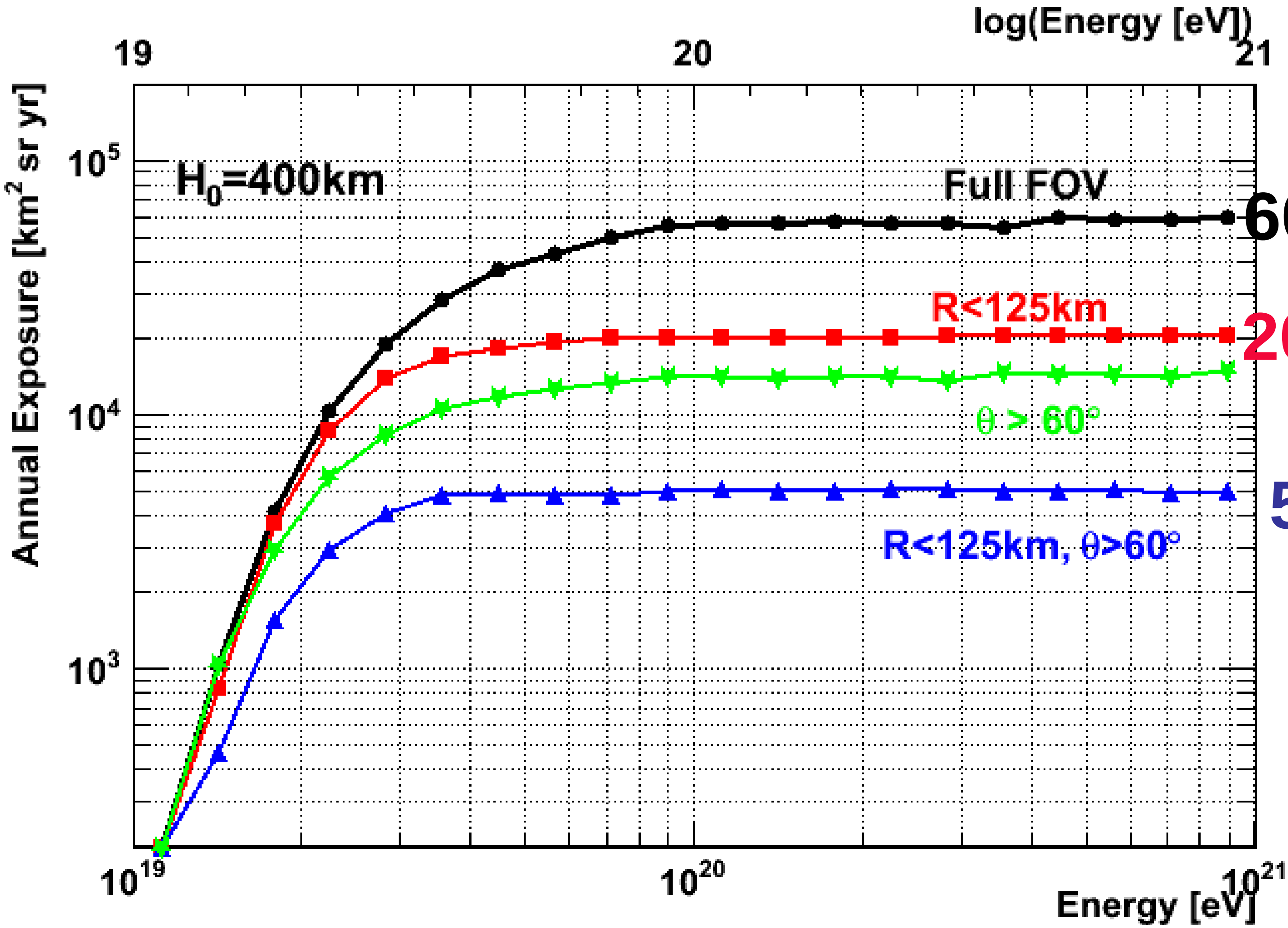
$4 \cdot 10^4$ km^{2}sr

K.Shinozaki et al., ID979

Annual Exposure (…Nadir)

