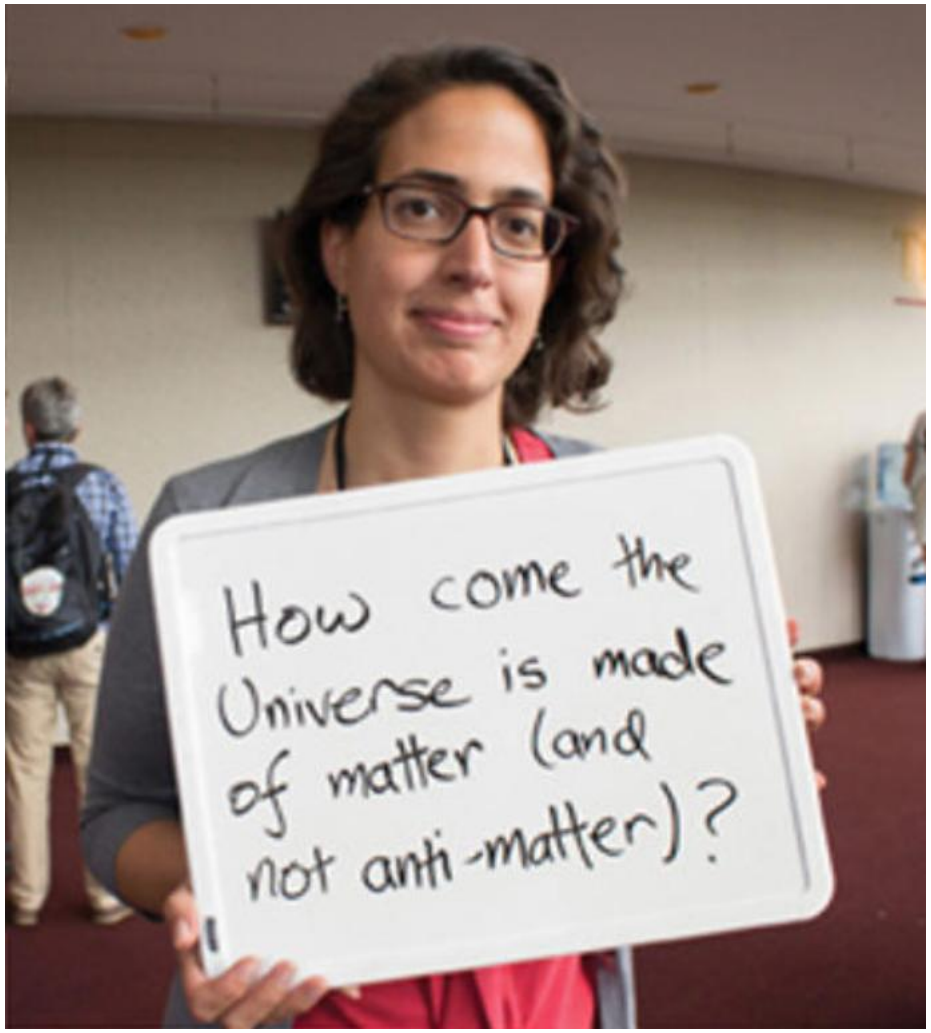
Cosmic ray studies and applications at IFUNAM: From the International Space Station to Chichén Itza

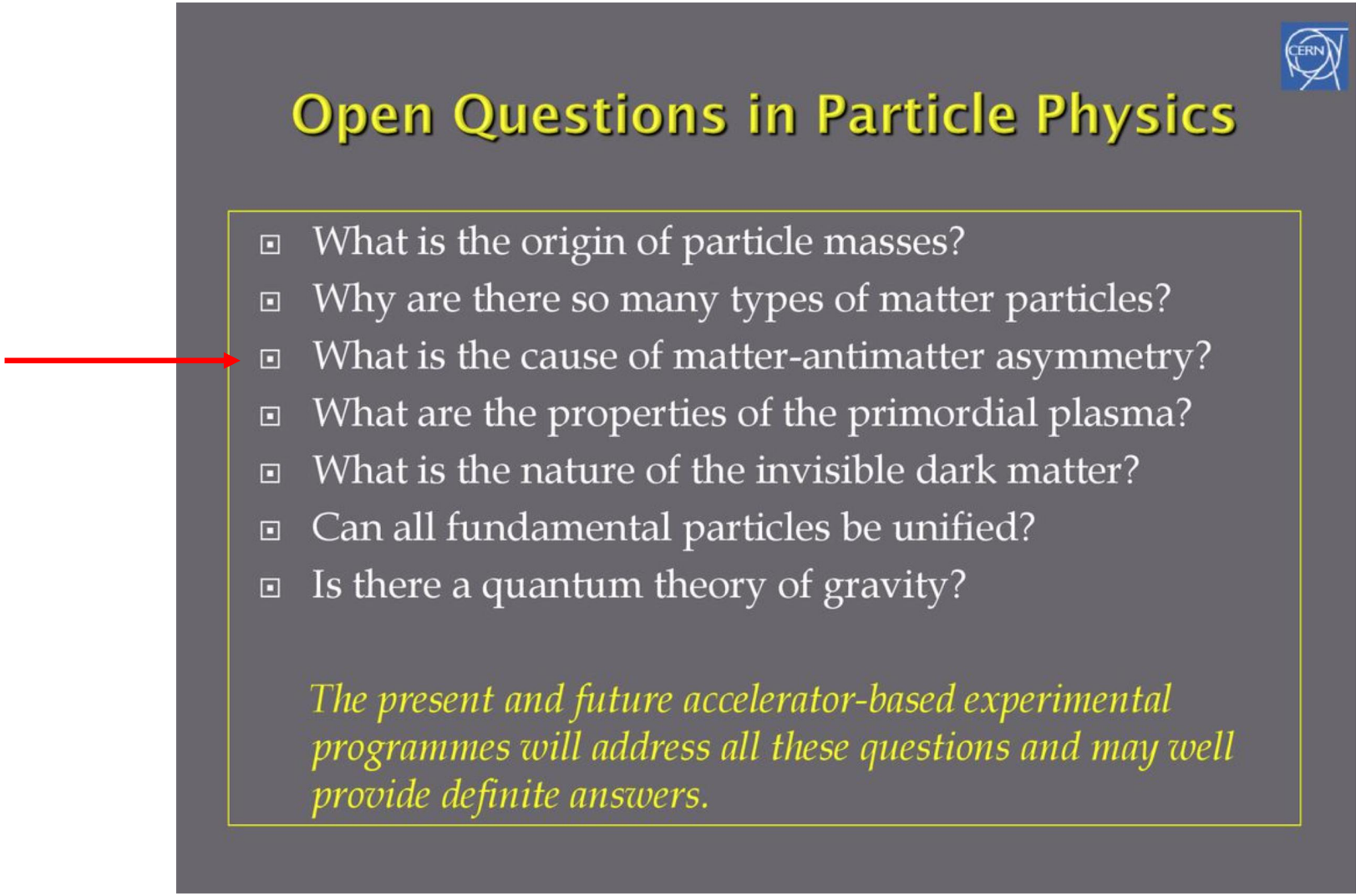
Arturo Menchaca-Rocha

CONHACYT: Proyecto Ciencia de Frontera 2042

Where did all the antimatter go?

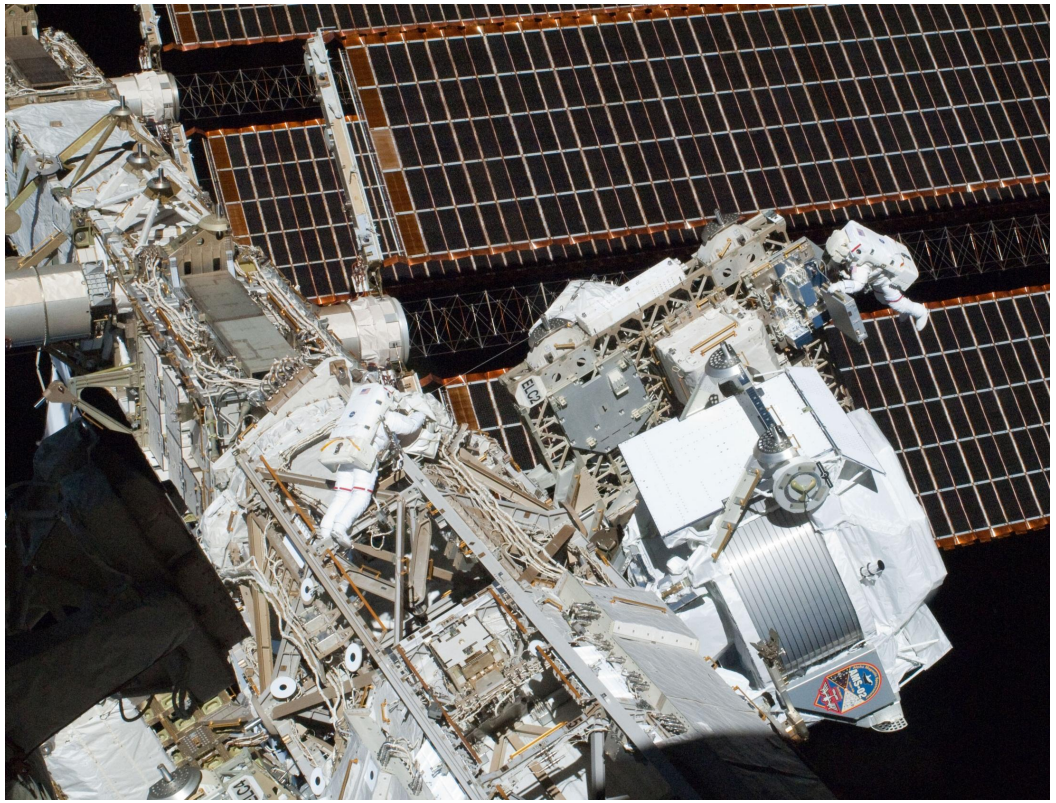


Who cares?


Open Questions in Particle Physics
What is the origin of particle masses?
Why are there so many types of matter particles?
What is the cause of matter-antimatter asymmetry?
What are the properties of the primordial plasma?
What is the nature of the invisible dark matter?
Can all fundamental particles be unified?
Is there a quantum theory of gravity?
The present and future accelerator-based experimental programmes will address all these questions and may well provide definite answers.

How we got involved?

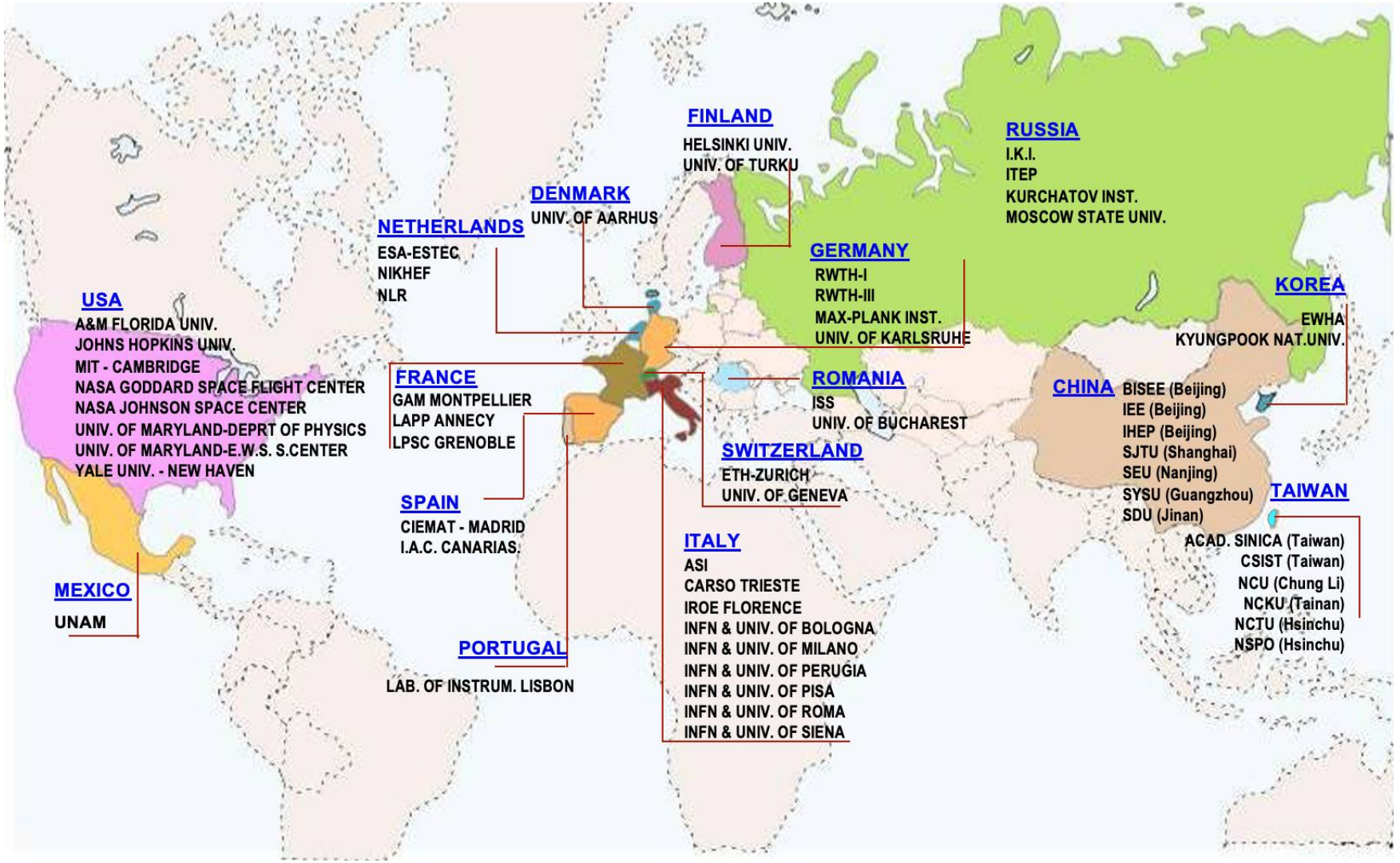
Sam Ting in 1999



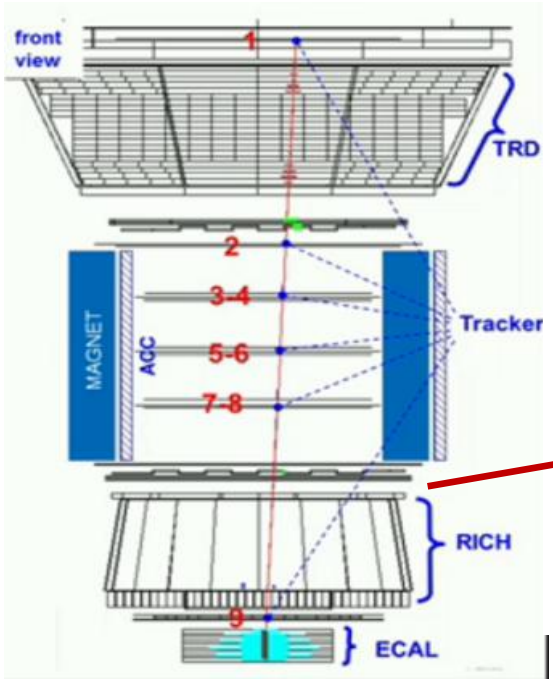
On the ISS since 2011

AMS-2 Collaboration

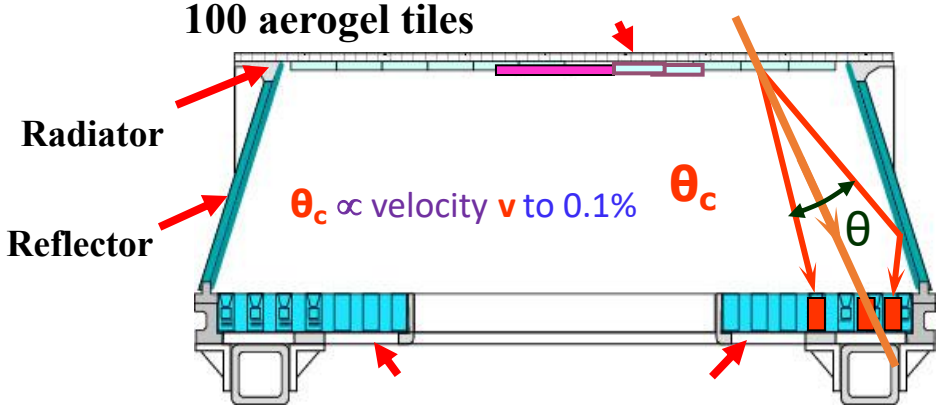
56 Institutions
220 Authors
3 UNAM



Ring Imaging Cerenkov Counter (RICH)



