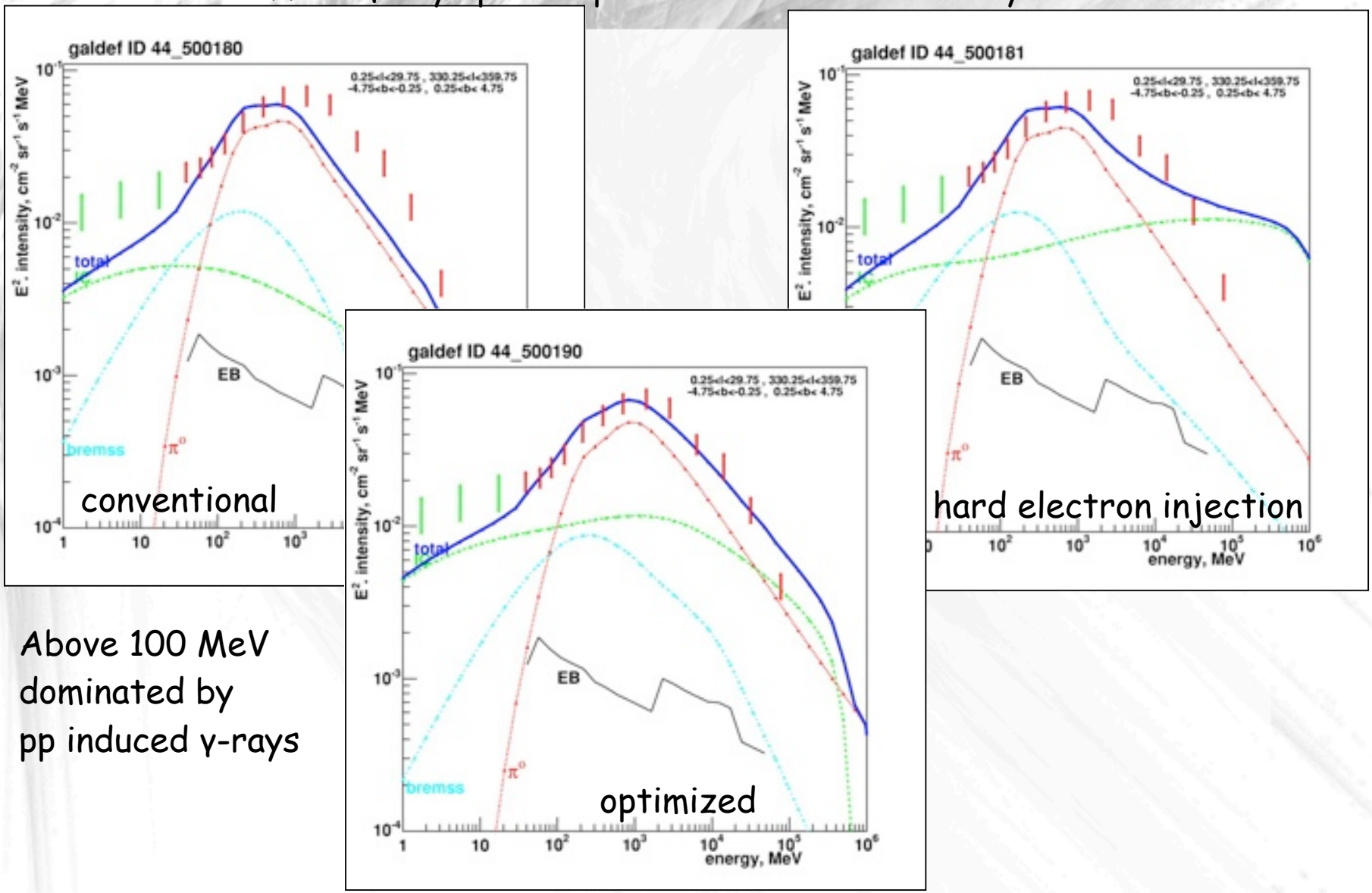
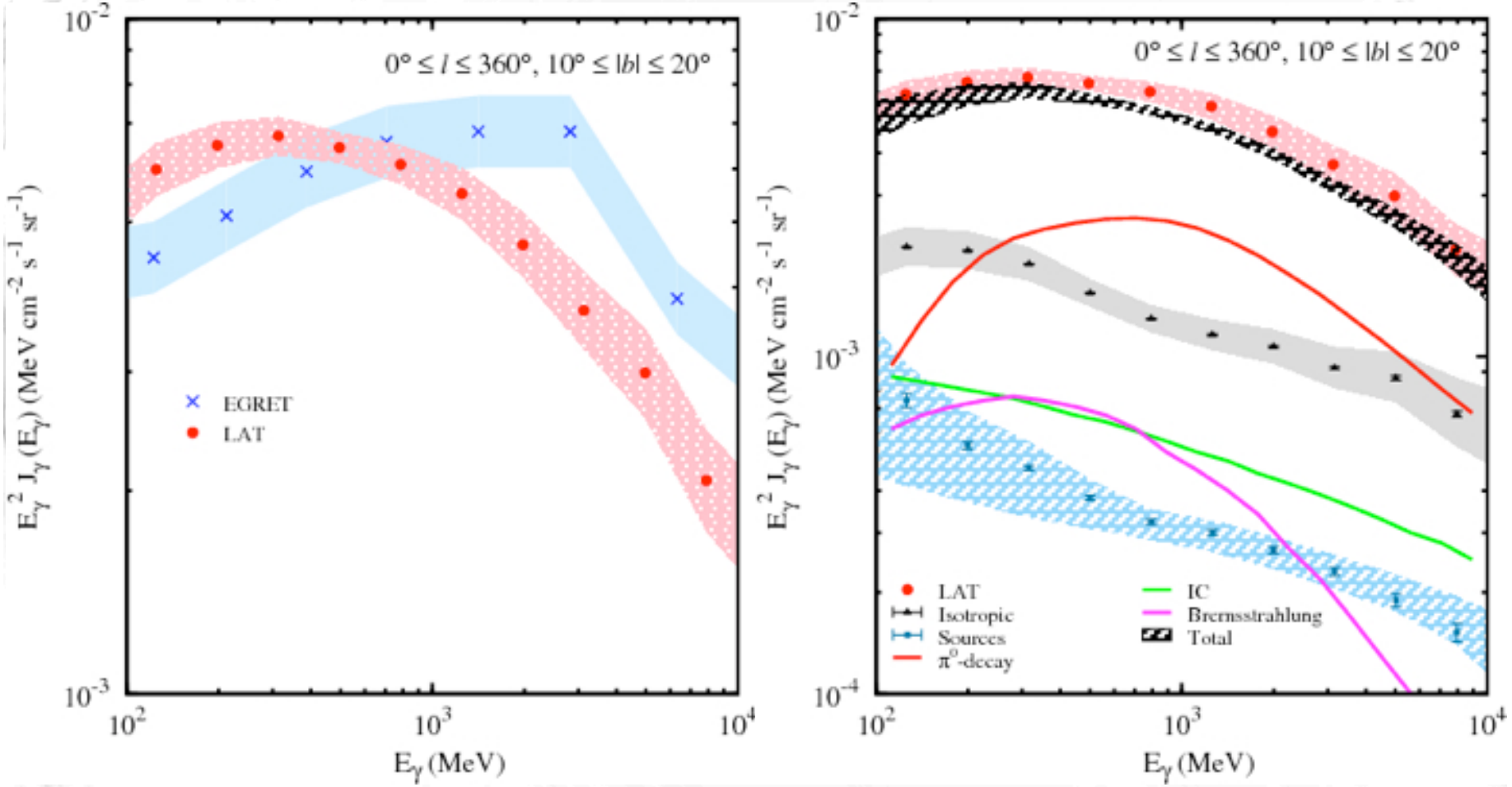
Diffuse γ-ray spectra predicted and observed by EGRET



