Auger Prime and MARTA

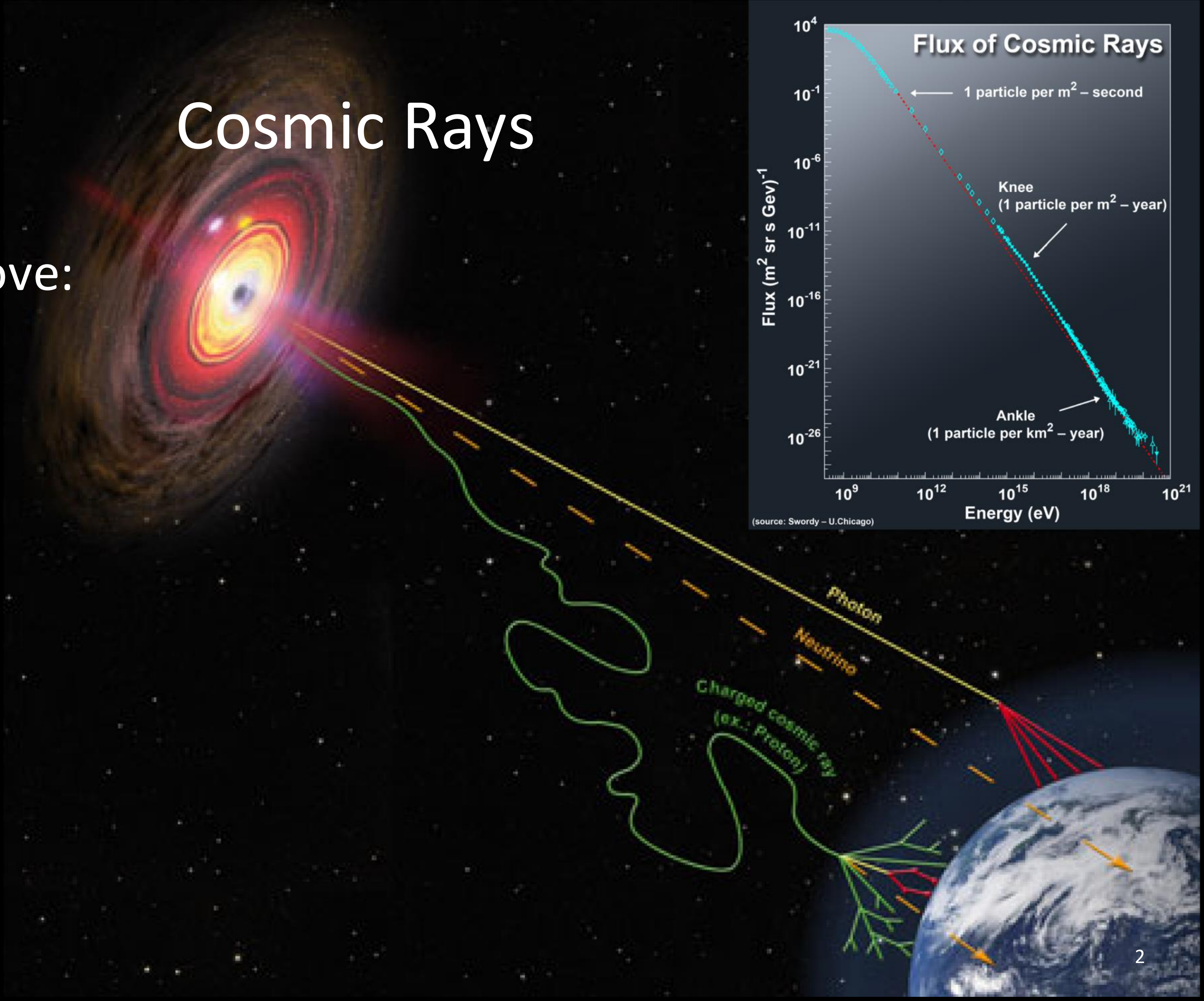
Pierre Auger Observatory

Mendoza, Argentina

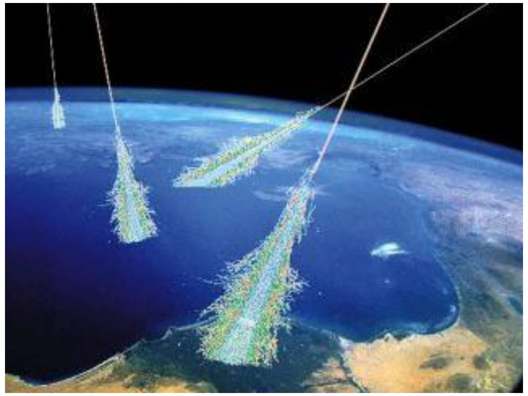
pedro.assis@lip.pt ● LIP, May 2024

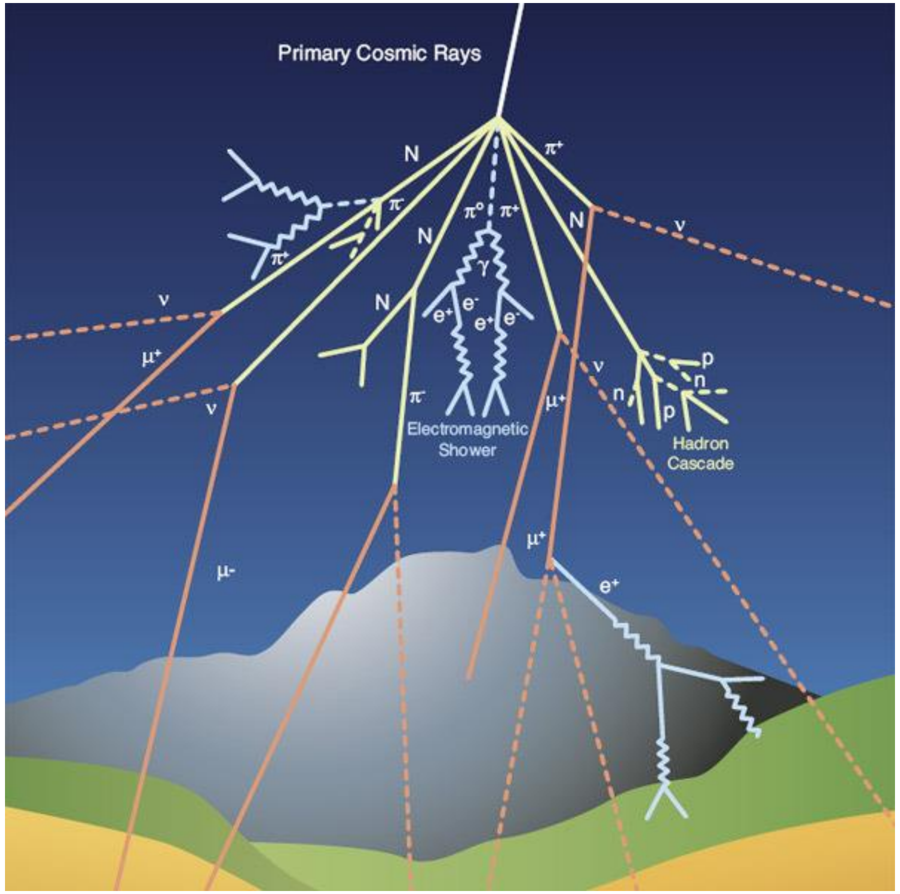
Cosmic Rays

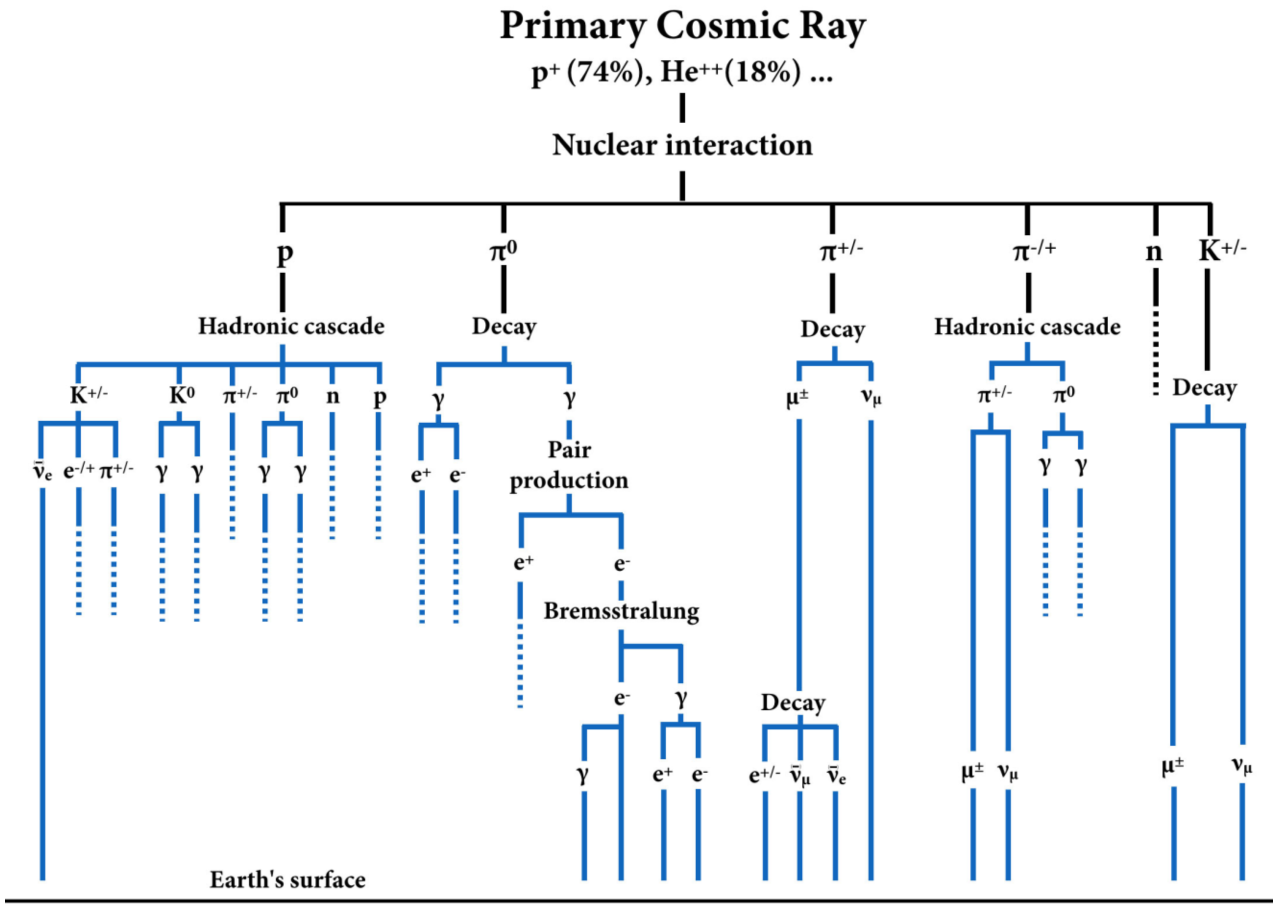
- Particles from above:
- Charged
  - electrons
  - Protons
  - Nuclei
- Neutral
  - Photons
  - neutrinos



Indirect detection of UHECR: Extensive Air Showers







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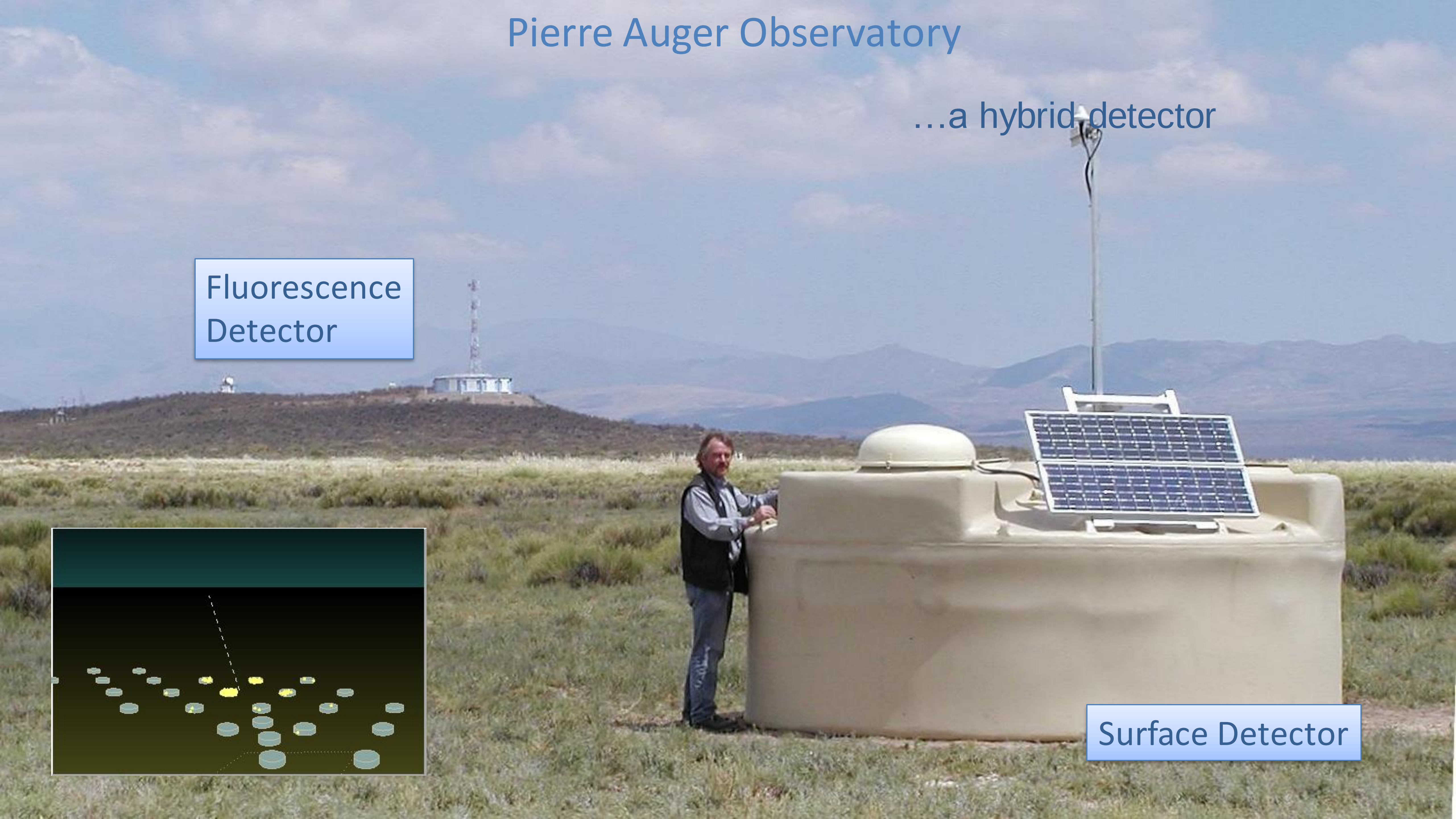
…a hybrid detector



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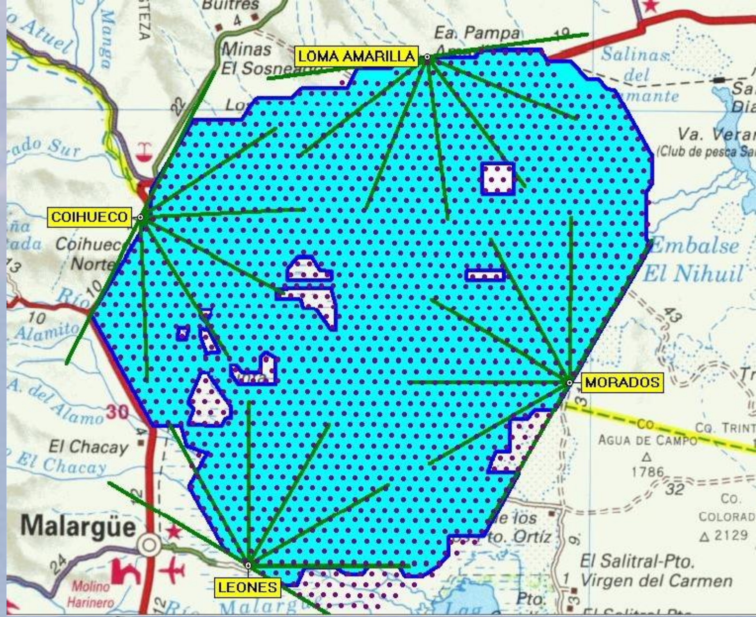
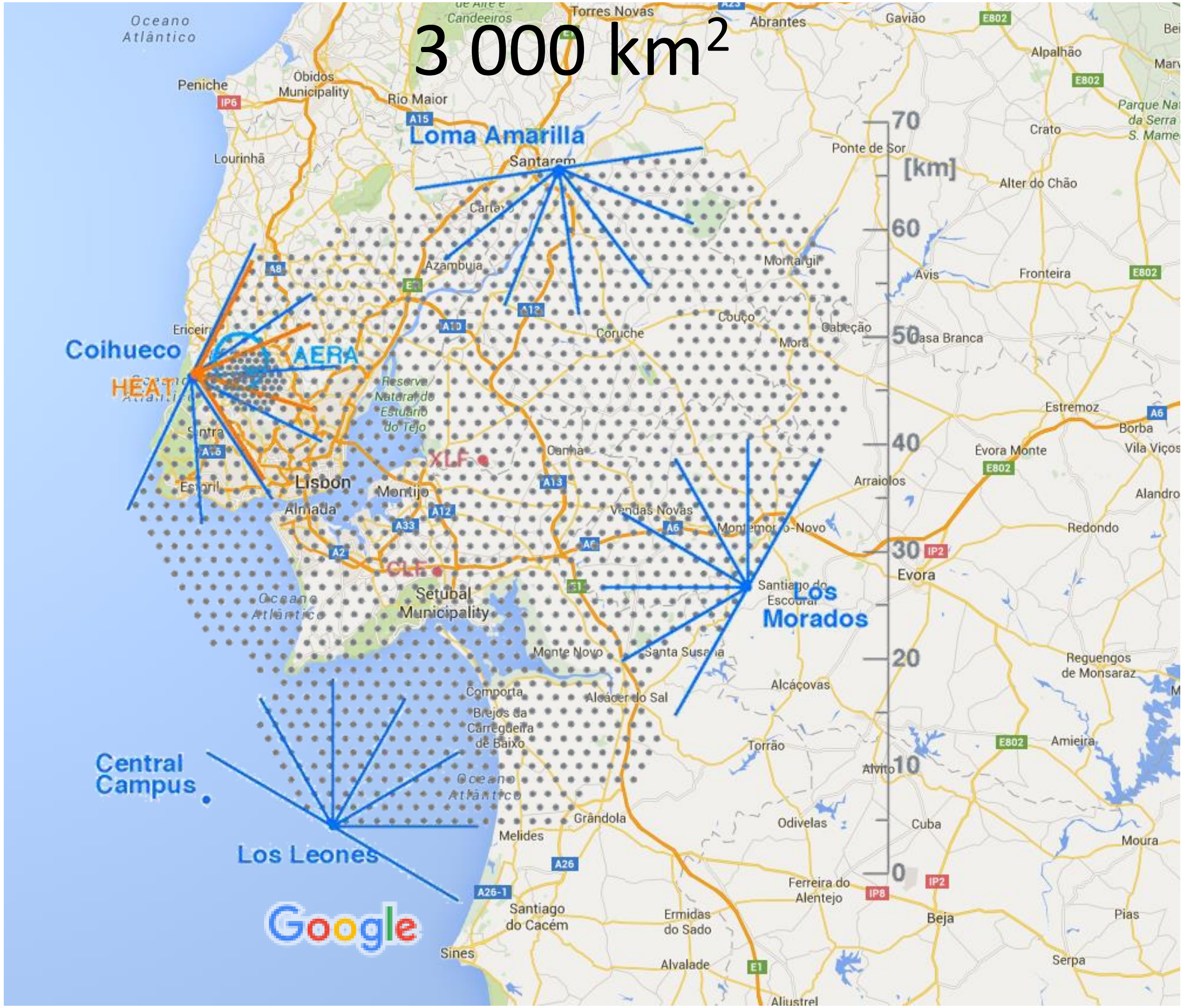


Hybrid Detector
1600 Detectors
(Water tanks – Cherenkov)
In a 1500m grid
Covered area = 3000 km^2
27 (24+3) fluorescence telescope

3 000 km^2



Loma Amarilla
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AERA
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Central Campus
Los Leones
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60
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40
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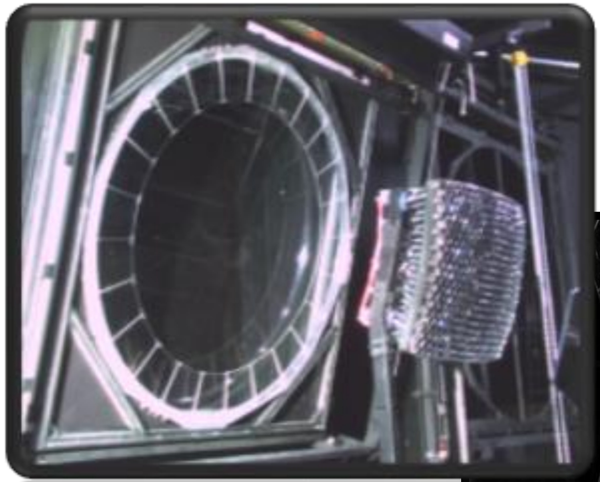
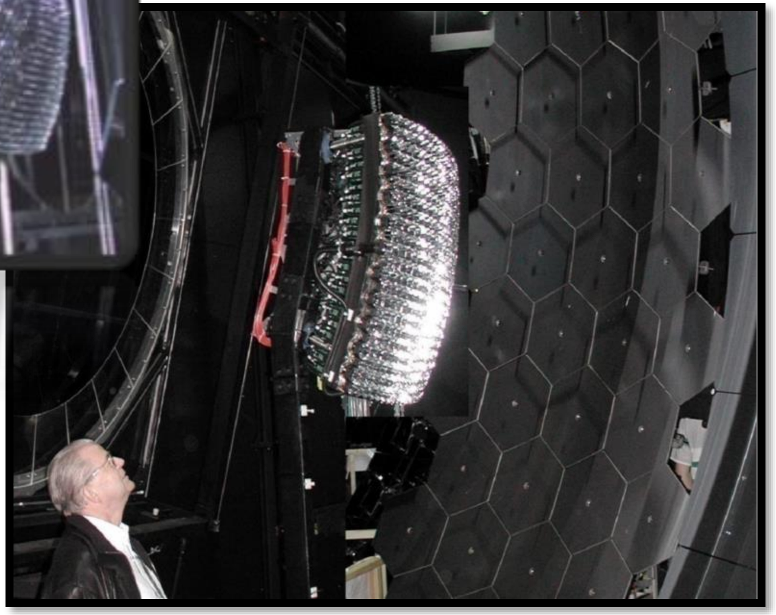
[km]

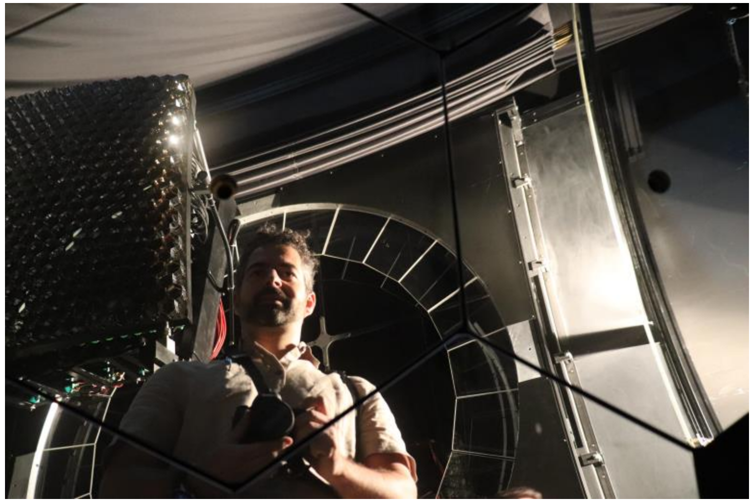
Auger – Fluorescence detector quasi calorimetric measurement



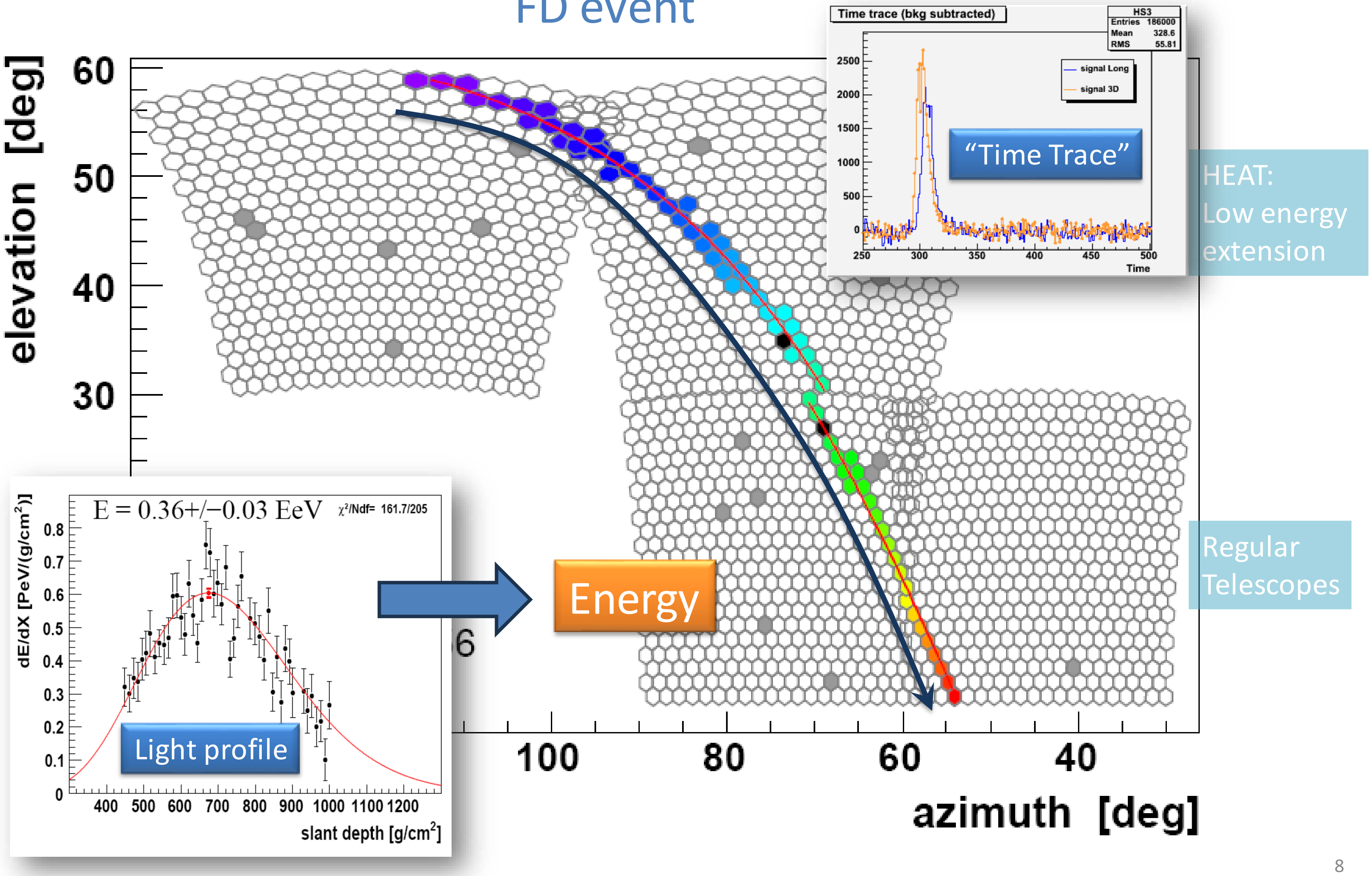


An UV telescope observing the atmosphere
Schimdt Telescope
Camera: 440 PMTs

Particles from shower ionize Nitrogen
Nitrogen de-excitation emit UV light



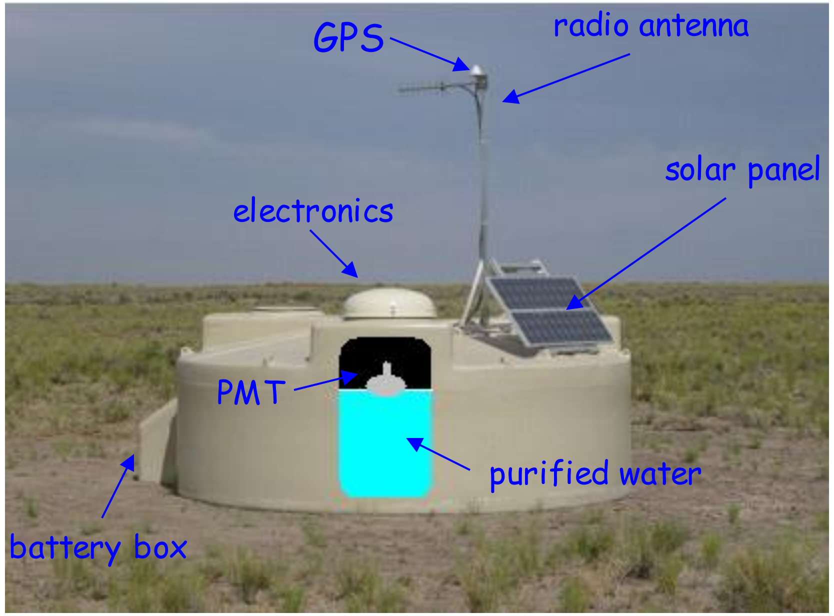
FD event



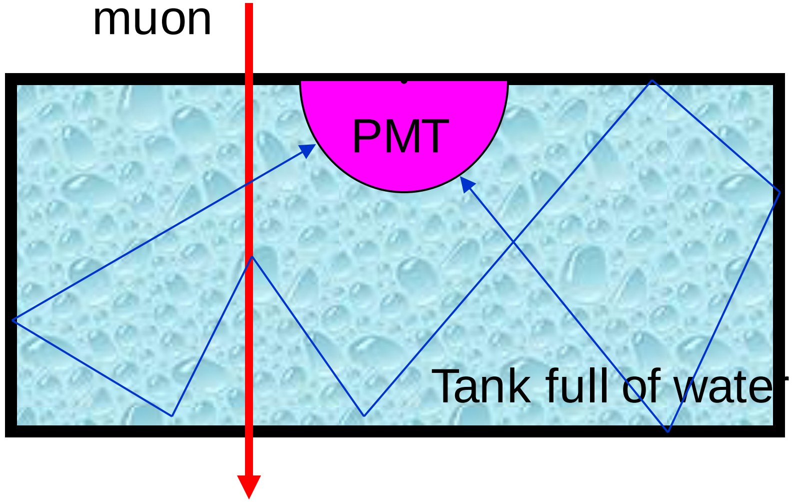
elevation [deg]
60
50
40
30
azimuth [deg]
100
80
60
40
Time trace (bkg subtracted)
HS3
Entries 186000
Mean 328.6
RMS 55.81
signal Long
signal 3D
Time
"Time Trace"
HEAT:
Low energy extension
Regular Telescopes
E = 0.36+/−0.03 EeV
χ²/Ndf= 161.7/205
dE/dX [PeV/(g/cm²)]
slant depth [g/cm²]
Light profile
Energy

Auger – Surface detector
Sample the particle disk

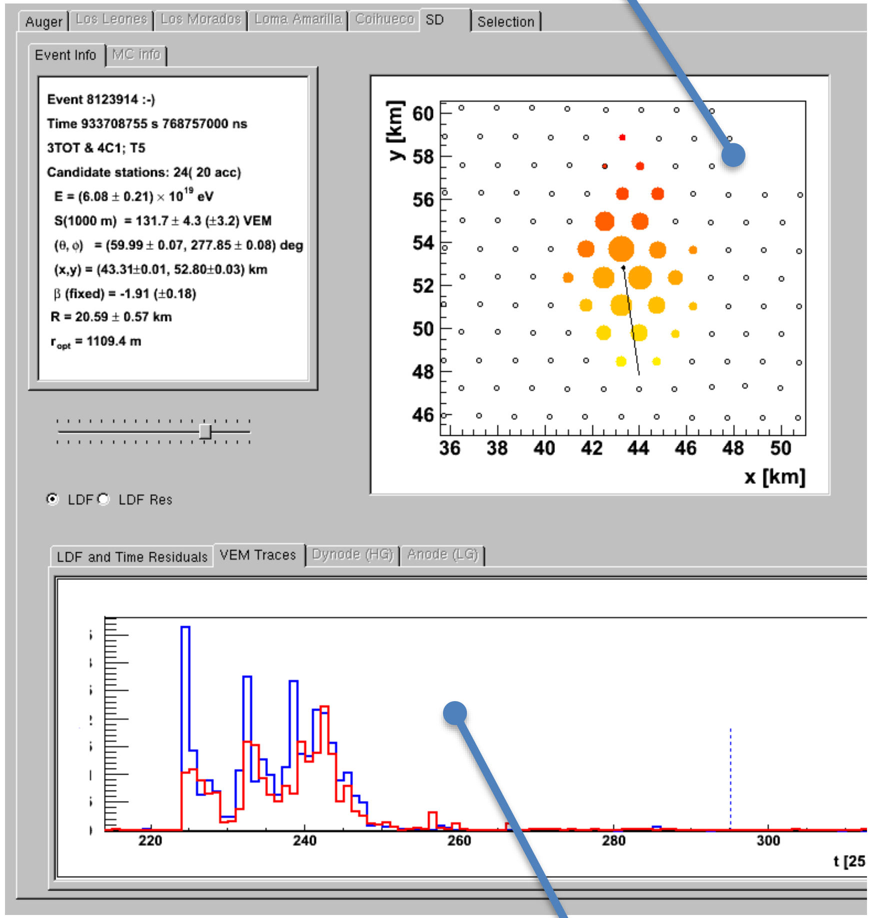
Cherenkov Water Tank Detectors



vertical
muon

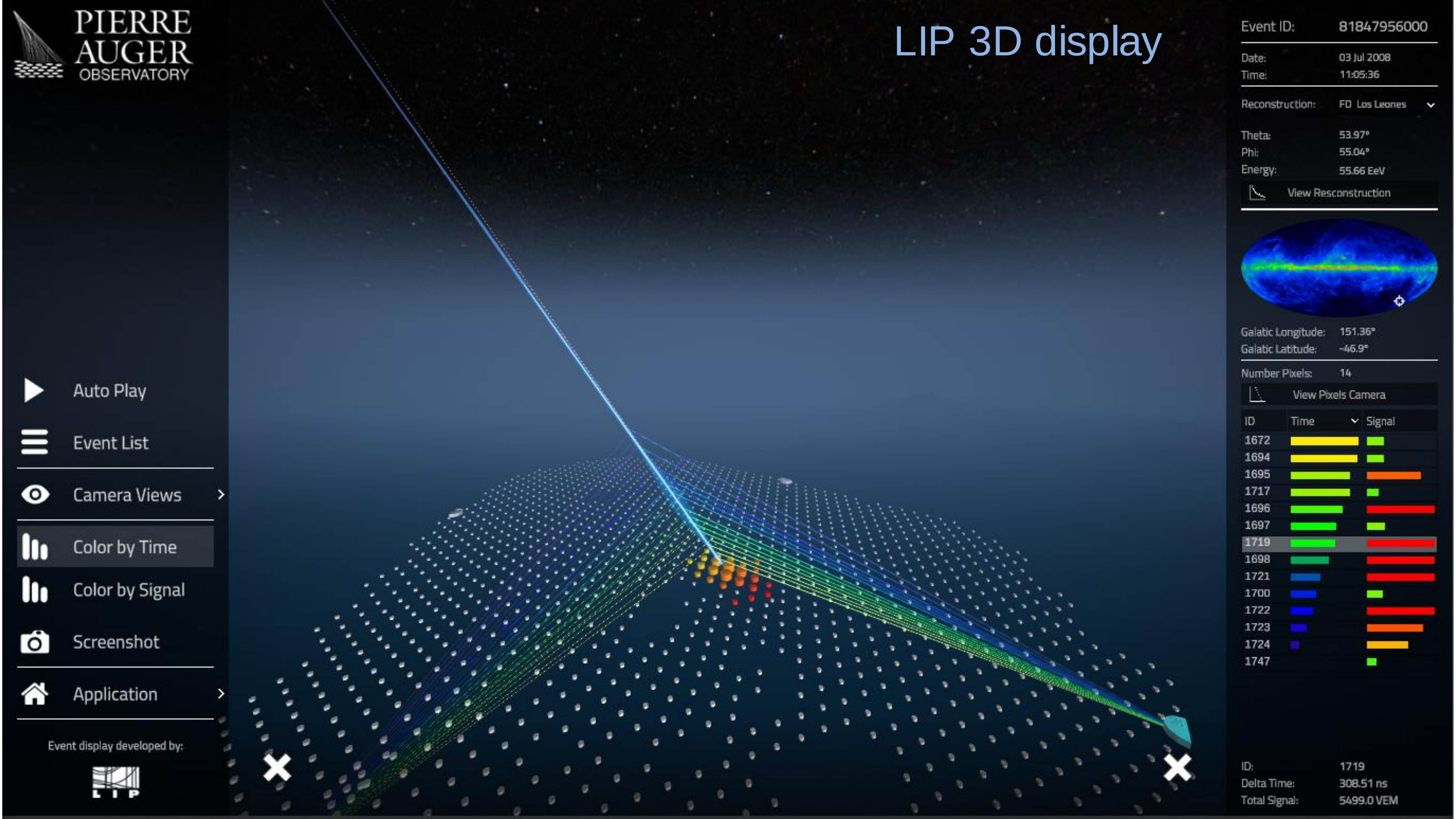


Size: Nº particles in tanks
Color: Time



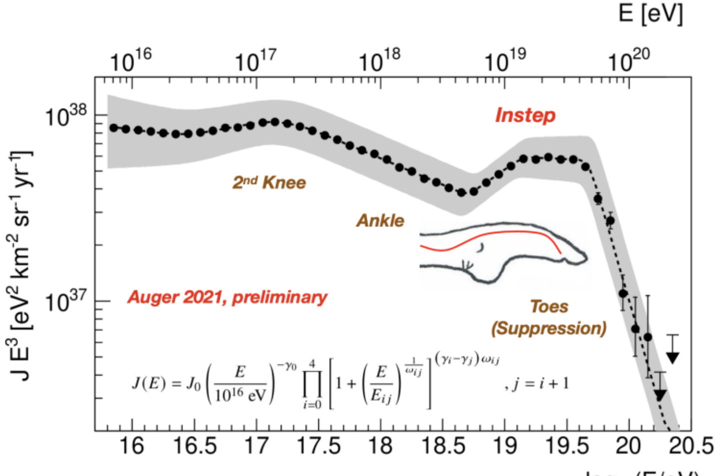
Sinal recorded in 1 Tank

LIP 3D display



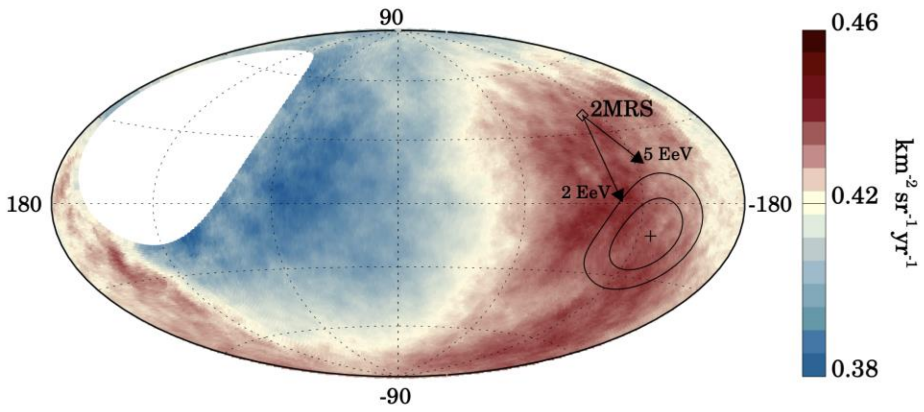
Pierre Auger collaboration results in a nutshell

UHECR energy spectrum features



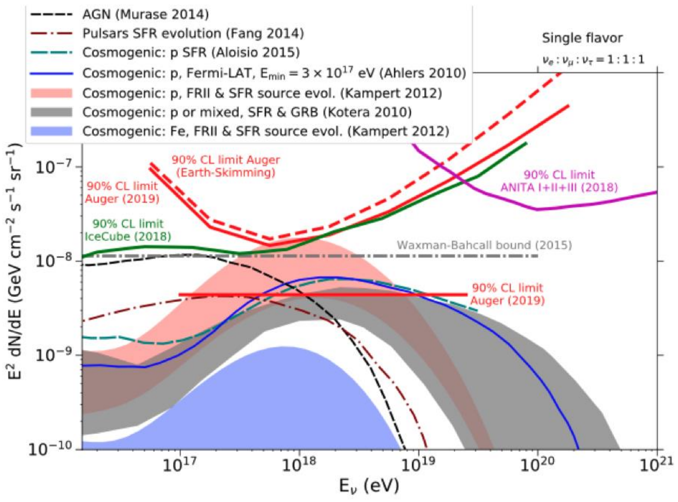
Phys. Rev. Lett. 125 (2020) 121106

UHECR have an extra-galactic origin



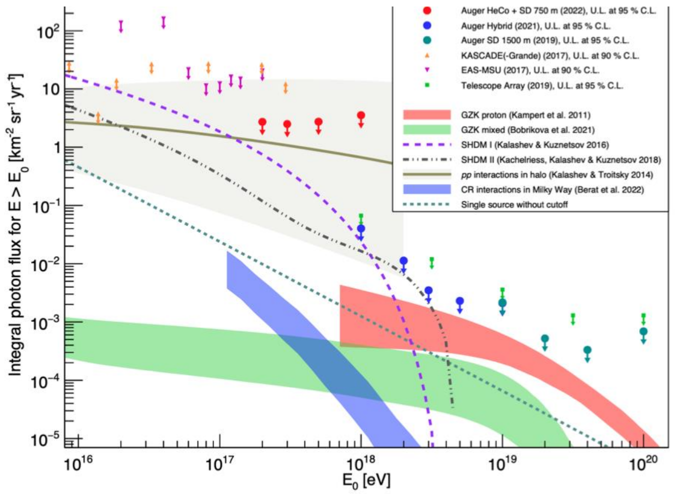
Science 357 (2017) 6537, 1266-1270

Stringent limits on UHE neutrinos



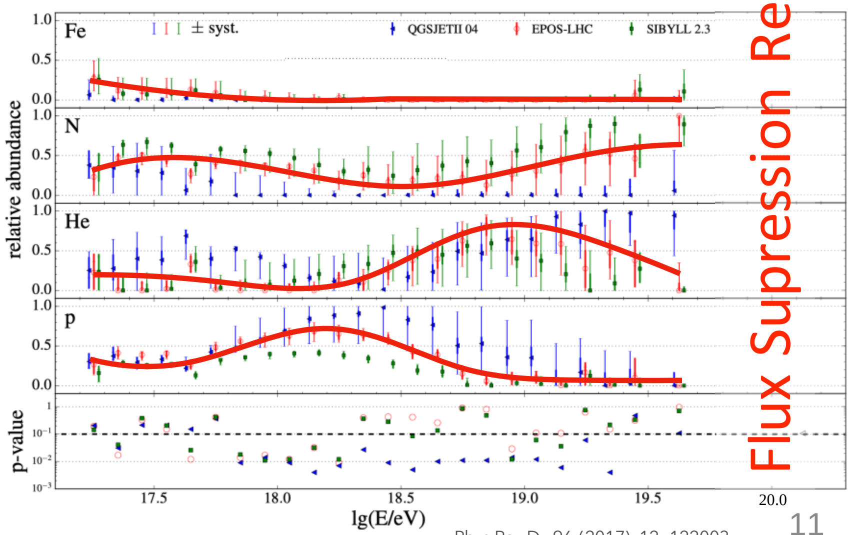
ApJ 902 (2020)105

Stringent limits on UHE photons



Astrophys.J. 933 (2022) 2, 125

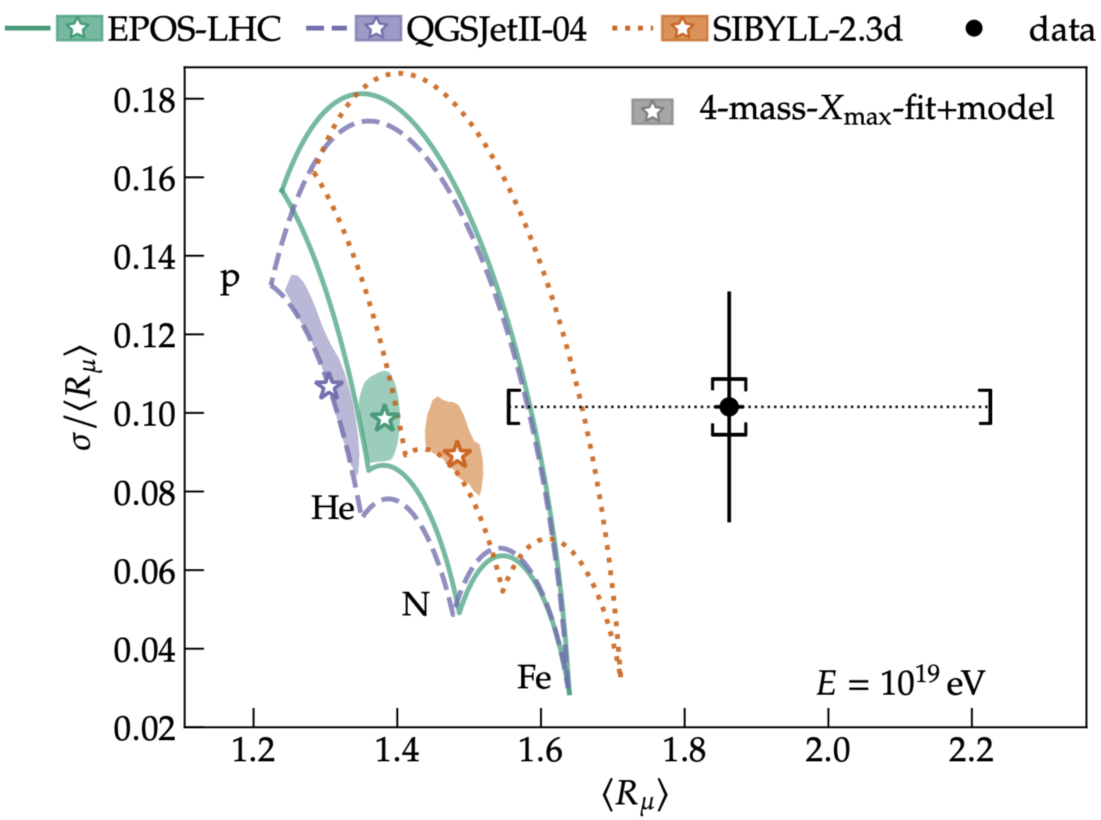
Mass composition evolution towards heavier elements



Flux Supression Region

Phys.Rev.D 96 (2017) 12, 122003

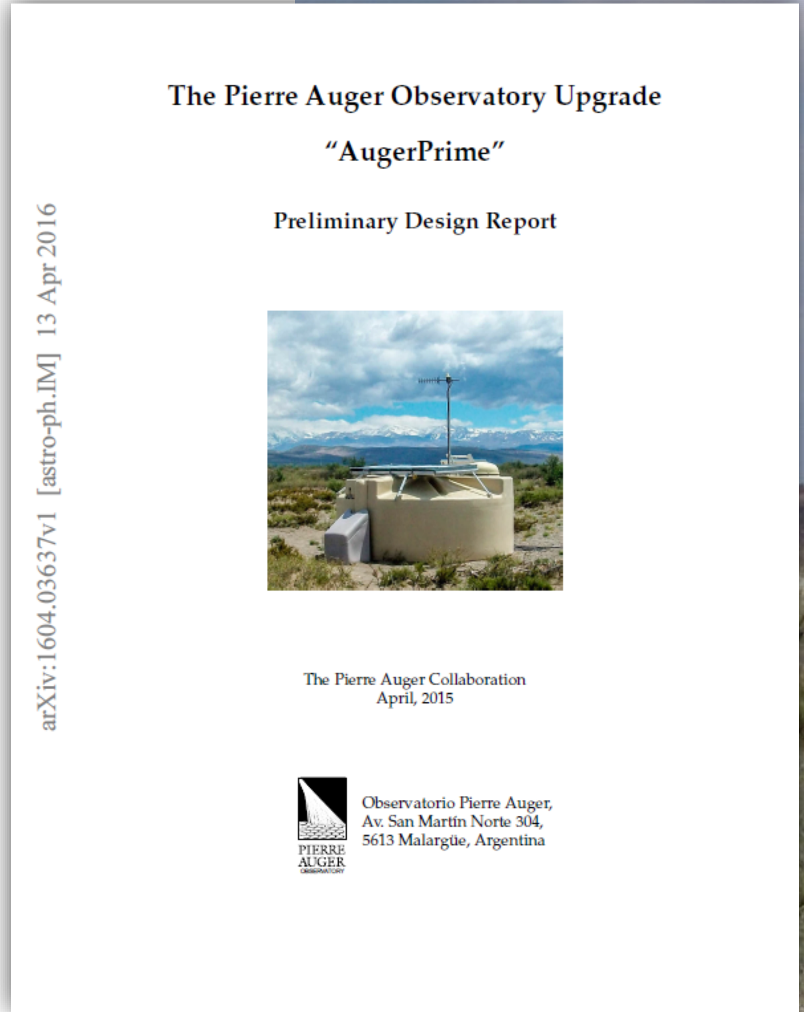
The muon puzzle



- **State-of-the-art** LHC-tuned hadronic interaction models **unable to consistently explain** the muon number measurements
  – Muon number scale off even accounting the huge uncertainties on the energy scale
  – The muon number relative fluctuations are consistent with model expectations

