UHE Cosmic Rays: The LHC link

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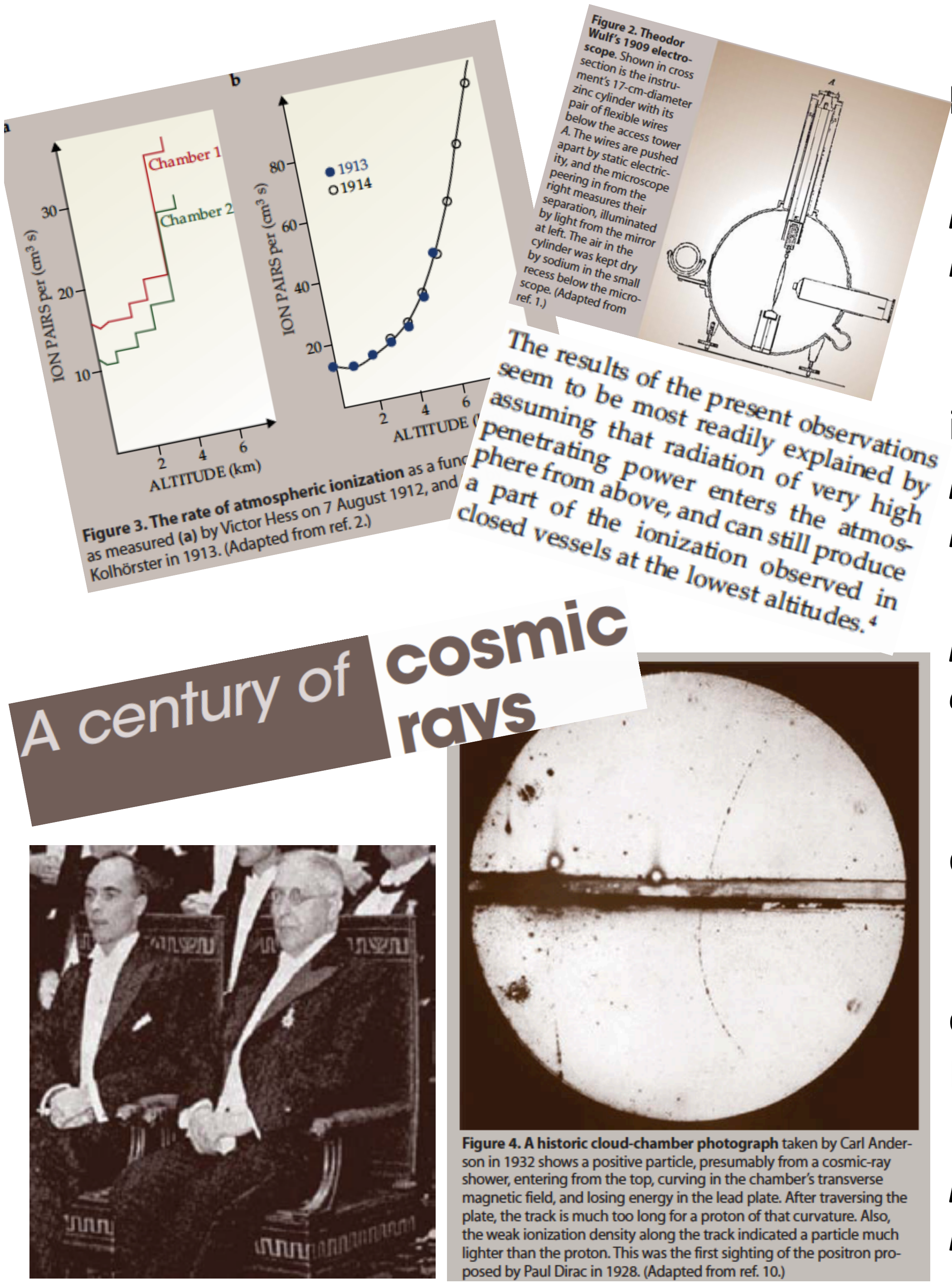
It is likely that further research into "showers" and "bursts" of the cosmic rays may possibly lead to the discovery of still more elementary particles, neutrinos and negative protons, of which the existence has been postulated by some theoretical physicists in recent years.

Victor Hess

Partikeldagarna, Stockholm, 26 November 2012



Per Carlson (Physics Today, Feb 2012)

1912: Victor Hess discovers cosmic rays – **Nobel Prize 1936**

*[1928: Paul Dirac predicts antimatter – **Nobel Prize** (shared with Erwin Schrodinger) **1933**]*

1932: Carl Anderson discovers the positron in cosmic rays *using a cloud chamber [invented by C T R Wilson in 1911 - **Nobel Prize 1927**]* **- Nobel Prize 1936**

*[1935: Hideki Yukawa predicts the existence of mesons – **Nobel Prize 1949**]*

1937: Seth Neddermeyer & Carl Anderson discover the muon in cosmic rays

1947: Cecil Powell discovers the pion in cosmic rays **– Nobel Prize 1950**; George Rochester & Clifford Butler discover the kaon

*[Patrick Maynard Stuart Blackett awarded **Nobel Prize 1948** "for his development of the Wilson cloud chamber method"]*

So there were indeed more fundamental discoveries in cosmic rays ... until accelerators took over the show in the '60s - but what have cosmic rays done for high energy physics since then?

Review of the safety of LHC collisions

John Ellis[1], Gian Giudice[1], Michelangelo Mangano[1], Igor Tkachev[2] and Urs Wiedemann[1] (LHC Safety Assessment Group)

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Abstract

The safety of collisions at the Large Hadron Collider (LHC) was studied in 2003 by the LHC Safety Study Group, who concluded that they presented no danger. Here we review their 2003 analysis in light of additional experimental results and theoretical understanding, which enable us to confirm, update and extend the conclusions of the LHC Safety Study Group. The LHC reproduces in the laboratory, under controlled conditions, collisions at centre-of-mass energies, less than those reached in the atmosphere by some of the cosmic rays that have been bombarding the Earth for billions of years. We recall the rates for the collisions of cosmic rays with the Earth, Sun, neutron stars, white dwarfs and other astronomical bodies at energies higher than the LHC. The stability of astronomical bodies indicates that such collisions cannot be dangerous.

... without high energy cosmic rays there may have been no LHC!

European Organization for Nuclear Research

The safety of the LHC

The Large Hadron Collider (LHC) can achieve an energy that no other particle accelerators have reached before, but Nature routinely produces higher energies in cosmic-ray collisions. Concerns about the safety of whatever may be created in such high-energy particle collisions have been addressed for many years. In the light of new experimental data and theoretical understanding, the LHC Safety Assessment Group (LSAG) has updated a review of the analysis made in 2003 by the LHC Safety Study Group, a group of independent scientists.

The experiments that we will do with the LHC have been done billions of times by cosmic rays hitting the Earth. ... They're being done continuously by cosmic rays hitting our astronomical bodies, like the moon, the sun, like Jupiter and so on and so forth. And the Earth's still here, the sun's still here, the moon's still here. LHC collisions are not going to destroy the planet.

John Ellis

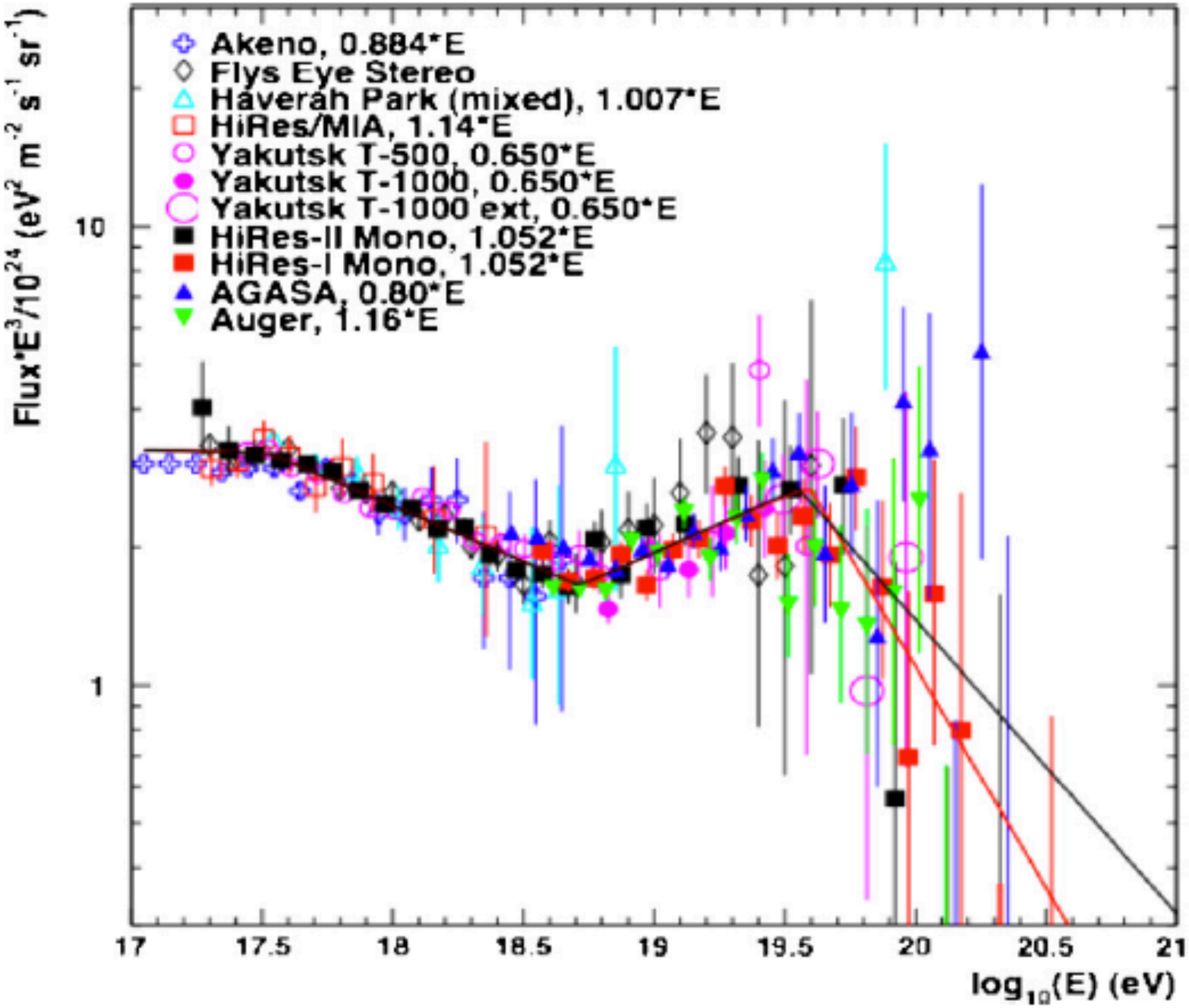


Figure 1. The spectrum of ultra-high-energy cosmic rays, as measured by several experiments [4]. Every cosmic ray with an energy shown in this plot, namely above 10^{17} eV, liberates in its collision with the atmosphere more energy, in the centre-of-mass frame, than does a proton–proton collision at the LHC.

As seen in figure 1, the highest energy cosmic rays observed attain energies of around 10^{20} eV, and the total flux of cosmic rays with energies of 10^{17} eV or more that hit each square centimetre of the Earth's surface is measured to be about 5×10^{-14} per second [4]. The area of the Earth's surface is about 5×10^{18} cm^2, and the age of the Earth is about 4.5 billion years. Therefore, over 3×10^{22} cosmic rays with energies of 10^{17} eV or more, equal to or greater than the LHC energy, have struck the Earth's surface since its formation. This means[4] that Nature has already conducted the equivalent of about a hundred thousand LHC experimental programmes on Earth, and the planet still exists.

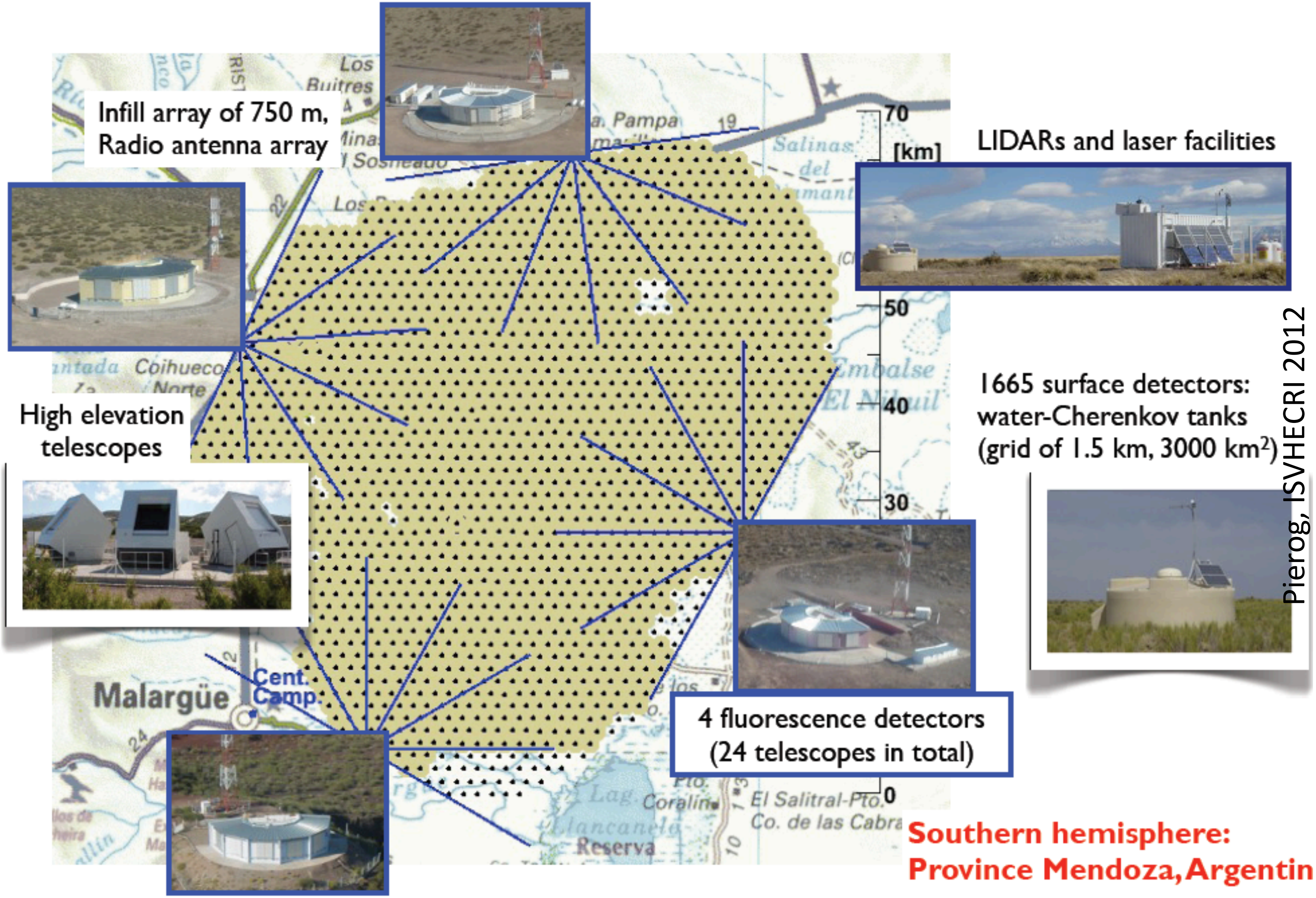
Other astronomical bodies are even larger. For example, the radius of Jupiter is about ten times that of the Earth, and the radius of the Sun is a factor of 10 larger still. The surface area of the Sun is therefore 10 000 times that of the Earth, and Nature has therefore already conducted the LHC experimental programme about one billion times[4] via the collisions of cosmic rays with the Sun, and the Sun still exists.

Moreover, our Milky Way galaxy contains about 10^{11} stars with sizes similar to our Sun, and there are about 10^{11} similar galaxies in the visible Universe. Cosmic rays have been hitting all these stars at rates similar to collisions with our own Sun. This means that Nature has already completed about 10^{31} LHC experimental programmes since the beginning of the Universe. Moreover, each second, the Universe continues to repeat about 3×10^{13} complete LHC experiments. There is no indication that any of these previous 'LHC experiments' has ever had any large-scale consequences. The stars in our galaxy and others still exist, and conventional astrophysics can explain all the detected astrophysical black holes.

Thus, the continued existence of the Earth and other astronomical bodies can be used to constrain or exclude speculations about possible new particles that might be produced by the LHC.

[4] This estimate would be reduced by a factor approximately equal to A if all the ultra-high-energy cosmic rays were nuclei with an atomic number A, since the cosmic-ray spectrum falls like $1/E^3$ at high energies, as seen in figure 1.

The Pierre Auger Observatory



Southern hemisphere:
Province Mendoza, Argentin

Pierog, ISVHECRI 2012

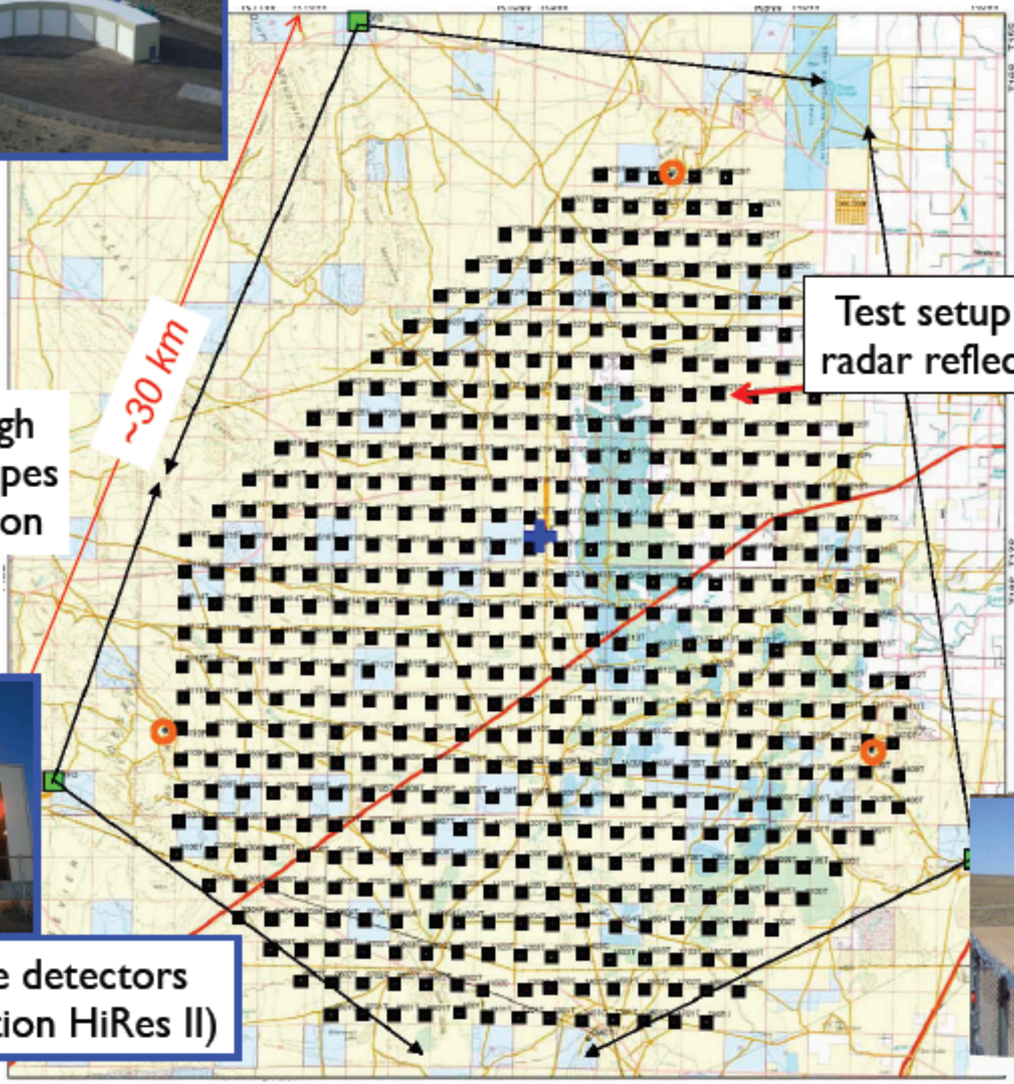
Telescope Array (TA)

Middle Drum: based on HiRes II

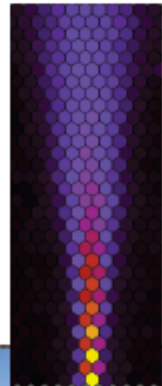
LIDAR
Laser facility

Infill array and high
elevation telescopes
under construction

3 fluorescence detectors
(2 new, one station HiRes II)



507 surface detectors:
double-layer scintillators
(grid of 1.2 km, 680 km^2)



