Geant4 Simulation of Extensive Air Shower

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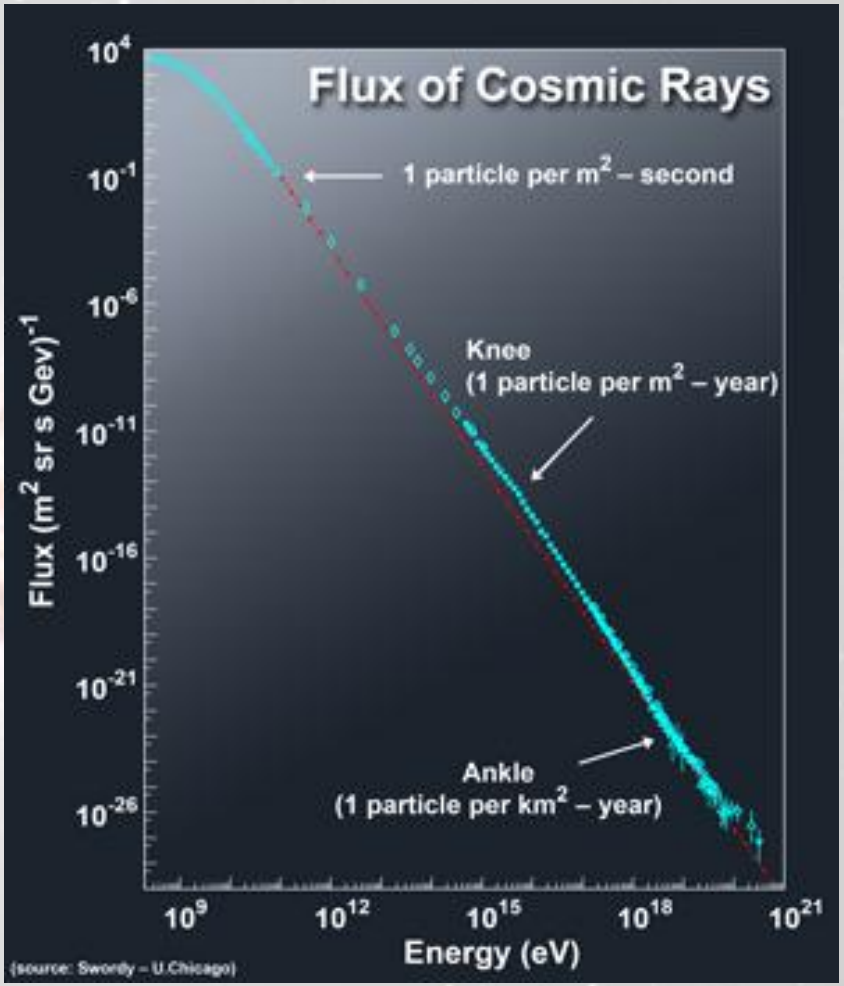
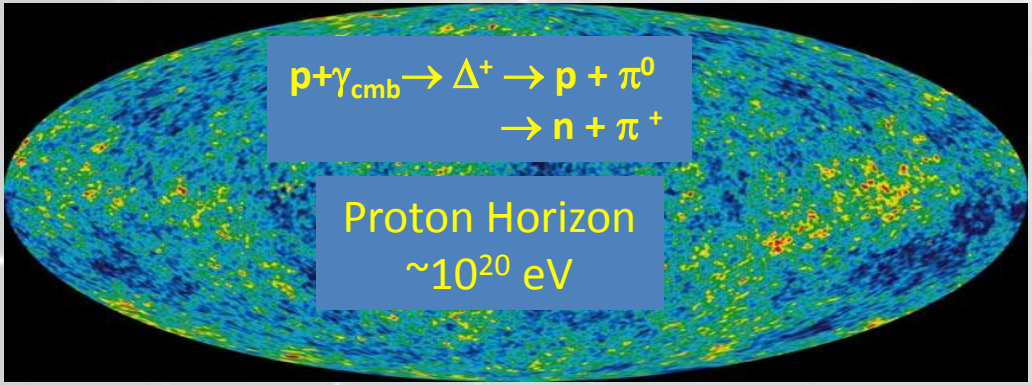
Cosmic Rays

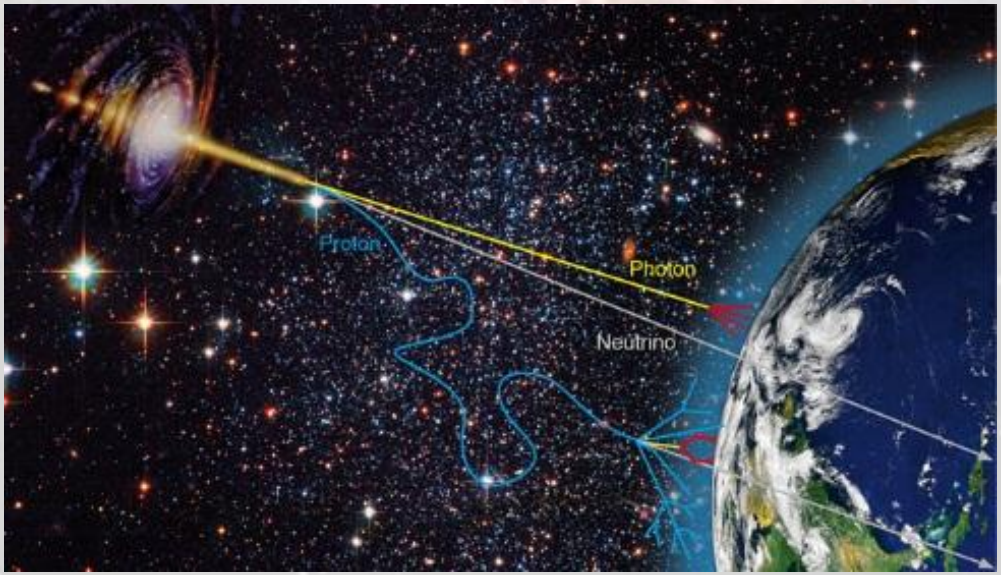
- High-energy protons and heavy ions
- Very broad range of energies
- Galactic and Extragalactic
- maximum energy predicted at 60×10^{18} eV (= 60 EeV) (GZK-cutoff)