=> Need to increase precision and measure muons

AUGER needs to upgrade: Auger Prime



arXiv:1604.03637v1 [astro-ph.IM] 13 Apr 2016

The Pierre Auger Observatory Upgrade

"AugerPrime"

Preliminary Design Report

The Pierre Auger Collaboration
April, 2015

PIERRE AUGER

Observatorio Pierre Auger,
Av. San Martín Norte 304,
5613 Malargüe, Argentina

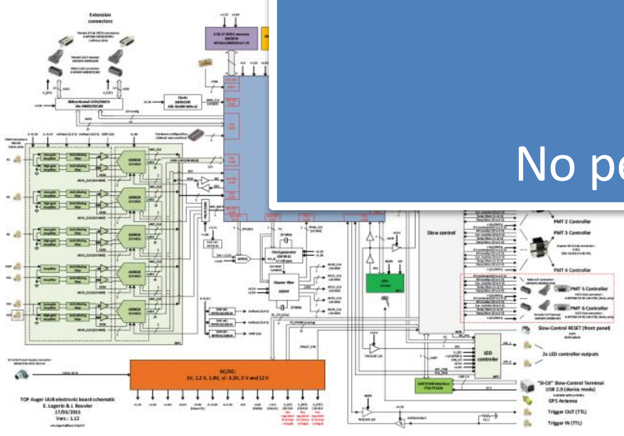
Auger Prime

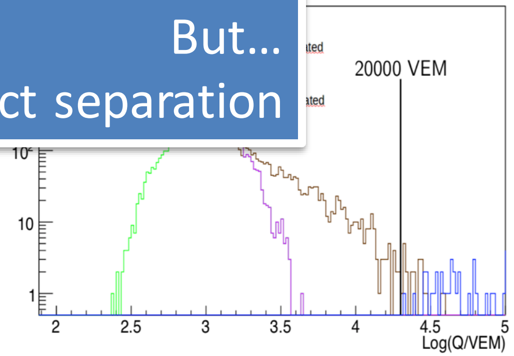
SSD: 3.8 m^2 scintillator on each WCD
UUB: Upgraded electronics
- Increase sampling rate
- support for new detectors

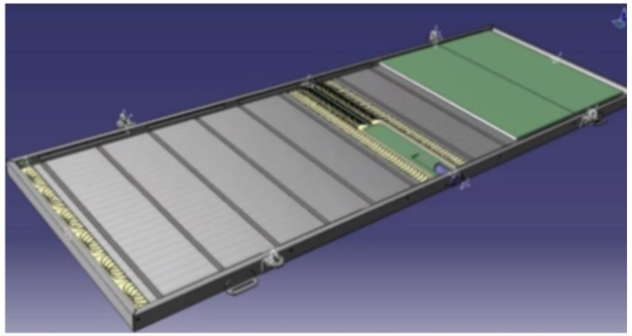
sPMT: A small PMT in center to address saturation
UMD: Buried scintillators to detect muons
RD: Radio antennae

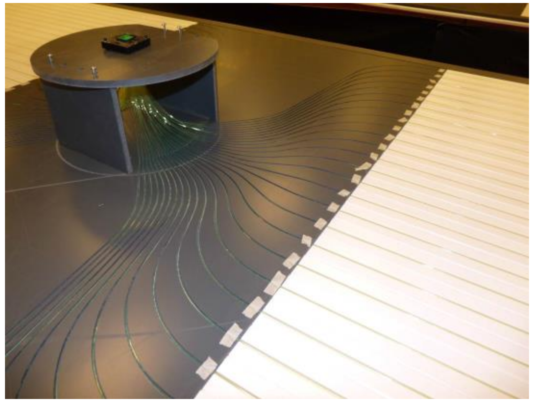
SSD – More sensitive to e.m.
Tank – More sensitive to muons

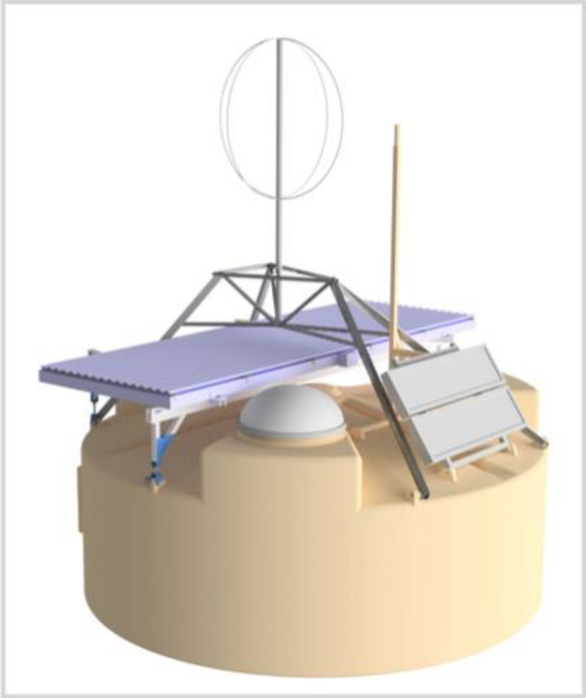
But…
No perfect separation





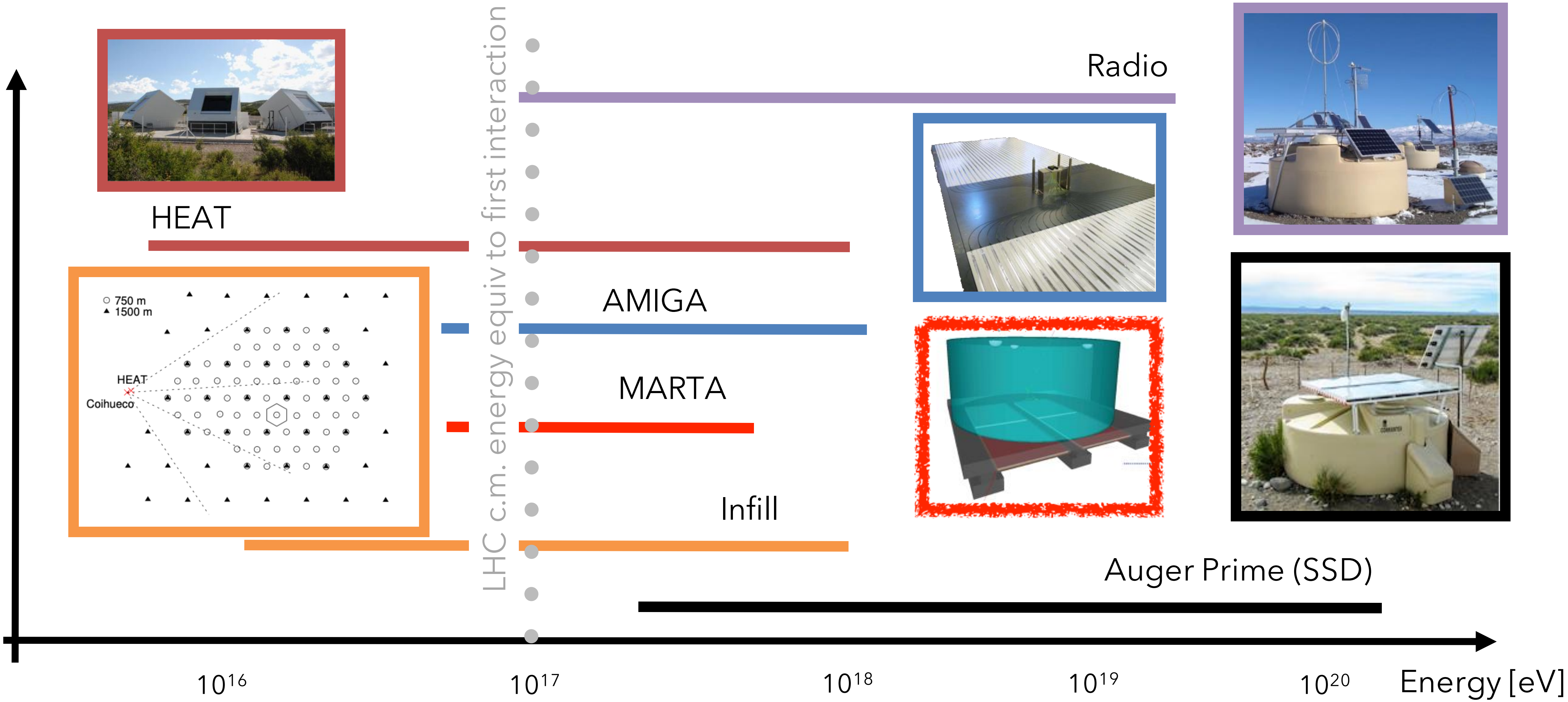






Auger Prime: Multi-hybrid shower events

(A plethora of measurements to fully understand the shower)



GAP2013-020

MARTA
Muon Auger RPC for the Tank Array
Design Report

V1.0

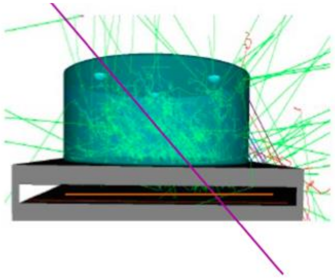
GAP2013-XXX

MARTA
Muon Auger RPC for the Tank Array
1st Progress Report

CBPF - Centro Brasileiro de Pesquisas Físicas, Brazil
FZU - Institute of Physics, Czech Academy of Sciences, Czech Republic
IFSC/USP - Instituto de Física de S. Carlos, Universidade de S. Paulo, Brazil
LIP - Laboratório de Instrumentação e Partículas, Portugal
UNICAMP - Universidade Estadual de Campinas, Brazil
UFRJ - Universidade Federal do Rio de Janeiro, Brazil
Universitá di Roma II, "Tor Vergata", Italy
Universitá di Napoli, "Federico II" and INFN, Napoli
USC - Universidade de Santiago de Compostela, Spain

with the collaboration of
Peter Mazur and Alan Watson

27 May 2013



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THE EUROPEAN PHYSICAL JOURNAL C

CrossMark

Regular Article - Experimental Physics

MARTA: a high-energy cosmic-ray detector concept for high-accuracy muon measurement

P. Abreu[1,2], S. Andringa[1], P. Assis[1,2], A. Blanco[1], V. Barbosa Martins[7], P. Brogueira[2], N. Carolino[1], L. Cazon[1], M. Cerda[3], G. Cernicchiaro[4], R. Colalillo[5], R. Conceição[1,2,a], O. Cunha[1], R. M. de Almeida[10], V. de Souza[7], F. Diogo[1], C. Dobrigkeit[8], J. Espadanal[1], C. Espirito-Santo[1], M. Ferreira[1], P. Ferreira[1], P. Fonte[1], U. Giaccari[6], P. Gonçalves[1,2], F. Guarino[5], O. C. Lippmann[4], L. Lopes[1], R. Luz[1], D. Maurizio[4], F. Marujo[4], P. Mazur[9], L. Mendes[1], A. Pereira[1], Mario Pimenta[1,2,b], R. R. Prado[7], J. Řídký[11], R. Sarmento[1], C. Scarso[3], R. Shellard[4], J. Souza[10], B. Tomé[1,2], P. Trávníček[11], J. Vícha[11], H. Wolters[1], E. Zas[12]

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which lack precision and direct validation. The first measurement of the mean number of muons in inclined ultra-

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[b] e-mail: pimenta@lip.pt

The MARTA (Muon Array With RPCs for Tagging Air Showers) Front-End Acquisition System

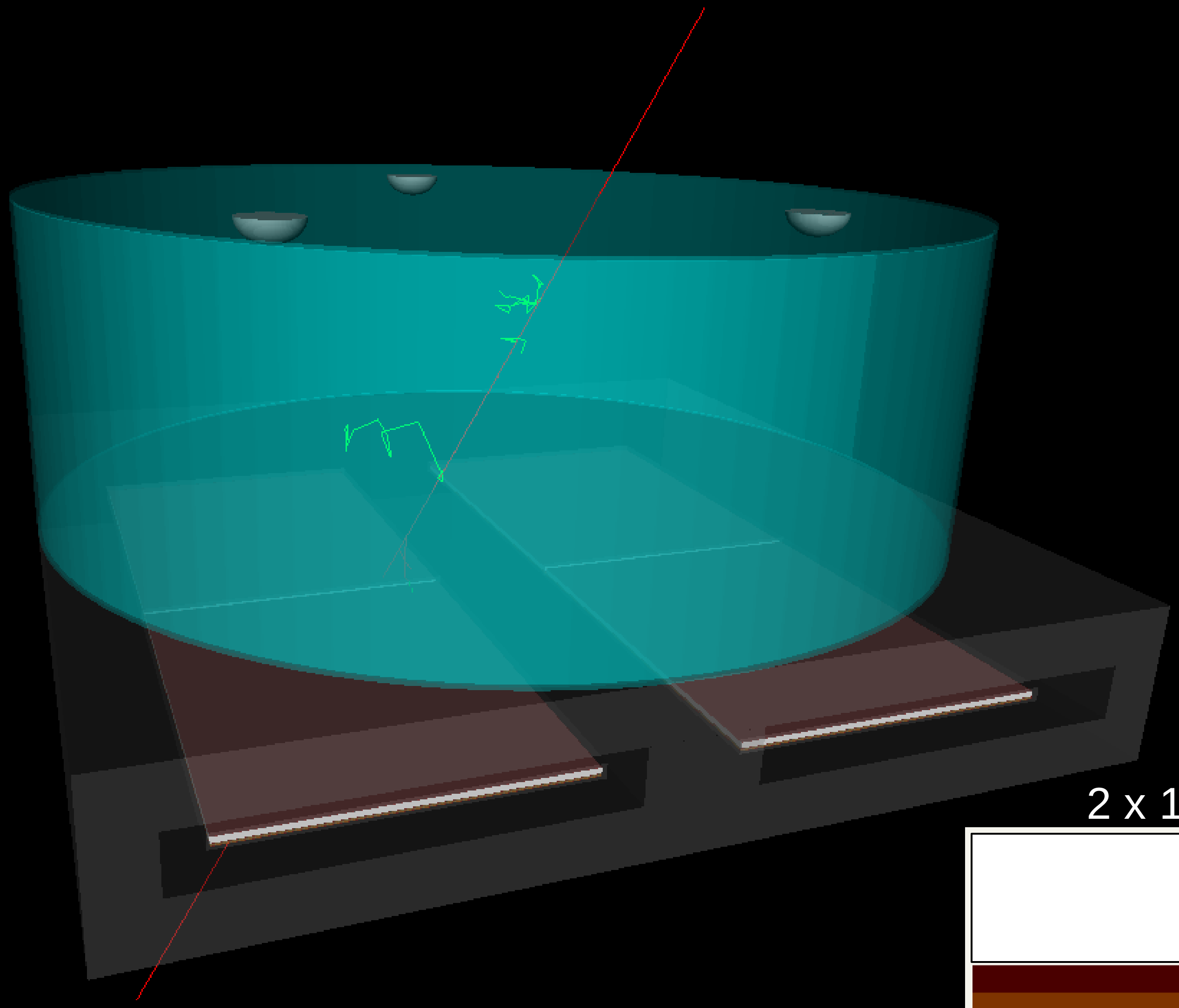
P. Assis, A. Blanco, P. Brogueira, M. Ferreira, and R. Luz

***Abstract*—The design and performance of a new front-end acquisition system is presented in this paper. It was developed to be used with muon array with resistive plate chamber (RPCs) for tagging air showers (MARTA's) RPC detectors that measure the muonic component of cosmic ray air showers. The system is hybrid and capable of counting active channels and performing a charge measurement. It is low power (1.43 W per 64 channels), compact (21.6 x 14.4 cm^2 per 64 channels), stable, and reliable to comply with the strict demands of field operation associated**

I. Introduction

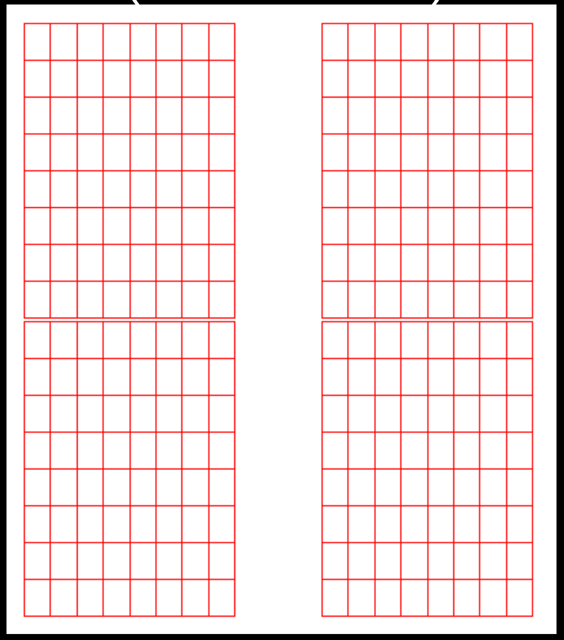
SEVERAL milestones in the understanding of high-energy cosmic rays have been reached over the past decade using detector array experiments, namely, the observation of a suppression in the cosmic ray flux that could be the Greisen–Zatsepin–Kuzmin cutoff [1]. Such experiments (see [2]–[4]) perform an indirect measurement by detecting

Baseline configuration



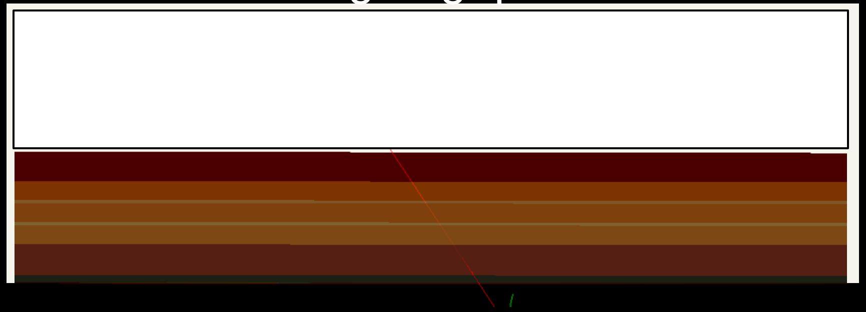
Concrete precast : 20 cm thick (~50 g/cm^2)

4 x (1.5 m x 1.2 m) RPC

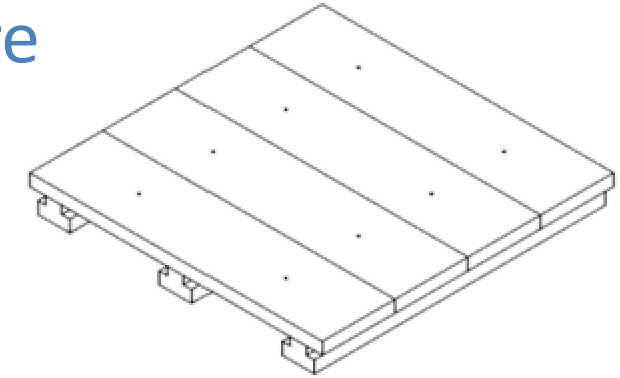


8x8 pads each RPC

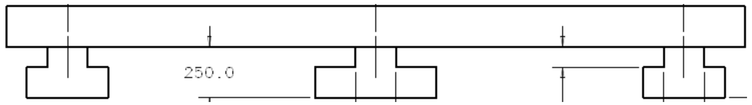
2 x 1 mm gas gap RPC inside Al case



The support structure



Precast structure built at the observatory
Transported to the field
Installed in a couple of hours
(Emptying/Filling the tank
is more time consuming)

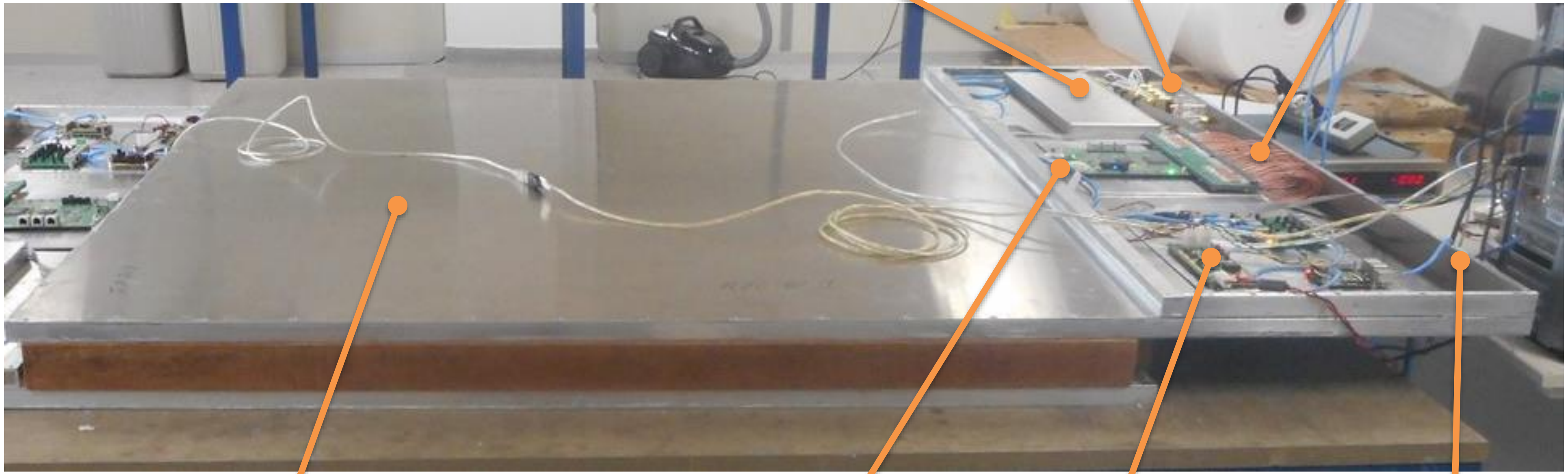


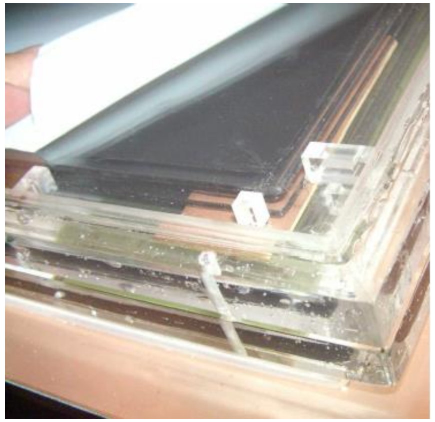
The MARTA module

HV
Controllable by SW

Gas
subsystem

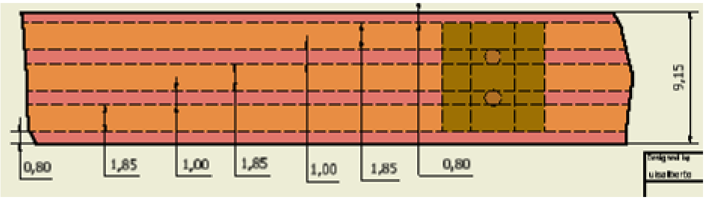
64 coax cables from
readout electrodes





RPC gaseous volume
(inside aluminum enclosure)

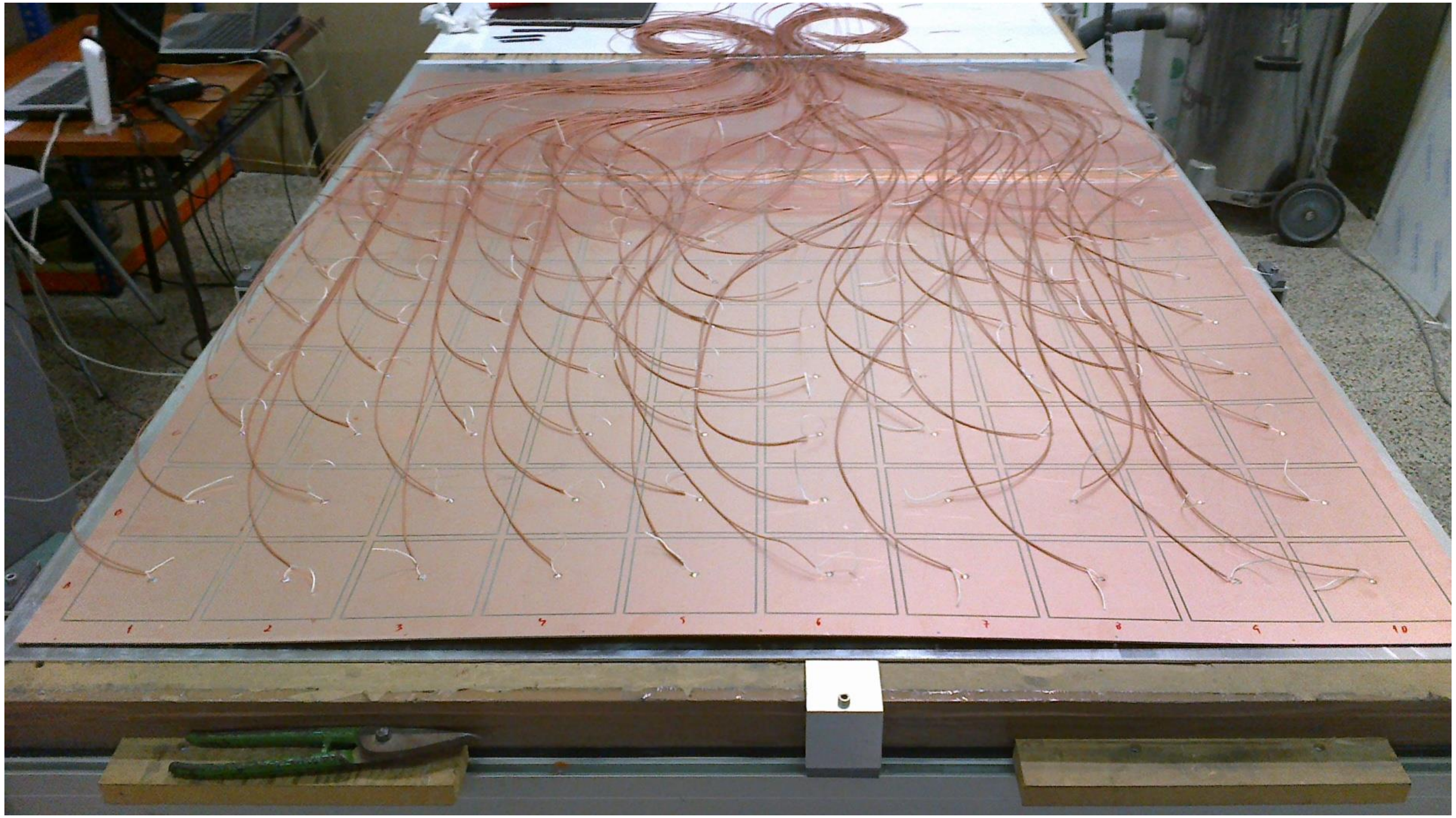
DAQ board

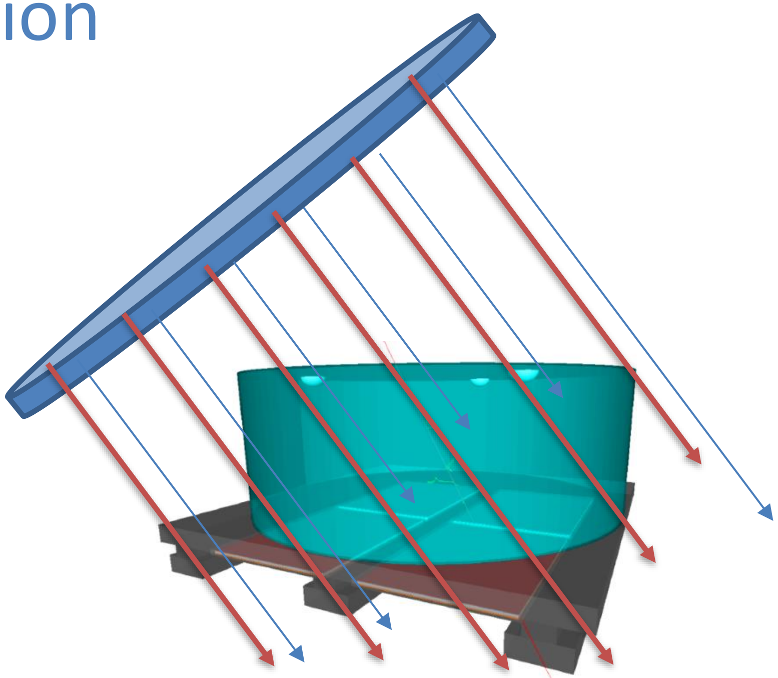


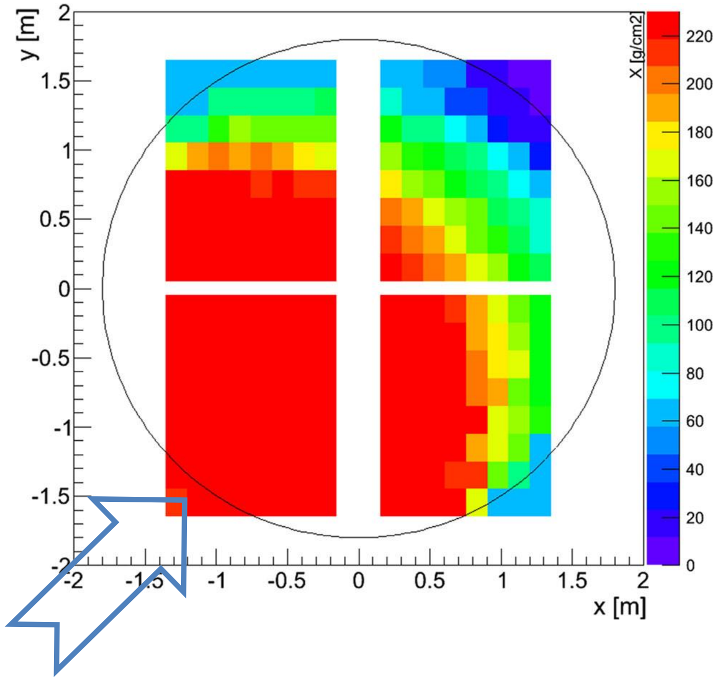
Power and control

DATA
interface

Readout electrodes: Segmentation



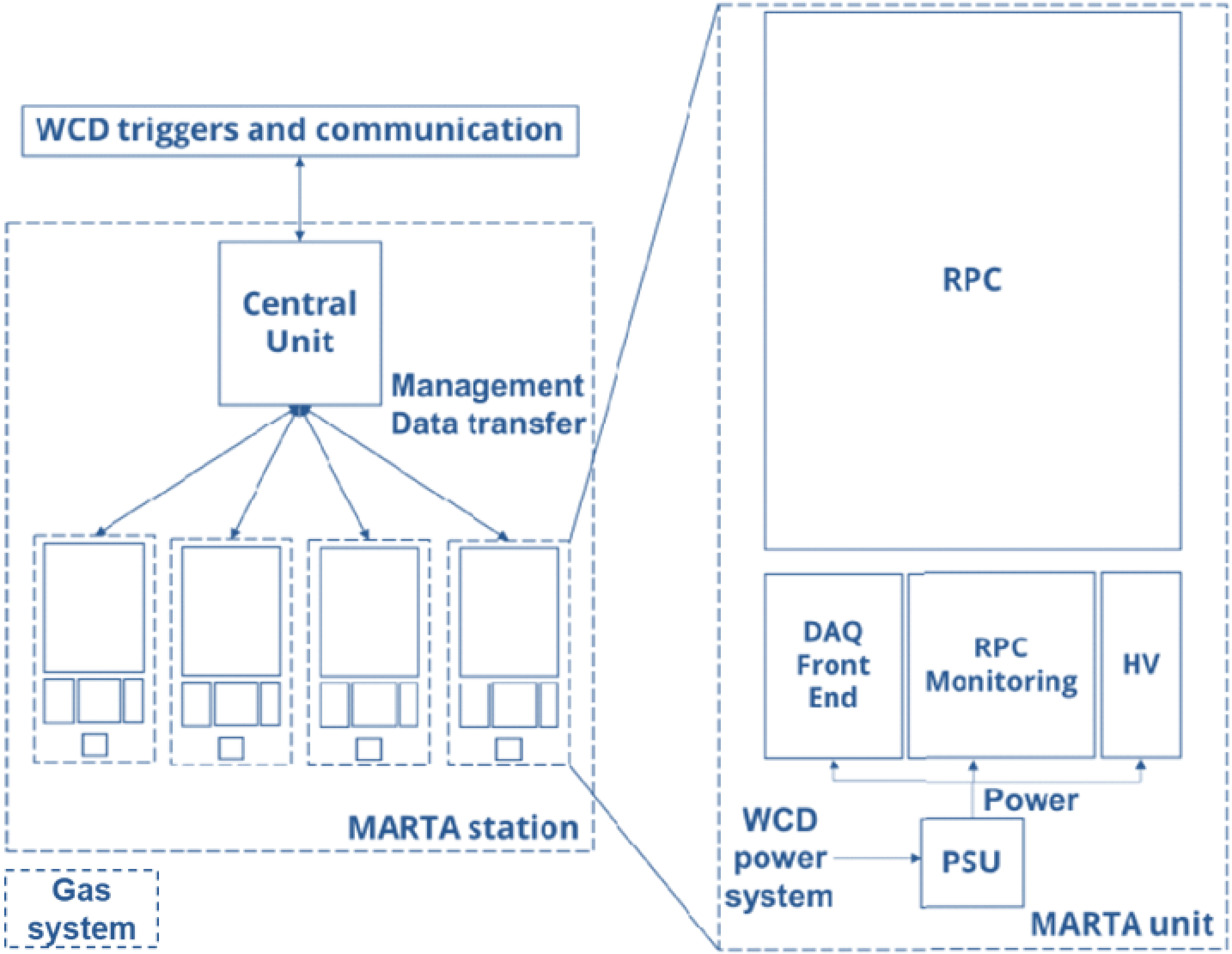




Segmented detector → select regions based on traversed matter:

- Low attenuation → everything
- High attenuation → Muons

The MARTA station



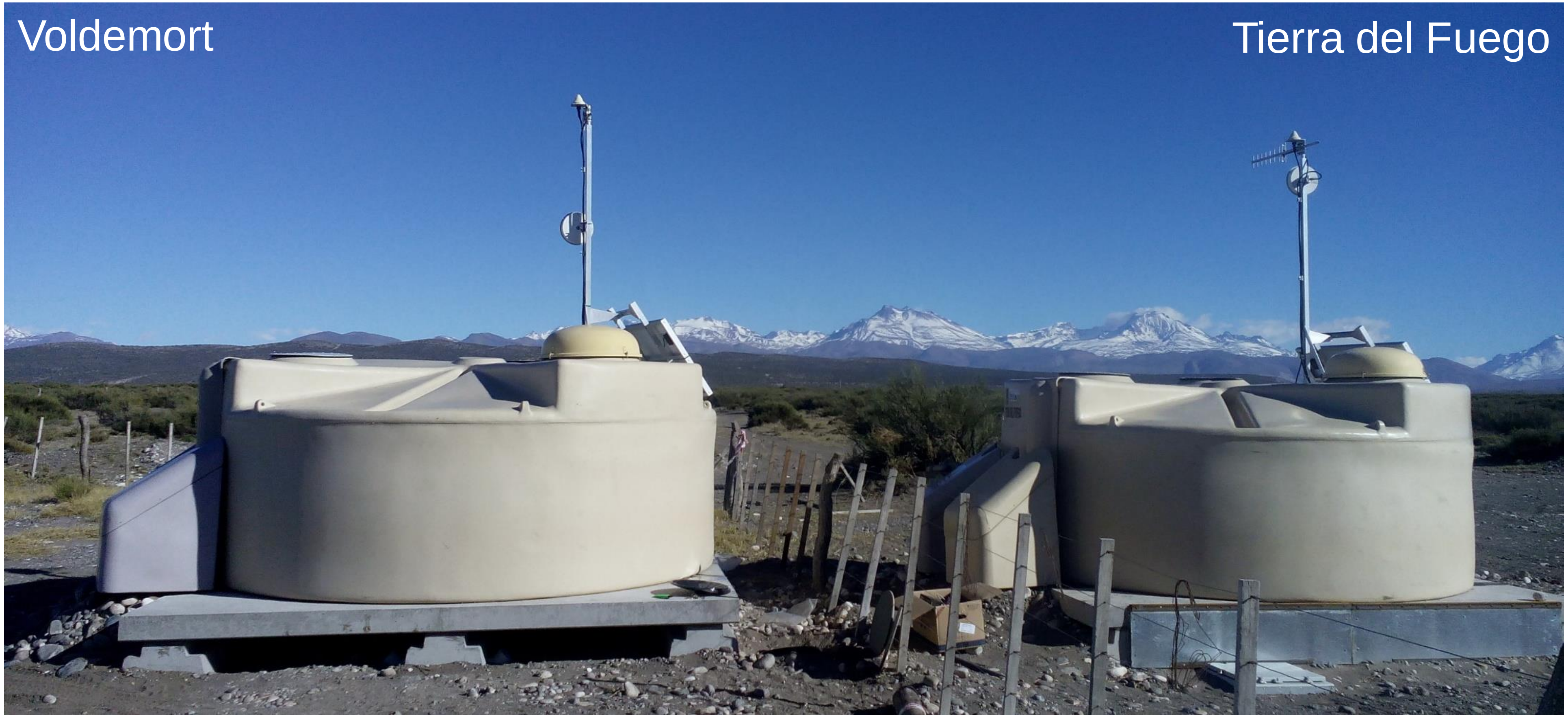
Transforming 4 modules in a functional station is not trivial:

- Autonomous
- Low power
- Low comms
- Interfaced to existing tank
- In the pampas environment
- 10000 km from PT
- 60 km from Malargüe

Station:

- 4 RPC Modules
- Controlled by a central unit
- Interfaced to WCD
- With slow control
- With gas system

The prototypes

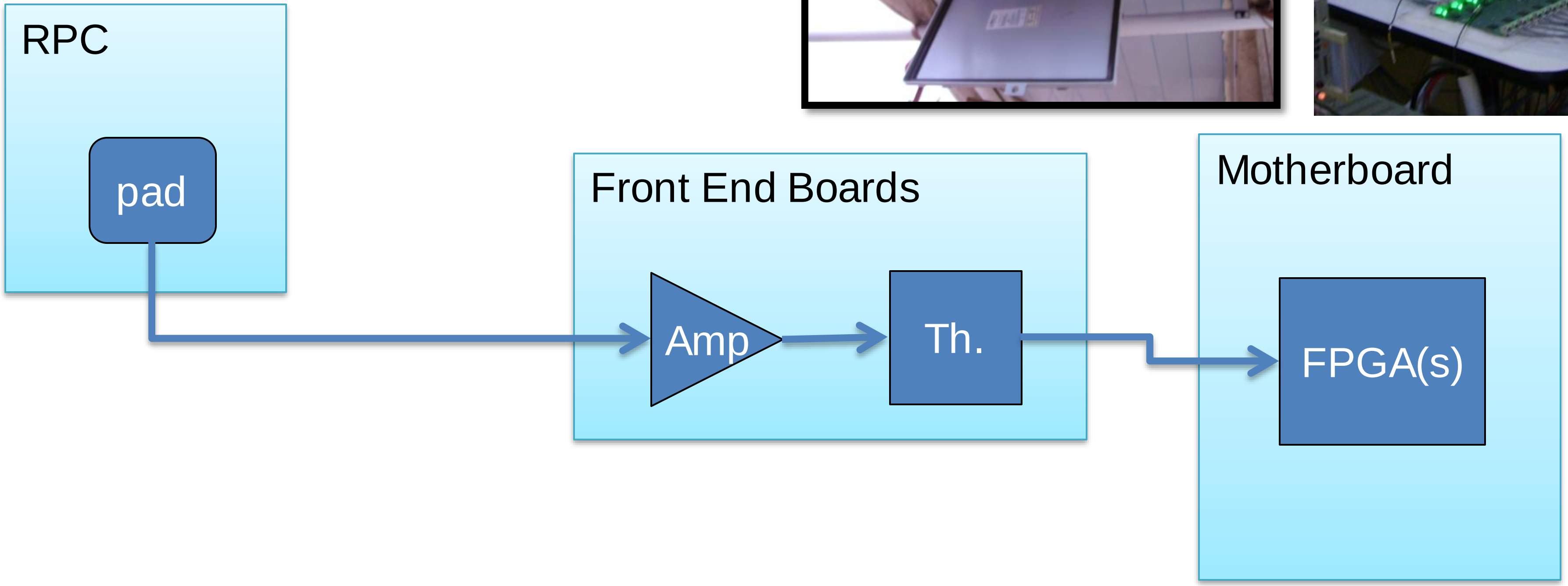


MARTA readout – the PREC

First readout for tests

- Up to 104 channels
- Each channel amplifier and threshold
- LVDS output to support long distances
- Low noise
- Better than few ns for timing

Concept of a single channel




"You just need to push it to place, even I can do it"
Undisclosed author

… but the prototype electronics demanded a lot of power.

There is a solar station nearby

But you need to protect the cables

MARTA readout

Requirements:

Constrains in power & space in field conditions

- Power from solar panel
- Real estate costly @ the pampa

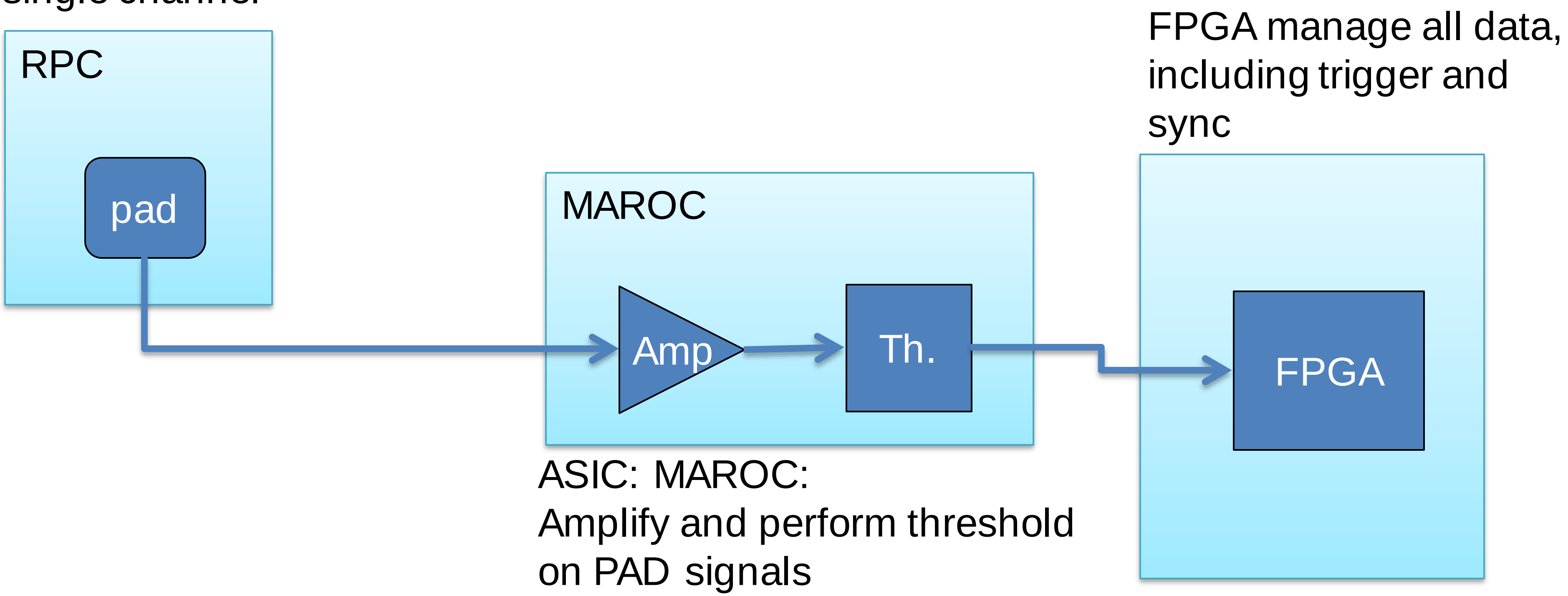
require integrated solution

- Minimize power (mW per channel)
- Minimize Data (only triggered pad in selected events)

