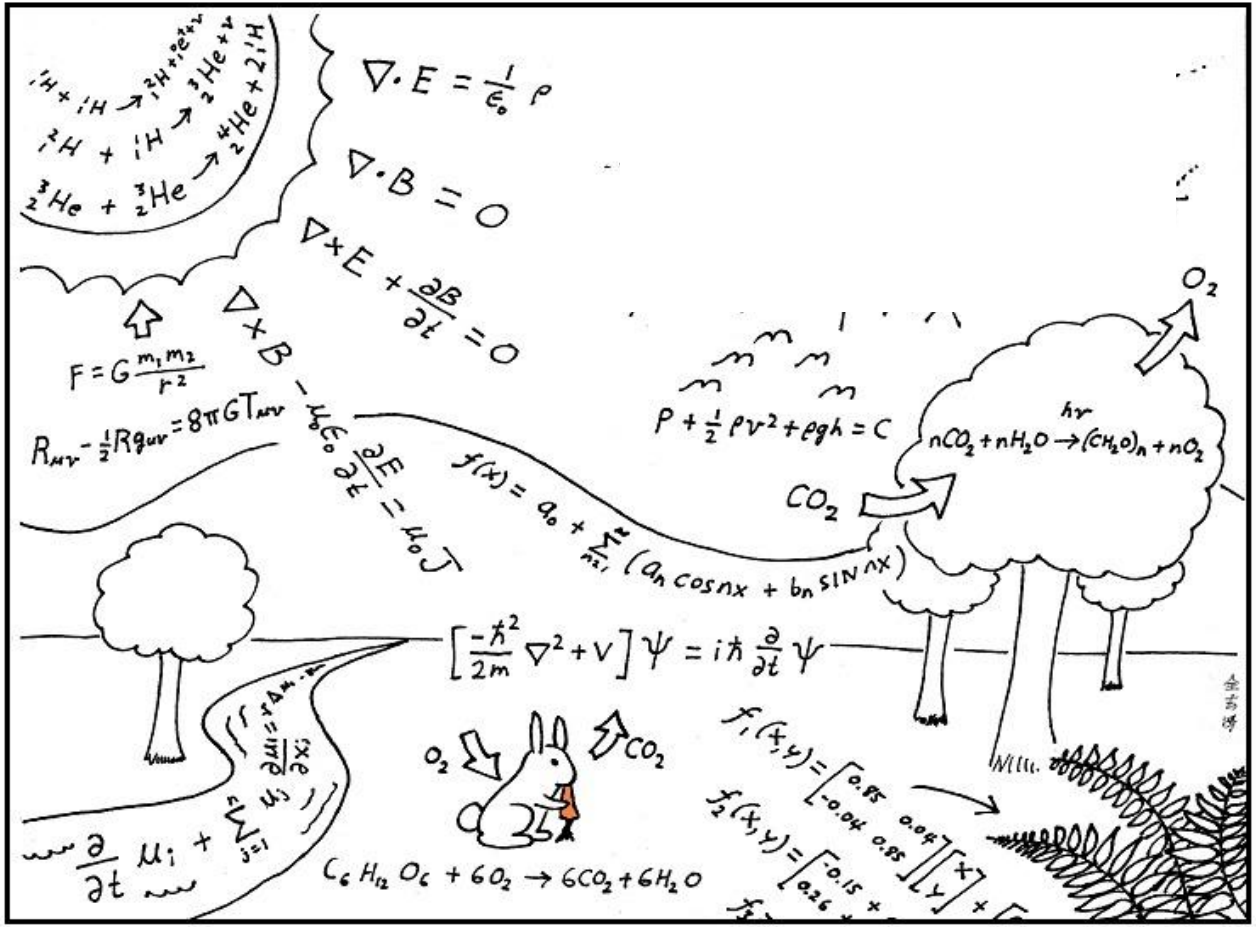
Explorando el Universo con IA: Nuevos Métodos en la Detección de Radiación y Rayos Cósmicos

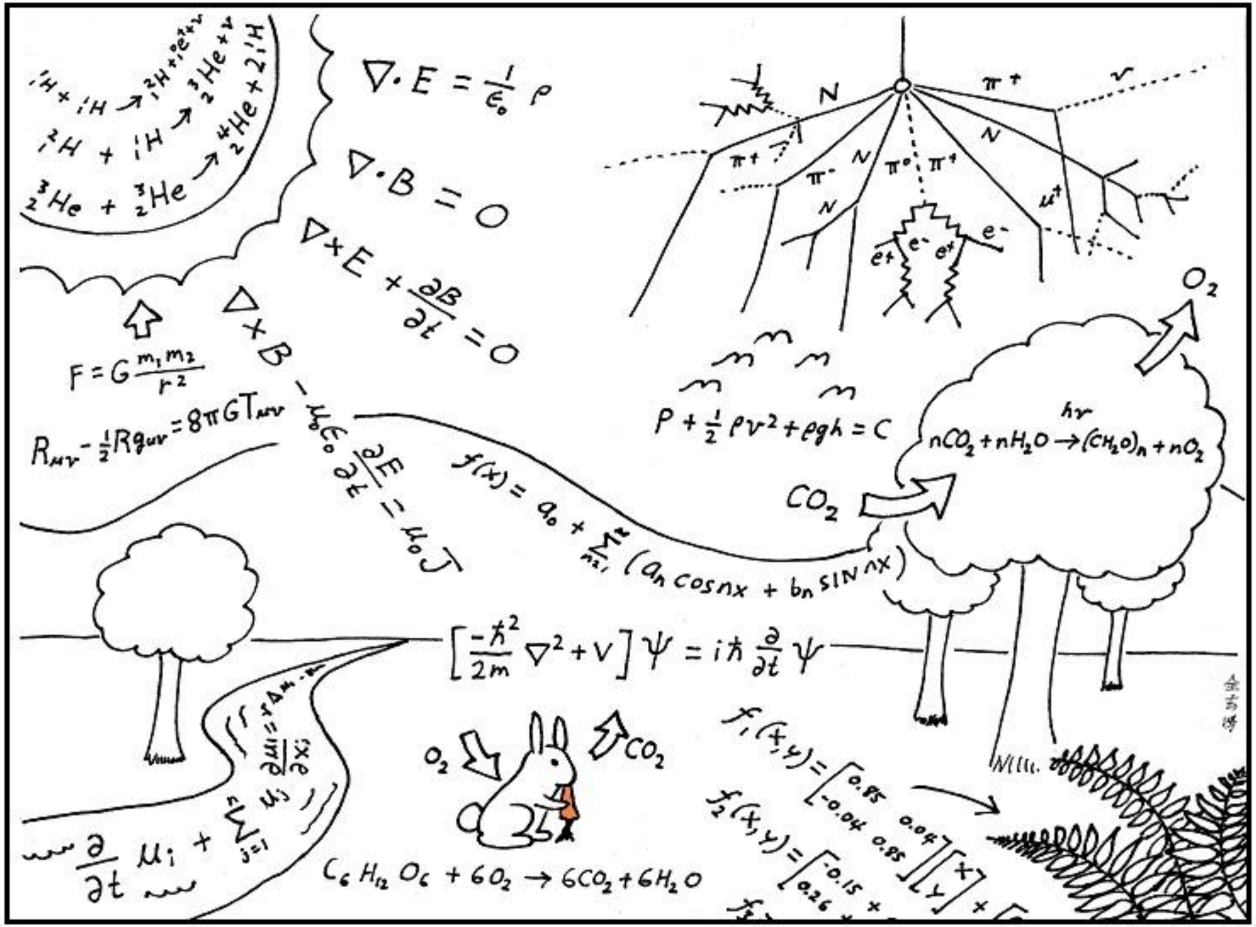
22–26 de septiembre de 2025
Universidad San Francisco de Quito USFQ

Introduzca su término de búsq

Luis Otiniano



$^1_1H + ^1_1H \rightarrow ^2_1H + ^0_{+1}e + \nu$
$^2_1H + ^1_1H \rightarrow ^3_2He + \gamma$
$^3_2He + ^3_2He \rightarrow ^4_2He + 2^1_1H$
$\nabla \cdot E = \frac{1}{\epsilon_0}\rho$
$\nabla \cdot B = 0$
$\nabla \times E + \frac{\partial B}{\partial t} = 0$
$\nabla \times B - \mu_0 \epsilon_0 \frac{\partial E}{\partial t} = \mu_0 J$
$F = G\frac{m_1 m_2}{r^2}$
$R_{\mu\nu} - \frac{1}{2}R g_{\mu\nu} = 8\pi G T_{\mu\nu}$
$f(x) = a_0 + \sum_{n=1}^{\infty}(a_n \cos nx + b_n \sin nx)$
$P + \frac{1}{2}\rho v^2 + \rho g h = C$
O_2
$nCO_2 + nH_2O \xrightarrow{h\nu} (CH_2O)_n + nO_2$
CO_2
$\left[\frac{-\hbar^2}{2m}\nabla^2 + V\right]\psi = i\hbar\frac{\partial}{\partial t}\psi$
$\frac{\partial}{\partial t}u_i + \sum_{j=1}^{n} u_j \frac{\partial u_i}{\partial x_j} = \nu\Delta u_i$
O_2
CO_2
$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$
$f_1(x,y) = \begin{bmatrix} 0.85 & 0.04 \\ -0.04 & 0.85 \end{bmatrix}\begin{bmatrix} x \\ y \end{bmatrix} +$
$f_2(x,y) = \begin{bmatrix} -0.15 & \\ 0.26 & \end{bmatrix}$



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$F = G \frac{m_1 m_2}{r^2}$
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N
π^+
ν
π^-
π^0
μ^+
e^-
e^+
O_2
$P + \frac{1}{2}\rho v^2 + \rho g h = C$
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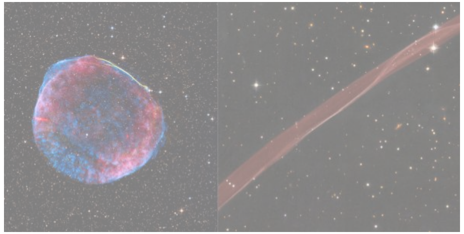
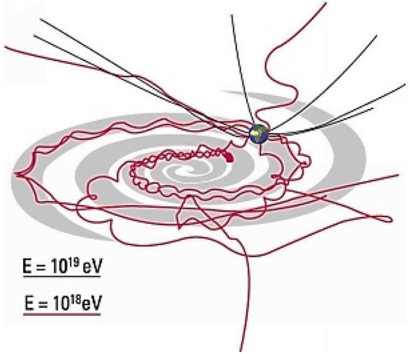
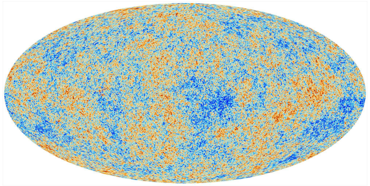
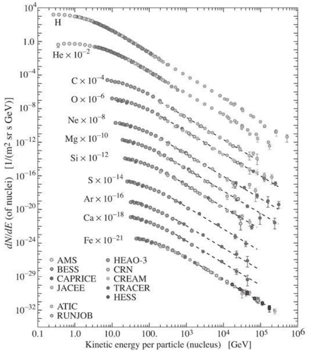
El Escenario

