Ricap '16 Villa Tuscolana 21-24 June 2016

The Pierre Auger Observatory Upgrade

G. Marsella

On behalf of the Pierre Auger Collaboration

Outlook

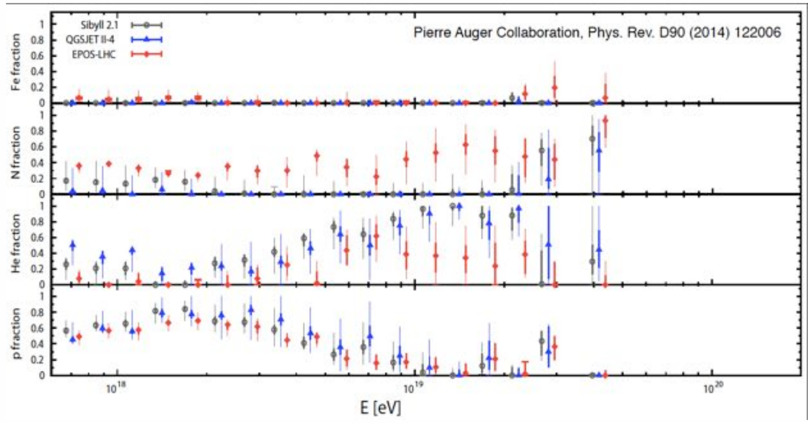
- Motivation for the Auger Upgrade
- Auger Upgrade program
  - **S**cintillator **S**urface **D**etector
  - Surface Detector Upgrade
  - **U**nderground **M**uon **D**etector
  - Fluorescence Detector DAQ extension time

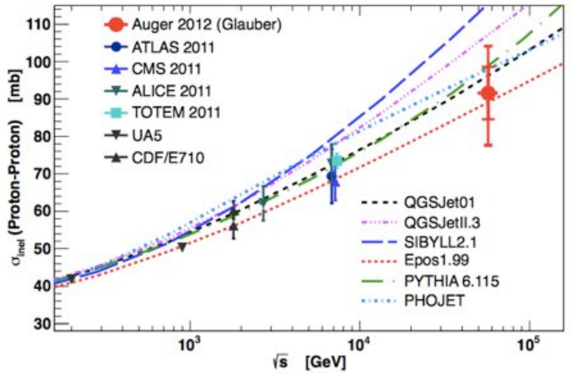
Auger Principal Results

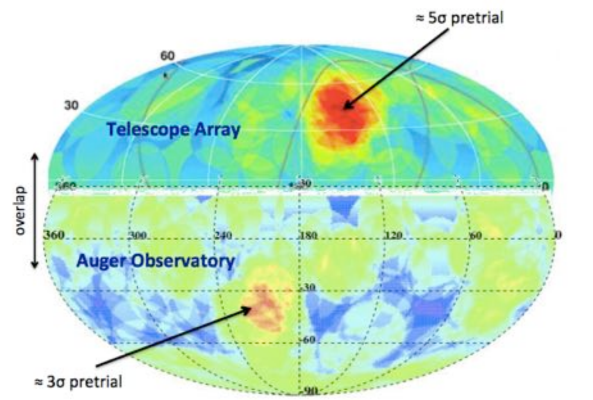
Contribution to this conference:

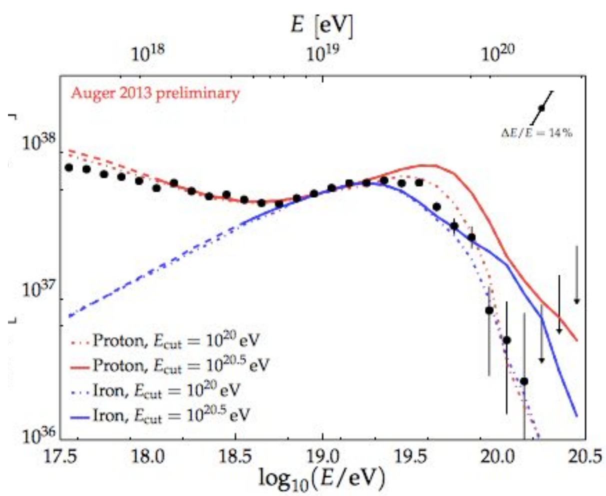
Corinne Berat: “AUGER status and result“

Armando Di Matteo:” Astrophysical interpretation of Pierre Auger Observatory measurements of the UHECR energy spectrum and mass composition”









Motivation for the upgrade

To provide additional measurements to allow us to address the following questions:

1. The origin of the flux suppression at the highest energies
Measurement of the mass composition beyond the reach of the FD.

2. Search for Proton contribution in the flux suppression region ($E > 5 \times 10^{19}$ eV)
Search of point sources and estimate the physics potential of existing and future cosmic ray, neutrino, and gamma-ray detectors.

3. Fundamental particle physics at energies beyond man-made accelerators
Study extensive air showers and hadronic multiparticle production.

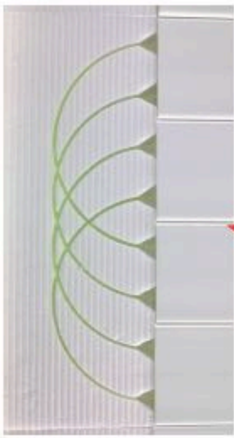
Mass composition measurement above 5×10^{19} eV
with a sensitivity to the proton flux as small as 10%.

Auger Upgrade

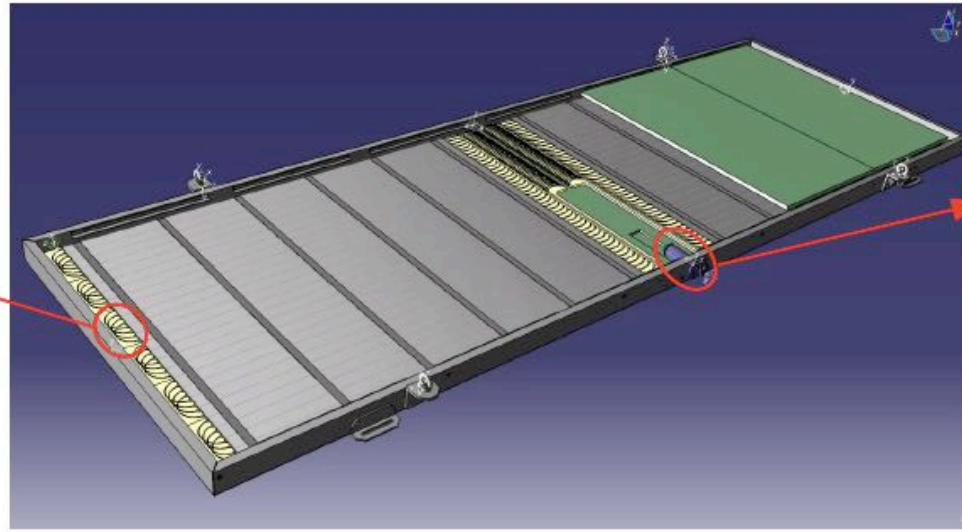
- A complementary measurement of the shower particles will be provided by a plastic scintillator plane (SSD) above the existing Water-Cherenkov Detectors (WCD).
  - This allows the sampling of the shower particles with two detectors having different responses to muons and electromagnetic particles.
- The surface detector stations will be upgraded with new electronics that will process both WCD and SSD signals.
  - Use of the new electronics also aims to increase the data quality (with faster sampling of ADC traces, better timing accuracy, increased dynamic range), to enhance the local trigger and processing capabilities (with a more powerful local station processor and FPGA) and to improve calibration and monitoring capabilities of the surface detector stations.
- An Underground Muon Detector (UMD) is required in the existing SD infill area of 23.5 km^2.
  - The UMD will provide important direct measurements of the shower muon content and its time structure, while serving as verification and fine-tuning of the methods used to extract muon information with the SSD and WCD measurements.
- In parallel with the Surface Detector upgrade, the operation mode of the Fluorescence Detector (FD) will be changed to extend measurements into periods with higher night sky background.
  - This will allow an increase of about 50% in the current duty cycle of the FD.