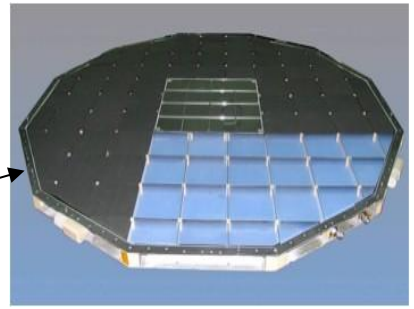
100 aerogel tiles

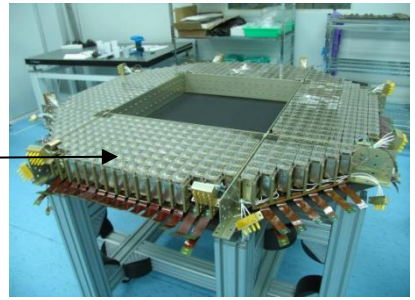


10,880 PMT channels

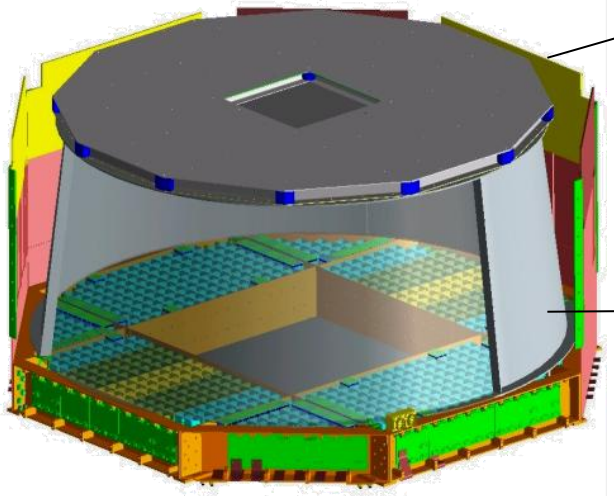
Measures (Z,v)

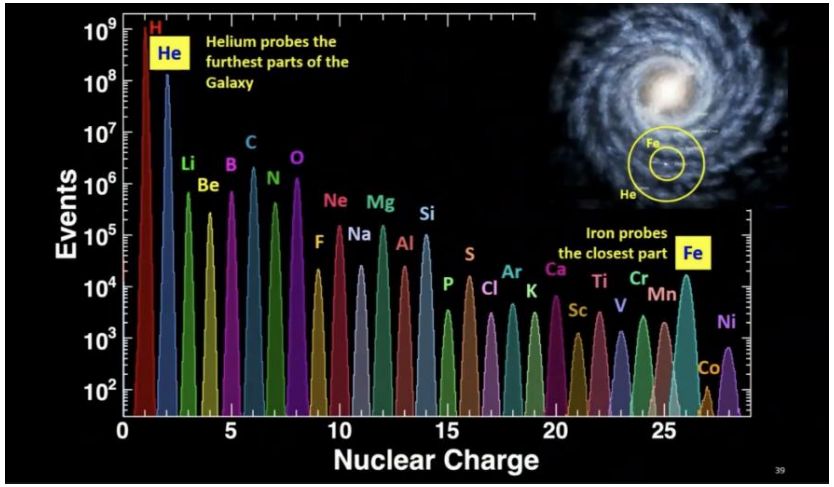
12.5 %: México





2%: México



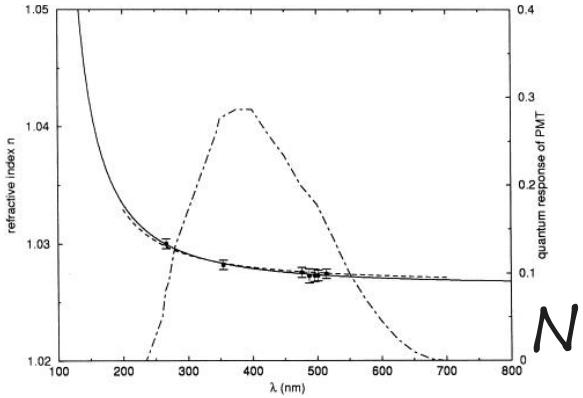


Aerogel characterization

UNAM Group 2005

Aerogel dispersion law
and
Characterization

Aerogel “Ageing”



M. Villoro et al.
NIM A 480 (2002) 456-462

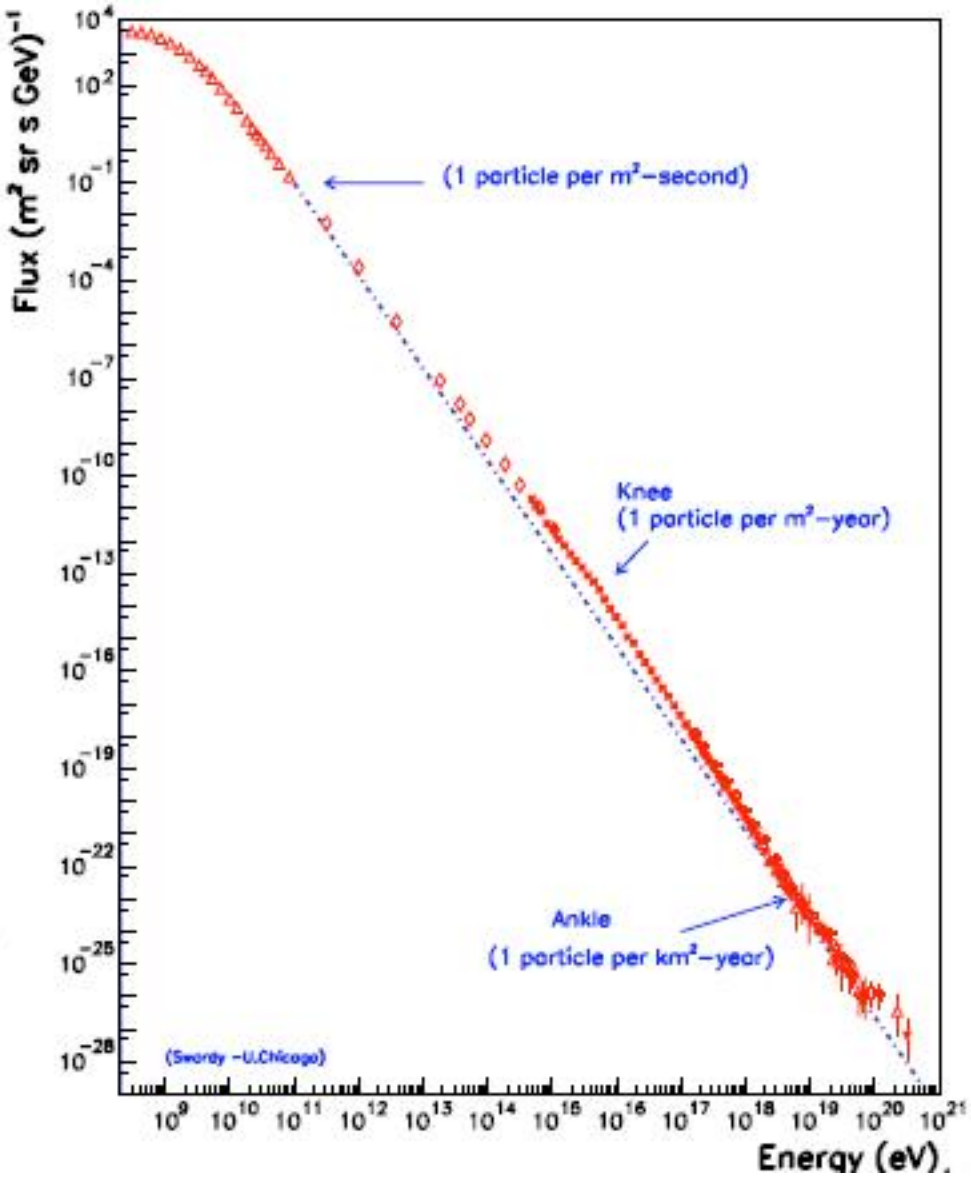
Cosmic ray integrated spectrum

Spectral index

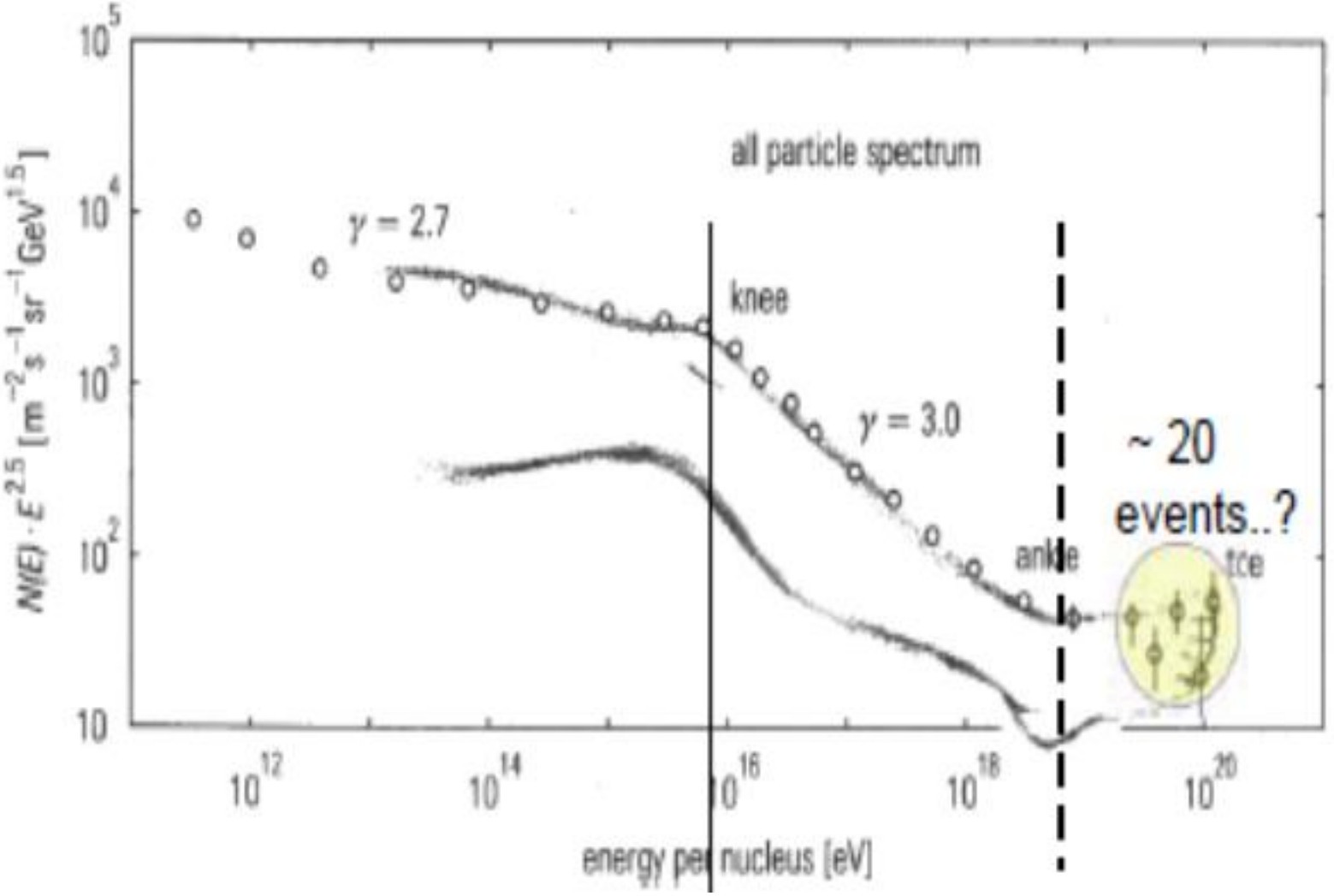
$$\frac{dN}{dEd\Omega dAdt} \propto E^{\gamma}$$