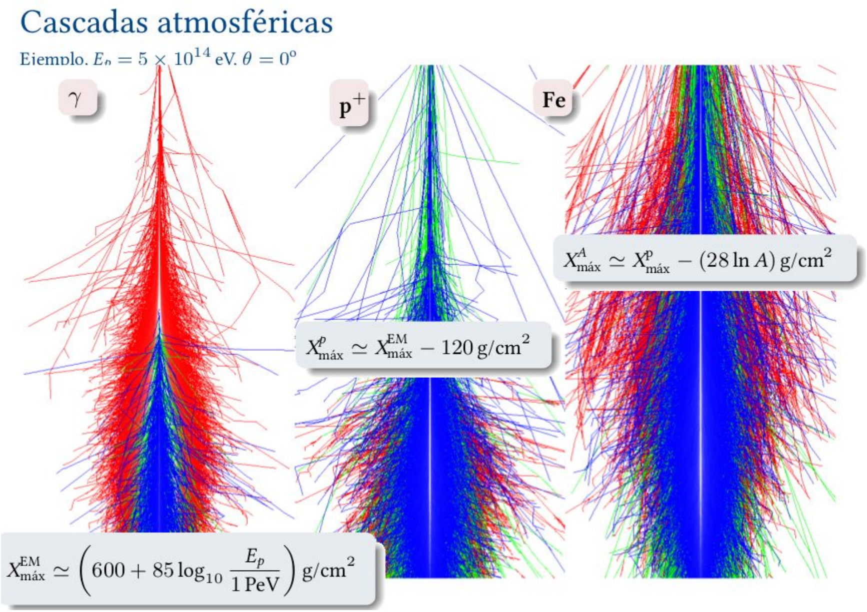


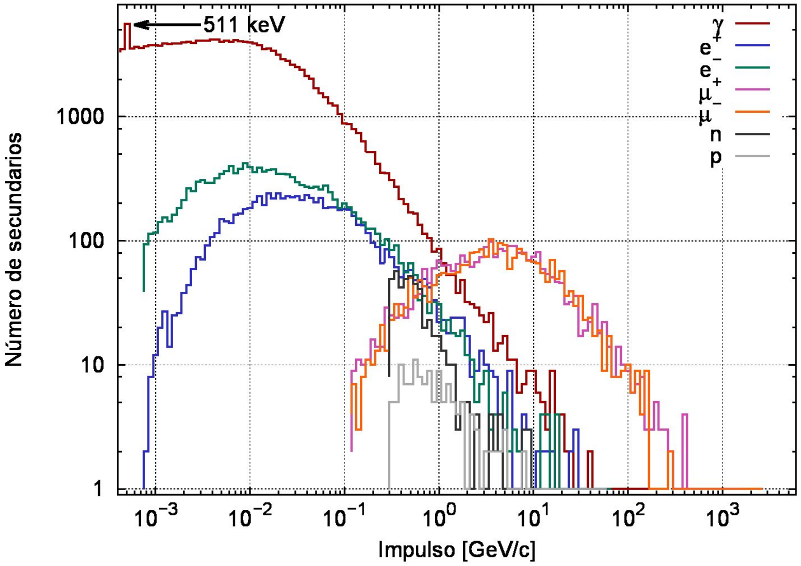




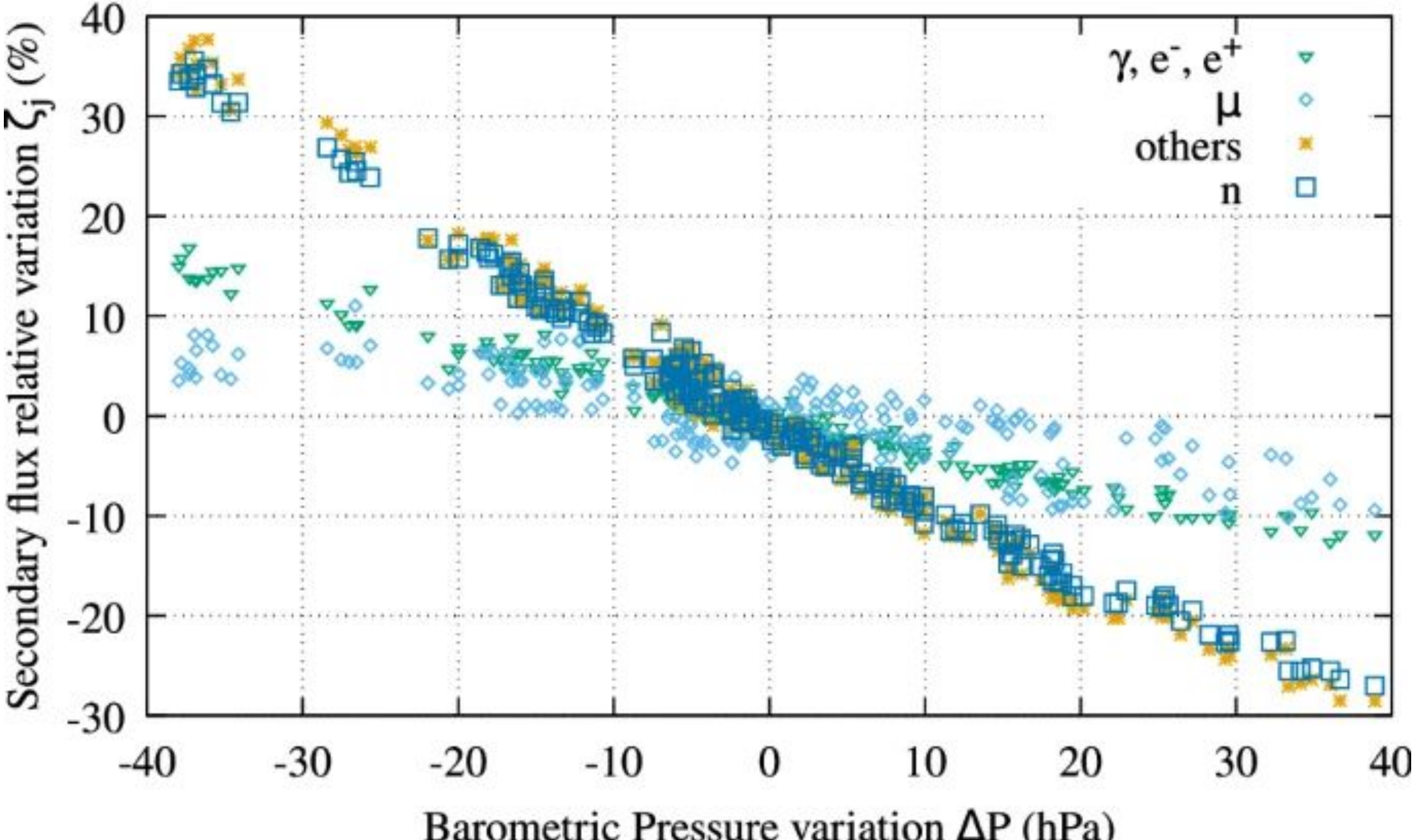


El Escenario



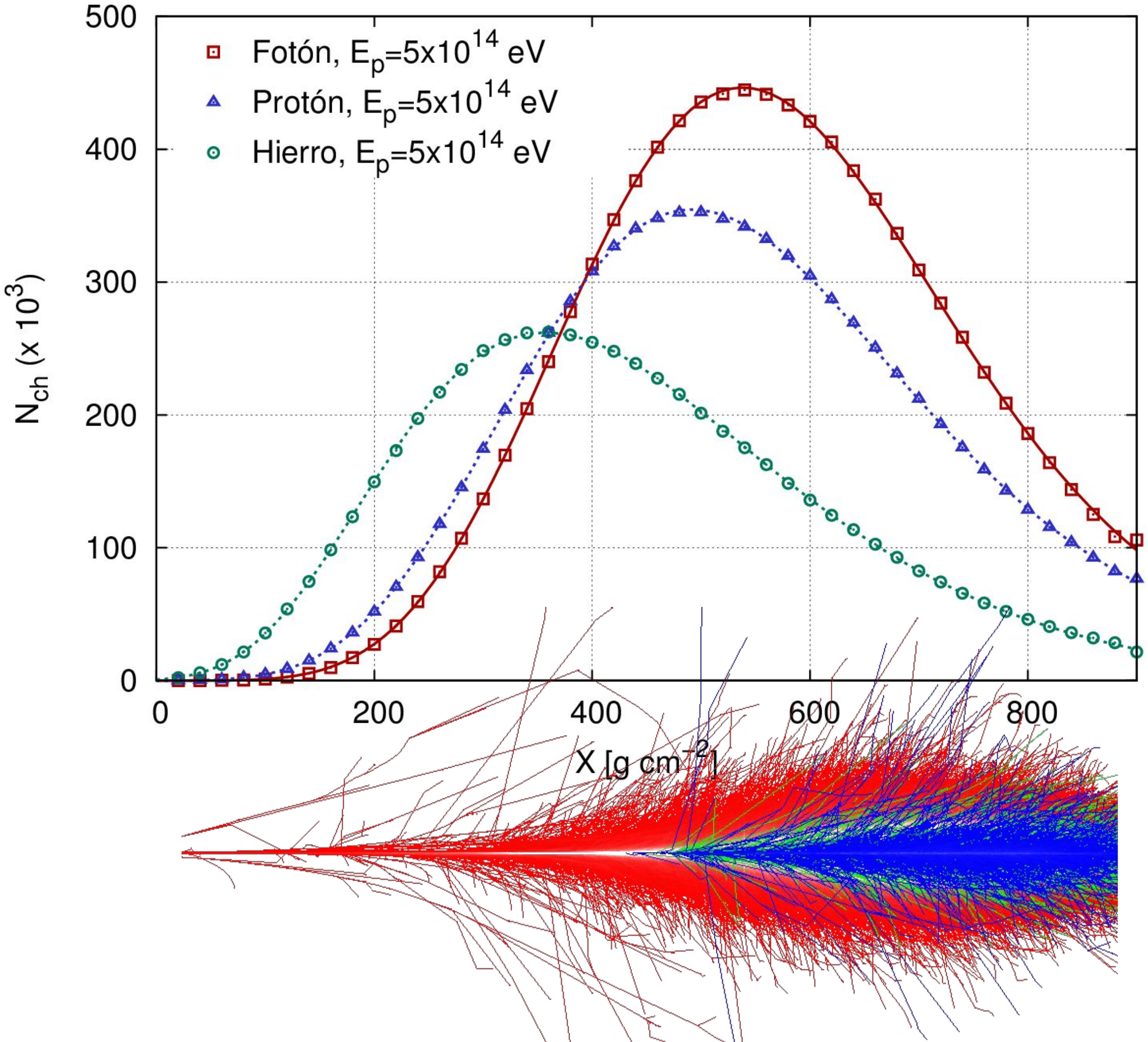


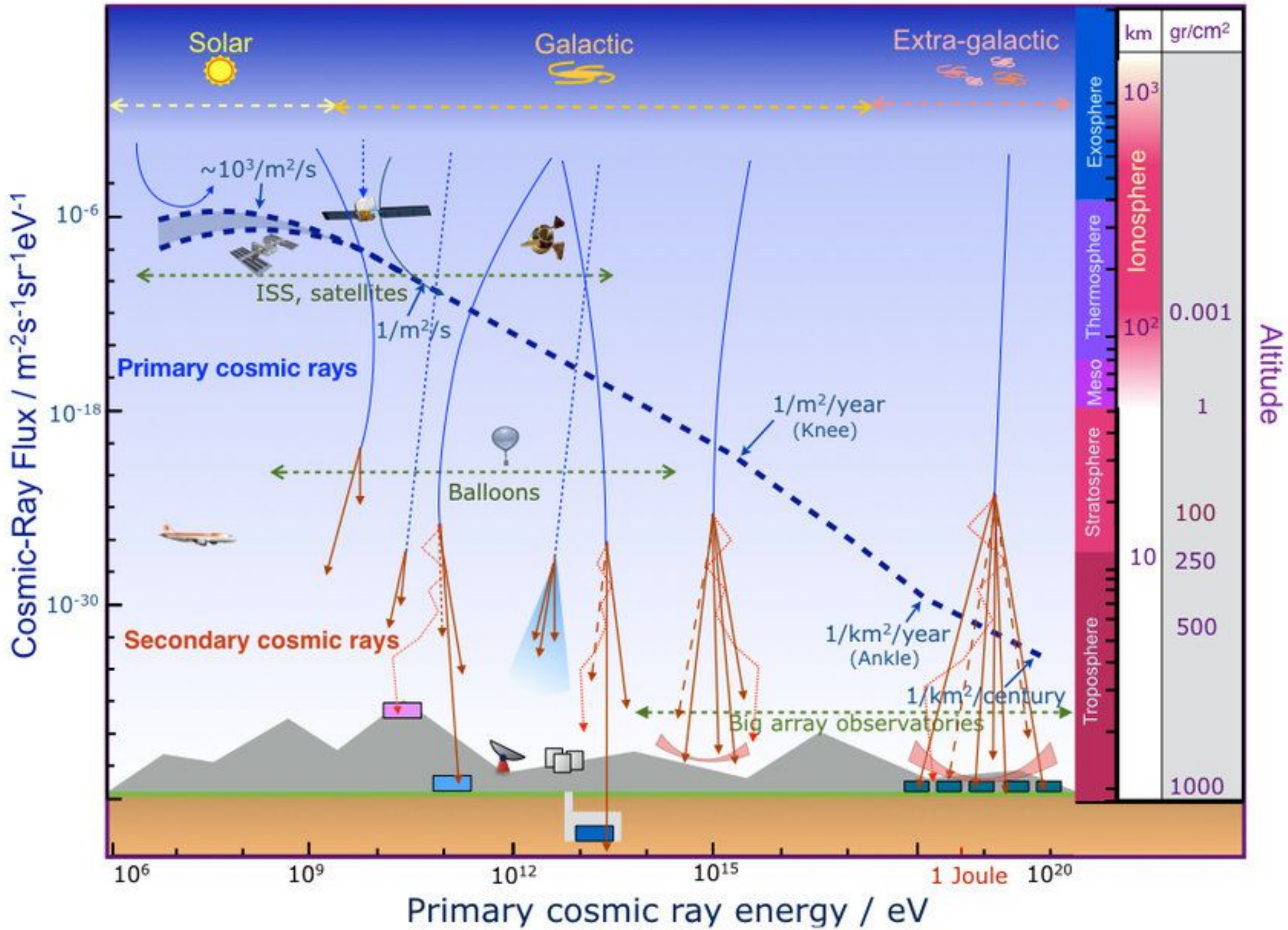
El Escenario



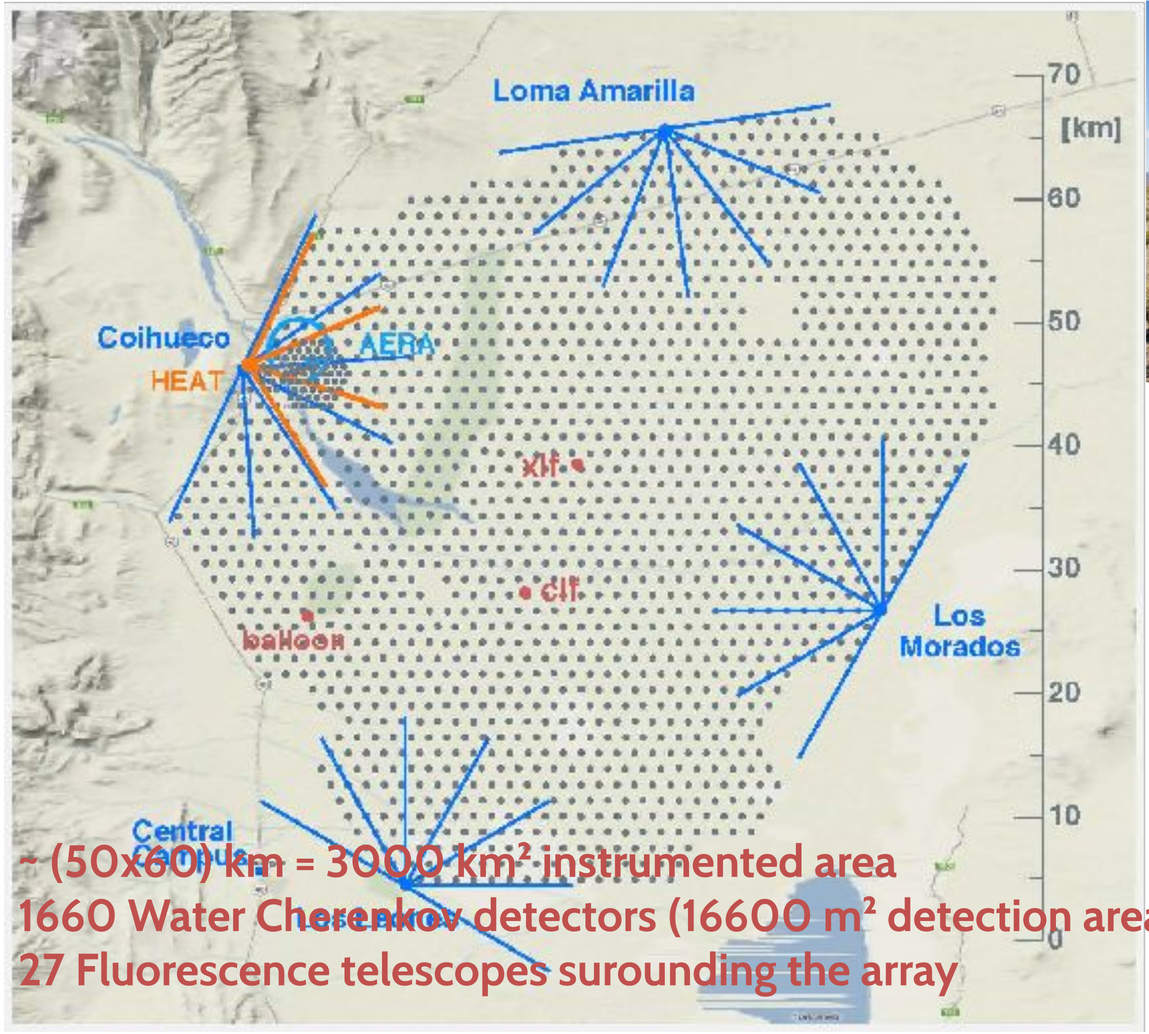
Detectores de rayos cósmicos

Función de Gaisser-Hillas

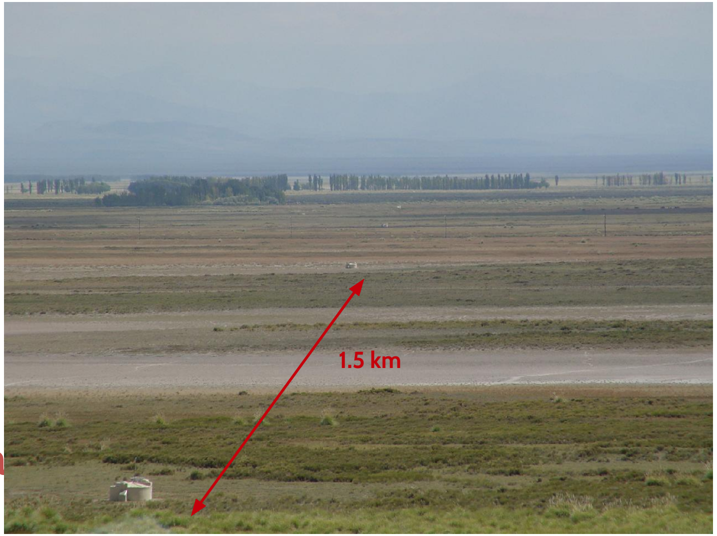


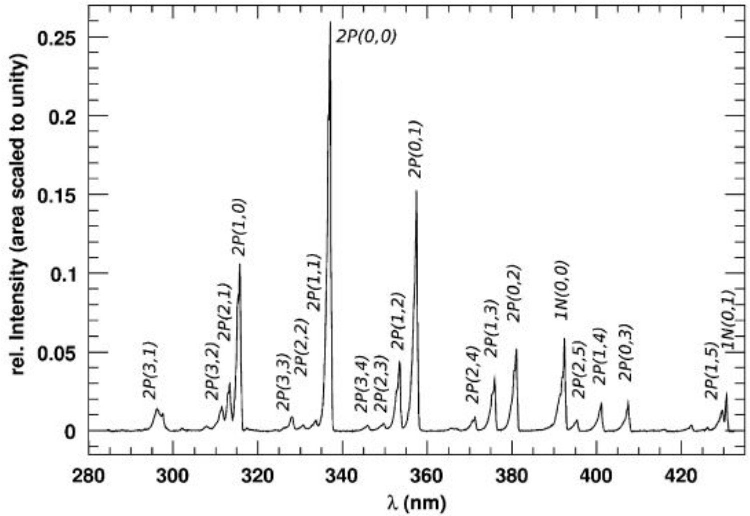


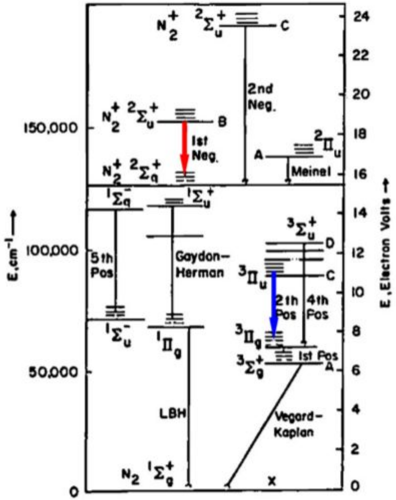
Solar
Galactic
Extra-galactic
km
gr/cm²
Exosphere
Thermosphere
Meso
Stratosphere
Troposphere
Ionosphere
10³
10²
10
0.001
1
100
250
500
1000
Altitude
~10³/m²/s
10⁻⁶
10⁻¹⁸
10⁻³⁰
ISS, satellites
1/m²/s
Primary cosmic rays
1/m²/year
(Knee)
Balloons
Secondary cosmic rays
1/km²/year
(Ankle)
1/km²/century
Big array observatories
Cosmic-Ray Flux / m⁻²s⁻¹sr⁻¹eV⁻¹
10⁶
10⁹
10¹²
10¹⁵
1 Joule
10²⁰
Primary cosmic ray energy / eV

