

Estimación de la composición química del suelo usando rayos cósmicos

Est. Luigui Miranda

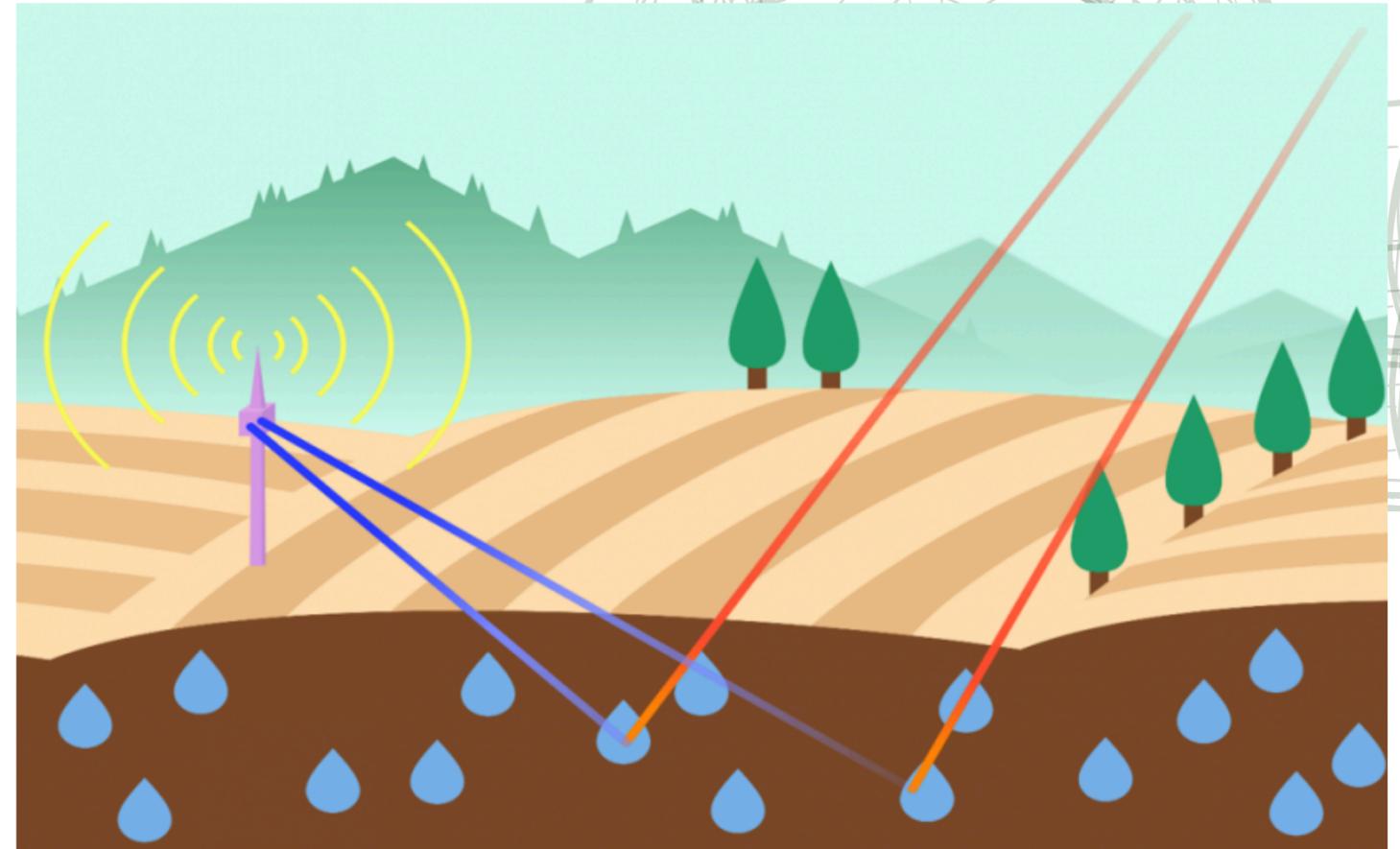
Dr. Christian Sarmiento

Dr. Luis Nuñez



¿Que estamos haciendo?

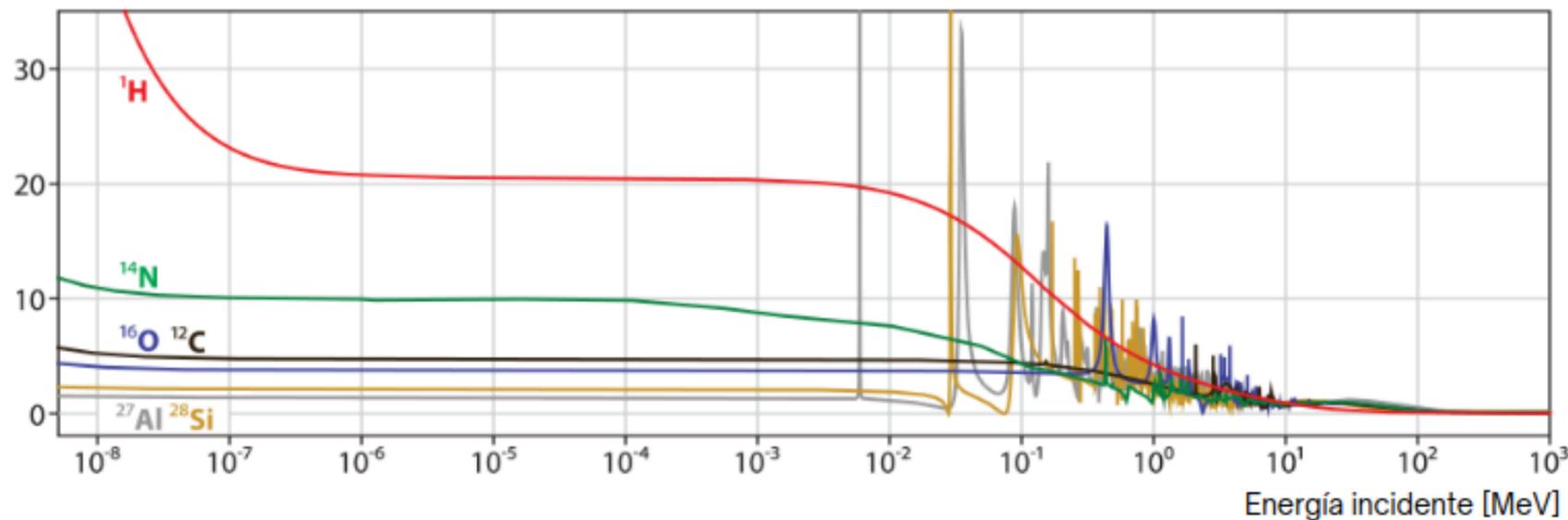
Pero... ¿Podemos utilizar los rayos cósmicos para determinar los elementos químicos del suelo?



GEANT4
A SIMULATION TOOLKIT

Relación entre los neutrones y el hidrógeno

Sección eficaz de dispersión de un neutrón [barn]



[Köhli et al., Water Resources Research, 51(7):5772–5790 2015]

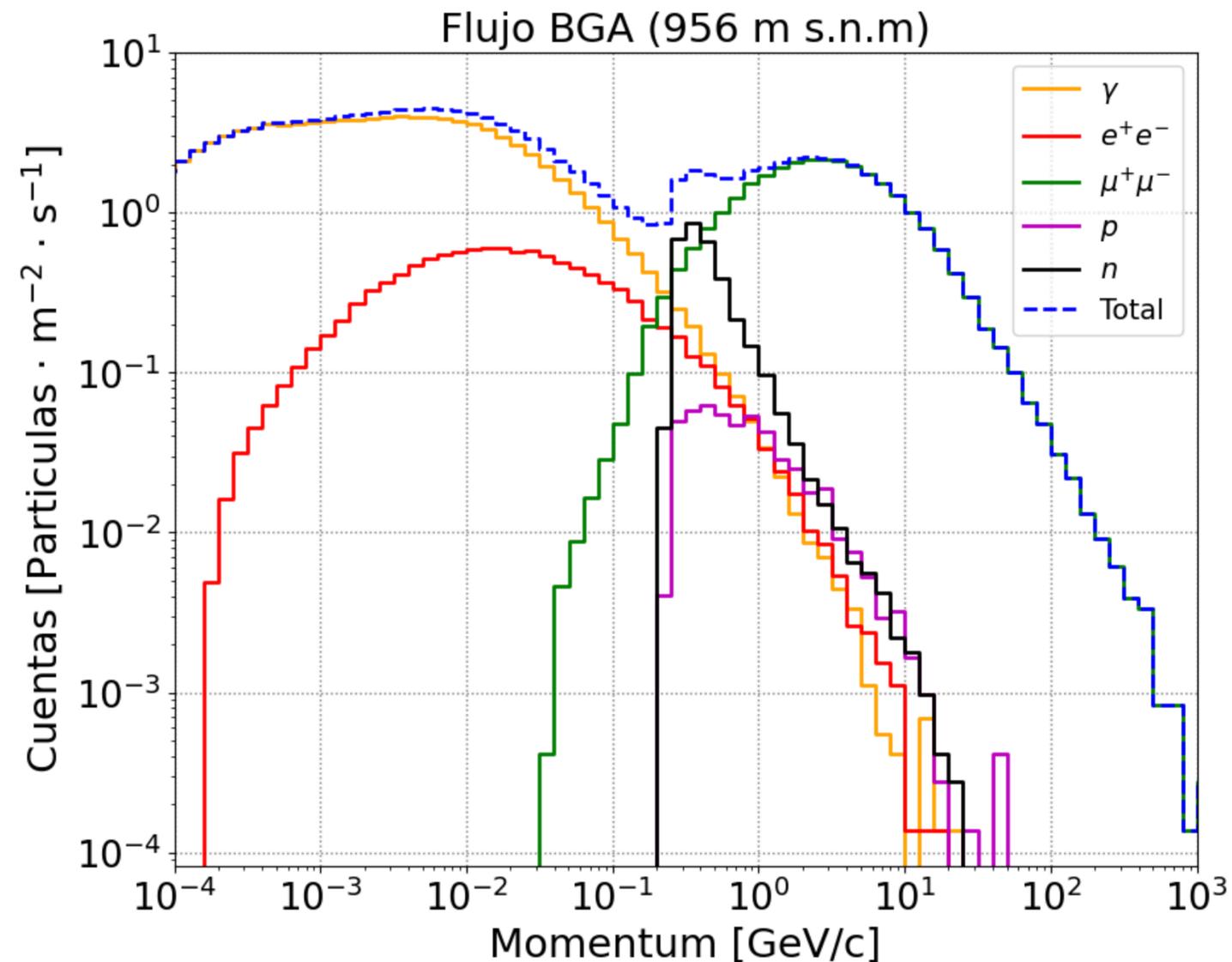
Los neutrones muestran la probabilidad **más alta de dispersión con el hidrógeno**. Además, esta interacción se caracteriza por tener la **tasa más alta de pérdida de energía**.

