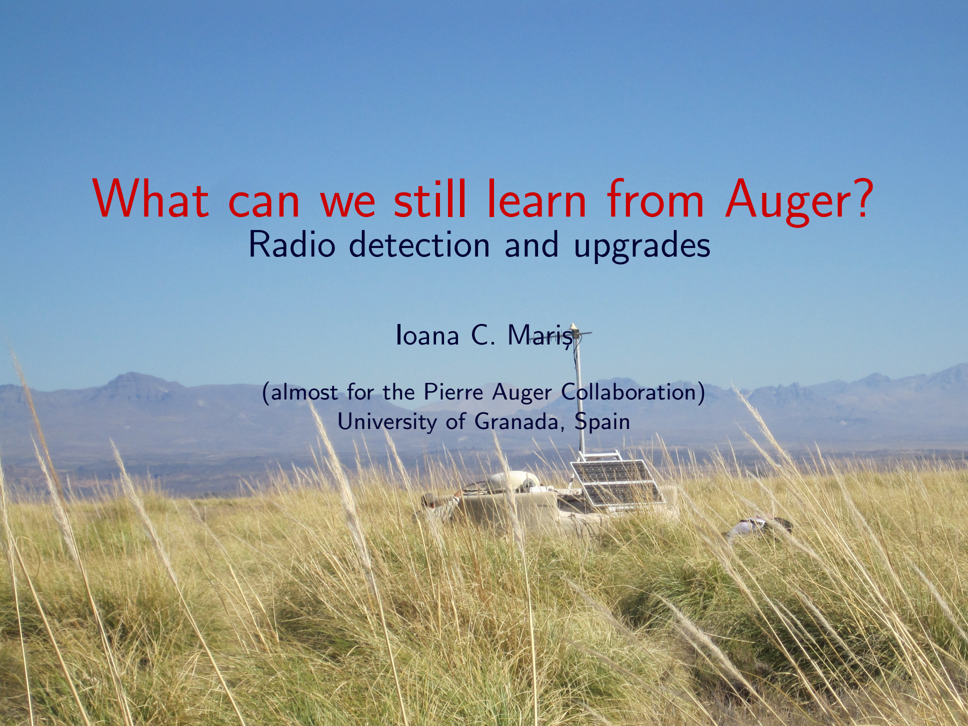
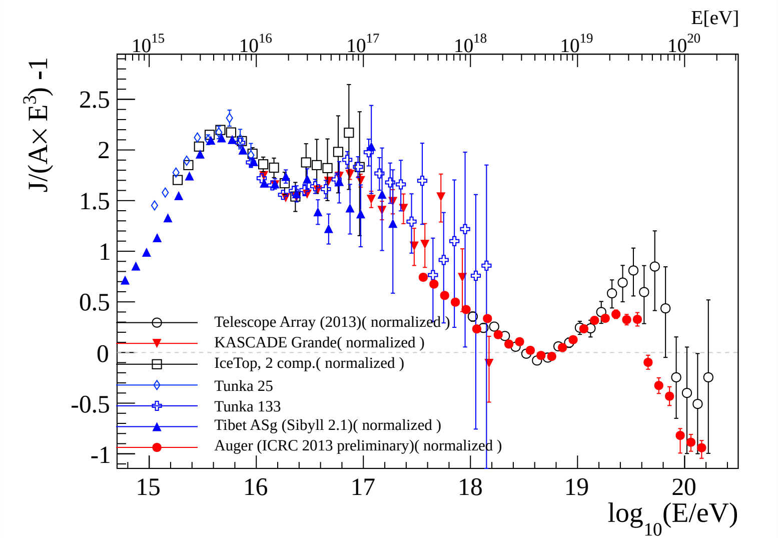
What can we still learn from Auger?

