UHECR2014, Oct. 12-15, 2014, Springdale (Utah)

Upgrade of the Pierre Auger Observatory

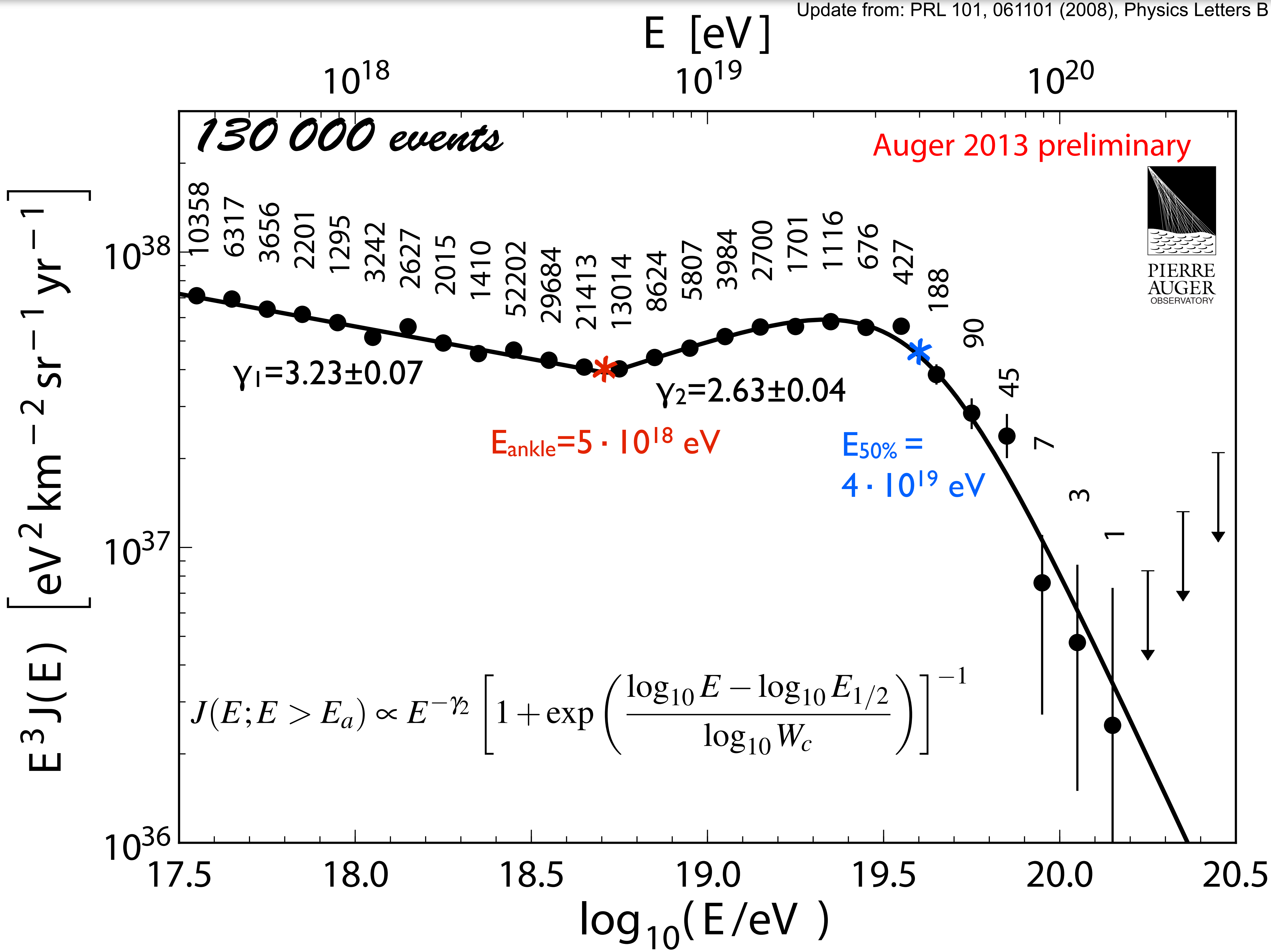
Karl-Heinz Kampert
for the Pierre Auger Collaboration

- Why doing an upgrade ?
- Technical Realisation and Expected Performance
- Timeline & Costs

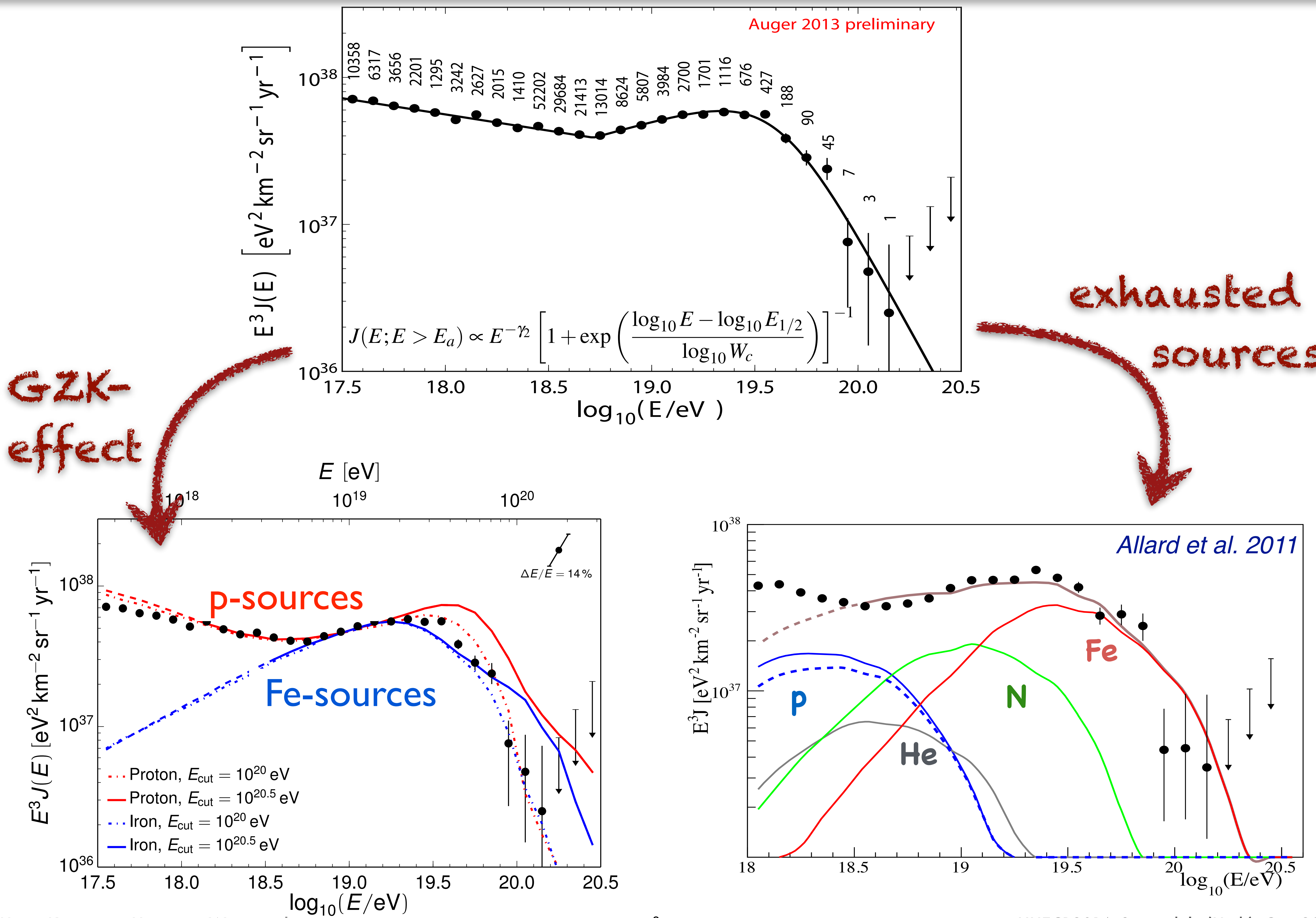
BERGISCHE
UNIVERSITÄT
WUPPERTAL

Observation of Flux Suppression

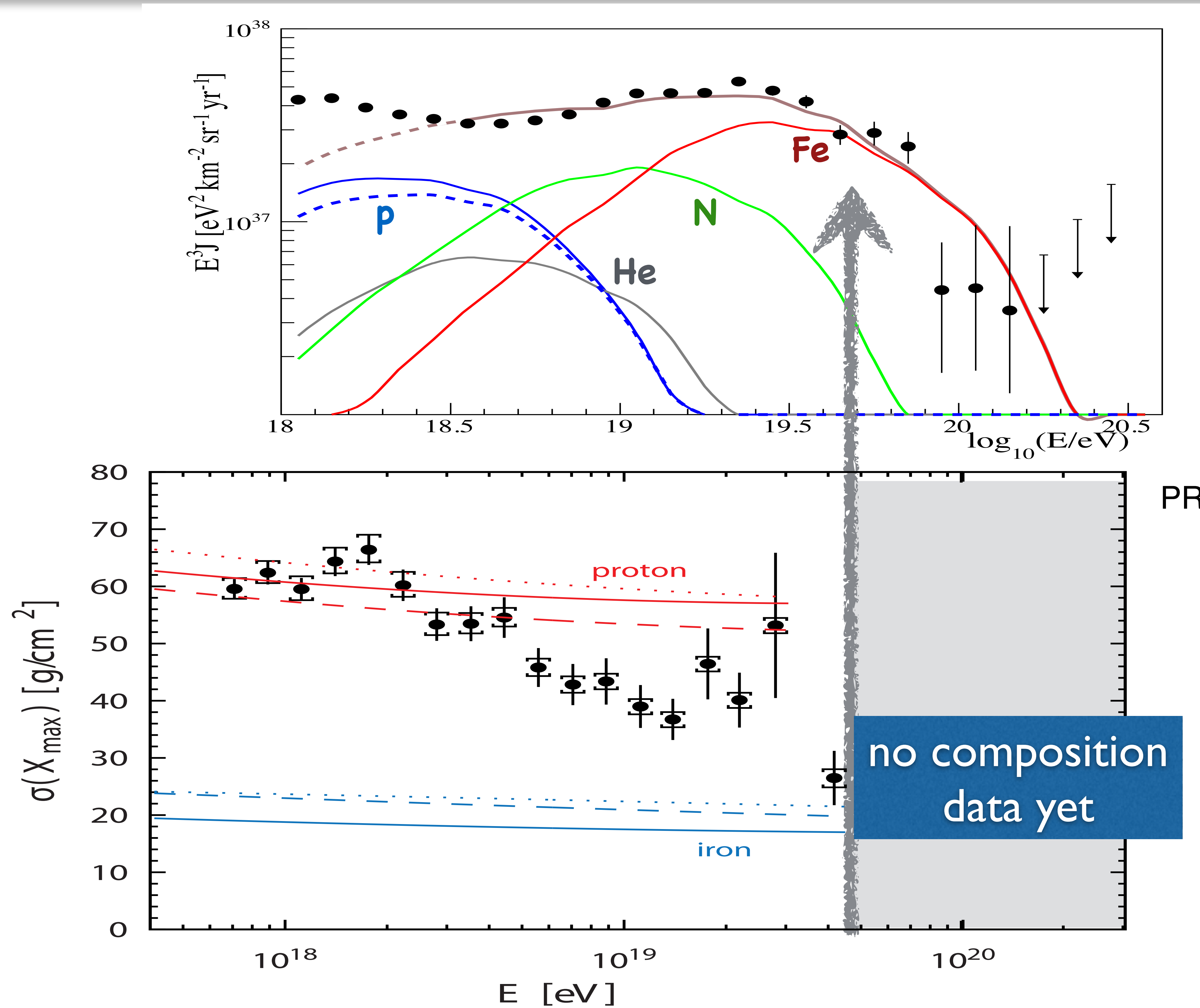
Update from: PRL 101, 061101 (2008), Physics Letters B 685 (2010) 239



Do we see the GZK-Effect ?

