A study of the impact of cosmic radiation on the International Space Station

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A study of the impact of cosmic radiation on the International Space Station

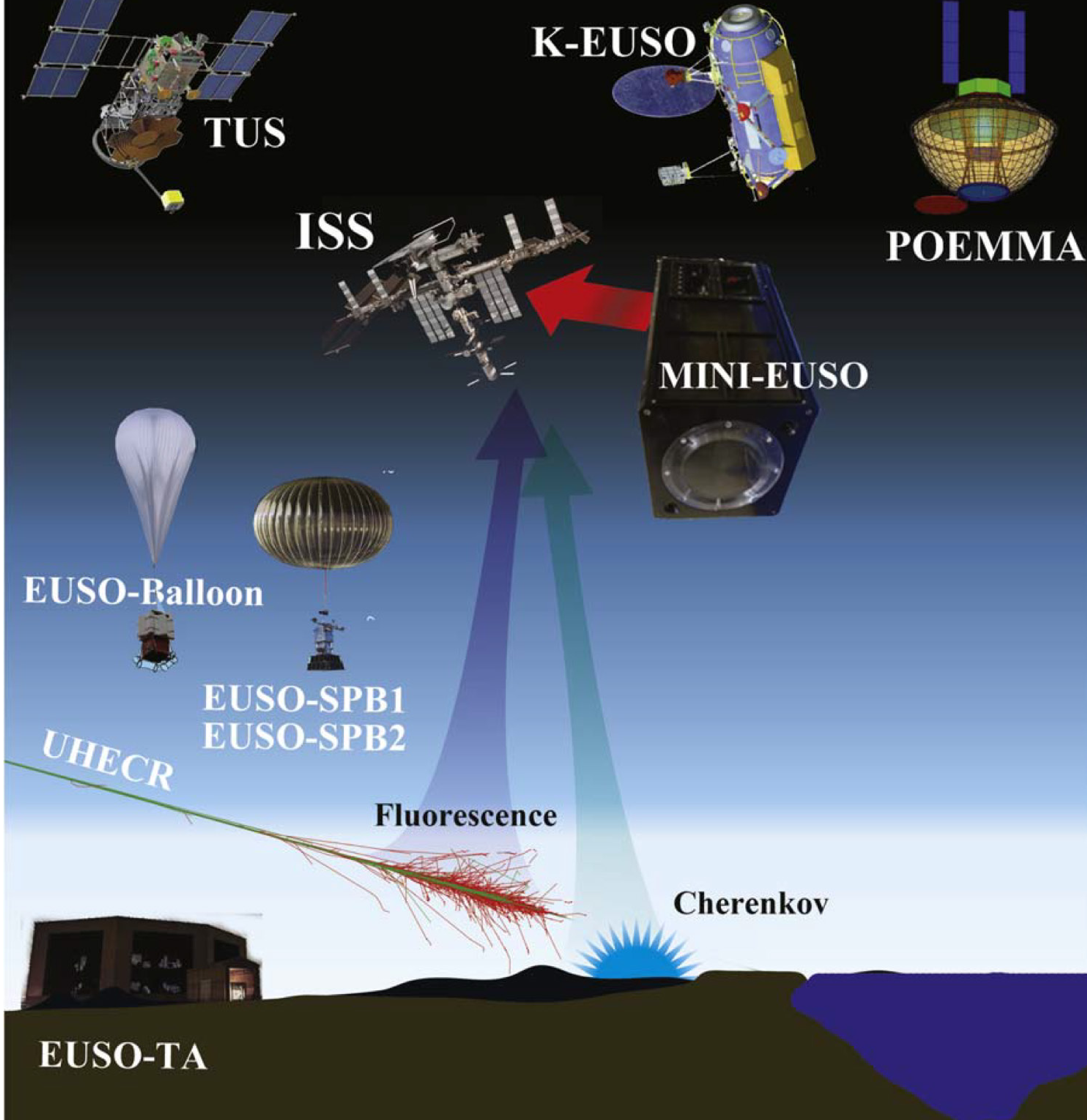
Chapter 1

MiniEUSO

MiniEUSO

The space program

It is part of the JemEUSO program for the Extreme Universe Space Observation. It works in three different areas: Earth surface, balloons and space.



MiniEUSO

The space program

It was launched on the 22 of August 2019 on board of a Soyuz Russian vector and insered in the Zvezda module of the ISS.

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MiniEUSO
ЭНЕРГИЯ
NIR
VIS
Планета
Королёва

MiniEUSO

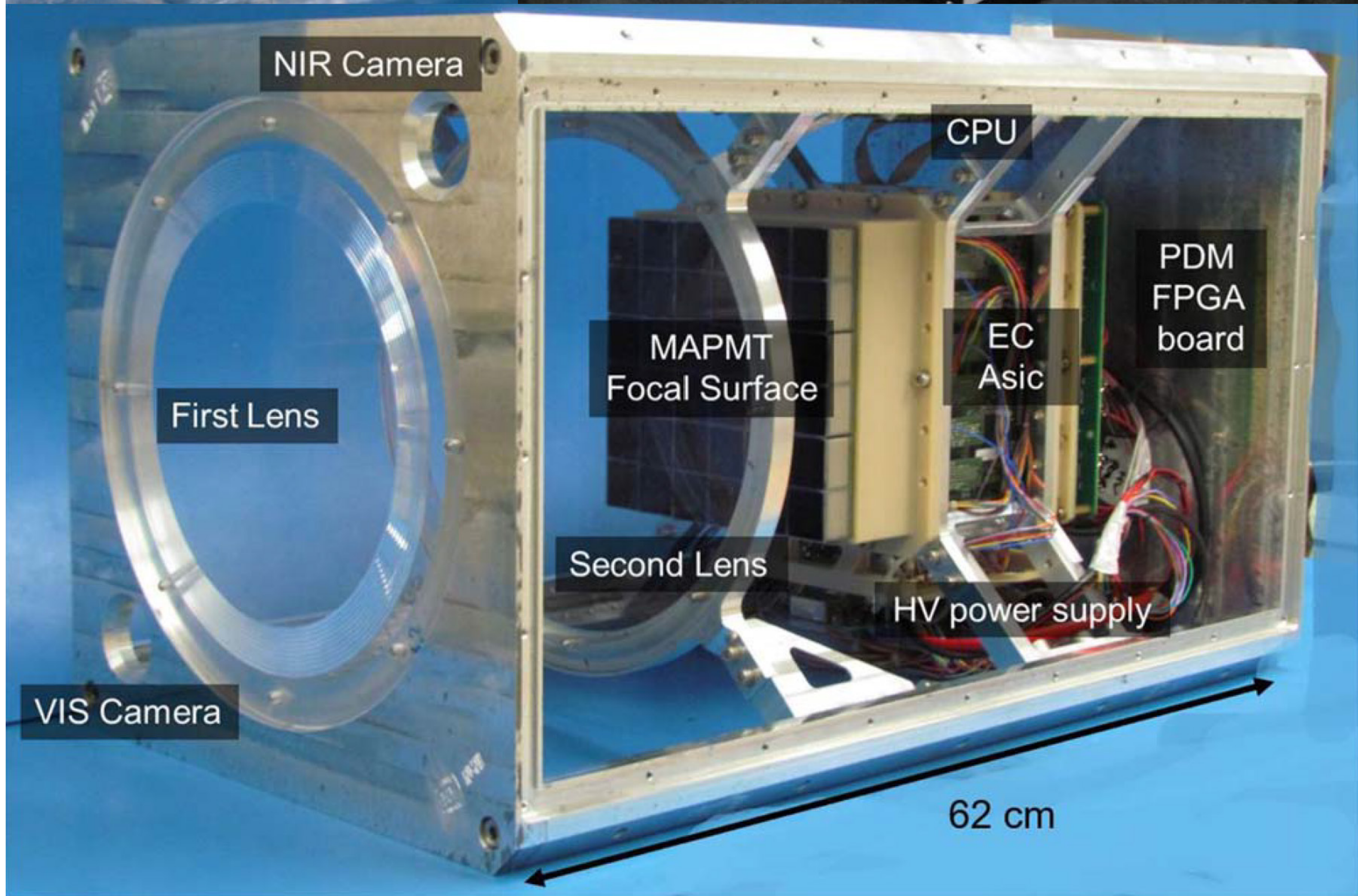
The space program

Characteristics

Dimensions:
37cmx37cmx62cm

Components:
- two Frenel lenses;
- 36 multianode photomultipliers, 64 pixels each;
- HV power supply;
- integrated CPU.

Detection:
single-photon detection in the near UV range (300-400nm)

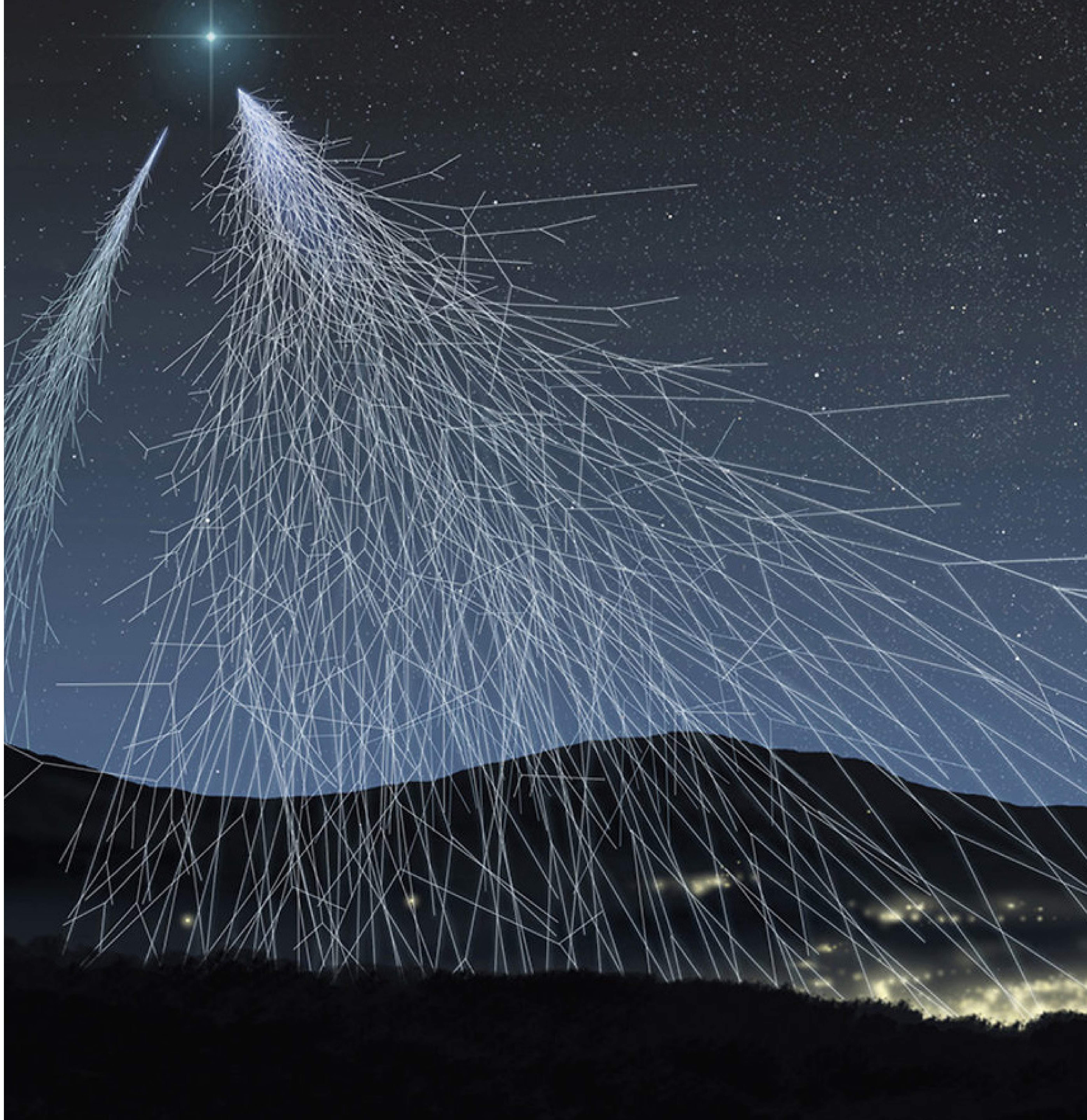


MiniEUSO

The space program

Capable of studying different scientific topics:

1) Night UV emissions from the Earth;
2) Airglow;
3) Space debris;
4) Meteors;
6) Ultra High Energy Cosmic Rays (UHECR).

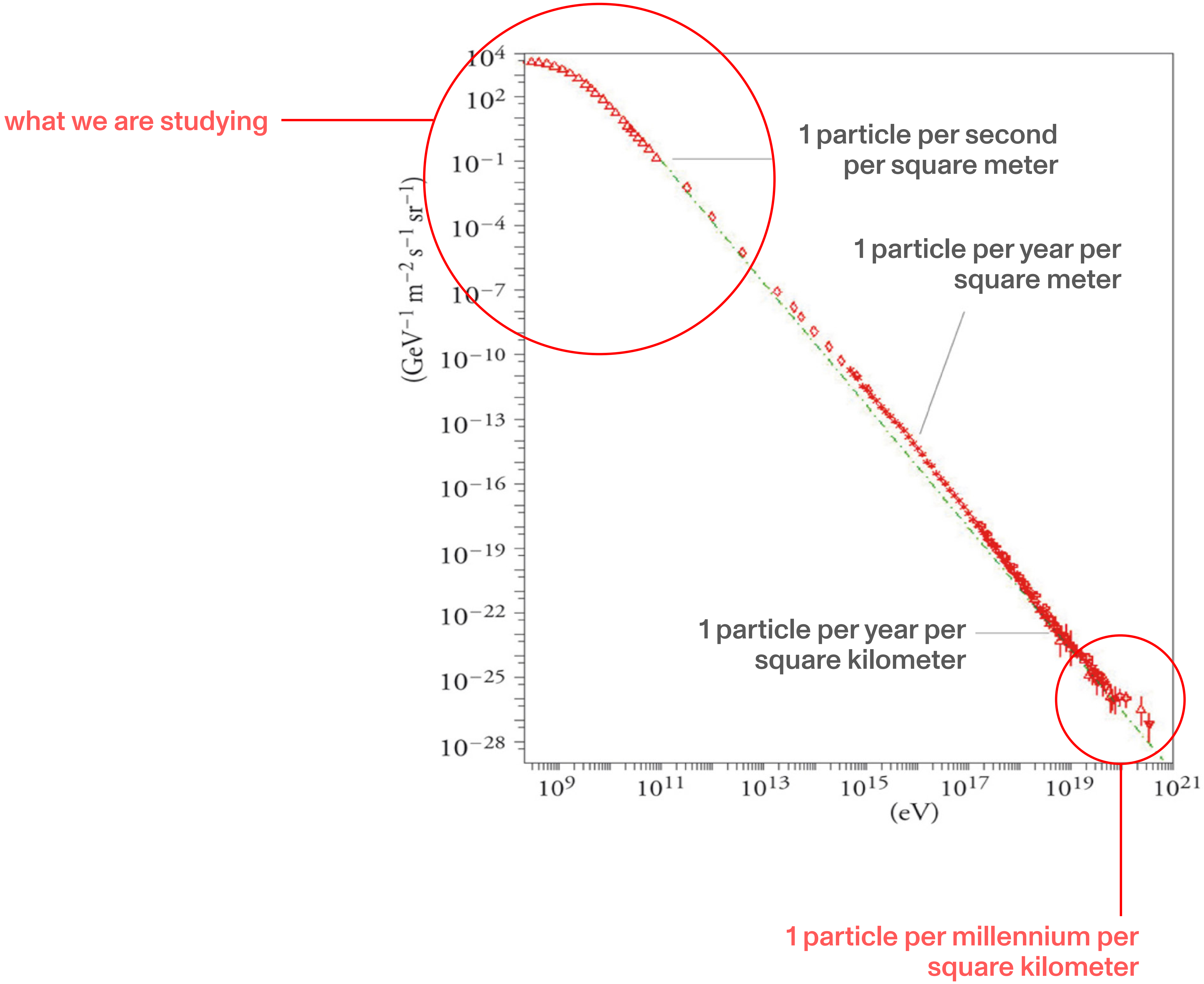


MiniEUSO

U.H.E.C.R.

Ultra High Energy Cosmic Rays have energies of about **10^{20}eV.**
They have an incidence rate of about **1 particle per square kilometer per millennium.**
They have not been observed yet by MiniEUSO.

What we are studying is low-energy cosmic rays as noise for other observations.

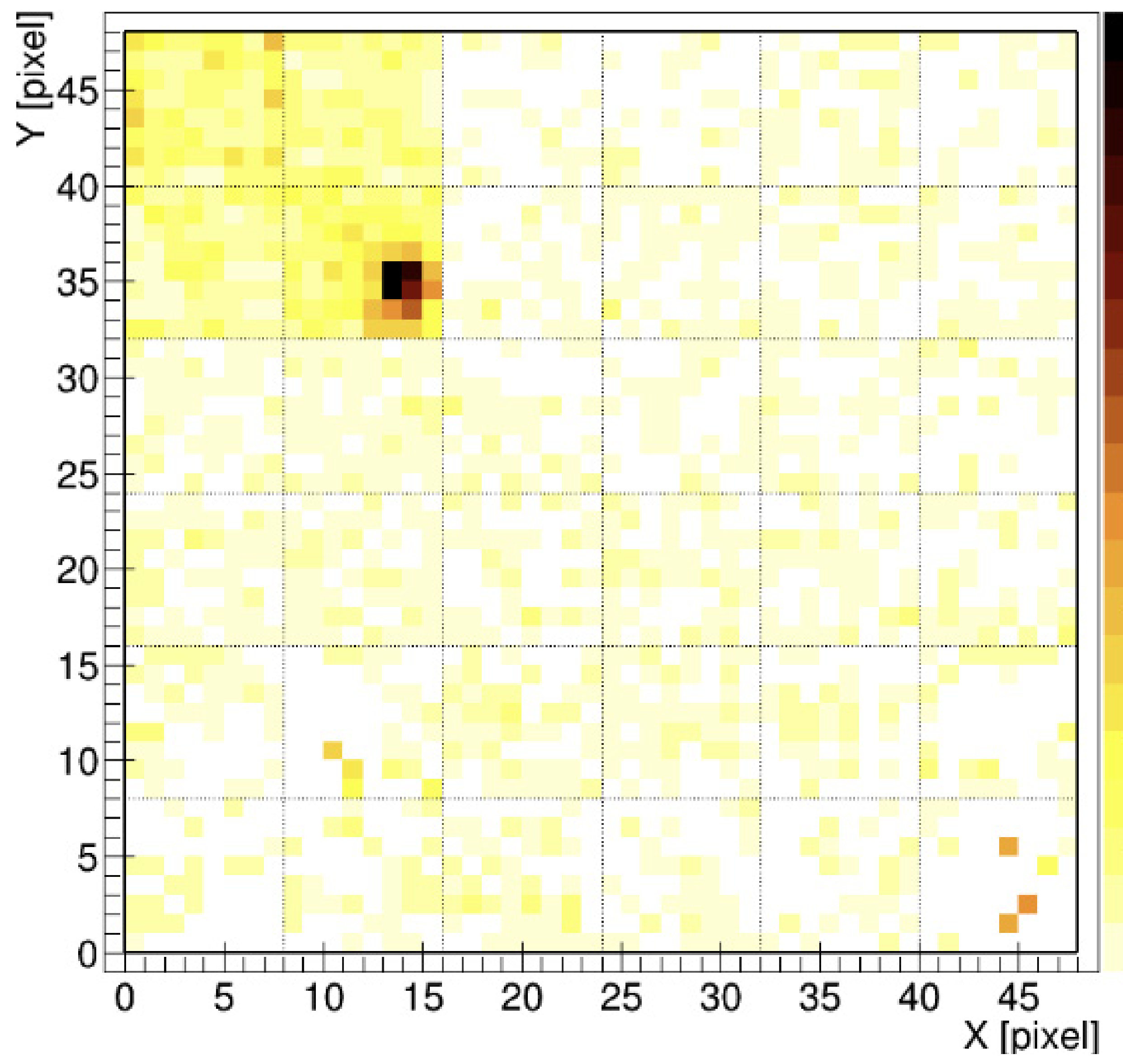


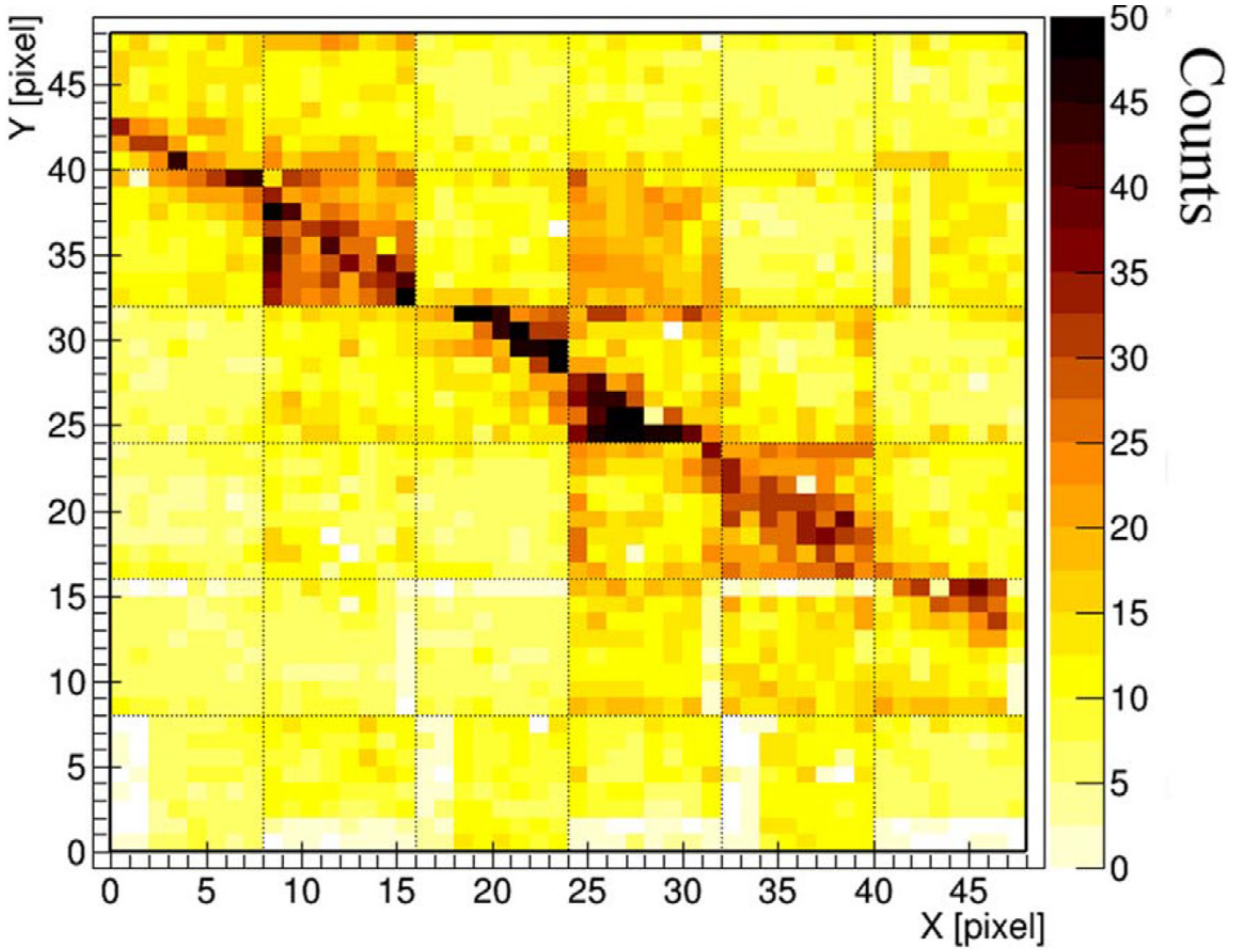
MiniEUSO

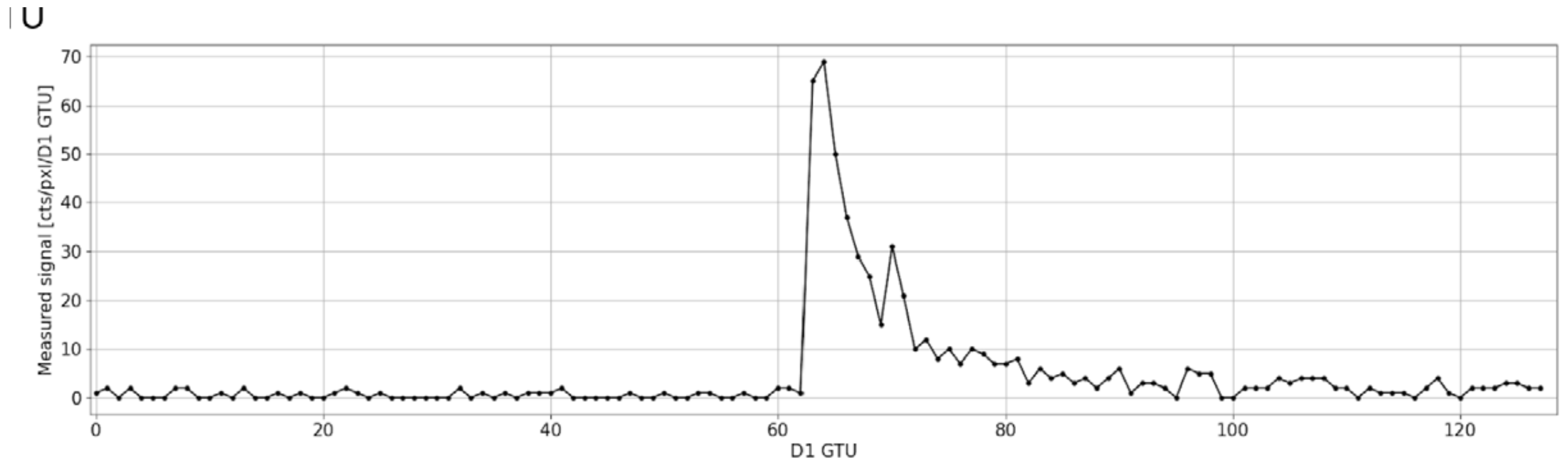
Direct cosmic rays observations

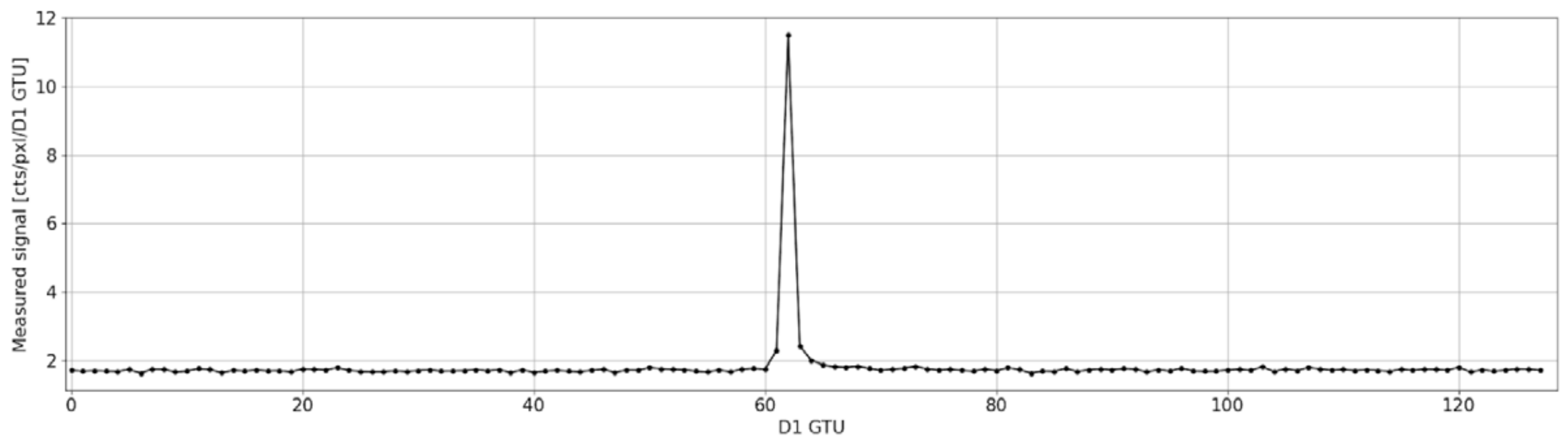
Interacting with photomultipliers low-energy cosmic rays can generate detectable photons. Signals are characterized by a **fast burst and an exponential decrease.**

It is possile to distinguish cosmic rays photo-signals from other light sources.





