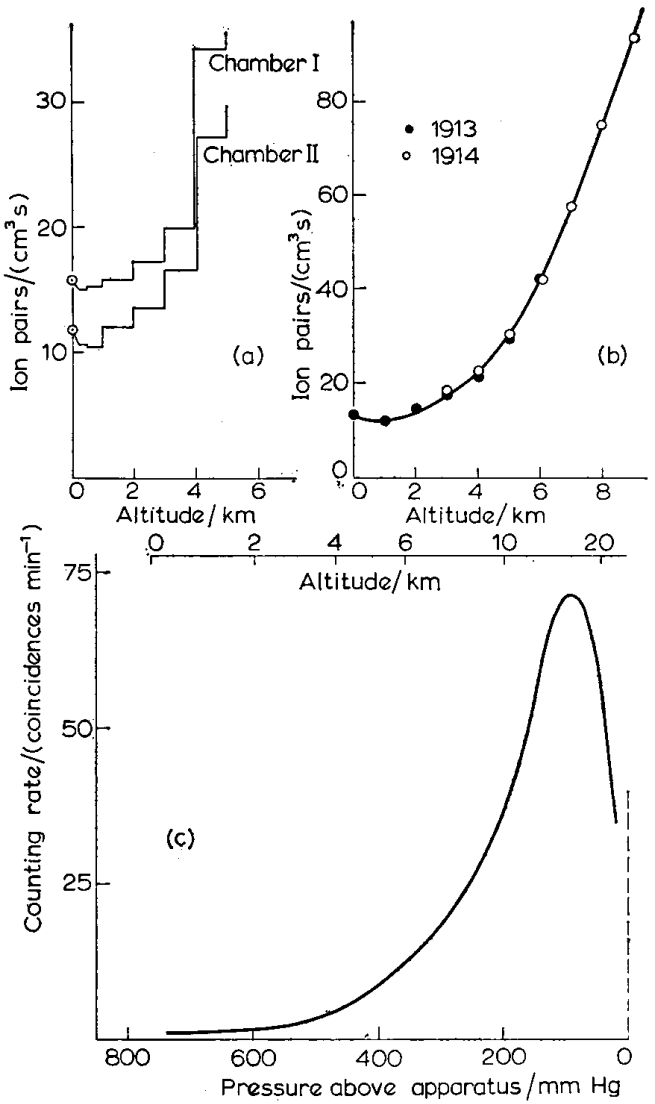
Auger 2015

Lisboa, April 2012
Jornadas LIP

Foi o Ruben que fez o template mas eu ajudei-o no início...

Cosmic Rays in 1912

Hess bei Ballonlandung (1912).



2. Altitude variation of ionization. (*a*) Balloon ascent by Hess (1912) carrying two ion chambers. (*b*) Ascents by Kolhörster (1913, 1914) using ion chambers. (*c*) Coincidence counter telescope flown by Pfotzer (1936).

Cosmic Rays in 2001

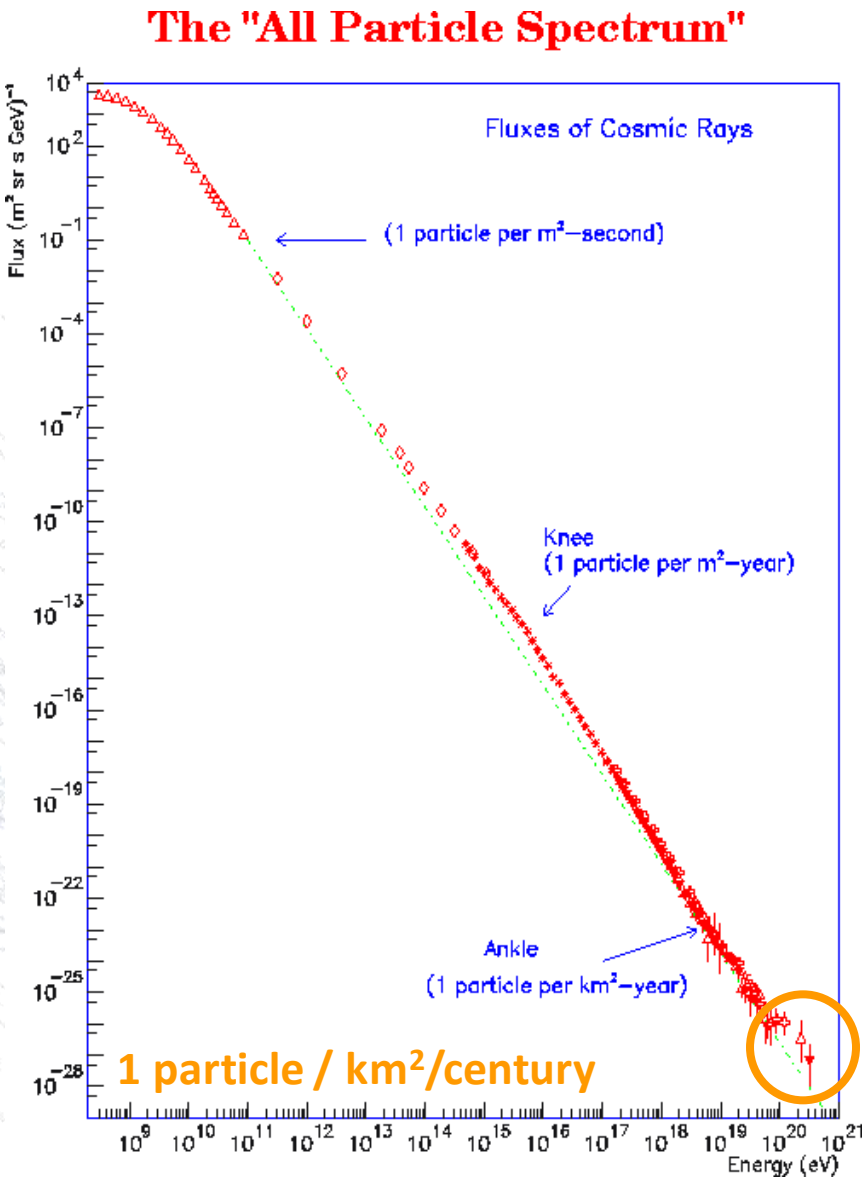
100 years This year!!

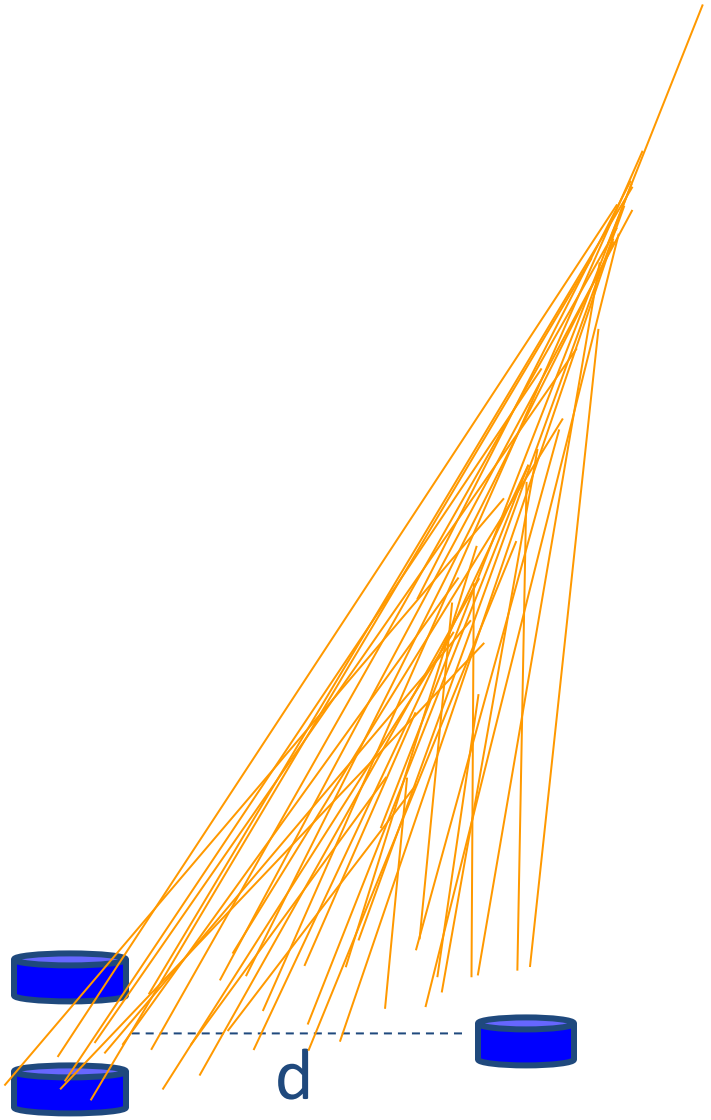
800 600 400 200 0
Pressure above apparatus / mm Hg

Hess bei Ballonfahrung (1912).

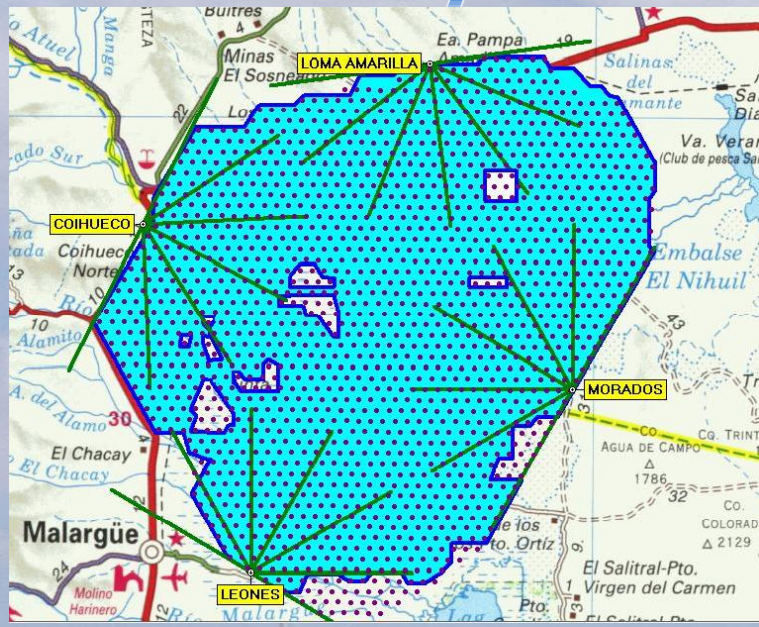
). Altitude variation of ionization. (*a*) Balloon ascent by Hess (1912) carrying two ion chambers. (*b*) Ascents by Kolhörster (1913, 1914) using ion chambers. (*c*) Coincidence counter telescope flown by Pfotzer (1936).

Cosmic Rays


The "All Particle Spectrum"
Fluxes of Cosmic Rays
(1 particle per m²–second)
Knee
(1 particle per m²–year)
Ankle
(1 particle per km²–year)
1 particle / km²/century
Flux (m² sr s GeV)⁻¹
Energy (eV)


d

Pierre Auger Observatory



Hybrid Detector

1600 Detectors

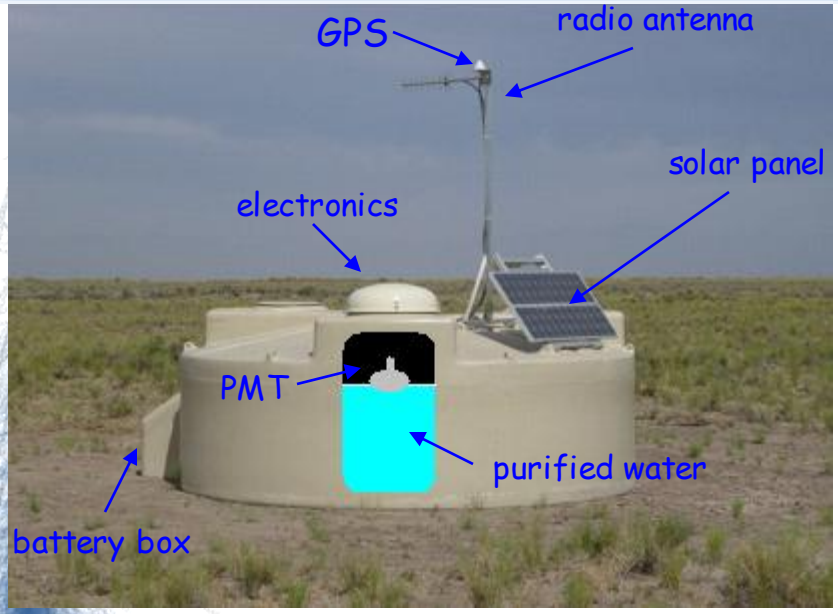
(Water tanks – Cherenkov)

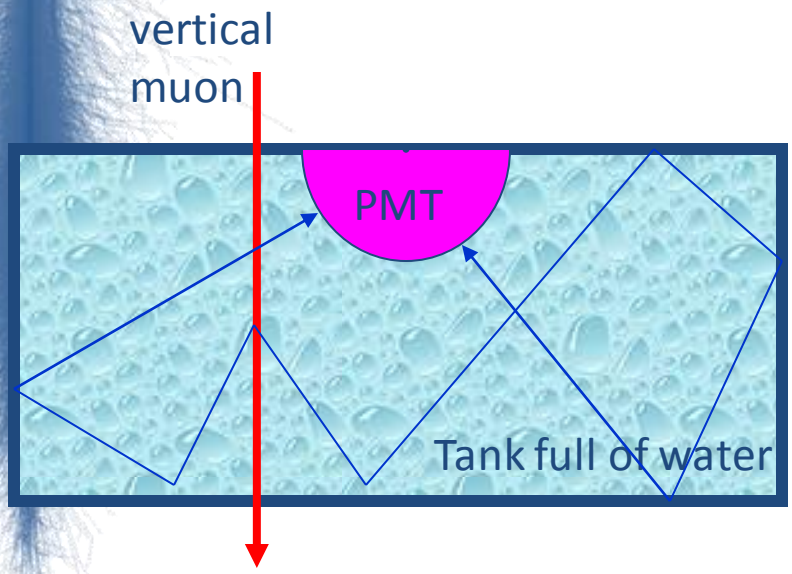
In a 1500m grid

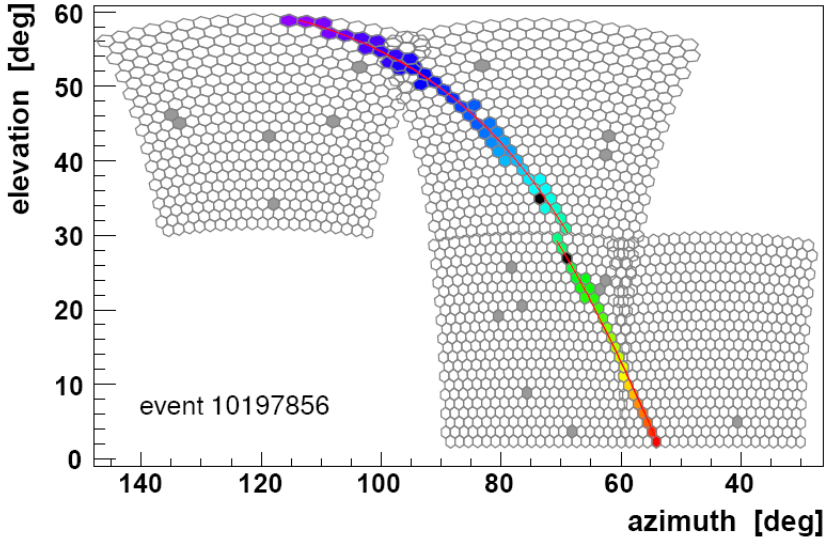
Covered area = 3000 km^2

27 (24+3) fluorescence telescope

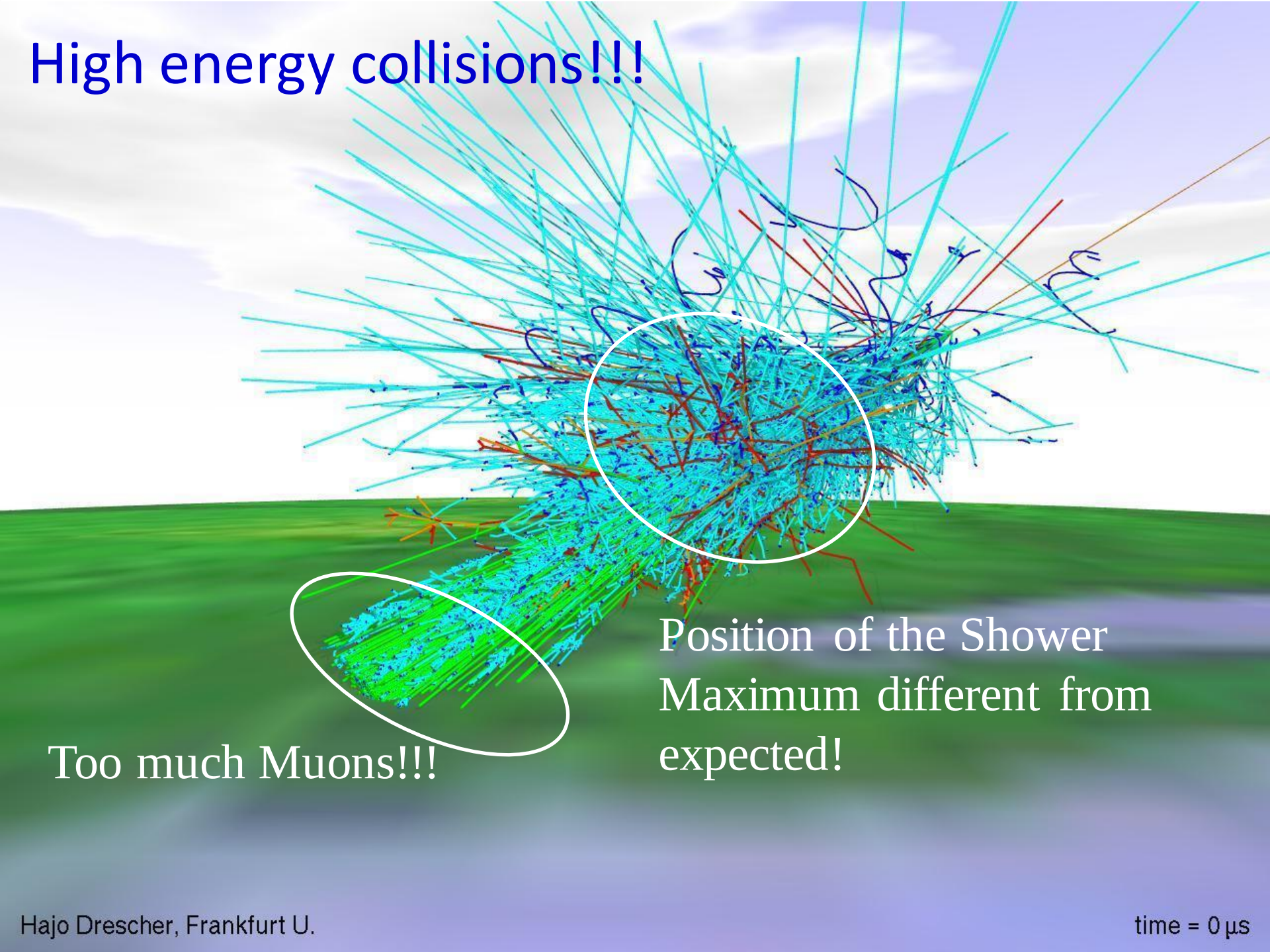
The detectors



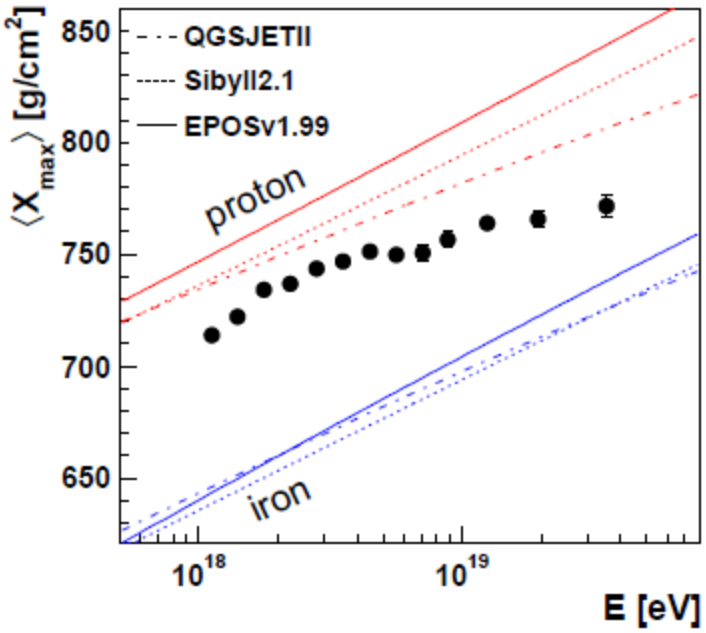


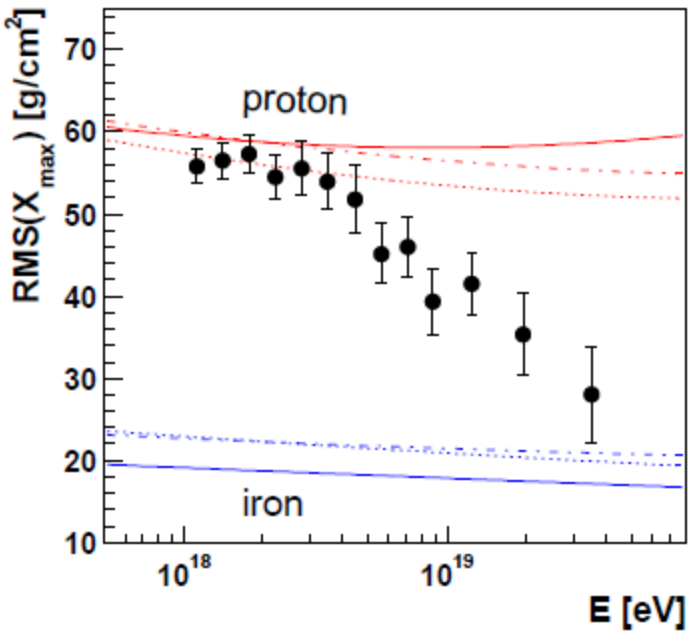


High energy collisions!!!

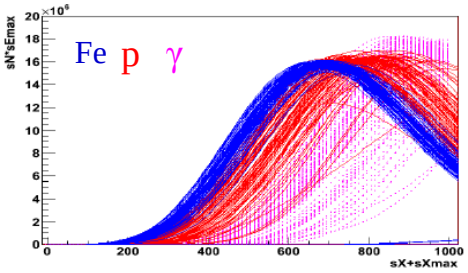


Xmax

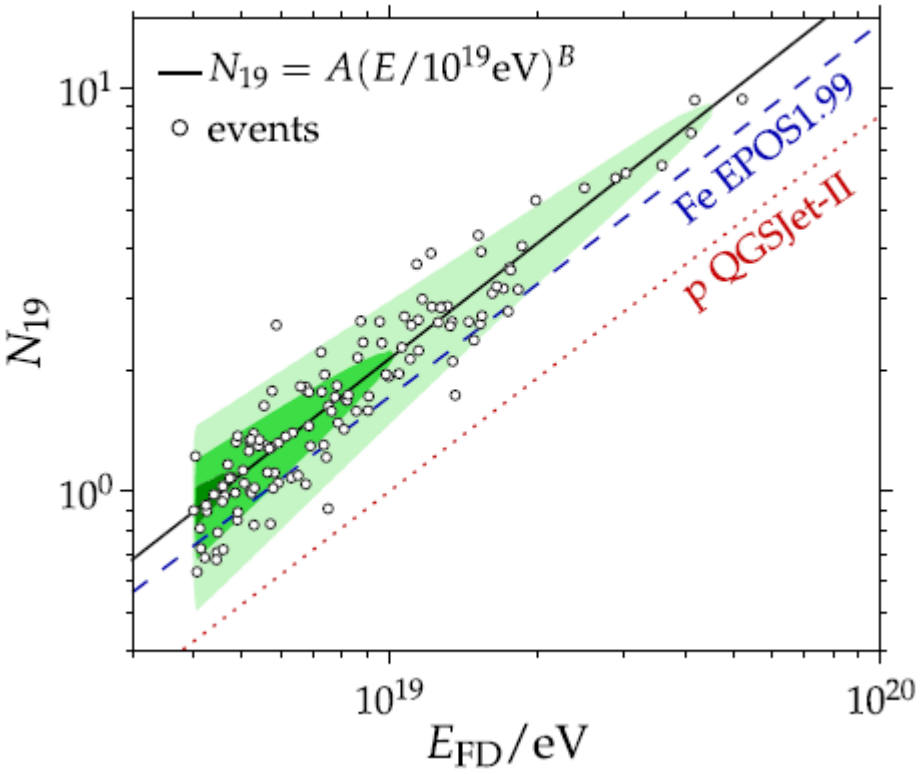




Heavy nuclei ? No simple model to explain it
Wrong Physics models ?

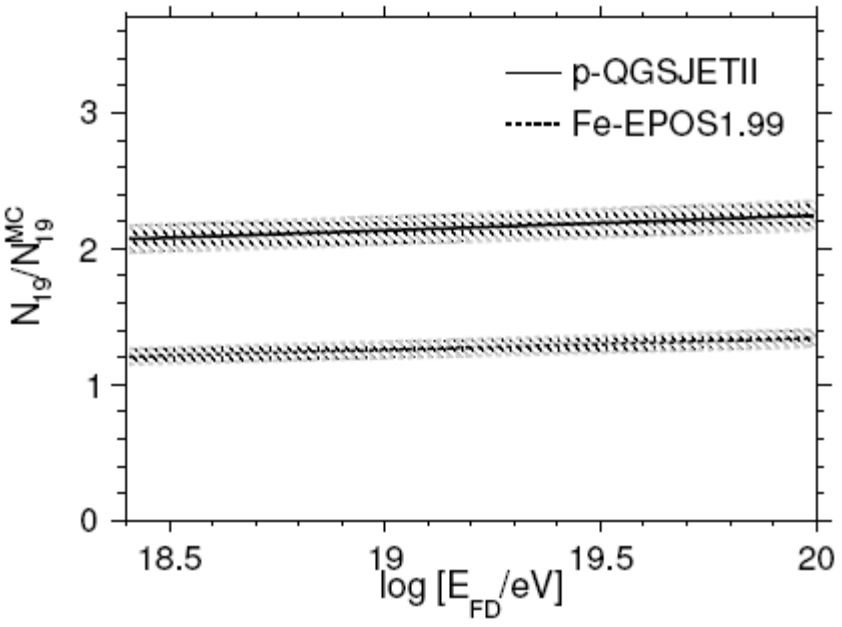


N_μ

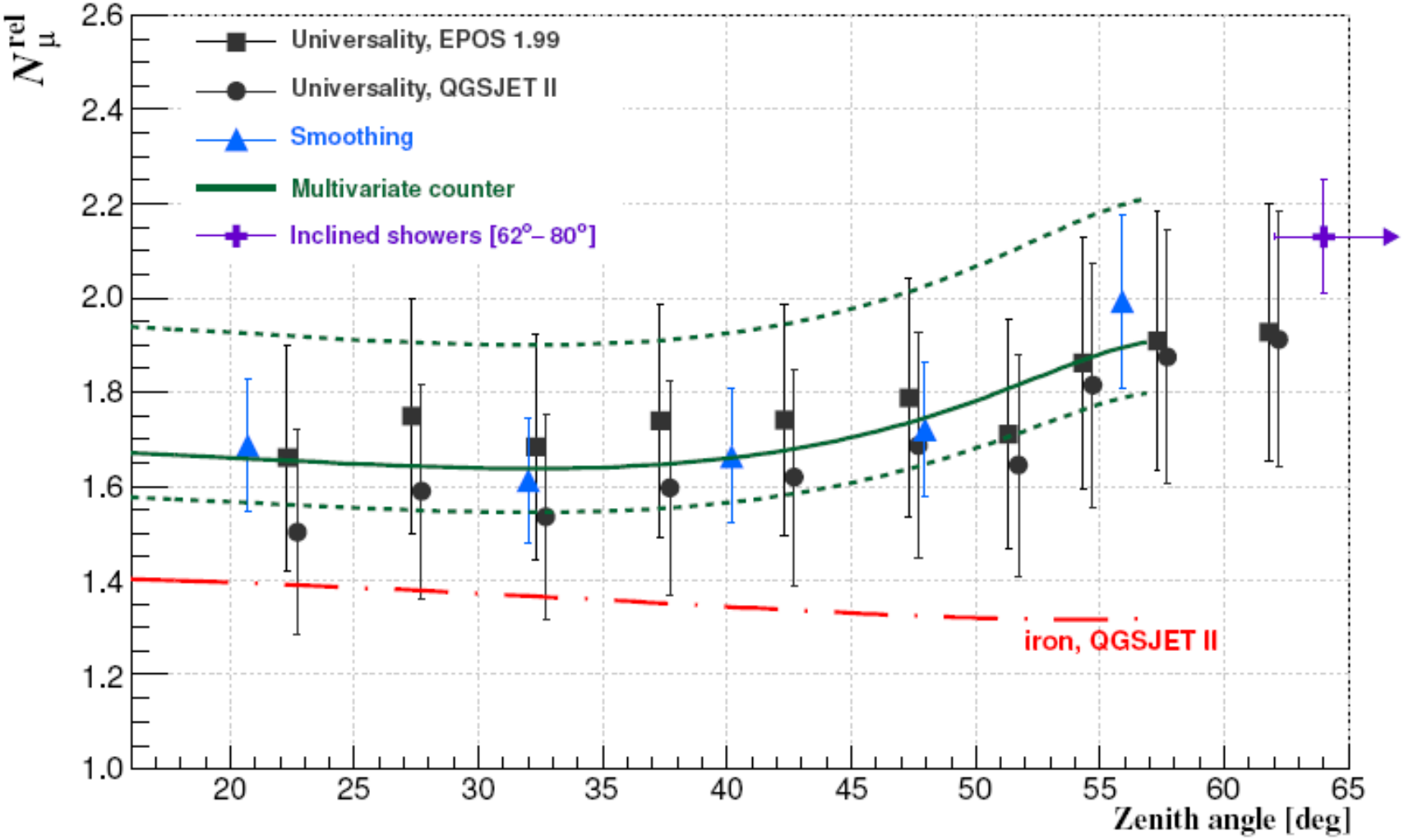


$$N_\mu^{rel} = 2.13 \pm 0.04(stat) \pm 0.11(sys)$$

with respect to p QGSJET II at 10 EeV



$N_\mu \sim E^{0.95}$



N_μ^{rel} — number of muons with respect to QGSJET II protons at 10 EeV

The challenge...

