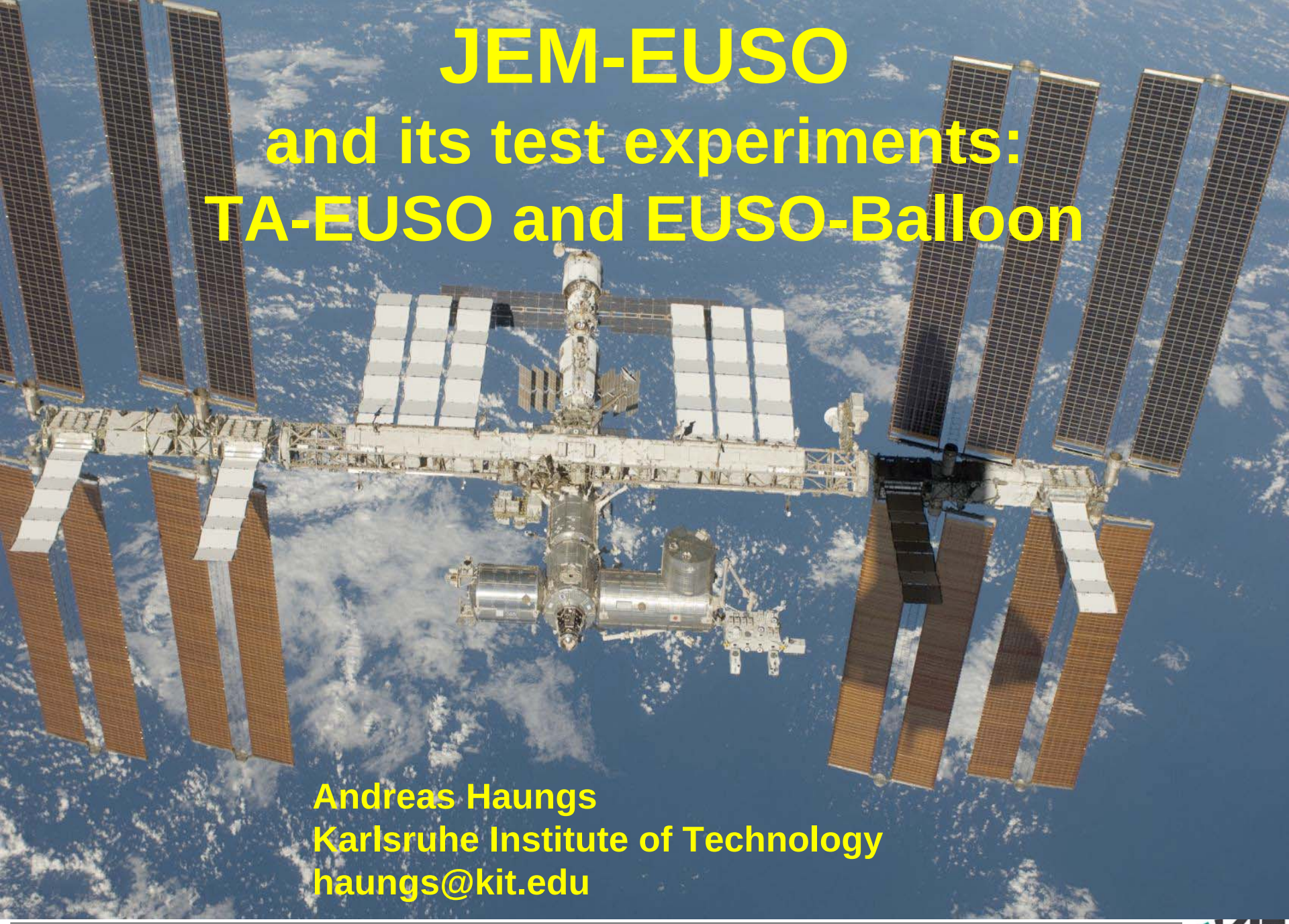

JEM-EUSO
and its test experiments:
TA-EUSO and EUSO-Balloon

Andreas Haungs
Karlsruhe Institute of Technology
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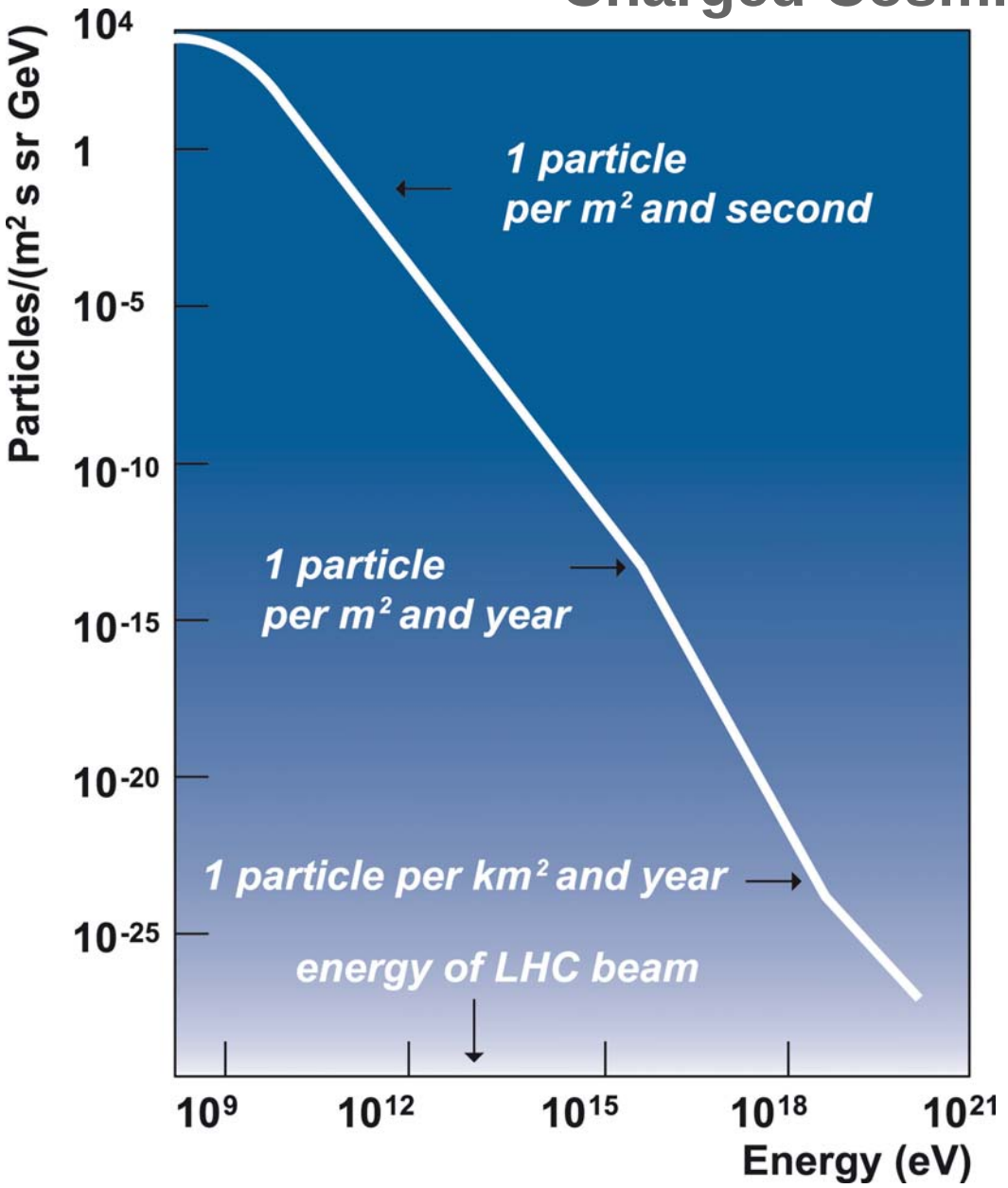
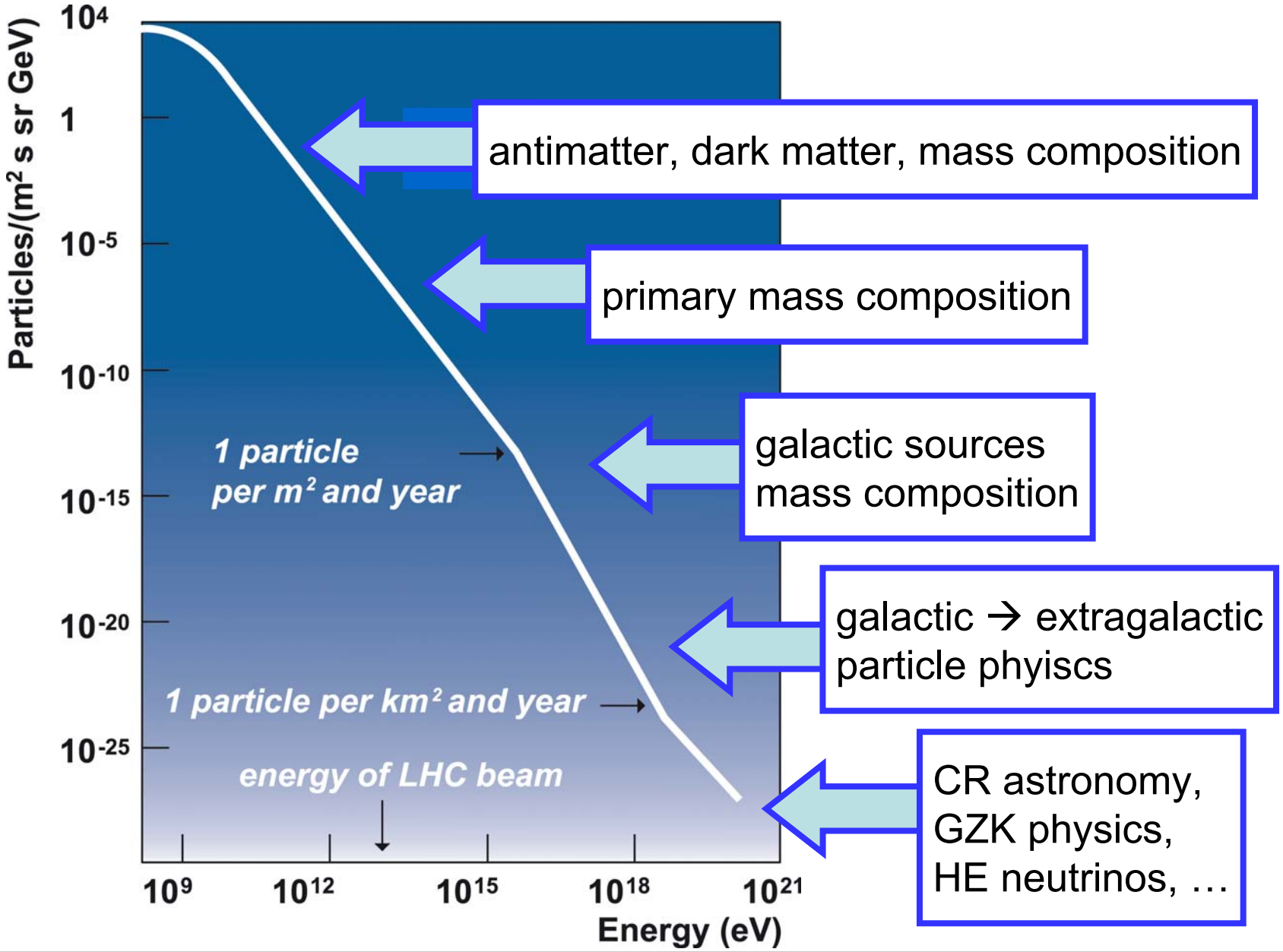
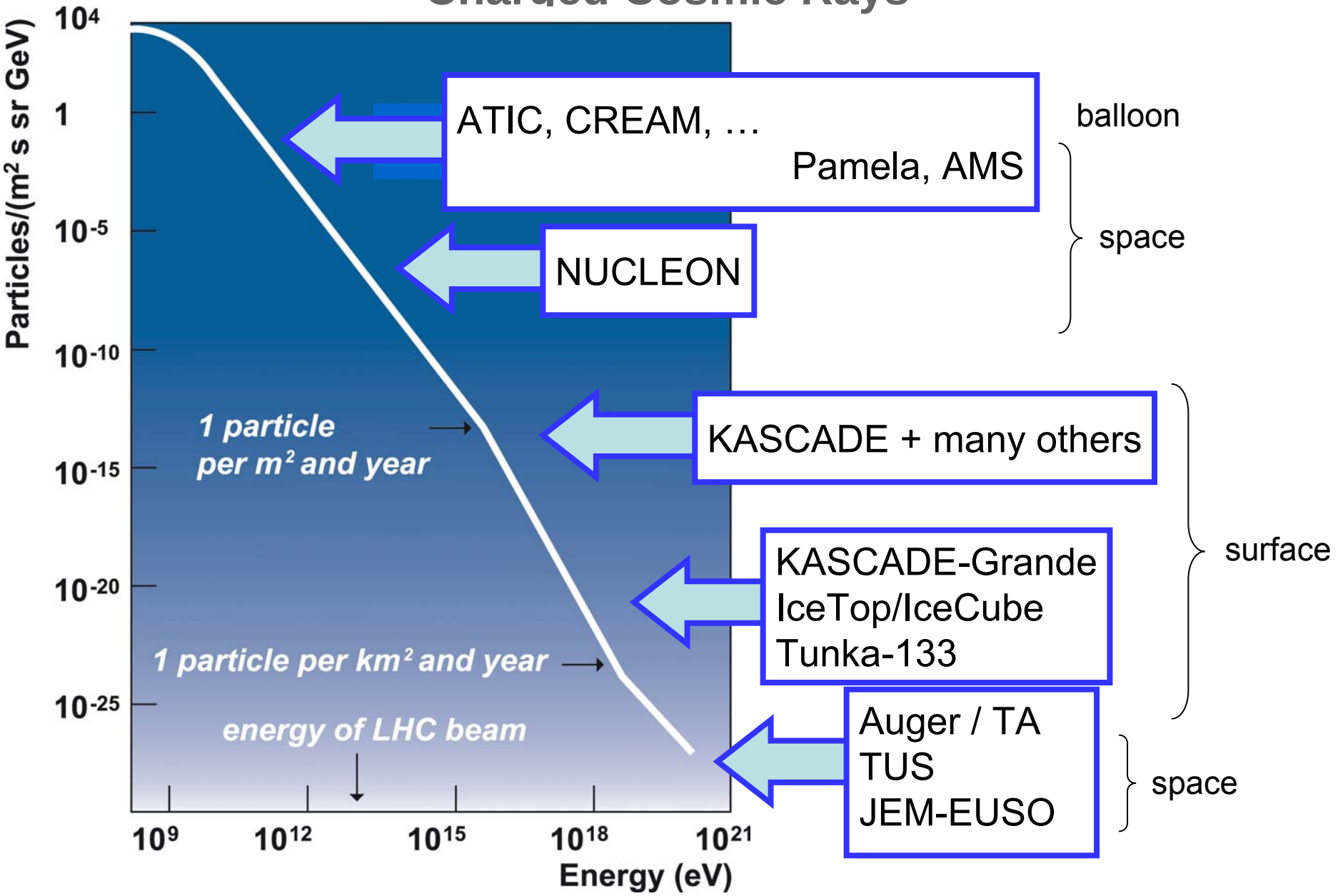
Charged Cosmic Rays



