# Pierre Auger Observatory and beyond: AugerNext and JEM-EUSO

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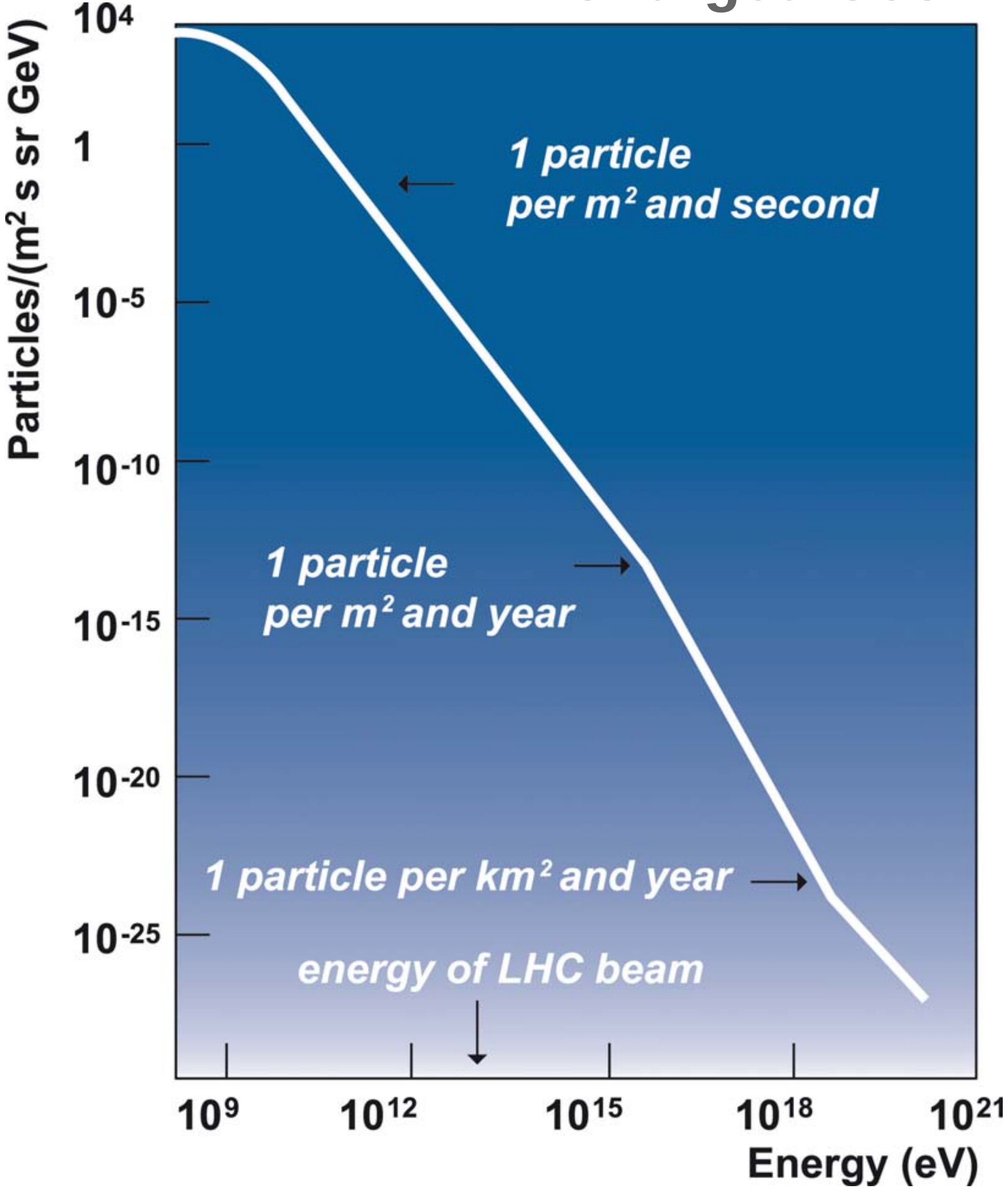
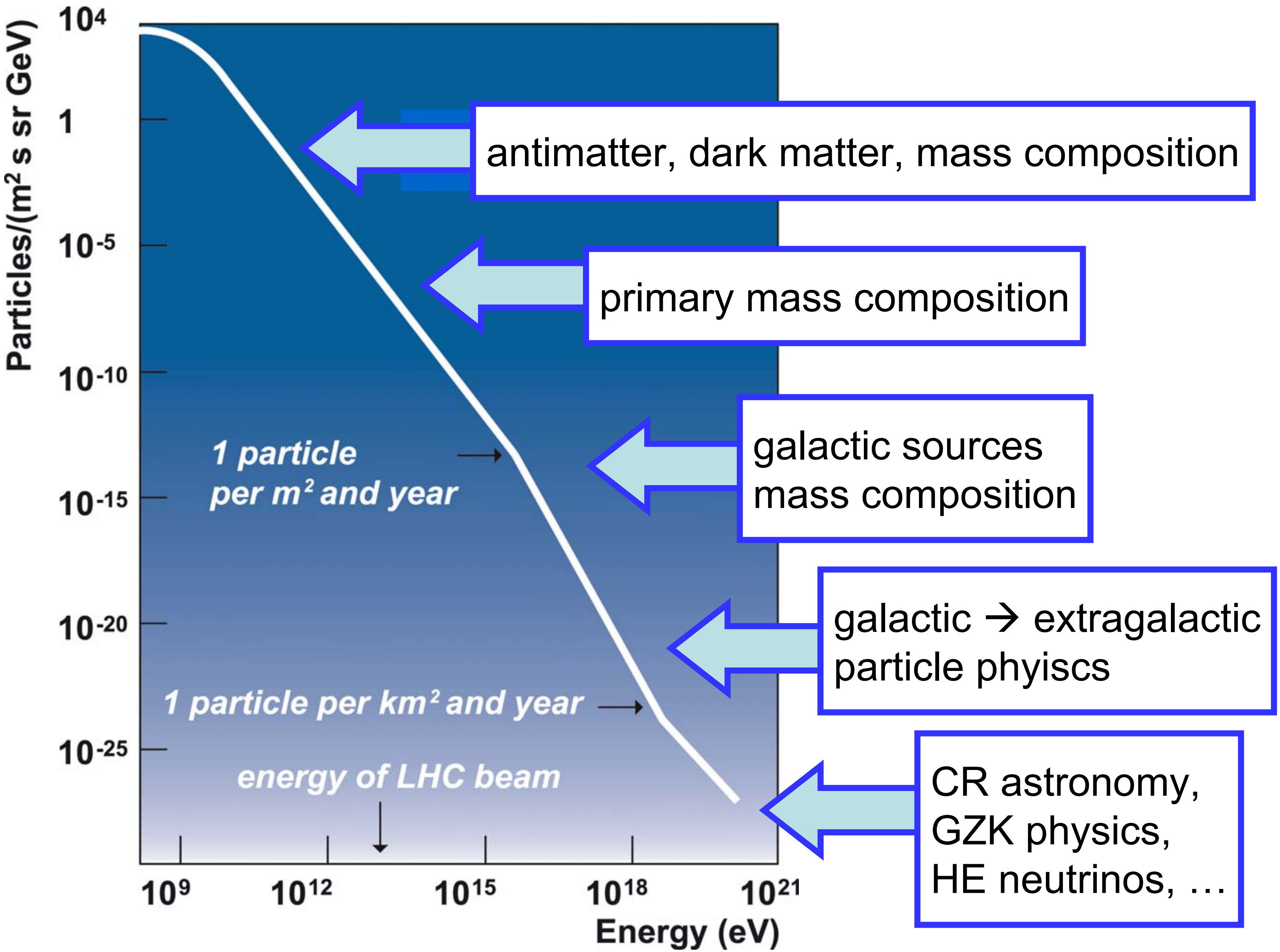
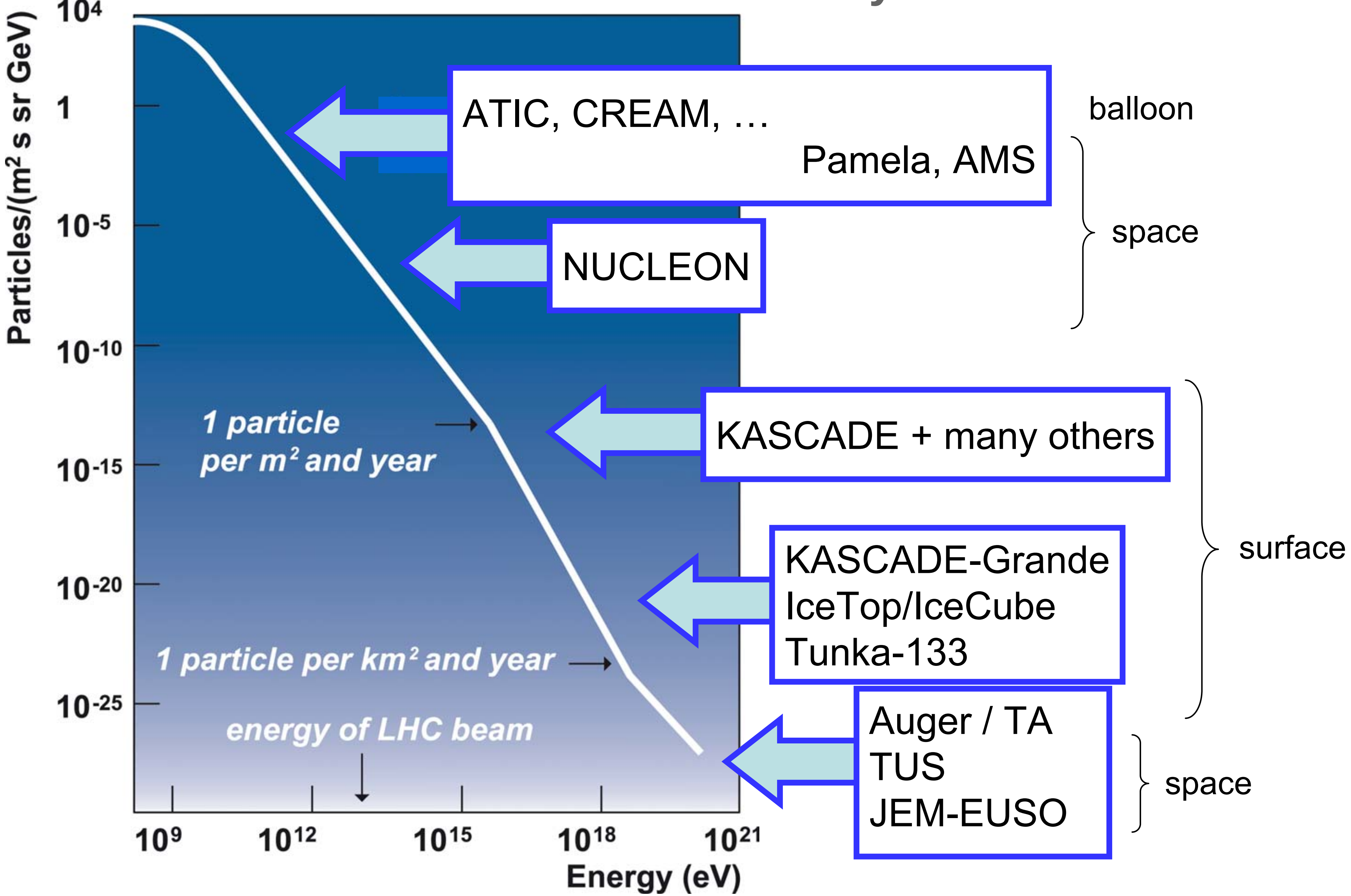
# Charged Cosmic Rays



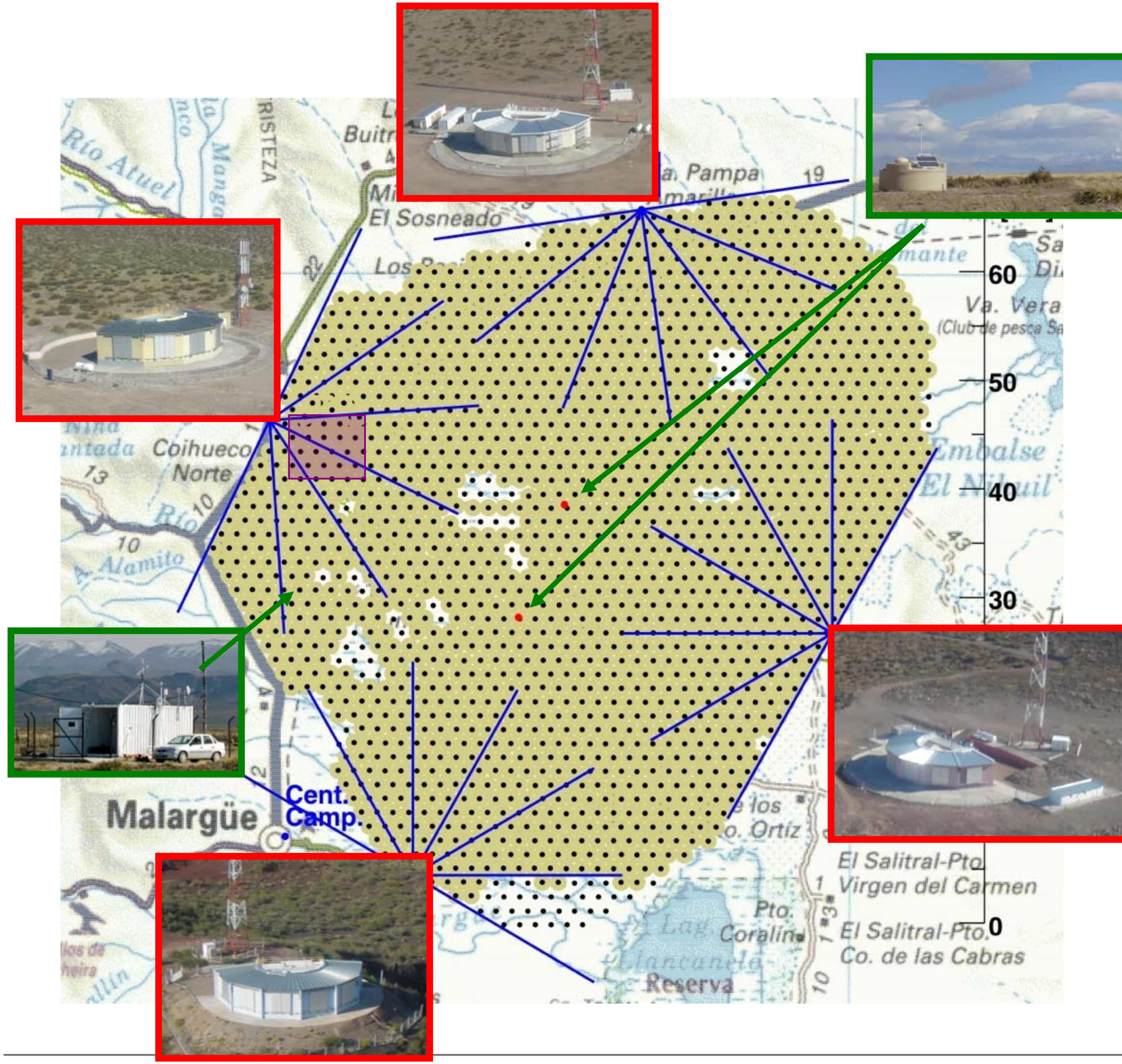
# Charged Cosmic Rays



# Charged Cosmic Rays



# The Pierre Auger Observatory: completed July 2008




**1600 surface detector stations: water-Cherenkov tanks**
**(triangular grid of 1.5 km)**

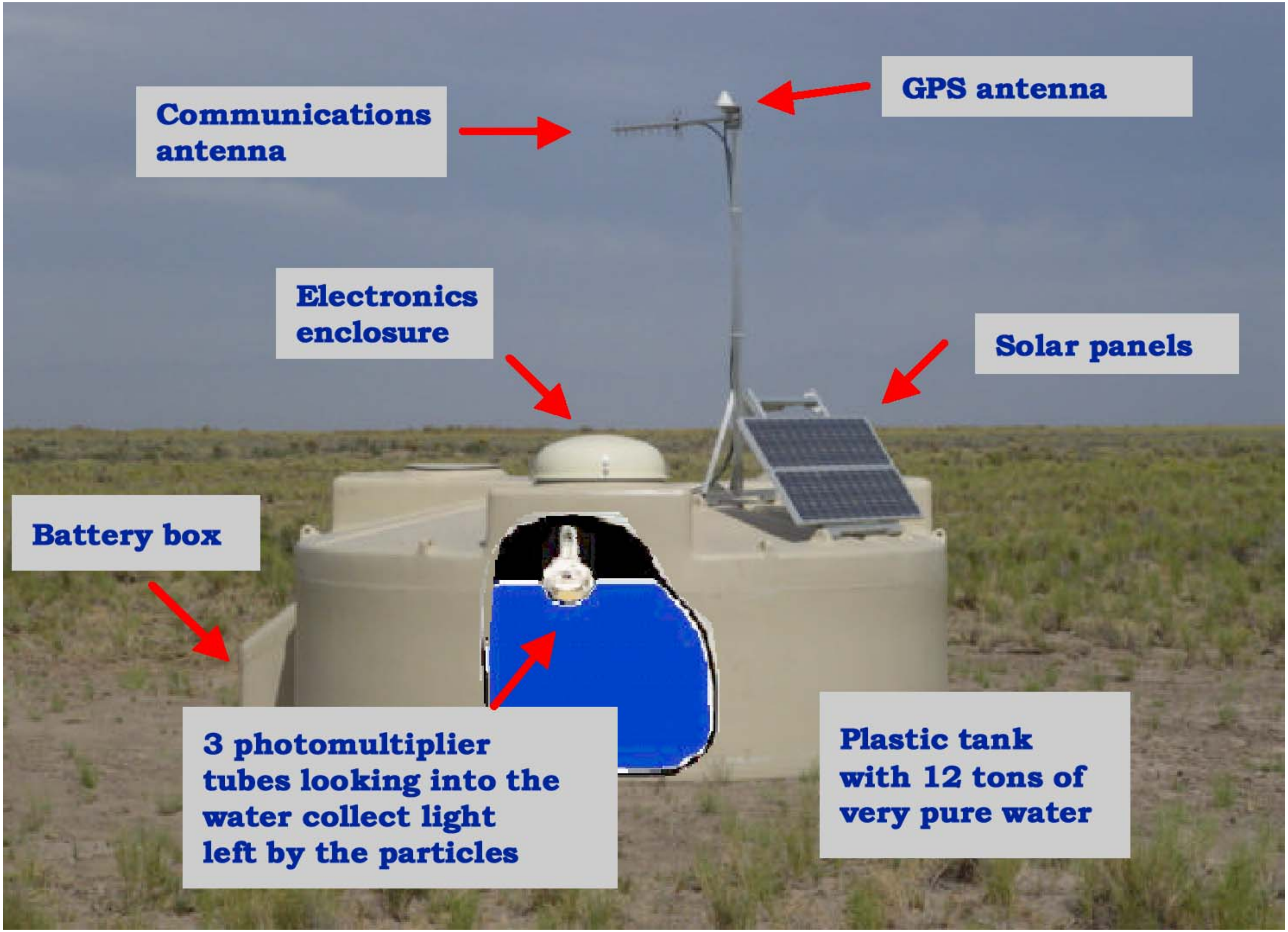
**4 fluorescence detectors (24 telescopes in total)**

**2 laser stations**
**balloon station**

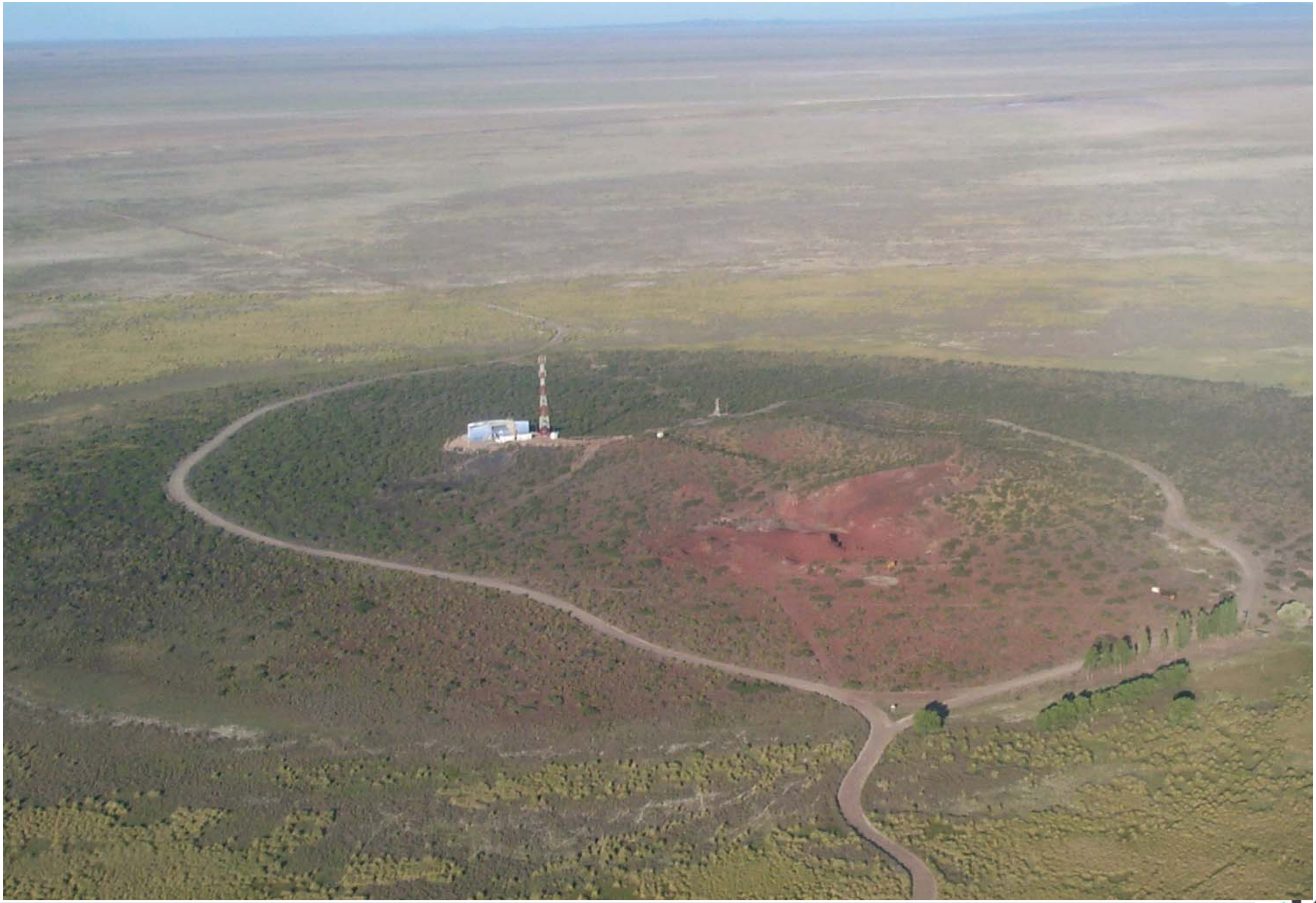
**~25km² infill area**
**HEAT, AMIGA, AERA**

