



Escuela José Antonio Balseiro 2016

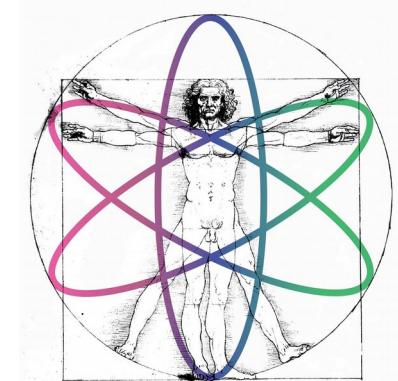
Nuevas Tendencias en Investigación en Física Médica

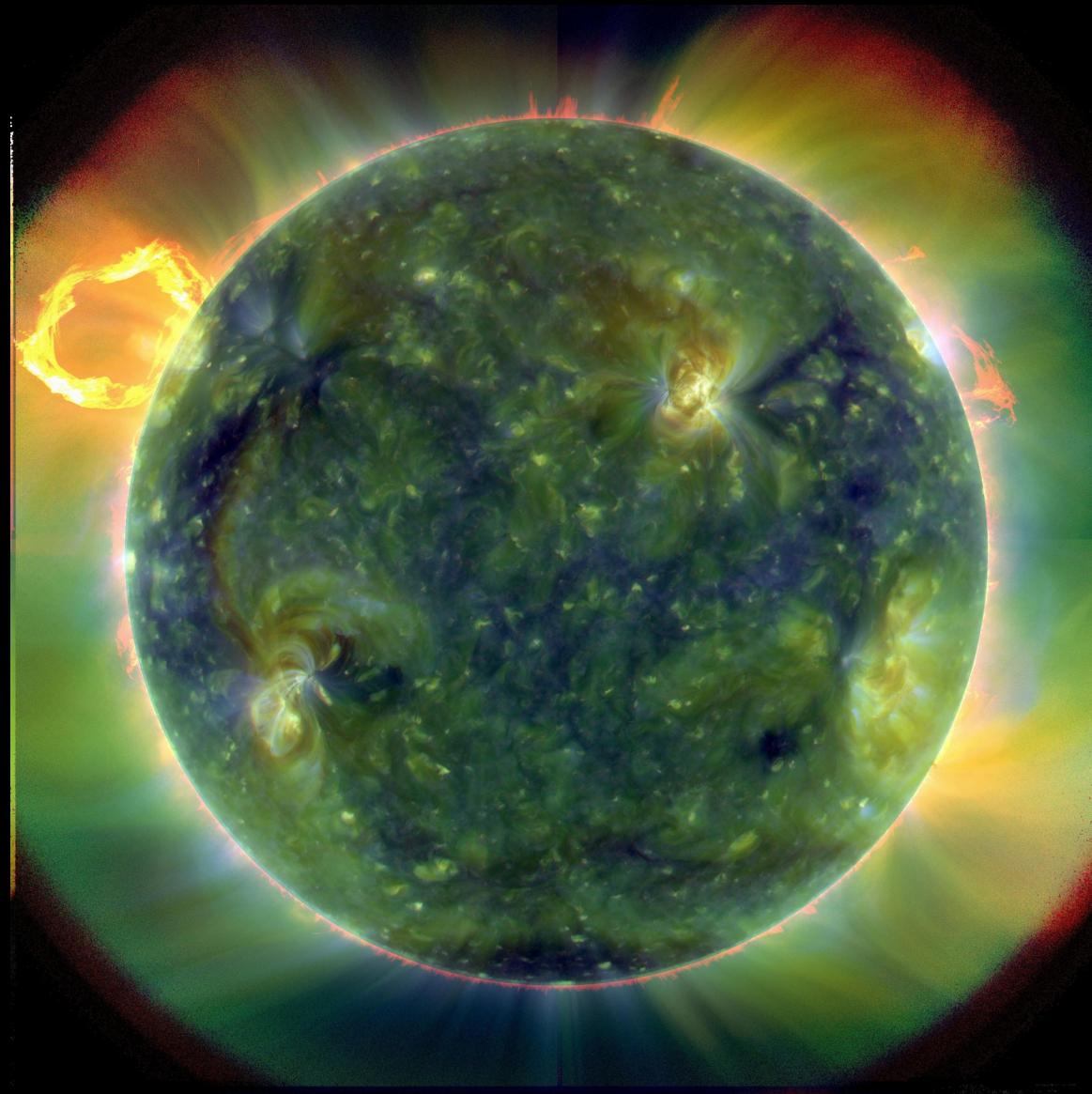
High energy simulations and (ultra) fast particle detection

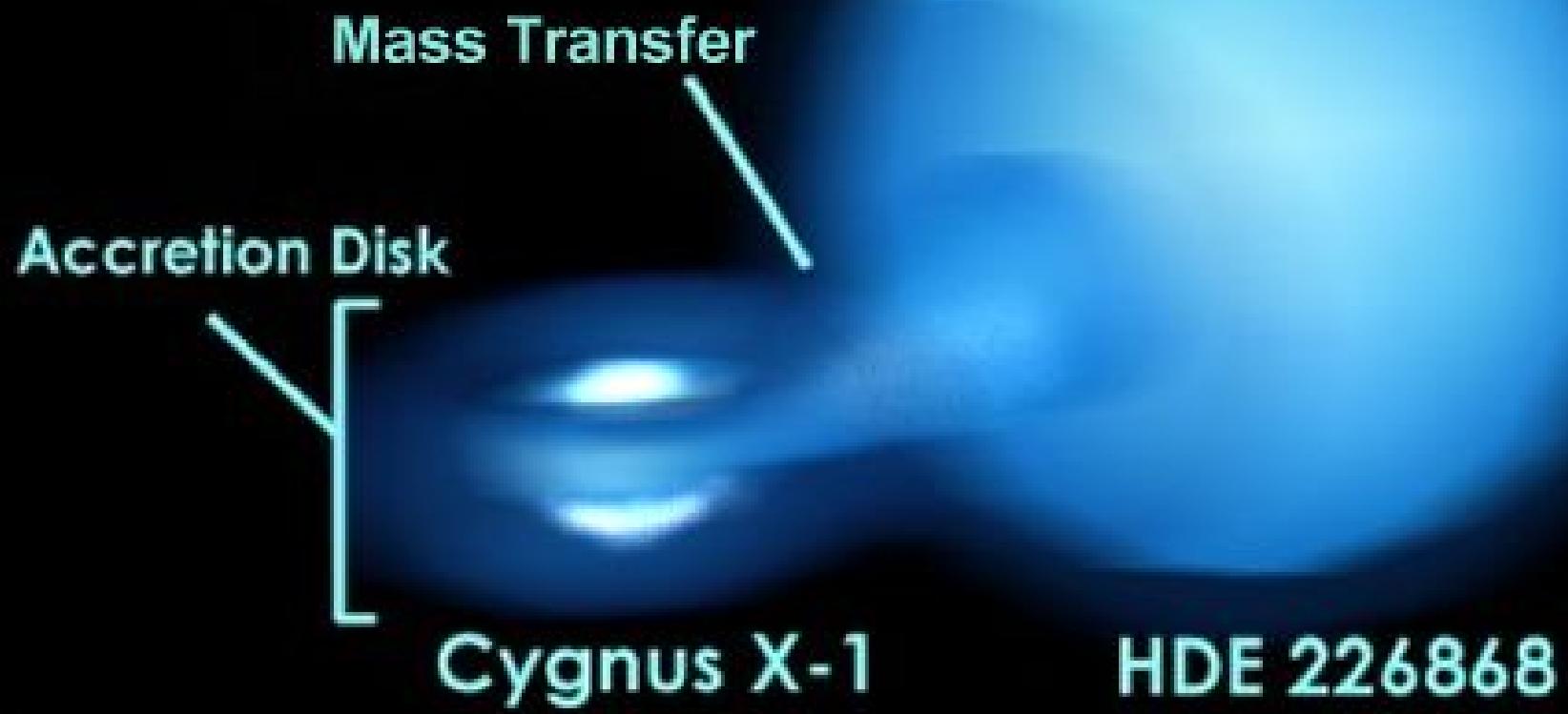
A (personal) compilation made by
Hernán Asorey

asoreyh@cab.cnea.gov.ar

Laboratorio Detección Partículas y Radiación
Centro Atómico Bariloche







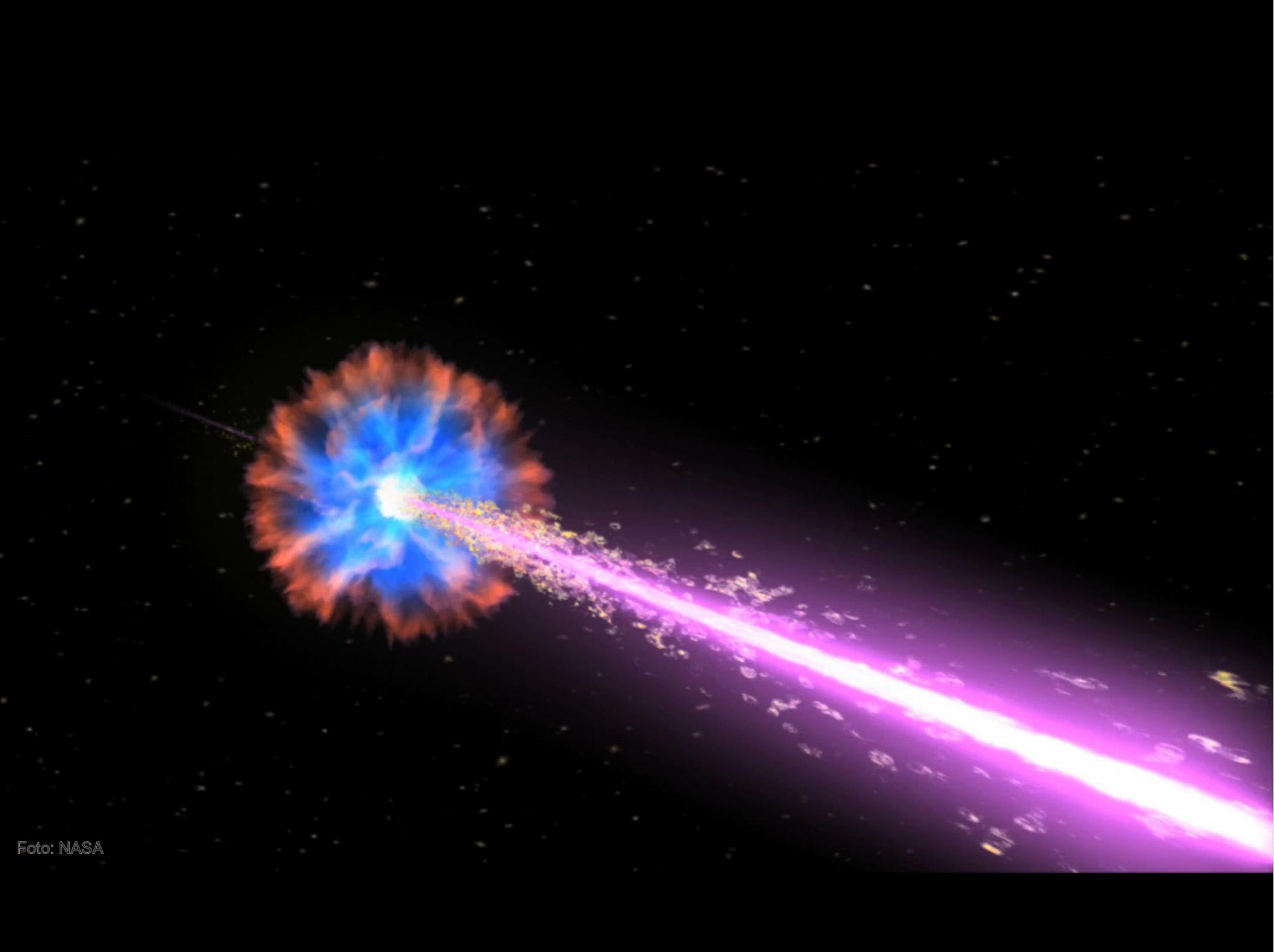
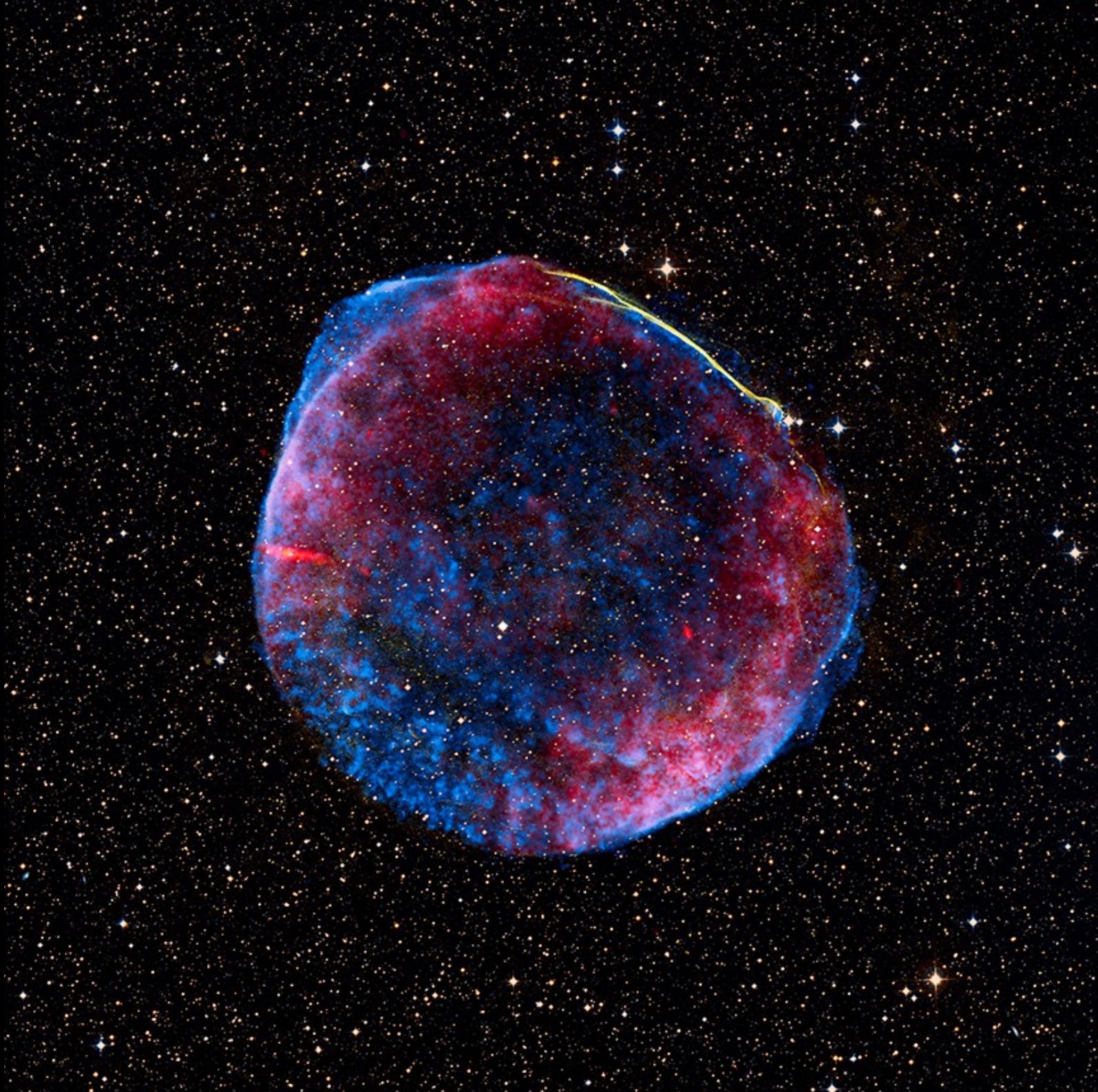


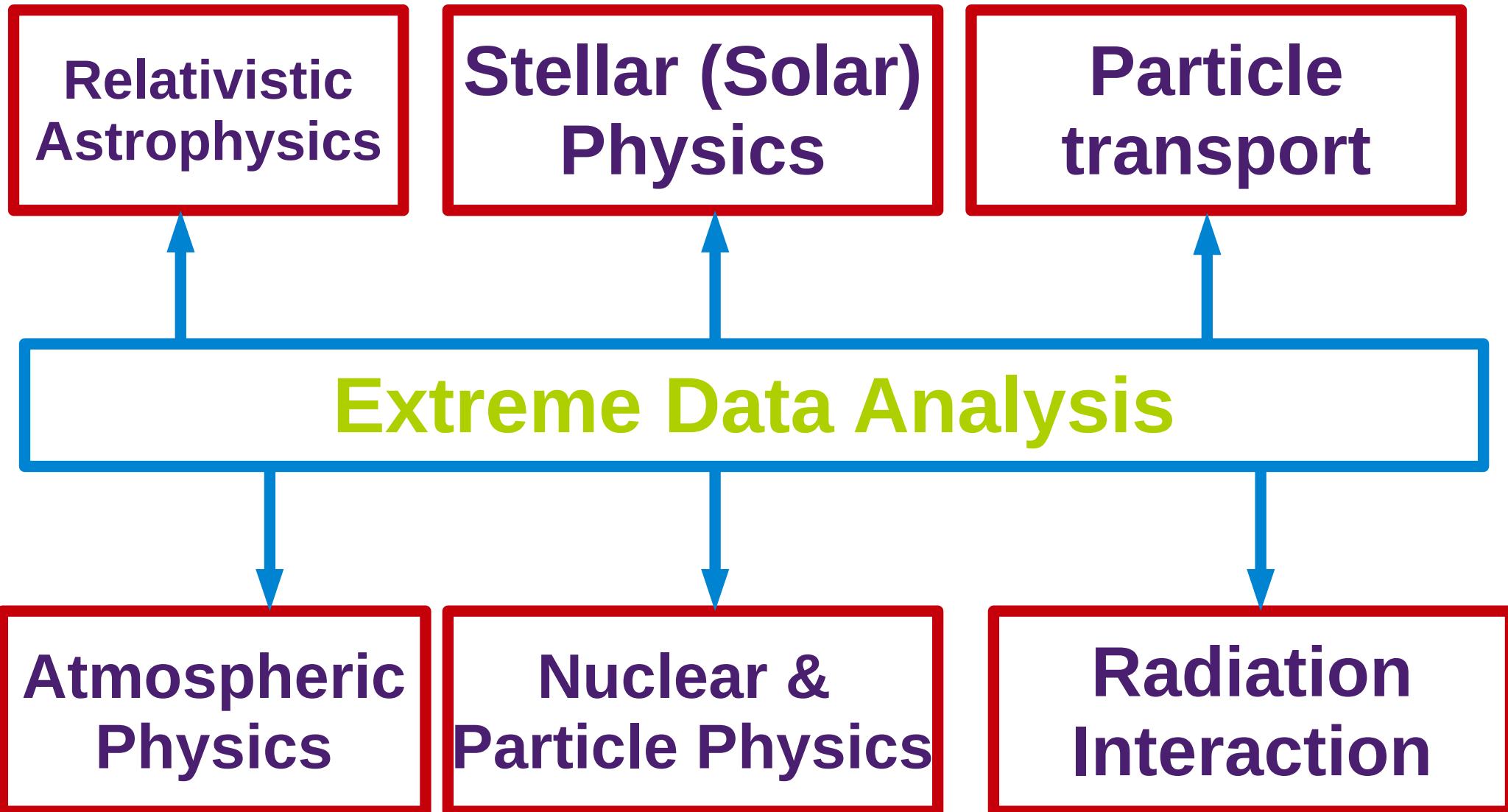
Foto: NASA





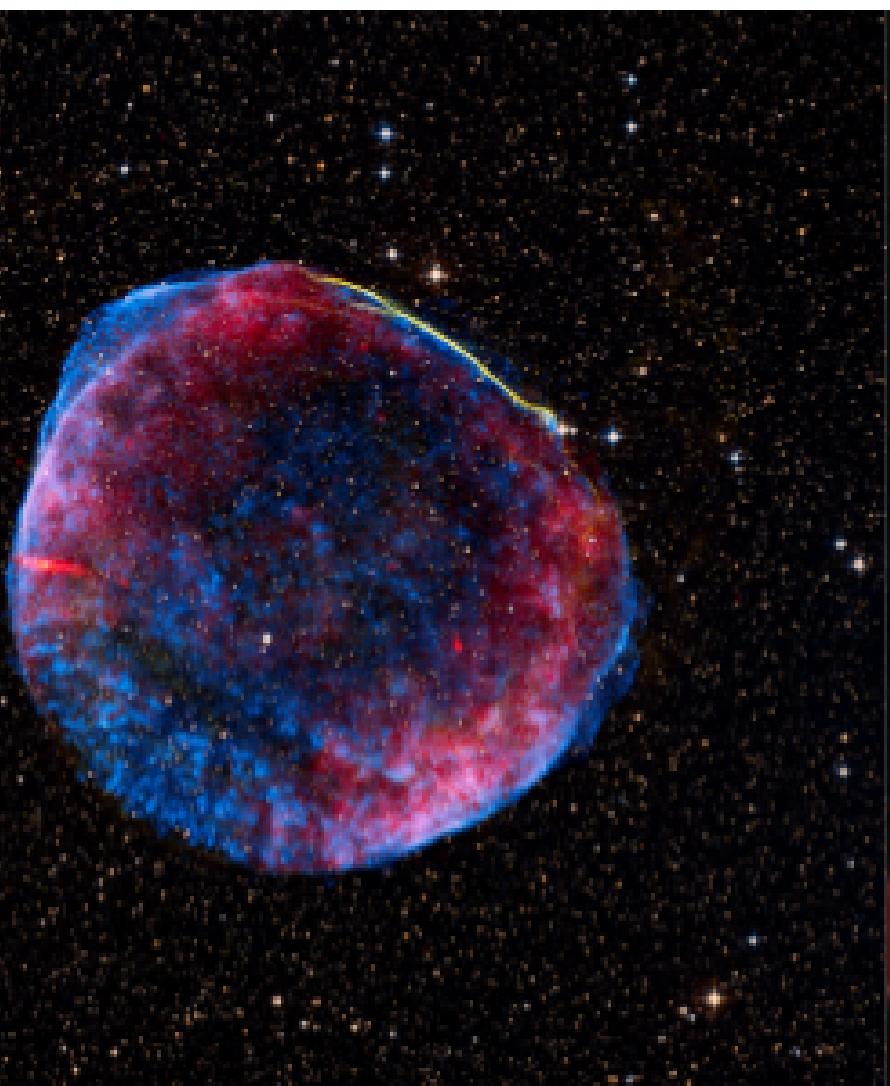


**Astroparticles are “witnesses” of the
most extreme phenomena
of the Universe**



Scopes

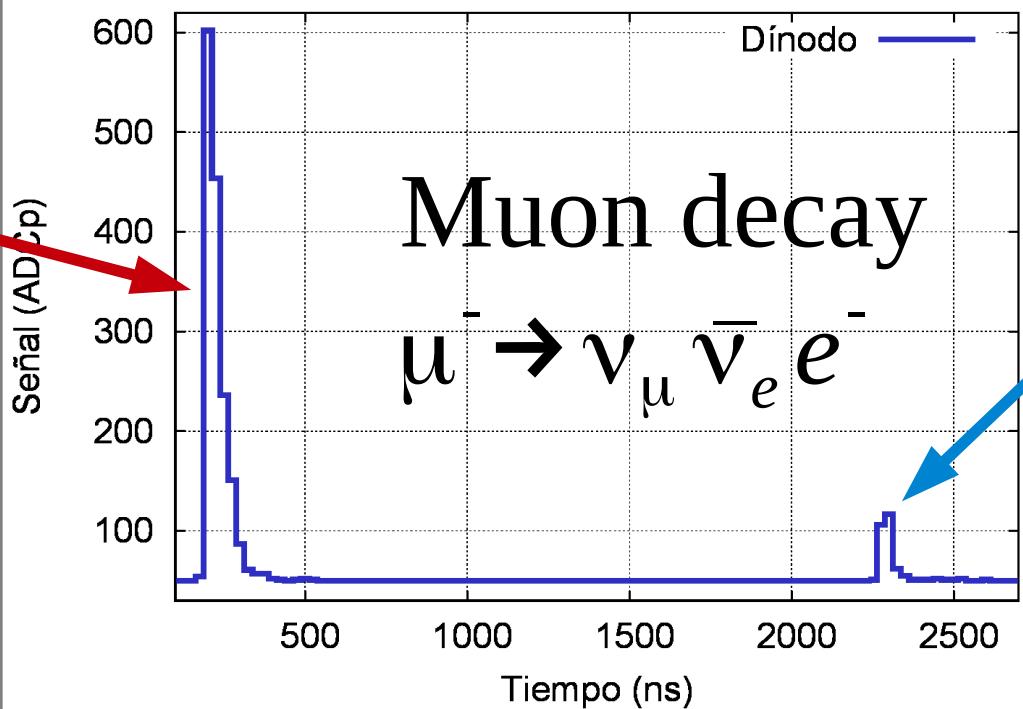
- It begins at a Supernova remnant



Scopes

- It begins at a Supernova remnant
- And it ends with complex analysis of complex data

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	



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

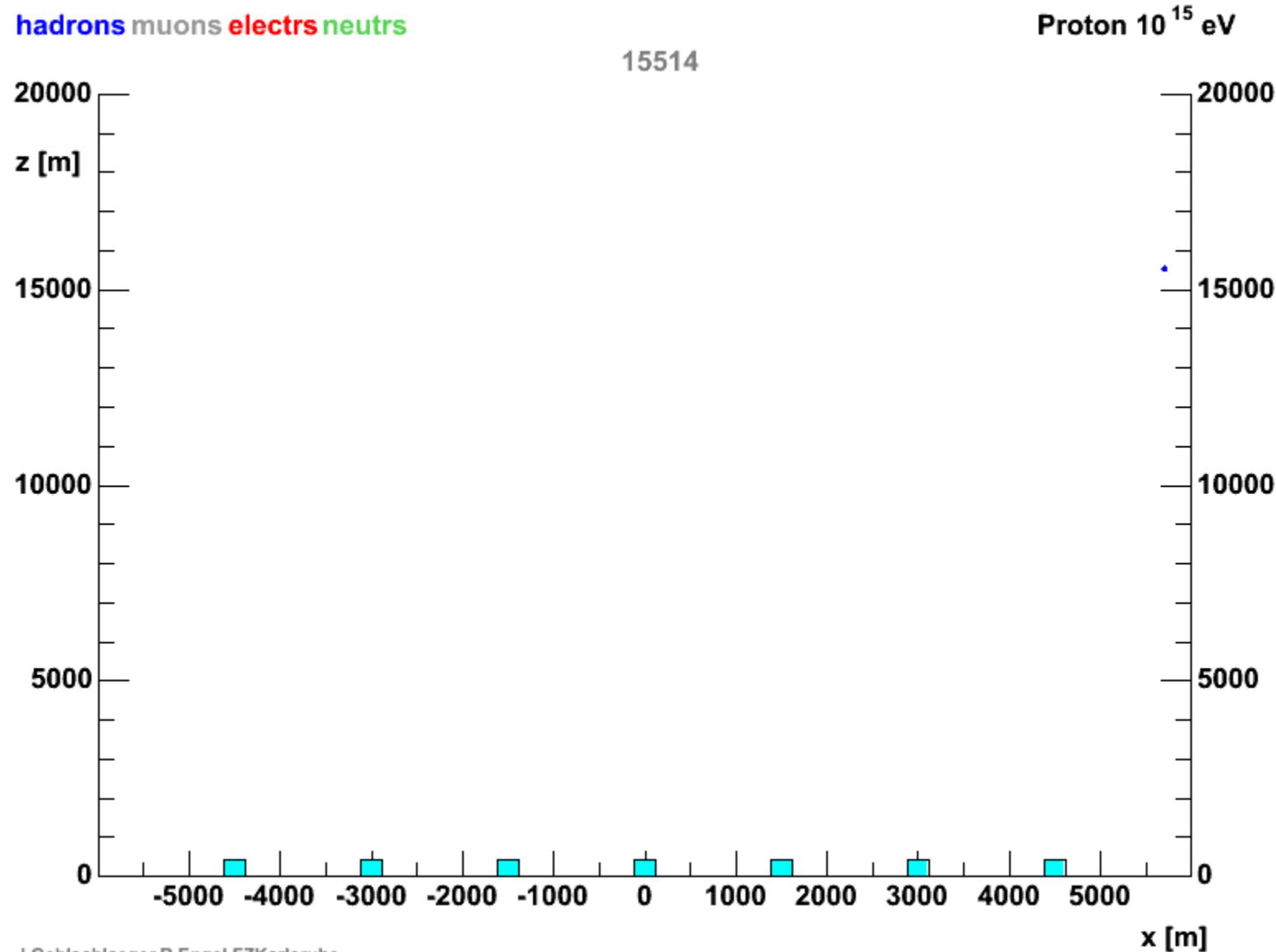
$$\Delta p = 1$$

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	

Extreme medium for the extreme Universe

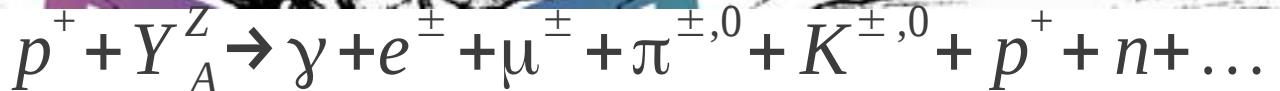
Cosmic Rays interact with the atmosphere, producing cascades of particles (secondaries) moving toward ground level at near the speed of light and in the direction of the incident (primary) particle

