Cosmic Ray Science on the International Space Station (ISS)

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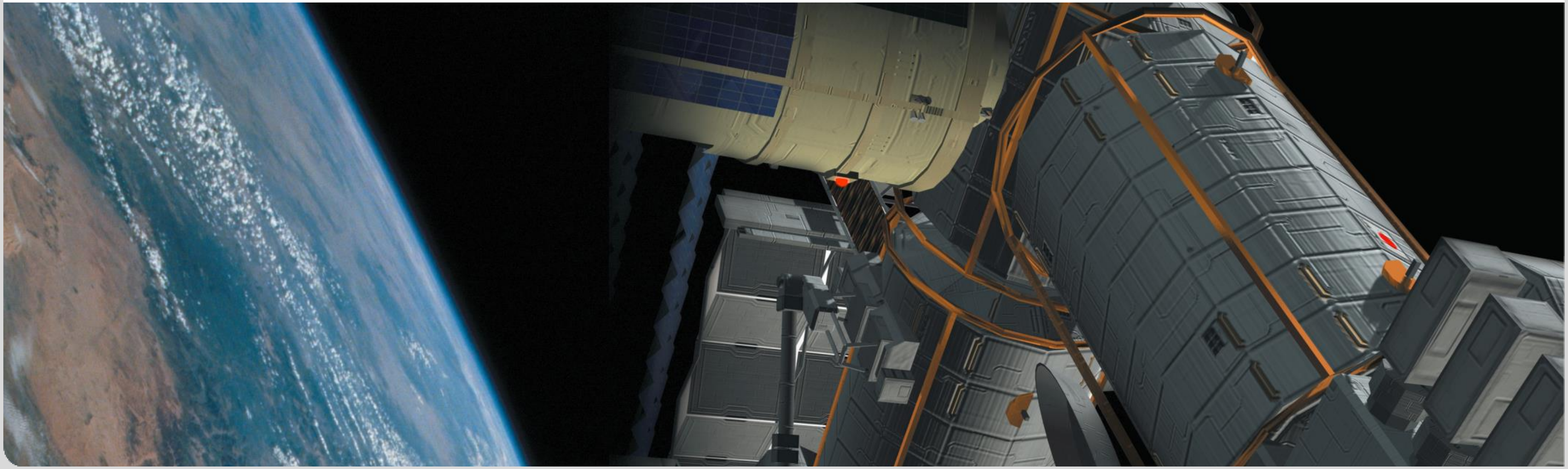


Outline

(1) Science
- Cosmic particles spectrum
- Measurement methods
- Scientific Goals of AMS-02 vs. JEM-EUSO

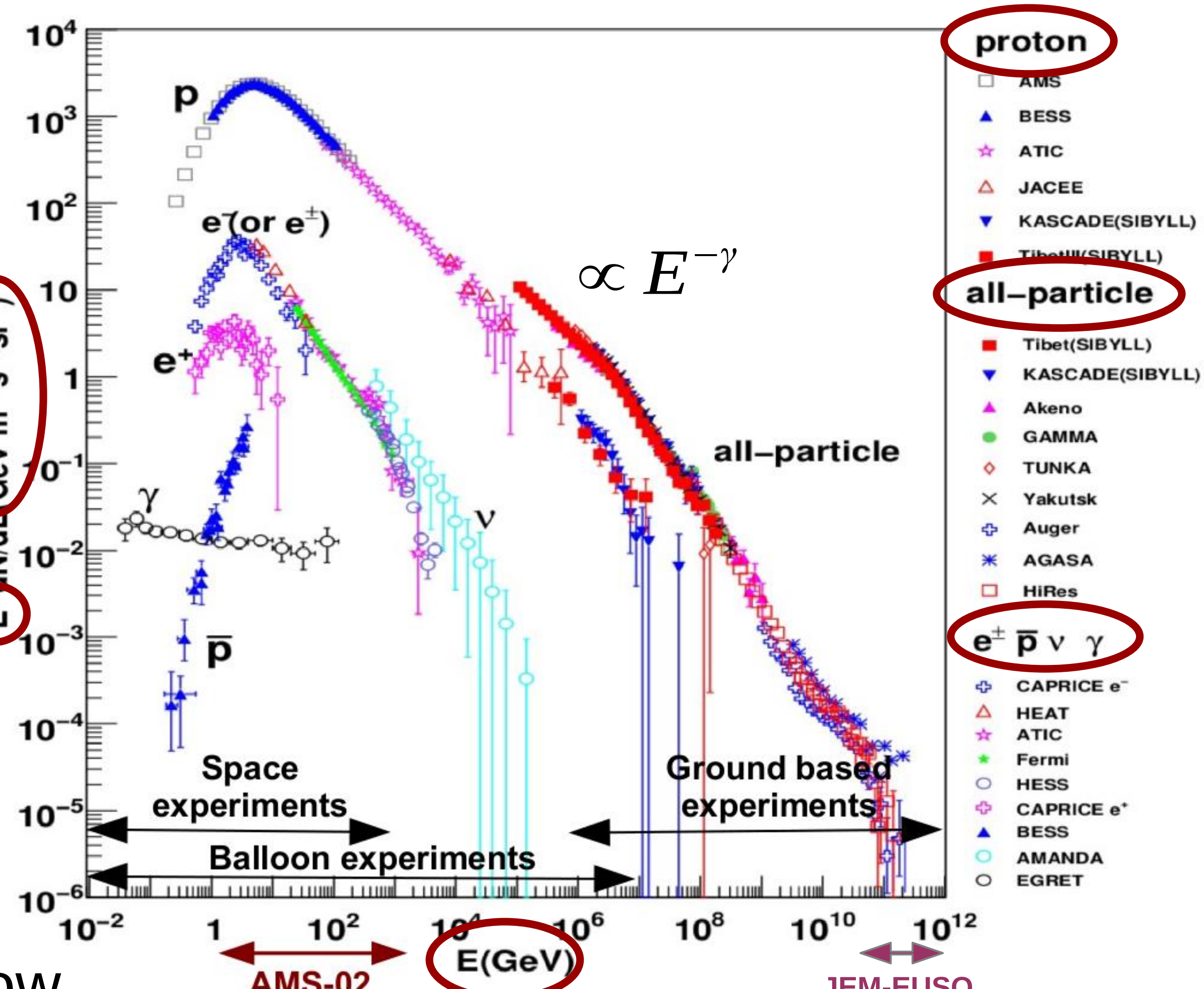
(2) The Instruments
- AMS-02
- JEM-EUSO
- Science on the International Space Station (ISS)

(3) Measurement Methods
- Particle Fluxes
- Lepton Flux with AMS-02
- Measurement with JEM-EUSO