Mass composition

Hadronic models

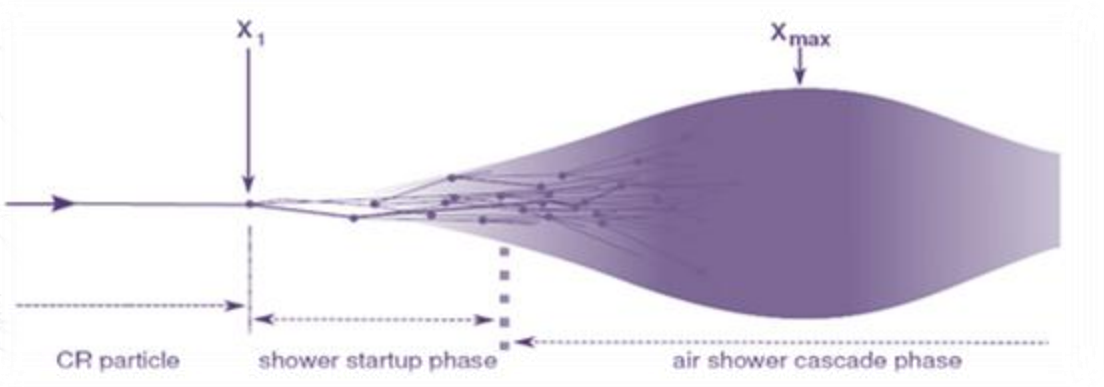
N_μ

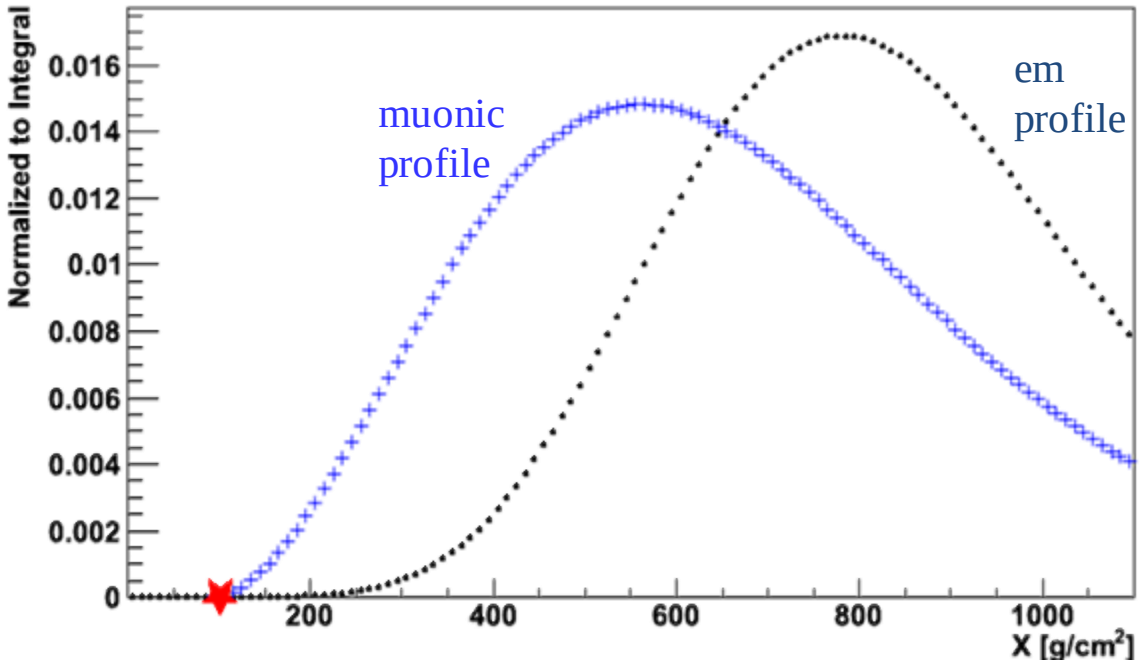
Xmax

Increase information

How can we improve our knowledge?
More statistics (just waiting) won't solve it!

Need better!





Better e.m. Profile
Better FD

Better muon info.

Auger 2015

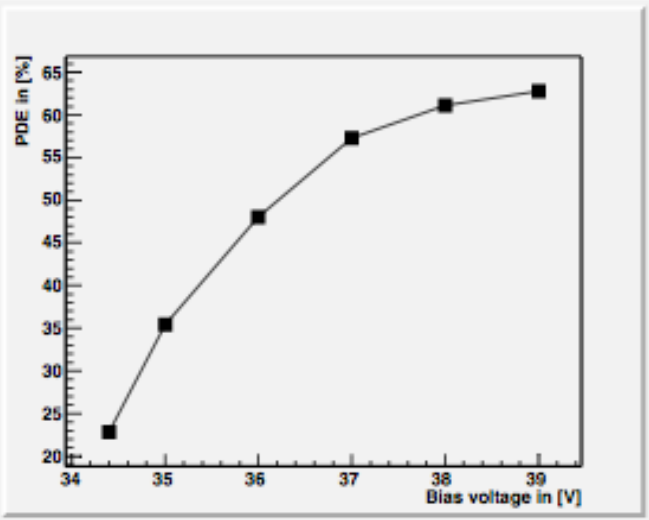
- Increase Information
- Higher performance of existing detectors
- Introduce new detectors

Better FD

Towards a FS with SiPM

Collaboration LIP, Aachen, MPI, Granada, Palermo, to develop a SiPM based Focal Surface

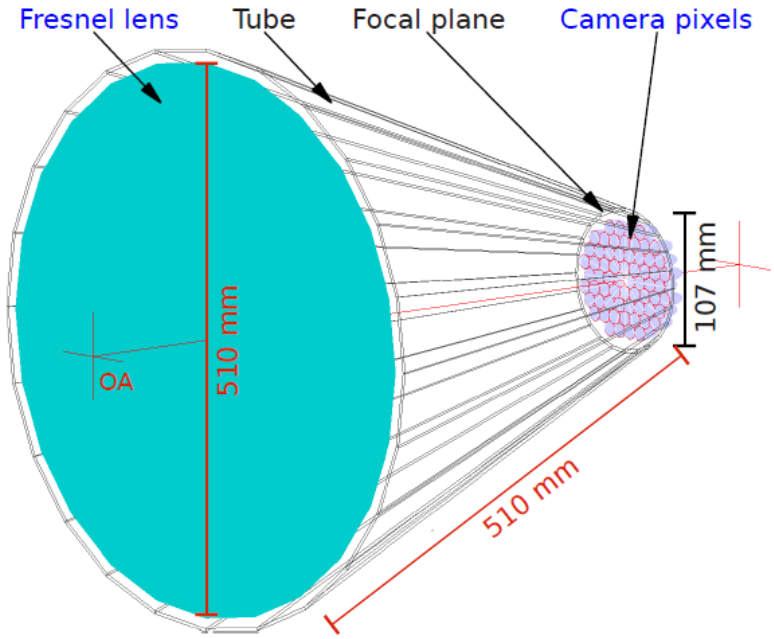
PMT typ. peak PDE 25%
SiPM could reach ~60%



Measurement of a "Dolgoshein" prototype

FAMOUS

First Auger Multi-pixel-photon-counter camera for the Observation of Ultra-high-energy air Showers

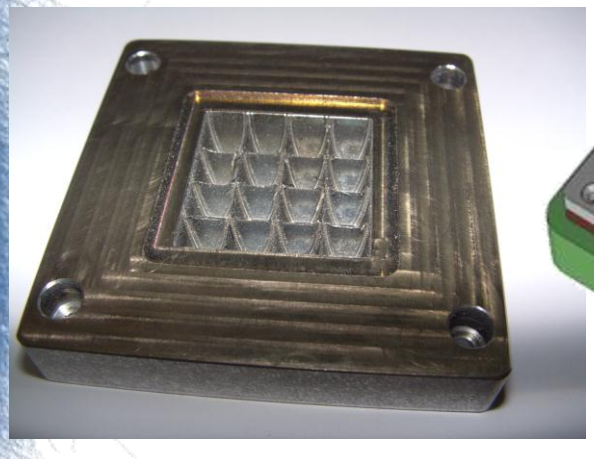


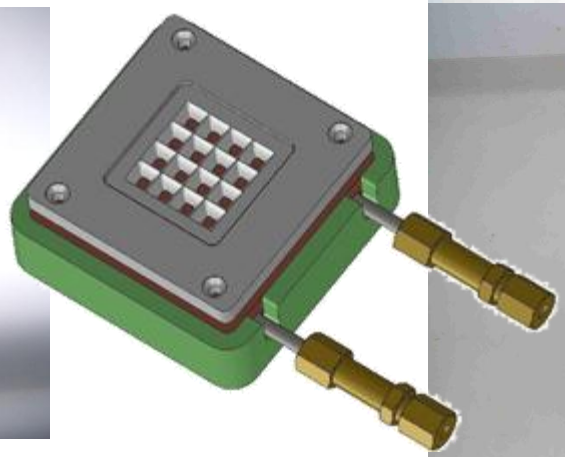
simple refractive design

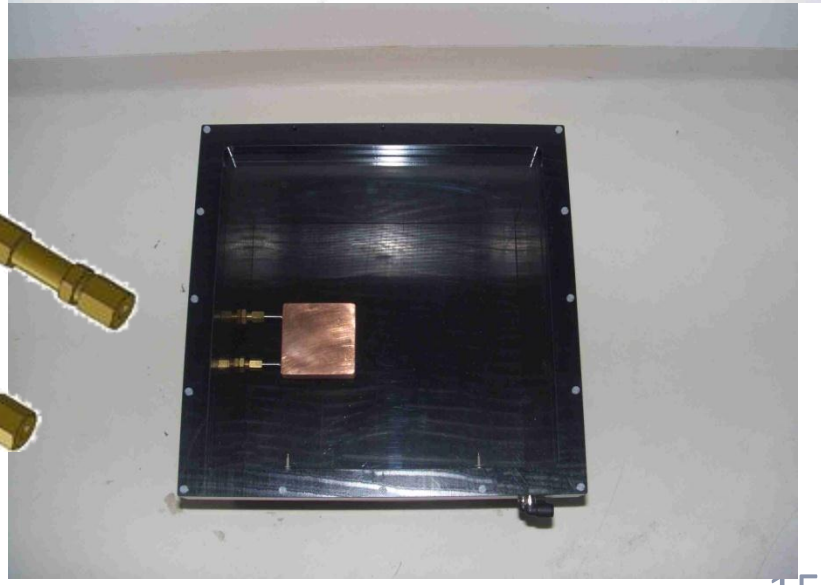
Better FD

Towards a FS with SiPM

Collaboration LIP, Aachen, MPI, Granada, Palermo, to develop a SiPM based Focal Surface

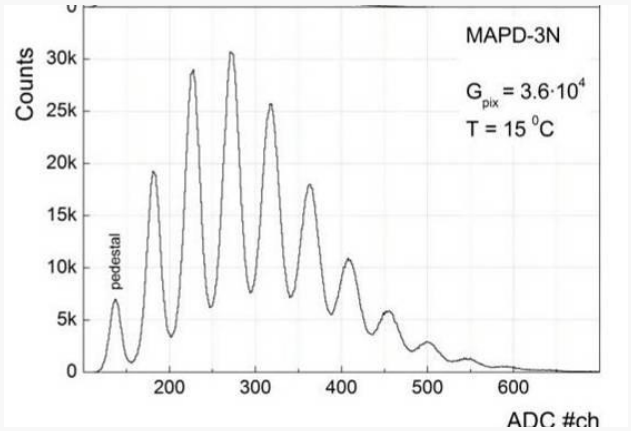




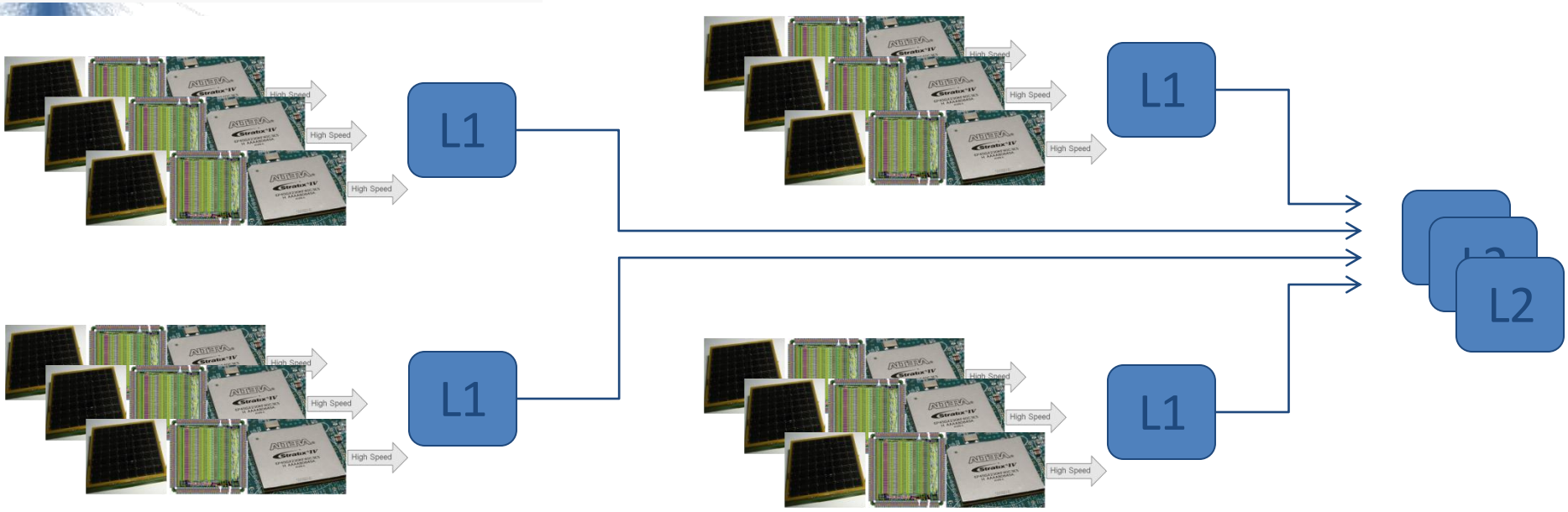


Readout Electronics

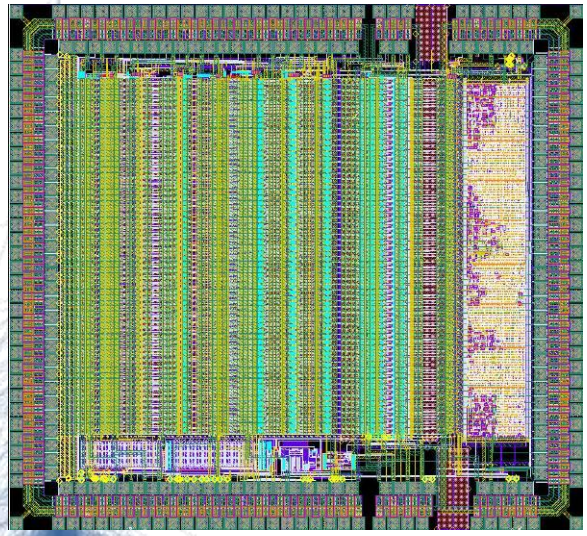
$1m^2 \rightarrow 10^5$ channels → compact electronics



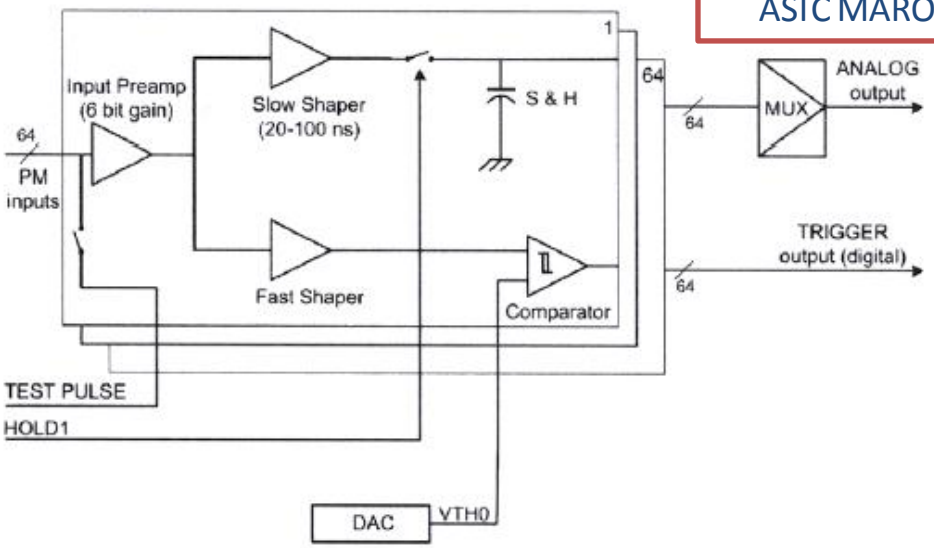
Main Options:
-Digital Photon Counting
-Signals digitized early
-Data transmitted by high-speed links
-Modular scalable design



Frontend Readout ASIC

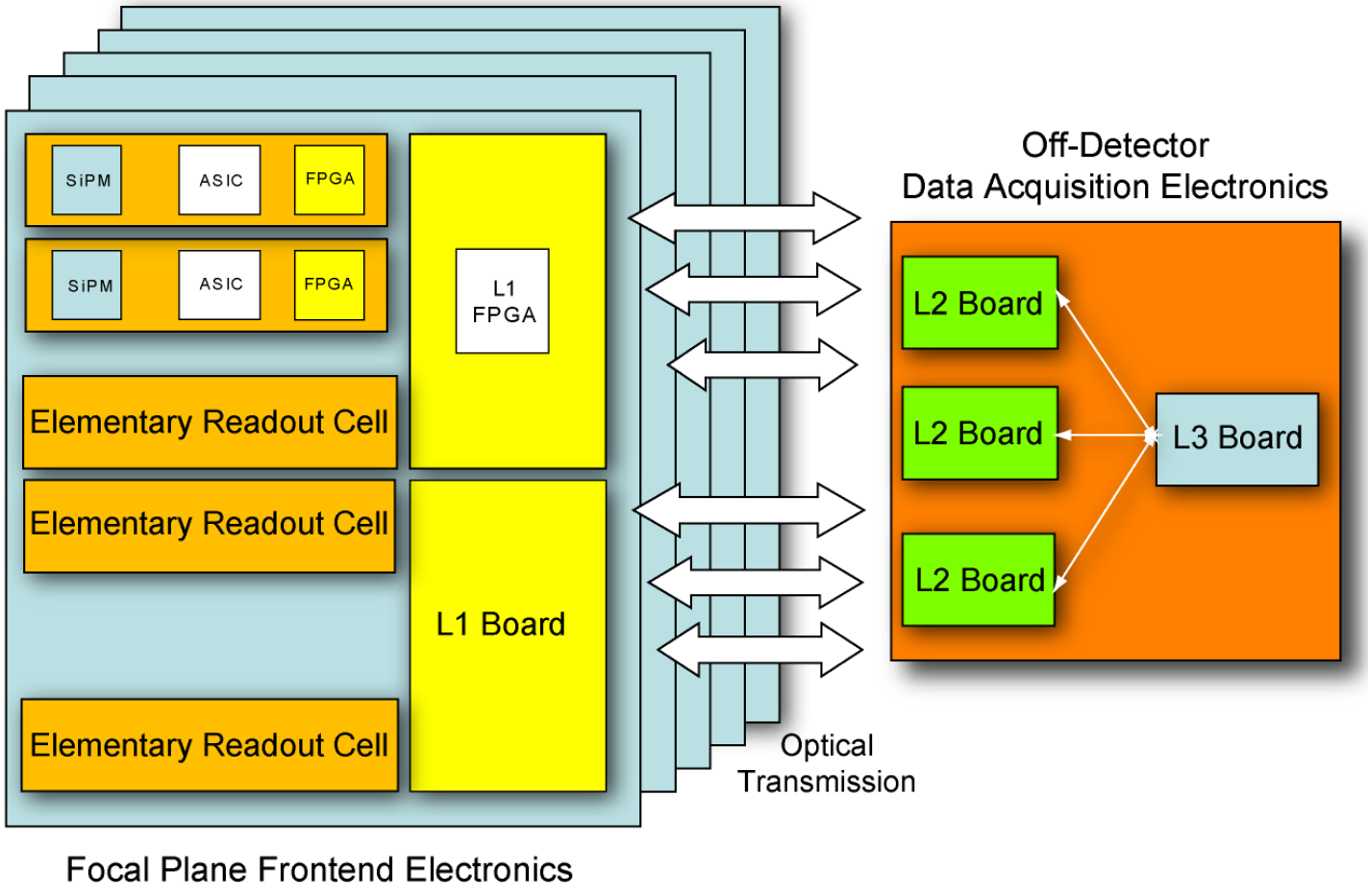


Baseline Option
ASIC MAROC3 (2009)



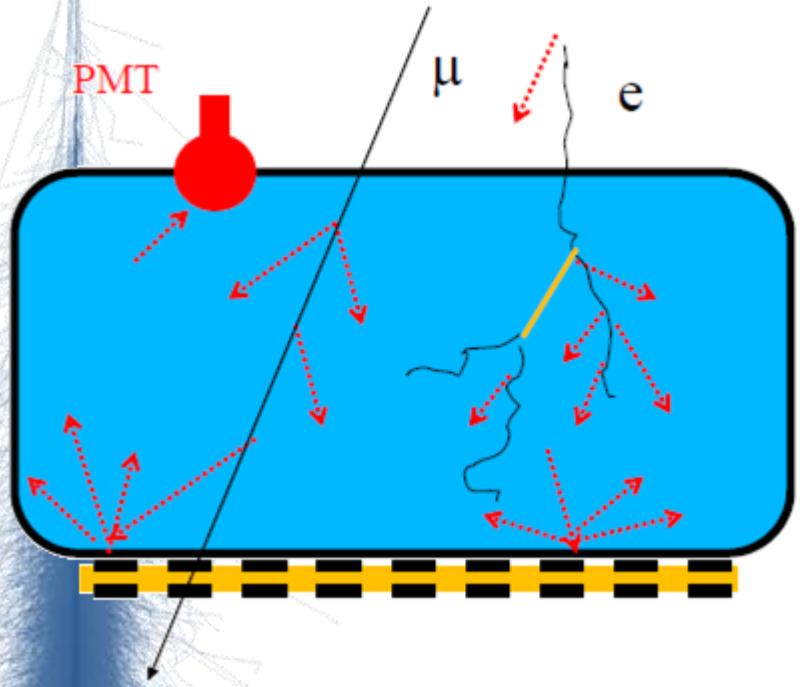
- 64 low impedance preamplifier
- Variable gain for each channel
- Minimum threshold at 100% trigger efficiency: 10 fC
- 64 logic trigger outputs
- 12 bits ADC (serial output: pedestal and maximum per channel)

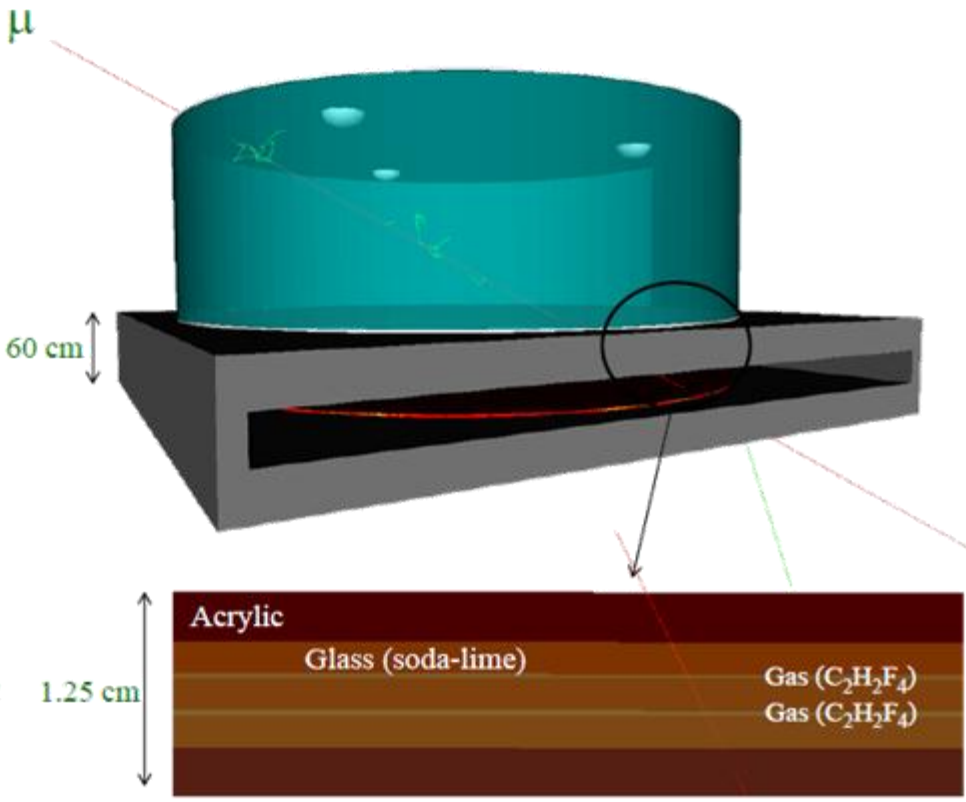
DAQ and Trigger Architecture



Better muon information

Add an aditional layer for the muons...
e.g. RPCs under the tanks



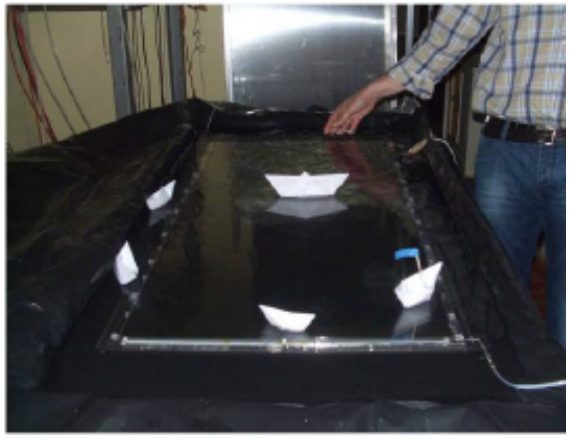


Better muon information

Add an aditional layer for the muons...
e.g. RPCs under the tanks

R&D in Coimbra for RPC chambers for Auger

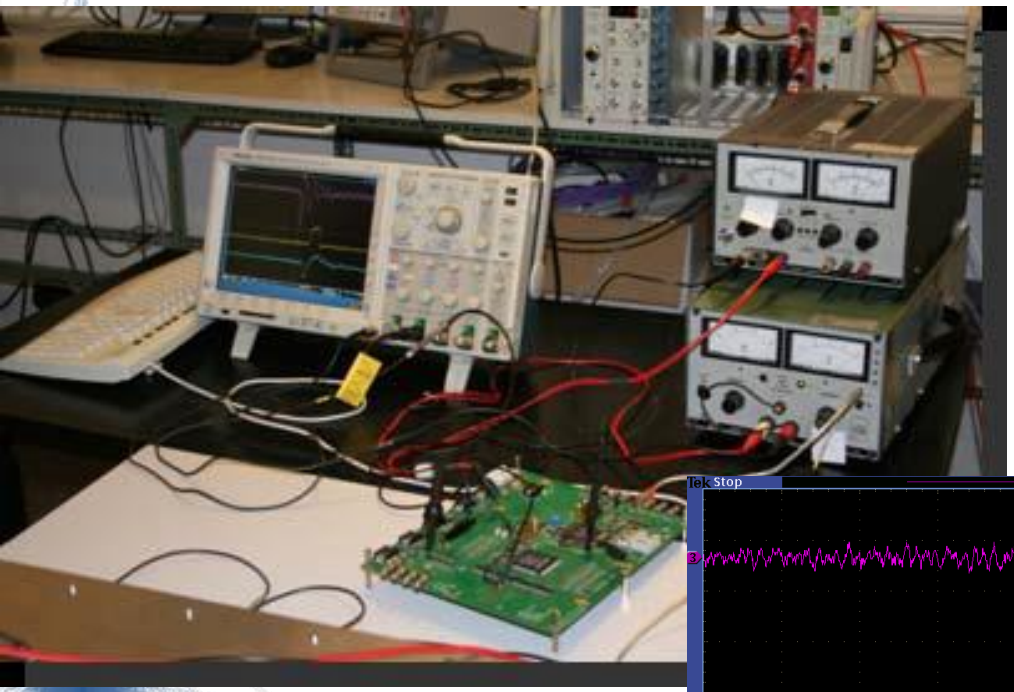
- ✔ Outdoor operation with minimum maintenance
  - ✔ Expected minimal gas flow : ~1 small (3 kg) bottle /3 years
  - ✔ Insensitivity to the environment
    - ✔ insensitive to humidity
    - ➡ very low temperature test to be carried
- ➡ Low power consumption
  - ➡ Requires integrated electronics
  - ➡ 1-10 mW / channel
    (depends on shaping, sampling,...)
- ✔ Affordable in large areas
  - ✔ 0.5x1 m^2 sealed chamber already developed
- ✔ Low cost



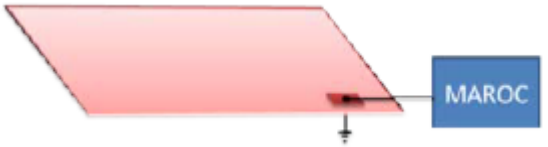
Radical humidity test
The chamber is actually on!