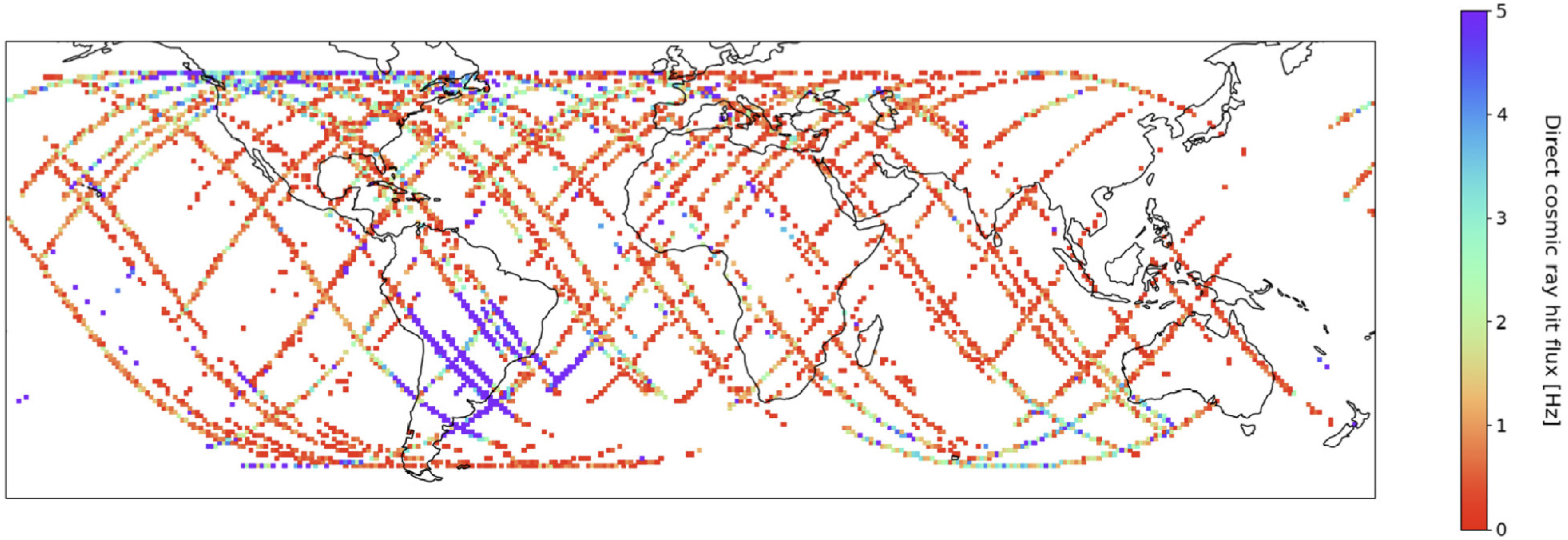




MiniEUSO

Direct cosmic rays observations

CR Average Counts frequency: 1Hz
CR Counts frequency while passing on the South Atlantic anomaly: x10%100



from: "The Mini-EUSO telescope on board the International Space Station: first results in view of UHECR measurements from space", M. Bertaina.

Our aim is to recreate the radiation enviroment in witch MiniEUSO is immersed

and to do so we need to:

a) recreate the cosmic rays source spectra as it is around the ISS;

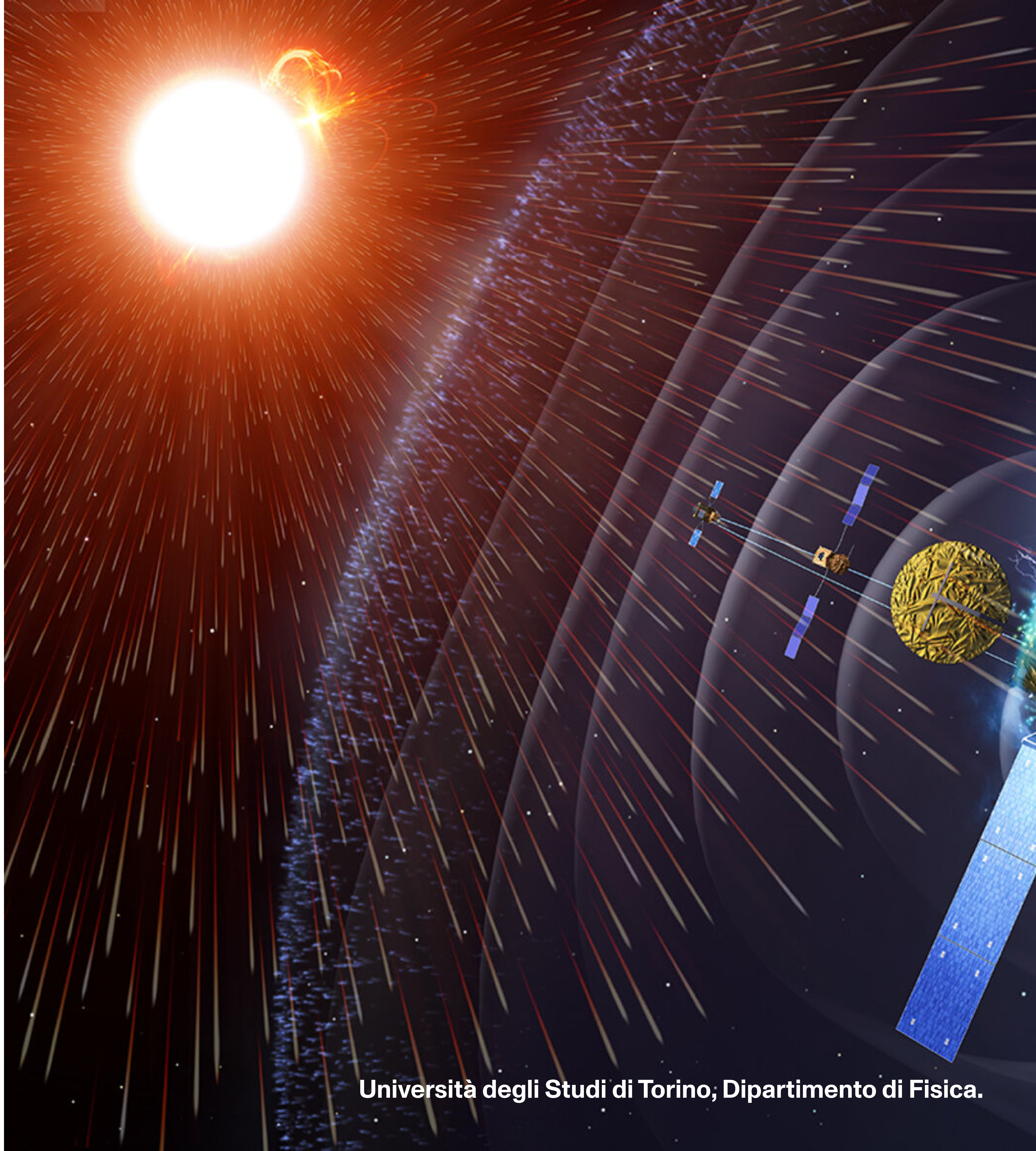
b) create a model of the Zvezda module in which MiniEUSO is insered;

c) simulate the interaction between the space module and cosmic rays radiation.

Chapter 2

How we built the simulation

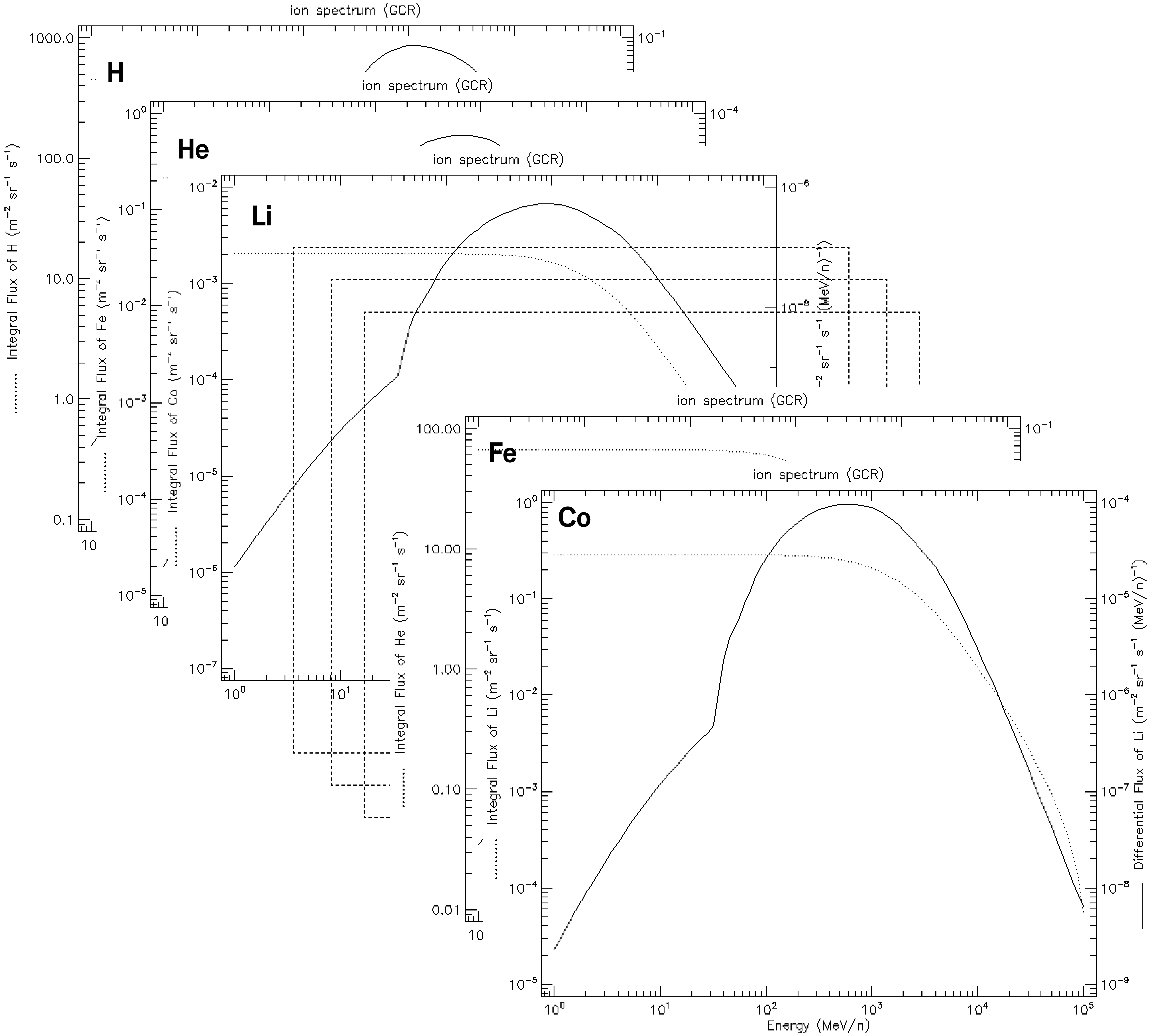
a) Recreate the radiation source



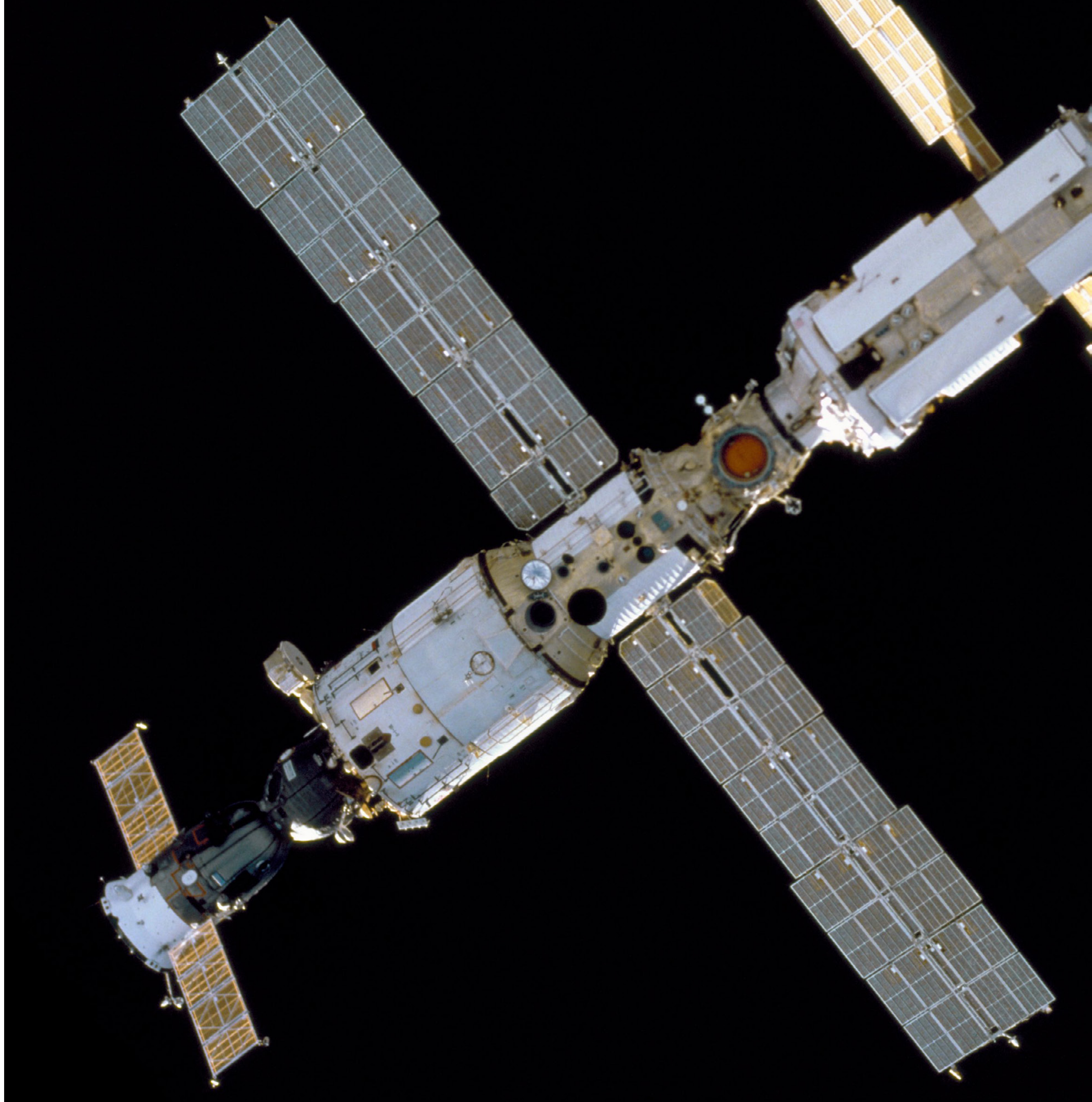
WWW interface to models of the space enviroment and its effects, including cosmic rays, natural radiation belts, solar energetic particles, and “micro-particles”

Mission Characteristics

Altitude from Earth’s surface: 408km
Orbital inclination: 51.64°
Mission START: 01/01/2020 - 00:00:00
Mission END: 31/12/2020 - 00:00:00

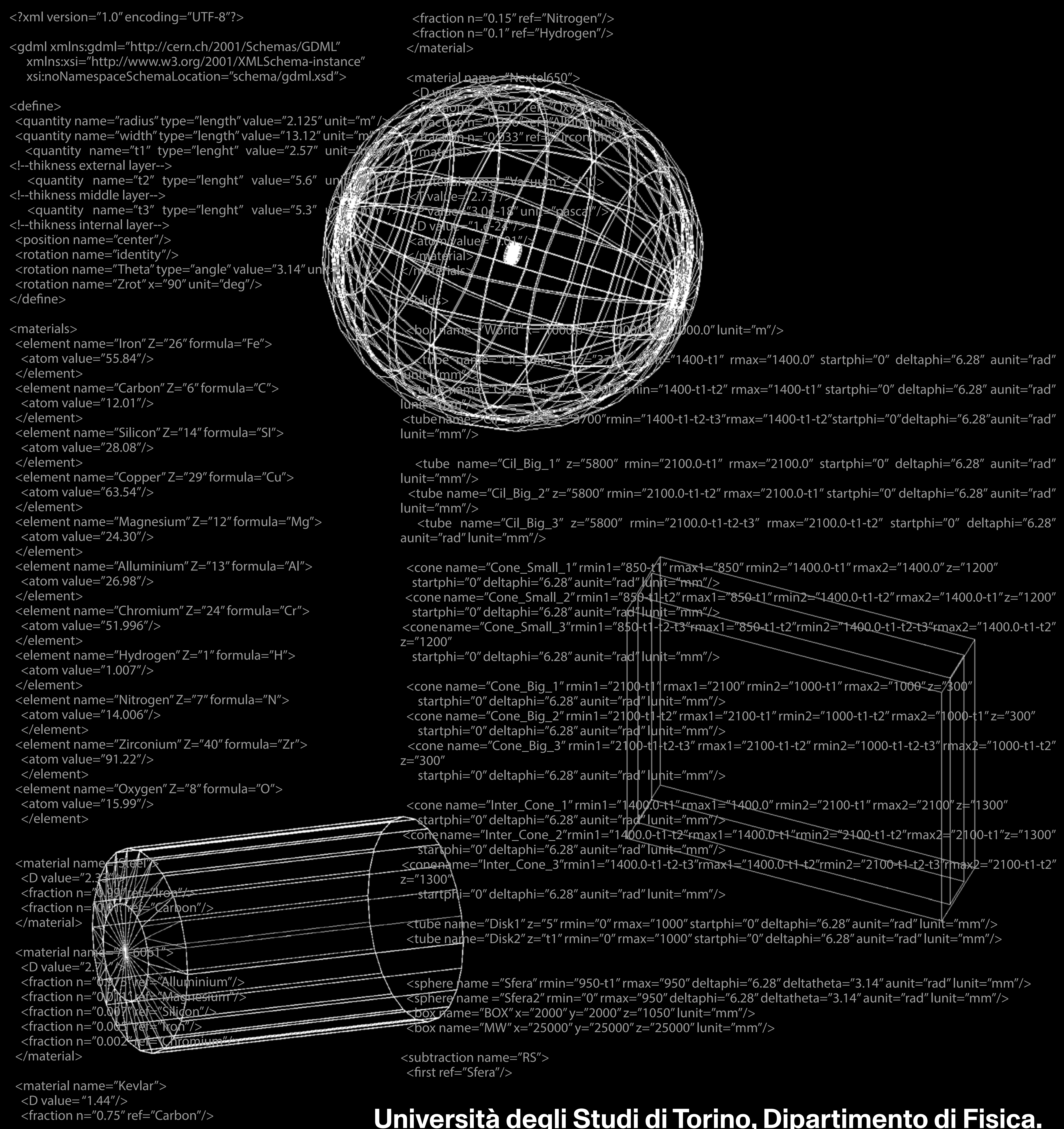


b) Recreate the Zvezda module



GDML

Geometry Description Markup Language is an application-indepedent geometry description format based on XML



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Big cilinder

Radius: 2.1m
Height: 5.8m

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<tube name=”Cil_Big_2” z=”5800” rmin=”2100.0-t1-t2”rmax=”2100.0-t1”startphi=”0”deltaphi=”6.28” aunit=”rad” lunit=”mm”/>
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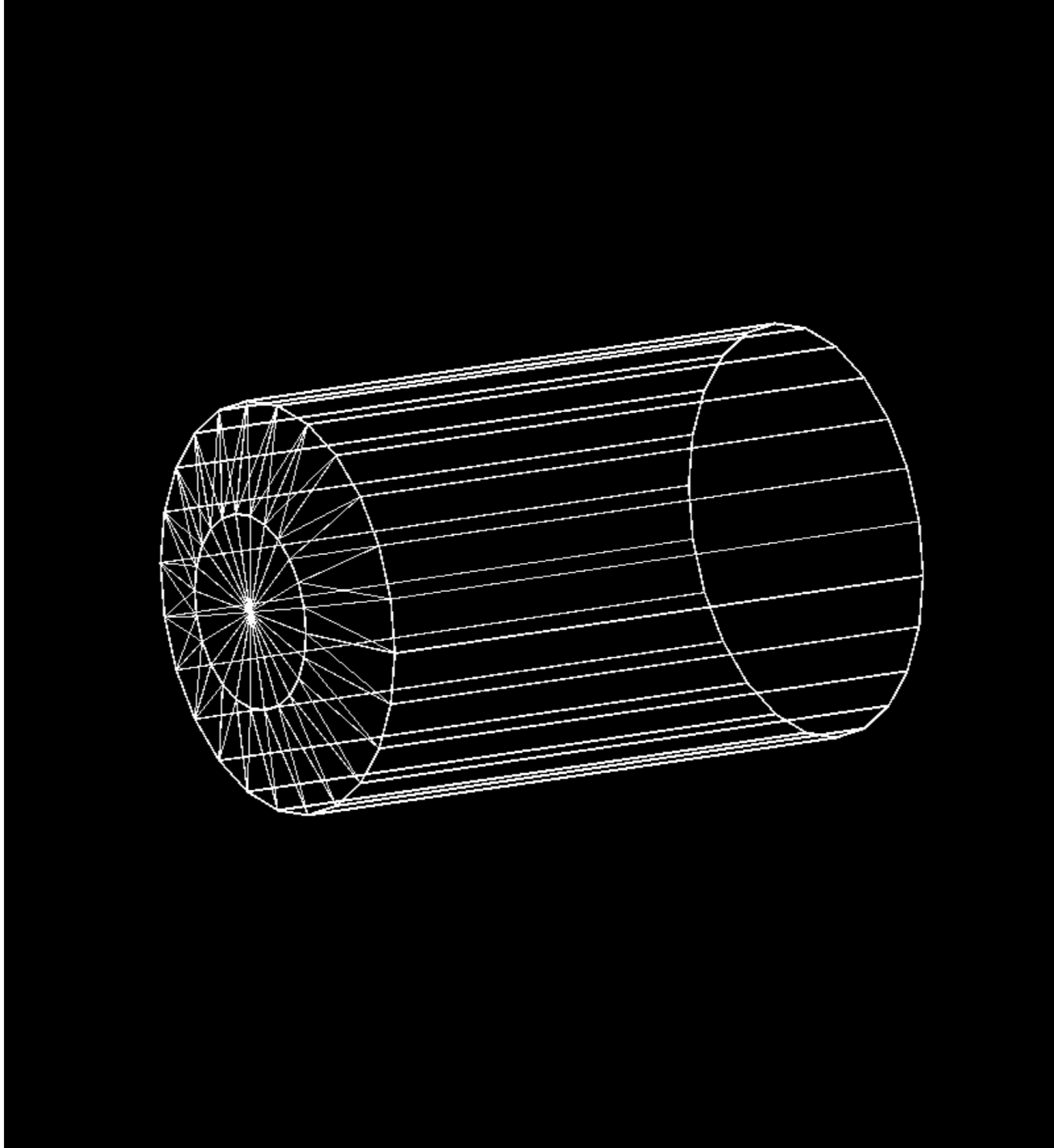
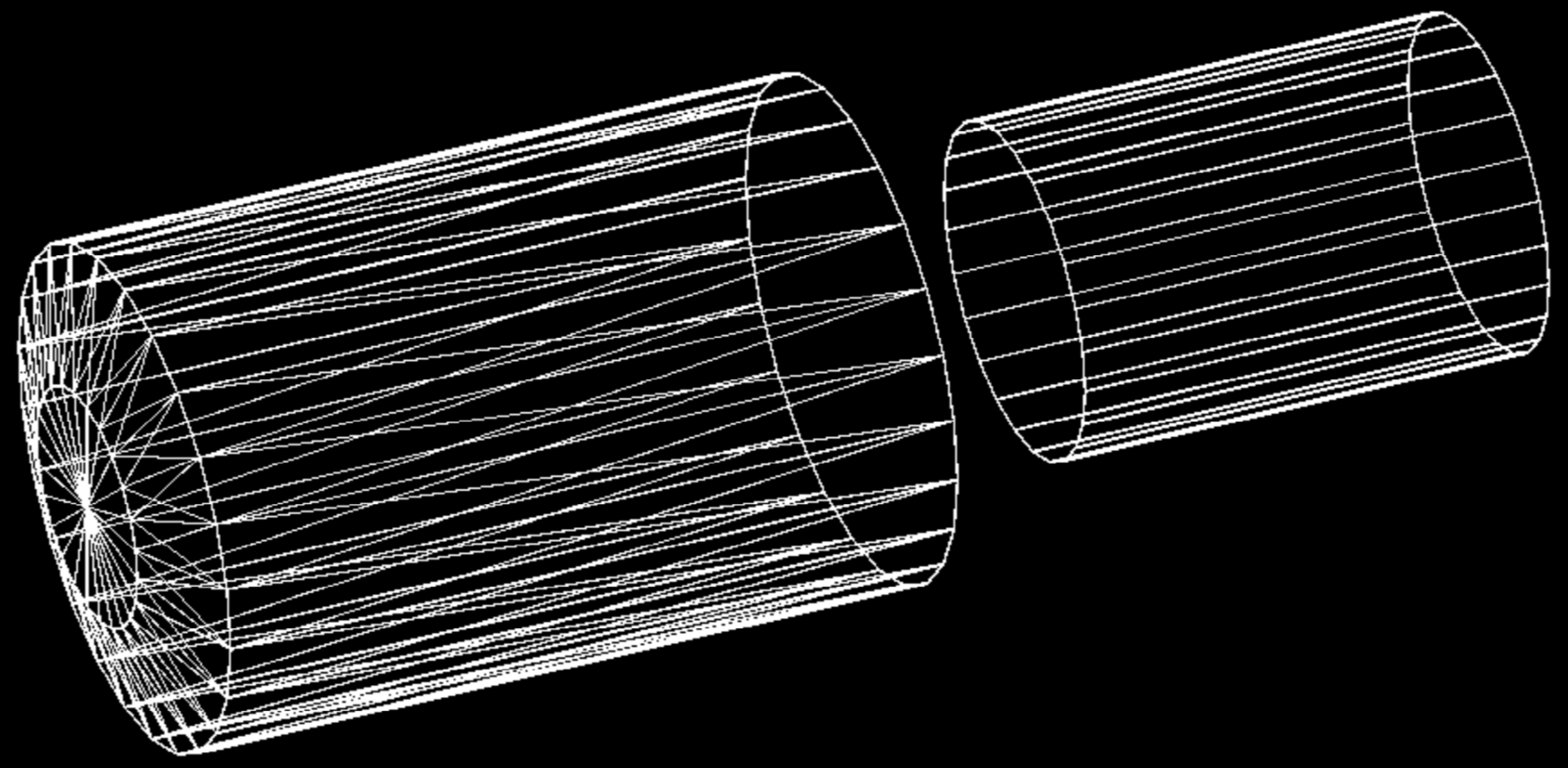