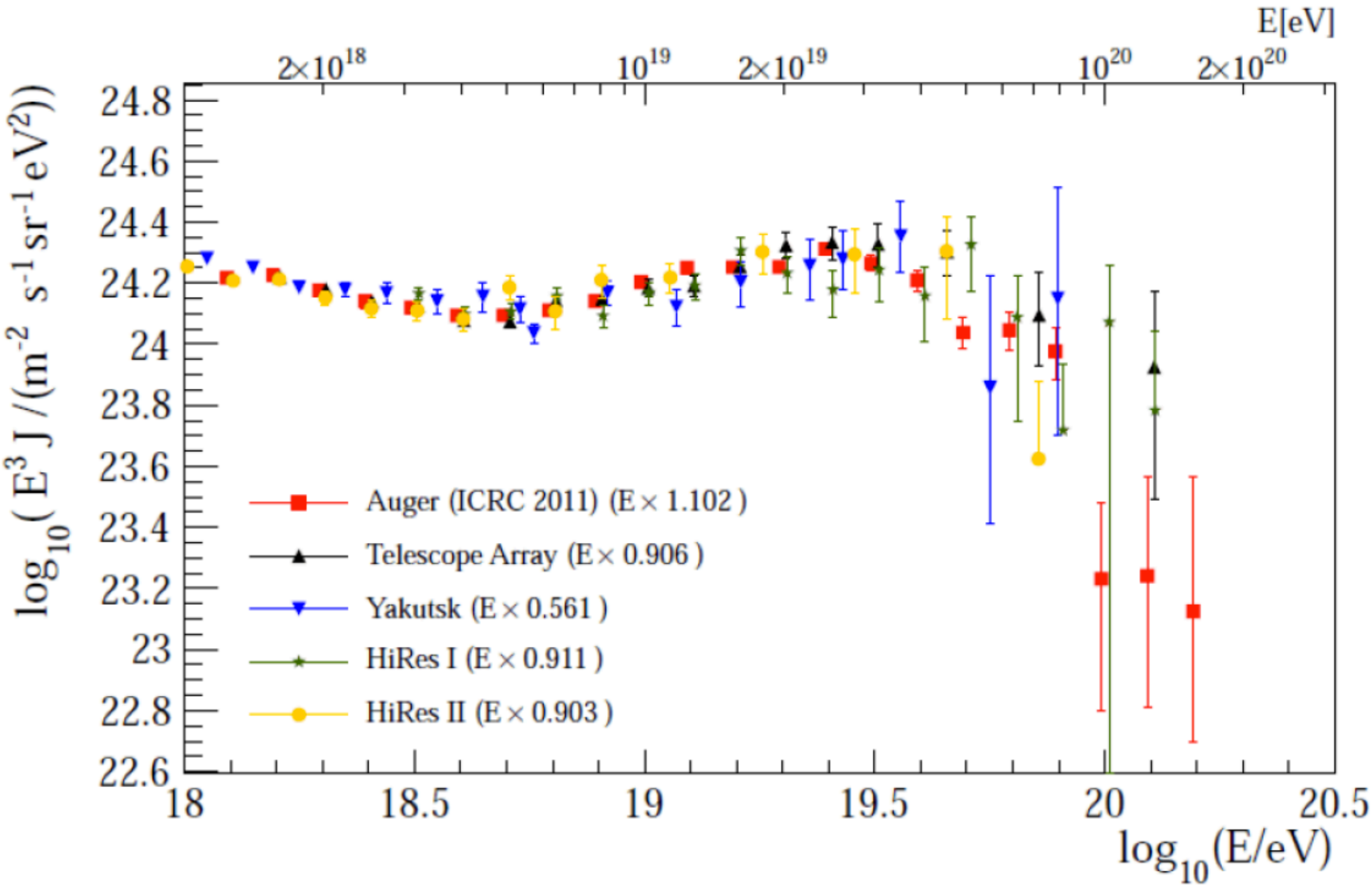
Electron light source
(ELS): ~40 MeV

Northern hemisphere: Utah, USA

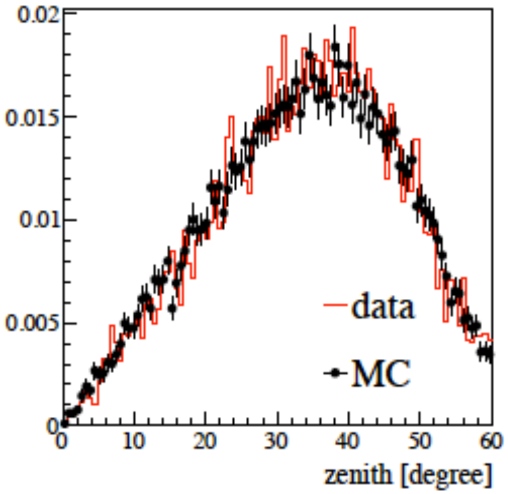
All experiments measuring UHE cosmic rays now give *consistent* results

(after suitable rescaling of the energy scale within estimated uncertainties)

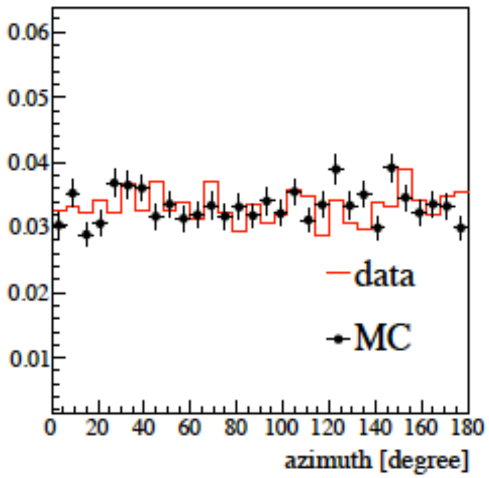
Y. Tsunesada et al. @ **UHECR 2012**



Auger event simulation for surface array

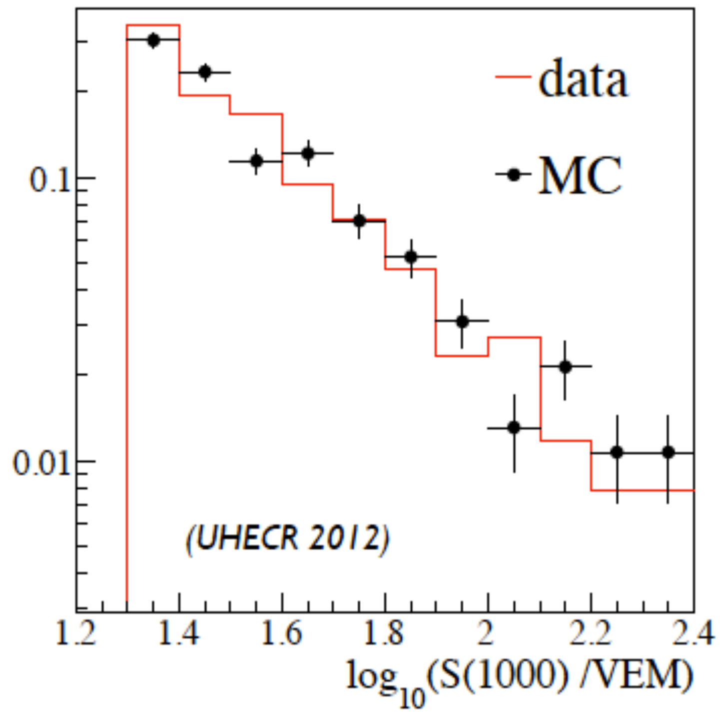


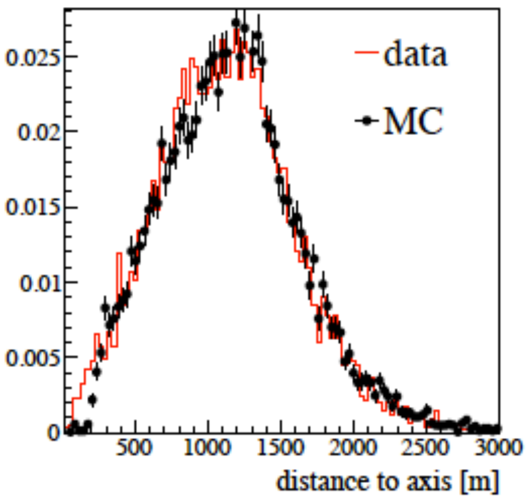
Zenith angle



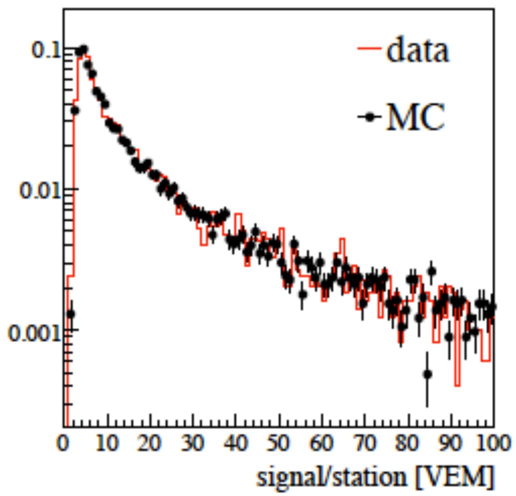
Azimuth angle

CORSIKA + full detector simulation (50% p + 50% Fe)





Distance of triggered stations

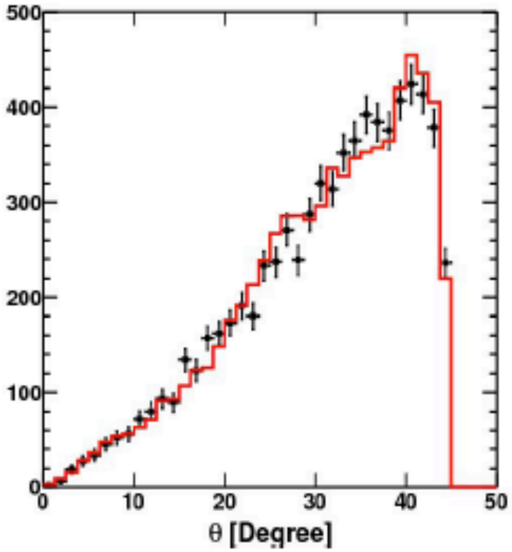


Signal per station

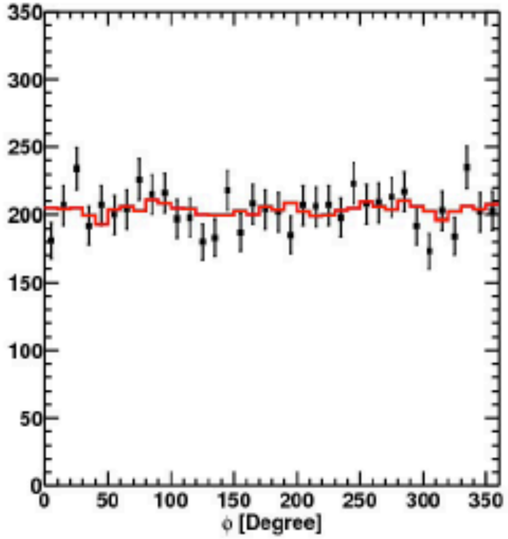
Very good agreement

Courtesey: Ralph Engel

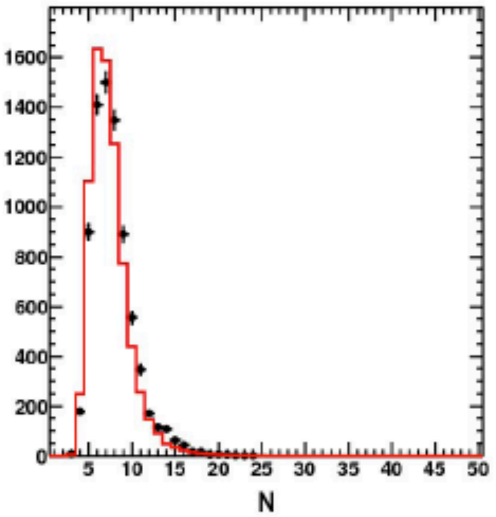
TA event simulation for surface array



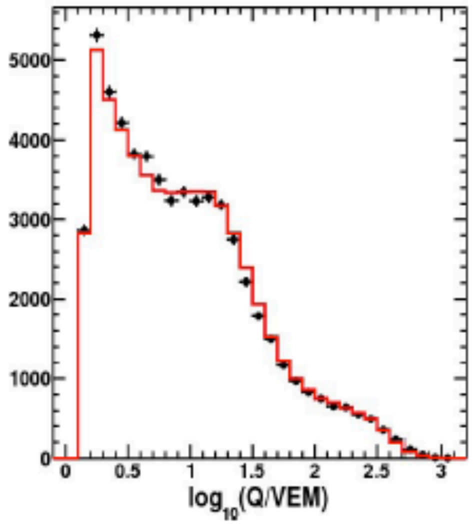
Zenith Angle



Azimuth Angle

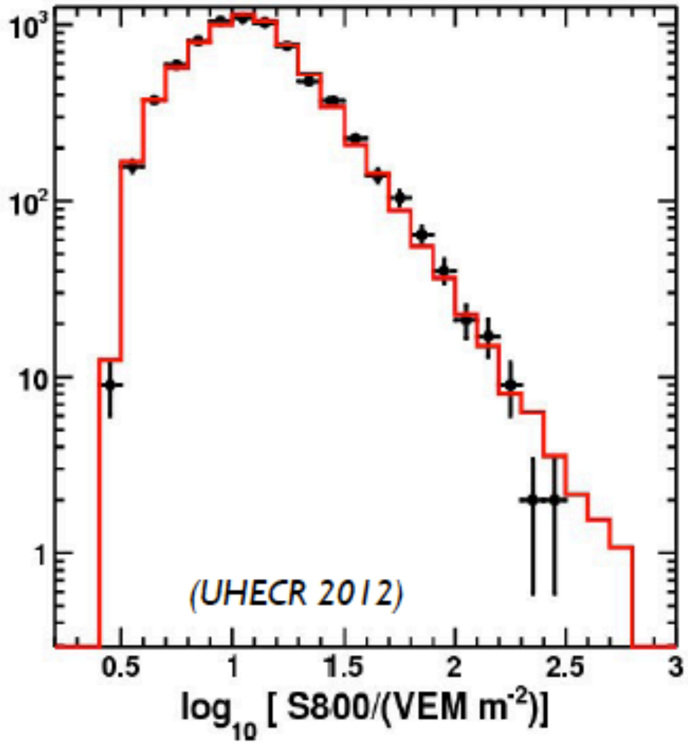


Number of Good Counters/Event



Charge/Counter/Event

CORSIKA + full detector simulation (proton primaries)



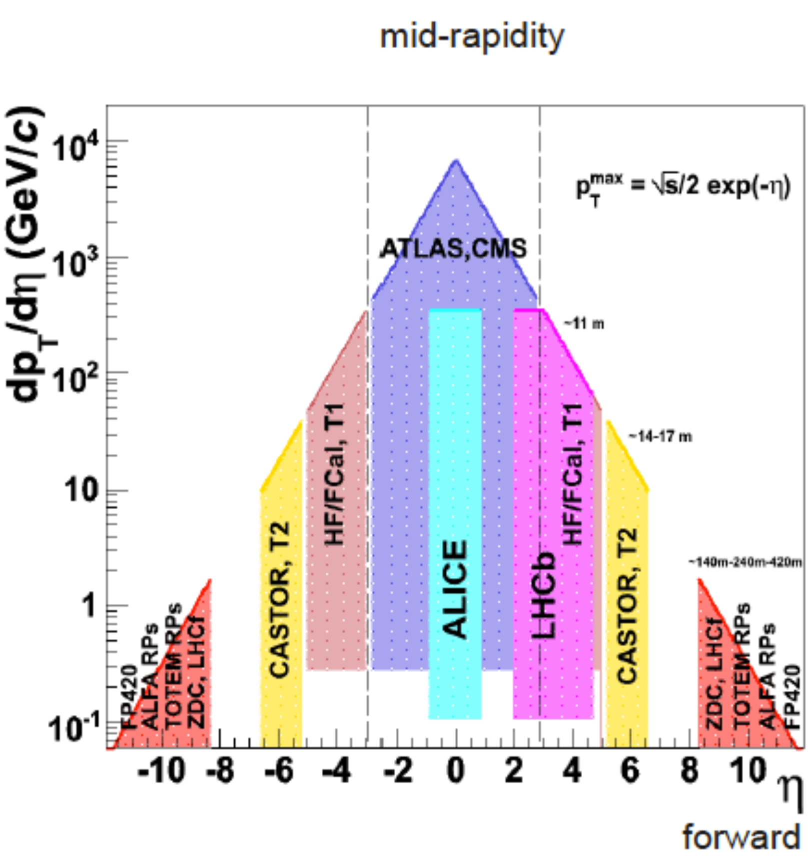
Very good agreement

Courtesey: Ralph Engel

But these energy/flux estimates are based on gross extrapolations of known physics

… how have air shower simulations fared against the LHC forward physics data?

Basic Observables



LHC : First hadron collider with full coverage.

- **Pseudorapidity**
  - emission angle of a particle from interaction point ("mid-rapidity" : η=0) :

$$\eta = -\ln\left[\tan\left(\frac{\theta}{2}\right)\right] \qquad \eta = \frac{1}{2}\ln\left(\frac{|\mathbf{p}| + p_L}{|\mathbf{p}| - p_L}\right)$$

  - when the mass of the particle is known the rapidity is used :

$$y = \frac{1}{2}\ln\left(\frac{E + p_L}{E - p_L}\right)$$

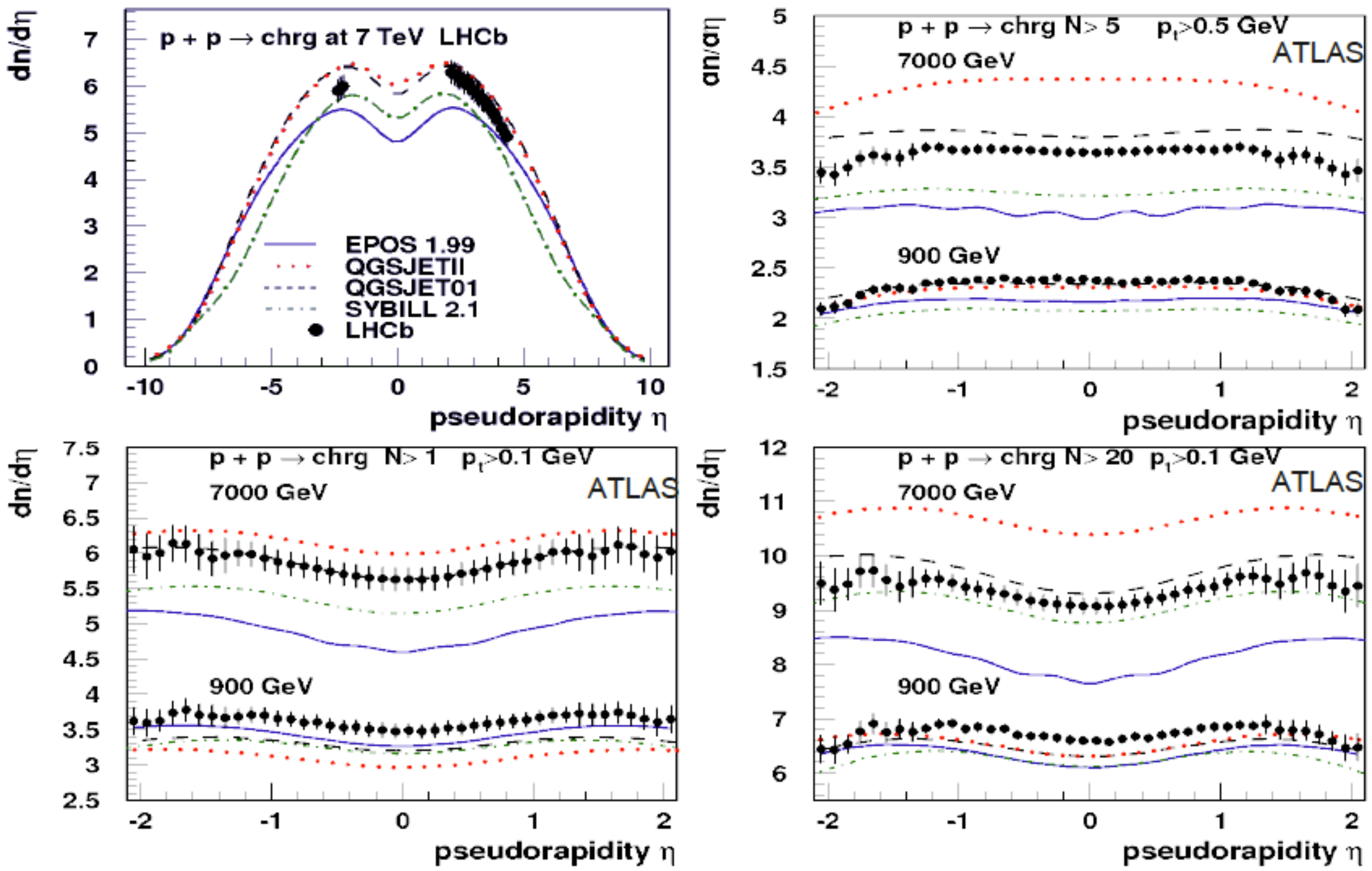
  - for EAS development, "forward" particles (with large η) are most important
- **Transverse momentum**
  - $p_t = \sqrt{p_x^2 + p_y^2}$
- **Multiplicity**
  - number of particles in a given η and p_t range

