Extensive Air Shower Simulations with CORSIKA: *A review*

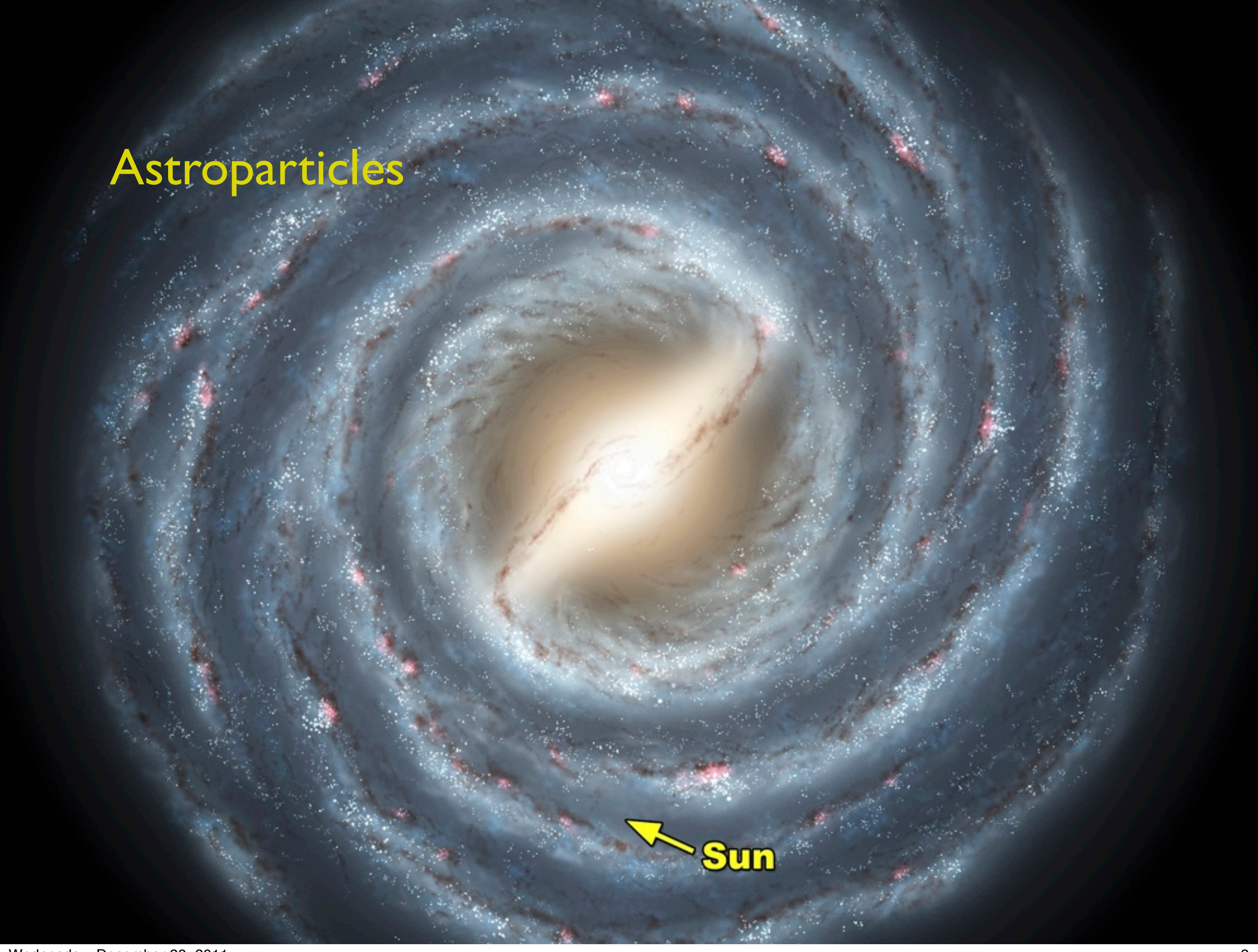
Dimitra Atri

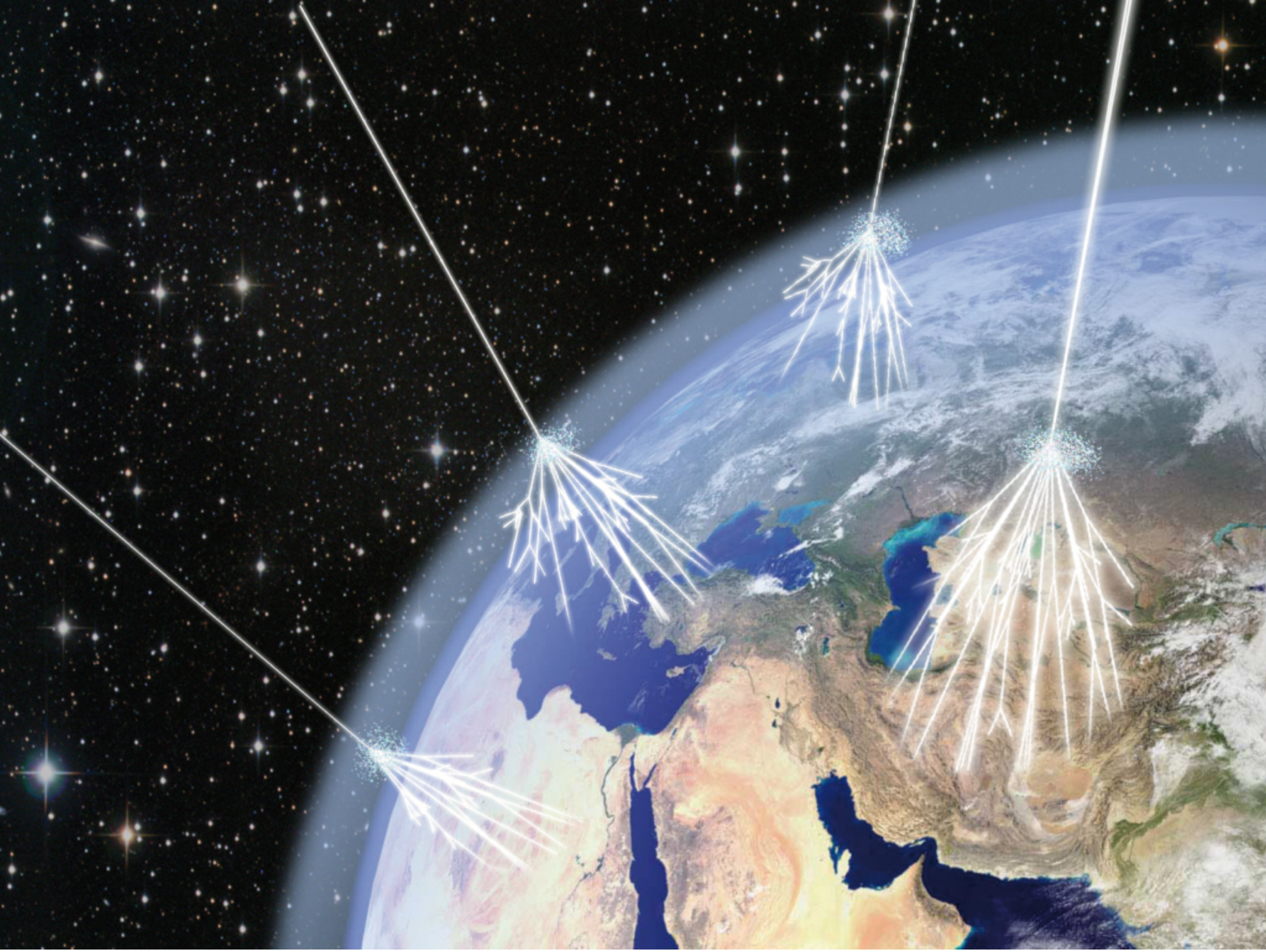
Department of High Energy Physics

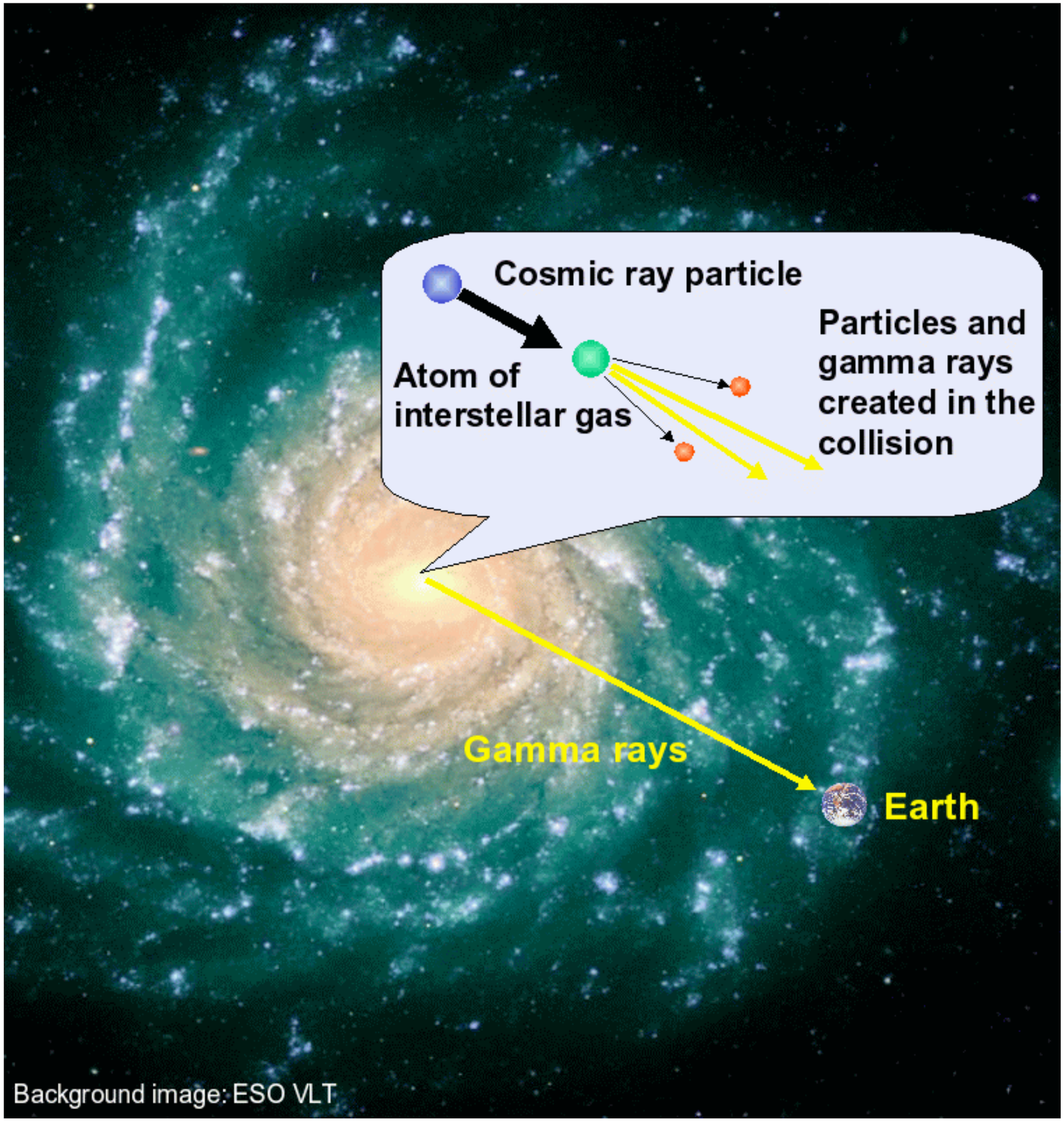
Tata Institute of Fundamental Research

atri@tifr.res.in

Astroparticles

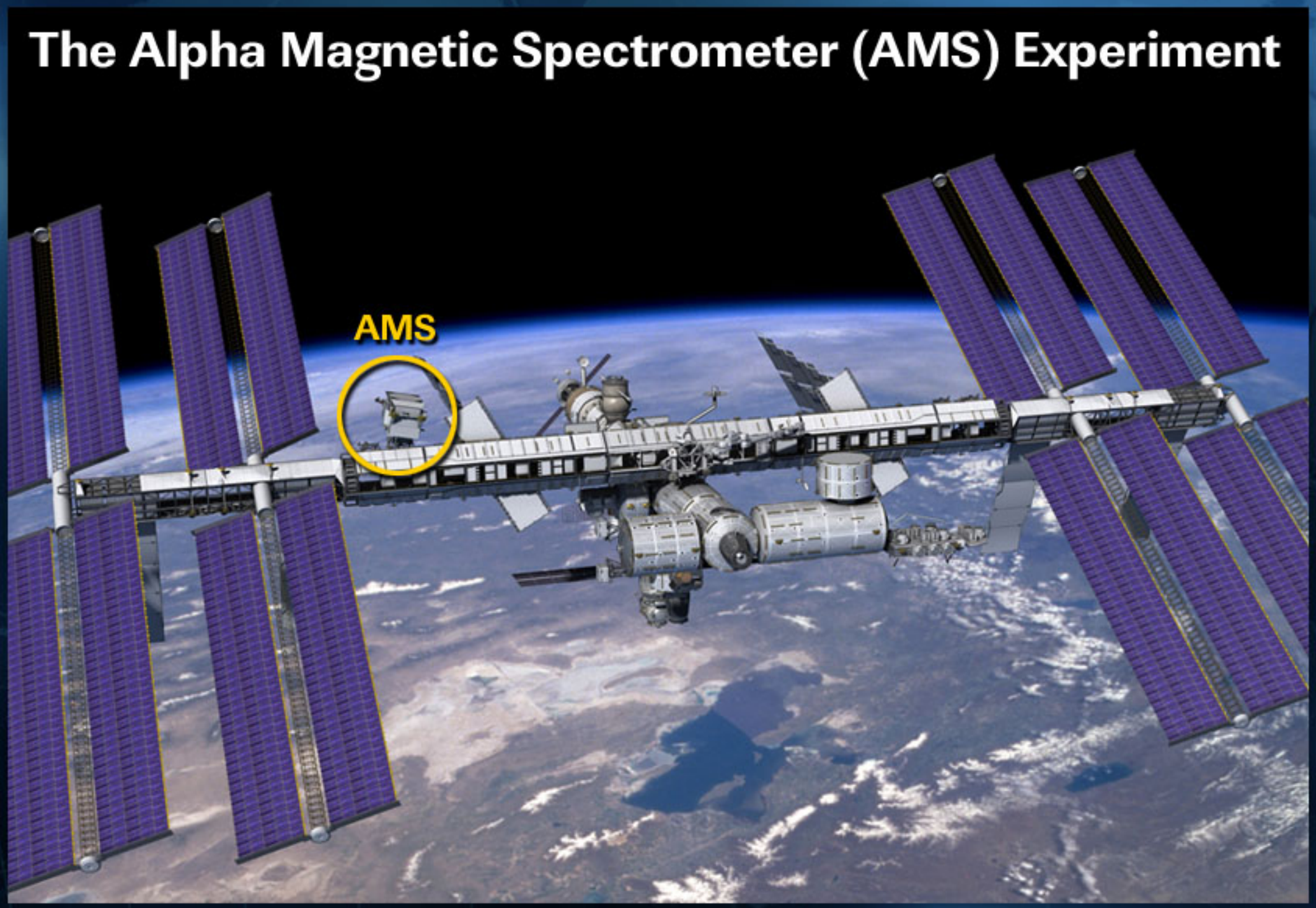




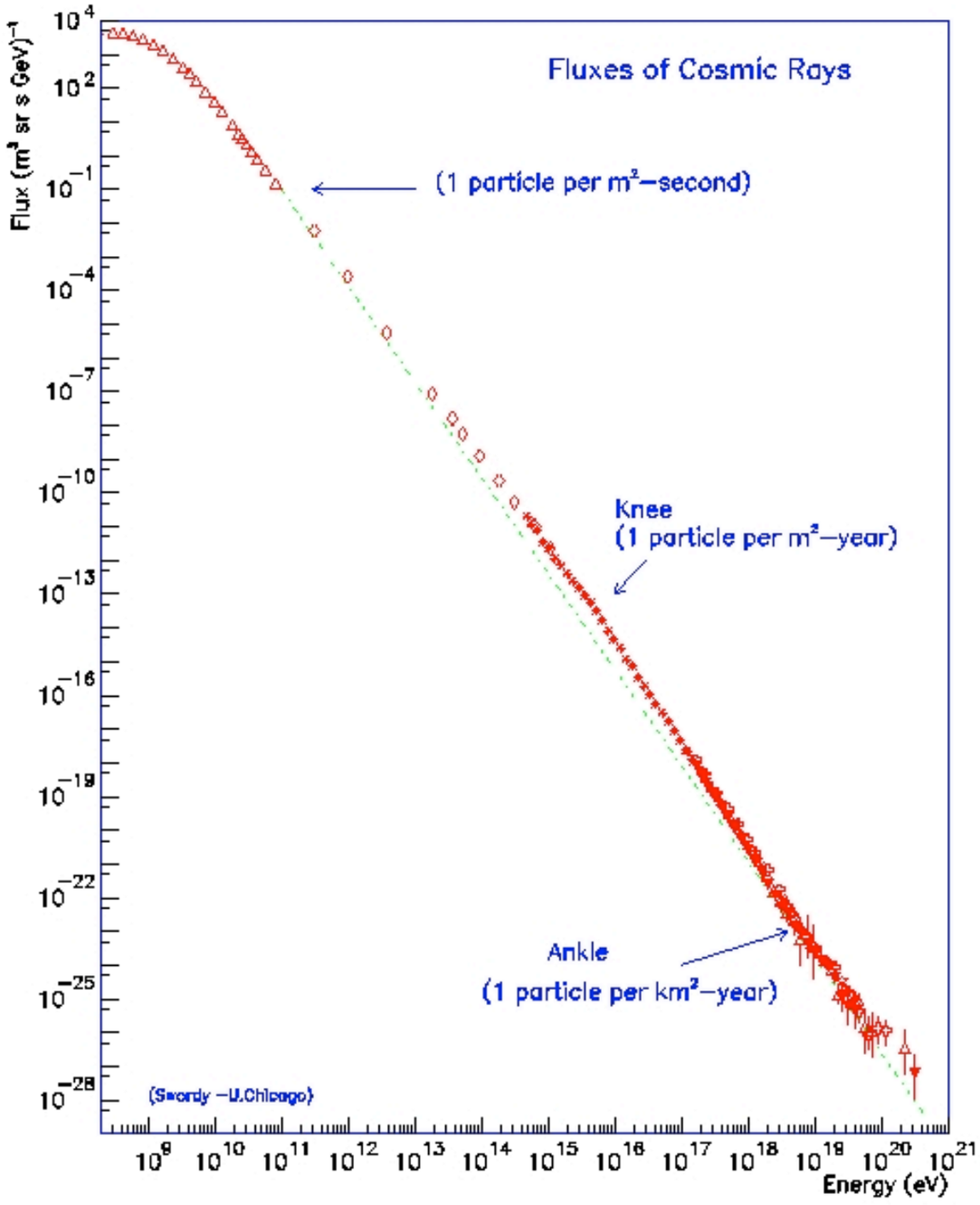

Cosmic ray particle
Atom of interstellar gas
Particles and gamma rays created in the collision
Gamma rays
Earth
Background image: ESO VLT

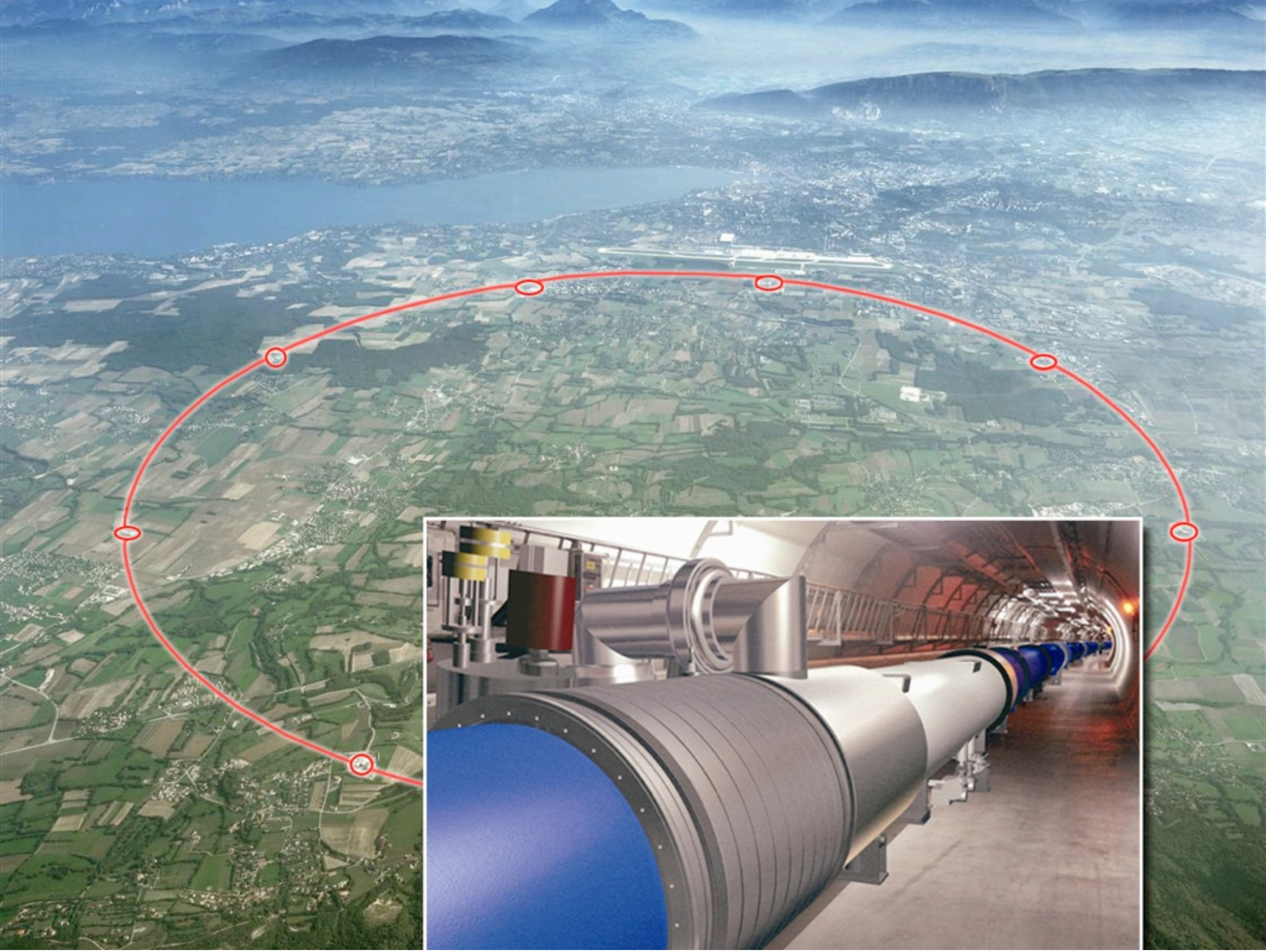
p (galactic cosmic ray) + air ⟶ What?