Small cilinder

Radius: 1.4m
Height: 3.7m



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Big truncated cone

Bigger Radius: 2.1m
Smaller Radius: 1.4m
Height: 1.3m

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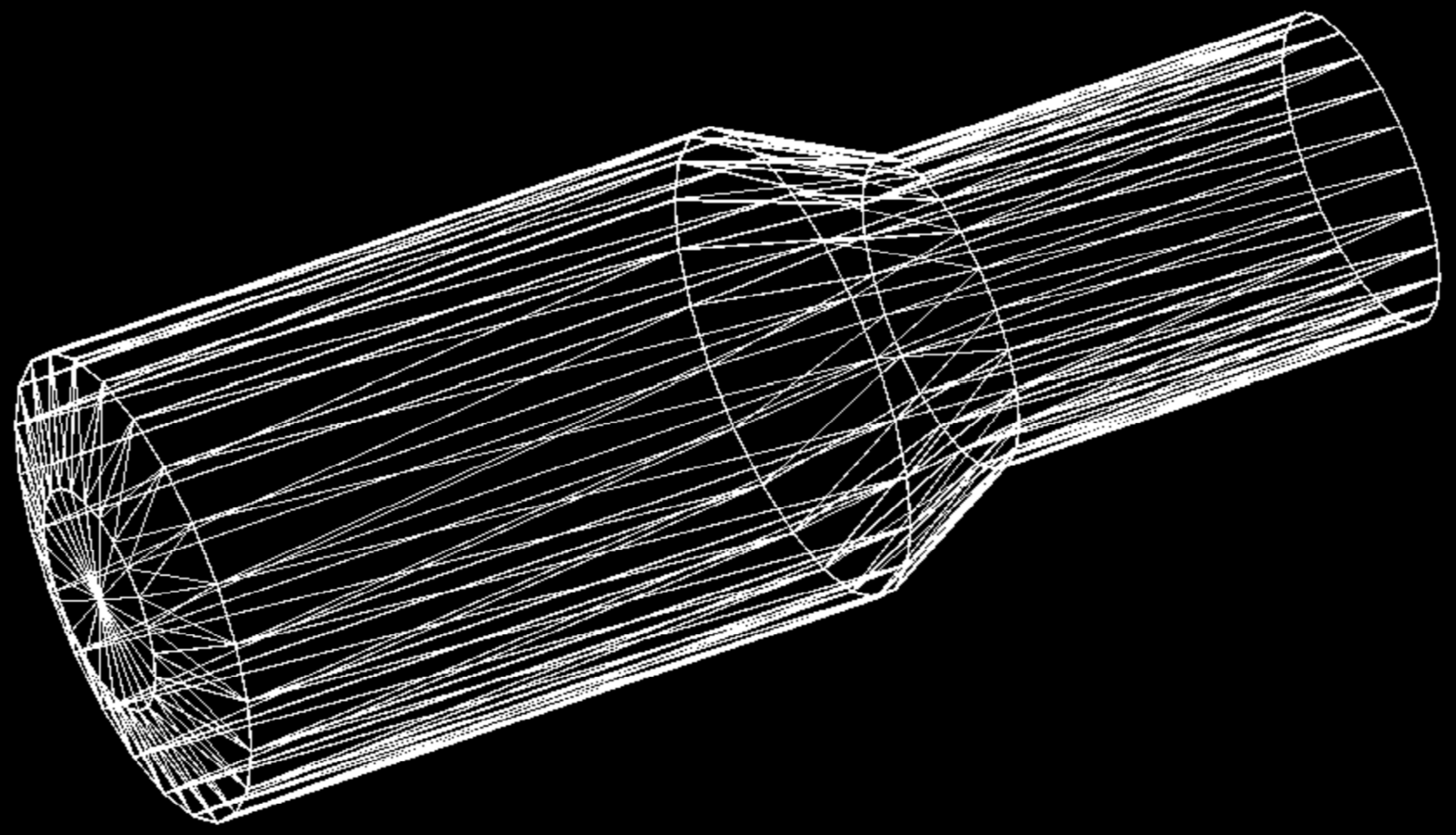
<conename=”Inter_Cone_3” rmin1=”1400.0-t1-t2-t3” rmax1=”1400.0-t1-t2” rmin2=”2100-t1-t2-t3” rmax2=”2100-t1-t2” z=”1300” startphi=”0” deltaphi=”6.28” aunit=”rad” lunit=”mm”/>W



Small truncated cone

Bigger Radius: 1.4m
Smaller Radius: 0.85m
Height: 1.2m

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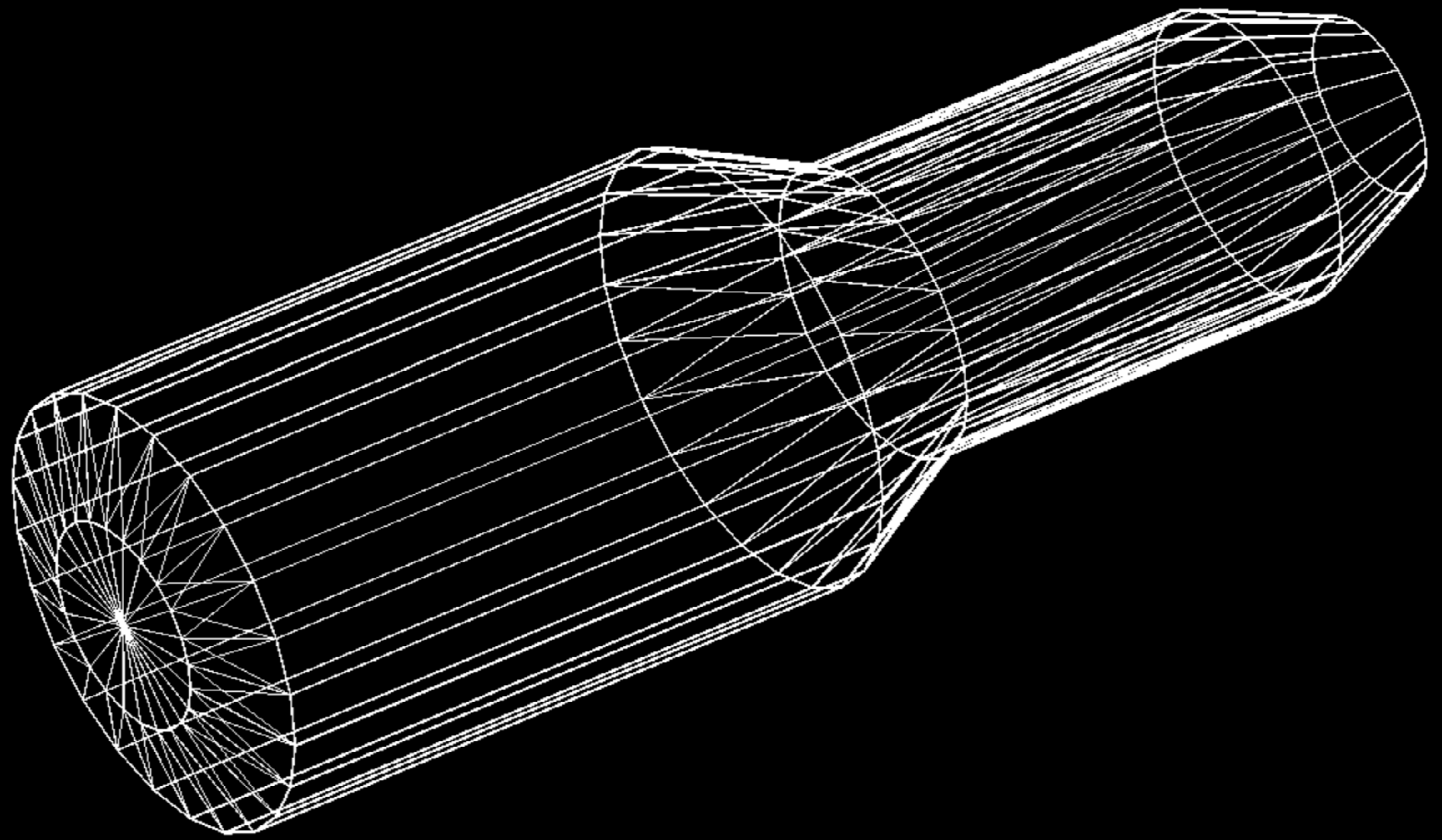

Half Sphere

Radius: 0.95m

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lunit=”mm”/>
   <sphere name =”Sfera2” rmin=”0” rmax=”950”
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lunit=”mm”/>
<box name=”BOX” x=”2000” y=”2000” z=”1050”
lunit=”mm”/>
<subtraction name=”RS”>
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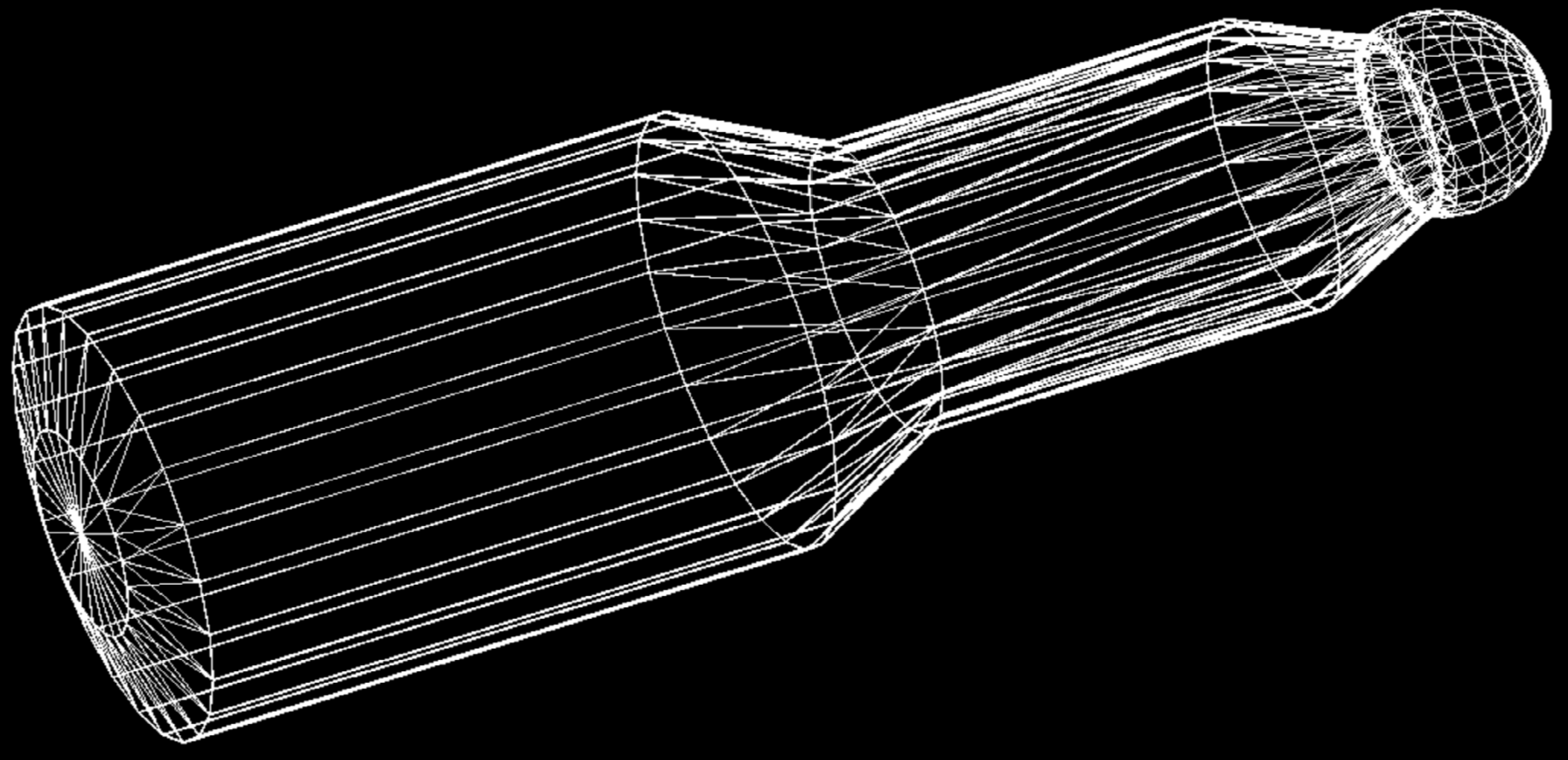
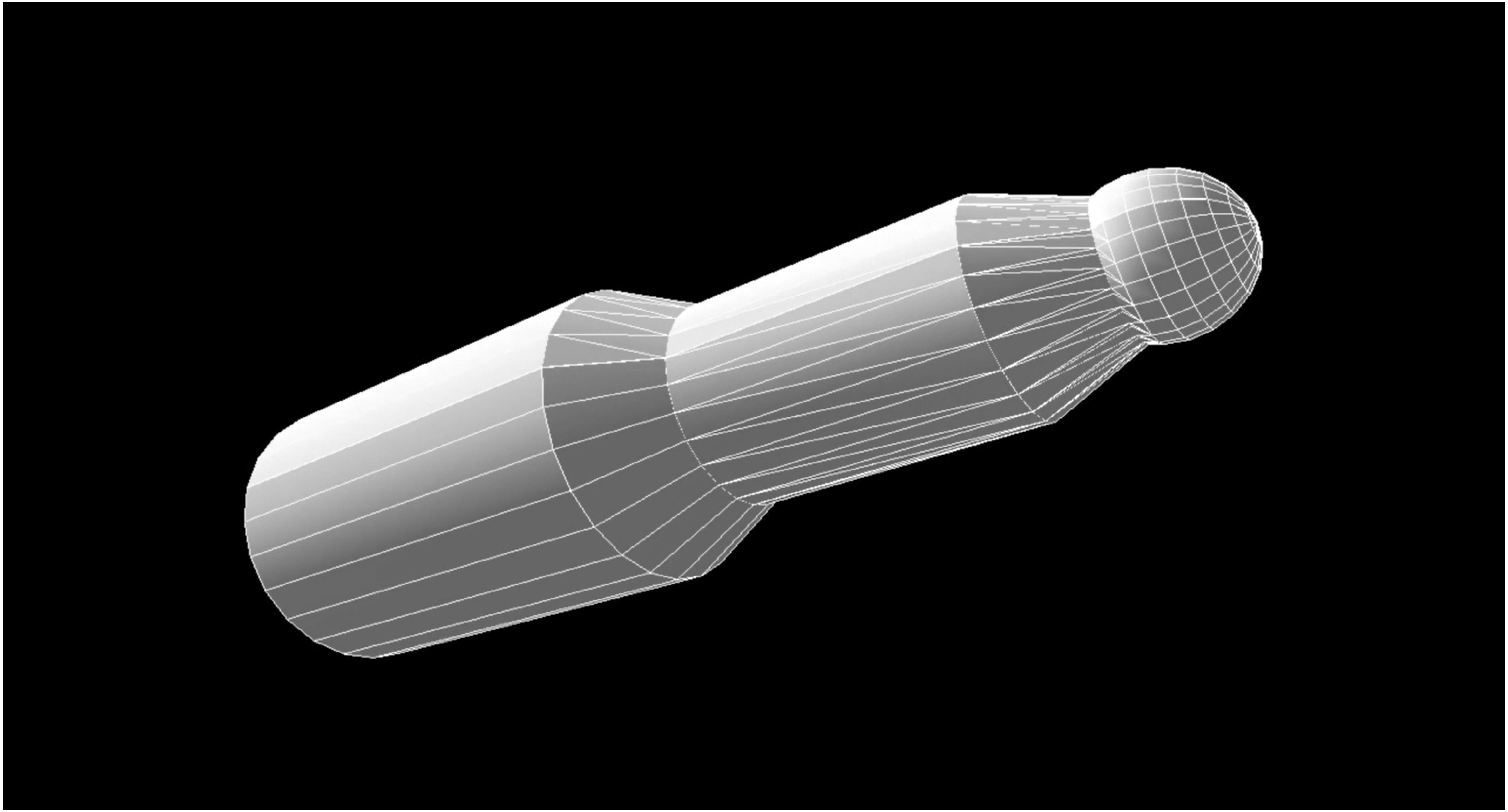
</subtraction>
```





Materials

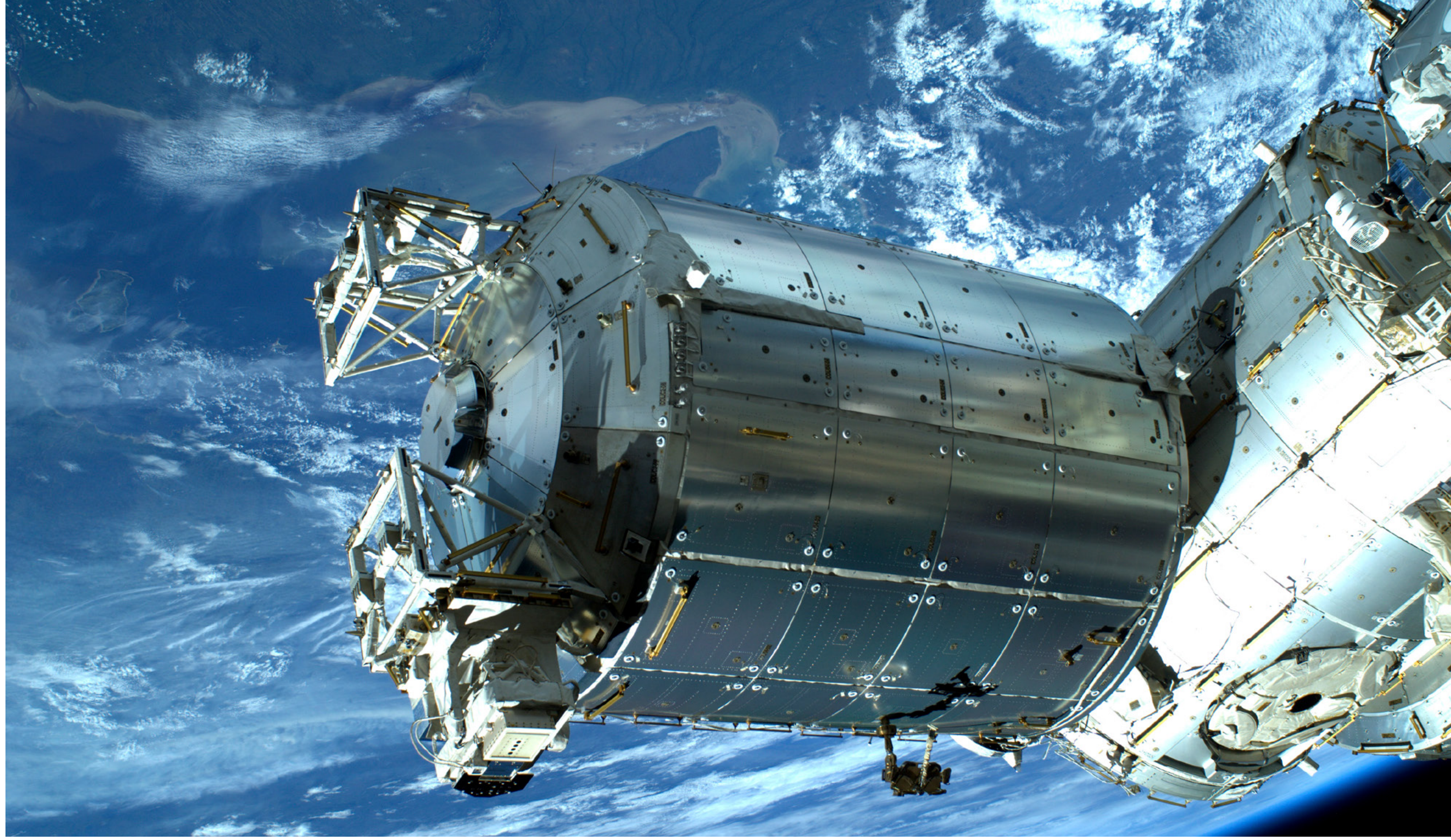
Not having access to informations about Zvezda's walls costituents materials, we have created a **Columbus**-like structural model.

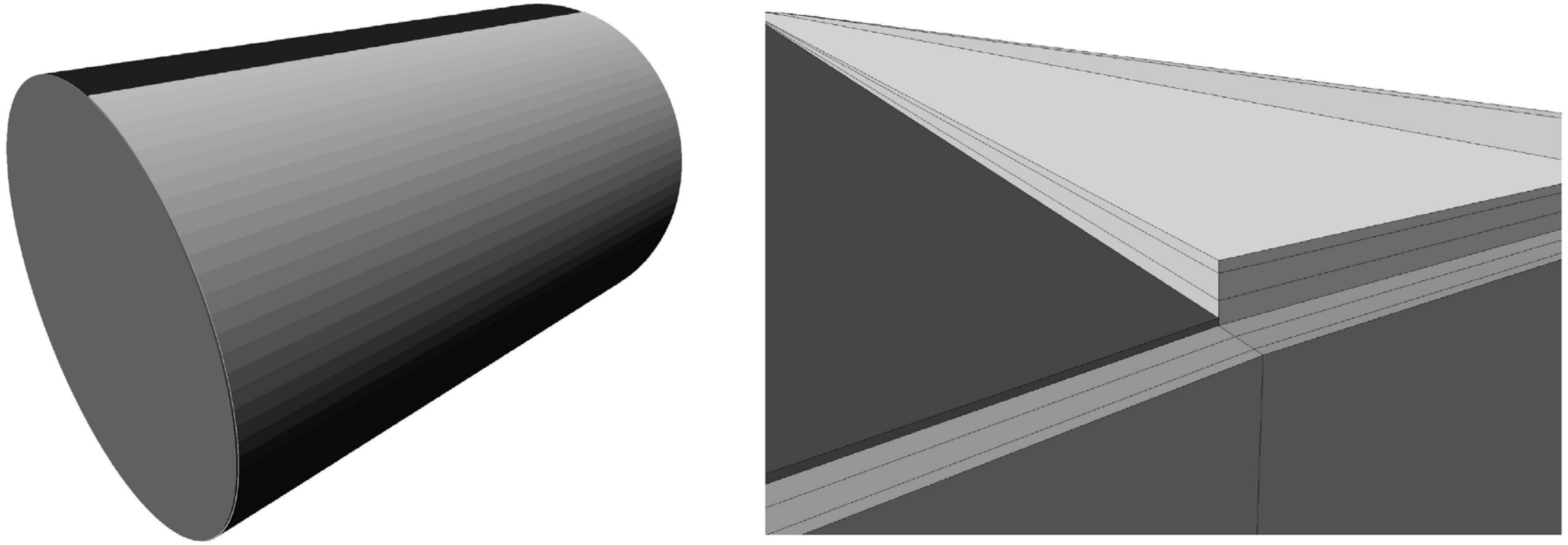
To get a Meteor and Debrits Protection system Columbus is made of three different layers:

- external layer
  2.7 mm of **Aluminium 6061T6**

- middle layer
  5.6 mm of **Kevlar**

- internal layer
  5.3 mm of **Nextel 650**





from: "Geant4 Monte Carlo Simulations of the International Space Station Radiation Environment", Tore Ersmark, 2006.

MiniEUSO

We have insered a 37cmx37cmx62cm Detector box between the two cilinders to reproduce MiniEUSO.

