Super-Preshowers

Astro Particle School 2016 in Obertrubach-Bärnfels

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12^{th} October 2016

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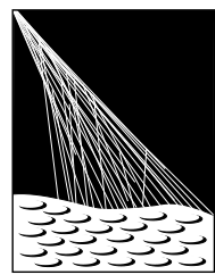
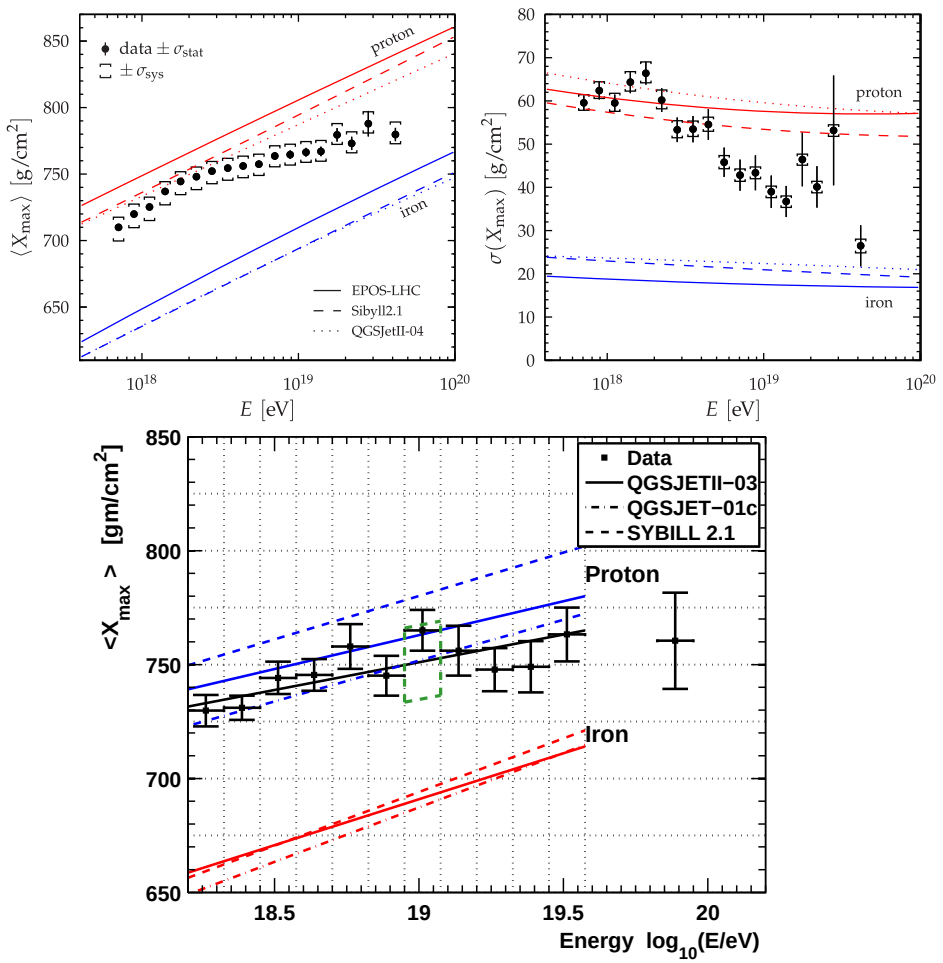


PIERRE
AUGER
OBSERVATORY

Motivation

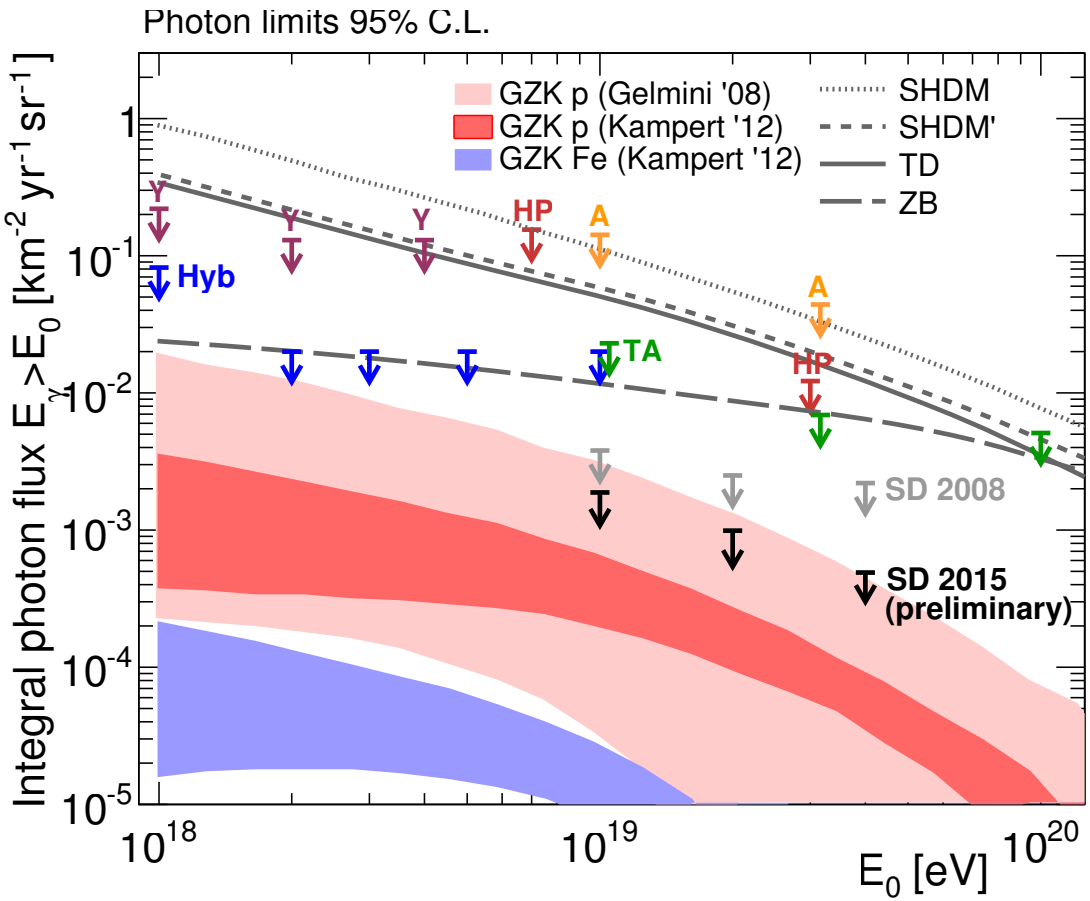
Observations at Pierre Auger:

- tension in Stereo and Hybrid data (Master thesis Markus Schauer) dependent on $B_\perp$ (?) and E (like preshowers)
- composition puzzle:
  - $\sigma(X_{max})$ shows heavier composition than $\langle X_{max} \rangle$
  - inconsistencies between Auger and TA
  - muon excess (inconsistent with hadronic interaction models)

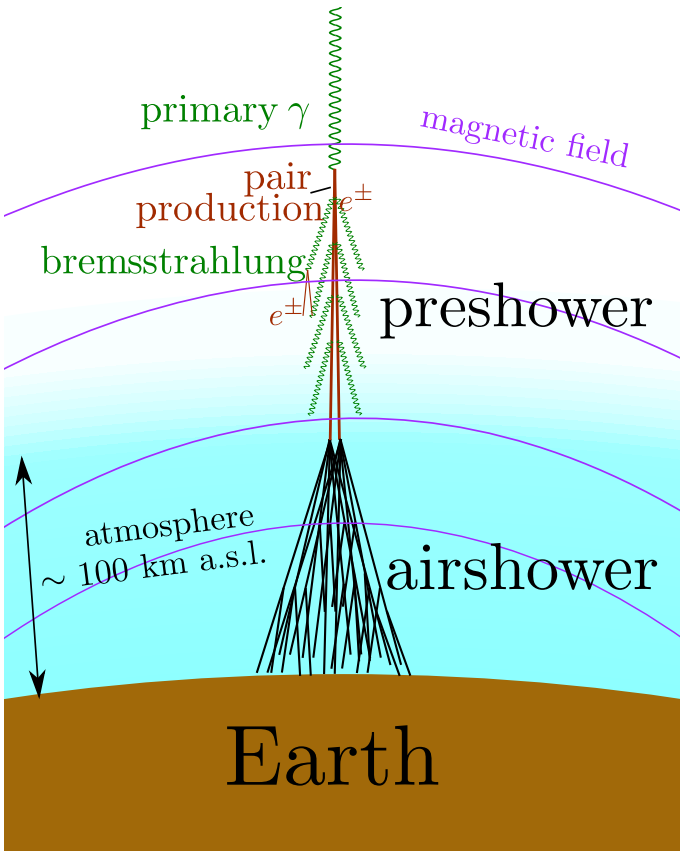


Motivation

- possible explanation: higher photon fraction + super-preshowers (SPS)?
- higher photons fractions imply exotic production models

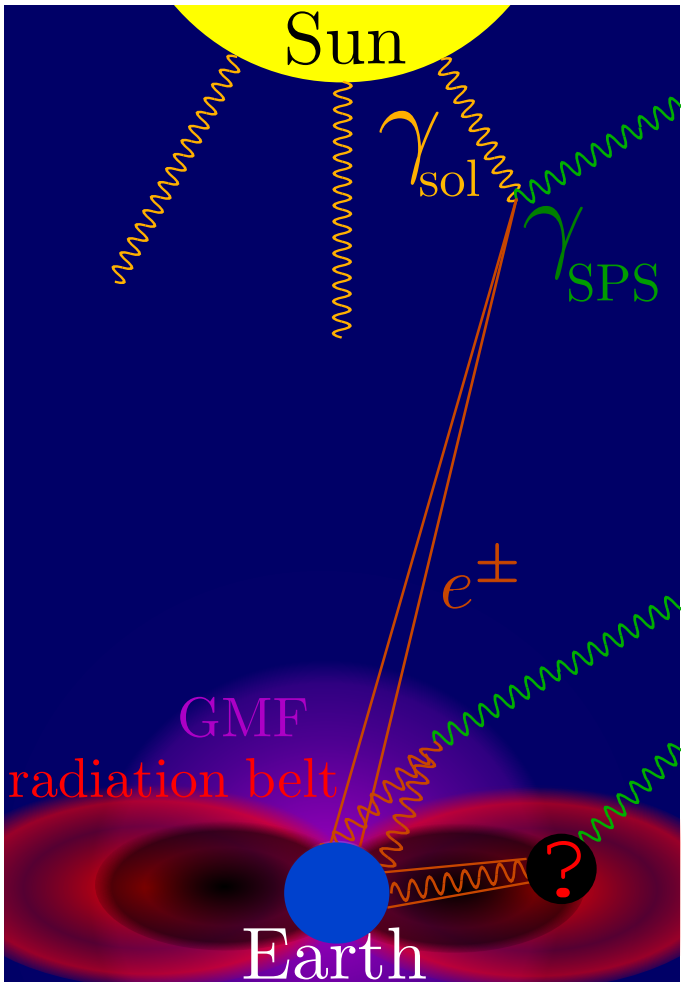


SPSs vs. preshowers



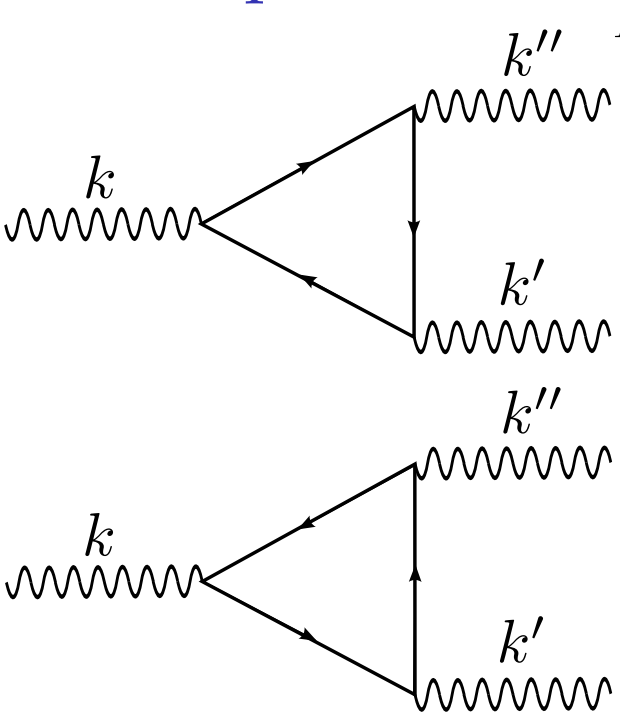
- preshower process:
  - pair production (PP) in geomagnetic field (GMF)
  - bremsstrahlung by $e^{\pm}$ in GMF
  - dependent on $B_{\perp}$ and E_{γ}