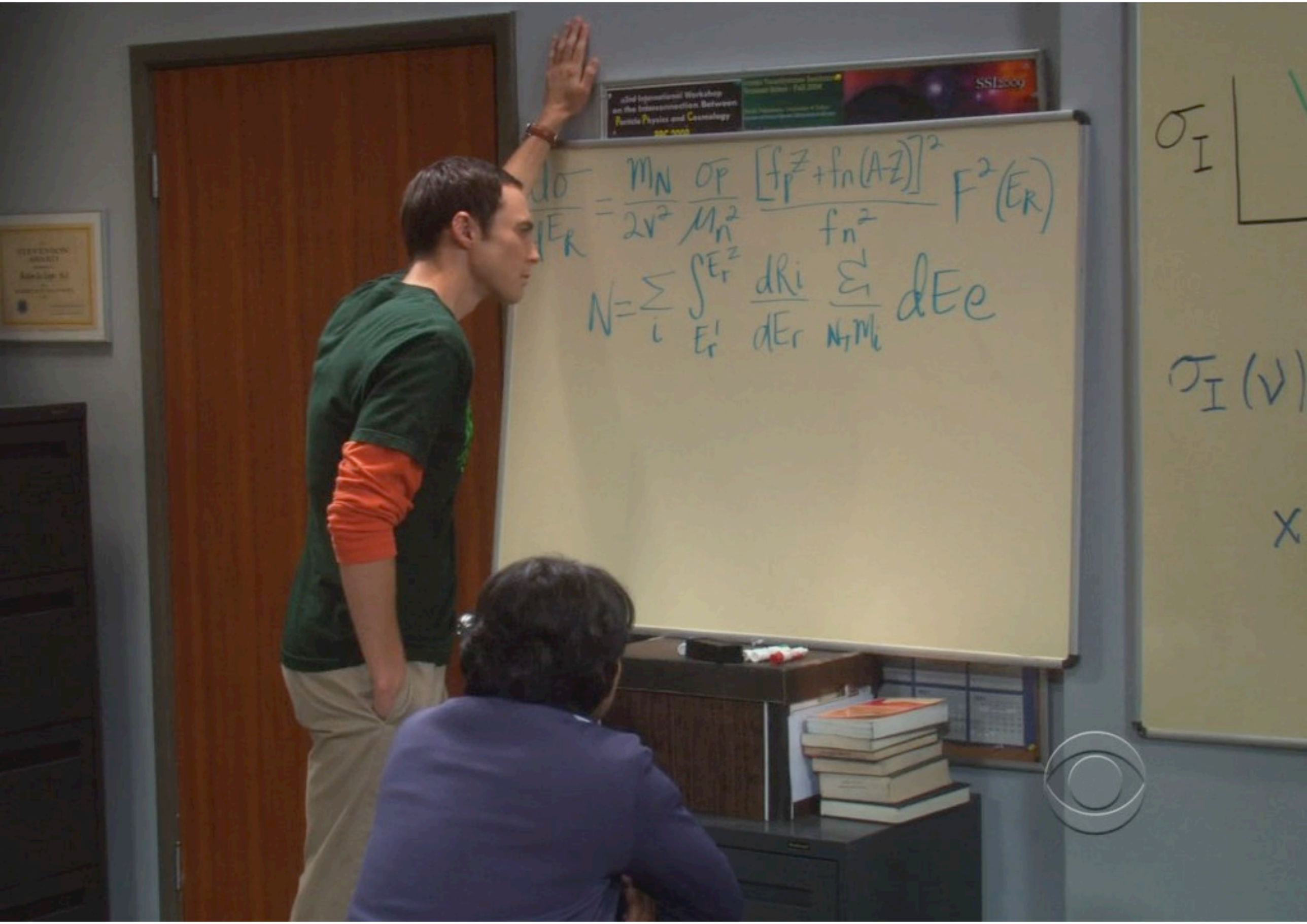
The Alpha Magnetic Spectrometer (AMS) Experiment



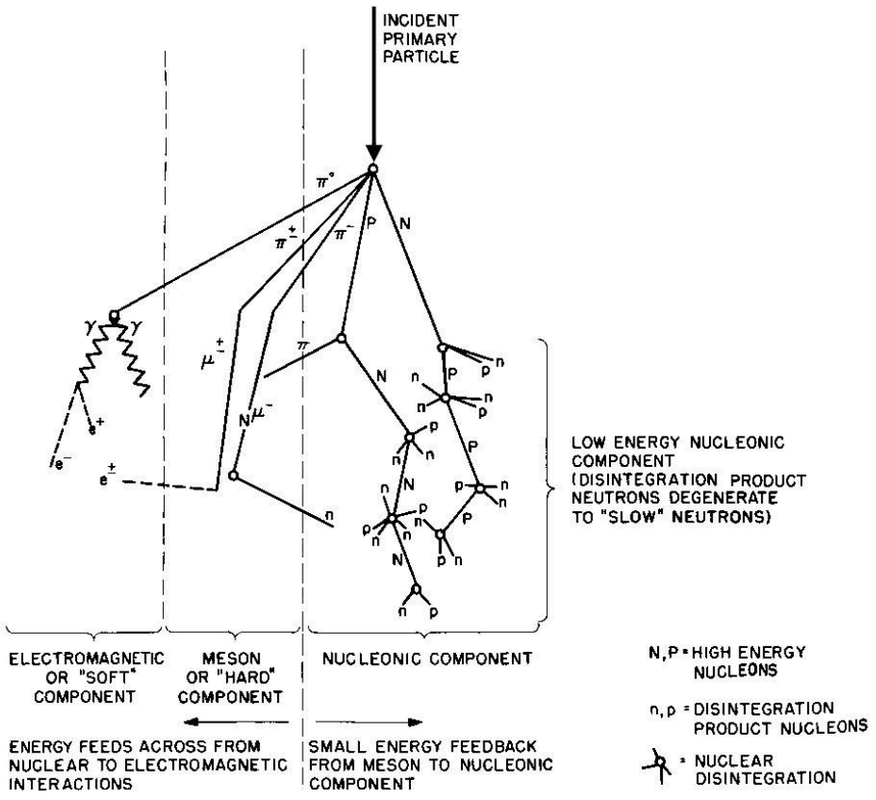
Cosmic Ray spectrum



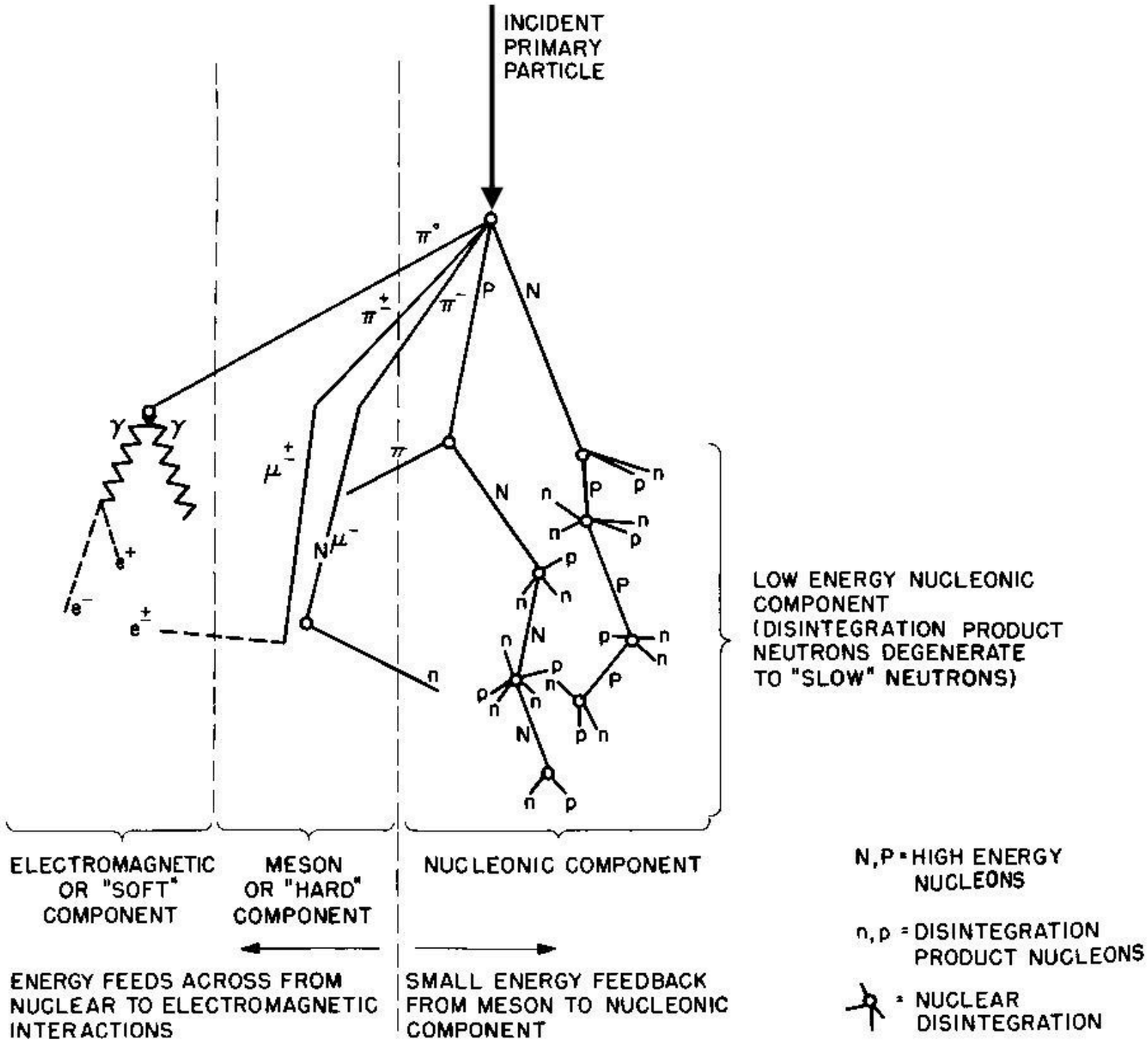



$\frac{d\sigma}{dE_R} = \frac{m_N}{2v^2} \frac{\sigma_p}{\mu_n^2} \frac{[f_p^Z + f_n(A-Z)]^2}{f_n^2} F^2(E_R)$
$N = \sum_i \int_{E_r'}^{E_r^z} \frac{dR_i}{dE_r} \frac{\Sigma_i}{N_T m_i} dE_e$
σ_I
$\sigma_I(v)$

p (galactic cosmic ray) + air ⟶ What?



Schematic Diagram of Cosmic Ray Shower



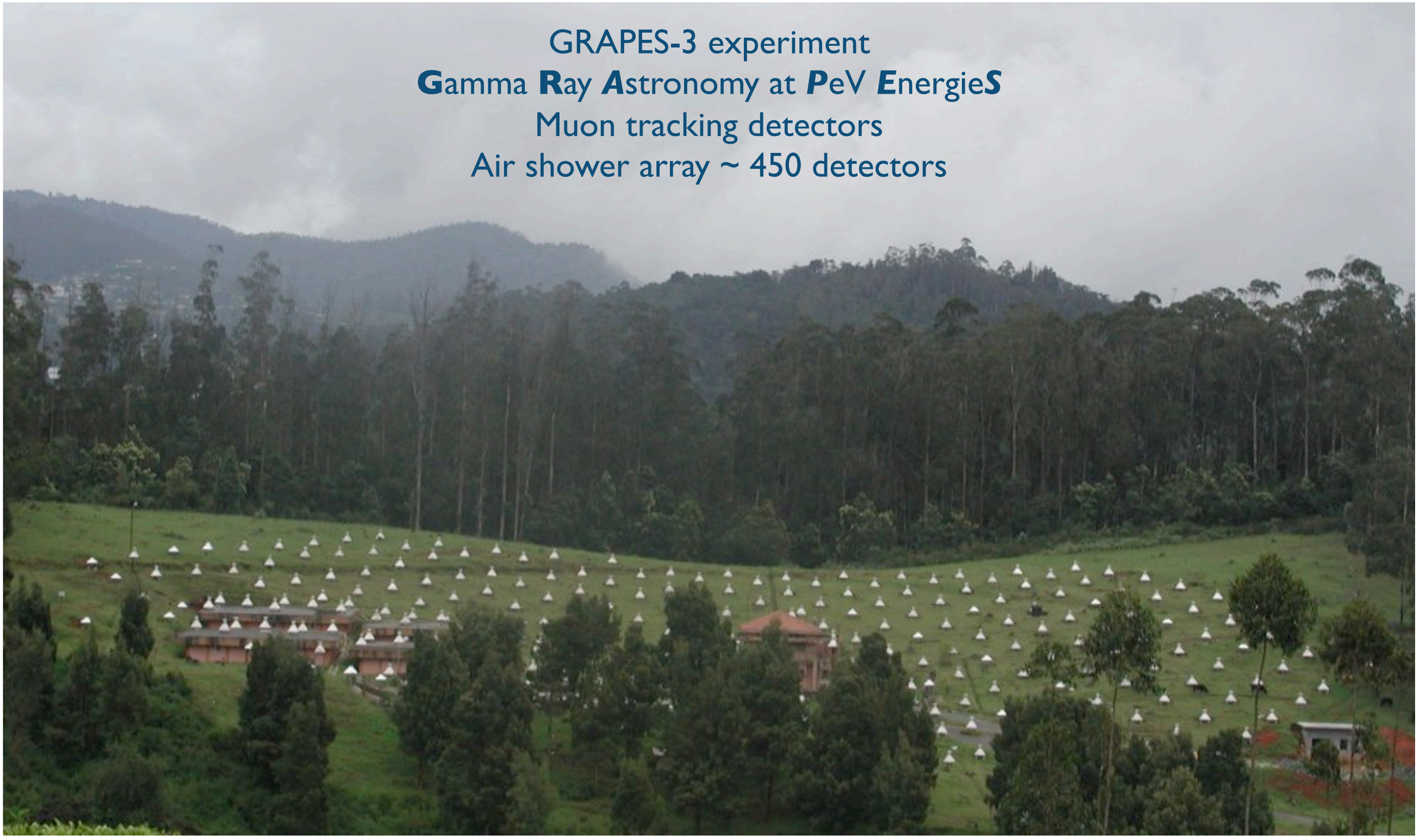
Schematic Diagram of Cosmic Ray Shower

GRAPES-3 experiment

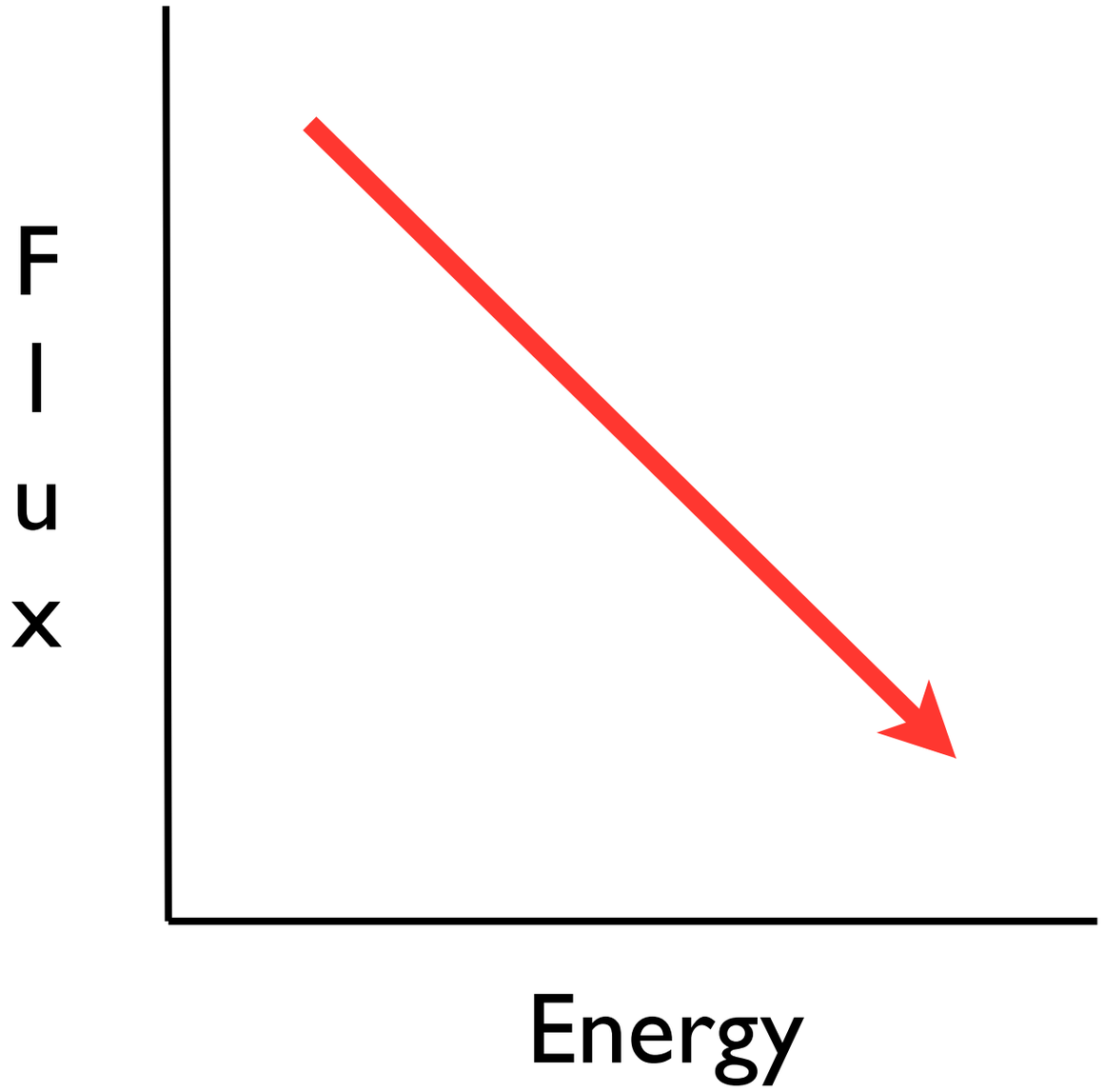
Gamma **R**ay ***A***stronomy at ***P***eV ***E***nergie***S***

Muon tracking detectors

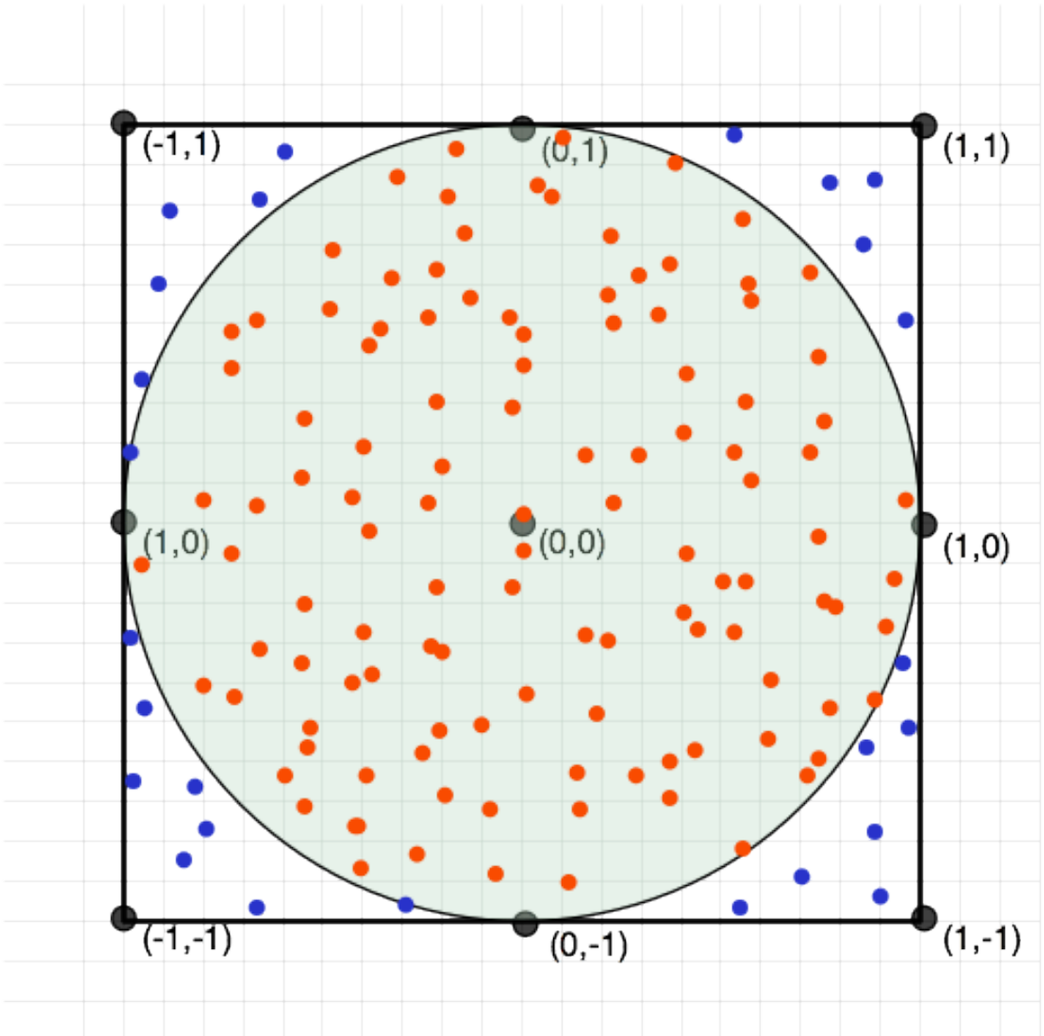
Air shower array ~ 450 detectors



Why simulations?



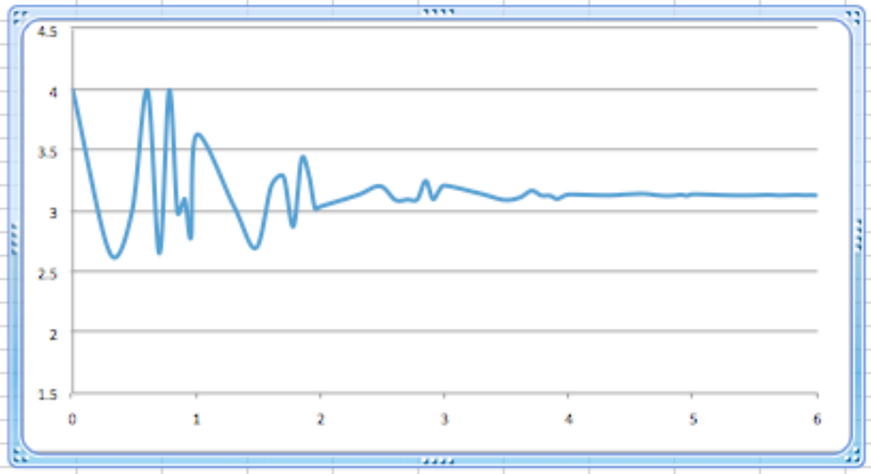
Monte Carlo Technique



n (circle) / n (square) = Area (circle) / Area (square)

Value of pi - Monte Carlo

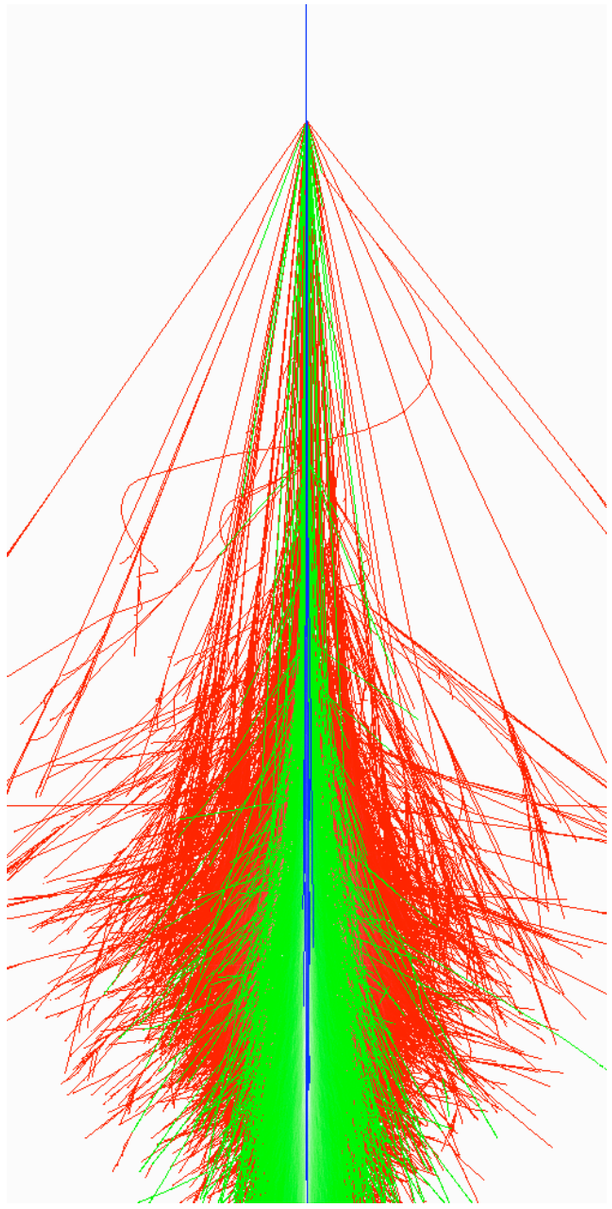
1	0	4
2	0.30103	2.6666
3	0.47712	3
4	0.60206	4
5	0.69897	2.6666
6	0.77815	4
7	0.8451	3
8	0.90309	3.1111
9	0.95424	2.8
10	1	3.6363
20	1.30103	3.0476
30	1.47712	2.7096
40	1.60206	3.2195
50	1.69897	3.2941
60	1.77815	2.8852
70	1.8451	3.4366
80	1.90309	3.3086
90	1.95424	3.0329
100	2	3.0495
200	2.30103	3.1442
300	2.47712	3.2159
400	2.60206	3.1022
500	2.69897	3.1057
600	2.77815	3.1081
700	2.8451	3.2582
800	2.90309	3.1111
900	2.95424	3.1786
1000	3	3.2207
2000	3.30103	3.1504
3000	3.47712	3.1029
4000	3.60206	3.1212
5000	3.69897	3.1777
6000	3.77815	3.1388
7000	3.8451	3.1378
8000	3.90309	3.1111
9000	3.95424	3.1325
10000	4	3.1472
20000	4.30103	3.1402
30000	4.47712	3.1488
40000	4.60206	3.153
50000	4.69897	3.1428
60000	4.77815	3.1362
70000	4.8451	3.1384
80000	4.90309	3.1451
90000	4.95424	3.1366
100000	5	3.1492
200000	5.30103	3.1405
300000	5.47712	3.1402
400000	5.60206	3.1442
500000	5.69897	3.1399
600000	5.77815	3.1422
700000	5.8451	3.1434
800000	5.90309	3.1408
900000	5.95424	3.1418
1000000	6	3.1397



Harishree, Devan, Souvik

Four parts

- General program frame handling I/O, decay of unstable particles, particle tracking, deflection by multiple scattering and geomagnetic field effects.
- ***Hadronic interactions*** of nuclei and hadrons with the air nuclei at ***higher energies.***
- ***Hadronic interactions*** at ***lower energies.***
- Transport and interaction of electrons, positrons and photons.