# Surface array in the Argentinean Pampa

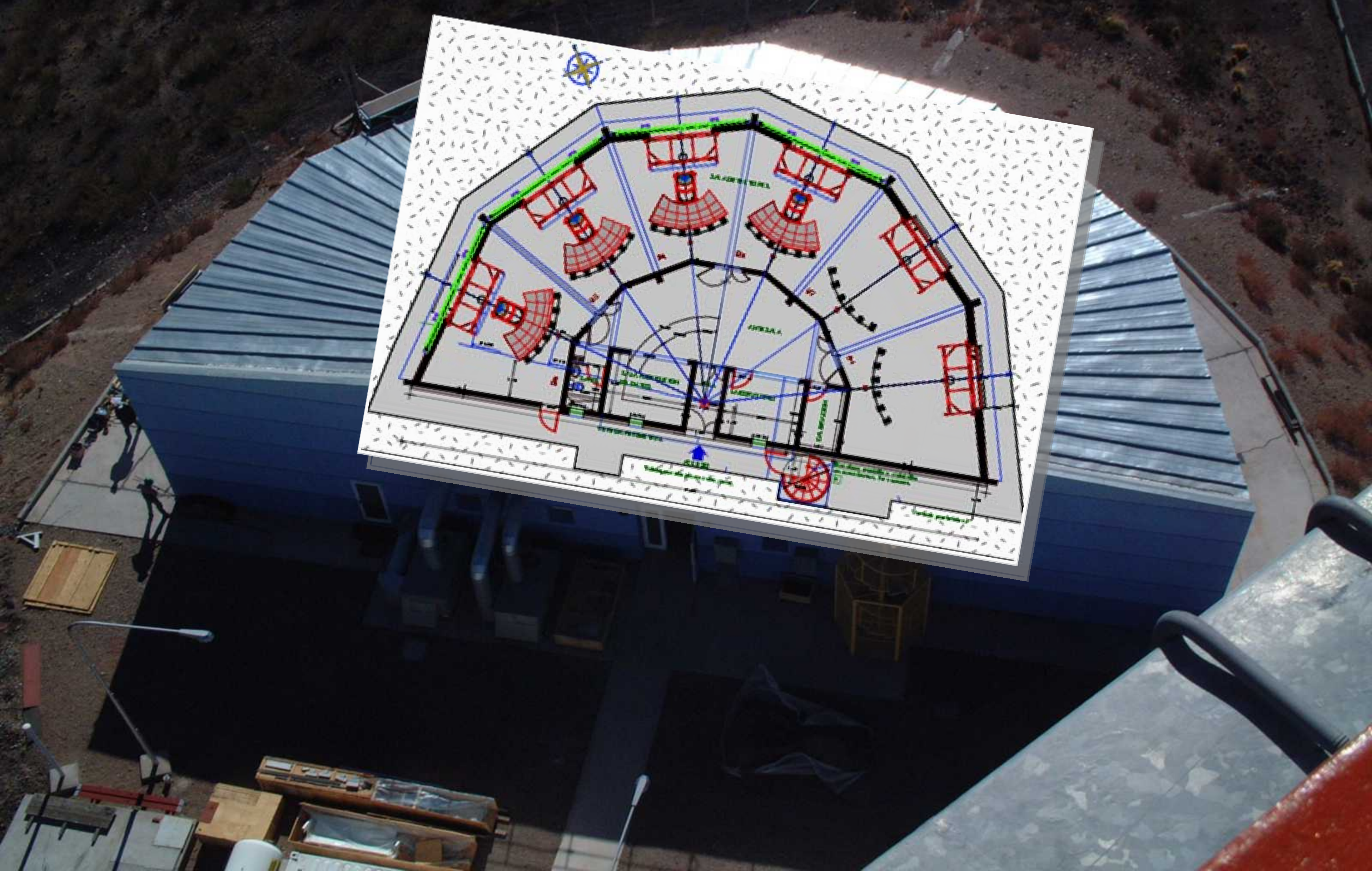
# Water Cherenkov Detector



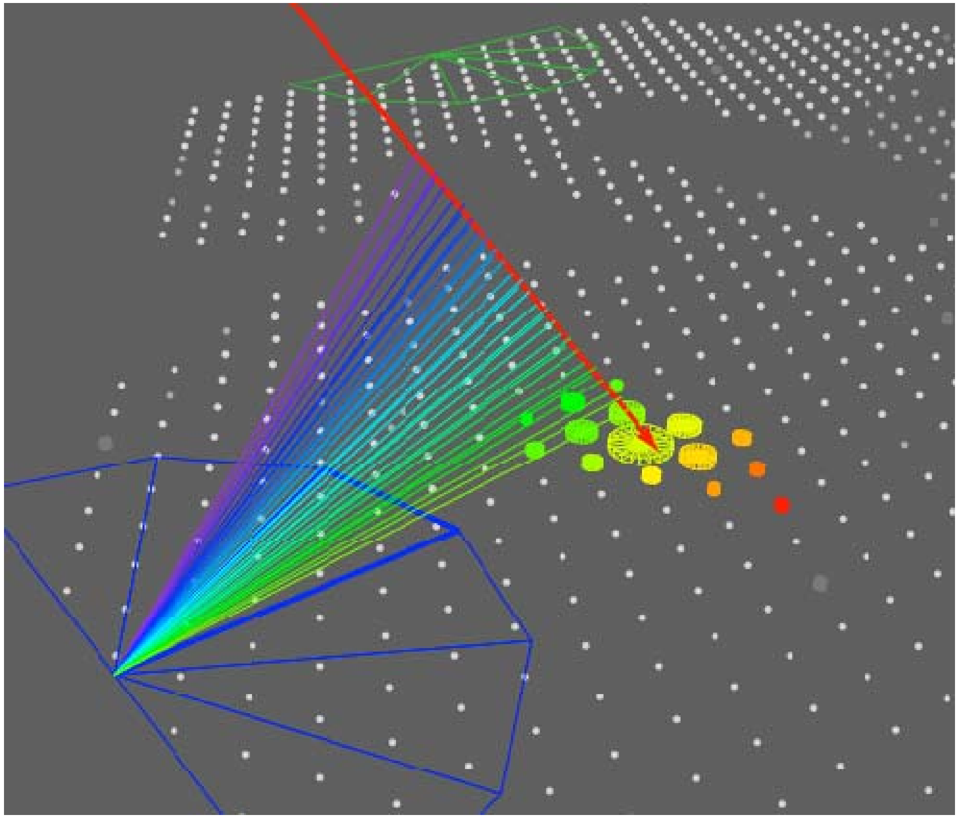
# Fluorescence Telescopes

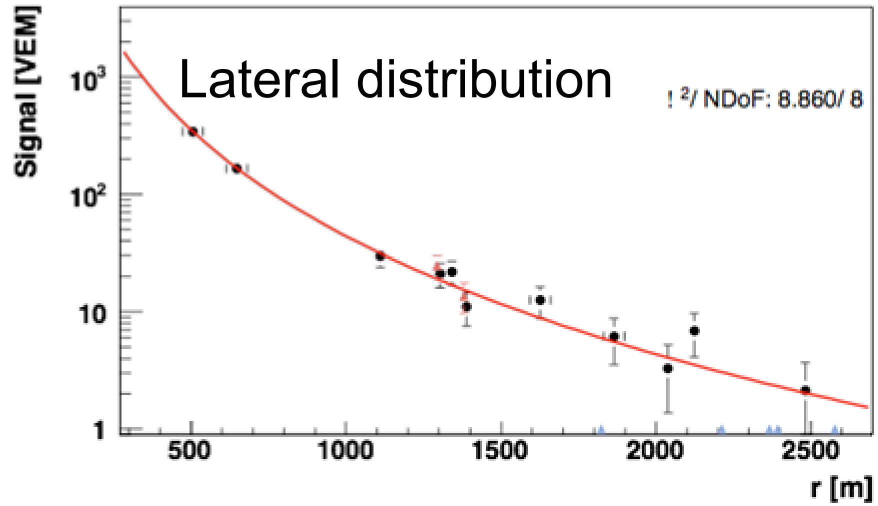


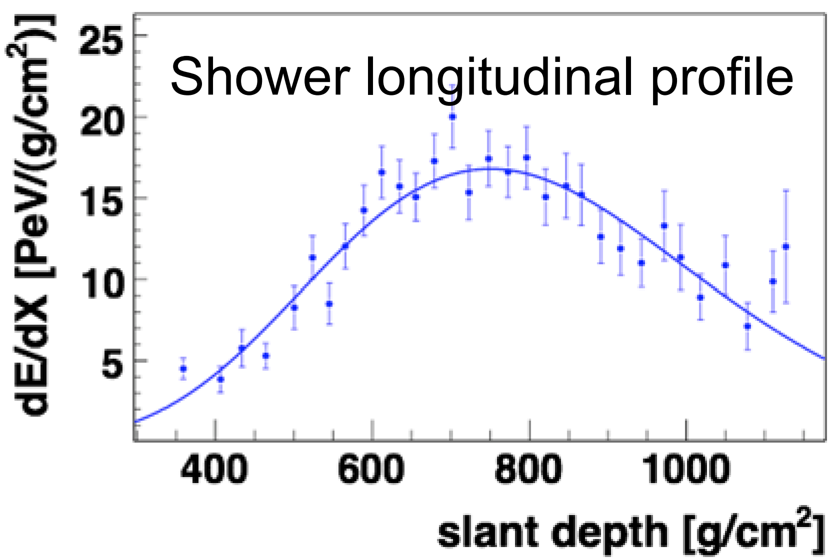
# six telescopes each viewing 30° by 30°



# Golden hybrid events

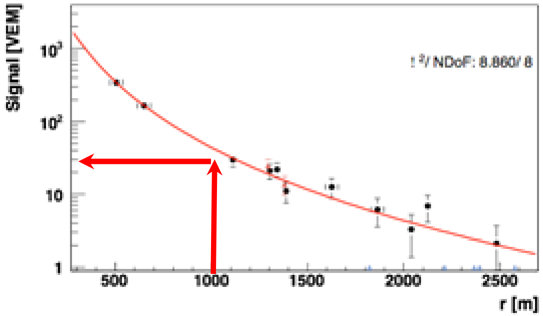


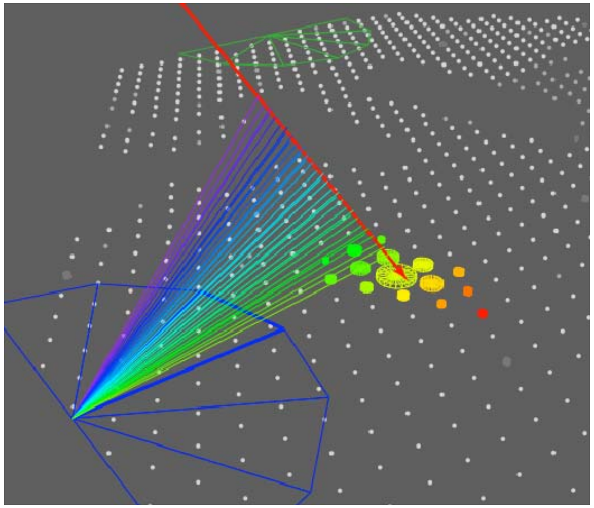


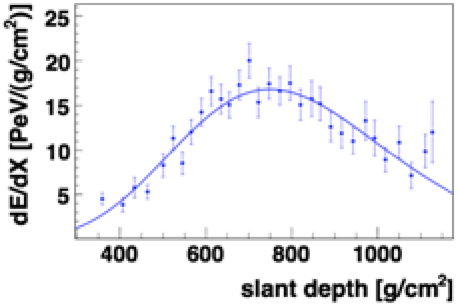




**Hybrid events**
**Golden hybrid events**

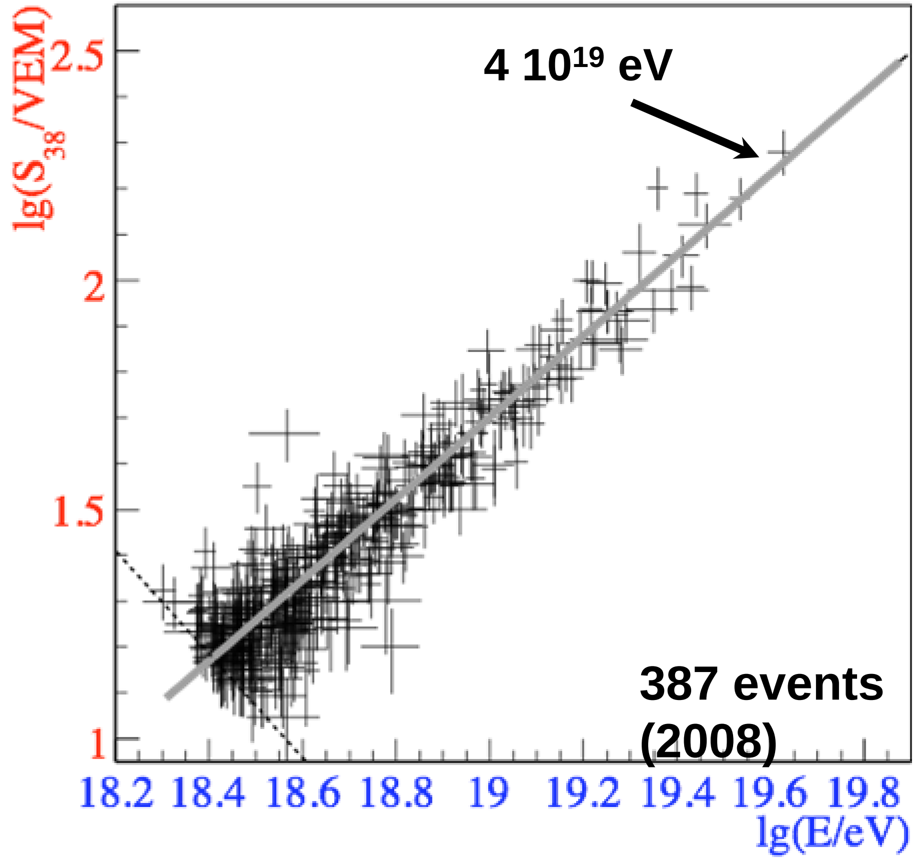
# Energy calibration of surface detector by Hybrid events





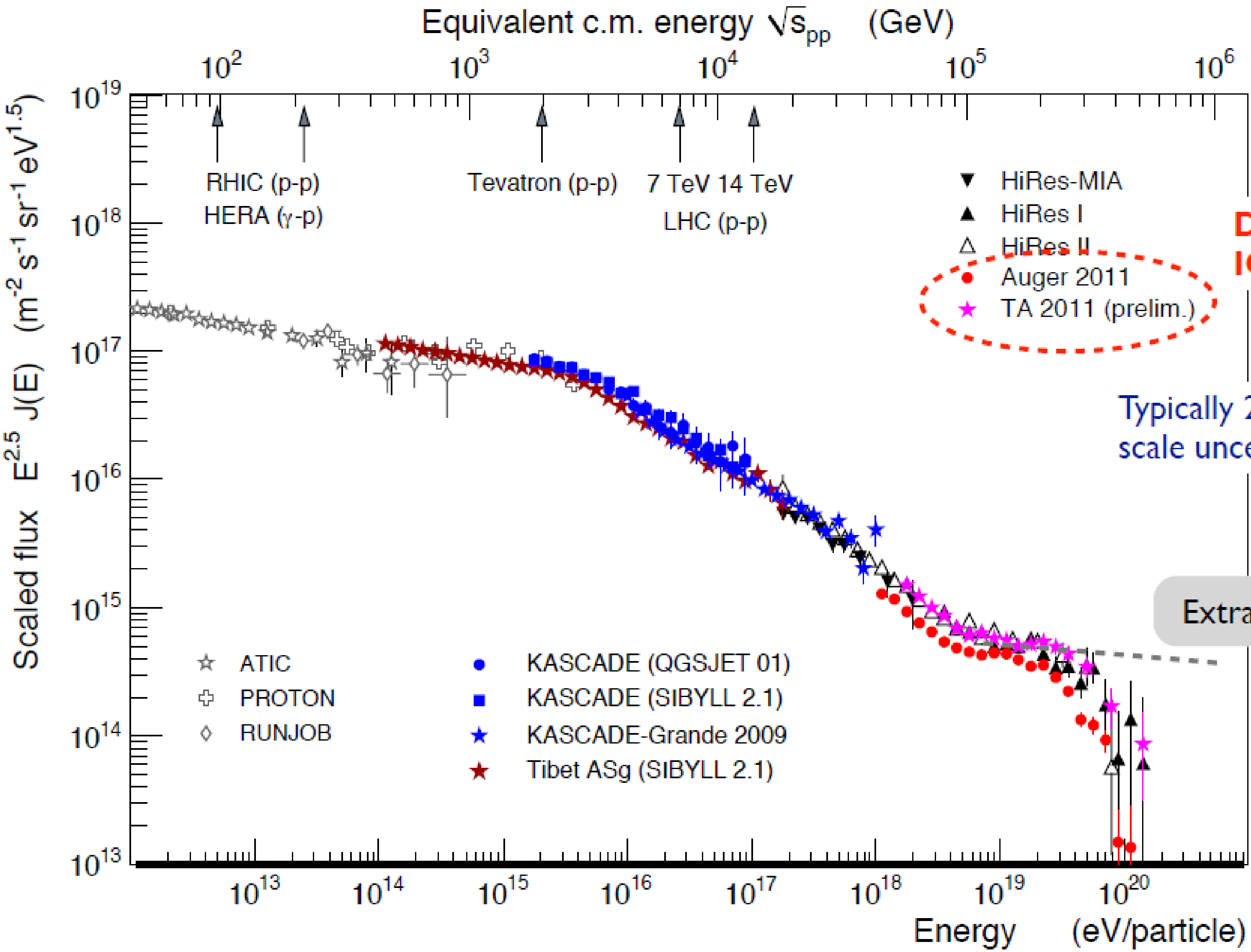

Shower size at 1000m and θ=38°




Fluorescence detector energy

$$E_{\text{prim}} = f_{\text{corr}} \cdot \int \frac{\mathrm{d}E_{\text{ion}}}{\mathrm{d}X}\,\mathrm{d}X$$

# Energy spectrum




Data from ICRC 2011

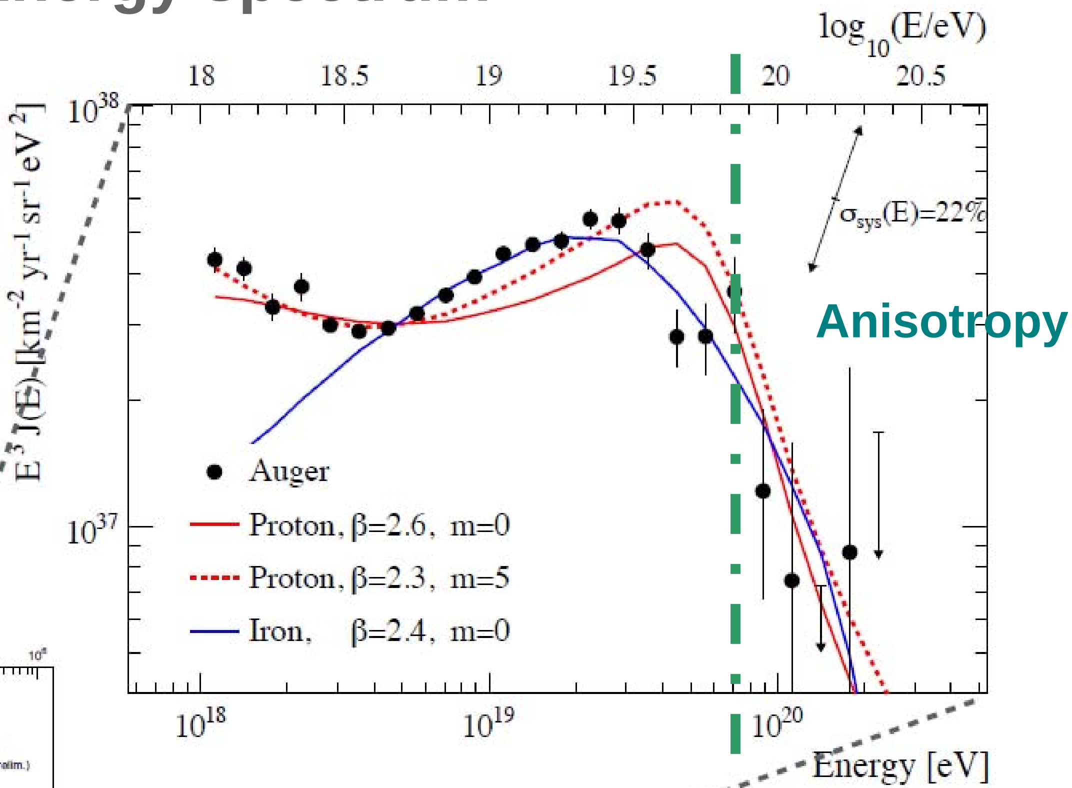
Typically 20% energy scale uncertainty

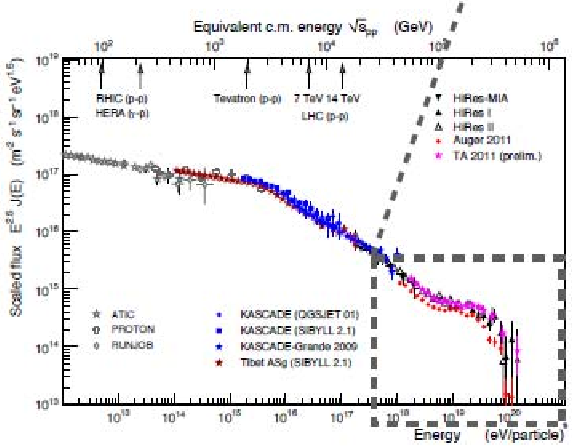
Extrapolated flux

# Energy spectrum

**Proton dominated flux**
Ankle: e⁺e⁻ pair production
Suppression: delta resonance

*(Dip model of Berezinsky et al.)*




**Iron dominated flux**
Ankle: transition to galactic sources
Suppression: giant dipole resonance

? Observed flux suppression is due entirely to GZK effect
? Observed flux suppression is signature of maximum acceleration energy
? Observed flux suppression is due to both source cutoff and GZK effect

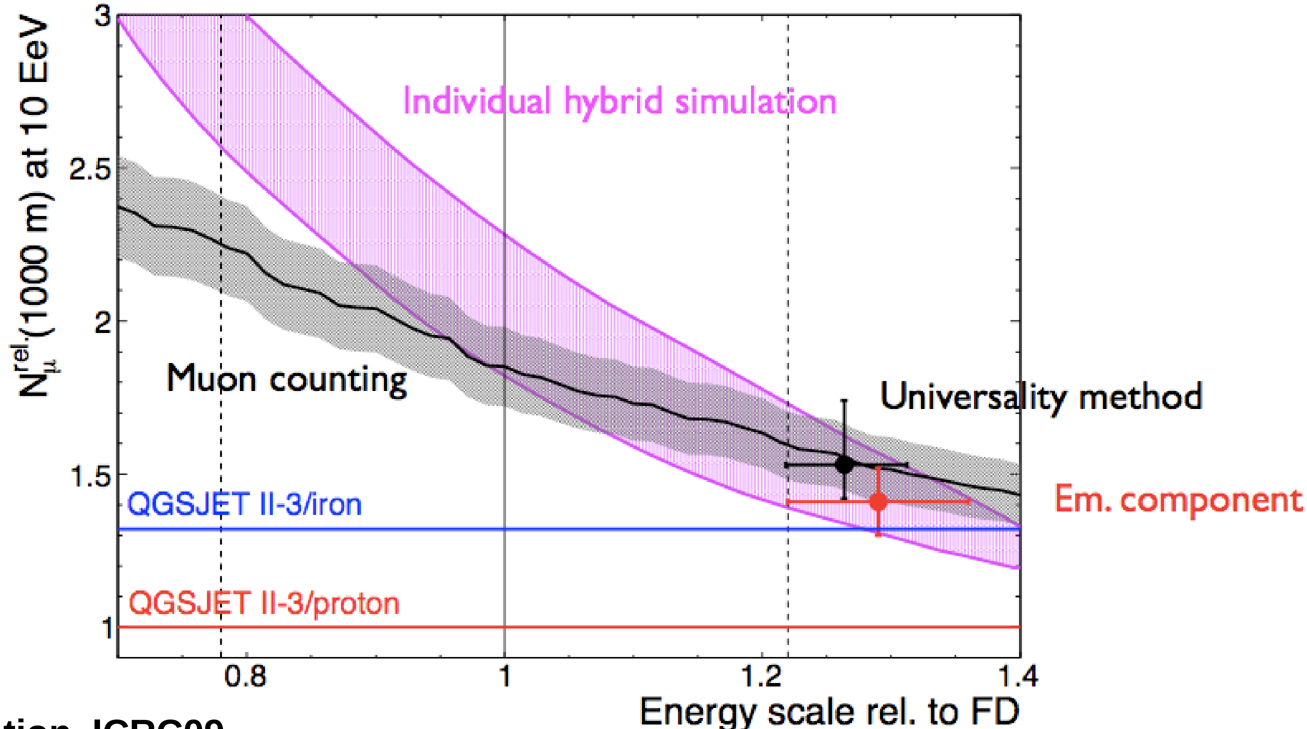
# Validity of hadronic interaction models

**A self consistent description of the Auger data is obtained only with a number of muons 1.3 to 1.7 times higher**

**than that predicted by QGSJET-II for protons at an energy 25-30% higher than that from FD calibration**

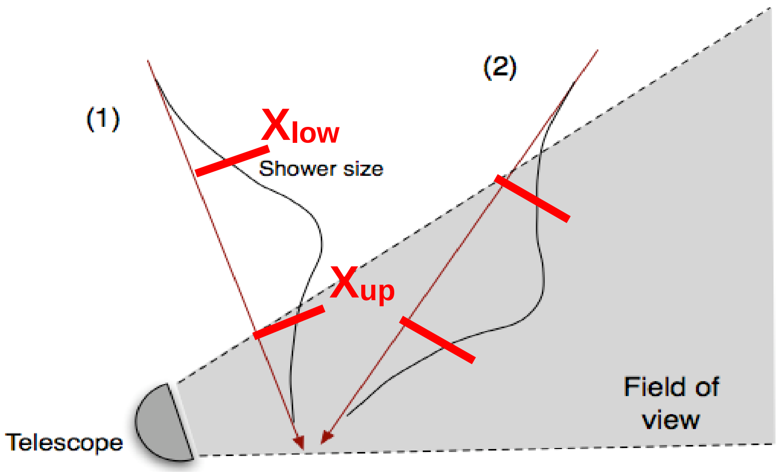
**The results are marginally compatible with the predictions of QGSJET-II for Iron primaries**