Radio detection and upgrades

Ioana C. Mariș

(almost for the Pierre Auger Collaboration)
University of Granada, Spain

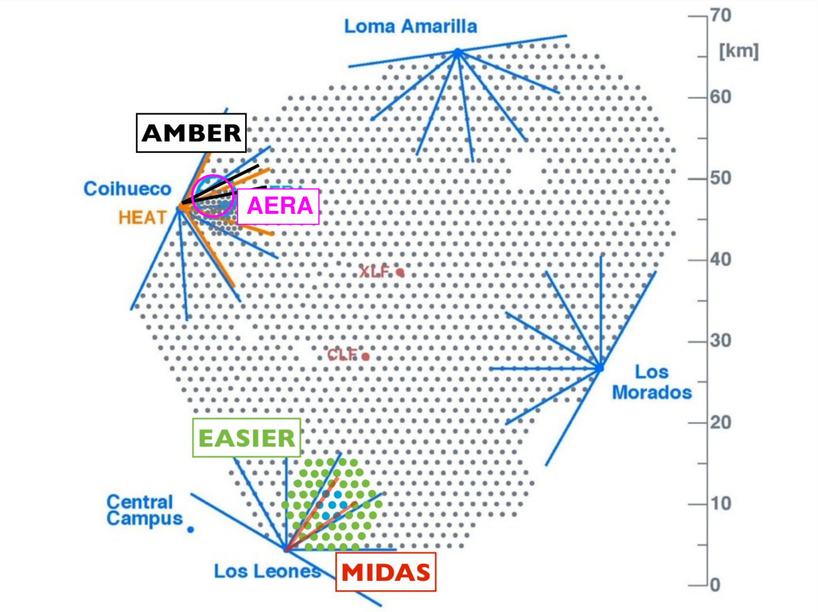




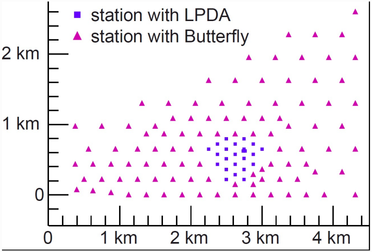
0.1-1 EeV: Enhancements and radio detection at Auger

Above 10 EeV: Upgrades of the surface detector

Radio activities at the Pierre Auger Observatory



AERA (Auger Engineering Radio Array)



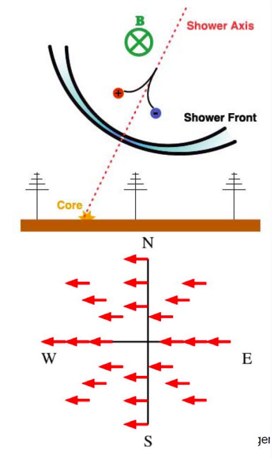
- autonomous trigger radio array
- frequency: 30-80 MHz
- antennas: 24 (150 m), 100 (250 m), 100 (375 m)
- 17 events, (04-07/2011)

→ What is the exact emission mechanism?

→ Can the radio technique improve cosmic ray measurements?

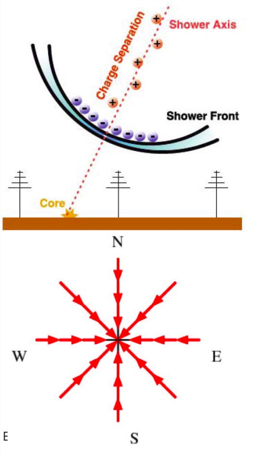
Emission mechanism

Primary emission: Geomagnetic effect



- time varying transverse currents
- $\mathbf{v} \times \mathbf{B}$

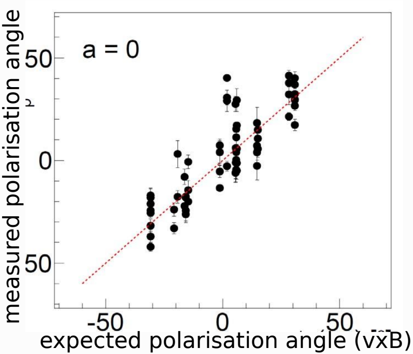
Secondary emission: Askarian effect

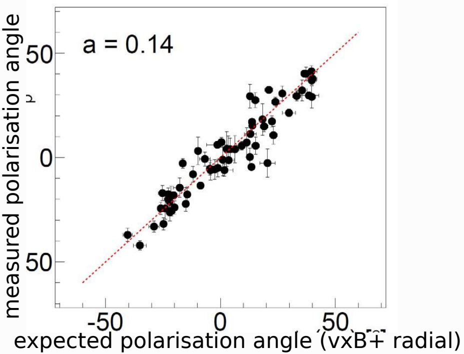


- time varying net charge excess
- radial polarization

Third emission: molecular bremsstrahlung?

