Experimental Overview

Advancements in Cosmic Ray Physics in Germany

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Thanks to Iris Gebauer, Frank Schröder, Dongwha Kang, Timo Karg and William Painter.

Participating Institutions

DESY Hamburg Auger, Tunka

DESY Zeuthen IceTop, Tunka

TU Dortmund IceTop

RUB IceTop

BUW Auger, IceTop, KASCADE-Grande

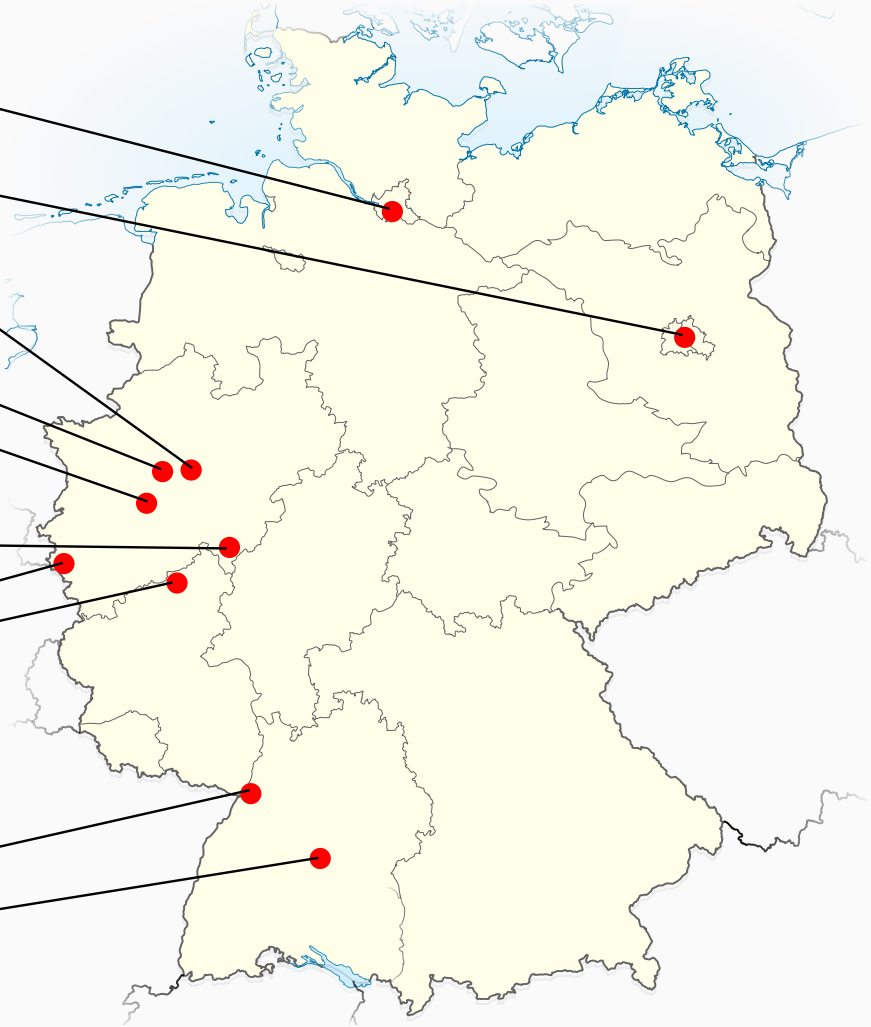
Siegen Auger, KASCADA-Grande

RWTH AMS, Auger, IceTop

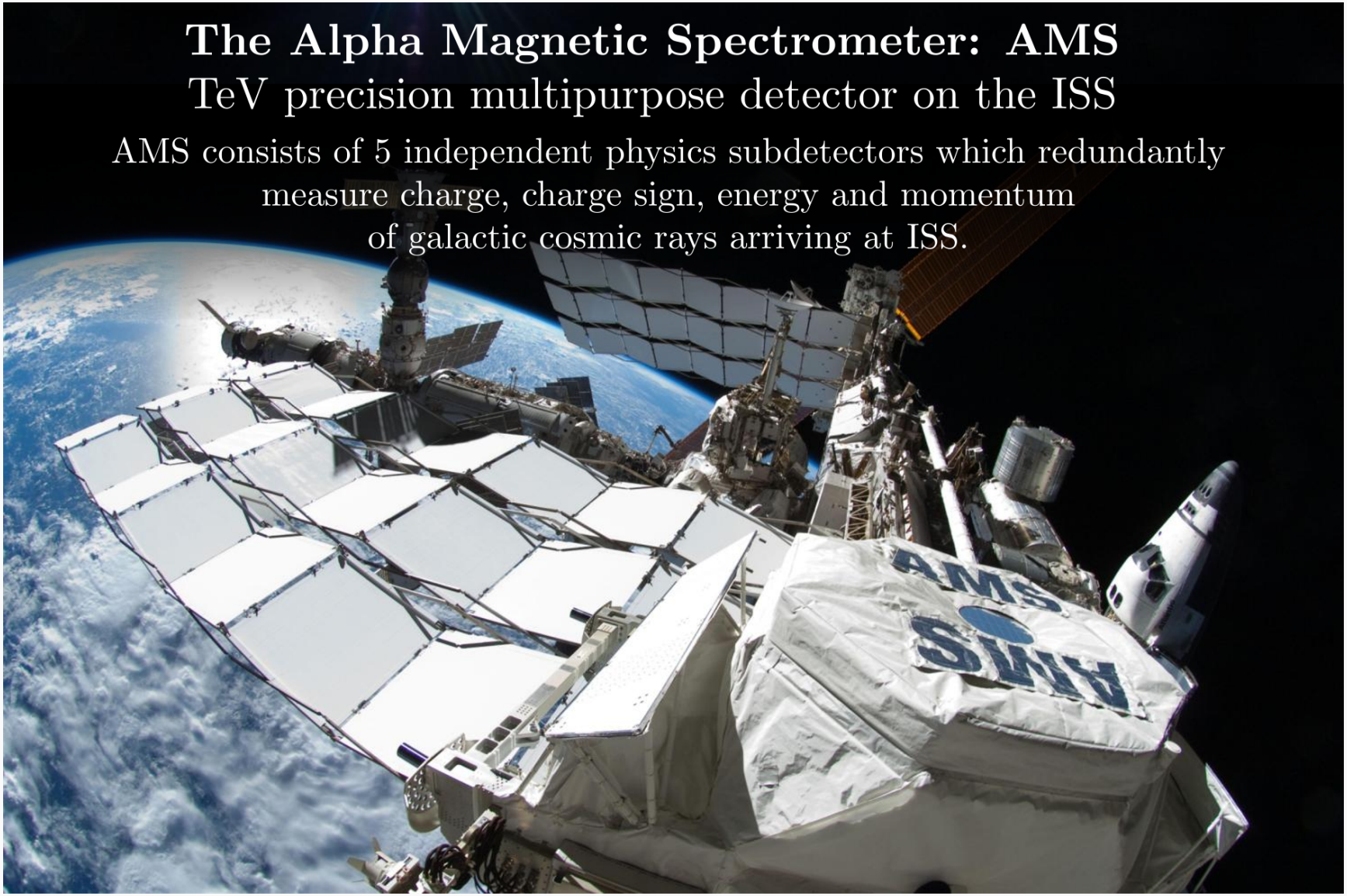
Bonn Auger

KIT AMS, Auger, EUSO, IceTop, KASCADA-Grande, Tunka

Tübingen EUSO

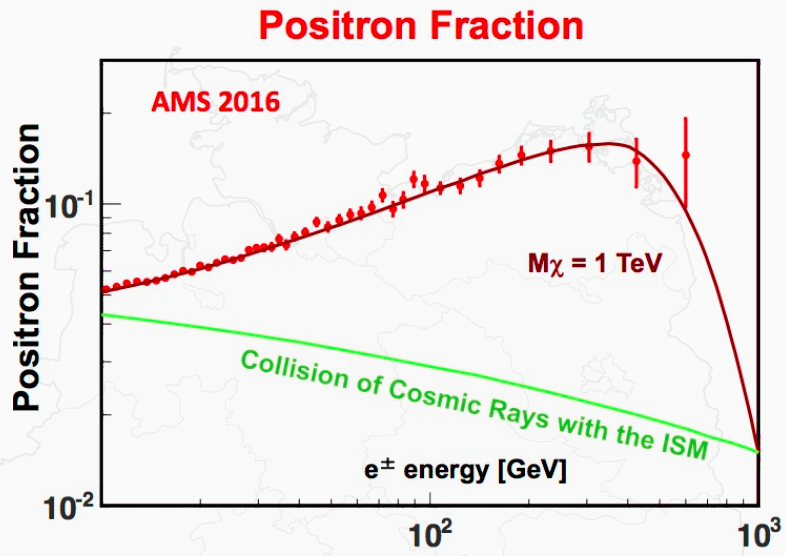


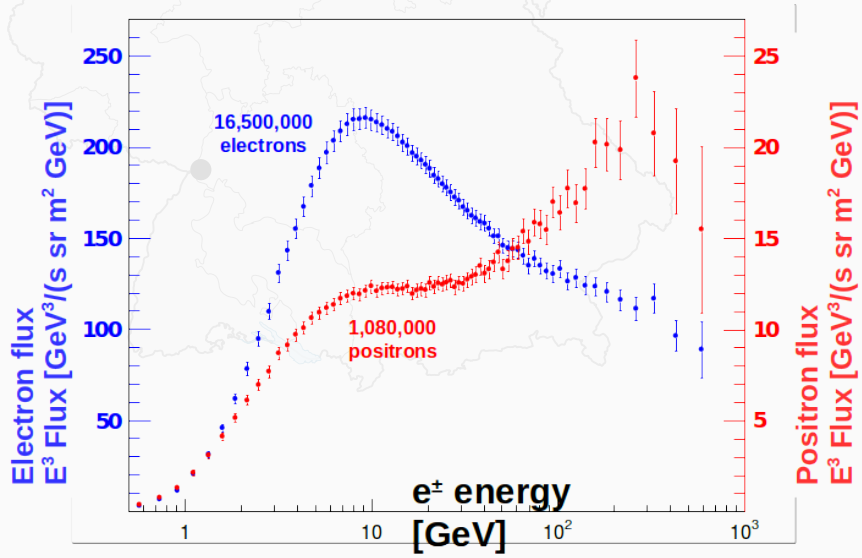
AMS


The Alpha Magnetic Spectrometer: AMS
TeV precision multipurpose detector on the ISS
AMS consists of 5 independent physics subdetectors which redundantly
measure charge, charge sign, energy and momentum
of galactic cosmic rays arriving at ISS.
AMS

e^+/e^- Spectrum / Positron Excess

- Observation: Unexpected rise in positron fraction $(e^+ + e^-)/e^+$
  - Incompatible with expectations from standard secondary e^+ production
- Possible sources:
  - local astrophysical point sources like pulsars
  - dark matter annihilation
- Electron and positron fluxes are compatible with a symmetric source