Surface Scintillator Detector (SSD)

Fibers routing



WLS fibers

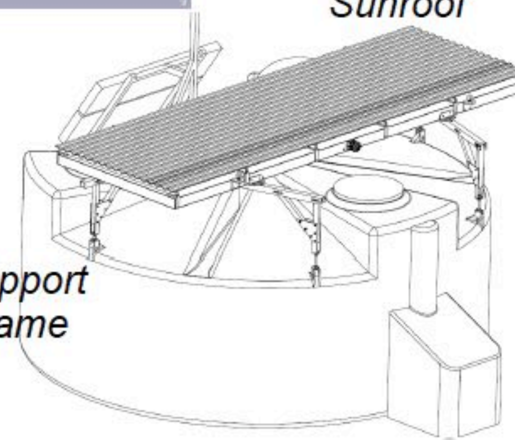


PMT/SiPM

Extruded scintillator bars (1600 x 50 x 10 mm)

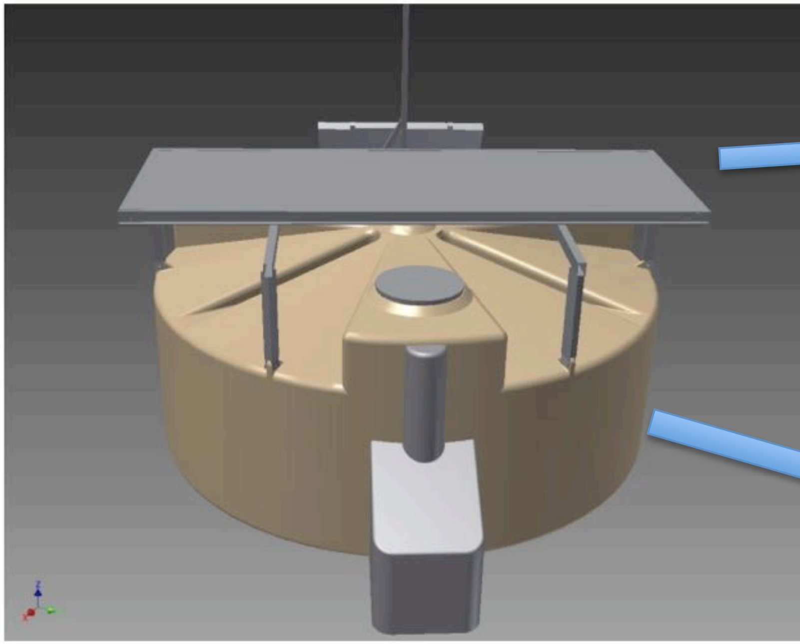
Alu enclosure

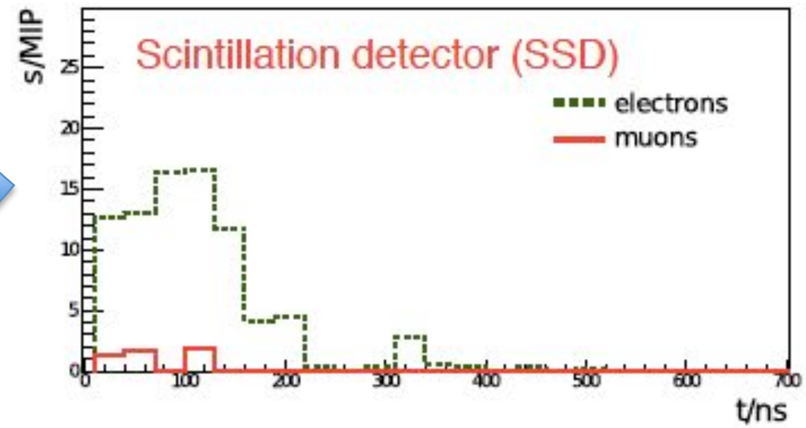
Sunroof

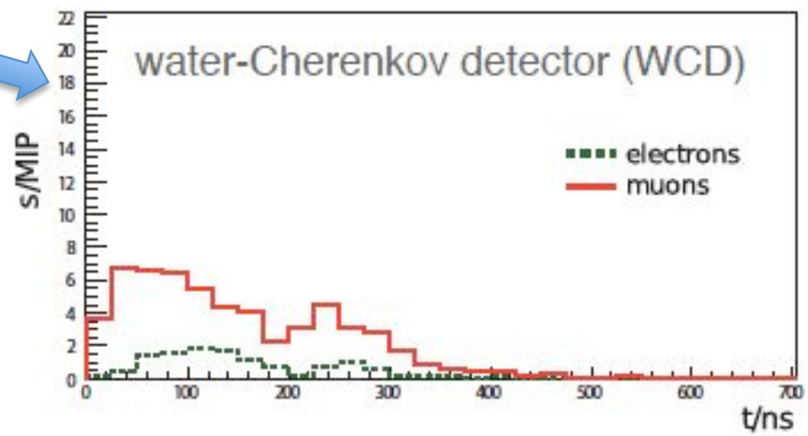


Support frame

WCD+SSD measurements







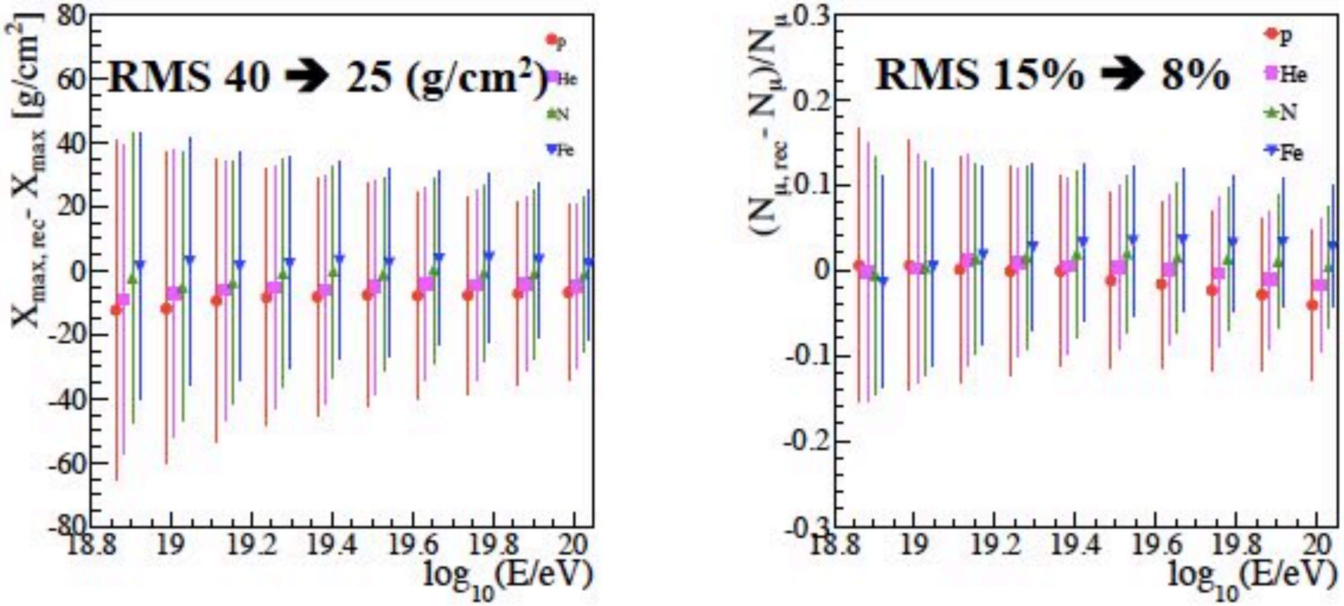
Complementarity of particle response used to discriminate electromagnetic and muonic components of air showers.

Matrix - Method

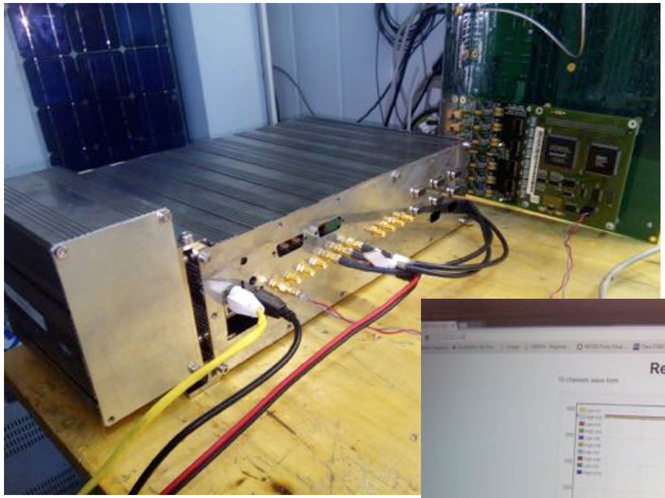
$$S_{\mu,\mathrm{WCD}} = a S_{\mathrm{WCD}} + b S_{\mathrm{SSD}}$$