Polarization measurements





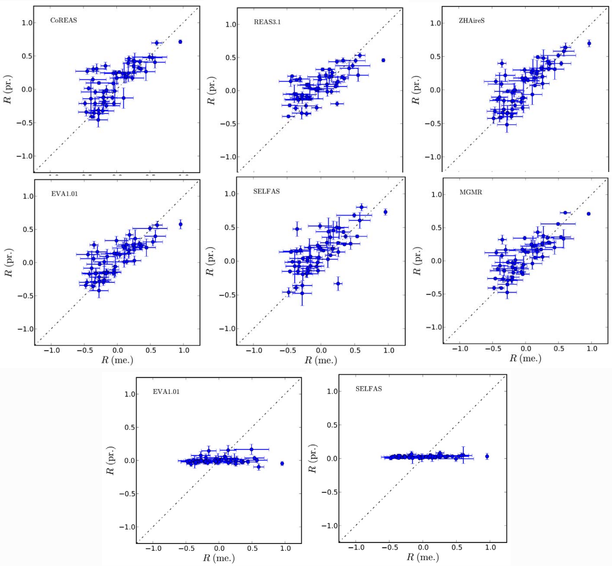
Relative strength of radial wrt. geomagnetic component

$$a = \frac{|E_r|}{E_g / \sin\alpha}$$

(measured from 55 stations, $a = 0.14 \pm 0.02$)

(T. Huege, Pierre Auger collaboration, ICRC 2013, submitted to PRD)

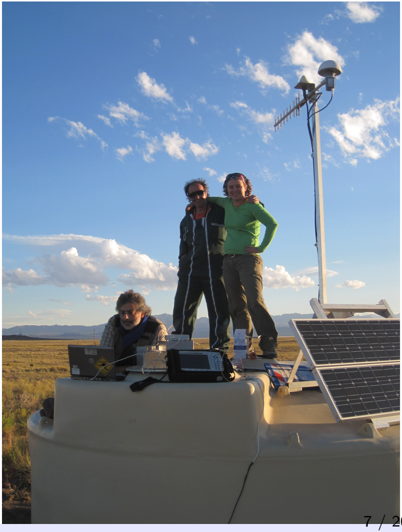
Simulations with/without charge excess



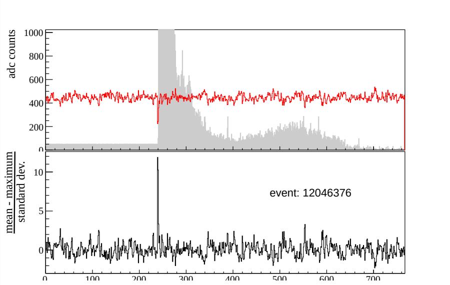
R quantifies deviations from pure geomagnetic polarization as a function of observed angle

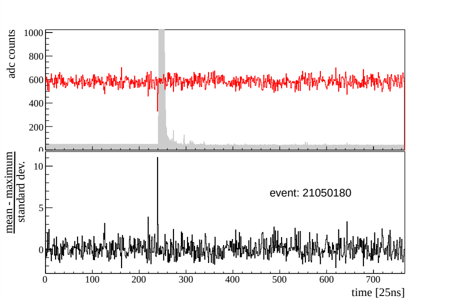
EASIER: Detector configuration

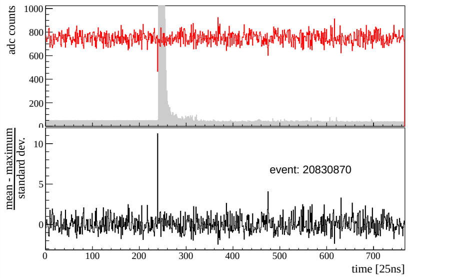
Slave detector (trigger and data acquisition from SD)
MHz detector: 30-80 MHz
GHz detector: 3.4-4.2 GHz