Pierog, ISVHECRI 2012

Comparisons with data from ATLAS, CMS, ALICE, LHCb, LHC-f and TOTEM show that the air shower models work (surprisingly) well

Pseudorapidity Distributions

- No model with perfect prediction : **but data well bracketed**



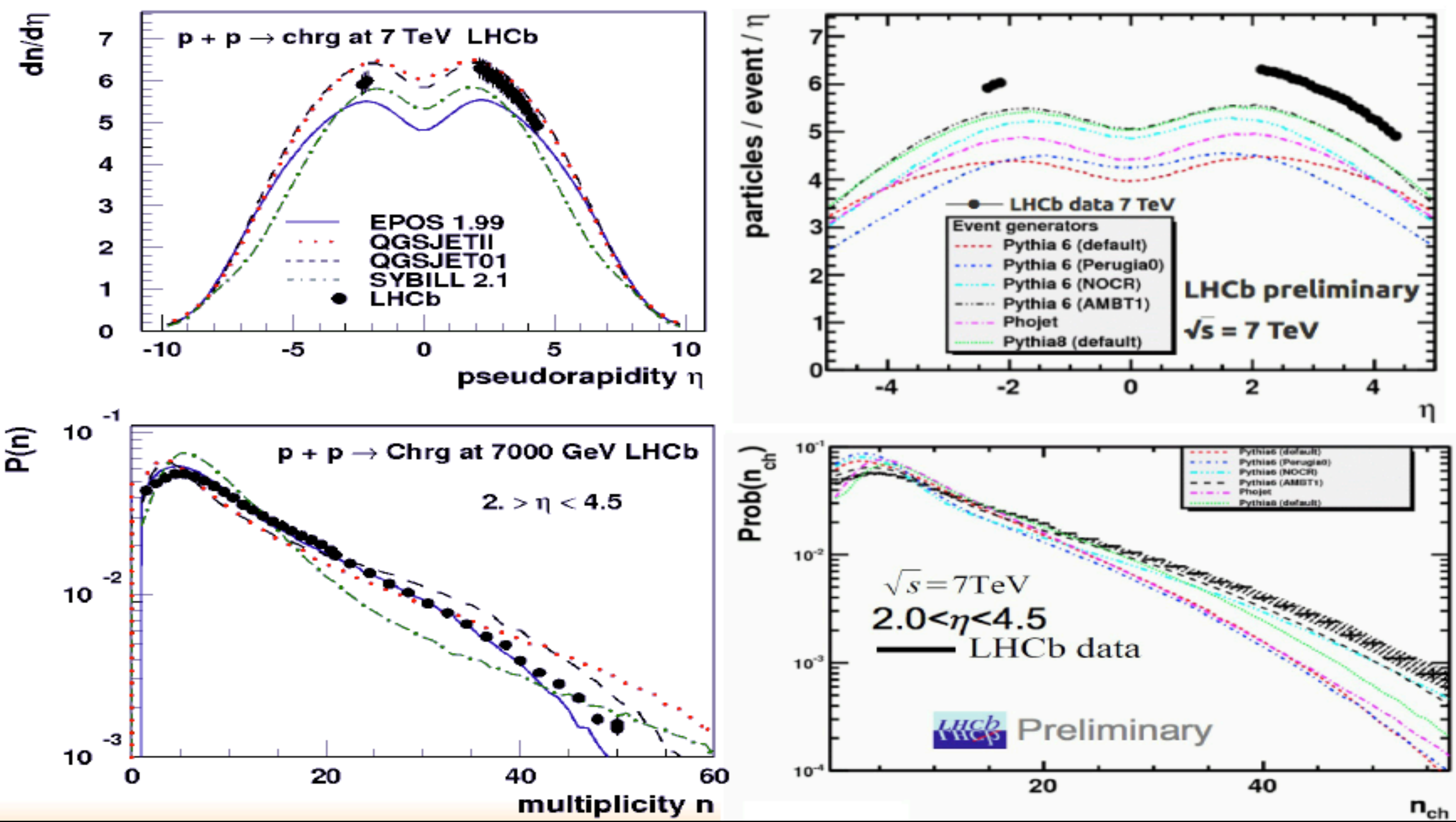
Predictions ! … newest model released in march 2009

Pierog, ISVHECRI 2012

It seems that the air shower simulations are really not so bad after all
… QGSJET-II (Ostapchenko) and EPOS (Werner) do rather well on the whole

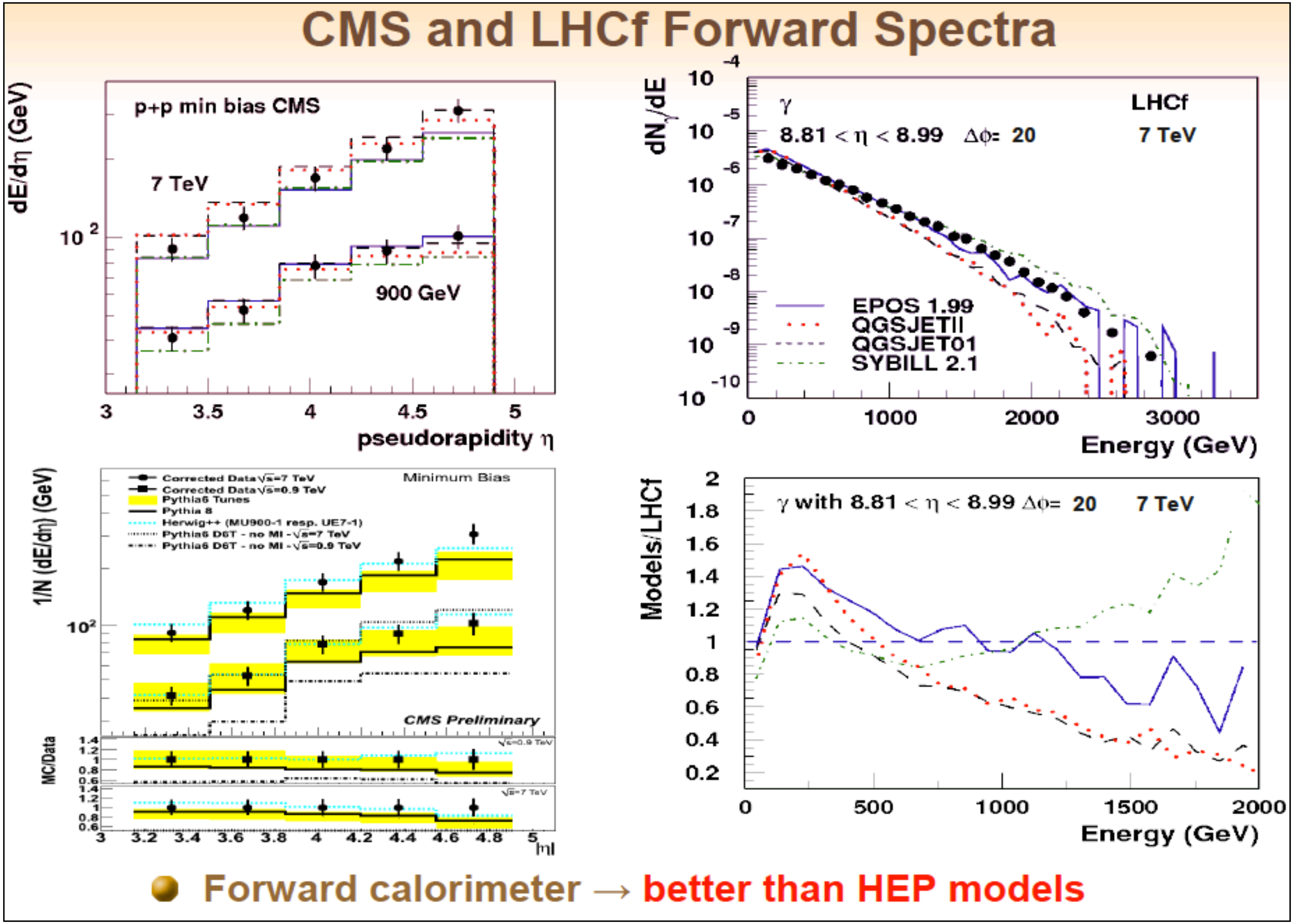
Pseudorapidity Distributions

- No model with perfect prediction : **but better than HEP MC**



Pierog, ISVHECRI 2012

In fact they give a *better* description (for soft physics) than the standard LHC event generators!

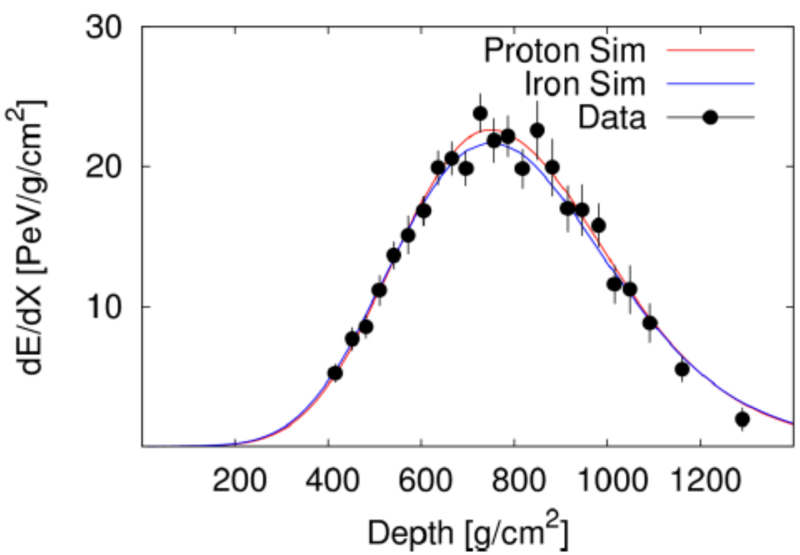


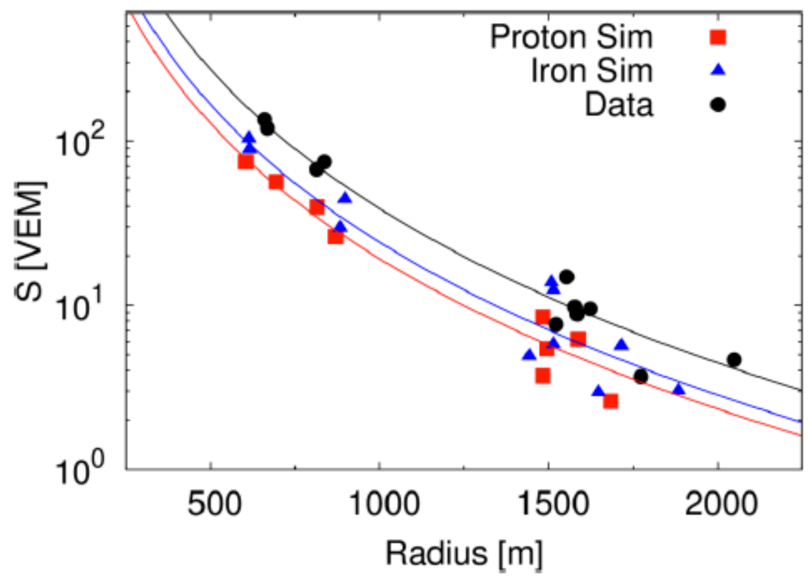
Pierog, ISVHECRI 2012

It is reassuring that energy estimates from air shower simulations are *robust*
… results from modern cosmic ray experiments can indeed be trusted!

Testing Models on Hybrid Events

- Hybrid events are well constrained
- Test models by matching the signals measured in SD and FD
- Find simulations which match measured FD profiles
- Compare the ground signals between the simulations and data





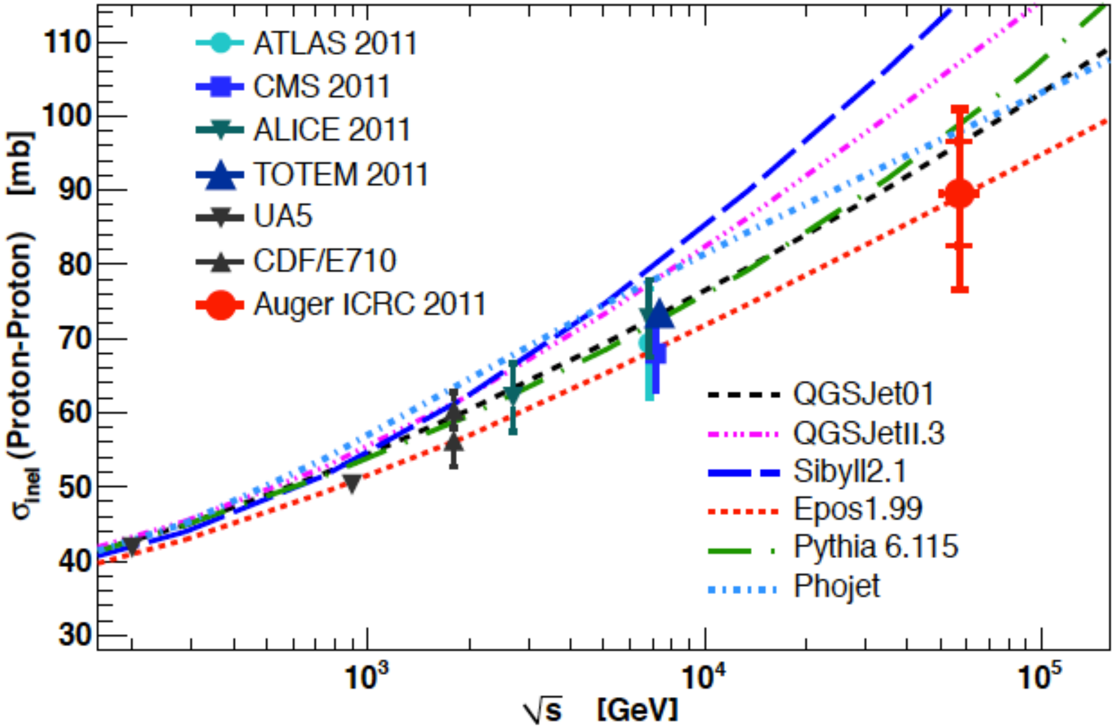
Yushkov for PAO UHECR2012, Allen for PAO ICRC2011

Only anomaly at present is a factor of ~2 overproduction of muons

Moreover Auger has provided new measurement of #-secns (test Glauber model)

Inelastic Proton-Proton Cross Section

Extended Glauber conversion + propagation of parameter uncertainties



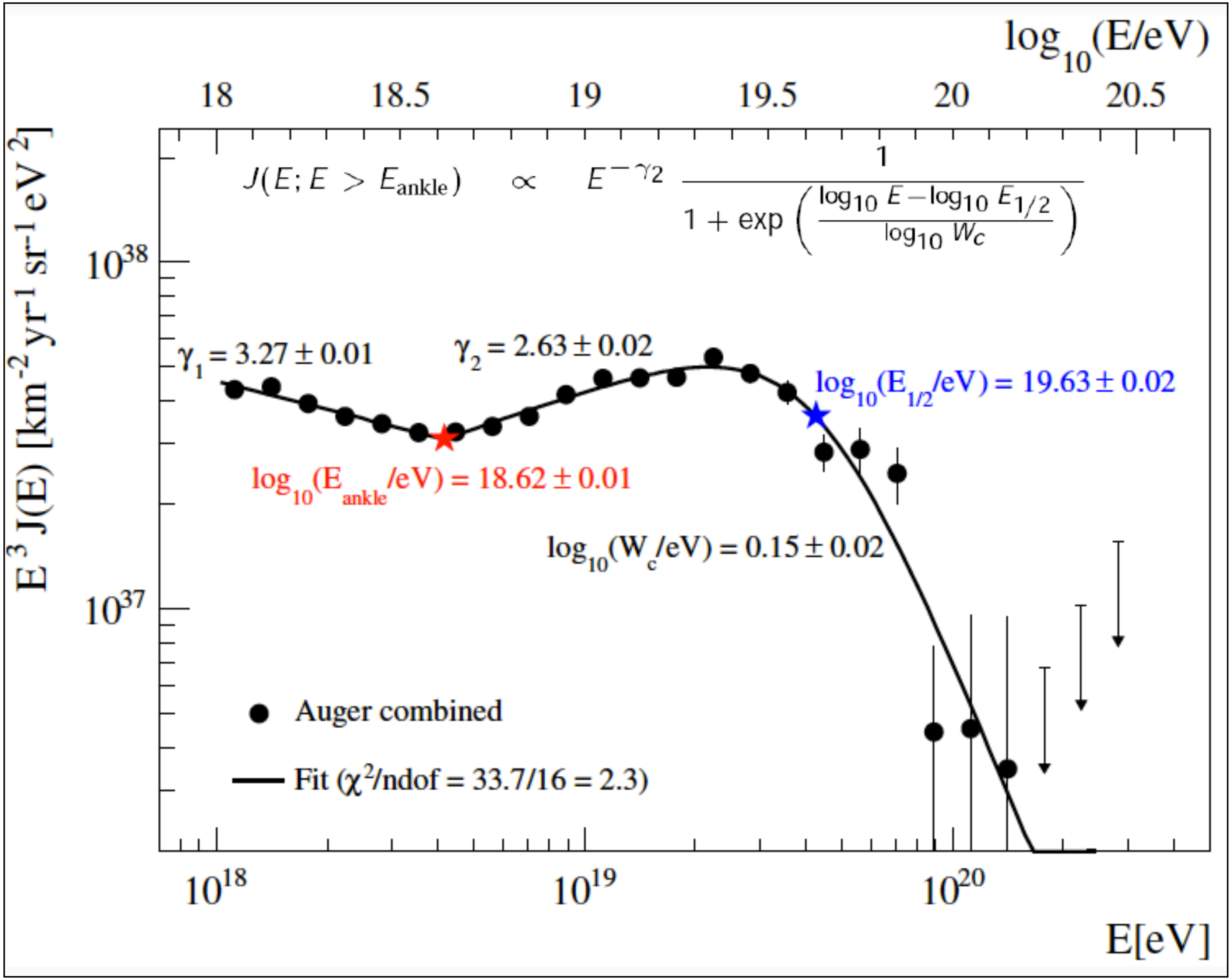
$$\sigma_{pp}^{inel} = \left[92 \pm 7(\text{stat}) \, {}^{+9}_{-11}(\text{sys}) \pm 7(\text{Glauber})\right] \text{ mb}$$

$$(\sigma_{pp}^{inel} = 90 \text{ mb for } \lambda = 0)$$

$$\sqrt{s_{pp}} = [57 \pm 0.3_{stat} \pm 6_{sys}] \text{ TeV}$$

Ulrich, ISVHECRI 2012

The GZK cutoff has supposedly been seen … *if* the primaries are protons *and* the sources accelerate them to energies >10^{20} eV *and* are homogeneously distributed



Auger collab., EPJ Plus (2012) to appear

… *if* so, we have the "guaranteed" cosmogenic neutrino flux

GZK mechanism :

$$p + \gamma_{CMB} \rightarrow \Delta^+ \rightarrow n + \pi^+$$

$$\rightarrow p + e^- + \bar{\nu}_e$$

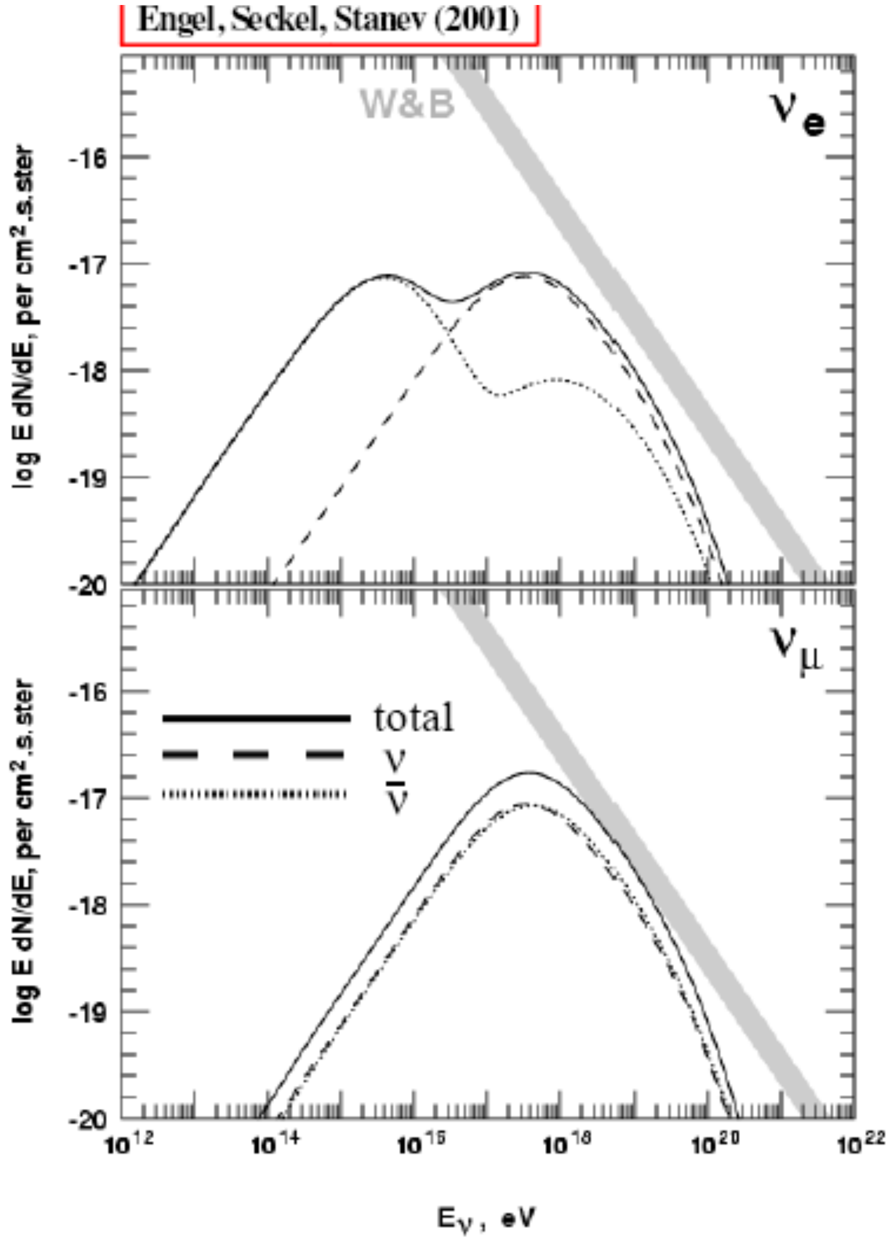
$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

$$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

$E_{THRESH.} \sim 6 \times 10^{19}$ eV

- Uncertainties in flux calculations :
  - UHECR luminosity; ρ_{CR}(local) $\neq \langle\rho_{CR}\rangle$
  - injection spectrum
  - cosmological evolution of sources
  - IRB & optical density of sources

