

# QCD at Ultrahigh Energies

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# a confusing situation...

## \* Correlations favor proton

- Correlation with local matter distribution
- Ursa Major Cluster
- Correlation with “AGN”
- Galactic magnetic deflections few degrees – c.f., Cen A analysis

COULD CORRELATIONS BE ACCIDENTS?

## \* Showers favor Heavy, “Fe”

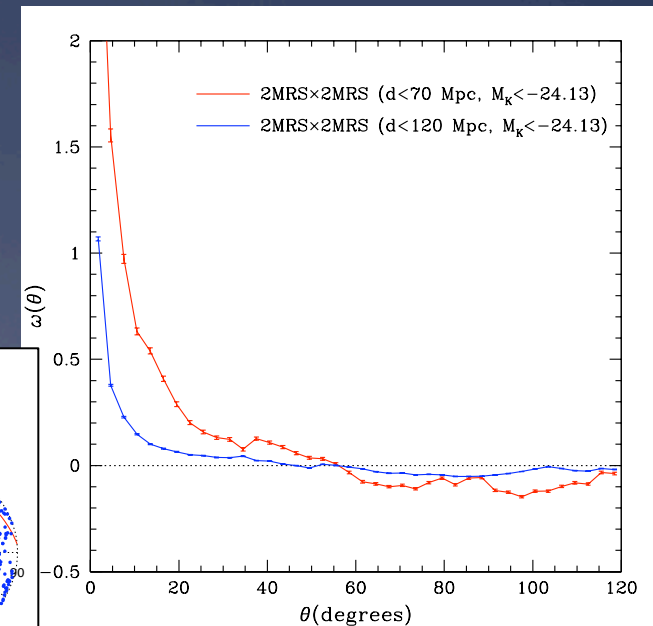
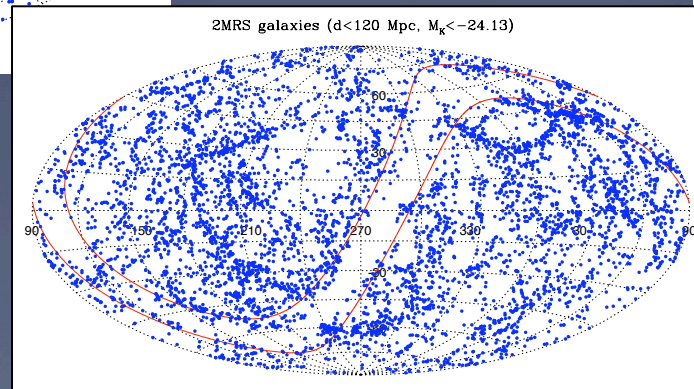
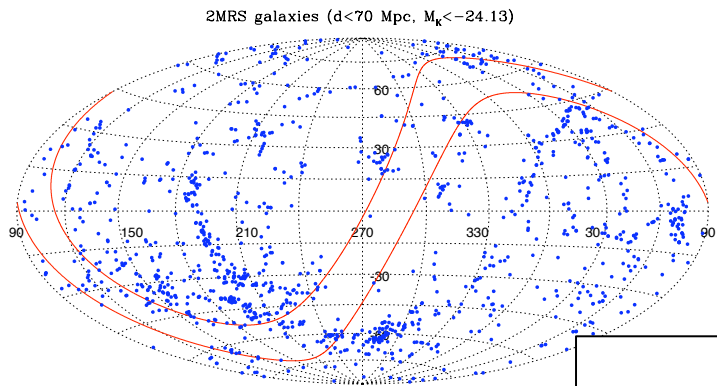
- Depth of shower max:  $\langle X_{\max} \rangle$
- Variance in  $X_{\max}$ :  $\text{RMS}_{X_{\max}}$
- $N_{\mu}$  – excess of muons compared to models
- But, .. Galactic magnetic deflections very LARGE

ARE MODELS ACCURATE?  
New Physics at UHE?

# UHECR-matter cross-correlation

*A. Berlind & GRF, 2009*

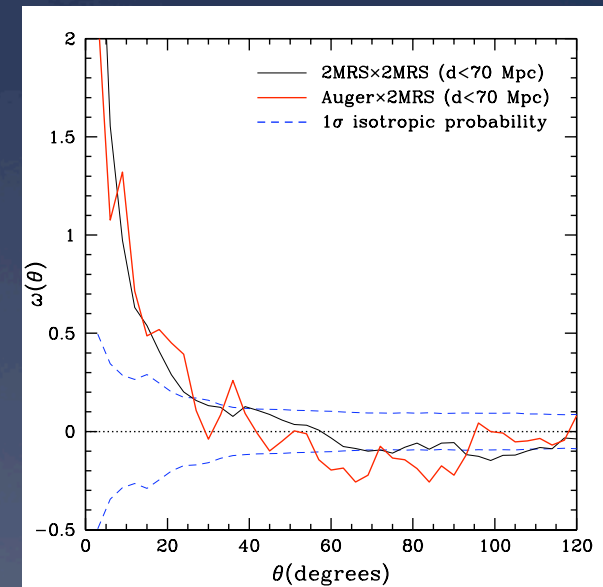
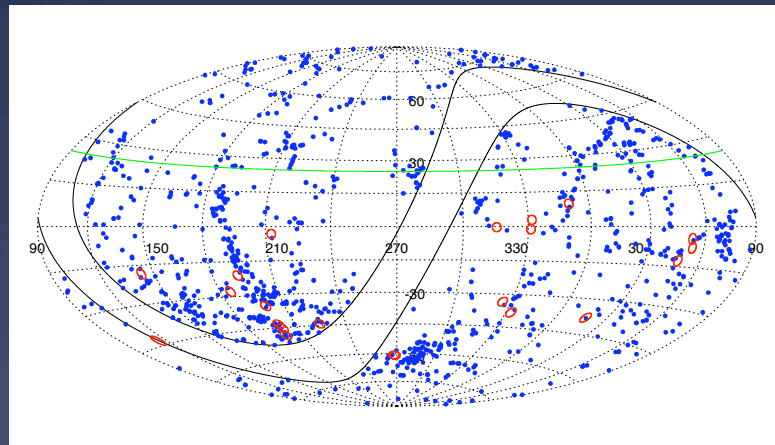
- \* Auto and cross-correlation: classic tools in astrophysics
- \* 2MASS Redshift Survey: excellent measure of local universe



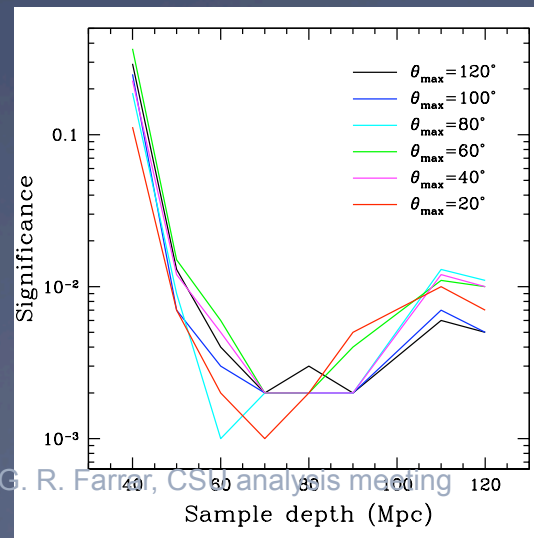
# UHECR-galaxy correlation

(27 Auger "Science" events; 2MASS galaxies)