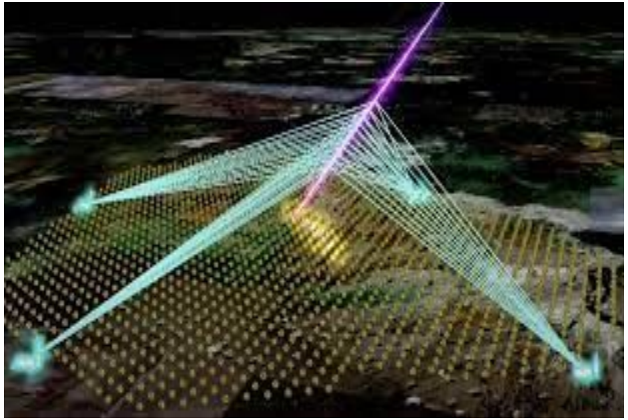


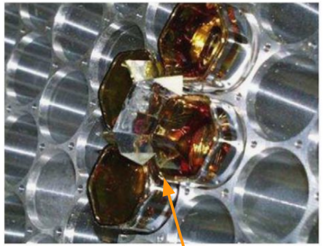
~ (50x60) km = 3000 km² instrumented area
1660 Water Cherenkov detectors (16600 m² detection area
27 Fluorescence telescopes surounding the array

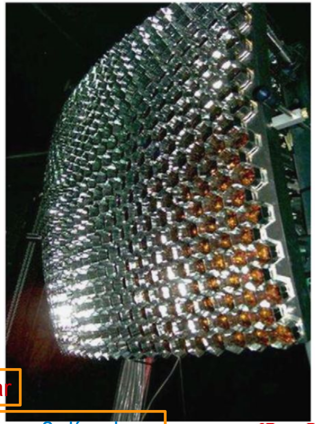


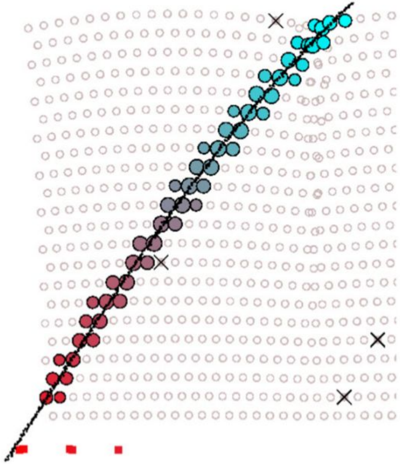


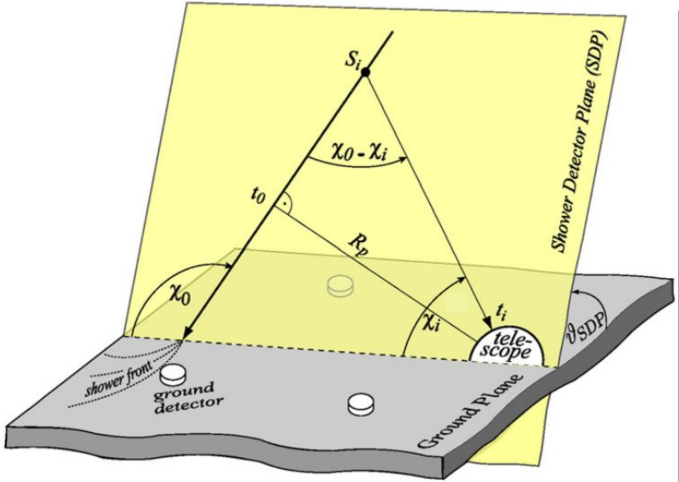








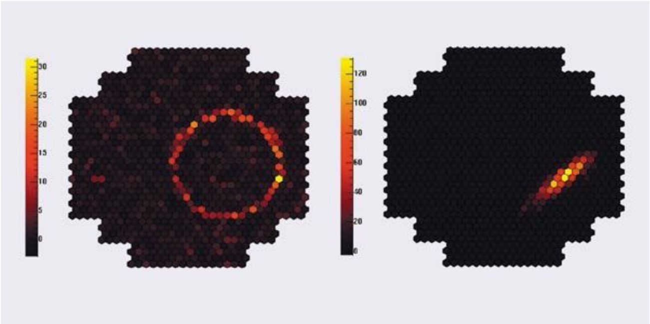


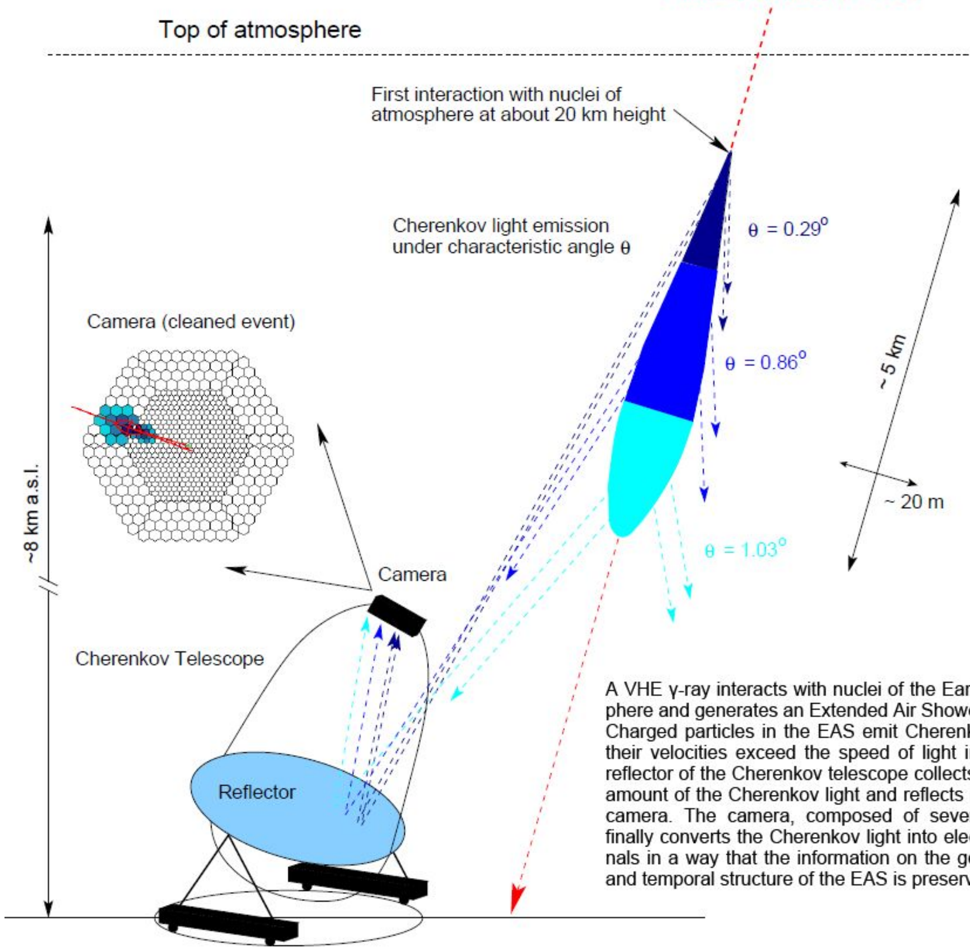


“Mercedes” Star

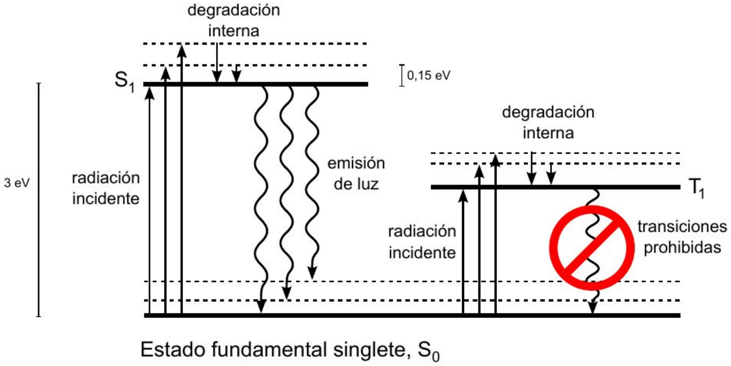
440 PMT Photonis XP3062 40mm, 8 dínodos,

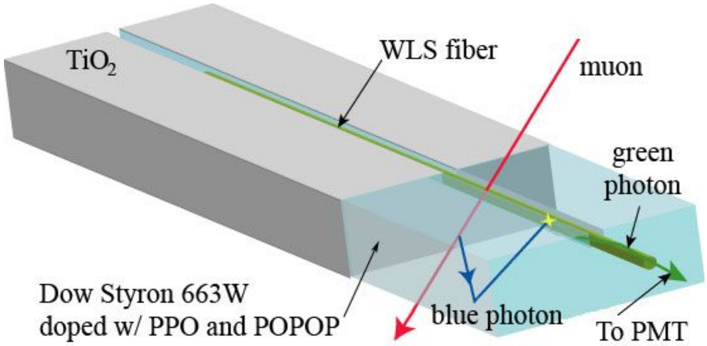
Illustration of an Imaging Air Cherenkov Telecope (IACT).

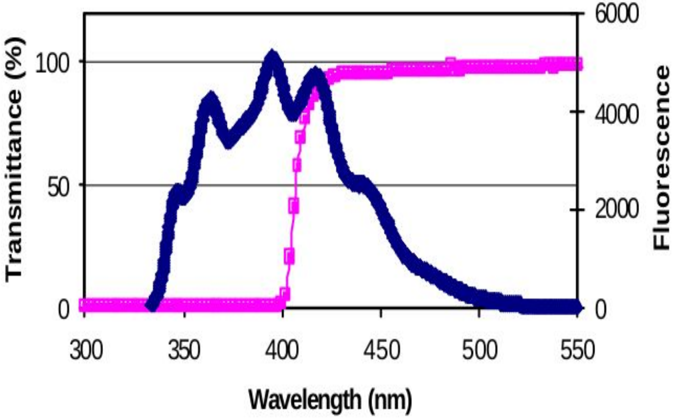


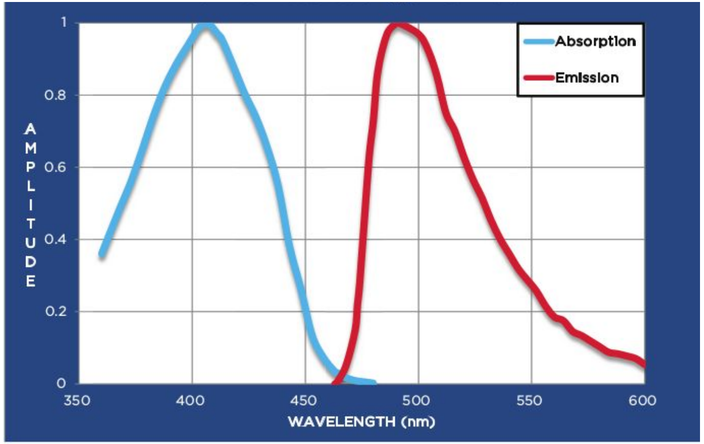


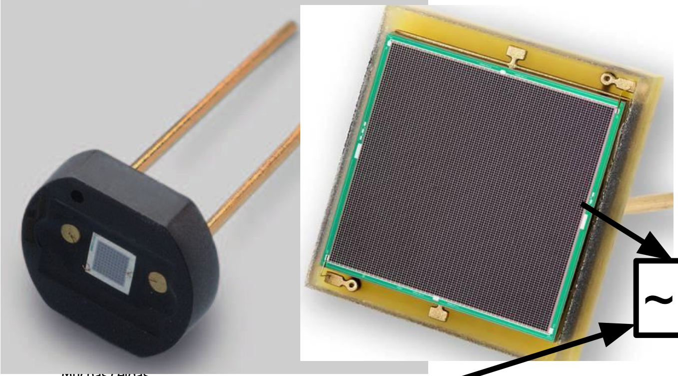
A VHE γ-ray interacts with nuclei of the Earth's atmosphere and generates an Extended Air Showers (EAS). Charged particles in the EAS emit Cherenkov light if their velocities exceed the speed of light in air. The reflector of the Cherenkov telescope collects a certain amount of the Cherenkov light and reflects it onto the camera. The camera, composed of several pixels, finally converts the Cherenkov light into electrical signals in a way that the information on the geometrical and temporal structure of the EAS is preserved.


degradación
interna
0,15 eV
S_1
3 eV
radiación
incidente
emisión
de luz
degradación
interna
T_1
radiación
incidente
transiciones
prohibidas
Estado fundamental singlete, S_0


TiO_2
WLS fiber
muon
green
photon
Dow Styron 663W
doped w/ PPO and POPOP
blue photon
To PMT


Transmittance (%)
100
50
0
300
350
400
450
500
550
Wavelength (nm)
6000
4000
2000
0
Fluorescence

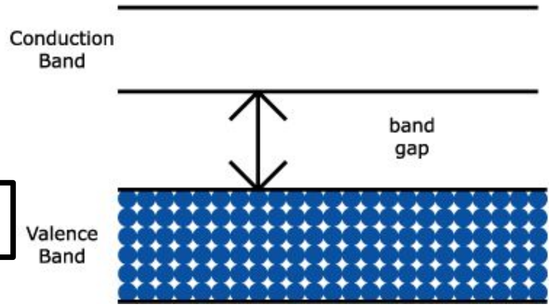

Absorption
Emission
AMPLITUDE
1
0.8
0.6
0.4
0.2
0
350
400
450
500
550
600
WAVELENGTH (nm)