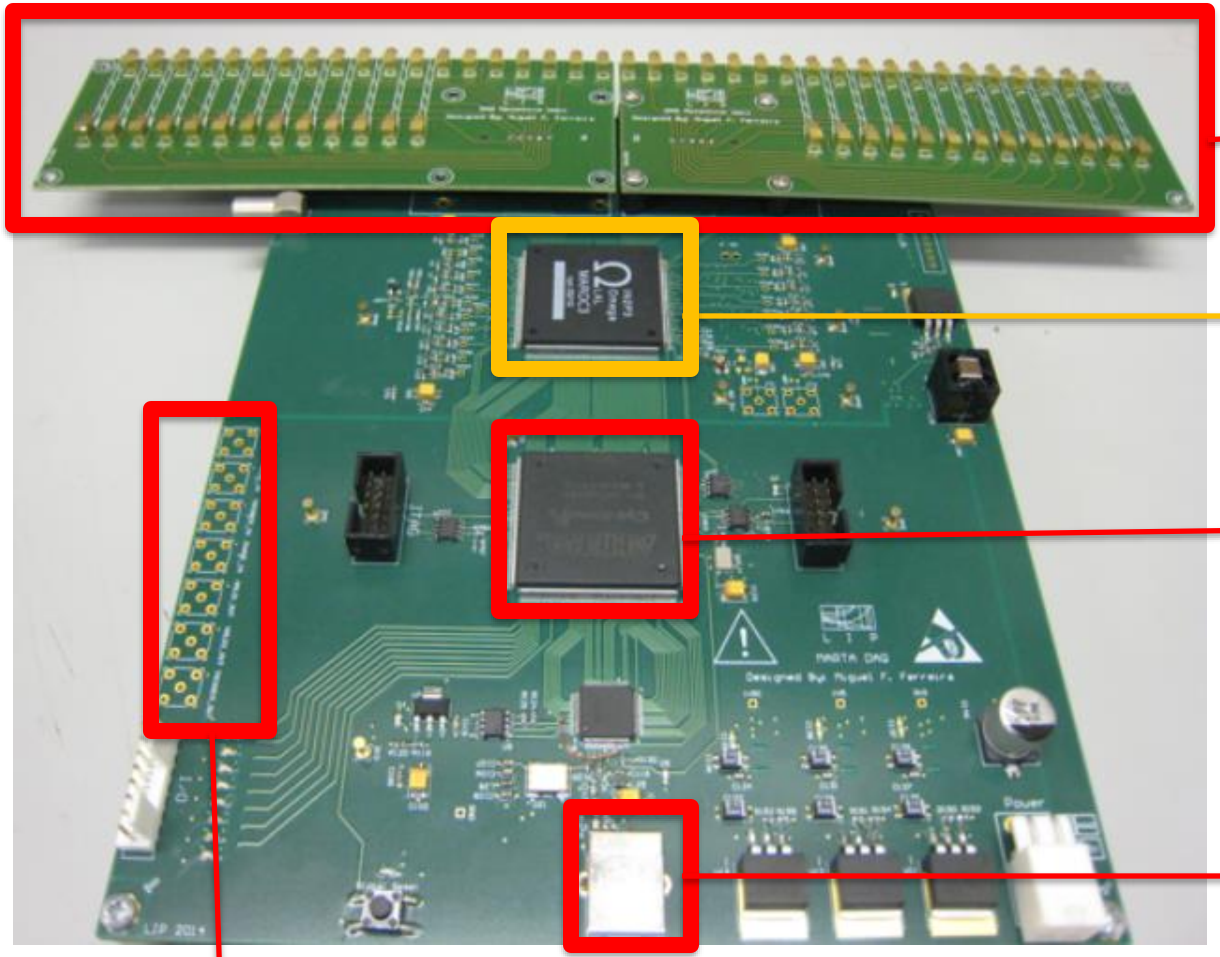
Chosen solution

- ASIC + FPGA

Concept of a single channel



MARTA Readout System



Inputs

MAROC

FPGA

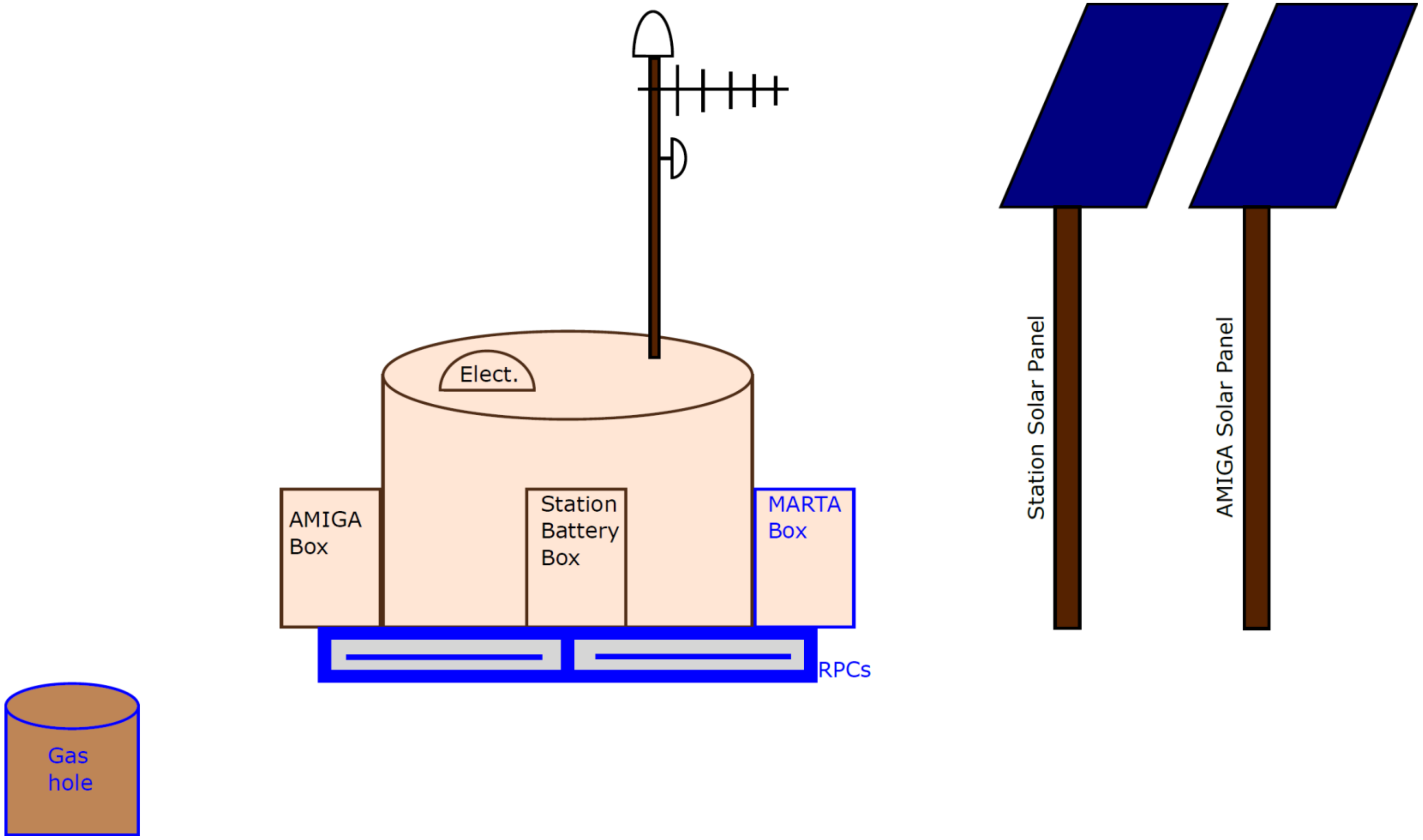
USB port

LVDS interface

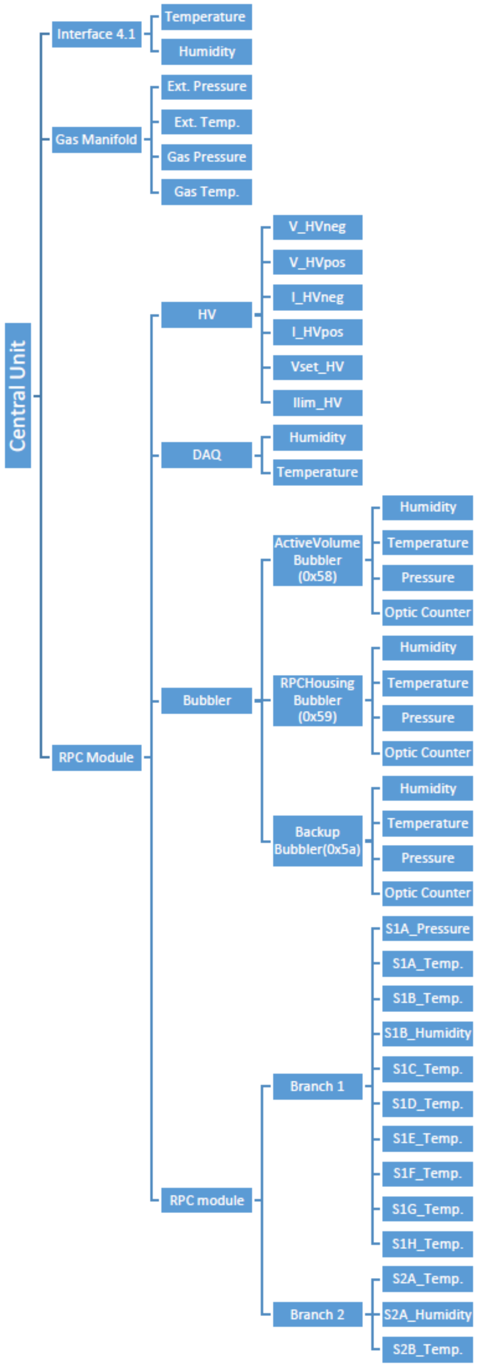
First field station

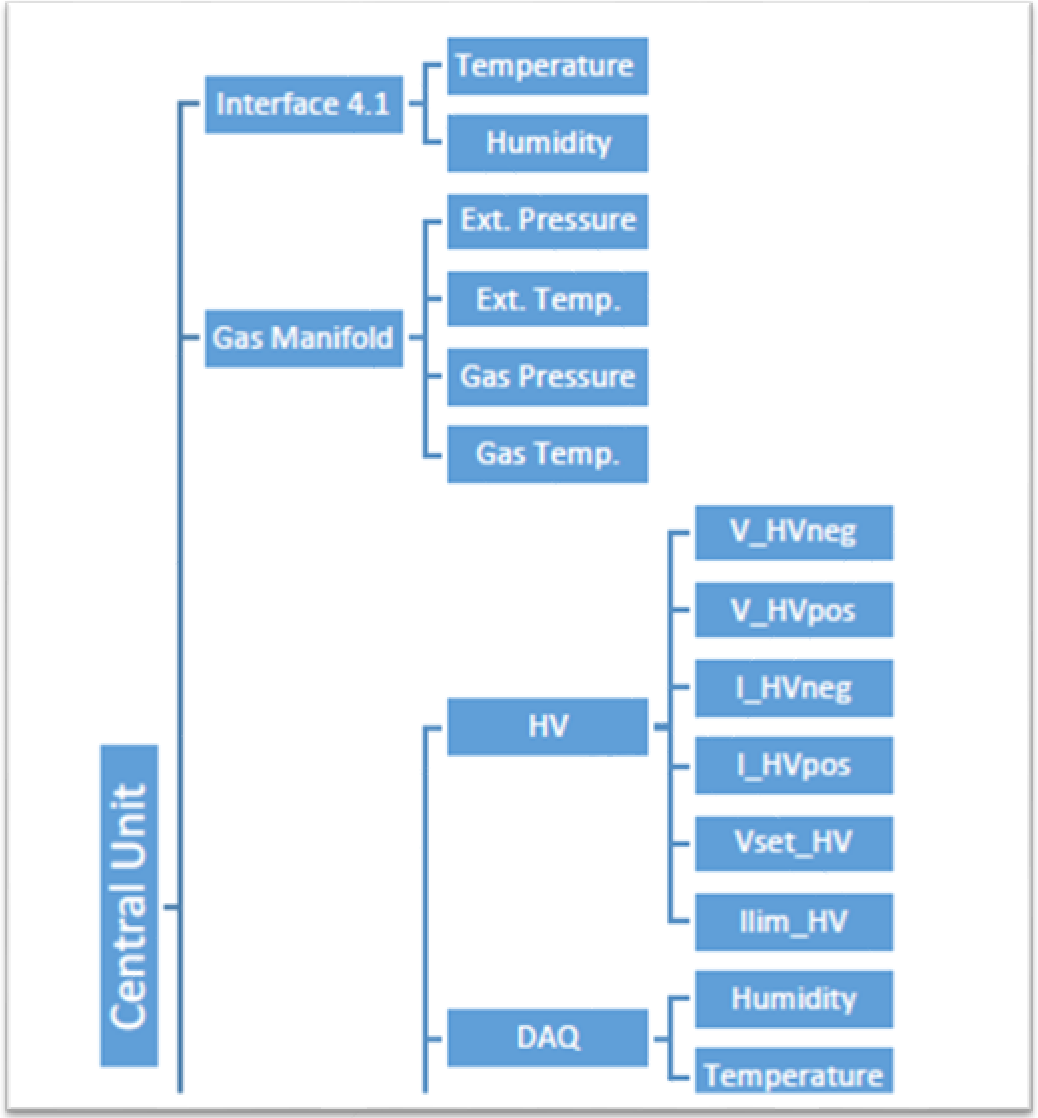
Inserted in the test area and in the infill
More low energy events for testing
Installed on a full upgrade station: SSD + AMIGA

First field station

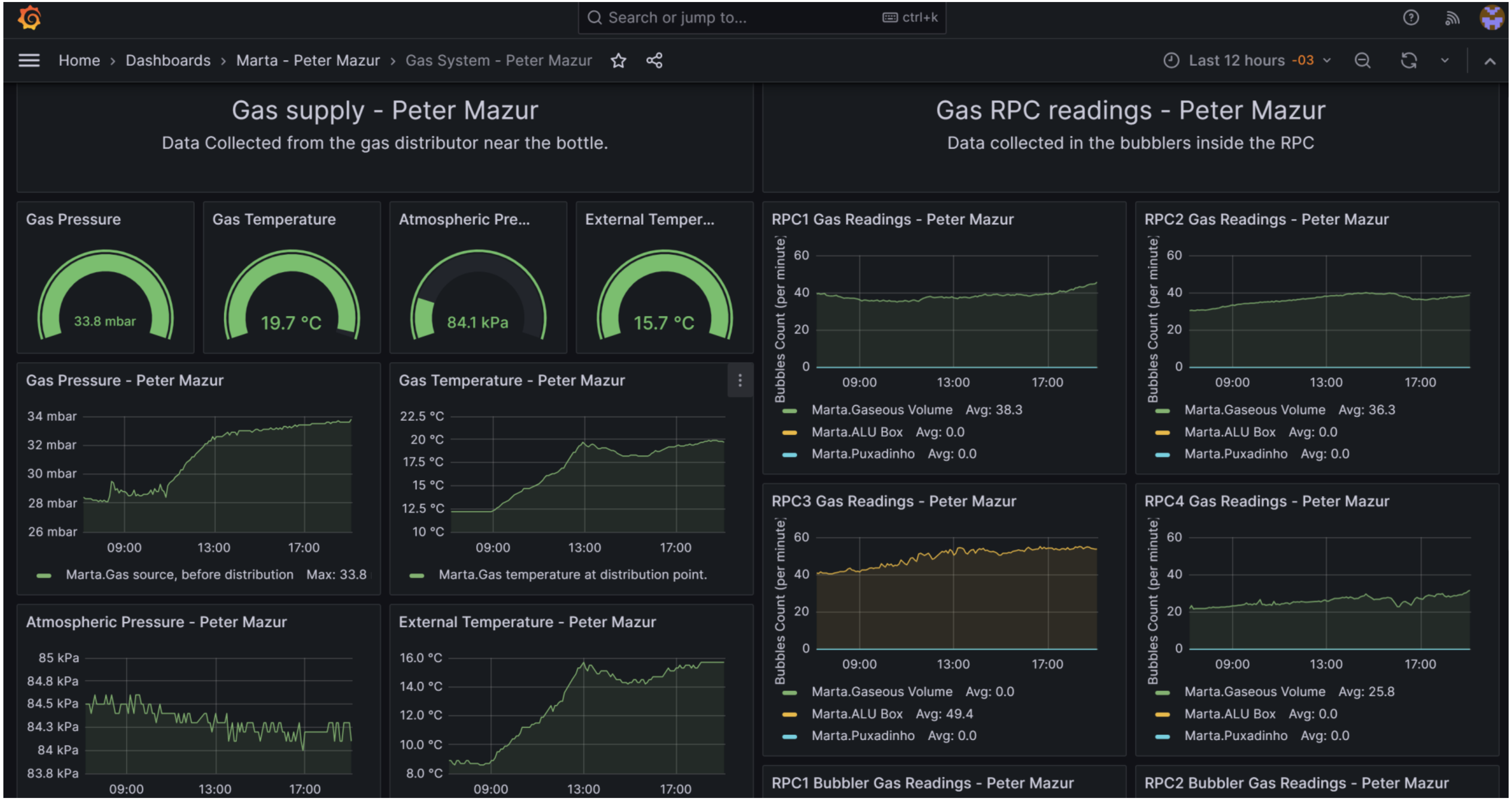


Slow control and monitoring



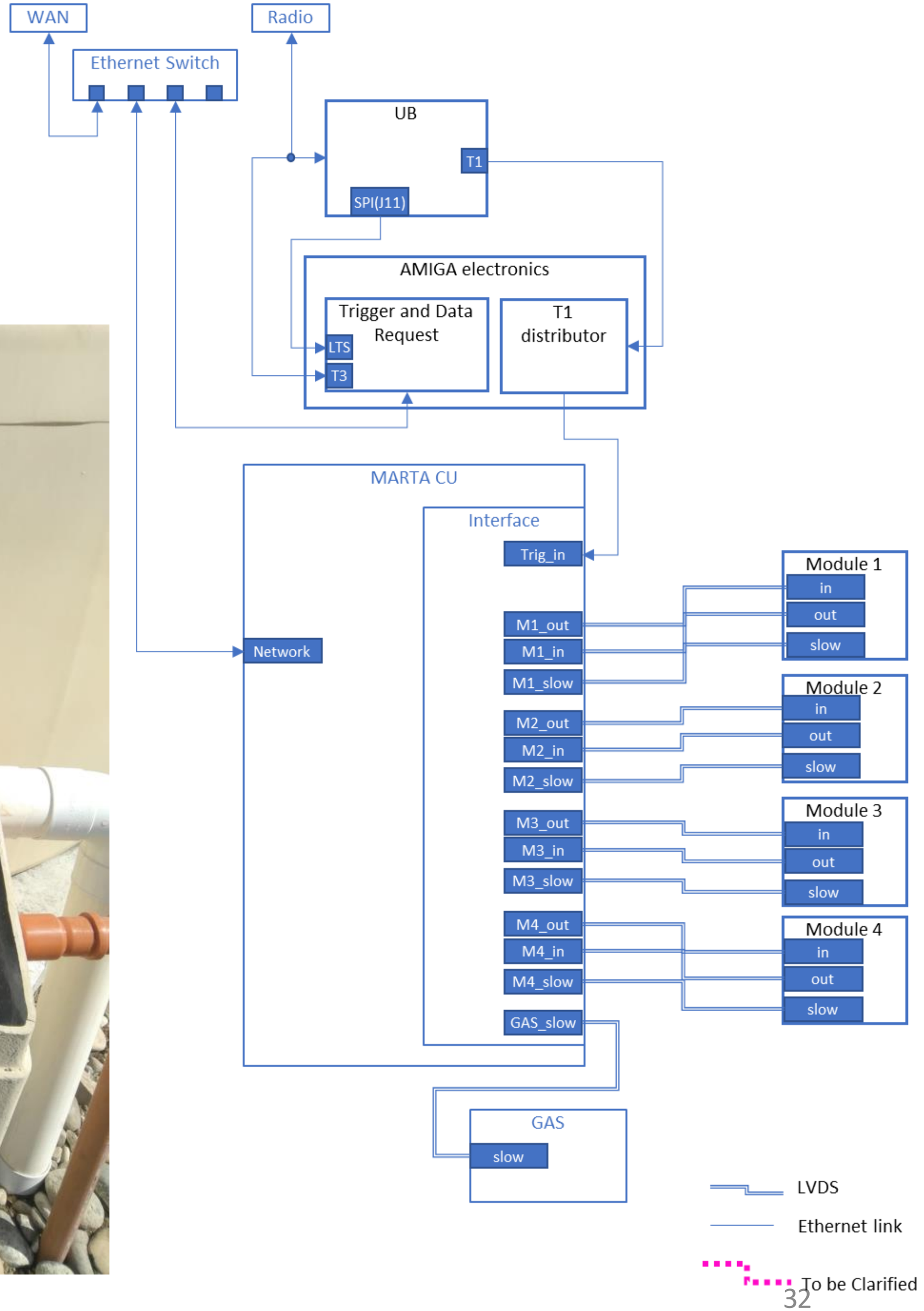


Monitoring


Search or jump to...
ctrl+k
Home › Dashboards › Marta - Peter Mazur › Gas System - Peter Mazur
Last 12 hours -03
Gas supply - Peter Mazur
Data Collected from the gas distributor near the bottle.
Gas RPC readings - Peter Mazur
Data collected in the bubblers inside the RPC
Gas Pressure
33.8 mbar
Gas Temperature
19.7 °C
Atmospheric Pre...
84.1 kPa
External Temper...
15.7 °C
Gas Pressure - Peter Mazur
Marta.Gas source, before distribution Max: 33.8
Gas Temperature - Peter Mazur
Marta.Gas temperature at distribution point.
Atmospheric Pressure - Peter Mazur
External Temperature - Peter Mazur
RPC1 Gas Readings - Peter Mazur
Bubbles Count (per minute)
Marta.Gaseous Volume Avg: 38.3
Marta.ALU Box Avg: 0.0
Marta.Puxadinho Avg: 0.0
RPC2 Gas Readings - Peter Mazur
Marta.Gaseous Volume Avg: 36.3
Marta.ALU Box Avg: 0.0
Marta.Puxadinho Avg: 0.0
RPC3 Gas Readings - Peter Mazur
Marta.Gaseous Volume Avg: 0.0
Marta.ALU Box Avg: 49.4
Marta.Puxadinho Avg: 0.0
RPC4 Gas Readings - Peter Mazur
Marta.Gaseous Volume Avg: 25.8
Marta.ALU Box Avg: 0.0
Marta.Puxadinho Avg: 0.0
RPC1 Bubbler Gas Readings - Peter Mazur
RPC2 Bubbler Gas Readings - Peter Mazur

Central Unit

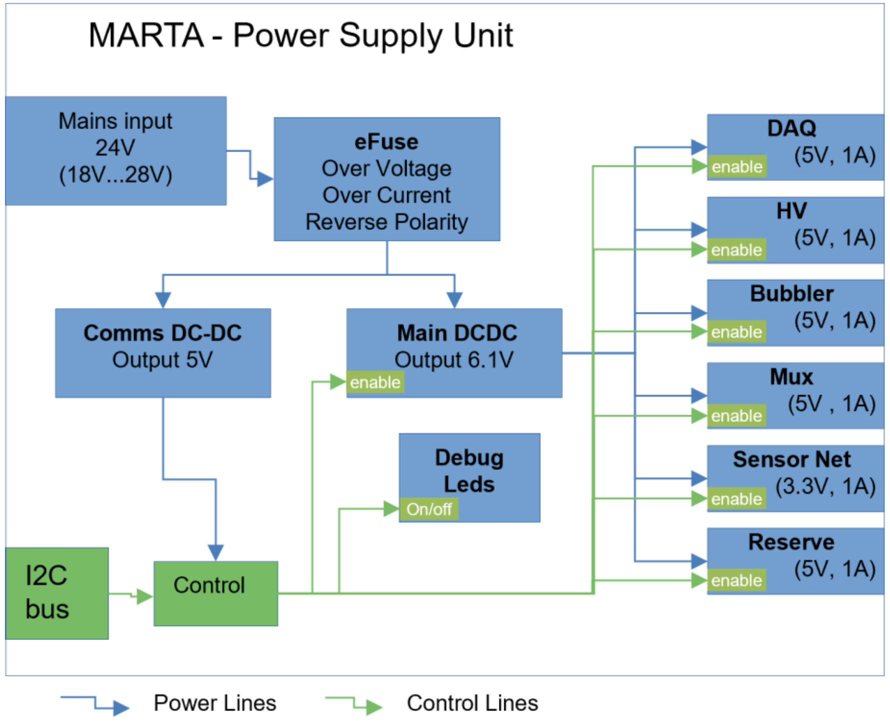
CPU + FPGA
Dev kit: SOC FPGA
Interface adapter developed

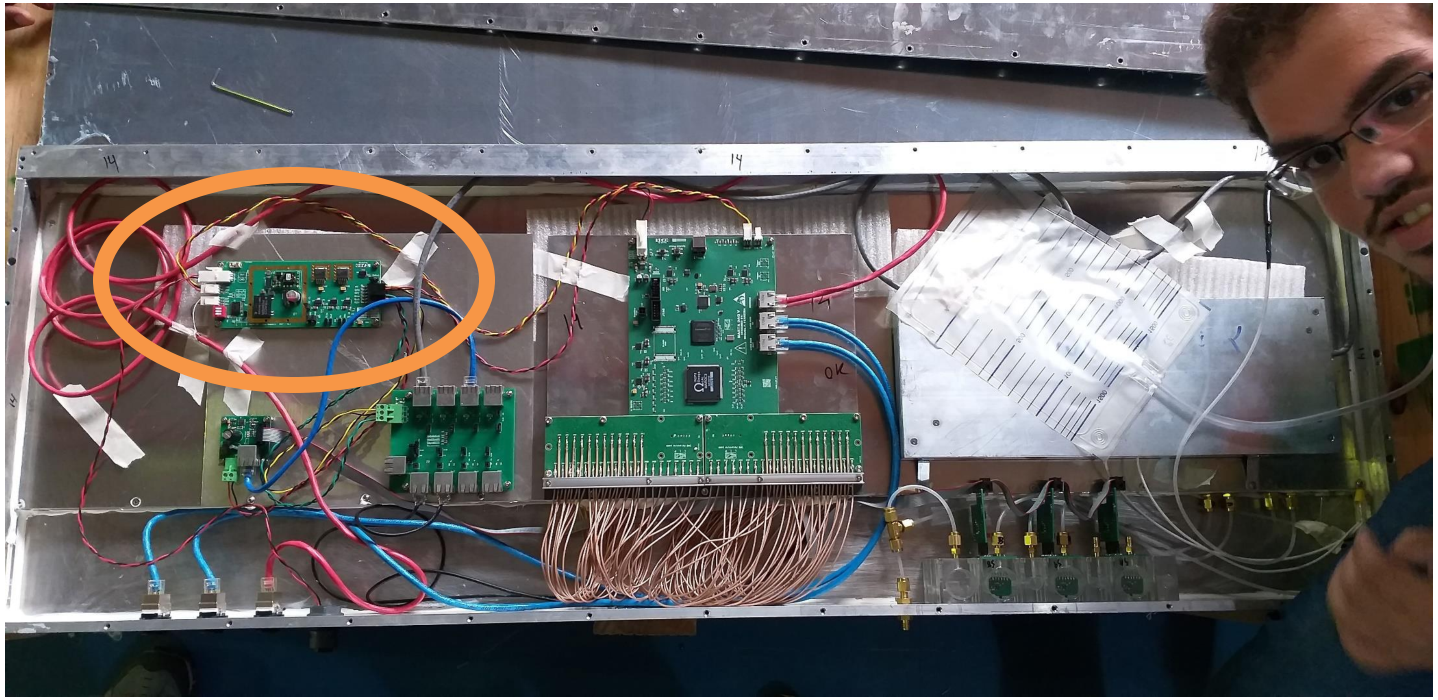


Lessons from the field
Power

Not having a socket is not so easy: the power system is not stable and you need to be efficient

MARTA PSU:





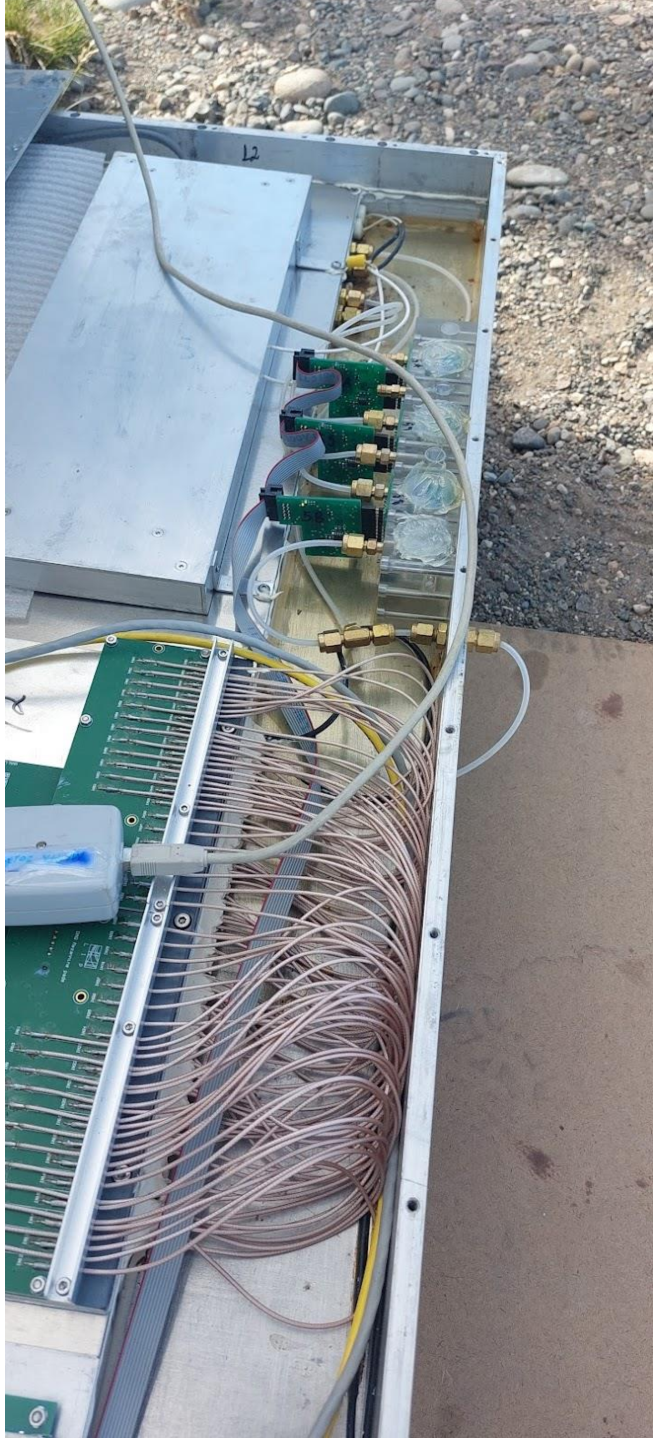
Lessons from the field

wildlife

Logistics

Lessons from the field

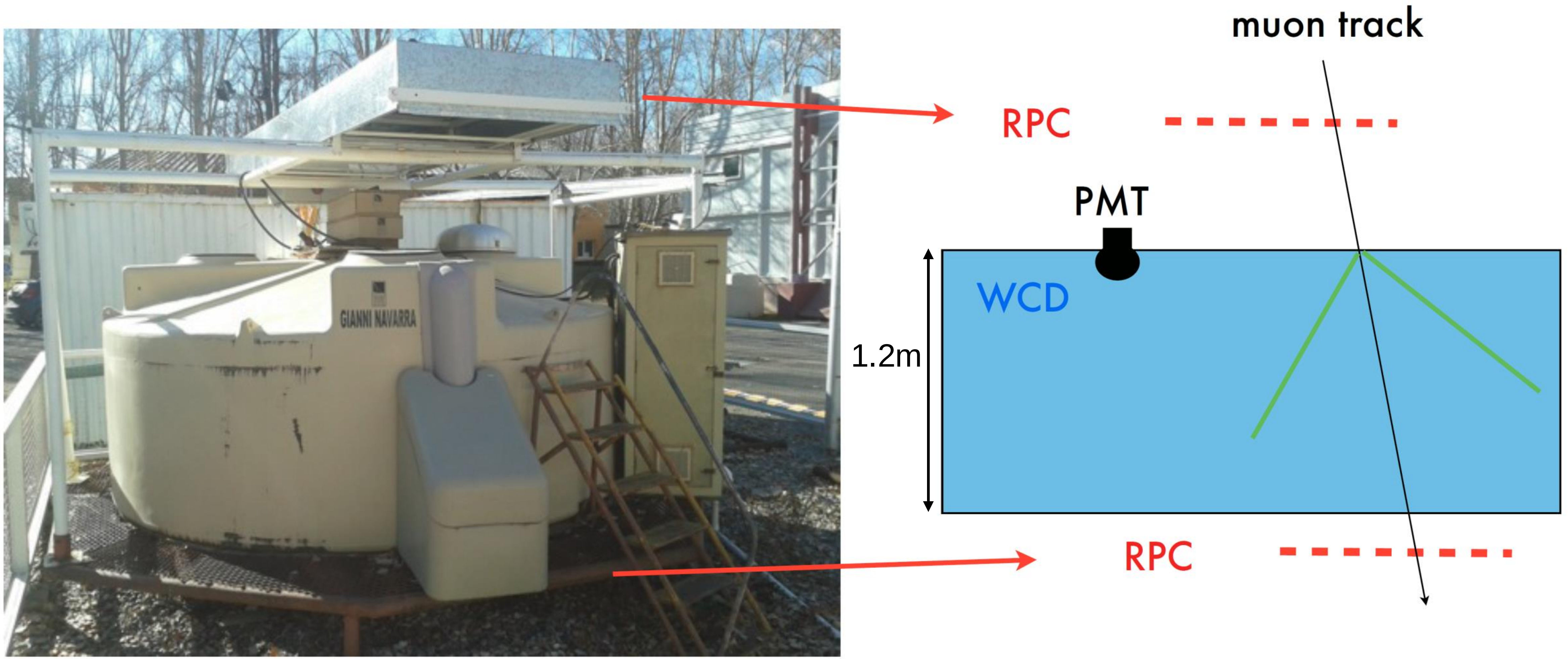
- The pampas is very aggressive
- Not ideal conditions to work
- Might need to wait for good weather
  (Sometimes you need to run…)
- Everything takes a long time
- Small changes imply a 1-2h trip
  (larger if you include lunch)
- Staff can help but are not experts!
- Some problems only appear during comissioning (even if tested in the lab)
- Interface only tested in the field
- Materials deteriorate
  e.g. all gas tubing needed to be replaced



Gianni: a spin-off

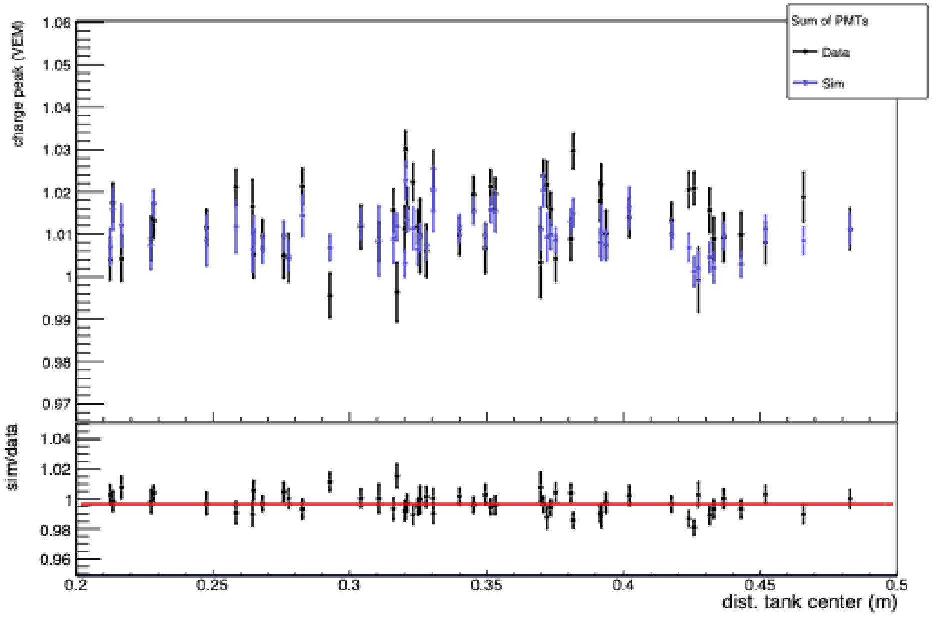
a muon hodoscope for WCD characterization and calibration

The Gianni Navarra setup



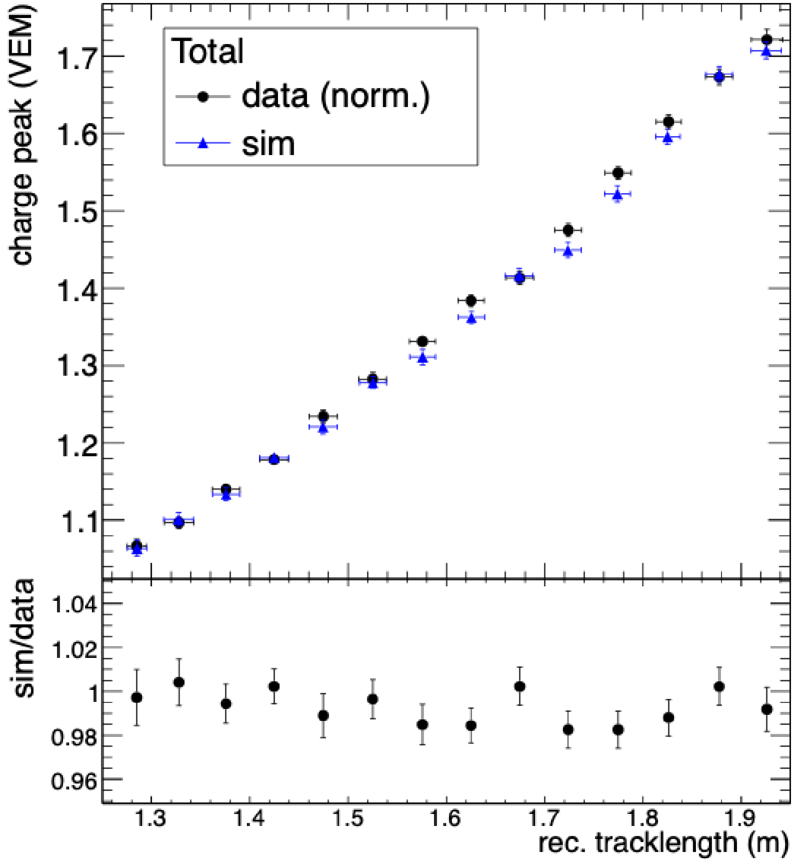
Results: Data vs Simulation

Testing the VEM: Vertical muons near the center



- Nearly vertical events near the center of the tank

Testing the response vs θ : Inclined muons



✧ Scan tank response from [15;55] degrees

✧ Compare data with simulation expectations

✧ Agreement within less than 2%

RPC installation @ Gianni

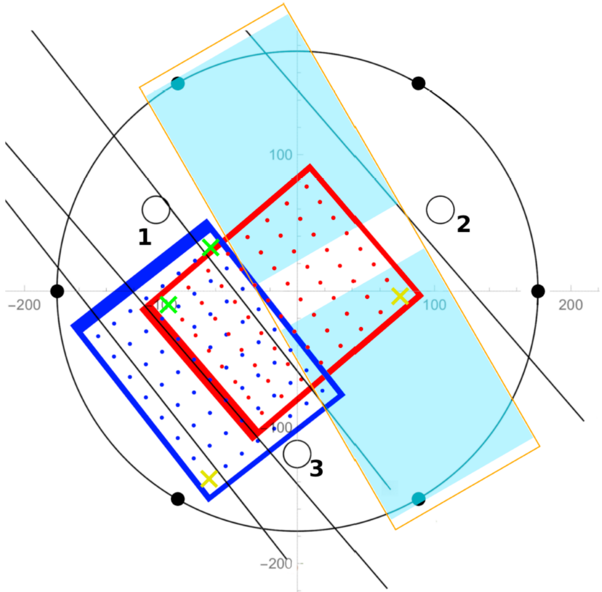
GIANNI upgrade

Recently the setup was upgraded:

- New top RPC
  (top RPC withstands 30º excursions)
  Production model of MARTA
- New electronics: MAROC
- New Central Unit for trigger, same solution as in field
- New UUB: upgraded SD electronics
- Installed SSD
  (scintillator on standard position

Can collect in one day data equivalent to months in previous setup

Dataset



Setup scheme: top view
Top RPC
SSD
WCD PMTs 1, 2, 3
Bottom RPC

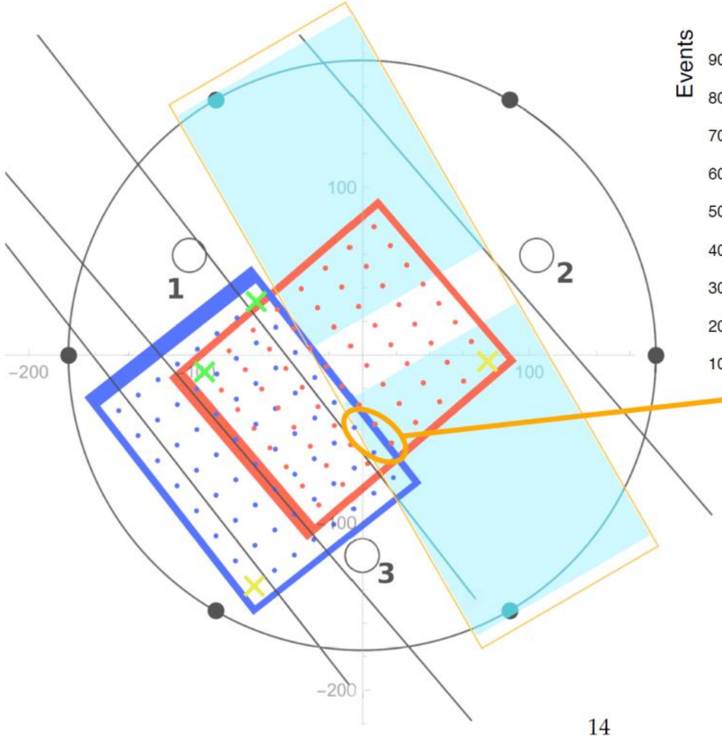
the straight lines indicate the current structures along which the RPCs may be moved

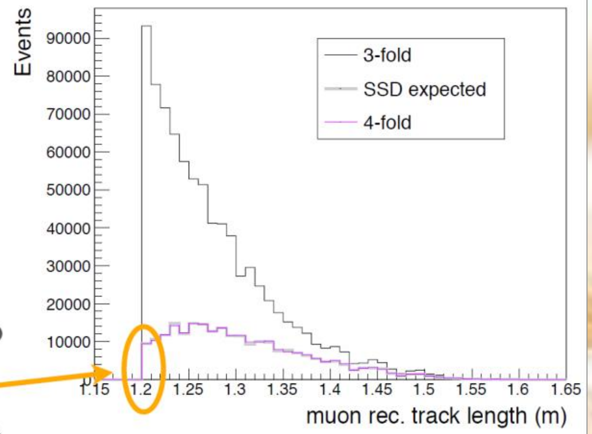
Date	April 10-11	
Duration	16.5 h	
Number of events	1M	
Multiple-hits / spurious triggers (13%)	128382	
Single-hits (87%)	871618	100%
No peak	50654	6%
Saturated	1525	0.2%
Baseline peak	5009	0.6%
Multiple peaks	439	0.05%
3-fold single peak	**815795**	93.6%
4-fold single peak	**235584**	27.0%

6

SSD events

- We do see the 4-fold single peak events where we expect them from geometrical considerations





- Selection of vertical MIPs mainly from a few pad combinations near the SSD border

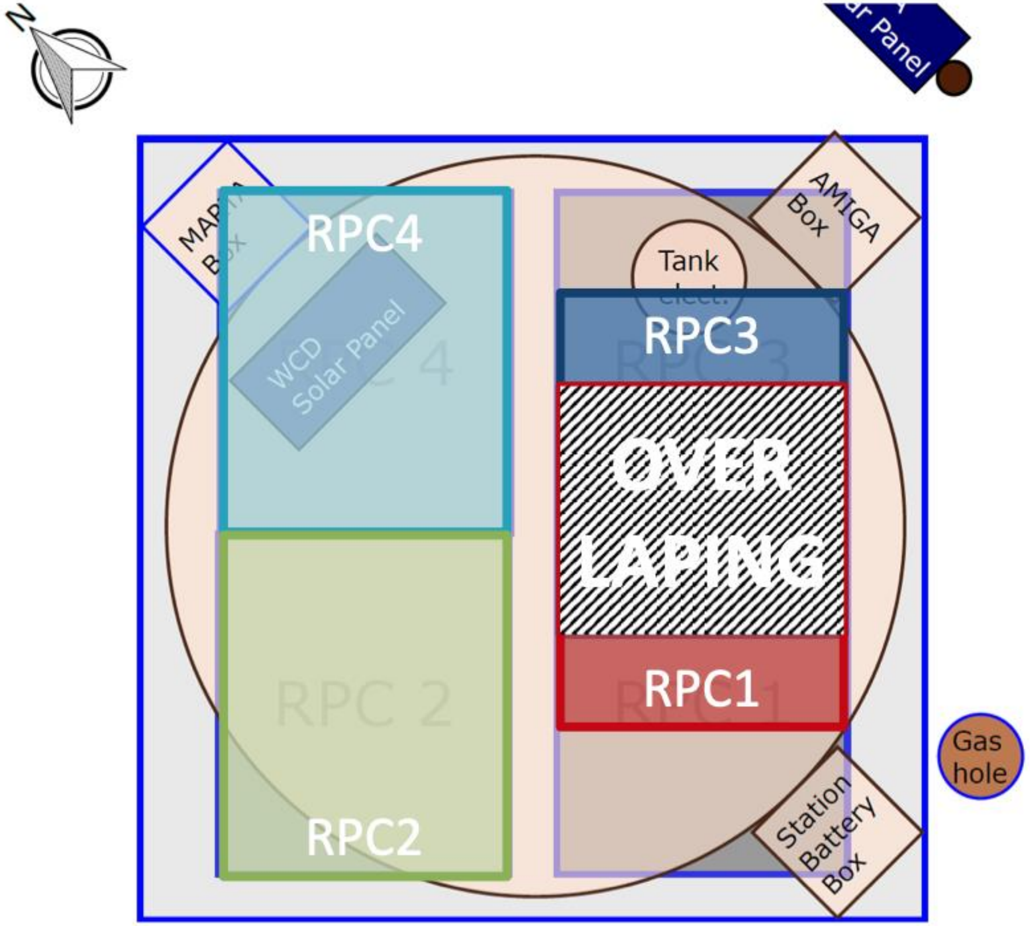
SSD analysis

First field station: PETER MAZUR wcd

Exploring data and capabilities

Peter Mazur: station configuration

First MARTA station in the field
Being commissioned and tested
Setup for efficiency measurements:
small loss of area, coincidence data



By Guilherme Neves

Pad Size: 14 x 18 cm^2

(electronics, HV, gas)

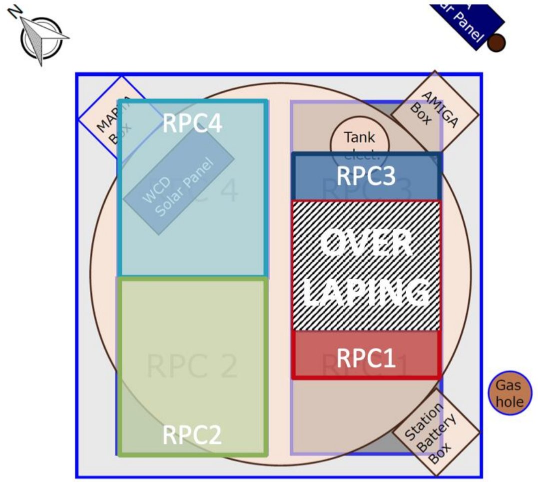
Top RPC

57	49	41	33	25	17	9	1
58	50	42	34	26	18	10	2
59	51	43	35	27	19	11	3
60	52	44	36	28	20	12	4
61	53	45	37	29	21	13	5
62	54	46	38	30	22	14	6
63	55	47	39	31	23	15	7
64	56	48	40	32	24	16	8

Bottom RPC

2	10	18	26	34	42	50	58
1	9	17	25	33	41	49	57

(electronics, HV, gas)



Pad Size: 14 x 18 cm^2

(electronics, HV, gas)

Top RPC

57	49	41	33	25	17	9	1
58	50	42	34	26	18	10	2
59	51	43	35	27	19	11	3
60	52	44	36	28	20	12	4
61	53	45	37	29	21	13	5
62	54	46	38	30	22	14	6
63	55	47	39	31	23	15	7
64	56	48	40	32	24	16	8

Bottom RPC

8	16	24	32	40	48	56	64
7	15	23	31	39	47	55	63
6	14	22	30	38	46	54	62
5	13	21	29	37	45	53	61
4	12	20	28	36	44	52	60
3	11	19	27	35	43	51	59
2	10	18	26	34	42	50	58
1	9	17	25	33	41	49	57

(electronics, HV, gas)

Pad combinations

Pad Size: 14 x 18 cm^2

11+56=67
19+48=67
12+55=67

horiz shift
11+48=59
vert shift
11+55=66

Bottom RPC

8	16	24	32	40	48	56	64
7	15	23	31	39	47	55	63
6	14	22	30	38	46	54	62
5	13	21	29	37	45	53	61
4	12	20	28	36	44	52	60
3	11	19	27	35	43	51	59
2	10	18	26	34	42	50	58
1	9	17	25	33	41	49	57

(electronics, HV, gas)

Top RPC

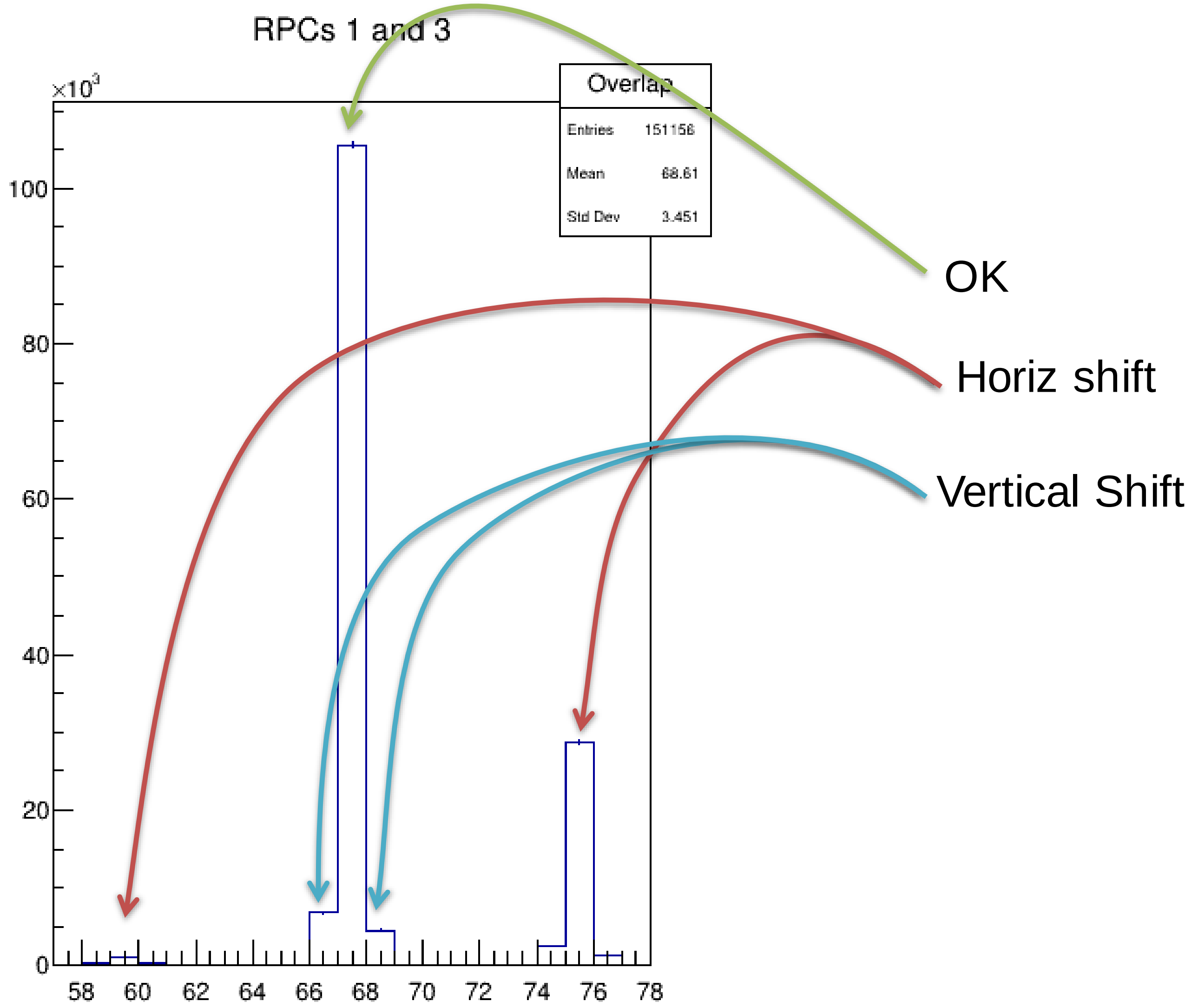
(electronics, HV, gas)

57	49	41	33	25	17	9	1
58	50	42	34	26	18	10	2
59	51	43	35	27	19	11	3
60	52	44	36	28	20	12	4
61	53	45	37	29	21	13	5
62	54	46	38	30	22	14	6
63	55	47	39	31	23	15	7
64	56	48	40	32	24	16	8