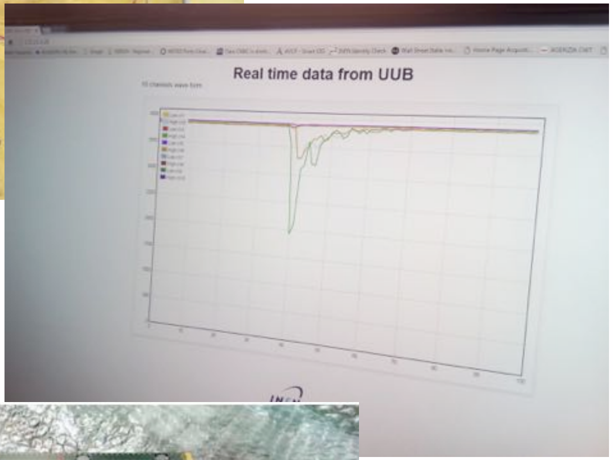
SSD: Universality

- Applying the Universality method it's possible to take in to account the **correlation between the WCD and the SSD**. The parameters now are more (X^{μ}_{max} ,$X_{max,}$ N_{μ}) in the model.
- This allow a measurements of the **number of muons event by event basis** and the relation bewteen X^{μ}_{max} ,X_{max} and N_{μ}^{rel} coul be calibrated.
- The **resolutions** of the method are obtained from parameterizations and interpolations of EPOS-LHC simulations at fixed energies and zenith angles and are shown for events up to 60º.



New Surface Detector Electronics (SDE)