Elemento	Masa [u]	Tasa de pérdida de energía ξ	n_{col} para termalizar
H	1	1	18
H ₂ O	-	0.92	20
N	14	0.134	135
O	16	0.12	153
Al	27	0.0723	255
Si	28	0.0698	264
Fe	56	0.0353	522
SiO ₂	-	0.11	166
Aire (seco)	-	0.135	135

[Köhli et al., Frontiers in Water, 2:544–847 2021].

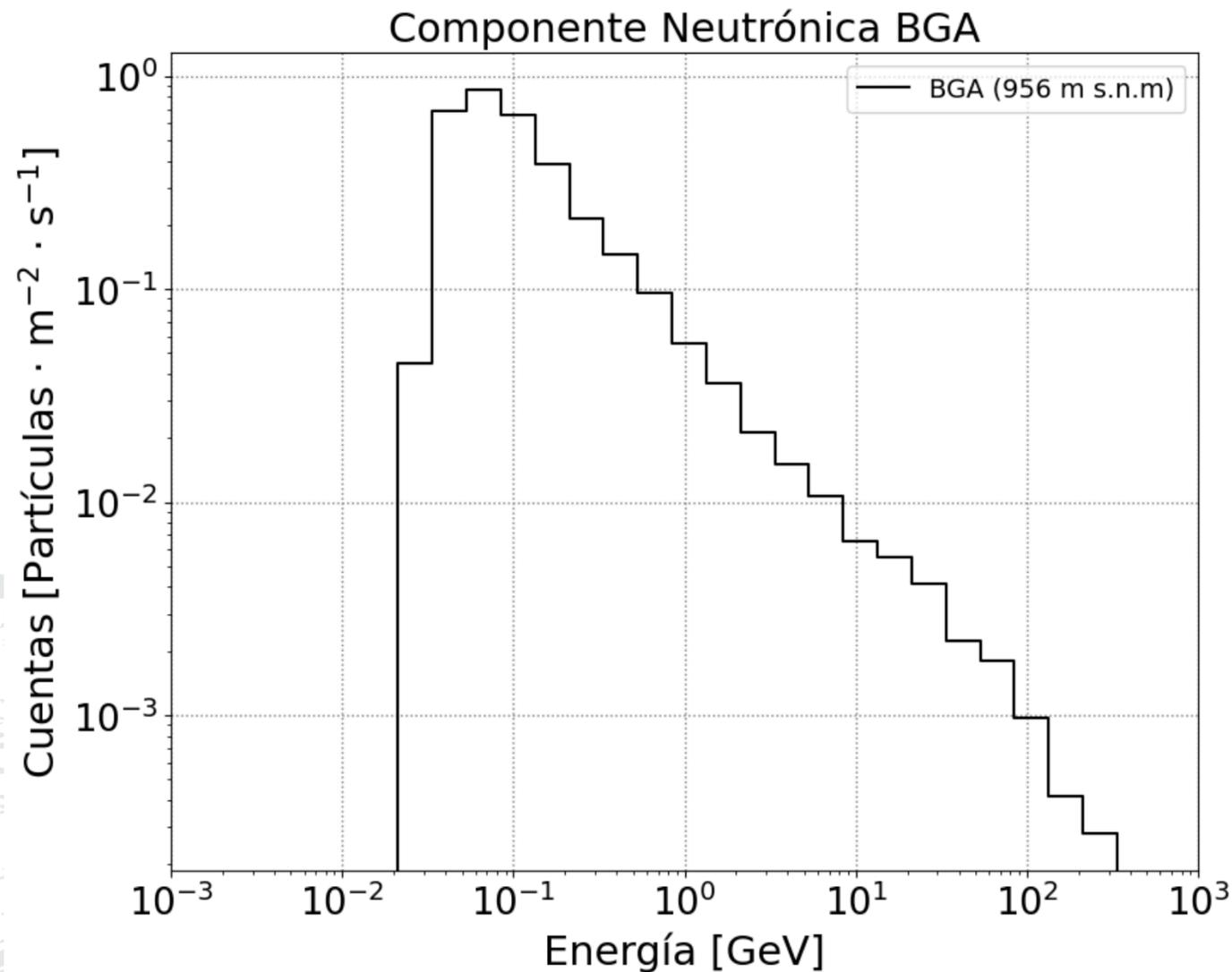
Flujo de neutrones cósmicos

[Sarmiento-Cano et al., 2022] presentan ARTI, un marco de trabajo para simular las EAS generadas por la interacción de rayos cósmicos primarios con la atmósfera.