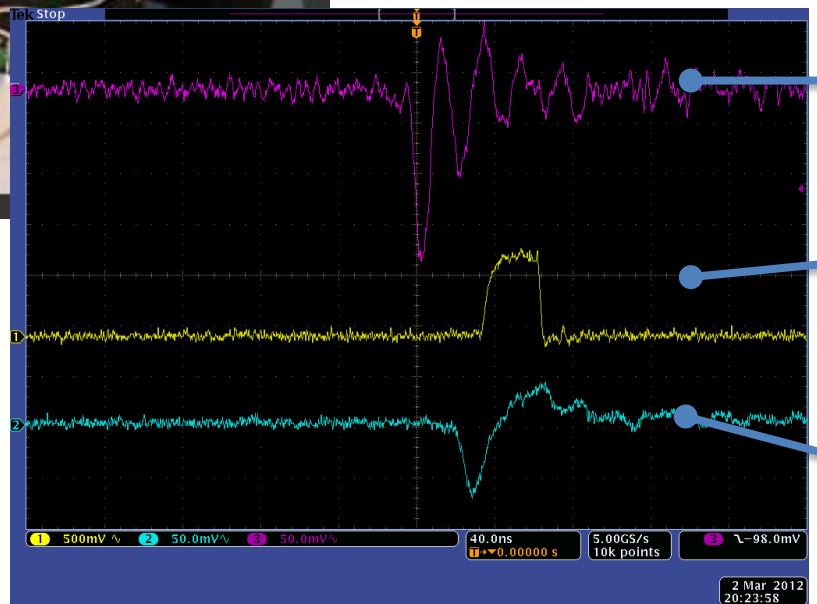
Better muon information

Add an aditional layer for the muons...
e.g. RPCs under the tanks



Electronics based on the MAROC ASIC





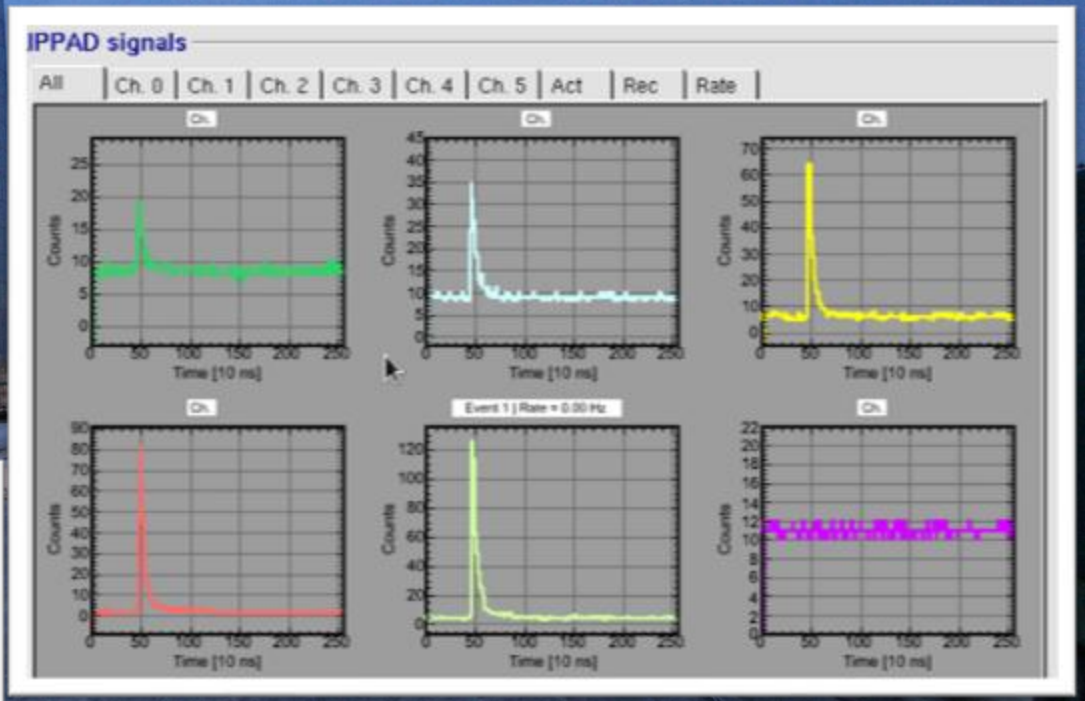
RPC signal

MAROC digital output

MAROC analog sum

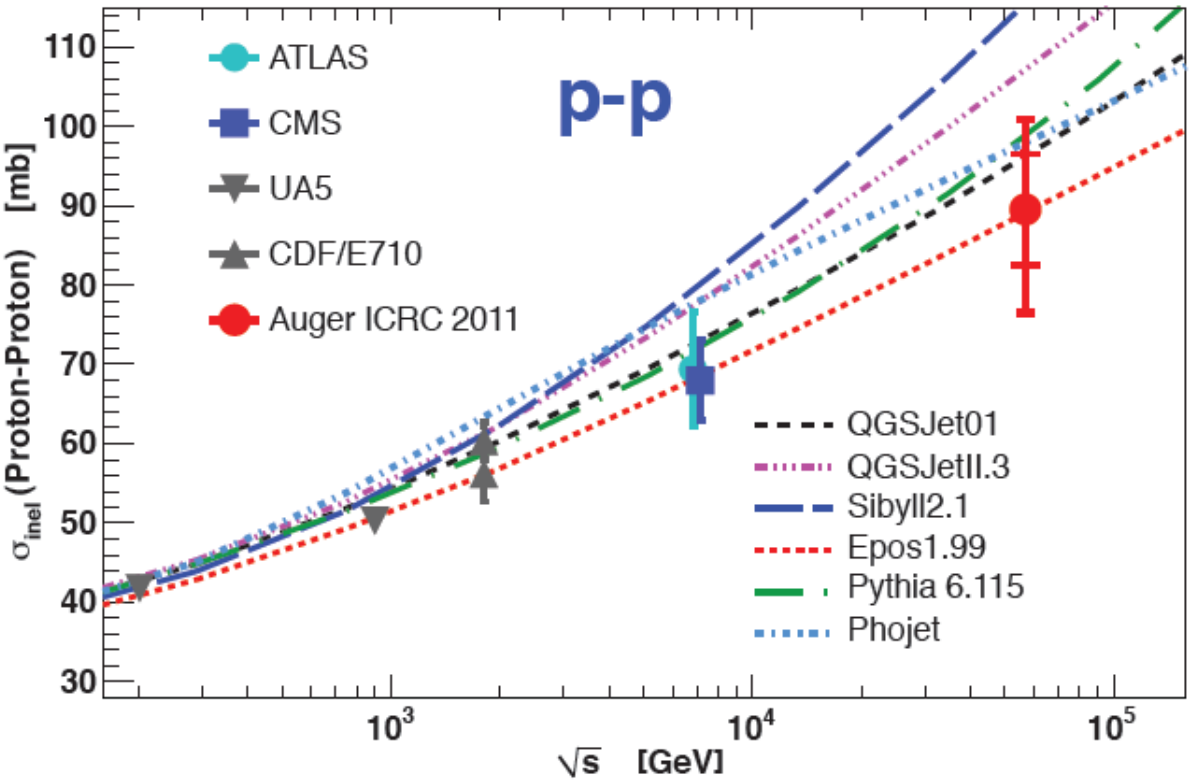
CRIVO

A small Cosmic Ray detector
Array of scintillators
Installed at DF-IST rooftop

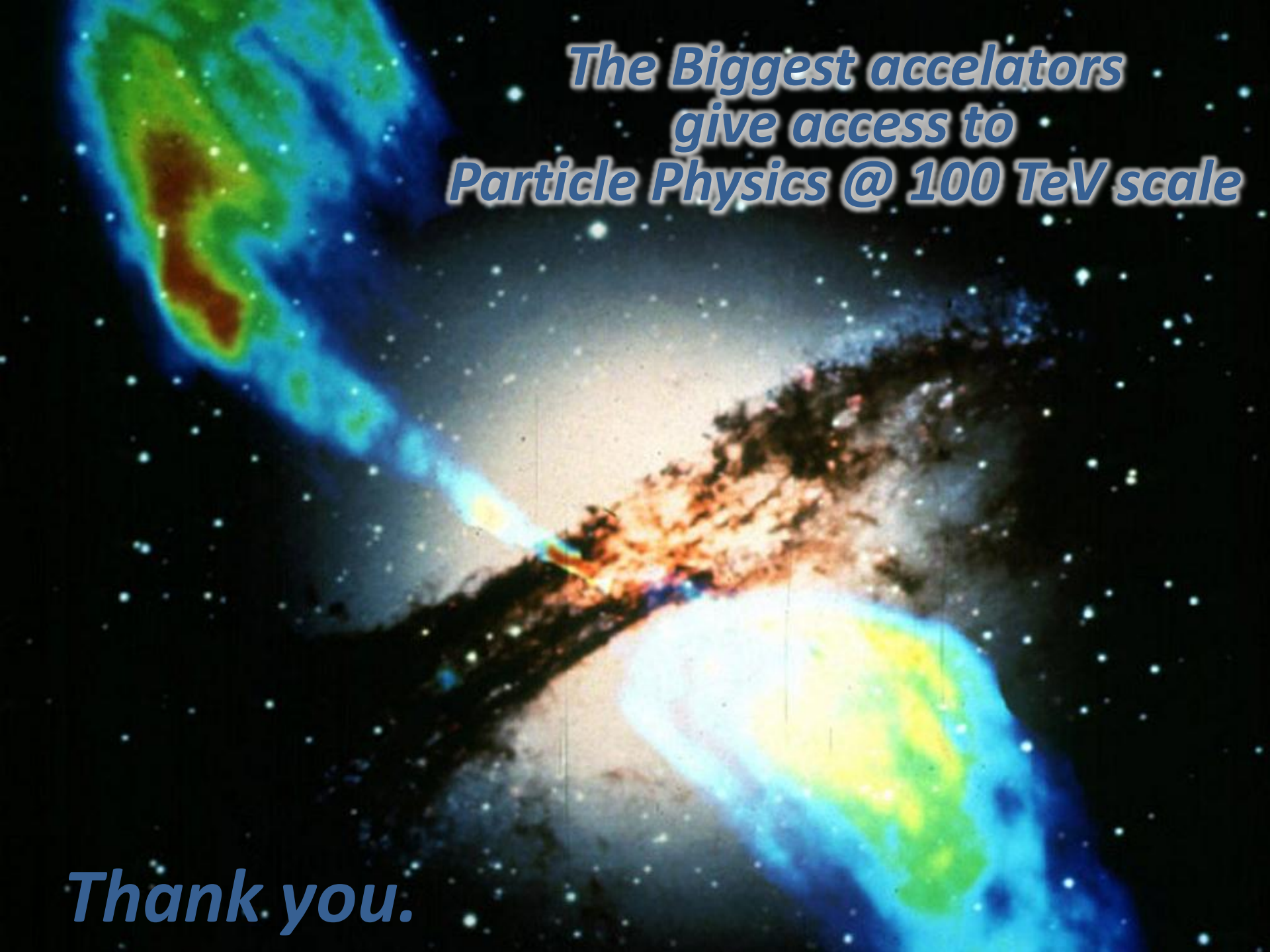


Under calibration...
Next: Install RPCs

Proton cross-section



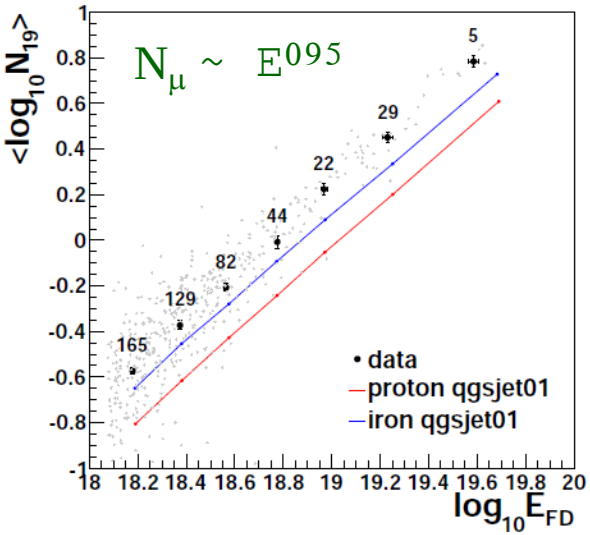
We have to do it at higher energies

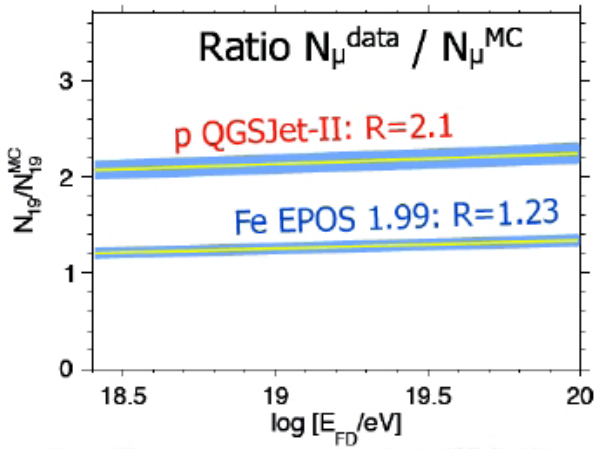

The Biggest accelators
give access to
Particle Physics @ 100 TeV scale
Thank you.

END

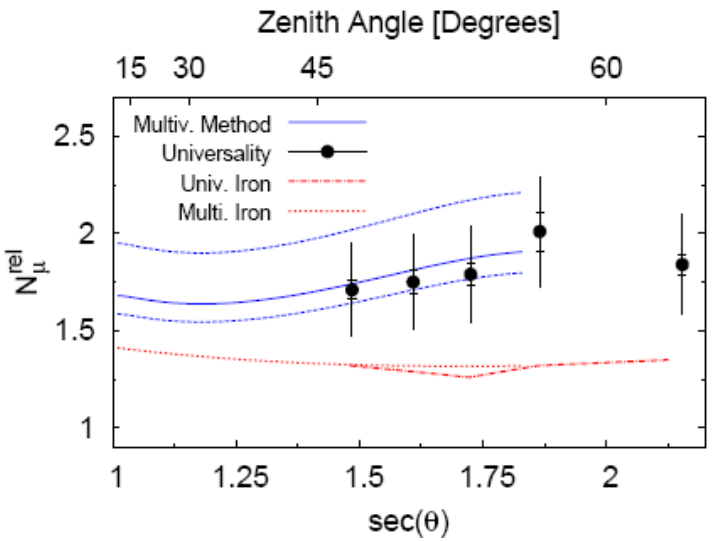
Number of muons

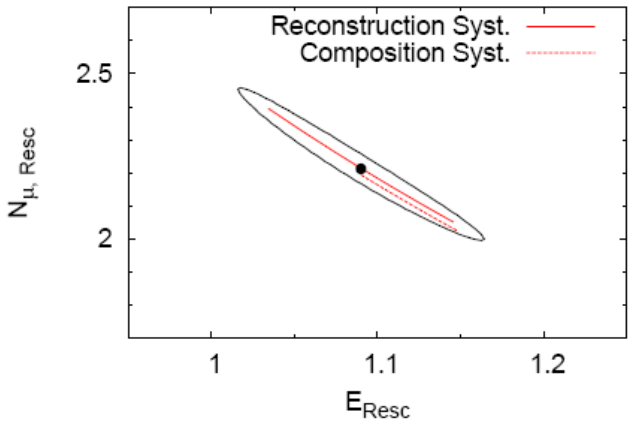
Inclined events





Multivariate and Universality

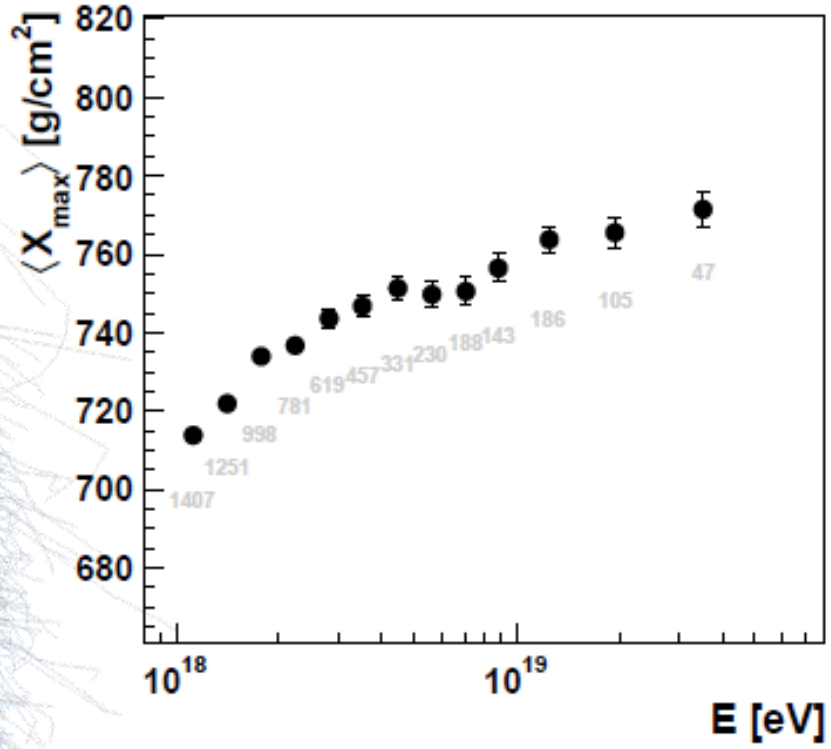


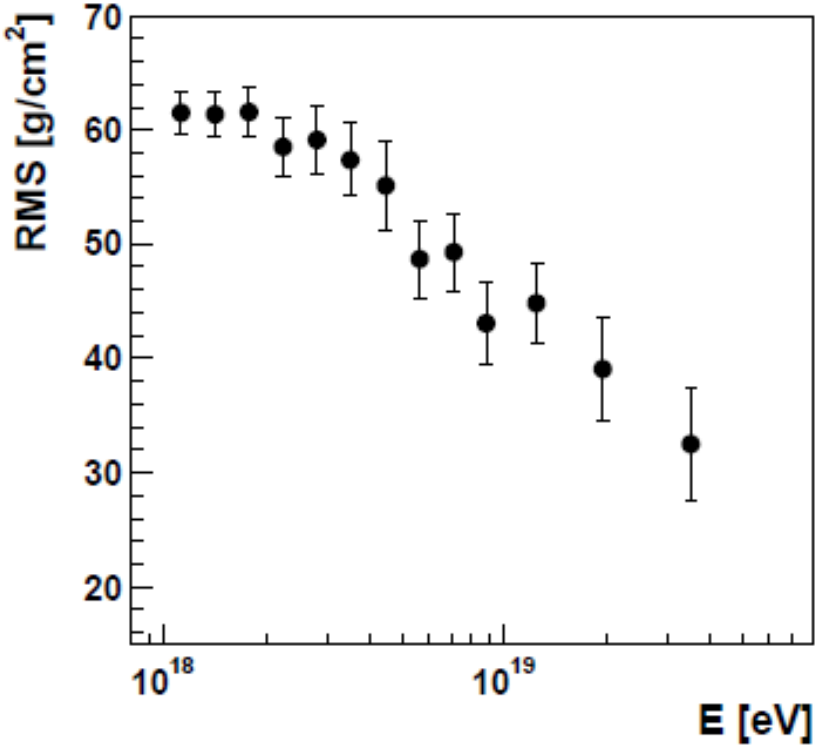


A significant excess of Muons is observed that can not be explained by composition alone

The results – What?

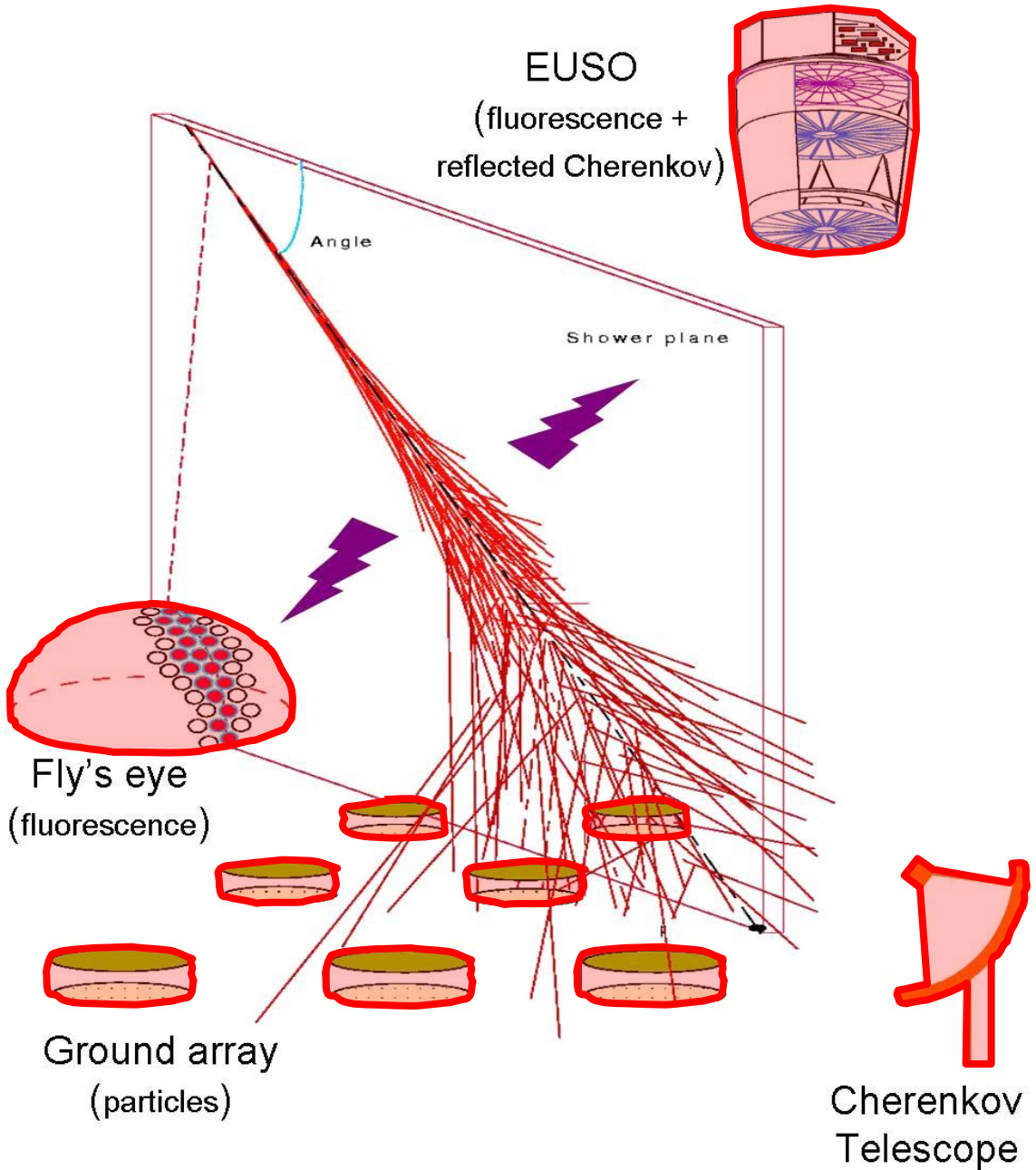
Xmax distributions



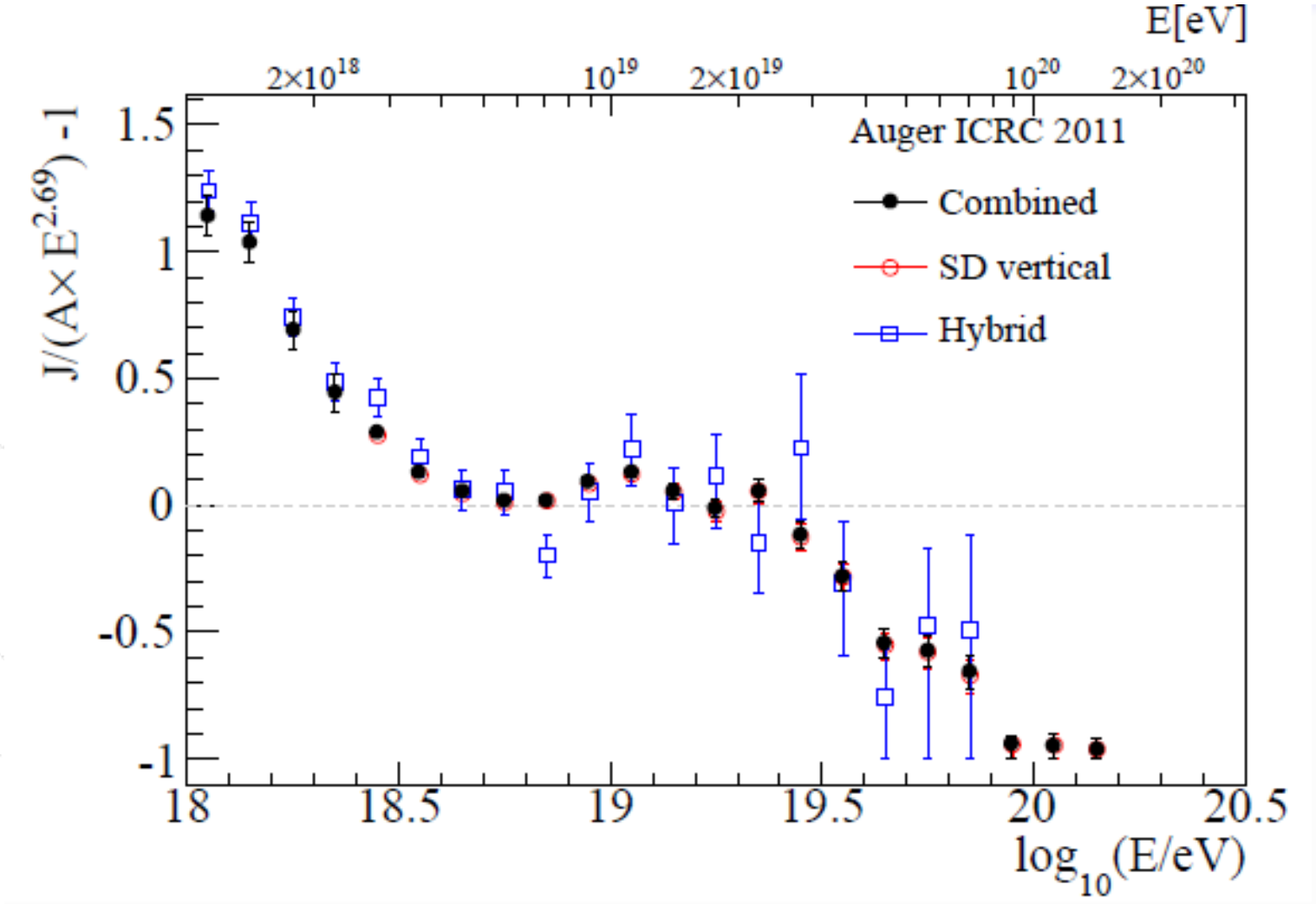


Extensive Air Showers

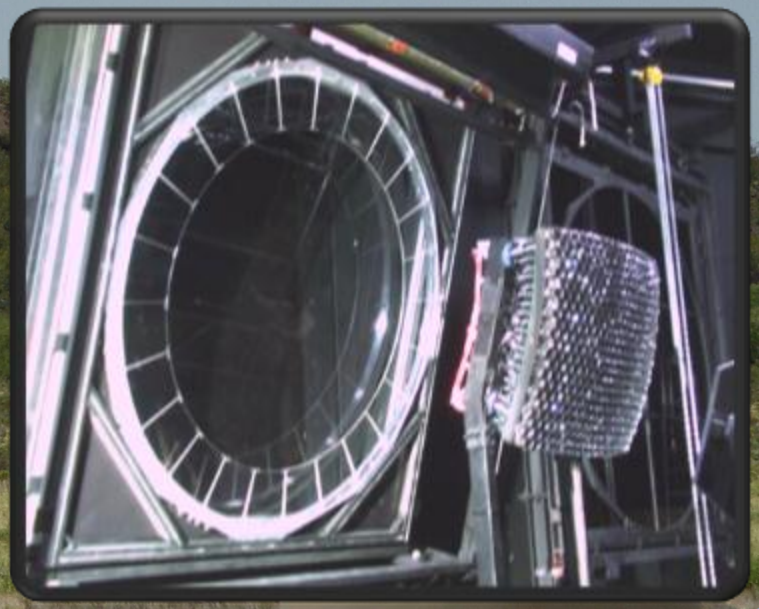
- Ground array
- Fluorescence Telescope
- Cherenkov Telescope
- Space Telescope