$\gamma \approx -2.7 \quad 10^{11}\ eV < E < 10^{15.5} eV$

$\approx -3.1 \quad 10^{15.5}\ eV < E < 10^{18.5} eV$

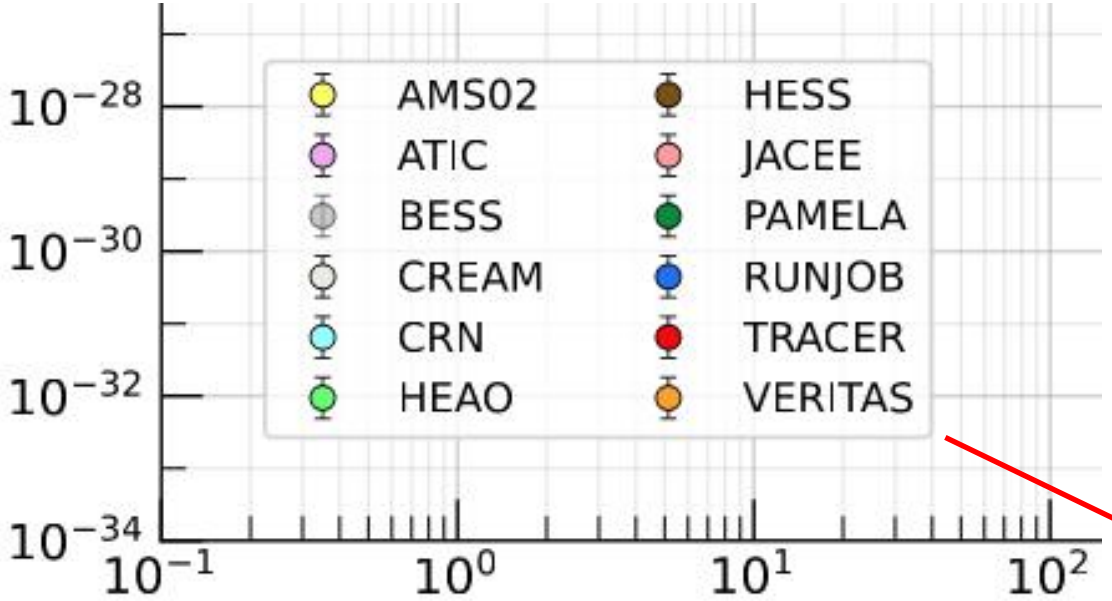


The leg model

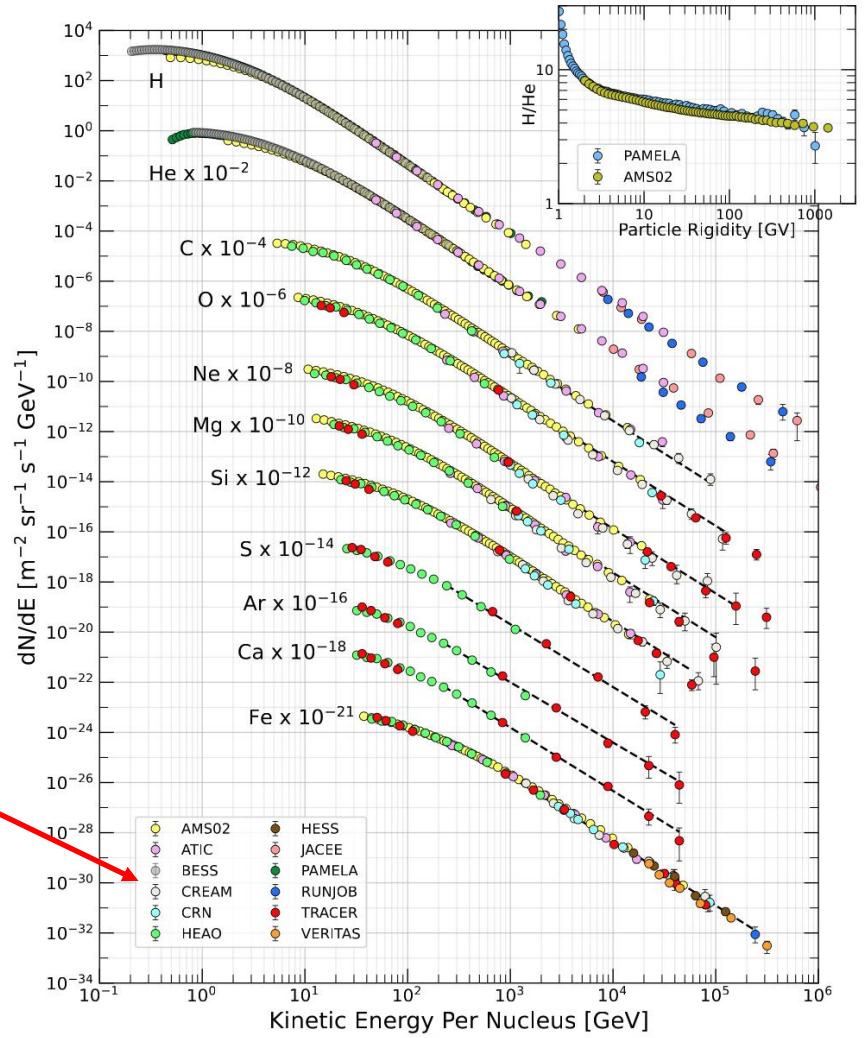


Element cosmic nuclei spectra

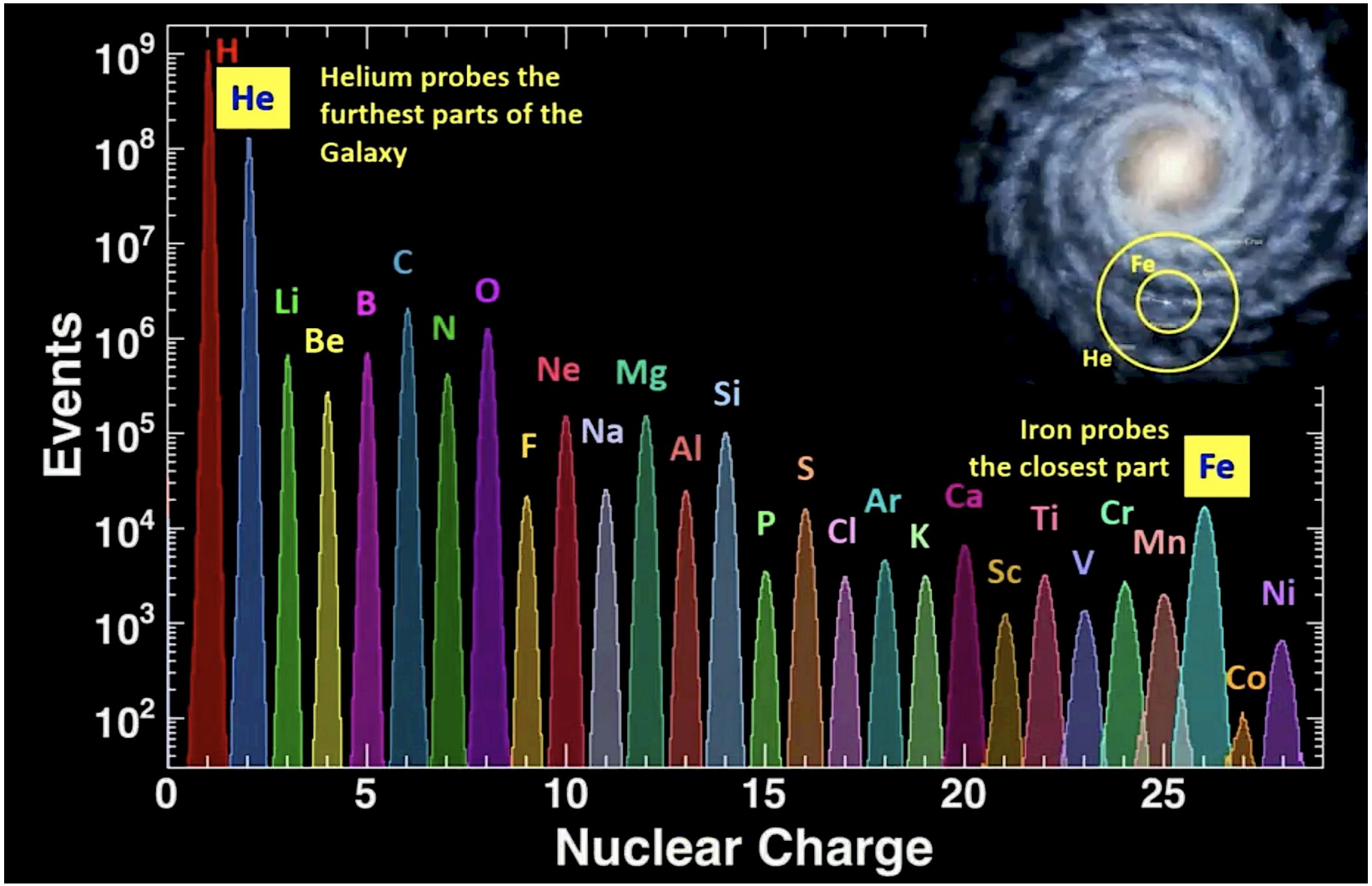
250 billion events



RPP-2023



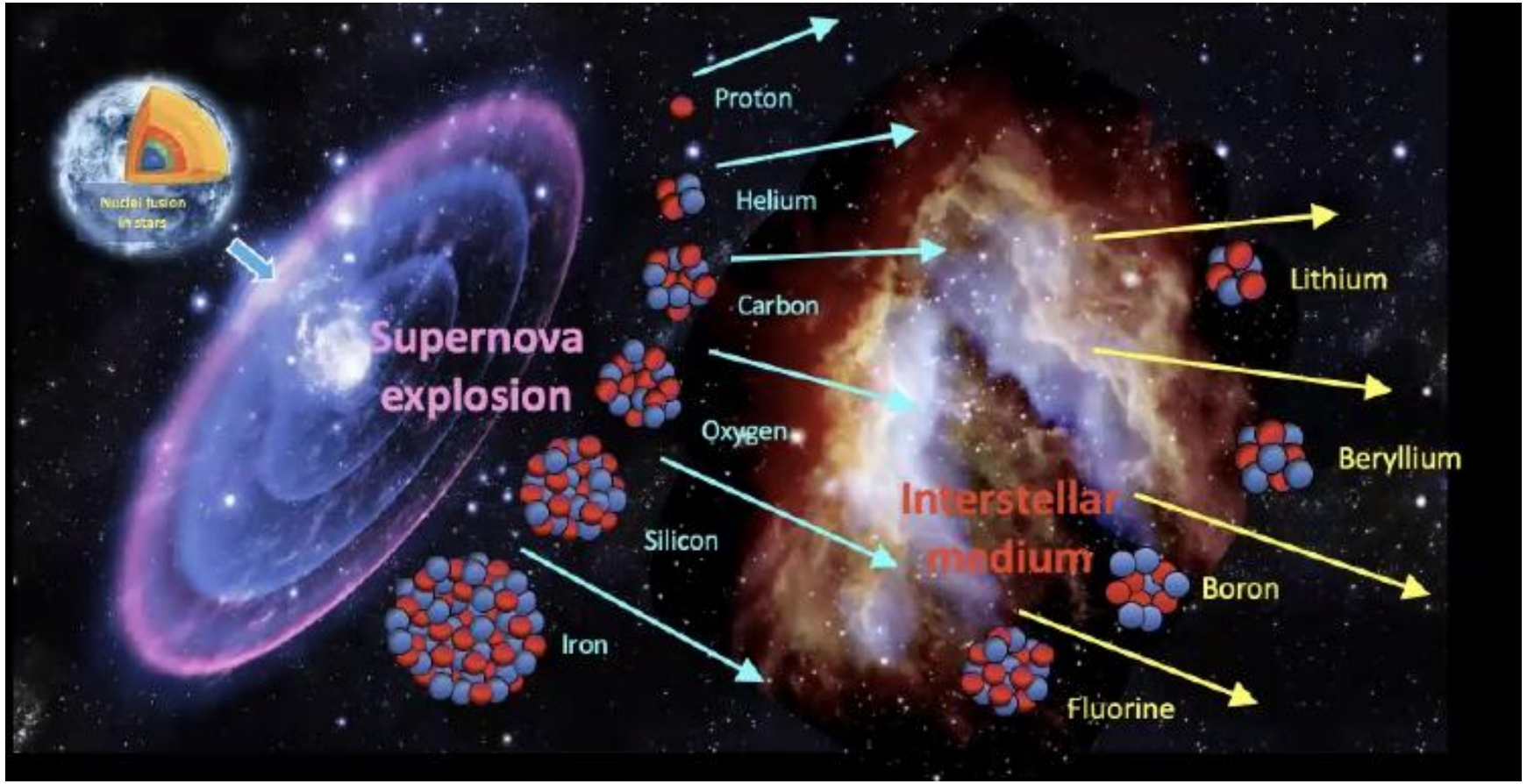
AMS relative element cosmic abundance



Near-Earth CR flux origin

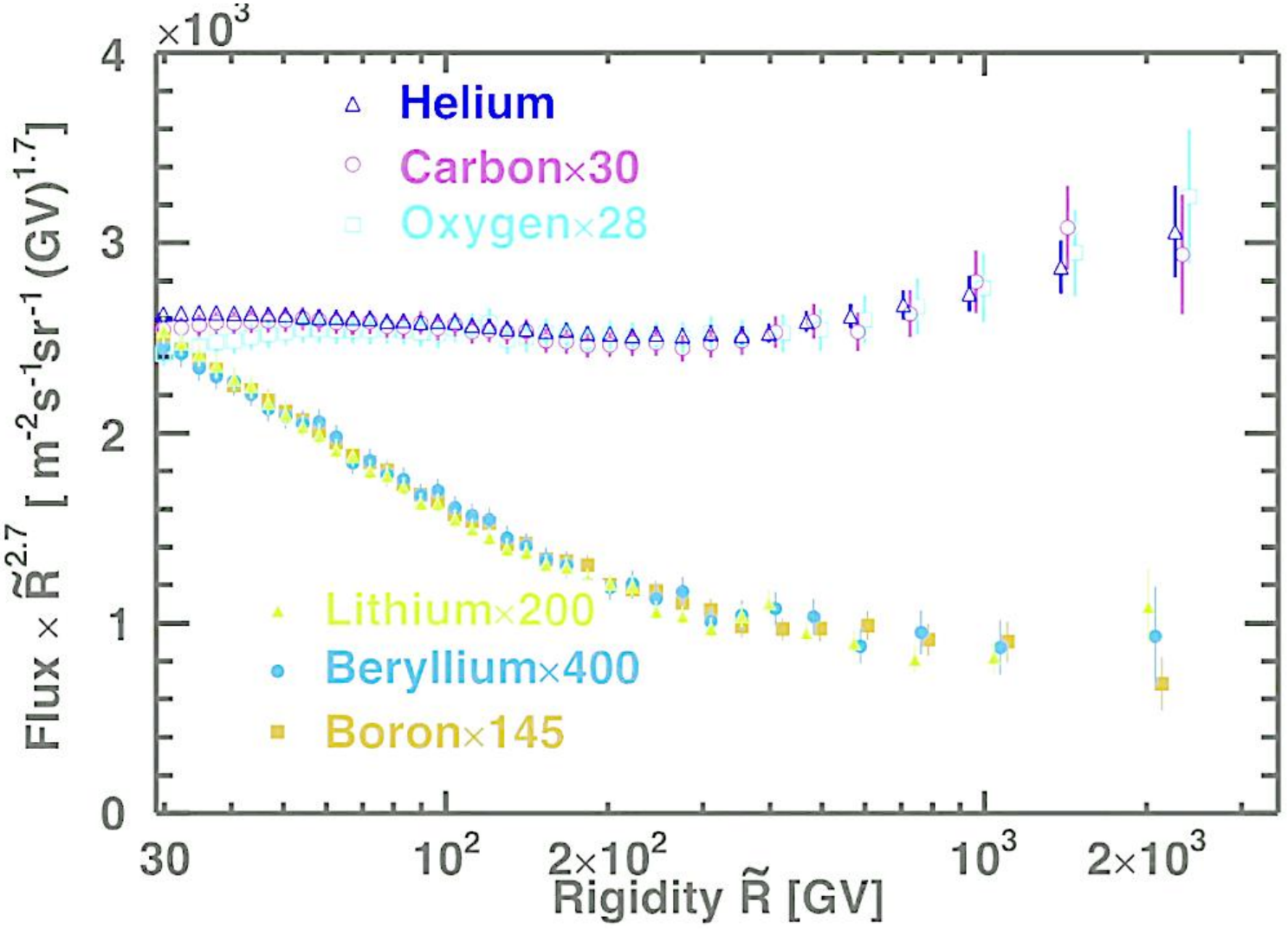
Primary Secondary

One every 40 years



Average transit time: 15 million years

Two power-law indexes

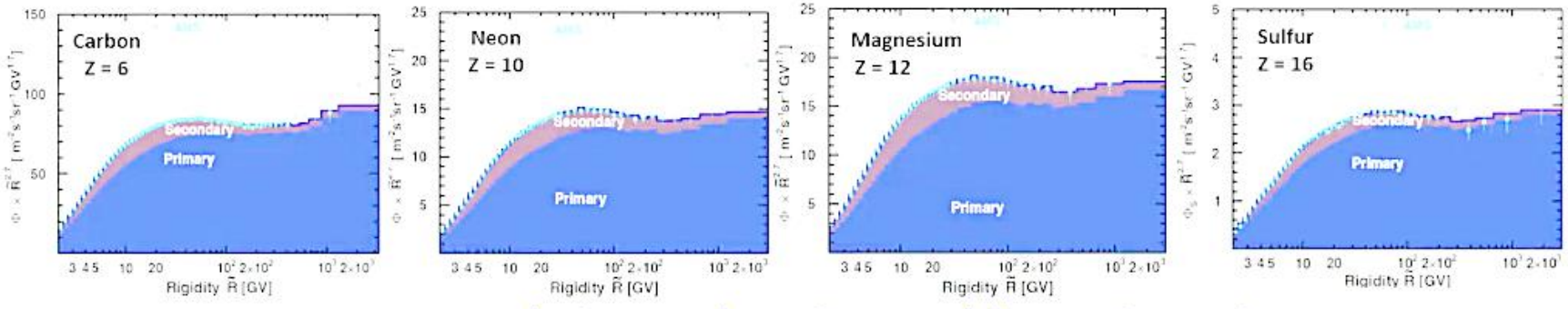


Primary

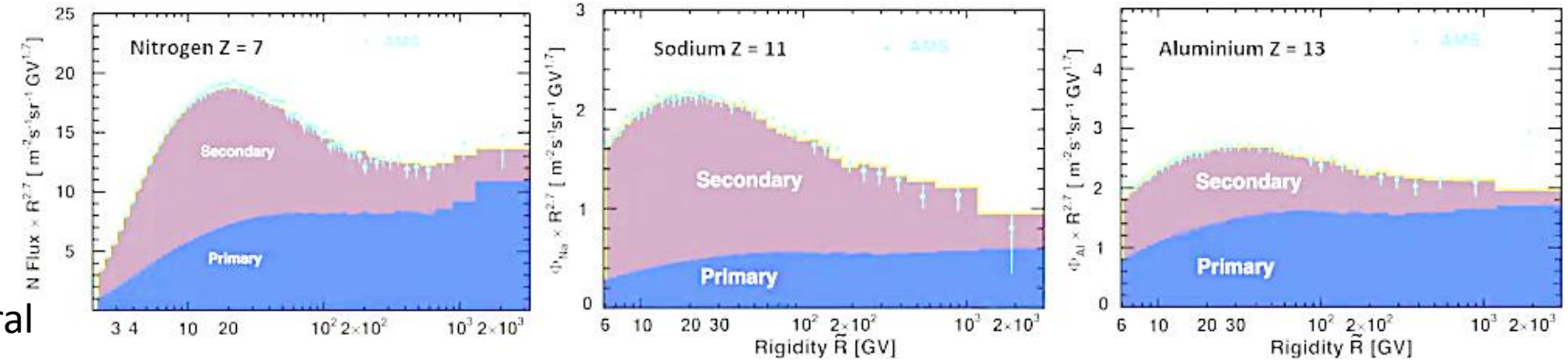
Secondary

See: D.M. Gómez Coral
LASNPA XIV/2024
Inivited Talk # 17

Primary-Secondary mix



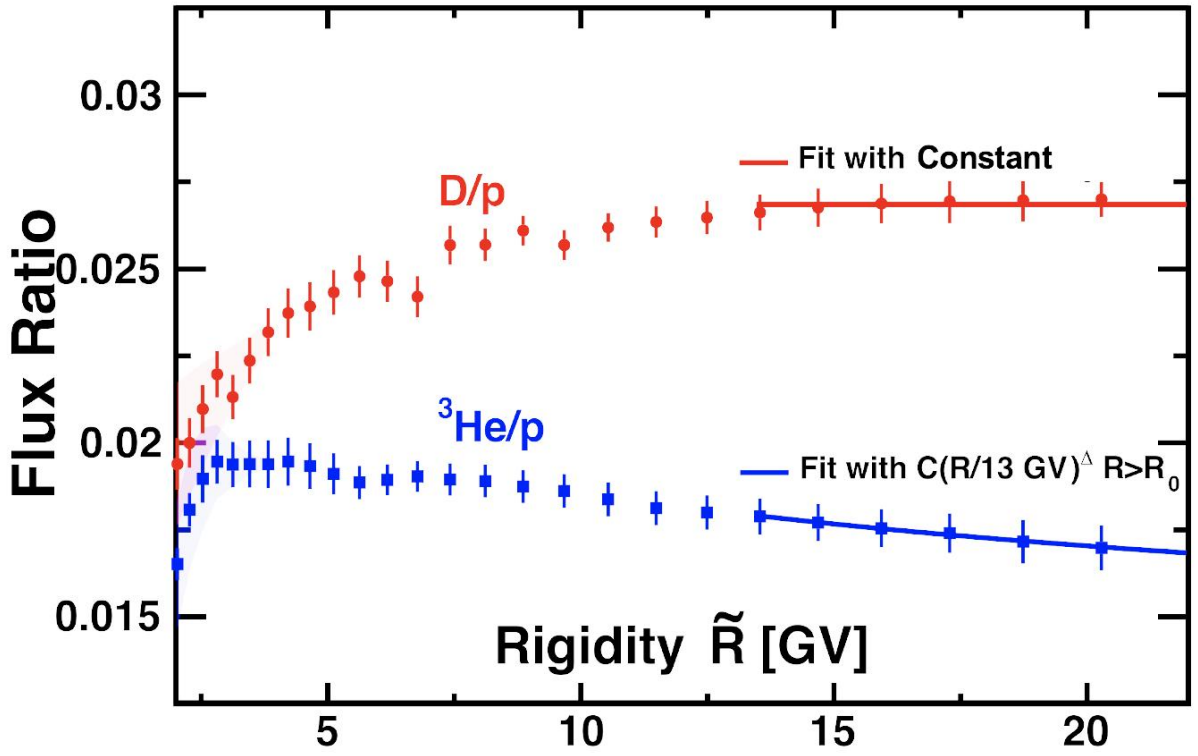
Even-Z nuclei are dominated by primaries