(4) First Results and Outlook

(5) Summary and Keywords

Cosmic Particles Spectra



Particle with energy per area, time and incoming angle

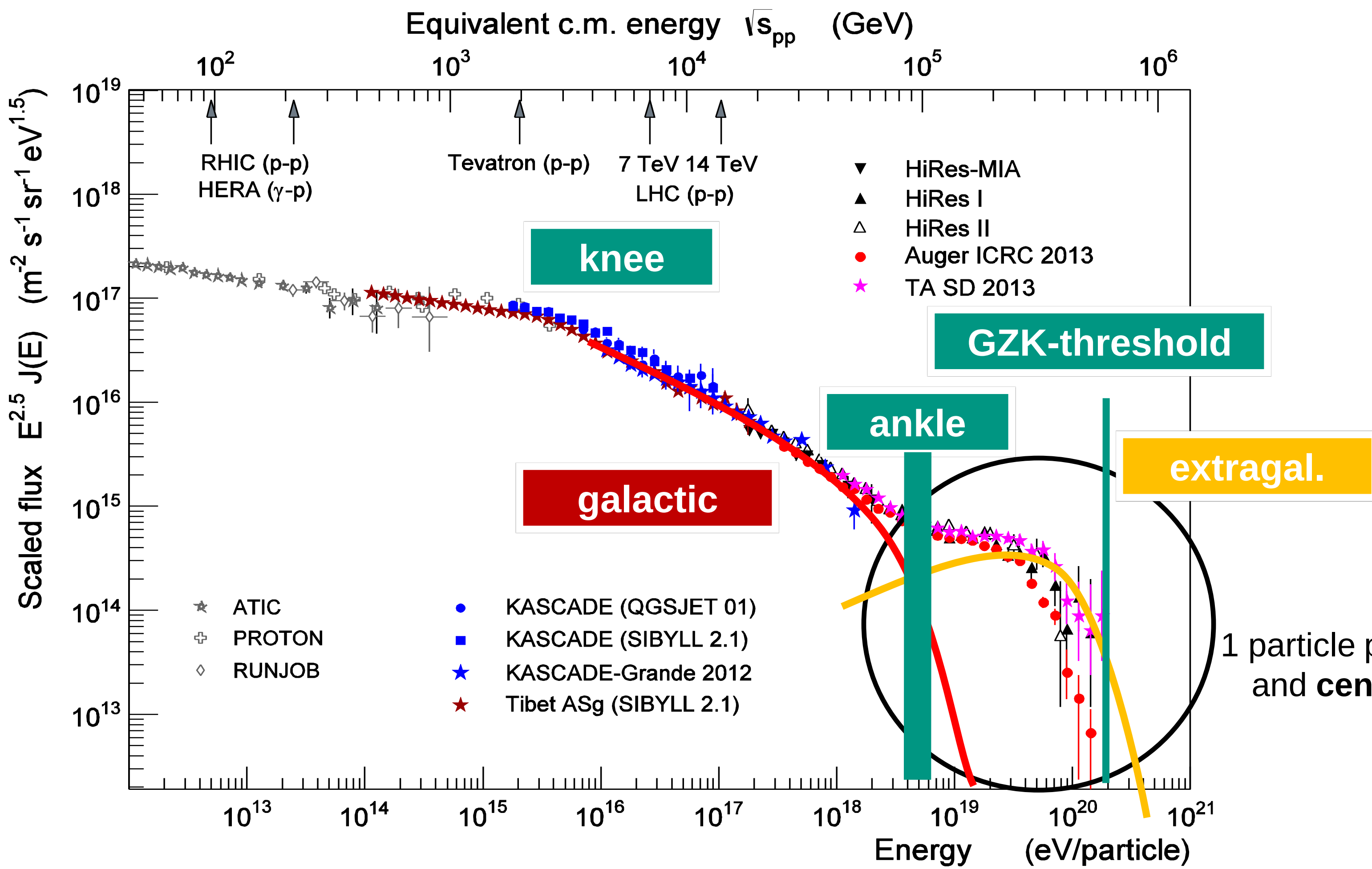
Flattened with energy squared

wide range of energies and very regular

In this tutorial:

What is a flux and how do we measure it?

Cosmic Ray Spectrum



1 particle per km² and **century!**

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Measurement Methods I
Direct Detection

Low energy regime:

✓ Rather high flux

✗ Particles get absorbed in the atmosphere

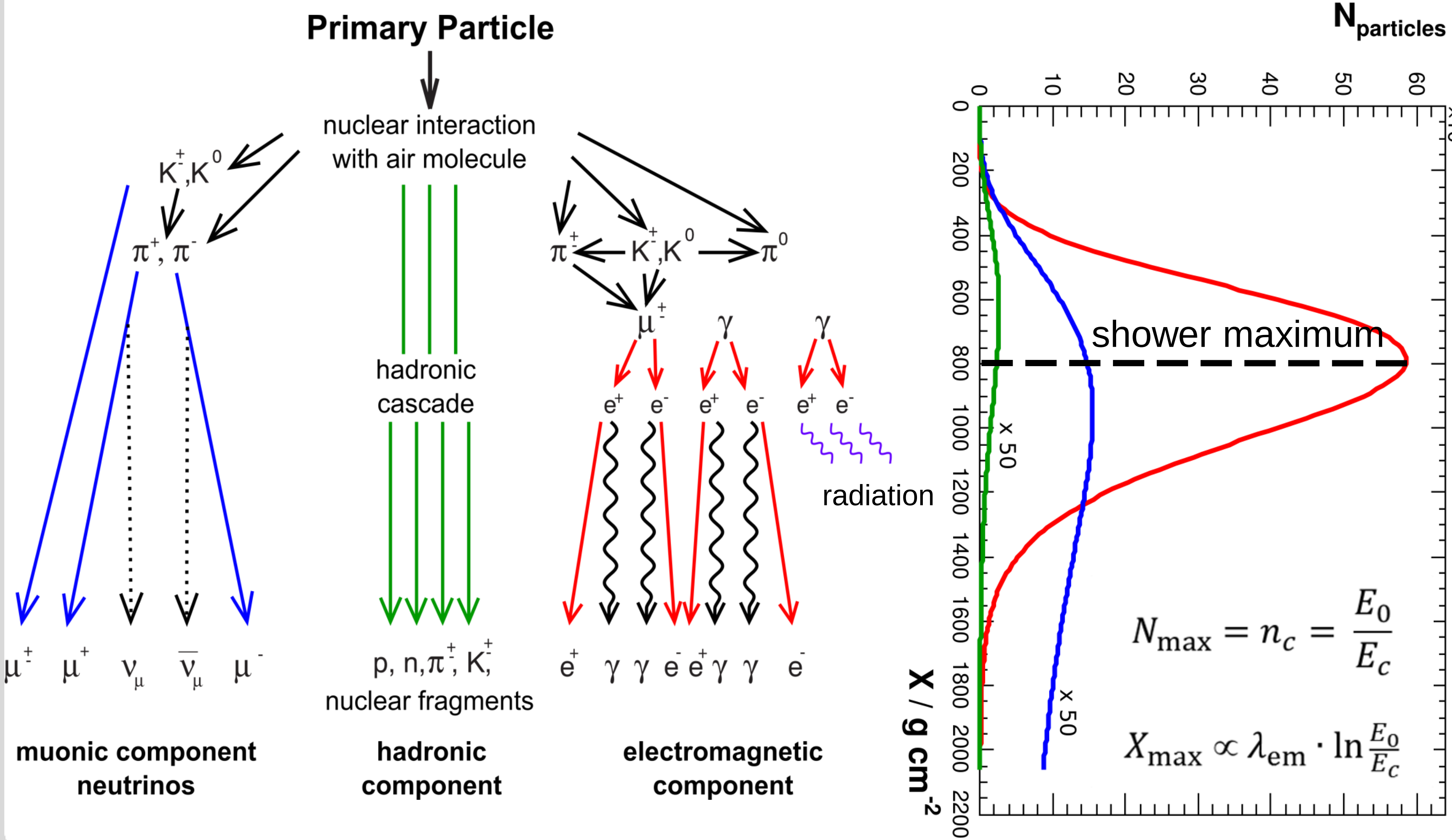
Bring **particle detectors** to the top of the atmosphere or to space:
- Balloons
- Satellites
- Space Station

CREAM VI

DK-1 with PAMELA

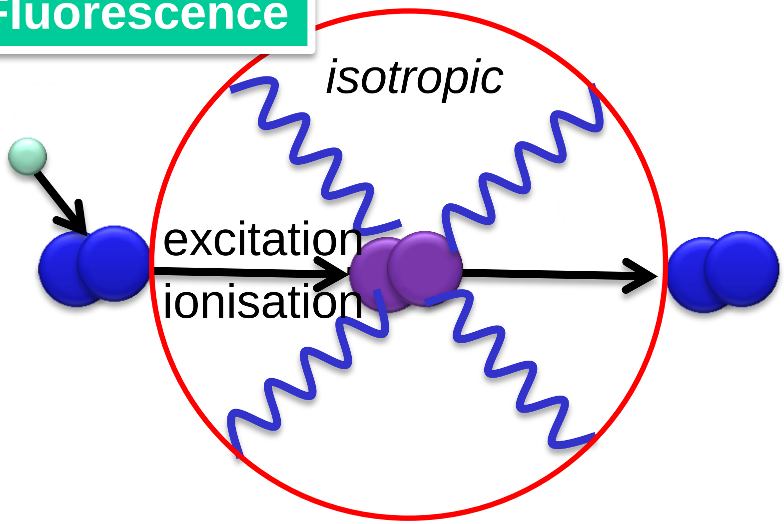
AMS-02 on ISS

Measurement Methodes II
Extensive Air Shower (EAS)



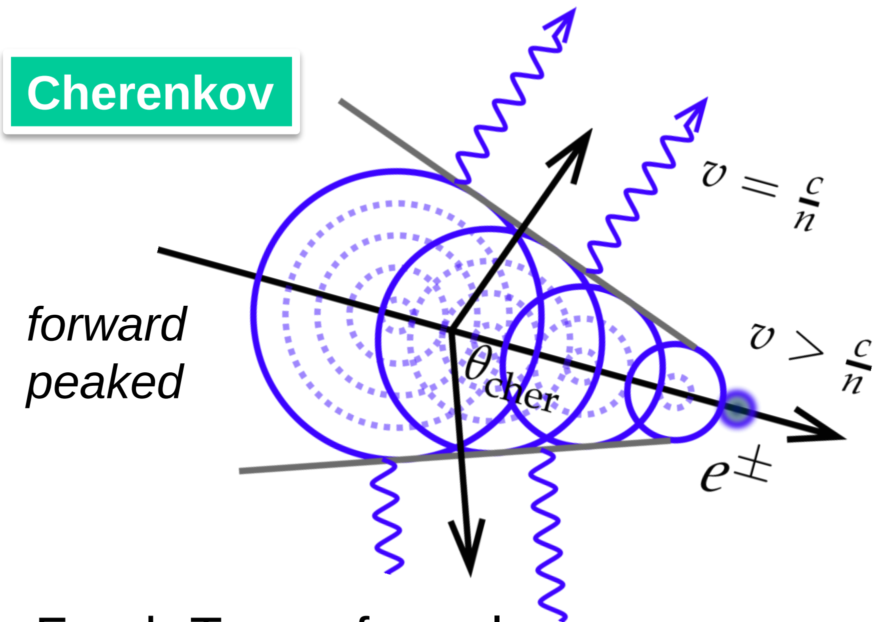
Light Emission

Fluorescence



Fluorescence yield

Cherenkov



Frank-Tamm formula (1 particle yield)