Above 100 MeV
dominated by
pp induced γ-rays

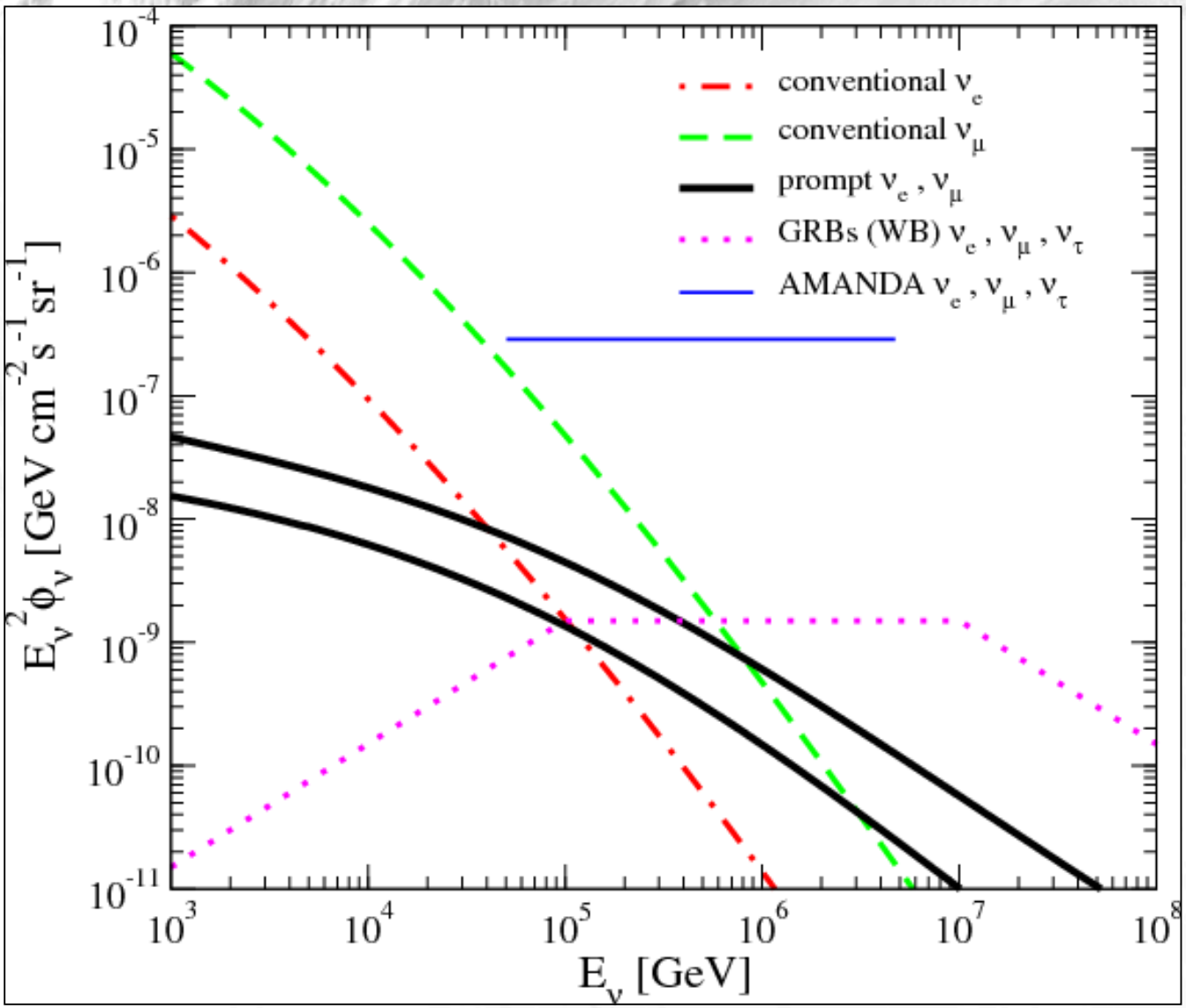
Strong, Moskalenko, and Reimer, ApJ 613 (2004) 962

But newest FERMI data do not show a GeV excess any more



Porter et al., FERMI collaboration, arXiv:0907.0294

The galactic neutrino flux is comparable to the galactic diffuse γ-ray flux



Candia and Beacom, JCAP 0411 (2004) 009

Recent Indirect Signatures of Dark Matter

Gamma-ray flux from galactic centre observed by H.E.S.S.

511 keV annihilation line from near the galactic centre observed by INTGRAL

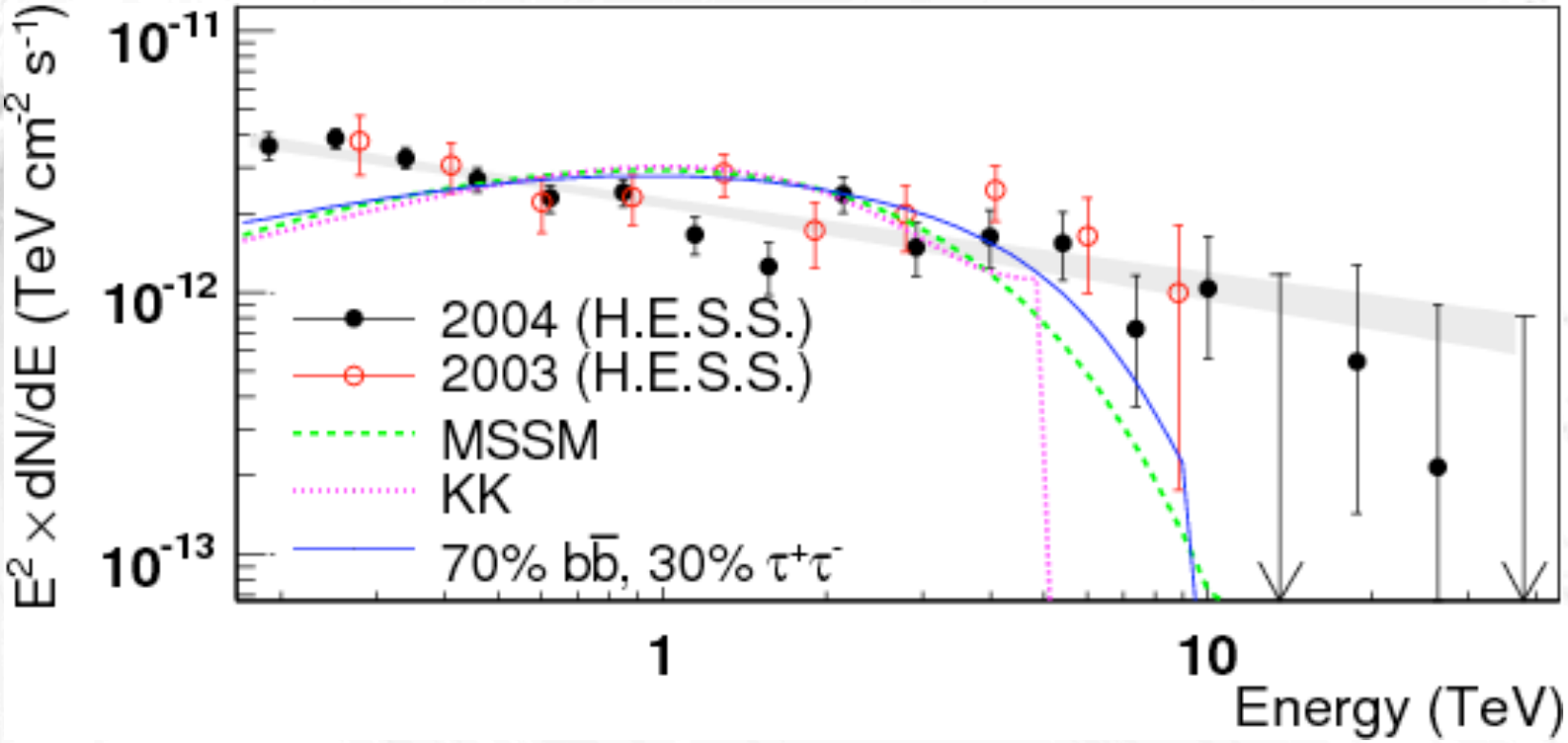
GeV galactic gamma-ray excess observed by EGRET, but not confirmed by Fermi-LAT; still, there may be a "Fermi haze"

The WMAP microwave haze of the inner Galaxy

Galactic positron excess observed by the PAMELA satellite (and earlier experiments)

An excess observed in the combined electron/positron flux observed by ATIC and FERMI/GLAST