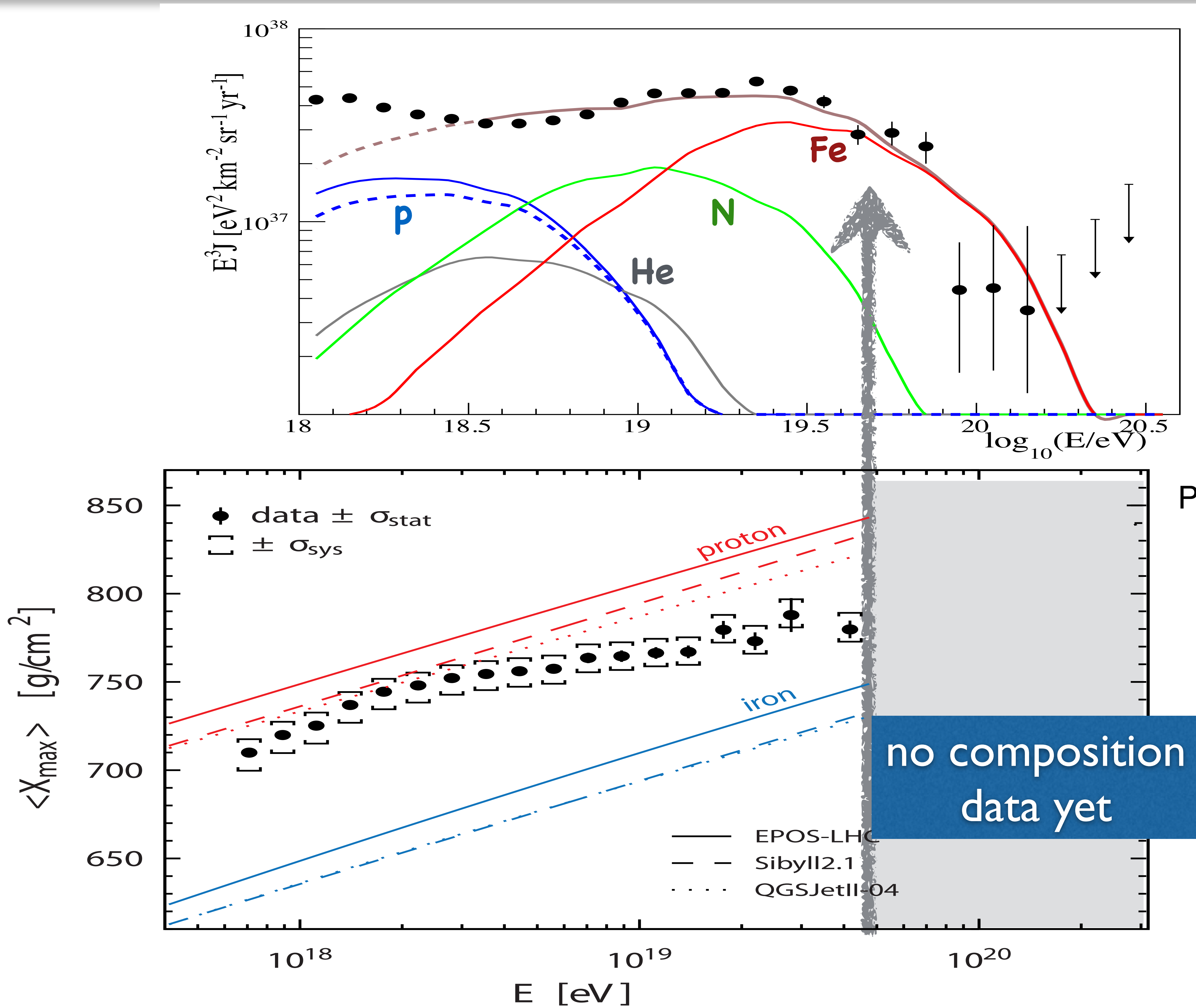


E_{max}-model supported by RMS(X_{max})…



PRD 2014 in press

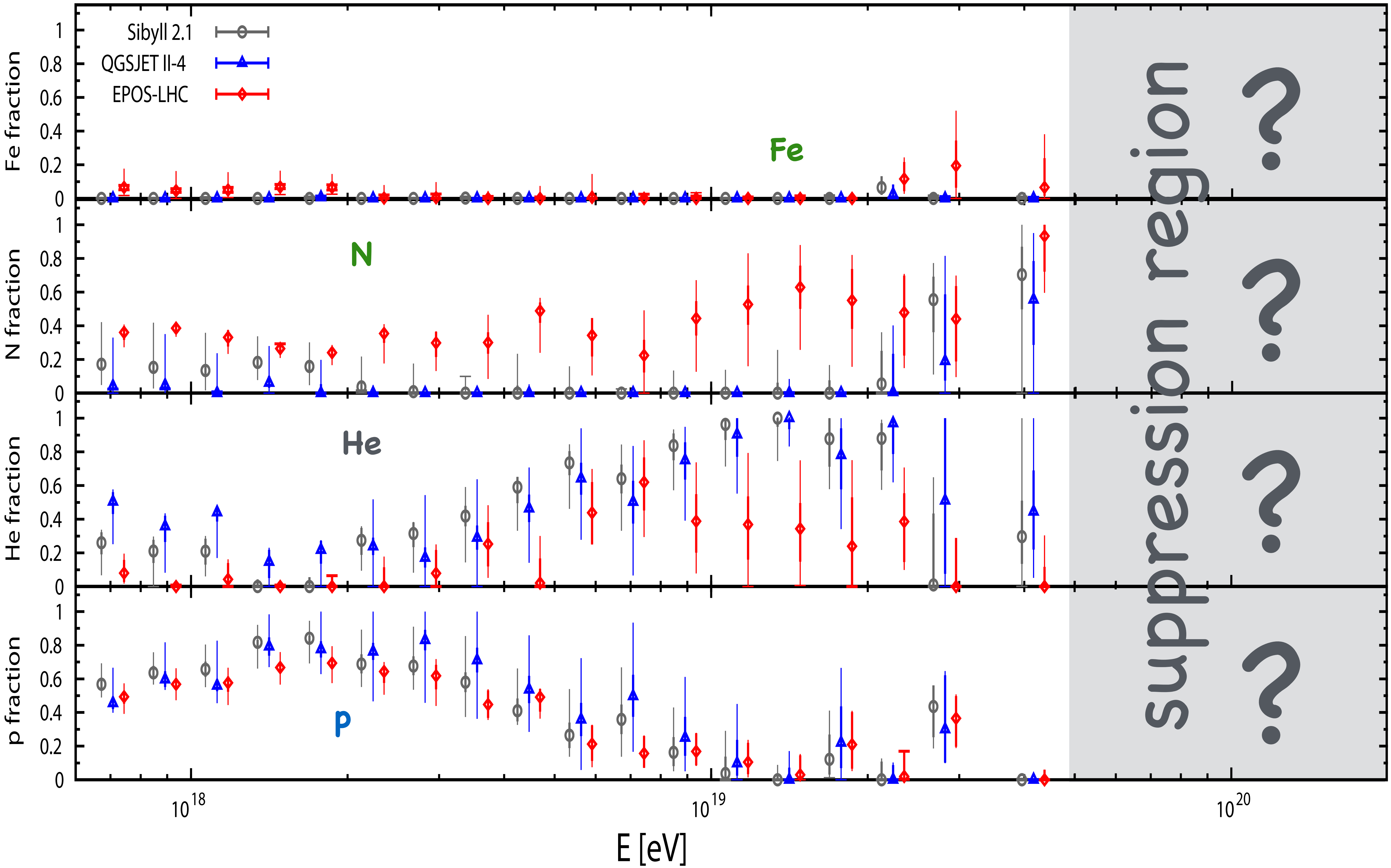
... and by <X_{max}>



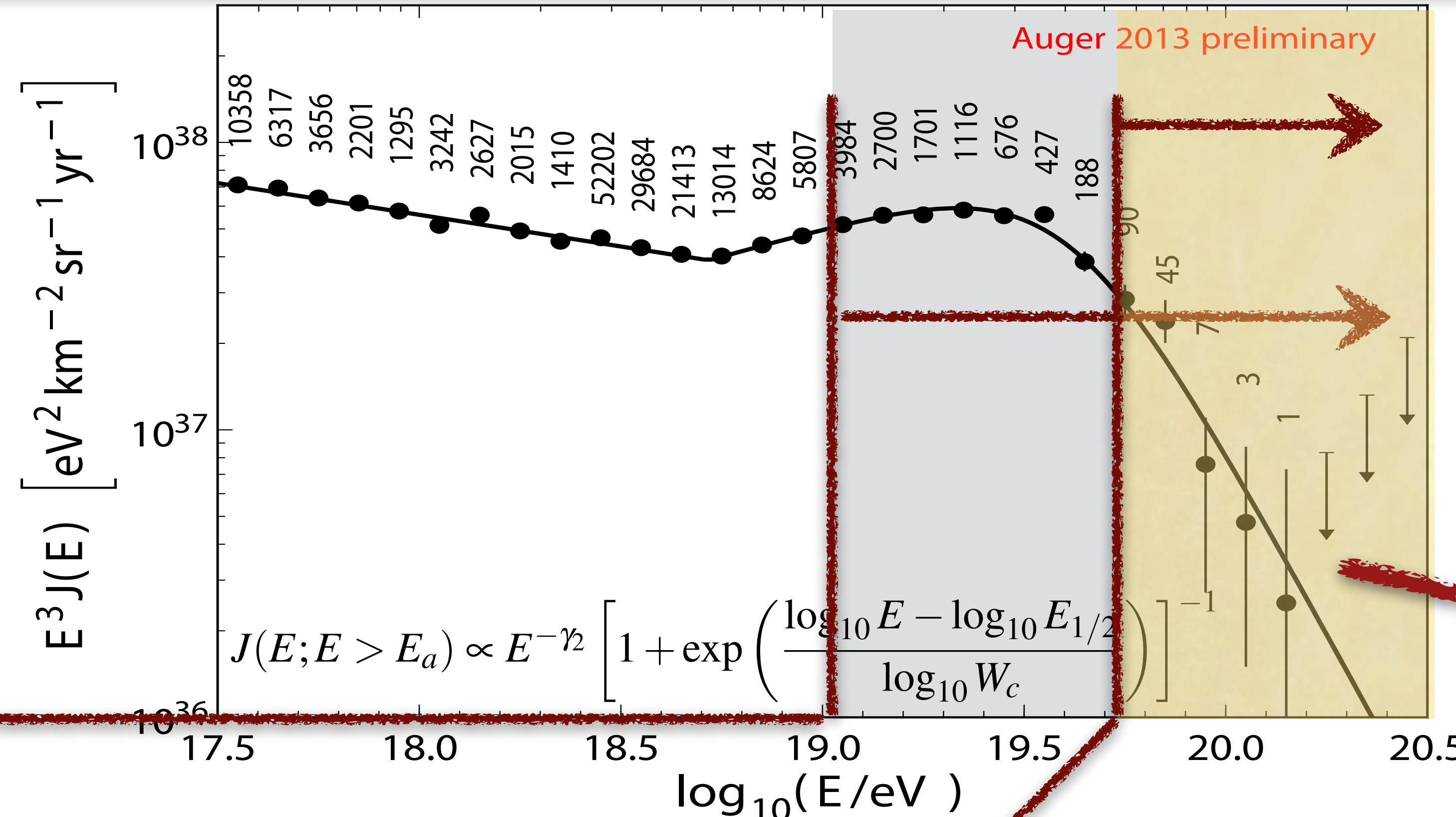
PRD 2014 in press

Decomposition of X_{max}-Distributions

PRD 2014 in press

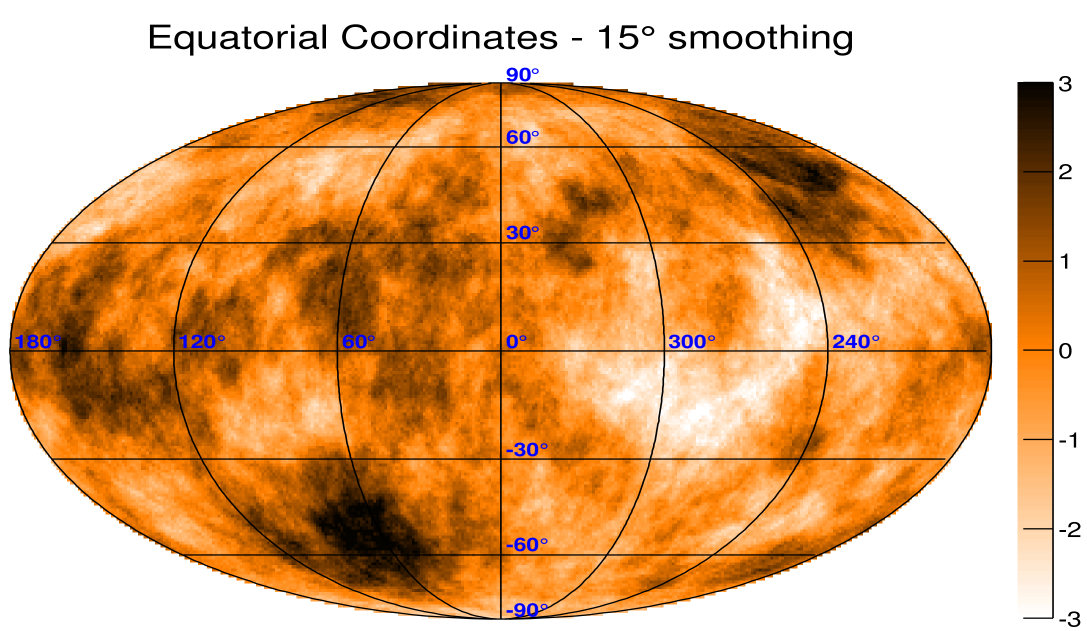


UHECR Sky highly isotropic



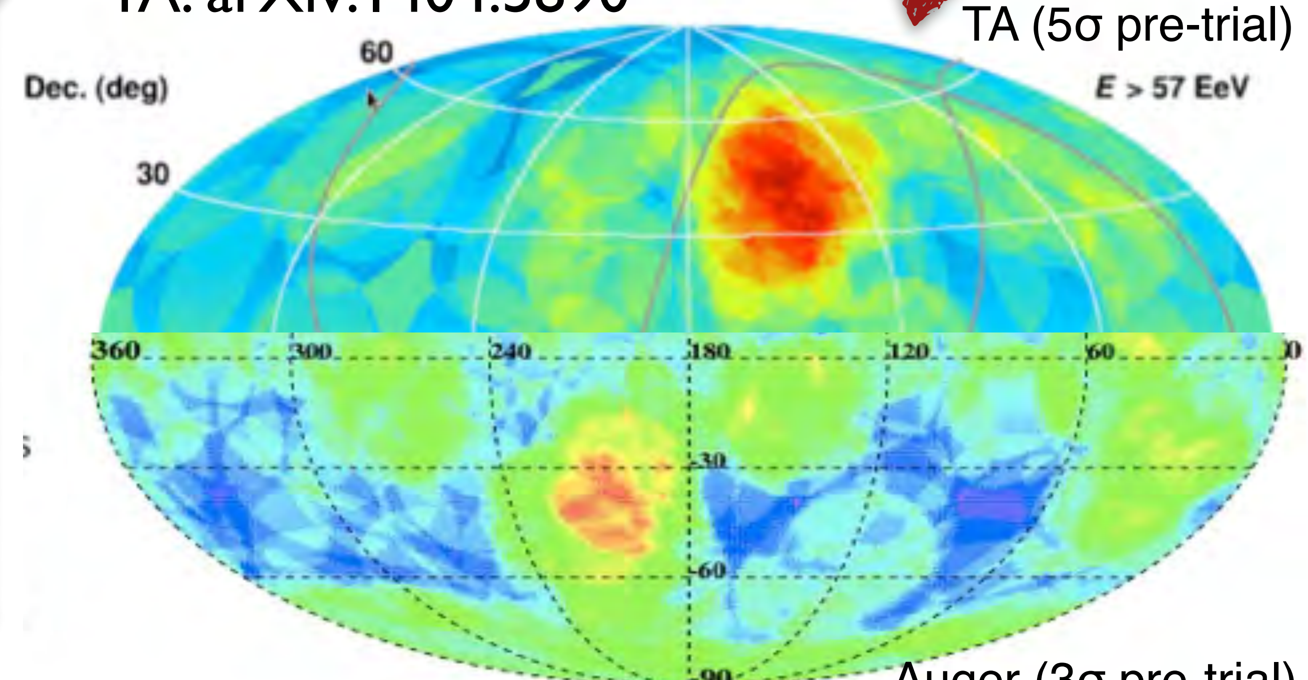
no sign. anisotropy seen

hot/warm spot

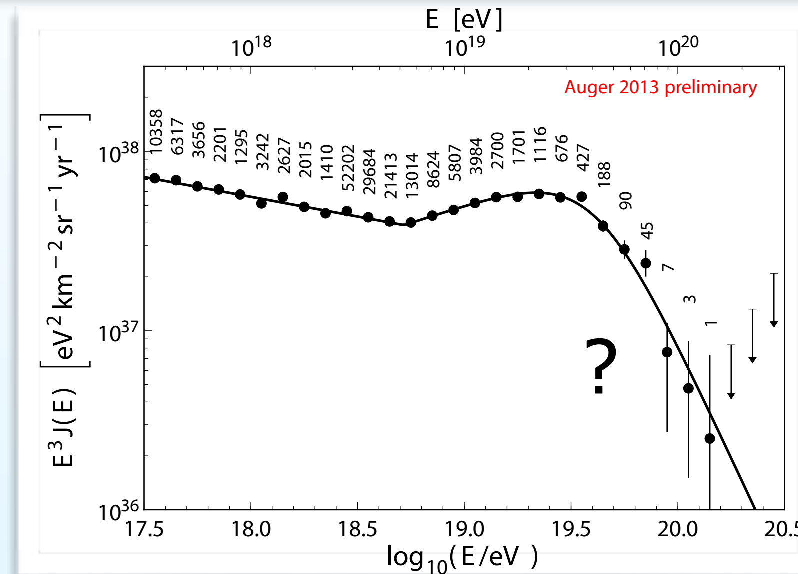


Auger & TA:
ApJ **794** 172 (2014)

TA: arXiv:1404.5890

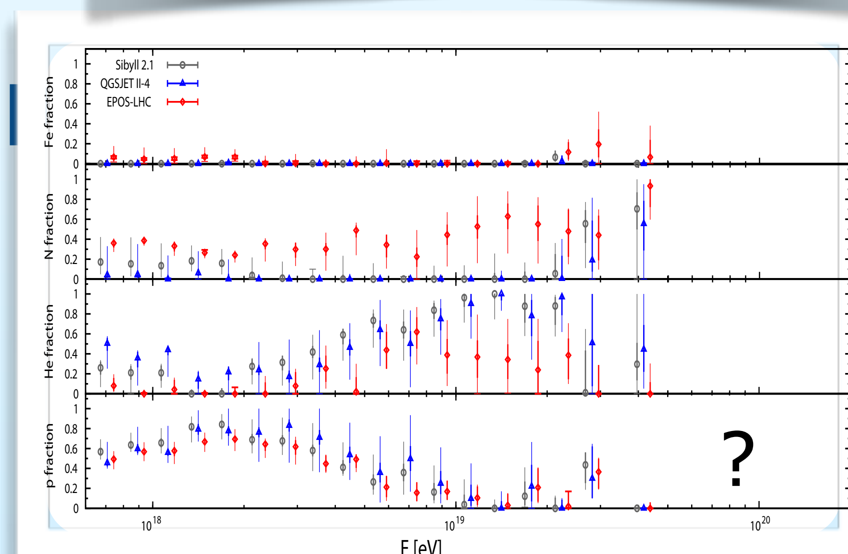


Science Goals of Auger Upgrade



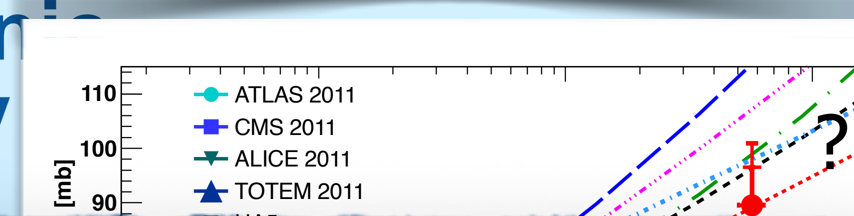
1. Elucidate the origin of the flux suppression, i.e. GZK vs. maximum energy scenario

