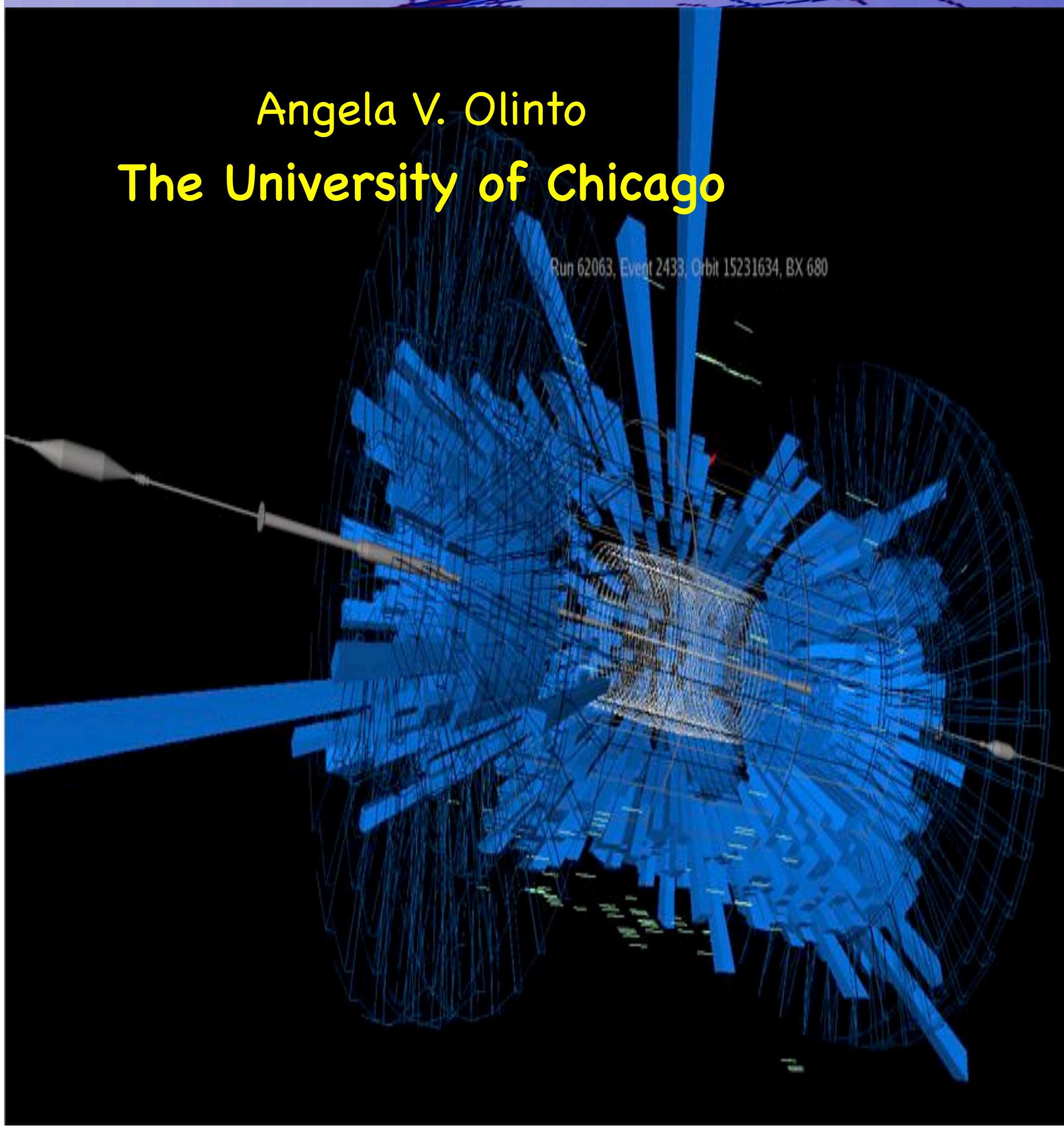
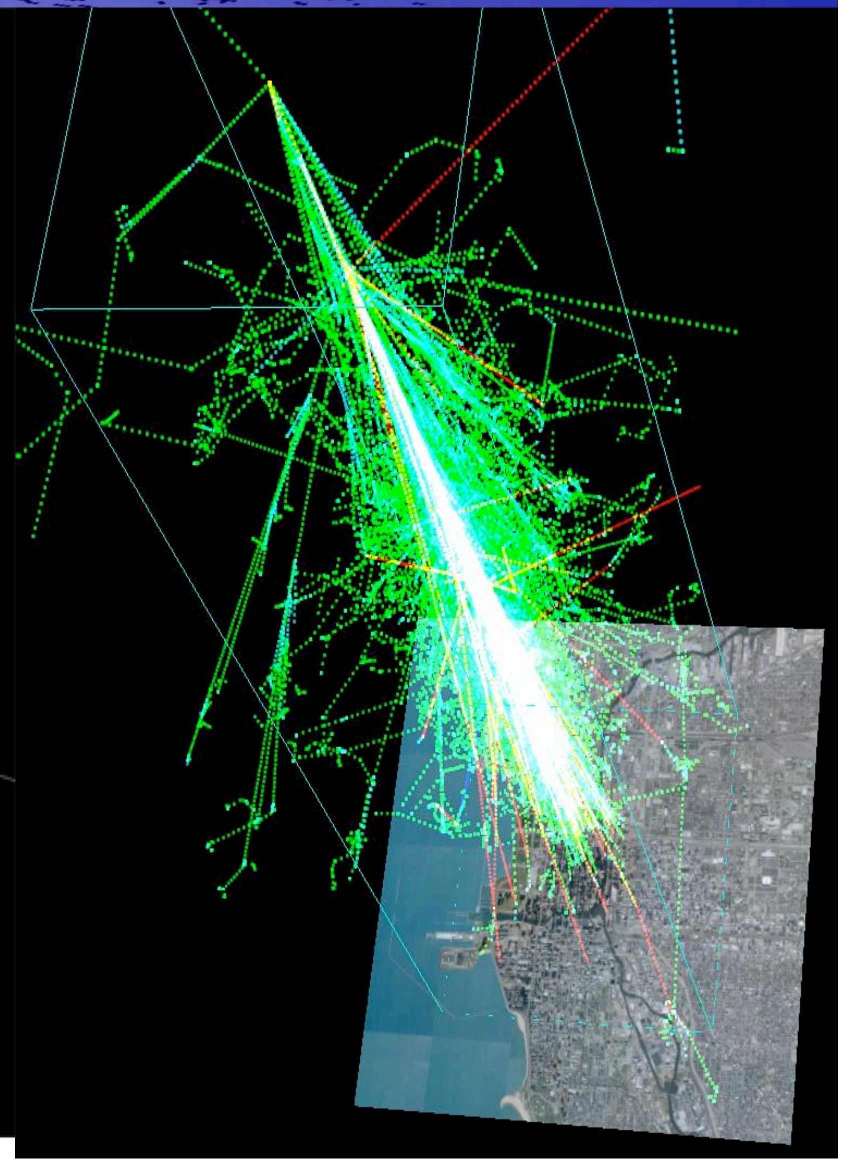
Theoretical Summary

Angela V. Olinto

The University of Chicago





13 contributions + imbedded discussion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GEOGRAPHIC
SOUTH
POLE
ROALD AMUNDSEN
Theorists deeply connected to experiments &/or observatories + v.v.

Theory Addressing:

What is the origin of Cosmic Rays?

at the knee?

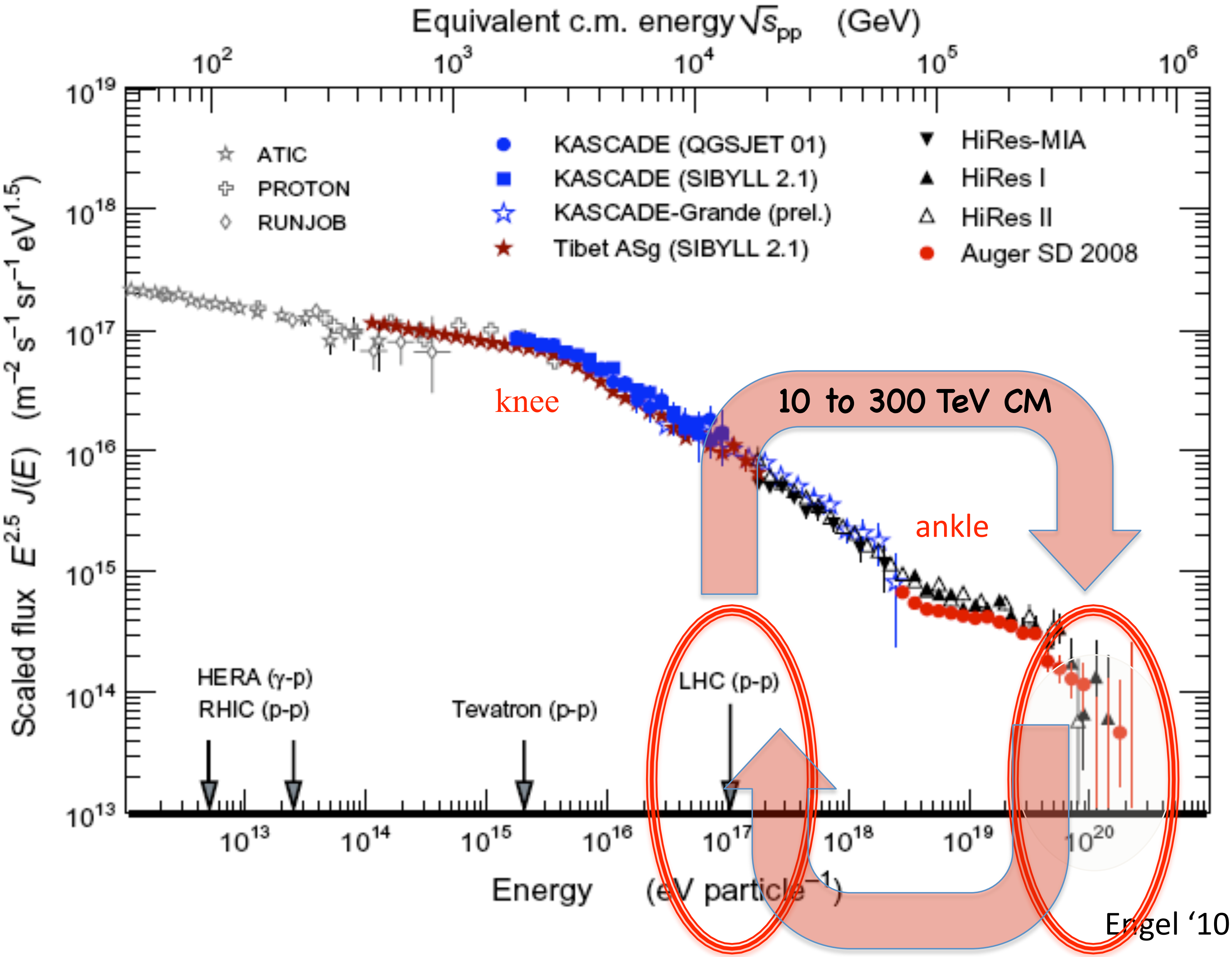
at UHEs?

How do particles interact?

at VHEs?

at UHEs?

Any Signatures of New Physics?



Equivalent c.m. energy $\sqrt{s}_{pp}$ (GeV)
10^2
10^3
10^4
10^5
10^6
10^{19}
10^{18}
10^{17}
10^{16}
10^{15}
10^{14}
10^{13}
Scaled flux $E^{2.5}$ $J(E)$ $(m^{-2} s^{-1} sr^{-1} eV^{1.5})$
ATIC
PROTON
RUNJOB
KASCADE (QGSJET 01)
KASCADE (SIBYLL 2.1)
KASCADE-Grande (prel.)
Tibet ASg (SIBYLL 2.1)
HiRes-MIA
HiRes I
HiRes II
Auger SD 2008
knee
10 to 300 TeV CM
ankle
HERA (γ-p)
RHIC (p-p)
Tevatron (p-p)
LHC (p-p)
10^{13}
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}
10^{20}
Energy (eV particle^{-1})
Engel '10

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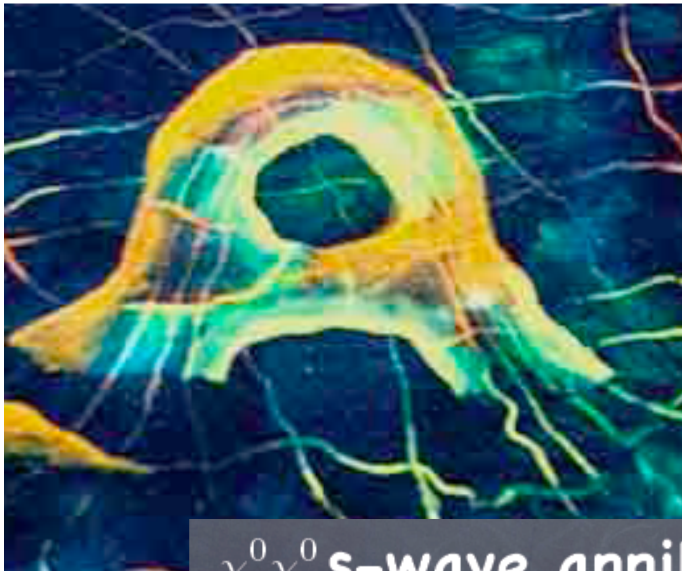


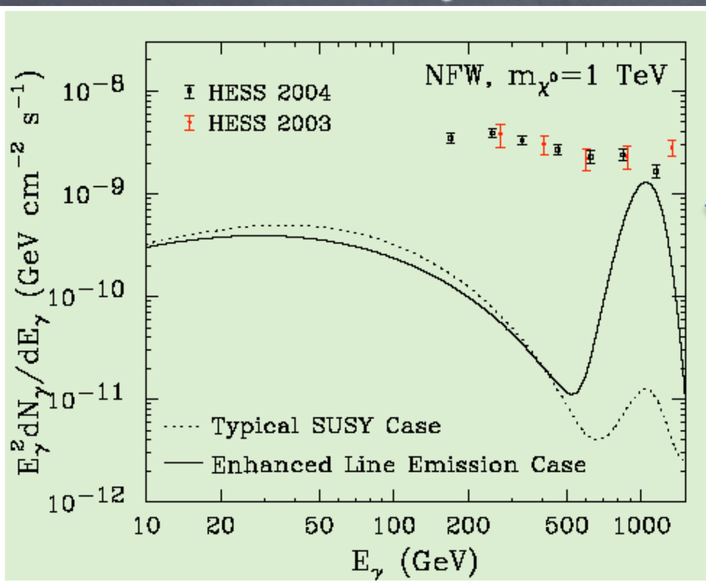
dark matter cares about topological superstrings

$\chi^0\chi^0$ s-wave annihilation into gauge bosons

Luis Anchordoqui

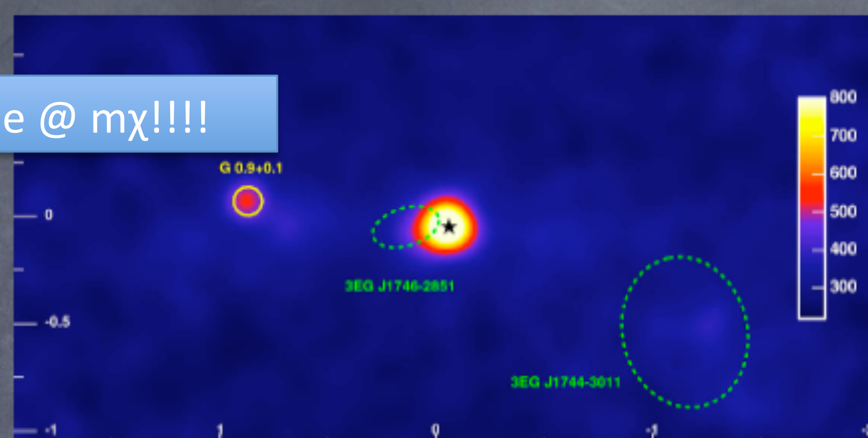
$$\mathcal{L}_{\rm eff} \;=\; 3g_s^3 N M_s^{-3} \tilde{F}^{(0,3)}\,({\rm Tr}WW)\,({\rm Tr}WW)|_{\theta\theta} + {\rm h.c}$$

Gamma-ray Flux from annihilation in GC

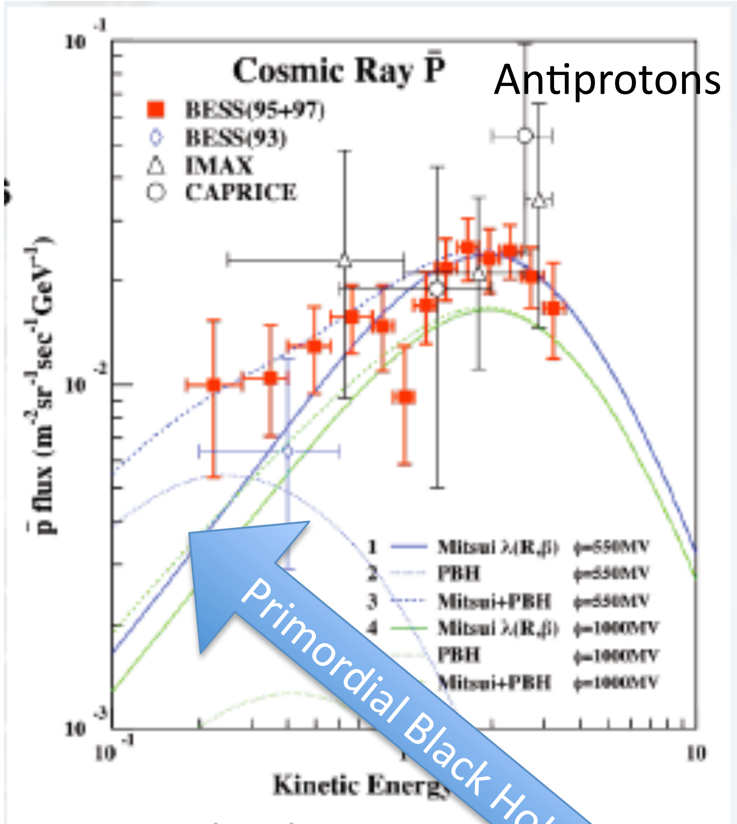


Line @ mχ!!!!

H.E.S.S and Galactic Center

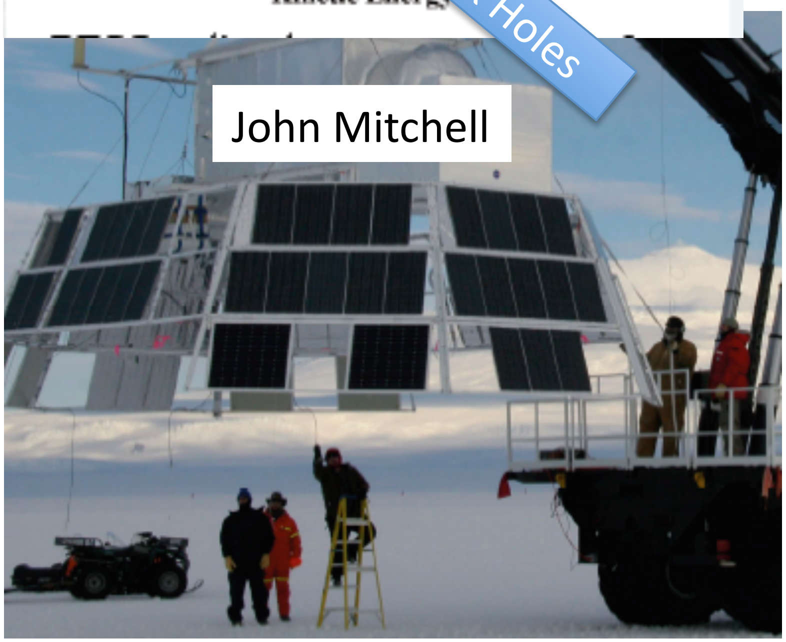


Antiprotons



Primordial Black Holes

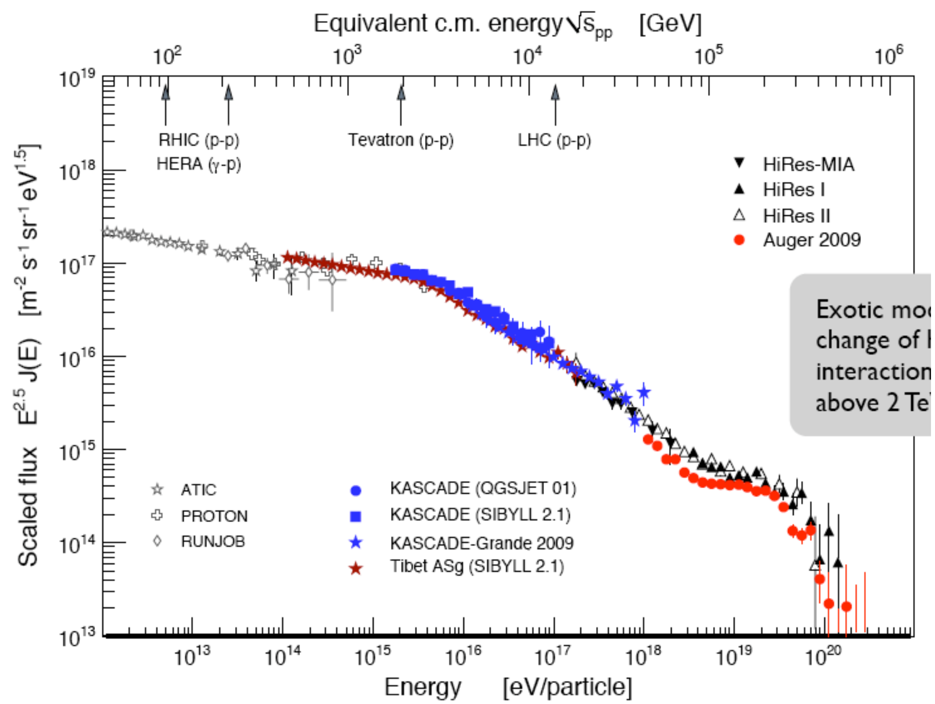
John Mitchell



Ralph Engel

Exotic models for knee: change of hadronic interaction characteristics above 2 TeV c.m.s.

Ruled OUT!



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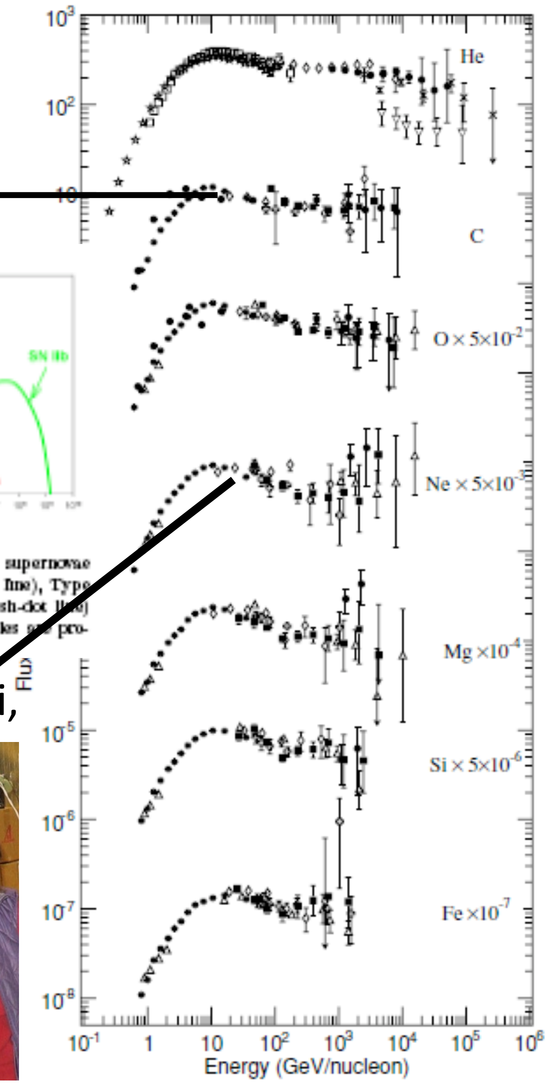
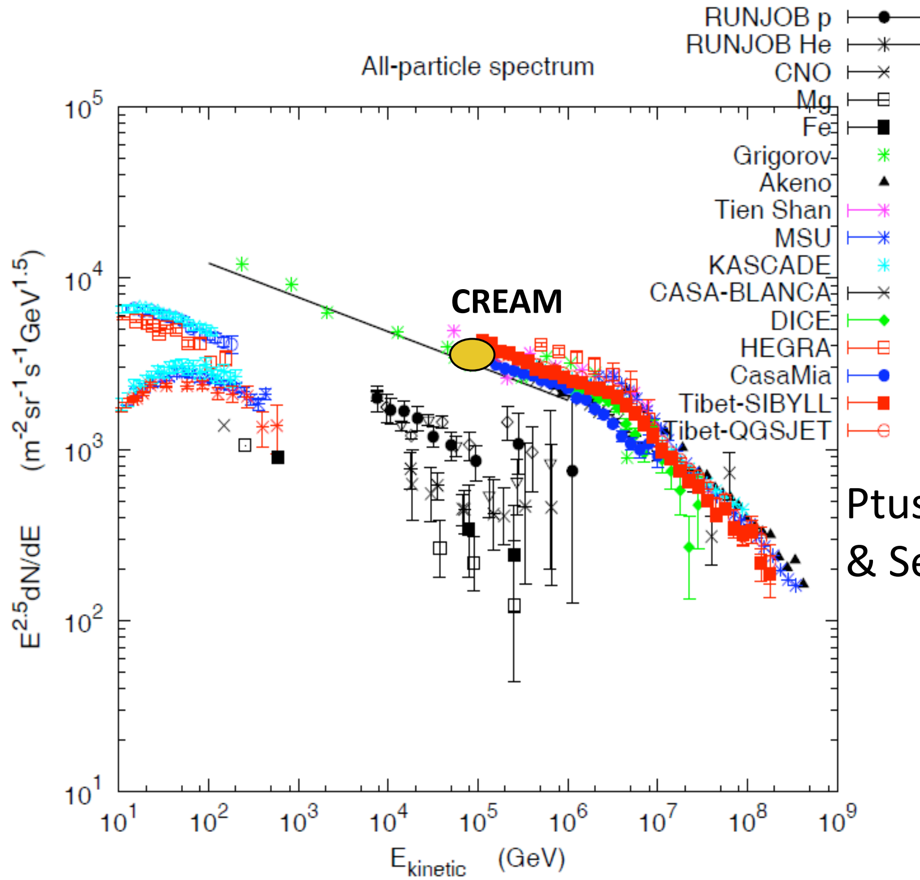
Cosmic Rays: Status Report

Concave spectrum suggestive of
non-linear diffusive shock acceleration

Now



Anchor EAS to direct measurements



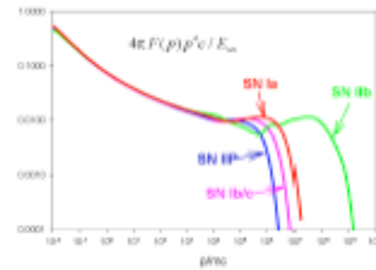


Fig. 1.— Source spectra produced by supernovae Type Ia (solid line), Type IIP (dash line), Type Ib/c (dotted line), and Type IIb (dash-dot line) assuming that the accelerated particles are protons.

