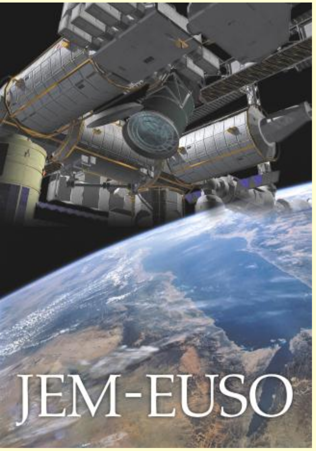
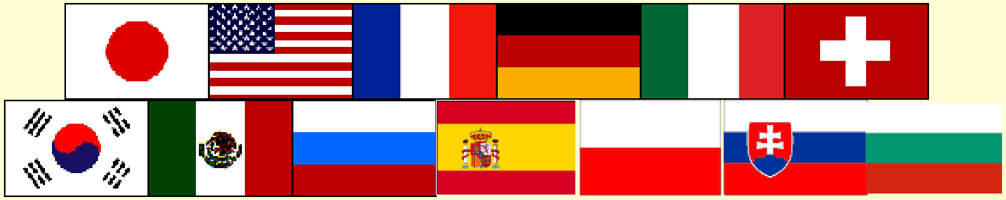




"Doing astronomy by looking downward"

"Ultra High Energy Neutrinos with JEM-EUSO"

*Andrea Santangelo**

Advanced Studies Institute, Riken, Wako

Kepler Center for Astro and Particle Physics,

Eberhard-Karls-Universität , Tübingen

**** Global Coordinator of the JEM-EUSO Collaboration***

Outline of the presentation

I. The JEM-EUSO Mission

Why from space and How?

What is JEM-EUSO?

Status of the mission

II. The science case: the Neutrino Universe at UHE

Why neutrinos at UHE?

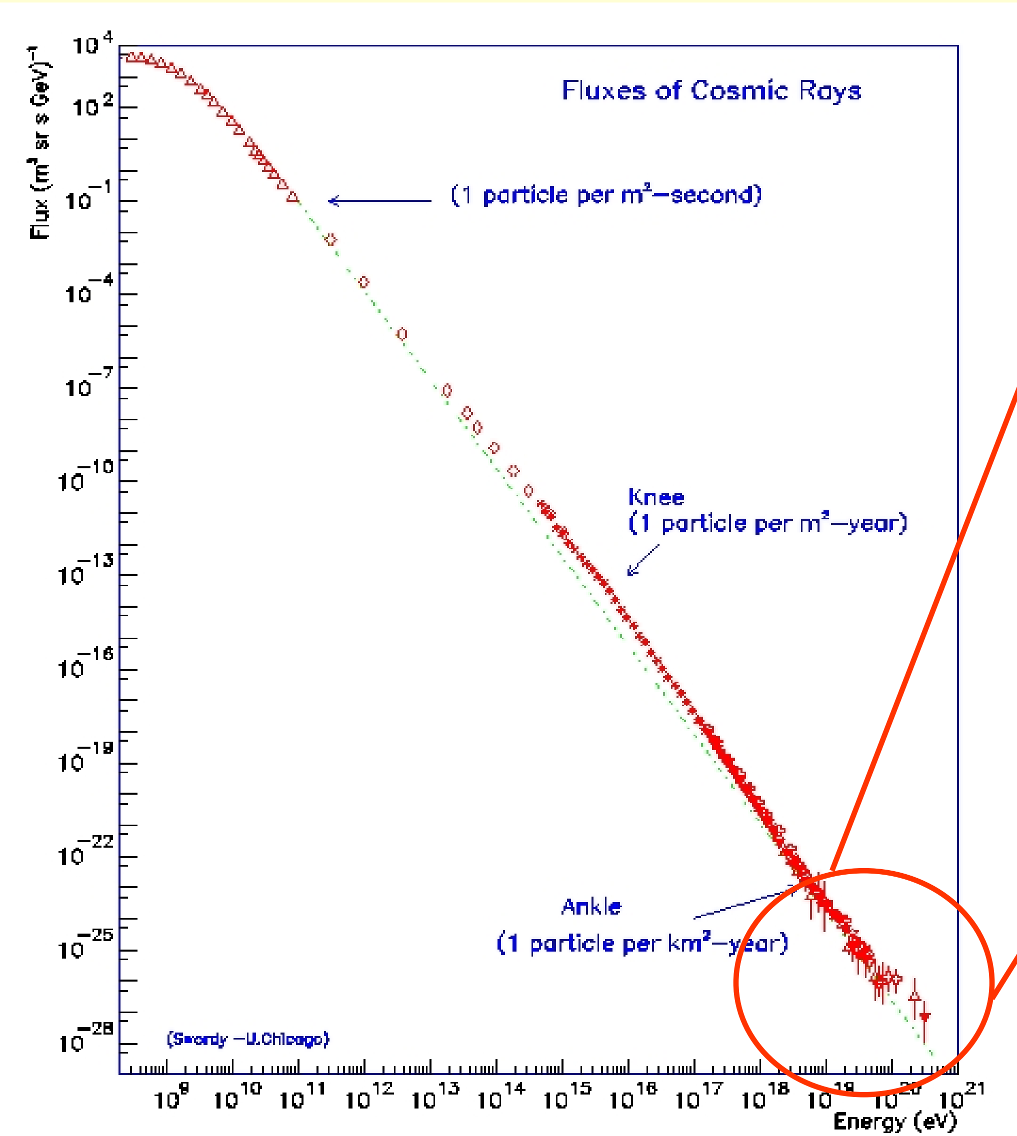
Perspectives for JEM-EUSO

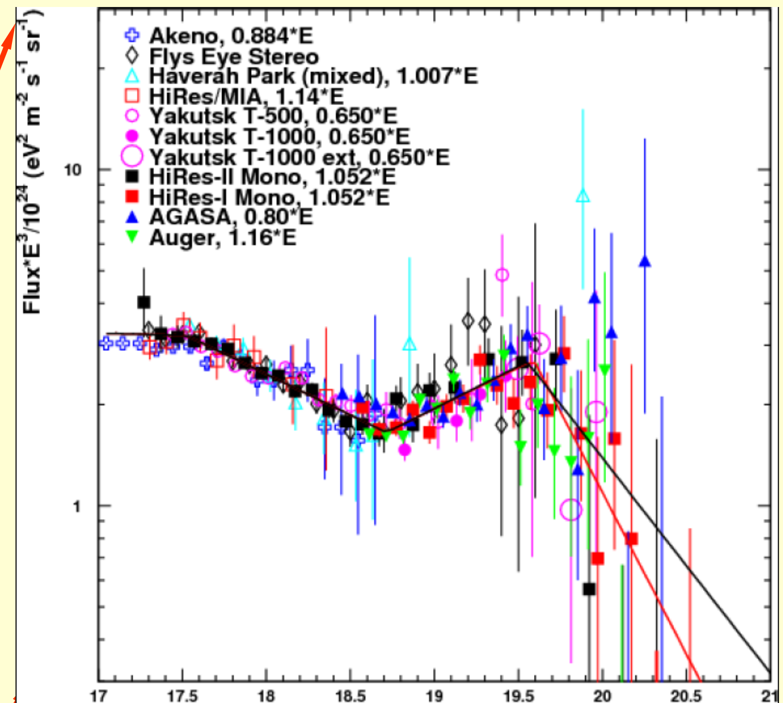
III. Conclusions

I. The JEM-EUSO mission

(…to explore the UHE Universe)

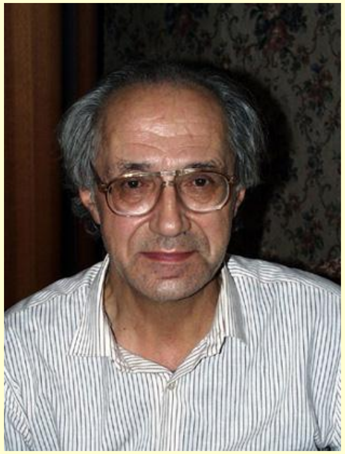
UHE → $E > (5\text{-}6) \times 10^{19}$ eV ($\sim 10^{16}$ keV)





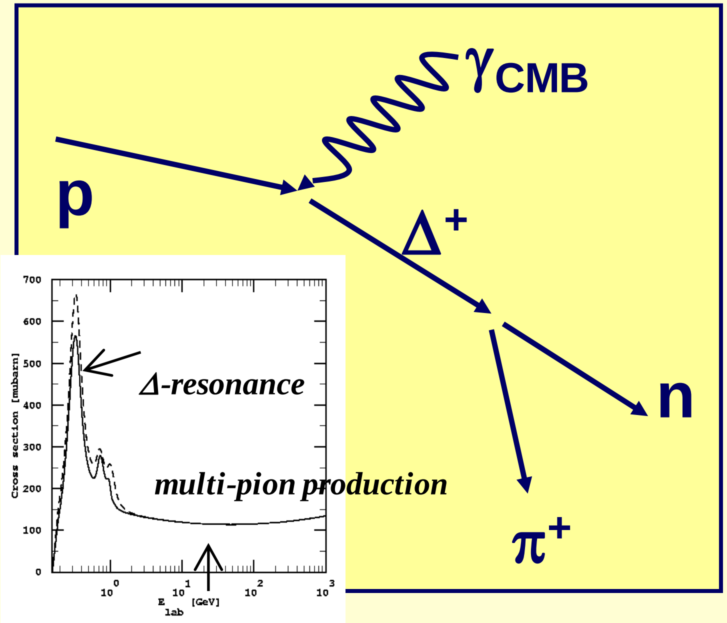
Their Origin, their Nature and even their Route to Earth presents an extraordinary puzzle

Highest energies: The GZK Effekt



Greisen (1966) and, *independently* Zatsepin & Kuz'min (1966)

Kenneth Greisen | **George Zatsepin** | **Vadim Kuzmin**



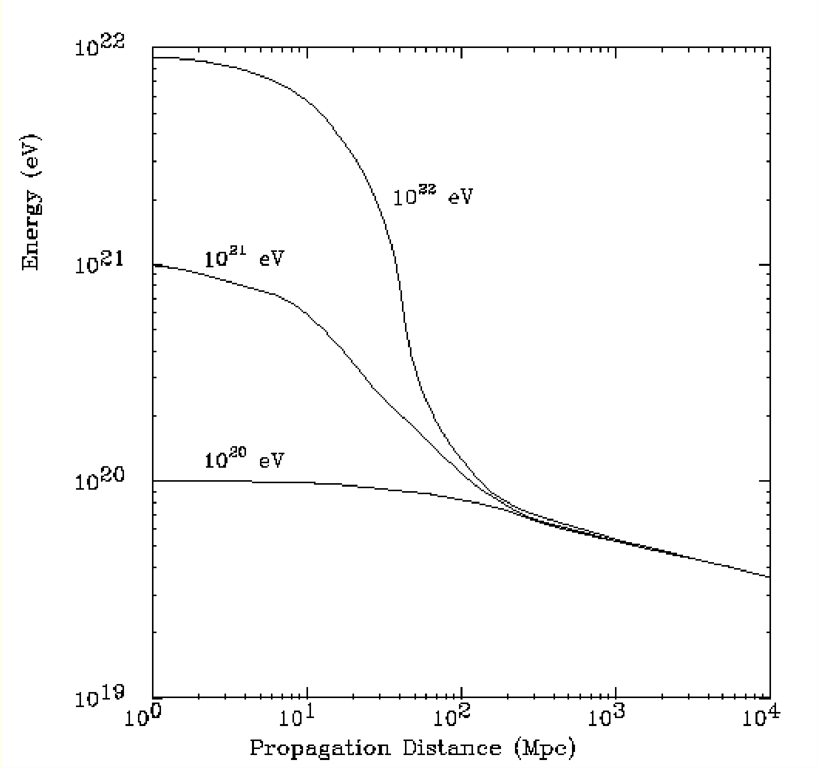
$$E_{th} = \frac{2m_N m_\pi + m_\pi^2}{4\varepsilon} \approx 5\times 10^{19}\,\mathrm{eV}$$

$$p + \gamma \rightarrow n + \pi^+$$

$$p + \gamma \rightarrow p + \pi^0$$

$$p + \gamma \rightarrow p + e^+ + e^-$$

Attenuation length, a limited horizon



$$\Delta E_p \approx 20\% E_p$$

$$l_{\mathrm{int}}$$ » 10 Mpc

$$L^{GZK}_{Hor}$$ » 100 Mpc

Nagano & Watson, Rev. Mod. Phys, Vol. 72, N° 3 (2000)

A + hn → (A-1) + N

A + hn → (A-2) + 2N

A + hn → A+ e^++e^-

Photodisintegration (Puget et al., 1976)

Pair production (Blumenthal, 1970)

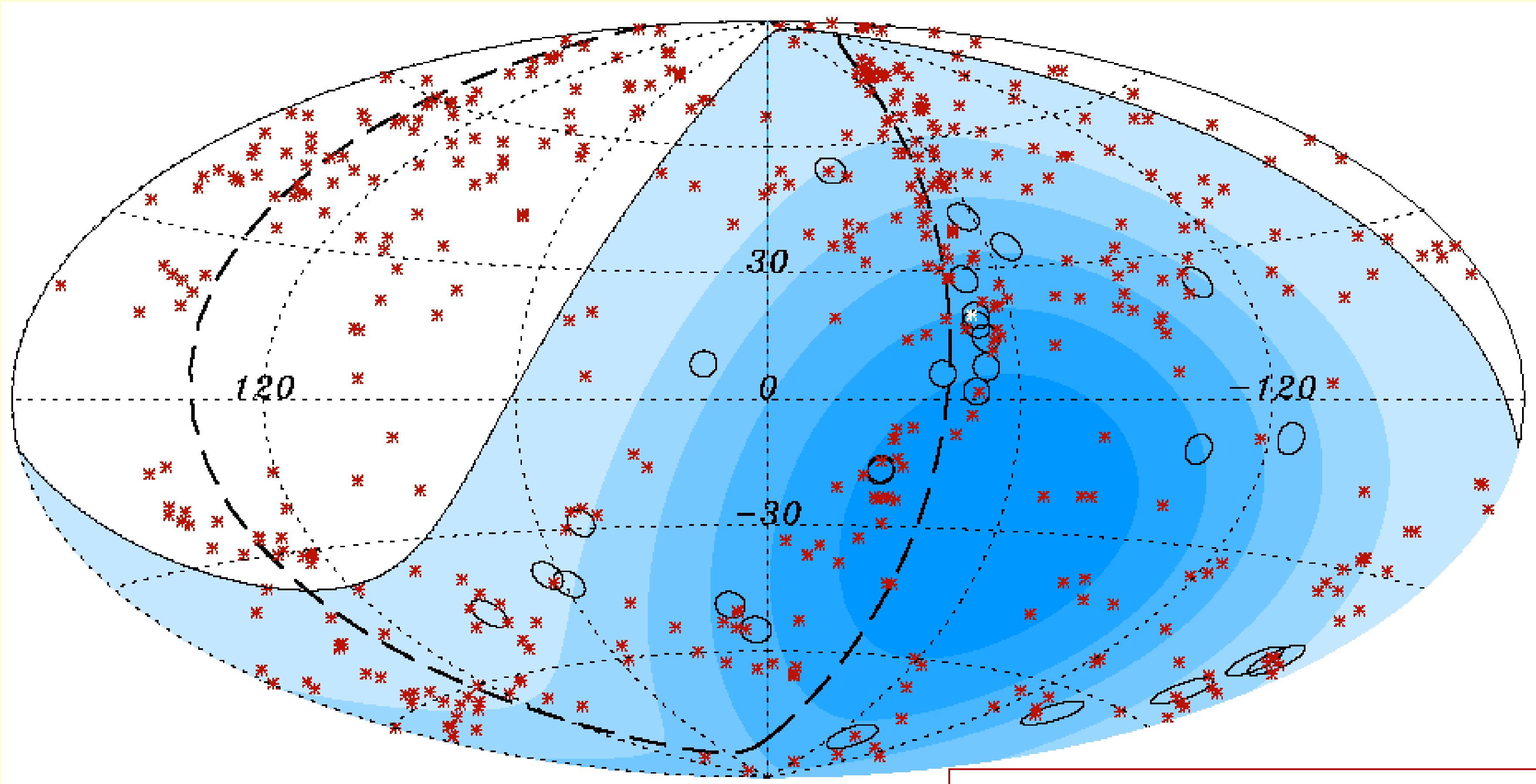
E ~ $2*10^{20}$ eV (nuclei)

GZK effect? May be…

A key result from Auger

The Auger Collaboration (2007)

Ang. Sep. ψ < 3.1° , z < 0.018 (75 Mpc) and E > 56 EeV



Observation anisotropy of UHE particles at E>5x10^{19} eV

Enables Particle Astronomy

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

EUSO

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
- 77 Institutions, more than 250 researchers
- RIKEN: Leading institution

Main Scientific Objectives (1)

- Main Objective: Astronomy and Astrophysics through the particle channel
  - *Identification of sources* by high-statistics arrival direction analysis (+multi-wavelength!)
  - *Measurement of the energy spectra* of individual sources (spectral shape, flux, power)

→ *Understand and constrain acceleration and emission mechanisms*

Physics and Astrophysics at $E>5.\times 10^{19}$eV

Exploratory Scientific Objectives (2)

- Exploratory Objectives: new messengers
  - *Discovery of UHE neutrinos* by neutrino discrimination and identification via X_0 and X_{max}
  - *Discovery of UHE Gammas* by discrimination of X_{max} due to geomagnetic and LPM effect

- Exploratory Objectives: magnetic fields
  - *Constrains on the galactic and local extragalactic fields*

→ *High discovery potential; tests of new physics models*

Take home messages:

Physics and Astrophysics at E>5. ×10^{19} eV

But also… Explore new physics in the energy range E≈1
10^{21}eV

Highest statistics and therefore largest exposures at extreme energies

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

Lower Energies are important for overlapping with current generation observatories with significant statistics…

$$E < 5 \times 10^{19} eV$$

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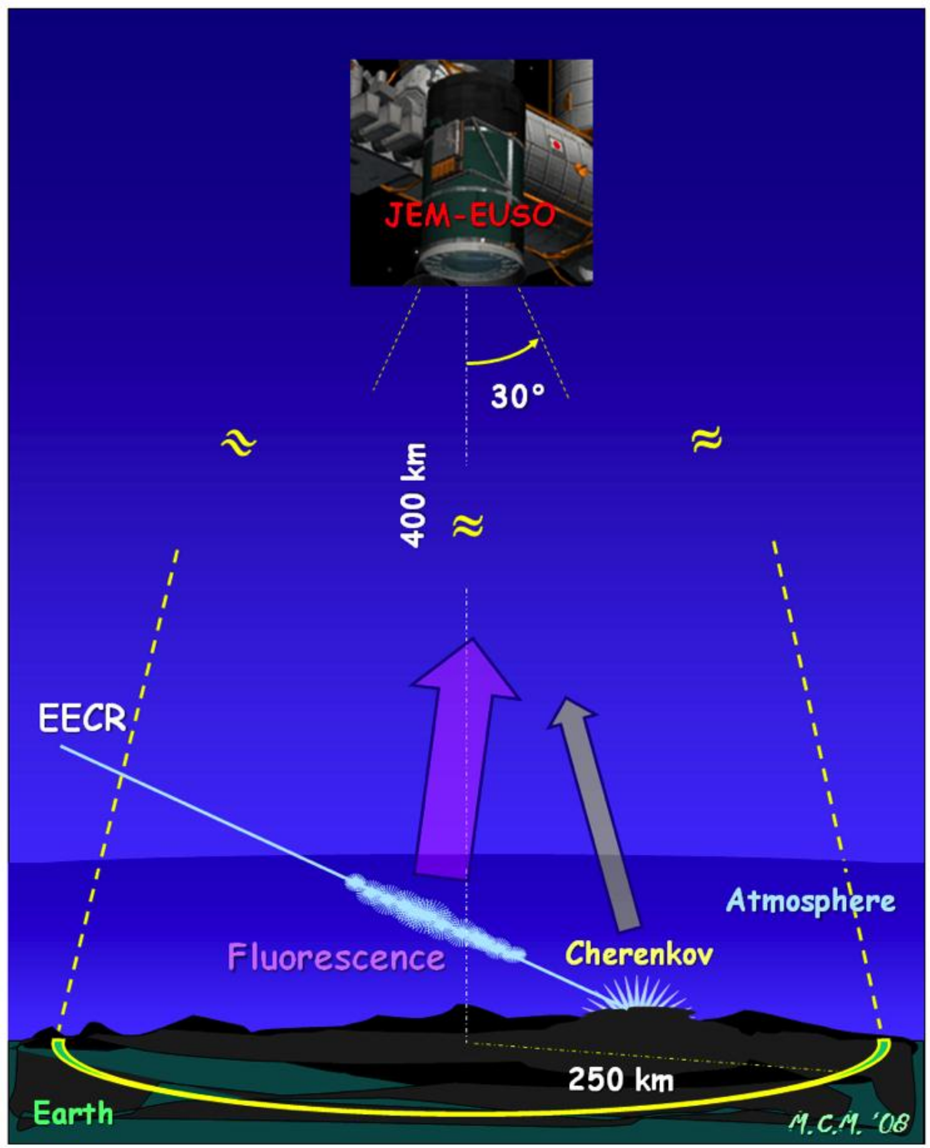
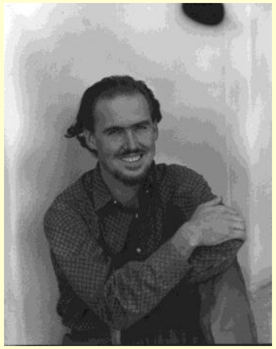
Kepler Center-Tü