Galactic Centre gamma-ray Flux

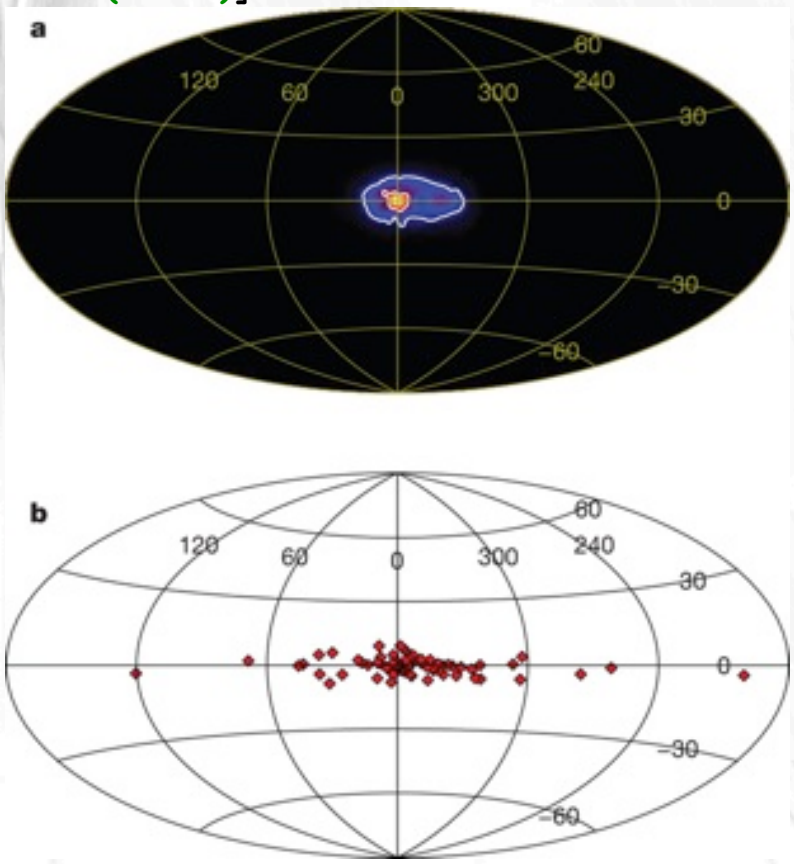


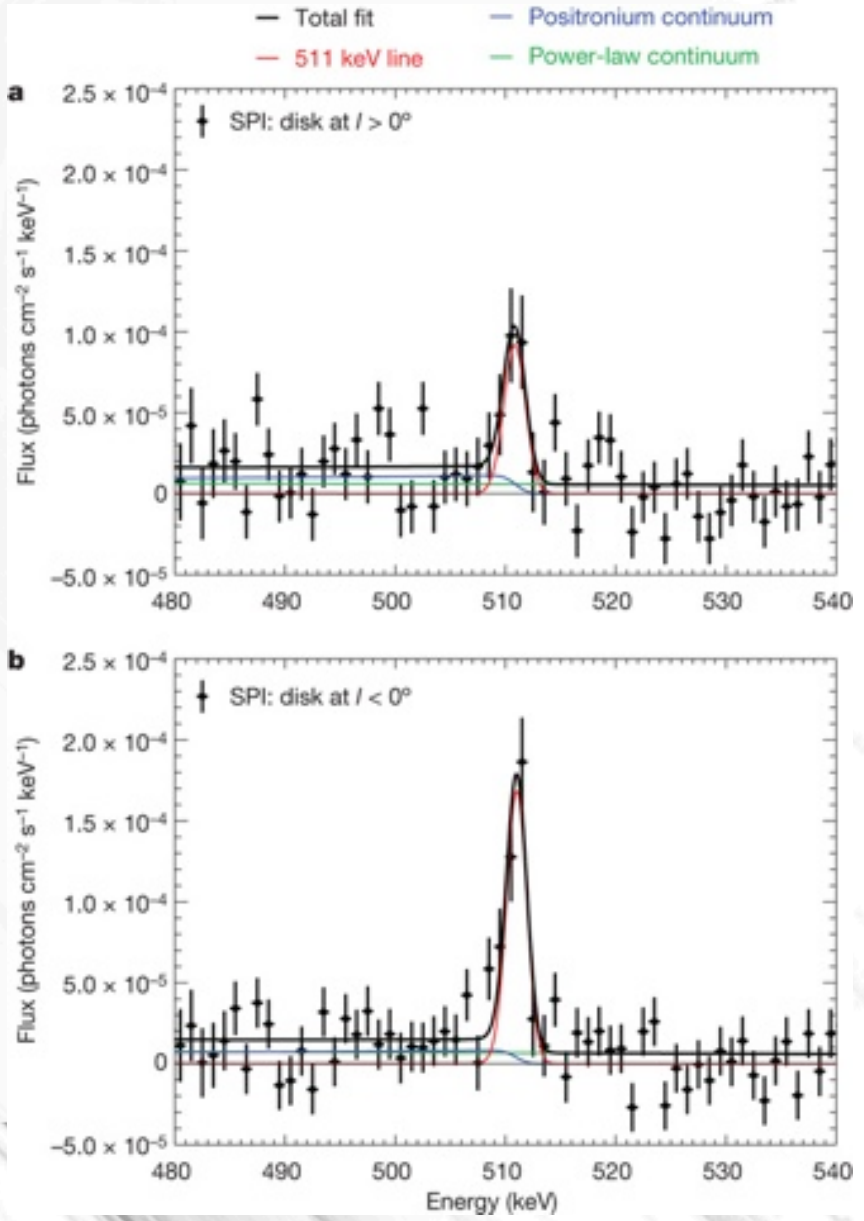
The H.E.S.S. data extends to beyond 30 TeV which is would require unnaturally large dark matter masses; newest data consistent with acceleration with cut-off.

Galactic Centre 511 keV Annihilation Line

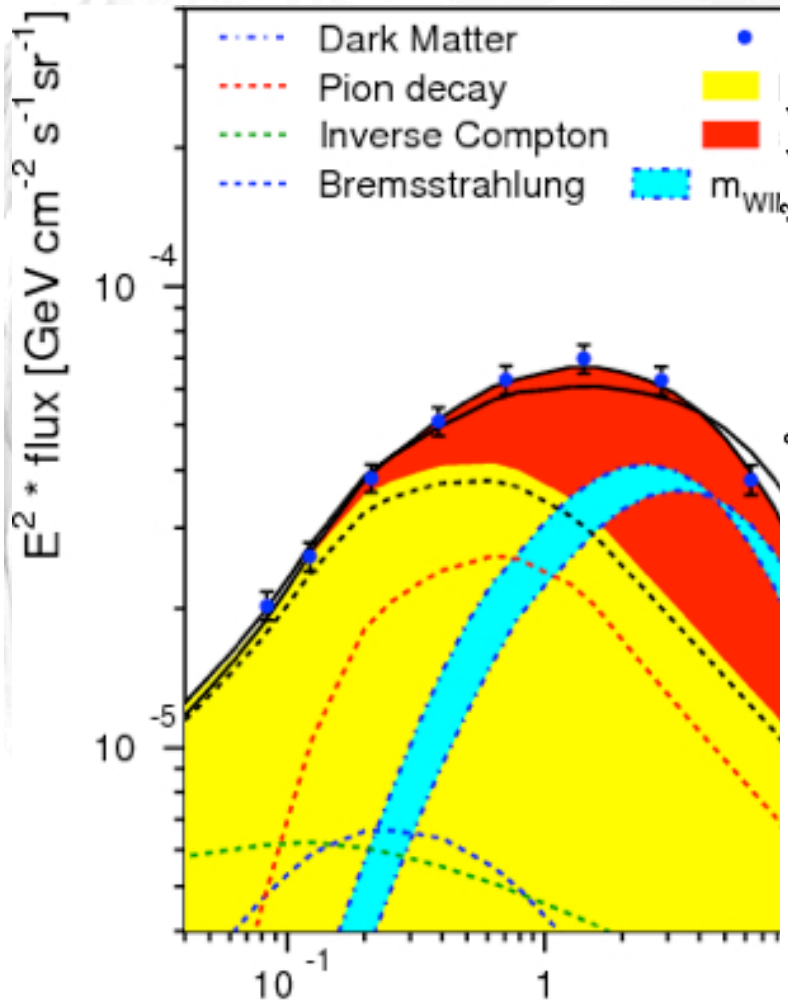
But new INTEGRAL data shows line emission is not spherically symmetric as expected if from a dark matter halo. It seems instead to correlate with the Galactic bulge

[Weidenspointner et al., Nature 451, 159 (2008)]