- → fundamental constraints on UHECR sources
- → galactic vs extragalactic origin
- → reliable predictions of GZK ν- and -γ fluxes



2. Search for a flux contribution of protons u highest energies at a level of ~ 10%

- → proton astronomy up to highest energies
- → prospects of future UHECR experiments

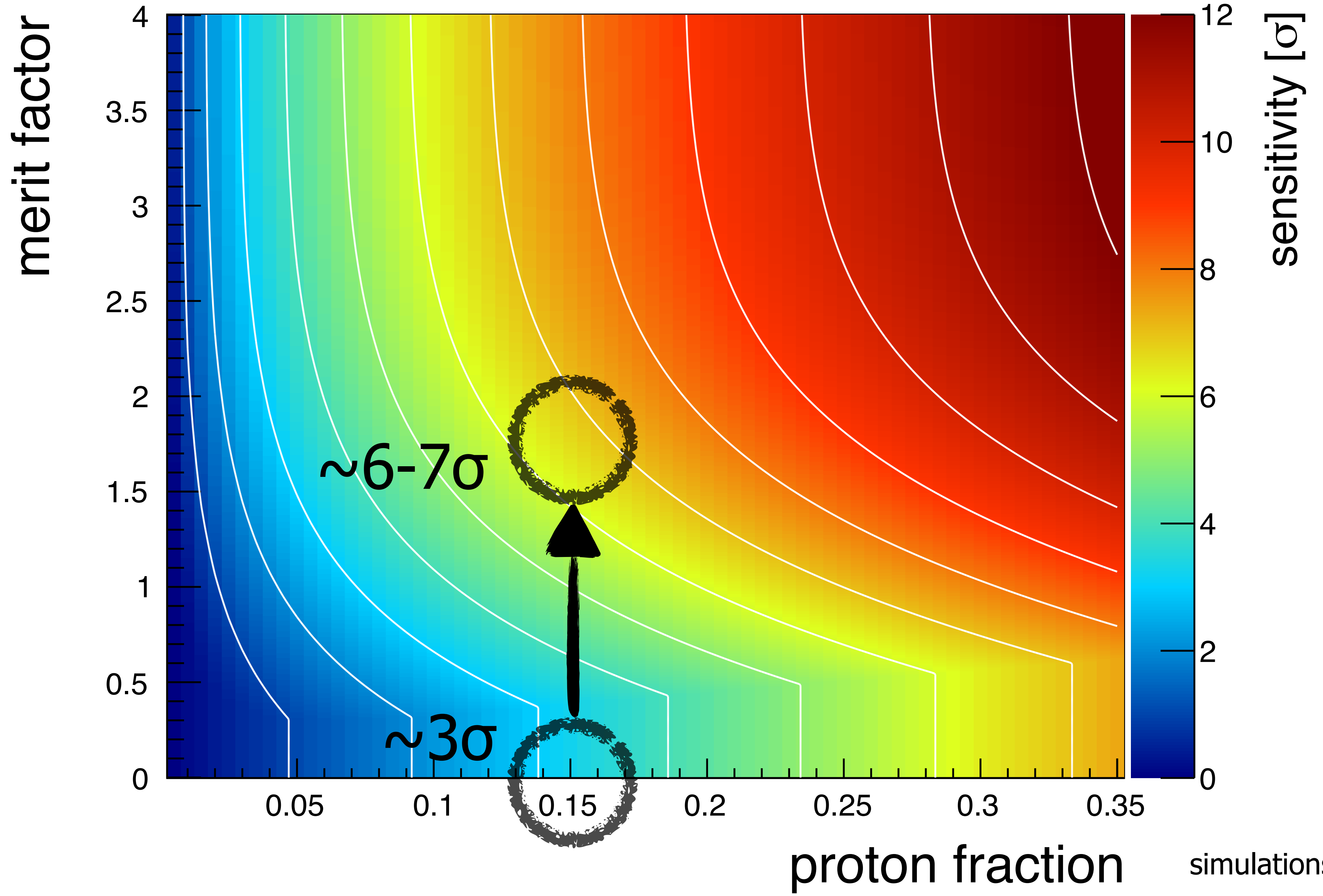


3. Study of extensive air showers and hadron multi-particle production above √s=70 TeV

Need to study composition event-by-event into the flux suppression region !

Power of Composition Enhanced Astronomy

assume present statistics: N=146 events (E>57 EeV), P_{iso}=0.21
and study correlation significance when protons correlate, but Fe does not

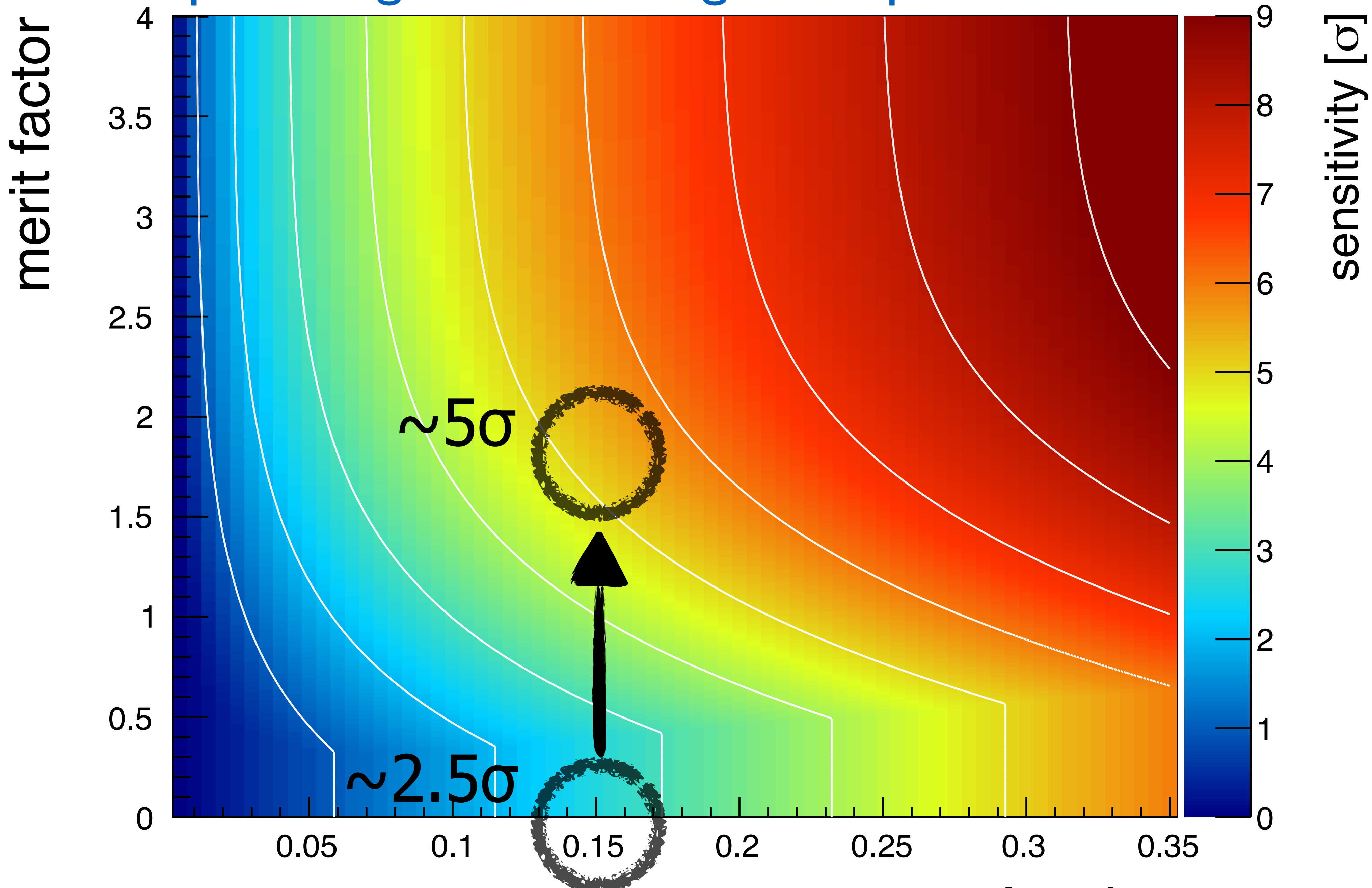


simulations by M. Unger

white lines: contour levels at sigma = 1, 2, 3, ...

Power of Composition Enhanced Astronomy

assume present statistics: N=146 events (E>57 EeV), P_{iso}=0.21
and study correlation significance when protons correlate, but Fe does not
Add 20% isotropic background: catalog incompleteness, distant sources, …

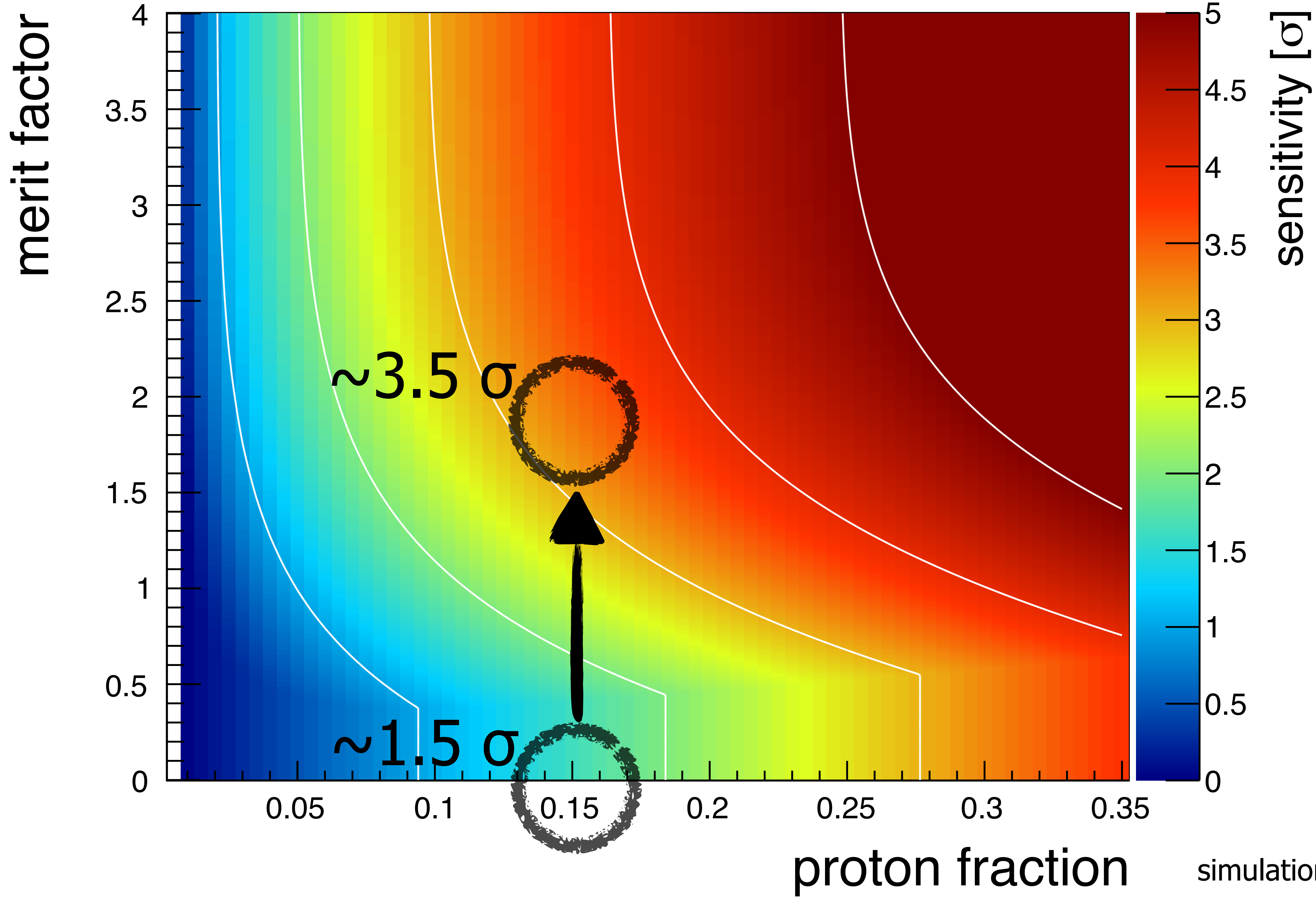


simulations by M. Unger

white lines: contour levels at sigma = 1, 2, 3, ...

Power of Composition Enhanced Astronomy

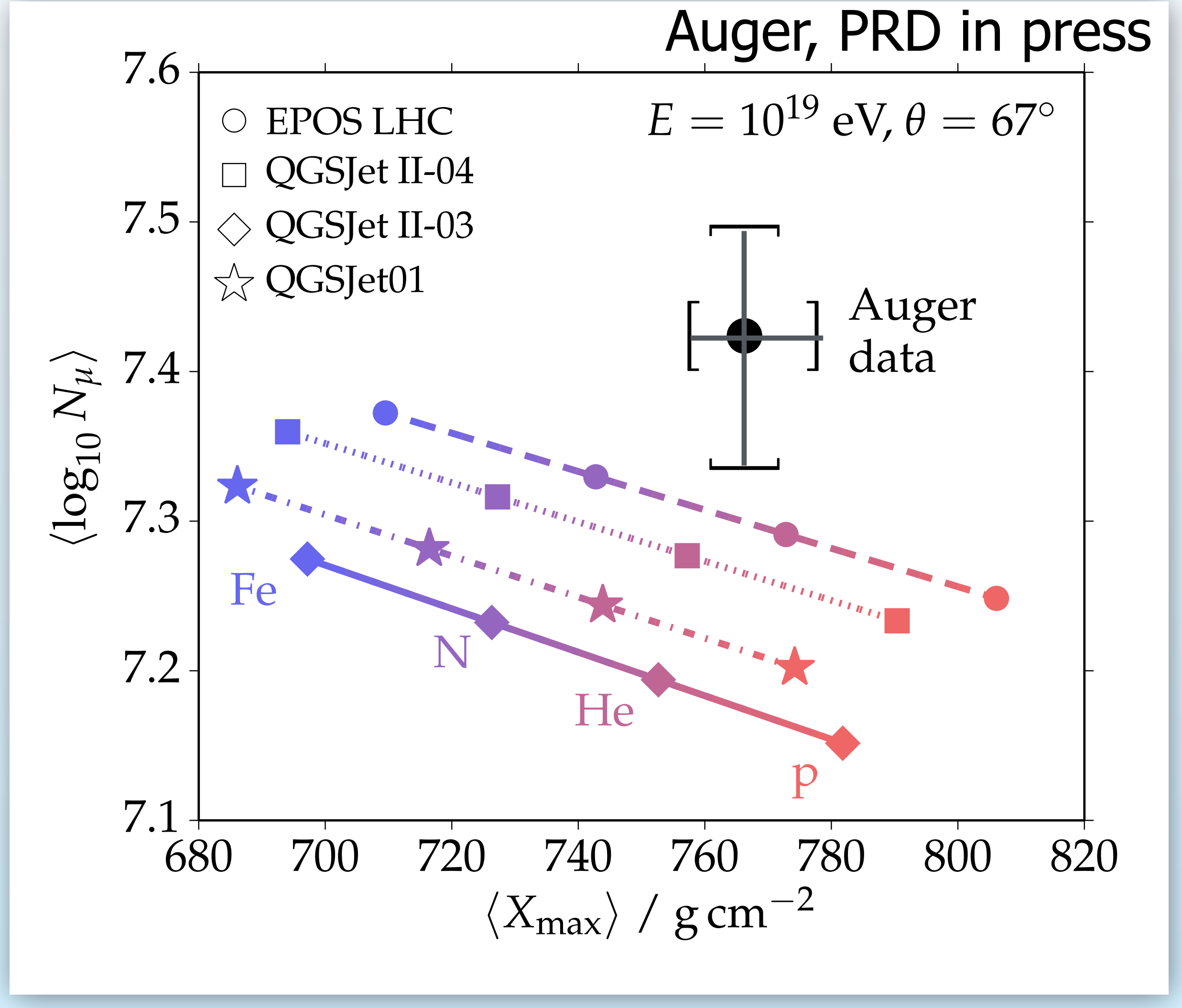
assume present statistics: N=146 events (E>57 EeV), P_{iso}=0.21
and study correlation significance when protons correlate, but Fe does not
Add 50% isotropic background: catalog incompleteness, distant sources, …



simulations by M. Unger

white lines: contour levels at sigma = 1, 2, 3, ...