$D_{\max} = 70$  Mpc



$D_{\max}$  dependence



With full dataset to Mar 31, 2009:  
isotropic UHECRs excluded at  
 $< 2 \times 10^{-4}$  at 90% CL



# Ursa Major Cluster

- \* 4 events in AGASA + HiRes (94 total) *HiRes+GRF 05*

Same position within  $< 1^\circ$ ,

20,000 sq degree

Chance probability:  $2 \cdot 10^{-3}$  *GRF 05*

*Not in Auger field of view!*

- \* SDSS => foreground empty!

Extragalactic magnetic deflection low

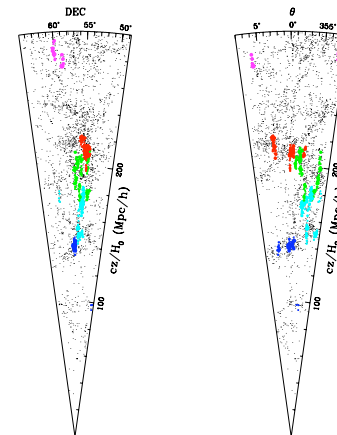
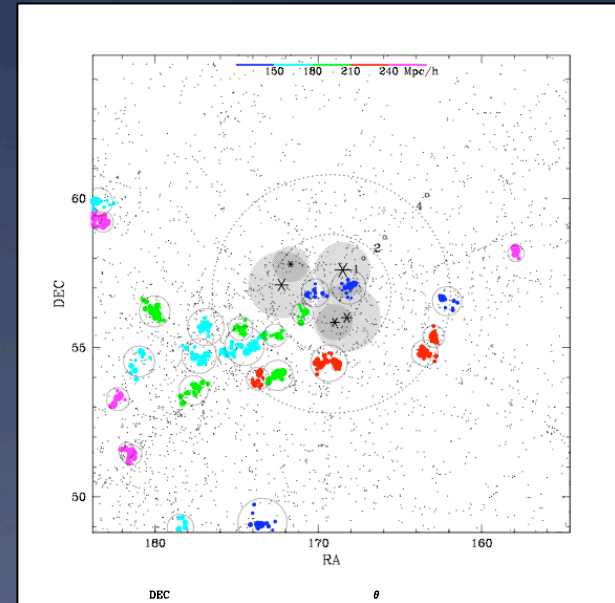
"confusion" problem reduced

*GRF, Berlind, Hogg 06*

- \* Galactic magnetic deflection

$$\Delta \theta \sim 1^\circ Z$$

*Evidence for proton composition*

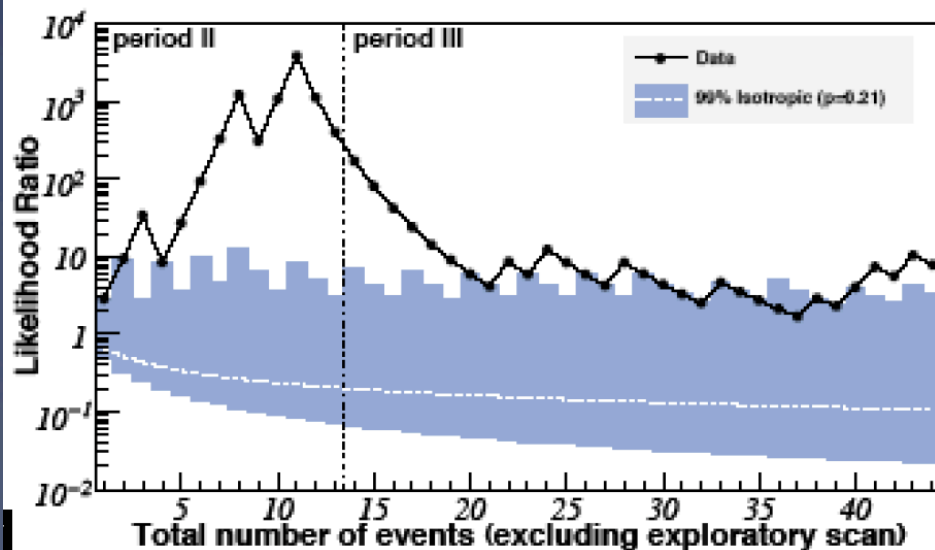
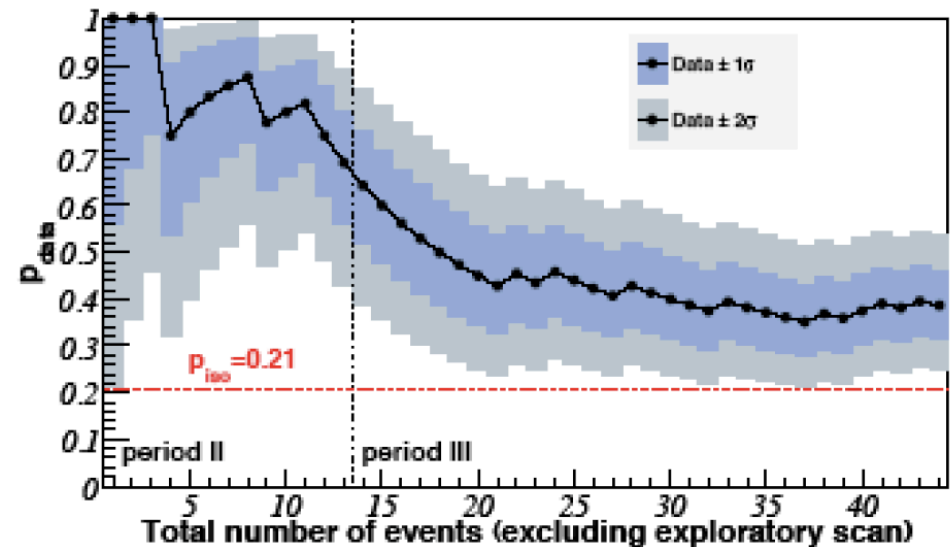


# Updated Auger AGN correlation

## Status of the Prescribed Anisotropy Test

(correlation with VCV catalog of AGNs)

39% correlate (post exploration)  
(21% expected for isotropy)