Goals of…

AMS-02

- Cosmic rays composition and fluxes
  - Propagation models
  - Origin of cosmic rays
  - Search for dark matter
- Low energy particles
  - exposure to manned space flights
- Anti matter
- Exotic matter (Strangeletts)

"The most exciting objective of AMS is to probe the unknown; to search for phenomena which exist in nature that we have not yet imagined nor had the tools to discover"

S.C.C. Ting

JEM-EUSO

- Detection of EECR particles ($E > 5 \cdot 10^{19}$ eV)
  - Source identification
  - Reason for flux suppression
  - Recovery of the spectrum
- Explorative potential
  - Multi messenger
    - UHE gamma rays
    - UHE neutrinos
  - Galactic magnetic fields
  - Relativity and quantum gravity
  - Atmospheric science
    - Nightglow
    - Lightning, Plasma discharges
    - Meteors, meteoroids

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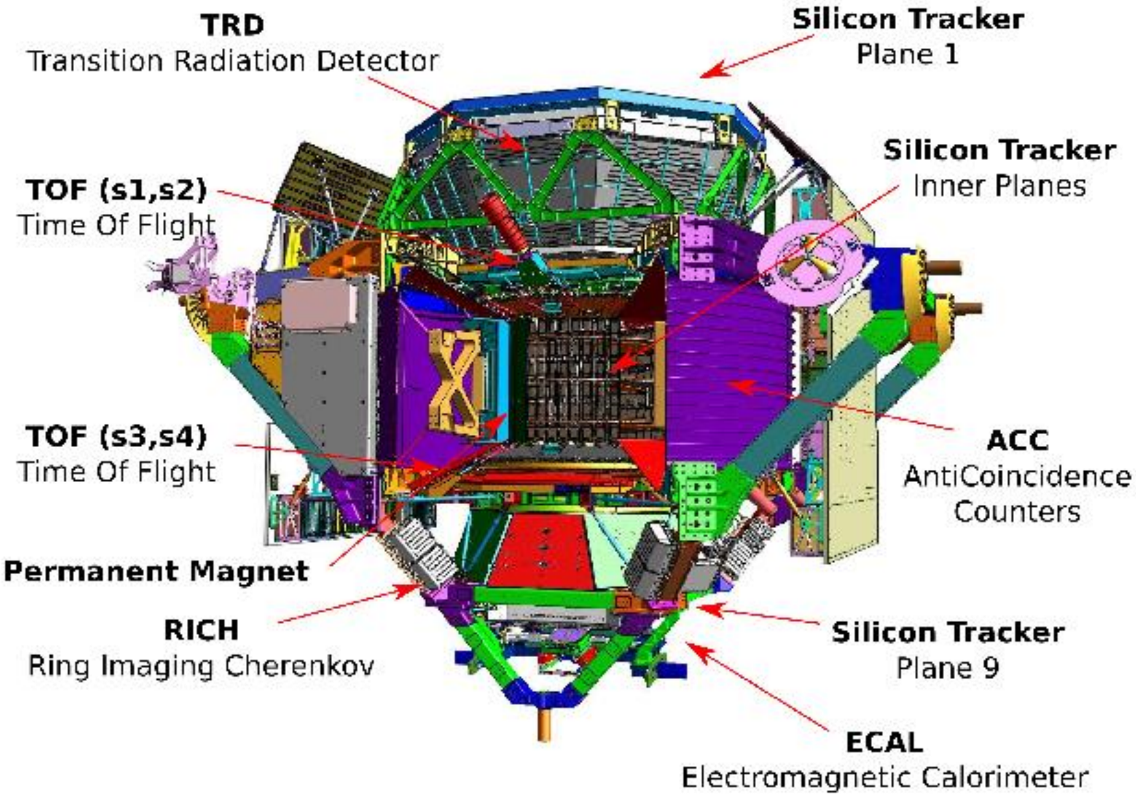
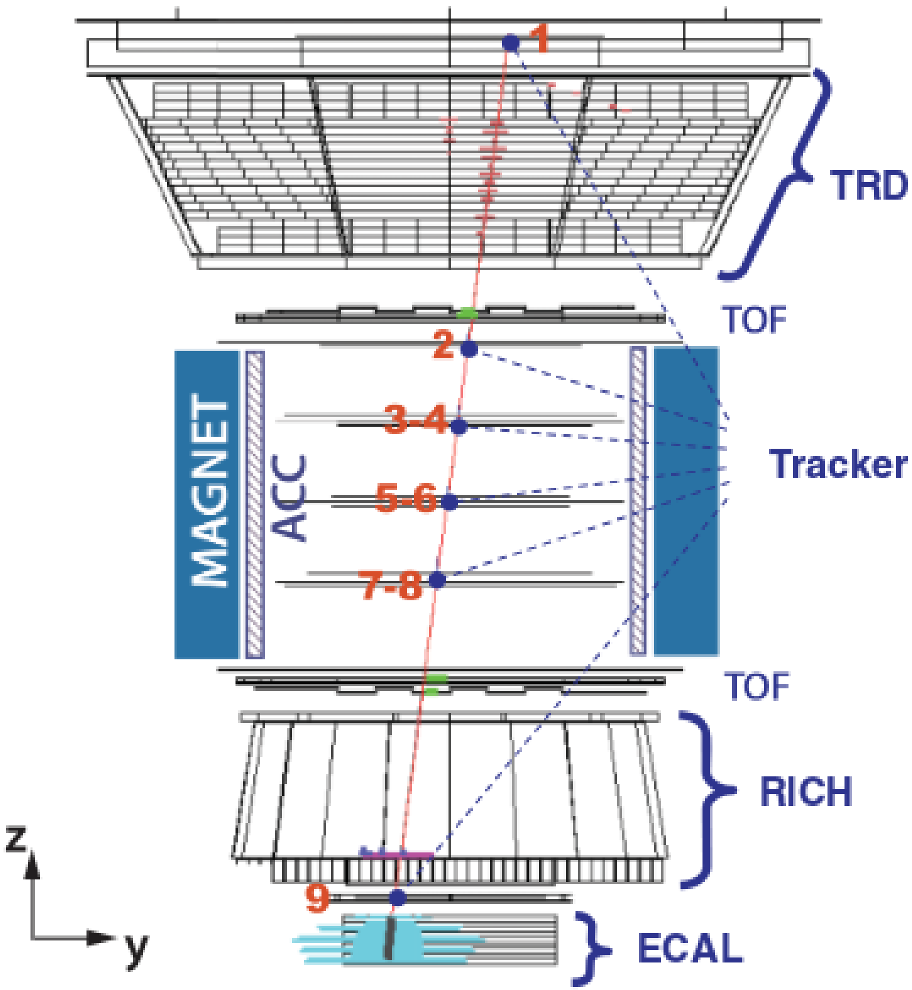
The AMS-02 Detector



- Weight 8500 kg
- Volume 64 cubic meters
- Power 2500 watts
- Data downlink 9 Mbps (average)

The AMS-02 Detector



TRD:
- Tracking
- Charge by dE/dx
- Gamma factor
  → Lepton Identification

TOF:
- Relative velocity
- Charge by dE/dx
- Trigger and veto counter

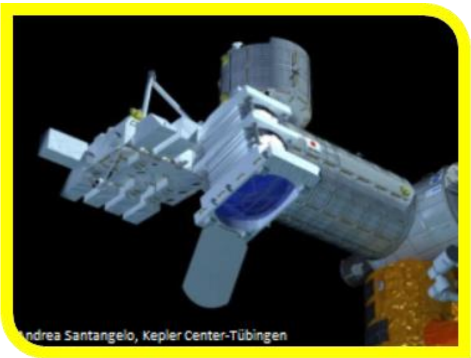
Tracker:
- Particle trajectory
- Charge by dE/dx
- Rigidity → Charge sign

RICH:
- Relative velocity
- Mass

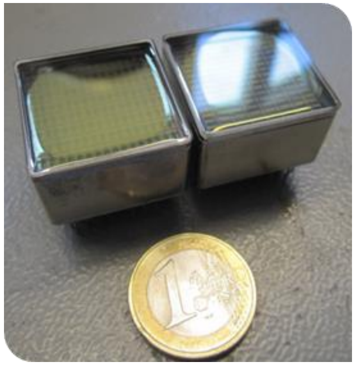
ECAL:
- Energy of Leptons
- 3D shower reconstruction
  → Lepton identification