Ptuskin, Zirakashvili, & Seo '10

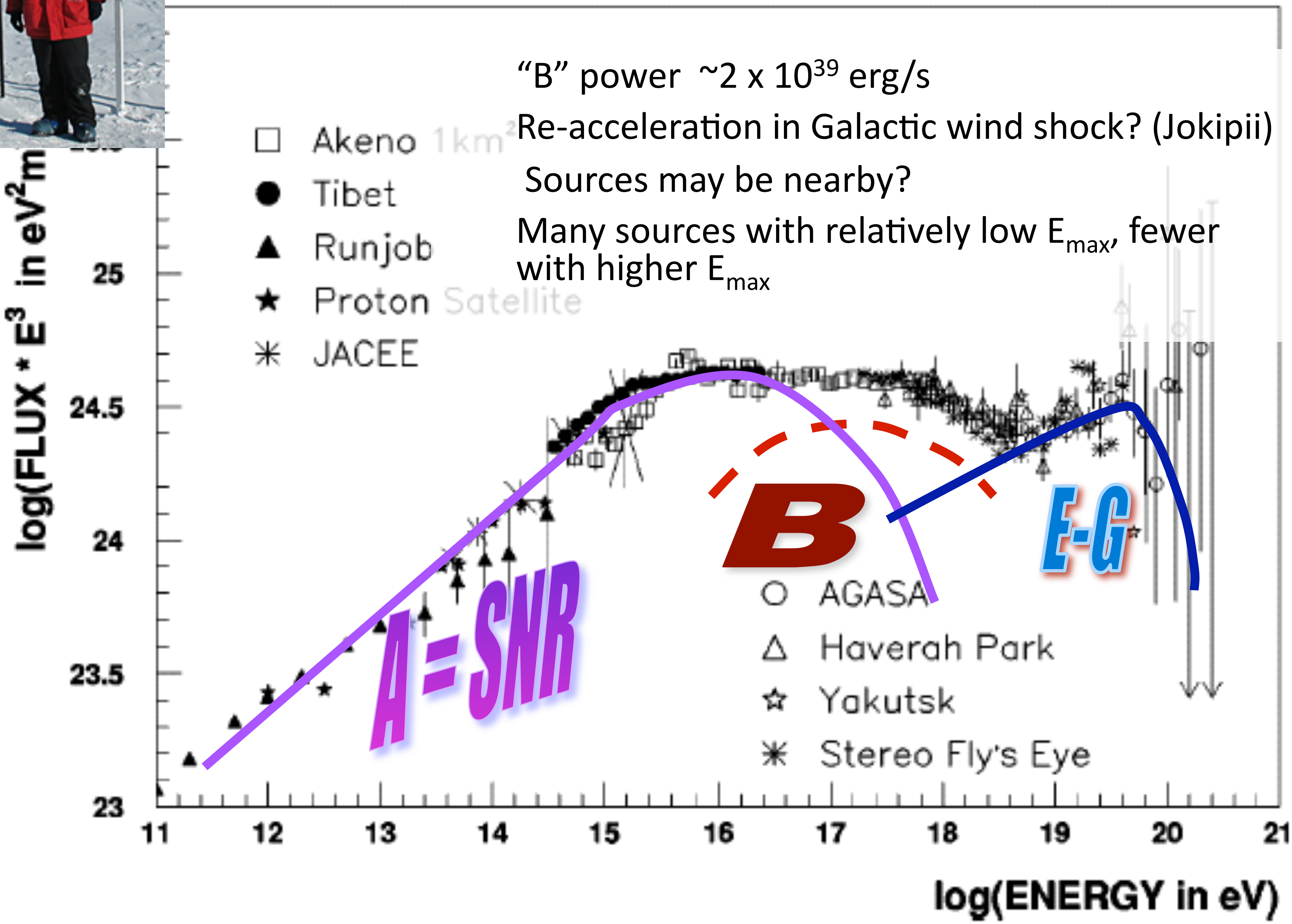
Hillas: Galactic components A & B ?
B needed if transition at ankle

"B" power ~2 x 10^{39} erg/s

Re-acceleration in Galactic wind shock? (Jokipii)

Sources may be nearby?

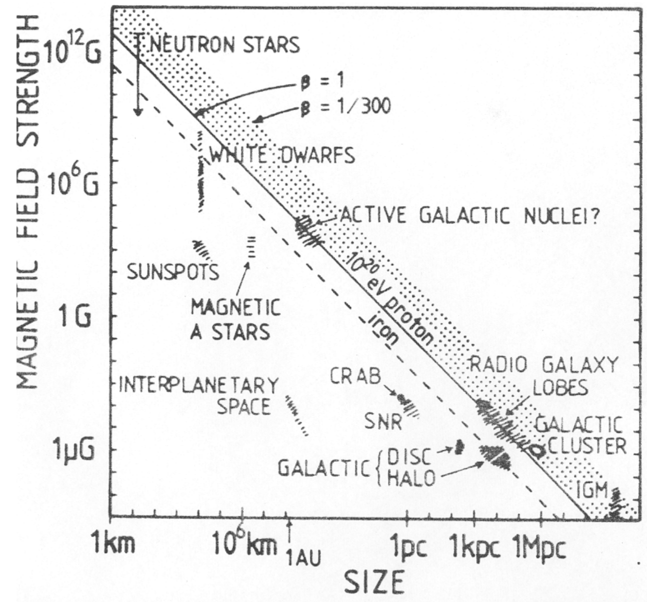
Many sources with relatively low E_{max}, fewer with higher E_{max}



Summary comment - III

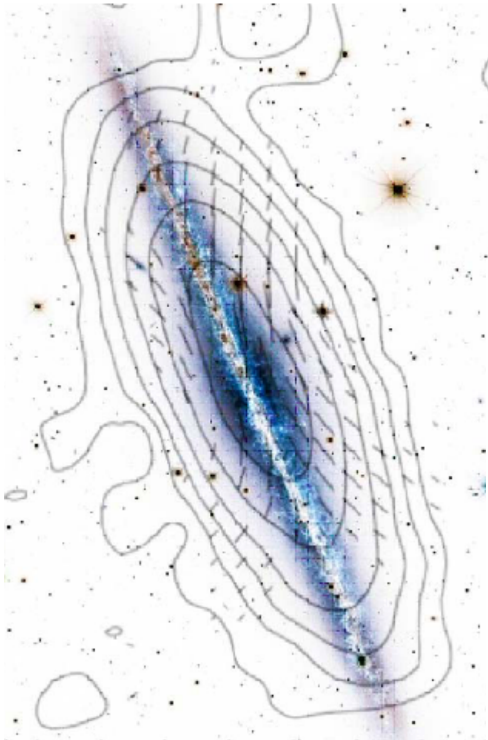
Remember the Hillas plot:

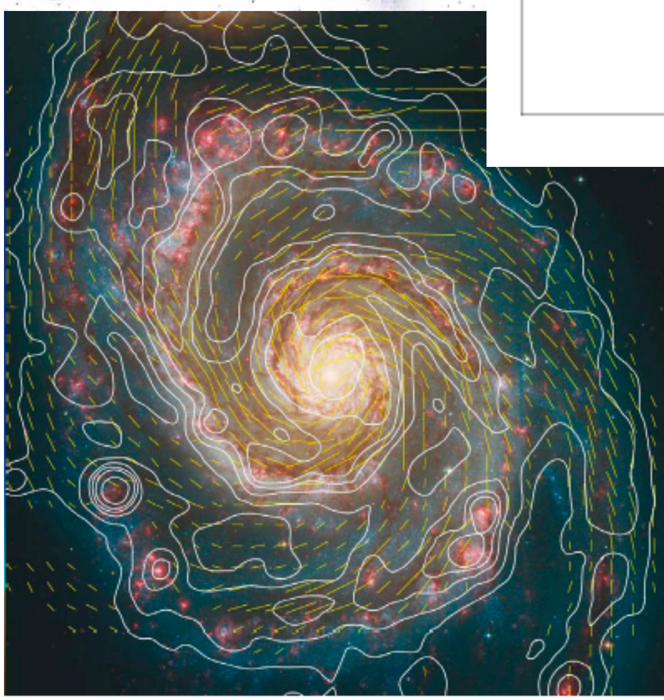
- Acceleration to 10^{20} eV is marginal
- "Cutoff" observed by HiRes, Auger could be a real cutoff at E_{max} of accelerator and not the GZK suppression
- This scenario more likely if Auger heavy composition is correct

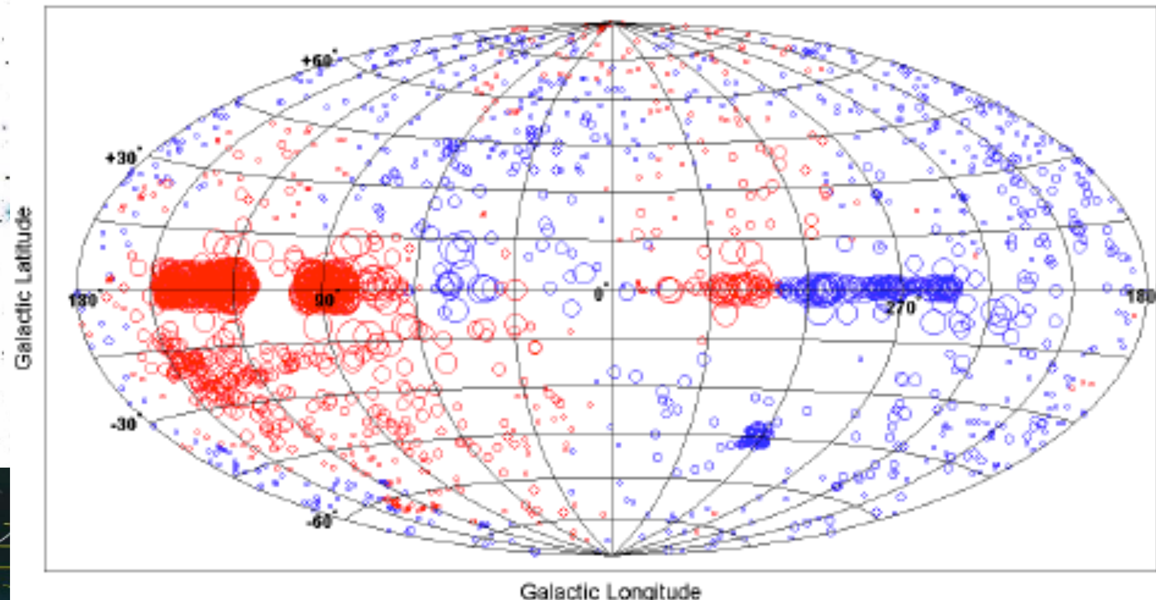


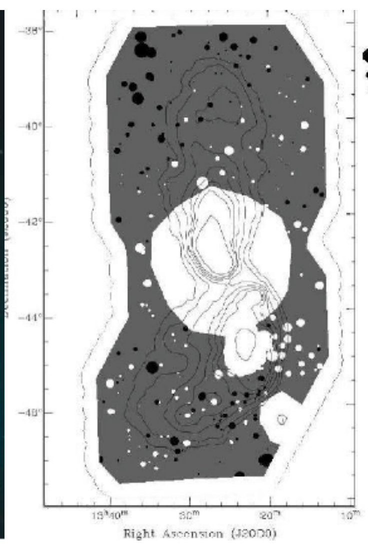
Cosmic magnetic fields and HE particle interactions

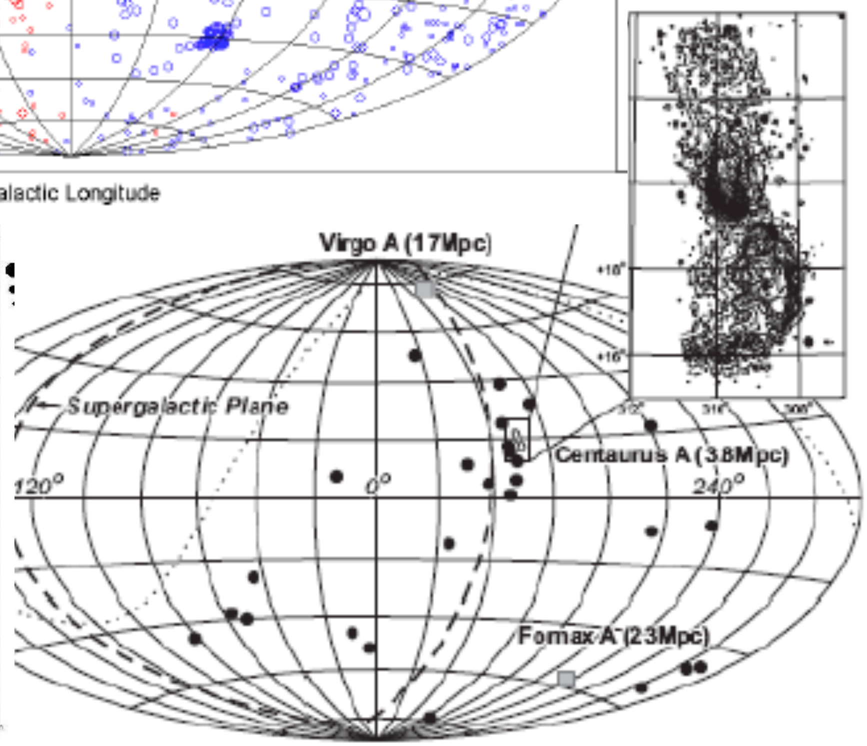
Philipp Kronberg



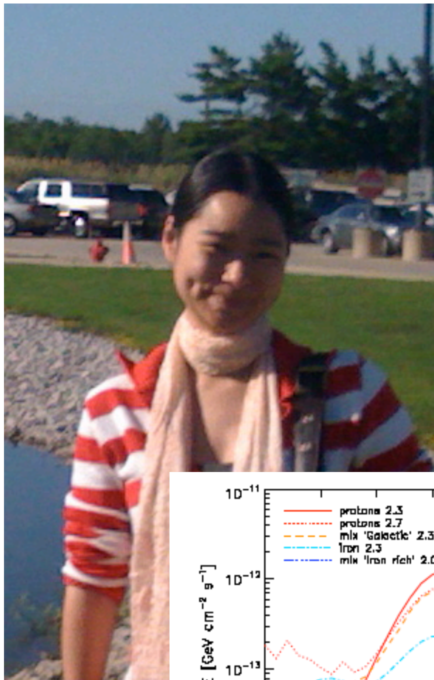


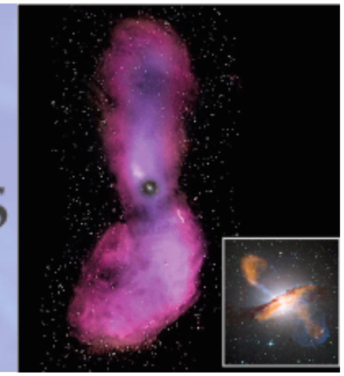




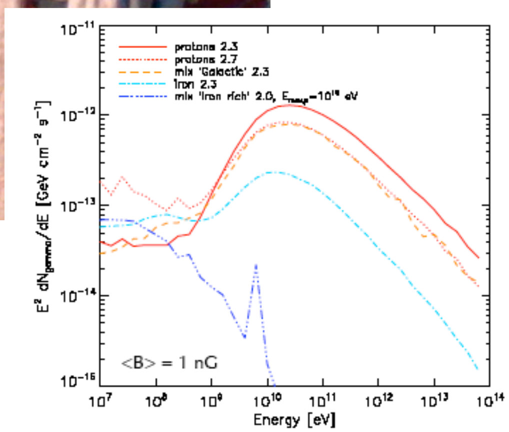


Are signatures of ultrahigh energy cosmic rays detectable in gamma rays?

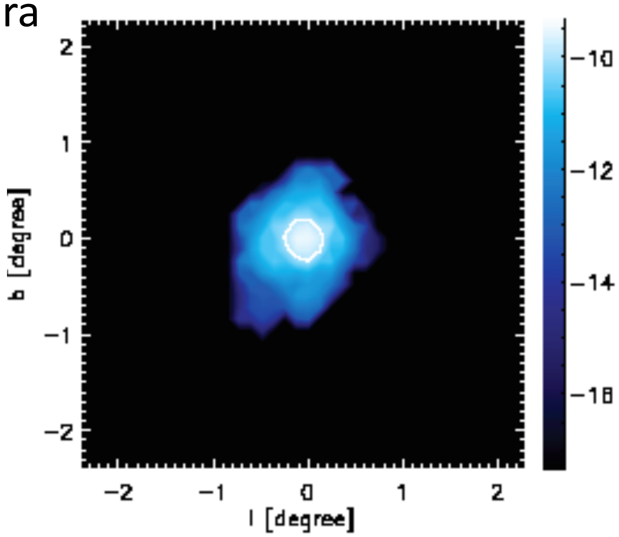


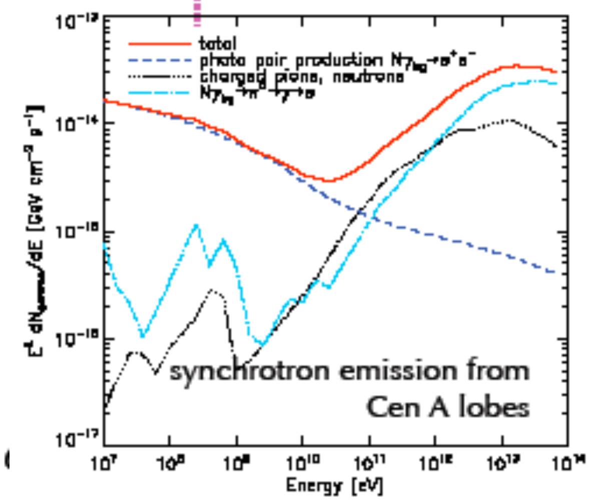


Kumiko Kotera



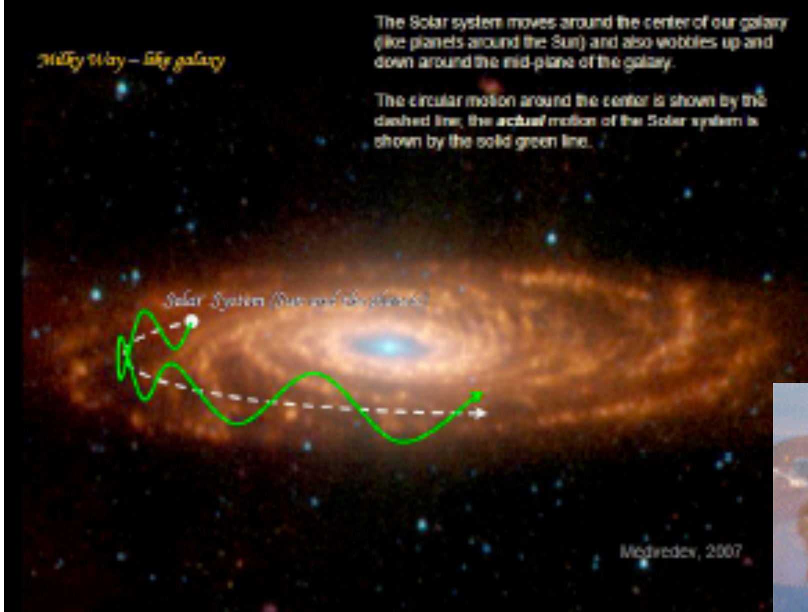
Chemical compositions of primary UHECR



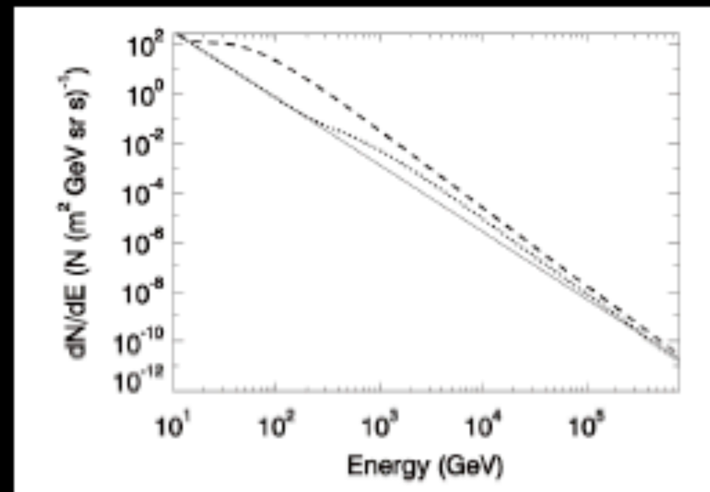


- average type of sources not observable by current and upcoming instruments (2 orders of magnitude)
- powerful sources:
  - $L_{19}=10^{44}$ erg s^{-1} at 100 Mpc **at limit of observed CR spectrum**, would produce a **detectable γ halo of ~2°**
  - $L_{19}=10^{46}$ erg s^{-1} at 1 Gpc produce **10% of observed CR spectrum**, and a **detectable γ halo of ~1°**
  - Note: **halo = clear signature of UHECR**
- close-by sources: Cen A
  - synchrotron radiation due to injection of UHECR in lobes not observable
  - **UHE emission** potentially observable with Auger if Cen A is responsible for 10% of the 6×10^{19} eV flux

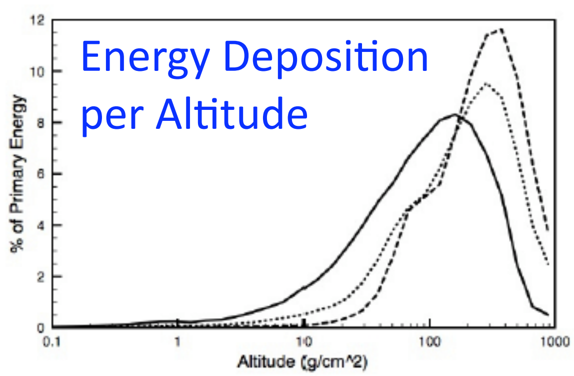
Periodicity in terrestrial biodiversity



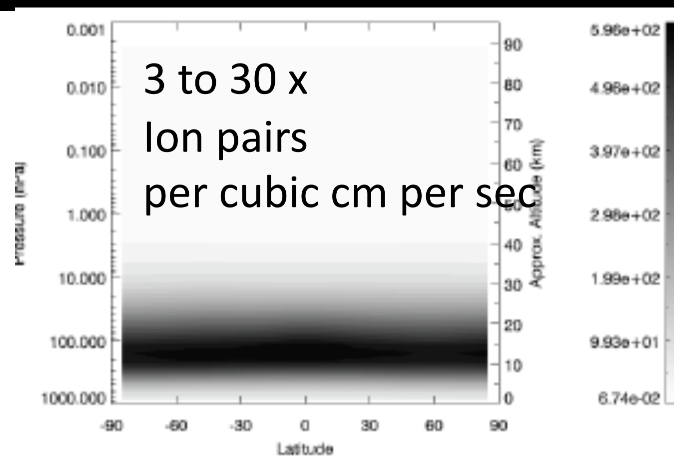
Dimitra Atri



Enhanced spectra in the extragalactic shock model (Medvedev and Melott, 2007).



Ozone Depletion
Serious Suntan!!!!