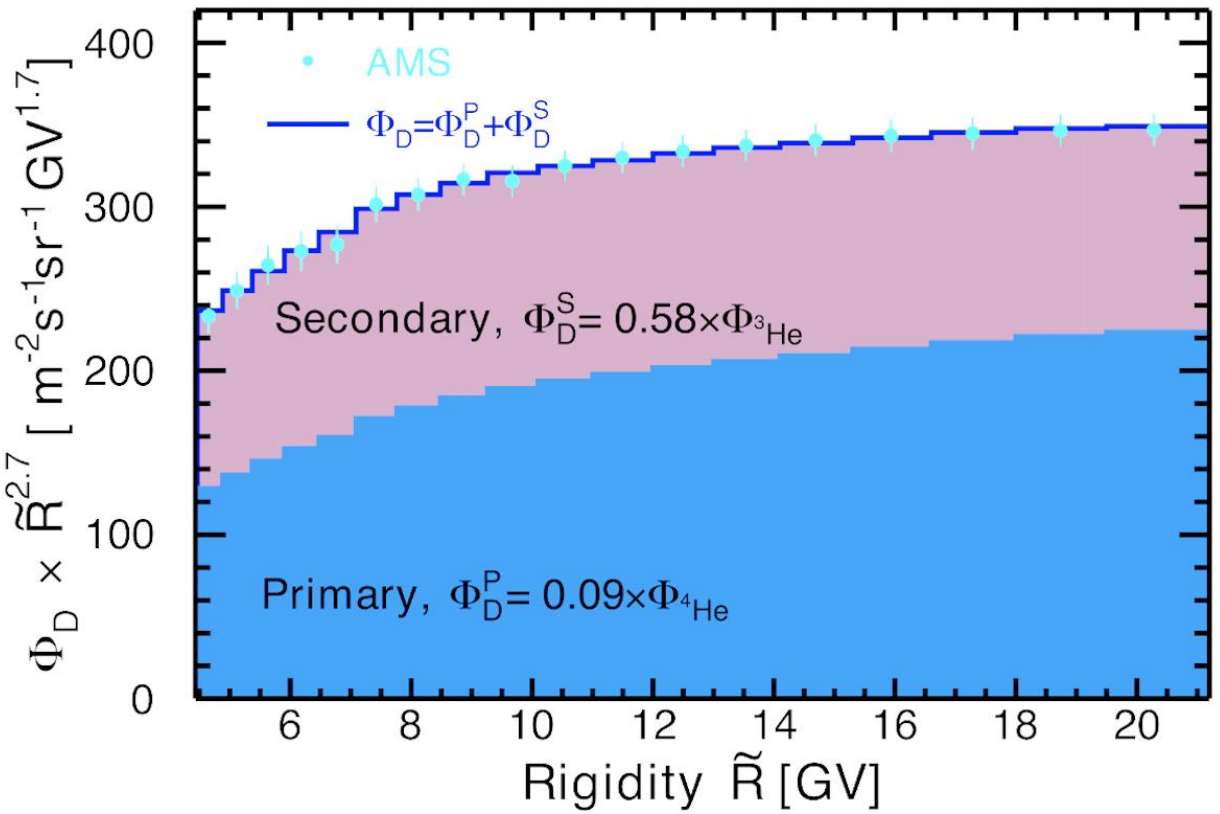


Odd-Z nuclei are dominated by secondaries

See: D.M. Gómez Coral
LASNPA XIV/2024
Inivited Talk # 17

d´s have a considerable primary-like component



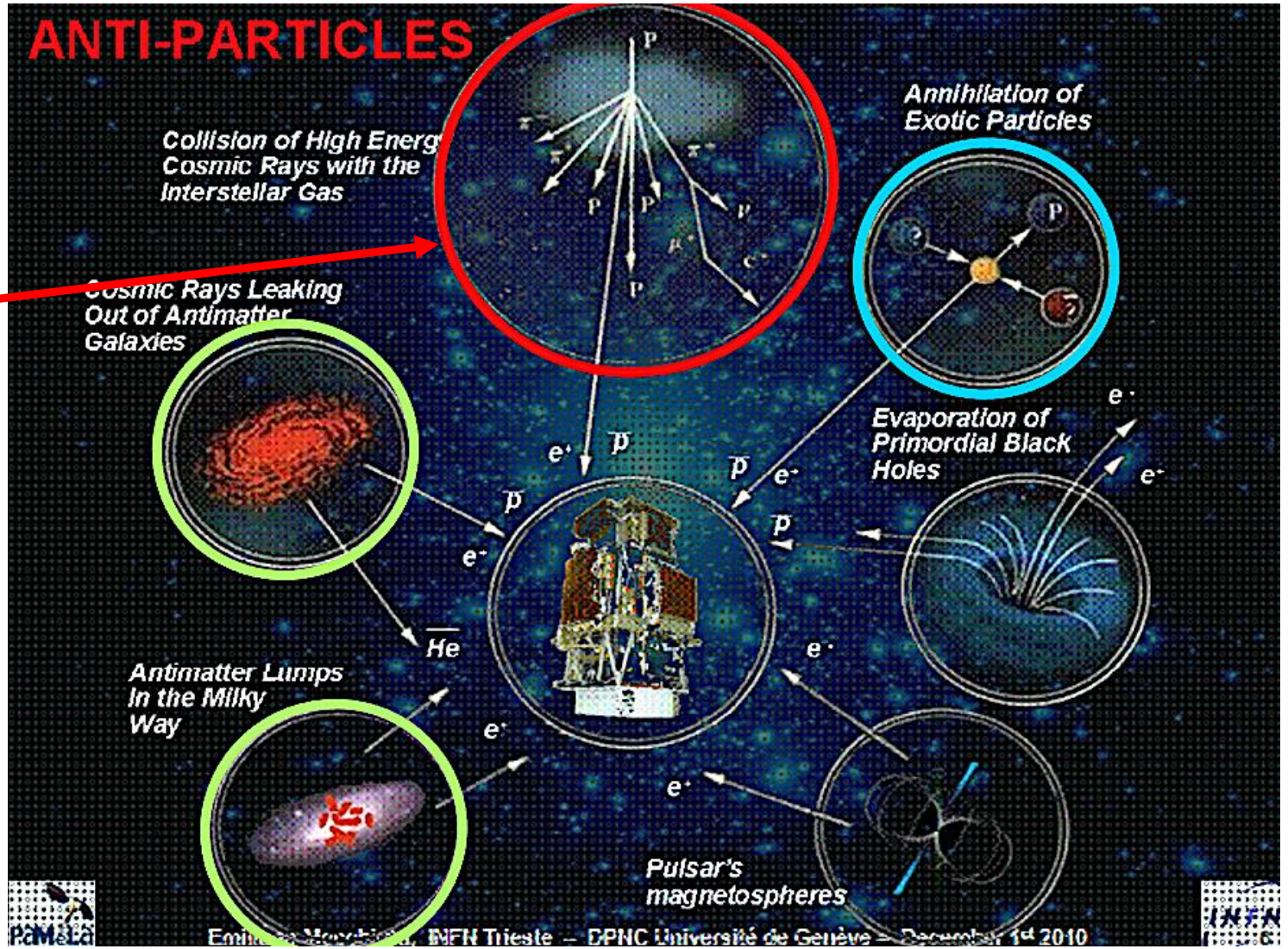


Precision Measurement of Cosmic Ray Deuterons with Alpha Magnetic Spectrometer accepted

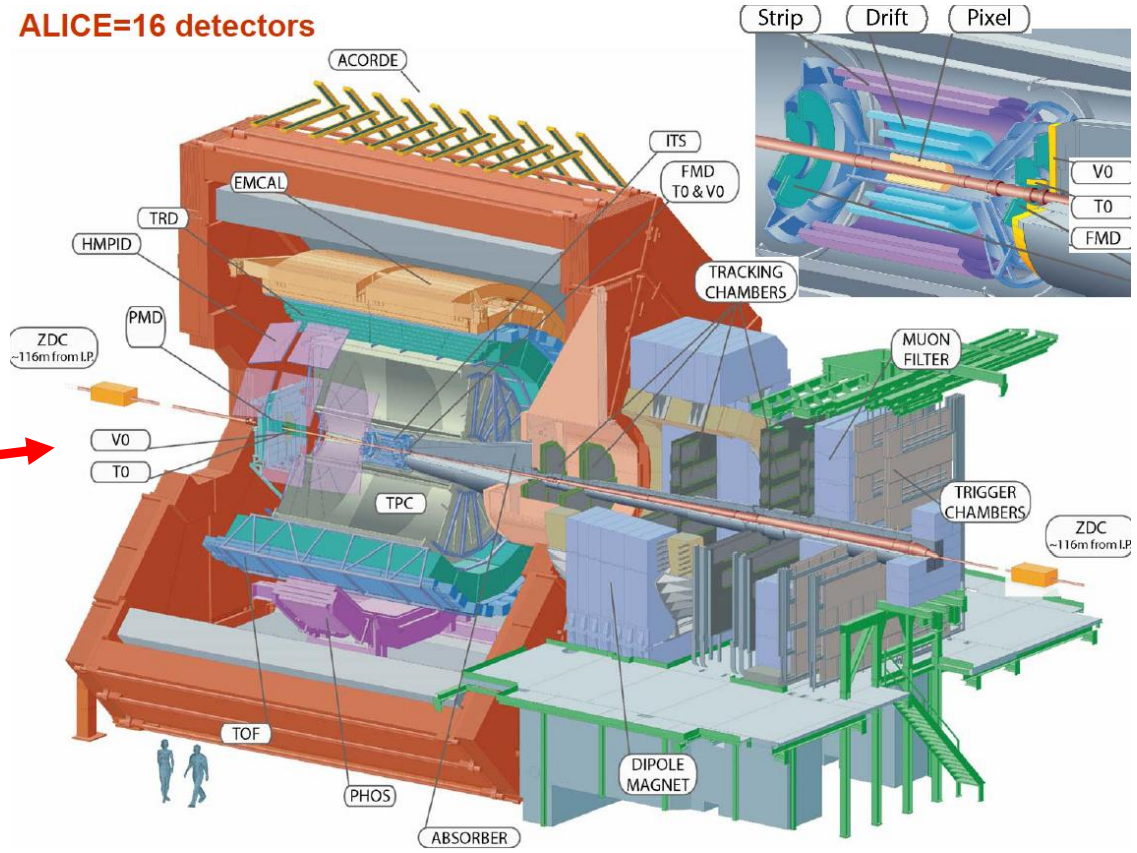
See: D.M. Gómez Coral
LASNPA XIV/2024
Inivited Talk # 17

What about cosmic antinuclei sources?

$p + X \rightarrow p+X+p+n+\bar{d}$
(coalescence)
x-section can be measured on an earthly lab, and the corresponding near-Earth flow estimated using GALPROP

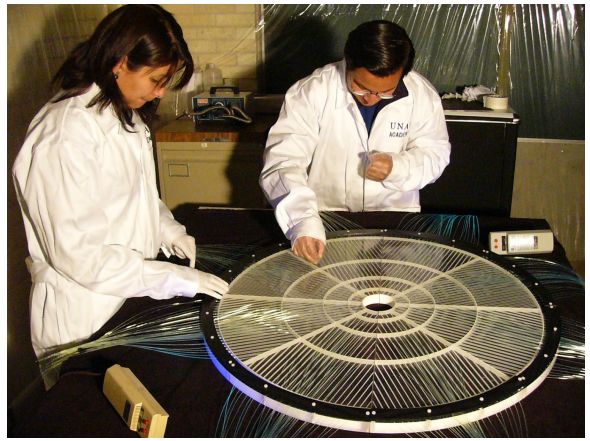


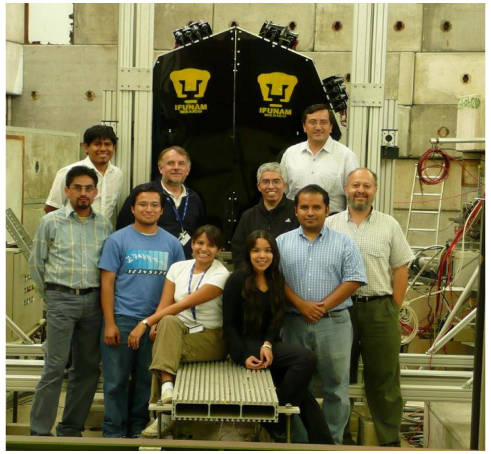
IFUNAM in ALICE-LHC

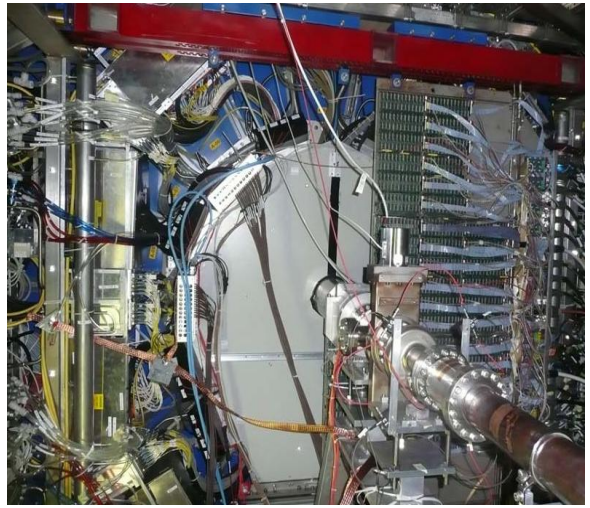


ALICE

ALICE Plastic Scintillator Triggers

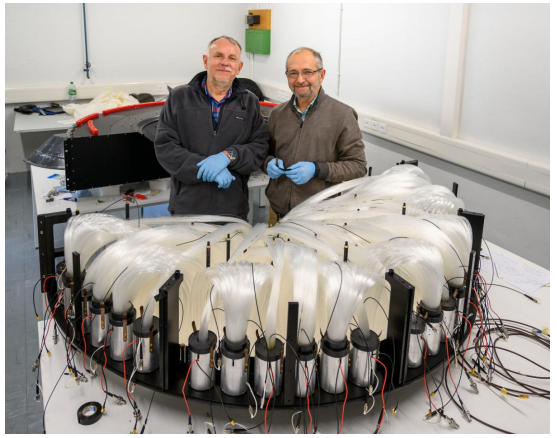


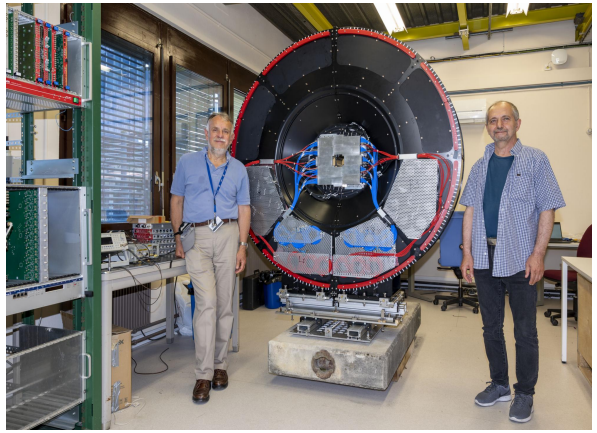




ALICE RUN 1&2

V0A (2017)