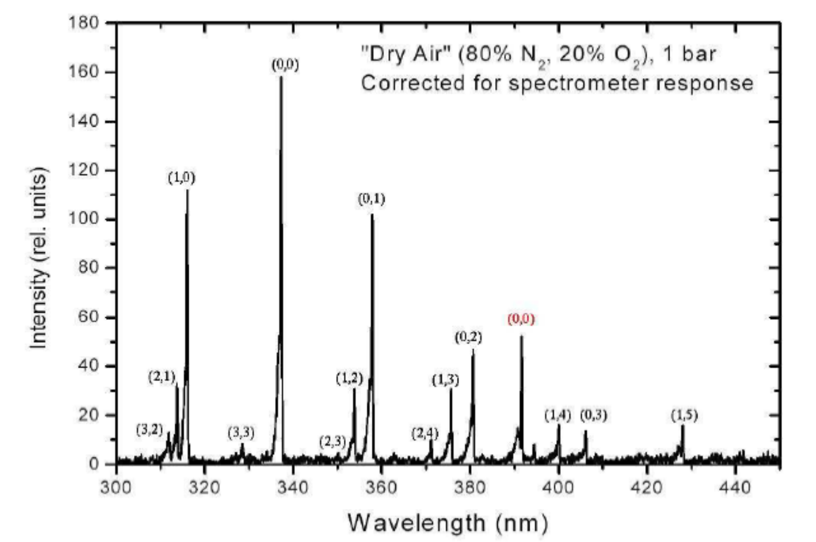
Observational Technique: fluorescence from space





J. Linsley

Y. Takahashi



330 - 400 *nm*, UV

Kakimoto et al., 1996   A. Bunner, 1967; Nagano, 2009;

$$e^- + N_2 \longrightarrow N_2^{*+} + e^- \ (+e^-)$$

$$e^- + N_2 \longrightarrow N_2^{*+} + e^- \ (+e^-)$$

$$N_2^{*+} + e^- \longrightarrow N_2^*$$

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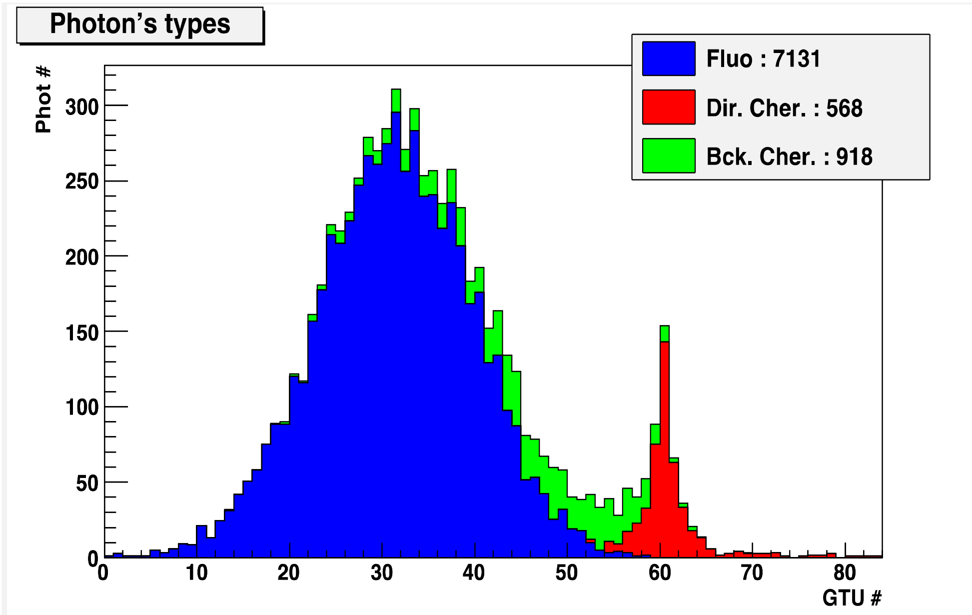
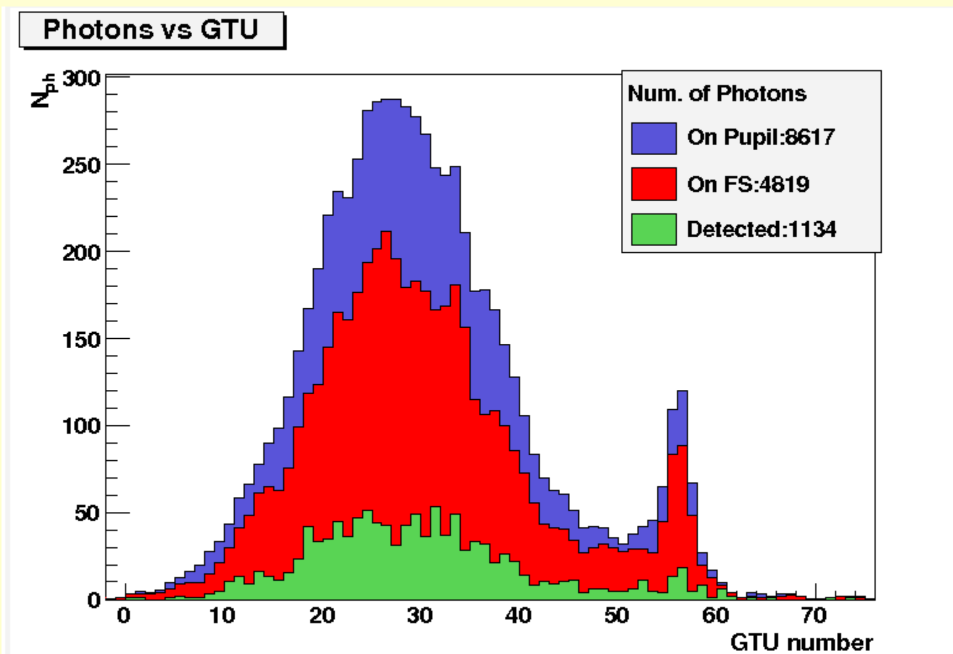


GTU time units



a) Fluorescence

b) Scattered Cherenkov

c) Direct (diffusively reflected Cherenkov)

$$1\ GTU = 2.5\ \mu sec$$

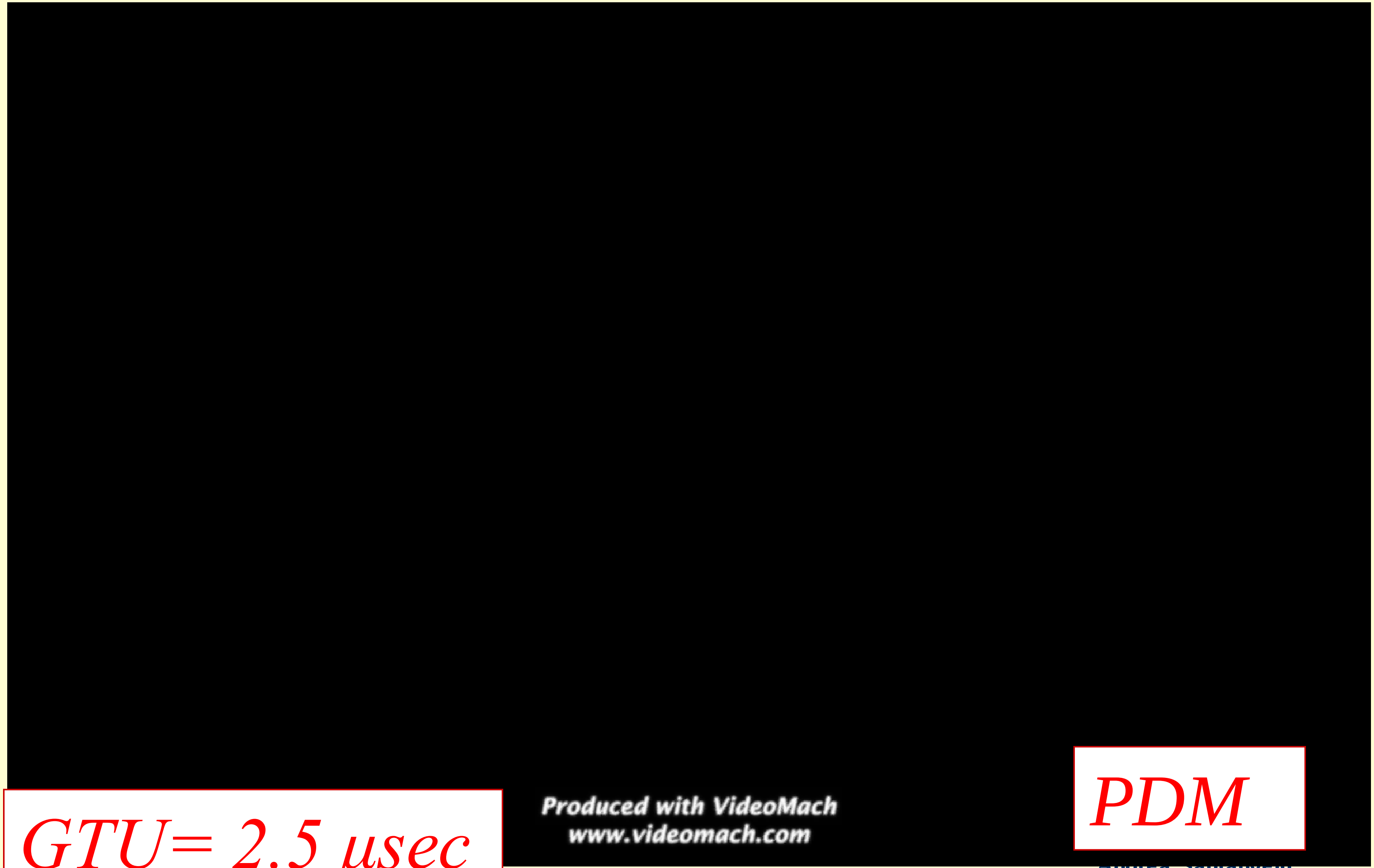
$$Back. = 500 / (m^2\ sr\ ns)$$

FAST SIGNAL

$$duration \approx 50 - 150\ \mu s$$

Simulation of the light profile observed at the entrance pupil (above) and throught the instrument using the ESAF code

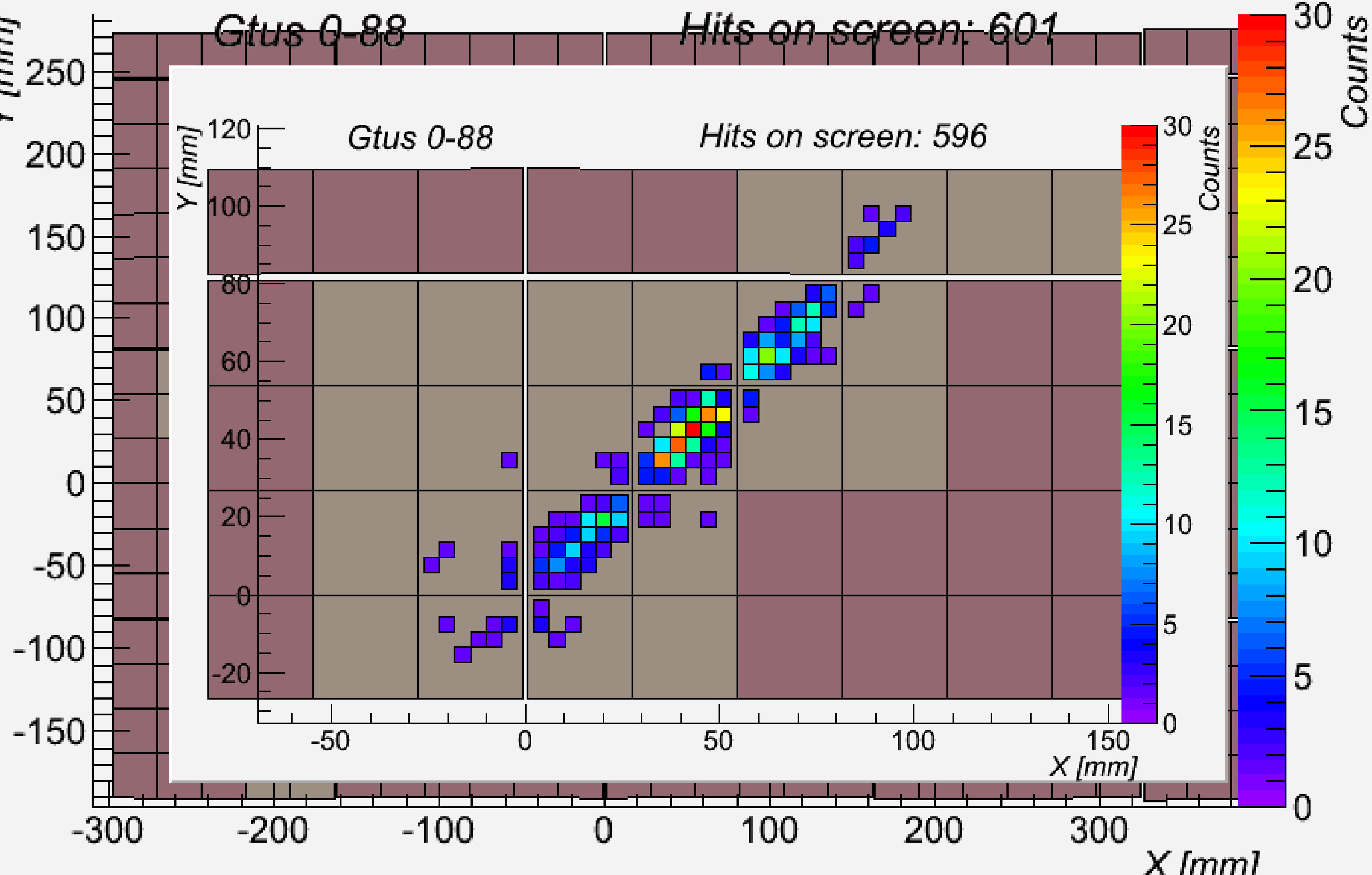
Proton Shower (60 deg, 10^{20}eV)



PDM

GTU= 2.5 μsec

Result of end-to-end simulation



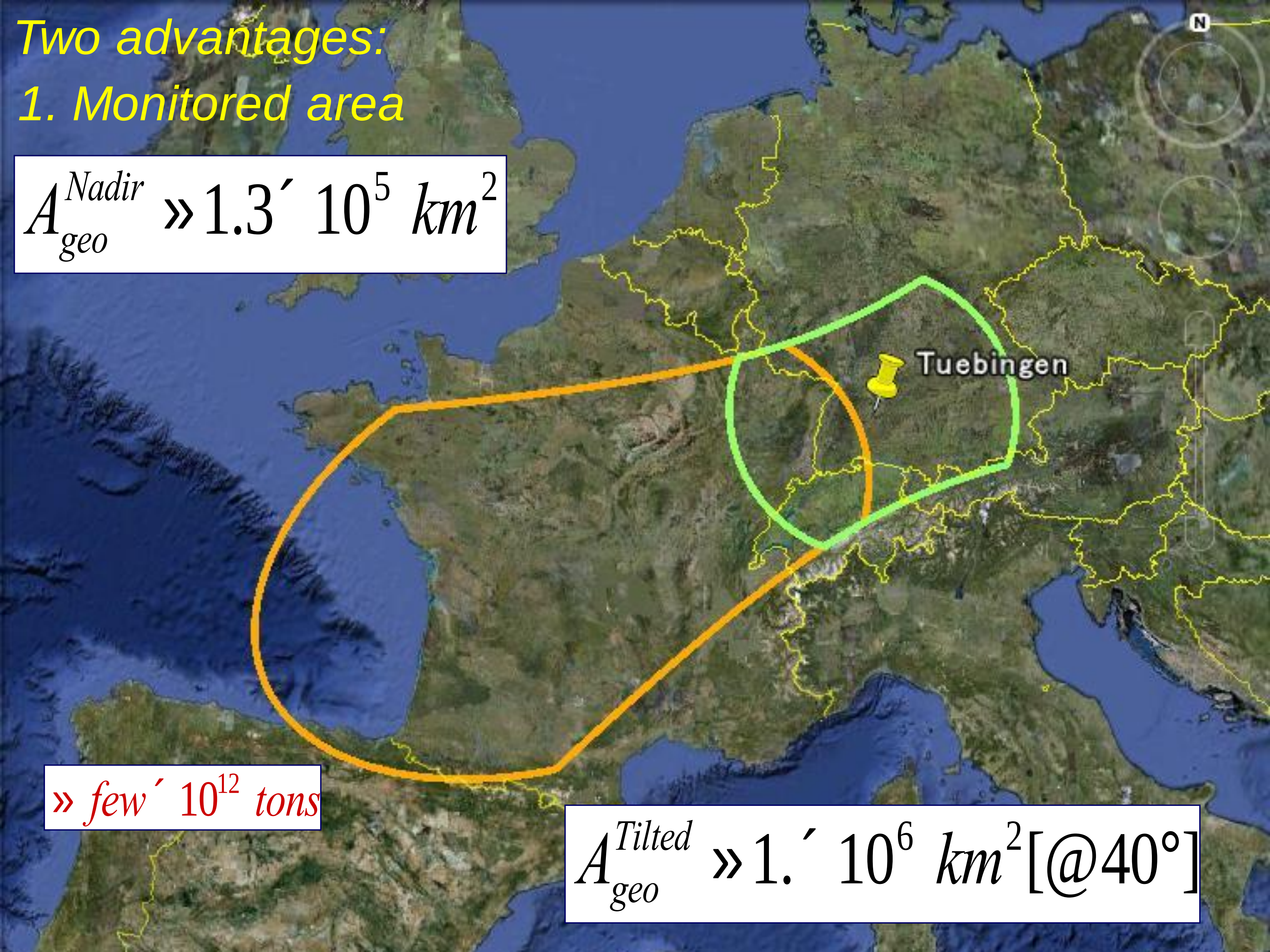
Two advantages:

1. Monitored area

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

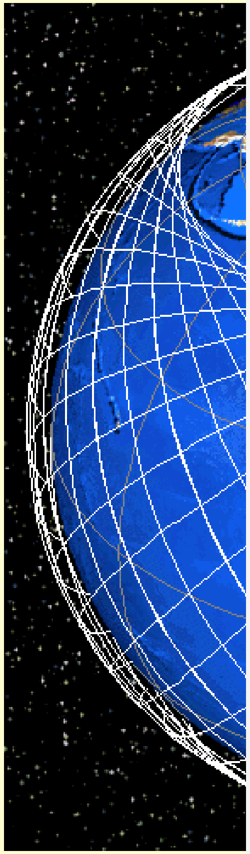
$$\approx few \times 10^{12}\ tons$$

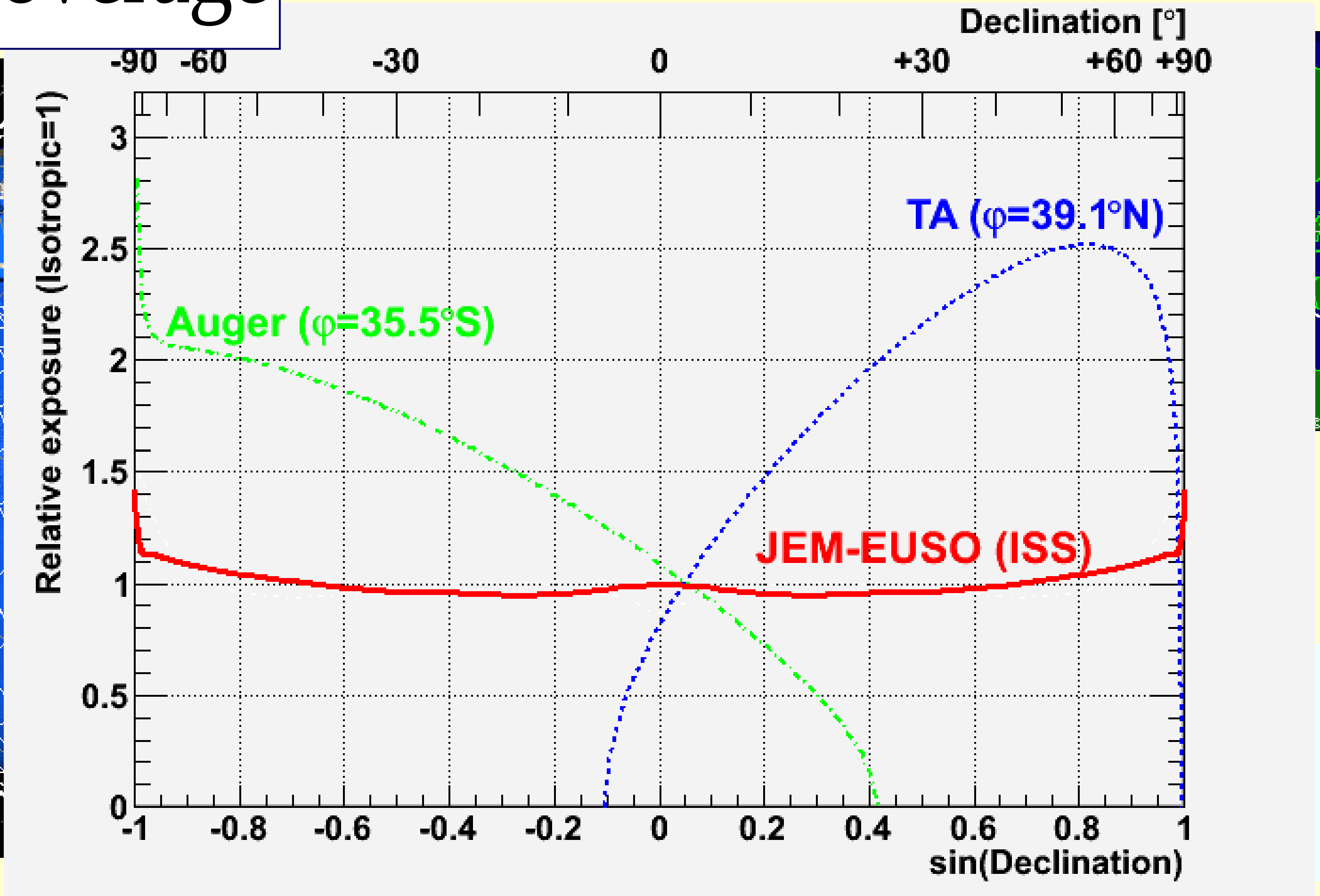
$$A_{geo}^{Tilted} \approx 1. \times 10^{6}\ km^{2} [@40°]$$