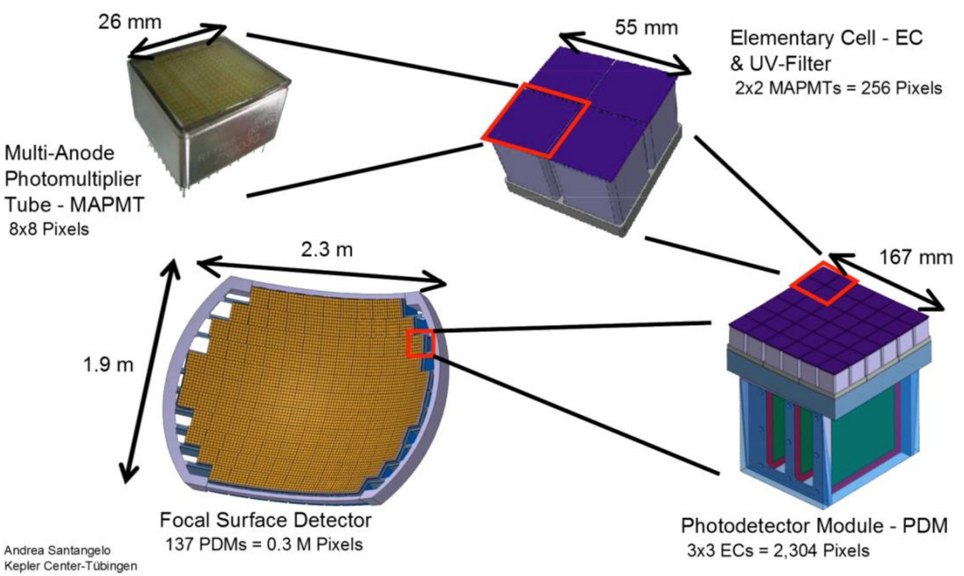
JEM-EUSO

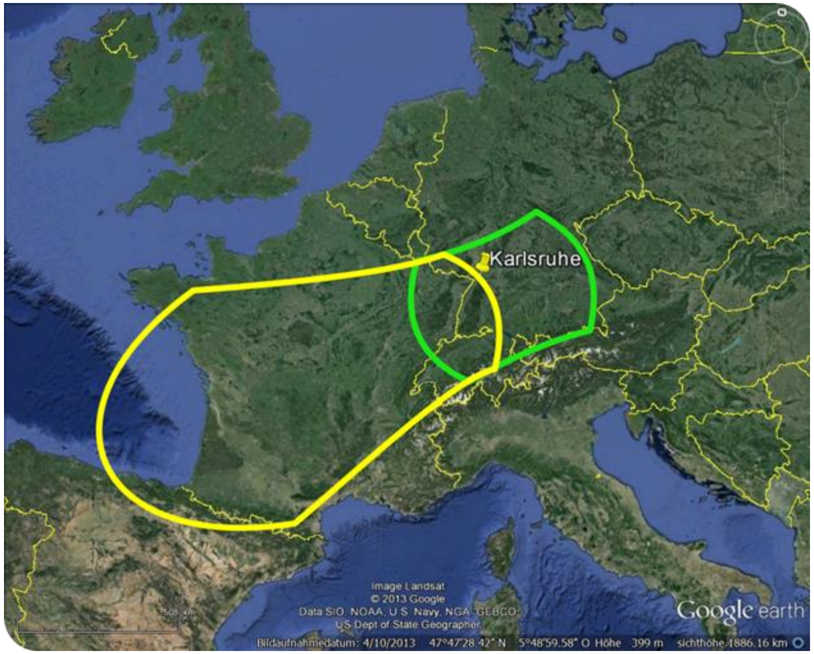
Nadir mode



Tilt mode







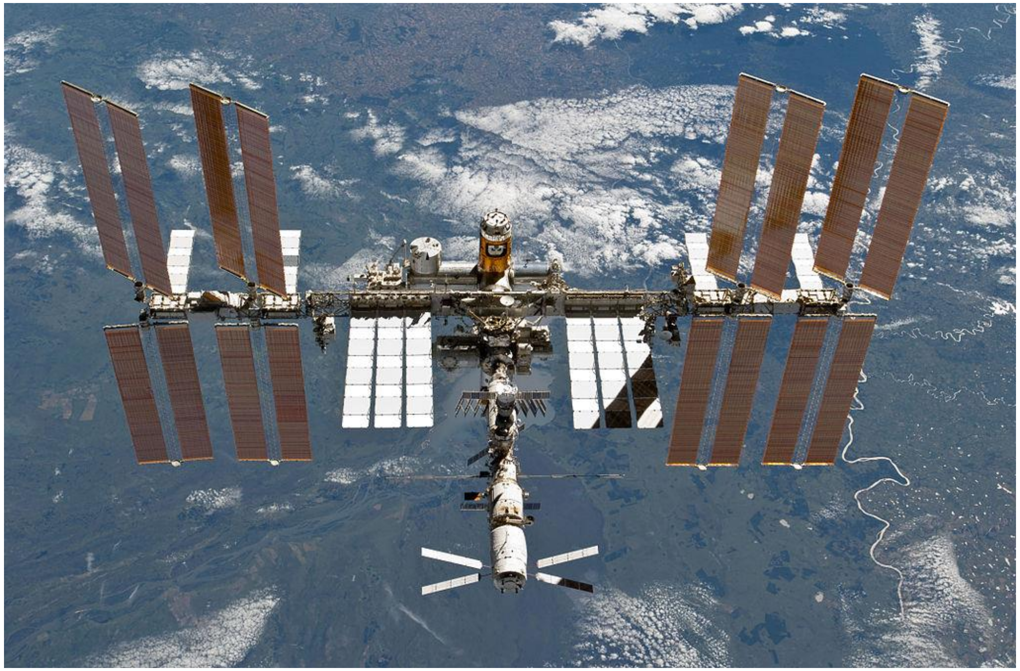
Science on the ISS

Why do astroparticle physics on the International Space Station (ISS)?

ISS Provides:

- Power
- Data up- and down-link
- High mass possible
- Long term measurement (at least till 2020)
- Maneuvering

→ Focus on the detector, not space flight!



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Data Flow

AMS Laptop at ISS

TDRS Satellites

Ku-Band
S Band

White Sands Stations

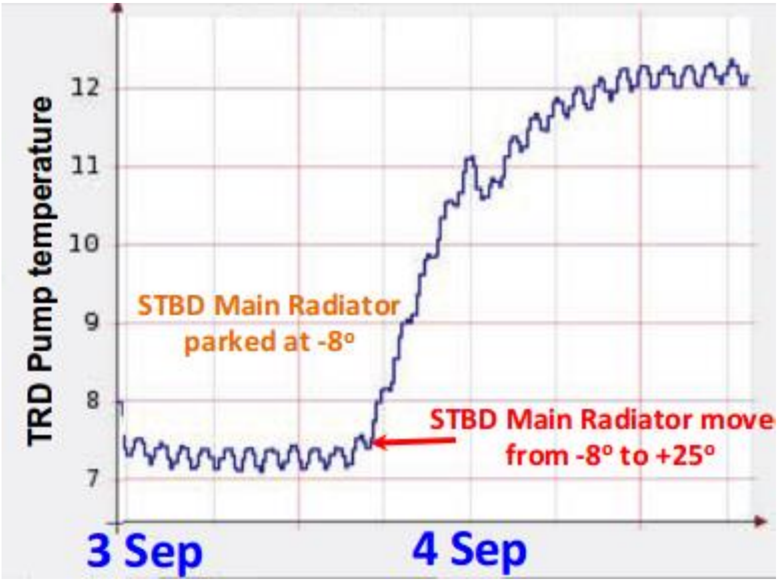
AMS POCC at CERN

MSC → JSC

Detector Monitoring

Detector is monitored in 5 shift positions 24/7 at the Payload Operation Control Center **(POCC)** at CERN and a backup POCC in Taiwan:

- Temperatures
- Data stream/acquisition
- Data quality
- Detector status



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Particle Fluxes

Describes the number of particles with certain energy per measurement area, time and incoming angle independent from detector.

$$\Phi(E) = \frac{N(E)}{Acc(E)\varepsilon_{Trig}\varepsilon_{Sel}T_{\exp}\Delta E}$$

