LATTES: a new detector concept for a large field-of-view gamma-ray experiment in the Southern hemisphere

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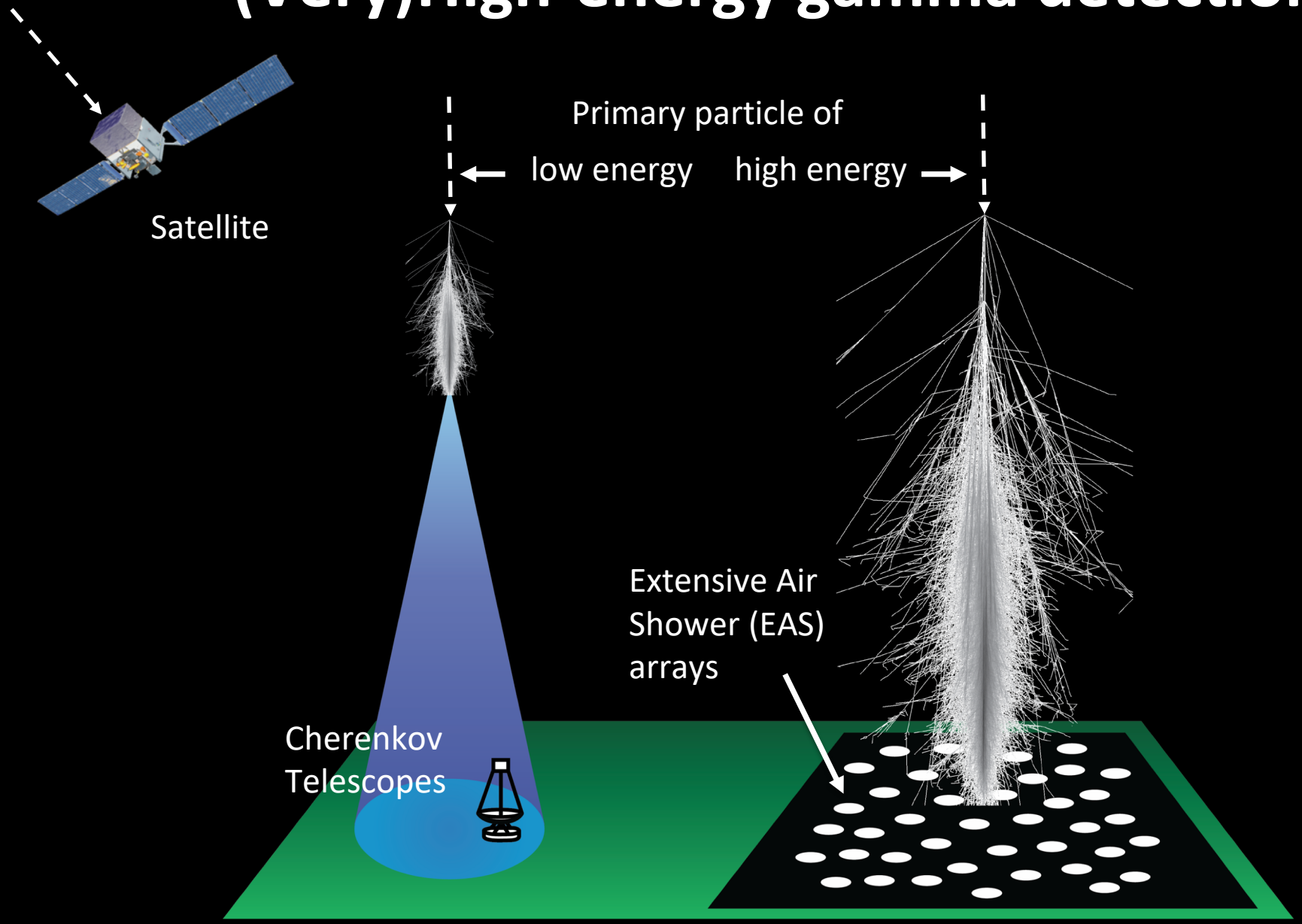
on behalf of the LATTES team

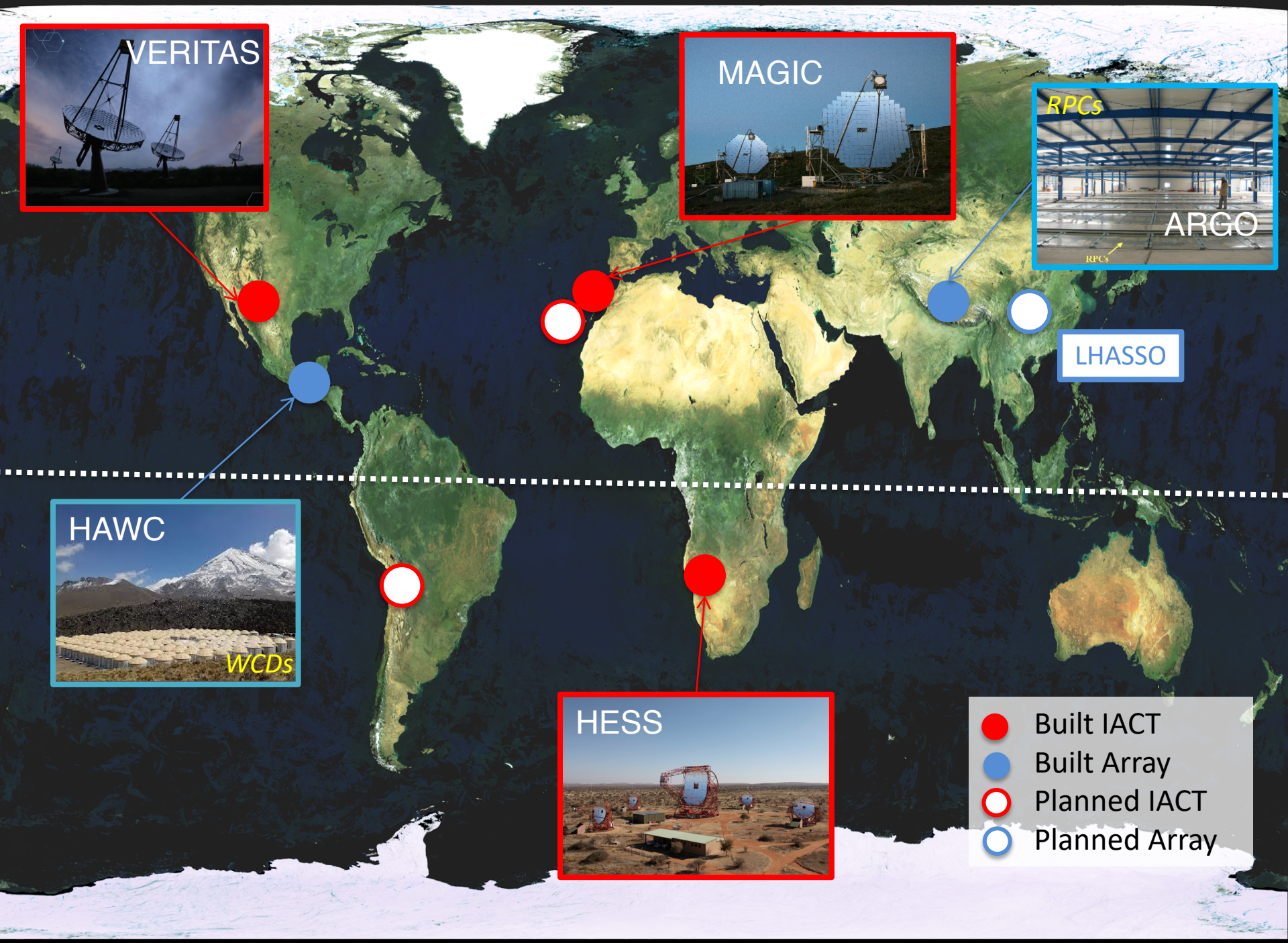
www.lip.pt/experiments/lattes/

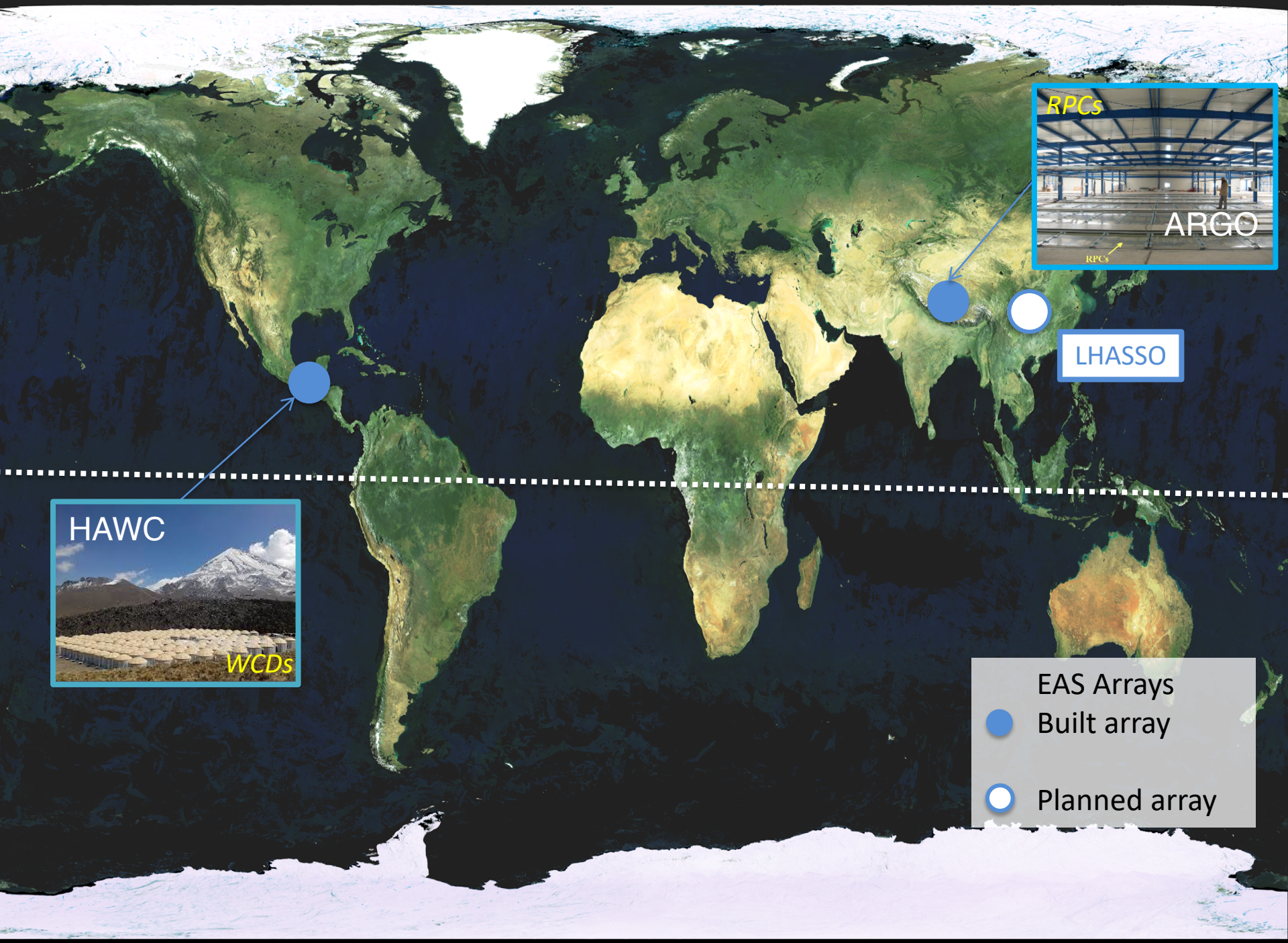
30th Rencontres de Blois, June 2018, Blois, France

(Very)High-energy gamma detection

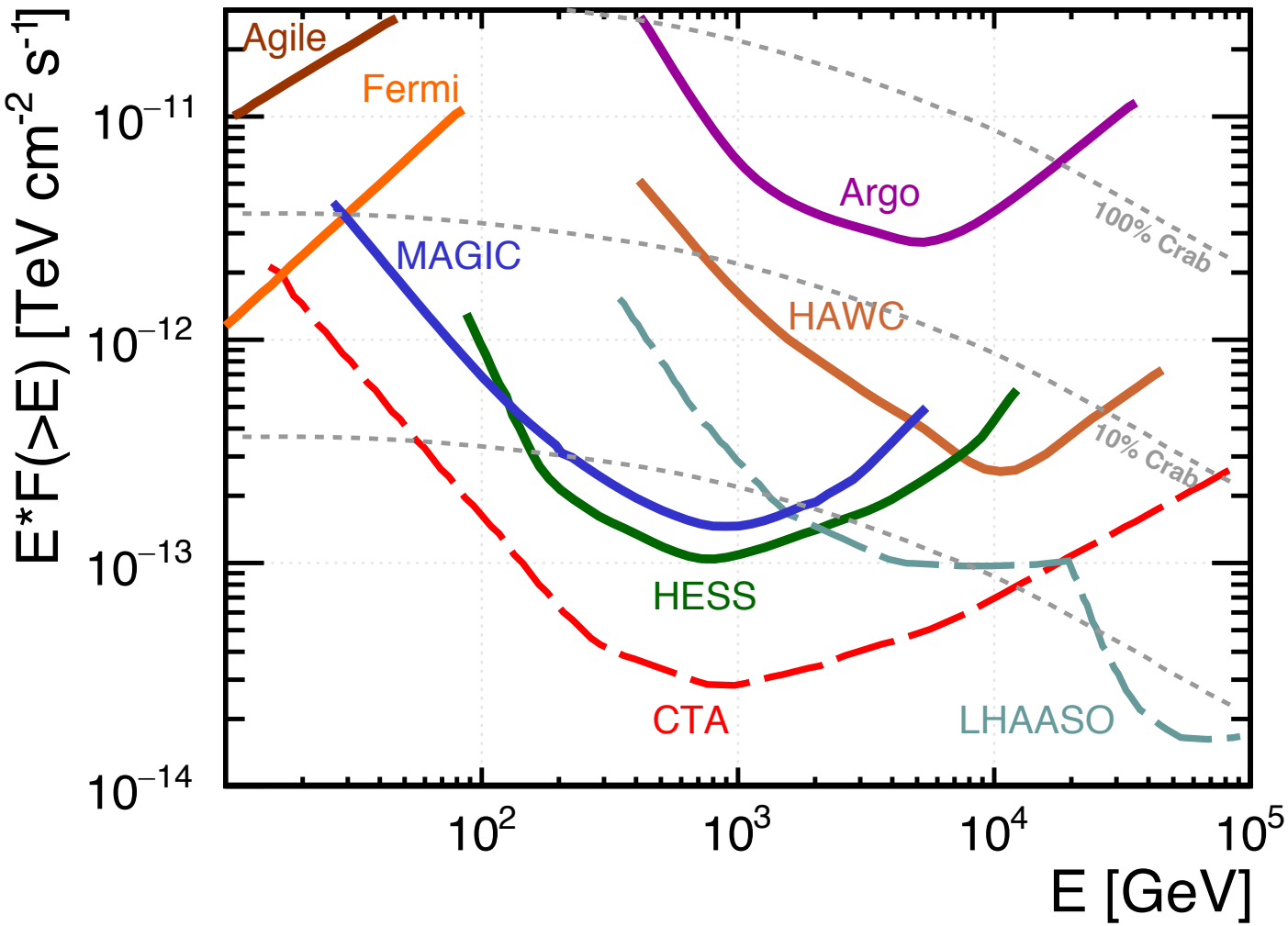


Extensive air shower arrays at high-altitude = large field of view + large duty cycle + low energy

