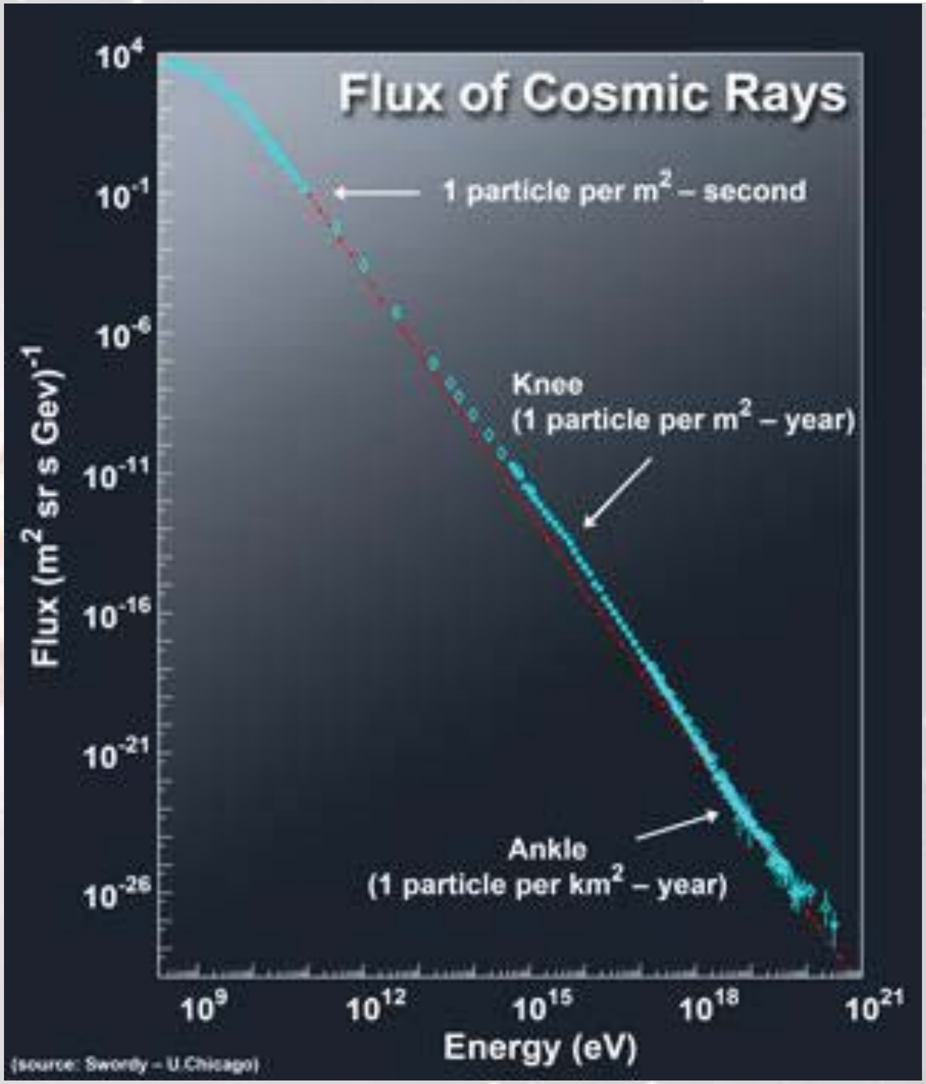
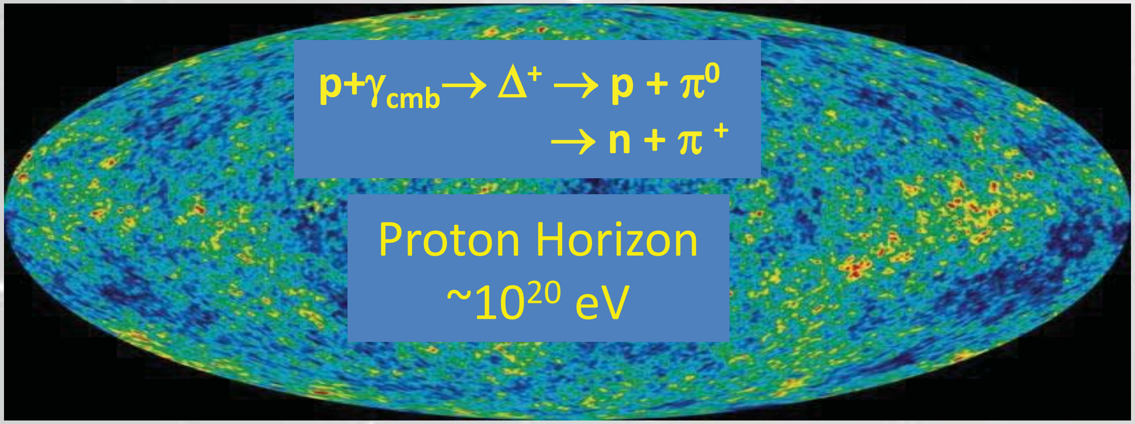
Geant4 Simulation of Air Showers using Thinning Method

Mohammad S. Sabra[1]
Mark J. Christl[1], John W. Watts[2]
[1]Marshall Space Flight Center, Huntsville AL
[2]CSPAR, University of Alabama, Huntsville, AL

Cosmic Rays

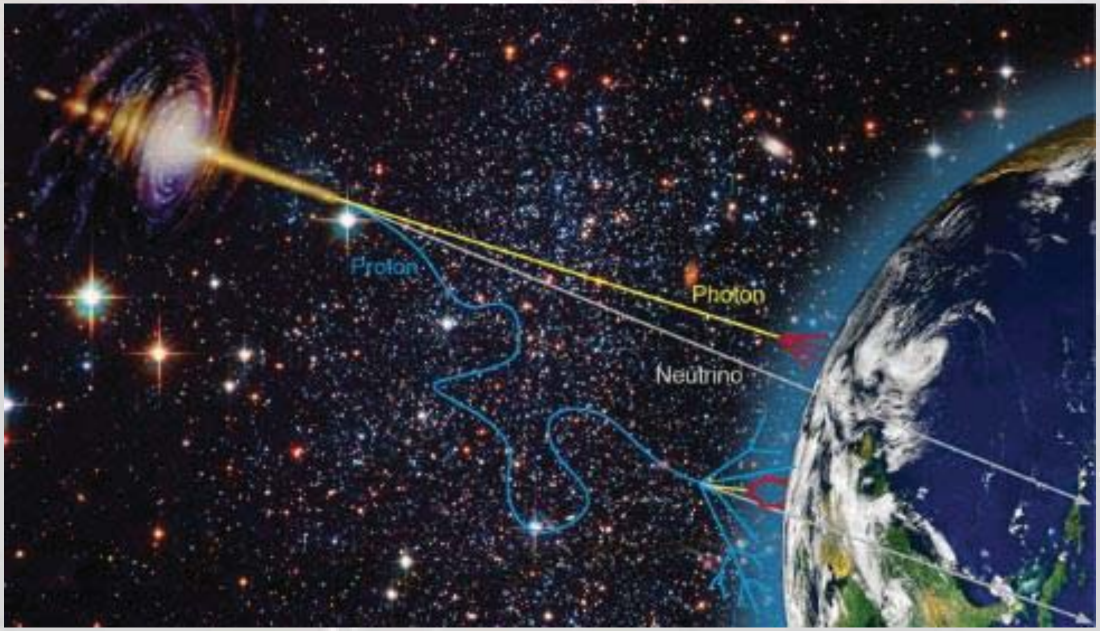
- High-energy protons and heavy ions
- Very broad range of energies
- Galactic and Extragalactic
- maximum energy predicted at 60×10^{18} eV (= 60 EeV) (GZK-cutoff)