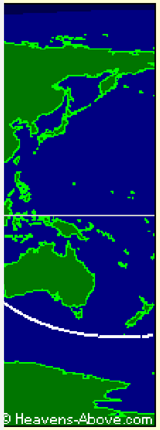


2. ISS Orbit→ Full sky Coverage…

4*p* coverage







… and uniform exposure

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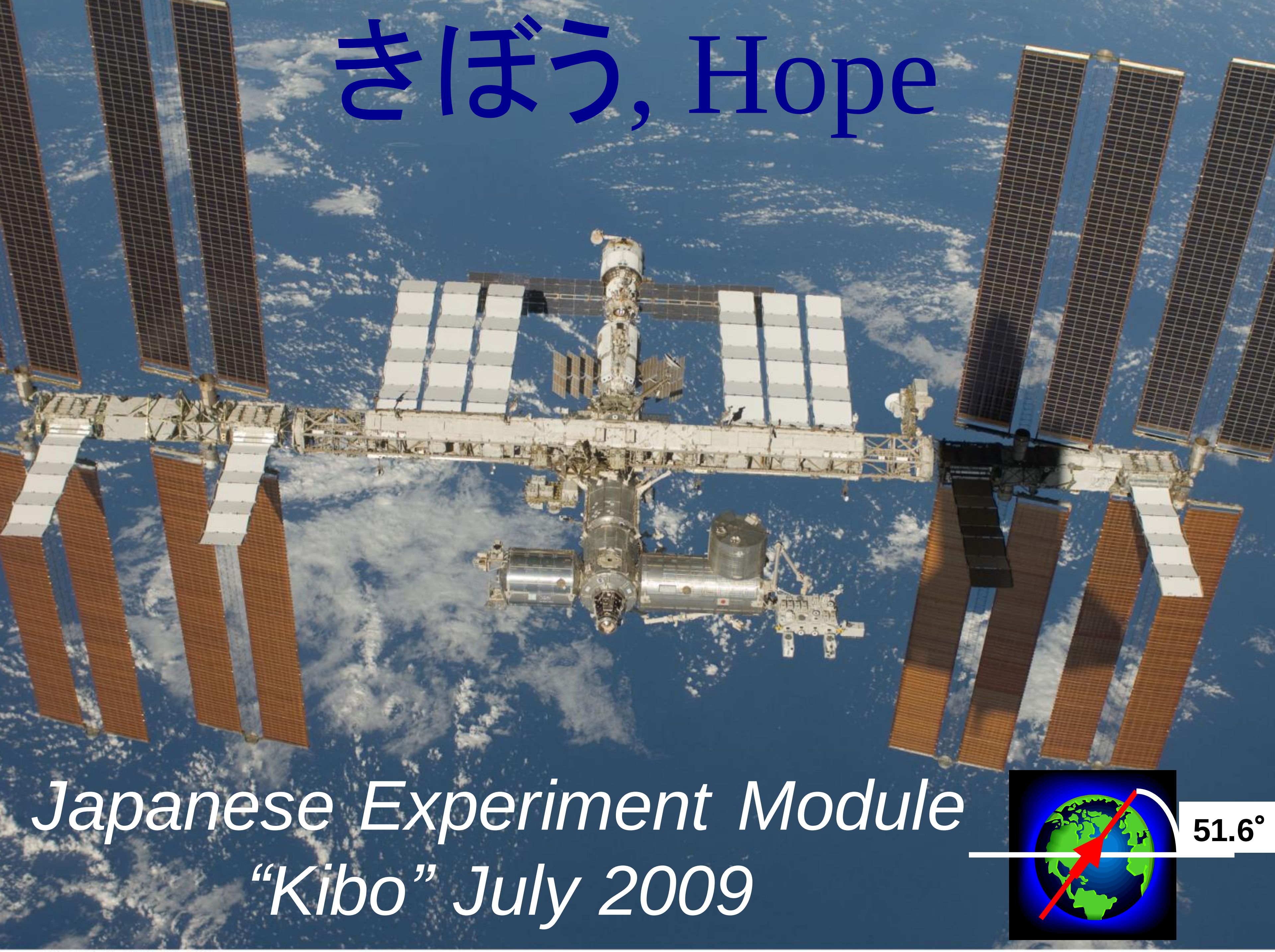
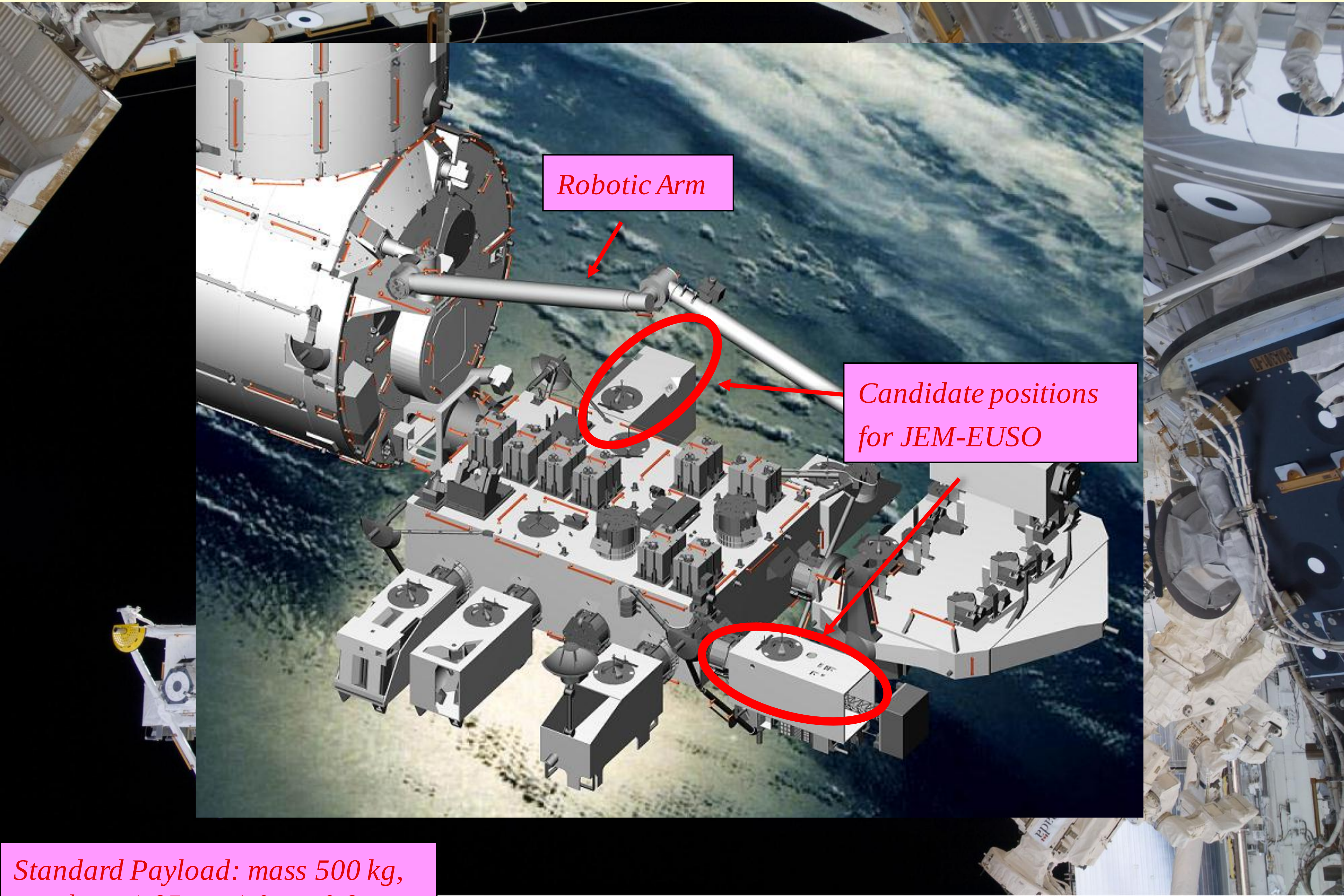
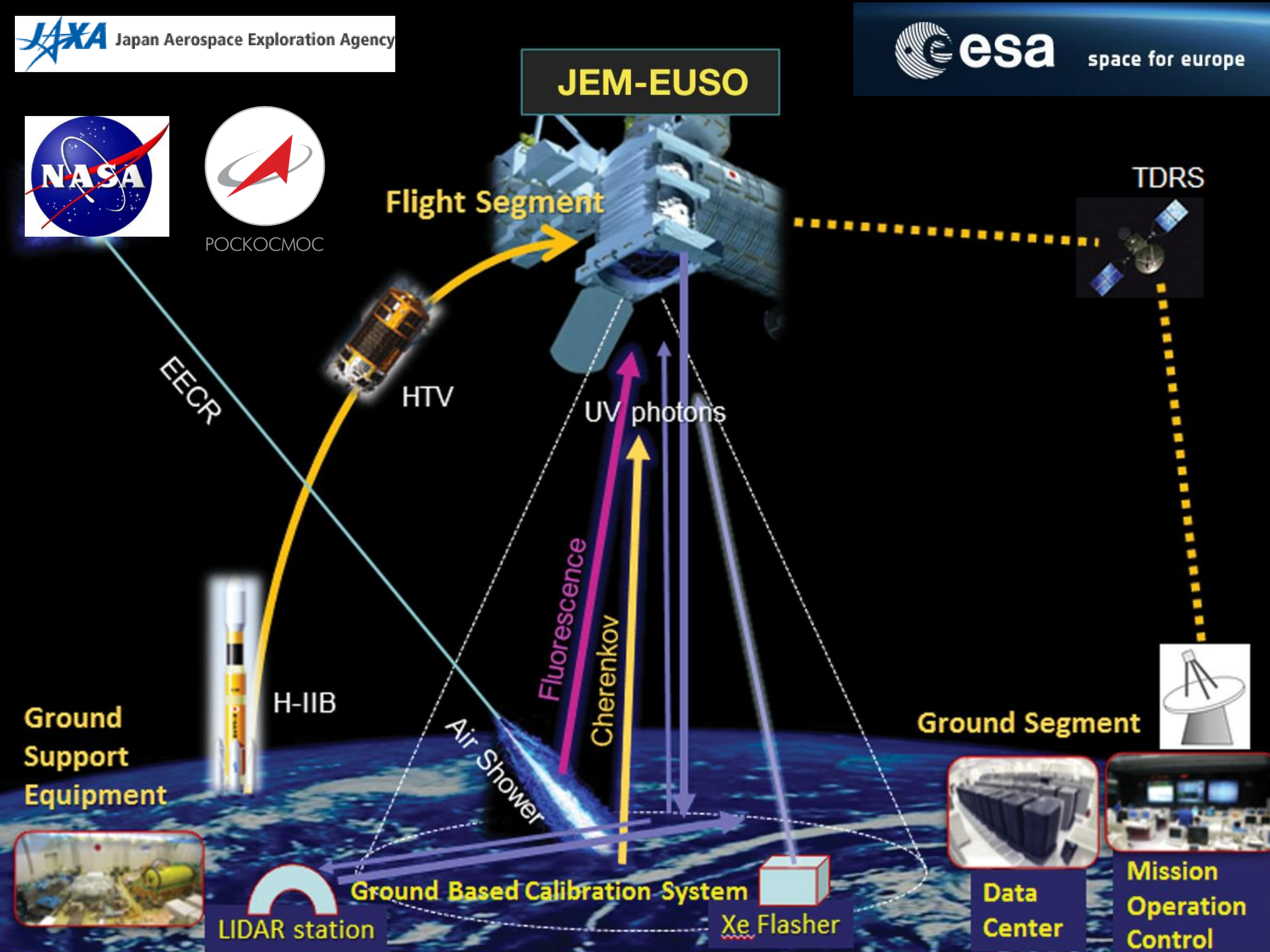

きぼう, Hope
Japanese Experiment Module
“Kibo” July 2009
51.6°



Standard Payload: mass 500 kg, envelope:1.85m ×1.0m ×0.8m

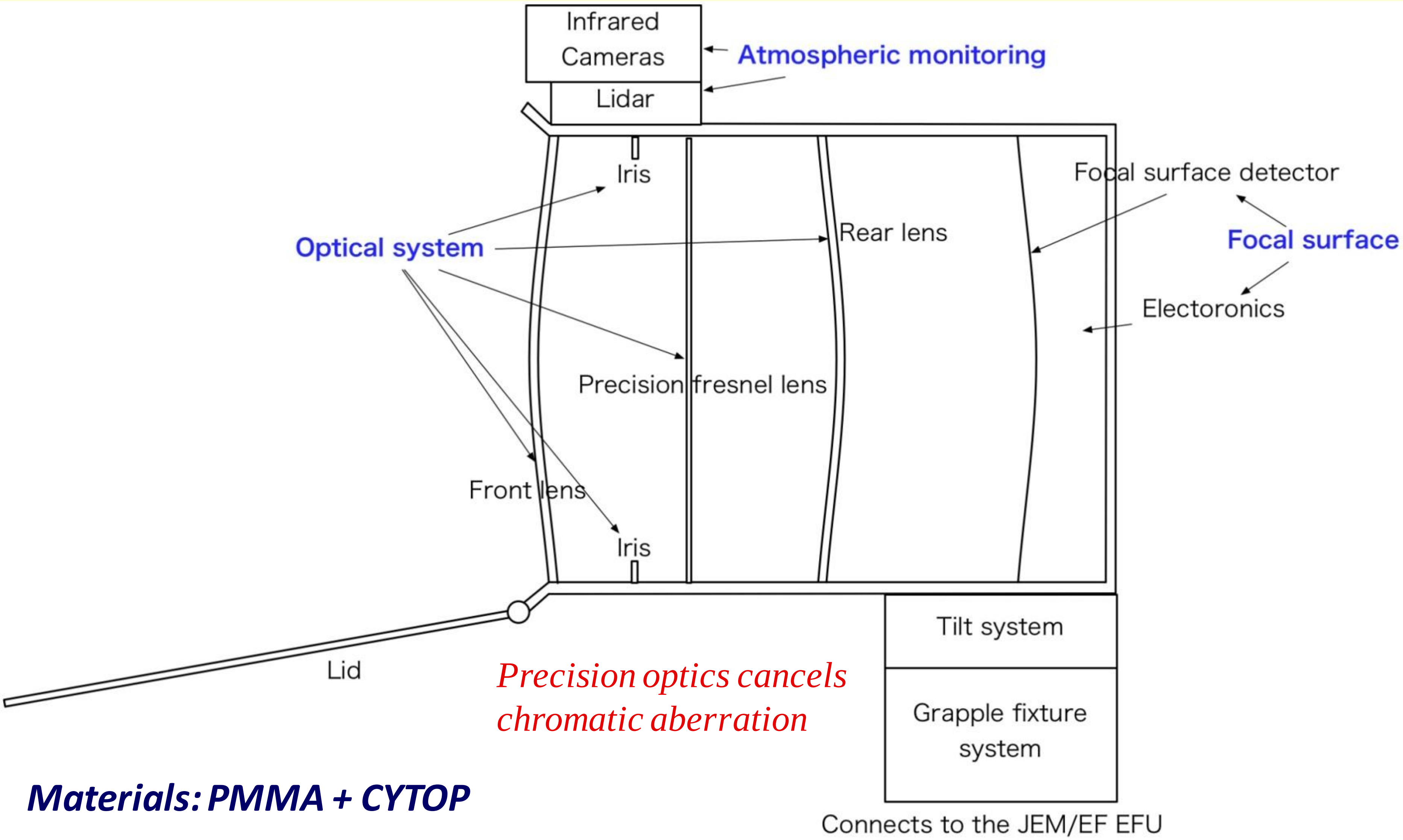
Mission aspects have been successfully studies by JAXA and RIKEN

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°



Japan Aerospace Exploration Agency
esa
space for europe
JEM-EUSO
NASA
РОСКОСМОС
Flight Segment
TDRS
HTV
EECR
UV photons
Fluorescence
Cherenkov
H-IIB
Air Shower
Ground Segment
Ground Support Equipment
Ground Based Calibration System
LIDAR station
Xe Flasher
Data Center
Mission Operation Control

Conceptual View of the JEM-EUSO Telescope

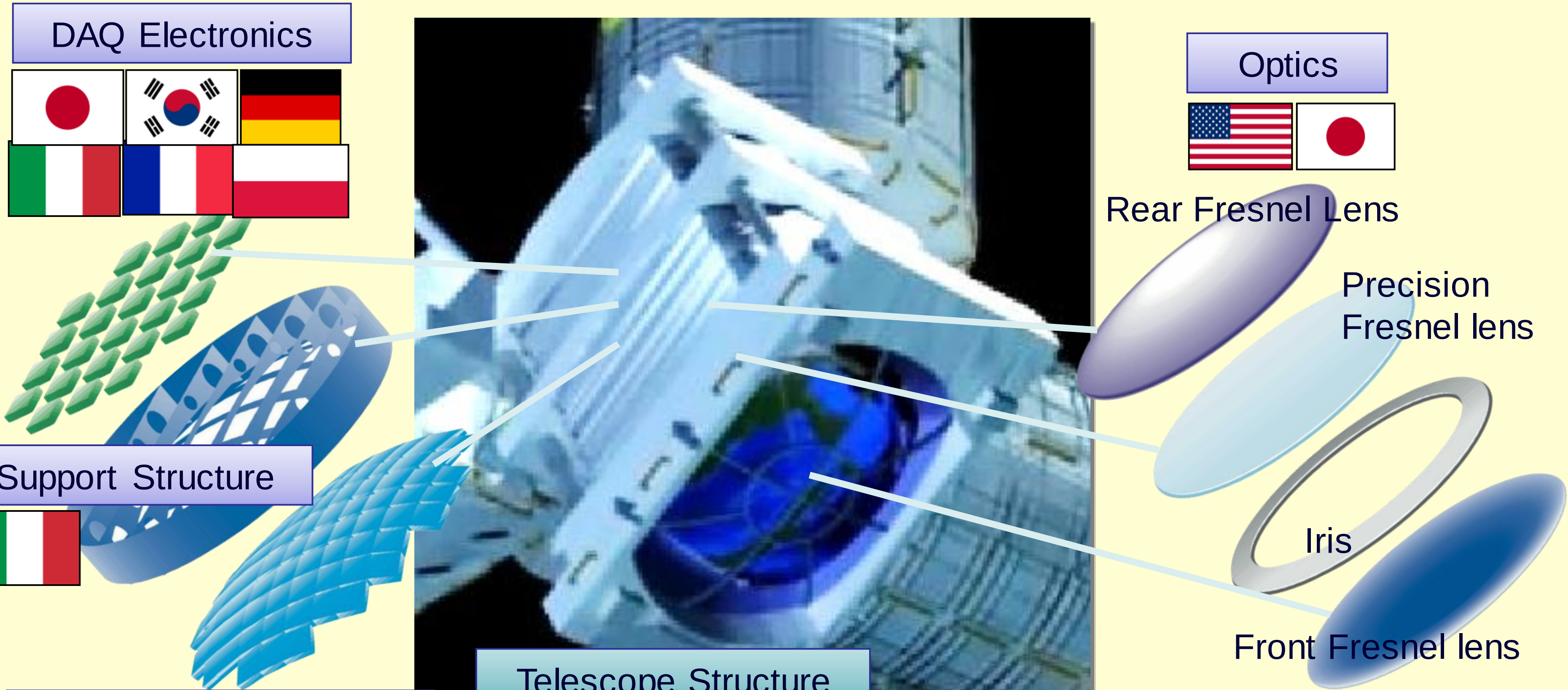


Precision optics cancels chromatic aberration

Materials: PMMA + CYTOP

International Role Sharing

DAQ Electronics



Optics

Support Structure

Focal Surface Detector

Telescope Structure

BUS System : JAXA

On-board Calibration

Housekeeping

Ground Based Calibration

Atmospheric Monitoring

Ground Support Equipment

Simulation : Worldwide

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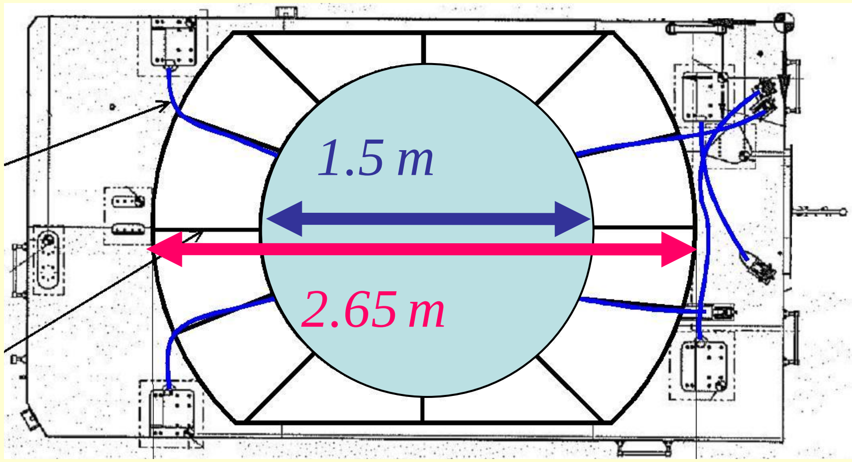
ler Center-Tü

The UV Telescope Parameters

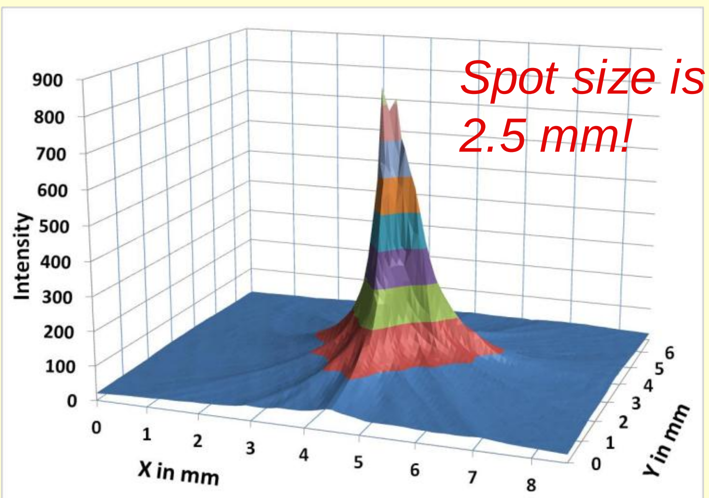
Parameter	Value
Field of View	±30°
Monitored Area	>1.3×10^5 km^2
Telescope aperture	≥2.5 m
Operational wavelength	300-400 nm
Resolution in angle	0.075°
Focal Plane Area	4.5 m^2
Pixel Size	<3 mm +
Number of Pixels	≈3×10^5
Pixel size on ground	≈560 m
Time Resolution	2.5 μs
Dead Time	<3%
Detection Efficiency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

