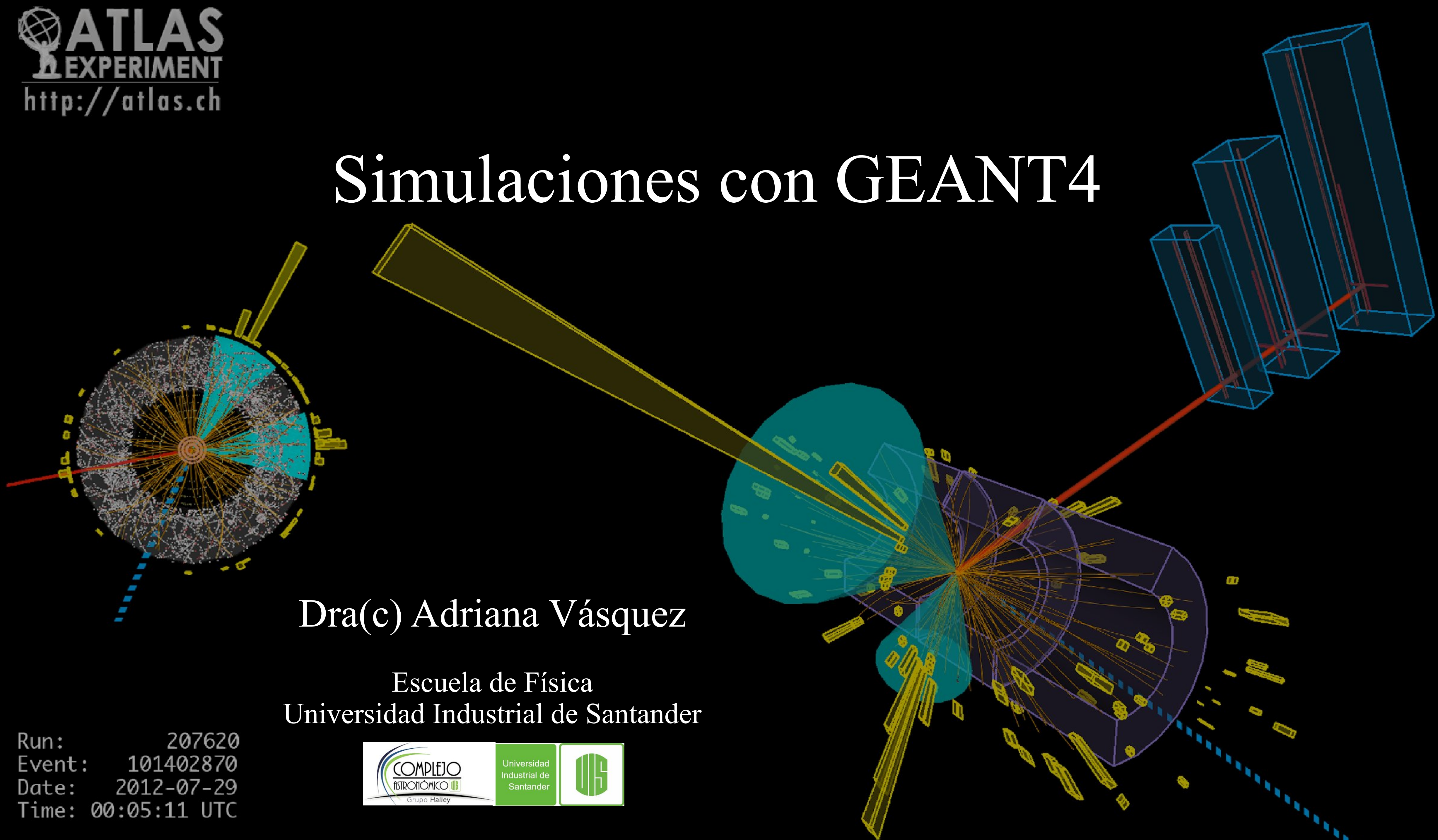
Simulaciones con GEANT4



Dra(c) Adriana Vásquez

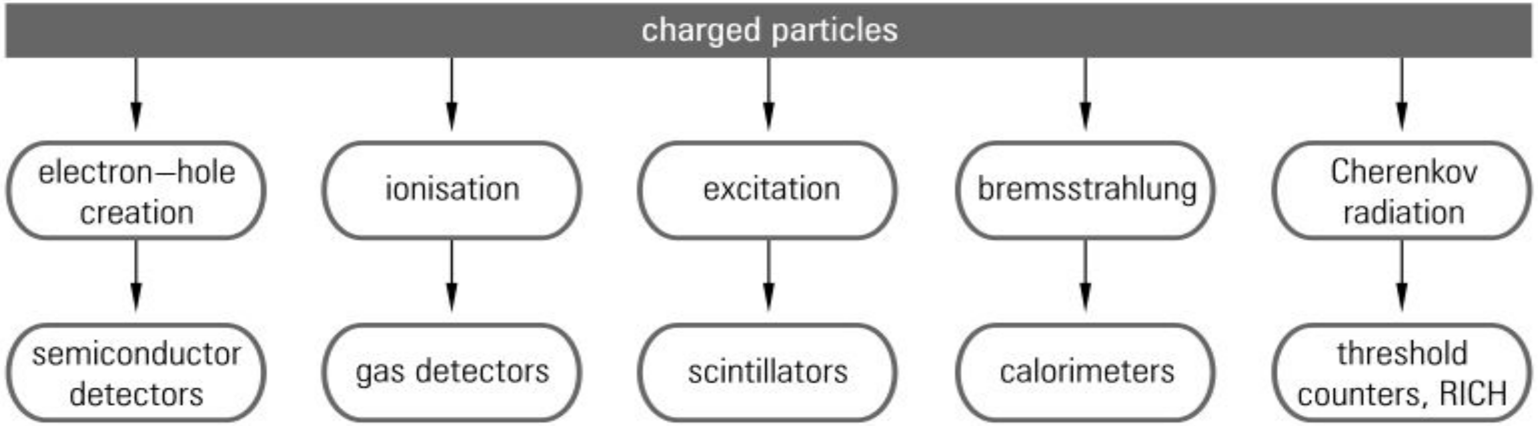
Escuela de Física
Universidad Industrial de Santander

Tipos de detectores

Procesos físicos de interacción partícula-materia

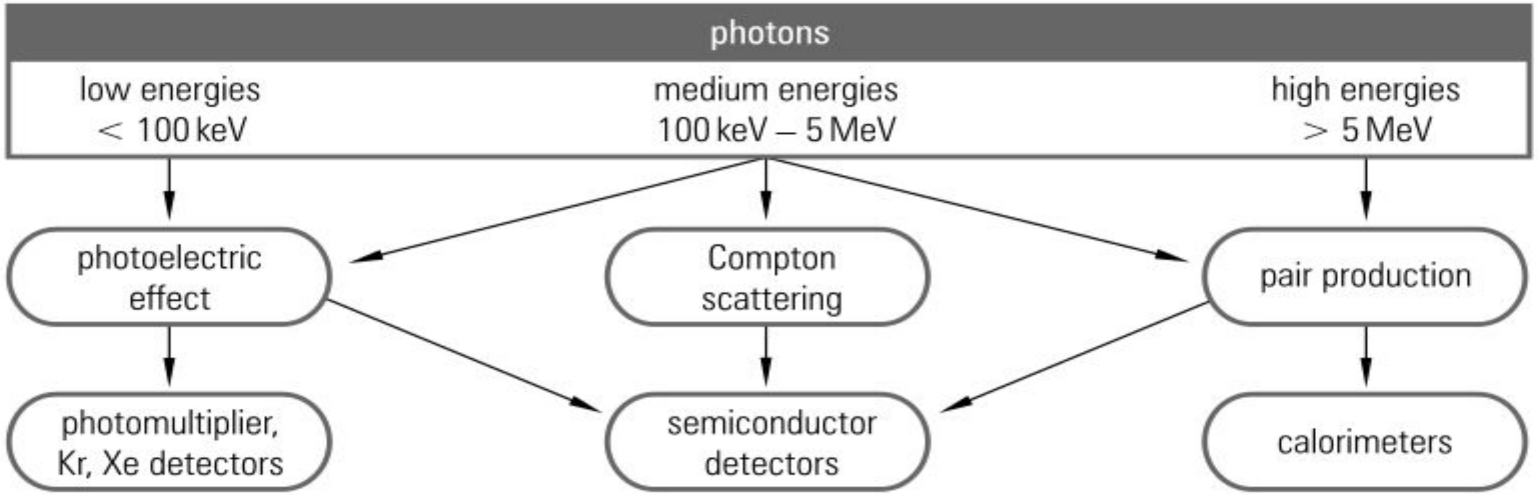
Process

Detector

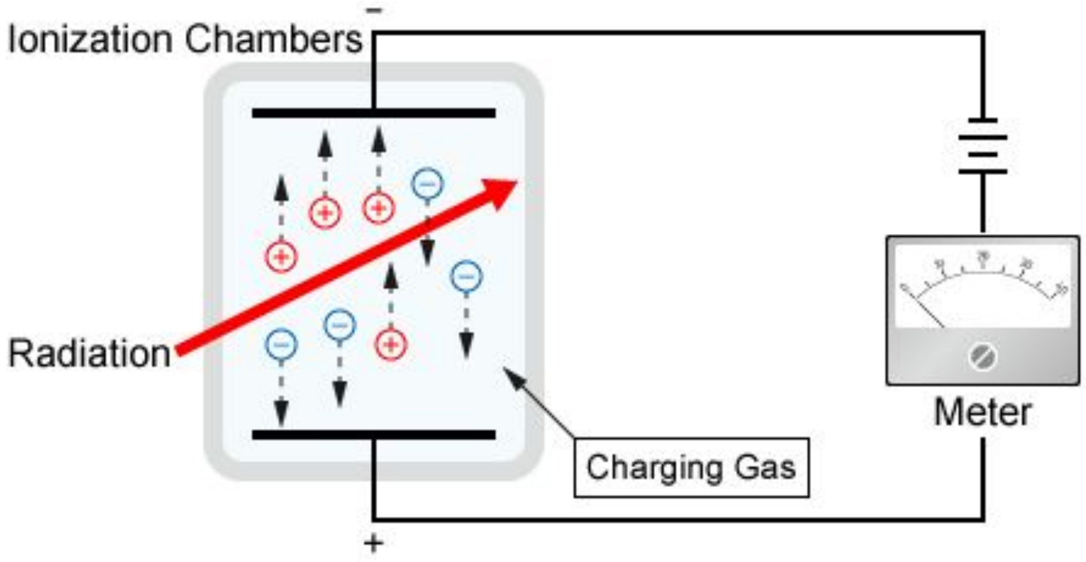


Process

Detector



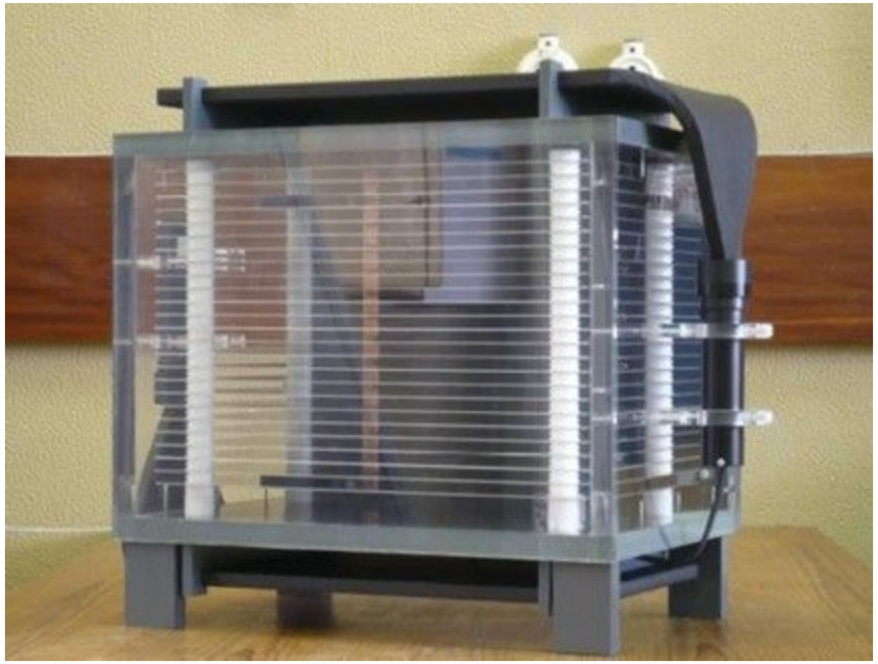
Detectores gaseosos



La radiación ioniza las moléculas del gas produciendo iones y electrones.

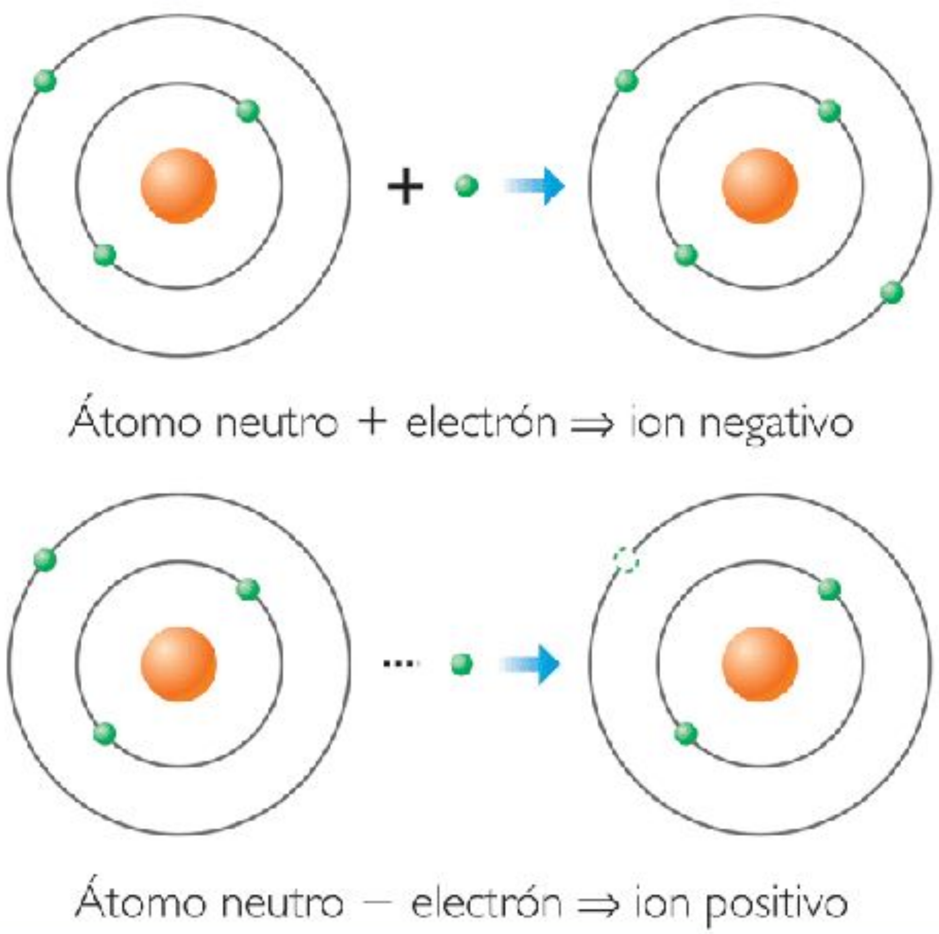
Los electrones son atraídos hacia el electrodo positivo y los iones con carga positiva hacia el electrodo negativo, produciendo una corriente eléctrica en el circuito.

Cámara de chispas



https://www.youtube.com/watch?v=Uf_0-eODN4Y&ab_channel=PIEUCM

Ionización



Si una partícula cargada posee la **energía mínima** necesaria para **arrancar un electrón** de un átomo neutro, puede ionizar el átomo.

Los rayos cósmicos o radiación ionizante son los responsables de la ionización atmosférica.

Creación de pares electrón-hueco

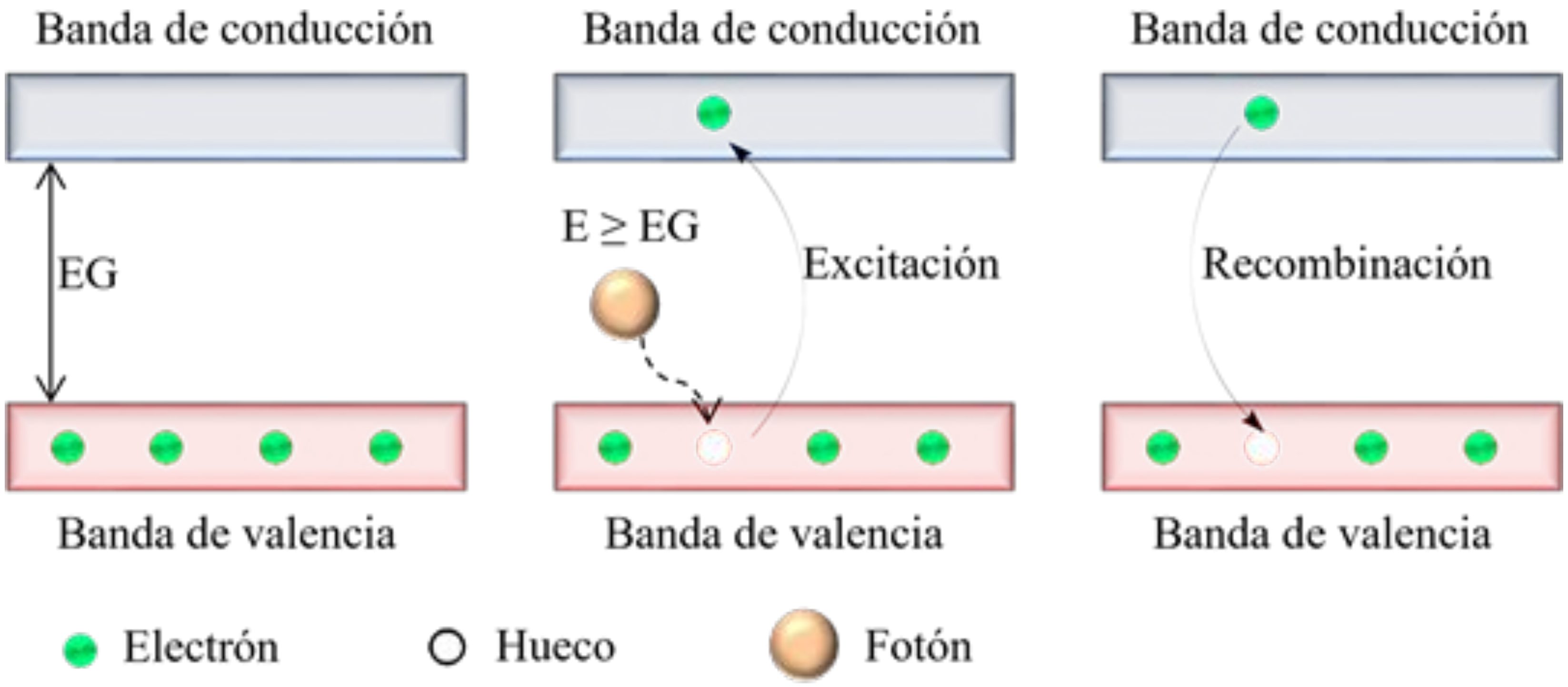
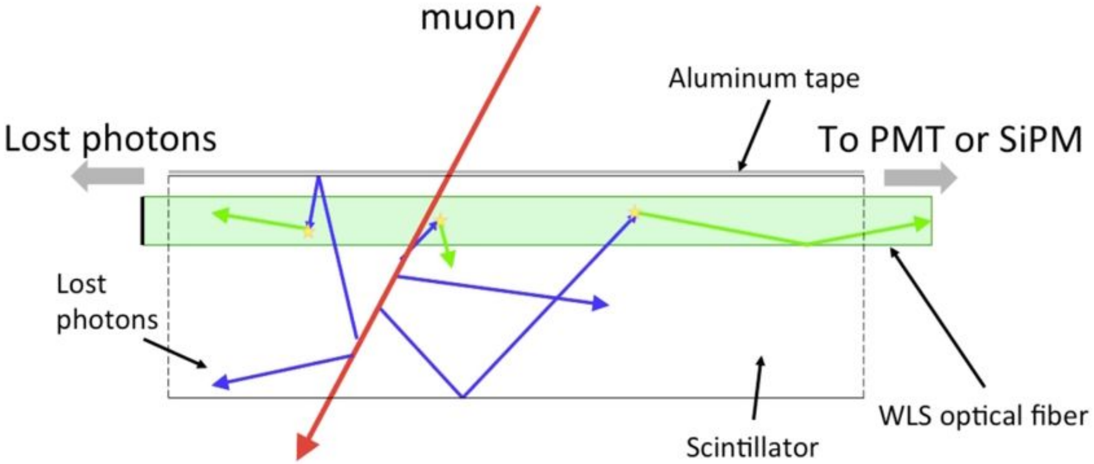
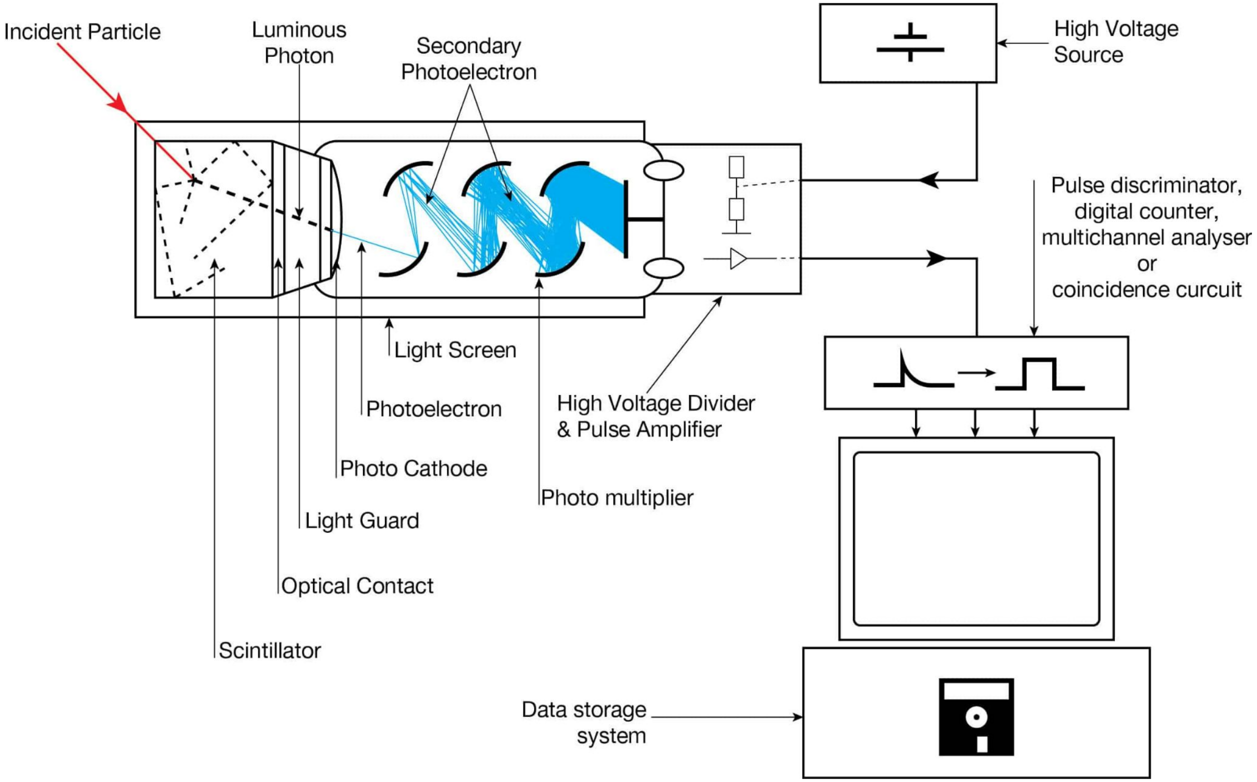