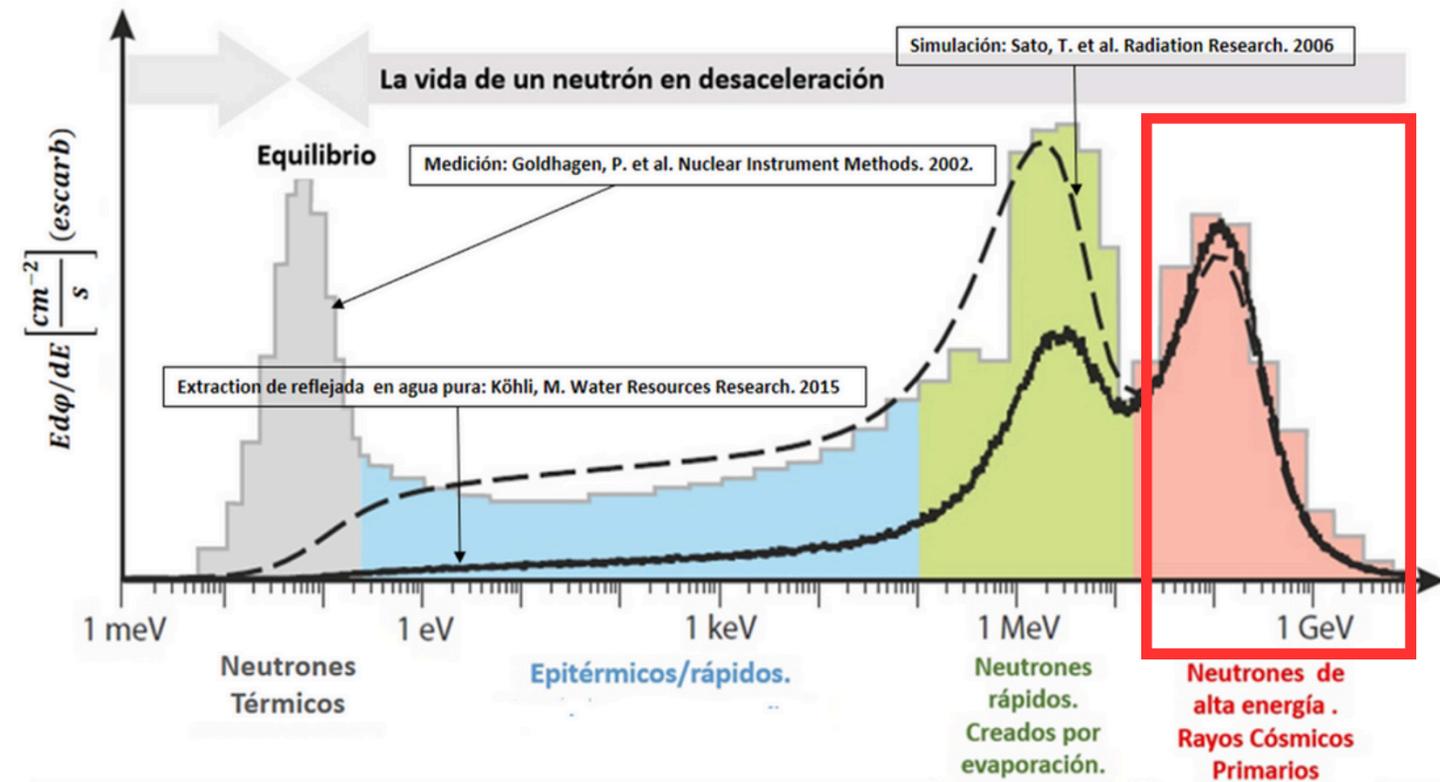


Flujo de neutrones cósmicos

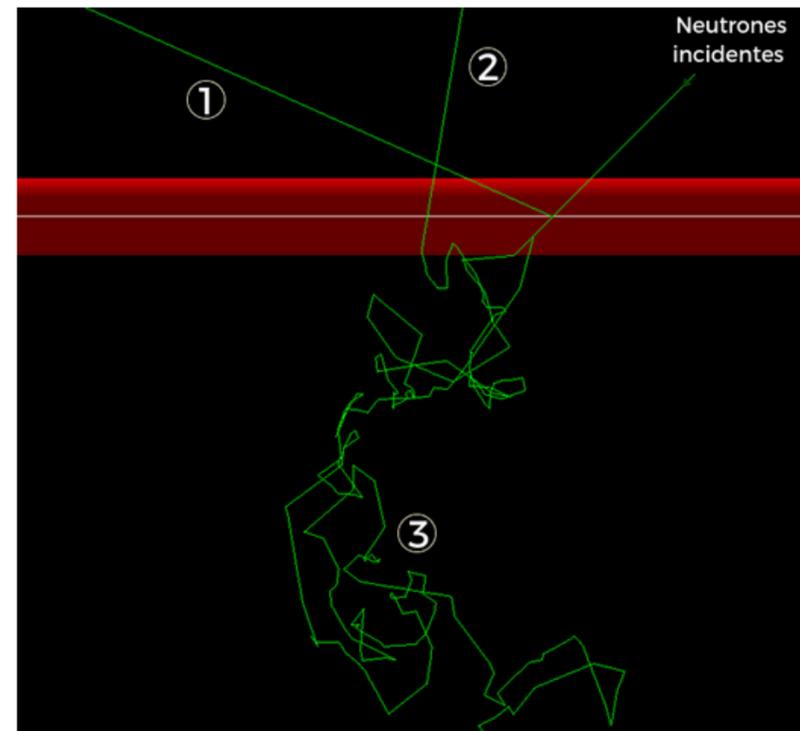
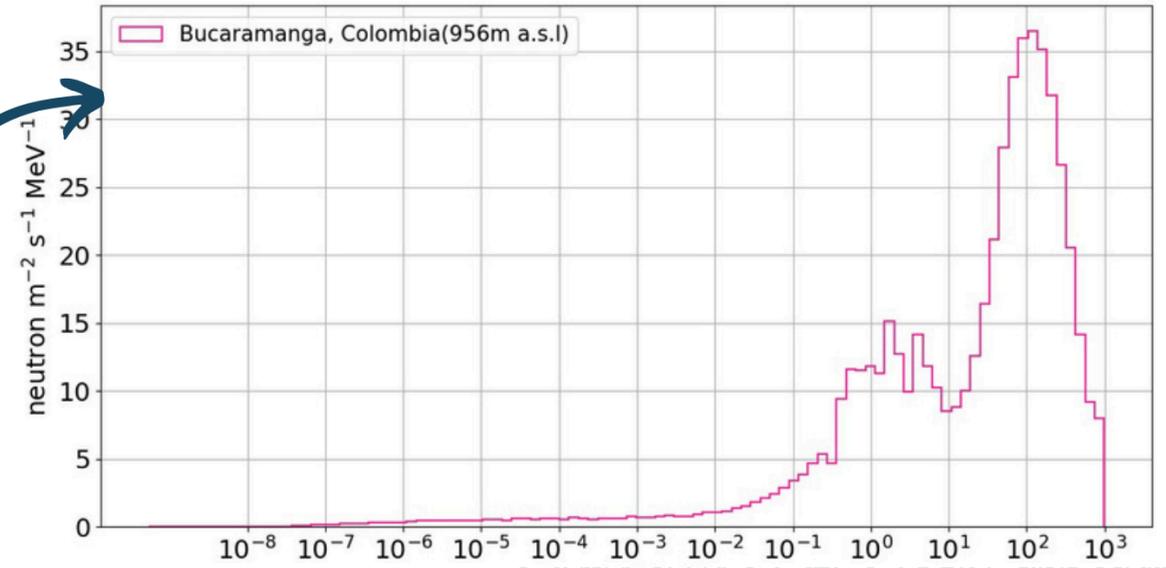
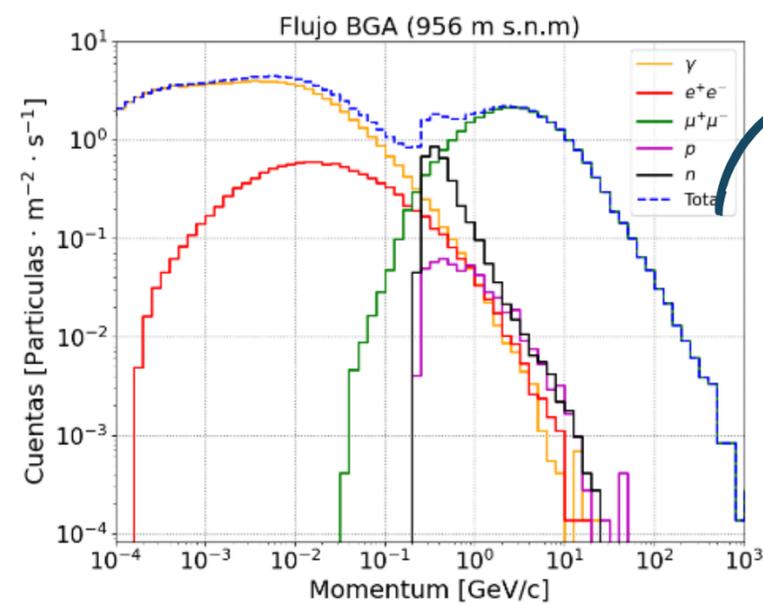
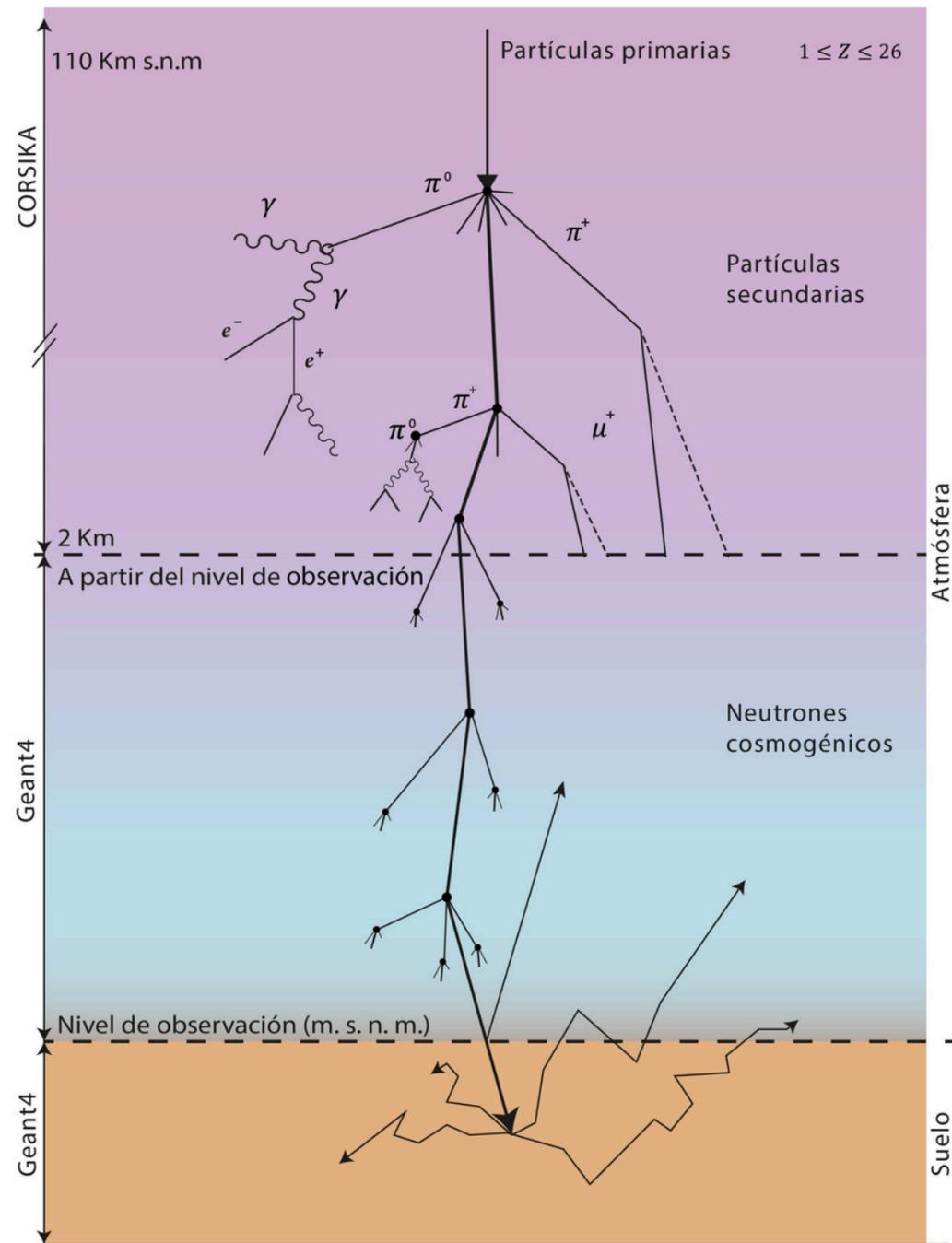