But the *shape* of the energy spectrum constrains the injection and evolution parameters … as do observational constraints on the associated γ-ray cascade



Additional uncertainties if the primaries are heavy nuclei (Hooper *et al* 2004, Ave *et al* 2004)

The sources of cosmic rays *must* also be neutrino sources

Waxman-Bahcall Bound :

- $1/E^2$ injection spectrum (Fermi shock).
- Neutrinos from photo-meson interactions in the source.
- Energy in ν's related to energy in CR's :

$$[E_\nu^2 \Phi_\nu]_{\rm WB} \approx (3/8)\, \xi_Z\, \epsilon_\pi\, t_{\rm H}\, \frac{c}{4\pi}\, E_{\rm CR}^2 \frac{d\dot{N}_{\rm CR}}{dE_{\rm CR}}$$

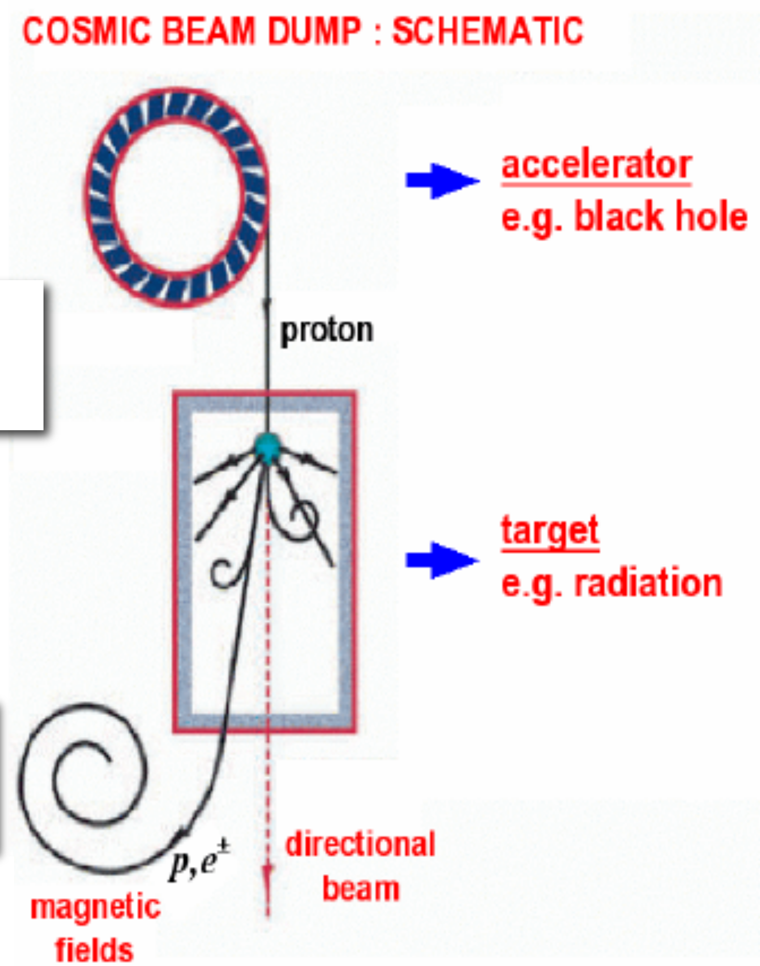
Fraction of CR primary energy converted to neutrinos

Hubble time

From rate of UHE CR's (10^{19}-10^{21} eV)

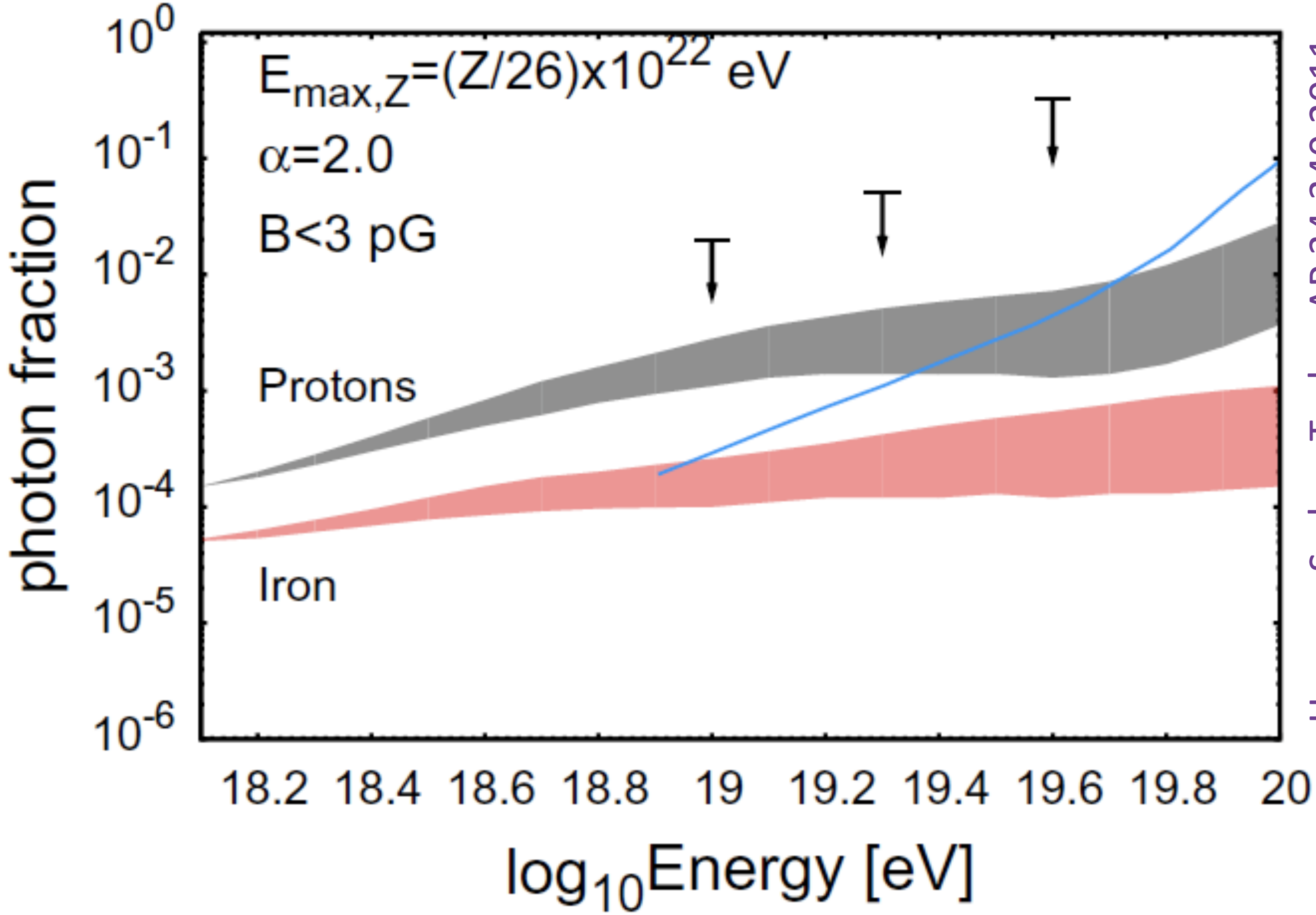
$$\approx 2.3 \times 10^{-8}\, \epsilon_\pi\, \xi_Z\, {\rm GeV\, cm^{-2}\, s^{-1}\, sr^{-1}}$$

➡Making a reasonable estimate for ε_π allows this to be converted into a flux *prediction*



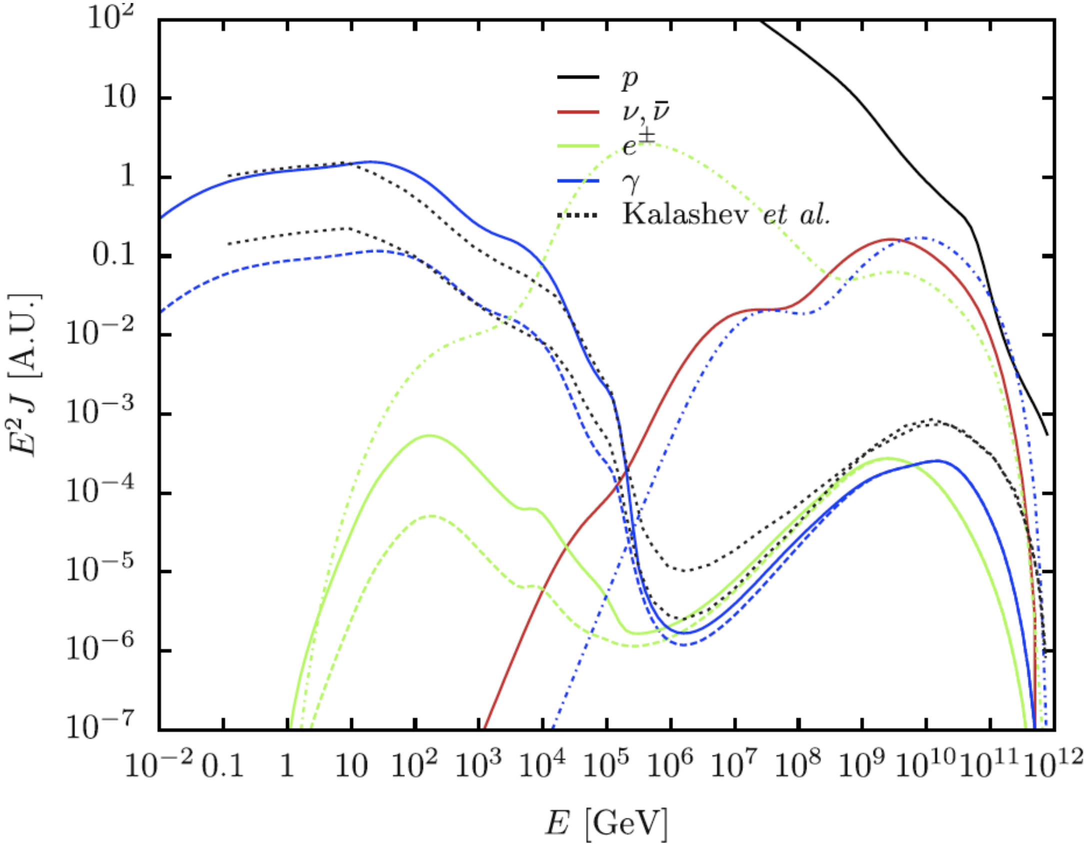
… would be *higher* if extragalactic cosmic rays become dominant at energies well *below* the ‘ankle’ as in Berezinsky *et al*’s model of the ‘dip’ as due to e^+e^- production

There is also a GZK **photon** flux from π^0 decay, pair production *etc* …
challenging target for air shower arrays (Gelmini, Kalashev, Semikoz 2007)



Hooper, Sarkar, Taylor, AP 34:340,2011

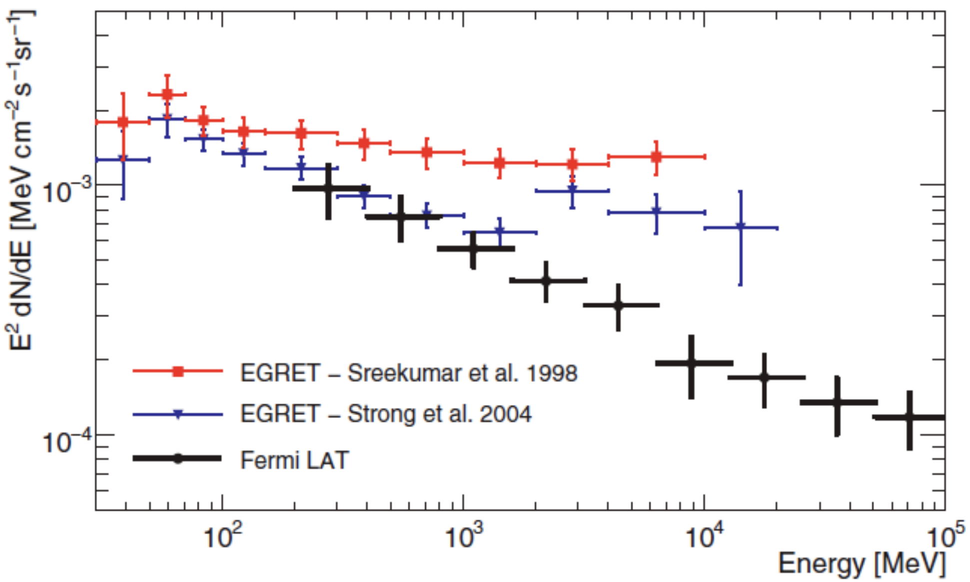
Auger has set stringent limits and may ultimately have the sensitivity to detect this flux (blue line above) … alternatively can wait for the photons to be degraded to lower energies and then detect them with e.g. Fermi-LAT



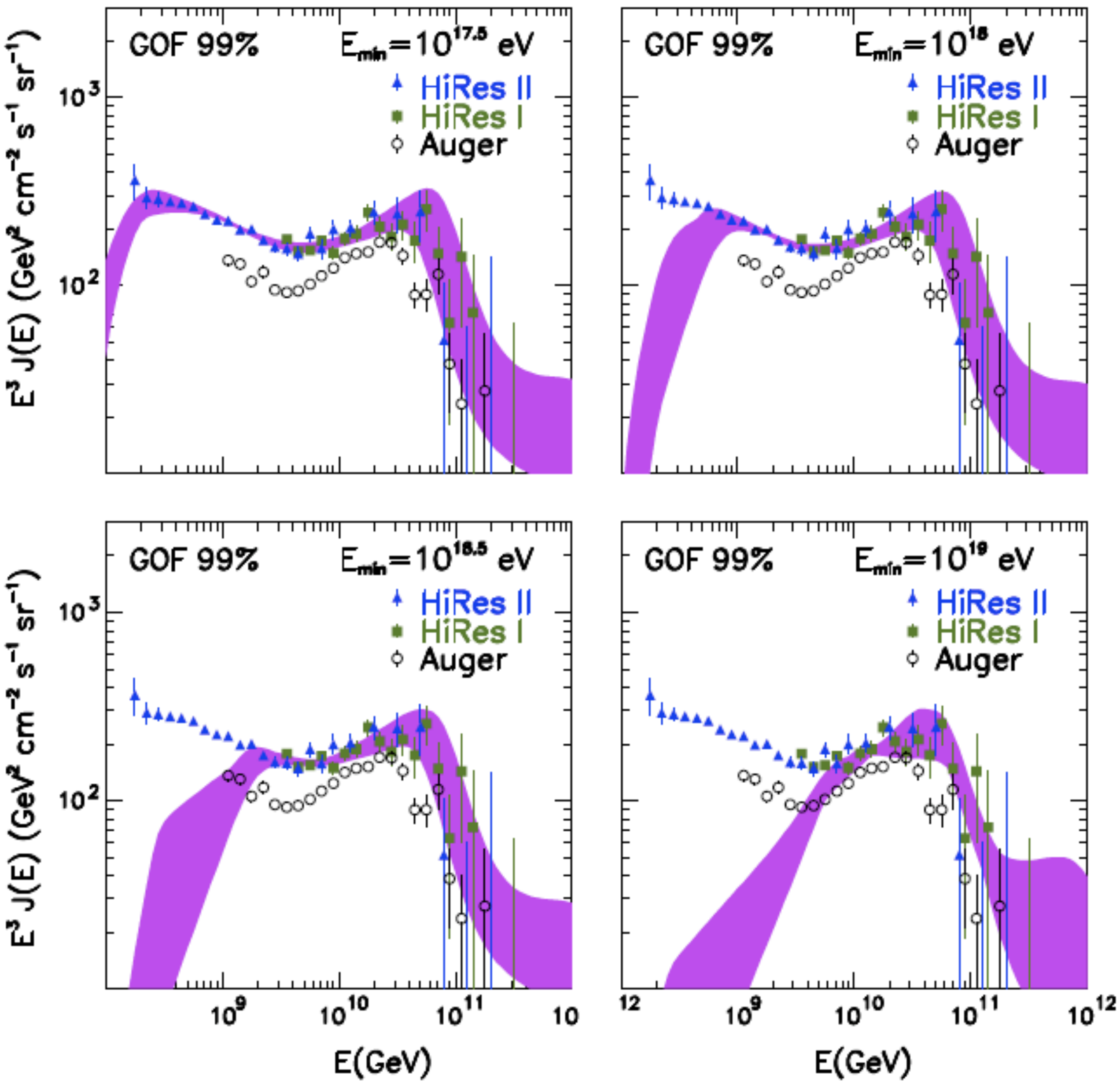
The GZK photons will 'cascade' on intergalactic radiation backgrounds and generate a diffuse γ-ray background at ~GeV to TeV energies … we calculate this taking into account all EM interactions on CMB and EBL (IR and optical)

Ahlers, Anchordoqui, Gonzalez-Garcia, Halzen, Sarkar, Astropart. Phys. 34:106,2010

This is well constrained by the measurement by Fermi-LAT of the extragalactic diffuse γ-ray bkgd. (well *below* older EGRET estimate)

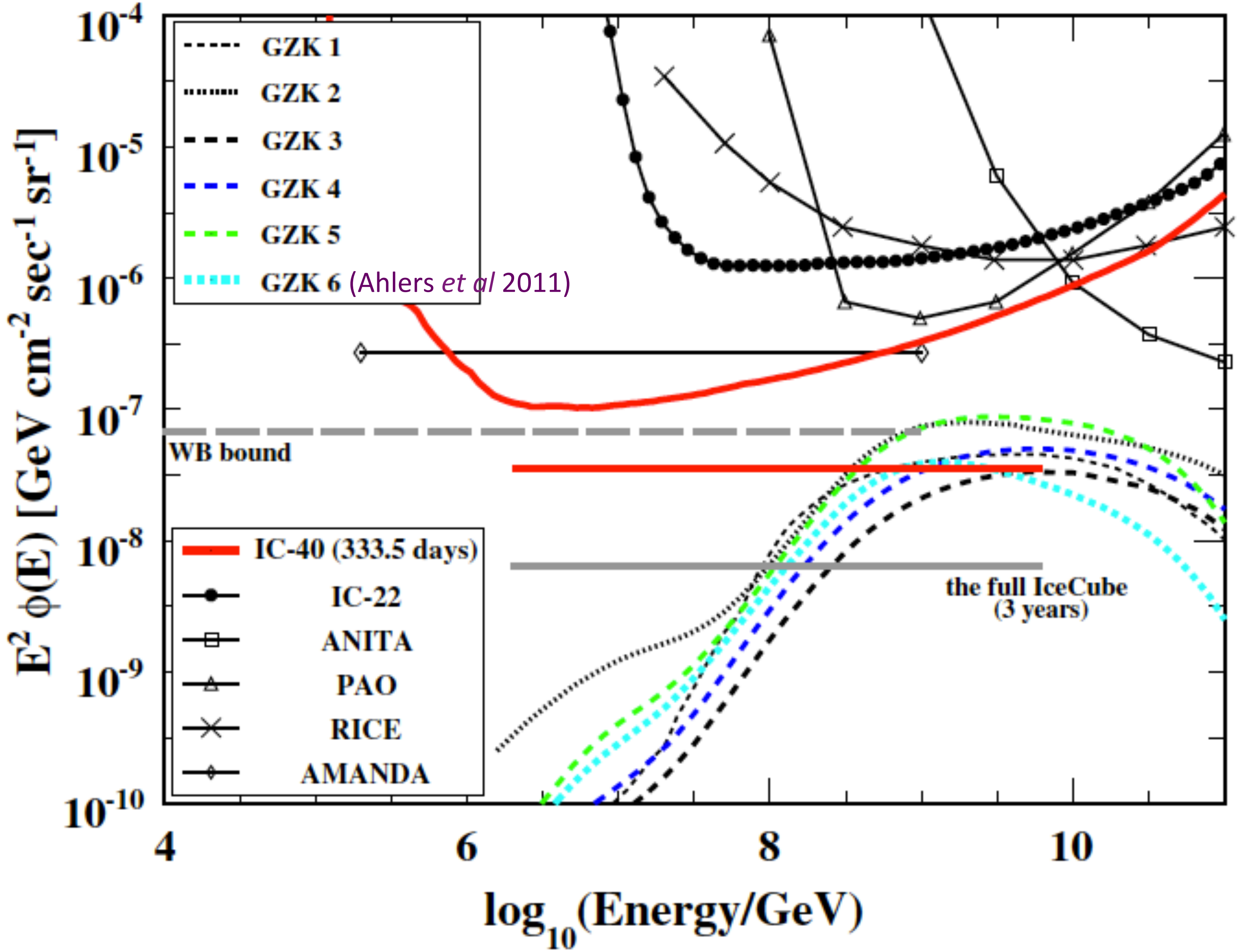


We can fit the observed spectrum for various combinations of injection spectral index, maximum energy *et cetera,* as well as the 'cross-over' energy at which the extragalactic cosmic rays begin to **dominate** over the galactic component