Particle interaction

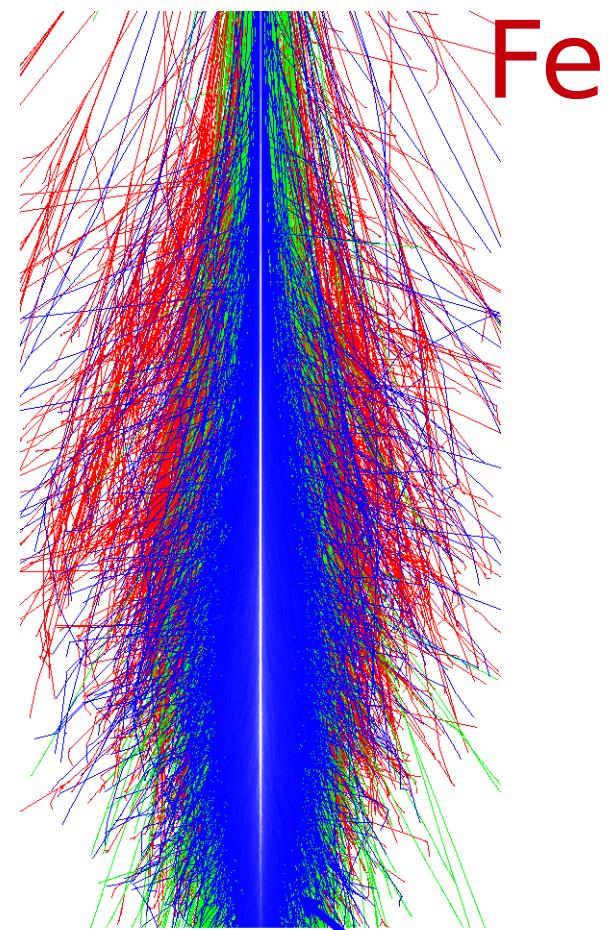
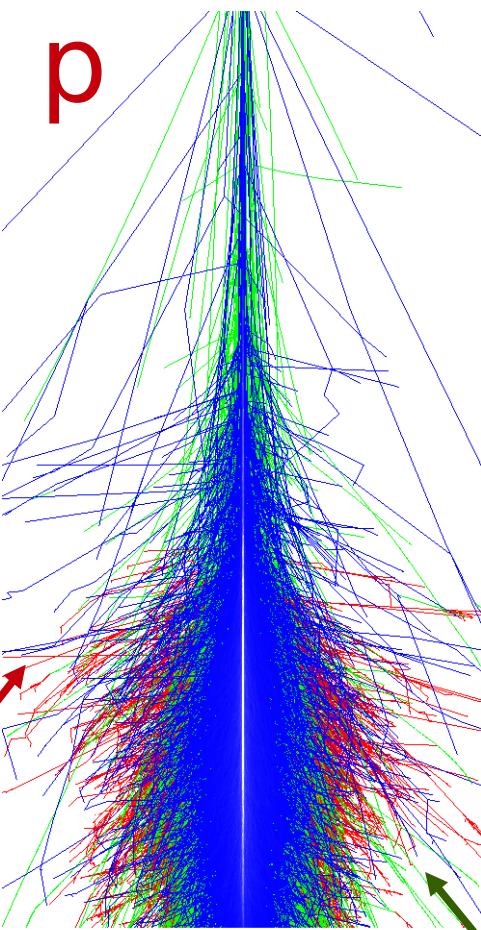
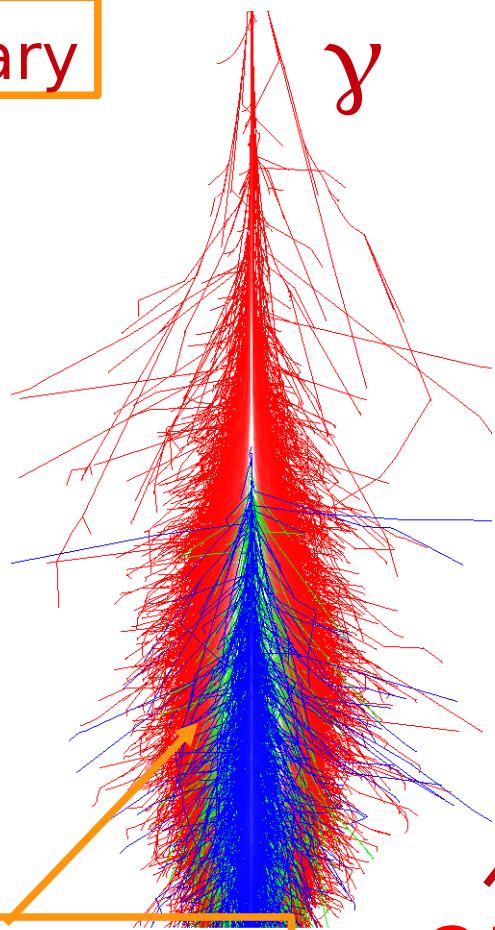


EAS: Extensive Air Showers

$E=5 \times 10^{14}$ eV



Primary



Secondaries

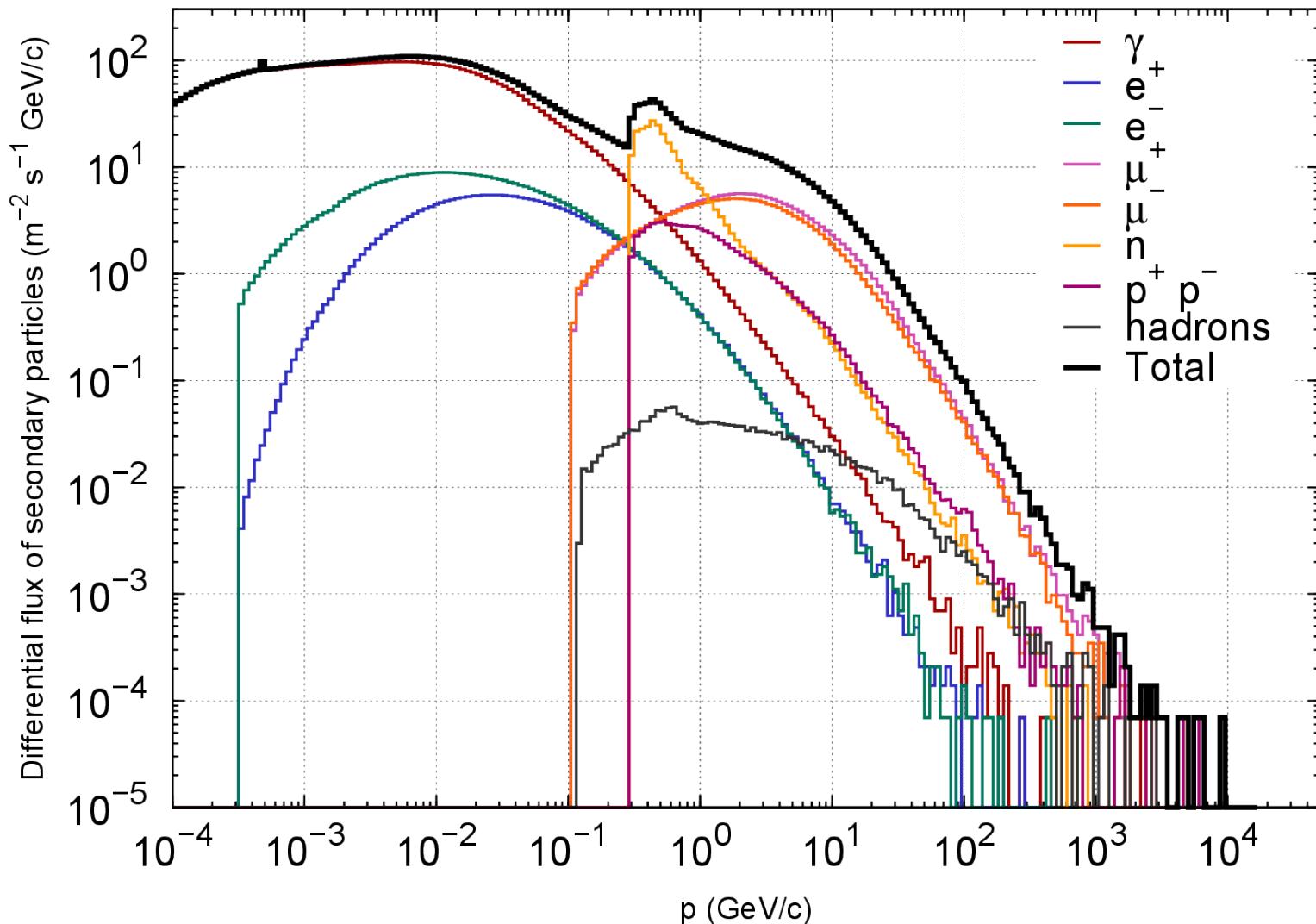
em

mu

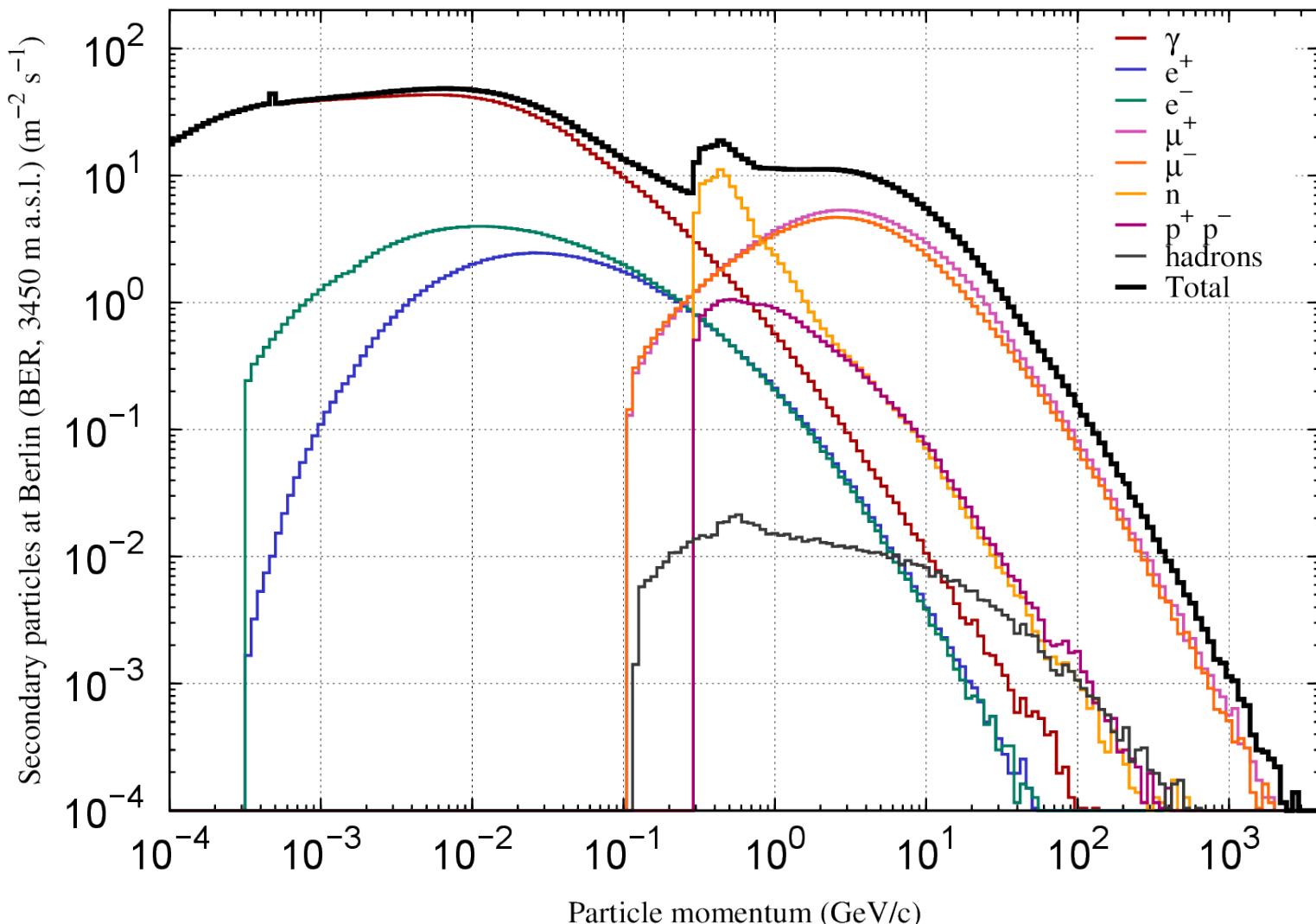
hd

Composition dependent development

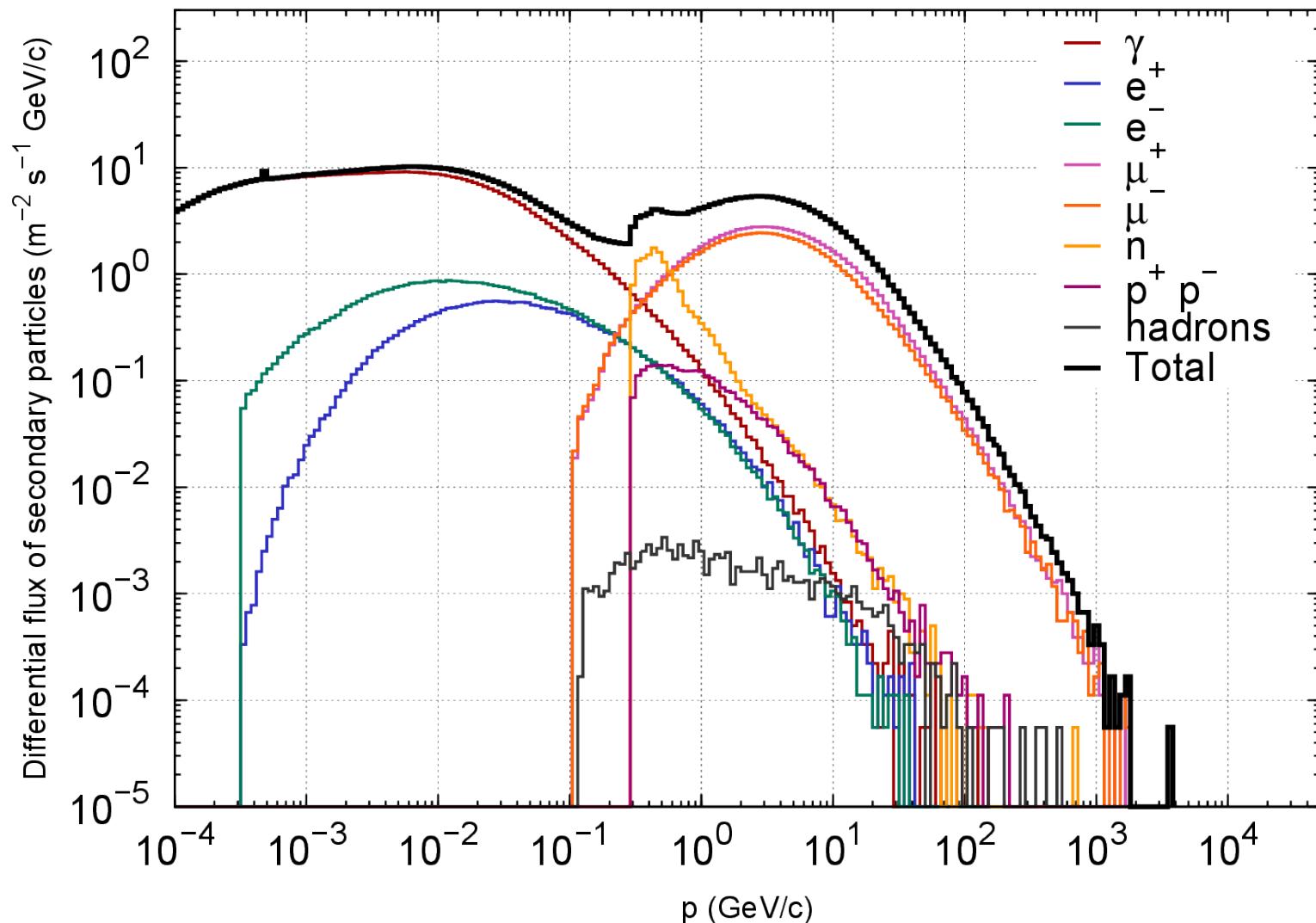
Chacaltaya, Bolivia, 5300 msnm



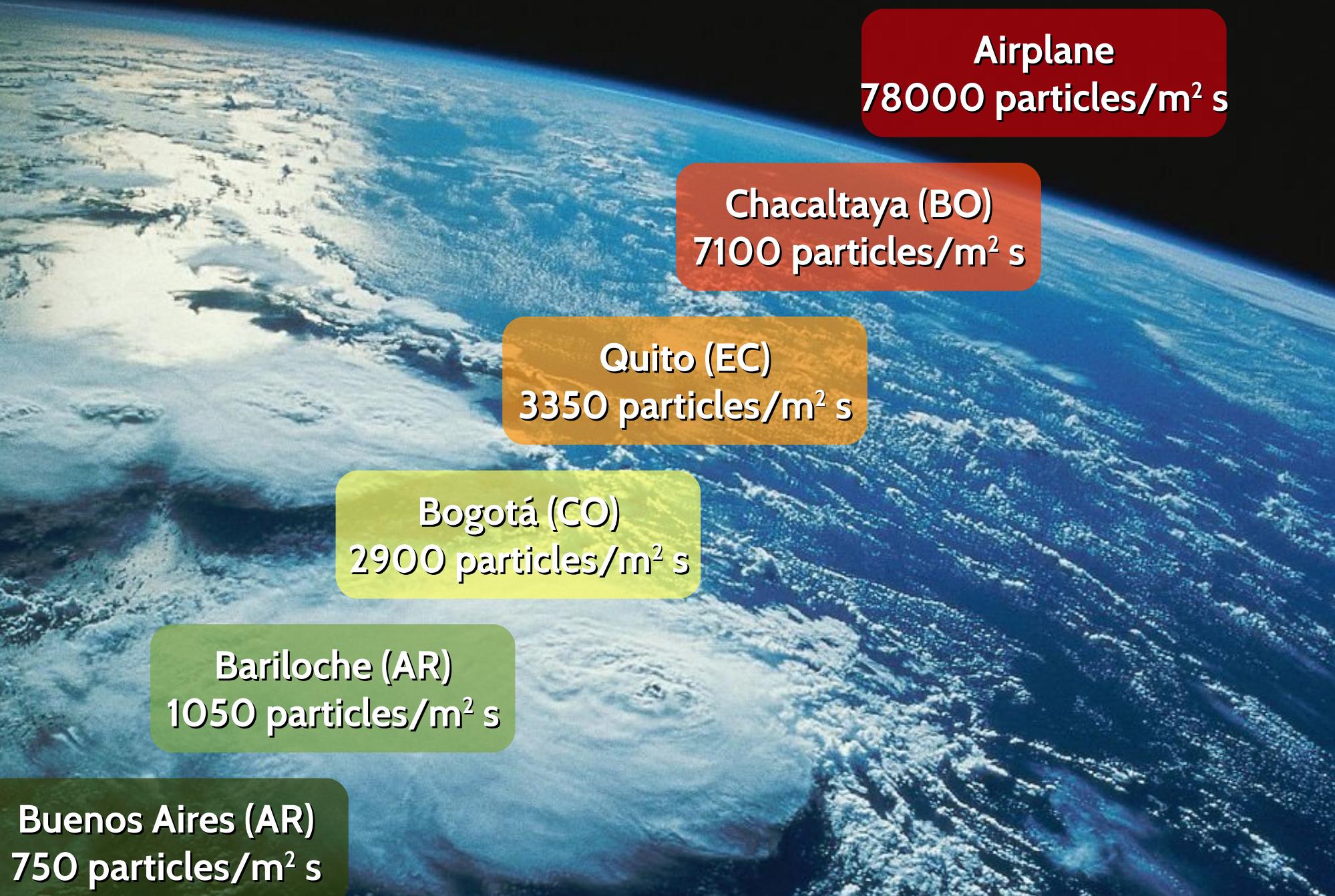
Berlín, Colombia, 3450 msnm



Bariloche, Argentina, 850 msnm



Shielding: 1 atm ~ 90 cm of Lead



Extreme simulations for extreme calculations

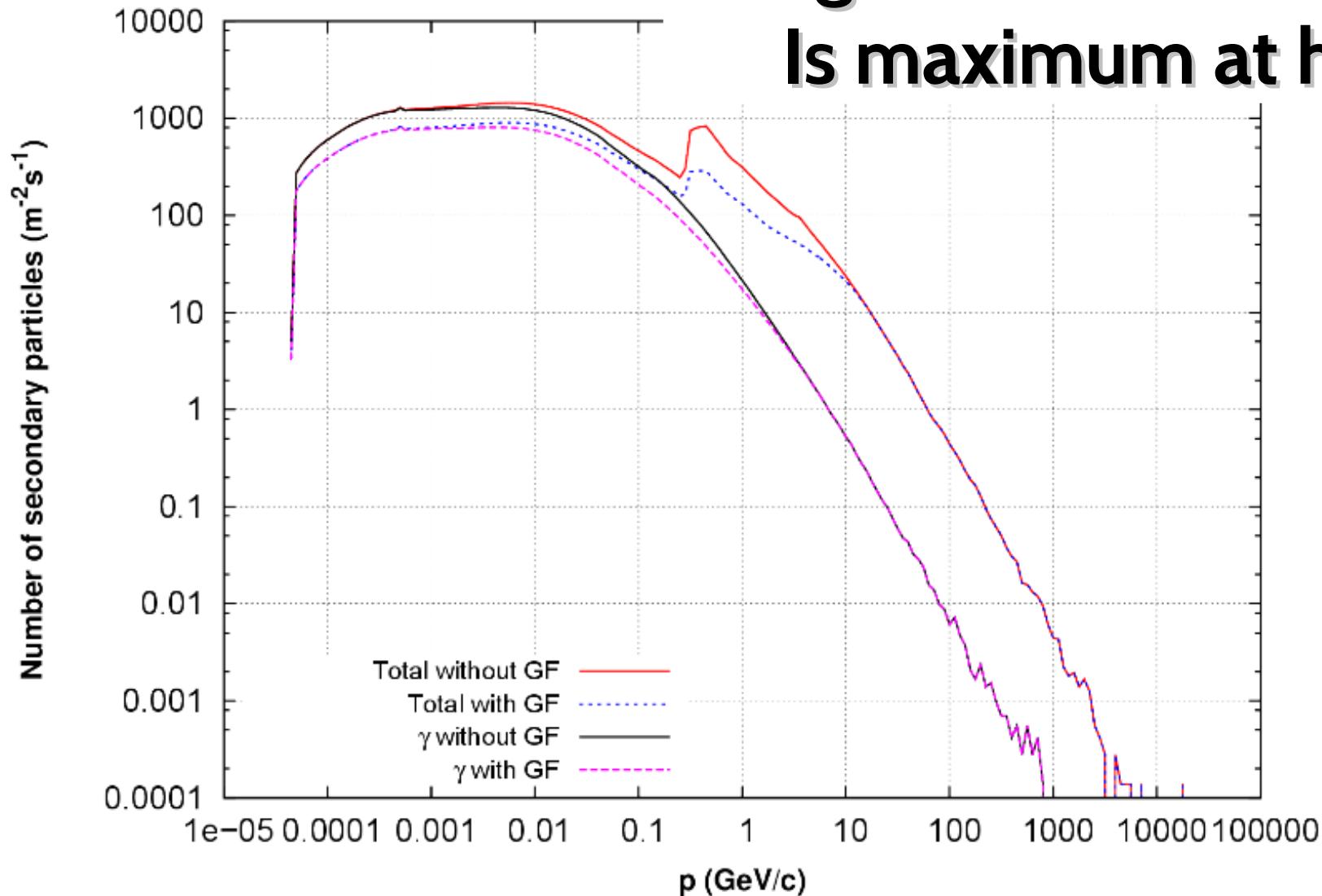
2 Background Radiation on Board

To calculate the expected flux of secondary particles in any place along the plane trajectory, we use a method based on the simulation of the complete flux of primaries within a given range of energy [9], that includes the effect of the rigidity cut-off at different locations in the Earth, that we summarize here:

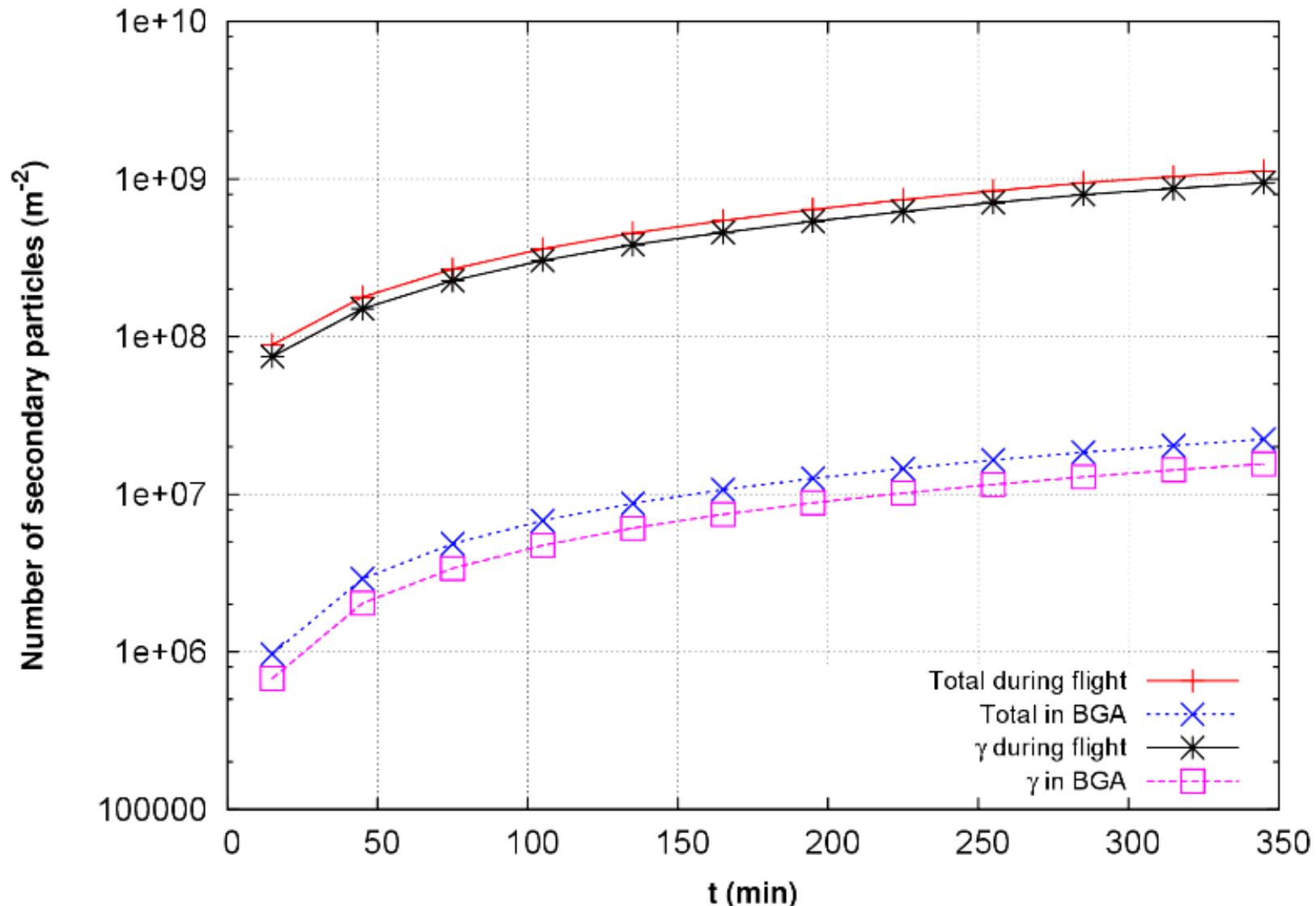
1. Simulation of showers at different altitudes using *CORSIKA*. Features of injected primaries at the top of the atmosphere:
 - Primary nuclei injected: $1 \leq Z_p \leq 26$, $1 \leq A_p \leq 56$
 - Very low initial rigidity cut-off rigidity: $R_c = 4GV$
 - Energy and arrival direction: $(R_c \times Z_p) \leq (E_p/GeV) \leq 10^6$, $0^\circ \leq \theta_p \leq 90^\circ$, $0^\circ \leq \phi_p \leq 360^\circ$
 - Simulation time: $t = 7200s$ (primary particles flux is constant and isotropic)
2. Selection and discretization of routes.
3. Computation of rigidity cut-offs for each point in the trajectory using *Magnetocosmics*.