Disentangling Int.-Models from Composition



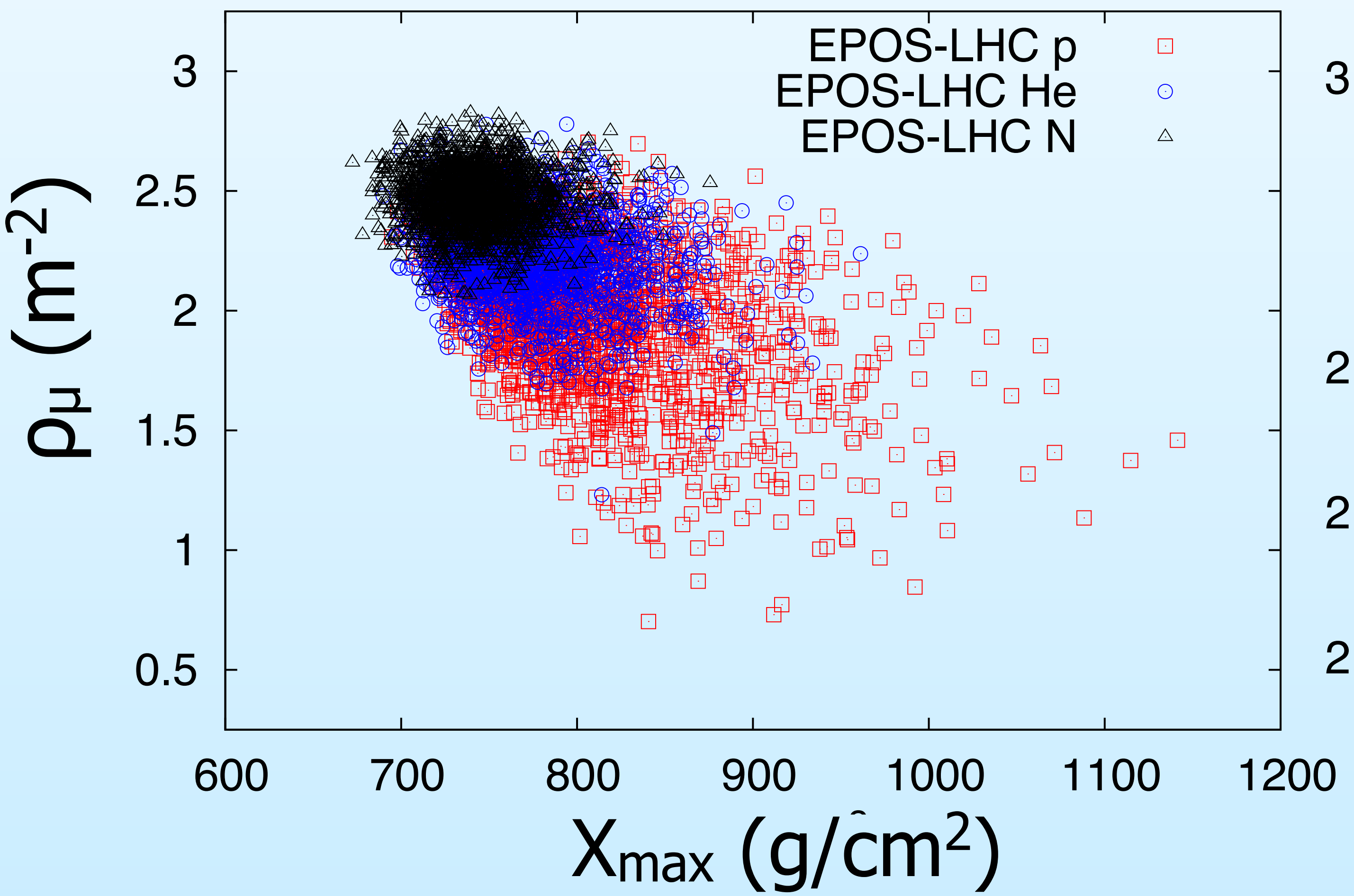
Muon deficit in models
(see M. Unger, tomorrow)

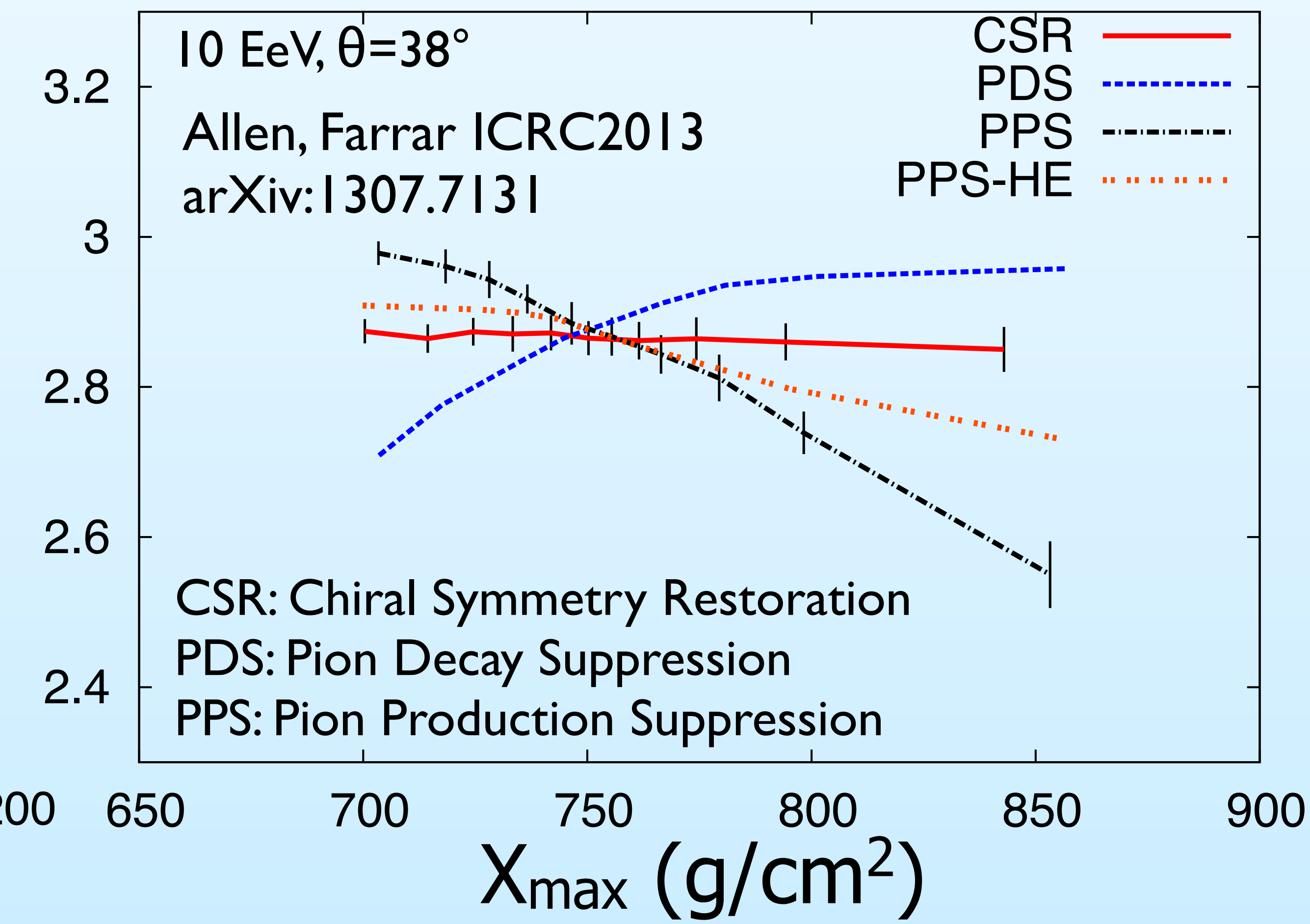
Conservative Approach:
Composition enhanced Anisotropy does not need to know absolute μ-numbers,
just select X % of most μ-poor an most μ-rich events

More ambitious:
want to know if μ-poor events are compatible with protons…

Disentangling Int.-Models from Composition

$\langle \rho_\mu \rangle$ and RMS(ρ_μ) in a mixed composition changes distinctively different with X_{max} as compared to models of a pure p-composition





Note: p-dominated composition at $10^{18.3}$ eV serves as benchmark for Fe at $10^{19.7}$ eV (superposition model)

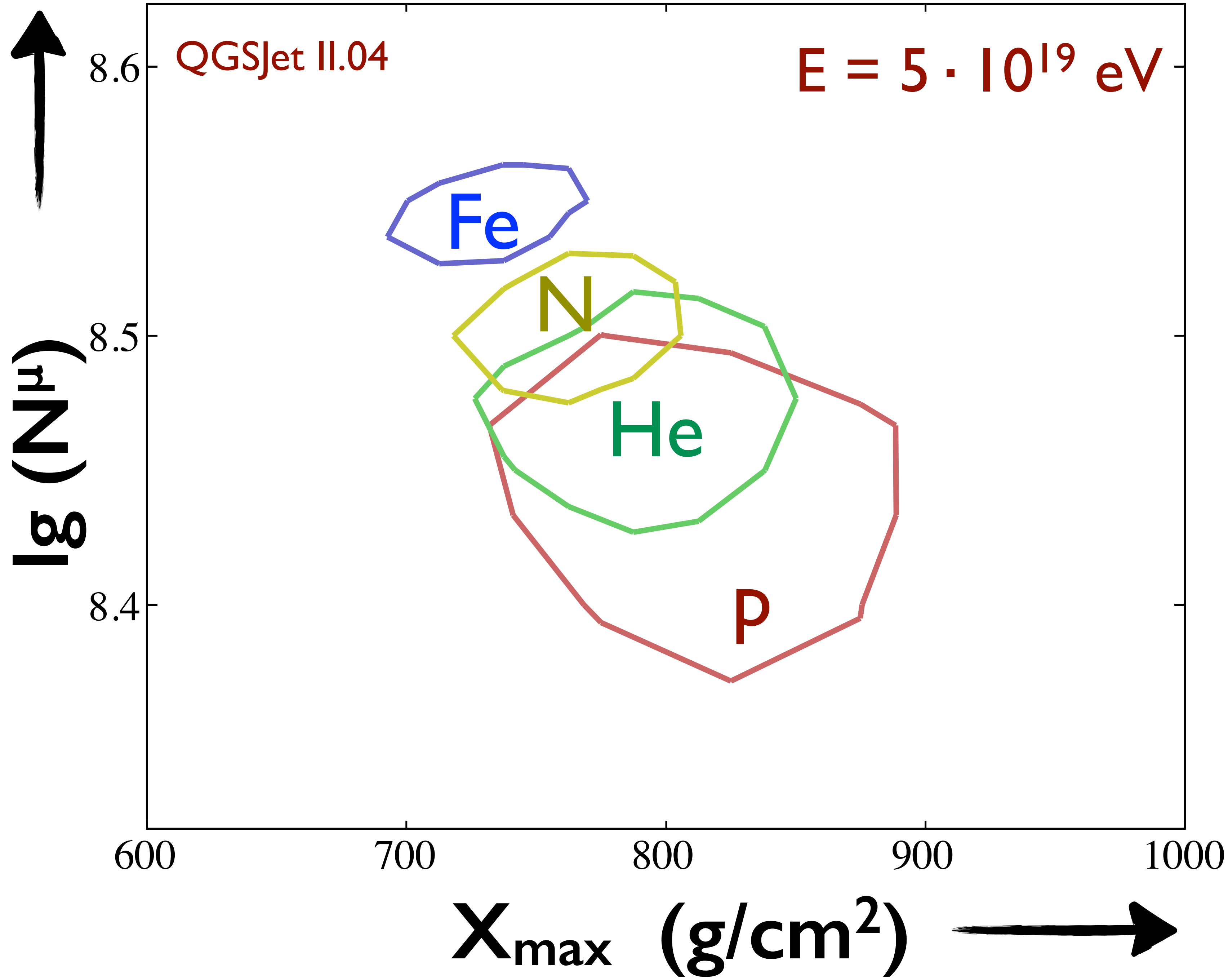
Rational of Auger Upgrade

Enhancing the surface detector array for better e/μ separation will boost the science of Auger

- → factor of ~10 in statistics for composition measurements
- → discriminate GZK vs maximum energy scenario
- → composition enhanced anisotropy (~10% protons?)
- → learn about global features of hadronic interactions at $\sqrt{s}$ > 70 TeV
- → decisive prediction of UHE (cosmogenic) ν-fluxes
- → decisive for next generation UHECR Experiments

Auger Observatory is in place to address all these questions now

N^{μ}_{max} vs X_{max}



Muons may even outperform X_{max} at highest energies !