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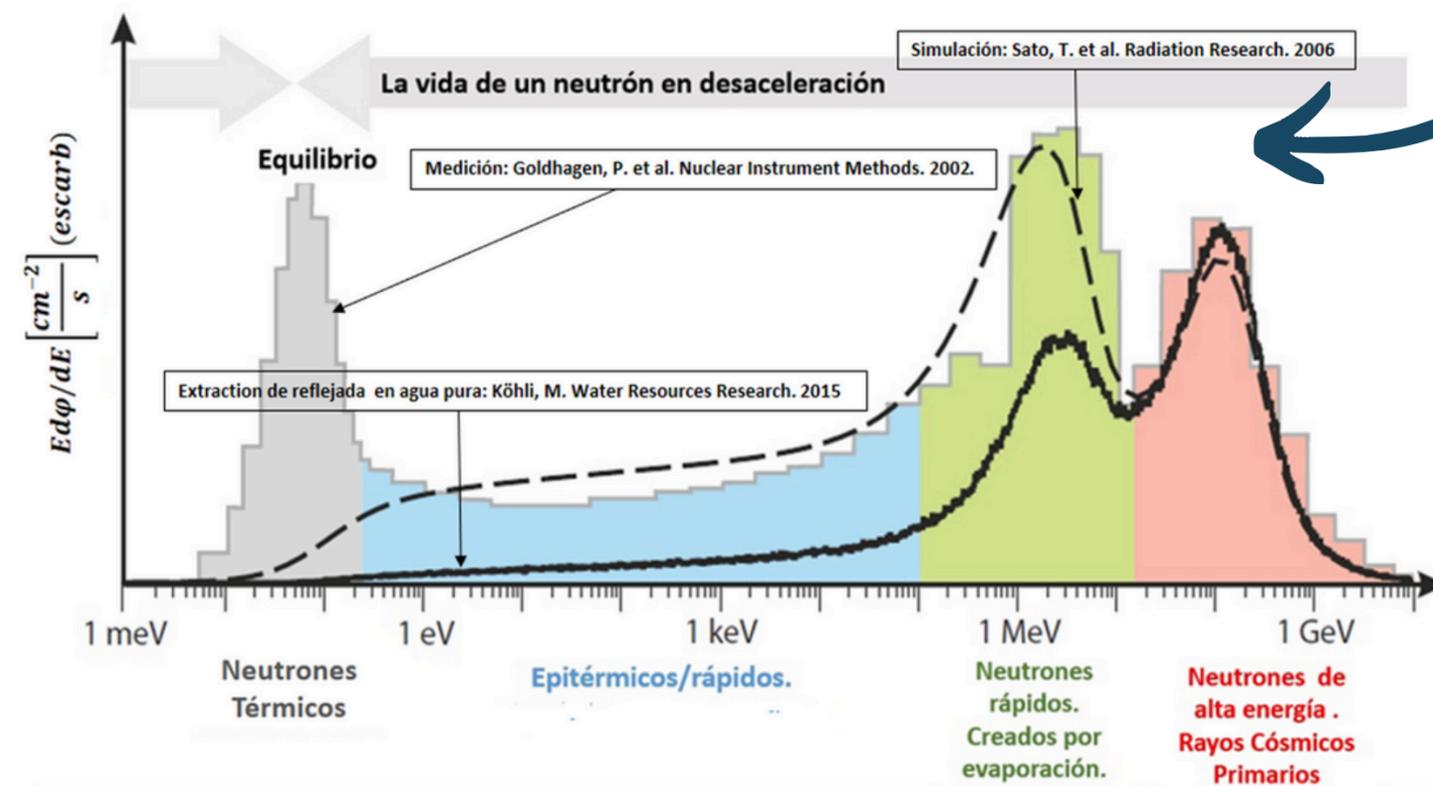
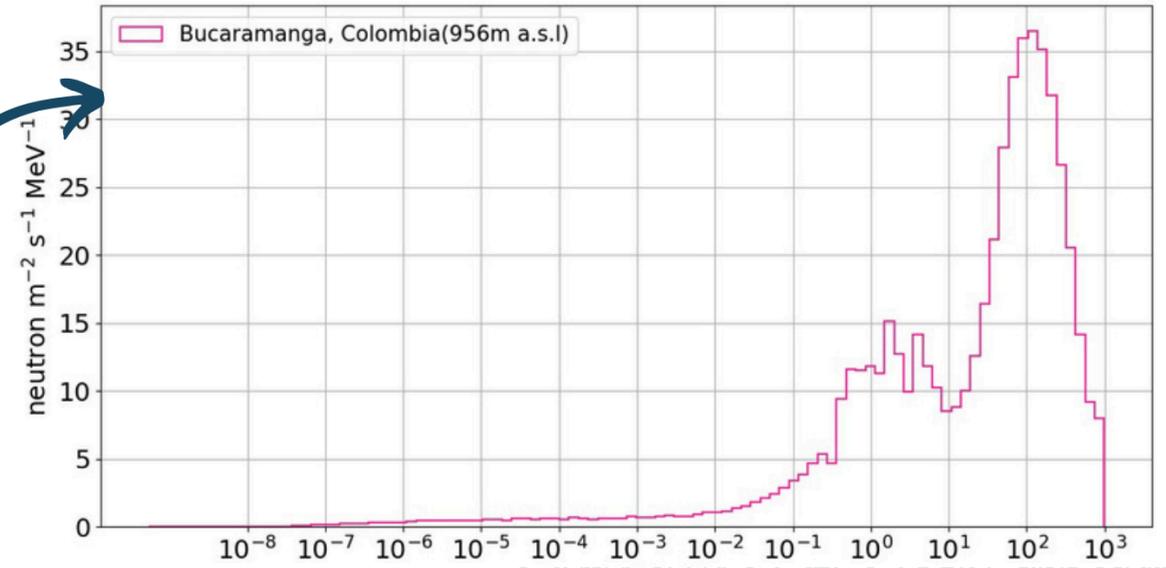
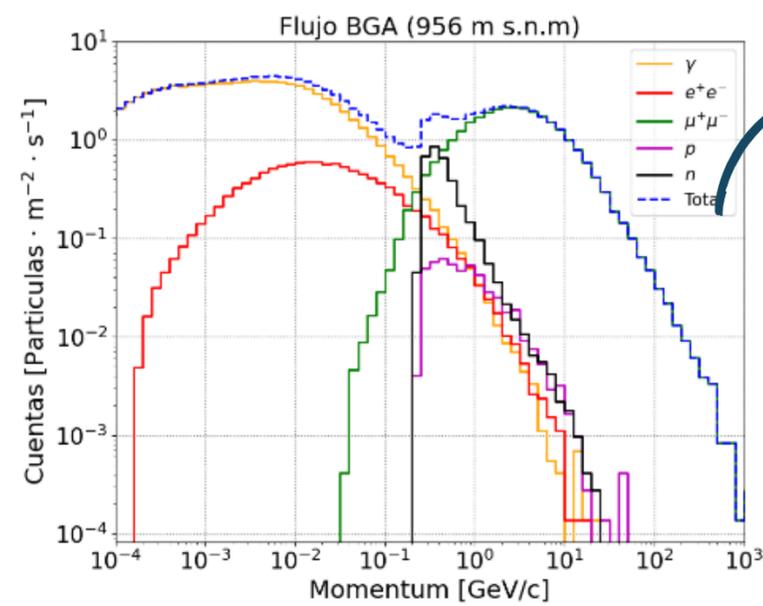
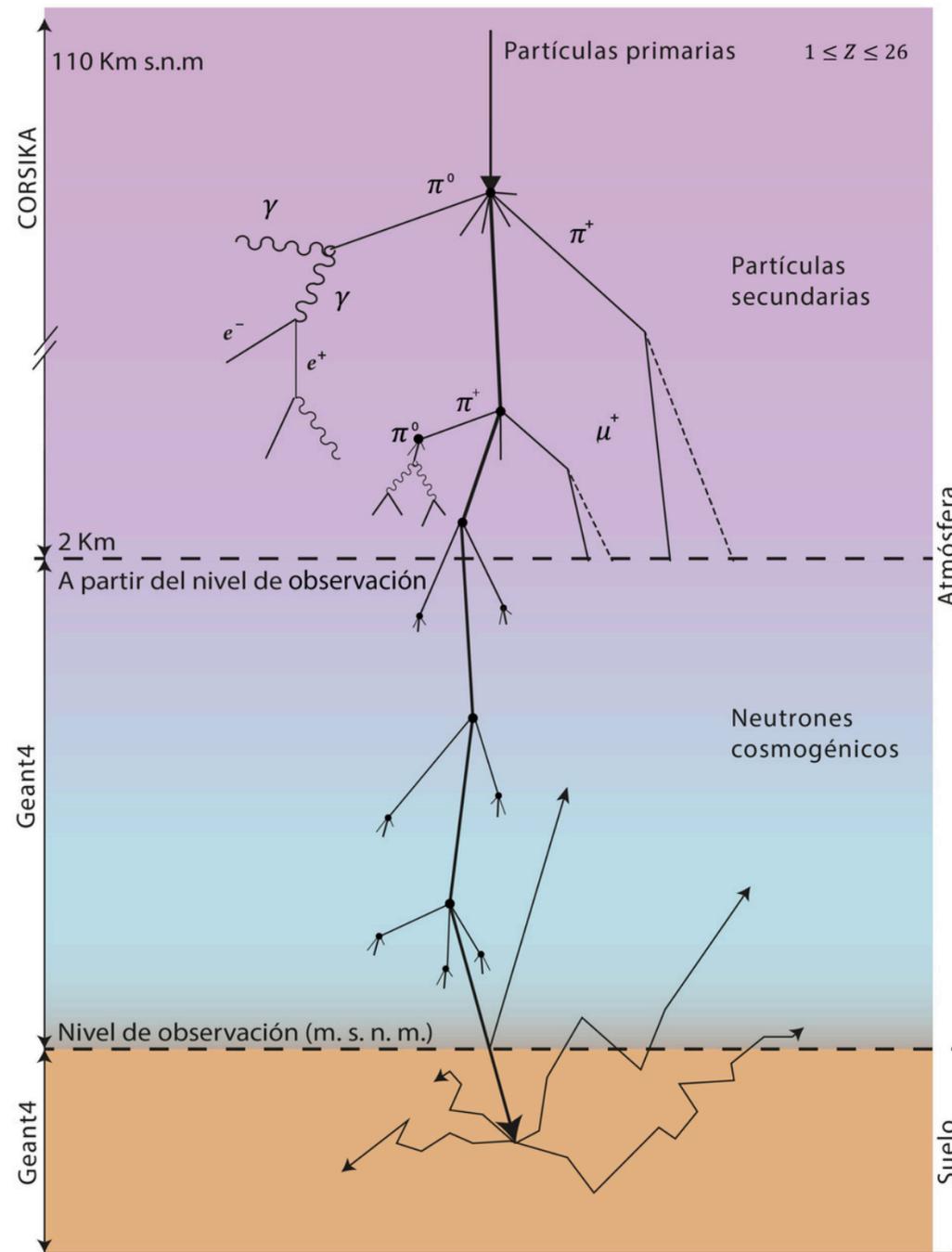
CORSIKA realiza un corte de energía aproximadamente a 20 MeV para los neutrones.