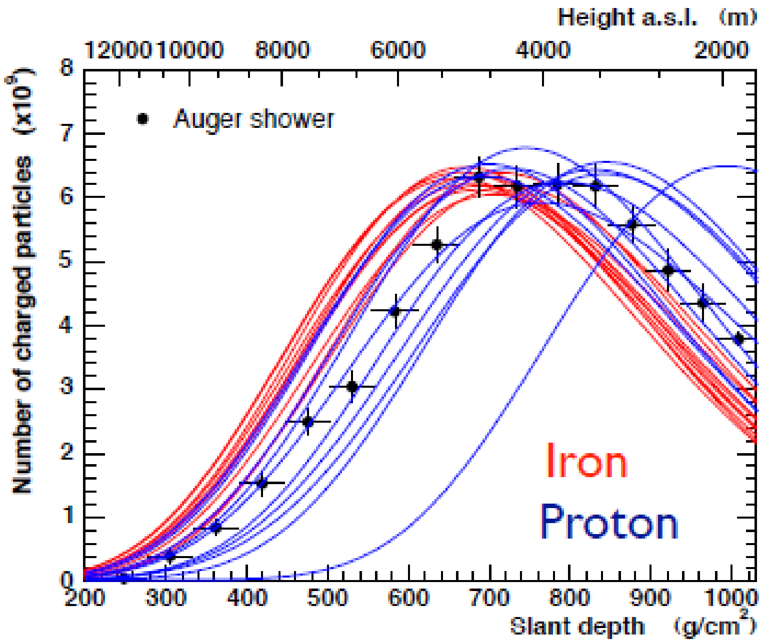
**Discrepancy: shower profile and muons at ground**




**A.Castellina-Auger Collaboration, ICRC09**

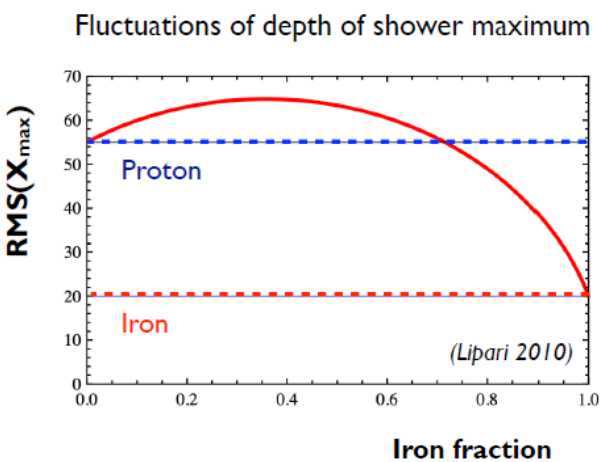
# Composition: measurement of longitudinal profile




**Field of view bias needs to be accounted for**

**$X_{low}$, $X_{up}$ are determined from data, no simulation needed**

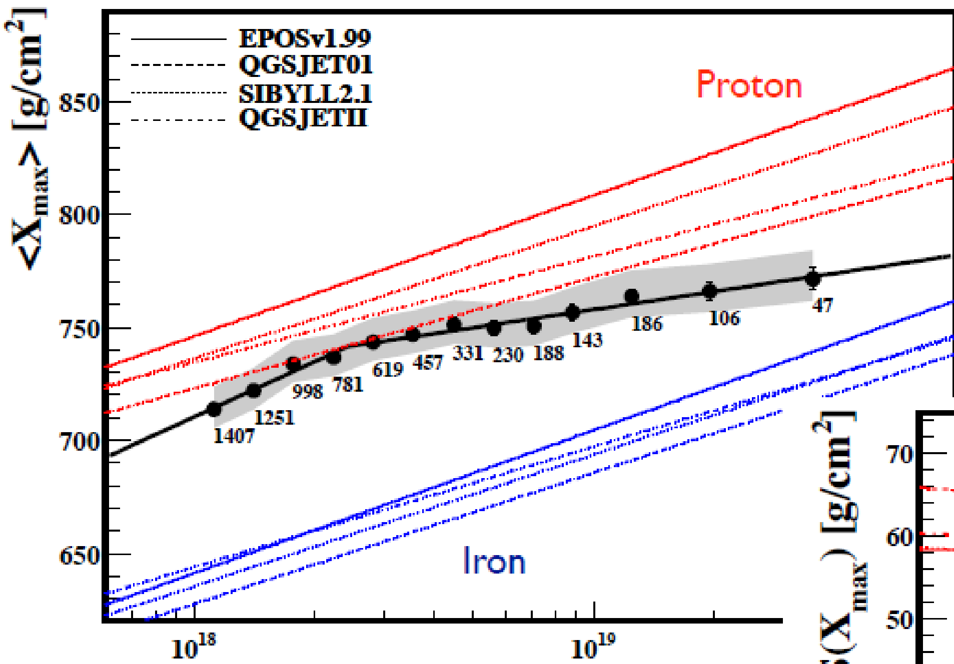



**Mean depth of shower profiles and shower-to-shower fluctuations as measure of composition**

*(Unger et al., ICRC 2007)*

# Composition: mean depth and rms of shower maximum

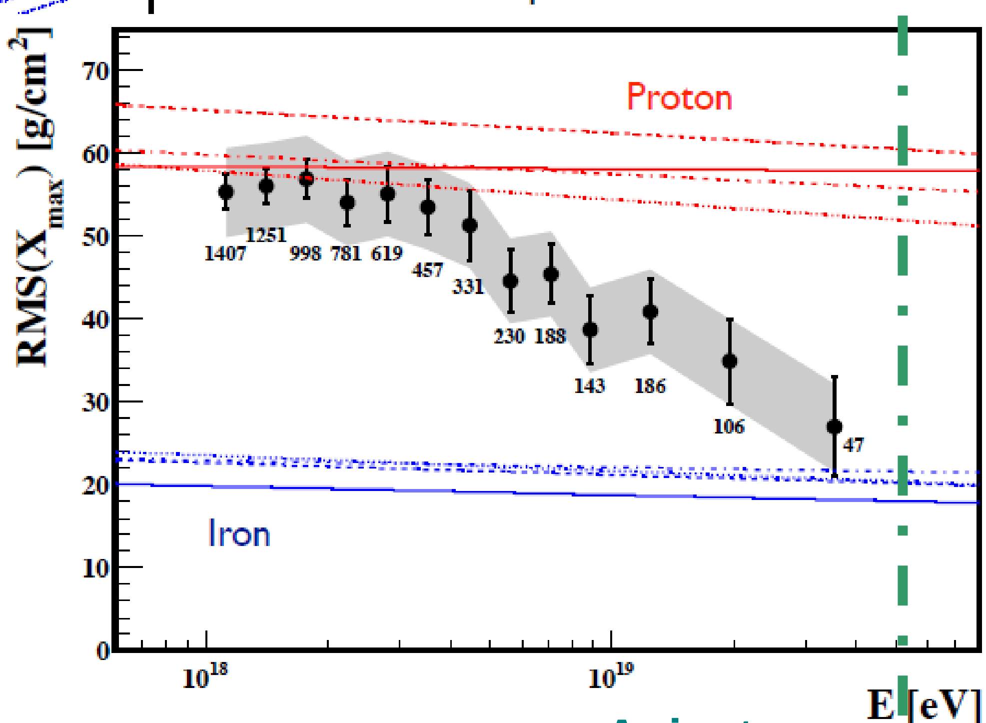
Mean depth of shower maximum




Change of cosmic ray composition from mixed or light to heavy ?

*(Auger Collab. PRL 104, 2010, updated: Facal, ICRC 2011)*

Fluctuations of depth of shower maximum



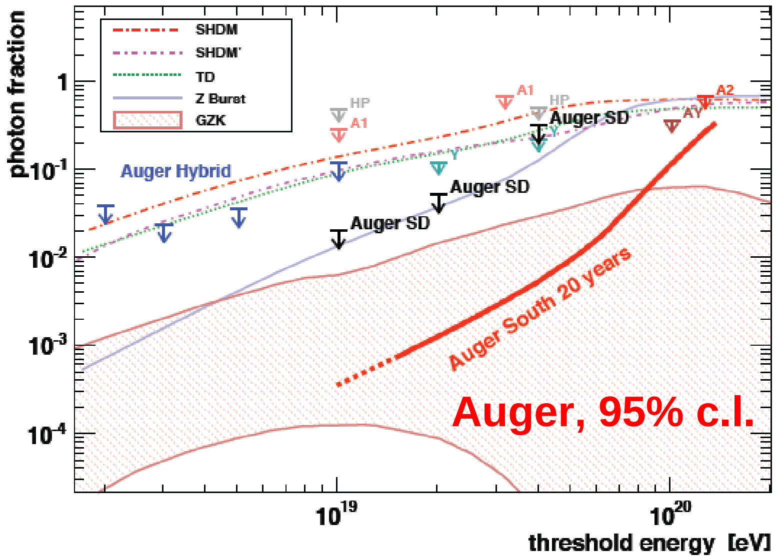

Sys. uncertainty: 13 g/cm$^2$ (mean)
6 g/cm$^2$ (RMS)

Independent confirmation from other composition indicators

**J.Bellido-Auger Collaboration, ICRC09**

**Anisotropy**

## Limit on fraction of photons in UHECR flux

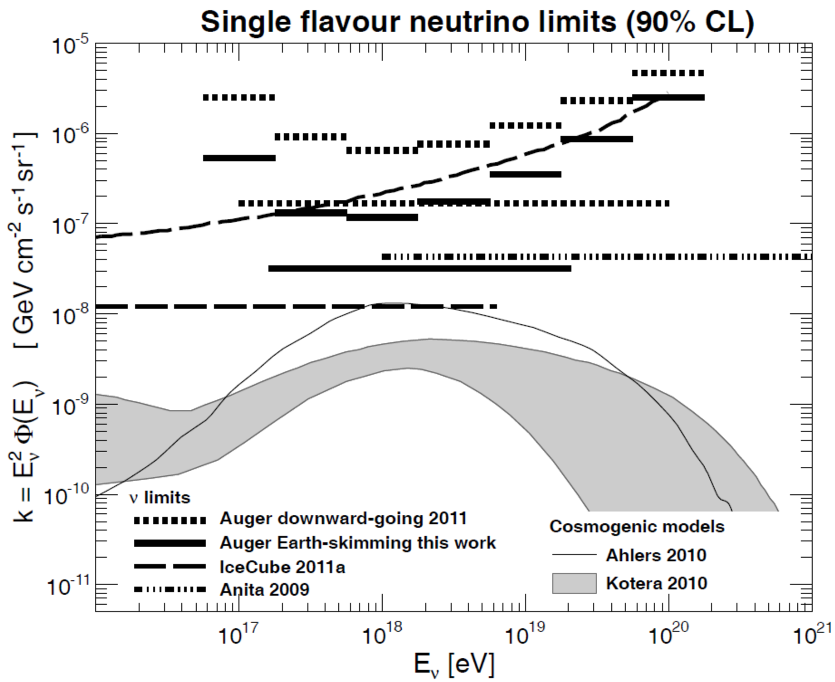



**Photons penetrate deeper in Atmospheres and have less muons**

**Many exotic source scenarios excluded**

*Astropart. Phys. 29 (2008) 243*
*Astropart. Phys. (2009), arxiv 0903-1127*

## Limit on flux of neutrinos in UHECR flux

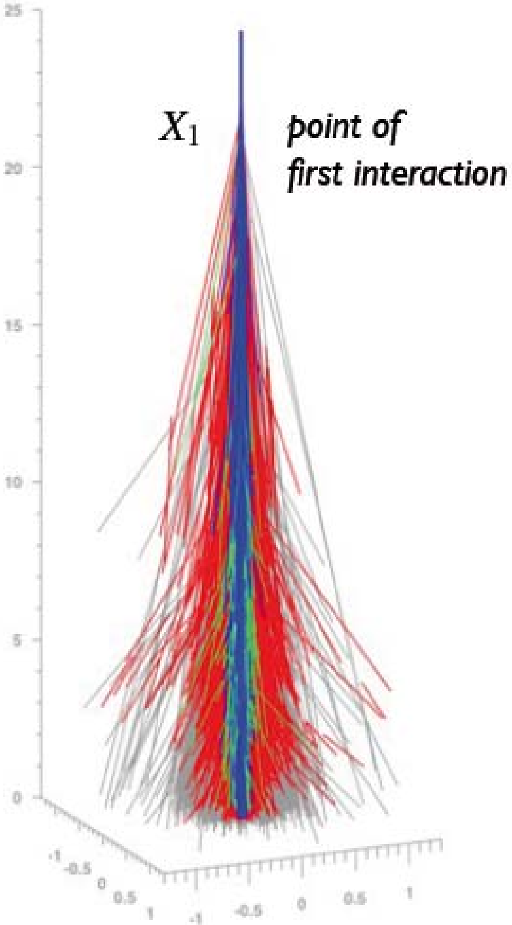


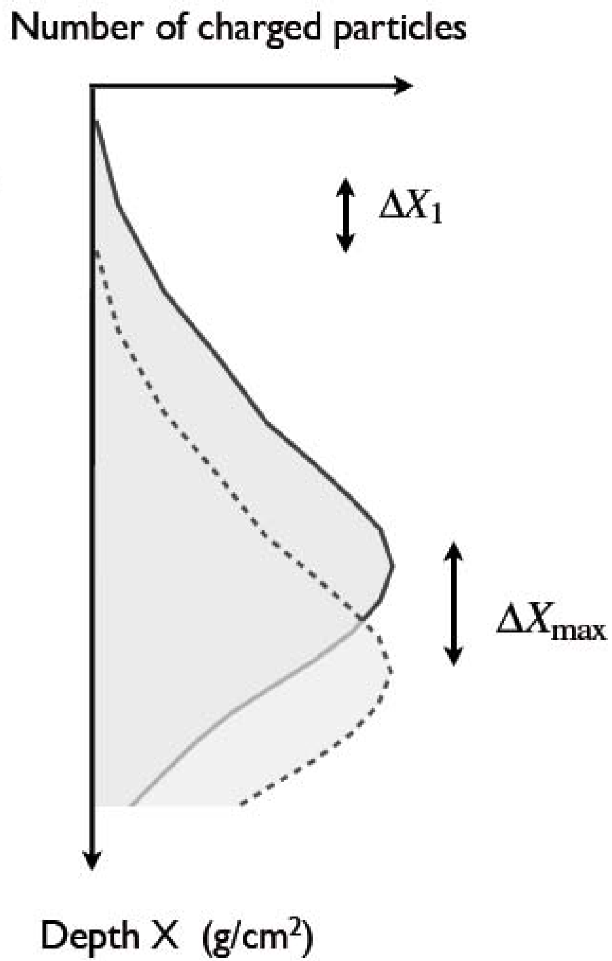

**Horizontal or Earth skimming EAS with electromagnetic component**

**No Neutrinos detected**

*PRL 100 (2008) 211101*
*ApJ (2012) accepted*

# Particle Physics: Cross section




$$\frac{dP}{dX_1} = \frac{1}{\lambda_{int}} e^{-X_1/\lambda_{int}}$$

$$\mathrm{RMS}(X_1) = \lambda_{int}$$

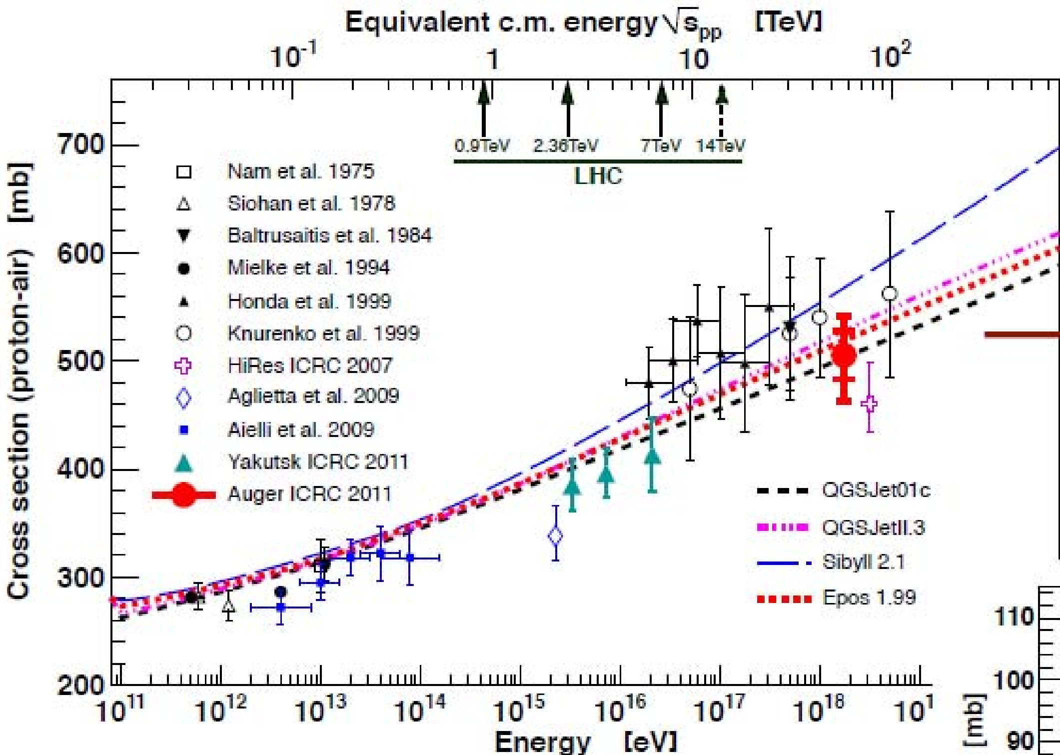
$$\sigma_{p-air} = \frac{\langle m_{air} \rangle}{\lambda_{int}}$$

**Difficulties**

- mass composition
- fluctuations in shower development (model needed for correction)
  $\mathrm{RMS}(X_1) \sim \mathrm{RMS}(X_{max} - X_1)$
- experimental resolution ~20 g/cm²

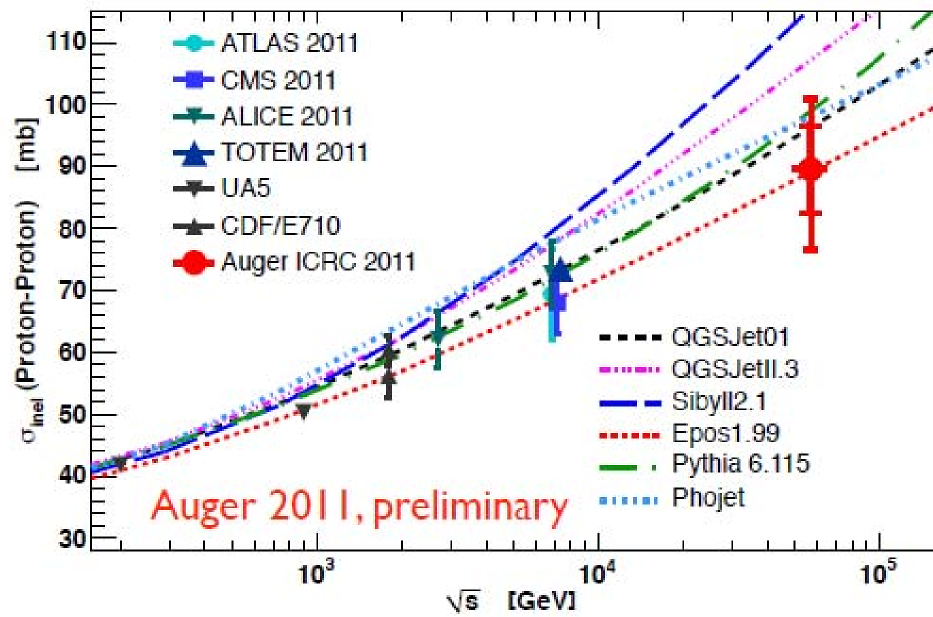
*R. Ulrich et al. NJP 11 (2009) 065018*

# Cross section




Conversion from p-air to p-p cross section always model-dependent

*Glauber model*

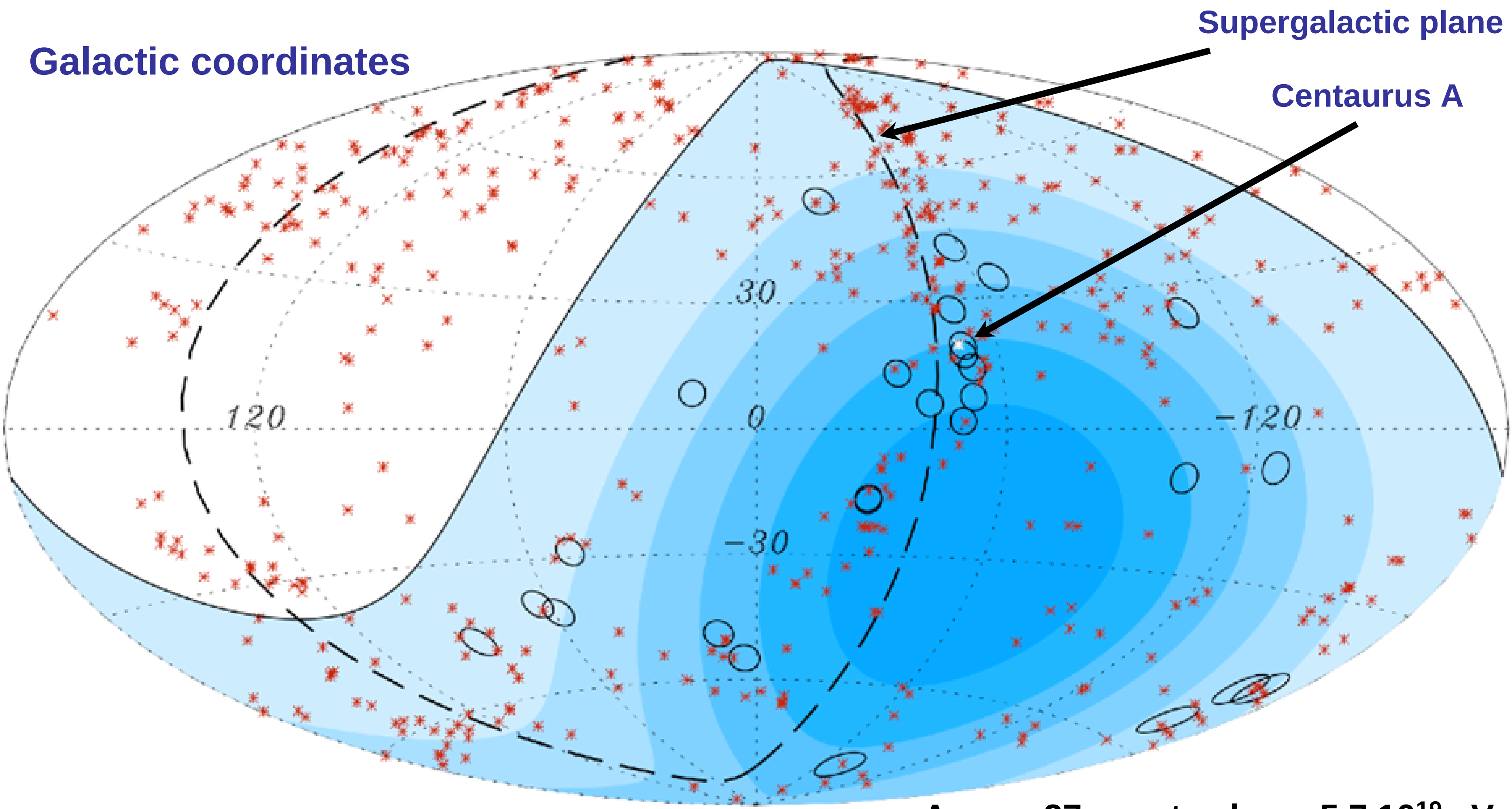



Cross section independent of LHC data, very good agreement with extrapolated data

Physical Review Letters, in press, 2012

*(Pierre Auger Collab. 1107.4804)*

# Anisotropy of ultra-high energy cosmic rays




**Veron-Cetty: 472 AGN (z< 0.018, ~75 Mpc)**
**318 in field of view of Auger**

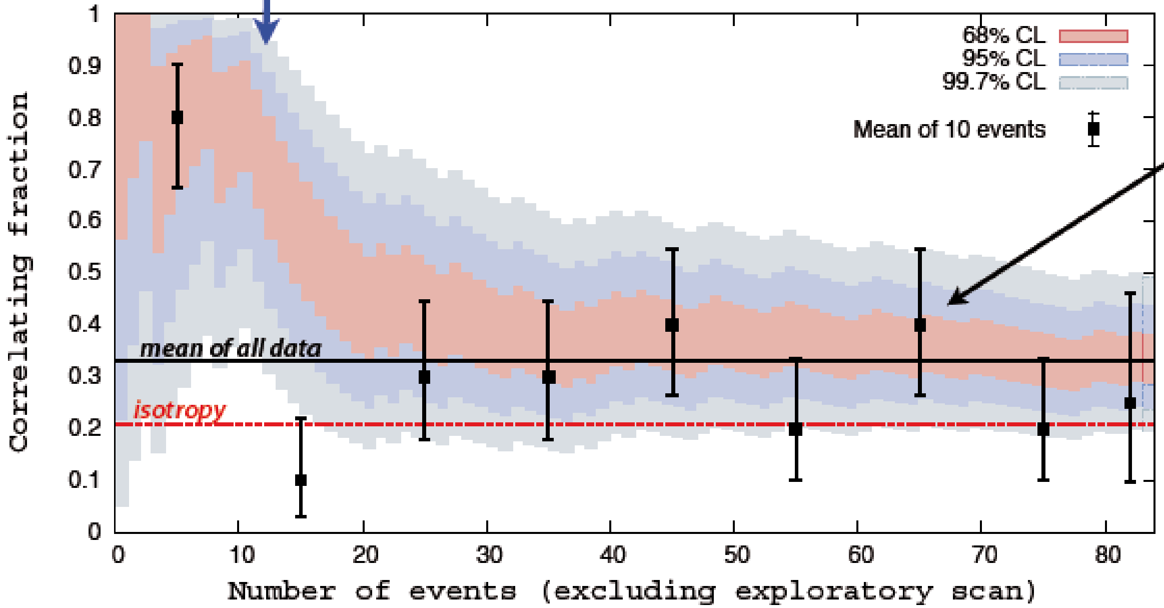
**Auger: 27 events above 5.7 $10^{19}$ eV,**
**20 correlated within 3.1°,**
**5.7 expected**