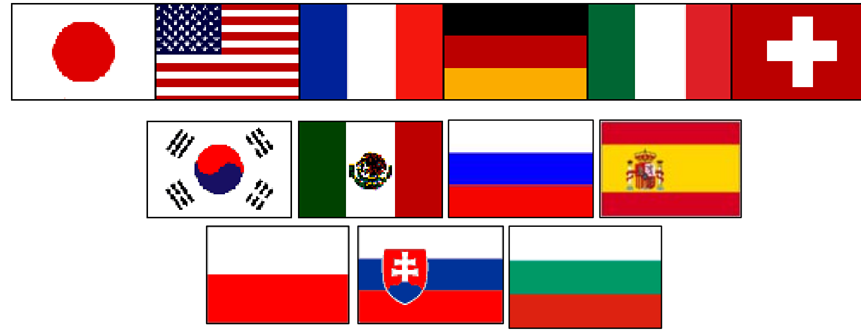
Charged Cosmic Rays



Charged Cosmic Rays



JEM-EUSO Collaboration



J.H. Adams Jr.[md], S. Ahmad[ba], J.-N. Albert[ba], D. Allard[bb], M. Ambrosio[df], L. Anchordoqui[me], A. Anzalone[dh], Y. Arai[eu], C. Aramo[df], K. Asano[es], P. Barrillon[ba], T. Batsch[hc], J. Bayer[cd], T. Belenguer[kb], R. Bellotti[db], A.A. Berlind[mg], M. Bertaina[dl,dk], P.L. Biermann[cb], S. Biktemerova[ia], C. Blaksley[bb], J. Błęcki[he], S. Blin-Bondil[ba], J. Blümer[cb], P. Bobik[ja], M. Bogomilov[aa], M. Bonamente[md], M.S. Briggs[md], S. Briz[ke], A. Bruno[da], F. Cafagna[da], D. Campana[df], J-N. Capdevielle[bb], R. Caruso[dc], M. Casolino[ev,di,dj], C. Cassardo[dl,dk], G. Castellini[dd], O. Catalano[dh], A. Cellino[dm,dk], M. Chikawa[ed], M.J. Christl[mf], V. Connaughton[md], J.F. Cortés[ke], H.J. Crawford[ma], R. Cremonini[dl], S. Csorna[mg], J.C. D'Olivo[ga], S. Dagoret-Campagne[ba], A.J. de Castro[ke], C. De Donato[di,dj], C. de la Taille[ba], L. del Peral[kd], A. Dell'Oro[dm,dk], M.P. De Pascale[di,dj], M. Di Martino[dm,dk], G. Distratis[cd], M. Dupieux[bc], A. Ebersoldt, T. Ebisuzaki[ev], R. Engel[cb], S. Falk, K. Fang, F. Fenu[ca], I. Fernández-Gómez[ke], S. Ferrarese[dl,dk], A. Franceschi, J. Fujimoto[eu], P. Galeotti[dl,dk], G. Garipov, J. Geary[md], U.G. Giaccari[df], G. Giraudo[dk], M. Gonchar[ia], C. González Alvarado, P. Gorodetzky[bb], F. Guarino[df,dg], A. Guzmán[cd], Y. Hachisu[ev], B. Harlov[ib], A. Haungs[cb], J. Hernández Carretero[kd], K. Higashide, T. Iguchi[ei], H. Ikeda[eo], N. Inoue[eq], S. Inoue[et], A. Insolia[dc], F. Isgrò[df,dg], Y. Itow[en], E. Joven[kf], E.G. Judd[ma], A. Jung[fc], F. Kajino[ei], T. Kajino[el], I. Kaneko[ev], Y. Karadzhov[aa], J. Karczmarczyk[hc], K. Katahira[ev], K. Kawai[ev], Y. Kawasaki[ev], B. Keilhauer[cb], B.A. Khrenov[ic], Jeong-Sook Kim[fb], Soon-Wook Kim[fb], Sug-Whan Kim[fd], M. Kleifges[cb], P.A. Klimov[ic], S.H. Ko[fa], D. Kolev[aa], I. Kreykenbohm[ca], K. Kudela[ja], Y. Kurihara[eu], E. Kuznetsov[md], G. La Rosa[dh], J. Lee[fc], J. Licandro[kf], H. Lim[fc], F. López[ke], M.C. Maccarone[dh], L. Marcelli[di,dj], A. Marini[de], G. Martin-Chassard[ba], O. Martinez[gc], G. Masciantonio[di,dj], K. Mase[ea], R. Matev[aa], A. Maurissen[la], G. Medina-Tanco[ga], T. Mernik[cd], H. Miyamoto[ev], Y. Miyazaki[ec], Y. Mizumoto[el], G. Modestino[de], D. Monnier-Ragaigne[ba], J.A. Morales de los Ríos[kd], B. Mot[bc], T. Murakami[ef], M. Nagano[ec], M. Nagata[eh], S. Nagataki[ek], T. Nakamura[ej], J.W. Nam[fc], S. Nam, K. Nam, T. Napolitano[de], D. Naumov[ia], A. Neronov[lb], K. Nomoto[et], T. Ogawa[ev], H. Ohmori, A.V. Olinto, P. Orleański, G. Osteria[df], N. Pacheco[kc], M.I. Panasyuk[ic], E. Parizot[bb], I.H. Park[fc], B. Pastircak, T. Patzak, T. Paul[me], C. Pennypacker[ma], T. Peter[lc], P. Picozza[di,dj,ev], A. Pollini[la], H. Prieto[kd,ka], P. Reardon[md], M. Reina[kb], M. Reyes[kf], M. Ricci[de], I. Rodríguez[ke], M.D. Rodríguez Frías[kd], F. Ronga[de], H. Rothkaehl[he], G. Roudil[bc], I. Rusinov[aa], M. Rybczyński[ha], M.D. Sabau[kb], G. Sáez Cano[kd], A. Saito[ej], N. Sakaki[cb], M. Sakata[ei], H. Salazar[gc], S. Sánchez[ke], A. Santangelo[cd], L. Santiago Crúz[ga], M. Sanz Palomino[kb], O. Saprykin[ib], F. Sarazin[mc], H. Sato[ei], M. Sato[er], T. Schanz[cd], H. Schieler[cb], V. Scotti[df,dg], M. Scuderi, A. Segreto[dh], S. Selmane[bb], D. Semikoz[bb], M. Serra[kf], S. Sharakin[ic], T. Shibata[ep], H.M. Shimizu[em], K. Shinozaki[ev], T. Shirahama[eq], G. Siemieniec-Oziębło[hb], H.H. Silva López[ga], J. Sledd[mf], K. Słomińska, A. Sobey[mf], T. Sugiyama[em], D. Supanitsky[ga], M. Suzuki[eo], B. Szabelska[hc], J. Szabelski[hc], F. Tajima, N. Tajima, T. Tajima[cc], Y. Takahashi[er], H. Takami[eu], M. Takeda[eg], Y. Takizawa[ev], C. Tenzer[cd], L. Tkachev, T. Tomida, N. Tone[ev], F. Trillaud[ga], R. Tsenov[aa], K. Tsuno[ev], T. Tymieniecka[hd], Y. Uchihori[eb], O. Vaduvescu, J.F. Valdés-Galicia[ga], P. Vallania[dm,dk], L. Valore[df], G. Vankova[aa], C. Vigorito[dl,dk], L. Villaseñor, P. von Ballmoos[bc], S. Wada[ev], J. Watanabe[el], S. Watanabe[er], J. Watts Jr.[md], M. Weber[cb], T.J. Weiler, T. Wibig[hc], L. Wiencke[mc], M. Wille[ca], J. Wilms[ca], Z. Włodarczyk[ha], T. Yamamoto[ei], Y. Yamamoto[ei], J. Yang, H. Yano[eo], I.V. Yashin[ic], D. Yonetoku[ef], K. Yoshida[ei], S. Yoshida[ea], R. Young[mf], A. Zamora[ga], A. Zuccaro Marchi[ev]