Germany: KIT/RWTH

[PRL. 110, 141102 (2013)] Editors' suggestion

[PRL. 113, 121102 (2014)] Editors' suggestion

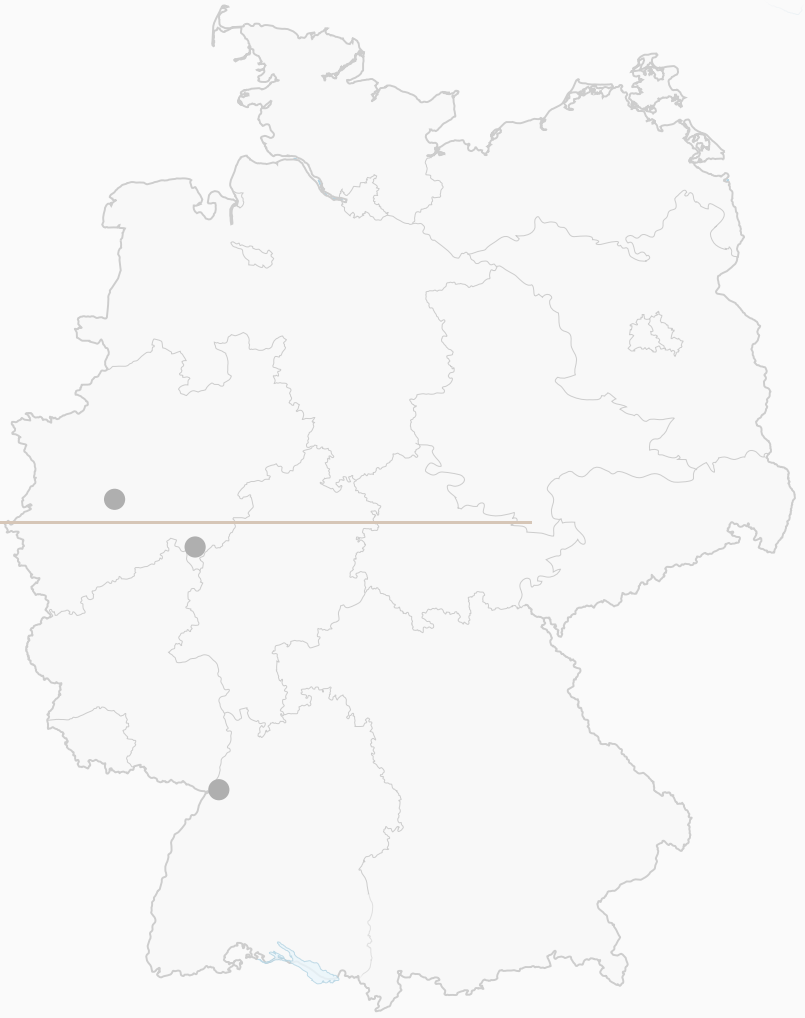
Summary

- In the foreseeable future AMS-02 will continue to be the only cosmic ray experiment with charge sign identification.
- Since 2011 AMS has collected a total of 125 billion events.
- The accuracy of the data is challenging our understanding of cosmic ray transport.
- AMS will continue to take data until 2024 or longer.

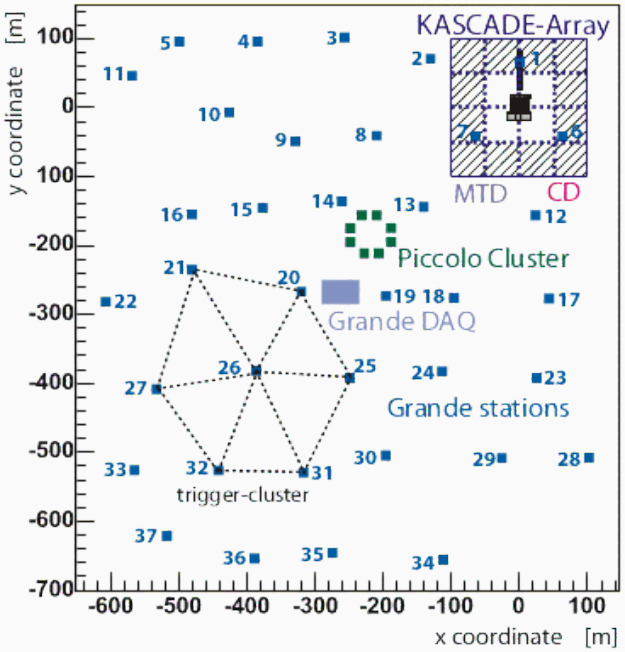
What to Expect in the Future

- High statistics antimatter fluxes dark matter searches.
- Heavier nuclei $\rightarrow$ understanding of cosmic ray sources and propagation (+ CALET, DAMPE, ISS-CREAM).
- Complex antimatter ($\overline{\text{He}}$, $\overline{\text{d}}$) $\rightarrow$ search for primordial antimatter.

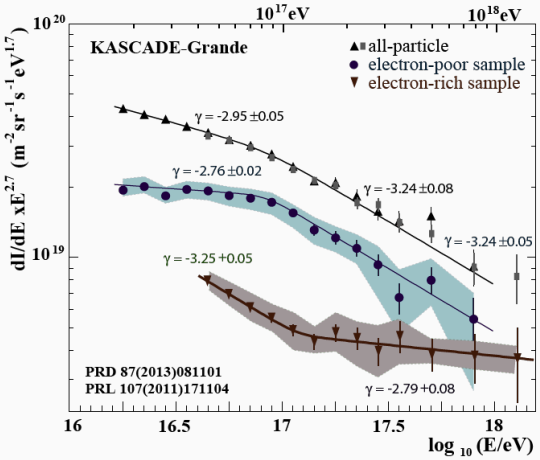
KASCADE-Grande

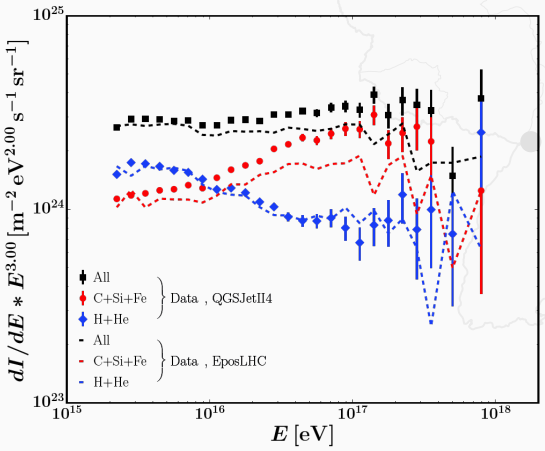


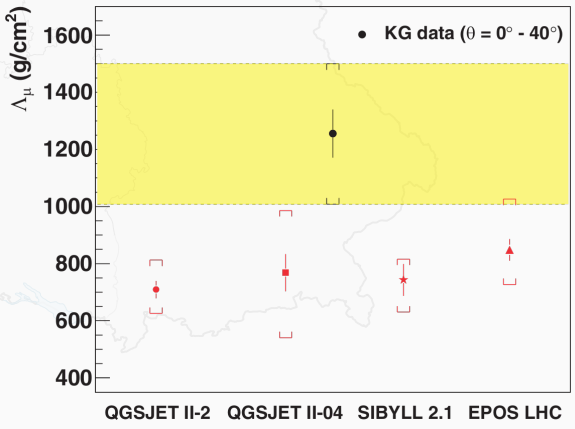
Overview



- 20 years of high quality data
  → Data taking finished in 2013
  → analysis still on going!
- Field critical results
  → Discovered light/heavy knee
  → Hadronic model tension Muon excess
- Working for the science community
  → Detectors used in LOFAR and Tunka
  → Pioneer in open data access



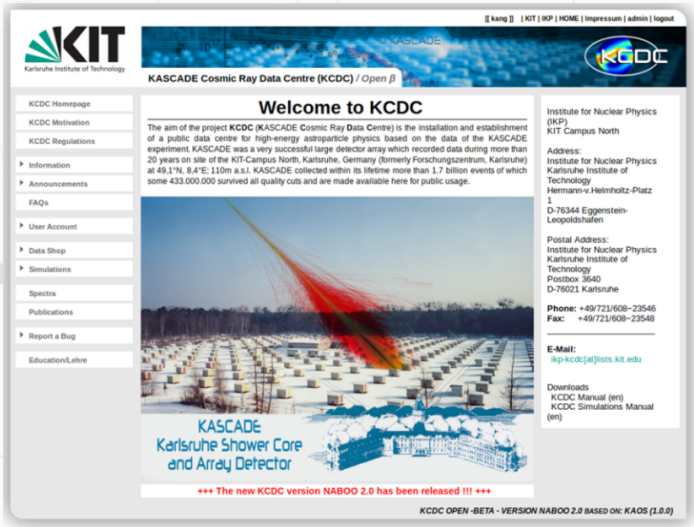




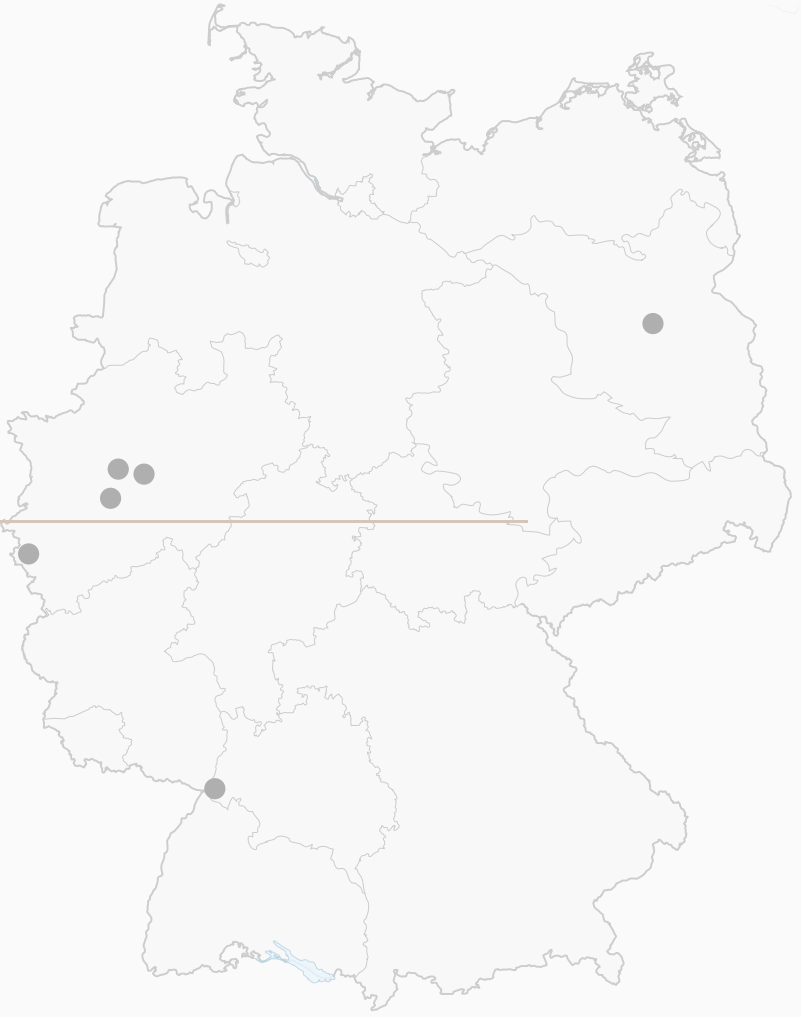
KCDC: Open Data!

https://kcdc.ikp.kit.edu/

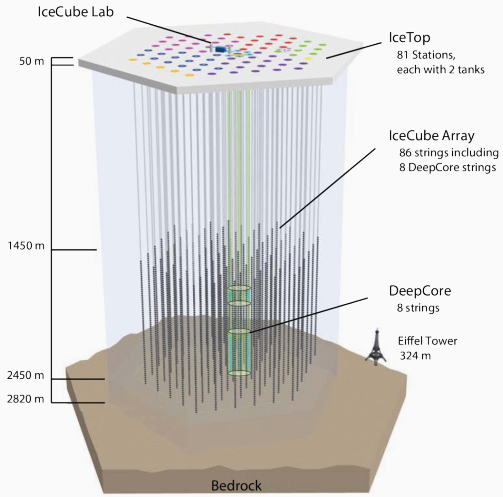
- KCDC (KASCADE Cosmic ray Data Centre): means publishing research data from KASCADE
- Motivation and Idea of Open Data:
  - general public has full access/use of the data
  - the data is preserved for future generations
- Web portal:
  - provide a modern software solution
  - release the software as Open Source
  - educational examples
- Data access:
  - latest release (Feb. 2017) with 4.3×10^8 EAS events
  - simulation data
  - energy spectra of other experiments
- Pioneering work in publishing research data