Secondary particles at flight level

Integrated radiation levels
Is maximum at h~14 km

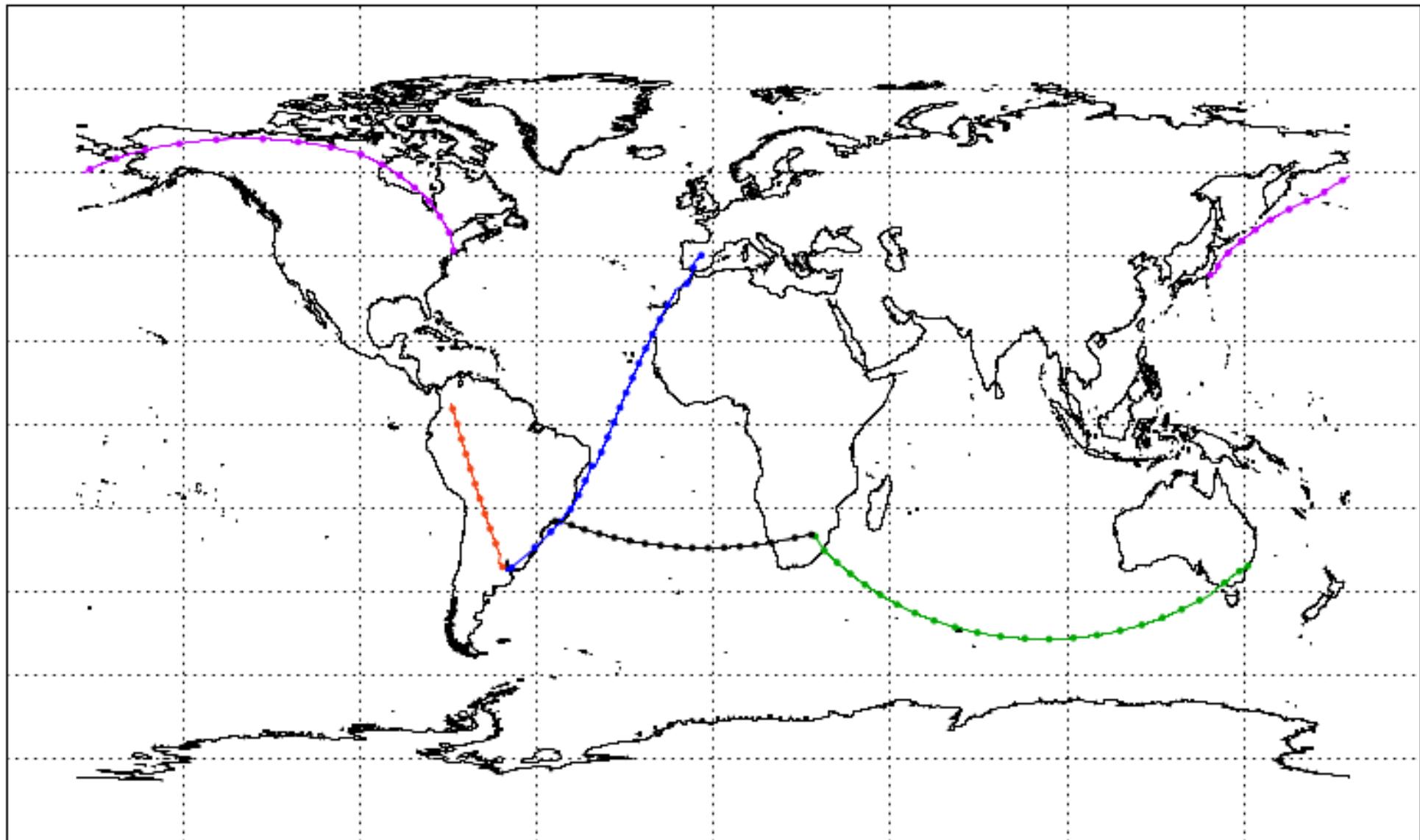


Integrated number of particles

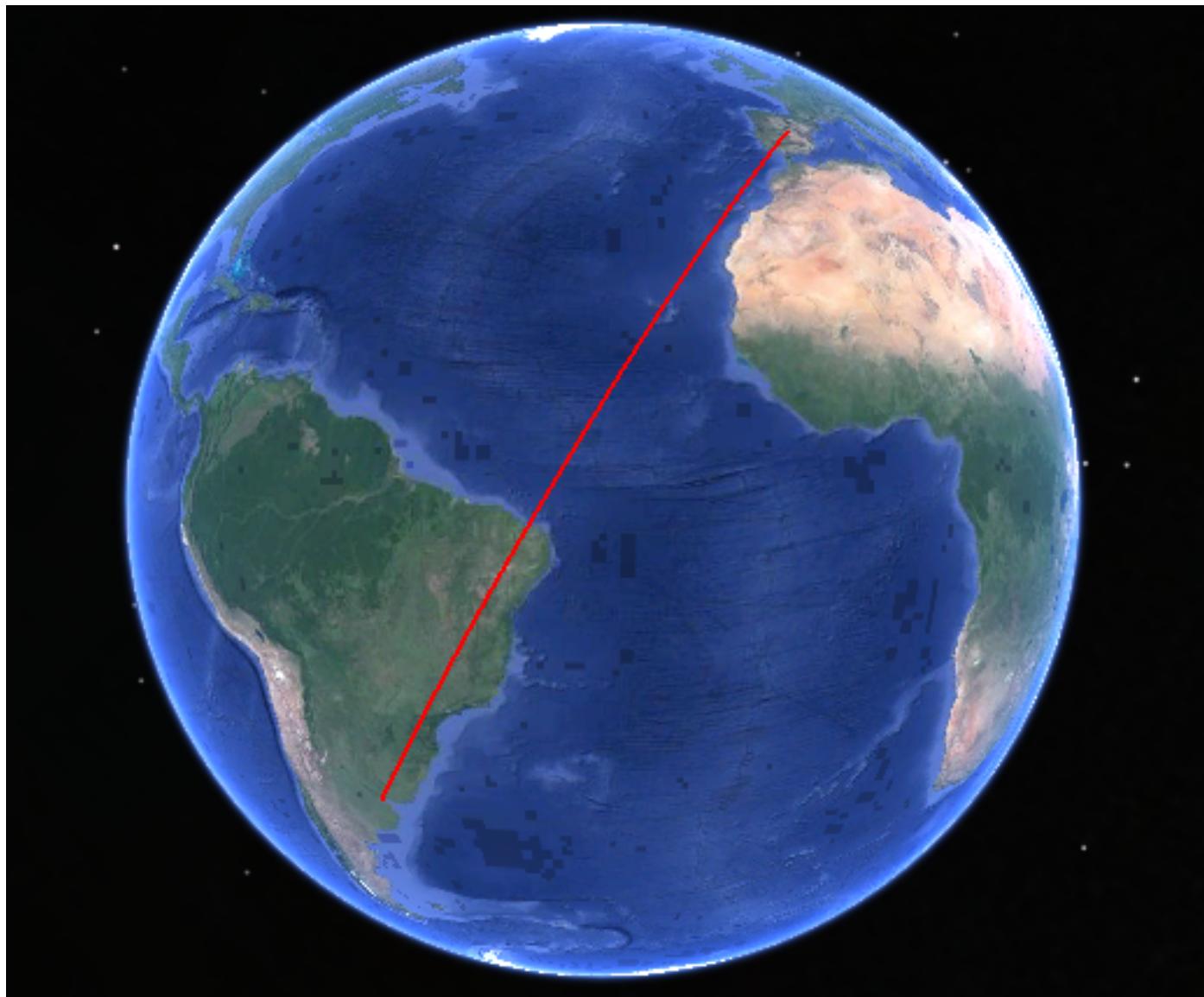


Five commercial routes at h=11km

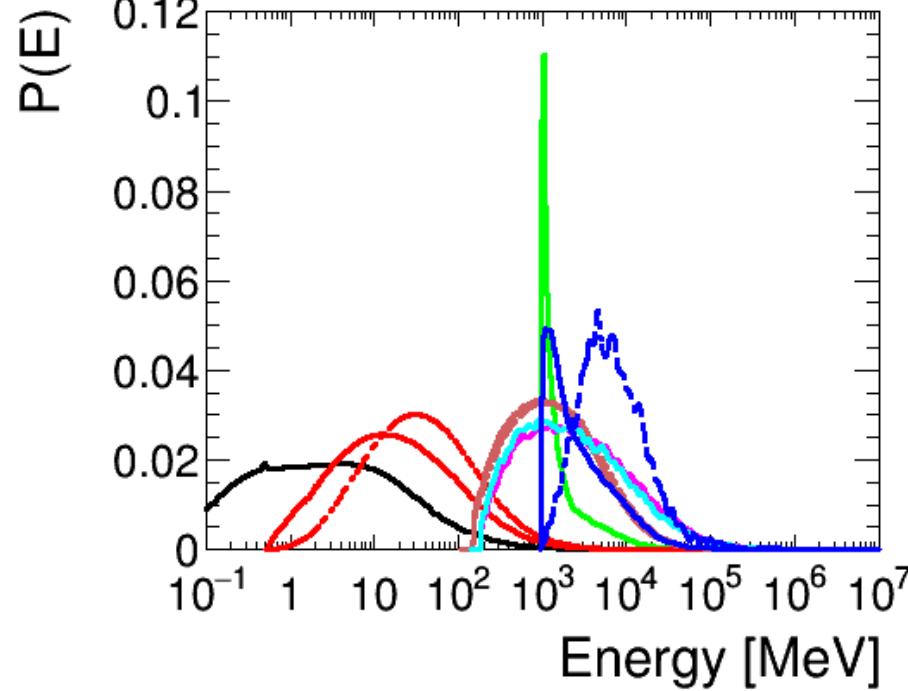
S. Pinilla, H. Asorey, F. Quiñonez, M. Suarez, L. Núñez, 2015, 2016



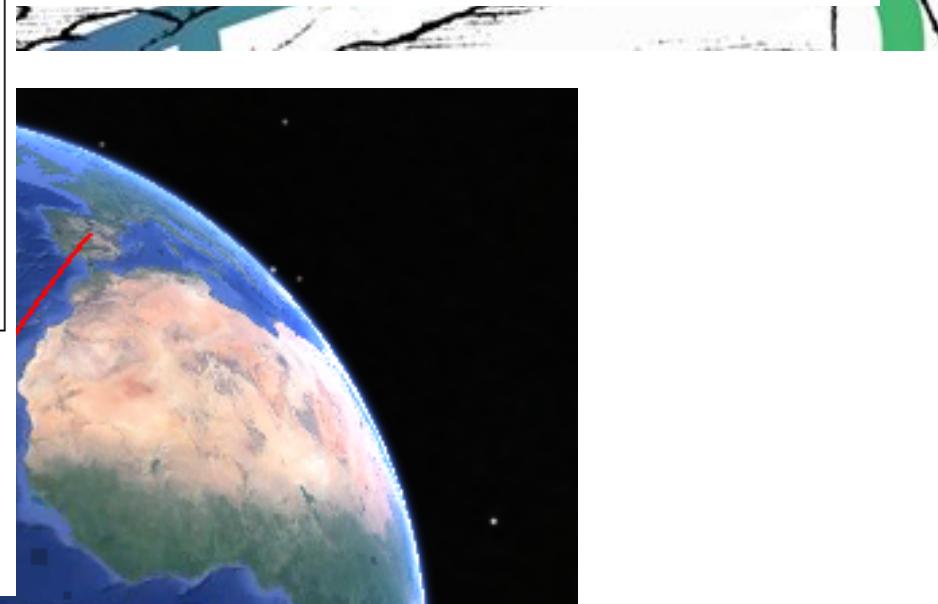
Buenos Aires-Madrid



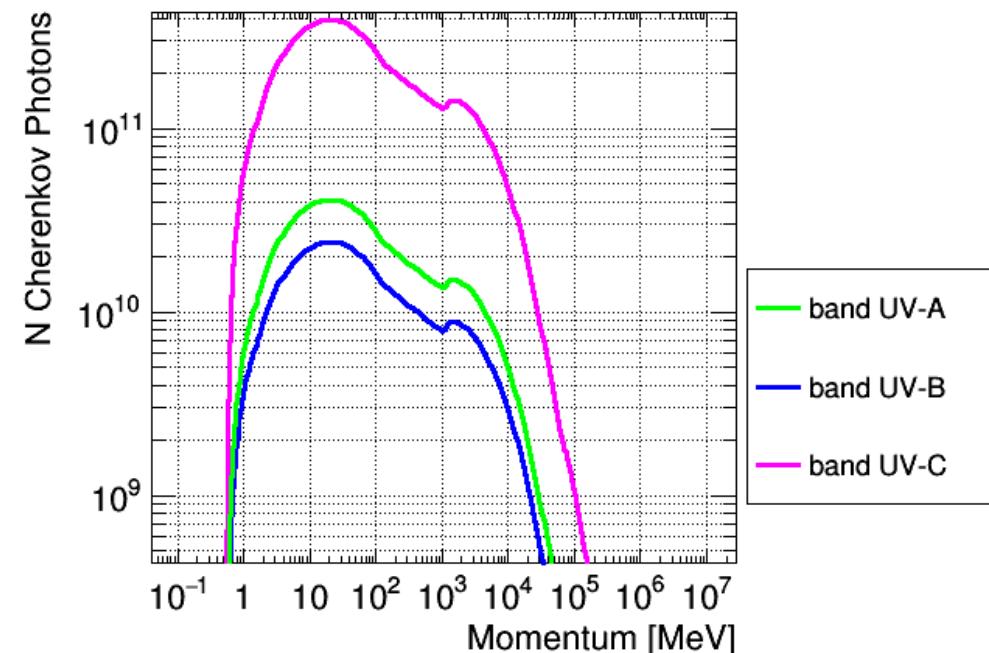
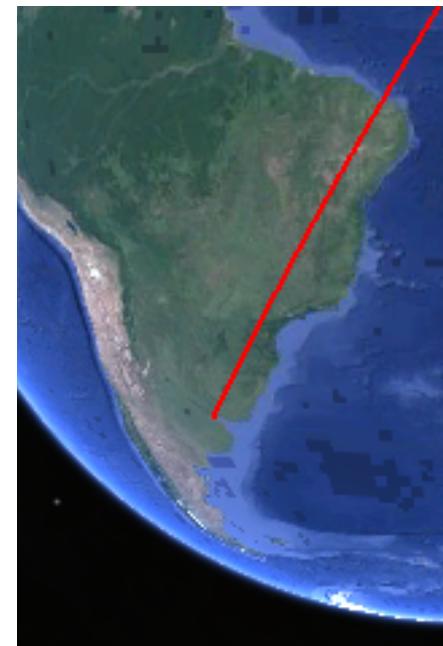
Buenos Aires-Madrid



- γ
- e^-
- ... e^+
- μ^-
- ... μ^+
- π^-
- π^+
- Neutron
- Proton
- ... Anti-Proton

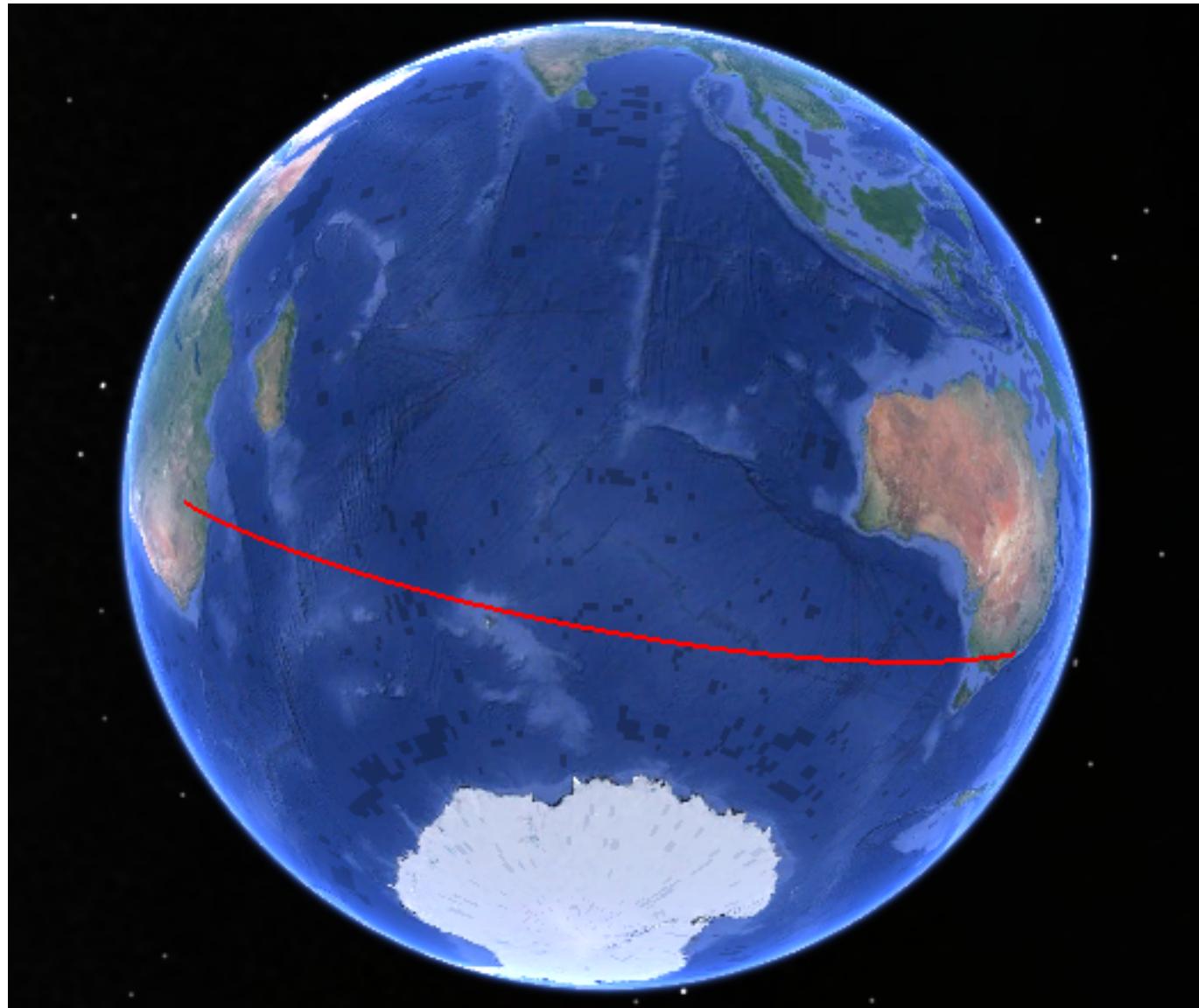


Particle	Number
γ	1735067944
e^-	127663451
e^+	71851951
n	64671348
p	23201761
μ^+	21225806
μ^-	20050559
π^+	267108
π^-	262524
\bar{p}	32565
Duration	40560 s
Displacement	10062 km

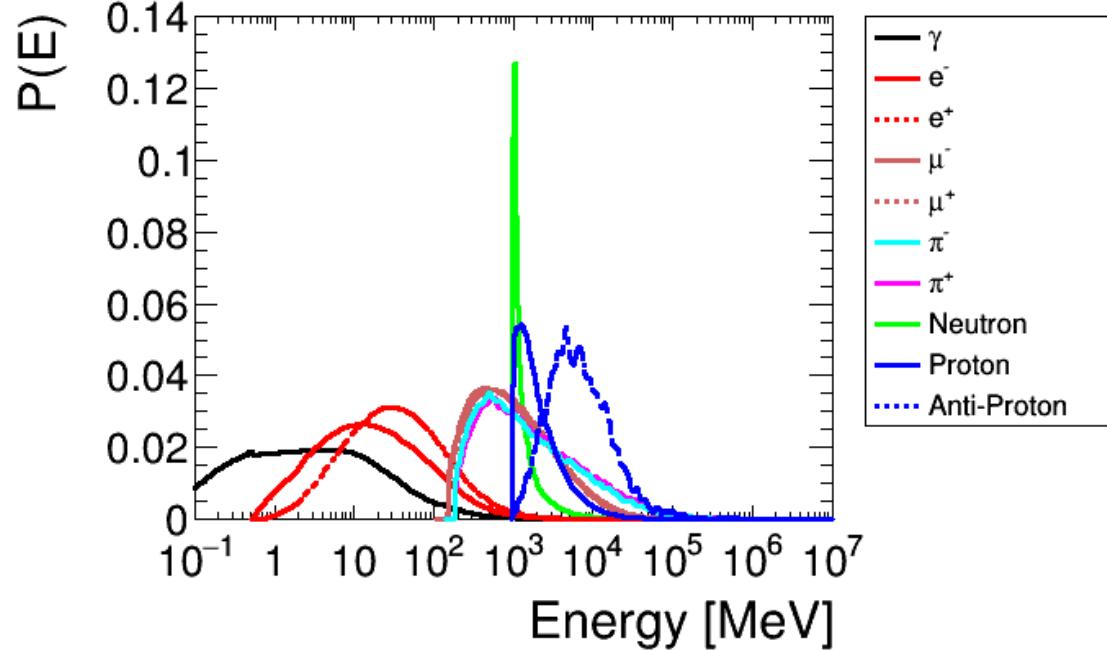


- band UV-A
- band UV-B
- band UV-C

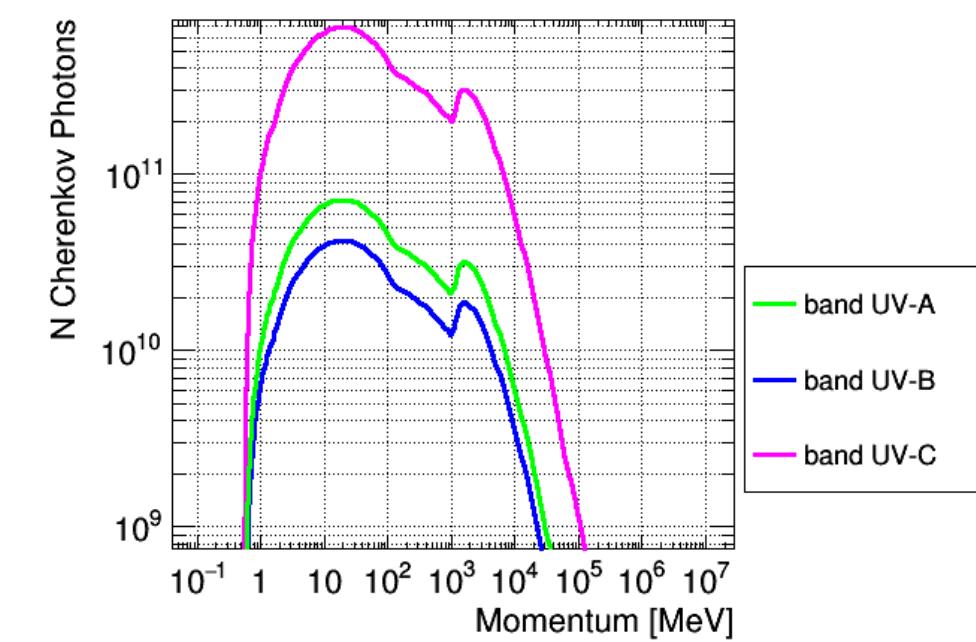
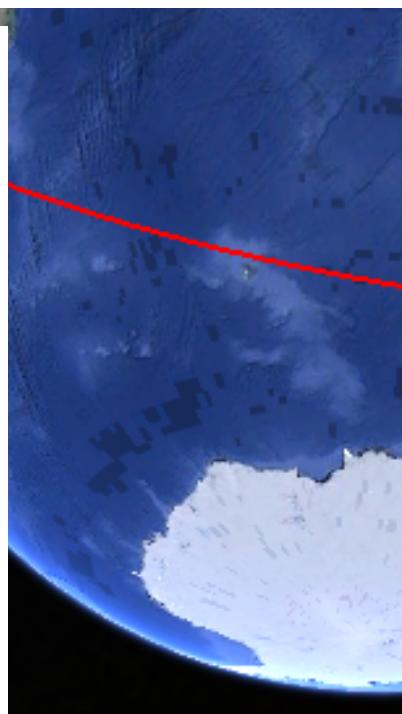
Johannesburg-Sydney



Johannesburg-Sydney



Particle	Number
γ	3095648594
e^-	218150006
e^+	122000905
n	299676745
p	91430532
μ^+	36246475
μ^-	32678029
π^+	417862
π^-	409534
\bar{p}	35628
Duration	42000 s
Displacement	11046 km



Same exposure time at secular GMF conditions

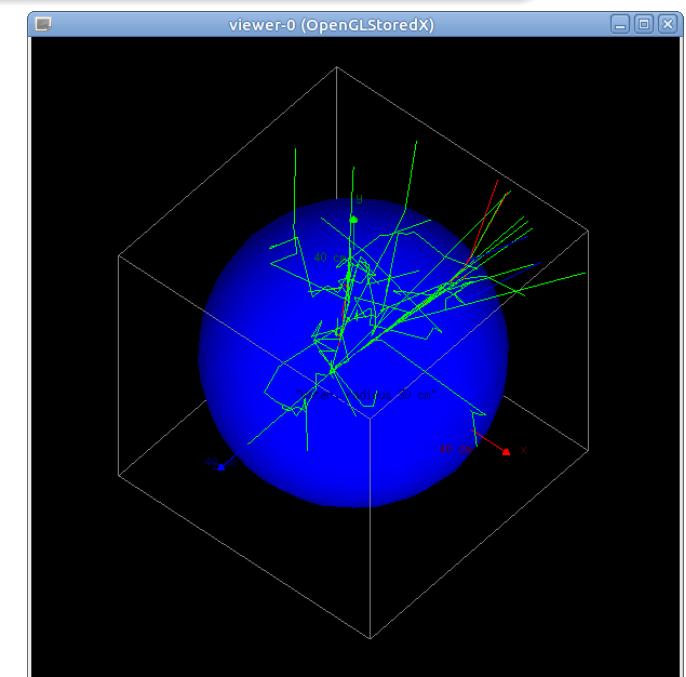
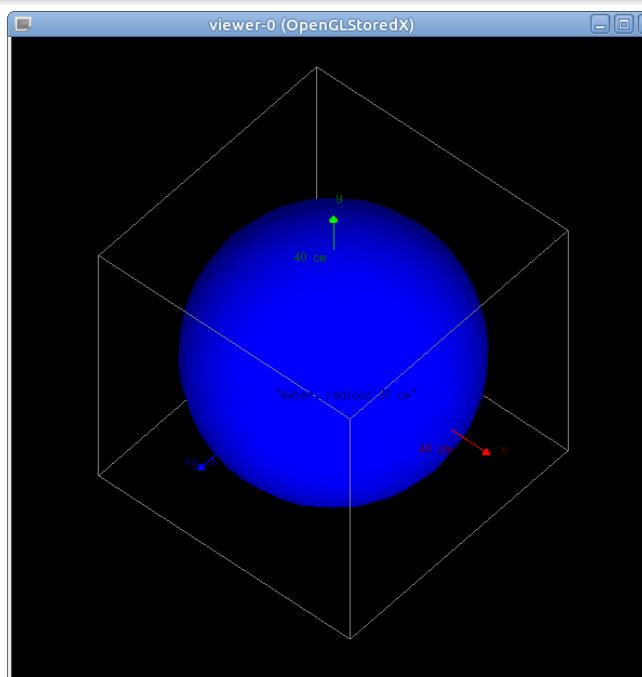
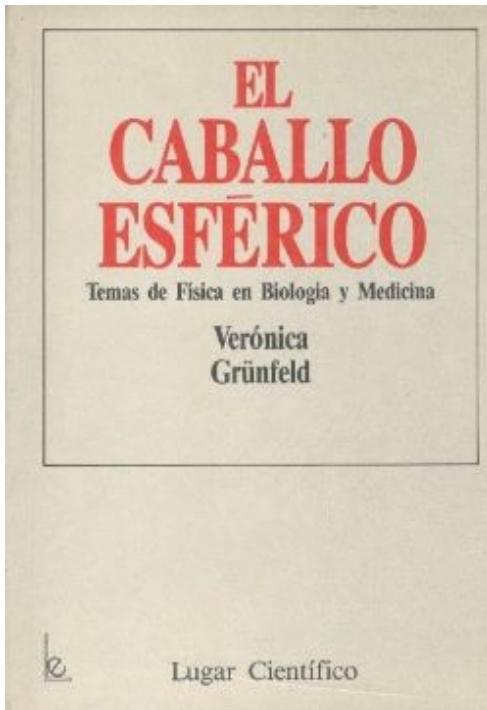
$$d_N = \frac{N_{\text{ruta}} - N_{\text{BGA}}}{N_{\text{BGA}}} \quad (10)$$

Ruta	γ	e^+	e^-	μ^+	μ^-	n^0	p^+	Otros	Total
BOG-BUE	55.5	56.0	56.2	3.5	3.9	84.6	165.8	122.6	46.1
BUE-MAD	56.6	57.0	57.3	3.6	4.0	90.7	175.9	124.6	47.1
JNB-SYD	93.3	89.3	90.3	6.2	6.5	388.7	638.0	195.6	82.2
NYC-TYO	91.0	87.2	88.1	6.1	6.3	380.6	621.9	190.4	80.2
SAO-JNB	71.3	70.5	70.8	4.9	5.3	162.7	296.6	151.7	60.3

OpenGATE, a GEANT4 implementation for RT

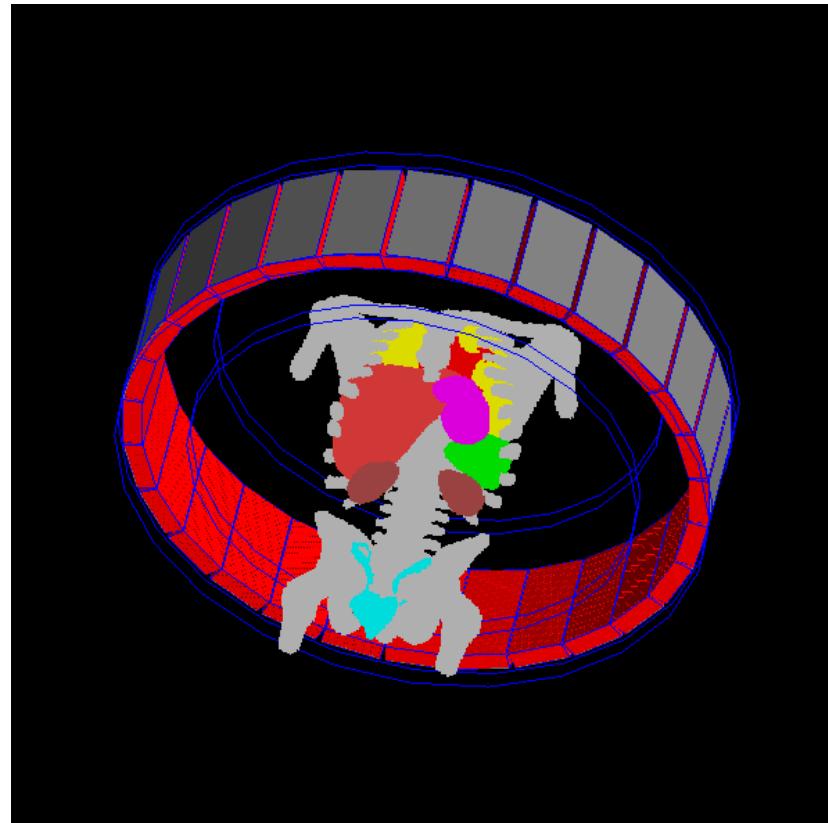
QGSP_BERT_HP is based on QGSP_BERT list, which is the most recommended list for HEP, it is used in ATLAS. Includes all the standard EM processes. The suffix HP make reference to High Precision on **Neutron interactions**.