Ahlers, Anchordoqui, Gonzalez-Garcia, Halzen, Sarkar, AP 34:106,2010

The corresponding cosmogenic flux can then be calculated … imposing the Fermi-LAT constraint, its maximum value is severely *restricted*



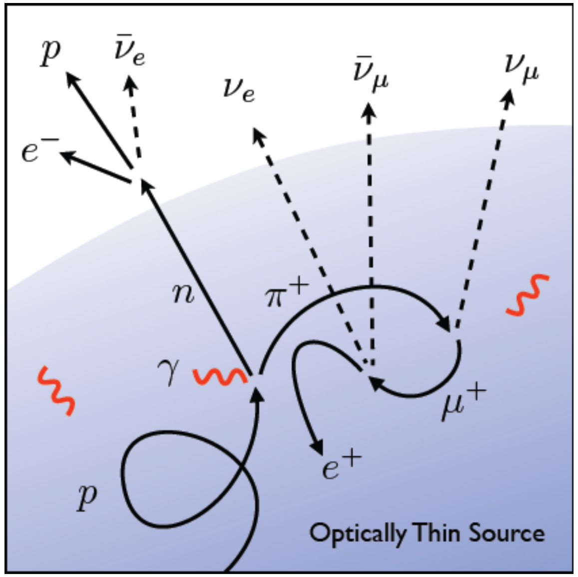
Abbasi *et al*. [IceCube collab.], PR D83:092003,2011

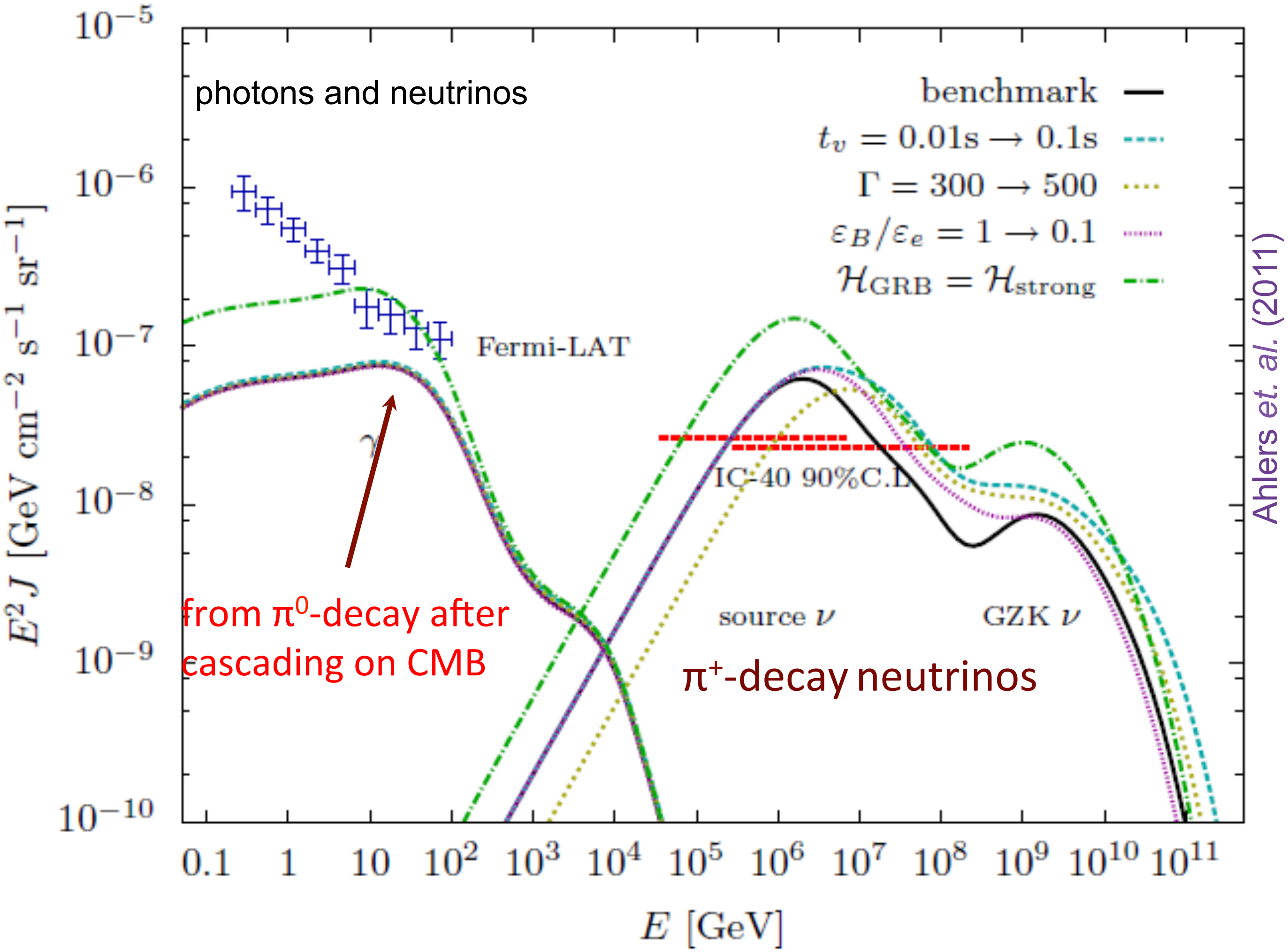
The Ahlers *et al* (2011) best-fit with the Fermi-LAT constraint is shown as GZK 6

A similar argument can be applied to constrain *neutrinos* from e.g. Gamma-Ray Bursts (‘fireball model’)

– Protons from n-decay fitted to observed UHE cosmic ray spectrum

– Photons from π^0-decay ‘cascade’ down in energy through scattering on the on the CMB





IceCube begins to challenge GRBs as major sources of UHE cosmic rays

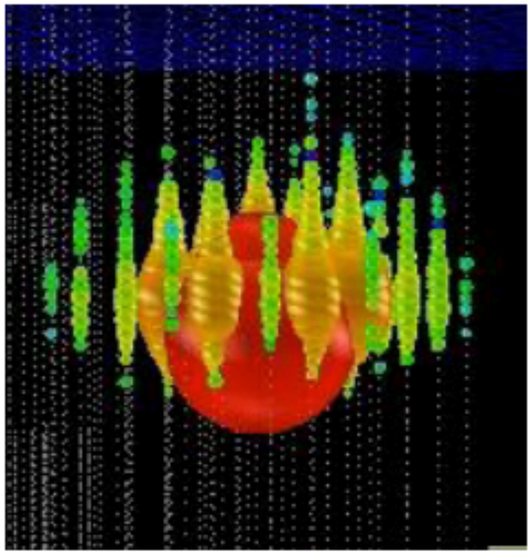
STOP PRESS: Now we do have …

2 ν_e-like PeV events in IceCube 86

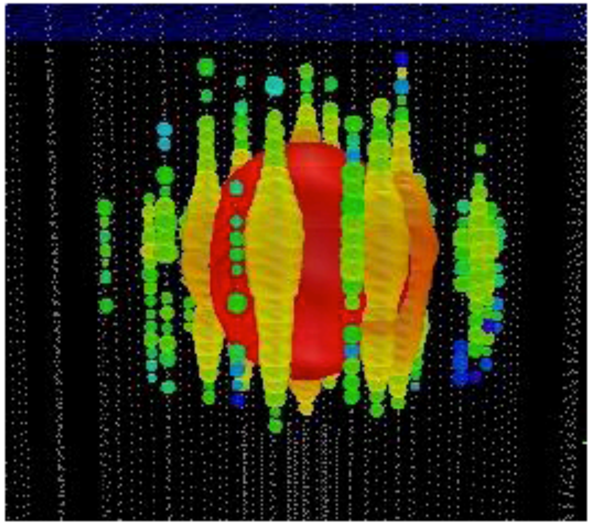
Found in search for cosmogenic neutrinos with IC79 & IC86 (May 2010 – May 2012)

2 events / 672.7 days - background (atm. μ + conventional atm. ν) expectation 0.14 events
preliminary p-value: 0.0094 (2.36σ)

Run119316-Event36556705
Jan 3rd 2012
NPE 9.628×10^4
Number of Optical Sensors 312



Run118545-Event63733662
August 9th 2011
NPE 6.9928×10^4
Number of Optical Sensors 354

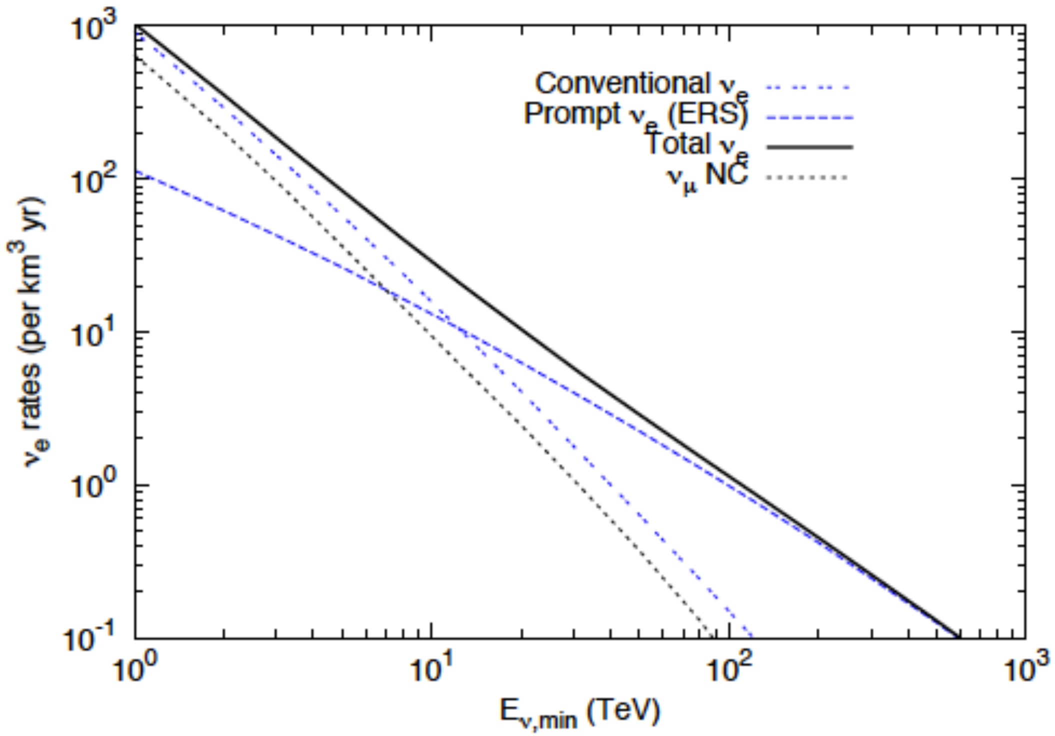


Aya Isihara, Neutrino 2012; See talk by Eike Middell at this meeting, ISVHECRI2012

Electron neutrinos

These are unlikely to be due to charm (in the atmospheric neutrino flux) …

Event rates: ν_e per km^3 yr



- < 0.1 event per year at PeV
- Look for charm at ~100 TeV

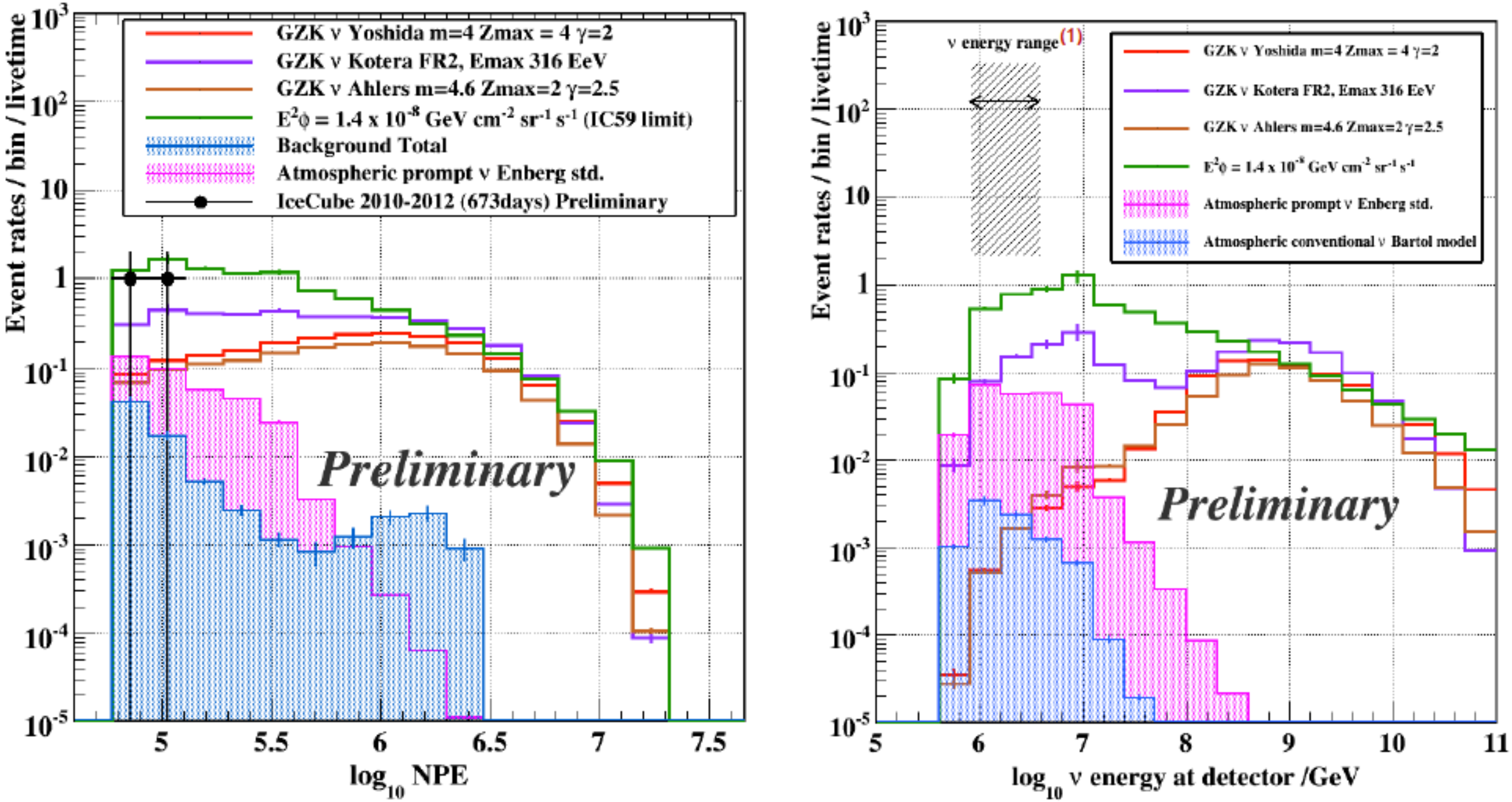
$$\mathrm{Rate}(> E_\nu) = 2\pi\, T\, N \times \int_E \frac{\mathrm{d}n_{\nu+\bar{\nu}}}{\mathrm{d}E'\mathrm{d}A\mathrm{d}\Omega\mathrm{d}t} \sigma_\nu^{cc}(E')\,\mathrm{d}E$$

Cross sections (average of ν, anti-ν): Cooper-Sarkar, Mertsch, Sarkar (2011)

Gaisser, ISVHECRI 2012

… and their energies are well below the Glashow resonance

NPE and energy distributions



Can they be cosmogenic (from decay of neutrons produced by photodissociation of heavy cosmic ray primaries)?

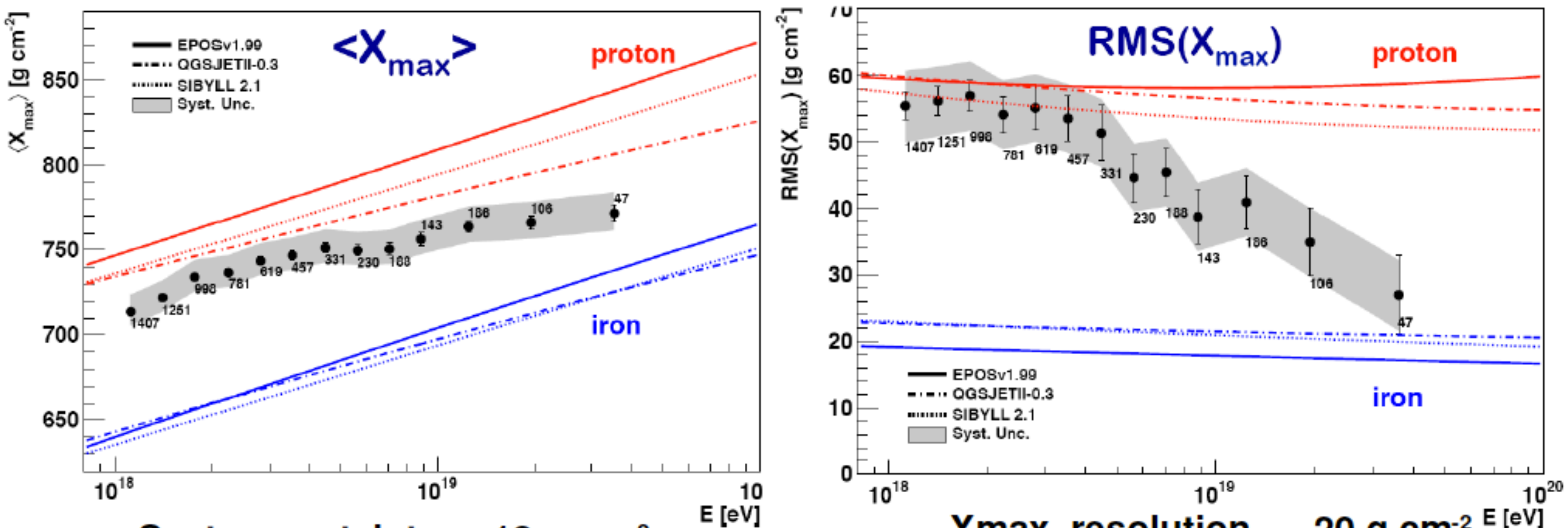
(1) shaded energy range includes contribution from neutral current interactions of an E^{-2} all flavor neutrino flux. NC events cause larger error bar.