Extreme Energy Cosmic Rays (EECRs)

- EECRs (E > 60EeV) suffer almost no deflection from magnetic field in extragalactic, galactic, and solar system
- They point back directly to the location of their original sources → "Charged Particle Astronomy"
- Detection of EECRs gives us information about their sources



Eleven Science Questions for the New Century*

Question 6:

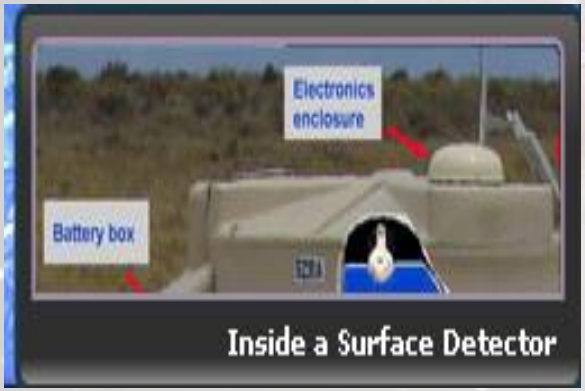
How Do Cosmic Accelerators Work and What Are They Accelerating?

*”Connecting Quarks with the Cosmos: Eleven Science Questions for the New Century Committee on the Physics of the Universe”, National Research Council , ISBN: 0-309-50569-0 (2003)

HiRes (Utah)

Detecting EECR

TA (Utah)



Auger (Argentina)

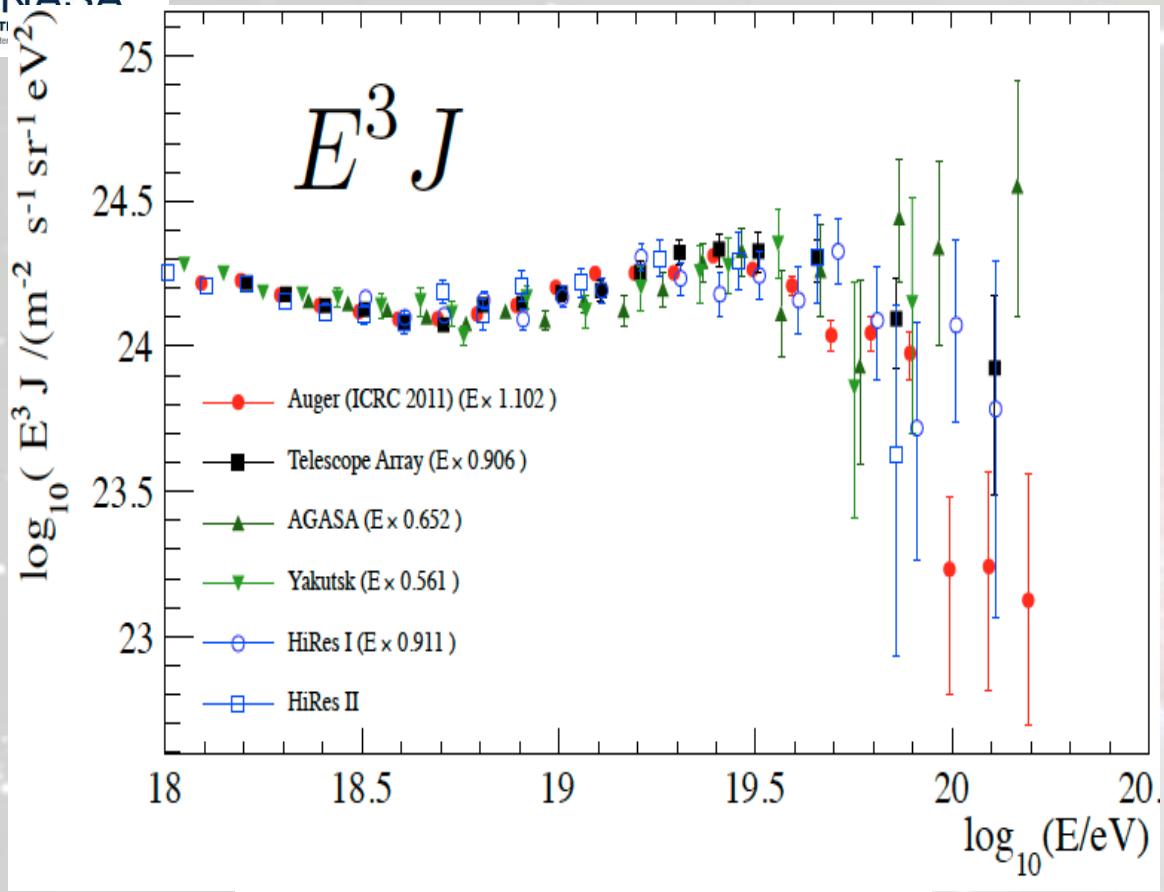
Yakutsk (Siberia)