+ *Optics Throughput*

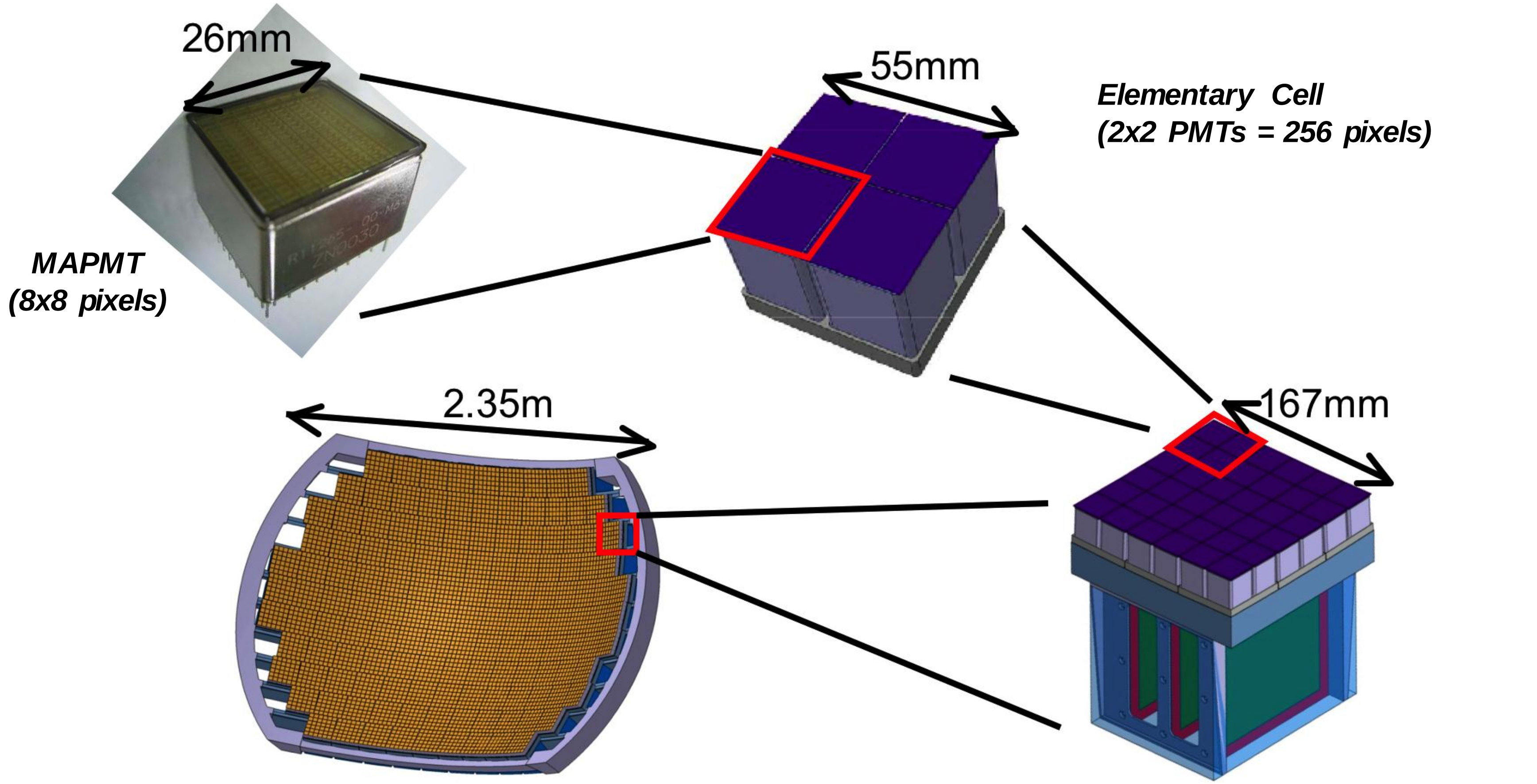
BBM of the Optics (Protypes)



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
137 PDMs = 0.3M Pixels

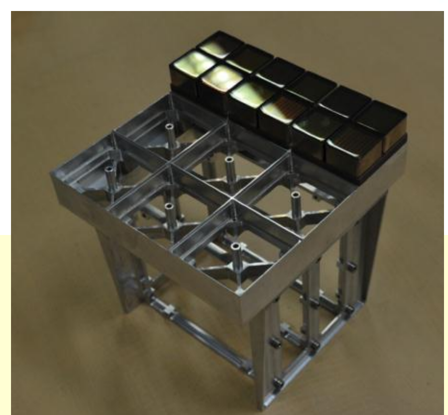


Photo-Detector Module
(3x3 ECs = 2,304 pixels)

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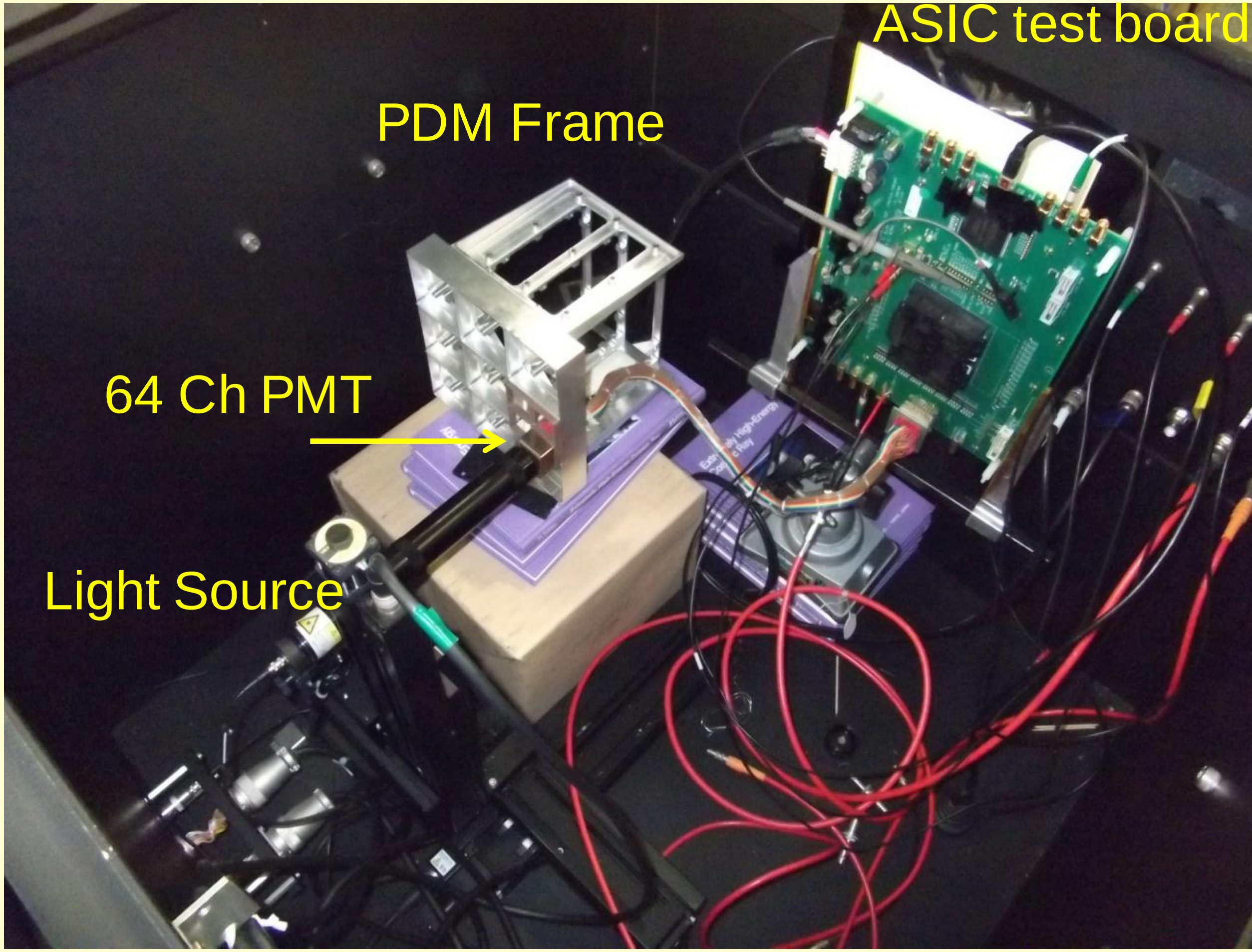
Detector and electronics

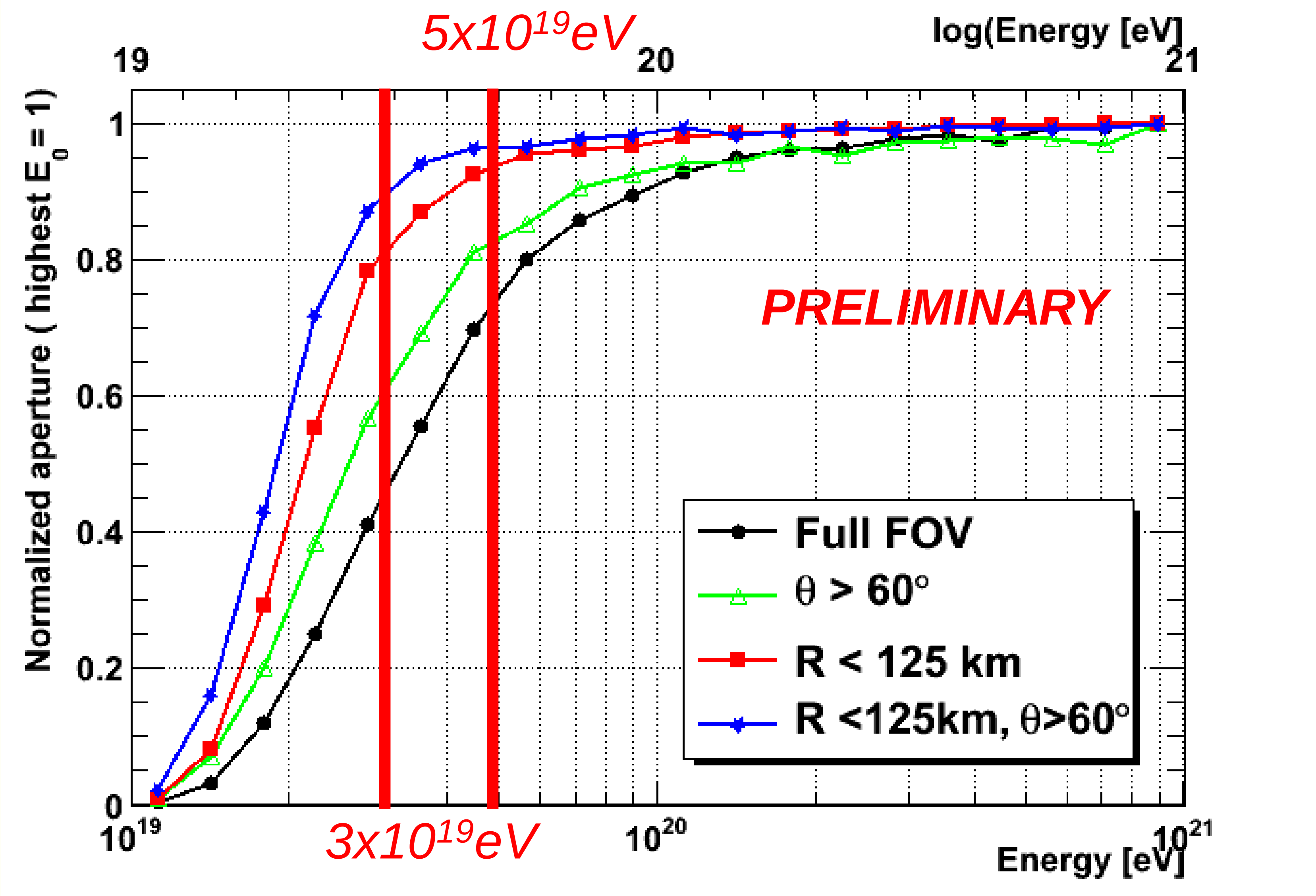
- MAPMT-64
- ASIC *Spaciroc*
- *Electronic Cell* Board
- 137 PDM *1st trigger and readout*
- CCB *2nd trigger*



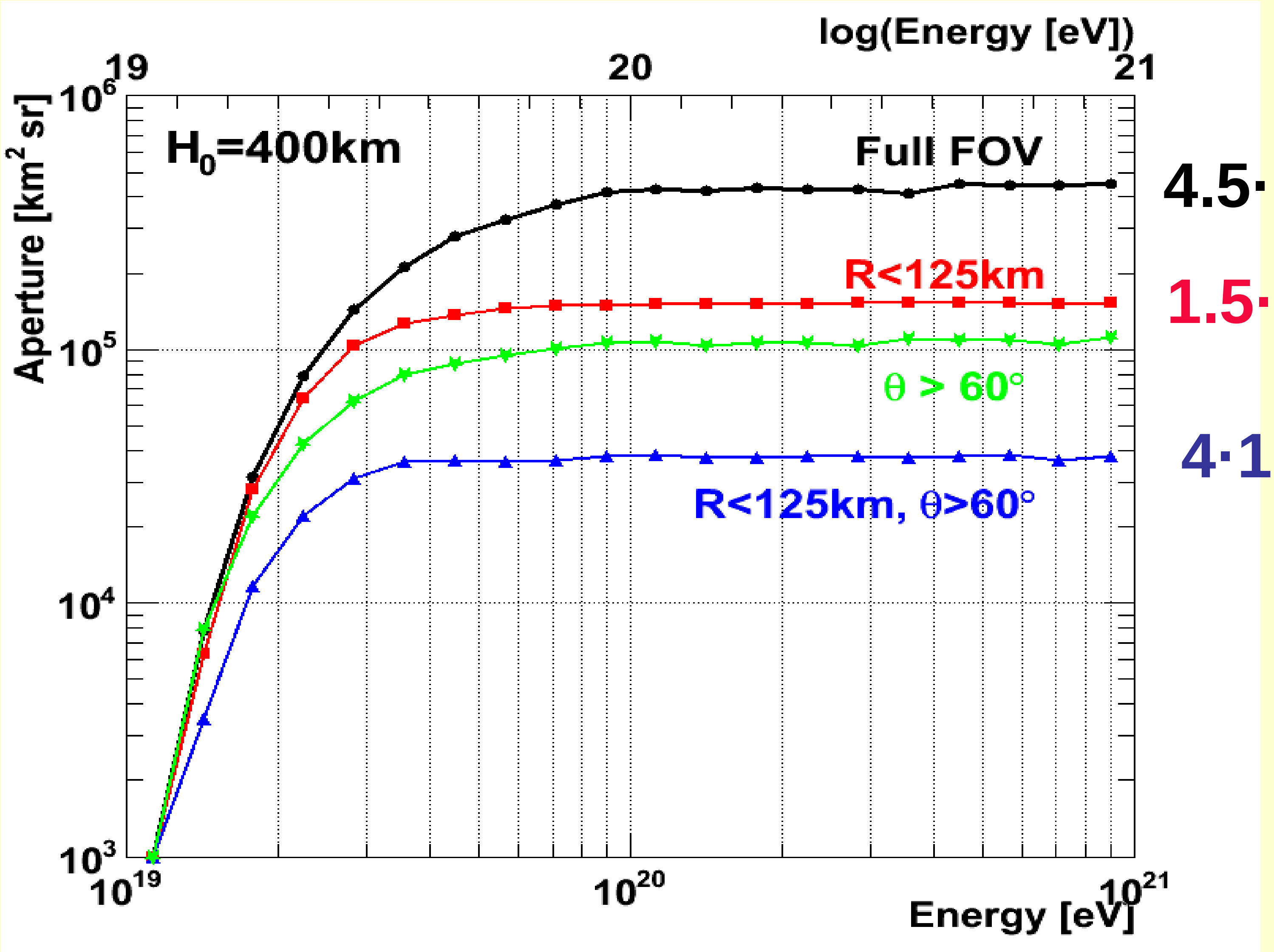
From 9.6 GB/s to 3 GB/day on the entire FS

PDM Bread board model integrated at RIKEN

Normalised Aperture: Efficiency



Instantaneous Aperture



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

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

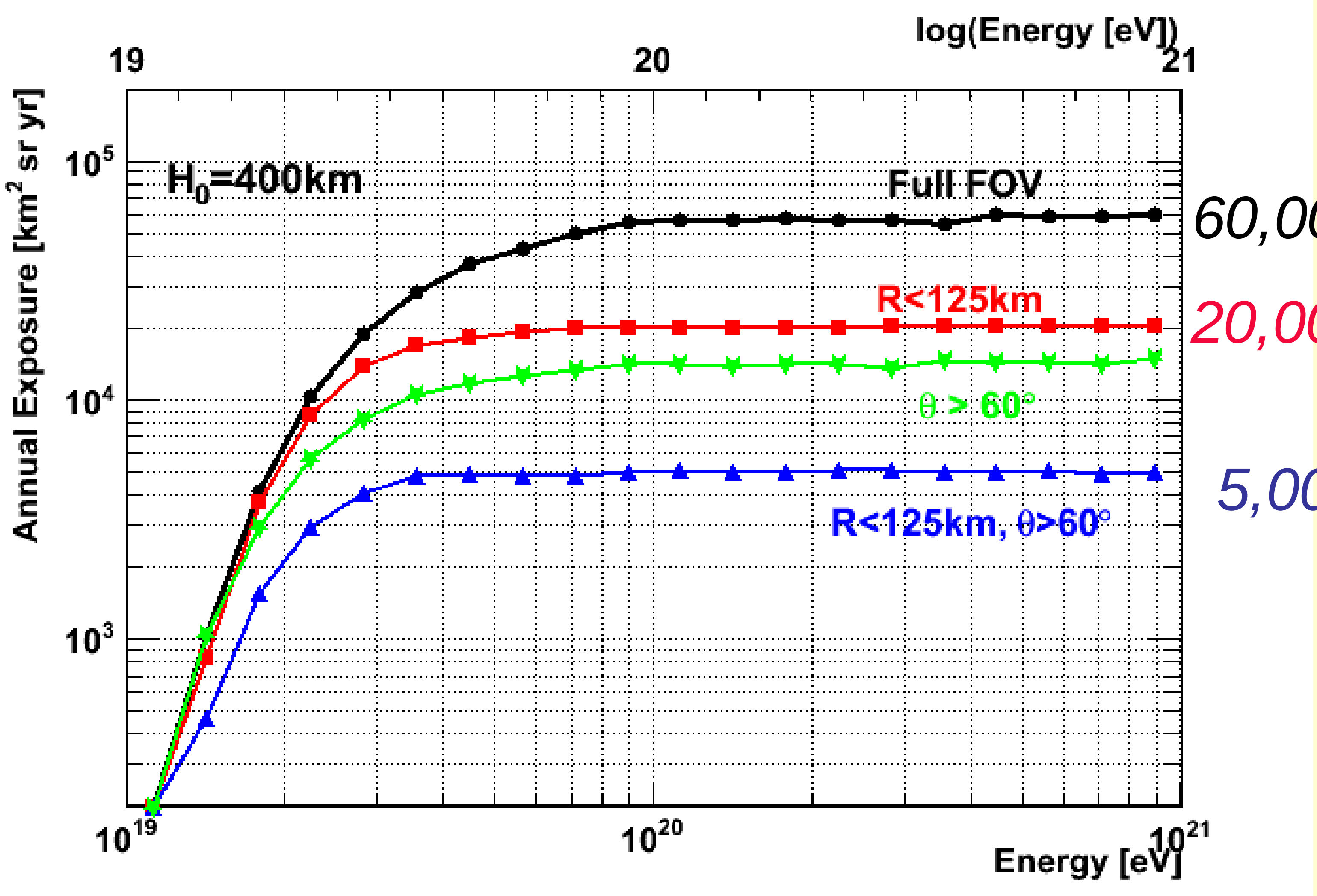
$4 \cdot 10^4$ km^{2}sr

K.Shinozaki et al., 2011

Annual Exposure (…Nadir)