What is CORSIKA

- CORSIKA - COsmic Ray SImulation for KAscade (Dieter Heck, Tanguy Pierog, Johannes Knapp *et al.*)

- Detailed Monte Carlo program to study the evolution and properties of extensive air showers in the atmosphere.

- Initially developed to perform simulations for the KASCADE experiment at Karlsruhe in Germany.

- Simulates particle interactions in an air shower.

- **Photon interaction -**

- Photoelectric - important only at very low energies compared to the binding energy of atomic electrons

- Compton effect - important at few MeVs

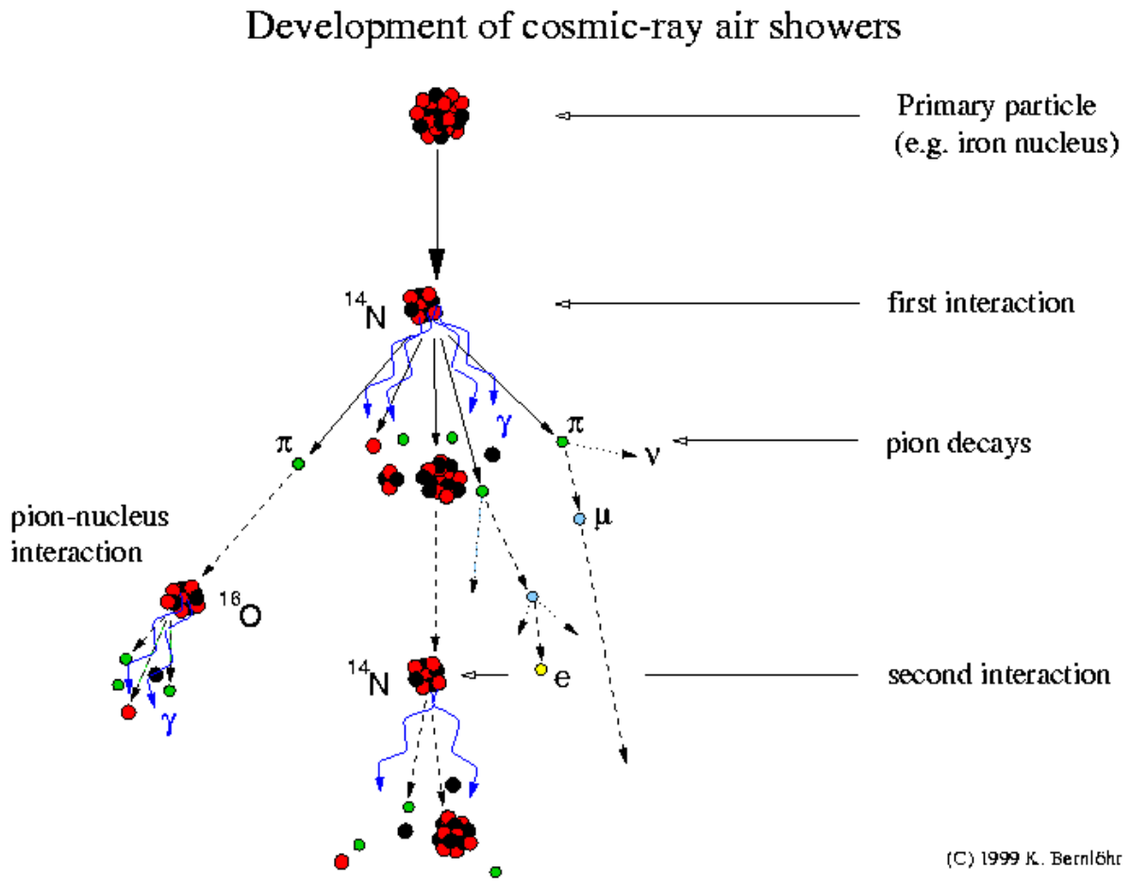
- Pair production - E > 1 MeV - photon interacting with the coulomb field of the nucleus - pair creation probability is independent of the energy of the photon

- Depends only on the fraction of energy (v) taken by one of the pair. (E(electron) = v E(photon)

- **Electron interaction -**

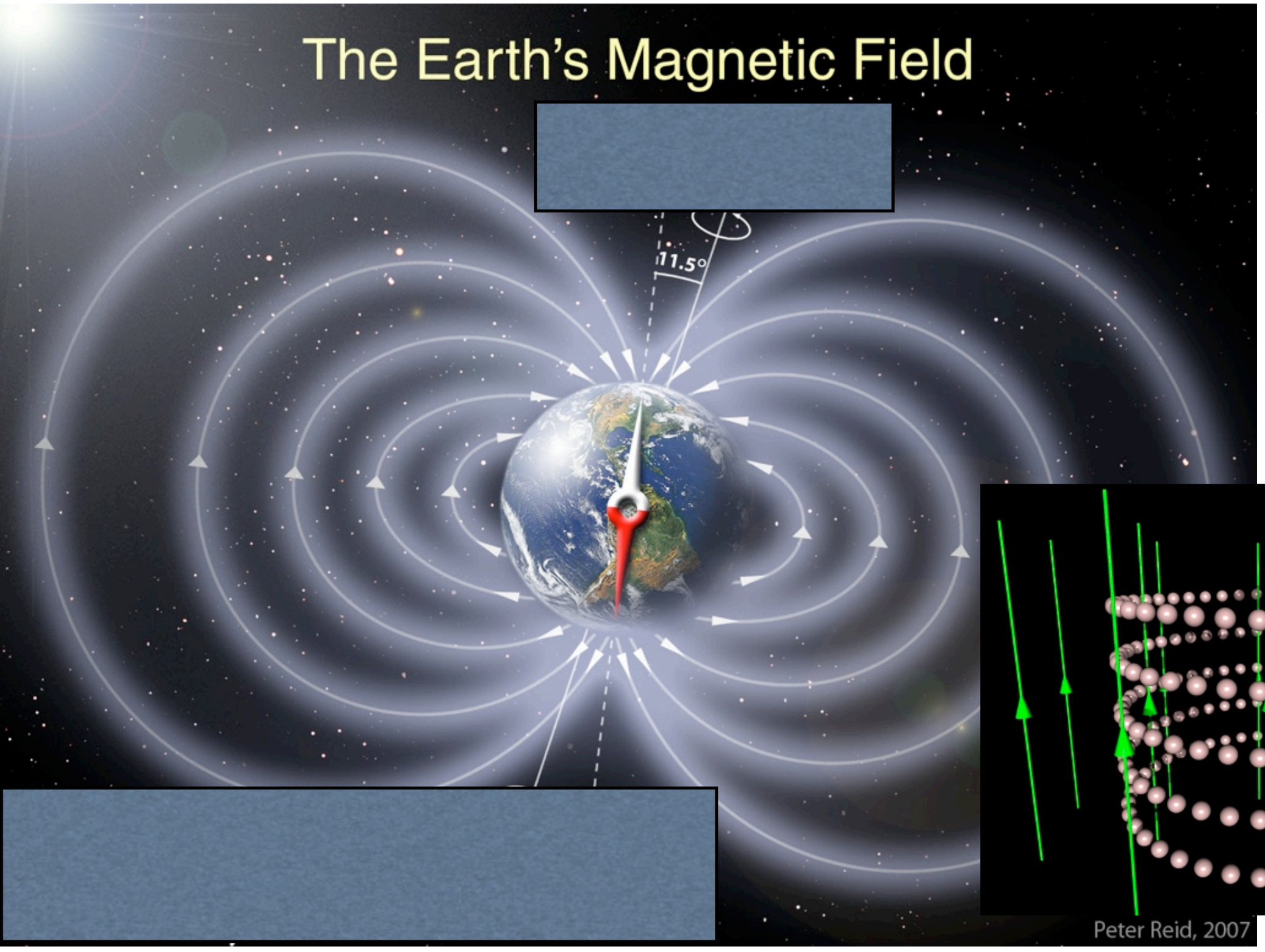
- Ionization - Bethe-Bloch Equation - dE/dx ~ density of the target

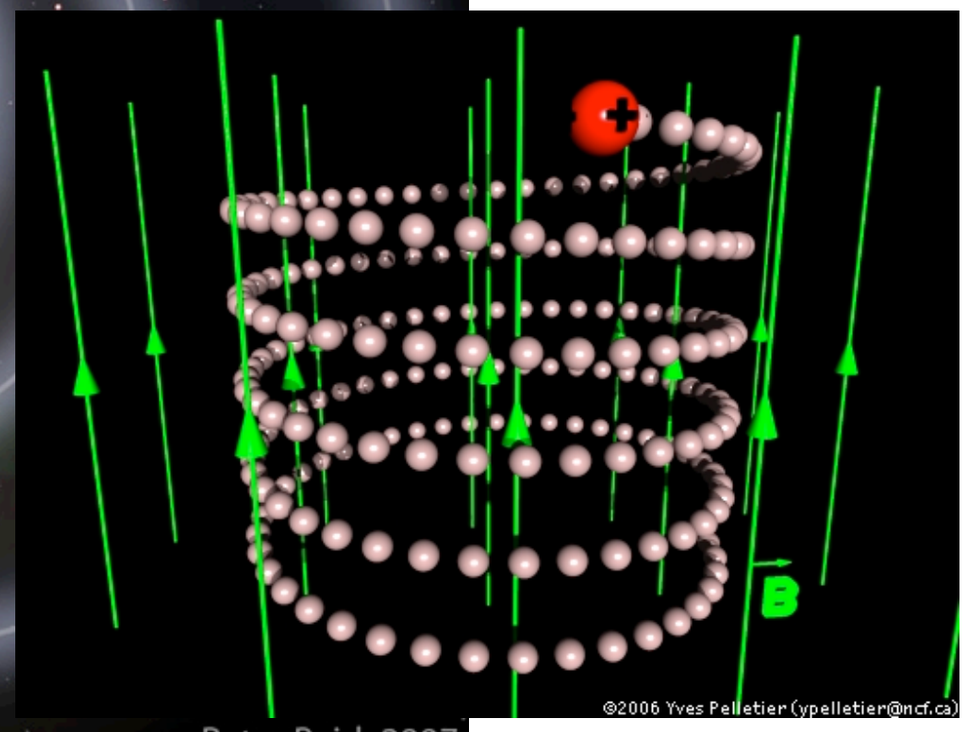
- Bremsstrahlung - radiation associated with the acceleration of electrons in the electrostatic field of ions and the nuclei of atoms



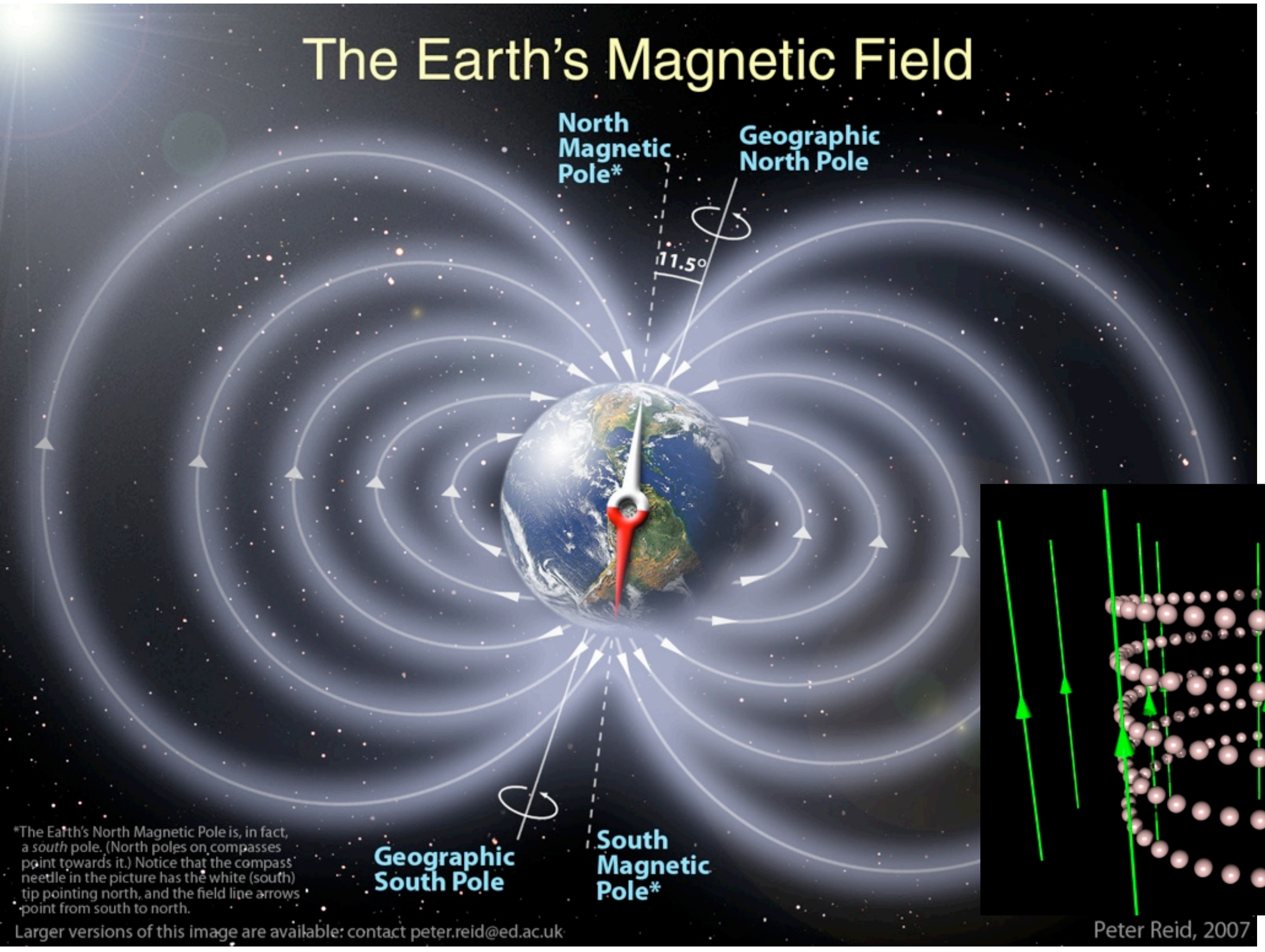
- A ⟶ B (decay)
- A + X ⟶ C (interaction)

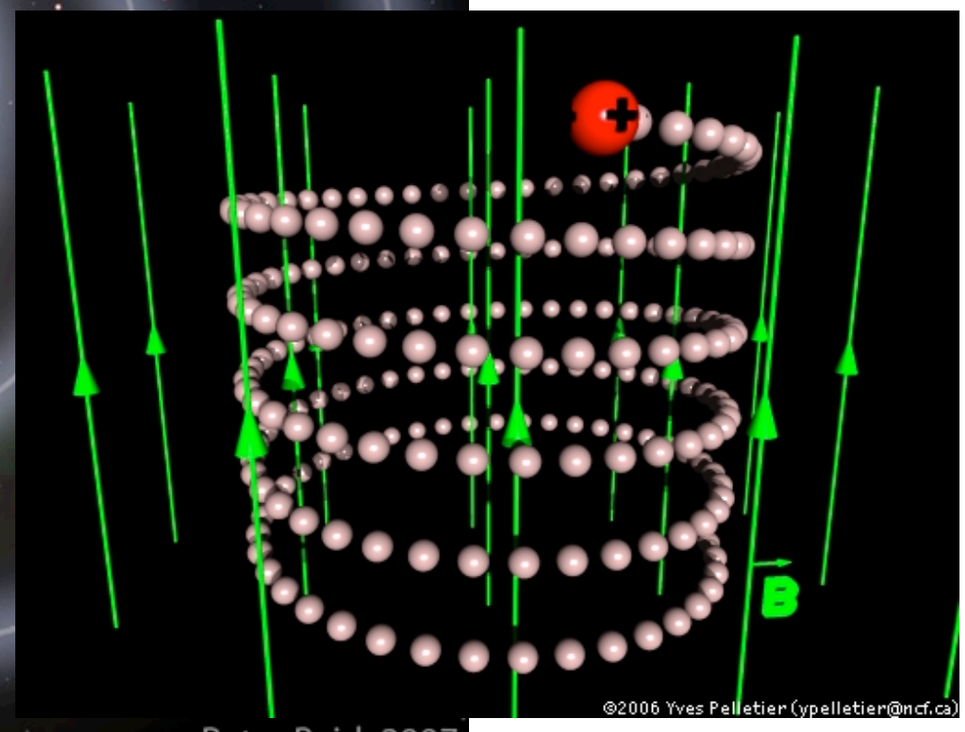
Charged particles in geomagnetic field





Charged particles in geomagnetic field



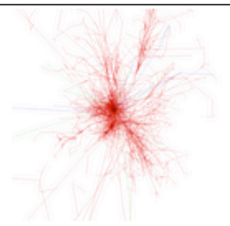
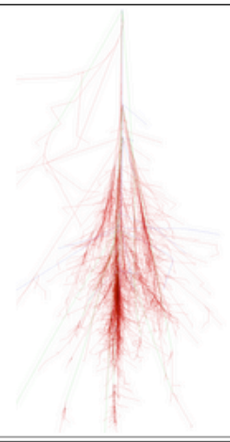
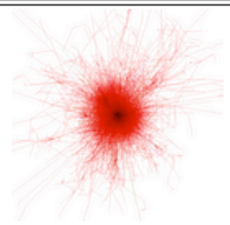
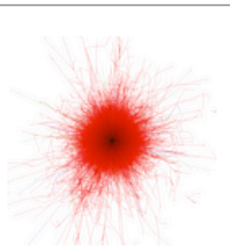
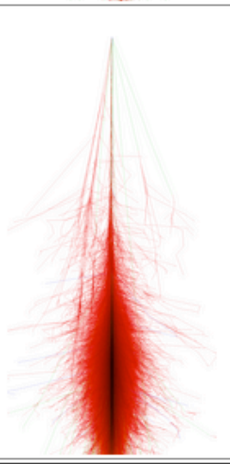
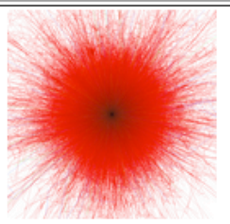
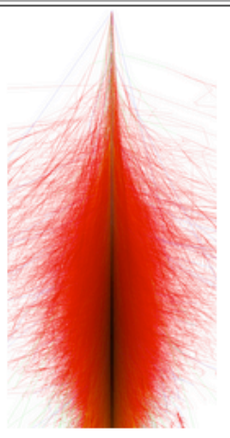


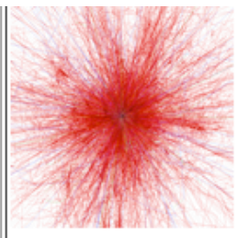
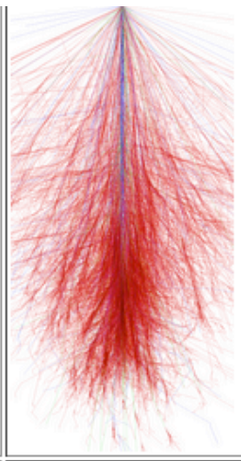
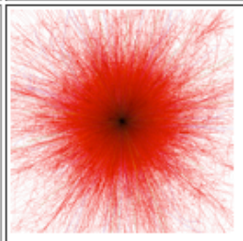
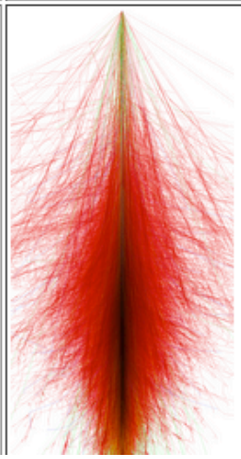
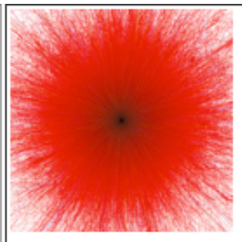
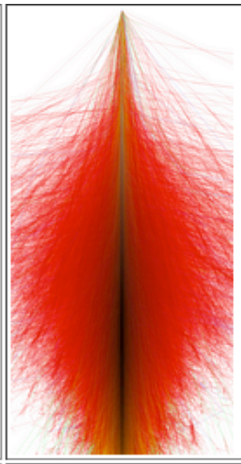
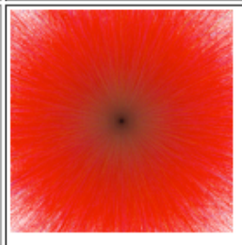
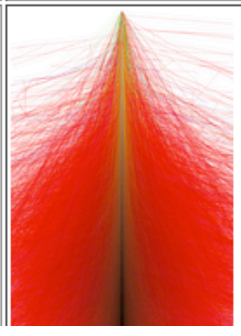
Terminal — nano — 106×47