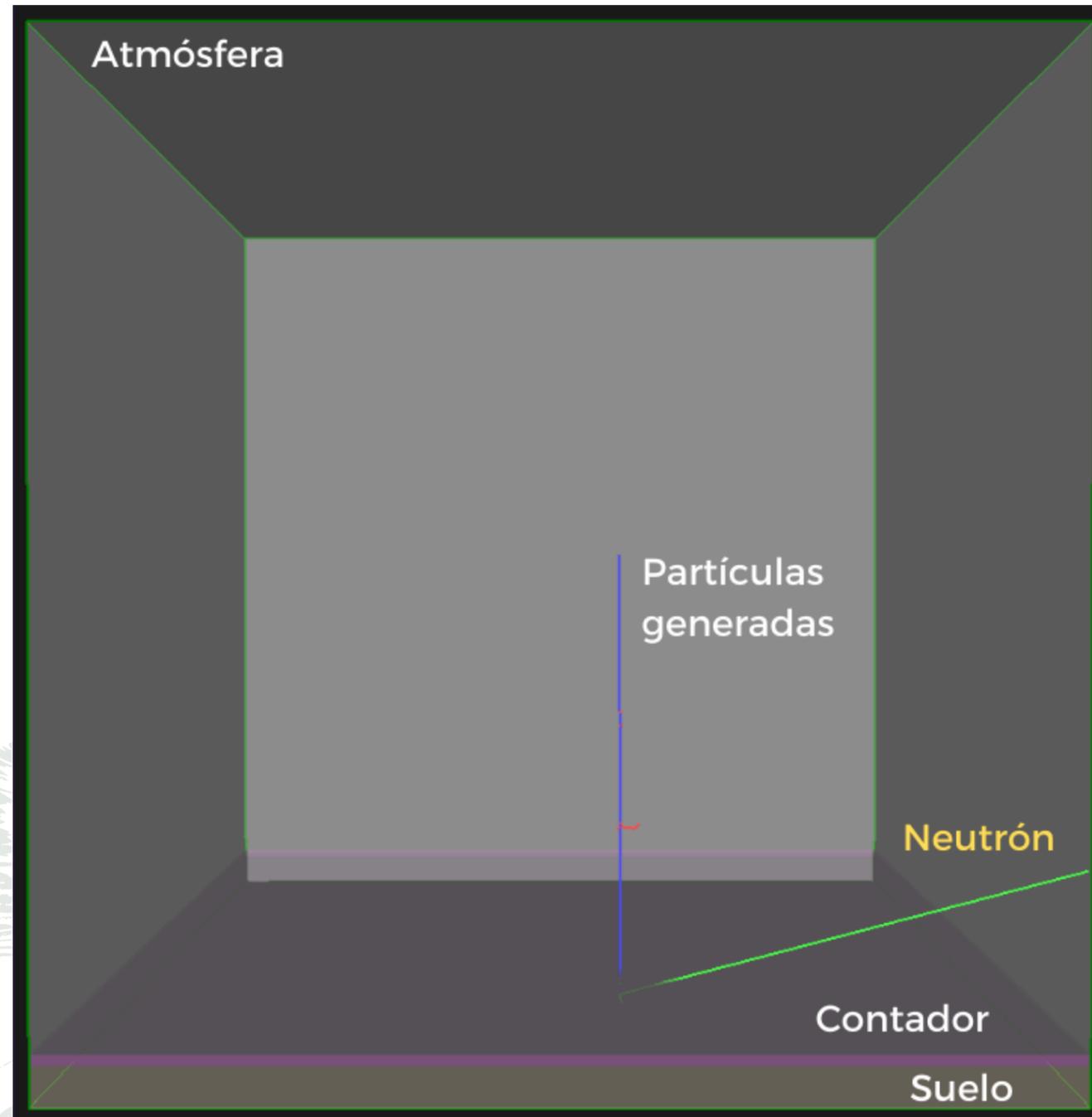
Flujo de neutrones cósmicos



Flujo de neutrones cósmicos

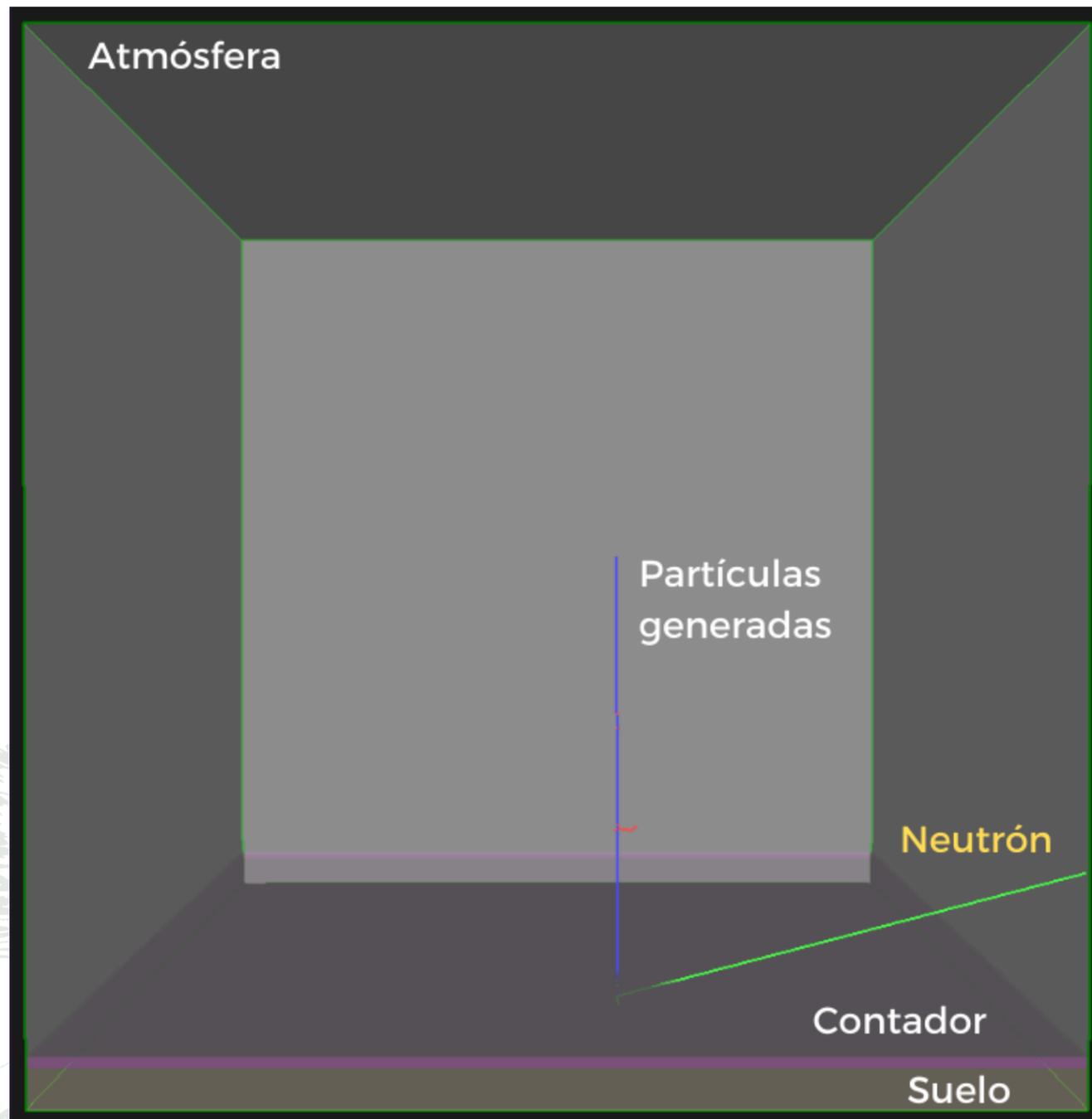


Sistema físico

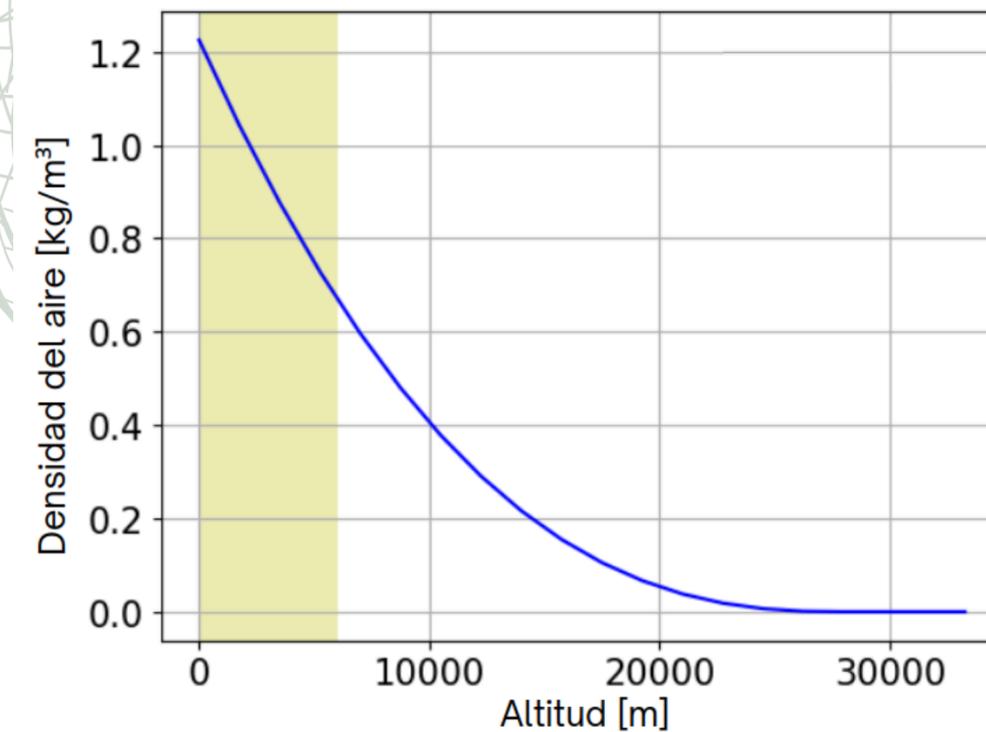


Sistema físico implementado en Geant4 para medir el flujo de neutrones que llegan al nivel del suelo después de haber recorrido 2km de atmósfera