*Science 318 (2007) 939*

# Current status of correlation with AGNs

**Auger Observatory (2011)**

Science publication: 9/13 events ~69% correlated, expectation for isotropy 21%




Differential estimate every 10 events

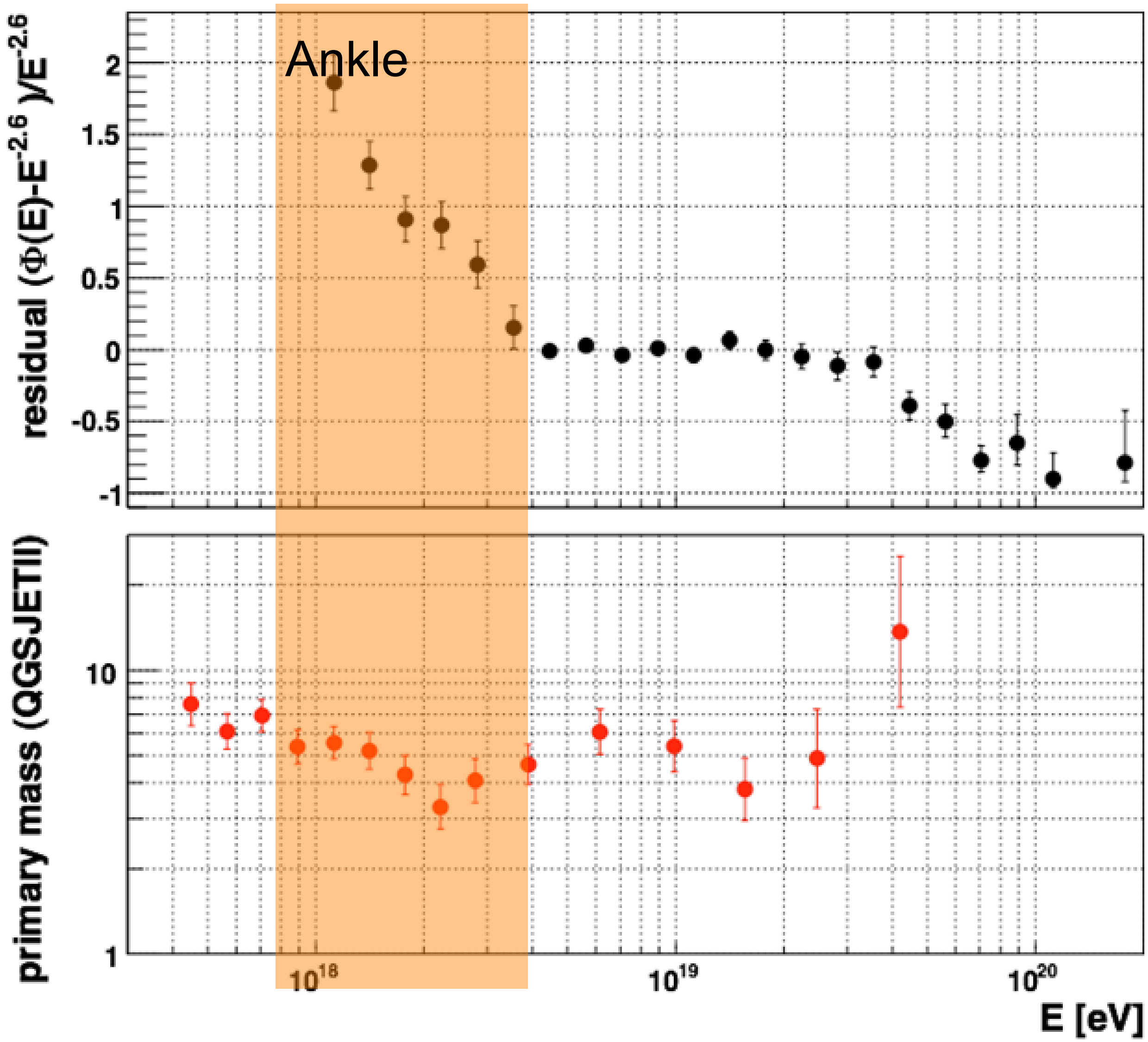
June 2011: 28 out of 84 correlated estimate now 33 ± 5% (P = 0.006)

## Indications for weak anisotropy

# Auger Enhancements: investigating the ankle

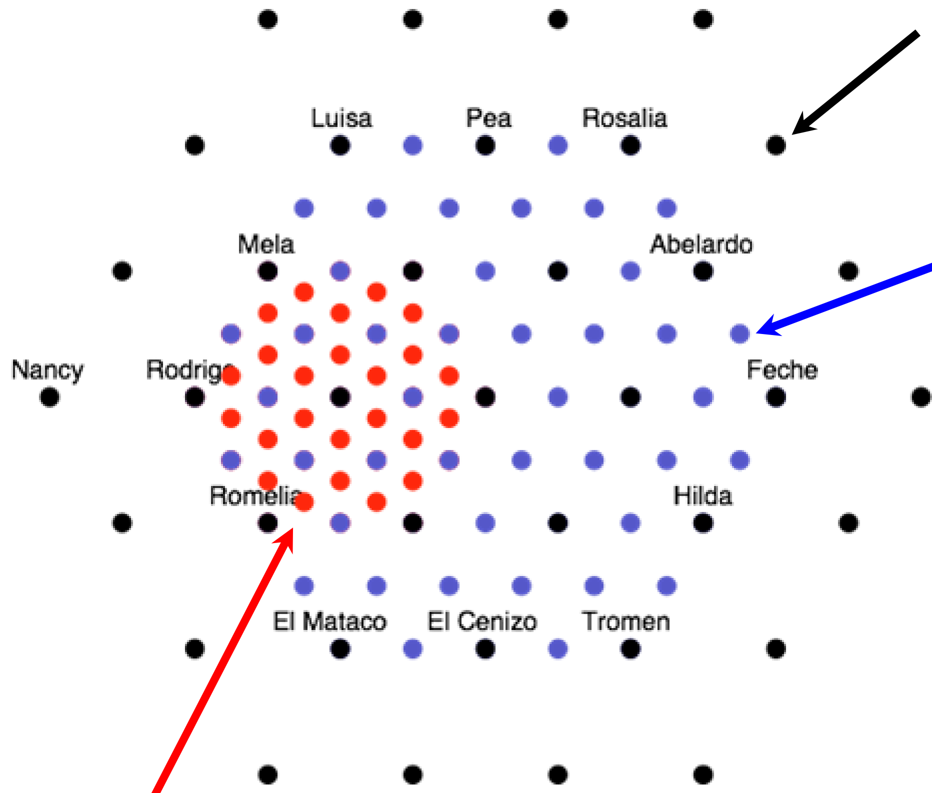
**Deviation from $E^{-2.6}$ flux**

**Mean mass number**



# AMIGA: Auger Muons and Infill for the Ground Array

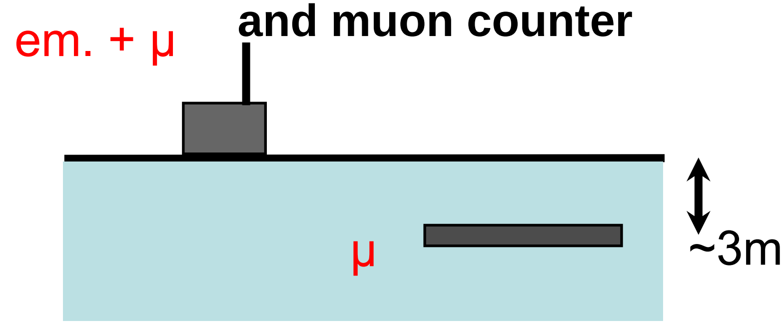
**Existing tank array 1500m**



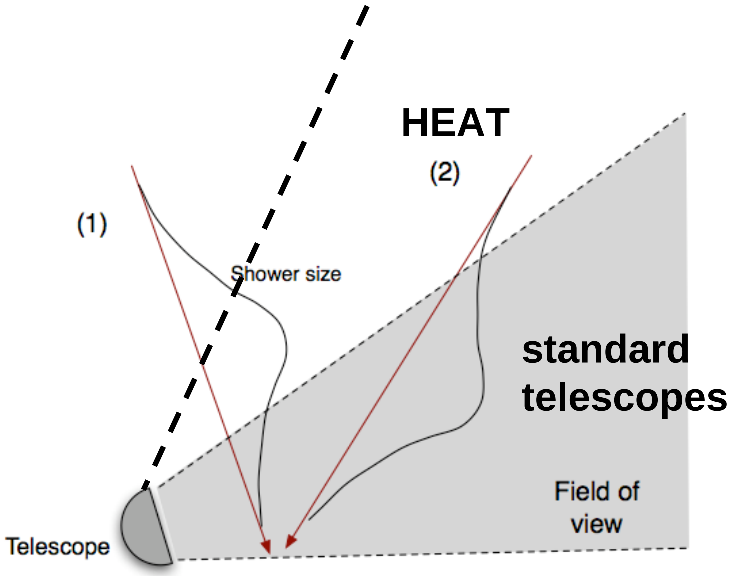

**Infill array 750m**
**42 additional detectors**
**Area ~ 23.5 km²**
**(first spectrum will be published soon)**

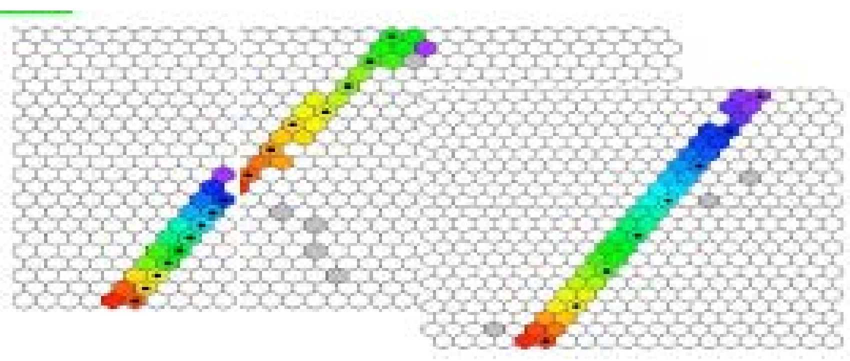
**Infill array 433m**
**24 additional detectors**
**Area ~ 5.9 km²**

**Each of the 85 detectors:**
**pair of Cherenkov tank and muon counter**



# HEAT: High Elevation Auger Telescopes



- 3 ``standard´´ Auger telescopes tilted to cover 30 - 60° elevation
- Custom-made metal enclosures
- Also prototype study for next generation experiment

**M.Kleifges-Auger Collaboration, ICRC09**

**Telescopes in operation!**
**(Spectrum will be published soon)**

# AERA: Auger Engineering Radio Array

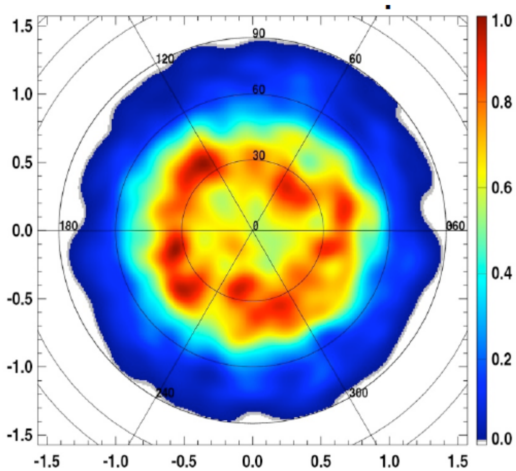
**Aims:**
- Establish radio detection technique
- Establish test self-trigger concepts for $E > 5 \times 10^{17}$ eV
- Calibrate radio signal
- Investigation of transition from galactic to extragalactic CR

**Plan:**
- Array of 20 $km^2$
- 30 - 80 MHz
- 200 Ms/s
- 25 antennas since spring 2010
- 150 antennas by end of 2012

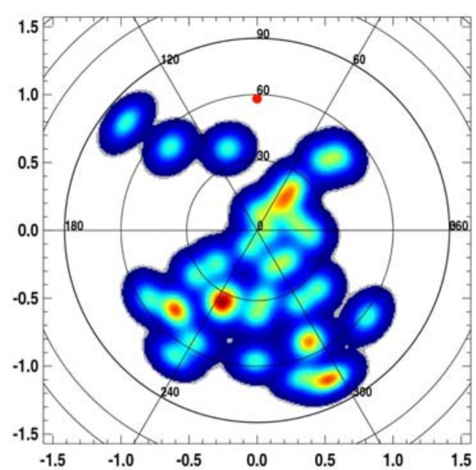
# AERA: Auger Engineering Radio Array

- detectors have successfully self-triggered on radio pulses
- found self-triggered radio events coincident with SD events
- Now also external SD trigger possible!
- 72% of the radio-triggered events come from south
  - threshold effect
  - confirmation of dominant geomagnetic radio emission mechanism

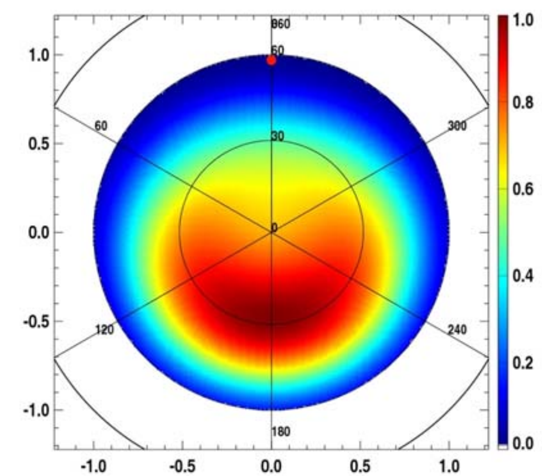
**SD events**




**Radio events**

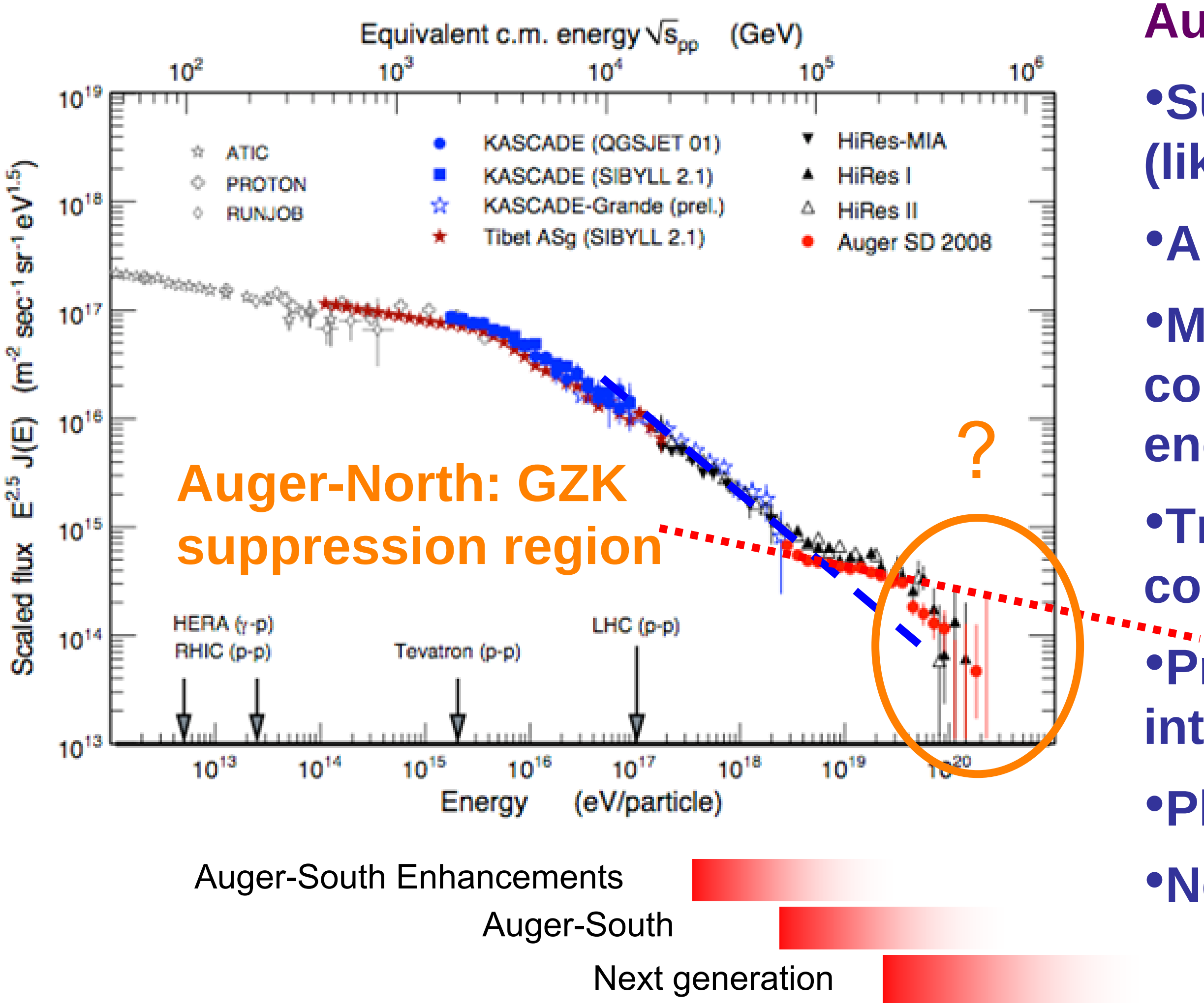



**v x B model**




**A.van den Berg – Auger Coll., ICRC09**

# Go for highest energies




## Auger results

- Suppression of flux (like GZK effect)
- Anisotropy E > 6x10$^{19}$ eV
- Mixed cosmic ray composition at lower energy
- Trend to heavy composition >10$^{19}$eV
- Problems with hadronic interaction models
- Photon fraction small
- Neutrino flux low



*special thanks to Ralph Engel*

# Motivation and Idea of AugerNext

***Results from Auger have shown***

- ***that the spectrum has a characteristic break-off at c. 50 EeV;***
- ***that events with higher energy arrive anisotropic;***
- ***that CR at highest energies are not build up by Hydrogen only.***

**➔requirements for the next generation experiment:**

- **it needs to be considerably increased in size;**
- **it needs a better sensitivity to composition;**
- **it should cover the full sky.**

**Such a facility should be specified within the next years.**
**Intermediate step: Auger upgrade…**

**Main tasks to be considered are**
**- investigations of the science case**
**- improvement of the composition sensitivity**
**- improvement techniques to enhance the variability of possible sites**
**- partner and site search**

**AugerNext**

ASPERA

www.aspera-eu.org

## AStroParticle ERAnet

**ASPERA is a network of national government agencies responsible for Astroparticle Physics**

- BMBF, DESY/PT
- CNRS, CEA
- FRS-FNRS, FWO
- HRZZ
- MEYS, FZU
- DEMOKRITOS
- INFN
- FOM
- NCBiR
- FCT
- IFIN-HH
- MICINN
- VR
- SNF
- STFC
- NIH
- CERN
- ARRS
- RIA
- RFBR


**The ASPERA calls:**

**- Targeted R&D and design studies in view of the realization of future Astroparticle infrastructures**

**- 2nd call was targeted towards future high energy cosmic rays and neutrino mass experiments. (first call: high energy gamma rays and dark matter)**

## ➔ AugerNext

**Innovative Research Studies for the Next Generation Ground-Based Ultra-High Energy Cosmic-Ray Experiment**

| | | |
|---|---|---|
| **(A) MHz** | 1. EASIER-M | |
| | 2. HAS Antenna | |
| | 3. 100 km$^2$ array | |
| **(B) GHz** | 1. EASIER-G | |
| | 2. CROME | |
| | 3. FDWave | |
| **(C) γ - sens** | 1. SiPMs focal plane | |
| | 2. PMT - tests SD/FD | |
| **(D) Coms** | 1. Com Com | |
| | 2. Netw. Topology | |
| | 3. Comparison Studies | |
| **(E) RPC** | Prototype in SD | |

# The work packages:

Tasks in ASPERA:

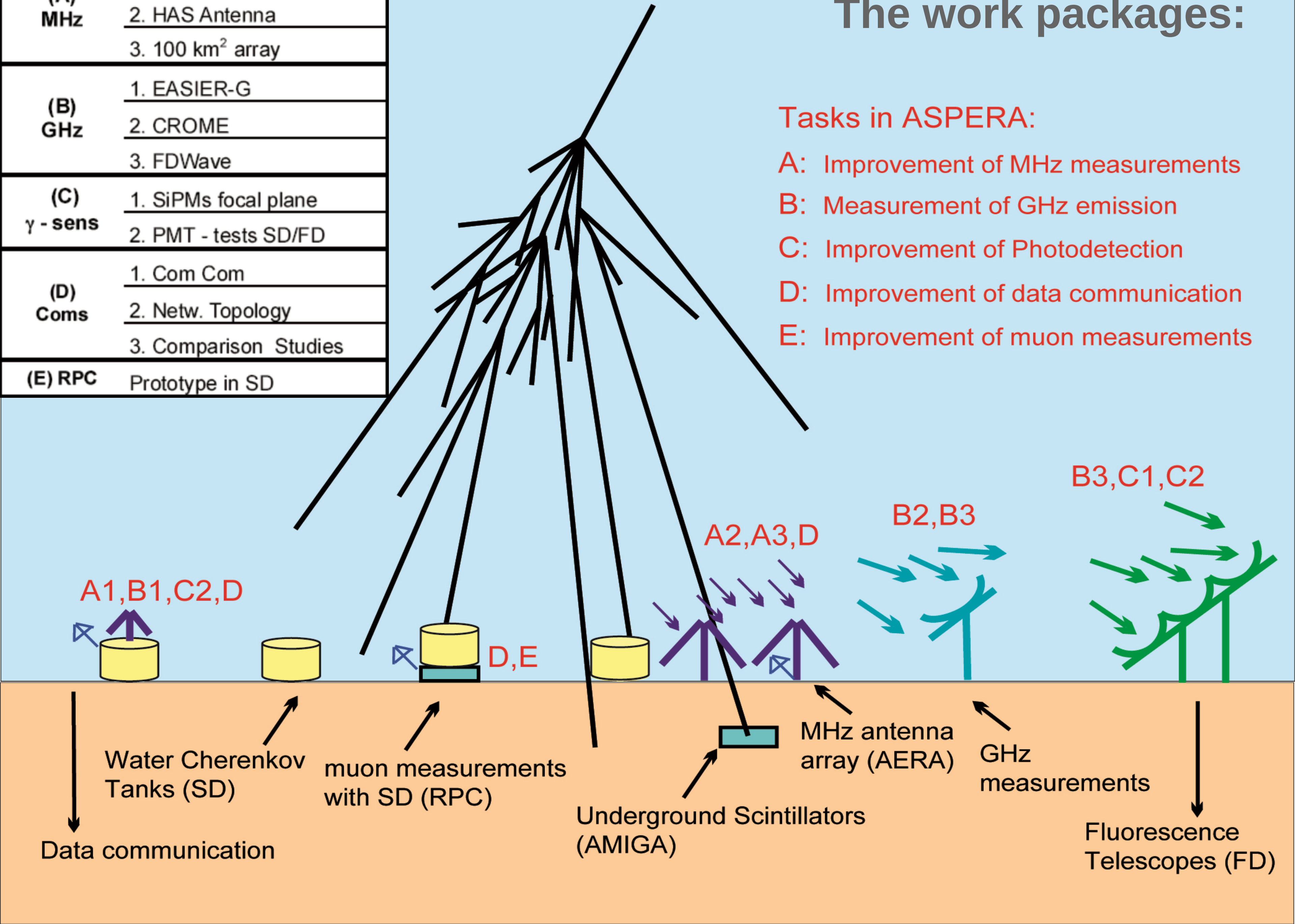
A: Improvement of MHz measurements

B: Measurement of GHz emission

C: Improvement of Photodetection

D: Improvement of data communication

E: Improvement of muon measurements



# (A) Air Shower Radio Emission (MHz)

**5-year goal:**

**- Resolution and sensitivity to E/A/dir@$10^{19}$eV (in hybrid with SD)**

**Subtasks and milestones:**

**A1: Development of embedded radio sensors (EASIER-M)**

**Prototype measurements**

**Decisions on large-scale applications**

**A2: Development of a radio test-station for horizontal air-showers (HAS)**

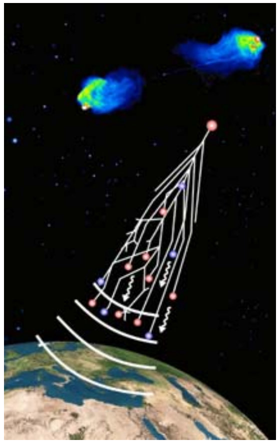
**R&D studies on antenna types including simulations**