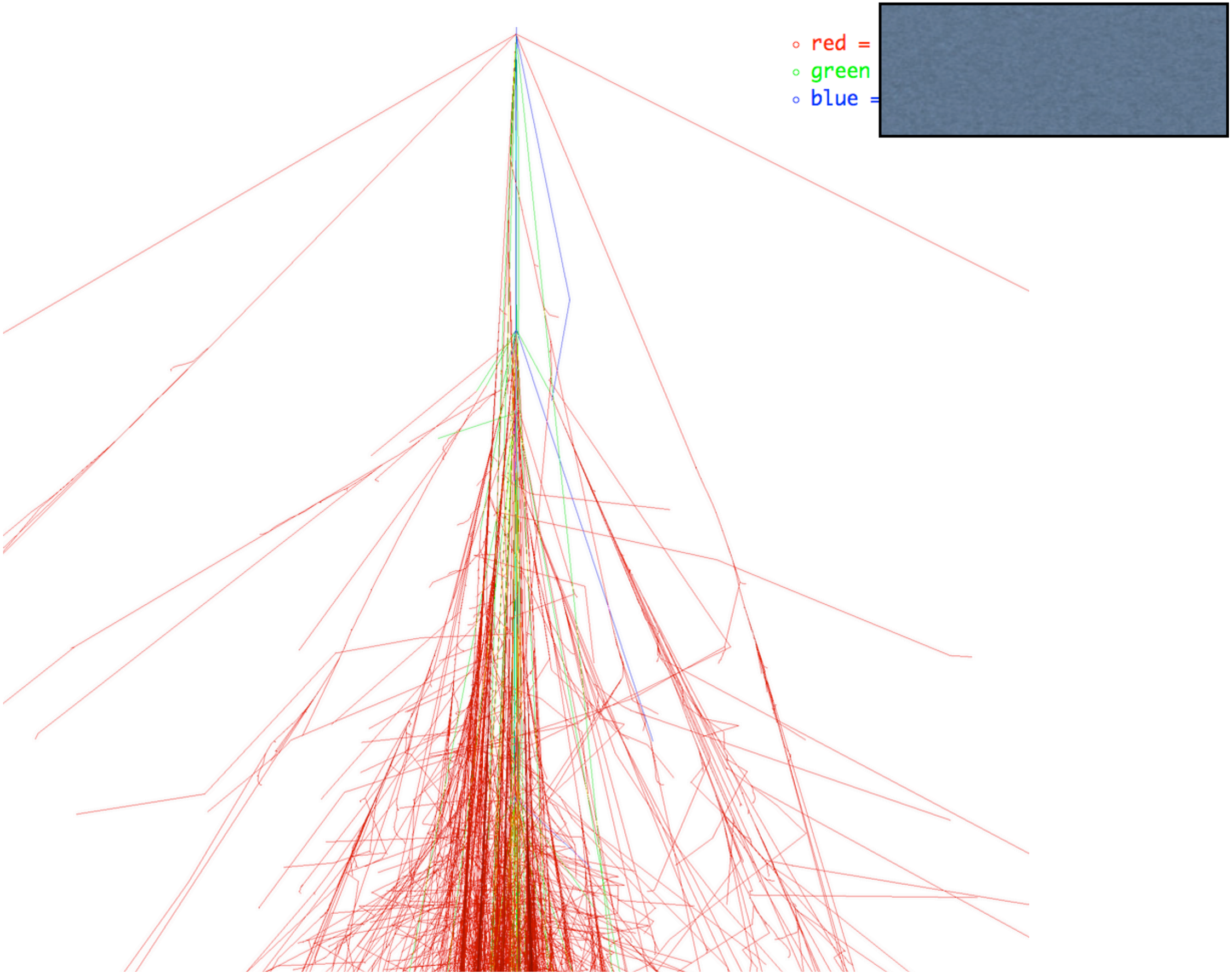
```
 GNU nano 2.0.6                File: all-inputs

RUNNR   1                              run number
EVTNR   1                              number of first shower event
NSHOW   1                              number of showers to generate
PRMPAR  14                             particle type of prim. particle
ESLOPE  -2.7                           slope of primary energy spectrum
ERANGE  1.E3  1.E3                     energy range of primary particle
THETAP  20.  20.                       range of zenith angle (degree)
PHIP    -180.  180.                    range of azimuth angle (degree)
SEED    1   0   0                      seed for 1. random number sequence
SEED    2   0   0                      seed for 2. random number sequence
OBSLEV  110.E2                         observation level (in cm)
FIXCHI  0.                             starting altitude (g/cm**2)
MAGNET  20.0  42.8                     magnetic field centr. Europe
HADFLG  0  0  0  0  0  2               flags hadr.interact.&fragmentation
ECUTS   0.3  0.3  0.003  0.003         energy cuts for particles
MUADDI  T                              additional info for muons
MUMULT  T                              muon multiple scattering angle
ELMFLG  T   T                          em. interaction flags (NKG,EGS)
STEPFC  1.0                            mult. scattering step length fact.
RADNKG  200.E2                         outer radius for NKG lat.dens.distr.
ARRANG  0.                             rotation of array to north
LONGI   T  20.  T  T                   longit.distr. & step size & fit & out
ECTMAP  1.E3                           cut on gamma factor for printout
MAXPRT  100                            max. number of printed events
DIRECT  ./                             output directory
DATBAS  T                              write .dbase file
PAROUT  T F                            write DAT file
USER    you                            user
DEBUG   F  6  F  1000000               debug flag and log.unit for out
EXIT                                   terminates input

^G Get Help   ^O WriteOut   ^R Read File   ^Y Prev Page   ^K Cut Text   ^C Cur Pos
^X Exit       ^J Justify    ^W Where Is    ^V Next Page   ^U UnCut Text ^T To Spell
```

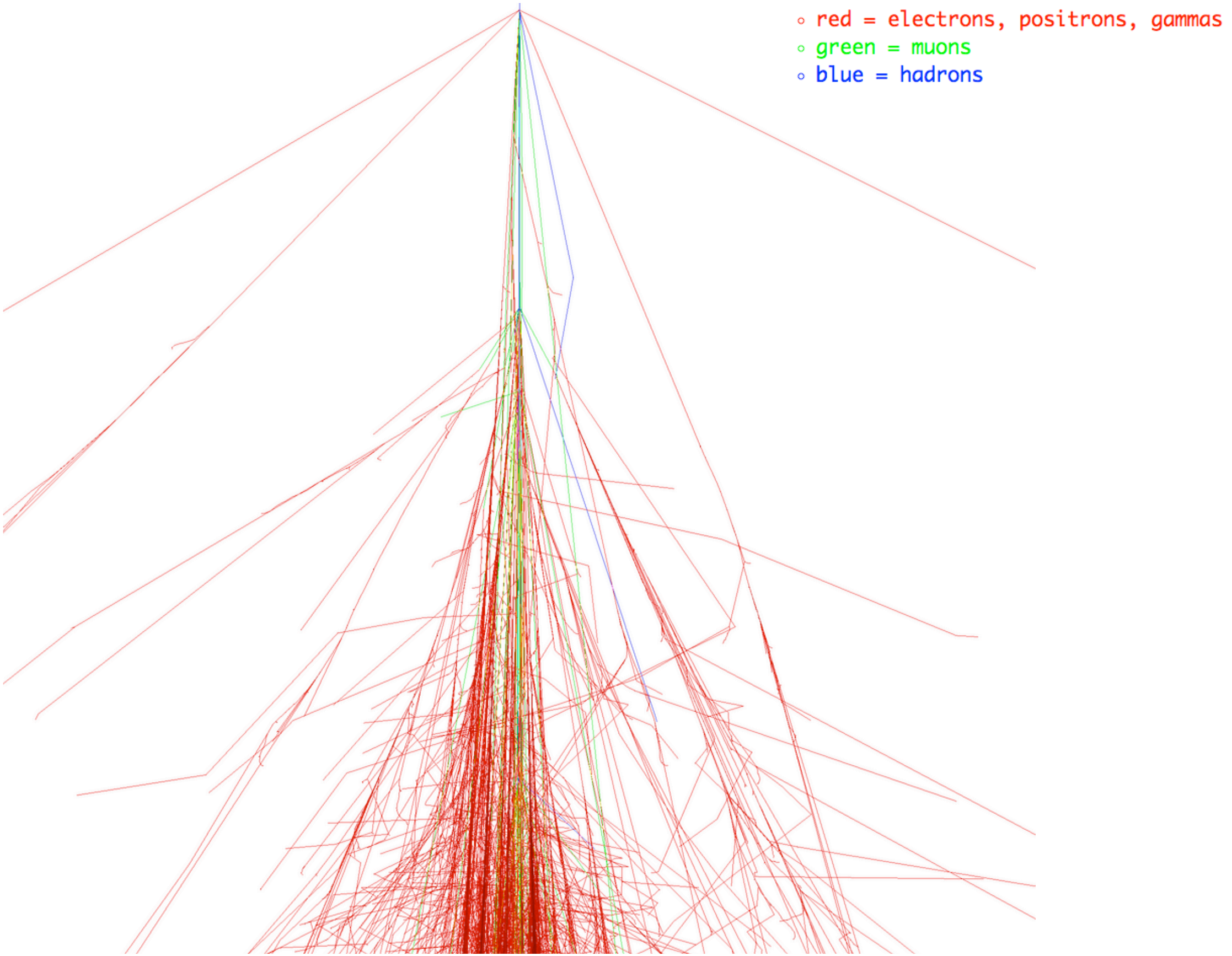
CORSIKA OUTPUT

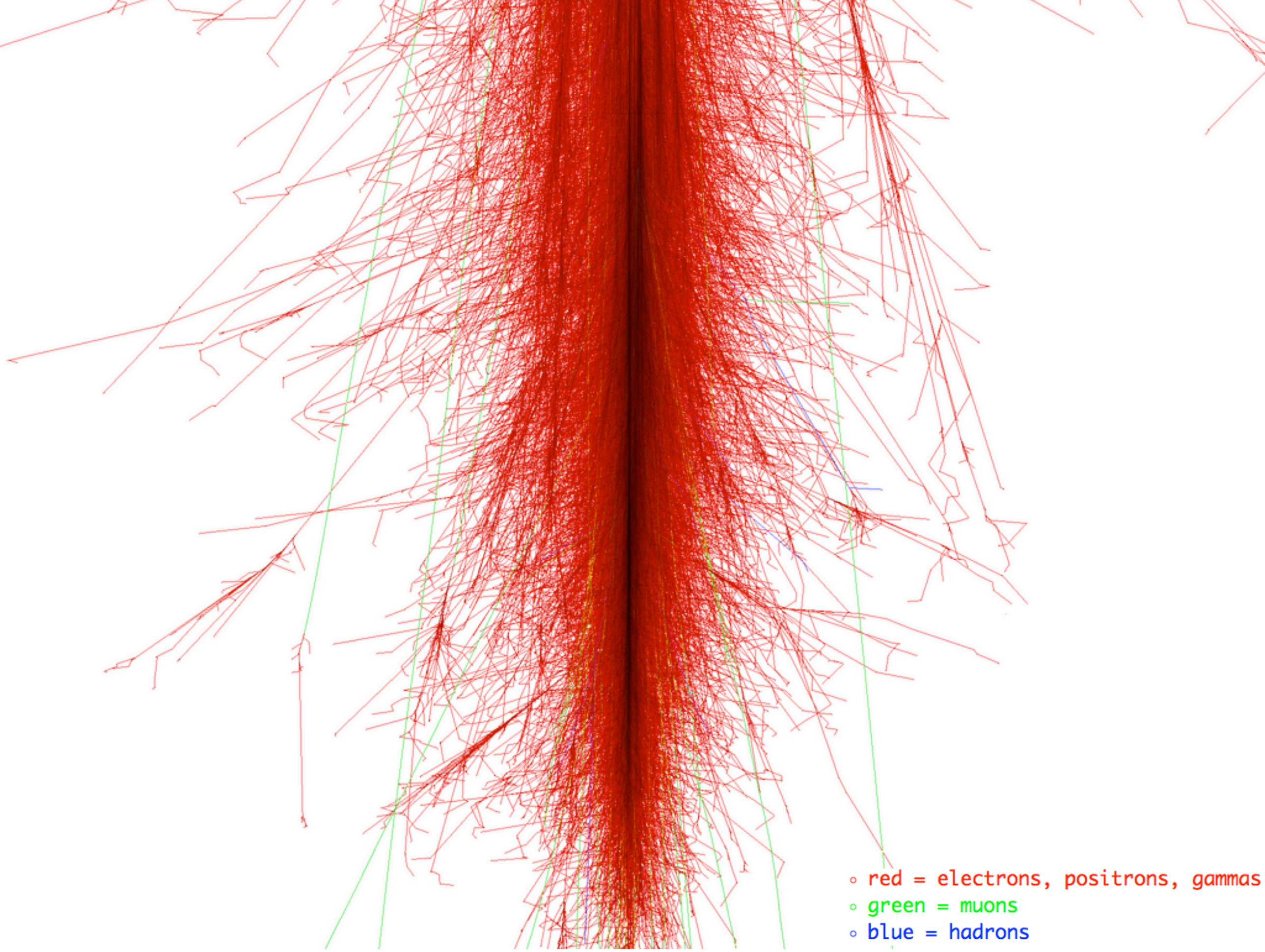
```
mss 0/0> ls -lh
total 64K
-rw-r----- 1 dimitra drx common  AR 203M Sep 28  2010 DAT000001
-rw-r----- 1 dimitra drx common  AR 1.6K Sep 28  2010 DAT000001.dbase
-rw-r----- 1 dimitra drx common  AR 836M Sep 28  2010 DAT000001.long
-rw-r----- 1 dimitra drx common  AR 9.5G Sep 28  2010 DAT000001.tab
mss 0/0>
```

Proton	10^11 (100 GeV)	0 deg		
Proton	10^12 (1 TeV)	0 deg		
Proton	10^13 (10 TeV)	0 deg		
Proton	10^14	0 deg		

Iron (56)	10^12 (1 TeV)	0 deg		
Iron (56)	10^13 (10 TeV)	0 deg		
Iron (56)	10^14	0 deg		
Iron (56)	10^15	0 deg		


red =
green
blue =


red = electrons, positrons, gammas
green = muons
blue = hadrons


red = electrons, positrons, gammas
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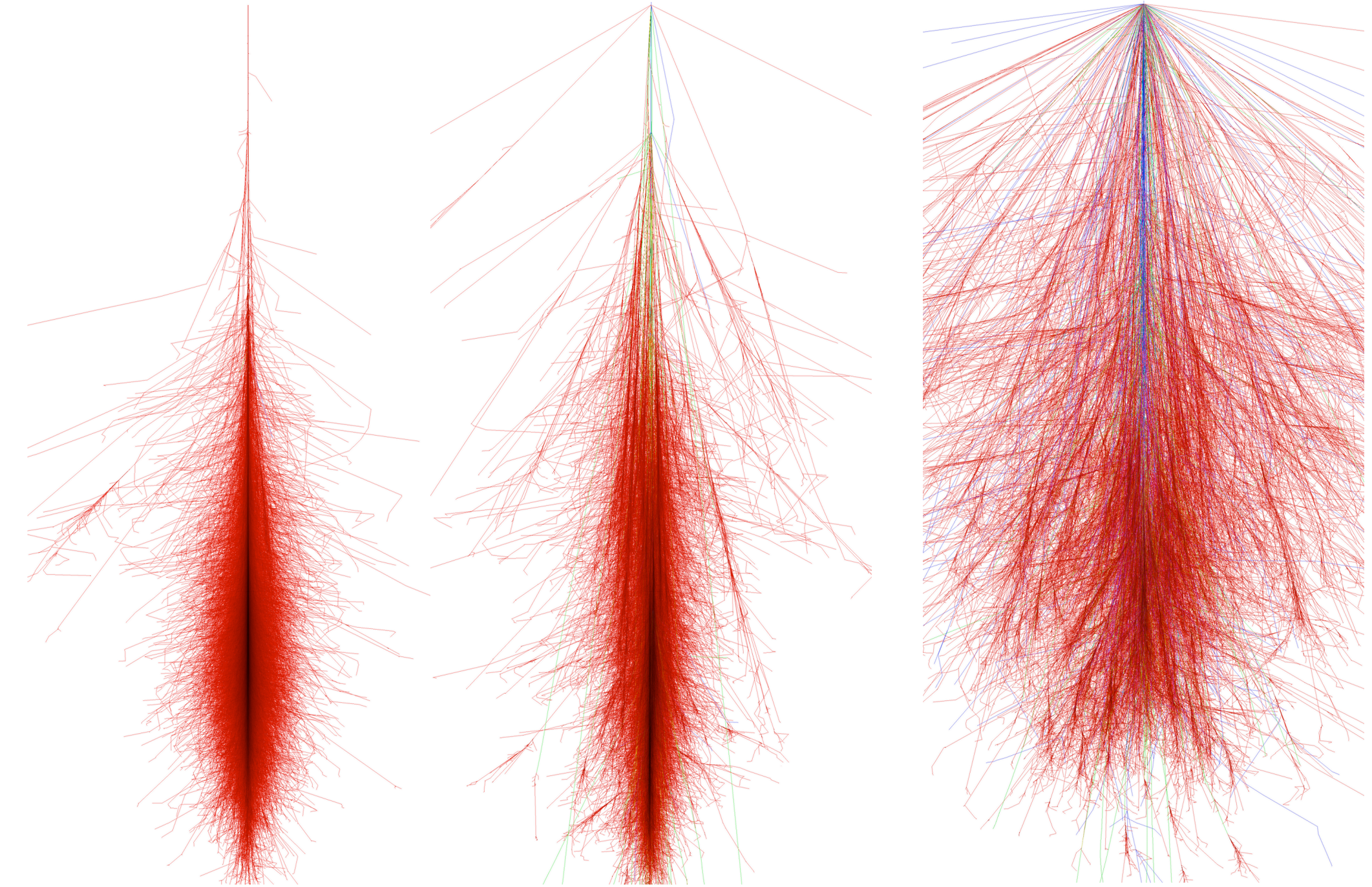
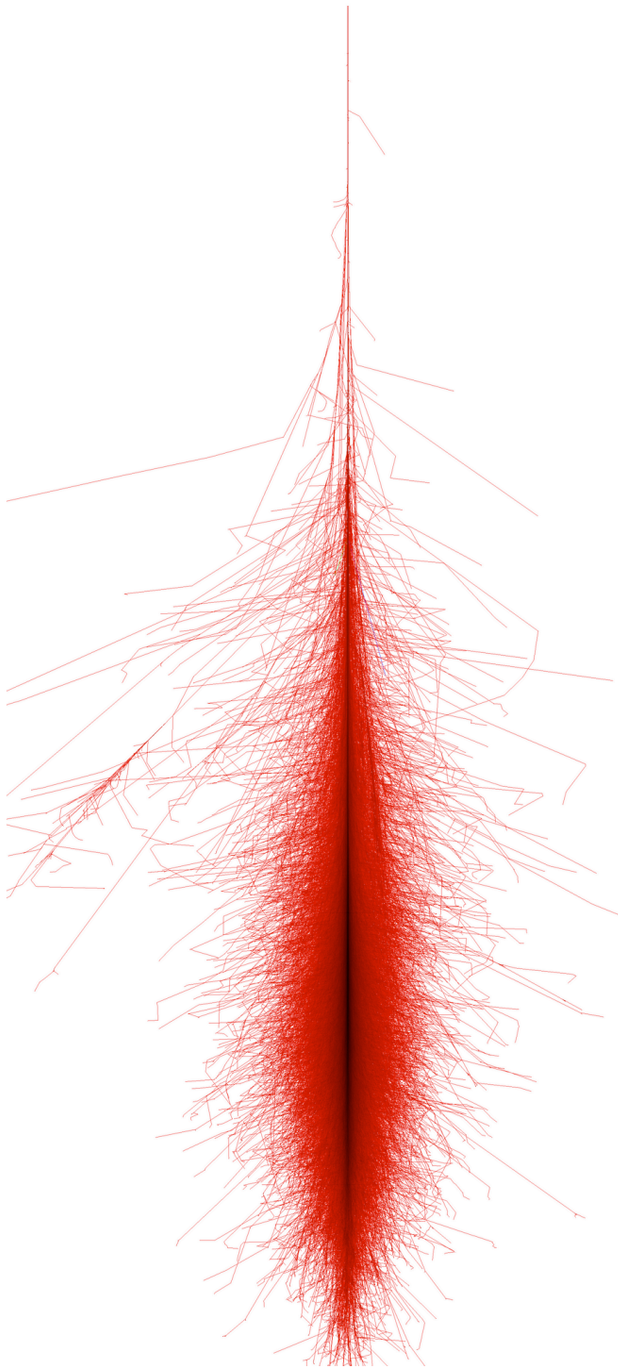
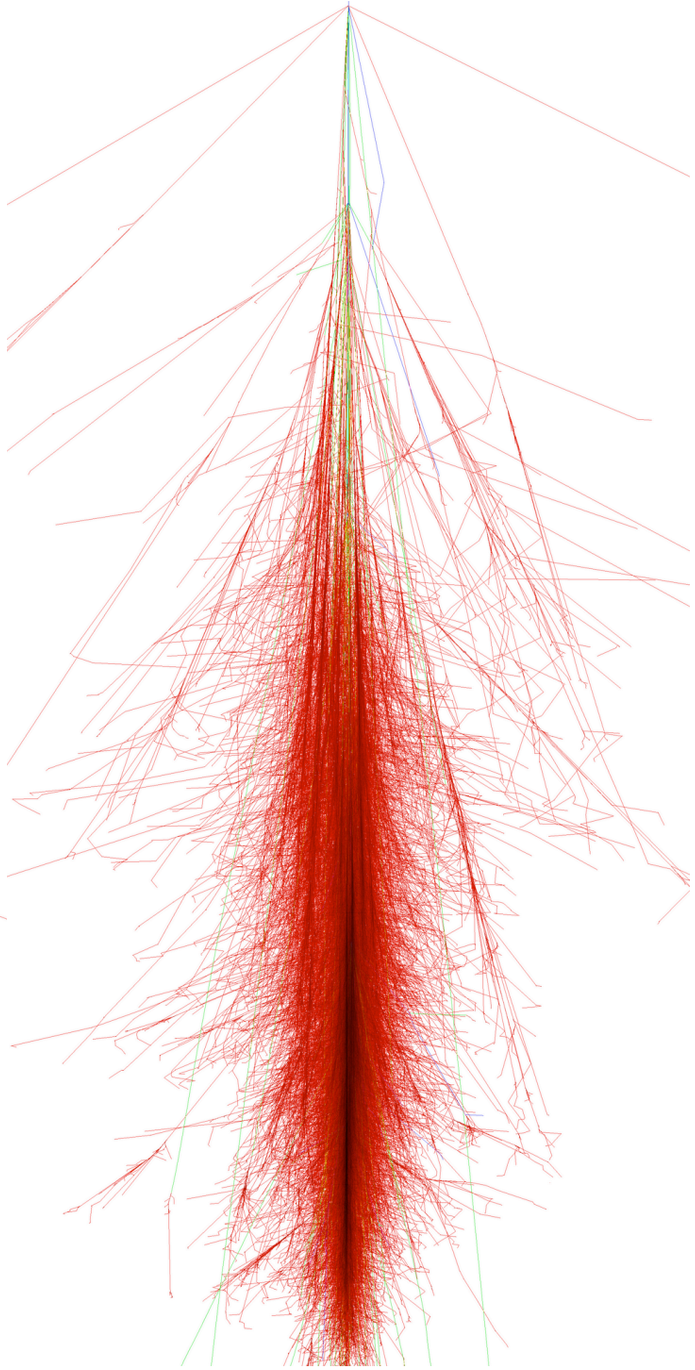