Middel, ISVHECRI 2012

Auger data on the depth of air shower maximum + fluctuations do indicate increasingly *heavier* composition at $E > 10^{18}$ eV

Mass Composition: mean X_{max} and its RMS

G. Pinto, P.Facal @ **ICRC 2011**



Syst uncertainty < 13 g cm^{-2} **Xmax resolution ~ 20 g cm^{-2}**

6744 hybrid events (Dec 2004 – Sept 2010) $E > 10^{18}$ eV
break of the elongation rate at around 2.4 10^{18} eV (close to the ankle)

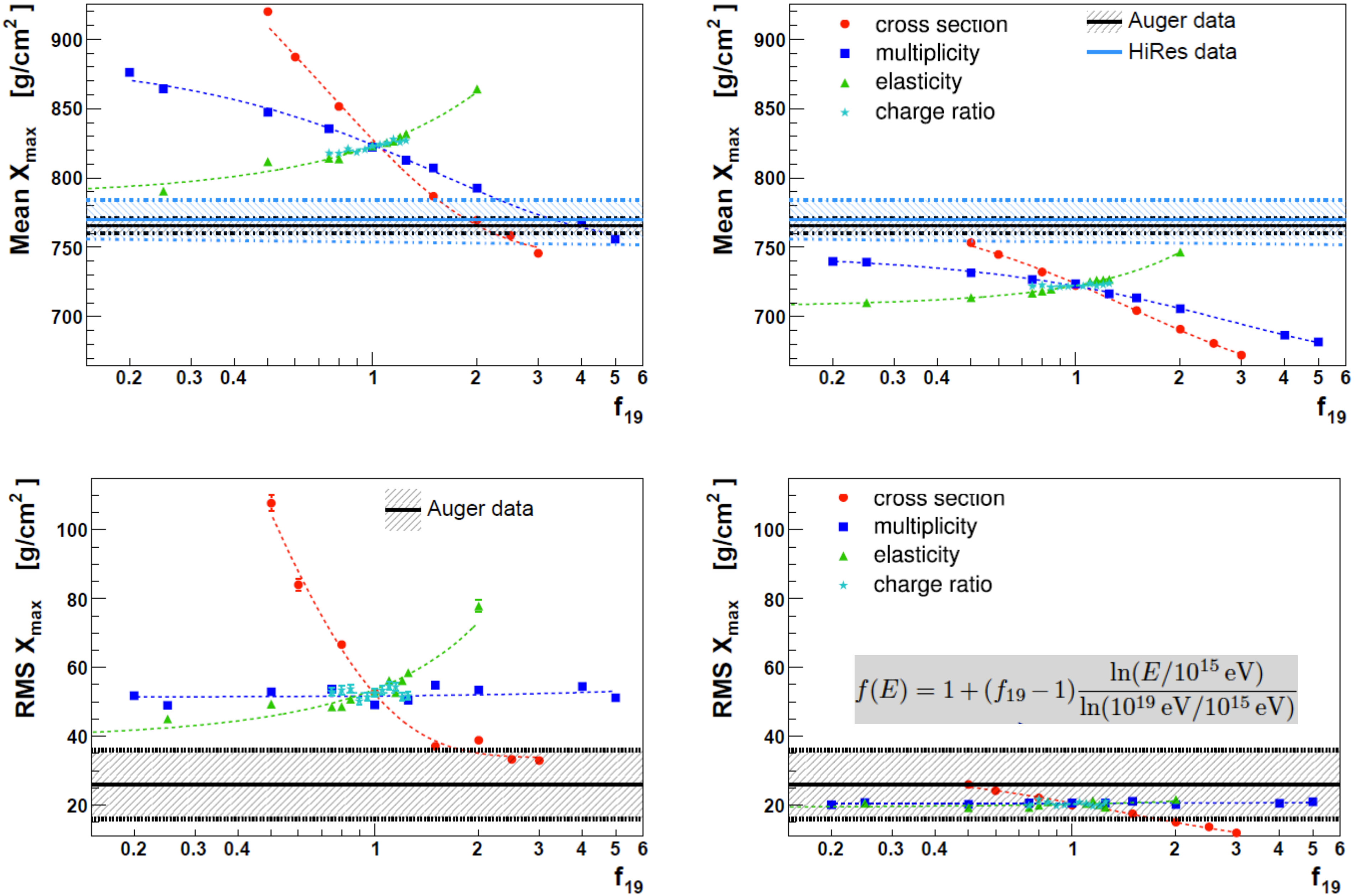
Xmax distributions become narrower with energy

→ **increase of the mean mass with the energy**

→ **interpretation depends on hadronic interaction models**

This conflicts with results from HiRes/TA which are *consistent* with protons

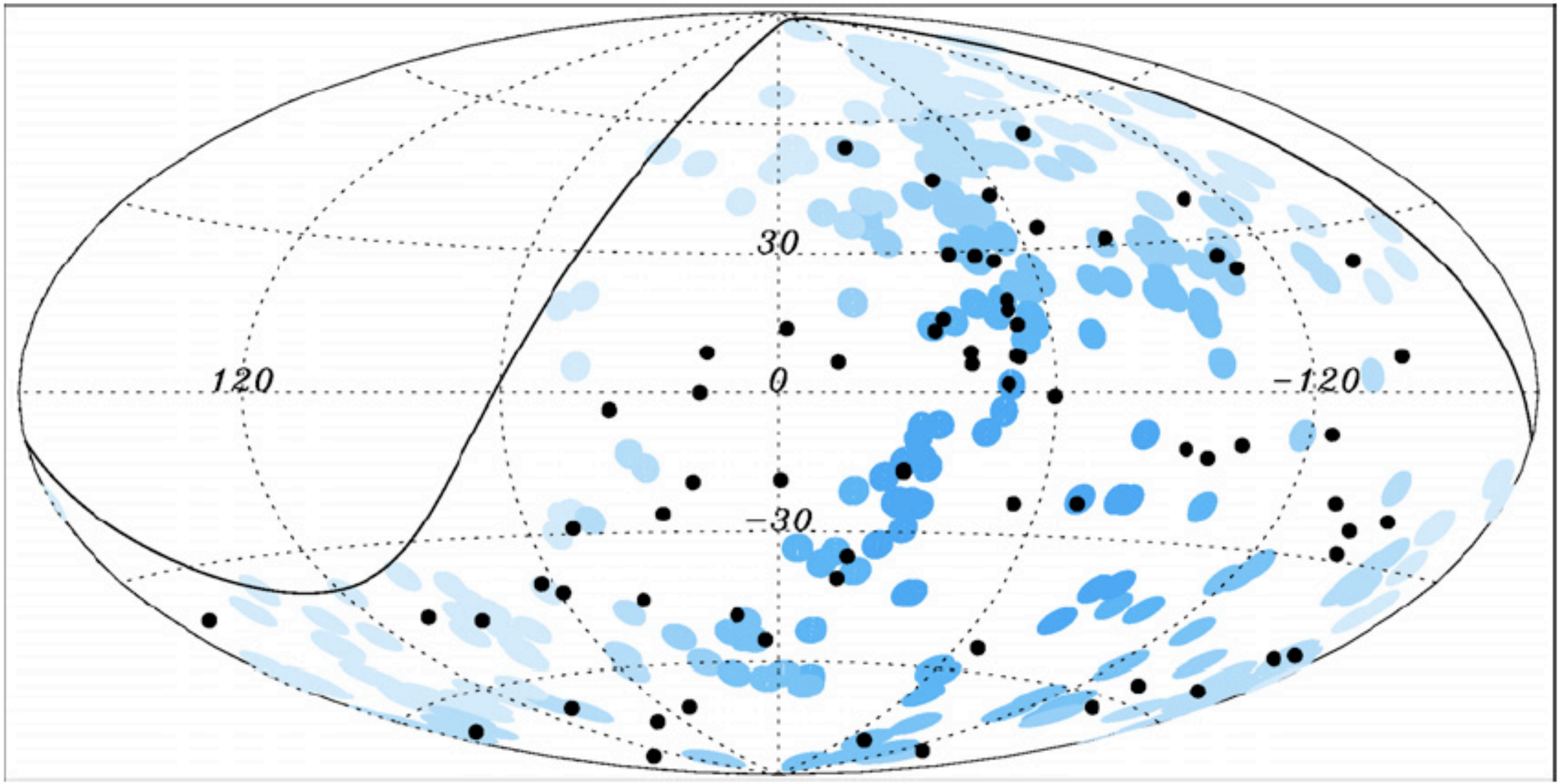
… or is it due to a change in UHE interactions?



(Ulrich, Engel, Unger, PRD 83:054026,2011)

Joint working group (Auger+TA) formed to investigate this vexed issue

Puzzle: correlation of Auger arrival directions at E > 4×10^{19} eV (within ~few degrees) with nearby AGNs suggests the primaries are protons



Abreu *et al* [Auger collab.] AP 34:314,2010

BUT If the primaries were heavy nuclei with Z >>1 (and protons and nuclei ~equally abundant at source), then would expect *increased* anisotropy at E ~ 4×10^{19}/Z eV … contrary to observation! (Lemoine & Waxman JCAP 11:009,2009)

The photodisintegration of UHECR nuclei on the CIB can be studied *analytically*

$$\frac{\mathrm{d}N_1(E)}{\mathrm{d}L} = \frac{N_n(L,E_n)}{L_n(E_n)} + \frac{N_{n-1}(L,E_{n-1})}{L_{n-1}(E_{n-1})} + \ldots \frac{N_2(L,E_2)}{L_2(E_2)} \quad \Rightarrow \quad N_1(L',E_1) = \int_0^{L'} \mathrm{d}L \sum_{m=2}^{n} \frac{N_m(L,E_m)}{L_m(E_m)}$$

Obtain solution in *excellent* agreement with Monte Carlo simulations:

$$\frac{N_q(L,E_q)}{N_n(0,E)} = \sum_{m=q}^{n} L_q(E_q) L_m(E_m)^{n-q-1} \exp\left(\frac{-L}{L_m(E_m)}\right) \prod_{p=q(\neq m)}^{n} \frac{1}{L_m(E_m) - L_p(E_p)}$$

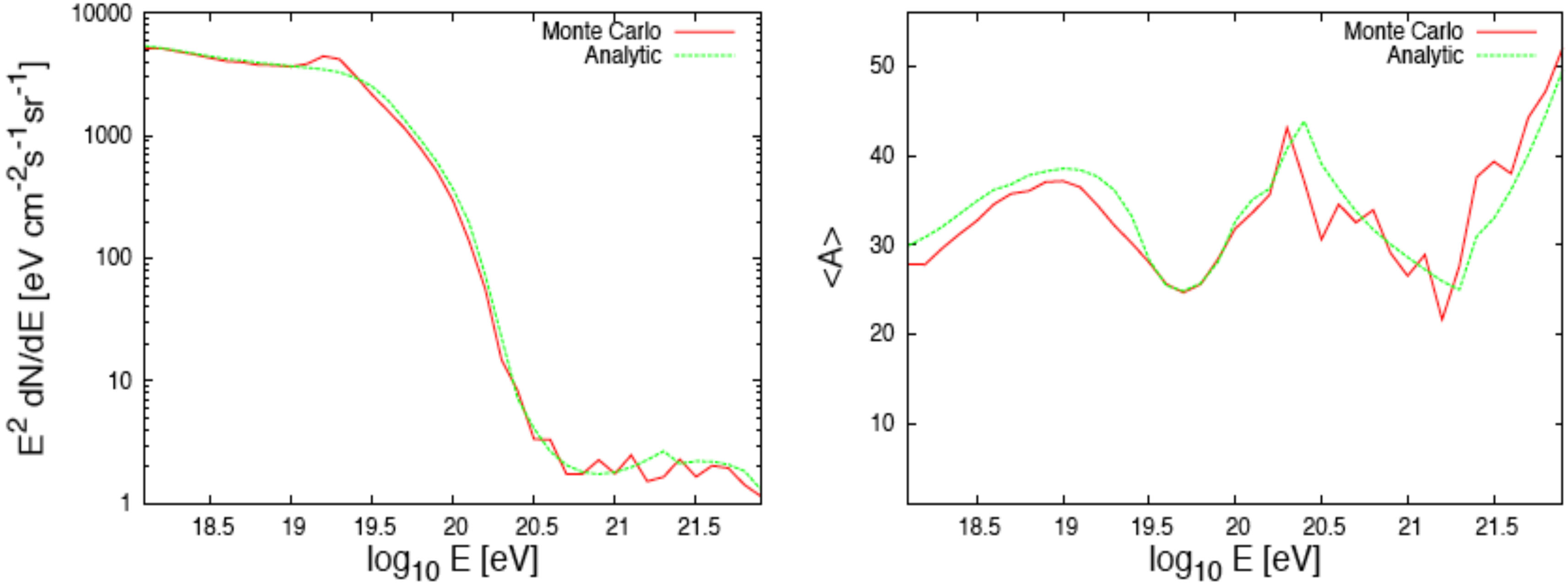
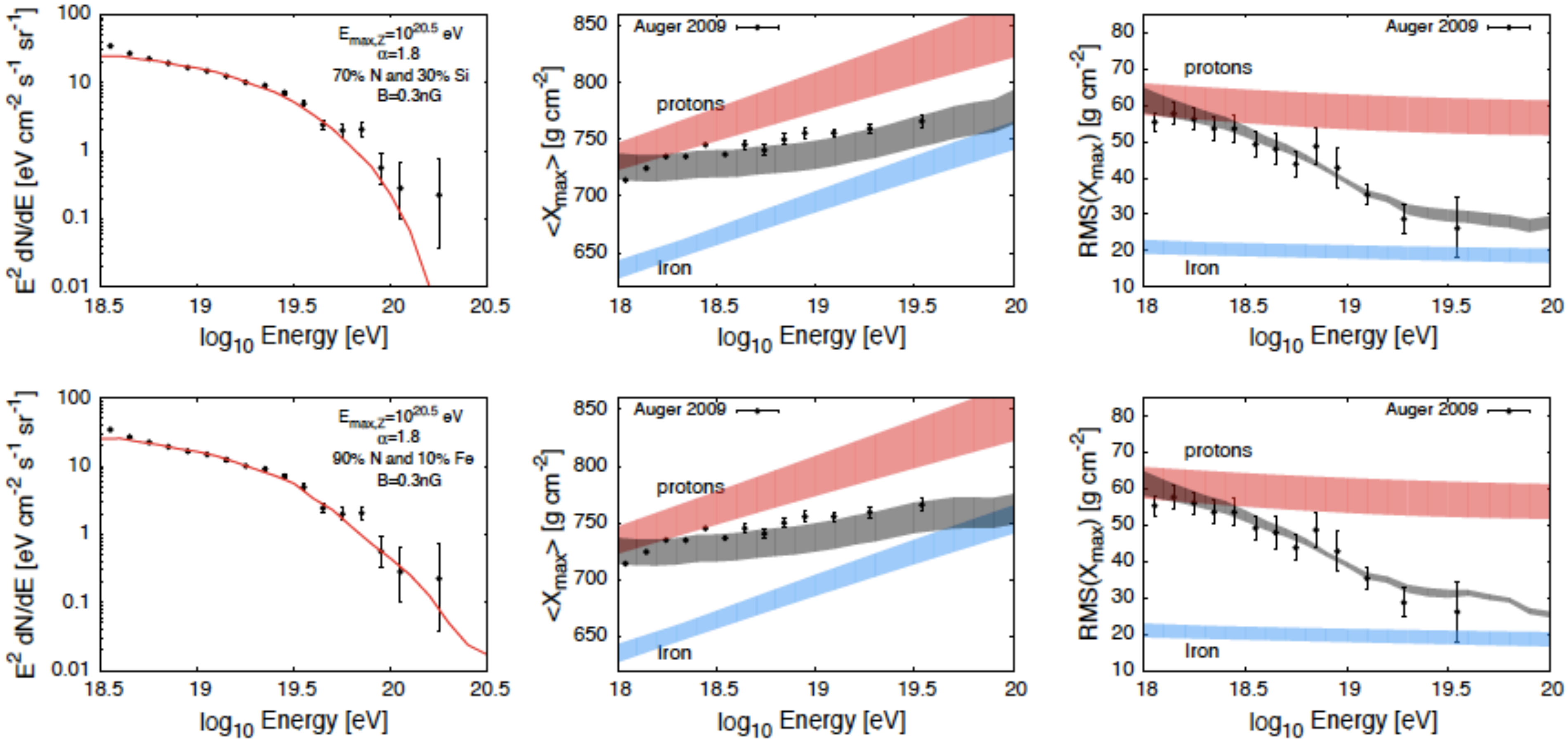


FIG. 4: The ultra-high energy cosmic ray spectrum (left) and average composition (right) calculated using both analytic and Monte Carlo techniques. These results are for the case of iron nuclei injected from a homogeneous distribution of sources with a spectrum of $\mathrm{d}N/\mathrm{d}N \propto E^{-2}$ up to a maximum energy of 5×10^{21} eV.

Hooper, Sarkar, Taylor, PRD82:123005,2010

The data *can* be well fitted if the primaries are heavy nuclei

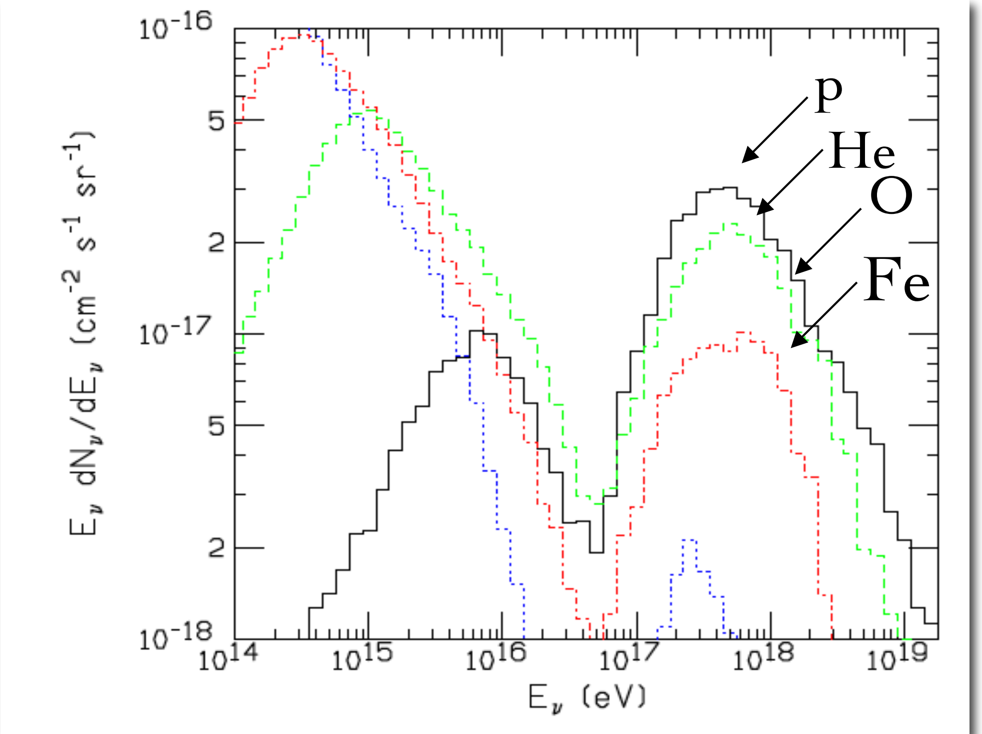
(NB: When propagated through the cosmic infrared background, photodisintegration results in a *mixed* composition at Earth)