13 countries

75 institutes

258 members

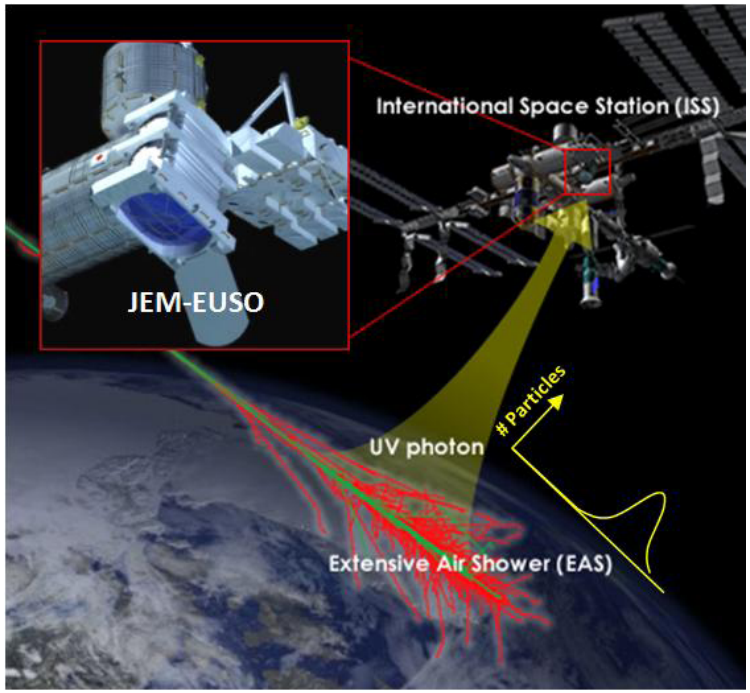
JEM-EUSO main features

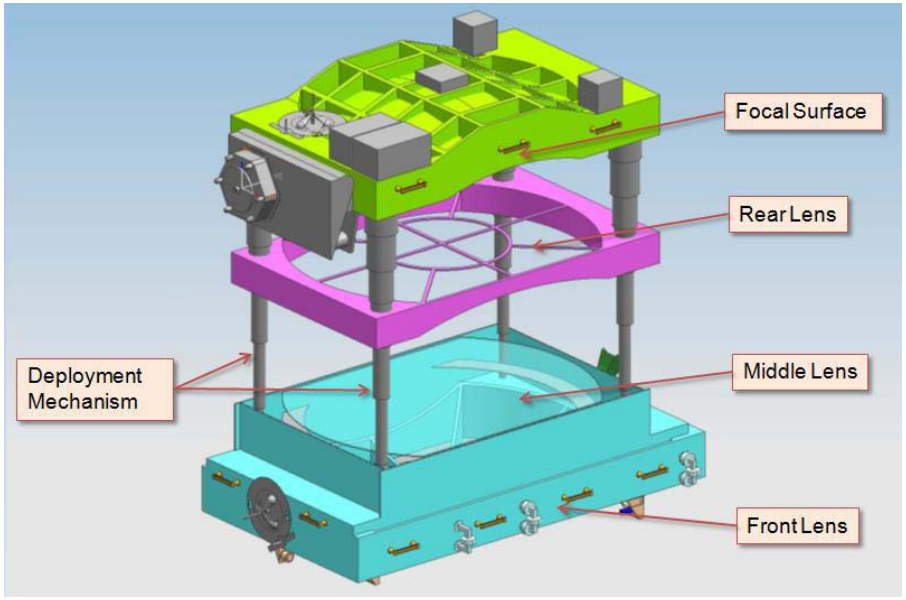
Method: fluorescence (full calorimetric)

Large field of view: ± 30° thanks to double sided spherical Fresnel lenses

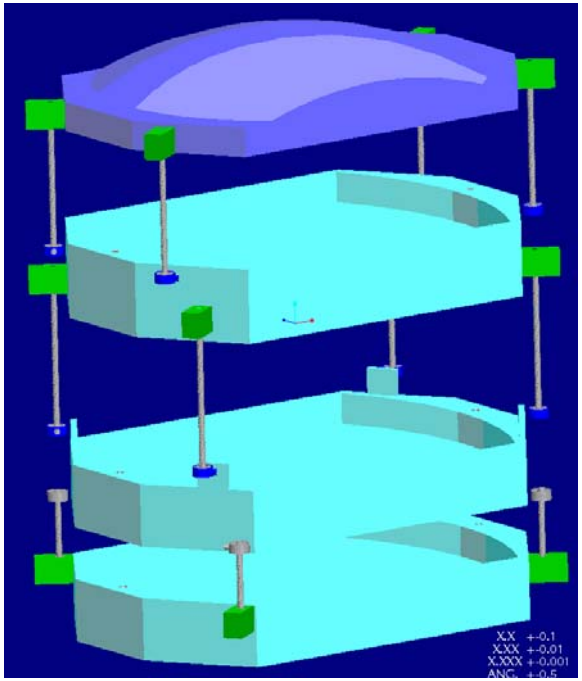
At 400 km (ISS): 2 10^5 km^2 (nadir mode) up to 10^6 km^2 (tilted mode)

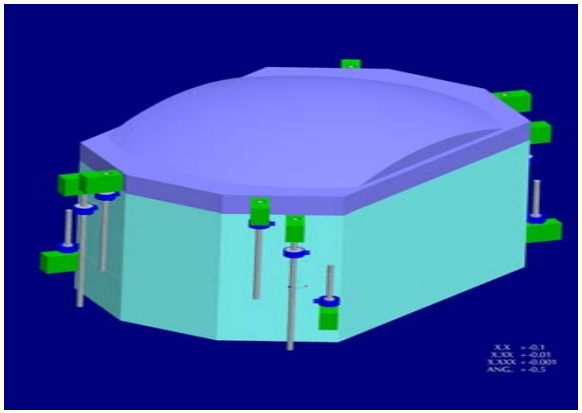
No need for stereo: 400 km >> shower length (TPC with a drift velocity = c)





JEM-EUSO telescope





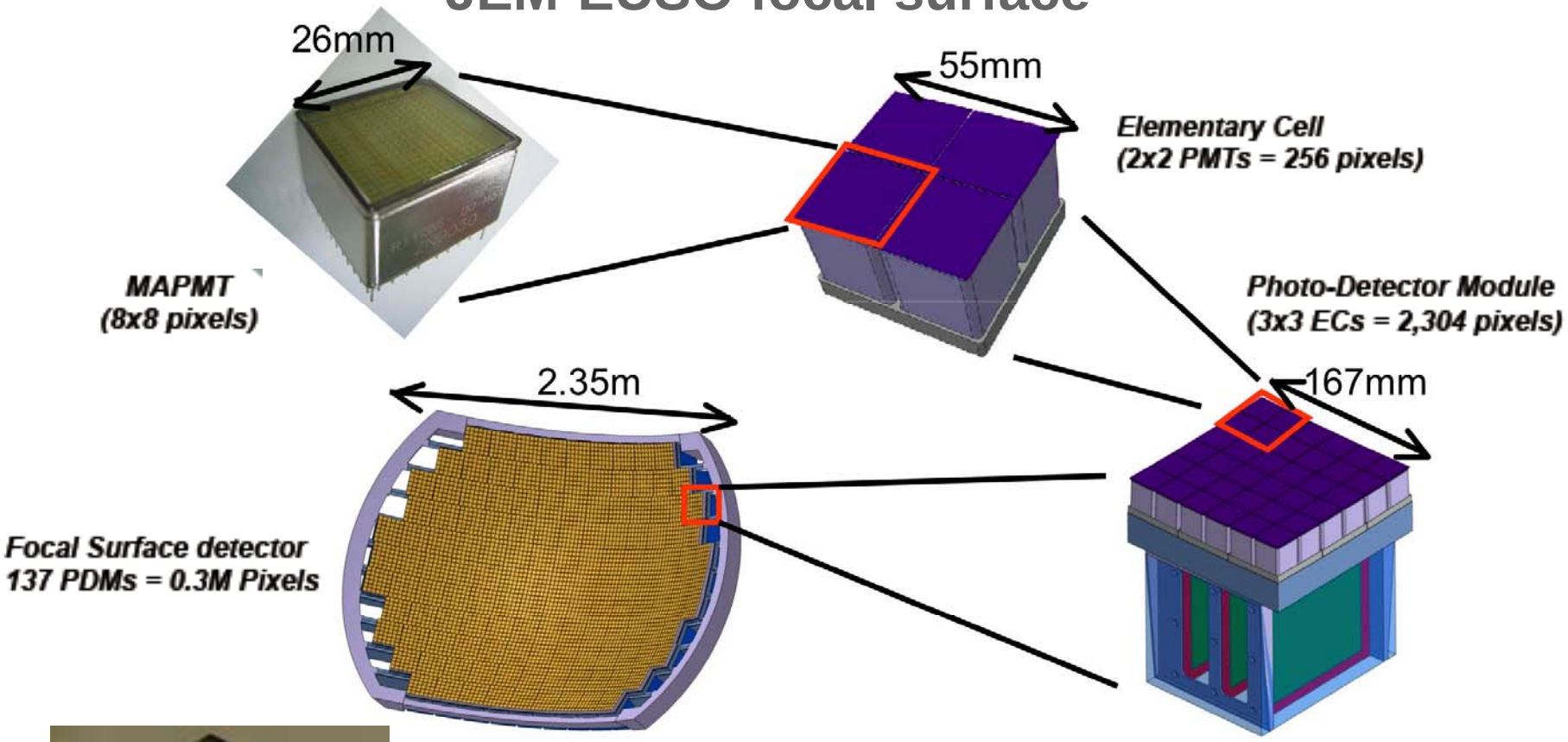
Lenses:

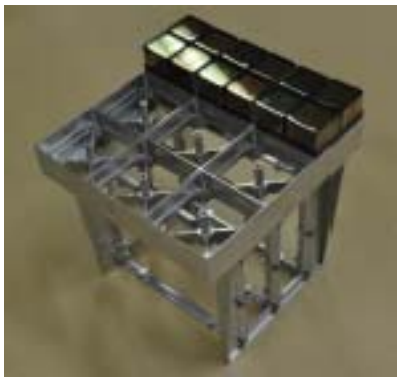
- produced in Japan + tested in US
- PSF = 3 mm (PMT pixel = 2.88 x 2.88 mm)

Mechanics:

- extendable system developed by Russia

JEM-EUSO focal surface

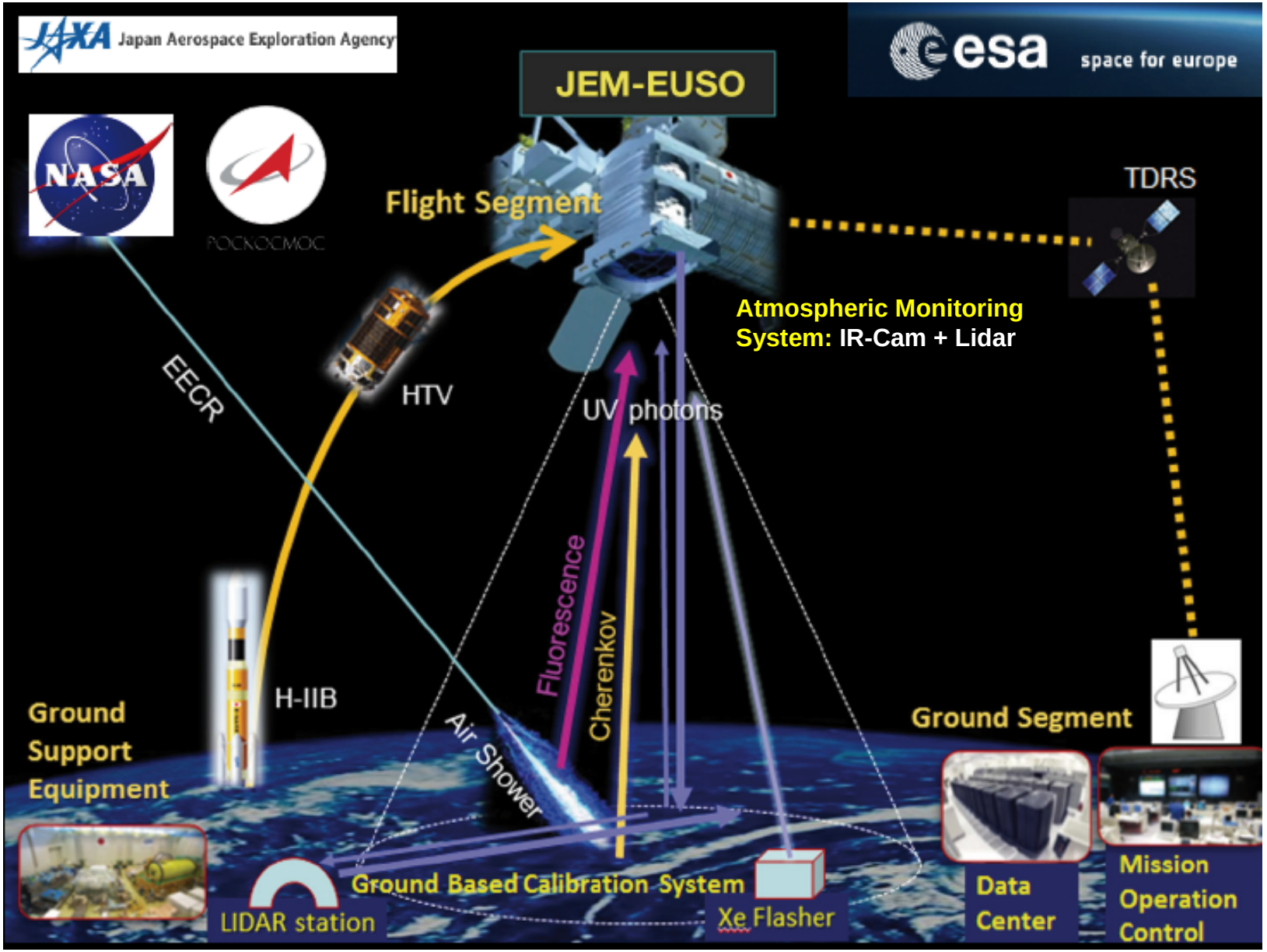




Focal surface:

- prototypes of PDM in preparation
- FoV of 1 PDM = 27 x 27 km^2

JEM-EUSO: the full machine



Main Physics Program

Main scientific objectives

- Measurement of Ultra-high energy Cosmic Rays

➔ Astronomy and Astrophysics through the particle channel

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

Exploratory scientific objectives

- Exploratory Objectives: new messengers
  - – Discovery of UHE neutrinos

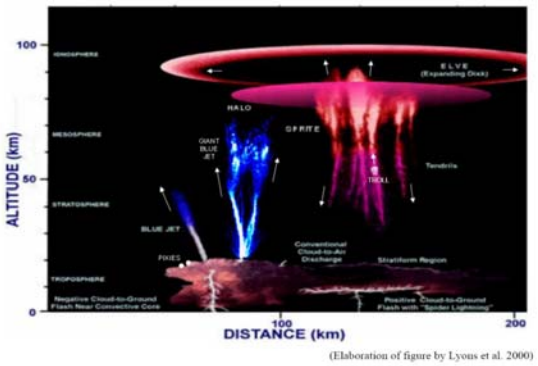
    discrimination and identification via X_0 and X_{max}
  - – Discovery of UHE Gammas

    discrimination of X_{max} due to geomagnetic and LPM effect

- Exploratory Objectives: magnetic fields

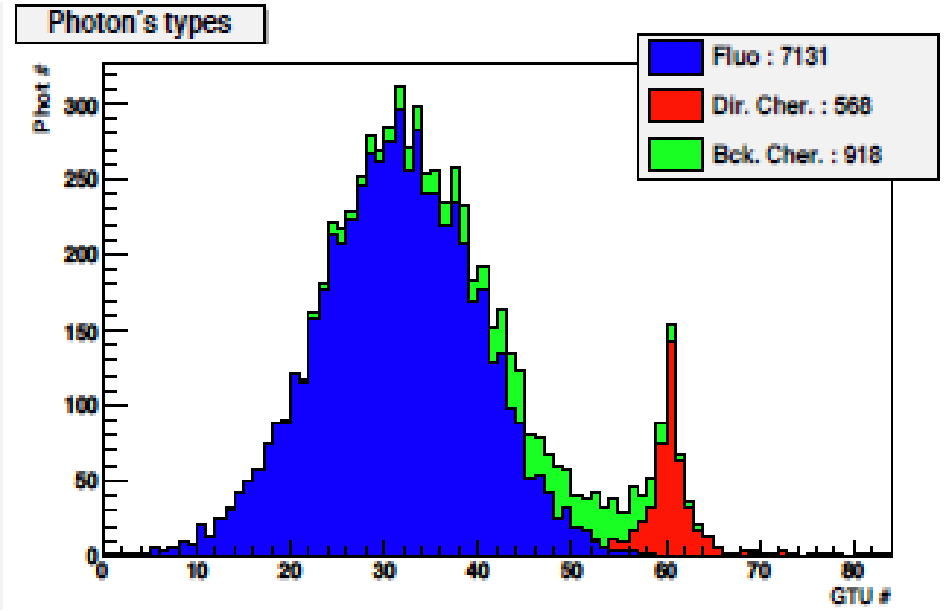
- Exploratory Objectives: Atmospheric science
  - Nightglow
  - Transient luminous events
  - Space-atmosphere interactions
  - climate change

  ➔ with the fast UV monitoring of the Atmosphere



(Elaboration of figure by Lyons et al. 2000)

The observation technique

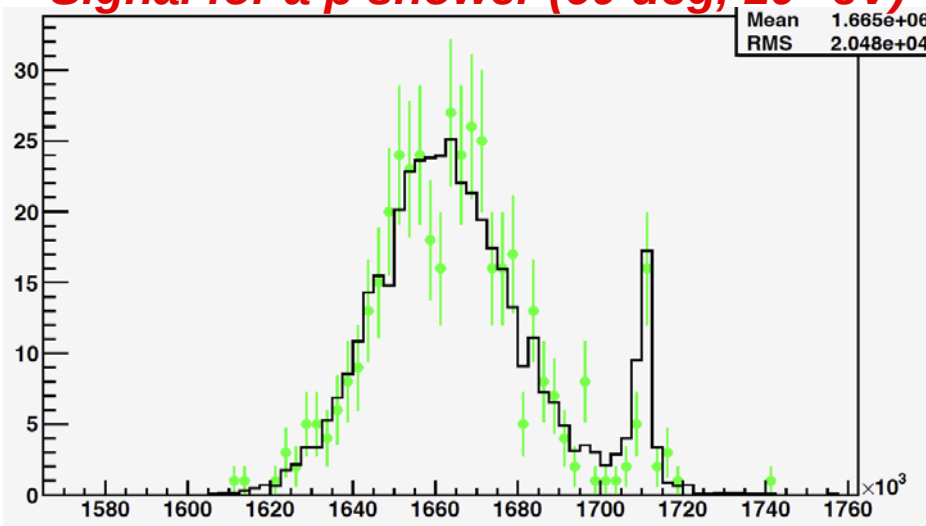


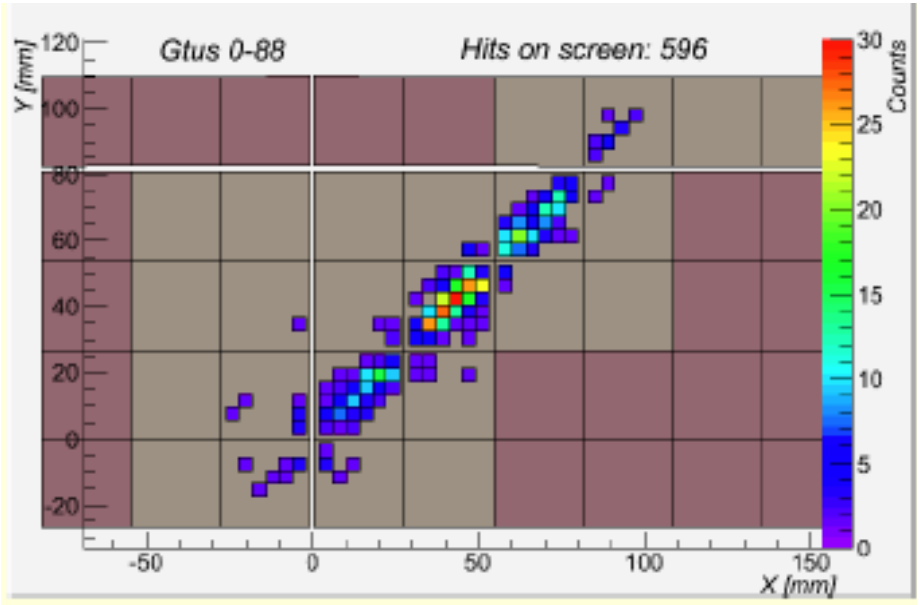
1 GTU = 2.5μs

Background = 500 ph / m^2 sr ns (from Tatiana satellite)

Fast signal: ~50-150μs

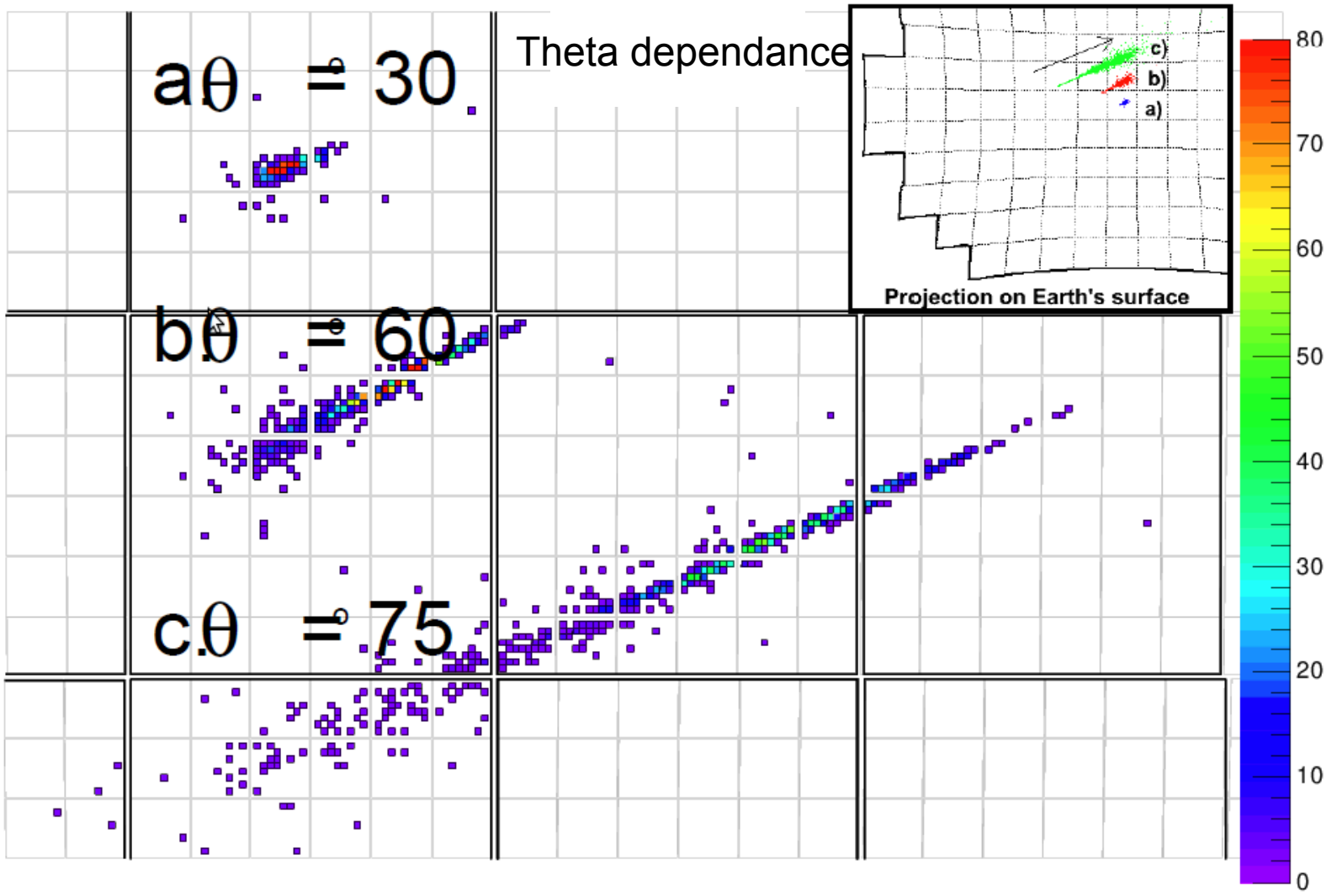
Signal for a p shower (60 deg, 10^{20}eV)