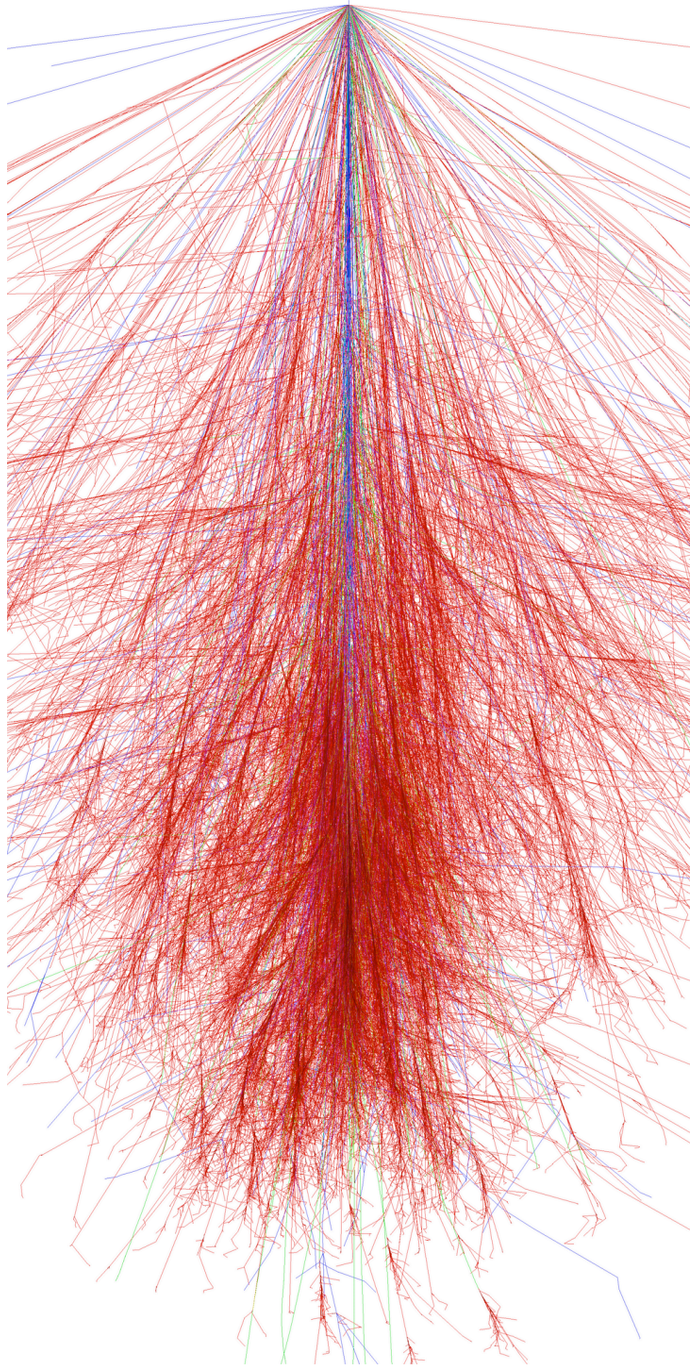
photon



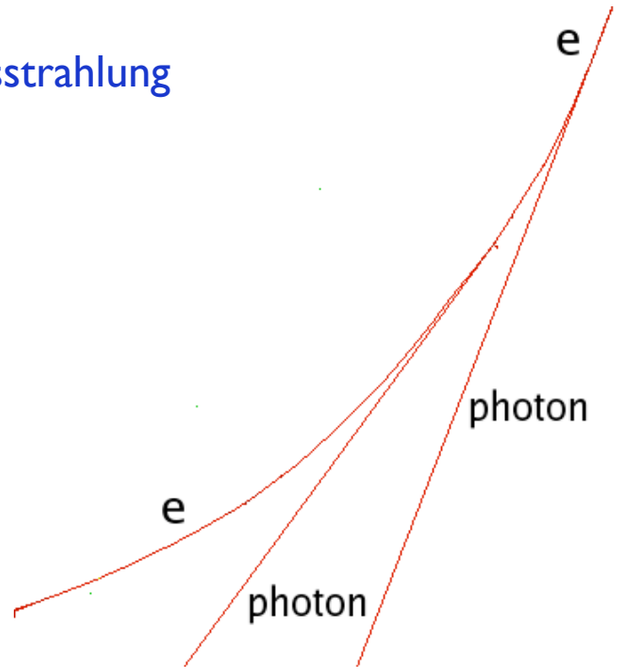
proton



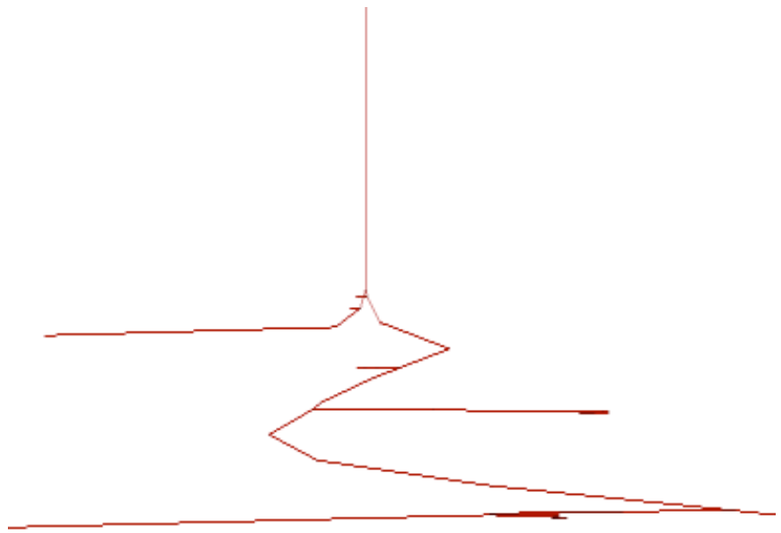
Fe (56)

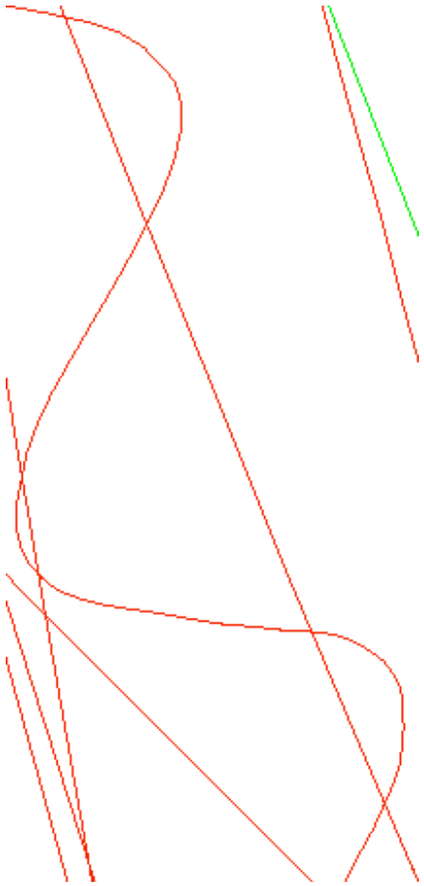


Bremsstrahlung



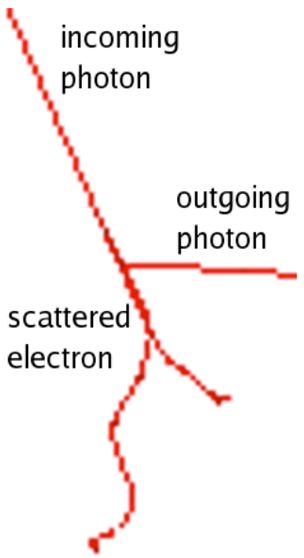
Pair production





Deflection in Earth's magnetic field

Compton scattering



Student projects

Conducted by Hariharan and myself. Thanks to Ajay Singh (Bose Inst.) for the necessary arrangements!

20 students (so far)