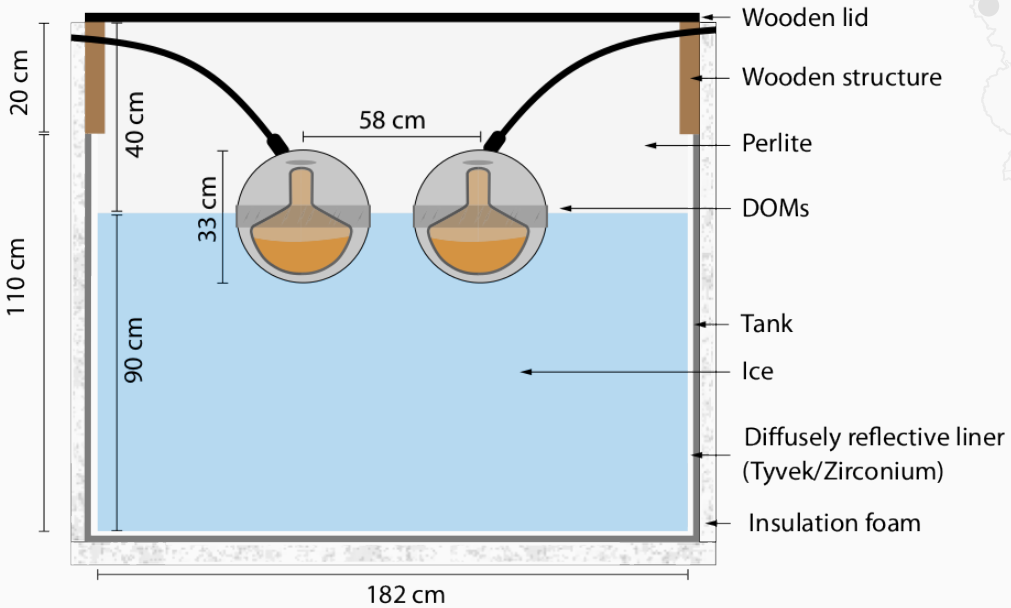


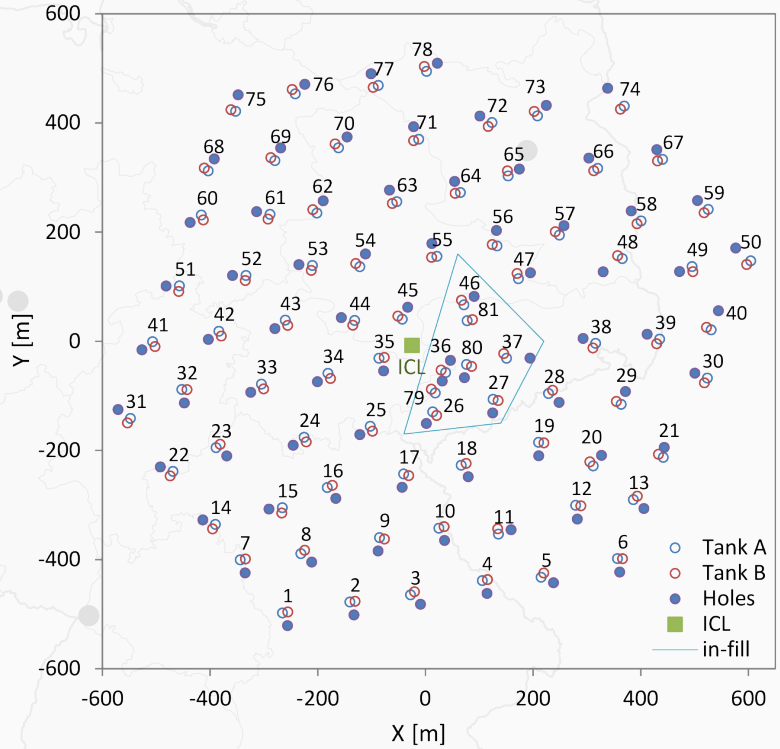
IceTop



Overview

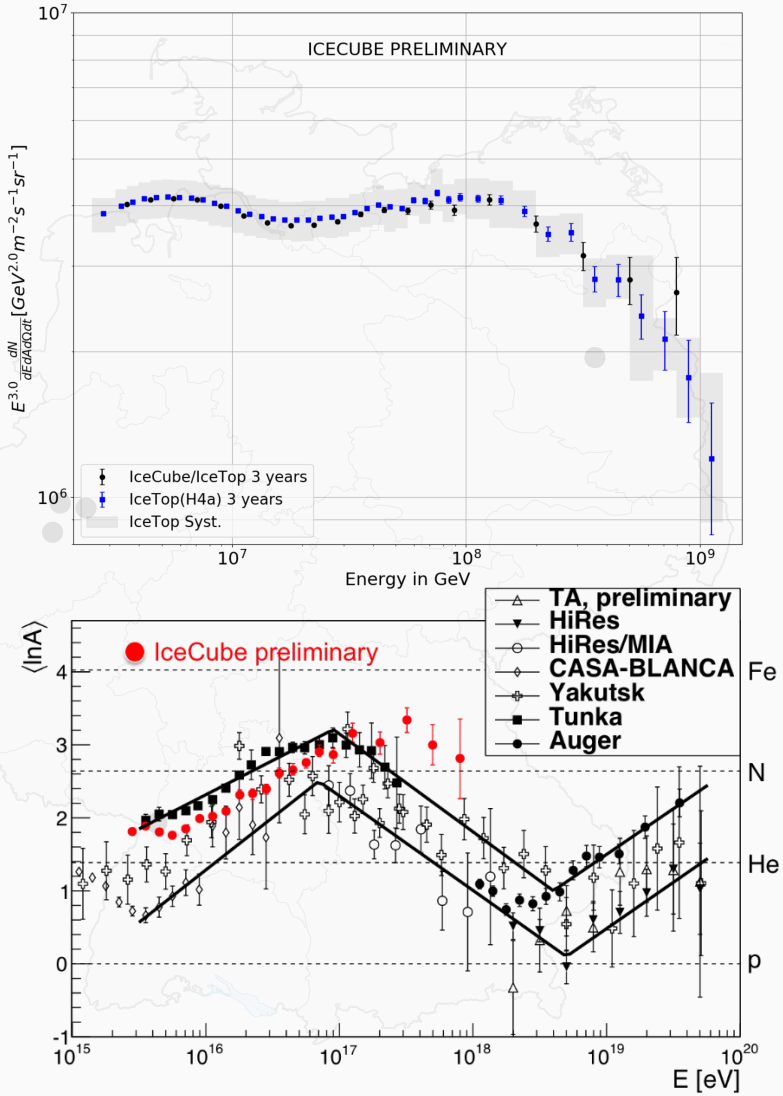

IceCube Lab
IceTop
81 Stations,
each with 2 tanks
50 m
IceCube Array
86 strings including
8 DeepCore strings
1450 m
DeepCore
8 strings
Eiffel Tower
324 m
2450 m
2820 m
Bedrock


20 cm
110 cm
40 cm
58 cm
33 cm
90 cm
182 cm
Wooden lid
Wooden structure
Perlite
DOMs
Tank
Ice
Diffusely reflective liner
(Tyvek/Zirconium)
Insulation foam


Y [m]
X [m]
ICL
Tank A
Tank B
Holes
ICL
in-fill

IceTop/IceCube Combined Analysis

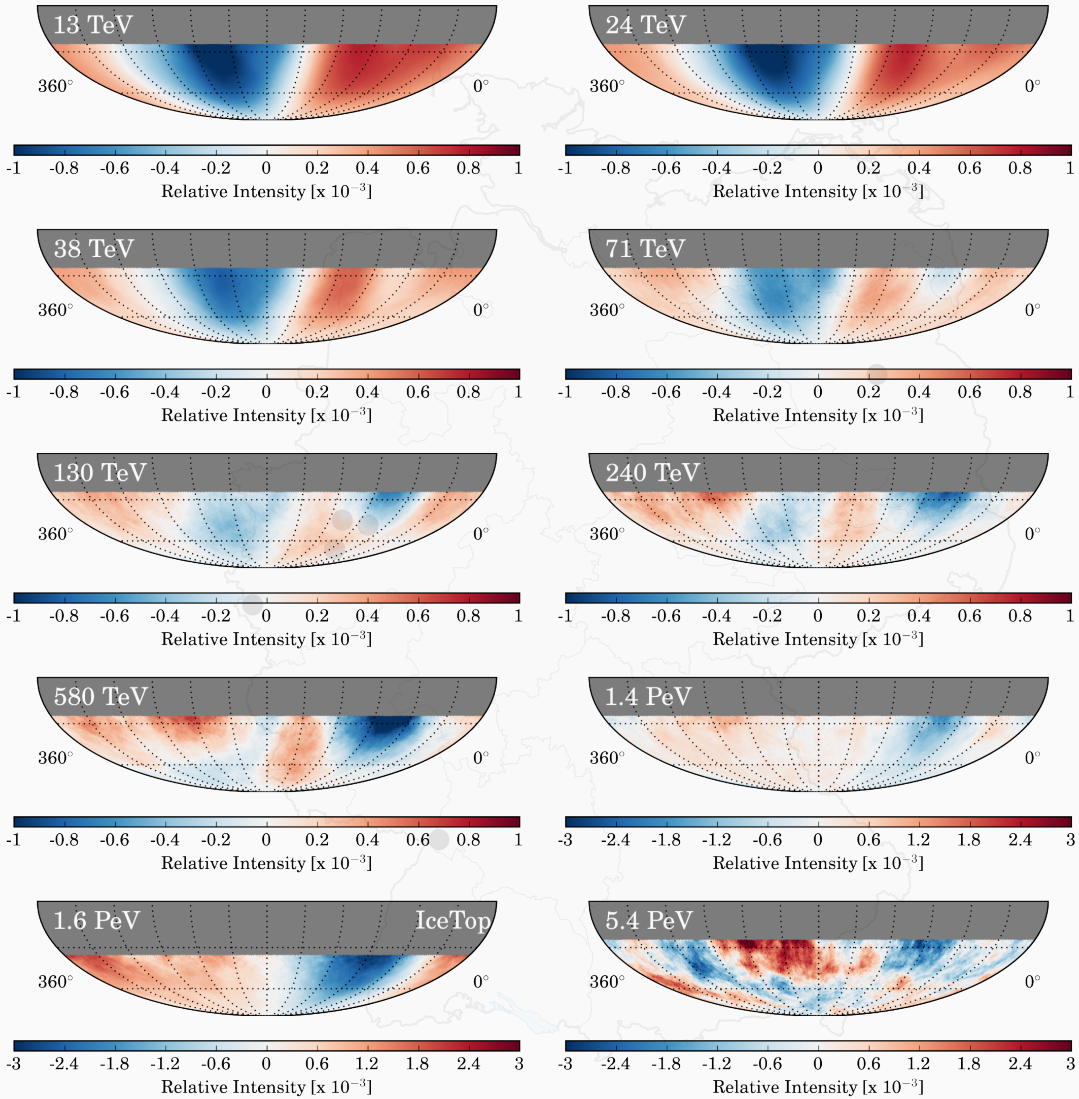
- Spectrum
  - 3 years of data
  - combines IceTop and IceCube signals
  - Very good matching between combined analysis and IceTop only analysis
- Composition
  - Shown is the log of the primary mass with the results of other experiments
  - analysis combines IceTop signal with information from deep muon signal in IceCube
  - represents 3 years of data



T. Gaisser et al. Nucl. B Proceedings 00 (2016) 1-9

Dipole

- Relative intensity of cosmic rays from 7 years of IceTop data
- Dipole strengthens with energy then begins to flip at 100TeV
- Shown to be stable over time
- matches with HAWC data
  → arXiv:1708.03005



R. Abb et al. ICRC2017, arXiv:1710.01194

ASTROPARTICLE PHYSICS IN GERMANY
Status and Perspectives
Mainz | 17–19 Sept 2018

The IceTop Enhancement for Improved Air-Shower Measurements

Ms. BALAGOPAL, Aswathi[1] ; Mr. HUBER, Thomas[2] ; Ms. LESZCZYNSKA, Agnieszka[1] ; Ms. OEHLER, Marie[1] ; Mr. RENSCHLER, Max[1]