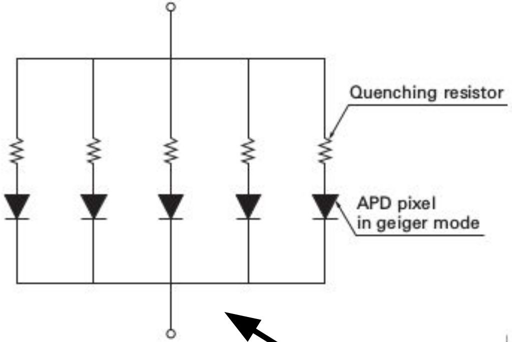
~ 3600

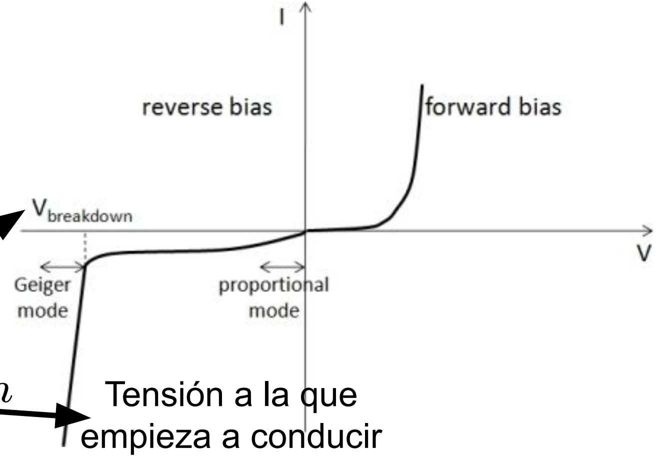
$(50\mu m)$

- Semiconductor



- Diodo polarizado en inversa





$$v_{overvoltage} \equiv v_{bias} - v_{breakdown}$$

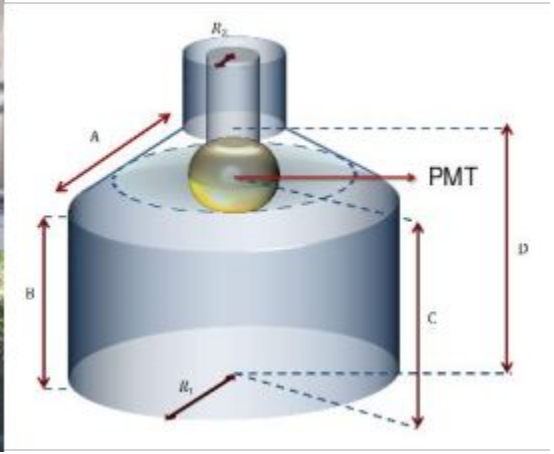
Tensión aplicada al SiPM

Tensión a la que empieza a conducir

El Detector Cherenkov de Agua de LAGO

El detector de LAGO

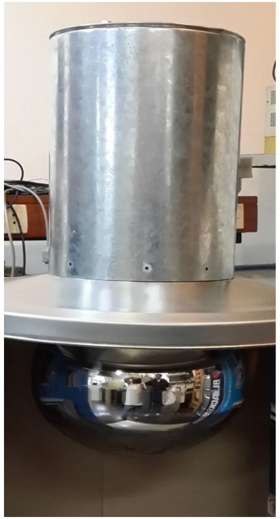
Autonomous, reliable, simple, cheap and smart (based on SBC and COTS)
WCD with a single PMT (usually provided by LAGO in most of the participating countries)



New own designed electronic based on SteamLab RedPitaya
H. Arnaldi et al, IEEE2020

SaaS (Sensors as a Service) Concept
H. Asorey et al, PoS(ICRC2015)

Diversidad de detectores de LAGO

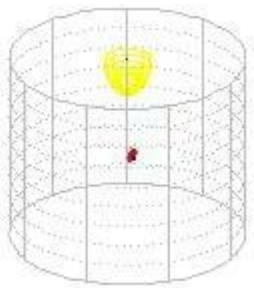


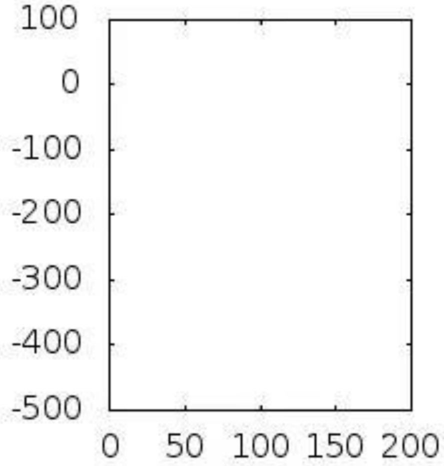
Clima Espacial en LAGO

LAGO studies Earth-Sun connection by measuring the time-evolving secondary signals from ground level. Atmospheric and geomagnetic conditions are continuously monitored

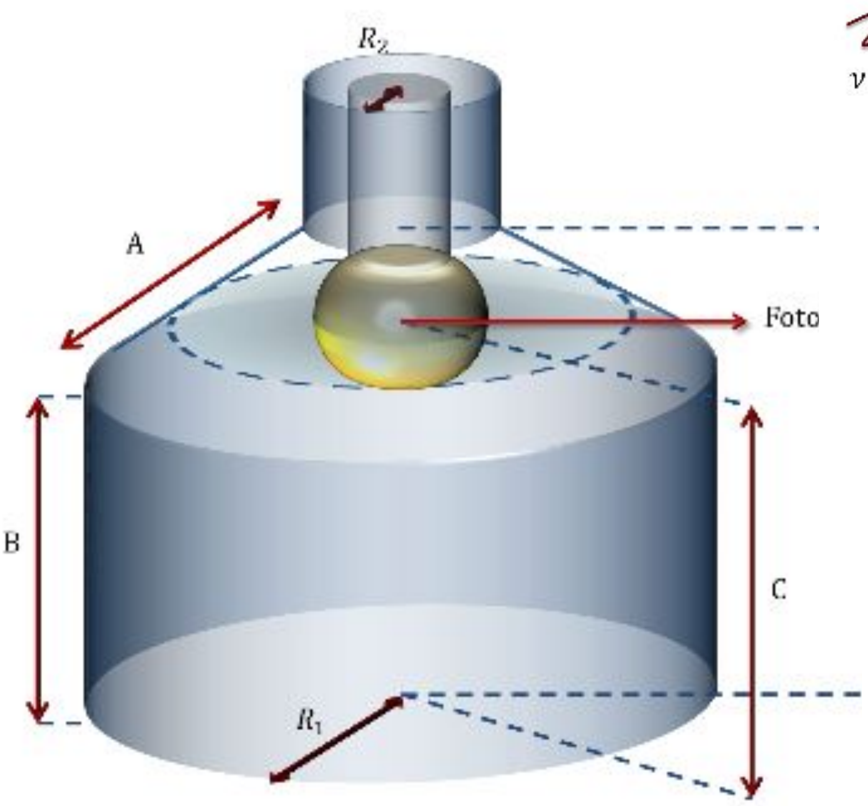
Antarctic dedicated SW sites

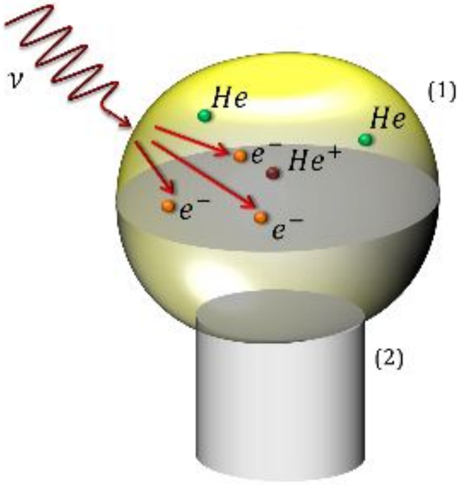
Una simulación de Detector Cherenkov de Agua

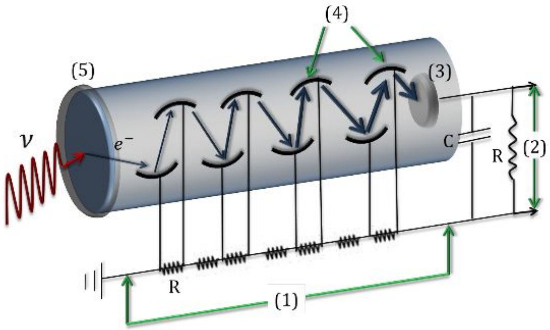




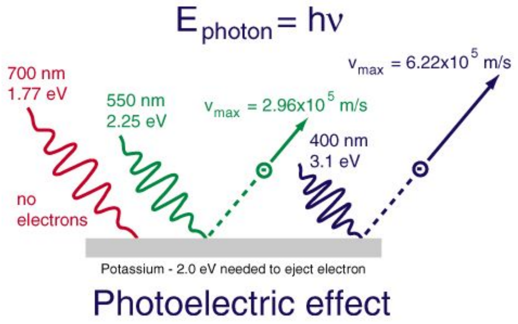
El detector Cherenkov de Agua

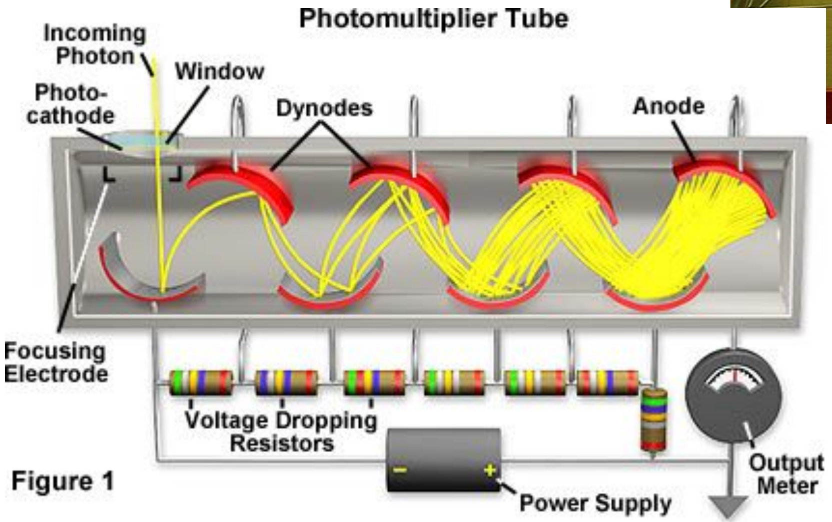






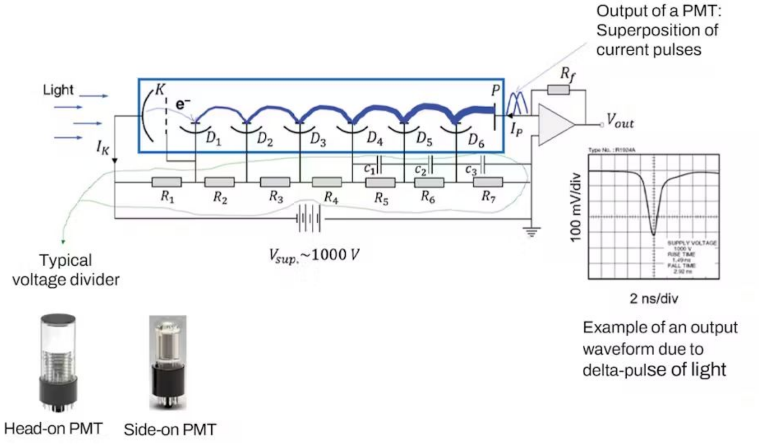
El tubo fotomultiplicador (PMT):

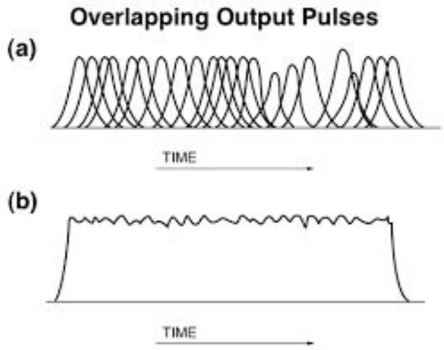


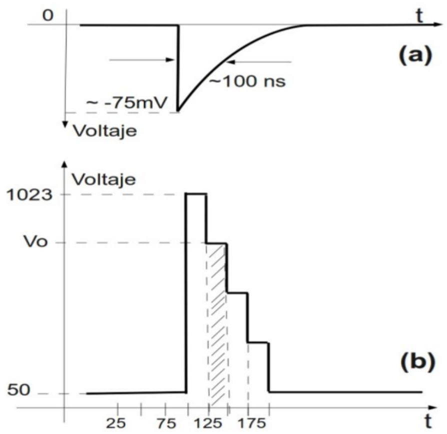


- Transductor: Fotón a una señal de corriente.
- Tubo al vacío.
- Material del fotocátodo: Bialkali.
- Acelera electrones a través de un efecto casada
- Típica corriente de salida del orden de uA