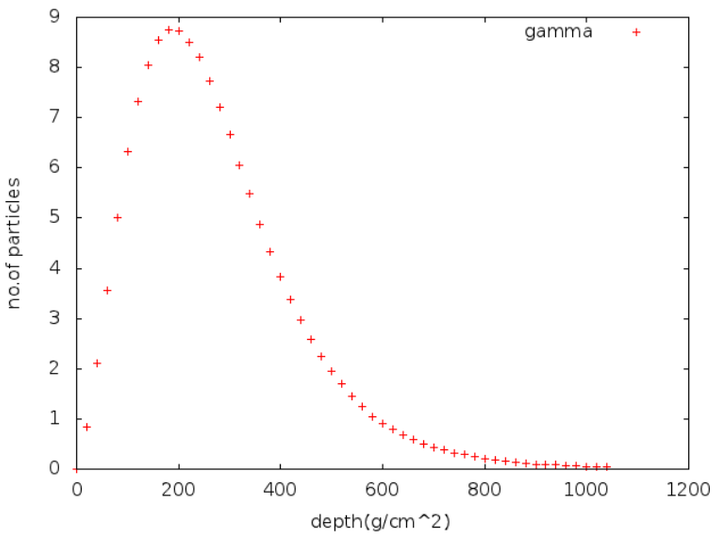
17 baby projects! *Completed*

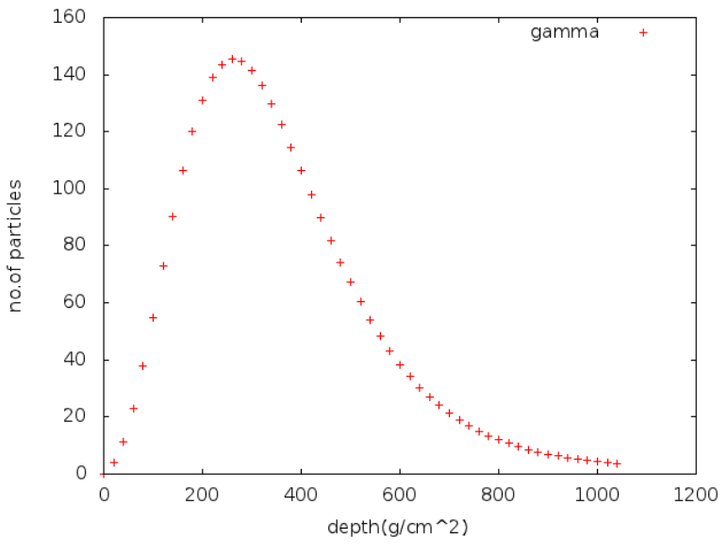
Students with diverse background

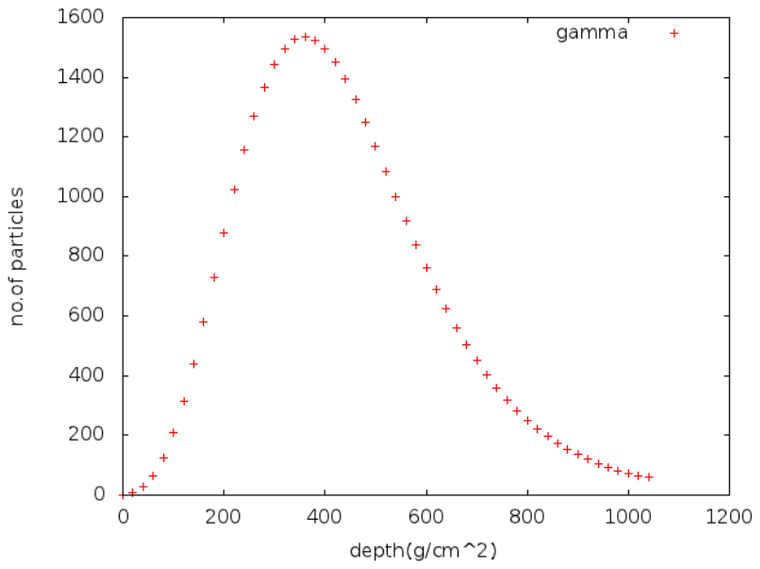
B. Tech, M. Sc., Ph. D. students

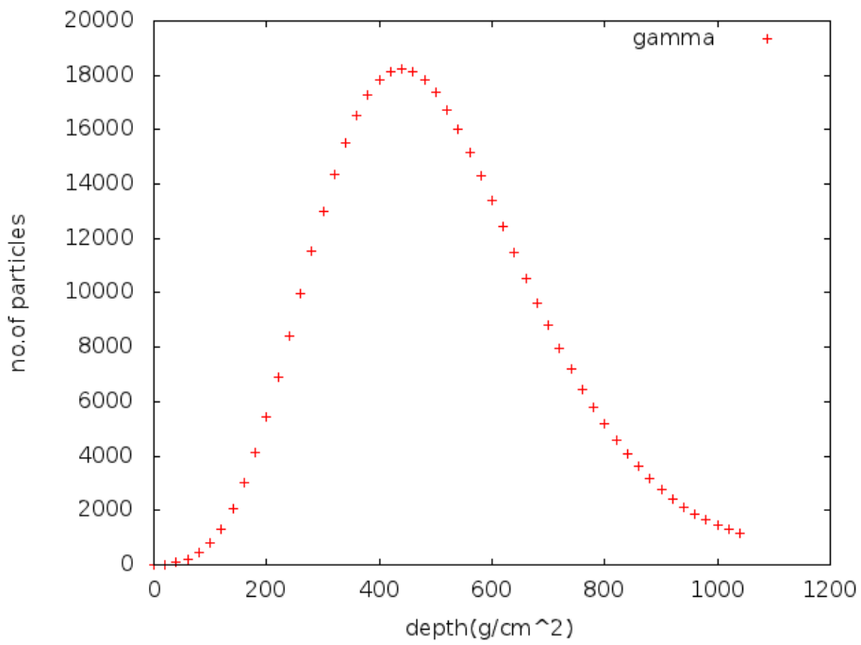
Computer literacy

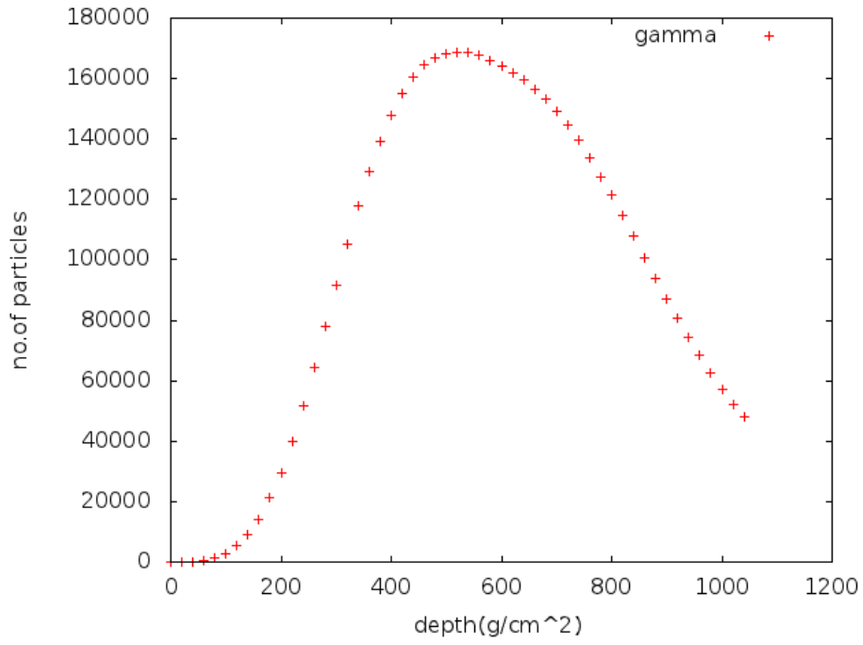
Particle distribution



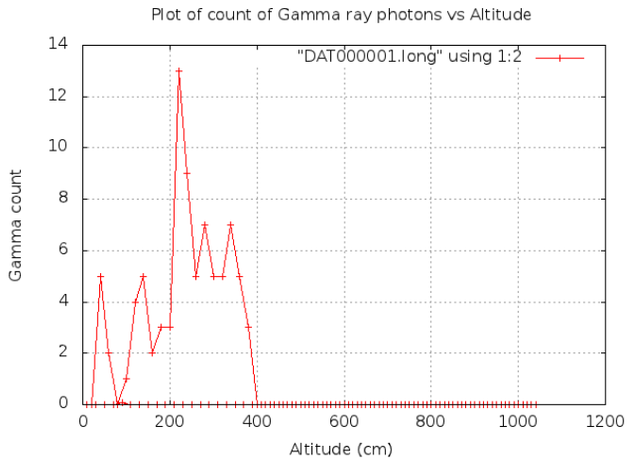


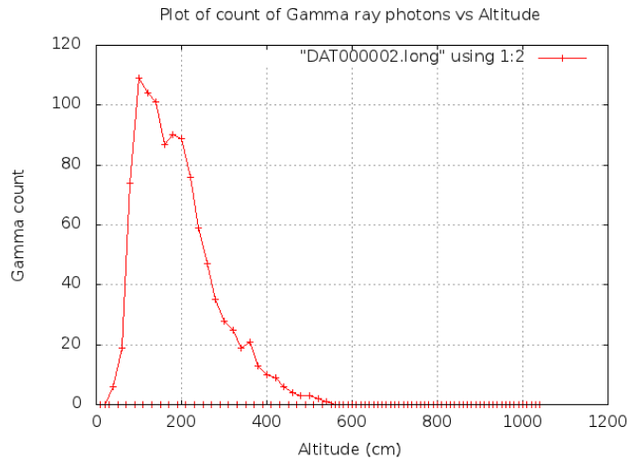


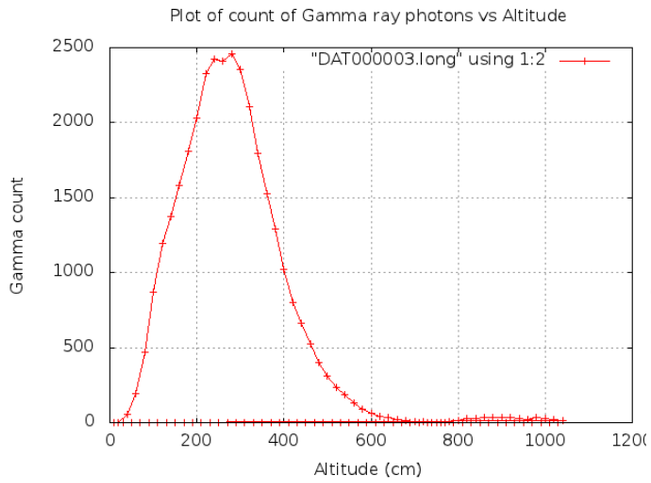


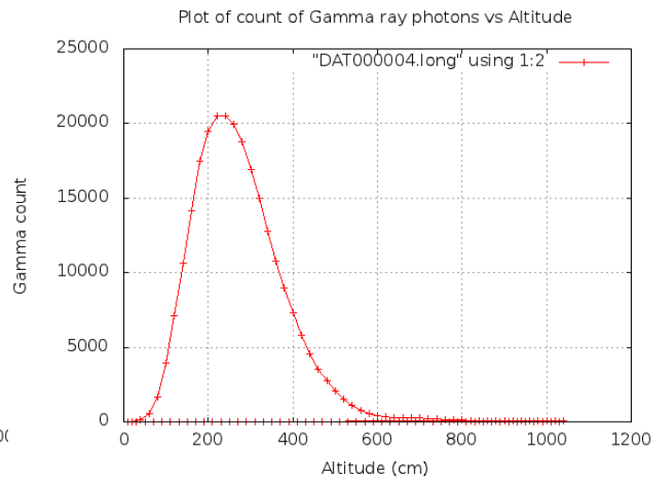


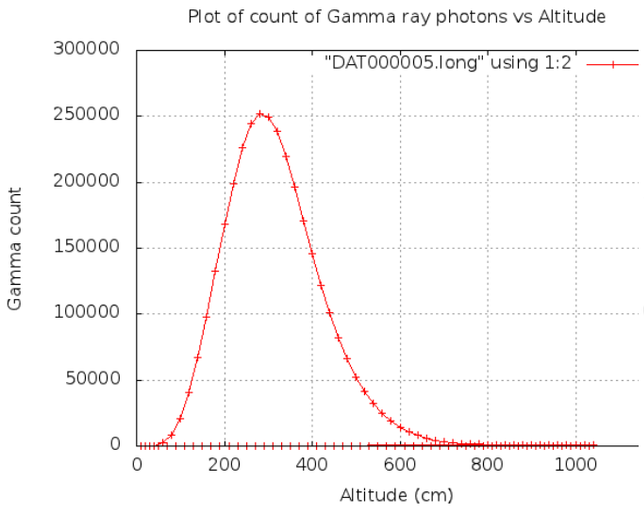
Hari Sree Krishnamurthy

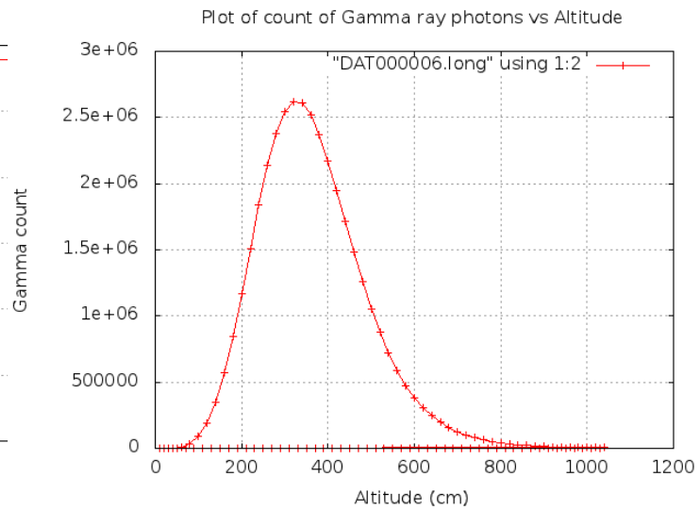




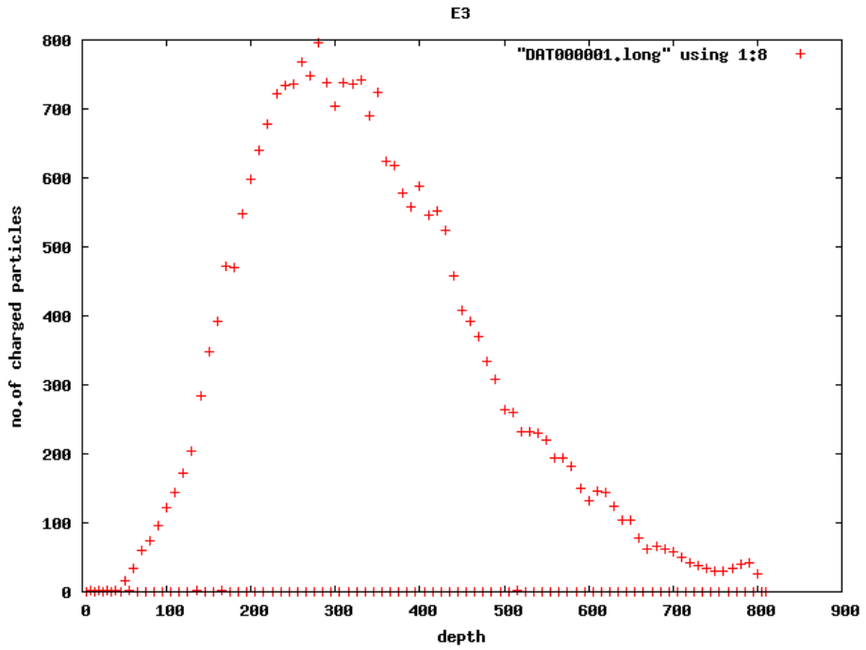


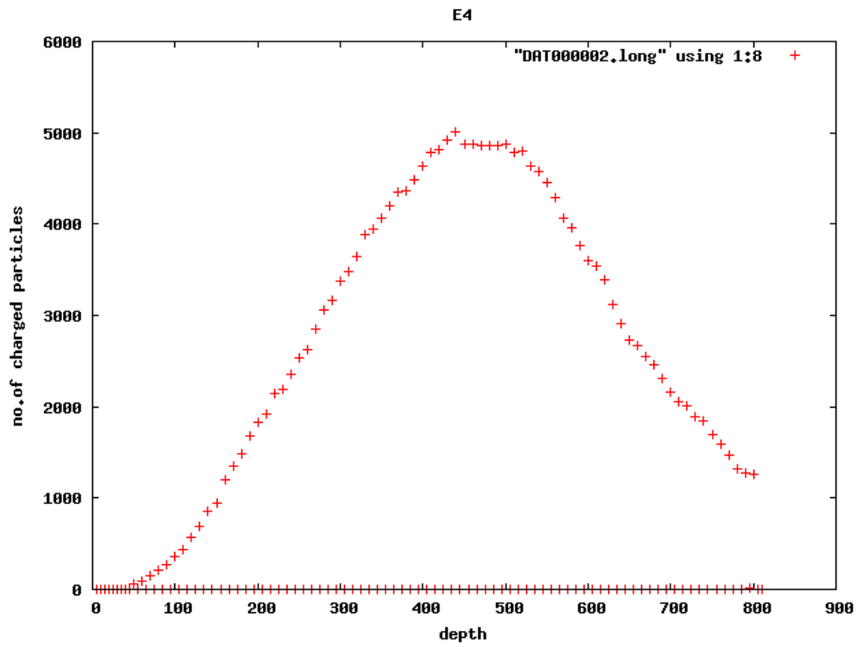


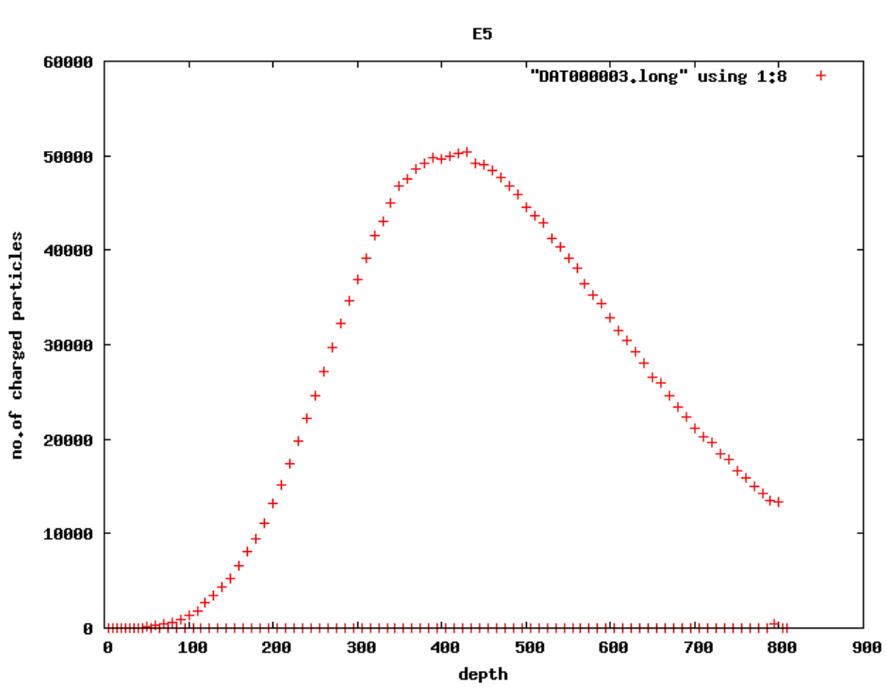


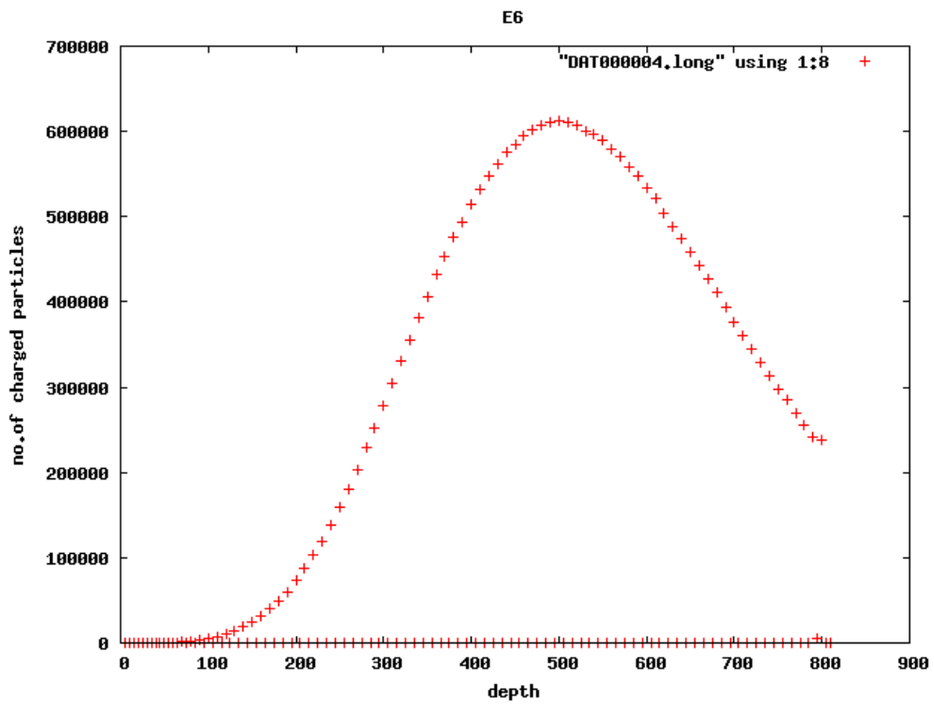


Kartheik Iyer

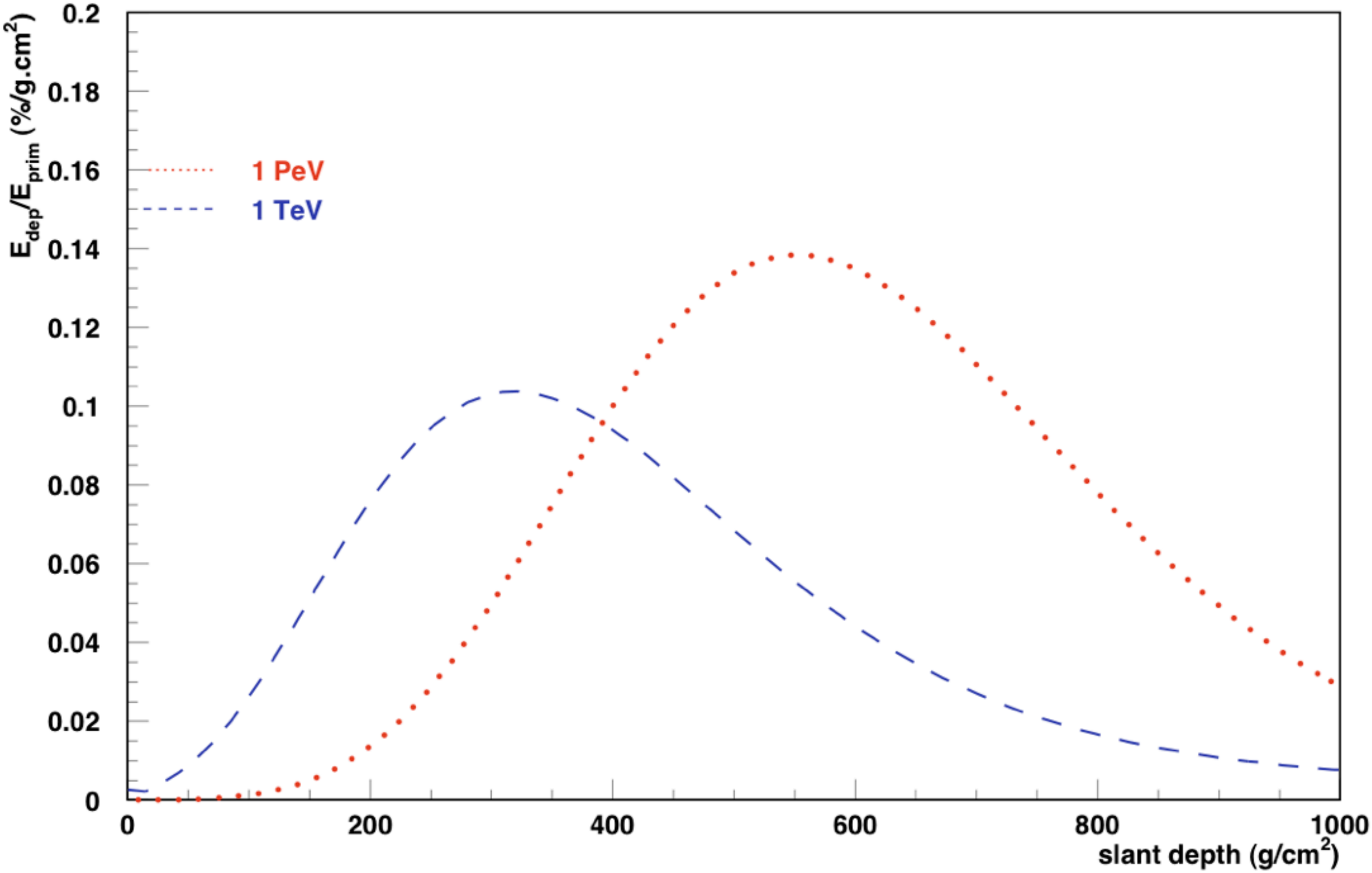


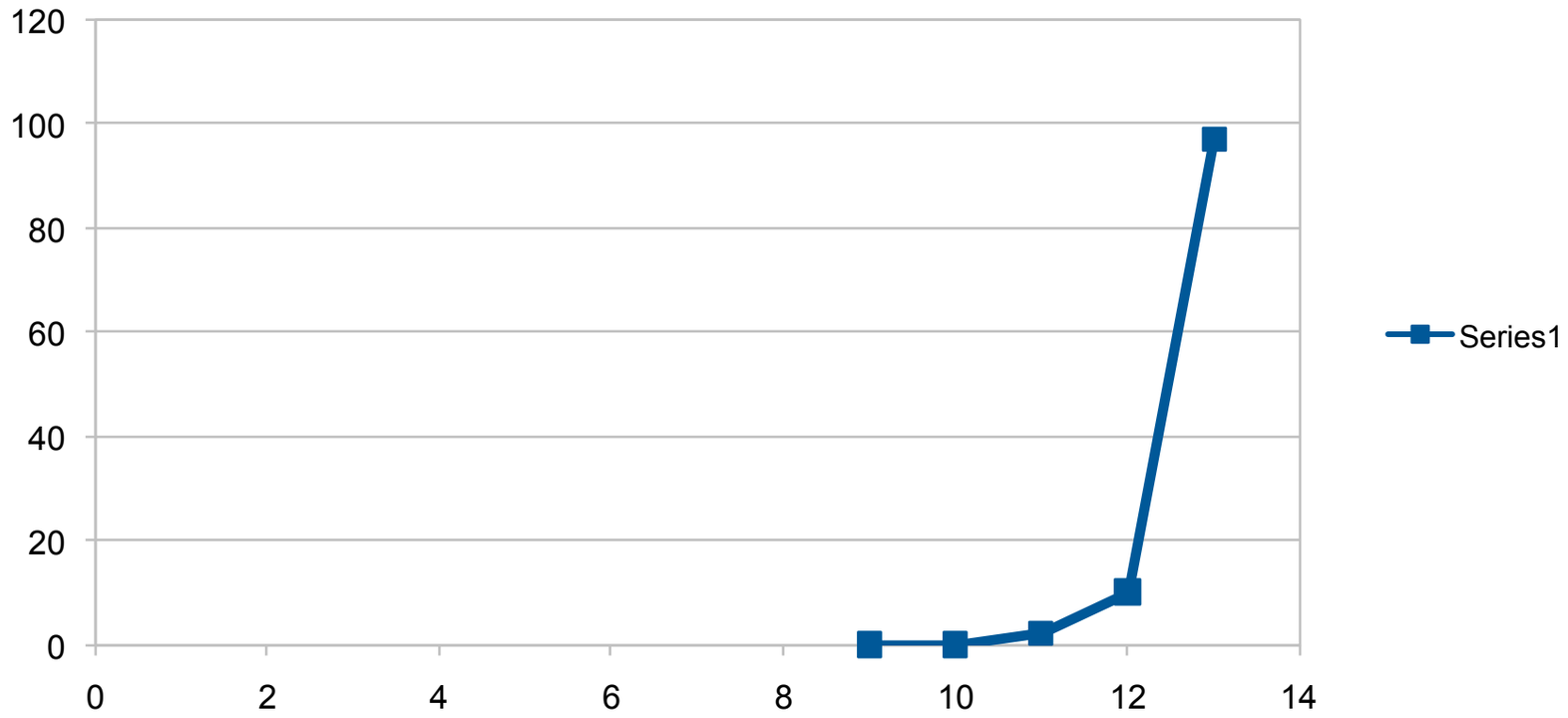






Rupamoy Bhattecharyya


E_{dep}/E_{prim} (%/g.cm^2)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1 PeV
1 TeV
0
200
400
600
800
1000
slant depth (g/cm^2)

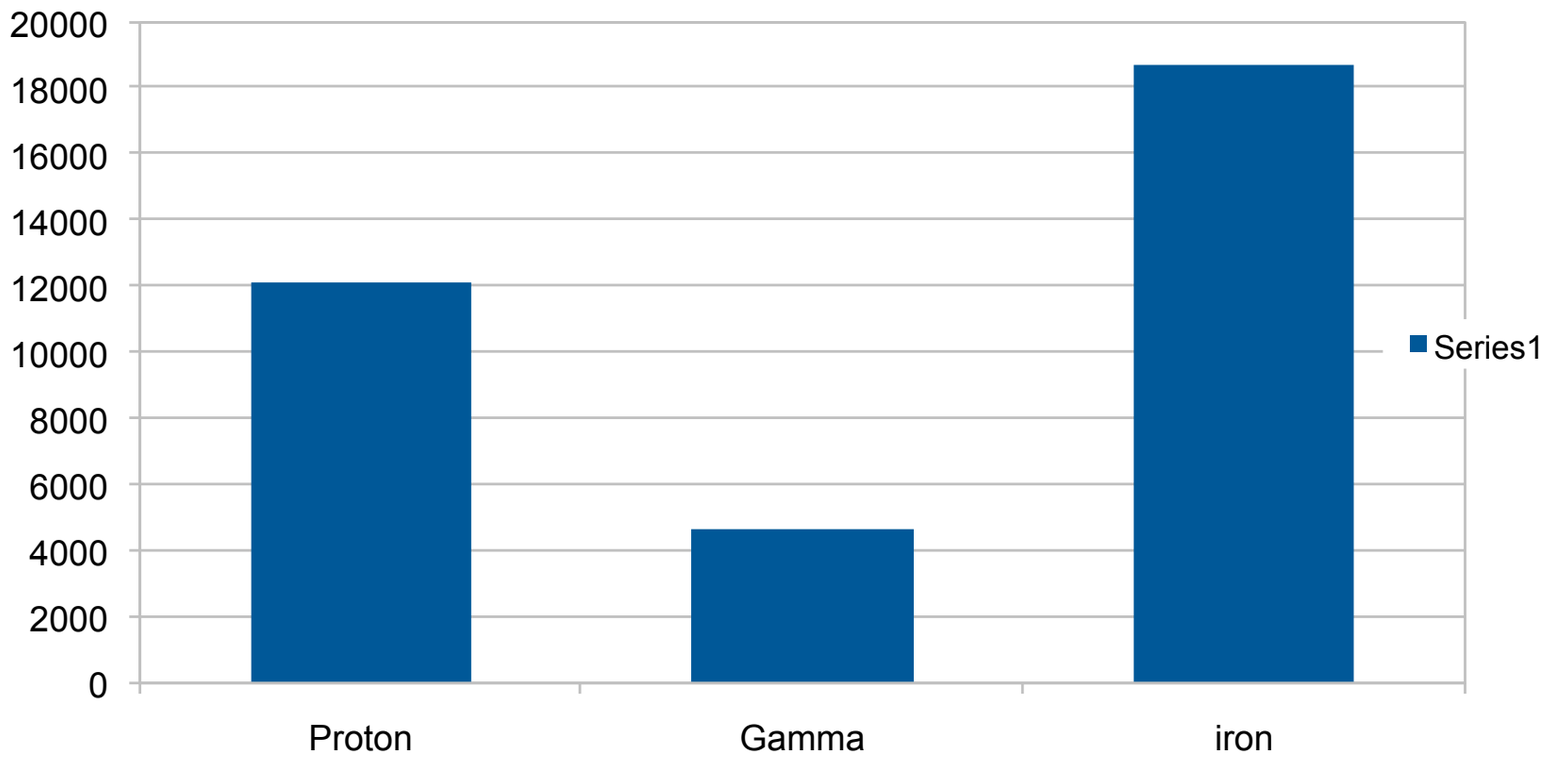


Number of muons vs Energy

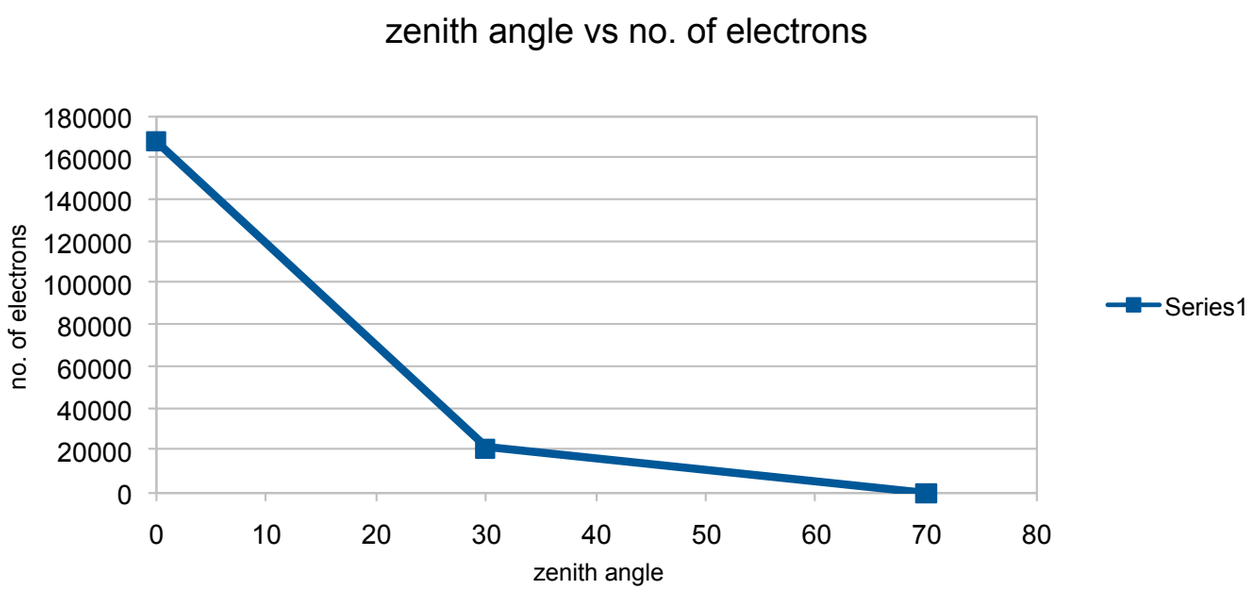
Bonita Das

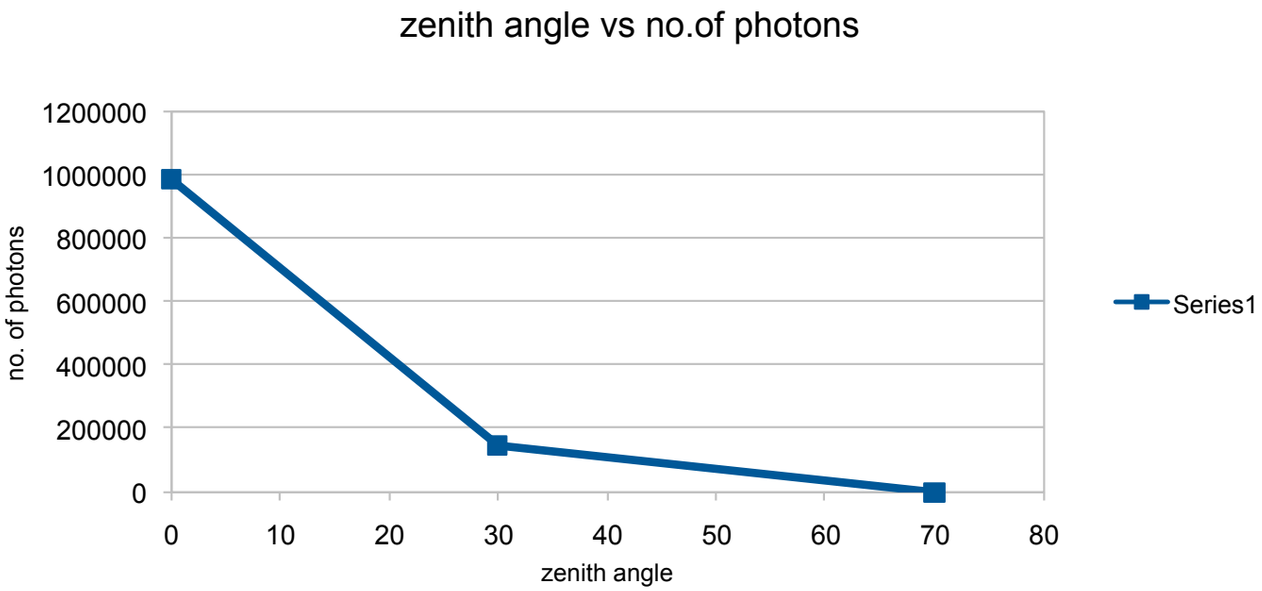
Total number of particles

1 PeV primary



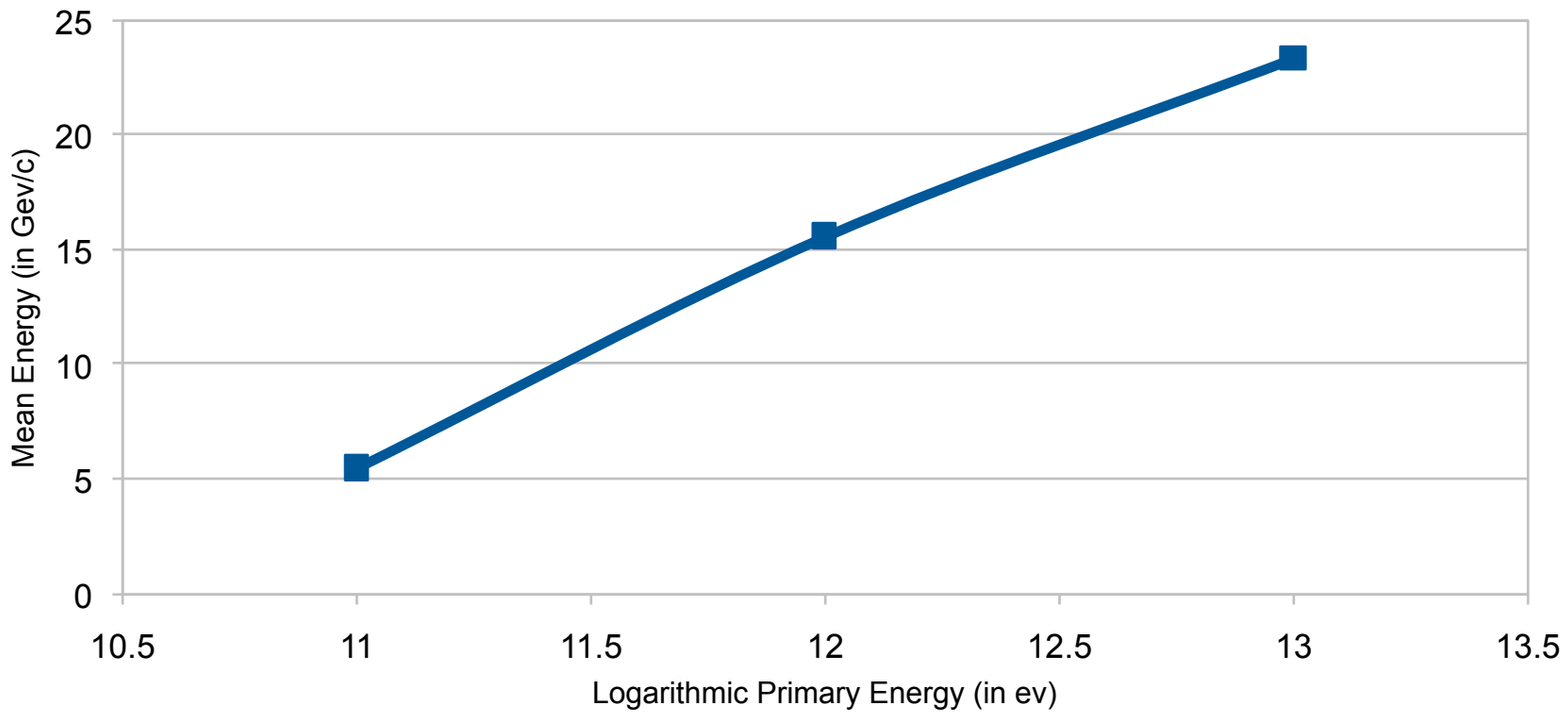
Mridusmita Buragohain


zenith angle vs no. of electrons
no. of electrons
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
0
10
20
30
40
50
60
70
80
zenith angle
Series1