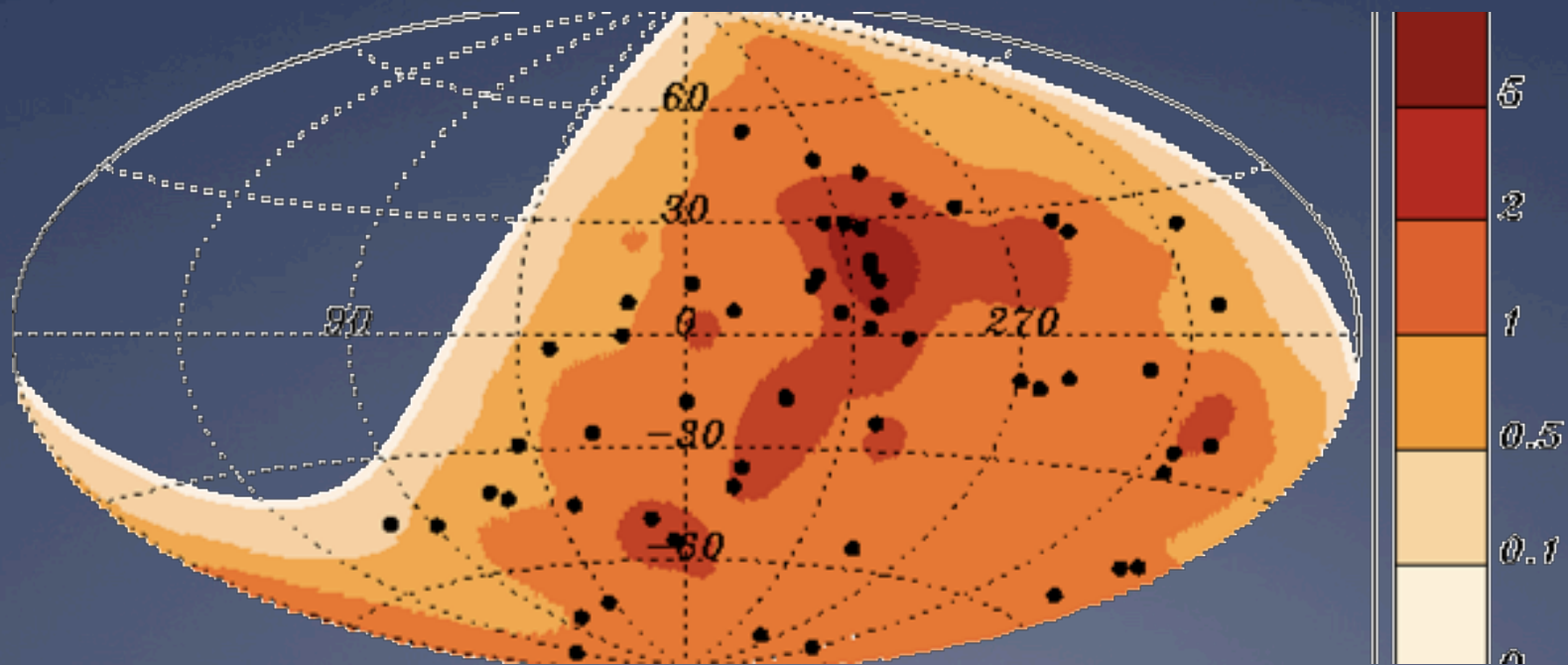


Present confidence level: 99.4%

99% of simulations based on isotropy

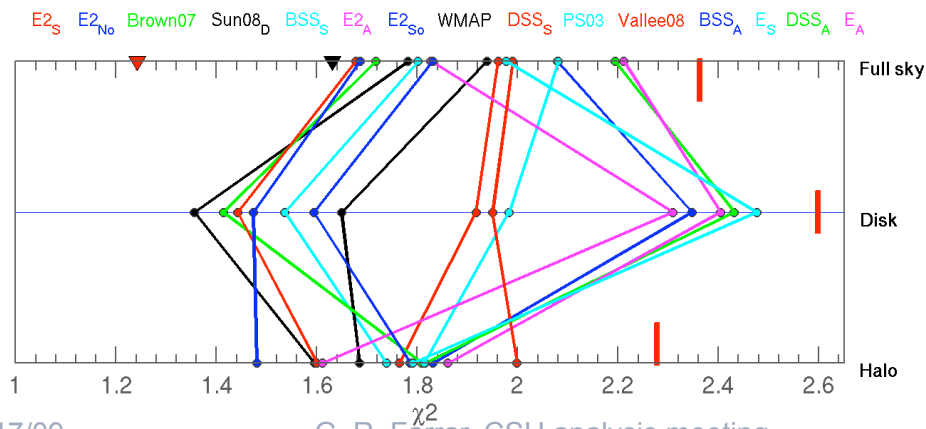
# Auger Events $> 60 \text{ EeV}$

- \* 58 Events up to Mar 31, 2009
- \* Correlation with Swift BAT AGNs shown



# Galactic Magnetic Field

- **Much better understood now** – Jansson et al 2009, and in prep.
- General parameterization, global & random fields
- Constrain parameters using
  - WMAP polarized emission intensity (sensitive to  $B_{\text{perp}}$ )
  - All Extragalactic rotation measures (sensitive to  $B_{\text{par}}$ )
  - 168 new RMs surrounding Cen A (I. Feain, 2009)



10/17/09

G. R. Farrar, CSU analysis meeting

New GMF model gives a much better fit than previous best models

# Deflections near Cen A

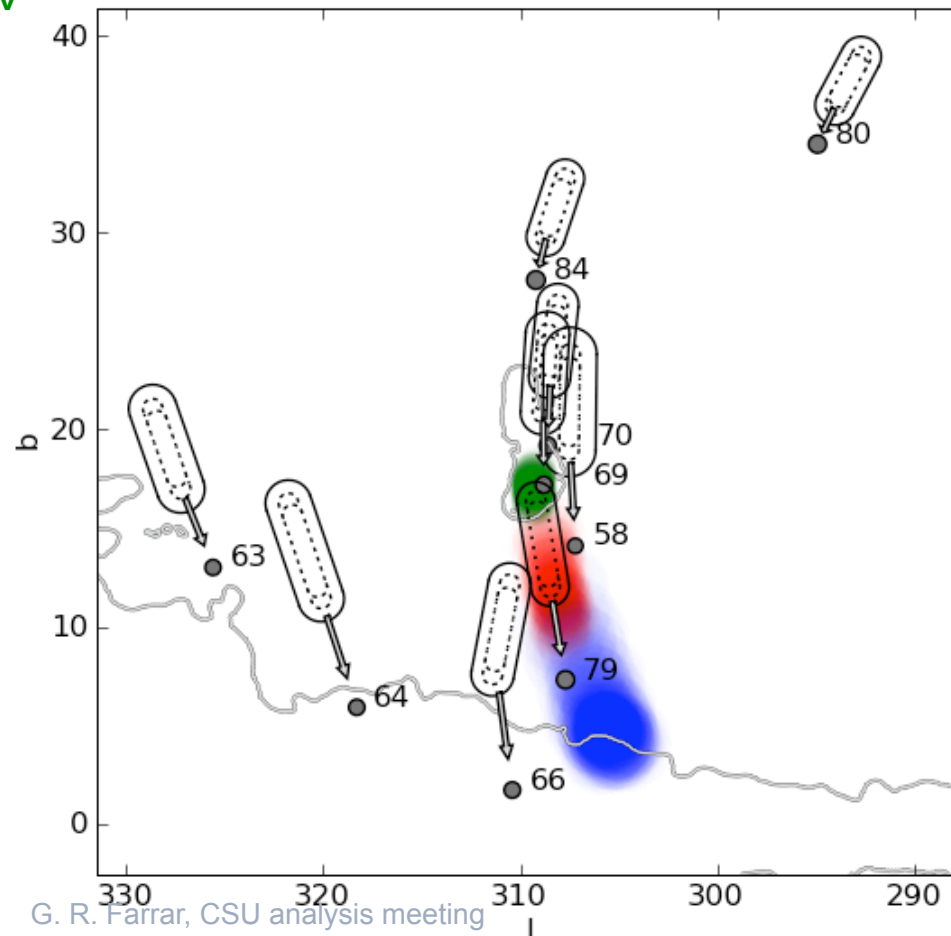
4 events can be protons from Cen A; large Z not