Key Elements of Upgrade

1) New Electronics for Surface Detector

→ faster sampling, better triggers, larger dynamic range, more channels

2) Enhanced Muon-Counting in Surface Detector

Two options (out of five originally) under study:

a) introduce vertical segmentation of tanks
b) add scintillator on top of each tank

3) Extended operation of fluorescence telescopes

may double observation time

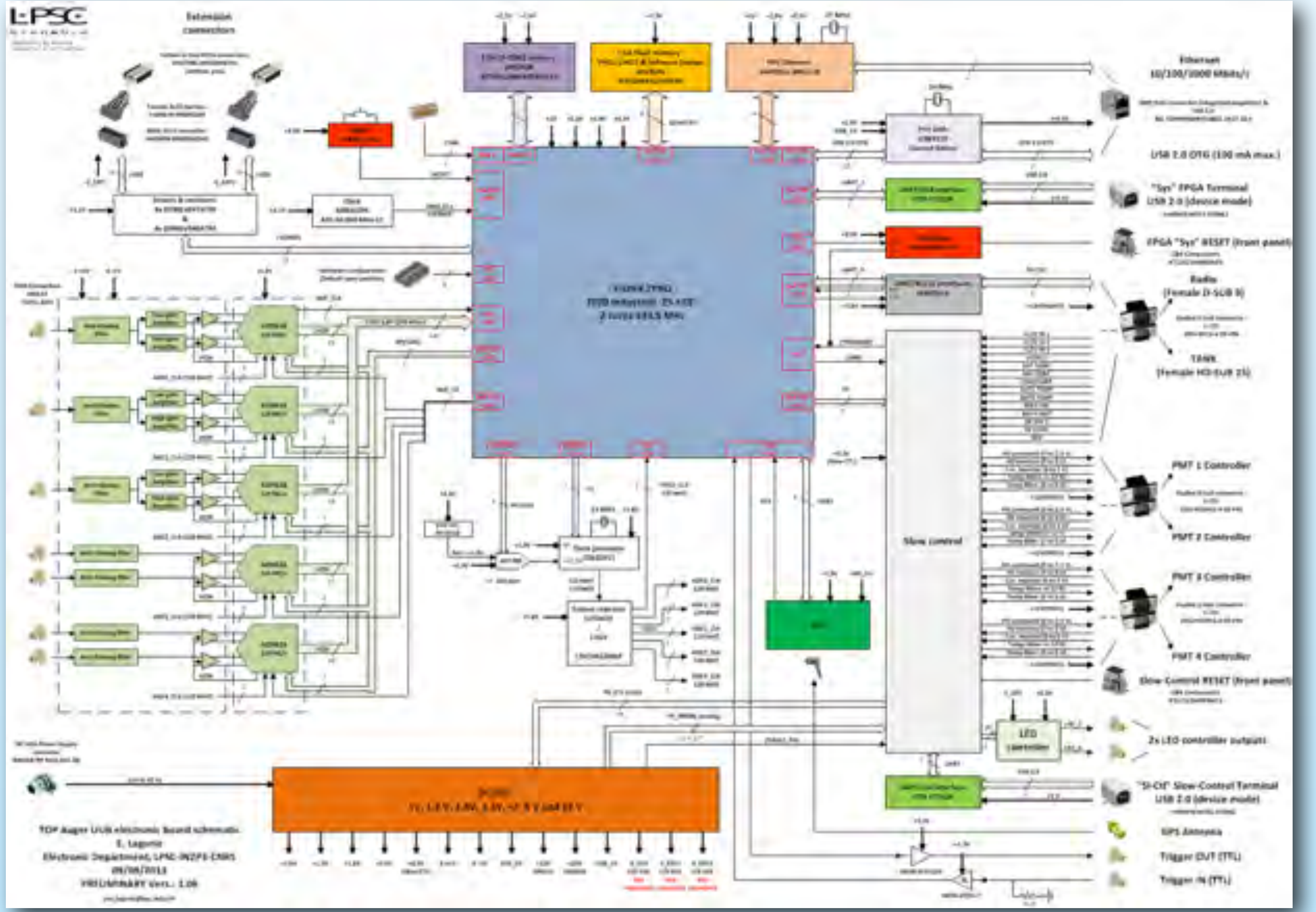
4) High Precision Array with shielded muon detectors

1) New SD-Electronics

Purpose:

- facilitate the readout of new electronic channels (PMTs)
- faster sampling (40➔120 MHz) for better timing and μ-identification
- enhanced dynamic range (by adding a small PMT)
- faster data processing and more sophisticated triggers
- better data monitoring

- design is ready
- prototypes are now being produced

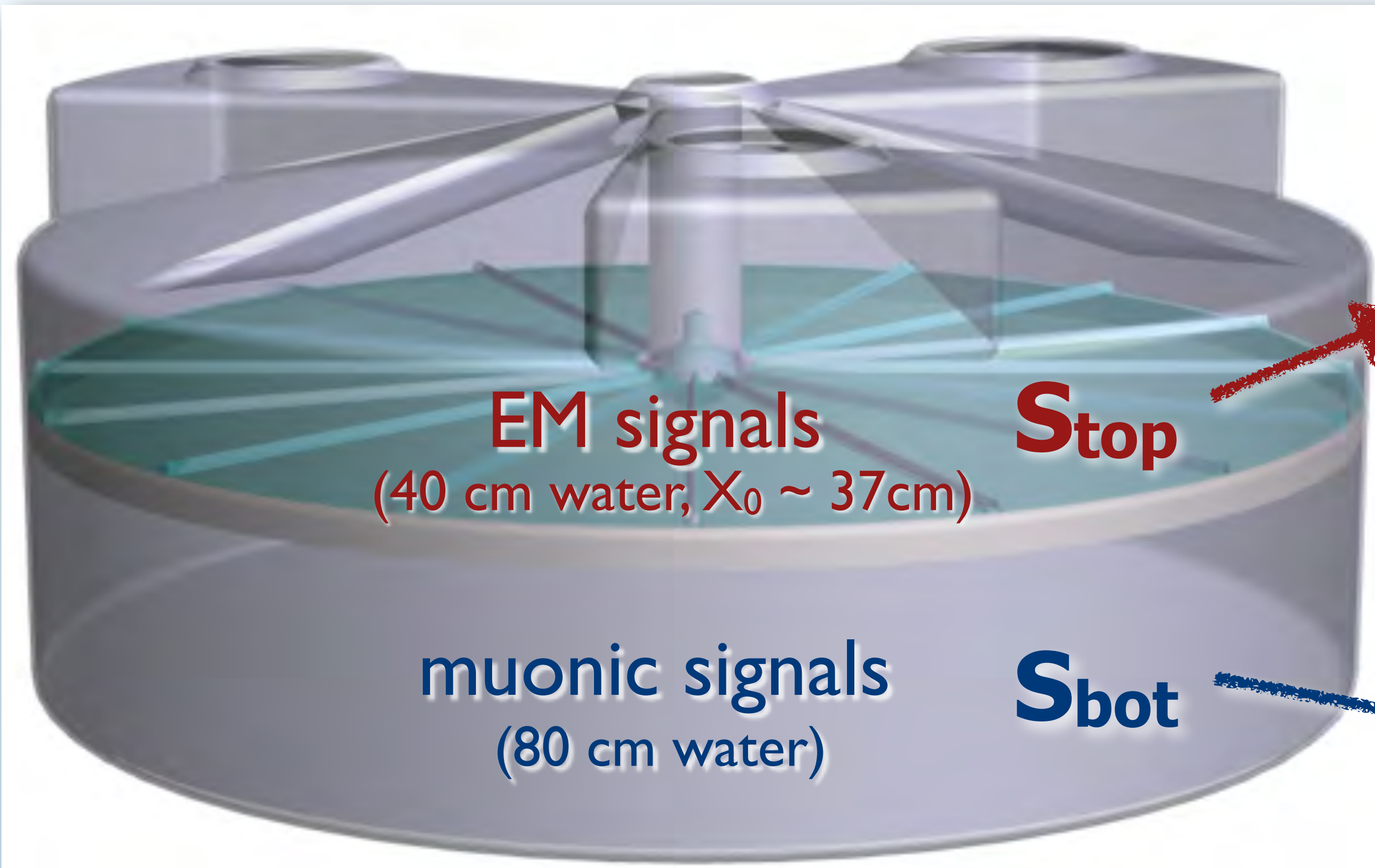


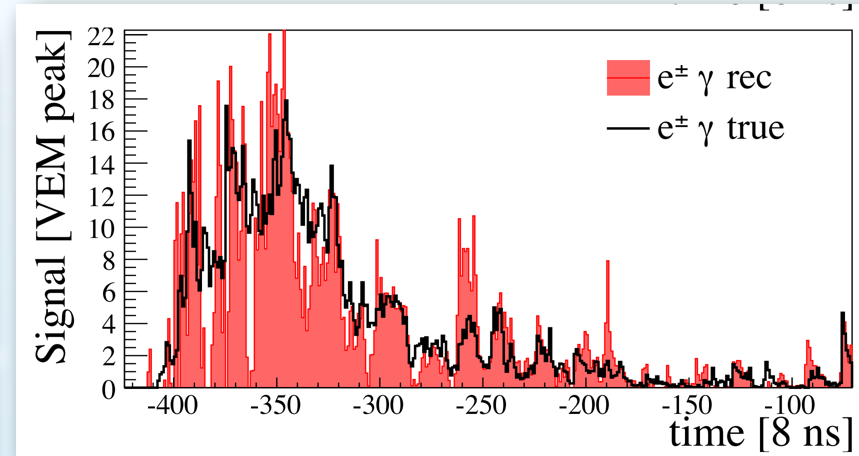
2a) Enhanced Muon Counting: LSD

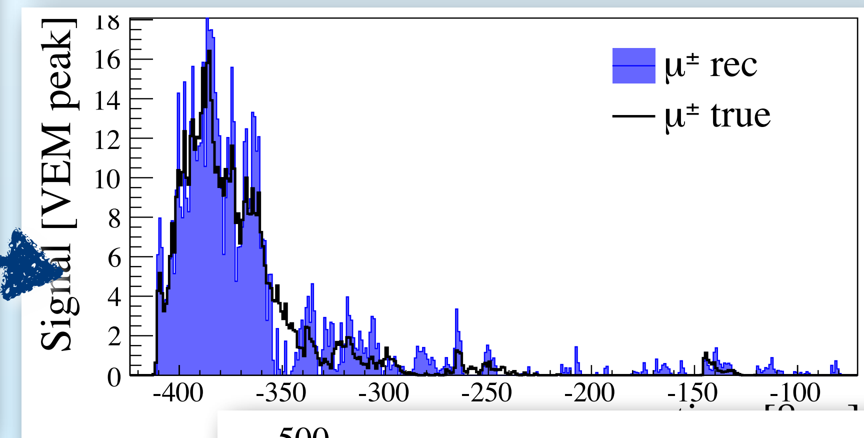
LSD: Layered Surface Detector

a) longitudinally segmented tanks (LSD)

Letessier-Selvon et al., NIM A767 (2014) 41



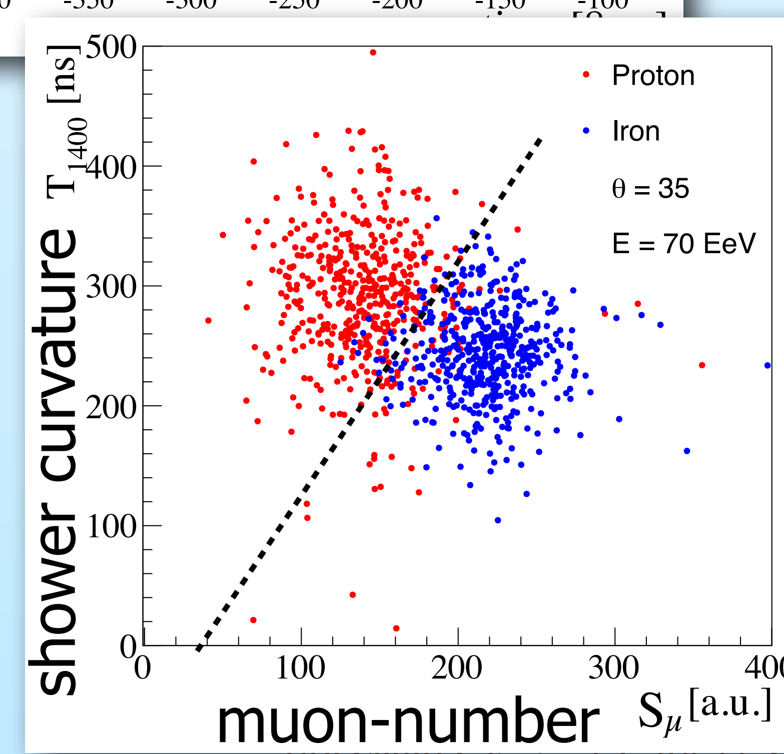




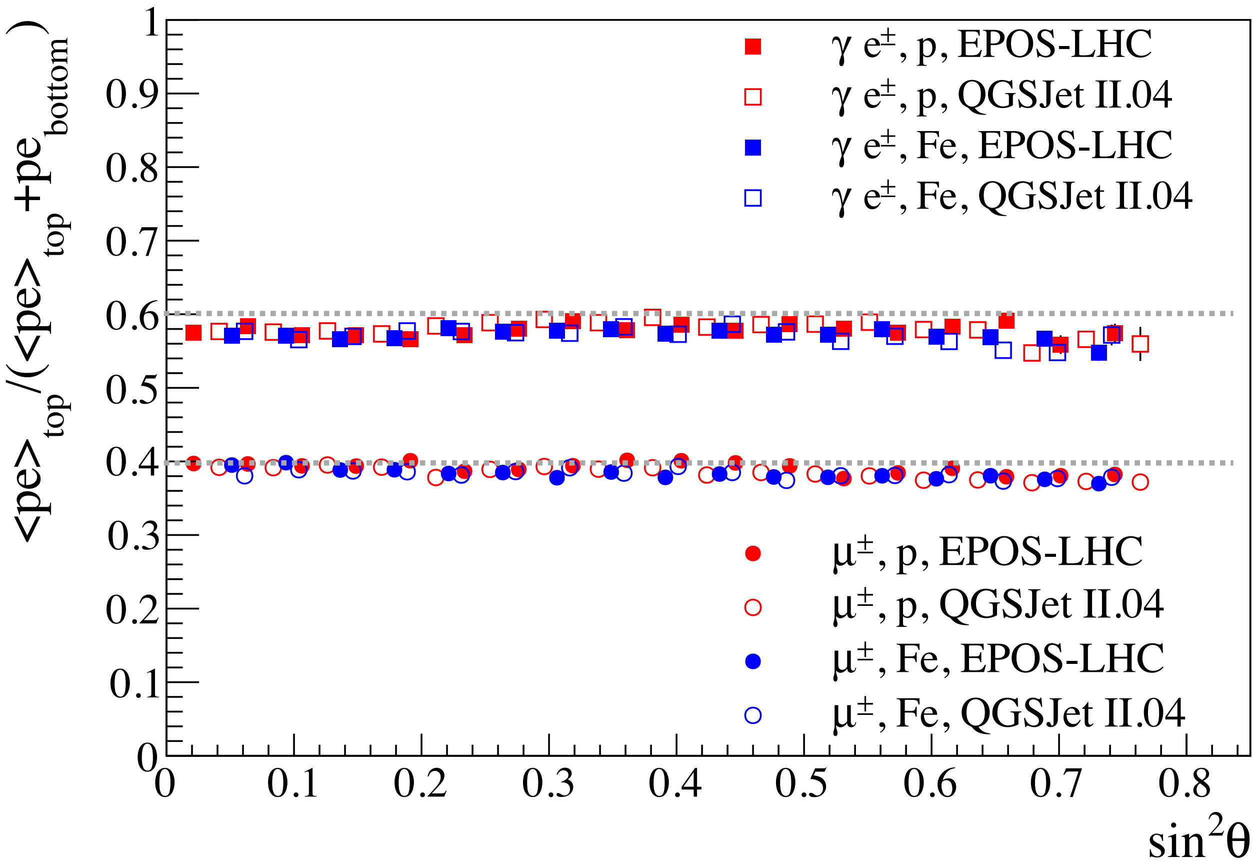
Linear system of equations:

$$\begin{pmatrix} S_{\rm top} \\ S_{\rm bot} \end{pmatrix} = \begin{pmatrix} a_{\rm em} & a_\mu \\ 1-a_{\rm em} & 1-a_\mu \end{pmatrix} \begin{pmatrix} S_{\rm em} \\ S_\mu \end{pmatrix}$$

$$\begin{pmatrix} S_{\rm top} \\ S_{\rm bot} \end{pmatrix} \simeq \begin{pmatrix} 0.6 & 0.4 \\ 0.4 & 0.6 \end{pmatrix} \begin{pmatrix} S_{\rm em} \\ S_\mu \end{pmatrix} \Rightarrow \begin{pmatrix} S_{\rm em} \\ S_\mu \end{pmatrix}$$