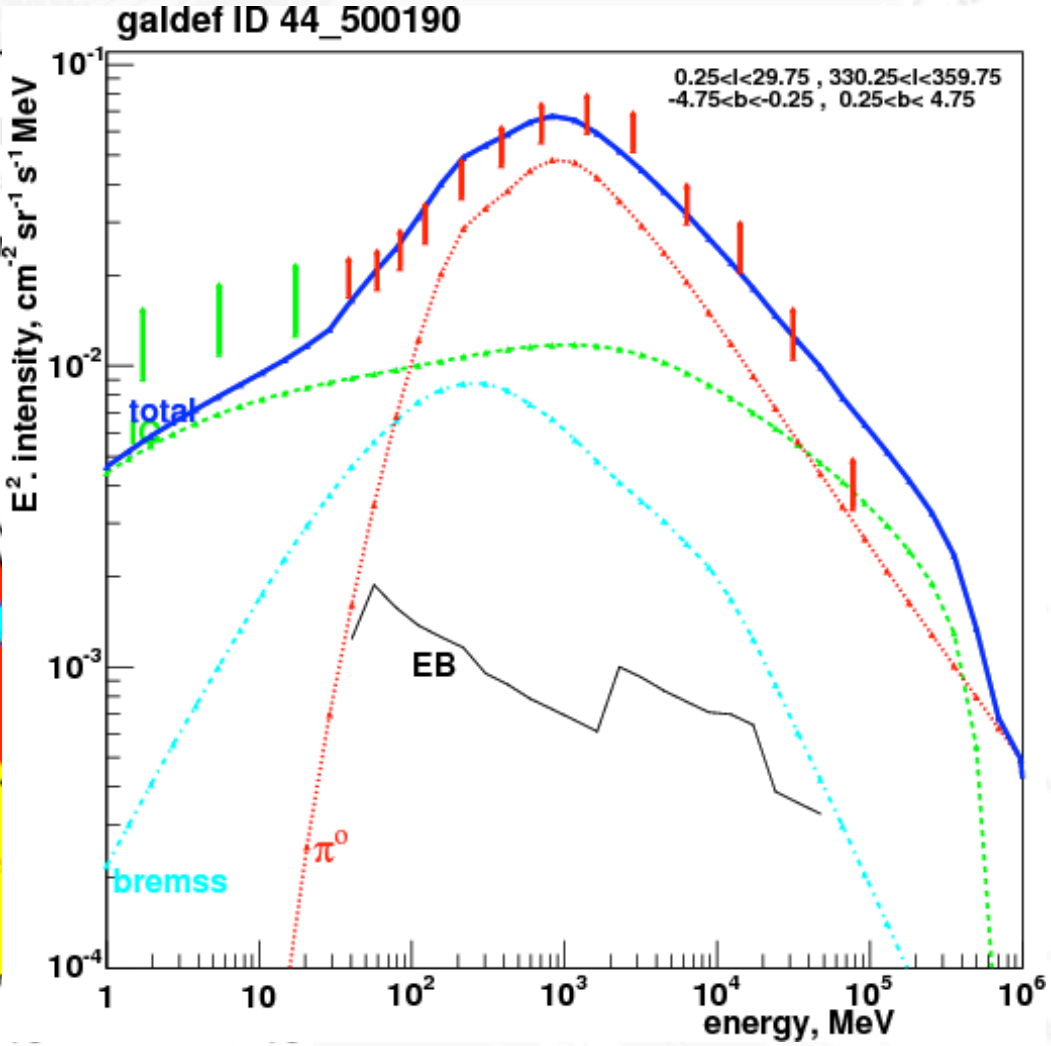


Galactic GeV gamma-ray excess seen by EGRET



Signal ?

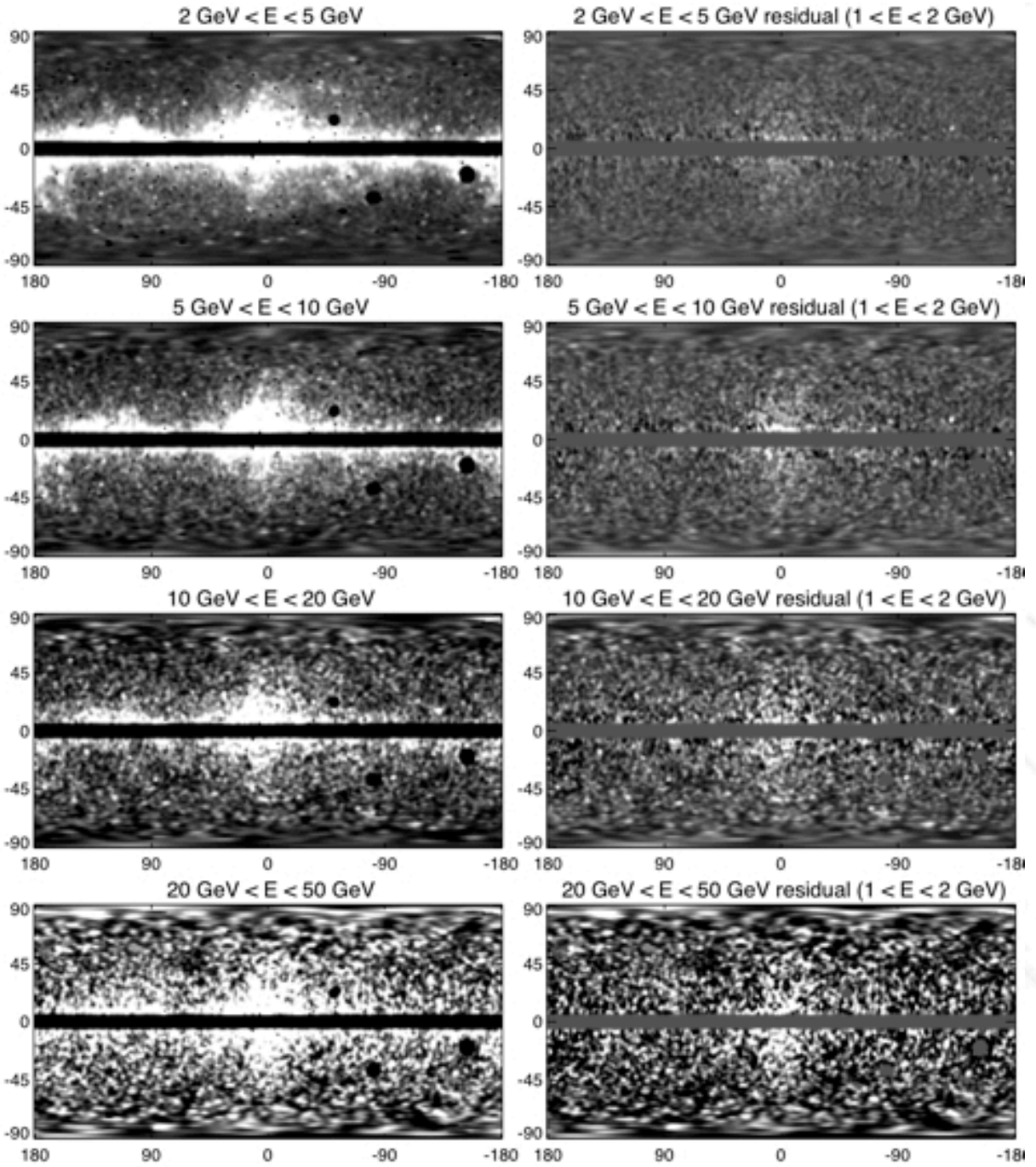
De Boer et al, Astron.Astrophys. 444, 51 (2005)



Or cosmic ray background ?

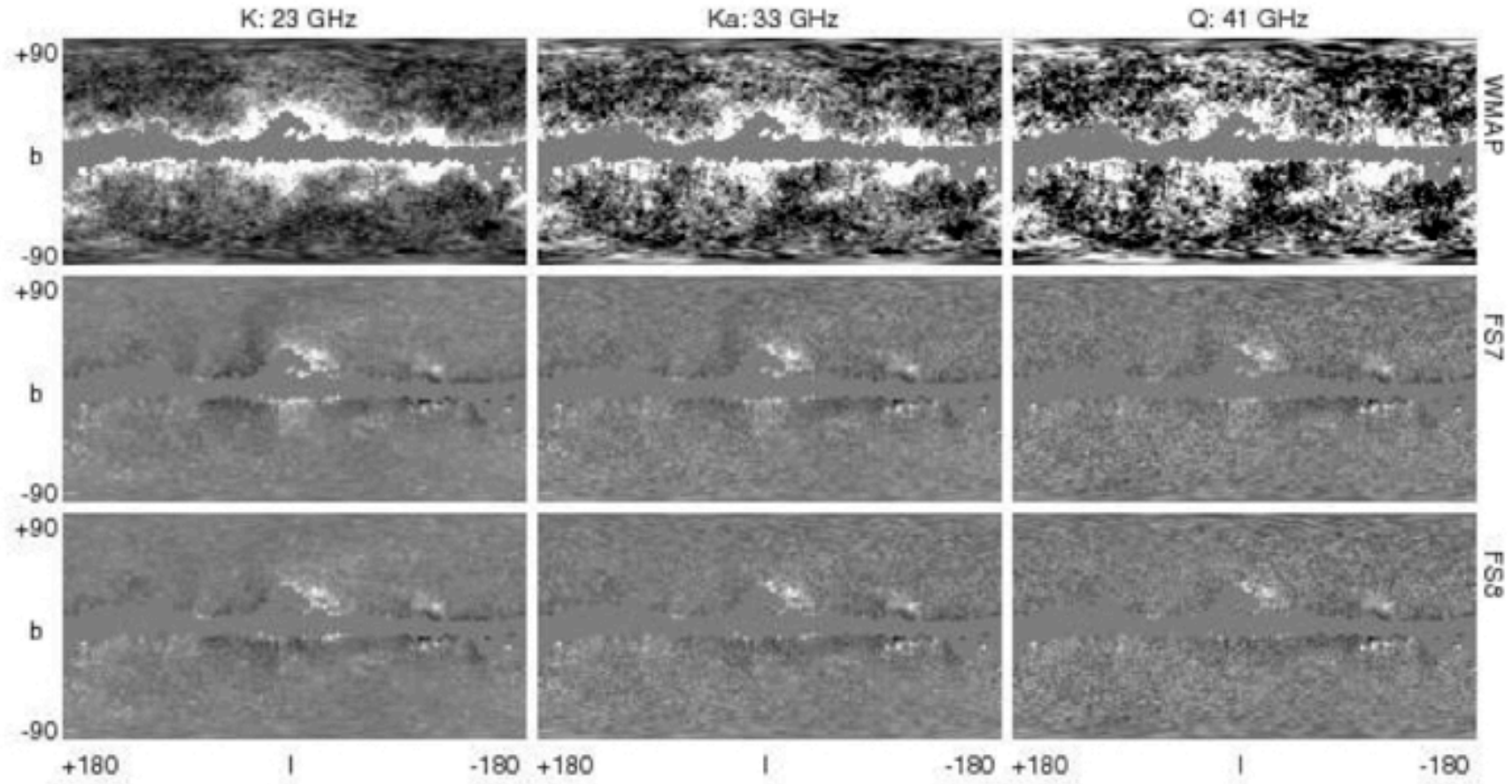
Strong, Moskalenko, and Reimer, ApJ 613 (2004) 962