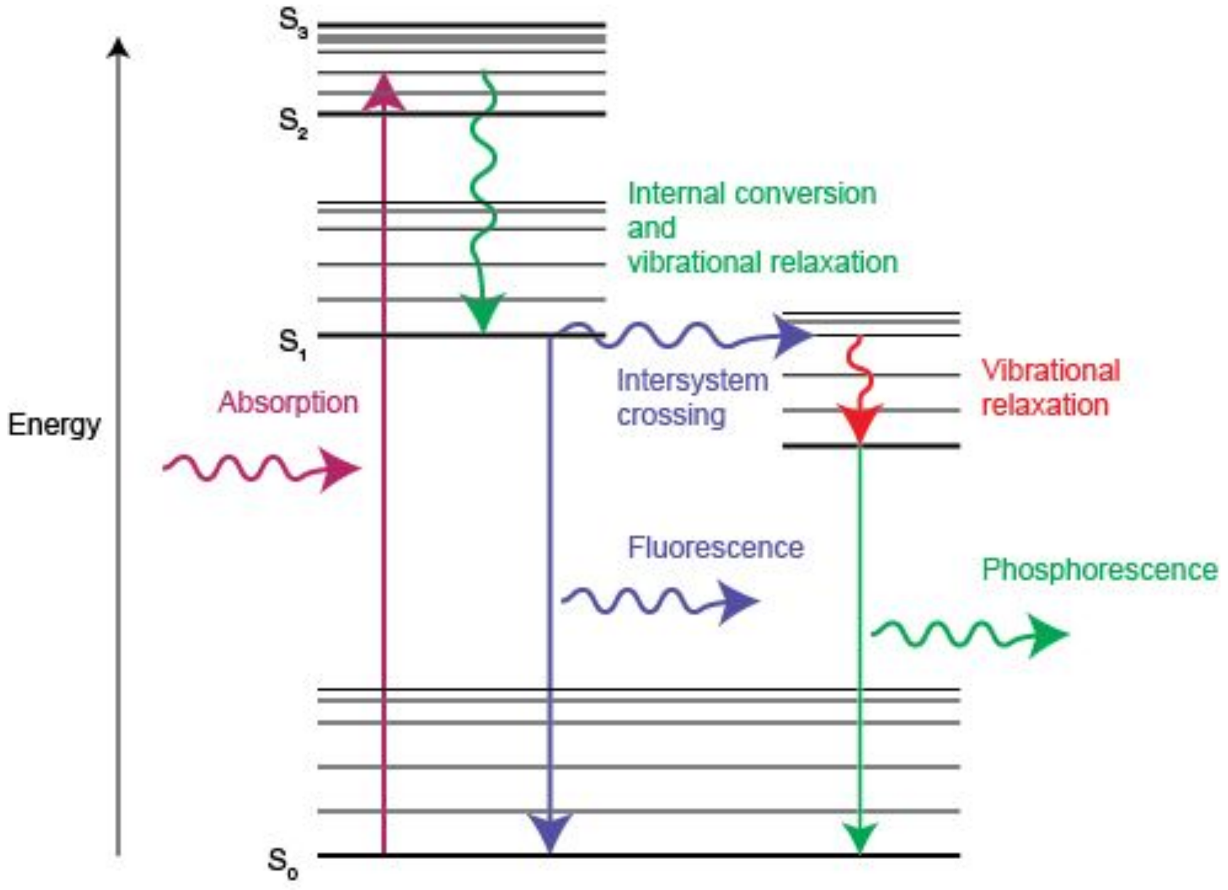
Figura I.14. Generación del par electrón-hueco.

Centelladores y fotomultiplicadores



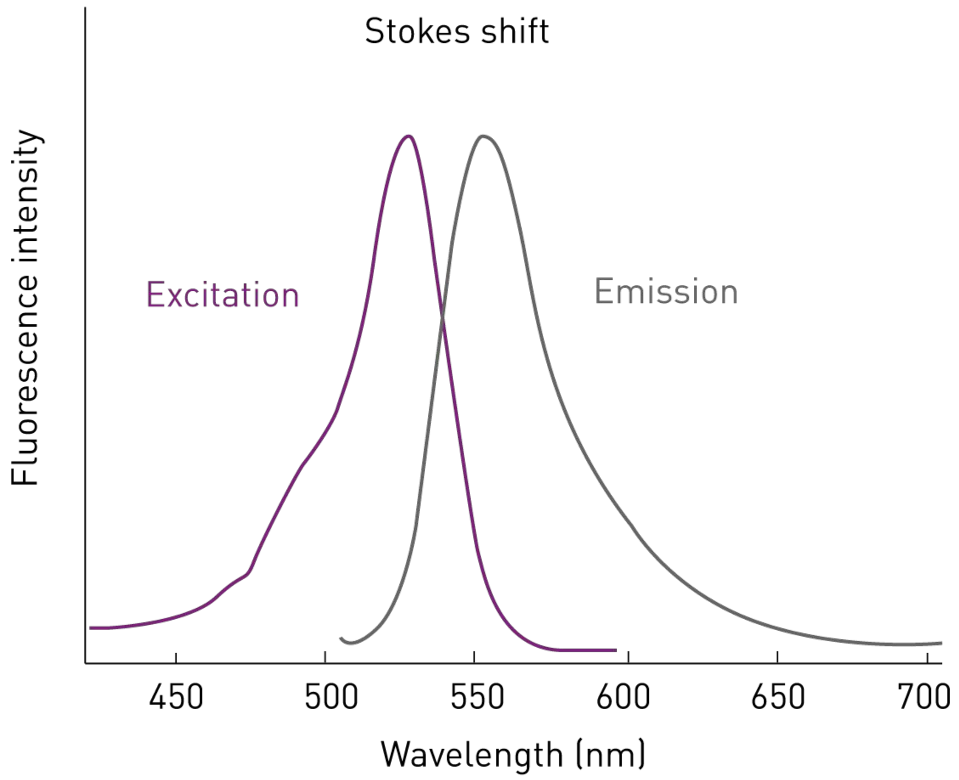


Excitación



τ ≈ nsec. - µsec. **Fluorescence**

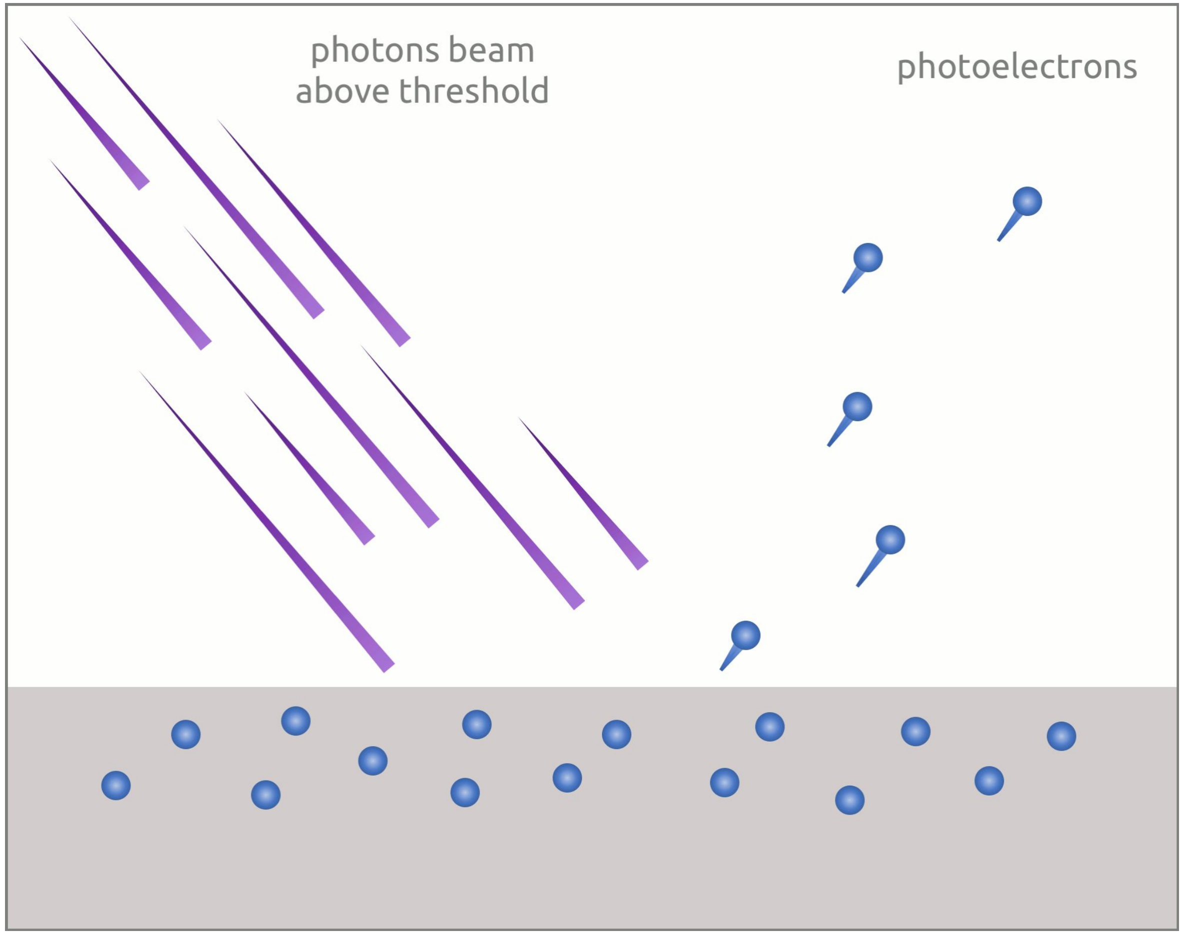
τ ≈ µsec. - mins **Phosphorescence**



Efecto fotoeléctrico

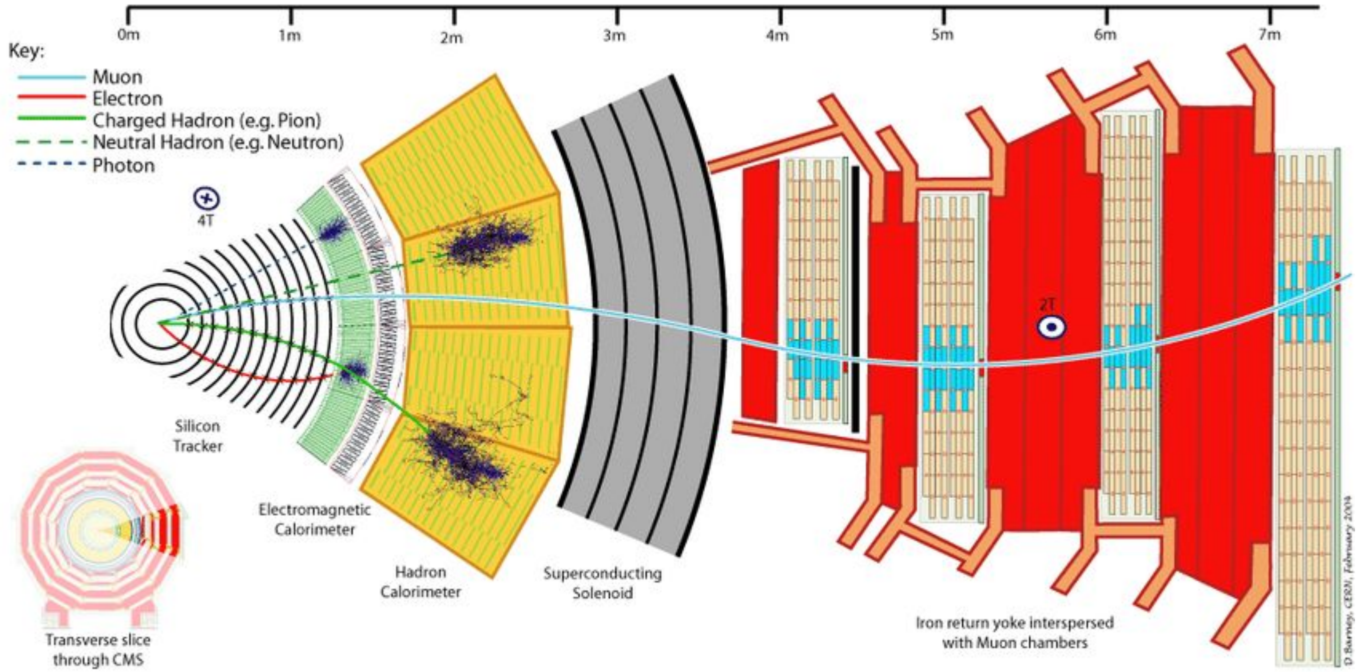
La incidencia de fotones sobre un material puede **liberar electrones**, siempre y cuando tengan la energía suficiente para arrancarlos.

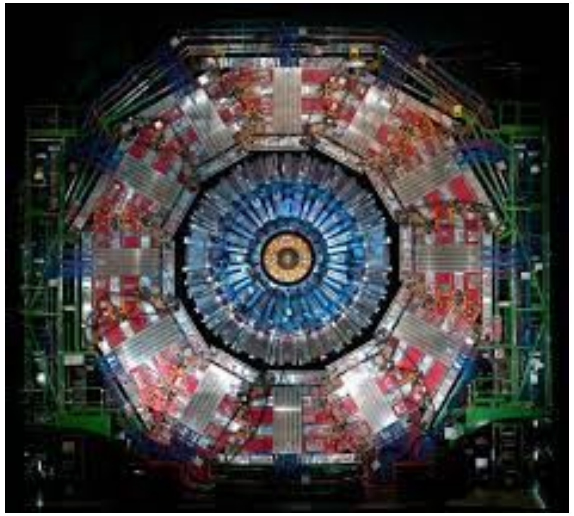
La energía de los electrones emitidos no depende de la intensidad de la radiación que le llega, sino de su **frecuencia**.

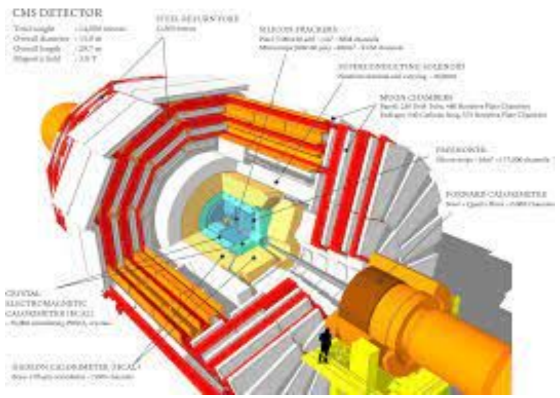


Calorímetros

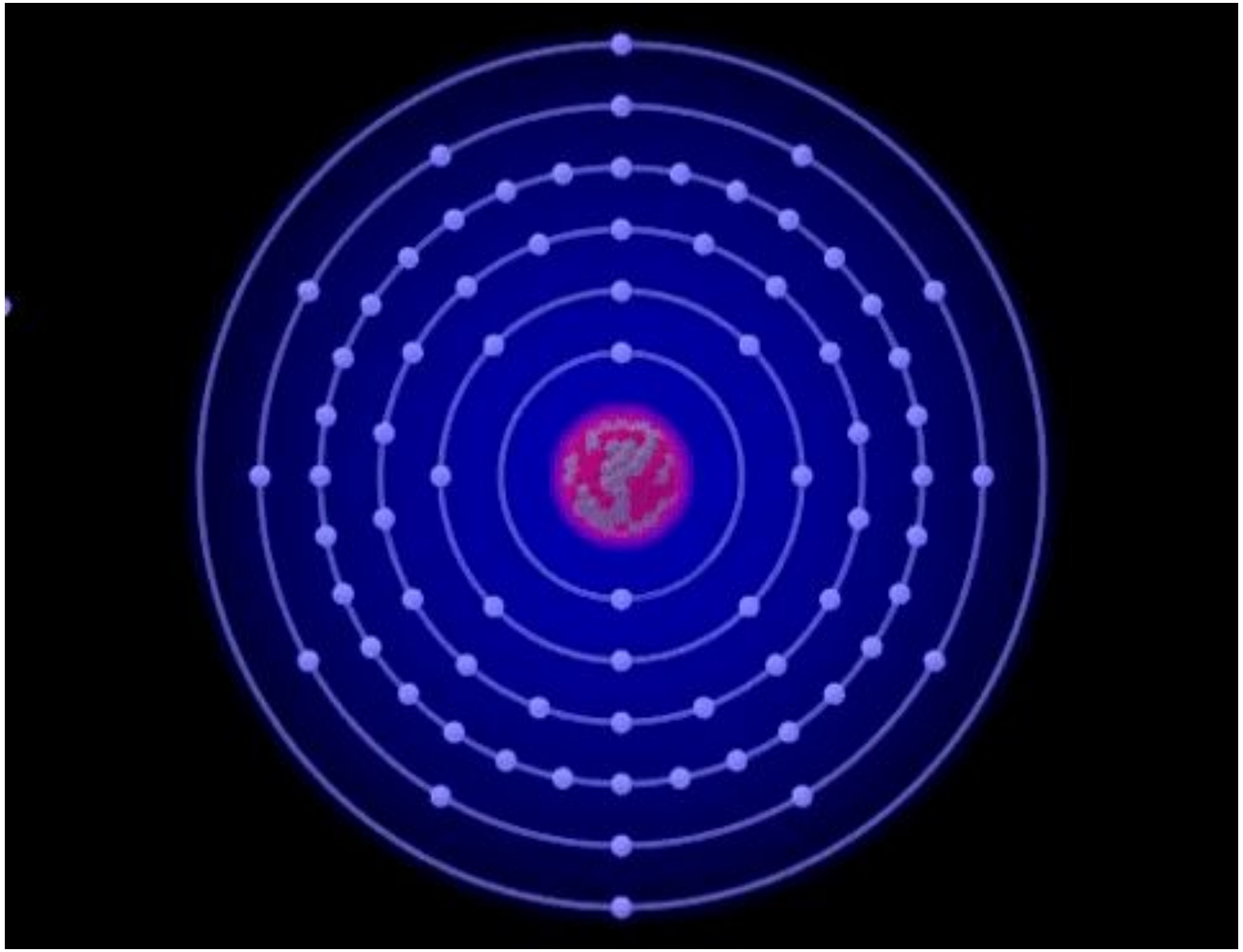
https://www.youtube.com/watch?v=pQhbhpU9Wrg&t=28s&ab_channel=CERN