Constancy of a_{em} and a_μ

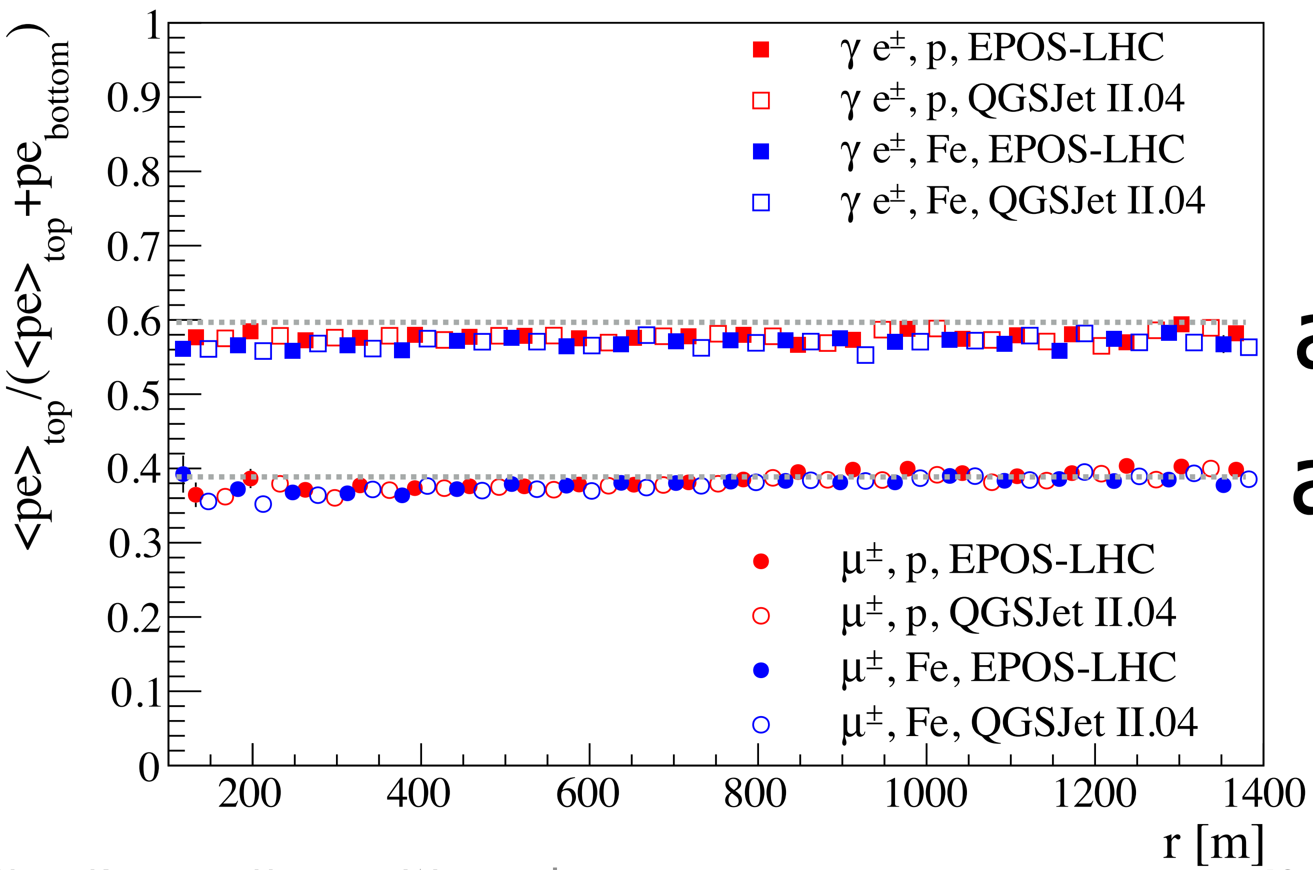


from: Letessier-Selvon et al., NIM A767 (2014) 41

a_{em}

a_μ

... as a fct of zenith angle



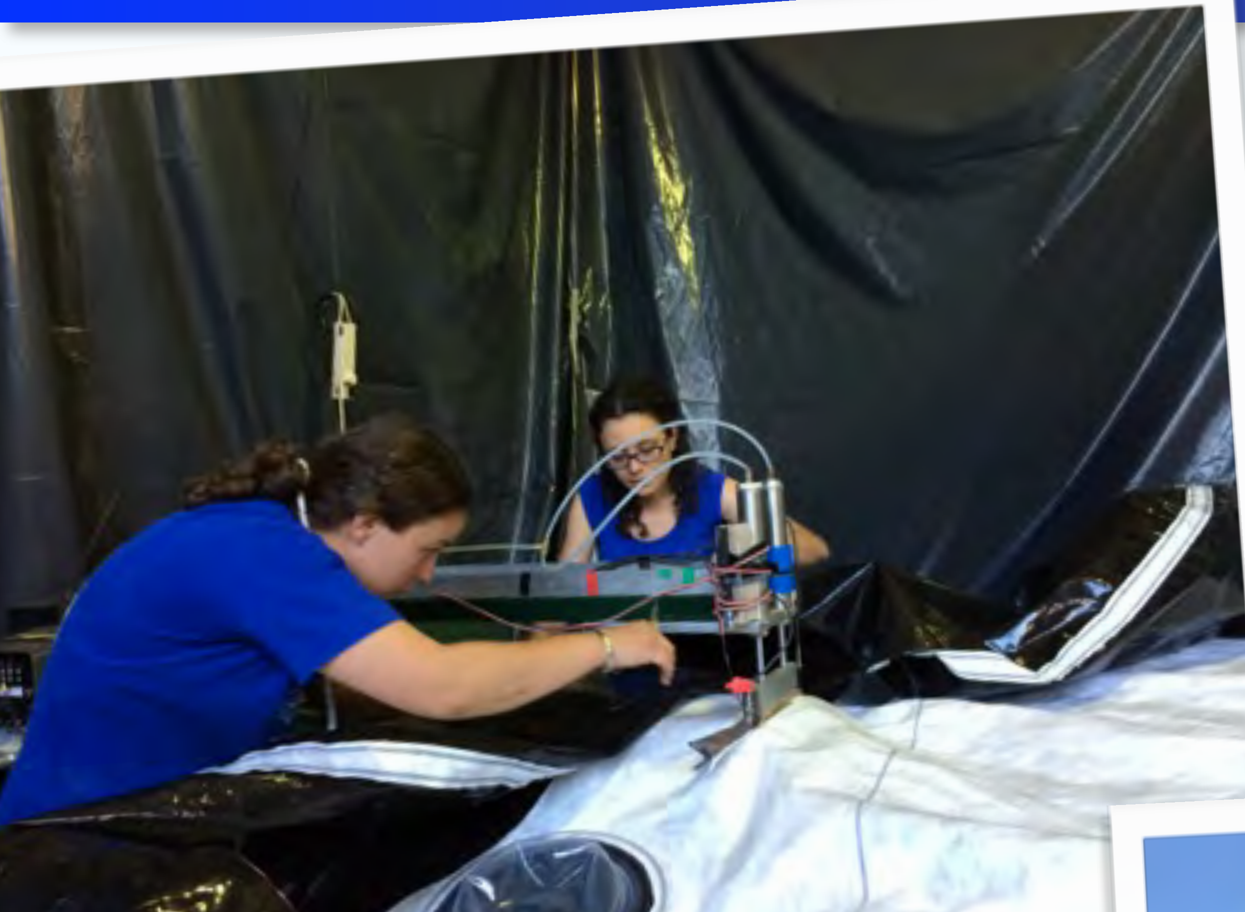
a_{em}

a_μ

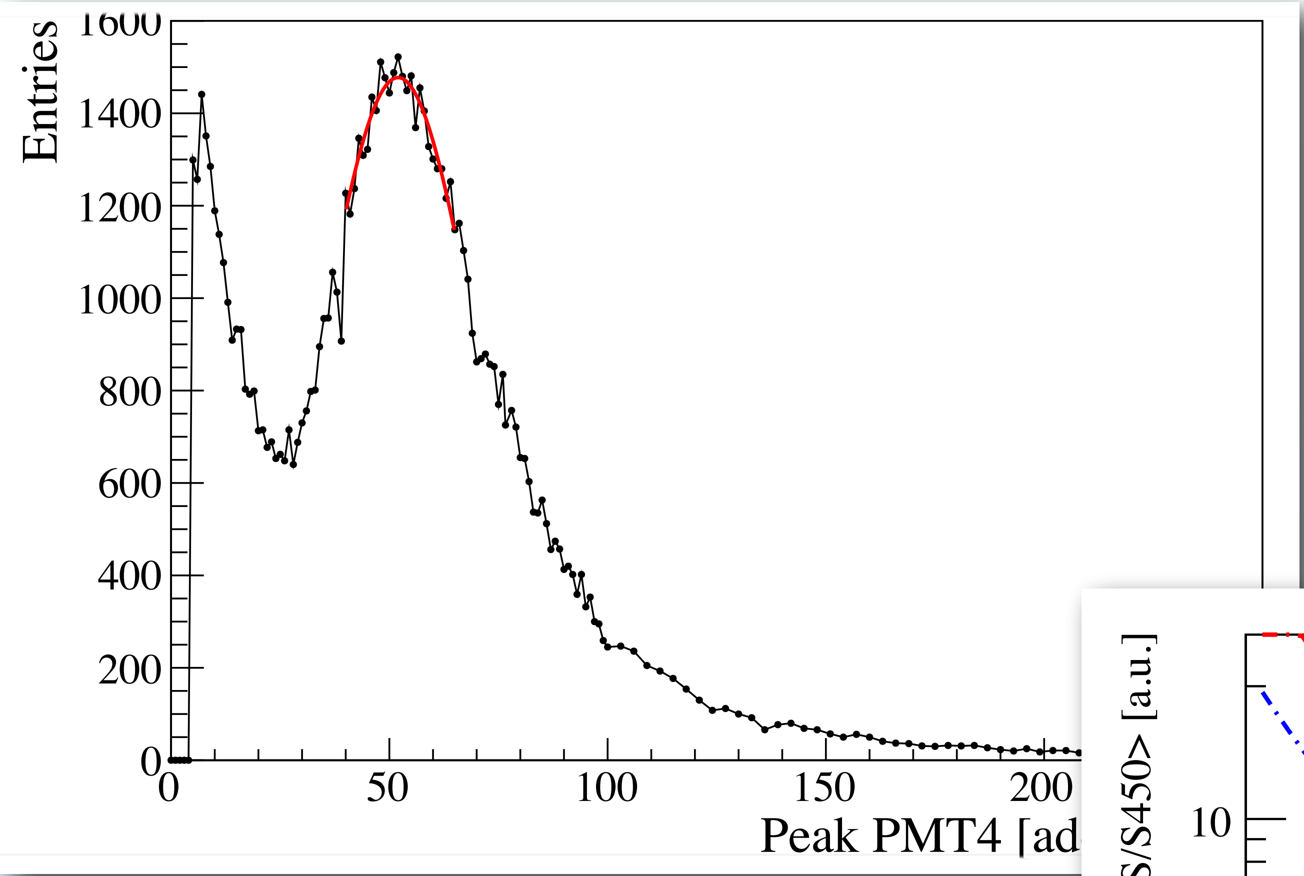
... as a fct of core distance

... no model dependency!

Construction & Commissioning of LSD Tank

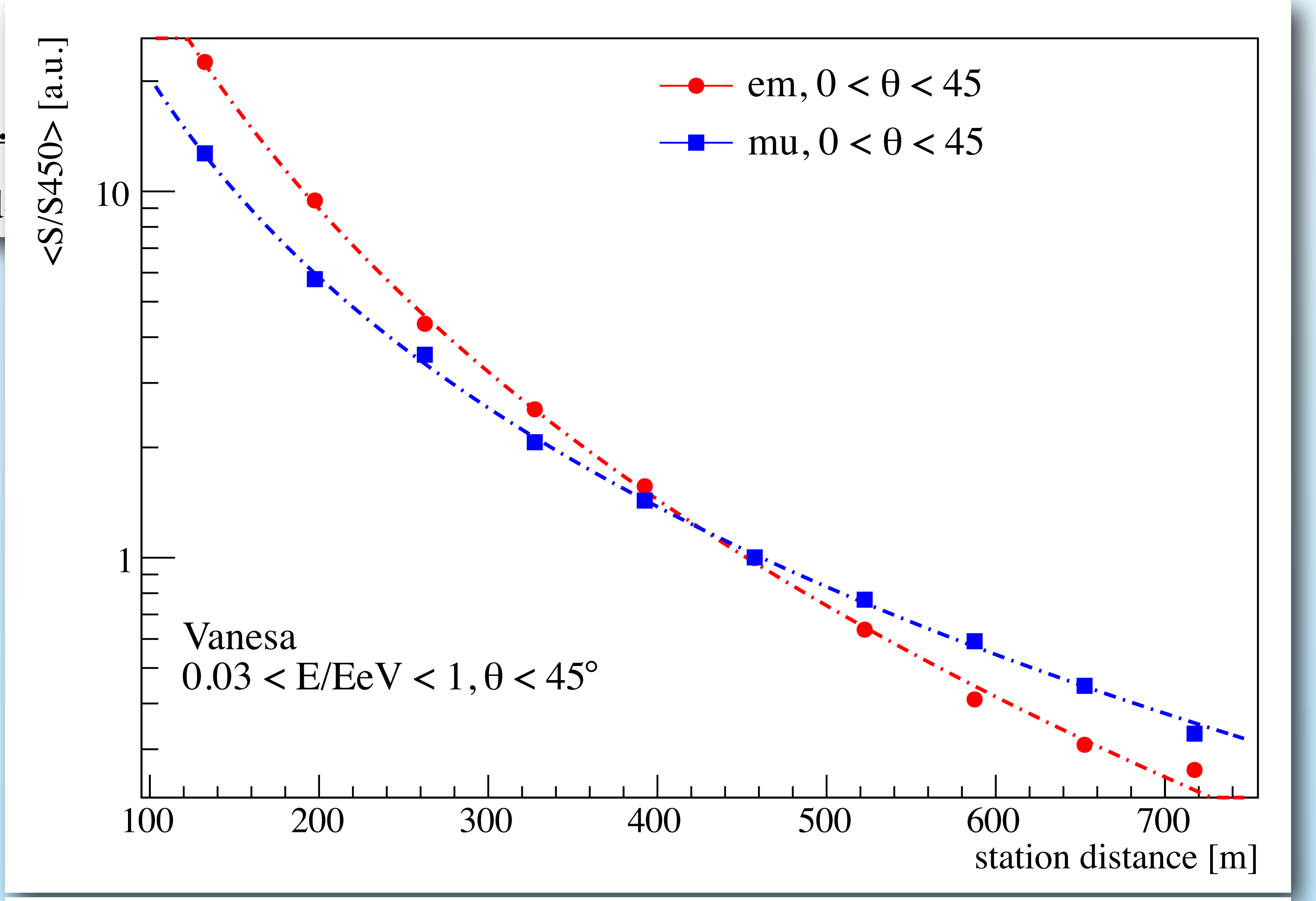


LSD Protoype Results



Muon peak → calibration

Reconstructed muon and electron lateral distribution



2b) Enhanced Muon Counting: ASCII

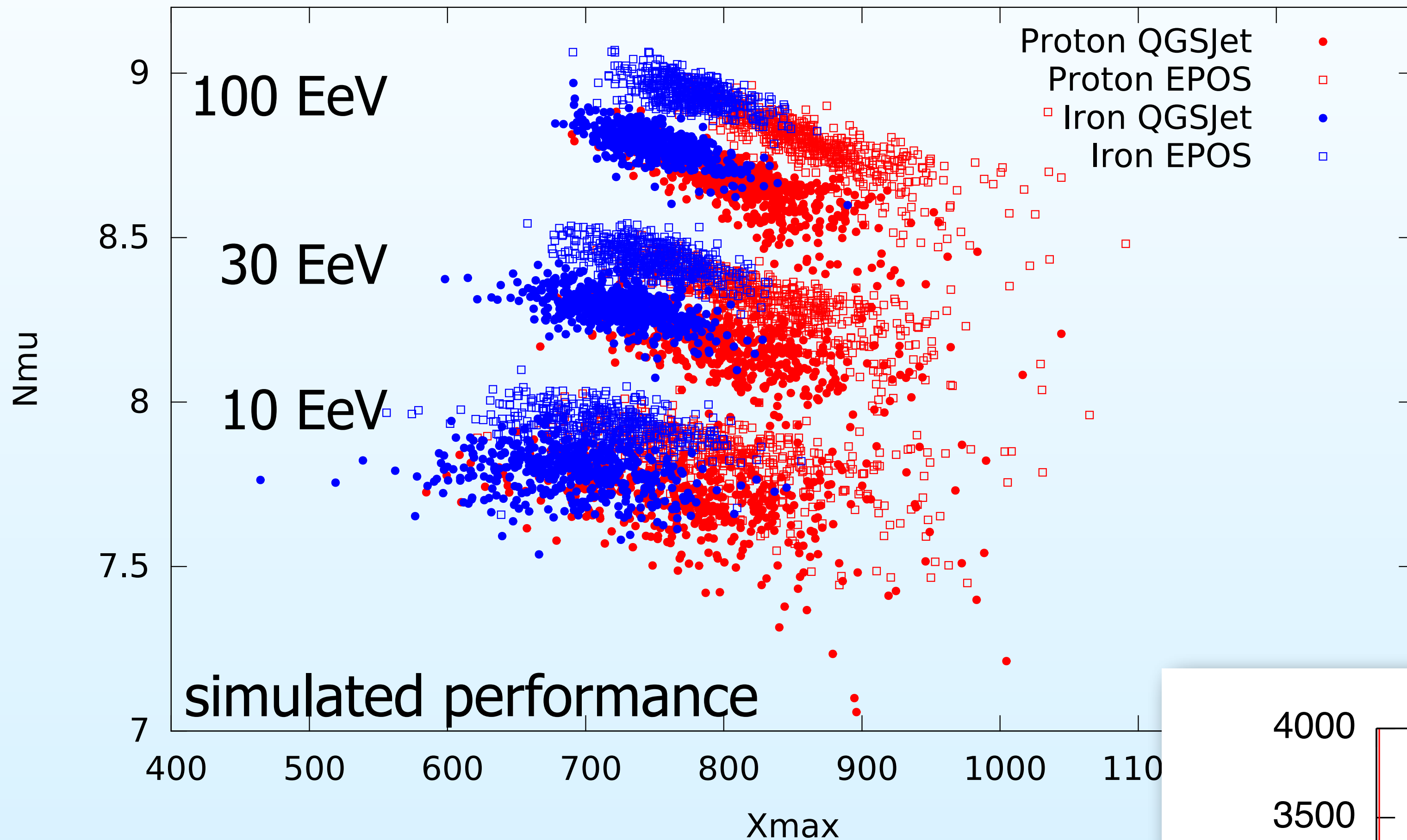
ASCII: Auger Scintillator for Composition II