Fermi haze residual after subtracting template from Fermi sky at 1-2 GeV itself, which should be dominated by π^0 channel



Dobler et al, arXiv:0910.4583

WMAP haze



Dobler and Finkbeiner, ApJ 680 (2008) 1222

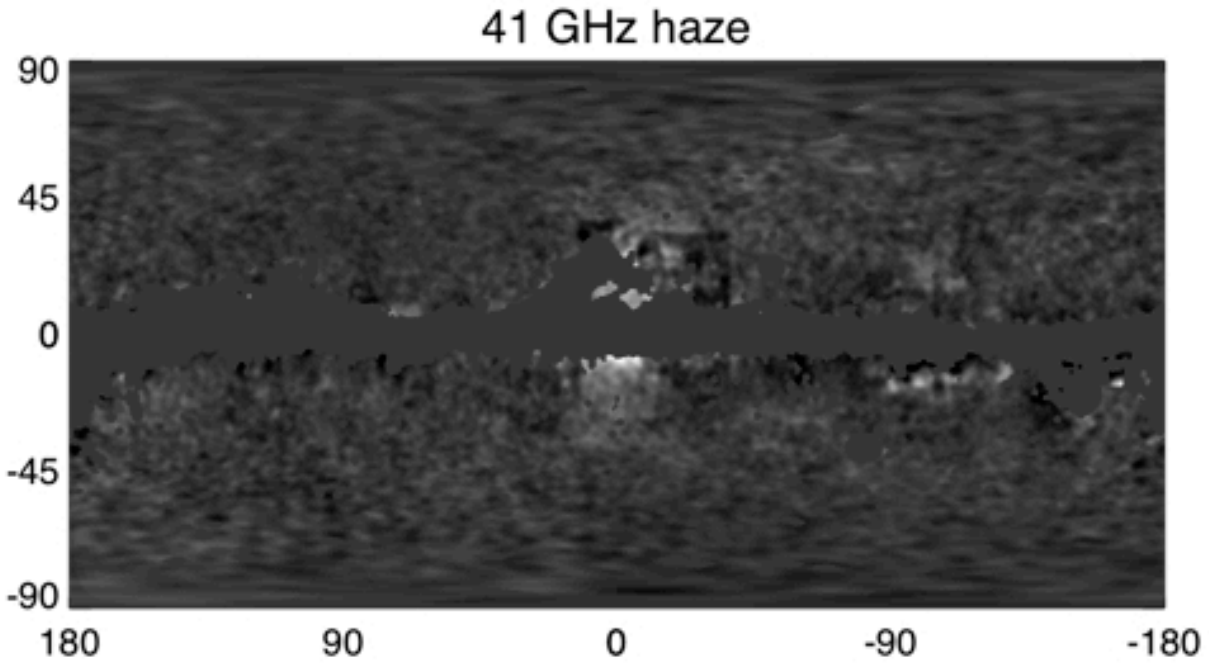
WMAP haze is the residual after subtracting a template obtained from extrapolating the Haslam 408 MHz map.

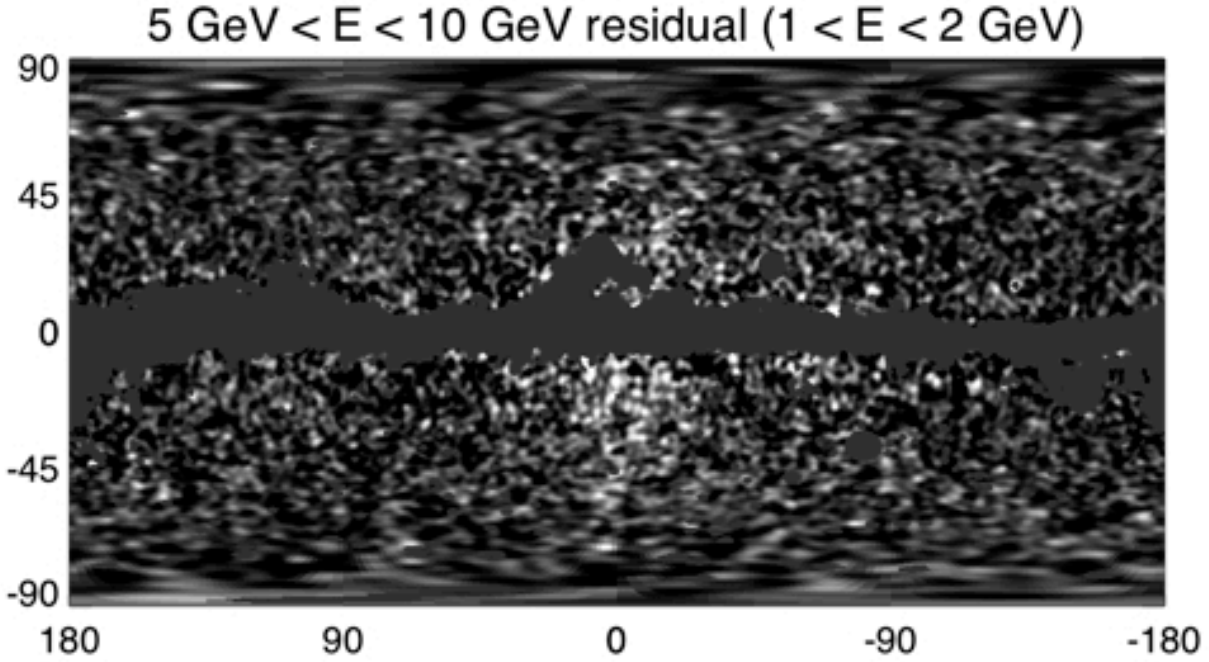
But distribution of primary electrons may be different for these energies, e.g. Mertsch and Sarkar arXiv:1004.3056

Morphology of Fermi haze and WMAP haze seem to correlate

An electron component harder than acceleration spectra could explain both due to synchrotron and inverse Compton, respectively

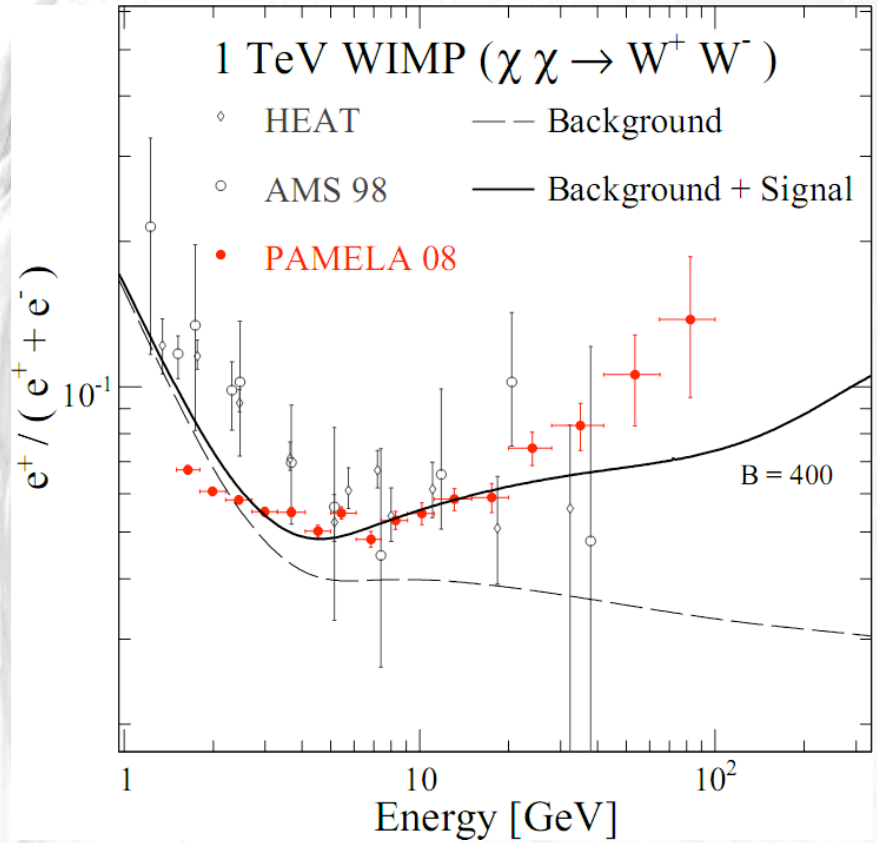
But excesses are of order the astrophysical background uncertainties