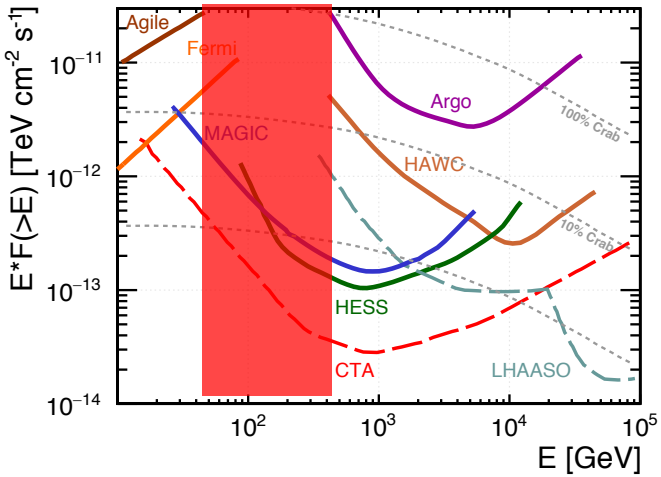

VERITAS
MAGIC
RPCs
ARGO
RPCs
LHASSO
HAWC
WCDs
HESS
Built IACT
Built Array
Planned IACT
Planned Array


RPCs
ARGO
RPCs
LHASSO
HAWC
WCDs
EAS Arrays
Built array
Planned array

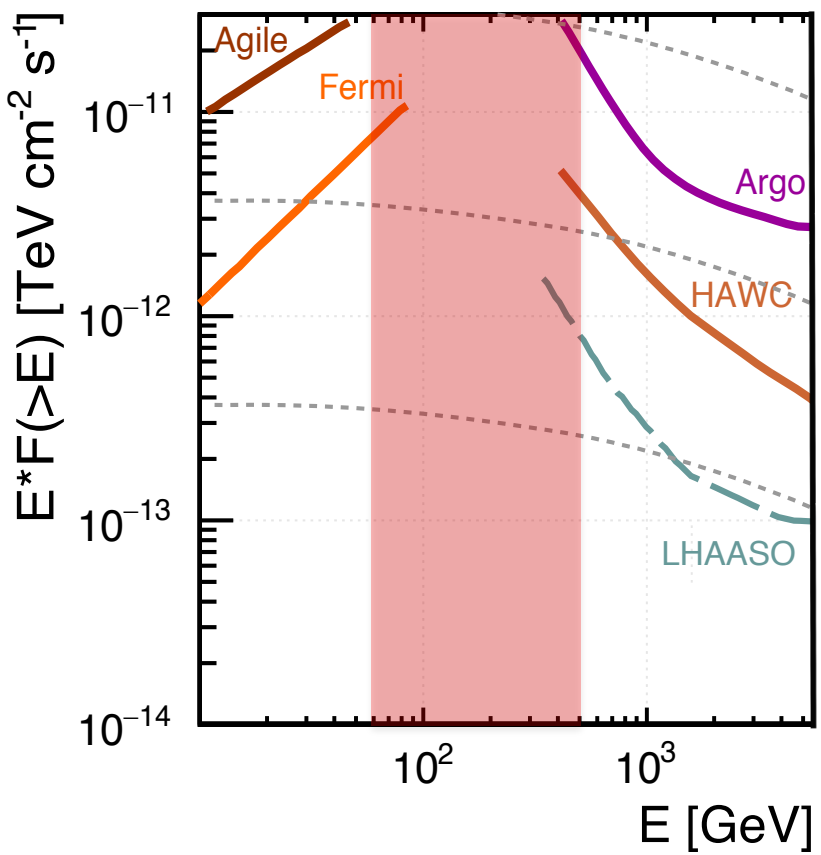
Sensitivity to high-energy gamma-rays



Wide FoV experiments



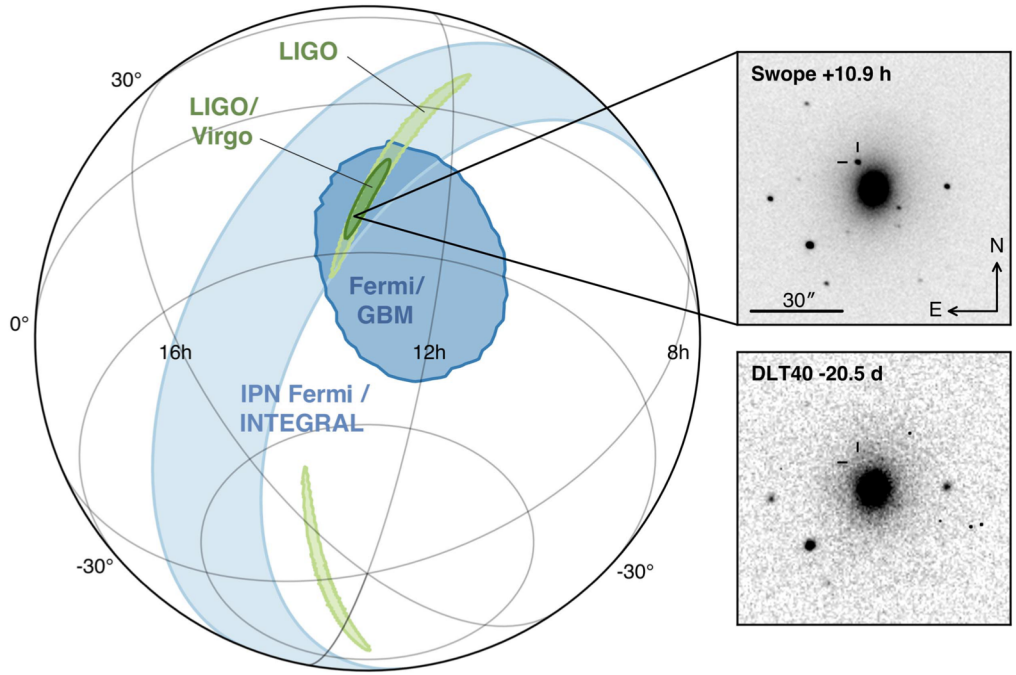
- No wide field-of-view experiment covering the southern hemisphere sky
- Gap around 100 GeV between satellite and ground based observations



The era of multi-messenger observations

physicsworld BREAKTHROUGH OF THE YEAR 2017

Joint publication of LIGO, VIRGO, INTEGRAL, Fermi, IceCube, Pierre Auger …



- Simultaneous observation of a Gravitational Wave + electromagnetic counterparts
- Study of transient phenomena in all energy windows is one of the main ingredients
- Large sky coverage to maximize chances for multi-detection

LATTES

Large Array Telescope for Tracking Energetic Sources

Astroparticle Physics 99 (2018) 34–42

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journal homepage: www.elsevier.com/locate/astropartphys

Design and expected performance of a novel hybrid detector for very-high-energy gamma-ray astrophysics

P. Assis[a,b], U. Barres de Almeida[c], A. Blanco[d], R. Conceição[a,b,*], B. D'Ettorre Piazzoli[e], A. De Angelis[f,g,b,a], M. Doro[h,f], P. Fonte[d], L. Lopes[d], G. Matthiae[i], M. Pimenta[b,a], R. Shellard[c], B. Tomé[a,b]

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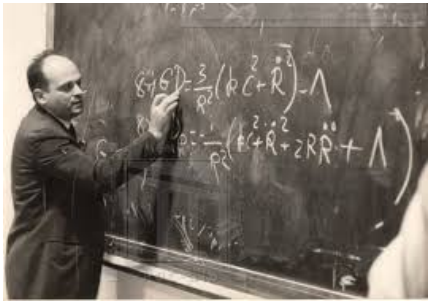
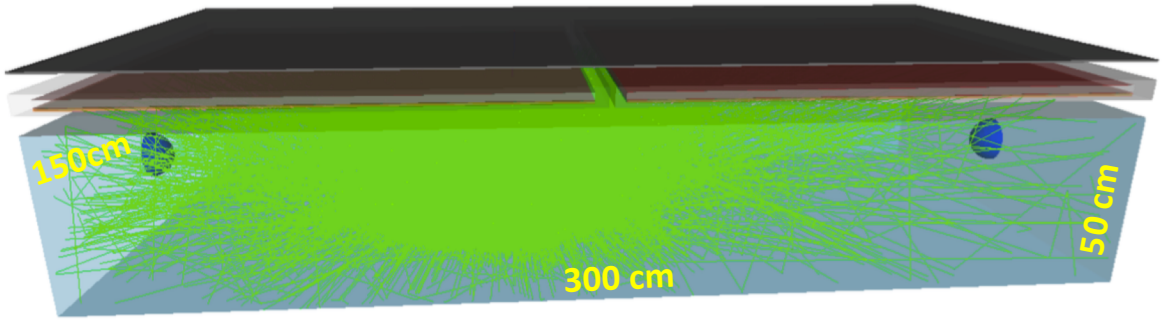


Cesar Lattes

- A next generation large FoV gamma-ray observatory :
  - Located in the South Hemisphere
  - Low energy threshold:
    - High altitude
    - Hybrid detector concept

LATTES hybrid detector concept



Pb

RPC

WCD

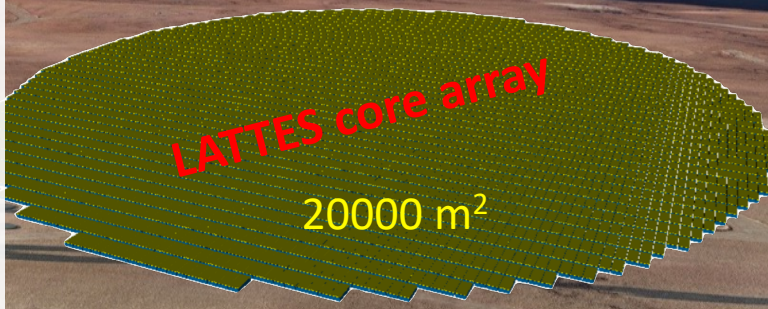
RPCs : time and spatial resolution

WCDs: e.m. energy, g/h discrimination and trigger

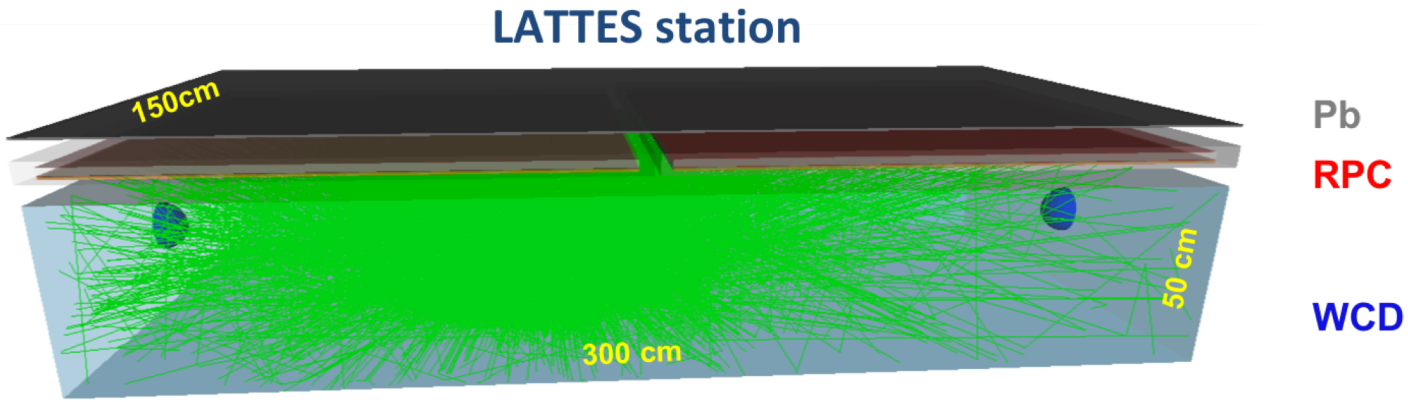
LATTES

Large Array Telescope for Tracking Energetic Sources

- Joint Brazil/Italy/Portugal initiative
- Czech group joined recently
- Possible sites:
  - Atacama Large Millimeter Array site - Chajnantor plateau (5200 m)
  - North of Argentina (~ 5000 m)
  - …
- LATTES array baseline
  - Compact core array
    - Area: 20 000 m^2
    - Target lowest energies (E_{min} ~ 100 GeV)
  - Sparse array
    - Area: 100 000 m^2
    - Cover energies up to 100 TeV



LATTES hybrid concept
baseline design



Thin lead plate (Pb)

- 5.6 mm (one radiation length)

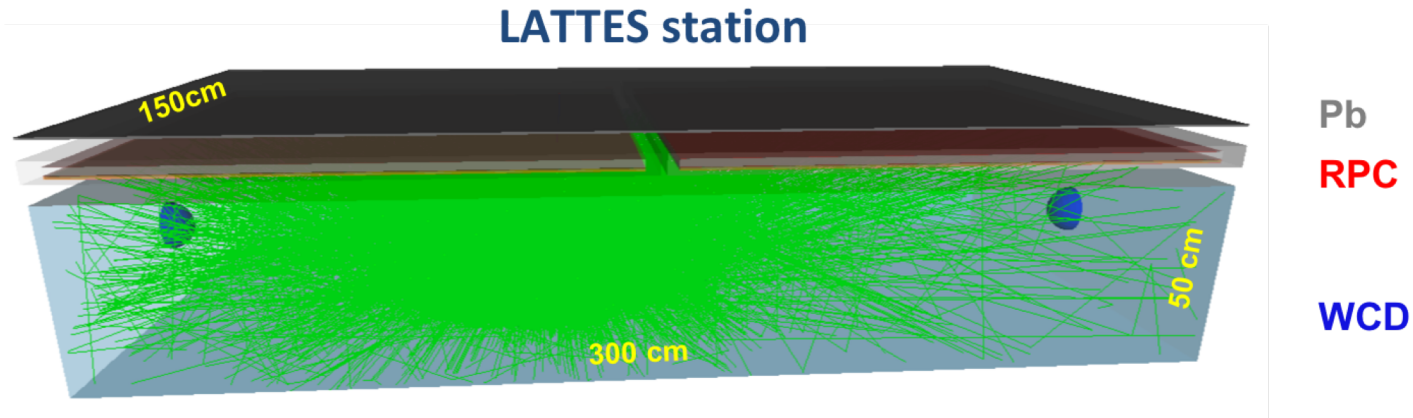
Resistive Plate Chambers (**RPC**)

- 2 RPCs per station
- Each RPC with 4x4 readout pads

Water Cherenkov Detector (**WCD**)

- 2 PMTs; 15 cm diameter
- inner walls covered with white diffusing Tyvek

LATTES hybrid concept



Thin lead plate (Pb)

- Convert the shower photons;
- Improve angular reconstruction

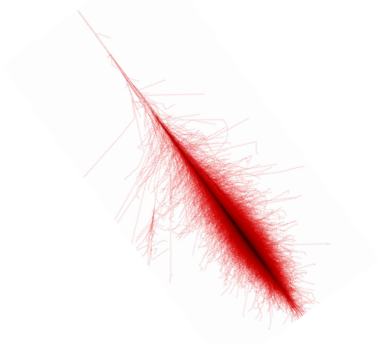
Resistive Plate Chambers (**RPC**)

- Sensitive to charged particles
- Very good time (1 ns) and spatial resolution (tens of cm)
- Improve geometric reconstruction
- Explore shower particle patterns at ground