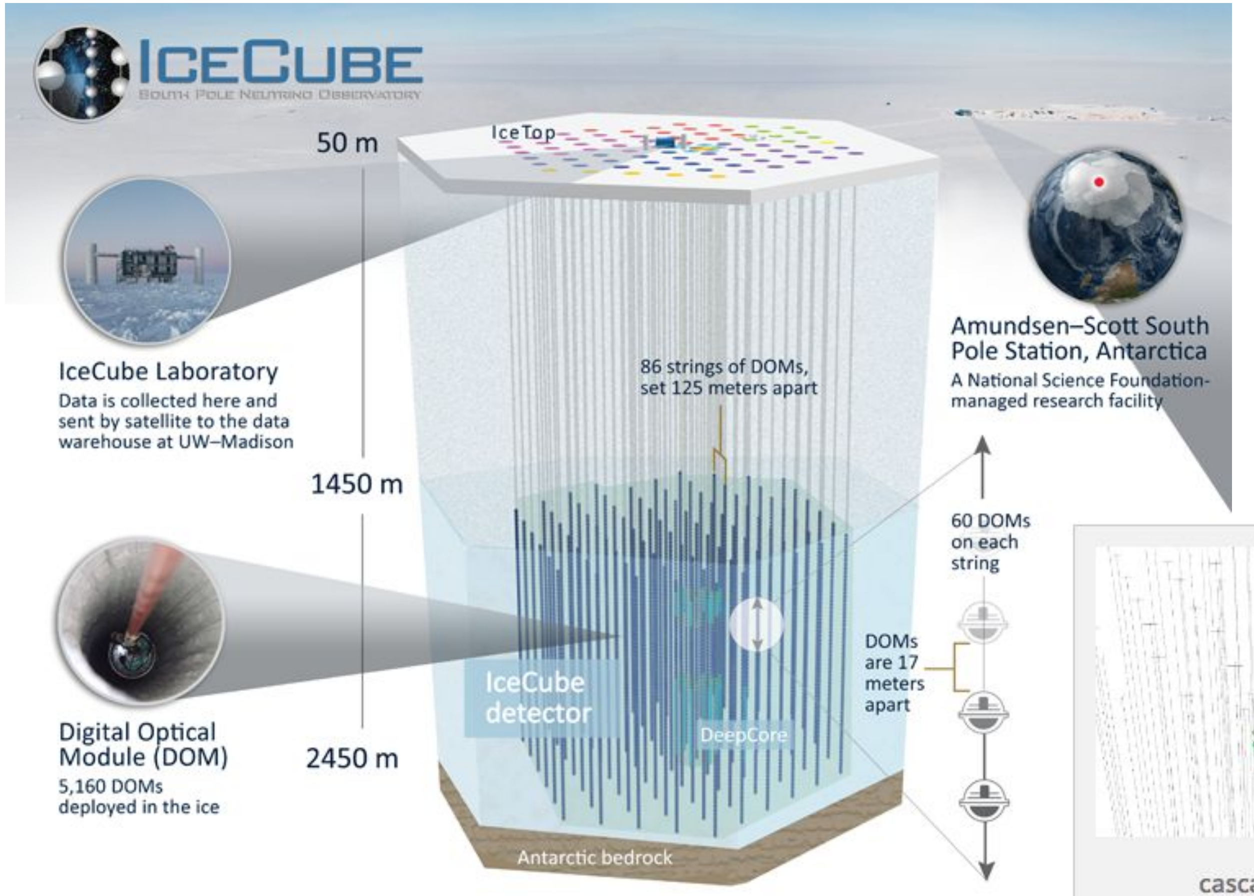


Bremsstrahlung (Radiación de frenado)



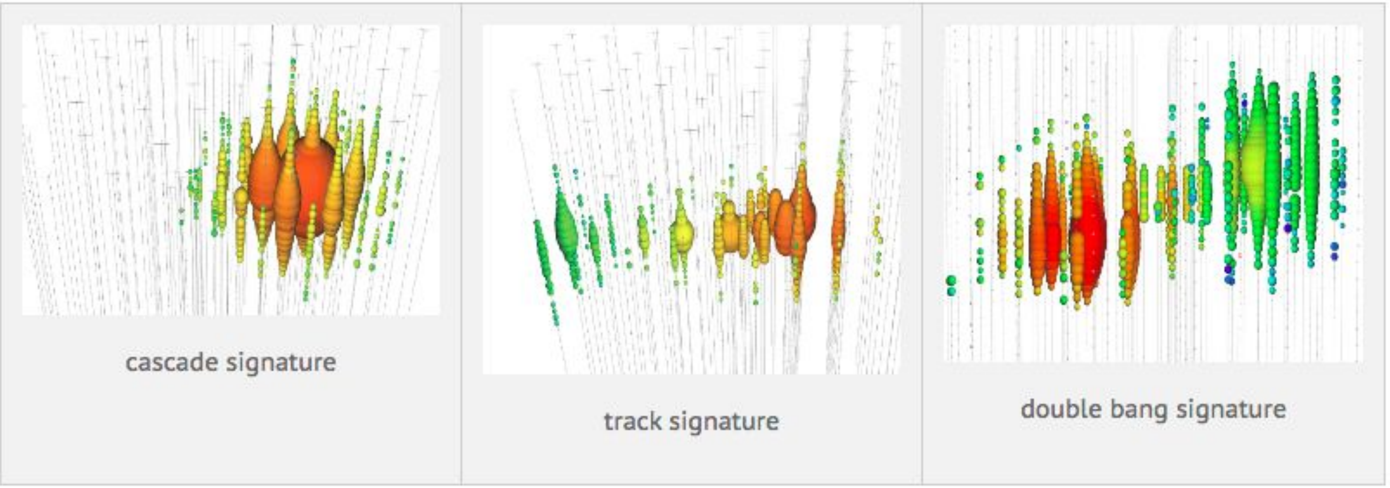
Radiación electromagnética producida por la **desaceleración** de una partícula cargada debido al campo eléctrico producido por otra partícula con carga

Detectores de radiación Cherenkov



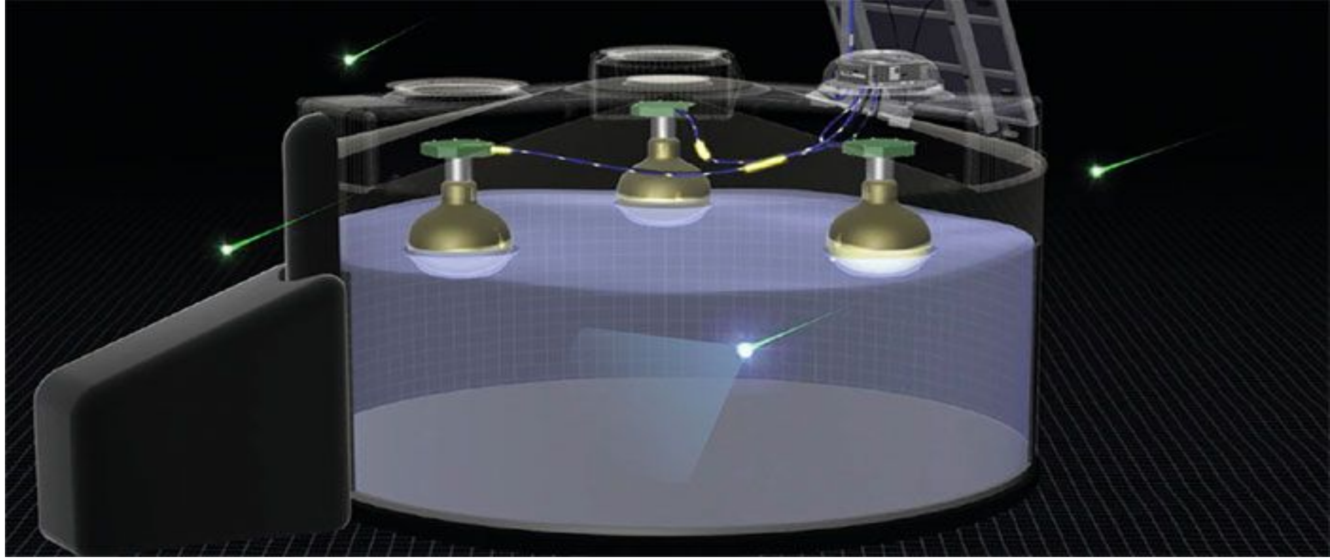
https://www.youtube.com/watch?v=rSwbL2coz_Y&ab_channel=IceCubeNeutrinoObservatory

https://www.youtube.com/watch?v=eybbrQVN3F4&ab_channel=IceCubeNeutrinoObservatory



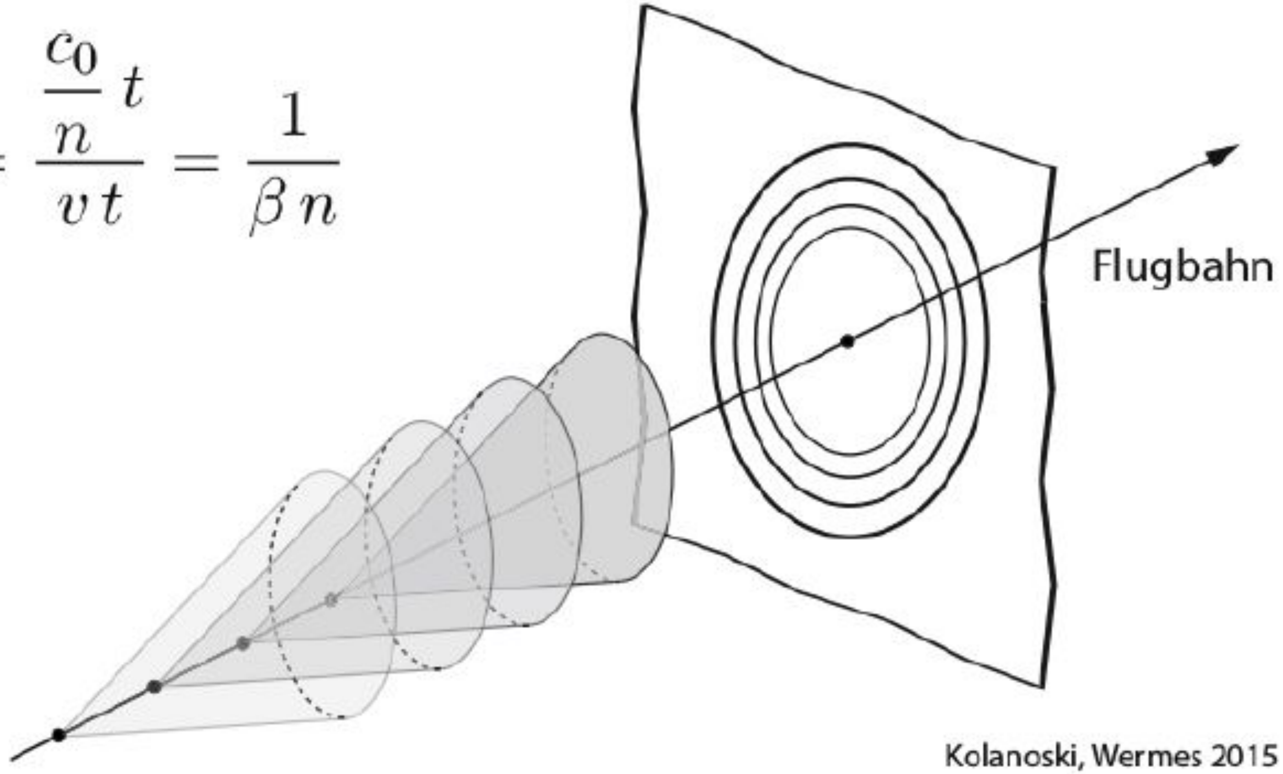
- El **patrón en cascada** (izquierda) es un patrón típico de un **neutrino electrónico.**
- Cuando un **neutrino muónico** interactúa en IceCube crea un muón como partícula secundaria, que cruza todo el detector dejando **una traza** de luz (centro).
- El **patrón de doble explosión** (derecha) es producido por un neutrino tauónico, que interactúa con el hielo creando una cascada hadrónica (la primera cascada de color rojizo) y un tau, el cual decae casi inmediatamente creando una segunda cascada de partículas de color verdoso.

Radiación de Cherenkov



Ángulo de emisión Cherenkov

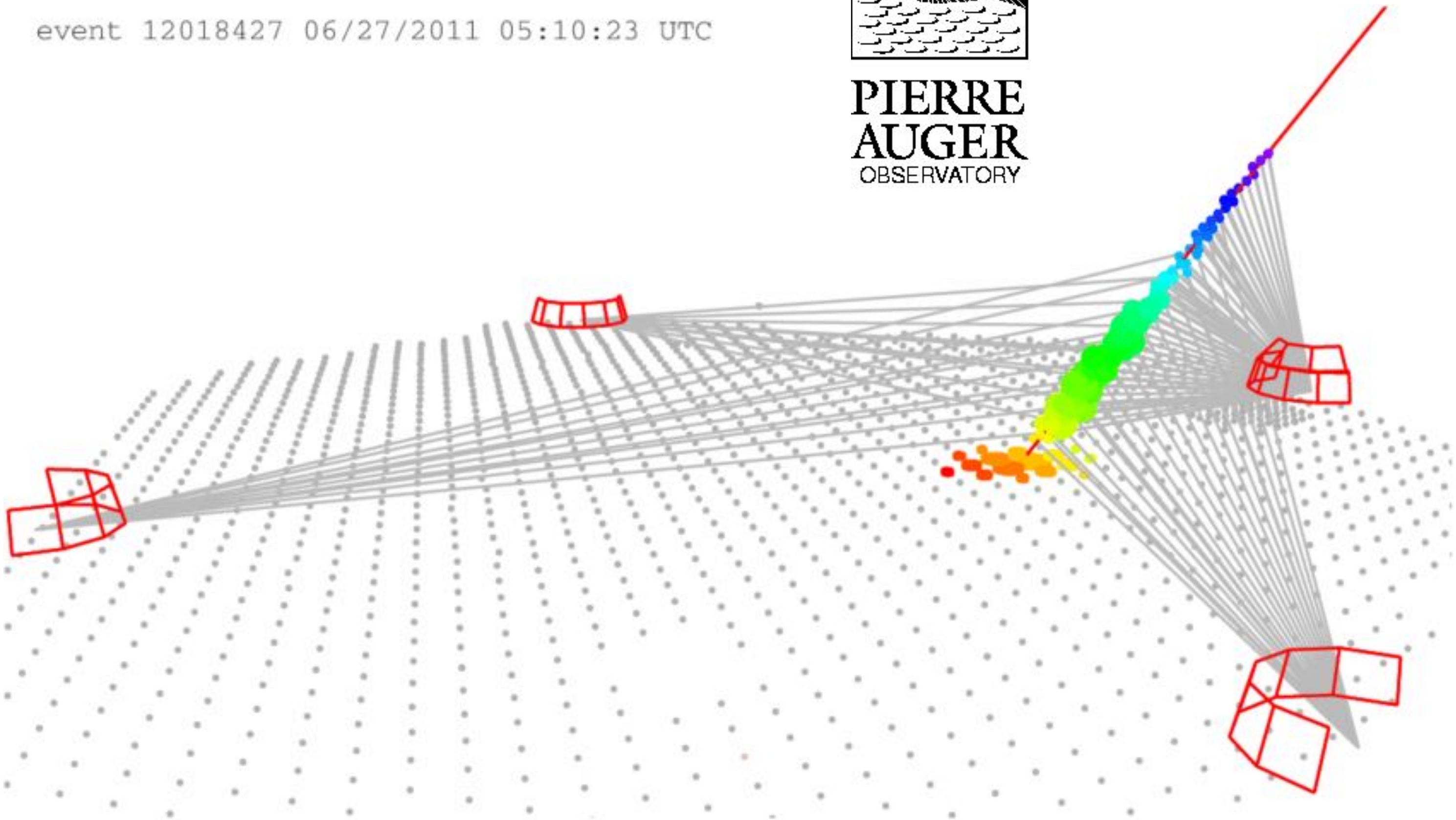
$$\cos\theta_c = \frac{\frac{c_0}{n}t}{v\,t} = \frac{1}{\beta\,n}$$

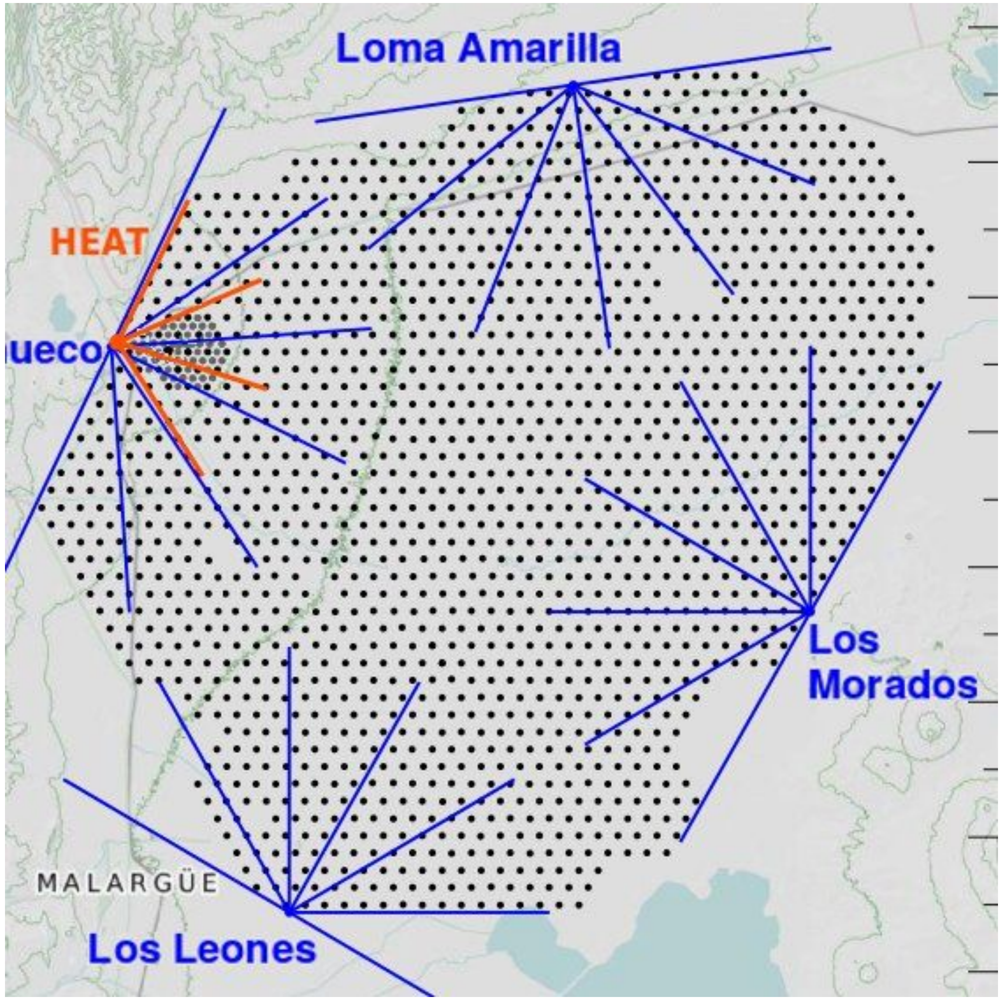


Kolanoski, Wermes 2015

Ocurre cuando una partícula cargada viaja con una **velocidad mayor a la de la luz** en un medio dieléctrico.