$TA \times \eta \times k$

~14%



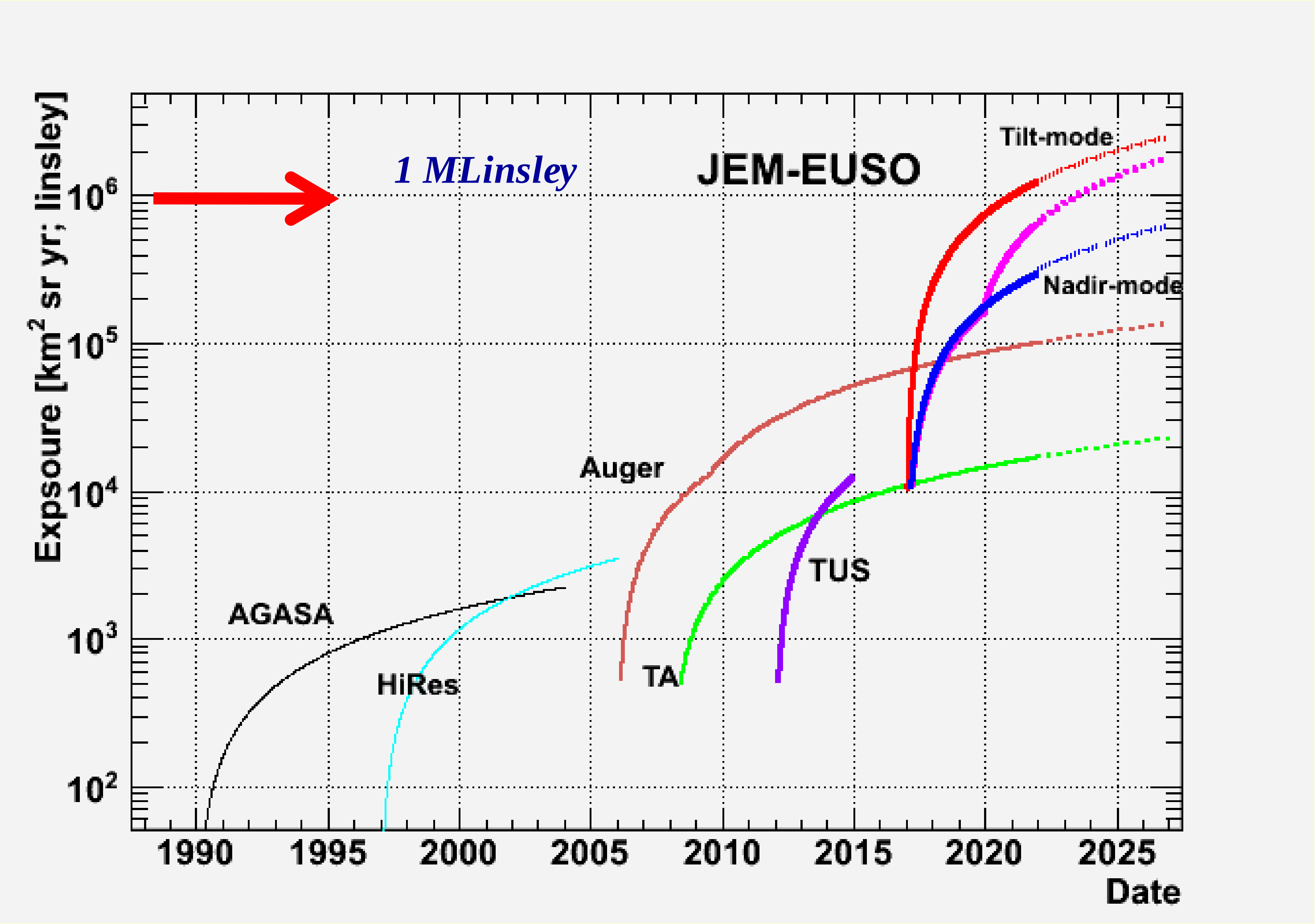
60,000 $km^2 sr\ yr$

20,000 $km^2 sr\ yr$

5,000 $km^2 sr\ yr$

K.Shinozaki et al., 2011

Why JEM-EUSO? Large exposure + Full sky coverage

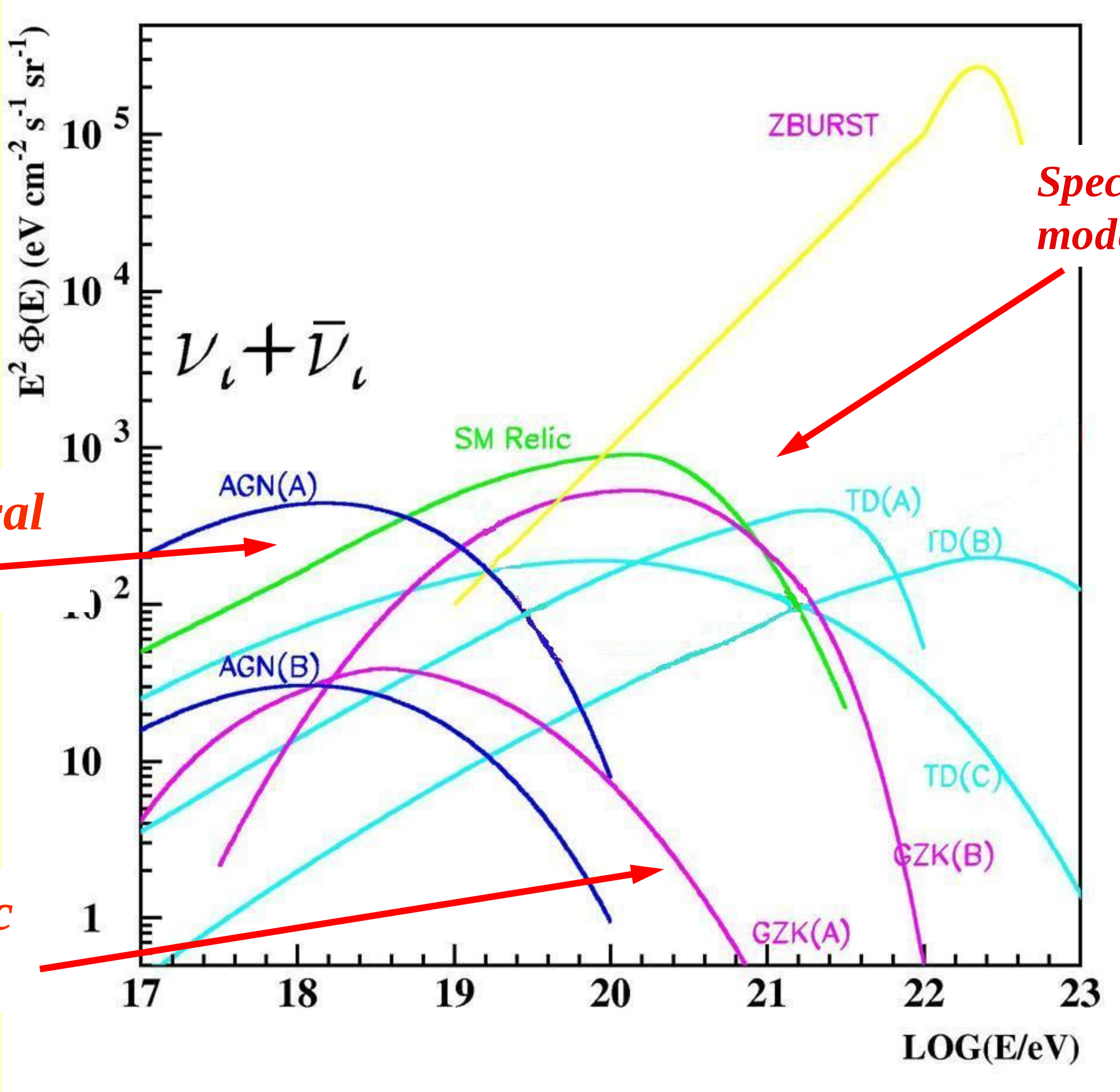


II. Science case:
JEM-EUSO and UHE neutrinos

AGN
Mannheim (1995)
B)high – A)low

GZK(B) Kalashek, Kuzmin, Semokov, Sigl (2002)

GZK(A)
Protheroe (1995)



Speculative models

Astrophysical models

Cosmogenic Neutrinos

Old EUSO plot by Bottai et al., 2003

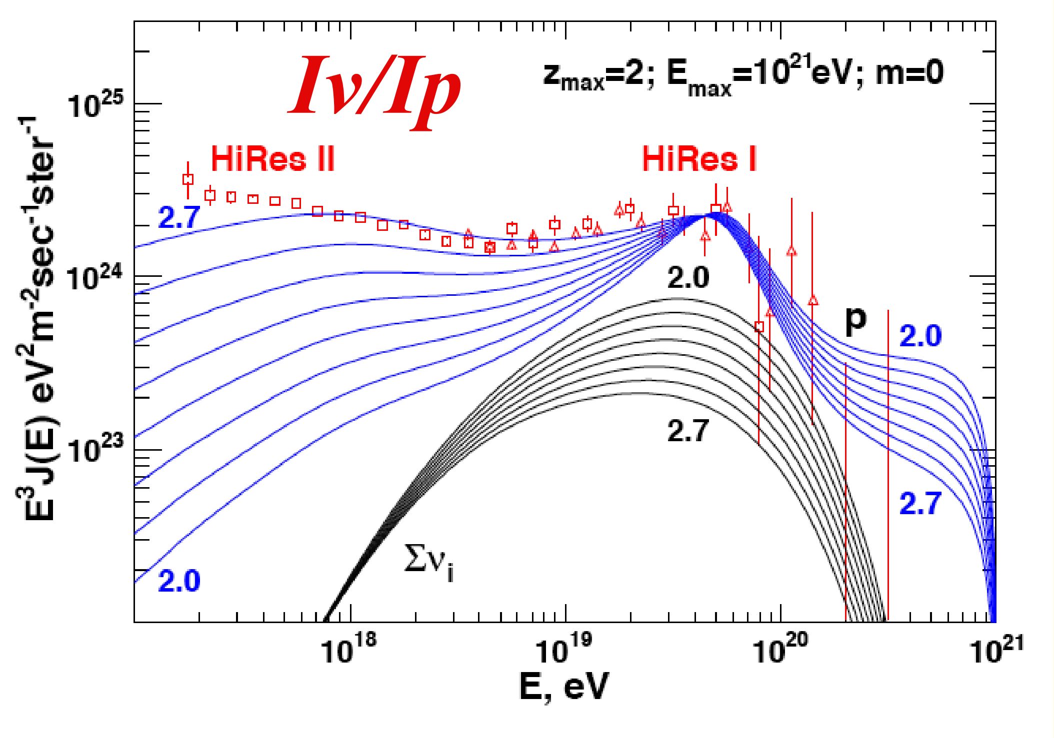
Cosmogenic Neutrinos

$$p + g_{CMB} \rightarrow p^{\pm} \rightarrow m^{\pm} + n_m(\bar{n}_m)$$

$$\downarrow$$

$$e^{\pm} + n_e(\bar{n}_e) + n_m(\bar{n}_m)$$

- Engel, Seckel, Stanev 2001
- Kalashev, Kuzmin, Semikoz, Sigl 2002
- Fodor, Katz, Ringwald , Tu 2003
- VB, Gazizov, Grigorieva 2003



Maximal Energy, Composition, Evolution of sources… is it really feasible?

Berezinsky & Zatsepin, (1969, 1970) Berezinsky (2005)

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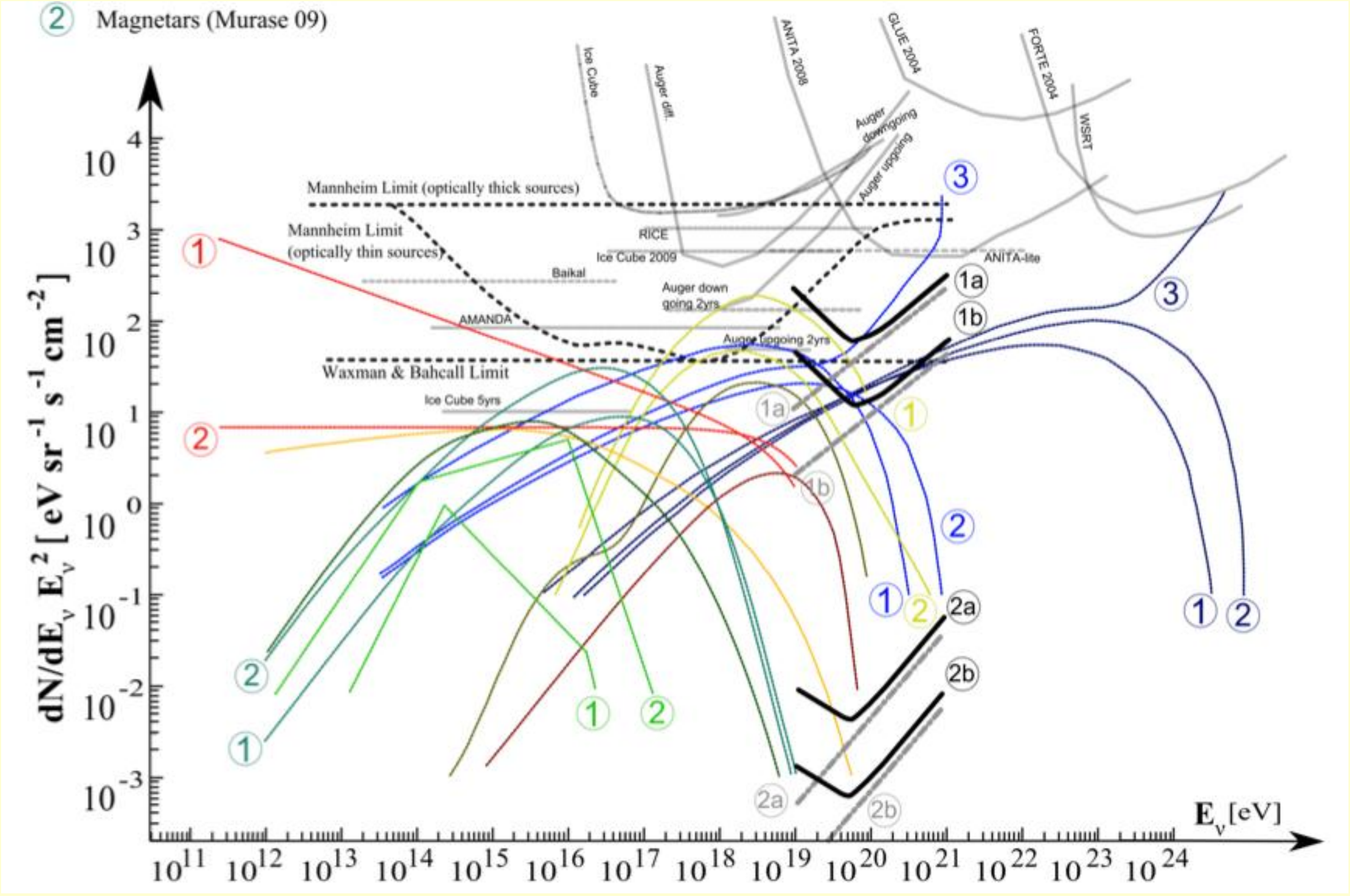
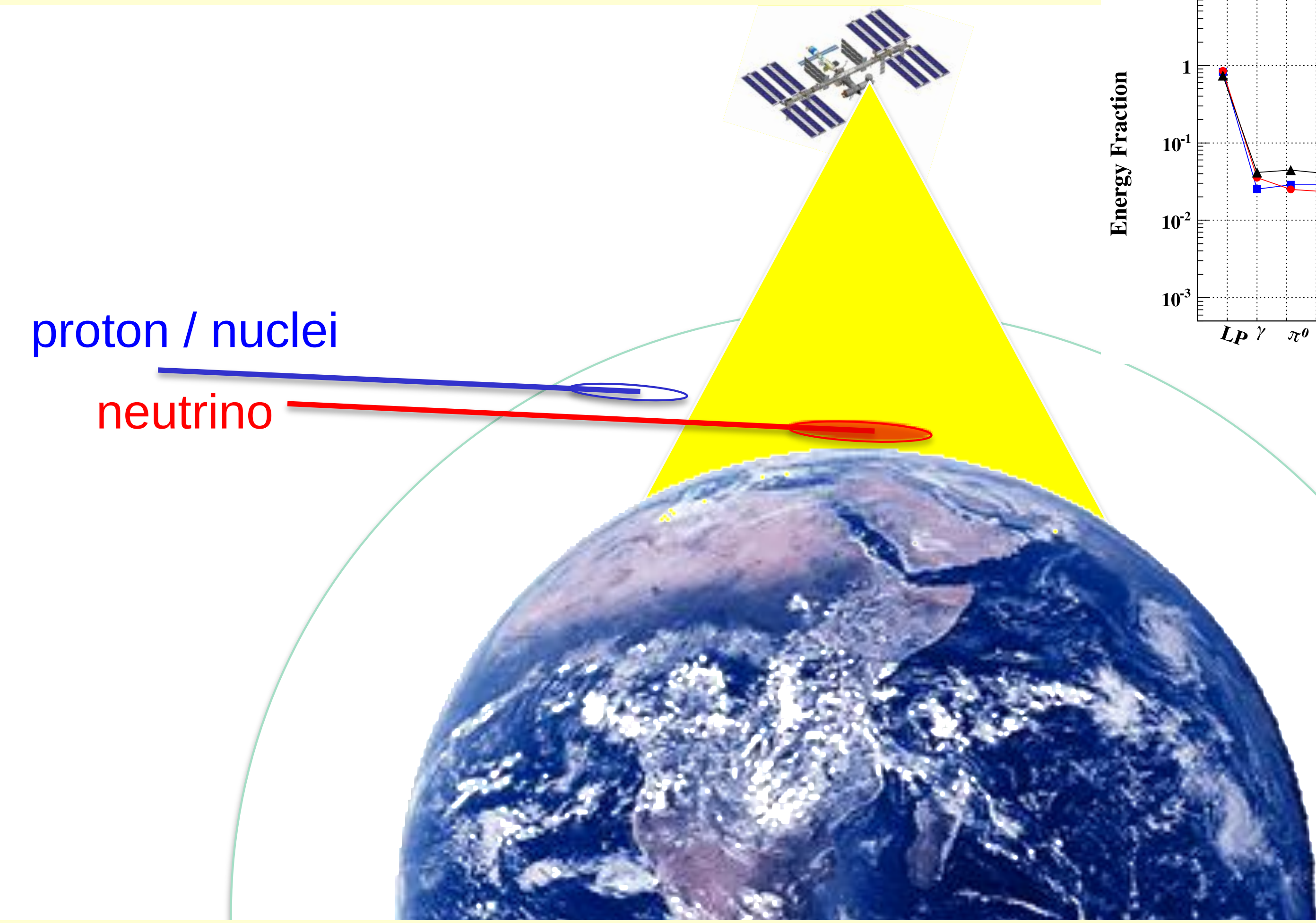
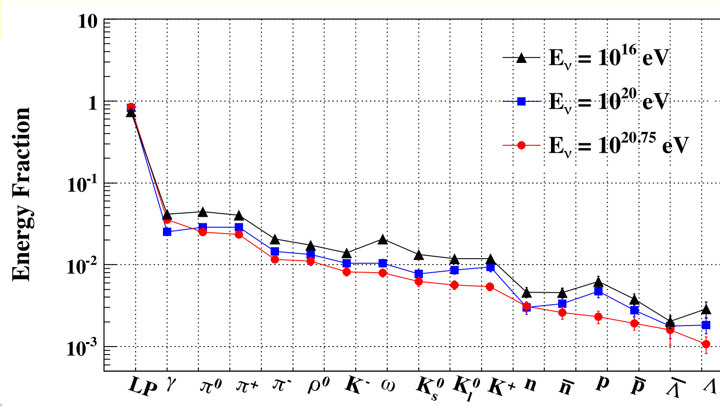
Bittermann, 2010

The Zoo of neutrino models



The key concept





$$(CC)\ n_l N \rightarrow l + hadrons$$

$$(NC)\ n_l N \rightarrow n_l + hadrons$$

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Kepler Center-Tü

Neutrino shower simulation

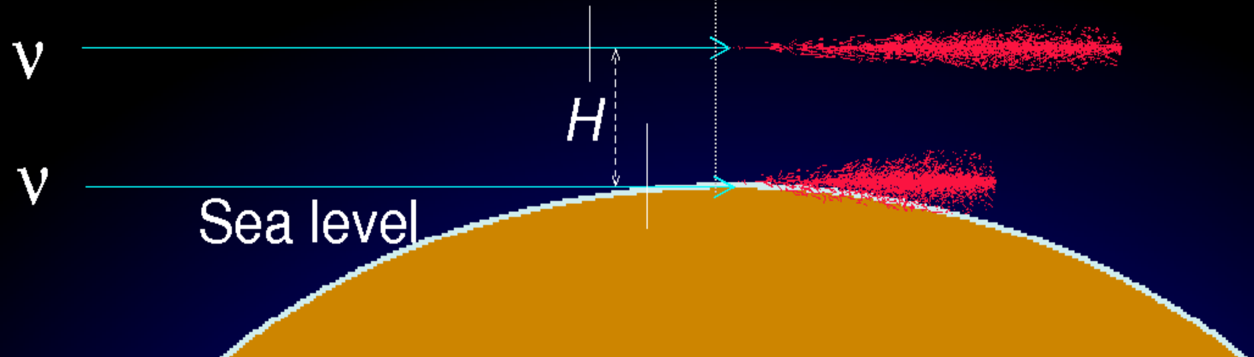
Horizontally incident neutrinos

Survival prob. to come in FOV

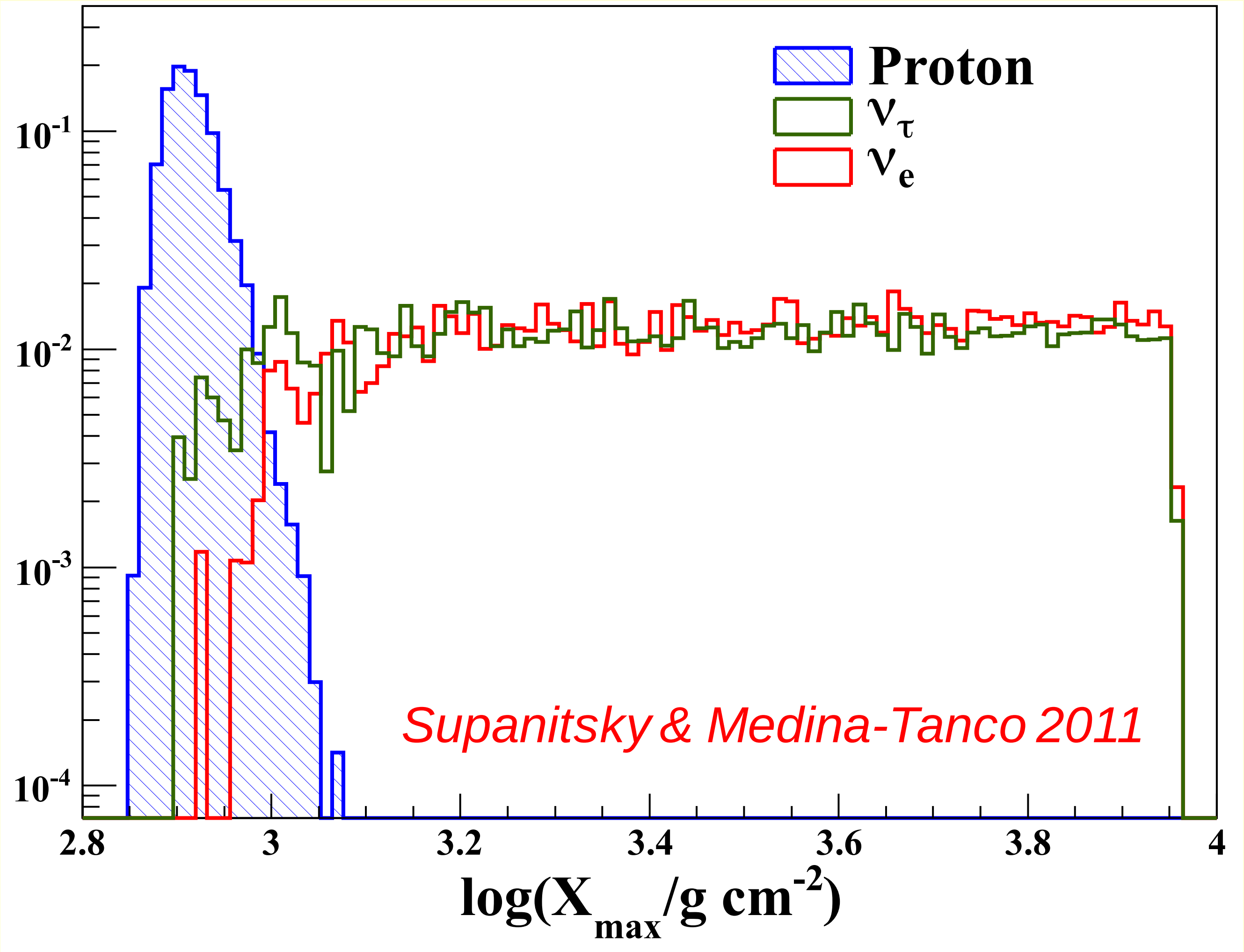
Neutrino: ~exp(-0.001)