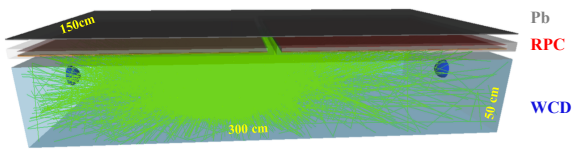
Water Cherenkov Detector (**WCD**)

- Sensitive to shower photons and charged particles
- Measure energy flow at ground
- Improve trigger capability
- Improve gamma/hadron discrimination

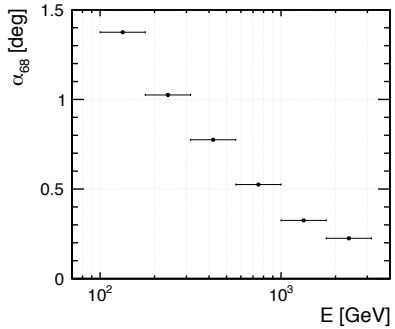
Simulating LATTES performance



Shower simulation
(CORSIKA)



Detector simulation
(Geant4)



Shower reconstruction
(LATTESrec)

LATTES

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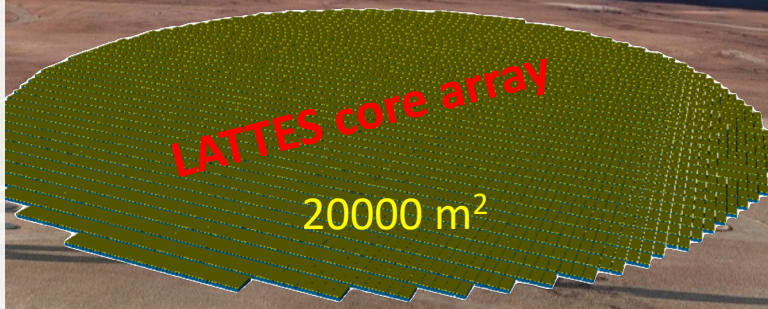
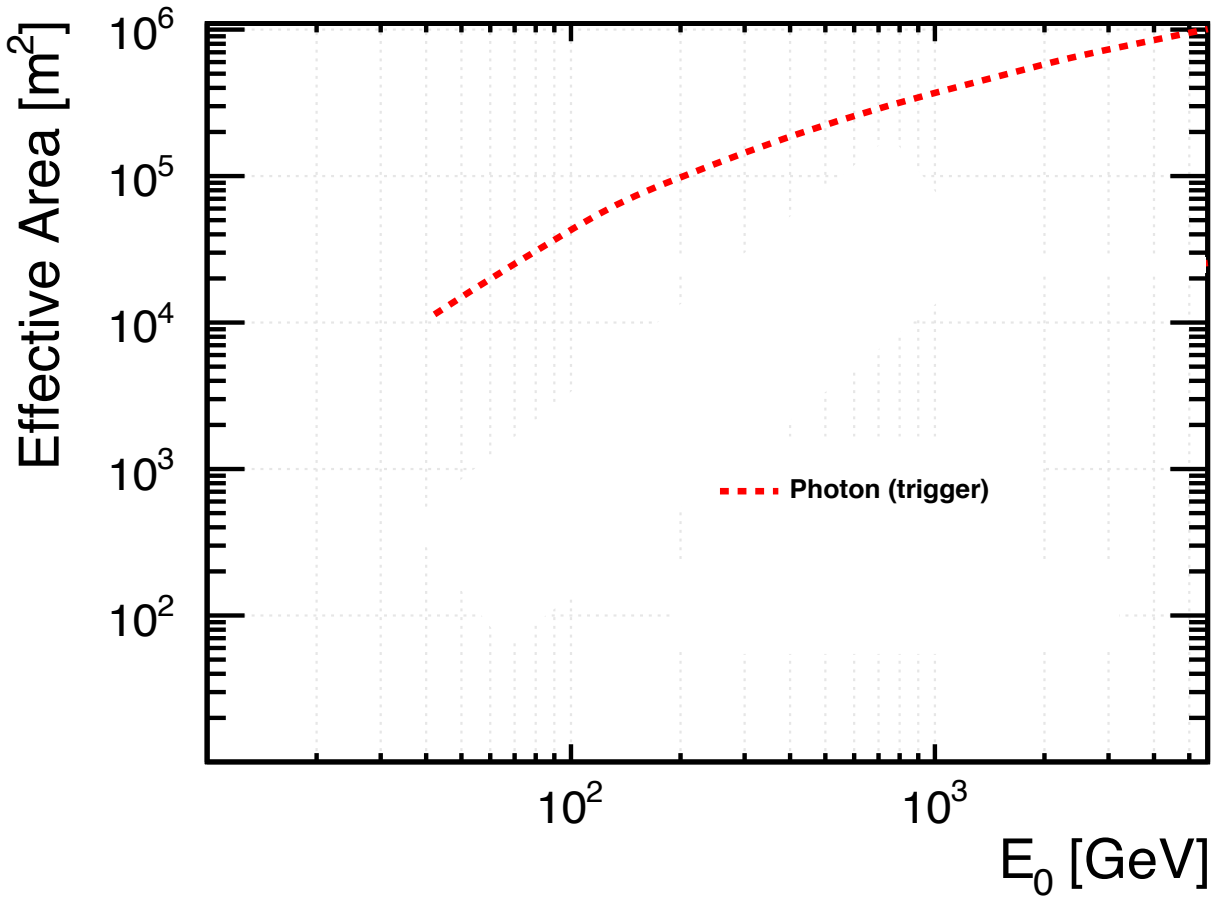


Trigger efficiency

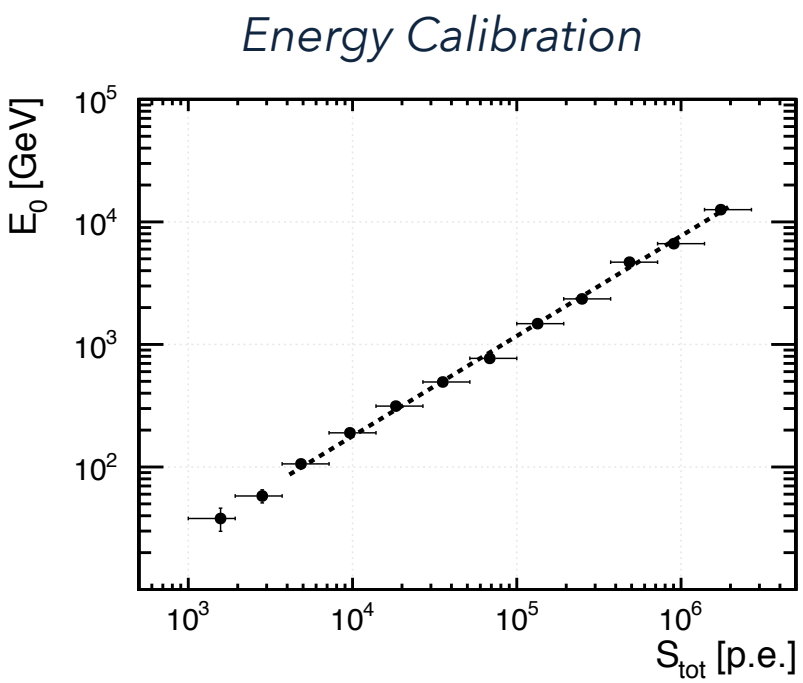


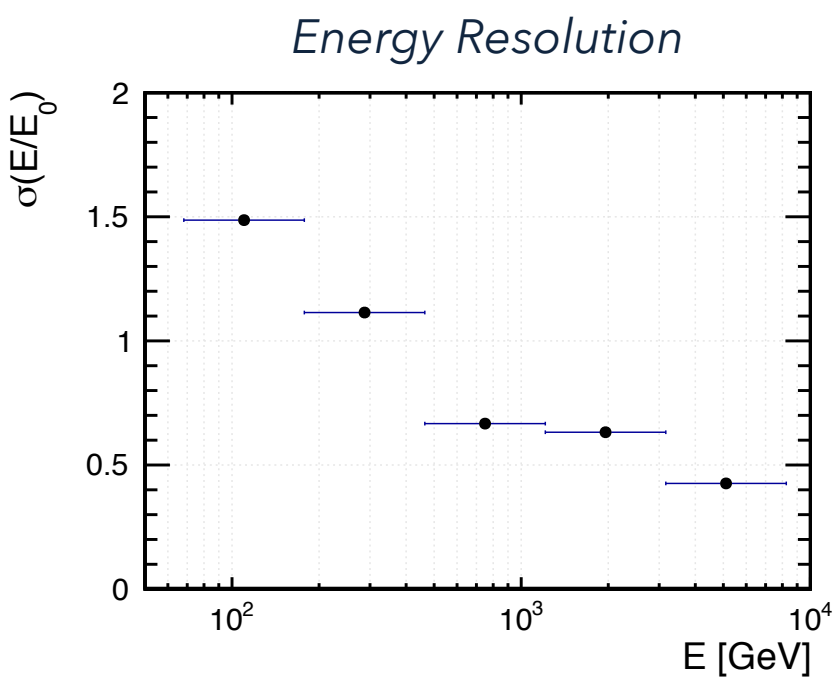
- Use WCD stations to improve trigger at low energies
  - Trigger condition
    - Station: require more than 5 p.e. in each PMT
    - Event: require 3 triggered stations
- Trigger efficiency of the order of 10% @ 50 GeV

Energy reconstruction

$E_0 \rightarrow$ Simulated energy

$E \rightarrow$ Reconstructed energy



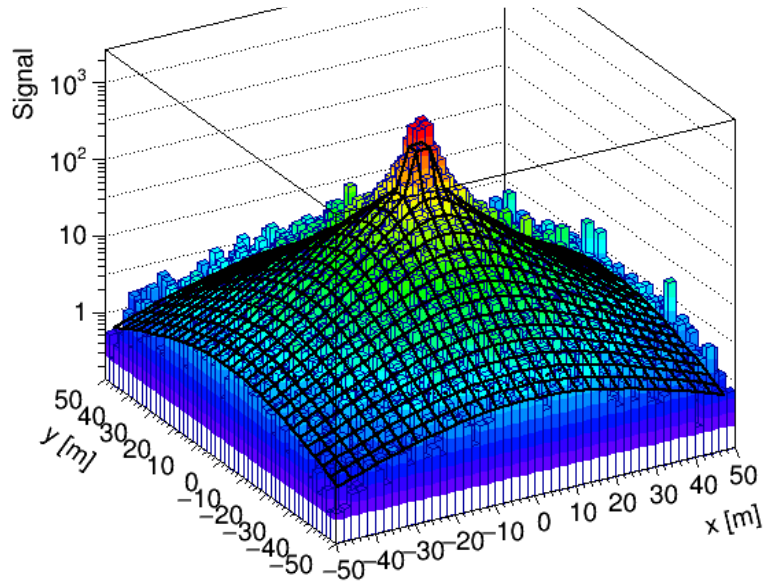


- Use as energy estimator the total signal recorded by WCDs
  - Use only shower cores reconstructed inside array
  - Not accounting for shower fraction outside the array
- Energy resolution at low energy dominated by shower to shower fluctuations

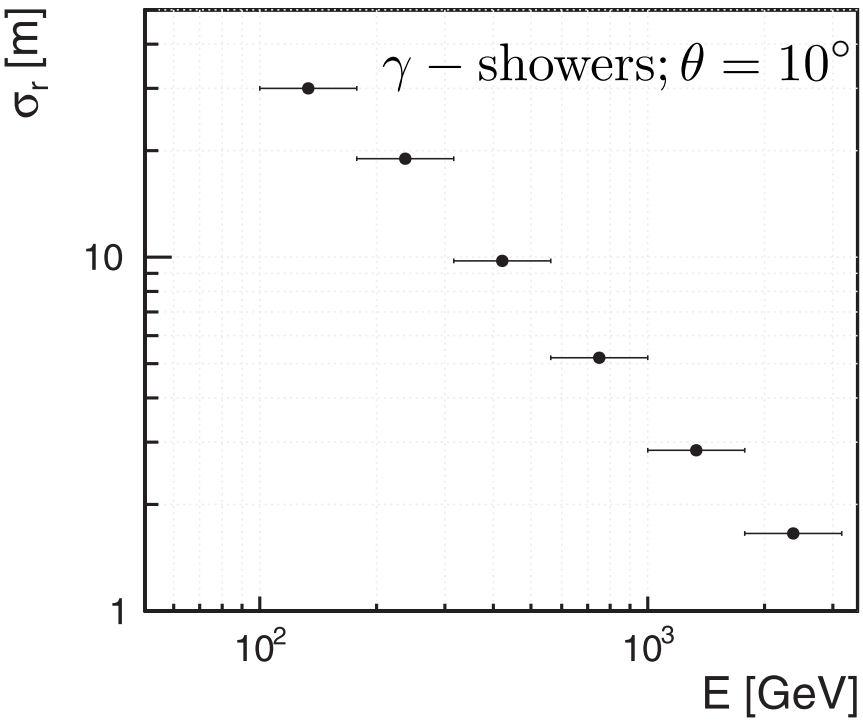
Shower geometry reconstruction

core position

$$S_i = S(A, \vec{x}, \vec{x}_i) = A\left(\frac{1}{2\pi\sigma^2} e^{-|\vec{x}_i - \vec{x}|^2/2\sigma^2} + \frac{N}{(0.5 + |\vec{x}_i - \vec{x}|/R_m)^3}\right)$$



- Fit the LDF of the WCD signal:
  - Photon average LDF to fix the shape
    - Function inspired in HAWC
    - Nearly no evolution with energy
  - Position of maximum gives the shower core

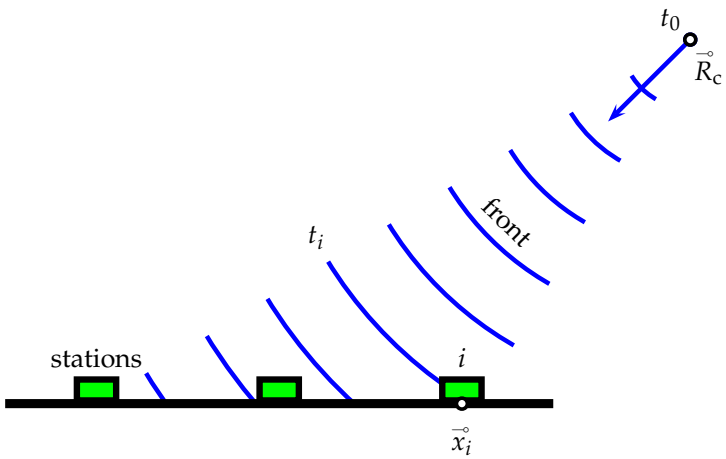


- Resolution better than 10 m for E > 300 GeV.