**Prototype set-up**

**A3: Towards a 100 km2 radio array (100km$^2$)**

**Design of improved stations - scalability**

**Prototyping**



# (B) Detection of the microwave emission in air shower

**<u>5-year goal:</u>**

**-Proof-of-principle of the technique and threshold estimation**

**<u>Subtasks and milestones:</u>**

**B1: Development of embedded radio sensors (EASIER-G)**

**Prototype measurements and simulations**

**Decisions on possible large-scale applications**

**B2: Development of a non-imaging detector for GHz radiation (CROME)**

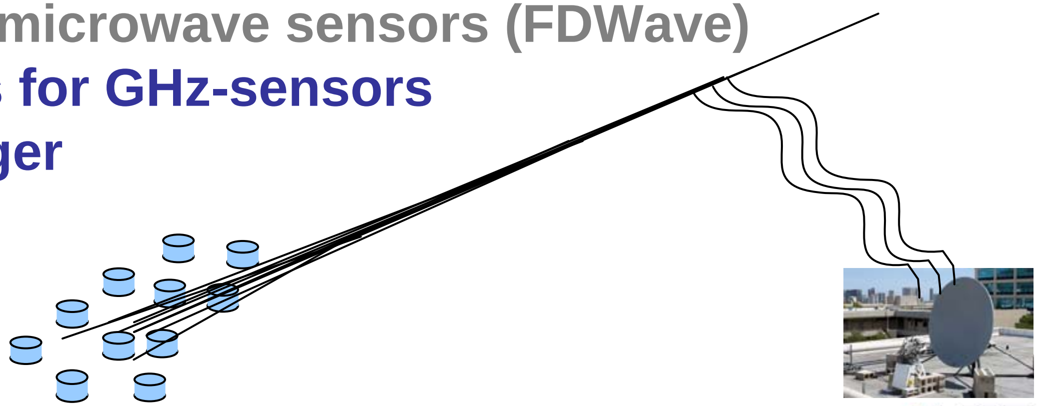
**Installation of large-size parabolic antenna**

**Development of calibration system**

**B3: Development of an imaging microwave sensors (FDWave)**

**Study of using FD optics for GHz-sensors**

**Deployment at FD of Auger**



# (C) Improvement of photo sensors

**5-year goal:**

-higher Quantum-efficiency and better res. for large scale appl. (SD,FD)

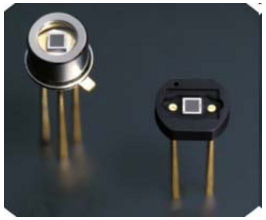
**Subtasks and milestones:**

C1: Development of a new focal plane for FD (SiPM)

- Testing and selecting appropriate SiPM
- Design and testing of optics and electronics
- Prototype installation

C2: Improvement of PMT sensitivity (PMT)

- Design of appropriate camera for new generation of HQE-PMTs
- Installation of prototype at Auger South
- Investigations on a multi-PMT sphere for a surface detector tank



# (D) Generalizing the data communication system

**<u>5-year goal:</u>**

**- General, worldwide applicable remote-controlled comm.-system.**

**<u>Subtasks and milestones:</u>**

**D1: Adapting self healing communication system (ComCom)**

**Production, adaption and integration of a commercial system**

**Demonstration of scalability**

**D2: Development of suitable network topologies (Topology)**

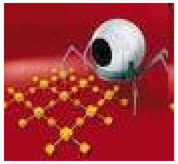
**Study and simulation of different network topologies**

**Evaluation and reporting of results**

**D3: Comparison studies of different approaches (Compare)**

**Development of a test facility for valuable comparisons studies**

**Demonstration of the scalability**



# (E) Studies for a hybrid muon detector

**5-year goal:**

- Demonstration that RPC can serve as large timing detector for UHECR

**Milestones:**

Development of a first prototype detector

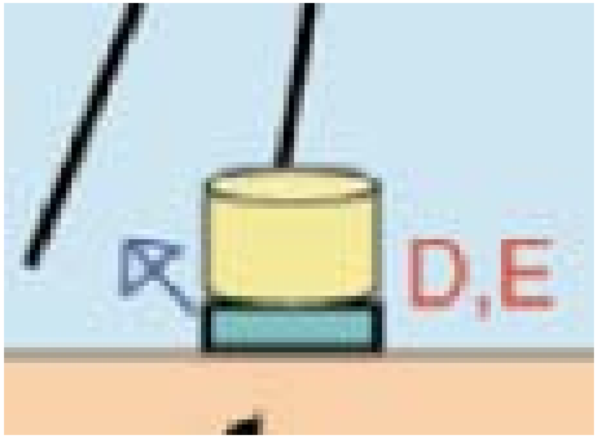
-development of a low-cost sealed glass RPC;

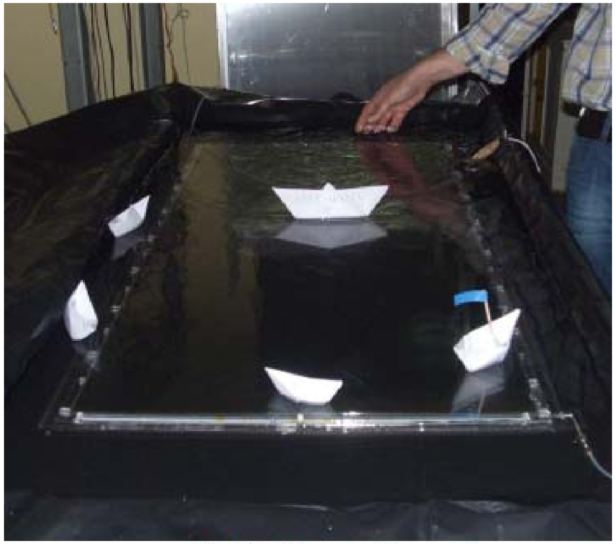
-the development of the readout electronics,

-performing indoor tests

-first outdoor tests in Europe

Simulation and reconstruction software



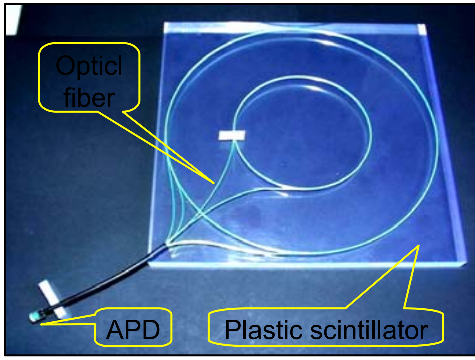
Radical humidity test

The chamber is actually on!

# Ideas for Co-operation with Russia:

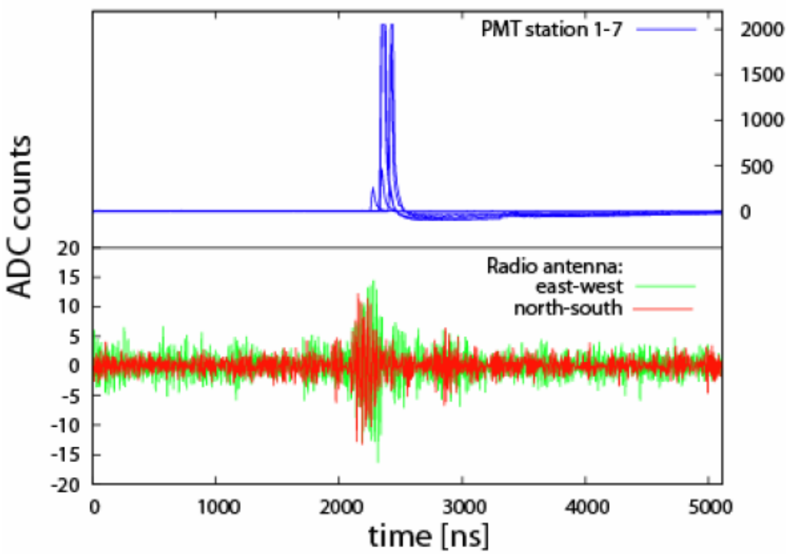
**- Russia is now member of ASPERA!!**
**- Russia interested to join next generation experiment!?**
**➔ activity within AugerNext??**

- **development of Radio Detection Technique**
  with high statistics cross-checks of longitudinal development at Tunka
- **new generation of Photo Sensors**
  co-operation with companies
- **theory of the GHz emission in air showers**
  Monte Carlo calculations or accelerator tests
- **muon detectors by scintillators from INR RAS**
  Flat plastic scintillation detectors on the base of Avalanche Photo-Detectors (APD)



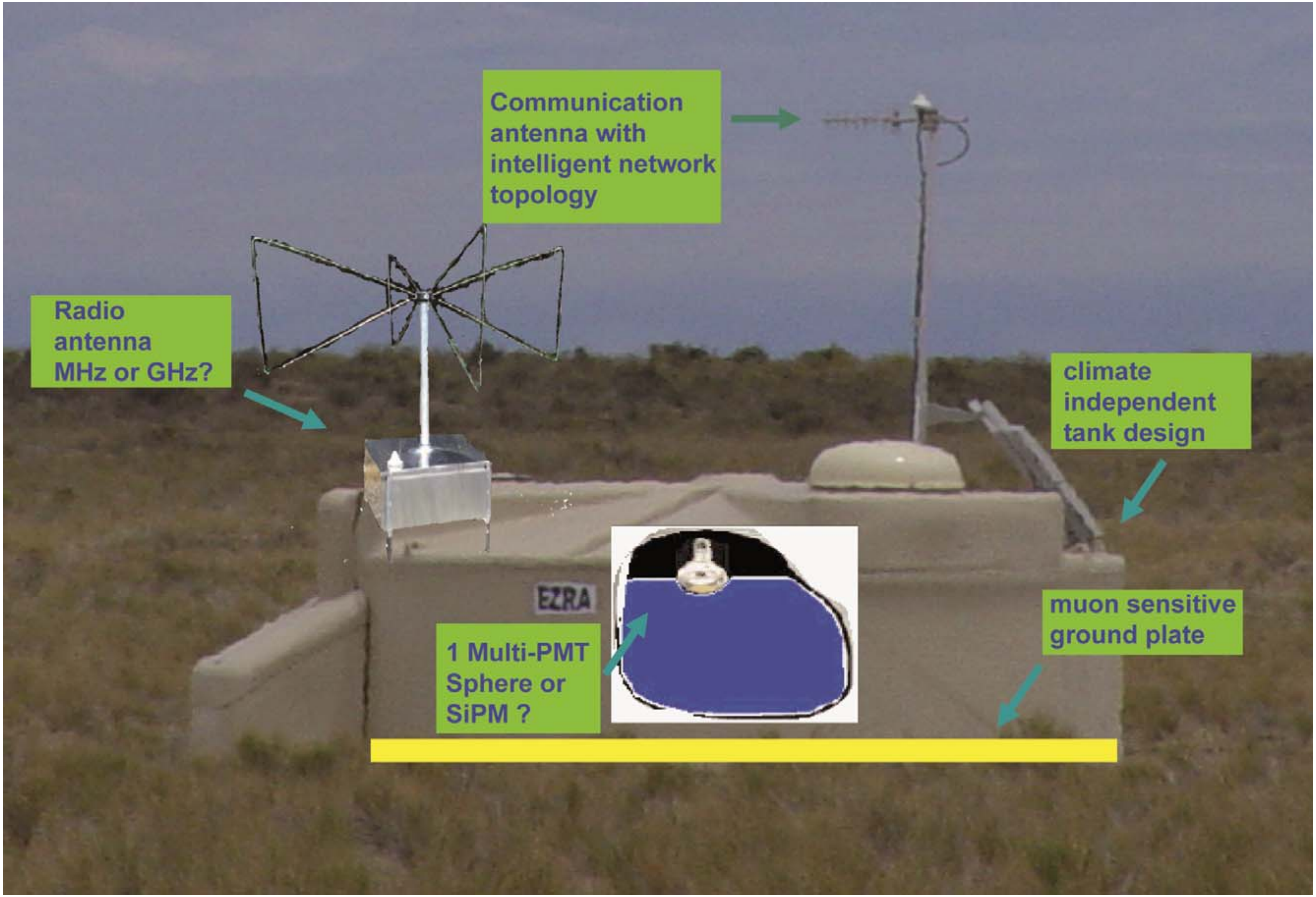

**← possibilities presently explored**

# T-Rex: Tunka-RadioExtension




- **Tunka:**
  Cherenkov array in Siberia
- **1 antenna installed in 2010**
  “proof of principle”
- **2011 approval of HRJRG**
  **(KIT, Uni Hamburg, DESY)**
  HiSCORE Gamma-Ray prototype
  Radio extension of Tunka
- **2012 start of larger radio array**
  **within HRJRG**
  Cross-Correlation with
  Cherenkov light

# Future (next generation) surface detector:



AugerNext

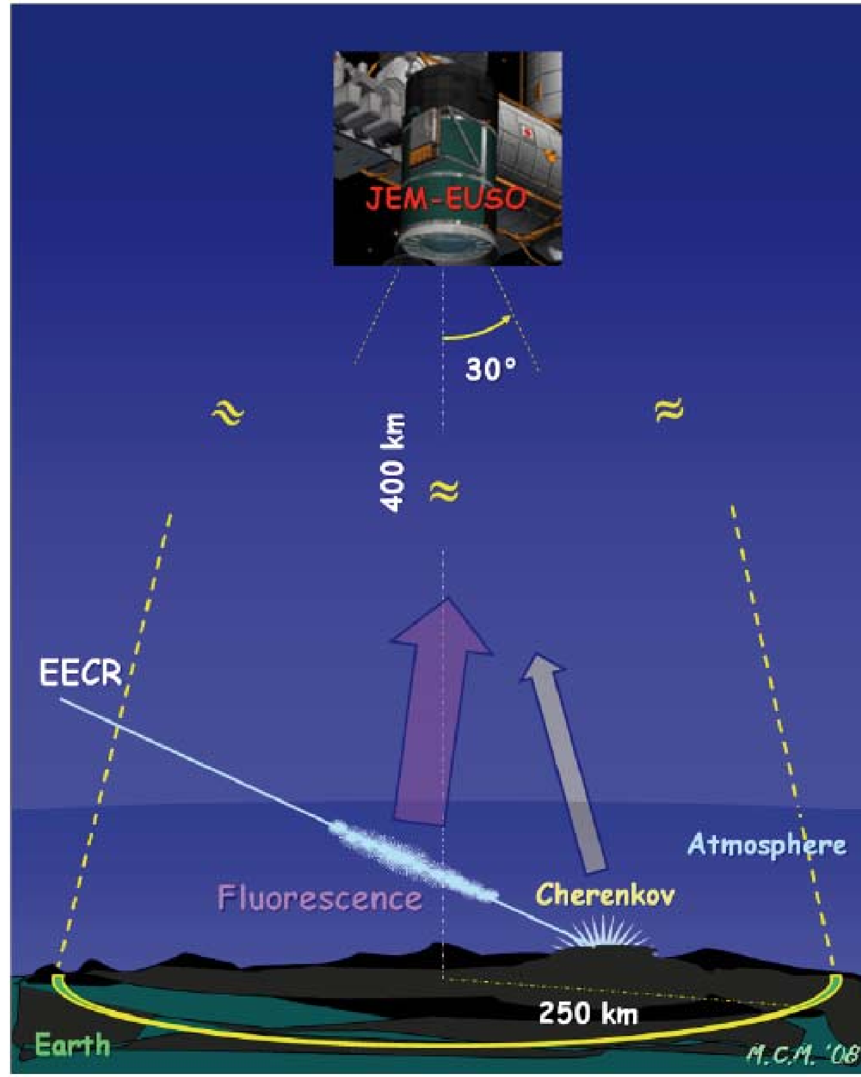
*Innovative Research Studies*
*for the Next Generation*
*Ground-Based Ultra-High*
*Energy Cosmic-Ray Experiment*

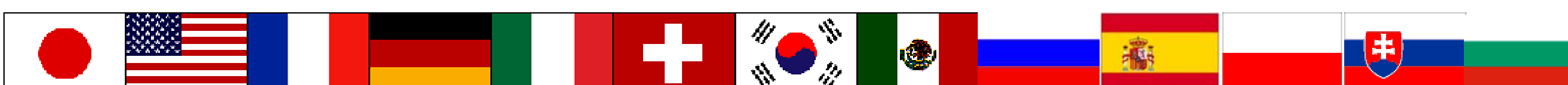

➔

**rich R&D program**
**and on-site activities**
**at the Pierre Auger Observatory**
**for (at least) the next 5 years.**

# Observation from space: JEM-EUSO


- Detection of fluorescence light and reflected Cherenkov light
- Energy threshold $10^{19.7}$ eV
- Full sky coverage



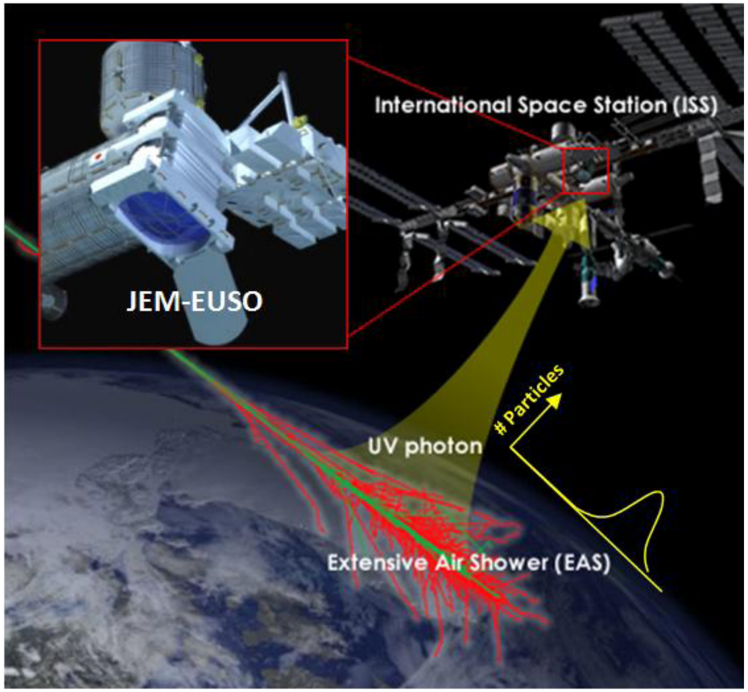
# JEM-EUSO main features

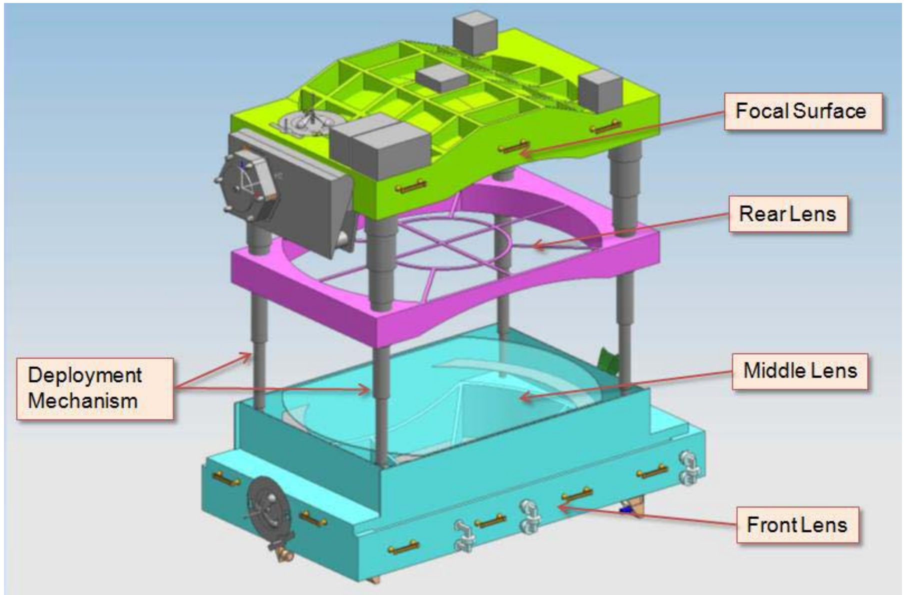
**Method: fluorescence (full calorimetry)**

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

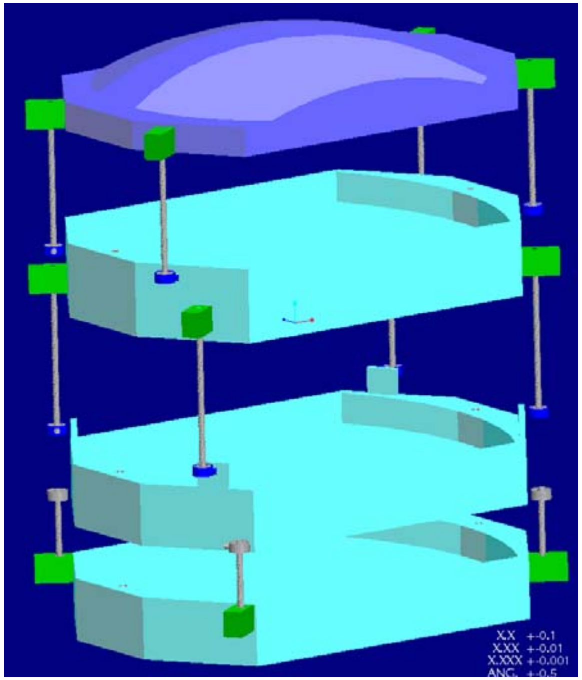
**At 400 km (ISS): 2 $10^5$ km$^2$ (nadir mode) up to $10^6$ km$^2$ (tilted mode)**

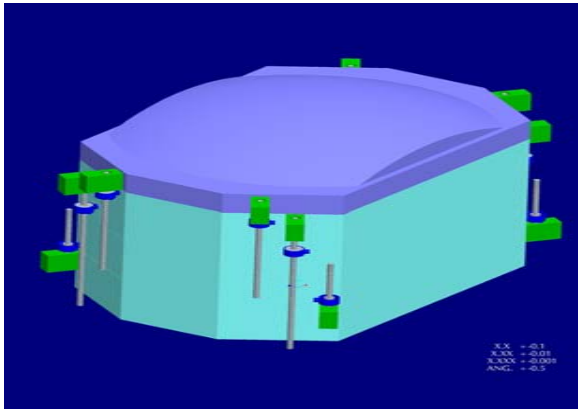
**No need for stereo: 400 km >> shower length (TPC with a drift velocity = c)**