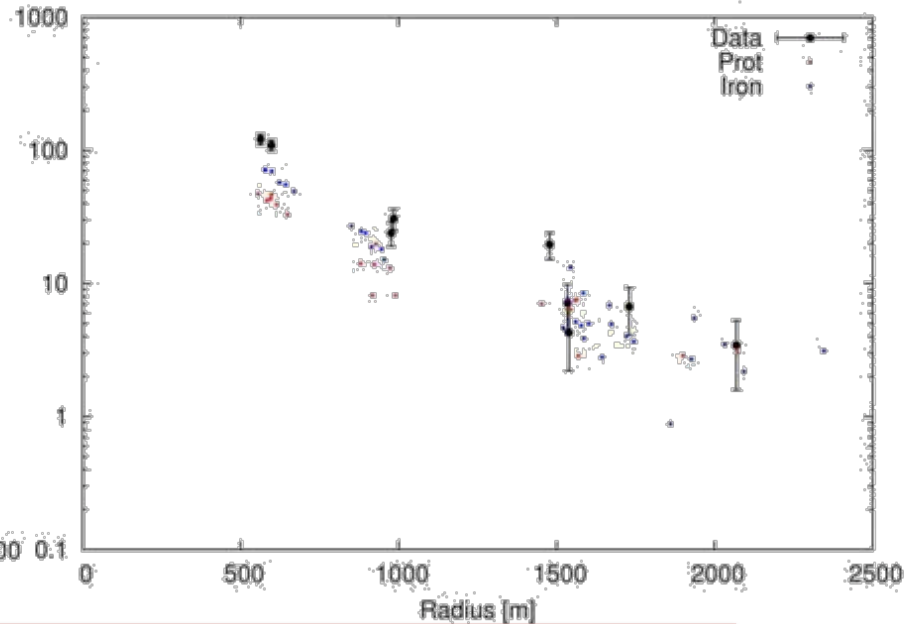
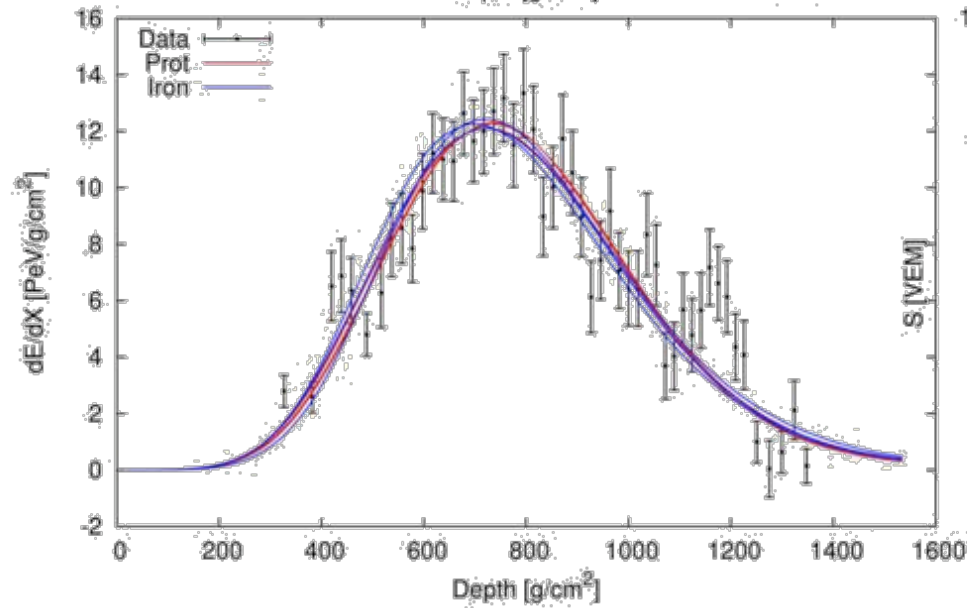
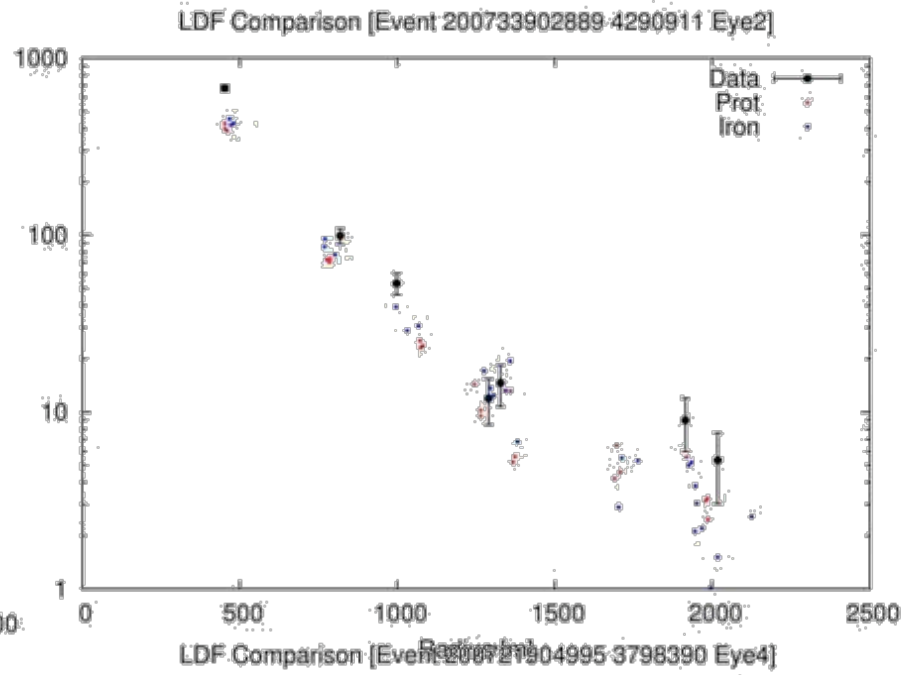
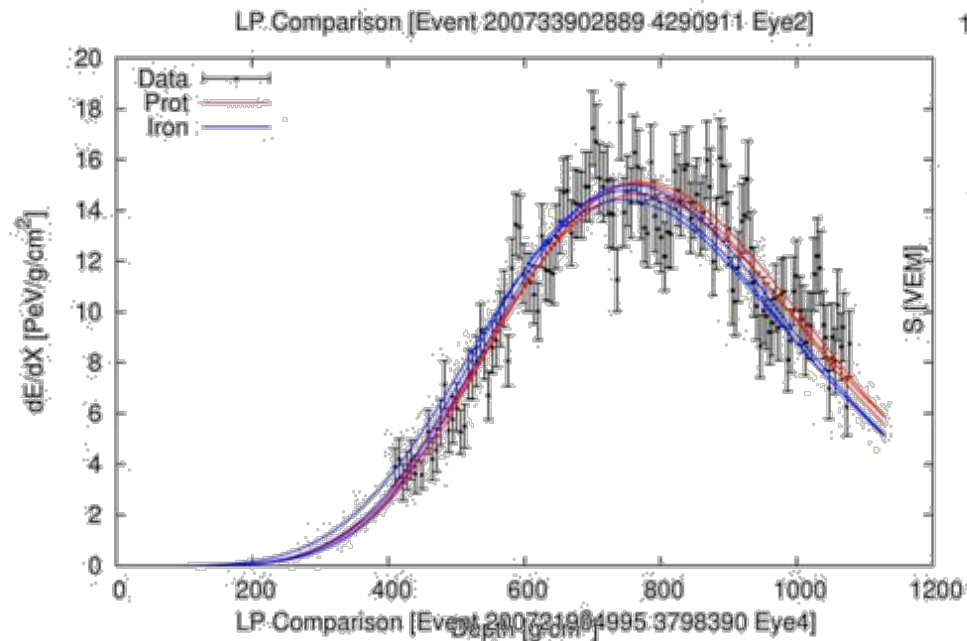
Rigidity:

200 EeV

60 EeV

40 EeV





PREDICTED FLUX AT GROUND IS FACTOR 1.5 - 2 TOO LOW IN ALL CASES!



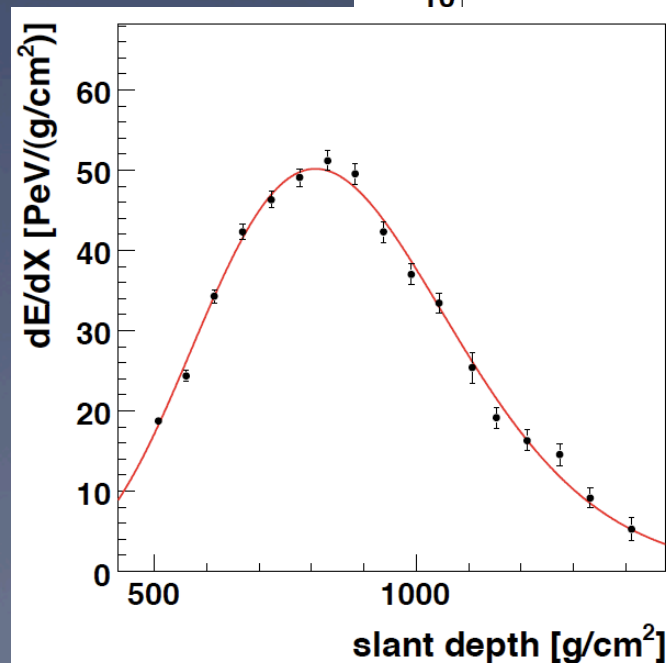
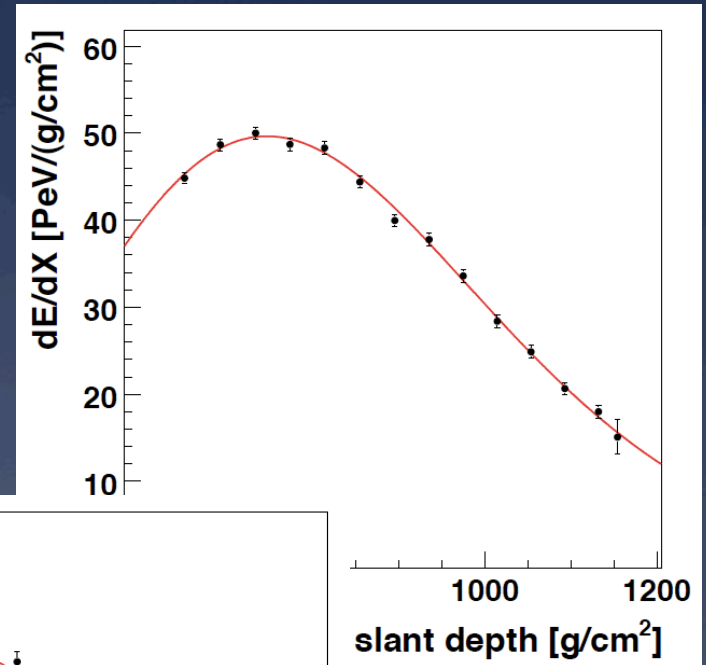
# Cosmic Rays Test Hadronic Physics

- \* Three main measurements

- \*  $\langle X_{\max} \rangle$
- \*  $\text{RMS}_{X_{\max}}$
- \*  $N_{\text{mu}}$

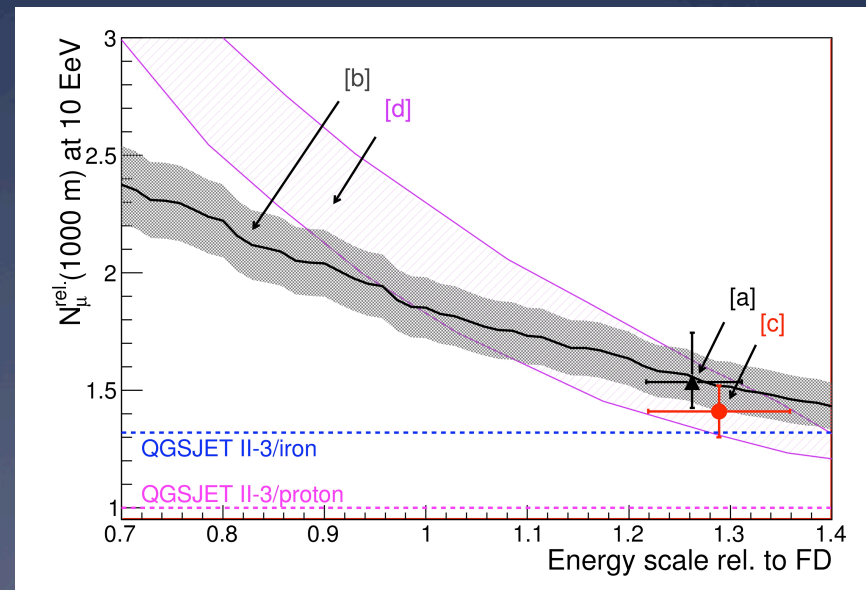
- \* Depend on hadronic event generators