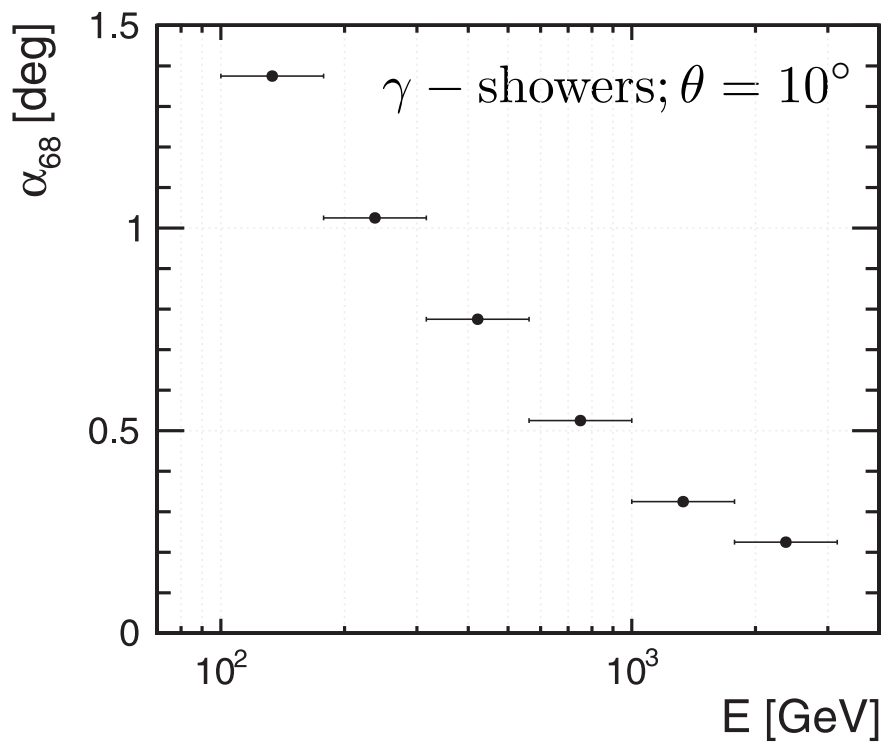
Shower geometry reconstruction

direction

$$\chi^2 = \sum (c \cdot (T_n - T_0) - X_n \cdot l - Y_n \cdot m - R_n \cdot \alpha)^2$$

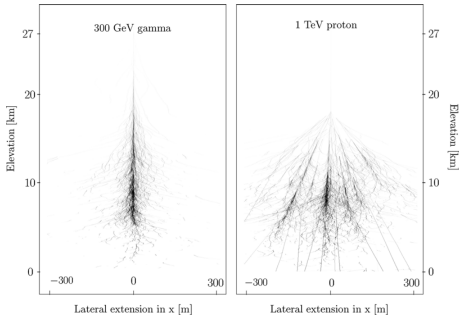


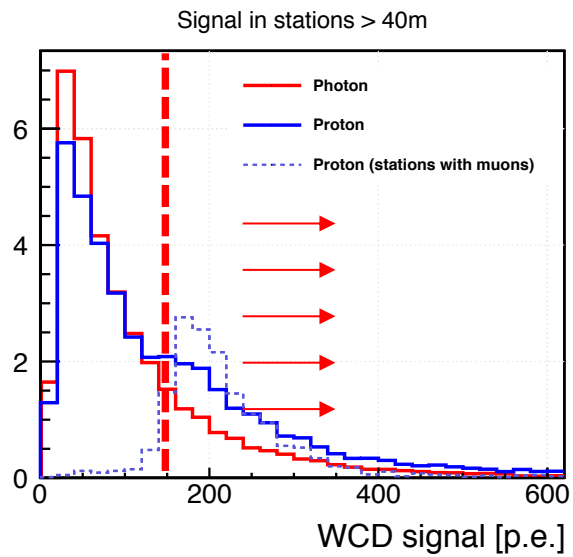
- Fit the RPC hit times:
  - Take advantage of RPCs **high spatial and time resolution**
  - Fit the shower geometry using a shower conic front model
  - Good angular resolution for all events reconstructed inside the array;

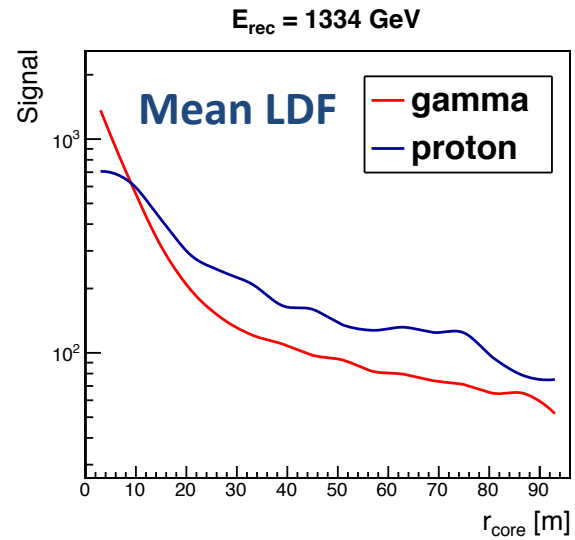


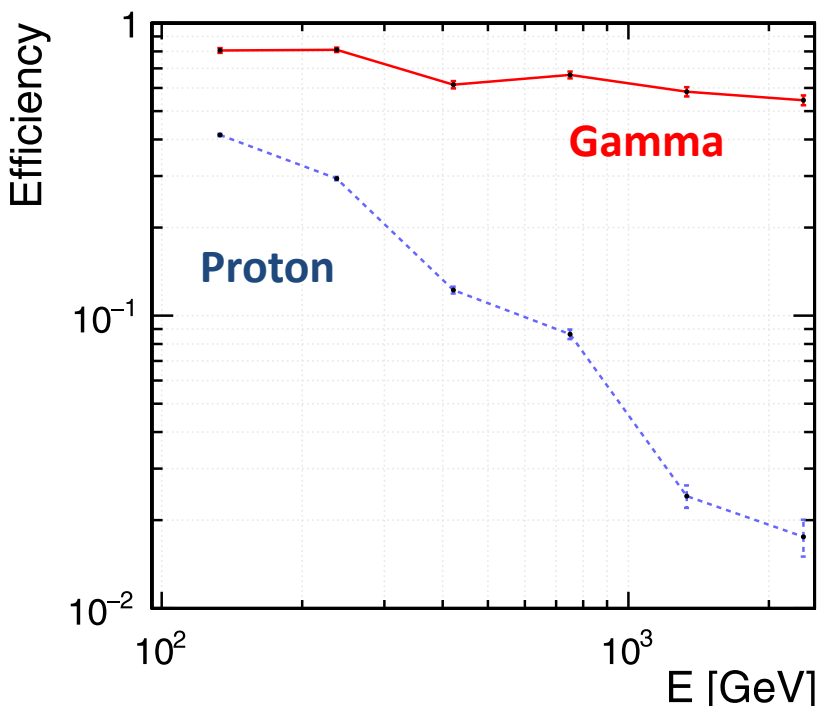
- Resolution better than 1.5° for E > 100 GeV

Gamma/hadron discrimination



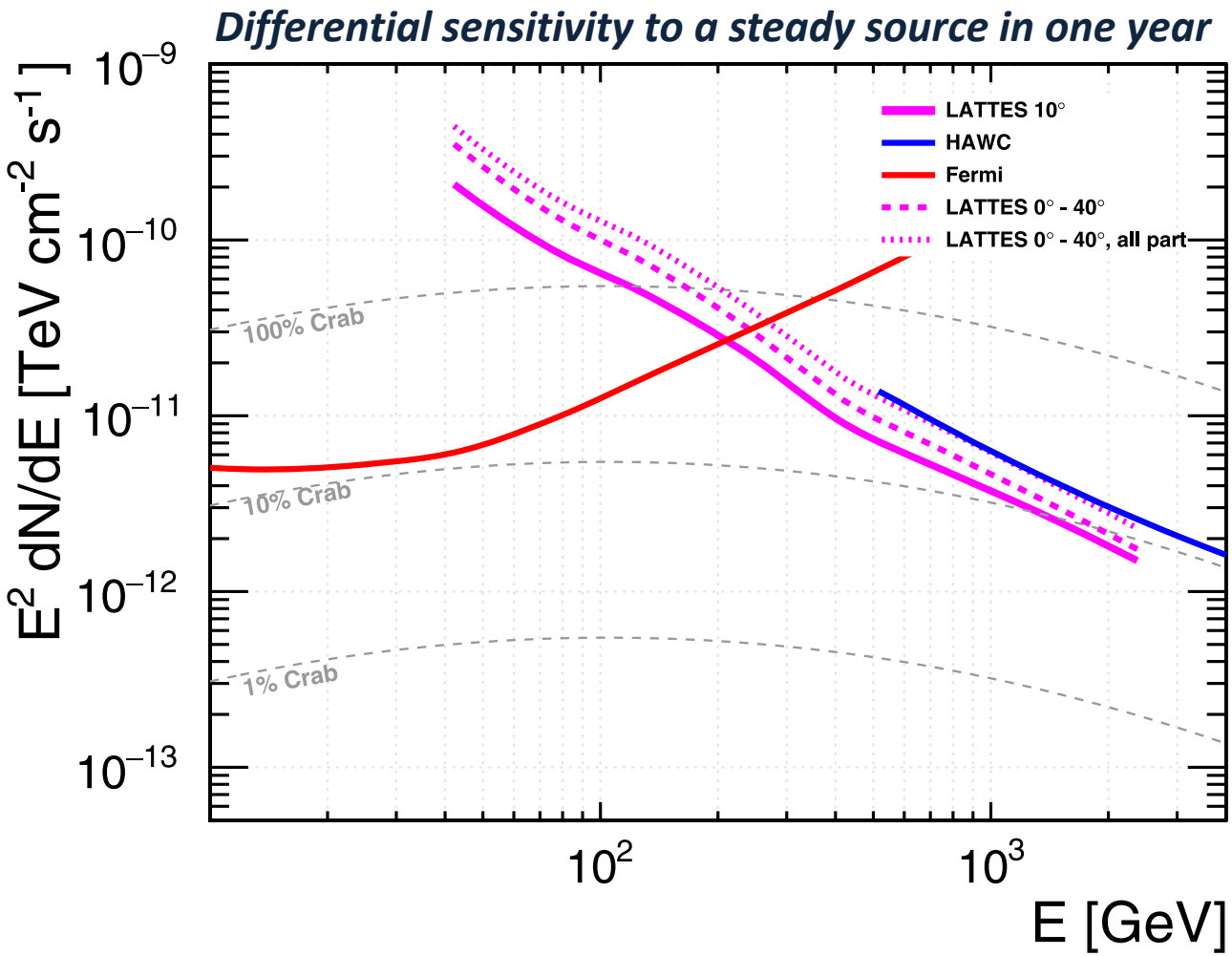






- Explore shower footprint on ground:
  - Use info from WCD only;
  - Look for high p_t sub-showers and/or muons;
  - Shower compactness discrimination variable
    - LDF of gamma showers is more steep than the LDF of hadron showers
  - Fisher discriminant analysis to combine variables
- Room for improvements

LATTES sensitivity



- LATTES concept fulfills the main requirements for a next-generation large FoV gamma-ray experiment :
  - Good sensitivity at low energies (down to 100 GeV) :
    - Cover the gap between satellite and ground based measurements
  - Survey the southern sky, in particular the center of the galaxy :
    - powerful tool to trigger observations of variable sources and to detect transients
    - Complementary project to CTA
  - Important contribution in future multi-messenger observations
- High-energy extension with a sparse array is being studied
    - energies up to 100 TeV;
    - improve lower energies