Proton: ~exp(-1000) for 10^{20} eV

CONEX code used for shower simulation in atmosphere



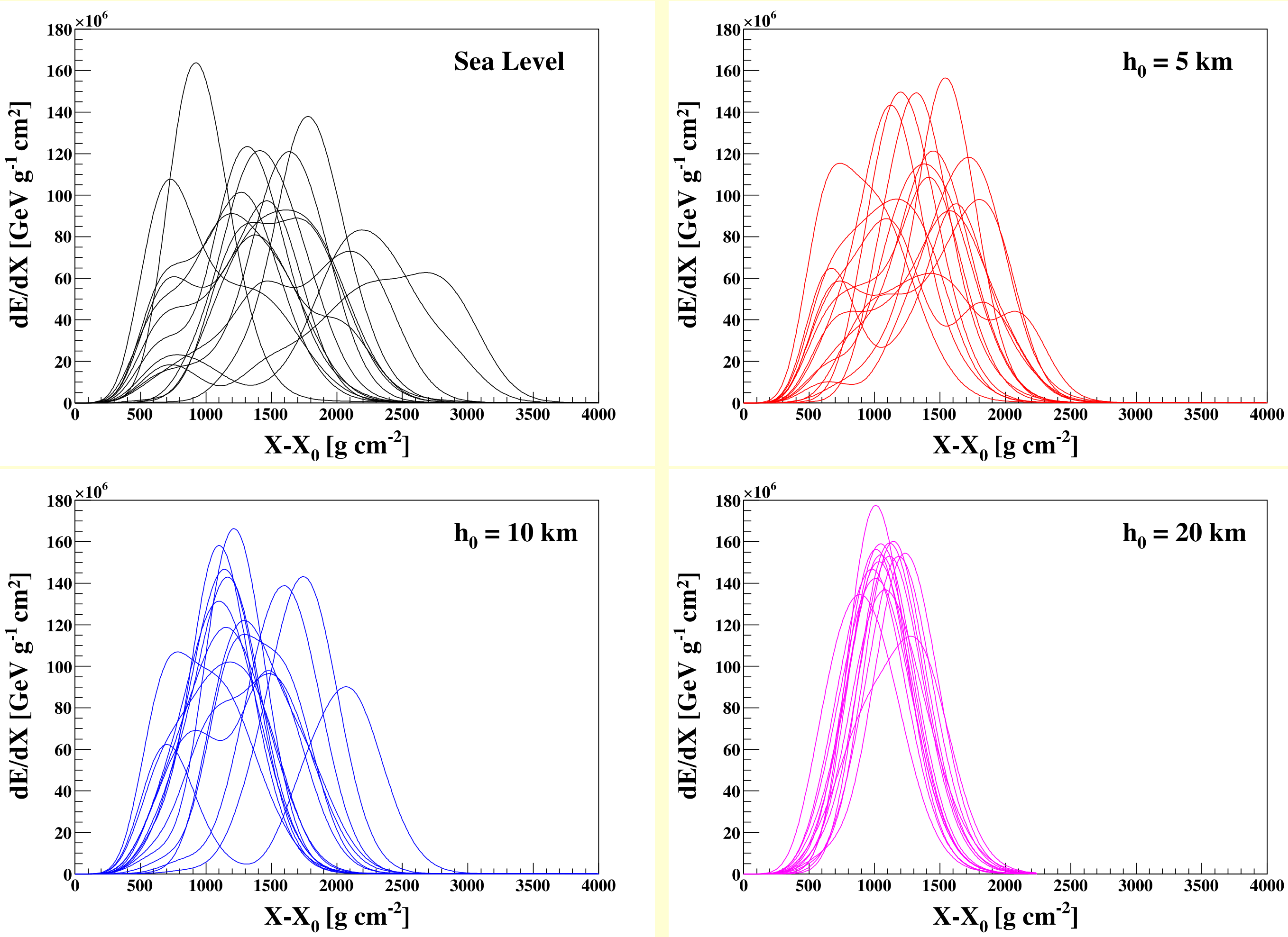
Neutrinos vs. Protons: X_{max}



Distribution of X_{max} for protons and neutrinos for $E=10^{20}$ eV and $\theta=85°$ (First Peak of the shower profile)

Profiles

First peak from the hadronic and the em part of the shower, second and more from the em part.



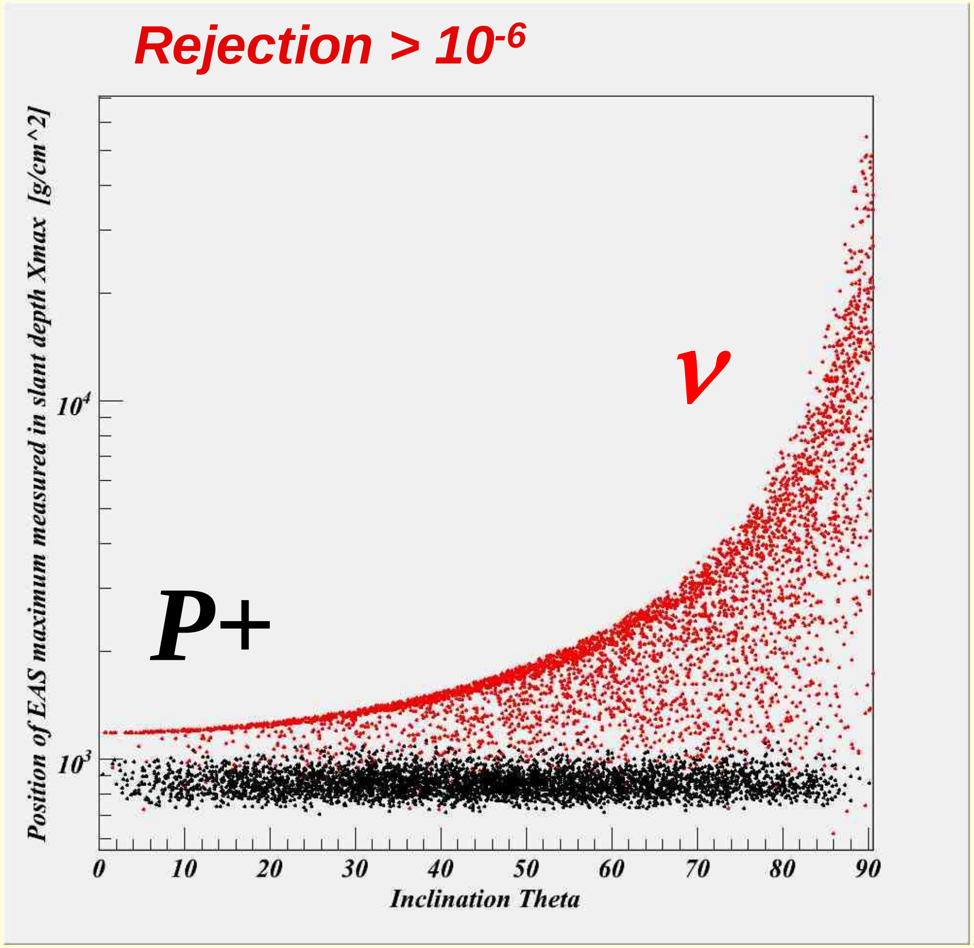
LPM effect reduces with altitude*

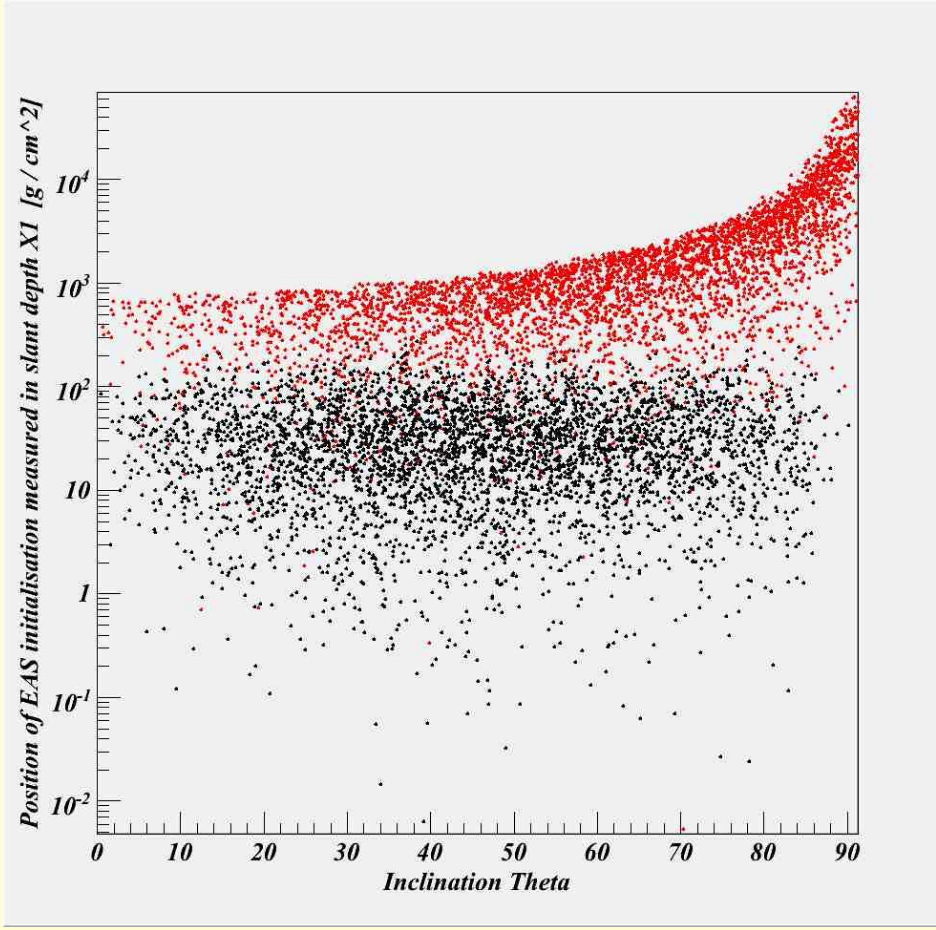
** Landau Pomeranchuk Migdal*

Profile of the shower for horizontal electron neutrinos at $E=10^{20}$ eV for four different altitudes

Bittermann, 2010

Discrimination of Neutrinos vs Protons





Xmax

X1 initial point

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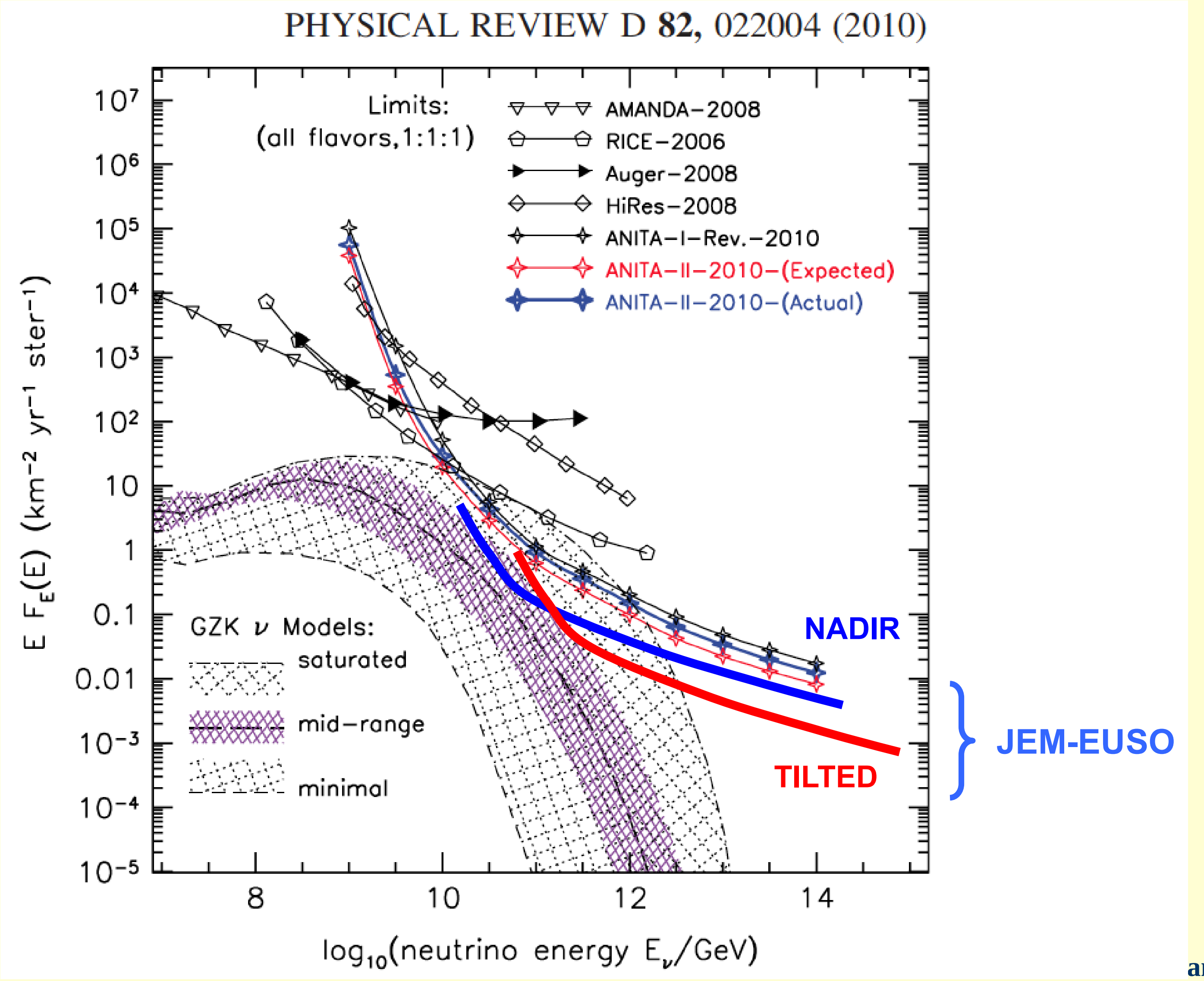
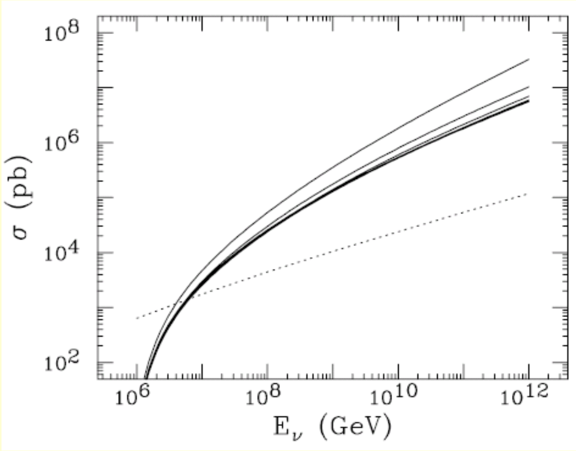
Upper limits on neutrino fluxes



New Physics from Neutrinos?

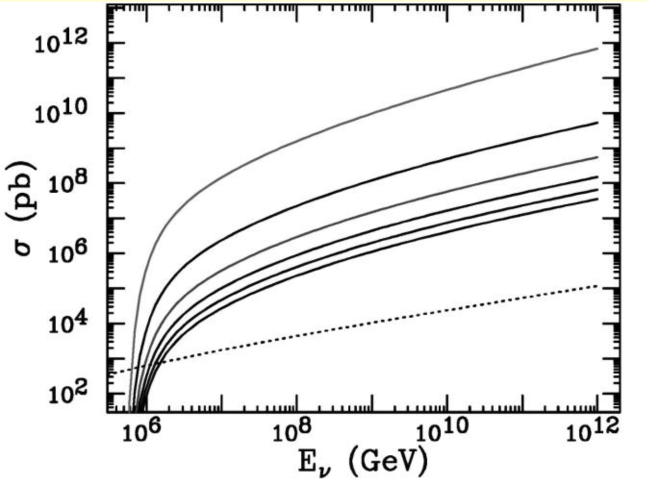
Neutrino cross sections

Black Hole production



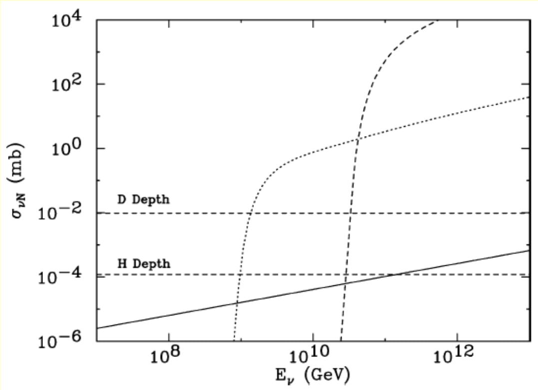
Feng & Shapere, 2002

p-brane production



Anchordoqui, Feng and Goldberg, 2002

EW instanton effects

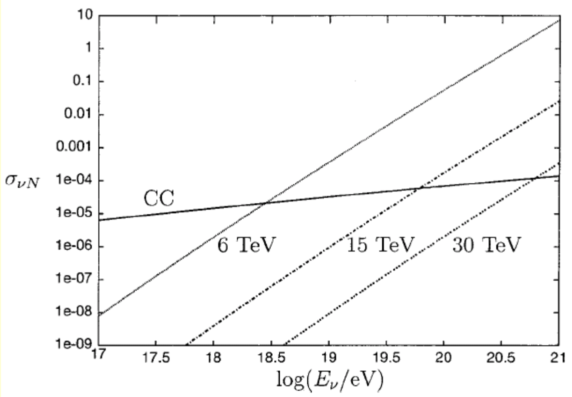


Bezrukov et al., 2003a, 2003b

Ringwald, 2003

Han & Hooper, 2004

Exchange of KK modes



Kachelriess & Plümacher, 2000

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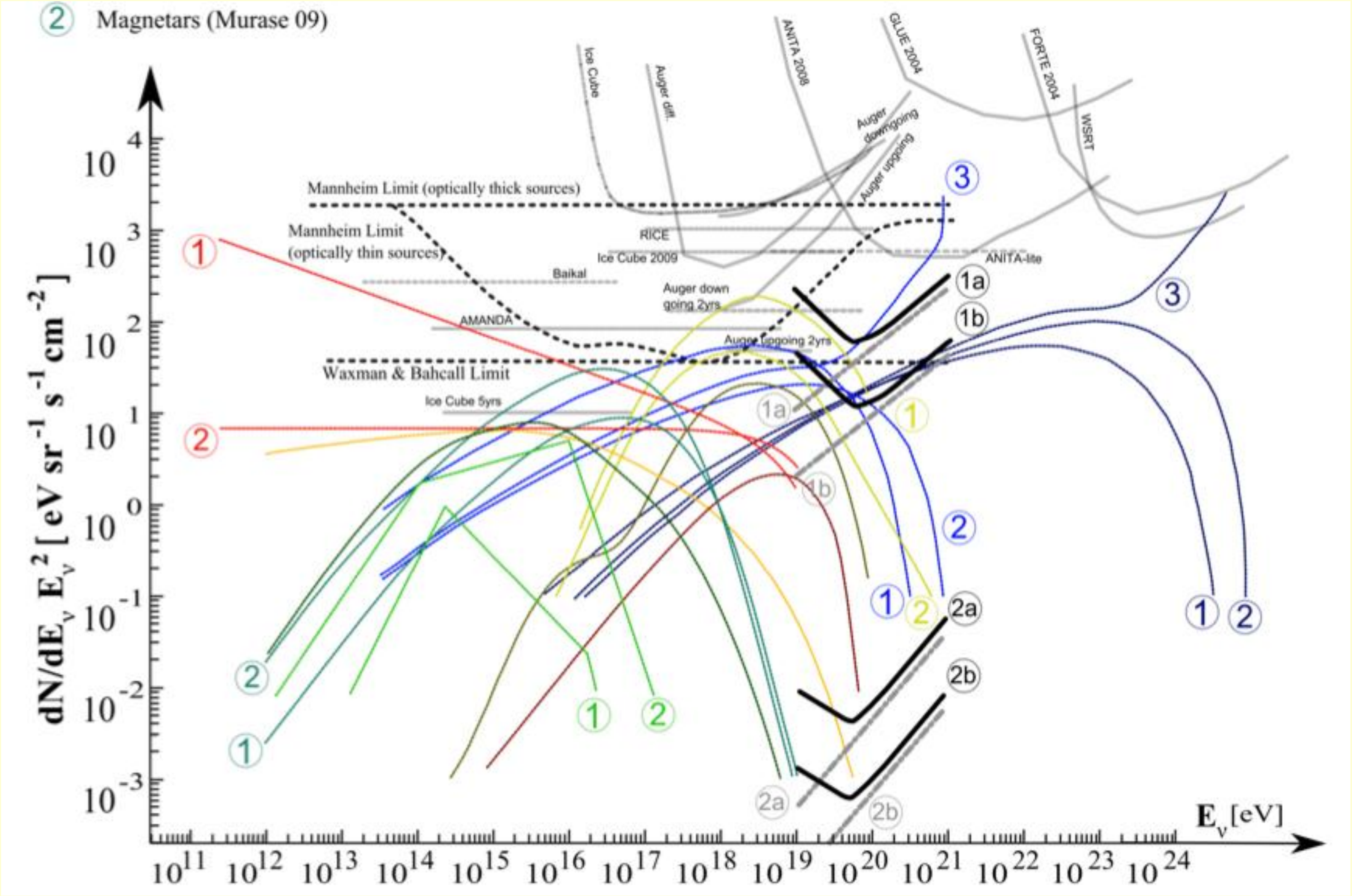
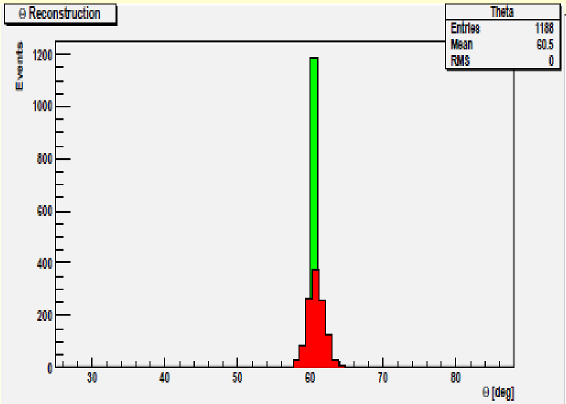
Bittermann, 2010