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



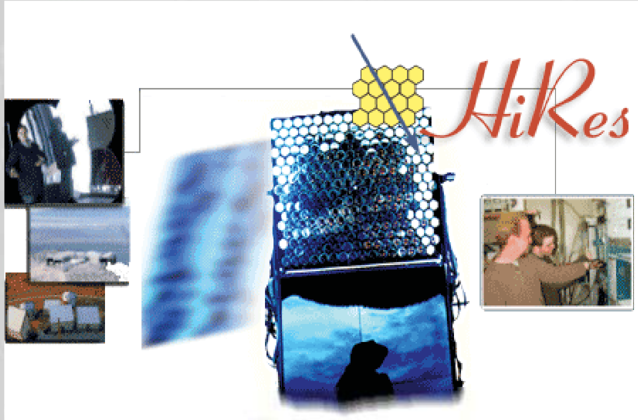
Eleven Science Questions for the New Century*

Question 6:

How Do Cosmic Accelerators Work and What Are They Accelerating?

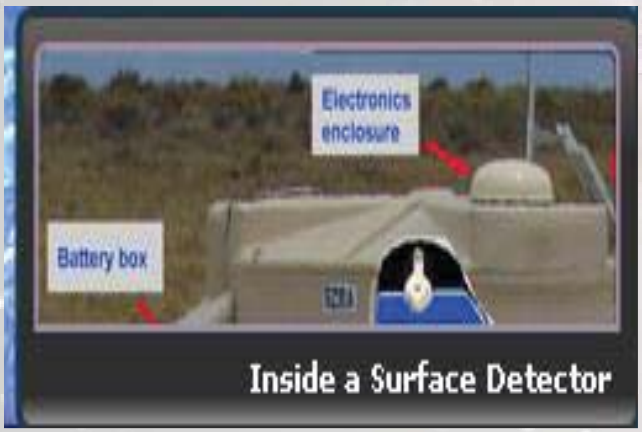
***"Connecting Quarks with the Cosmos: Eleven Science Questions for the New Century Committee on the Physics of the Universe", National Research Council ,** ISBN: 0-309-50569-0 (2003)

Detecting EECR



HiRes (Utah)

TA (Utah)

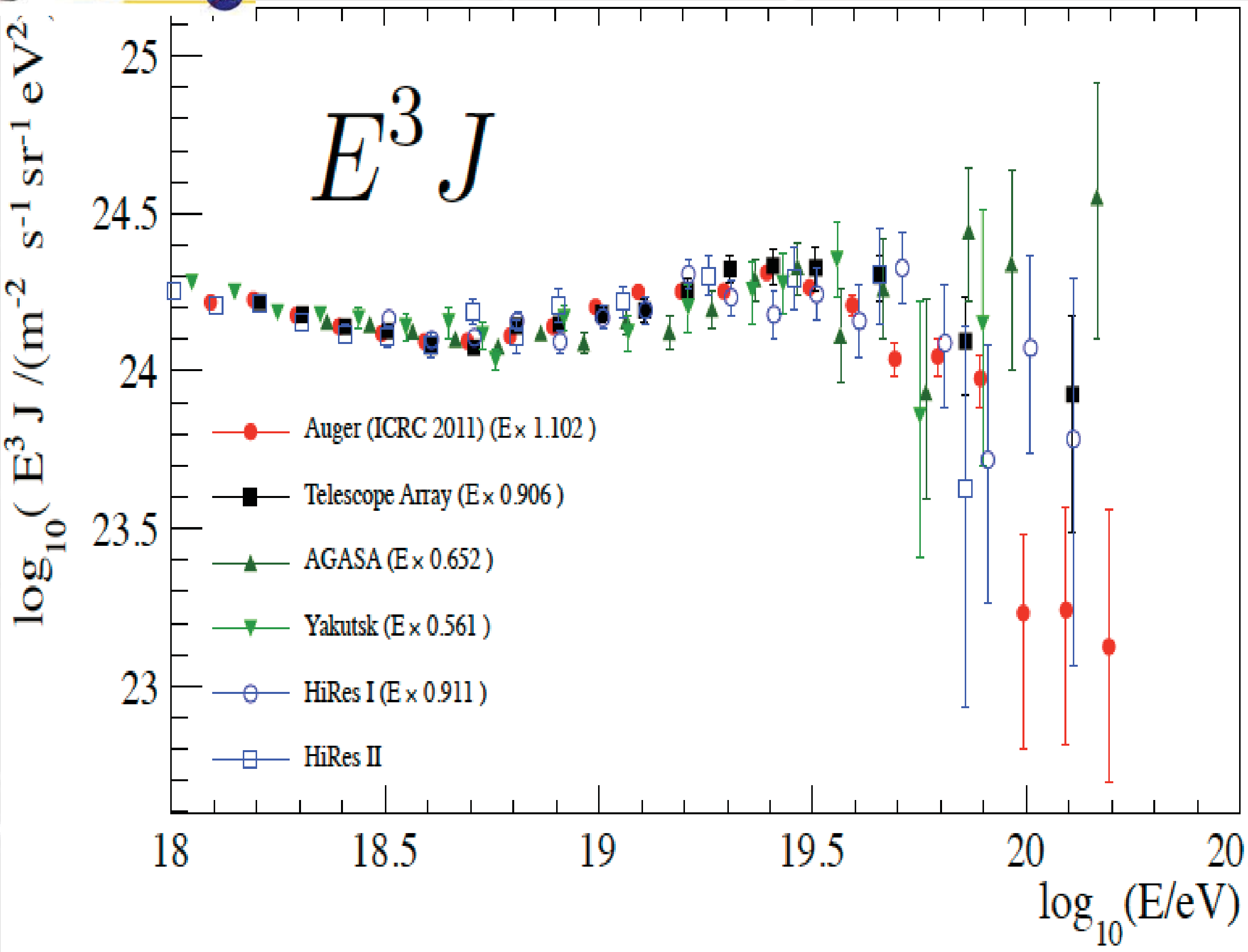


Auger (Argentina)