TA ×η×k

~19%×70%



60,000 km^{2}sr yr

20,000 km^{2}sr yr

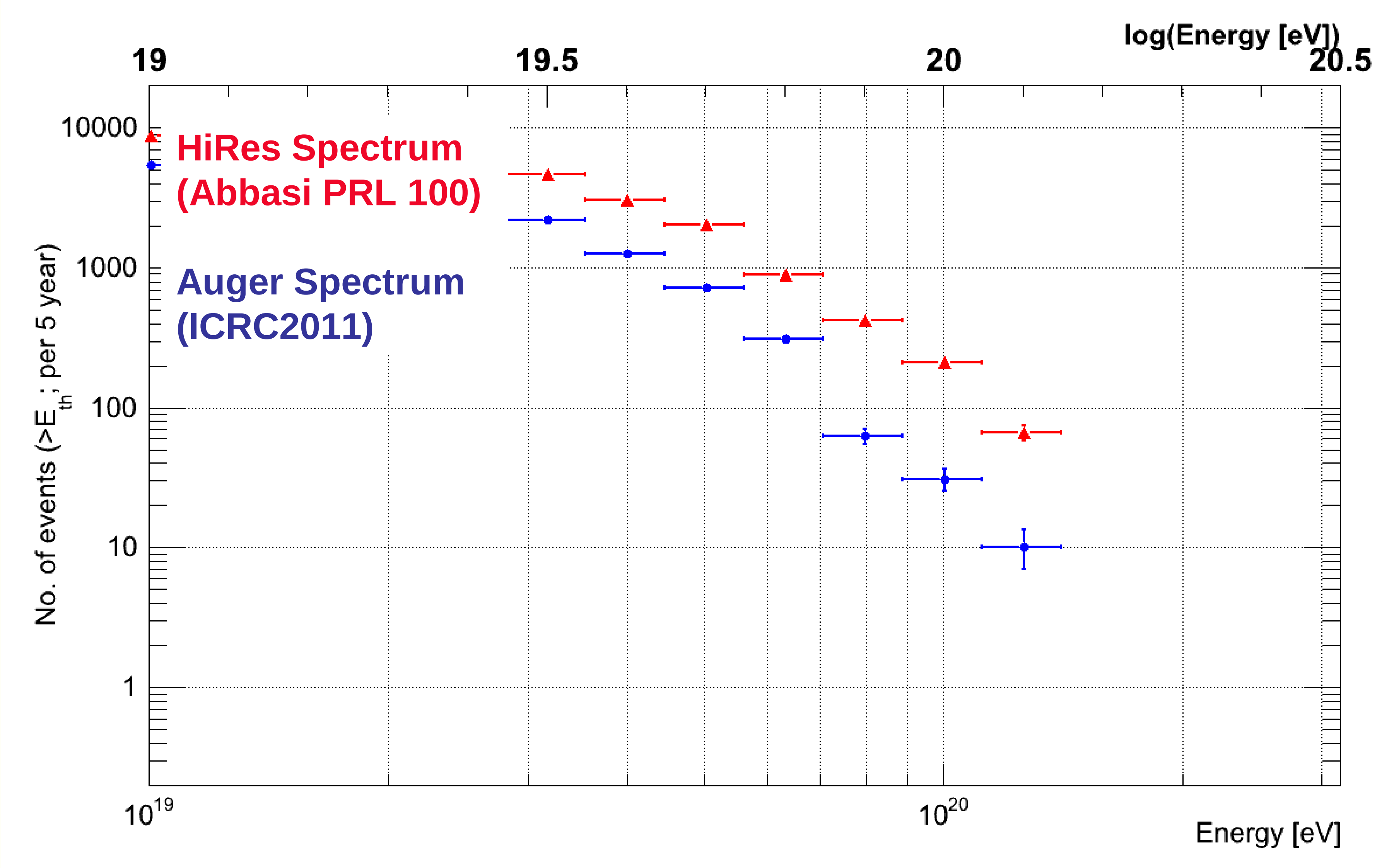
5,000 km^{2}sr yr

K.Shinozaki et al., ID979

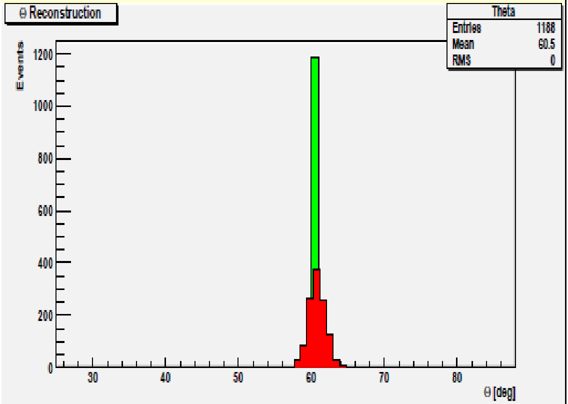
Comparison with current observatories

Observatory	Aperture km^2 sr	Status	Start	Lifetime yrs	Duty cycle	Annual Exposure km^2 sr yr	Relative to Auger
Auger	7,000	Running	2006	4 (16)	1	7000	1
TA	1,200	Running	2008	2 (14)	1	1,200	0.2
TUS	30,000	Developed	2012	5	0.14	4,200	0.6
JEM-EUSO ($E \approx 10^{20}$ eV)	430,000	Design	2017	5	0.14	60,000	9
JEM-EUSO (highest energies) Tilted mode 35°	1,500,000	Design	2017	5	0.14	200,000	28

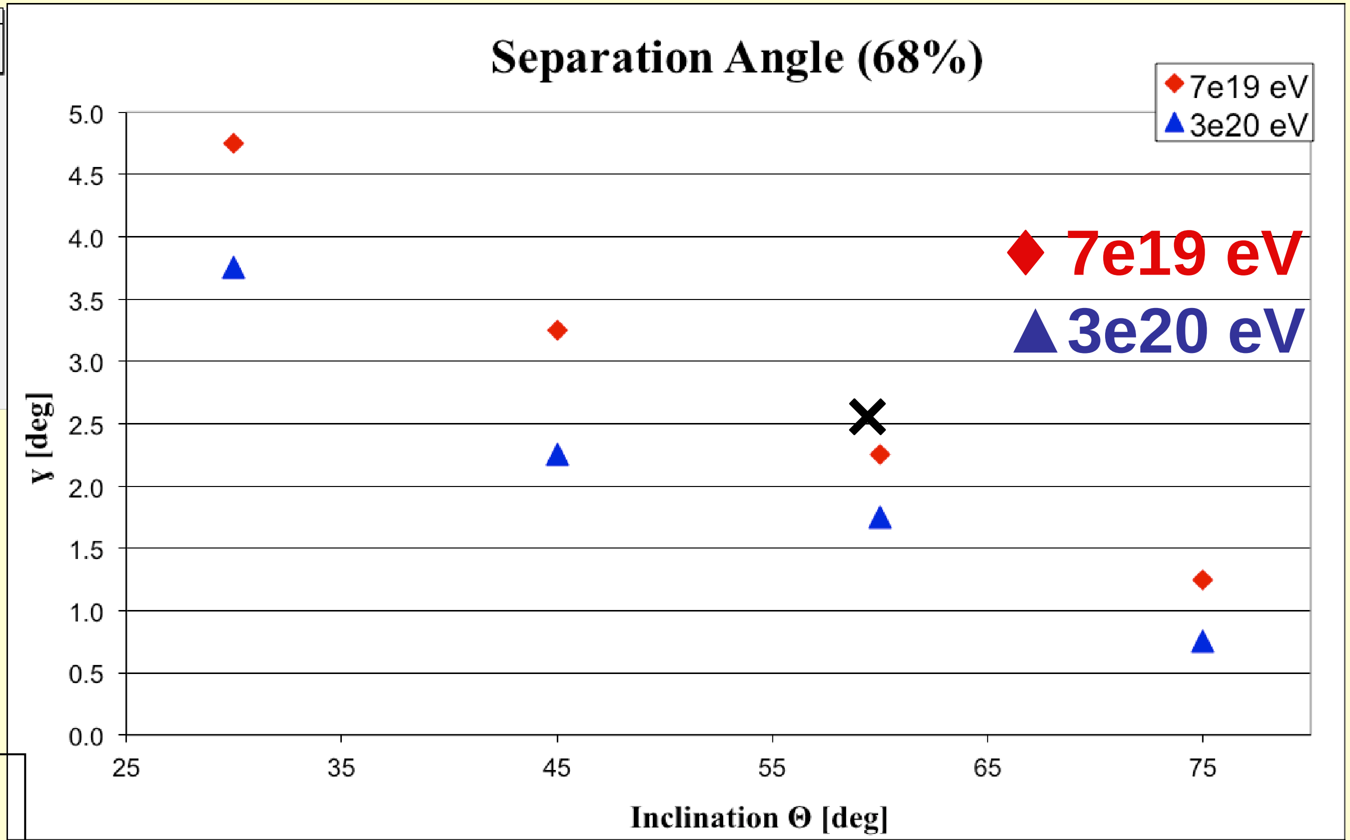
Expected number of events 5 years (>E)



Angular Resolution



α(deg)



