miniTRASGO: A Compact Muon Detector for Global Cosmic Ray Monitoring and Space Weather Studies

September 25th 2025, Caen

European Nuclear Physics Conference 2025

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Introduction

The problem of measuring the Cosmic Rays flux

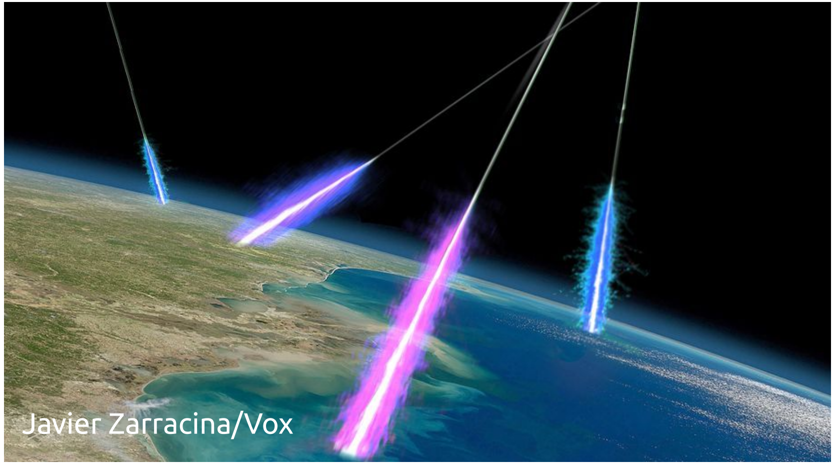
Nuclear reactions in the upper atmosphere

$$p + A \to p + n + \pi^0 + \pi^\pm + \ldots$$

$$\pi^\pm + A \to \pi^0 + \pi^\pm + \ldots$$

$$\pi^+ \to \mu^+ + \nu_\mu$$

$$\pi^- \to \mu^- + \bar{\nu}_\mu$$

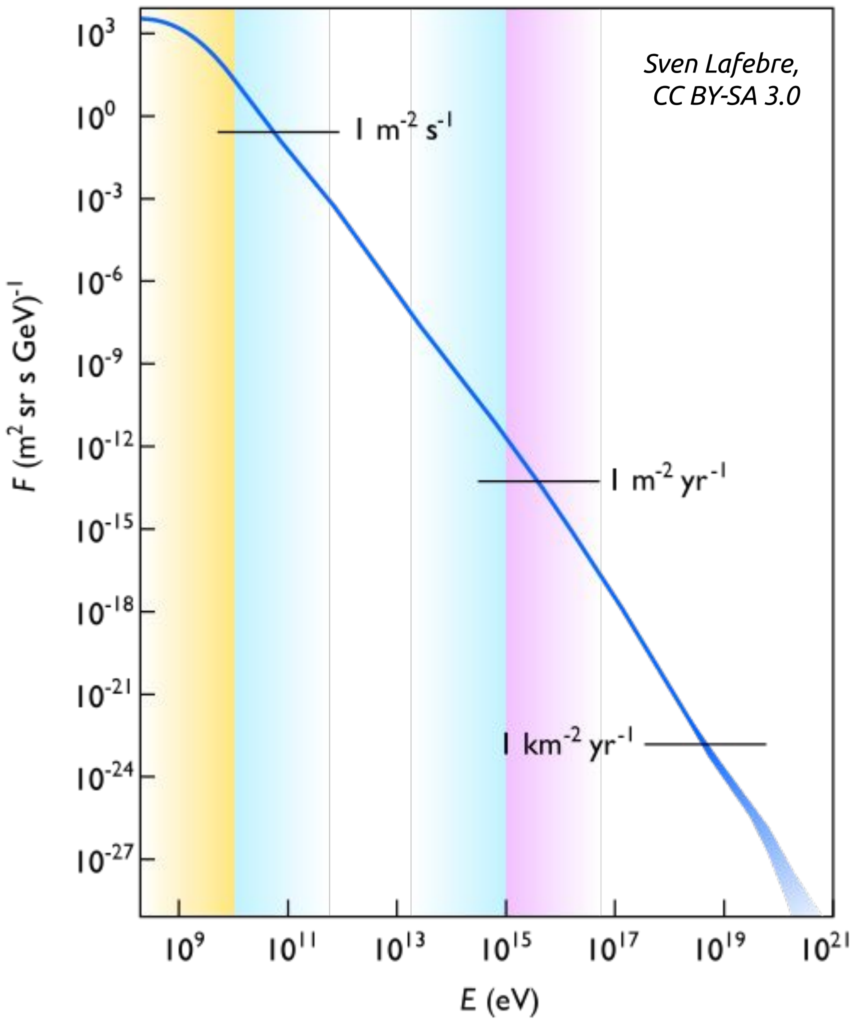


Cosmic ray spectrum

Primary Cosmic Rays are mostly protons and light nuclei

Most in the low-energy range…

… so they are modulated by *galactic*, ***solar*** and ***terrestrial*** **magnetic fields**



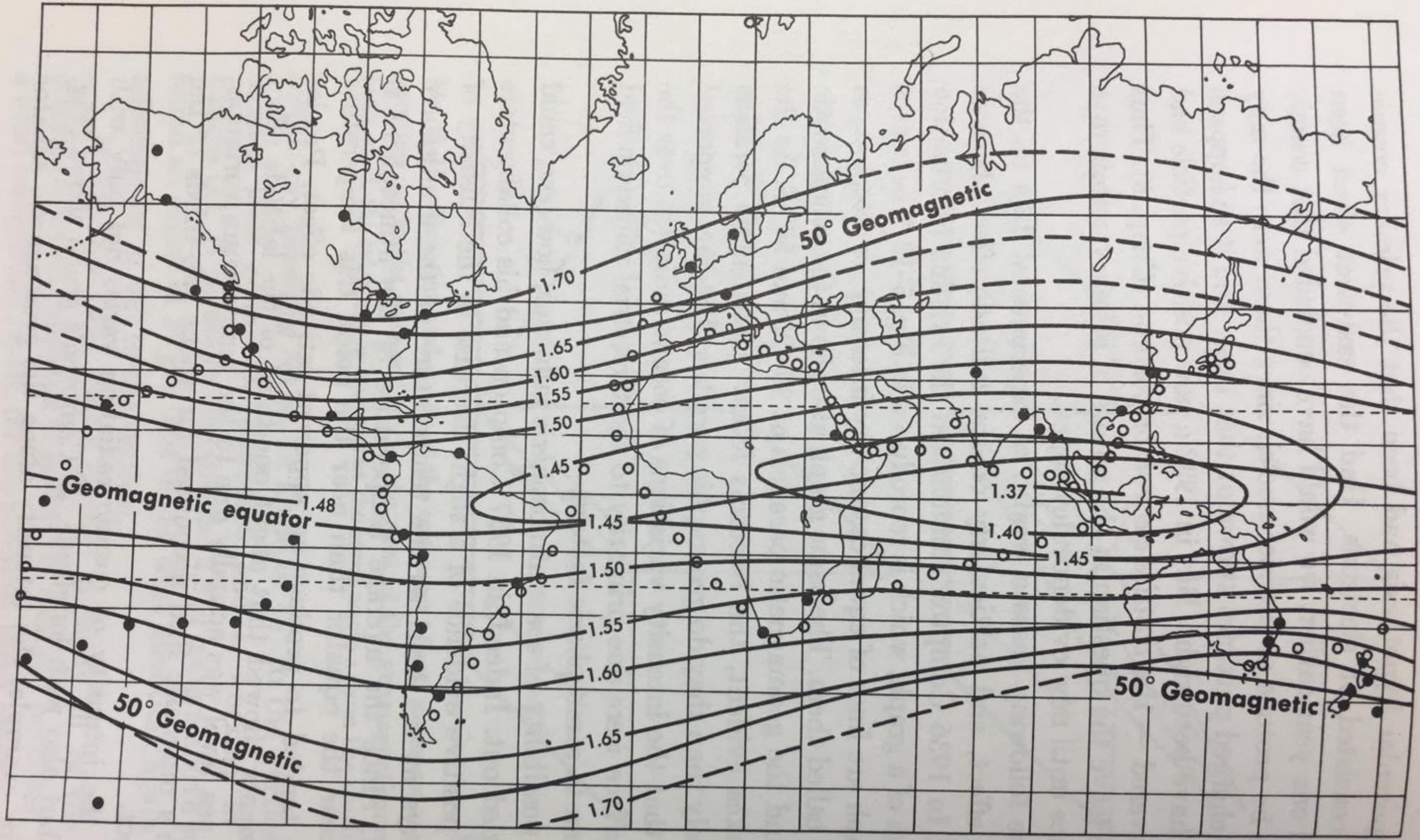


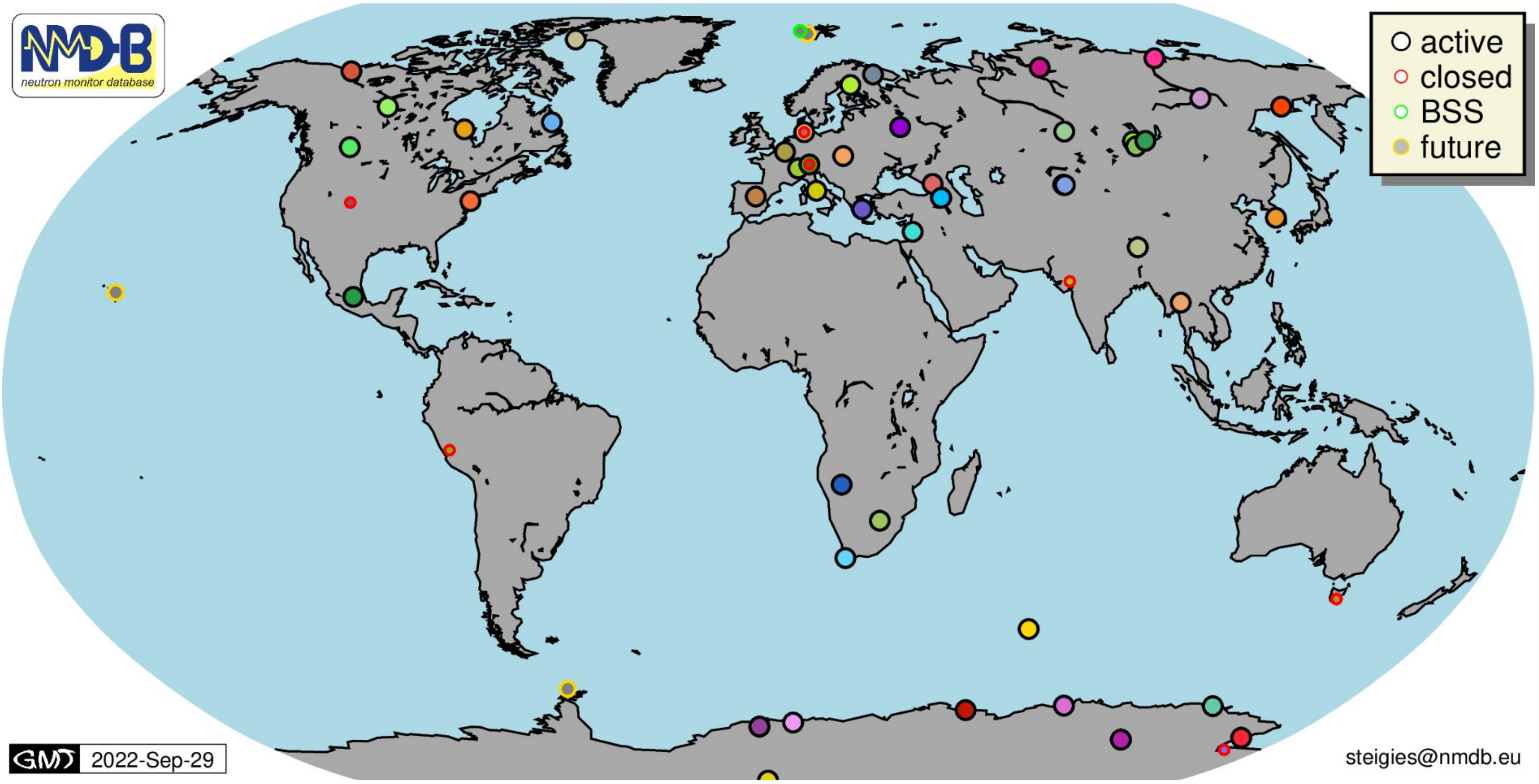
Fig. 5-12 Isocosms, or curves of equal cosmic-ray intensity, according to A. H. Compton. The numbers on the curves give the intensity of the cosmic radiation level, as measured by the number of ion pairs they produce in 1 cm^3 of air at standard temperature and pressure. Dots show locations where measurements were made. The graph also shows the geomagnetic equator and two geomagnetic parallels (50° N and S). (From a paper in *Review of Scientific Instruments*, vol. 7, p. 70, 1936.)

From Bruno Rossi's ***Cosmic Rays*** (McGraw-Hill, 1964)

Earth can be used as a ***selection filter***

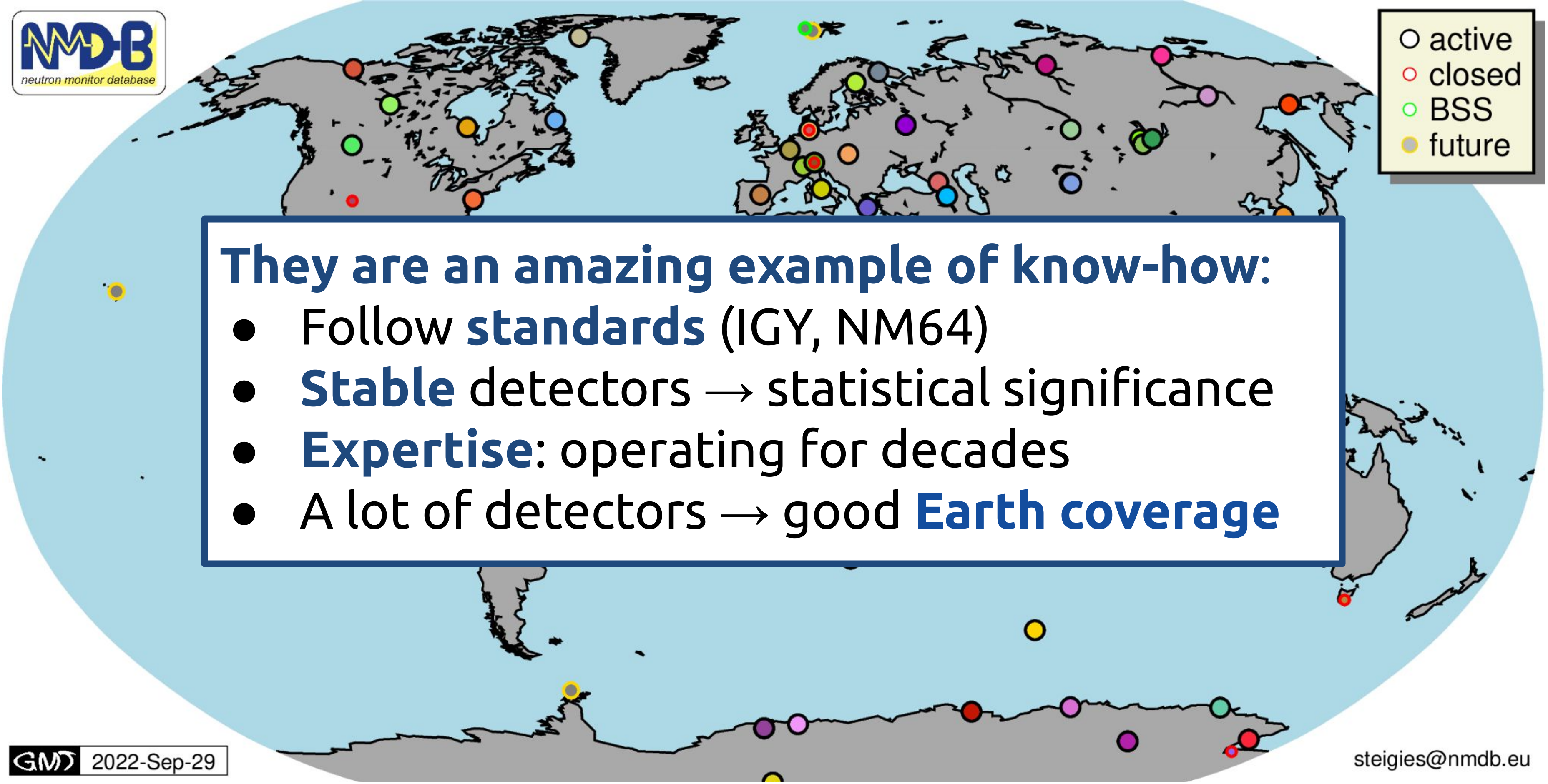
The current solution

The Neutron Monitor DataBase (NMDB)