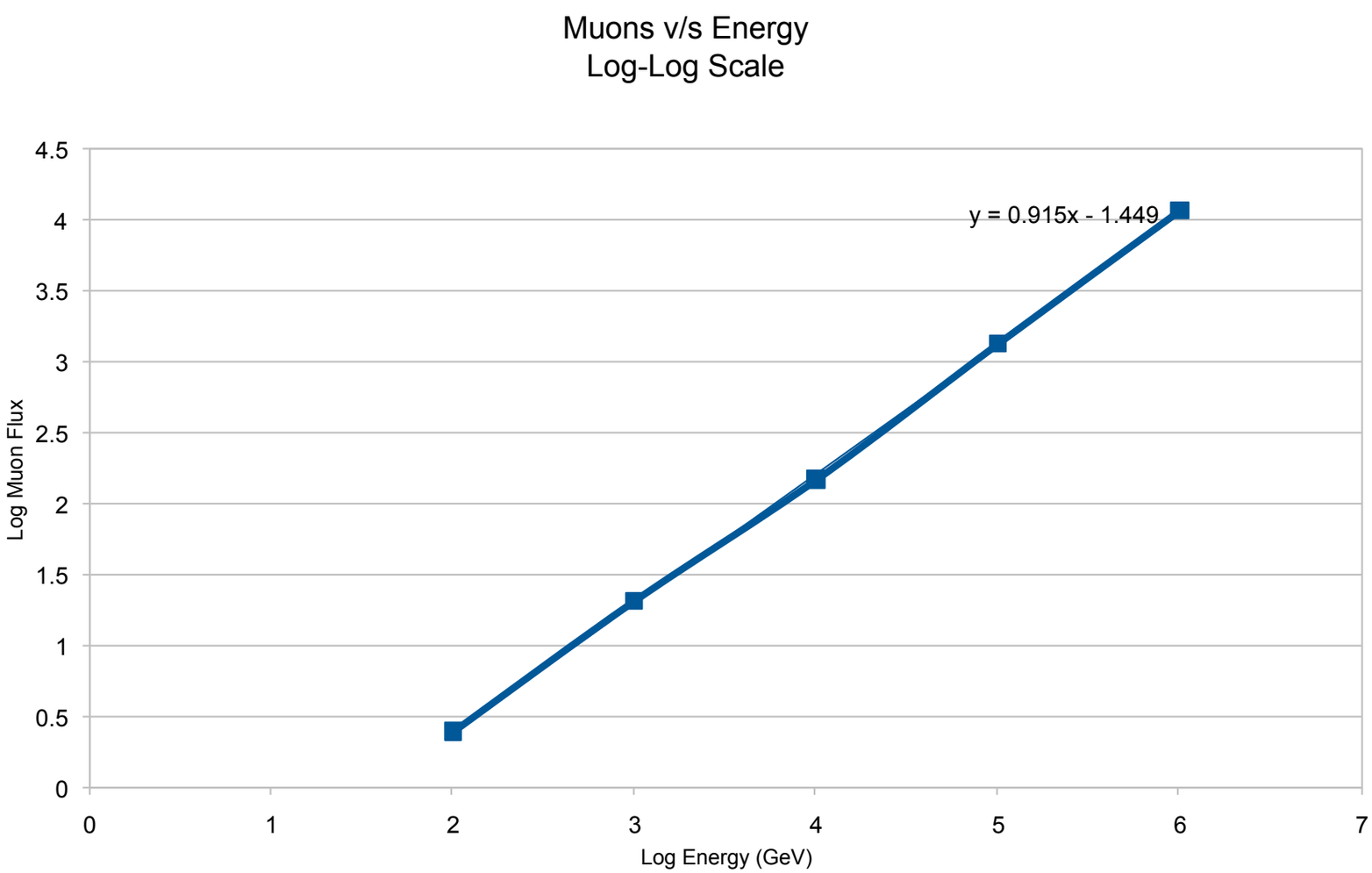

zenith angle vs no.of photons
no. of photons
1200000
1000000
800000
600000
400000
200000
0
0
10
20
30
40
50
60
70
80
zenith angle
Series1

Tanuj Modi

Mean energy of muon vs Primary Energy

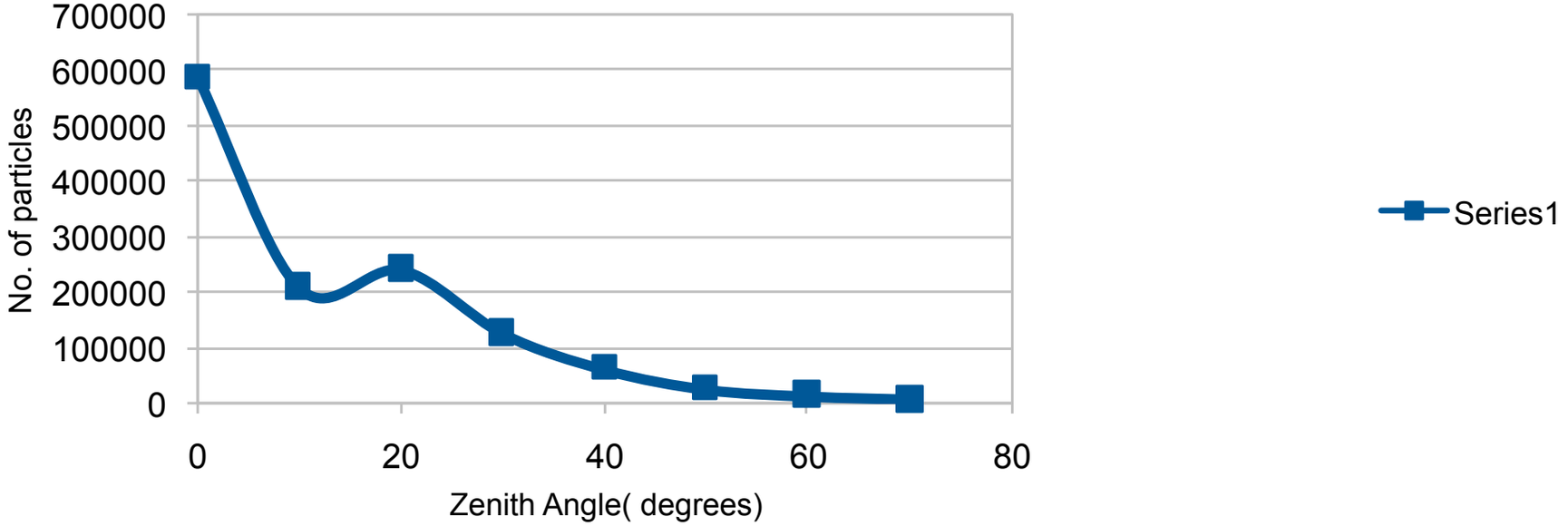


Sarfraz Qureshi

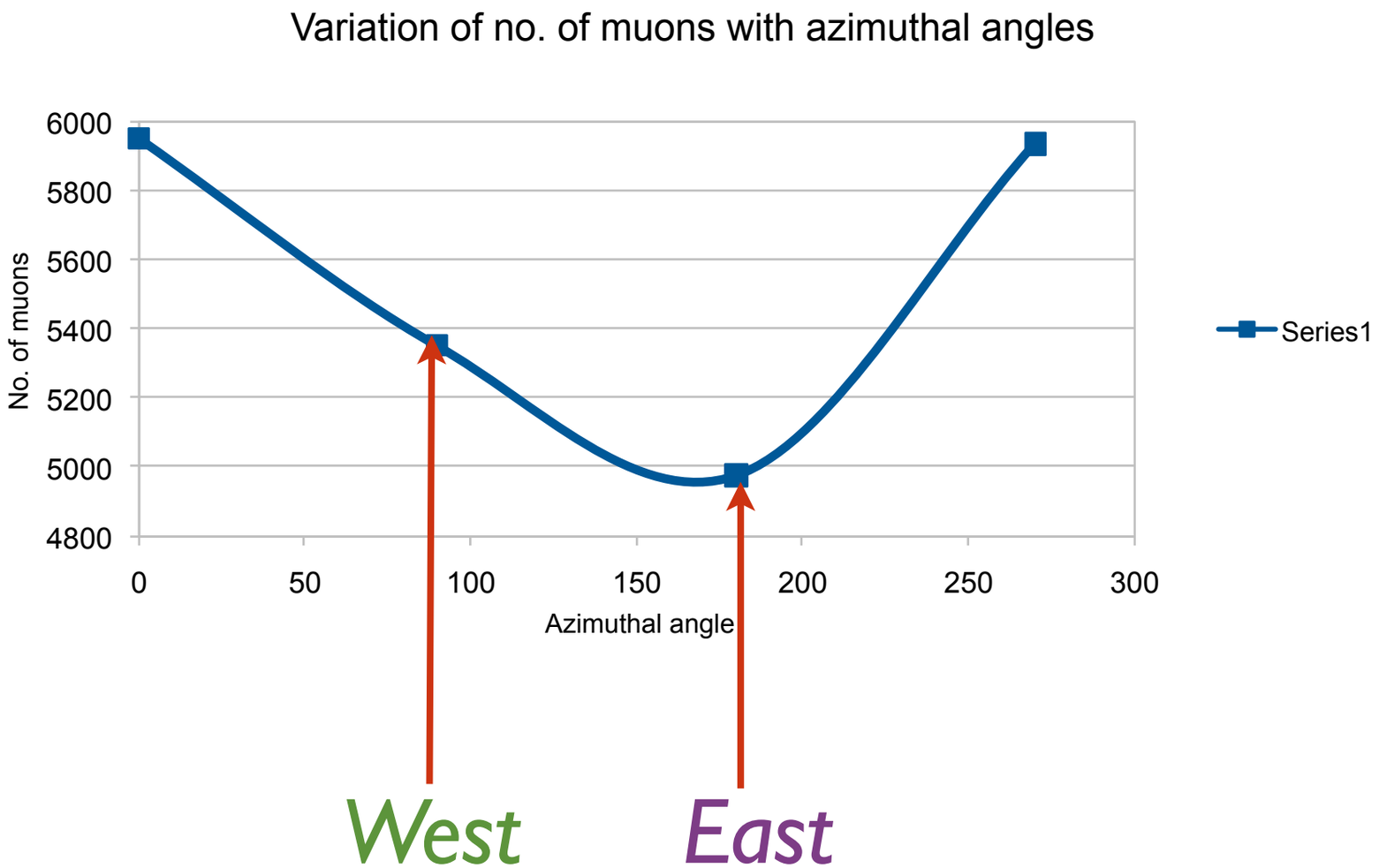


Souvik Dutta

Zenith Variation at Ground Level



Rishav Dewan

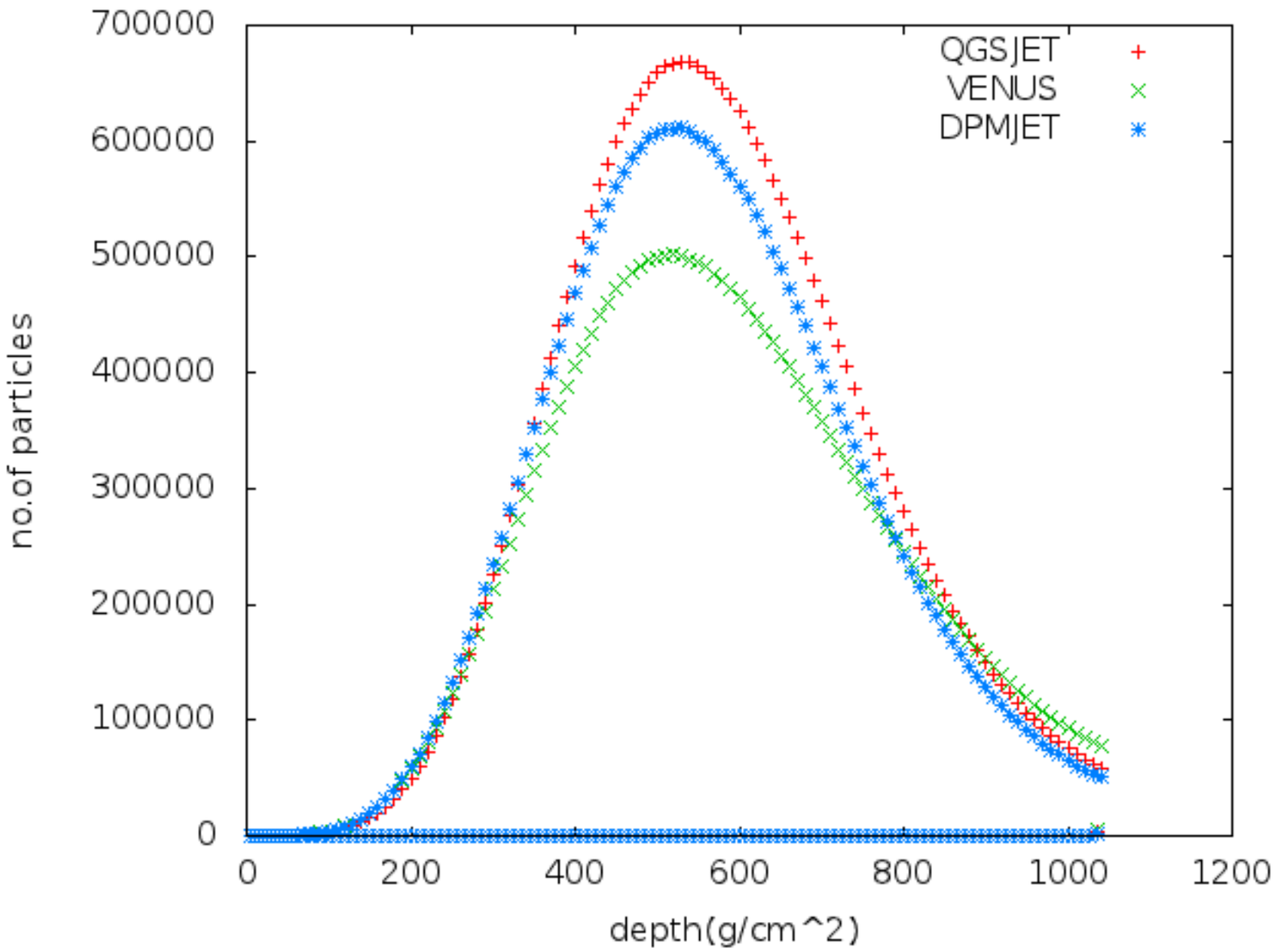


Utsab Shrestha and G Gayatri

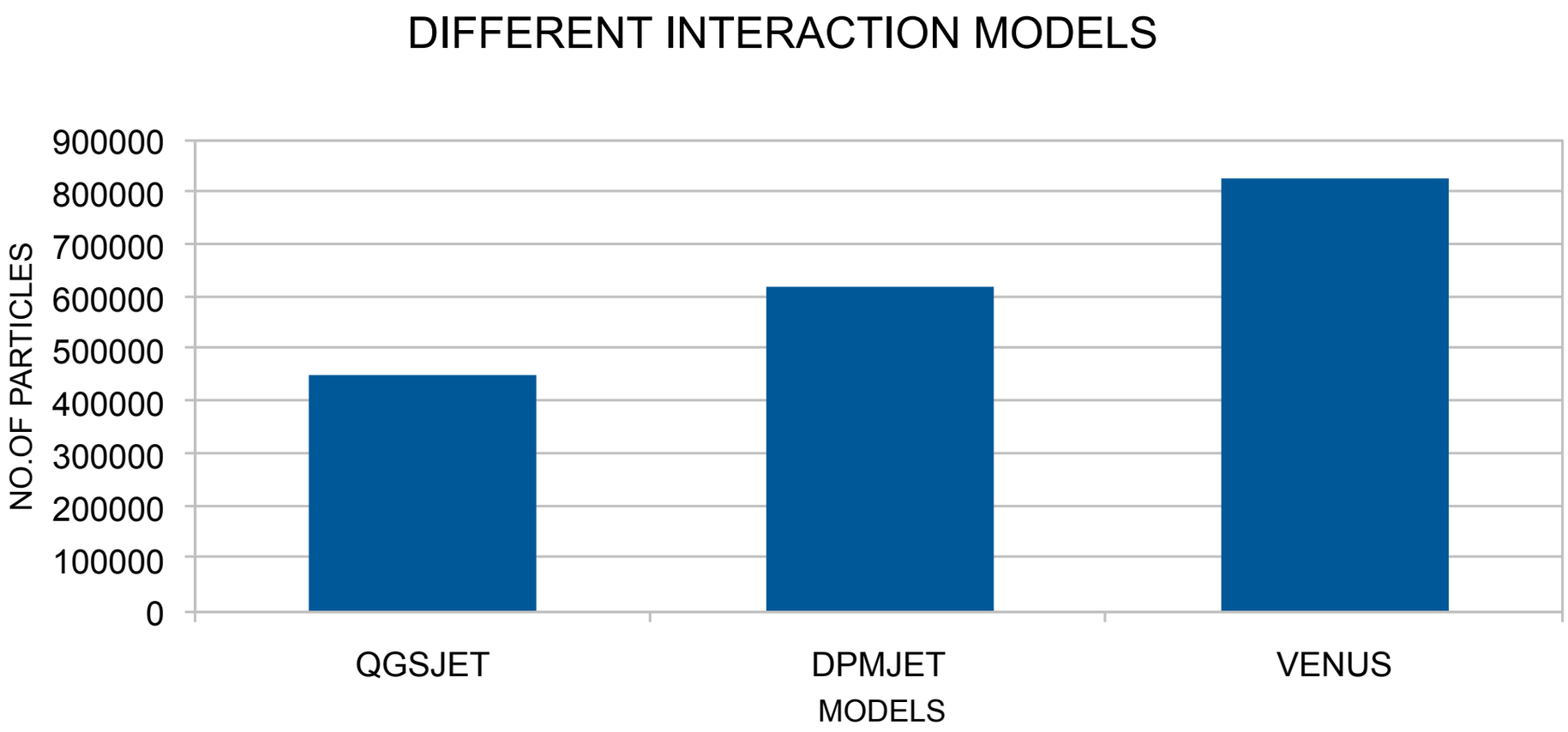
High Energy Hadronic Interaction models

DPMJET, EPOS, HDPM,
NEXUS, QGSJET, SIBYLL,
VENUS

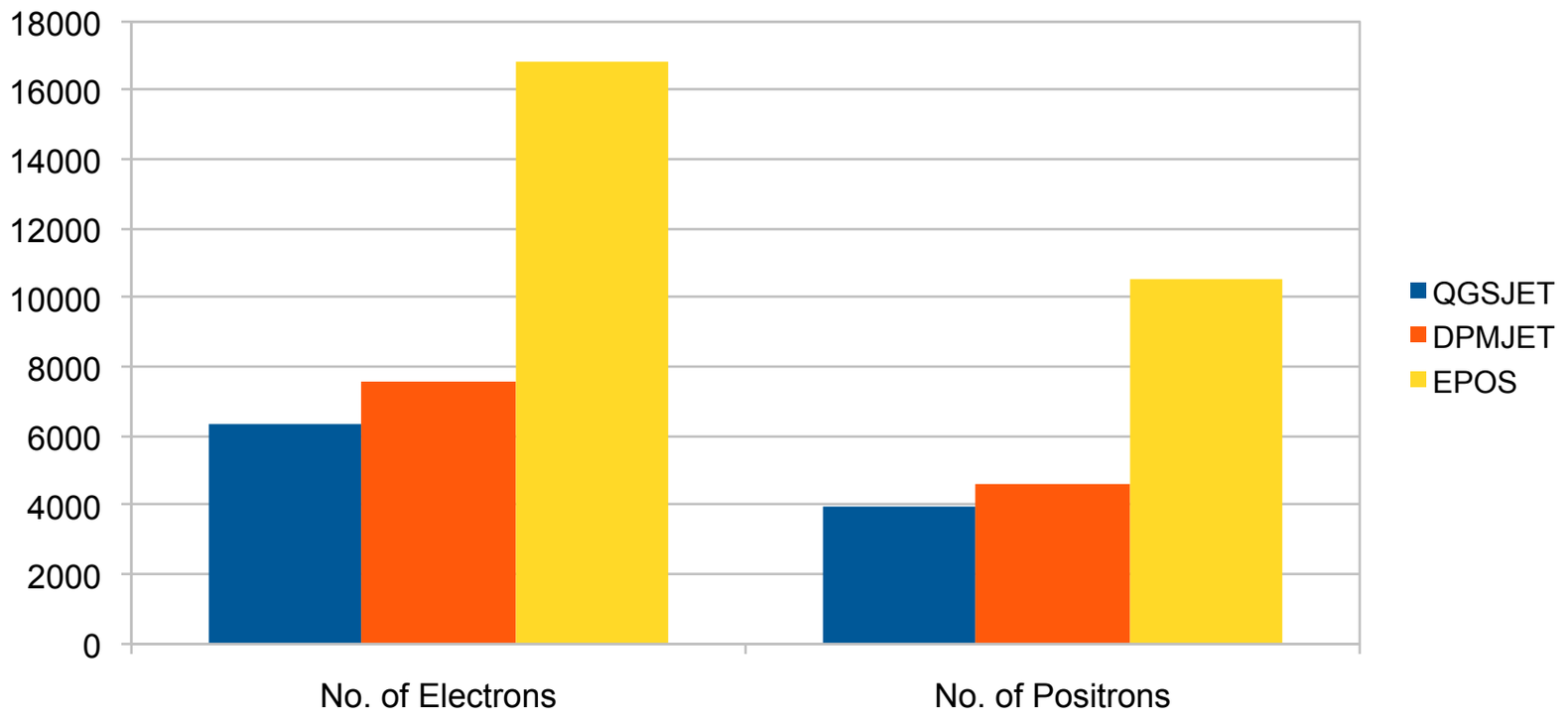
Testing different hadronic interaction models



Niklesh Sekar


DIFFERENT INTERACTION MODELS
NO.OF PARTICLES
900000
800000
700000
600000
500000
400000
300000
200000
100000
0
QGSJET
DPMJET
VENUS
MODELS