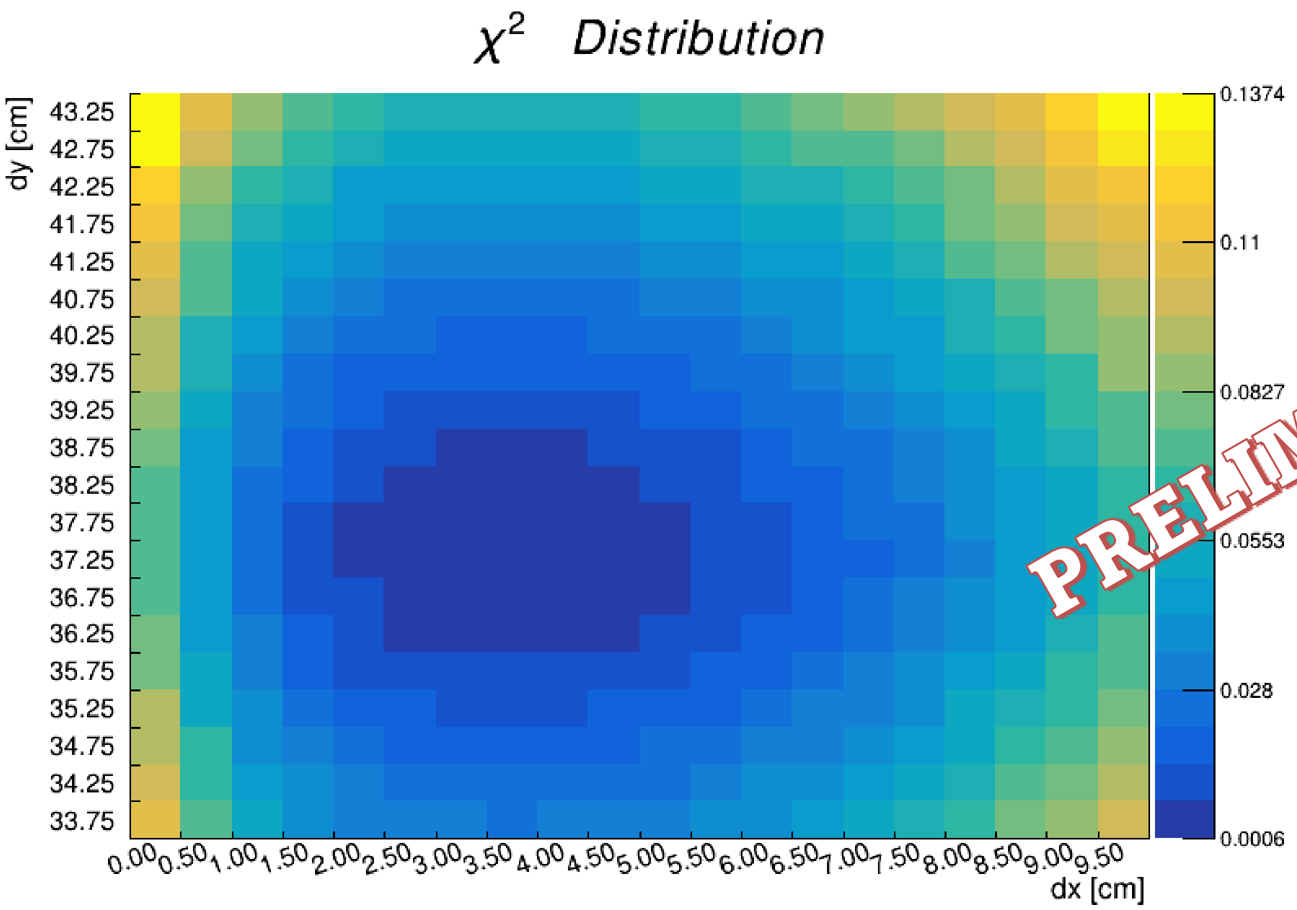
46+21=67
54+13=67
47+20=67

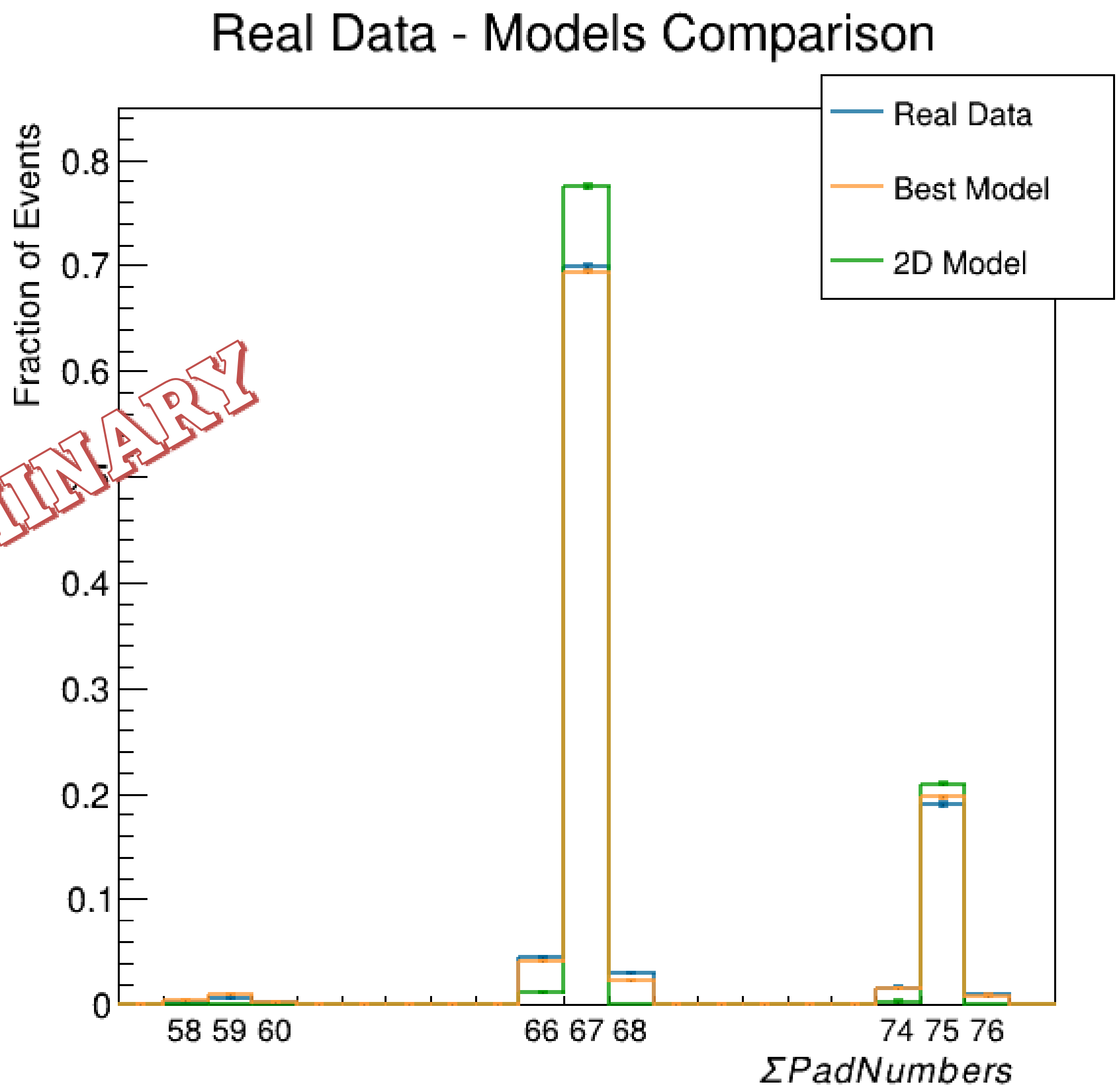
Horiz shift
46+11=59
Vert shift
46+18=66

MARTA-efficiency

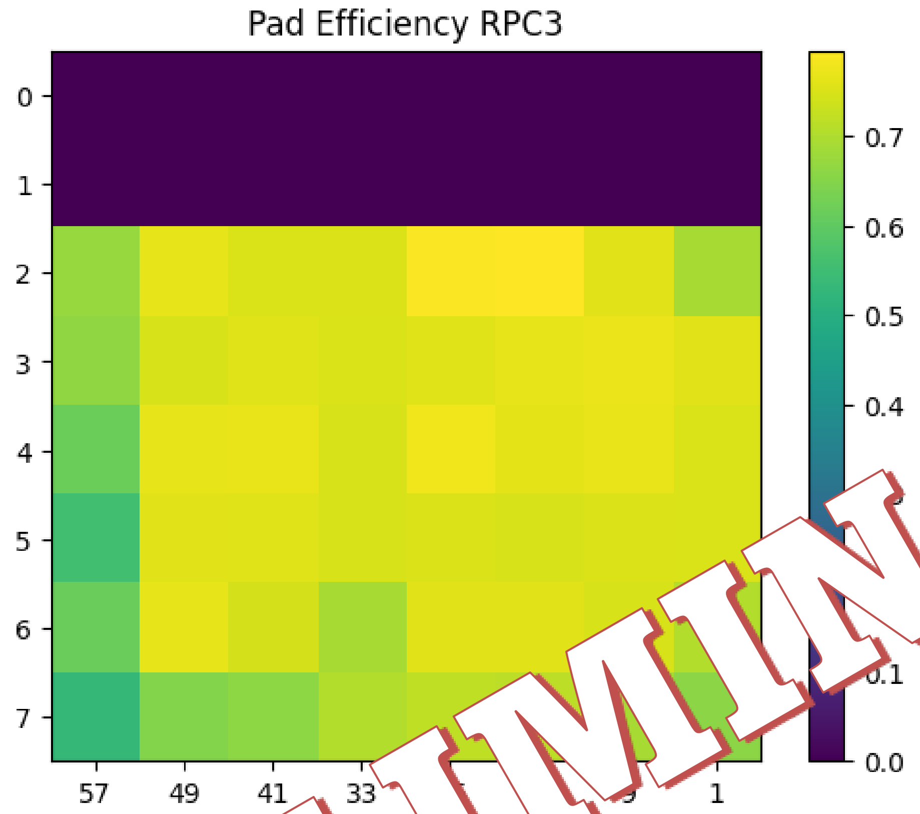


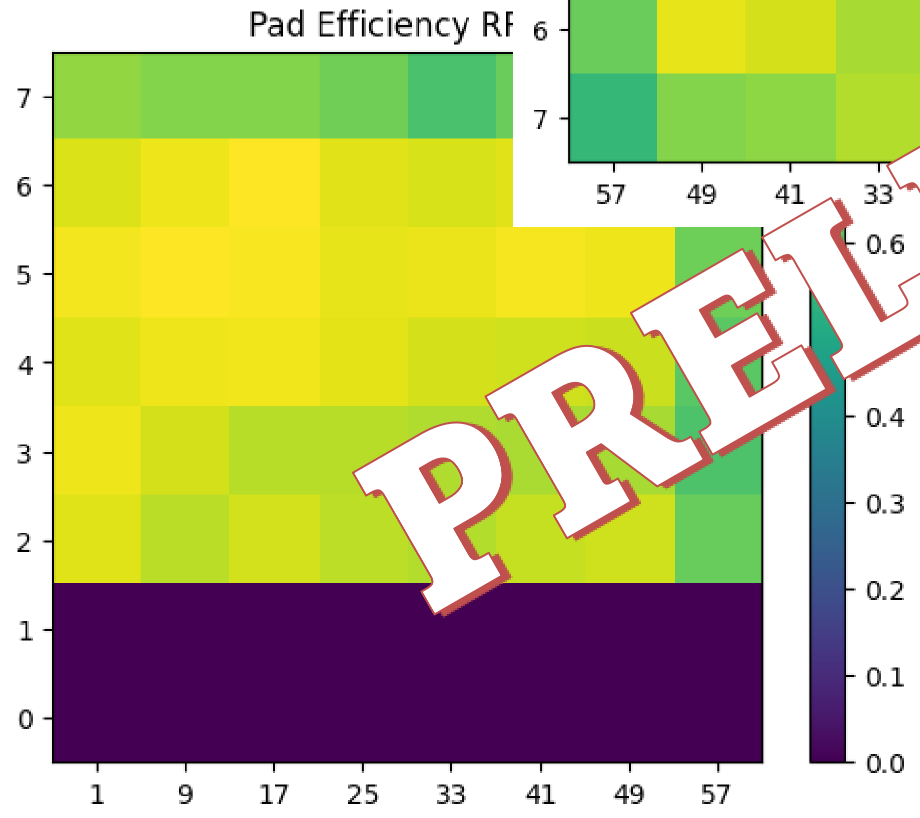
MARTA-efficiency



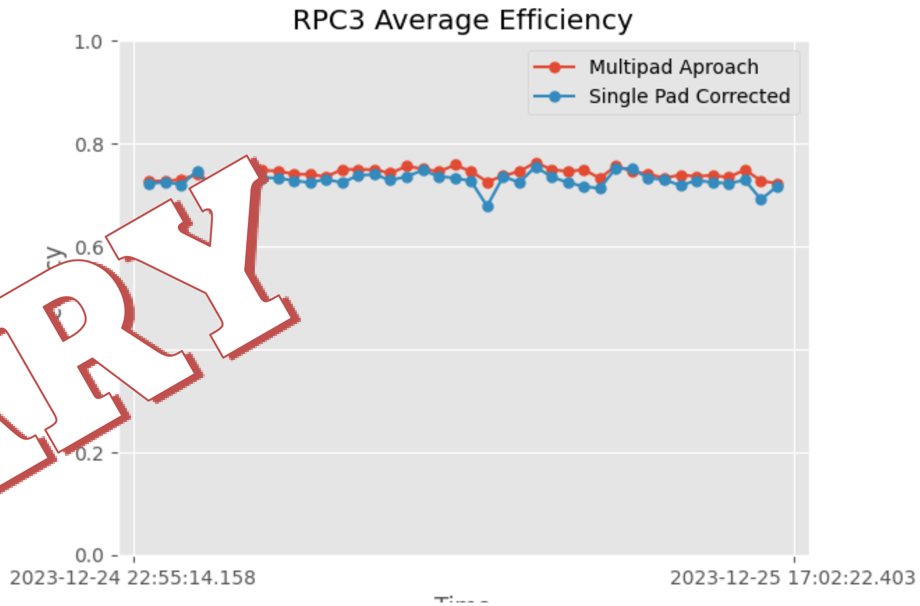


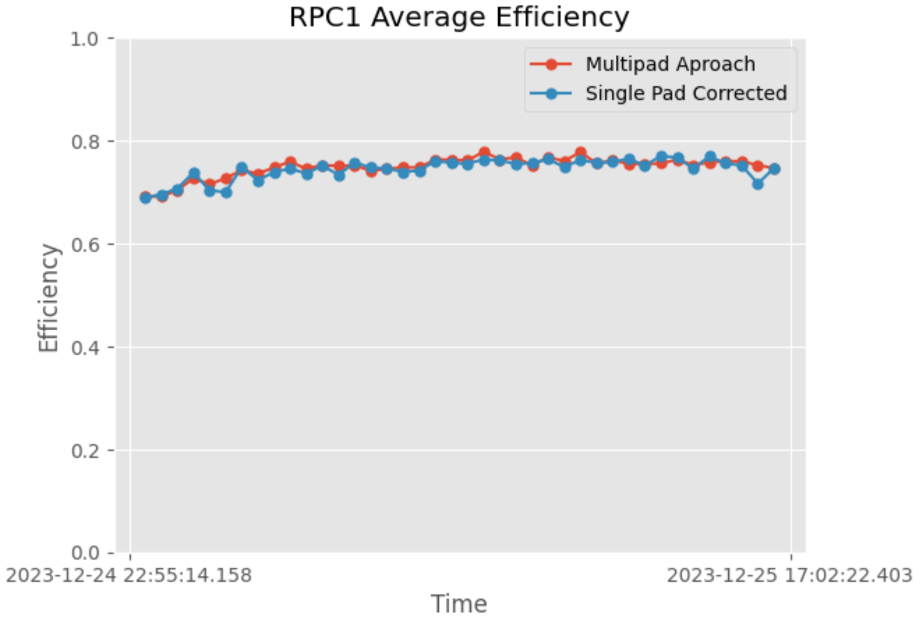
Data suggests a shift of about 3-4cm in width. Final numbers to appear



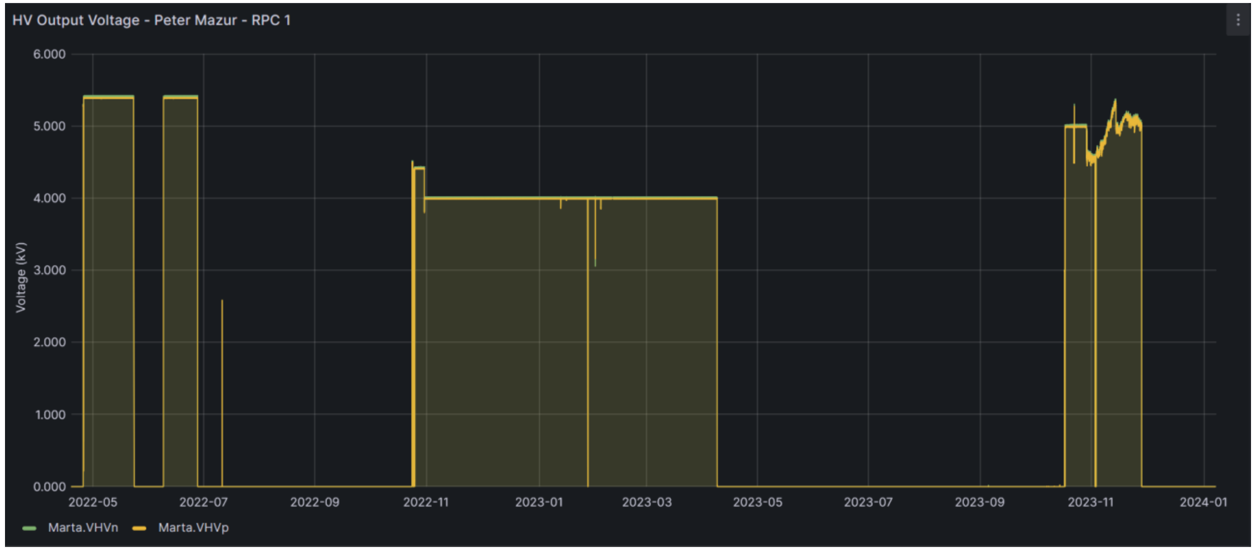


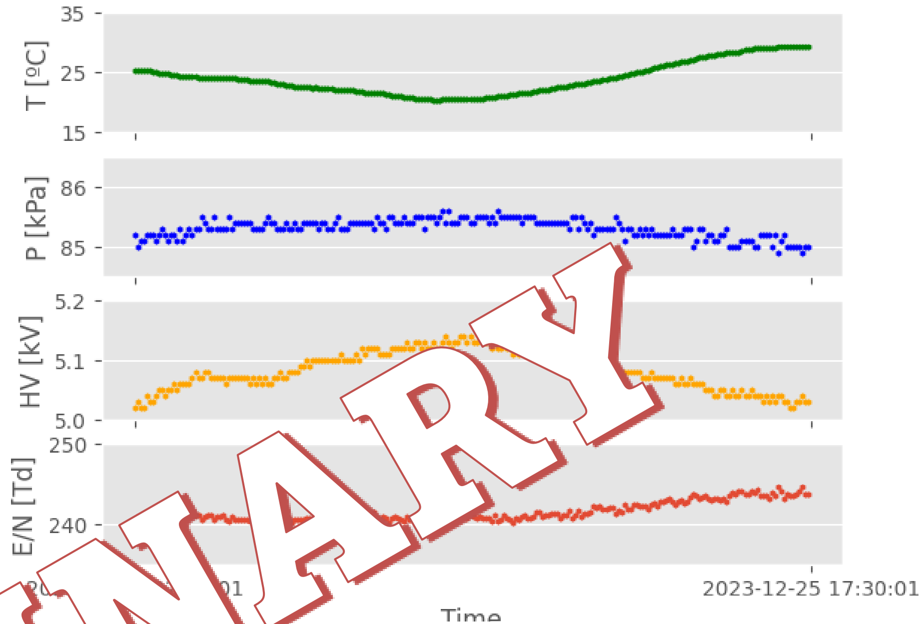
PRELIMINARY

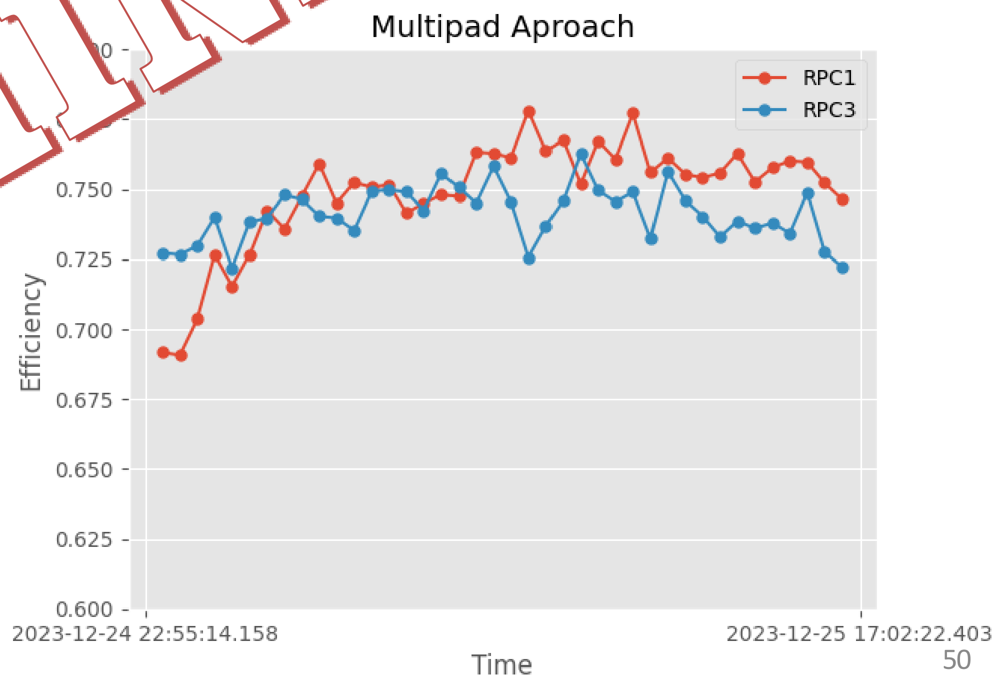




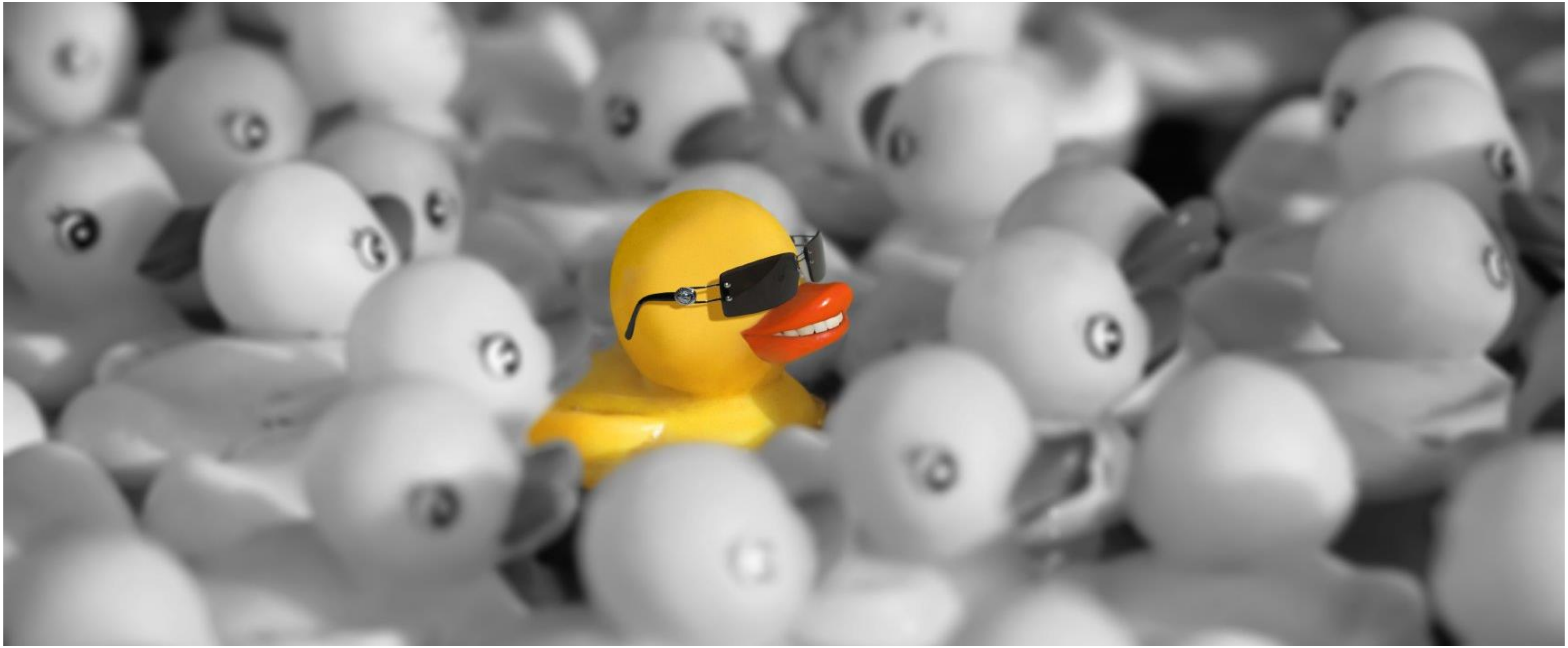
Next: Correlate with Slow control





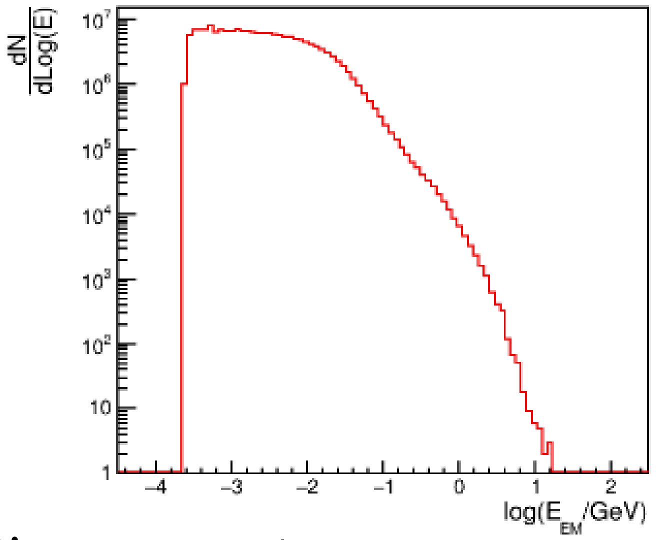


The power of a single station



By Milton Freitas

Assessing the particle energy spectrum



Electromagnetic component particle energy spectrum

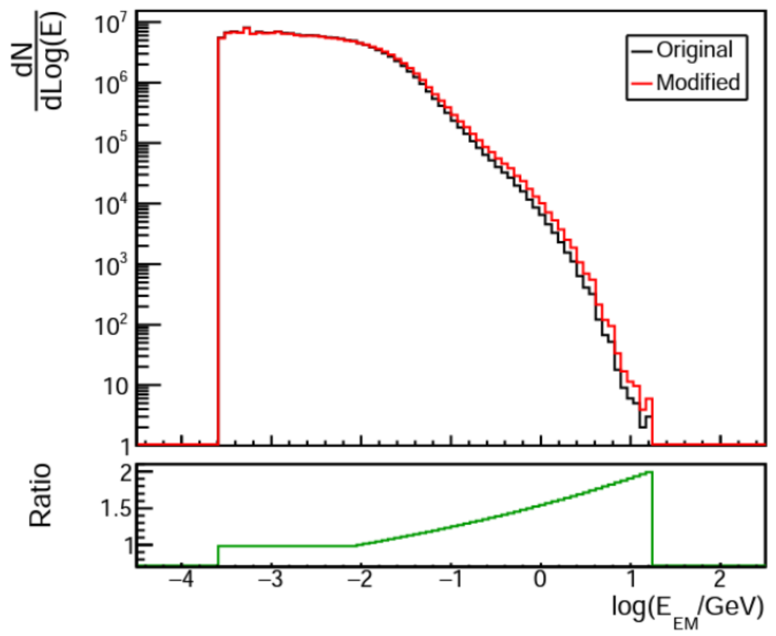
- Particle energy distributions in air showers have yet to be measured
- Measurement of the muon energy spectrum may yield information on the muon puzzle

Three detectors with different response behavior:

- **SSD:** Functions primarily as a particle counter (MIP)
- **WCD:** signal proportional to:
  - **E.m.:** particle energy
  - **Muons:** tracklength; below 1 GeV, signal depends on particle β
- **RPC:** Segmented counter shielded by non-uniform WCD mass-overburden

MARTA SD Station

Modifying the particle energy distribution

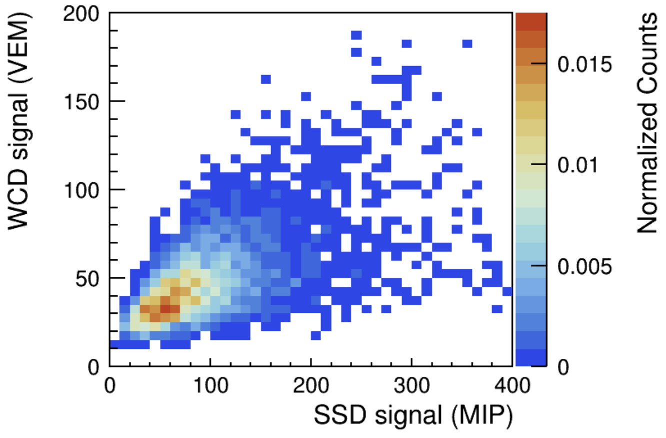


- Modifying the high-energy tail of the electromagnetic distribution with:

$$f(E) = \exp\left\{ \frac{\ln(c)}{b-a} \cdot (E-a) \right\}$$

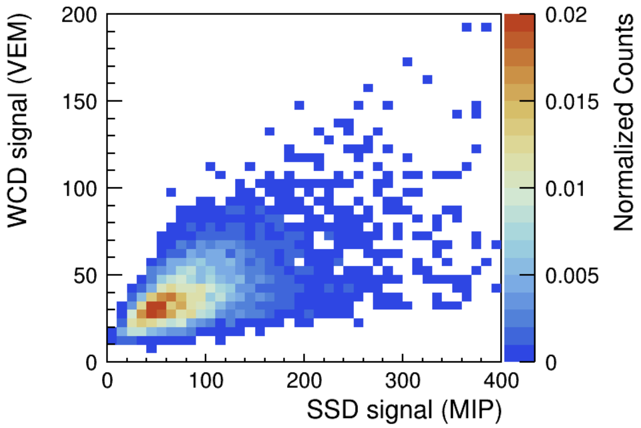
- a and b define the region, c controls the magnitude

Modified



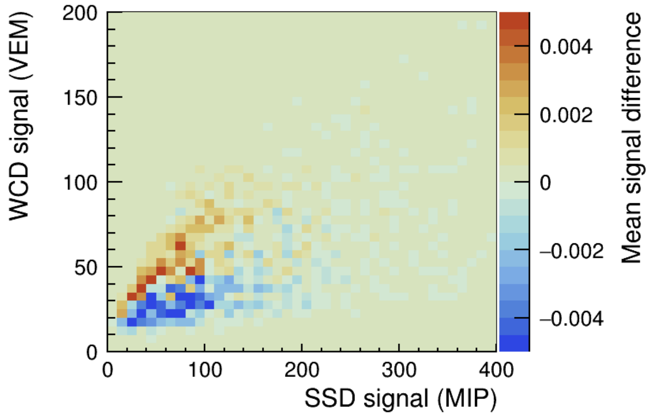
-

Original

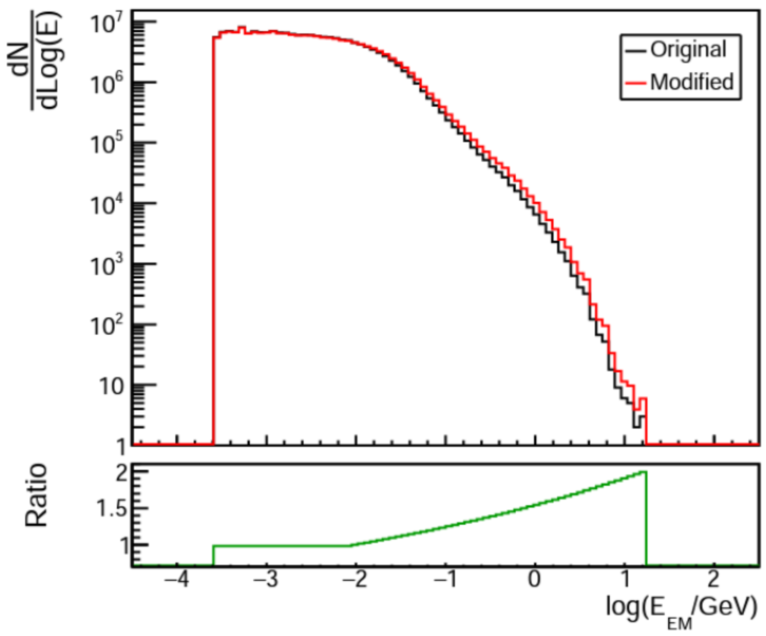


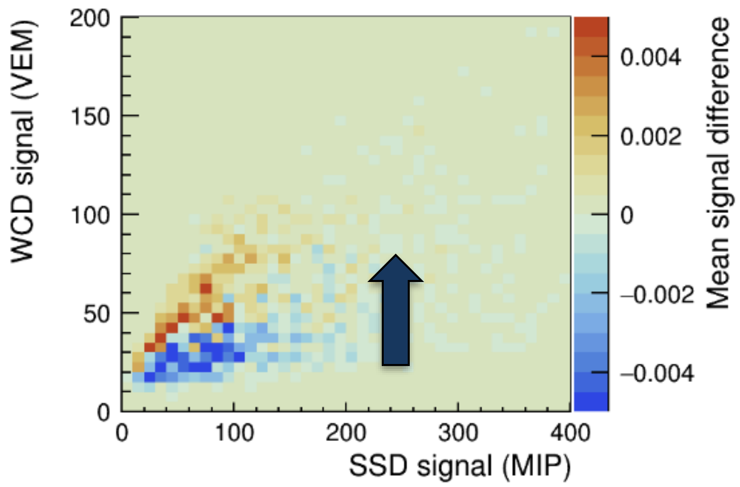
=

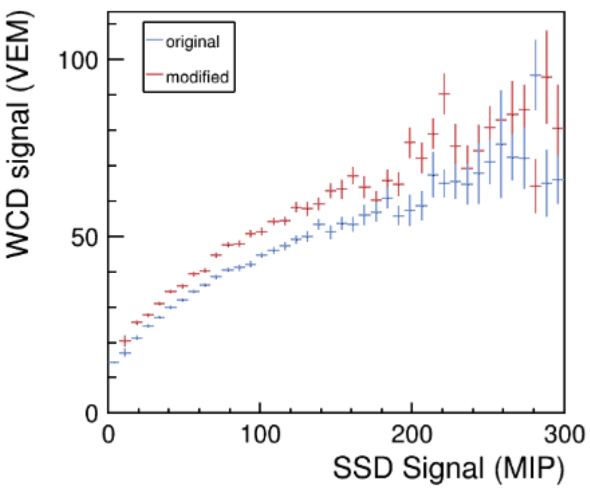
Difference Plot



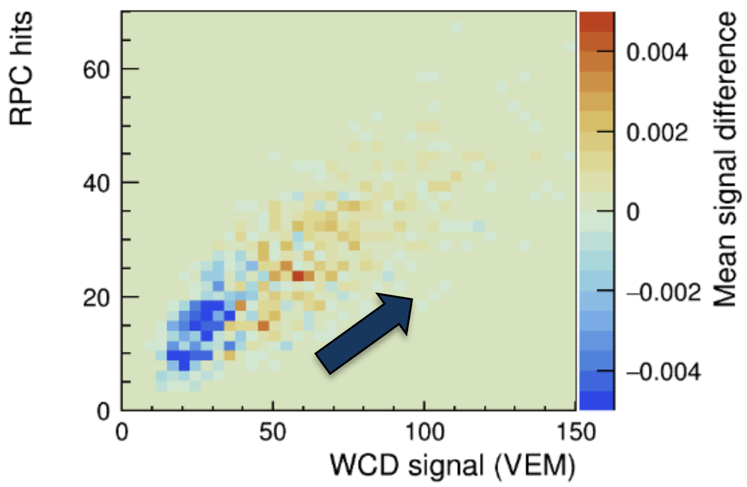
EM component distribution

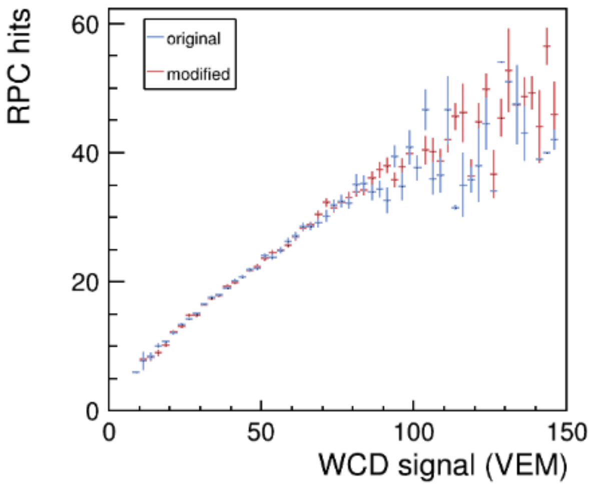






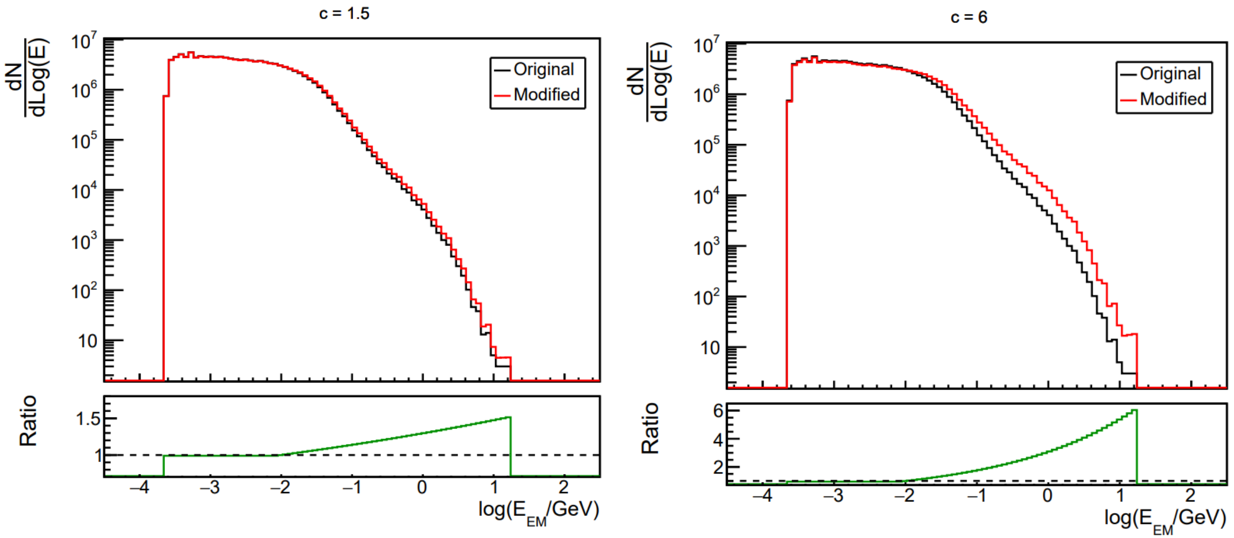
- Consider a fixed station near the shower core
- Modifying the high-energy tail of the electromagnetic distribution

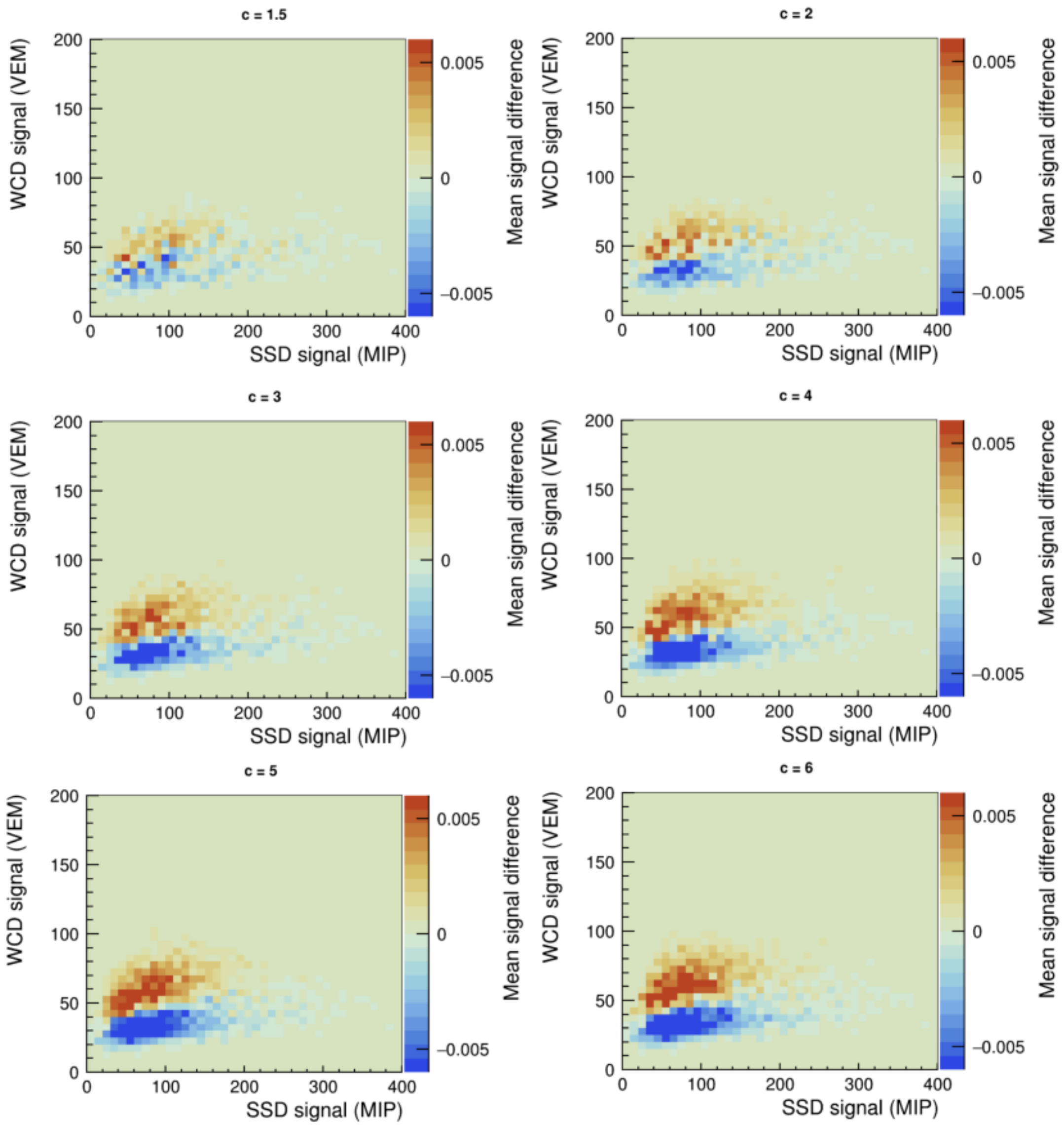




Quantifying the sensitivity

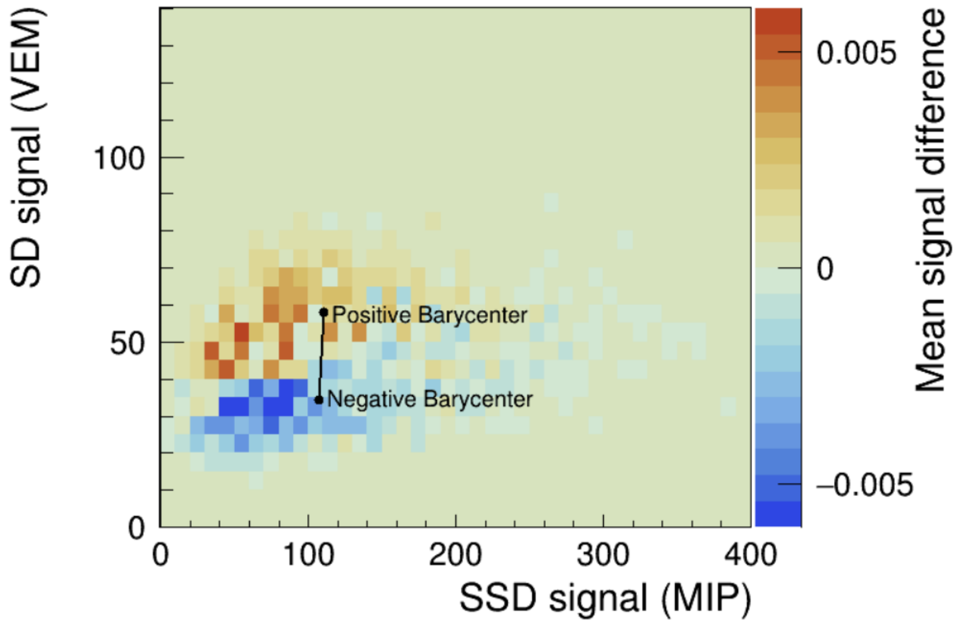
- $f(E) = \exp\left\{ \frac{\ln(c)}{b-a} \cdot (E-a) \right\}$
- Use different values of parameter c
- Quantify the response of the detectors to the modifications

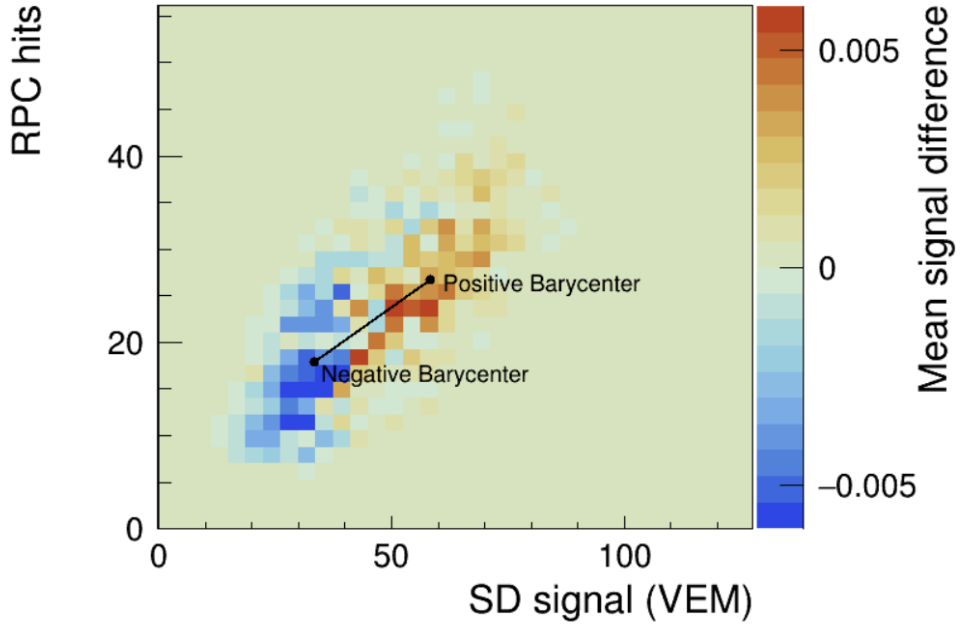




Quantifying the sensitivity

- The goal is to find a variable that can relate detector sensitivity with the magnitude of the modification
- Define two sets to separate bins with positive and negative values and take the barycenter of each
- From here we can consider two quantities:
  - The **distance** between the barycenters which is proportional to parameter c
  - The **angle** corresponding to the slope of the line formed by these two points