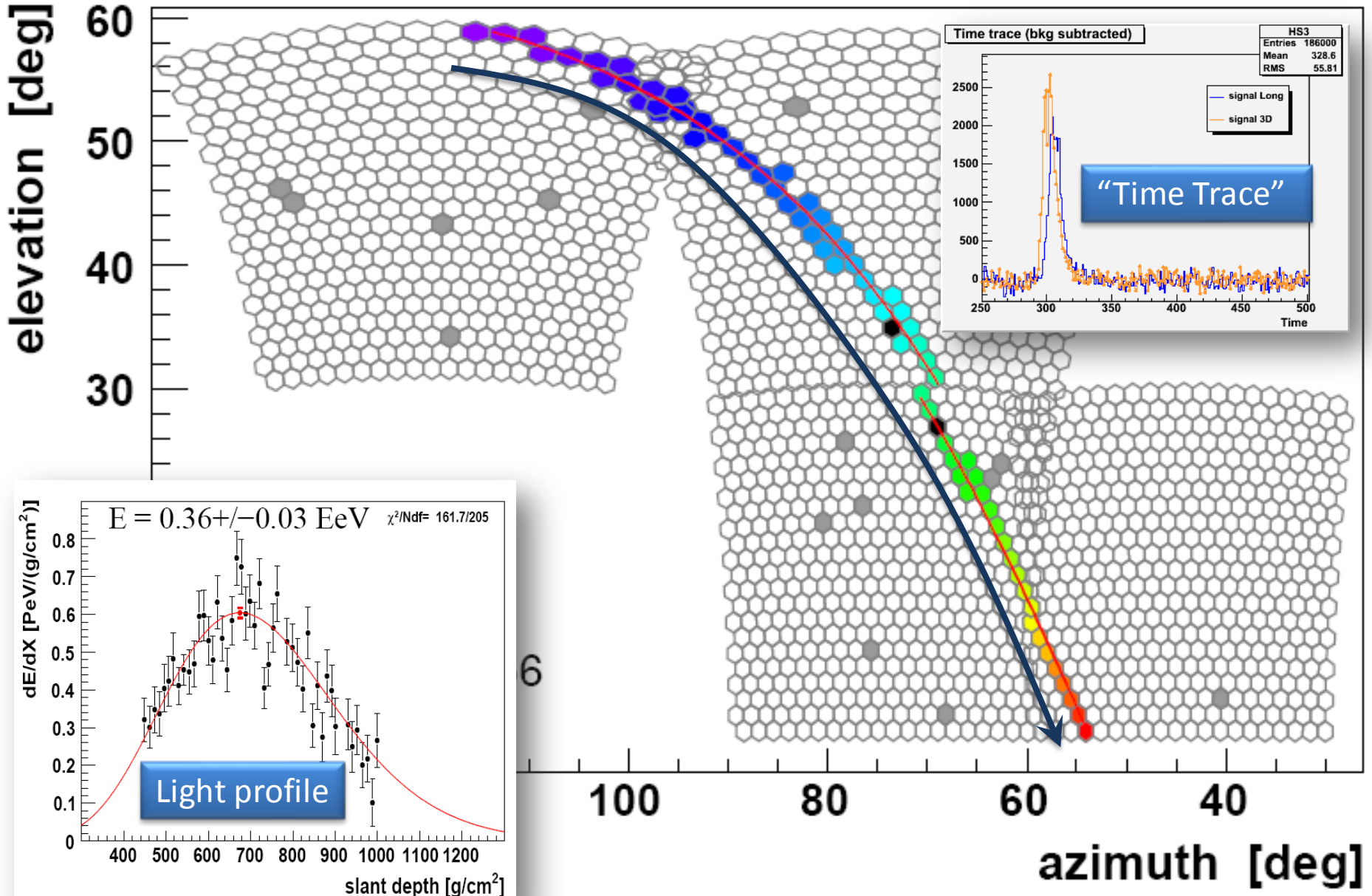
The results – How many?



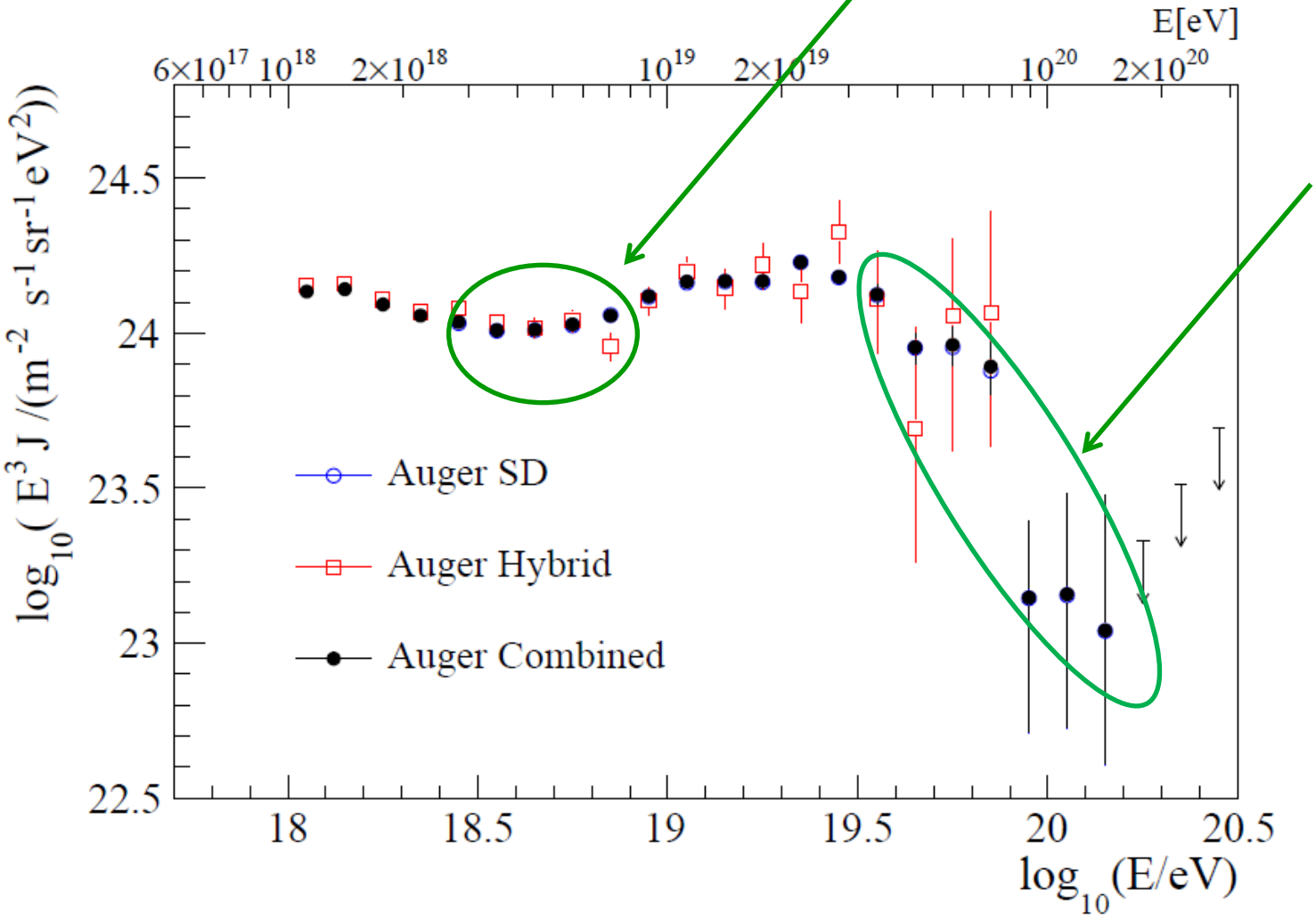
The detectors: Fluorescence Detector

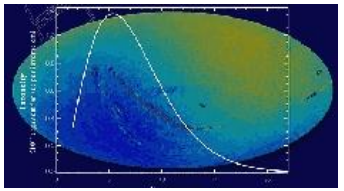


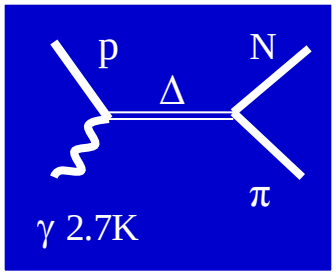
The detectors: Fluorescence Detector



The results – How many?

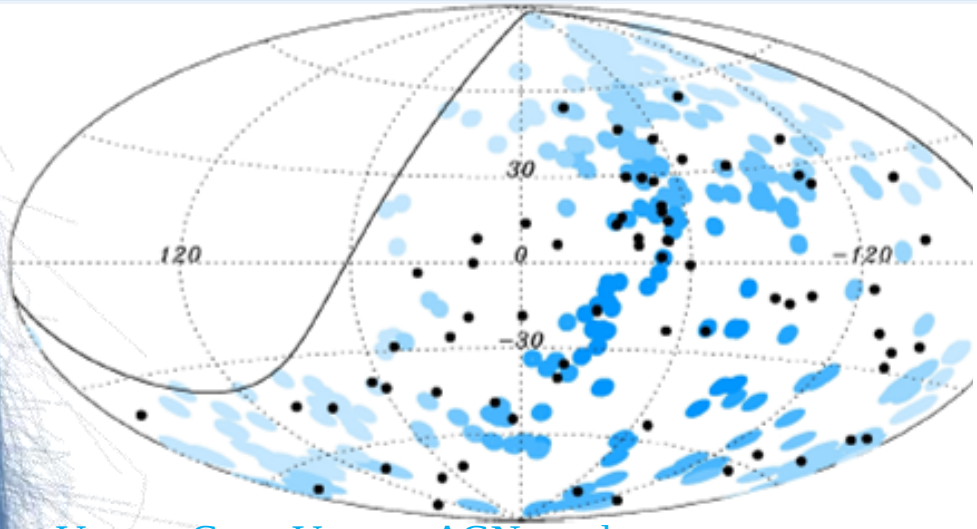




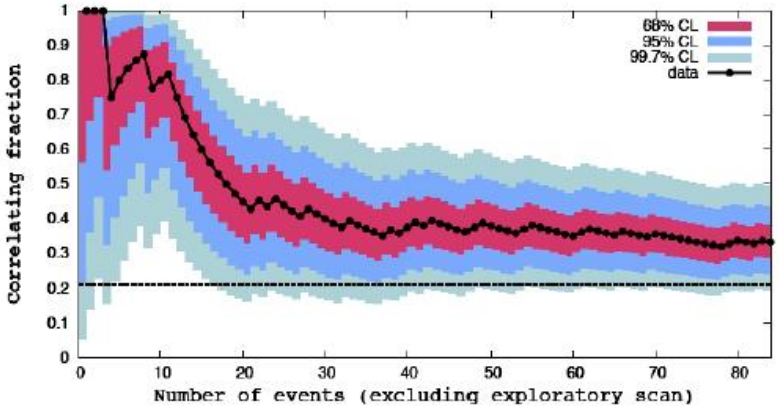


GZK like suppression !!!

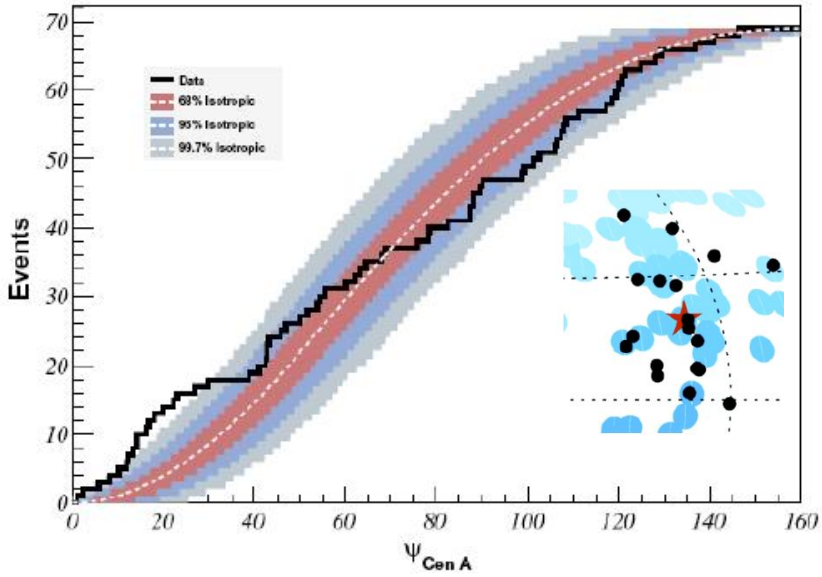
The results – from where?



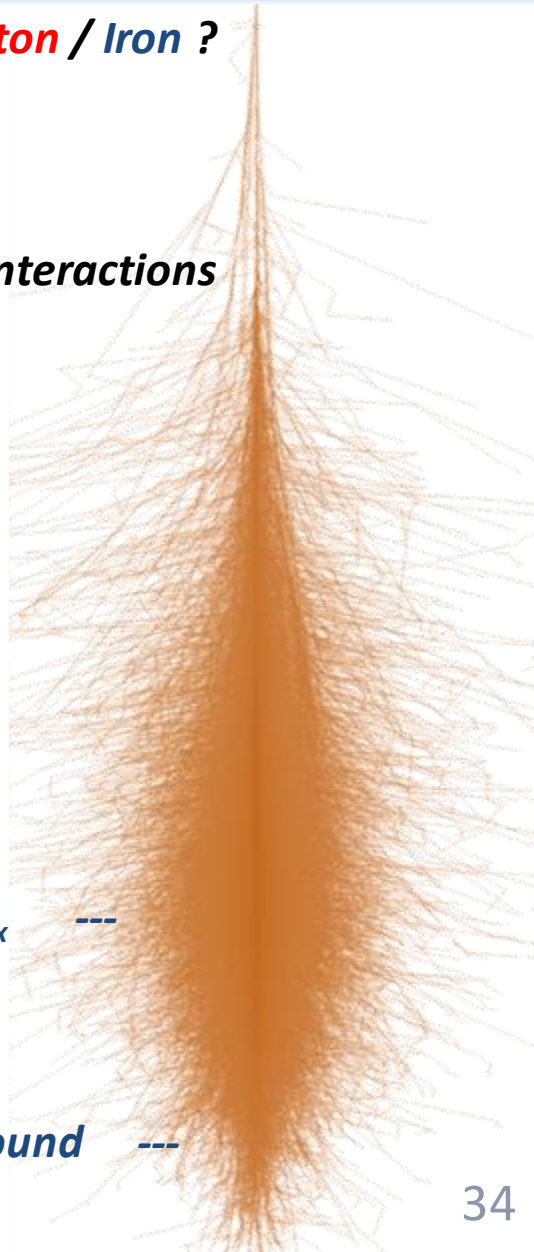
Vernon-Cetty-Vernon AGN catalog
E > 57 EeV, z<0.018, distance < 3.1 deg.



28 out of 84 correlate



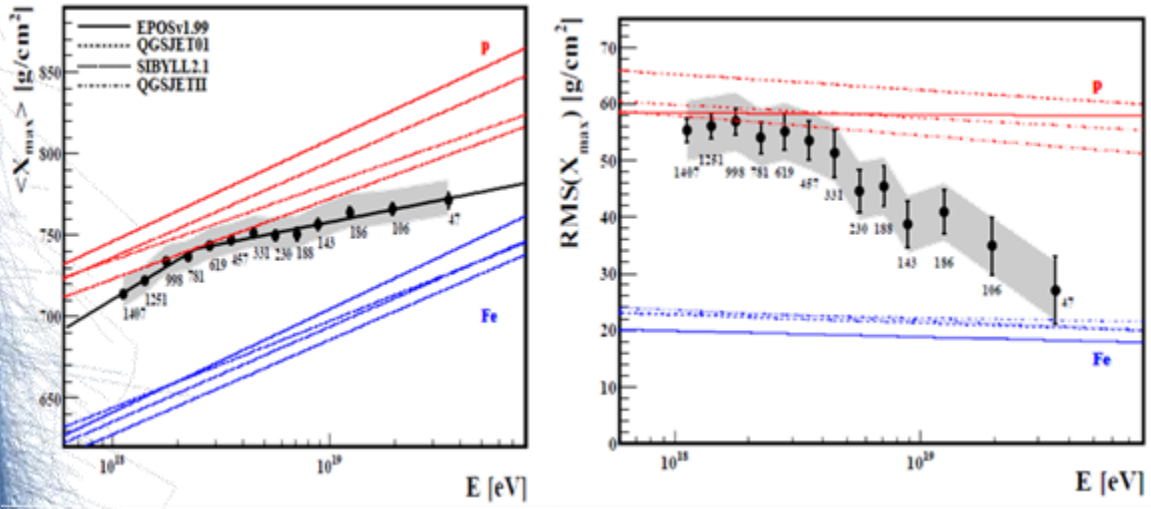
Observables

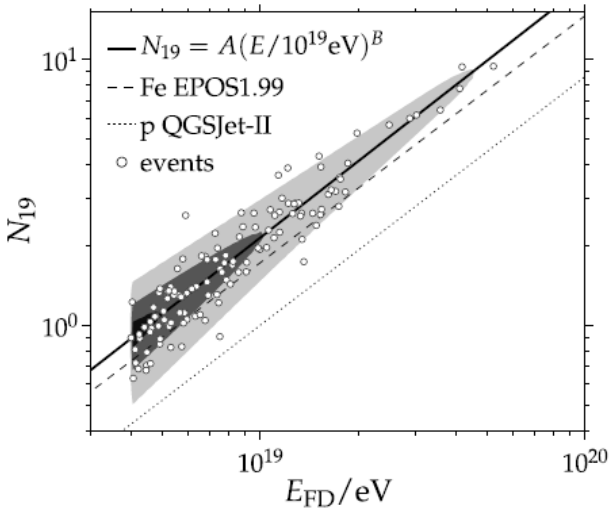


- Primary particle is infered through the shower behavior
  - X_{max}, Signal at ground...
- High energy Hadronic Interactions
  - Rule the shower development
  - Large uncertainties
    - Extrapolation from accelerator data (forward region)
    - New phenomena?
      - E=10^{19} eV → ($\sqrt{s} = 100$ TeV)
- Multivariate analyses

Data and Simulation

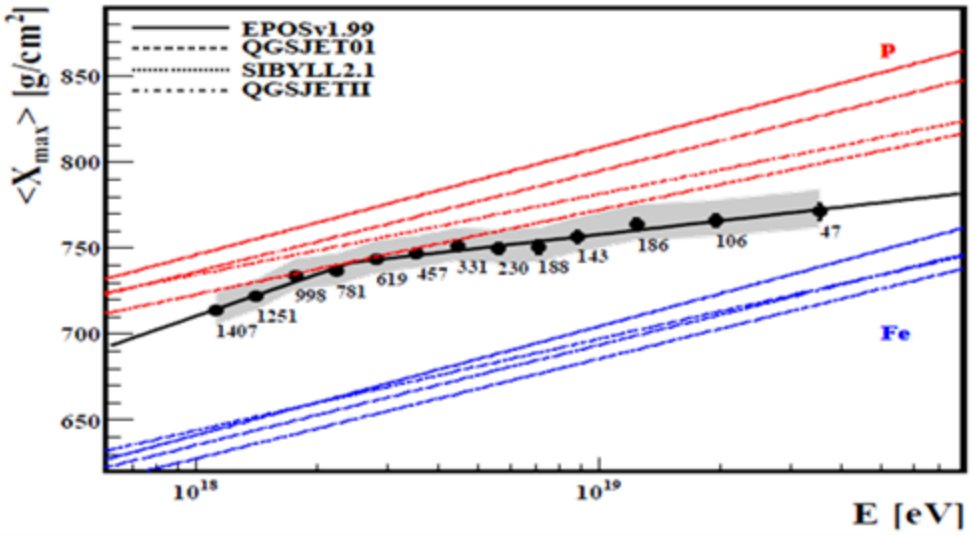
- Pierre Auger Observatory Data

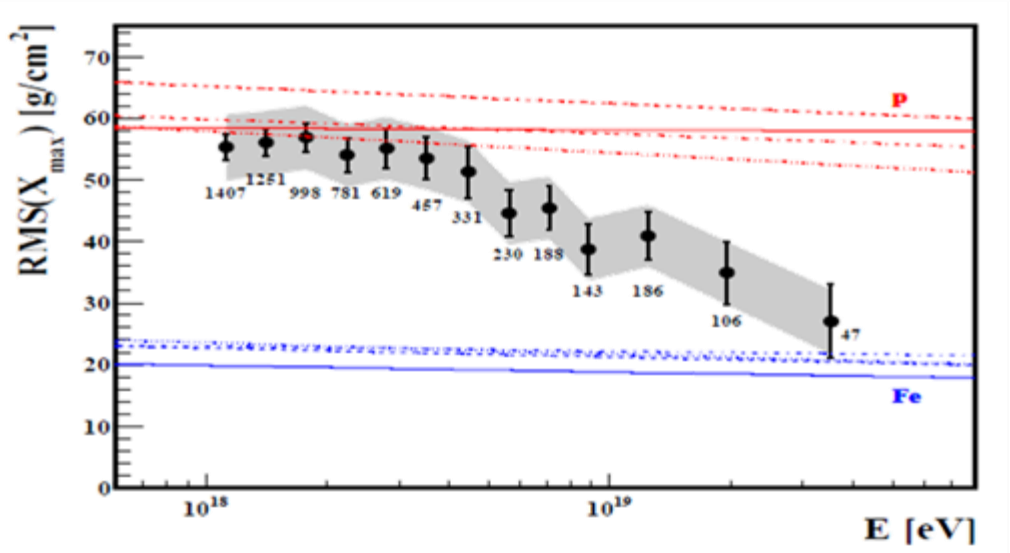




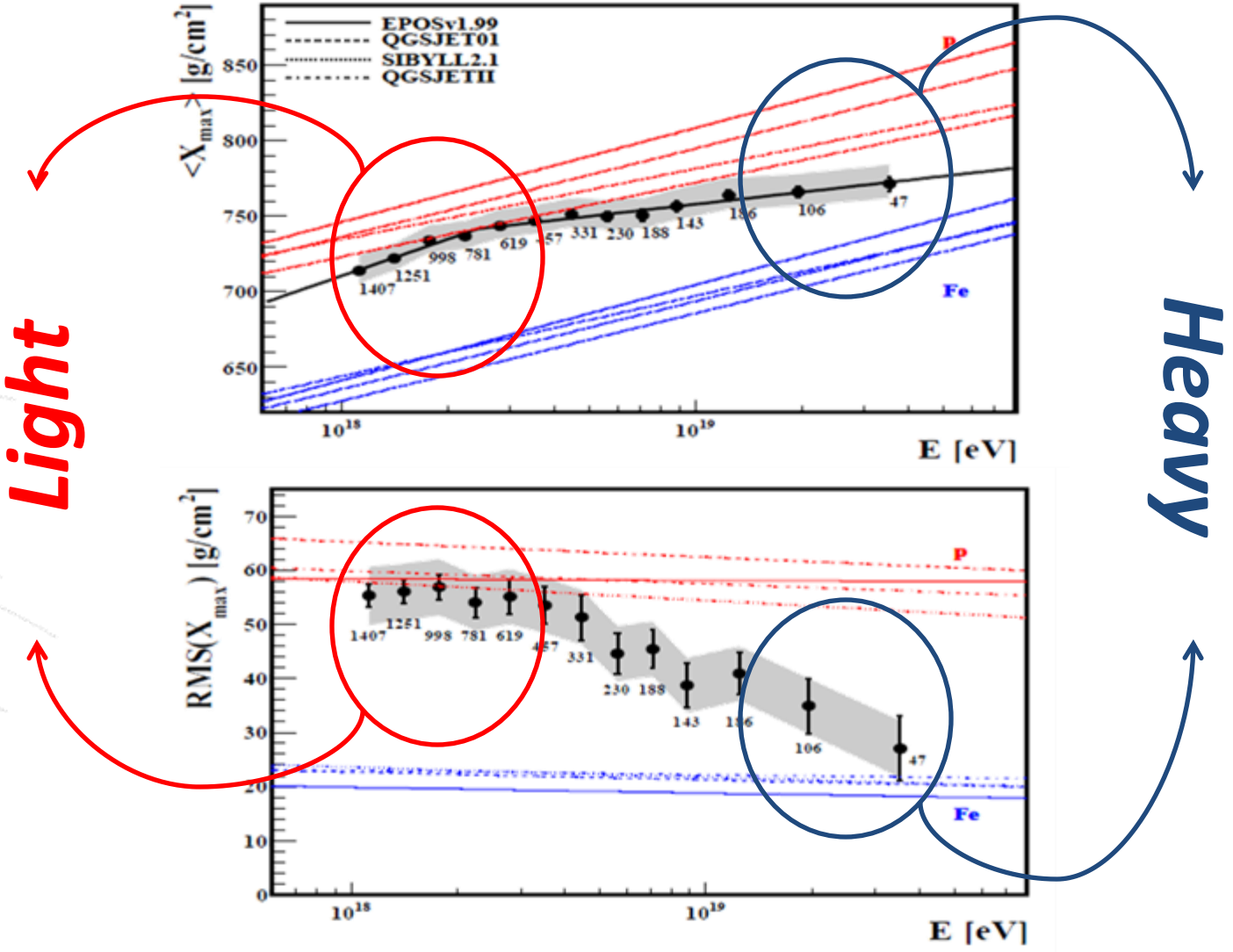
  - Average X_{max} and its fluctuations
  - Number of muons at ground
- Simulation
  - CONEX (50 000 shower per energy per primary)
  - QGSJET-II.03

$\langle X_{max} \rangle$ and RMS(X_{max})



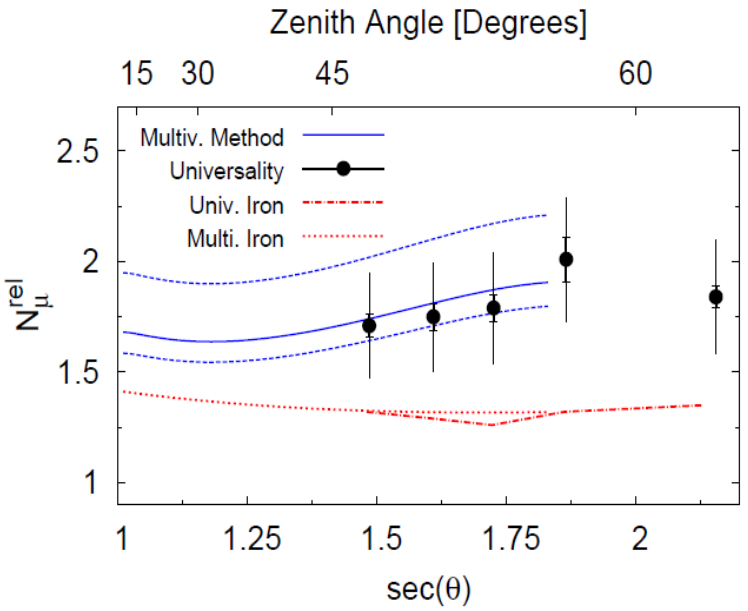


$\langle X_{max} \rangle$ and RMS(X_{max})

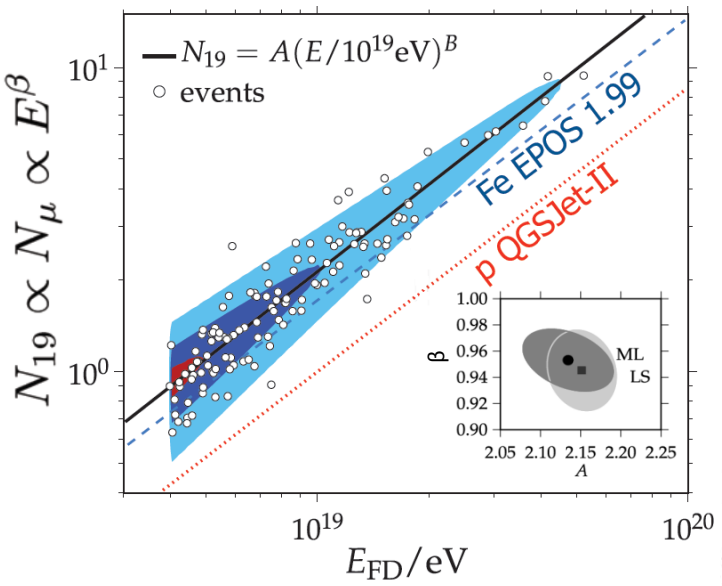


Number of muons at ground

Vertical Showers



Inclined Showers



- Muon deficit in EAS simulations for ALL hadronic interaction models even considering iron primaries
  - Indication of incorrect description of high energy hadronic interactions
- N_μ is also sensitive to composition