PIERRE AUGER OBSERVATORY





https://www.youtube.com/watch?v=cBgUHPyvjhU&ab_channel=UniverzavNoviGorici%2FUniversityofNovaGorica

https://www.youtube.com/watch?v=1ZORGubbOes&ab_channel=CONICETDialoga

GEANT4

GEANT4

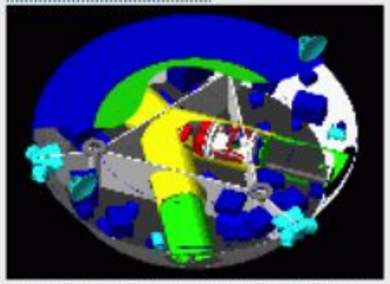
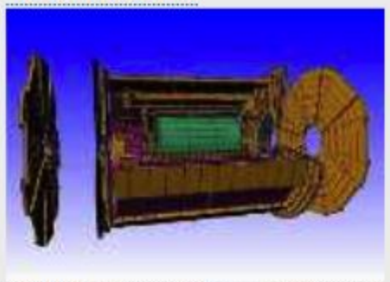
A SIMULATION TOOLKIT

Geant4

https://geant4.web.cern.ch/node/1

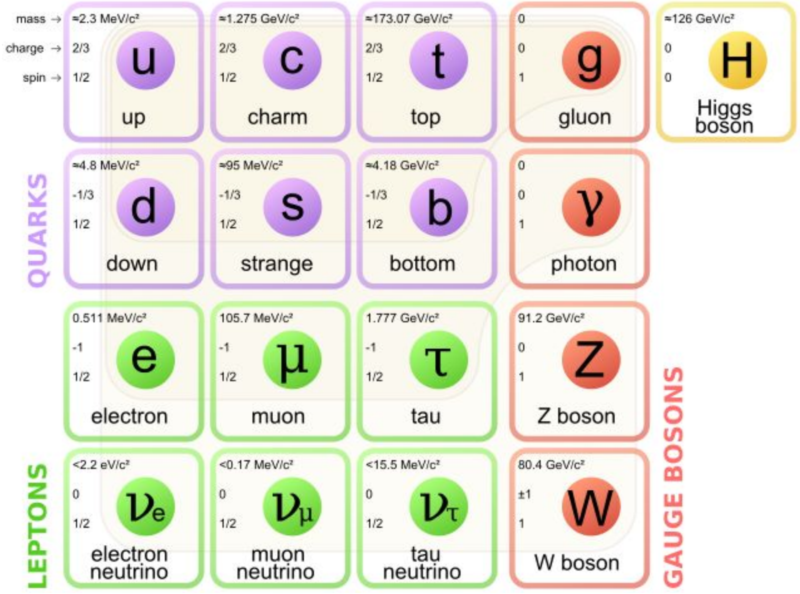
Overview

Geant4 is a toolkit for the simulation of the passage of particles through matter. Its areas of application include high energy, nuclear and accelerator physics, as well as studies in medical and space science. The three main reference papers for Geant4 are published in Nuclear Instruments and Methods in Physics Research A 506 (2003) 250-303 , IEEE Transactions on Nuclear Science 53 No. 1 (2006) 270-278 and Nuclear Instruments and Methods in Physics Research A 835 (2016) 186-225 .

Applications	User Support	Publications	Collaboration
			
A sampling of applications, technology transfer and other uses of Geant4	Getting started, guides and information for users and developers	Validation of Geant4, results from experiments and publications	Who we are: collaborating institutions, members, organization and legal information

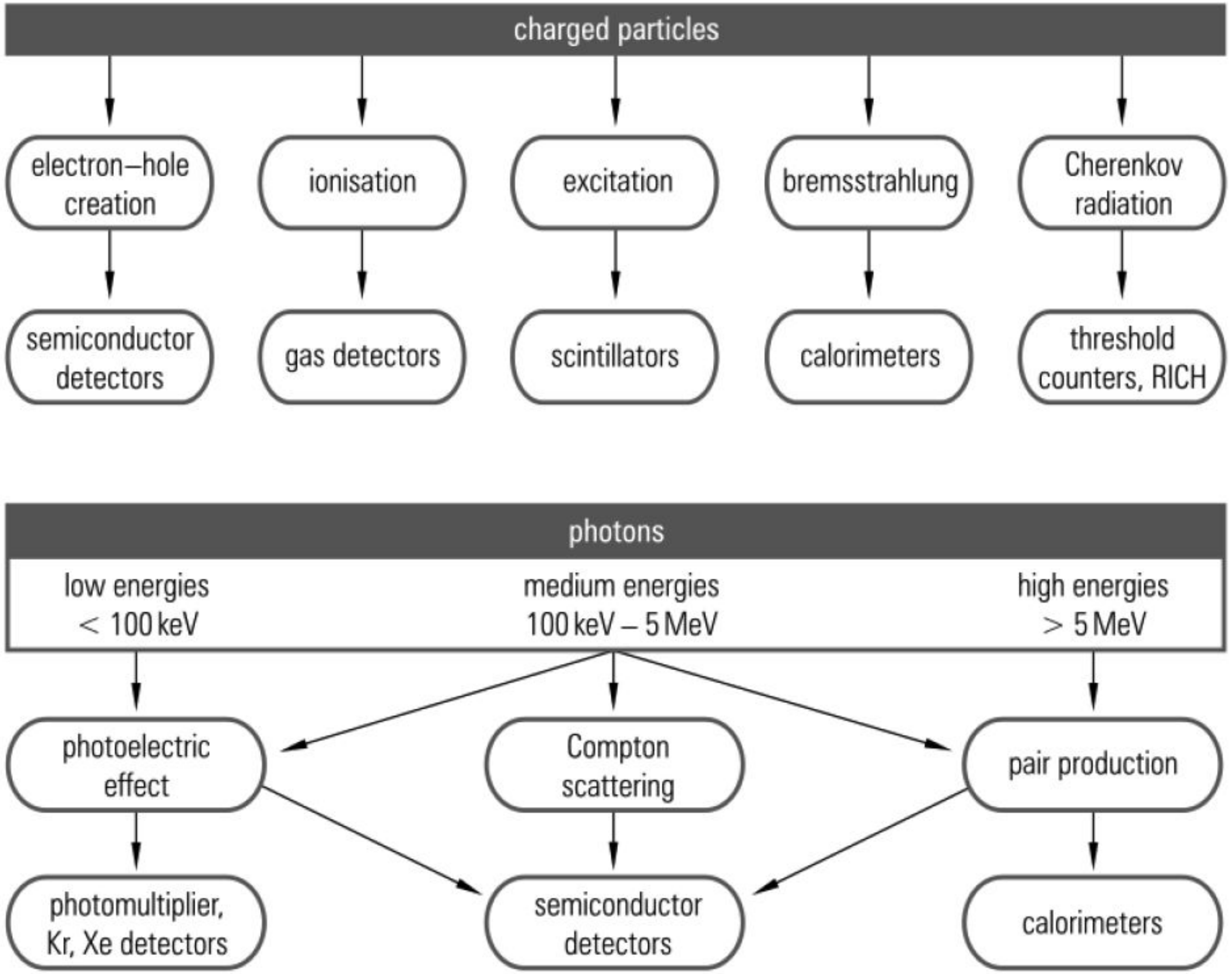
¿Cómo detectamos partículas?

Modelo estándar
de partículas

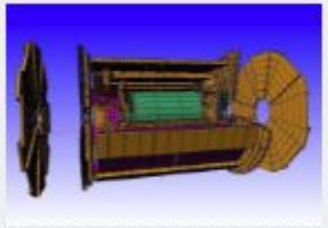
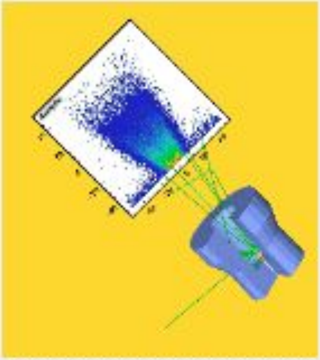
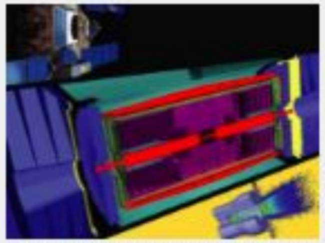


Fenómeno

Detector



Aplicaciones

High Energy Physics	Space and Radiation	Medical	Technology Transfer
			

https://geant4.web.cern.ch/applications

Medical Applications

G4DNA
Geant4-DNA project

G4MED (in Japanese)
Geant4 Medical Physics in Japan

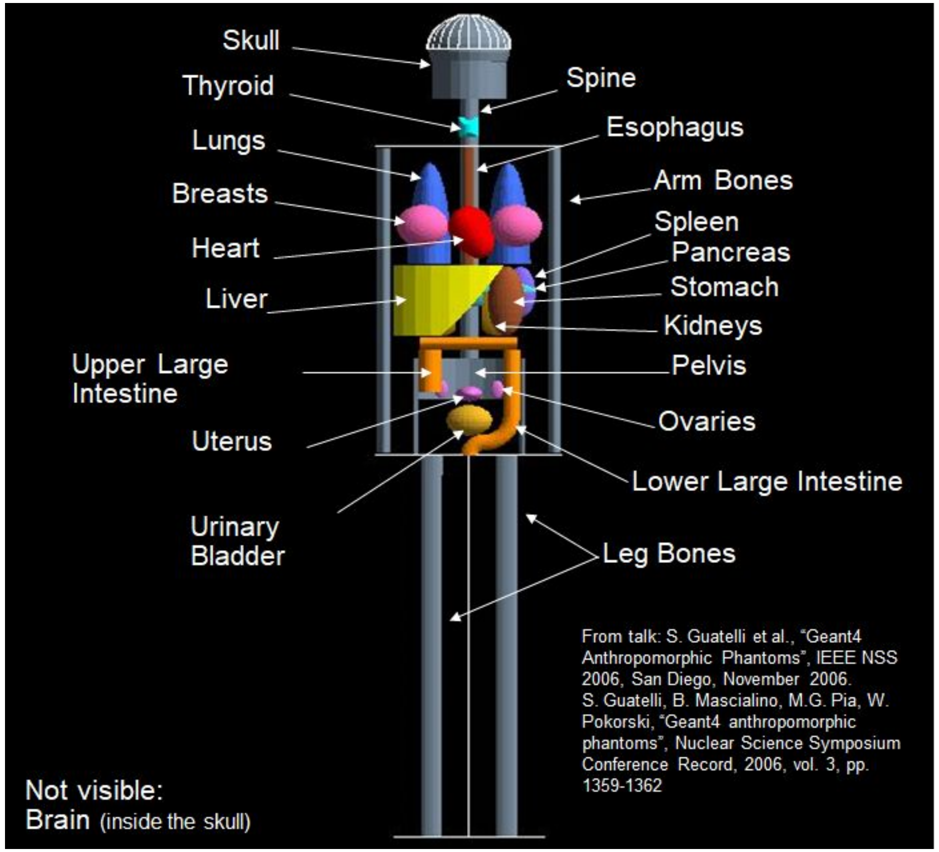
G4NAMU
Geant4 North American Medical User Organization

GAMOS
Geant4-based Architecture for Medicine-Oriented Simulations

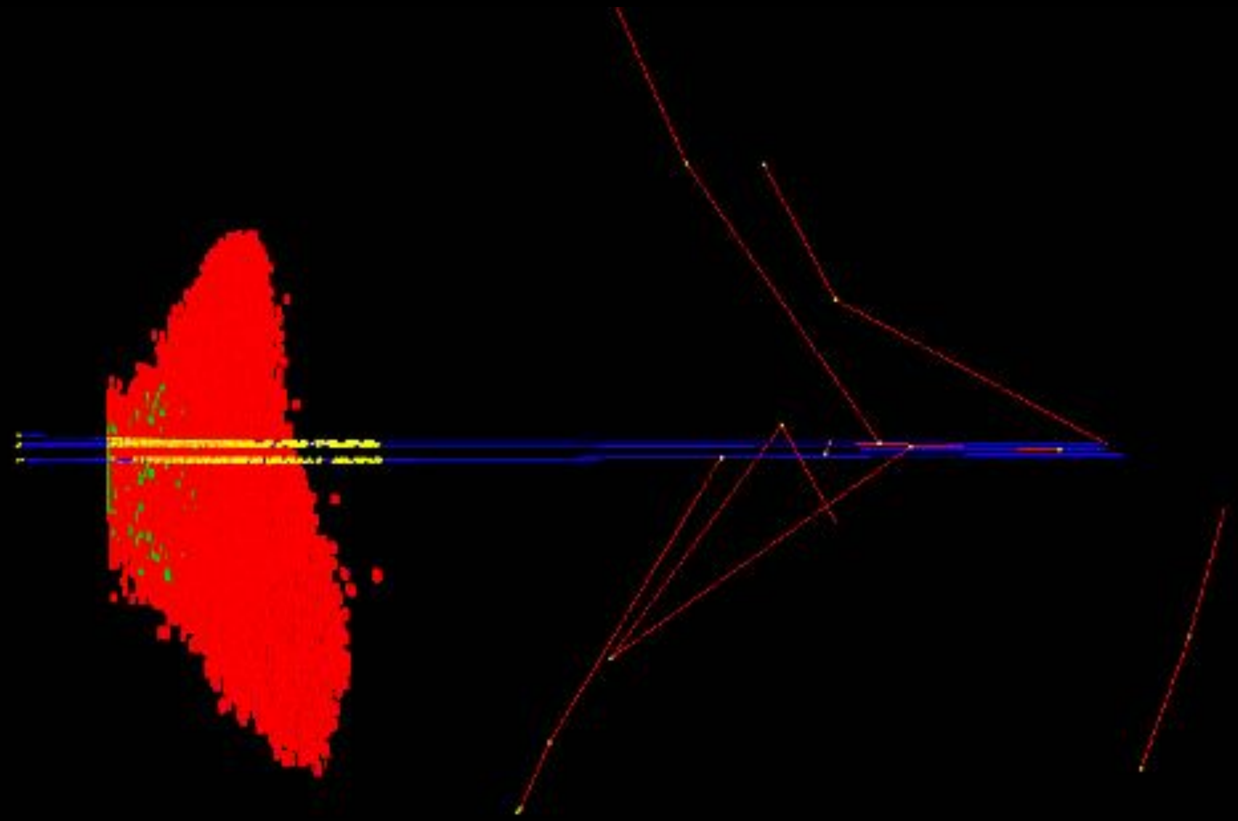
GATE
Geant4 Application for Tomographic Emission

TOPAS
Geant4 Monte Carlo Platform for Medical Applications

The **human_phantom** example model



https://geant4.web.cern.ch/applications/medical_applications



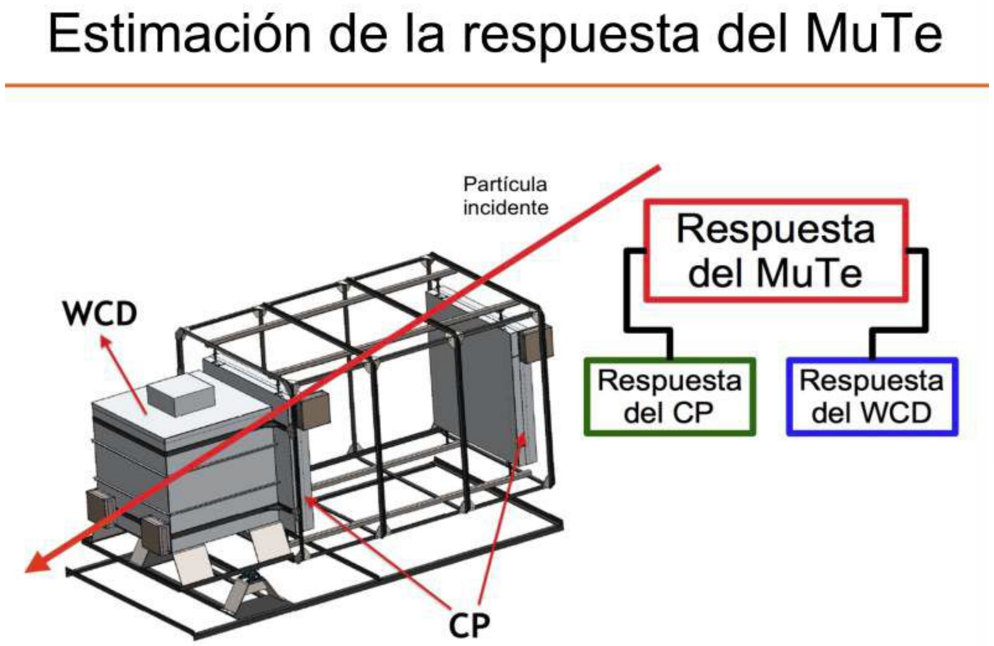
LP2iB-CENBG microbeam irradiation of a keratinocyte with alpha particles
from the « microbeam » Geant4 advanced example -
- movie courtesy of L. Garnier (CNRS) -

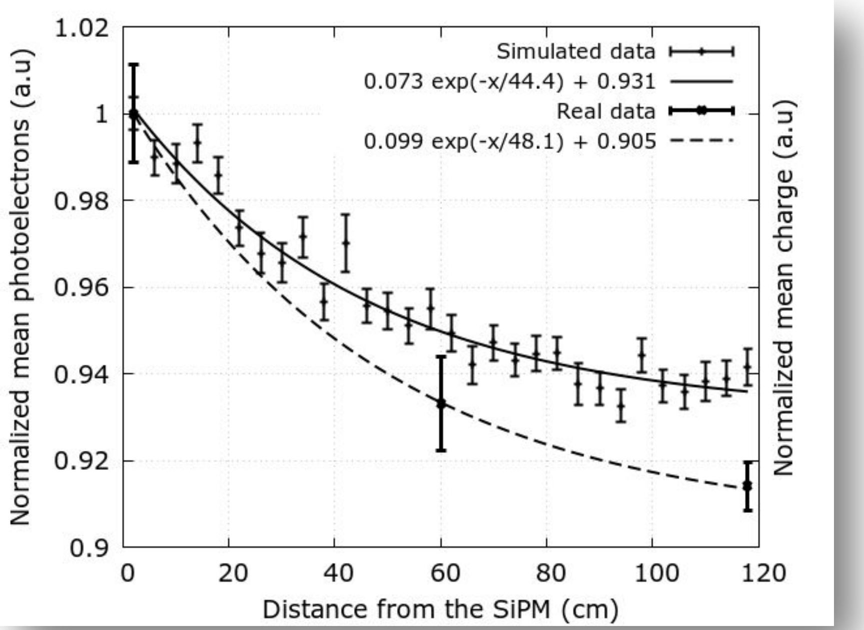
Mi experiencia:

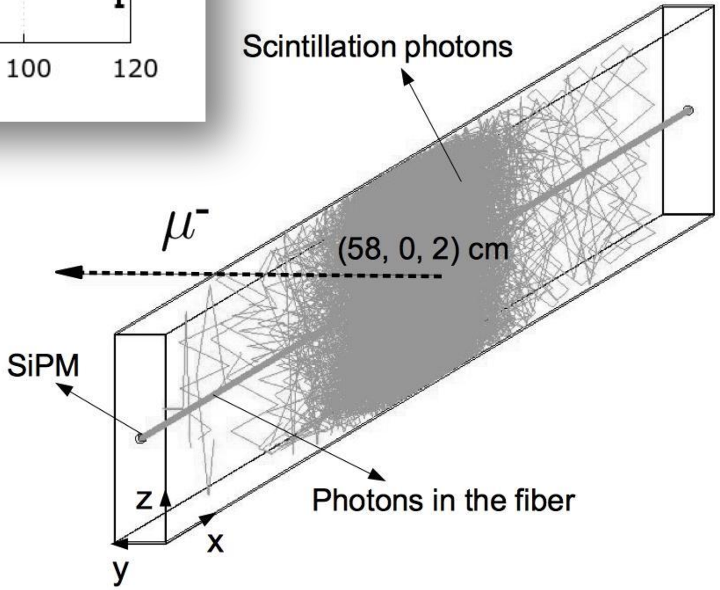
Simulación de los detectores
MuTe y LAGO