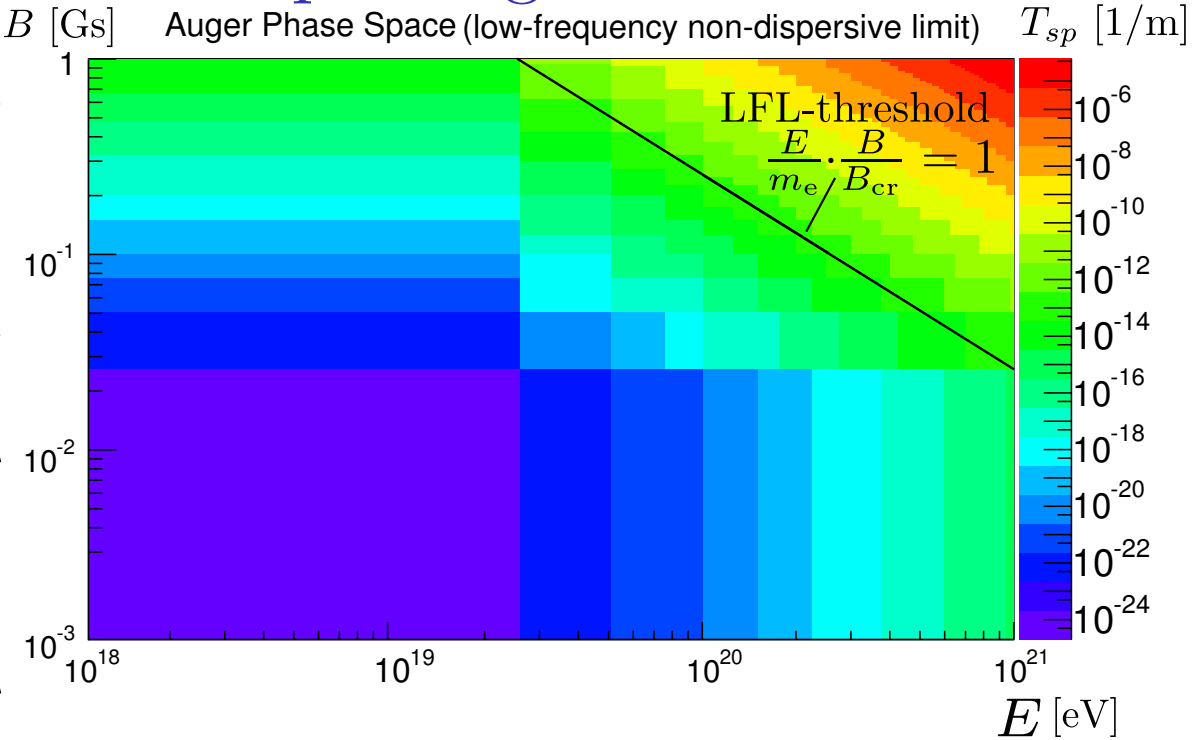
SPSs vs. preshowers



- SPSs occur at higher altitudes
  $\rightarrow$ PP in GMF too unlikely for SPSs!
- candidate mechanisms:
  - photon splitting in (geo-)magnetic field
  - pair production with solar photons
  - interactions in radiation belts (not yet studied)
- analysis:
  1. calculate probability of proposed mechanisms
  2. simulate SPS-induced air showers

Possible processes: Photon splitting





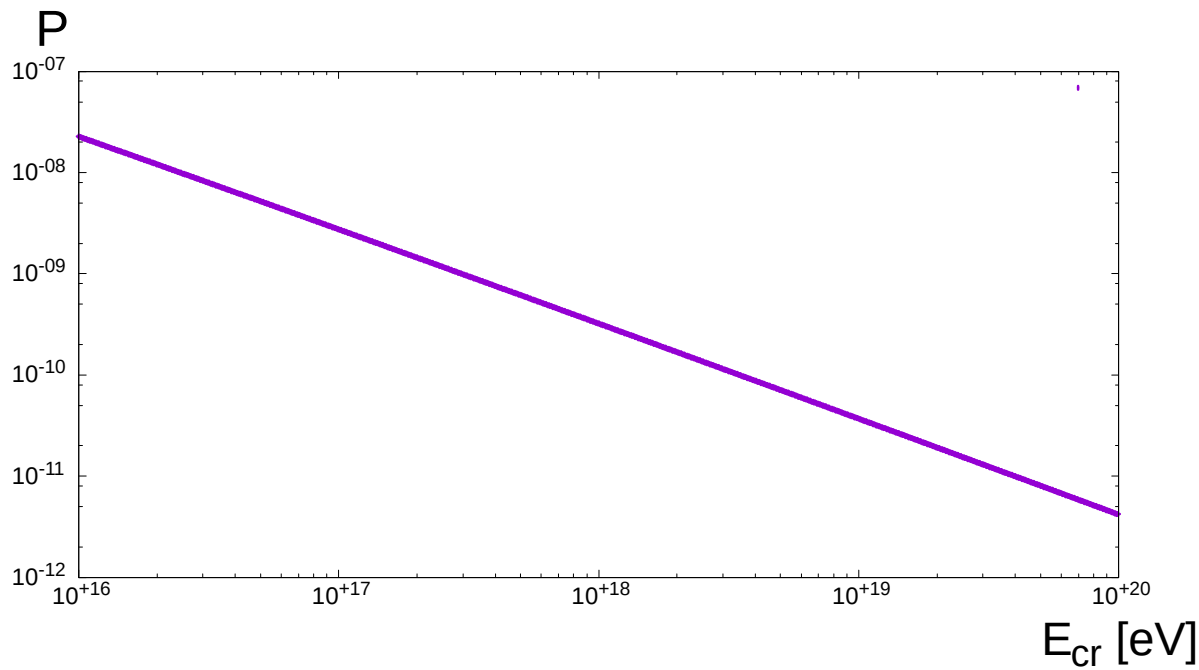
- photon splitting (PS) competing process to pair production (PP)
- PS can dominate PP for high B and low E $\rightarrow$ maybe also for Auger conditions?
- absorption coefficient too small in low-frequency limit (LFL)
- not clear for larger B and E (no convergence with literature outside LFL)