- Use Bertini cascade model for hadrons with $E < 10$ GeV.
- Use QGSP (Quark Gluon String Parton) for hadrons with $E \geq 10$ GeV.
- High Precision for Neutrons with $E < 20$ MeV.

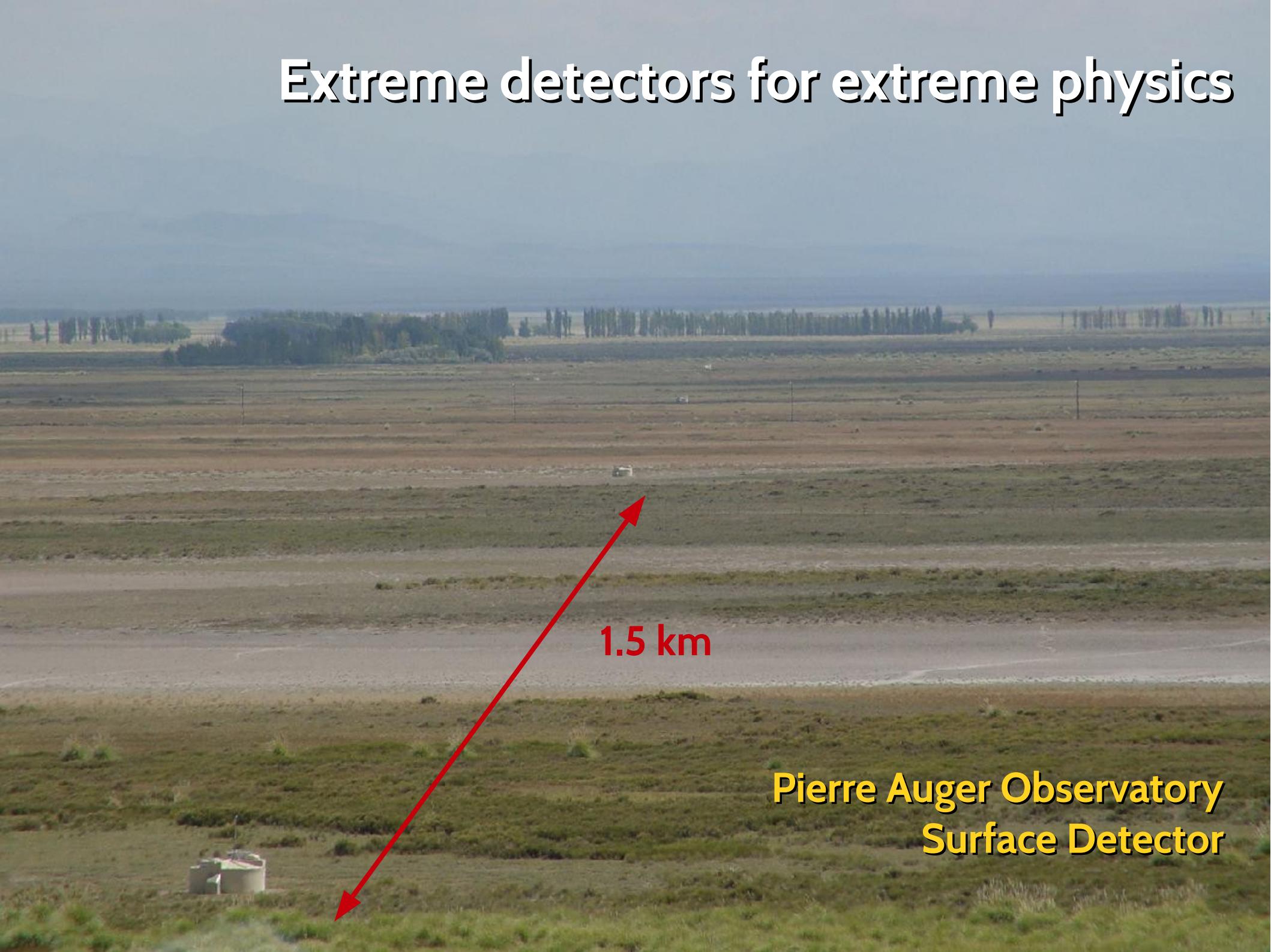


Extreme simulations for extreme calculations

- Work in progress: improve aircraft shielding, improve phantom, detailed studies of resulting Bragg curves, ...
- Very preliminary results (last week!) indicates equivalent dose could reach mSv level under certain space weather conditions
- Results were validated at ground level using Water Cherenkov detectors. Need to validate at flight level using portable detectors
- Starting to work on RT and protontherapy Geant4 simulations (CPU and GPU parallelization)

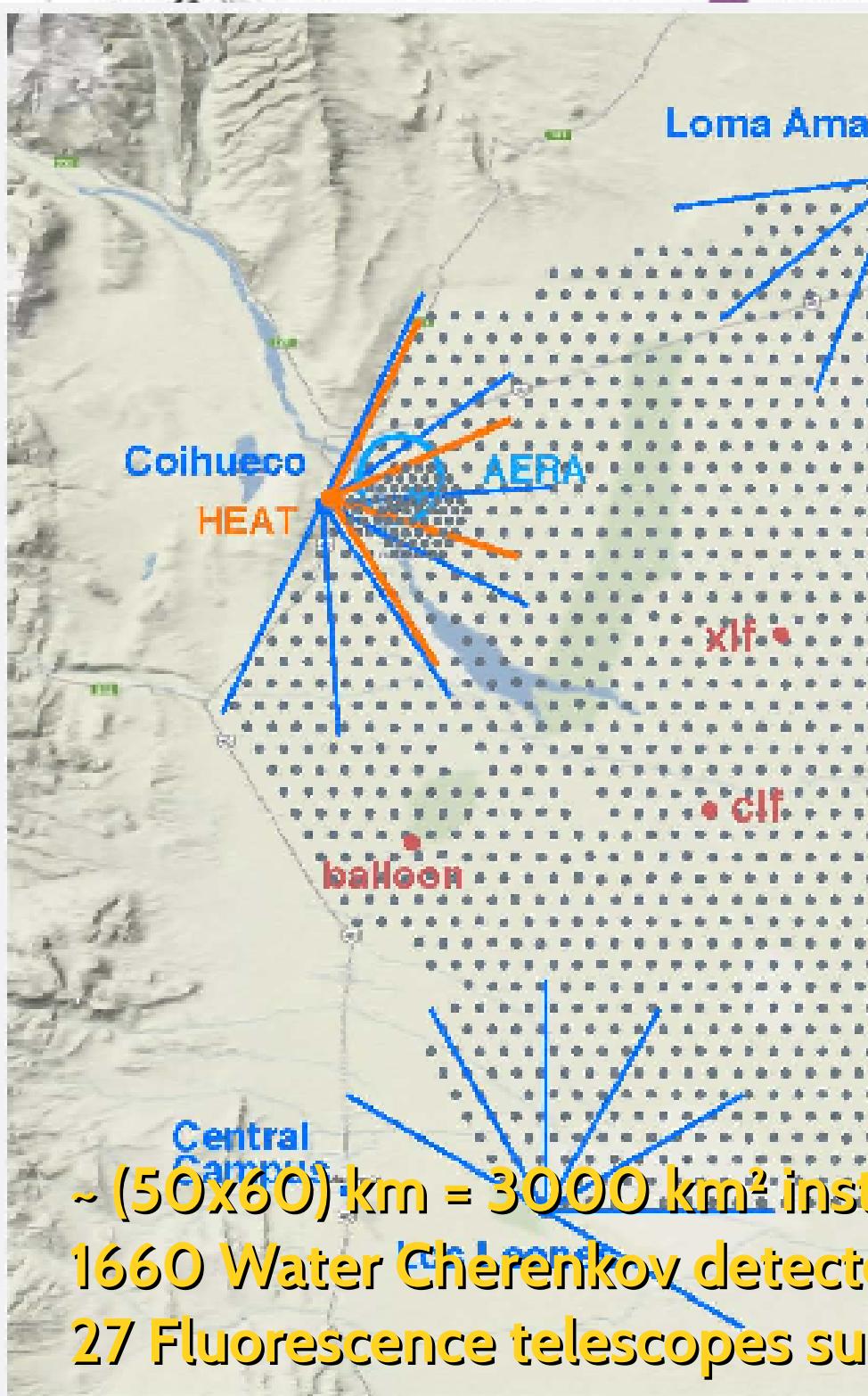


Extreme detectors for extreme physics



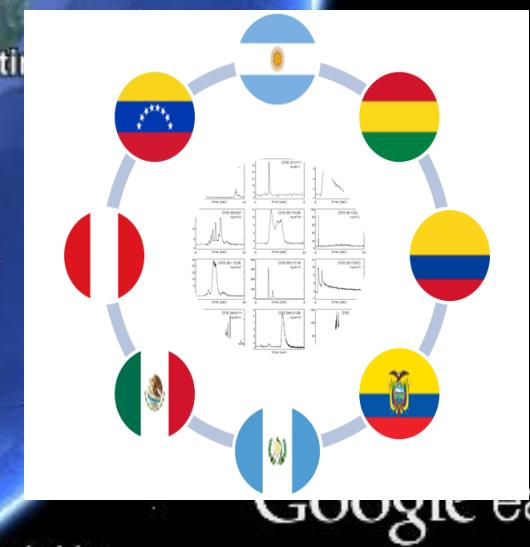
1.5 km

Pierre Auger Observatory
Surface Detector

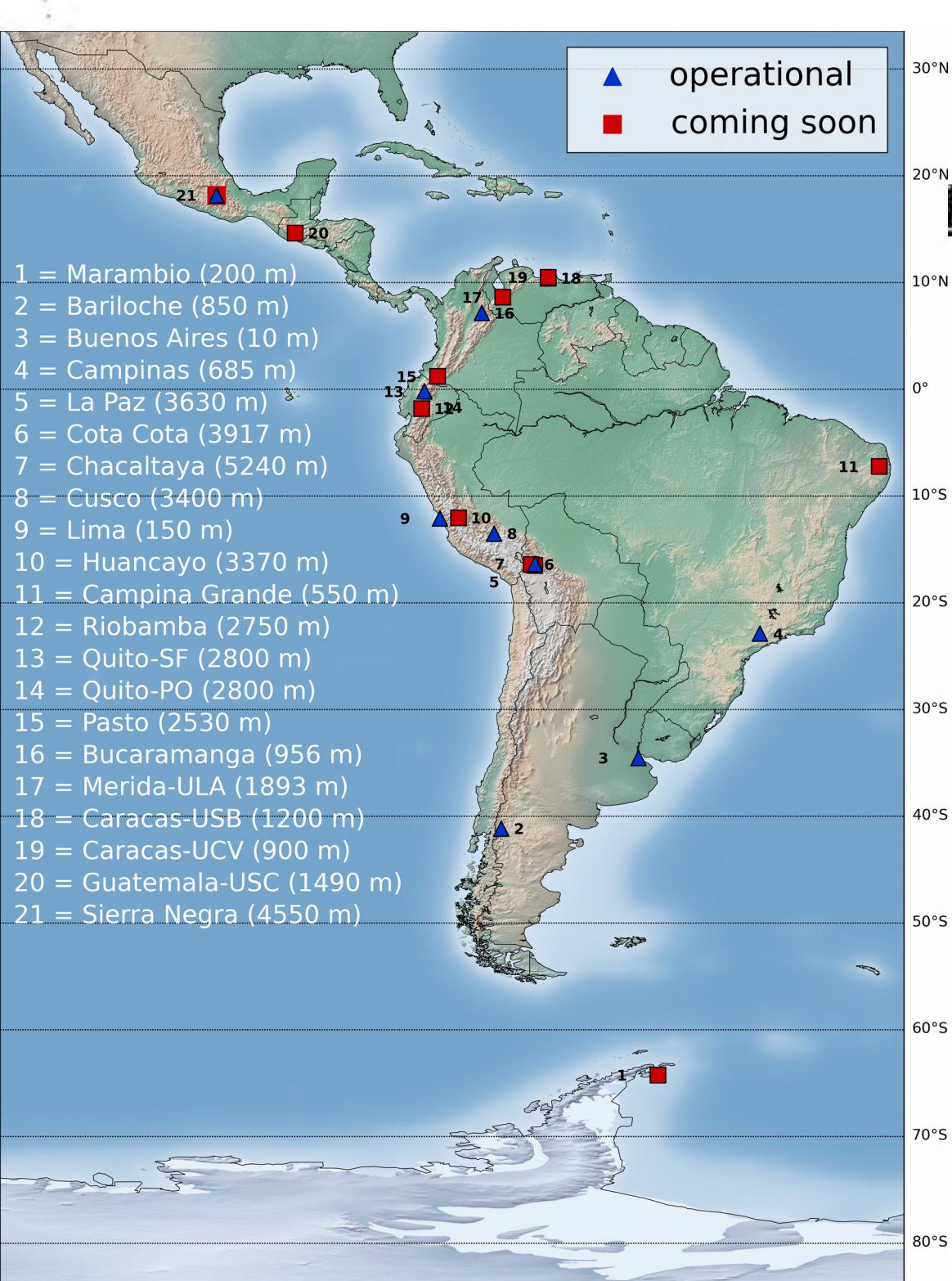


LAGO: The Latin American Giant Observatory

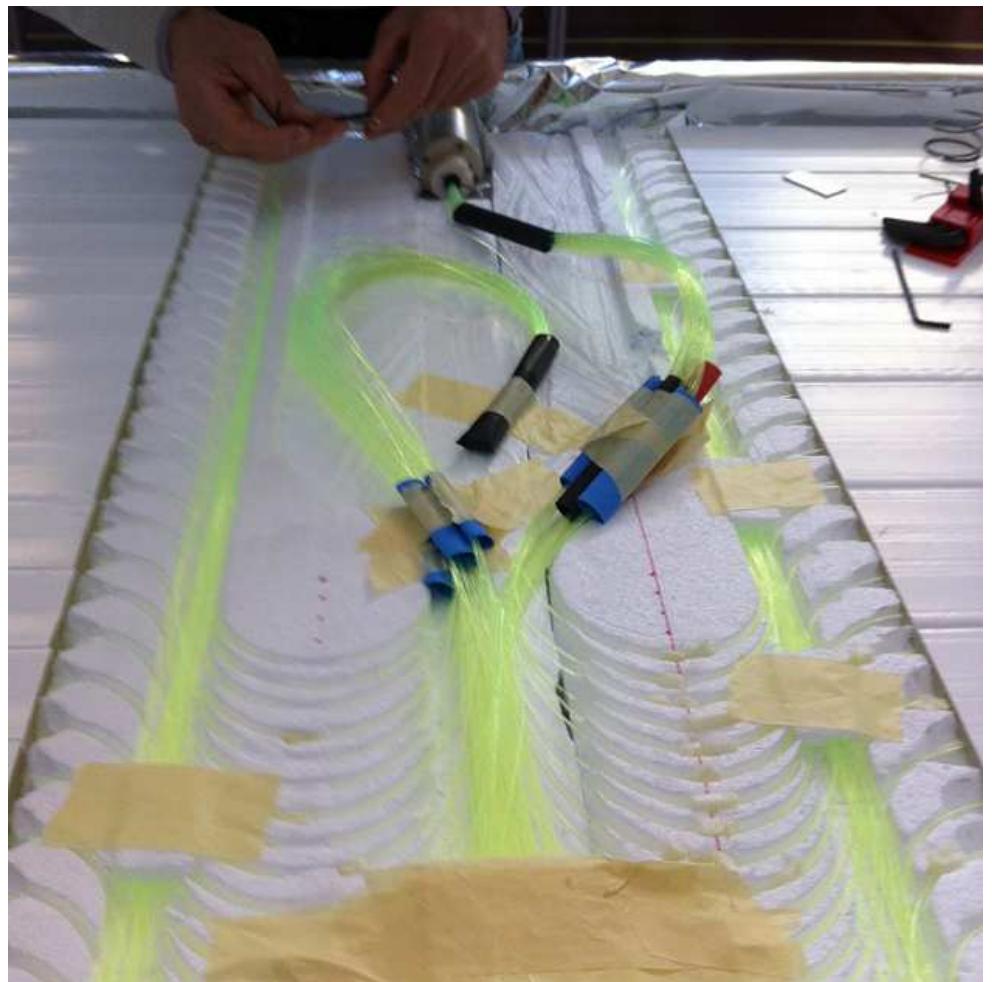
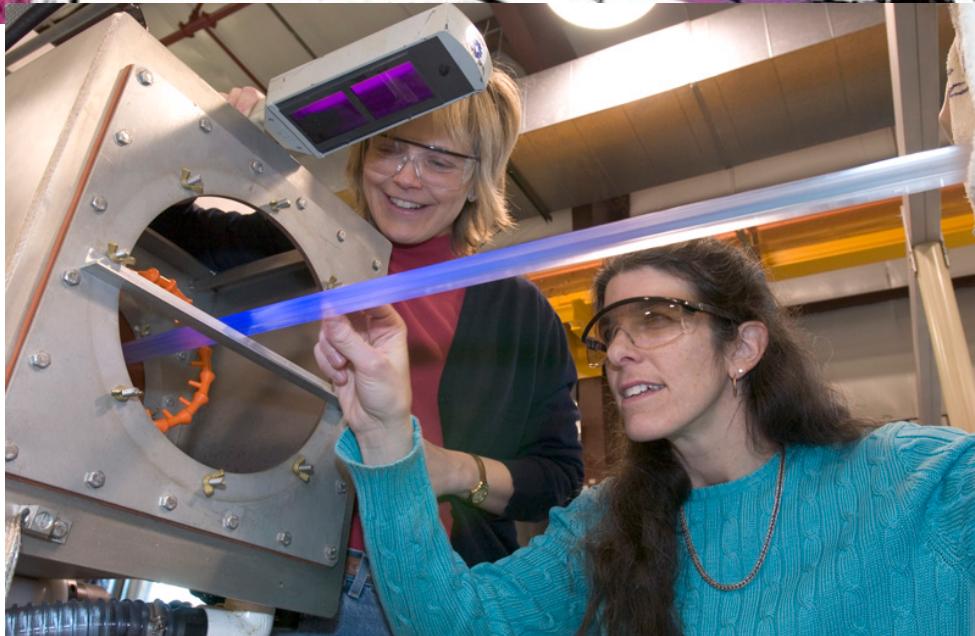
- Nine LA countries + Spain
- LAGO Collaboration: first astroparticle network at LA (80 members, 25 institutions)
- A very long baseline array of Water Cherenkov Detectors
- From Mexico to Antarctica



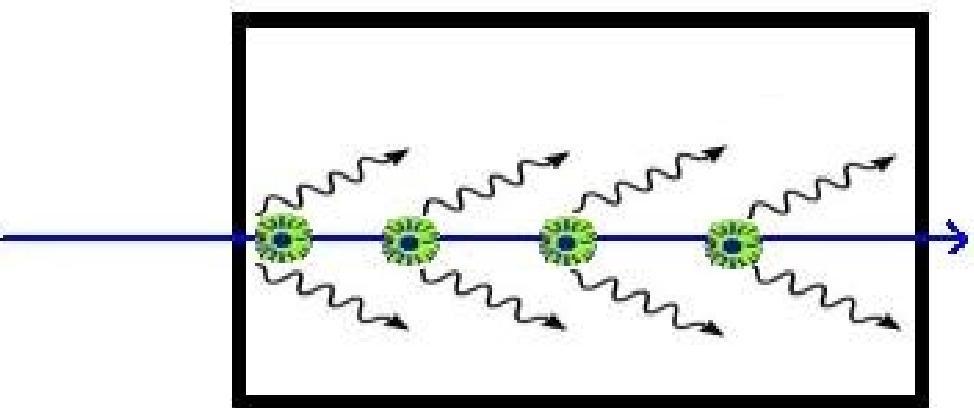
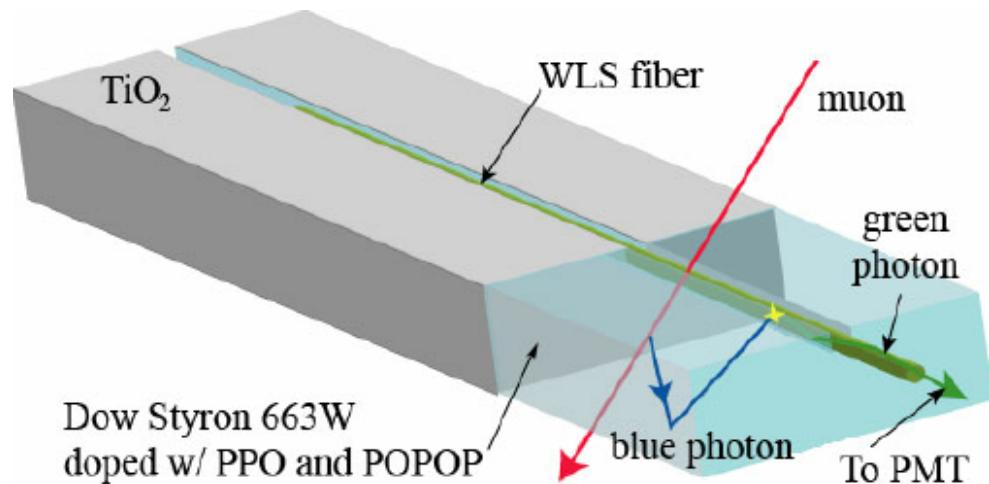
Present status and future perspectives



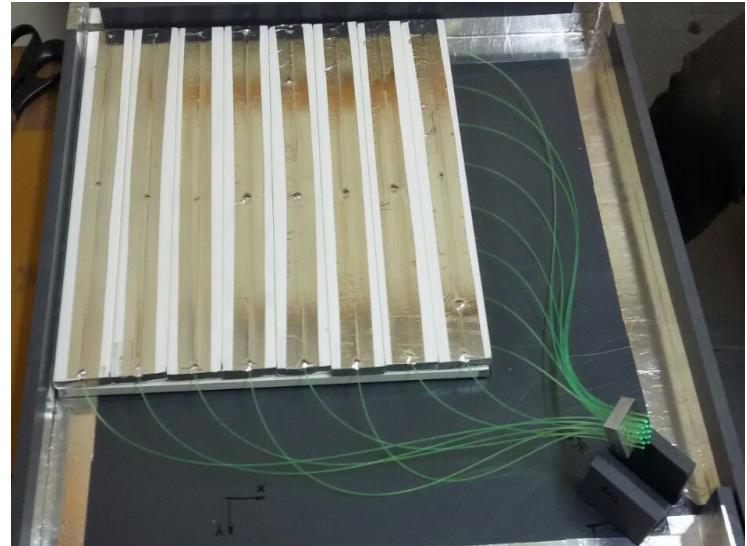
SSD, The Auger Upgrade: plastic scintillators



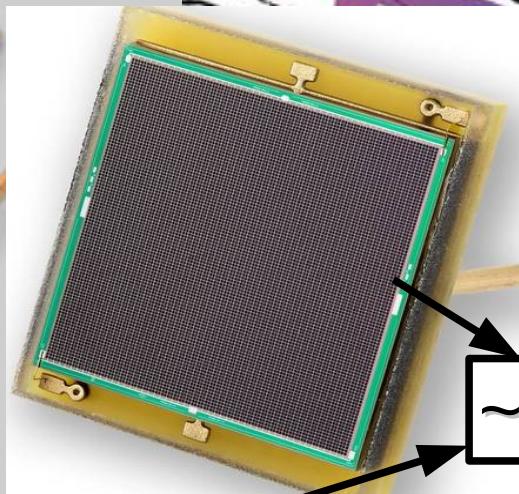
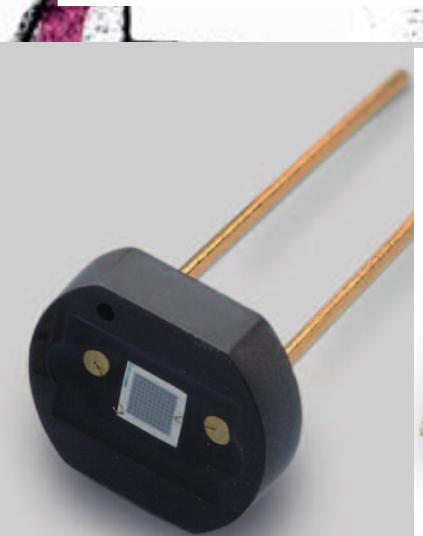
Plastic scintillators



- Polystyrene dopped with PPO (organic scintillator & PoPop (Wavelength shifter)
- New materials improve usage at high radiation environments



Multi-pixel Silicon PhotoMultiplier (MPPC SiPM)

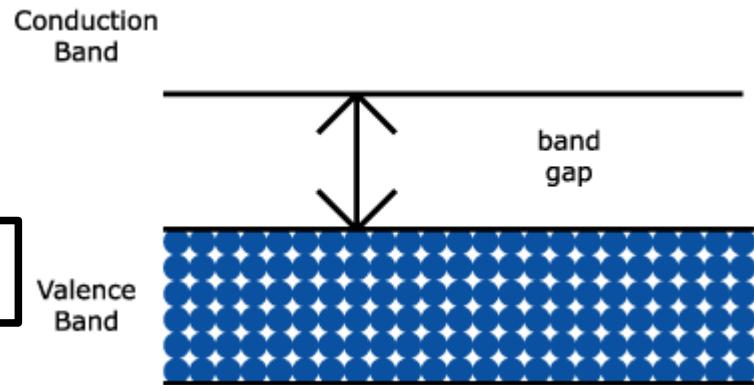


~ 3600

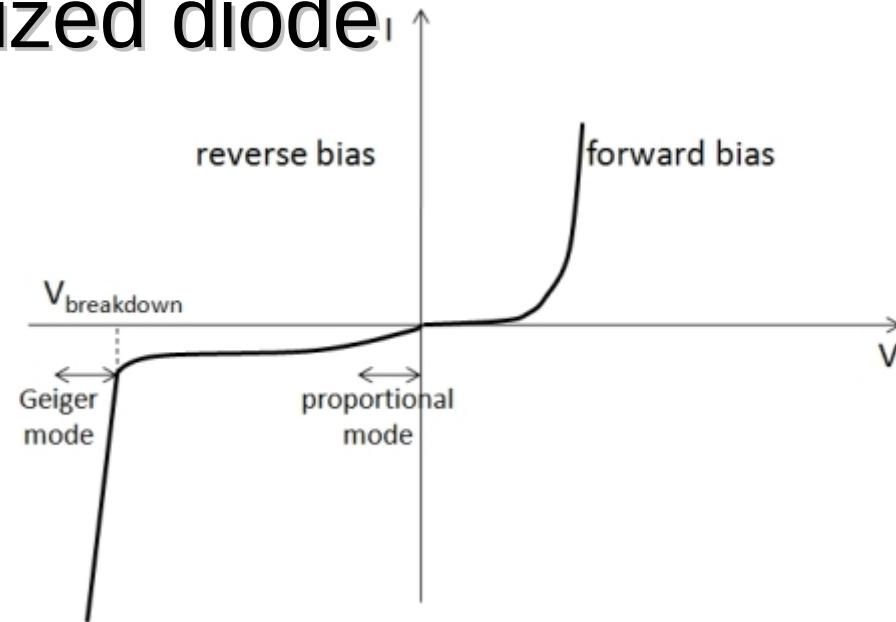
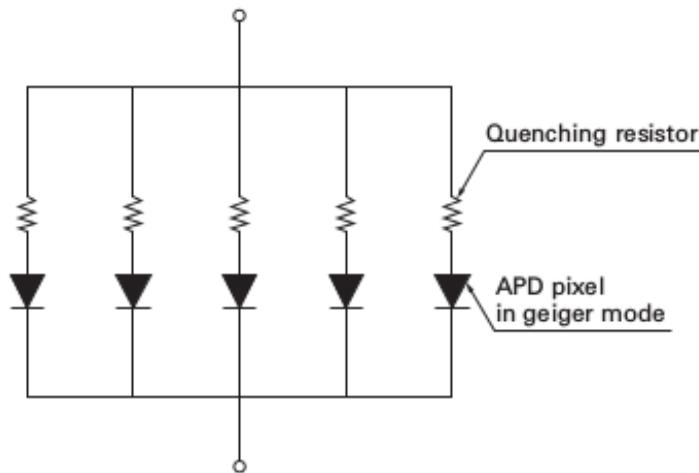
- Multiple pixel