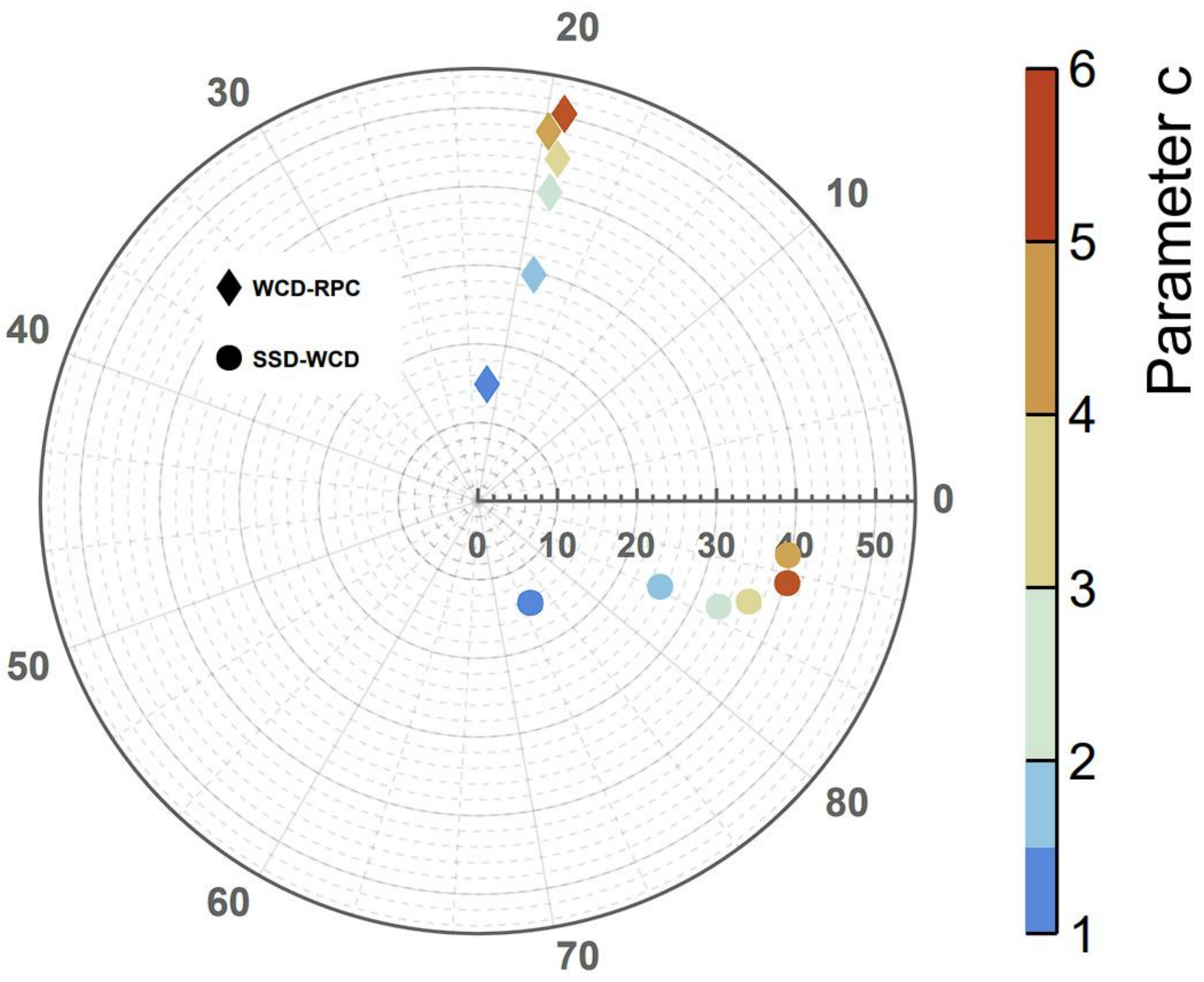




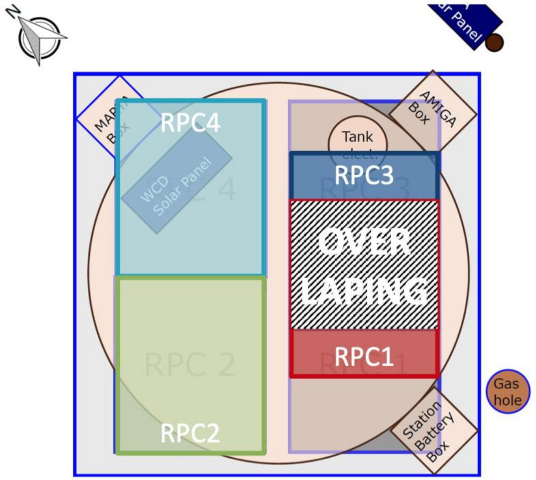
Quantifying the sensitivity

- As expected, distance between barycenters seems to be proportional to the parameter c
- WCD-RPC has a very well-defined angle between the barycenters, indicating the correlation between detectors

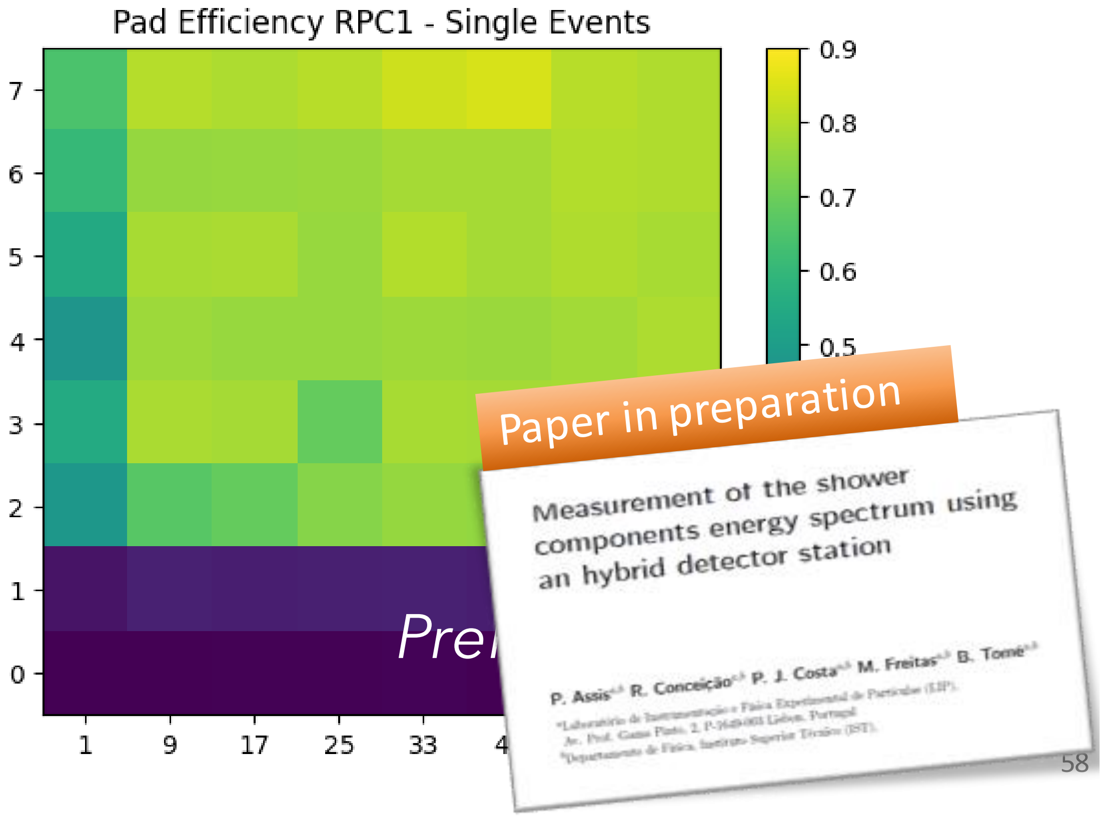
•**Distance ->** Intensity of the modification
•**Angle ->** Relative information on the detectors and types of modifications



MARTA @ Peter Mazur SD station



- **Peter Mazur: First MARTA station being commissioned and taking data**
- First SD-MARTA data being analysed showing a stable RPC behaviour
- Possibility to apply the method shown in this presentation in this single R&D station



Conclusions

- Auger data from phase-I raised new puzzling questions
- Great effort to increase data quality and address systematic uncertainties
- Studies to disentangle primary variations from Shower development ongoing
- MARTA allows to provide direct information from muons crossing the tanks
- Even with only one station can give important contributions

Plans for the future

- Operate, test and explore PeterMazur tank data
- Hodoscope (?) for ML applied to shower events
  Engineering necessary
- WCD and SSD response studies
- Enlarge the Engineering array:
  - Twin station nearby with full area
  - Other stations on the SD1500 array

Thank you

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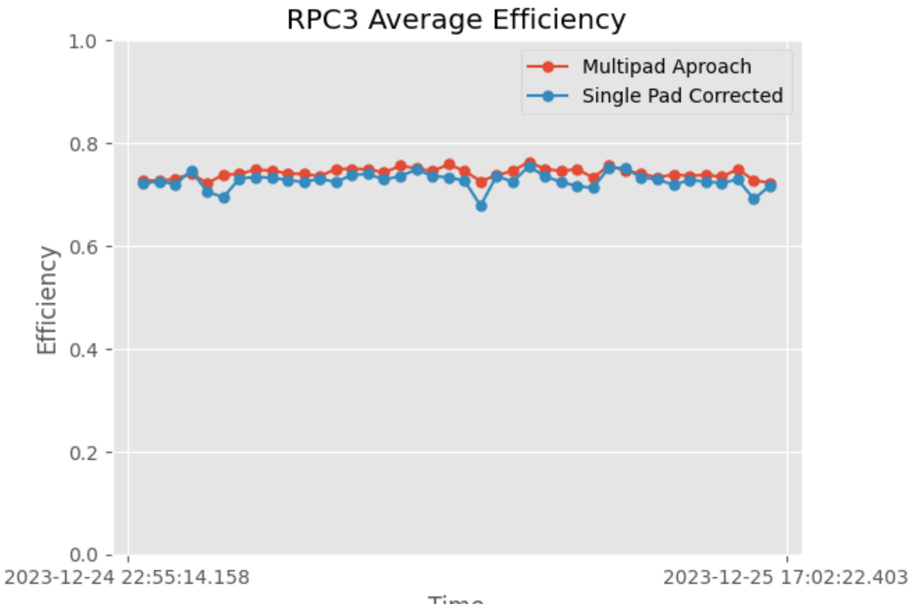
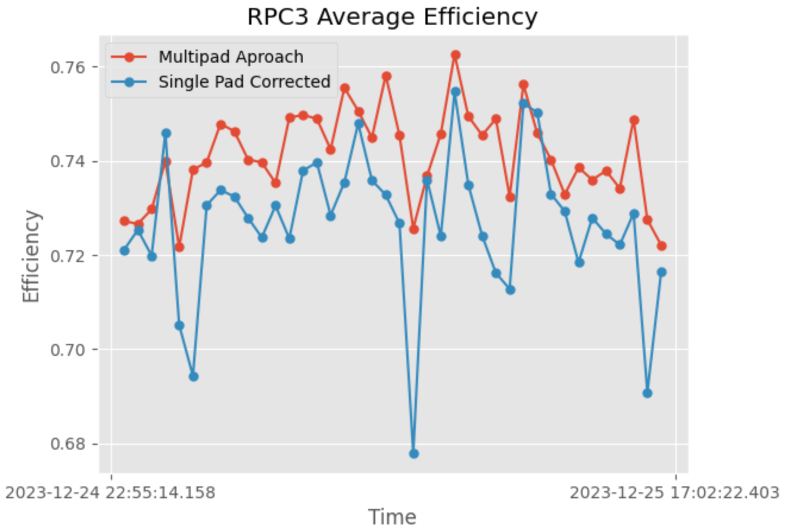
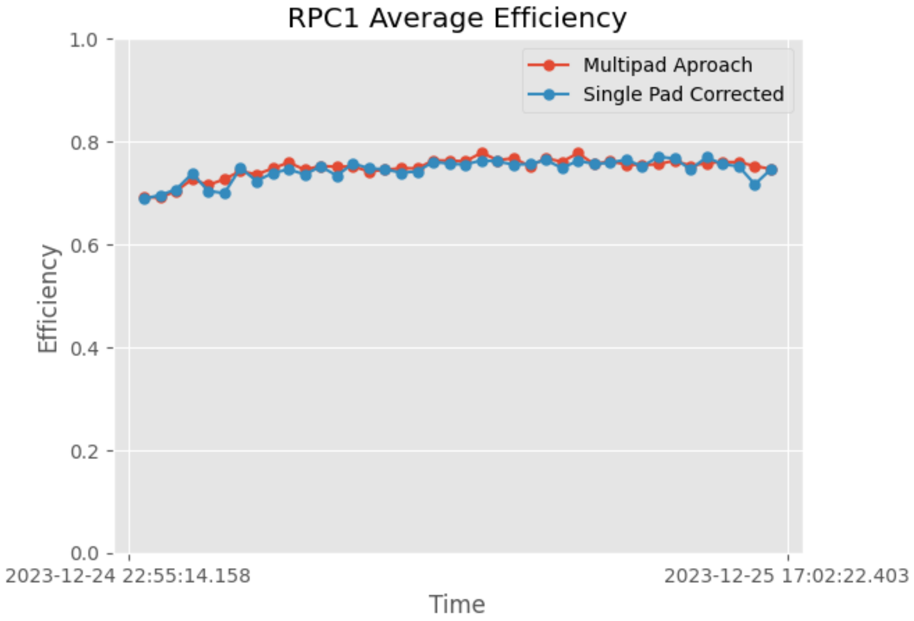
REPÚBLICA PORTUGUESA

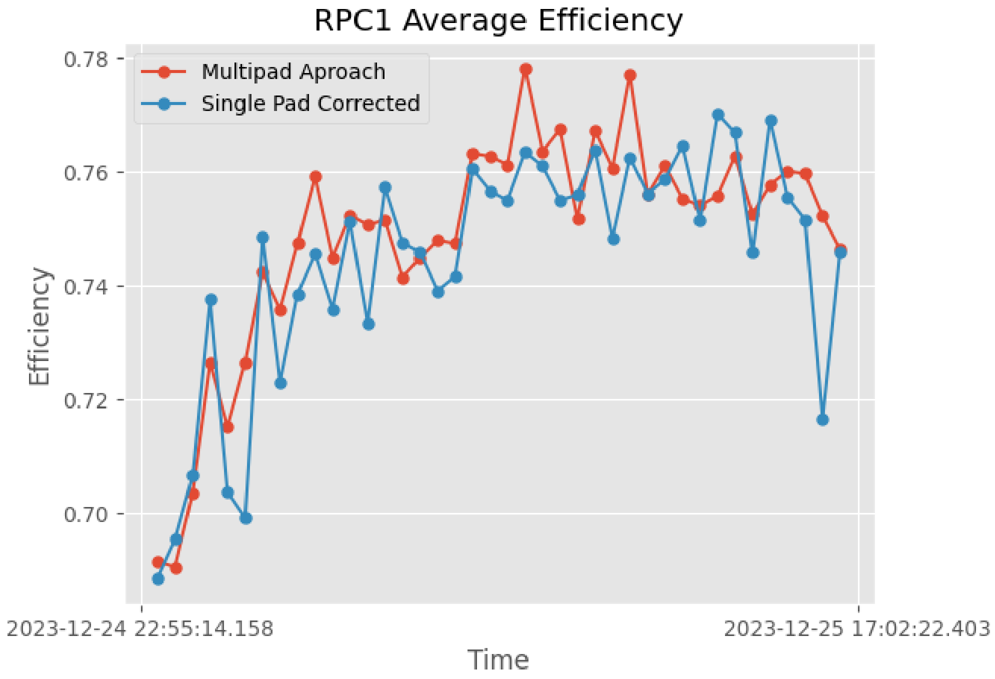
LIP

TÉCNICO LISBOA


RPC3 Average Efficiency
Multipad Aproach
Single Pad Corrected
Efficiency
1.0
0.8
0.6
0.4
0.2
0.0
2023-12-24 22:55:14.158
2023-12-25 17:02:22.403


RPC3 Average Efficiency
Multipad Aproach
Single Pad Corrected
Efficiency
0.76
0.74
0.72
0.70
0.68
2023-12-24 22:55:14.158
2023-12-25 17:02:22.403
Time


RPC1 Average Efficiency
Multipad Aproach
Single Pad Corrected
Efficiency
1.0
0.8
0.6
0.4
0.2
0.0
2023-12-24 22:55:14.158
2023-12-25 17:02:22.403
Time


RPC1 Average Efficiency
Multipad Aproach
Single Pad Corrected
Efficiency
0.78
0.76
0.74
0.72
0.70
2023-12-24 22:55:14.158
2023-12-25 17:02:22.403
Time

- Designed for the ATLAS detector;
- 64 input channels;
- 64 trigger outputs;
- Able to measure charge.

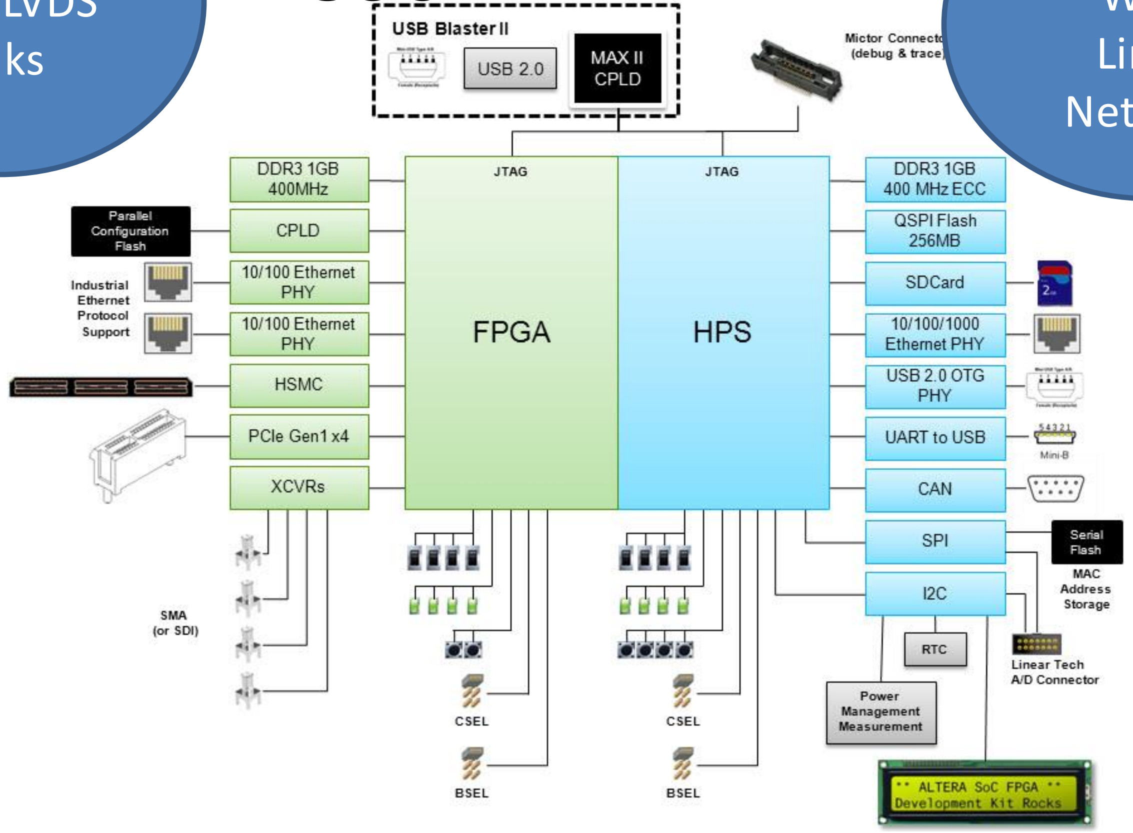
Area:16 mm^2;
Power consumption: 200 mW ➔ 3.5 mW per channel;
Power supply: 3.5 V.

Central unit

FPGA with FAST LVDS links

Cyclone V SOC

Computer With Linux Network



Data

Trigger

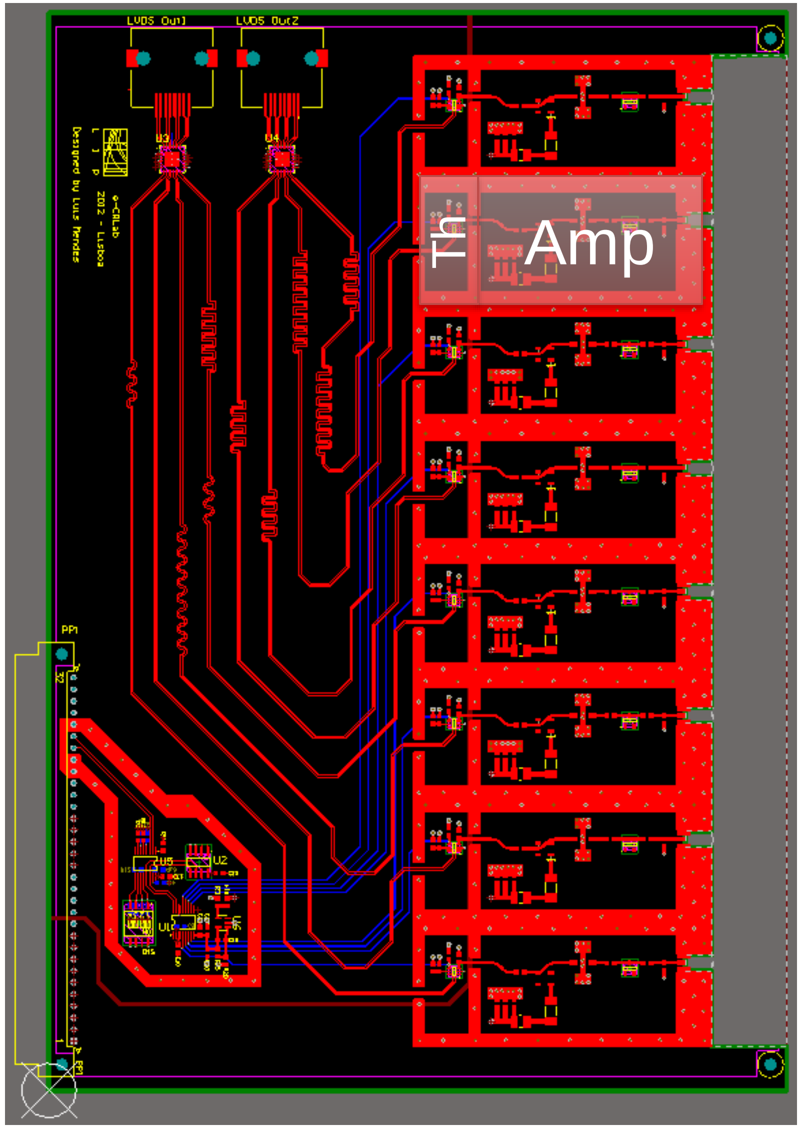
Synchro

Control

(LVDS links)

Being developed for Auger-MARTA

Front-End



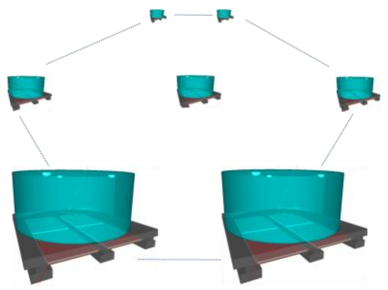
6U form factor

40 boards produced
Board tested with success at
Lx, Coimbra

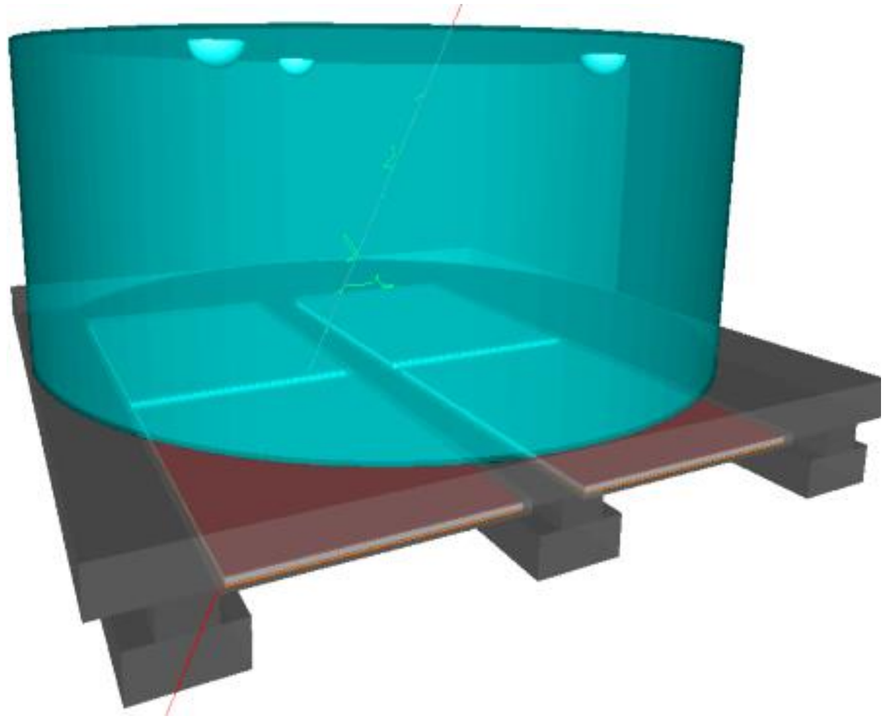
Gianni Setup

The MARTA Engineering Array

FCT – FAPESP project
(Portugal – Brasil)



Results from a specific call FAPESP-FCT
- RPC R&D
- RPC technology @ Brasil
- Build RPC detectors
- Install EA (hexagon) in Auger



Synergies with AugerPrime
- RPC hodoscopes for testing SSD
- Cross-calibration
- Physics at E=10^17 eV

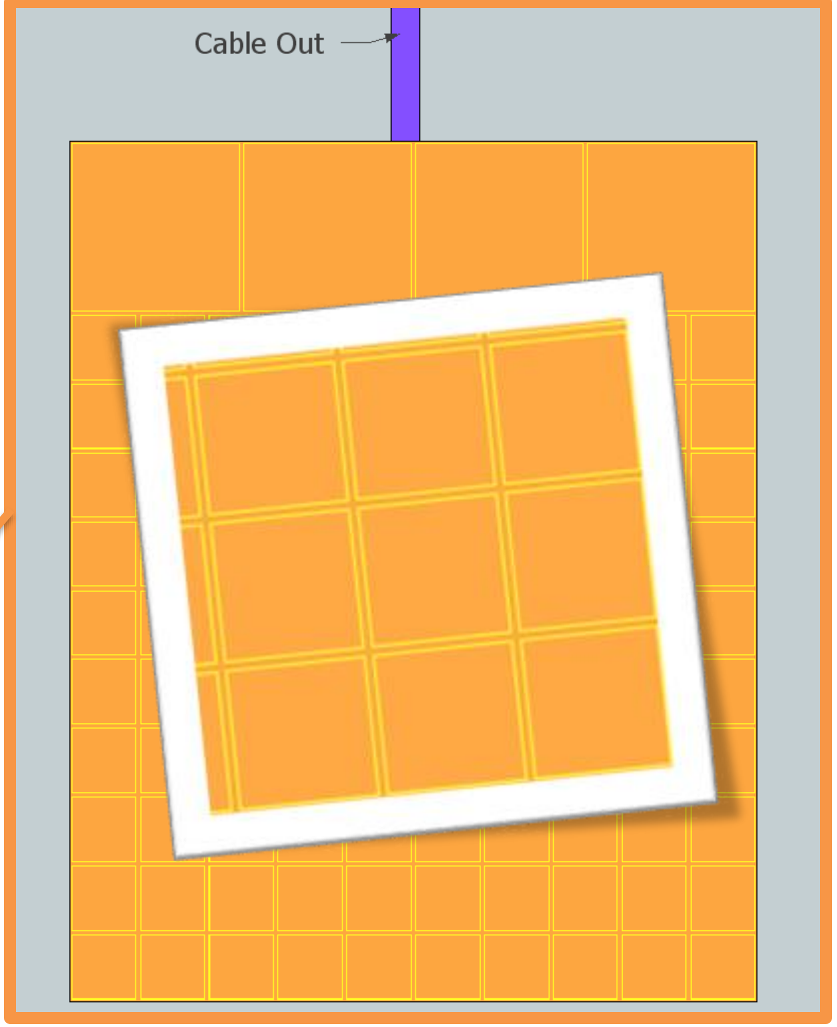
Install a unitary cell (hexagon)
In the infill area, in AMIGA tanks

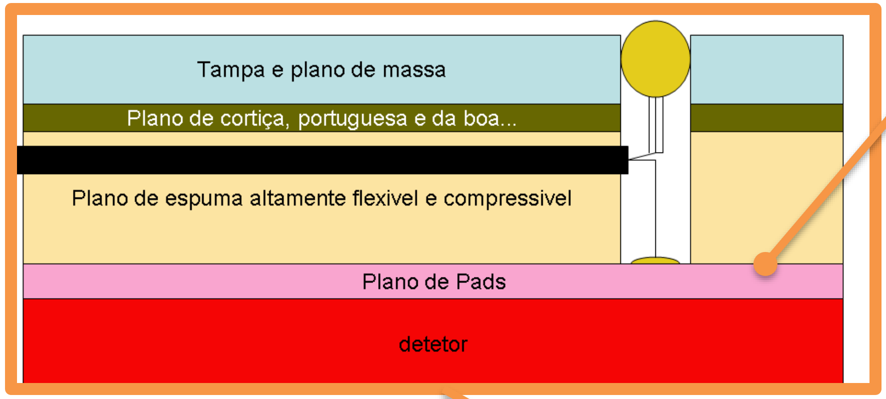
The MARTA module

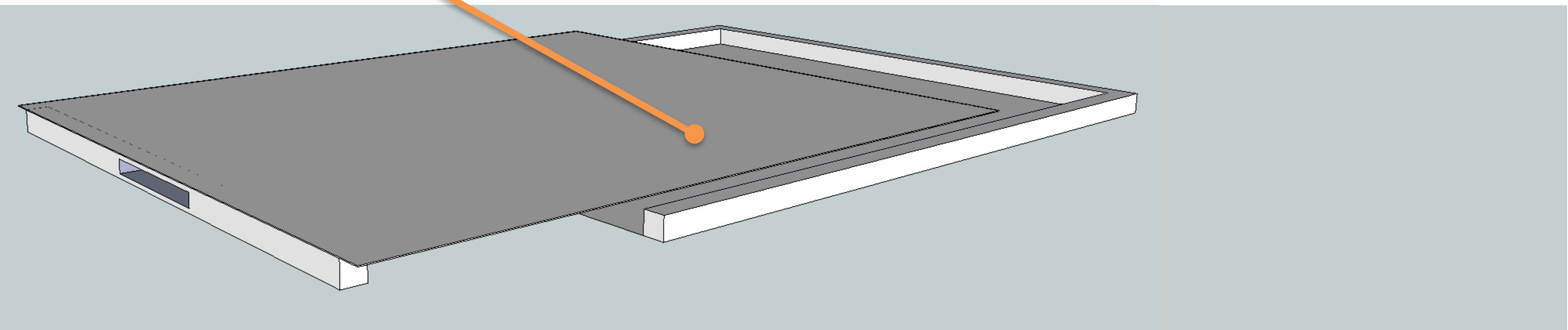
Pads & Housing

(first design)

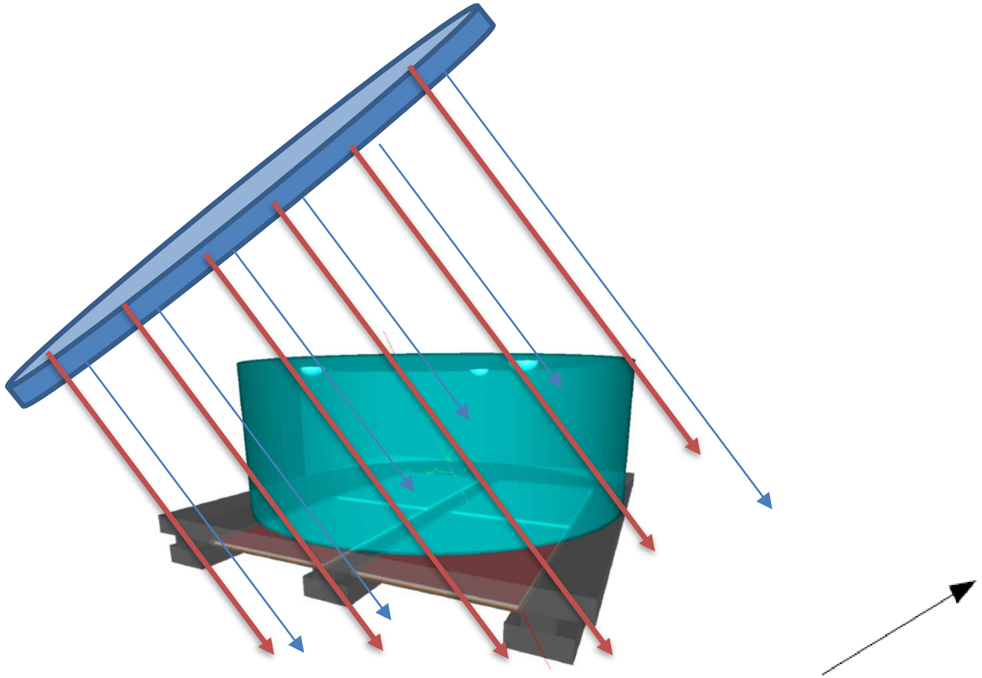
Pads are defined in PCB boards. Routed with 2mm leaving ground between them

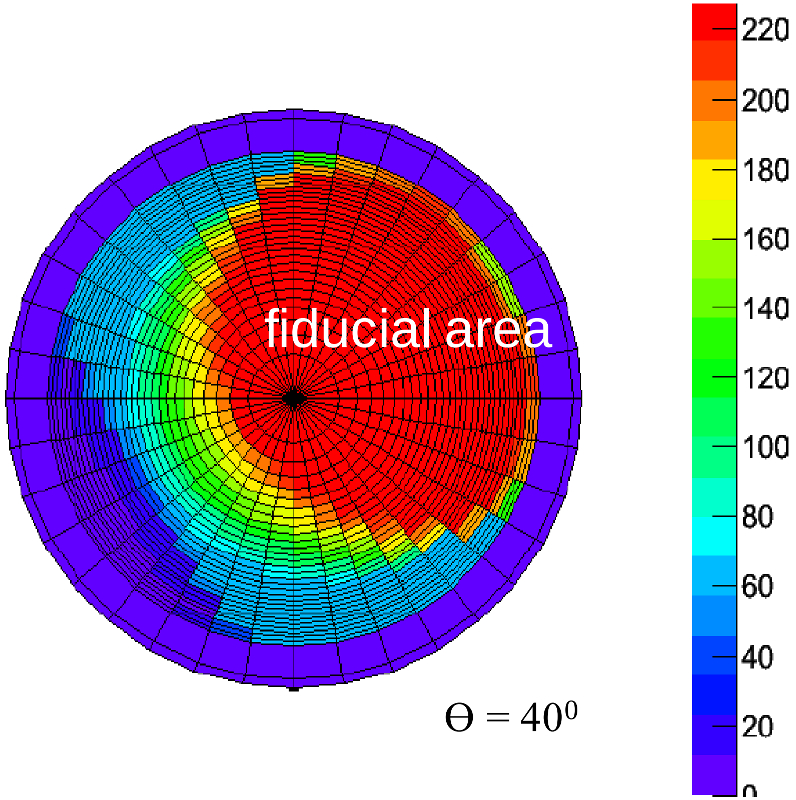






Add a segmented detector under the tank → get only the muons

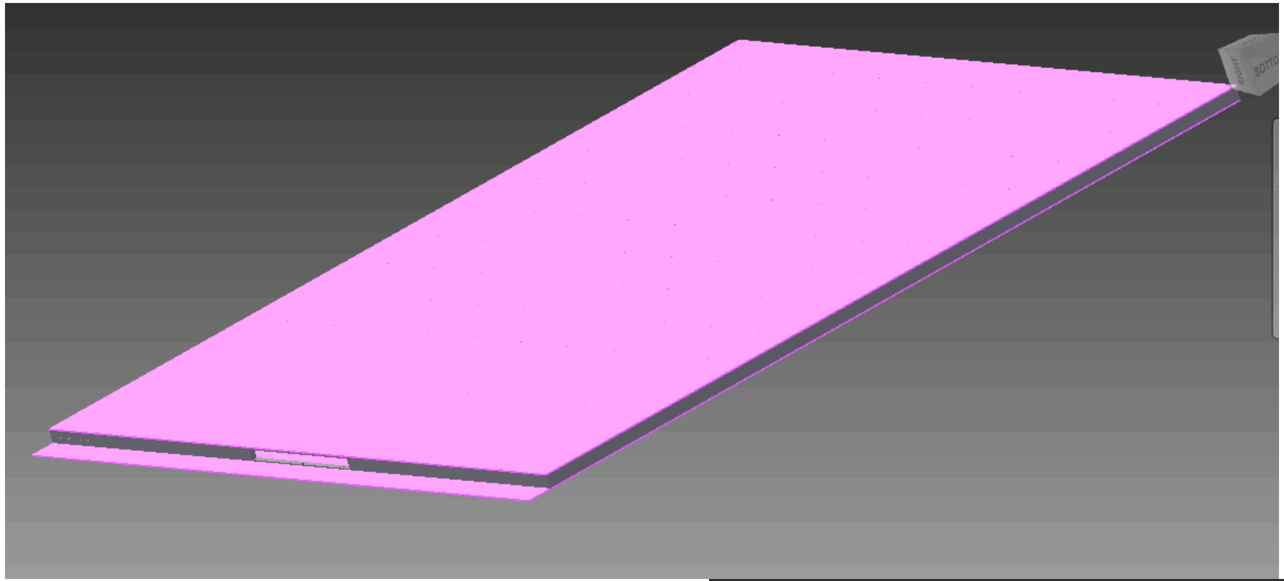


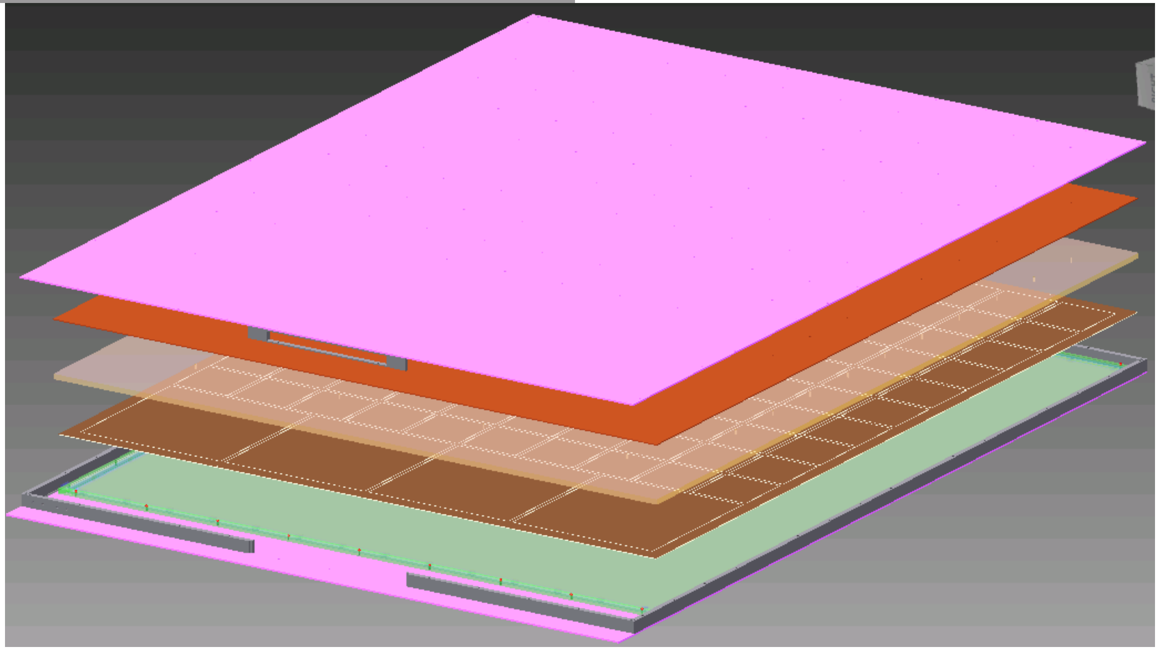


$\Theta = 40^0$

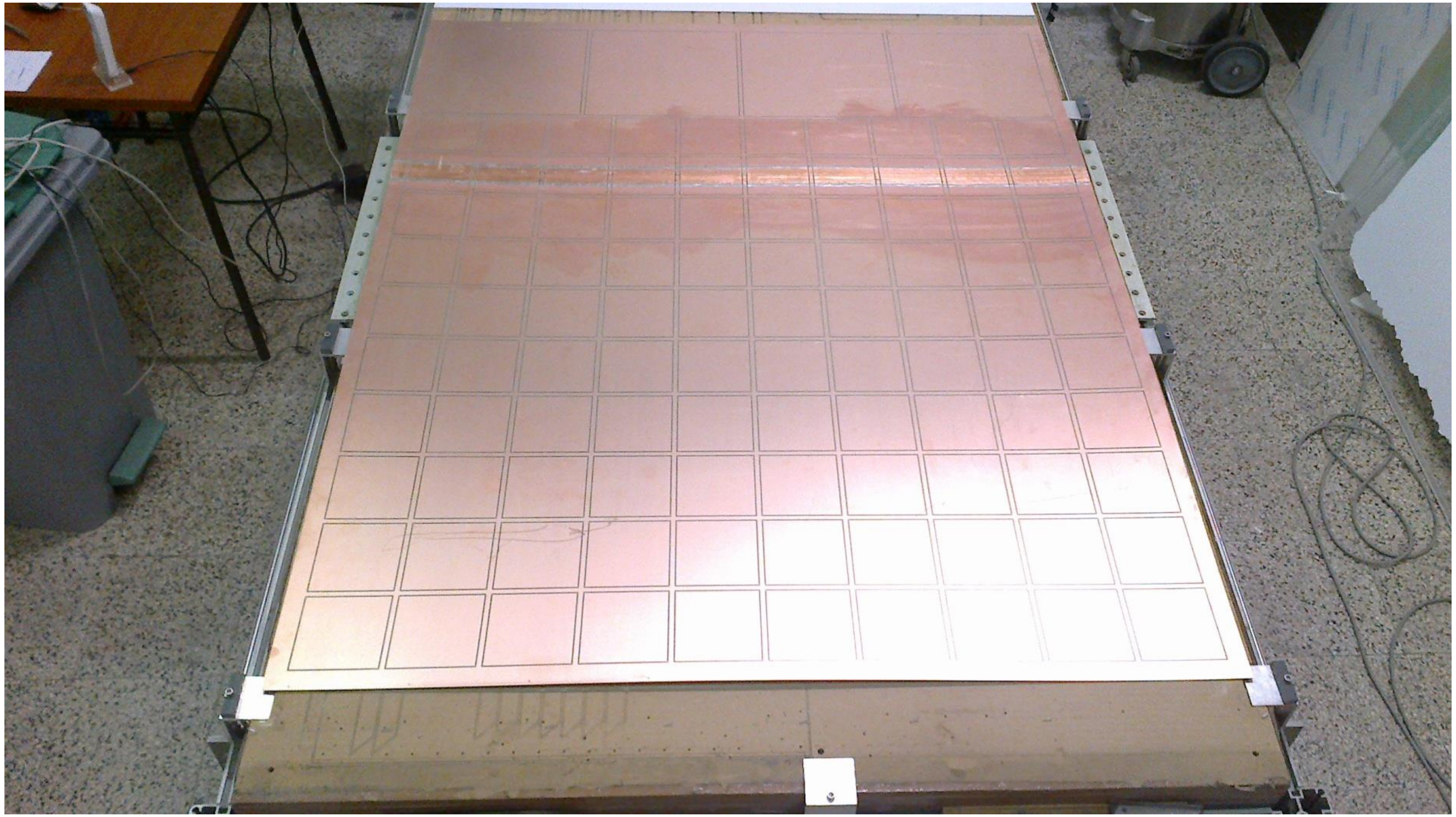
The amount of material crossed can be accurately computed for each pad and each shower geometry

RPC Module





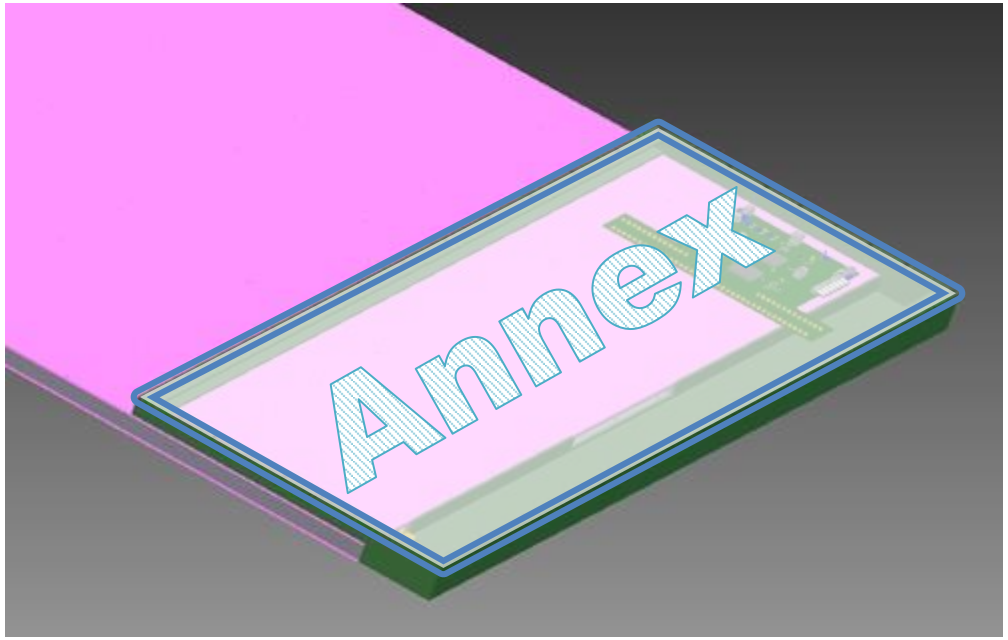
Read-out: Segmentation



The MARTA module

Each module contains:

- Sensitive volume
- Pickup system
- sensors
- Enclosure
- Annex:
  - DAQ
  - HV
  - PSU
  - Control Board
  - Bubbler



Gas Volume: Coimbra
Gas control: Coimbra
HV: Coimbra
Electronics: Lisboa
Housing: São Carlos
Integration: São Carlos, Rio

Script:

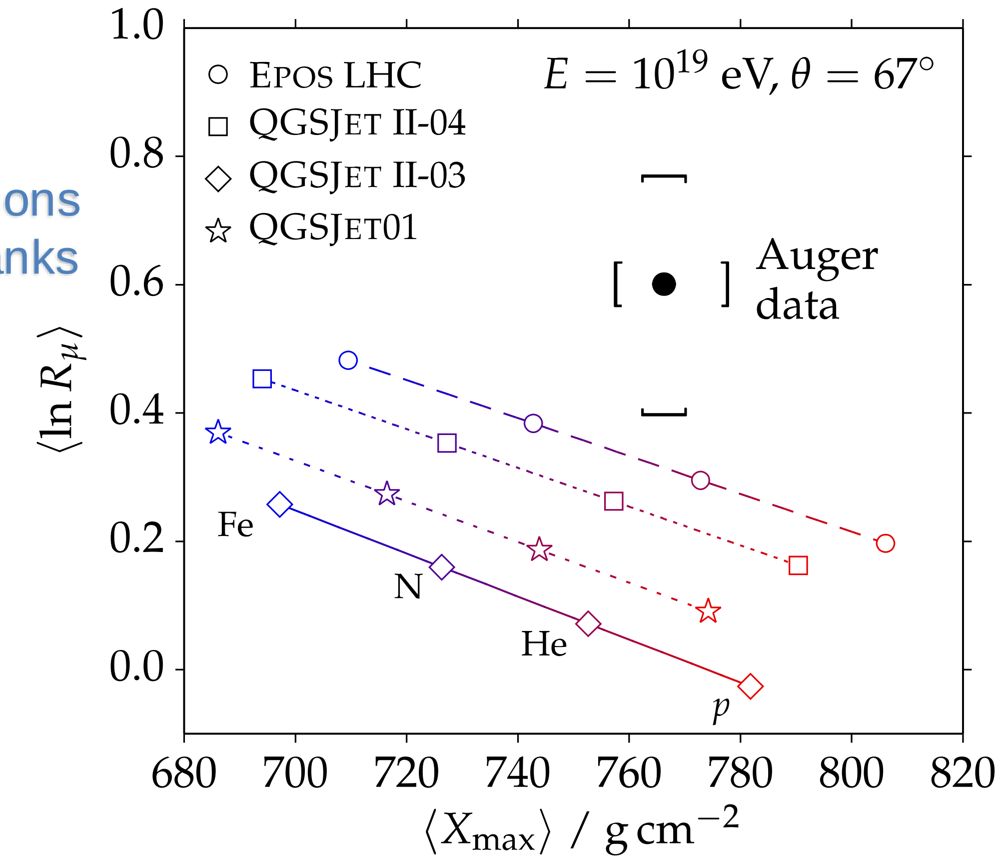
- UHECR
- Auger
- Muon Puzzle
- (Auger Prime)
- Marta (Paper)
    - Concept
    - Gianni
    - Field (Peter Mazur)
    - Efficiency
    - Milton
- Conclusion
    - Marta R&D
    - Hodoscopios ML + calib showers
    - EA aberto but on SD-1500

The muon puzzle

- Simplistic astrophysical scenarios: Proton or Iron + GZK effect
- The change in spectra can be due to source exhaustion, implying composition change
- Shower development models can mimic different behaviours