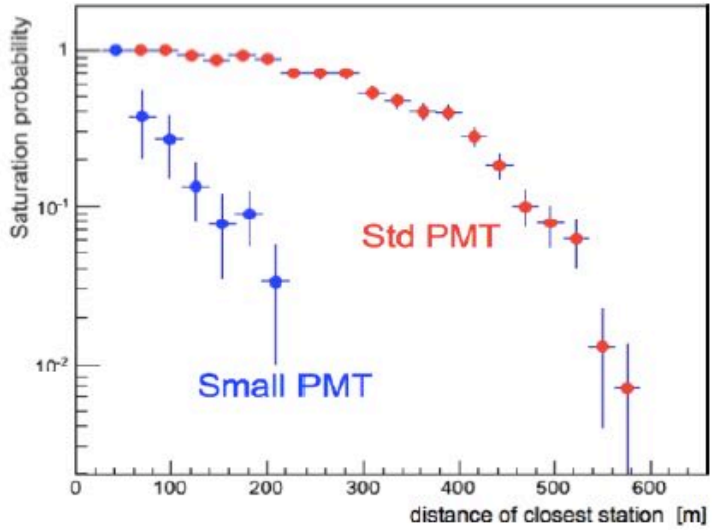


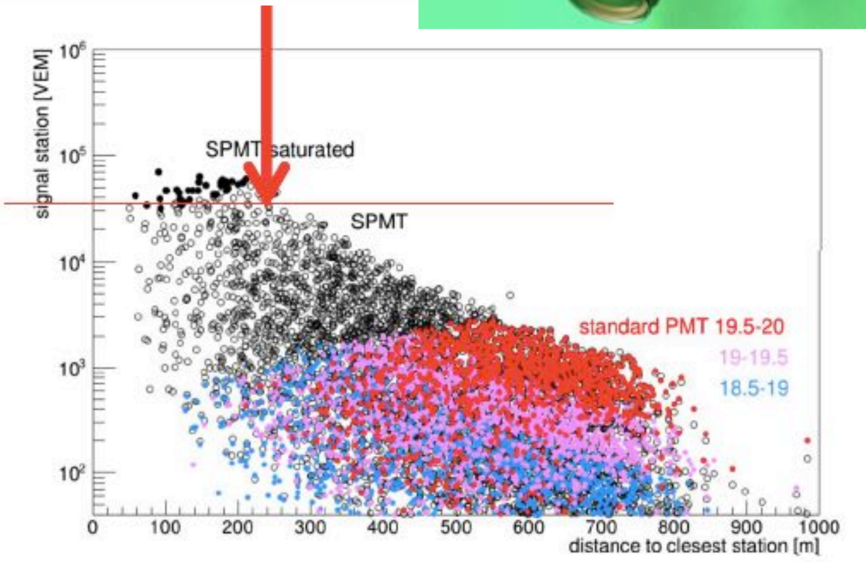
- The surface detector stations will be upgraded with new electronics that will process both WCD and SSD signals.
- Increase the data quality with faster sampling of ADC traces (120MHz) , better timing accuracy.
- Increased dynamic range(12 bits), to enhance the Local trigger and processing capabilities (with a more powerful local station processor and FPGA)
- To improve calibration and monitoring capabilities of the surface detector stations.
- The surface detector electronics upgrade (SDEU) can be easily deployed, and will have only minimal impact on the continuous data taking of the Surface Detector.

The upgrade of the Water-Cherenkov Detectors (WCD): SPMT

Add a 4th PMT of 1/9 diameter wrt the PMTs of the WCD

1. dynamic range from fractions of VEM to >20000 VEM
2. less than 2% saturated events at the higher energies
3. unambiguous determination of the particle density
   down to < 300 m from the core





The upgrade of the Water-Cherenkov Detectors (WCD)

- New full dynamic of the WCD

Range	Intent	Dynamic Range																					
bits		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Small Signals	VEM	AnodeX32																					
Medium Signals	Showers						Anode																
High Signals	Cores											SPMT											
Ipeak (mA)		0.0006					0.02		0.08			1.2						40					
Vpeak (mV)		0.03					1		3.9			64						2000					
Ipeak SPMT (mA)												0.02						1.25					40
Vpeak SPMT (mV)												1						64					2000
Npart (VEM)		0.01					0.3		1.2			10						600					20000

Underground Muon Detector: performance considerations

- An Underground Muon Detector (UMD) is required in the existing SD infill area of 23.5 km^2.

- The UMD will provide important direct measurements of the shower muon content and its time structure.

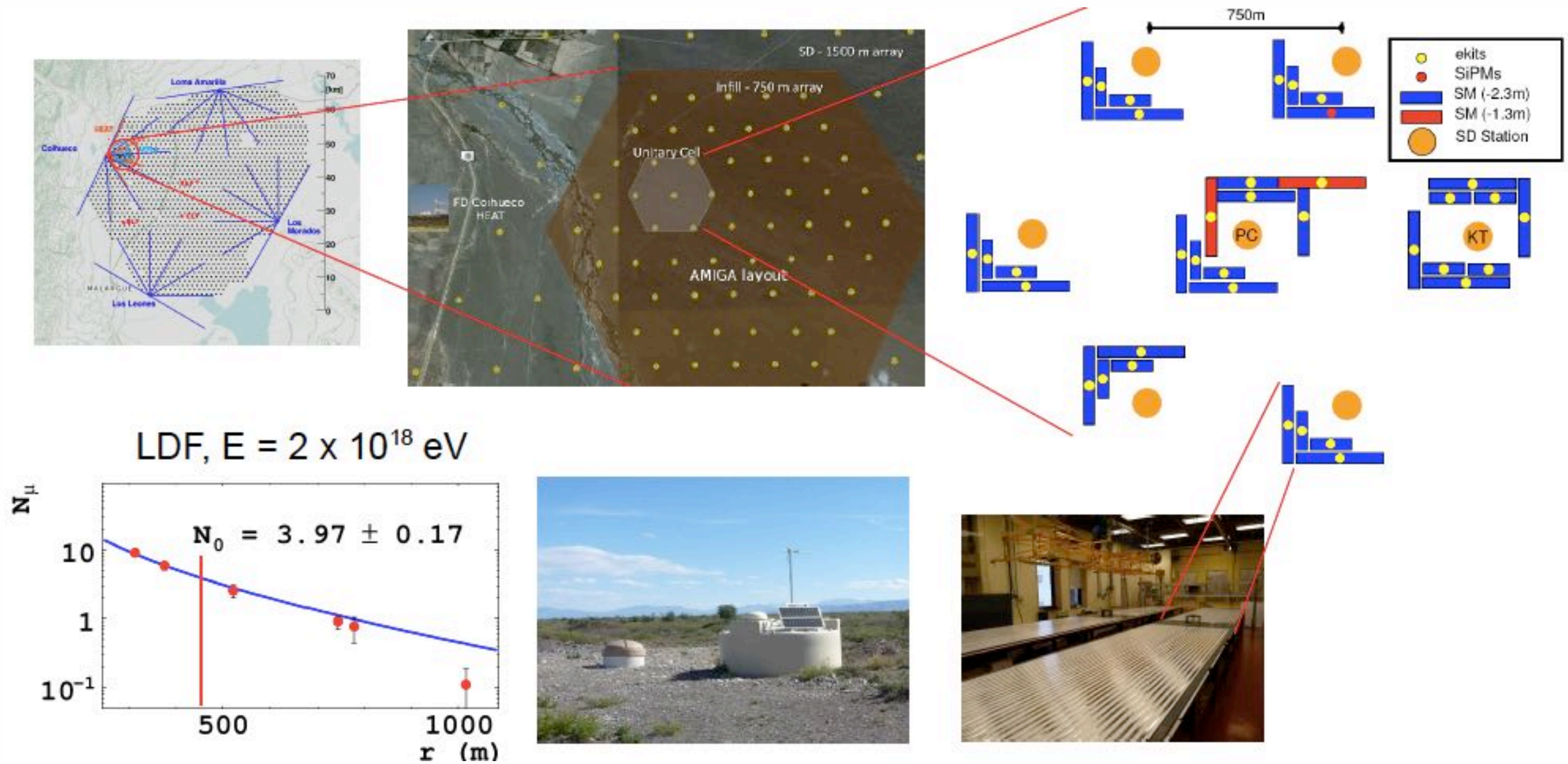
- UMD serving as verification and fine-tuning of the methods used to extract muon information with the SSD and WCD measurements.

- The performance and characteristics of the AMIGA match these requirements, and thus the completed AMIGA array will serve as the UMD.