Simulación de minas antipersonas

Simulación del panel de centelleo del MuTe



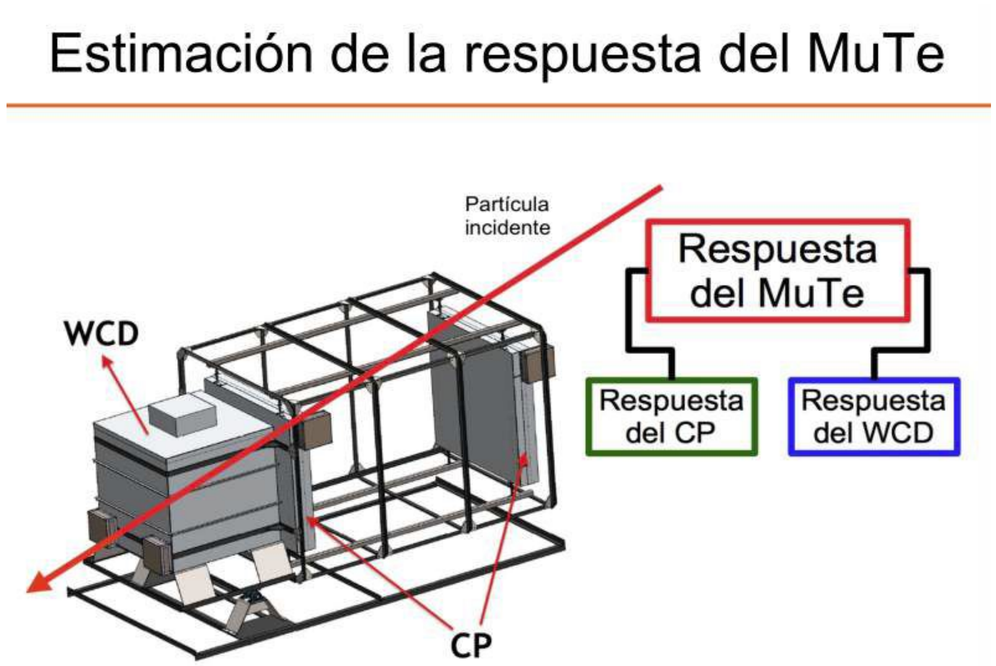


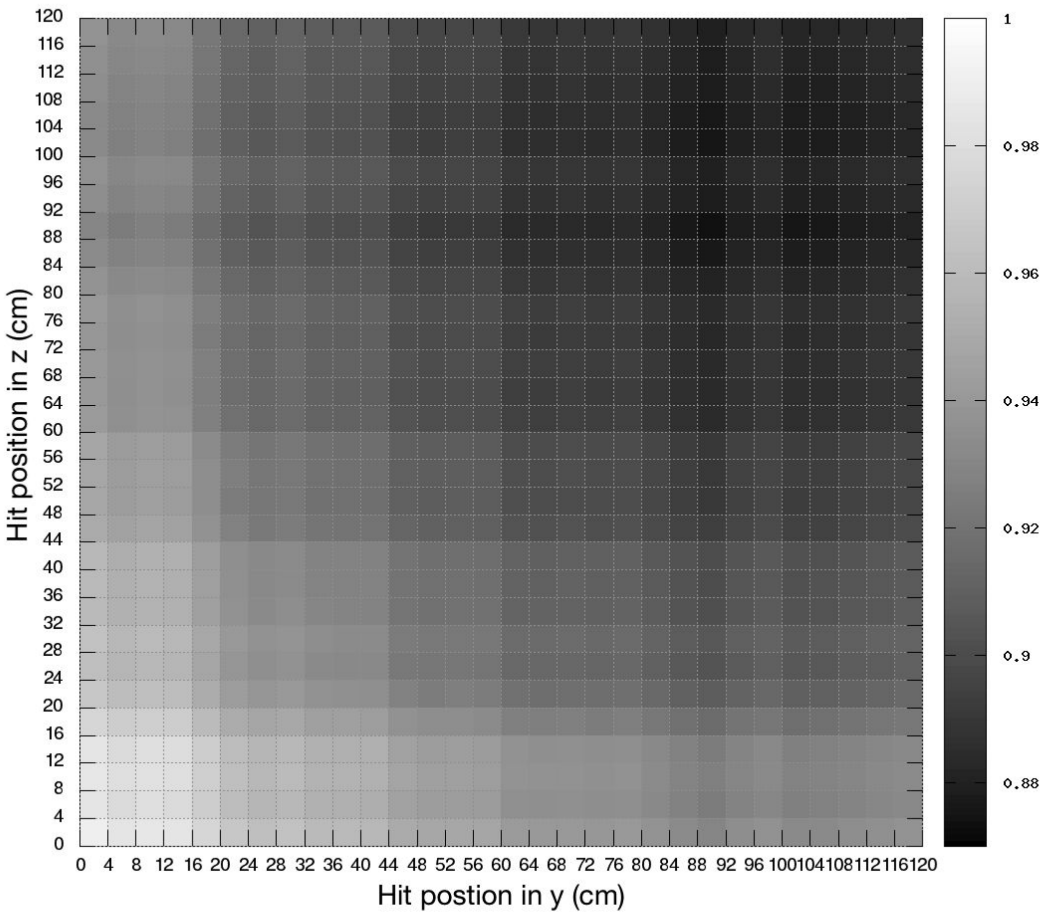


A. Vásquez-Ramírez *et al* 2020 *JINST* **15** P08004

https://iopscience.iop.org/article/10.1088/1748-0221/15/08/P08004/meta

Simulación del panel de centelleo del MuTe

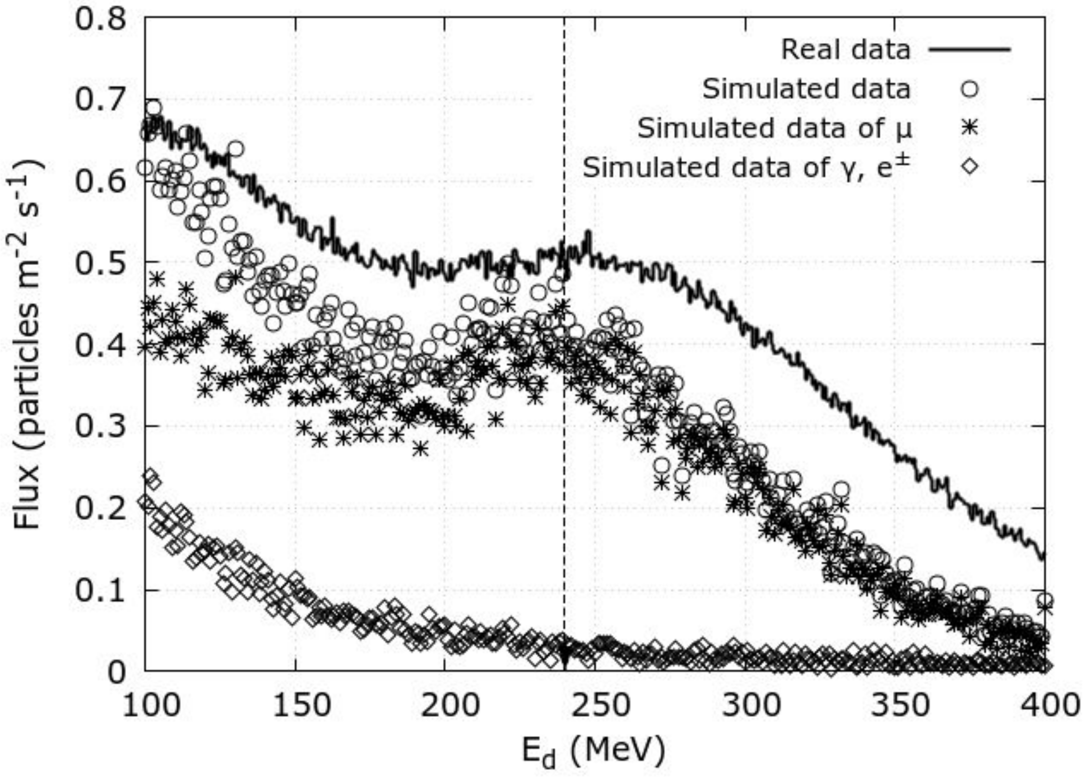


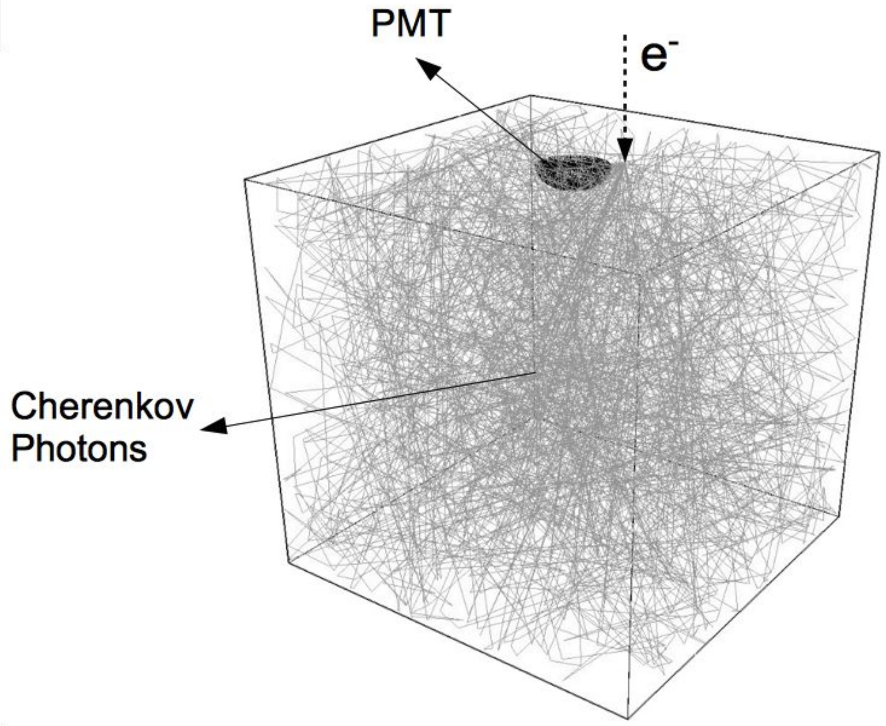


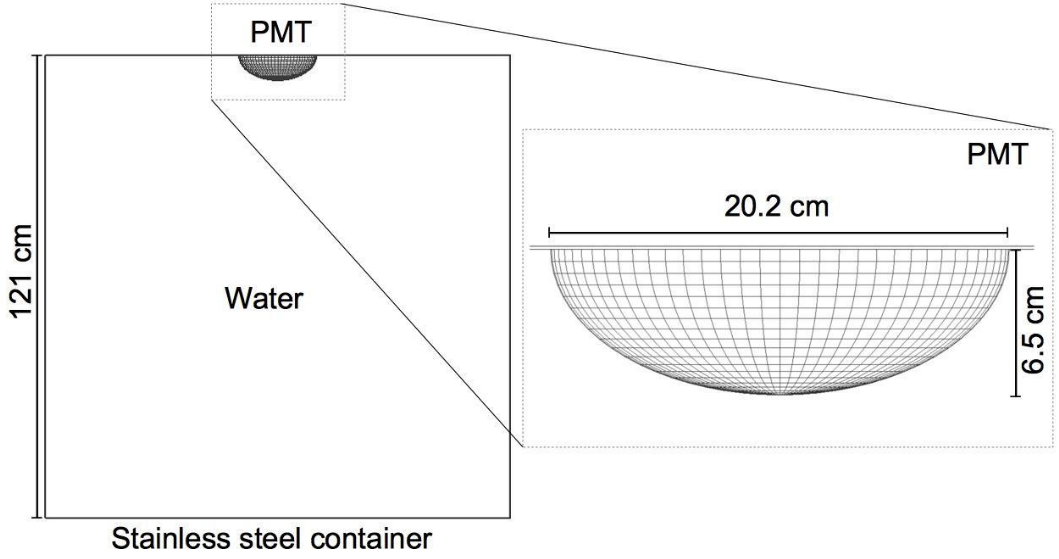
A. Vásquez-Ramírez *et al* 2020 *JINST* **15** P08004

https://iopscience.iop.org/article/10.1088/1748-0221/15/08/P08004/meta

Simulación del WCD de MuTe



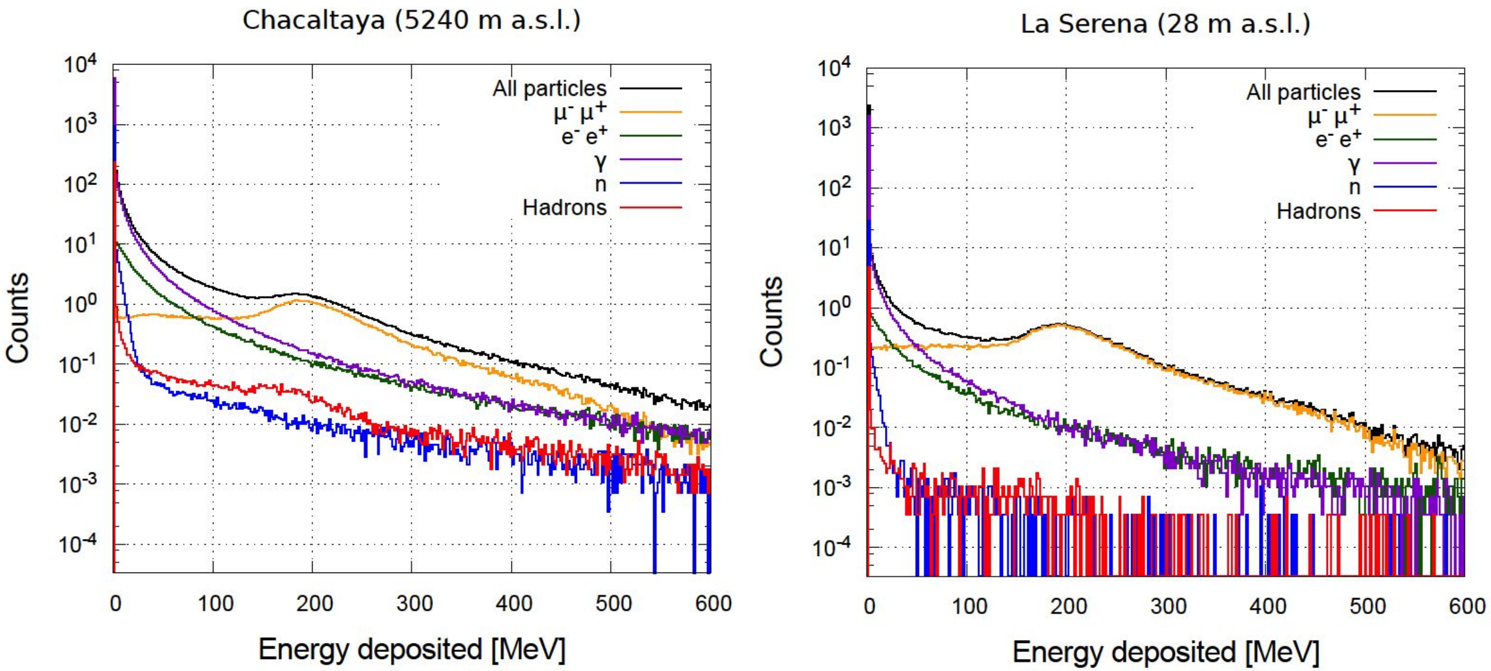




A. Vásquez-Ramírez *et al* 2020 *JINST* **15** P08004

https://iopscience.iop.org/article/10.1088/1748-0221/15/08/P08004/meta

Simulación de WCDs en varias ubicaciones del Latin American Giant Observatory (LAGO)



C. Sarmiento-Cano *et al* 2019 *PoS ICRC2019 412*

https://pos.sissa.it/358/412/pdf

Improvised Explosive Devices and cosmic rays

A. Vásquez-Ramírez*, M. Ariza-Gómez, M. Carrillo-Moreno, V.G. Baldovino-Medrano, H. Asorey and L.A. Núñez
*presenter e-mail: adriana2168921@uis.edu.co

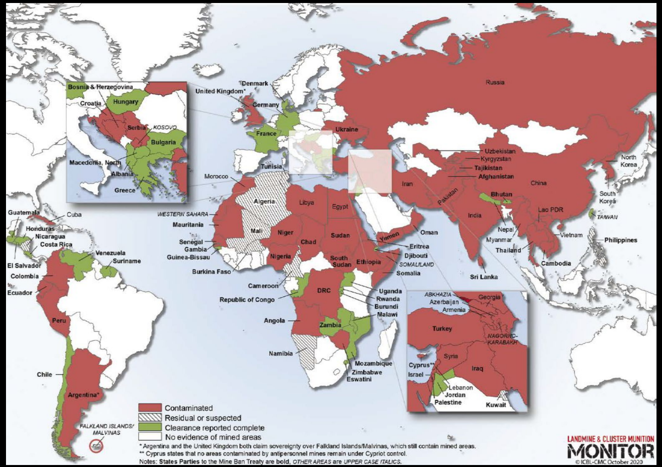
ONLINE ICRC 2021 THE ASTROPARTICLE PHYSICS CONFERENCE Berlin | Germany 37th International Cosmic Ray Conference 12–23 July 2021

COMPLEJO ASTRONÓMICO UIS Grupo Halley

Universidad Industrial de Santander

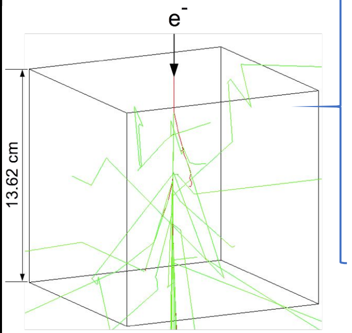
About **60 countries** and territories are still contaminated with Improvised Explosive Devices (IEDs)

Monitor, L. et al., *Concord* (2020)



It is possible to use cosmic radiation for the detection of IEDs?

Simulation: interaction between an IED and cosmic radiation

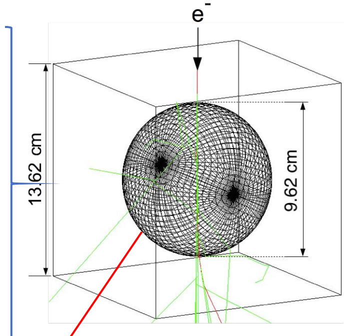


a) Dry soil model

1 Dry soil model
Juárez, M. et al., *U. de Alicante* (2006)

2 Humid soils models
90 wt.% Dry soil + 10 wt.% water
70 wt.% Dry soil + 30 wt.% water

2 Fertilized soil models
Dry soil + ammonium nitrate (1 ppm and 2 ppm)



b) Dry soil + IED

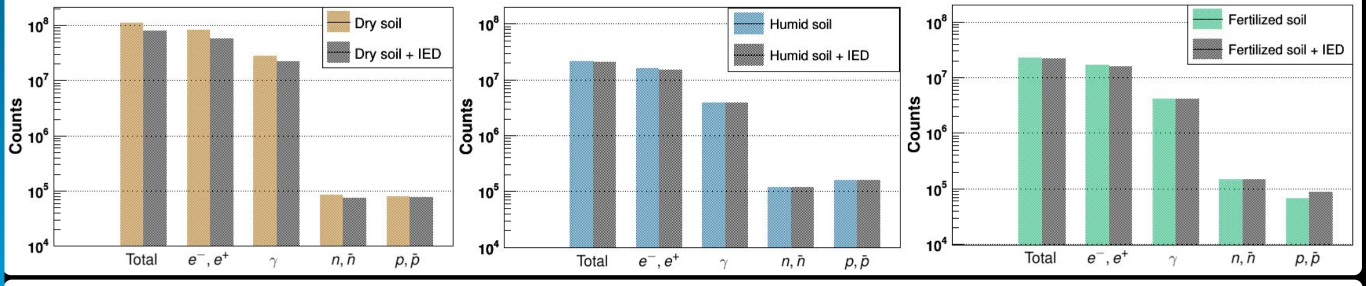
ANFO = 94.3% Ammonium nitrate + 5.7% Diesel oil No.2

A. contra minas, *Tech. Rep. Ejército Nacional* (2011)

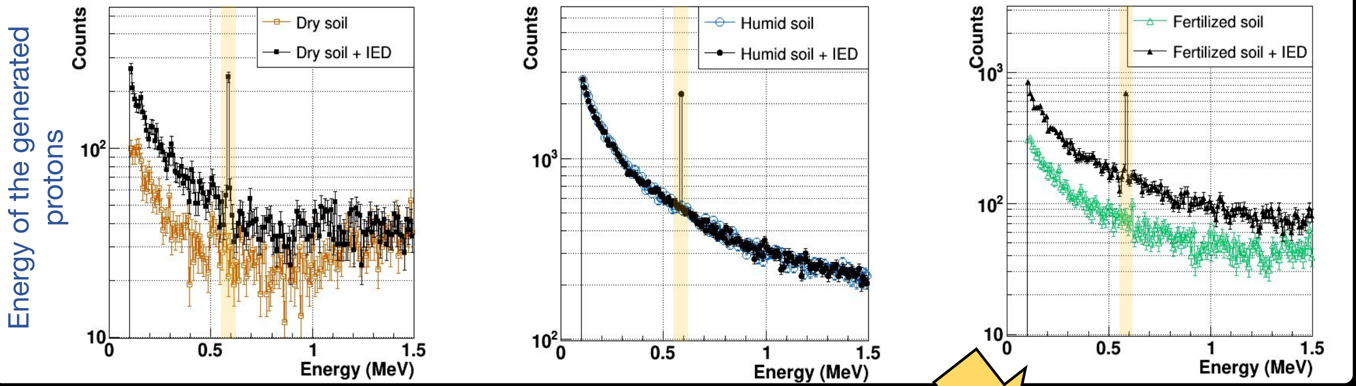
Using the LAGO-ARTI framework
(for WCDs simulation response)
Sarmiento-Cano, C. et al., *PoS ICRC2019* (2020).