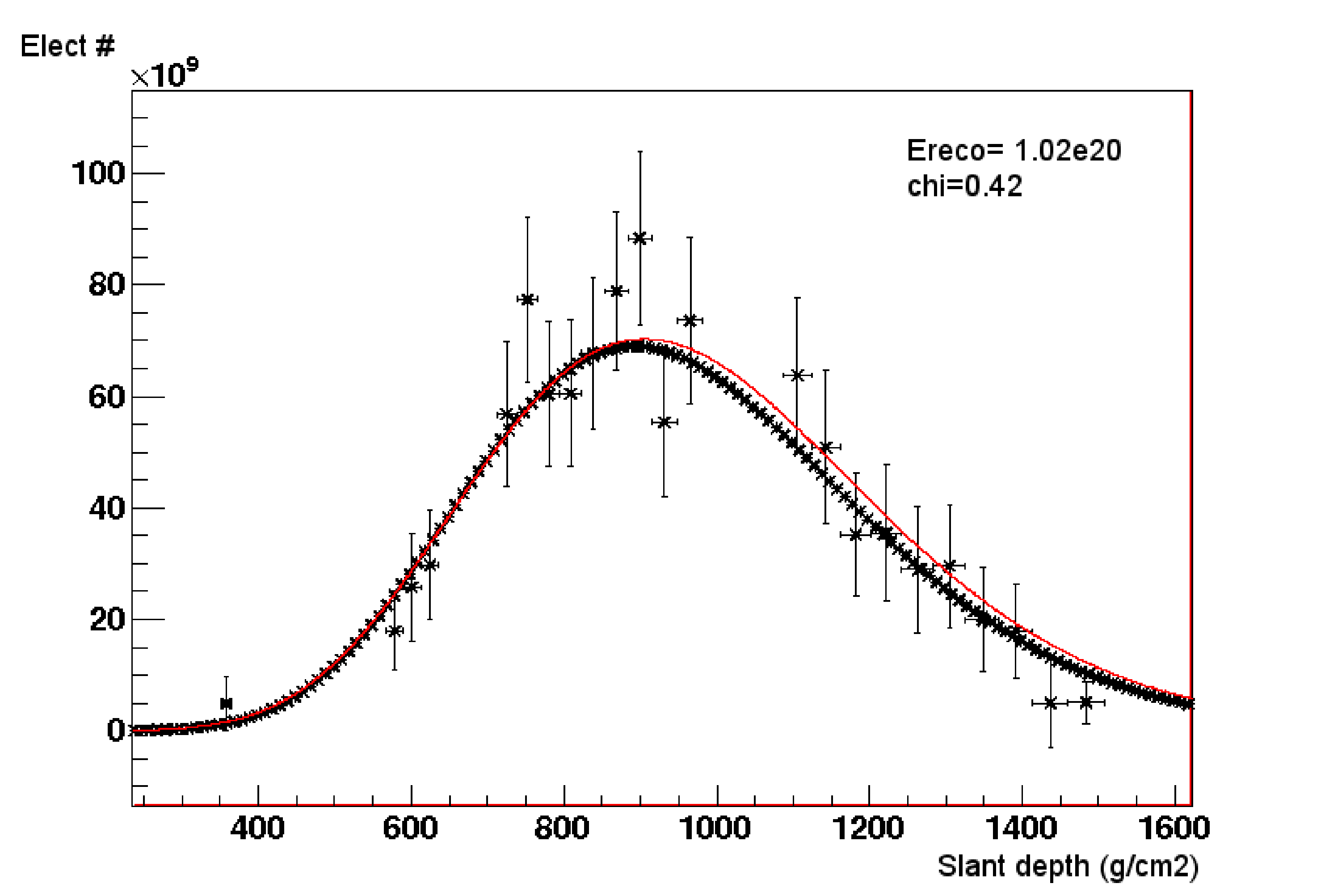
× Requirement
α<2.5°@
E=10^20 eV, θ=60°

Zenith Angle θ(deg)

End to end simulations show that the requirement is met.