- Muon detectors shielded by 1.3 m of soil

Underground Muon Detector

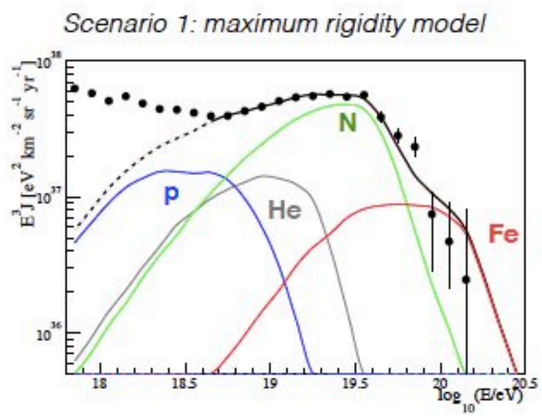
The Underground Muon Detector
61 AMIGA muon detectors (30 m^2) are planned
Will be deployed on a 750m grid (a total area of 23.5 km^2)

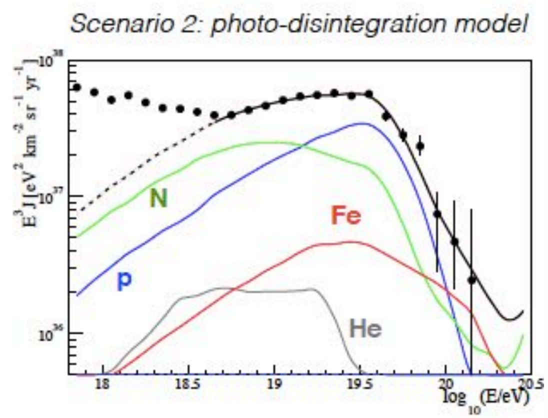


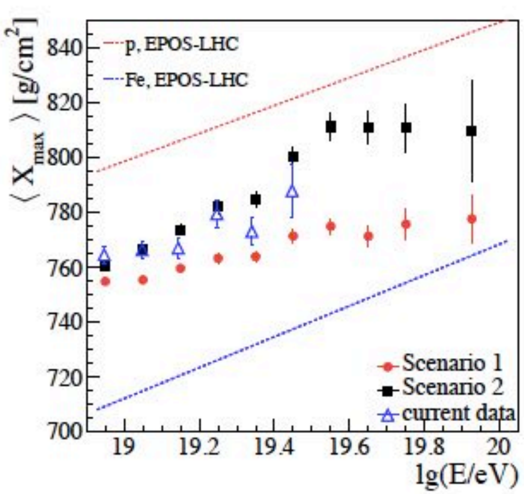
Expected Phyisics: mass sensitivity & discrimination of scenarios

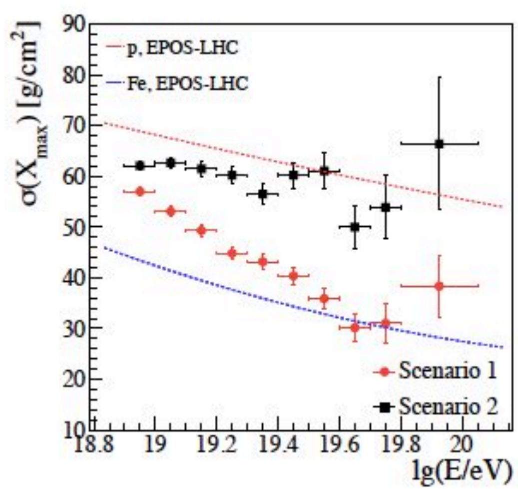
Illustration with two benchmark scenarios

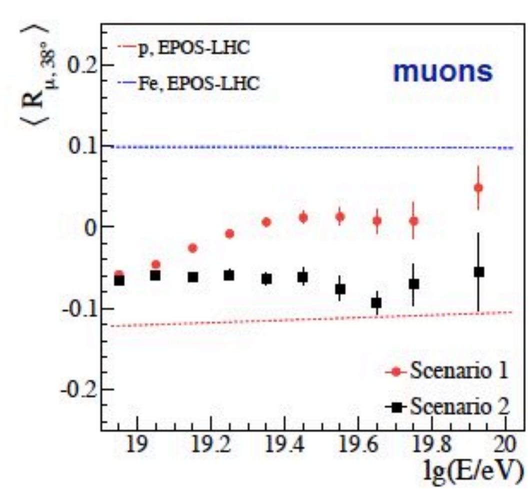
WCD and SSD only









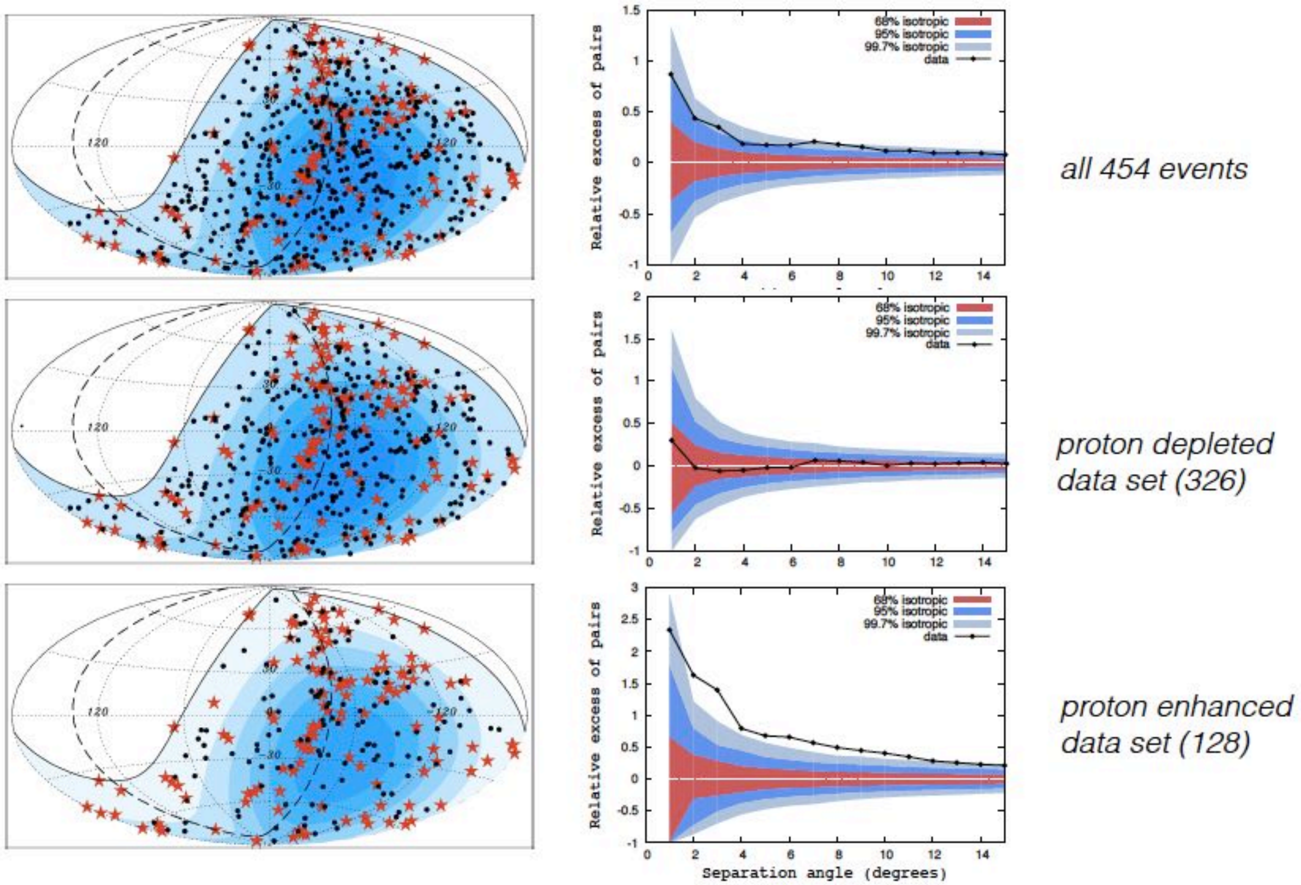


Expected Phyisics: composition-enhanced anisotropy

Modified Auger data set
(E > 4×10^{19} eV, 454 events)