First events







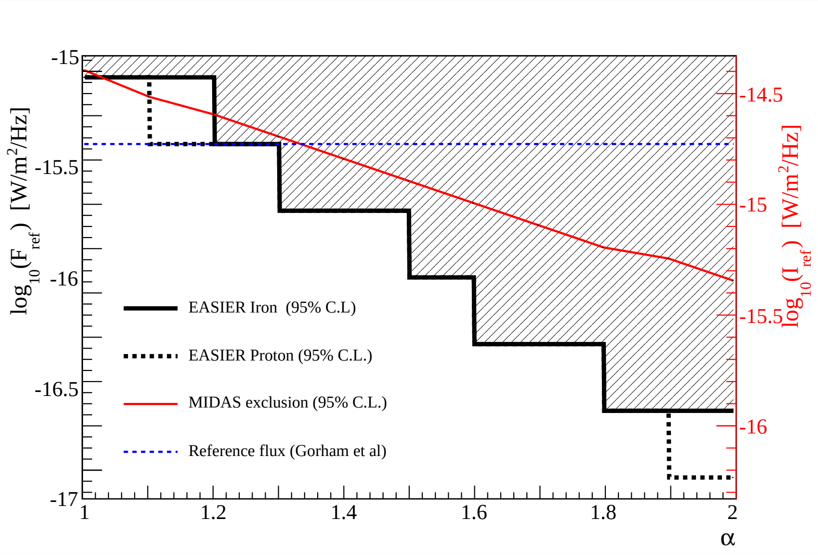
- very short distances to the axis ($d < 300\,\mathrm{m}$)
- short pulse length ($\Delta t < 75\,\mathrm{ns}$)
- energy: 2.6, 13.2 and 17.1 EeV

Same beamed emission from the MHz range or signal compression from isotropic emissions ?

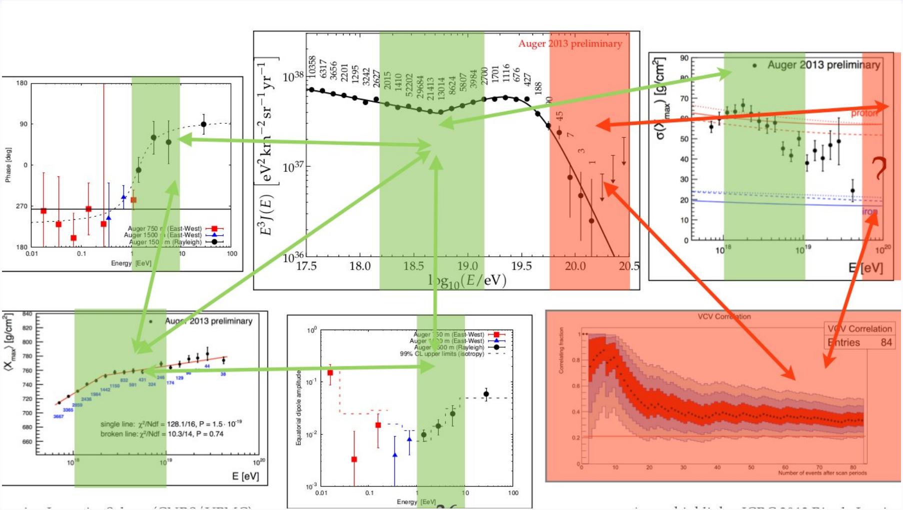
(R. Gaior for the Pierre Auger collaboration, ICRC 2013)