EXPLORING POSSIBLE SCENARIOS

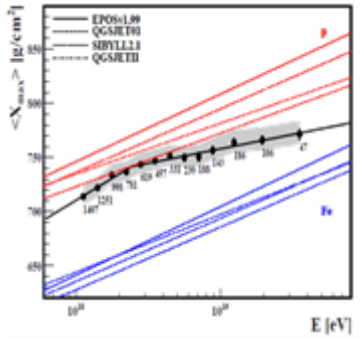
- Mass Composition Scenarios (*bimodal*)
  - Pure Proton to pure Iron
  - Mixed Composition to Iron
- Change on Hadronic interaction physics
  - Cross-section increase

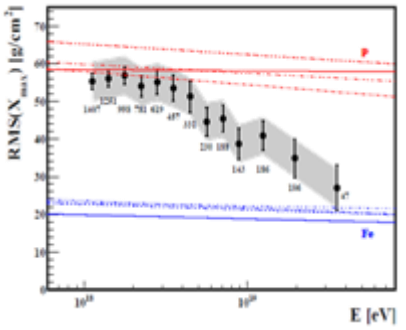
In line with many other works

Here considering only simple and extreme scenarios

EXPLORING POSSIBLE SCENARIOS

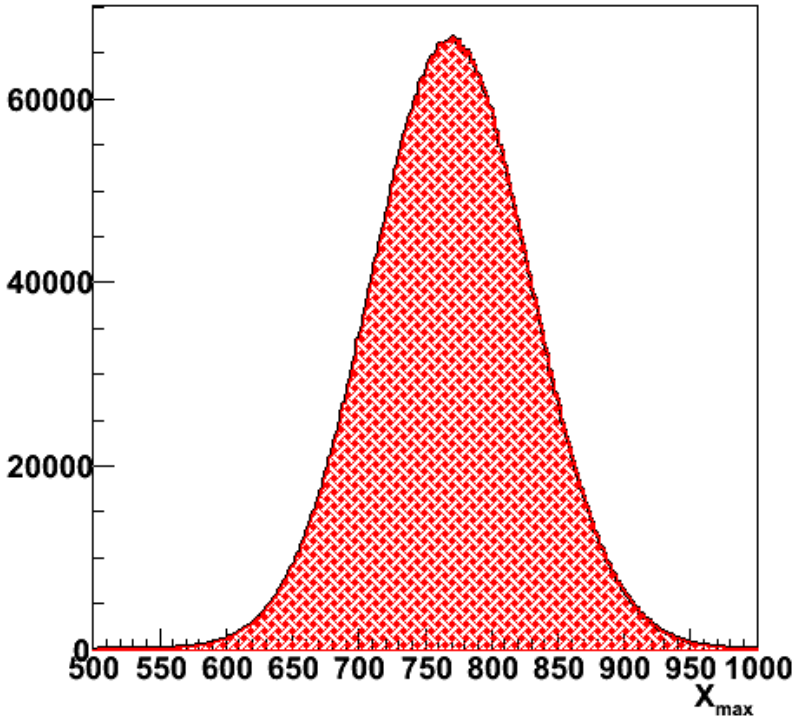
- Mass Composition Scenarios (*bimodal*)
  - Pure Proton to pure Iron
  - Mixed Composition to Iron
- Change on Hadronic interaction physics
  - Cross-section increase

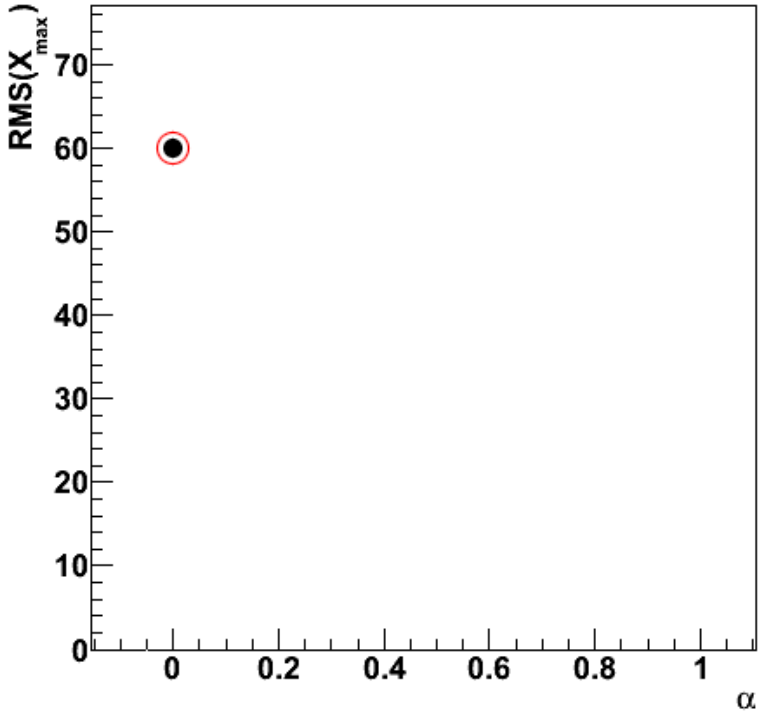




But if just proton and iron...

α : iron fraction ; $(1-\alpha)$: proton fraction





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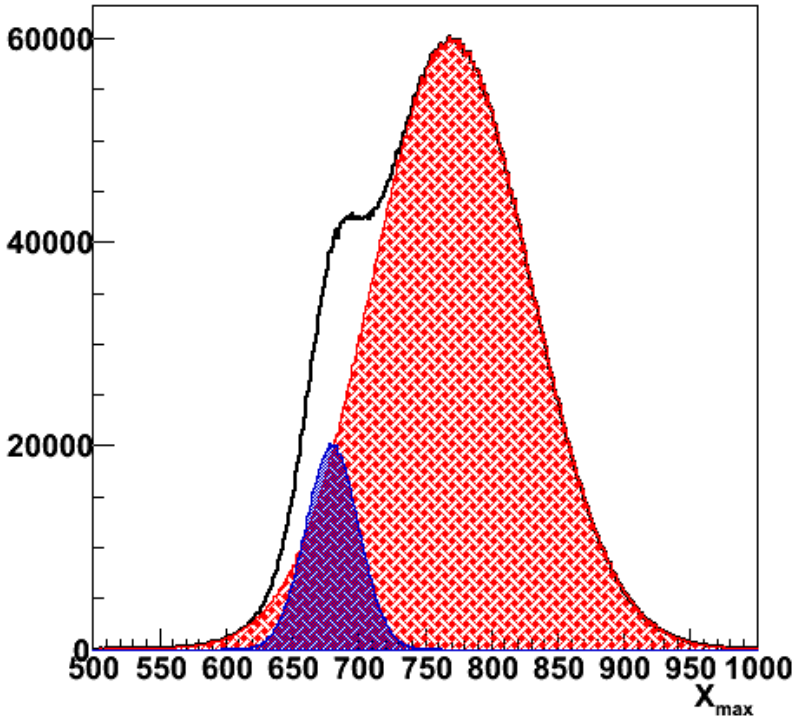

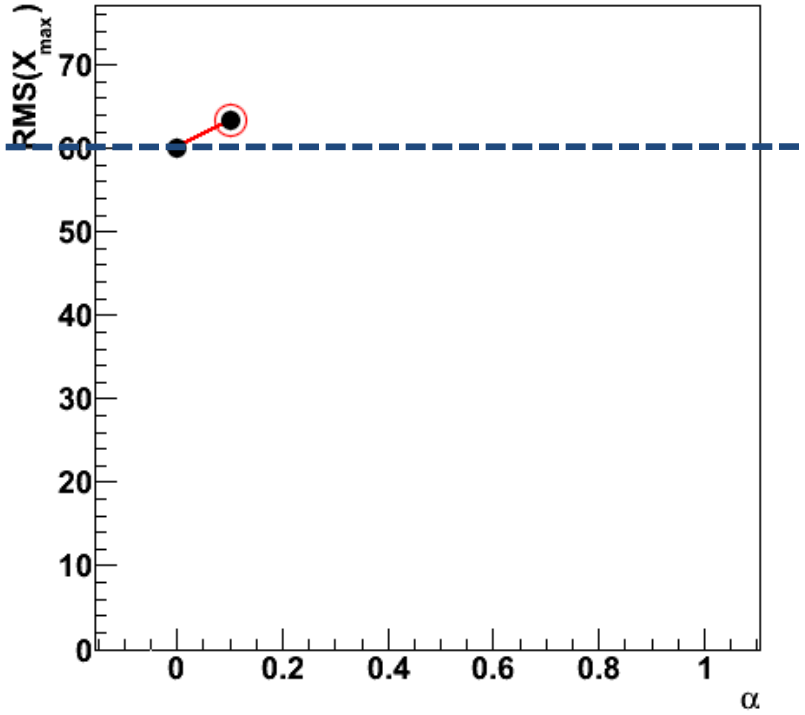

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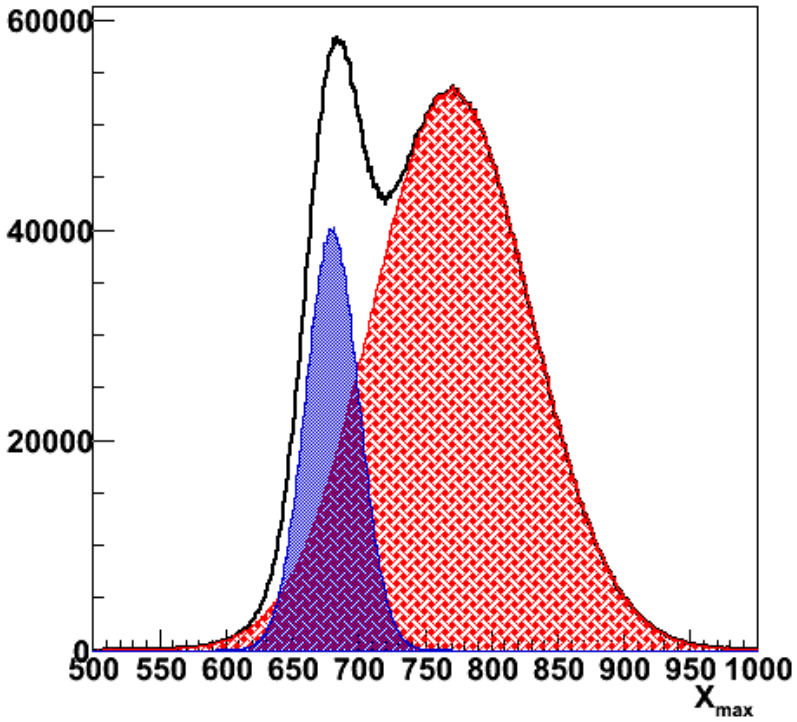

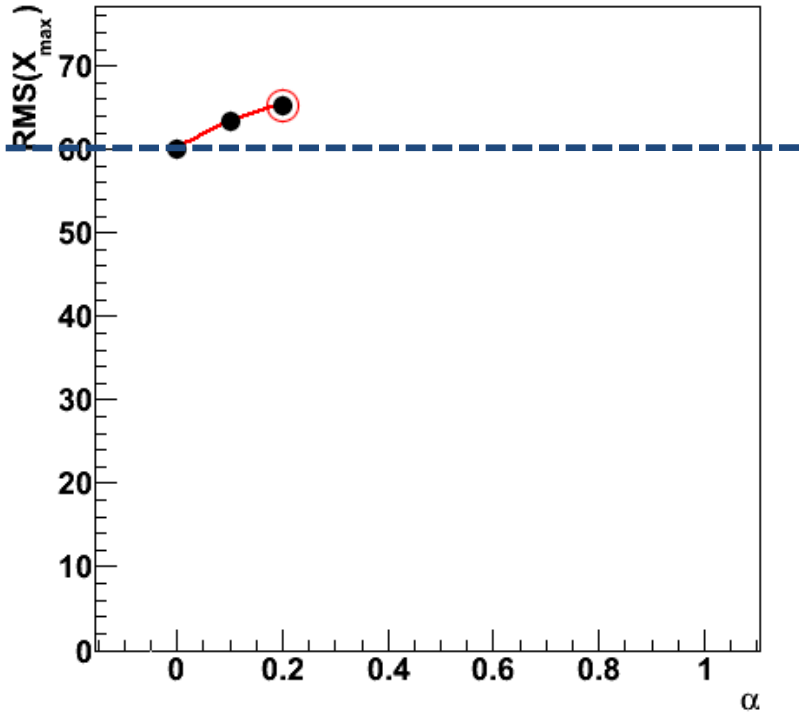

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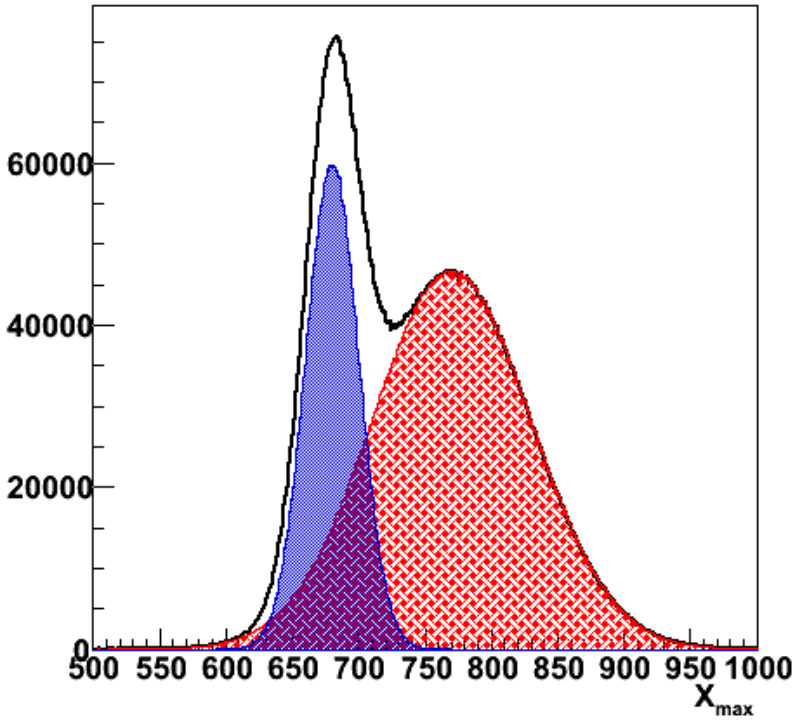

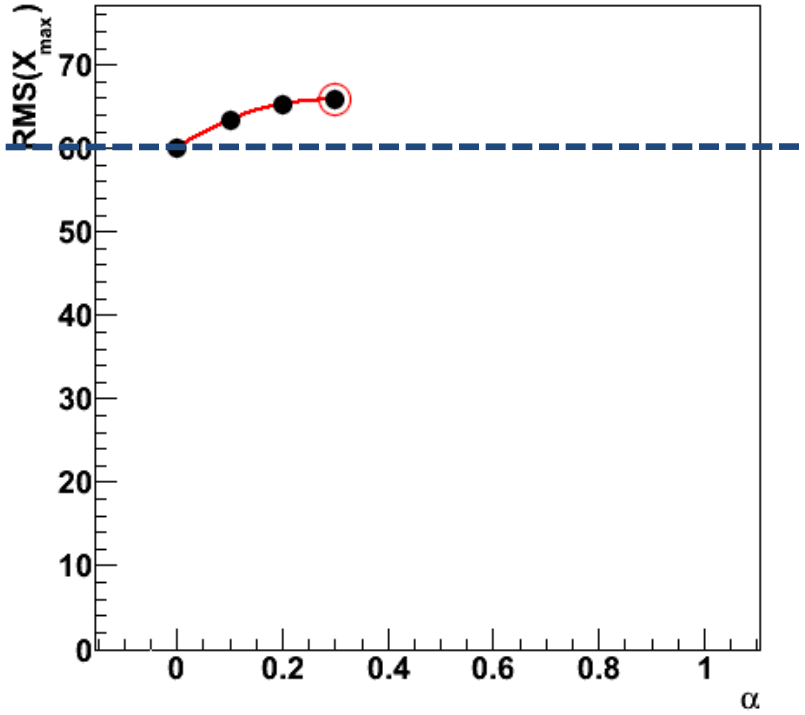

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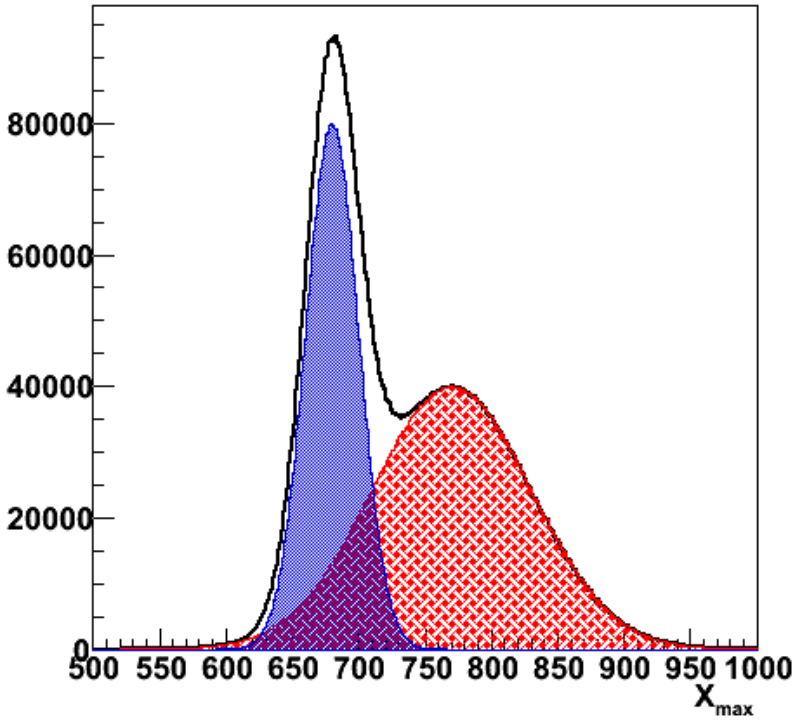

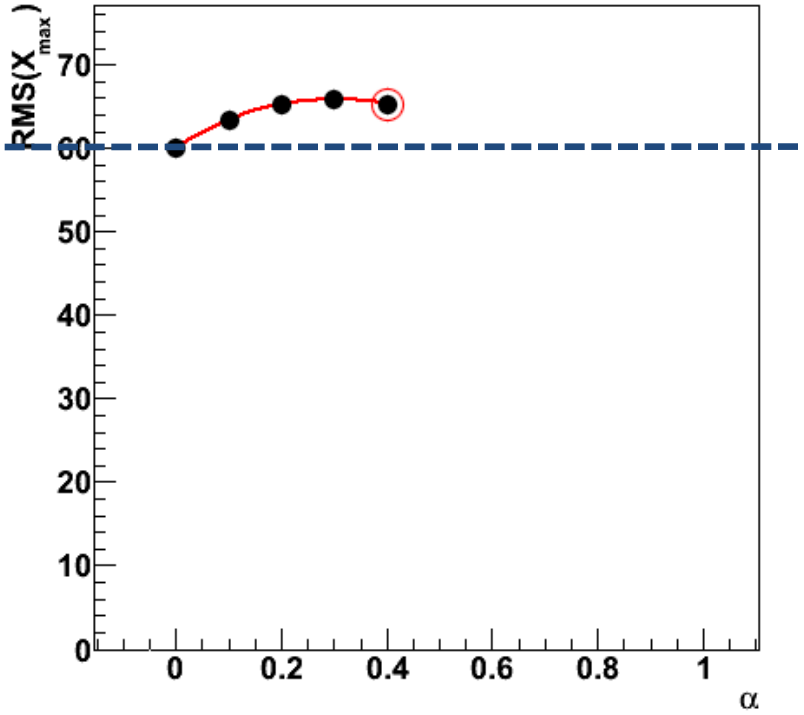

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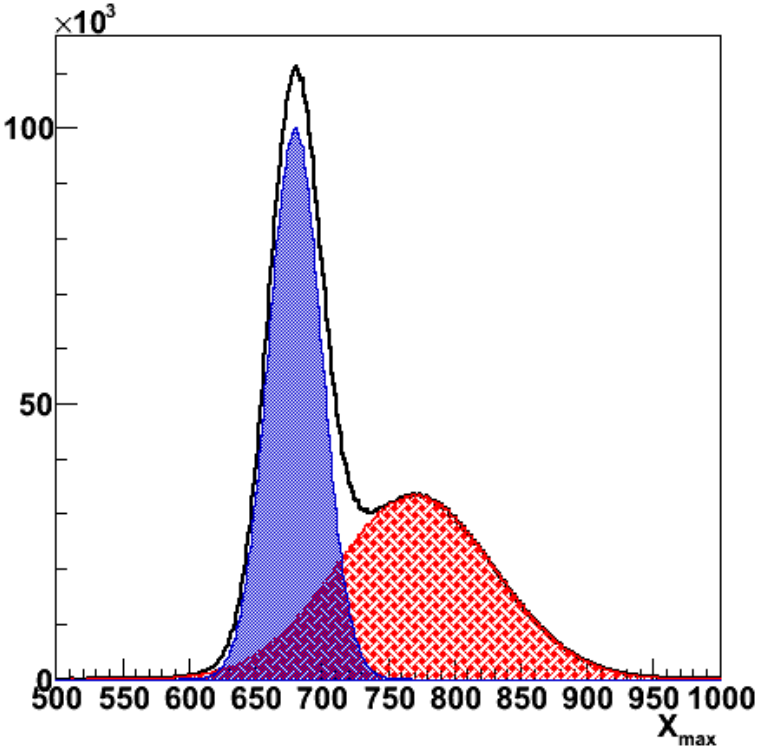

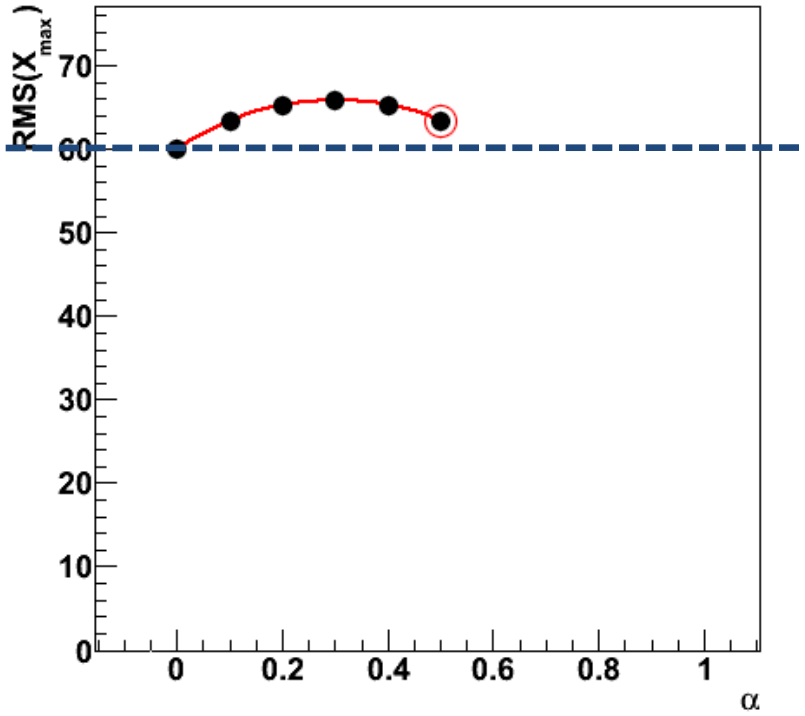

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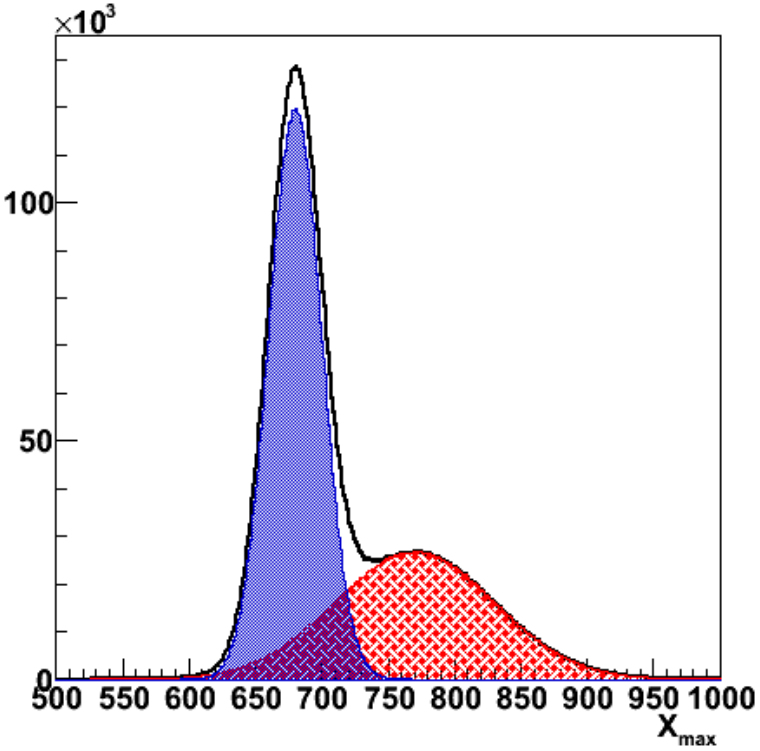

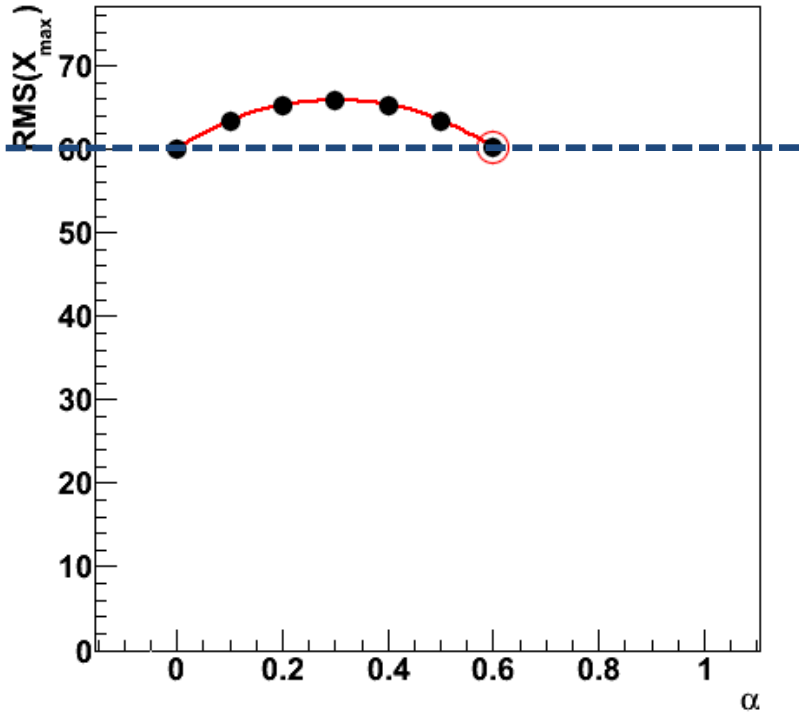

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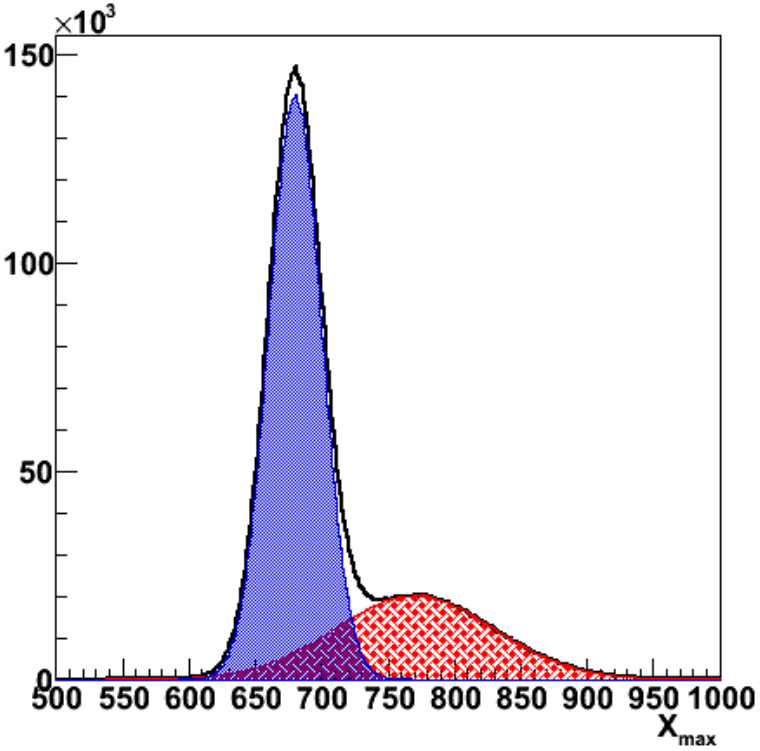