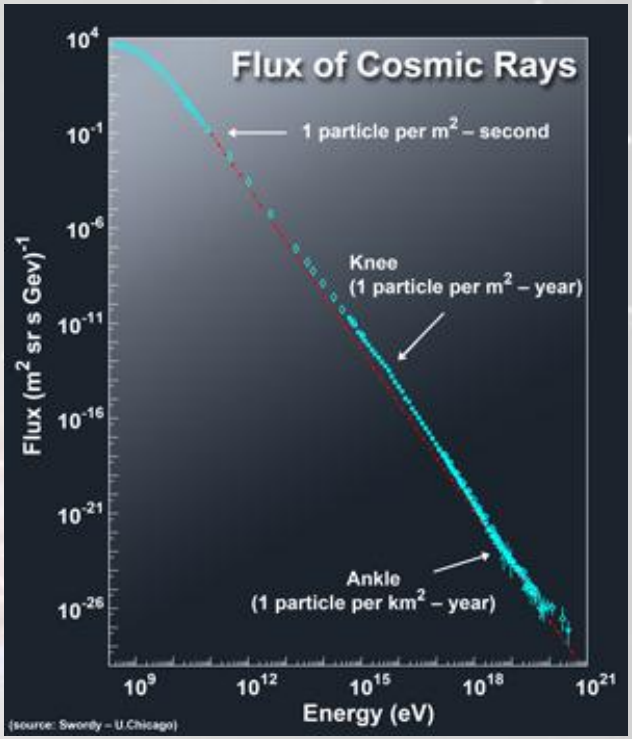
AGASA (Japan)