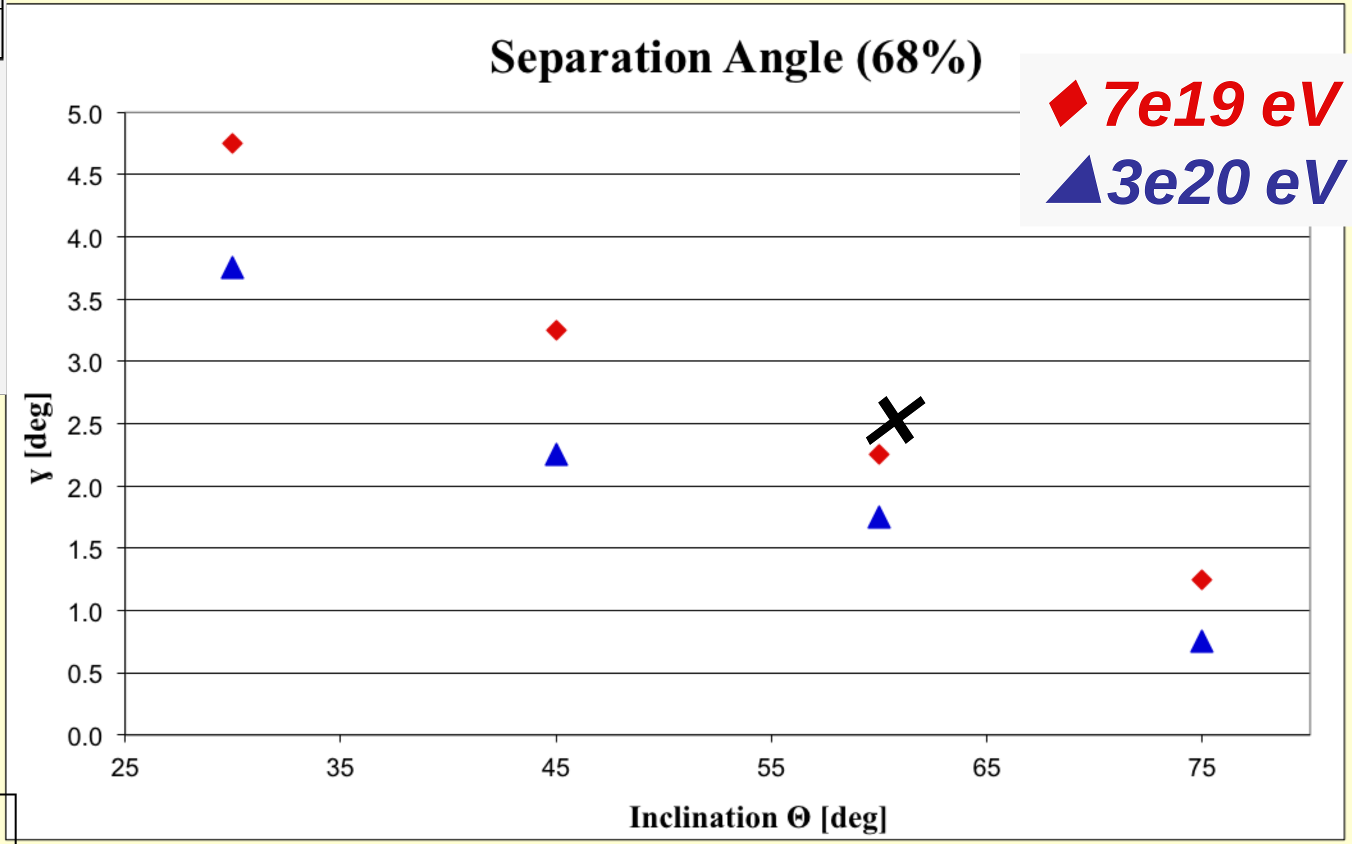
The Zoo of neutrino models



Angular Resolution



α(deg)



Zenith Angle q(deg)

Requirement

a<2.5° @

E=10^{20}eV, q=60°

End to end simulations show that the requirement is met.

T. Mernik et al., 2011

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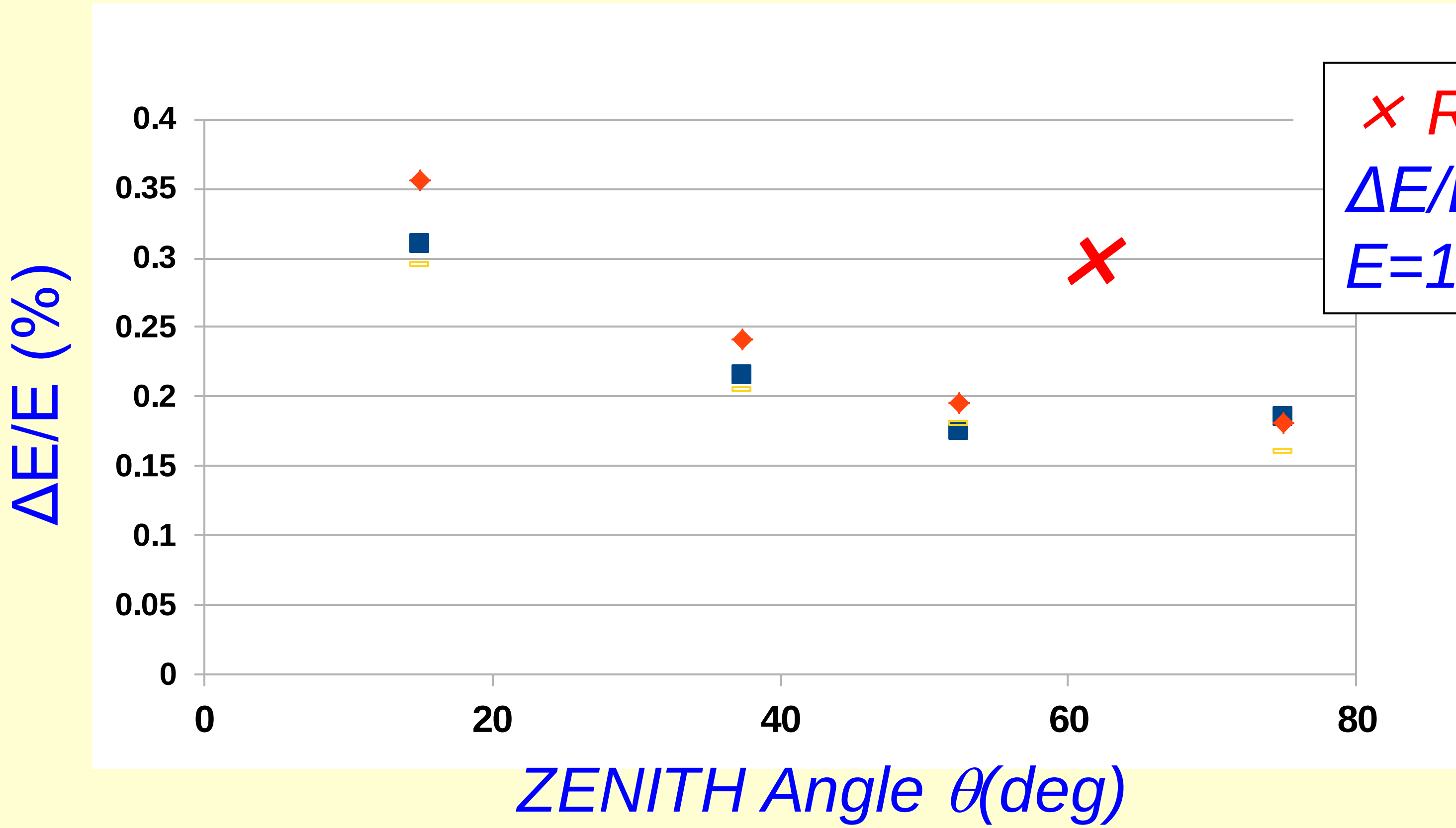
Energy Resolution



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

End to end simulations show that the requirement is met.

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

T.Mernik et al., 2011

Conclusions

- Science: UHECR → Evidence for GZK, Indication for Anisotropy, hints of sources but *puzzling scenario* (PAO, HiRes, TA). *No UHE neutrinos discovered…*
- Current generation of UHE Observatories is too small: *We need next generation to solve the puzzle and to explore the unknown → Neutrinos, Photons, new physics*
- *Breakthrough can come from space:* Large and uniform exposures of the entire sky, *JEM-EUSO is the pathfinder* with likely outstanding science output.
- JEM-EUSO will have *enough exposure and reconstruction capability at* 3×10^{19} *eV to overlap* with current generation observatory.
- The JEM-EUSO duty cycle and cloud impact have been thoroughly *estimated to be* $\eta \approx 20\%$ *and* $\kappa > 70\%$.

Conclusions

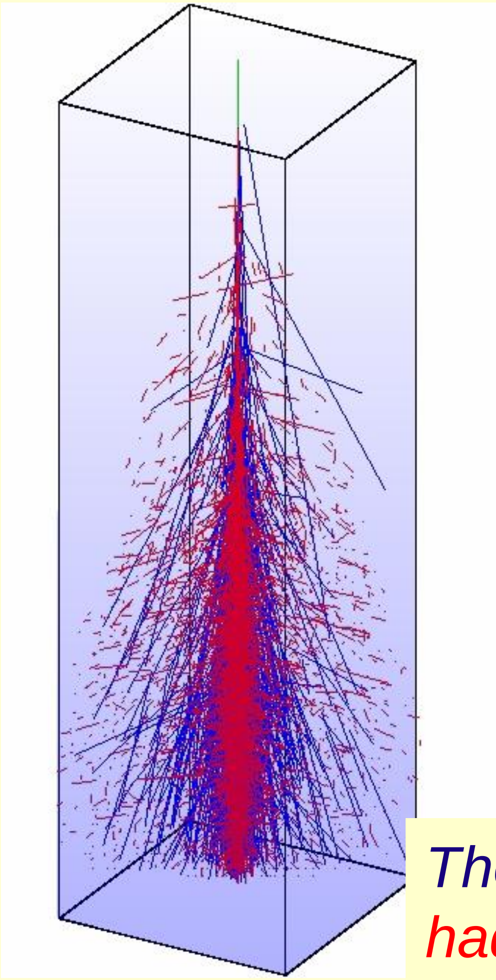
- JEM-EUSO is designed to have a annual exposure about *9xAuger at 10^{20} eV in nadir mode* and *28xAuger* at the highest unexplored energies in tilt mode.
- Simulation shows that JEM-EUSO can distinguish neutrino- from proton-induced showers *with high confidence on the basis of X_{max}, X_0 and the shower shape.*
- Simulations (in nadir mode) shows that the energy, angular and X_{max} resolution meet the requirements.
- *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 (?)* Stay tuned for surprises…

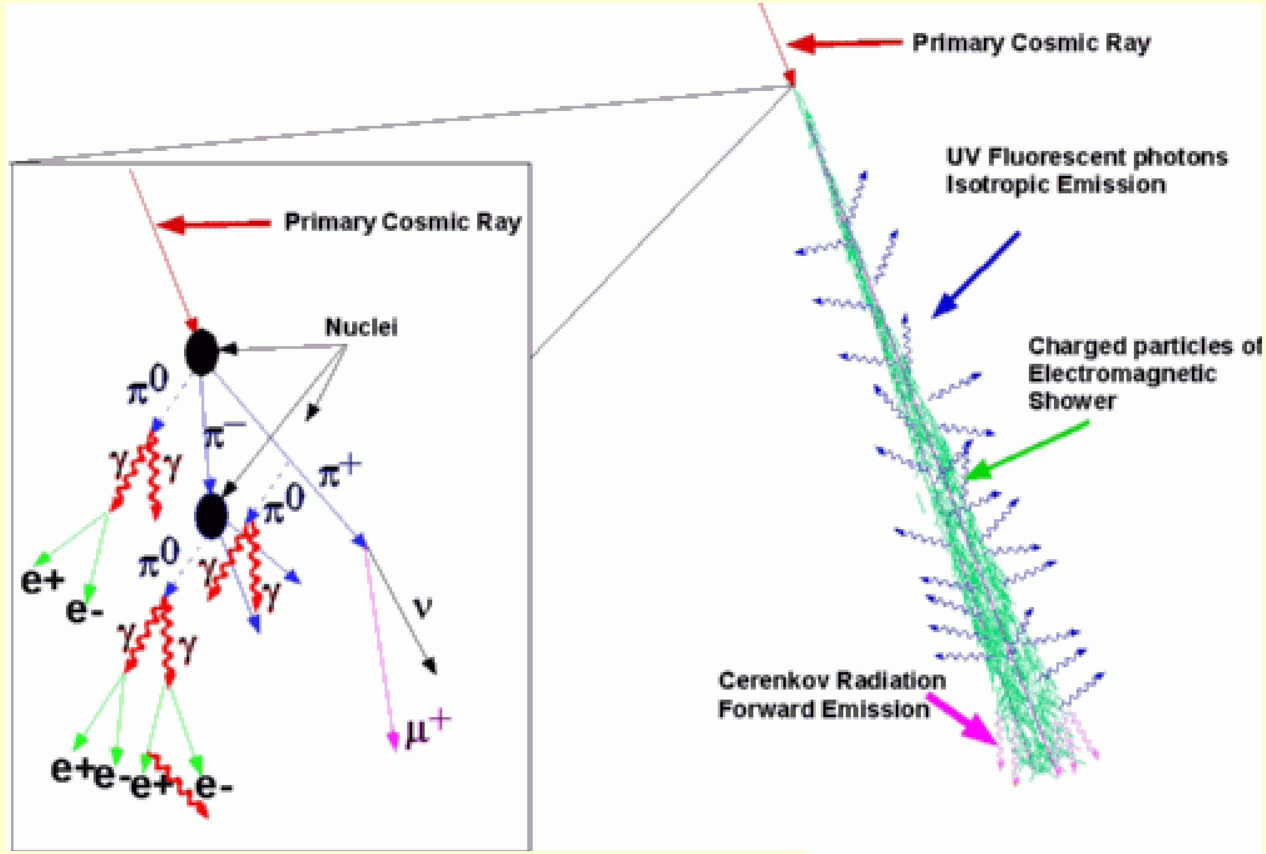
Comparison with current observatories

Observatory	Aperture km^2 sr	Status	Start	Lifetime	Duty cycle	Annual Exposure km^2 sr yr	Relative to Auger
Auger	7,000	Operations	2006	4 (16)	1	7000	1
TA	1,200	Operations	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

Let me open a parenthesis:
How do we detect UHE particles?
(in a nutshell...)

Extend Air Shower





10-100 km

30-300 μs

The primary interaction can be hadronic. A number of secondaries mainly pions are generated. These give rise to further hadronic interactions

Hadronic Cascade

Charged pions→muons

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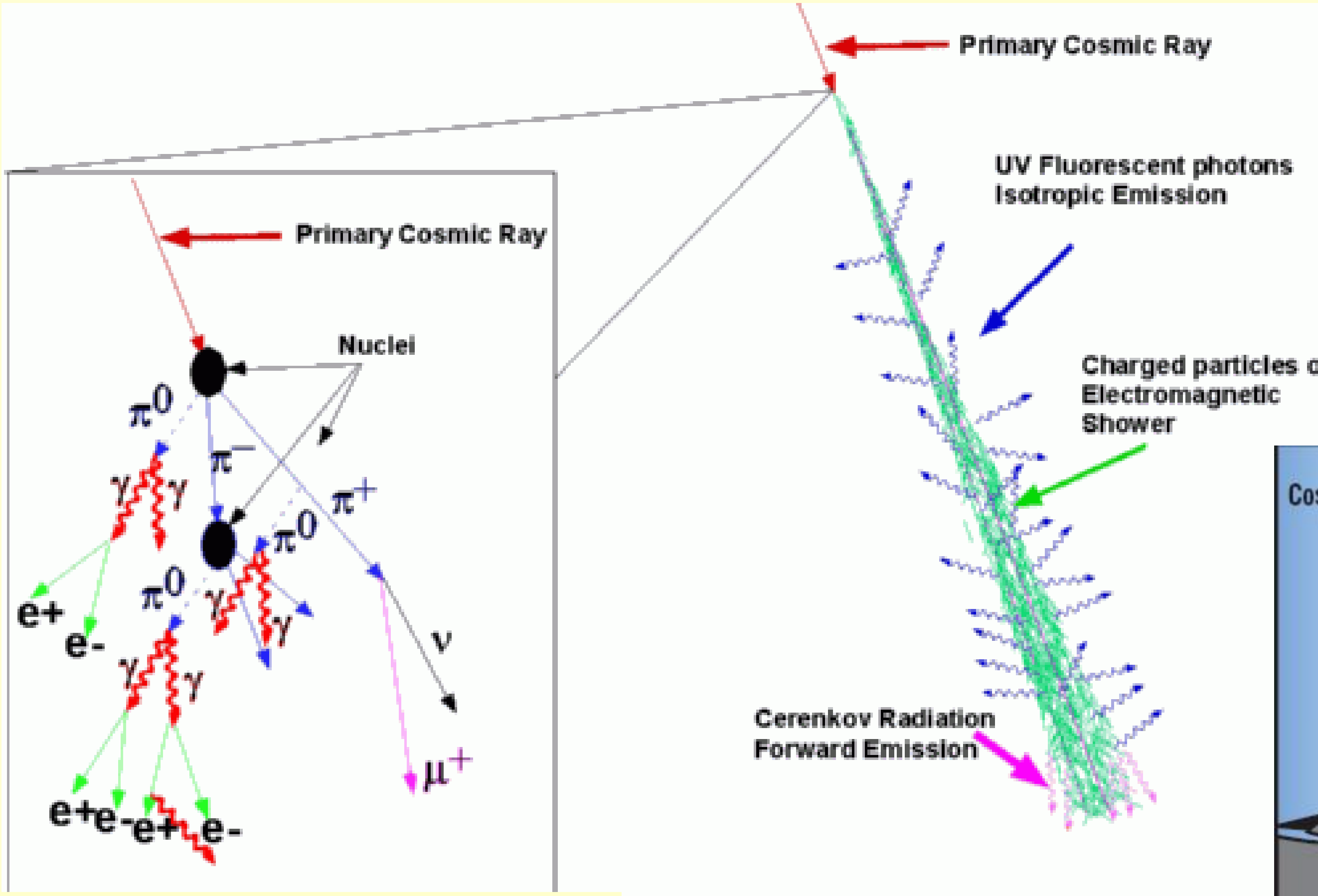
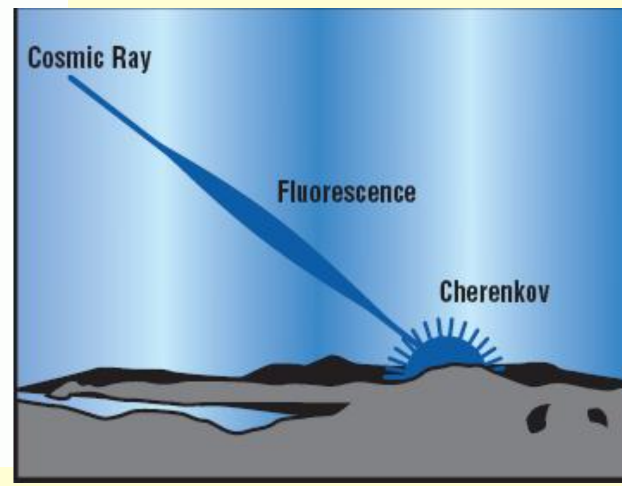
Electromagnetic Component



At each step 1/3 of the energy is given to neutral pions which decay into gamma photons



Photons produce e-pairs and Compton electrons, which produce photons via bremsstrahlung

Two types of light are produced:

- **Fluorescence photons** (isotropic)
- **Cherenkov photons** (beamed)

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Viewed from a distance, an EAS appears as a ***luminous disc moving at the speed of light***. Its luminosity increases up to a maximum and gradually fades

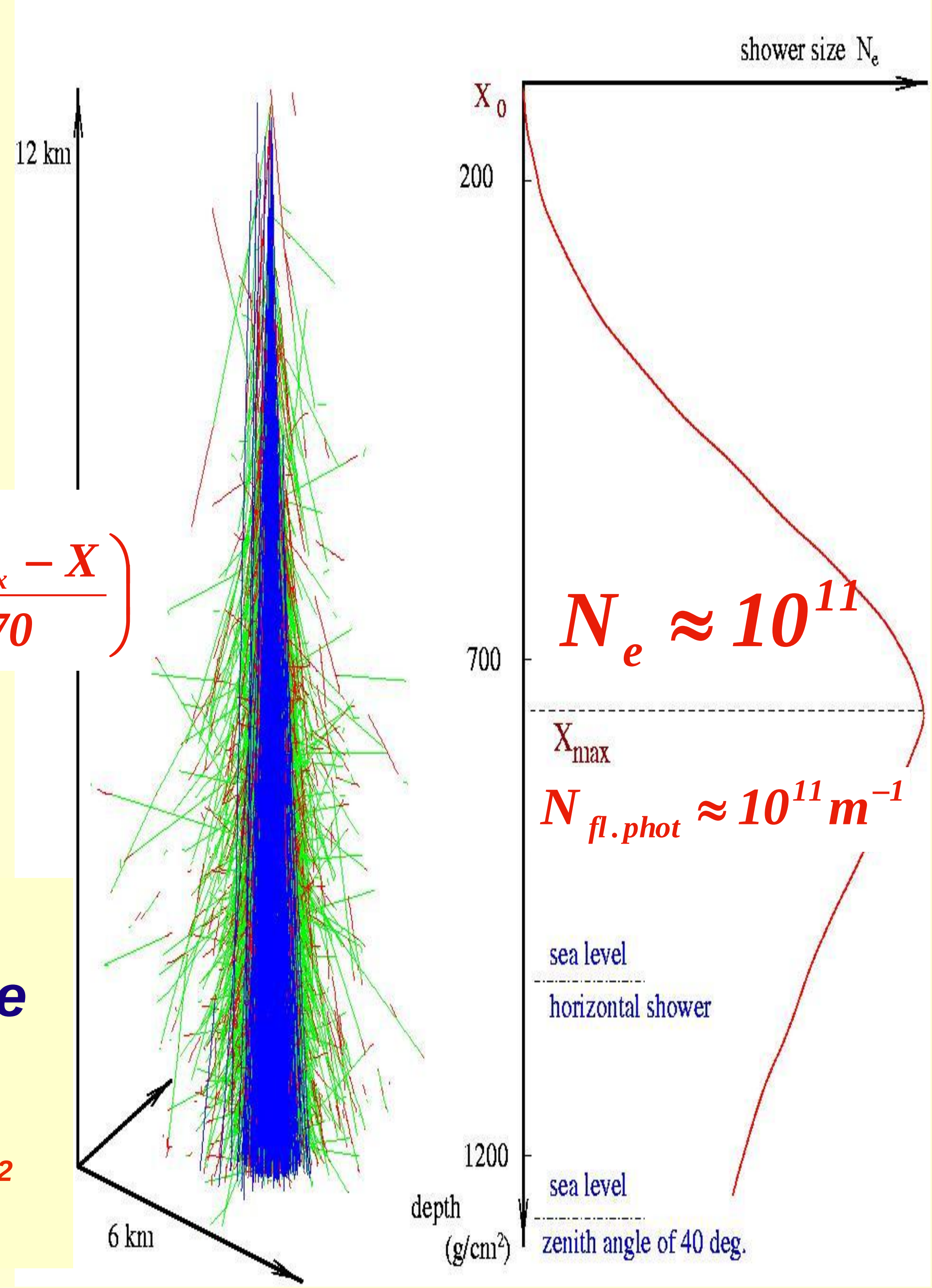
The number of charged particles (mainly e+ and e-) can be parametrized by the Gaisser-Hillas function

$$N_e = N_{max}\left(\frac{X - X_0}{X_{max} - X_0}\right)^{\frac{X_{max}-X_0}{70}} exp\left(\frac{X_{max} - X}{70}\right)$$

X_0 is the depth of the first interaction

X_{max} is the depth of the maximum (Energy, particle type)

X is the cumulate slant depth, in g/cm^2 (thickness of air traversed)



$$N_e \approx 10^{11}$$

$$N_{fl.phot} \approx 10^{11} m^{-1}$$

Open Questions remain

- *Is this the GZK suppression?* Or are the sources *running out of fuel*…
- Do we see a recovery of the spectrum ?
- Has the spectrum an end? *Which is the maximum energy*

Do we have a high statistics description of the spectrum?