Possible processes: Pair production with solar photons

number density (from solar output/blackbody radiation)

$$dP = n \quad \sigma \quad dx$$

X-section (from literature on QED, e.g. Greiner) thickness of layer



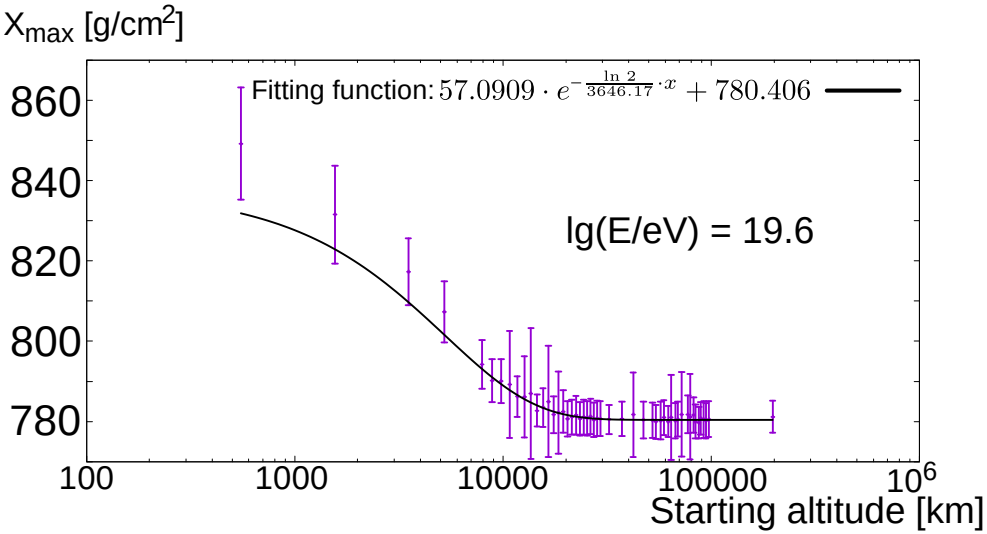
$\rightarrow$ probability (after x = 1 AU) $\lesssim 10^{-8}$; too low!

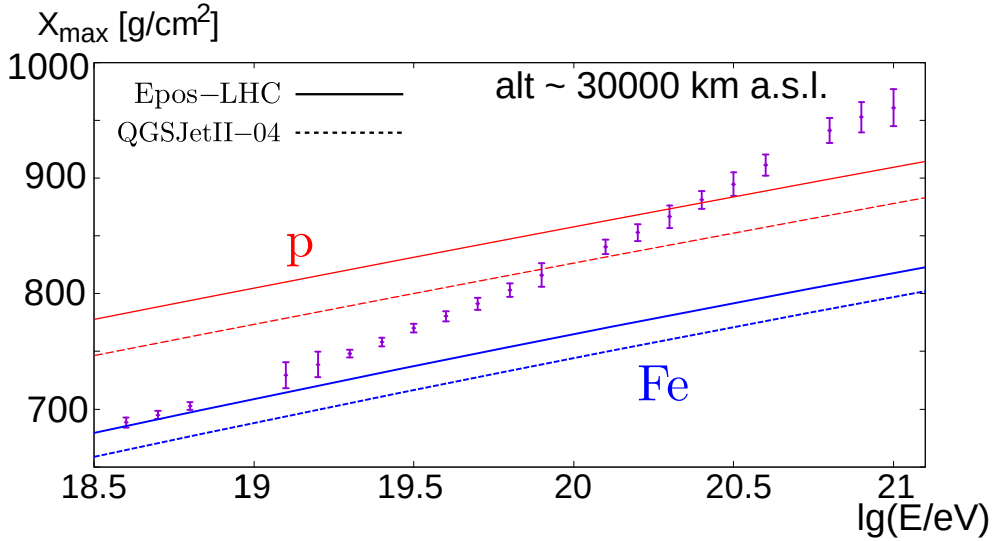
Simulations with CONEX

- analyse effect of SPSs on observables
- here: energy deposit (X_{max} and longitudinal profile) and muon production (N_μ and dN_μ)
- implement SPSs in simulation code (PRESHOWER) by forcing first conversion

X_{max} vs. E

- X_{max}(alt) and X_{max}(E)
- arrival direction: $\theta = 60°$, $\phi = 180°$ (strong $B_\perp$ direction)