[1] *KIT*

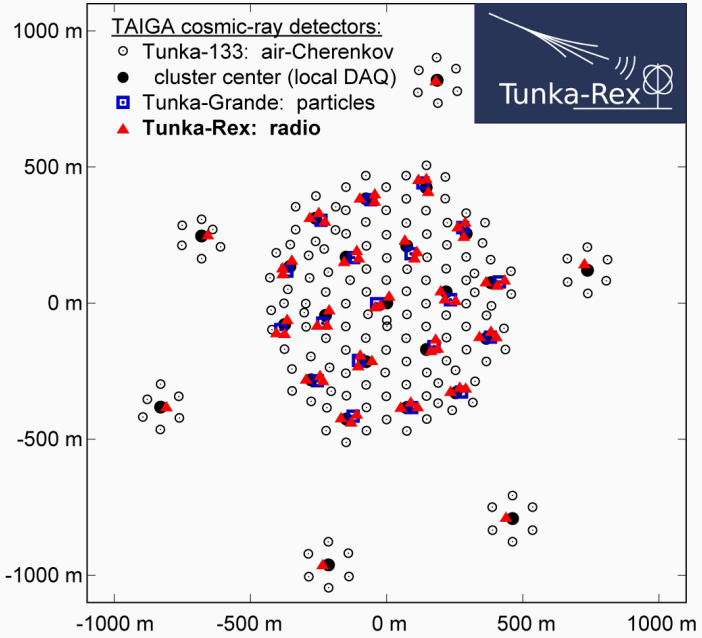
[2] *KIT, DESY*

Corresponding Author(s): aswathi.balagopal@kit.edu

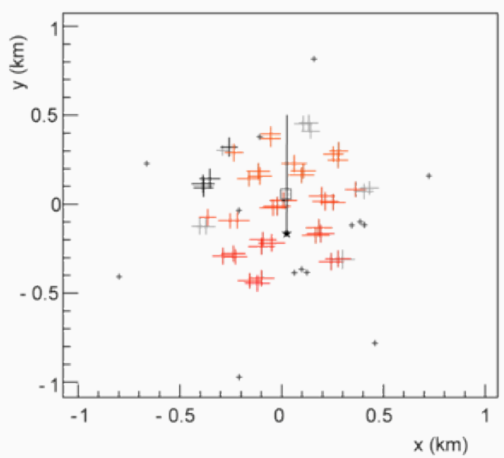
The IceCube Neutrino Observatory, located at the South Pole, detects neutrinos of the highest energy in the Universe. IceTop, the surface array of IceCube measures cosmic rays, and acts as a veto for the in-ice observatory. An enhancement of IceTop using scintillation and radio detectors is foreseen. Two prototype scintillation detector stations have been deployed at the Pole in the austral summer of 2017/2018. The features of the detectors as well as the detailed simulations of the future scintillation array will be shown. Apart from this it is planned to deploy prototype radio antennas operating at 50-350 MHz, which includes the optimal band of 100-190 MHz thereby improving the signal-to-noise ratio. The results of the studies for the radio enhancement will also be shown.

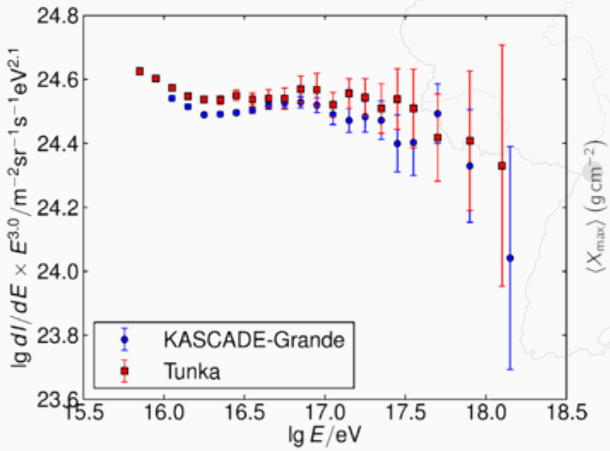
TAIGA: Tunka-Rex

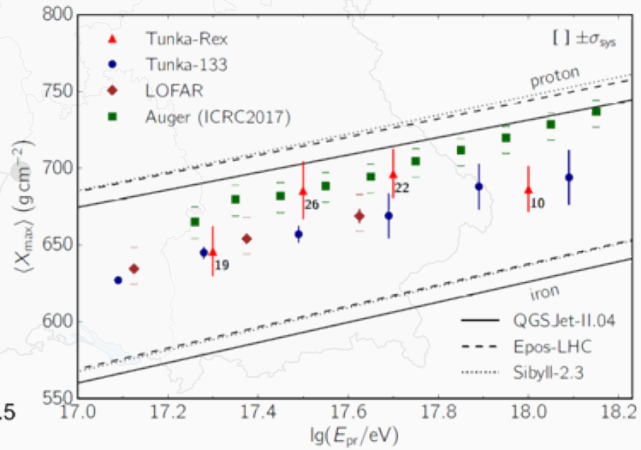
Tunka-Rex Overview



- Located at TAIGA facility in Siberia for Gamma Astronomy and Cosmic Rays
- 63 antennas on 3 km^2
  - 3 antenna stations per cluster
  - Cluster spacing of 200 m
- Frequency range: 30 - 80 MHz
- Trigger:
  - Air-Cherenkov detectors (Tunka-133)
  - Particle detectors (Tunka-Grande)



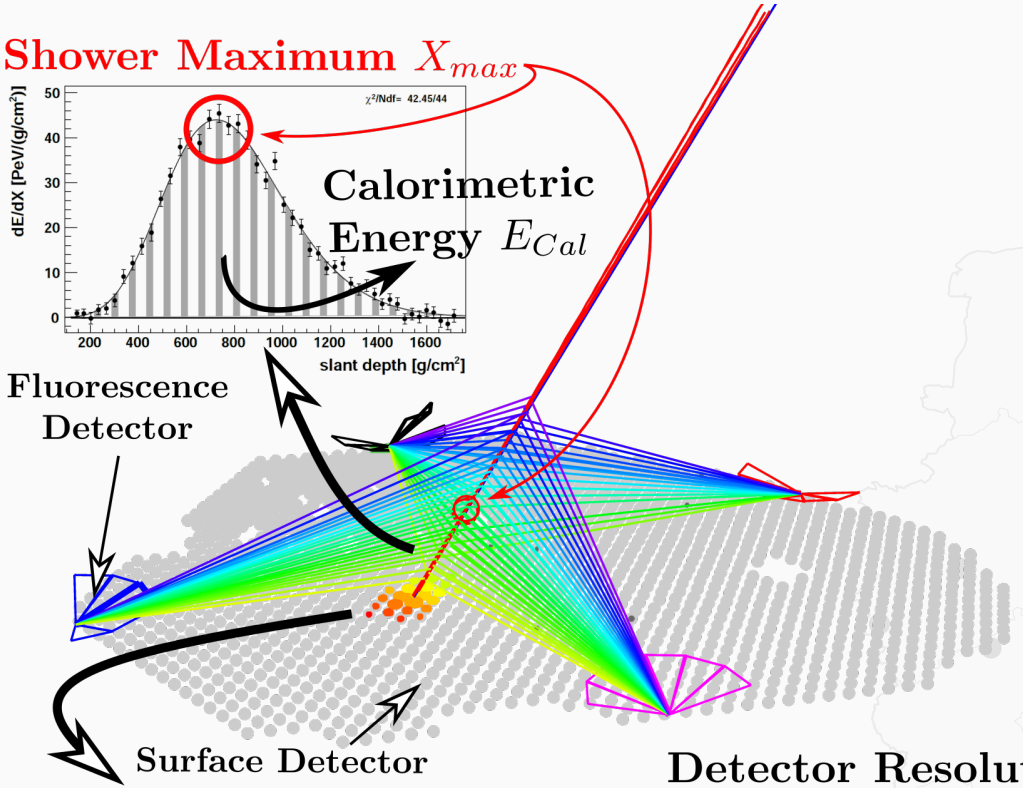


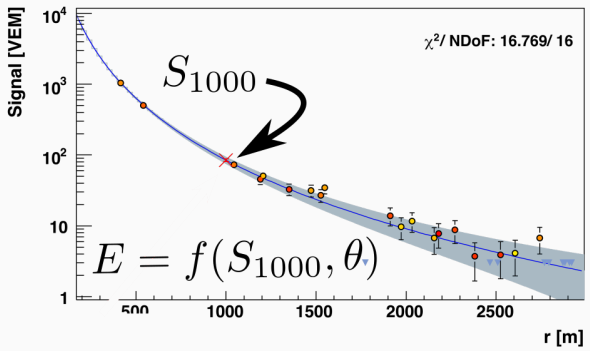


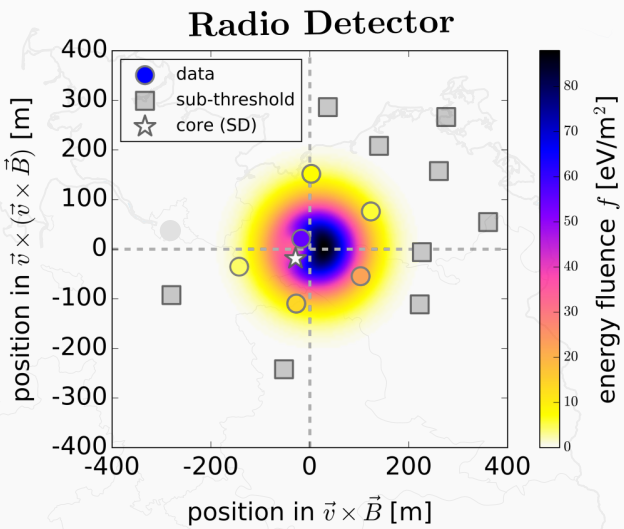
F. Schröder et al, PoS ICRC2017, 459

The Pierre Auger Observatory

Pierre Auger Observatory Overview







X_{max}, E_{Cal}

Detector Resolution:

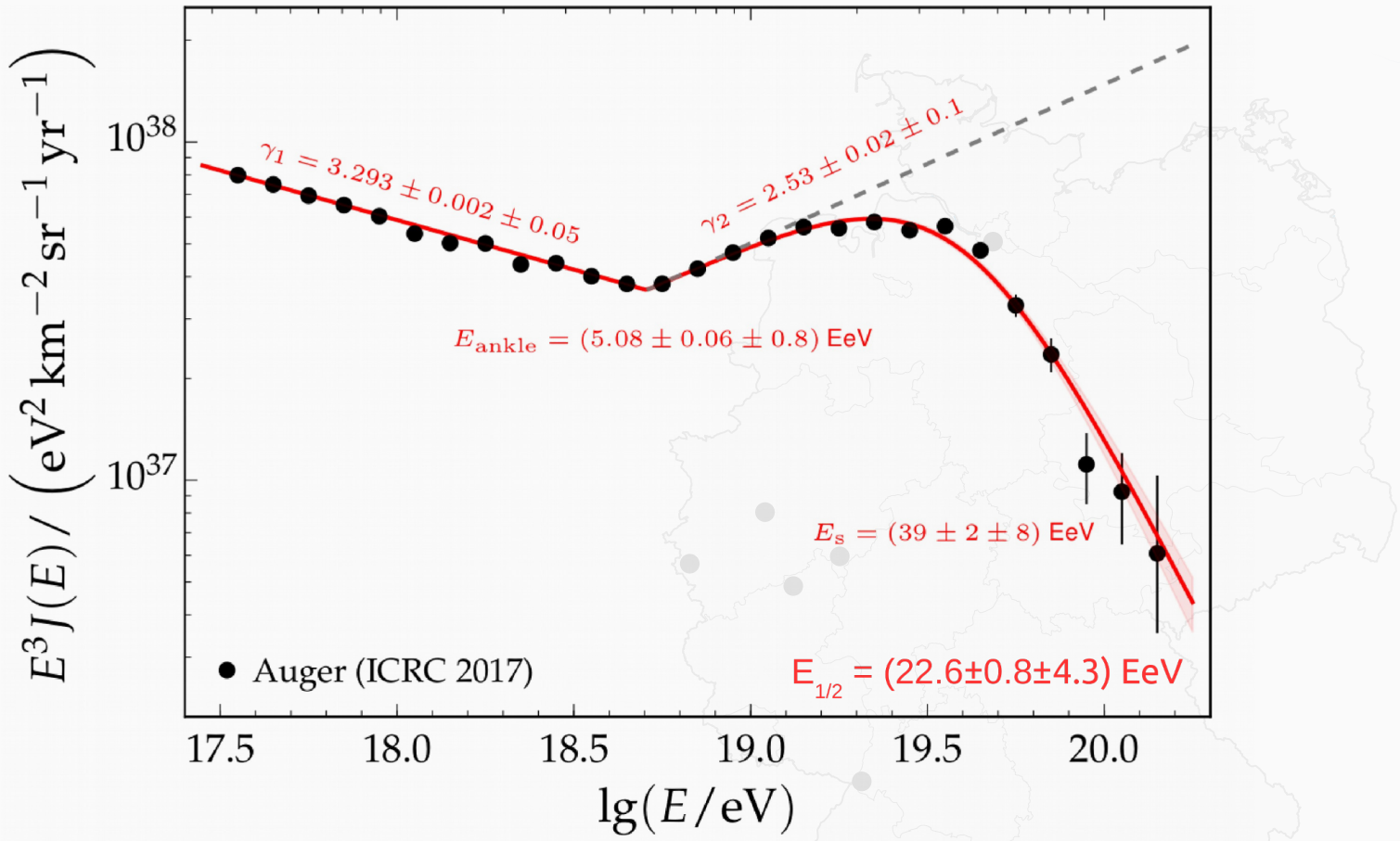
- $\sigma E / E \sim 8\%$
- $\Delta E_{sys} \approx 15\%$
- $\sigma X_{max} \leq 20\,\mathrm{g/cm^2}$
- $\Delta X_{max\,sys} \leq 10\,\mathrm{g/cm^2}$

exposure

Auger 9.0*10⁴ km² sr yr

TA 0.8*10⁴ km² sr yr

Spectrum



$$E < E_{ankle}: \quad \Phi(E) \propto E^{\gamma_1}$$

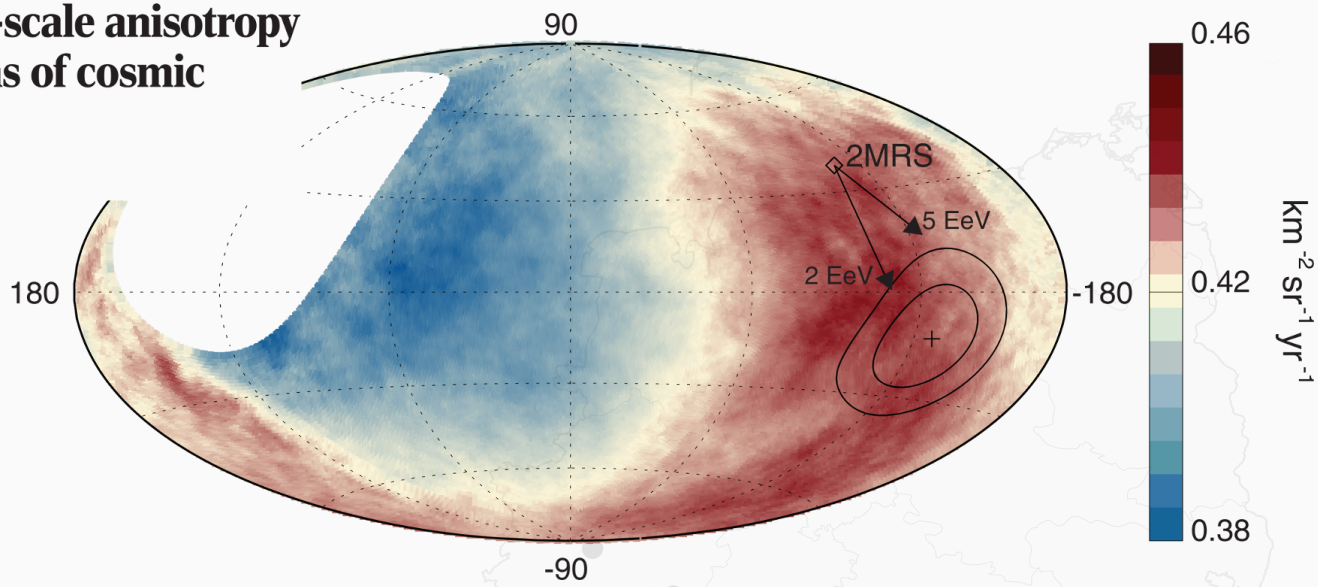
$$E > E_{ankle}: \quad \Phi(E) \propto E^{\gamma_2} \left[1 + \left(\frac{E}{E_s}\right)^{\Delta\gamma}\right]^{-1}$$

Cosmic Ray Dipole

Observation of a large-scale anisotropy in the arrival directions of cosmic rays above 8×10^{18} eV

The Pierre Auger Collaboration*†

physicsworld TOP 10 BREAKTHROUGH 2017



- Large scale anisotropy detected at $>$ 5.2 sigma
- Dipole amplitude of 6.5%
- Dipole analysis and interpretation extended down to 4×10^{18} eV
- Definitive signal of extra-galactic sources!

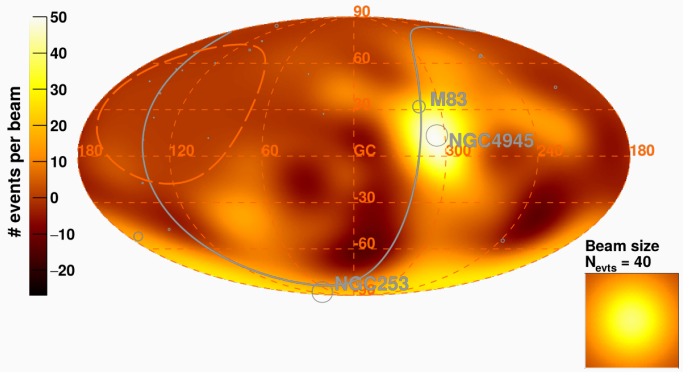
A. Aab et al., Science 357 (2017) 1266

Indication of Anisotropy at Higher Energies

Data Maps

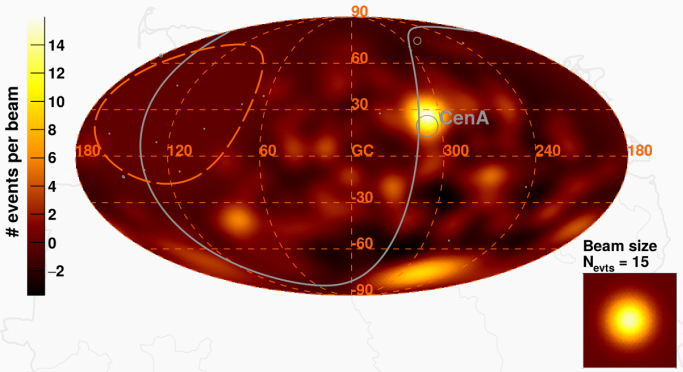
Observed Excess Map - E > 39 EeV

starburst



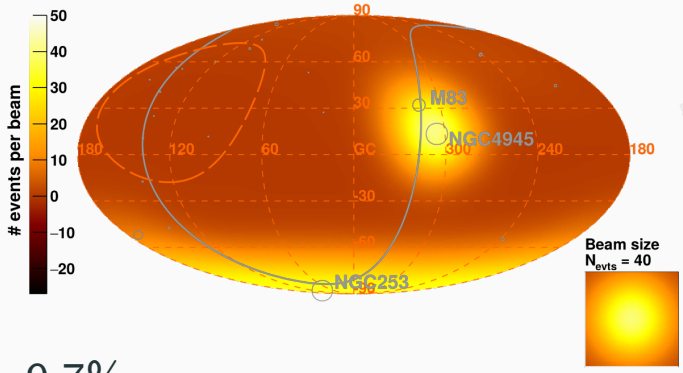
Observed Excess Map - E > 60 EeV

AGN

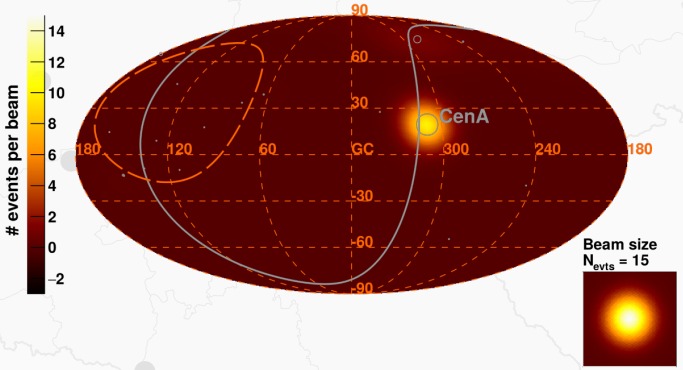


Model Maps

Model Excess Map - Starburst galaxies - E > 39 EeV



Model Excess Map - Active galactic nuclei - E > 60 EeV



SBG fraction: 9.7%
search radius: 12.9°
pre-trail p-value: 3.8×10^{-6}
post-trial p-value: 3.6×10^{-5}

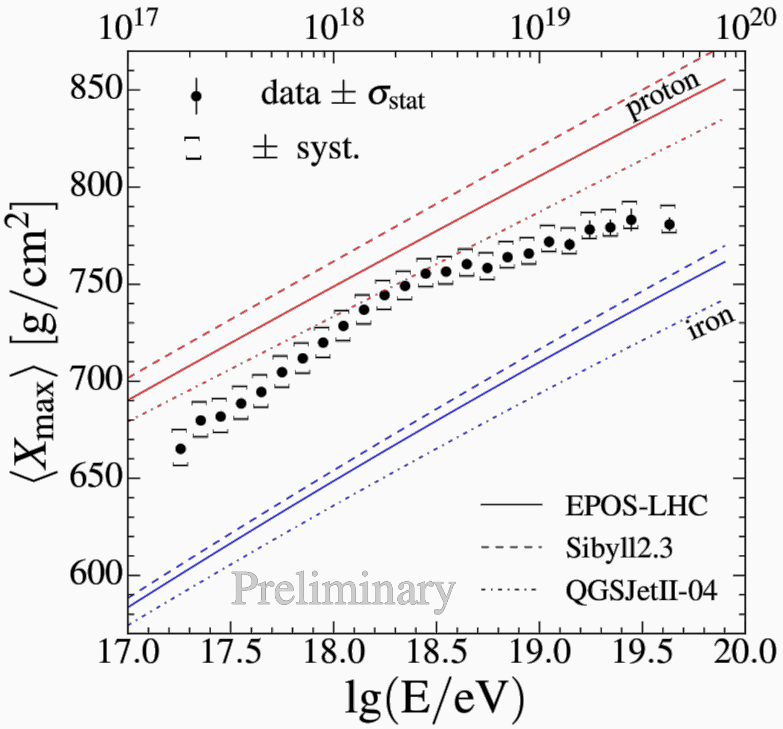
post-trial significance: 4.0 σ

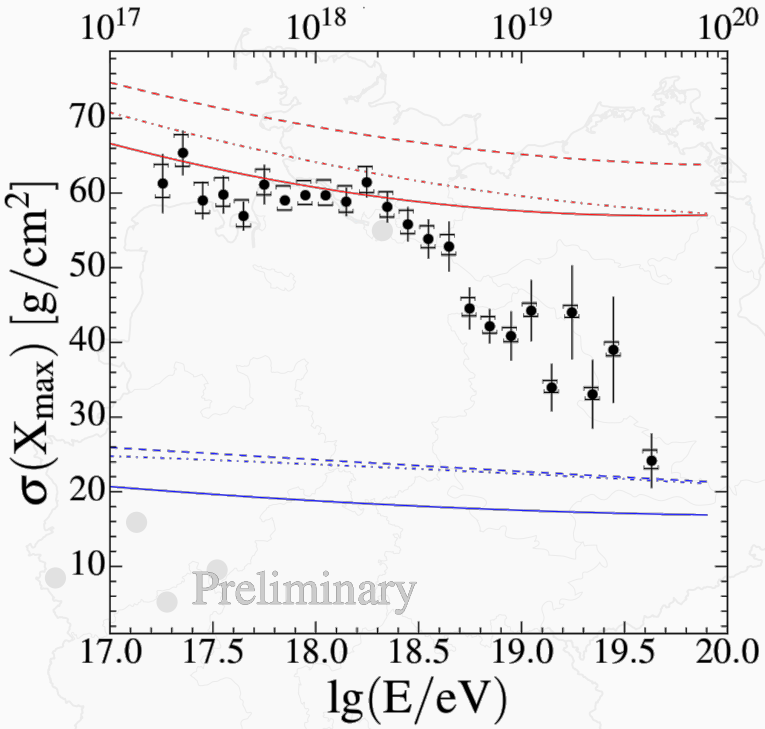
A. Aab et al. ApJ 835 (2018) L29

search radius: 6.9°
pre-trail p-value: 5.1×10^{-4}
post-trial p-value: 3.1×10^{-3}