Preliminary limit on the isotropic emission

(from stations with a distance of more than 300 m



Auger current picture of UHECRs



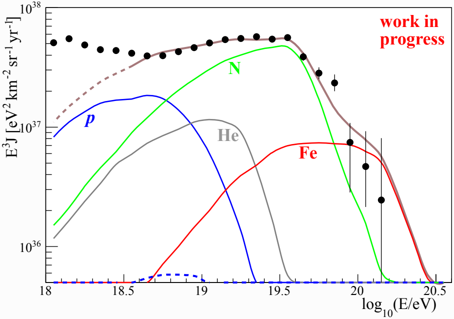
- Very high quality data and the highest statistics
- Coherent results in multiple variables

→ Can we do more than that?

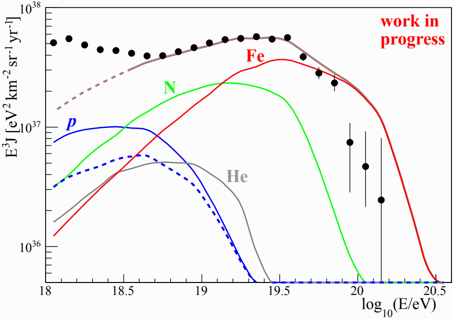
WARNING: All the next plots are preliminary/ work in progress!!

Strong motivations to continue with Auger

photo-disintegration?



maximum energy at sources?

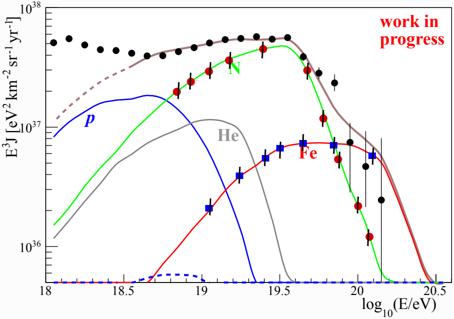


(Taylor & Hooper)

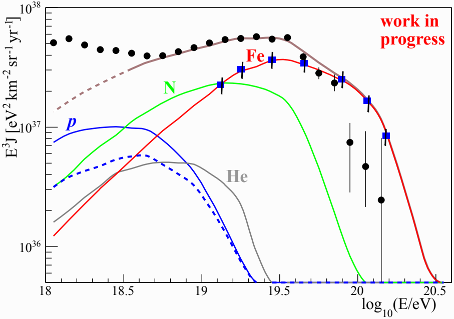
- elucidate the origin of the flux suppression
- determine the fraction of light elements at the highest energies
- study of the extensive air-showers and hadronic interactions
- we need mass composition sensitivity ($X_{\max}$ and N_μ) with SD

Strong motivations to continue with Auger

photo-disintegration?



maximum energy at sources?

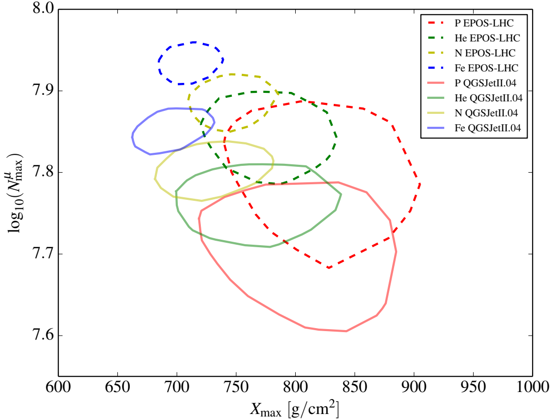


(Taylor & Hooper)

- elucidate the origin of the flux suppression
- determine the fraction of light elements at the highest energies
- study of the extensive air-showers and hadronic interactions
- we need mass composition sensitivity ($X_{\max}$ and N_μ) with SD