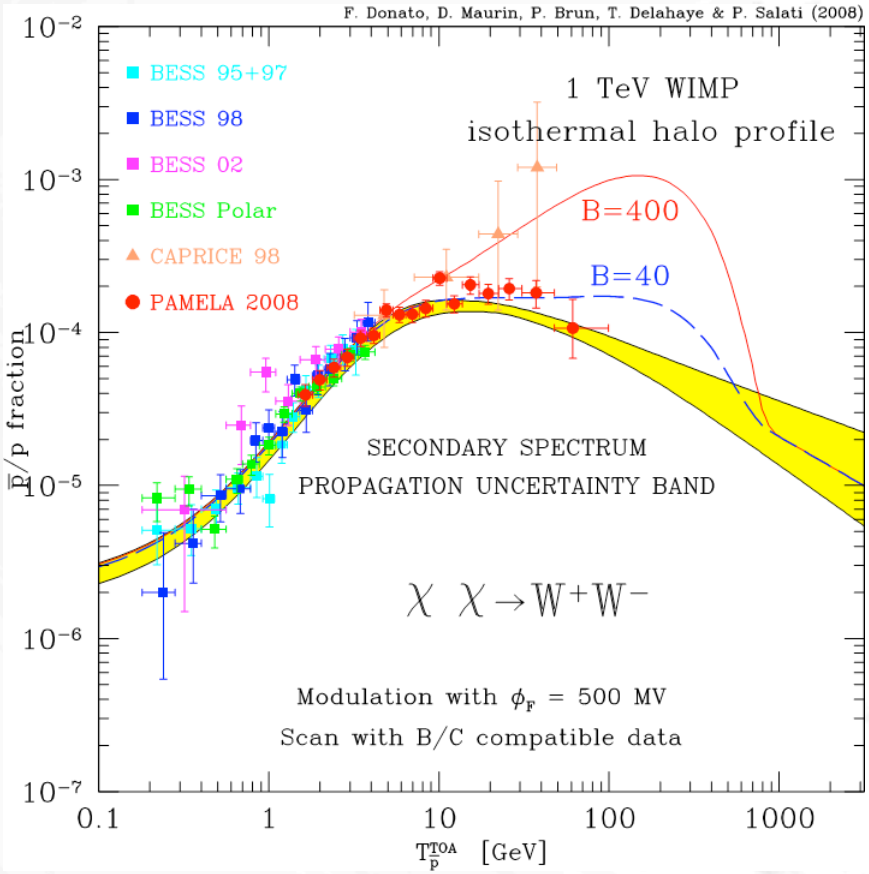




Dobler et al, arXiv:0910.4583

Galactic Positron Fraction Excess



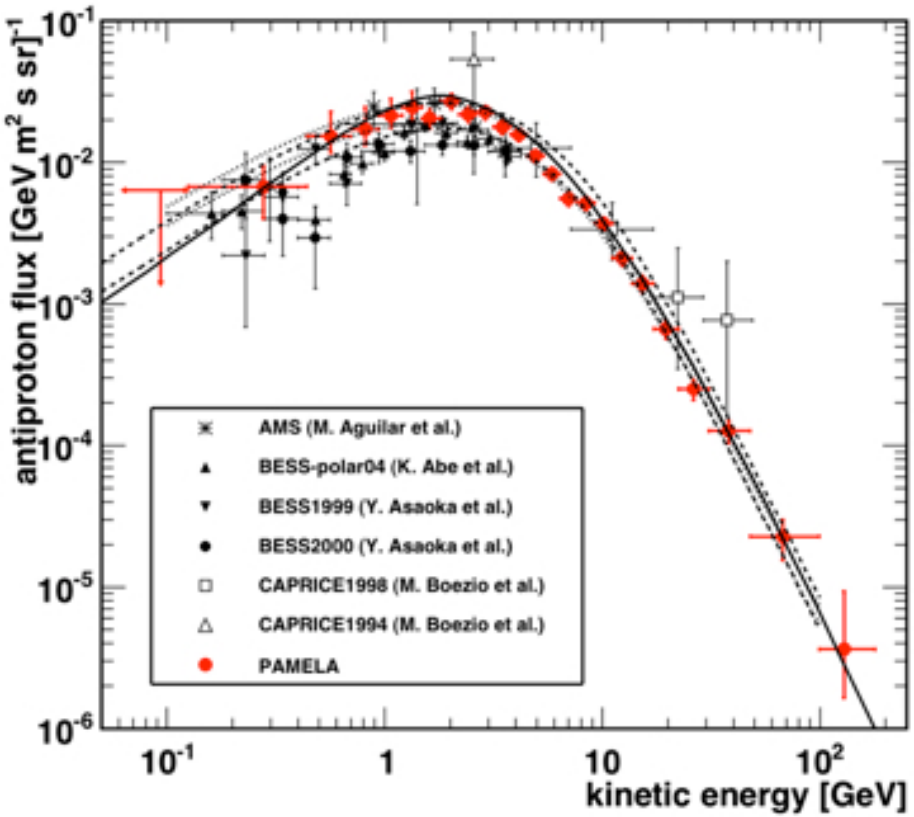


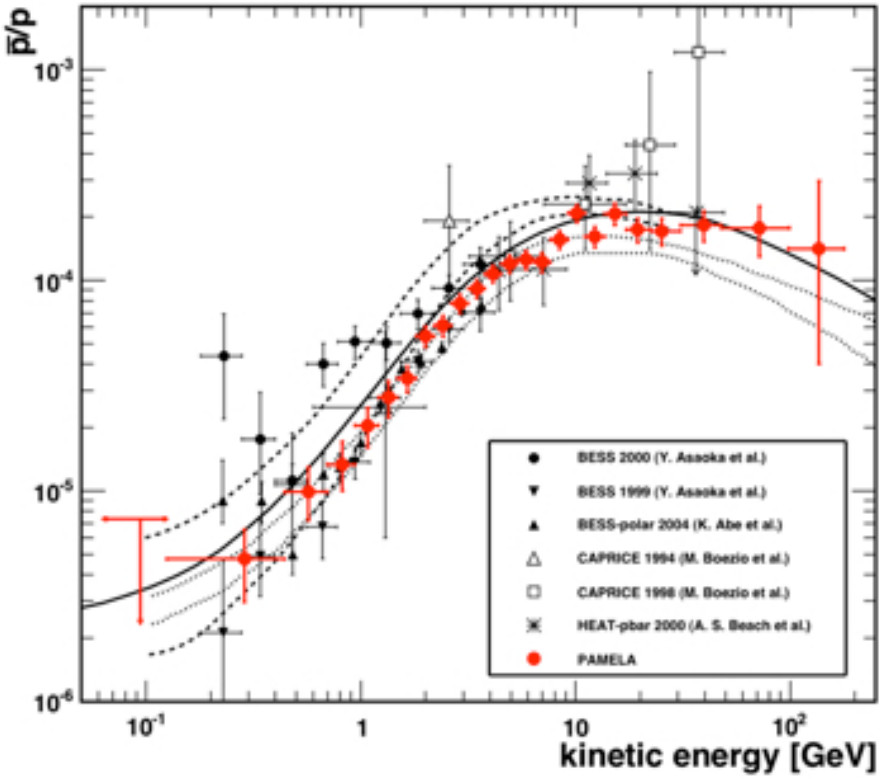
Positron fraction: Excess beyond expected secondary production from homogeneous cosmic ray source distribution

Antiproton fraction: No significant enhancement beyond expected secondary production by cosmic rays

Donato et al., Phys.Rev.Lett.102, 071301 (2009)