(50 μ m)

- Semiconductor based

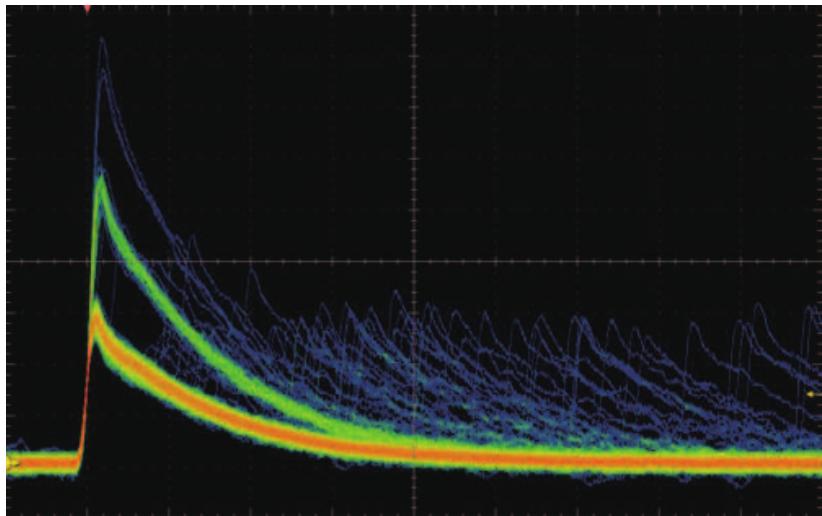


- Works as a reversed polarized diode



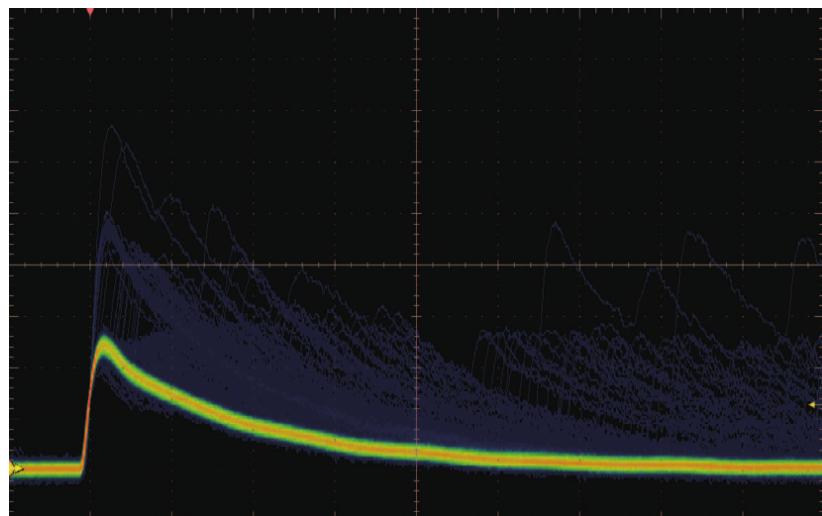
Output

- S11



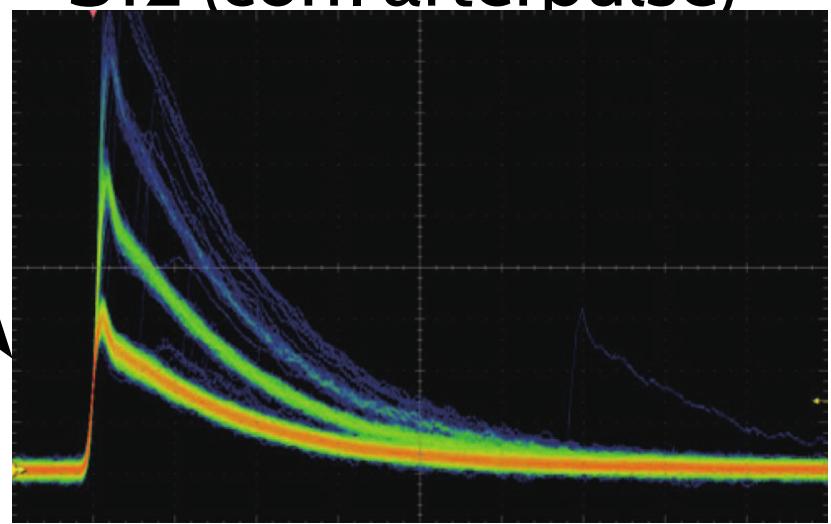
Datasheet

- S13 (corr. crosstalk)

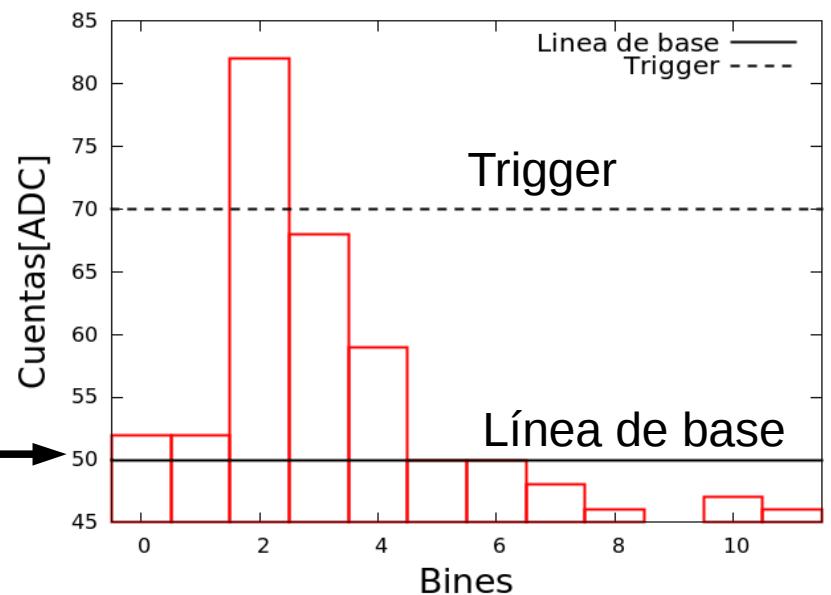


Data

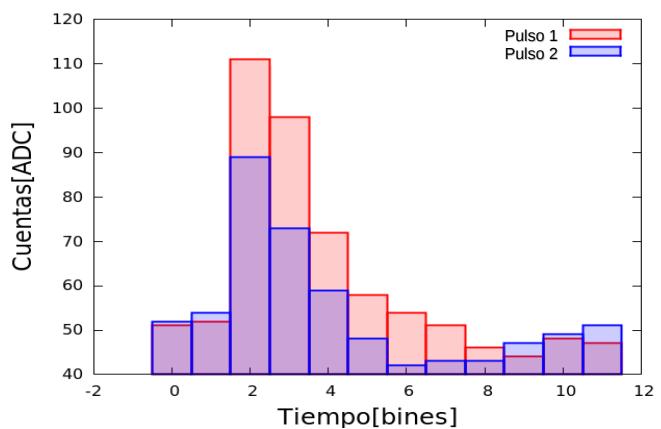
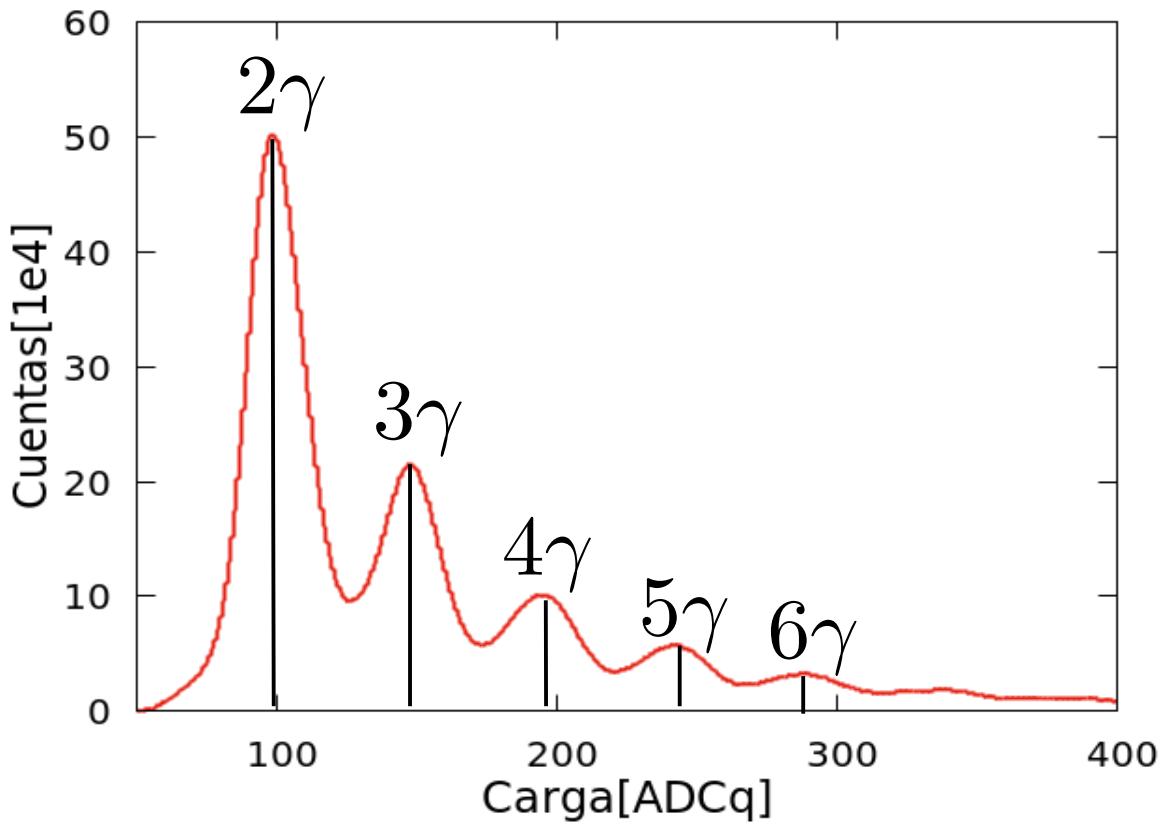
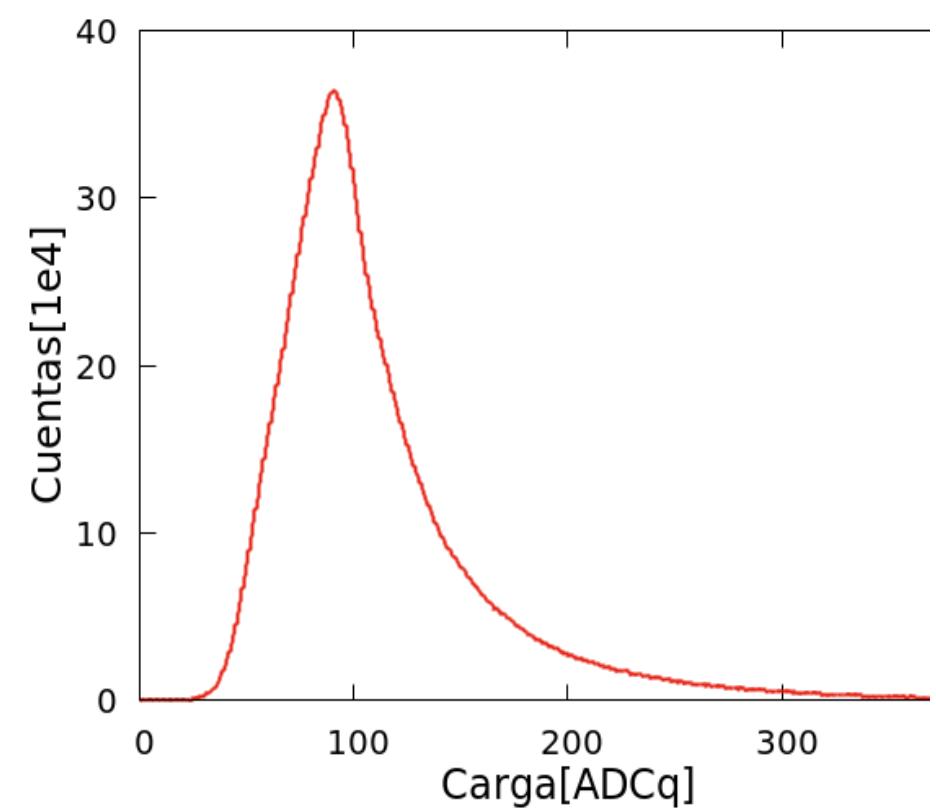
- S12 (corr. afterpulse)



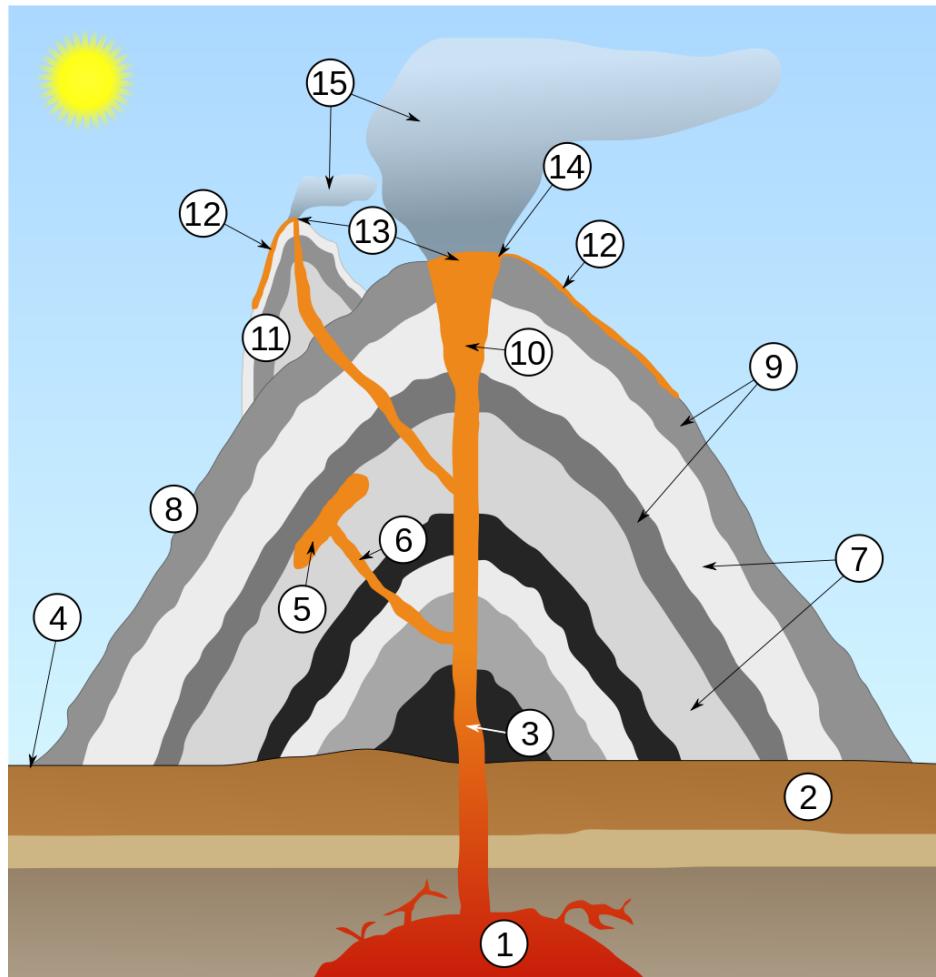
- Discretized



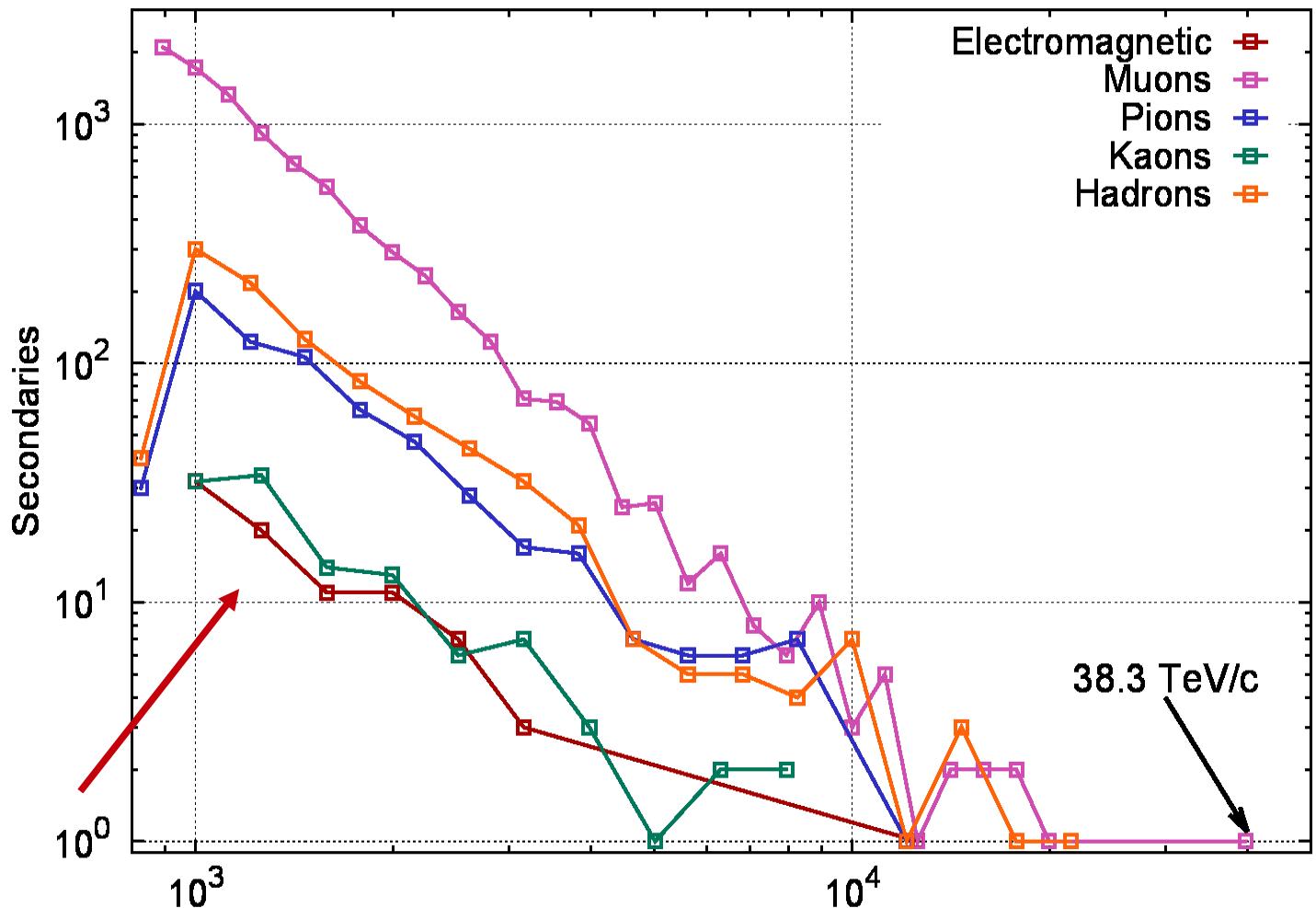
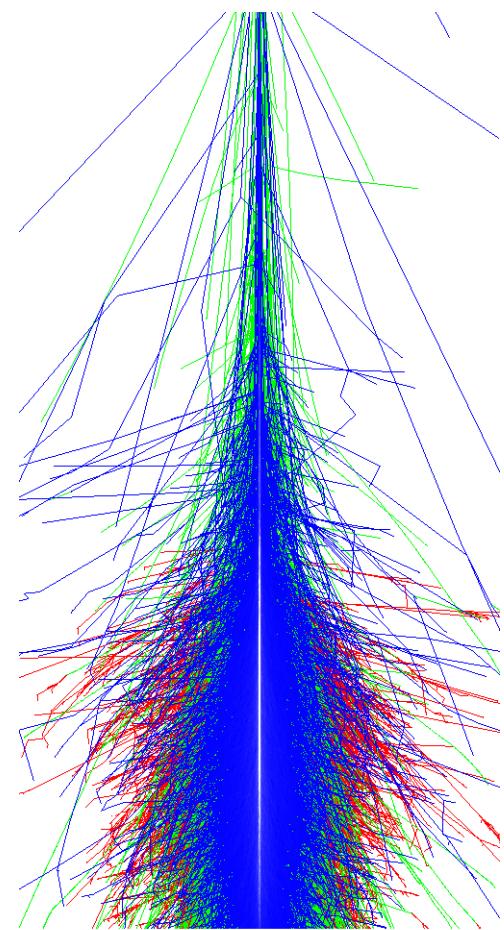
Pulse charge histogram: single photon counts



We want to take a look to volcanoes interior...

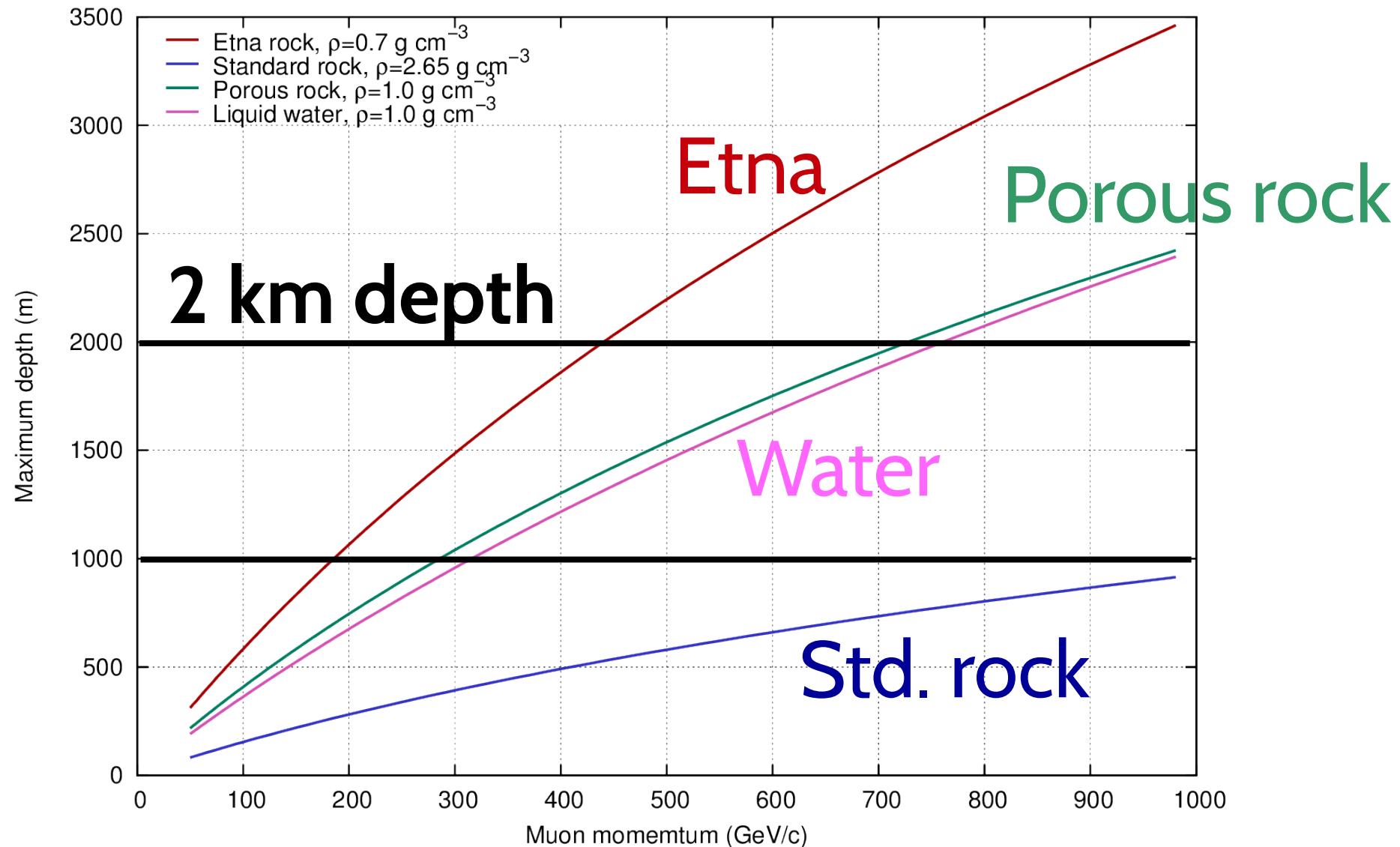


High energy atmospheric muons



4000 m a.s.l. HE ($E > 800$ GeV) secondaries simulated flux (1 m², 1 month)

Muon range in some standard materials

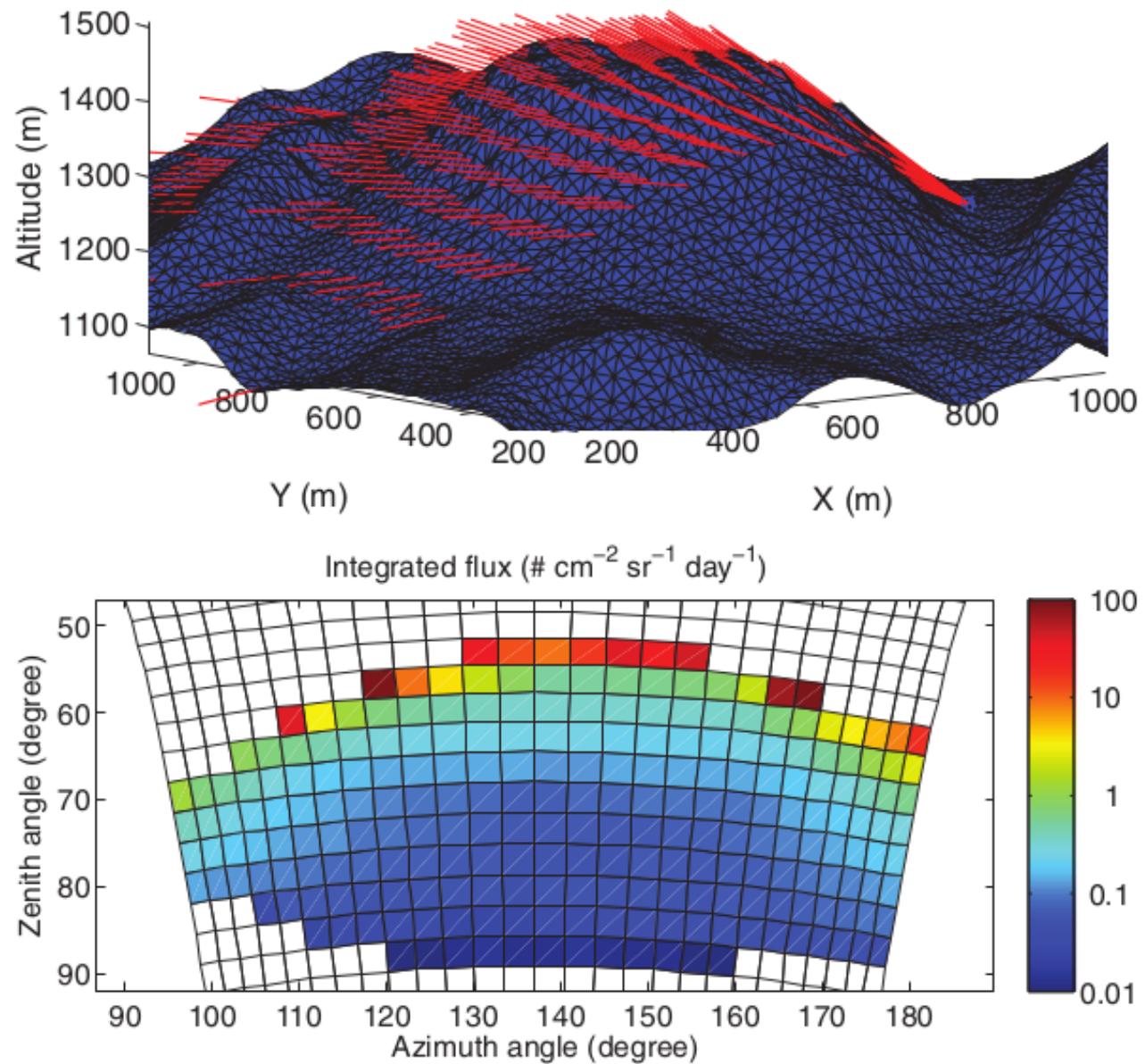


Muon radiography → “Muongraphy”

- Suppose you have an object with an unknown density profile, then...
 - ... measure the directional muon flux through this object
 - ... and compare with the muon reference flux
 - → **you get the directional opacity of this object [g/cm²]**
- Additionally...
 - ... obtain the external geometry of the object
 - → **and calculate the directional interaction distance [cm]**
- Finally, from...
 - directional opacity
 - directional interaction distances
 - → **you get the internal density profile along muon propagation direction**