ΔE/E < 30% for ~90% of events

The observation technique



JEM-EUSO Performance: Annual Exposure

Depends on zenith angle and energy …

and is determined by four factors:

$$TA \times \eta \times k \times l$$

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

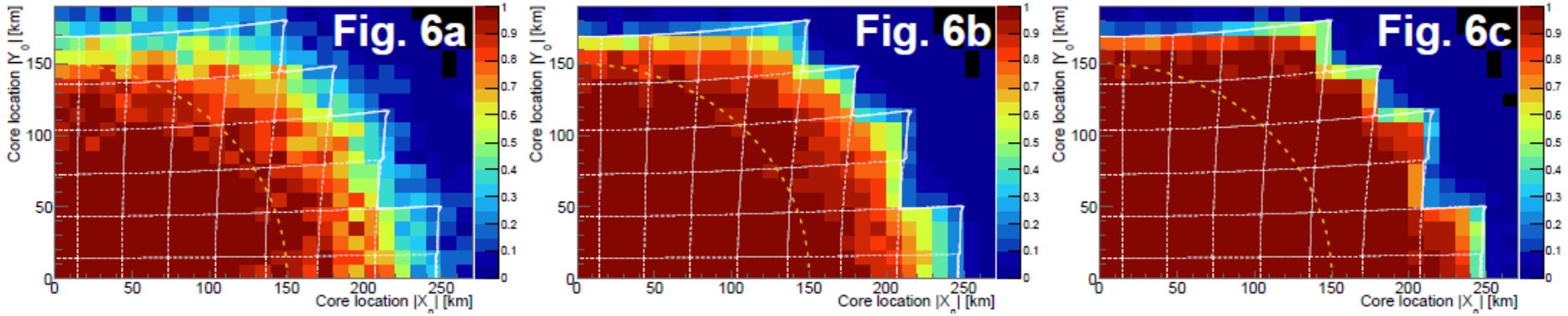
$\eta \rightarrow duty\ cycle$ — **Determined by the background (and operation)**

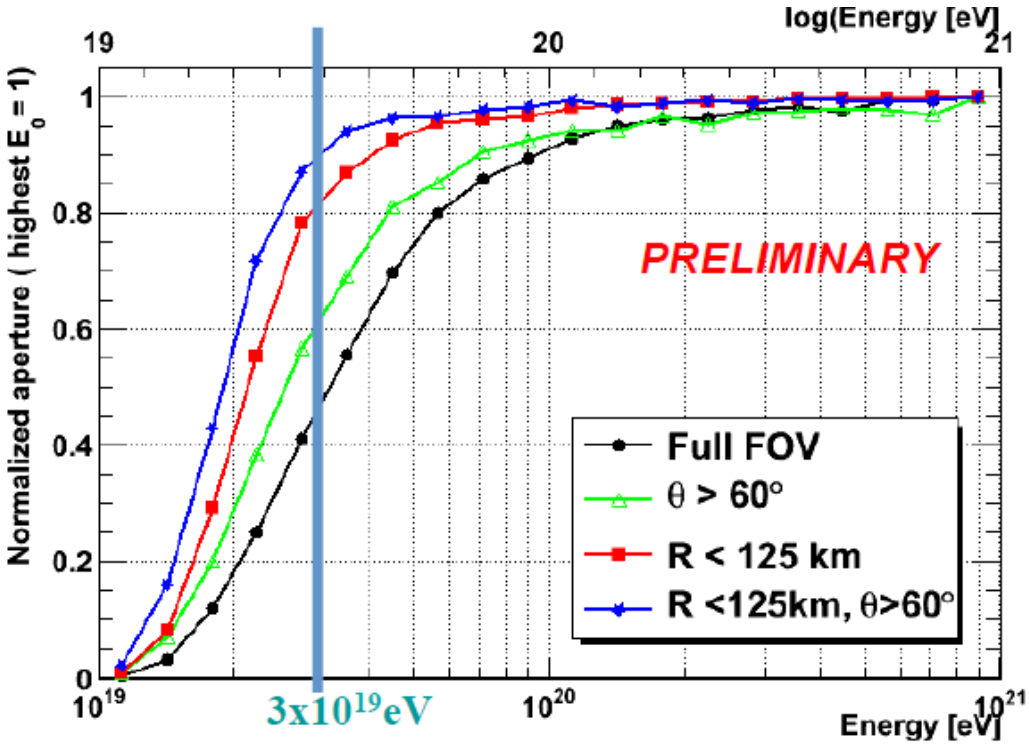
$\kappa \rightarrow cloud\ impact$ — **Determined by the cloud coverage**

$l \rightarrow citylights\ \&\ lightnings$ — **Local effects which limit the aperture**

JEM-EUSO Performance: Efficiency

E > 4·10¹⁹eV; Θ > 60° | **E > 5.5·10¹⁹eV** | **E > 10²⁰eV**



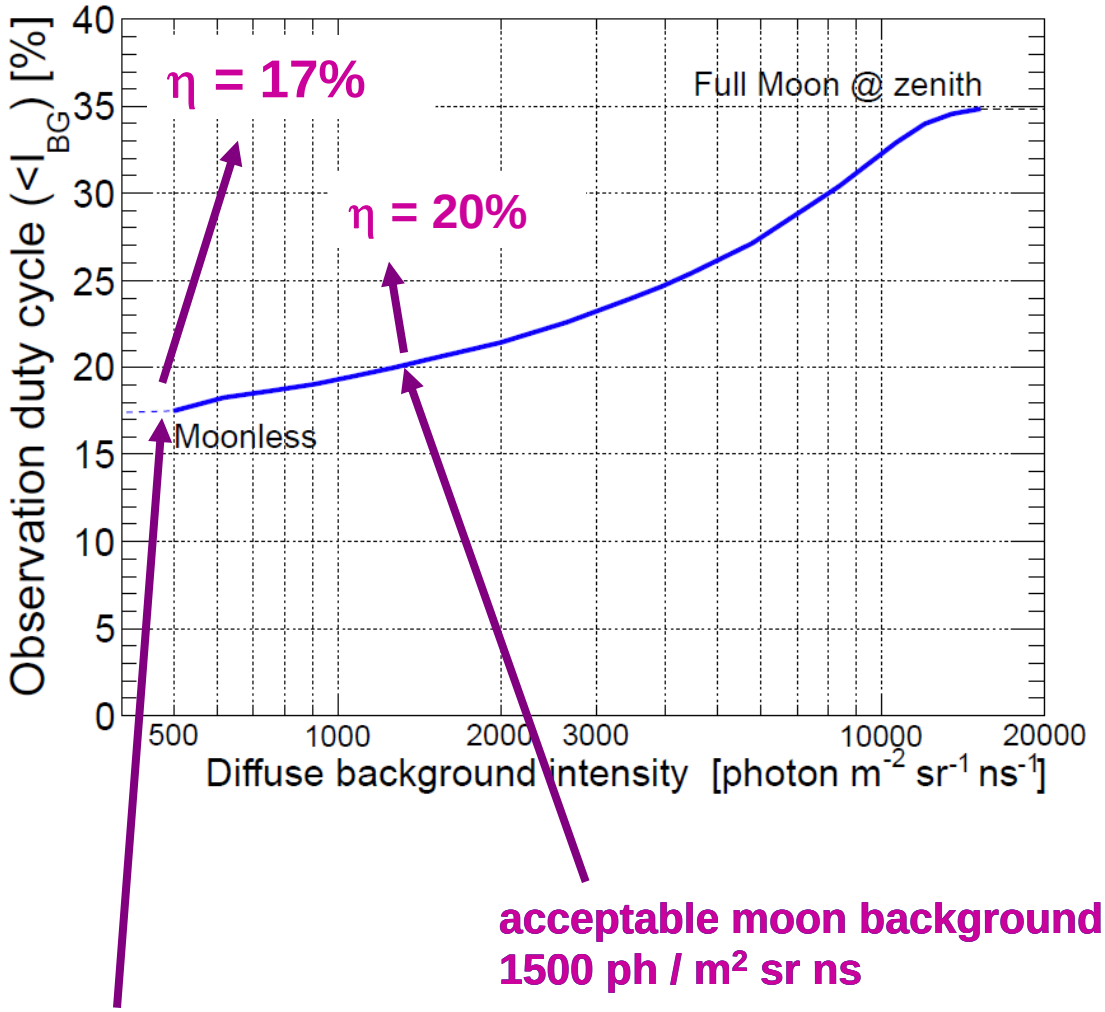


Trigger Efficiency

- **100% at E = 4·10¹⁹eV when Θ> 60° and R < 150 m**
- **90% at E = 10²⁰eV when full FoV**

Including bg = 500 ph / m² sr ns (Tatiana satellite)

JEM-EUSO Performance: duty cycle



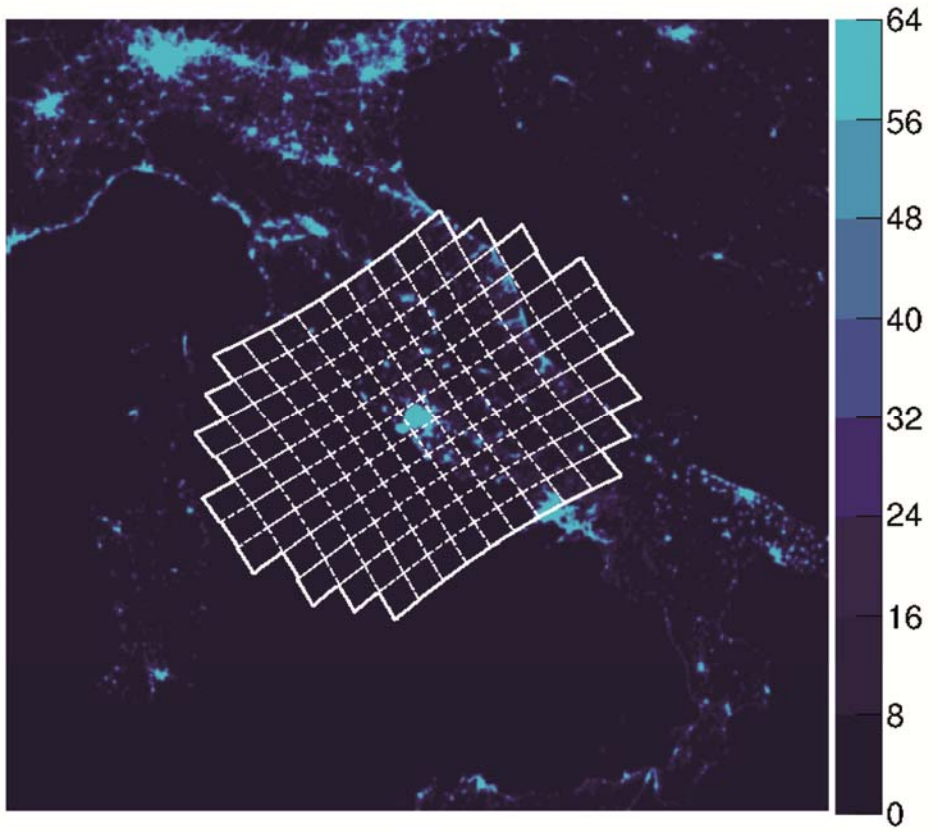
acceptable moon background:
1500 ph / m² sr ns