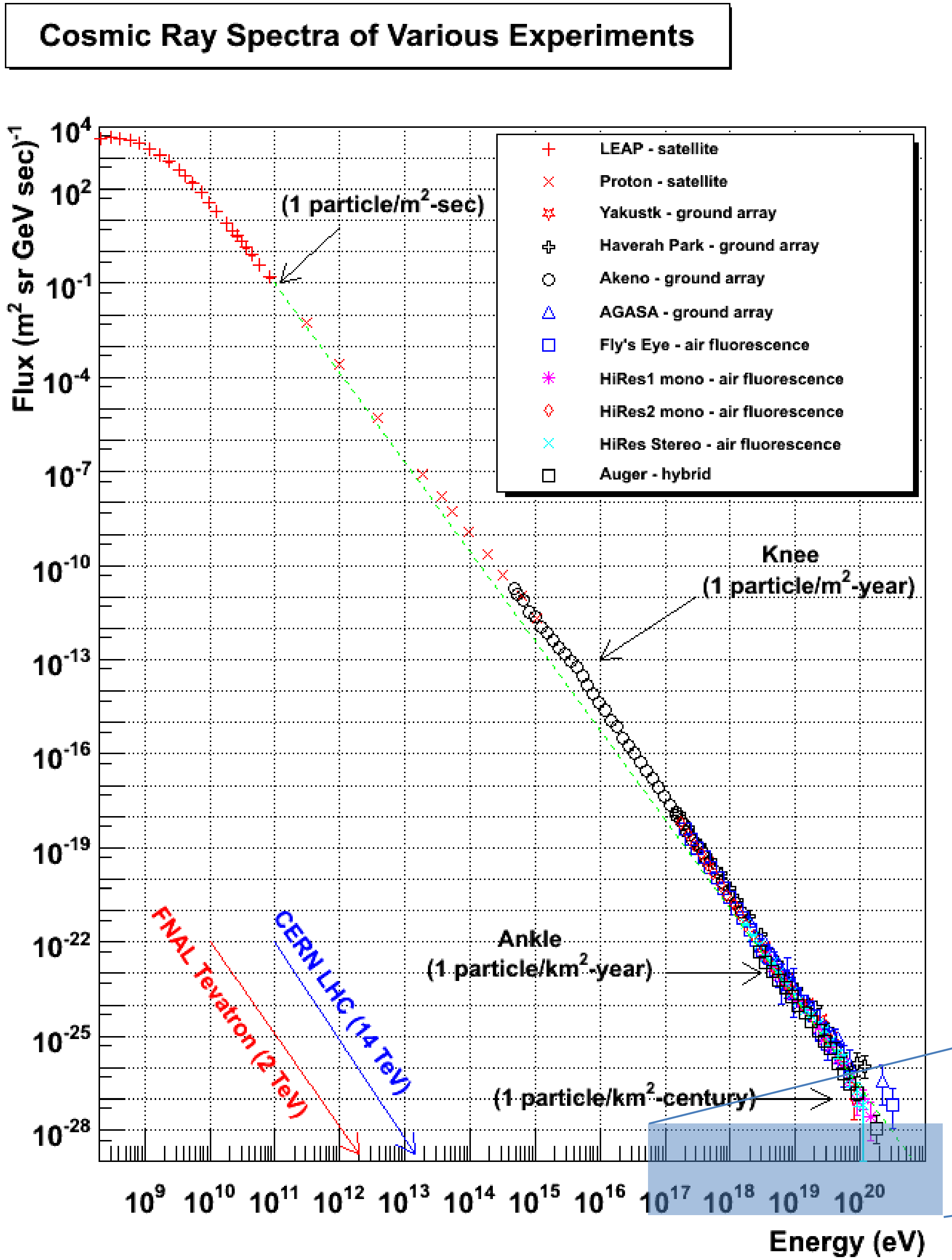
Primary composition is key! Muons can give a hint to the composition…
Auger data on muons:

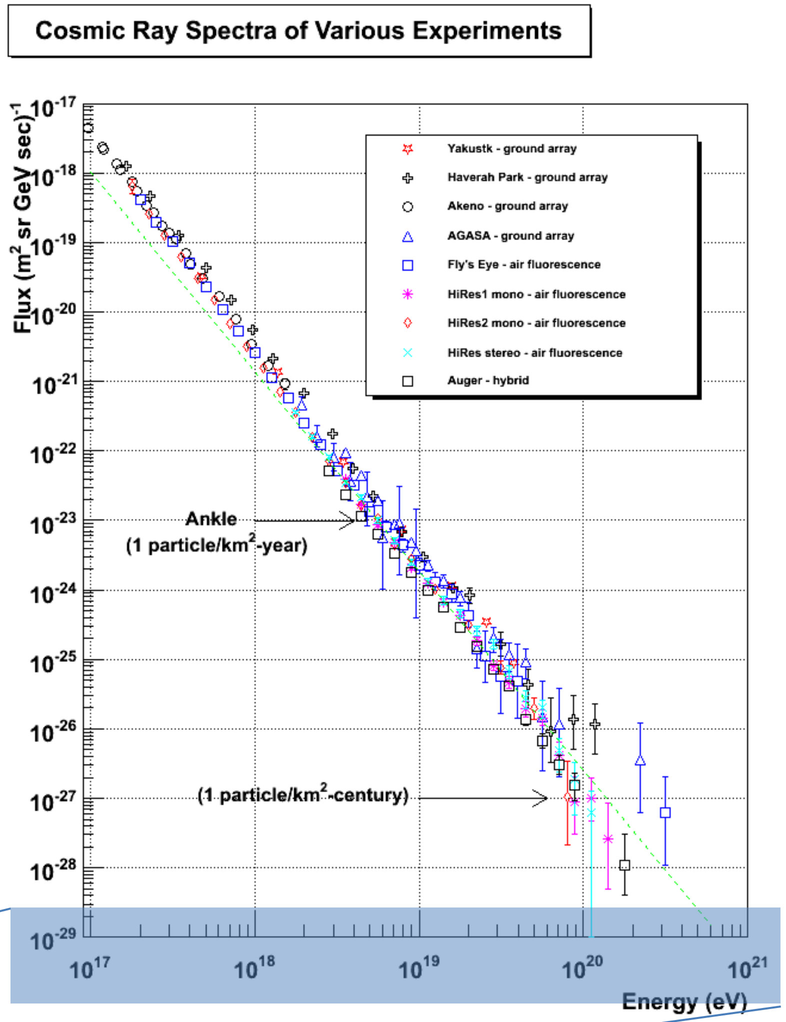
“number” of muons
Measured by tanks



Depth of shower – Measured by FD

Cosmic Rays – (rare) free energetic particles

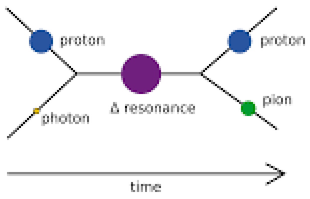


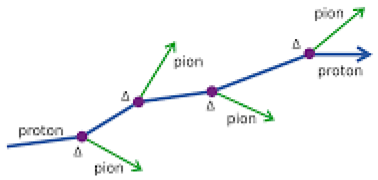


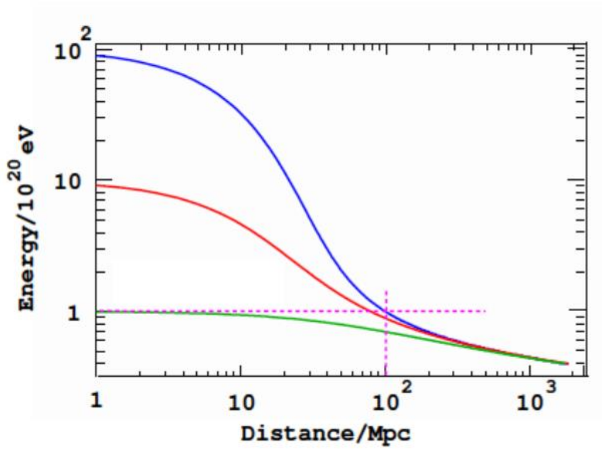
https://w eb.physics.utah.edu/~whanlon

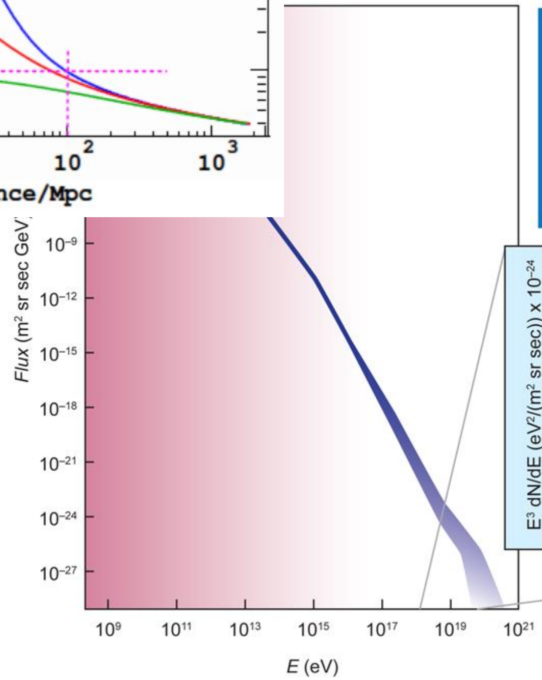
Cosmic Rays – particle physics in space

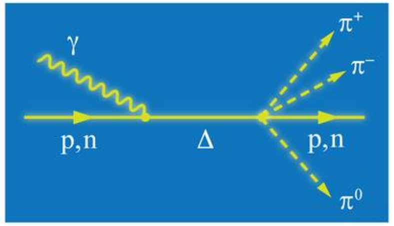
The GZK effect

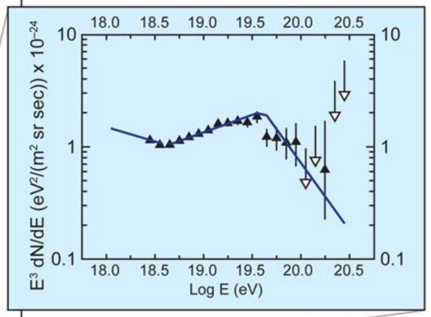


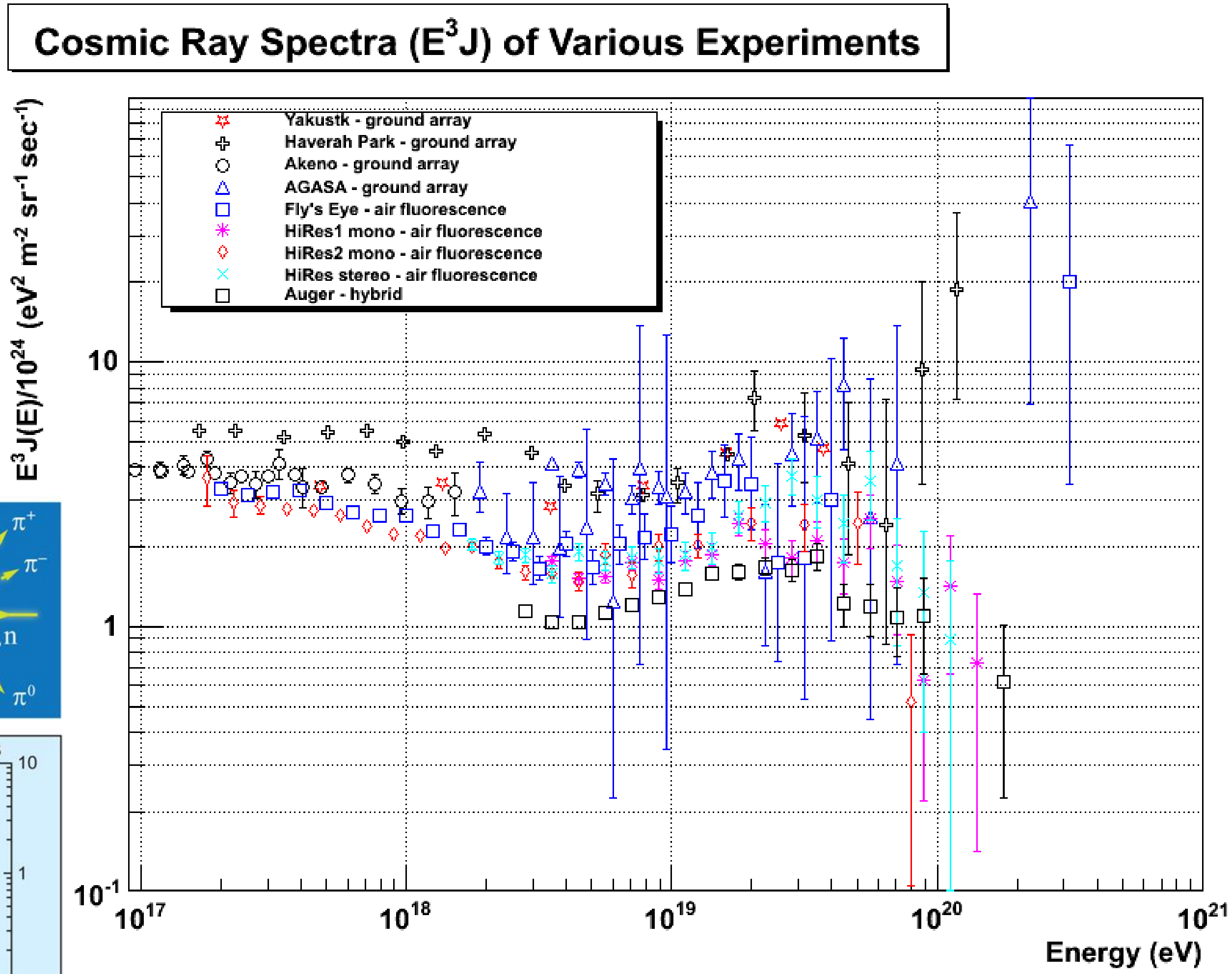








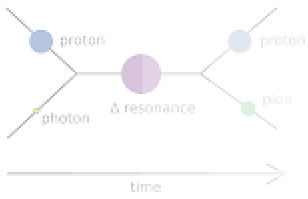


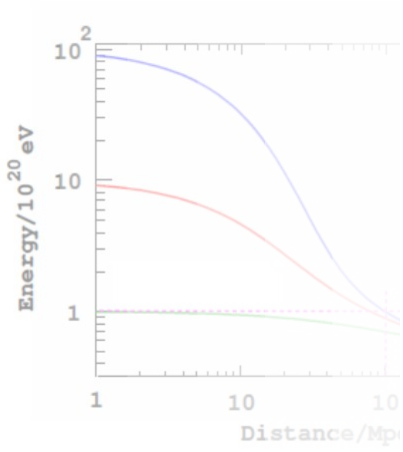


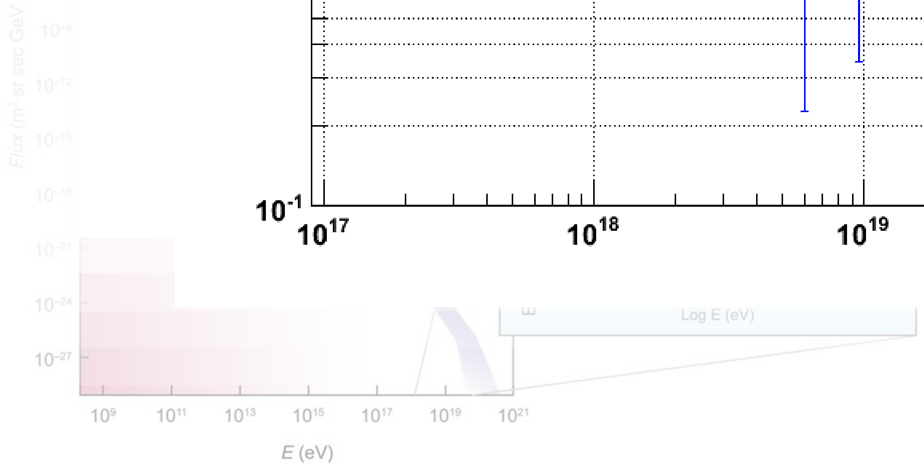
https://w eb.physics.utah.edu/~whanlon

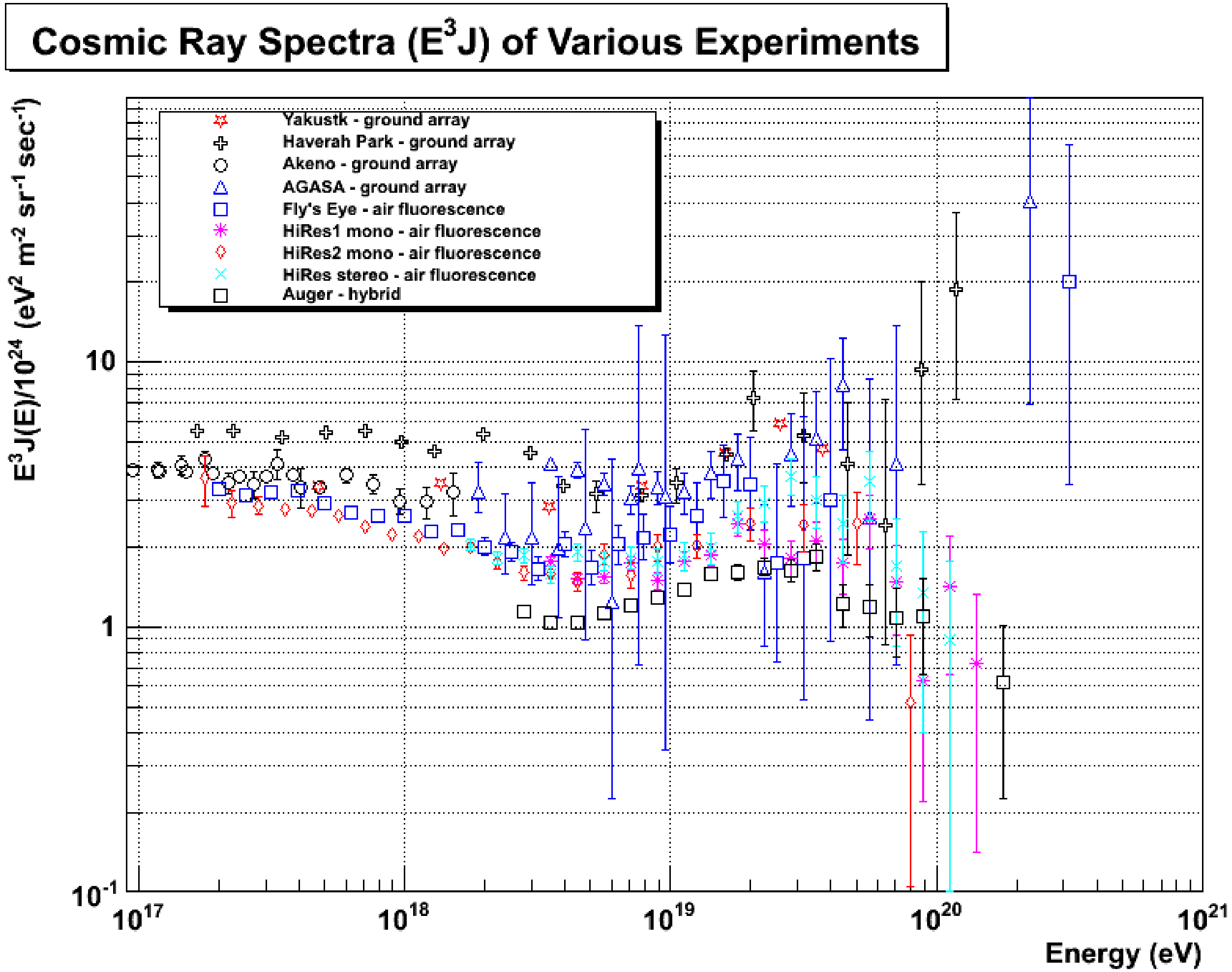
Cosmic Rays – particle physics in space

The GZK effect







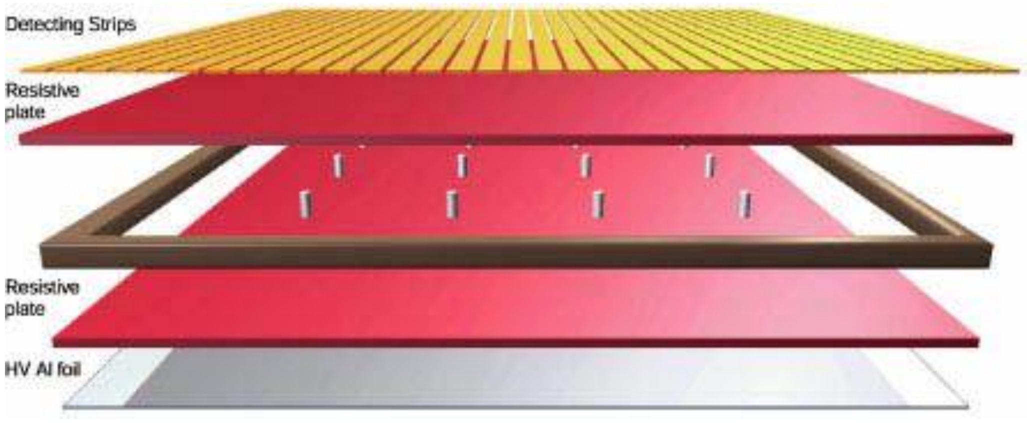


https://w eb.physics.utah.edu/~whanlon

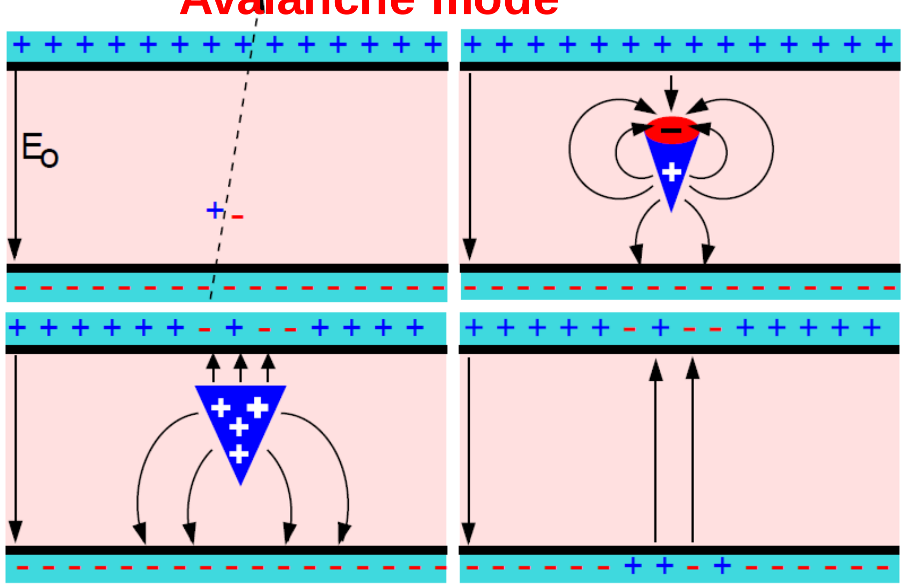
The chosen detector - RPC

Resistive Plate Chamber

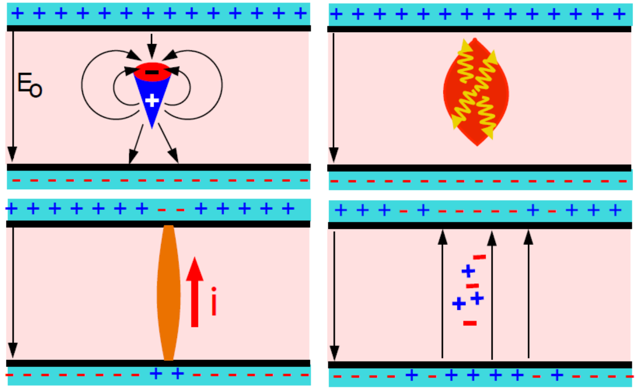
- Gaseous detector
- Planar geometry
- uniform electrical field imposed.
- High resistive plates in between the electrodes limit the avalanche current.
- Signal is picked up by the induction of the avalanche in the readout pads.



Avalanche mode



Streamer mode

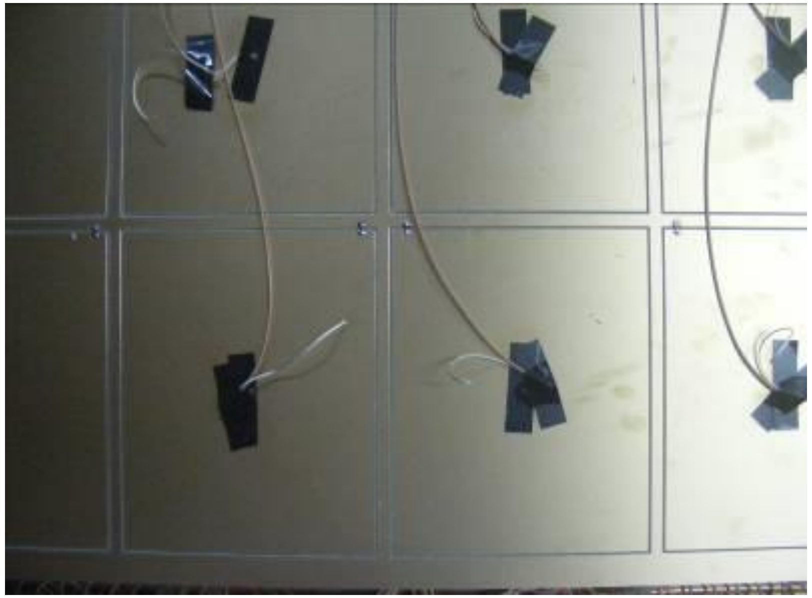


SIGNAL PICKUP MODULE

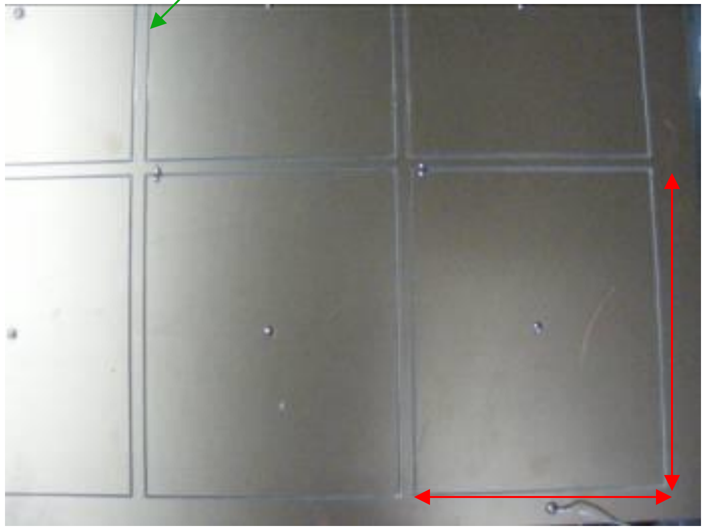
Total area 150x120 = 18000 cm^2

Area covered with pads, “efficient” area
64x18x14=16128 cm^2 ⇔ 90 % of the total area

Area covered with guard rings,
18000 - 16128 = 1872 cm^2 ⇔
10 % of the total area

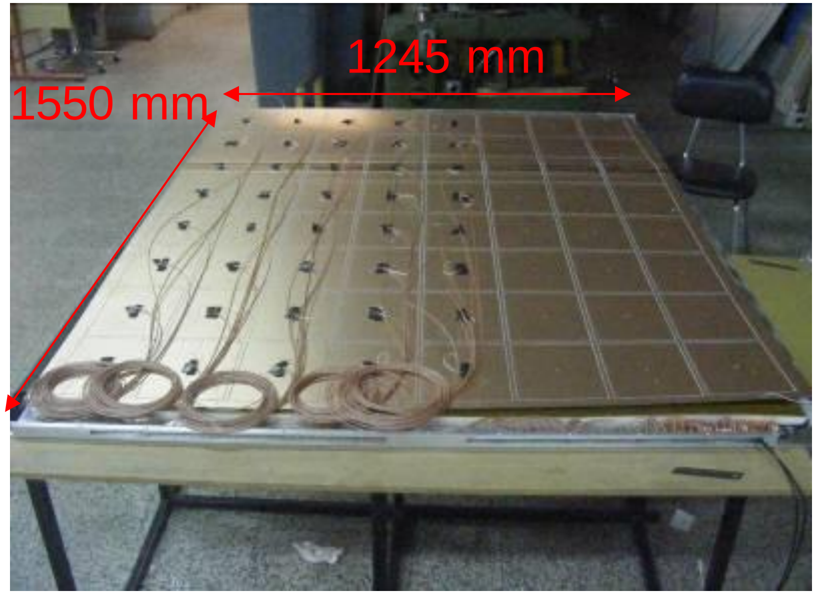


6 mm guard ring

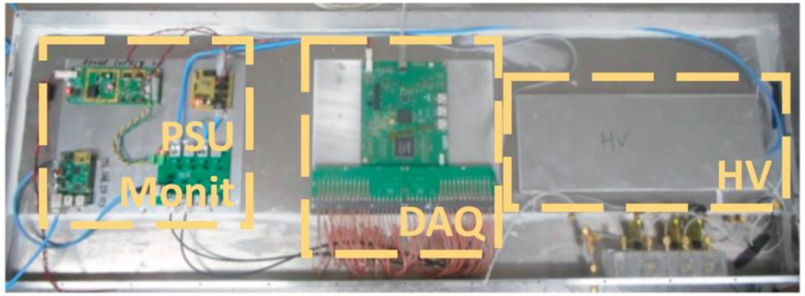


180 mm

140 mm

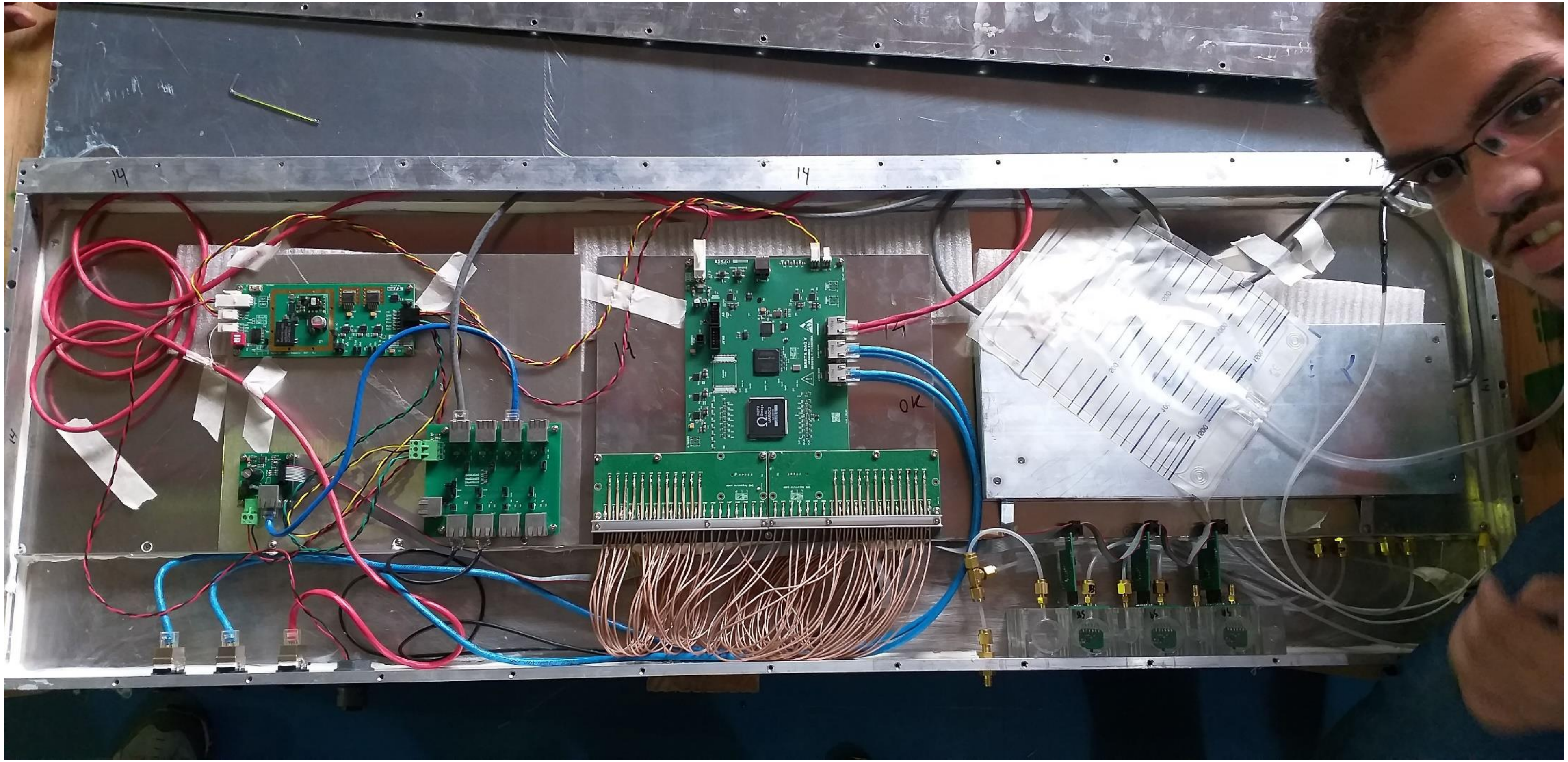


The RPC module



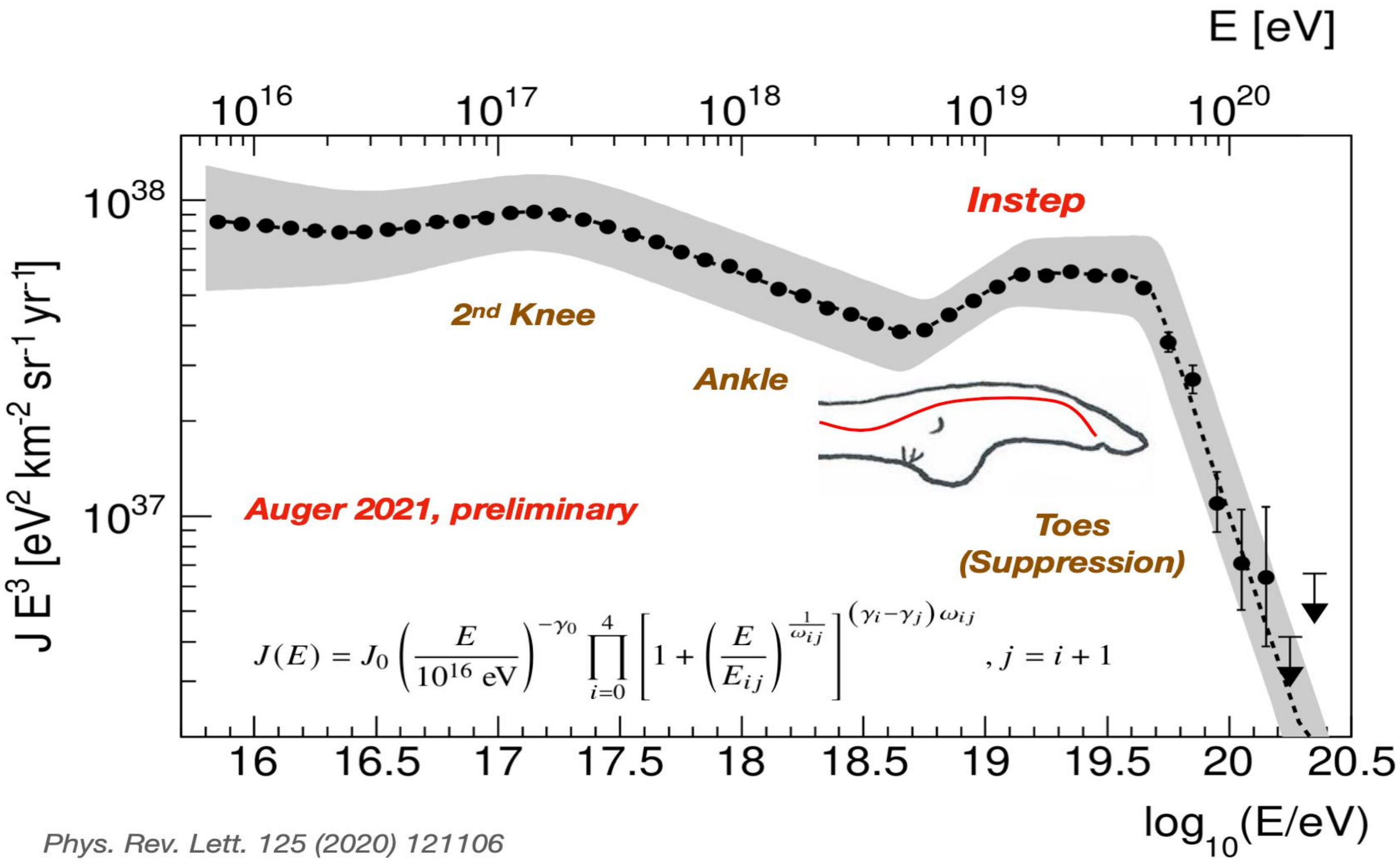
Electronics box (1285 x 407 mm^2)

Designed, developed, built @ LIP



Selected Results

Flux of Cosmic Rays

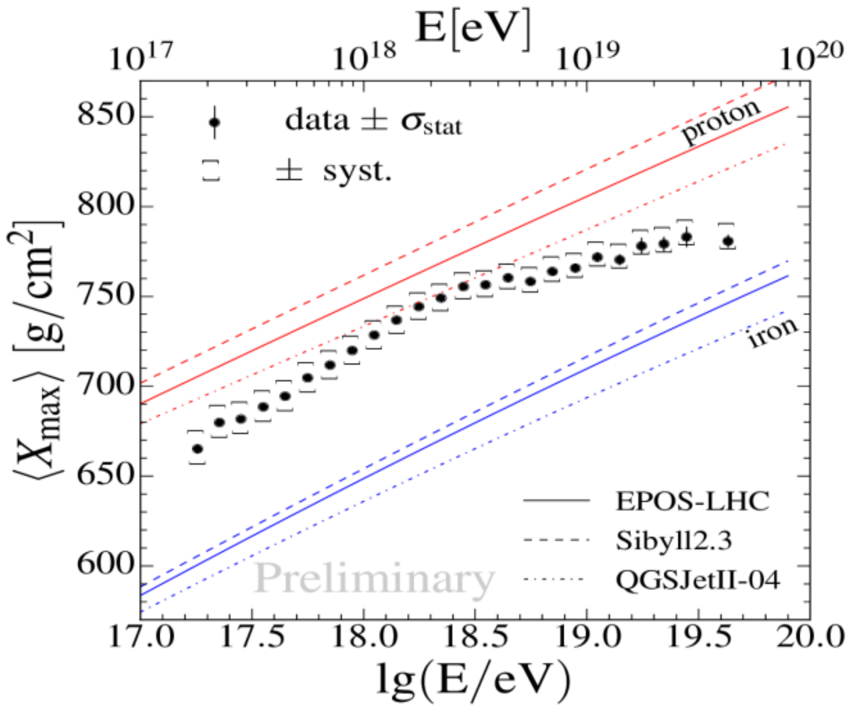


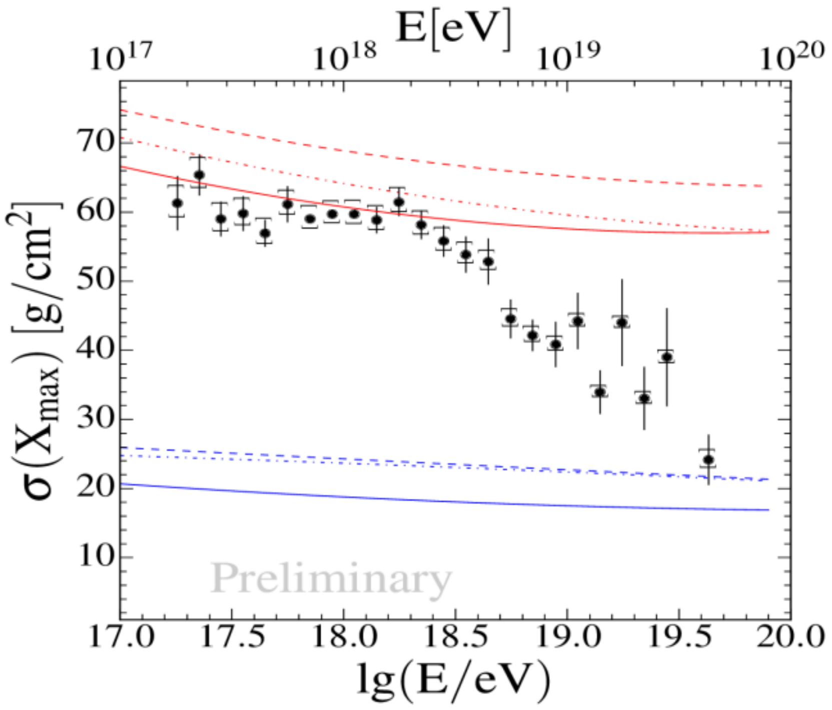
Phys. Rev. Lett. 125 (2020) 121106

Suppression clearly established

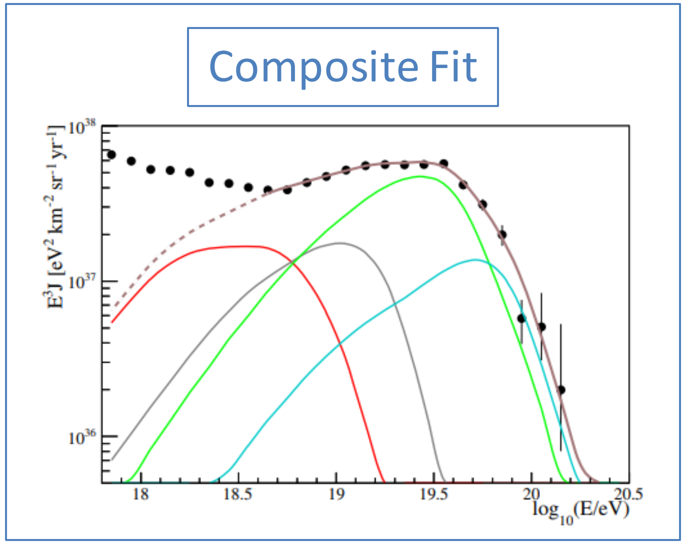
Elongation rate, the development of shower

Depth of shower related with nature of primary

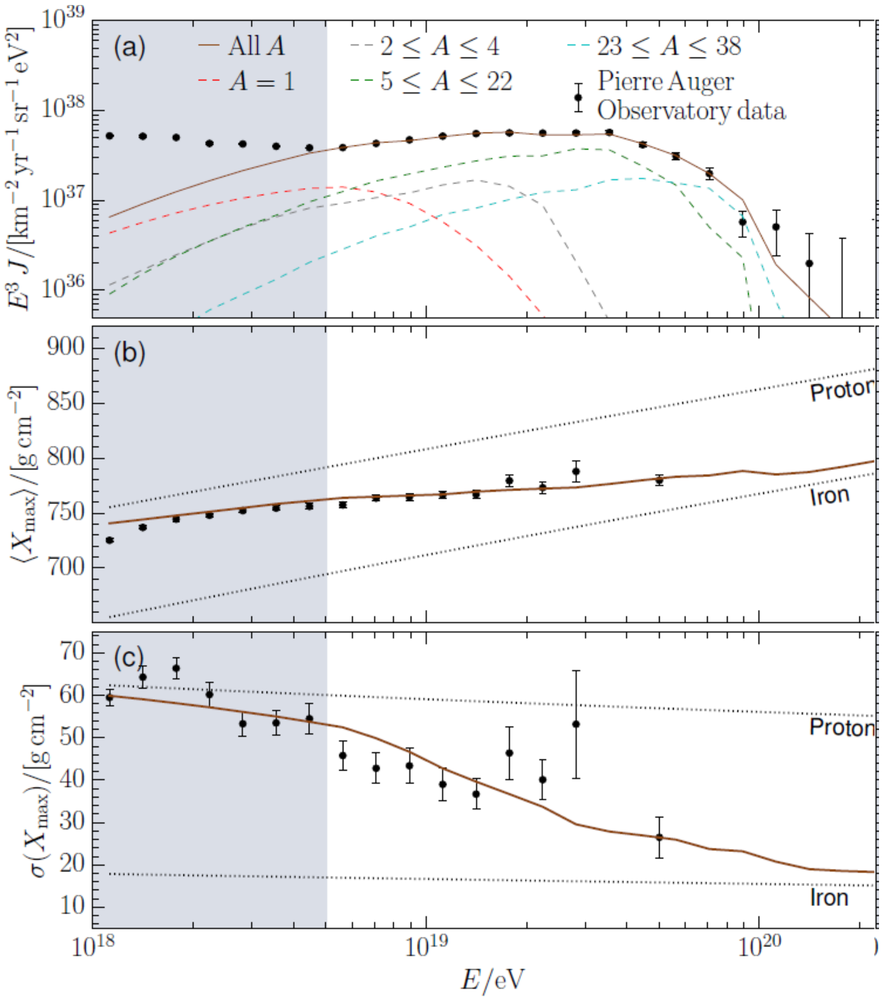


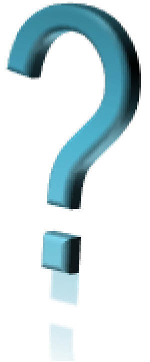


Transition to shallower showers



Combined fit





Can we explain the spectrum suppression via source exhaustion

Development of new observable

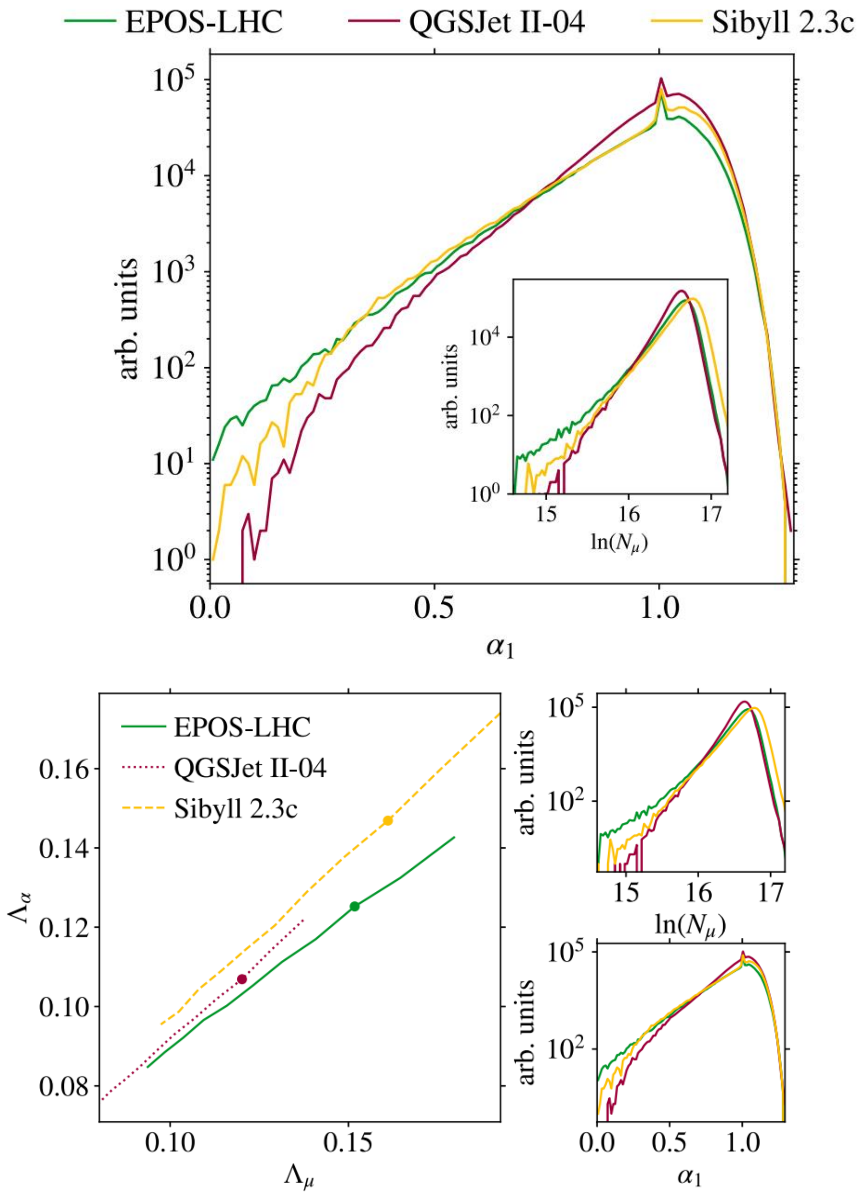
- Shower Physics and Data Analysis
  - Focus on the EAS muon distributions
- Hadronic Models and interface with accelerator measurements
  - Impact on showers

- Example:

Lorenzo Cazon, Ruben Conceição, Miguel Alexandre Martins, and Felix Riehn: "Constraining the energy spectrum of neutral pions in ultra-high-energy proton-air interactions", *Phys. Rev. D 103, 022001*

- Exploring the relation between tail of muon distribution and energy spectrum of pions from first interactions.

Shown for the first time that it is possible to access the first interaction multi-particle production properties!