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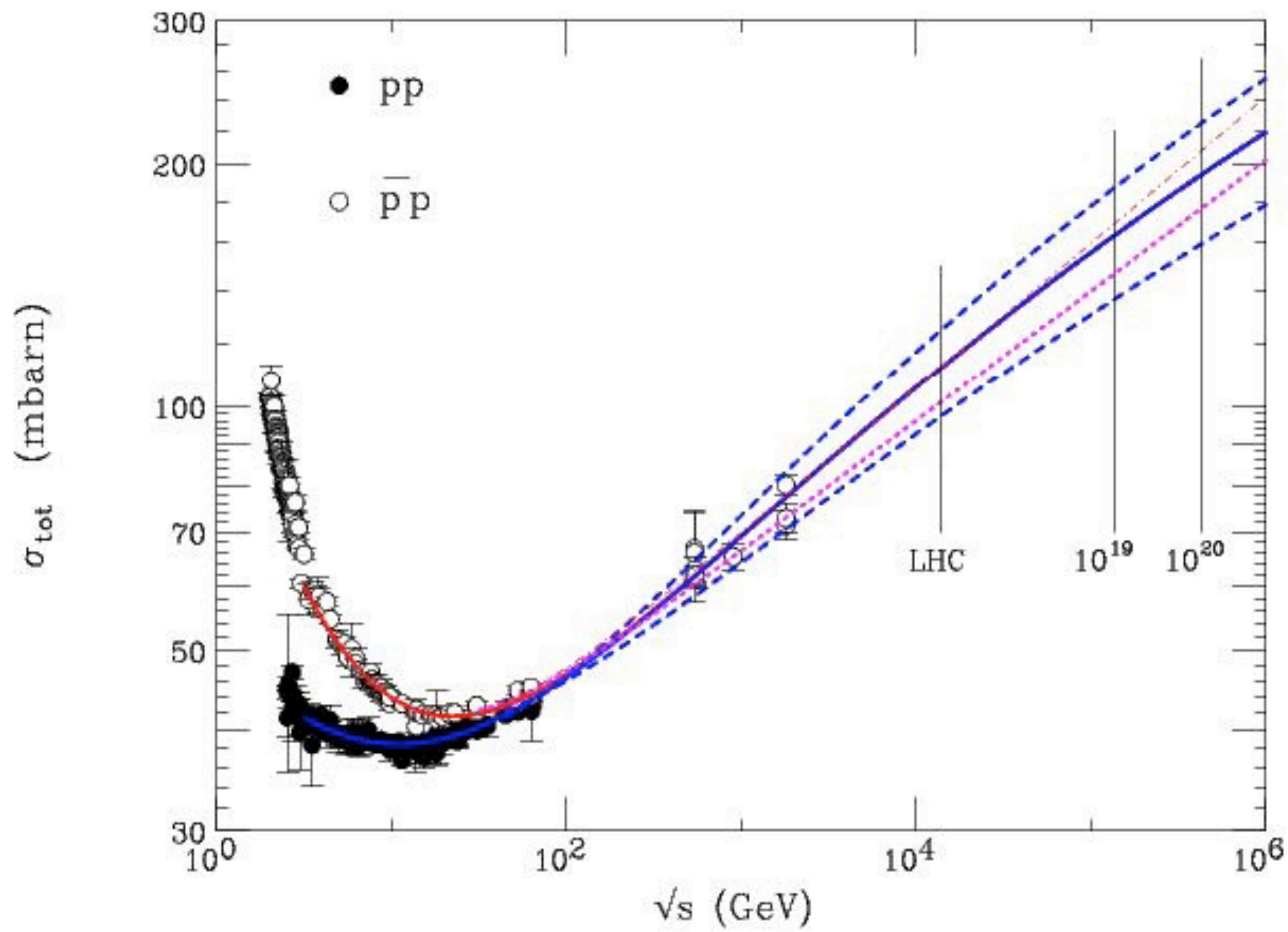
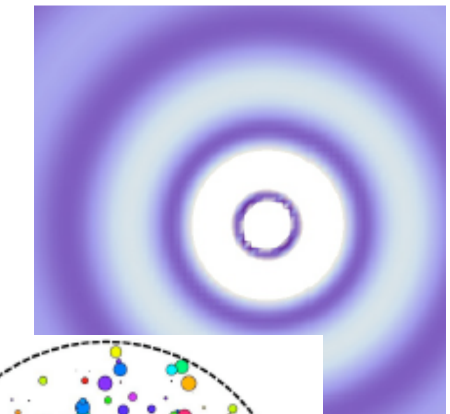
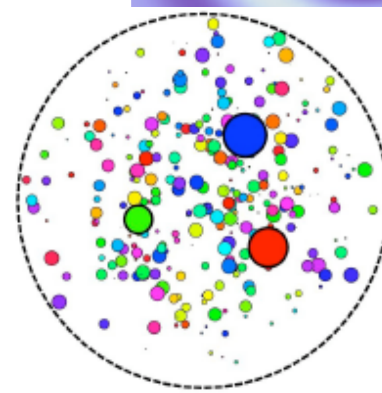
Accelerator Data & HECRs







Paolo Lipari

2.a Crucial moment for
Particle Physics and accelerators.

2.b Very exciting moment for
Cosmic Ray science and
High Energy Astrophysics

3. Possibility [in fact need] for comunication

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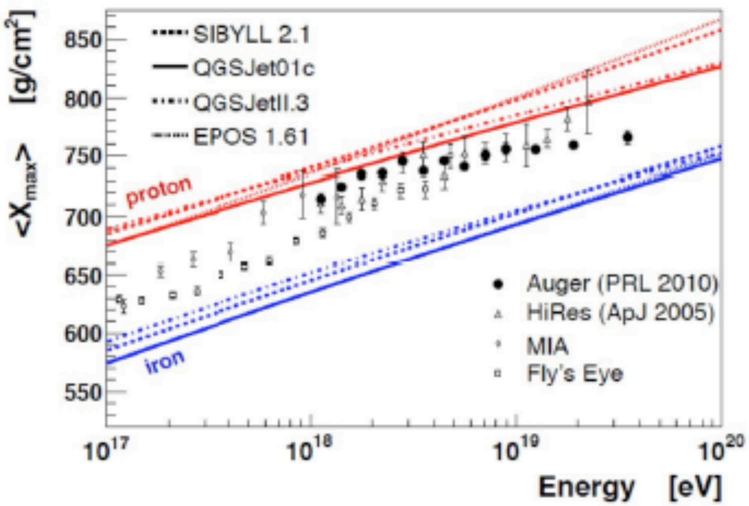
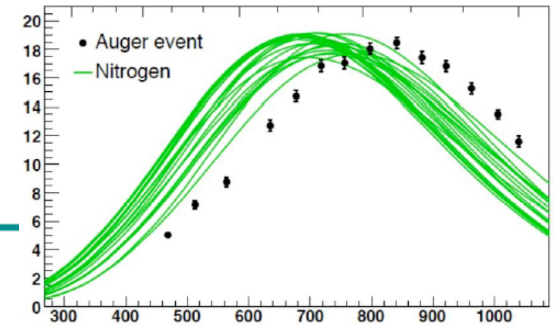
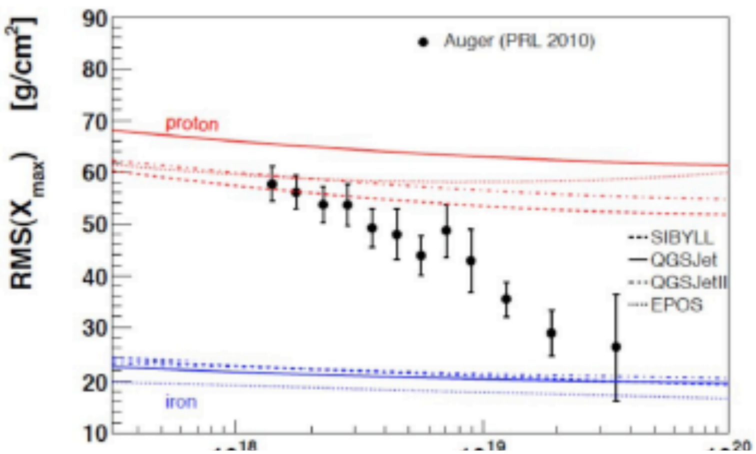


AUGER
Fluctations result.

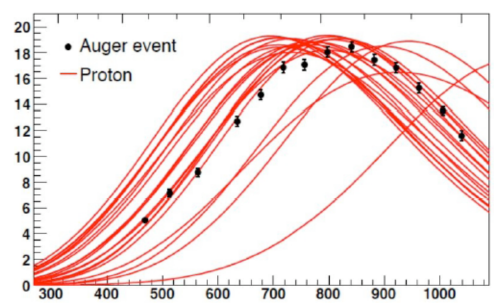
Sufficient
[after experimental
confirmation]
to establish
That the highest particle
Mass is close to iron ?

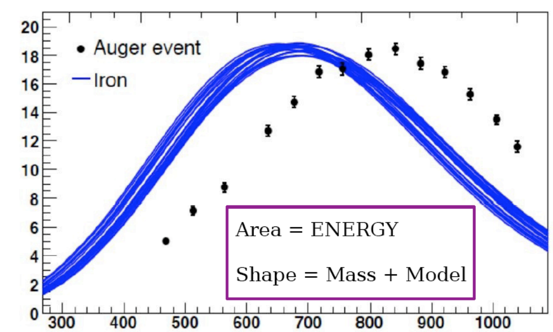


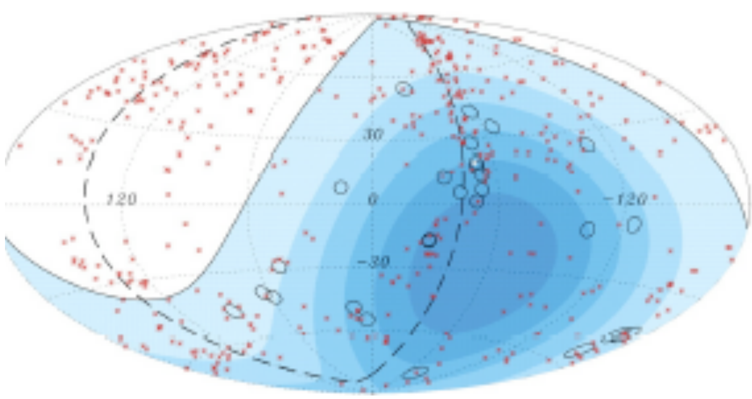


But then also in
This case one should change
the interaction model.

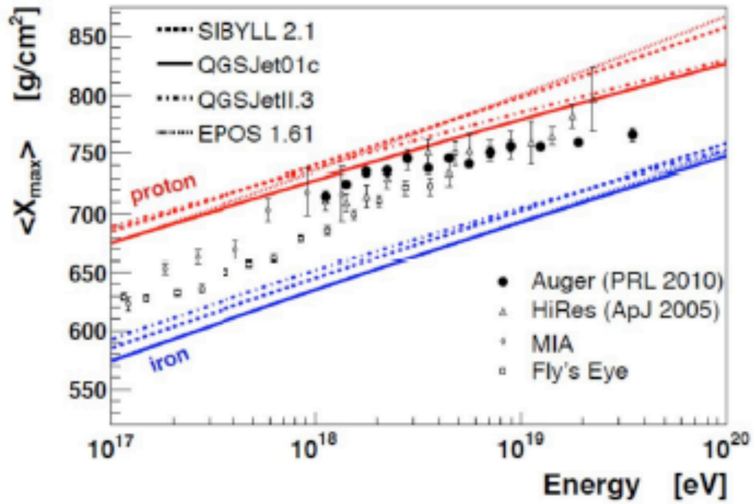
In the "opposite direction":
Longer showers







Protons are preferred [....? ....]



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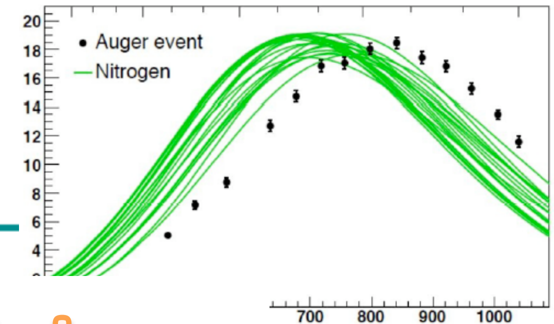
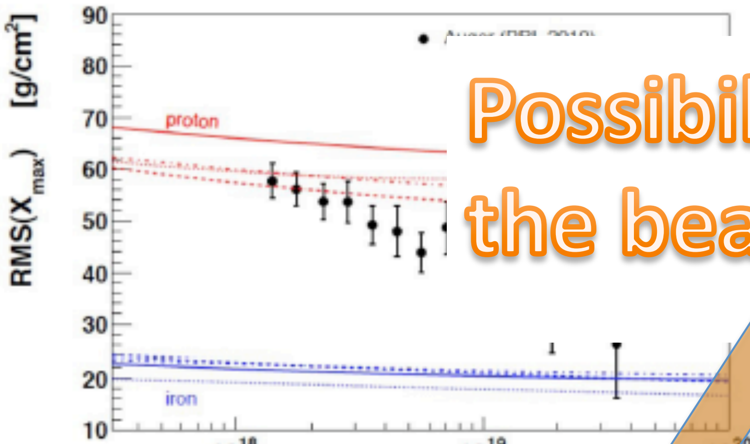
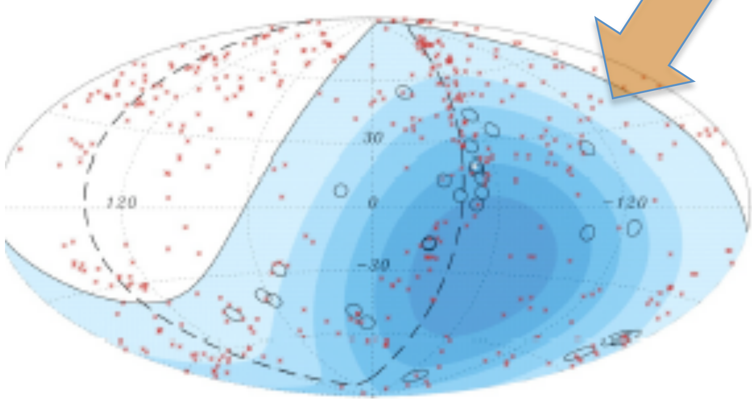
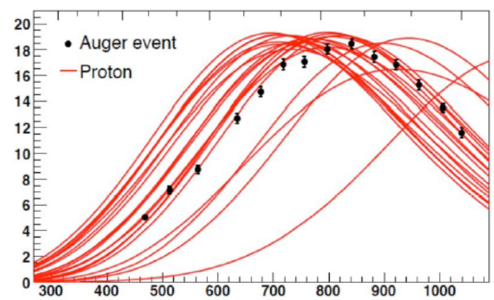


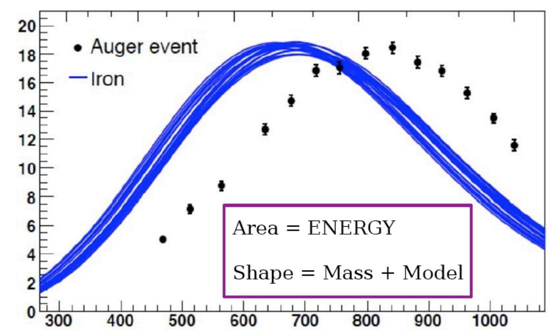


Possibility of determining the beam astrophysically!!!

Longer showers

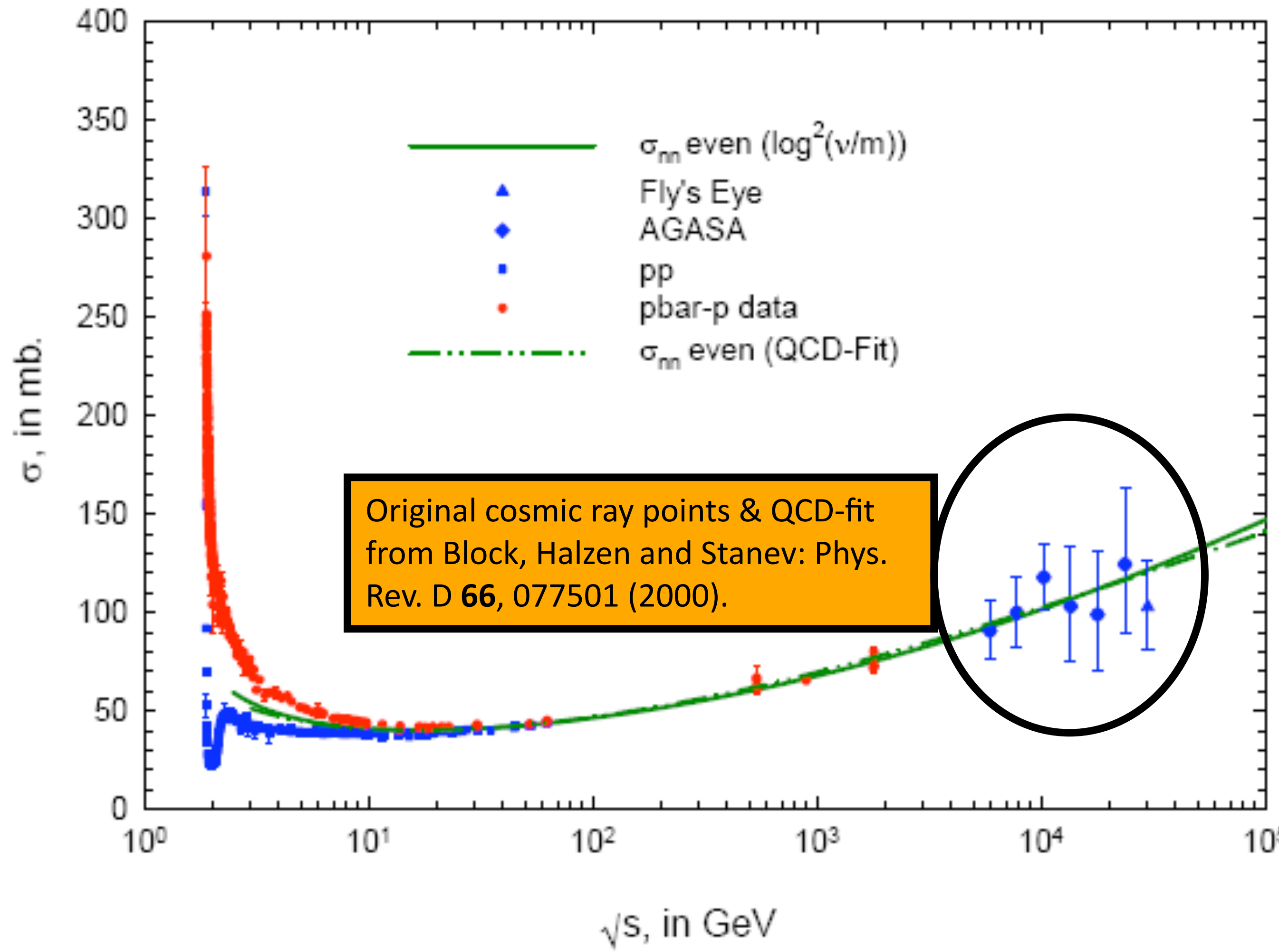


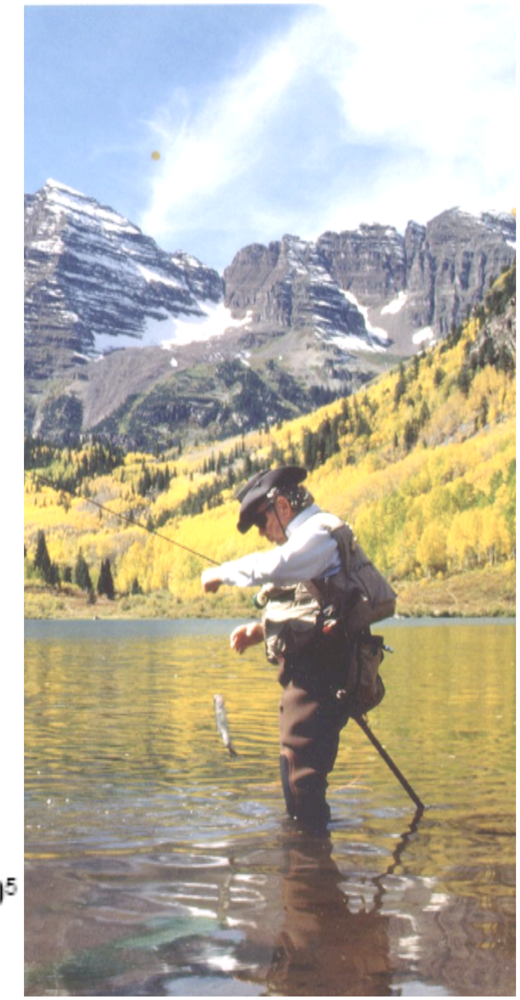




Protons are preferred [....? ....]

Saturating the Froissart Bound: σ_{pp} and σ_{pbar-p} $\log^2(\nu/m)$ fits, with world's supply of data





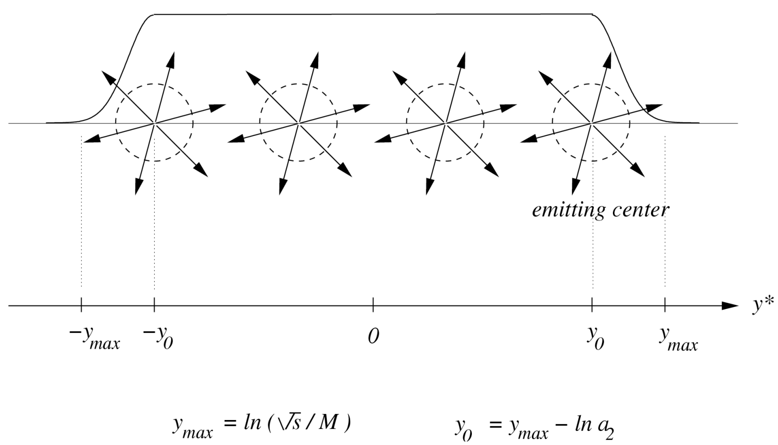
At the LHC, σ_{tot} = 107.3 ± 1.2 mb, ρ = 0.132±0.001

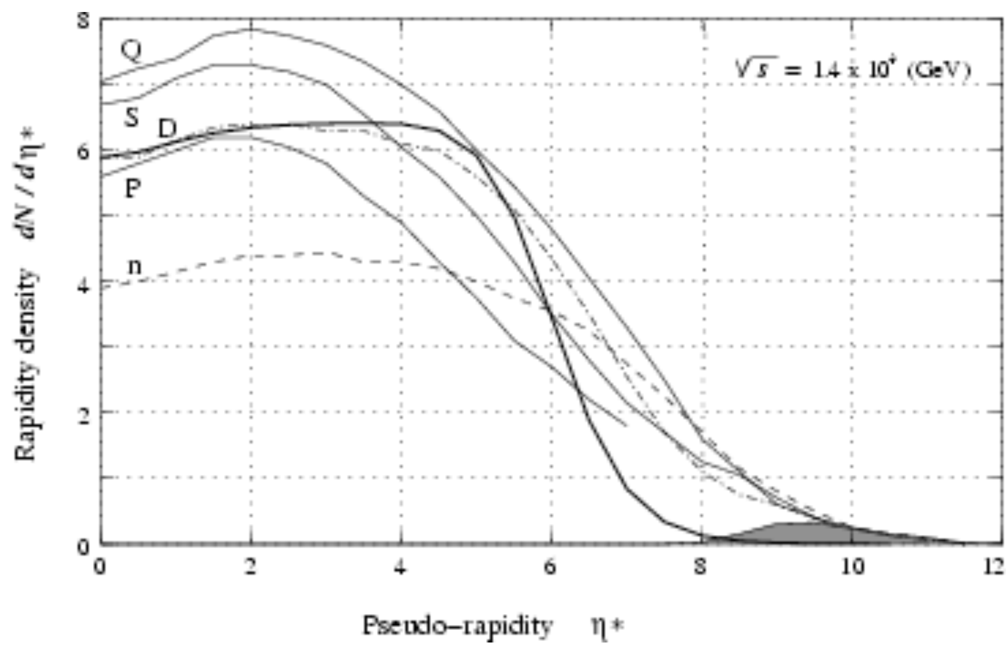
M. Block

Phenomenological approach to multiple particle production

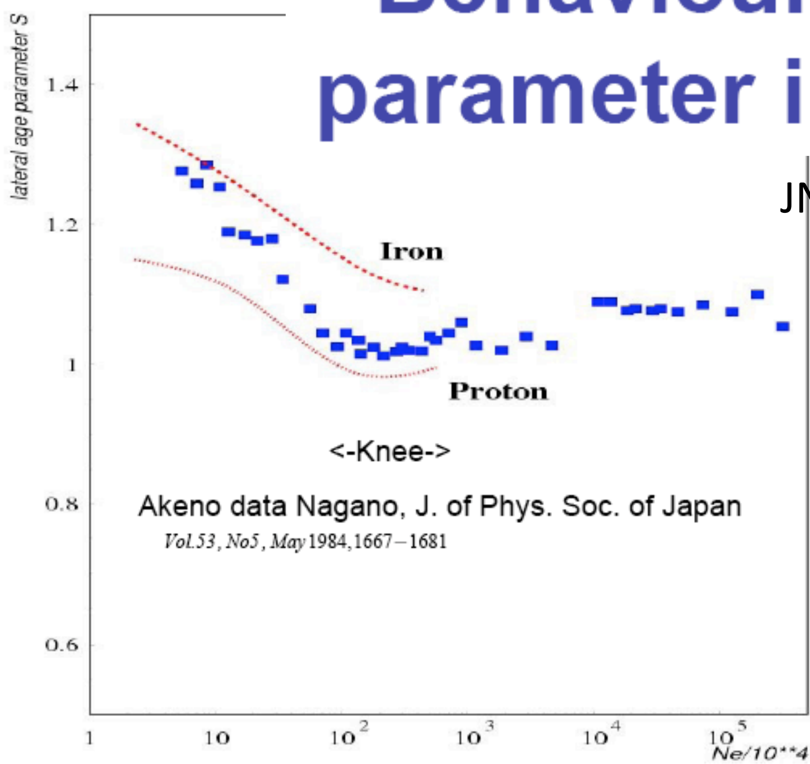
A. Ohsawa*, E.H. Shibuya** and M. Tamada***

A model to describe (pseudo-) rapidity density distributions and transverse momentum distributions

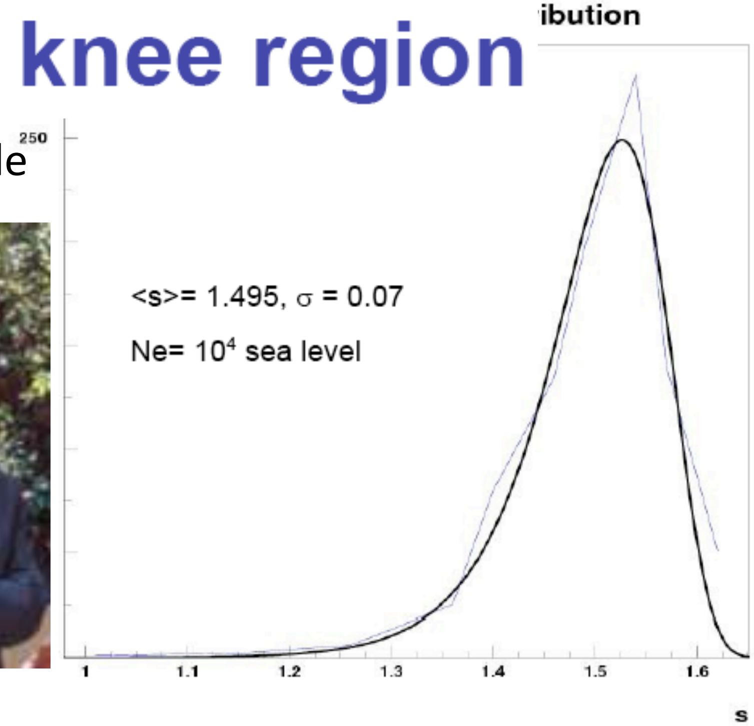




Behaviour of the EAS Age parameter in the knee region



JN Capdevielle



Relation between s(r) , s(long), and s(lat)
s(long)= 1.25 s(lat) in 1st approximation

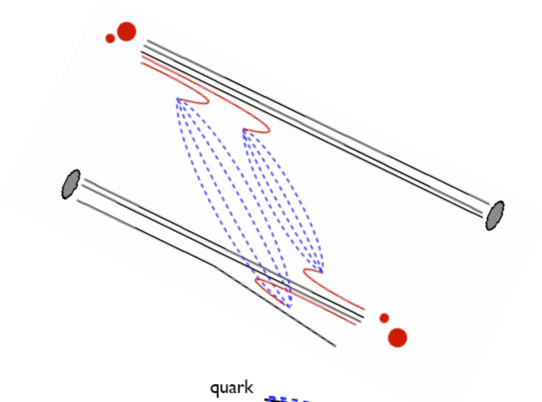
More accurately s(lat) = ∫s (r)rdr/ ∫rdr with integration on the shower disk taking into account the grid interval, the size of the detectors and the conditions of trigger.