Night glow background:
500 ph / m² sr ns

Duty Cycle

- **No moon: ~17%**
- **Accepting little moon light: ~20.5%**
  (from analytical calculations)

JEM-EUSO Performance: city lights & lightnings



CITY LIGHTS:

~ 7% (DMSP data)

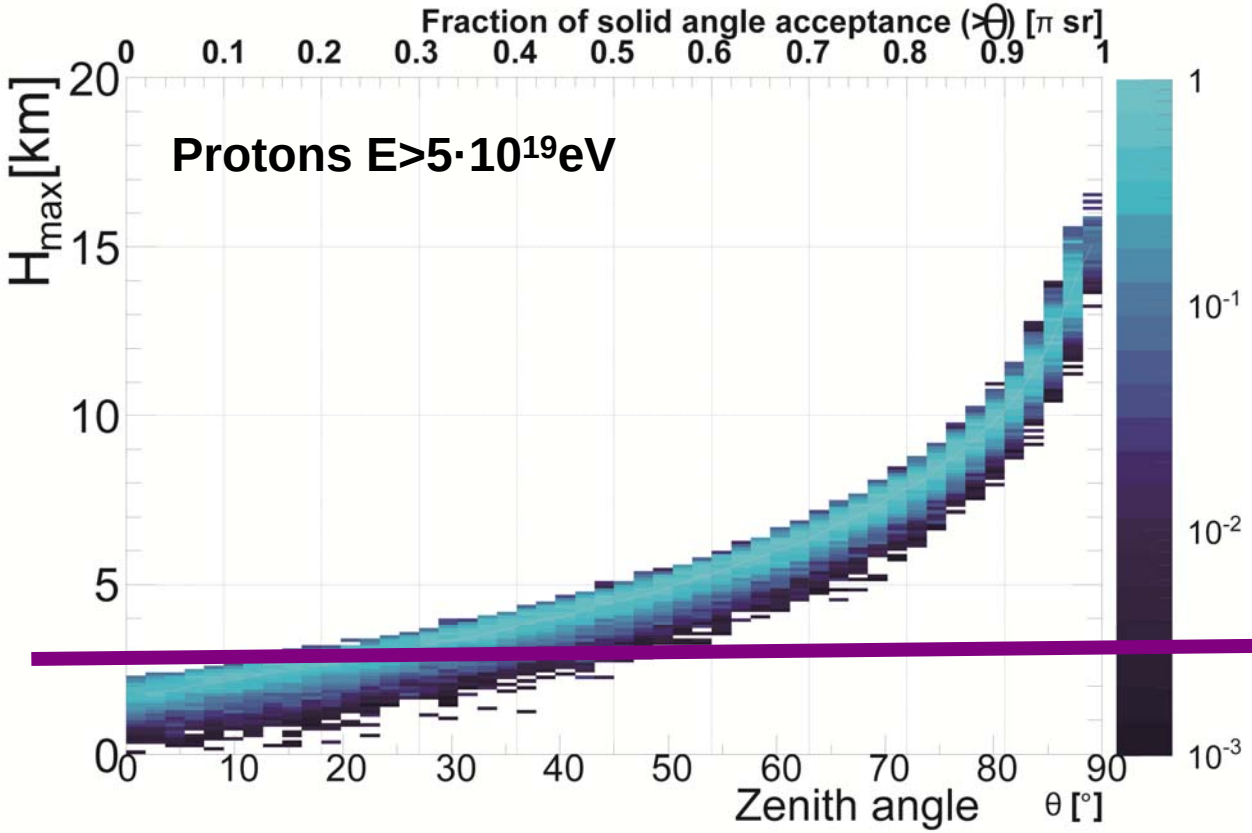
LIGHTNINGS:

~ 2% (Tatiana data)

➔ *l* = 91%

$$l \rightarrow citylights \,\&\, lightnings$$

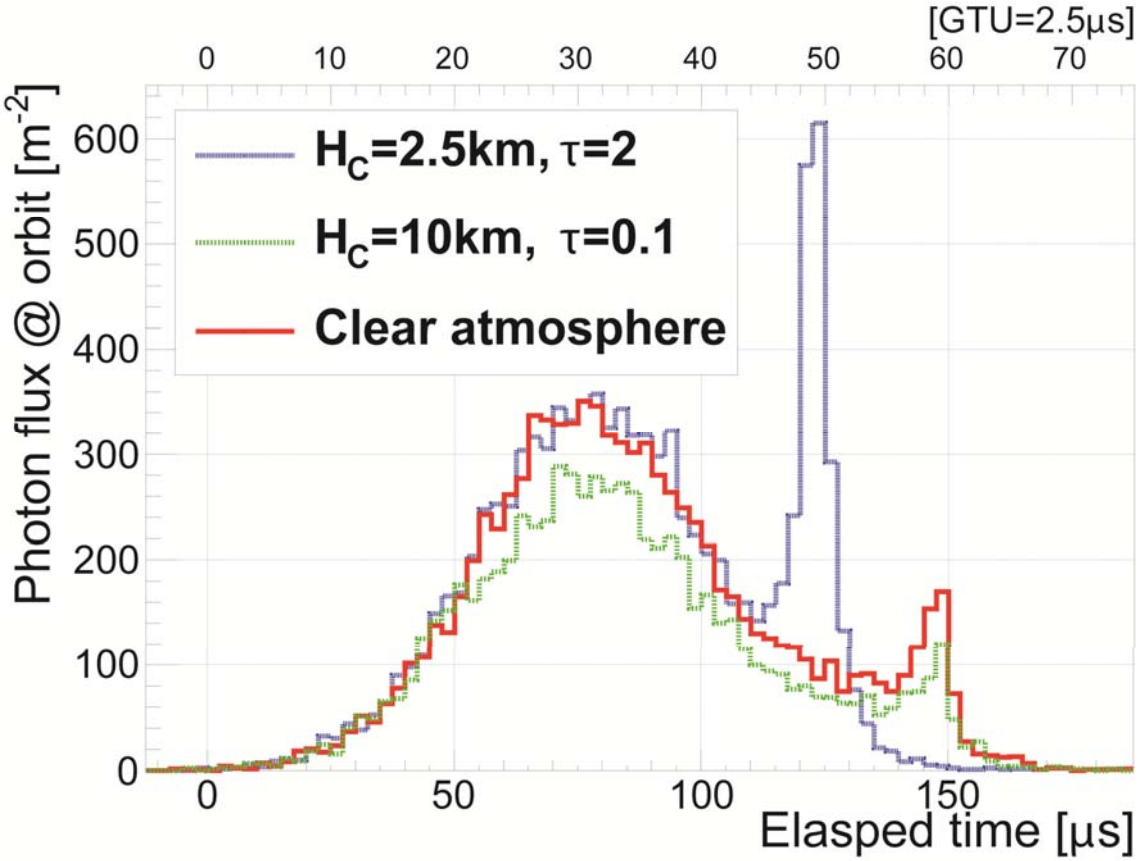
JEM-EUSO Performance: cloud impact



3 km

➔ **Most EAS relevant for JEM-EUSO reach maximum above the typical cloud altitudes!**

JEM-EUSO Performance: reconstruction with clouds



- shower profiles are attenuated for optically thin clouds (eg. cirri).
- optically thick clouds (eg. strati) block photons emitted below cloud
- cloud reflected Cherenkov light improves the reconstruction

JEM-EUSO Performance: cloud coverage

Clear sky ~ 31%
Green band ~ 60%

Cloud top

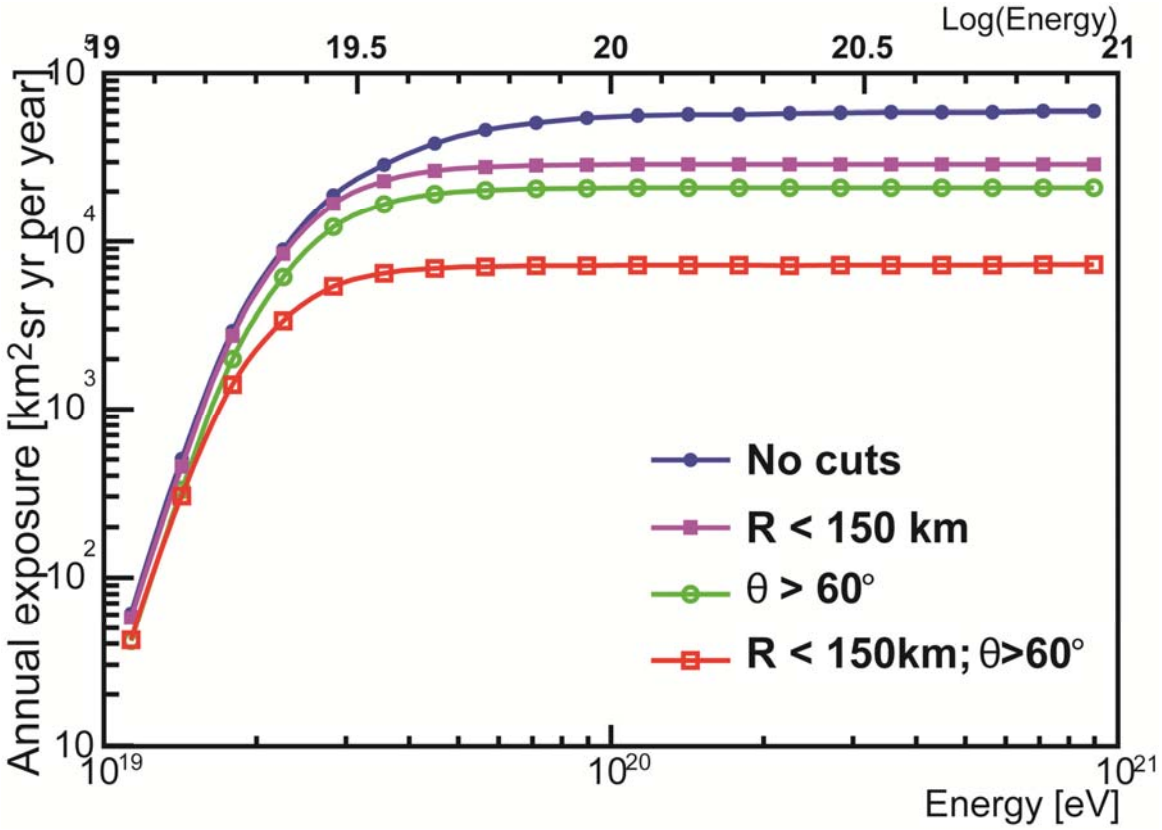
Optical Depth

	<3.2 km	3.2-6.5 km	6.5-10 km	>10 km
OD>2	16	5.9	8.6	5.0
OD:1-2	6.0	3.0	4.2	2.5
OD:0.1-1	6.5	2.0	3.2	5.0
OD<0.1	31	<0.1	<0.1	1.2