Λ_μ Λ_α are the slopes of exp. fit

Measure Muons and its fluctuations

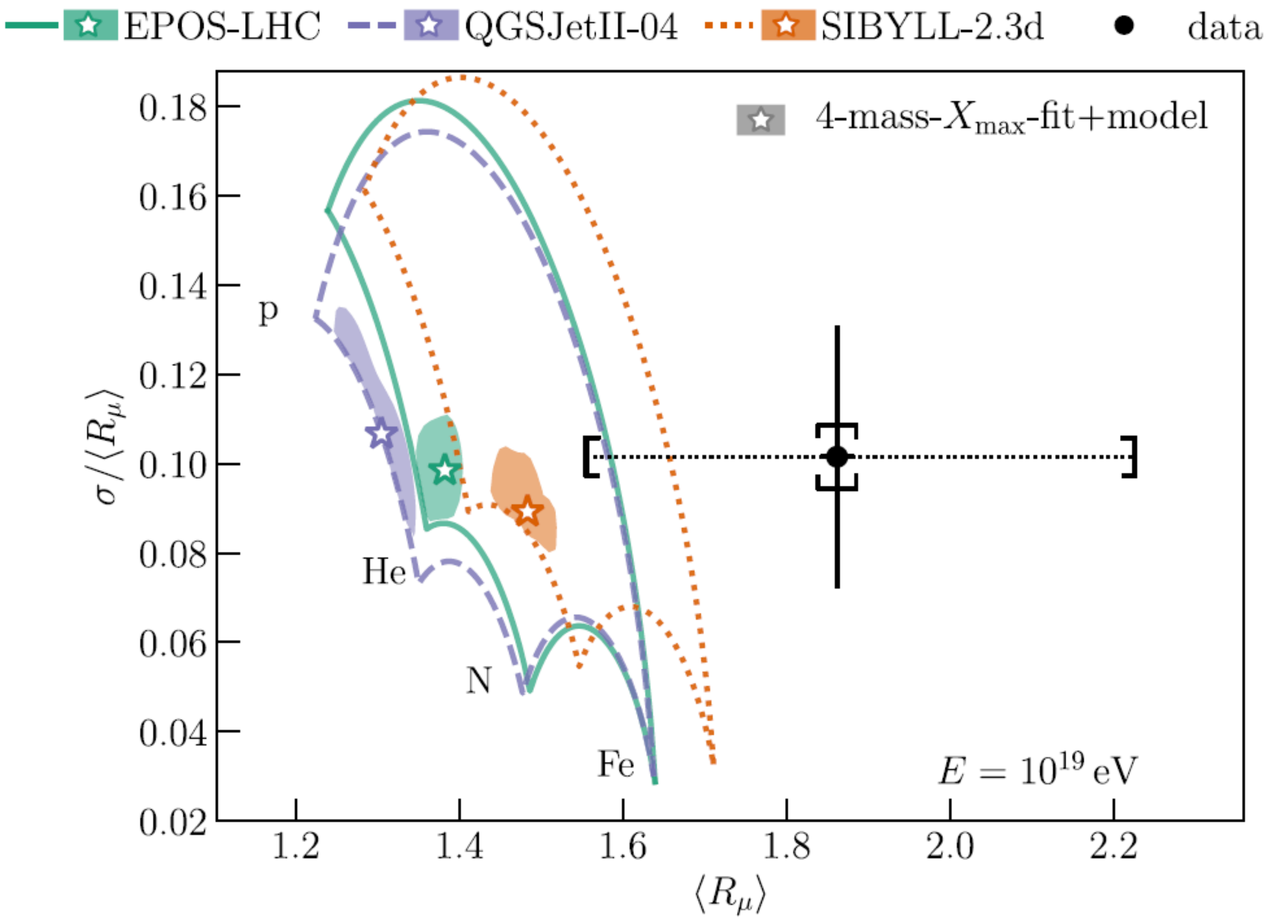
Improve the analysis to measure the fluctuation on the number of muons

For a limited set of events (inclined events), Auger can measure the muon content

Average is not compatible with models Underestimated in simulations

Fluctuations is compatible with models

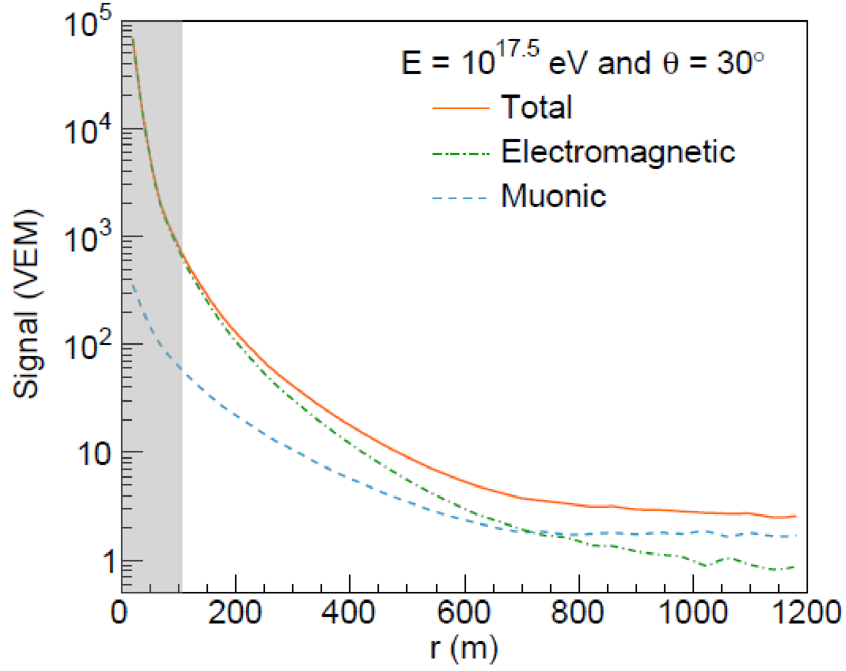
The Muon Puzzle



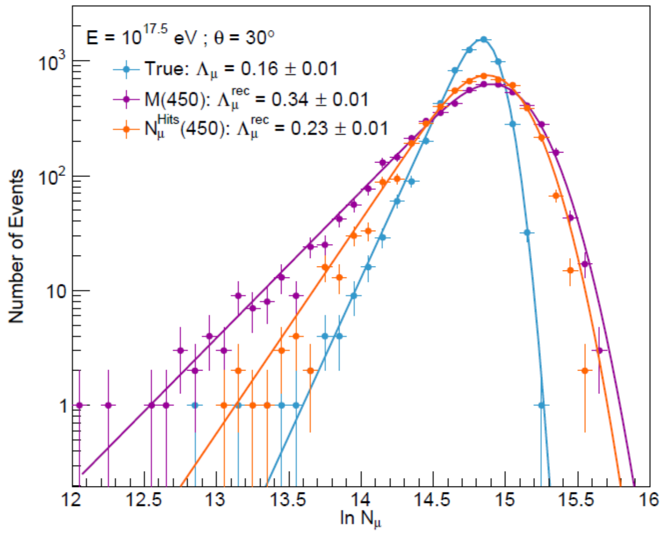
Phys.Rev.Lett. 126 (2021) 15, 152002

MARTA capabilities

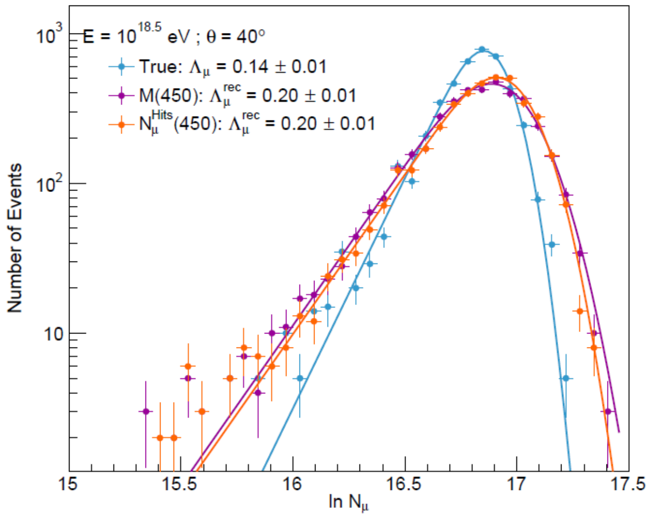
- Muon distributions with MARTA
- Can we measure the distribution tail and access the first interaction pion energy spectrum?
- Yes, provided that we get enough muons
  - Need to measure muons near the shower core



E=10^17.5

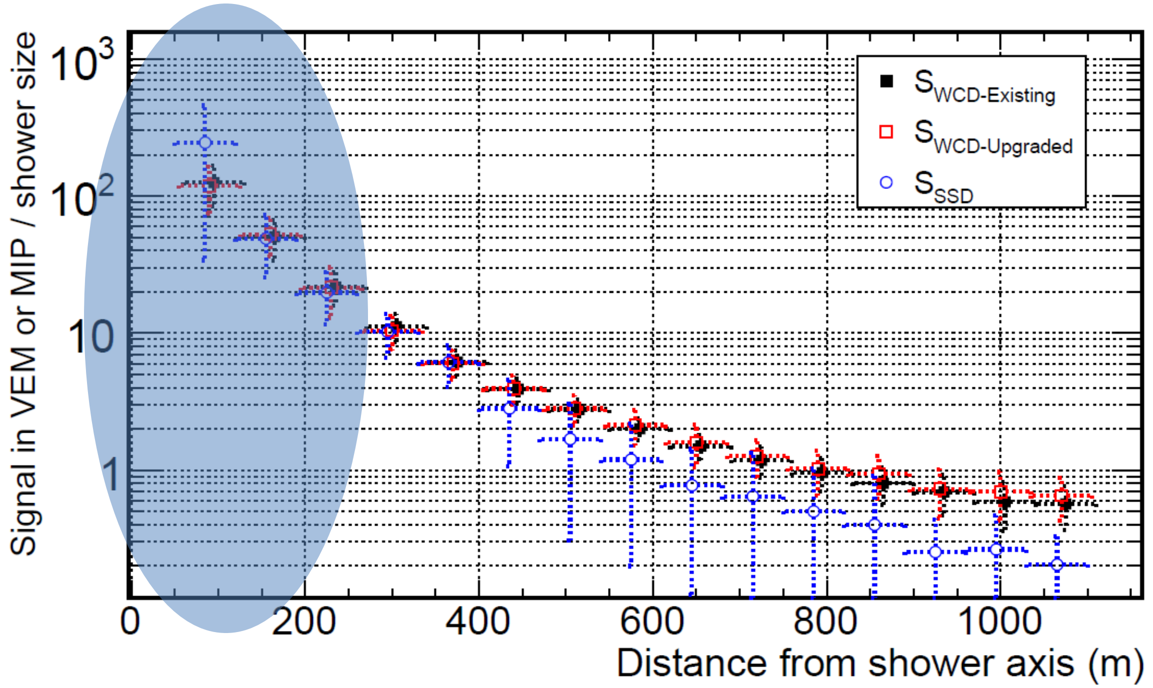


E=10^18.5



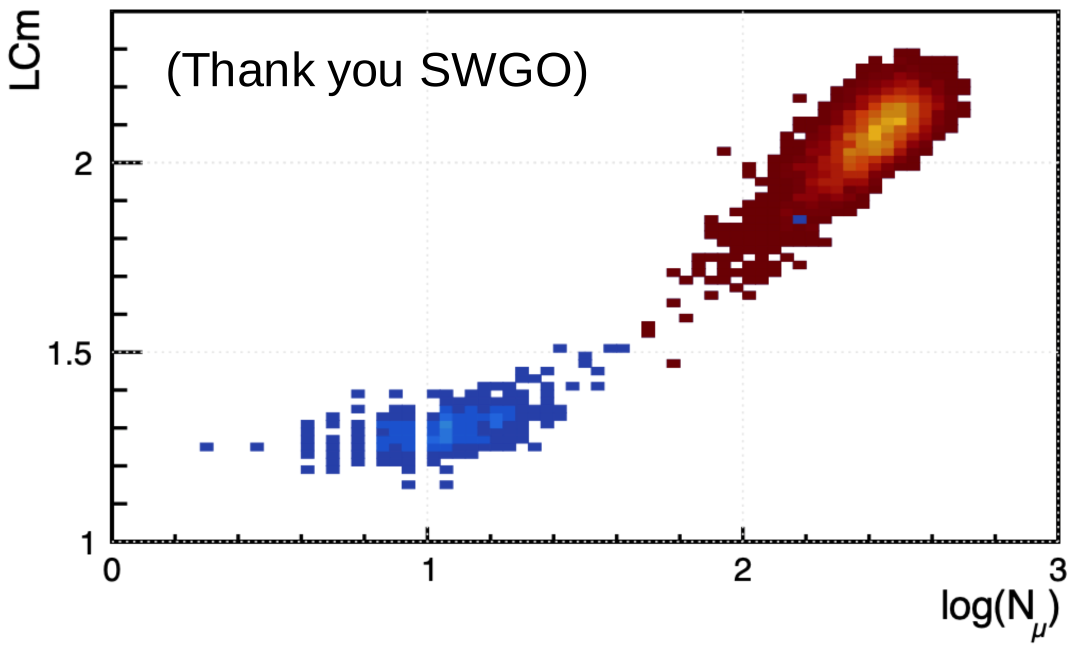
Use MARTA to get near the shower

- At low energies (10^{17}eV)
- Saturation prevents us to have measurements near the shower core
- Lower number of muons far from core
- Extend MARTA DAQ mode to get into the shower core



Apply novel analysis

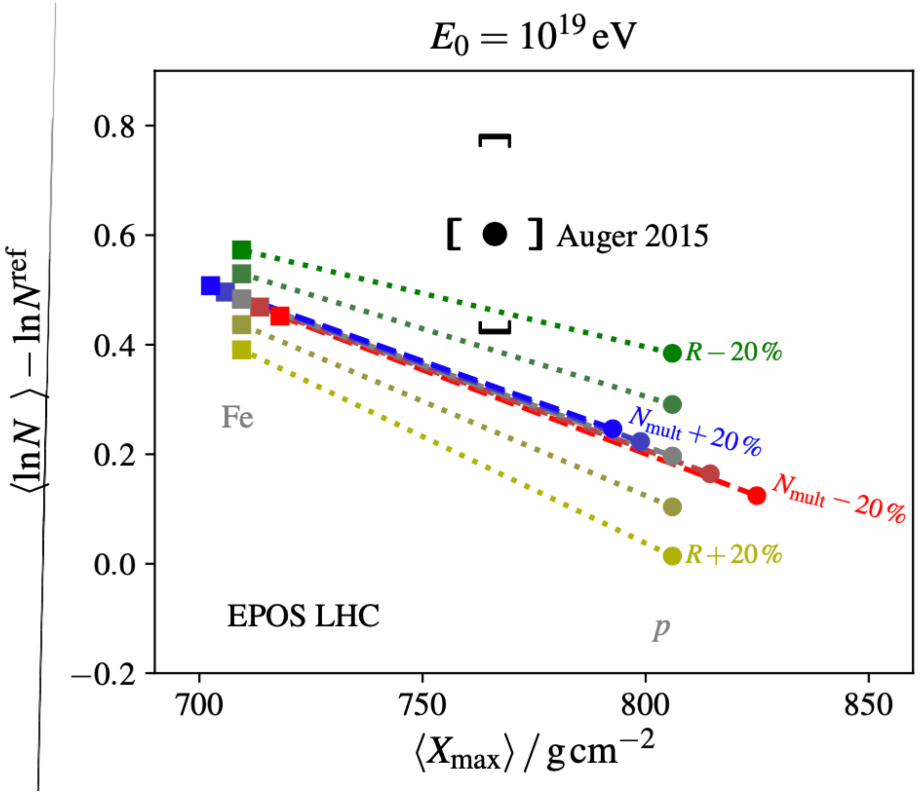
- Novel analysis for shower classification (shower azimuthal fluctuations)
  - Developed in the context of SWGO
  - Can it be applied in Auger?
- Can we extend the shower identification? Measure the muon content by higher level analysis?



Pedro Costa

QGP?

- Cosmic Rays provide a very high energy environment
- Could QGP get turned on?
- What are the influence in the shower development?
- What are the signatures on ground?
- Tweak the hadronic simulation codes to include the phenomena



Beatriz Artur

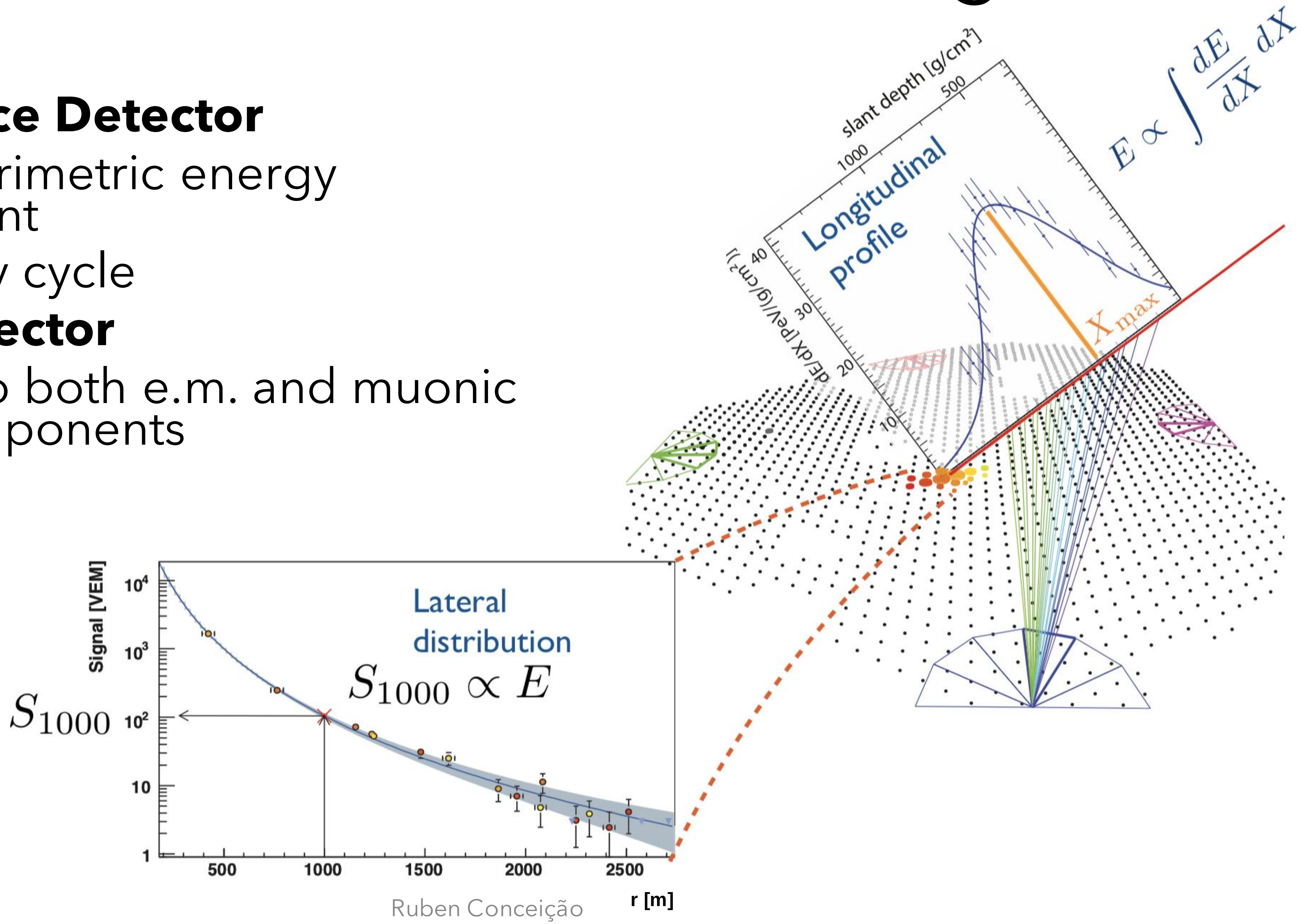
Look at sky

- Auger provides a unique instrument to look for very high energetic particles from the sky
- The upgrade will boost shower classification
- Can we search the sky? Namely look at photon sources? Do we have sufficient discriminant power? Can we improve it with new instruments?

The Detector field

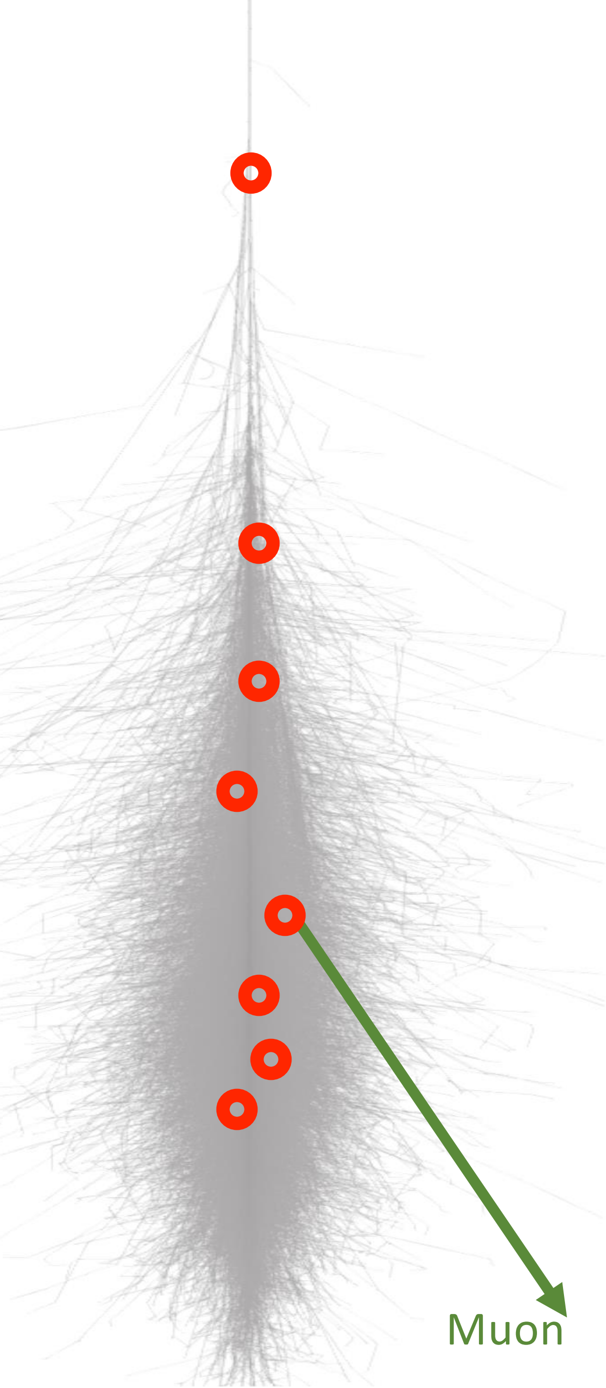
Measurement of EAS at Auger

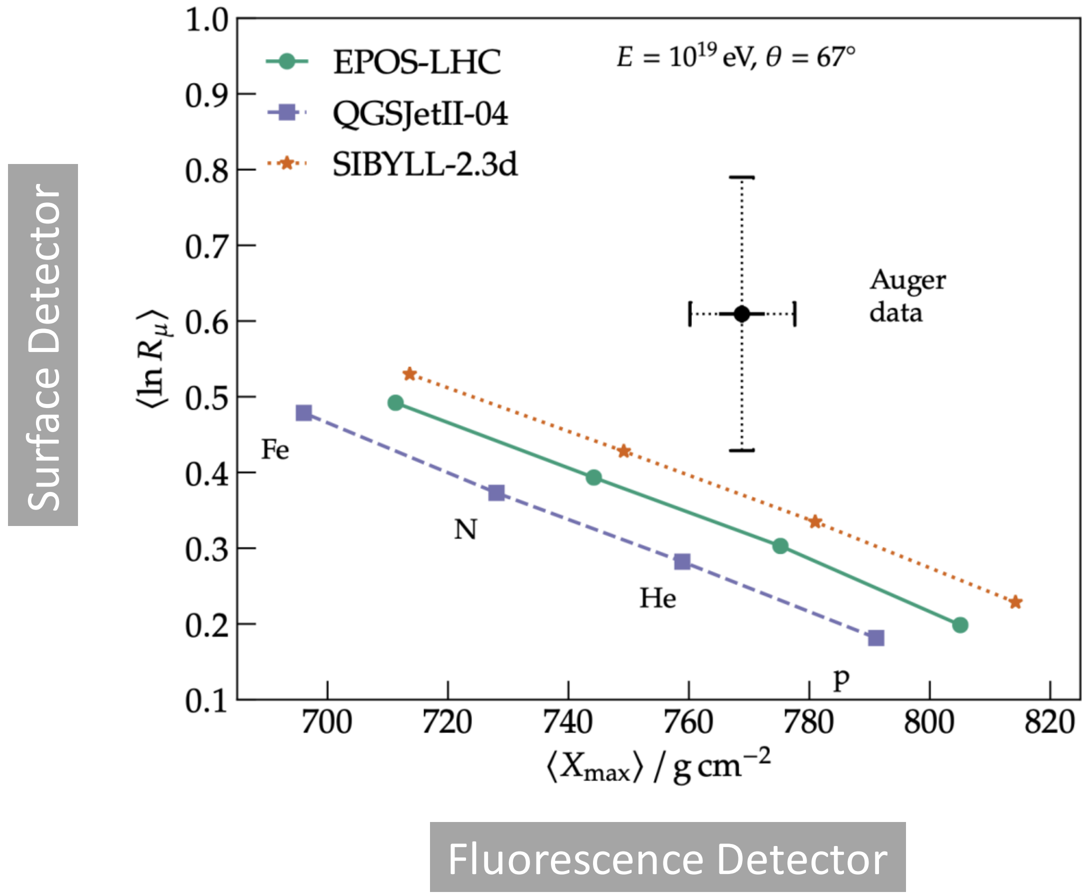
- ✧ **Fluorescence Detector**
  - ✧ Quasi-calorimetric energy measurement
  - ✧ ~ 15% duty cycle
- ✧ **Surface Detector**
  - ✧ Sensitive to both e.m. and muonic shower components



ıower description

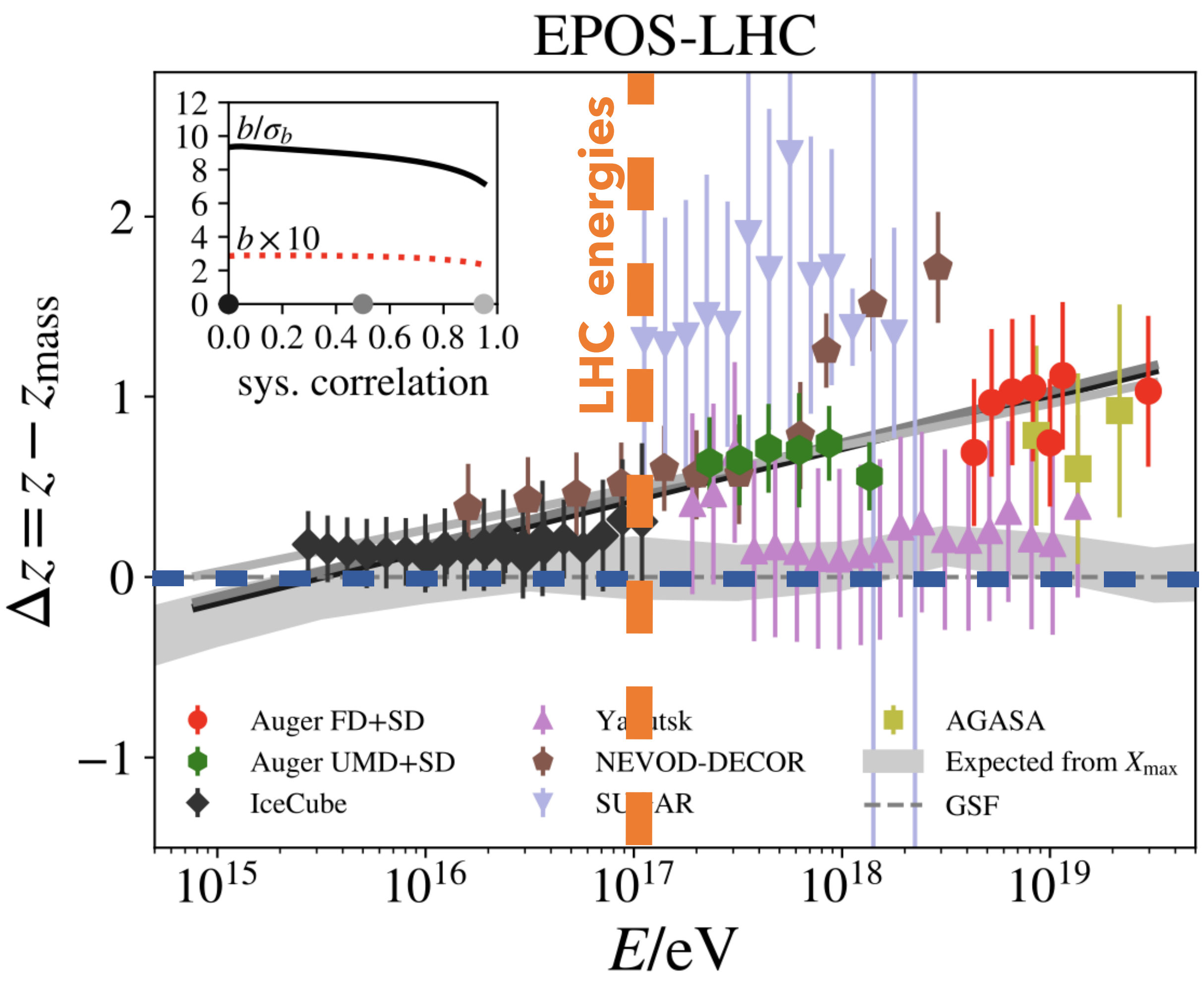
Phys.Rev.Lett. 126 (2021) 15, 152002





Combination of different measurements **reveals tension between data and all hadronic interaction models**

Muon excess seen by several experiments

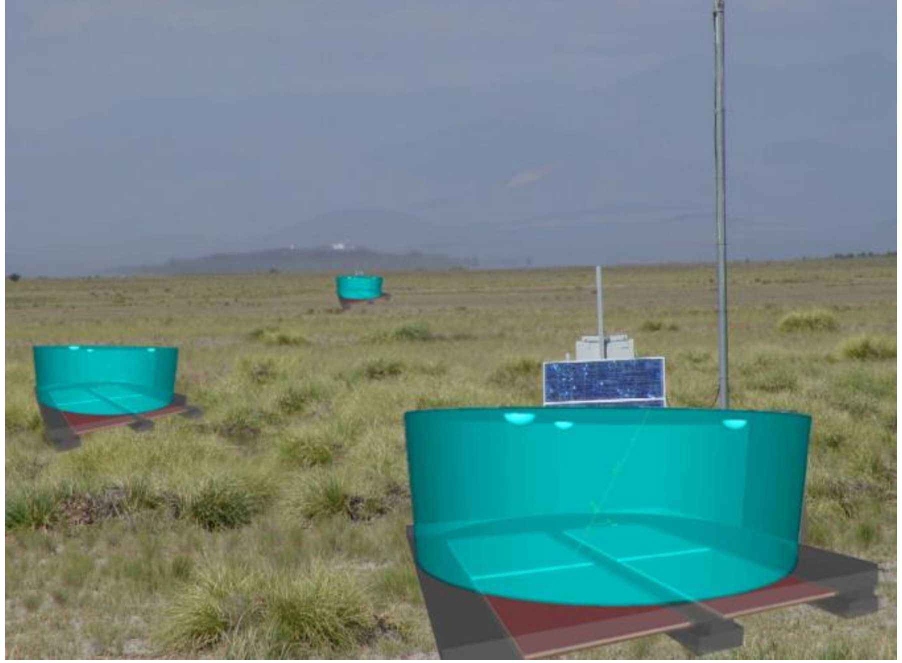


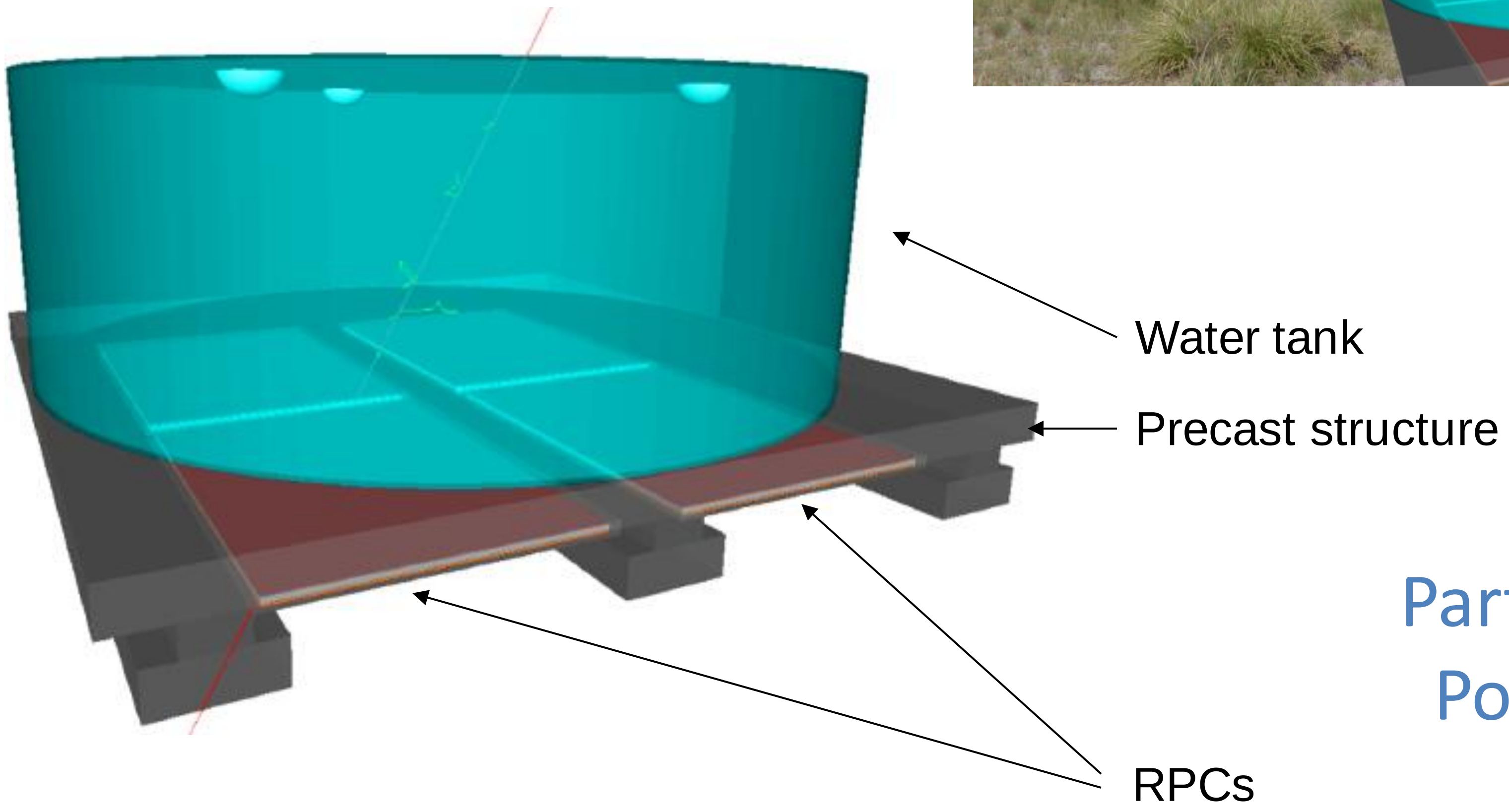
Mass composition expectations according to the fluorescence detector data

Ruben Conceição

Measuring Muons : MARTA

A dedicated muon detector:
An array of particle detector
installed beneath the tanks.

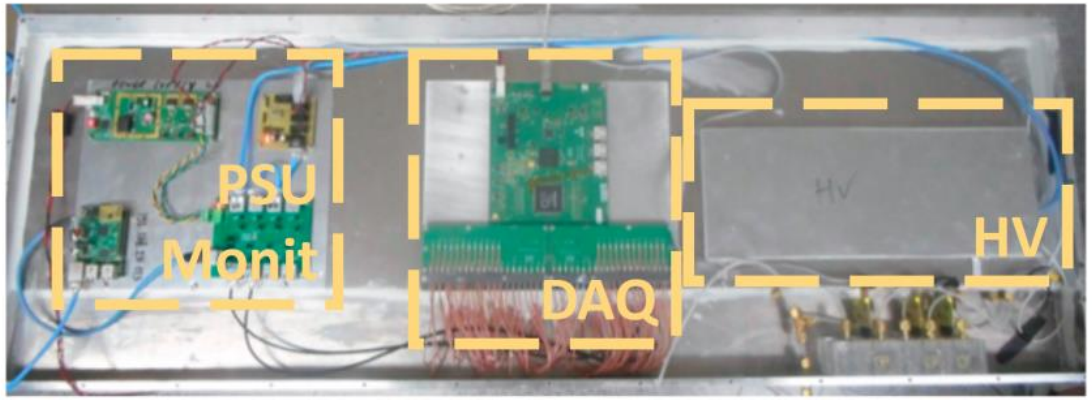




Partnership between
Portugal and Brazil

Improving detection capabilities:
New detectors with LIP expertise

All electronics: LIP



Electronics box (1285 x 407 mm^2)

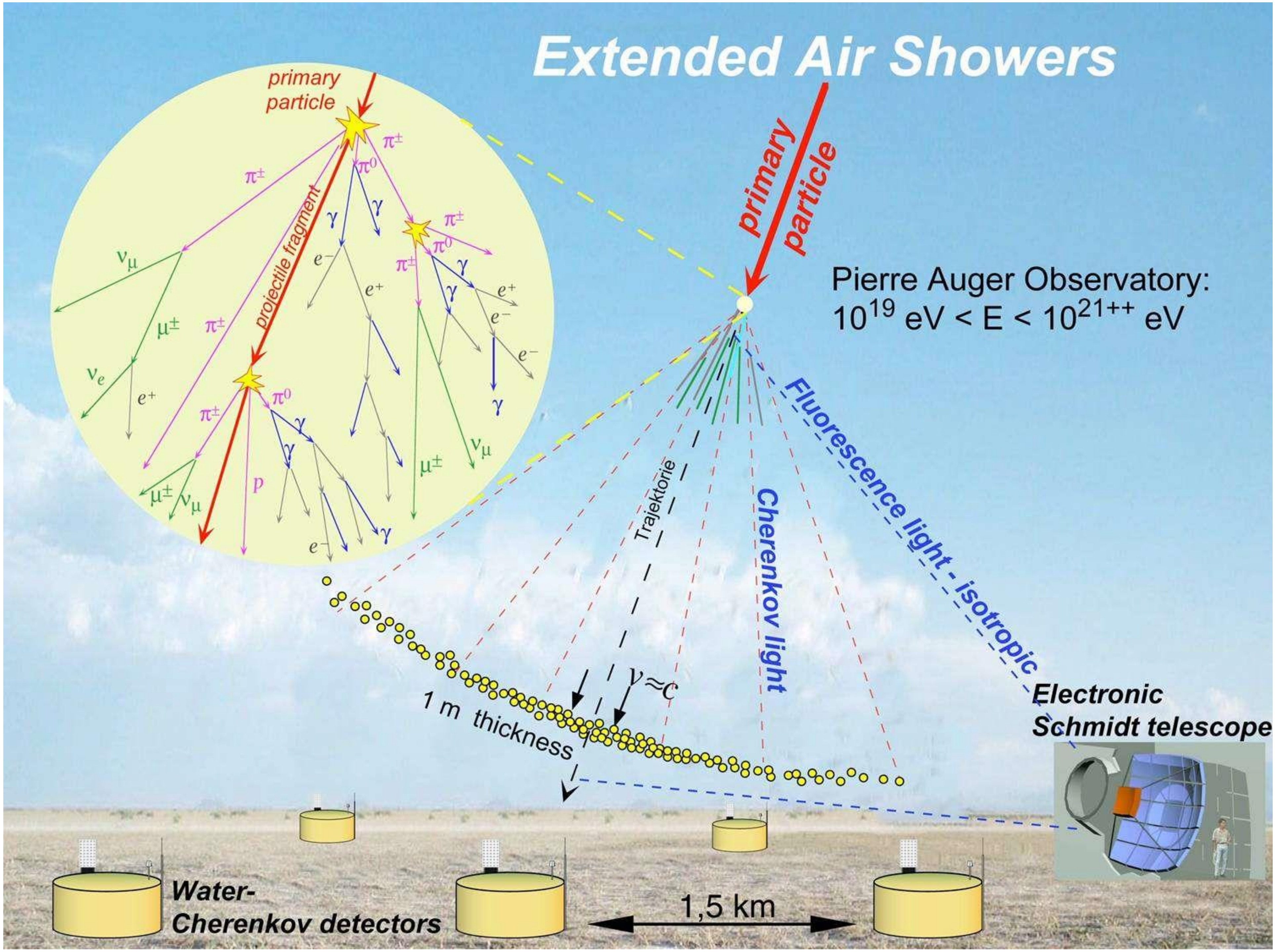
Must develop the detector, electronics, slow control, logistics, ...


PETER MAZUR

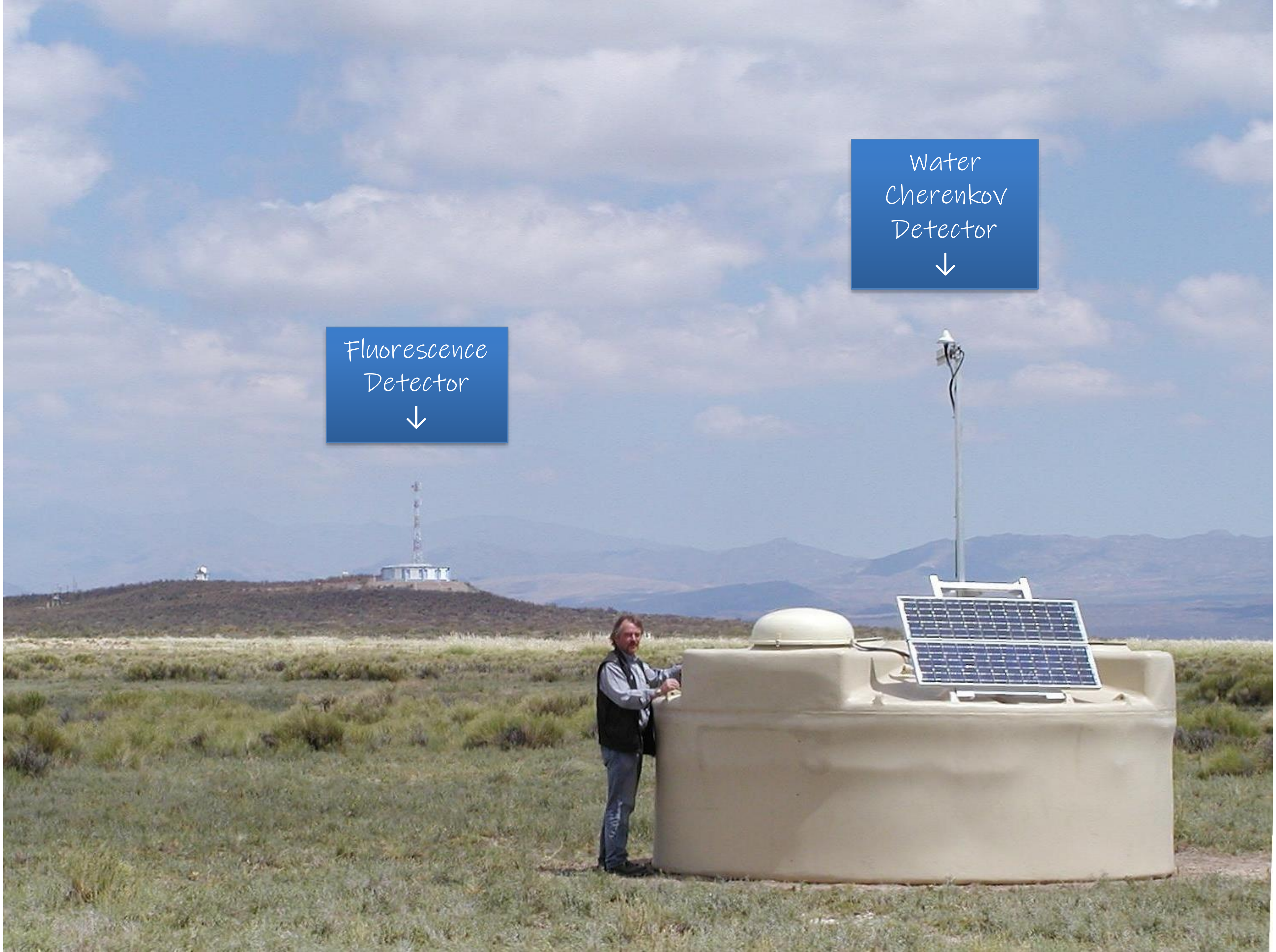

PETER MAZUR

November 2019

Spin-offs



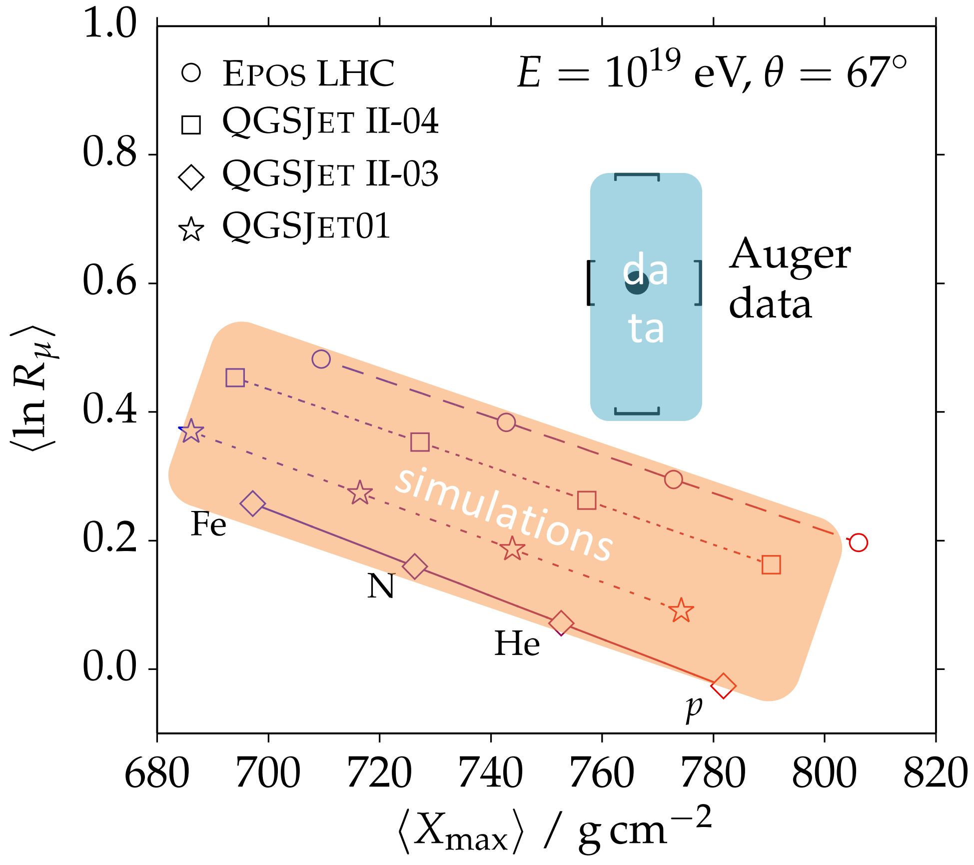
Extended Air Showers
primary particle
projectile fragment
Pierre Auger Observatory:
10^{19} eV < E < 10^{21++} eV
Trajektorie
Cherenkov light
Fluorescence light - isotropic
v≈c
1 m thickness
Electronic
Schmidt telescope
Water-
Cherenkov detectors
1,5 km


Water Cherenkov Detector
Fluorescence Detector

Making precision measurements to shed light on what's the muon content

The muons "problem"