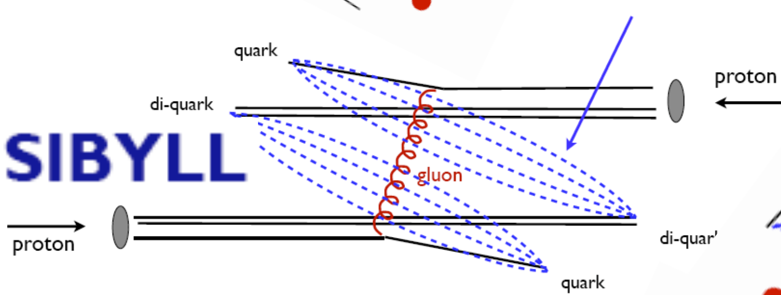
After suitable corrections of bias introduced by the NKG global fitt to the lateral distribution, s behaviour versus size is a good indicator of intrinsic cascading and mass composition.

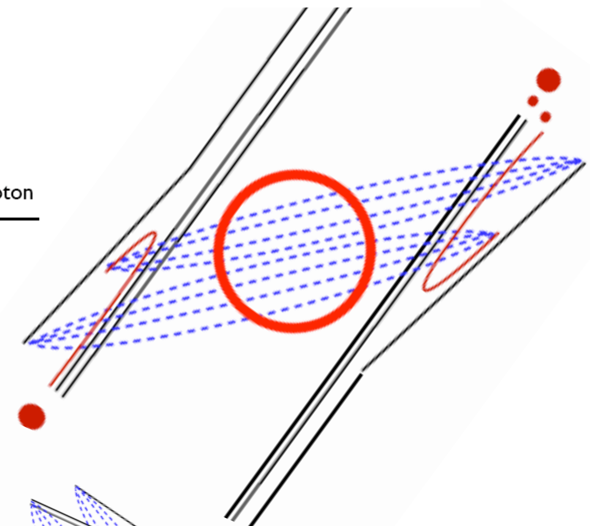
- Local age parameter behavior at fixed primary energy (larger near axis, a minimum near 40-50m and a clear increase at large distance)
- It can explain the experimental behavior of S(lat) versus energy, with an apparent minimum in knee region and followed by a kind of bump by pure phenomenological effects, remaining in agreement with a mixed composition.
- Next simulations with EGS and also above 50 PeV are in progress,as well as interpretation of Kascade Grande data.

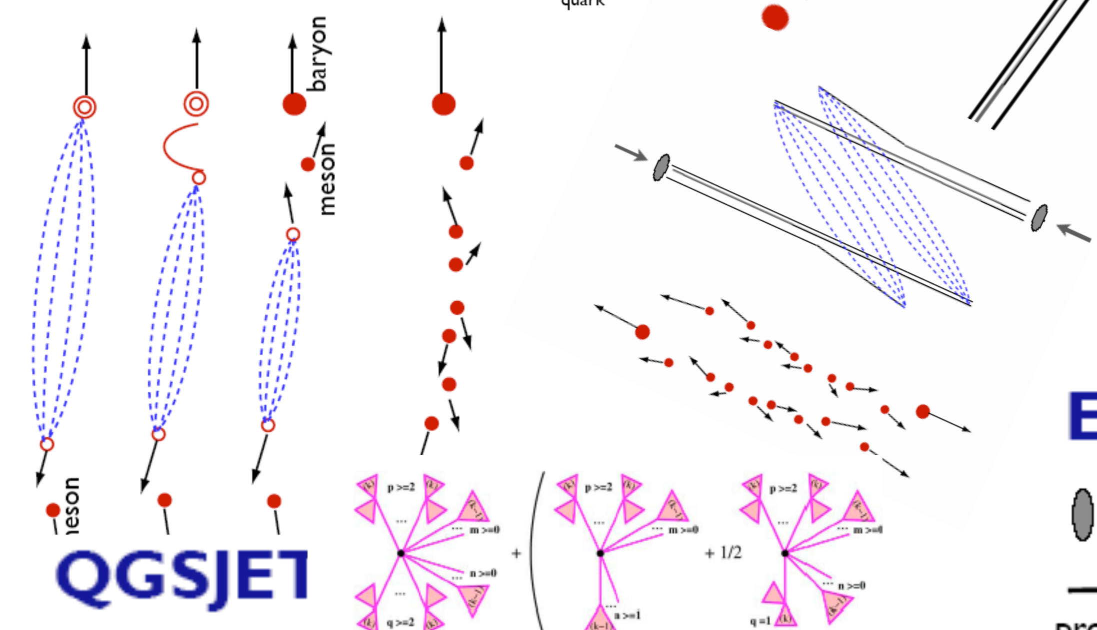
Modeling Hadronic Multiparticle Production at High Energy

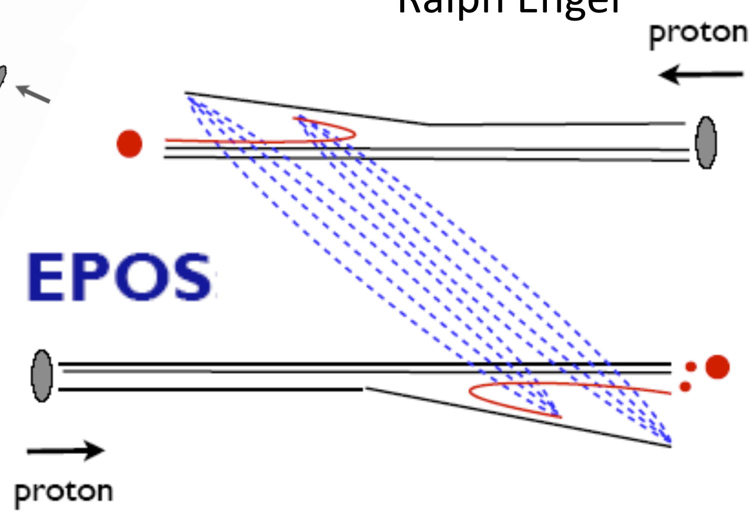
Excellent Review of Hadronic Interaction Models





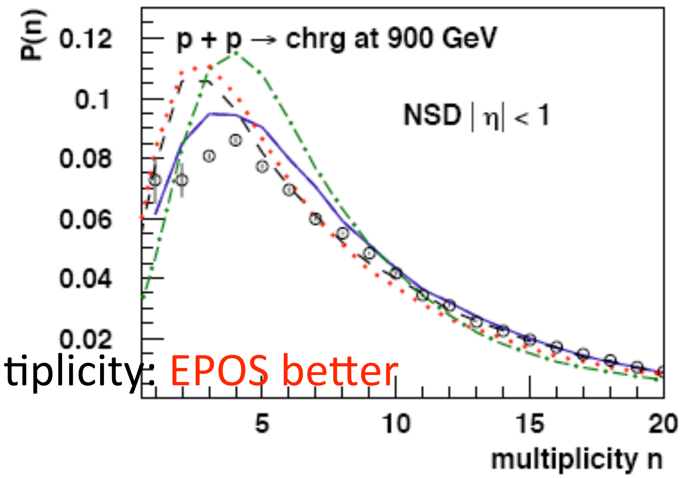




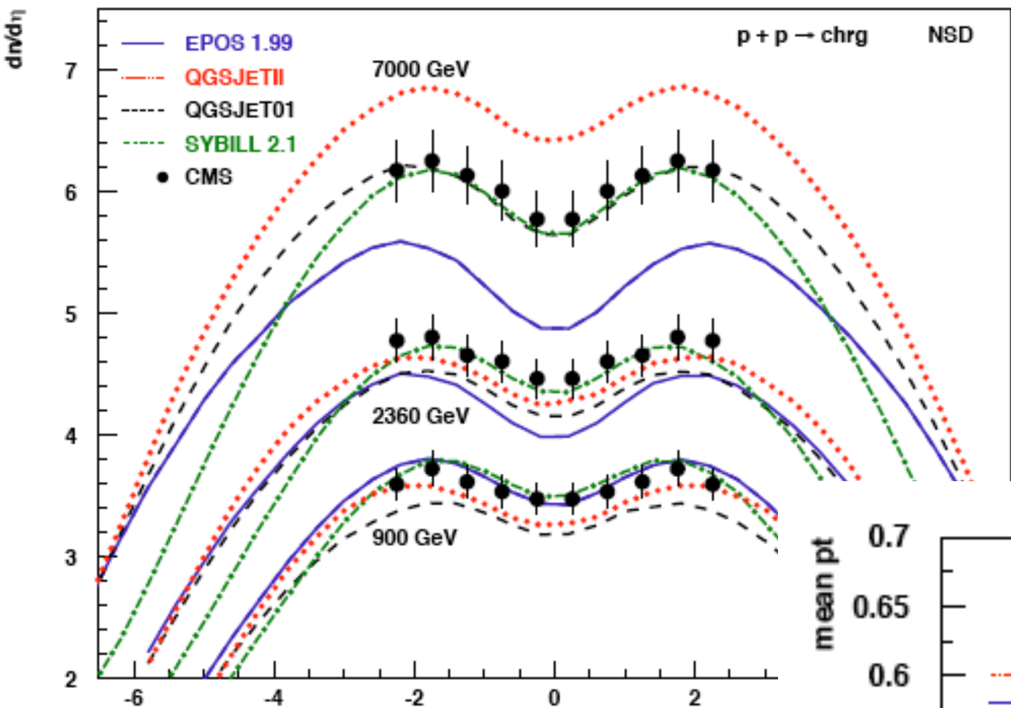


Ralph Engel

Comparison to first LHC data

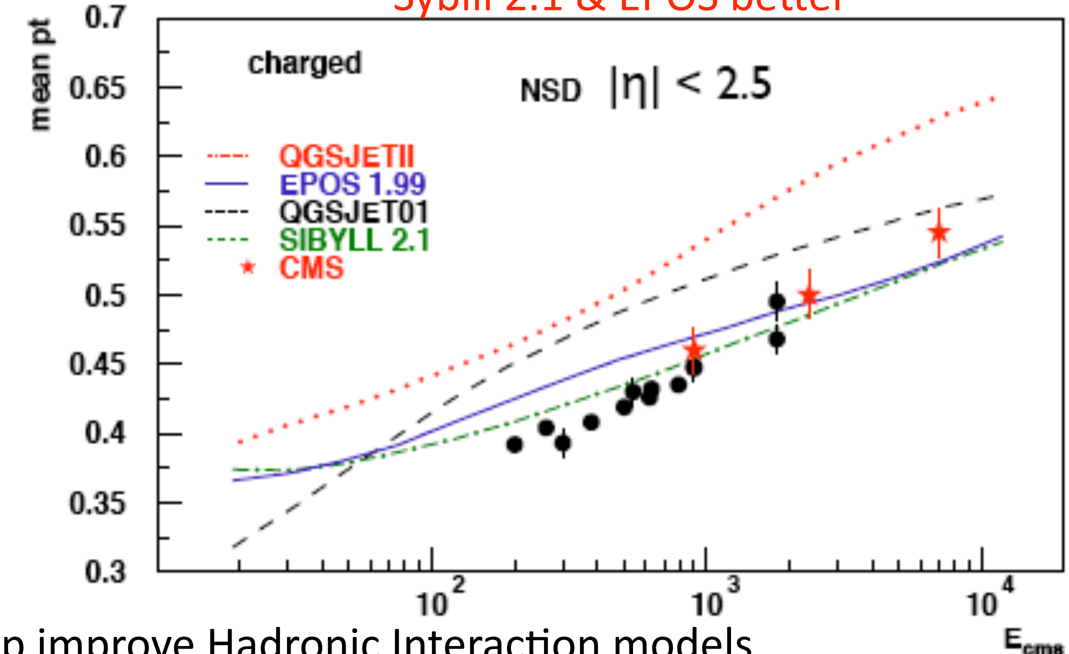


Multiplicity: EPOS better

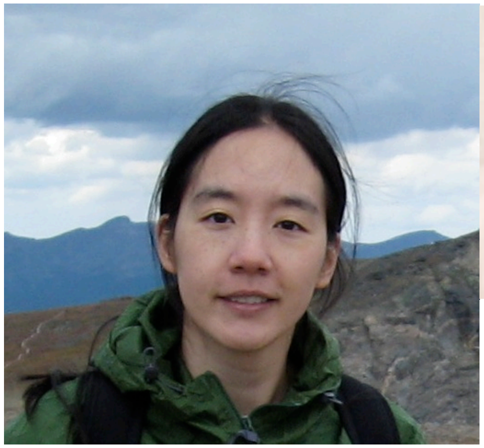


Pseudorapidity Distribution
of Charged Particles
Sybill 2.1 & QGSjet 01 better

Mean pt
Sybill 2.1 & EPOS better

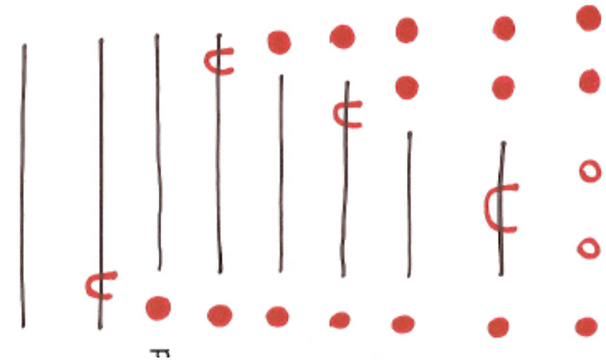


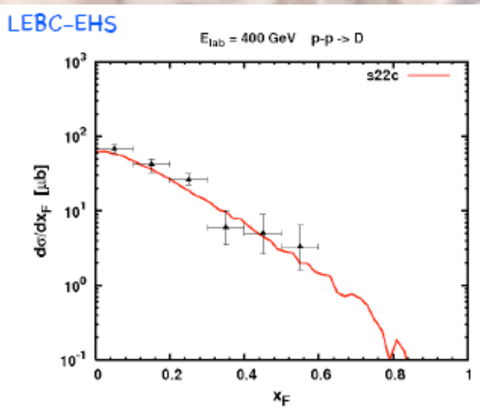
NO "PERFECT" MODEL YET –
great data period is beginning - to help improve Hadronic Interaction models

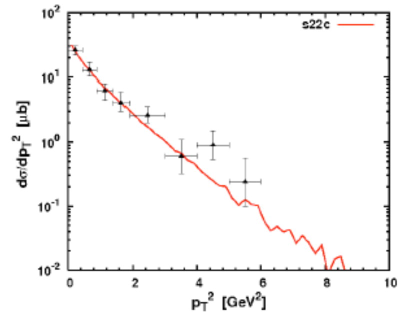


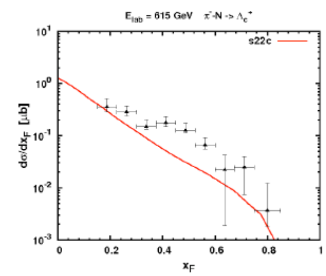
Eun-Joo (Sein) Anh

Sibyll with charm





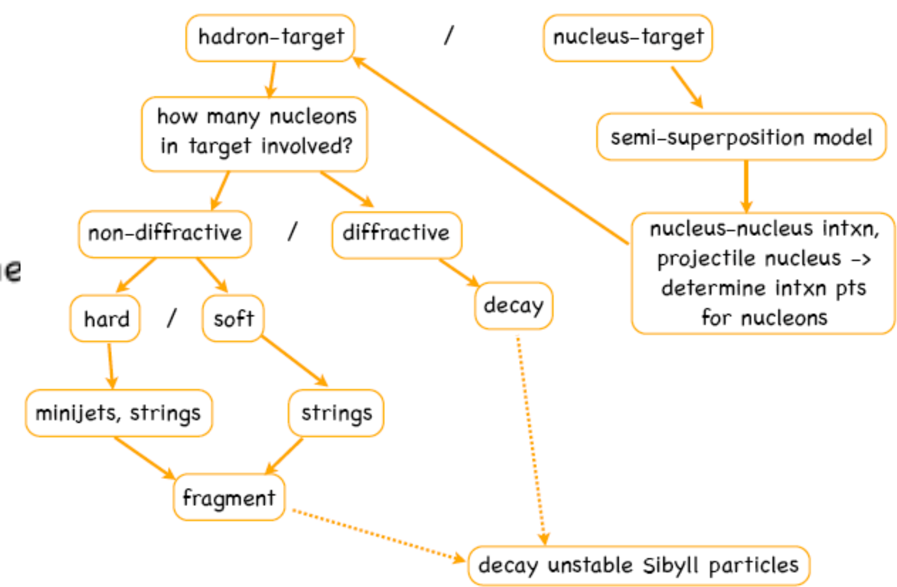




✤ New to 2.2c:

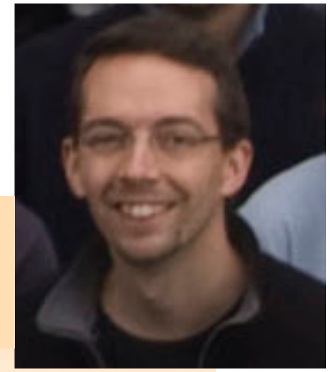
1. Charm quark added
2. Smoother diffraction – non-diffraction transition
   - increase phase-space ("fireball") decay range
   - non-sharp distribution of diffracted particle's ene
3. Minor bugfix
   - better p_T, higher multiplicitiy
4. Increased s quark fraction

Overall structure



New Developments of EPOS 2

EPOS first designed to be used for particle physics experiment analysis (SPS, RHIC, LHC)



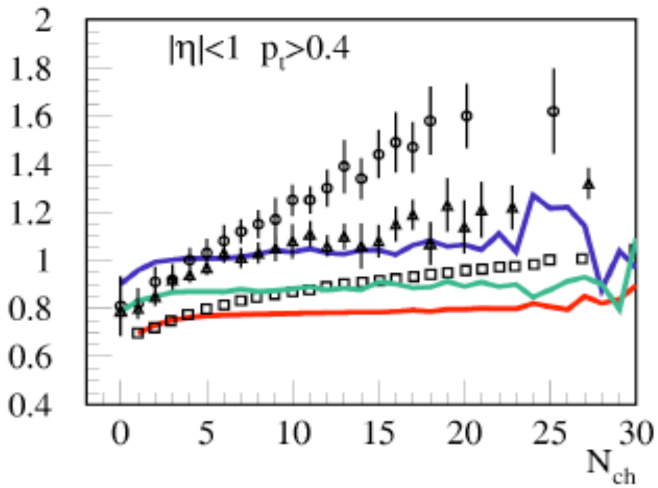
Tanguy Pierog

$\langle p_t \rangle$ vs multiplicity ap-p@1.8 TeV : EPOS 2

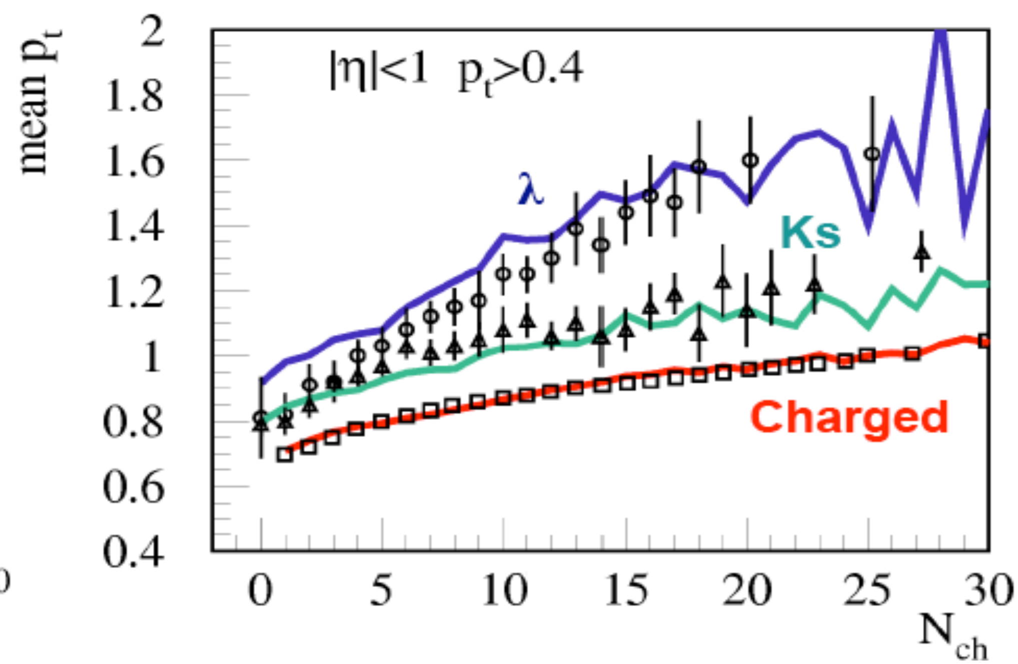
- **Using small flux tube size**
  - Very good description of CDF data
  - No additional parameter
  - Hadron mass dependence