La señal del fotomultiplicador



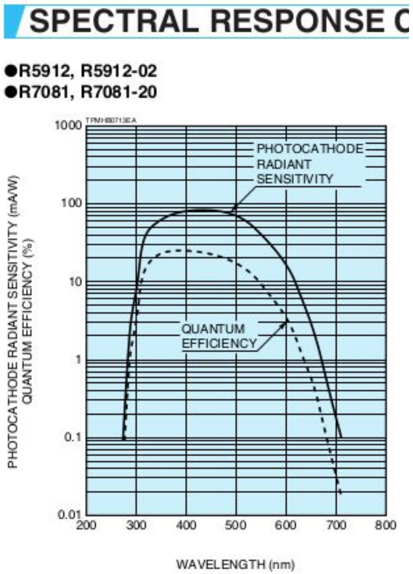


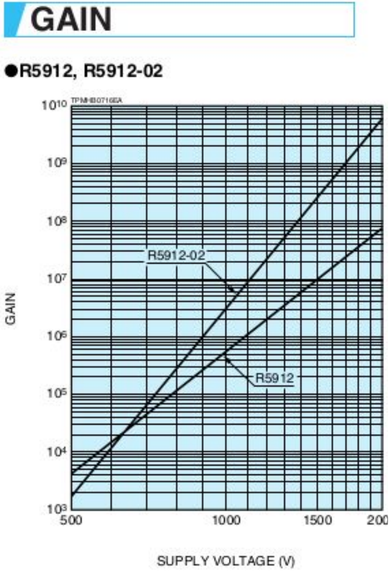


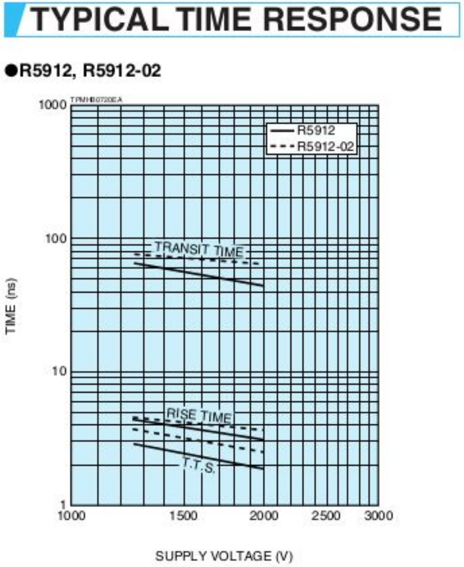
Área bajo la curva

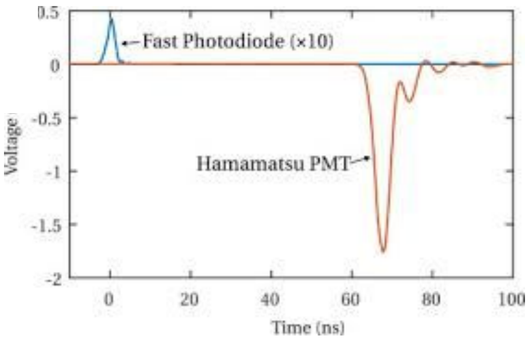
Es proporcional al número de fotones

Hamamatsu R5912





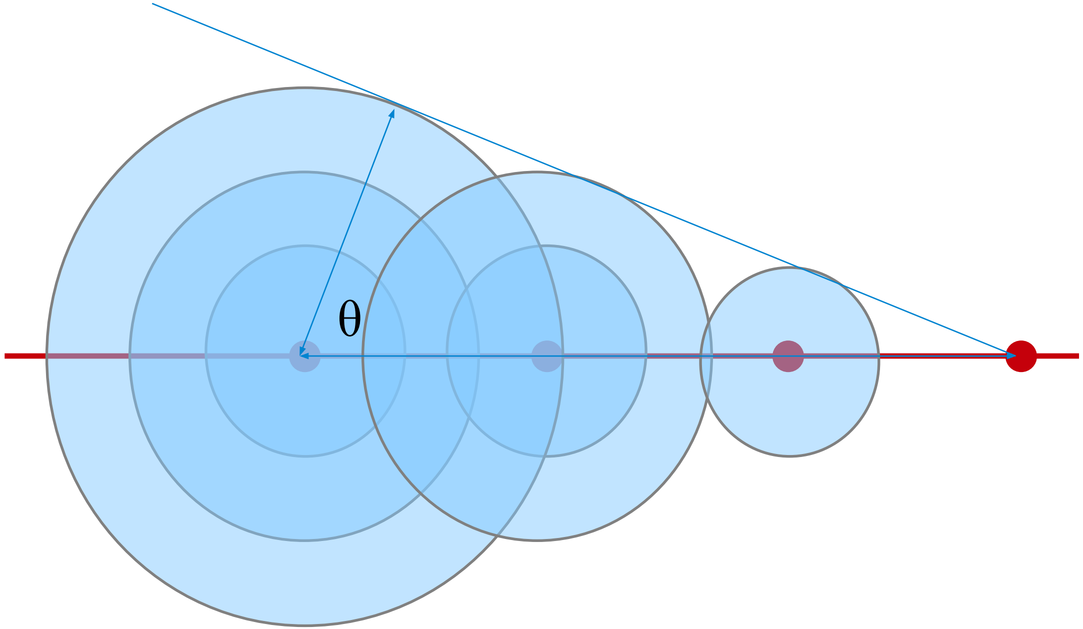


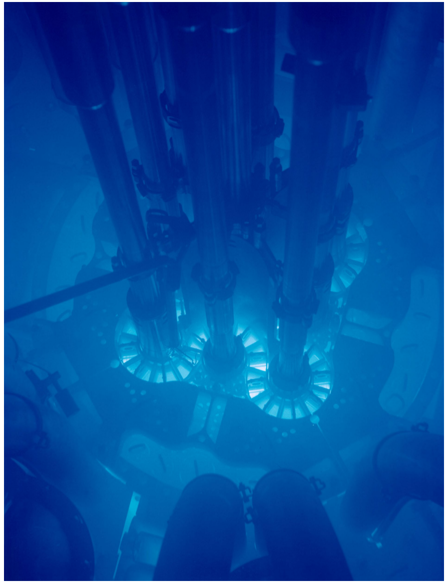


SPECIFICATIONS

Type No.	Diameter (mm) / (inch)	Minimum Effective Area (mm)	Surface Area Min. (cm²)	Surface Area Typ. (cm²)	Dynode Structure	Dynode Number of Stages	Weight (g)
R5912	202 / 8	φ190	330	380	Box & Line	10	approx. 1100
R5912-02	202 / 8	φ190	330	380	Box & Line	14	approx. 1100

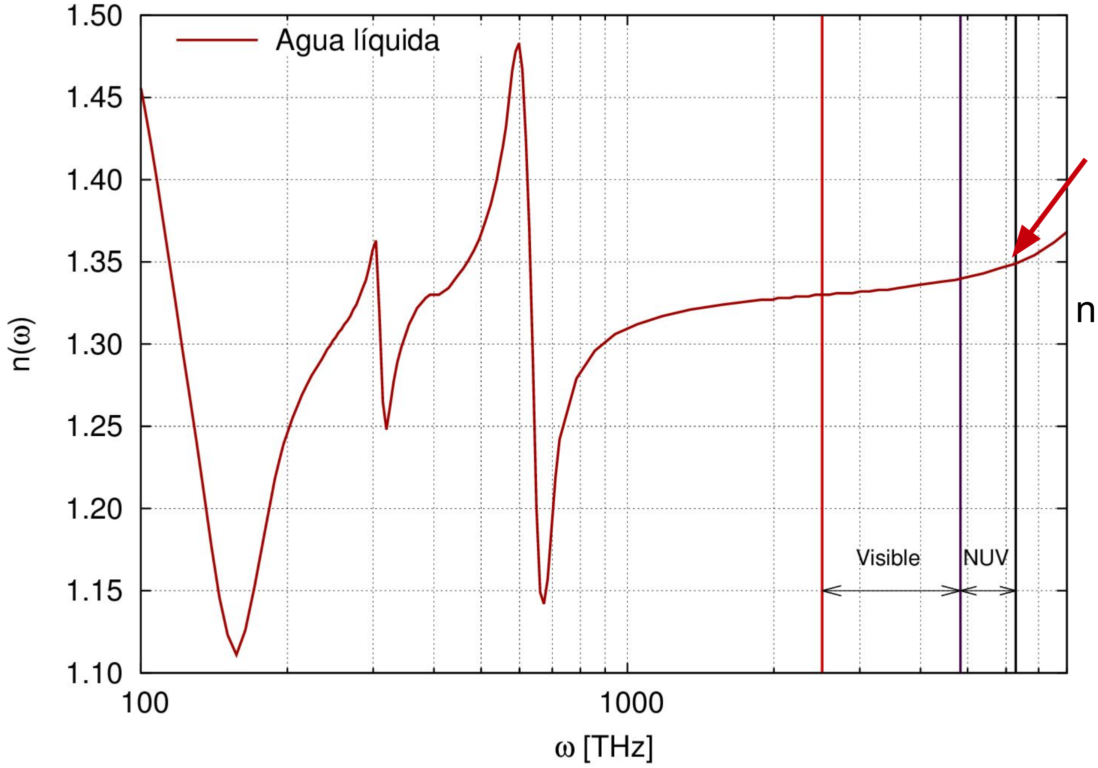
Efecto Cherenkov simplificado





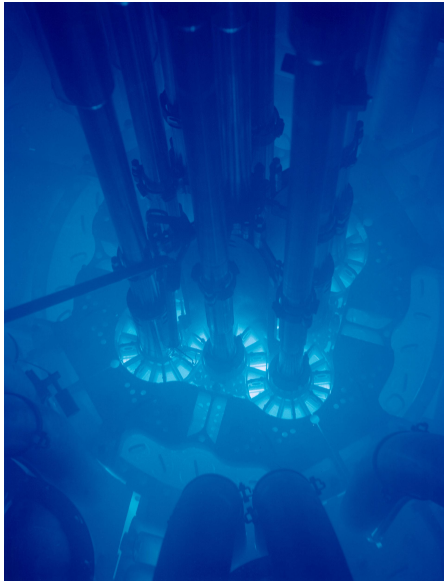
- Medio material con índice de refracción n = cte
- Partícula cargada con velocidad β c > (c/n)

Índice de refracción agua



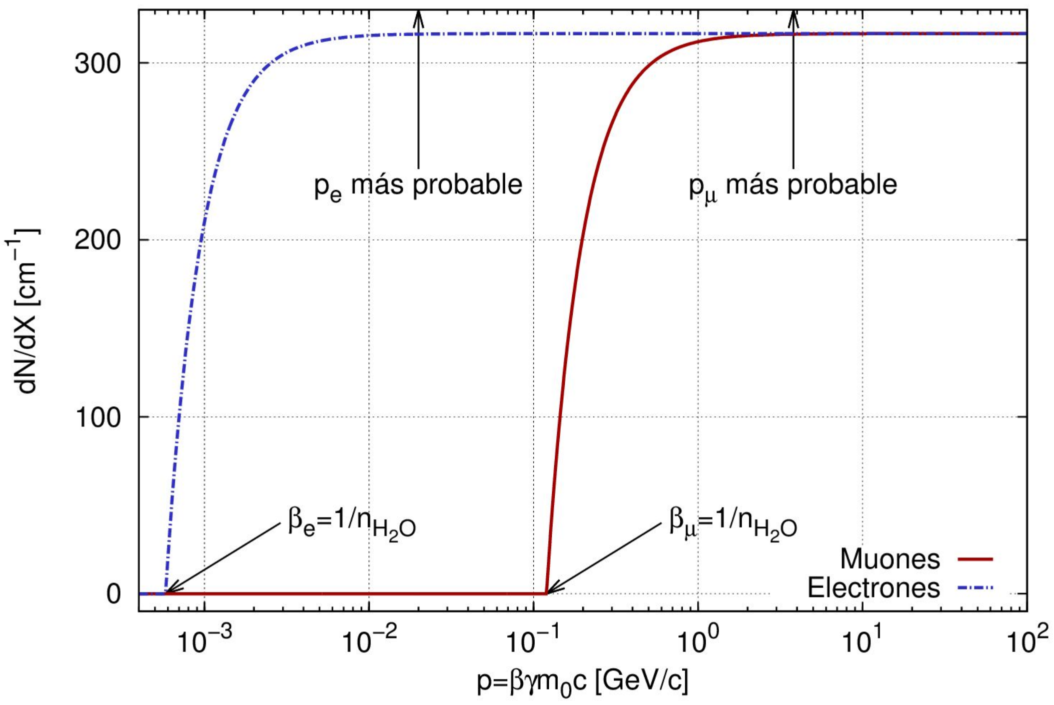
Emisión Cherenkov en Agua

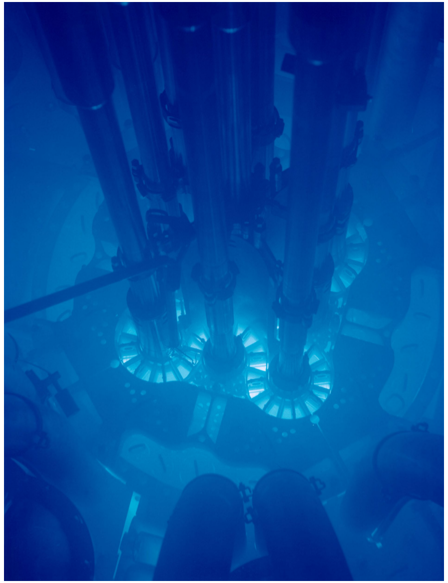
n=1.333



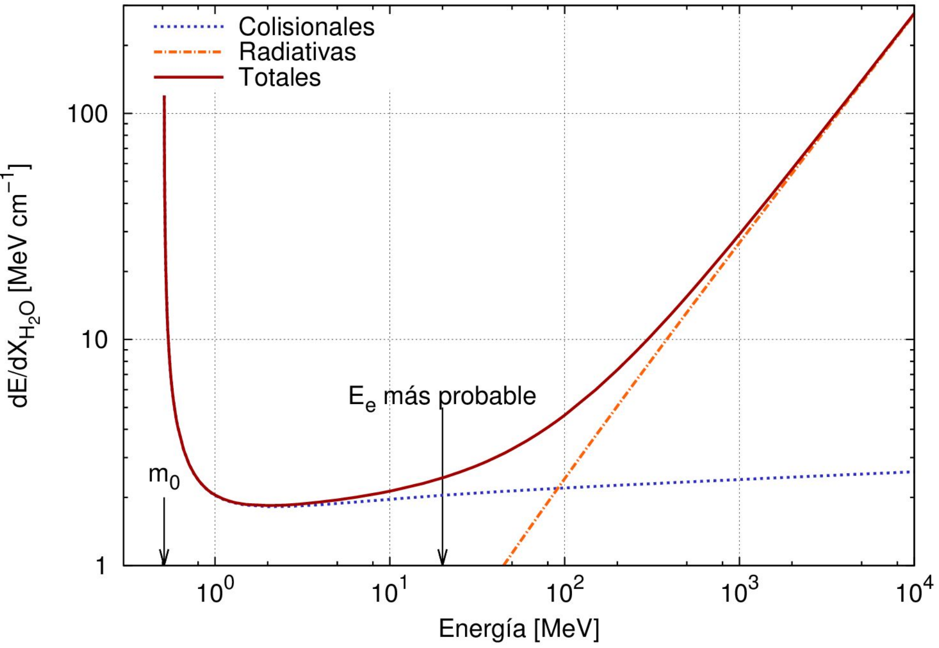
Calcular el camino de un fotón en el tanque

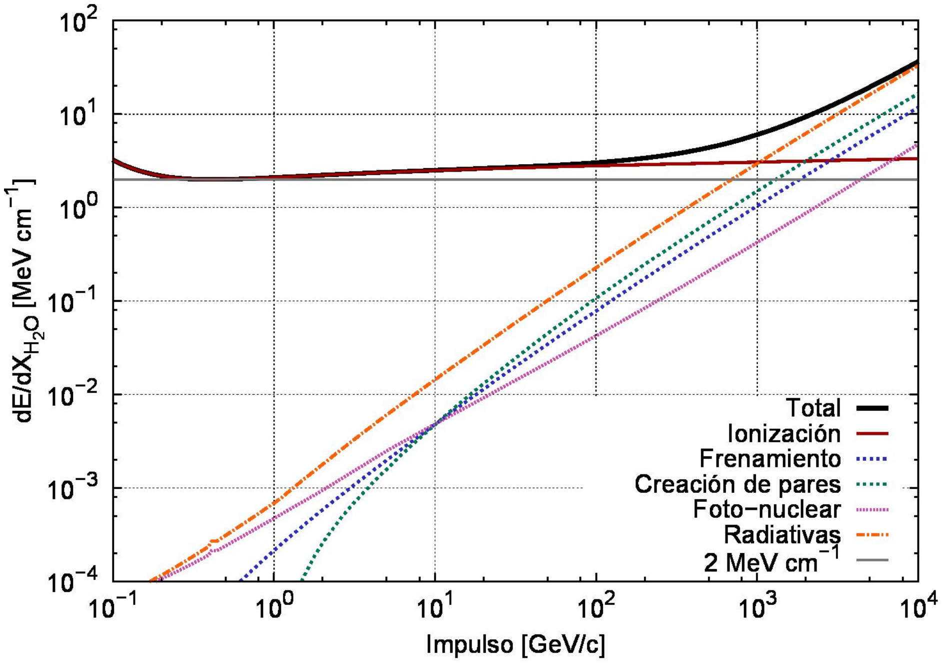
Producción Cherenkov en agua





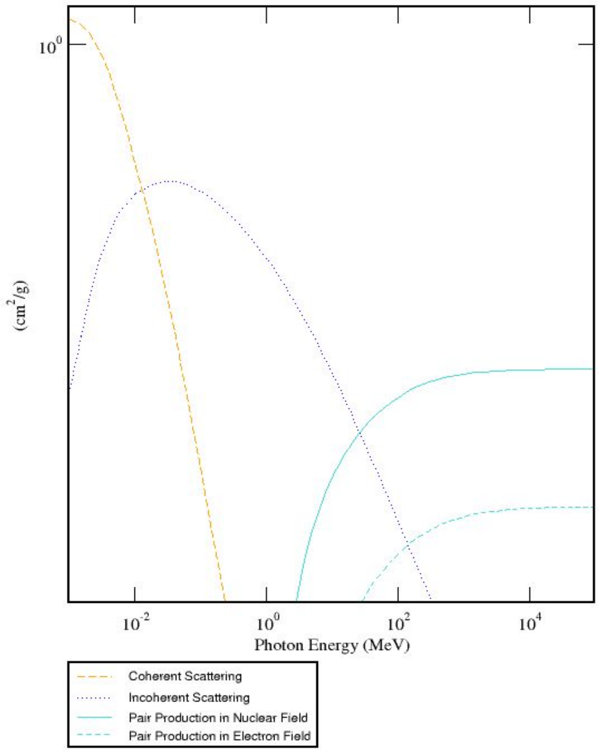
dE/dX electrones vs muones en agua





Calcular el número de fotones y la energía depositada por un muon vertical

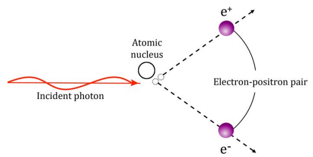
¿Qué pasa con los fotones?