Universality of air-shower development

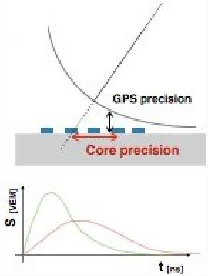
10 EeV, 38 degrees

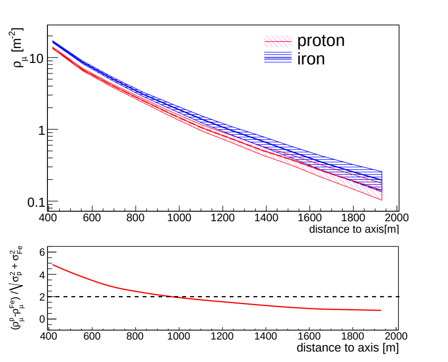


If we can obtain N_μ and $X_{\max}$ we win :)

- On ground, for a fixed energy, age, and geometry the lateral distribution functions (LDF) are universal

- From general timing and geometry (shower front curvature approach): $\sigma X_{\max} \approx 60\,\mathrm{g/cm^2}$
- Separating the em and the muonic time information: $\sigma X_{\max} < 30\,\mathrm{g/cm^2}$





- we need at least 100 μ (not to be dominated by the statistical fluctuations)
- measure the N_μ at $r < 900\,\mathrm{m}$ (25% p/Fe difference)

Beyond 2015 proposals

Surface detector electronics

- faster FADC sampling 40 $\mathrm{MHz} \rightarrow$ 120 MHz
- increased dynamic range: small PMT, and 10 $\mathrm{bits} \rightarrow$ 12 bit, total dynamic range: 19 bits
- improved energy resolution and timing at the highest energies

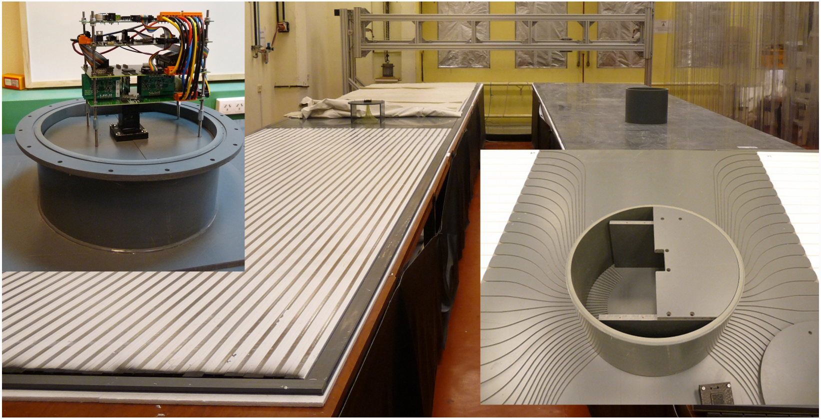
Huge R&D activities for muon detectors

- scintillators: AMIGA, TOSCA, ASCII
- resistive plate chambers(RPC): MARTA
- layered surface detecor: LSD

High quality events, running the observatory 2017-2023:
10200 ($>$ 10 EeV), 60 ($>$ 60 EeV)

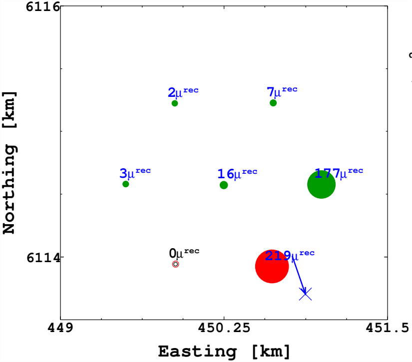
AMIGA-Grande/ TOSCA

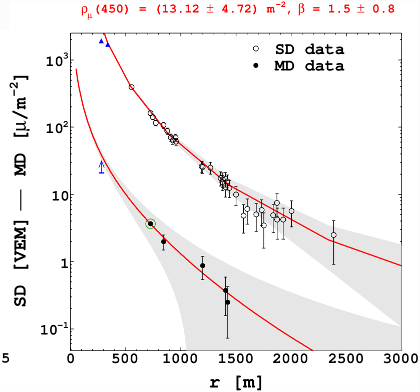
- enlarge the AMIGA enhancement (14 modules already in the field)
- $10\,\mathrm{m}^2$ segmented scintillator counters with 320 MHz readout electronics
- different spacing arrays to cover the entire area: 1500 m, 2600 m
- buried at 70-100 cm below the SD