"number" of muons
Measured by tanks



Depth of shower – Measured by FD

GAP2013-020

MARTA
Muon Auger RPC for the Tank Array
Design Report

V1.0

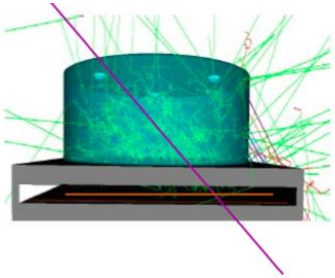
GAP2013-XXX

MARTA
Muon Auger RPC for the Tank Array
1st Progress Report

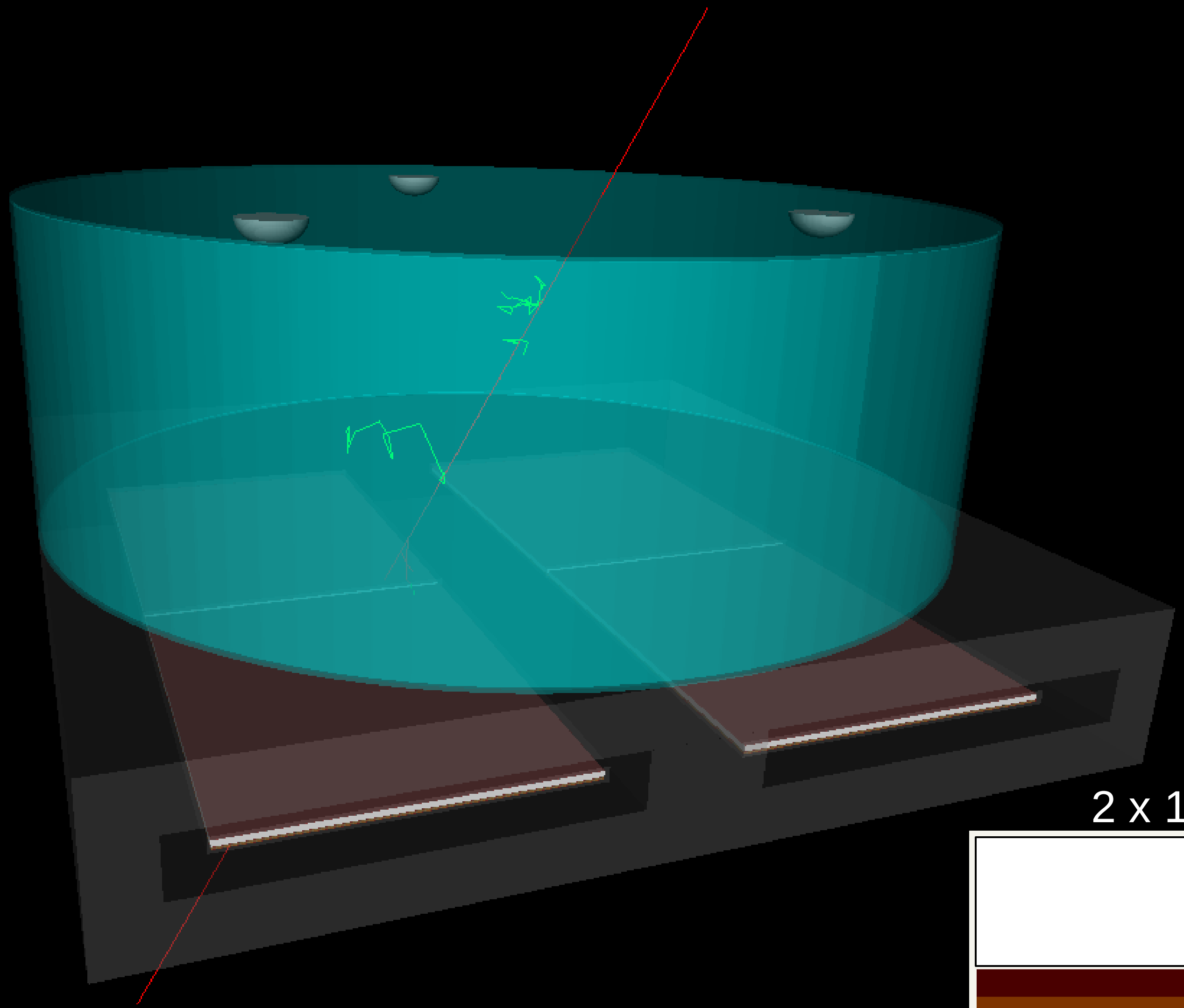
CBPF - Centro Brasileiro de Pesquisas Físicas, Brazil
FZU - Institute of Physics, Czech Academy of Sciences, Czech Republic
IFSC/USP - Instituto de Física de S. Carlos, Universidade de S. Paulo, Brazil
LIP - Laboratório de Instrumentação e Partículas, Portugal
UNICAMP - Universidade Estadual de Campinas, Brazil
UFRJ - Universidade Federal do Rio de Janeiro, Brazil
Universitá di Roma II, “Tor Vergata”, Italy
Universitá di Napoli, “Federico II” and INFN, Napoli
USC - Universidade de Santiago de Compostela, Spain

with the collaboration of
Peter Mazur and Alan Watson

27 May 2013

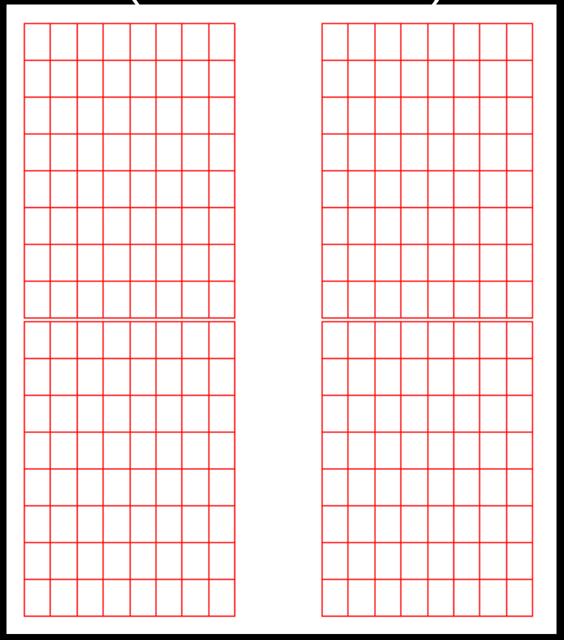


Baseline configuration



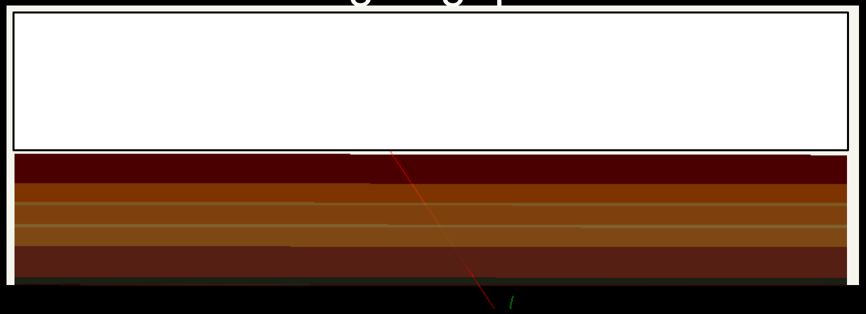
Concrete precast : 20 cm thick (~50 g/cm^2)

4 x (1.5 m x 1.2 m) RPC



8x8 pads each RPC

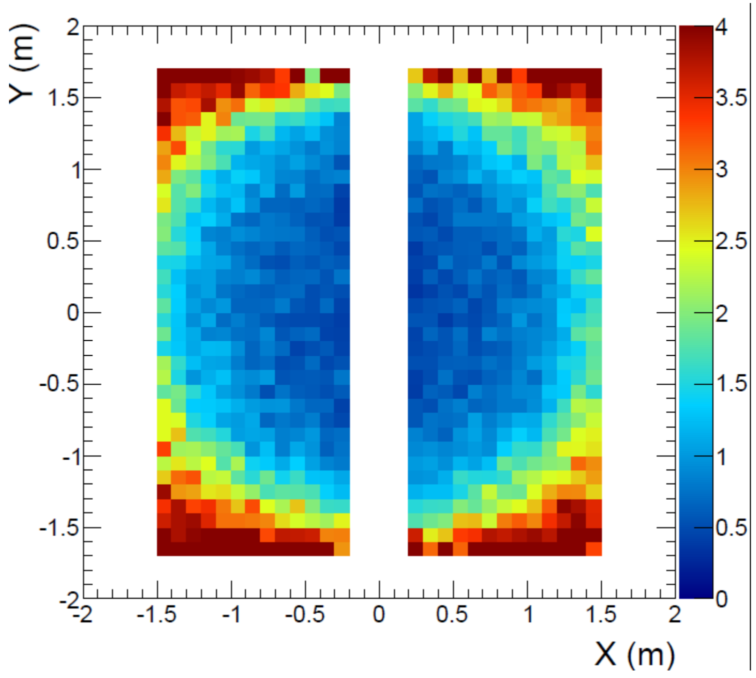
2 x 1 mm gas gap RPC inside Al case

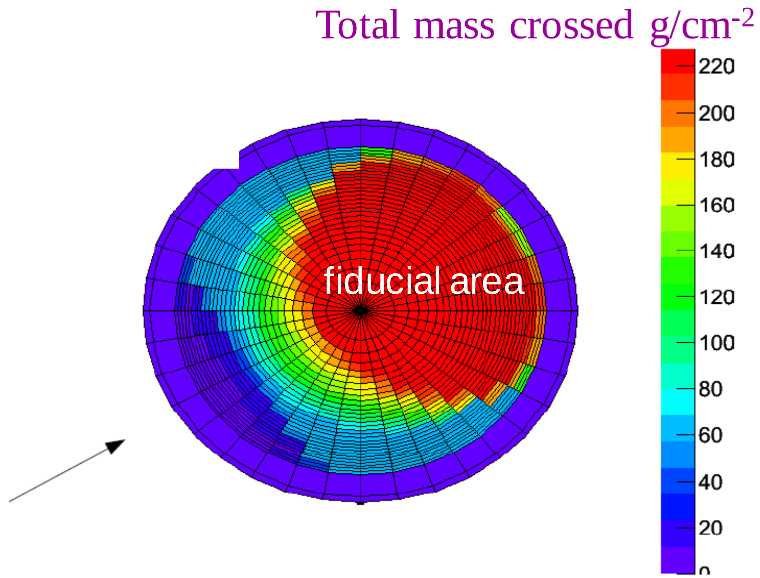


Punch-through

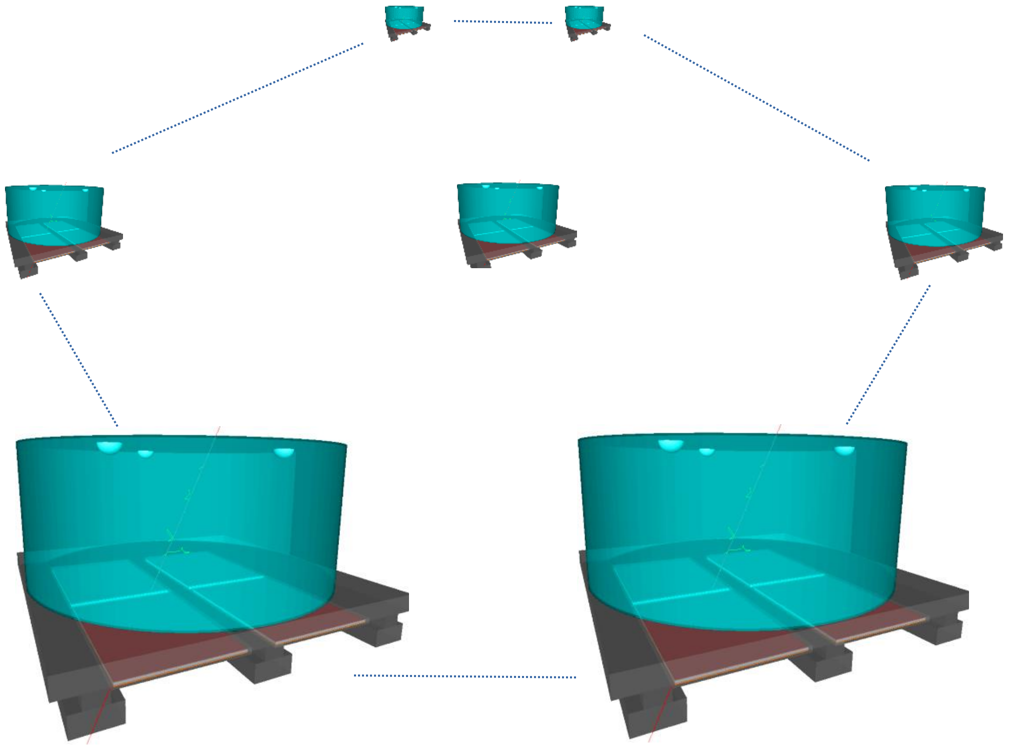
- "only muons reach the RPCs"

- Some parts of the RPC are more "exposed"
  - Segmented readout allows to create e.m. contamination maps
  - Dynamically define a fiducial area (shower to shower, dependent on station-shower distance)
  - Only pads with e.m. contamination below predefined threshold are used
  - Allows for muon measurement with small bias from e.m. component



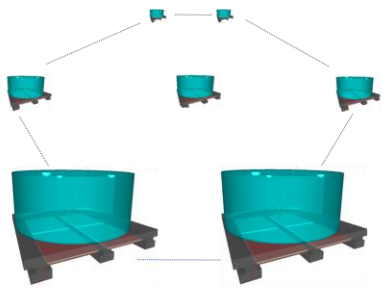


MARTA EA



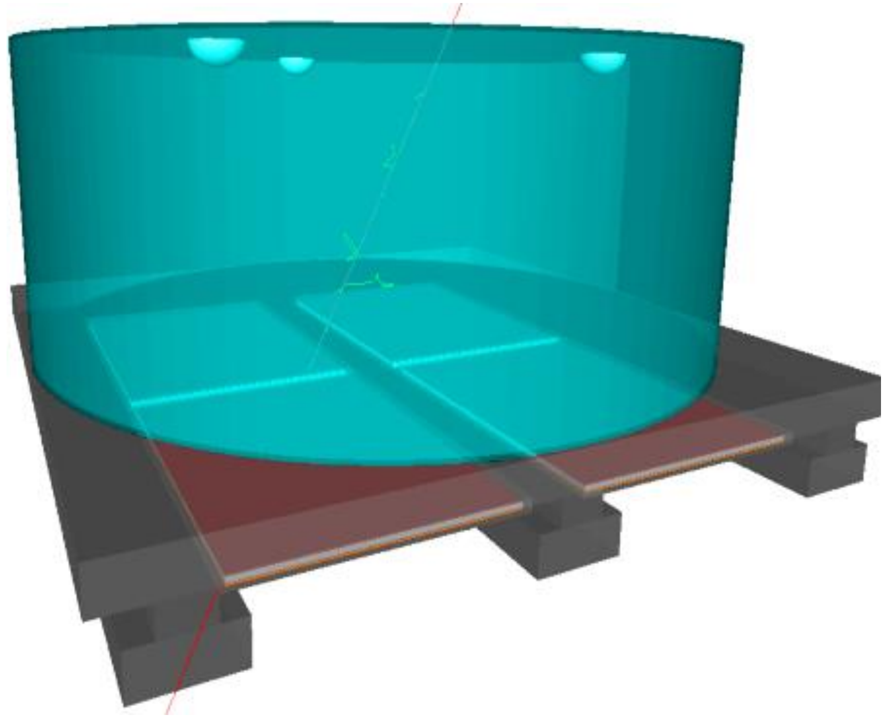
The MARTA Engineering Array

FCT – FAPESP project
(Portugal – Brasil)



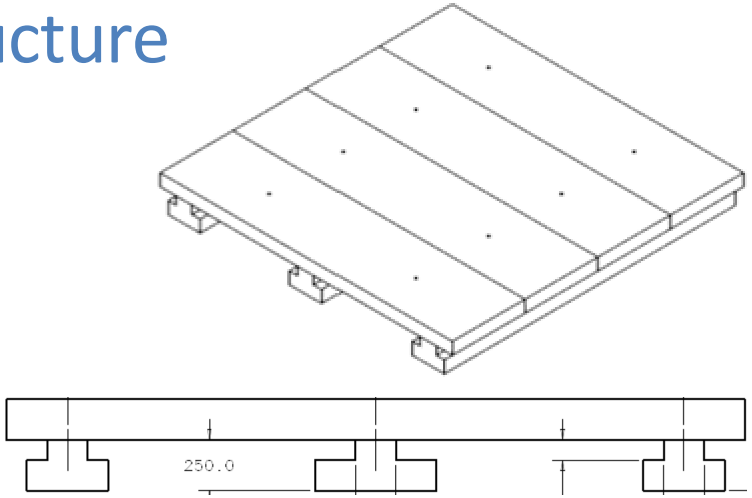
Results from a specific call FAPESP-FCT
- RPC R&D
- RPC technology @ Brasil
- Build RPC detectors
- Install EA (hexagon) in Auger

Synergies with AugerPrime
- RPC hodoscopes for testing SSD
- Cross-calibration
- Physics at E=10^17 eV



Install a unitary cell (hexagon)
In the infill area, in AMIGA tanks

The support structure

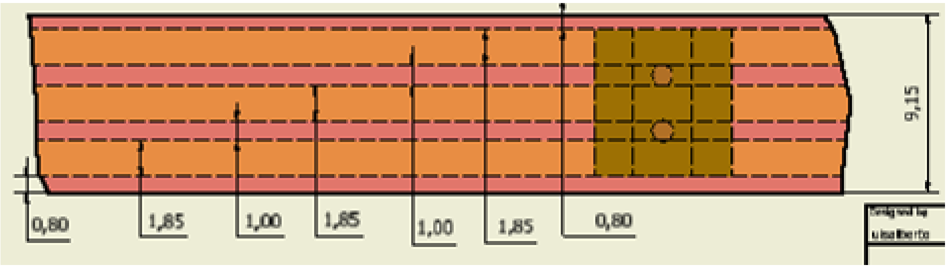


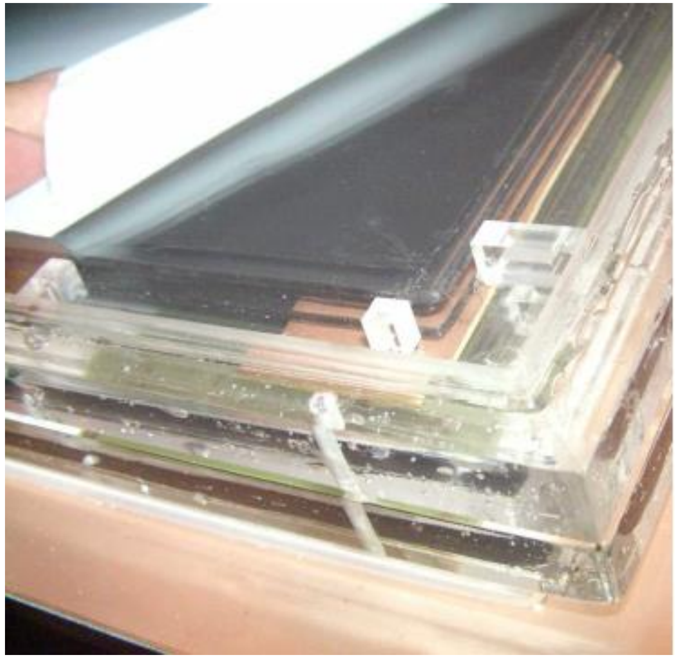
Precast structure built at the observatory
Transported to the field
Installed in a couple of hours
(Emptying/Filling the tank
is more time consuming)

The modules

4 modules of RPC to be installed in each station
Triggered by the WCD

The active medium

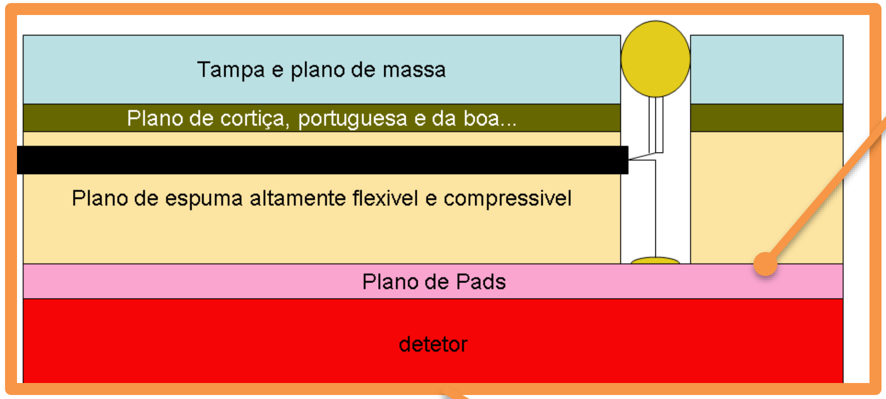


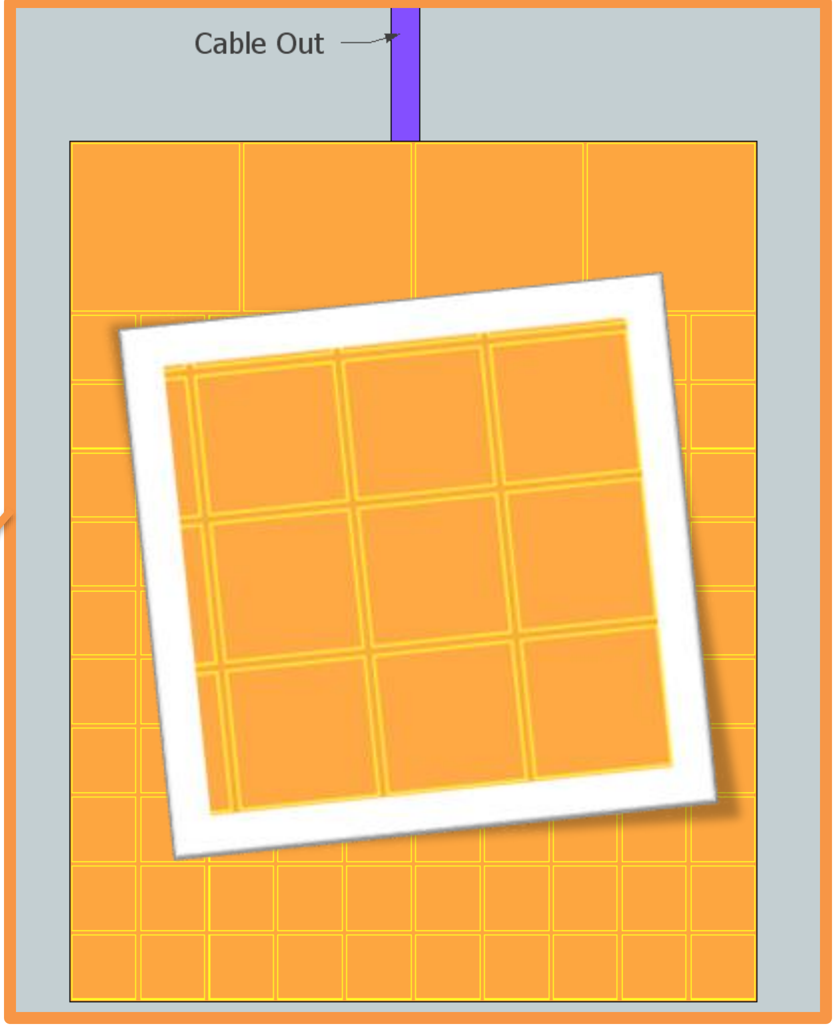


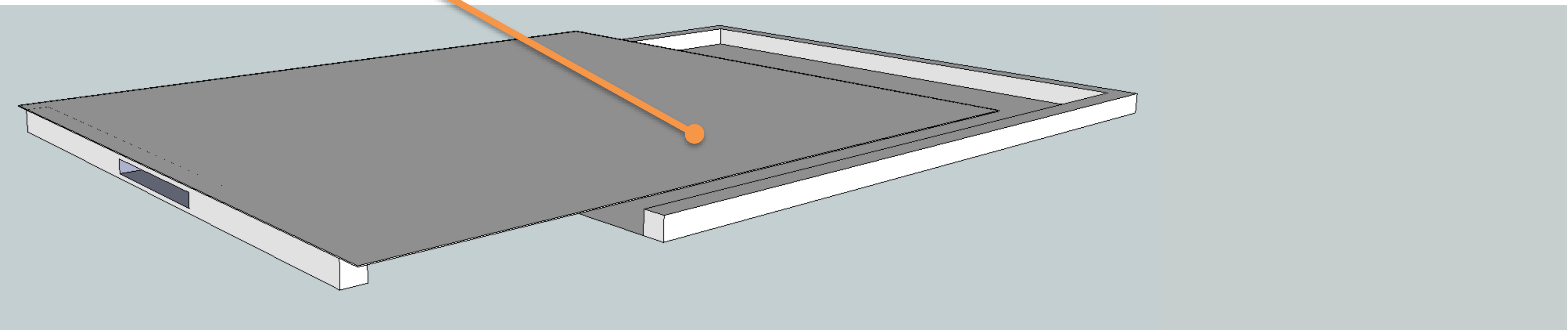
Pads & Housing

(first design)

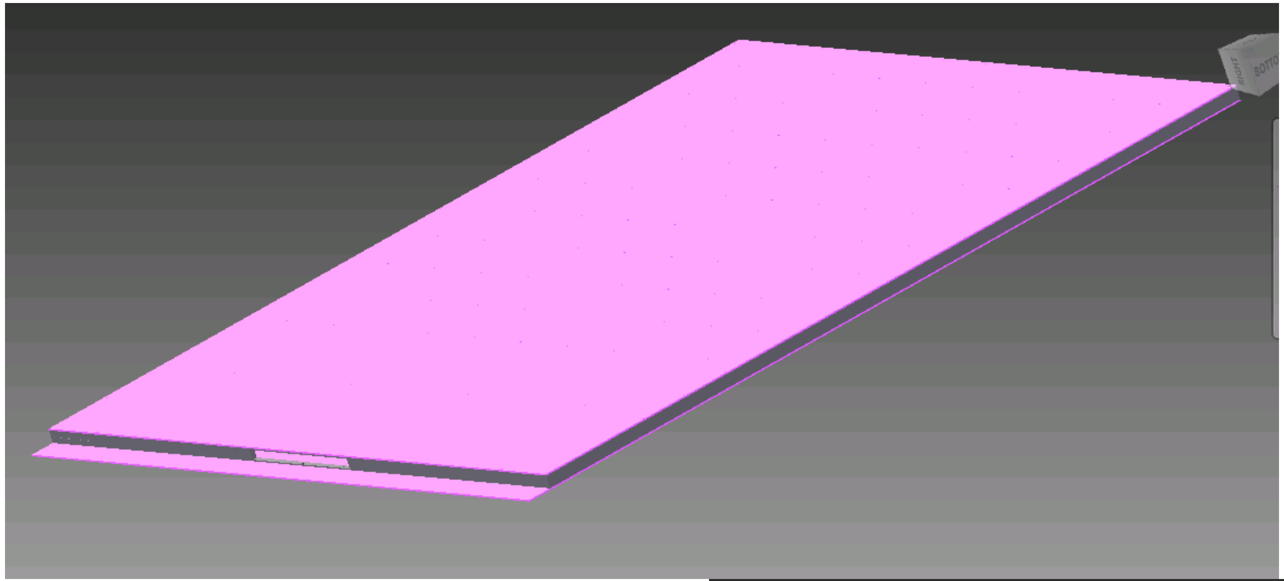
Pads are defined in PCB boards. Routed with 2mm leaving ground between them

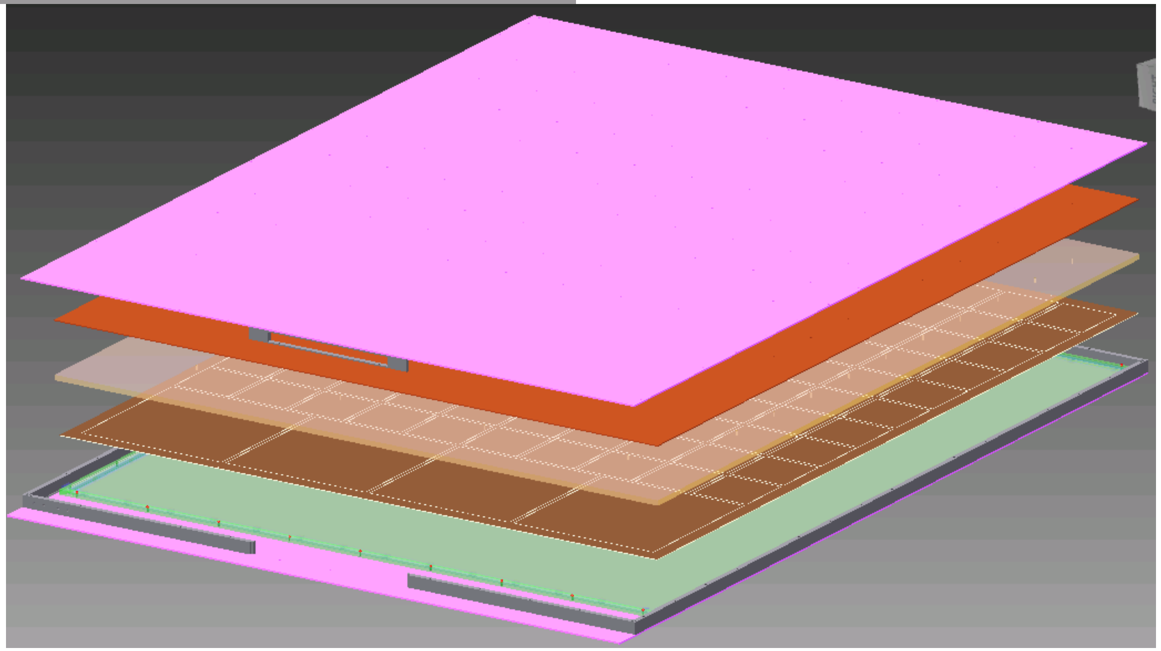




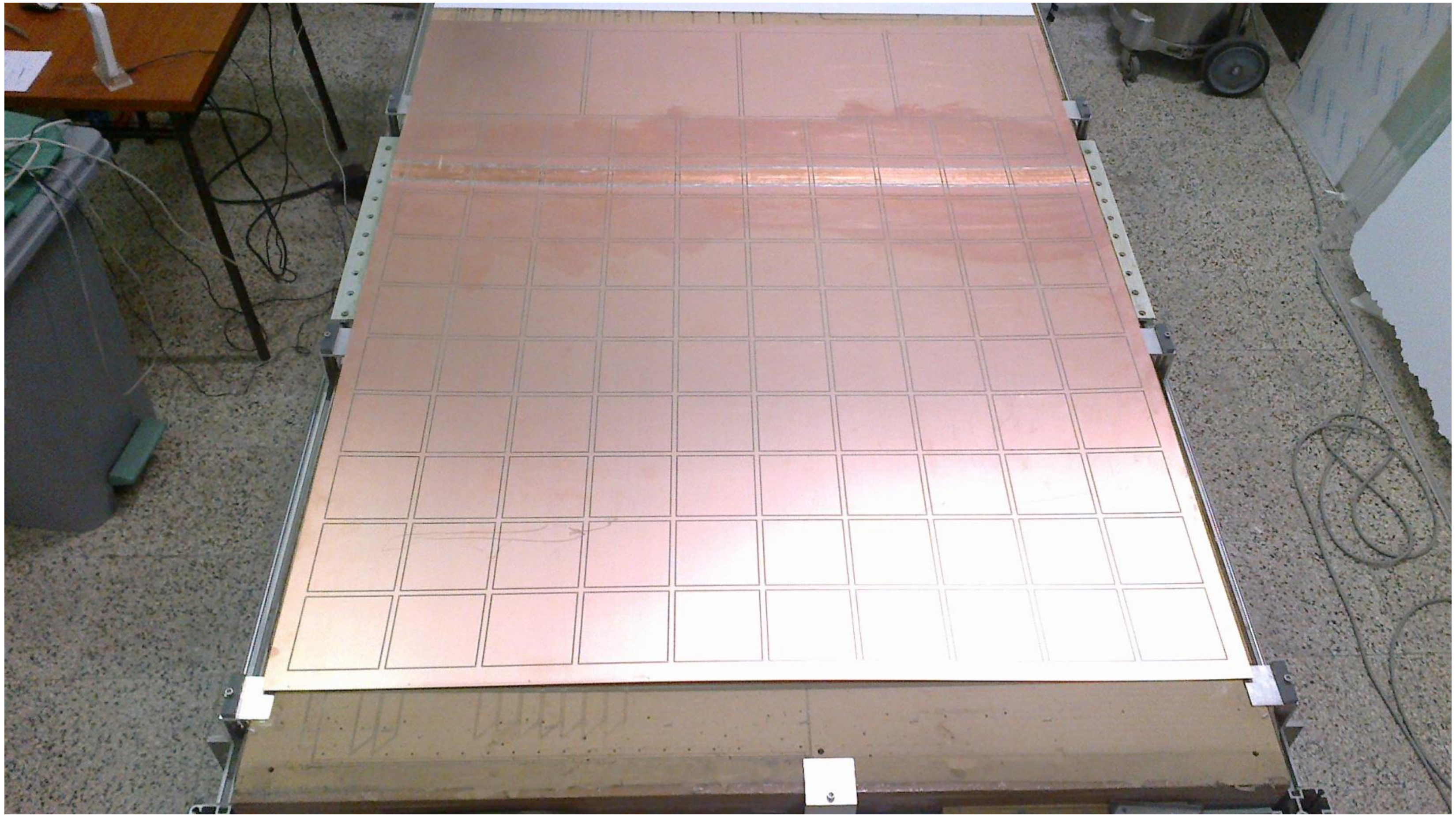


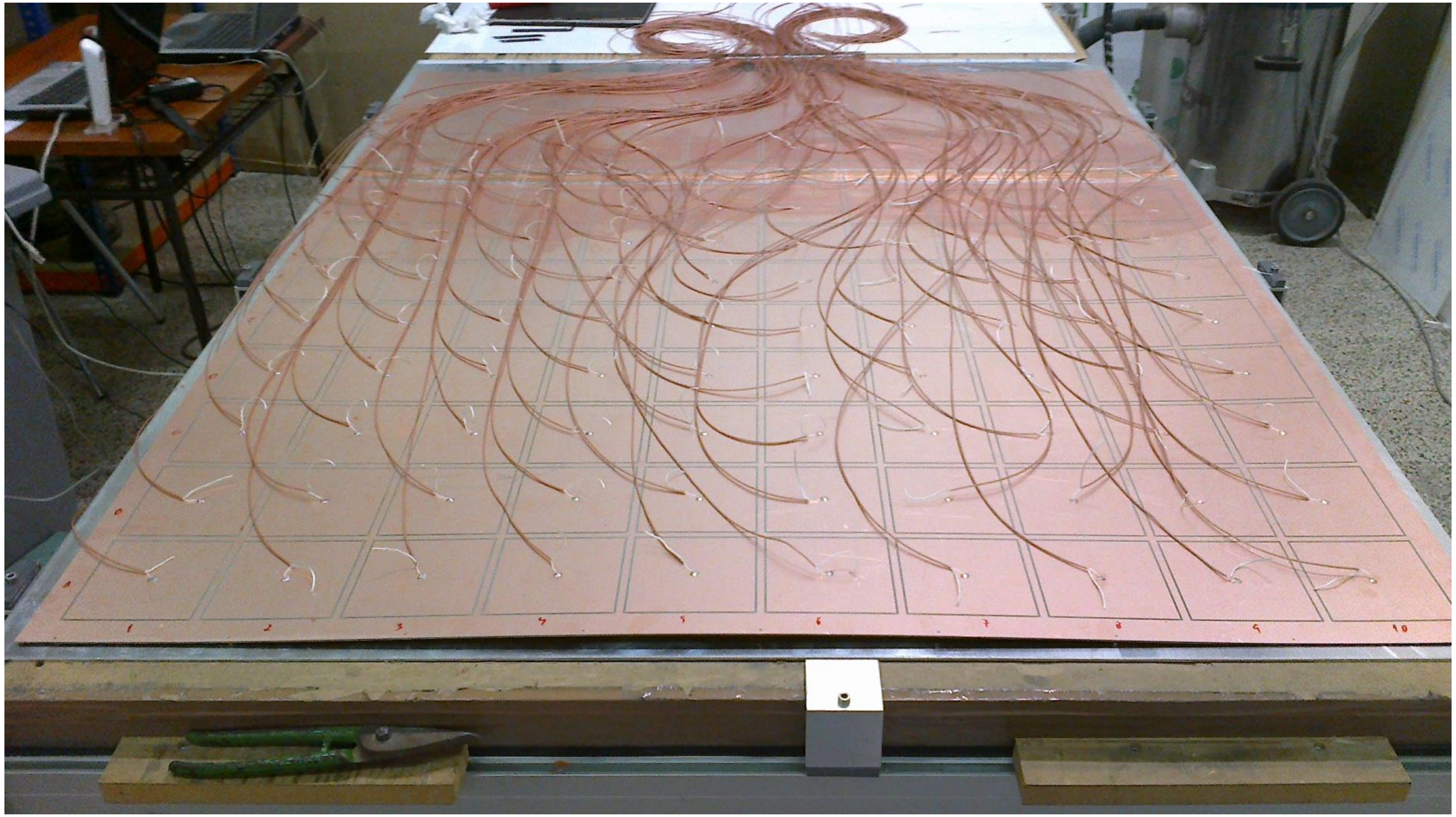
RPC Module





Read-out: Segmentation

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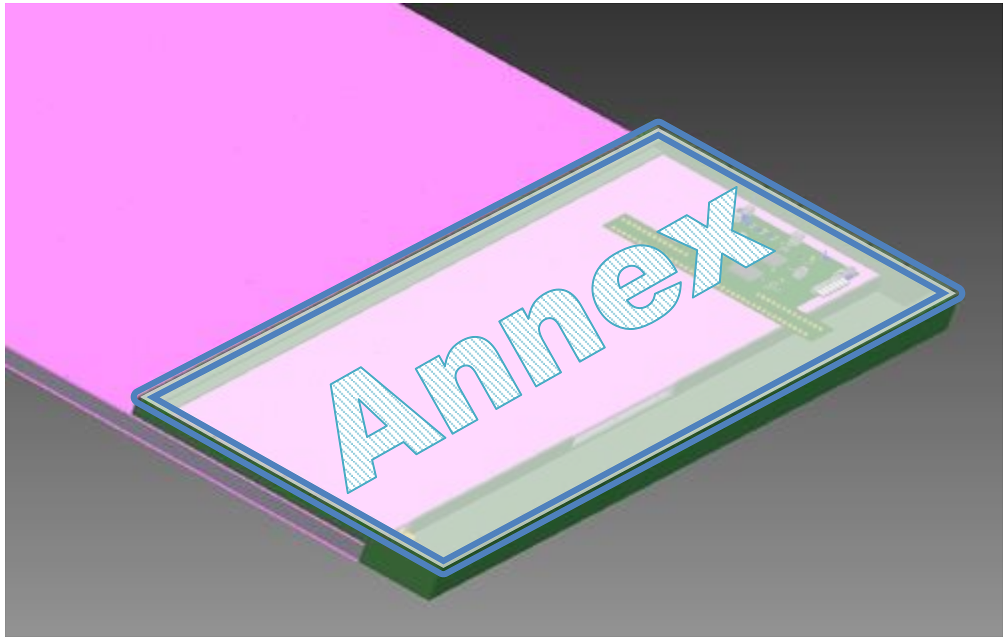
The MARTA module

Each module contains:

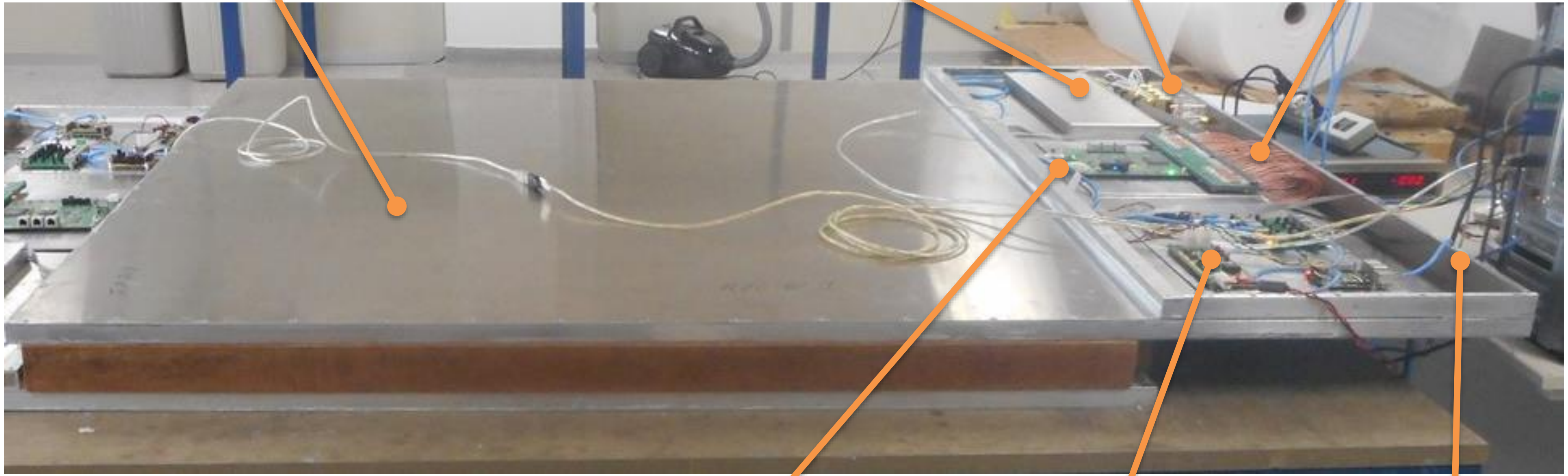
- Sensitive volume
- Pickup system
- sensors
- Enclosure
- Annex:
  - DAQ
  - HV
  - PSU
  - Control Board
  - Bubbler



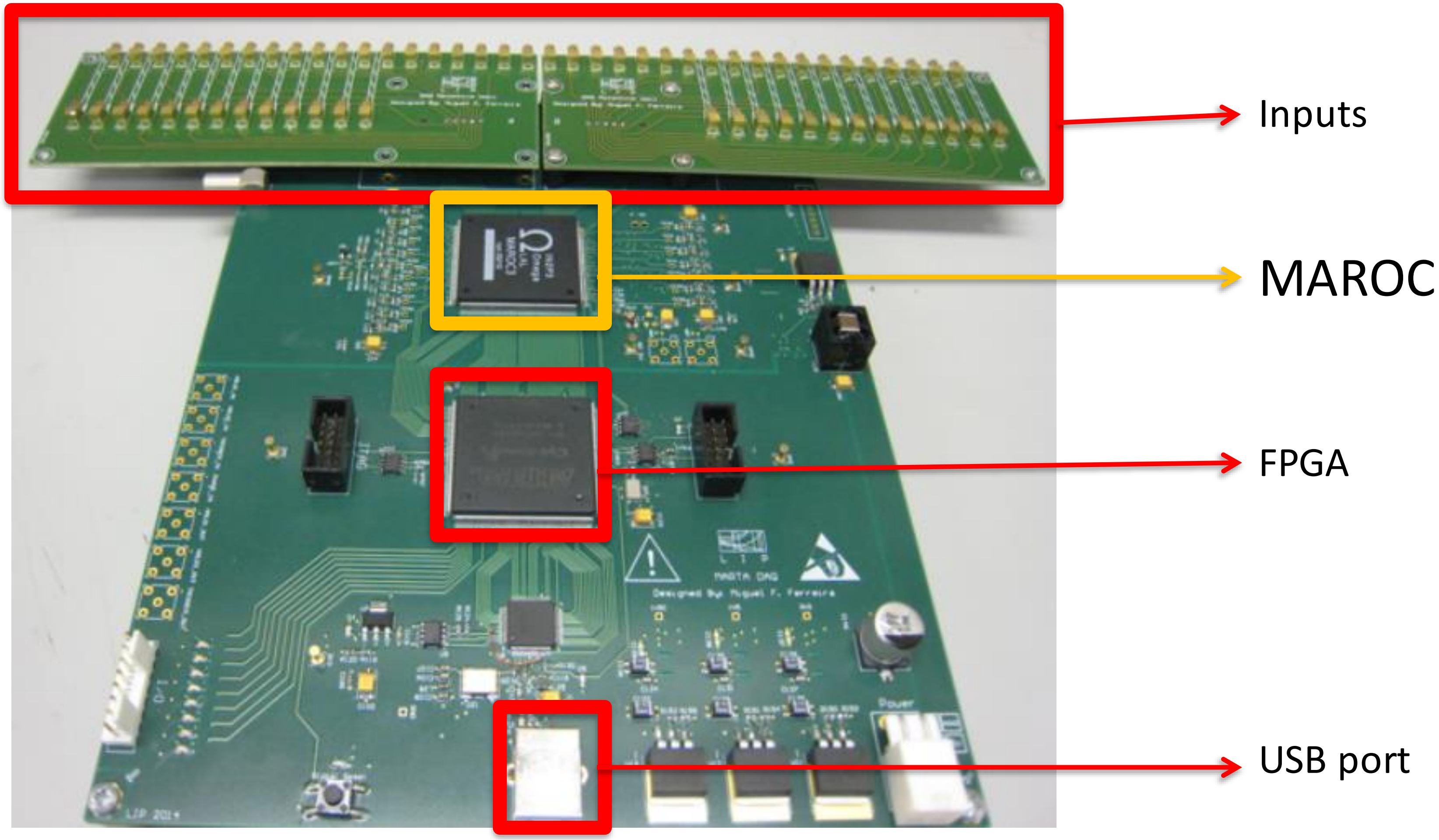
Gas Volume: Coimbra
Gas control: Coimbra
HV: Coimbra
Electronics: Lisboa
Housing: São Carlos
Integration: São Carlos, Rio

The MARTA module

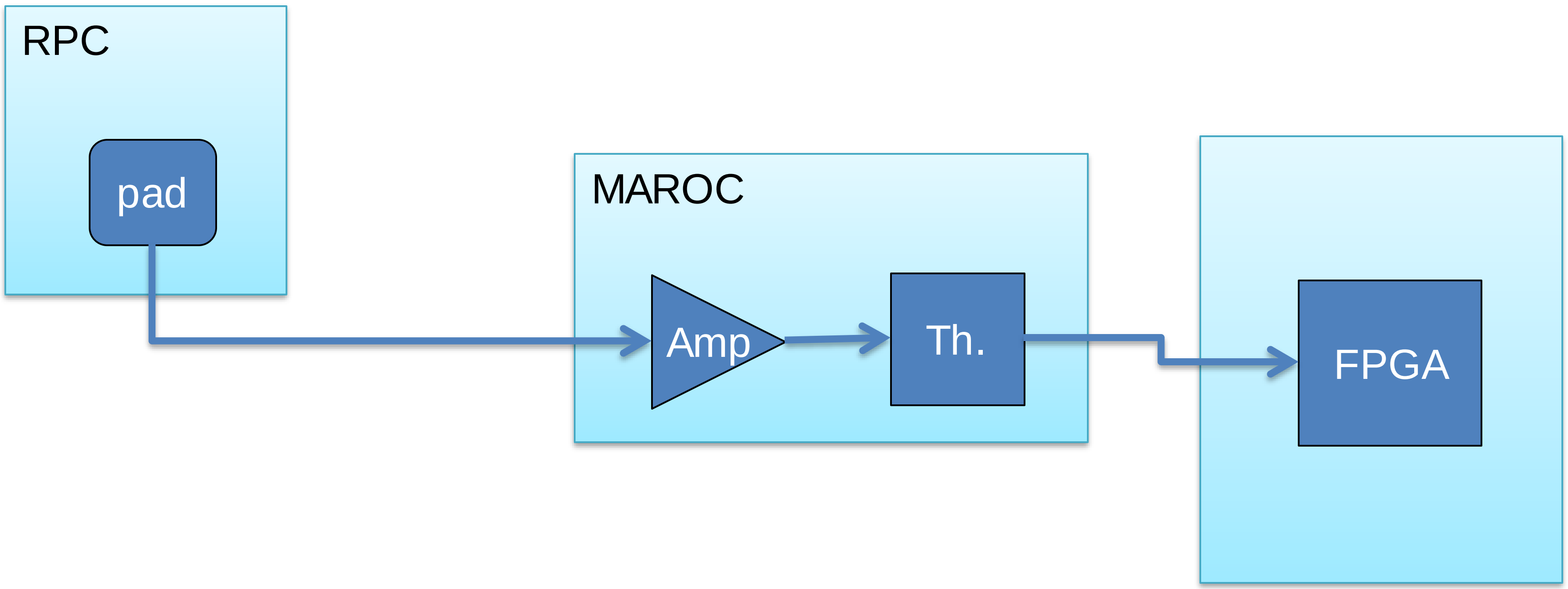
The MARTA module



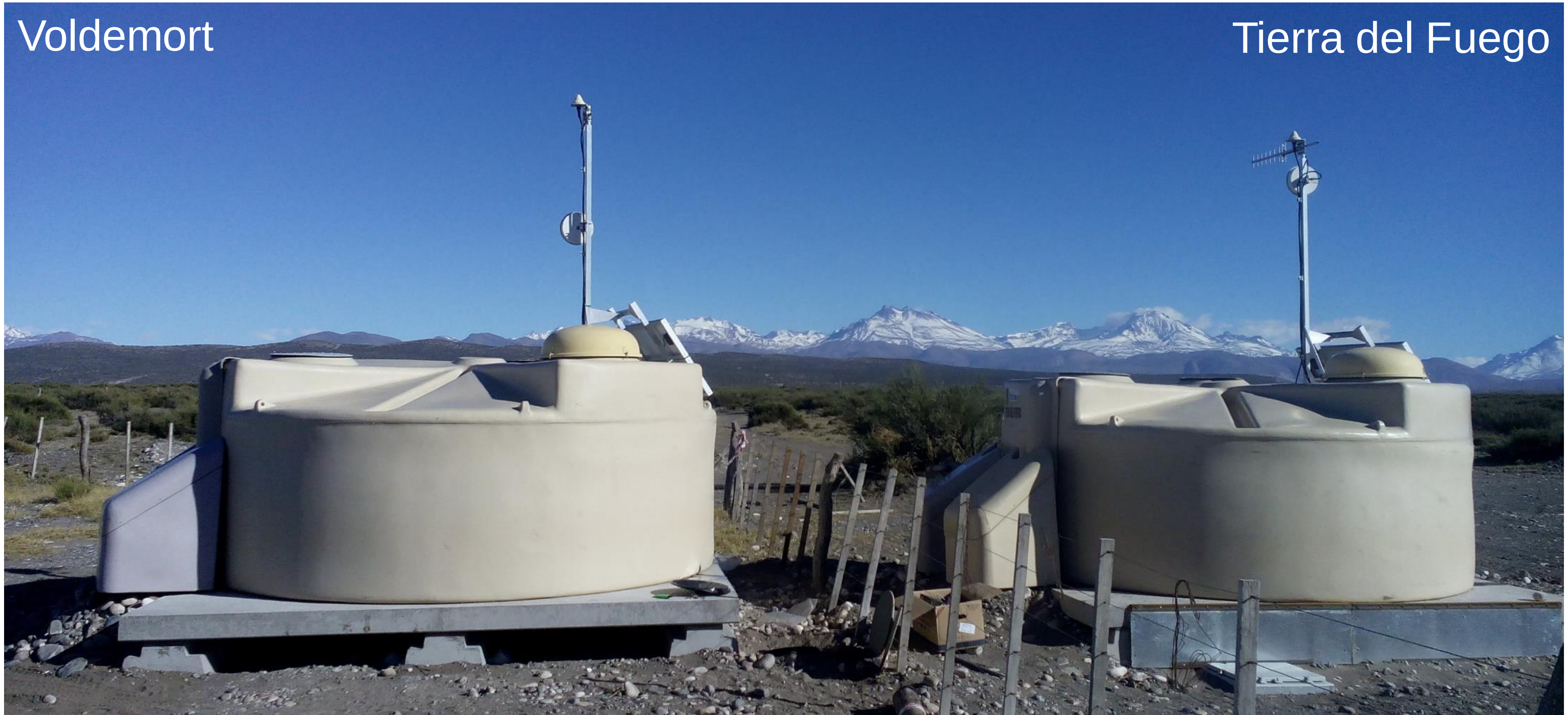
MARTA Readout System



RPC channel



The prototypes



First field station