post-trial significance: 2.7 σ

X_{max} Moments 17.2 – 19.6 ICRC17



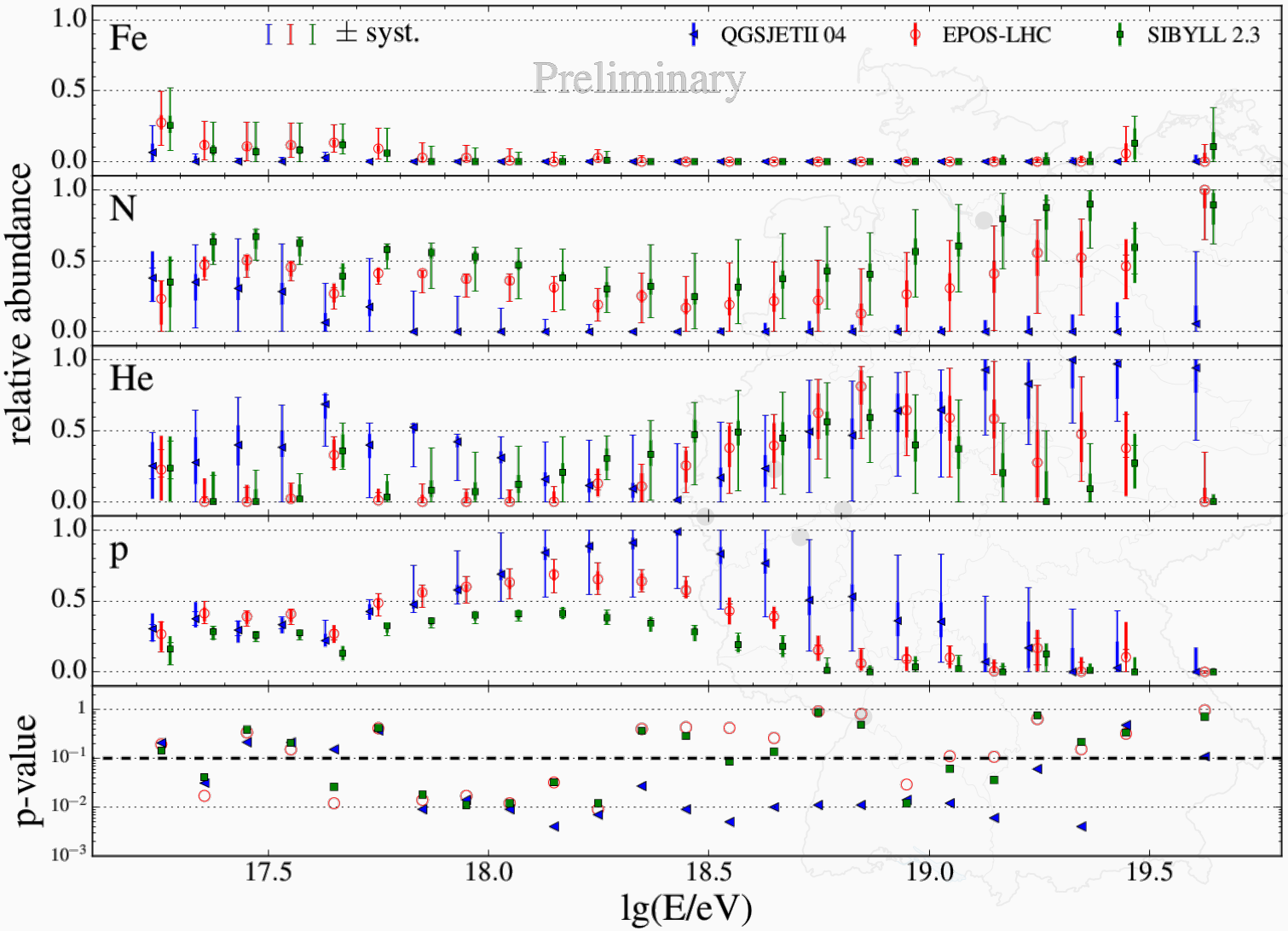


Interesting elongation rate break at 18.27 lg[E/eV]

$79 \pm 1\,\mathrm{g/cm^2/decade} \rightarrow 26 \pm 2\,\mathrm{g/cm^2/decade}$

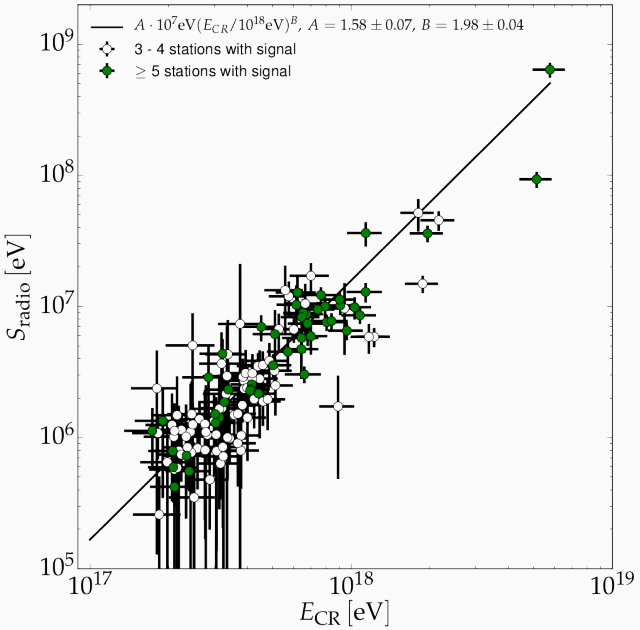
Pierre Auger Collaboration. ICRC 2017 arXiv:1708.06592

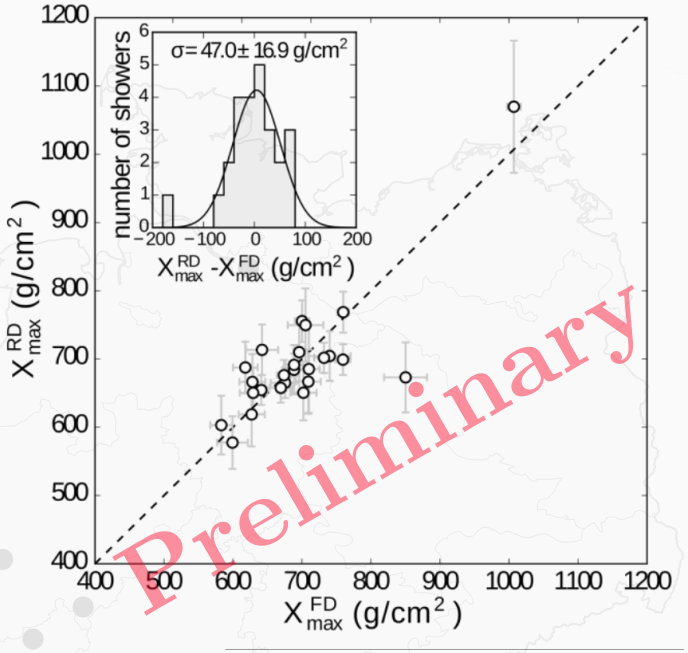
Mass Fractions



Pierre Auger Collaboration. PRD 90, 122006 (2014)

AERA E/Xmax Res





Radio energy consistent with surface detector
3-4 station $\sigma = 20\%$, $\geq$5 station $\sigma = 14\%$

Radio Xmax consistent with fluorescence detector
45 g/cm^2 combined FD + RD Resolution
$\rightarrow$ 37 g/cm^2 RD Resolution

Pierre Auger Collaboration. PRD 93, 122005 (2016) 12

Horizontal Air Showers (HAS) with AERA

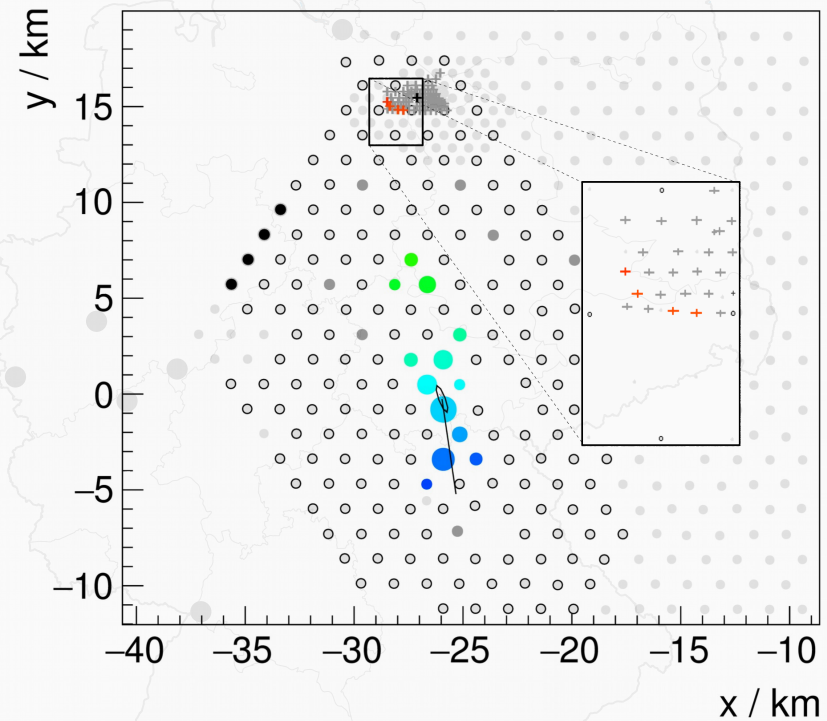
HAS in Radio :

- Footprint size increases with θ $\rightarrow$ larger distance from source (X_{max})

Huge Radio Footprints :

- SD core $\sim$15 km from AERA
- E_{SD} 2.9 EeV
- (θ_{SD}, ϕ_{SD}): (82.6°, 277.4°)
- (θ_{RD}, ϕ_{RD}): (87.1°, 277.1°)
- First observation of radio footprint $>$ particle footprint