1 cm thick scintillator read out by green WLS

Scintillator on top of tank

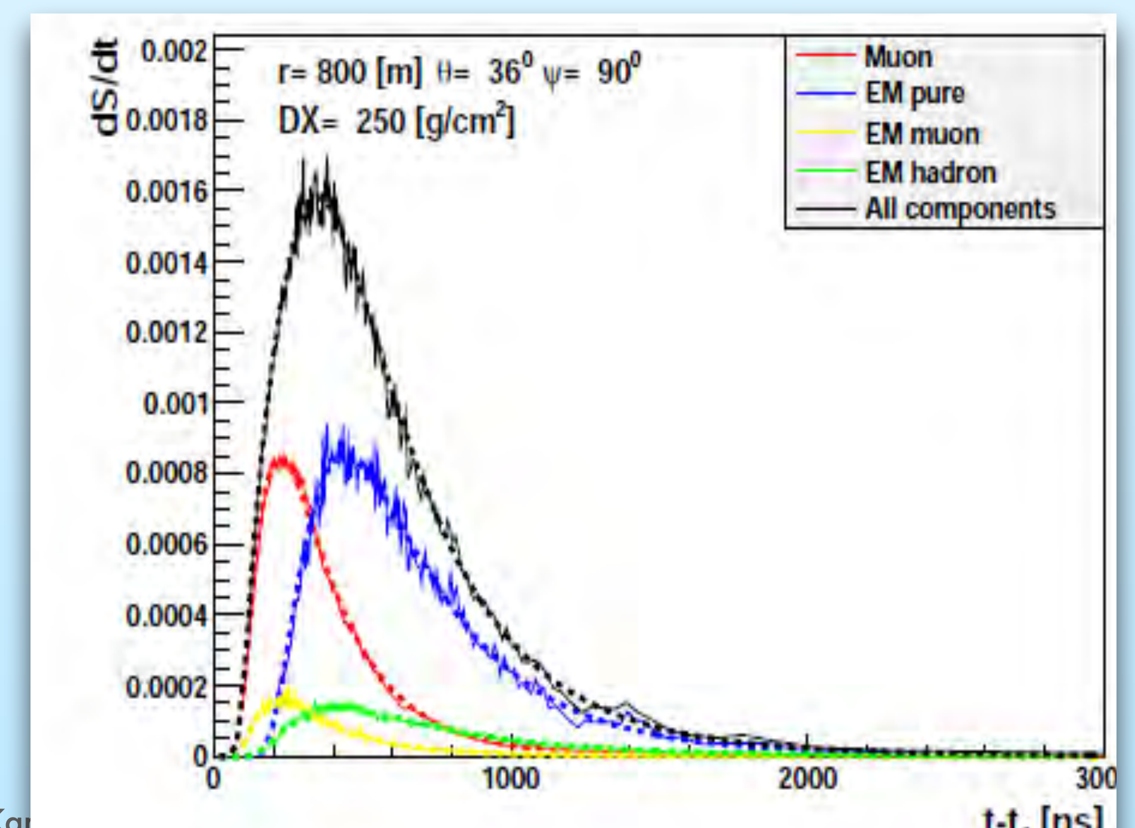
$4\ m^2$ ASCII prototype

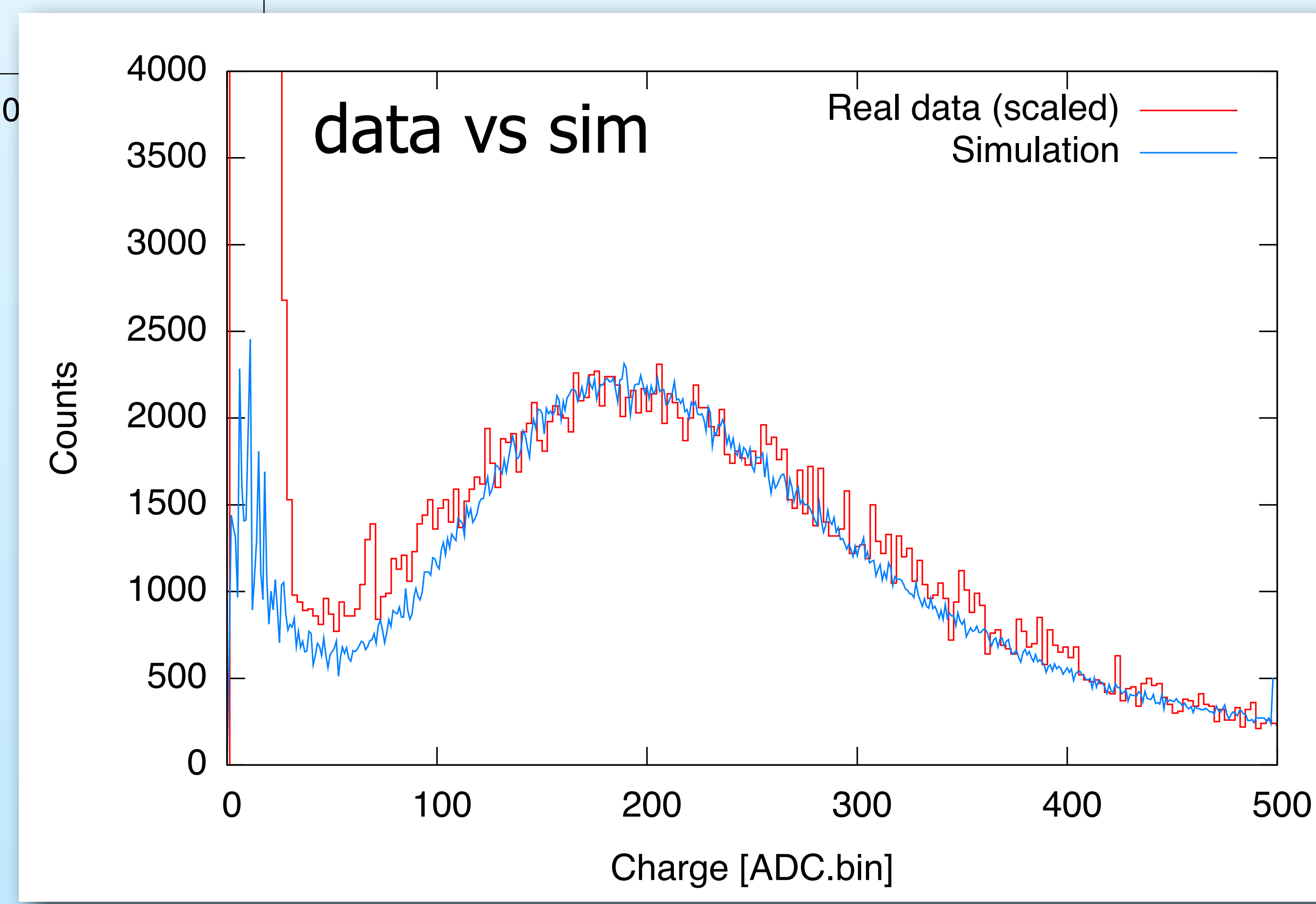
Performance of ASCII



Method of matrix inversion works again, similar to LSD; for 4 m^2 ASCII:

$$\begin{pmatrix} S_{\mathrm{Scin}} \\ S_{\mathrm{WCD}} \end{pmatrix} = \begin{pmatrix} 0.54 & 0.3 \\ 0.46 & 0.7 \end{pmatrix} \begin{pmatrix} S_{\mathrm{em}} \\ S_{\mu} \end{pmatrix}$$





Prototype experiences accompanied by detailed performance estimates

CORSIKA Shower libraries were generated with different
- energies (fixed and continuous)
- primaries
- zenith angles
- interaction models

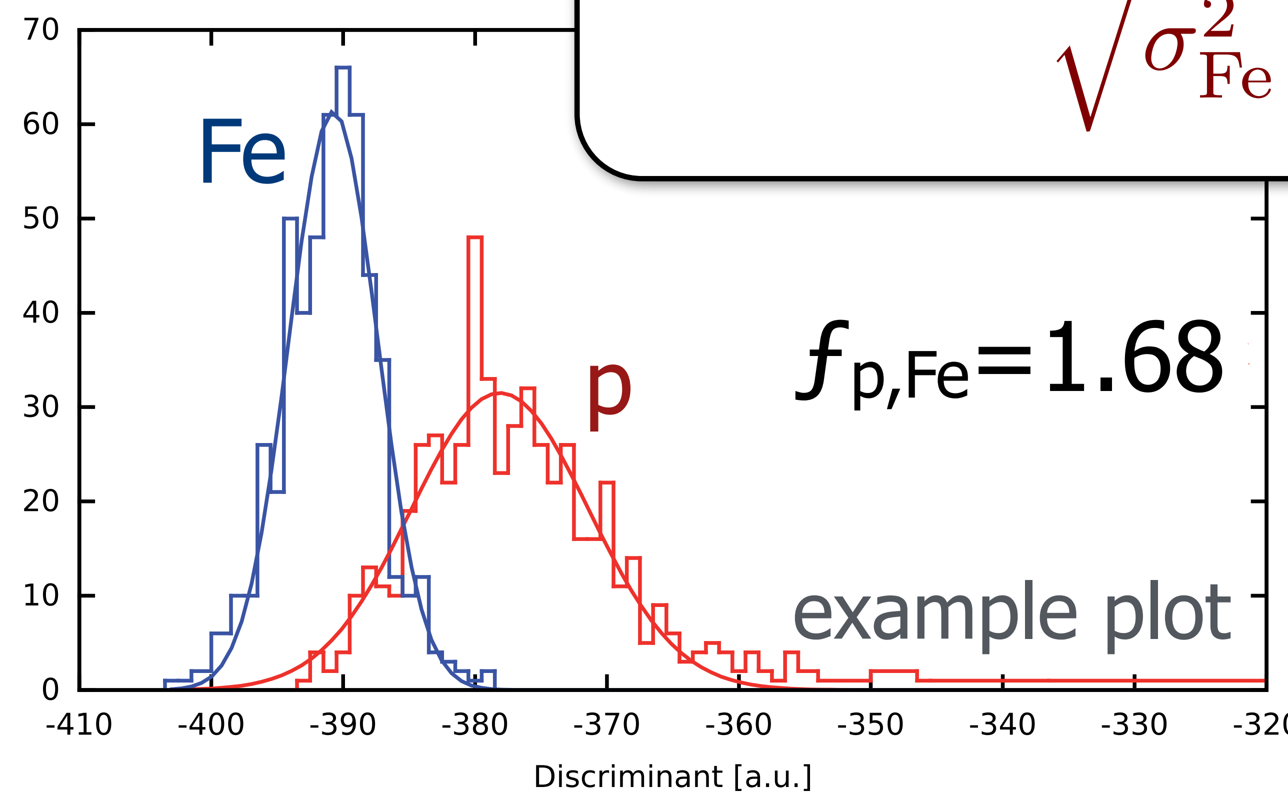
performance then studied
- per station and
- per event

Note: enhanced SD helps also improving photons and neutrino detection

⇒ M. Settimo, tomorrow

➡ **Merit Factor** (discrimination power):

$$f_{p,\mathrm{Fe}} = \frac{|\langle S_{\mathrm{Fe}} \rangle - \langle S_p \rangle|}{\sqrt{\sigma^2_{\mathrm{Fe}} + \sigma^2_p}}$$



3) Extended Operation of FD-Telescopes

Present FD data taking:

- illuminated fraction of moon < 70%
- longer than 3 hrs below horizon

⇛ 22% theoretical uptime
(-5% bad weather -2% short nights)
~ 15% effective uptime

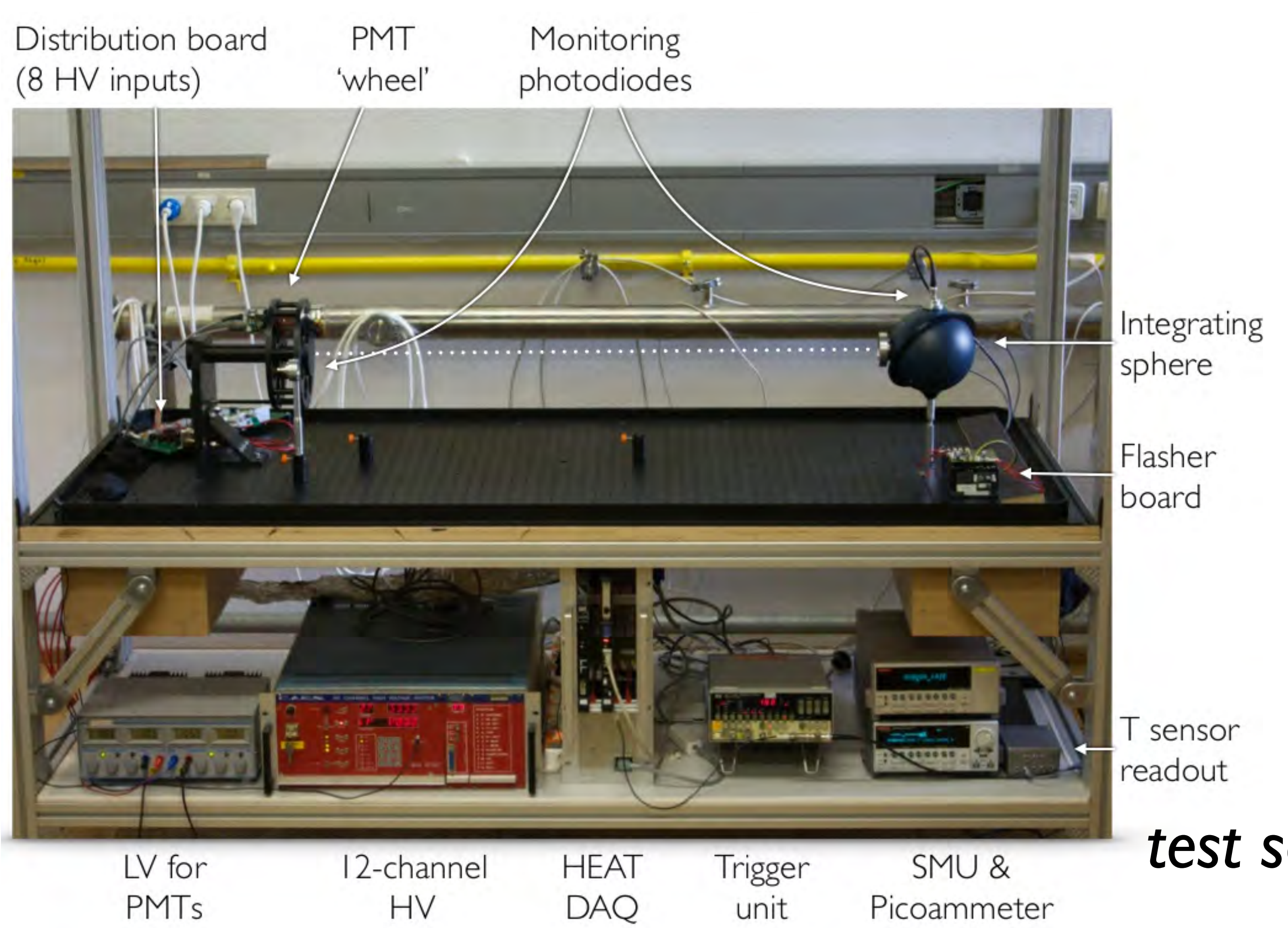
Future plan:

astronom. (nautical) twilight:
sun 18° (12°) below horizon
moon >5° from telescope