```
    <box  name=”DTT”  x=”320”  y=”320”  z=”620”
lunit=”mm”/>
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  <subtraction name=”SH”>
   <first ref=”sh”/>
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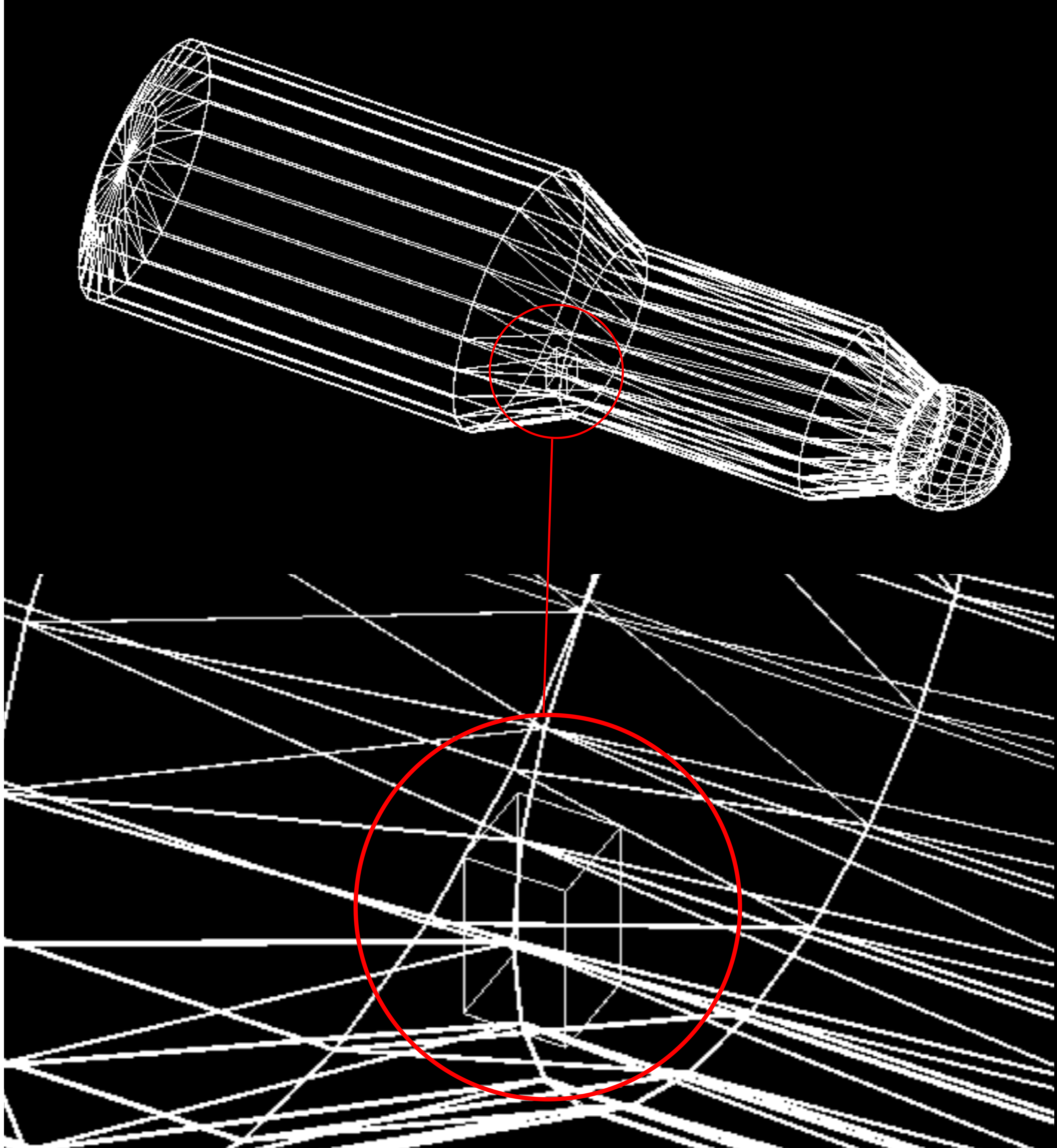
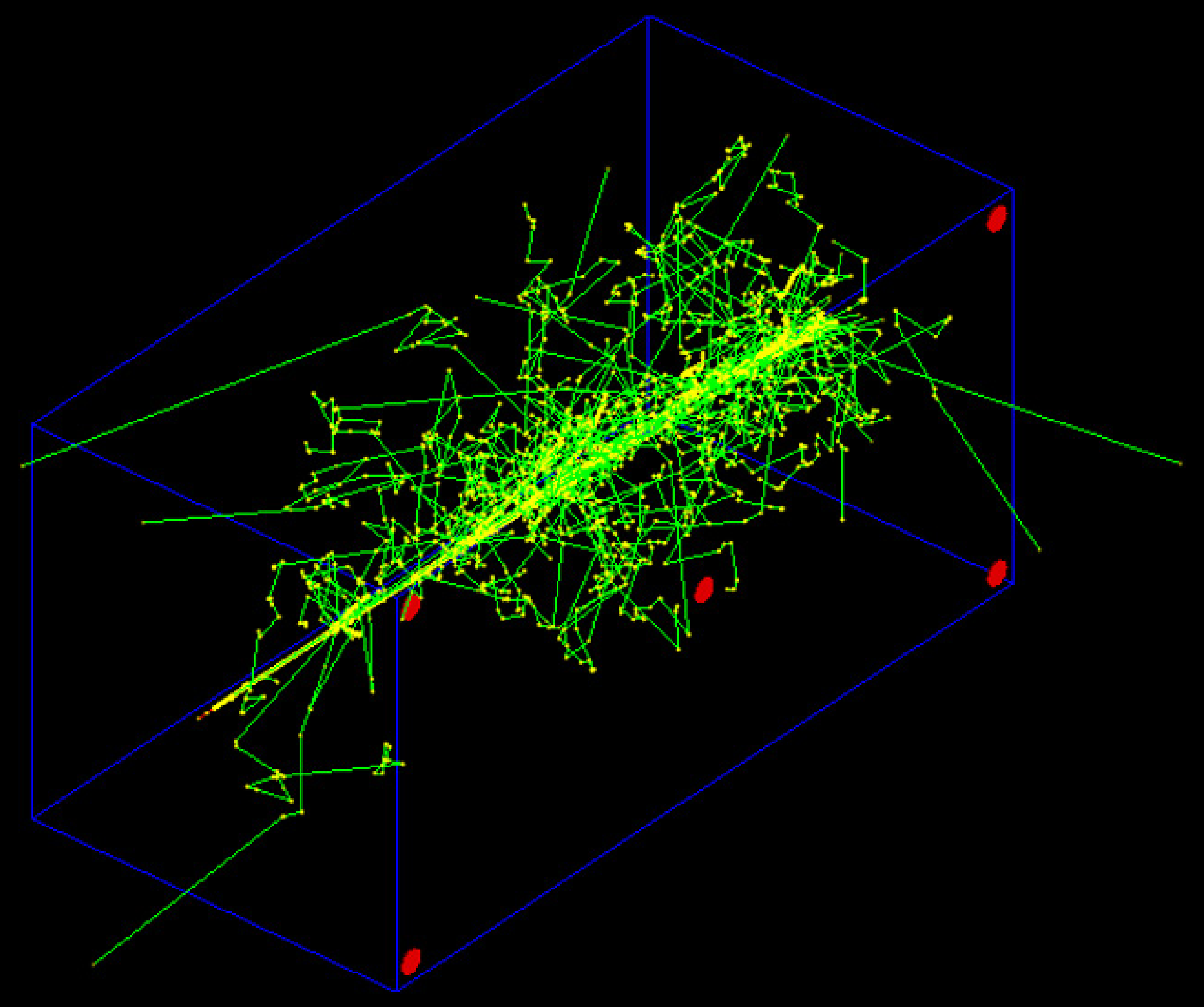
  </subtraction>
```



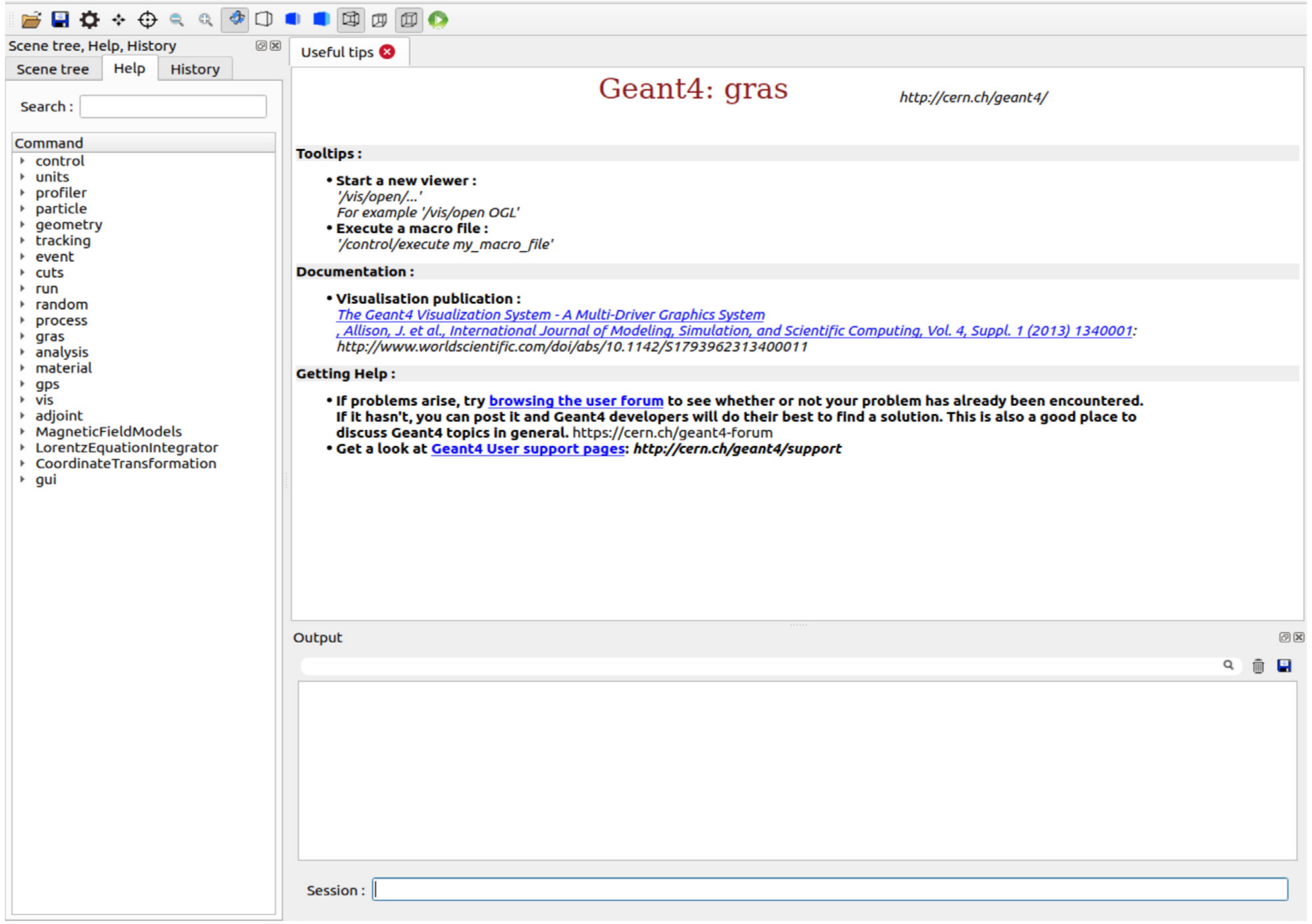
c) Simulate the interaction



GRAS

Geant4 Radiation Analysis for Space

a Geant4-based tool that deals with common radiation analyses types (TID, NIEL, fluence, SEE, path length, charge deposit, dose equivalent, equivalent dose, ...) in generic 3D geometry models.



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2.8000E+00, 4.5255E+02, 6.5011E-06
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```

SPENVIS
The Space Environment Information System

1_H.txt

```
#SOURCE TYPE DEFINITION
Species=["1_H","2_He","3_Li","4_Be","5_B","6_C","7_N","8_O","9_F","10_Ne","11_Mg","12_Na","13_Al","14_Si","15_P","16_S","17_Cl","18_Ar","19_K","20_Ca","21_Sc","22_Ti","23_V","24_Cr","25_Mn","26_Fe","27_Co"]
A_Mass=["1","4","7","9","11","12","14","16","19","20","23","24","27","29","31","32","35","40","39","40","45","48","51","52","55","56","57"]
for s in Species:
  name=s+".g4mac"
  f=open(name,"w")
    direc="/home/alindo/Desktop/GRAS/Spenvis/Datas/"+s+".txt"
  with open(direc) as file:
        while line := file.readline():
                line.rstrip()
                init = line[:12]
                second = line[-12:-1] #DIFFERENTIAL INFOs
                final = "/gps/hist/point " + init + "   " + second + "\n"
                f.write(final)
                print(final)


#SOURCE GEOMETRY DEFINITION
Source=open("Source.g4mac","w")
i=1
for s in Species:
    Source.write("#PARTICLE TYPE AND ENERGY SPECTRUM for "+s+" \n")
  Source.write("/gps/source/add 1 \n")
  Source.write("/gps/particle ion \n")
  Source.write("/gps/ion "+str(i)+" "+A_Mass[i-1]+" "+str(i)+" \n")
 #Source.write("/gps/ion "+str(i)+""+A_Mass[i-1]+" \n")
  i=i+1
  Source.write("/gps/ene/type Arb \n")
  Source.write("/gps/hist/type arb \n")
 Source.write("/gps/ene/min 1.0000E+00 MeV \n")
 Source.write("/gps/ene/max 1.0000E+05 MeV \n")
      Source.write("/control/execute    D.E.S./"+s+".g4mac \n")
  Source.write("/gps/hist/inter Lin \n")
  Source.write(" \n")
    Source.write("#SOURCE GEOMETRY for "+s+" \n")
  Source.write("/gps/pos/type Surface \n")
  Source.write("/gps/pos/shape Sphere \n")
  Source.write("/gps/pos/centre 0 0 0 m \n")
  Source.write("/gps/pos/radius 15000 mm \n")
  Source.write("/gps/ang/type cos \n")
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  Source.write(" \n")
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Macro.py

```
#PARTICLE TYPE AND ENERGY SPECTRUM for 1_H
/gps/source/add       1
/gps/particle         ion
/gps/ion        1     1     1
/gps/ene/type         Arb
/gps/hist/type        arb
/gps/ene/min    1.0000E+00   MeV
/gps/ene/max    1.0000E+05   MeV
/control/execute      D.E.S./1_H.g4mac
/gps/hist/inter       Lin

#SOURCE GEOMETRY for 1_H
/gps/pos/type         Surface
/gps/pos/shape        Sphere
/gps/pos/centre   0   0   0   m
/gps/pos/radius   15000   mm
/gps/ang/type         cos
/gps/ang/mintheta   0   deg
/gps/ang/maxtheta   90  deg


#PARTICLE TYPE AND ENERGY SPECTRUM for 2_He
/gps/source/add       1
/gps/particle         ion
/gps/ion        2     4     2
/gps/ene/type         Arb
/gps/hist/type        arb
/gps/ene/min    1.0000E+00   MeV
/gps/ene/max    1.0000E+05   MeV
/control/execute      D.E.S./2_He.g4mac
/gps/hist/inter       Lin

#SOURCE GEOMETRY for 2_He
/gps/pos/type         Surface
/gps/pos/shape        Sphere
/gps/pos/centre   0   0   0   m
/gps/pos/radius   15000   mm
/gps/ang/type         cos
/gps/ang/mintheta   0   deg
/gps/ang/maxtheta   90  deg

#PARTICLE TYPE AND ENERGY SPECTRUM for 3_Li
/gps/source/add       1
/gps/particle         ion
/gps/ion        3     7     3
/gps/ene/type         Arb
/gps/hist/type        arb
/gps/ene/min    1.0000E+00   MeV
/gps/ene/max    1.0000E+05   MeV
/control/execute      D.E.S./3_Li.g4mac
/gps/hist/inter       Lin

#SOURCE GEOMETRY for 3_Li
/gps/pos/type         Surface
/gps/pos/shape        Sphere
/gps/pos/centre   0   0   0   m
/gps/pos/radius   15000   mm
/gps/ang/type         cos
/gps/ang/mintheta   0   deg
/gps/ang/maxtheta   90  deg


#PARTICLE TYPE AND ENERGY SPECTRUM for 4_Be
/gps/source/add       1
/gps/particle         ion
/gps/ion        4     9     4
/gps/ene/type         Arb
/gps/hist/type        arb
/gps/ene/min    1.0000E+00   MeV
/gps/ene/max    1.0000E+05   MeV
/control/execute      D.E.S./4_Be.g4mac
/gps/hist/inter       Lin

#SOURCE GEOMETRY for 4_Be
/gps/pos/type         Surface
/gps/pos/shape        Sphere
/gps/pos/centre   0   0   0   m
/gps/pos/radius   15000   mm
/gps/ang/type         cos
/gps/ang/mintheta   0   deg
/gps/ang/maxtheta   90  deg


#PARTICLE TYPE AND ENERGY SPECTRUM for 5_B
/gps/source/add       1
/gps/particle         ion
/gps/ion        5     11    5
/gps/ene/type         Arb
/gps/hist/type        arb
/gps/ene/min    1.0000E+00   MeV
/gps/ene/max    1.0000E+05   MeV
/control/execute      D.E.S./5_B.g4mac
/gps/hist/inter       Lin
```

GEANT4
A SIMULATION TOOLKIT

Source.g4mac

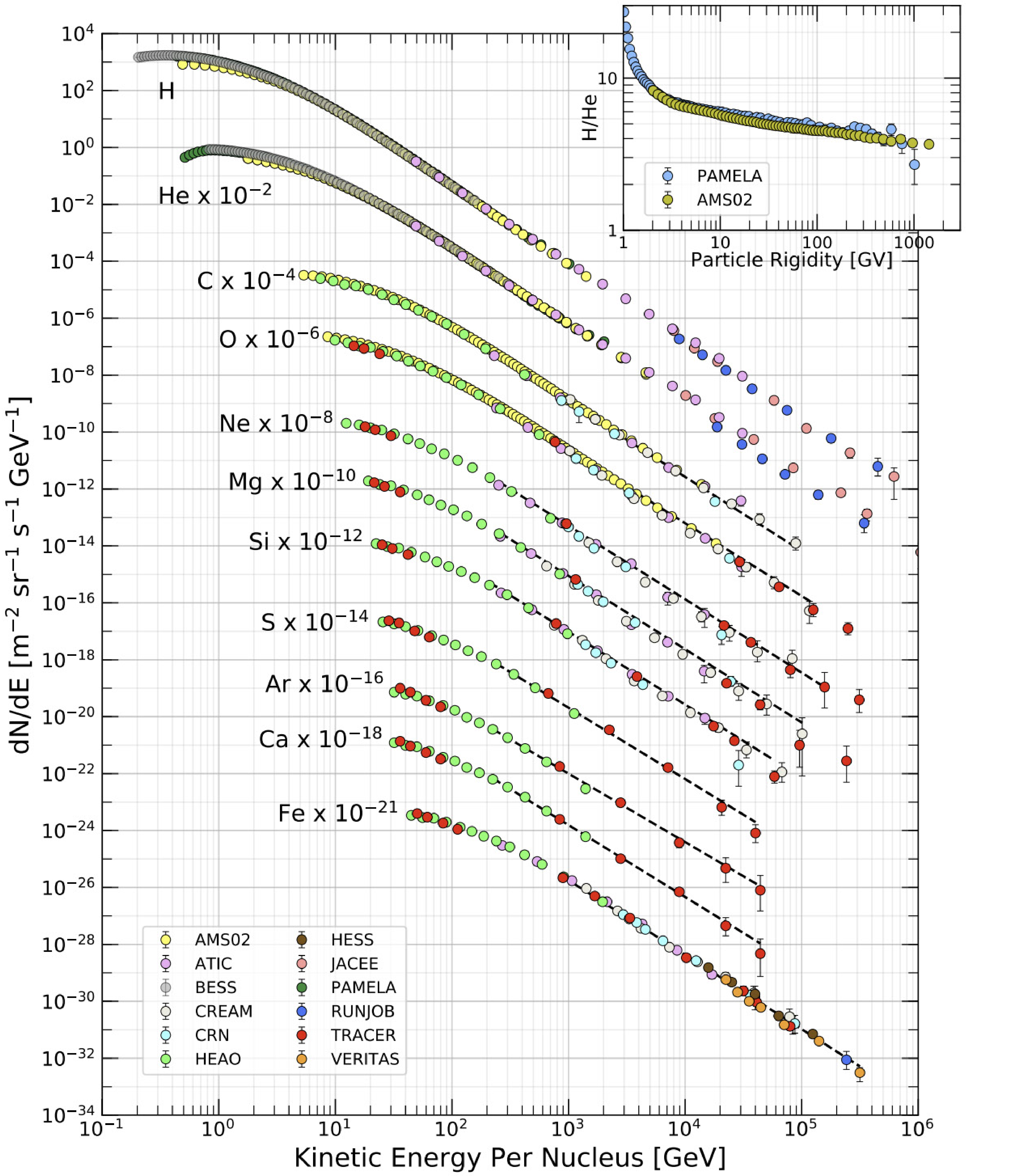
Source

Adding weight to all species

Nuclei of different species have been weighted with their relative abundance

Z	Element	F	Z	Element	F
1	H	550	13–14	Al-Si	0.19
2	He	34	15–16	P-S	0.03
3–5	Li-B	0.40	17–18	Cl-Ar	0.01
6–8	C-O	2.20	19–20	K-Ca	0.02
9–10	F-Ne	0.30	21–25	Sc-Mn	0.05
11–12	Na-Mg	0.22	26–28	Fe-Ni	0.12

F being the relative abundances of cosmic-ray nuclei



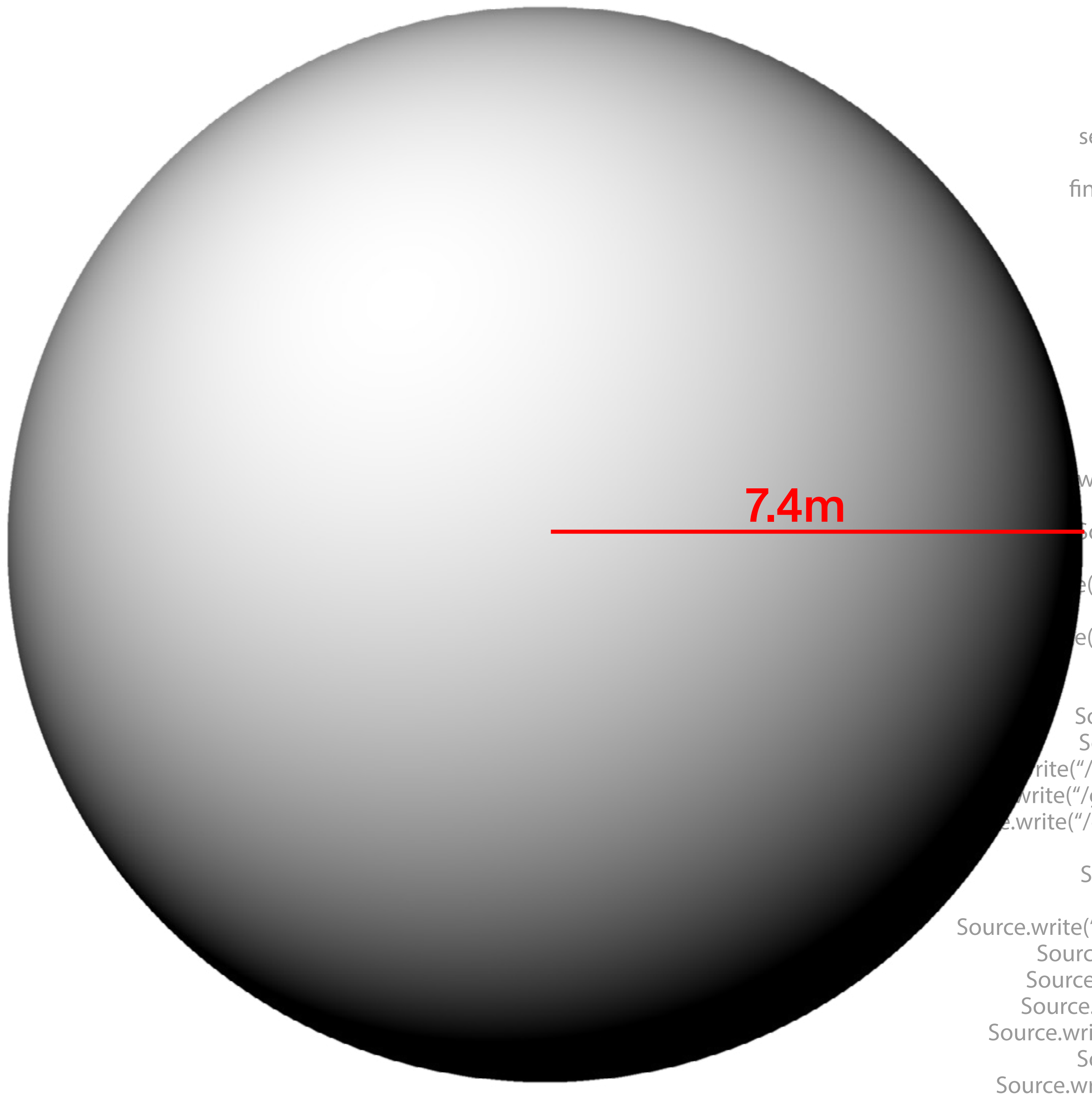
from: “Cosmic Rays”, J.J. Beatty , J. Matthews and S.P. Wakely, 2019.

Source

Defining the isotopry with GPS

GPS, General Particle Source, is part of the Geant4 toolkit for MonteCarlo high-energy particle transport.

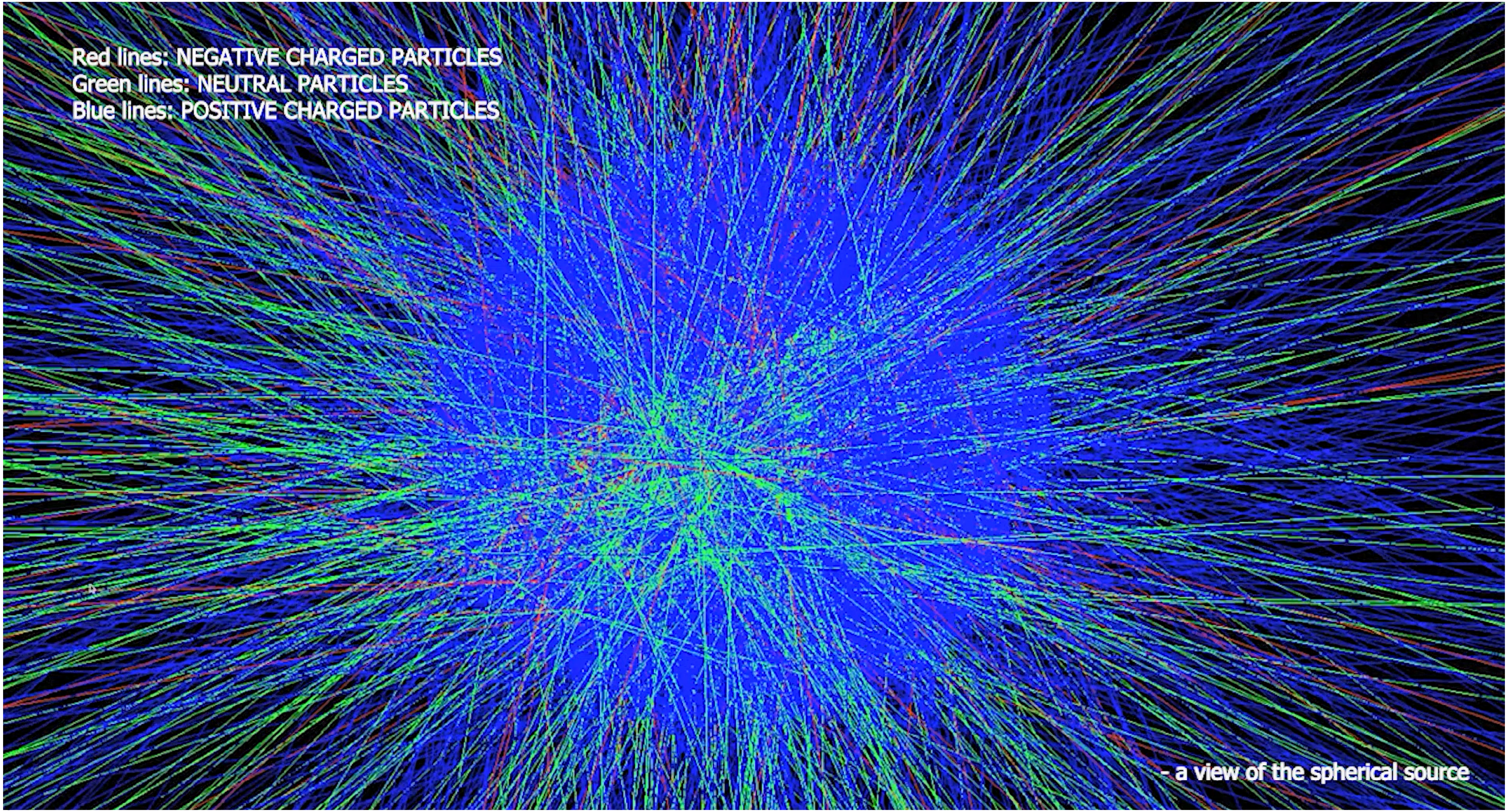
We have defined a **spherical source** of radius 7.4m all around Zvezda.
Every point of the surface of the sphere randomly generates one particle of the pre-defined spectrum with a cosine law distribution.