- **Occurrence of clouds (in %) between 50° N and 50° S on TOVS database**
  (Confirmed by ISCCP,CACOLO & MERIS database)

➔ **In ~72% of the cases the UV track including X_{max} is observable**

JEM-EUSO Exposure (…Nadir mode)



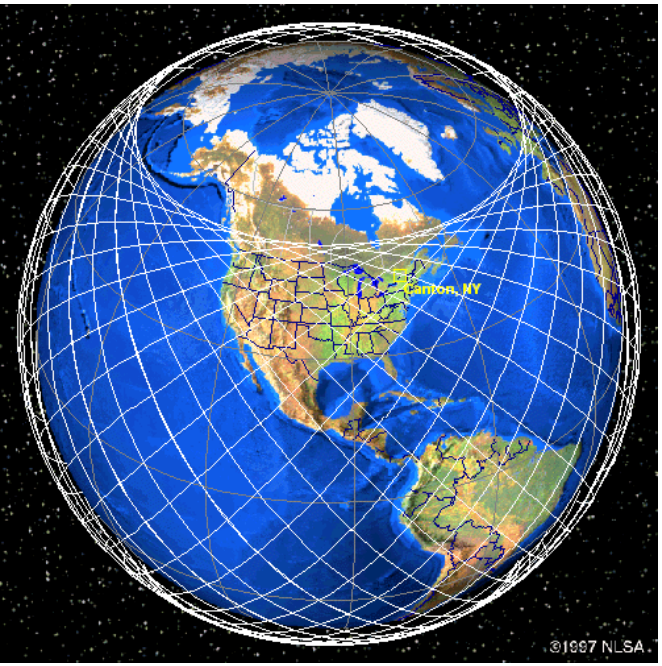
60,000 km²sr yr

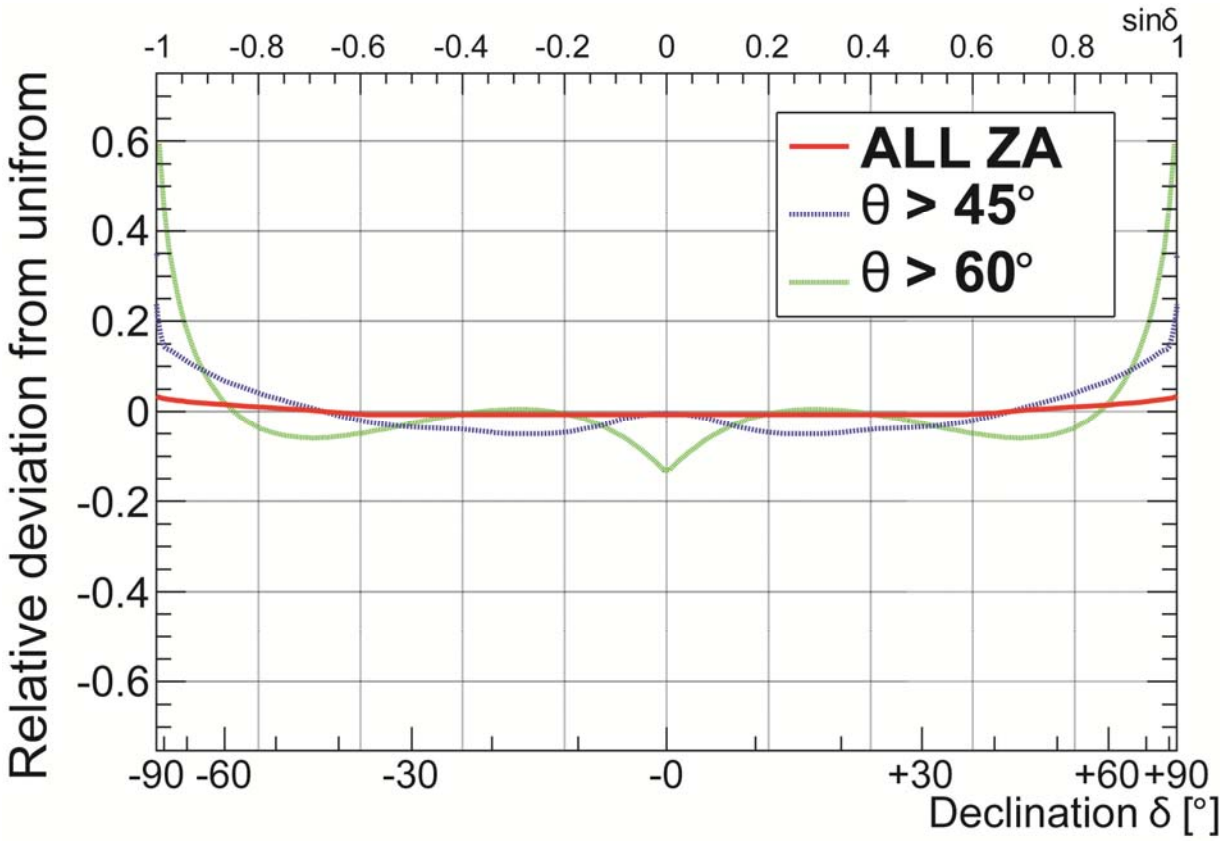
7,000 km²sr yr

$$TA \times \eta \times k \times l$$

- **With tight geometrical cuts a direct comparison with ground-based observatories possible**
- **full FOV provides about one order higher exposure than Auger at higher energies**
- **When accepting higher BG level improvements possible**

JEM-EUSO: aperture





- **Uniform coverage of both hemispheres!**

JEM-EUSO: status funding agencies

- *ESA:* JEM-EUSO is being studied (since 2010) as a project of the ELIPS program. ESA acts toward a coordinated interagency effort.
- ROSCOSOMOS: *Tsniimash (Roscosmos ISS) has expressed a clear interest* in pursuing a wider participation of Russia in JEM-EUSO; now with endorsement of the Scientific Committee.
- *NASA:* US proposal to SALMON AO (2011) was not selected. ISS resources are the key item. New proposal to the APRA program has been accepted, for both, resources for the EUSO Balloon and for the main mission.
- *JAXA:* They encourage the participation of ROSCOSMOS but still consider NASA an essential partner. (Japan manages its participation to the ISS via NASA.) Collaboration with TA is very important.
- *In the countries different level of funds:* EUSO Balloon and TA-EUSO running at full speed, in parallel phase A study of the main mission.

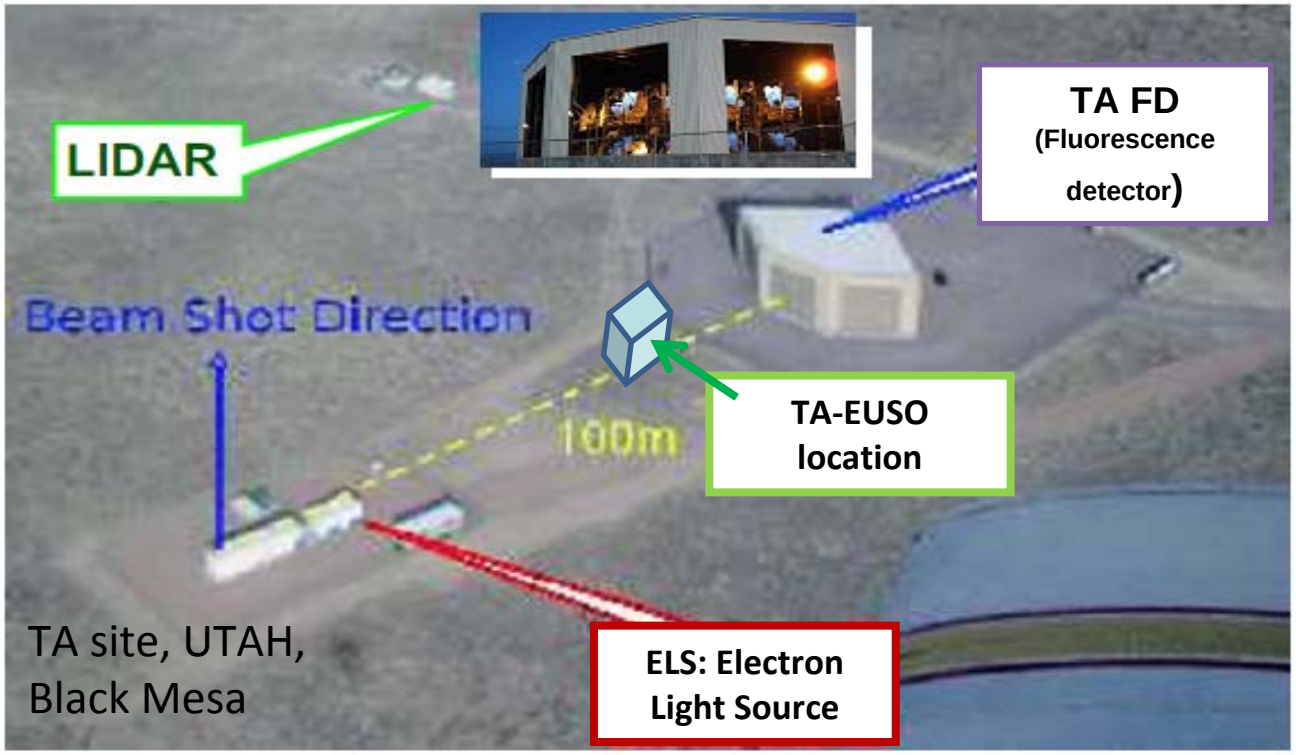
?

TA-EUSO
Cross-calibration tests at Telescope Array site, Utah

Main purpose: calibration using existing FD telescope

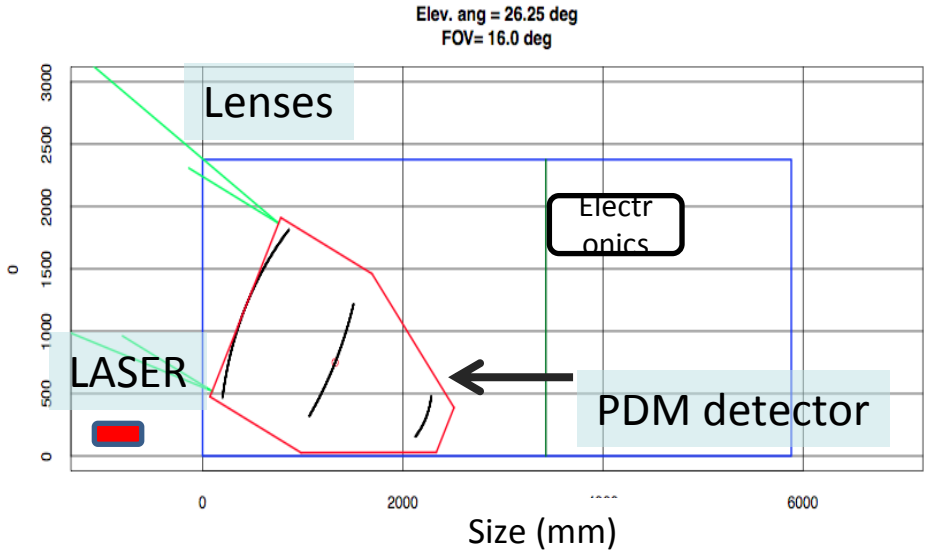
- **Lidar and electron beam ➔ absolute calibration**
- **Few showers in coincidence with TA**
- **Later repeat also at the Pierre Auger Observatory**

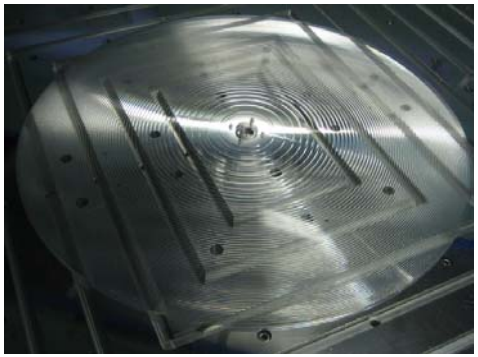
Operation early 2013!