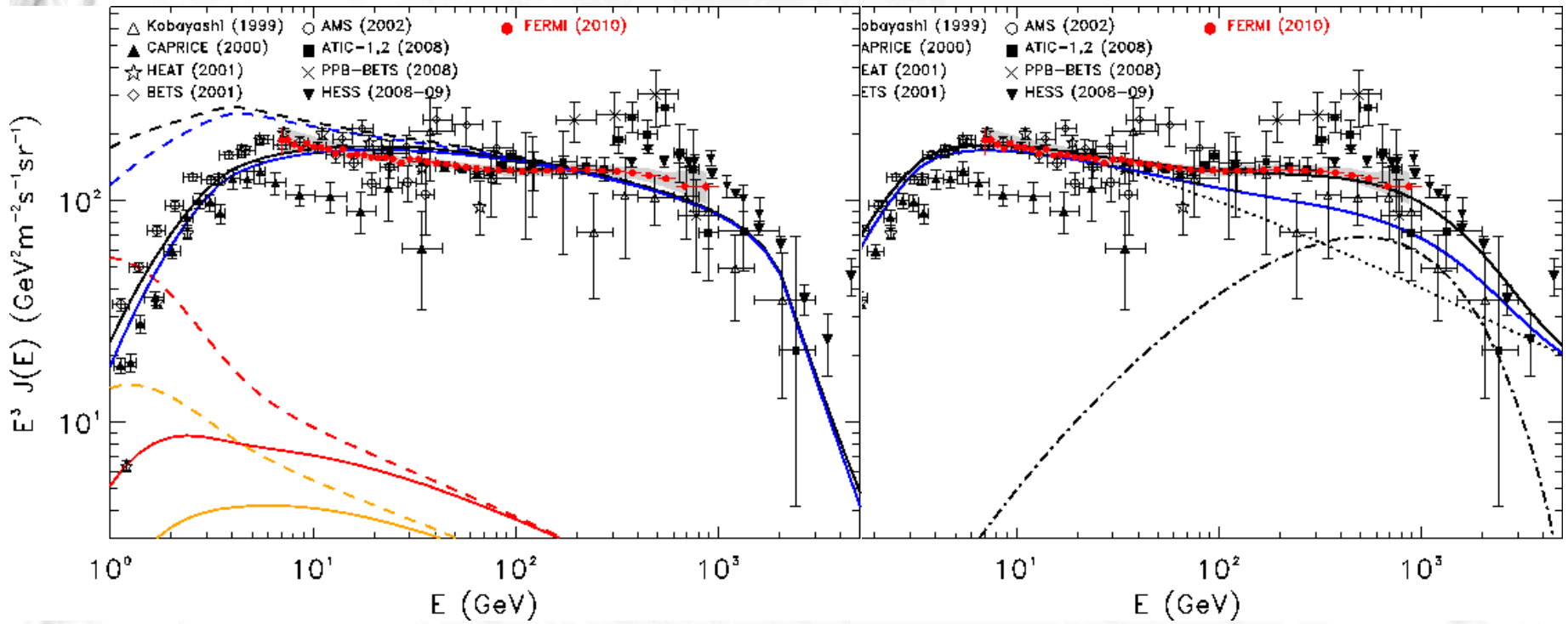
But no significant enhancement of anti-proton fraction observed:





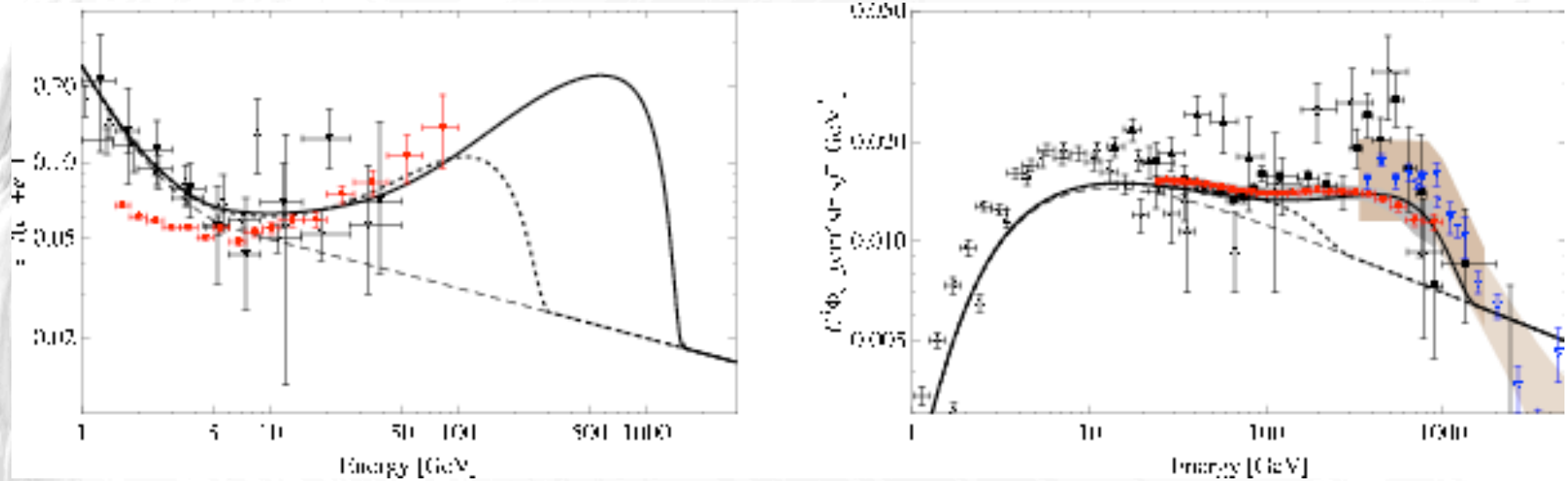
Pamela collaboration, Adriani et al., arXiv:1007.0821

Galactic Electron+Positron Flux requires at least two components



Fermi LAT collaboration, arXiv:1008.3999

Galactic Electron+Positron Excess

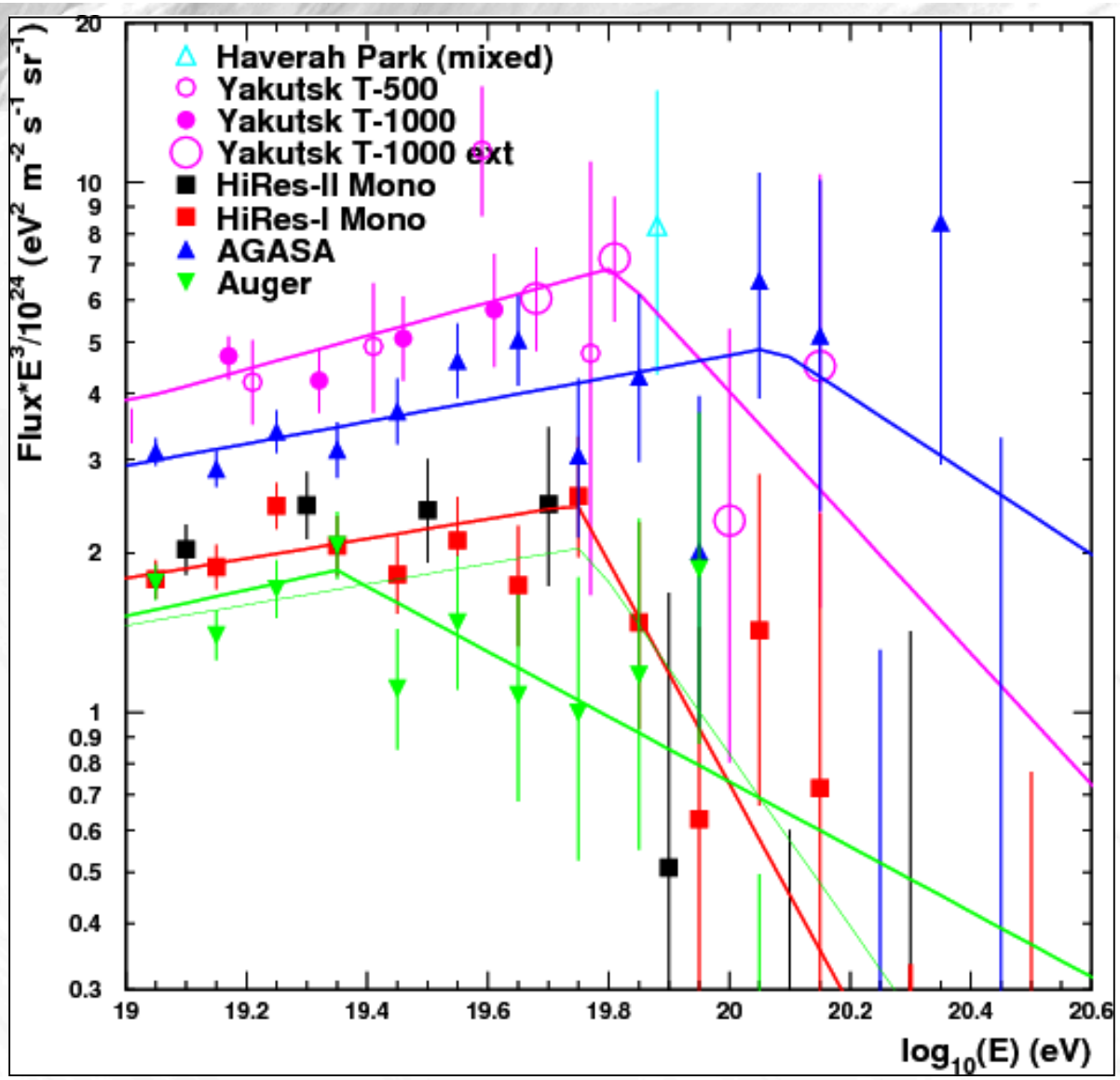


Ibarra, Tran, Weniger, arXiv:0906.1571

Decaying dark matter fits to positron fraction and electron-positron flux:
Decay into W^{+-} μ^{-+} with mass 600 GeV (dotted line) and 3000 GeV (solid line)