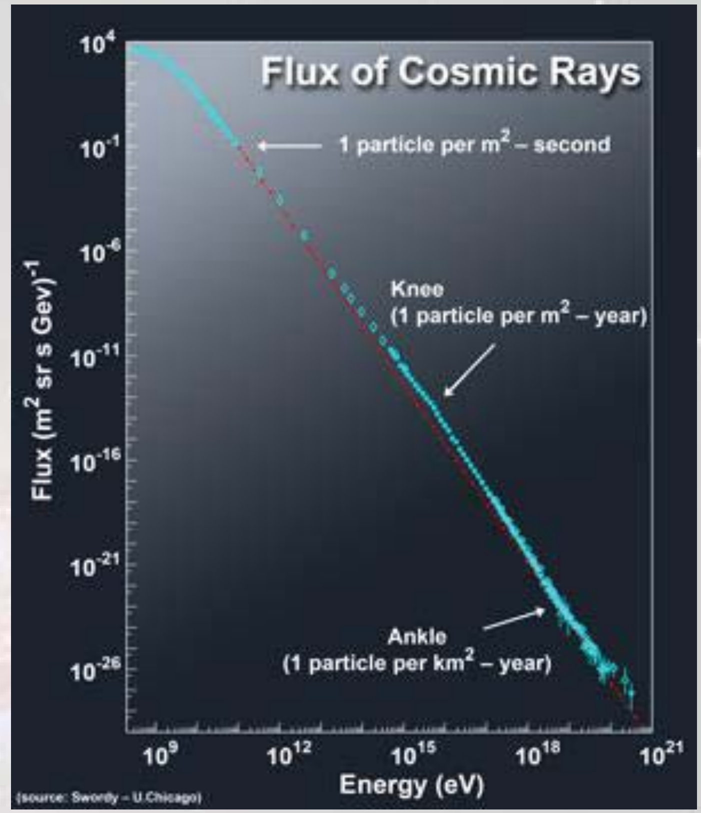
Yakutsk (Siberia)

AGASA (Japan)