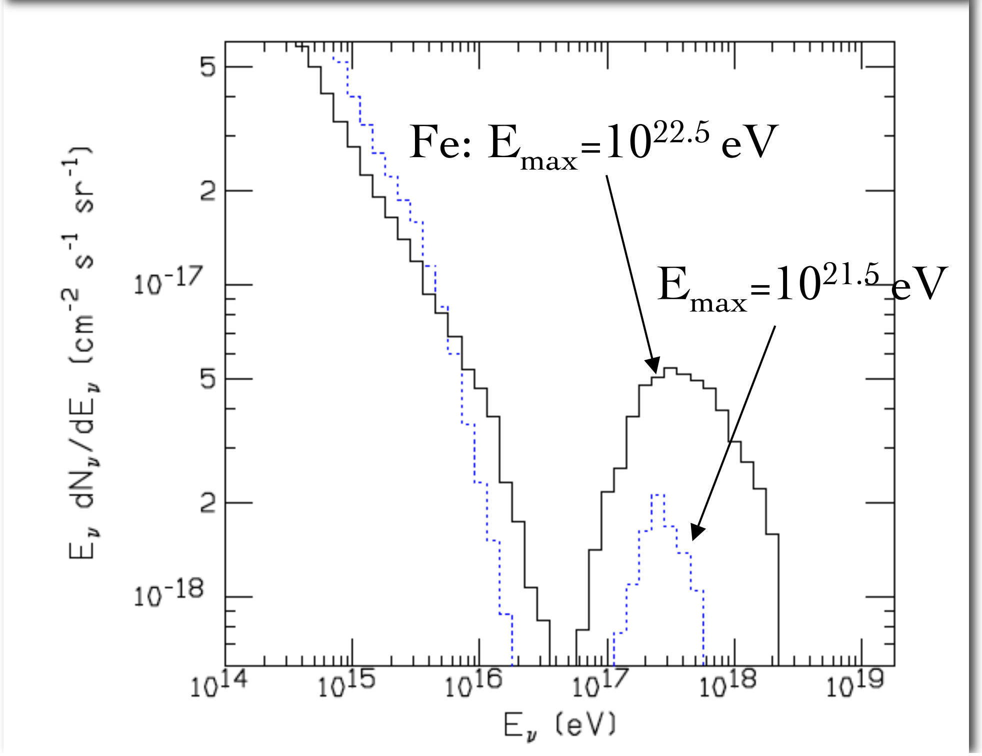


Hooper & Taylor, AP 33:151,2010

This is *not* the GZK cutoff, so π production and ν_μ flux will be *suppressed*

… but the ν_e flux from neutron decay may be *boosted*





In order to contribute to the cosmogenic ν flux, the photo-disassociated protons must *exceed* the GZK cutoff in energy, hence the original nuclei must have energies > E_{GZK} x A

$$^{56}Fe + \gamma_{CMB/CIB} \rightarrow \; ^{55}Mn + p,$$

$$^{55}Mn + \gamma_{CMB/CIB} \rightarrow \; ^{54}Mn + n,$$

…

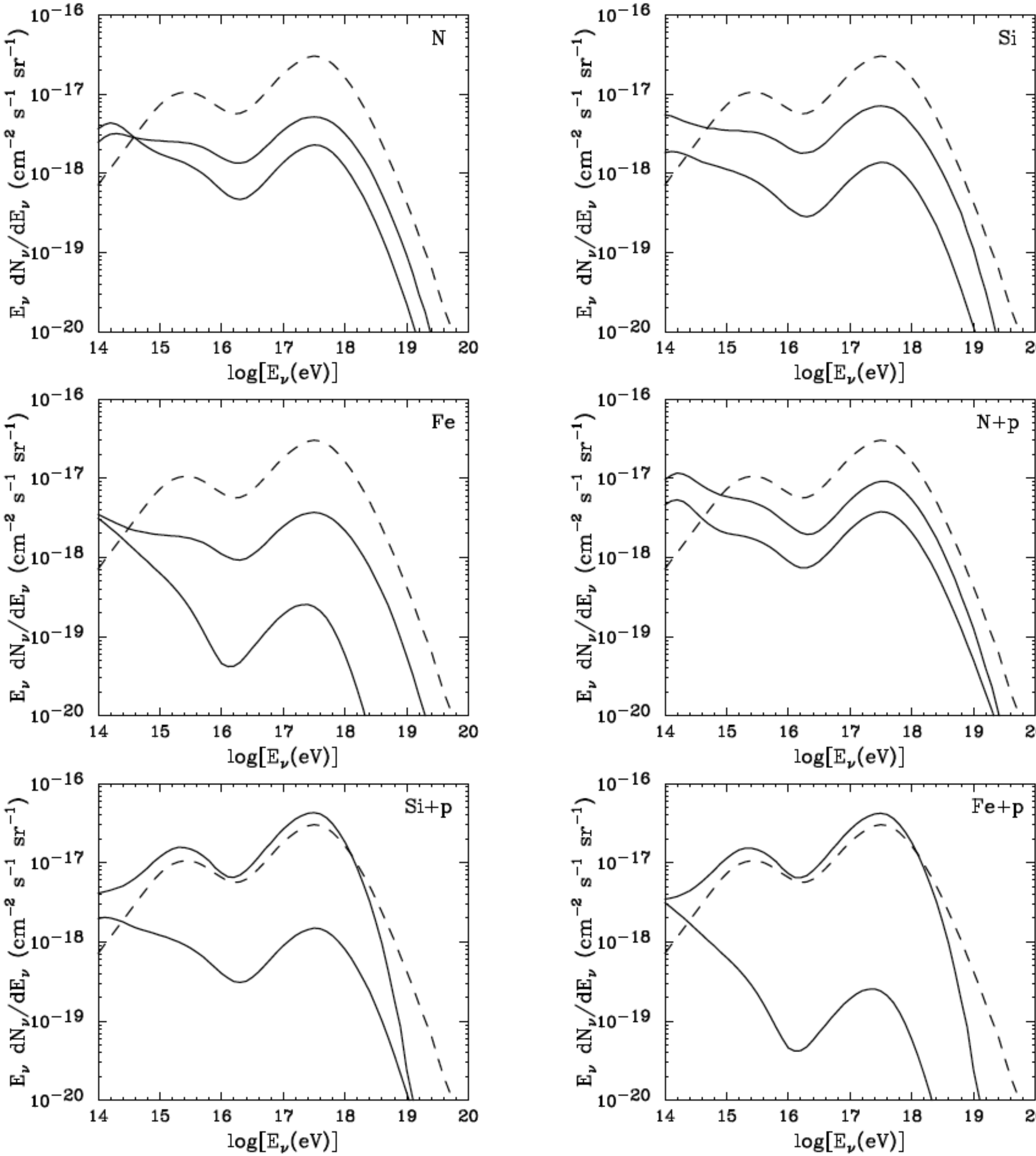
Hence the (high energy) ν_μ flux is suppressed but the (lower energy) ν_e flux is *boosted* (sensitive to E_{max}!)

Hooper, Sarkar & Taylor, AP 23:11,2005

But when *normalised* to the Auger/HiRes energy spectrum, the cosmogenic ν_e flux is *not* enhanced relative to the value for proton primaries … and the ν_μ flux is suppressed too

So detection may require ~10^{2-3} km^3 volume … might be possible using radio (e.g. ARA, ARIANNA)

Is it worth it just to confirm that there is a cosmogenic flux?



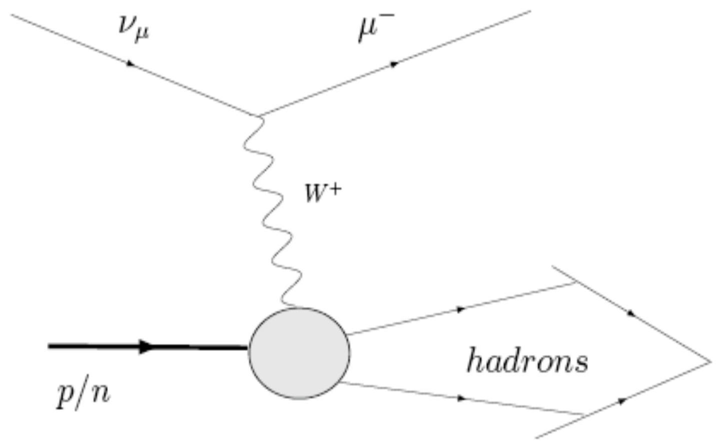
Anchordoqui, Hooper, Sarkar, Taylor Phys.Rev.D76:123008,2007

ν-N deep inelastic scattering

$$\frac{\partial^2 \sigma_{\nu,\bar{\nu}}^{CC,NC}}{\partial x \partial y} = \frac{G_F^2 M E}{\pi} \left(\frac{M_i^2}{Q^2 + M_i^2} \right)$$

$$[\frac{1+(1-y)^2}{2} F_2^{CC,NC}(x,Q^2) - \frac{y^2}{2} F_L^{CC,NC}(x,Q^2)$$

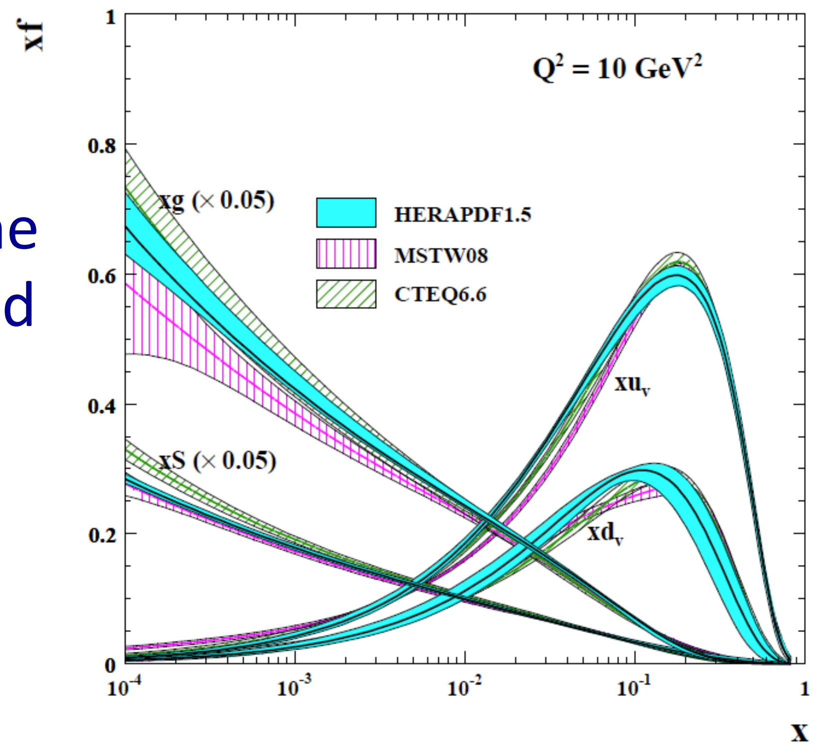
$$\pm y \left(1 - \frac{y}{2}\right) x F_3^{CC,NC}(x,Q^2)]$$



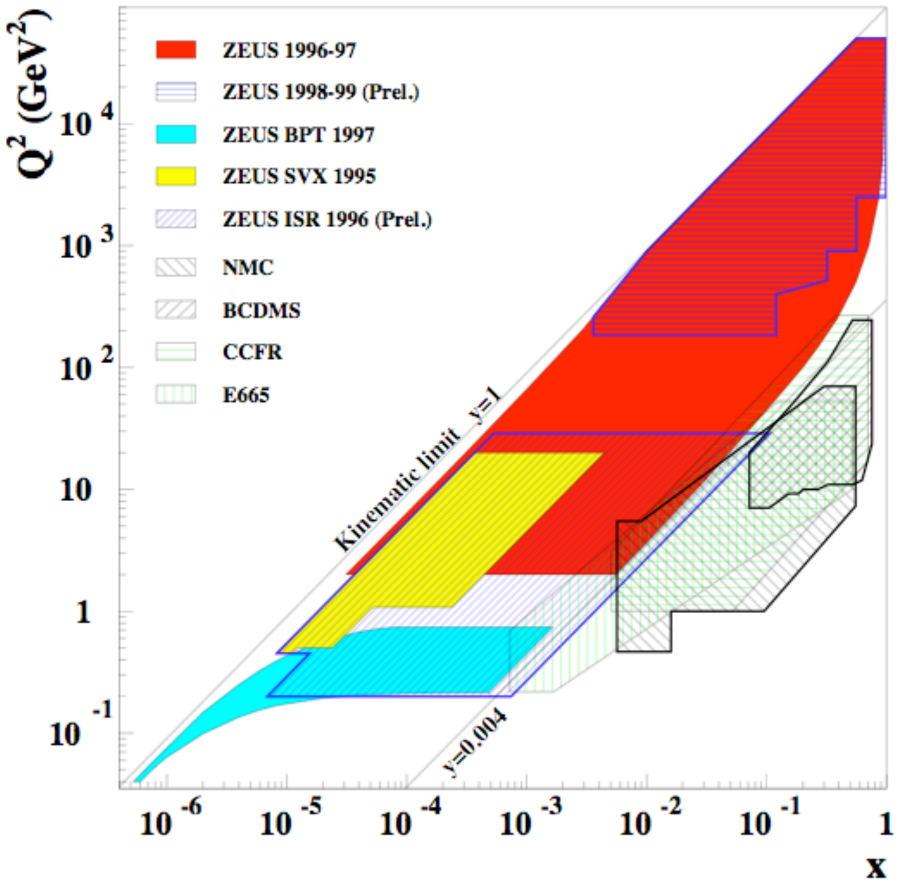
Most of the contrib. to #-secn is from:

$$Q^2 \sim M_W^2 \ and \ x \sim \frac{M_W^2}{M_N E_\nu}$$

So for cosmogenic vs with E ~ 10^{10} GeV, the kinematic region of $x \sim 10^{-6}$ is being probed



The HERA experiments showed that the gluon structure function rises steeply at low x
... but it *cannot* keep rising indefinitely!
Saturation/screening *must* set in (exactly *how* this happens is an open question)



At *leading* order, structure functions are given by:

$$F_2^\nu = x(u + d + 2s + 2b + \bar{u} + \bar{d} + 2\bar{c}) ,$$
$$F_L^\nu = 0 ,$$
$$xF_3^\nu = x(u + d + 2s + 2b - \bar{u} - \bar{d} - 2\bar{c}) ,$$

… more complicated at NLO (which we adopt)

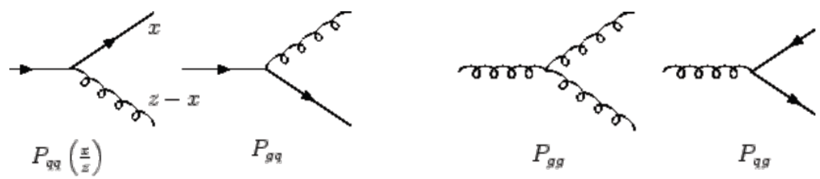
The kinematic region relevant for cosmogenic νs has *not* been directly explored at colliders - so parameterise as:

$$xg = x^{\lambda_g}(1-x)^{\eta_g} P_g(x)$$
$$xS = x^{\lambda_S}(1-x)^{\eta_S} P_S(x)$$

… evolve, using the DGLAP equations, to scale of measurement: $Q_0^2 \rightarrow Q^2$

$$\frac{\partial q^{\mathrm{NS}}(x,Q^2)}{\partial \ln Q^2} = \frac{\alpha_s}{2\pi}\left(q^{\mathrm{NS}} \otimes P_{qq}\right)$$

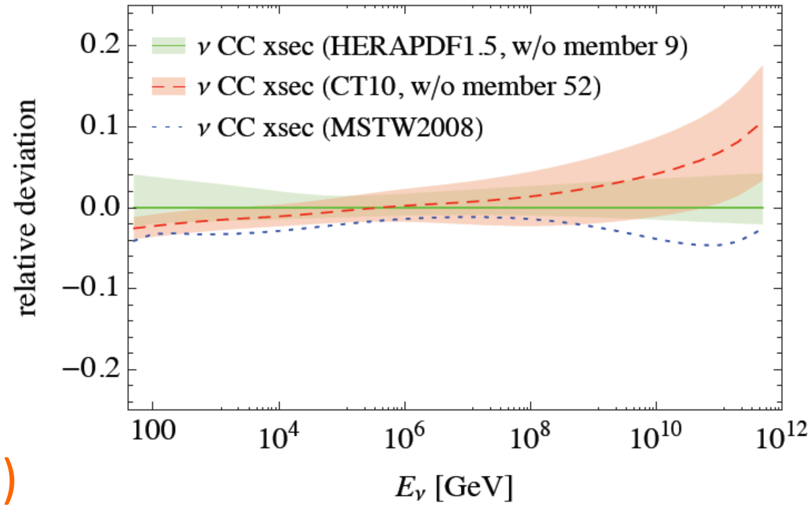
$$\frac{\partial \Sigma(x,Q^2)}{\partial \ln Q^2} = \frac{\alpha_s}{2\pi}\left(\Sigma \otimes P_{qq} + g \otimes 2n_f P_{qg}\right)$$
$$\frac{\partial \Sigma(x,Q^2)}{\partial \ln Q^2} = \frac{\alpha_s}{2\pi}\left(\Sigma \otimes P_{gq} + g \otimes 2n_f P_{gg}\right)$$

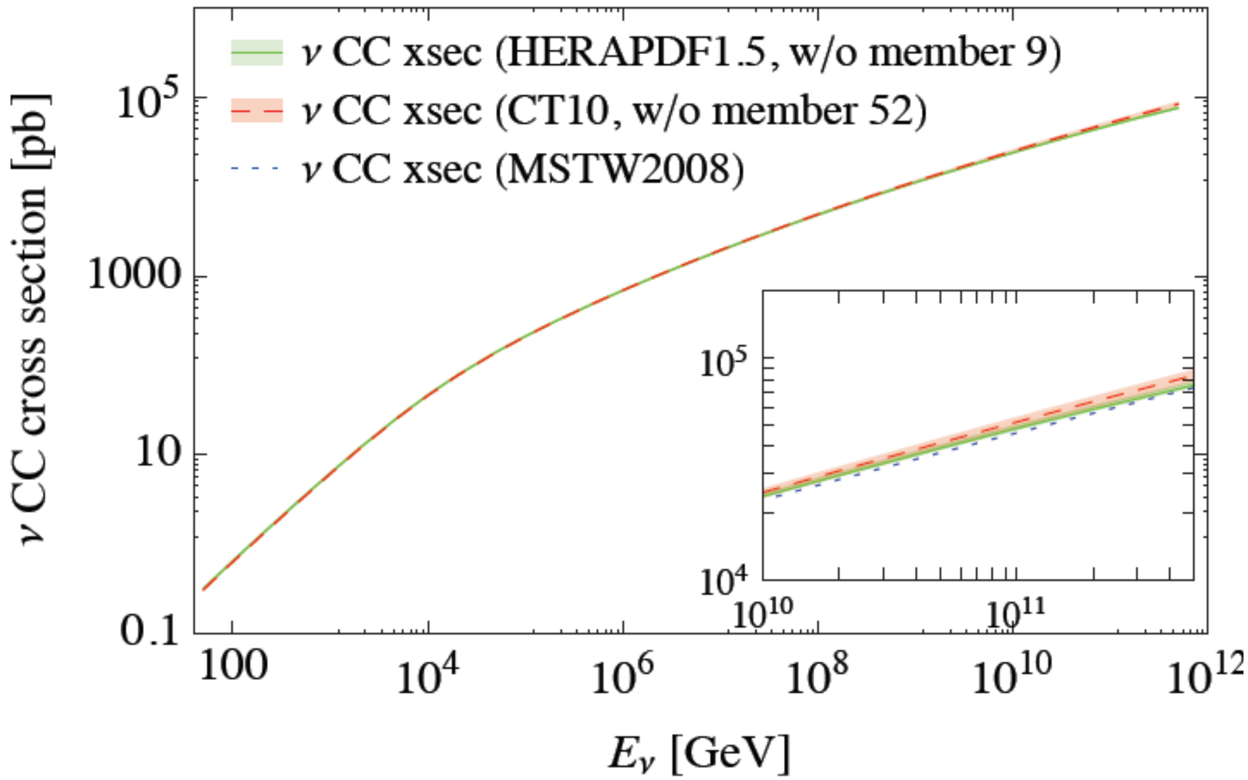


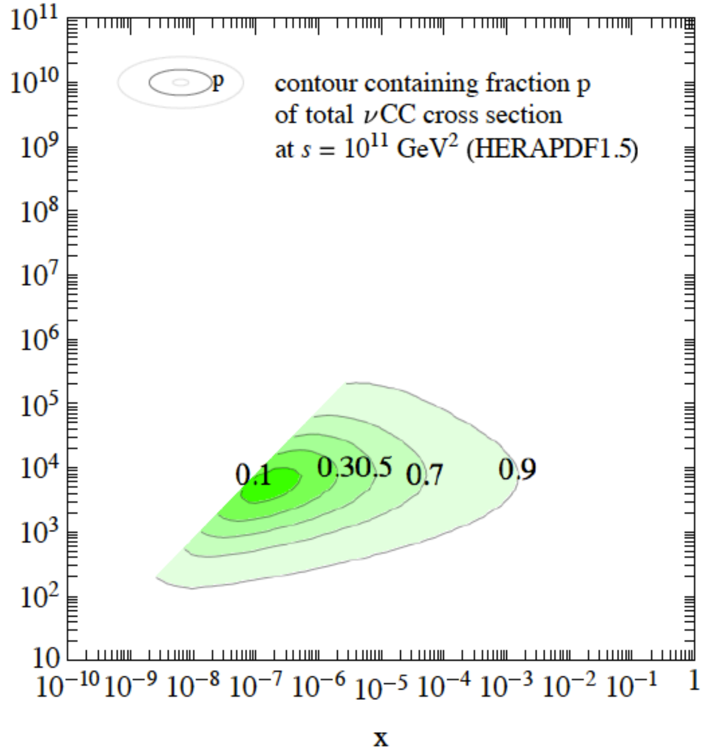
DGLAP evolution of measured PDFs to very low-x then yields the ν-N #-section

… the (**perturbative** SM) uncertainty is estimated accounting for all experimental and model uncertainties (excluding all unphysical extrapolations leading to *negative* F_2, xF_3, F_L)

All modern PDF sets (e.g. PDF4LHC recommended) give *consistent* results (excluding 'rogue' members)