NMDB
neutron monitor database
active
closed
BSS
future
GMD 2022-Sep-29
steigies@nmdb.eu

They are an amazing example of know-how:

- Follow **standards** (IGY, NM64)
- **Stable** detectors → statistical significance
- **Expertise**: operating for decades
- A lot of detectors → good **Earth coverage**



But…

- **Expensive** (lead…), very big installations.
- **Identical channels** → safe, but redundant information
- **Only counting** (no spectral information)

Our proposal

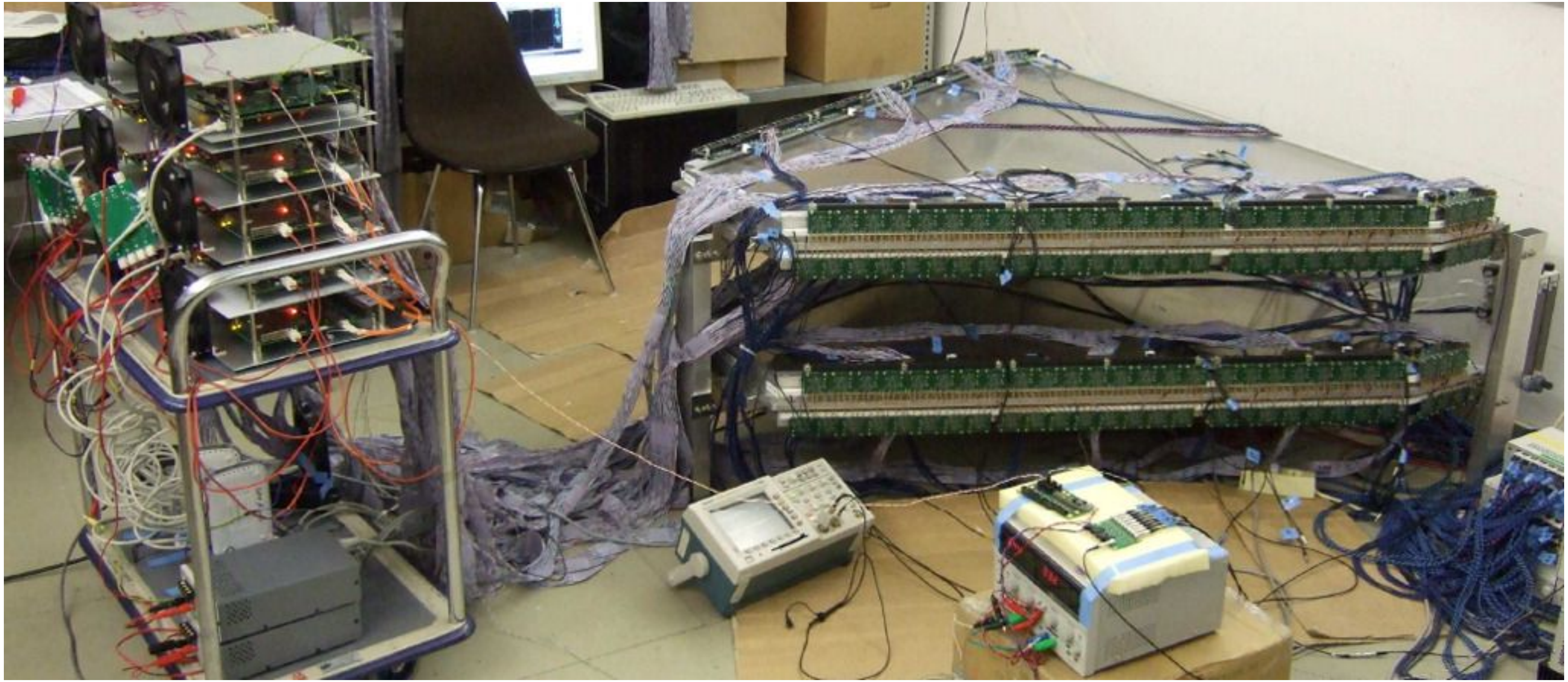
The miniTRASGO Cosmic Ray Telescope

The TRASGO project

Muons, electrons...

- Measure **secondary charged cosmic rays** with ***tracking*** using compact detectors
  - ***Not only counts, but angular counts!***
- TRASGO concept: **TRAck reconStructinG bOx**

RPC based!



HADES Time-of-Flight Wall (commissioning)

- D. Belver et al., *TRASGO: A proposal for a timing RPCs based detector for analyzing cosmic ray air showers*, NIM A, 2012, https://doi.org/10.1016/j.nima.2010.09.173
- A. Blanco et al., *RPC HADES-TOF wall cosmic ray test performance*, NIM A, 2012, https://doi.org/10.1016/j.nima.2010.08.068
- D. Belver et al., *Analysis of the space-time microstructure of cosmic ray air showers using the HADES RPC TOF wall*, JINST, 2012, 10.1088/1748-0221/7/10/P10007

TRAGALDABAS

- A Blanco et al., *TRAGALDABAS: a new RPC based detector for the regular study of cosmic rays*, JINST, 2014, DOI 10.1088/1748-0221/9/09/C09027
- I. Riádigos et al., *Revisiting the limits of atmospheric temperature retrieval from cosmic-ray measurements*. Earth and Space Science, 2022, https://doi.org/10.1029/2021EA001982
- I. Riádigos et al., *Atmospheric temperature effect in secondary cosmic rays observed with a 2 m² ground-based tRPC detector*. Earth and Space Science, 2020, https://doi.org/10.1029/2020EA001131

- Logicmelt, *Stratos DS – Stratospheric temperature prediction using artificial intelligence*, Logicmelt – Use Cases, 2025, https://logicmelt.com/en/use-cases_eng/stratos-ds-prediction-of-the-stratosphere-temperature/
- NAC-Intercom, *Project STRATOS – Ground Station for Continuous Monitoring of the Stratosphere Temperature through Cosmic Ray Directional Flow*, NAC-Intercom – Projects, 2025, https://www.nac-inter.com/en/content/30-project-stratos

STRATOS

TRISTAN

- J.P. Saraiva, et al., *The TRISTAN detector—2018–2019 latitude survey of cosmic rays. Journal of Instrumentation*, JINST, 2020, https://doi.org/10.1088/1748-0221/15/09/C09024

The *HUGE* TRASGO ???

The miniTRASGO !

C. Soneira-Landín et al., NIM A, 2025, https://doi.org/10.1016/j.nima.2025.170511
C. Soneira-Landín et al., Adv. Space Res., 2025, https://doi.org/10.1016/j.asr.2025.07.096
C. Soneira-Landín et al., PoS(ICRC2025)1368

The miniTRASGO !

Main features:

- Versatile and **compact**
- Not cost demanding
  - **<12000 euro!**
- **Standard**

C. Soneira-Landín et al., NIM A, 2025, https://doi.org/10.1016/j.nima.2025.170511
C. Soneira-Landín et al., Adv. Space Res., 2025, https://doi.org/10.1016/j.asr.2025.07.096
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The miniTRASGO !

Main features:

- Versatile and **compact**
- Not cost demanding
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- **Standard**

Ideal for a network!

C. Soneira-Landín et al., NIM A, 2025, https://doi.org/10.1016/j.nima.2025.170511
C. Soneira-Landín et al., Adv. Space Res., 2025, https://doi.org/10.1016/j.asr.2025.07.096
C. Soneira-Landín et al., PoS(ICRC2025)1368

miniTRASGO network

Warsaw 🇵🇱

Madrid 🇪🇸

Puebla 🇲🇽

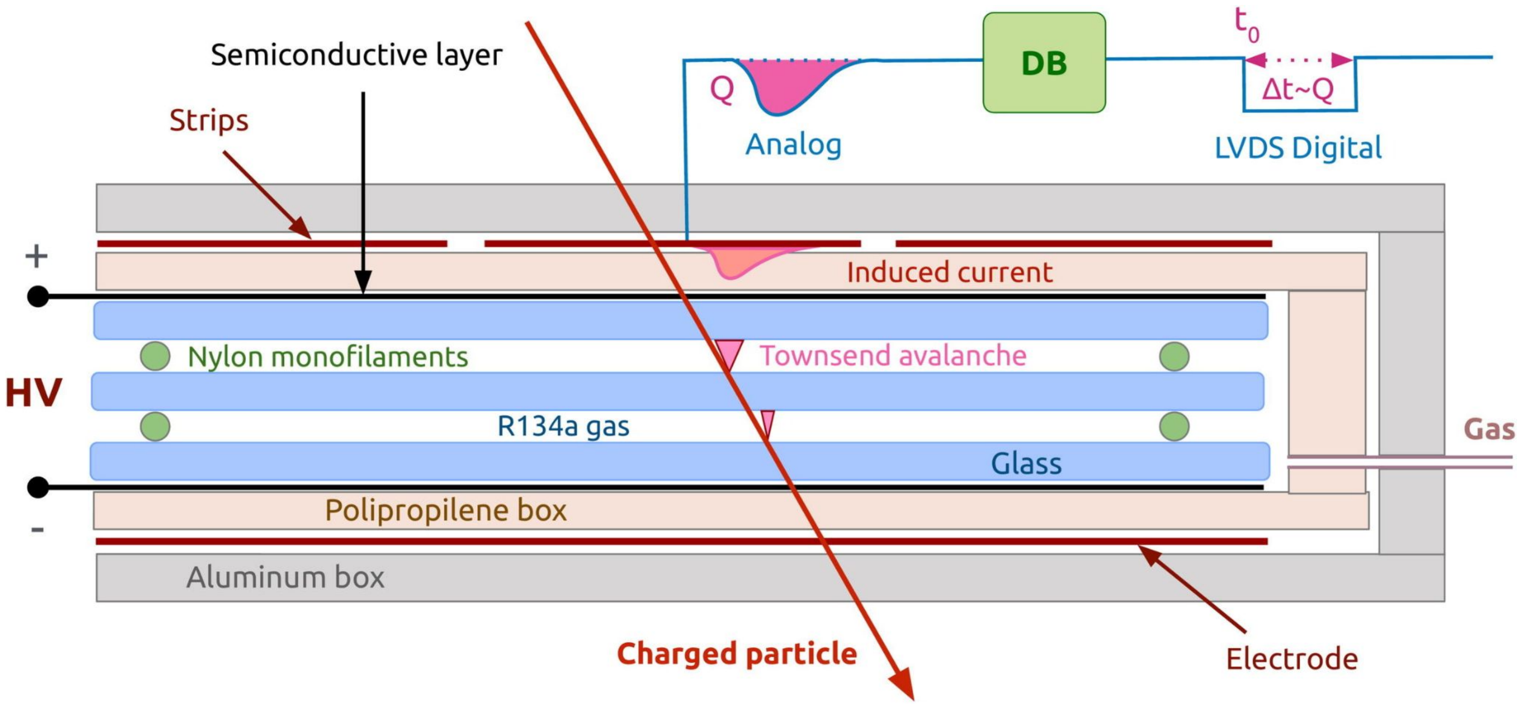
Monterrey 🇲🇽

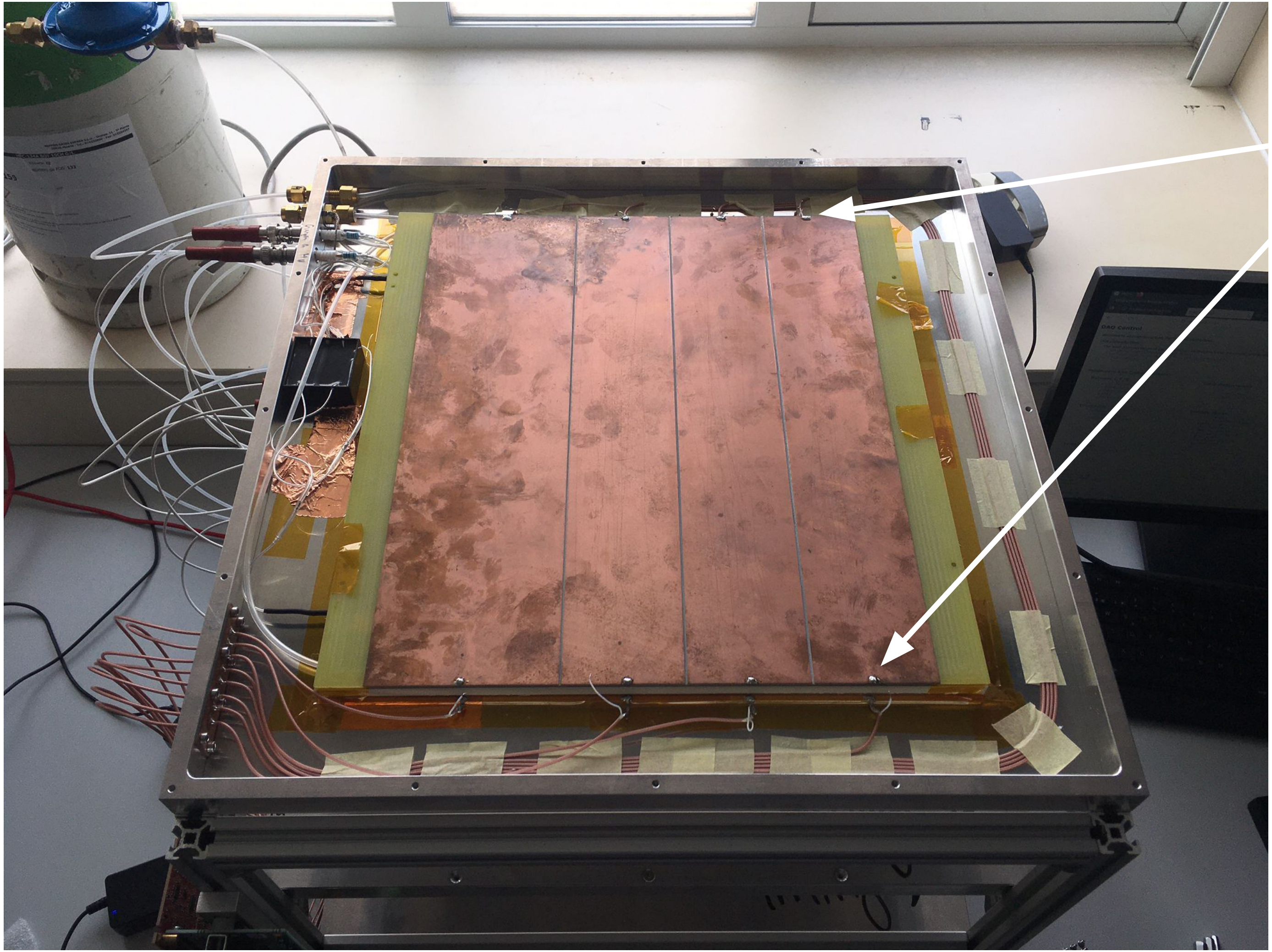
Yet…

… are they good counting detectors?