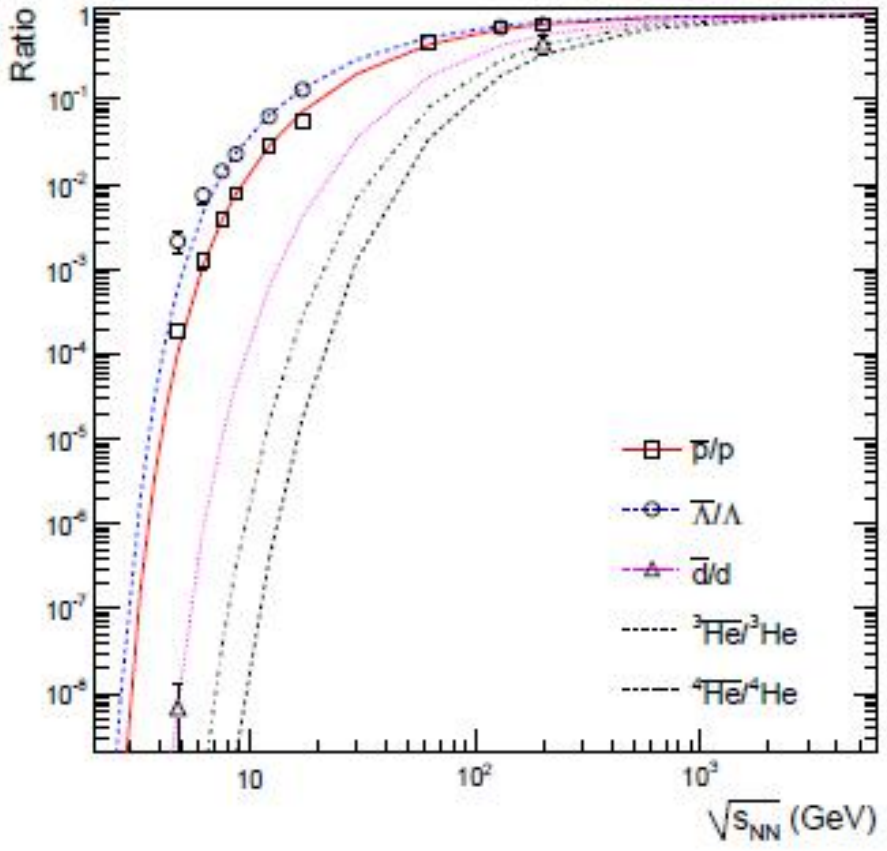


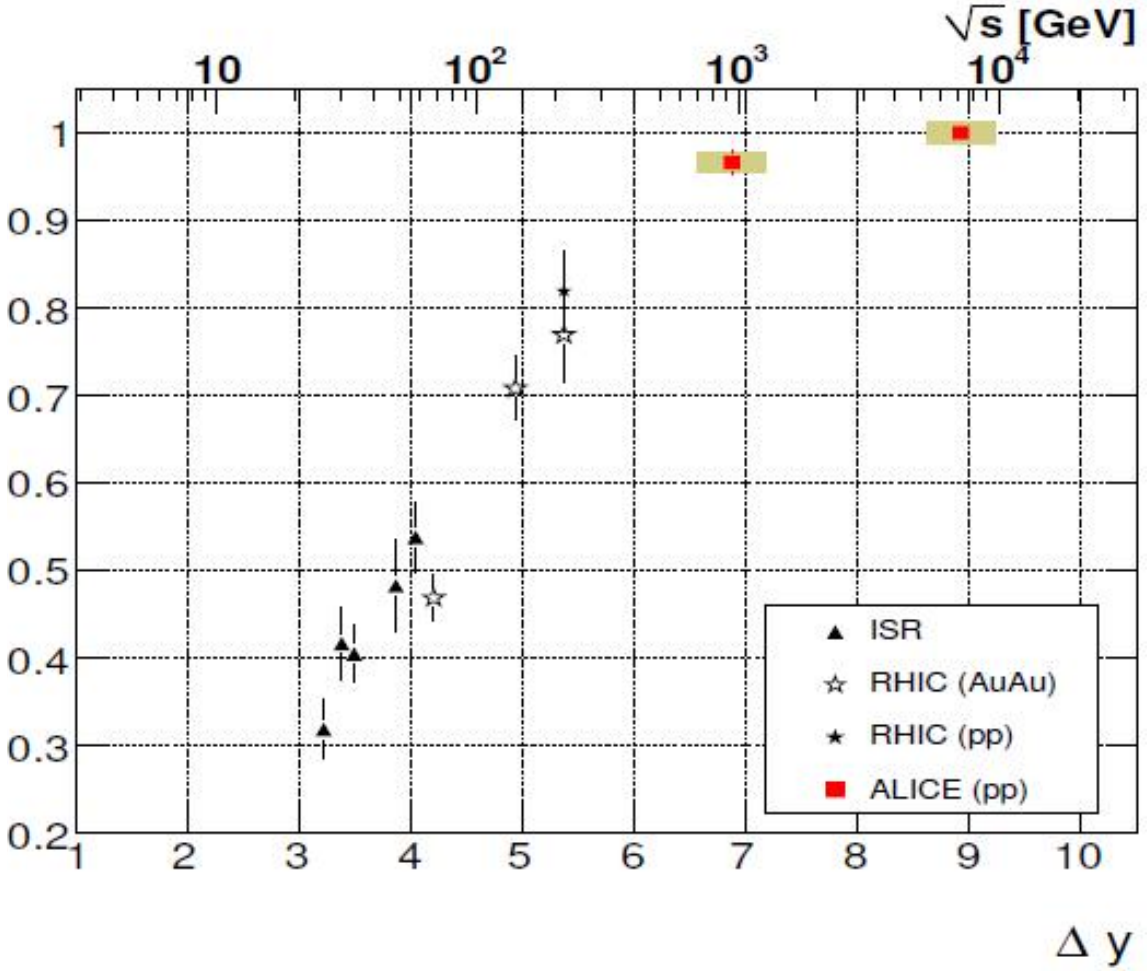


ALICE RUN 3

V0 Plus (2022)

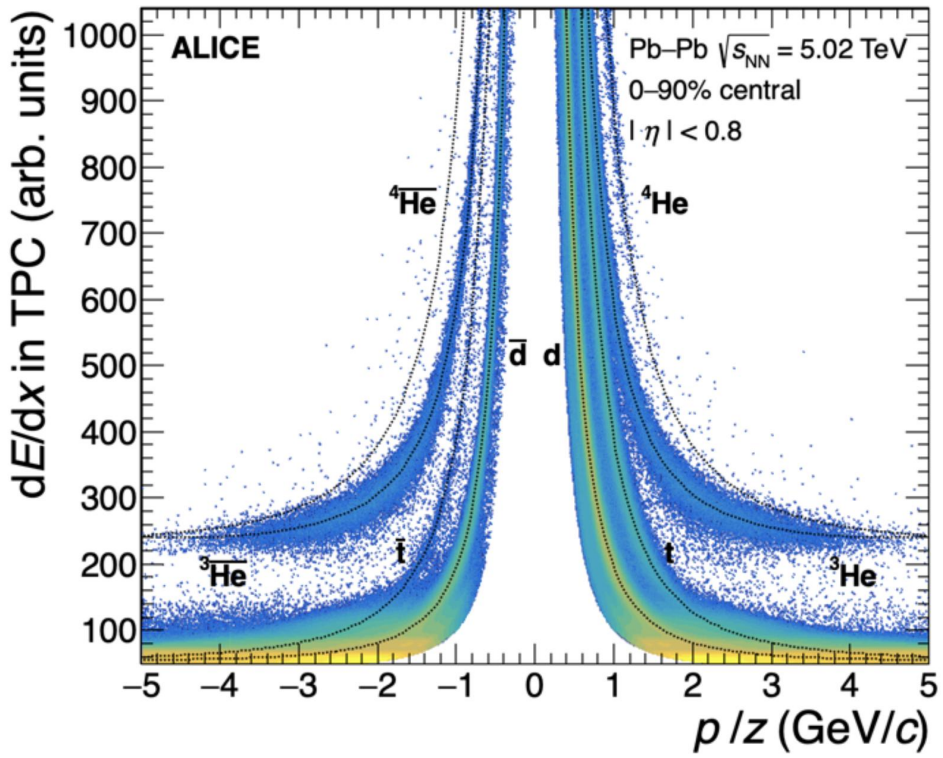
LHC advantage: → B ≈ 0





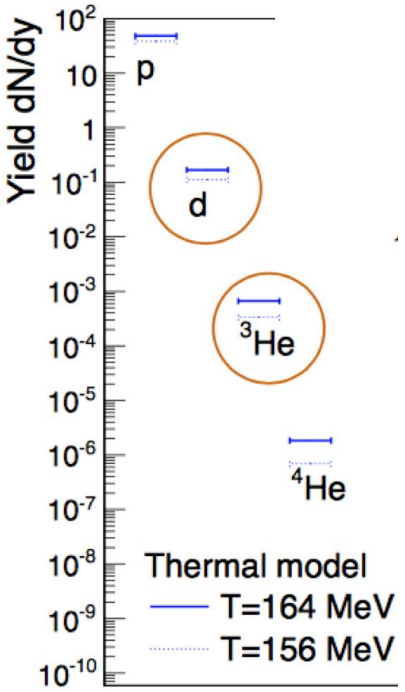
PHYSICAL REVIEW LETTERS, 105, 7, 2010, 072002

$\bar{d}$ production is abundant in ALICE



≈ 1/1000

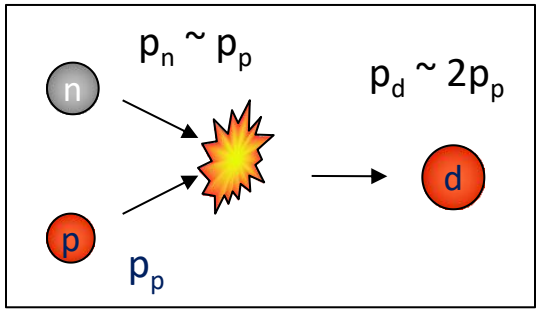
“ALICE Recipe”



PhD Thesis, Eulogio Serradilla, 2014
Phys. Rev. C 97 (2018) 024615

Coalescence

Phase espace



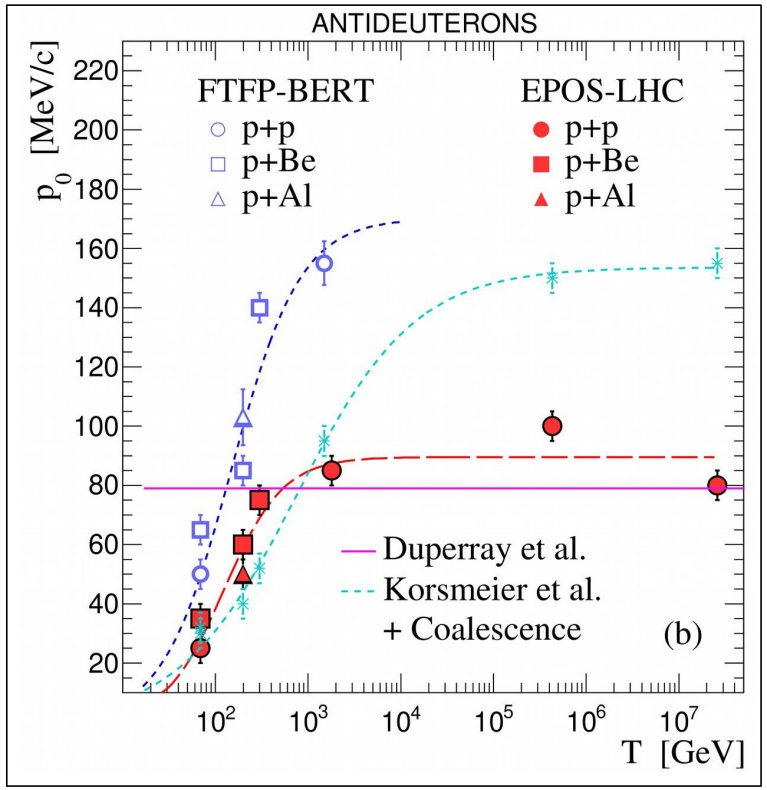
Coalescence parameter

$$\gamma_d \frac{d^3N_d}{dp_d^3} = \frac{4\pi}{3} p_0^3 \left(\gamma_p \frac{d^3N_p}{dp_p^3}\right)\left(\gamma_n \frac{d^3N_n}{dp_n^3}\right) \propto \left(E_p \frac{d^3N_p}{d\vec{p}_p^3}\right)^A$$

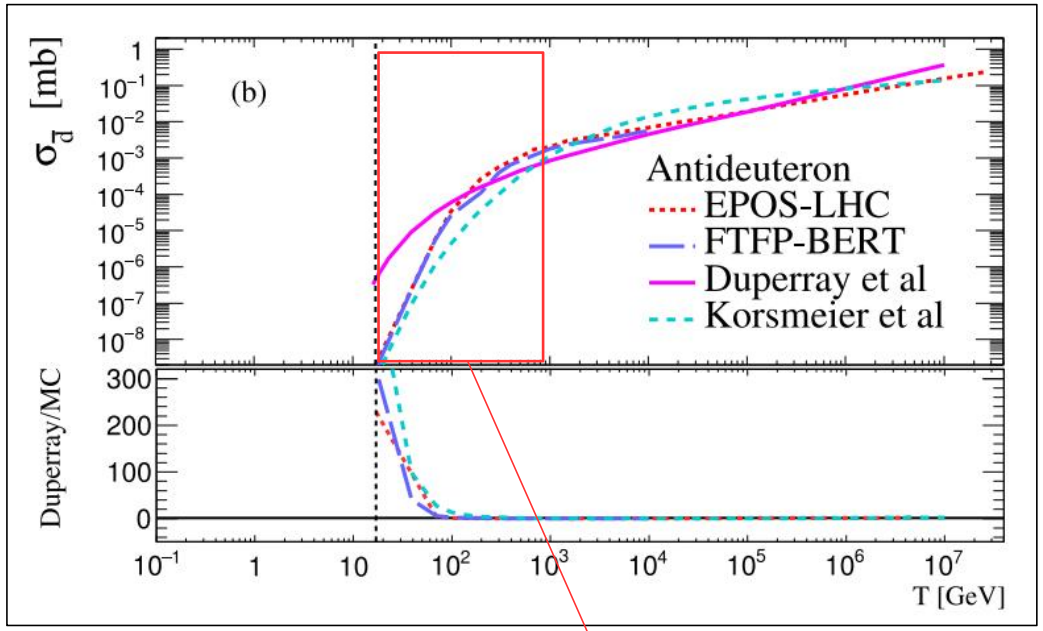
Measured in Earthly experiments, ALICE

Unkown, but can b measured!
See: LASNPA XIV/2024
F. Lugo, Invited Talk # 26

p_0 and cross sections for $\bar{d}$, vs proton energy



$p+p \rightarrow X + \bar{d}$



- p_0 variation occurs @ low T
- p_0 is similar for p+p y p+Be.

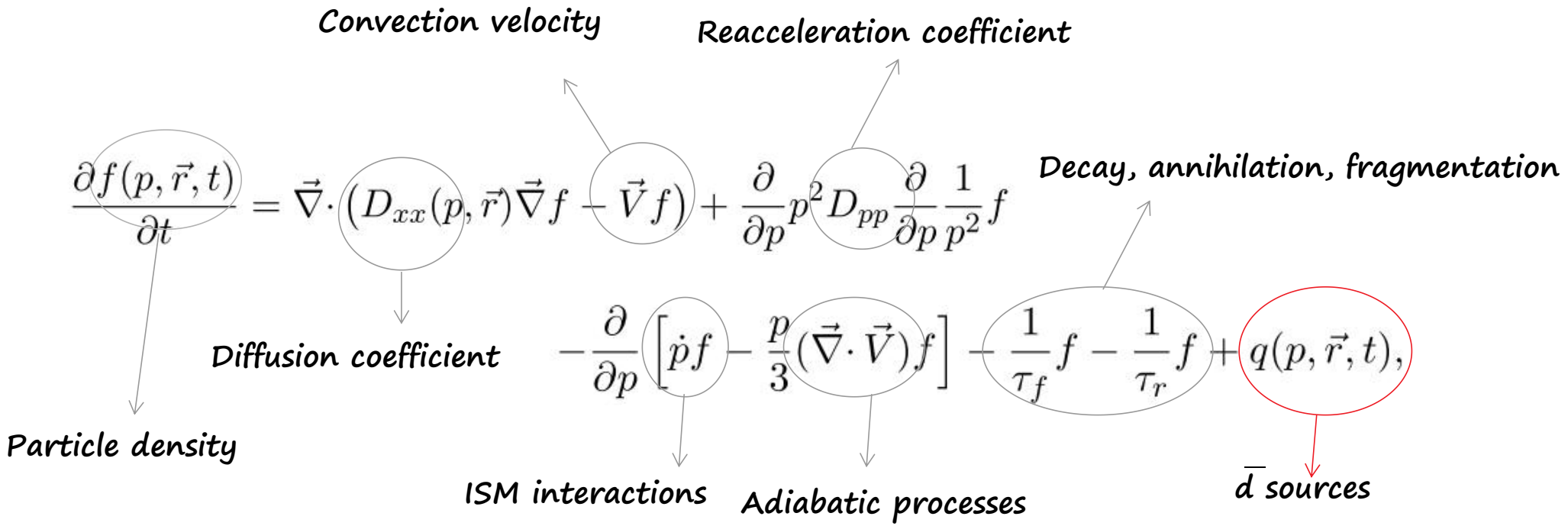
- P_0 variation in the region most relevant for CR´s

Diego Gómez-Coral, PhD Thesis (2019)

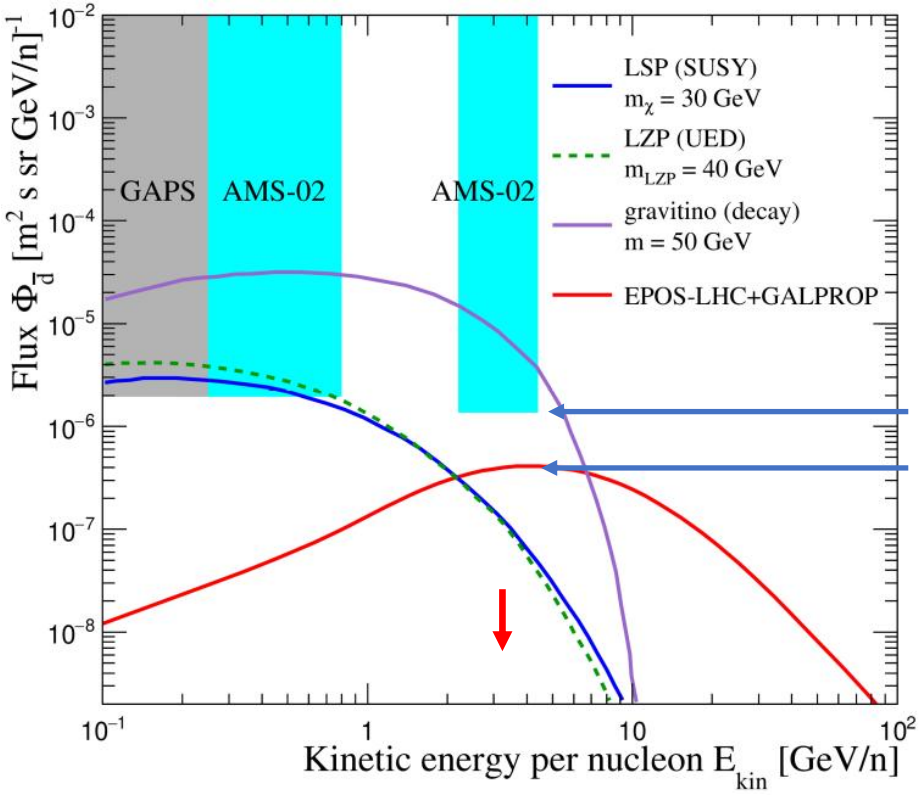
Phys. Rev. D 98, 023012 (2018) arXiv:1806.09303 [astro-ph.HE]