X_{max} assignment according to maximum rigidity scenario

10% protons added, half of which from within 3° of AGNs

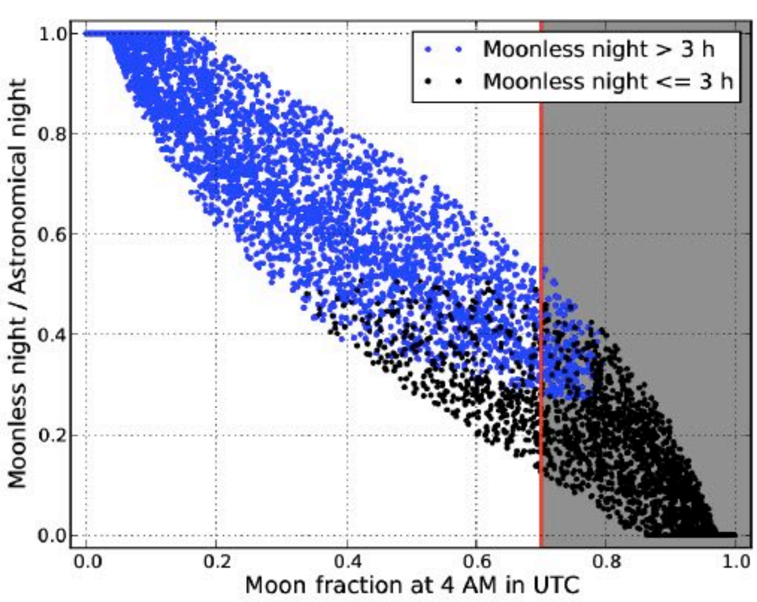


Fluorescence Detector

FD provides exceptional information (e.g. model-independent energy reconstruction & mass composition measurement).

The main limitation of the FD is its duty cycle (15% nowadays).

The current criteria for FD measurement:
1. The sun more than 18^{o} below the horizon
2. The moon remains below horizon for longer than 3 hours
3. The illuminated fraction of the moon must be below 70%



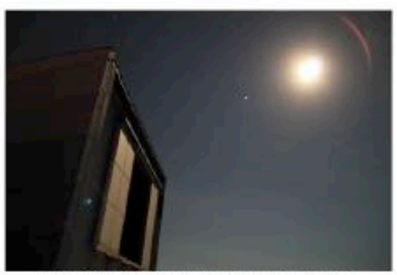
Pierre Auger Coll., NIMA 798 (2015)

Measurement periods (~17 nights long),
limit on the PMT illumination (i.e. no rapid aging),
and the PMT response stays linear.

Extended FD operation

15% duty cycle

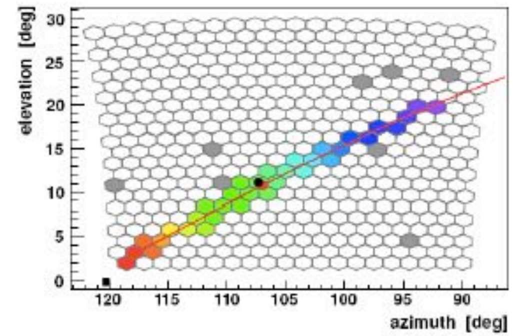
Increase by 50% by measurement during high night sky background

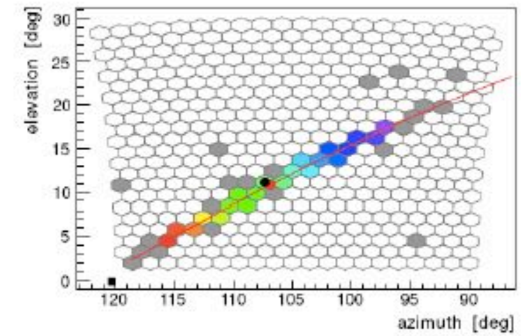


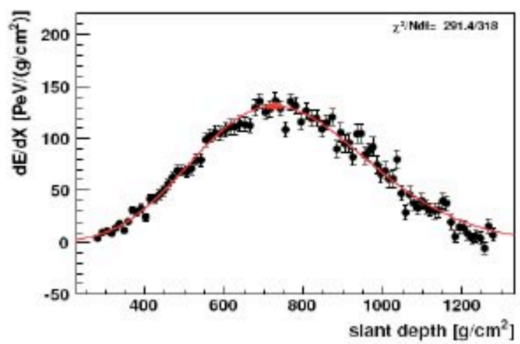
The moon and Jupiter above Los Leones in the morning on 4 Mar, 2015.

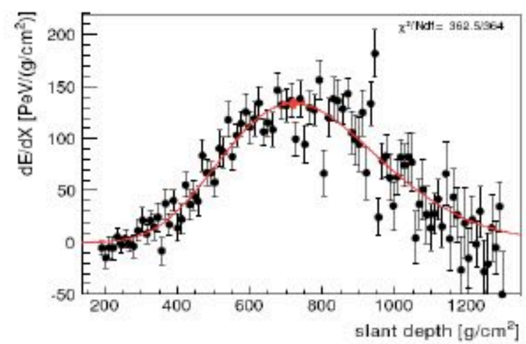
Clear sky, no moonlight

40 times higher NSB (90% moon)