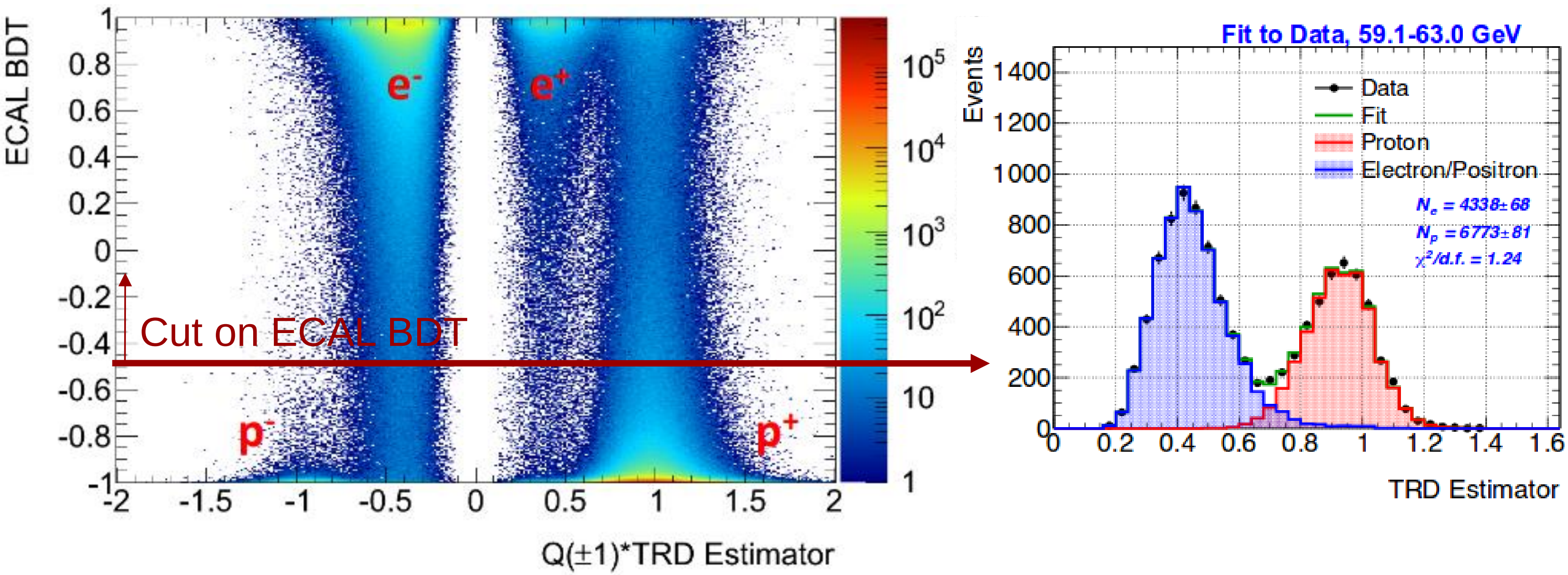
Ingredients for the flux:

N: Number of particles found
Acc: Acceptance [m^2 sr] is the effective detection area
Ɛ_Trig: Efficiency of Trigger
Ɛ_Sel: Efficiency in event selection
T_exp: Exposure Time [s]
ΔE: Energy bin width [eV]

AMS-02 Electron Flux

Particle identification

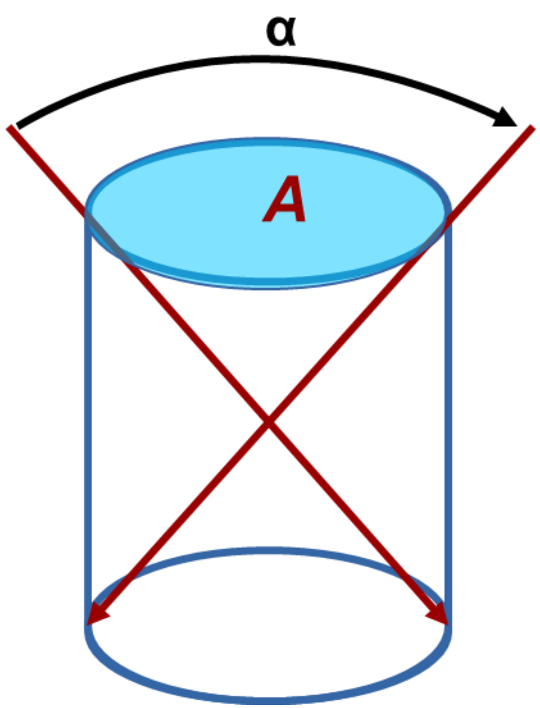
1.) **Cut on ECAL** estimator to reduce proton background



2.) Total number of electrons is obtained by a **fit using TRD estimator**

AMS-02 Electron Flux
Acceptance

Geometric:

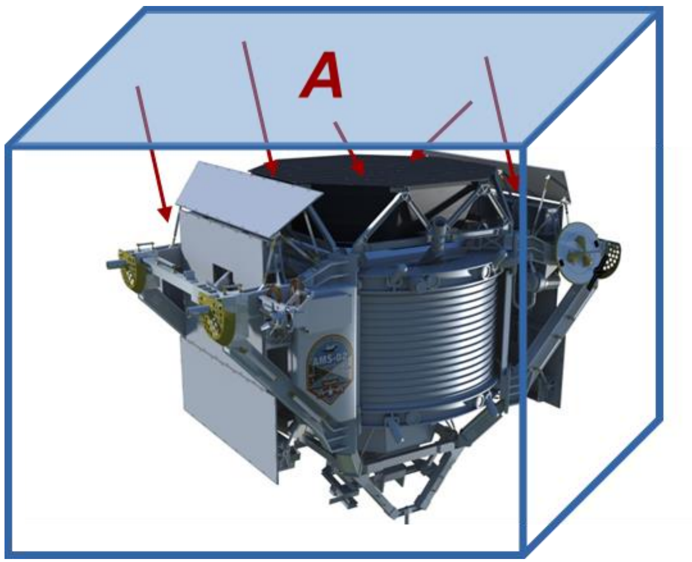


$$Acc = A \times \alpha$$

- Not easy for more complicated geometries
- Does not include inefficiencies

Simulation:

Shot MC electrons frome plane A within incoming angle α.



$$Acc = A \times \alpha \times \frac{N_{Triggered}}{N_{Generated}}$$

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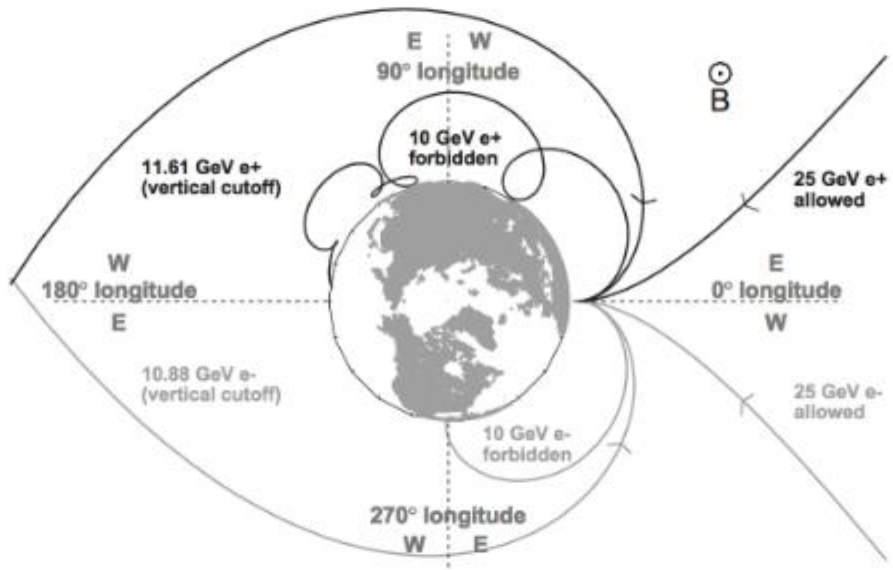
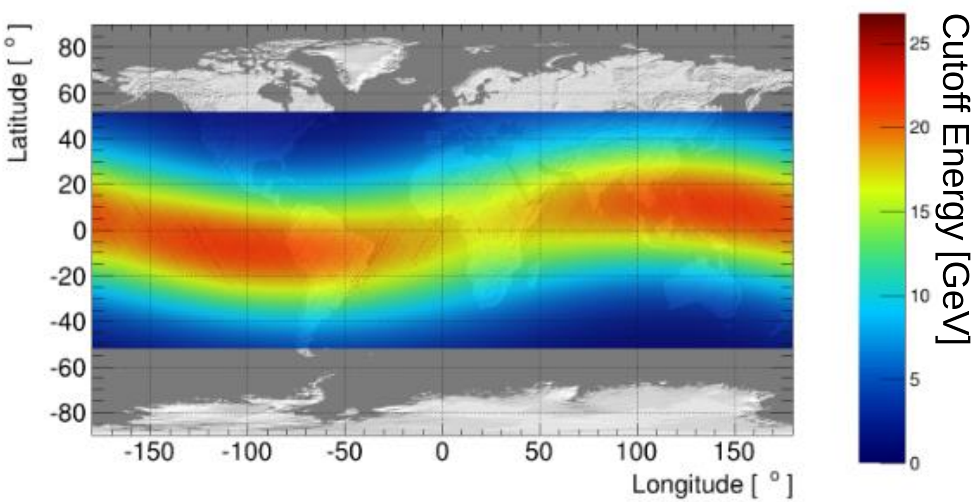
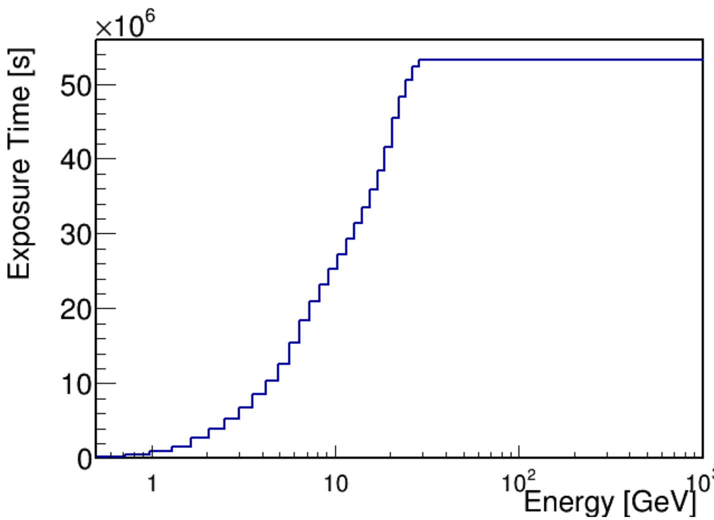
AMS-02 Electron Flux
Exposure Time

Earth magnetic field bends low energy particles trajectory.