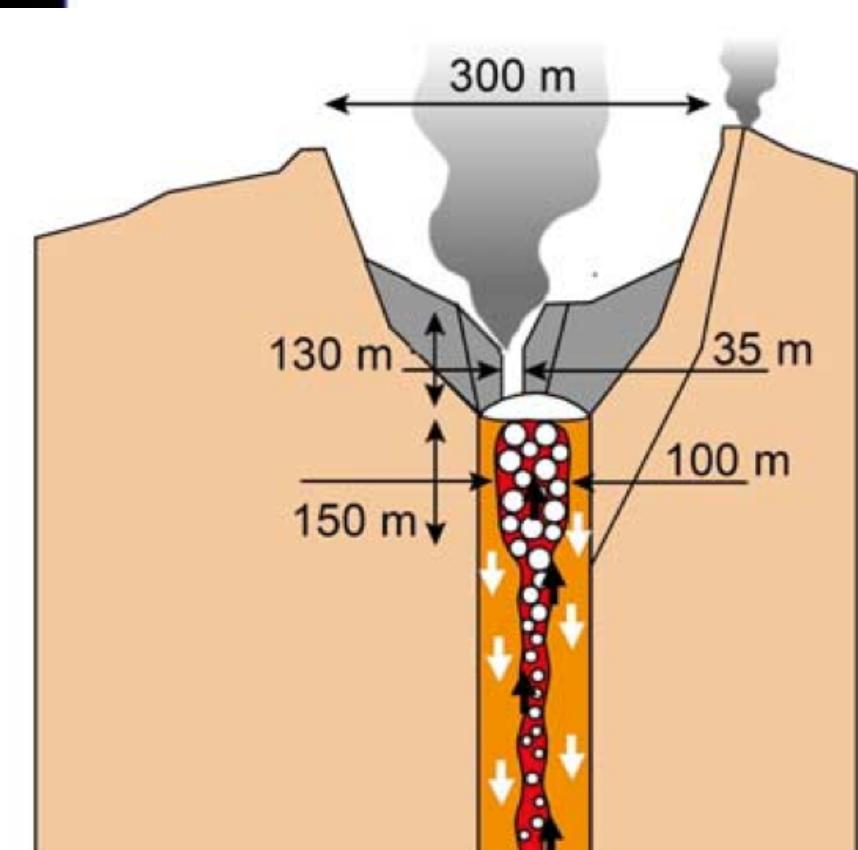
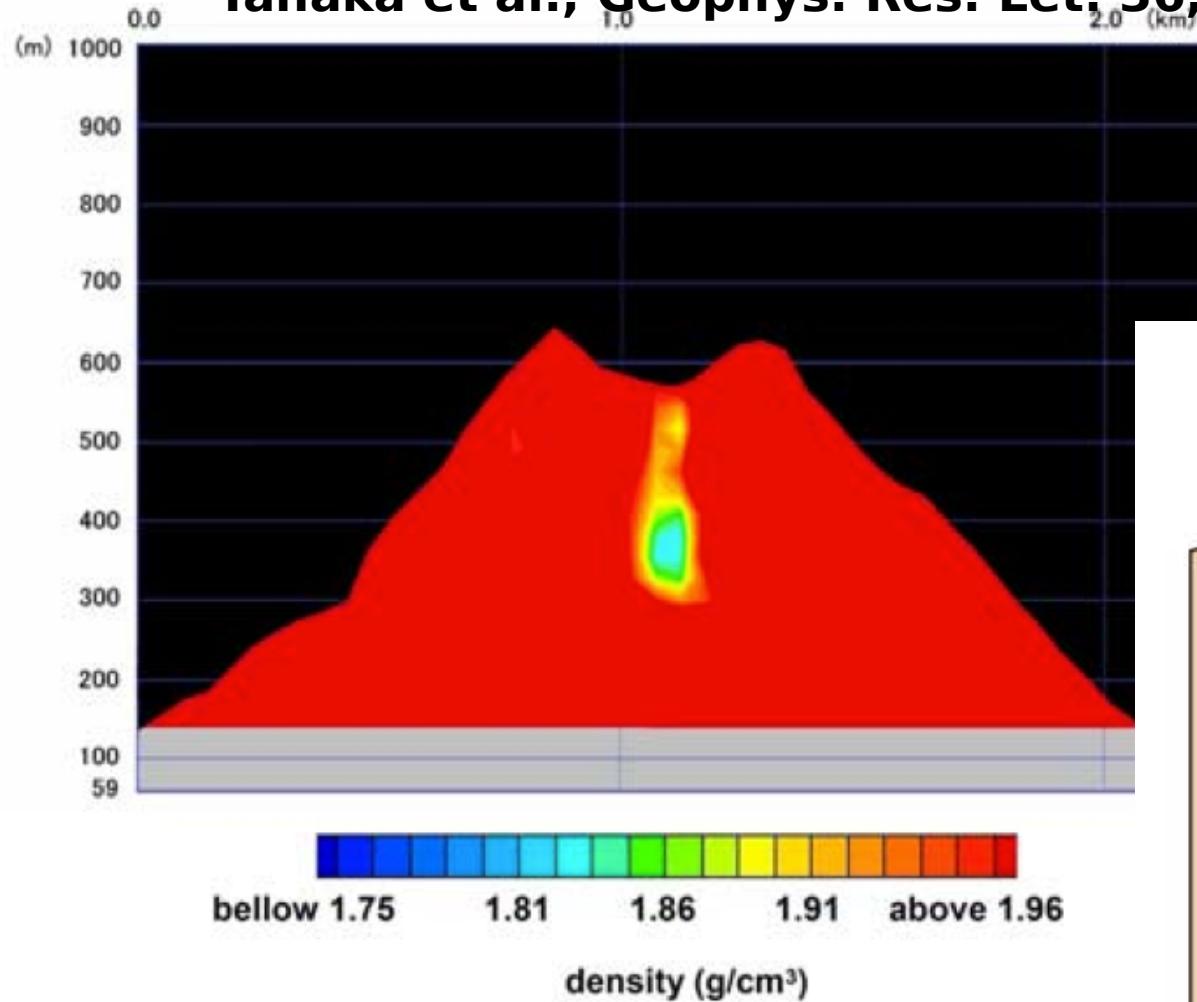
$$\varrho(L) \equiv \int_0^L \rho(\xi) d\xi,$$

Muon directional flux measurement

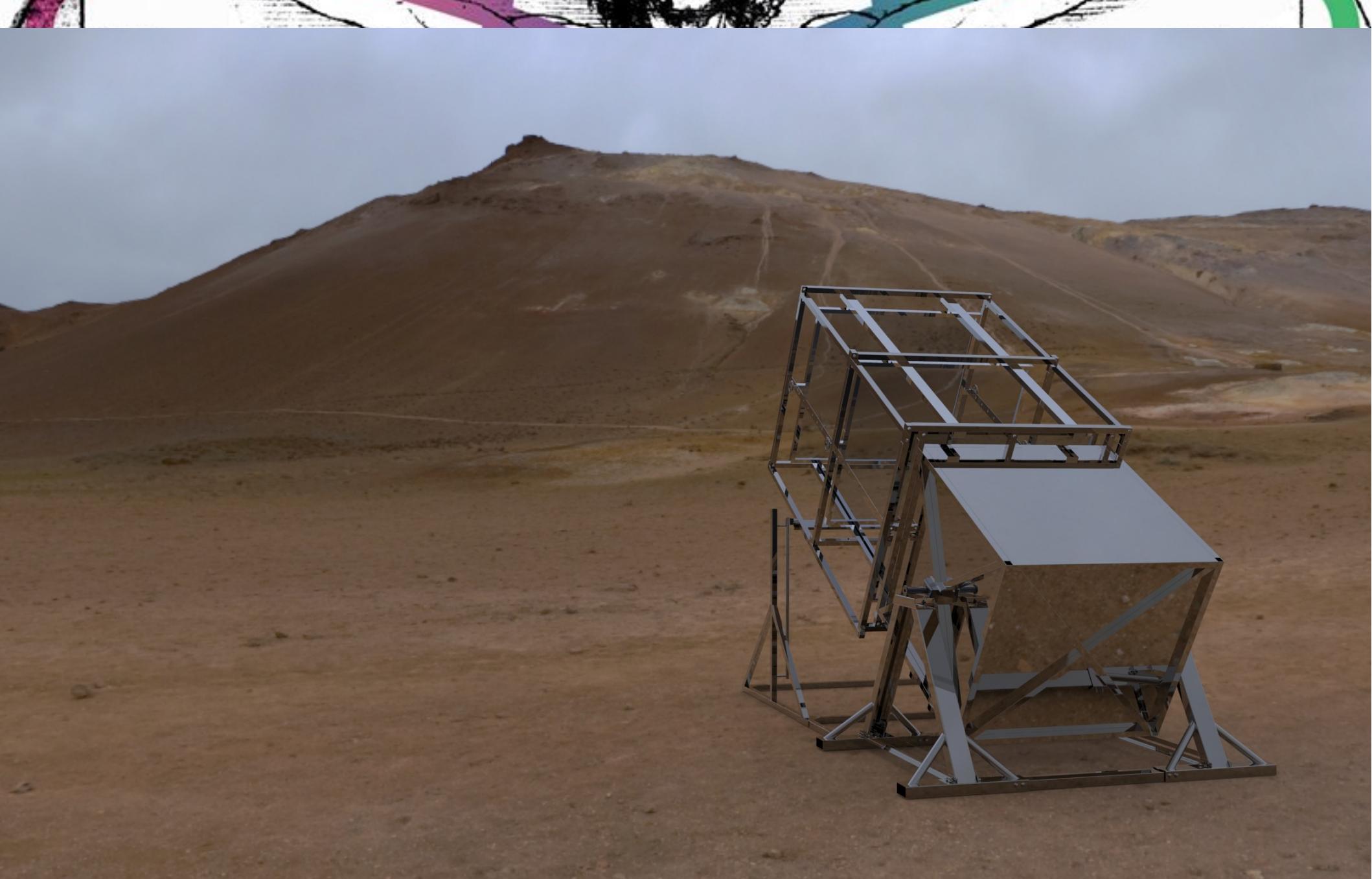


Volcanoes Muongraphy: Mt. Iwodake (Japan)

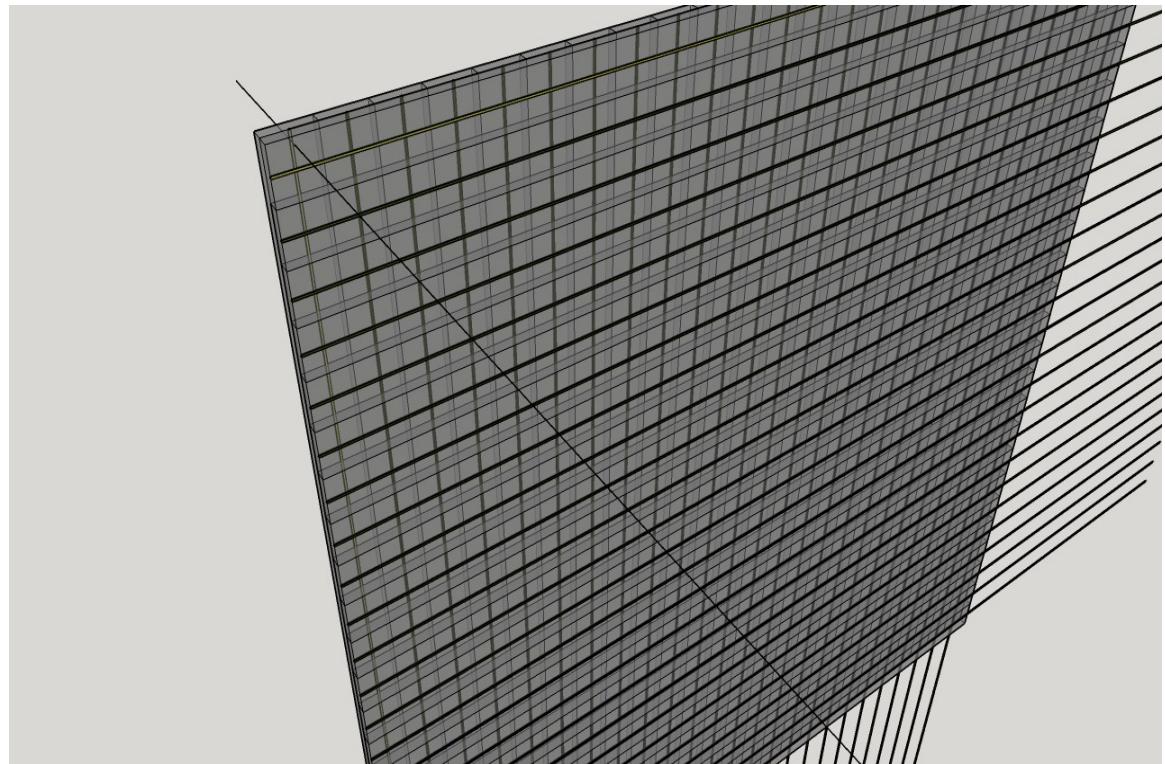
Tanaka et al., Geophys. Res. Lett. 36, L01304, 2009



MuTe/MuBar: Muon Telescope for muongraphy



Muon Camera

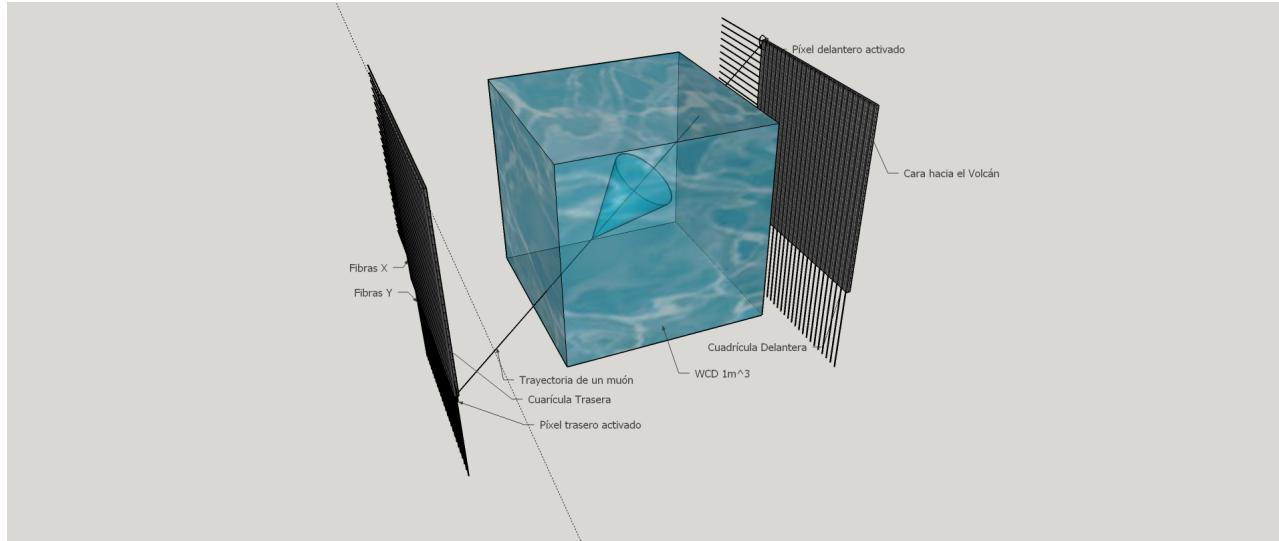


- 30 (4x1)cm plastic scintillator strips
→ 900 pixels (XY plane)
- Two XY planes separated by 2 m
- One water Cherenkov detector in between to obtain a high energy electromagnetic veto

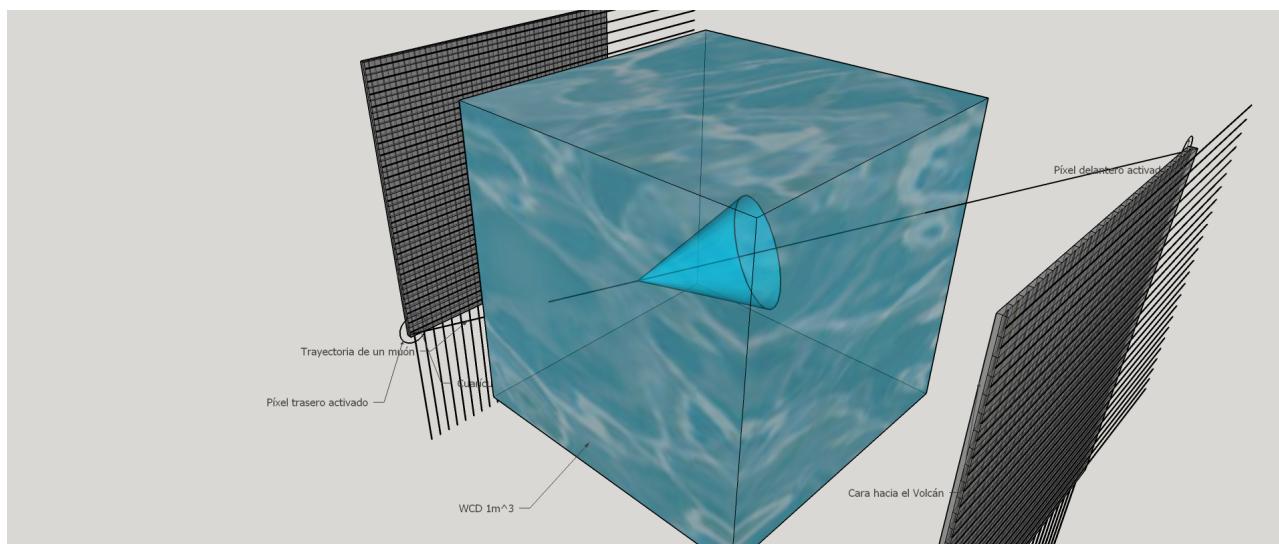
24/Oct/2016

- Two planes of “Minos” like polyestyrene plastic scintillator
 - (PoP+PoPoP) organic scintillator mixture
- Clad and wavelength shifter optical fiber at strip centre
- 120 SiPM (Hamamatsu MPPC)
- Raspberry-Arduino based atmospheric monitoring system
- CITIROC based electronic
- Programmable and configurable on board self trigger using FPGA
- Low power automatic and autonomous system

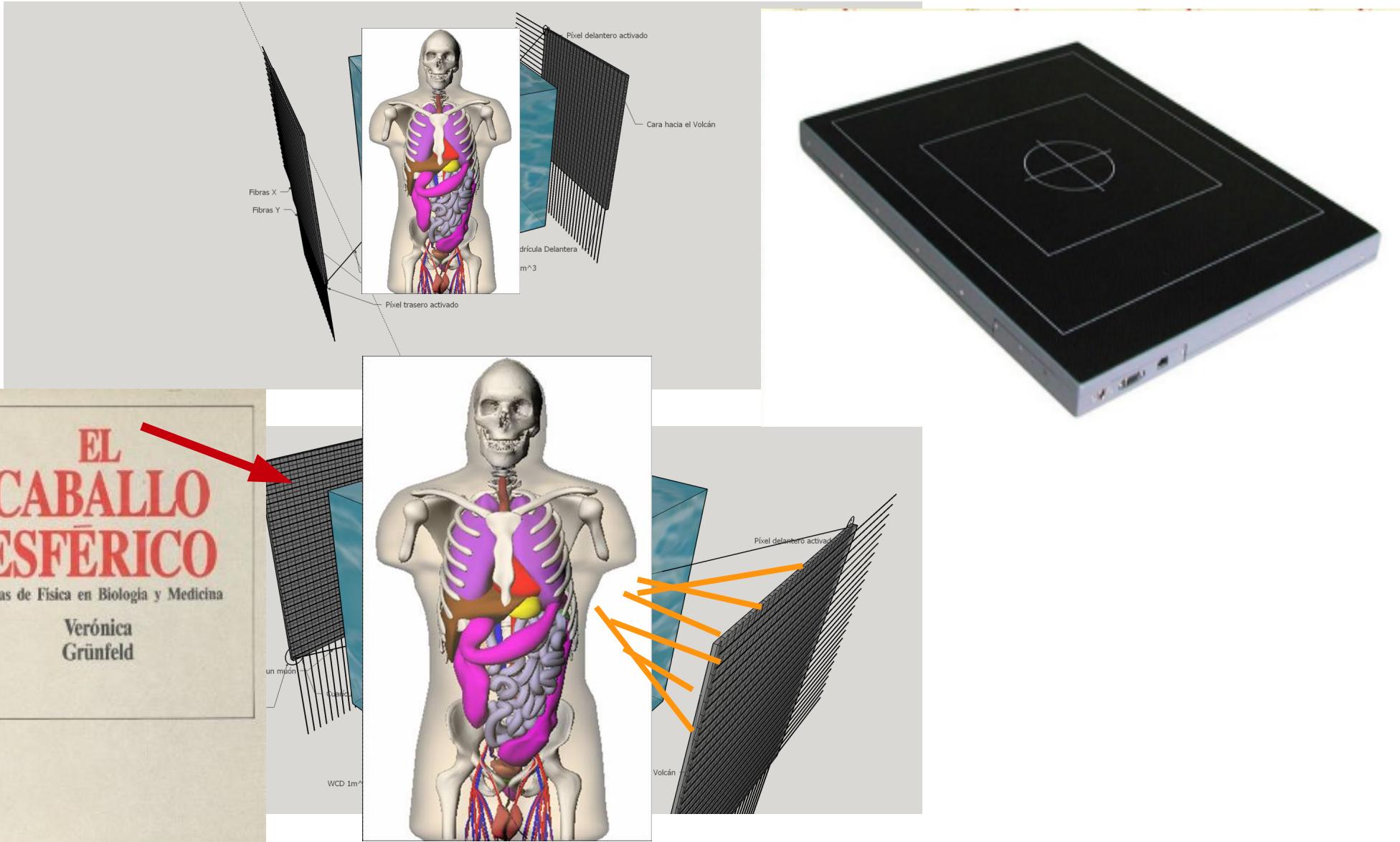
MuTe (Muon Telescope)



- Innovative:
 - Use a WCD as an active absorbant
 - 1.2m water $\rightarrow \sim 5 X_{EM}$
- Local measurement of atmospheric muon flux
- SiPM instead of multi-anode pixel
 - No crosstalk
 - Lower budget
 - Lower power consuption
 - Simple global design



Now replace “water” by “warm salt water”... and use, eg, amorphous Silicon flat panels





Ionizing radiation detection using commercial CMOS COTS

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Mariano Gómez Berisso¹

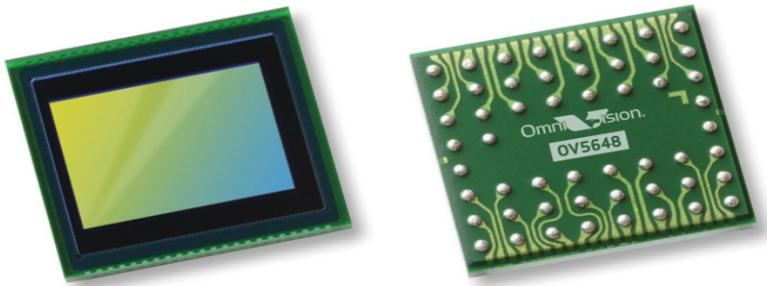
¹ División Bajas Temperaturas, CAB, CNEA, CONICET

²Laboratorio de Detección de Partículas y Radiación, CAB, CNEA, CONICET

³Departamento de Física de Neutrones, CAB, CNEA, CONICET
*previamente



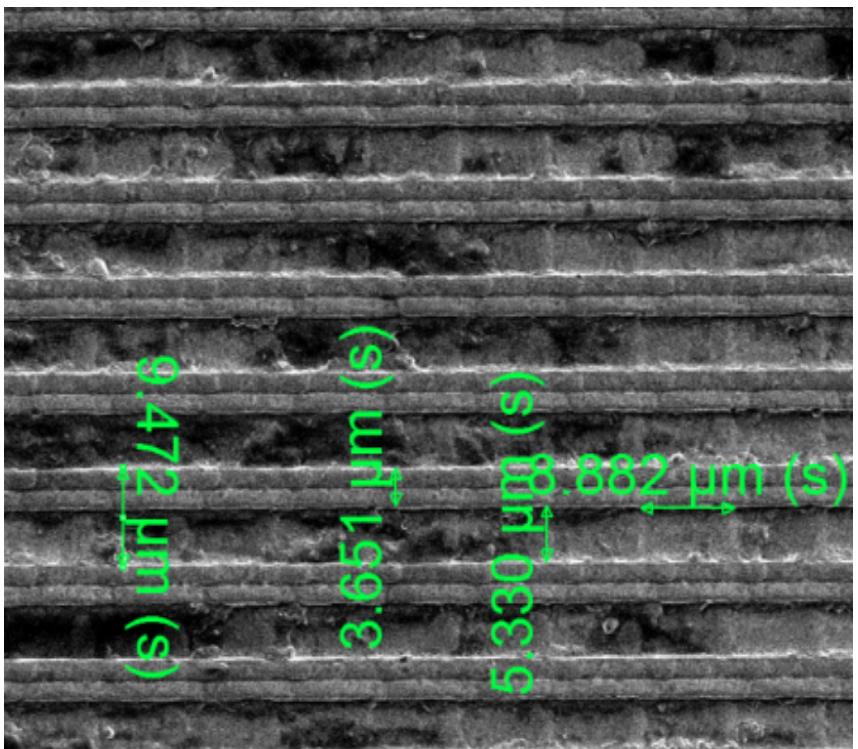
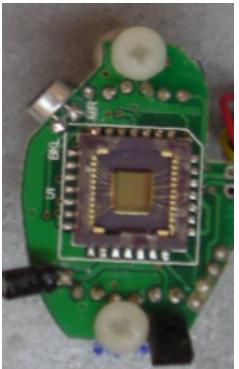
- Improved sensitivity, consumption, speed and cost, when compared with CCD
- System on chip: amplifier, signal conversion and prosesing in a single chip
- Camera universality → don't blame us of Instagram cat pictures



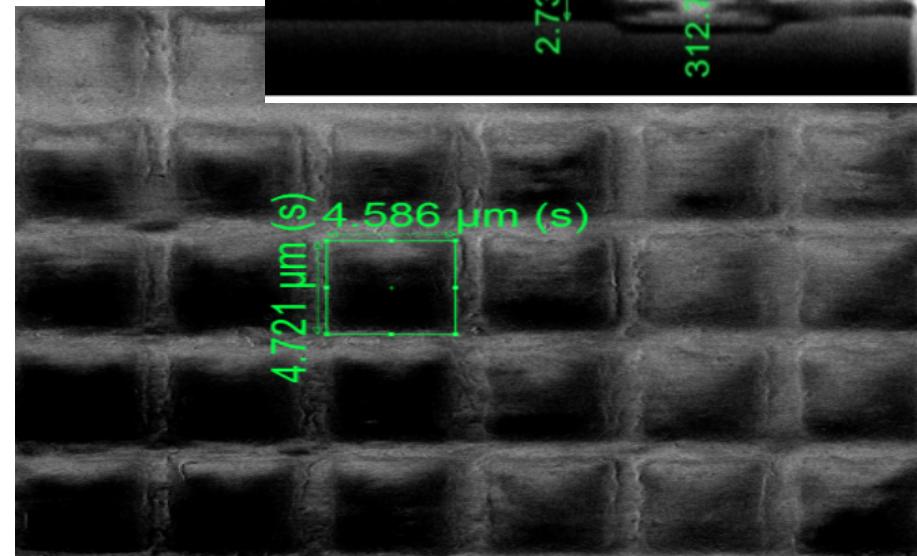
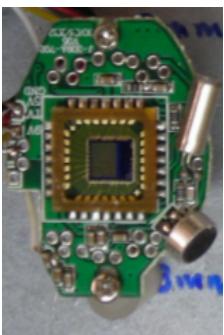
Typical commercial imaging sensors

CMOS COTS

Sensor ByN:
OmniVision OV5116N
0.25" 640 x 480 pixels
11 μ m pitch



Sensor Color:
APTINA MT9VO11
0.25" 640 x 480 pixels,
5.6 μ m pitch



Ionizing particle detection

We can see
1- Events
2- Fixed points
3- Non zero
Background
(average dark
current)

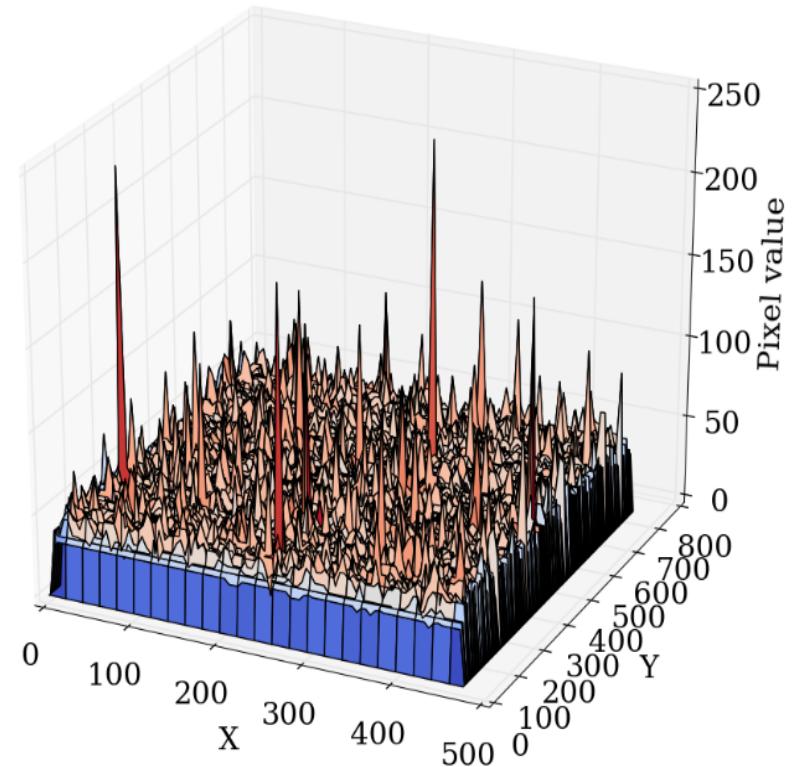
Fixed points (FPN)