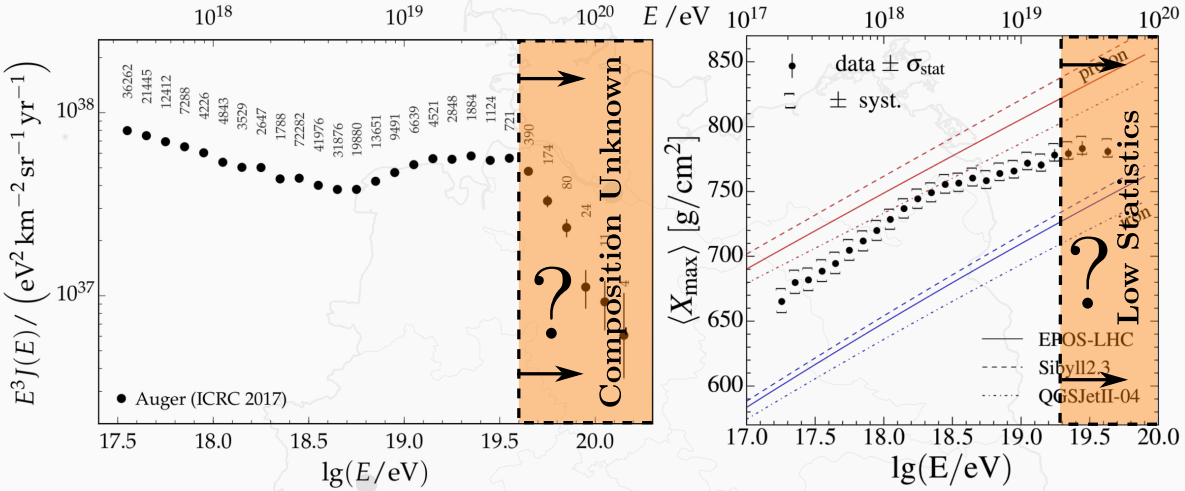
Sparse 1.5 km radio array possible for high energy HAS showers

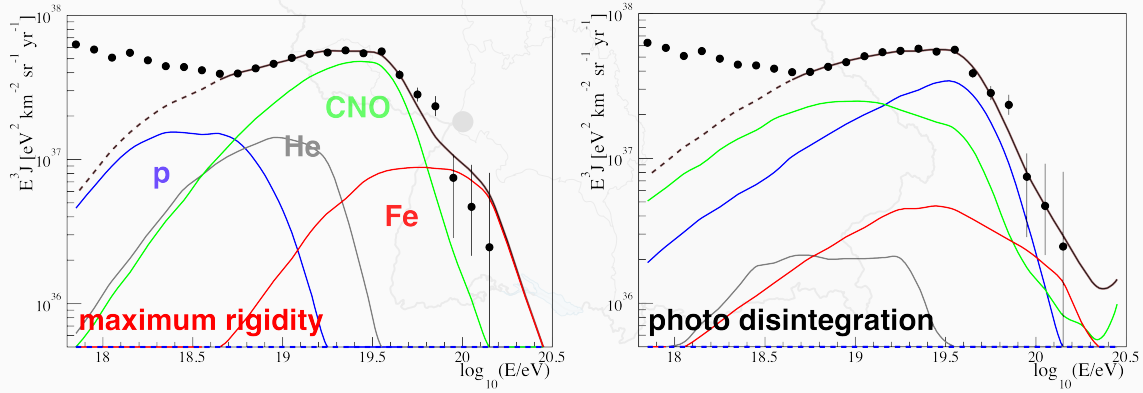


Auger Upgrade Motivation

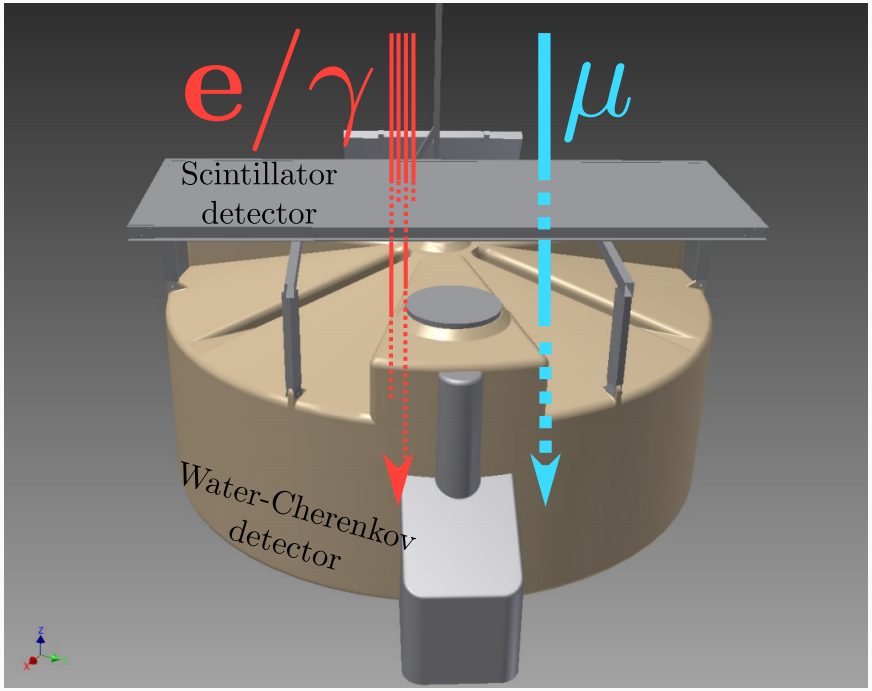
Key Science questions:

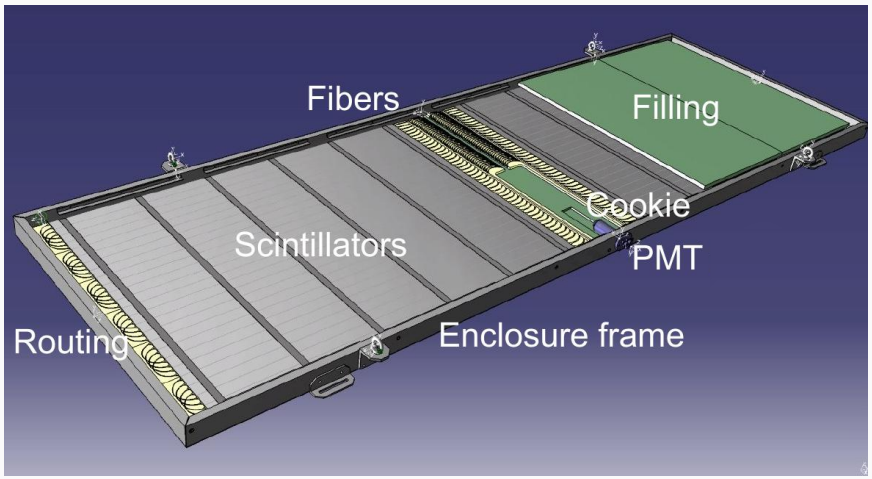
- What are the sources and acceleration mechanisms of UHECRs?
- Do we understand particle acceleration and physics at energies well beyond the LHC scale?
- What is the fraction of protons, photons, and neutrinos in cosmic rays at the highest energies?





Auger Prime





Upgrade underway:

- Adding a 3.8m^2 scintillator detector SSD to each of the 1600 stations in the array
- Upgrade the electronics of increase sampling rate
- Increase FD duty cycle by up to 50%

Physics benefits of upgrade:

- full duty cycle shower by shower composition measurements
  $\rightarrow$ composition of cutoff
- Measurements of muon spectrum at high energies
  $\rightarrow$ shower physics and model testing
- increased energy accuracy and reduced systematics
  $\rightarrow$ easier to combine results with TA
- increased geometric reconstruction accuracy
  $\rightarrow$ reduced systematics across the board
- **full sensitivity down to $\sim 60^\circ$ zenith**

Auger Prime Progress

Upgrade Status:

- Full upgrade is 70% funded
- Engineering Array: good results and stability

SSD Assembly:

- Production ramping up
- More than 600 modules built
- Assembly at: **Aachen**, Grenoble, **Karlsruhe**, Krakow, Leece, Nikhef
- Deployment by 2019, run into 2025

For more details see Poster!

AugerPrime Engineering Array: Status and Analysis

Sonja Schröder[1], Alexander Streich[2], Alvaro Taboada[2] for the Pierre Auger Collaboration[#]

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[2] Karlsruher Institut für Technologie, alexander.streich@kit.edu, alvaro.taboada@kit.edu
[#] Full author list at http://www.auger.org/archive/authors_2018_09.html

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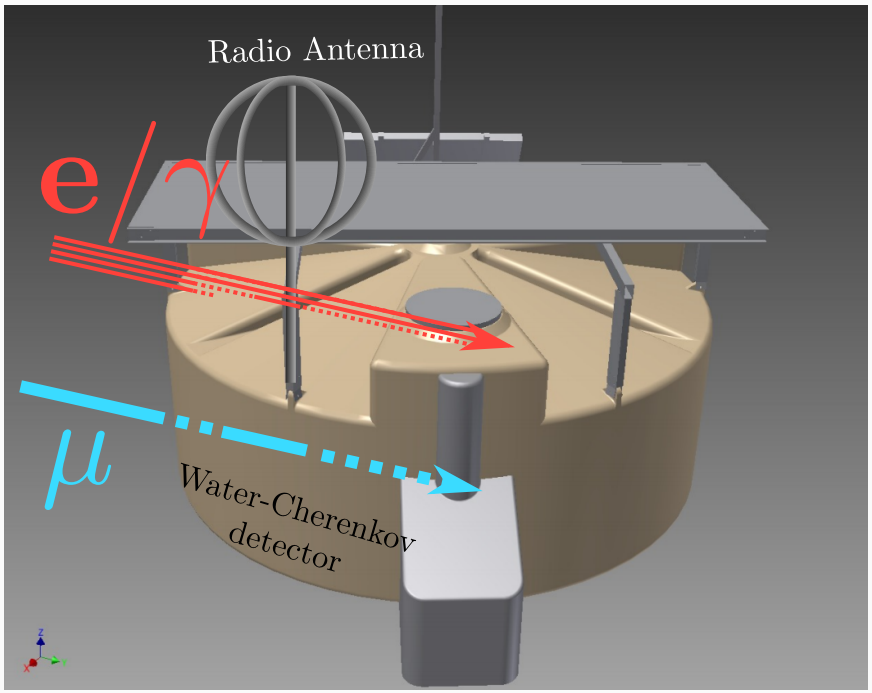
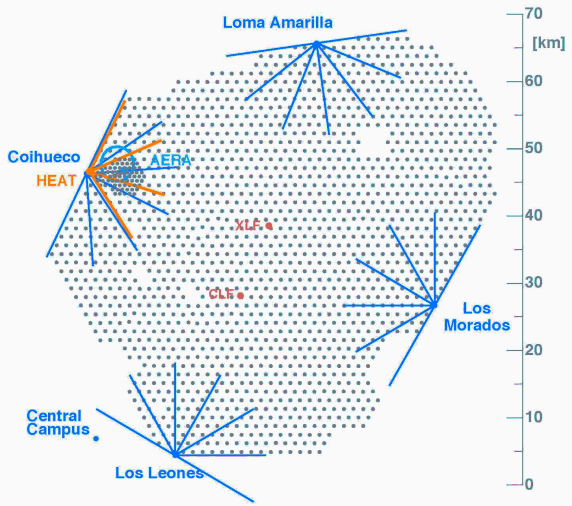
BERGISCHE UNIVERSITÄT WUPPERTAL