Geomagnetic cutoff leads to energy dependance in exposure time.







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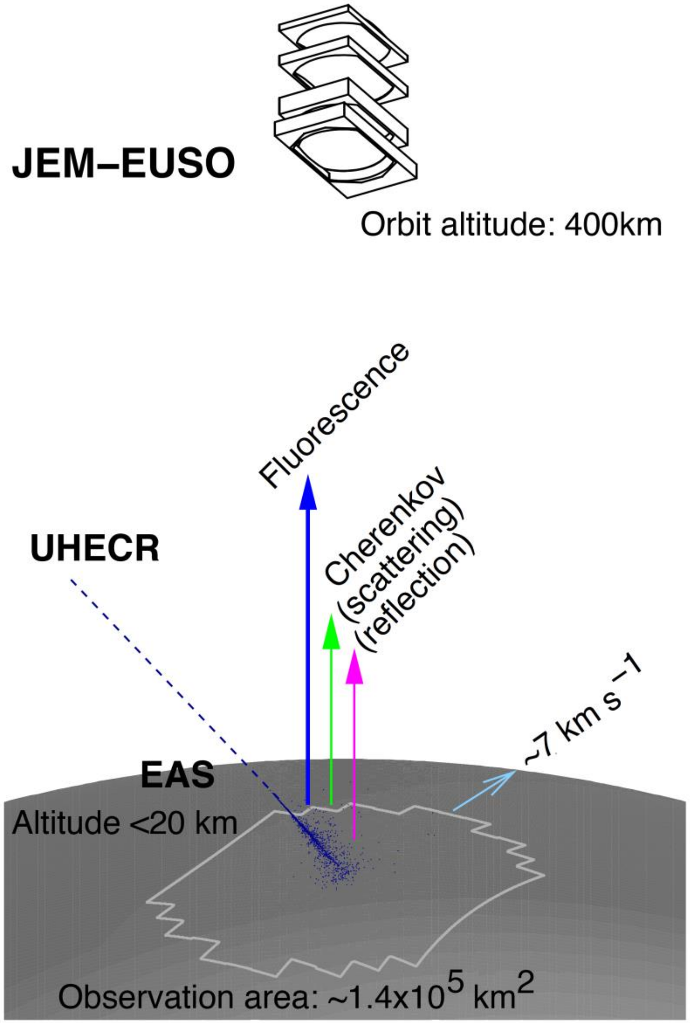
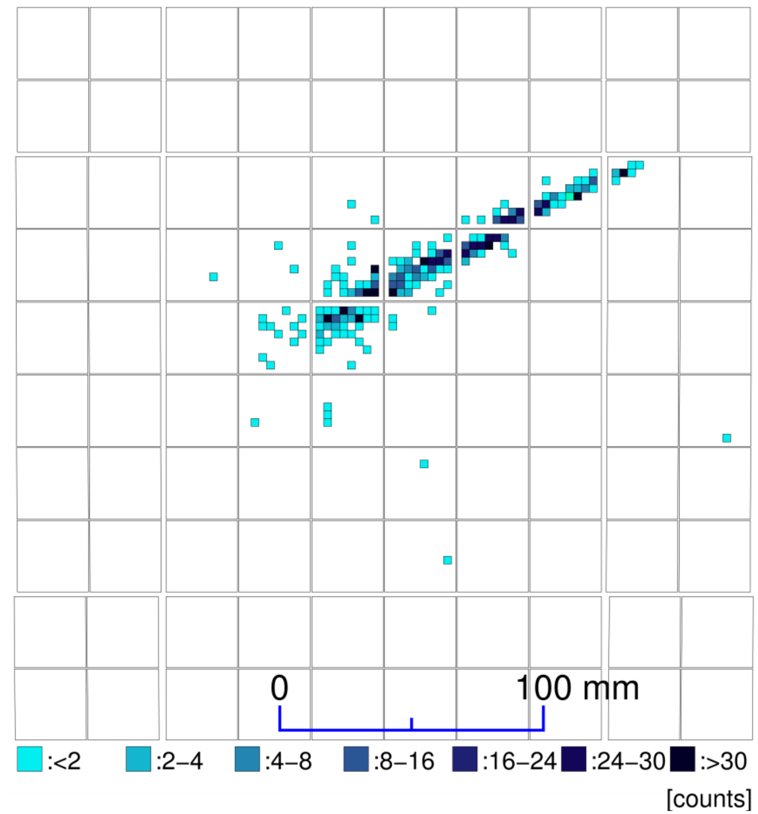
JEM-EUSO Measurements





JEM-EUSO Measurements

UV light emission by EAS

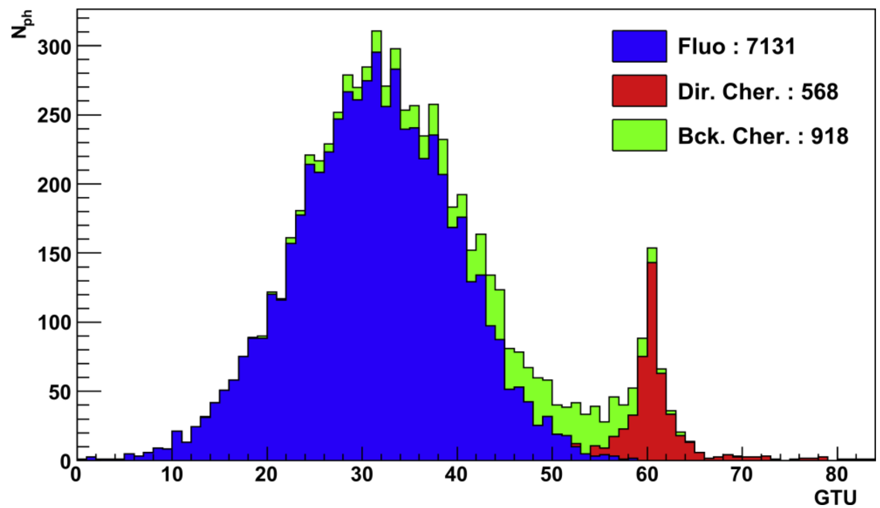
- Fluorescence (Isotropic)
- Cherenkov (forward beamed)

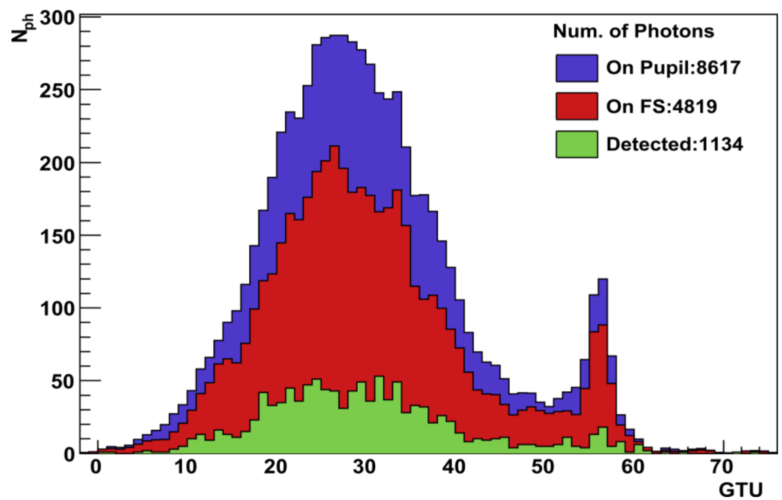
Detection of

- Direct fluorescence light
- Scattered light
- Ground reflected light

Detection influenced by

- Transmission in atmosphere
- Optics transmission
- Quantum efficiency of MAPMT





JEM-EUSO Aperture and Exposure

Key effects

a) EAS development in the atmosphere

b) Detector properties (FOV, orbit, etc.)

$\rightarrow \eta_0 = 20\%$

c) Steady background light (nightglow, moonlight, etc.)

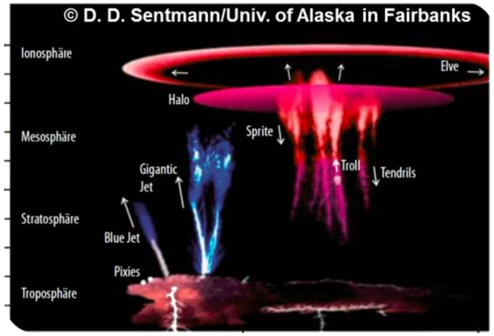
$\rightarrow 500 \text{ photons}/(\text{m}^2 \text{ sr ns})$

d) Atmospheric transmittance (especially clouds)

$\rightarrow \kappa_C = 72\%$

e) Variant background light (anthropogenic light, lightning, etc.)