- \* Cross section
- \* Multiplicity
- \* Inelasticity



# Number of Muons

- \* Effort at Auger to measure muon content in air showers
  - Universality
  - Smoothing
  - Jump counting
  - Golden Hybrid Analysis
- \* At least 50% more muons necessary => Even QGSJETII iron isn't muon rich enough
- \* Muon richness strongly favors iron, but  $X_{\max}$  observables favor mixed composition



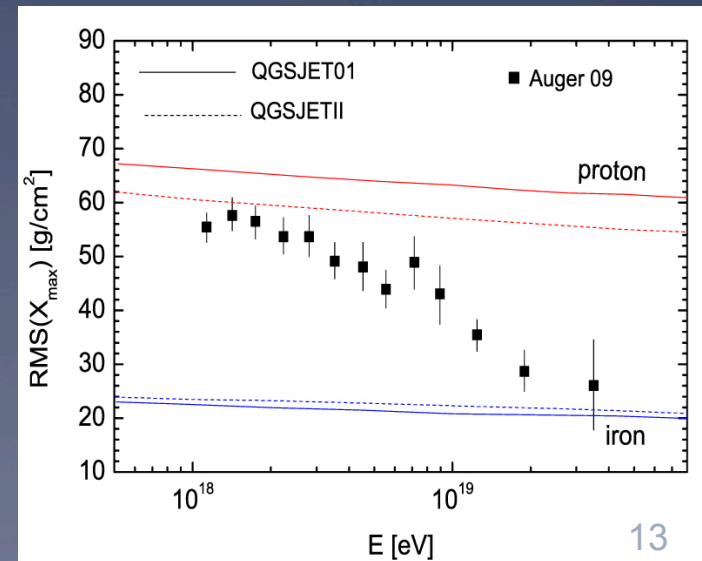
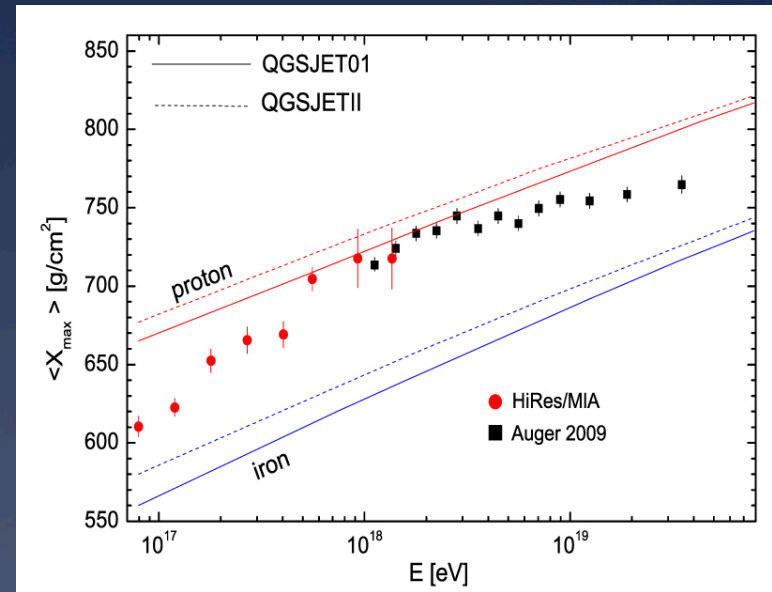
# Longitudinal Profile

\* Above 3 EeV:

$\langle X_{\max} \rangle$  and  $\text{RMS}_{X_{\max}} \Rightarrow$   
heavier composition

\* For QGSJET and SYBIL,  
 $\langle X_{\max} \rangle$  and  $\text{RMS}_{X_{\max}}$  are  
inconsistent!

- $\langle X_{\max} \rangle$  favors mixed composition
- $\text{RMS}_{X_{\max}}$  strongly favors iron



# $X_{\max}$ , $RMS_{X_{\max}}$

\* EPOS 1.99 (Pierog, Werner)  
new event generator  
designed to increase  $N_{\text{mu}}$

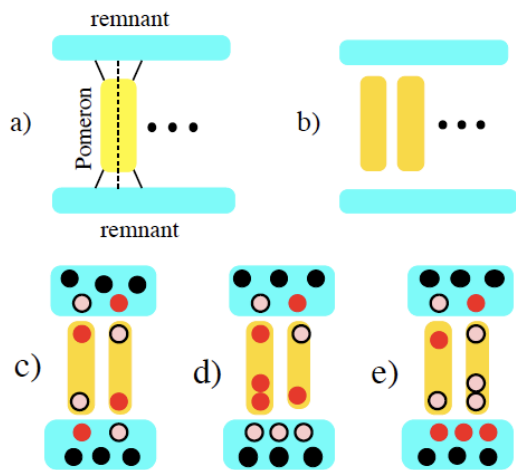
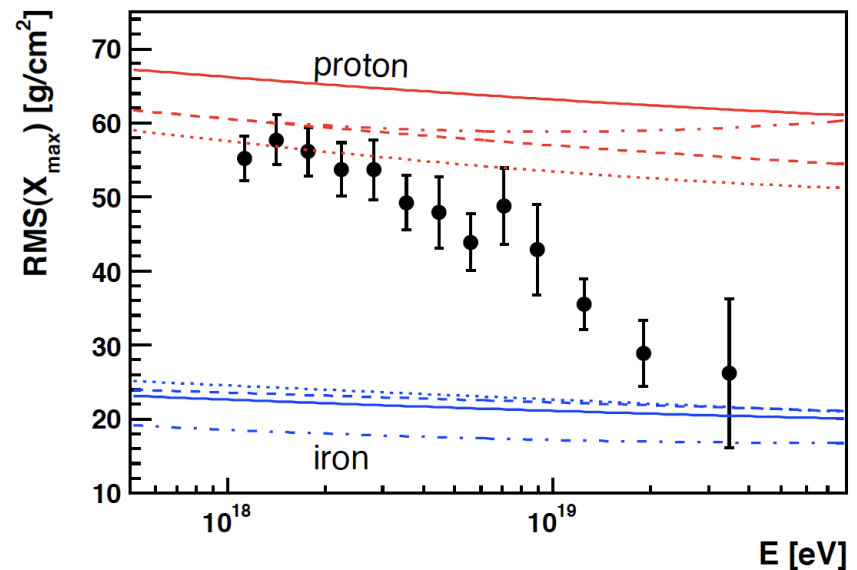
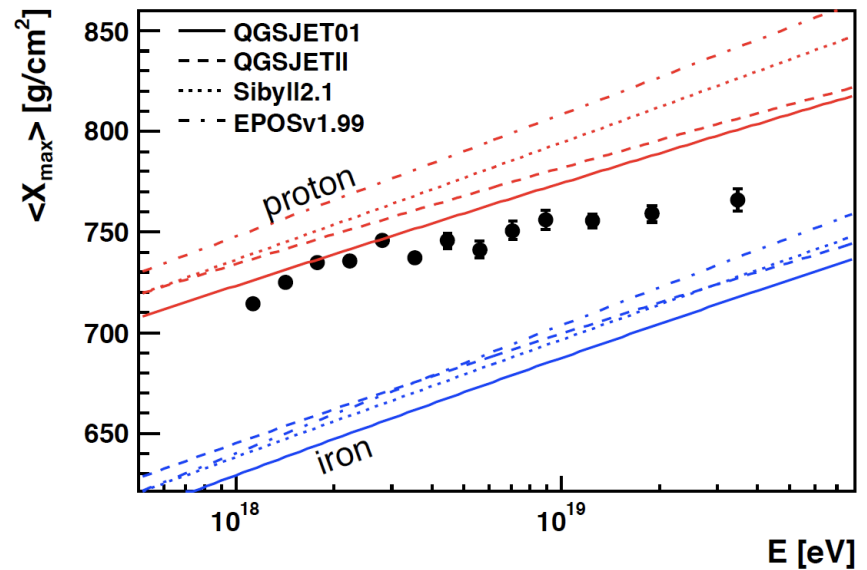