GALPROP

Diffusion-convection and reacceleration



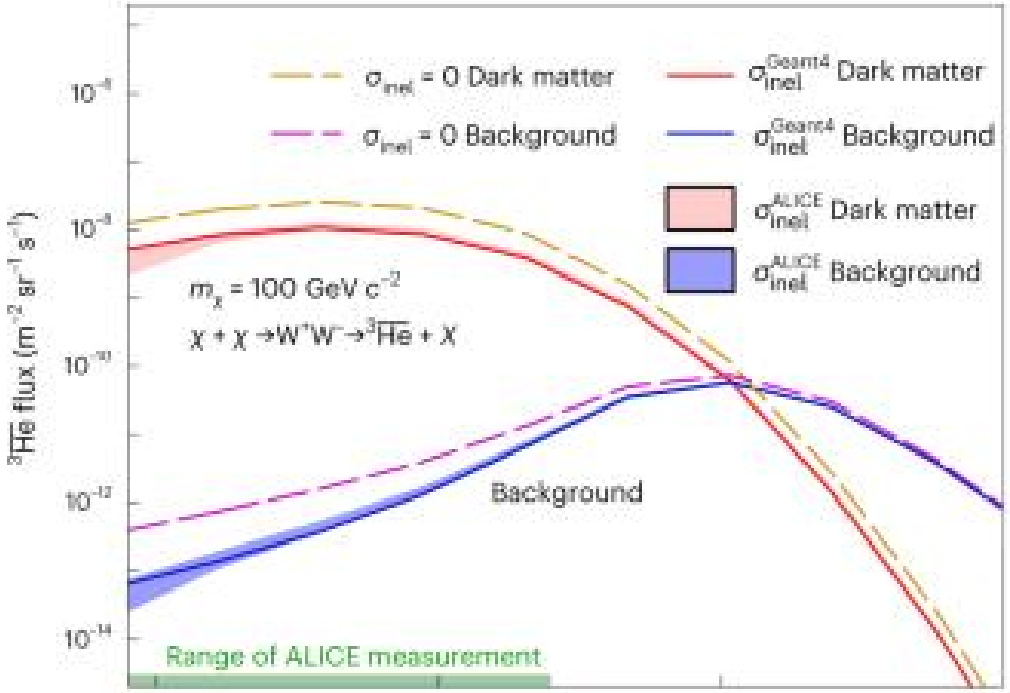
GALPROP-predicted dispersion $\bar{d}$ component

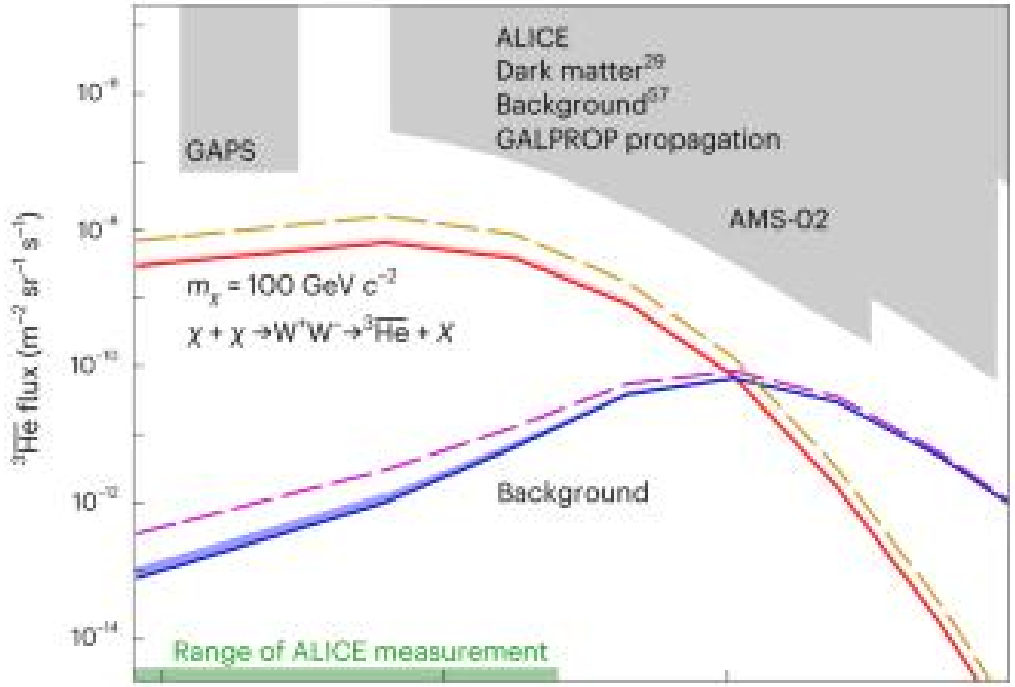


Conlusion: AMS will be insensitive to $\bar{d}$ flux

D. Gómez-Coral and A. Menchaca-Rocha, J. Phys. CS 1602 012005 (2020)

ALICE reached a similar conclusion for $^{3}\bar{\text{He}}$

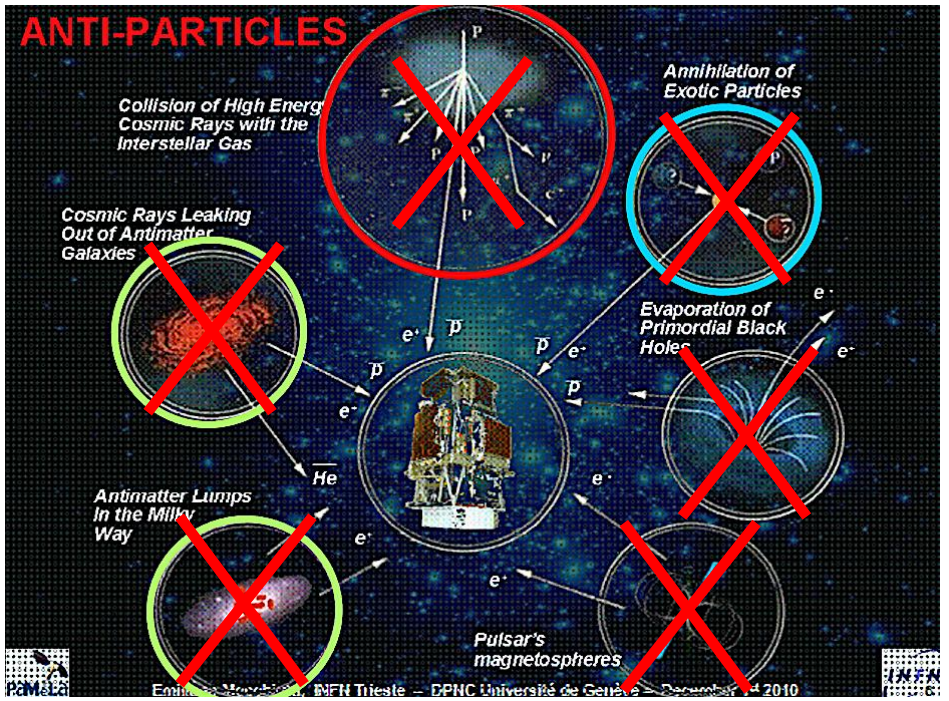




The ALICE Collaboration. Measurement of anti-^{3}He nuclei absorption in matter and impact on their propagation in the Galaxy. *Nat. Phys.* **19**, 61–71 (2023)

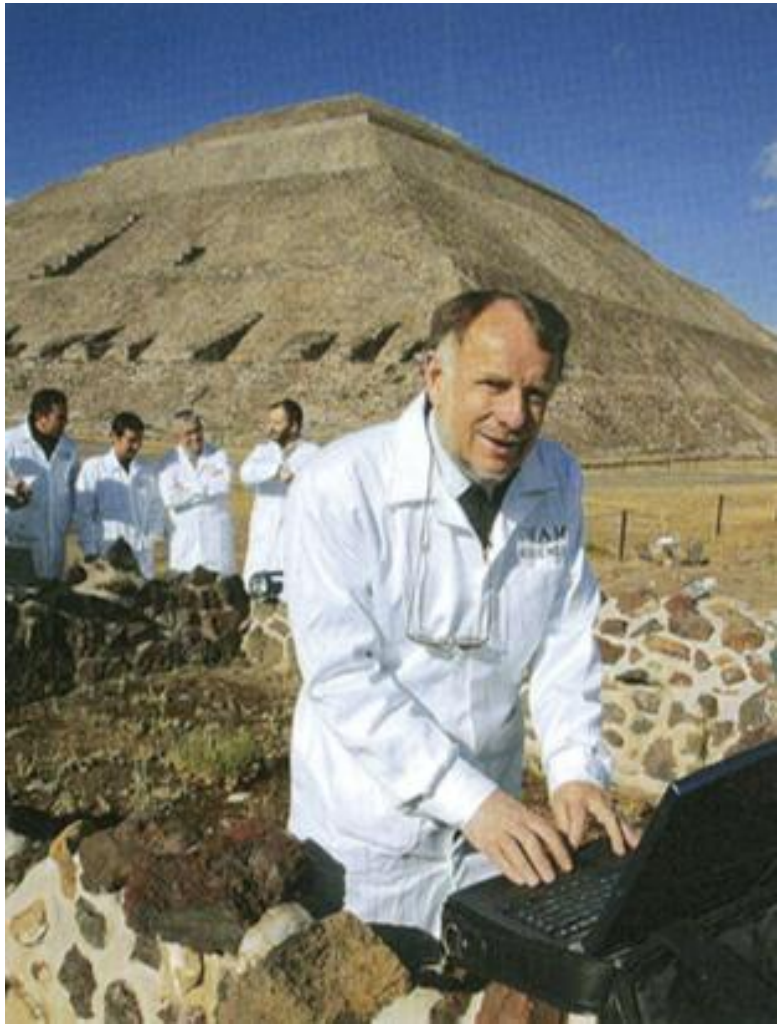
Eppur si muove……

- Near-Earth light anti nuclei flux?
- AMS: preliminary*
  - 7 $\bar{D}$?
  - 10 $\bar{He}$?



* e.g. V.A. Choutko, AMS days at la Palma (2018)

Applications to archaeology



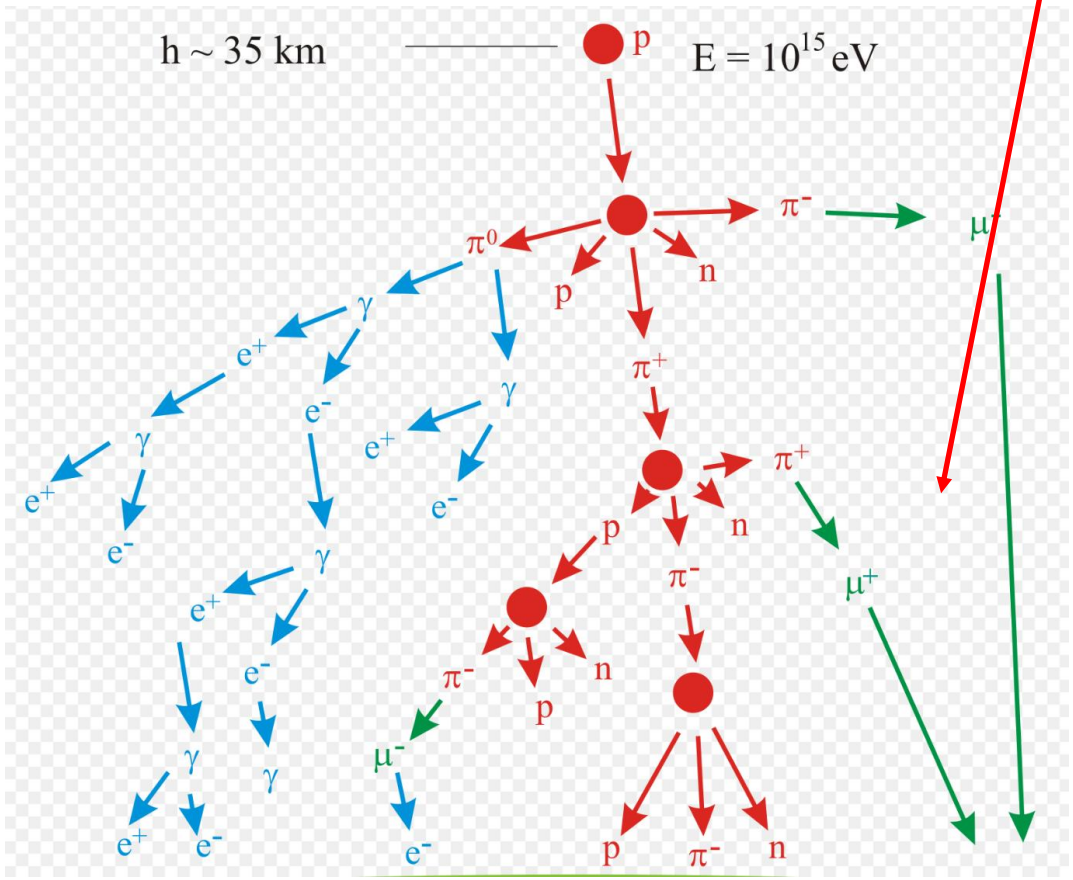
Teotihuacan (2007-2014)

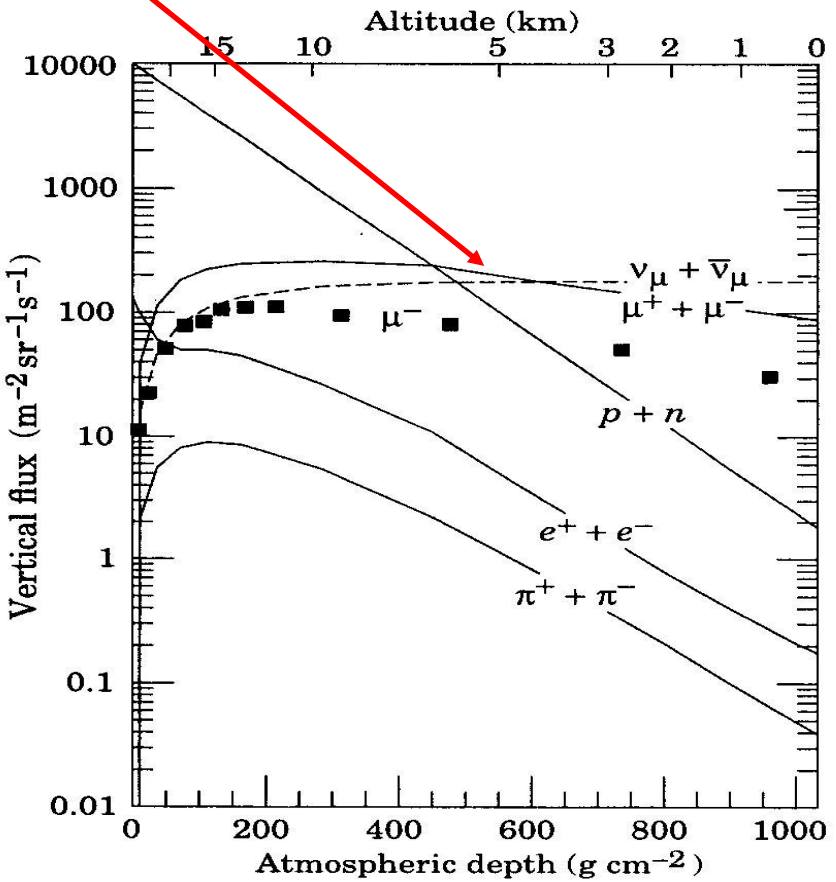
Chichén Itzá (2022-)