Resistive Plate Chamber summary

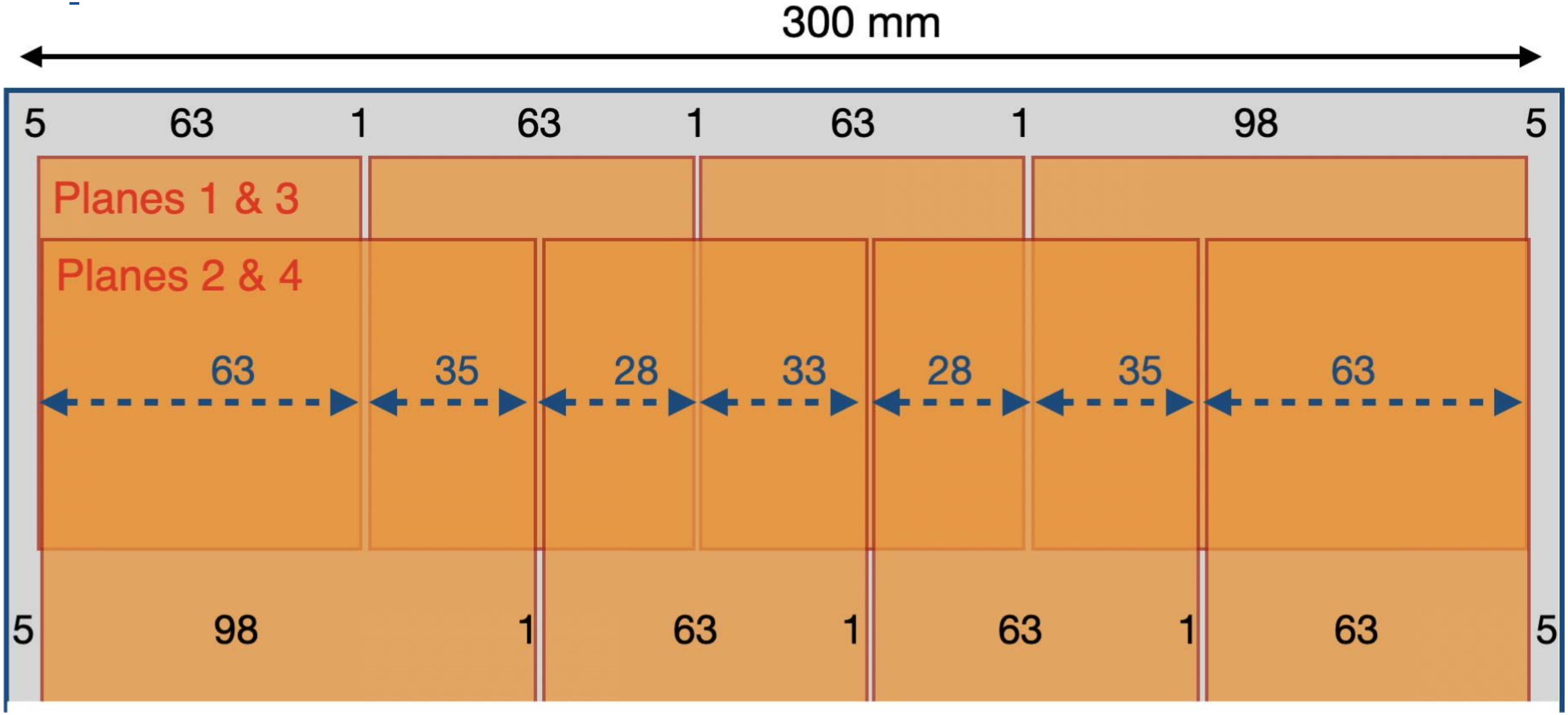
- 4 parallel 30x30 cm^2 **Multigap glass Resistive Plate Chambers** (MRPCs)
  - **~400 ps** timing
  - **~3 cm** spatial resolution
- **Gas:** R134a, flux of <1 kg/month





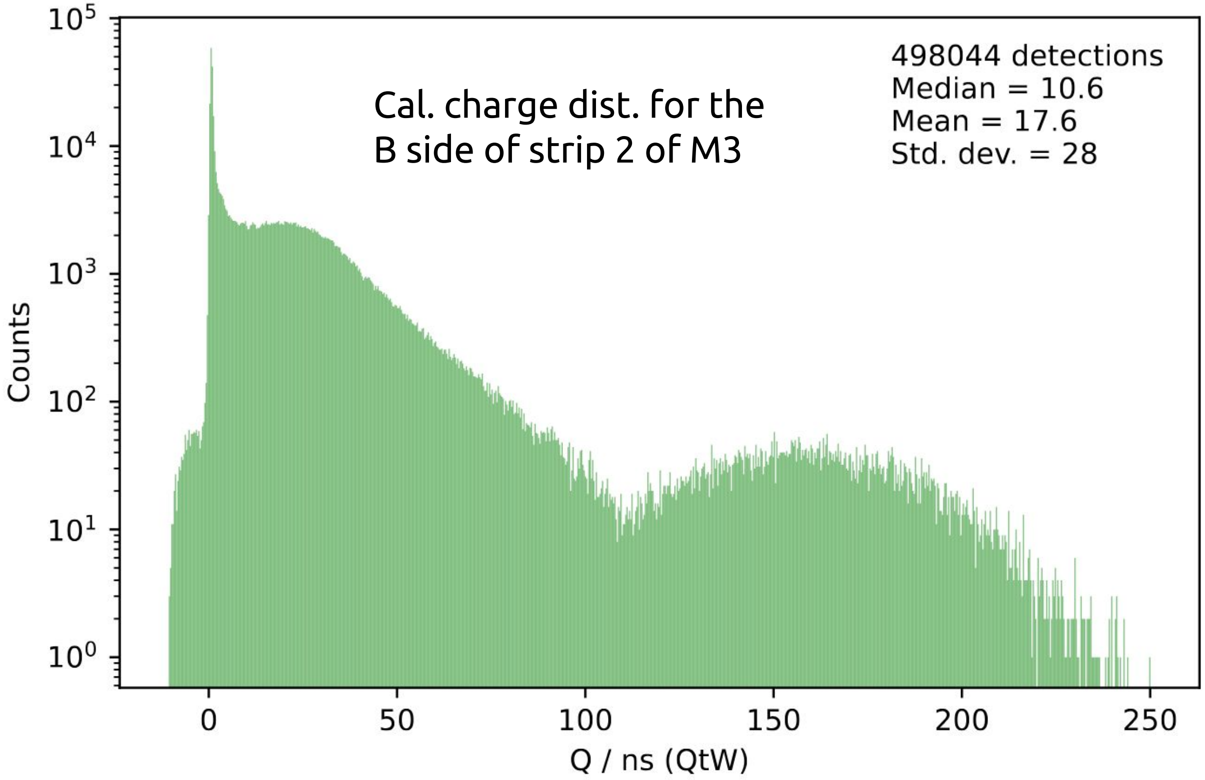
Asymmetric parallel **Cu** strips read in Front and Back (32 channels)

The guts of a detecting plane


300 mm
5
63
1
63
1
63
1
98
5
Planes 1 & 3
Planes 2 & 4
63
35
28
33
28
35
63
5
98
1
63
1
63
1
63
5

Measure: time and charge in F and B per strip

Time sum → Incidence time
Time diff → Position
Charge sum → Total charge
Charge diff → Monitor



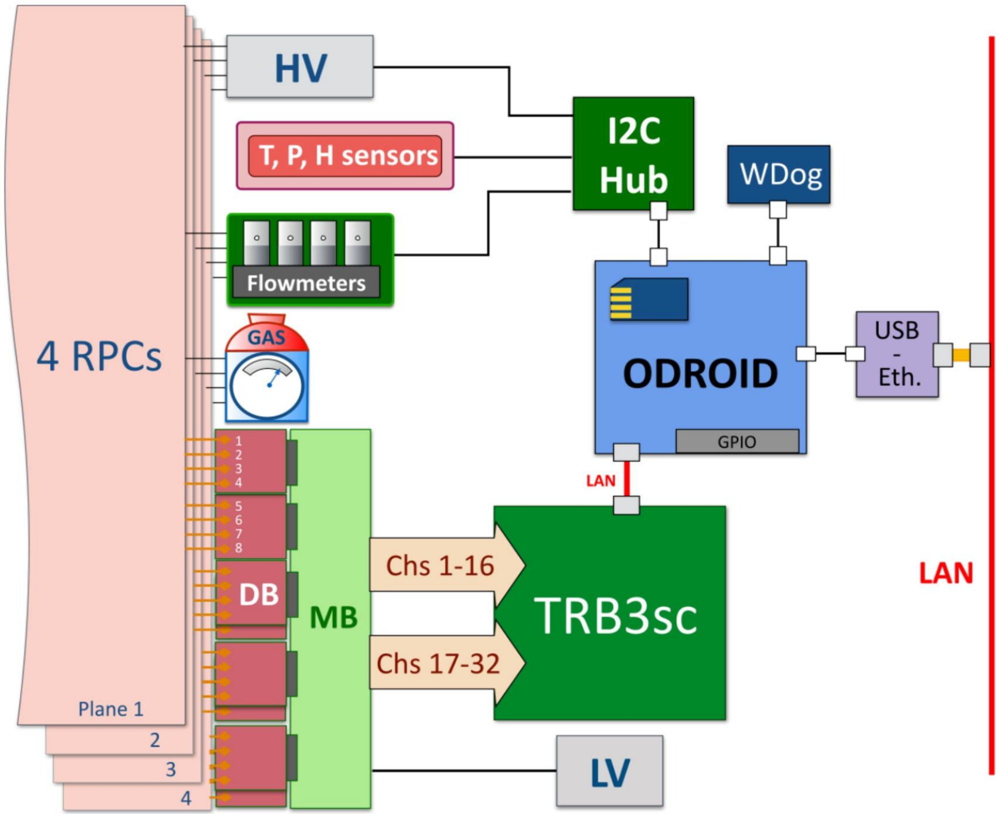
Compact and autonomous

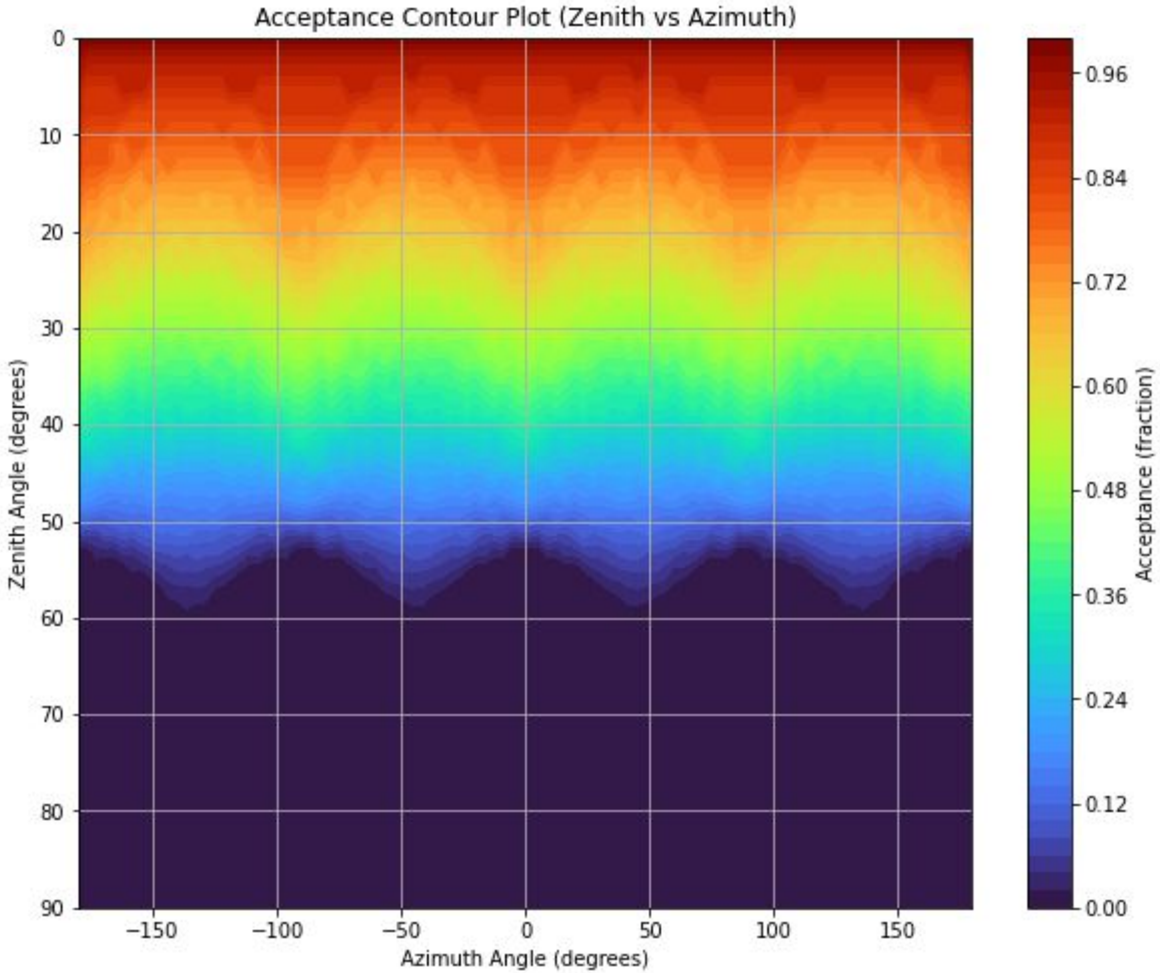
Only three connections:

- **Power** (standard plug)
- **Gas** bottle (15 kg)
- **Ethernet** (not required)

Includes:

- environment sensors, flowmeters, DAQ and a PC for data analysis and storage

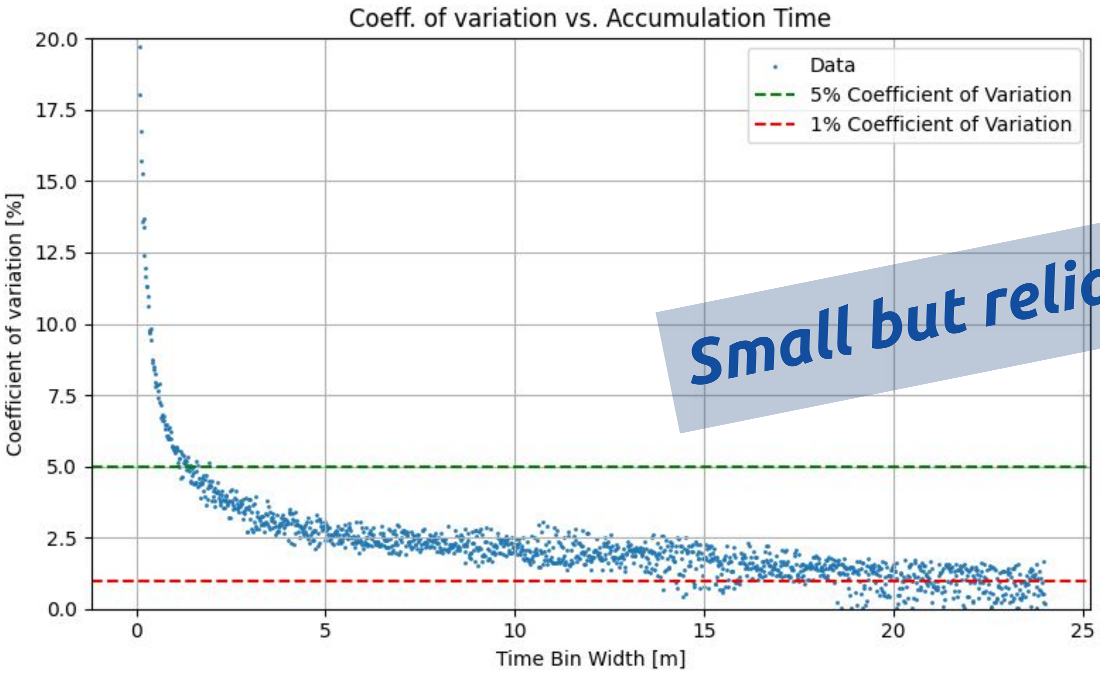




Acceptance study from simulation

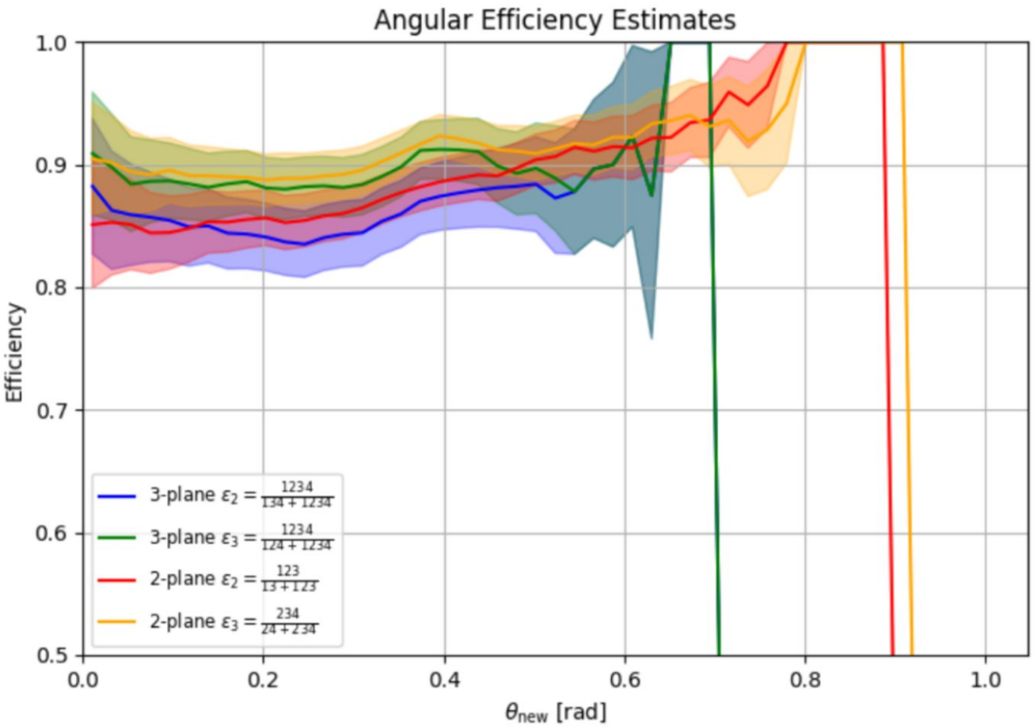
Good sky coverage, >80% of total muons

Standard deviation of the miniTRASGO count rate for different time windows shows a **<1% deviation for >20 min windows**