AMIGA-Grande/ TOSCA

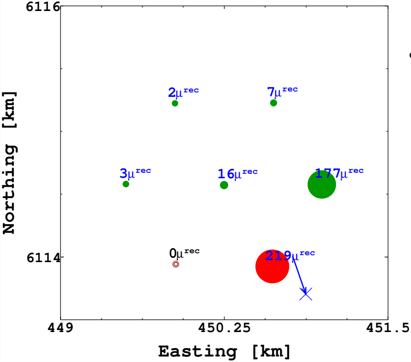
- enlarge the AMIGA enhancement (14 modules already in the field)
- $10\,\mathrm{m}^2$ segmented scintillator counters with 320 MHz readout electronics
- different spacing arrays to cover the entire area: 1500 m, 2600 m
- buried at 70-100 cm below the SD

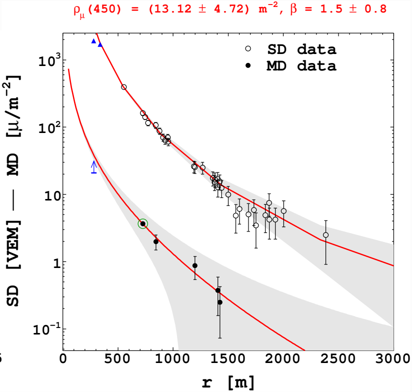




AMIGA-Grande/ TOSCA

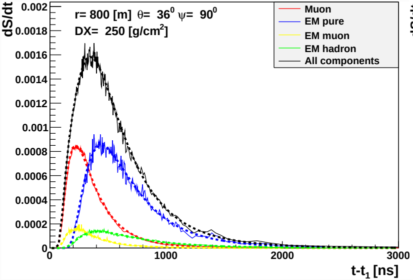
- enlarge the AMIGA enhancement (14 modules already in the field)
- $10\,\mathrm{m}^2$ segmented scintillator counters with 320 MHz readout electronics
- different spacing arrays to cover the entire area: 1500 m, 2600 m
- buried at 70-100 cm below the SD



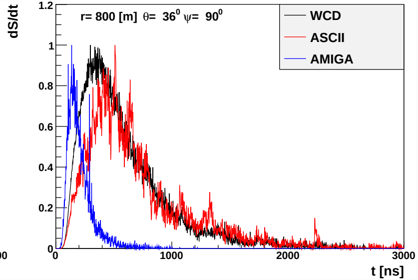


TOSCA: Similar to AMIGA, PMTs different design, close to the WCD simulations:

mean time distributions

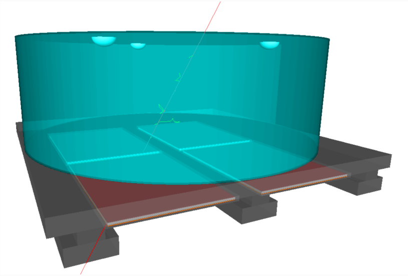


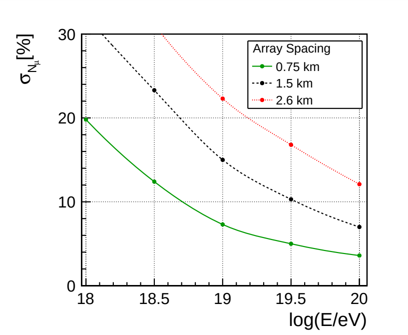
detector response



- very easy installation on top of the tank, $2\,\mathrm{m}^2$ scintillators
- could cover the entire array with 1500 m spacing
- no direct measurement of the muons, but timing information of the signal shape gives $\sigma X_{\max} < 50\,\mathrm{g/cm}^2$