Cosmic radiation @ Earth´s surface

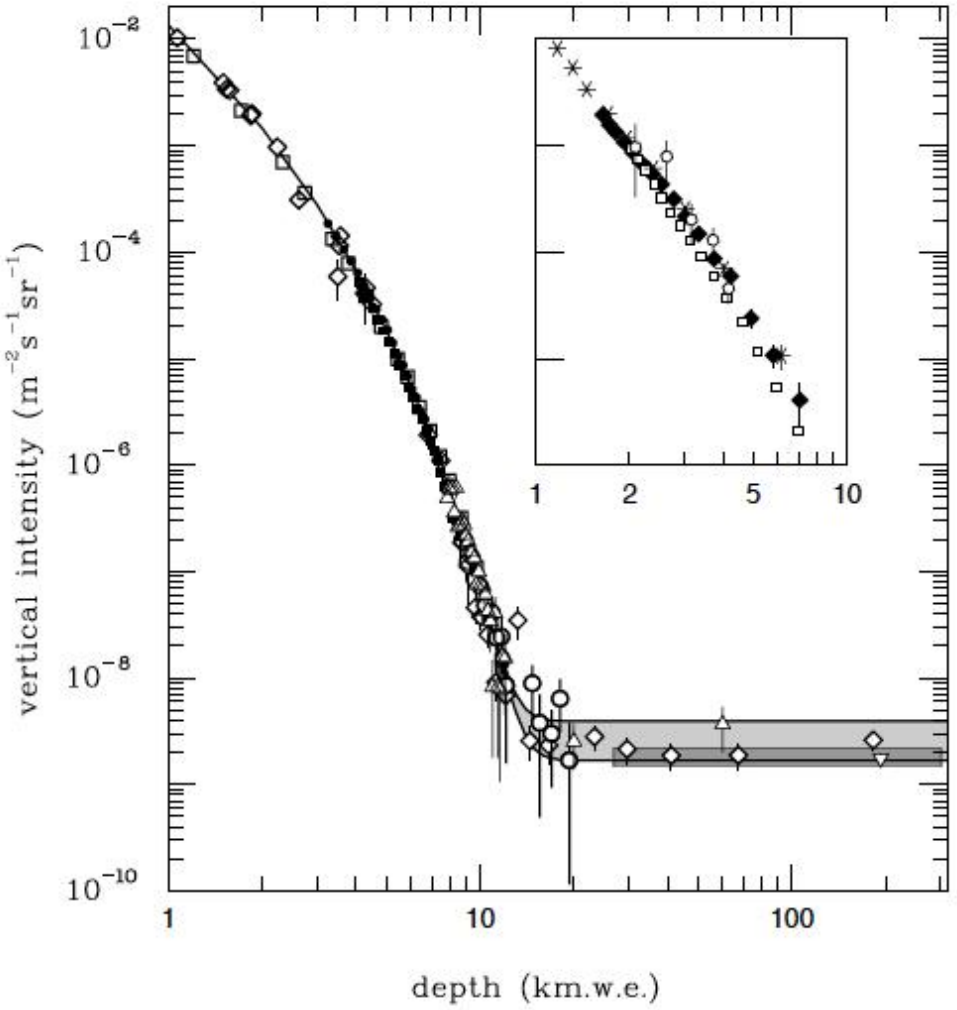
Atmospheric muons

CR Shower

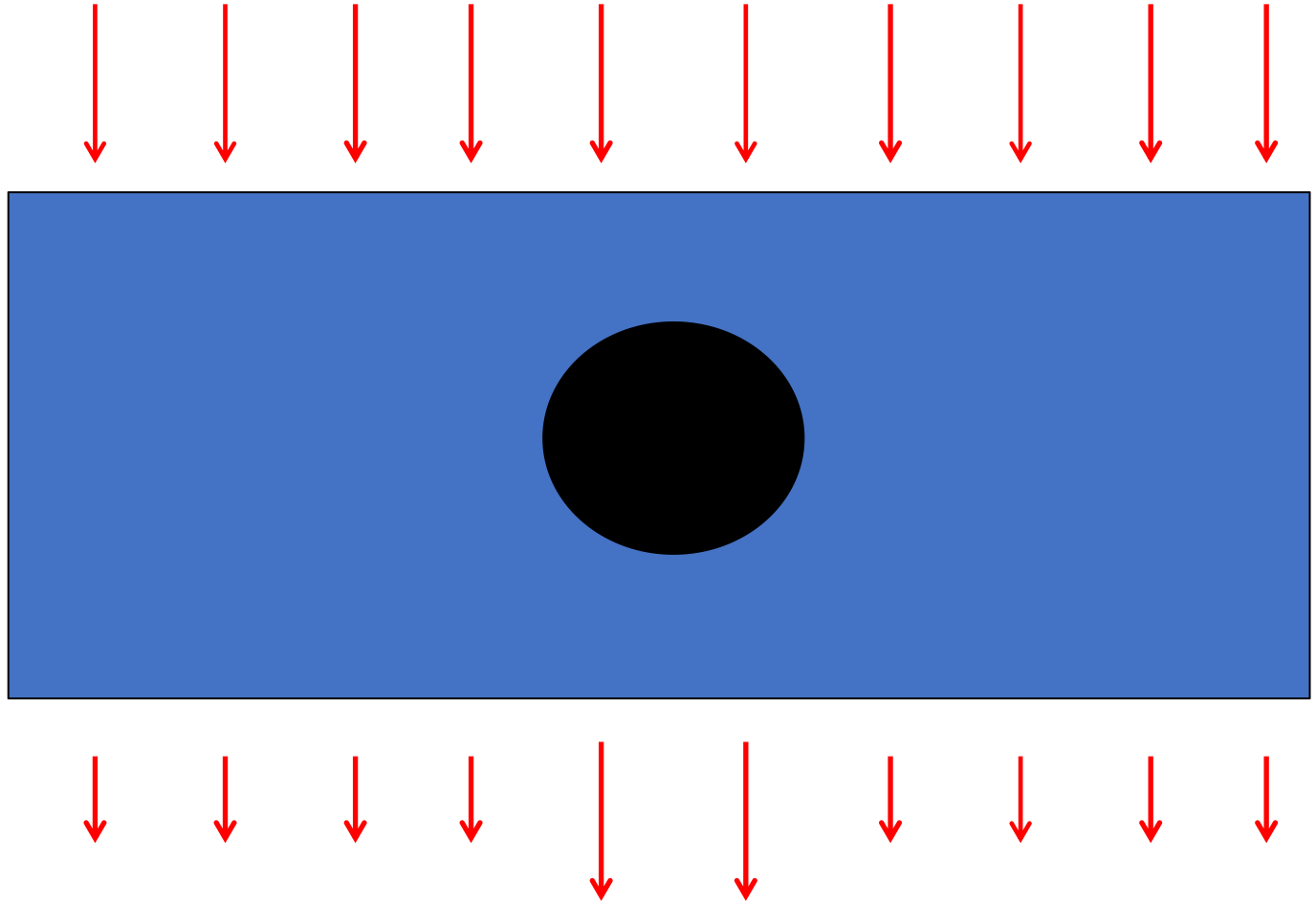




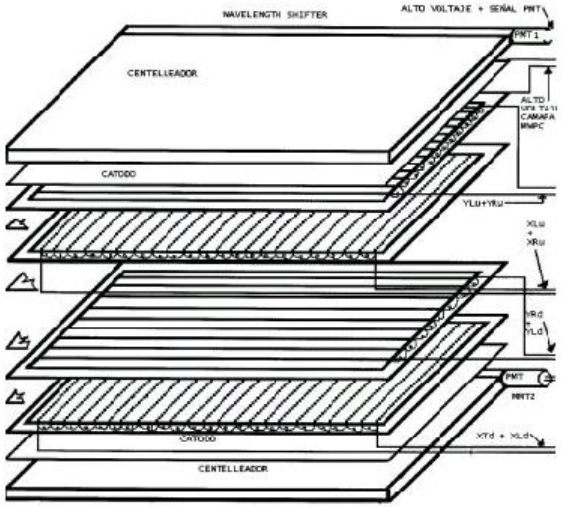
Muon penetration



Muon flux attenuation



Pyramid of the Sun project (concluded)

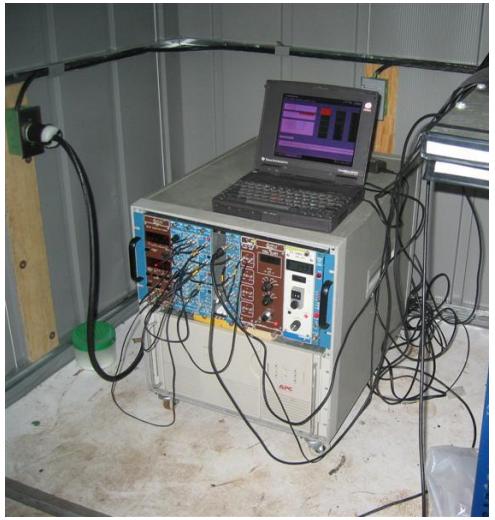


BBC NEWS UK EDITION

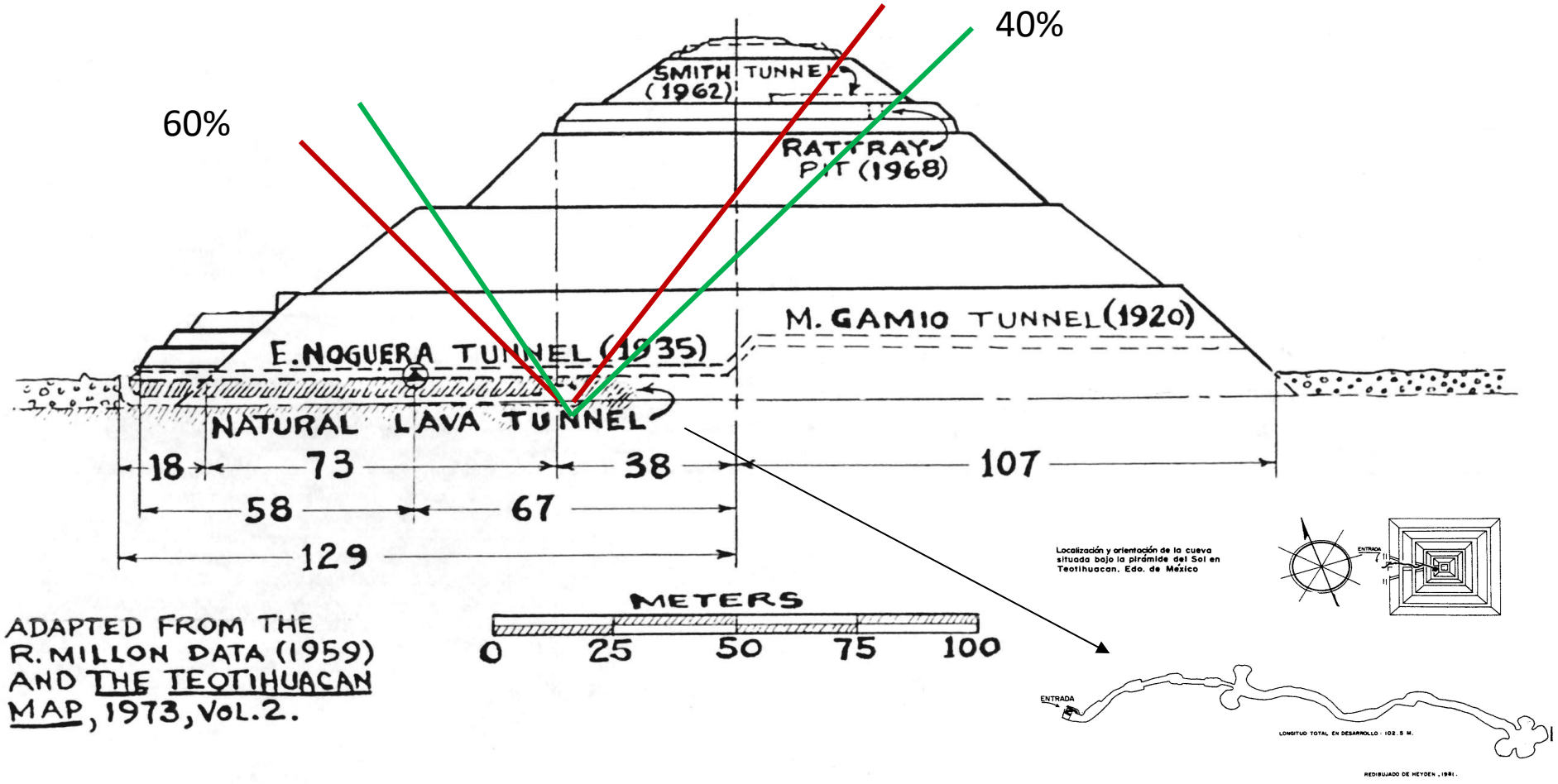
PHYSICS TODAY

nature

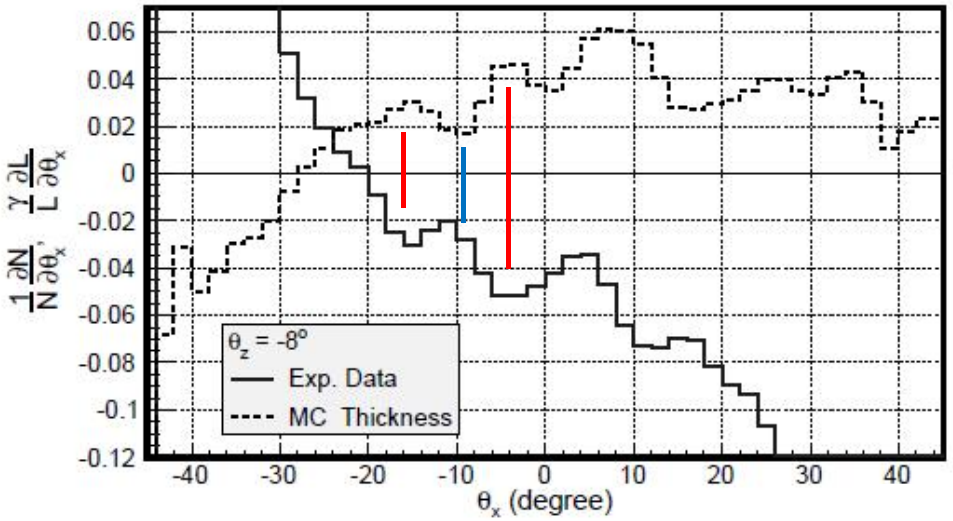
Work on site (2007)

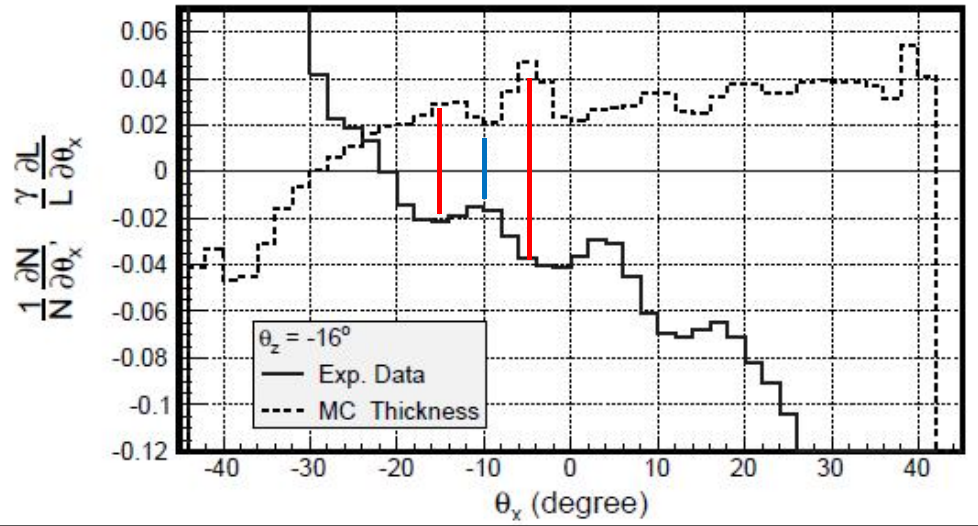


Prehispanic tunnel

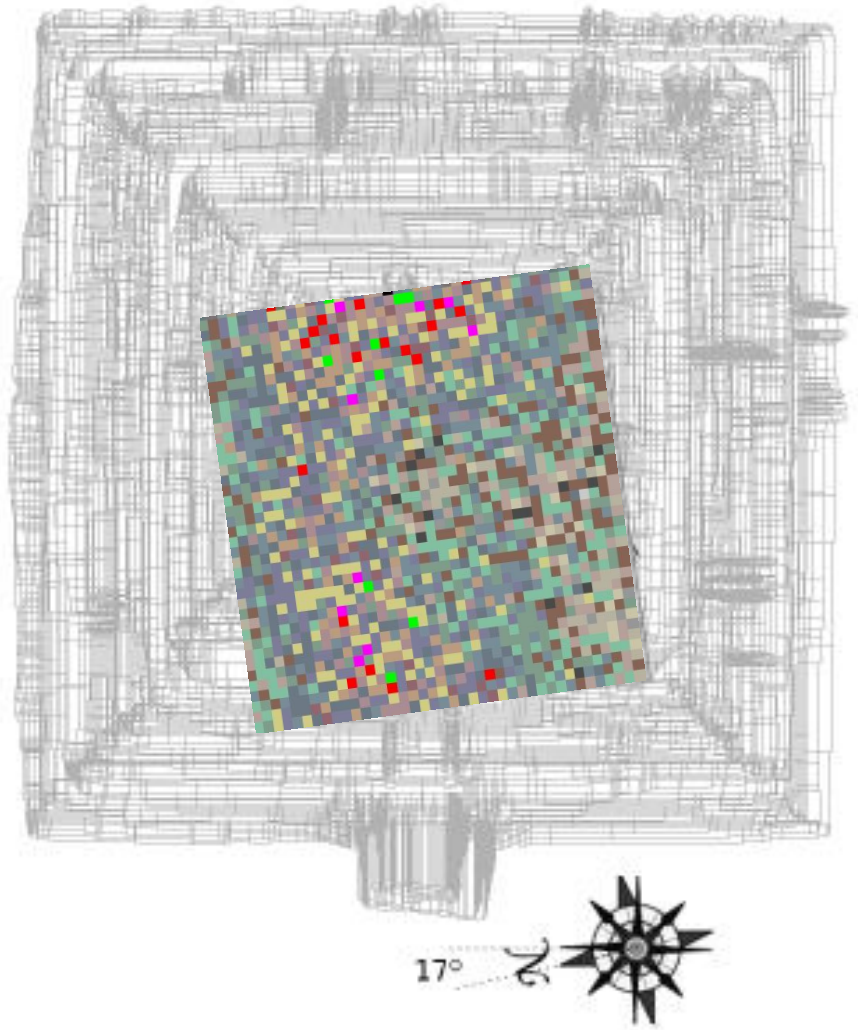


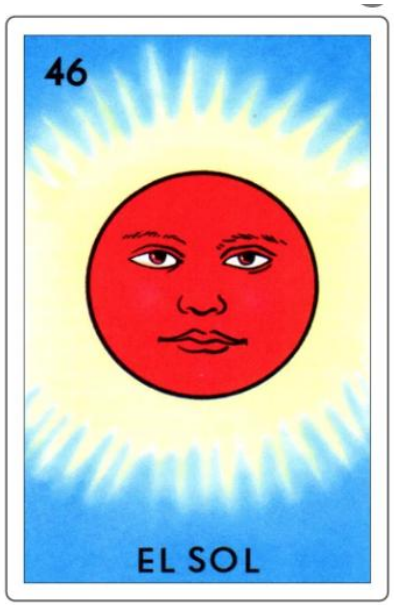
Callibration





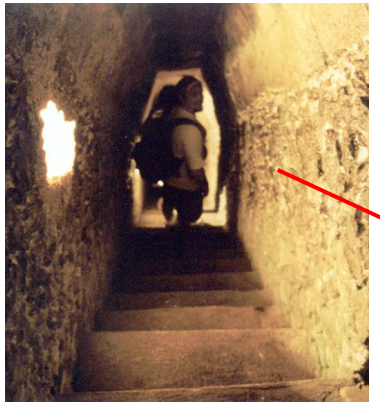
A Sun-dryed pyramid?