# JEM-EUSO telescope



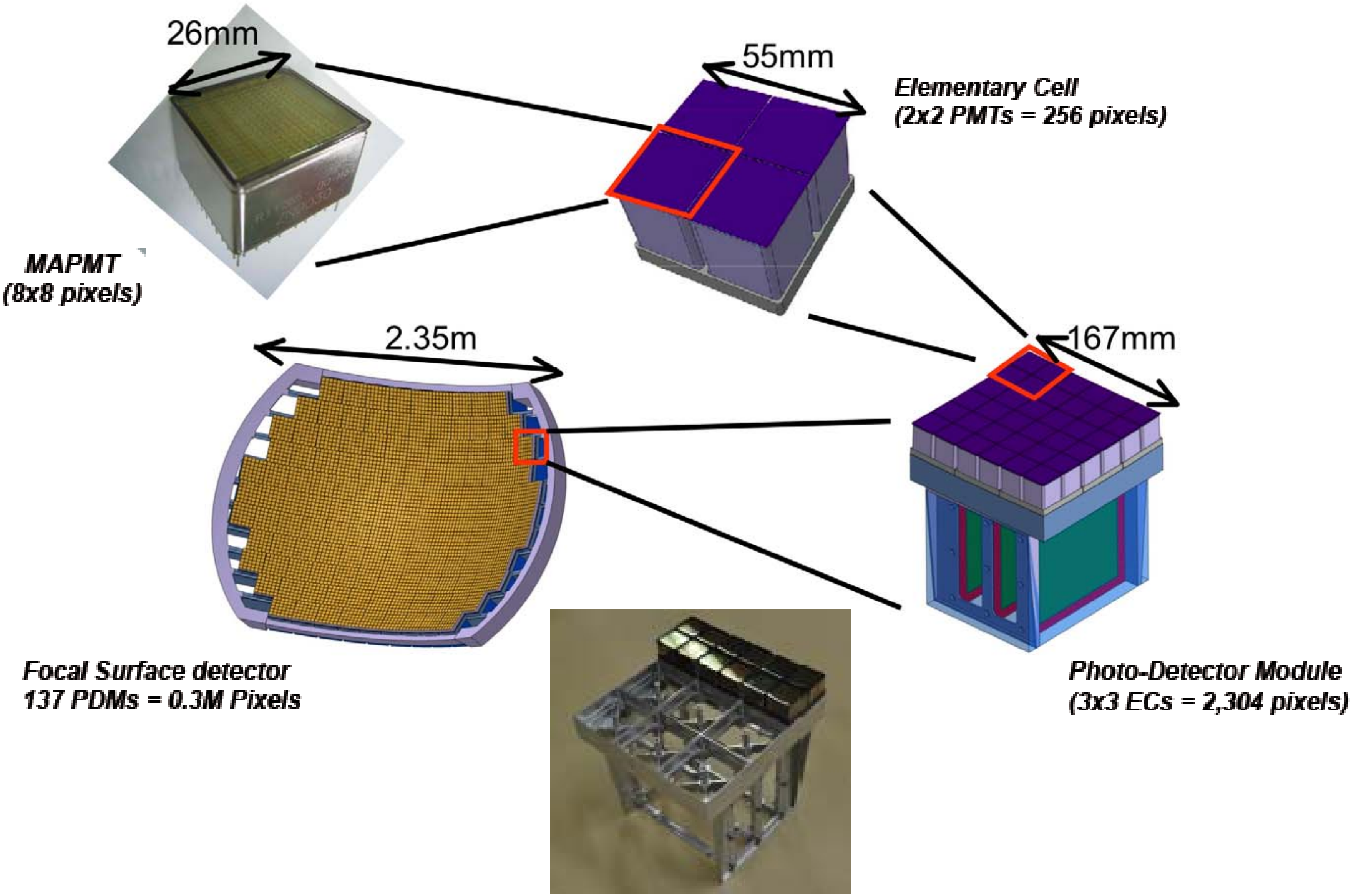


**Lenses:**

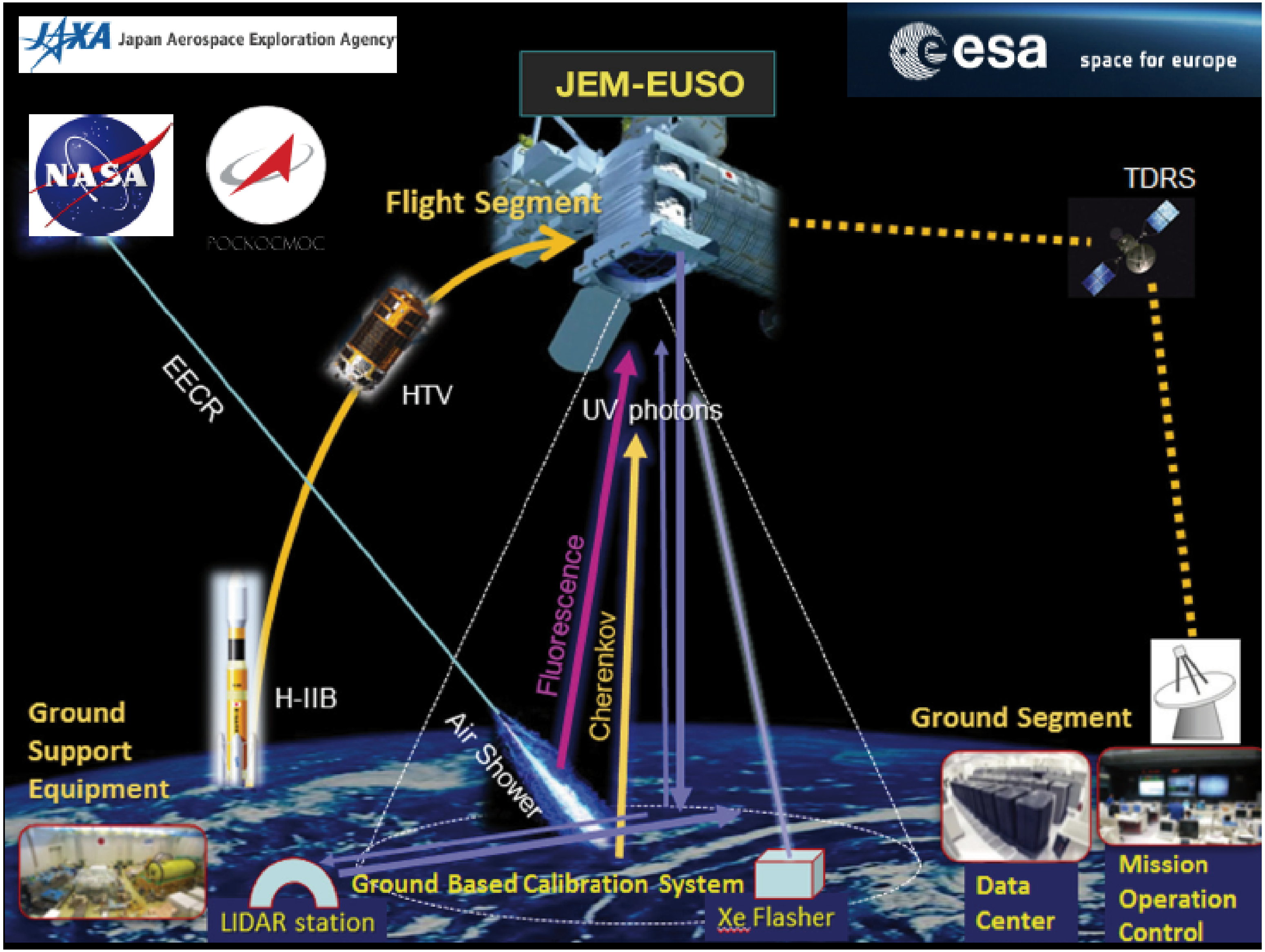
**- produced in Japan + tested in US**

**- PSF = 3 mm (PMT pixel = 2.88 x 2.88 mm)**

# JEM-EUSO camera



# JEM-EUSO: the full machine



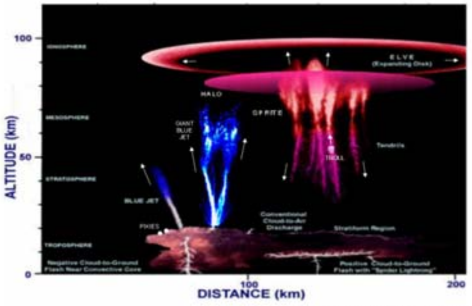
# Physics program

## *Main scientific objectives*

- •Cosmic ray showers
- •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 by neutrino discrimination and identification via X0 and Xmax
- – Discovery of UHE Gammas by discrimination of Xmax due to geomagnetic and LPM effect
- •Exploratory Objectives: magnetic fields

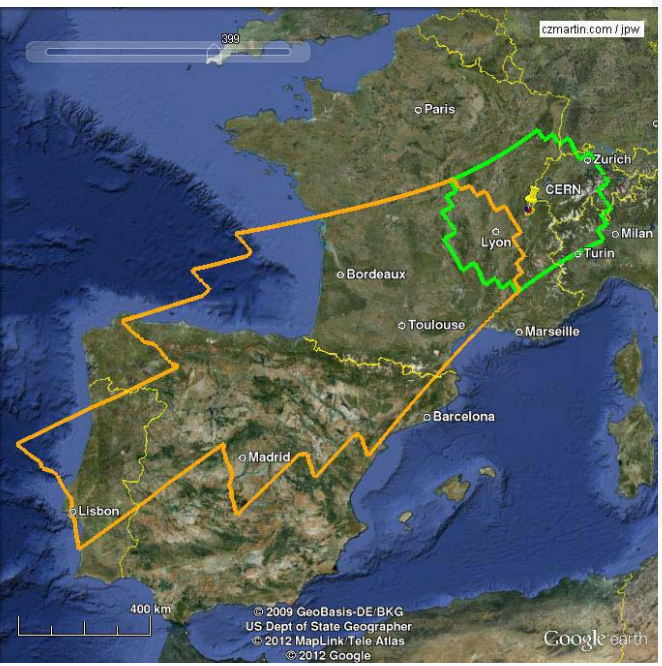


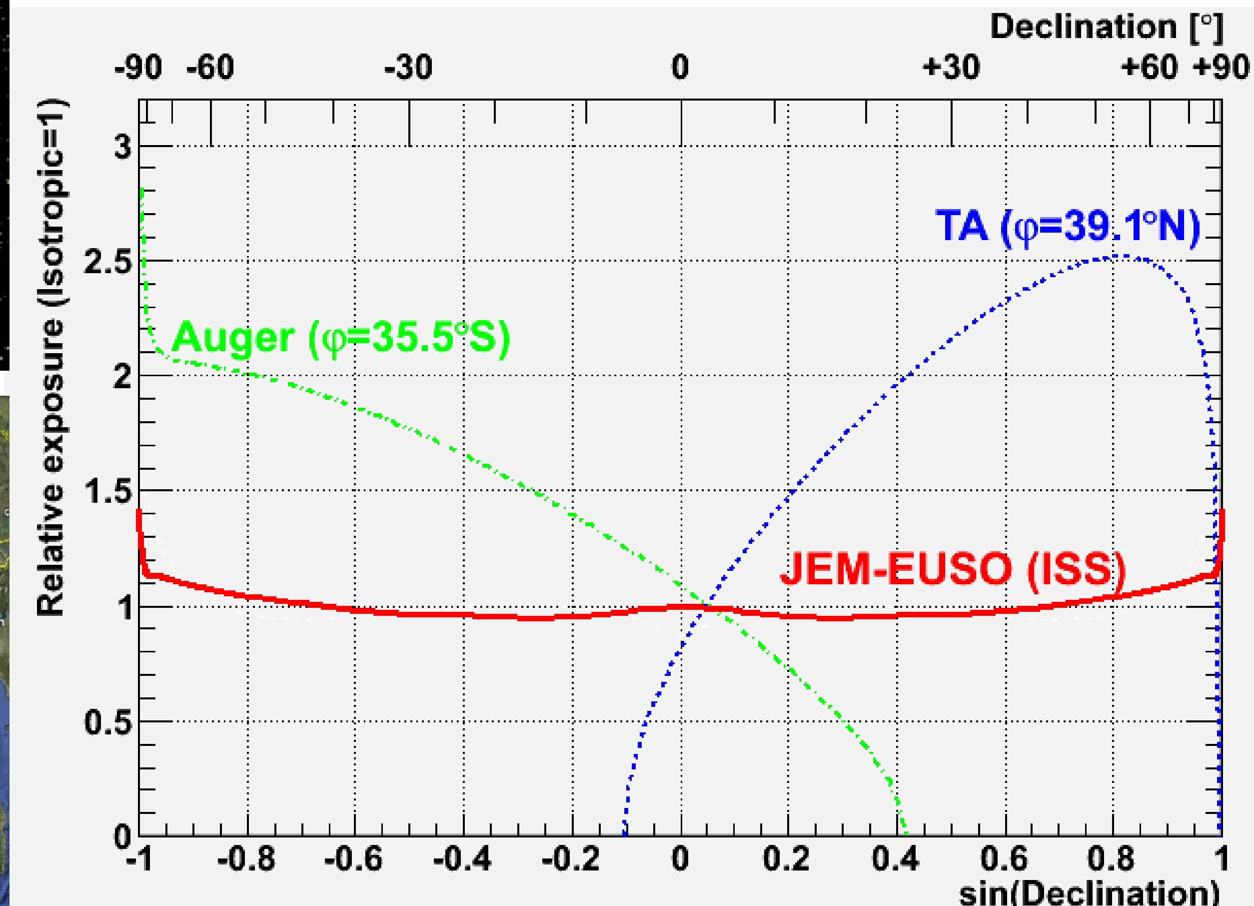
(Elaboration of figure by Lyons et al. 2000)

## *Exploratory scientific objectives*

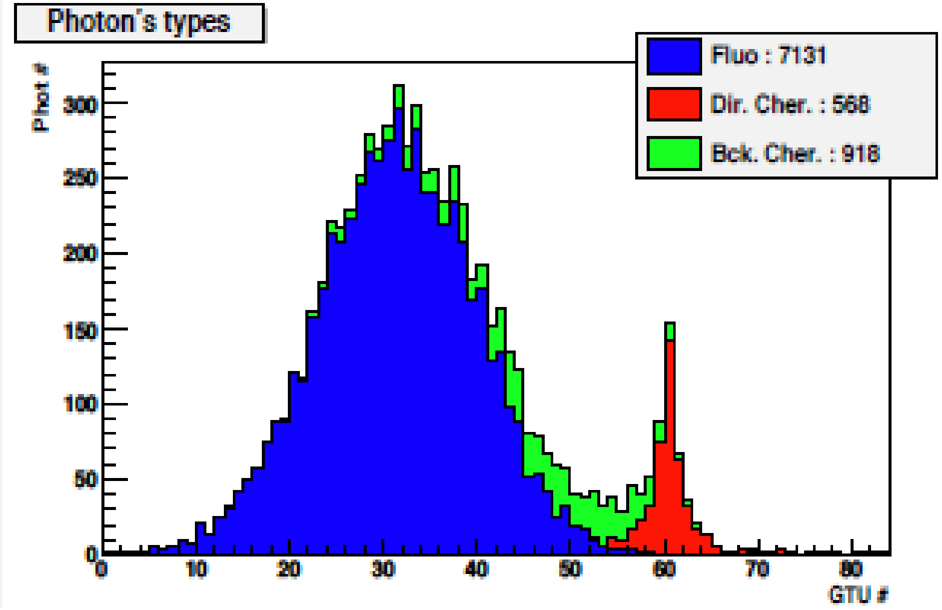
- •Exploratory Objectives: Atmospheric science
  - – Nightglow / Transient luminous events
  - – Space-atmosphere interactions and climate change
- •A fast UV monitoring of the Atmosphere


# JEM-EUSO: aperture



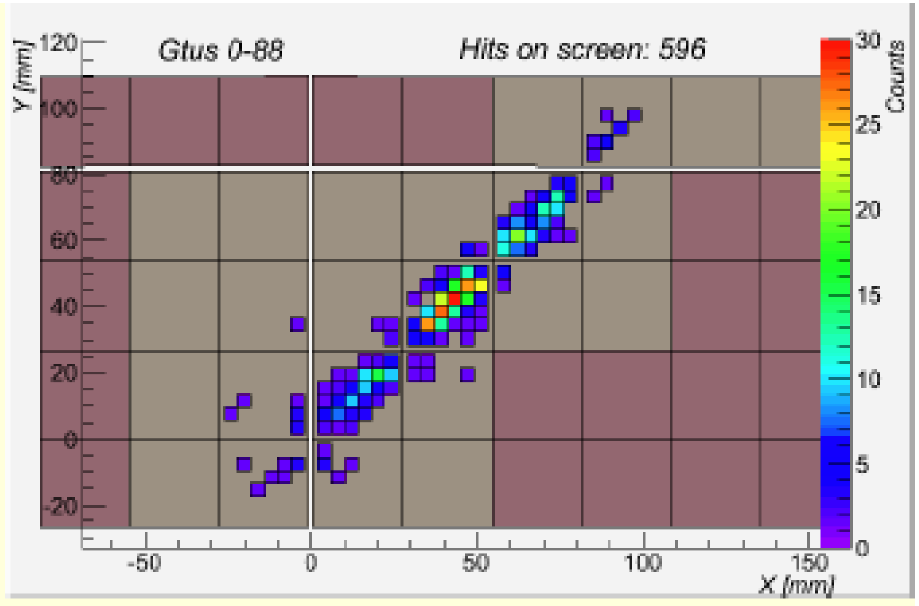
# The observation technique



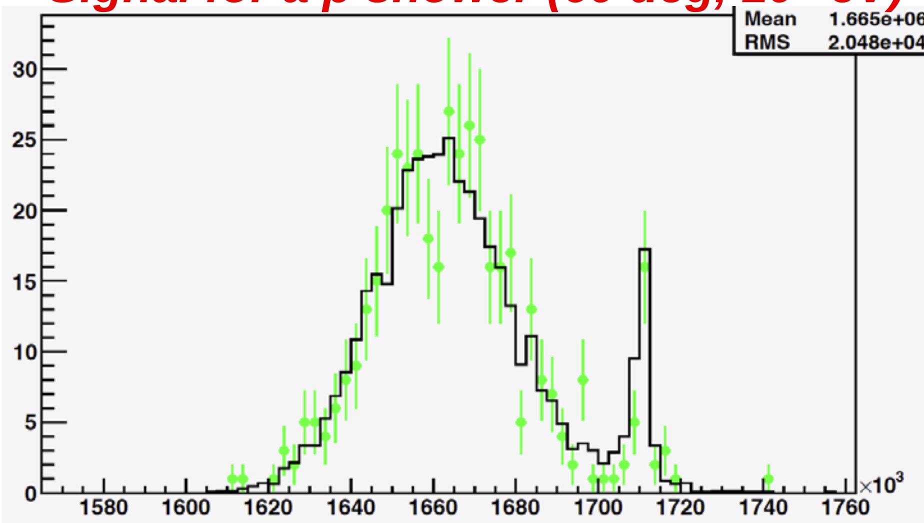

1 GTU = 2.5µs

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

# JEM-EUSO Exposure

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

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

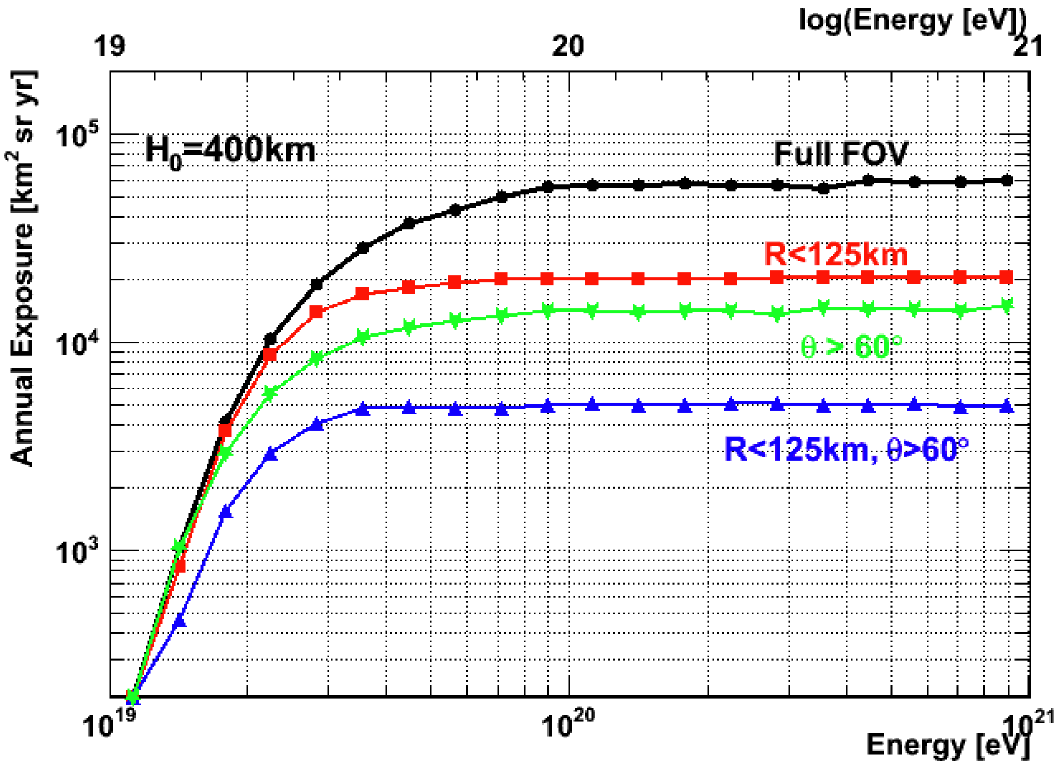
$\eta \rightarrow duty\ cycle$ — Determined by the background (and operation)

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

**19%**

**70%**

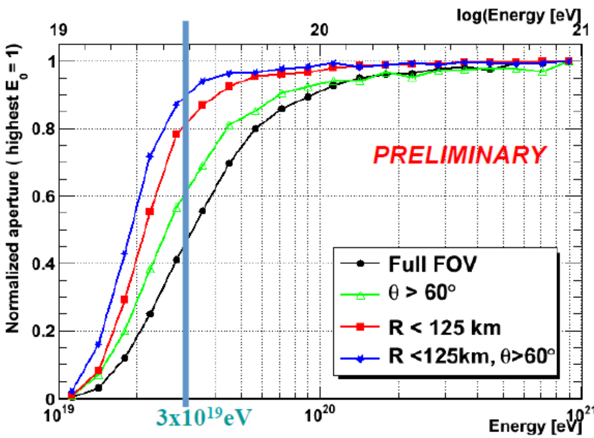
**➔ ~13%**




**60,000 km2sr yr**

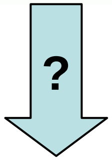
**20,000 km2sr yr**

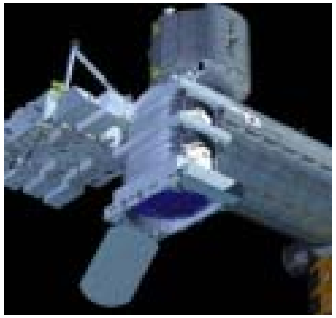
**5,000 km2sr yr**



# 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 STEC 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 submitted, asking both resources for the EUSO Balloon and for the main mission. *A new stronger team is emerging in the US.*
- *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.