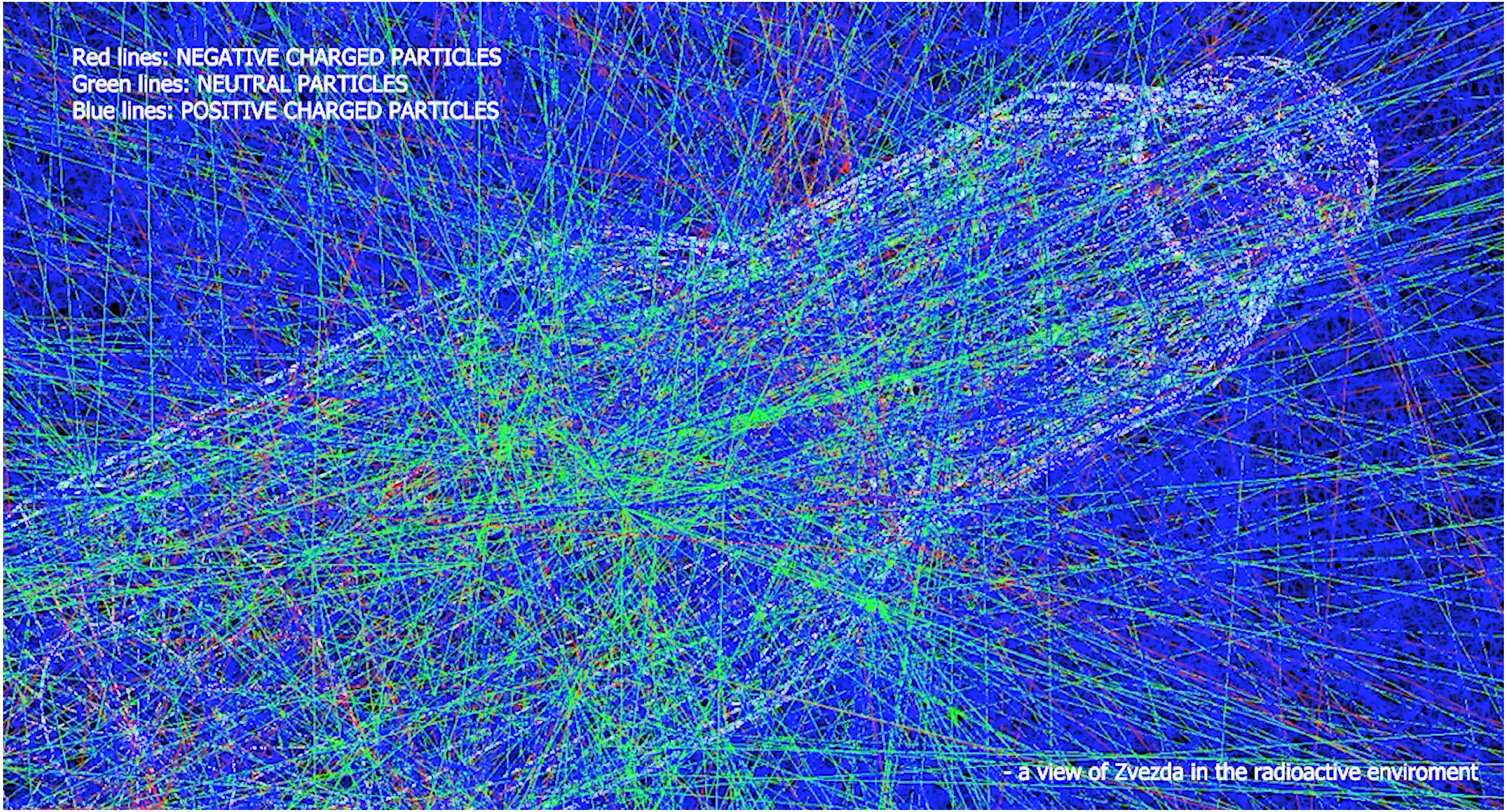



```
#SOURCE TYPE DEFINITION
Species=["1_H","2_He","3_Li","4_Be","5_B","6_C","7_
N","8_O","9_F","10_Ne","11_Mg","12_Na","13_Al","14_
Si","15_P","16_S","17_Cl","18_Ar","19_K","20_Ca","21_
Sc","22_Ti","23_V","24_Cr","25_Mn","26_Fe","27_Co"]
A_Mass=["1","4","7","9","11","12","14","16","19","20","23",
24","27","29","31","32","35","40","39","40","45","48","51","5
2","55","56","57"]
for s in Species:
name=s+".g4mac"
f=open(name,"w")
direc="/home/alindo/Desktop/GRAS/Spenvis/
Datas/"+s+".txt"
with open(direc) as file:
while line := file.readline():
line.rstrip()
init = line[:12]
second = line[-12:-1] #DIFFERENTIAL
INFOs
final = "/gps/hist/point " + init + "   " +
second + "\n"
f.write(final)
print(final)


#SOURCE GEOMETRY DEFINITION
Source=open("Source.g4mac","w")
i=1
for s in Species:
write("#PARTICLE TYPE AND ENERGY
SPECTRUM for "+s+" \n")
ource.write("/gps/source/add 1 \n")
Source.write("/gps/particle ion \n")
e("/gps/ion "+str(i)+" "+A_Mass[i-1]+"
"+str(i)+" \n")
e("/gps/ion "+str(i)+" "+A_Mass[i-1]+"
\n")
i=i+1
Source.write("/gps/ene/type Arb \n")
Source.write("/gps/hist/type arb \n")
rite("/gps/ene/min 1.0000E+00  MeV \n")
write("/gps/ene/max 1.0000E+05  MeV \n")
.write("/control/execute D.E.S./"+s+".g4mac
\n")
Source.write("/gps/hist/inter Lin \n")
Source.write(" \n")
Source.write("#SOURCE GEOMETRY for "+s+" \n")
Source.write("/gps/pos/type Surface \n")
Source.write("/gps/pos/shape Sphere \n")
Source.write("/gps/pos/centre 0 0 0 m \n")
Source.write("/gps/pos/radius 15000 mm \n")
Source.write("/gps/ang/type cos \n")
Source.write("/gps/ang/mintheta  0  deg \n")
Source.write("/gps/ang/maxtheta 90  deg \n")
Source.write(" \n")
Source.write(" \n")
```

from: "Geant4, General Particle Source".


Red lines: NEGATIVE CHARGED PARTICLES
Green lines: NEUTRAL PARTICLES
Blue lines: POSITIVE CHARGED PARTICLES
- a view of the spherical source


Red lines: NEGATIVE CHARGED PARTICLES
Green lines: NEUTRAL PARTICLES
Blue lines: POSITIVE CHARGED PARTICLES
- a view of Zvezda in the radioactive enviroment

Chapter 3

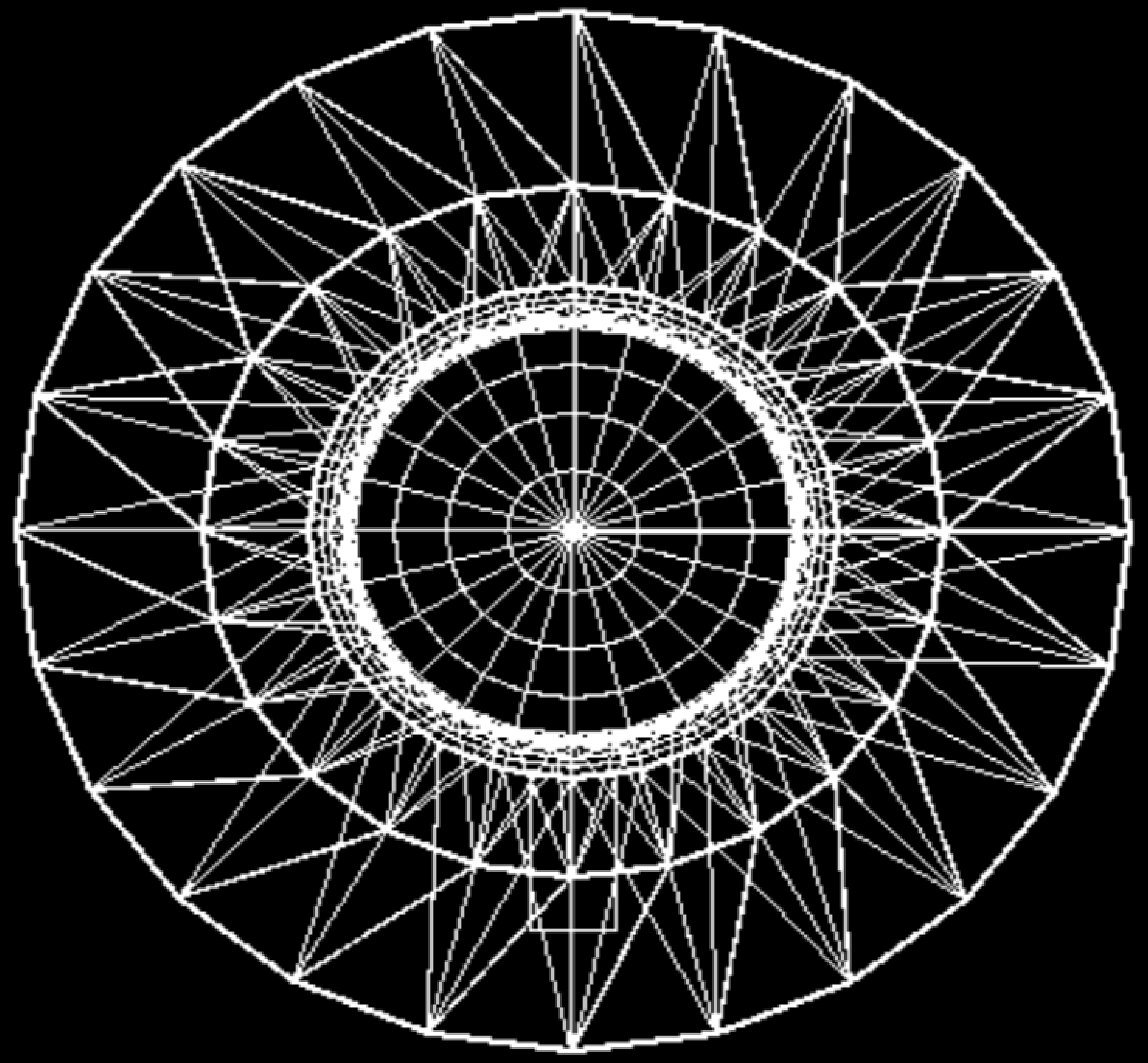
First Results

Università degli Studi di Torino, Dipartimento di Fisica.

First Results
Fluence analysis

We used GRAS Fluence Analysis Module to compute the particle flux entering the Zvezda module, hitting the Detector (i.e. MiniEUSO) and entering the Detector.

We focused on the analysis of the **proton flux.**

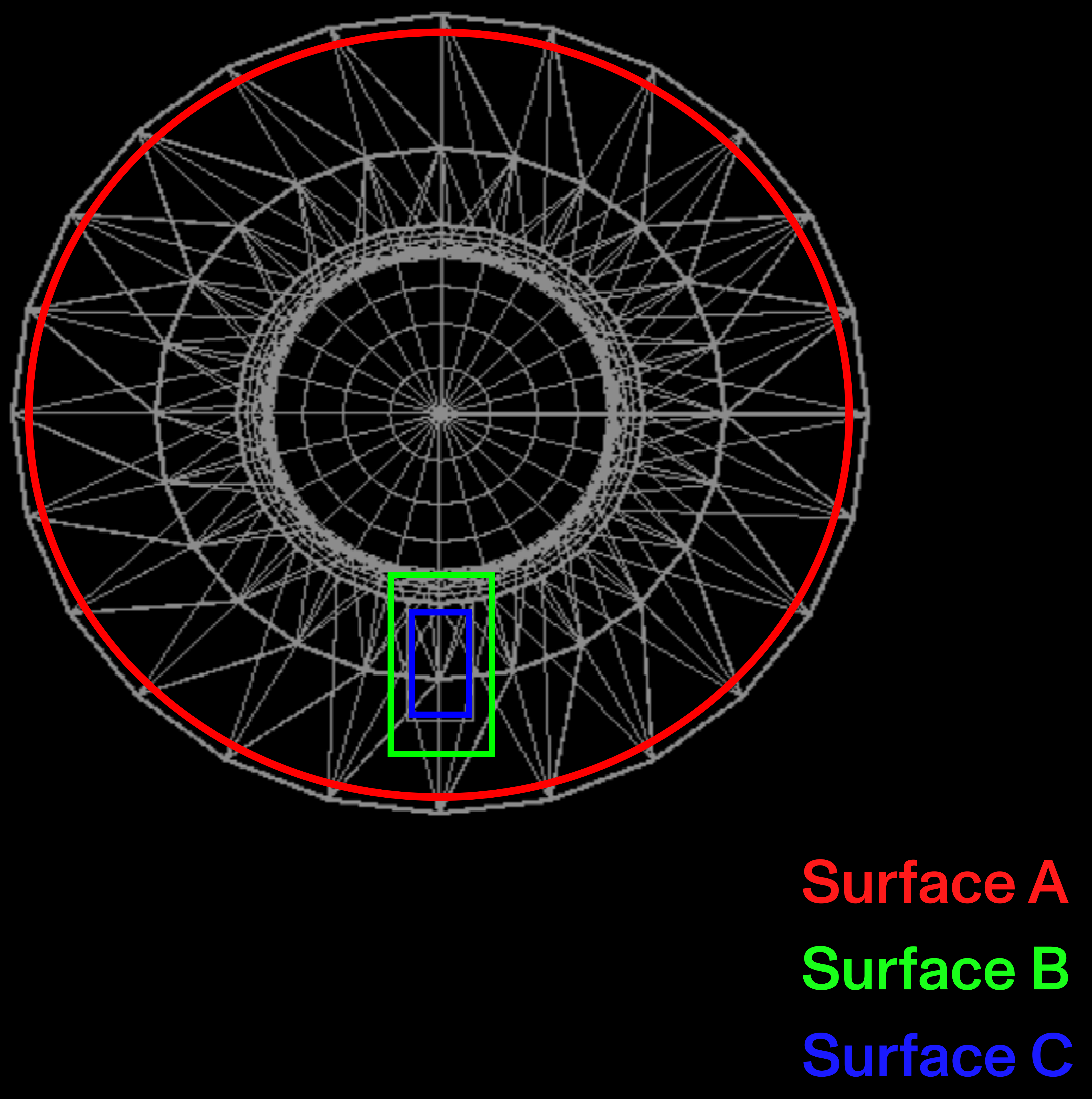


View of Zvezda from the back of the biggest cilinder

First Results

Fluence analysis

Surface A: proton flux entering the module
Surface B: proton flux hitting MiniEUSO
Surface C: proton flux entering MiniEUSO

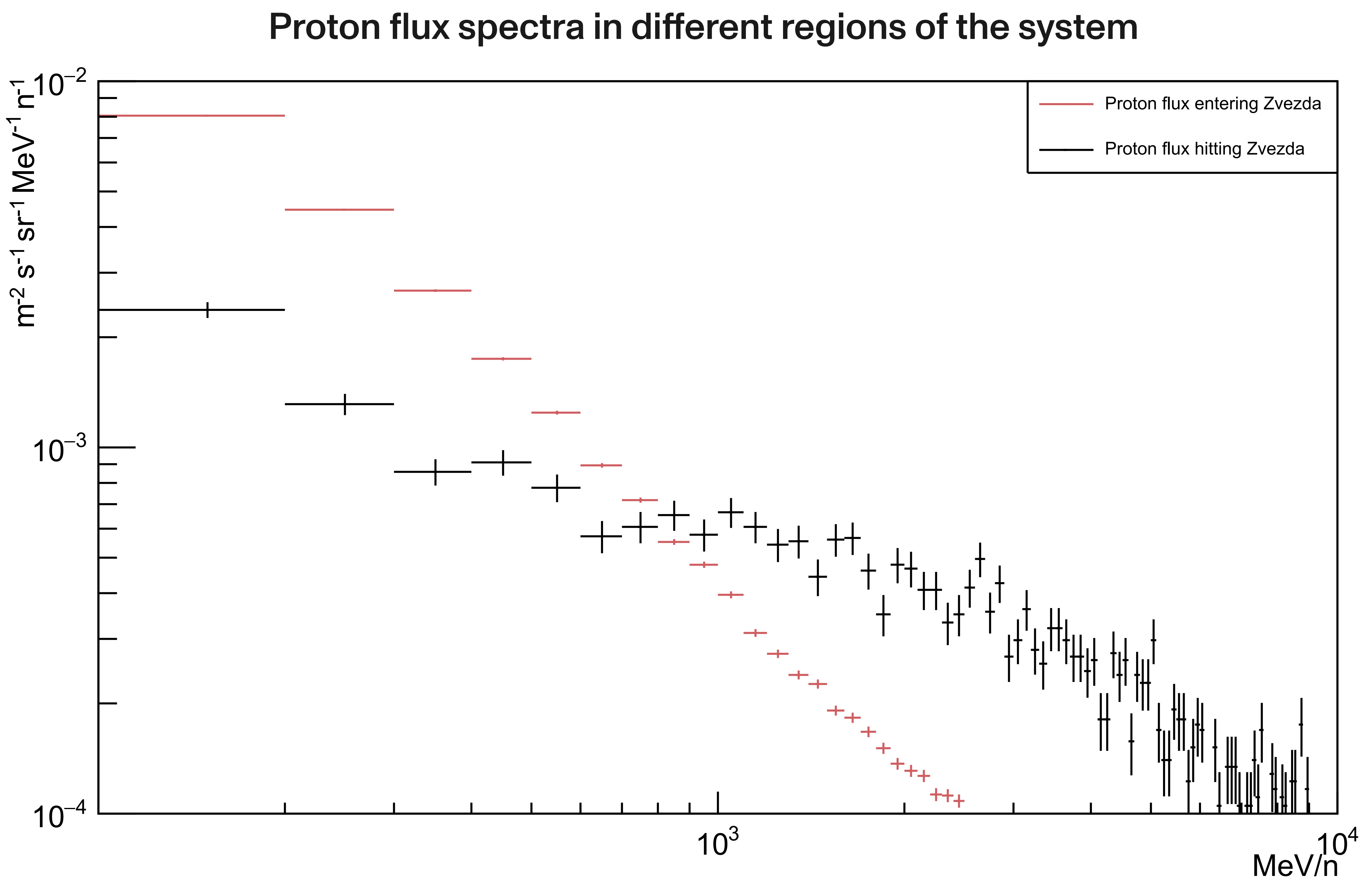


View of Zvezda from the back of the biggest cilinder

First Results

Incidence Rate

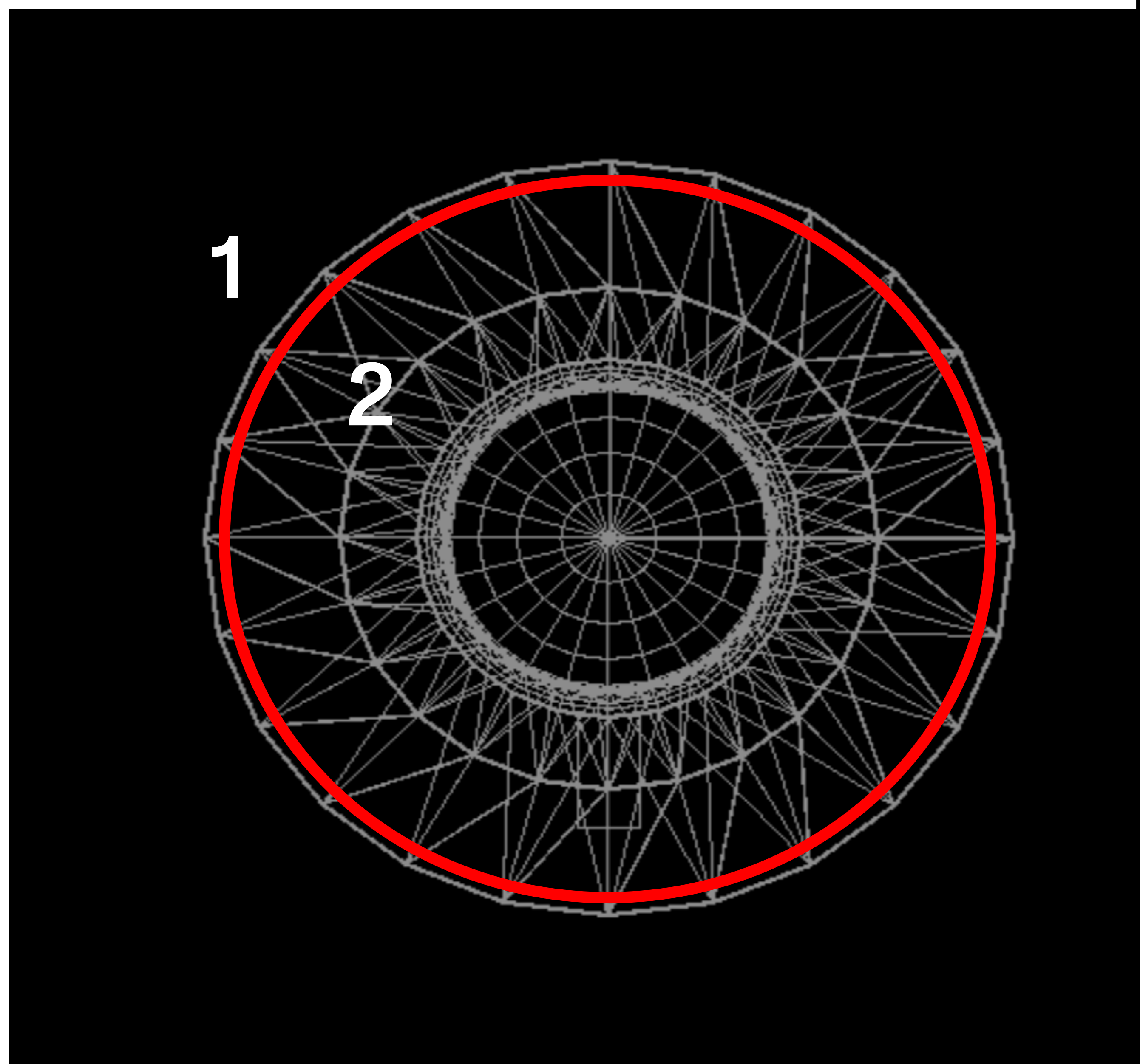
Computing the flux across the Surface A we register an **increase** of about **50%** in the number of protons from region 1 to region 2.



Heavy particles do fragmentation while interacting with walls's materials.

We register an **increase in the slope** of the flux distribution between the protons of the source and the protons entering Zvezda.

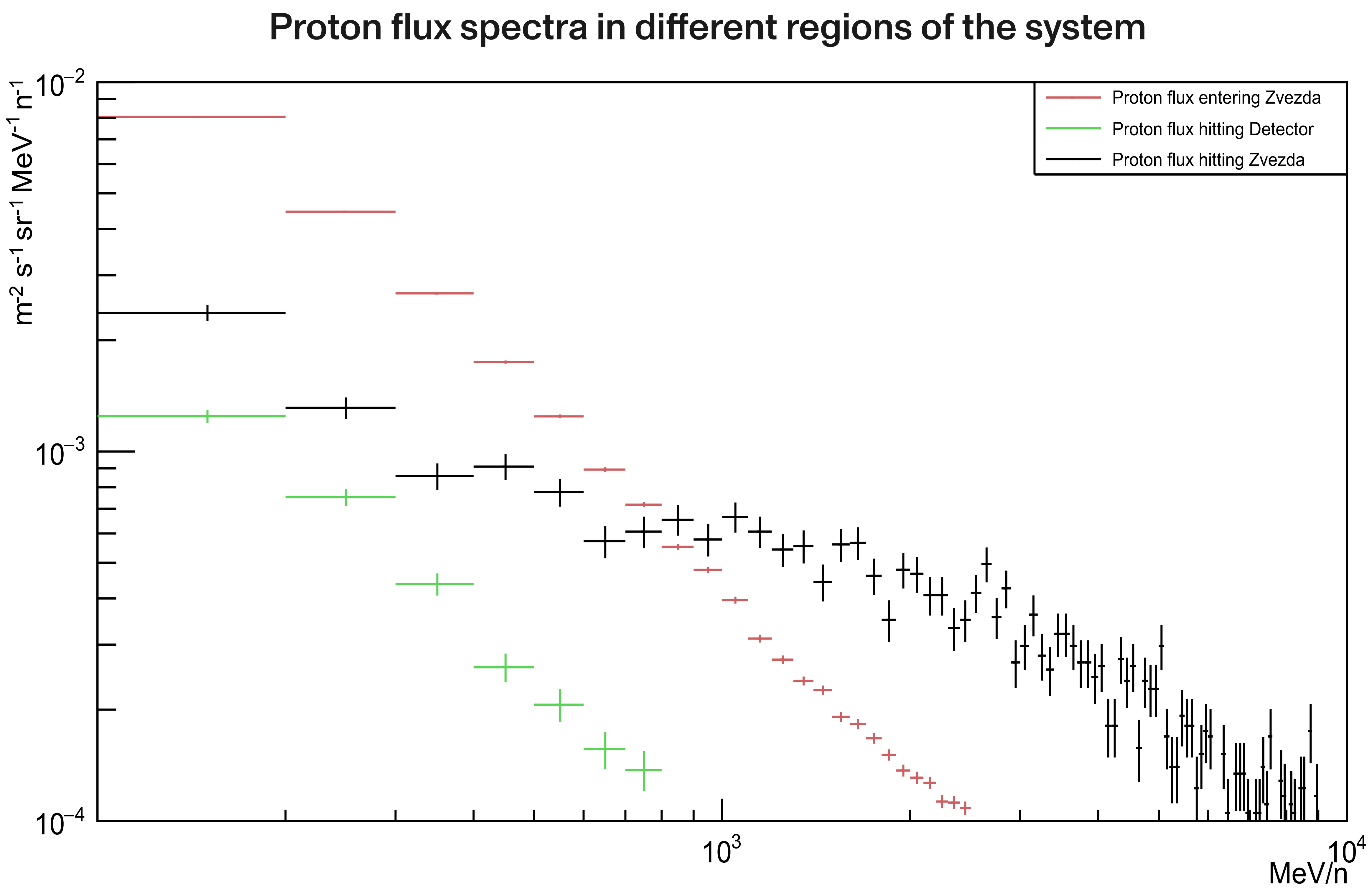
High energy protons lose part of their **energy** while interacting with walls' materials.

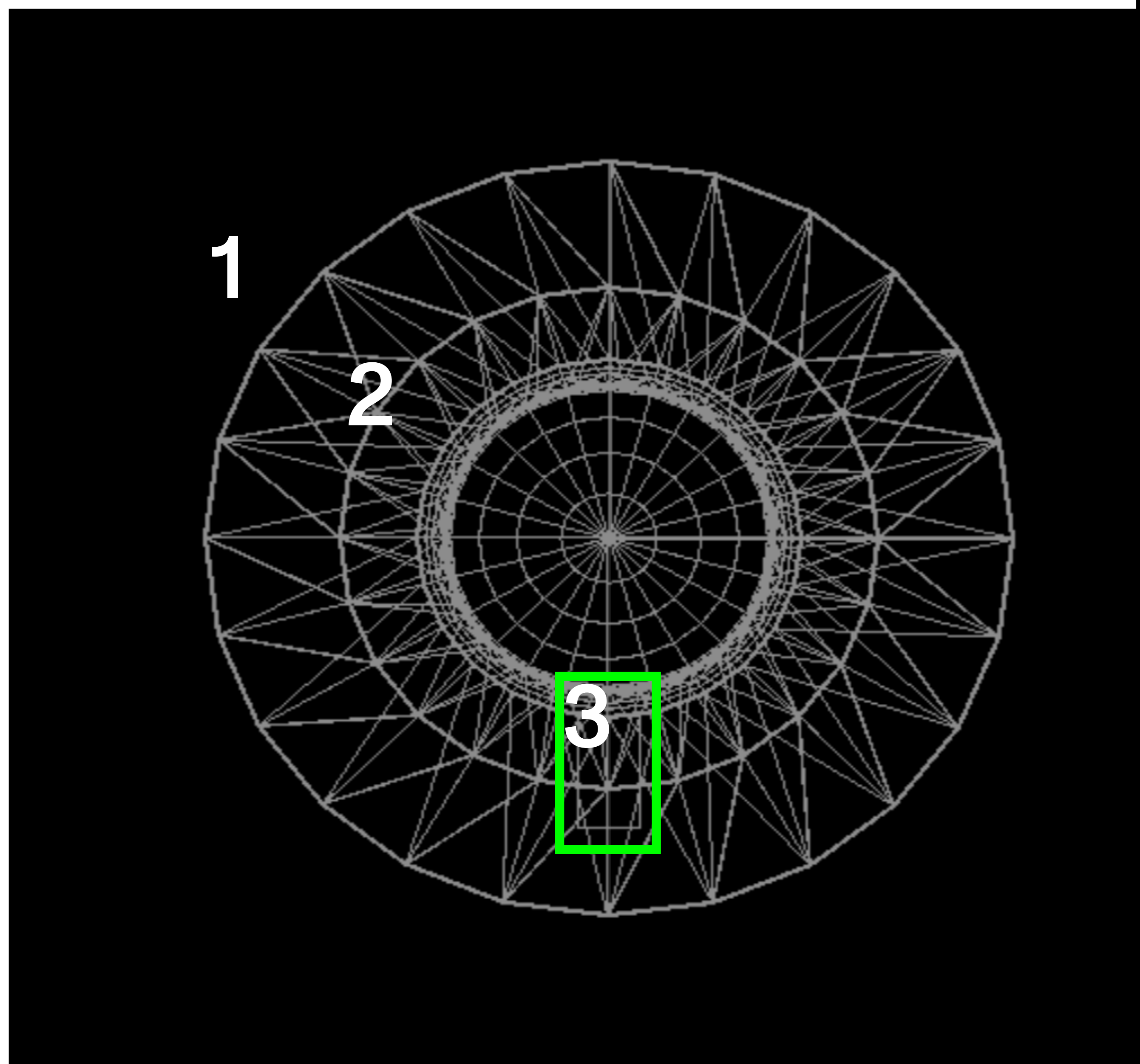


First Results
Incidence Rate

Computing the flux across the Surface A we register an **increase** of about **50%** in the number of protons from region 1 to region 2.