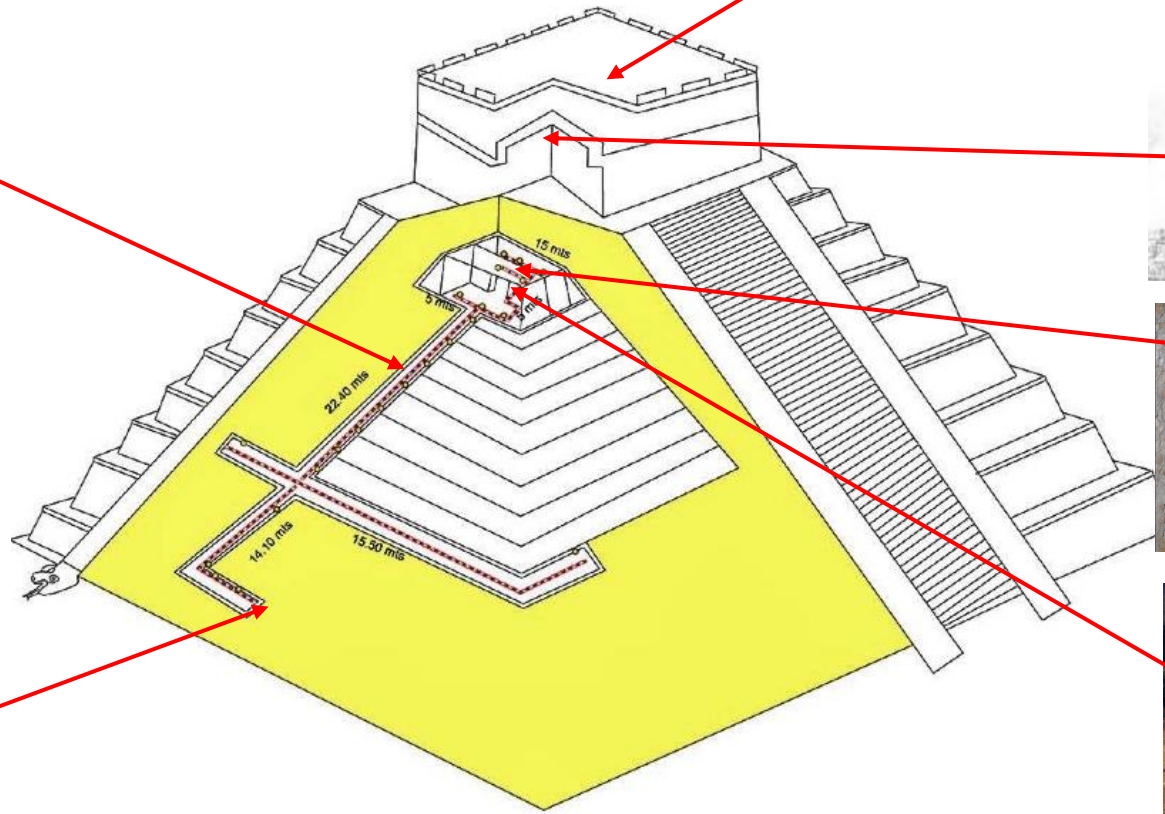


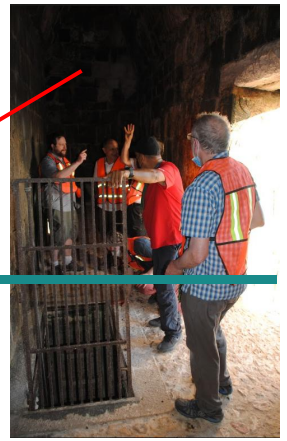


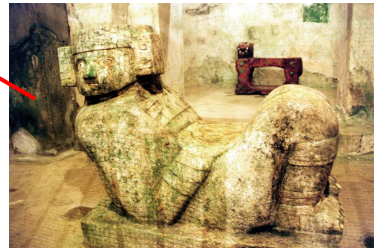
Media impact

Chichén Itzá

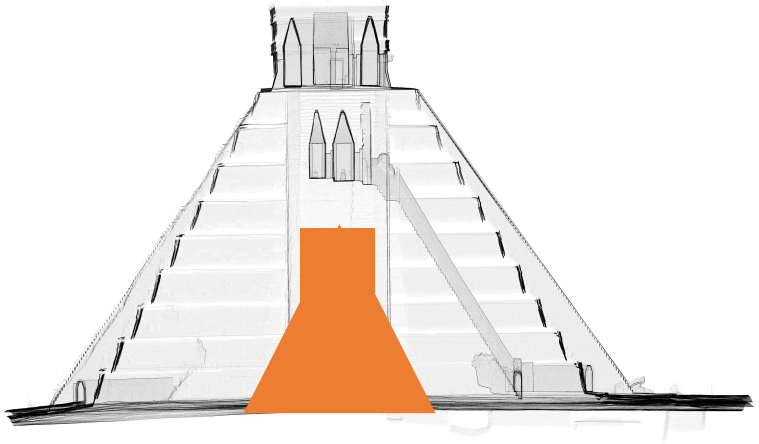








Resistivity measurements (2018)



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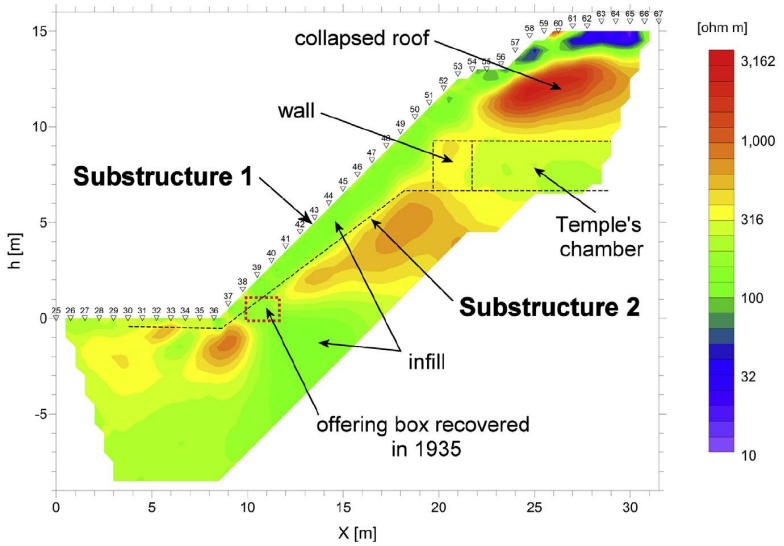
'Illuminating' the interior of Kukulkan's Pyramid, Chichén Itzá, Mexico, by means of a non-conventional ERT geophysical survey

Andrés Tejero-Andrade [a], Denisse L. Argote-Espino [b,*], Gerardo Cifuentes-Nava [c], Esteban Hernández-Quintero [c], René E. Chávez [c], Alejandro García-Serrano [a]

[a] Facultad de Ingeniería, Universidad Nacional Autónoma de México, Circuito Escolar, Ciudad Universitaria, Coyoacán, C.P. 04510, Mexico City, Mexico
[b] Dirección de Estudios Arqueológicos, Instituto Nacional de Antropología e Historia, Lic. Primo Verdad 3, Col. Centro, Cuauhtèmoc, C.P. 06060, Mexico City, Mexico
[c] Instituto de Geofísica, Universidad Nacional Autónoma de México, Circuito de Investigación, Ciudad Universitaria, Coyoacán, C.P. 04510, Mexico City, Mexico



The NAUM (Non-invasive Archaeometry Using Muons) Project

Edmundo Garcia-Solis, Austin Harton (Chicago State University)

Joseph Sagerer (Dominican University)

Mark Adams (UIC/Fermilab-QuarkNet)

Sten Hansen (Fermilab-Retired)

Eduardo Pérez de Heredia (Tecnologia Zero)

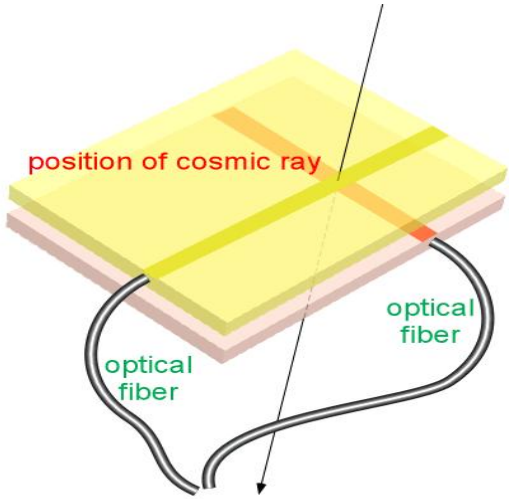
Jose Osorio, Marco Antonio Santos Ramirez (Instituto Nacional de Arqueologia e Historia - INAH)

Arturo Menchaca Rocha, Azucena Cervantes, Hesiquio Vargas (Universidad Nacional Autnoma de Mexico - UNAM)

CDMX, IFUNAM, Marzo 15, 2022

This project is supported by the National Science Foundation under awards PHY-2011339 and PHY-2011442

NAUM Instrument development



, y) coordinates from
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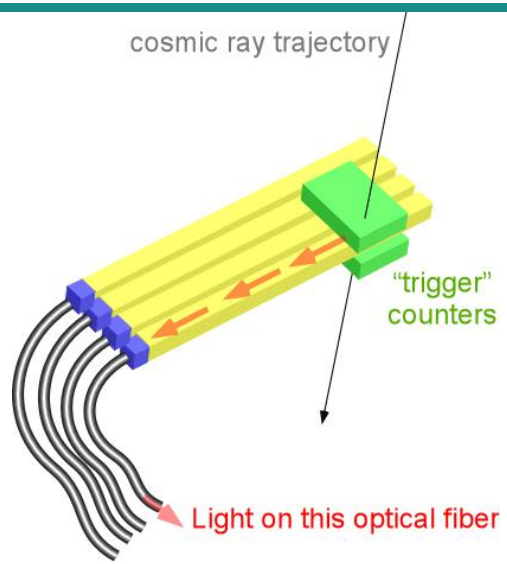

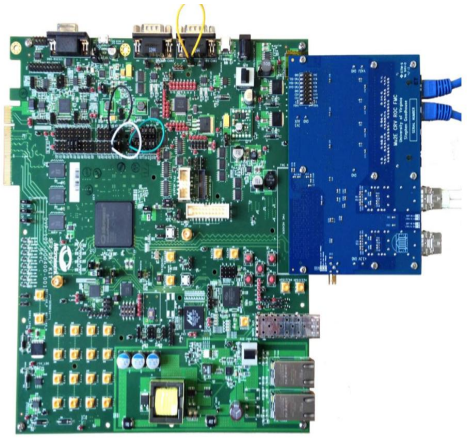

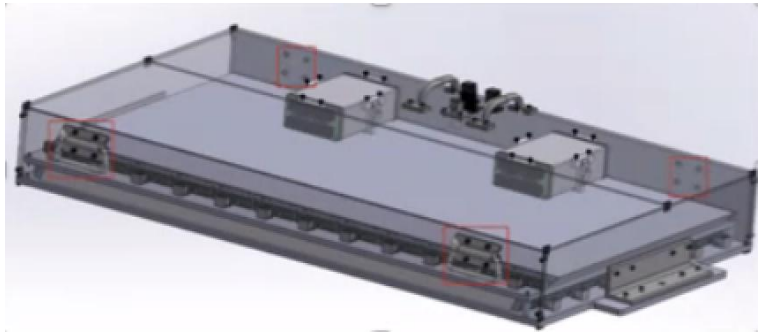

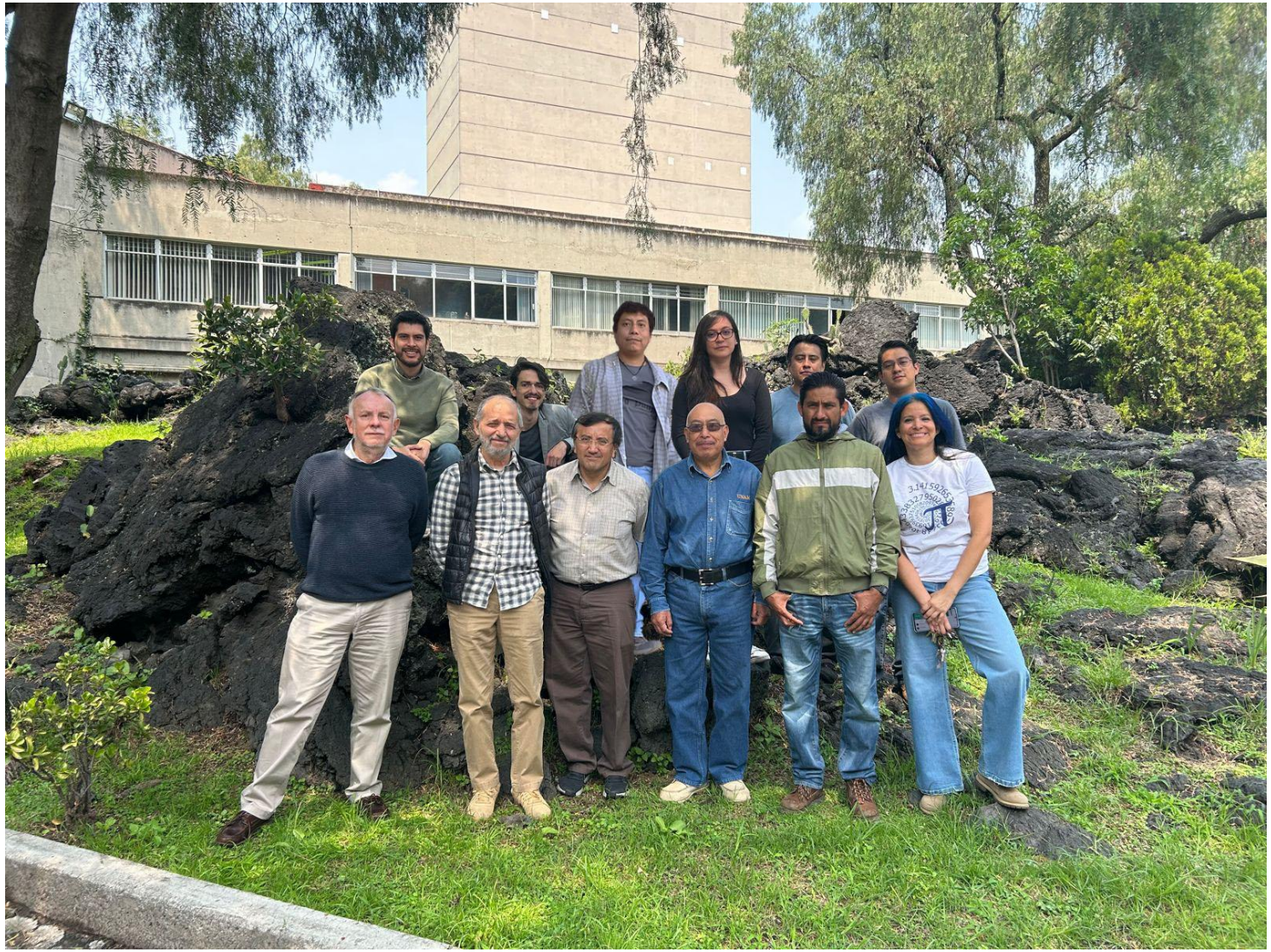

Thanks!