Fixed Pattern Noise

Defective pixels and thermal noise introduce a non-zero background (fixed pattern noise, FPN)

Auto-regressive filter: fast and low computational cost.
Can be easily implemented on FPGA systems



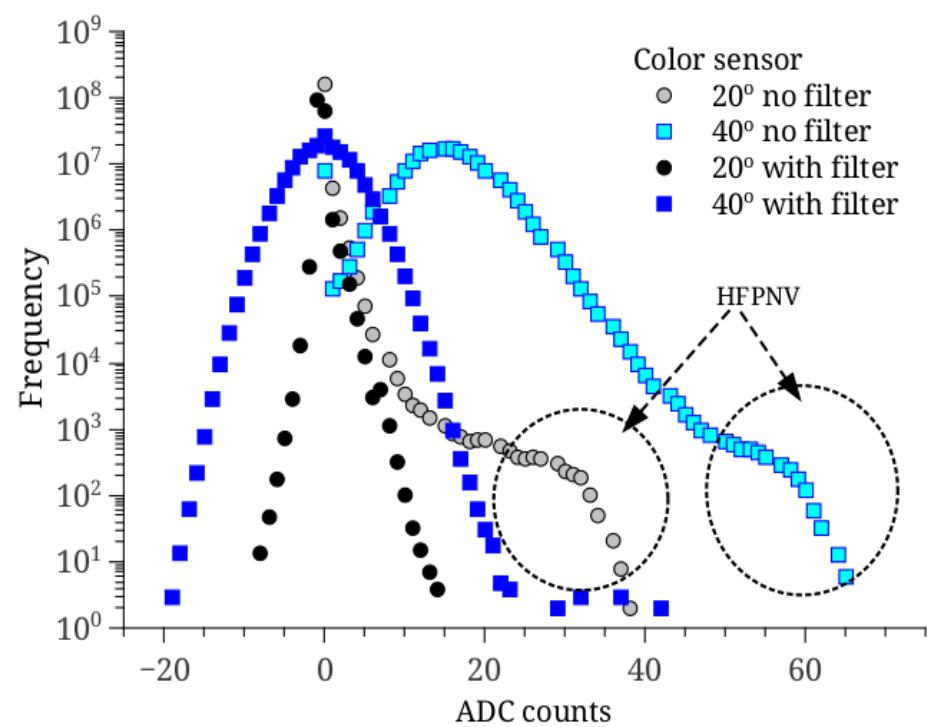
$$I_{FPN}(n) = I_{FPN}(n-1) \cdot (1 - a) + I_{READ}(n) \cdot a$$

$$I_{CLEAN}(n) = I_{READ}(n) - I_{FPN}(n)$$

Fixed Pattern Noise

Extremely reduced false-positives pixels

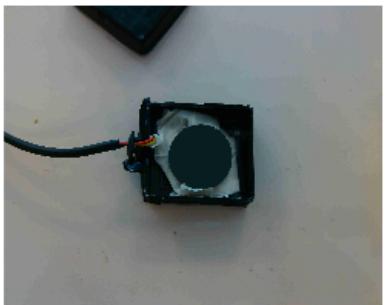
Pixels with signals above a low threshold can be considered as a real (physics) event



Particle response

Different particle sources
irradiation:

- β , γ ^{137}Cs
- X-ray ^{55}Fe
- β ^{152}Eu
- γ ^{60}Co , ^{133}Ba
- α , γ ^{241}Am and ^{235}U



^{235}U



^{137}Cs



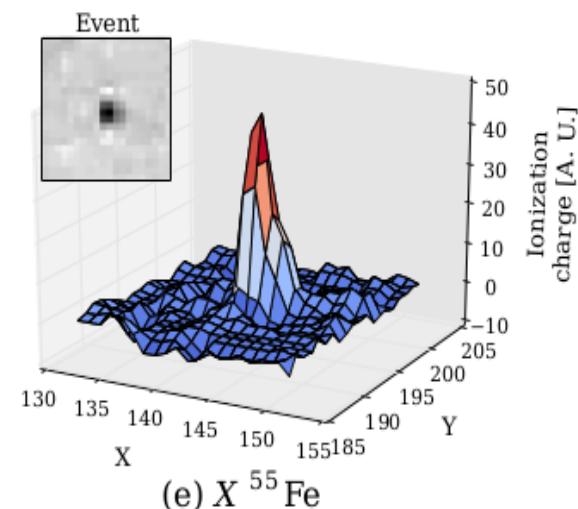
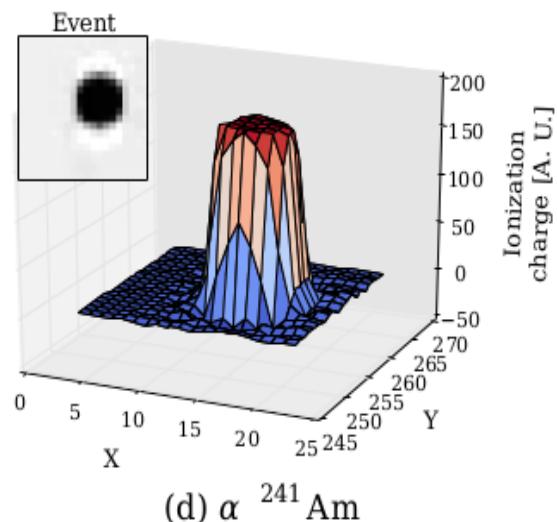
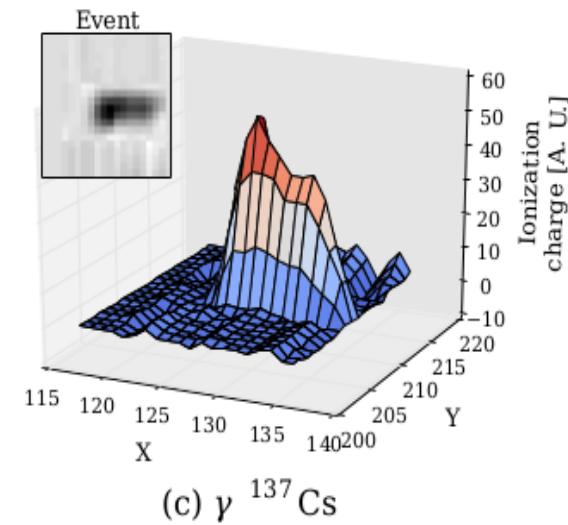
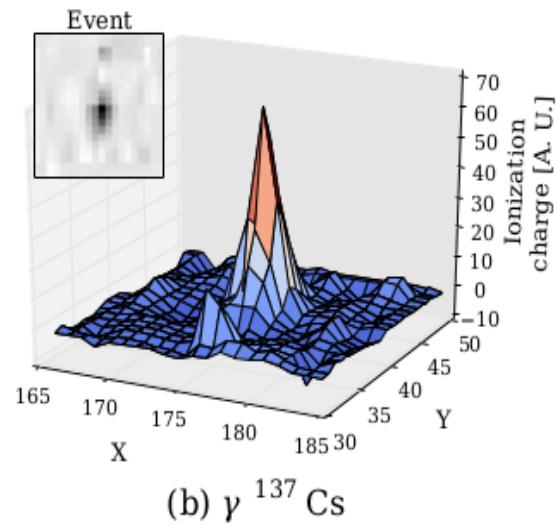
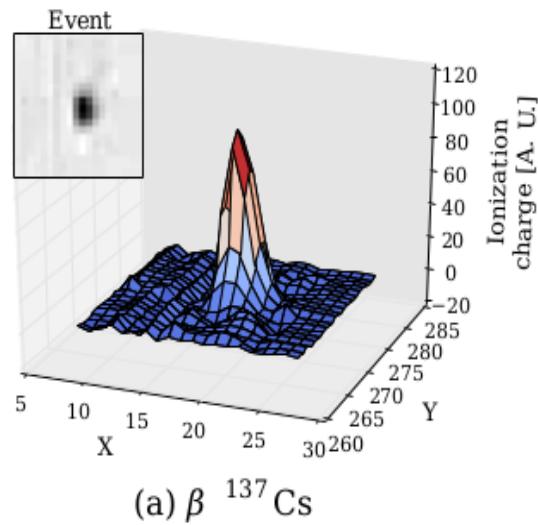
^{60}Co



^{241}Am (con blindaje)

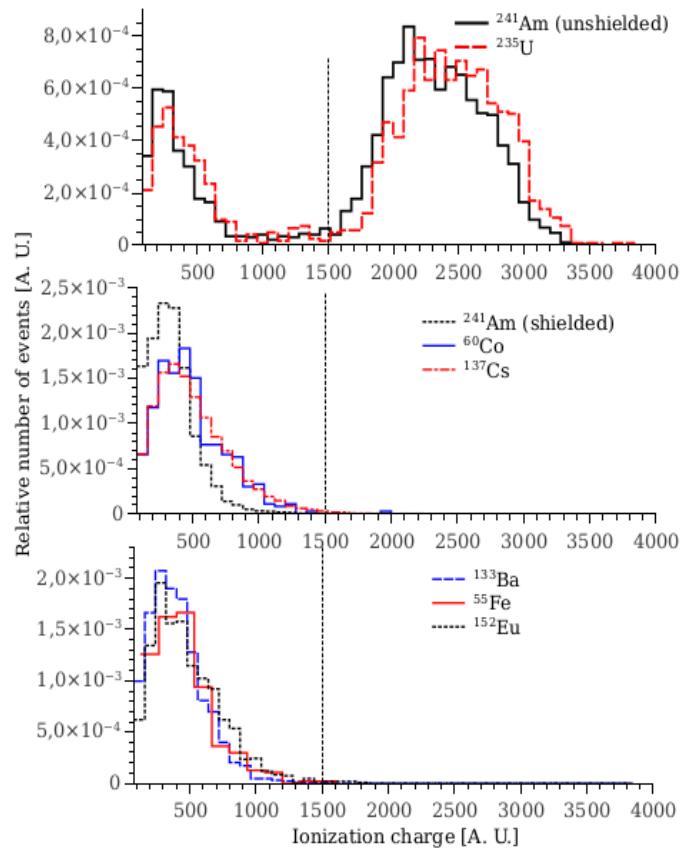


Particle response

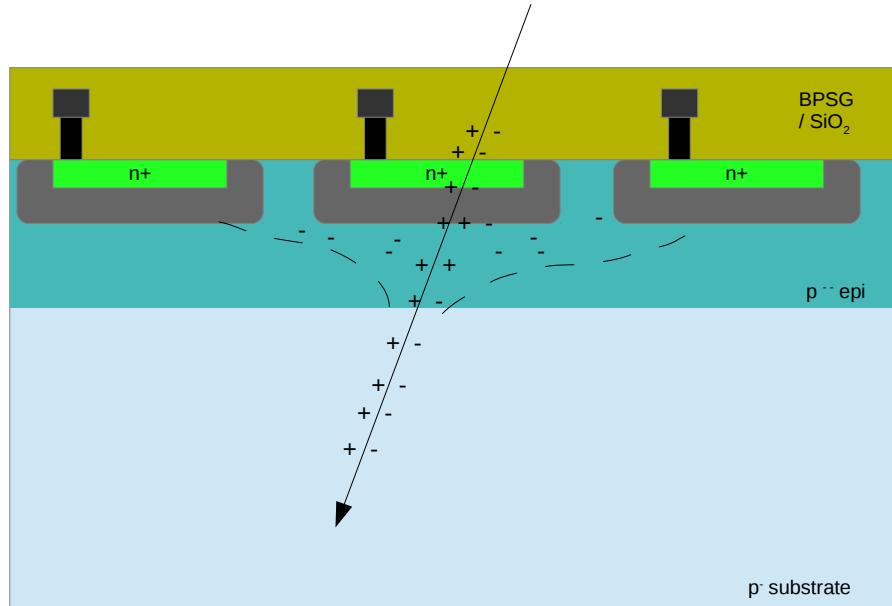
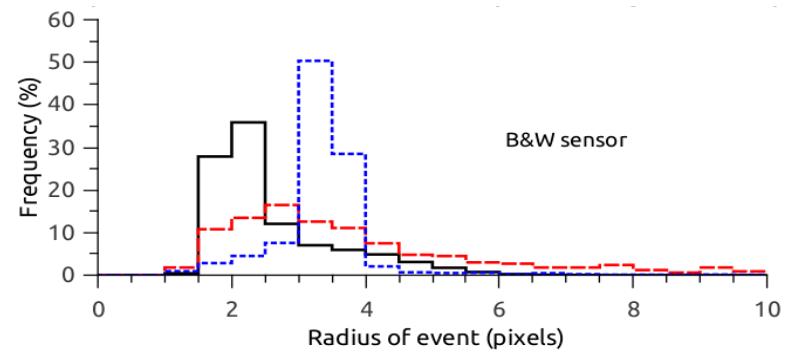


Pixel clusterization

Radius (px)

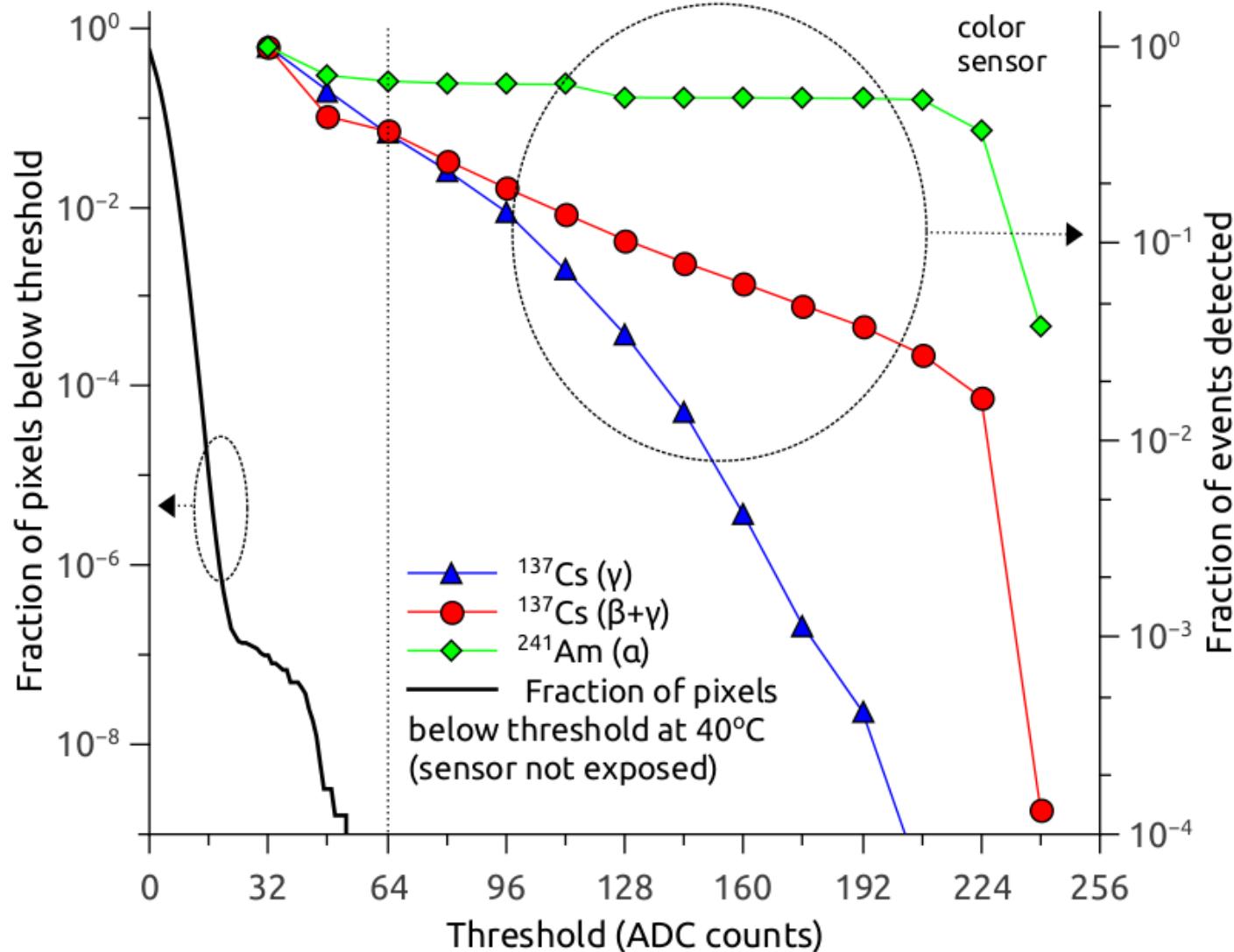


Deposited charge

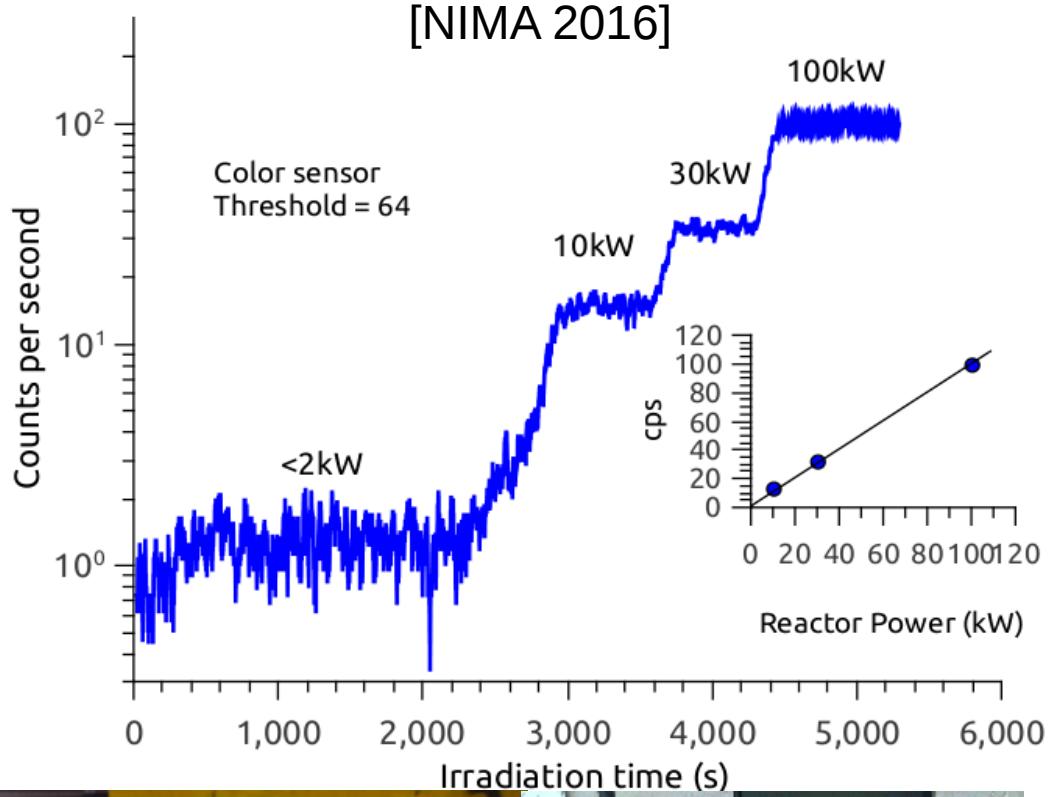
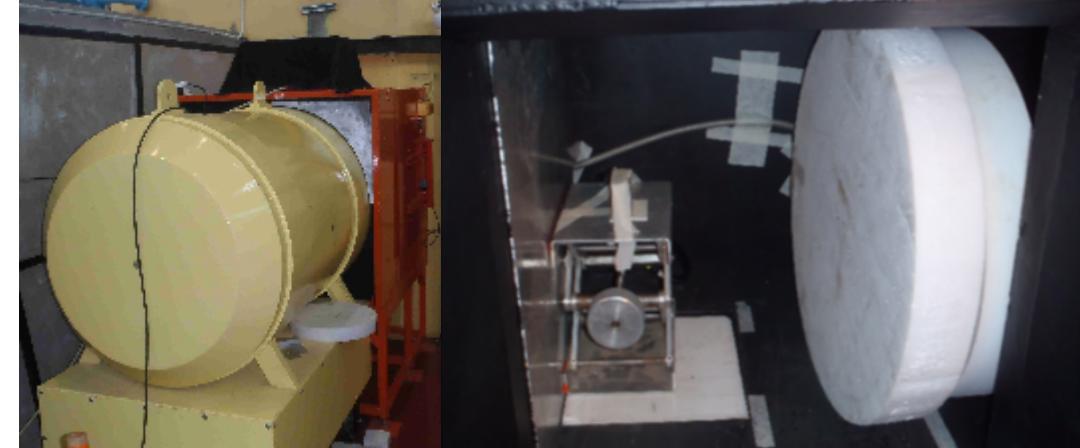


Detections threshold optimization

Robustness vs sensitivity Tradeoff



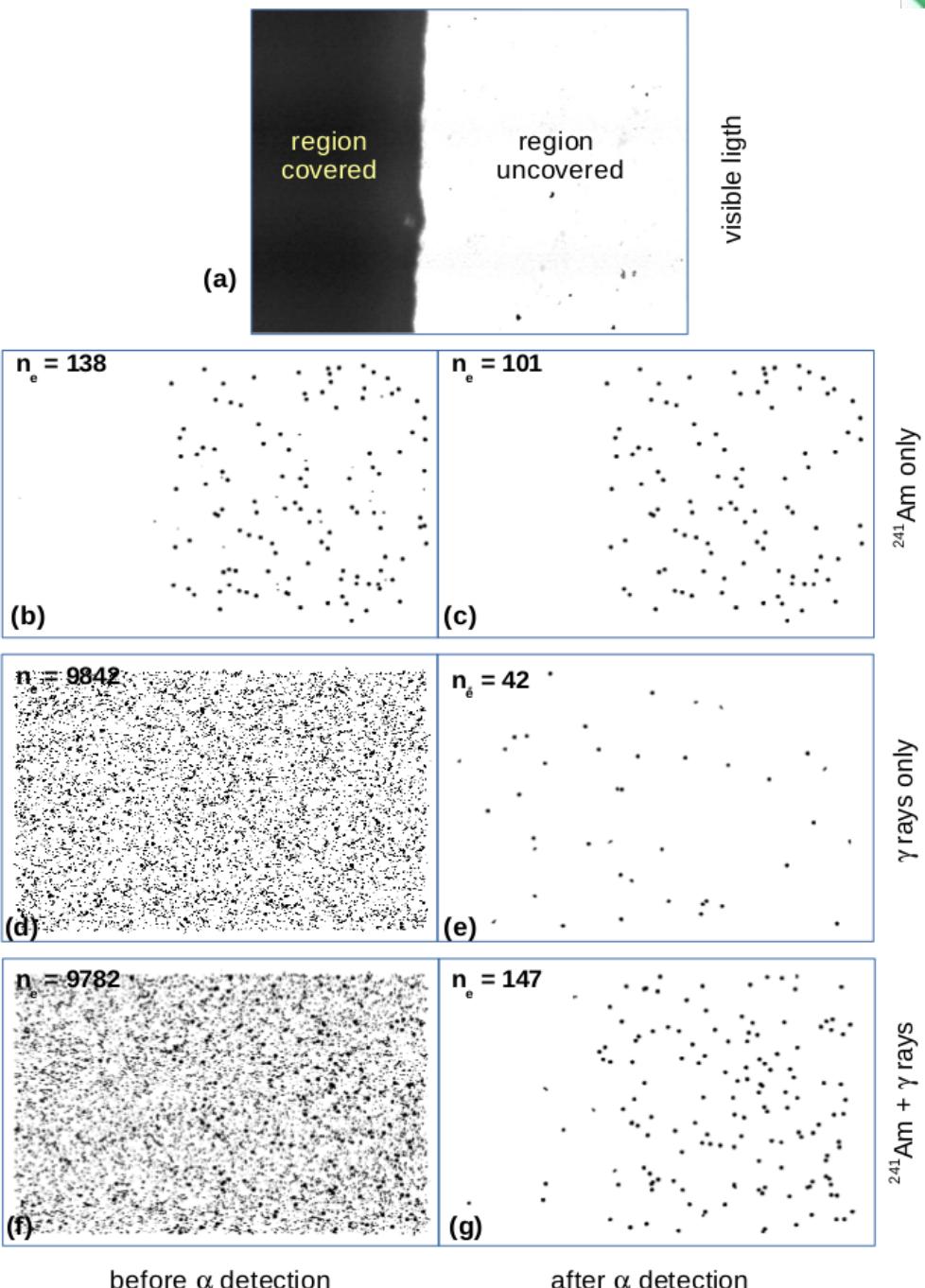
RA6 experiment tests



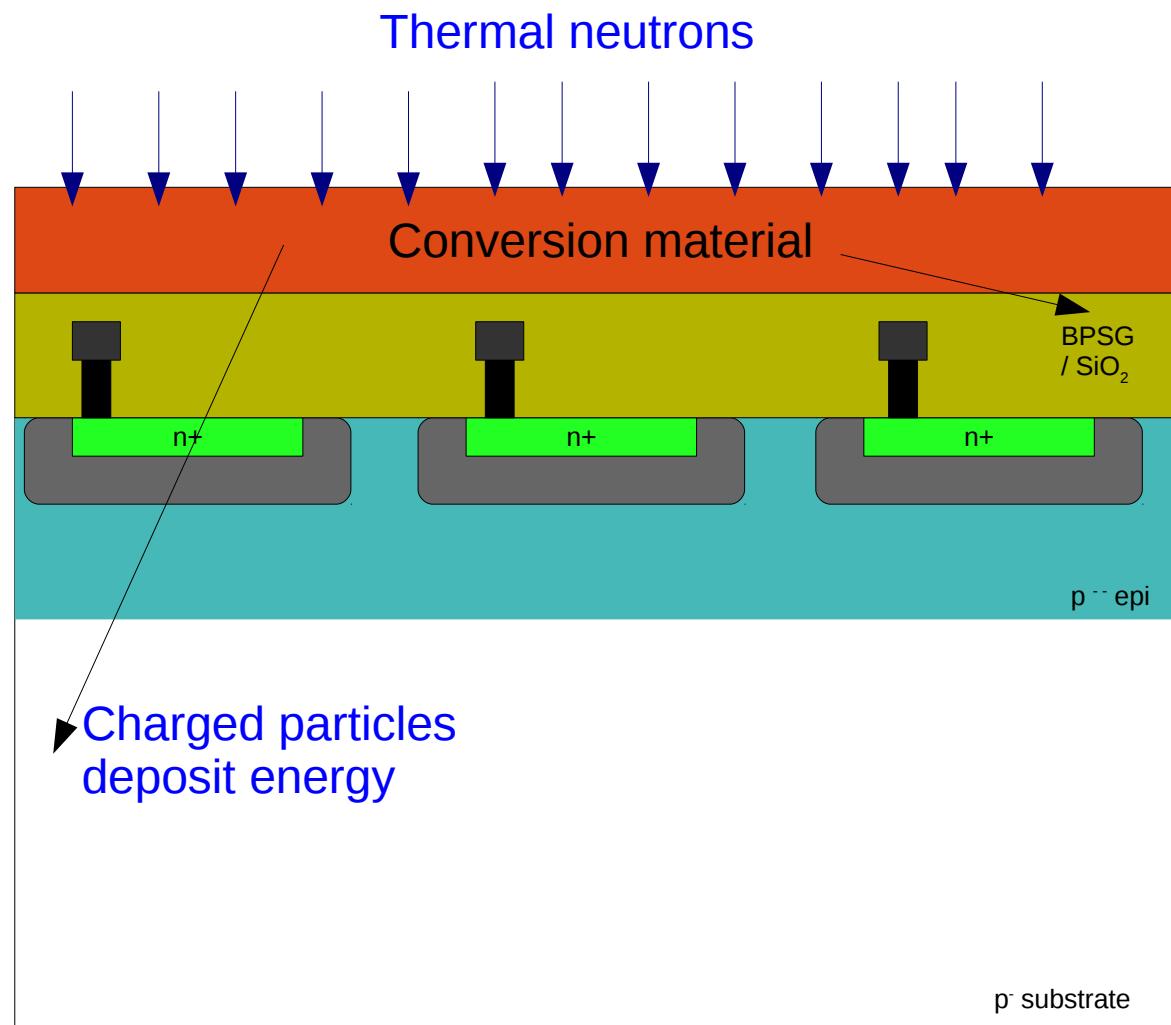
Particle identification

$q > 3000$ adc counts
radii > 2.5
max > 125

0.4% false-positive (gammas instead of alpha)



Thermal neutron detection

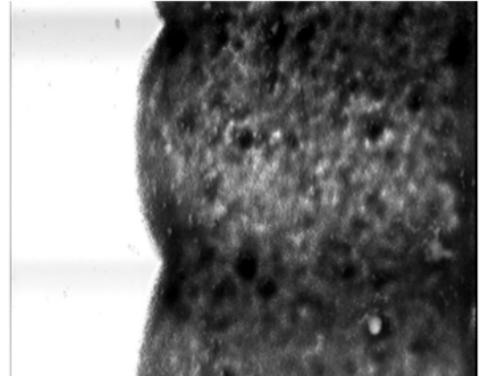


Boron and Gadolinium conversion

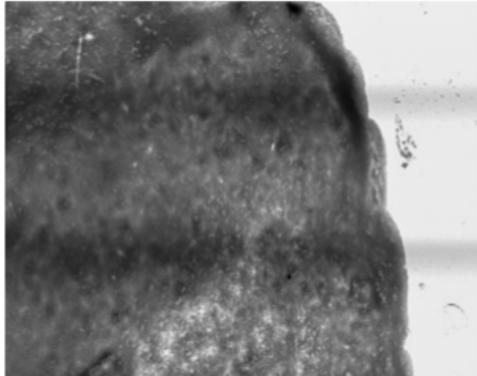
BNCT, neutrography, space weather, homeland security safeguard