Computing the flux across the Surface B we register a **decrease** of more than **90%** in the number of protons from region 2 to region 3.





Flux decrease is only due to geometrical proprieties of the system.

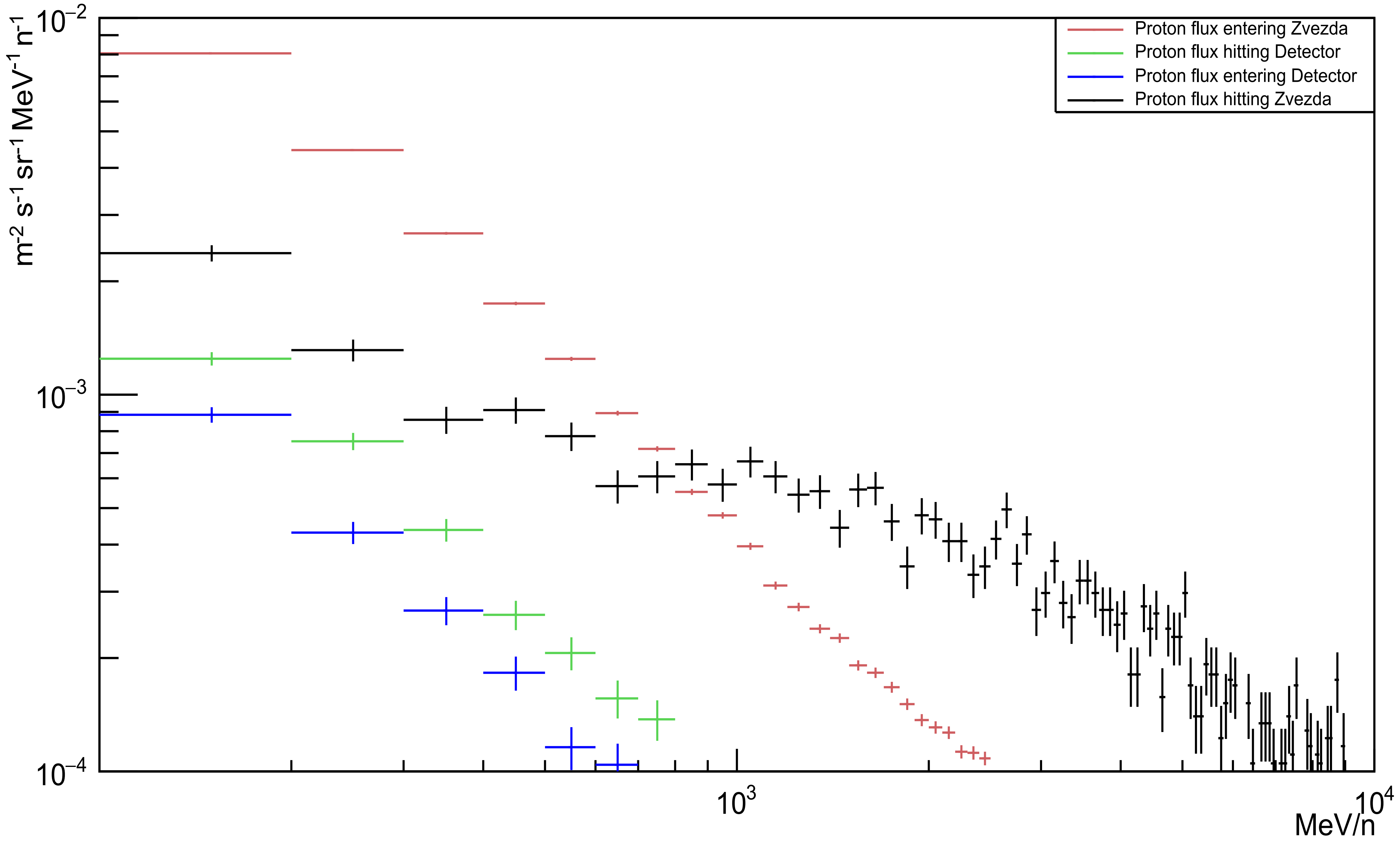
First Results
Incidence Rate

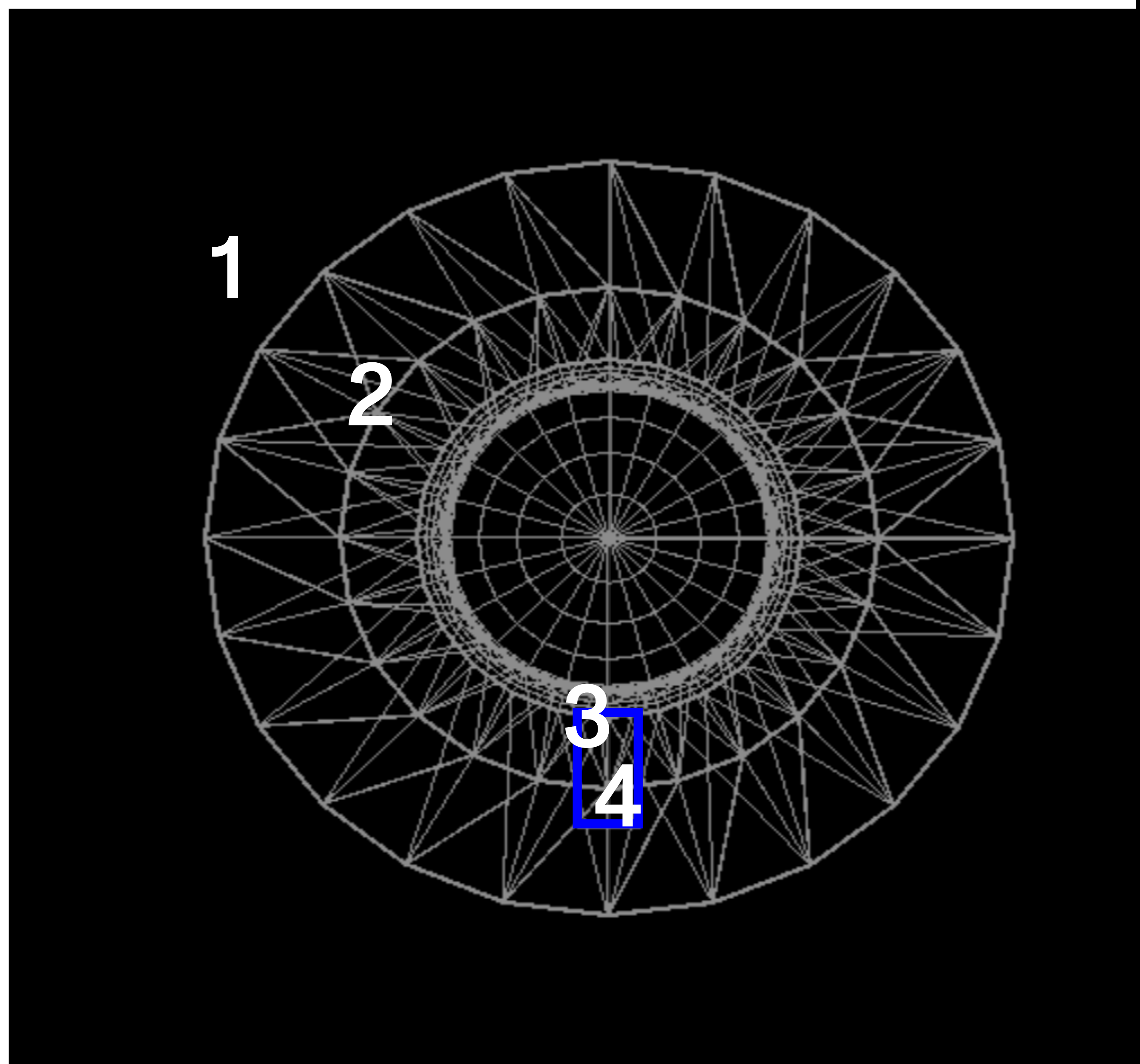
Computing the flux across the Surface A we register an **increase** of about **50%** in the number of protons from region 1 to region 2.

Computing the flux across the Surface B we register a **decrease** of more than **90%** in the number of protons from region 2 to region 3.

Computing the flux across the Surface C we register a **decrease** of about **30%** in the number of protons from region 3 to region 4.

Proton flux spectra in different regions of the system





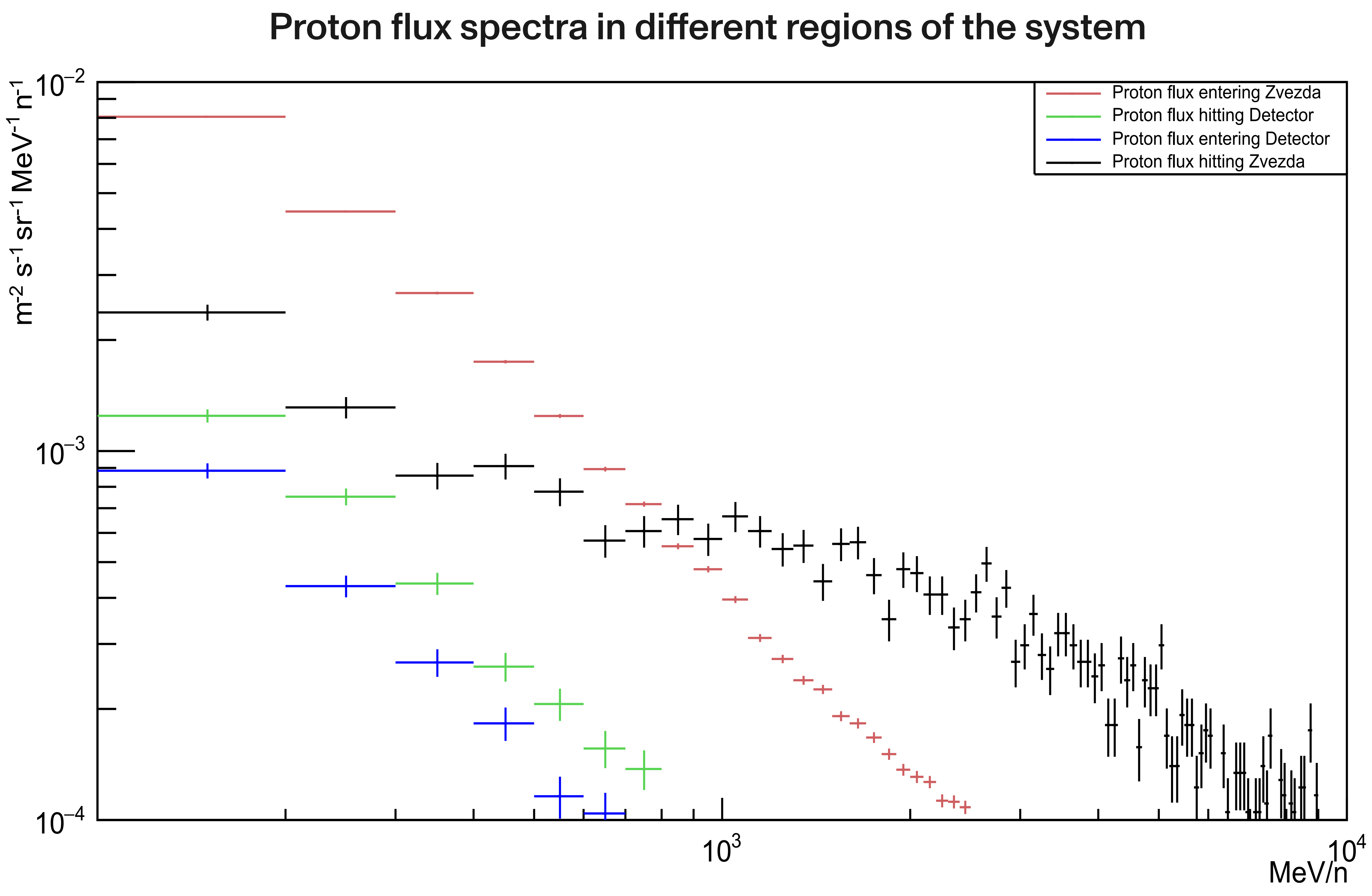
First Results
Incidence Rate

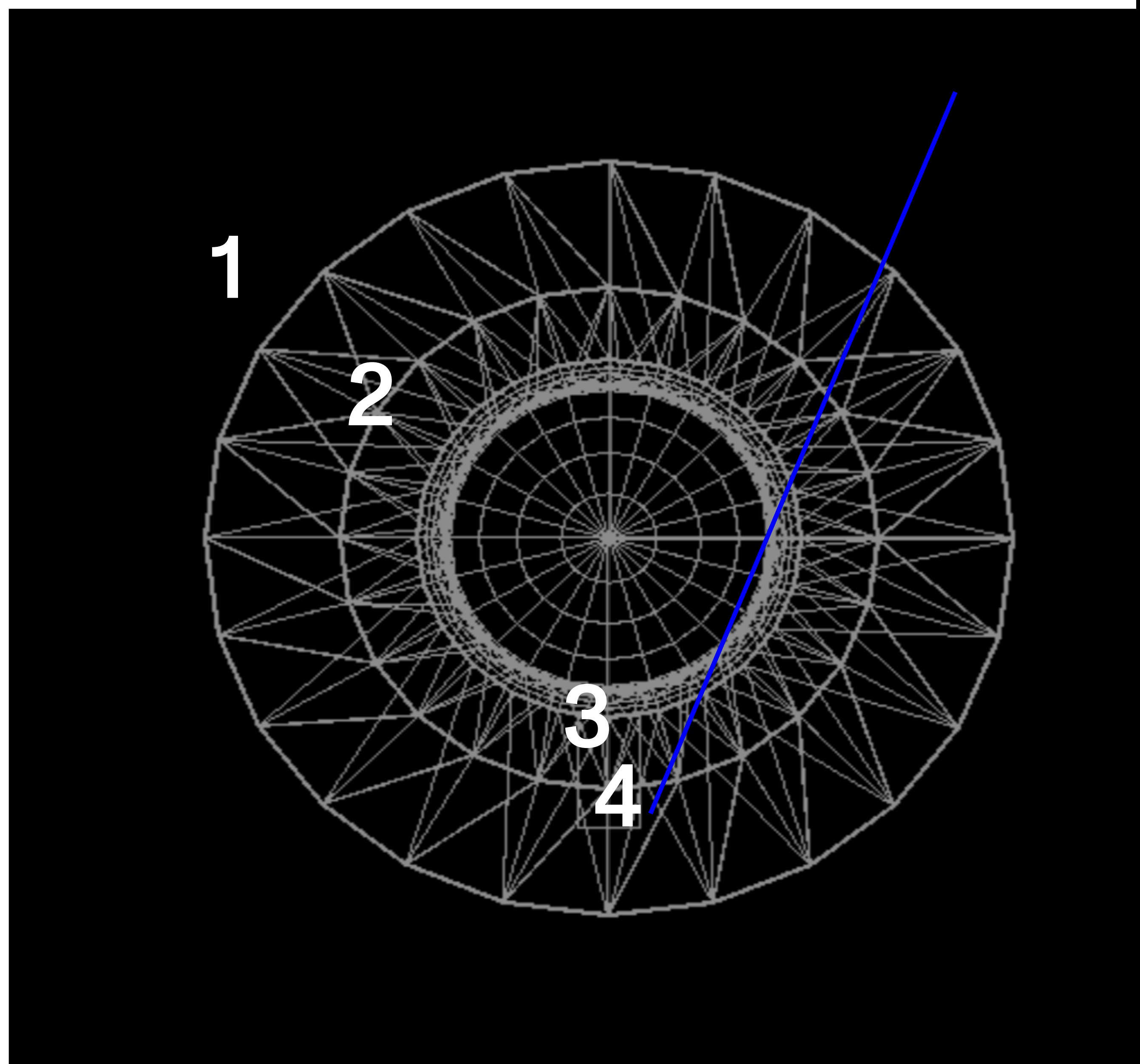
Computing the flux across the Surface A we register an **increase** of about **50%** in the number of protons from region 1 to region 2.

Computing the flux across the Surface B we register a **decrease** of more than **90%** in the number of protons from region 2 to region 3.

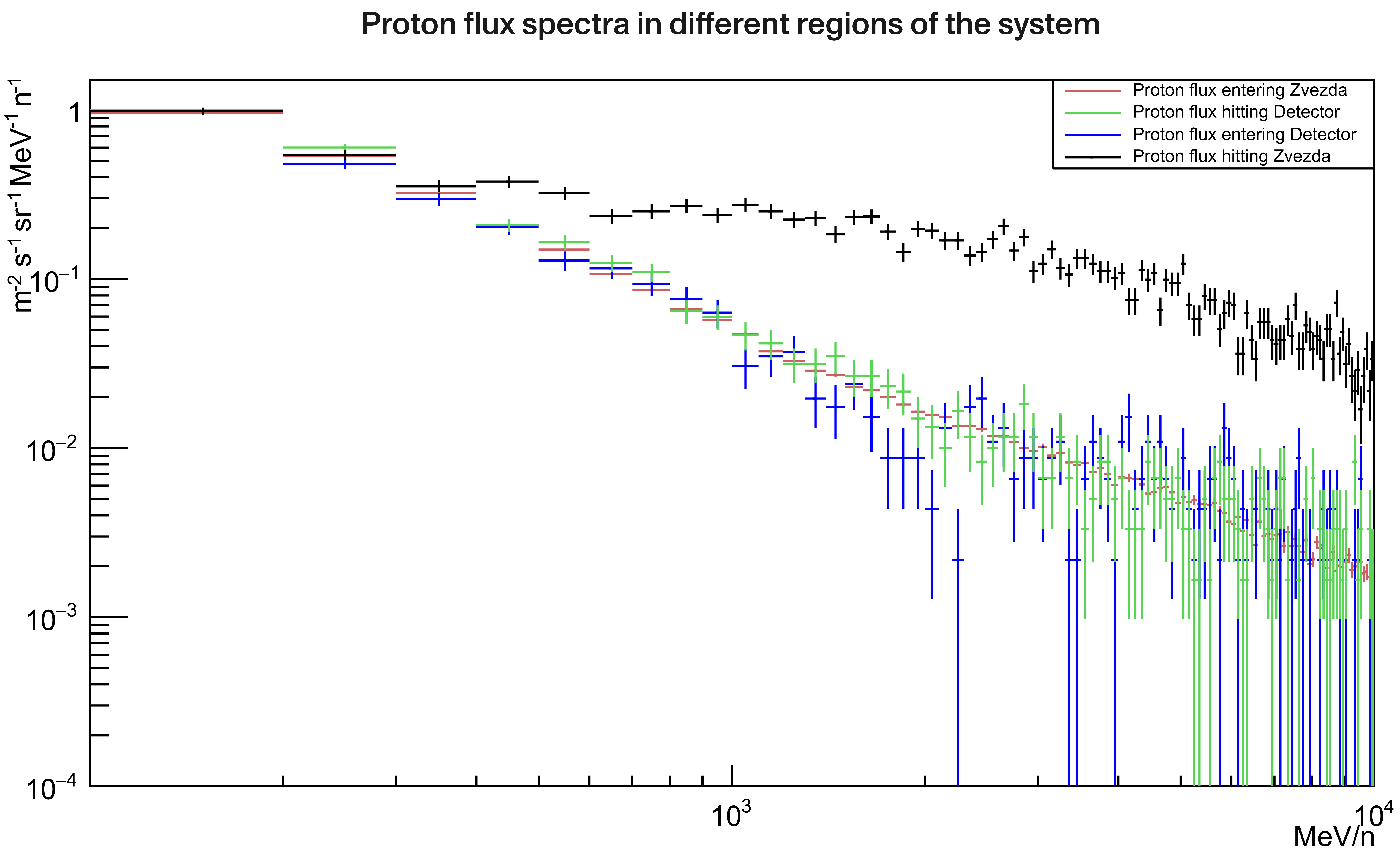
Computing the flux across the Surface C we register a **decrease** of about **30%** in the number of protons from region 3 to region 4.

Protons entering MiniEUSO are less than the **1%** of the protons coming from the external source (from region 1 to 4).



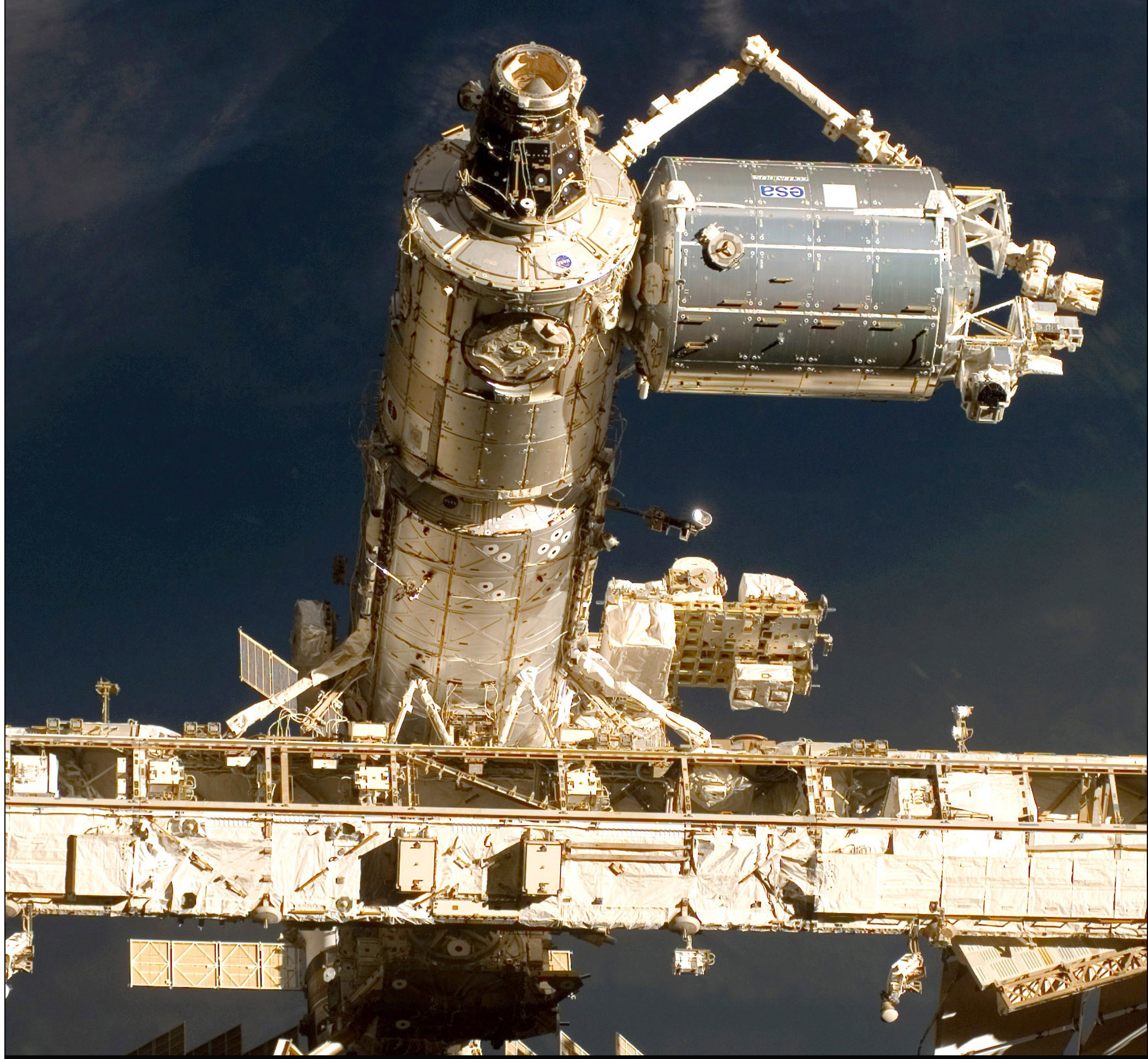


Normalized Proton Energy Spectra

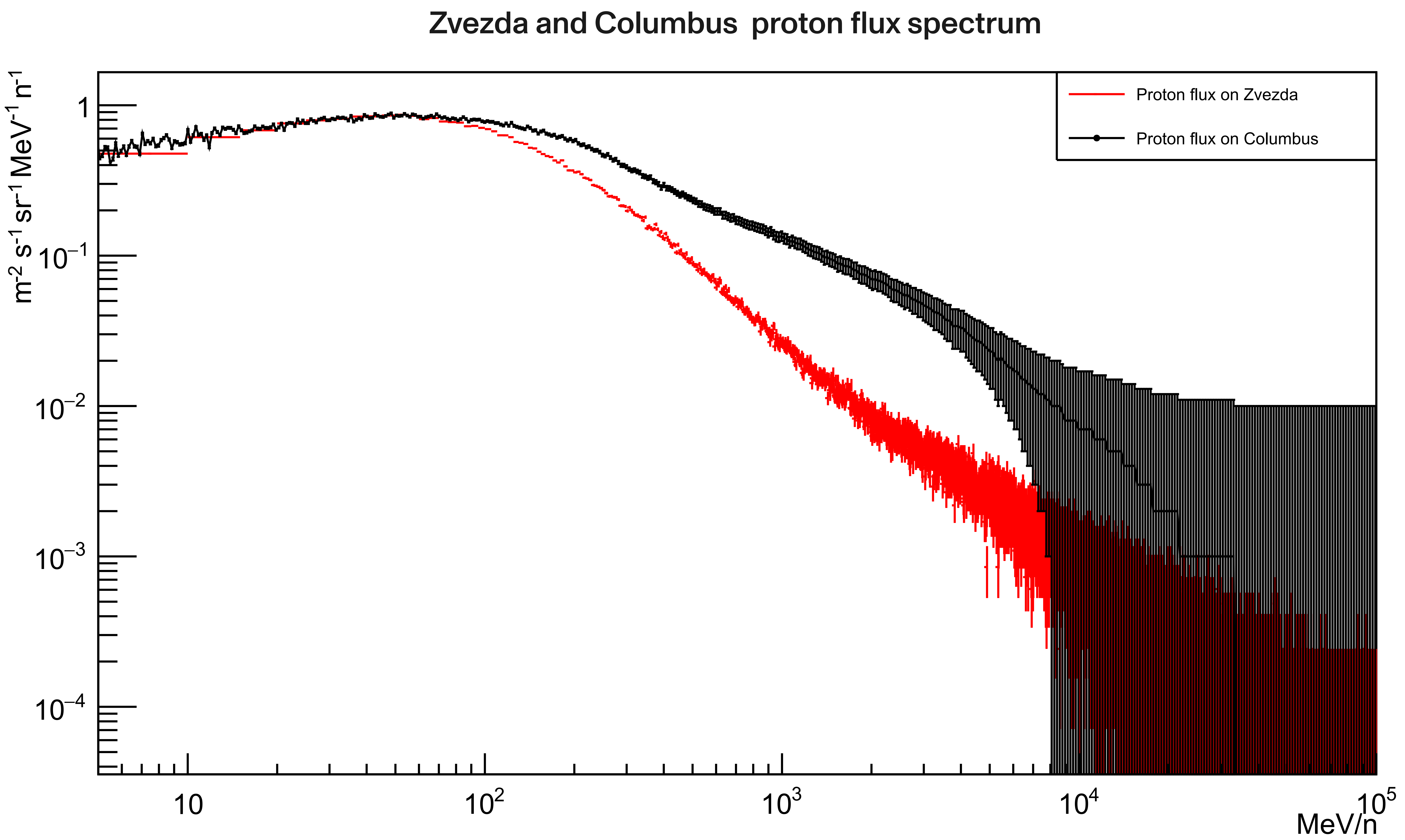

Proton flux spectra in different regions of the system
Proton flux entering Zvezda
Proton flux hitting Detector
Proton flux entering Detector
Proton flux hitting Zvezda
m-2 s-1 sr-1 MeV-1 n-1
1
10−1
10−2
10−3
10−4
10^3
10^4
MeV/n

First Results
Comparison with Columbus proton spectrum

We had access to results from a similar study made on **Columbus** and we compared them to ours.



from a study by G.Romolo,
Rome Tor Vergata University.