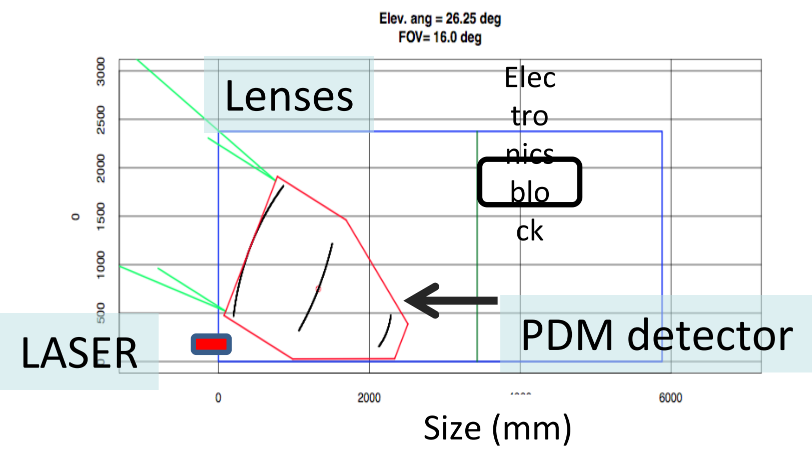



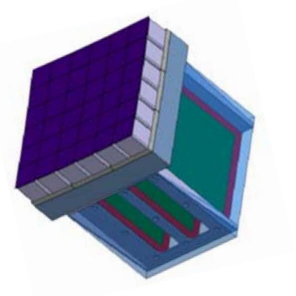
# TA-EUSO
# Cross-calibration tests at Telescope Array site, Utah

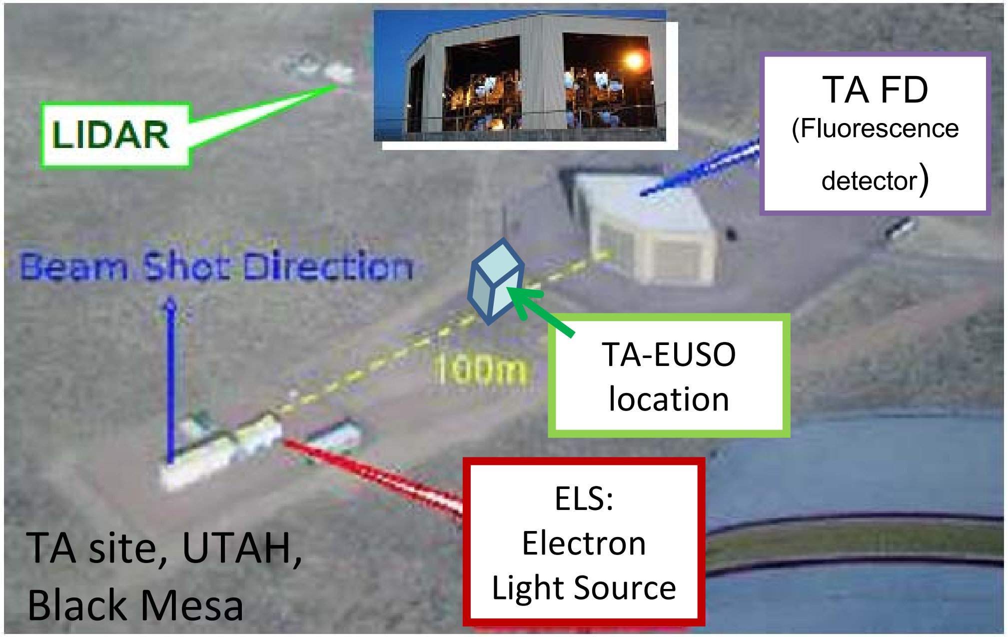
**Main purpose: calibration using existing FD telescope**

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

**Operation early 2013!**



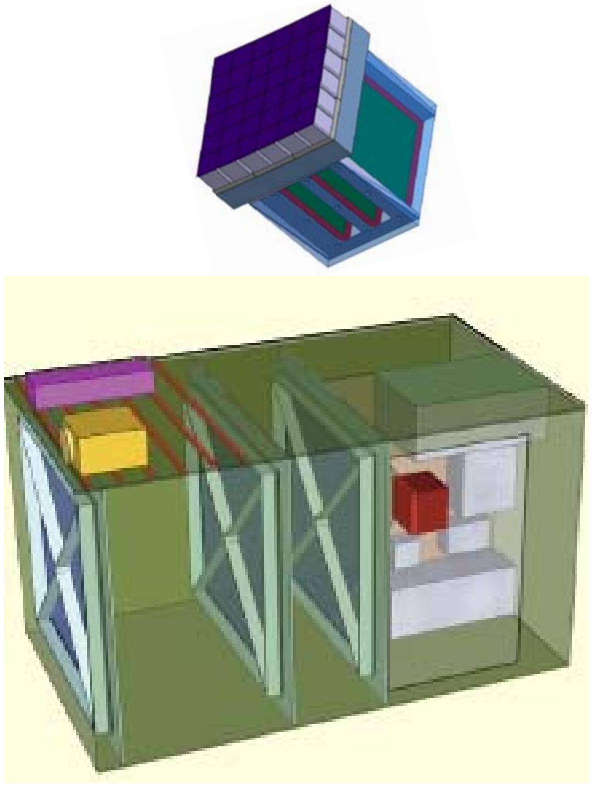
# EUSO-Balloon
# JEM-EUSO prototype at 40km altitude

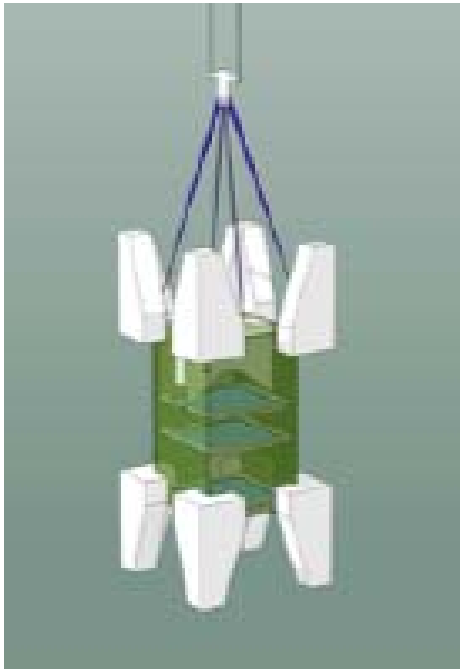
**Main purpose: Background measurements and engineering tests**

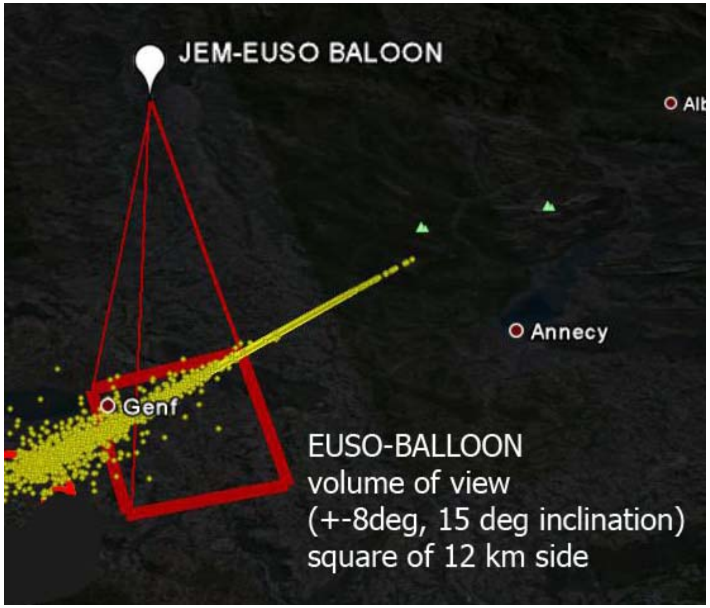
- Engineering test
- UV-Background measurement
- Air shower observations from 40 km altitude

**First flight: 2014!**

CENTRE NATIONAL D'ETUDES SPATIALES

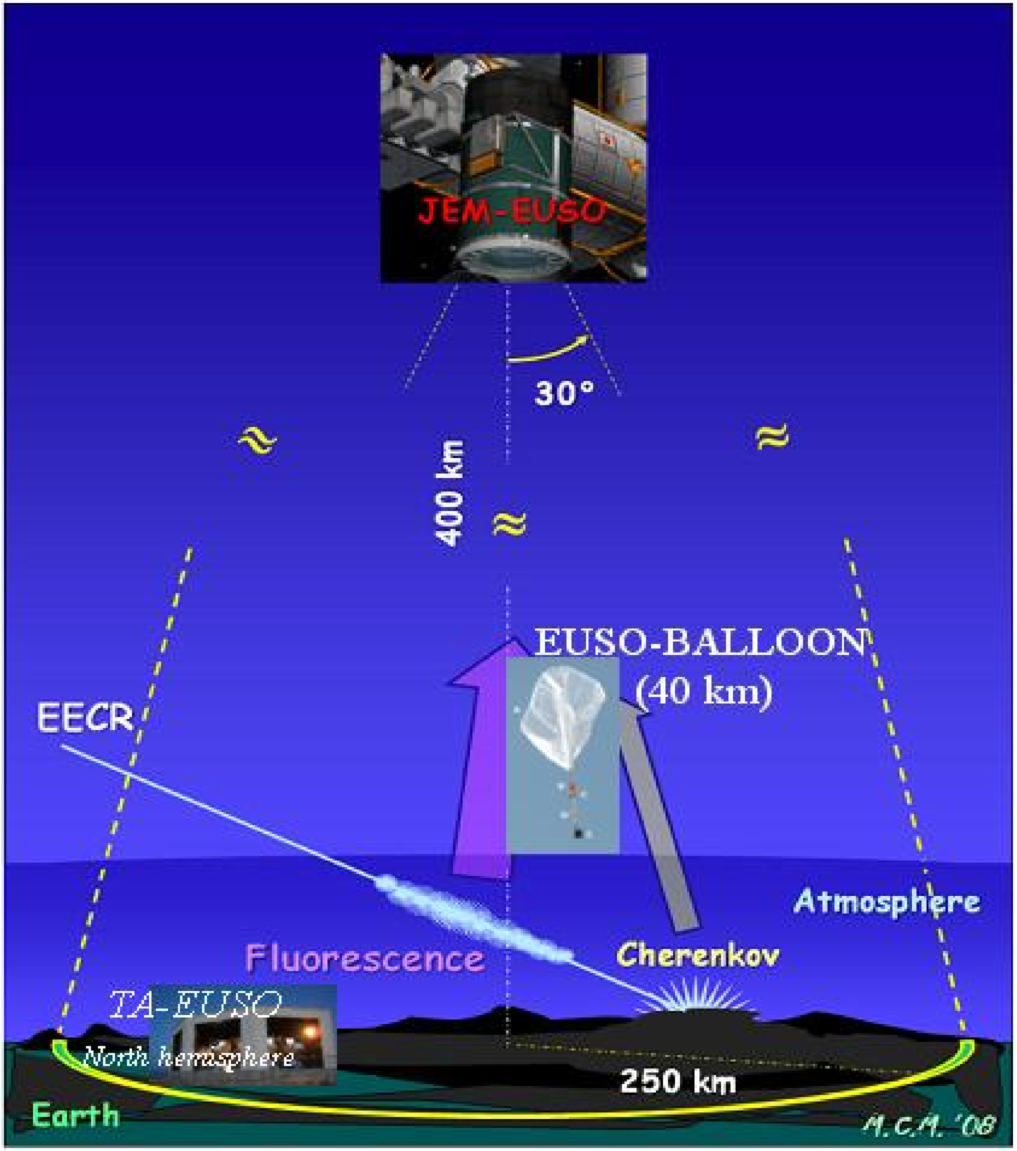


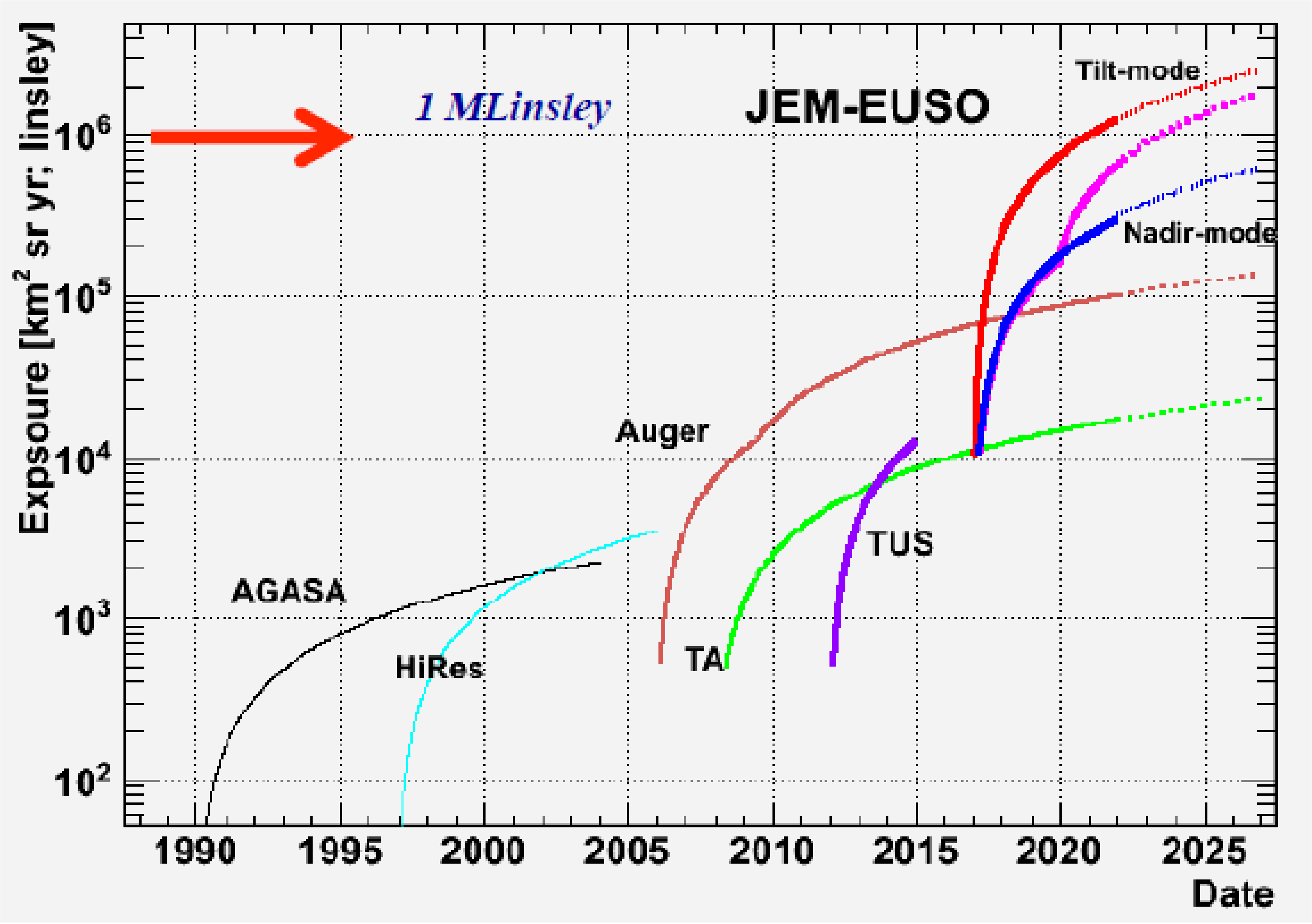




# Summary EUSO-Balloon

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




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

- Backup

# Pierre Auger Observatory: Science Objectives

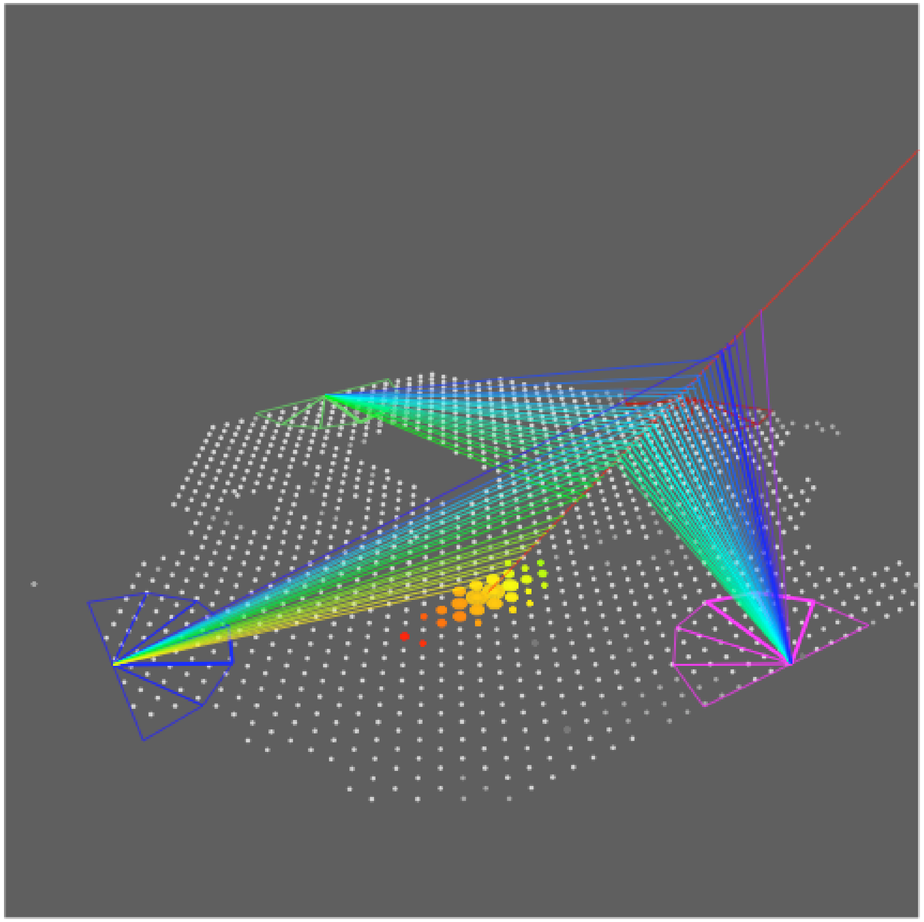
- understand the nature, origin and propagation of UHECR
  - point sources?
  - An-/Isotropy of arrival directions?
  - GZK cut-off or continuing spectrum or other structures?
  - primary particle mass, type?
  - acceleration or decay of exotics?
- measure cosmic rays with high statistics and quality
  - aperture > 7 000 $km^2 sr$ @$10^{19}$eV in each hemisphere
  - ~ degree angular resolution, zenith angle θ°... 90°
  - primary particle discrimination (light, heavy, γ, ν)
  - calorimetric energy calibration

➔ hybrid design:

surface detectors and fluorescence telescopes

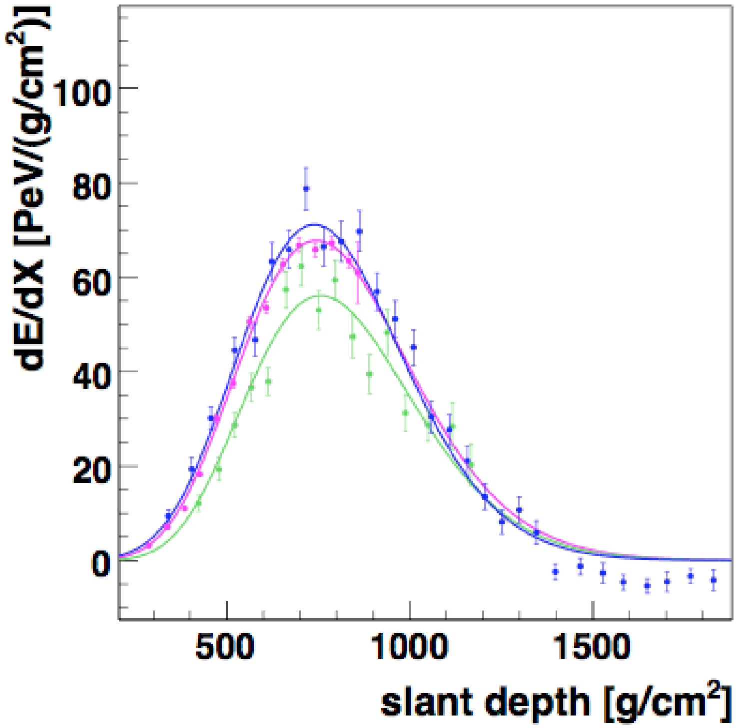
- measurement of direction, energy and composition of primaries

# Golden hybrid events: many cross checks possible



Event 200716104390 (11.6.2007)

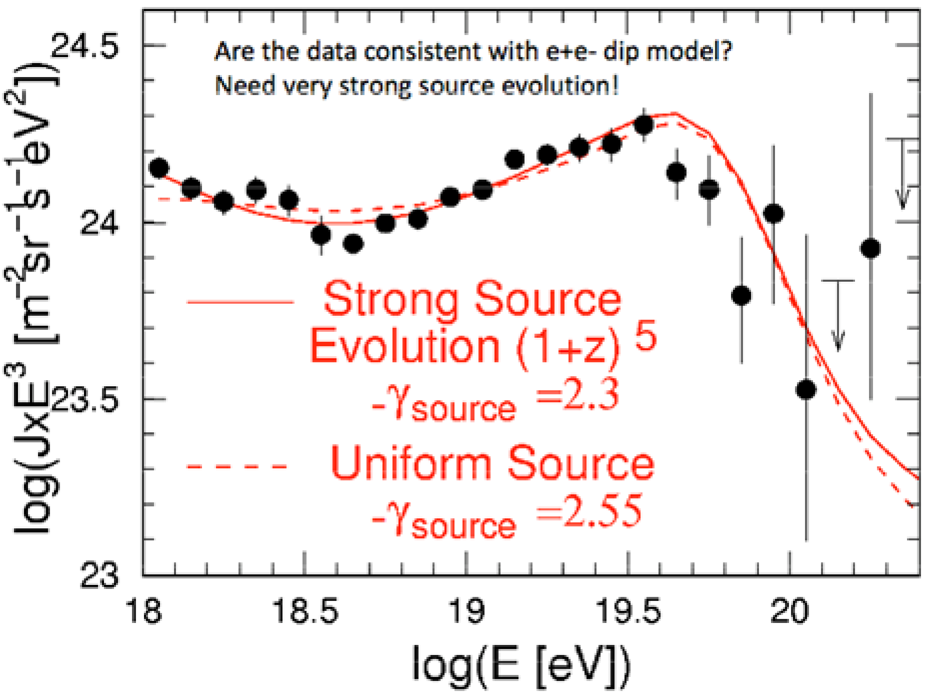
**Independent profile reconstuctions**



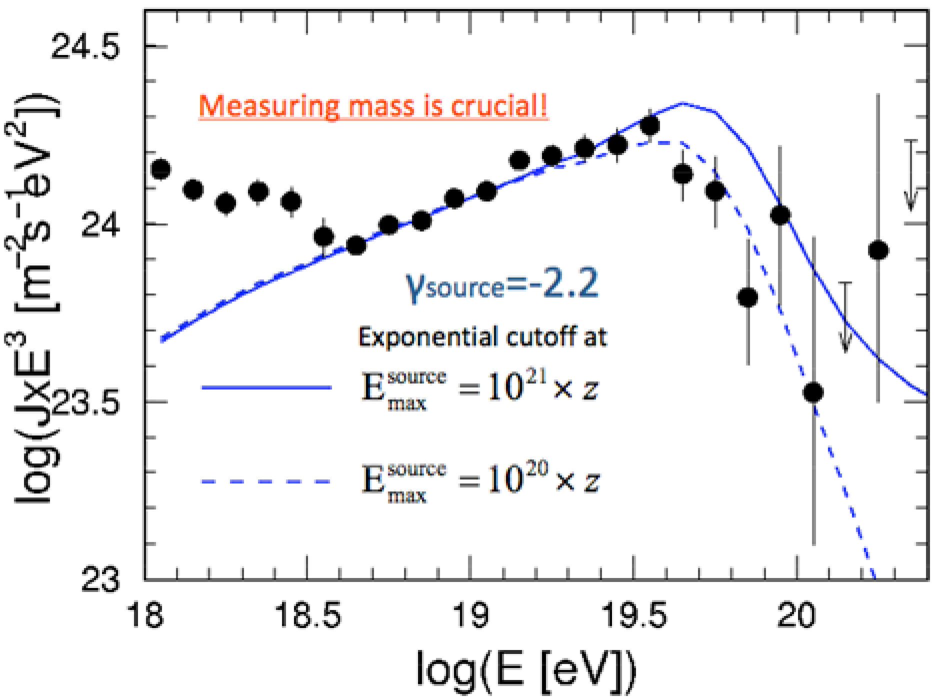
# Comparison with GZK suppression models

? Observed flux suppression is due entirely to GZK effect
? Observed flux suppression is signature of maximum acceleration energy
? Observed flux suppression is due to both source cutoff and GZK effect

**Pure proton model**
(Berezinsky et al.)

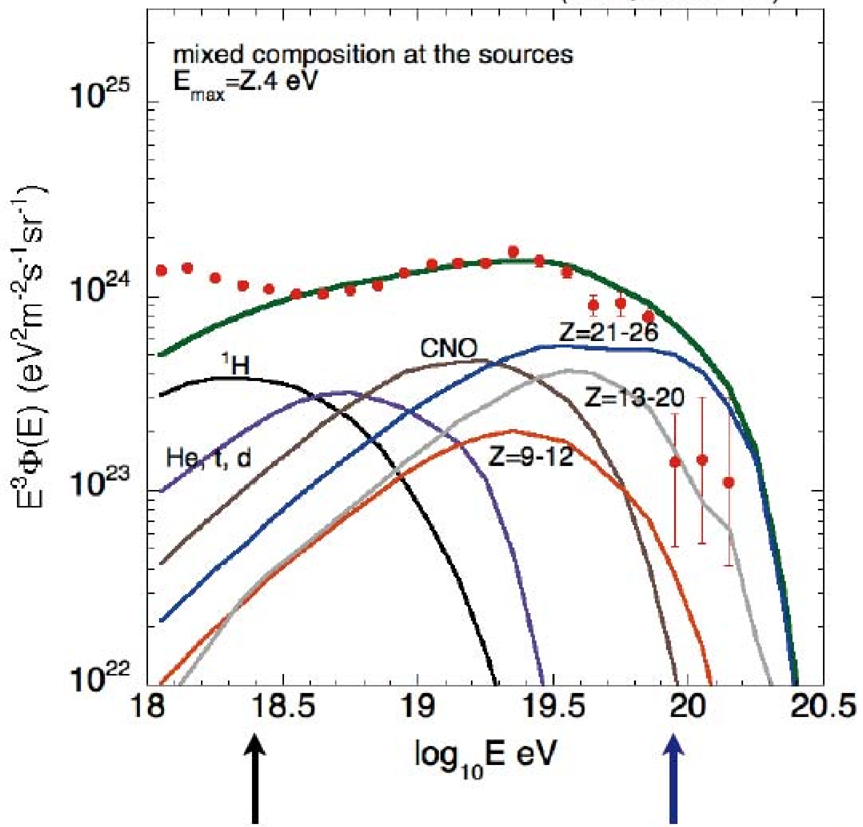



**Mixed composition model**
(Allard et al., Hillas)



# Comparison with GZK suppression models

*Particle flux* *(Allard, 1111.3290)*

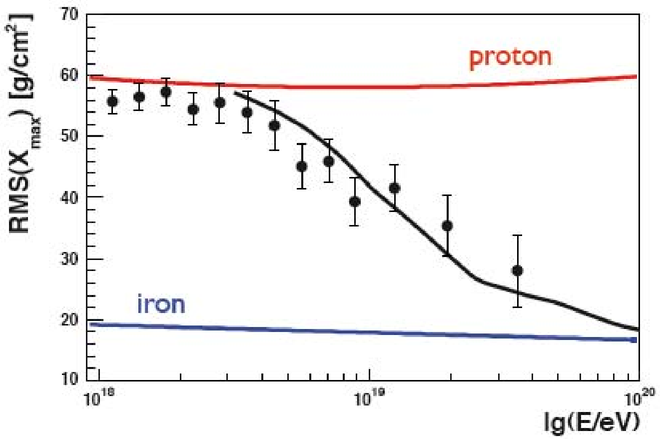



**Protons $E_{max,p} = 10^{18.4}$ eV**

**Iron $E_{max,Fe} = 26\ E_{max,p} = 10^{20}$ eV**

Natural transition to heavier composition at high energy !