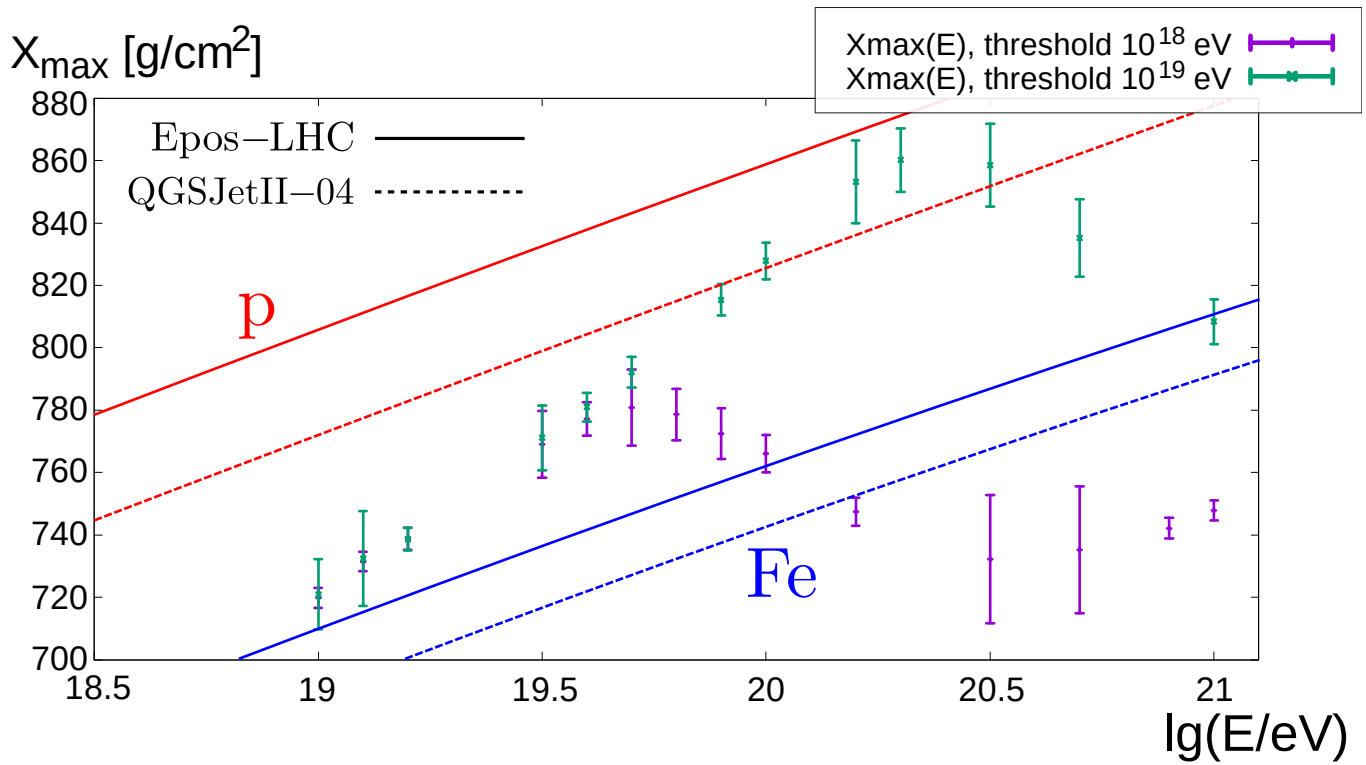




→ within hadronic range for large energy range
(above lg(E/eV) > 20.5 no data!)

X_{max} vs. E

- secondary interactions: conversions for all photons energies above E_{thresh} (all at once!)
- shower configuration: strong $B_{\perp}$ direction

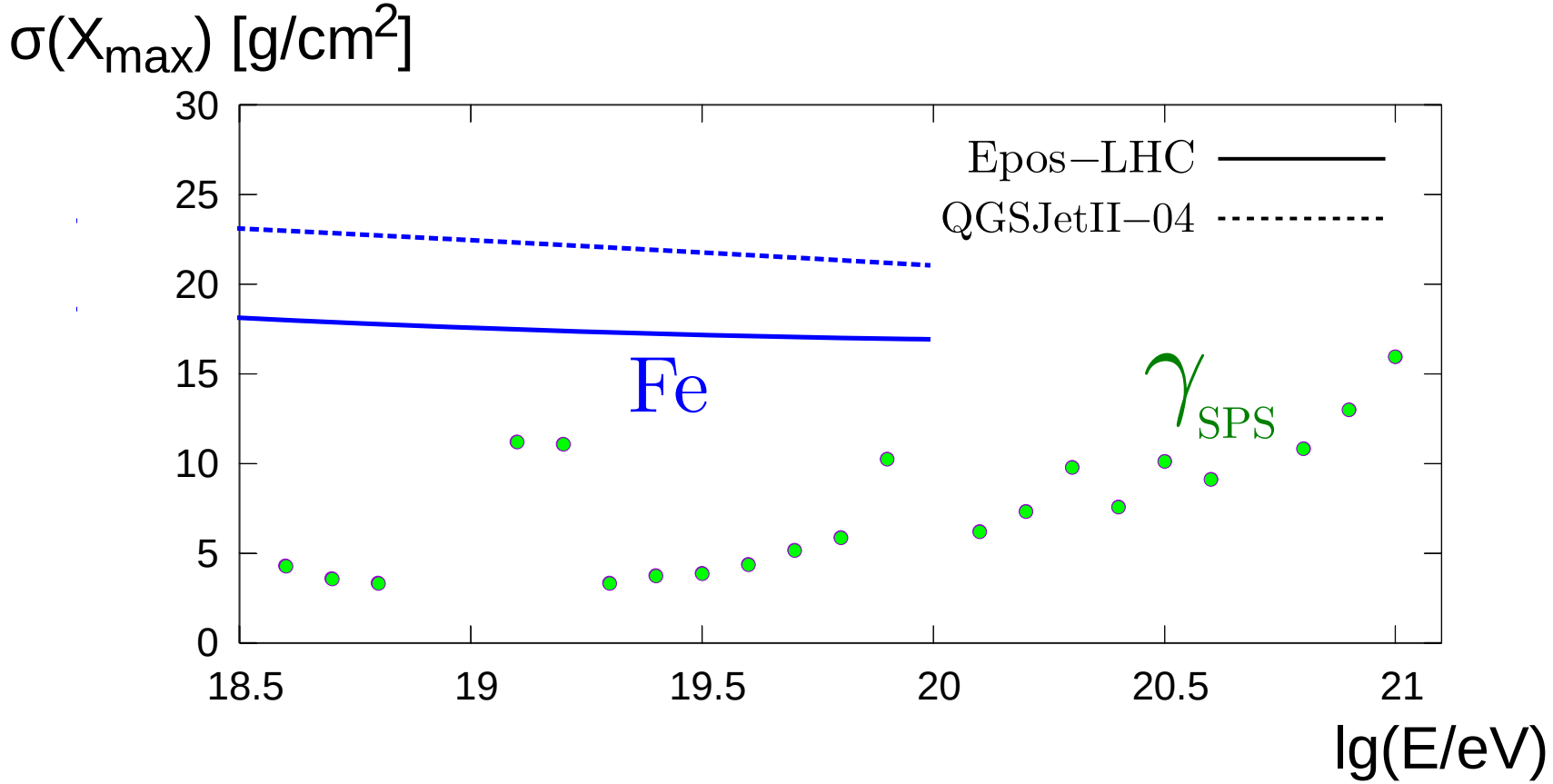


→ potential extension of acceptable range

→ details depend on processes (this is just "proof of concept")