Acknowledgements

FCT
Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA EDUCAÇÃO E CIÊNCIA

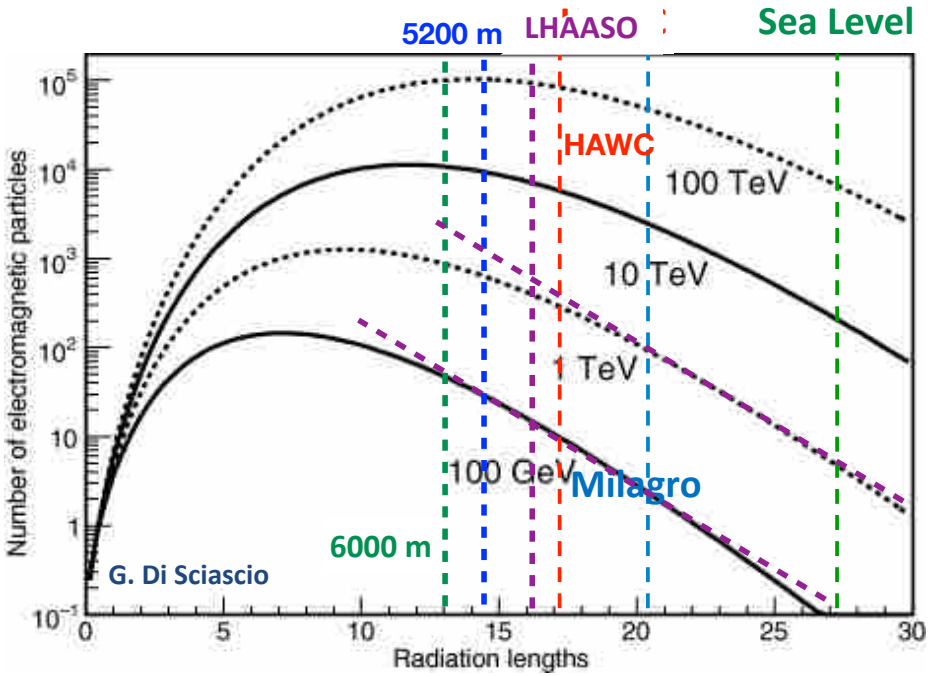
REPÚBLICA PORTUGUESA

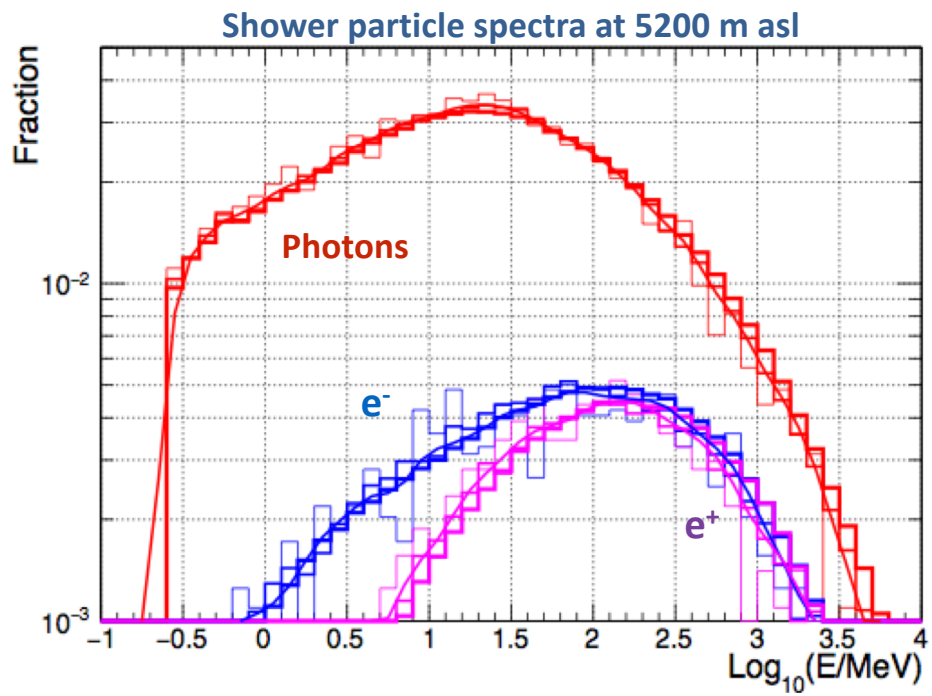
LIP

TÉCNICO LISBOA

BACKUP SLIDES

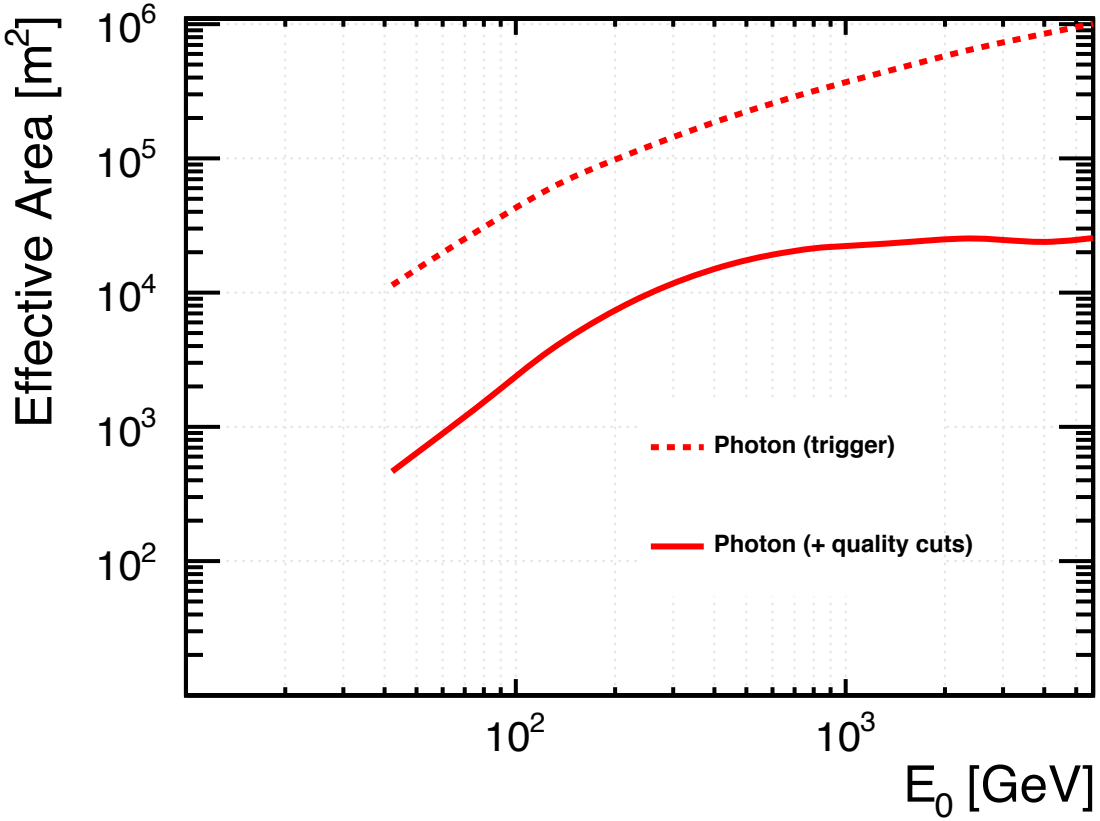
The low energy challenge





- Need to:
  - Go to high altitude;
  - Convert the shower photons;
  - Measure energy flow.

Effective Area

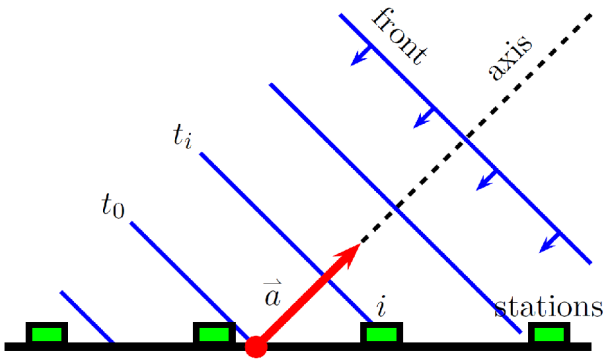


Even applying all quality cuts LATTES

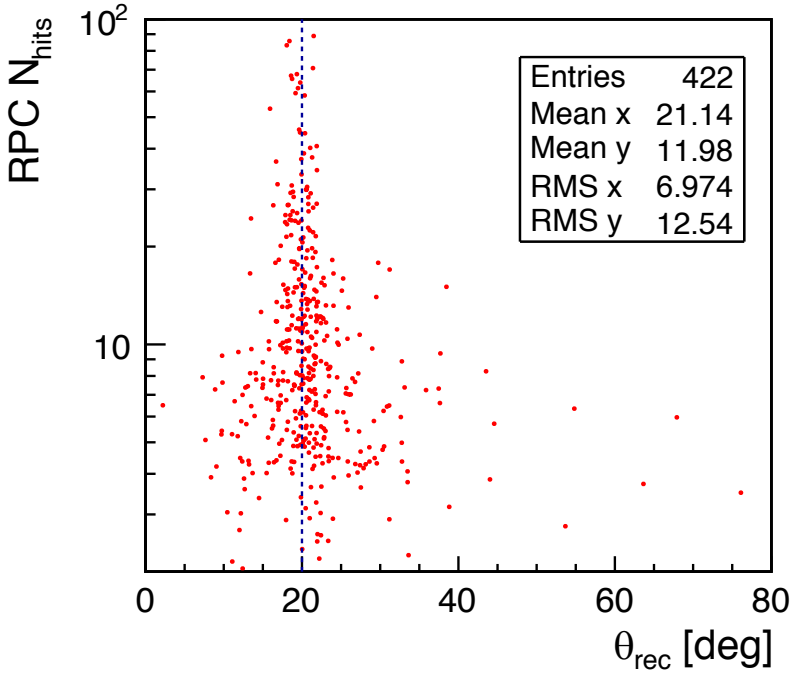
gets an effective area of ~1000 m^2 for E = 100 GeV

Reconstruction of shower geometry

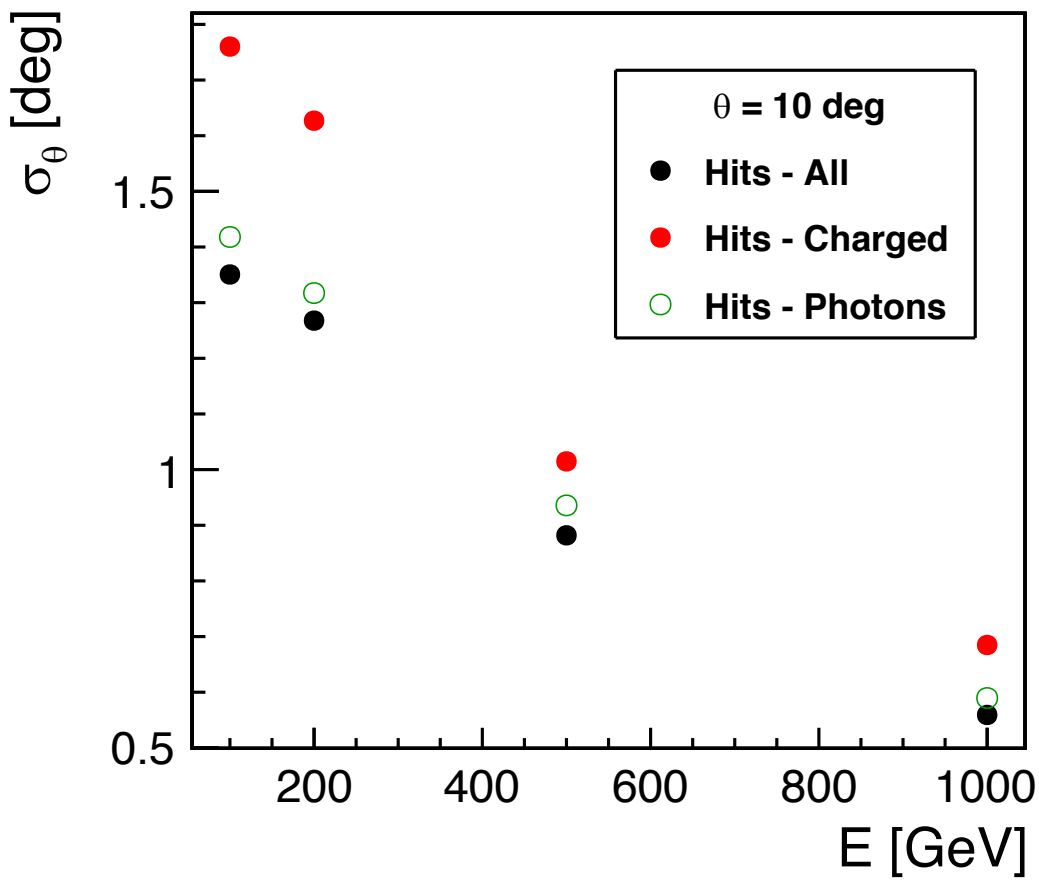
- **Use RPC hit time** information to reconstruct the shower
  - Take advantage of **high spatial and time resolution**



- Shower geometry reconstruction:
  - Use **shower front plane approximation**
  - Analytical procedure
  - Apply trigger conditions
  - Apply **cut** on the **number of registered hits** by the RPCs

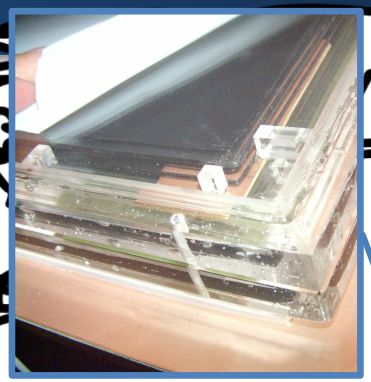


Contributions to the geometric reconstruction

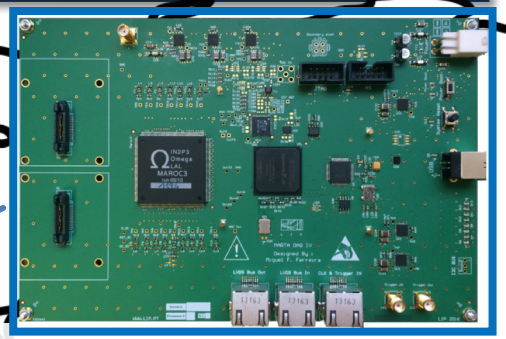


- **Photons** retain a **higher correlation** with the **shower geometry** than charged particles
- Could we measure photons with the RPC instead?

Ongoing developments and tests on RPCs, electronics and read-out systems



RPC developments



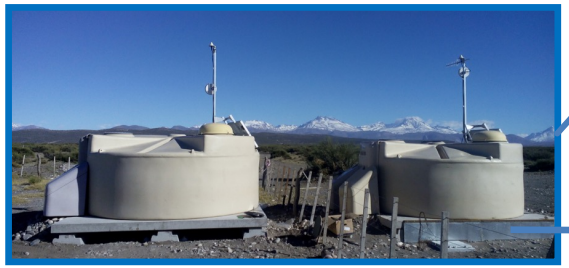
DAQ Engineering prototype

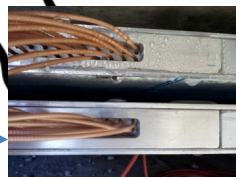
RPC based muon hodoscope for precise studies of the Auger WCD

Construction and Assembling

RPC hodoscope

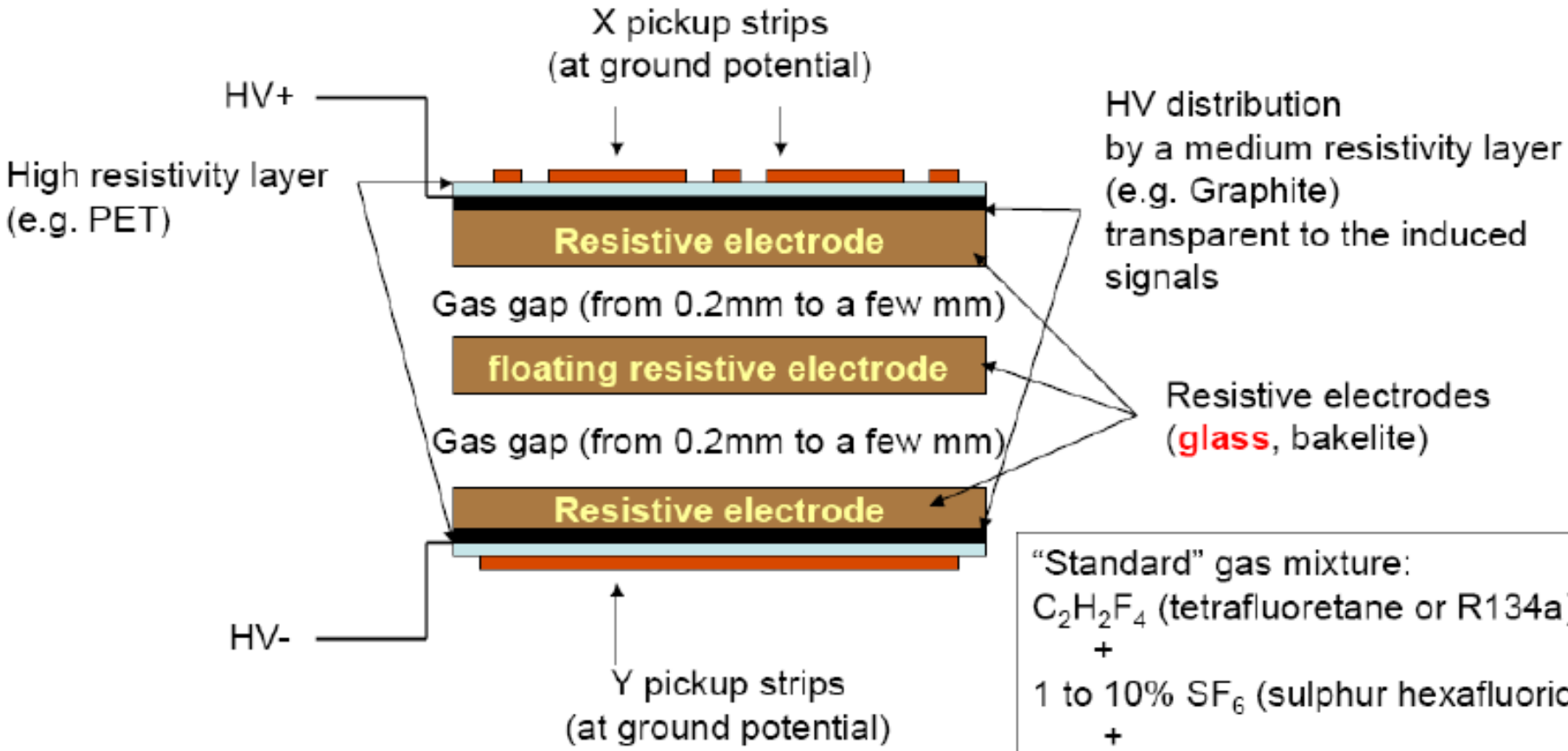
RPCs in the field @ Auger





RPCs – basic structure

Many variations allowed



"Standard" gas mixture:
$C_2H_2F_4$ (tetrafluoretane or R134a)
+
1 to 10% SF_6 (sulphur hexafluoride)
+
0 to 5% C_4H_{10} (isobutane)

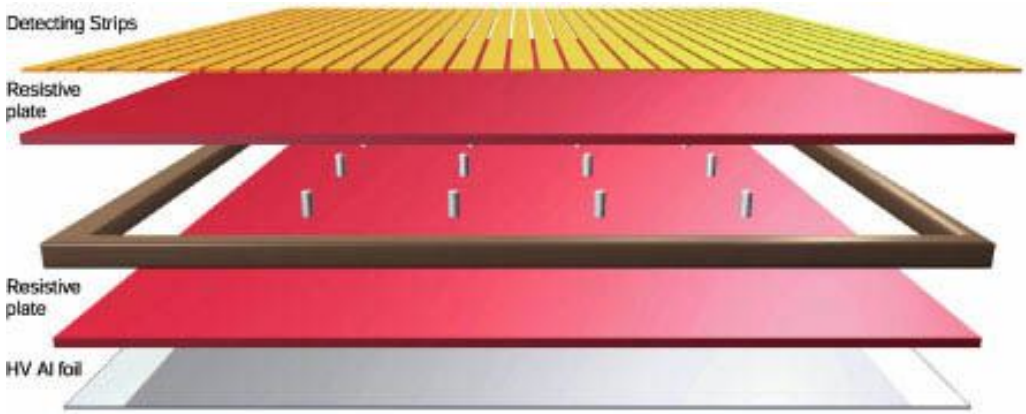
The current is limited by the resistive electrodes: no sparks by construction