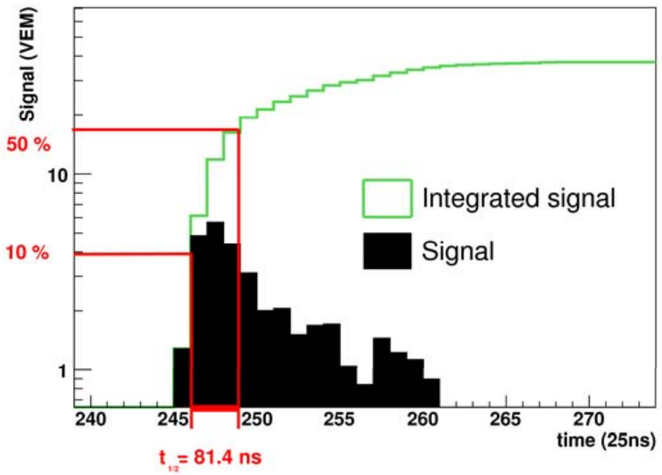
*Fluctuations of $X_{max}$* *(Unger 2012)*



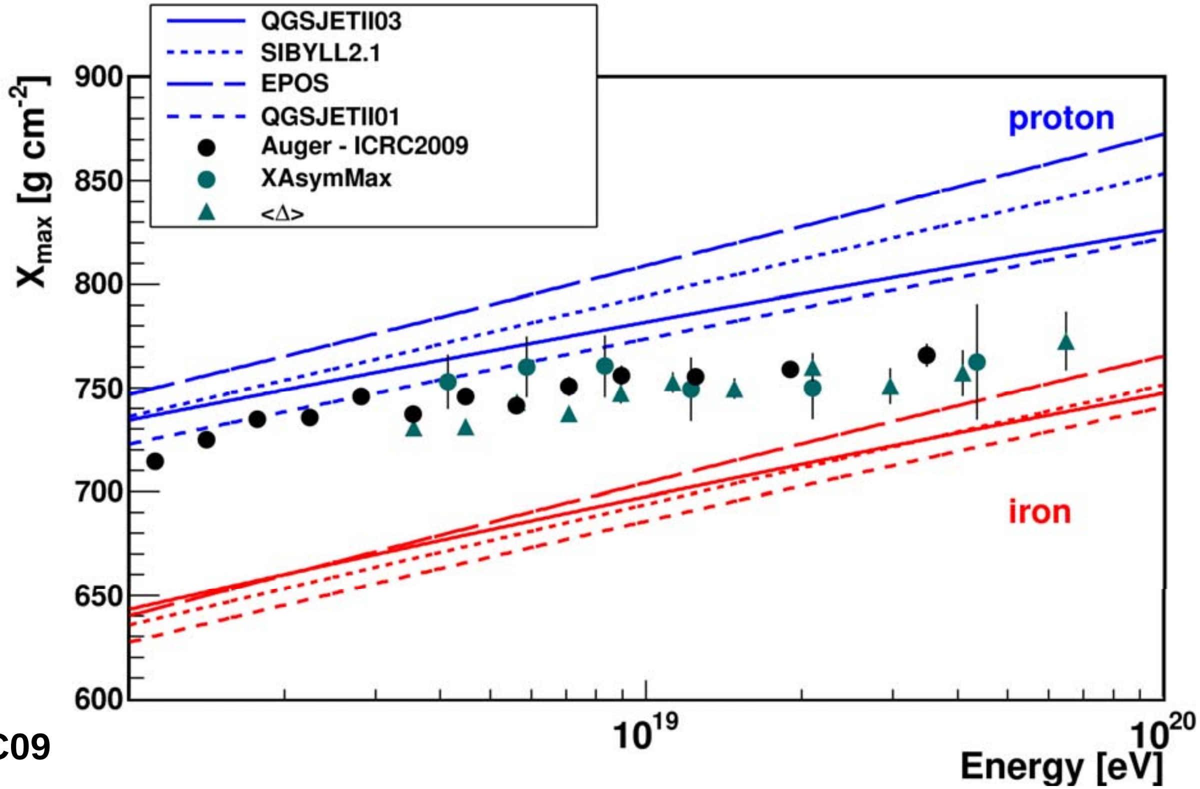

Flux not suppressed due to GZK effect

*(Calvez et al. 2010, Aloisio et al. 2011)*

# Composition with SD



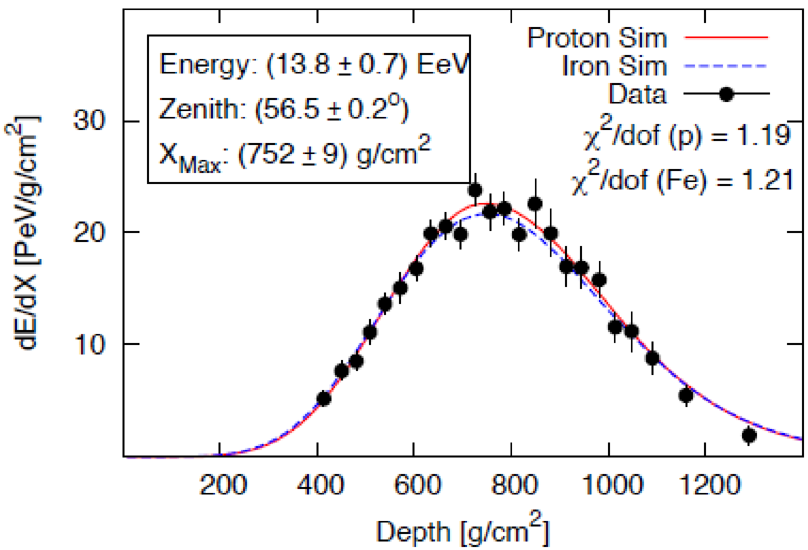

**Two approaches:**
**1) Azimuthal asymmetry in the signal risetime**
**2) Signal risetime in surface detectors to infer Xmax**

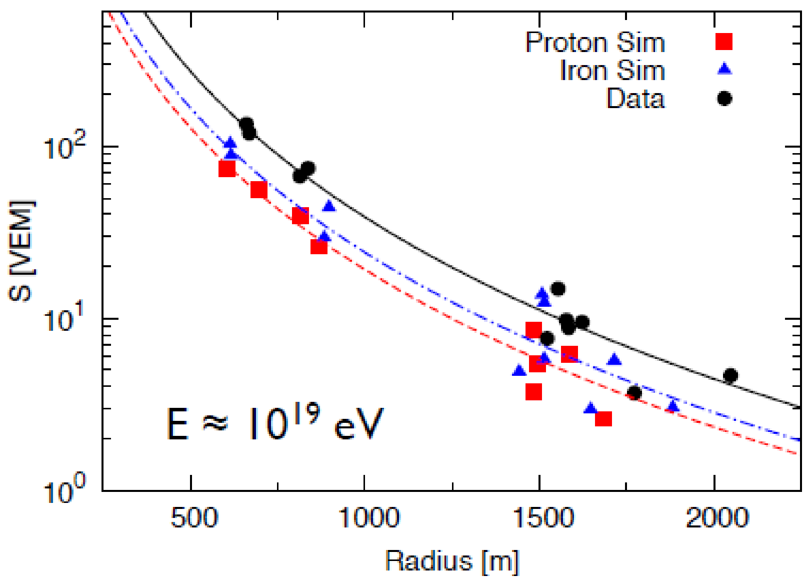



**- Up to now dominated by statistical uncertainties**
**- Energy range where SD detector is full efficient**

**H.Wahlberg-Auger Collaboration, ICRC09**

# Validity of hadronic interaction models



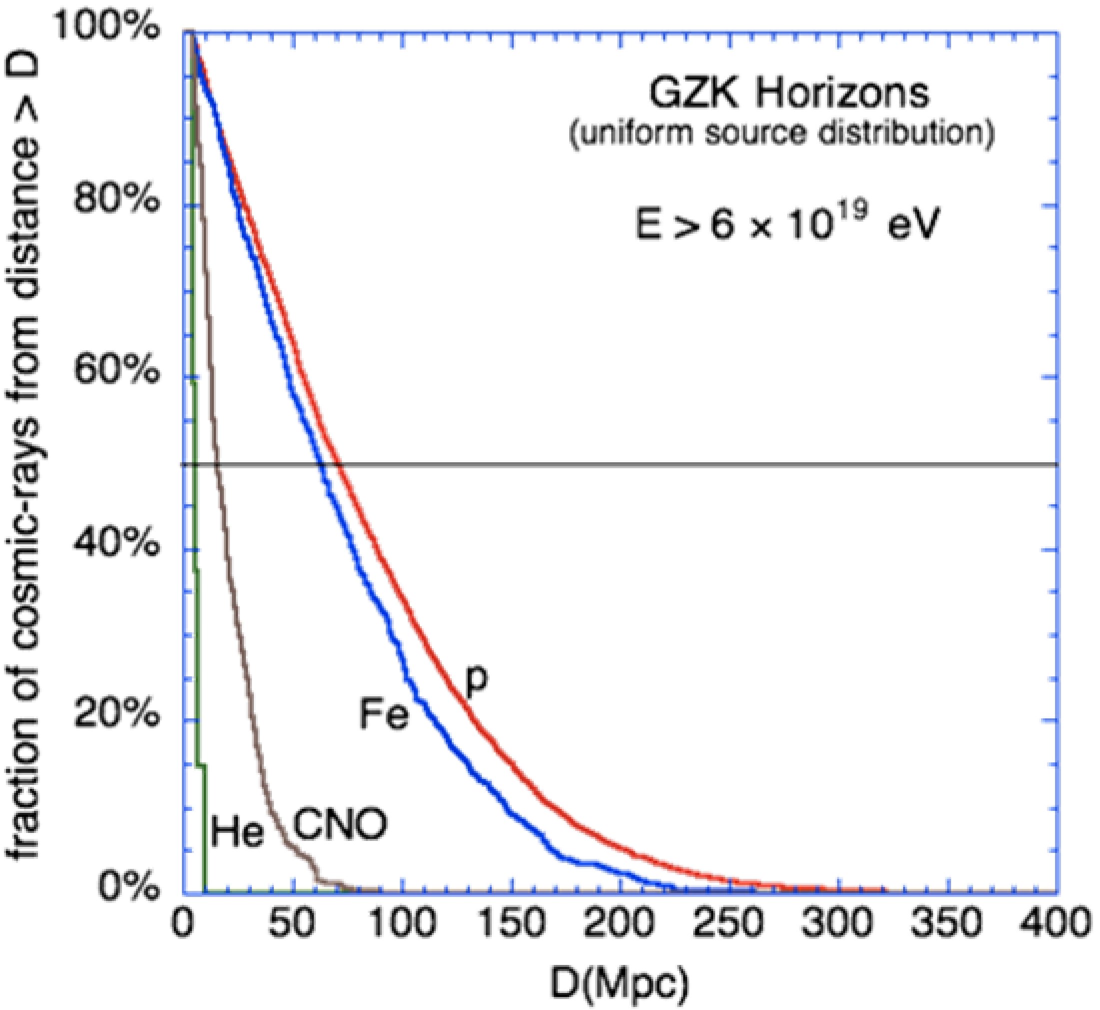

**Discrepancy:**
**shower profile and muons at ground**

## Highest energies: Trans GZK composition is simpler

**Light and intermediate nuclei photodisintegrate rapidly.**

**Only protons and/or heavy nuclei survive more than 20 Mpc distances.**

**Cosmic magnetic fields should make highly charged nuclei almost isotropic.**



## Proposal of the ASPERA Pierre-Auger-Consortium:

**Project Coordinator:**

**Partner 1: Andreas Haungs, KIT– Helmholtz Sector, IK, Karlsruhe, Germany**

**Co-applicants:**

**Partner 2: Johannes Blümer, KIT–University Sector, IEKP, Karlsruhe, Germany**

**Partner 3: Martin Erdmann, RWTH Aachen, Germany**

**Partner 4: Karl-Heinz Kampert, University of Wuppertal, Germany**

**Partner 5: Ad van den Berg, KVI Groningen, The Netherlands**

**Partner 6: Zbigniew Szadkowski, University of Lodz, Poland**

**Partner 7: Henryk Wilczynski, Inst. of Nuclear Physics PAN, Cracow, Poland**

**Partner 8: Antoine Letessier-Selvon, IN2P3/CNRS , France**

**Partner 9: Mario Pimenta, LIP–Lab.de Instr.e Física Exp. de Partículas, Portugal**

**Partner 10: Enrique Zas, University of Santiago de Compostela - USC, Spain**

**Partner 11: Valerio Verzi, INFN Roma Tor Vergata, Italy**

**Partner 12: Iliana Brancus, IFIN-HH Bucharest, Romania**

**Associated Partners:**

**Partner 13: Masahiro Teshima, MPI für Physik, München, Germany**

**Partner 14: Martina Bohacova, Inst. of Physics - FZU, Prague, Czech Republic**

# AugerNext in this proposal:

**This proposal is (initially within the Pierre Auger Collaboration) an integral part of the formulation of the specification of the future experiment in 3-5 years from now on.**

**Specific areas were chosen**

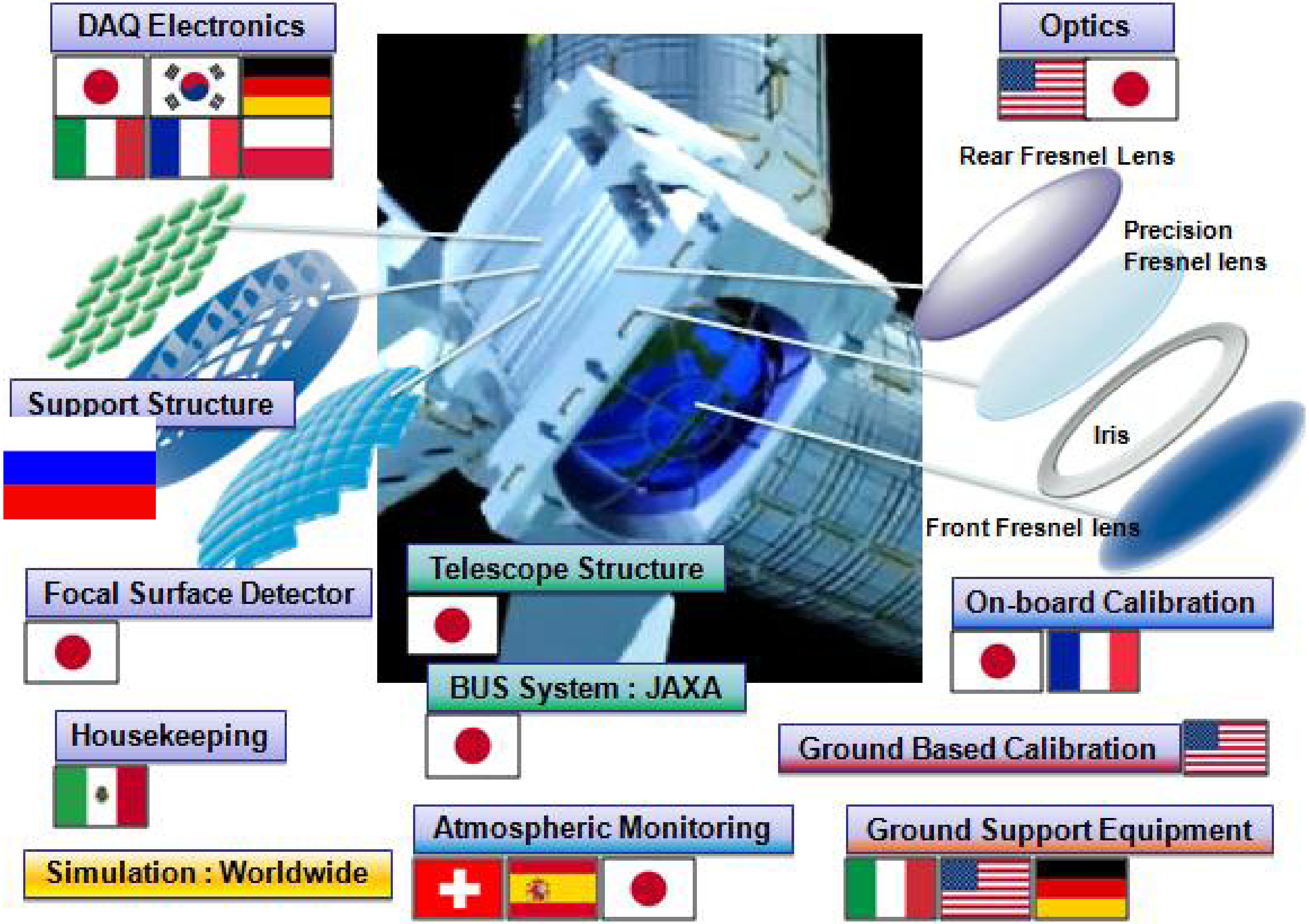
- **by available expertise of the involved European partners**
- **by prospects in structuring efforts on a European level.**
- **subtasks which have a highly innovative character.**

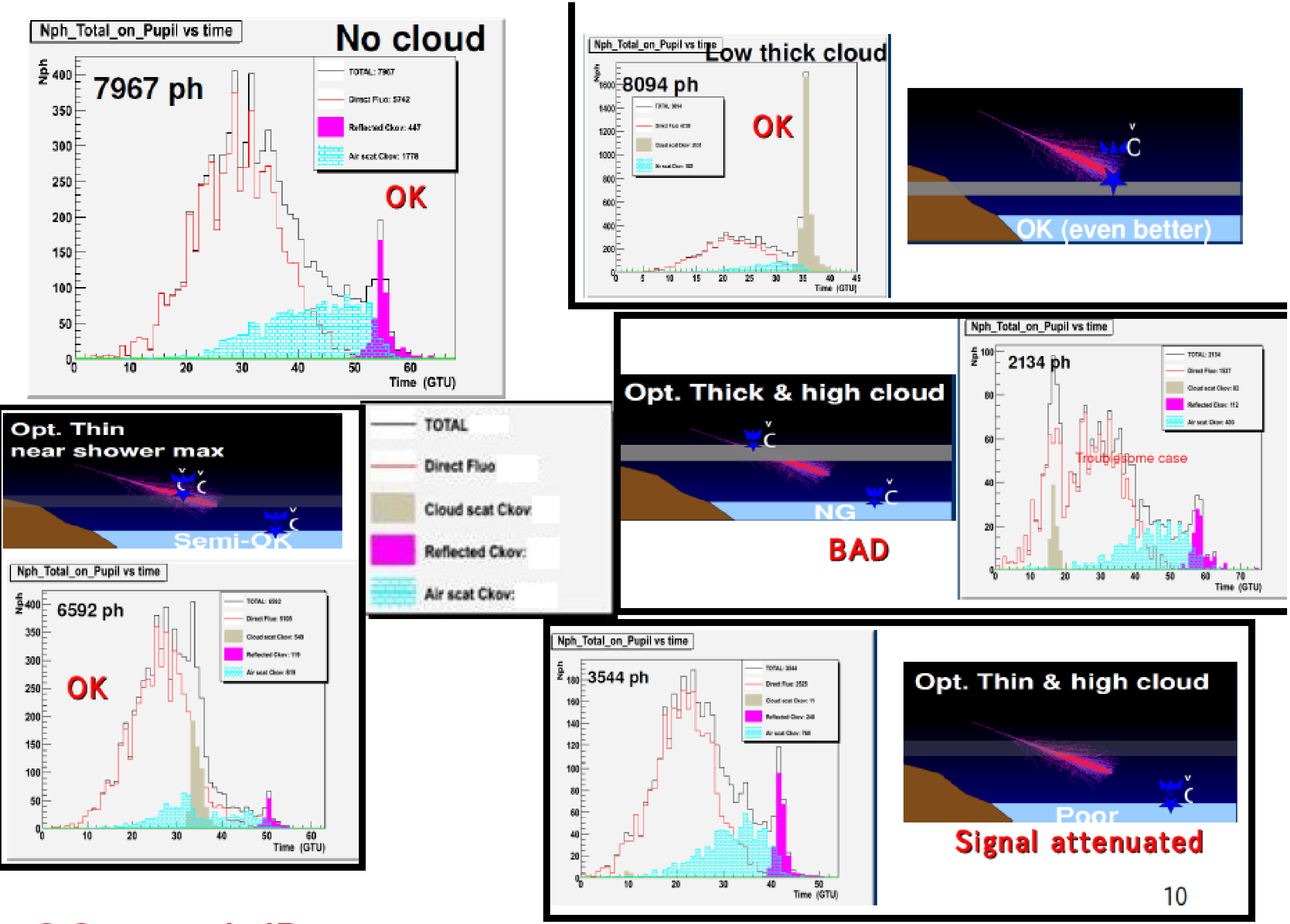
**The work packages are**

**(A) Investigation of the FM radio emission in air showers.**
**(B) Detection of the microwave emission in air shower.**
**(C) Improvement of photo sensors.**
**(D) Generalizing the data communication system.**
**(E) Studies for a hybrid muon detector.**

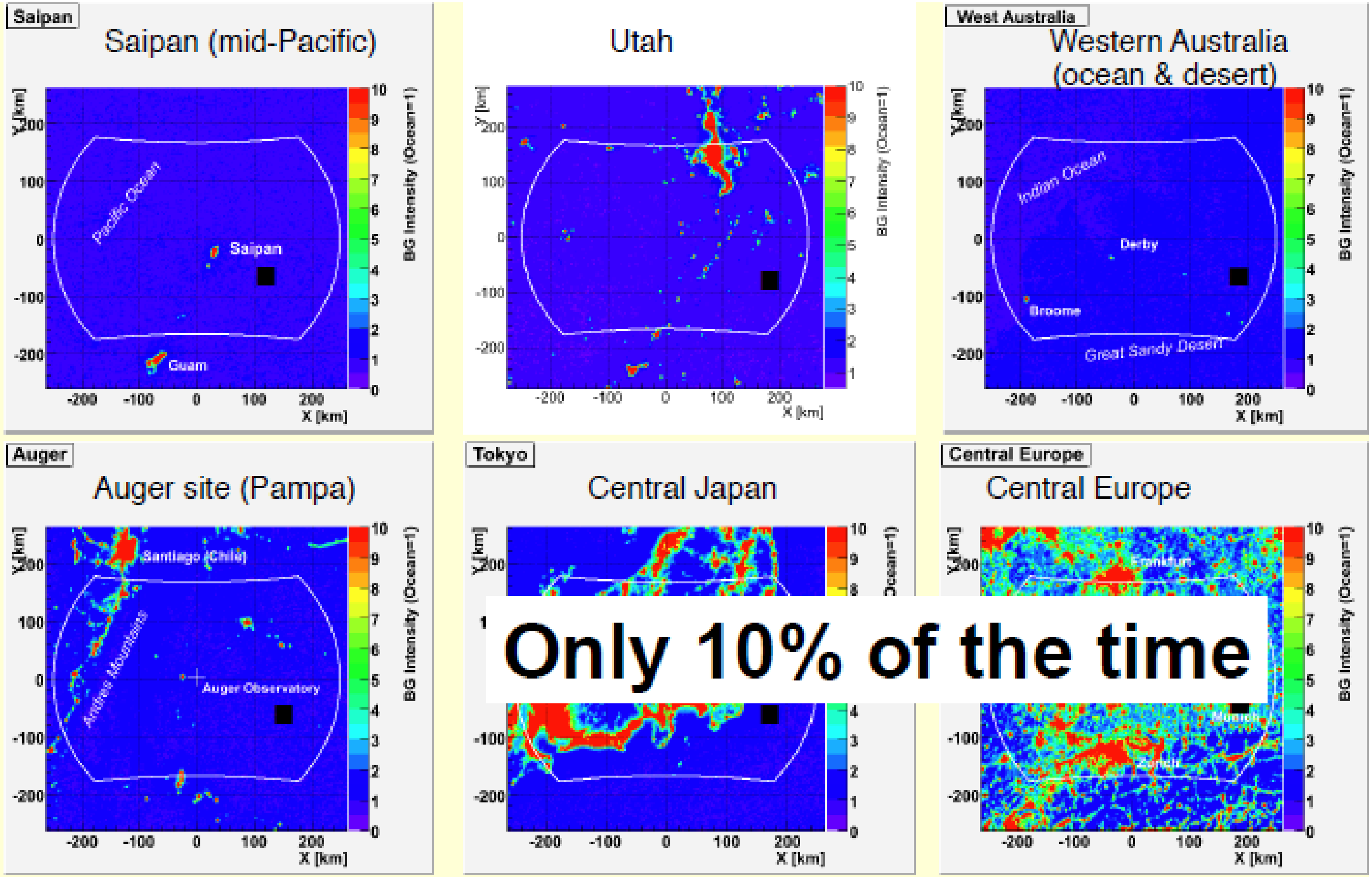
**The results of this project are thought to provide structured, well investigated input for formulating the proposal of the \`next generation experiment´**

# JEM-EUSO components






*G.Saez et al., ID1034*




**Only 10% of the time**

FoV of 1 PDM (27km x 27 km) ■ **BG Ocean = 1 = 500 ph/m$^2$/ns/sr**

In the city impact we assumed that 1 PDM is blind if 1 km x 1km area sees $I > I_o^{10}$

*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*

14