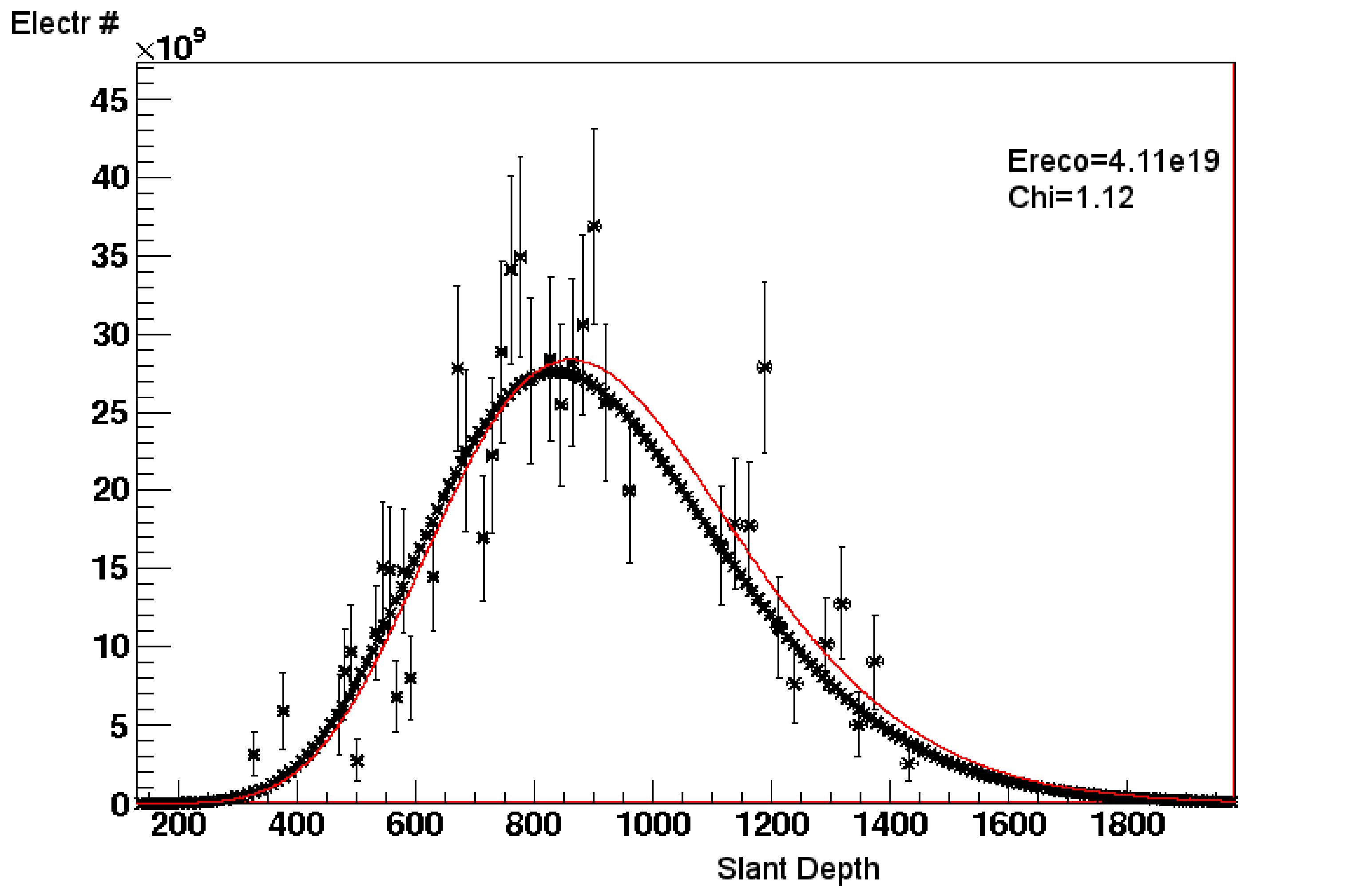
T.Mernik et al., ID633

Typical shower profile for a 10^{20}eV proton, θ= 60°



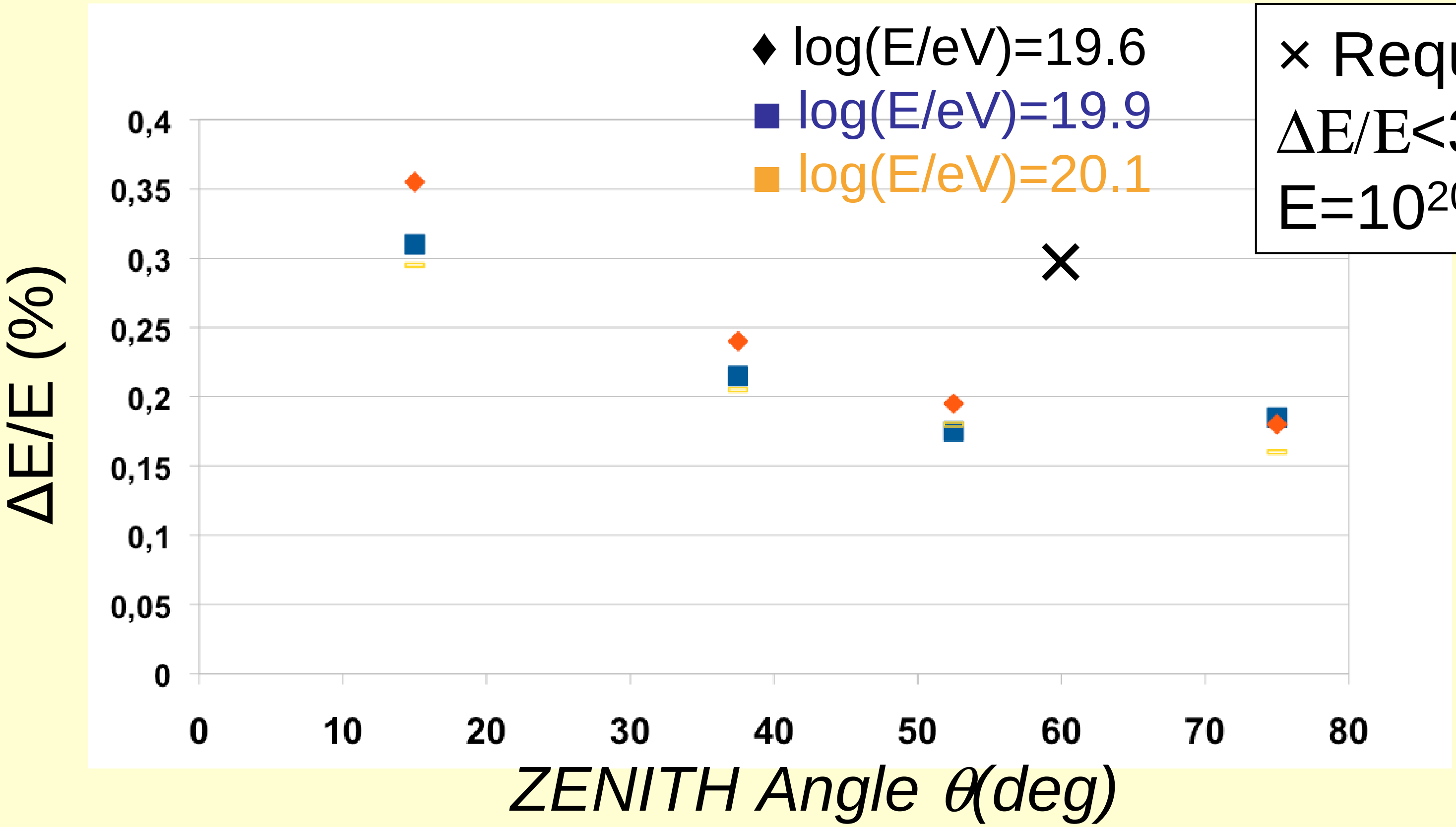
ΔE/E < 30% for ~90% of events

Typical shower profile
for a 4·10^{19}eV proton, θ= 80°, R<100km



ΔE/E < 30% for ~90% of events

Energy Resolution



× Requirement
ΔE/E<30% @
$E=10^{20}$eV, θ=60°

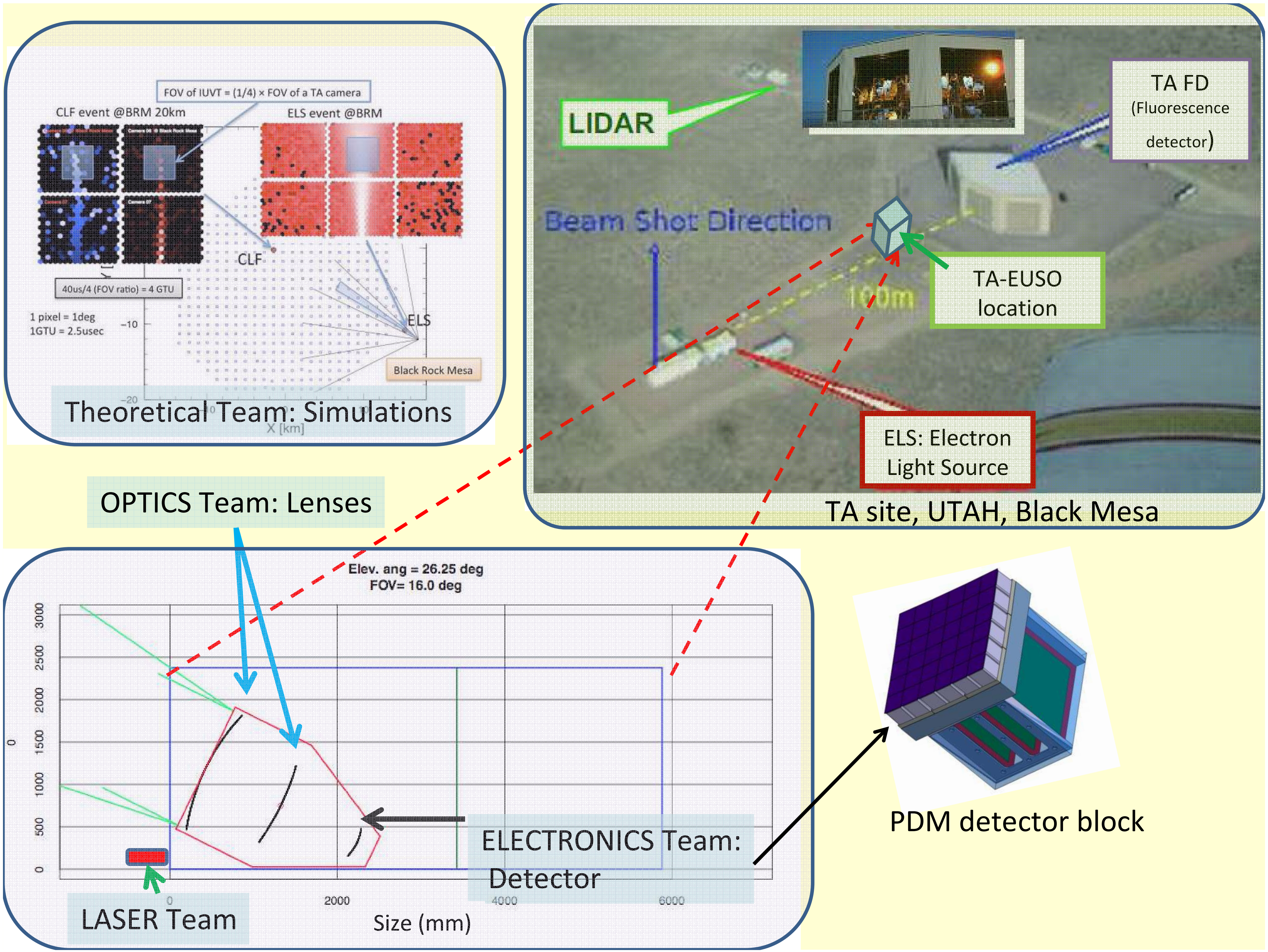
End to end simulations show that the requirement is met.