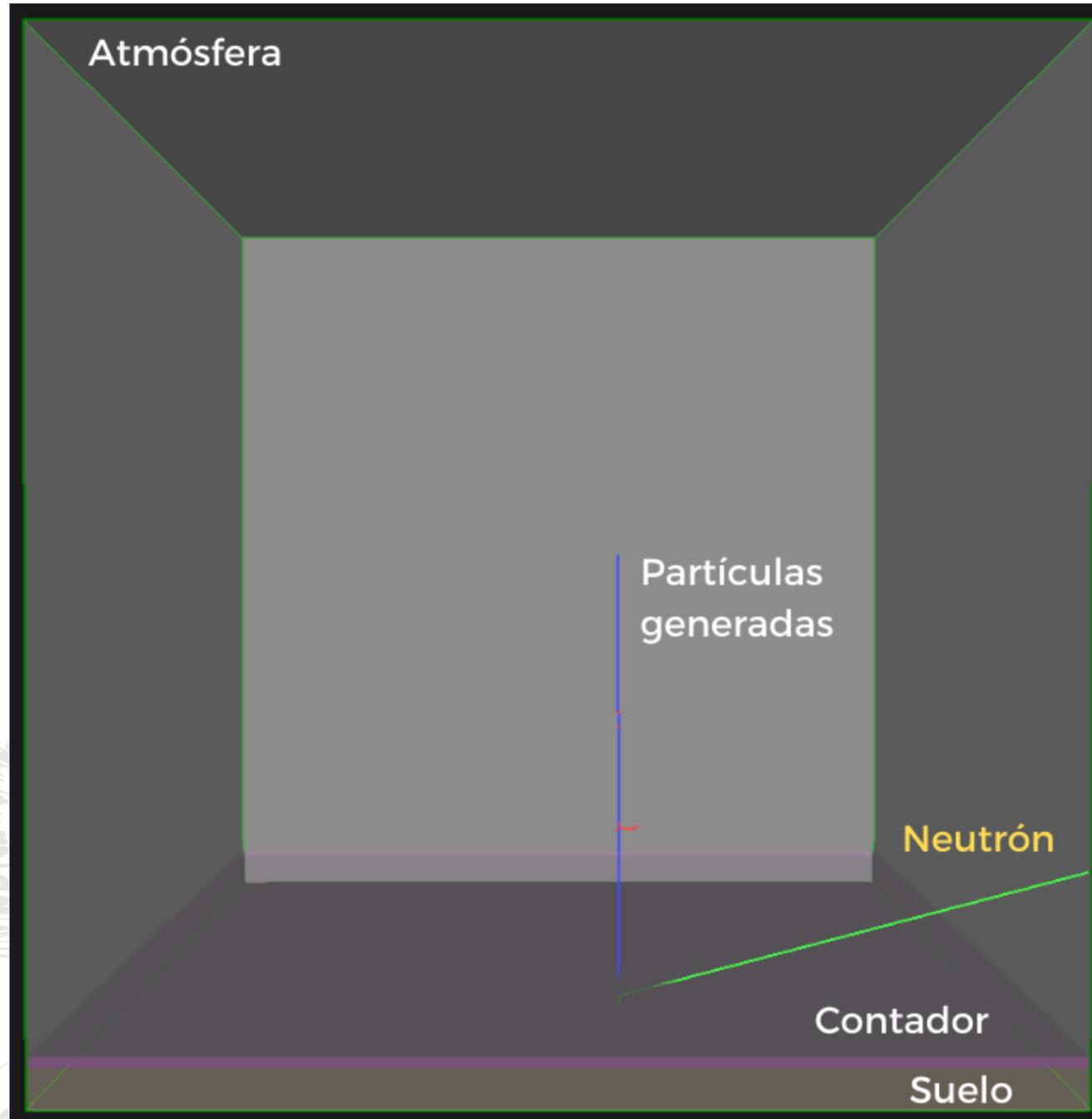
Sistema físico atmósfera



Elemento	Fraccion
N	0.7808
O	0.2095
Ar	0.0090



Sistema físico suelo



Elementos presentes en el suelo seco	Concentración [%]
O	49
Si	33
Al	7.13
Na	0.63
K	1.36
Ca	1.37
Fe	3.8
Mg	0.6
C	2
S	0.08
N	0.1
P	0.9
Ti	0.46
H	0.38

```

//Dry Soil
SoilBS = new G4Material("SoilBS", 2.7*g/cm3, 14);
SoilBS->AddElement(eLO, 0.49);
SoilBS->AddElement(eLSi, 0.33);
SoilBS->AddElement(eLAl, 0.0713);
SoilBS->AddElement(eLNa, 0.0063);
SoilBS->AddElement(eLK, 0.0136);
SoilBS->AddElement(eLCa, 0.0137);
SoilBS->AddElement(eLFe, 0.0380);
SoilBS->AddElement(eLMg, 0.0060);
SoilBS->AddElement(eLC, 0.02);
SoilBS->AddElement(eLS, 0.0008);
SoilBS->AddElement(eLN, 0.001);
SoilBS->AddElement(eLP, 0.0009);
SoilBS->AddElement(eLTi, 0.0046);
SoilBS->AddElement(eLH, 0.0038);

// Soil 5% moisture
SoilBH5 = new G4Material("SoilBH5",2.7*g/cm3,2);
SoilBH5->AddMaterial(SoilBS,0.95);
SoilBH5->AddMaterial(Water,0.05);

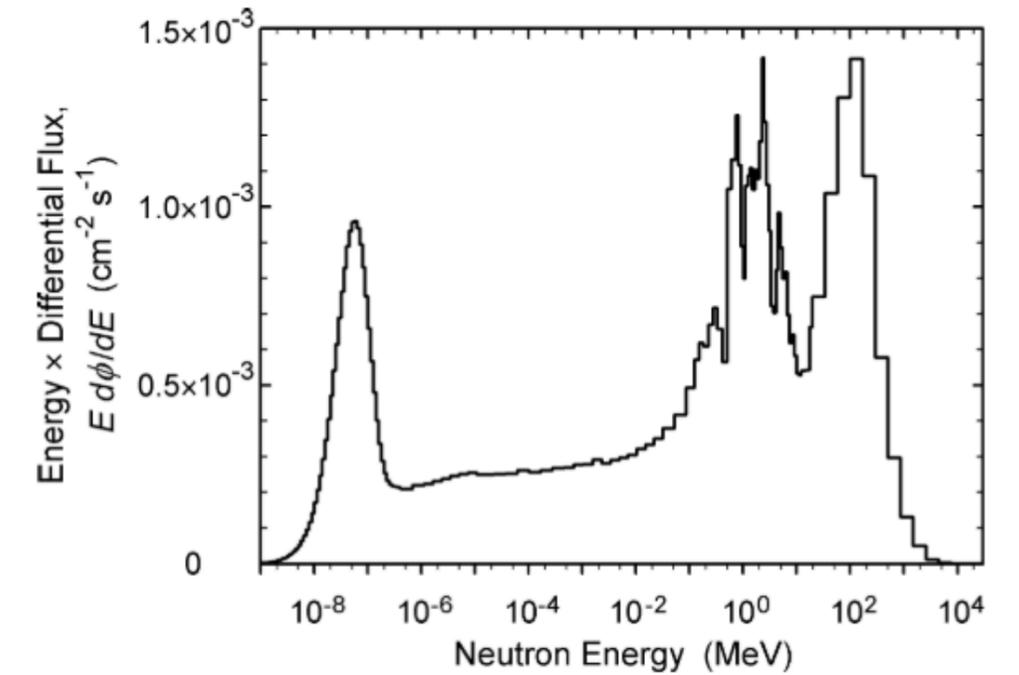
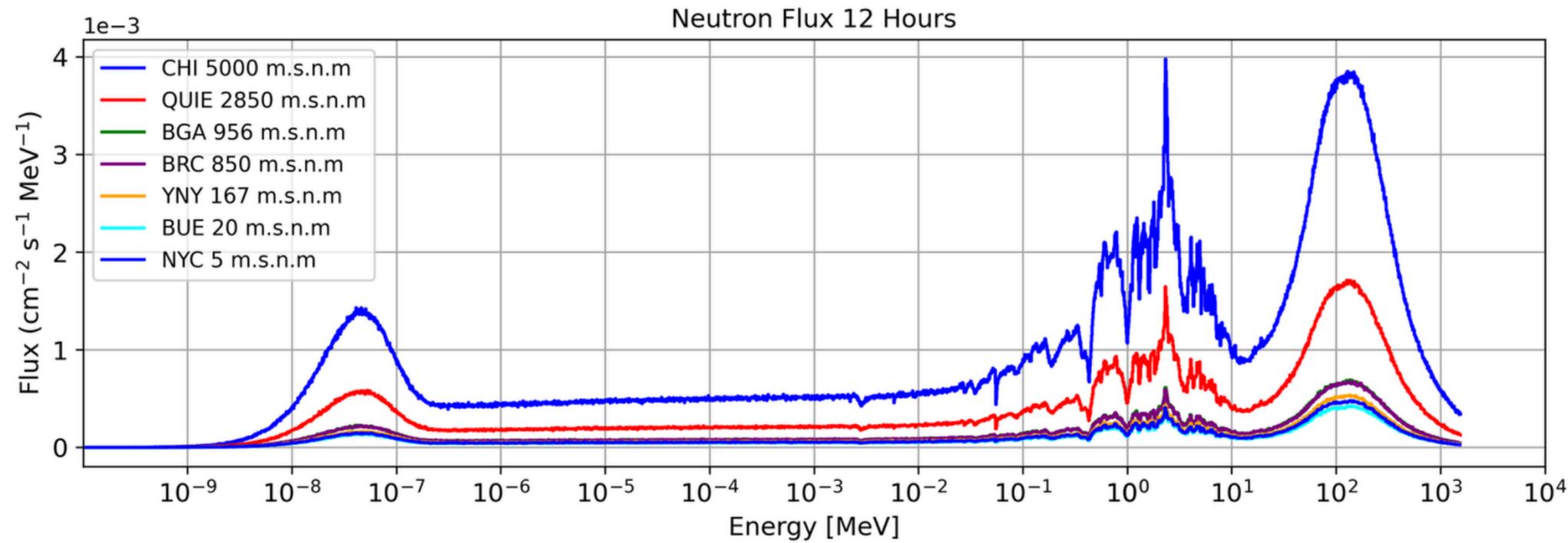
//Soil 10% moisture
SoilBH10 = new G4Material("SoilBH10",2.7*g/cm3,2);
SoilBH10->AddMaterial(SoilBS,0.9);
SoilBH10->AddMaterial(Water,0.1);

//Soil 15% moisture
SoilBH15 = new G4Material("SoilBH15",2.7*g/cm3,2);
SoilBH15->AddMaterial(SoilBS,0.85);
SoilBH15->AddMaterial(Water,0.15);

//Soil 25% moisture
SoilBH25 = new G4Material("SoilBH25",2.7*g/cm3,2);
SoilBH25->AddMaterial(SoilBS,0.75);
SoilBH25->AddMaterial(Water,0.25);

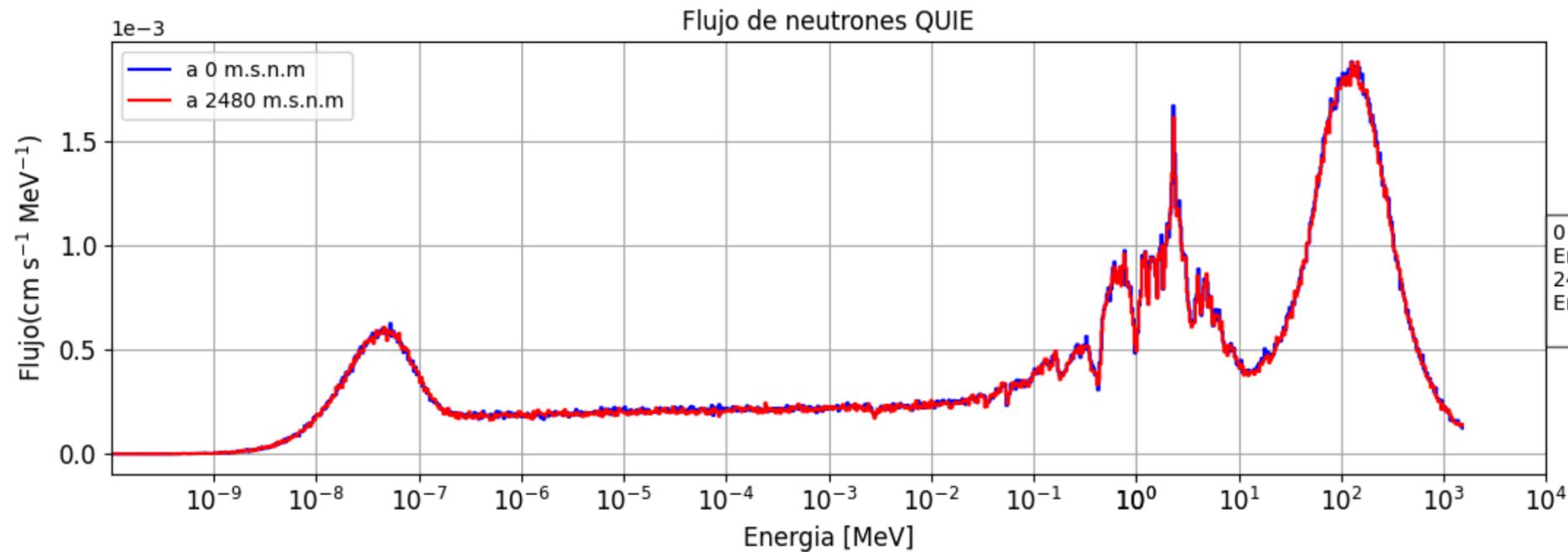
//Soil 30% moisture
SoilBH30 = new G4Material("SoilBH30",2.7*g/cm3,2);
SoilBH30->AddMaterial(SoilBS,0.7);
SoilBH30->AddMaterial(Water,0.3);
    
```

Flujo de neutrones cósmicos



[Gordon et al., IEEE Transactions on Nuclear Science, 51(6), 3427-3434 2004.]