KIT Karlsruher Institut für Technologie

Auger Radio Upgrade





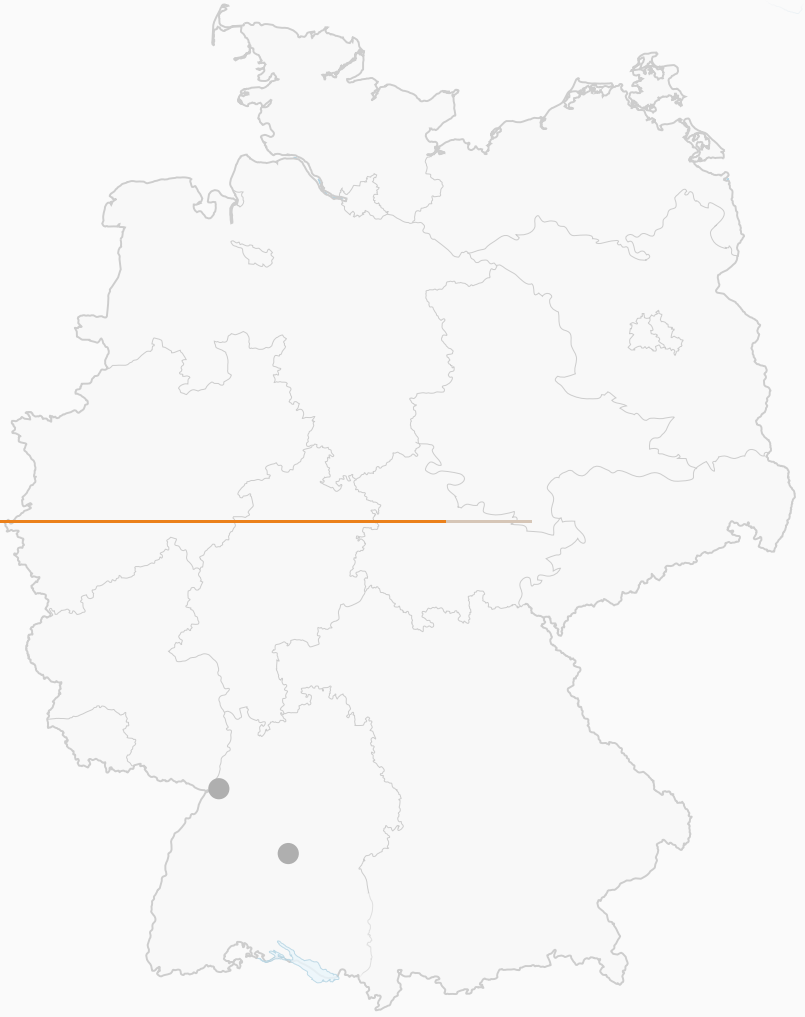
Upgrade plan:

- Add a SALLA Radio Antenna to each surface station: 30-80 MHz
- Use/upgrade existing electronics and power infrastructure
- Already fully funded!

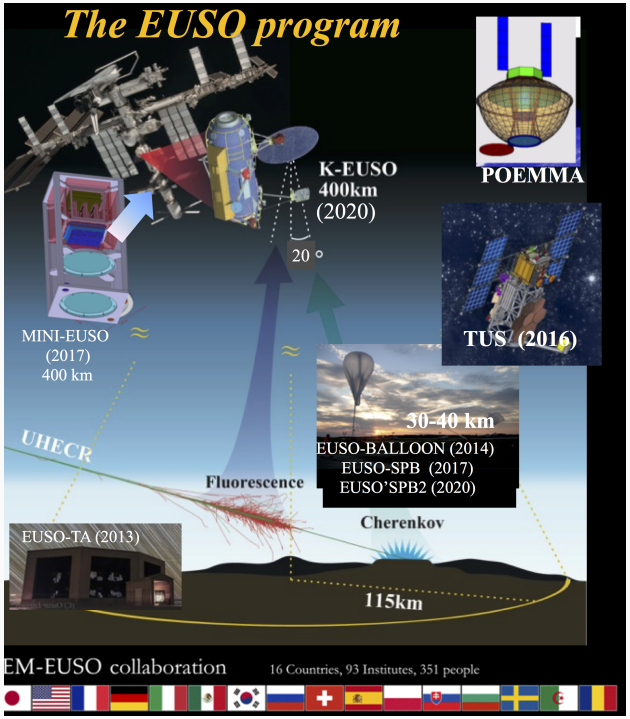
Physics benefits of upgrade:

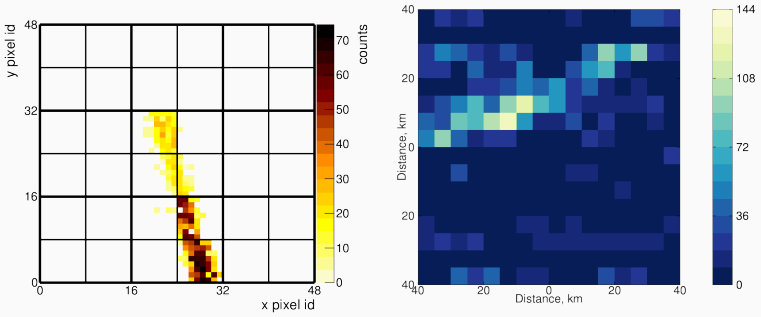
- **Extends e/m-μ sensitivity to showers below $\sim$60° zenith**
  $\rightarrow$ Extends SSD analyses to low zeniths
  $\rightarrow$ increase composition sensitive sky-coverage
  $\rightarrow$ more overlap with TA
- Independent mass scale
  $\rightarrow$ lowers uncertainties of all mass measurements
- Energy reconstruction independent of FD
  $\rightarrow$ lowers uncertainties due to atmospheric conditions
- clean e/m measurements
  $\rightarrow$ shower physics and model testing

EUSO



The Extreme Universe Space Observatory (E





Goals:

- Pathfinder for space based Fluorescence/Cherenkov telescopes
- Huge footprint gives access to highest energy CRs, γ-rays and neutrinos
- Direct measurement of shower profile

Experiments:

X JEM-EUSO: proposed full telescope on ISS

√ Mini-EUSO: single camera module in ISS

√ EUSO-TA: camera module at TA

√ EUSO-SPB: camera balloon payload

√ TUS: free-flying single telescope

○ K-EUSO: approved full telescope on ISS

? POEMMA: Stereo free-flying telescopes

Summary

Summary

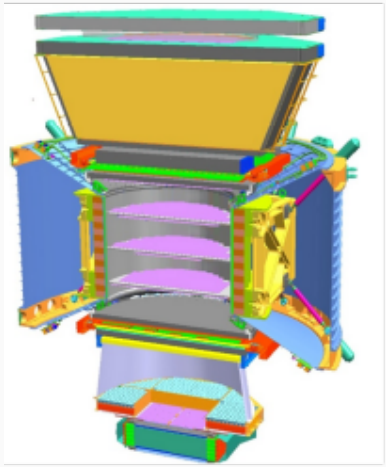
- The German contribution to cosmic ray physics underpins the field
- Many of the highest impact results in the field are coming from German lead analyses
- Lots of recent big discoveries cosmic ray experiments
  - AMS: Positron Excess
  - IceTop/IceCube: Cosmic ray dipole anisotropy in the TeV to PeV scale
  - Pierre Auger Observatory: Dipole anisotropy above 8EeV
- Big changes and improvements on the horizon
  - Auger Prime
  - Auger Radio upgrade

Thank you for your support!

Questions?

AMS in Germany

AMS is an international collaboration consisting of
~500 physicists from 56 institutes in Europe, the US and Asia.
The detector was build all over the world.



German contribution:
(RWTH: St. Schael/KIT: I.Gebauer)

Construction:

- Transition radiation detector TRD
- Anti-coincidence counter ACC
- Tracker alignment system TAS

Operations (24/7):

- TRD, LEAD

Analysis:

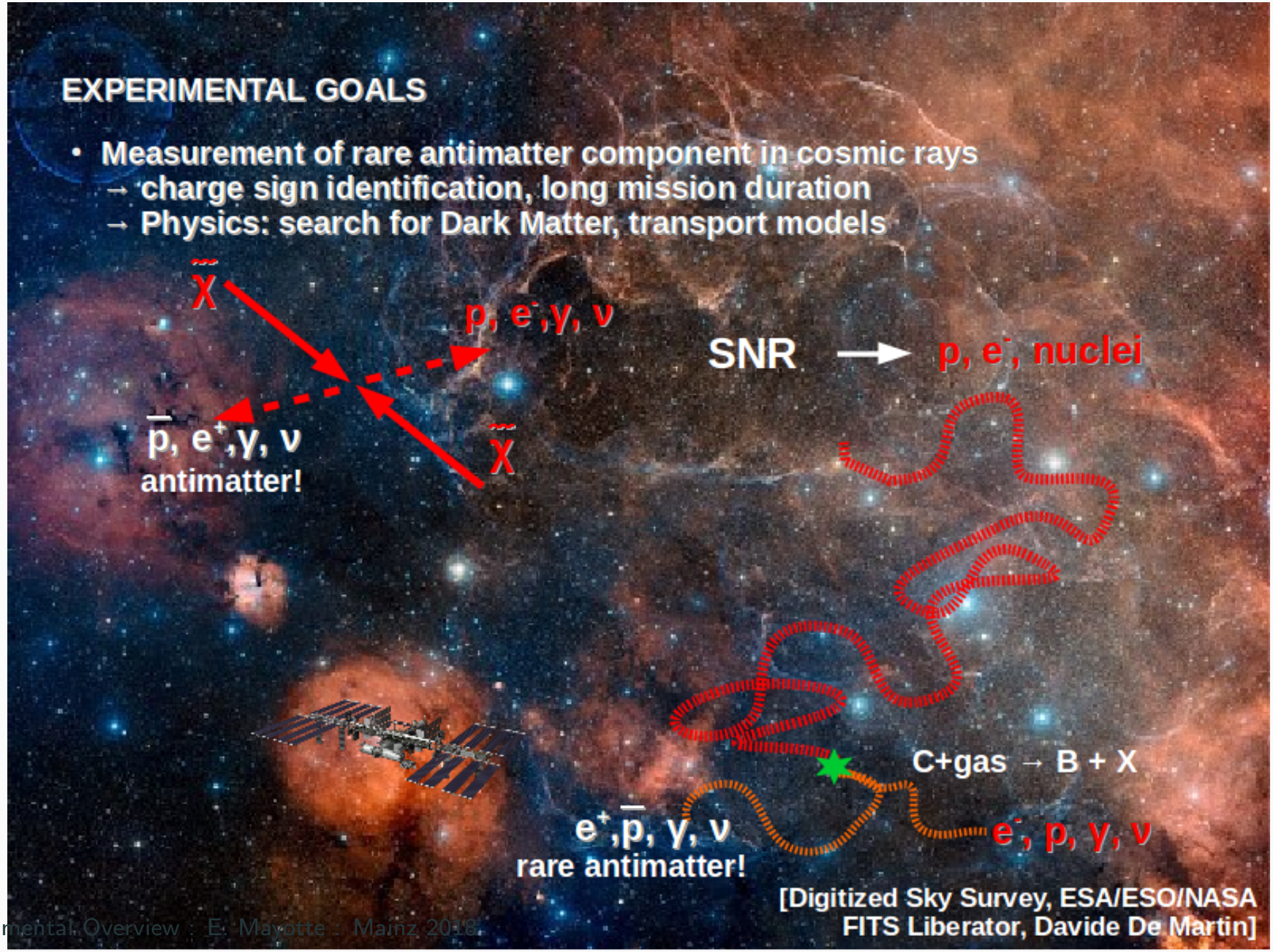
- Focussed on dark matter searches

DLR Deutsches Zentrum für Luft- und Raumfahrt
German Aerospace Center

Covers Operations
but not analysis

Payload Operations and
Control Center at CERN

AMS Mission


EXPERIMENTAL GOALS
• Measurement of rare antimatter component in cosmic rays
→ charge sign identification, long mission duration
→ Physics: search for Dark Matter, transport models
$\tilde{\chi}$
p, e⁻,γ, ν
SNR → p, e⁻, nuclei
$\bar{p}$, e⁺,γ, ν
antimatter!
$\tilde{\chi}$
C+gas → B + X
e⁺,$\bar{p}$, γ, ν
rare antimatter!
e⁻, p, γ, ν
[Digitized Sky Survey, ESA/ESO/NASA
FITS Liberator, Davide De Martin]