$\sigma(X_{max})$ vs. E

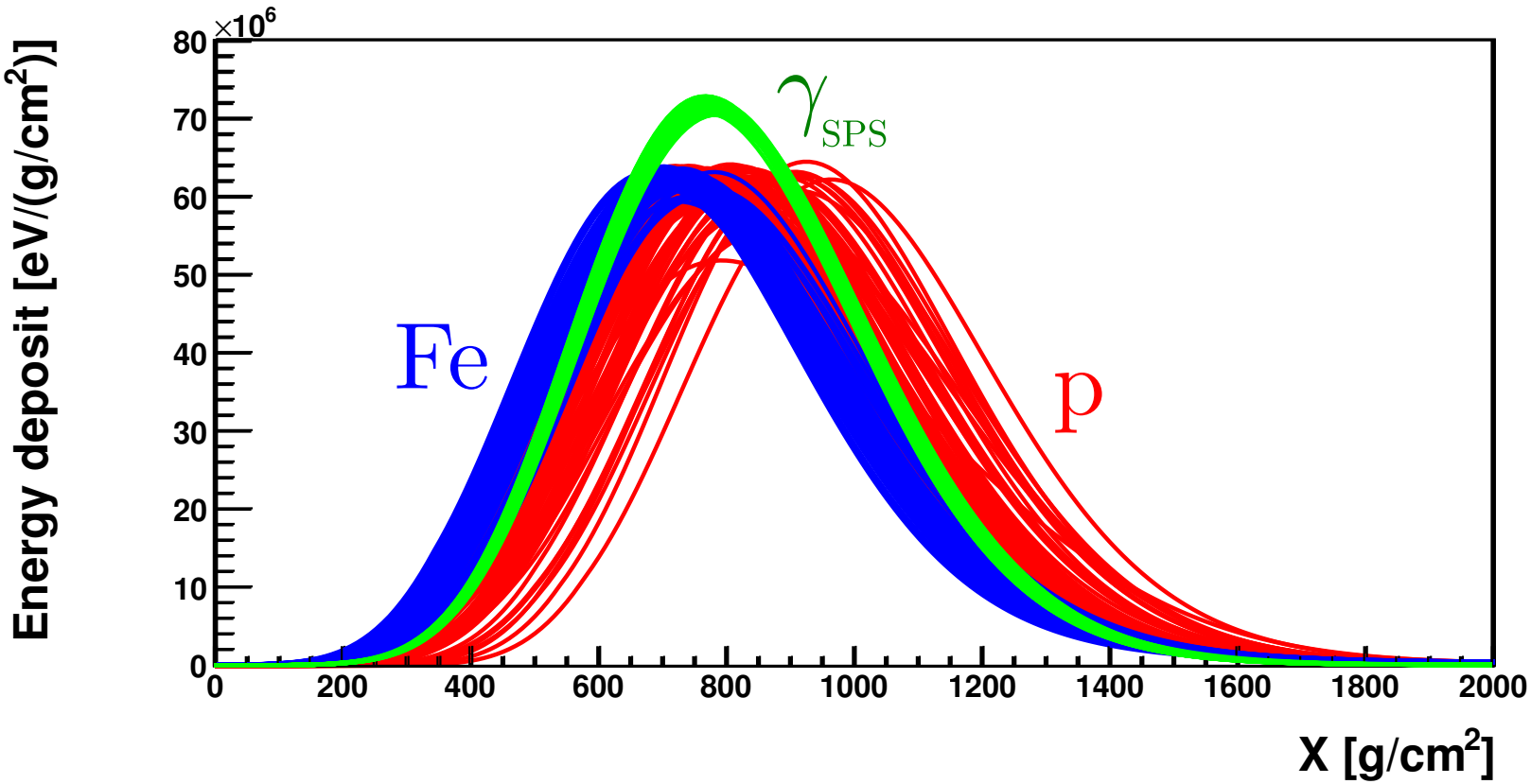
- shower configuration: strong $B_\perp$ direction; $\lg(E/eV) = 19.6$
- note: no error bars, "jumps" due to small number of showers



$\rightarrow \gamma$ showers have less shower-to-shower fluctuations than hadrons!

Longitudinal profile of dE/dX

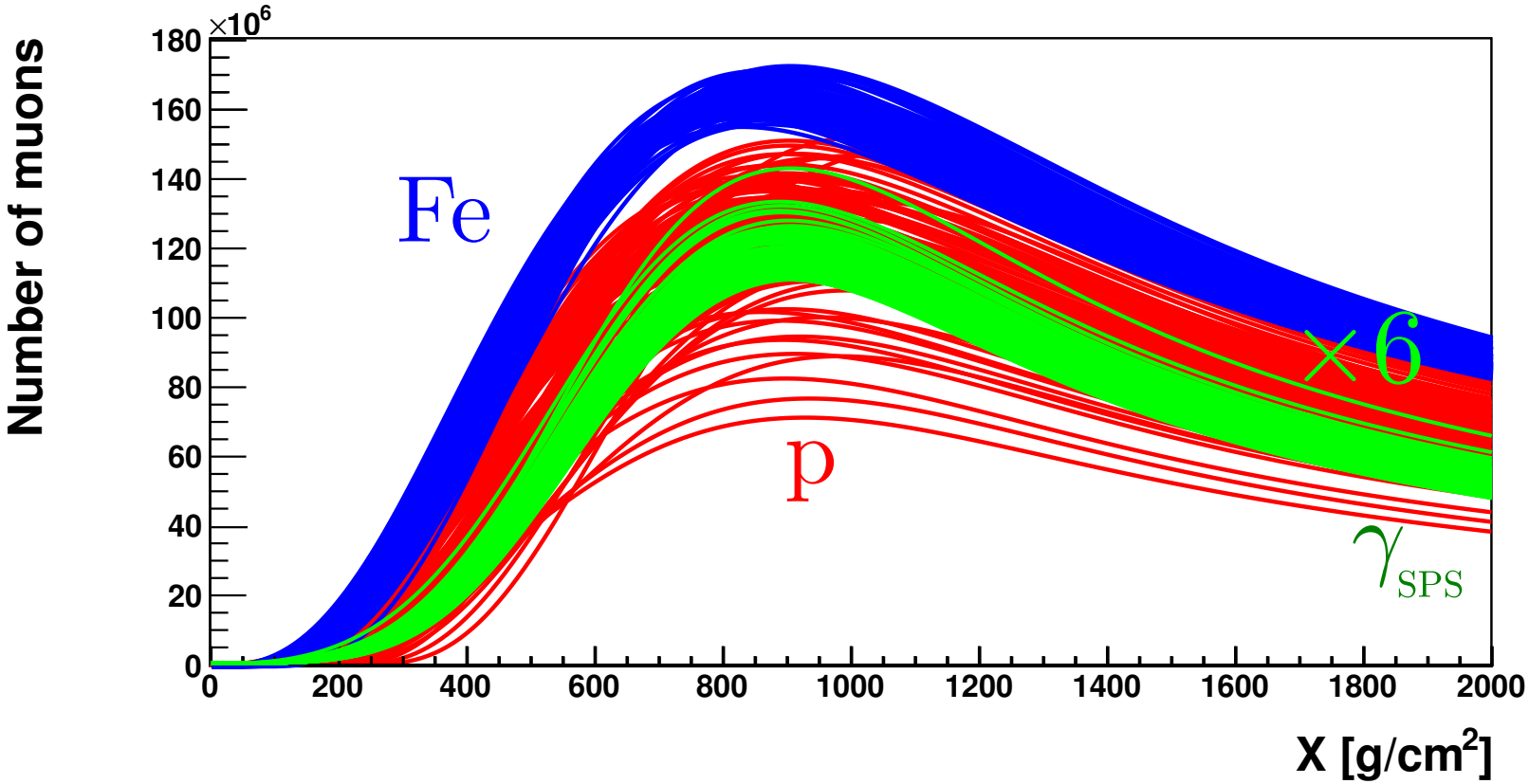
- shower configuration: strong $B_\perp$ direction; $\lg(E/eV) = 19.6$



→ longitudinal profiles also very similar (apart from shower-to-shower fluctuations)

Muon production

- shower configuration: strong $B_\perp$ direction; $\lg(E/eV) = 19.6$



→ lower muon production for SPS, but not so severe (maybe underestimation of energy? Photonuclear X-section?)