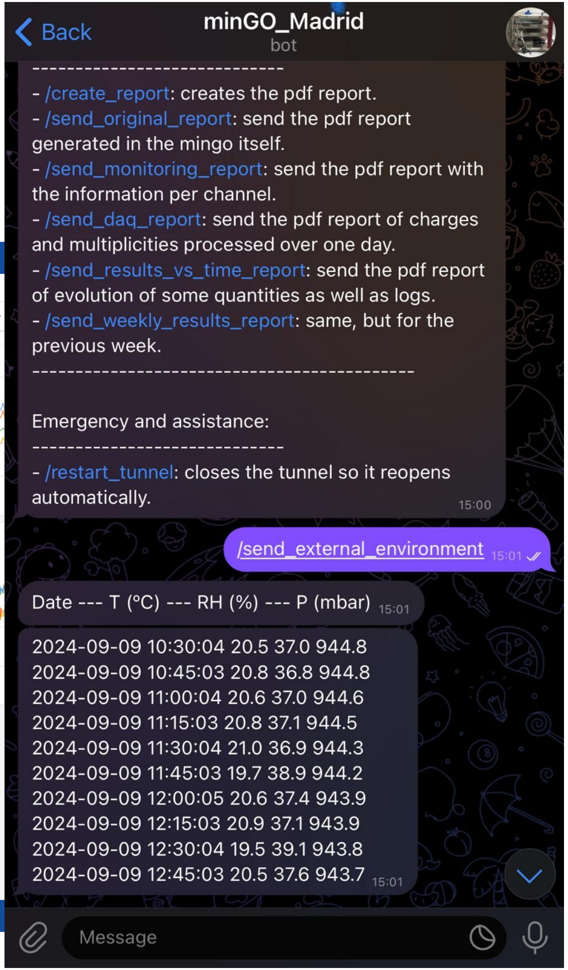
Small but reliable

Efficiency vs. incident zenith muon angle



Oblique tracks spend more time in the active volume

Grafana and Telegram control



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miniTRASGO Documentation

Last updated: August 2025

Welcome to the official documentation for the miniTRASGO (miniature TRASGO) cosmic ray telescope. miniTRASGO is a compact, cost-effective muon tracker based on Resistive Plate Chambers. It monitors secondary cosmic rays to study solar activity, atmospheric correlations, and space weather. With stations operating in Madrid, Warsaw, and Puebla and another planned for Monterrey, the project is building a scalable network across different latitudes. This site collects everything needed to operate a miniTRASGO unit and analyze its data.

Project Resources

- **Logbook** – track activities in the miniTRASGO logbook
- **Notebook** – detailed notes and calcul

csoneira.github.io/miniTRASGO-documentation/

Repositories

- **Documentation** – miniTRASGO documentation repository.
- **Software** – analysis and monitoring tools.

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Forbush Decrease

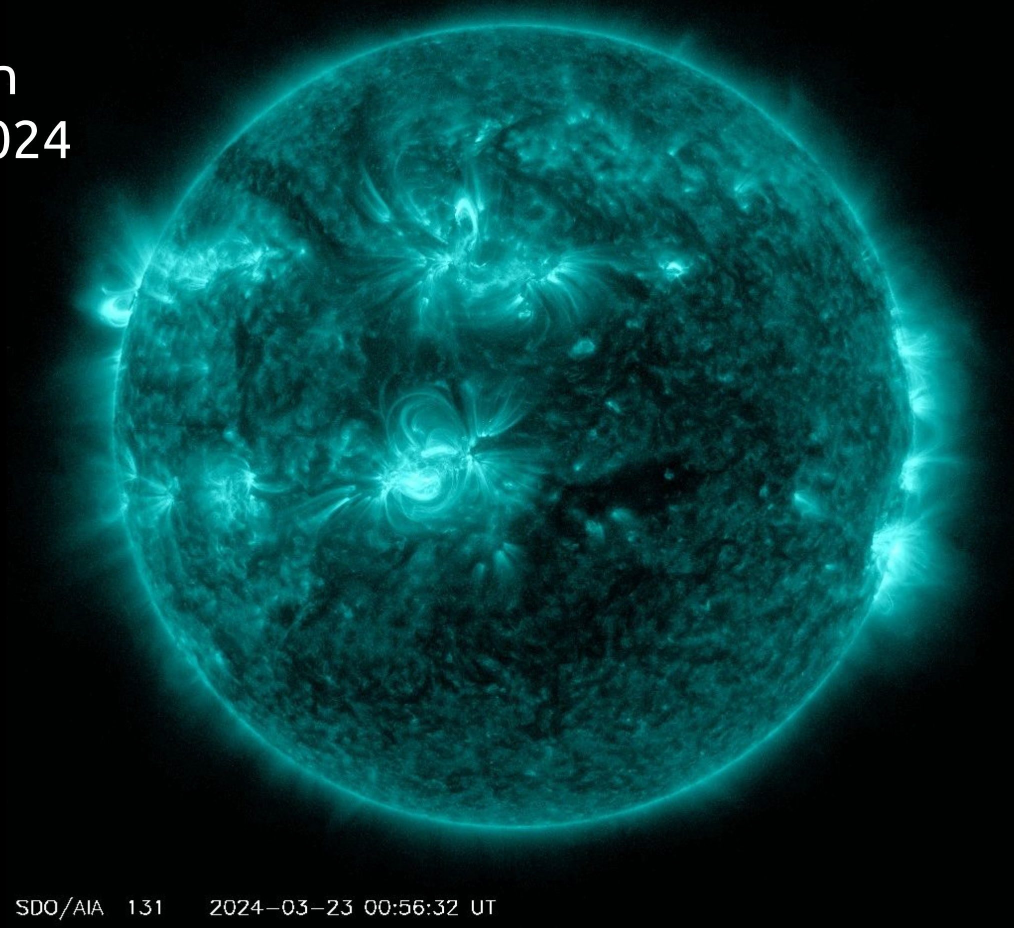
On March 2024

Two Sunspots exploded in tandem on March 23rd 2024 (03:30 CET)

↓

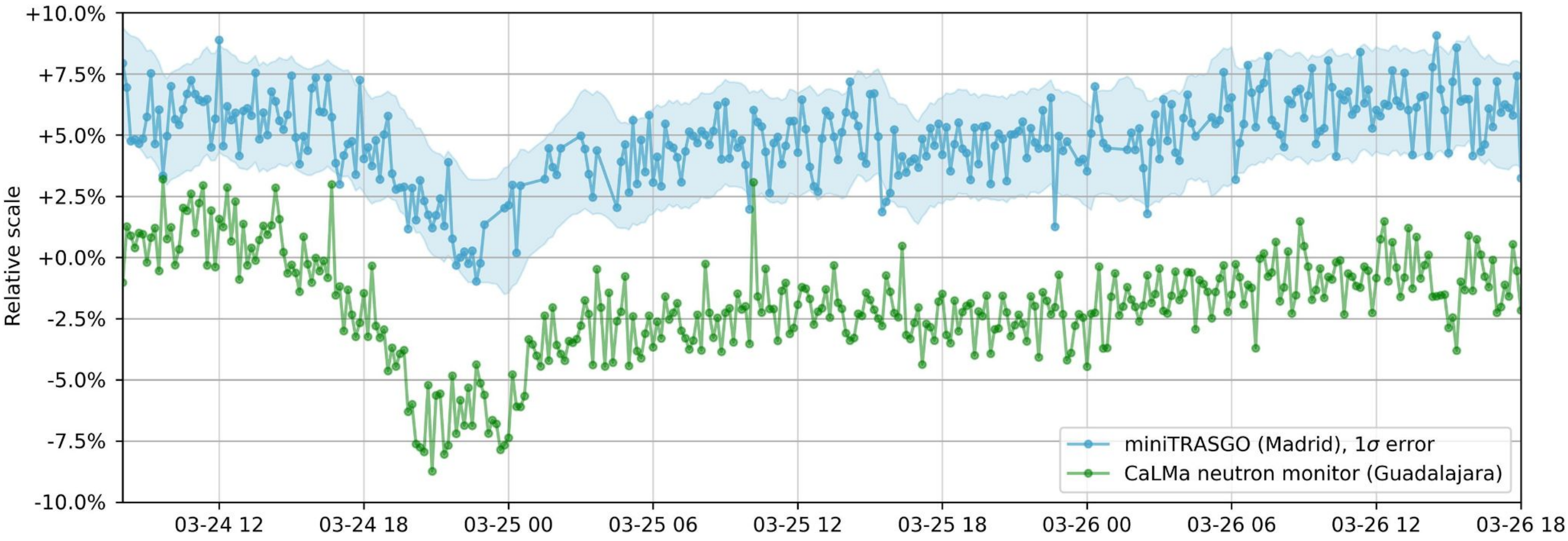
8 hours later…

From Solar Dynamics Observatory, NASA



Eff. and pressure corrected rate

→ the Forbush Decrease can be seen



GUADALAJARA SPAIN

Conclusions

and a look into the future

Conclusions and future prospects

- **Stable, not expensive,** secondary charged CR detector
- *Forbush Decrease* detection

  → **useful for Space Weather**

To do next:

- Create a ***long-term dataset*** to share with the community
- ***Network and angular*** capabilities:
  - Monterrey, Puebla, Warsaw, Madrid are online

Merci!

Questions?

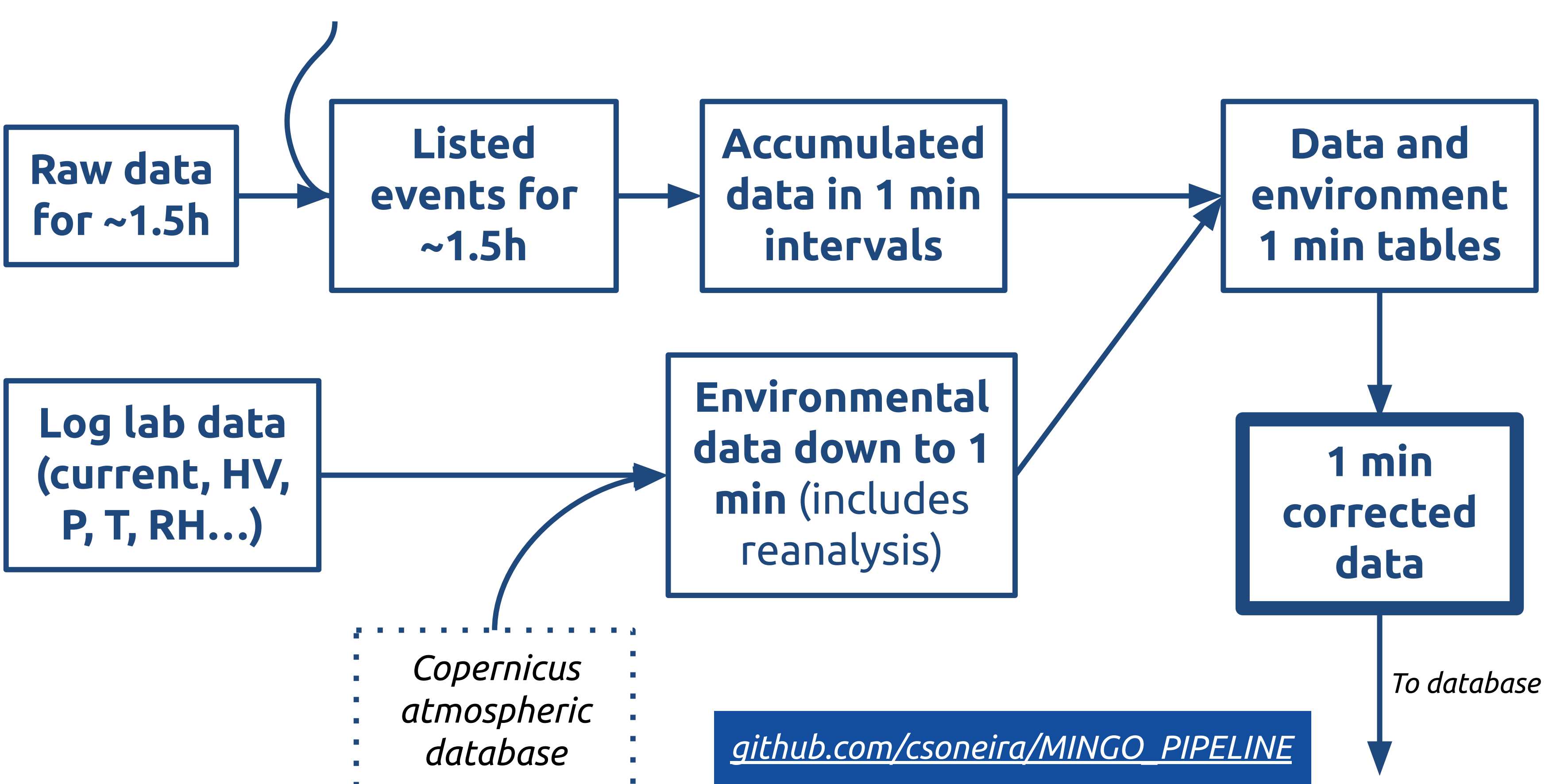
miniTRASGO: A Compact Muon Detector for Global Cosmic Ray Monitoring and Space Weather Studies

csoneira@ucm.es
C. Soneira-Landín

Back-up slides

for those curious

Efficient pipeline for Cosmic Ray data



github.com/csoneira/MINGO_PIPELINE

Analysis of Event Distribution

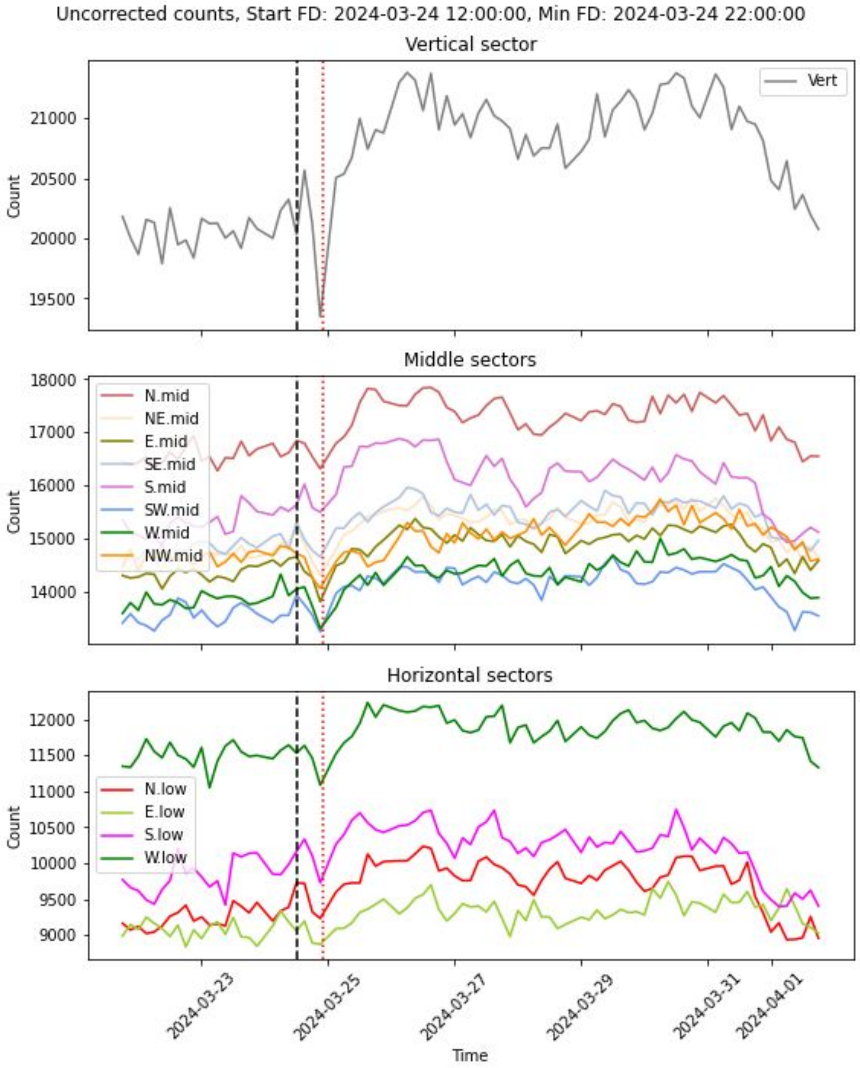
- **80%** of total events are in only one strip.
- **20% in two strips, we check numbers in histogram of charge ratio min/max**:
    - **78%** are double adjacent sharing charge → **15%** of total events.
    - **23%** are actually single hits → **5%** of total events.