Hydro in EPOS 2

No collective effects



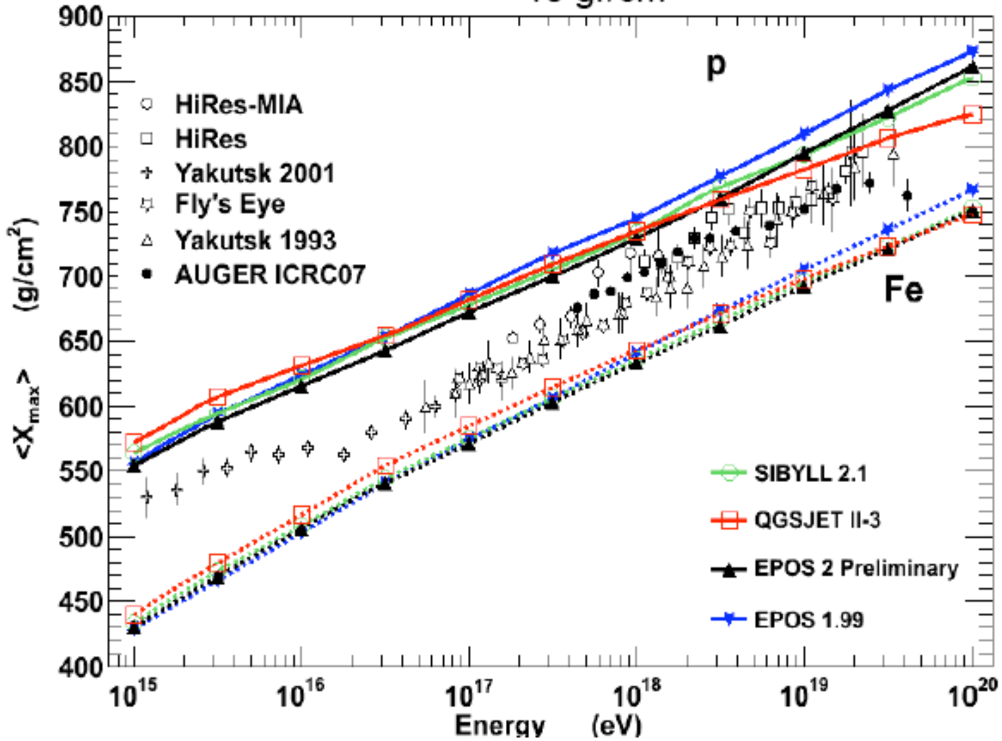
hydro+hadronic cascade

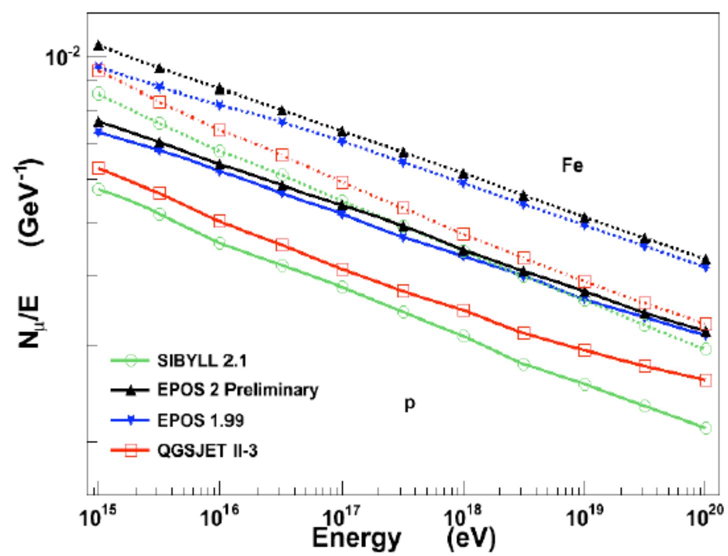


New Developments of EPOS 2

On-going developments : EPOS 2

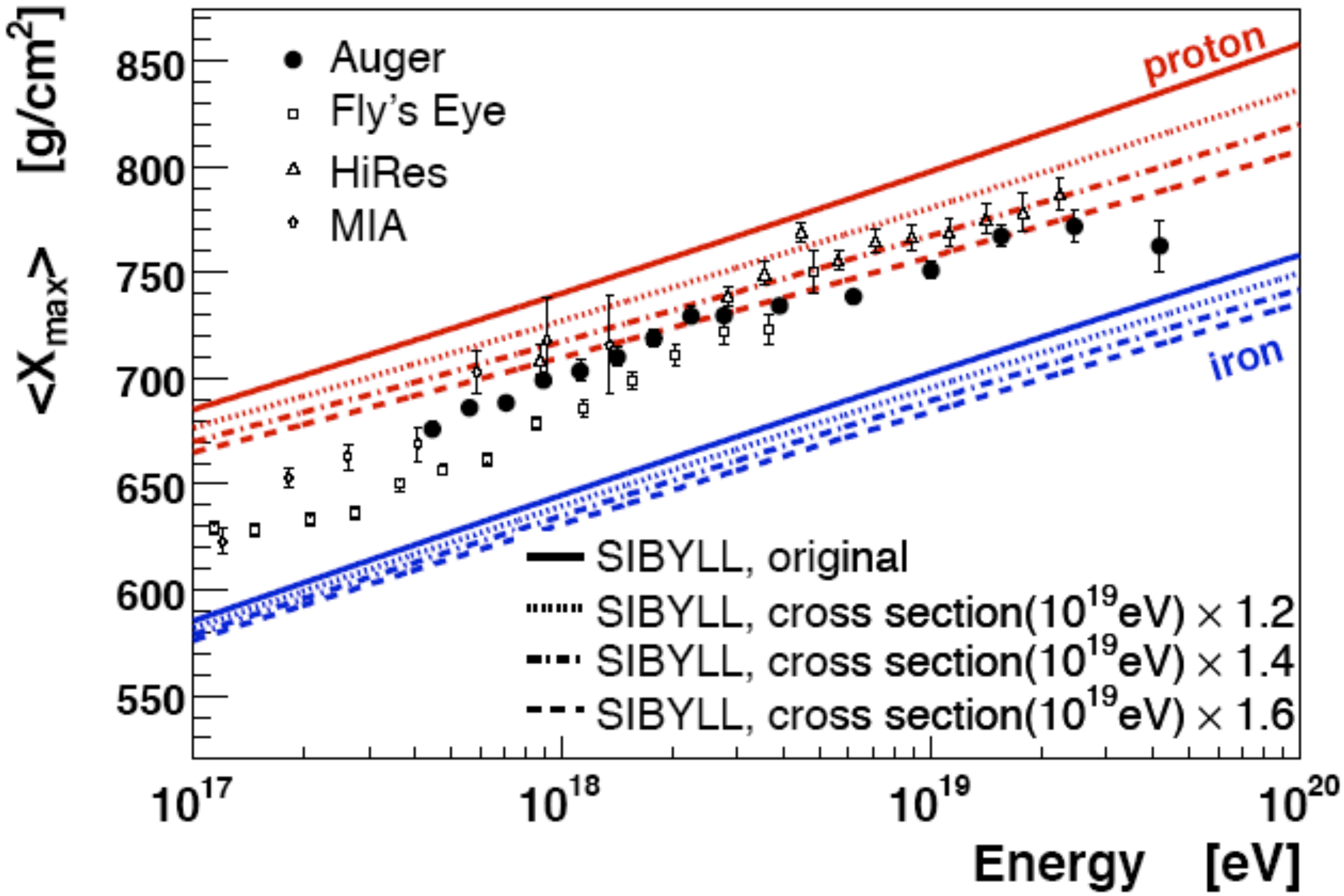
- Real hydrodynamical evolution
- Hard scattering (PDF and Jets) correctly described
- First test with LHC data
  - Good in average
  - Inconsistency pt/multiplicity : more checks needed
- No dramatic change for air shower development
  - ~ 10 gr/cm²

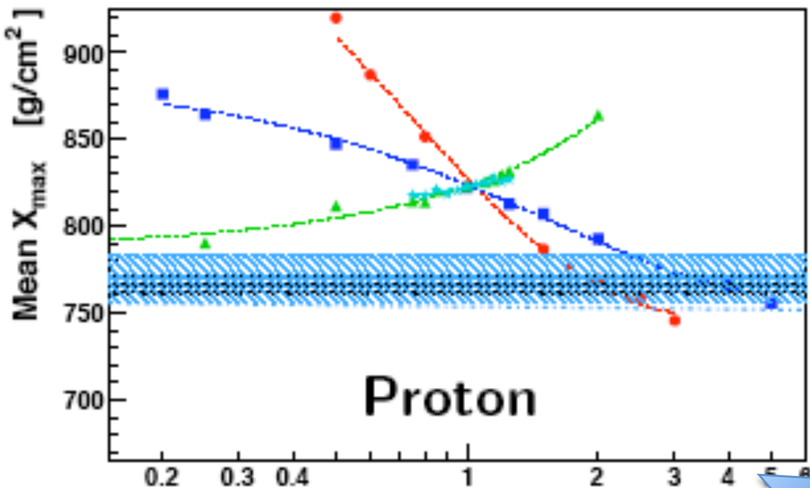


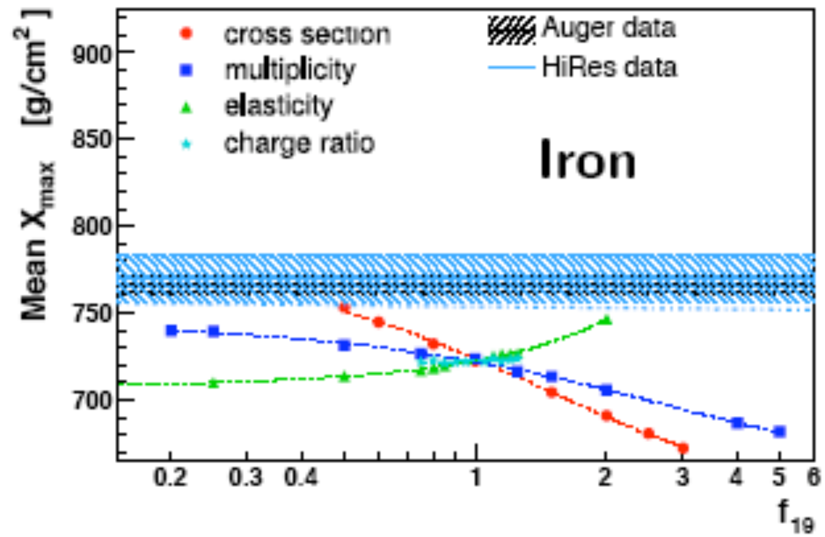


Relation of Interaction Characteristics at Ultra-High Energies to Extensive Air Shower Observables

Ralph Ulrich







$\langle X_{\max} \rangle$ can be shifted significantly

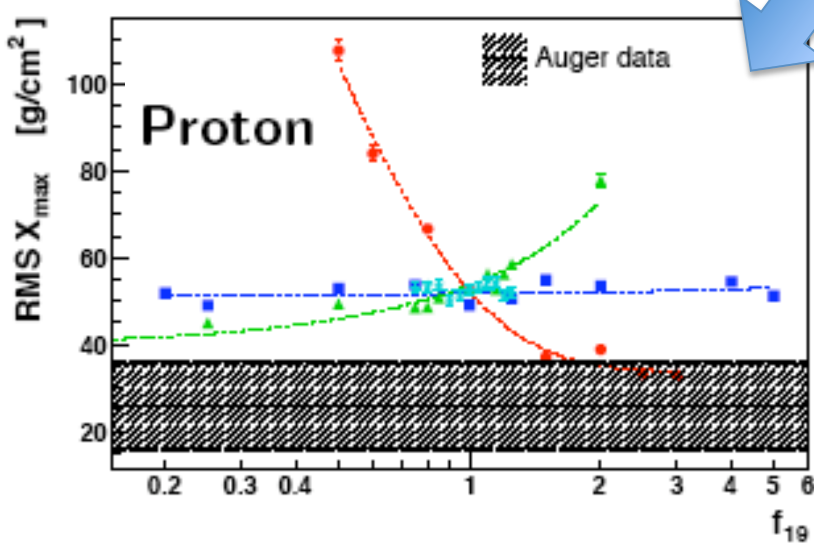
Auger and HiRes data are suggesting

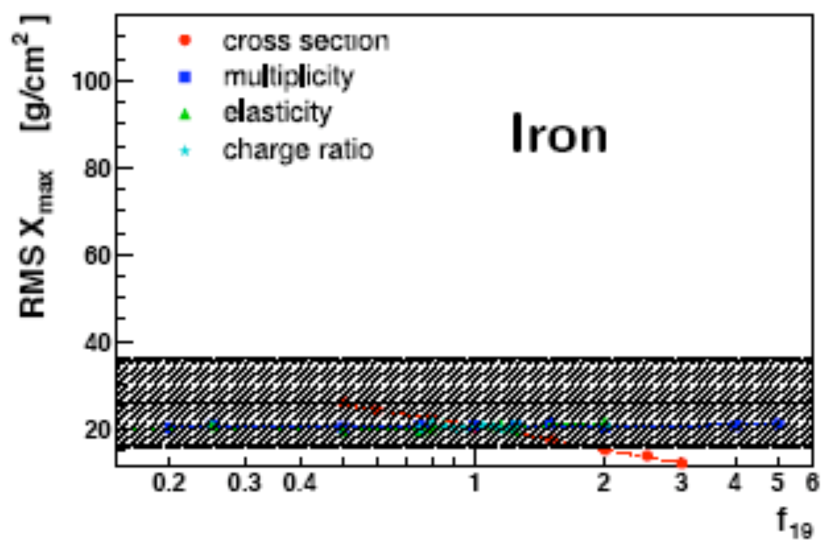
- Large cross section for a proton dominated composition
- Small cross section for a iron dominated composition
- or: intermediate mass, mixed composition

RMS($X_{\max}$) mostly impacted by cross section, and elasticity

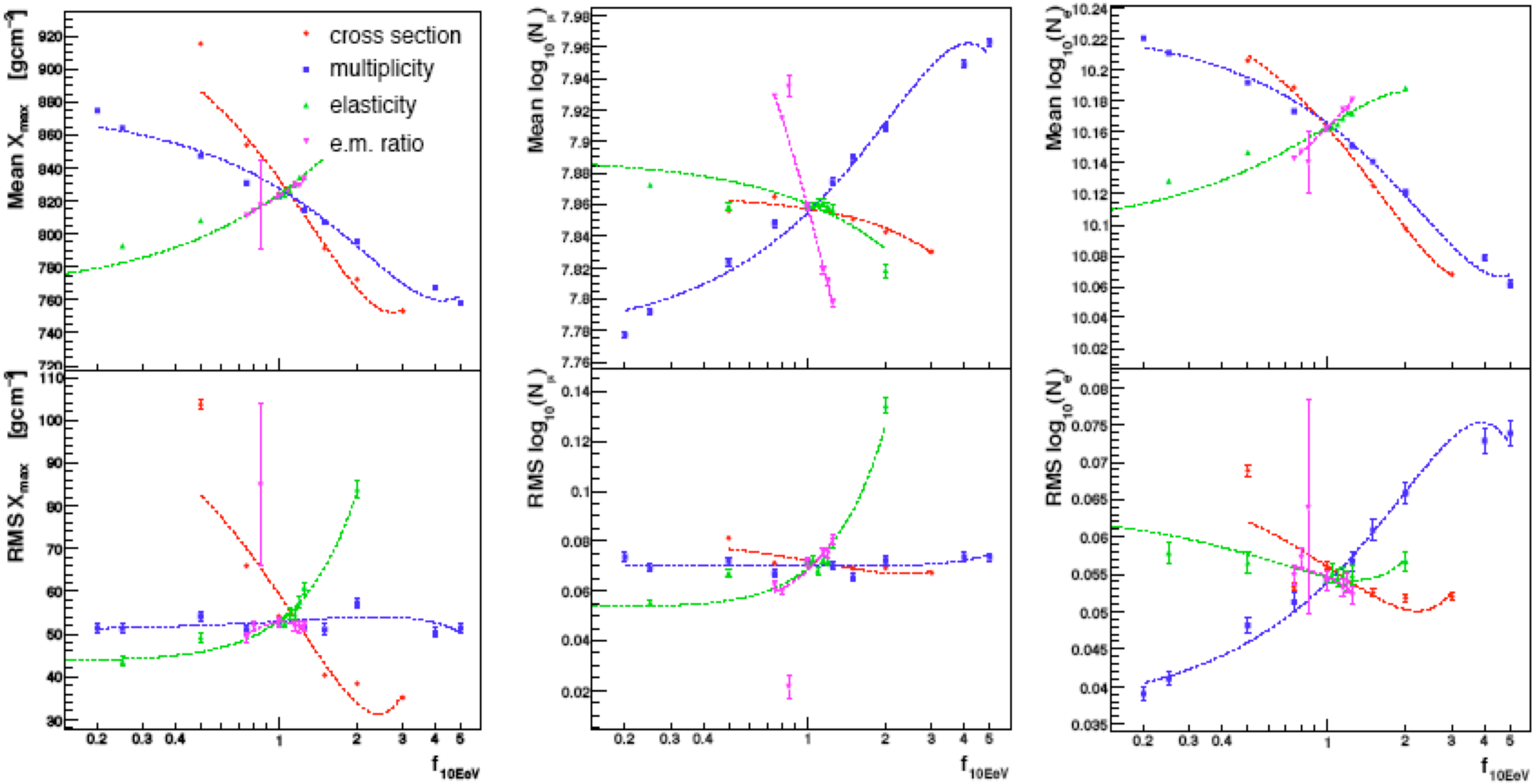
Iron induced showers very robust

Auger data only marginally compatible with protons in a high cross section scenario





Hadronic Interactions Parameters

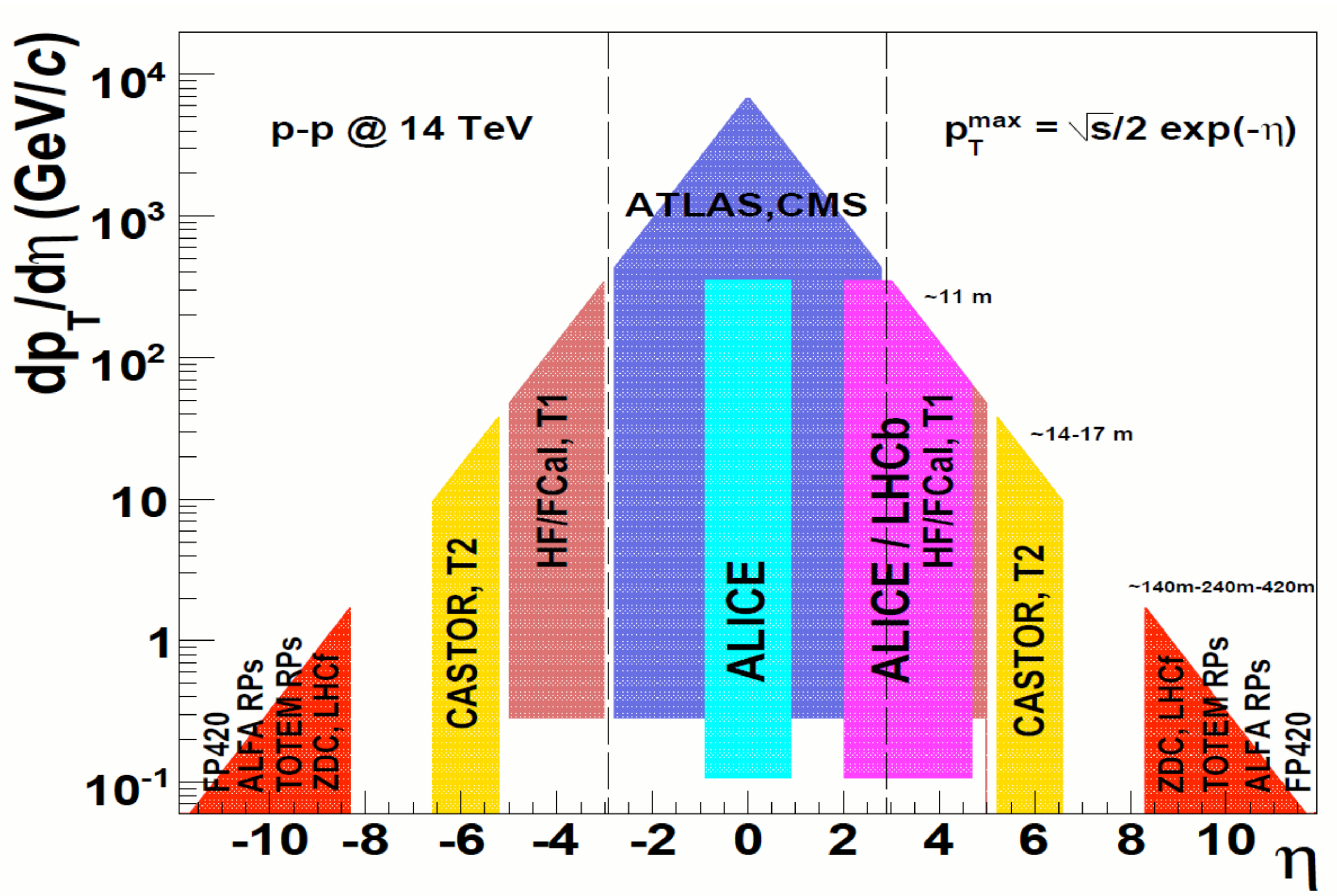


Scaling factor at 10^{19} eV

(Ralf Ulrich, 16-Oct-2008)


WISH LISTS...

Accelerators vs. Cosmic Rays



p-p @ 14 TeV
$p_T^{max} = \sqrt{s}/2\ exp(-\eta)$
ATLAS,CMS
ALICE
ALICE / LHCb
HF/FCal, T1
HF/FCal, T1
CASTOR, T2
CASTOR, T2
FP420
ALFA RPs
TOTEM RPs
ZDC, LHCf
ZDC, LHCf
TOTEM RPs
ALFA RPs
FP420
~11 m
~14-17 m
~140m-240m-420m
$dp_T/d\eta$ (GeV/c)
η

Tanguy's wish list:

Direct measurements

1. Cross section measurements: **TOTEM**
2. π^0 & n forward spectra (x_f>0.3): **LHCf**

   3 o.o.m improvement in energy constraints on meson & baryon forward spectra. VERY important for air shower development (scaling, inelasticity); which change both X_{max} & N_μ, if very good precision (systematics?)

Indirect measurements

1. forward calorimeter **CASTOR**: no particle ID, but observes energy flow and inelasticity. Better if associated to TOTEM trackers.
2. **LHCb** not as forward but does particle ID: anti-proton & strange particle yields @ 10 energy - important for Nμ. Will help understand baryon production – crucial for Nμ.
3. **ALICE, ATLAS or CMS**: no leading particle (like in air showers) but important to test models: measure inelasticity (X_{max}), $N_{baryons}$ (N_μ and LDF) and the average p_t (LDF). Help understand the dynamic of the collision & the underlaying physics.

Wish List II

Cross Sections:

NEEDS workshop: http://www-ik.fzk.de/~needs/

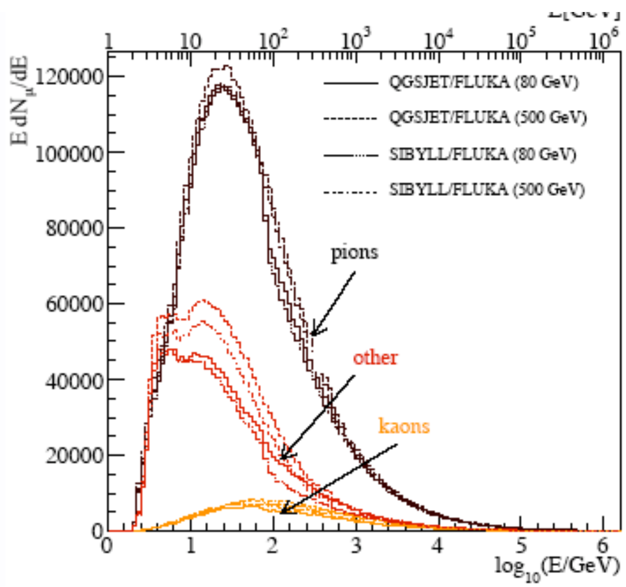
preferentially p-air (which means p-C), but also π-C, and K-C at high energy (π interact before decay).