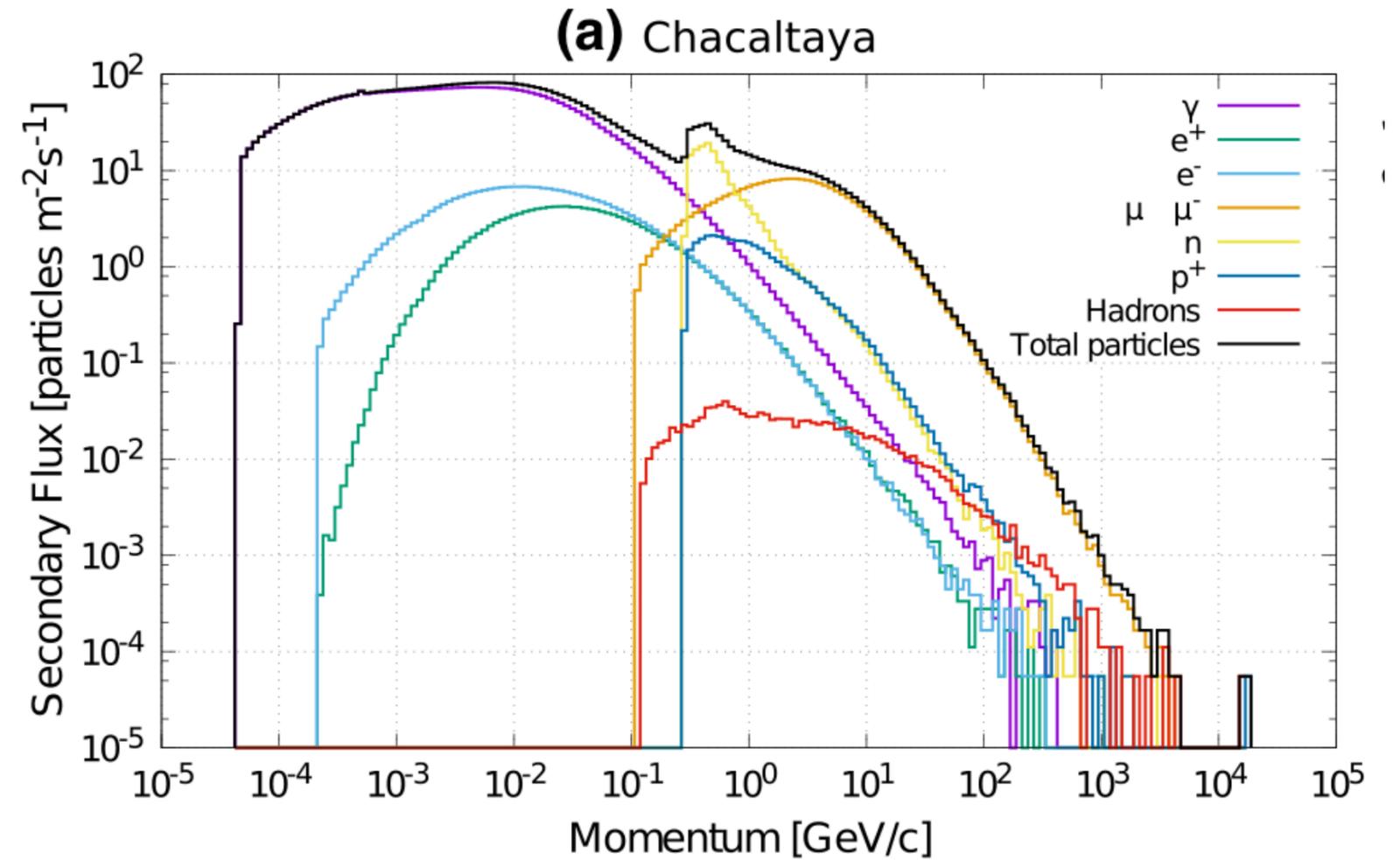
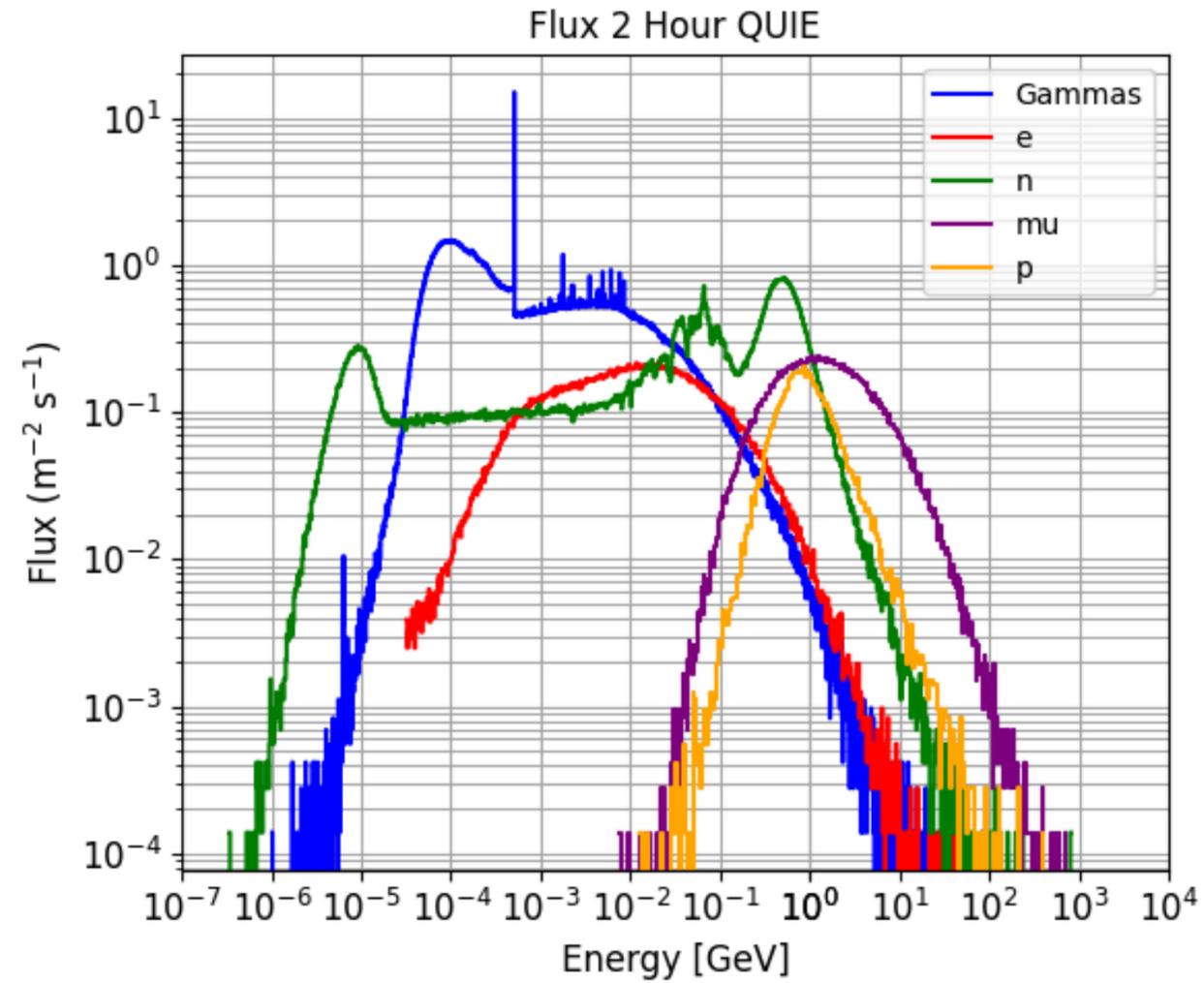
Flujo de neutrones cósmicos



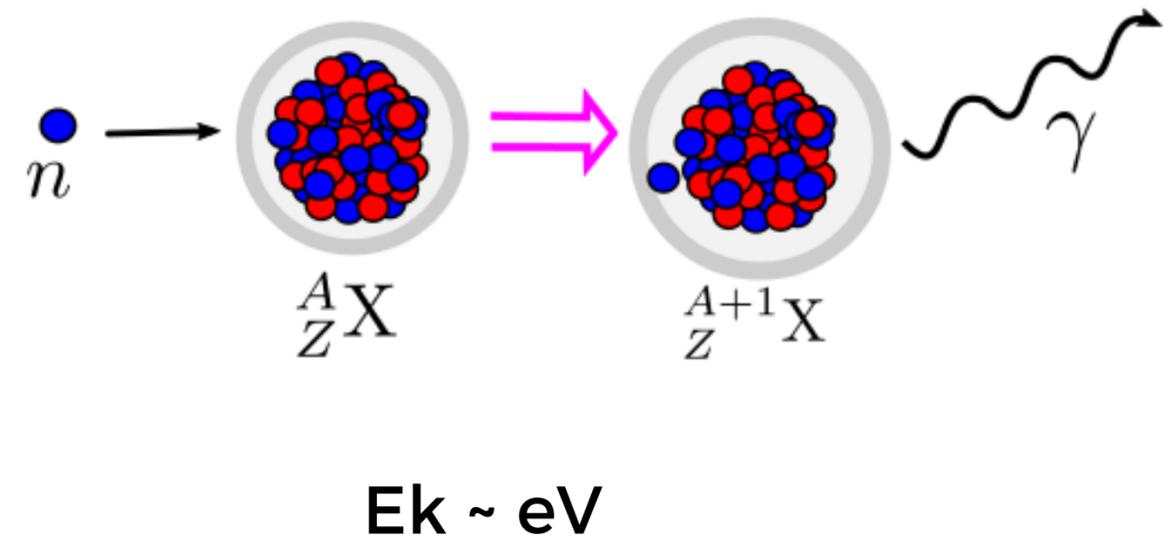
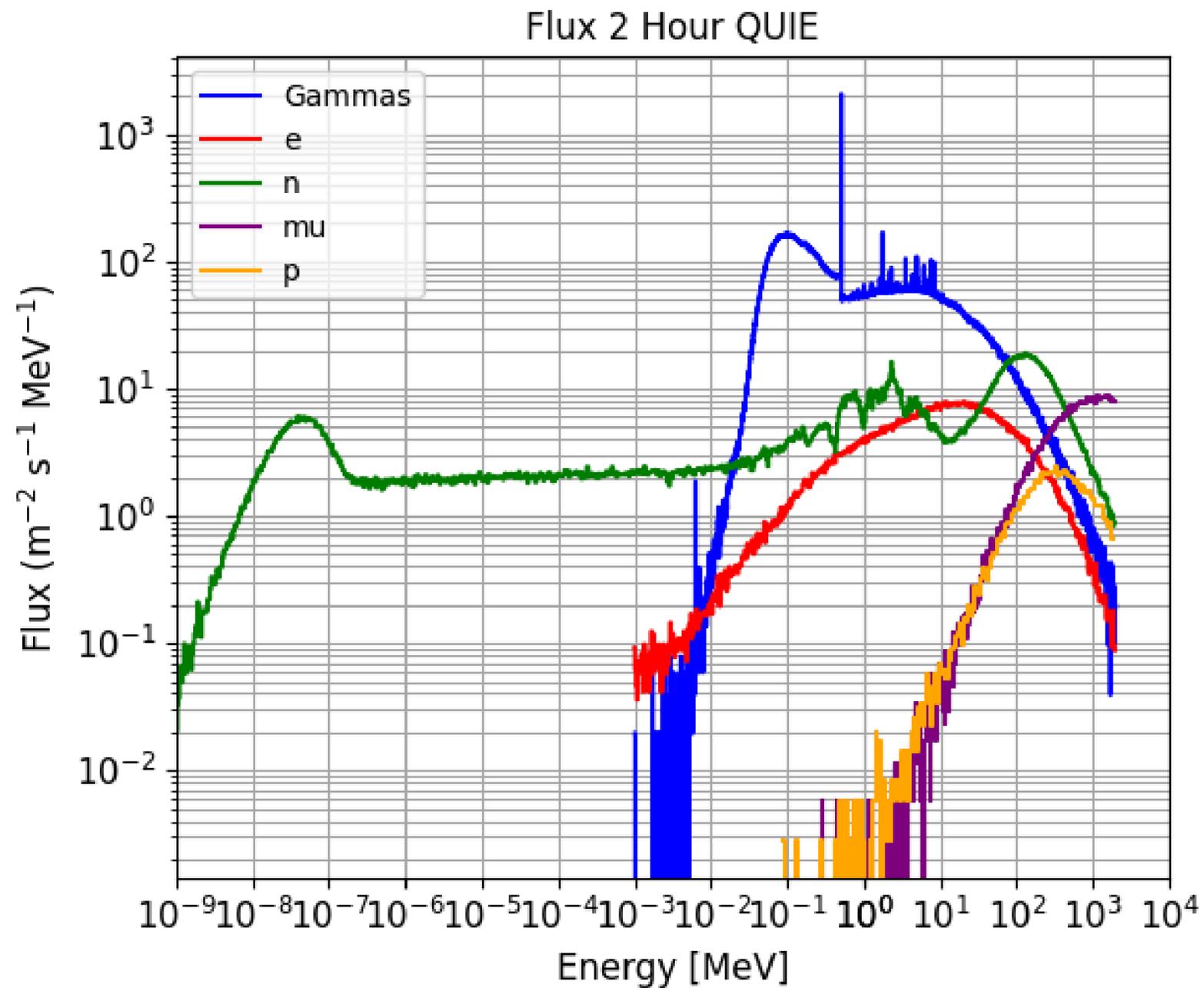
Diferencia porcentual < 2%

```
*****
layer          height(m)          density(g/cm3)
Altura inicial: 2850 m
Layer: 1 | Height (m): 2850 | Density (g/cm3): 0.000989233
-----
Altura inicial: 2850 m
Layer: 2 | Height (m): 3050 | Density (g/cm3): 0.000973326
-----
Altura inicial: 2850 m
Layer: 3 | Height (m): 3250 | Density (g/cm3): 0.000957506
-----
Altura inicial: 2850 m
Layer: 4 | Height (m): 3450 | Density (g/cm3): 0.000941773
-----
Altura inicial: 2850 m
Layer: 5 | Height (m): 3650 | Density (g/cm3): 0.000926127
-----
Altura inicial: 2850 m
Layer: 6 | Height (m): 3850 | Density (g/cm3): 0.000910568
-----
Altura inicial: 2850 m
Layer: 7 | Height (m): 4050 | Density (g/cm3): 0.000895098
-----
Altura inicial: 2850 m
Layer: 8 | Height (m): 4250 | Density (g/cm3): 0.000879716
-----
Altura inicial: 2850 m
Layer: 9 | Height (m): 4450 | Density (g/cm3): 0.000864423
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Altura inicial: 2850 m
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*****
```