~30 % effective uptime

condition	I_A (μA)	σ^2 (ADC^2)
no moon	0.5	25
1/4 moon	5	250
full moon	50	2500

will reduce HV to reduce aging
(effective increase of threshold)

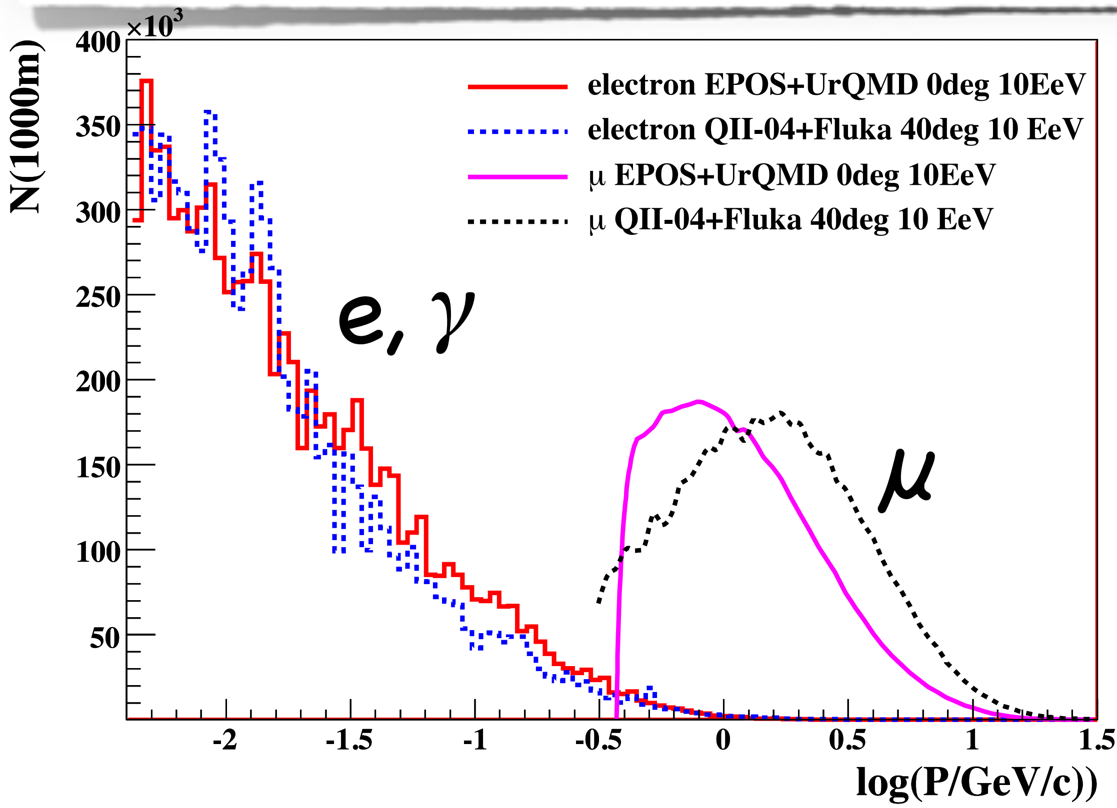


test setup to aging/noise studies

4) High Precision Complementary Array

Primary Aims:

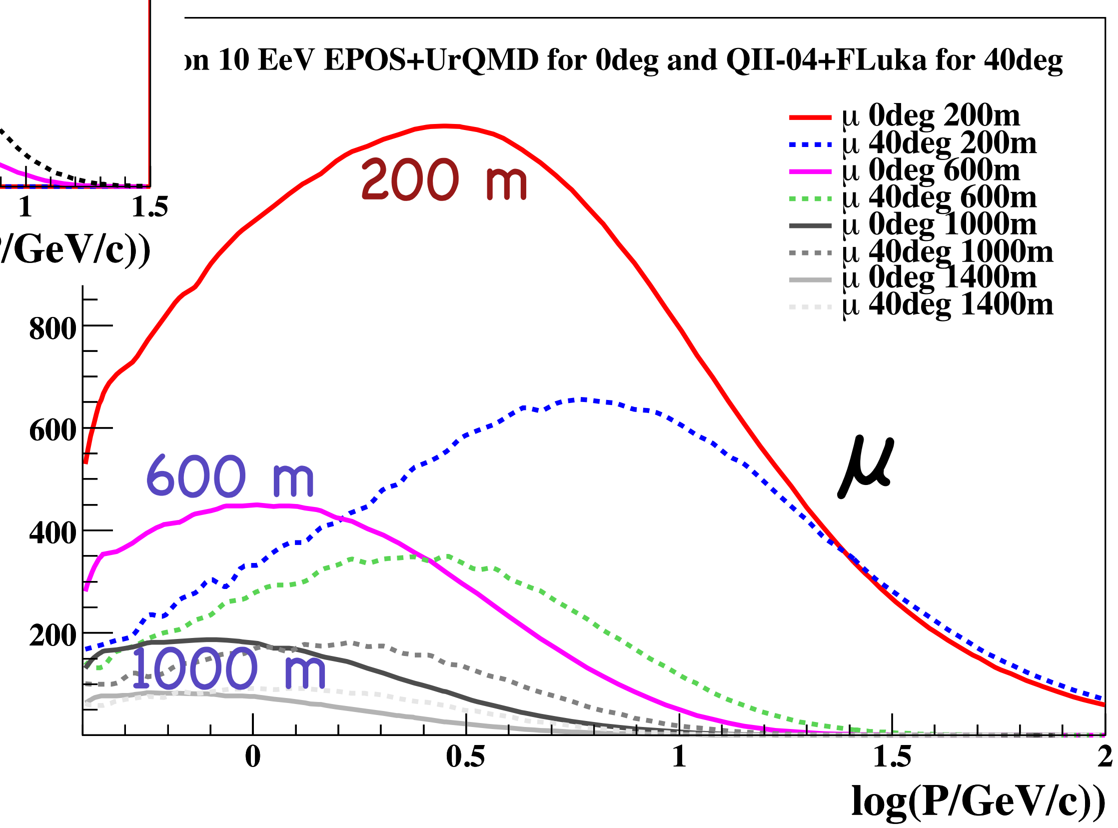
- Complementary (and high-precision) measurement of S_{em} / S_{μ} for fraction of events
- Cross-check of S_{em} / S_{μ} separation of individual upgraded detector stations
- improve understanding of particle physics models



Particle energy spectra at 1000m

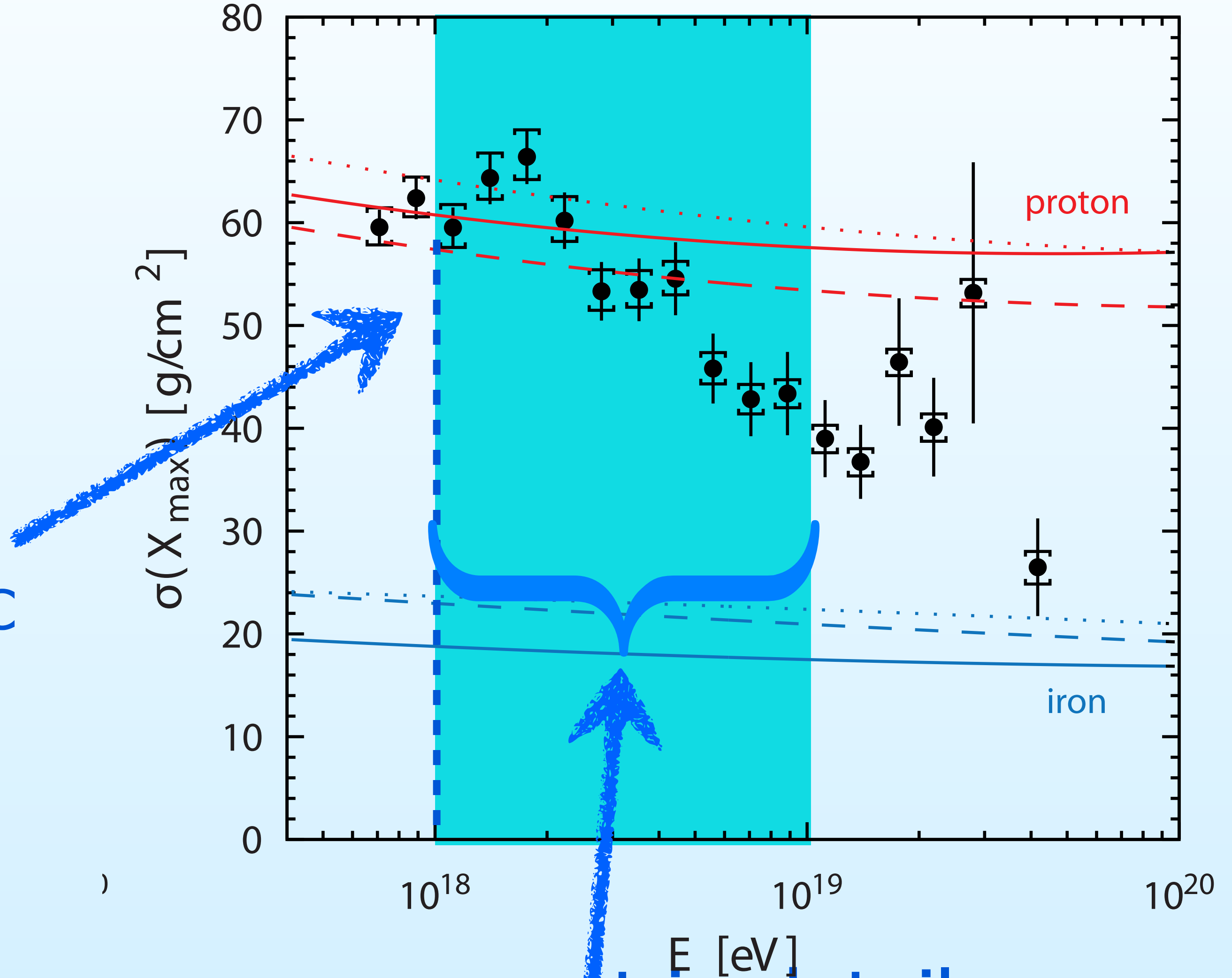
muon energy distr. highly variable and model dependent

(Simulations by Tanguy Pierog)



- Electrons and photon distributions universal to very good degree
- Muon energy distribution highly variable (and model dependent)

High Precision Array: Optimal E-range



E_{CM} = 3*E_{LHC}
p dominated

study X_{max}, em-, μ-component in detail

➔ change of composition or change of hadr. interaction ?
E_p @ $5 \cdot 10^{18}$ eV anchor point for E_{Fe} @ 10^{20} eV

e.g. **O(100 km²)** ⇒ 30/yr @ ≥10^{19} eV

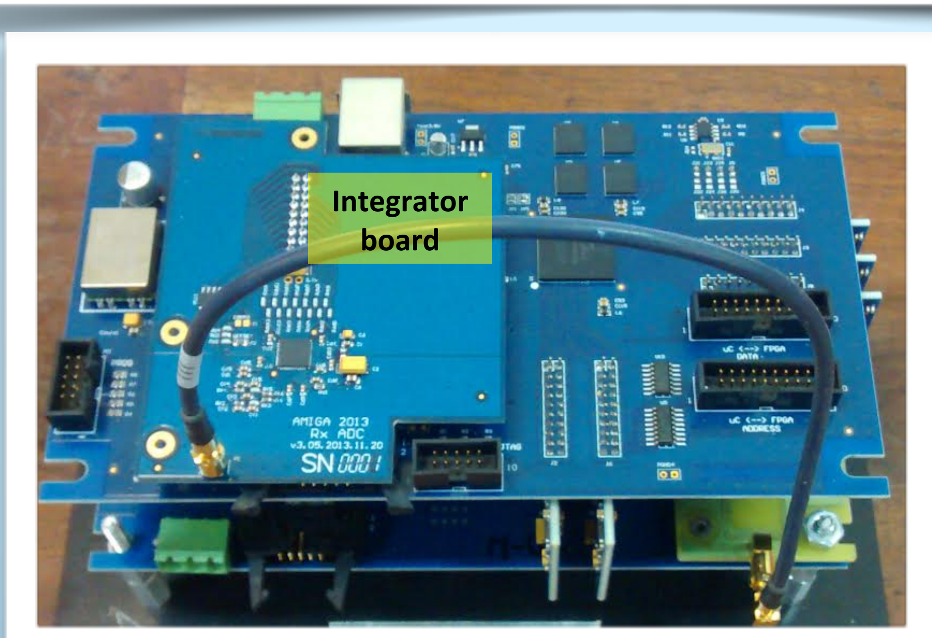
61 stations @ infill + 40 @ 1500 m

High Precision Array

Scintillators shielded by tank and concrete…

Two options considered

… or by 1.5 m soil



Documentary: CDR, PDR, TDR...

y Positive Evaluation by International Science
Advisory Committee

PIERRE
AUGER
OBSERVATORY

Plans for a Proposal to Upgrade the Pierre Auger Observatory

Pierre Auger Collaboration

October 28, 2013

Submitter: Pierre Auger Collaboration
Observatorio Pierre Auger,
Av. San Martin Norte 304,
5613 Malargüe,
Argentina

Review of ongoing R&D
in March 2014

PIERRE
AUGER
OBSERVATORY

Proposal for Detector Upgrade

OVERVIEW

Pierre Auger Collaboration

October 27, 2013

Submitter: Pierre Auger Collaboration
Observatorio Pierre Auger,
Av. San Martin Norte 304,
5613 Malargüe,
Argentina

Time Line

	2013				2014				2015				2016				2017				2018			
Science Proposal subm			•																					
Review of Science Proposal					•																			
Prototyping in field			X	X	X	X																		
Selection of Prototype							[•]																	
Submission of TDR								•																
Final Evaluation								X																
Seeking funds / **construction**								[•]		X	X	X	X	X	X	X	X	X						
take data													X	X	X	X	X	X	X	X	X	X	X	→
upgrade finished																						•		

- Selection of full array upgrade option very soon
- Data taking into 2023 will double the statistics of all data up to 2015

Estimates of Costs (investment and personell)

WBS-Estimates: **~ 10-12 M€**

This includes (at least part of) prototyping and engineering

Nearly all of the materials, services and effort to implement the upgrade will be provided by in-kind contributions from the collaborating countries

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	Sum
Funding Upg (M€)	0,0	0,5	4,0	4,0	2,5	0,5	0,0	0,0	0,0	0,0	0,0	11,5
Operation (M€)	1,4	1,4	1,5	1,5	1,5	1,6	1,6	1,6	1,6	1,6	1,6	16,9
Researchers	525	525	525	525	525	525	525	525	525	525	525	
Engineers (FTE)	1,5	4	4	4	1,5	0	0	0	0	0	0	15

Summary: Auger Upgrade

Precise UHECR measurements lead to many surprising results and new questions

Need to resolve open puzzles

Observatory in unique position and collaboration is ready to go

Decisive for future experiments