Results

Particles generated from the interaction of soil models with the Bucaramanga secondary flux of 24 h



Energy of the generated protons



Conclusions

The interaction between the main chemical compounds of the most commonly IED found in Colombian soils with the background flux of cosmic rays at Bucaramanga level generates particles that can be detected, suggesting a possible IED detection criterion.

The number of protons with 0.58 MeV in mined soils is around 237% greater than protons in **dry soil** model, 2278% in **humid soil** (30wt.\%) and 688% for **fertilized soil** (2 ppm).

There is an excess of protons around 0.58 MeV in the presence of the IED

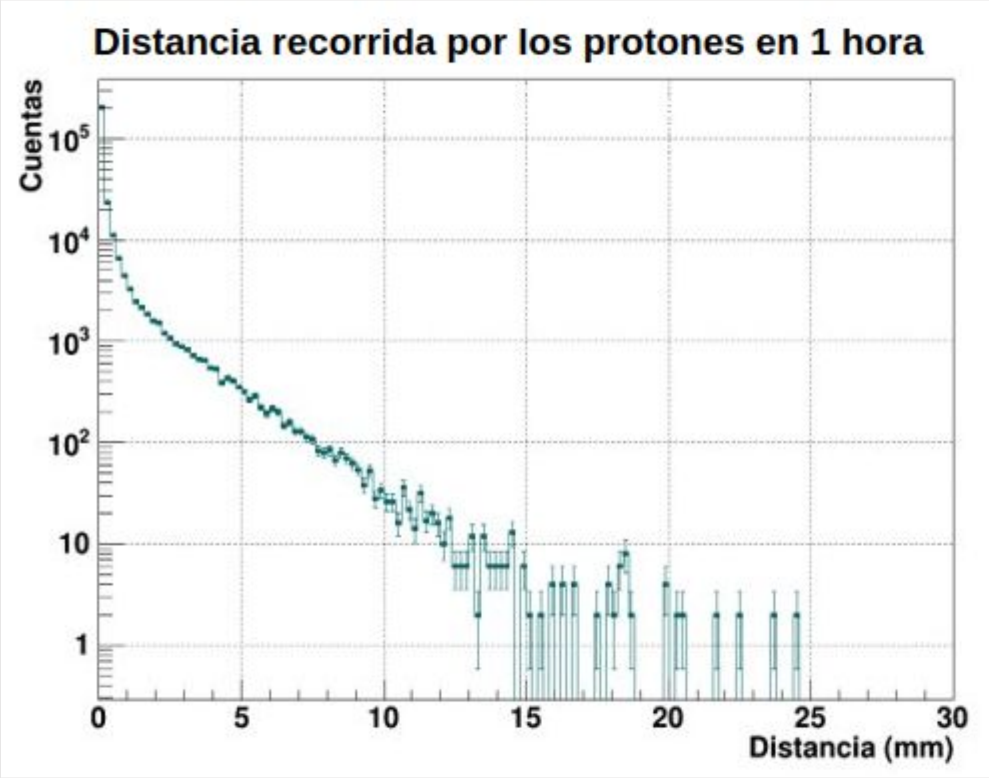
https://pos.sissa.it/395/480/pdf

Improvised Explosive Devices and cosmic rays

A. Vásquez-Ramírez*, M. Ariza-Gómez, M. Carrillo-Moreno, V.G. Baldovino-Medrano, H. Asorey and L.A. Núñez
*presenter e-mail: adriana2168921@uis.edu.co

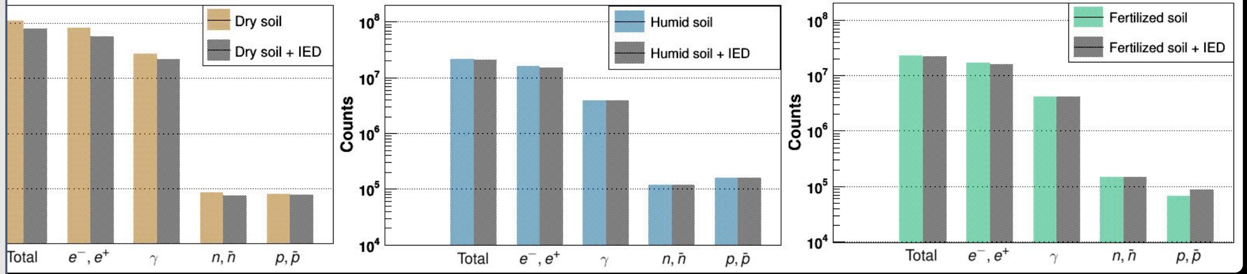
About
with In
Monitor, L. et

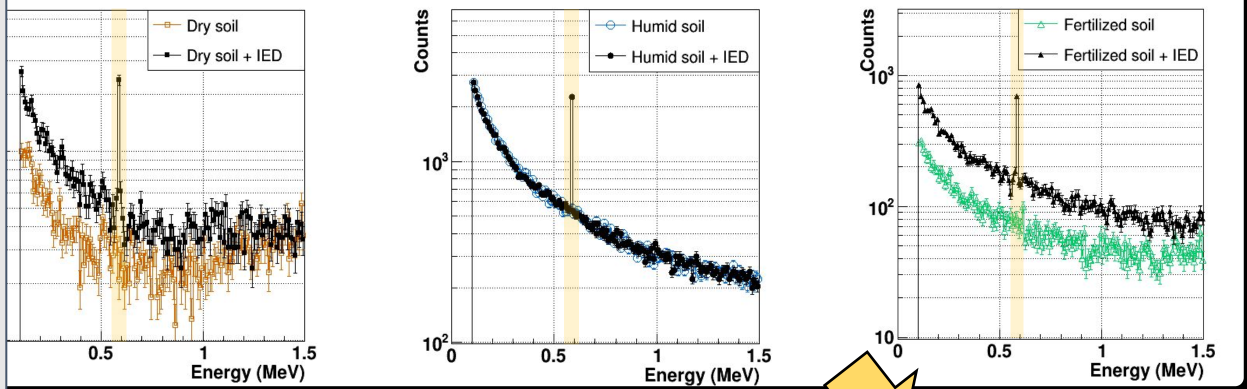
Sim

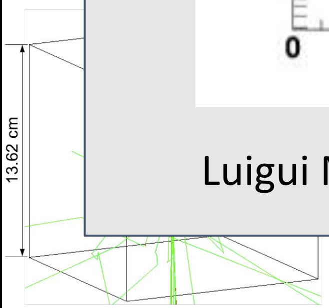


Luigui Miranda

es generated from the interaction of soil models with the Bucaramanga secondary flux of 24 h







a) Dry soil model

b) Dry soil + IED

Using the LAGO-ARTI framework
(for WCDs simulation response)
Sarmiento-Cano, C. et al., *PoS ICRC2019* (2020).

ANFO = 94.3% + 5.7%
Ammonium nitrate | Diesel oil No.2

A. contra minas, *Tech. Rep. Ejército Nacional* (2011)

ns

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https://pos.sissa.it/395/480/pdf

Pasos fundamentales para una simulación sencilla

Pasos fundamentales para una simulación sencilla

1. Definir la geometría del sistema físico
2. Definir los materiales
3. Definir los procesos y propiedades físicas
4. Escoger las condiciones iniciales
5. Extracción de datos

https://geant4-userdoc.web.cern.ch/UsersGuides/ForApplicationDeveloper/html/GettingStarted/gettingStarted.html

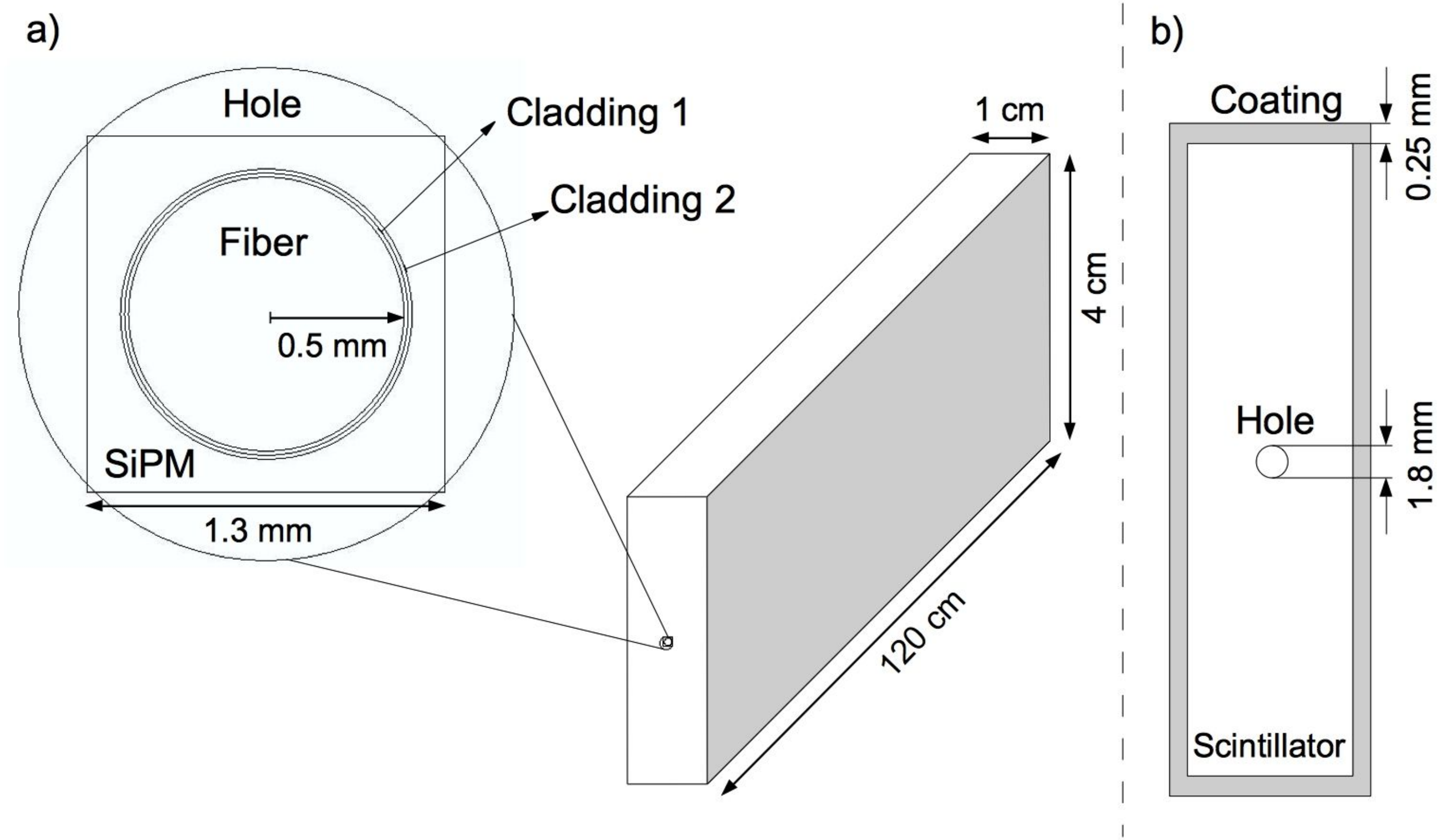
Getting Started with Geant4 - Running a Simple Example

- How to Define the main() Program
  - A Sample `main()` Method
  - `G4RunManager`
  - User Initialization and Action Classes
  - `G4UImanager` and UI CommandSubmission
  - `G4cout` and `G4cerr`
- How to Define a Detector Geometry
  - Basic Concepts
  - Create a Simple Volume
  - Choose a Solid
  - Create a Logical Volume
  - Place a Volume
  - Create a Physical Volume
  - Coordinate Systems and Rotations
- How to Specify Materials in the Detector
  - General Considerations
  - Define a Simple Material
  - Define a Molecule
  - Define a Mixture by Fractional Mass
  - Define a Material from the GEANT4 Material Database
  - Define a Material from the Base Material
- How to Specify Particles
  - Particle Definition
  - Range Cuts
- How to Specify Physics Processes
  - Physics Processes
  - Managing Processes
  - Specifying Physics Processes
- How to Generate a Primary Event
  - Generating Primary Events
  - G4VPrimaryGenerator
- GEANT4 General Particle Source
  - Introduction
  - Configuration
  - Macro Commands
  - Example Macro File
- How to Make an Executable Program
  - Using CMake to Build Applications
  - Use of `Geant4Config.cmake` with `find_package` in CMake
- How to Set Up an Interactive Session
  - Introduction
  - A Short Description of Available Interfaces
  - How to Select Interface in Your Applications

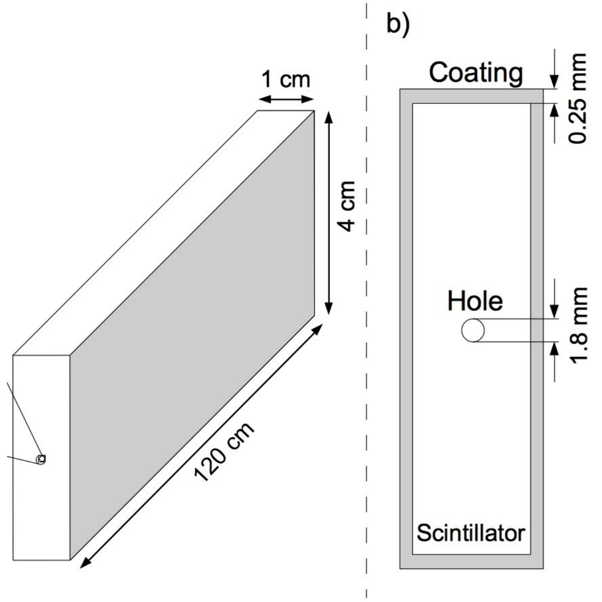
https://geant4-userdoc.web.cern.ch/UsersGuides/ForApplicationDeveloper/html/GettingStarted/gettingStarted.html

Vamos a simular un Detector de Centelleo

1. Definir la geometría del centellador



1. Definir la geometría del centellador




```
//-----------------
// World (air)
//-----------------
G4VSolid* solidWorld = new G4Box("World", fWorldSizeX, fWorldSizeY, fWorldSizeZ);

fLogicWorld = new G4LogicalVolume(solidWorld, Air, "World");

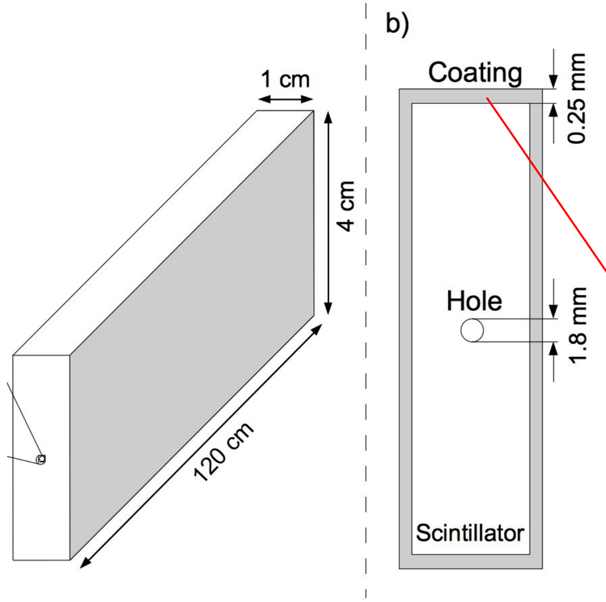
fPhysiWorld = new G4PVPlacement(0,G4ThreeVector(),fLogicWorld,"World",0,false,
                                0, checkOverlaps);
```

Dimensiones

Material

Ubicación

1. Definir la geometría del centellador




```
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// World (air)
//-----------------
G4VSolid* solidWorld = new G4Box("World", fWorldSizeX, fWorldSizeY, fWorldSizeZ);

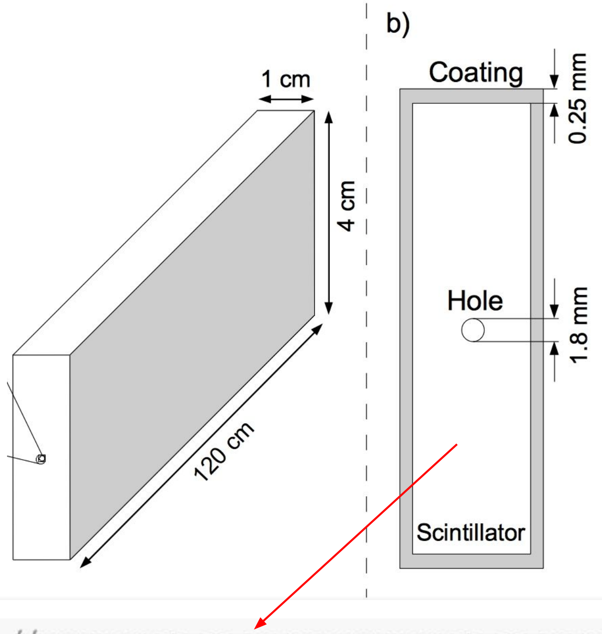
fLogicWorld = new G4LogicalVolume(solidWorld, Air, "World");

fPhysiWorld = new G4PVPlacement(0,G4ThreeVector(),fLogicWorld,"World",0,false,
                                0, checkOverlaps);
```

```
//--------------------
// Extrusion (TiO2)
//--------------------
G4VSolid* solidExtrusion =
      new G4Box("Extrusion",fBarBase,4*fBarBase,fBarLength);

G4LogicalVolume* logicExtrusion1 =
                    new G4LogicalVolume(solidExtrusion,
                                        Coating,
                                        "Extrusion1");
new G4PVPlacement(0,G4ThreeVector(0.*cm, 0.*cm, 0.*cm),logicExtrusion1,
                  "Extrusion1",fLogicWorld,false,0, checkOverlaps);
```

1. Definir la geometría del centellador




```
//-----------------
// World (air)
//-----------------
G4VSolid* solidWorld = new G4Box("World", fWorldSizeX, fWorldSizeY, fWorldSizeZ);

fLogicWorld = new G4LogicalVolume(solidWorld, Air, "World");

fPhysiWorld = new G4PVPlacement(0,G4ThreeVector(),fLogicWorld,"World",0,false,
                                0, checkOverlaps);
```

```
//--------------------
// Extrusion (TiO2)
//--------------------
G4VSolid* solidExtrusion =
      new G4Box("Extrusion",fBarBase,4*fBarBase,fBarLength);

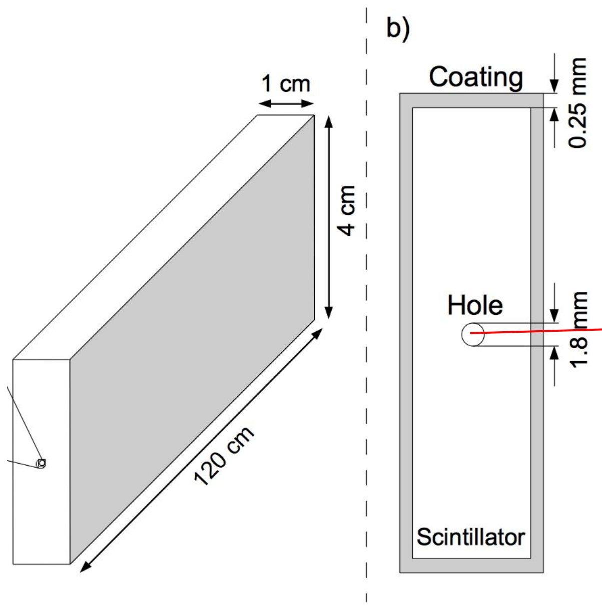
G4LogicalVolume* logicExtrusion1 =
                    new G4LogicalVolume(solidExtrusion,
                                        Coating,
                                        "Extrusion1");
new G4PVPlacement(0,G4ThreeVector(0.*cm, 0.*cm, 0.*cm),logicExtrusion1,
                                        rld,false,0, checkOverlaps);
```

```
//---------------------------------------------------
// Scintillator (Polystyrene)
//---------------------------------------------------
G4VSolid* solidScintillator = new G4Box("Scintillator",
                              fBarBase-fCoatingThickness,
                              4*fBarBase-fCoatingThickness,
                              fHoleLength);

G4LogicalVolume* logicScintillator1 =
                          new G4LogicalVolume(solidScintillator,
                                              Polystyrene,
                                               "Scintillator1");

 new G4PVPlacement(0, G4ThreeVector(),  logicScintillator1,"Scintillator1",
                 logicExtrusion1,false,0, checkOverlaps);
```