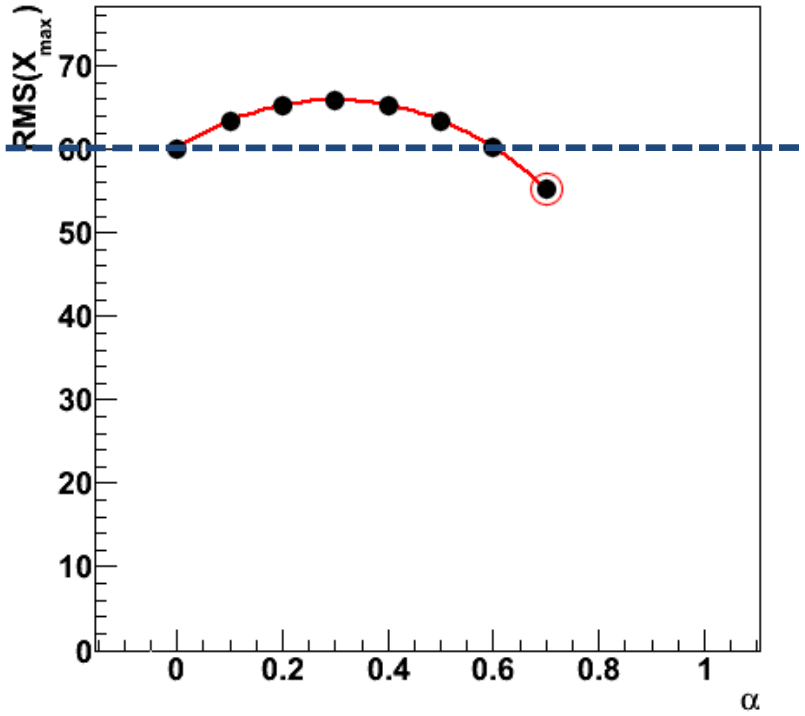

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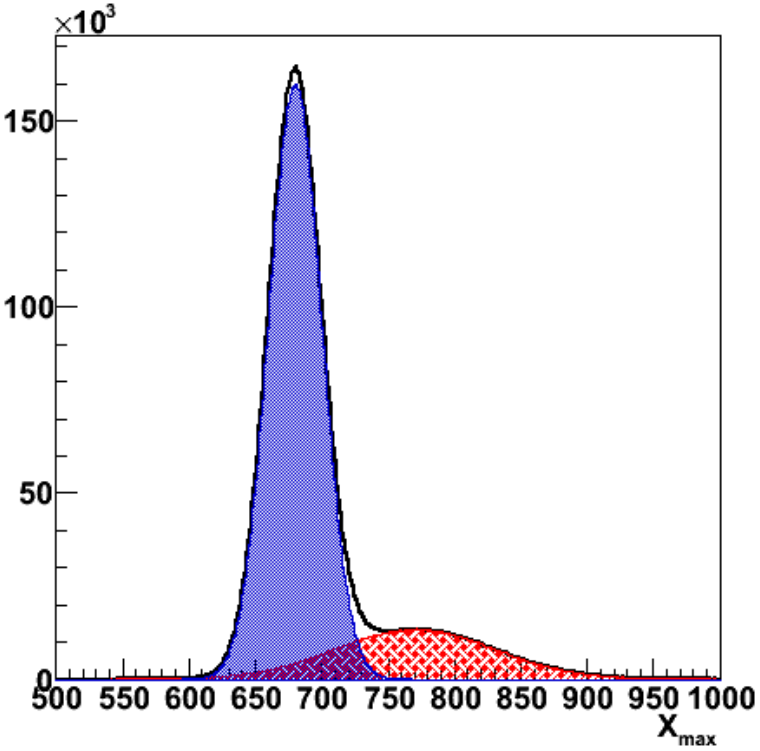

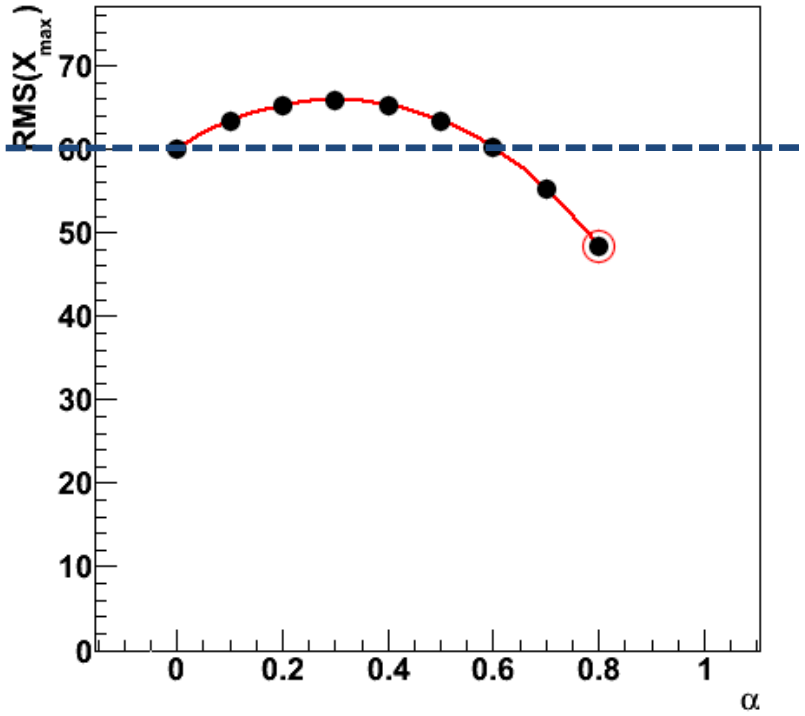

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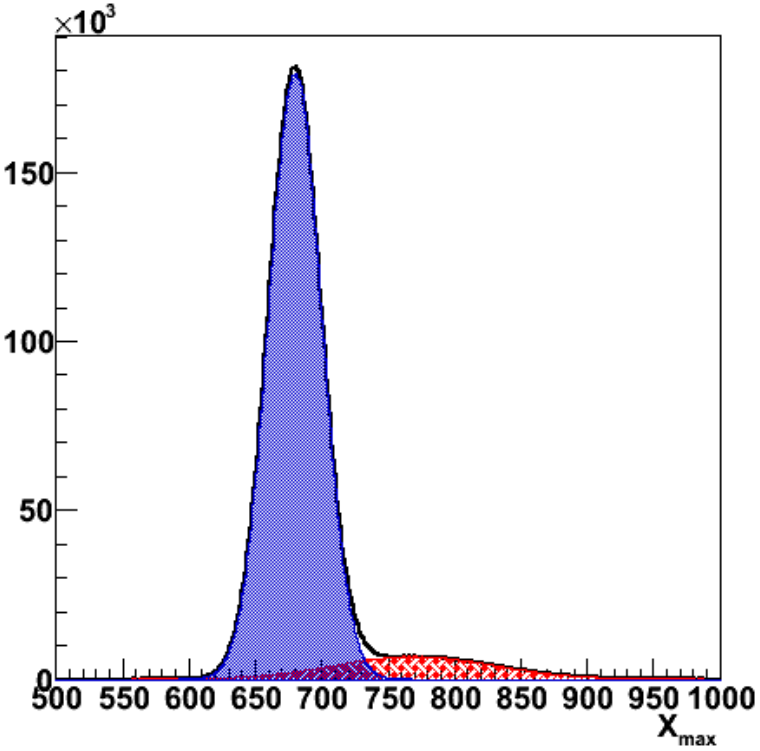

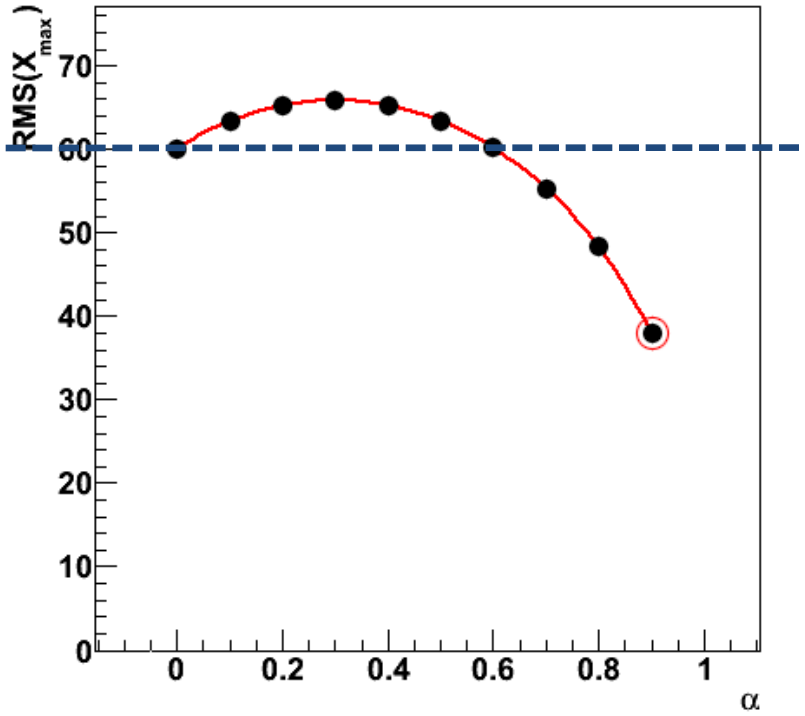

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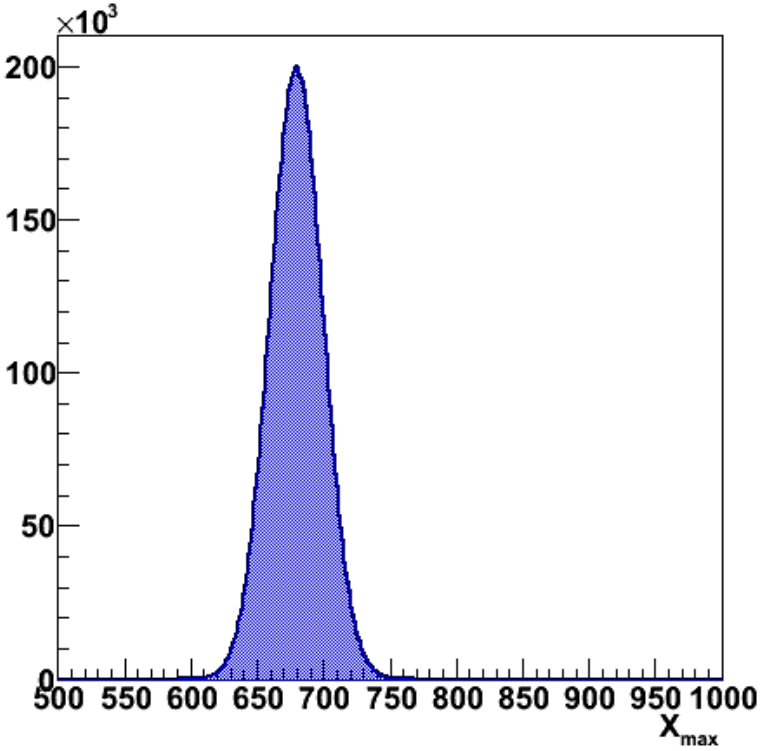
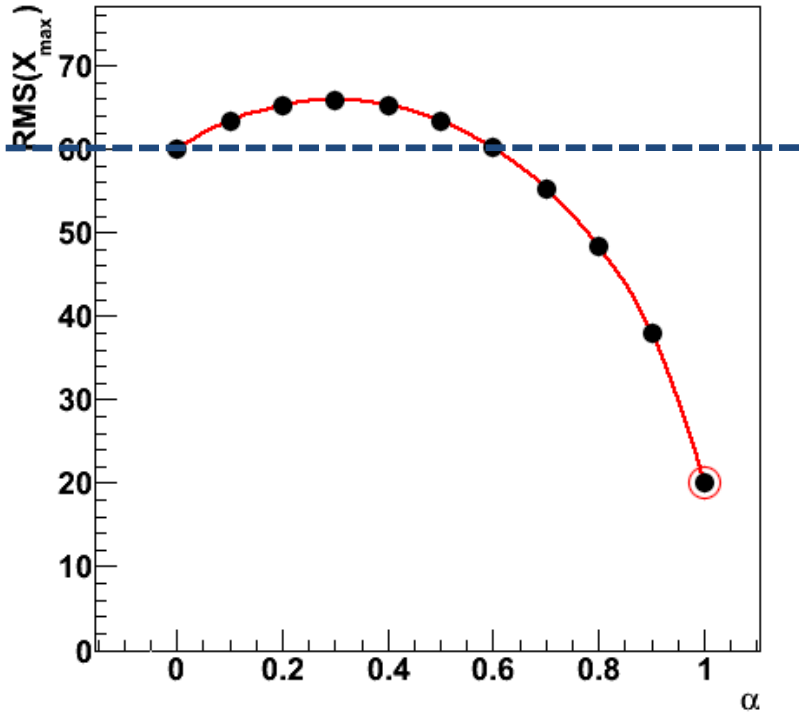


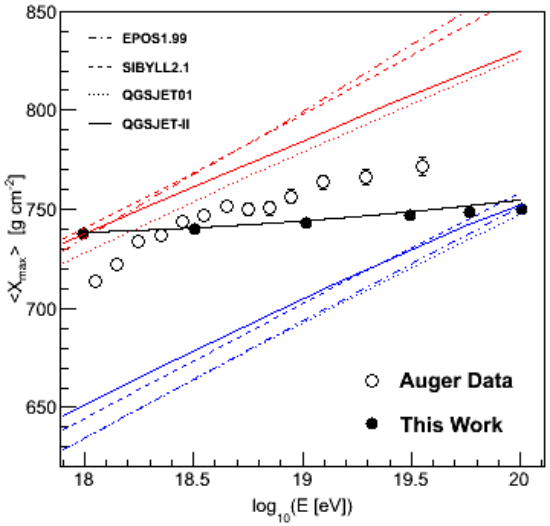


$$RMS^2(X_{max})(\alpha) = (1-\alpha)\,RMS^2(X_{max})_p + \alpha\,RMS^2(X_{max})_{Fe} + \alpha(1-\alpha)\left(\langle X_{max}\rangle_p - \langle X_{max}\rangle_{Fe}\right)^2$$

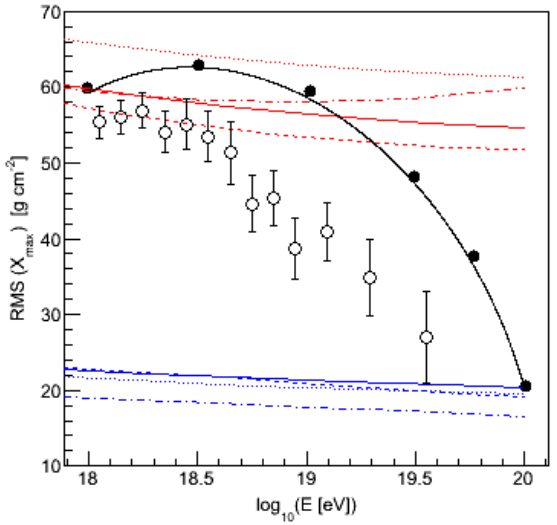
100% p → 100% Fe

X_{max}

Mean



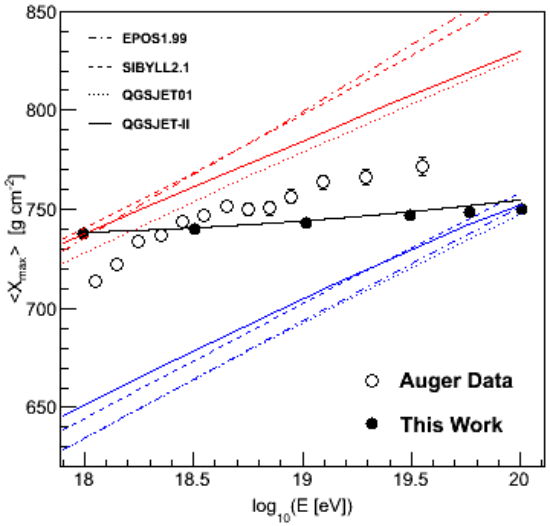
RMS

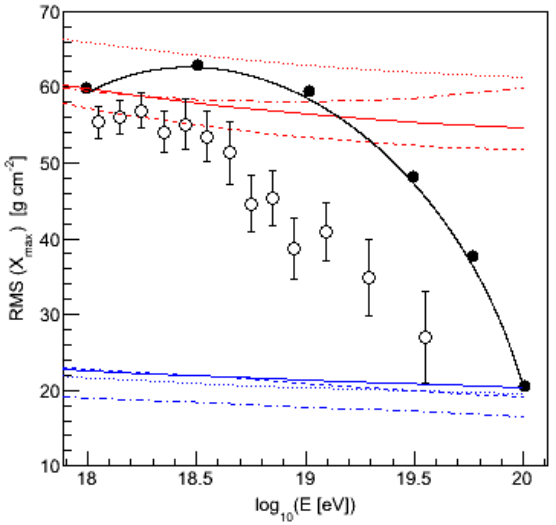


100% p → 100% Fe

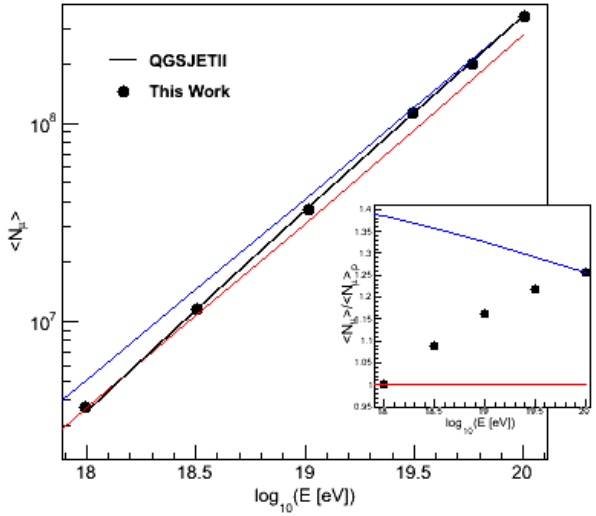
Mean **RMS**

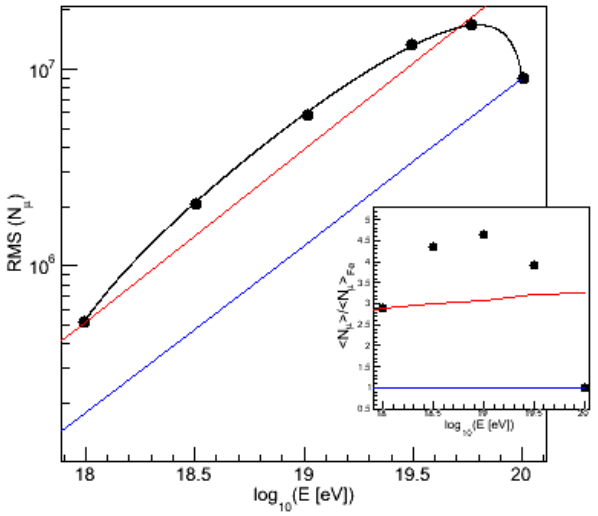
X_{max}





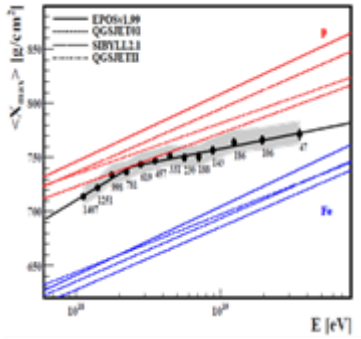
N_μ

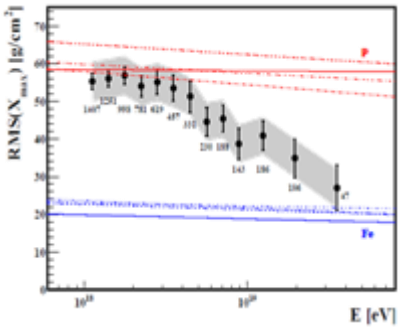




EXPLORING POSSIBLE SCENARIOS

- Mass Composition Scenarios (*bimodal*)
  - Pure Proton to pure Iron
  - Mixed Composition to Iron
- Change on Hadronic interaction physics
  - Cross-section increase