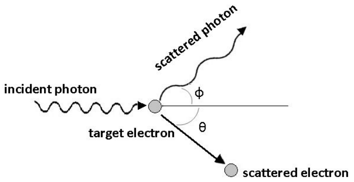
Particulas sin carga → No hay Cherenkov

Pero hay dos efectos adicionales:

1) Producción de pares: un fotón puede producir un par que produzca señal

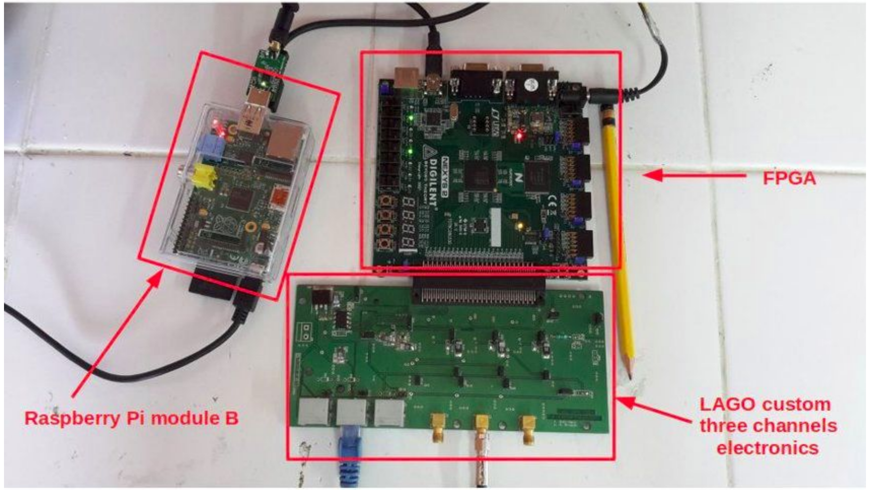


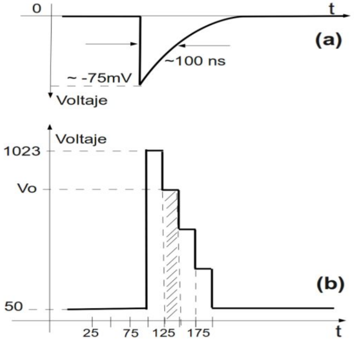
2) Compton: por scattering compton un electrón puede ser promovido



Adquisición de datos

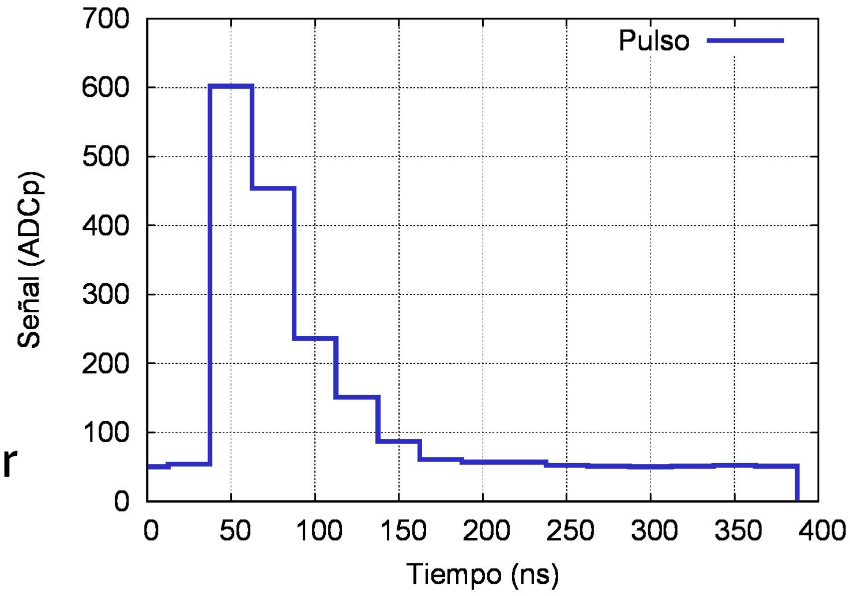
- Señales analógicas (pulsos) en el PMT
- Amplificación de la señal
- Hasta tres canales independientes
- Digitalización FADC 10 bits a 40 MHz (25 ns)

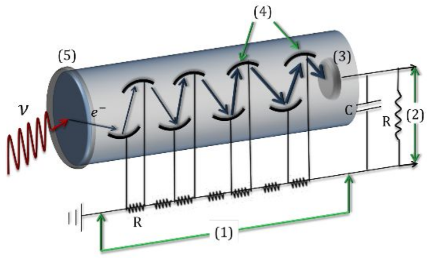




Calcular la corriente

- Datos:
  - Tres (Dos) canales de señales digitalizadas
- Metadatos
  - Id del Detector
  - Telemetría del detector
  - Datos atmosféricos, PyT
  - Datos monitoreo GPS
  - ....
- Una hora por archivo





```
50 50 50
61 49 54
139 49 602
91 51 454
59 50 236
60 50 151
53 50 87
53 50 61
50 50 57
51 51 57
50 50 52
51 49 51
51 50 50
50 49 51
51 50 52
50 50 51
# t 4 30008562
# c 663486982
```

Tag temporal y número de pulso

Definiciones

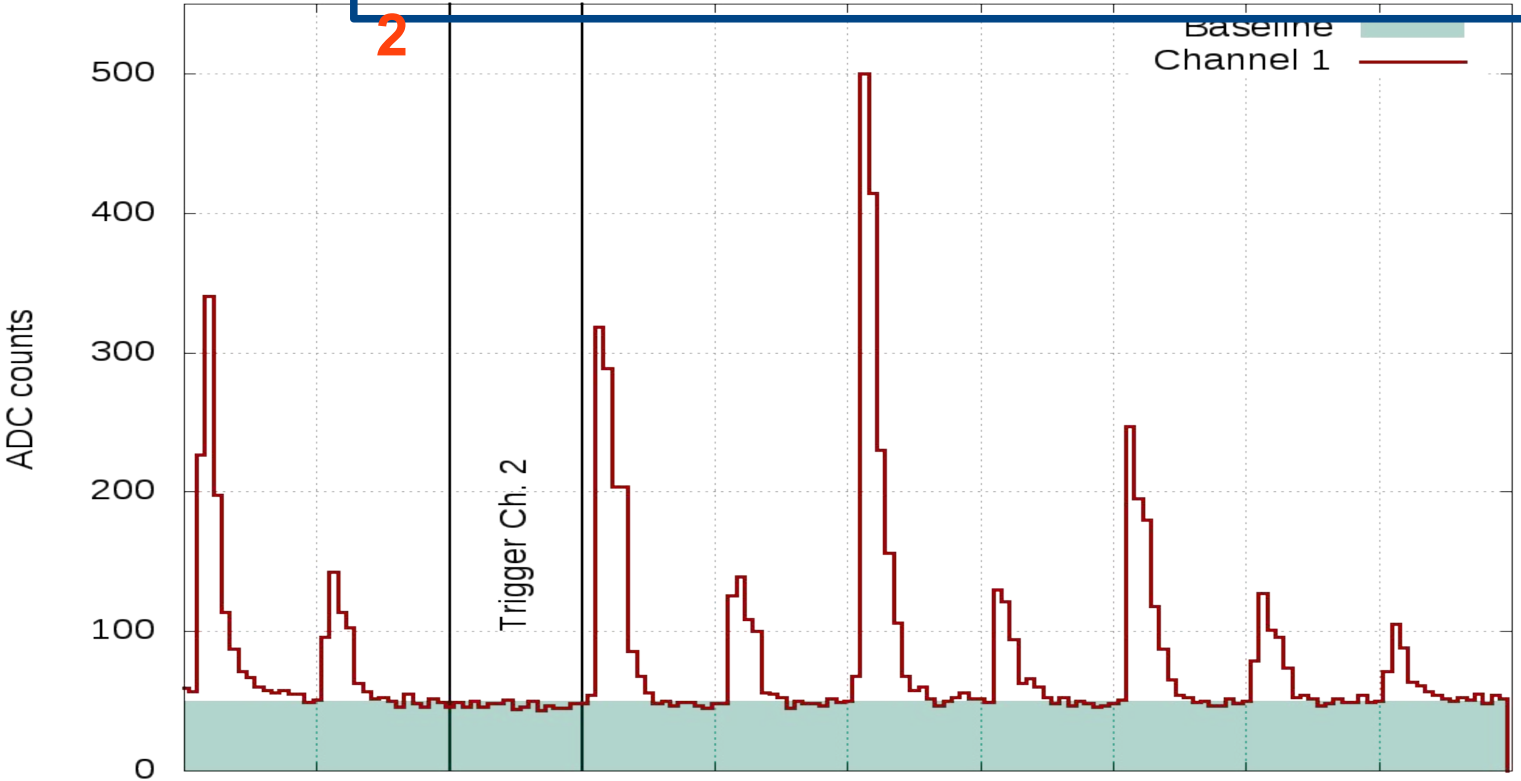
50 50 50
61 49 54
139 49 602
91 51 454
59 50 236
60 50 151
53 50 87
53 50 61
50 50 57
51 51 57
50 50 52
51 49 51
51 50 50
50 49 51
51 50 52
50 50 51
t 4 30008562
c 663486982

50 50 50
49 51 51
62 50 106
53 50 117
51 51 62
50 50 55
50 50 51
53 51 51
51 50 51
49 49 52
51 50 51
51 49 51
51 50 52
50 49 50
50 51 50
52 50 51
t 4 30008646
c 663486983

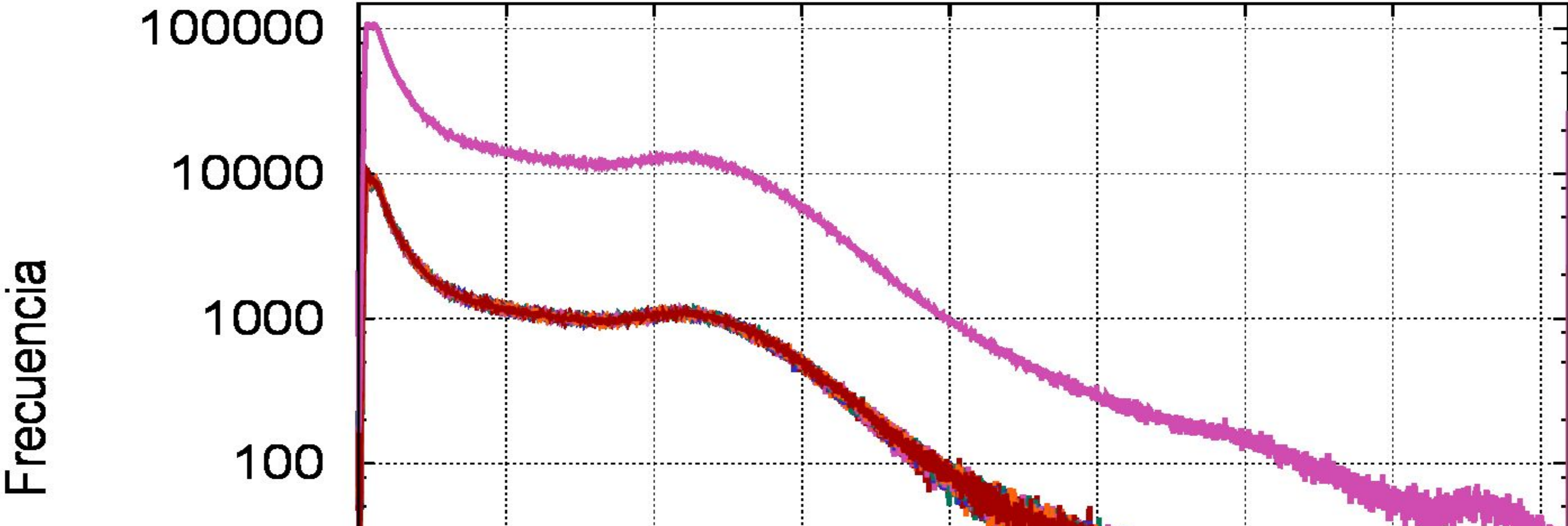
- Pulso canal j
- Pico
- Área ← Energía depositada
- Área sobre Pico:
- Δt (independiente de j)