Þ very safe detector, although limited to low particle rates (~2kHz/cm^2)

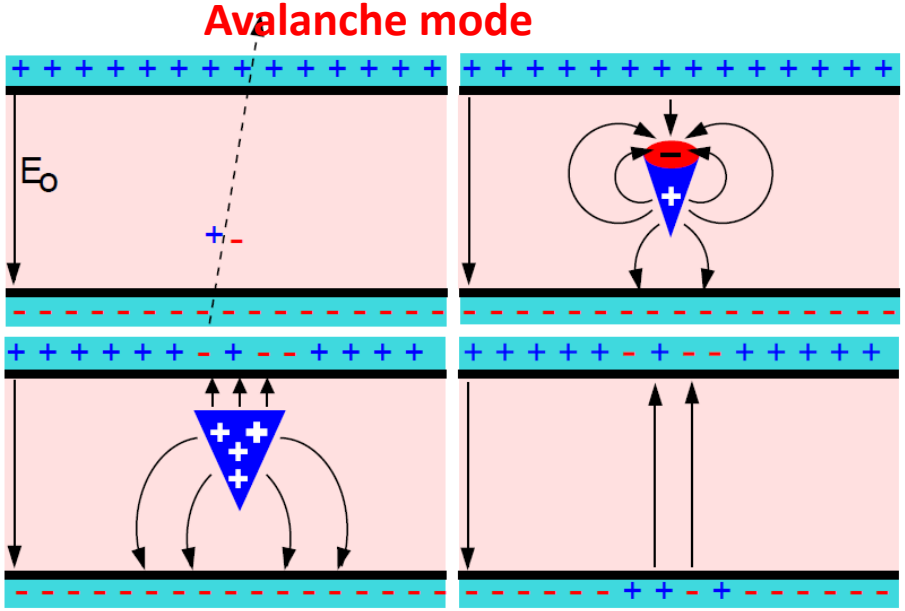
Þ excellent efficiency (99%), time (~50 ps) and position resolution (~100μm)

RPCs Resistive Plate Chamber

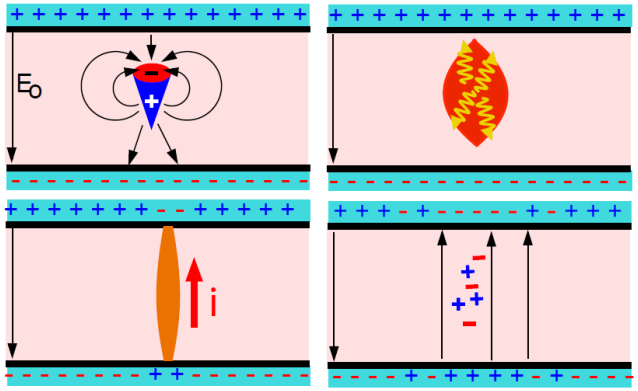
- Gaseous detector
- Planar geometry
- uniform electrical field imposed.
- High resistive plates in between the electrodes limit the avalanche current.
- Signal is picked up by the induction of the avalanche in the readout pads.



Avalanche mode

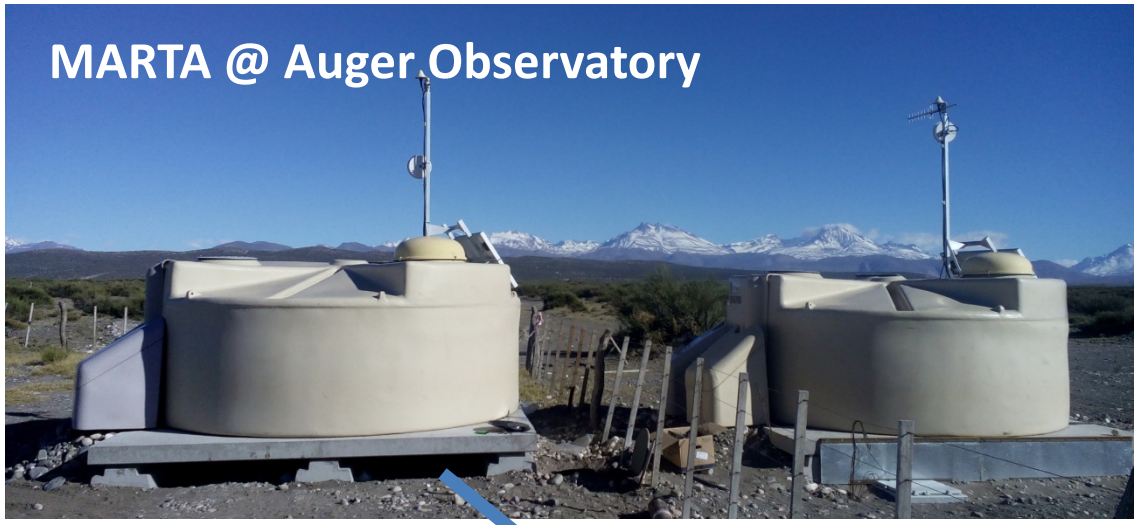


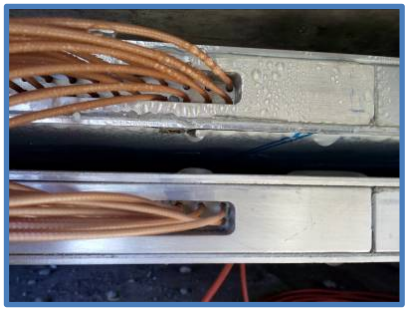
Streamer mode



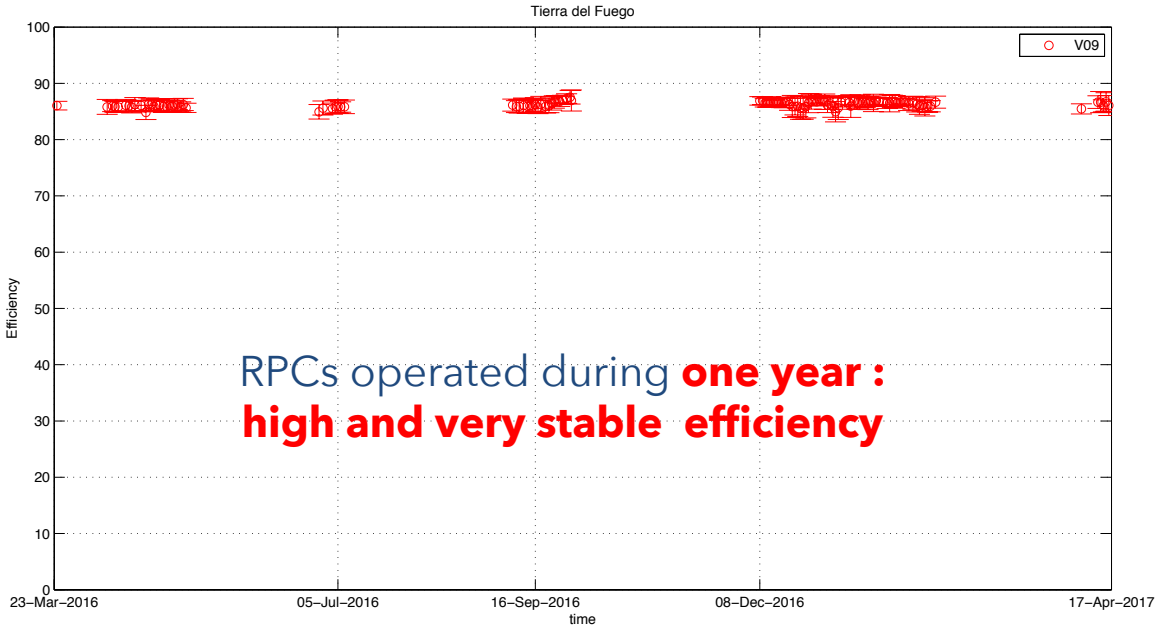
Outdoor field operation

- Several RPCs operating in the Pampa for more than one year





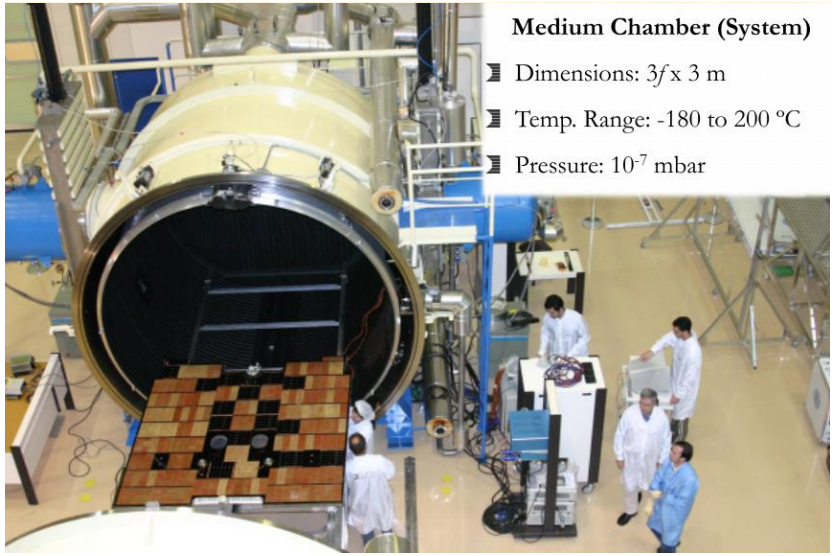
RPCs under the WCD



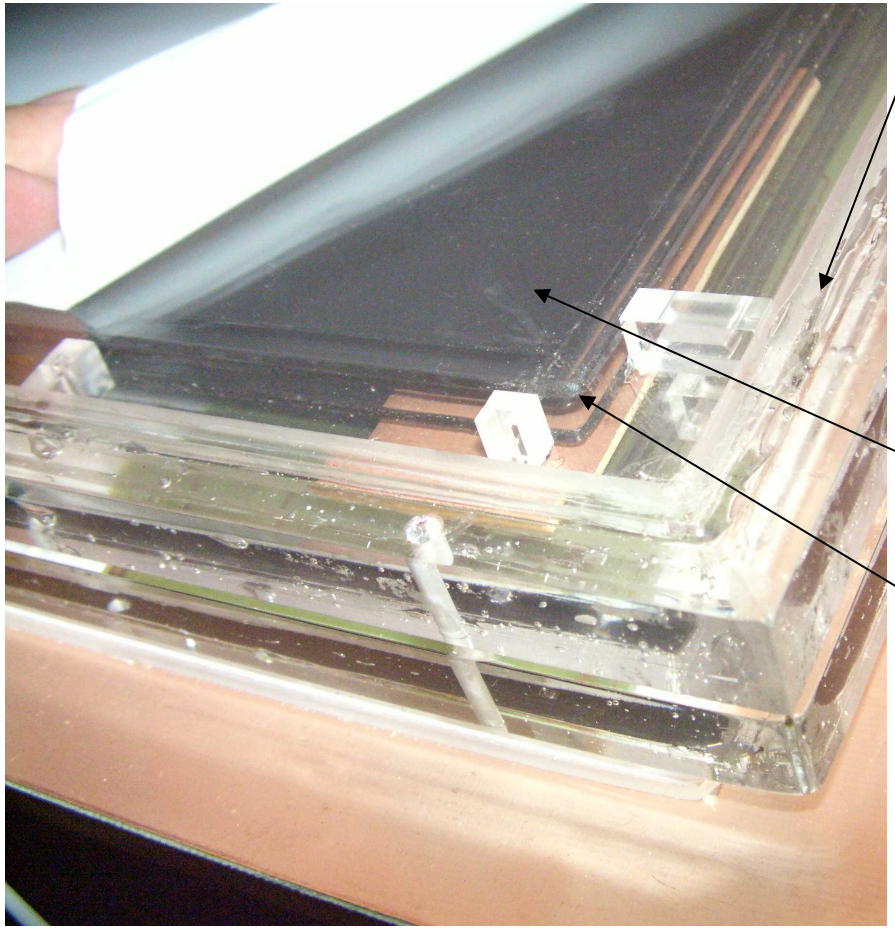
Low pressure tests

São Paulo, Brazil

National Institute for Spatial Research



CONSTRUCTION DETAILS



Signal-transparent and nice-looking acrylic box, 1mm thick covers

Permanently glued

RPC fits tightly inside

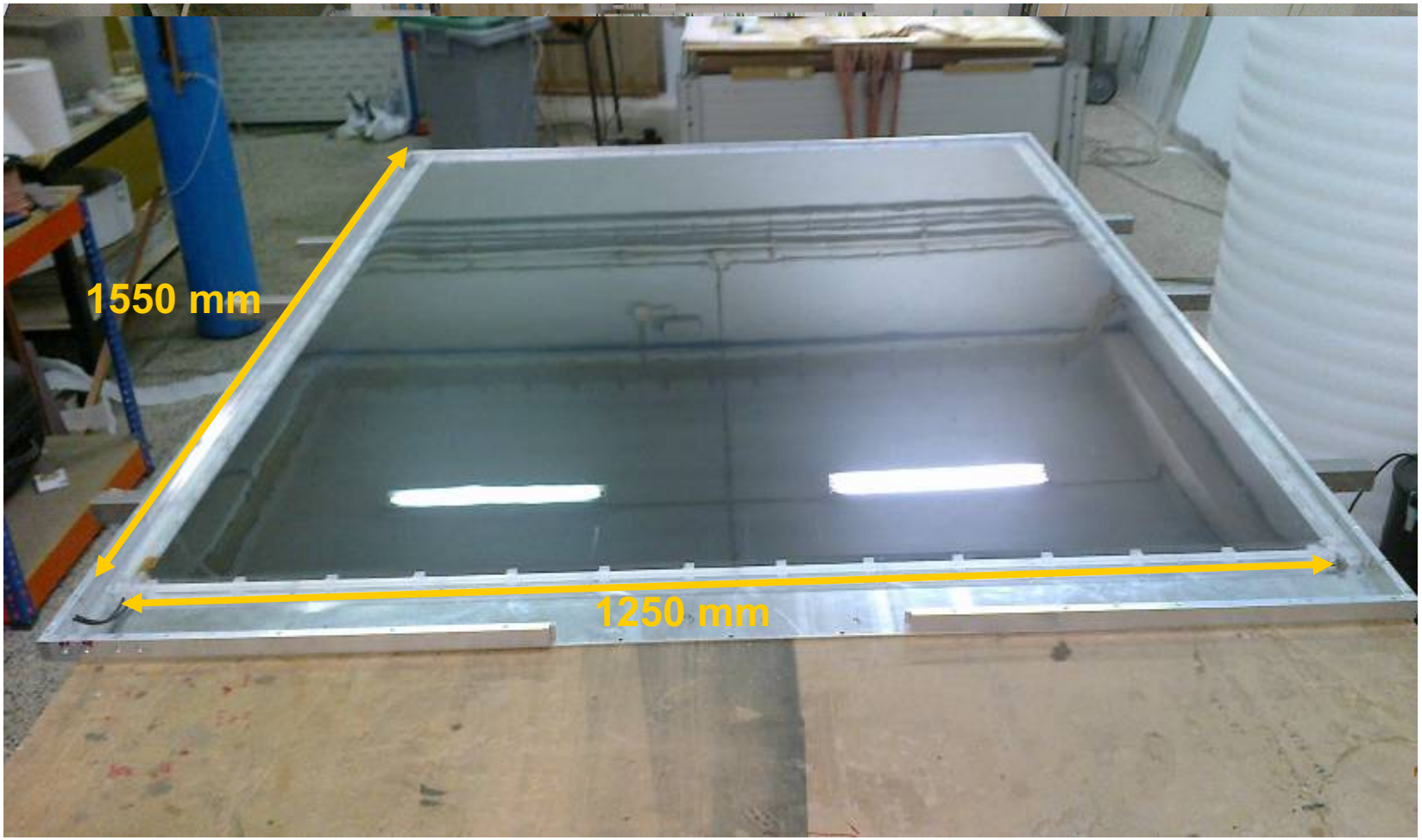
- ✓ good electrode support mechanics
- ✓ excellent HV insulation
- ✓ excellent gas tightness