Zvezda and Columbus proton flux spectrum
Proton flux on Zvezda
Proton flux on Columbus
m-2 s-1 sr-1 MeV-1 n-1
1
10−1
10−2
10−3
10−4
10
10^2
10^3
10^4
10^5
MeV/n

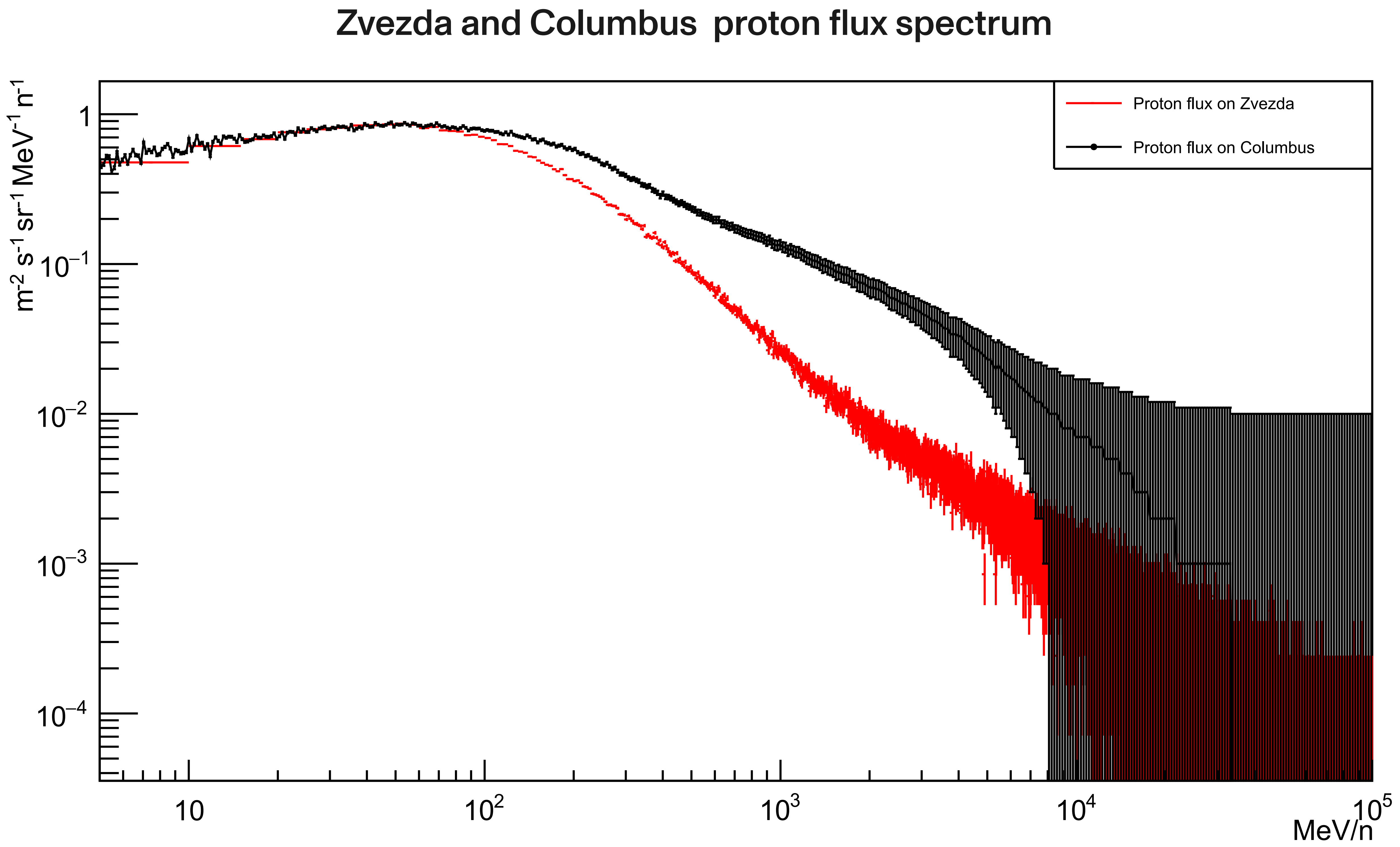
First Results

Comparison with Columbus proton spectrum

We had access to results from a similar study made on **Columbus** and we compared them to ours.

The High-Energy Gap could be due to:

- **differences in the geometry** of the module;
- **lack of enviromental informations** in the Zvezda simulation;
- **ISS shielding;**
- others.



Chapter 4

Conclusions

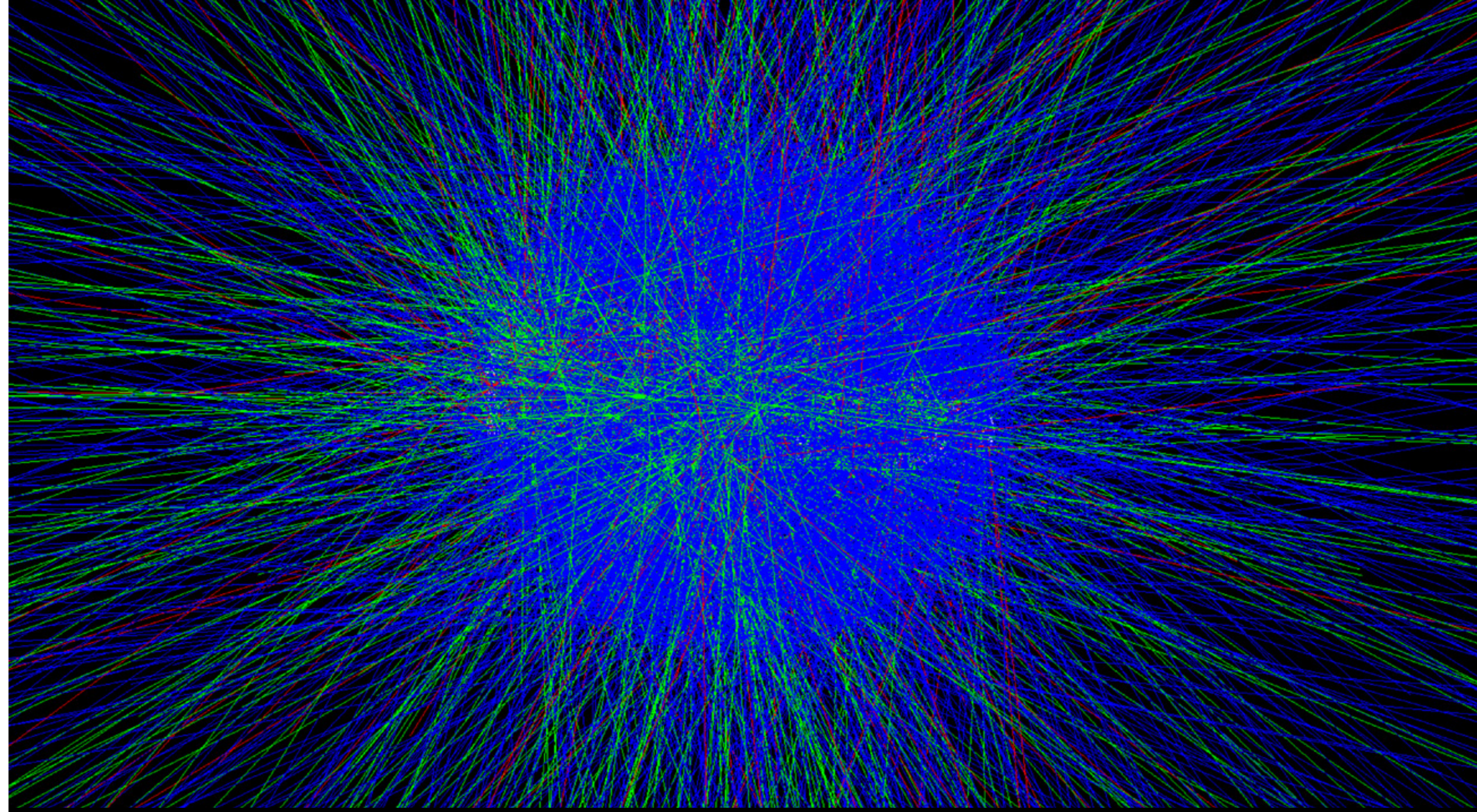
Conclusions
Simulation

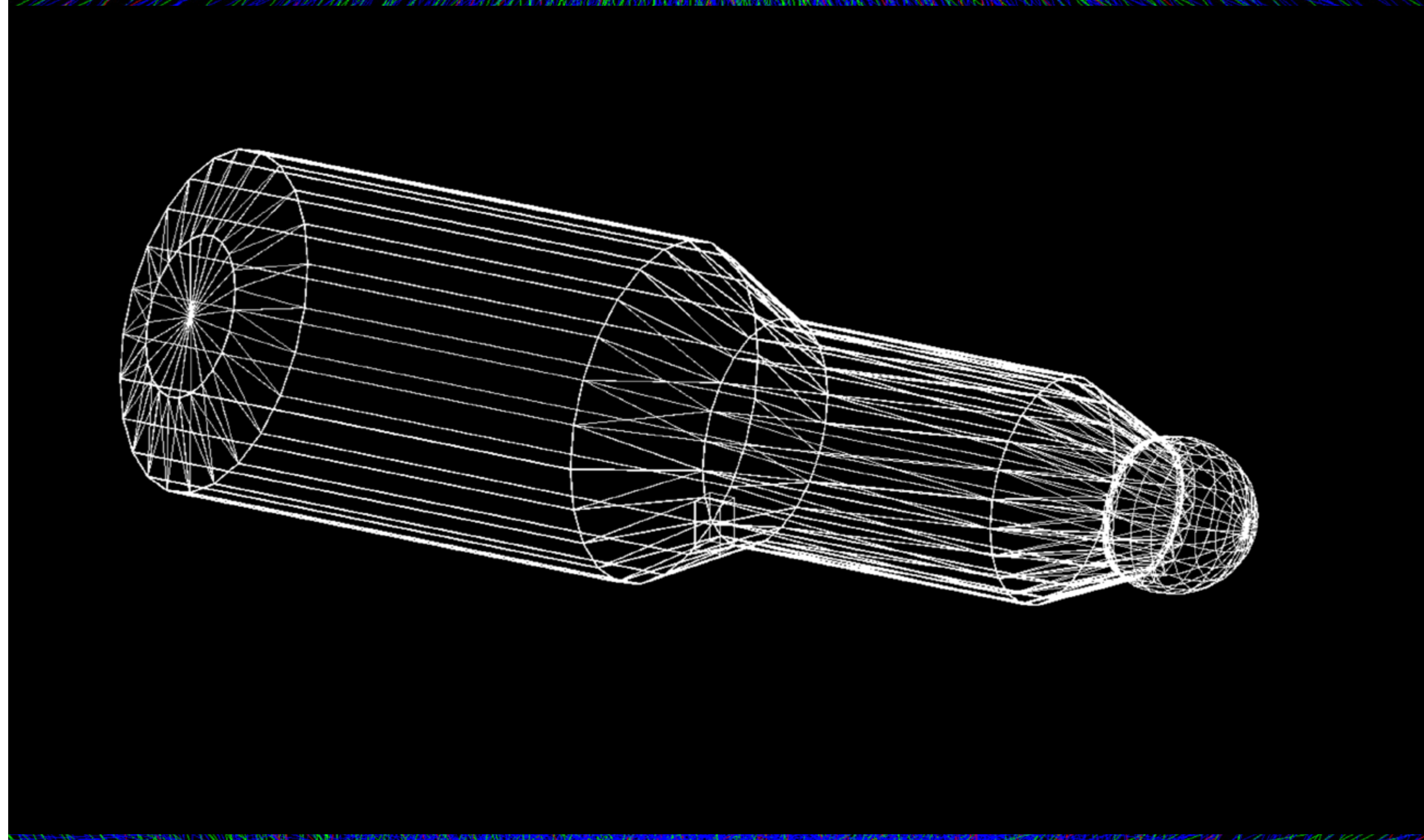
By means of **Spenvis** we have successfully recreated the cosmic ray enviroment around the ISS;

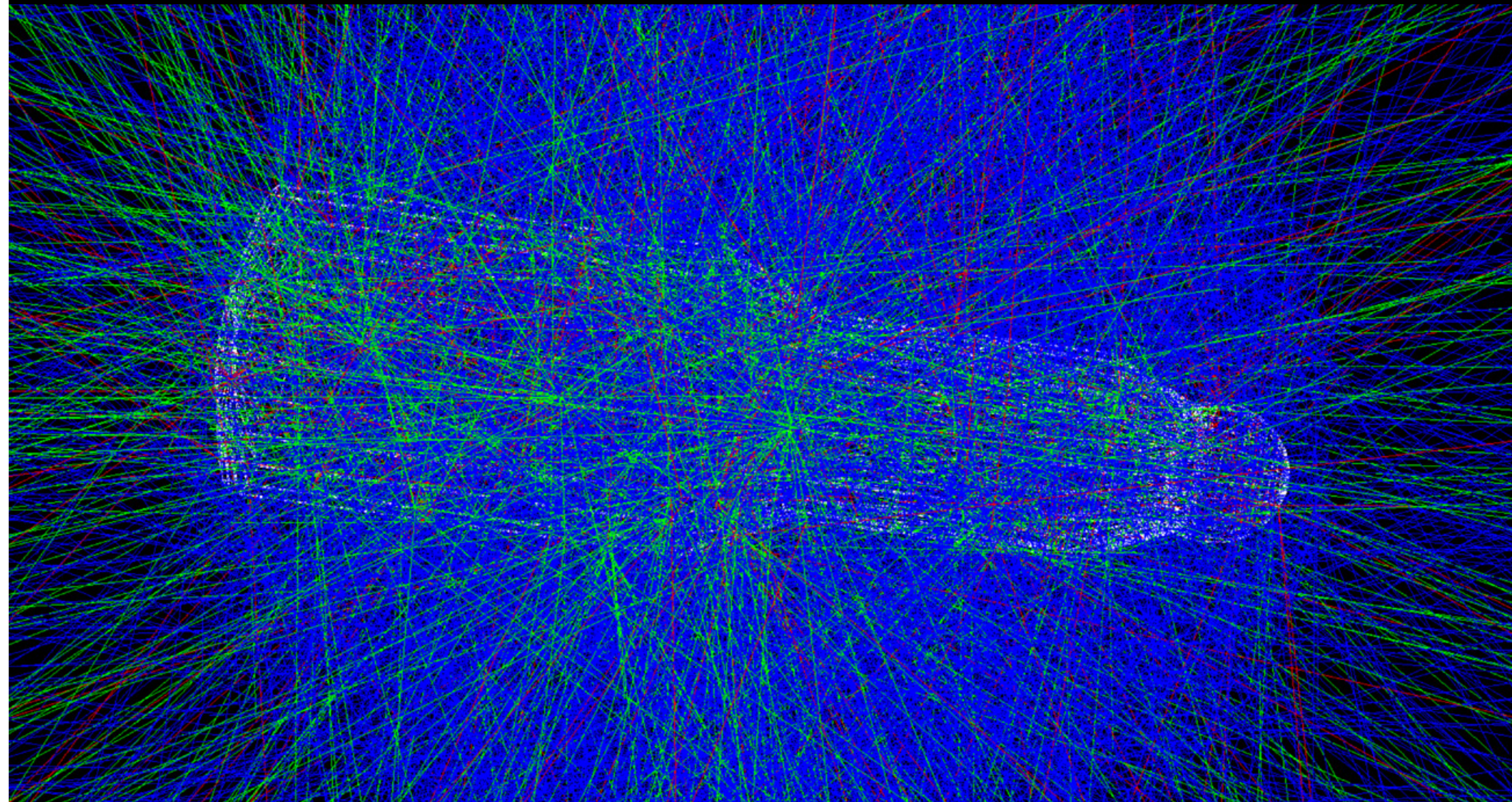
By means of the **GDML** programming language we have created a simple 3D of the Zvezda Russian Space Module in which MiniEUSO is insered;

By meand of **GRAS** we have successfully simulated the interaction between the predefined cosmic ray source and the 3D geometry and obtained informations about the nature of the most penetrating radiation.

We have successfully created a full chain that goes from cosmic ray flux to MiniEUSO's walls response.





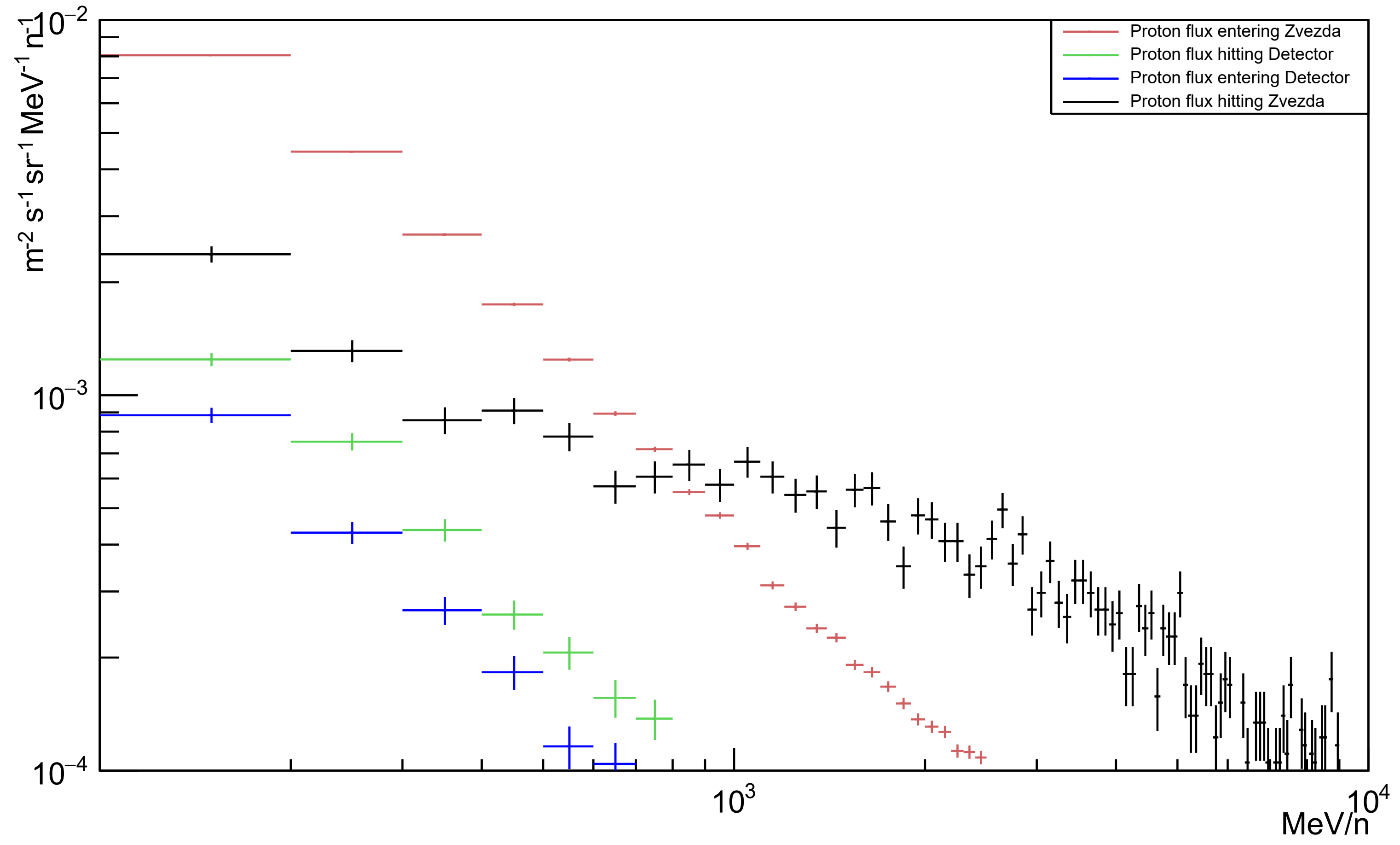


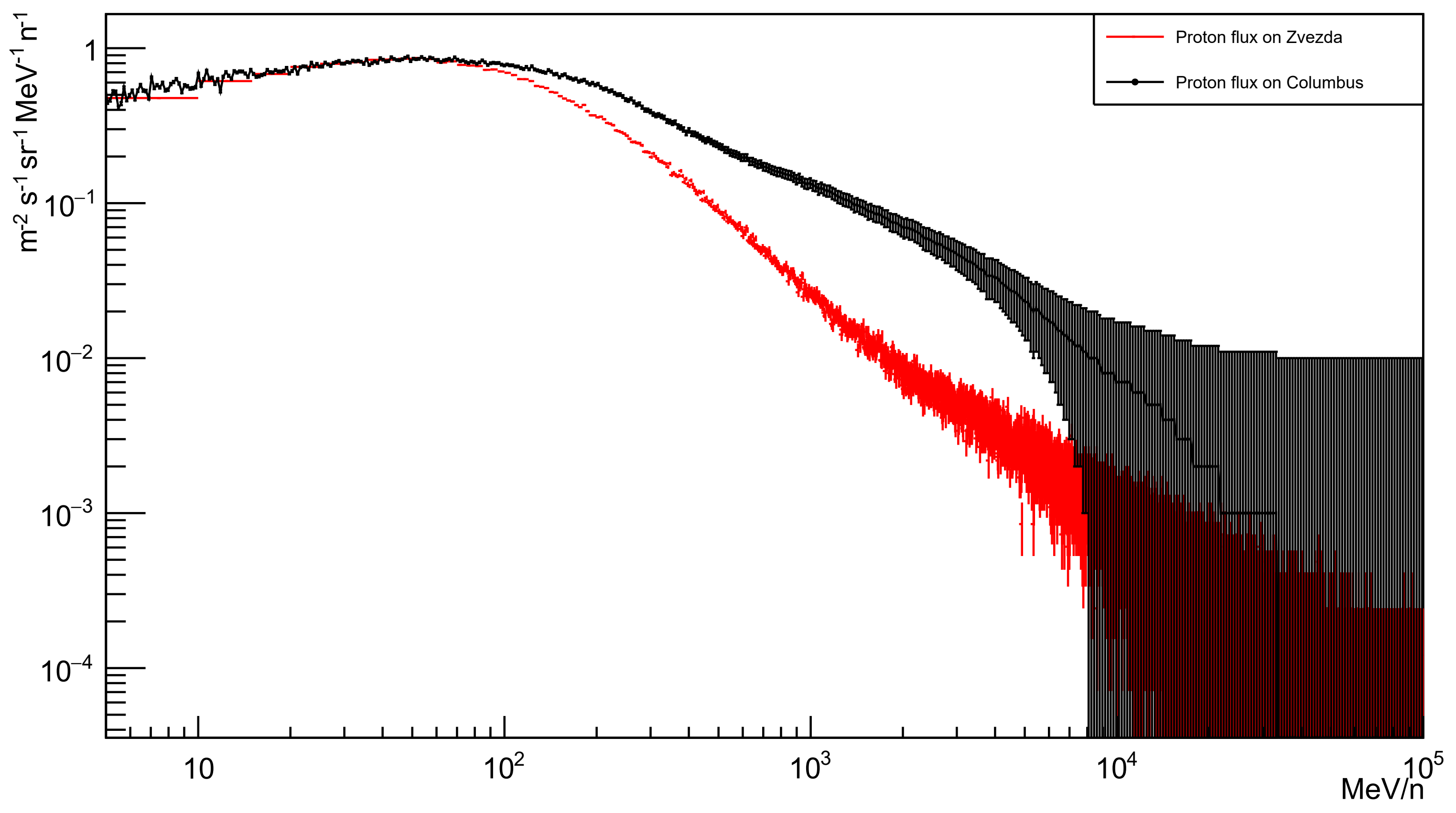
Conclusions

First Results

We have obtained a first result of the **proton flux** entering the space module and interacting with MiniEUSO;

We have reproduced Columbus proton flux spectrum **at the first order of magnitude**.
Some differences have been noticed and will be subject to further implementations.



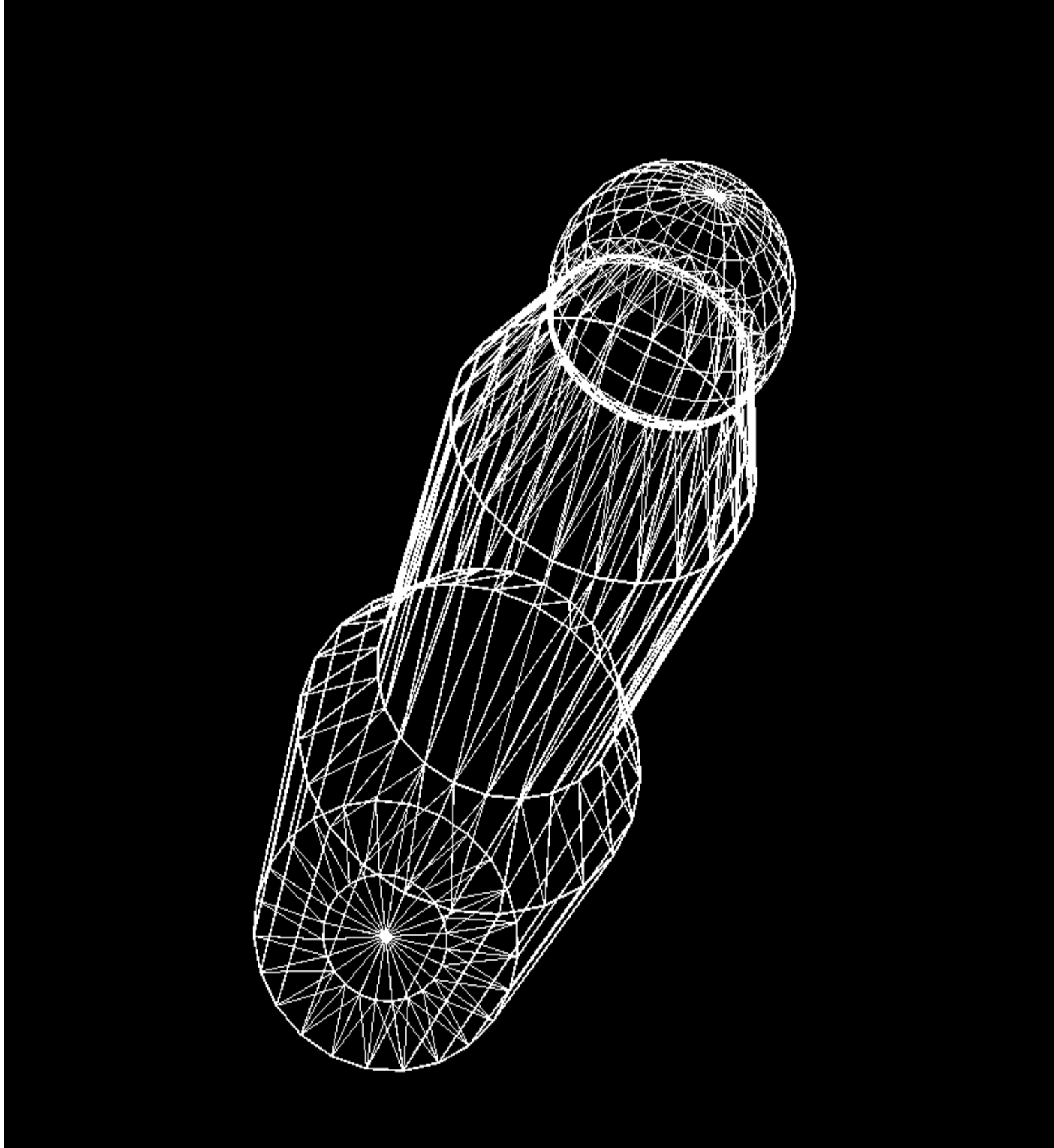


Chapter 5

Implementations

to increase the level of realism

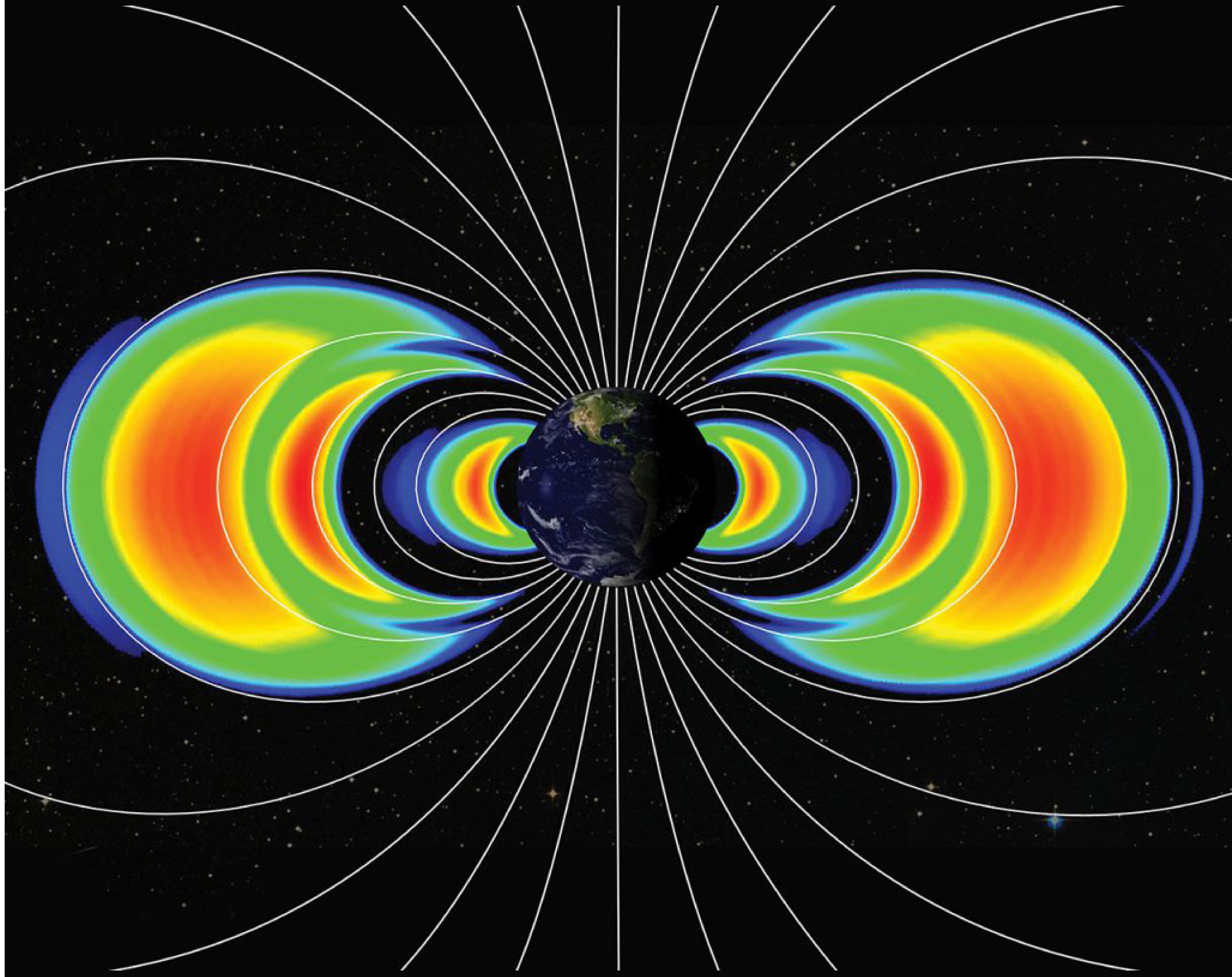
The simulation we built **is a prototype** and it needs to be implemented if one wants to increase the level of realism.