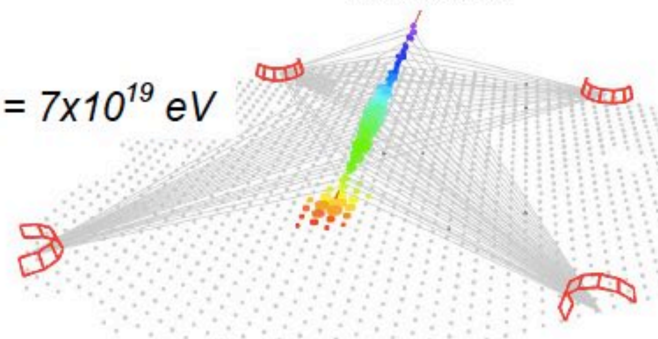








E = 7x10^{19} eV



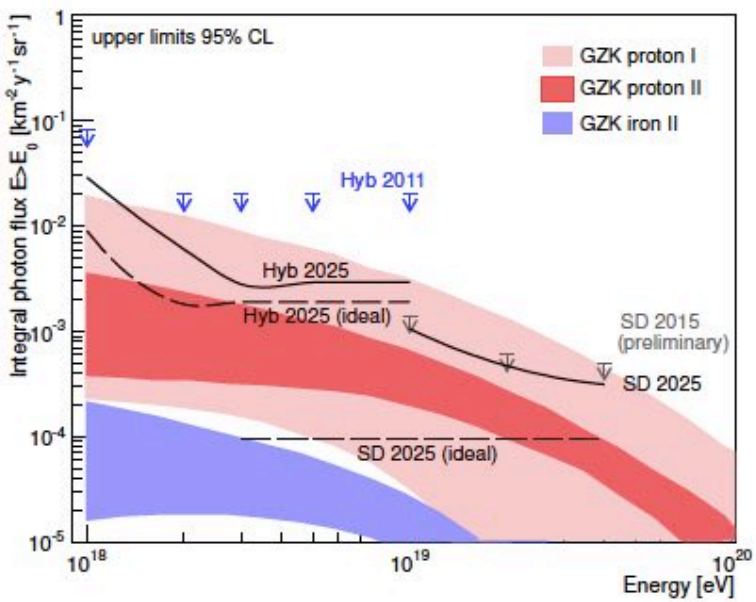
$E = 72 \pm 3$ EeV

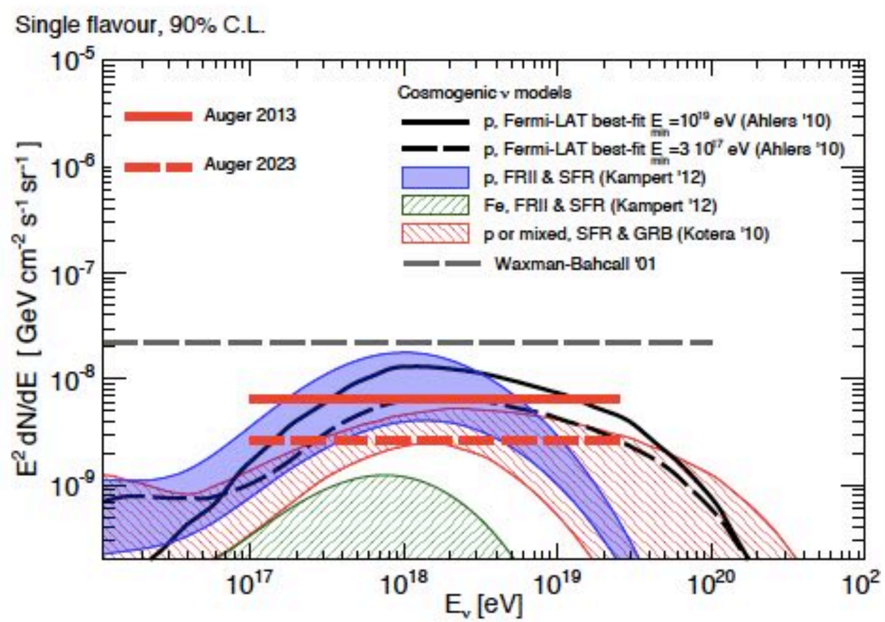
10x reduced PMT gain by reducing supplied HV.

Successful test has been done last year.

Expected Phyisics: photon and neutrino flux limits

Expected improvements compared to current limits (ICRC 2015)





- increased exposure
- improved low-energy trigger (low-energy threshold)
- improved separation power (needs still to be evaluated)

Summary

Auger Prime will allow a study of mass composition above 5 x 10^{19} eV and address:

1. Origin of the flux suppression (GZK energy loss vs. maximum energy of sources)
2. Proton contribution of more than 10% above 5 x 10^{19} eV? (particle astronomy, GZK γ and ν fluxes → future experiments)
3. New particle physics beyond the reach of LHC?

Mass composition info on event-by-event basis

Timeline for new SDE and SSD:

Nov 2016: Engineering Array (12 stations)

February 2017: Evaluation of detectors

2017-2018: Deployment

Till 2025: Data taking (up to 40,000 km^2 sr yr)

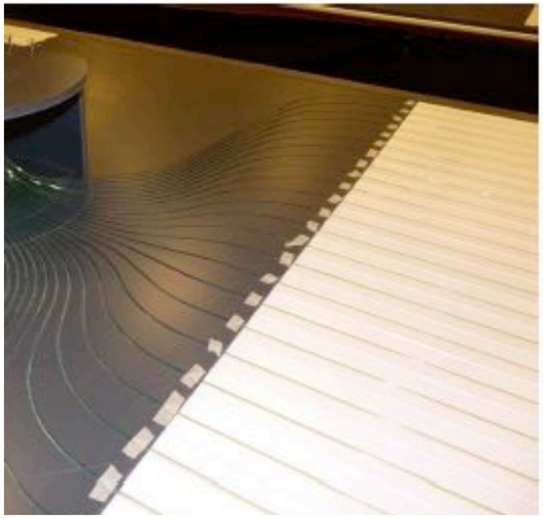
Similar event statistics as collected so far will be reached with upgraded detectors.

Total cost: about $12M

The FD duty cycle extension will be evaluated after additional tests.

- Backup Slides

Underground Muon Detector



Detector depth	70 cm 170 g/cm²		110 cm 265 g/cm²		150 cm 360 g/cm²	
r_{core} (m)	Rel. PT	$N_\mu/10\,m^2$	Rel. PT	$N_\mu/10\,m^2$	Rel. PT	$N_\mu/10\,m^2$
200	88%	512	14%	493	2.3%	461
600	38%	49	7%	43	1.1%	40
1000	16%	10	3%	9	0.5%	8.4
1400	3%	3	0.6%	2.6	0.1%	2.4

Relative punch-through (PT) for vertical showers of 10^{19} eV and number of muons for detectors at different depths in the Pampa soil (2.4 g/cm^3 average density).

Expected rate

$\log_{10}(E/\text{eV})$	$\text{d}N/\text{d}t\|_{\text{infill}}$ $[\text{yr}^{-1}]$	$\text{d}N/\text{d}t\|_{\text{SD}}$ $[\text{yr}^{-1}]$	$N\|_{\text{infill}}$ [2018-2024]	$N\|_{\text{SD}}$ [2018-2024]
17.5	11500	-	80700	-
18.0	900	-	6400	-
18.5	80	12000	530	83200
19.0	8	1500	50	10200
19.5	$\sim$1	100	7	700
19.8	-	9	-	60
20.0	-	$\sim$1	-	$\sim$9

The expected number of events per year, as well as the cumulative number for a data taking period from 2018-2024, are shown in Table for both the 750m array and the 1500m array for zenith angles less than 60.