- Requirement: A high precision measurement of the UHECR spectrum around and beyond the „GZK“ feature

Relevance of Auger's result:

- (Bad news for current observatories) it implies *a very low flux:*

$$1 particle/km^2/sr/century \quad E > 6 \times 10^{19} eV$$

$$1 particle/km^2/sr/millennium? \quad E > 10^{20} eV$$

- (Good news) It *limits the horizon* and gives us the possibility to find local sources:
  - *Large angular separation*
  - *Smaller magnetic deflections*

Sources?

III. Performances

Key observation and instrument requirements

Observation area (Nadir)	$\geq 1.3 \times 10^5 (H_{orbit}/400[km])^2$ km^2
Arrival direction determination accuracy	$\leq 2.5°$ (at $E=10^{20}$ [eV] and 60° zenith angle)
Energy determination accuracy	$\leq 30\%$ ($E=10^{20}$ [eV] and 60° zenith angle)
X_{max} determination accuracy	≤ 120 [g/cm^2] ($E=10^{20}$ [eV] and 60° zenith angle)
Energy threshold	$\leq 5.5 \times 10^{19}$ [eV]
Duty cycle	$\geq 17\%$
Lifetime	> 3 years (goal: > 5 years)

Which is the annual exposure?

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

$$TA´\ h´\ k$$

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

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

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

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P.Bobik et al., 2011

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)*

P. Bobik et al., 2011

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

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)

We can also operate at higher background rates (higher energies)

Cloud Coverage

F. Garino et al., 2011

Cloud top

Optical Depth

	<3 km	3-7 km	7-10 km	>10 km
τ >2	17.2	5.2	6.4	6.1
τ ≈ 1-2	5.9	2.9	3.5	3.1
τ ≈ 0.1-1	6.4	2.4	3.7	6.8
τ ≈ 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., 2011, K. Shinozaki et al. 2011

Cloud-impact to trigger efficiency

E>5·10^19 eV

Cloud top

Optical Depth

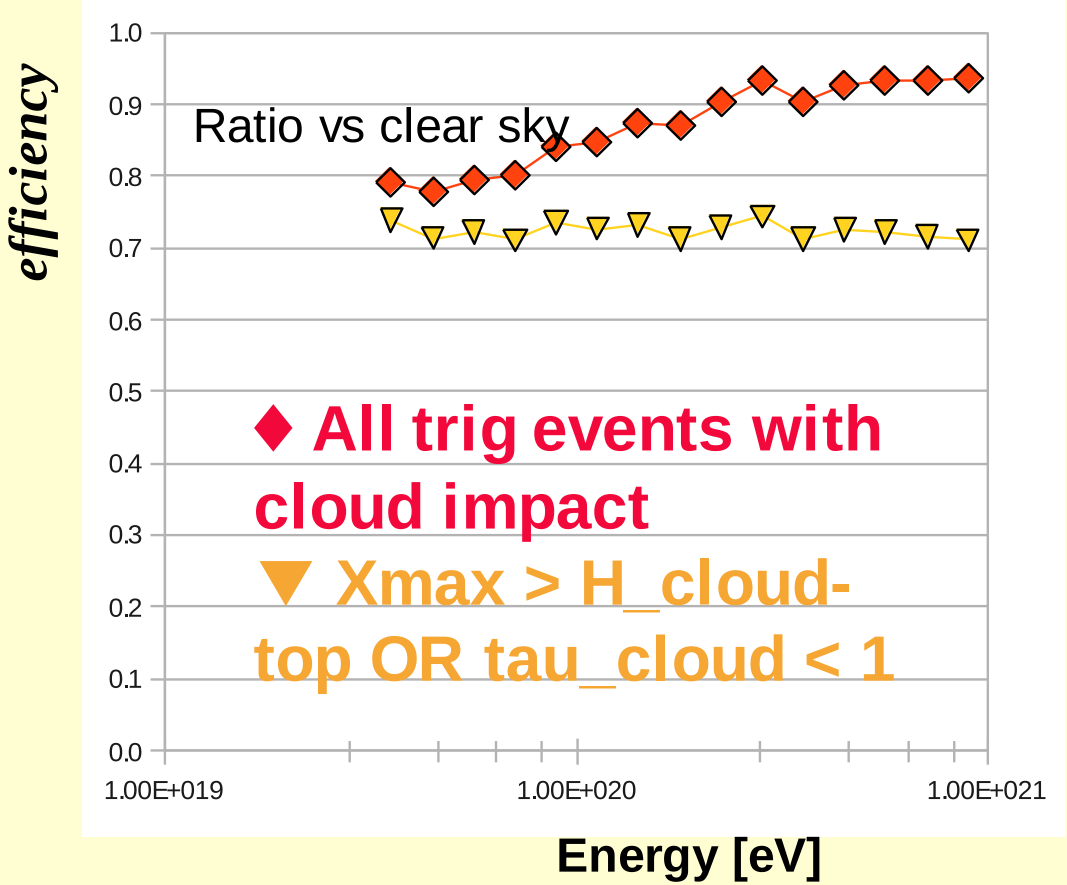
	<3 km	3-7 km	7-10 km	>10 km
$\tau > 2$	90%	65%	35%	20%
$\tau \approx 1\text{-}2$	90%	70%	45%	25%
$\tau \approx 0.1\text{-}1$	90%	80%	75%	70%
$\tau \approx 0.1$	90%	90%	90%	90%

Average efficiency* = 82% above 50 EeV

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

L. Saez et al., 2011

K.Shinozaki et al. 2011

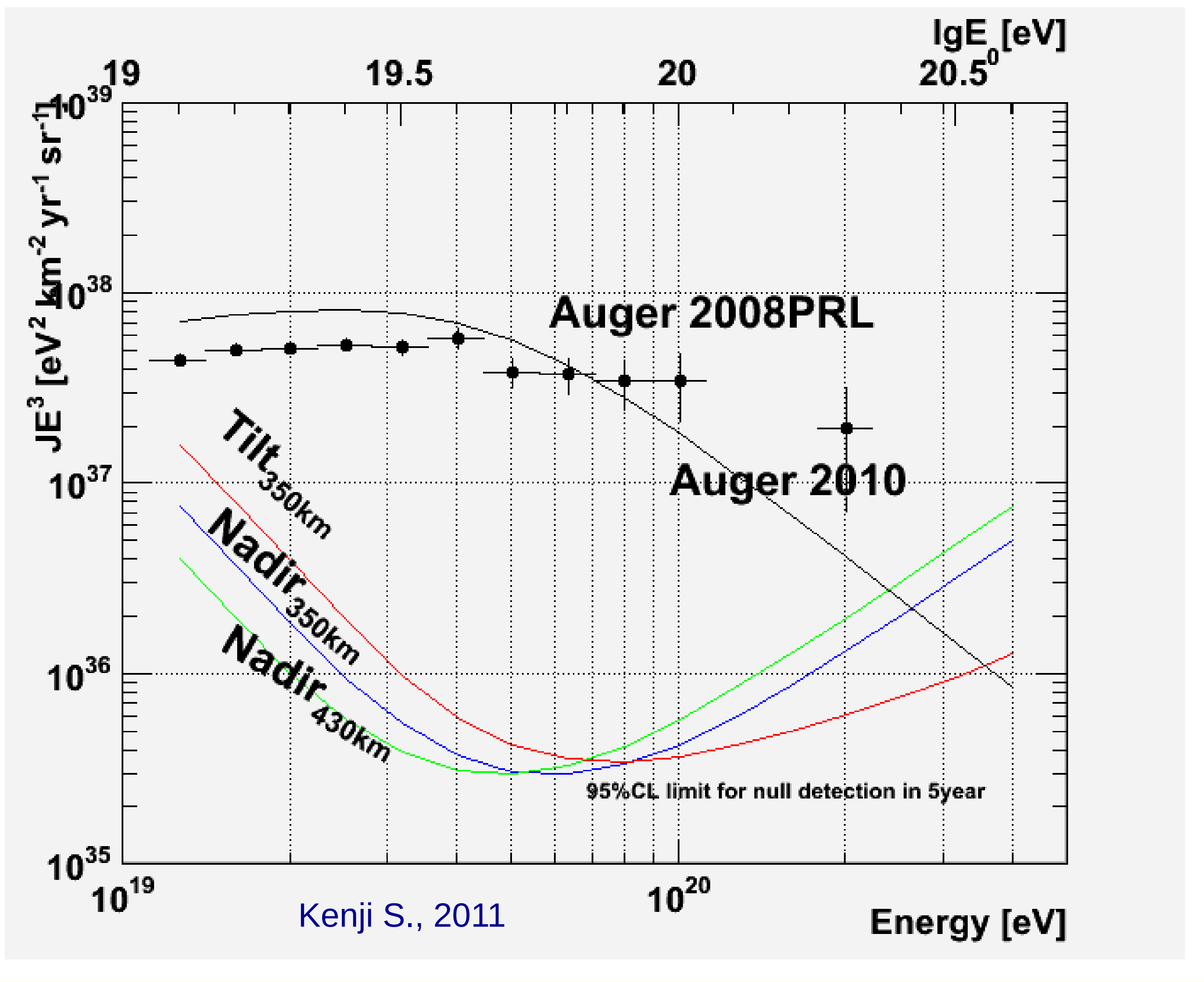


Basic conclusion:

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

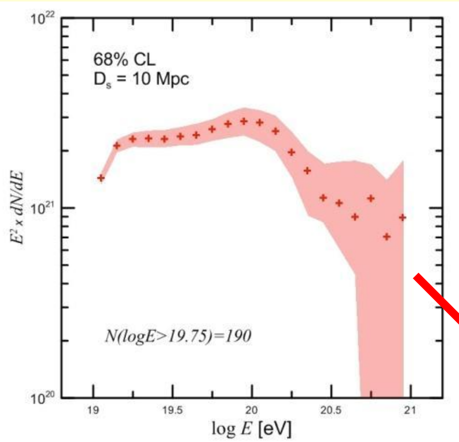
**Different geometrical conditions for optically thick or optically thin clouds*

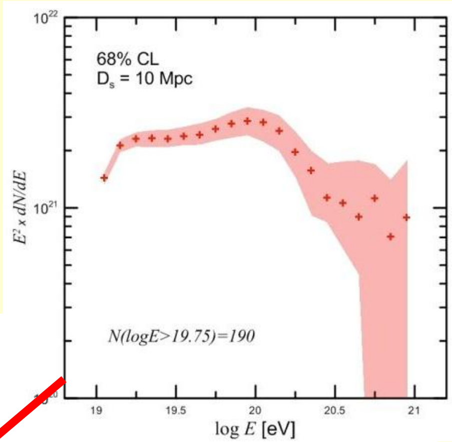
At the highest energies: recovery in the spectrum

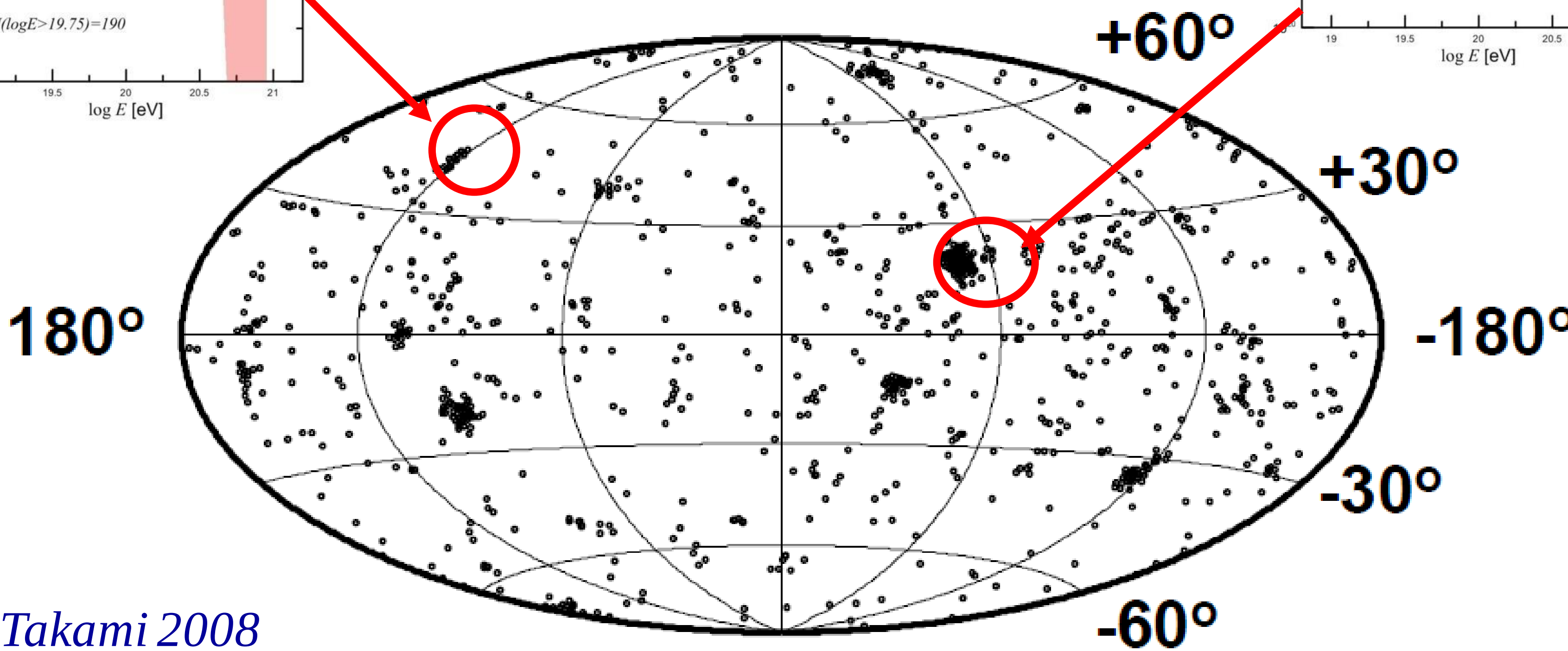


JEM-EUSO sky

Forecast in case of 1,000 events
Brightness proportional to AGN







Takami 2008

Brightness of particles ∝ X ray（AGN）

- *We expect to discover several tens of clusters*
- *Can observe the whole sky*

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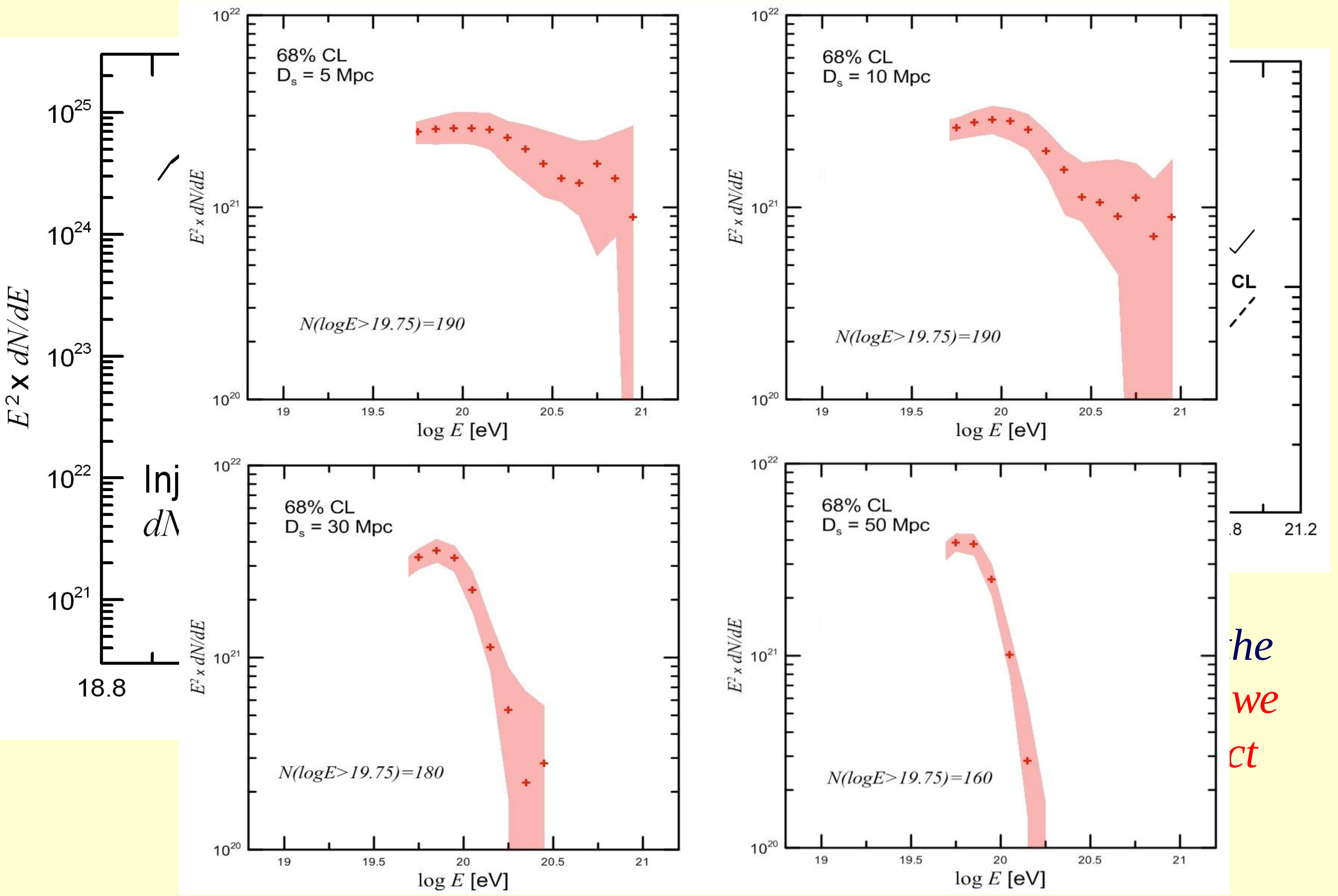
Test of the GZK effect



Other exploratory objectives

From Particle Astronomy:

- Galactic and local intergalactic Magnetic Fields

Exploratory Science Objectives:

- Neutrinos at UHE

- Photons at UHE

- Fundamental Physics

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 to solve the puzzle and to explore the unknown (Neutrinos, Photons, new physics)*
- *Breakthrough can come from space:* Large and uniform exposures of the entire sky, *JEM-EUSO is the pathfinder* with likely outstanding science output.
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Conclusions

- JEM-EUSO is designed to have a annual exposure about *9xAuger at 10^{20} eV in nadir mode* and *28xAuger* at the highest unexplored energies in tilt mode.
- To reach/approach 1ML integrated exposure it is *necessary to operate the mission also in tilted mode.*
- Simulations in nadir mode shows that the energy, angular and X_{max} resolution meet the requirements.
- *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 (?)* Stay tuned for surprises…

Conclusions

- *Science:* Evidence for GZK, Indication for Anisotropy, hints of sources but *puzzling scenario* (PAO, HiRes, TA)
  - Current generation of UHE Observatory 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.