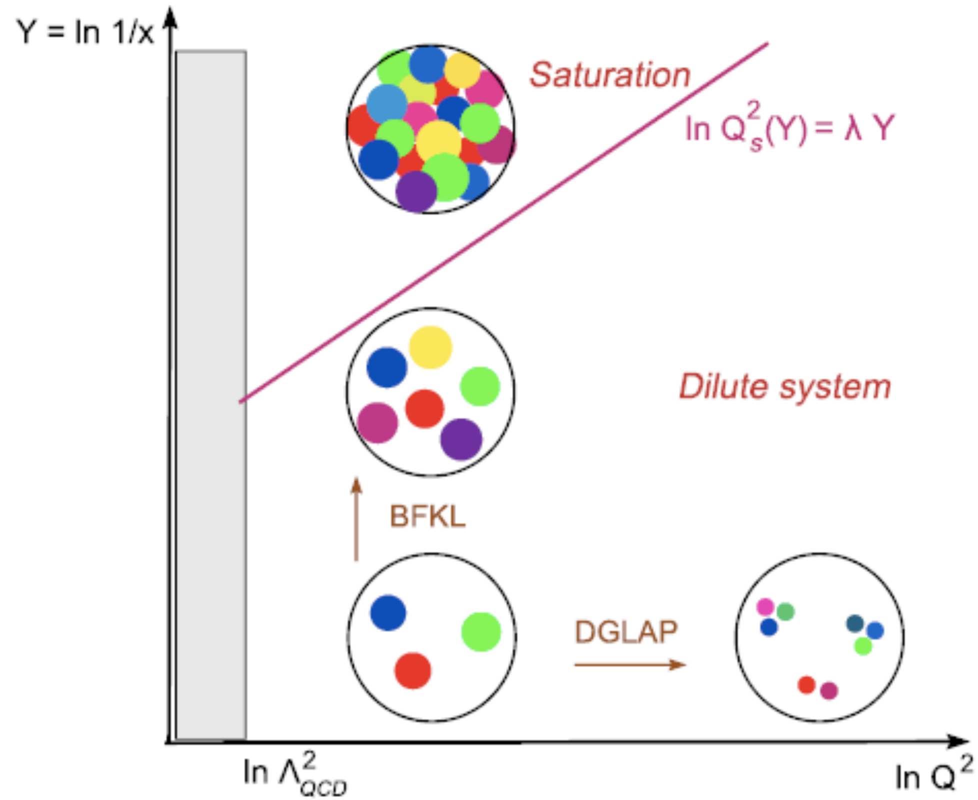






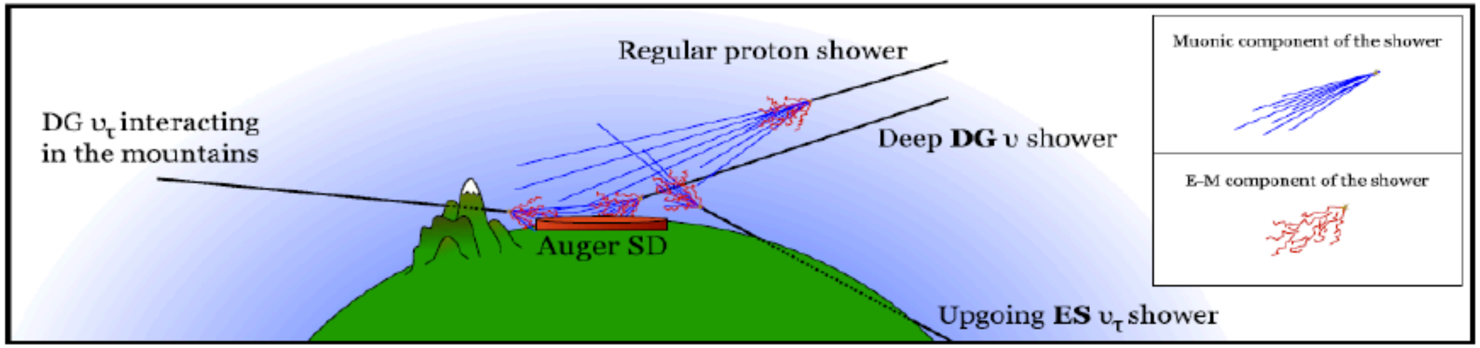
But this extrapolation *cannot* be right at low x …

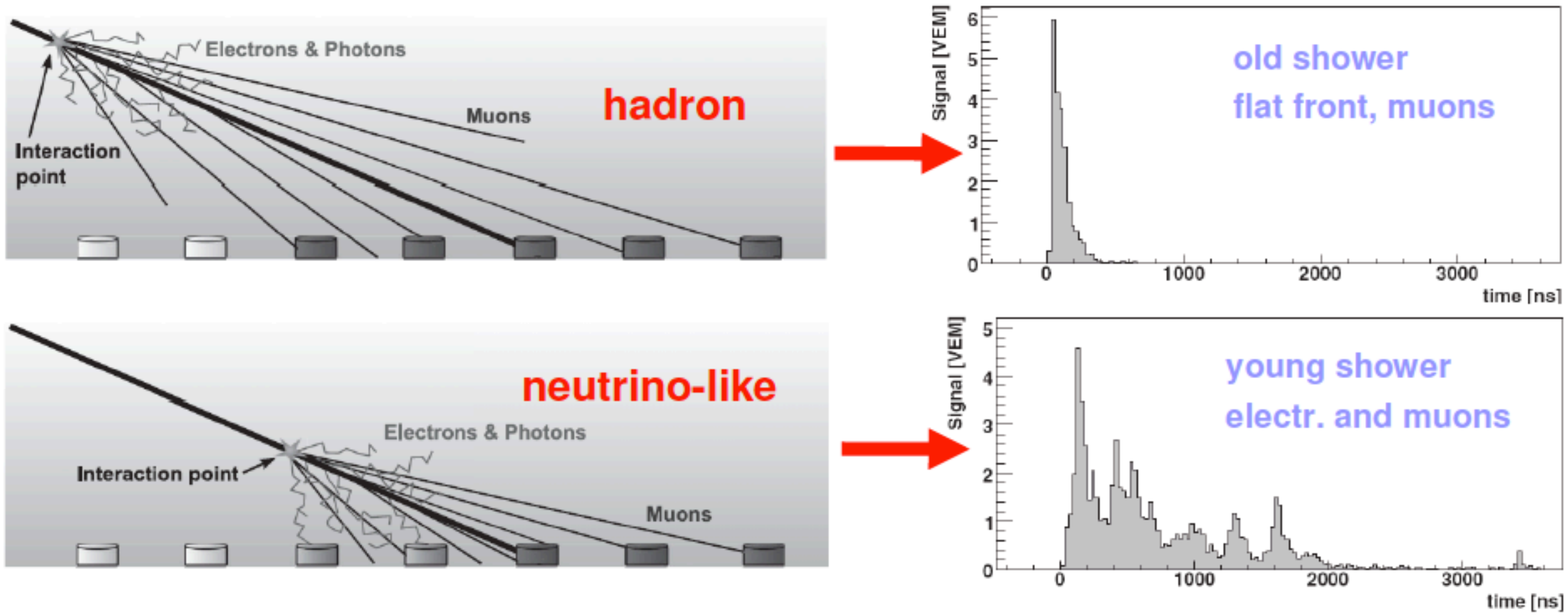
must sum ln(1/x) terms ("BFKL") and allow for screening/saturation ➙ color glass condensate?



The UHE neutrino #-section is *sensitive* to such non-perturbative effects in the SM (as well as to beyond-Standard-Model physics e.g. new dimensions at TeV scale) so a direct measurement of cosmogenic *ν* scattering will probe new *fundamental* physics

Search for neutrinos





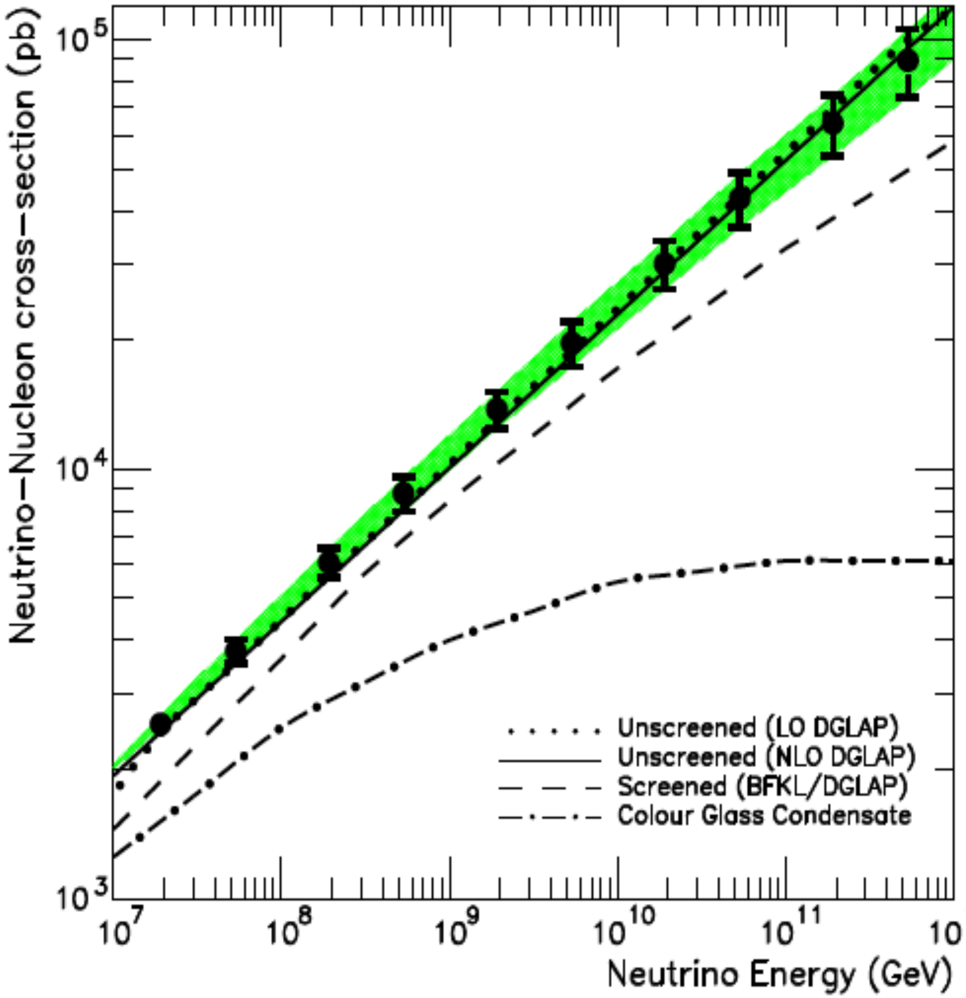
Important for neutrino detection: observable only if almost horizontal

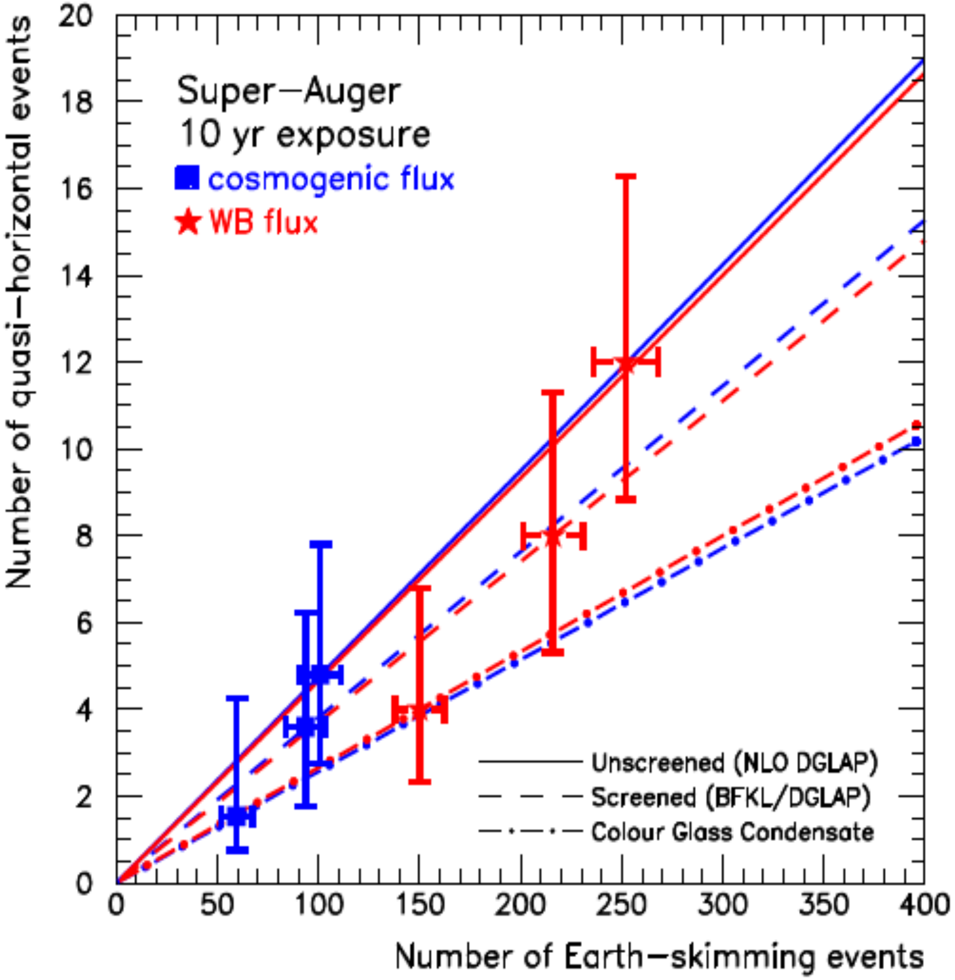
Neutrino signature: an inclined shower with large electromagnetic component

Deeply penetrating showers (all flavour) rate ∝ cosmic neutrino flux *and* to ν-N cross-section

Earth-skimming showers ($\nu_\tau \rightarrow \tau$) rate ∝ neutrino flux, but *independent* of ν-N #-section

Beyond HERA: probing low-x QCD with cosmic UHE neutrinos





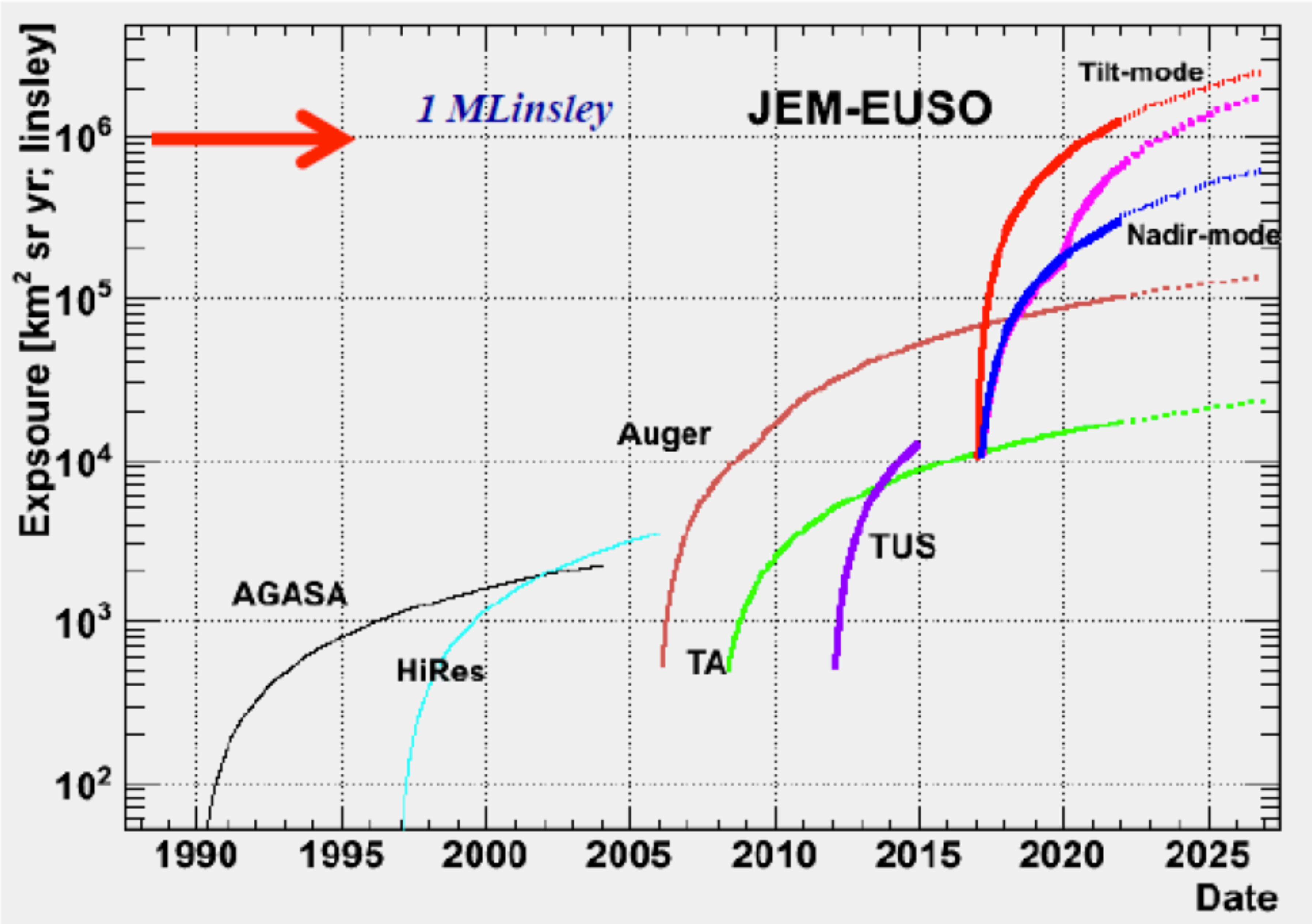
Anchordoqui, Cooper-Sarkar, Hooper, Sarkar, Phys.Rev.D74:043008,2006

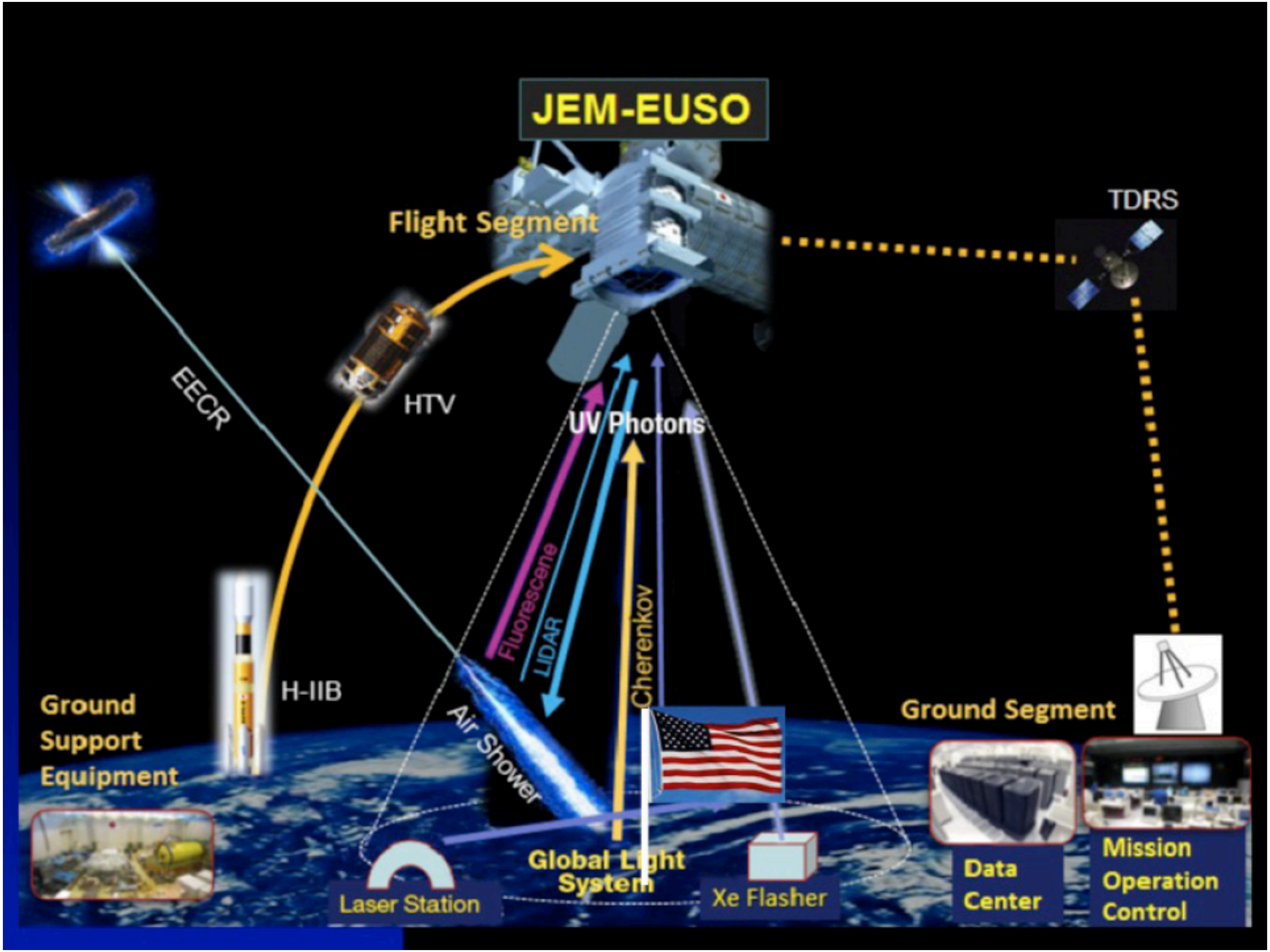
The steep rise of the gluon density at low-x must saturate (unitarity!)
⇒ suppression of the ν-N #-secn

The ratio of quasi-horizontal (all flavour) and Earth-skimming (ν_τ) events *measures* the #-section

To do this with the cosmogenic neutrino flux will require >100 x Auger exposure

Perhaps such a measurement be done by JEM-EUSO?




JEM-EUSO
Flight Segment
TDRS
HTV
EECR
UV Photons
Fluorescene
LIDAR
Cherenkov
H-IIB
Air Shower
Ground Support Equipment
Ground Segment
Global Light System
Laser Station
Xe Flasher
Data Center
Mission Operation Control

Summary

"The existence of these high energy rays is a puzzle, the solution of which will be the discovery of new fundamental physics or astrophysics" Jim Cronin (1998)

"On what can we now place our hopes of solving the many riddles which still exist as to the origin and composition of cosmic rays? It must be emphasized here above all that to attain really decisive progress greater funds must be made available"

Victor Francis Hess (1936)