Implementations

Adding trapped protons to the source

Low-energy particles from cosmic rays and solar activity can be trapped into the Van Allen Belts because of the Earth's geomagnetic field.



Visualization of Van Allen Belts

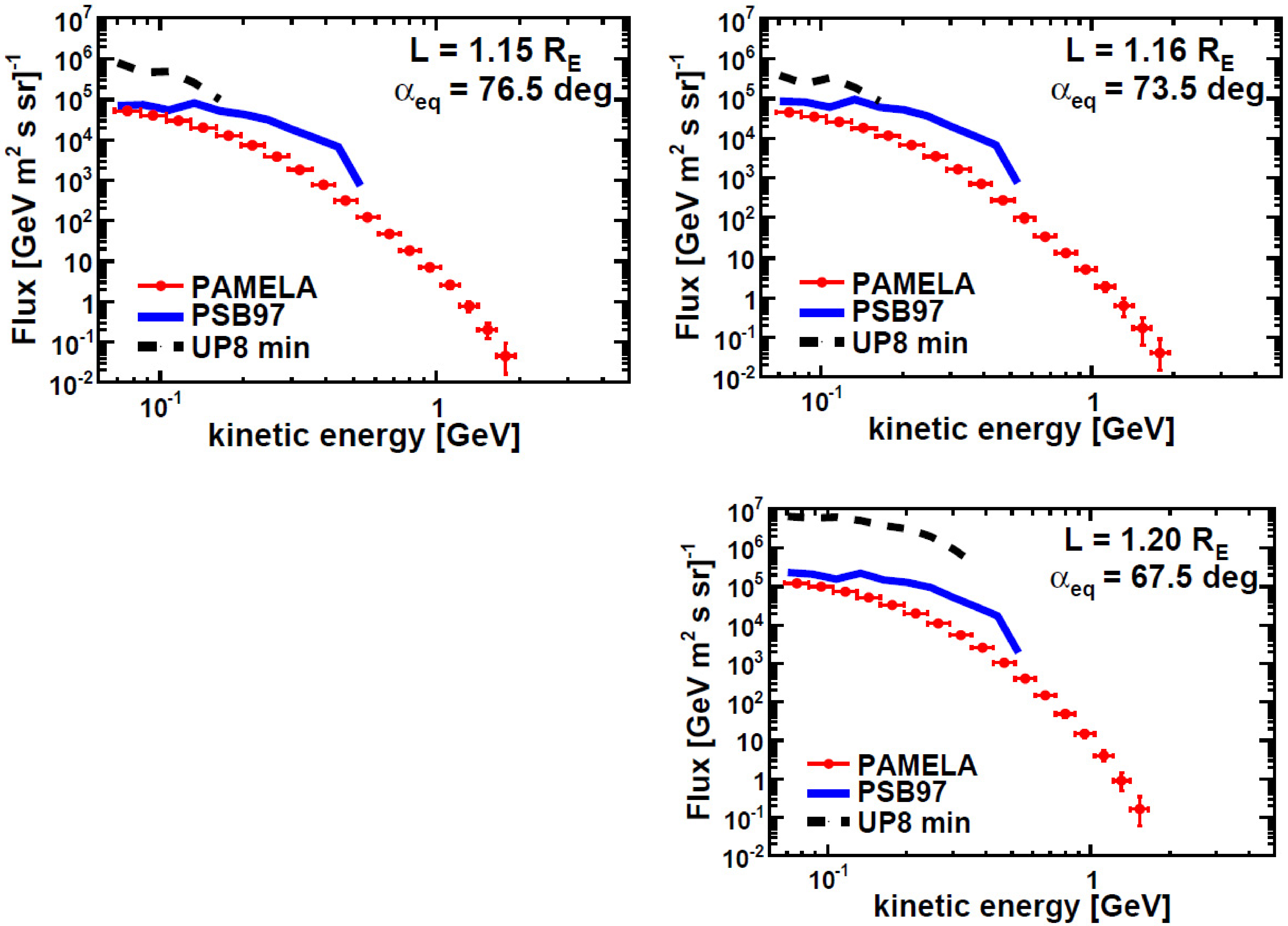
Implementations

Adding trapped protons to the source

Low-energy particles from cosmic rays and solar activity can be trapped into the Van Allen Belts because of the Earth's geomagnetic field.

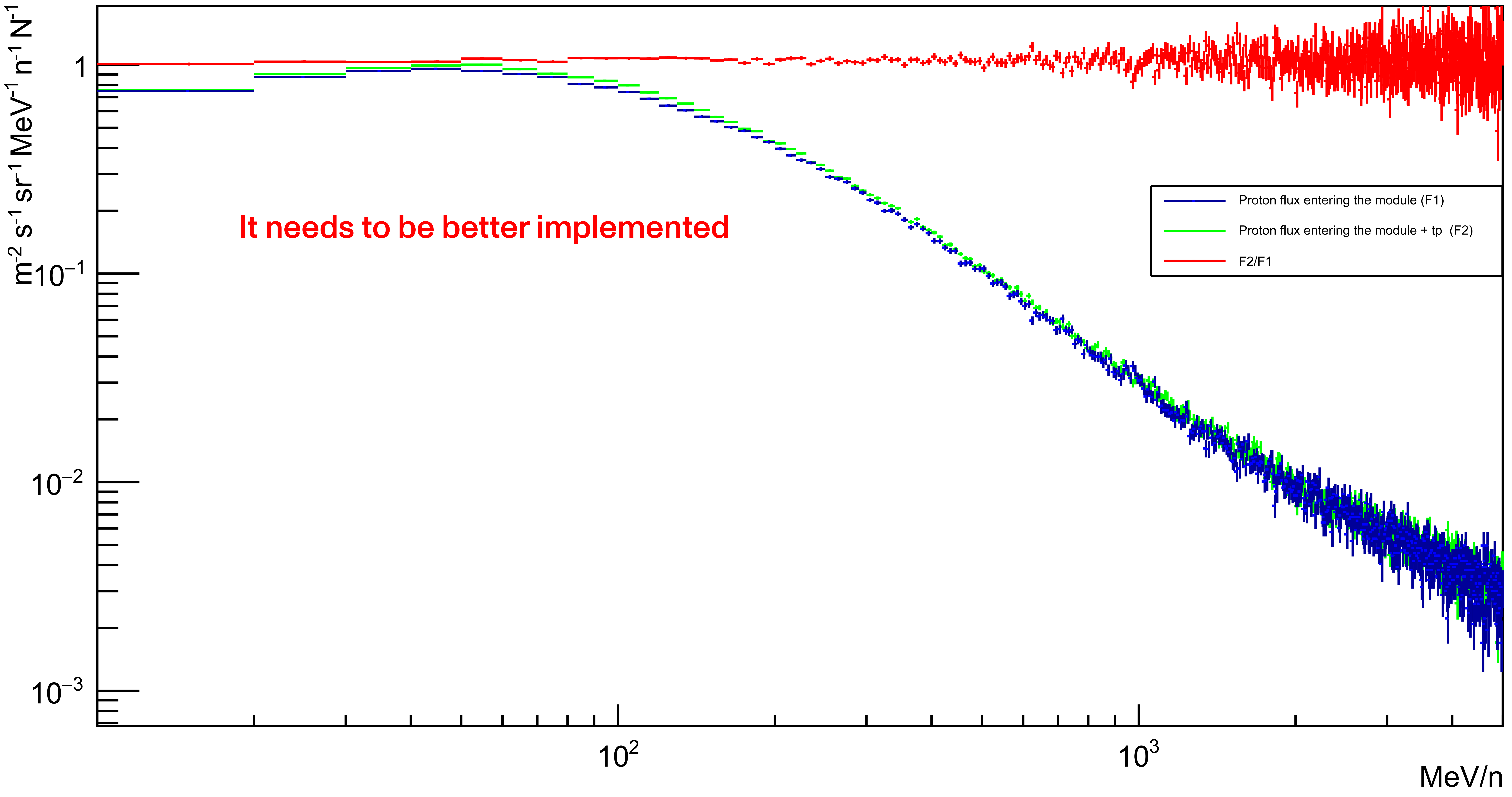
Protons in Van Allen Belts have energies **from 0 to 4GeV**, slightly depending on the orbital inclination.

We then implemented our particle source by adding the trapped protons contribution.



from: "Trapped proton fluxes at low Earth orbits measured by the PAMELA experiment", 2015.

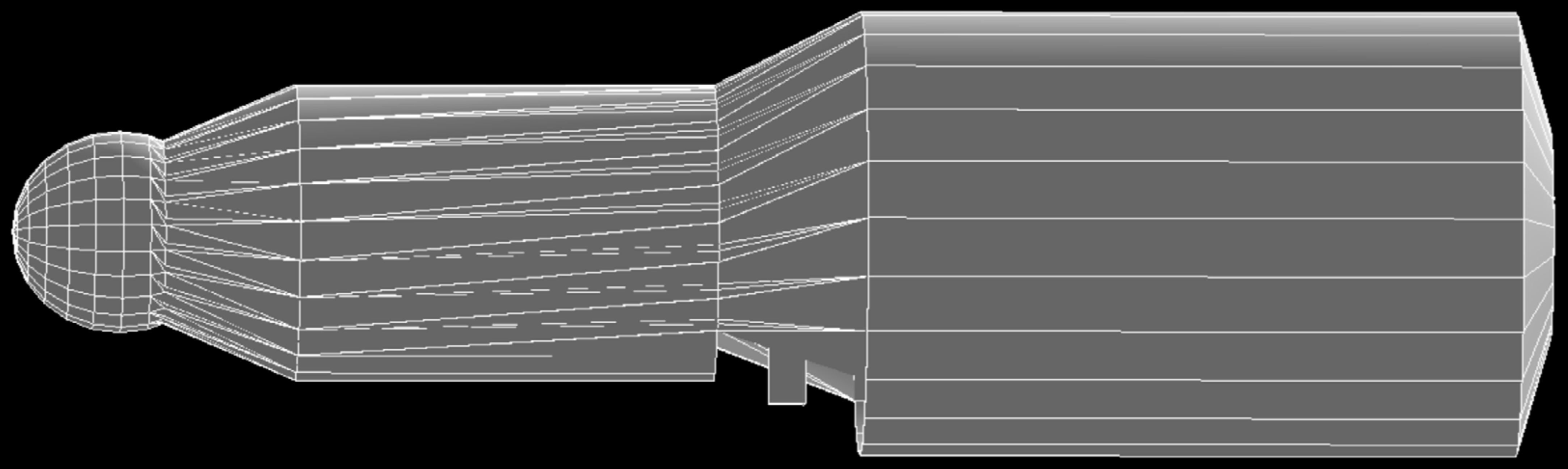
Proton flux spectra entreing the Zvezda module

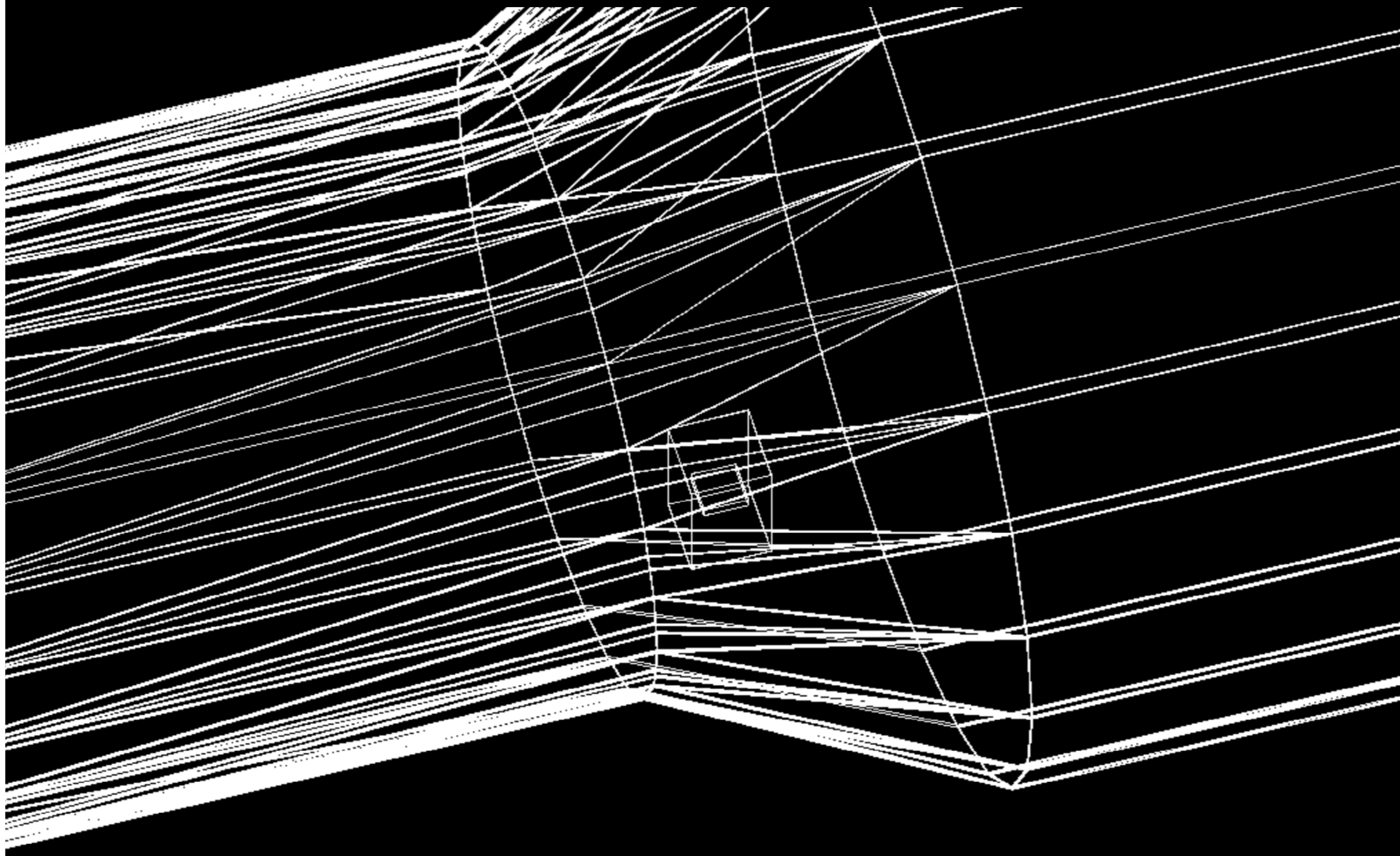


Implementations
Adding a window

We have removed a part of the external layer in the MiniEUSO region and substituted it with a **borosilicate glass window.**

We insered a glass plate inside MiniEUSO to reproduce the **photomultipliers plate**.





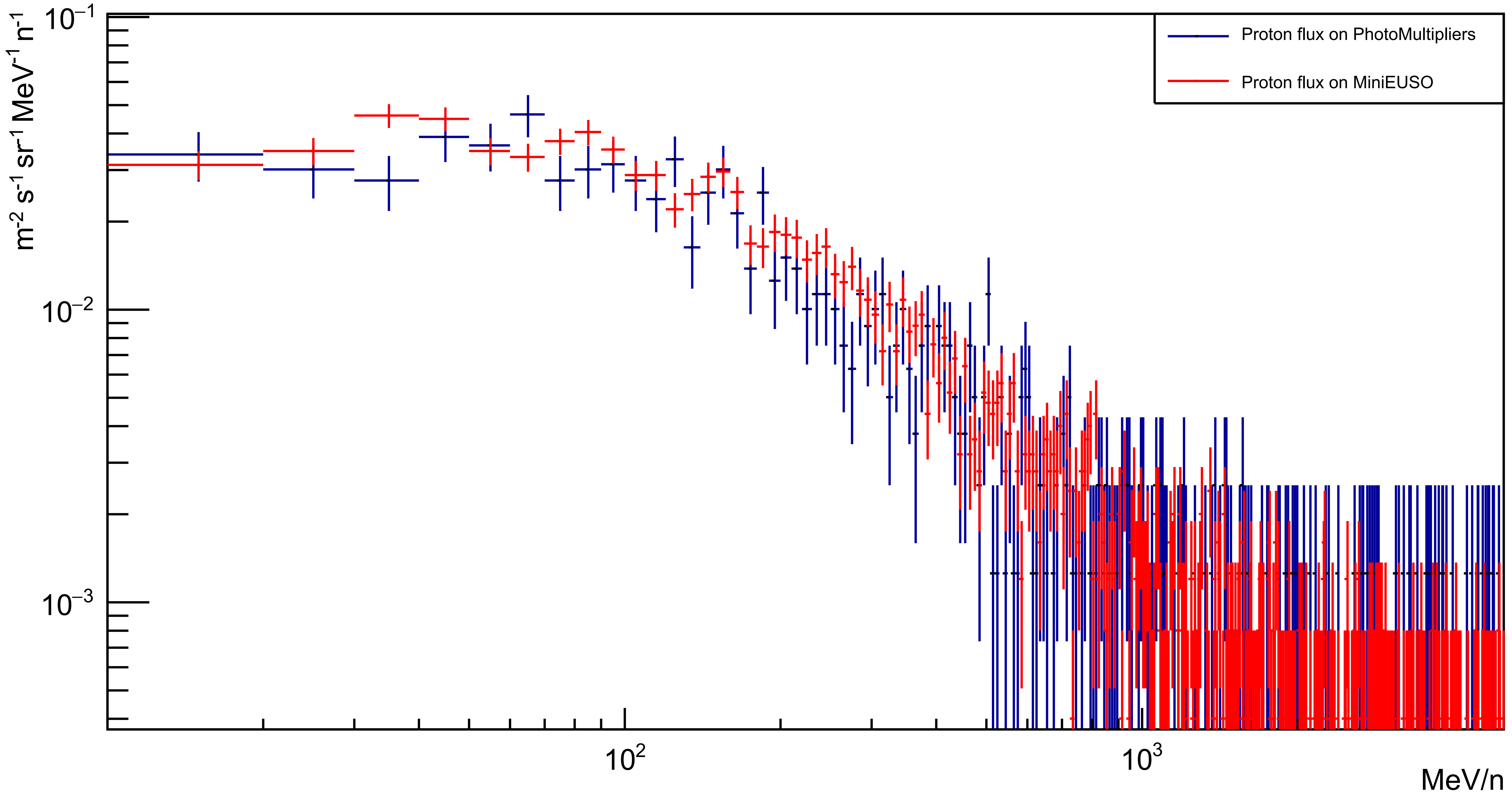
Implementations

Adding a window

We have removed a part of the external layer in the MiniEUSO region and substituted it with a **borosilicate glass window**.

We insered a glass plate inside MiniEUSO to reproduce the **photomultipliers plate**.

We have noticed **no significant differences** on the proton flux between protons reaching MiniEUSO and protons reaching the phtomultipliers.



Chapter 6

Further Implementations

to increase the level of realism

Further Implementations
to increase the level of realism

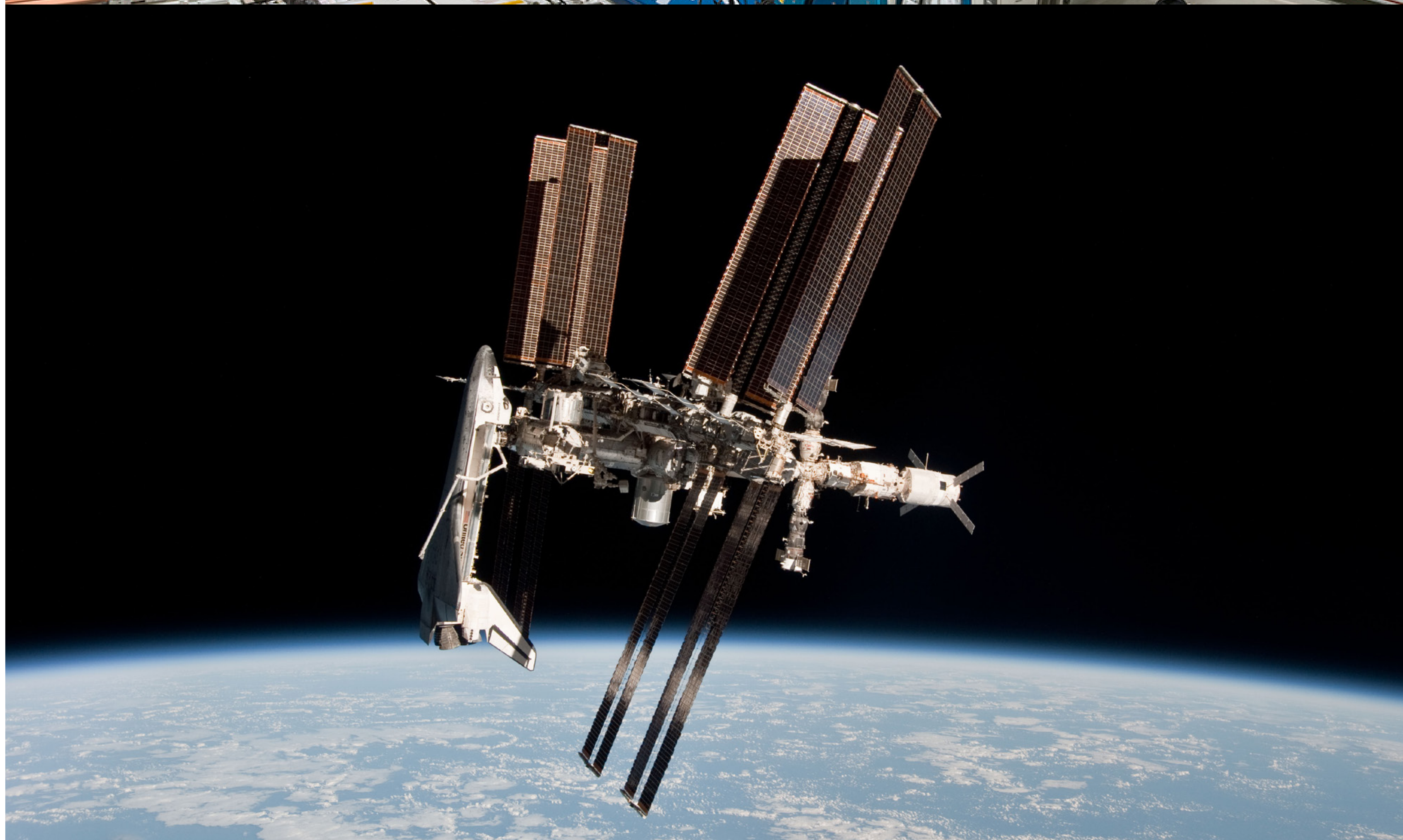
Some possible further implementations are:

insert new materials inside the space module to **recreate the space equipments** and its interaction with radiation;

modify the geometry of the source and reduce the isotropy;

make a species-by-species flux analysis to see which are the most probable to survive through interactions;

others.



Candidato **Antonio Lindo**
Relatore **Mario Edoardo Bertaina**
Co-Relatore **Alessandro Valetti**

Università degli Studi di Torino, Dipartimento di Fisica.
Anno Accademico 2021/2022

A study of the impact of cosmic radiation on the International Space Station

Extract from the bachelor thesis presentation.

One of the main problems in space exploration is the continuous impact of cosmic radiation on spaceequipment. In particular, being in orbit, the International Space Station (ISS) doesn’t have atmospheric shielding from cosmic radiation. Because of this, it is continuously hit by electrons, gamma rays, and high-energy nuclei from galactic cosmic rays and solar activity. Part of the radiation is absorbed by the materials of the ISS, but a significant amount can penetrate the external structure or interact with it generating fragmentation of the original nuclei and other daughter particles. This can have an impact on the equipment inside the ISS. Indeed the MiniEUSO detector inside the Russian Zvezda module of the ISS detects routinely this radiation. With this thesis, having used GRAS software to simulate both thegeometry and particle interactions, we present a study of the modeling of the Russian segment of the ISS where MiniEUSO is located and a preliminary estimation of the flux of cosmic rays entering the Russian module and their energy spectrum by means of the Spenvis tools.

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Università degli Studi di Torino, Dipartimento di Fisica.
Anno Accademico 2021/2022