Estructura del archivo de pulsos

name_(no)gps_YYYY_MM_DD_HHhMM.dat.bz2

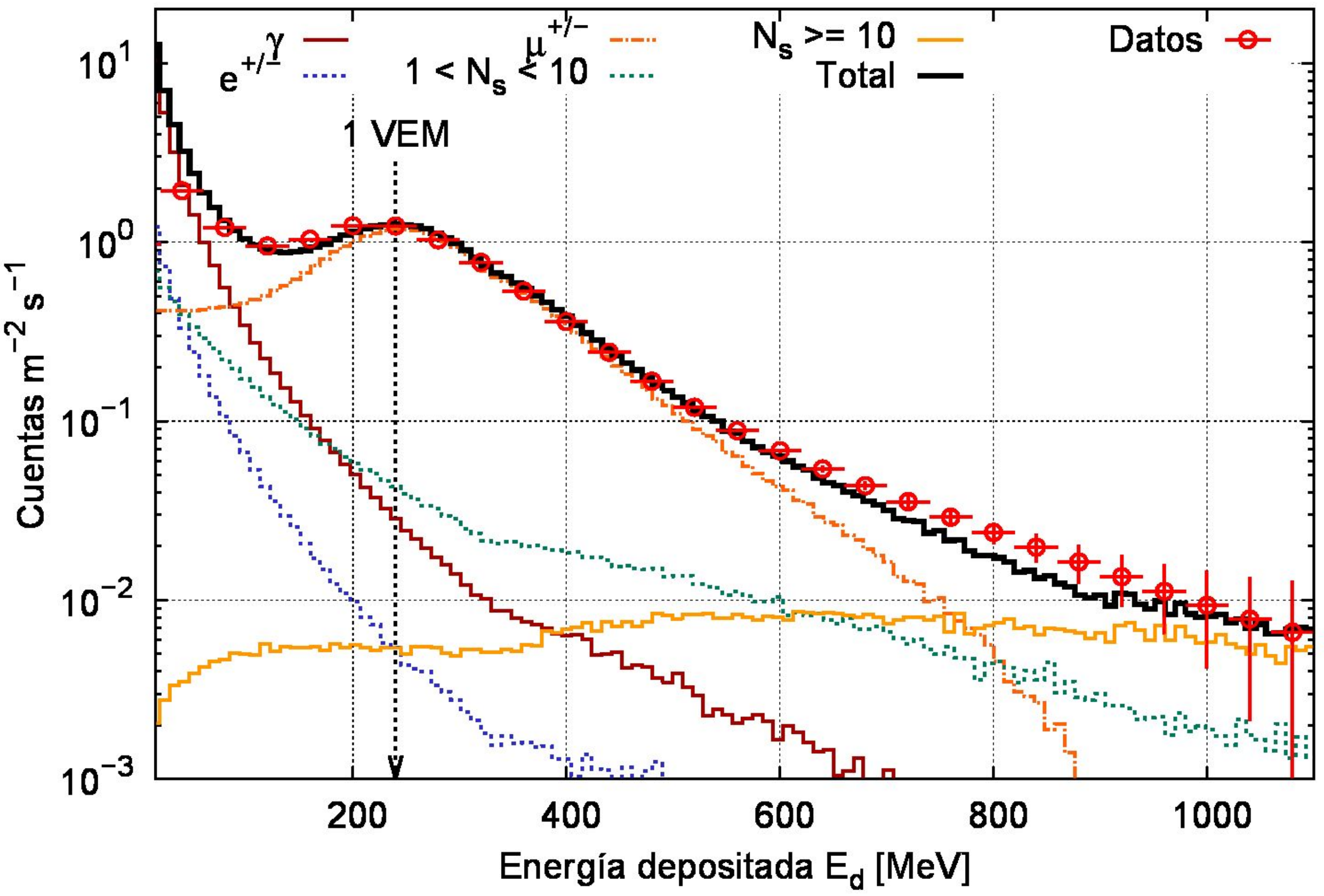


- Área A de cada pulso → histograma de áreas

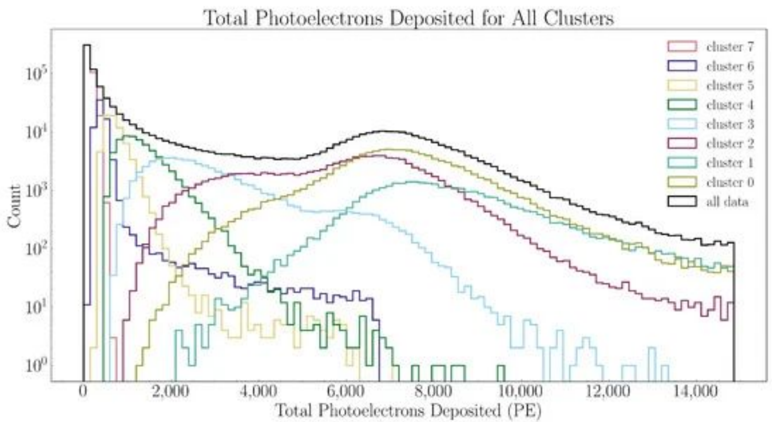


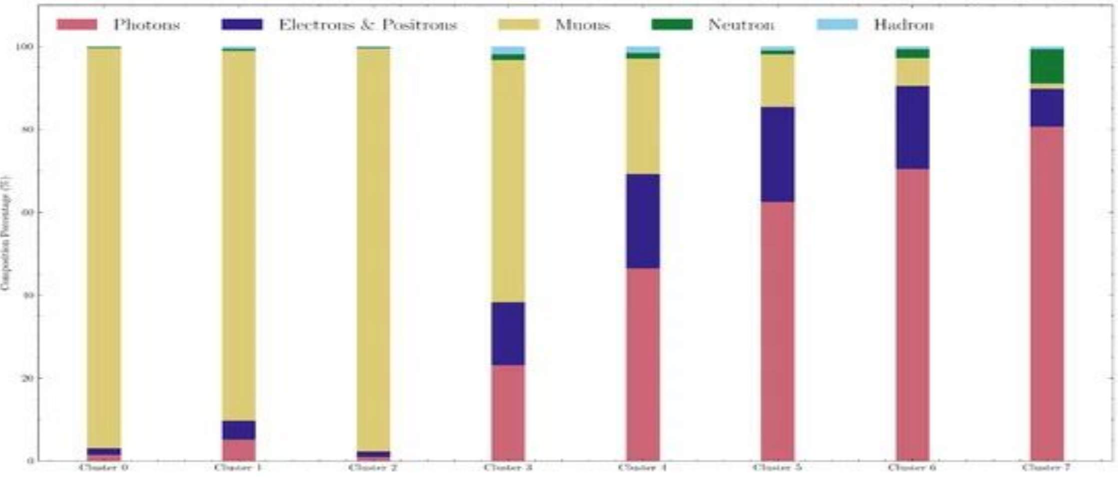
Flujo de primarios → (CORSIKA + Sitio) → Flujo de Secundarios

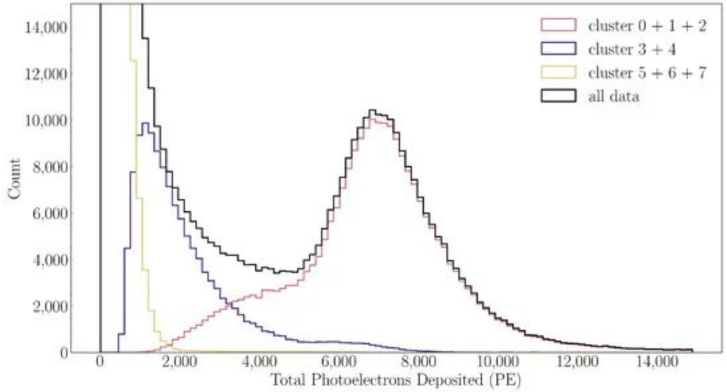
Flujo de secundarios → (G4+Detector) → Señales en el detector



Enhanced Particle Classification in Water Cherenkov Detectors Using Machine Learning: Modeling and Validation with Monte Carlo Simulation Datasets

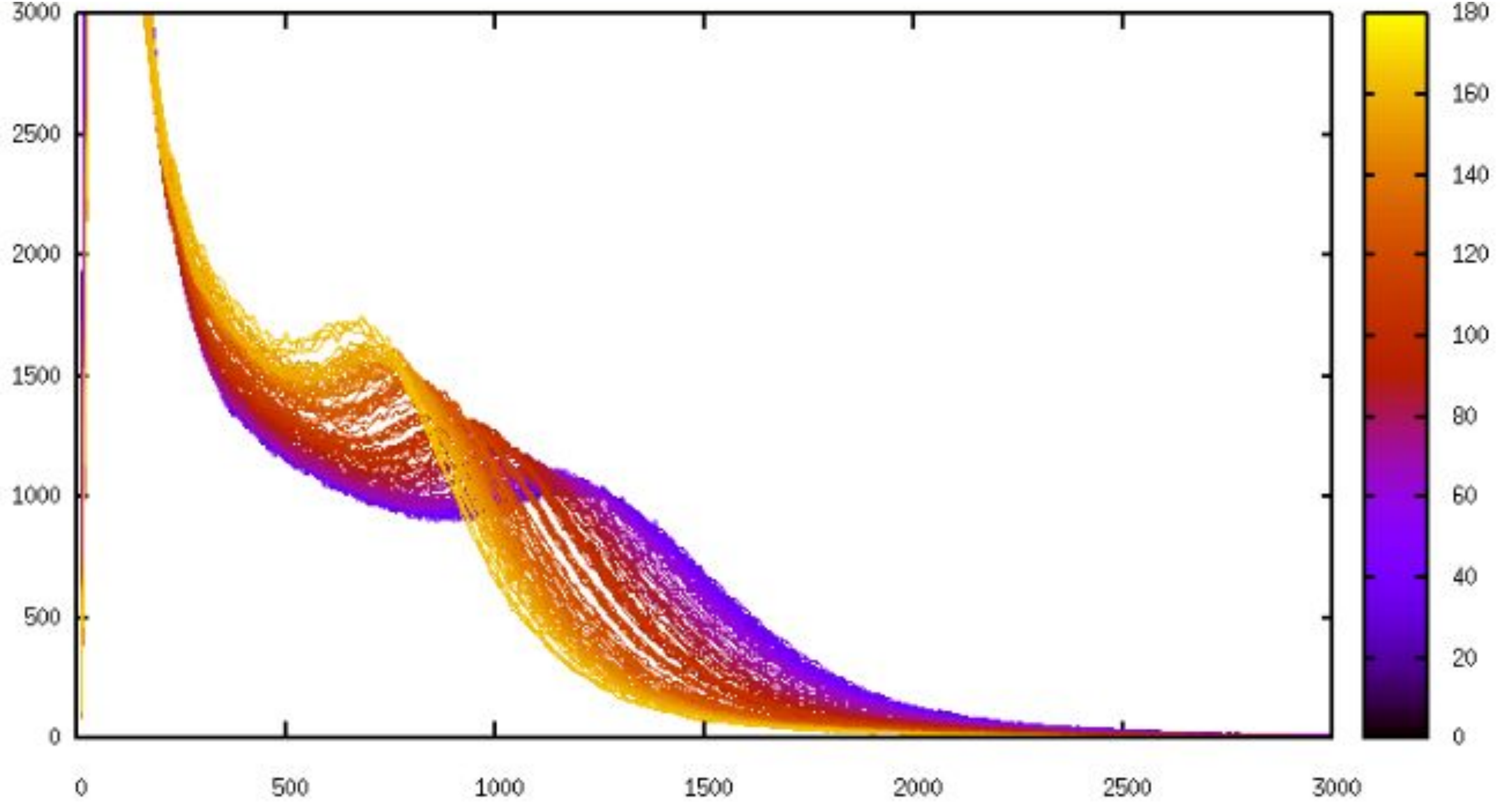






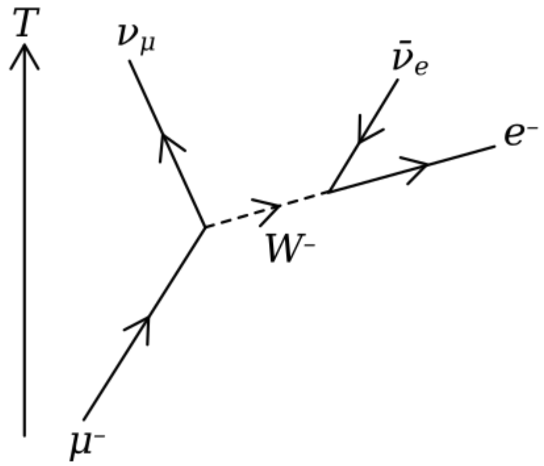
El detector real de LAGO

Impacto de la calidad del agua



¿Qué pasa con los muones que no atraviezan el detector?

Decaimiento del Muón



$$\tau_\mu = (2197.03 \pm 0.04)\,\text{ns}$$

Histograma de Diferencias Temporales

- Calculamos el Δt entre pulsos sucesivos
- La distribución de Δt es un muestreo de las distribucion de los procesos en el interior:
  - Flujo de secundarios

$$\left(\lambda_{\text{fondo}}\right)^{-1} \equiv \tau_{\text{fondo}} \simeq 2.5\,\text{ms} = 2.5 \times 10^{3}\,\mu\text{s}$$

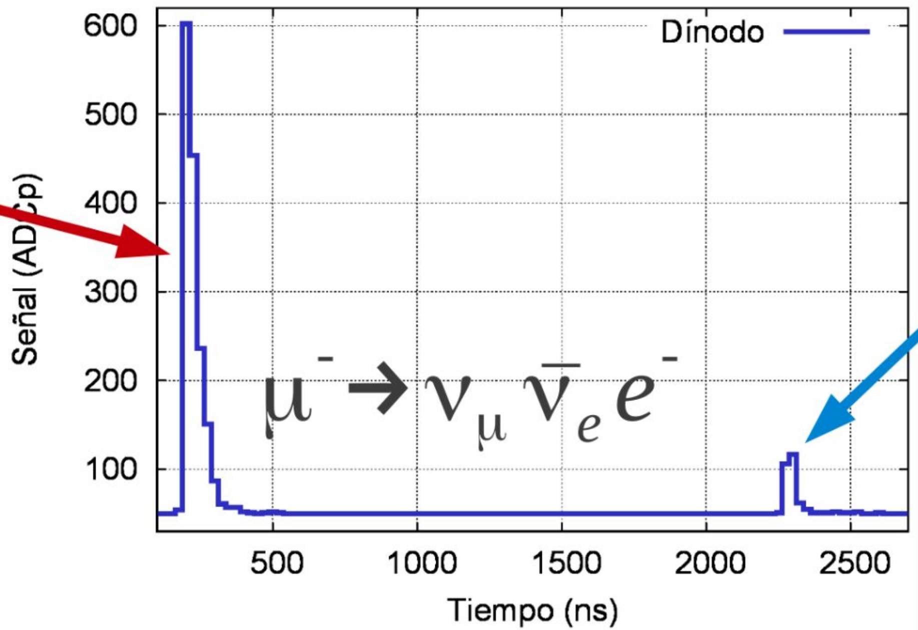
  - Decaimento de los muones en el interior del detector

$$\left(\lambda_{\mu}\right)^{-1} \equiv \tau_{\mu} \simeq 2.2\,\mu\text{s}$$

- Tiempos característicos muy diferentes

50	50	50
61	49	54
139	49	602
91	51	454
59	50	236
60	50	151
53	50	87
53	50	61
50	50	57
51	51	57
50	50	52
51	49	51
51	50	50
50	49	51
51	50	52
50	50	51

```
# t 4 30008562
# c 663486982
```



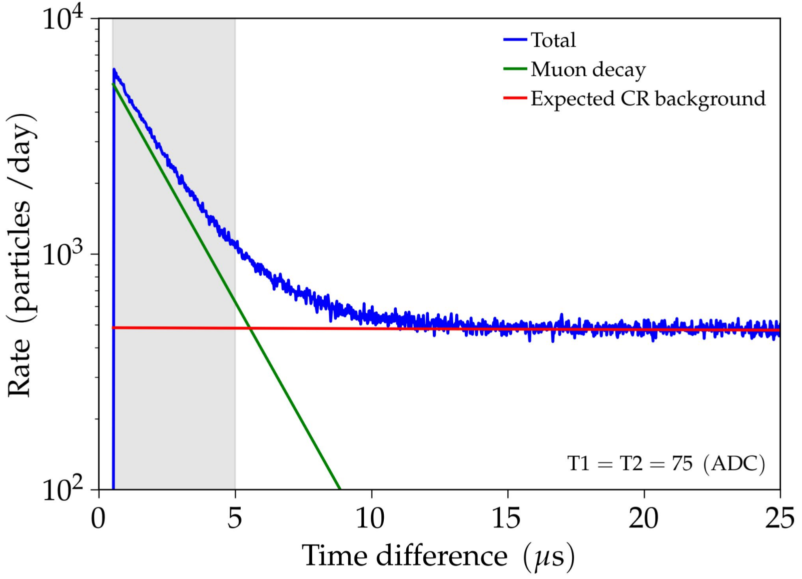
$$\Delta t = 84 \times 25 \text{ ns} = 2100 \text{ ns}$$