$\rightarrow f_{\text{loc}} = 10\%$



JEM-EUSO Aperture and Exposure

Geometrical aperture

$$A(E) = \frac{N_{\mathrm{trig}}}{N_{\mathrm{inject}}} \cdot S_{\mathrm{inject}} \cdot \Omega_0$$

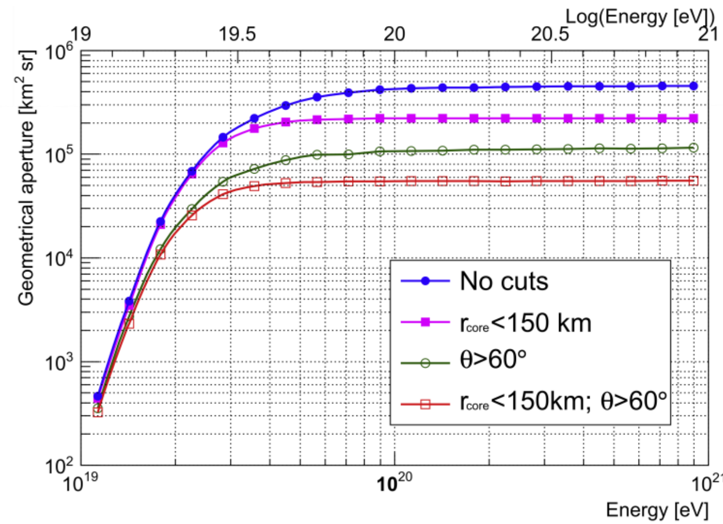
Annual Exposure

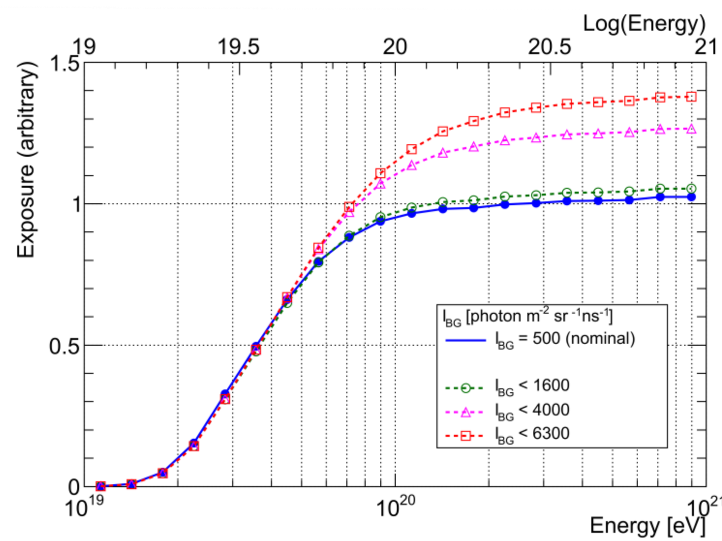
$$:= A(E) \cdot \underbrace{\kappa_{\mathrm{C}} \cdot \eta_0 \cdot (1 - f_{\mathrm{loc}})}_{0.13} \cdot (1[\mathrm{yr}])$$

Overall Exposure

$$\propto \int_0^{I^{\mathrm{thr}}} A\left(\sqrt{\frac{\langle I_{\mathrm{BG}} \rangle}{I_{\mathrm{BG}}}} \cdot E\right) \cdot p(I_{\mathrm{BG}})\, \mathrm{d}I_{\mathrm{BG}}$$

→ Exposure 9 x 7000 km² yr sr





JEM-EUSO Calibration

Main issues

a) Atmospheric conditions → IR camera, LIDAR + GDAS data

b) Background light levels → Slow acquisition mode

c) Timing uncertainties

d) Tilt angle

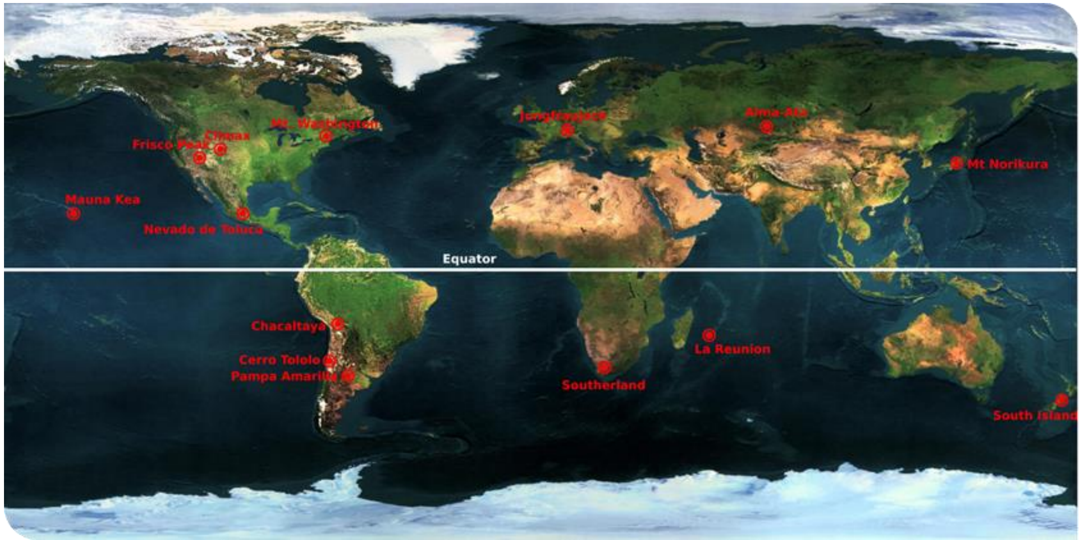
e) Pointing errors ($\mathrm{H}_{\mathrm{ISS}}(\mathrm{t})$) → Altitude monitoring

f) Temperature variation

g) Age of the instrument

⇒ Global Light System (GLS)

- World wide network of ground-based stations
- Airborne stations
- Xenon flasher lamps
- Steerable laser



Outline

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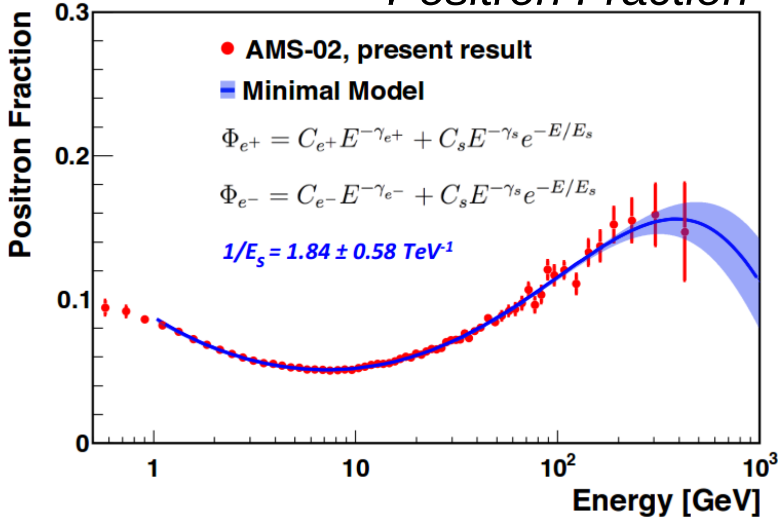
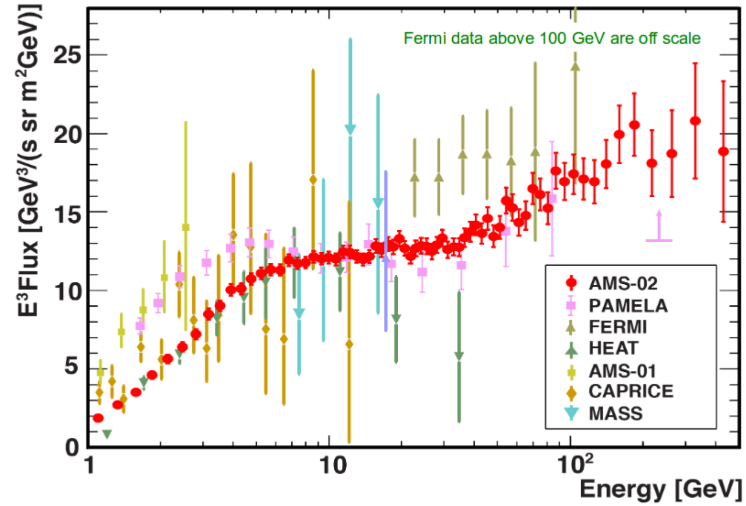
First Results of AMS-02