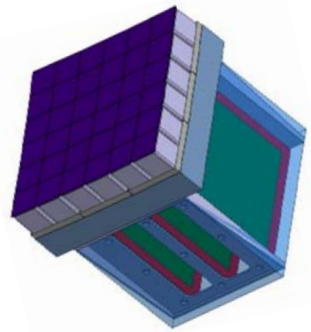


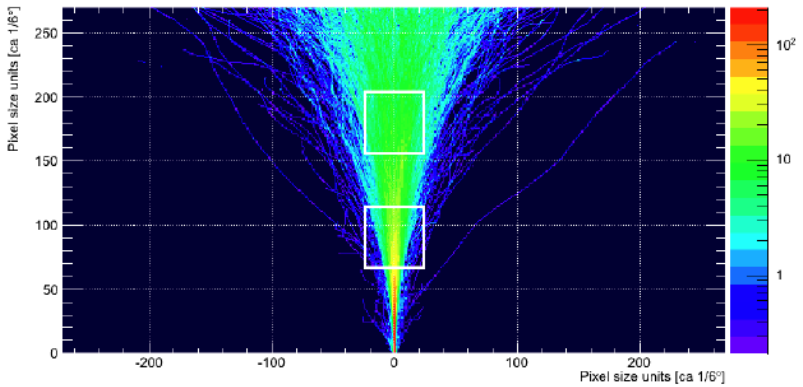
TA-EUSO
Cross-calibration tests at Telescope Array site, Utah

- 2 (squared 1 m^2) Fresnel Lenses ➔ FoV = 8 degree
- focal surface: 1 PDM (36 MAPMT, 2304 pixels)









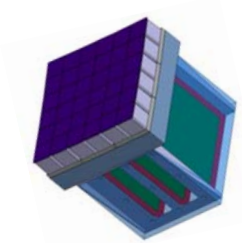
Simulation of UV photons of TA ELS
Squares: FoV of the EUSO-Ground telescope.

EUSO-Balloon
JEM-EUSO prototype at 40km altitude

Main purpose: Background measurements and engineering tests

- **Engineering test**
- **UV-Background measurement**
- **Air shower observations from 40 km altitude**

First flight: 2014!



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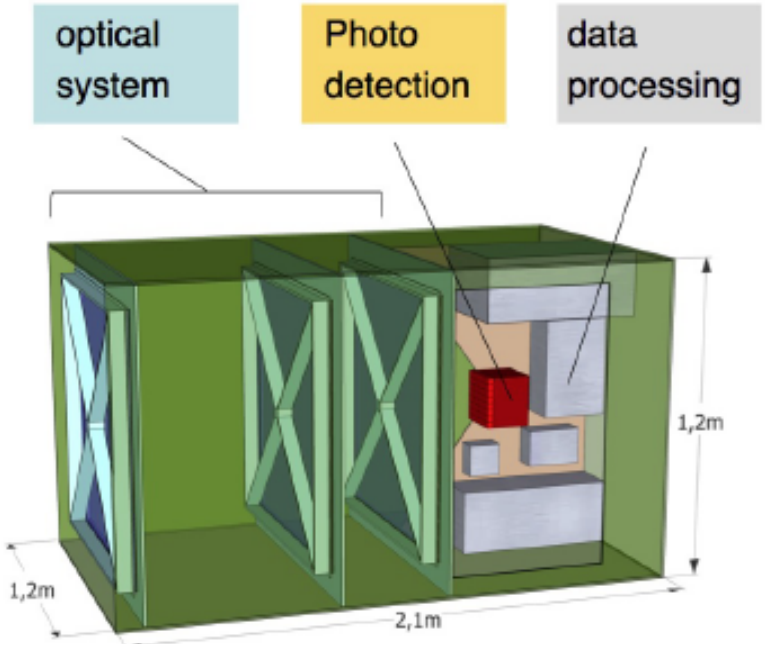
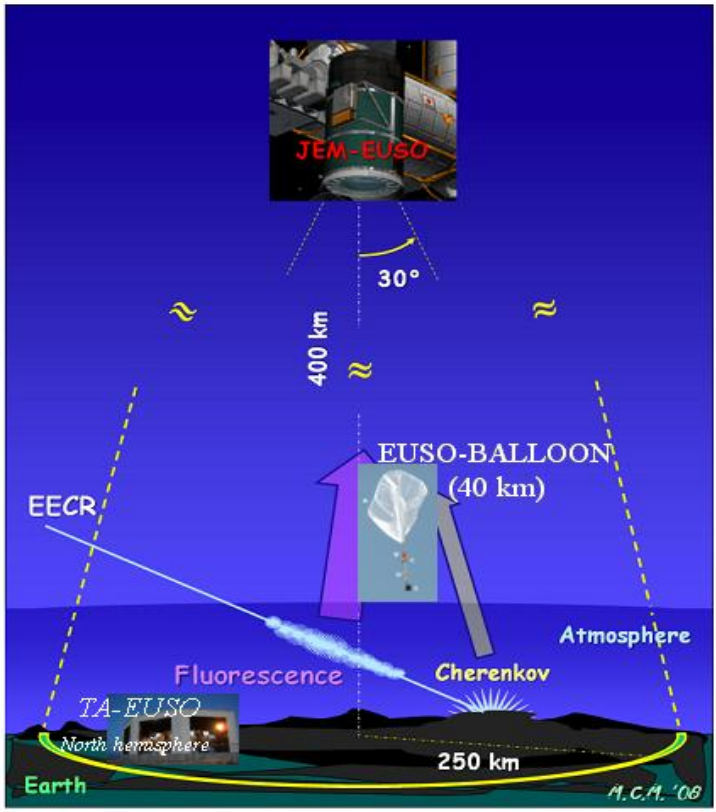
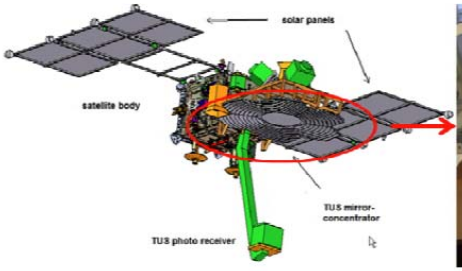


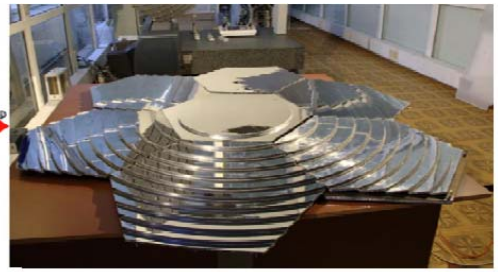
Summary EUSO-Balloon

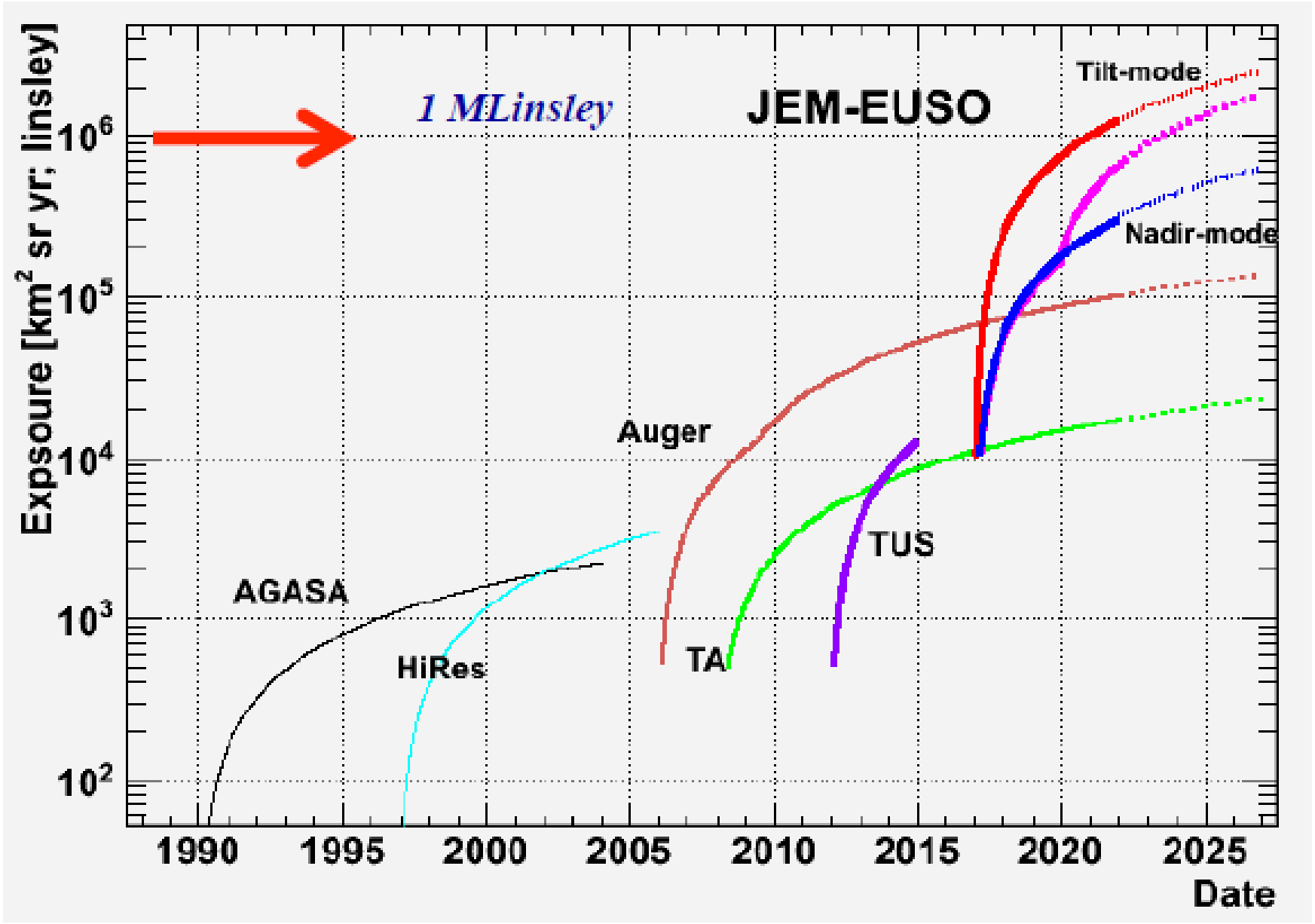
- **Study of EECR from**
  - **Ground (Utah) ➔ early 2013**
  - **Balloon (40 km) ➔ 2014-15**
  - **Space (ISS) ➔ launch 2017**



- TUS/KLYPVE on Lomonosov satellite launch 2012/13
  - technical pathfinder of EUSO
  - survey of UV-background






1 MLinsley
JEM-EUSO
Tilt-mode
Nadir-mode
Auger
TUS
TA
HiRes
AGASA
Exposure [km² sr yr; linsley]
10⁶
10⁵
10⁴
10³
10²
1990
1995
2000
2005
2010
2015
2020
2025
Date