Data accumulated



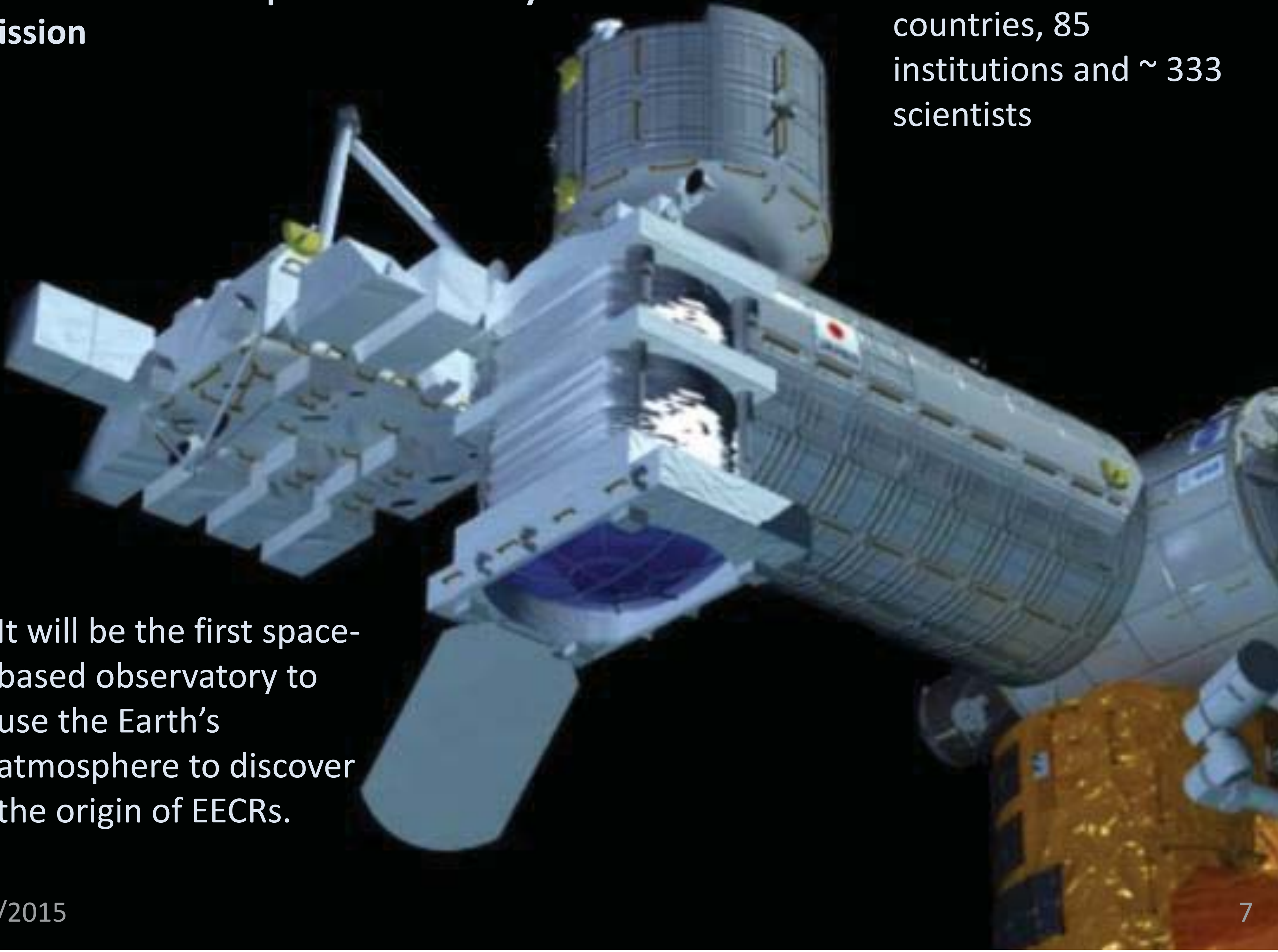
Spectra of leading EECRs observations



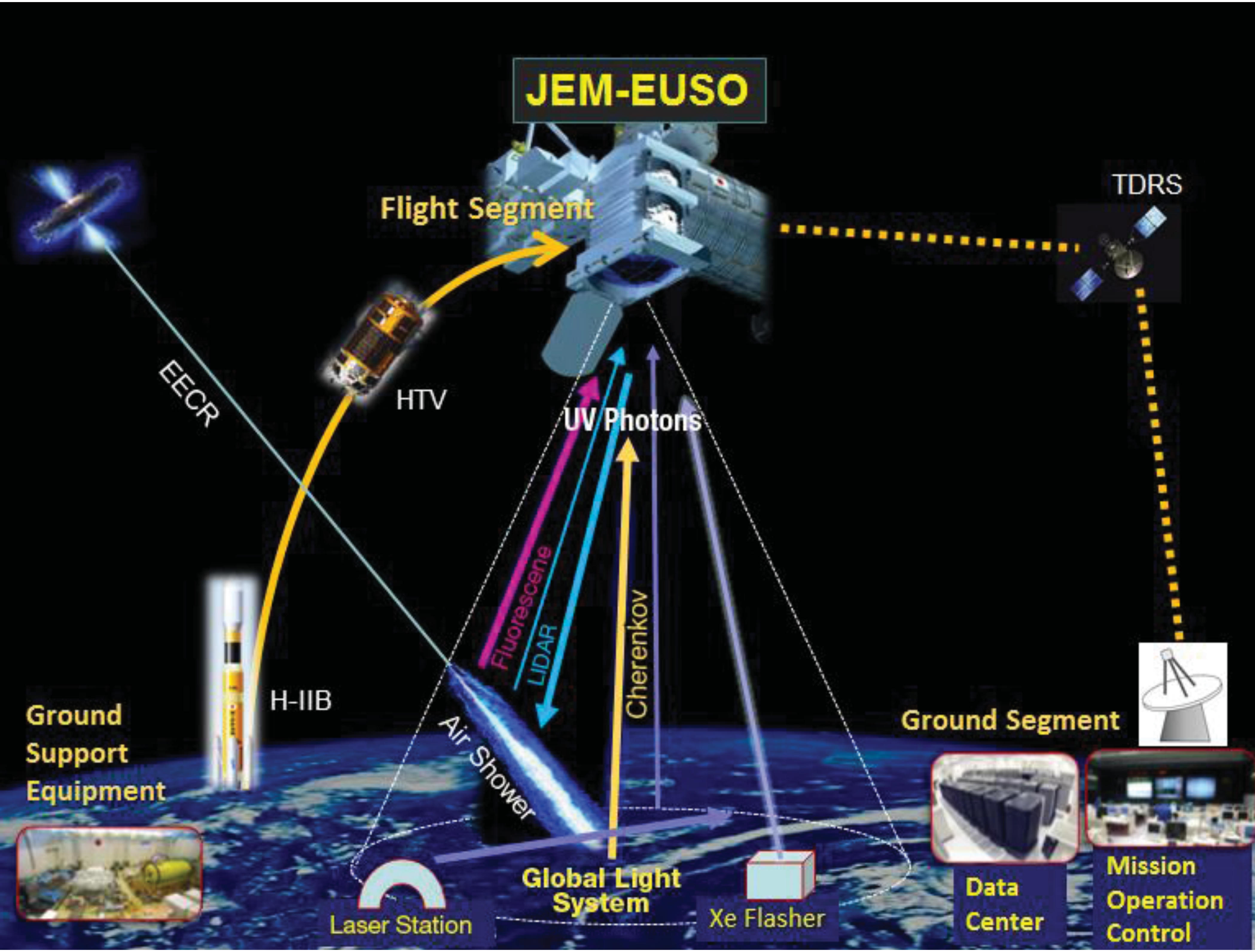
- EECRs Flux is low → of the order of 1 particle/km²/sr/century
- At high end of the spectrum → reduces to 1 particle/km²/sr/millennium!

Extreme Universe Space Observatory 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.

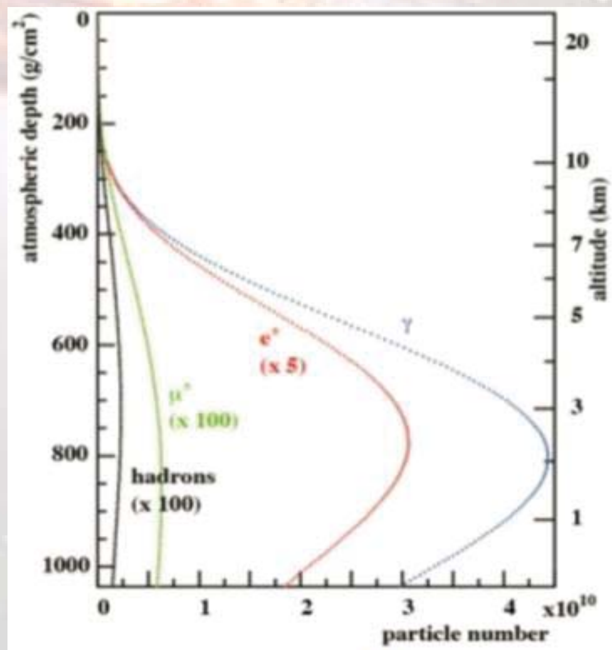


JEM-EUSO
Flight Segment
TDRS
EECR
HTV
UV Photons
Fluorescene
LIDAR
Cherenkov
H-IIB
Air Shower
Ground Support Equipment
Ground Segment
Global Light System
Laser Station
Xe Flasher
Data Center
Mission Operation Control