NASA POSTDOCTORAL PROGRAM

MARSHALL SPACE FLIGHT CENTER

Data accumulated



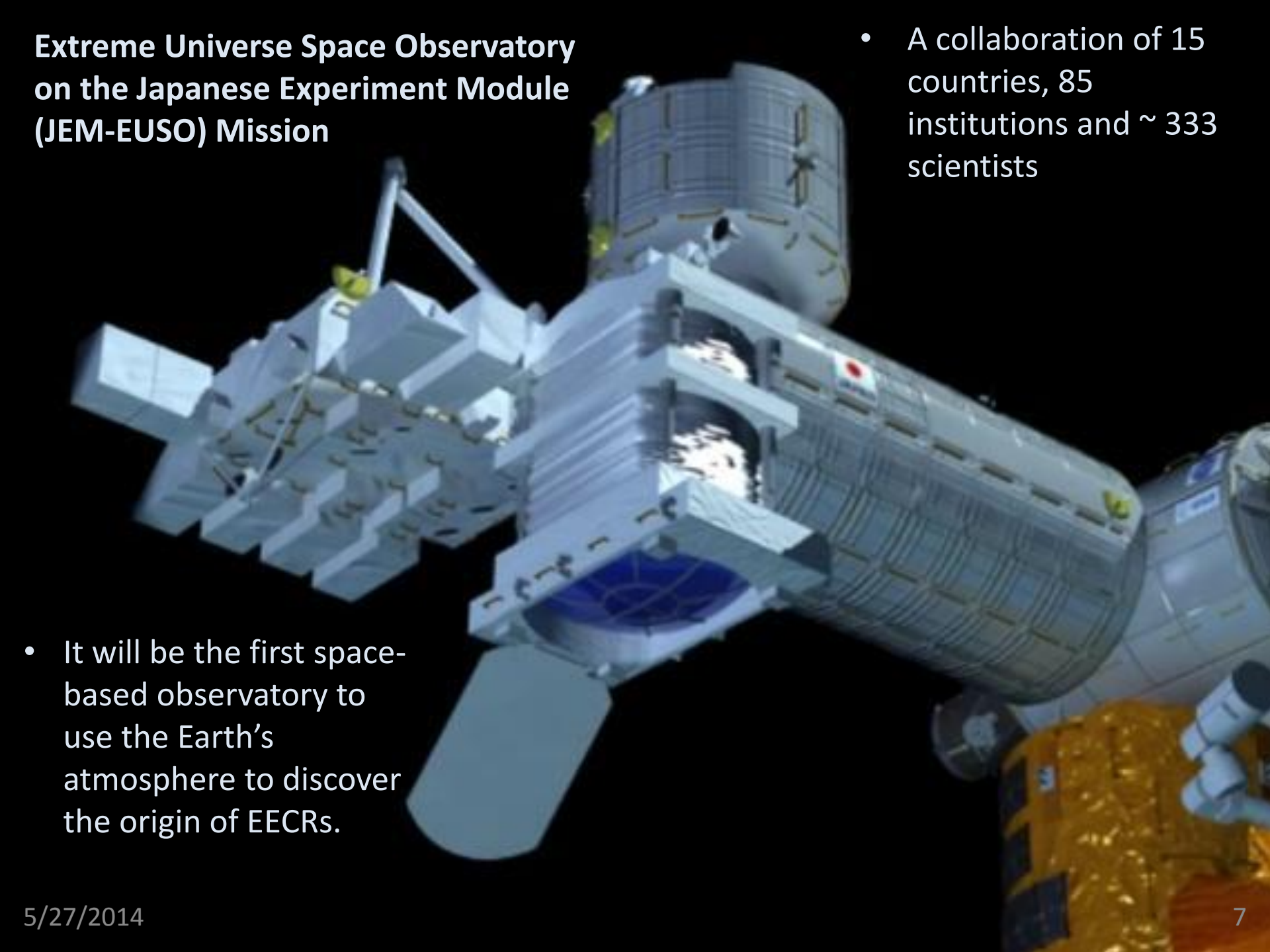


Spectra of leading EECRs observations

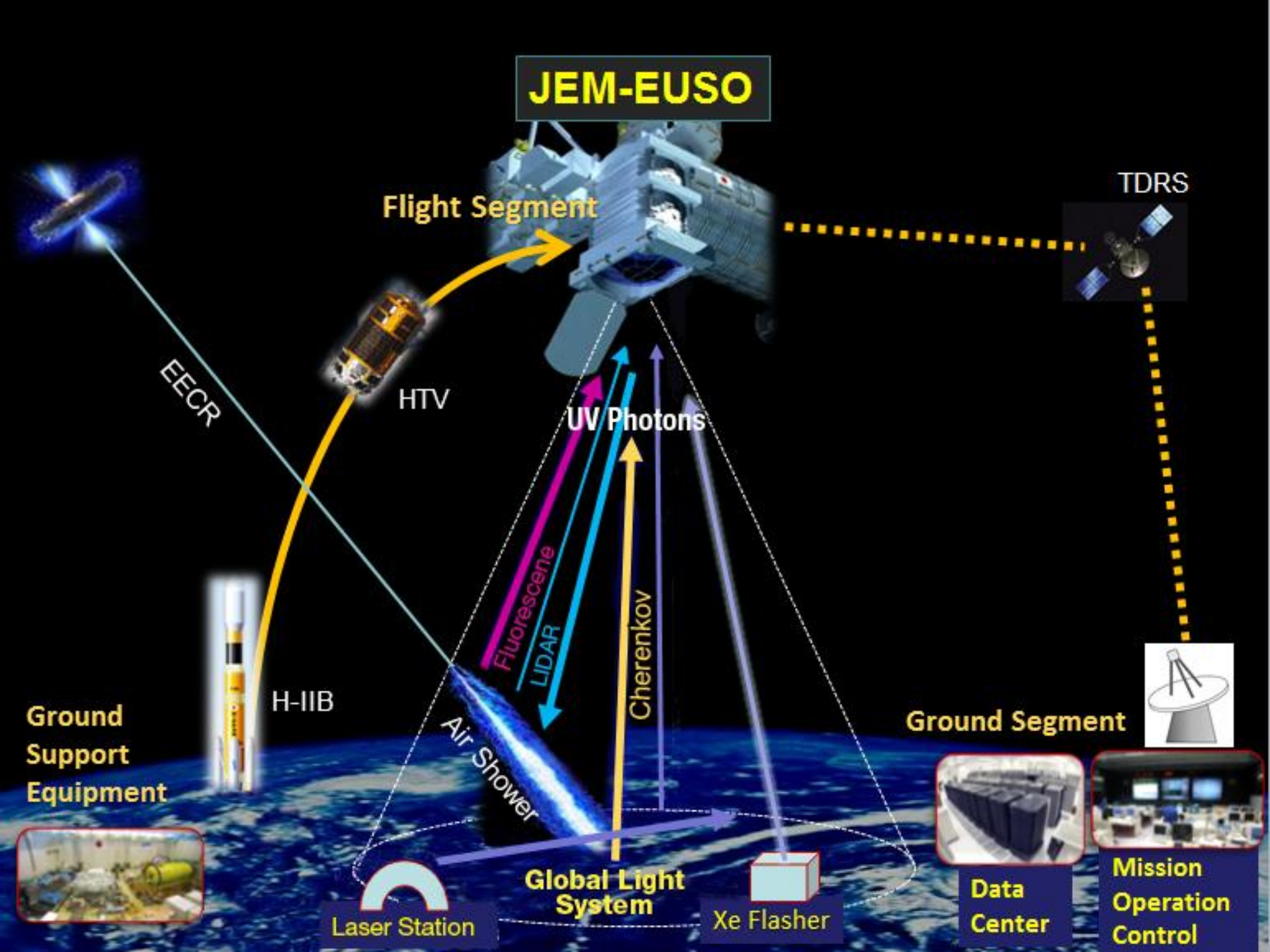
- EECRs Flux is low → of the order of 1 particle/km^2/sr/century
- At high end of the spectrum → reduces to 1 particle/km^2/sr/millennium!

Extreme Universe Space Observatory on the Japanese Experiment Module (JEM-EUSO) Mission

- A collaboration of 15 countries, 85 institutions and ~ 333 scientists