Classification Breakdown

- **85%** of total events = one particle in the interior of one strip (80% + 5%).
- **15%** of total events = one particle between two strips.

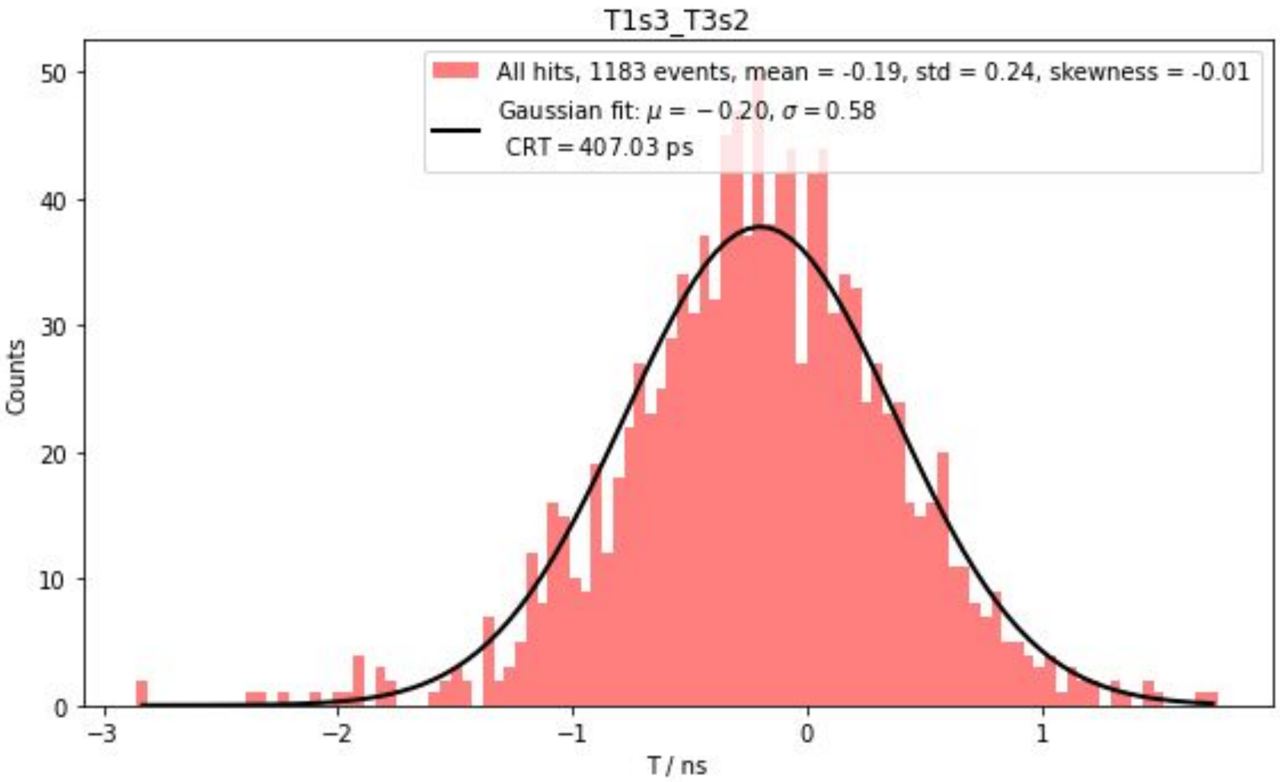
Ionization Section

- If the mean strip width = **63 mm**:
    - Ionization section = **2 × 9.8 mm = 20 mm (2 cm)**.
    - Consistent with the resistivity of these RPCs


Uncorrected counts, Start FD: 2024-03-24 12:00:00, Min FD: 2024-03-24 22:00:00
Vertical sector
Vert
Middle sectors
N.mid
NE.mid
E.mid
SE.mid
S.mid
SW.mid
W.mid
NW.mid
Horizontal sectors
N.low
E.low
S.low
W.low
Count
Time

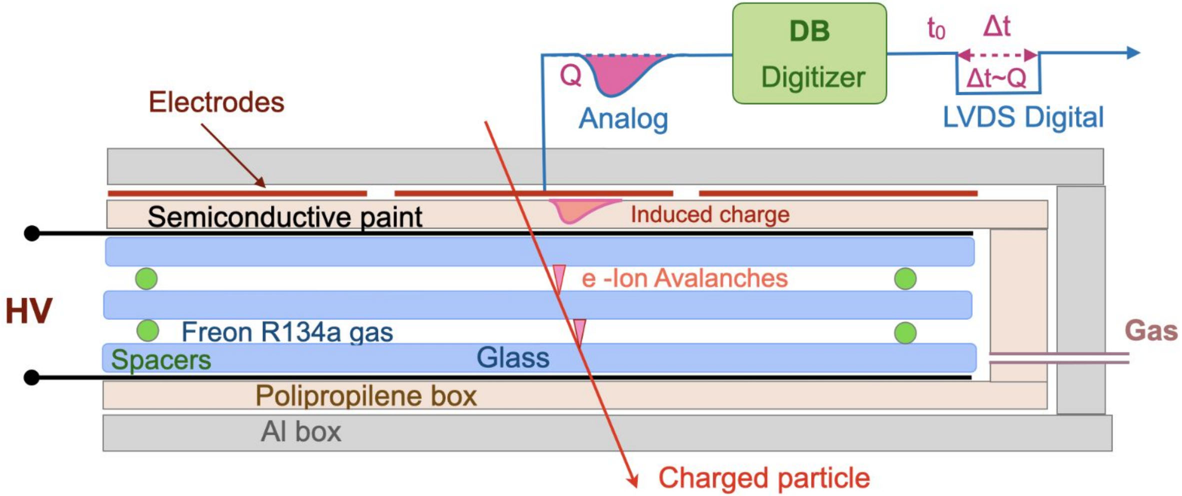
DAQ Overview

- **Front-end electronics (FEE)**: Developed for the **HADES detector** (GSI).
    - Daughterboards (DB): Converts RPC signals into LVDS (Low Voltage Differential Signal) using Hidronav technology. Key features:
    - Motherboard (MB): Powers DBs and transfers LVDS to the TRB.
- **TRB3sc** (Time-of-Flight Reconstruction Board): From HADES experiment.
    - **32** Time-to-Digital Converters (TDC).
    - Inputs LVDS from DB.
    - Outputs **digital timestamp** and **signal length** via USB.


T1s3_T3s2
All hits, 1183 events, mean = -0.19, std = 0.24, skewness = -0.01
Gaussian fit: $\mu = -0.20$, $\sigma = 0.58$
CRT = 407.03 ps
Counts
T / ns
0
10
20
30
40
50
−3
−2
−1
0
1

RPC summary

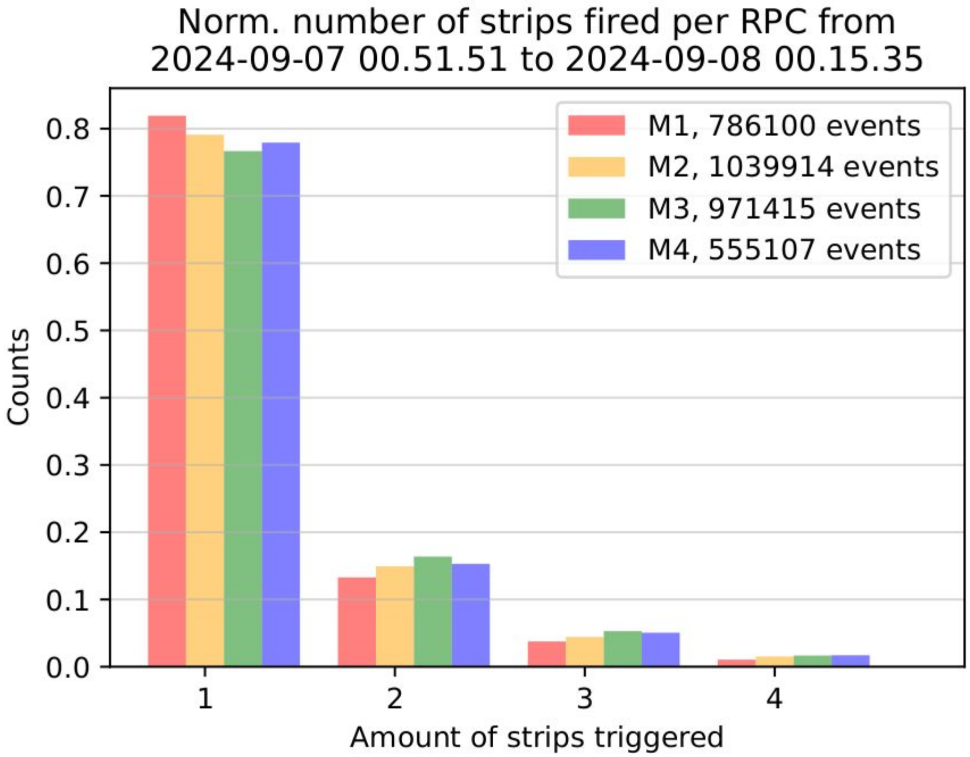
- **4 parallel square Multigap glass RPC**
  - 3 glass layers, 2 mm each
  - 2 gaps, 1 mm each (nylon monofilaments)
- **High Voltage**: WP ~5.52 kV/gap
- **Resistivity**: 10 MΩ/cm² = **10^7 Ω/cm²**
- **Gas**: R134a, flux of 1 kg/month
- **Active area**: 30x30 cm, approx. 0.1 m²



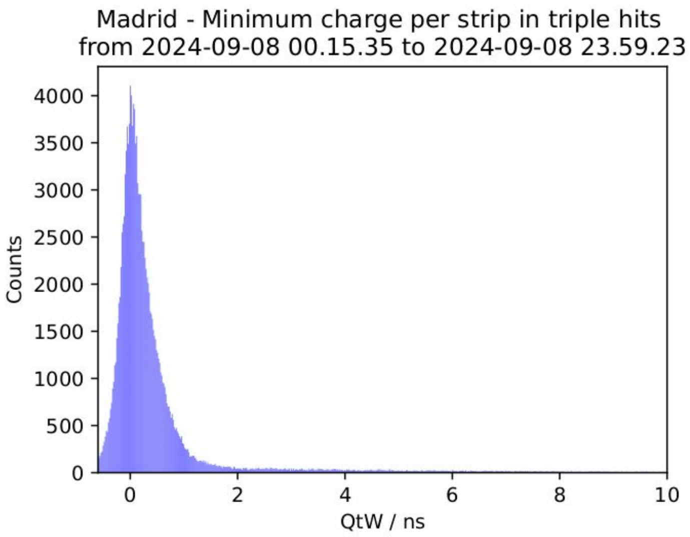
Cluster size

- ~80% of events leave charge in only one strip
- ~10-20 % of events in two strips
- ~5% in three

But first, charge spectra must be understood

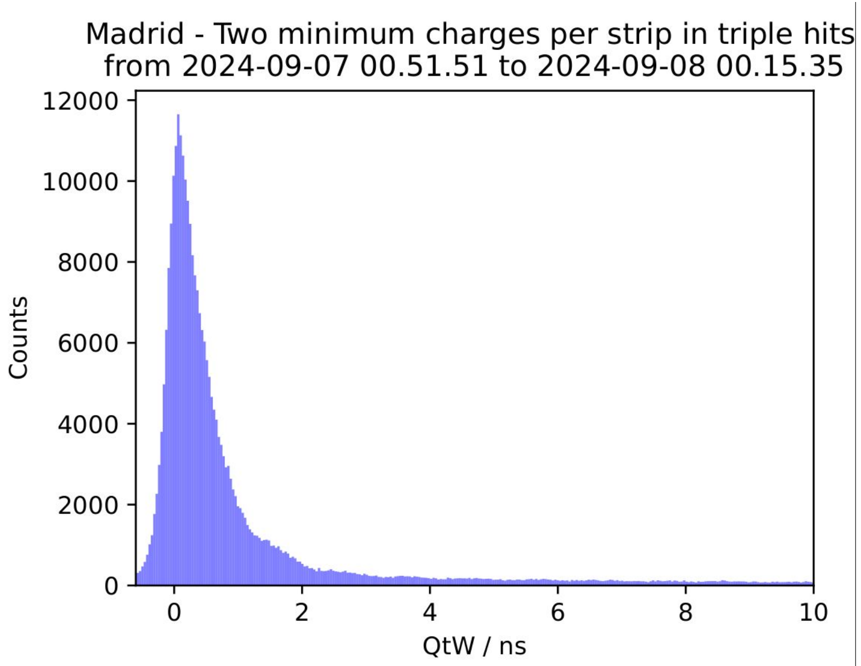


Crosstalk and Cluster Size 3 study



We learn:

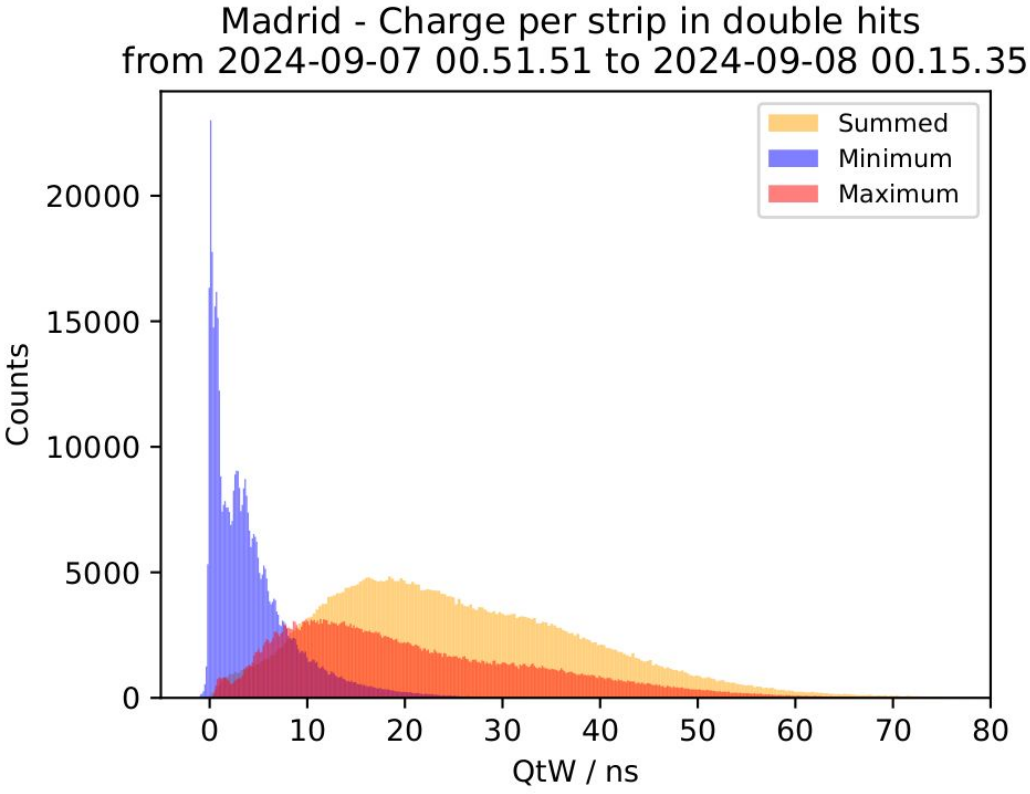
- 1 ns of QtW charge is a reasonable upper bound for the crosstalk charge.
- **Cluster Size = 3** cases are mainly caused by **crosstalk**, so in practice can be considered **Cluster Size = 2**



What about Cluster Size 2?