Figure 4. a) Each cut Pomeron is regarded as two strings b). c) The most simple and frequent collision configuration has two remnants and only one cut Pomeron represented by two  $q-\bar{q}$  strings. d) One of the  $\bar{q}$  string ends can be replaced by a  $qq$  string end. e) With the same probability, one of the  $q$  string ends can be replaced by a  $\bar{q}q$  string end.

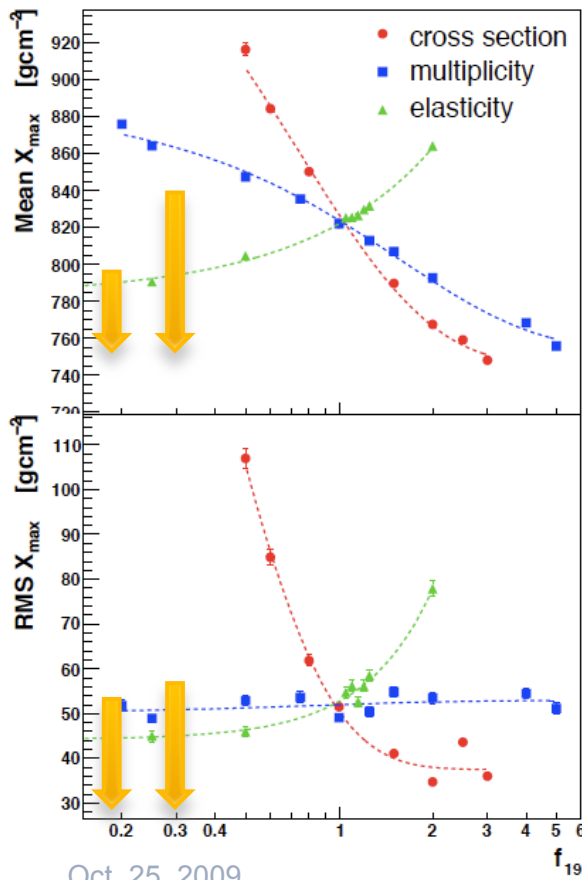


# Effect on $X_{\max}$ and $RMS_{X_{\max}}$ of scaling $\sigma$ , multiplicity and inelasticity by $f(E) = 1 + (f_{19} - 1) F(E)$

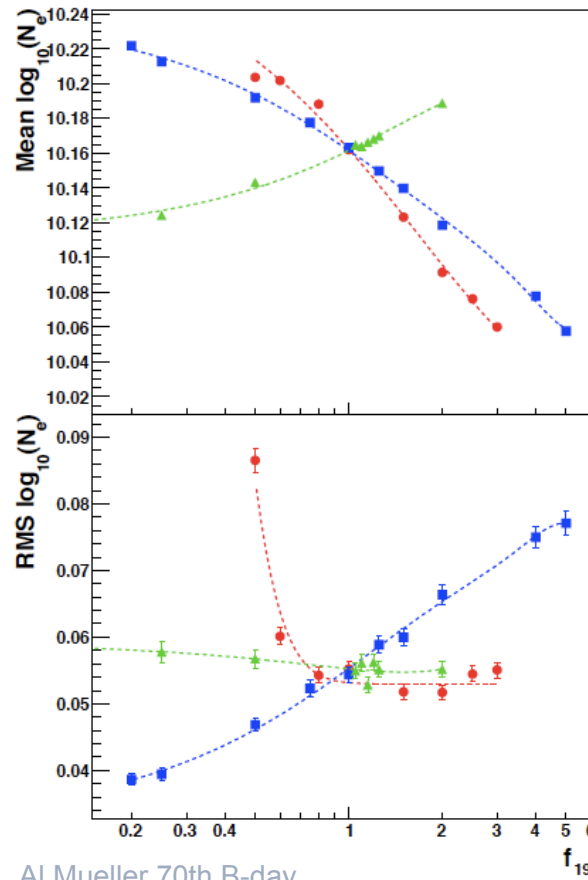
R. Ulrich et al 0906.0418

$$F(E) = \begin{cases} 0 & E \leq 1 \text{ PeV} \\ \frac{\ln(E/1 \text{ PeV})}{\ln(10 \text{ EeV}/1 \text{ PeV})} & E > 1 \text{ PeV} \end{cases}$$