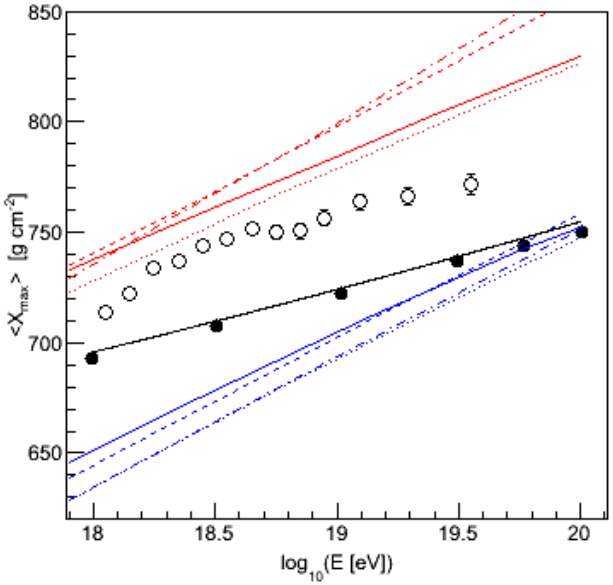




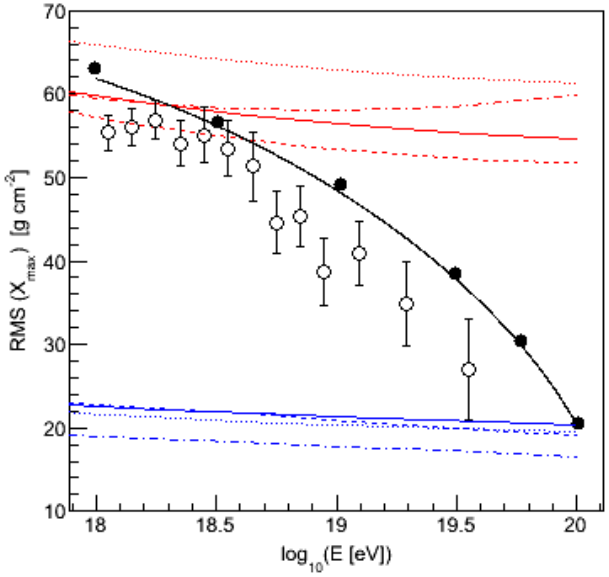
50% Fe → 100% Fe

X_{max}

Mean



RMS

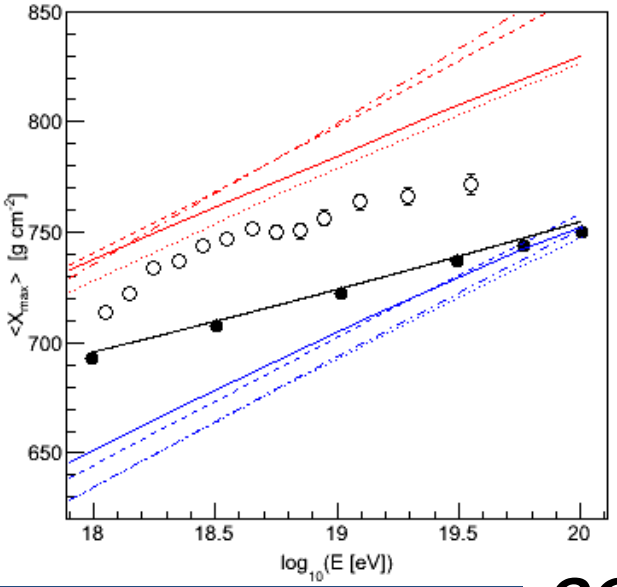


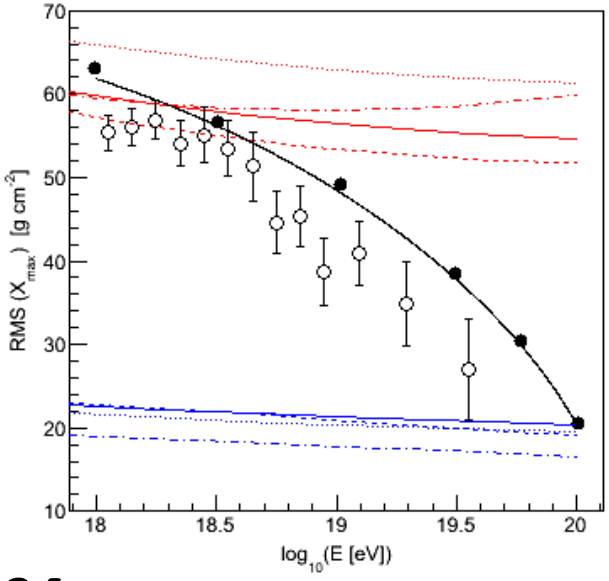
50% Fe → 100% Fe

Mean

RMS

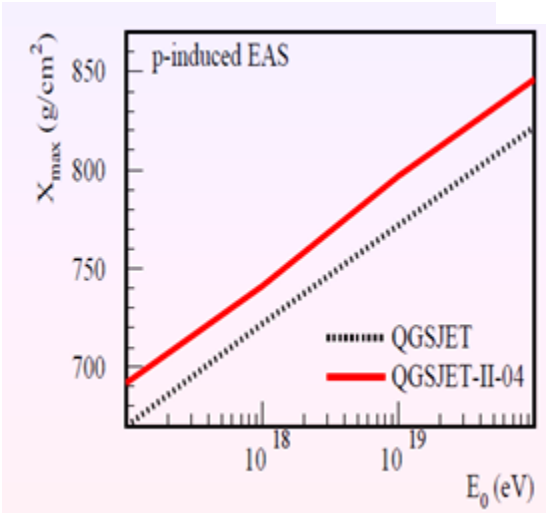
X_{max}

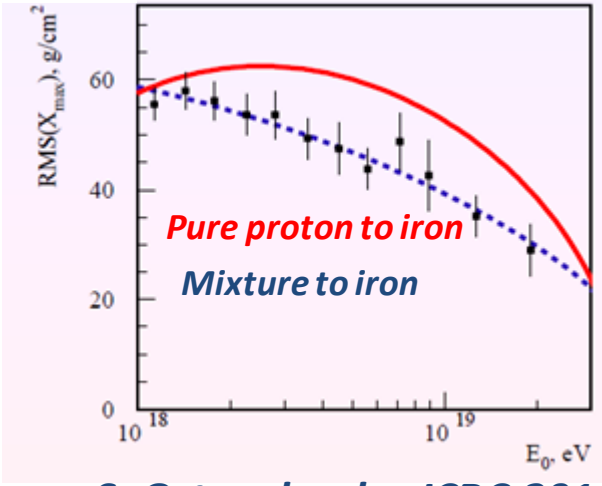




QGSJet-II.04

X_{max}



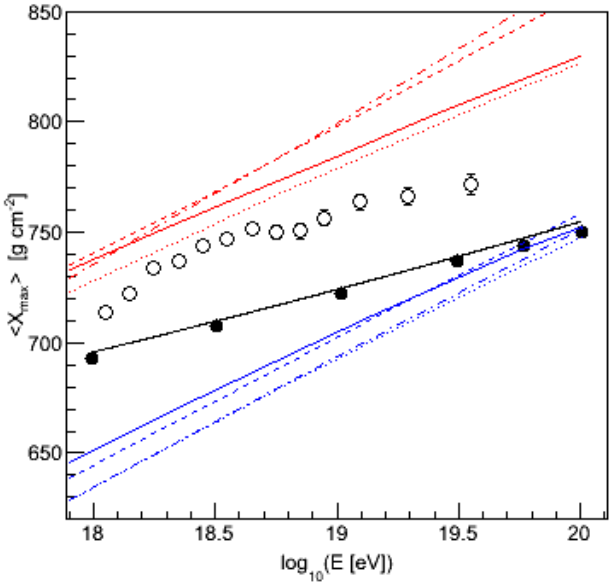


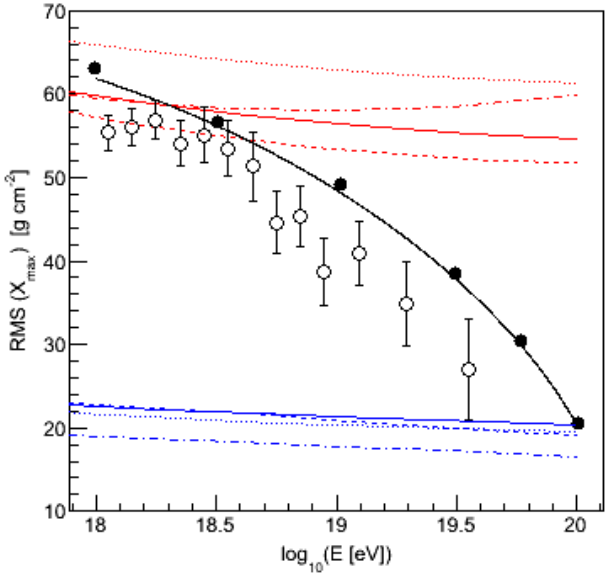
S. Ostapchenko, ICRC 2011

50% Fe → 100% Fe

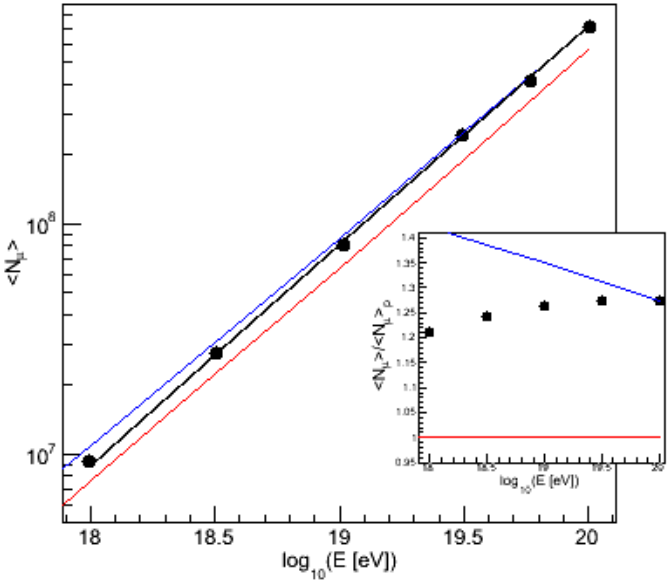
Mean | **RMS**

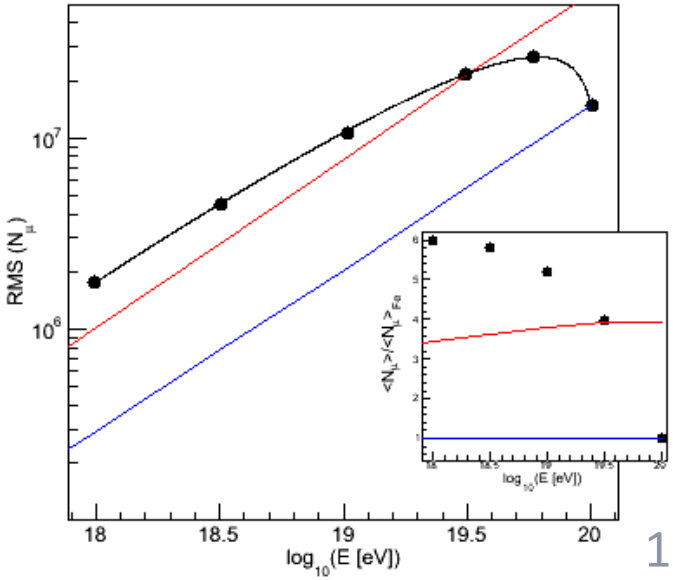
X_{max}





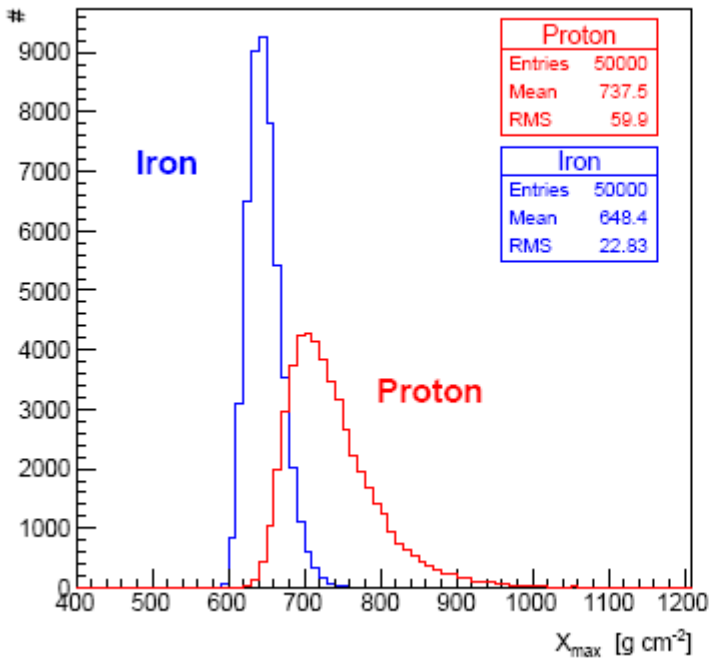
N_μ



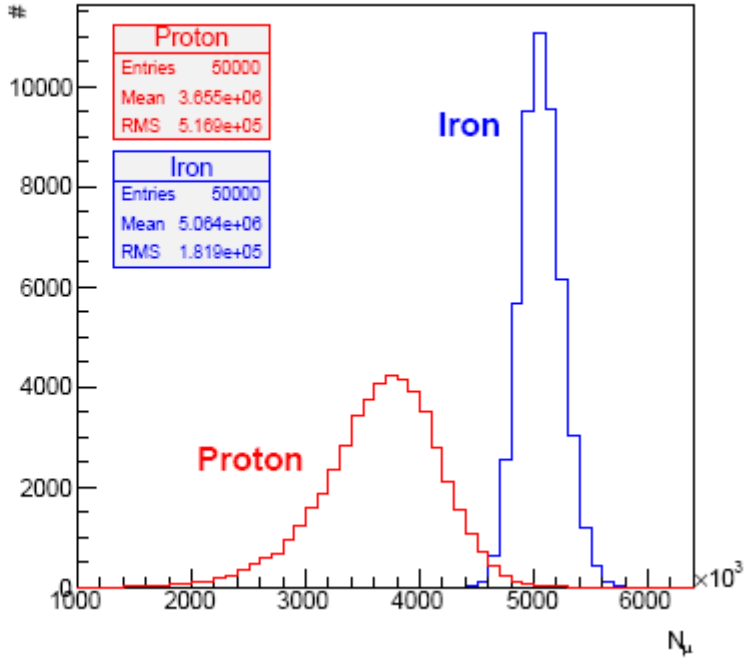


50% Fe at E = 10^{18} eV

X_{max}



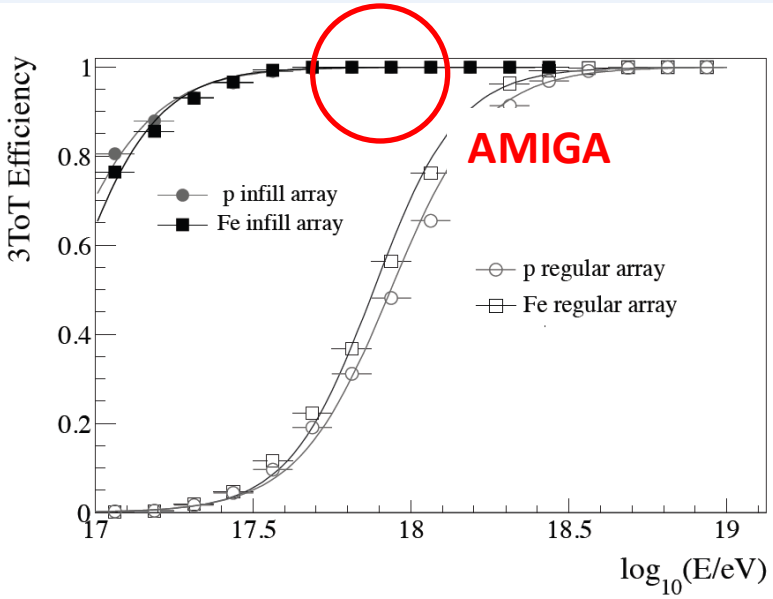
N_μ

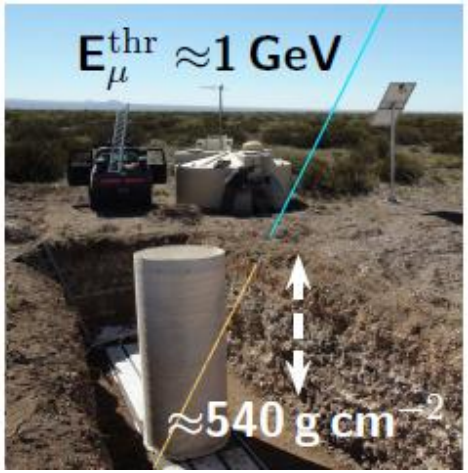


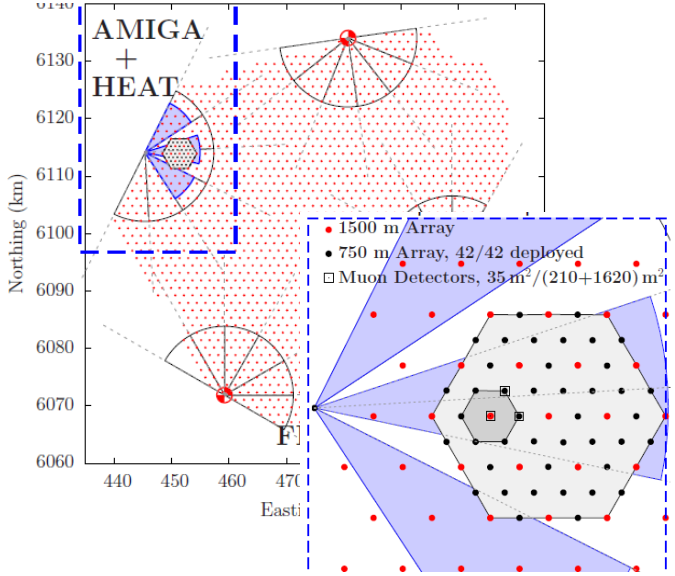
N_μ has a clear separated maxima even for 30% resolution in a event-by-event basis

“Calibration point”

- Use AMIGA to measure N_μ distribution
  - $E = 10^{18}$ eV

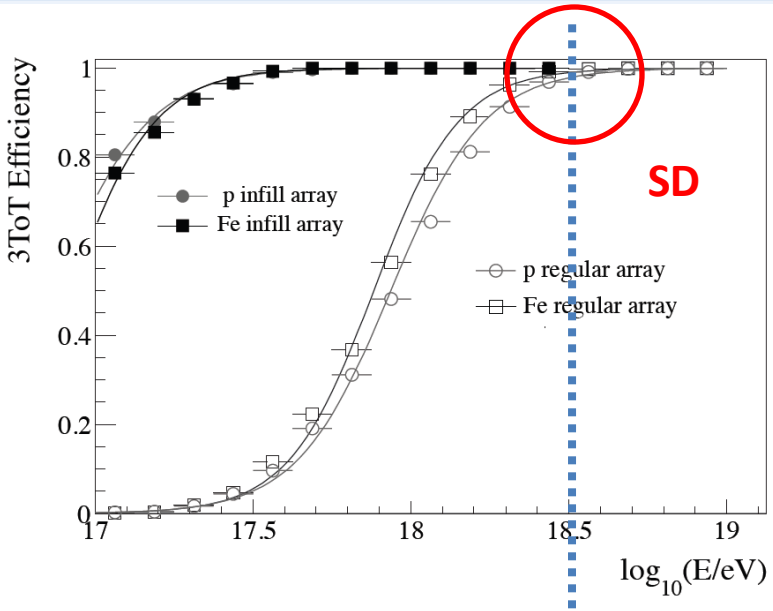


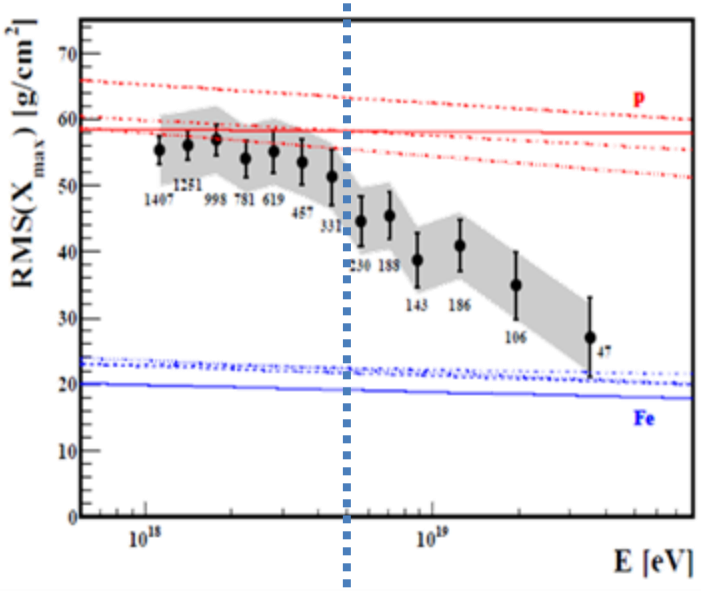




“Calibration point”

- Use AMIGA to measure N_μ distribution
  - $E = 10^{18}$ eV
- Use Surface Detector
  - Inclined events?
  - Before the transition
  - Compromise between efficience and statistics

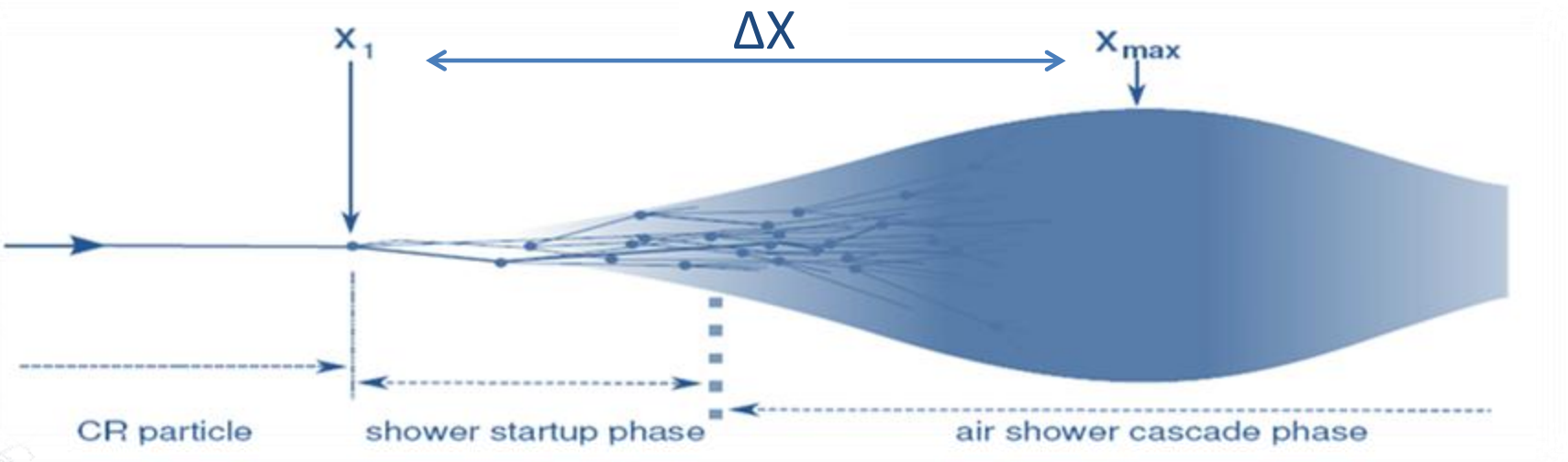




EXPLORING POSSIBLE SCENARIOS

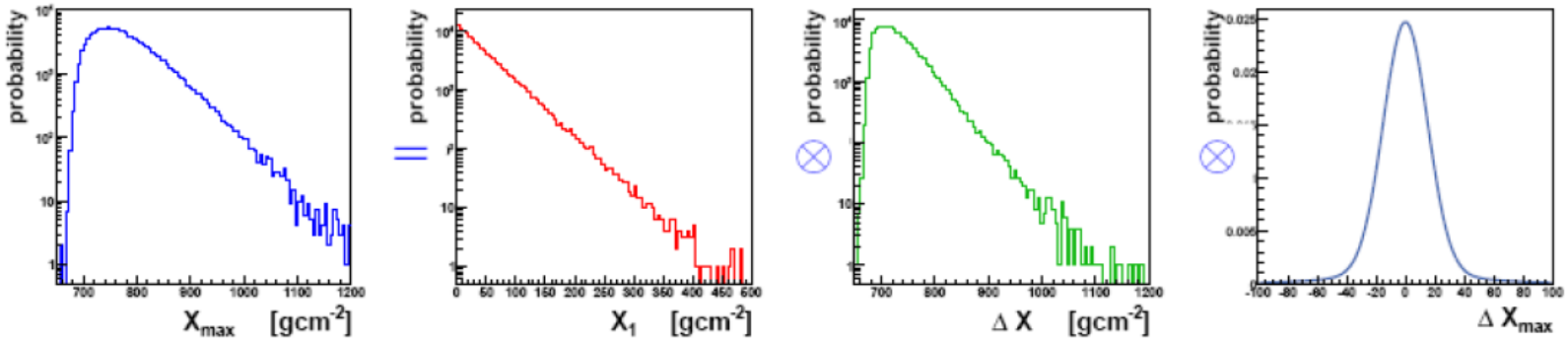
- Mass Composition Evolution (*bimodal*)
  - Pure Proton to pure Iron
  - Mixed Composition to Iron
- Change on Hadronic interaction physics
  - Cross-section increase

X_{max} distributions



$$\langle X_{max} \rangle = \langle X_1 \rangle + \langle \Delta X \rangle$$
$$RMS^2(X_{max}) = RMS^2(X_1) + RMS^2(\Delta X)$$

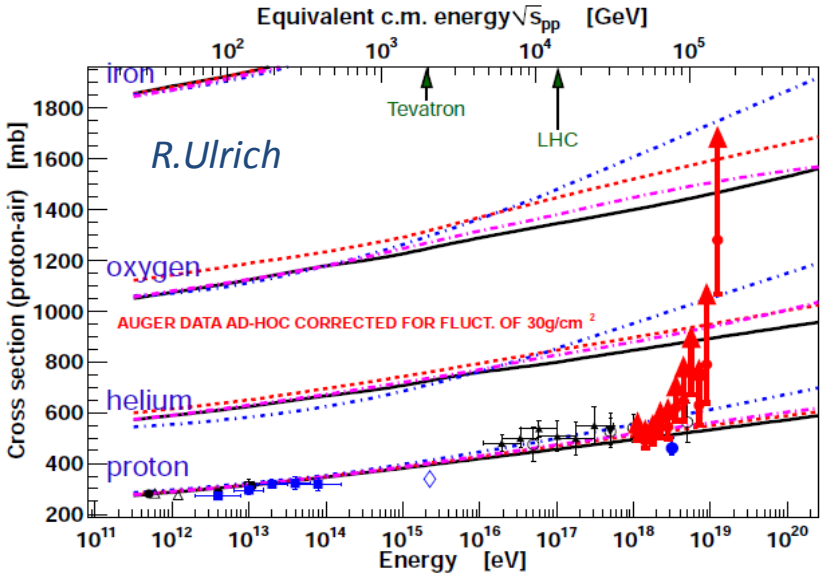
R. Ulrich

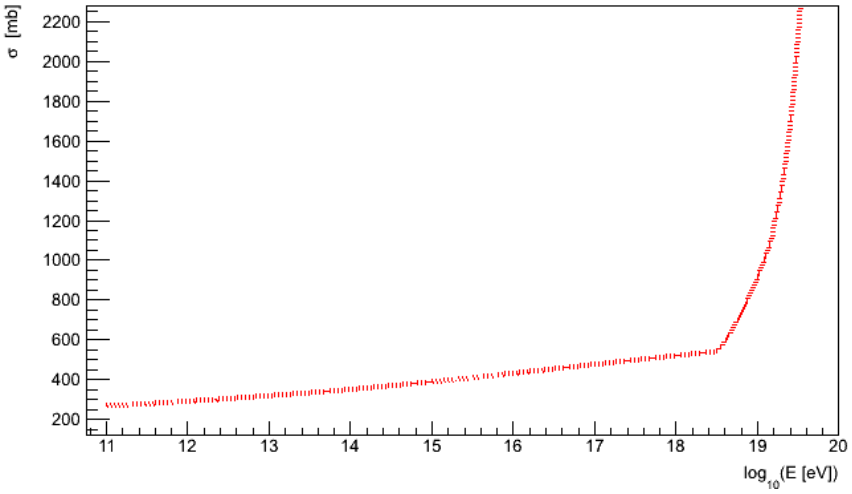


If just proton...

- Interpretation of the RMS(X_{max}) in terms of cross-section

- A dramatic increase in the proton-Air cross-section around

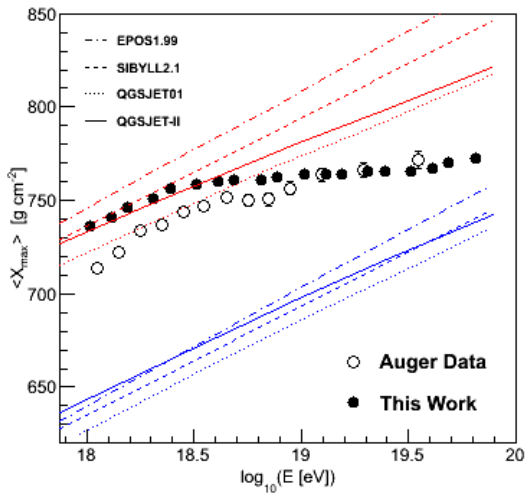


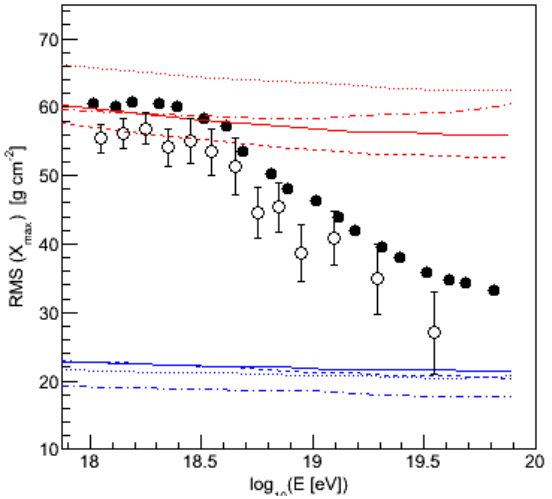


100% proton – Increase σ

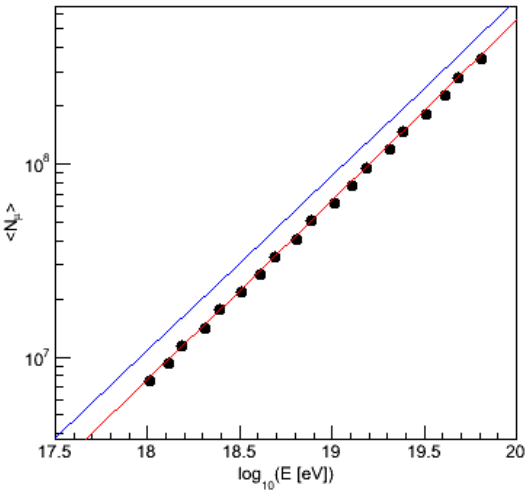
Mean ***RMS***

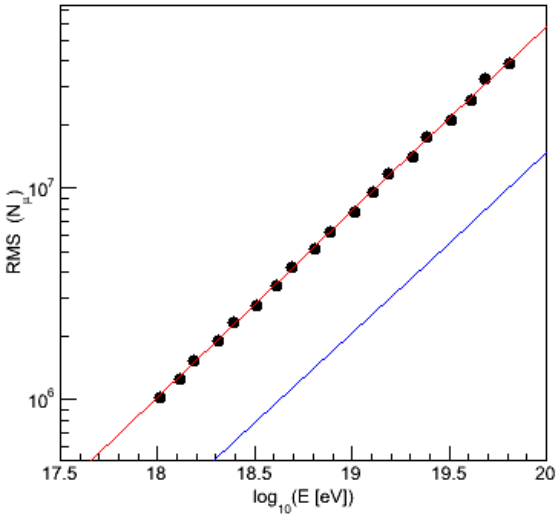
X_{max}



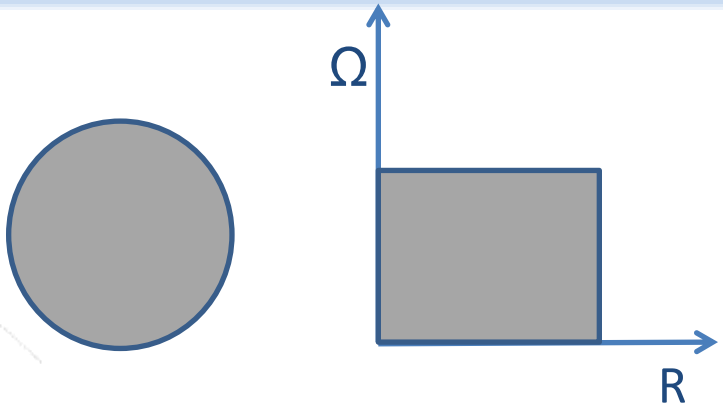


N_μ





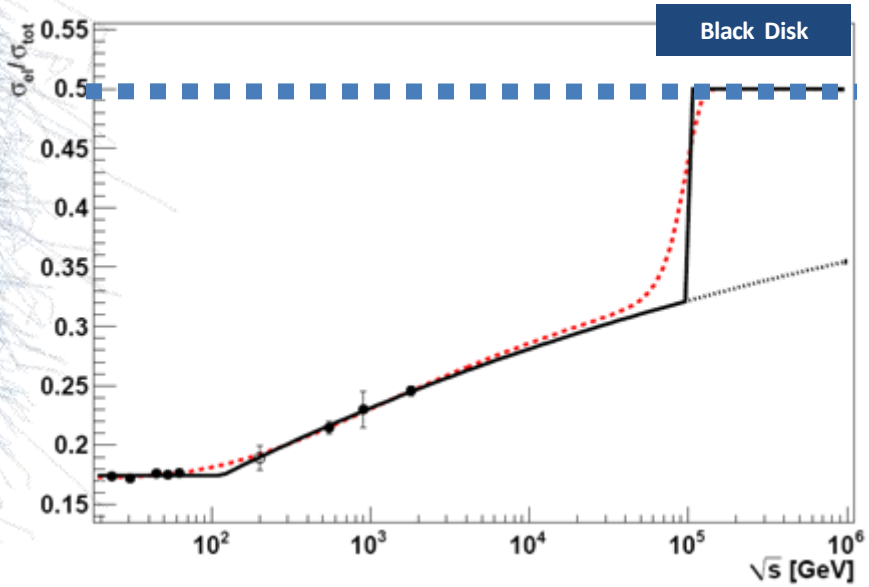
Grey disk model

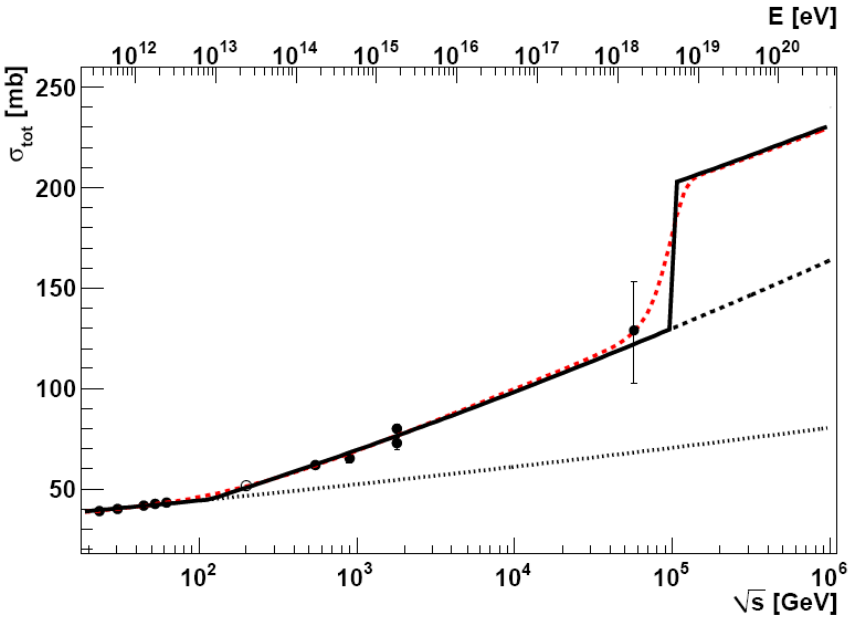


R. Conceição, J. Dias de Deus, M. Pimenta,
arXiv:1107.0912 [hep-ph]

A fast transition to the black disk at √s ~ 100 TeV can accommodate about 80% increase in the total cross-section without violating the Froissart bound

$$\frac{\sigma_{el}(s)}{\sigma_{tot}(s)} = \frac{1}{2}\left(1 - e^{-\overline{\Omega}(s)}\right)$$





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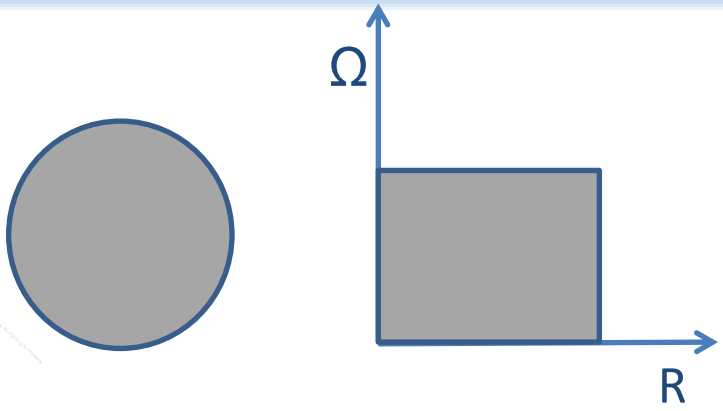