$\Delta X_{max} < 70 gr/cm^2$ (Requirement $\Delta X_{max} < 120 gr/cm^2$) OK

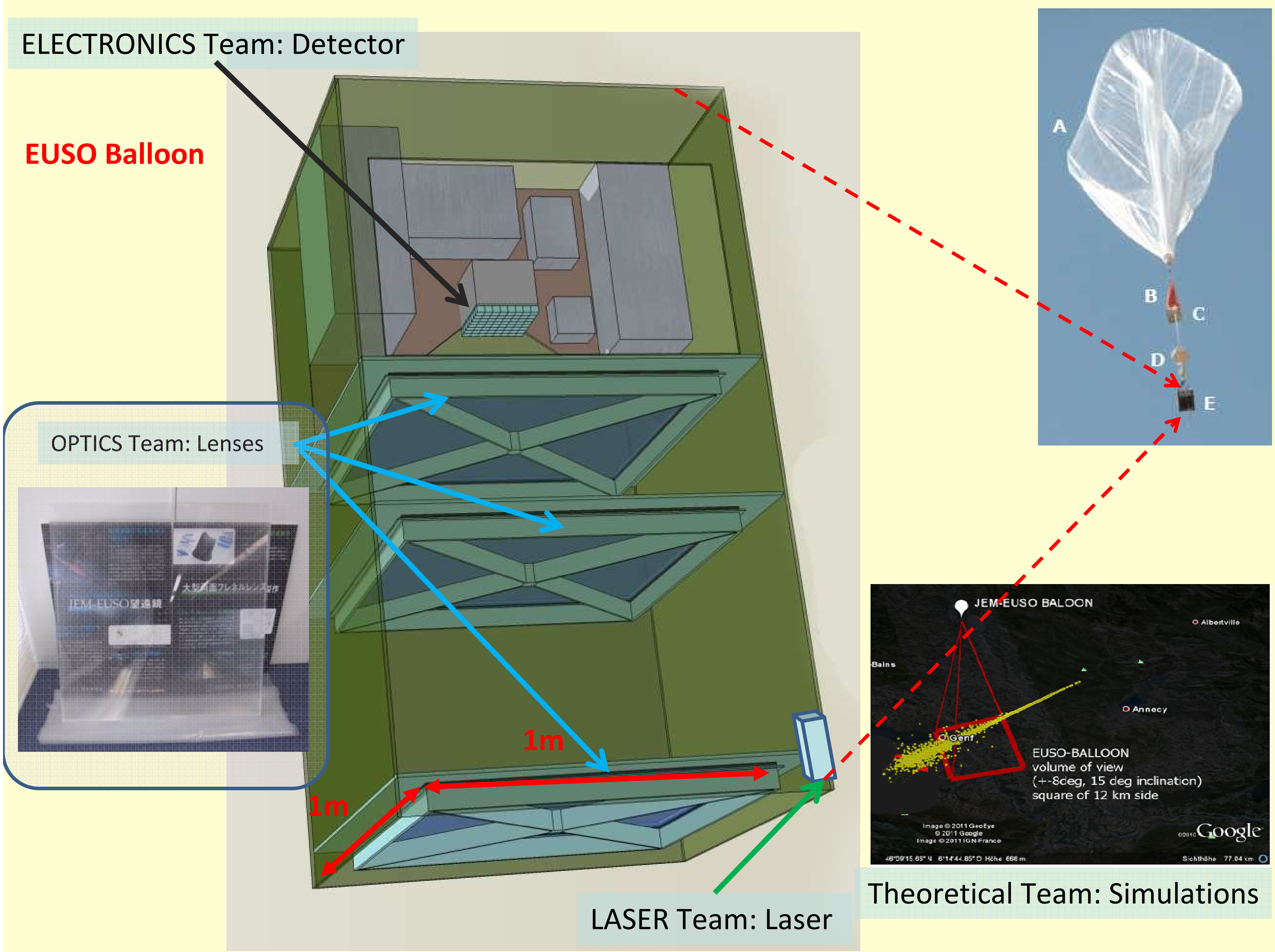
The JEM-EUSO pathfinders

- TA-EUSO at Telescope Array in Utah
  Installation on site Winter 2012.

- Several EUSO Balloon Flights with CNES
  First launch date early 2014



FOV of IUVT = (1/4) × FOV of a TA camera
CLF event @BRM 20km
ELS event @BRM
CLF
40us/4 (FOV ratio) = 4 GTU
1 pixel = 1deg
1GTU = 2.5usec
ELS
Black Rock Mesa
Theoretical Team: Simulations
X [km]
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
ELECTRONICS Team:
Detector
LASER Team
Size (mm)
PDM detector block


ELECTRONICS Team: Detector
EUSO Balloon
OPTICS Team: Lenses
1m
1m
LASER Team: Laser
A
B
C
D
E
JEM-EUSO BALOON
Albertville
Bains
Annecy
Genf
EUSO-BALLOON
volume of view
(+-8deg, 15 deg inclination)
square of 12 km side
Google
Theoretical Team: Simulations