HV layer, also signal-transparent

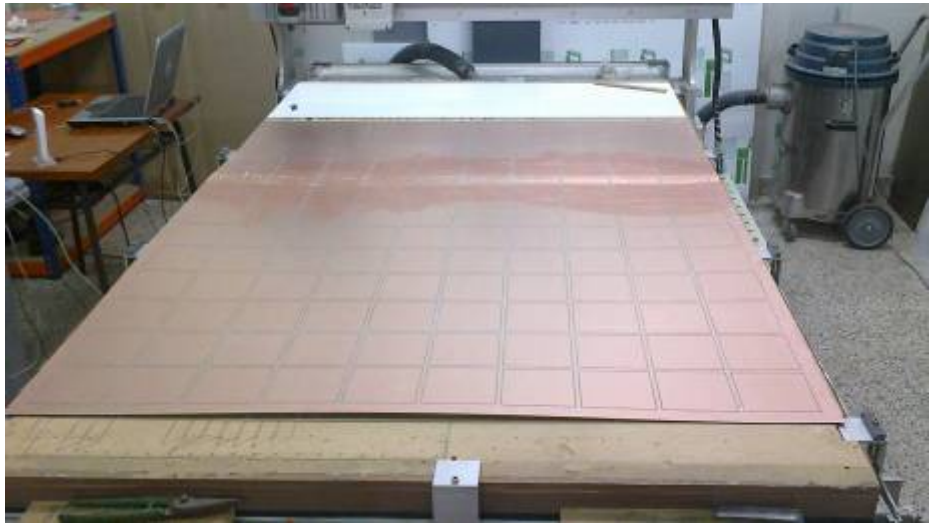
3 RPC glasses (2mm soda-lime)

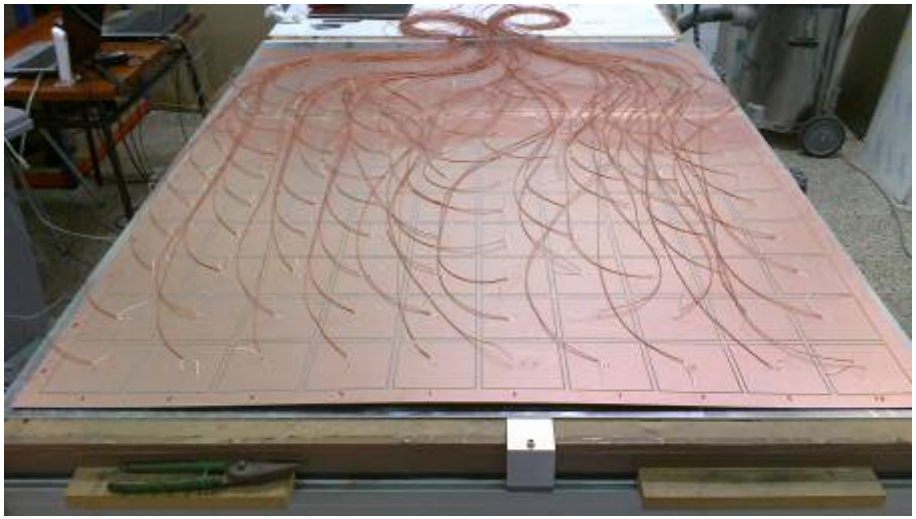
External pickup electrodes

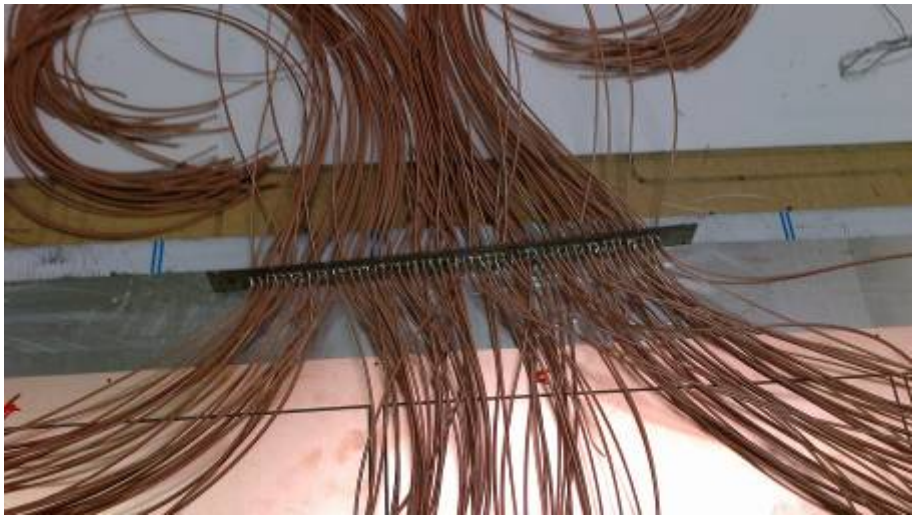
CONSTRUCTION DETAILS. RPC and gas volume