- It will be the first space-based observatory to use the Earth's atmosphere to discover the origin of EECRs.


JEM-EUSO
Flight Segment
TDRS
EECR
HTV
UV Photons
Fluorescene
LIDAR
Cherenkov
H-IIB
Air Shower
Ground Support Equipment
Ground Segment
Global Light System
Laser Station
Xe Flasher
Data Center
Mission Operation Control

Extensive Air Showers (EASs)

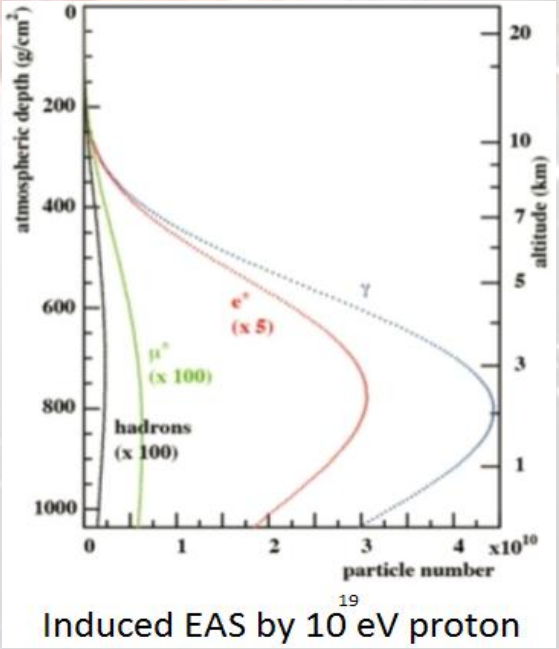
- Studies of the nature of EECRs are based on the measurement of EASs,
- EASs are cascades of secondary particles in the atmosphere as a result of the interaction of EECRs with the Earth's atmosphere