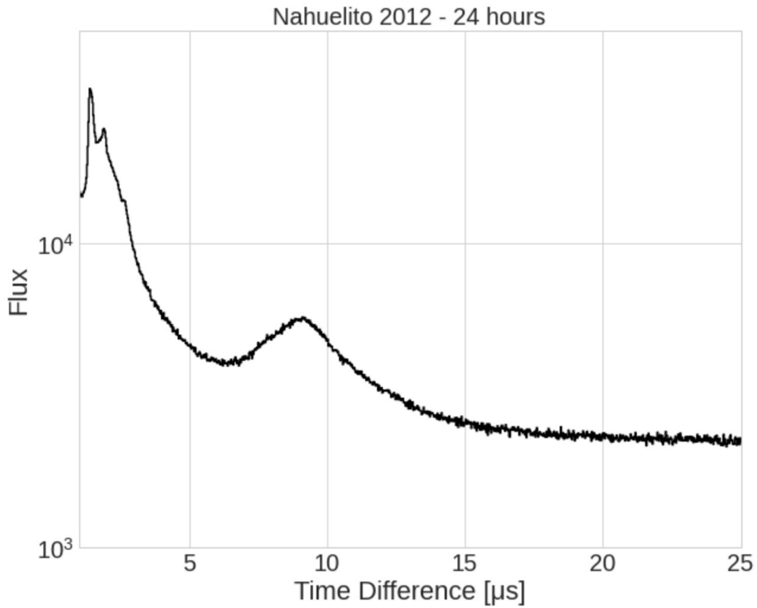
$$\Delta p = 1$$

50	50	50
49	51	51
62	50	106
53	50	117
51	51	62
50	50	55
50	50	51
53	51	51
51	50	51
49	49	52
51	50	51
51	49	51
51	50	52
50	49	50
50	51	50
52	50	51

```
# t 4 30008646
# c 663486983
```

Histograma de Diferencias Temporales

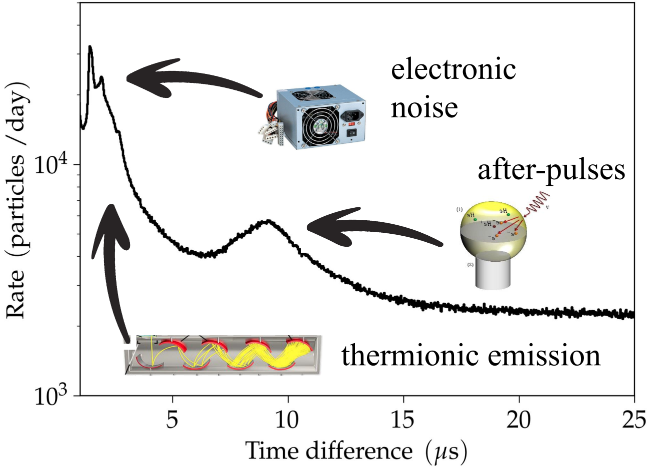




Measurement of the Muon Lifetime and the Michel Spectrum in the LAGO Water Cherenkov Detectors as a tool to improve energy calibration and to enhance the signal-to-noise ratio

L. Otiniano, A. Taboada, H. Asorey, I. Sidelnik, C. Castromonte, A. Campos-Fauth
for the LAGO Collaboration

Time difference between two consecutive pulses histogram

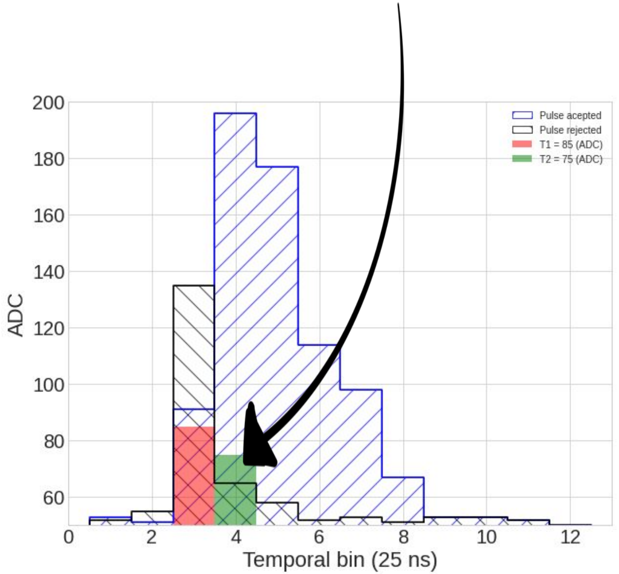


Noises in WCD are clearly visible

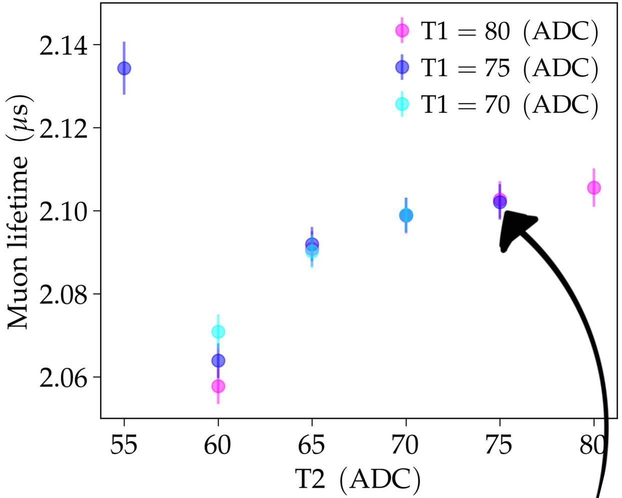
Short pulse width ~ ns

Noise Rejecting strategy

Impose a secondary trigger

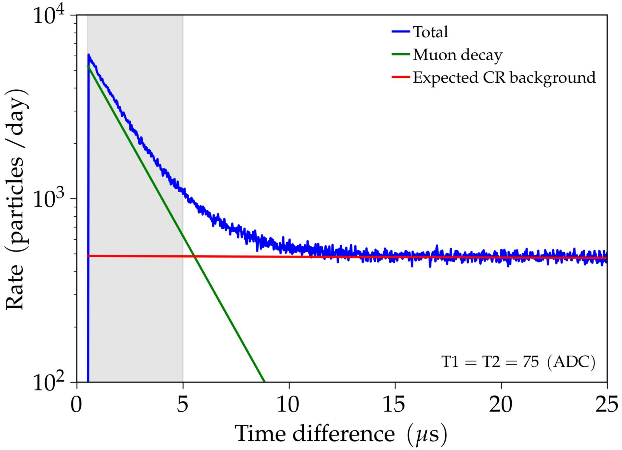


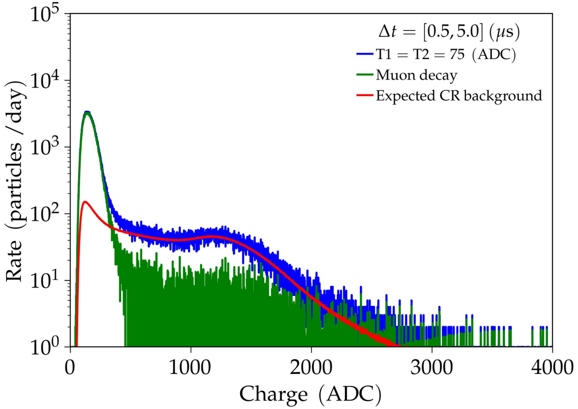
Measurement of the Muon Lifetime and the Michel Spectrum in the LAGO Water Cherenkov Detectors as a tool to improve energy calibration and to enhance the signal-to-noise ratio



We look for stable value of muon lifetime measure from time spectrum

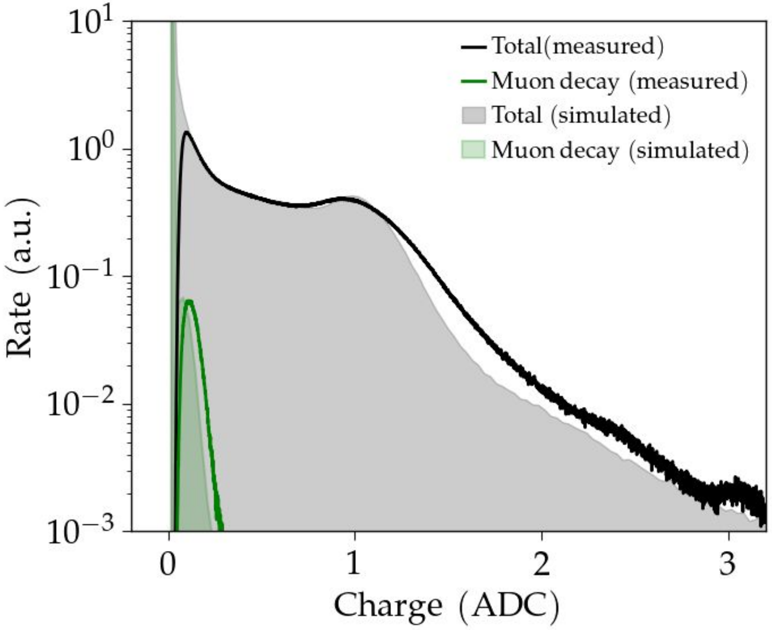
>90% of muon decay events are present in the 0.5-5 μs band of the time between consecutive pulses histogram





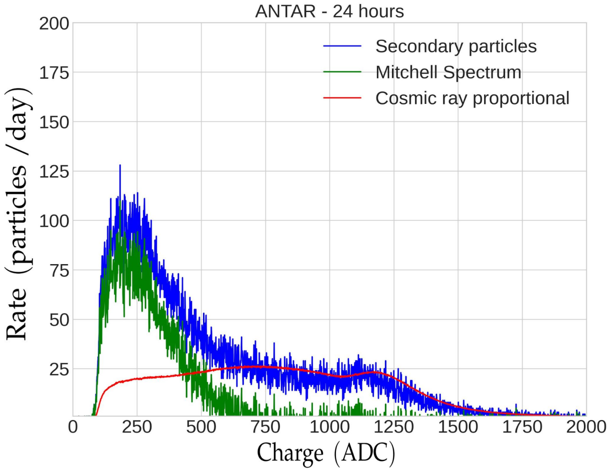
Michel spectrum is obtained from this band after background correction

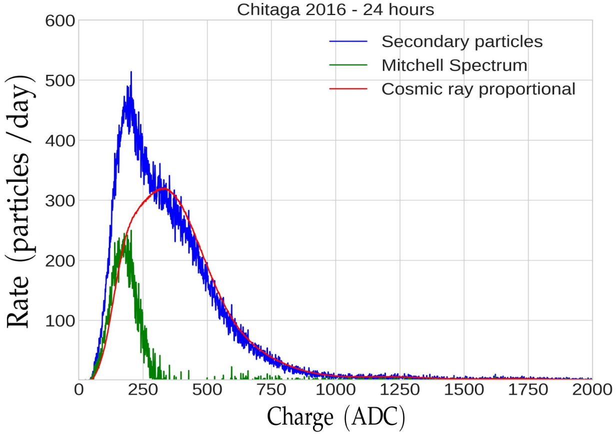
Measurement of the Muon Lifetime and the Michel Spectrum in the LAGO Water Cherenkov Detectors as a tool to improve energy calibration and to enhance the signal-to-noise ratio



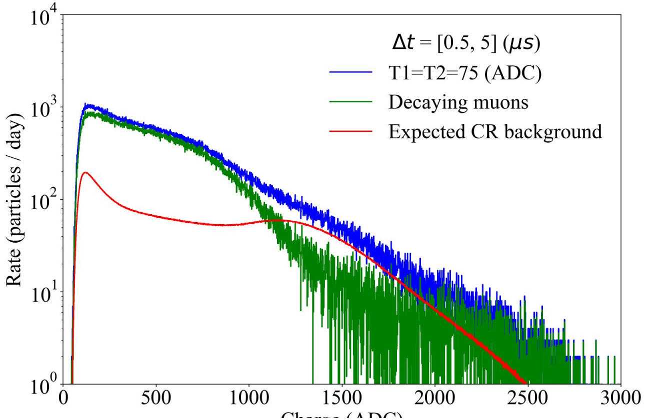
Good agreement with simulations

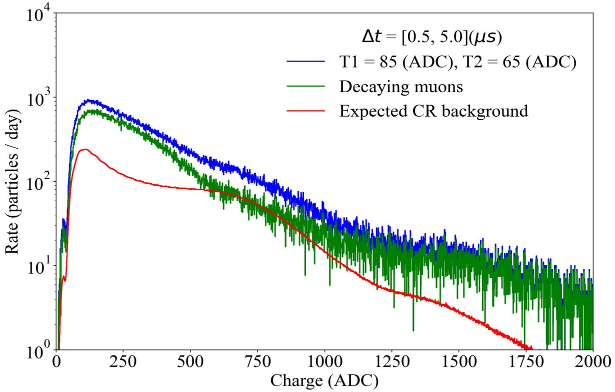
This process is being used for correcting operative datasets of LAGO WCDs





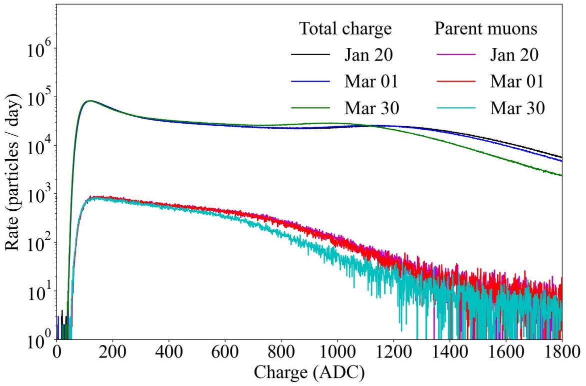
eMuon Decay as a Robust Long-Term Calibration Method for Water Cherenkov Detectors

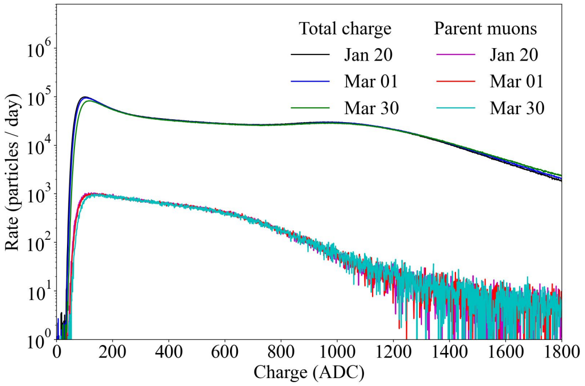


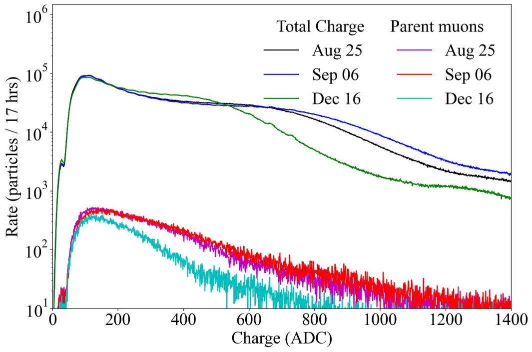


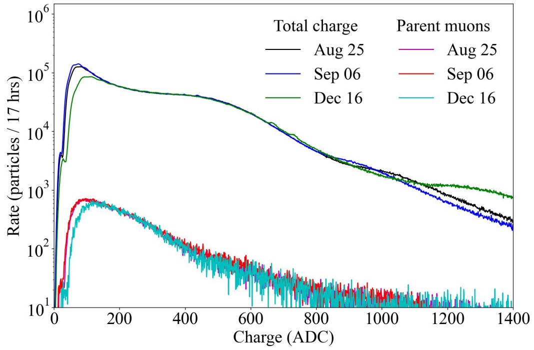
The ***charge spectrum of parent muons*** *is then estimated by selecting the* ***first pulse of both consecutive pulses with a time difference between 0.5 and 5 μs*** *subtracting from the* ***expected charge histogram the SP flux.***

eMuon Decay as a Robust Long-Term Calibration Method for Water Cherenkov Detectors









eMuon Decay as a Robust Long-Term Calibration Method for Water Cherenkov Detectors