Conclusions

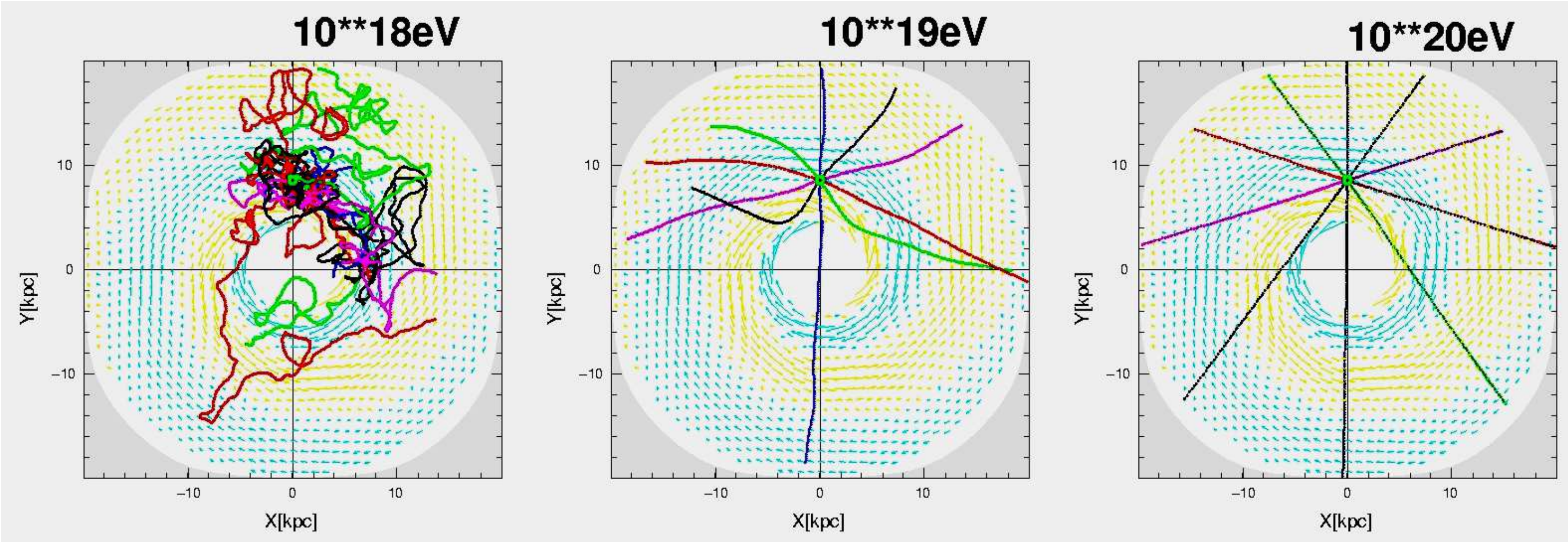
- The JEM-EUSO duty cycle and cloud impact have been thoroughly *estimated to be* $\eta \approx 19\%$ *and* $\kappa > 70\%$.
- JEM-EUSO will have *enough exposure and reconstruction capability at* $3x10^{19}$ *eV to overlap* with current generation observatory
- JEM-EUSO has an exposure in nadir mode almost one order of magnitude higher than current ground-based observatories.
- Simulations in nadir mode shows that the energy and angular resolution meet the requirements.

Conclusions

- *Science:* Evidence for GZK, Indication for Anisotropy, hints of sources but *puzzling scenario* (PAO, HiRes, TA)
  - Current generation of UHE Observatories is too small
  - *We need next generation*
  - *Exploration of the unknown*: UHE neutrinos, photons and new physics
- *Breakthrough can come from space:*
  - Large exposures, uniform exposures of the entire sky
  - JEM-EUSO is the pathfinder with potentially outstanding science output.
- *JEM-EUSO is feasible:*
  - Phase A/B studies of JAXA and of the Collaboration confirms it
  - Prototyping phase has been started. Tests on the key mission elements have been conducted.
- *Launch in 2017*

BACKUP SLIDES

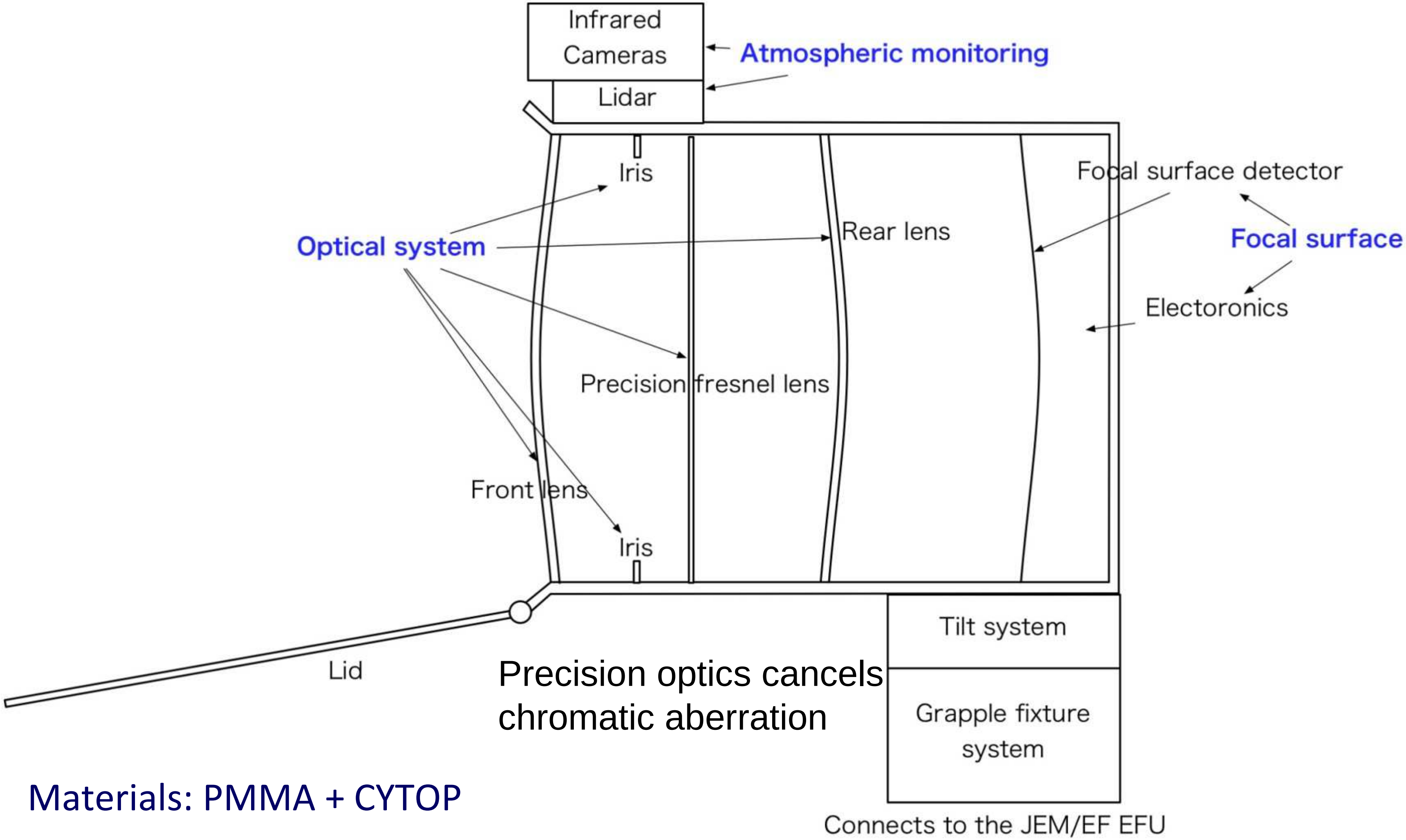
E>10^{20} eV particles do not bend



Simulation of trajectories inside our galaxy

We can specify origin of EECRs by arrival direction

Conceptual View of the JEM-EUSO Telescope



Precision optics cancels chromatic aberration

Materials: PMMA + CYTOP

P.Bobik et al., ID886

Duty cycle estimation

defined as **the fraction of time in which the nightglow background doesn't hamper EAS observation**