The same plot reveals a wider distribution:

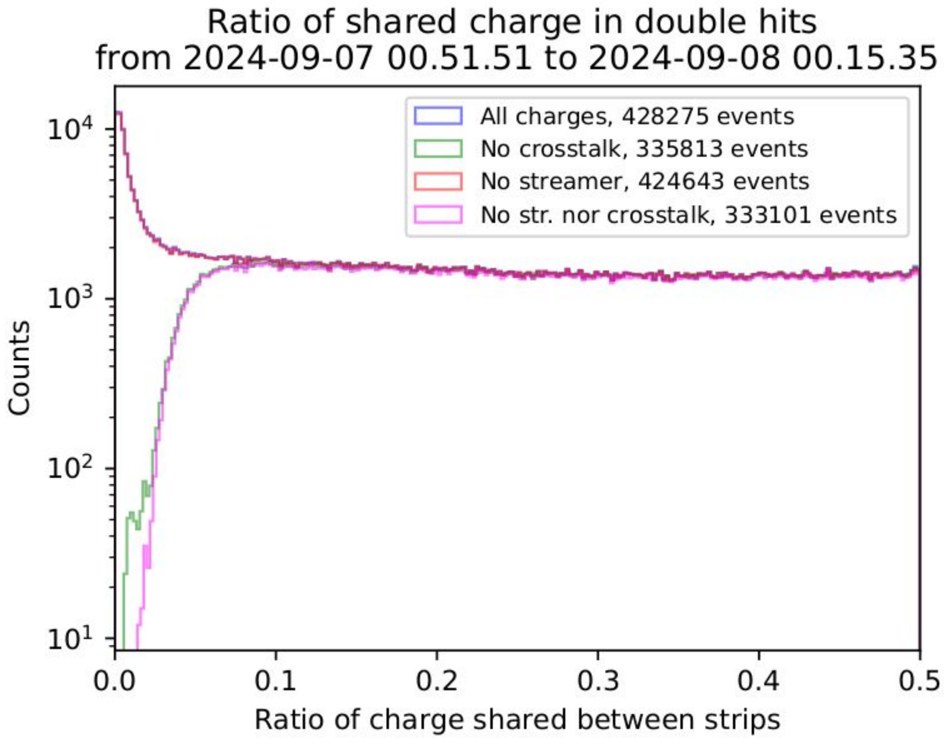
- **There is charge sharing**
  - **in two strips,**
  - **but not in three.**
- Induction section can be estimated



And sharing goes uniformly from 10% to the 50% of charge

If the mean strip width is **63 mm**:

- Induction section = 2 × 9.8 mm = 20 mm = **~2 cm**
- Consistent with the resistivity of these RPCs: **10^7 Ω/cm²**

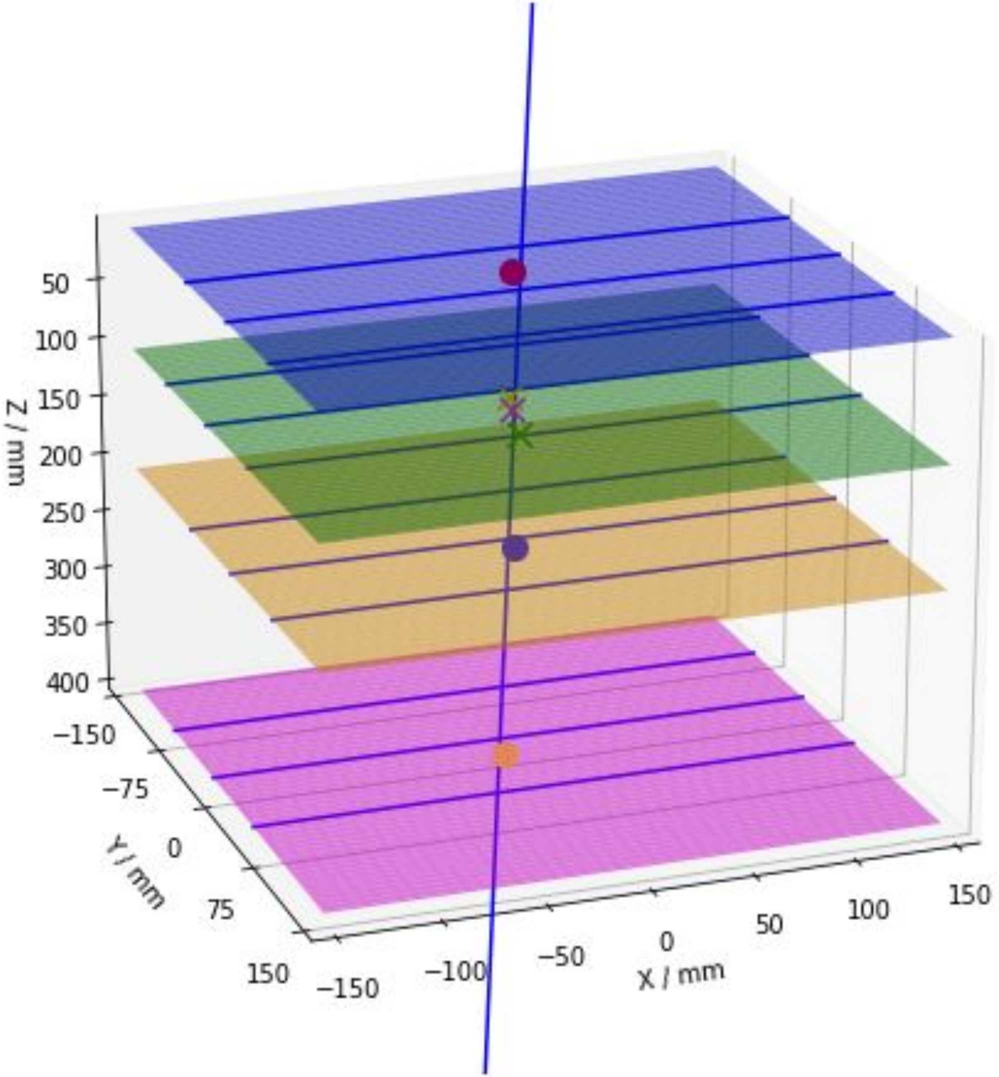


Percentage of Total Cosmic Ray Flux Measured from 0° to 60° Zenith Angle

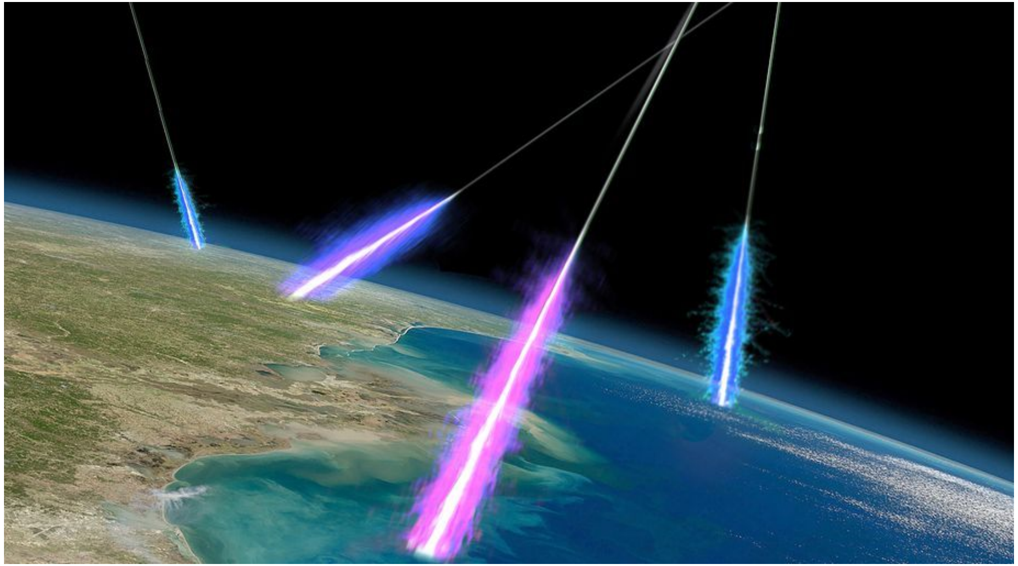
- **Flux Dependence:** The cosmic ray flux varies with zenith angle (θ) as F(θ) ∝cos2(θ)F(θ) ∝ \cos^2(θ)F(θ)∝cos2(θ).
- **Calculating the Fraction of Total Flux:**
    - **Formula:** Fraction = 1 minus $[\cos(60°)]^3$
    - **Calculation:**
        - cos(60°) = 0.5
        - $[\cos(60°)]^3 = (0.5)^3 = 0.125$
        - Fraction = 1 - 0.125 = 0.875
    - **Percentage:** 87.5%

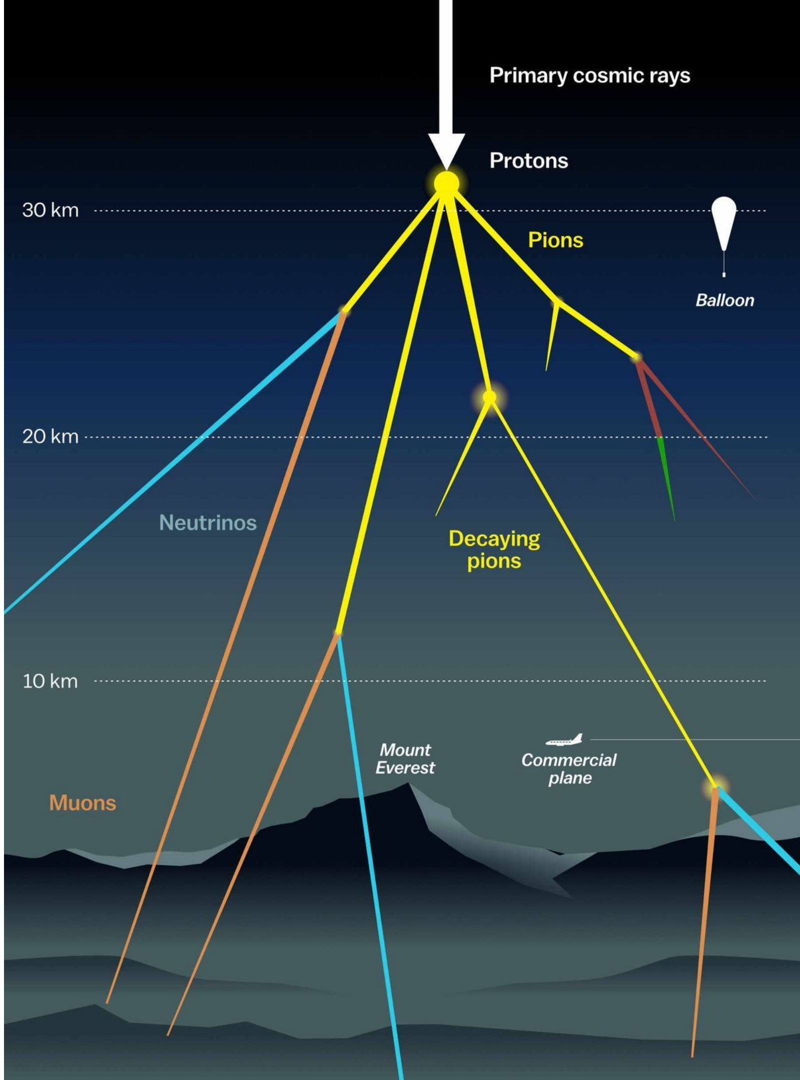
Conclusion: Measuring from 0° to 60° zenith angle captures approximately **87.5%** of the total cosmic ray flux.