1. Definir la geometría del centellador




```
//-----------------
// World (air)
//-----------------
G4VSolid* solidWorld = new G4Box("World", fWorldSizeX, fWorldSizeY, fWorldSizeZ);

fLogicWorld = new G4LogicalVolume(solidWorld, Air, "World");

fPhysiWorld = new G4PVPlacement(0,G4ThreeVector(),fLogicWorld,"World",0,false,
                                0, checkOverlaps);
```

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//--------------------
// Extrusion (TiO2)
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G4VSolid* solidExtrusion =
      new G4Box("Extrusion",fBarBase,4*fBarBase,fBarLength);

G4LogicalVolume* logicExtrusion1 =
                     new G4LogicalVolume(solidExtrusion,
                                         Coating,
                                         "Extrusion1");
new G4PVPlacement(0,G4ThreeVector(0.*cm, 0.*cm, 0.*cm),logicExtrusi
                 "Extrusion1",fLogicWorld,false,0, checkOverlaps);
```

```
//----------------------------------
// Hole (air)
//----------------------------------
     G4VSolid* solidHole = new G4Tubs("Hole",
                                      0.0*cm,
                                      fHoleRadius,
                                      fHoleLength,
                                      0.*deg,
                                      360.*deg);

     fLogicHole1 = new G4LogicalVolume(solidHole, Air,
                                      "Hole1");

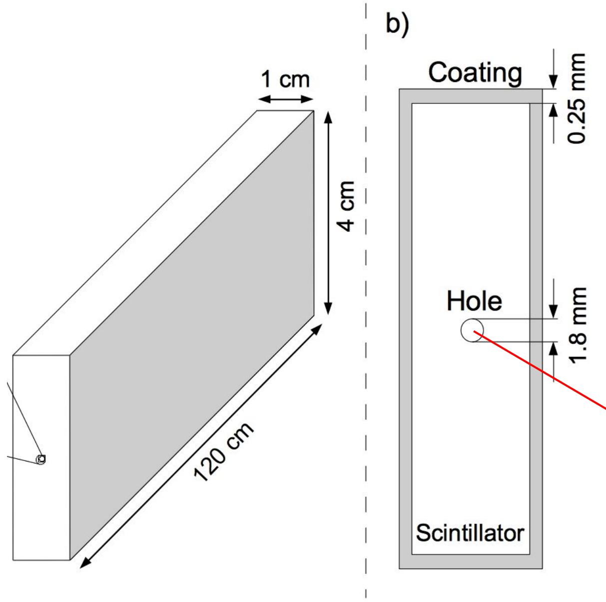
     fPhysiHole1 = new G4PVPlacement(0,
                                    G4ThreeVector(0.0,0.0,0.0),
                                    fLogicHole1,
                                    "Hole1",
                                    logicScintillator1,
                                    false,
                                    0, checkOverlaps);
```

```
//--------------------------------------------------
// Scintillator (Polystyrene)
//--------------------------------------------------
G4VSolid* solidScintillator = new G4Box("Scintillator",
                              fBarBase-fCoatingThickness,
                              4*fBarBase-fCoatingThickness,
                              fHoleLength);

G4LogicalVolume* logicScintillator1 =
                     new G4LogicalVolume(solidScintillator,
                                         Polystyrene,
                                          "Scintillator1");

 new G4PVPlacement(0, G4ThreeVector(),  logicScintillator1,"Scintillator1",
                  logicExtrusion1,false,0, checkOverlaps);
```

1. Definir la geometría del centellador




```
//-----------------
// World (air)
//-----------------
G4VSolid* solidWorld = new G4Box("World", fWorldSizeX, fWorldSizeY, fWorldSizeZ);

fLogicWorld = new G4LogicalVolume(solidWorld, Air, "World");

fPhysiWorld = new G4PVPlacement(0,G4ThreeVector(),fLogicWorld,"World",0,false,
                                0, checkOverlaps);
```

```
//--------------------
// Extrusion (TiO2)
//--------------------
G4VSolid* solidExtrusion =
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G4LogicalVolume* logicExtrusion1 =
                     new G4LogicalVolume(solidExtrusion,
                                         Coating,
                                         "Extrusion1");
new G4PVPlacement(0,G4ThreeVector(0.*cm, 0.*cm, 0.*cm),logicExtrusion1,
                  "Extrusion1",fLogicWorld,false,0, checkOverlaps);
```

```
//--------------------------------------
// Hole (air)
//--------------------------------------
      G4VSolid* solidHole = new G4Tubs("Hole",
                                       0.0*cm,
                                       fHoleRadius,
                                       fHoleLength,
                                       0.*deg,
                                       360.*deg);

      fLogicHole1 = new G4LogicalVolume(solidHole, Air,
                                        "Hole1");


      fPhysiHole1 = new G4PVPlacement(0,
                                      G4ThreeVector(0.0,0.0,0.0),
                                      fLogicHole1,
                                      "Hole1",
                                      logicScintillator1,
                                      false,
                                      0, checkOverlaps);
```

```
//--------------------------------------------------
// Scintillator (Polystyrene)
//--------------------------------------------------
G4VSolid* solidScintillator = new G4Box("Scintillator",
                              fBarBase-fCoatingThickness,
                              4*fBarBase-fCoatingThickness,
                              fHoleLength);

G4LogicalVolume* logicScintillator1 =
                     new G4LogicalVolume(solidScintillator,
                                         Polystyrene,
                                         "Scintillator1");

 new G4PVPlacement(0, G4ThreeVector(),  logicScintillator1,"Scintillator1",
                   logicExtrusion1,false,0, checkOverlaps);
```

```
//--------------------------------------------------
// WLS Fiber
//--------------------------------------------------
G4VSolid* solidWLSfiber;

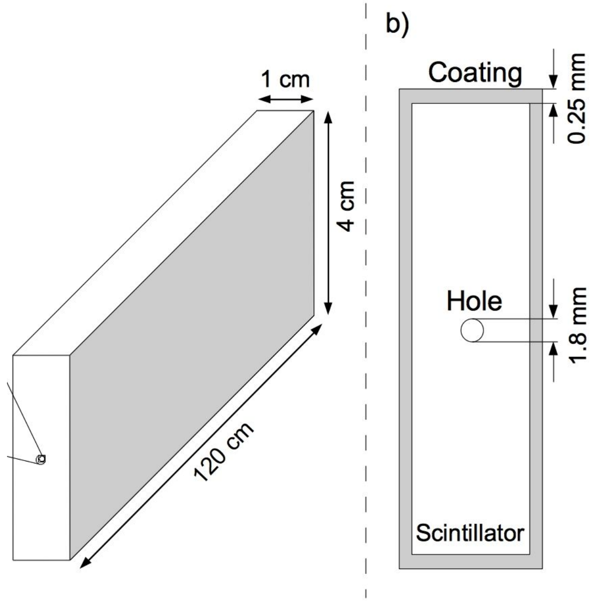
  solidWLSfiber =
      new G4Tubs("WLSFiber",0.,fWLSfiberRX,fWLSfiberZ,0.0*rad,twopi*rad);

 G4LogicalVolume* logicWLSfiber1 = new G4LogicalVolume(solidWLSfiber, PMMA,
 "WLSFiber1");

 G4VPhysicalVolume* physiWLSfiber1 = new G4PVPlacement(0,
                                     G4ThreeVector(0.0,0.0,fWLSfiberOrigin),
                                     logicWLSfiber1,
                                     "WLSFiber1",
                                     fLogicHole1,
                                     false,
                                     0, checkOverlaps);
```

Y faltan los 2 recubrimientos de la fibra y el SiPM

1. Definir la geometría del centellador




```
//------------------
// World (air)
//------------------
G4VSolid* solidWorld = new G4Box("World", fWorldSizeX, fWorldSizeY, fWorldSizeZ);

fLogicWorld = new G4LogicalVolume(solidWorld, Air, "World");

fPhysiWorld = new G4PVPlacement(0,G4ThreeVector(),fLogicWorld,"World",0,false[redacted]
                                0, checkOverlaps);
```

```
//--------------------
// Extrusion (TiO2)
//--------------------
G4VSolid* solidExtrusion =
      new G4Box("Extrusion",fBarBas[redacted]

G4LogicalVolume* logicEx[redacted]
[redacted] 0.*cm),logicExtrusion1,
[redacted],false,0, checkOverlaps);
```

```
[redacted] = new G4Tubs("Hole",
                             0.0*cm,
                             fHoleRadius,
                             fHoleLength,
                             0.*deg,
                             360.*deg);

    fLogicHole1 = new G4LogicalVolume(solidHole, Air,
                                      "Hole1");

    fPhysiHole1 = new G4PVPlacement(0,
                        G4ThreeVector(0.0,0.0,0.0),
                        fLogicHole1,
                        "Hole1",
                        logicScintillator1,
                        false,
                        0, checkOverlaps);
```

No se asusten y admiren el nivel de detalle del GEANT4

```
//--------------------------
// Scintillator (Pol[redacted]
//--------------------------
G4VSolid* solidScint[redacted]
[redacted]ckness,
[redacted]oatingThickness,
[redacted]ngth);

G4LogicalVolume* logicSc[redacted]illator1 =
                       new G4LogicalVolume(solidScintillator,
                                           Polystyrene,
                                           "Scintillator1");

 new G4PVPlacement(0, G4ThreeVector(),  logicScintillator1,"Scintillator1",
                   logicExtrusion1,false,0, checkOverlaps);
```

```
//--------------------------------------------------
// WLS Fiber
//--------------------------------------------------
G4VSolid* solidWLSfiber;

  solidWLSfiber =
      new G4Tubs("WLSFiber",0.,fWLSfiberRX,fWLSfiberZ,0.0*rad,twopi*rad);

 G4LogicalVolume* logicWLSfiber1 = new G4LogicalVolume(solidWLSfiber, PMMA,
 "WLSFiber1");

 G4VPhysicalVolume* physiWLSfiber1 = new G4PVPlacement(0,
                         G4ThreeVector(0.0,0.0,fWLSfiberOrigin),
                         logicWLSfiber1,
                         "WLSFiber1",
                         fLogicHole1,
                         false,
                         0, checkOverlaps);
```

2. Definir los materiales

```
// ----------------
// *** Elements ***
// ----------------
G4double a, z, density, fractionmass;

//N = new G4Element("Nitrogen", "N", z = 7 , a = 14.01*g/mole);
C = new G4Element("Carbon"   , "C", z = 6 , a = 12.01*g/mole);
O = new G4Element("Oxygen"   , "O", z = 8 , a = 16.00*g/mole);
H = new G4Element("Hydrogen", "H", z=1 , a = 1.01*g/mole);
Ti = new G4Element("Titanium", "Ti", z=22 , a = 47.867*g/mole);
```

2. Definir los materiales

Materiales a partir de elementos

```
// ---------------
// *** Elements ***
// ---------------
G4double a, z, density, fractionmass;

//N = new G4Element("Nitrogen", "N", z = 7 , a = 14.01*g/mole);
C = new G4Element("Carbon"   , "C", z = 6 , a = 12.01*g/mole);
O = new G4Element("Oxygen"   , "O", z = 8 , a = 16.00*g/mole);
H = new G4Element("Hydrogen", "H", z=1 , a = 1.01*g/mole);
Ti = new G4Element("Titanium", "Ti", z=22 , a = 47.867*g/mole);
```

```
//------------------------------------------------
// Polystyrene Material base del centellador
//------------------------------------------------
Polystyrene = new G4Material("Polystyrene", density= 1.050*g/cm3, 2);
Polystyrene->AddElement(C, 8);
Polystyrene->AddElement(H, 8);


//------------------------------------------------
// TiO2
//------------------------------------------------
TiO2 = new G4Material("TiO2", density= 4.26*g/cm3, 2);
TiO2->AddElement(Ti, 1);
TiO2->AddElement(O, 2);
```

2. Definir los materiales

```
// ---------------
// *** Elements ***
// ---------------
G4double a, z, density, fractionmass;

//N = new G4Element("Nitrogen", "N", z = 7 , a = 14.01*g/mole);
C = new G4Element("Carbon"  , "C", z = 6 , a = 12.01*g/mole);
O = new G4Element("Oxygen"  , "O", z = 8 , a = 16.00*g/mole);
H = new G4Element("Hydrogen", "H", z=1 , a = 1.01*g/mole);
Ti = new G4Element("Titanium", "Ti", z=22 , a = 47.867*g/mole);
```

Materiales a partir de elementos

```
//---------------------------------------------------
// Polystyrene Material base del centellador
//---------------------------------------------------
Polystyrene = new G4Material("Polystyrene", density= 1.050*g/cm3, 2);
Polystyrene->AddElement(C, 8);
Polystyrene->AddElement(H, 8);


//---------------------------------------------------
// TiO2
//---------------------------------------------------
TiO2 = new G4Material("TiO2", density= 4.26*g/cm3, 2);
TiO2->AddElement(Ti, 1);
TiO2->AddElement(O, 2);
```

Materiales a partir de otros materiales

```
//---------------------------------------------------
// Scintillator Coating
//---------------------------------------------------
Coating = new G4Material("Coating", density = 1.52*g/cm3, 2);
Coating->AddMaterial(TiO2, fractionmass = 15.0*perCent);
Coating->AddMaterial(Polystyrene, fractionmass = 85.0*perCent);
```

2. Definir los materiales

Materiales a partir de elementos

```
//------------------------------------------------
// Polystyrene Material base del centellador
//------------------------------------------------
Polystyrene = new G4Material("Polystyrene", density= 1.050*g/cm3, 2);
Polystyrene->AddElement(C, 8);
Polystyrene->AddElement(H, 8);


//------------------------------------------------
// TiO2
//------------------------------------------------
TiO2 = new G4Material("TiO2", density= 4.26*g/cm3, 2);
TiO2->AddElement(Ti, 1);
TiO2->AddElement(O, 2);
```

```
// ----------------
// *** Elements ***
// ----------------
G4double a, z, density, fractionmass;

//N = new G4Element("Nitrogen", "N", z = 7 , a = 14.01*g/mole);
C = new G4Element("Carbon"   , "C", z = 6 , a = 12.01*g/mole);
O = new G4Element("Oxygen"   , "O", z = 8 , a = 16.00*g/mole);
H = new G4Element("Hydrogen", "H", z=1 , a = 1.01*g/mole);
Ti = new G4Element("Titanium", "Ti", z=22 , a = 47.867*g/mole);
```

Algunos materiales ya están definidos en Geant4

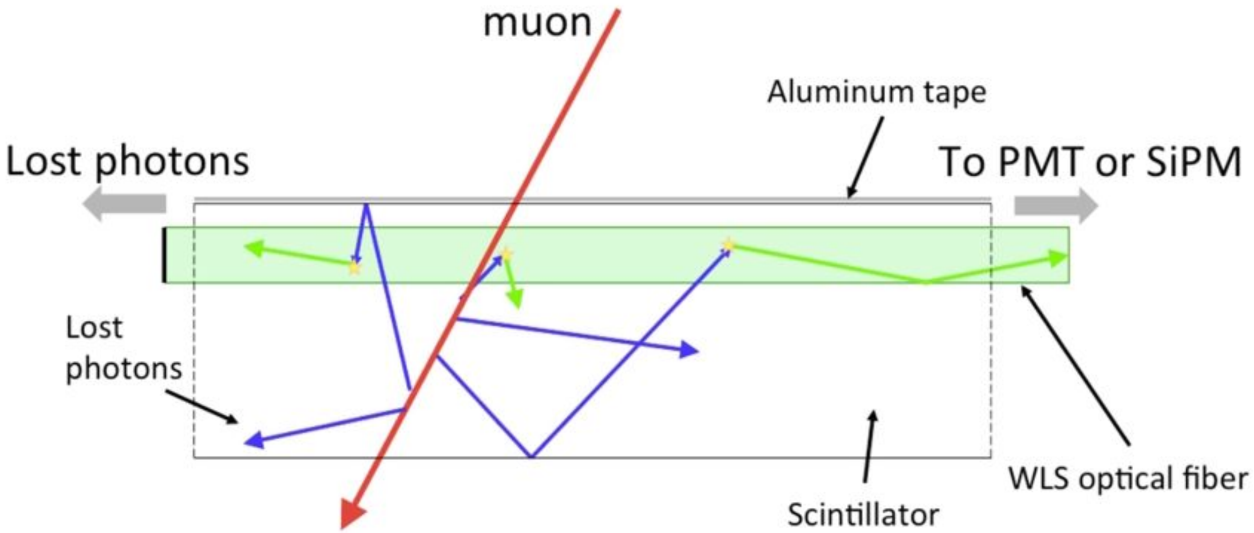
```
// *** Air ***
Air = nist->FindOrBuildMaterial("G4_AIR");

// *** Aluminio ***
Aluminio = nist->FindOrBuildMaterial("G4_Al");
```

Materiales a partir de otros materiales

```
//------------------------------------------------
// Scintillator Coating
//------------------------------------------------
Coating = new G4Material("Coating", density = 1.52*g/cm3, 2);
Coating->AddMaterial(TiO2, fractionmass = 15.0*perCent);
Coating->AddMaterial(Polystyrene, fractionmass = 85.0*perCent);
```

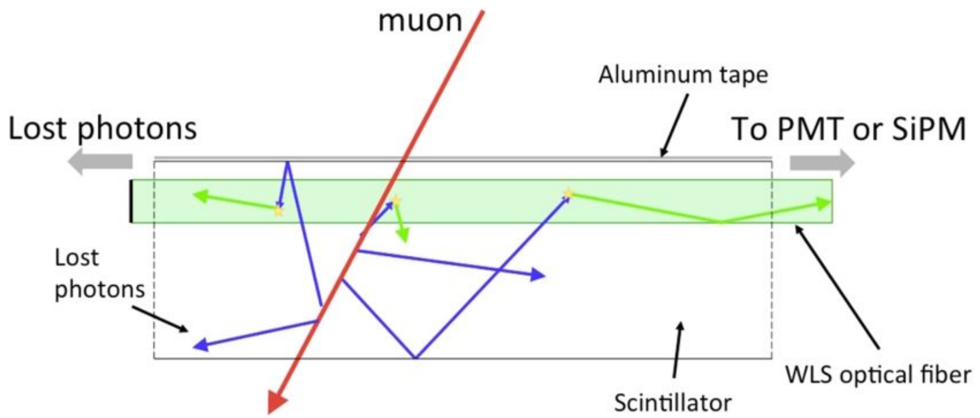
3. Definir los procesos y propiedades físicas

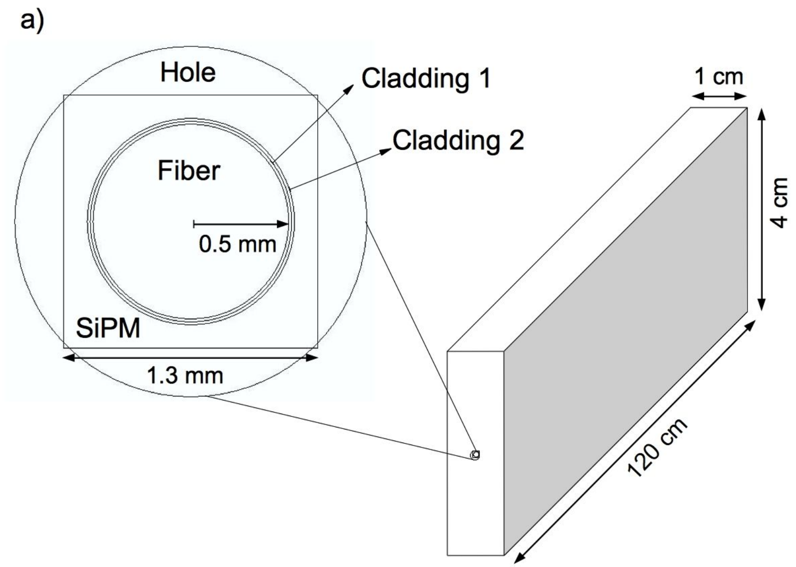


Activar procesos físicos según el detector