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

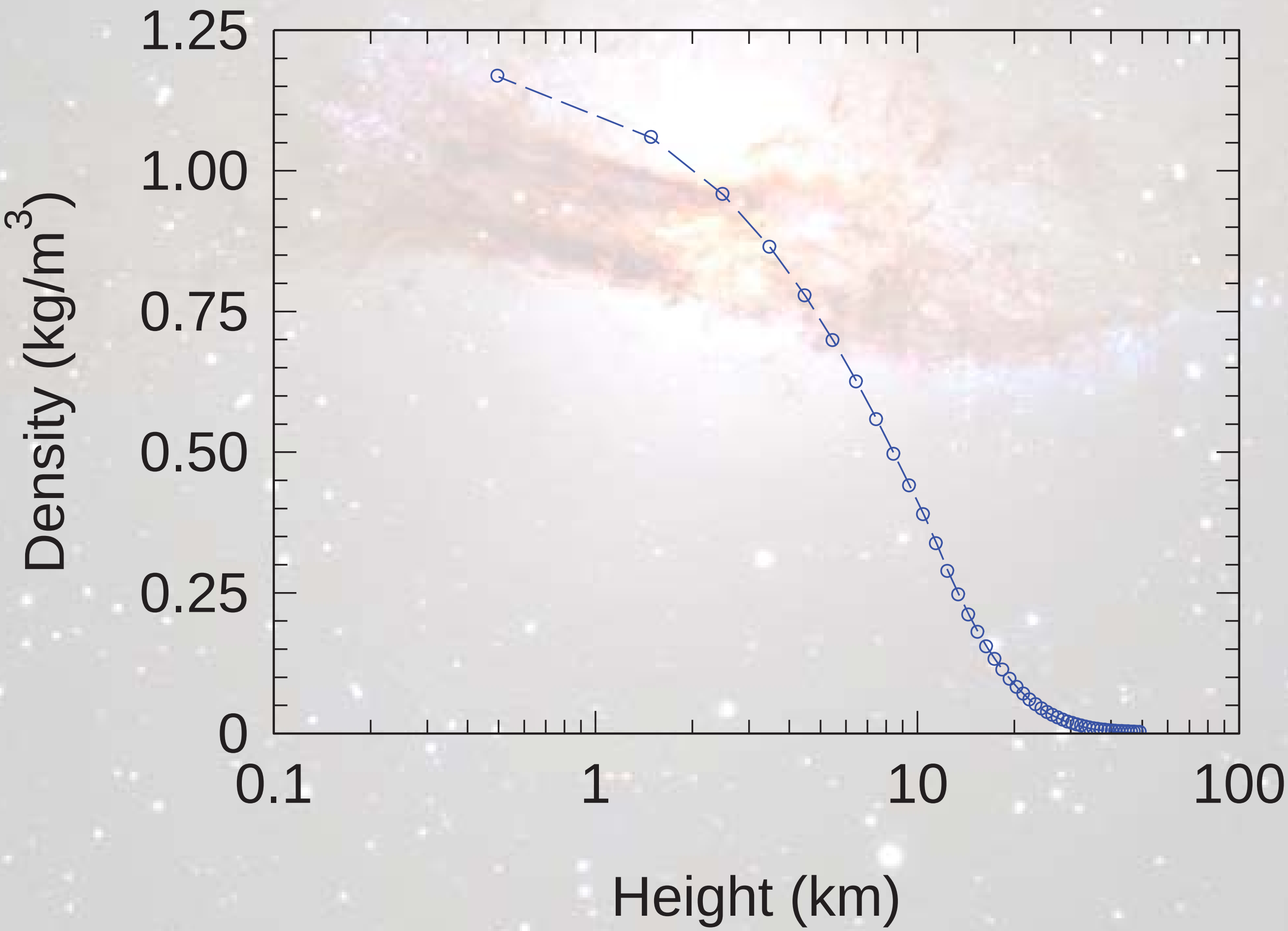
- Maximum atmospheric depth X_{max} depends on:
→ primary energy,
→ nature of the primary particle
→ details of the interactions



Induced EAS by 10^{19} eV proton

Modeling EAS using Geant4

- Atmosphere is modeled as cylinder of radius 0.5 km and divided into 112 layers of 1 km thickness and varying density



Modeling EAS using Geant4

- Using Geant4 model FTF_BIC

→ Proton and Iron as primaries

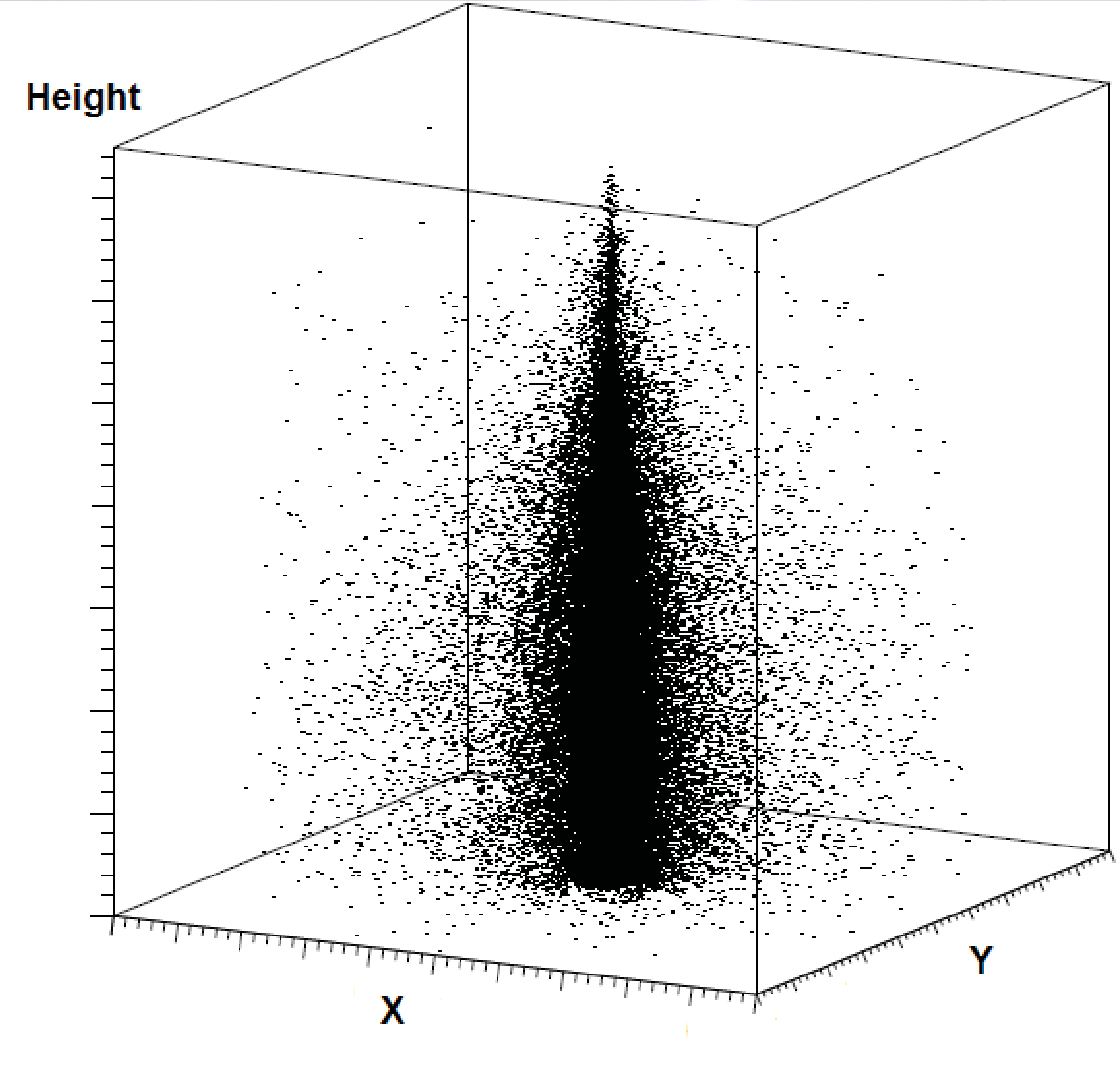
- Time and data size are huge!
- Simulating 1 event of 1TeV proton:

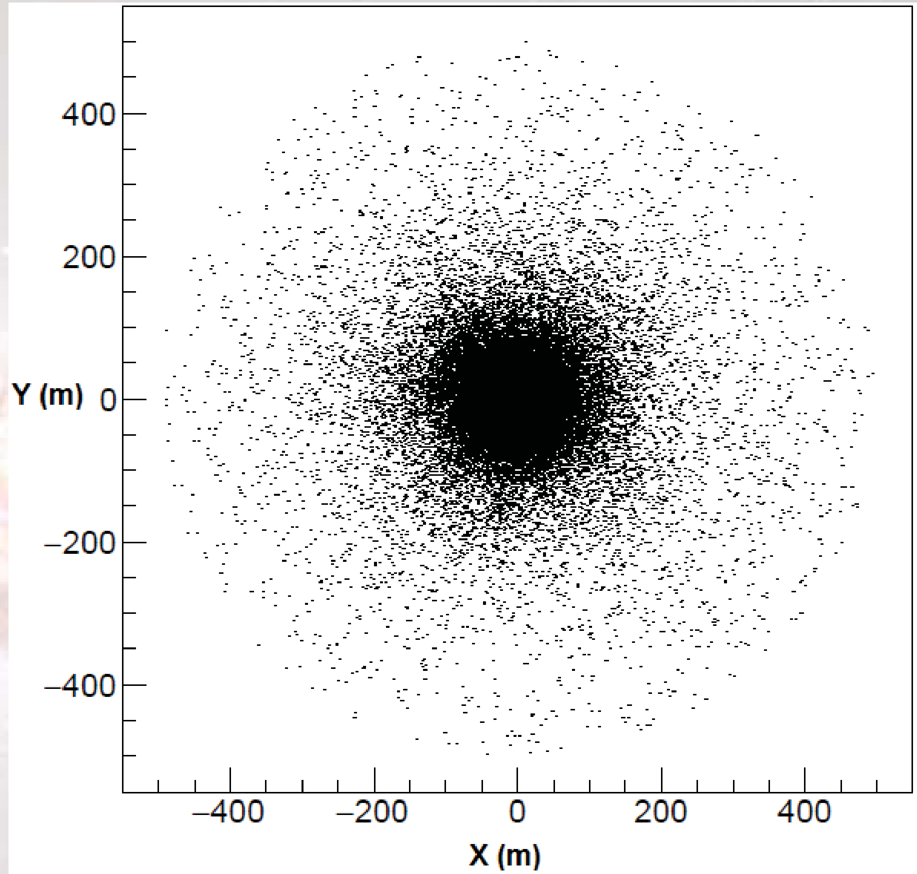
➢ Time ~ 20 hrs

➢ Size ~ 200GB

- Simulation time for EAS scales with energy of primary particle

Radial distance from core





Thinning Algorithm

- Let E_o be energy of primary particle, and E be energy of secondary particle

Thinning level → $E_{th} = E / E_o$

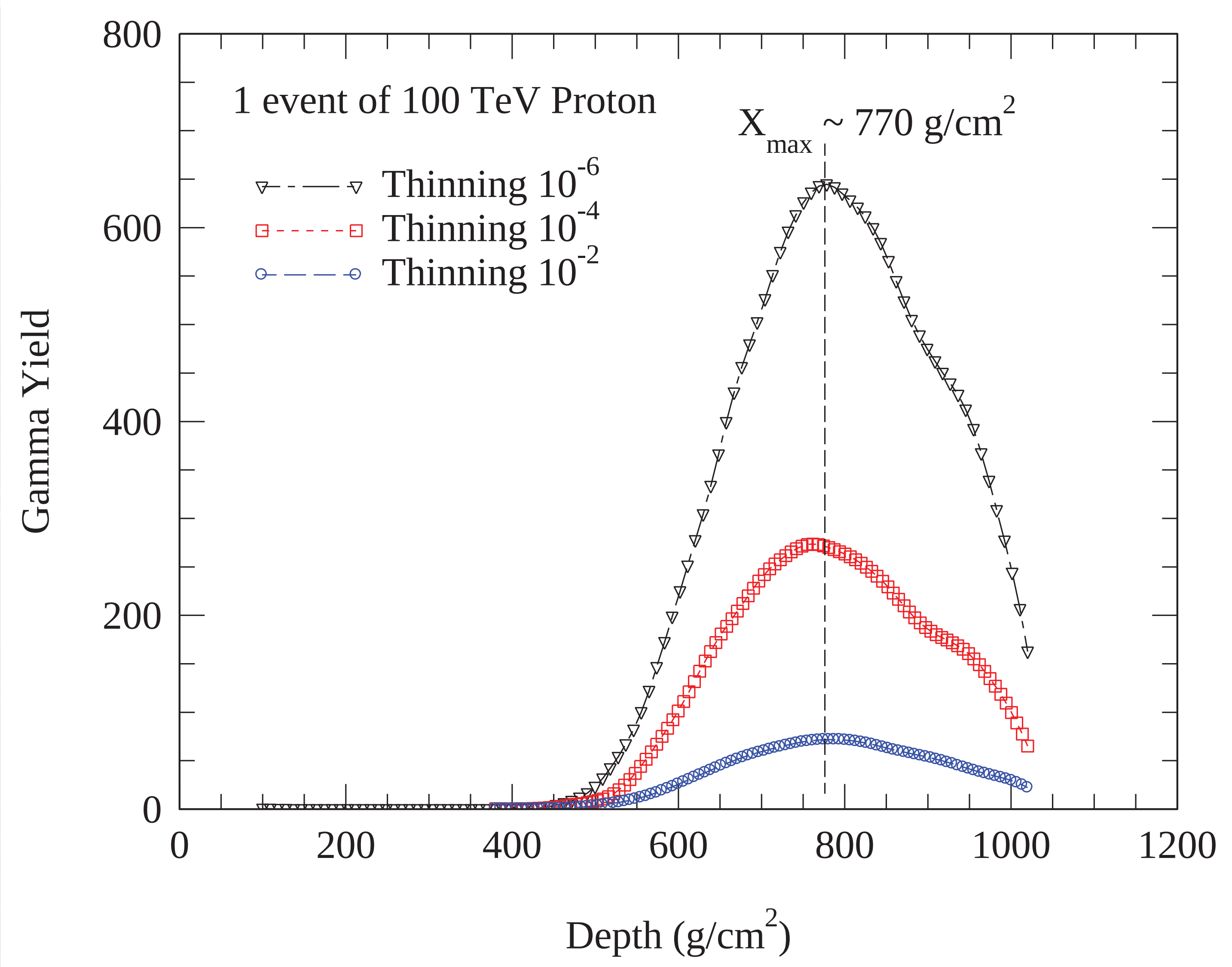
- All secondaries with energies greater than E_{th} are followed, BUT if the energy sum of all j secondaries produced in a certain interaction falls below thinning energy