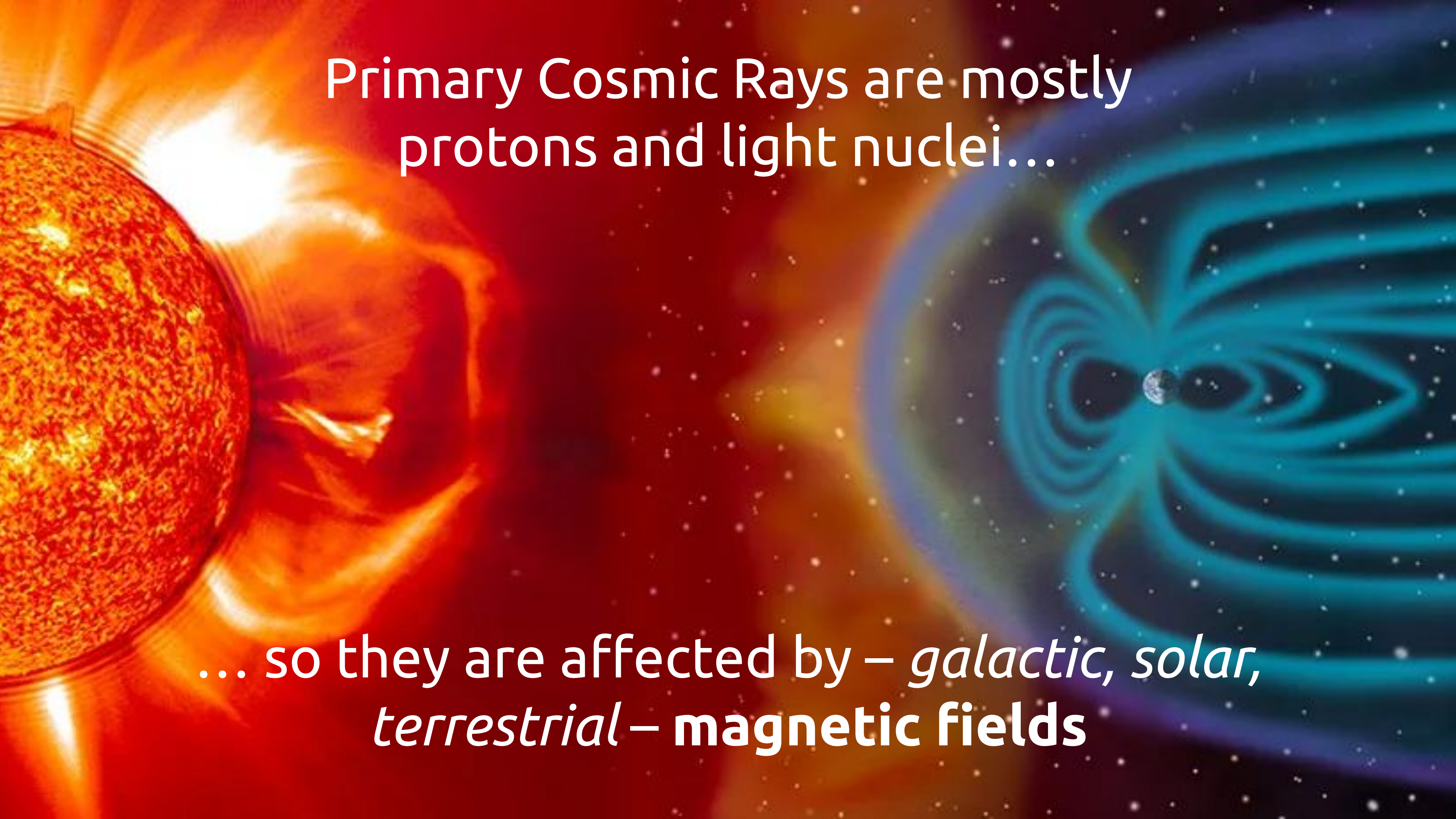
Efficiency calculation



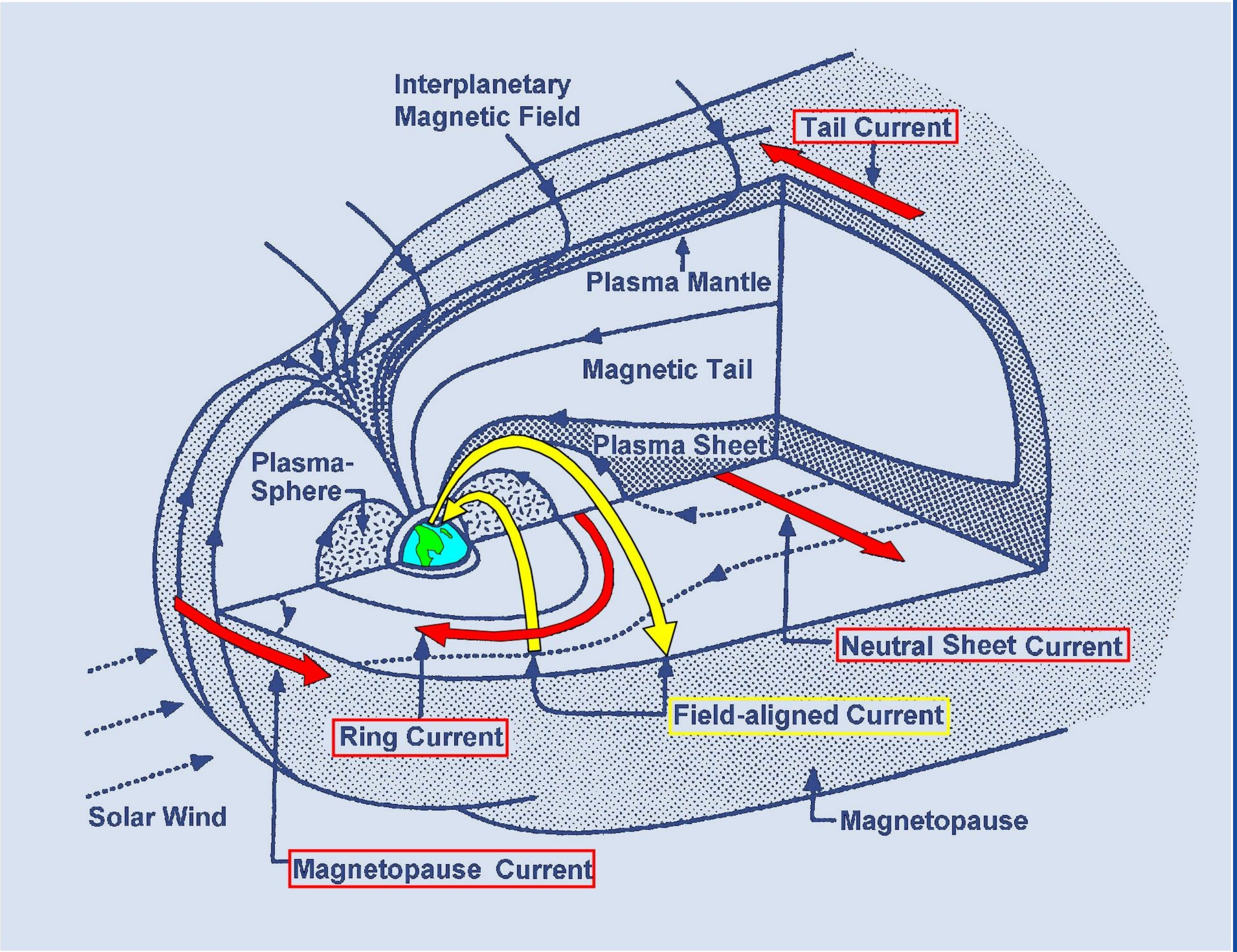
Primary Cosmic Rays
generate
Extensive Air Showers
typically 20-50 km of altitude





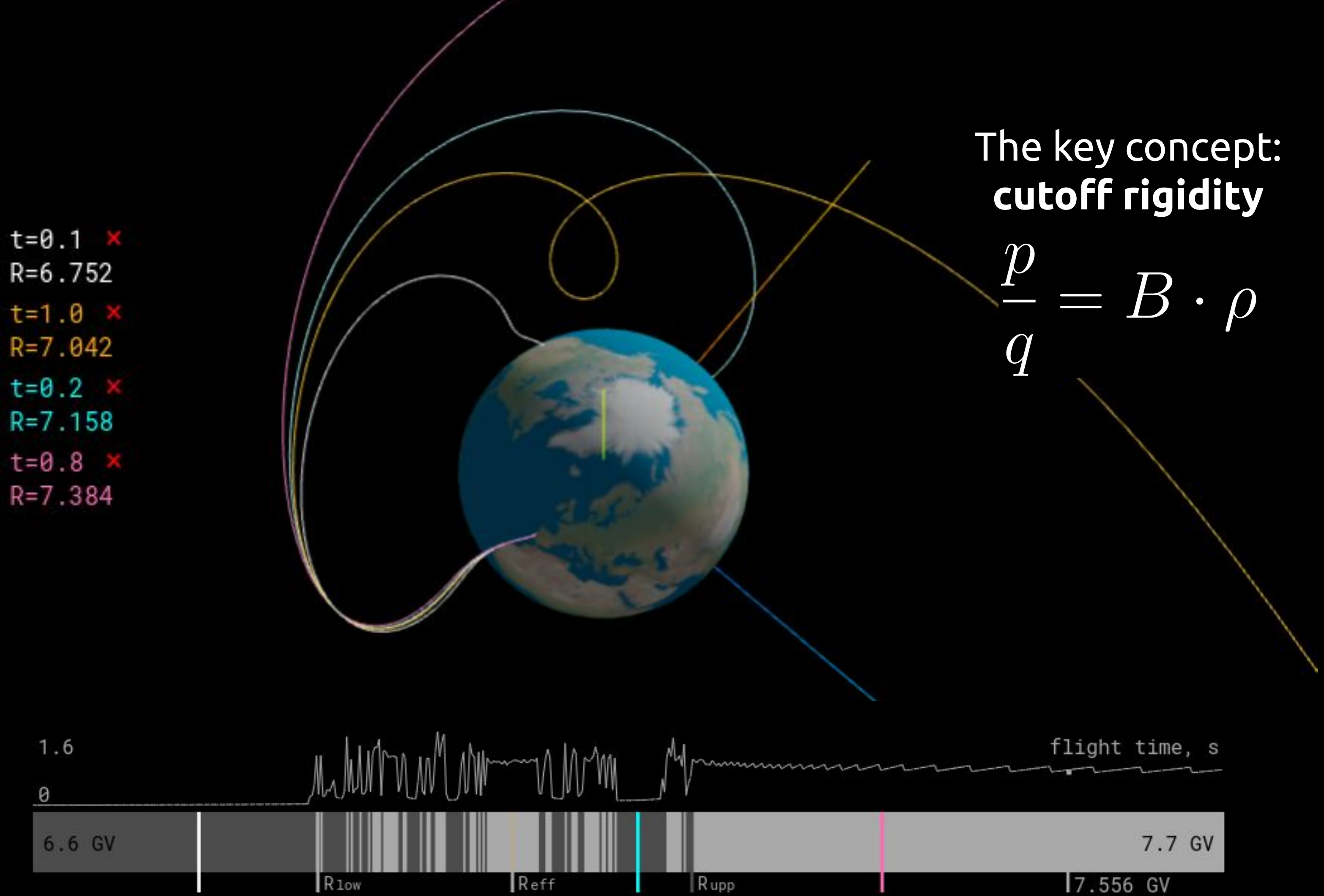

Primary Cosmic Rays are mostly protons and light nuclei…
… so they are affected by – *galactic, solar, terrestrial* – **magnetic fields**

Which are not simple at all!



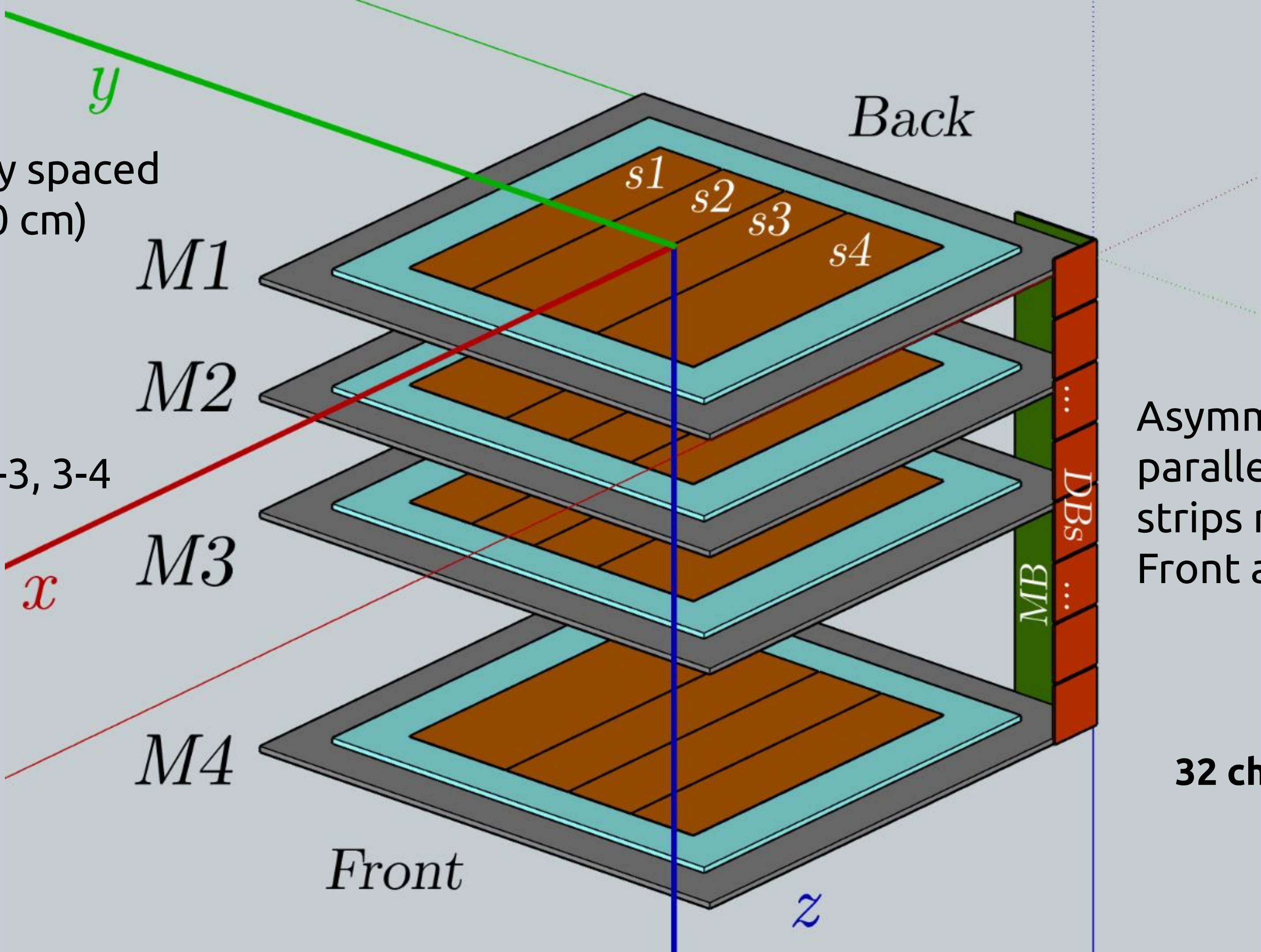
The key concept:
cutoff rigidity

$$\frac{p}{q} = B \cdot \rho$$



Not evenly spaced
(10 and 20 cm)

Trigger:
1-2, 1-3, 2-3, 3-4

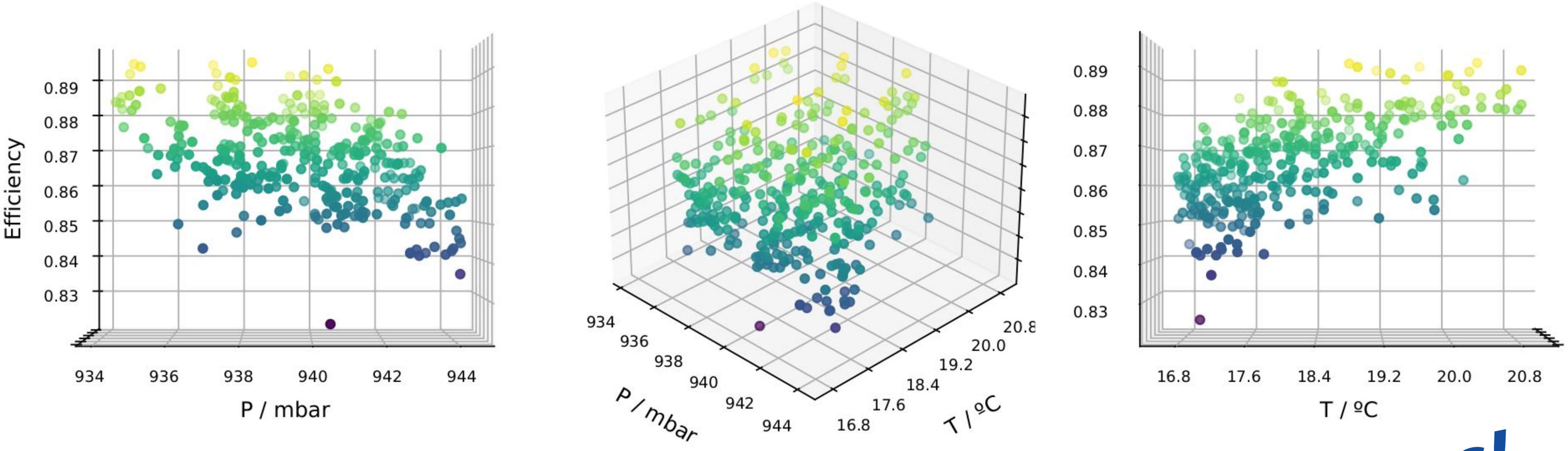


Asymmetric parallel **Cu** strips read in Front and Back

32 channels

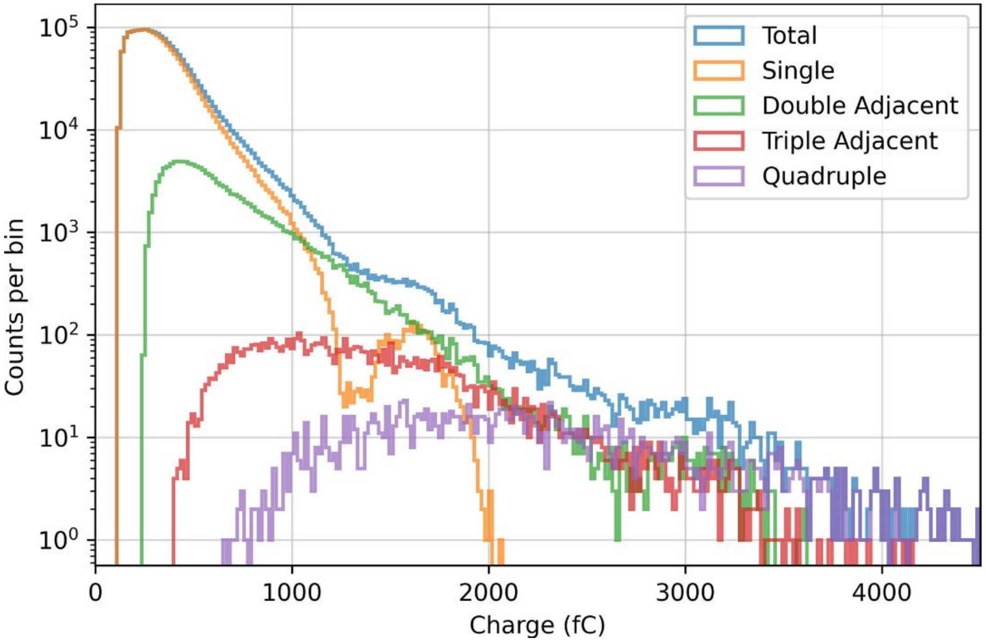
using the fourth plane

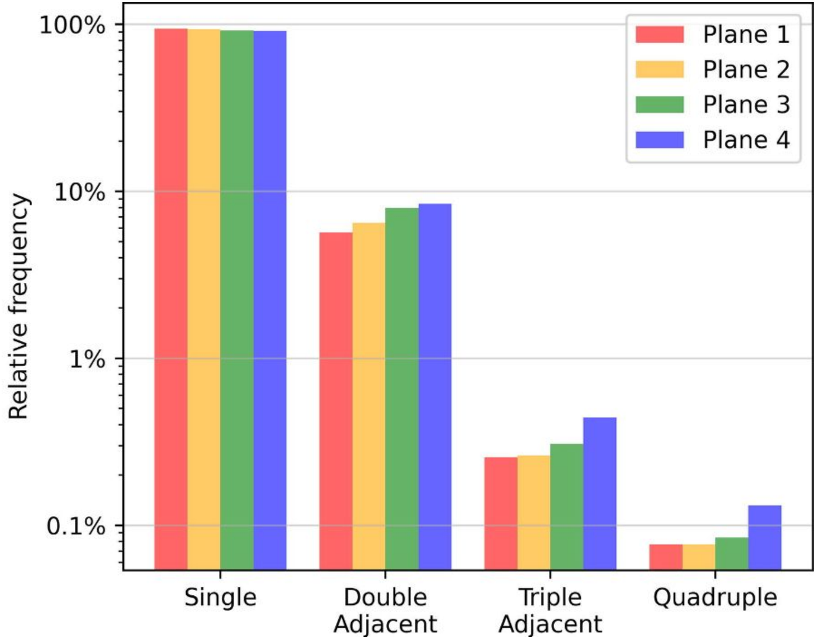
Efficiency: allows to correct for **Temp** and **Pres...**