Positron Fraction

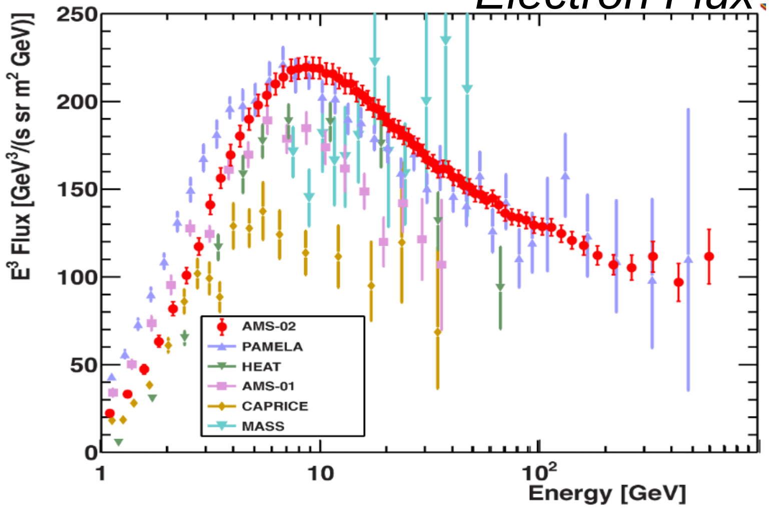


Positron Flux

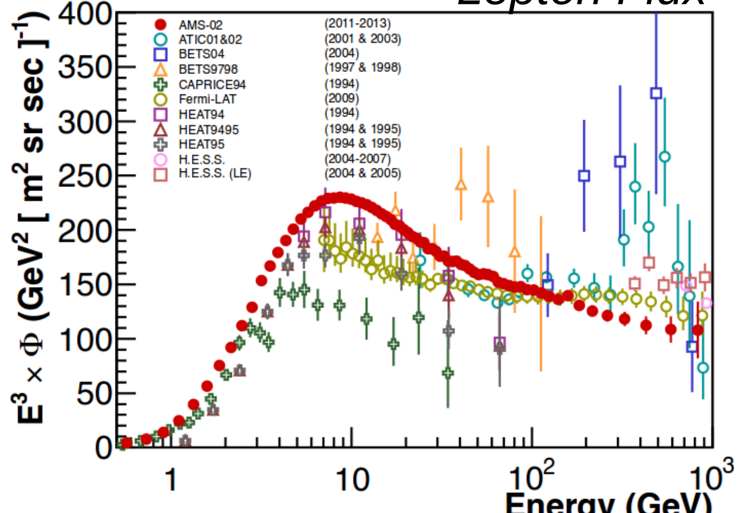


Z. Weng & V. Vagelli at ICHEP2014

Electron Flux



Lepton Flux



JEM-EUSO Prototypes

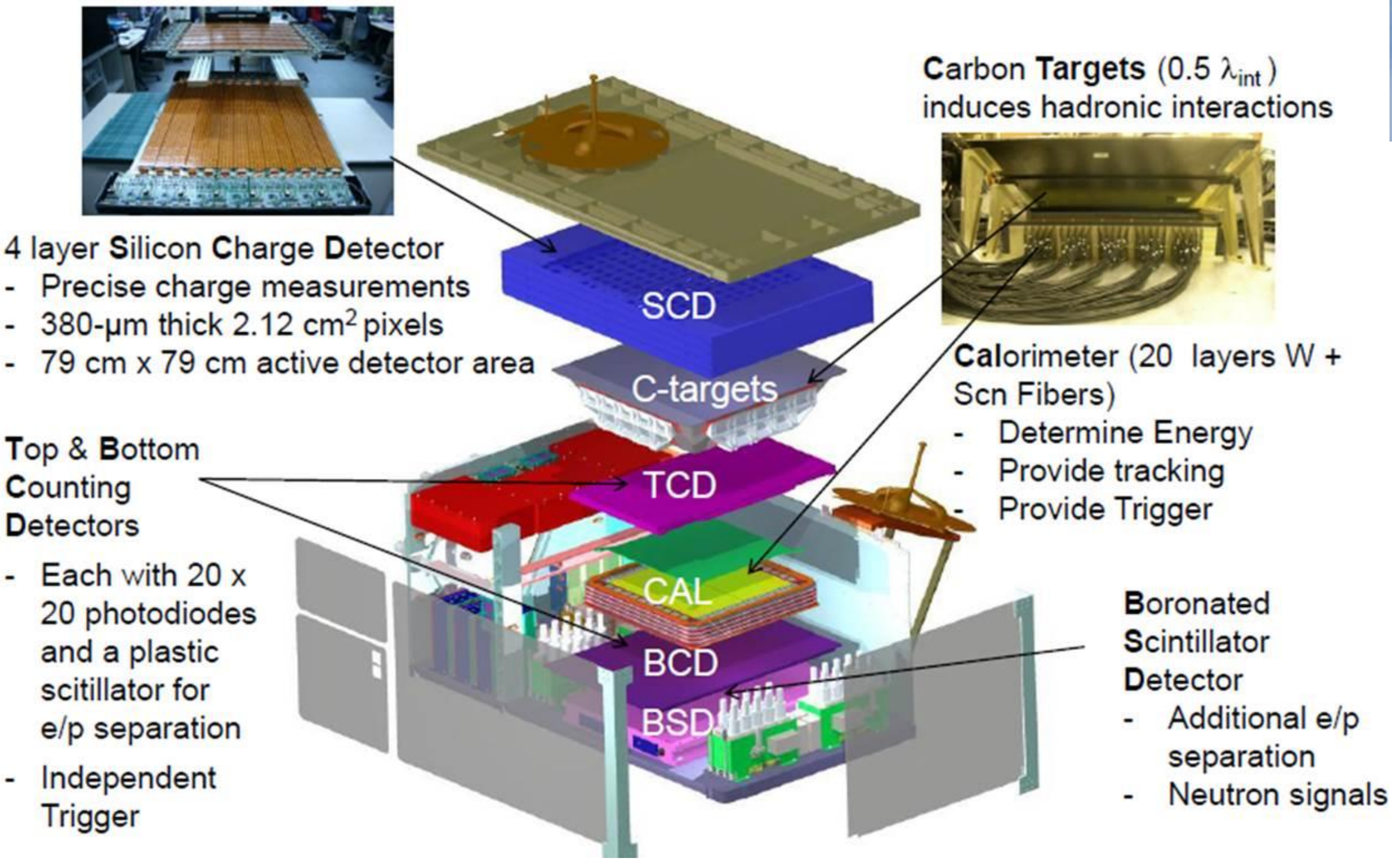
EUSO-Balloon
- Scheduled for CNES balloon flight in Timmins, Ontario (Canada) in August
- Background measurement
- Near space environment

EUSO-TA
- Telescope Area, Utah (USA)
- Calibration using CLF and ELS
- Cross calibration with TA
- External trigger for EAS

⇒ First data expected end of July

ISS-CREAM

- Direct measurement of cosmic rays with energies up to 100 TeV onboard ISS (former balloon experiment).
- Start Planed in **Dec 2014** with SpaceX-6 flight.



Summary

$$\Phi(E) = \frac{N(E)}{Acc(E)\varepsilon_{Trig}\varepsilon_{Sel}T_{\exp}\Delta E}$$

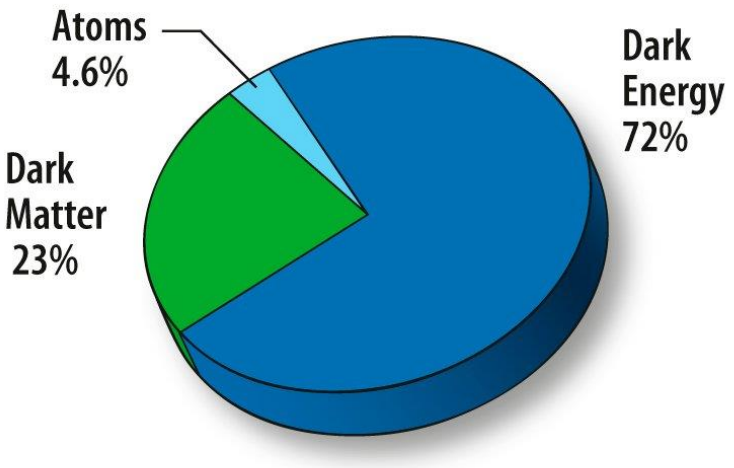
- The **flux** disentangles the measurement from the detector
- The International Space Station (ISS) is a perfect host for cosmic ray experiments
- **AMS-02** is measuring cosmic particles on the ISS since May 2011 without mayor interuptions
- **JEM-EUSO** will use the **air fluorescence** method for the first time in a space environment and measure the cosmic ray particle flux to energies beyond 10^20 eV

Thank you for your attention!

Goals of Astroparticle Physics

Use methods of particle physics to study astrophysical problems

- What does our universe look like (structure formation)?
- What is happening in our universe (origin of cosmic rays)?
- What did the early universe look like (Big Bang)?
- Where does Matter come from or where did the anti-matter go?
- What is Dark Matter?
- What is Dark Energy?



NASA/WMAP Science Team

"Never in the history of science we were so aware of our ignorance: We know that we do not know anything about what makes 95% of our universe"

R.Battiston

JEM-EUSO Specification

- Optics
  - Aperture 4.5 m²
  - Band width (UV) 300 – 430 nm
  - Field of view 0.85 sr (± 30°)
  - Observation area 1.4×10^5 km²
- FS detector and electronics
  - Sampling time 2.5 µs
  - Spatial angular resolution 0.074°
  - Pixel size at ground 0.51 km
  - Number of pixels 3.2×10^5
- Atmospheric Monitoring
  - IR camera
  - LIDAR
- Calibration system
  - Global Light System (GLS)
  - In flight