Summary and outlook

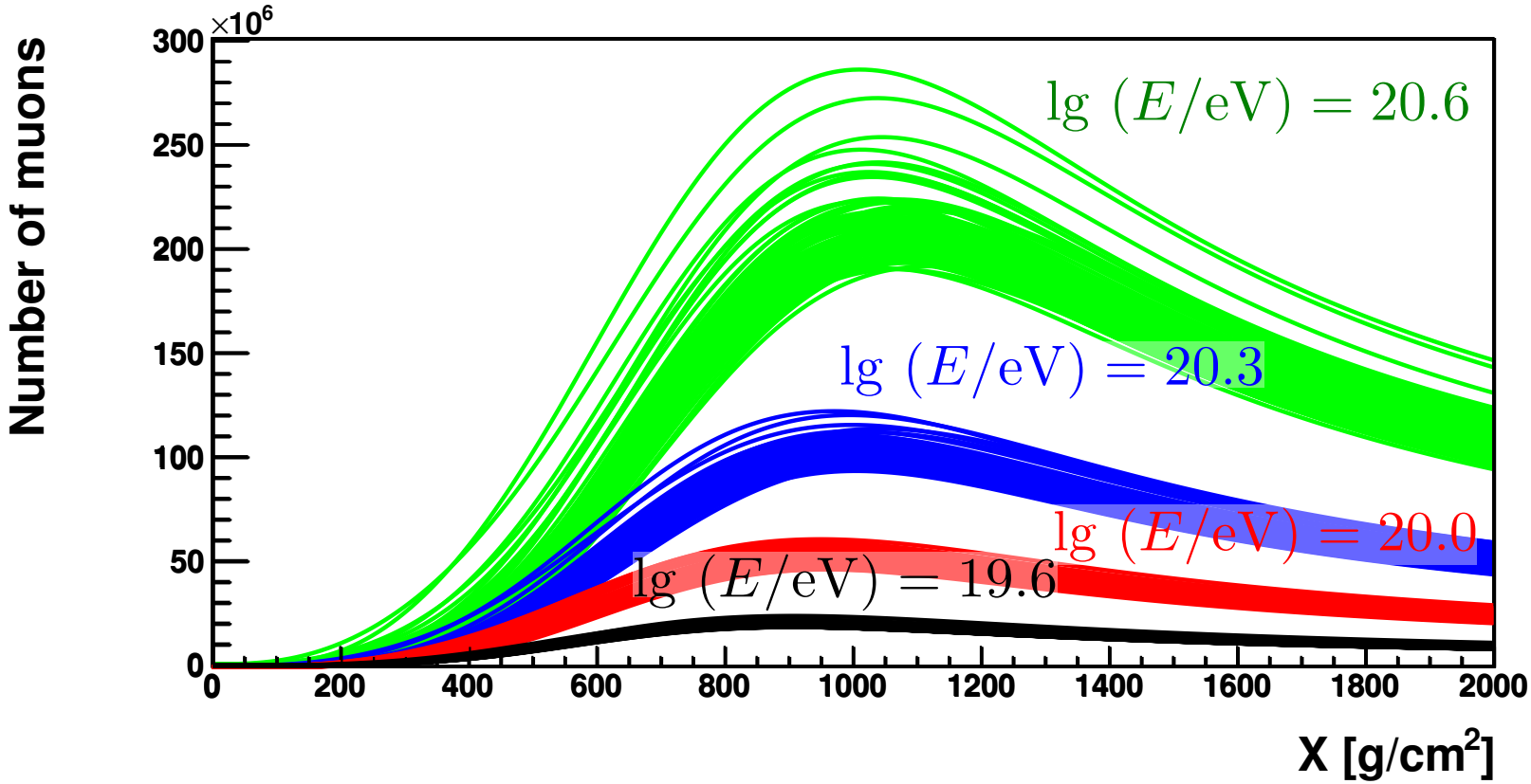
Summary:

- composition puzzle: not necessarily hadronic
  - SPSs could mimic hadronic showers for large energy range
  - SPSs may explain discrepancies and inconsistencies mentioned in motivation
- muon excess:
  - underestimation of energy for SPSs?
  - larger photonuclear X-section?
- no SPS process identified sofar! PP with solar photons ruled out!

Outlook:

- interactions in radiation belts a possible SPS mechanism?
- comparison for more shower observables (e.g. rise time)
- comparison with exotic production models (including E_{thresh}, other components, SPS simulations ...)