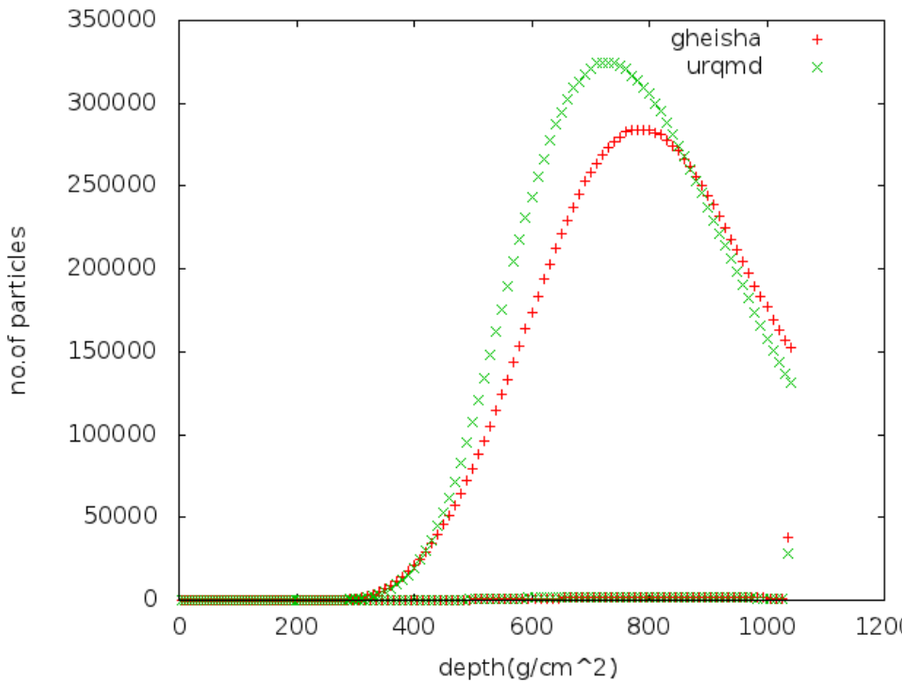
Rupa Basu

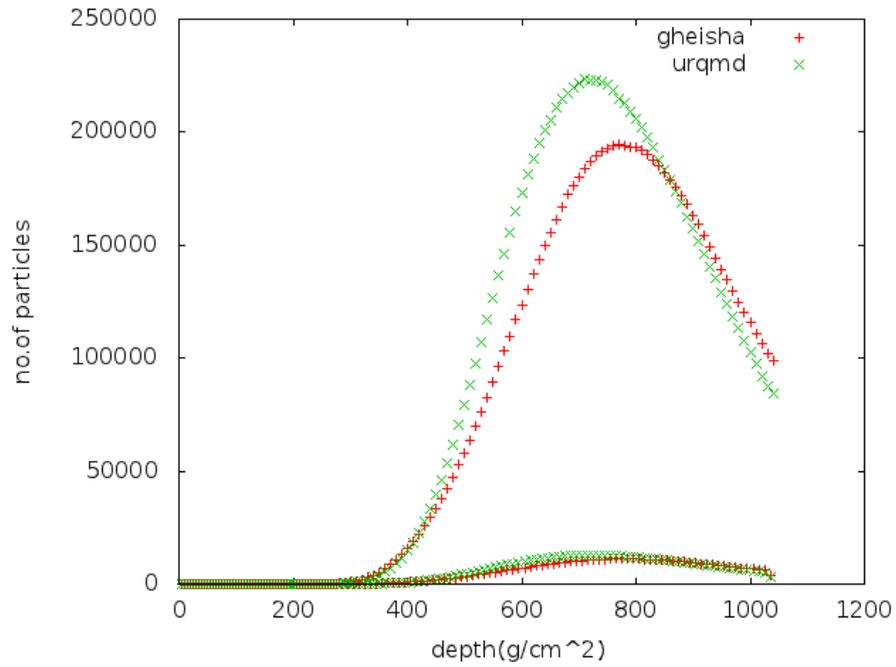


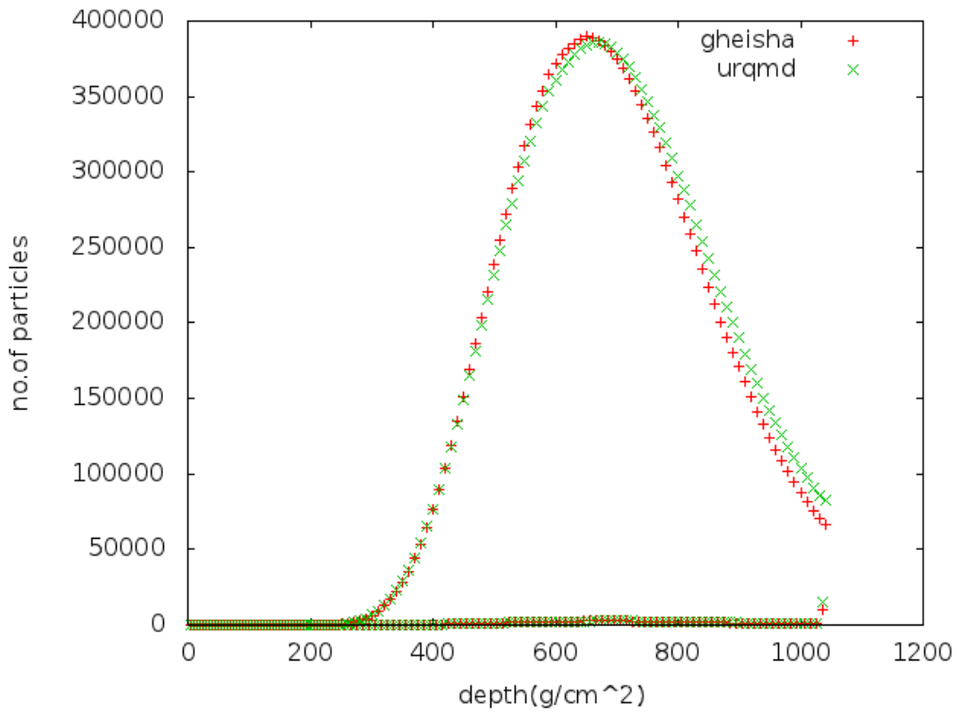
Prateek Prajapati

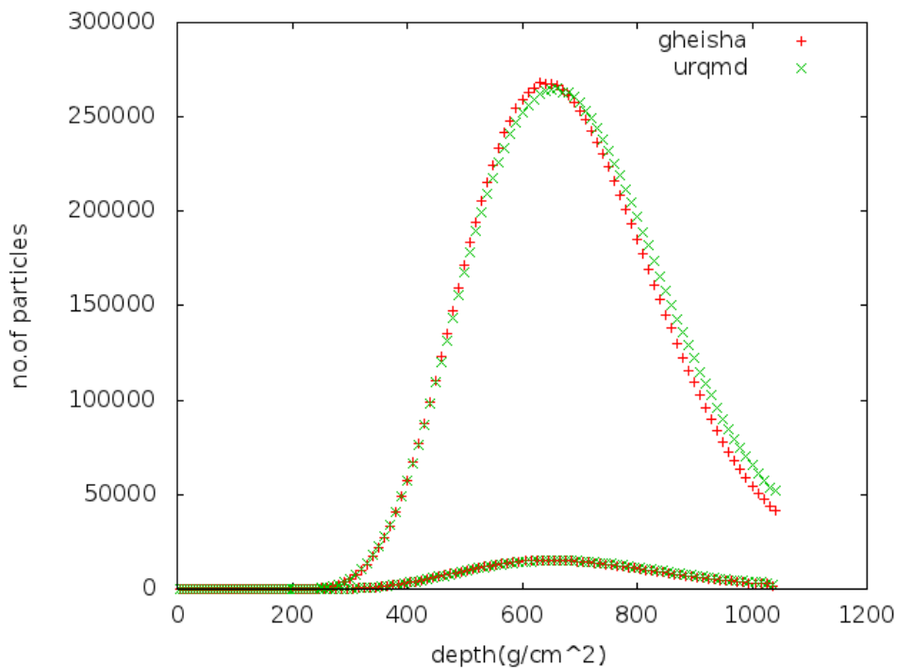
Low Energy Hadronic Interaction Models

FLUKA, GHEISHA, UrQMD

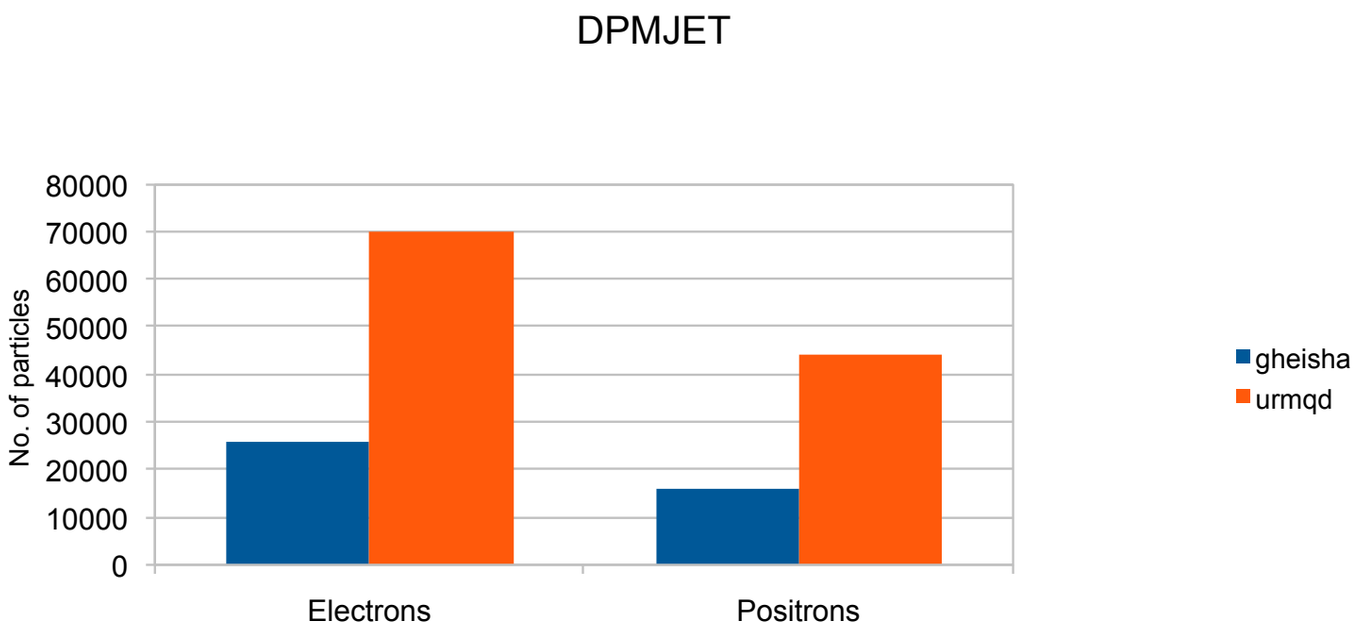


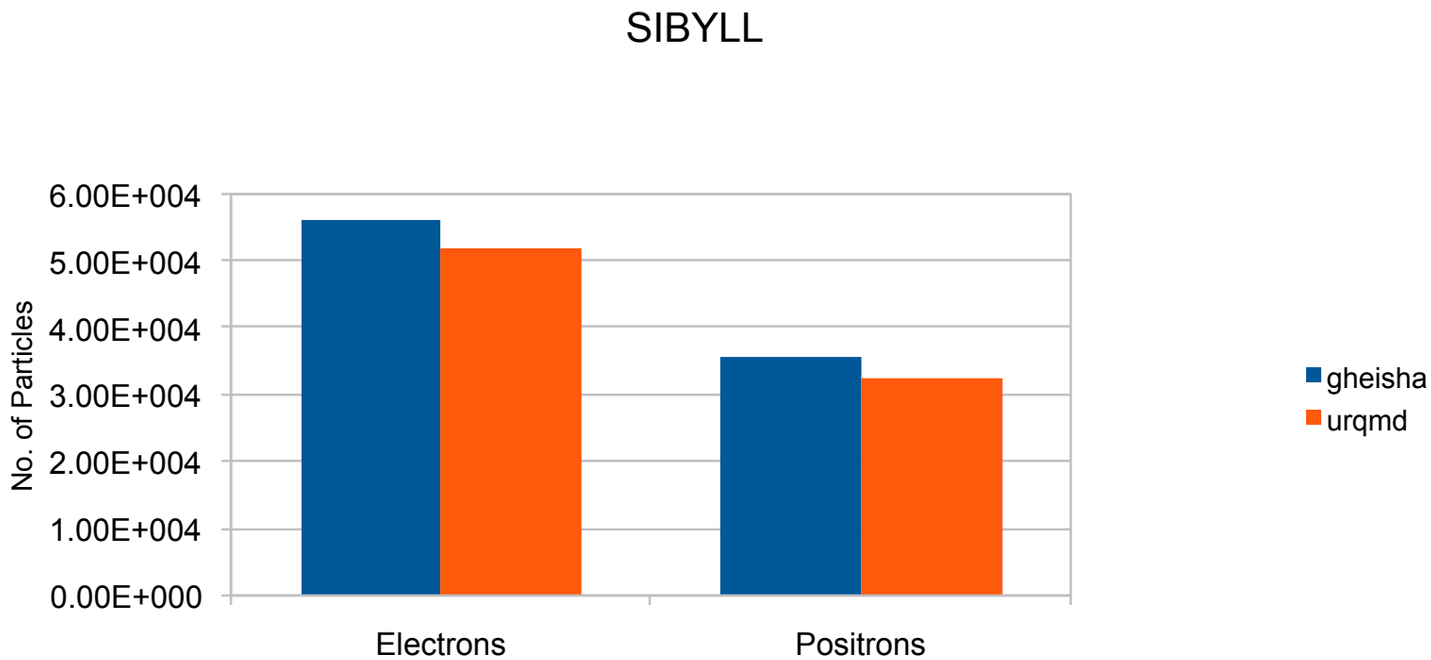






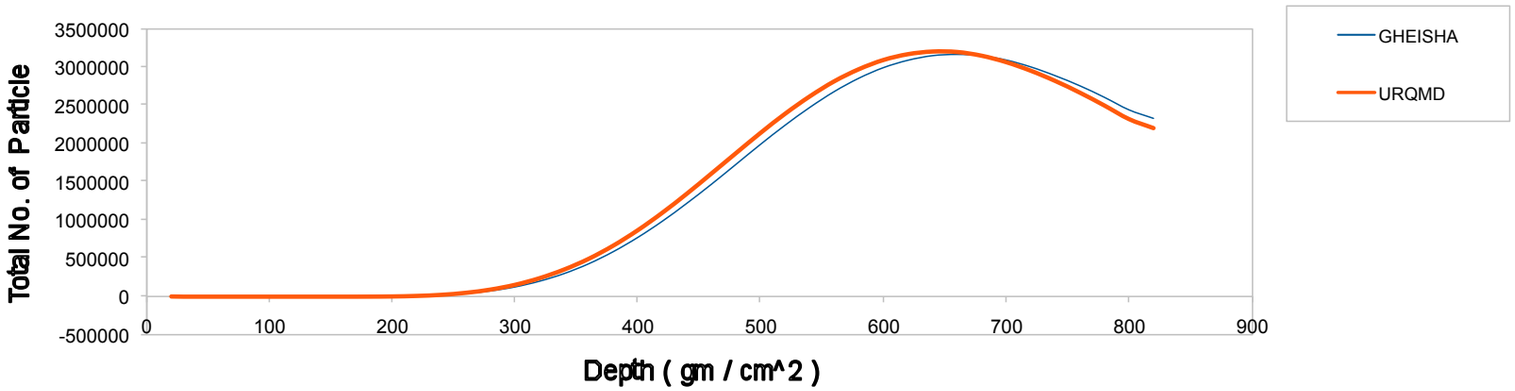
Neeti Keswani


DPMJET
80000
70000
60000
50000
40000
30000
20000
10000
0
No. of particles
Electrons
Positrons
gheisha
urmqd

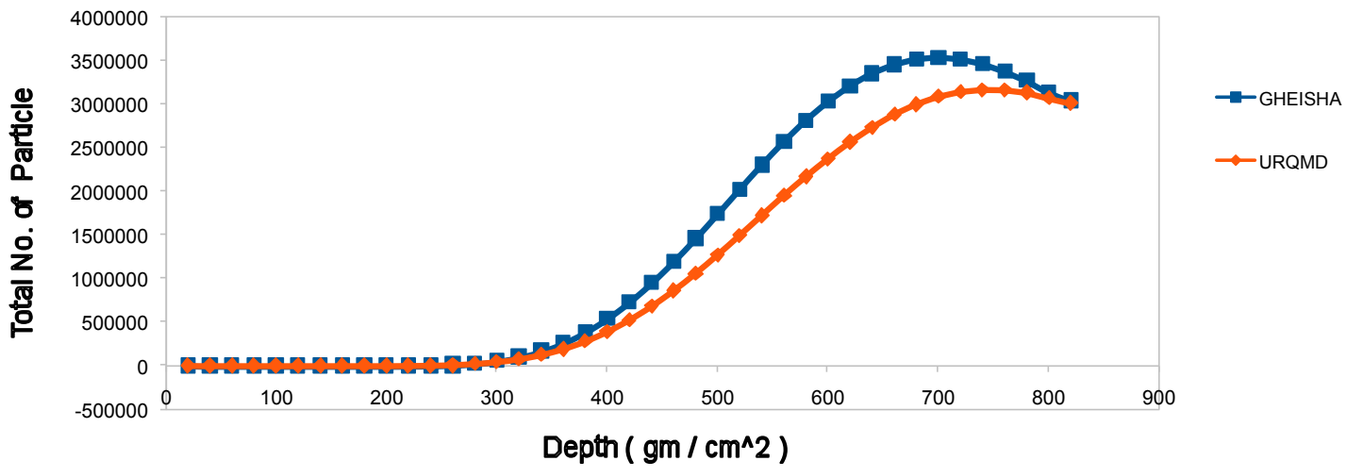

SIBYLL
6.00E+004
5.00E+004
4.00E+004
3.00E+004
2.00E+004
1.00E+004
0.00E+000
No. of Particles
Electrons
Positrons
gheisha
urqmd

Nitesh

High Energy Model at Darjeeling
Model Name : QGSJET



High Energy Model at Darjeeling
Model Name : SIBYLL



Siddhartha Bhattacharyya

Two things...

Be prepared for surprises

Get directions | My places

A Tifr, Mumbai, Maharashtra, India

B London, United Kingdom

Add Destination - Show options

GET DIRECTIONS

Suggested routes

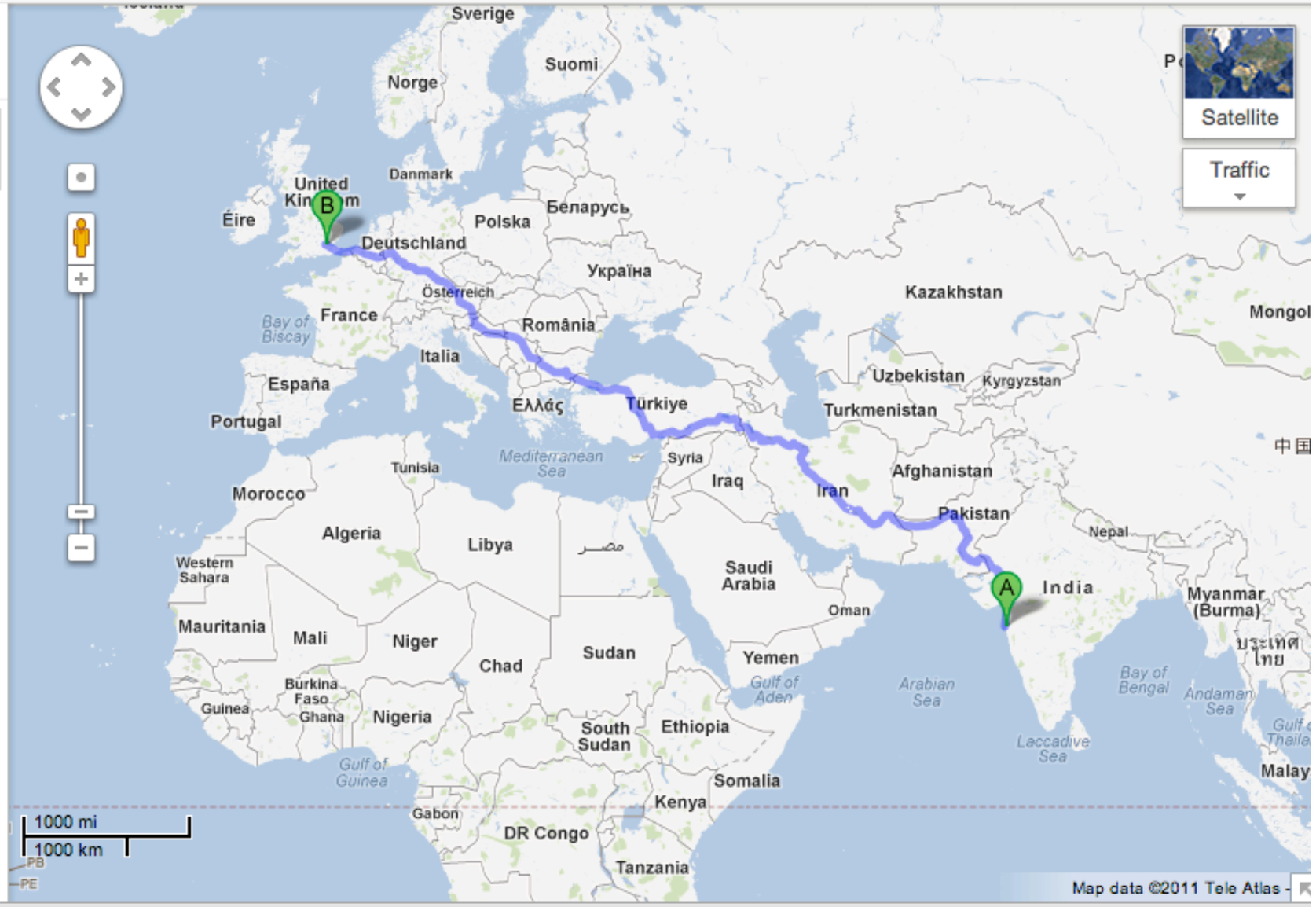
A3	**10,029 km, 5 days 1 hour**
Regional Cooperation for Development	9,583 km, 5 days 0 hours
M03	9,537 km, 5 days 1 hour

Driving directions to London, UK

3D

This route has tolls.
This route includes a car transport.

Tata Institute of Fundamental Research
Dr. Homi Baba Road, Kolaba, Navy Nagar
Mumbai, Maharashtra 400005, India




ELECTRONIC CALCULATOR
12345678901 12.
MRC
M−
M+
+/−
MU
GT
7
8
9
%
EX
4
5
6
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CE
1
2
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+
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AC
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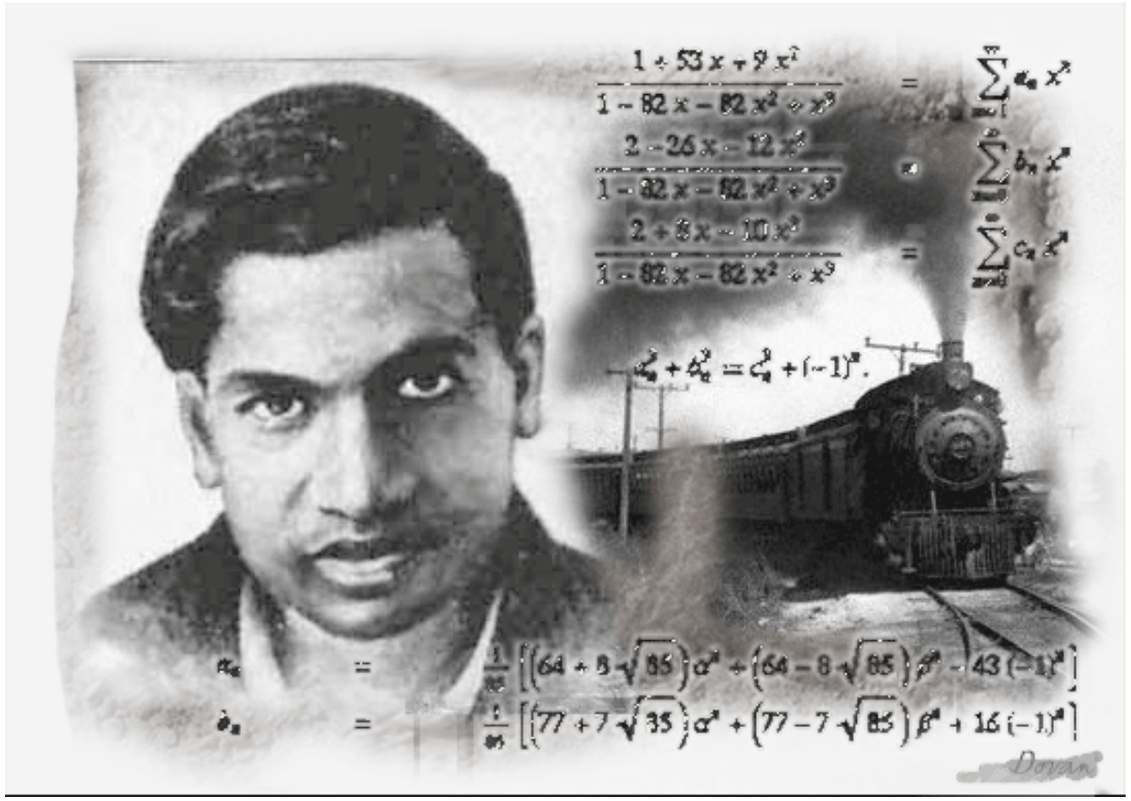
1 + 53x + 9x²
1 − 82x − 82x² + x³
2 − 26x − 12x²
1 − 82x − 82x² + x³
2 + 8x − 10x²
1 − 82x − 82x² + x³
c₄ + c₄² = c₅² + (−1)ⁿ.