```
fOpticalPhysics->GetCerenkovProcess()->SetVerboseLevel(verbose);
fOpticalPhysics->GetScintillationProcess()->SetVerboseLevel(verbose);
fOpticalPhysics->GetAbsorptionProcess()->SetVerboseLevel(verbose);
fOpticalPhysics->GetRayleighScatteringProcess()->SetVerboseLevel(verbose);
fOpticalPhysics->GetMieHGScatteringProcess()->SetVerboseLevel(verbose);
fOpticalPhysics->GetBoundaryProcess()->SetVerboseLevel(verbose);
```

3. Definir los procesos y propiedades físicas





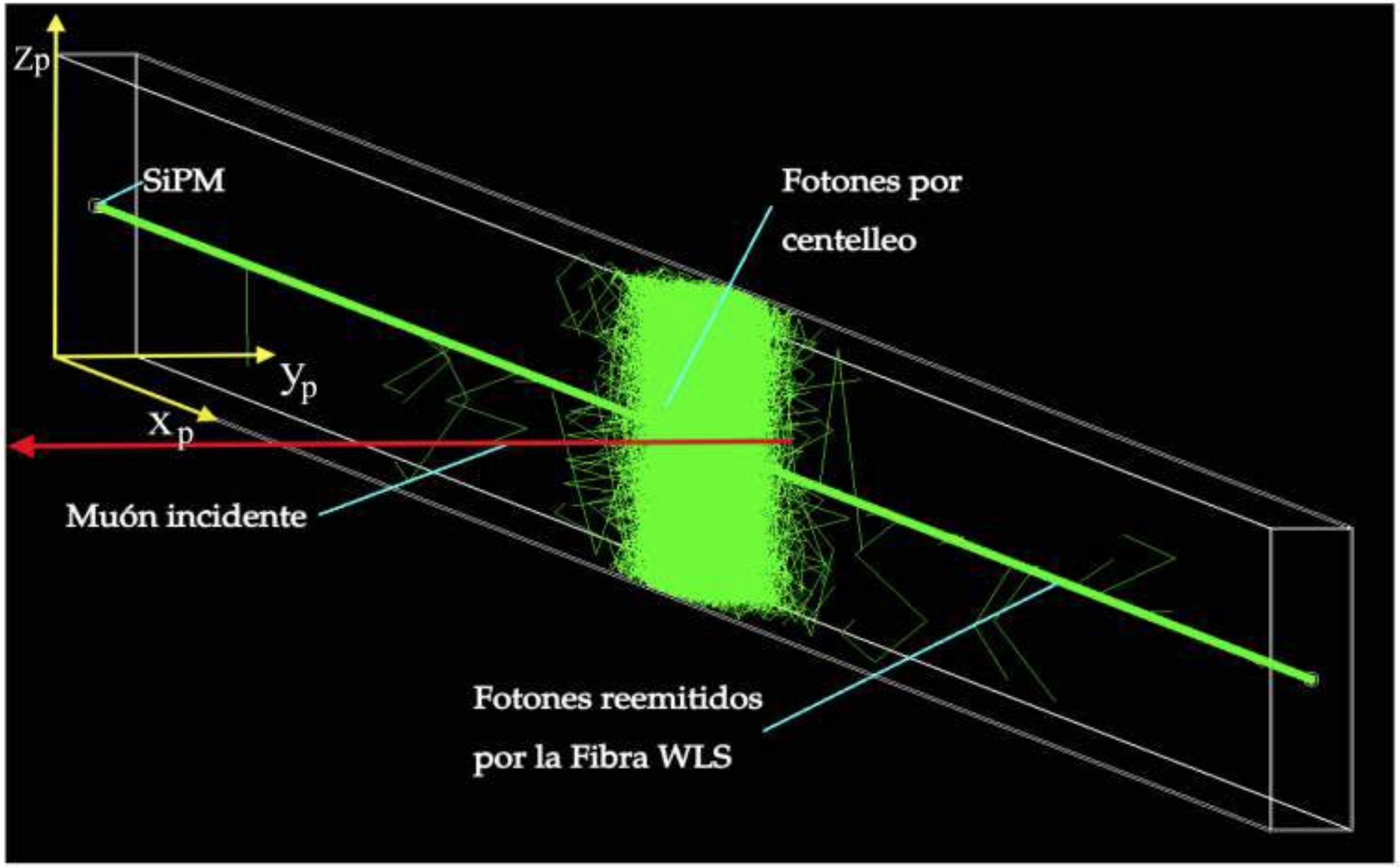
Activar procesos físicos según el detector

Propiedades físicas de los volúmenes

```
// Add entries into properties table
G4MaterialPropertiesTable* mptWLSfiber
    = new G4MaterialPropertiesTable();
mptWLSfiber->AddProperty("RINDEX",photonEnergy,
                         refractiveIndexWLSfiber,nEntries);
mptWLSfiber->AddProperty("WLSABSLENGTH",
                         photonEnergy,absWLSfiber,nEntries);
mptWLSfiber->AddProperty("WLSCOMPONENT",
                         photonEnergy,emissionFib,nEntries);
mptWLSfiber->AddConstProperty("WLSTIMECONSTANT", 0.5*ns);

PMMA->SetMaterialPropertiesTable(mptWLSfiber);
```

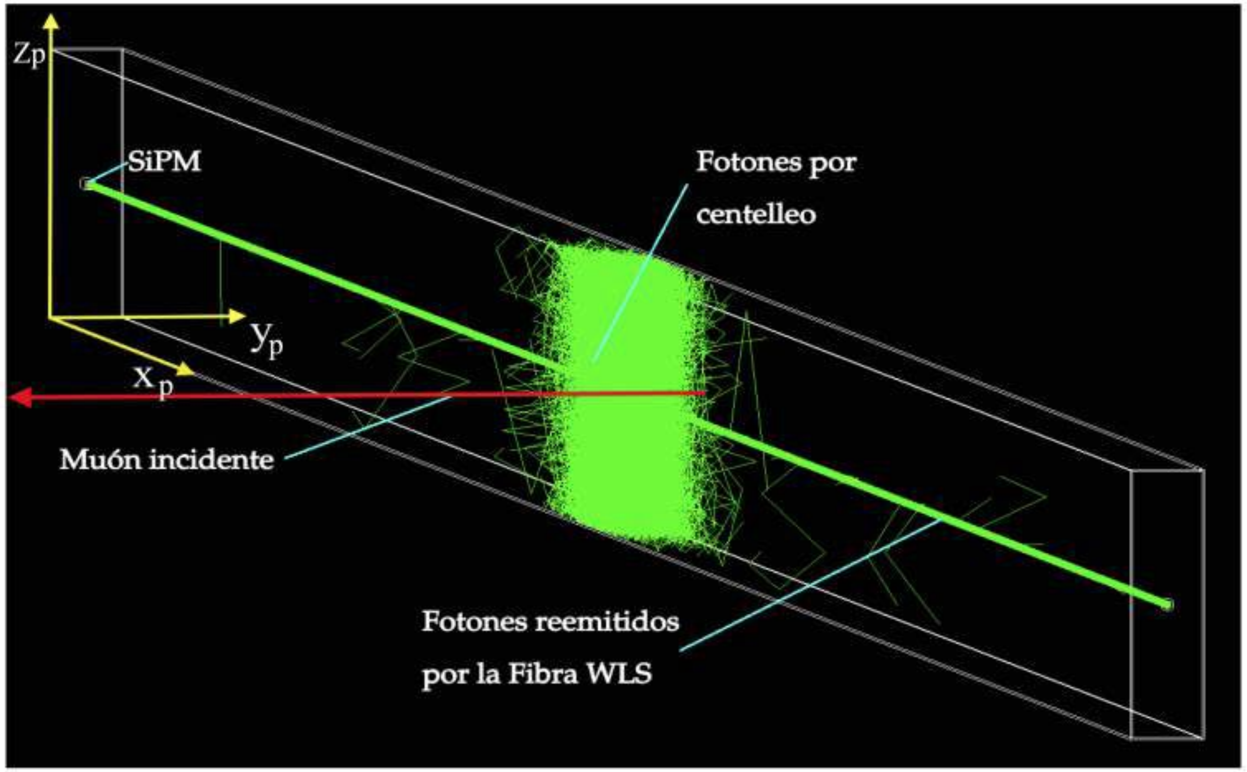
4. Escoger las condiciones iniciales



Partículas incidentes

Tipo: Muón
N partículas: 10^4
Energía: 1 GeV
Posición inicial: $x_p = (2 + 4n)$ cm
$y_p = 1$ cm
$z_p = 2$ cm
Dirección: (0, -1, 0)

4. Escoger las condiciones iniciales



Partículas incidentes

Tipo: Muón
N partículas: 10^4
Energía: 1 GeV
Posición inicial: x_p = (2 + 4n) cm
y_p = 1 cm
z_p = 2 cm
Dirección: (0, -1, 0)

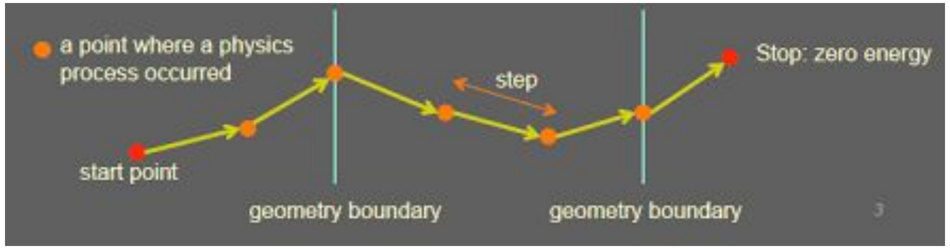
Tipo de partícula

Más partículas

Más energía

Más tiempo de cómputo!!!

5. Extracción de datos



https://indico.cern.ch/event/472305/contributions/1982331/attachments/1223729/1790331/Tracking.pdf

Los datos de salida se muestran en cada interacción de la partícula:

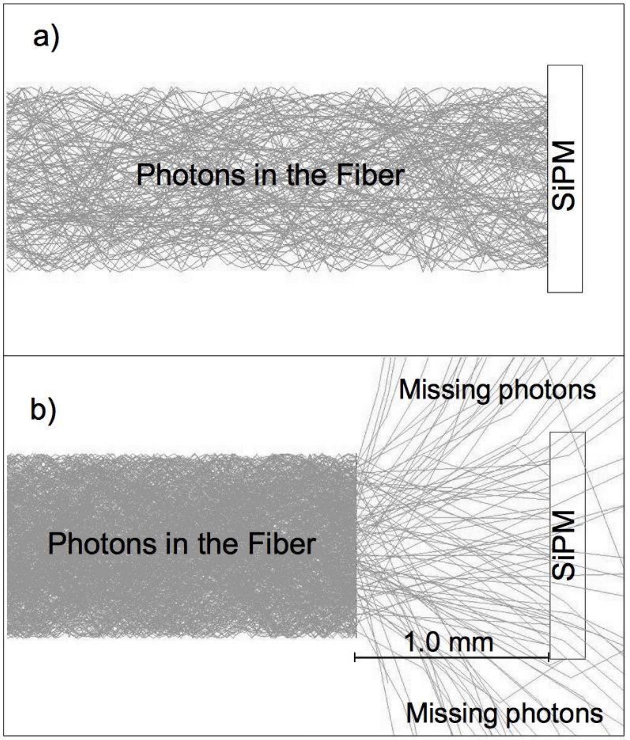
```
>>> Start event: 49

*********************************************************************************************
* G4Track Information:   Particle = proton,   Track ID = 1,   Parent ID = 0
*********************************************************************************************

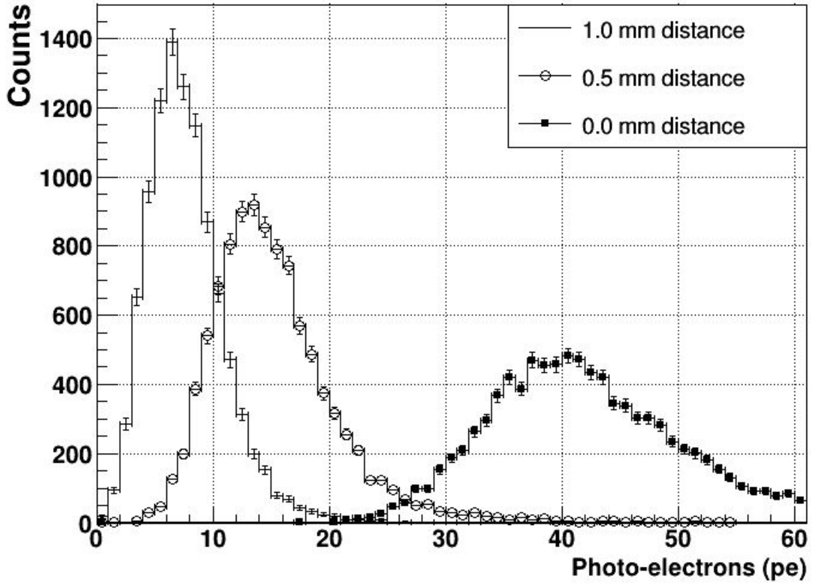
Step#    X(mm)    Y(mm)    Z(mm) KinE(MeV)  dE(MeV) StepLeng TrackLeng  NextVolume ProcName
    0    0.125   -0.439     -150       100        0        0         0       World initStep
    1    0.125   -0.439       -5       100 1.59e-23      145       145        Cube Transportation
    2    0.125   -0.439     2.81      94.4     5.49     7.81       153        Cube hIoni
    3    0.123   -0.442     3.19      93.9    0.342    0.384       153        Cube hIoni
    4    0.119    -0.45      4.1      93.1     0.71    0.913       154        Cube hIoni
    5    0.118   -0.453     4.35      92.8     0.16    0.249       154        Cube hIoni
    6    0.117   -0.461        5      92.4    0.434    0.647       155       World Transportation
    7    -5.46      -31    2e+03      92.4 2.32e-22    2e+03  2.15e+03  OutOfWorld Transportation
```

- Tipo de partícula
- Primaria o secundaria
- Posición
- Energía actual
- Cambio de energía
- Distancia recorrida
- Volumen donde está
- Tipo de interacción / Proceso Físico

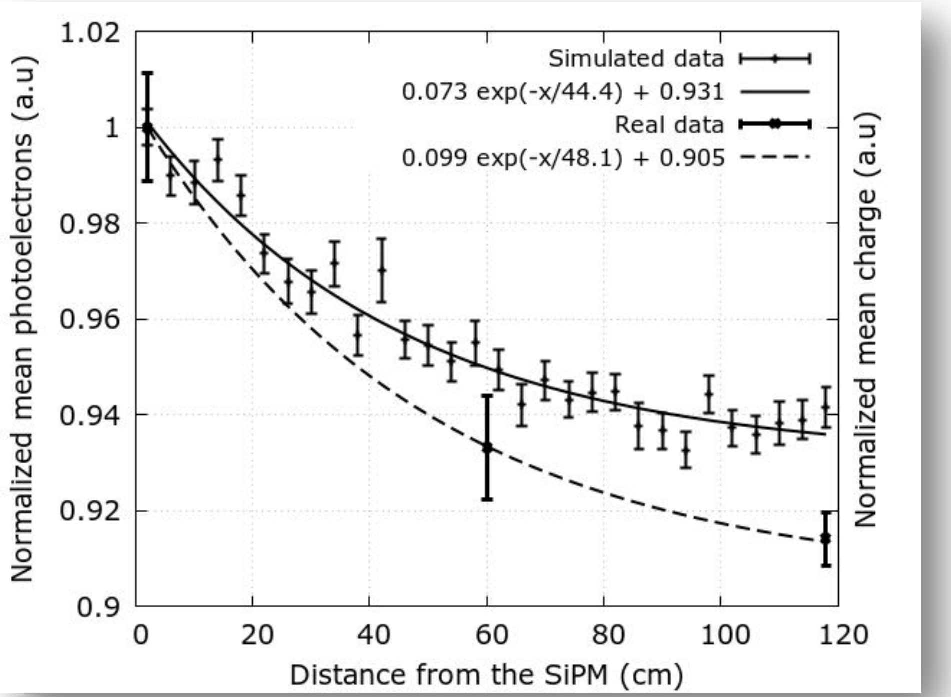
5. Extracción de datos



Pérdida de señal debido a un mal acople entre la fibra y el SiPM



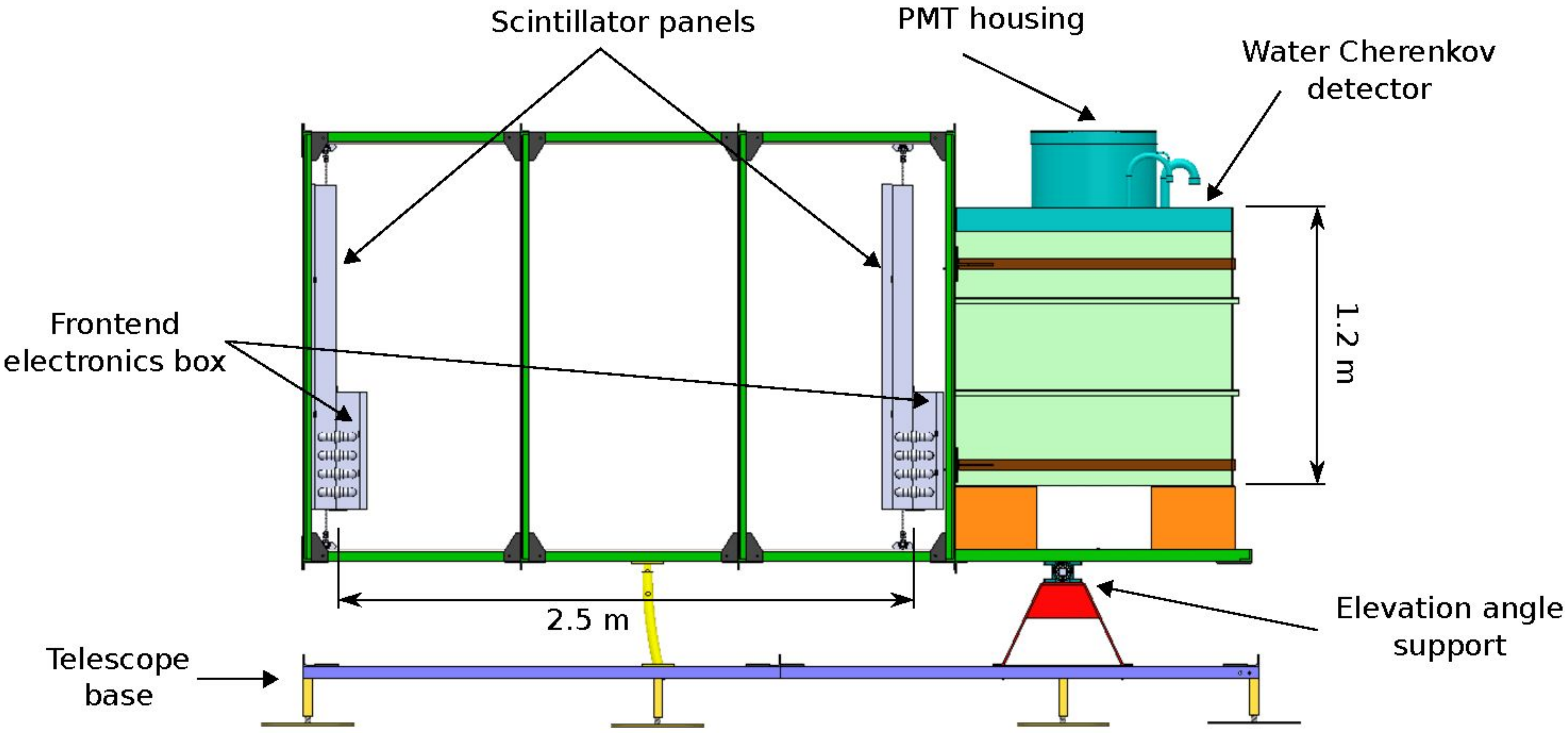
Atenuación del número de fotones respecto a la posición de impacto del muón en el centellador



A. Vásquez-Ramírez *et al* 2020 *JINST* **15** P08004

https://iopscience.iop.org/article/10.1088/1748-0221/15/08/P08004/meta

Acabamos de simular la respuesta de una barra centelladora del MuTe!!



Práctica en Geant4

https://github.com/adrianacvr/geant4-class

Tarea:

1. Lanzar las siguientes partículas:
   a. 1000 gammas de 2 MeV
   b. 1000 gammas de 4 MeV
   c. 1000 mu- de 100 MeV

   Para eso deben modificar el archivo run2.mac

2. Analizar los **histogramas** del archivo .root de cada caso

3. Guardar una **foto** del calorímetro con una partícula

4. Repetir pero con un **“absorber” de agua:** cambiar en el DetectorContruction.cc el material “G4_Pb por “G4_WATER” y compilar en una carpeta nueva

¿Preguntas?

Próxima clase:

Simulación de la barra centelladora de MuTe

GEANT4
A SIMULATION TOOLKIT

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Muchas gracias por su atención