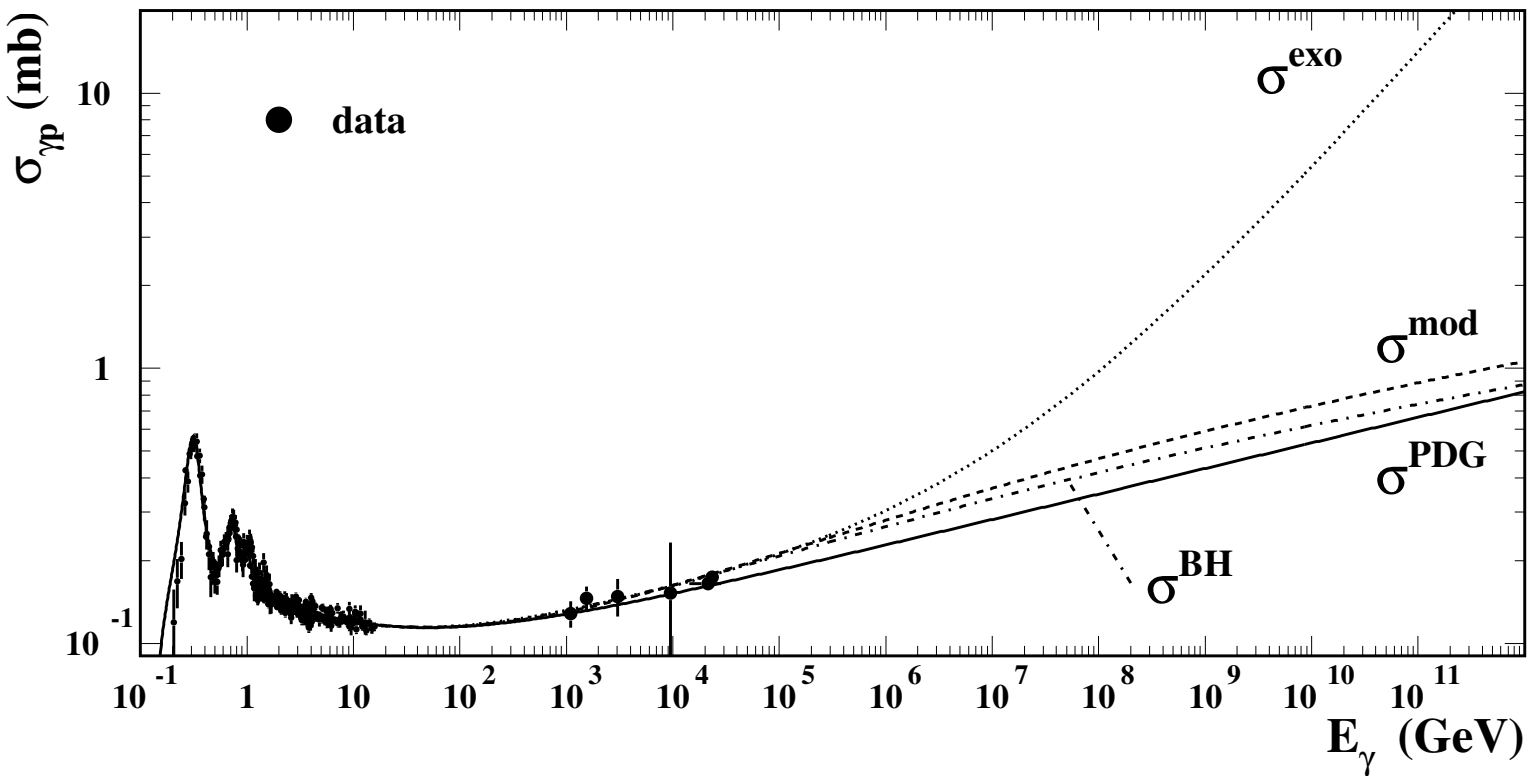
Muon production



- number of muons increases with energy

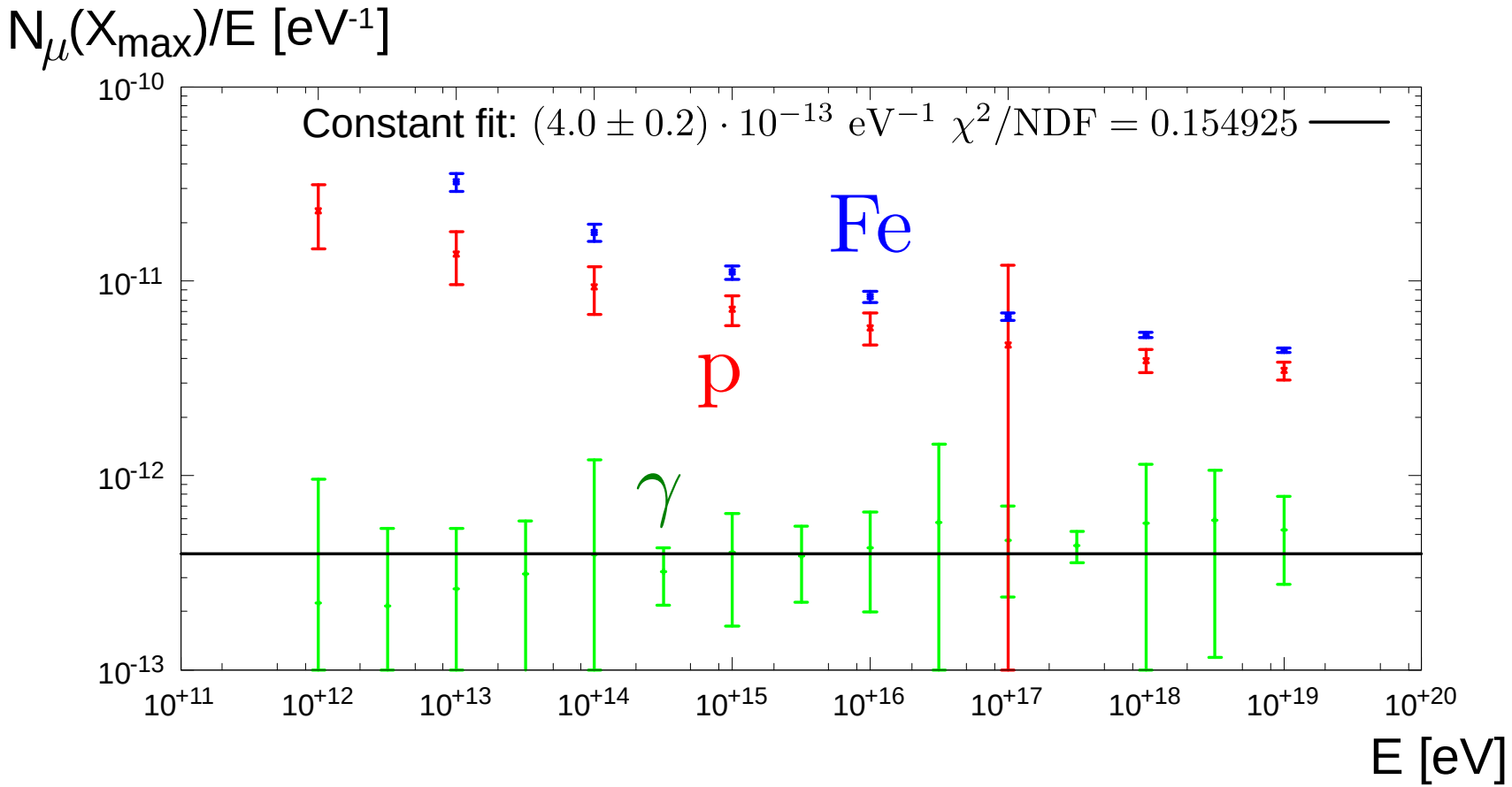
SPS simulations – N_μ

- photonuclear X-section extrapolated from lower energies
- higher values depending on model; normally, PDG trend used



Muon production

- not so consistent:



- muon production X-sections not dependent on E for γ
- does this make sense for SPS (with many low-energy photons)?