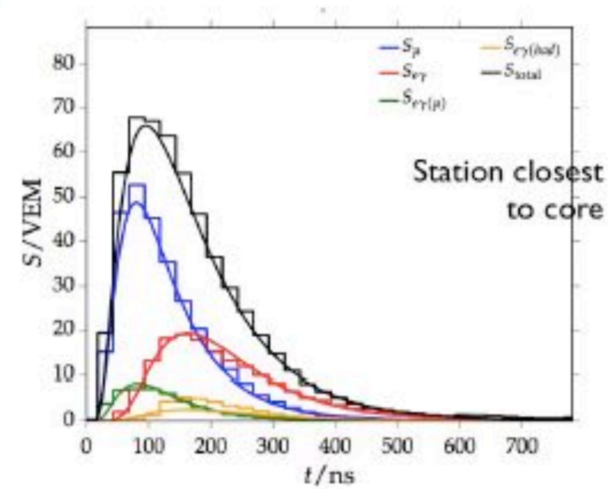
Horizontal air showers ($60^{o} < \theta < 80^{o}$) will add about 30% to the exposure and thus to the number of expected events.

Accounting for a detector resolution of 15% or better in determining the number of muons, this would allow for a separation of a fraction as small as 10% of protons from intermediate and heavy primaries.

SSD: Universality

- The shower universality method **predicts** for the entire range of **primary** masses the air-shower characteristics on the ground **using** only three parameters: ***E*****,** $\boldsymbol{X_{max}}$ **and** $\boldsymbol{N_\mu}$

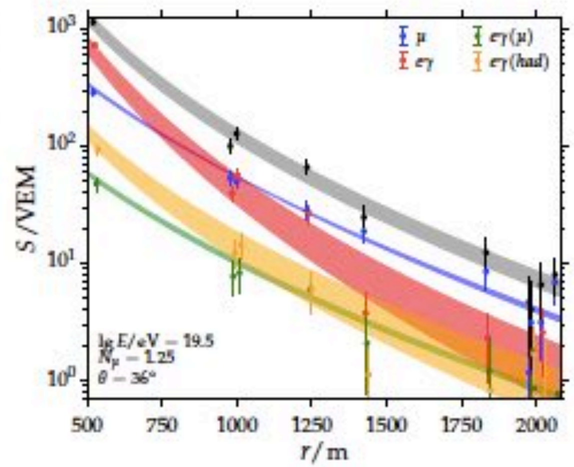
- The parameters could be **estimated from the integrated signal and the temporal structure** of the signal measured in the individual stations . Event-by-event basis.



$$\begin{aligned} S_{\text{tot}} = & S_{\text{em}}(DX, E) + \\ & N_\mu^{\text{rel}} S_\mu^{\text{QGS}}(DX, E) + \\ & N_\mu^{\text{rel}} S_{\text{em}}^{\mu}(DX, E) + \\ & (N_\mu^{\text{rel}})^\alpha S_{\text{em}}^{\text{jet}}(DX, E) \end{aligned}$$

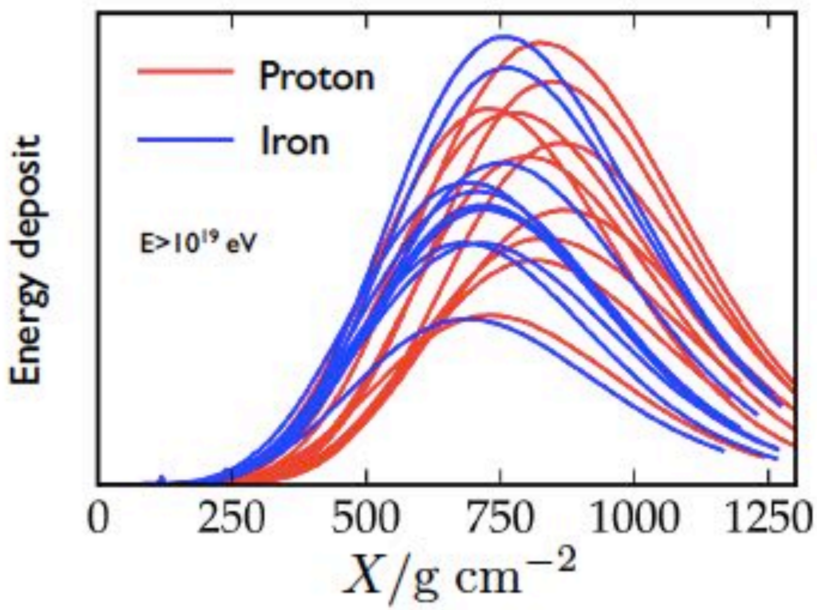
- Pure electromagnetic
- Muons
- Electromagnetic from muon decay
- Electromagnetic jets from hadrons

$$N_\mu^{\text{rel}} = \frac{S_\mu(DX, r, E)}{S_\mu^{\text{QGS}}(DX, r, E)}$$



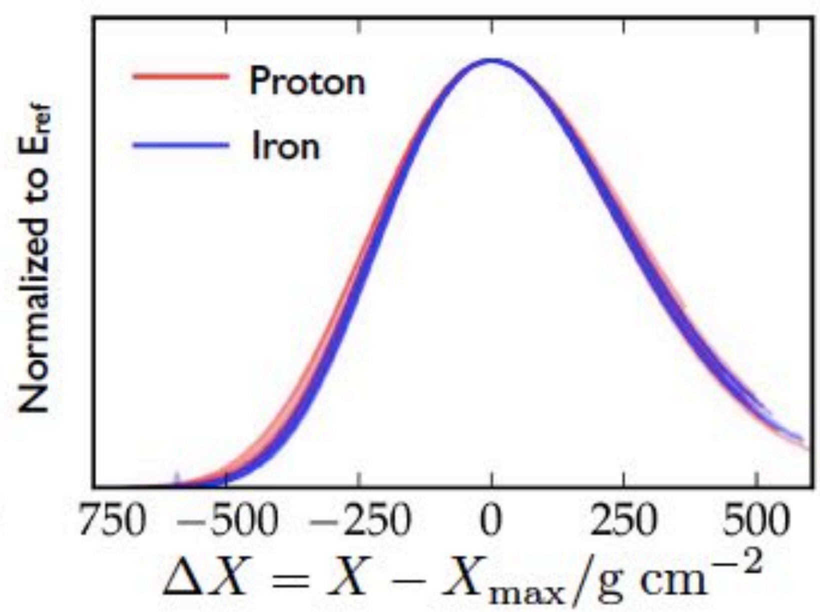
SSD: Universality

- The longitudinal profile depend on E and on the distance to X_{max} ($\Delta X = X - X_{max}$) ***<u>but not on mass</u>***



Simulated energy deposit along shower axis

Large fluctuation in shower development apparent



Universal longitudinal profile

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M. Roth @ ICRC 2015