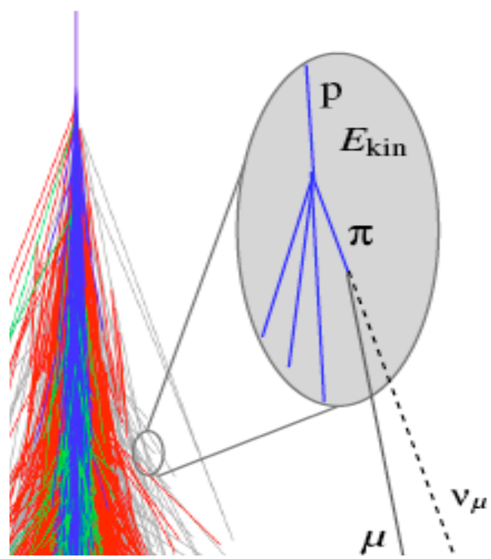
Feynman-x distributions of the production cross section for:

- π's , K's, p, n, pbar, nbar
- charm particles (Λ_c and D_c) – neutrino detectors

Transverse momentum distribution at low energy (< 250 GeV)

- to understand low-E interactions at large angles for muon production in Auger. (**MIPP would help a lot here!**)

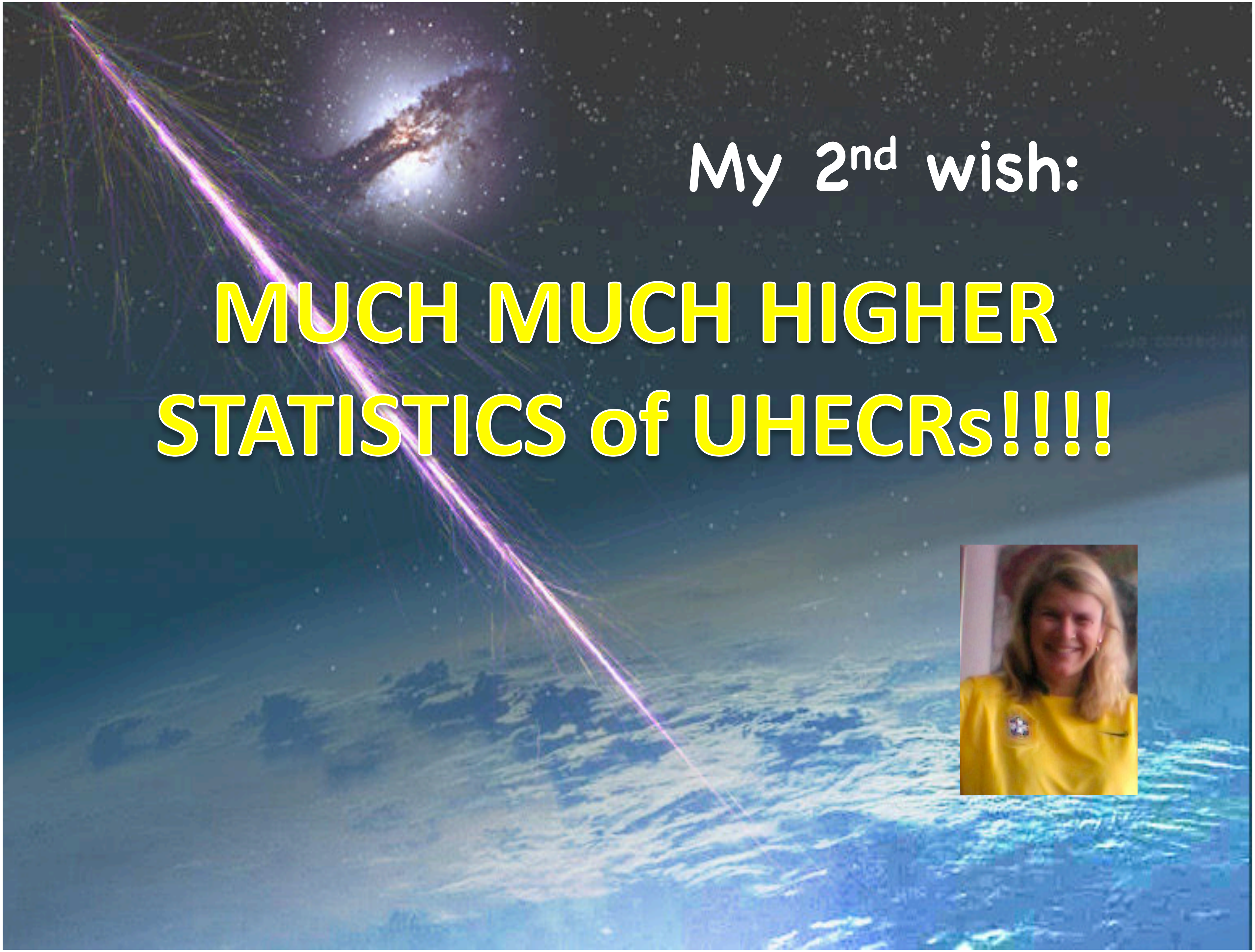




My wish list…

1st wish – not granted!!!!

Brasil 1 x 2 Netherlands


My 2nd wish:
MUCH MUCH HIGHER STATISTICS of UHECRs!!!!

May 2010 Physics Today

The highest-energy cosmic rays may be iron nuclei

Or perhaps, at energies far beyond what terrestrial accelerators can produce, protons just look fat.

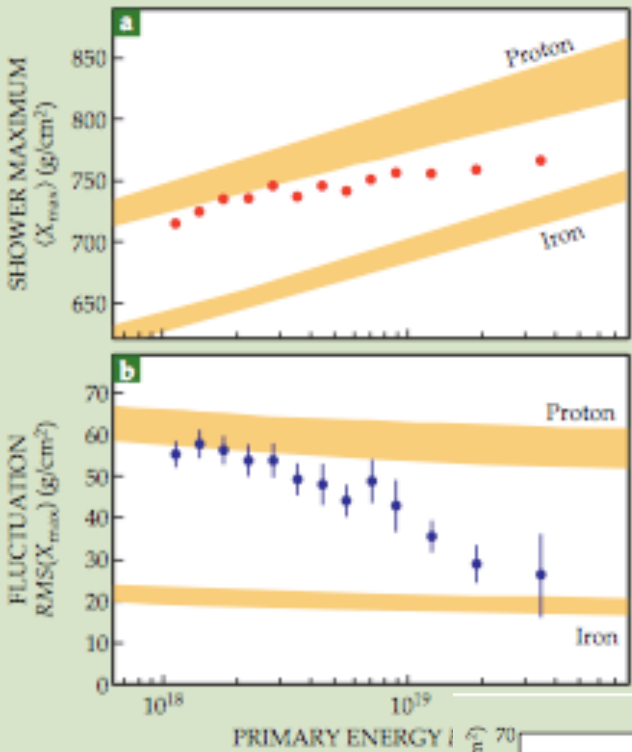


Figure 2. Comparing Auger shower-maximu data with a range of Monte Carlo simulatio (yellow swaths) for showers initiated by protons or iron nuclei. **(a)** The mean-shower-maximum ⟨X_{max}⟩ data of figure 1, shown her without error bars. **(b)** Root-mean-square fluctuation of the pen tration length X_{max} fro event to event at a given primary energy the Auger data. (Adap ed from ref. 1.)

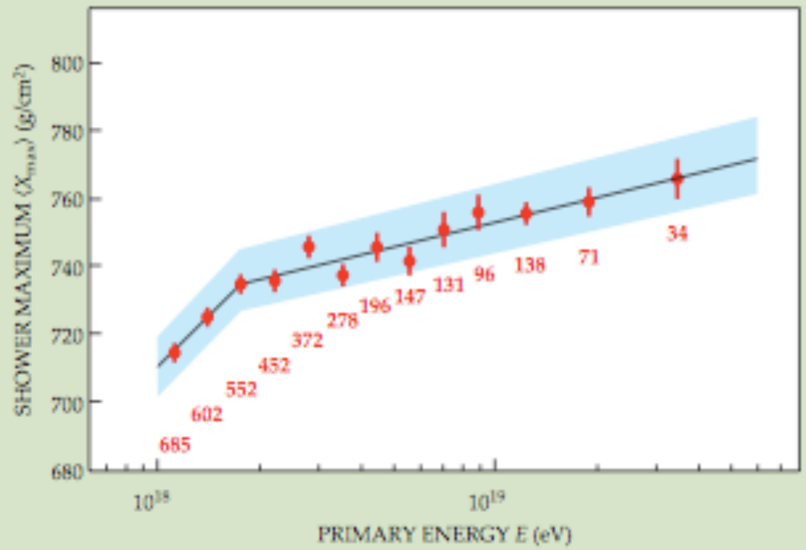


Figure 1. Mean value of the shower maximum—the penetration length X_{max} into the atmosphere at which a cosmic-ray shower reaches its maximum development. Given as an atmospheric column density, ⟨X_{max}⟩ is plotted against the energy E of the primary particle that initiated the shower. Each data point is labeled with the number of showers recorded by fluorescence telescopes at the Pierre Auger ... rgy bin. The highest bin includes events up to ... tes systematic uncertainties. The black line is a ... logarithmic slope. (Adapted from ref. 1.)

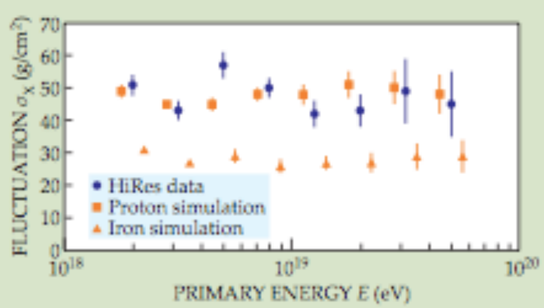
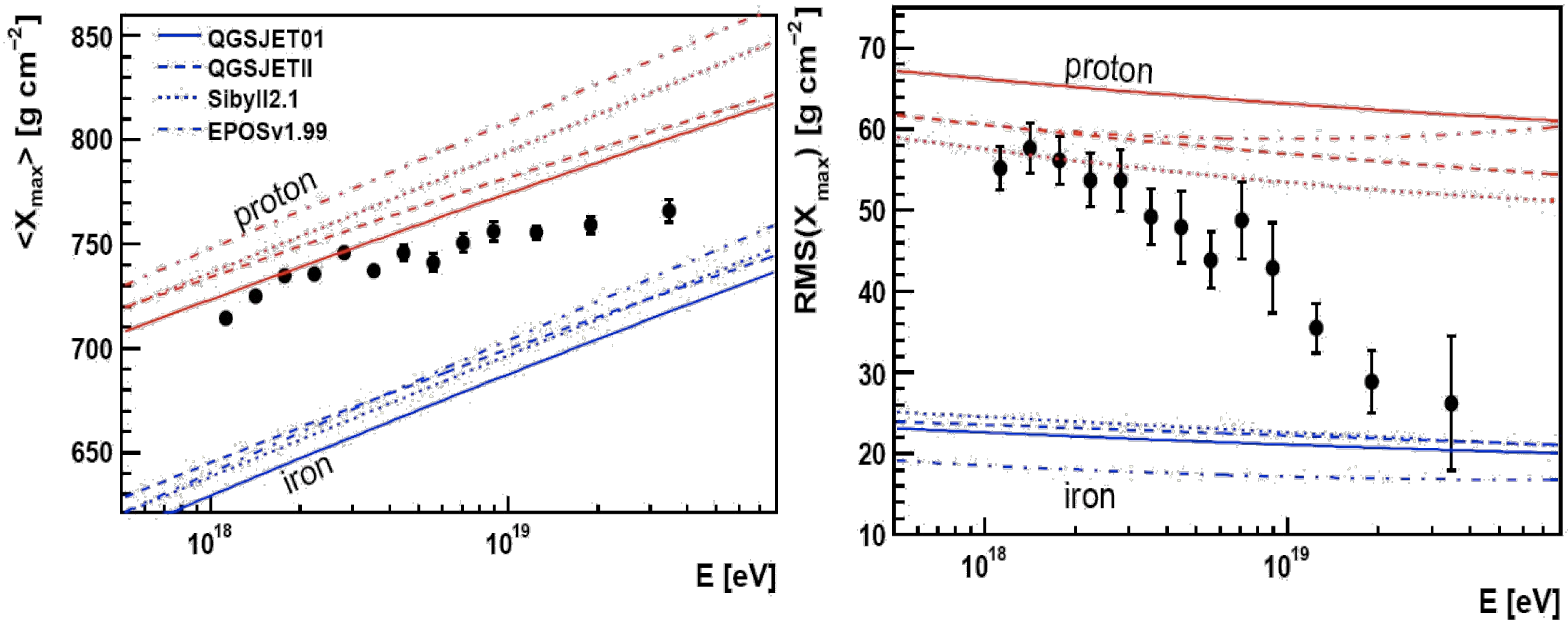


Figure 3. The HiRes collaboration's data on the event-by-event fluctuation of its X_{max} data for 814 events seen in stereo by both of the facility's fluorescence telescopes. Truncated Gaussian fluctuation widths σ_x are plotted as a function of the cosmic-ray primary's energy and compared with Monte Carlo simulations of what the stereo data should look like for pure proton and iron fluxes. (Adapted from ref. 3.)

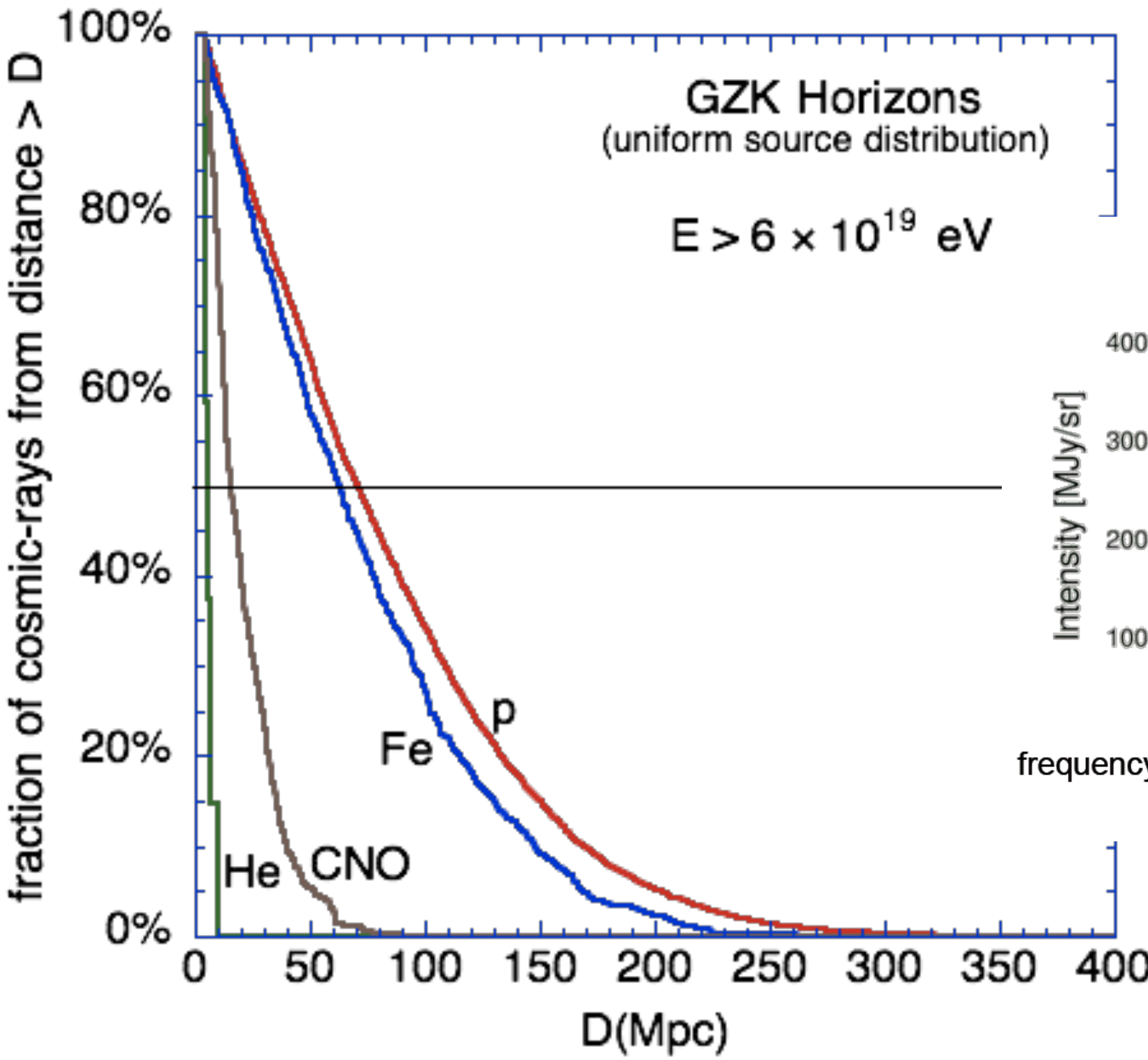
Shower Depths of Maximum X_{max}

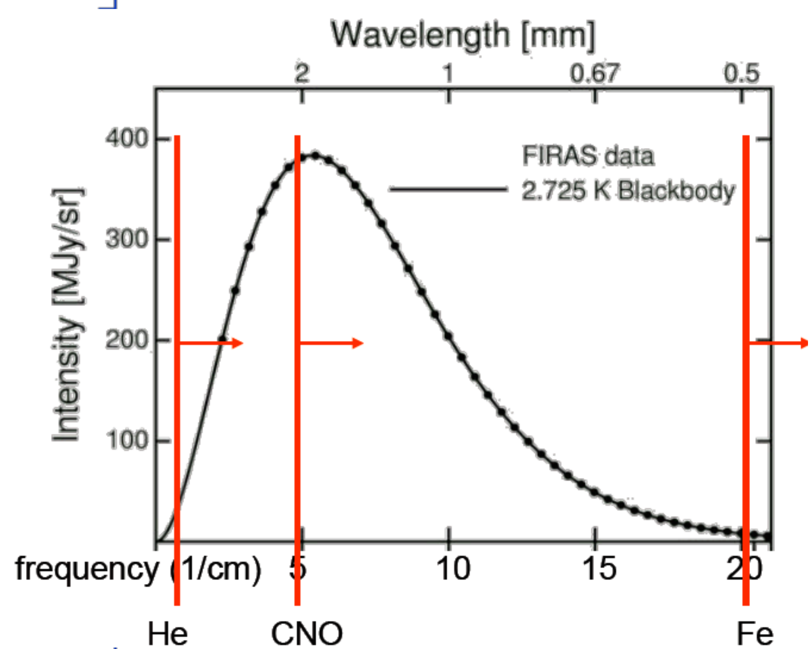


Heavy nuclei?

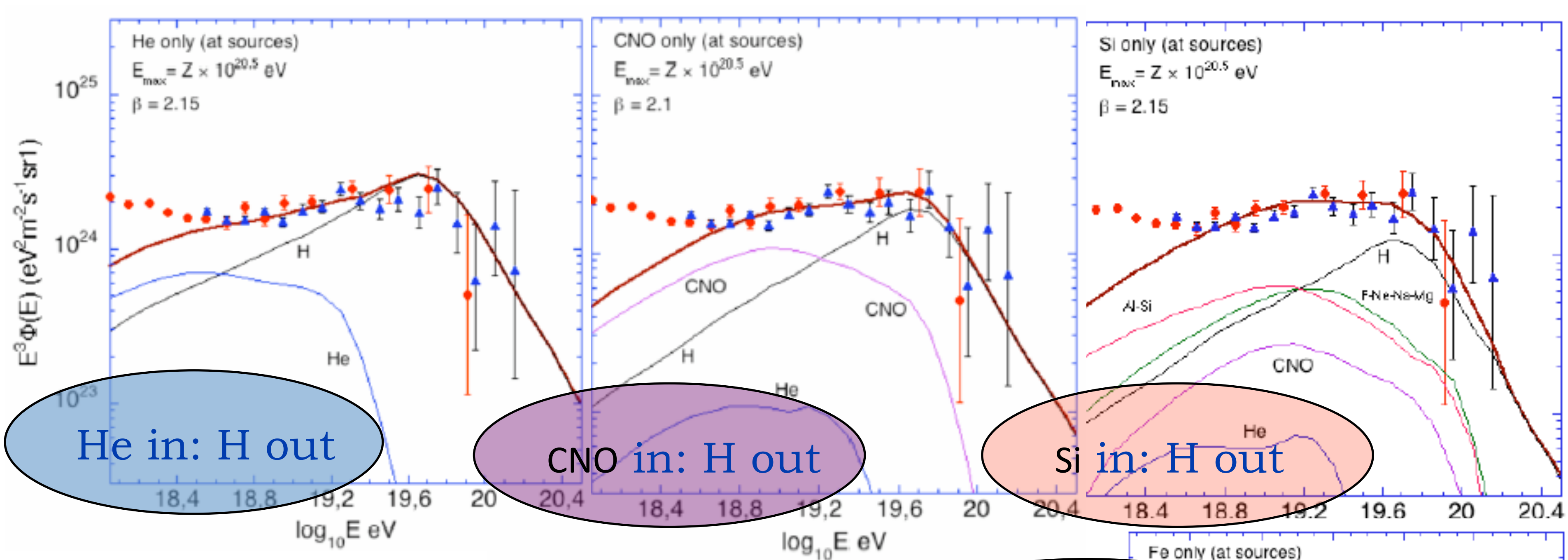
Protons? - Higher Cross section and/or high multiplicity at high energy.

Above 60 EeV: Simpler Composition either Protons or Iron-like



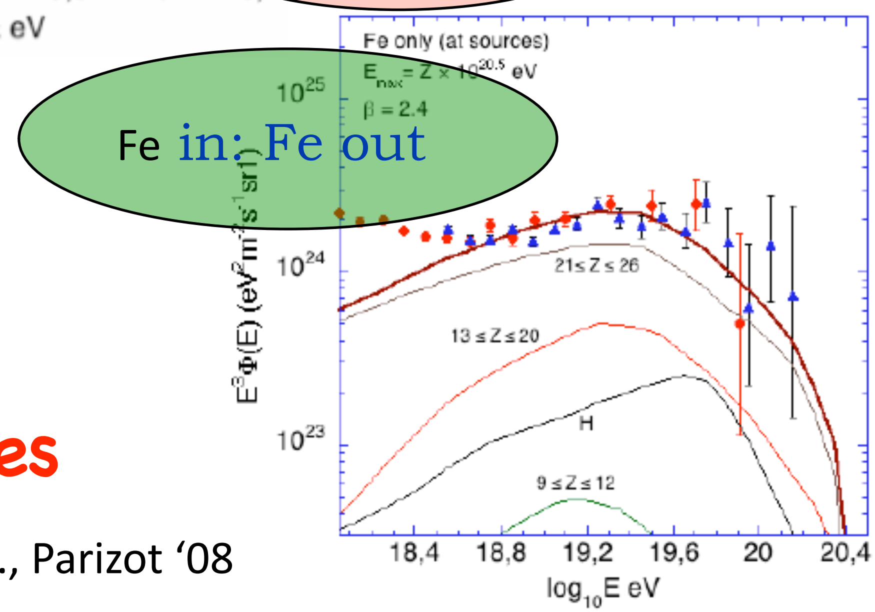


Pure Nuclei Injection



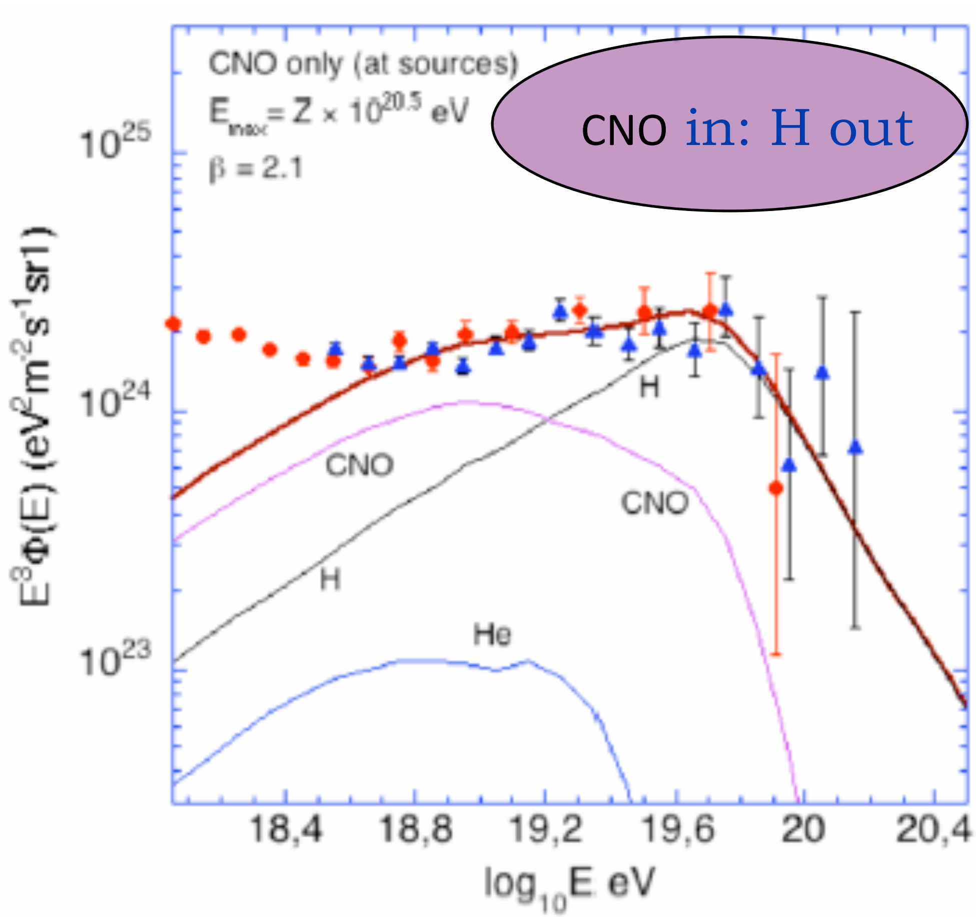
Propagation of pure nuclei in cosmic backgrounds