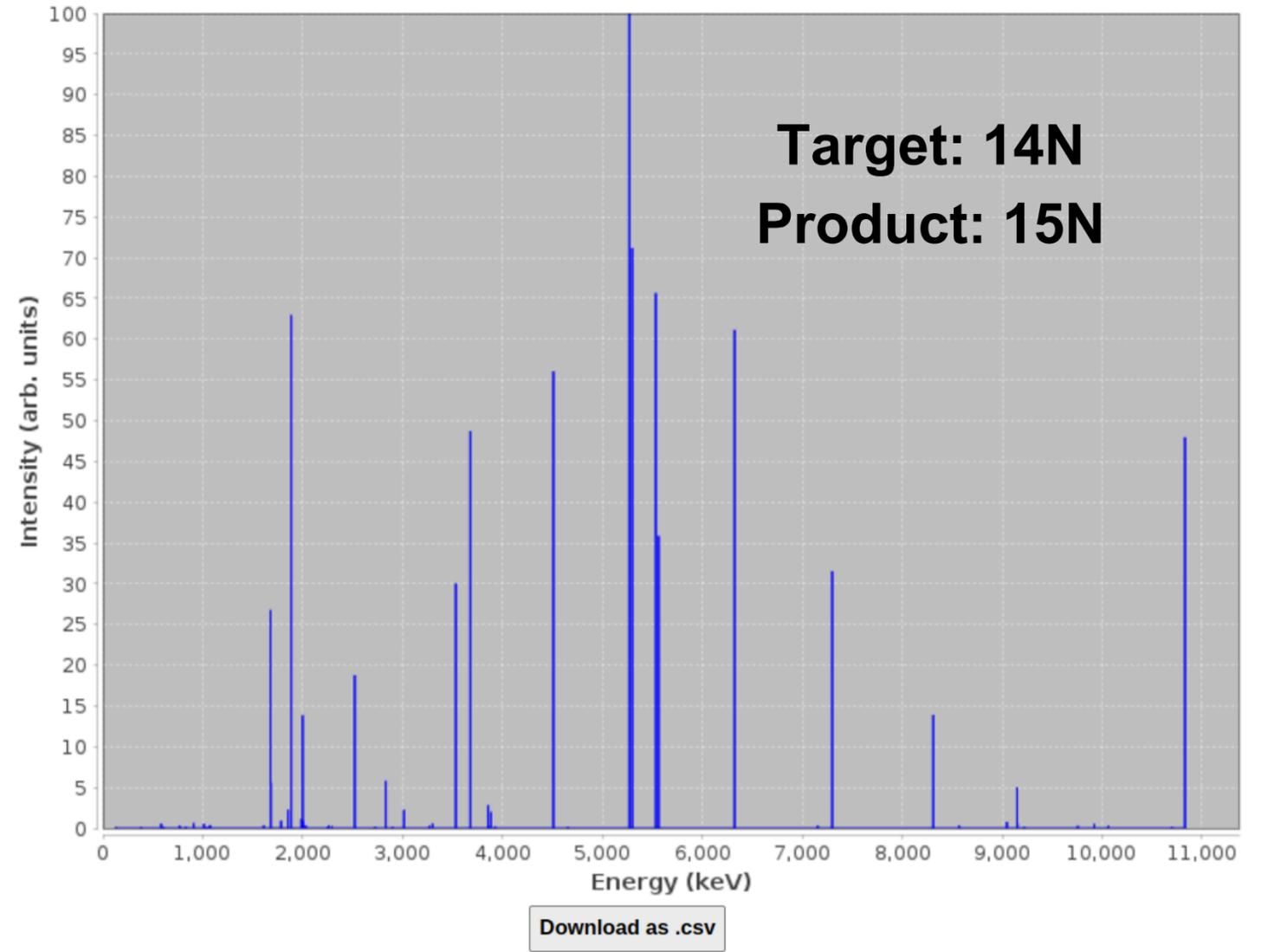
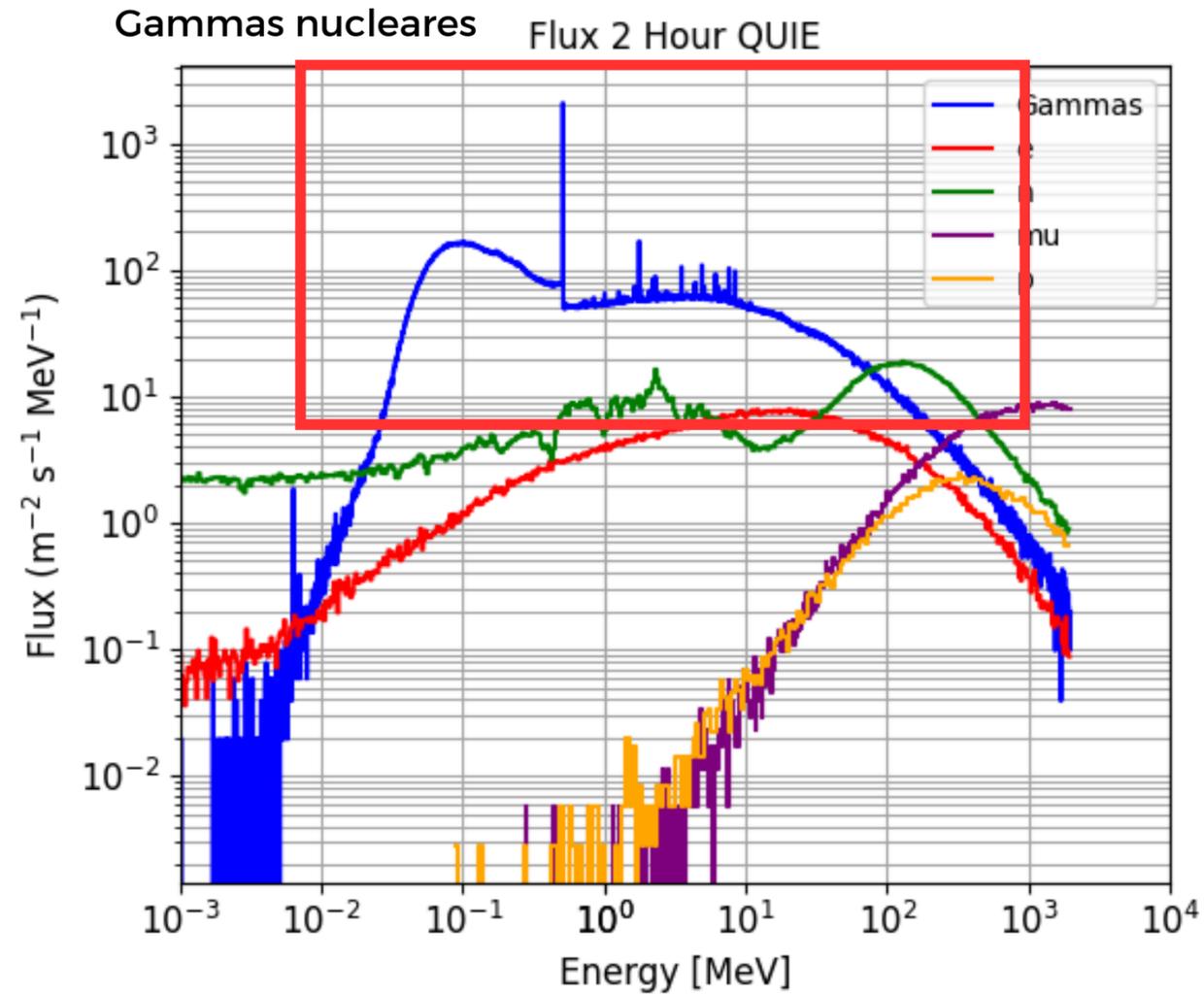
Flujo de Partículas secundarias



Flujo de Partículas secundarias



Flujo de Partículas secundarias



Datos: National nuclear data center (U.S)

Type	$E(\gamma)$ (keV)	$\Delta E(\gamma)$ (keV)	$I(\gamma)/I(\gamma)_{\text{max}} \times 100$	$\Delta(I(\gamma)/I(\gamma)_{\text{max}})$
Primary	131.44	0.07	0.0603	0.0134
Primary	383.0	0.4	0.0234	0.0100
Secondary	583.75	0.04	0.4756	0.0338
Secondary	608.3	0.5	0.0737	0.0134

Muchas gracias por su atención