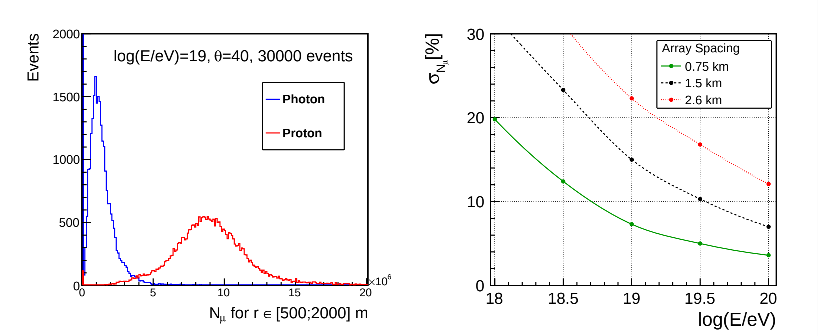
MARTA (Muon Auger RPC for the Tank Array)





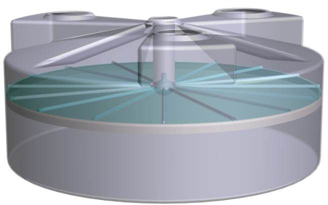
- Under the tank, with a concrete support
- Detection module: 1 mm gas gaps between 2 mm thick soda-lime glass layers, separated by Nylon monofilaments
- Good muon resolution above a few hundreds meters from the shower axis

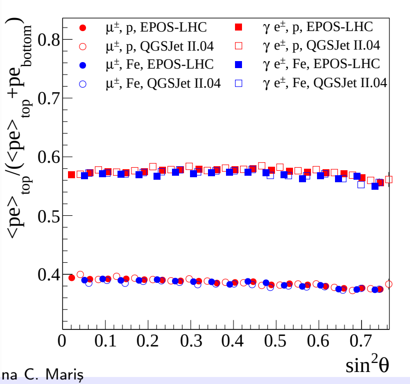
MARTA (Muon Auger RPC for the Tank Array)



- Under the tank, with a concrete support
- Detection module: 1 mm gas gaps between 2 mm thick soda-lime glass layers, separated by Nylon monofilaments
- Good muon resolution above a few hundreds meters from the shower axis

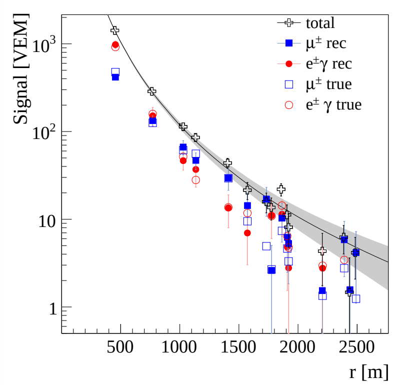
LSD: Layered surface detector

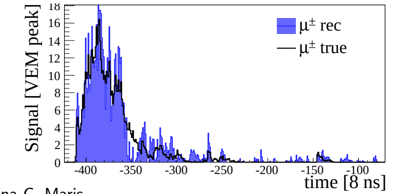




- modification of the current SD station: separate the water volume in two
- based on the different light produced by the electromagnetic and muonic components
- separate the components based on a simple matrix inversion
- 20% N_μ resolution and $\sigma X_{\max} < 40\,\mathrm{g/cm^2}$

LSD: Layered surface detector





- modification of the current SD station: separate the water volume in two
- based on the different light produced by the electromagnetic and muonic components
- separate the components based on a simple matrix inversion
- 20% N_μ resolution and $\sigma X_{\mathrm{max}} < 40\,\mathrm{g/cm^2}$

Future is bright!

Radio technique

- emission mechanism understood in the MHz region
- simulations reproduce very well data (LDF, etc)
- looking forward for the mass composition variables
- exploit new frequency ranges (?)

Upgrades of the surface detecor

- currently: simulations/ R&D going on
- March 2014: prototypes will be working in the field
- Summer 2014: decide on the muon detectors
- 2015-2017: hopefully building measuring building...
- 2017-2023: measuring measuring measuring...

After 2023: build a very large/high precision cosmic ray detector?