- Maximum atmospheric depth X_{max} depends on:

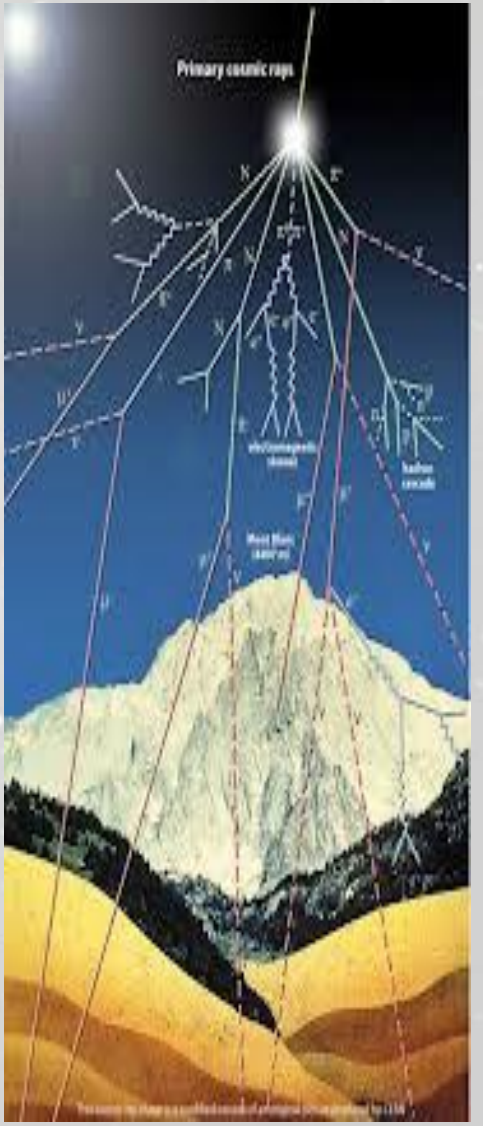
→ primary energy,

→ nature of the primary particle

→ details of the interactions



Induced EAS by 10^{19} eV proton

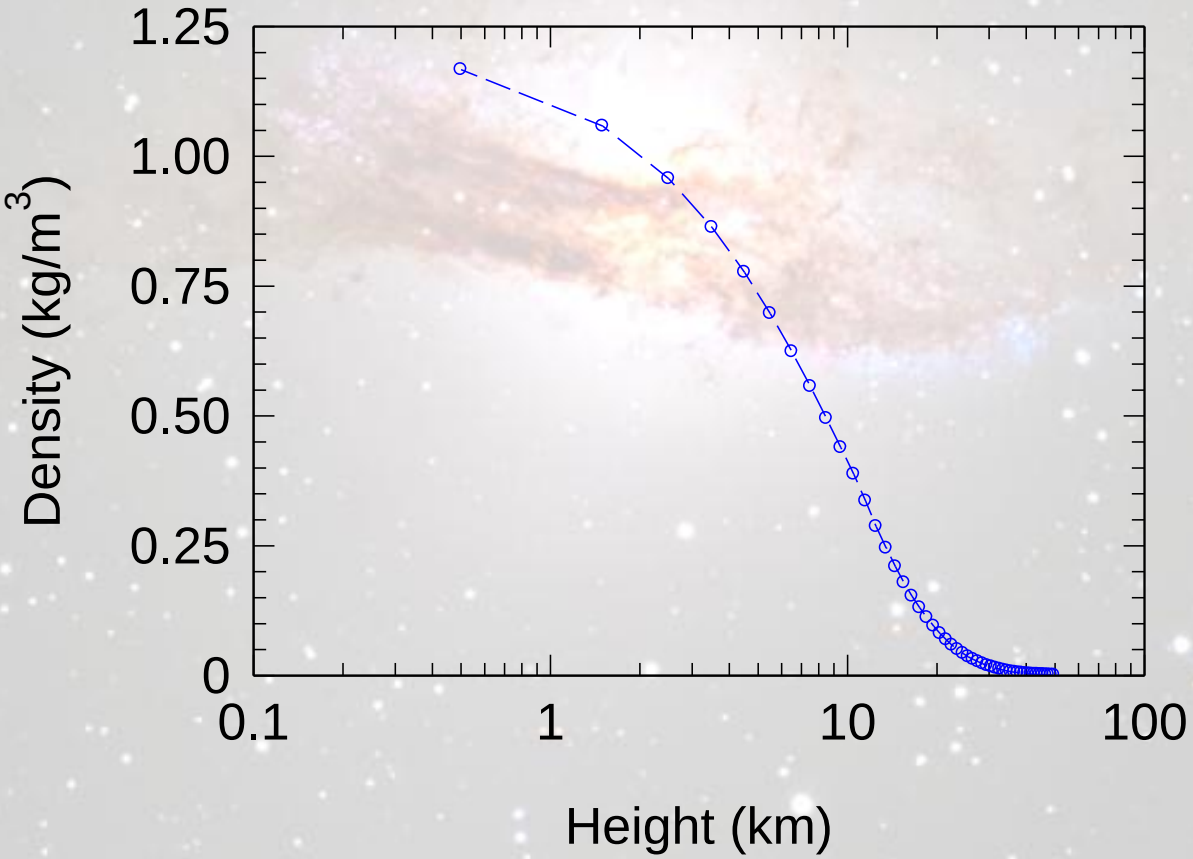


Modeling EAS using GEANT4

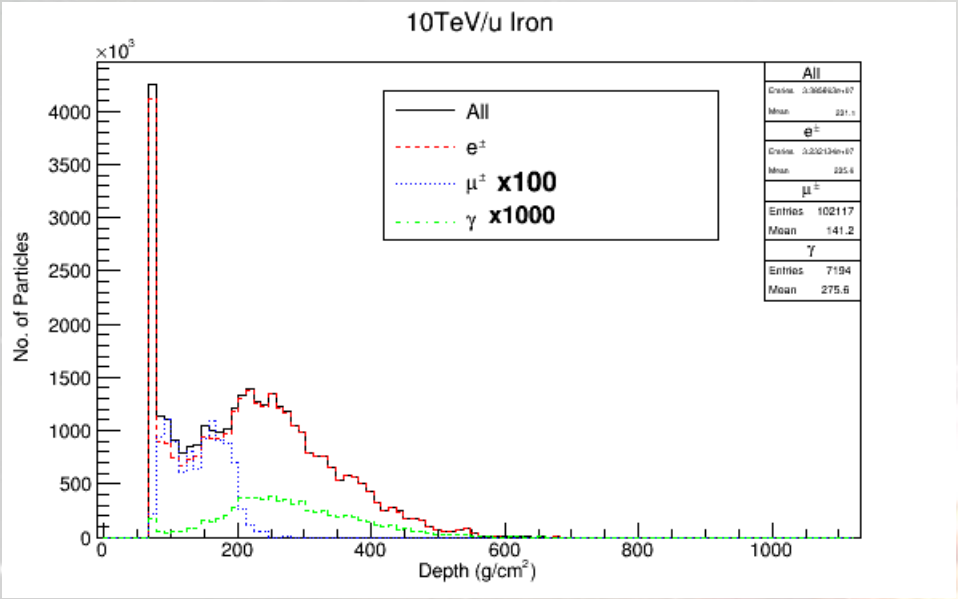
- In collaboration with JEMEUSO simulation team, Geant4 application is under development to simulate the interaction of EECR particle with Earth's atmosphere
- Compare with other traditional EAS simulation codes (CORSIKA used by JEMEUSO offline code)

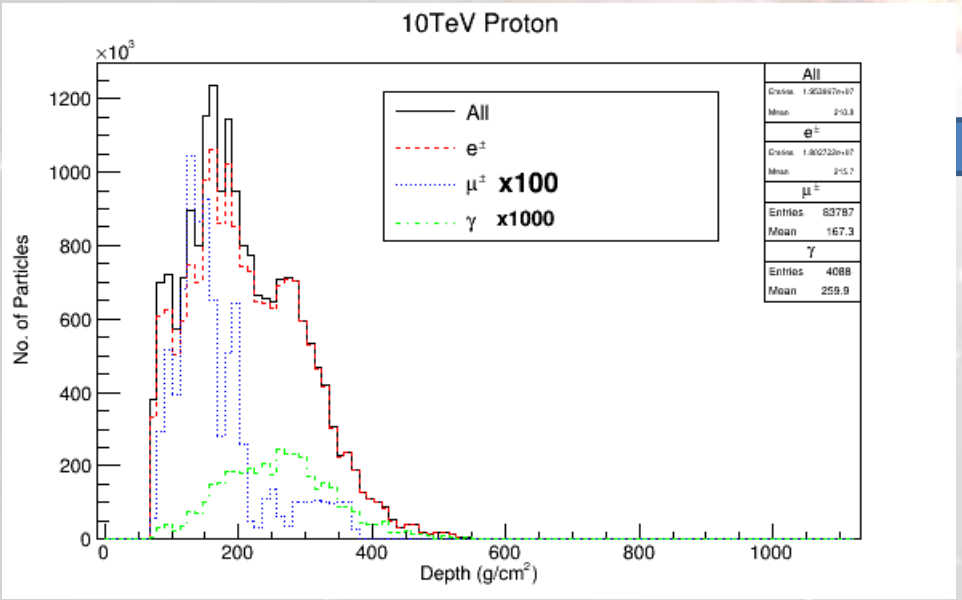
Modeling EAS using GEANT4

- Atmosphere is modeled as cylinder of radius 0.5 km and divided into 20 layers of 1 km thickness and varying density