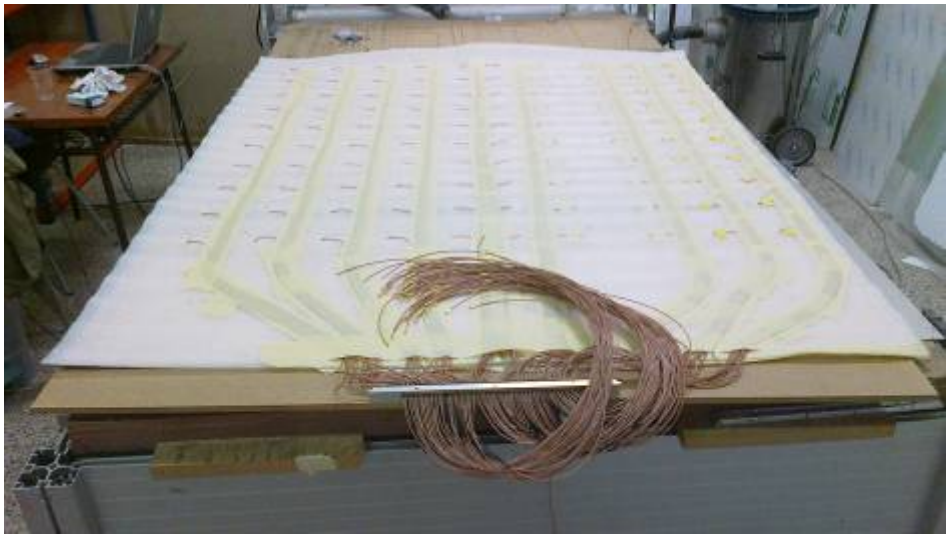
CONSTRUCTION DETAILS. Readout 8x8 pads

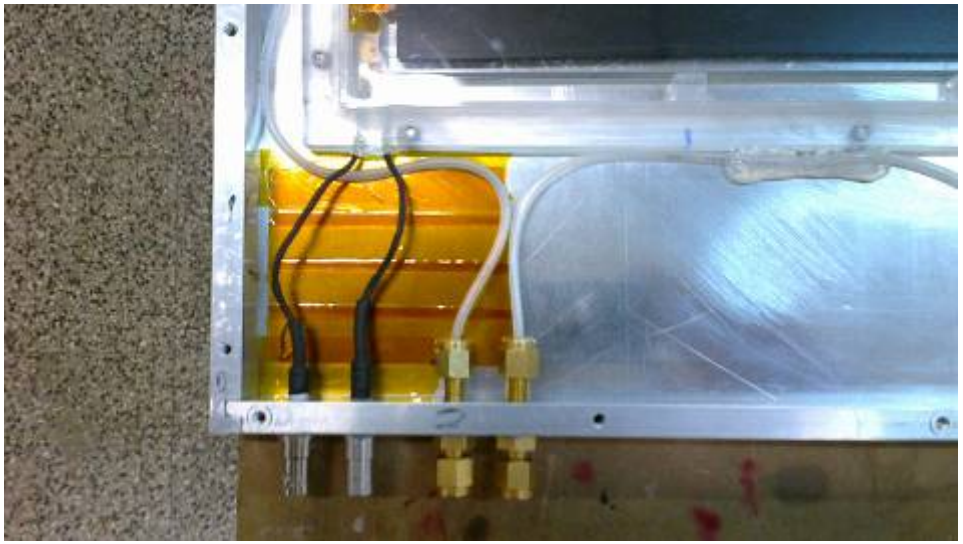


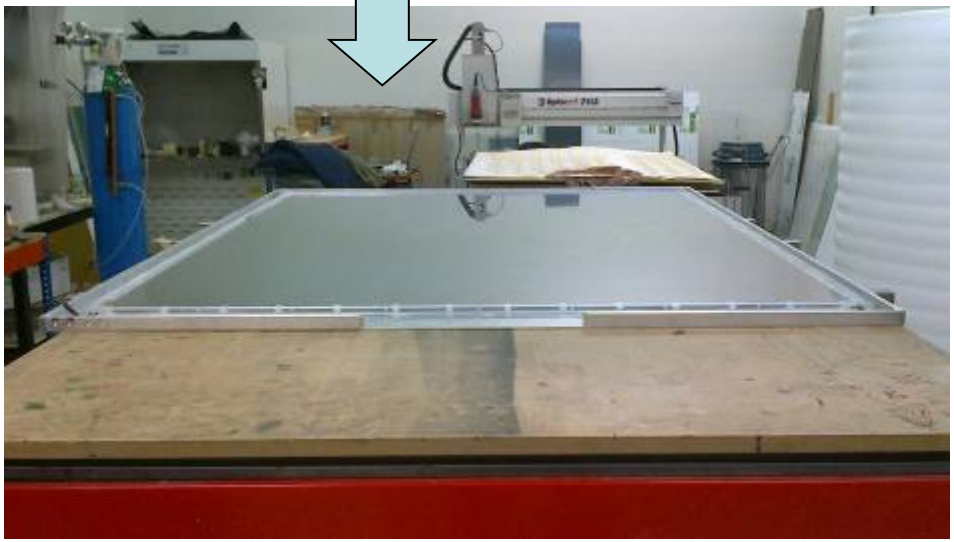




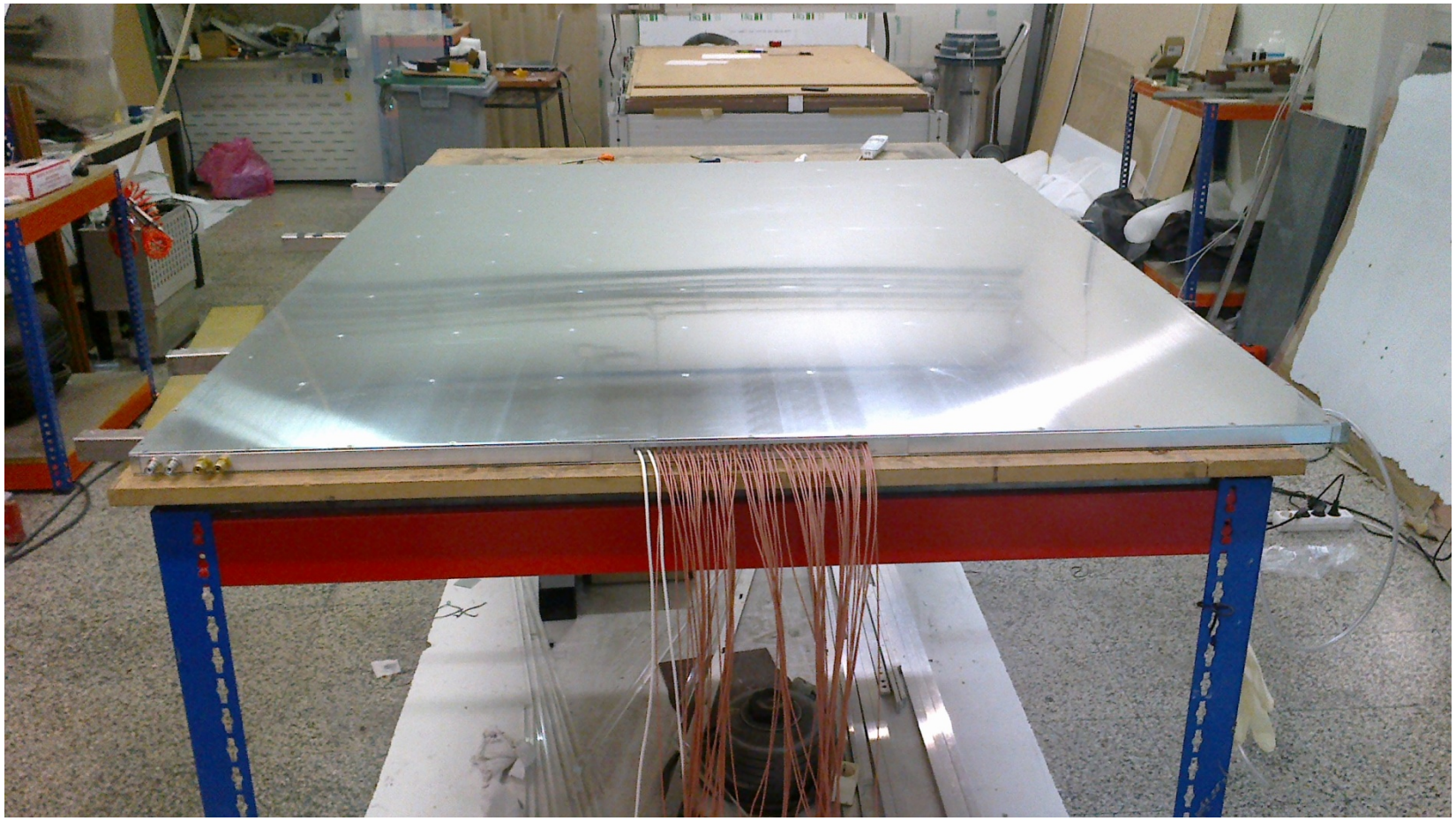
CONSTRUCTION DETAILS. Assembly



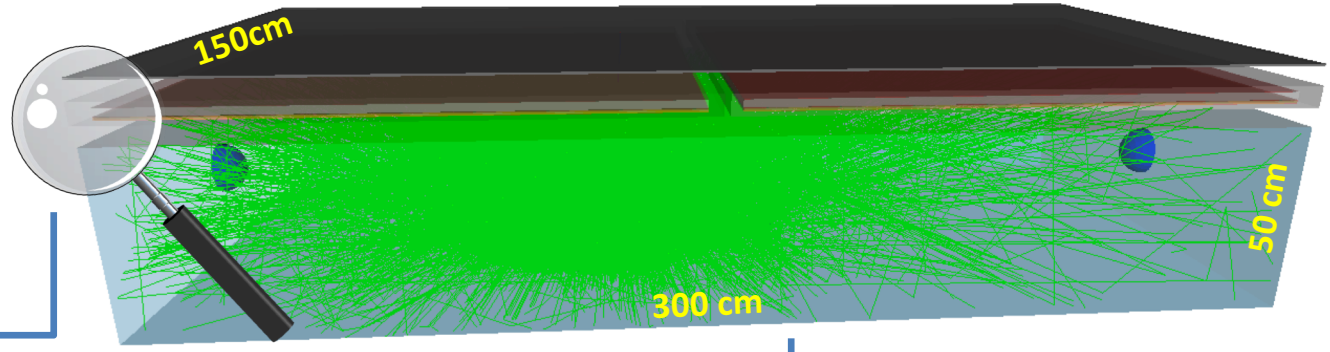




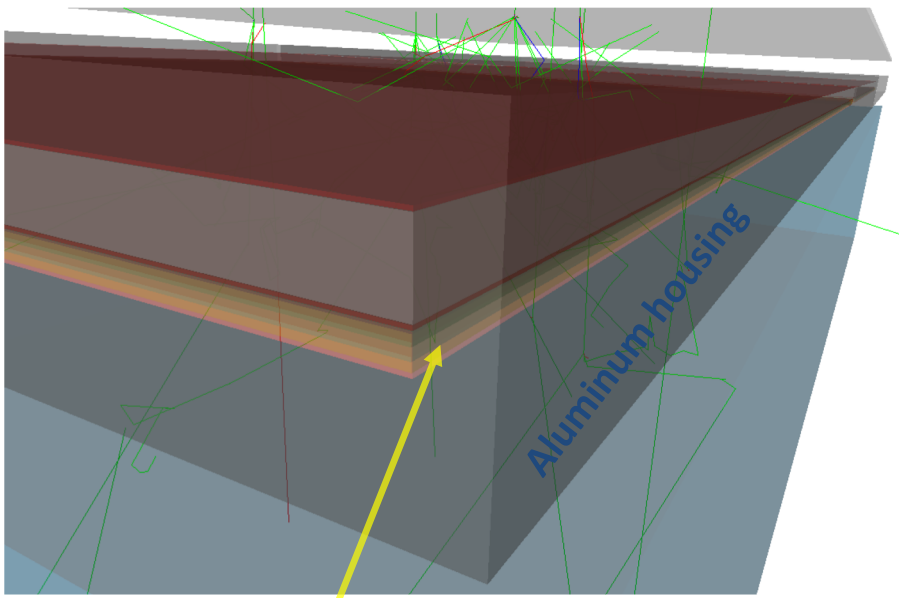
CONSTRUCTION DETAILS. RPC enclosed



LATTES station in Geant4



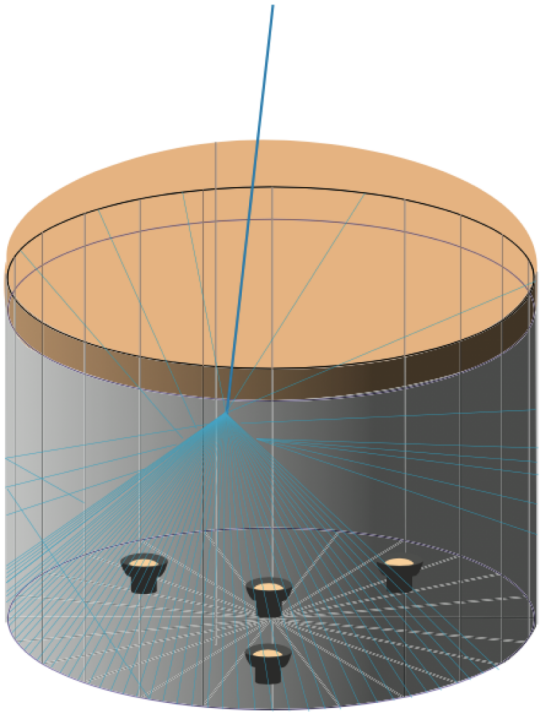
Detailed RPC structure

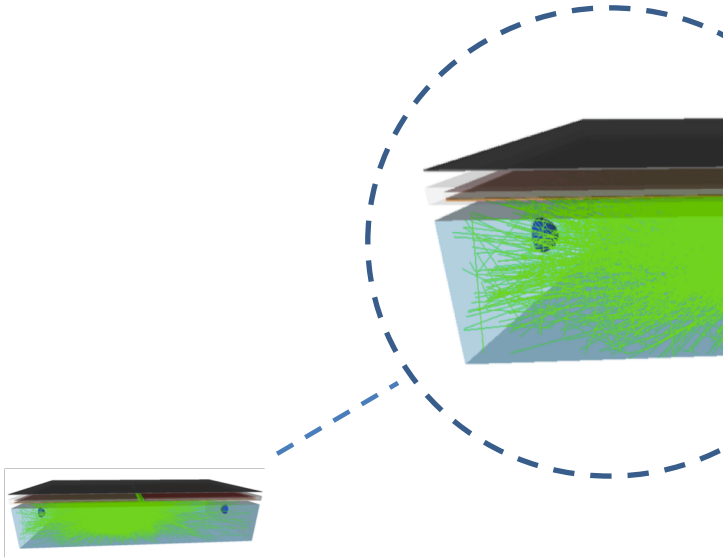


Acrylic box with glass electrodes and 1 mm gas gaps

- **Explore Geant4 capabilities to simulate optical photon propagation;**
- λ dependence of all relevant processes/materials taken into account;
- **Water**
  - Attenuation length ~ 80 m @ λ = 400 nm
- **PMT**
  - $Q.E._{max}$ ~ 30% @ λ = 420 nm
- **Tyvek**
  - Described using the G4 UNIFIED optical model;
  - Specular and diffusive properties;
  - R ~ 95%, for λ > 450 nm

Station: HAWC vs LATTES



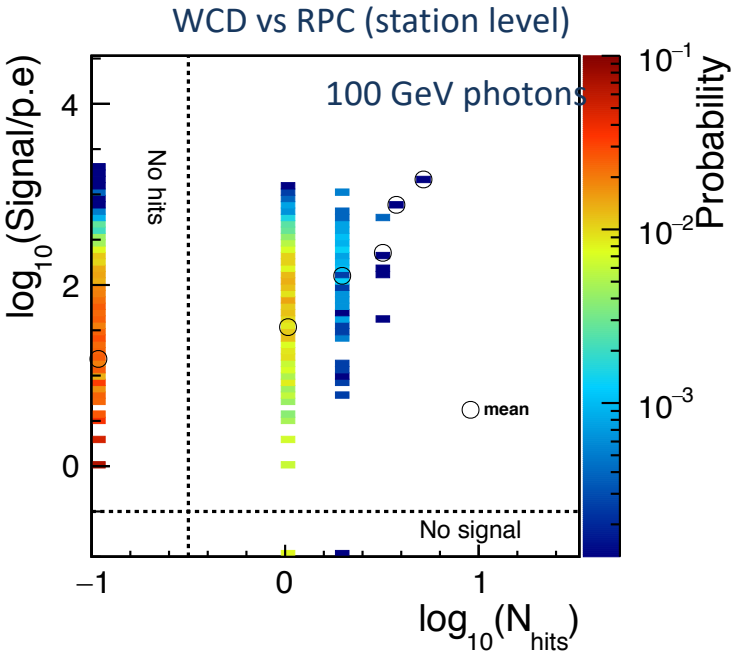


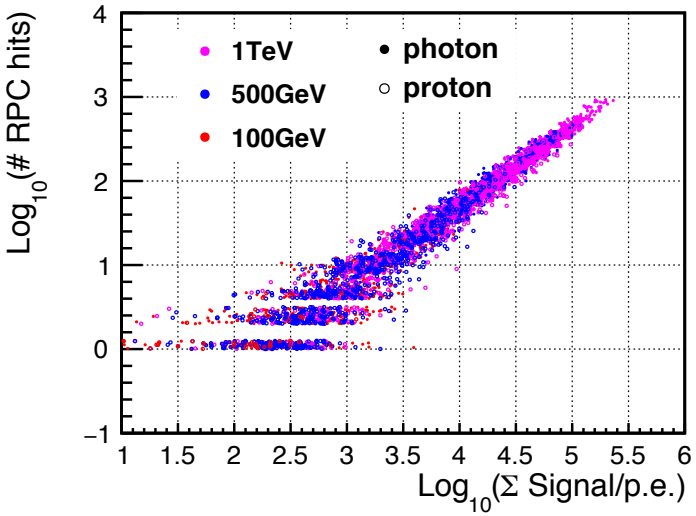
HAWC
(present detector)

LATTES
(next generation)

LATTES: complementarity

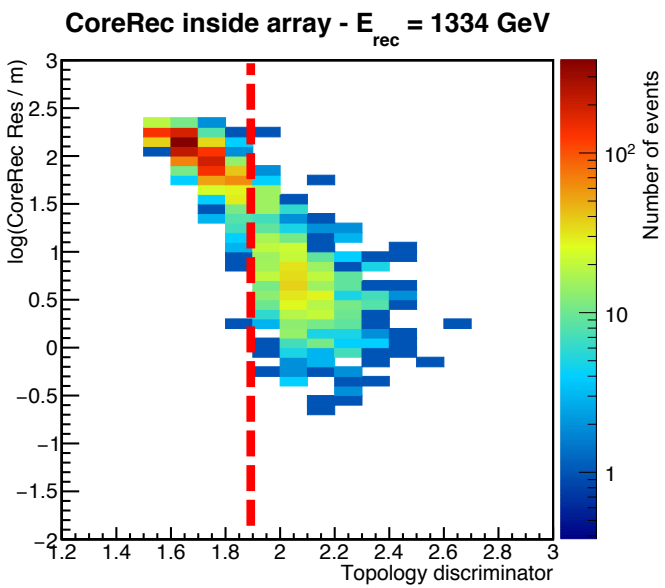
- Combined detection:
  - Lower the **energy threshold**
    - Improve the trigger conditions (WCD)
  - Enable detector **inter-calibrations**
    - Energy calibration can be used to control detector systematic uncertainties
    - Check Monte Carlo simulations performance
  - Enhance **gamma/hadron discrimination**
    - Explore shower characteristics
    - Access to combined Argo/HAWC discrimination techniques

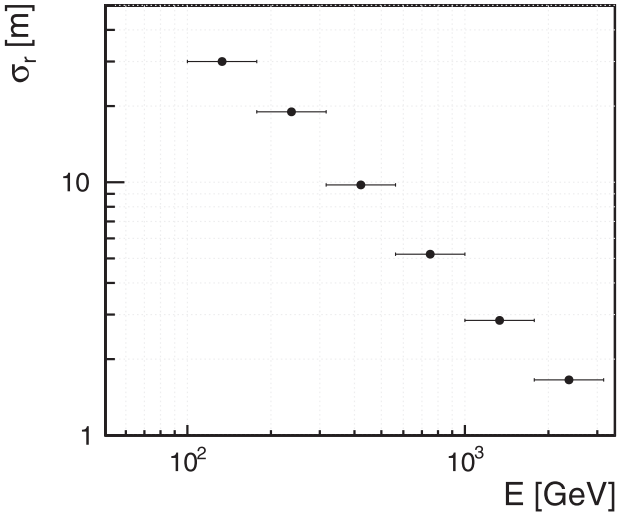




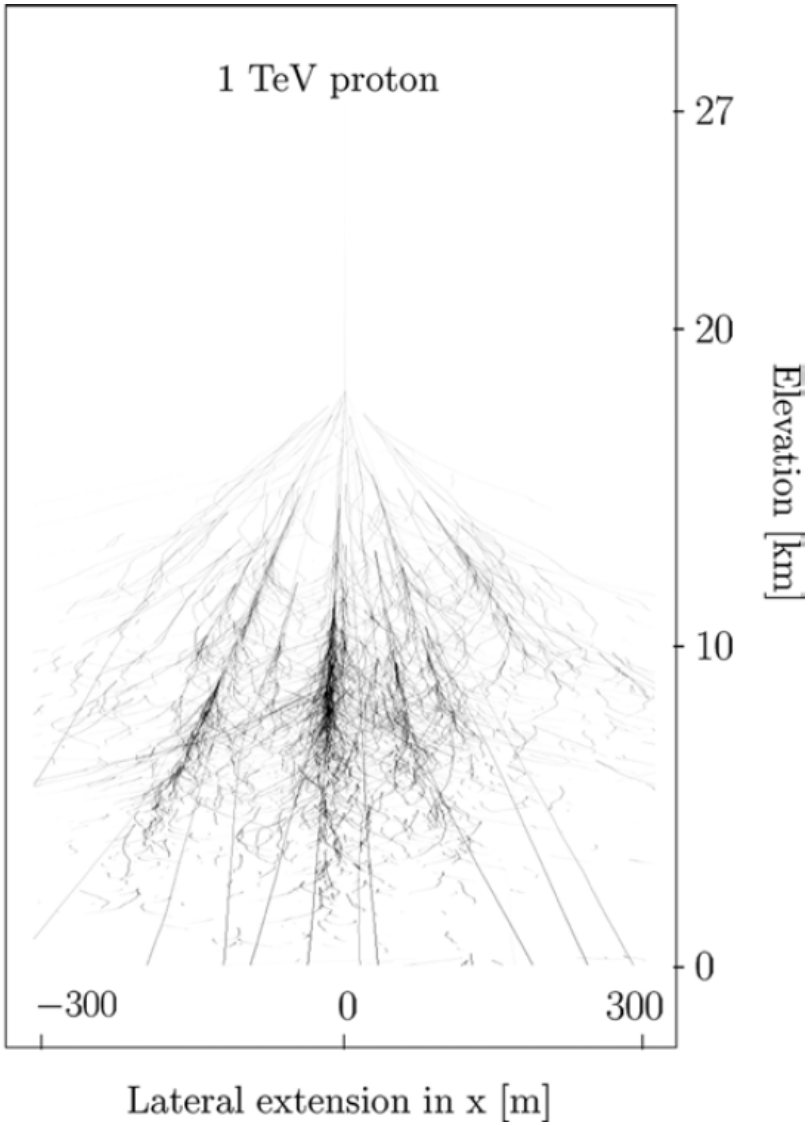
Shower core reconstruction

- Test whether the shower is inside/outside the array
  - Explore LDF topology
  - Is maximum observed inside of array?
  - Currently exploring the quality of the fit
  - Fixed cut for all energies
- Resolution better than 10 meters for showers above 300 GeV





Strategies for primary discrimination



- **Hit pattern at ground**
  - Hits from hadronic showers are more sparse than in gamma induced showers
  - RPC detectors
  - Explored by the ARGO collaboration
- **Search for energetic clusters far from the shower core**
  - Present only in hadronic showers
  - Water Cherenkov Detectors
  - Explored by the HAWC collaboration
- ***Combine both strategies using an hybrid detector: LATTES***
  - *Work on-going…*

High-energy discrimination strategy

- Get the photon average LDF for each reconstructed energy bin

- Fit the average LDF to each single event
  - Absorb the normalization factor

- Compute the shower compactness
  - Event LDF "distance" to the photon average LDF

$$\text{Compactness} = log_{10}\left(\sum_{i}^{n} \left|\langle LDF\rangle\left(x_i\right) - y(x_i)\right|\right)$$