- Based on the *Universitetsky Tatiana satellite*

G. K. Garipov et al. 2005a, 2005b

- Scaling of the UV intensity from Tatiana's to the ISS orbit

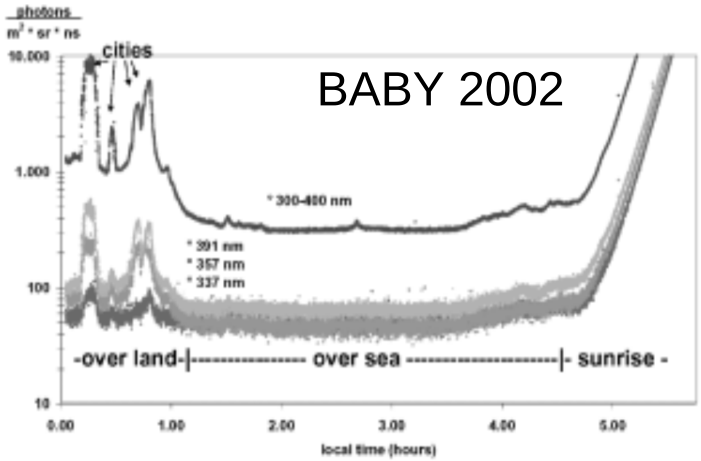
The JEM-EUSO duty cycle has been estimated *for a set of Solar Zenith angles* assuming an *UV background < 1500 photons/(m^2 ns sr)*

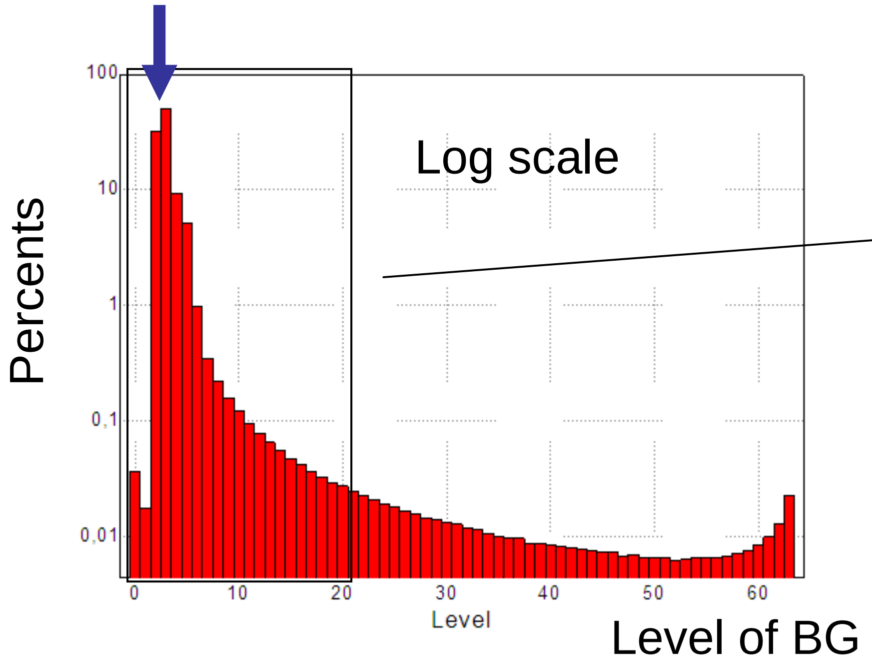
THE ROLE OF CITY LIGHTS

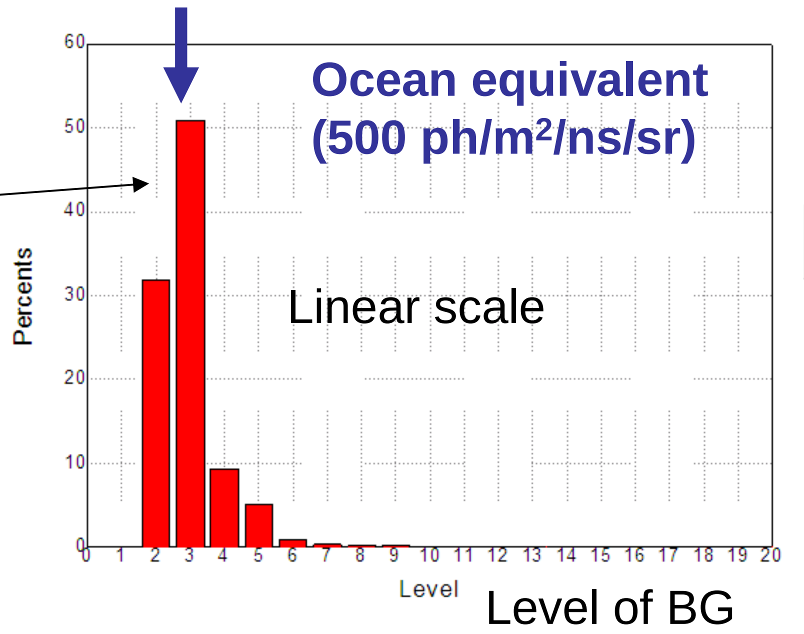
Defense Meteorological Satellite Program data

- – Annual average of cloudfree moonless intensity of ‘**Night Earth**’ in 30 arcseconds grid on surface
- **Light pollution cities mainly consisting of visible range**
- – Assuming UV intensity proportional to visible
- • **Estimating background intensity** in a unit of ‘oceanequivalent’
- – ‘Oceanequivalent’ background intensity

- assuming → 500 UVphotons / (m^2 sr ns)



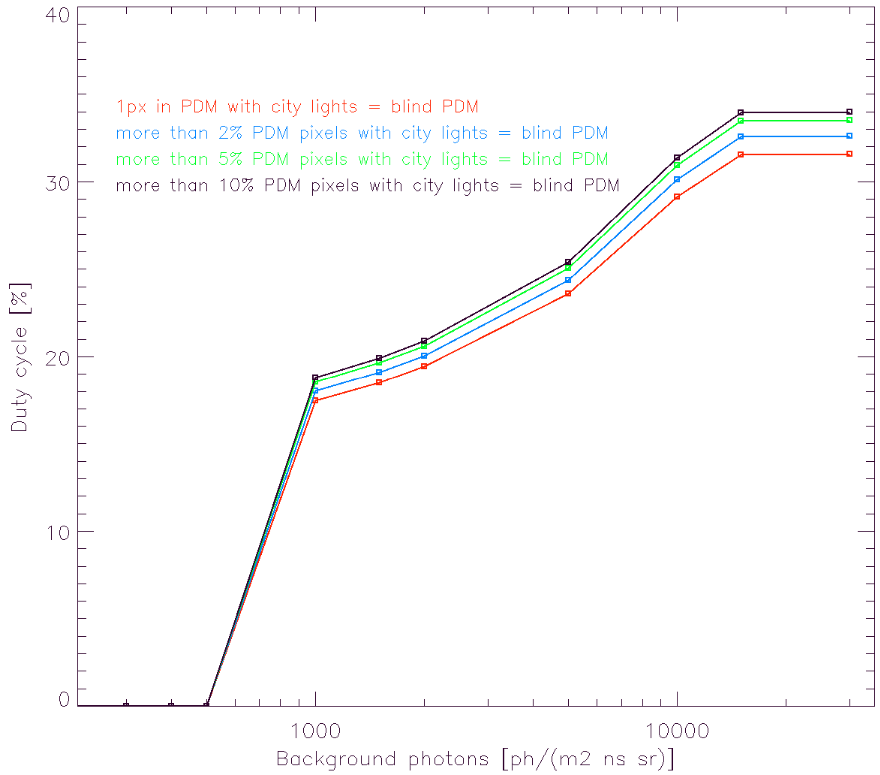




City lights effect - Operational efficiency

- DMSP data with intensity over level 7
- Real ISS trajectory, simulated moon light I_{MOON}
- Nadir mode of detector (area on Earth ~140 000 km^2)
- 137 PDMs projection on Earth surface
- conditions to exclude measurements over cities from JEM-EUSO duty/operational cycle – if more than selected number of pixels in PDM are blind (DSMP resolution 1 km pixels).
- $BG = BG_{MOON} + BG_{OCEANEQ\_500} + BG_{cities}$
- $BG_{OCEANEQ\_500} = 500$ ph / (m^2 ns sr)
- For allowed background 1500 ph/(m^2 ns sr) we get