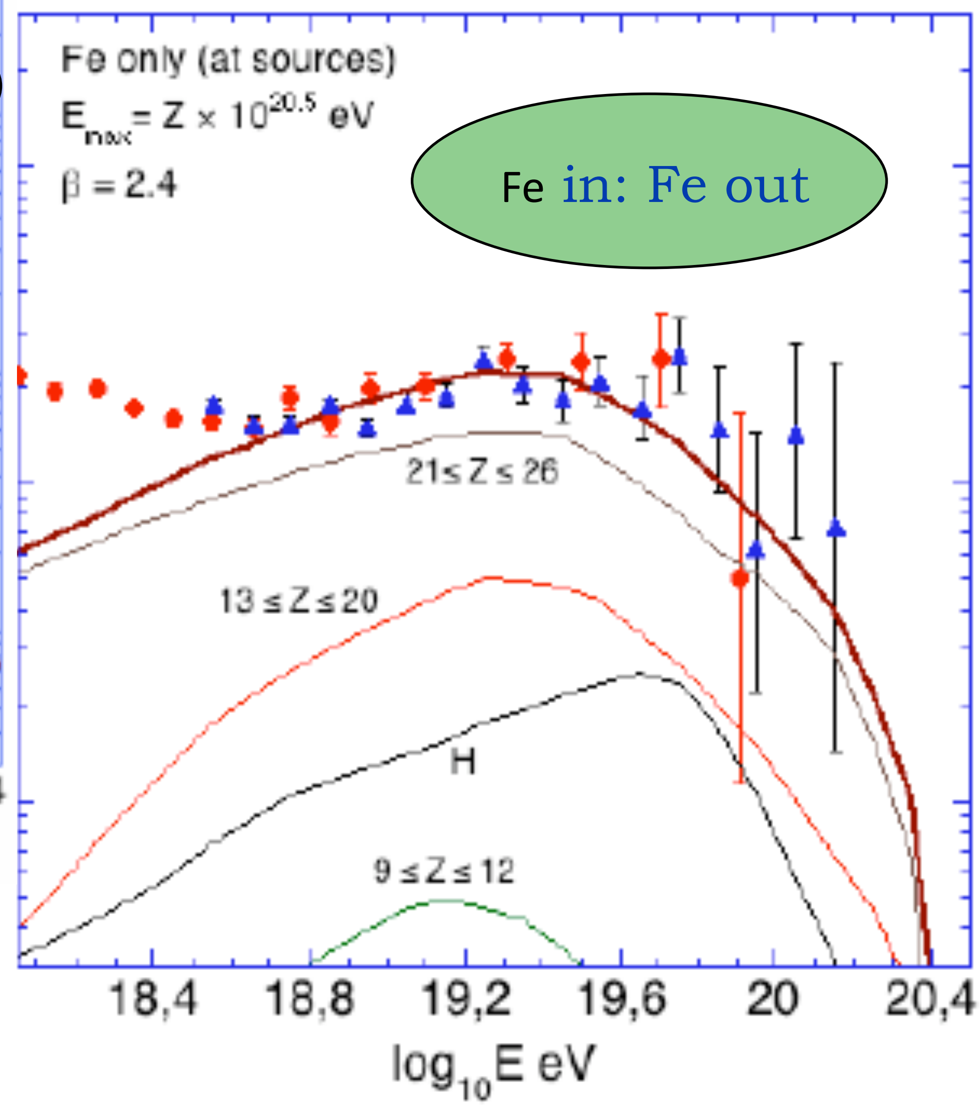
- spectra fit to observed
- abundances of secondaries



Allard, Busca, Decerprit, A.O., Parizot '08

Pure Nuclei Injection





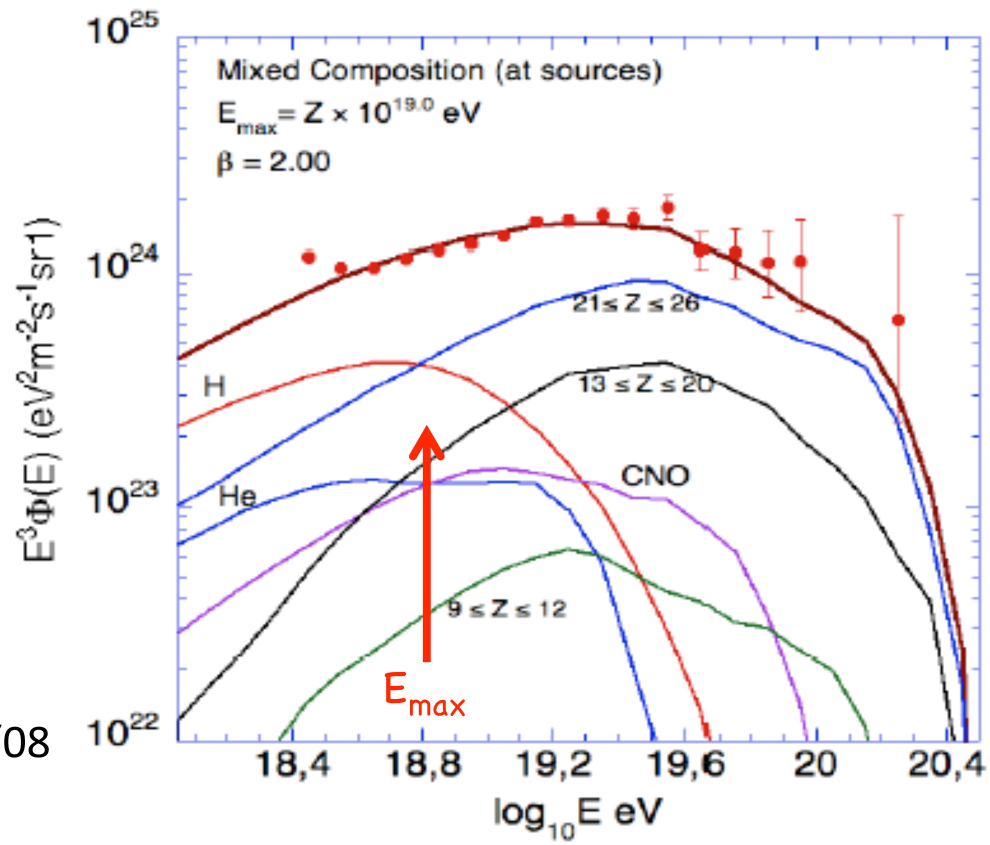
Allard, et al '08

Puzzling Composition

Unexpected Astrophysics:

Sources are very Iron rich: 4x Fe Galactic CRs!

and have low E_{max} (protons)



Allard, et al '08

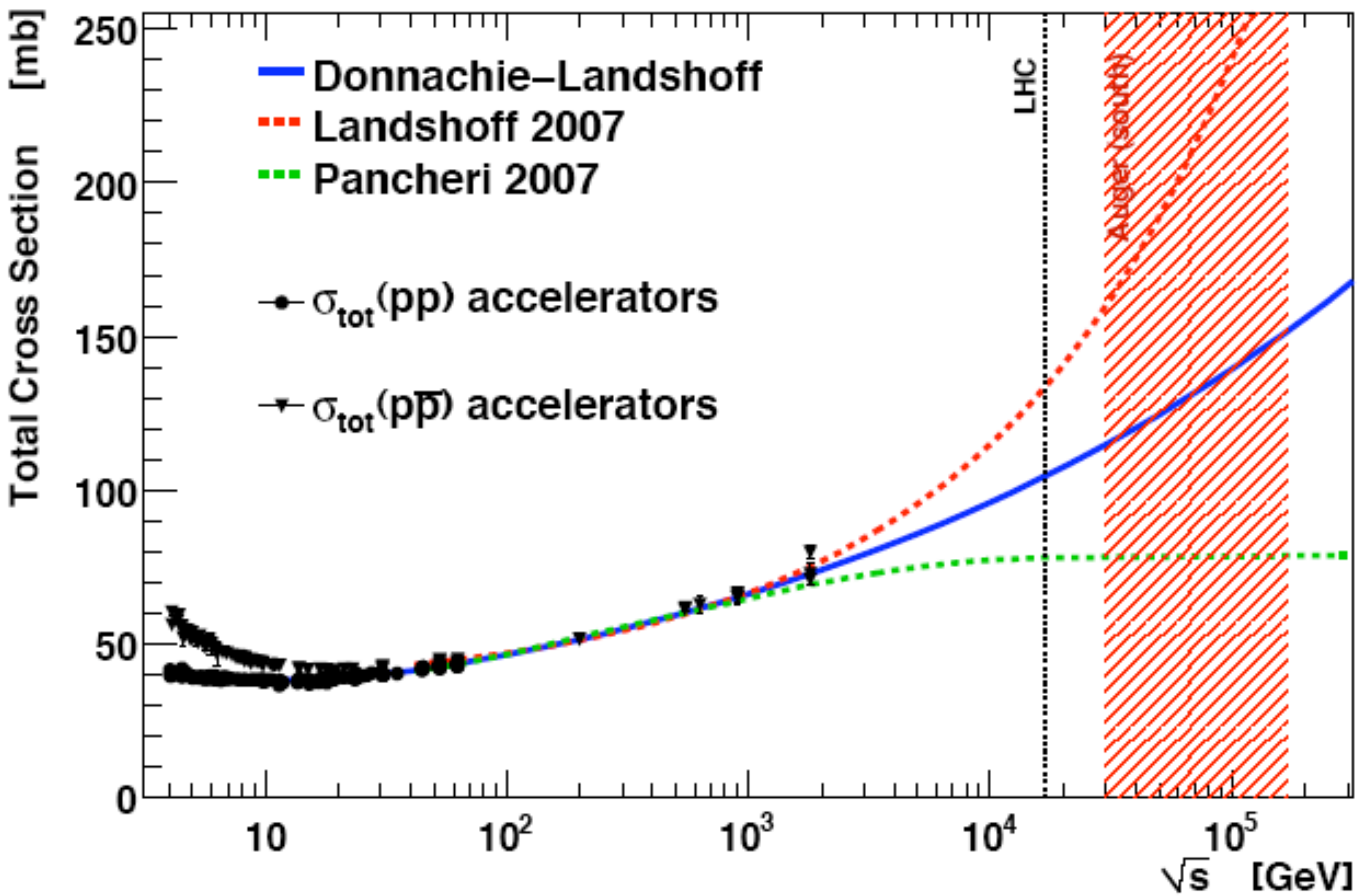
If Correlated with sources $< 10^o$ ➔ protons

Galactic & ExtraGalactic Magnetic Fields make iron deviate many 10^o's from source position

If Astrophysically shown to be protons then hadronic models can be tested knowing the primary composition.

For example, assume current data is protons ➔change the cross section…

Cross Section Uncertainties



Ulrich's talk

Puzzling Composition*

Unexpected Astrophysics:

Sources are very Iron rich

and have low E_{max}

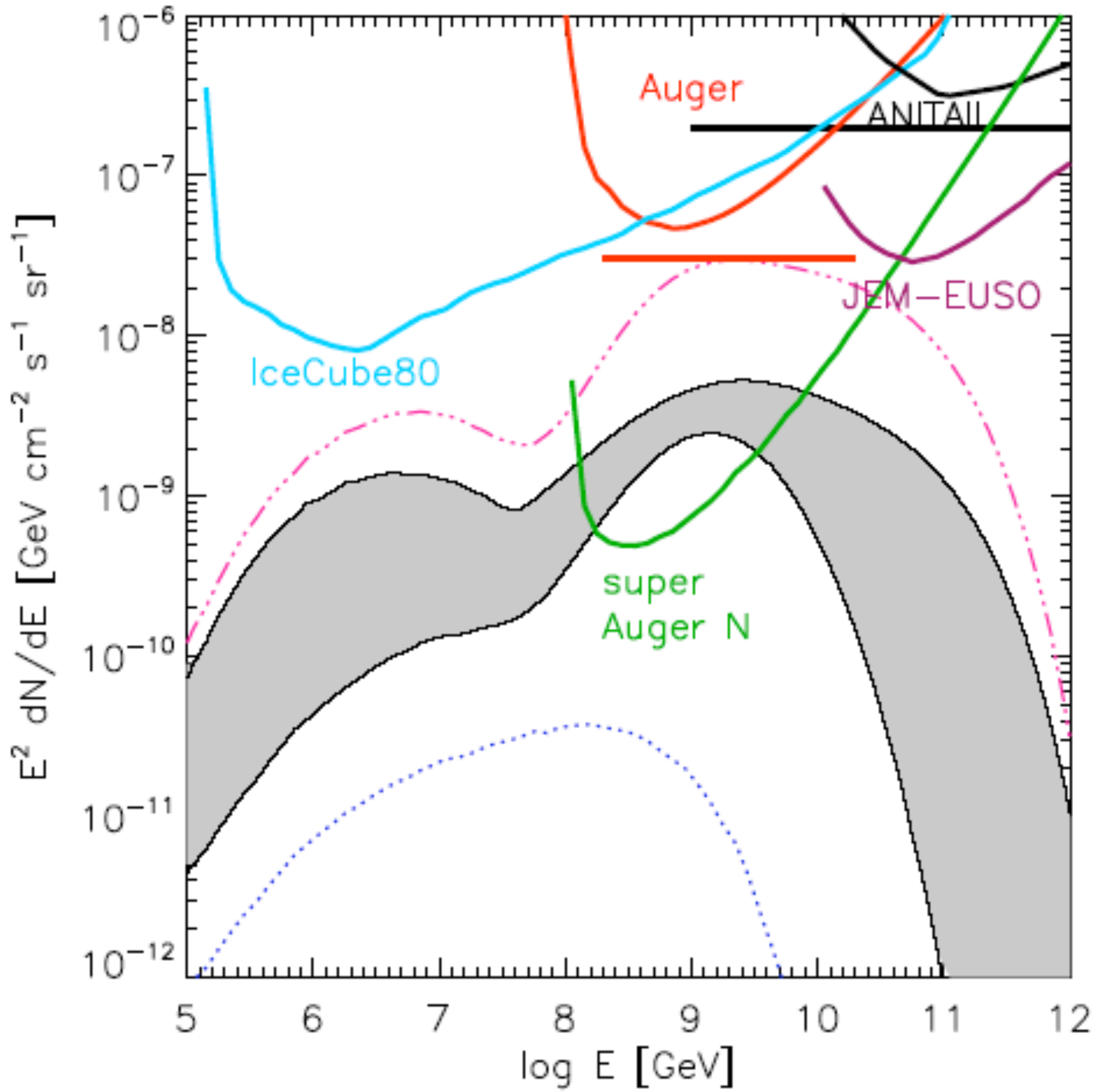
Very Bad News for Neutrino Detectors

Interesting Particle Physics:

Hadronic Models do not
represent well UHE interactions

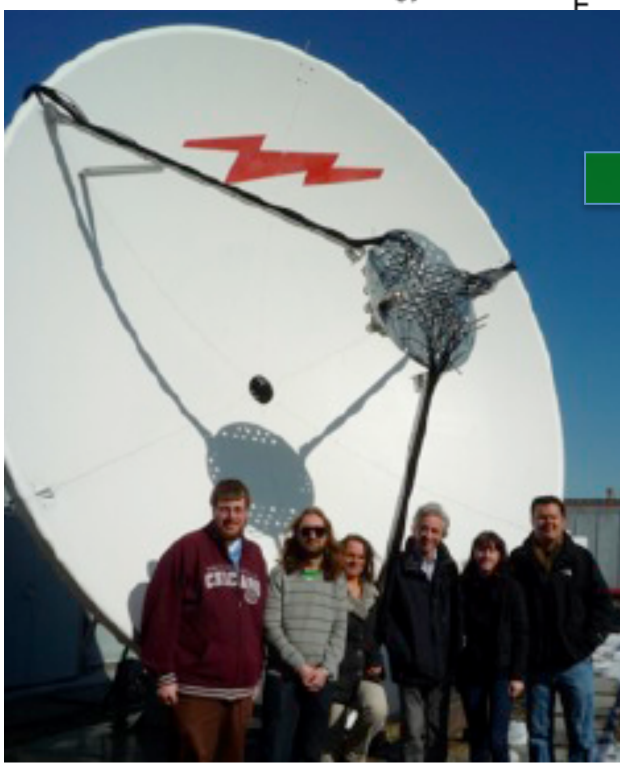
Higher Cross Sections or Multiplicities

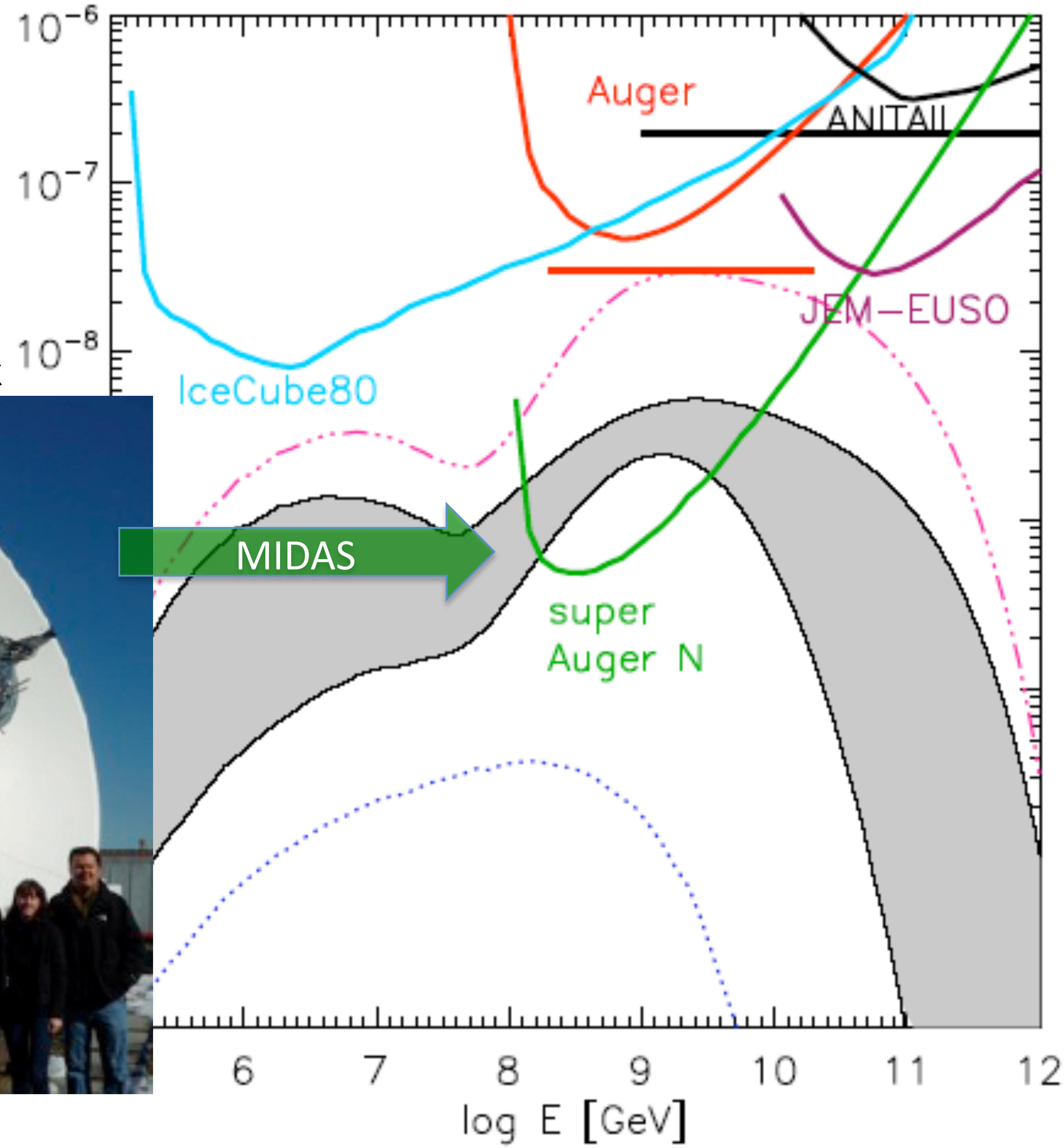
*based on Xmax up to 40 EeV



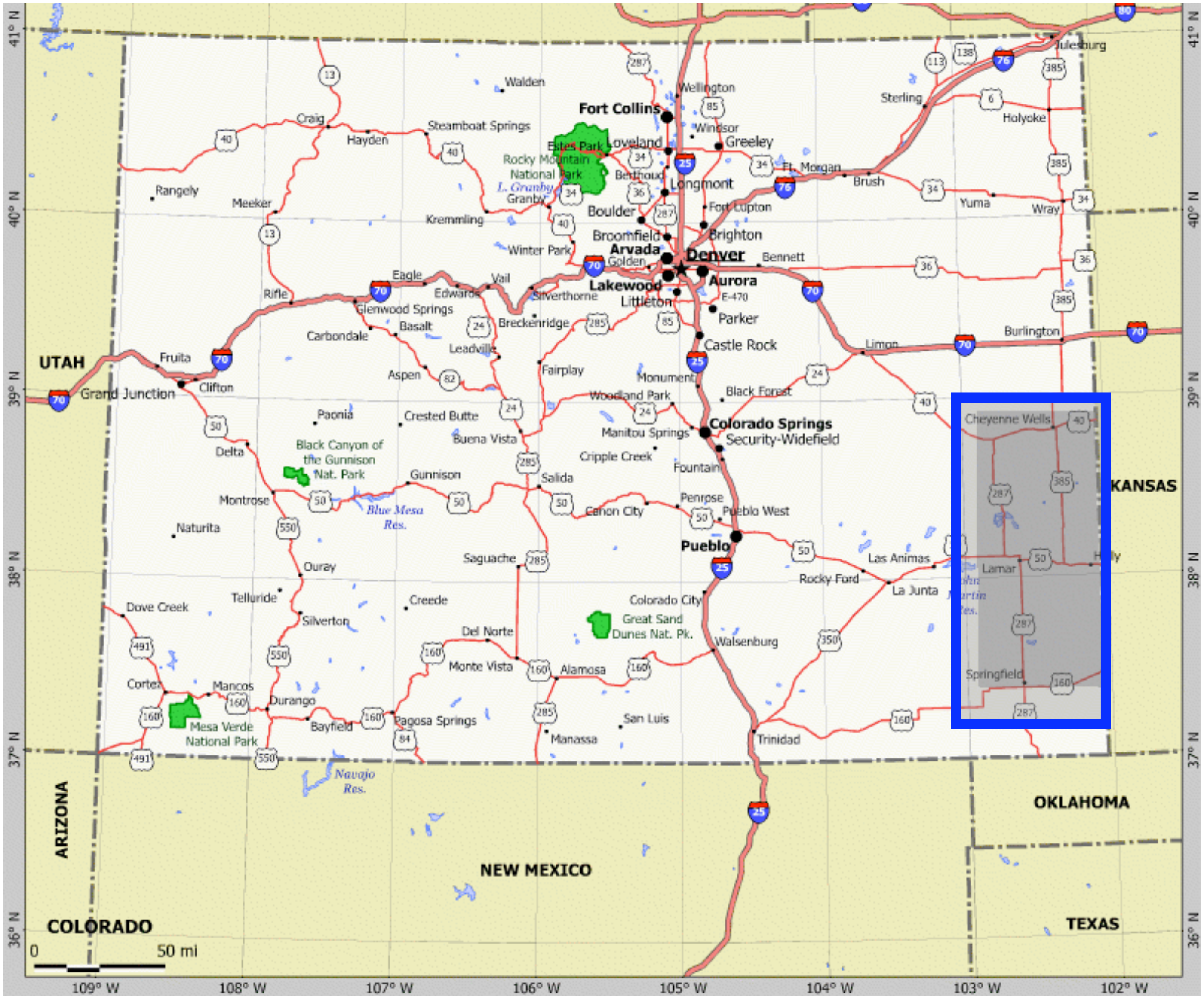
Kotera, Allard, A.V.O '10

Chris Williams talk

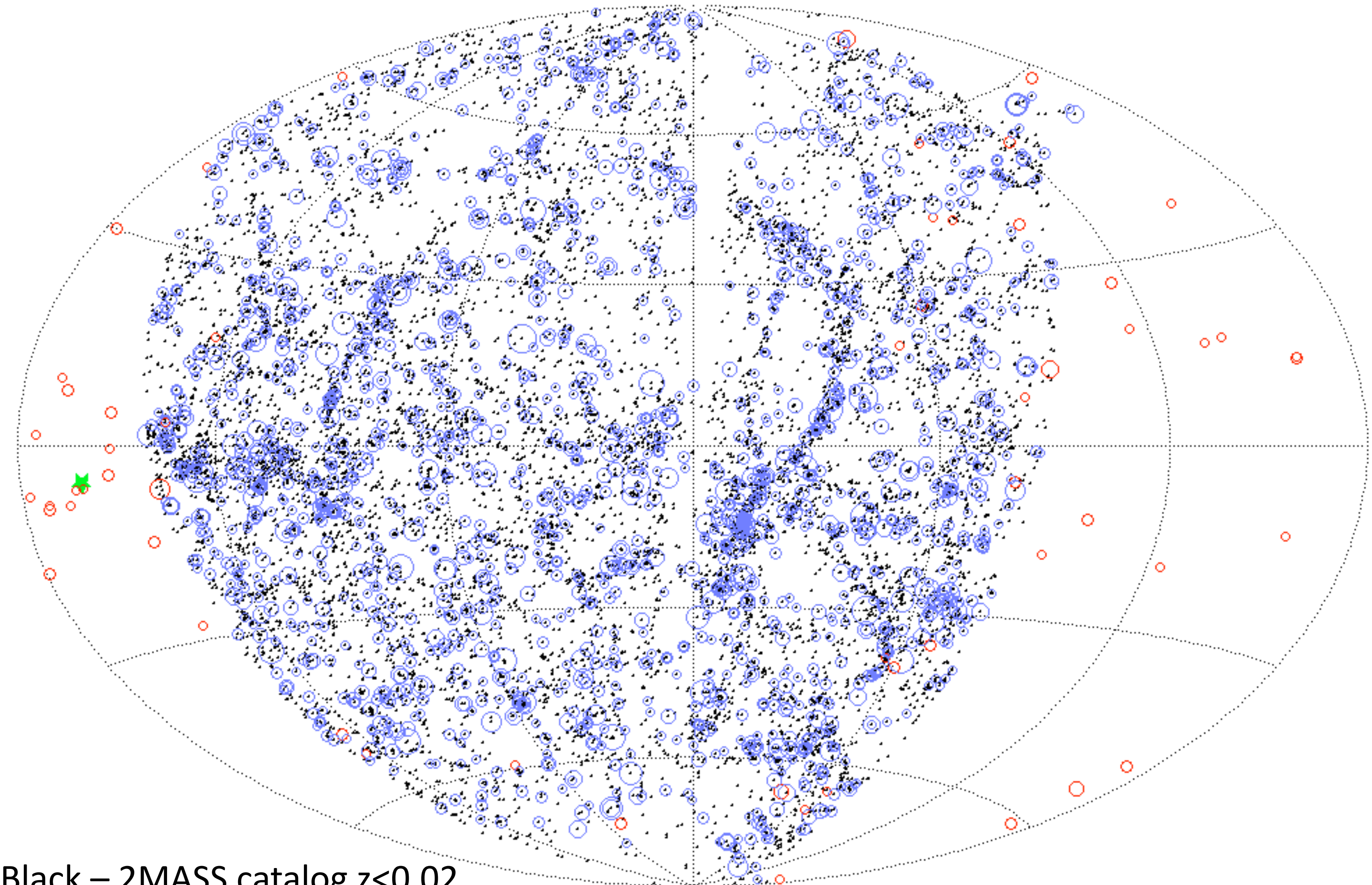




Auger North in SE Colorado



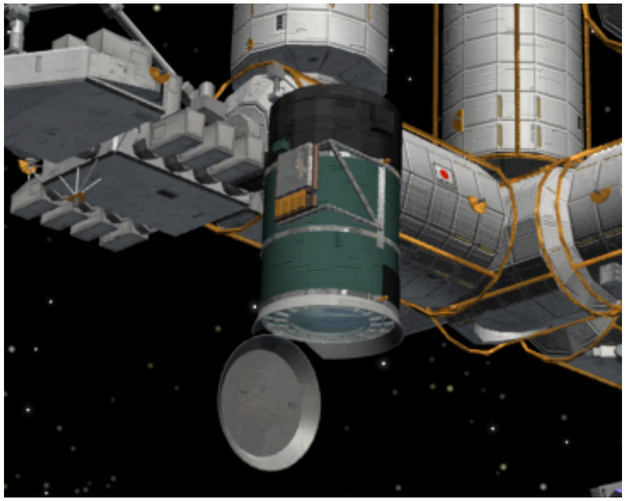
Auger North 10 yr



Black – 2MASS catalog z<0.02

Blue – Auger North simul Data – energy proportional to circle size

Red – Auger South Data



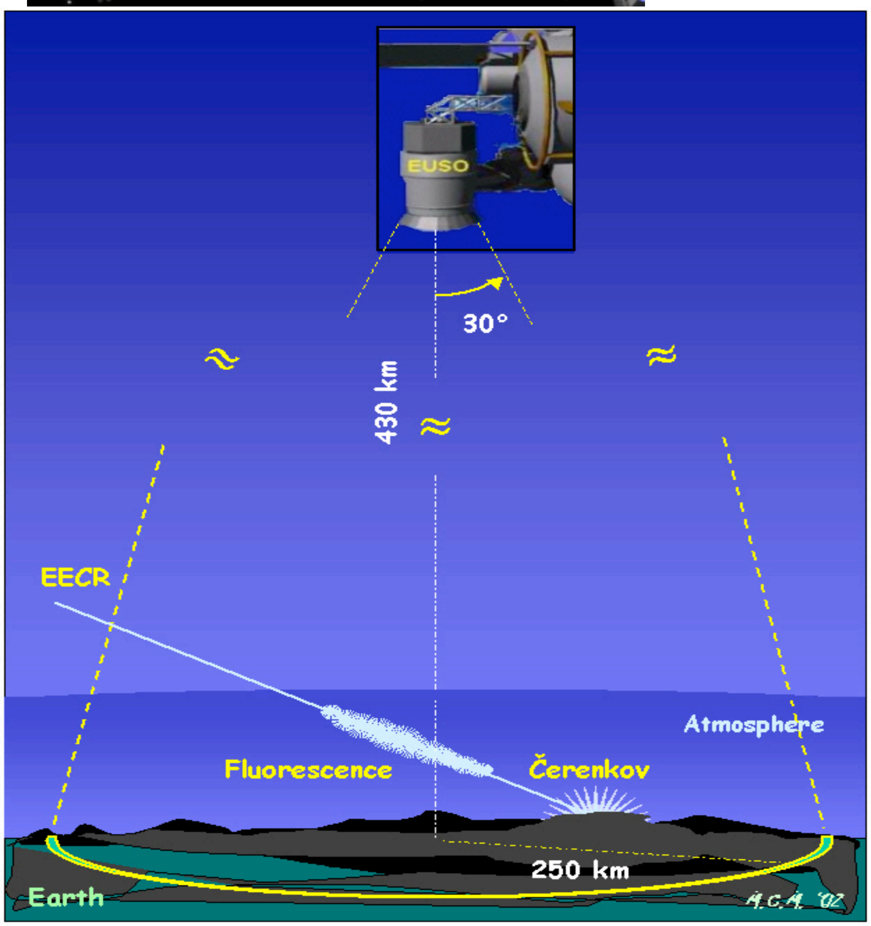
Nadir (2 yrs)

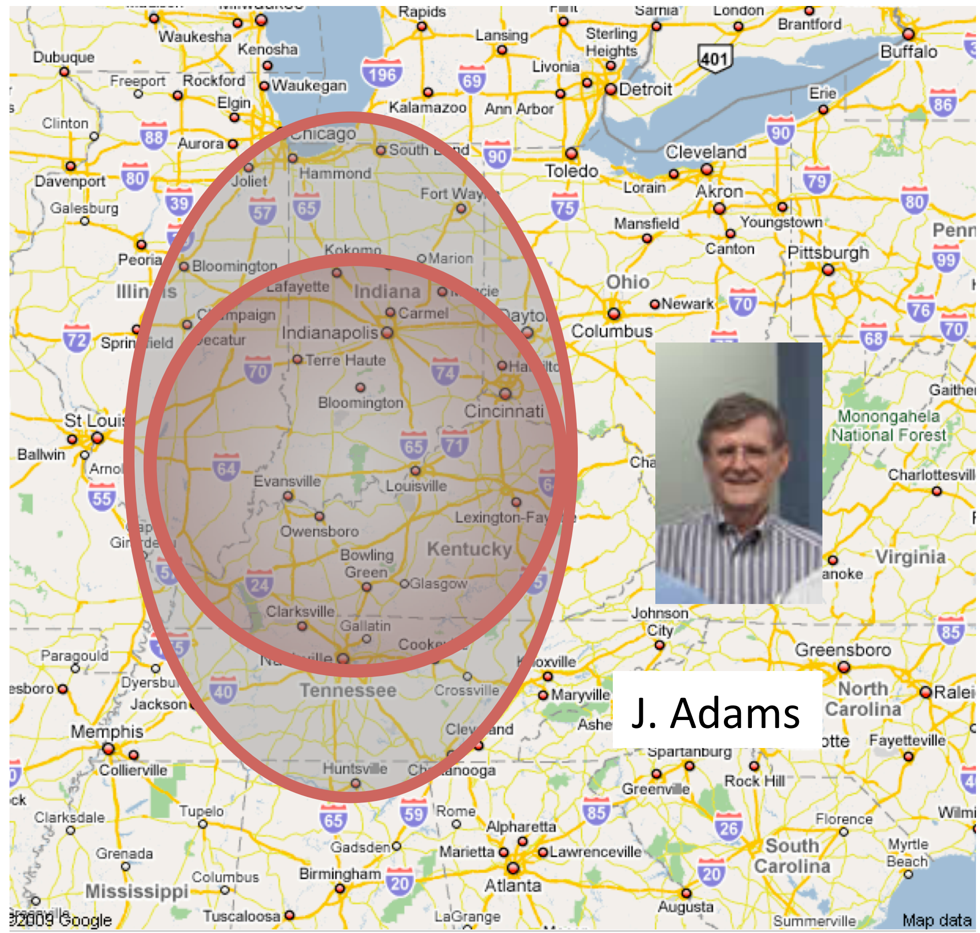
35º tilt (3 yrs)

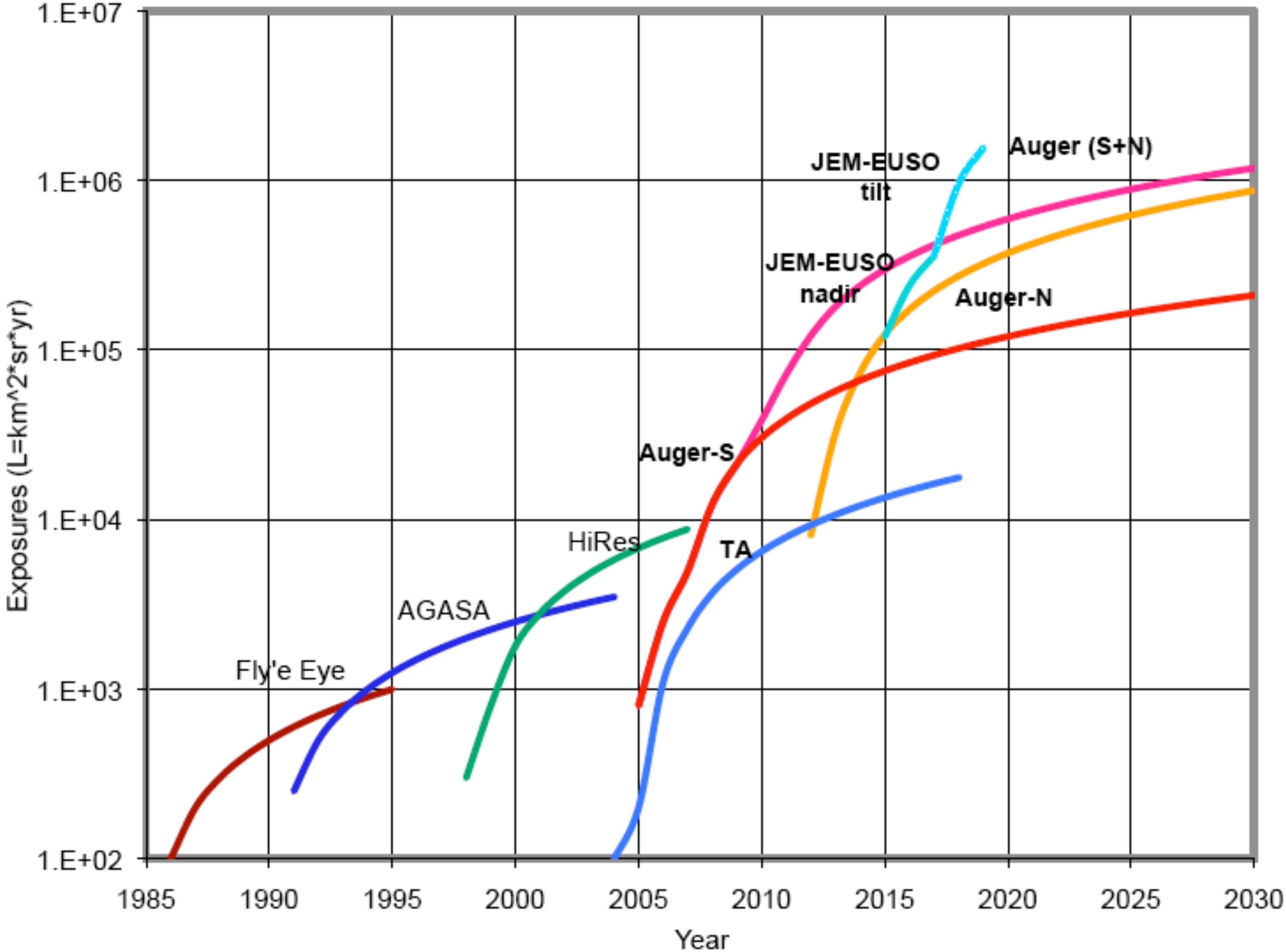
2015 launch

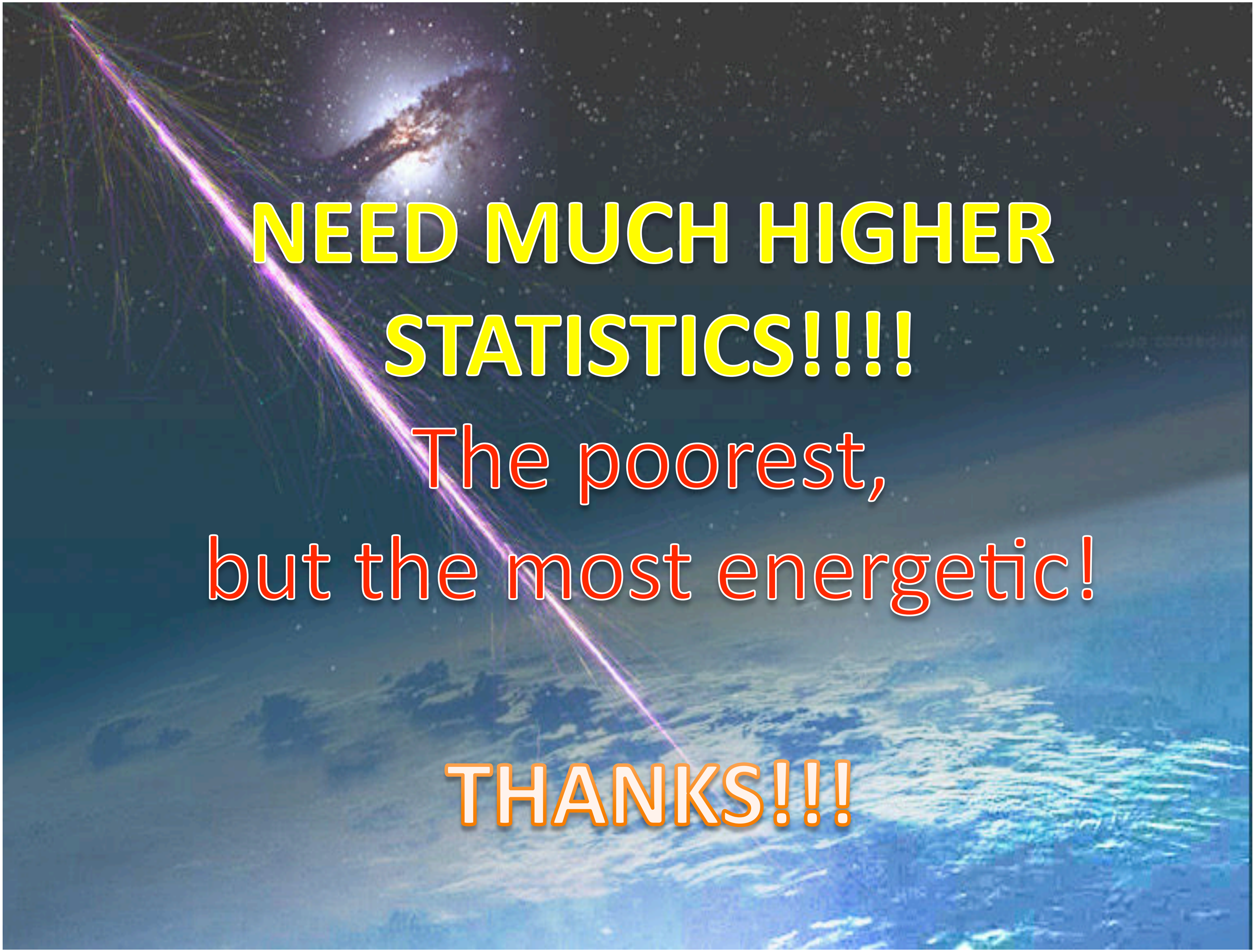
$E_{th} > 10^{20}$ eV

Fluorescence from Above

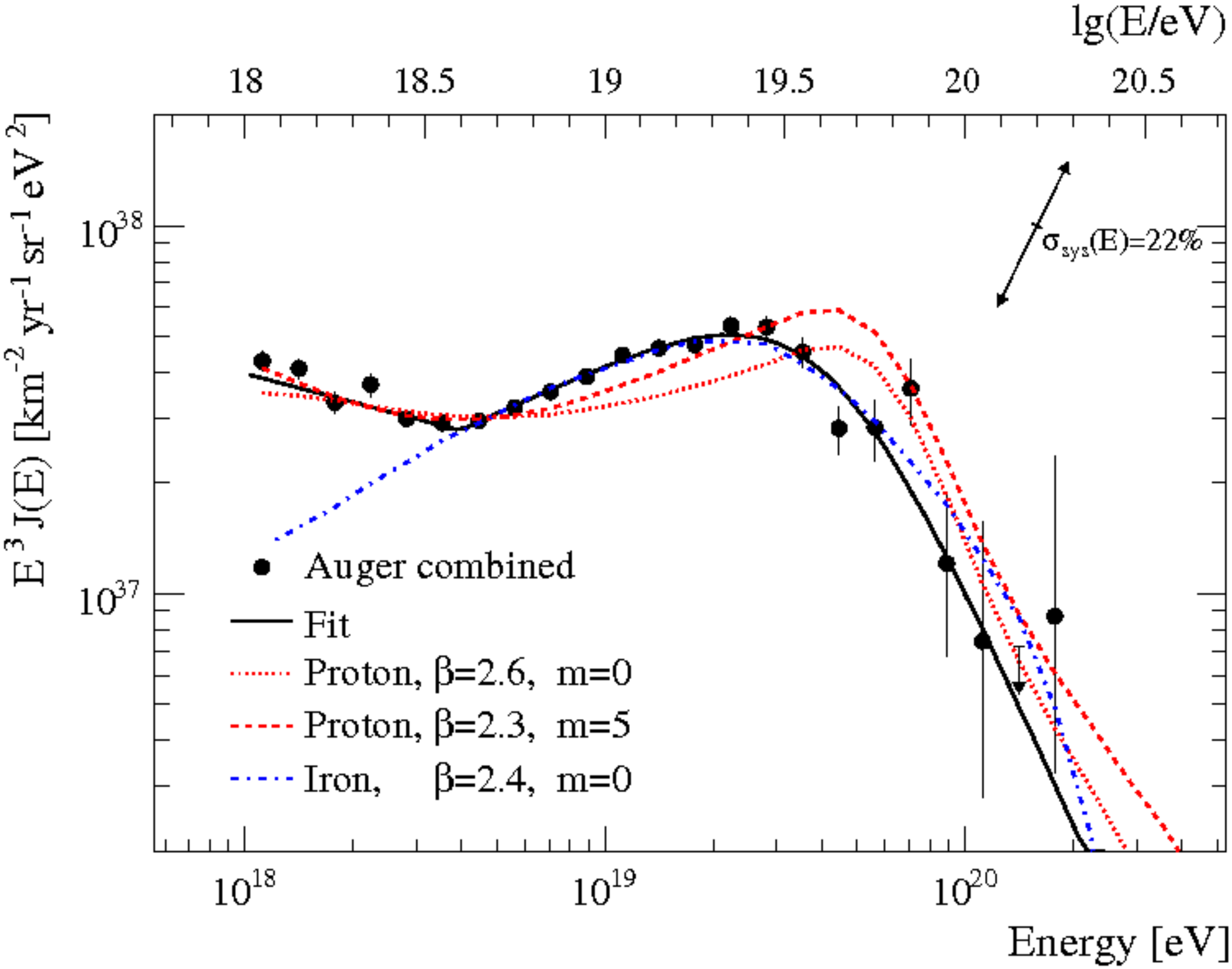




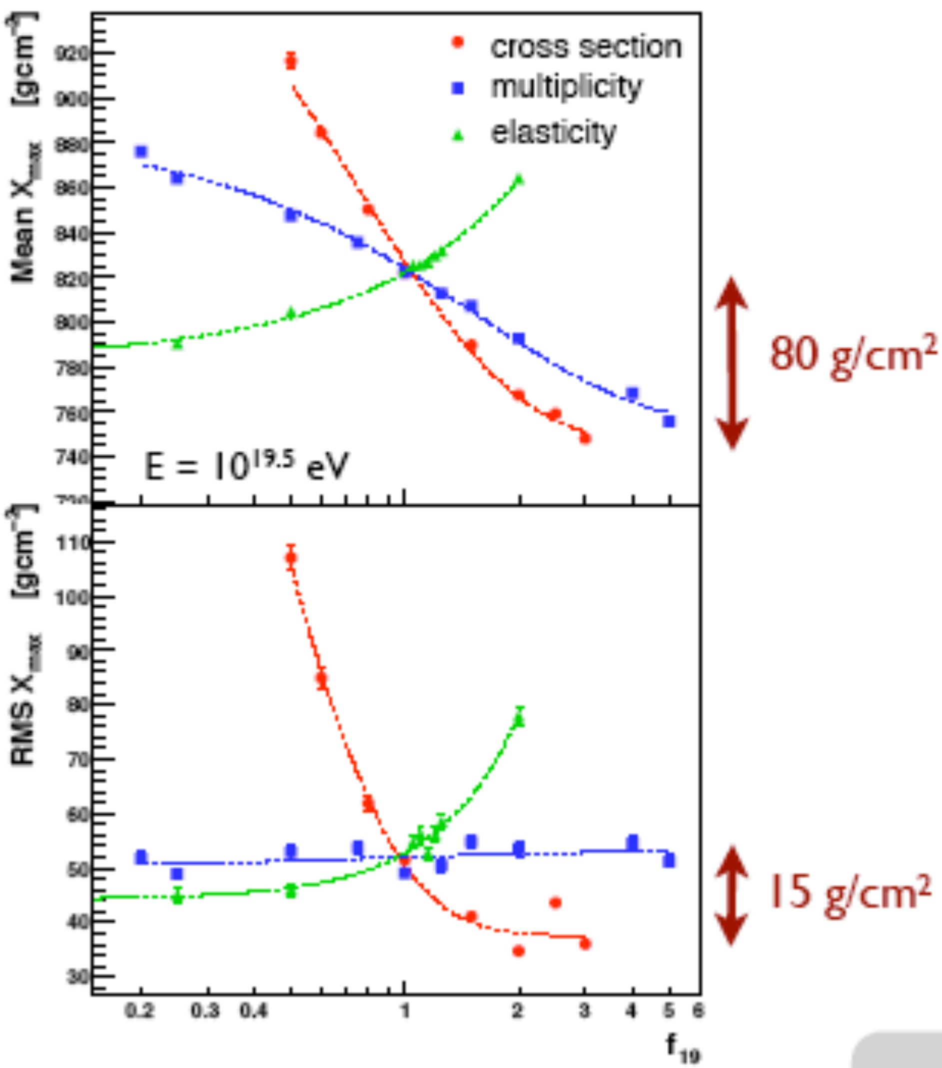

1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
Exposures (L=km^2*sr*yr)
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
Year
Fly'e Eye
AGASA
HiRes
Auger-S
TA
JEM-EUSO nadir
JEM-EUSO tilt
Auger (S+N)
Auger-N


NEED MUCH HIGHER STATISTICS!!!!
The poorest,
but the most energetic!
THANKS!!!

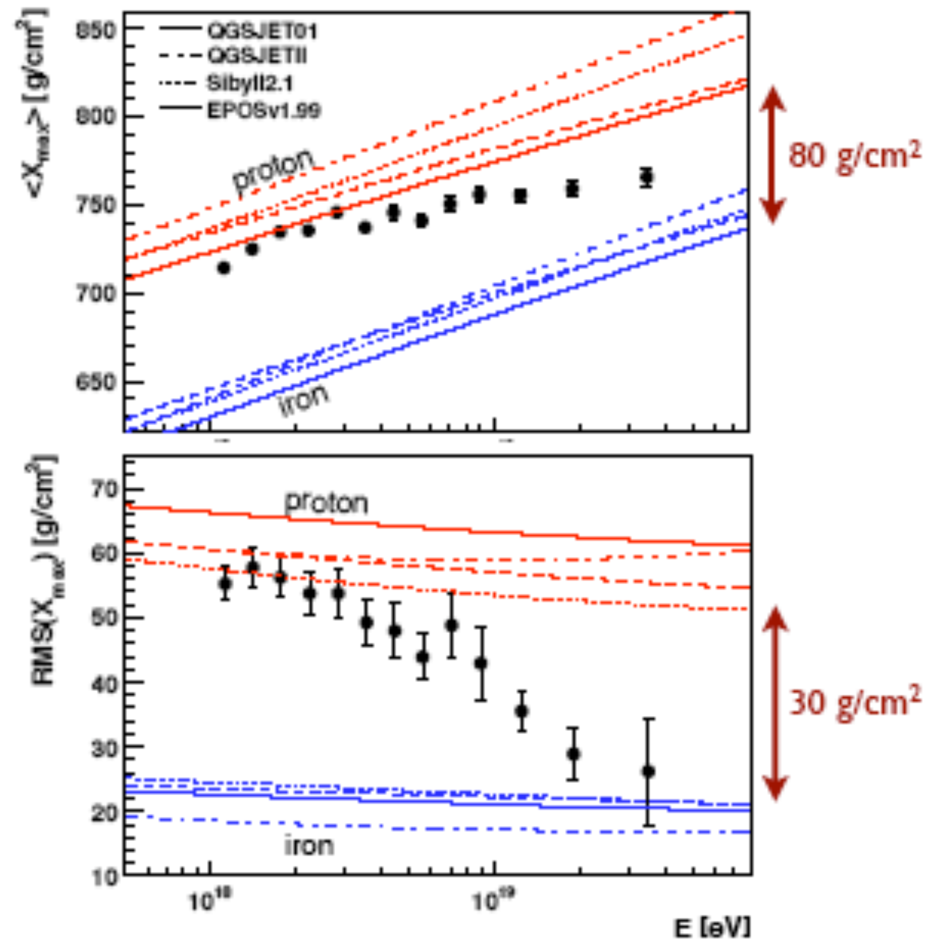
Composition & Spectrum



Modification of interaction characteristics?



Auger data 2009



(see talk by R. Ulrich)

- Variables influence differently mean and RMS
- Cross section most important