$$\sum_j E_j < E_{th} E_o$$

→ only one particle is followed

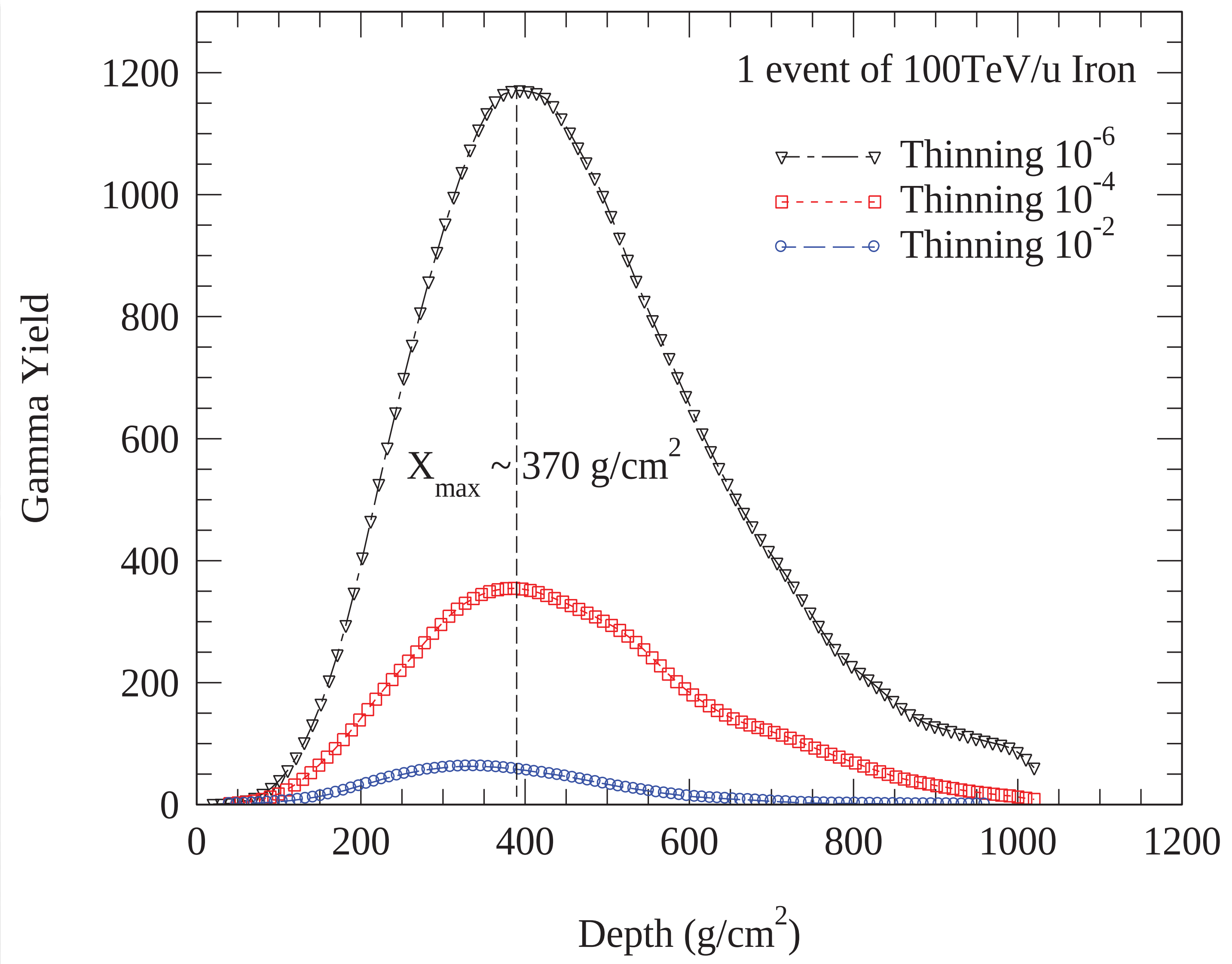
100TeV Proton

Thinning level	1E-2	1E-4	1E-6
Time (min)	17	66	130

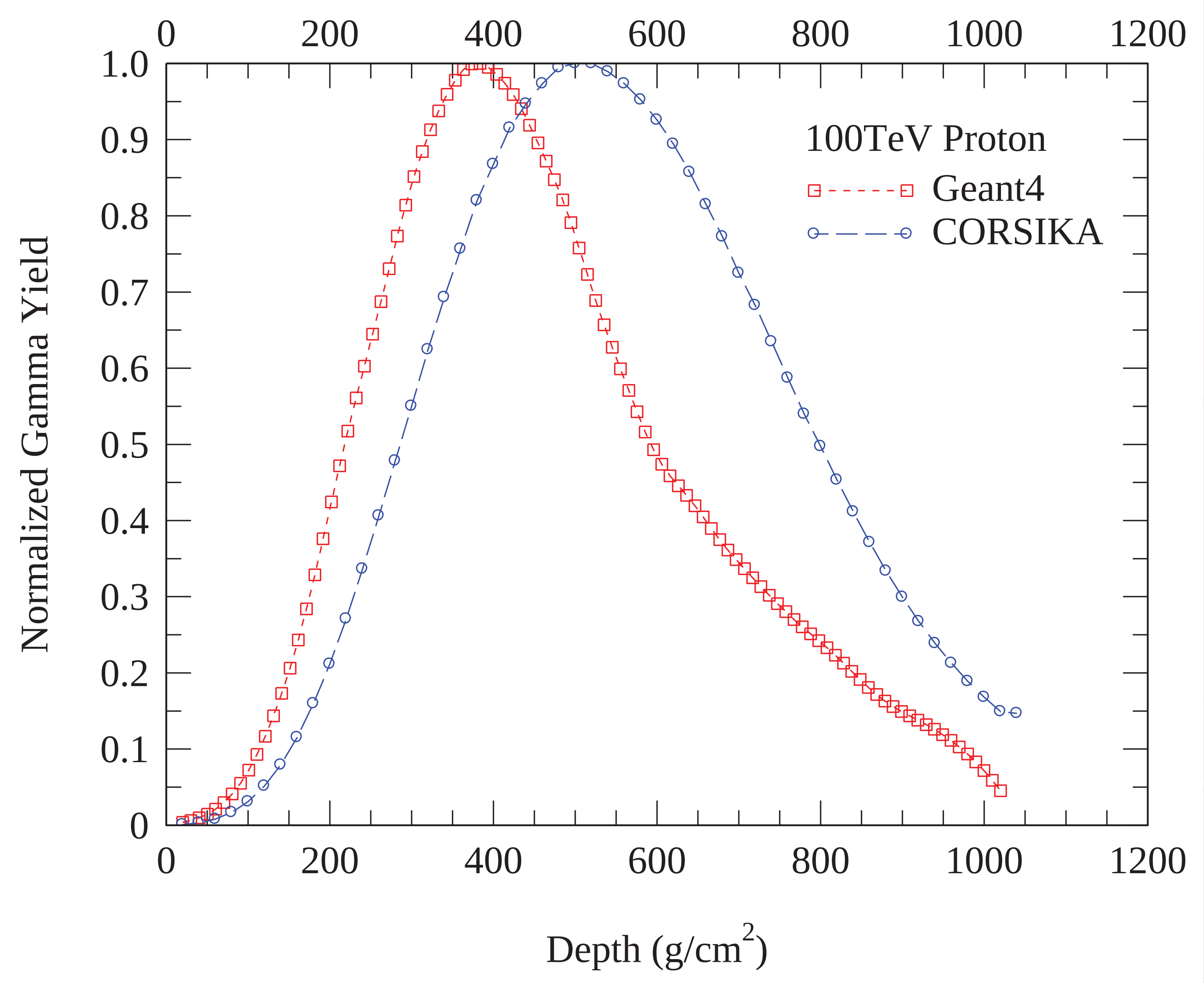


100TeV/u Iron

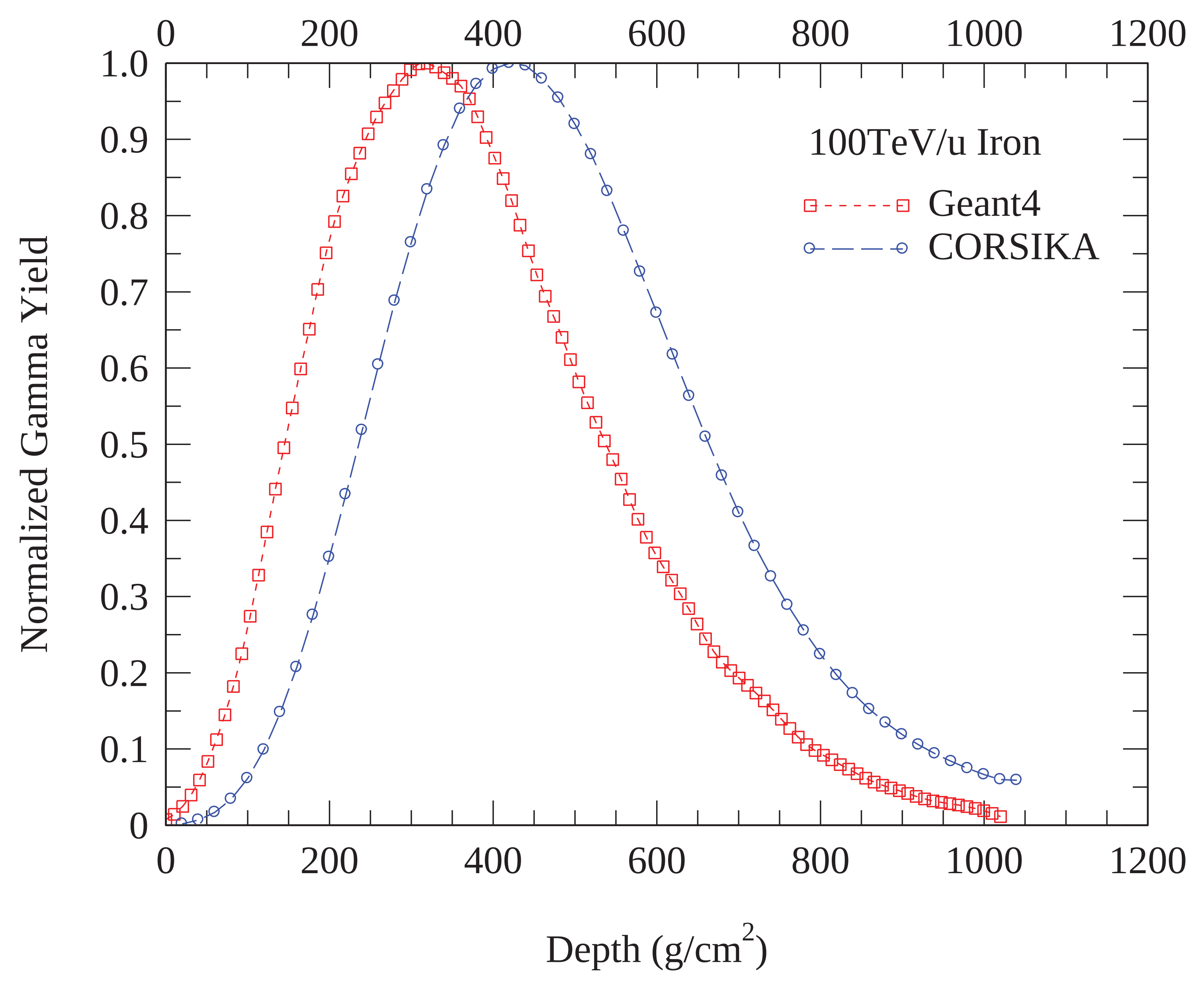
Thinning level	1E-2	1E-4	1E-6
Time (min)	21	120	380



Geant4 vs CORSIKA 100TeV Proton



Geant4 vs CORSIKA 100TeV/u Iron



Remarks

- Thinning algorithm cuts simulation time significantly
- X_{max} is not affected by thinning level
- Location of X_{max} depends on primary particle
- Preliminary calculations show that Geant4 predicts low X_{max} compared to CORSIKA:

➢ Magnetic Field

➢ Geometry

Acknowledgement

This work is supported by an appointment to the NASA Postdoctoral Program at Marshall Space Flight Center, administered by Oak Ridge Associated Universities through a contract with NASA

www.orau.org


Thank You!
Questions?