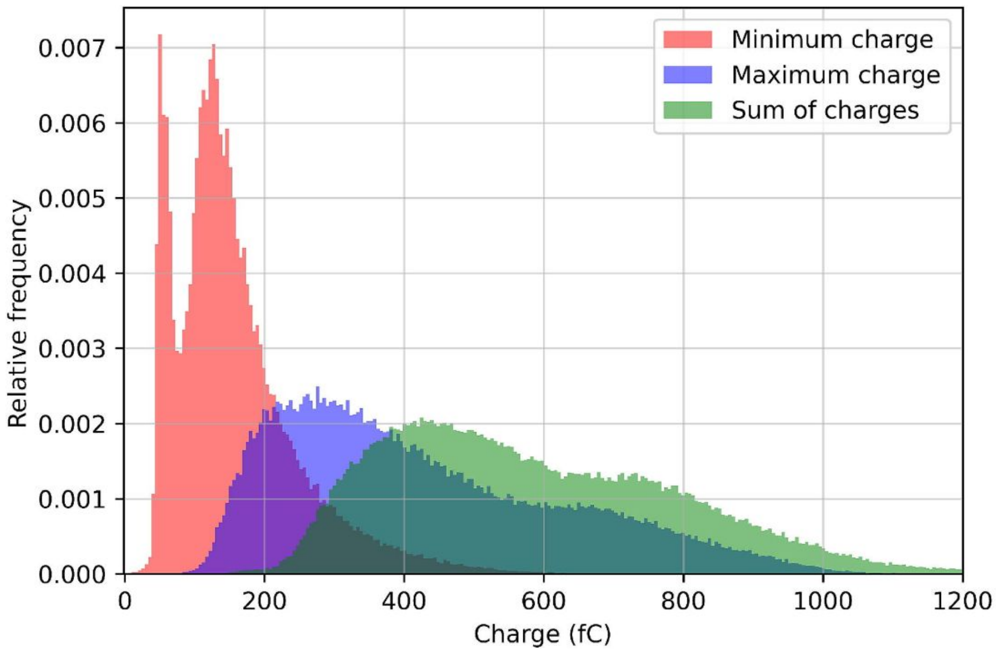


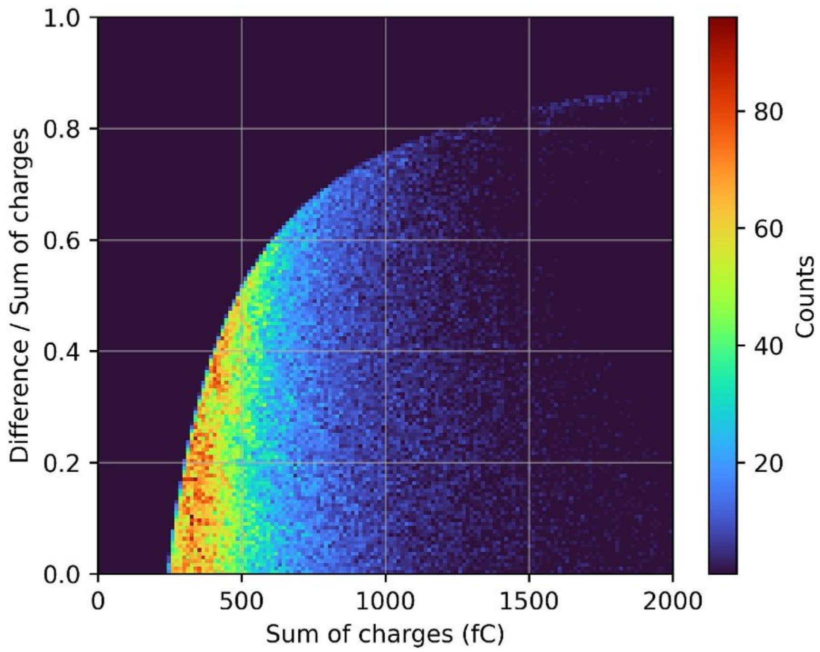
Data from the bot! → **minGO_Madrid_bot**

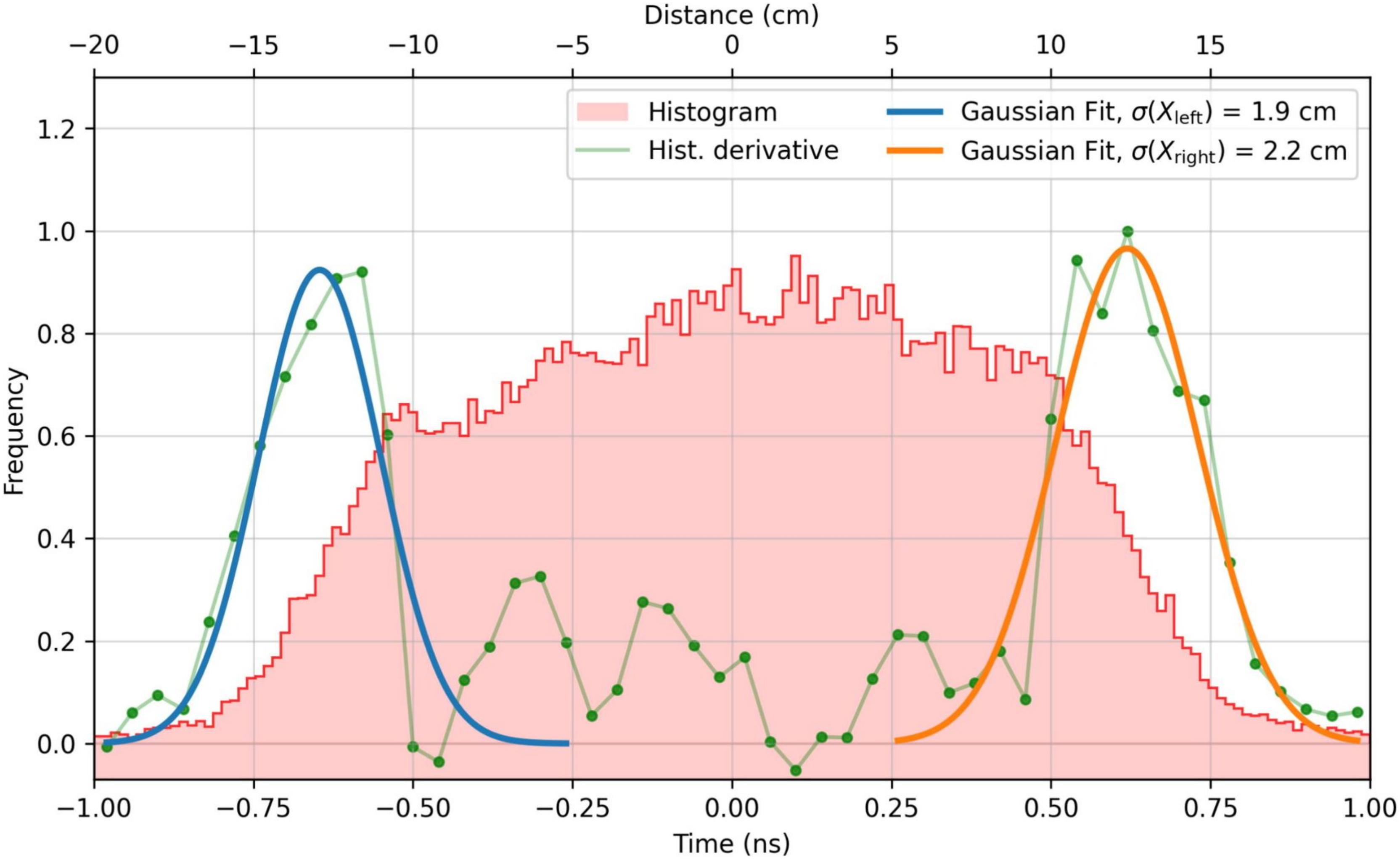
Work in progress!

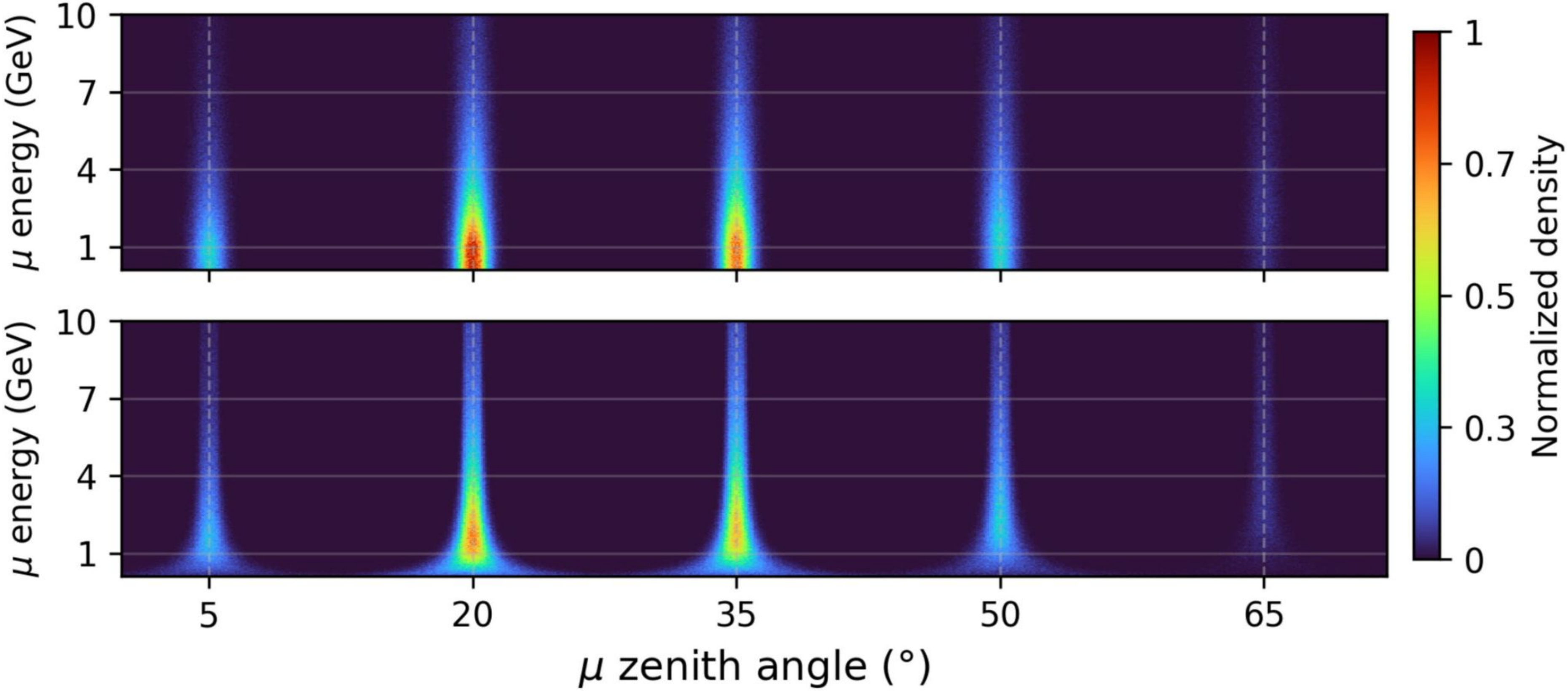

Total
Single
Double Adjacent
Triple Adjacent
Quadruple
Counts per bin
Charge (fC)
10^0
10^1
10^2
10^3
10^4
10^5
0
1000
2000
3000
4000


Plane 1
Plane 2
Plane 3
Plane 4
Relative frequency
100%
10%
1%
0.1%
Single
Double Adjacent
Triple Adjacent
Quadruple


Minimum charge
Maximum charge
Sum of charges
Relative frequency
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0.000
0
200
400
600
800
1000
1200
Charge (fC)


Difference / Sum of charges
1.0
0.8
0.6
0.4
0.2
0.0
0
500
1000
1500
2000
Sum of charges (fC)
Counts
80
60
40
20


Distance (cm)
−20
−15
−10
−5
0
5
10
15
Histogram
Hist. derivative
Gaussian Fit, $\sigma(X_{\mathrm{left}})$ = 1.9 cm
Gaussian Fit, $\sigma(X_{\mathrm{right}})$ = 2.2 cm
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Frequency
−1.00
−0.75
−0.50
−0.25
0.00
0.25
0.50
0.75
1.00
Time (ns)

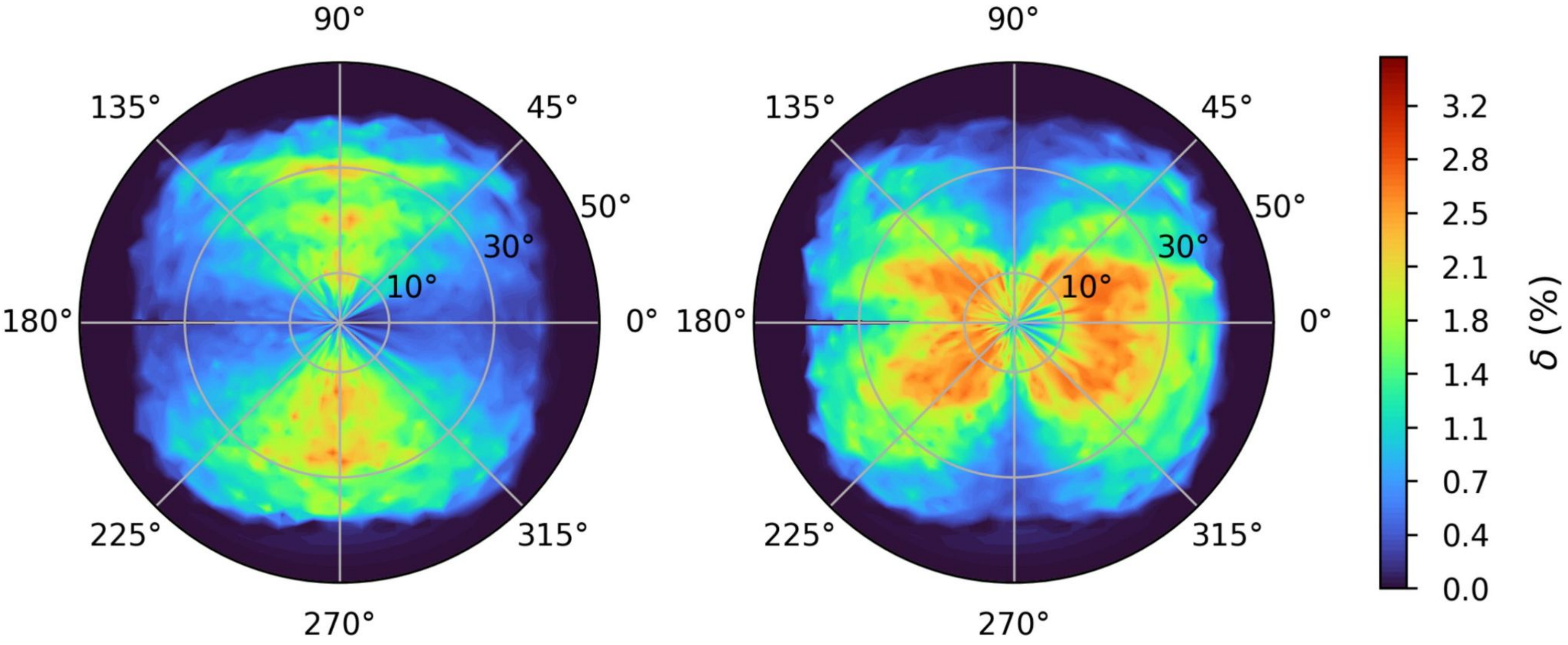

μ energy (GeV)
10
7
4
1
μ energy (GeV)
10
7
4
1
5
20
35
50
65
μ zenith angle (°)
1
0.7
0.5
0.3
0
Normalized density

For the miniTRASGO in Madrid during the observations reported in the present study, $\eta_P = -0.215 \pm 0.038\ \%/\ \mathrm{mbar}$.

$$\ln\left(\frac{I}{I_0}\right)\cdot 100\ \% = -\eta_P \cdot (P - P_0) \Rightarrow \tag{8}$$

$$I_{\mathrm{corr}} = I_{\mathrm{meas}} \cdot \exp\left(\frac{-\eta_P}{100\ \%} \cdot \Delta P\right)$$

Angular uncertainty in the celestial sphere



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