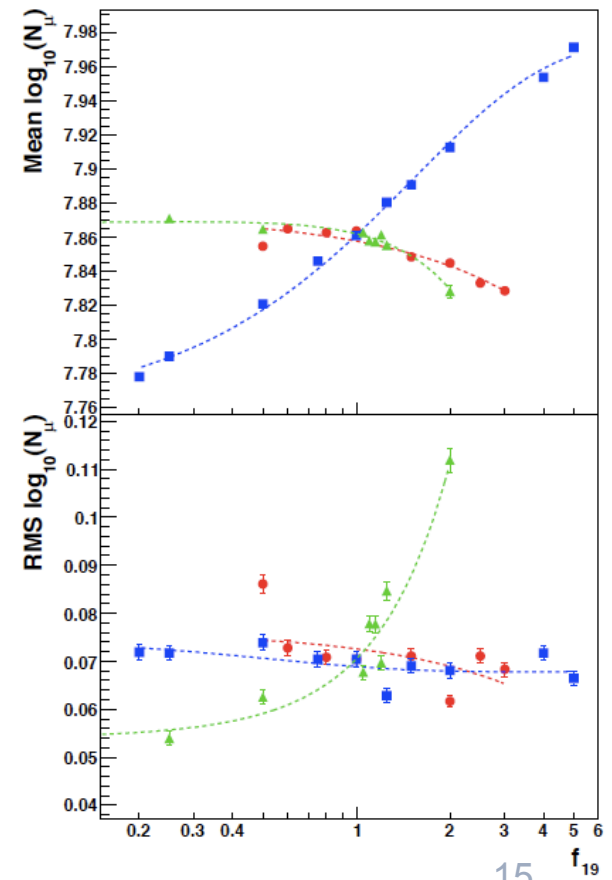
\* Figures at 30 EeV



(a) Shower maximum,  $X_{\max}$



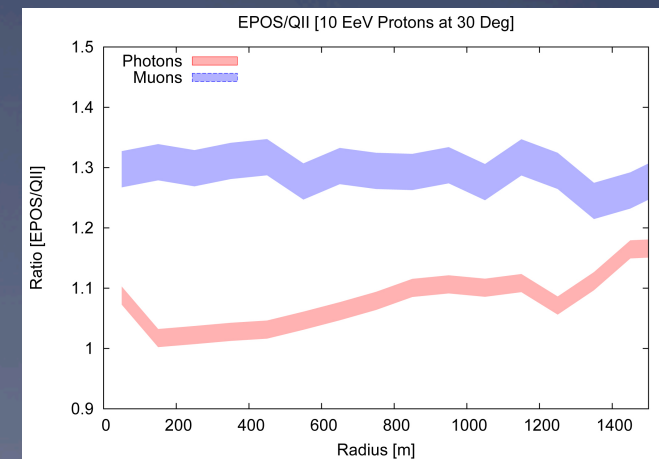
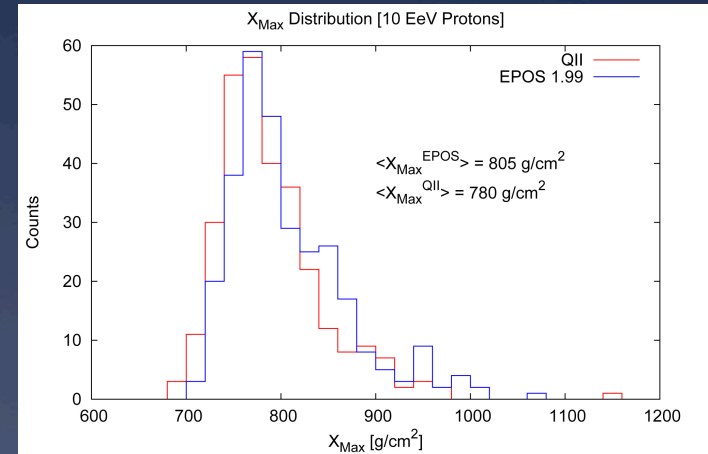
(b) Electrons,  $N_e$



(c) Muons,  $N_\mu$

# EPOS 1.99 continued

- \* Different results than QGSJET/SYBIL
  - \*  $X_{\max}$  tends to be deeper
  - \* Similar  $\text{RMS}_{X_{\max}}$
  - \* Showers more muon rich
- \* EPOS can fit data, for pure Fe





# Puzzle!

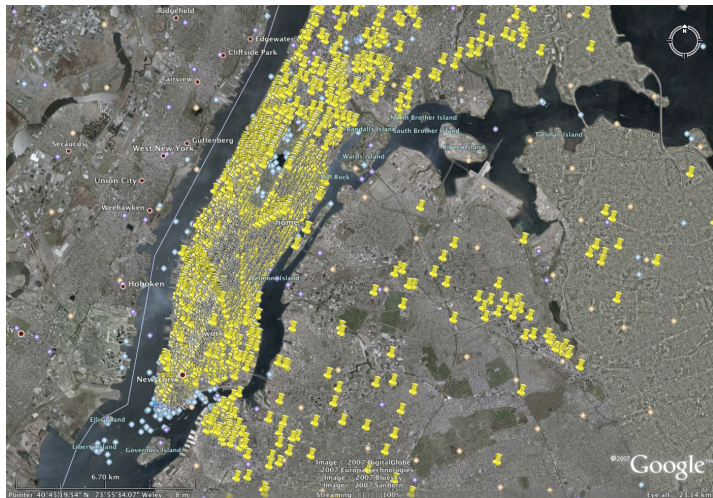
model	comp	$X_{\max}$	$RMS_{X_{\max}}$	$N_{\mu}$	$E_{\text{res}}$	Corrs?
Q&S,	mixed	Can fix one but not both		Better, but still too low	no change (too low)	no
Q&S, $2x\sigma$	proton	a little low	good	no change (too low)	no change (too low)	yes
EPOS	Fe			good	good	no

# Need more

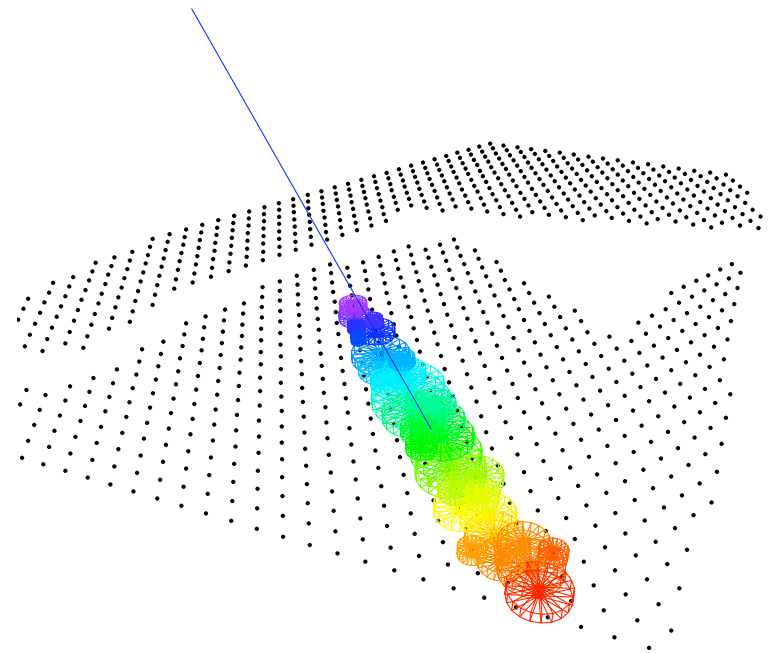
- \* UHECR data (correlations?)
- \* Theory (UHE cross-section, phase transition)
- \* Phenomenology (models compatible with RHIC data?)

# NY Cosmic Particle Telescope

- Make world's best HE neutrino telescope using 1k-4k rooftop watertanks in NYC (out of 15,000)



Up-going tau:  
 $E = 0.1 \text{ EeV}$   
 $\theta = 91^\circ$



Observational puzzles are  
the best  
gifts from Nature...

HAPPY BIRTHDAY AL !!!!