Gadolinium oxide (Gd_2O_3) response Signal amplification

Cámara blanco y negro



Cámara color



Captura tomada con luz de la zona del sensor cubierta con Gd

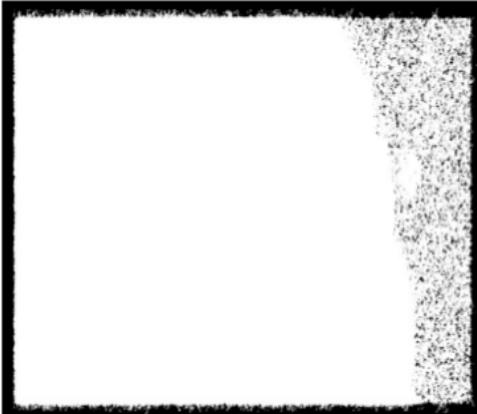
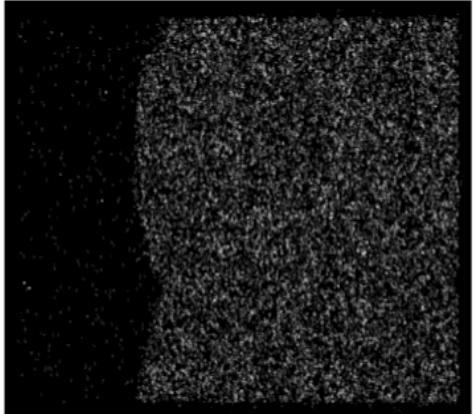
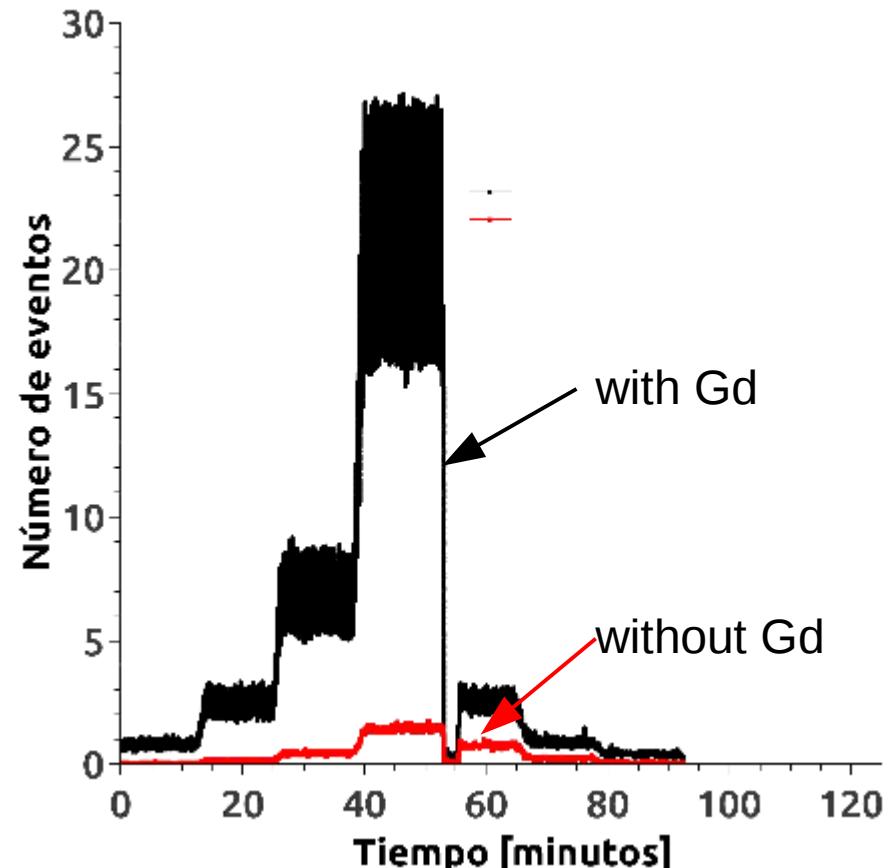
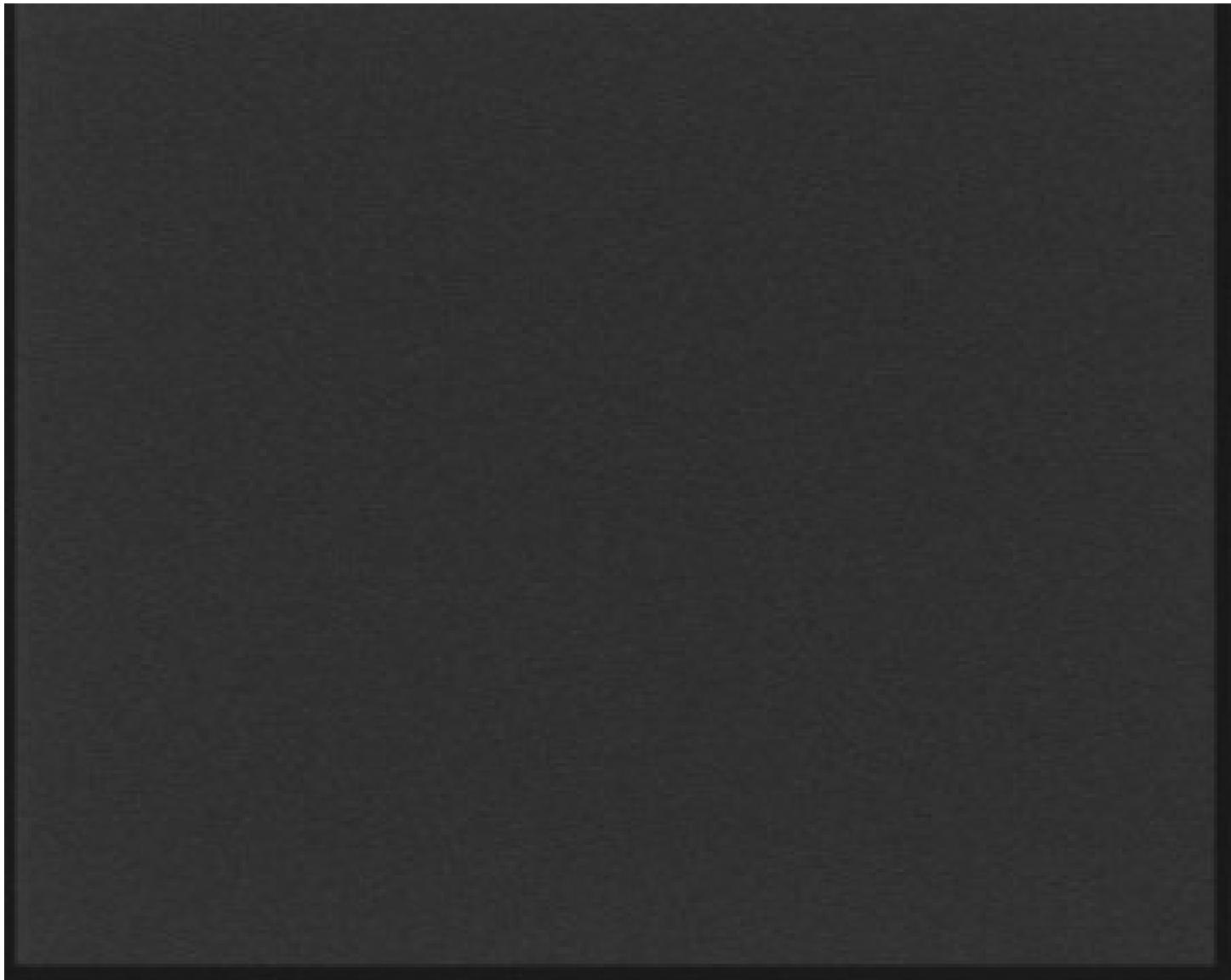


Imagen de todos los eventos capturados en el video



Integrated dose damage: ^{60}Co source (PISI-CNEA)



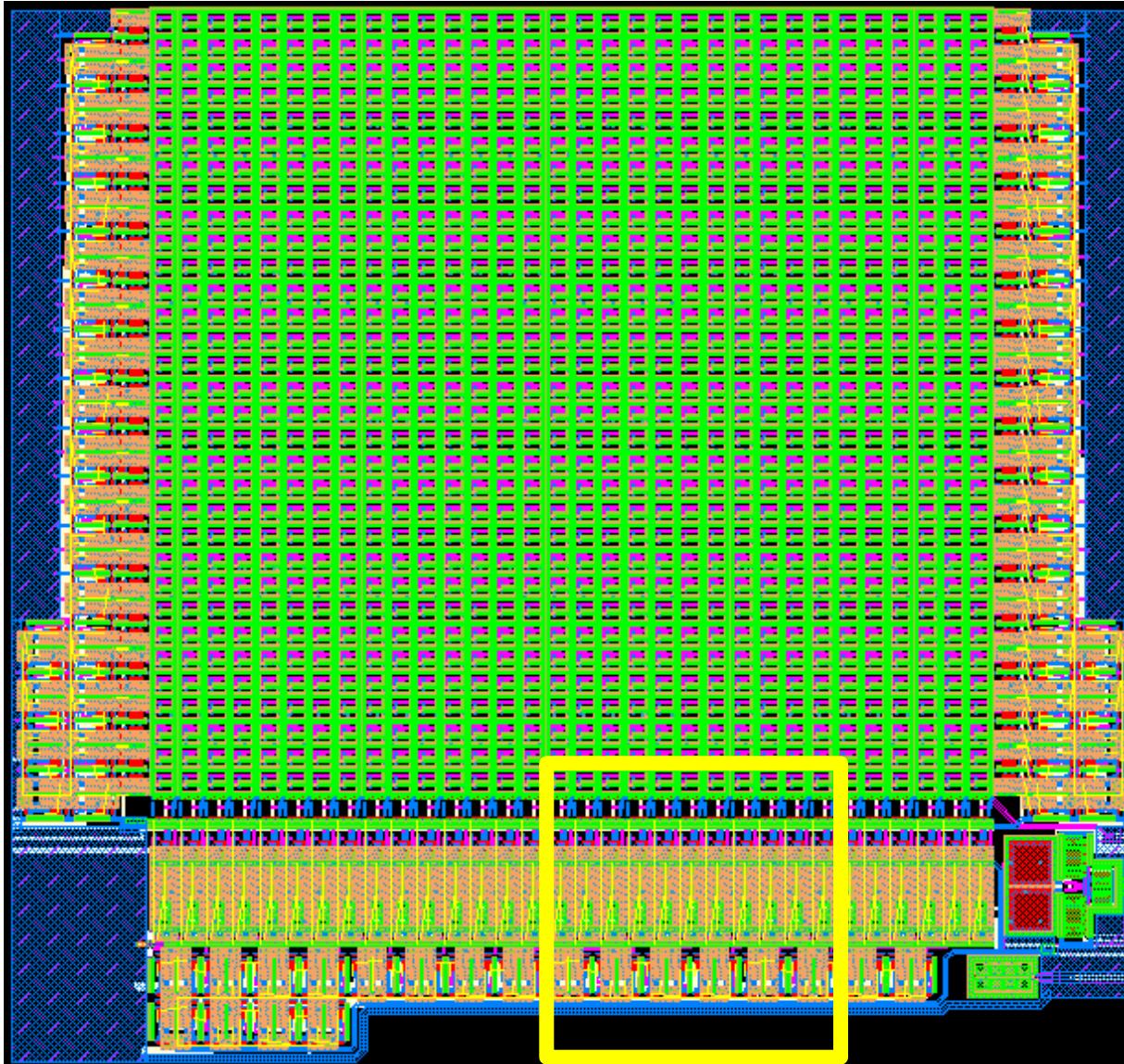
B&W camera, 2hs
exposure at
200Gy/h.

180Gy: dark current
increase

280Gy: Column
saturation

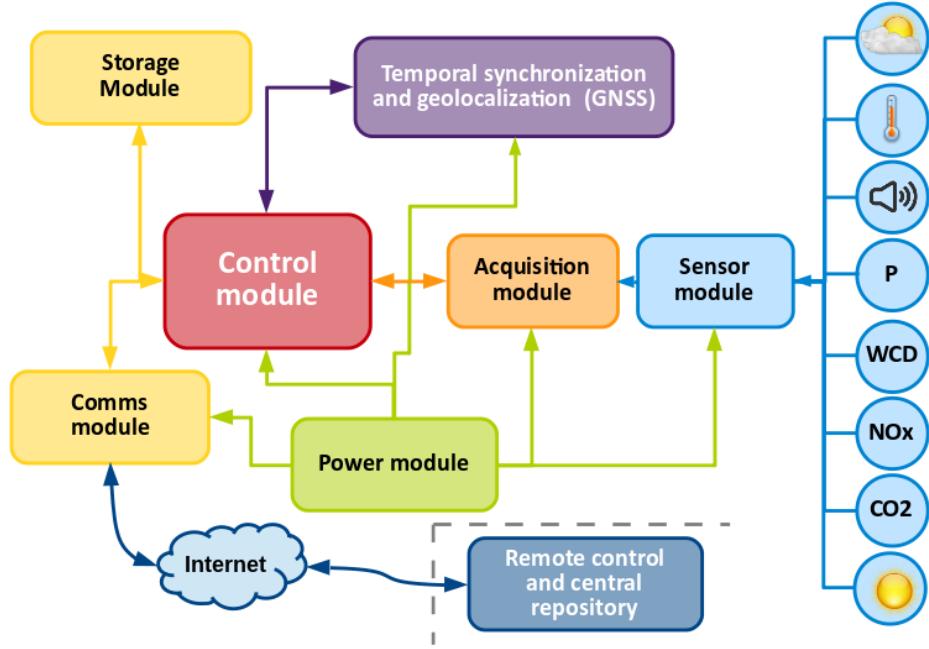
400Gy: Sync
issues

Own CMOS development for high radiation environments

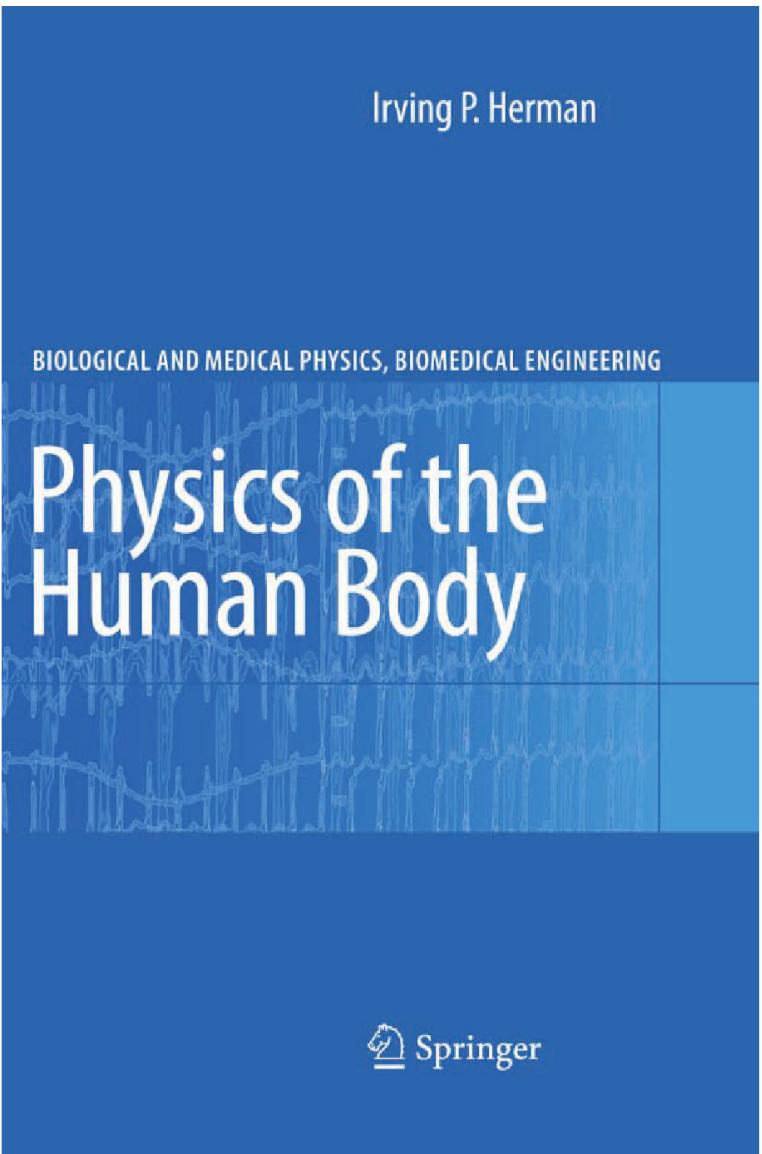


Extreme electronics for extreme detectors

- OMEGA based IN2P3 multi-channel ADC (MAROC, CITIROC)
- FPGA based electronics & “sensor as a peripheral concept”
- (Ultra) fast electronic response (> 100 Mhz)
- Commercial on-the-shelves adquisition and control modules: WiFi, Bluetooth, Linux, C++ & Python, low cost, low power consumtion

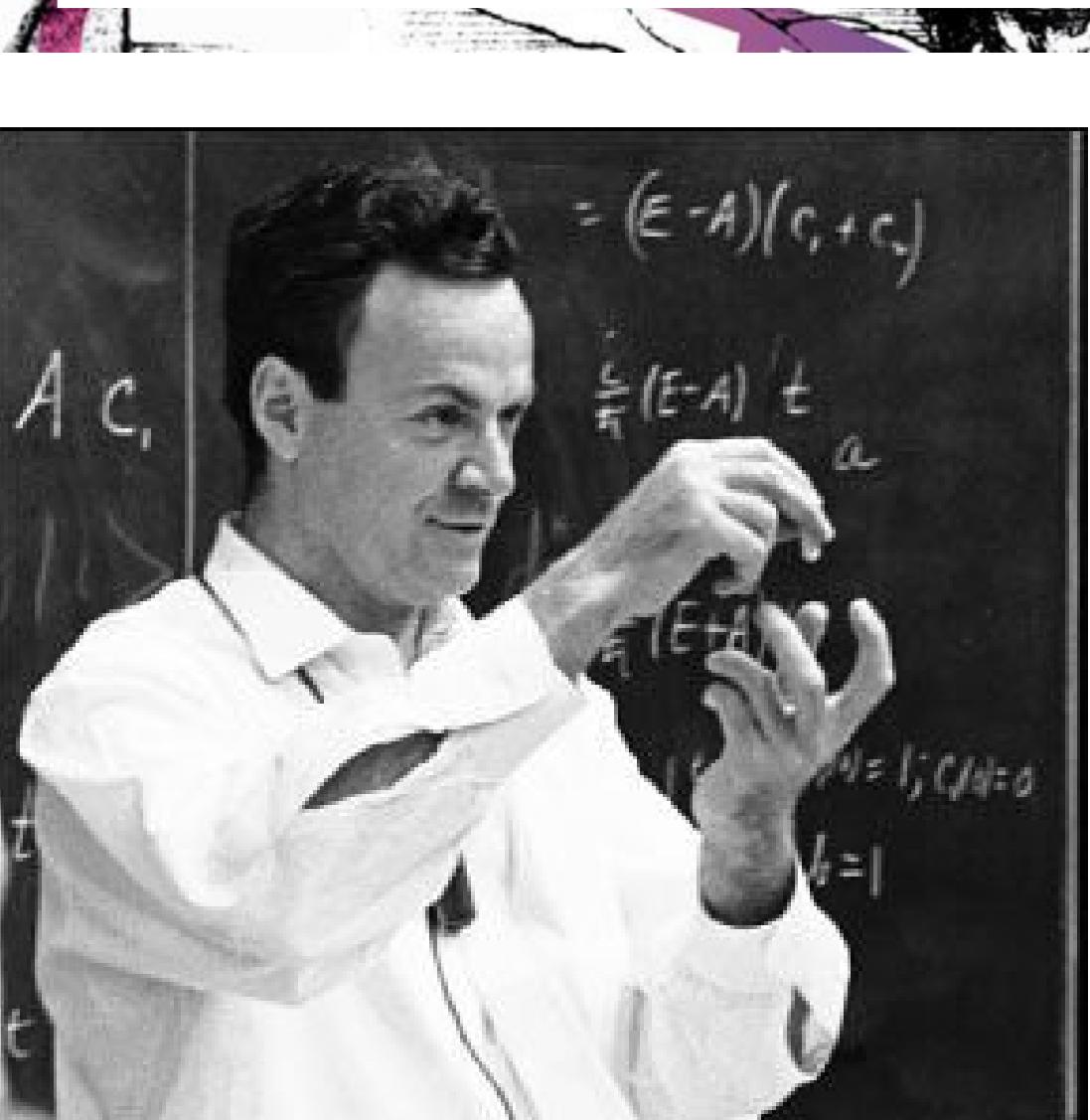


Why translational 1?



- “*Much of the problem we have in comprehending specialists in any field is in understanding their jargon, and not in understanding their ideas. This is particularly true for medicine. Much of medical jargon of interest to us is the terminology used in anatomy, and much of that in anatomy relates to directions and positions*”
- La medicina es descriptiva

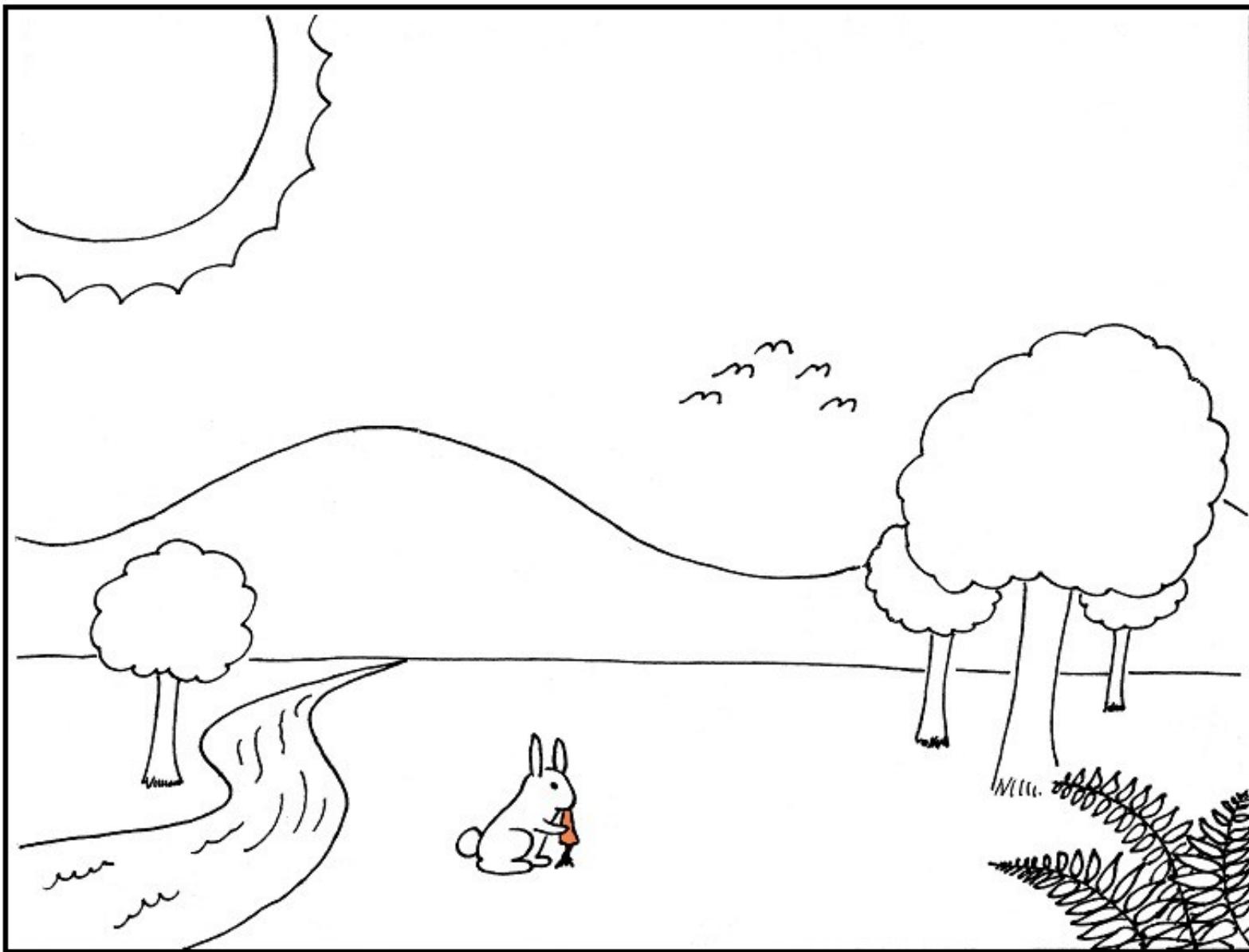
Why translational 2?



“By a direct translation of the solutions (of course the same mathematical equations must have the same solutions) it is possible to solve problems in other fields with the same ease—or with the same difficulty—as in electrostatics”

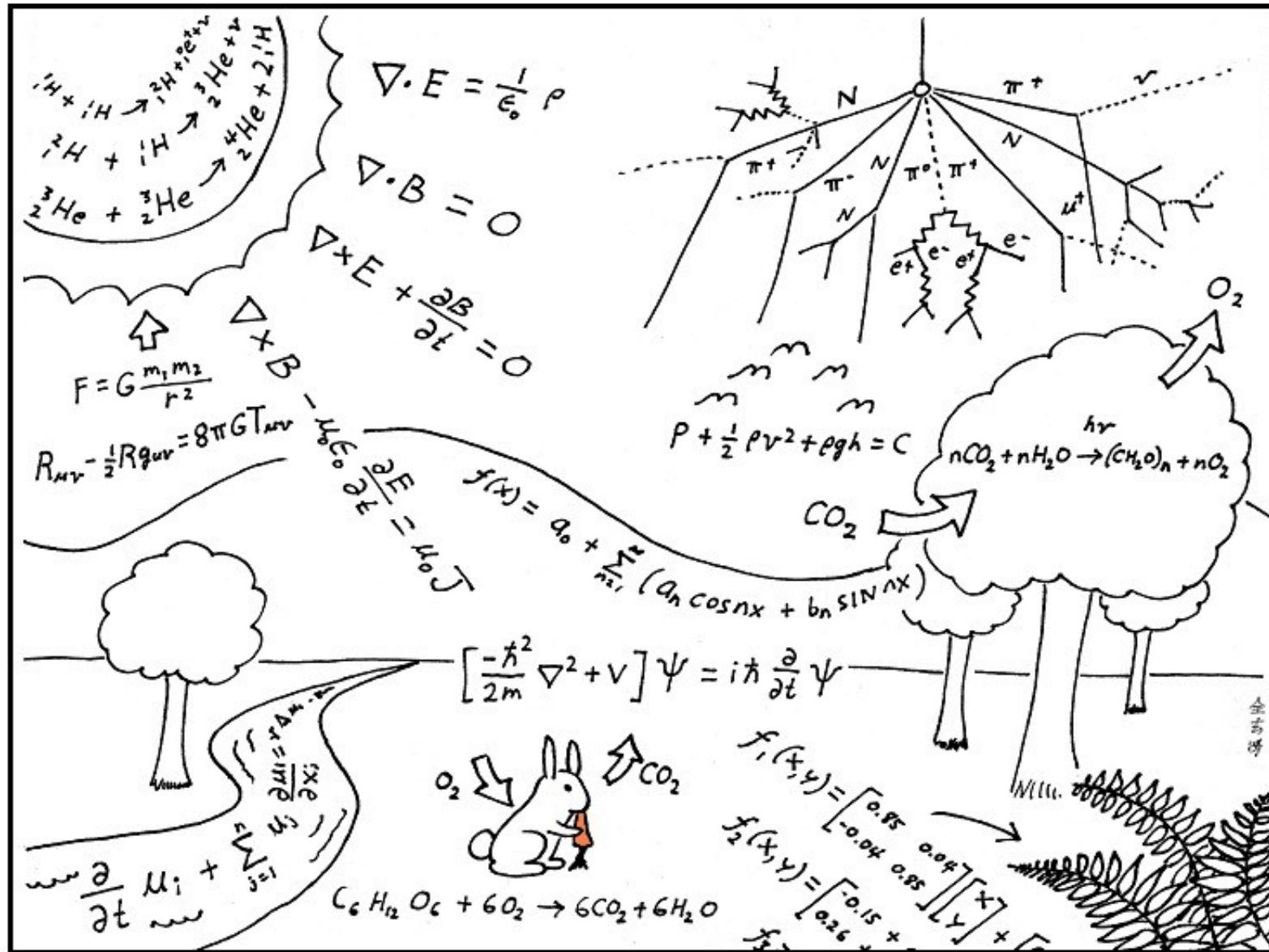
*Richard Feynmann, Lectures,
Vol II p 12-1*

Why translational 3?



This is what your University did to your brain

Sue them!



Extreme questions for extreme diseases

**Can we (physicists)
help people who is really
suffering a serious disease?**

Yes!

Let's do it together

Thank you very much