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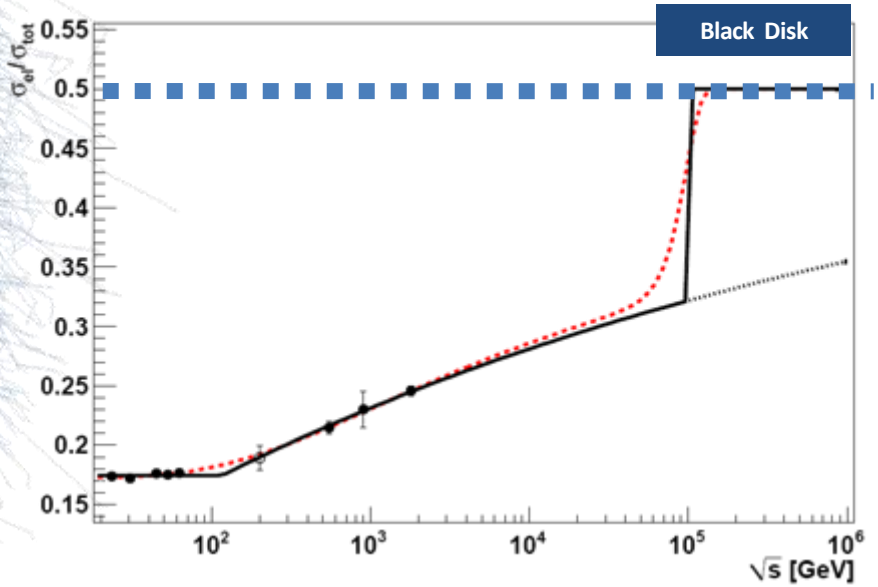
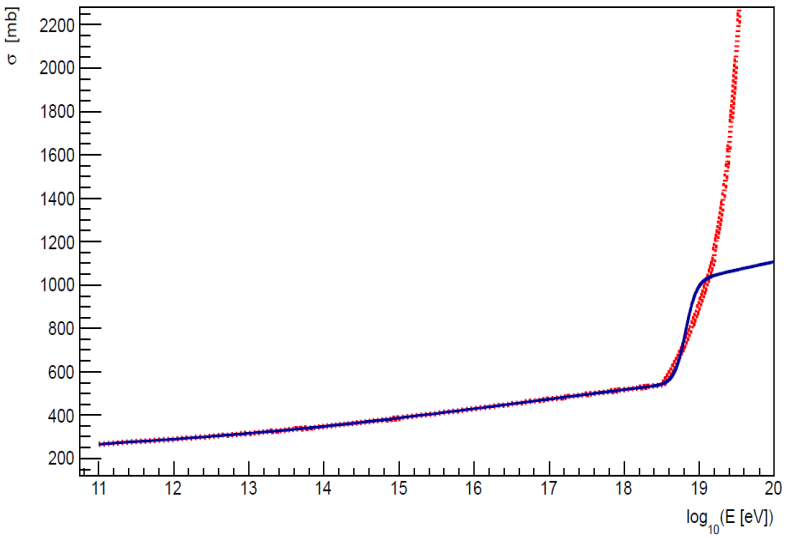
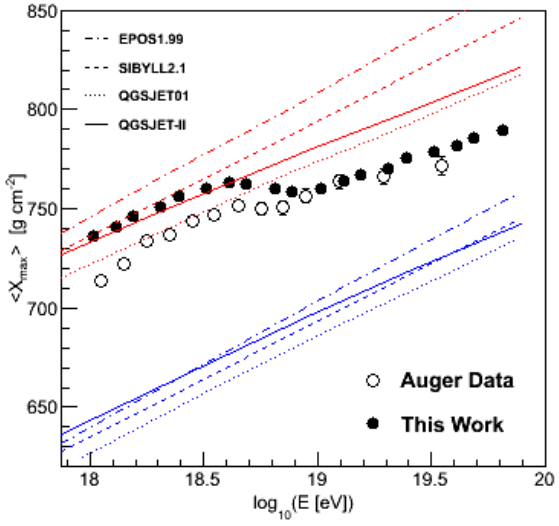


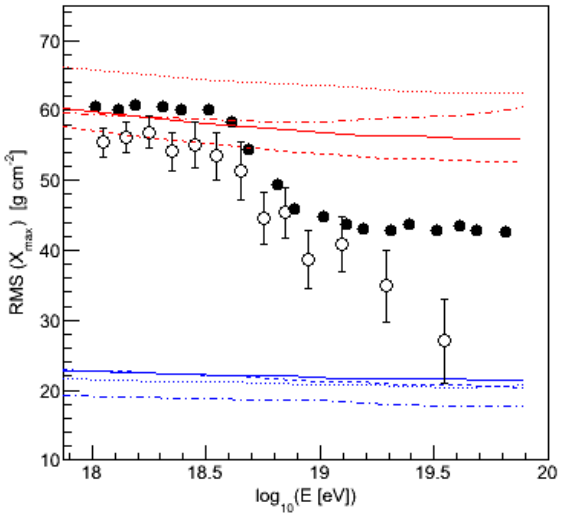


100% proton – Increase σ

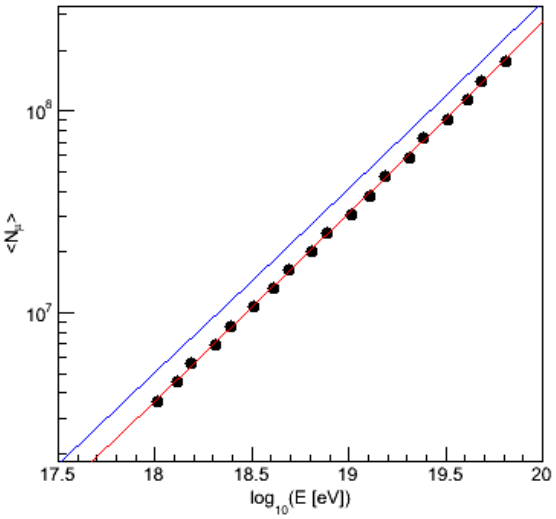
Mean **RMS**

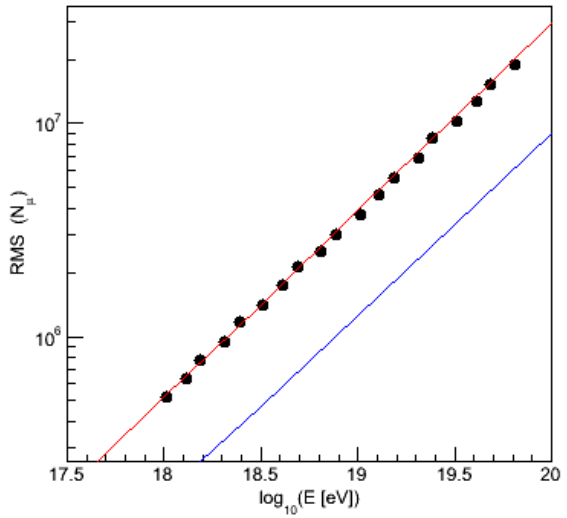
X_{max}



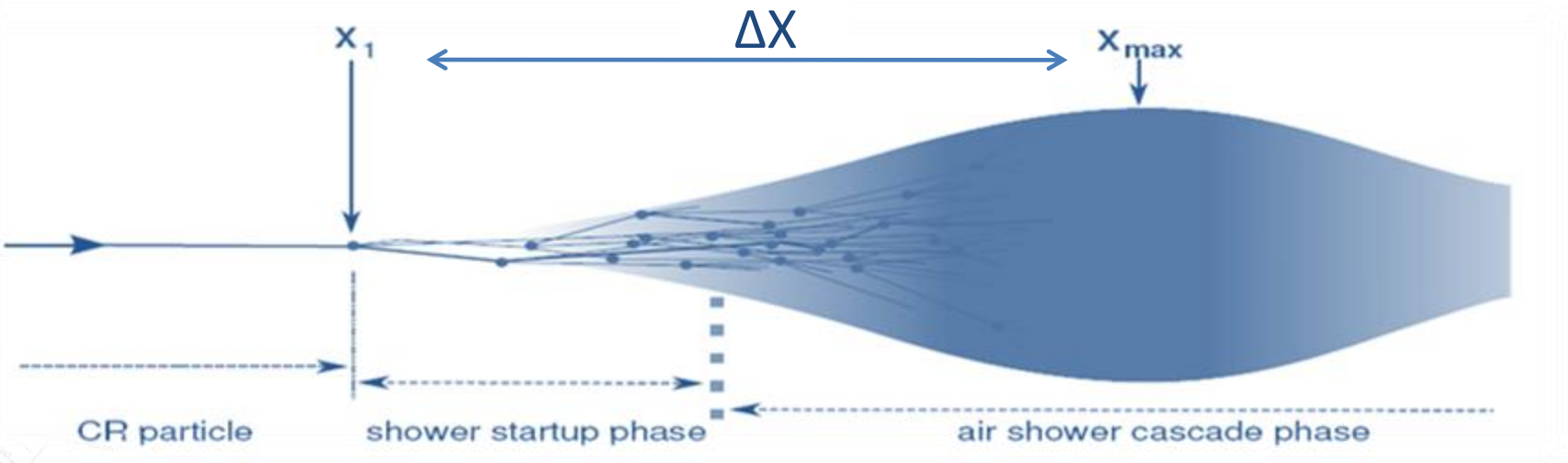


N_μ



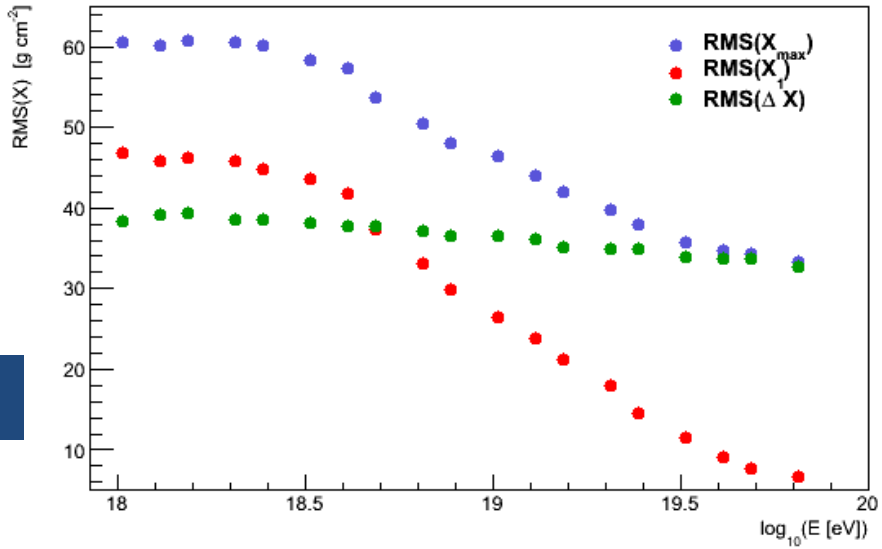


Sensitivity to the increase of σ

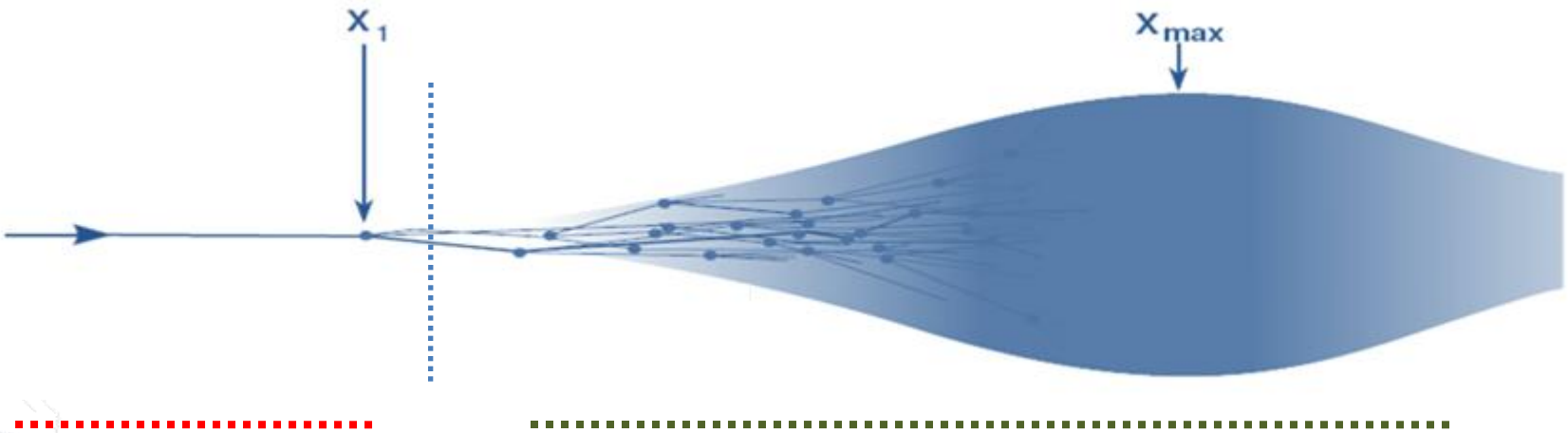


- Above ~ $10^{19.4}$ eV there is no sensivity to σ

$$RMS^2(X_{max}) = RMS^2(X_1) + RMS^2(\Delta X)$$



Impact of new physics



- New physics would also change particle production
  - Inelasticity, multiplicity
- This would affect <ΔX> but mainly its fluctuations
  - Average number of muons should also change less than its fluctuations (RMS)

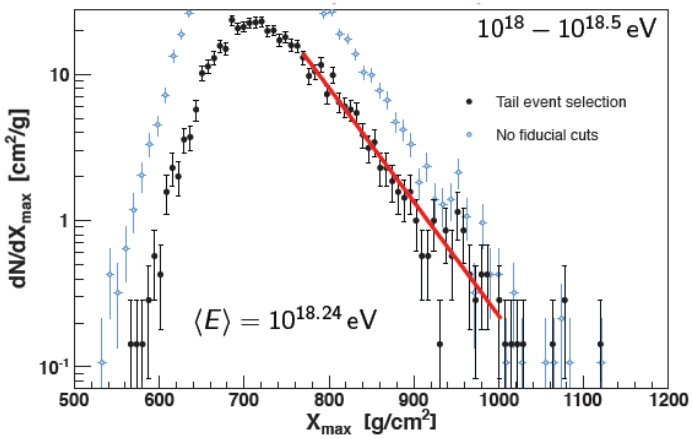
$$RMS^2(X_{max}) = RMS^2(X_1) + RMS^2(\Delta X)$$

Summary

- Mass compositions and Hadronic interaction must be analyzed together
  - Multi-variable analyzes needed (X_{max}, N_μ)
- Mass Composition simple scenarios
  - A pure proton → pure iron model does not explain simultaneously the $<X_{max}>$ and RMS(X_{max}) data
  - 50% proton → pure iron is a possibility
    - Can be identified by looking to the N_μ distribution at lower energies (E = 1 EeV)
  - Intermediate masses is also a possibility
    - Astrophysical input can help to constrain
- Hadronic interactions
  - Have to be changed in any case
  - With 100% proton a cross-section change can explain Xmax evolution
    - Can be identified by checking N_μ evolution with energy (both average and RMS)

BACKUP SLIDES

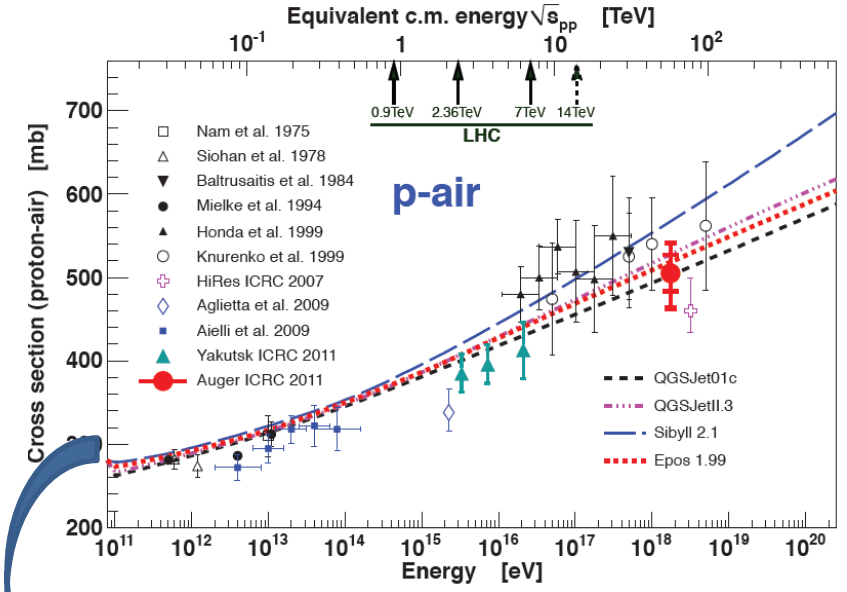
Proton-proton cross-section

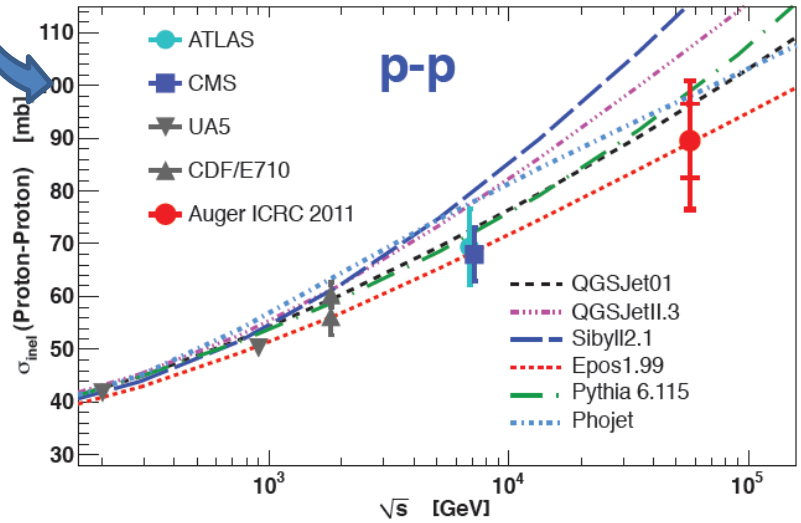


If % p > 20%, % He < 25%

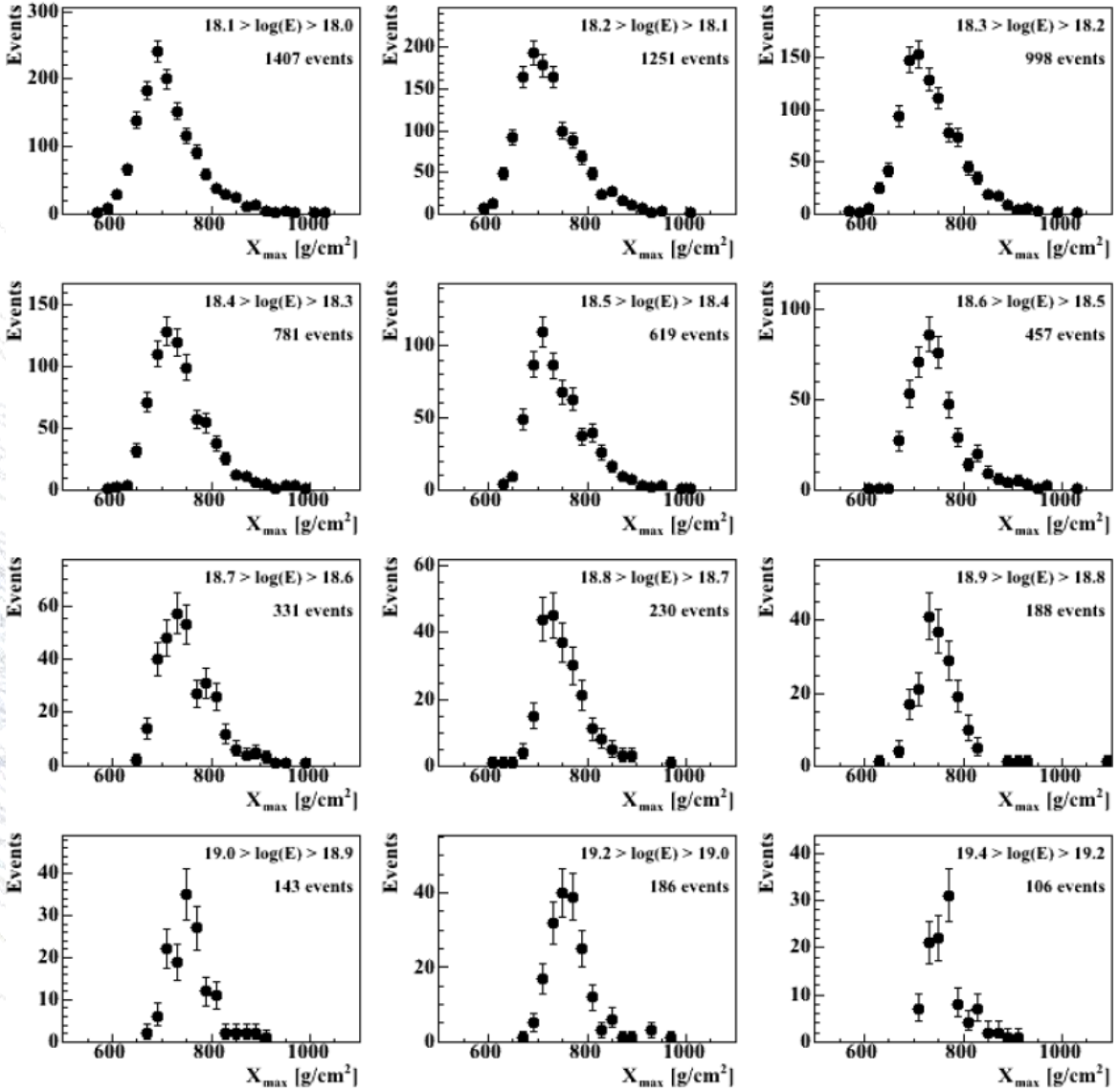
- *Slightly lower than expected by most of the models but in good agreement with recent LHC data*

Glauber

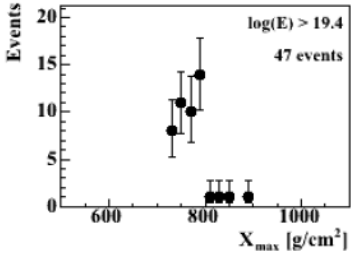




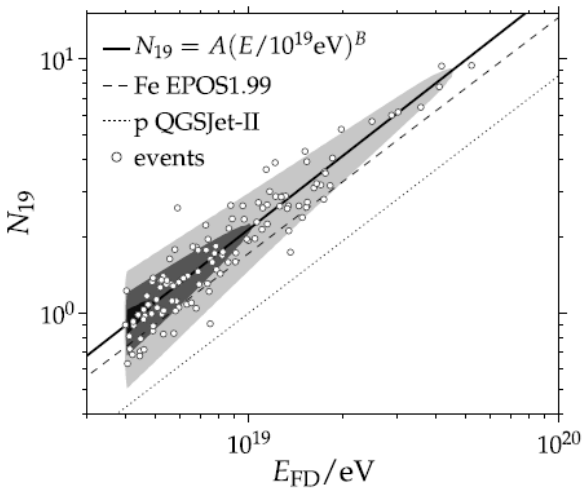
X_{max} distributions

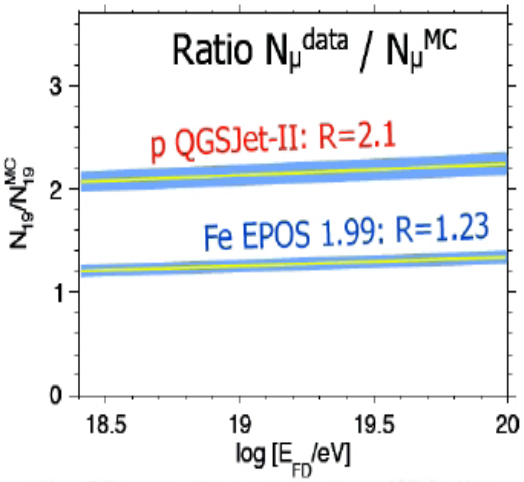


- New analysis with different approaches confirm the results on X_{max}
  - Anti-bias cut
  - MC efficiencies
- As the energy increases the distributions become narrower



Number of muons (Inclined)



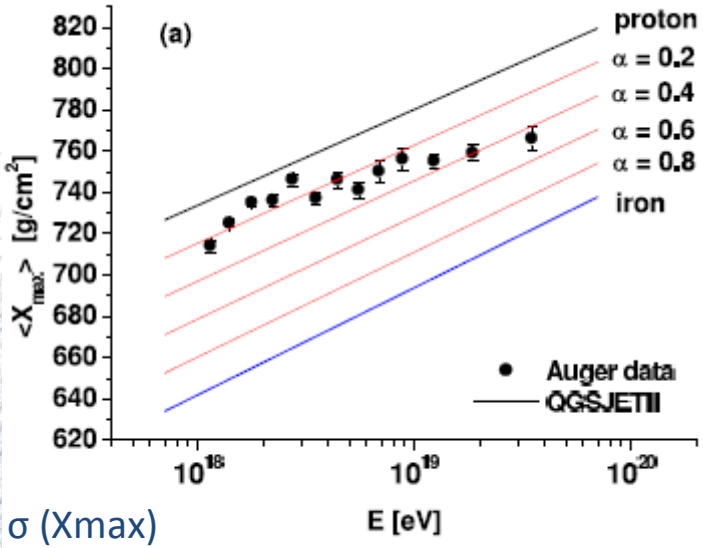


- Results presented at the ICRC 2011, Beijing
- $N_\mu \sim E^{0.95}$
- Data analysis reveals a muon deficit in the simulations
  - Even for iron induced showers
  - High energy hadronic interaction models are not able to describe the data
- No visible structure

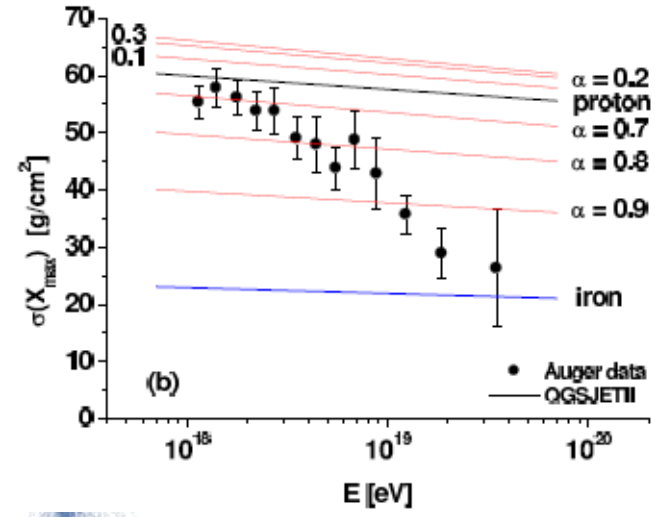
But if just proton and iron…

α : iron ; (1-α): proton

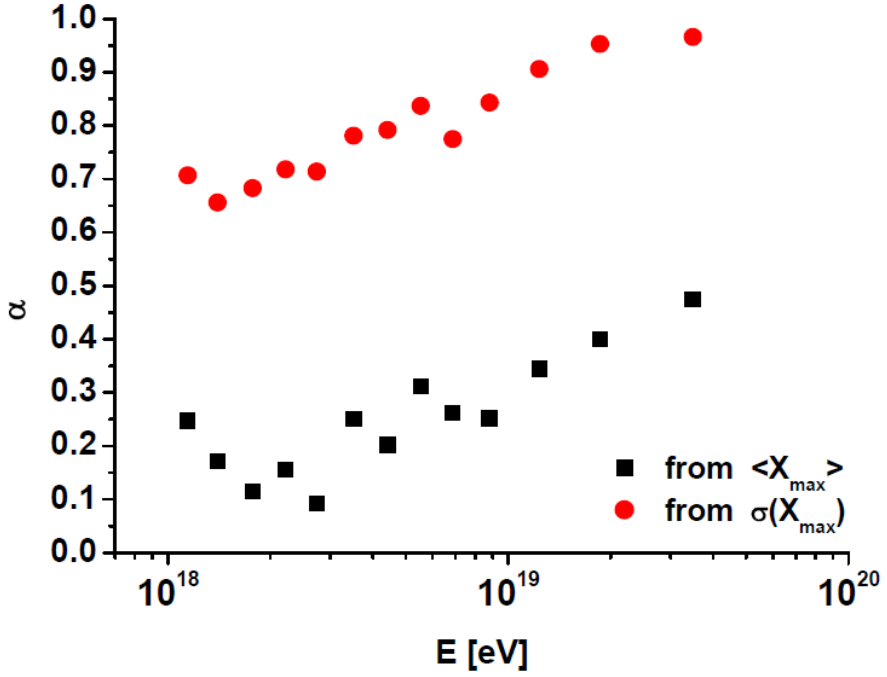
<Xmax>



σ (Xmax)



G. Wilk, Z. Wlodarczyk
(J. Matthews, V. Scherini)



Not possible to have just a two component model !

If just proton...

- Interpretation of the RMS(X_{max}) in terms of cross-section
- A dramatic increase in the proton-proton cross-section around:
  - $\sqrt{s} = 100$ TeV

R.Ulrich