Cities in PDM	Duty cycle [%]
0	18.51
< 2 %	19.11
< 5 %	19.64
< 10 %	19.91



L.Saez et al., ID1034, K.Shinozaki et al. ID979

Cloud-impact to trigger efficiency

$E>5\cdot10^{19}$eV

Cloud top

Optical Depth

	<3 km	3-7 km	7-10 km	>10 km
OD>2	90%	65%	35%	20%
OD:1-2	90%	70%	45%	25%
OD:0.1-1	90%	80%	75%	70%
OD<0.1	90%	90%	90%	90%

Average efficiency* = 82% above 50 EeV

A spectral distribution $dN/dE \propto E^{-3}$ is assumed

A cross-check with Auger location seen through TOVS data

AUGER region (lat: 29,7/38,9; long: 290,5/300,9)
Only 250 data available (~6% statistical error)

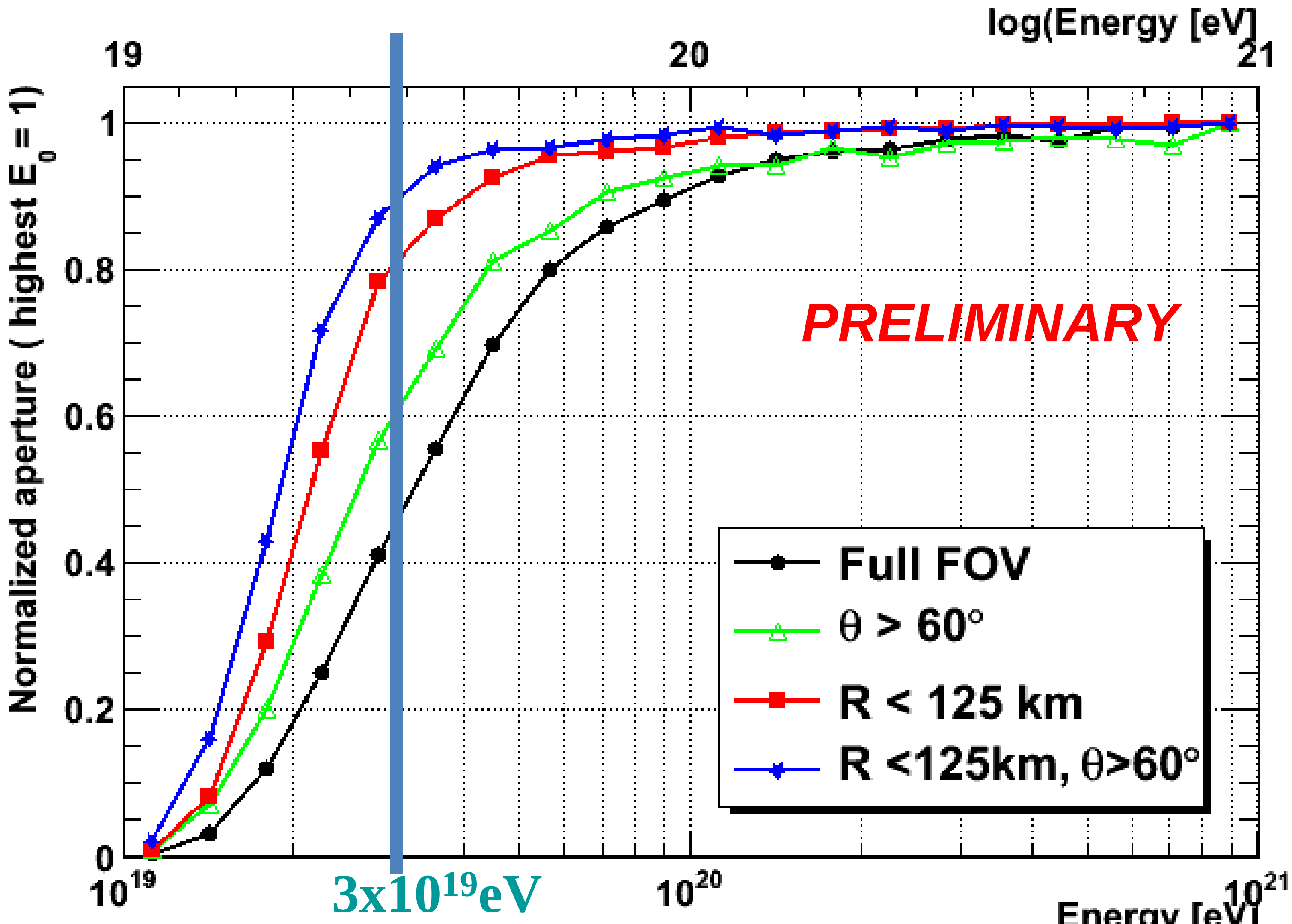
Clear sky ~ 42% - Better than world average (29%)
Green Band ~ 57% - similar to world average (60%)

Cloud top

Optical Depth

	<3 km	3-7 km	7-10 km	>10 km
OD>2	6	10	7	6
OD:1-2	3	5	5	1
OD:0.1-1	4	2	2	5
OD<0.1	42	0	0	2

Normalised Aperture: Efficiency



K.Shinozaki et al., ID979

Take home messages:

Physics and Astrophysics at $E>5\times10^{19}$ eV

But also…

Explore new physics in the energy range $E\approx10^{20}$-10^{21}eV

Highest statistics and therefore largest exposures at extreme energies

$$E \approx 10^{20-21} eV$$

But also … lower energies are important for overlapping with ground-based detectors and make a statistically significant comparison!

$$E < 5\times10^{19} eV$$

Ground and Space

- If no New Giant Detector, we will not understand what is UHECR.

- **If no JEM/EUSO, we will lose important future and hope.**

M. Fukushima, UHECR2012 – Summary Report

Energy Spectrum

1. Cutoff and dip established.
2. Energy scale error ~20%.
3. Power law fits agree among exp..
4. Spectral shapes seem differ above $10^{19.5}$ eV
   - Auger is based on muon (water tank)
   - HiRes, TA and Yaktsuk are based on e/γ (Air Fluor., plastic scint.)
   - CIC, MC zenith att. By MC, calorimetry

Fukushima, UHECR 2012