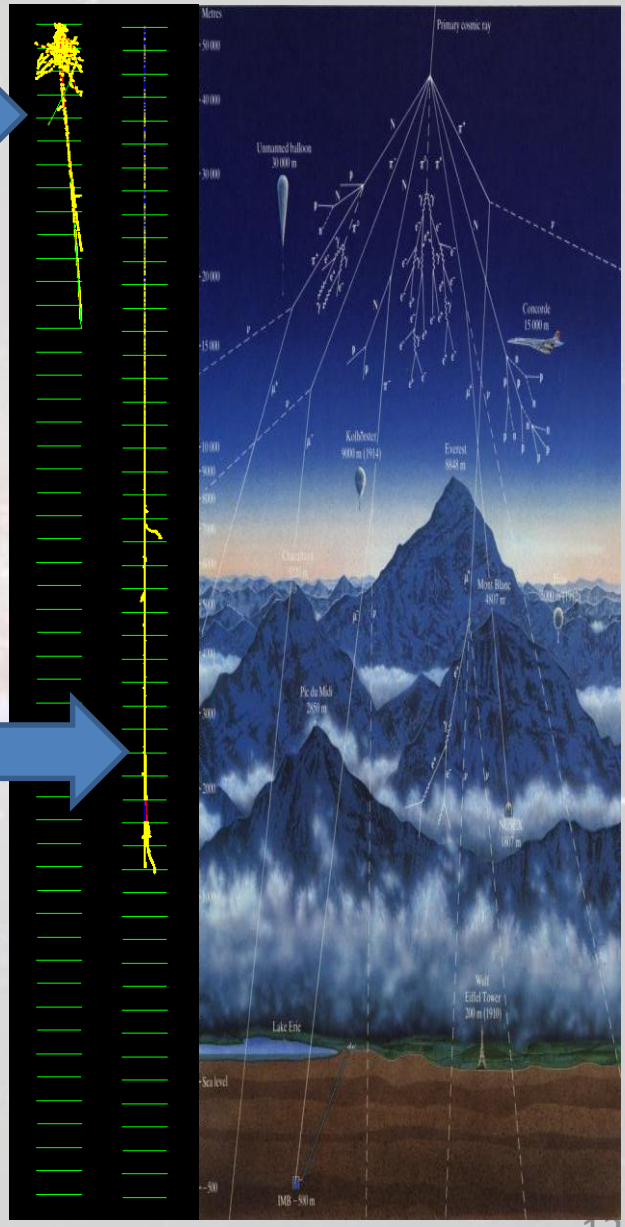
EAS induced by 10TeV/u proton and Fe



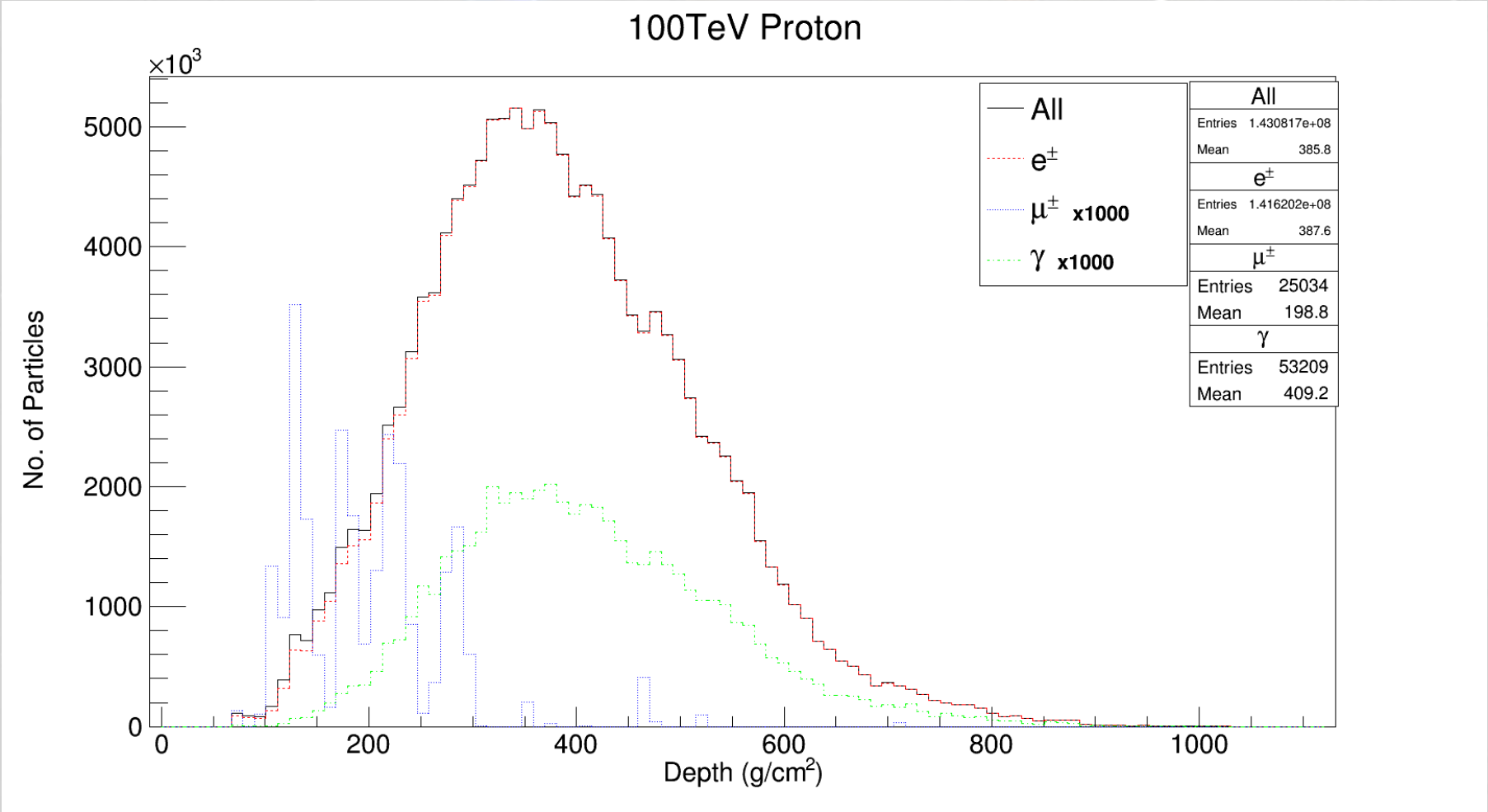


Iron

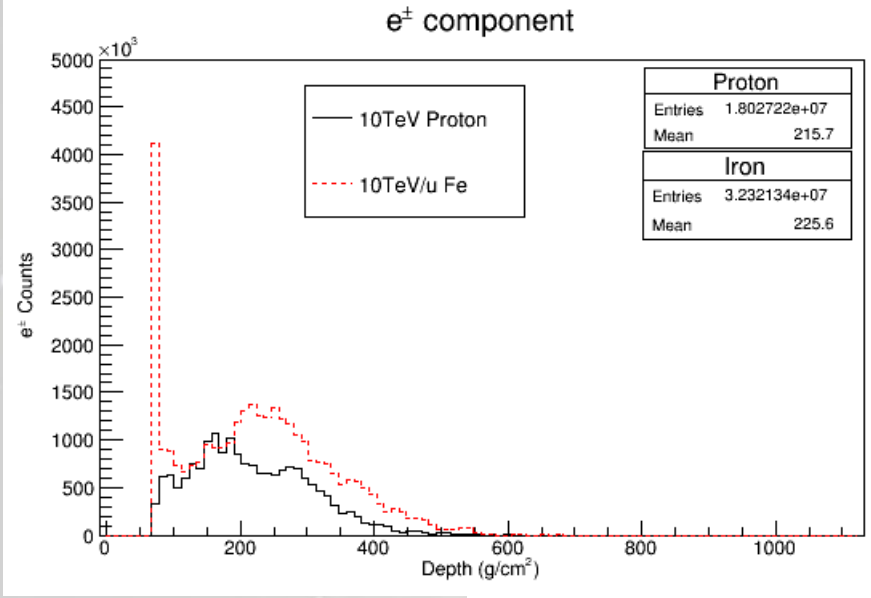
Proton

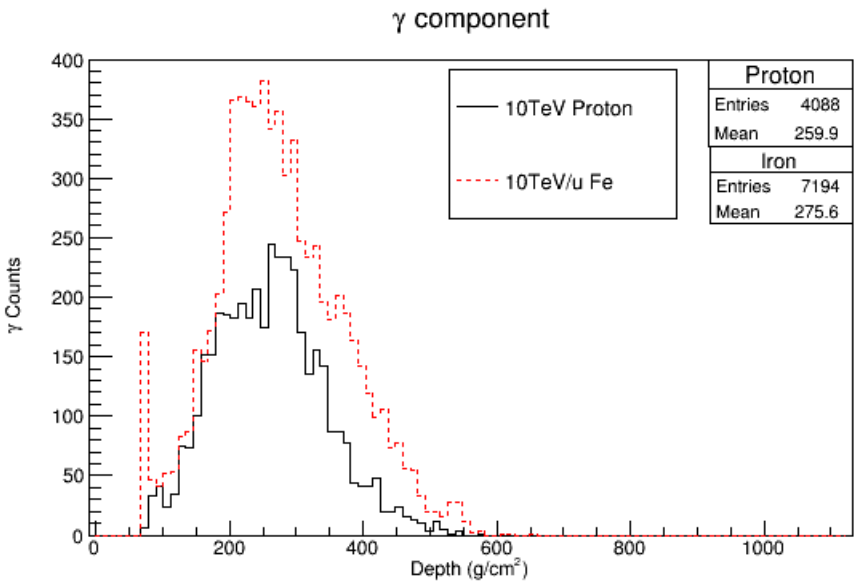


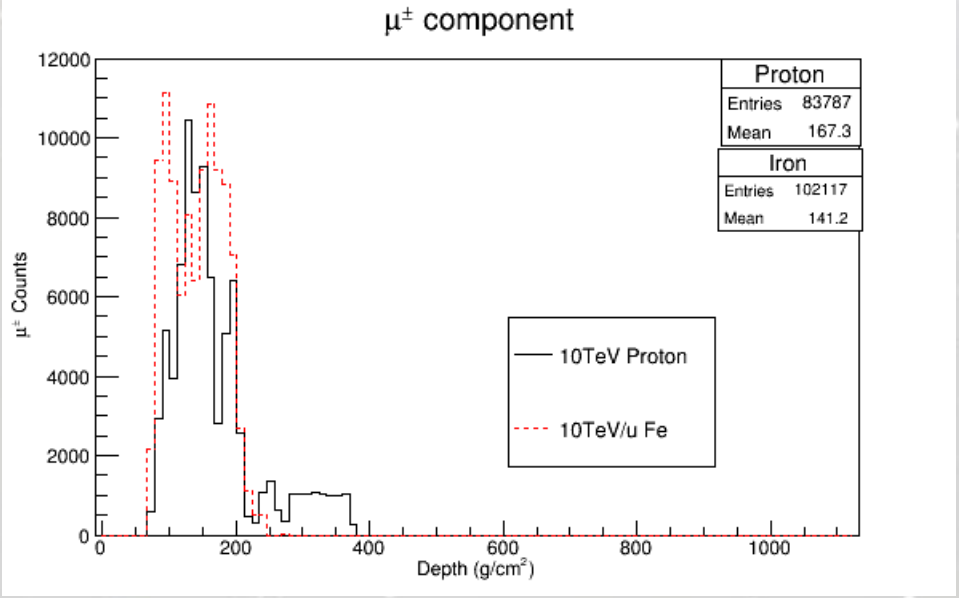
100TeV Proton – Depth



Proton vs Iron @ 10TeV/u







Remarks

- Particle densities in EASs are dependent on primary particle
- Extensive Air Showers have their shower maximum close to ground
- Computing time roughly scales with energy of primary particle:
  - For 10 TeV Proton → 1 hr / 5 events
  - Output file size ~ 180 GB for 1000 events!

Remarks

- For showers initiated by particles with primary energies $E > 10^{16}$ eV → computing times become excessively large → Apply Energy cuts

Future work

- **Go to higher energies 10^{19}eV**
- **Compare with other simulation codes (CORSIKA, CONIX)**
- **Compare with experimental data**

Acknowledgement

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Thank You!
Questions?

Height vs Depth