Ultra-High Energy Cosmic Rays

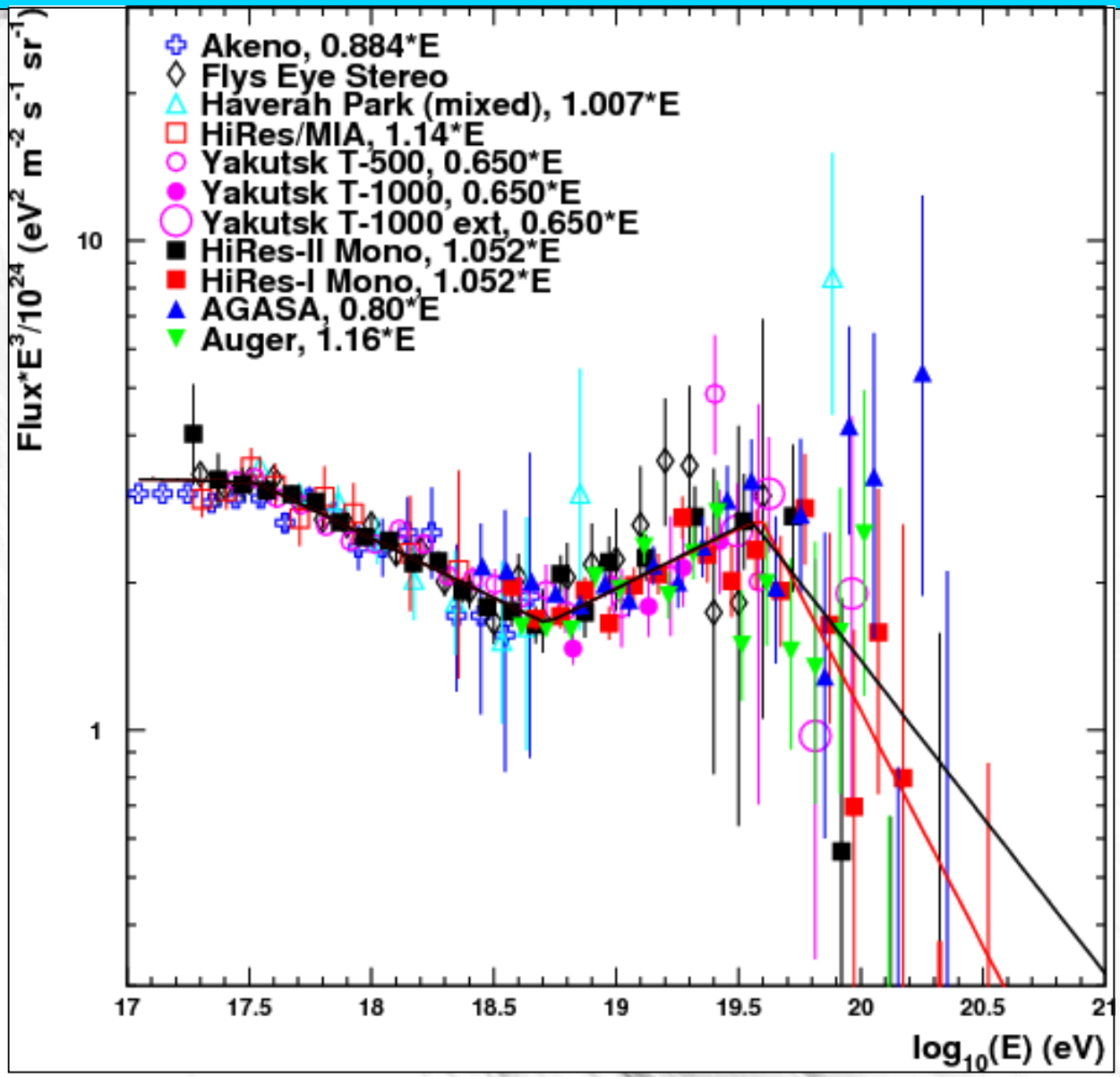
Lowering AGASA energy scale by about 20% brings it in accordance with HiRes up to the GZK cut-off, but maybe not beyond ?



Bergmann, Belz, J.Phys.G34 (2007) R359

May need an experiment combining ground array with fluorescence such as the Auger project to resolve this issue.

Comparison of Experimental Spectra at the Highest Energies

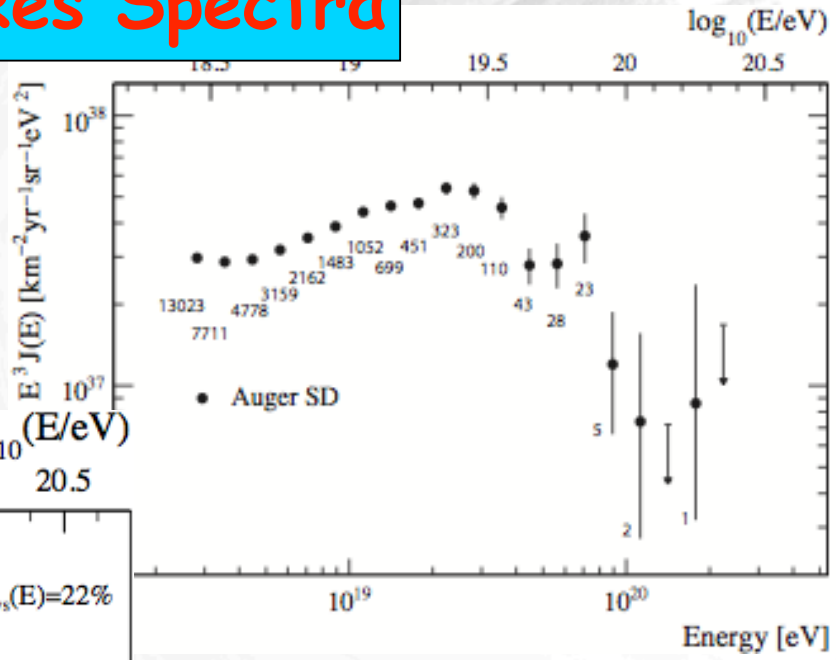


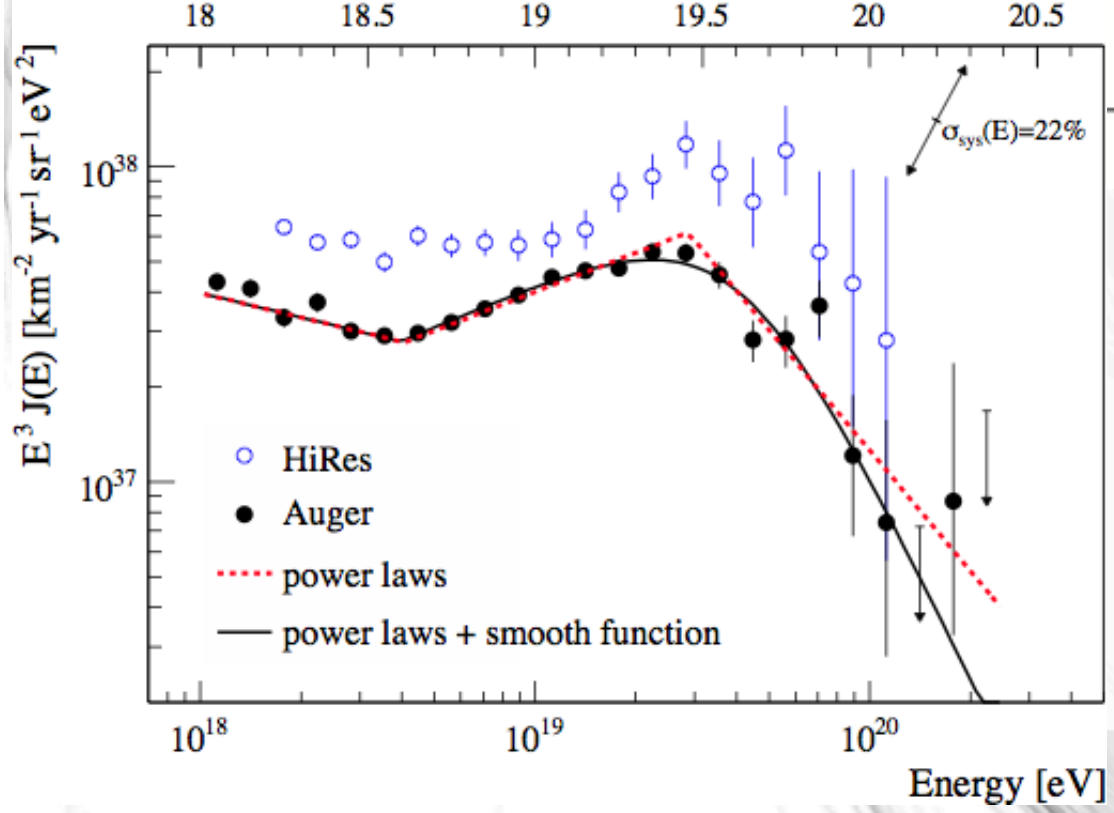
Bergmann, Belz, J.Phys.G34 (2007) R359

Auger and HiRes Spectra

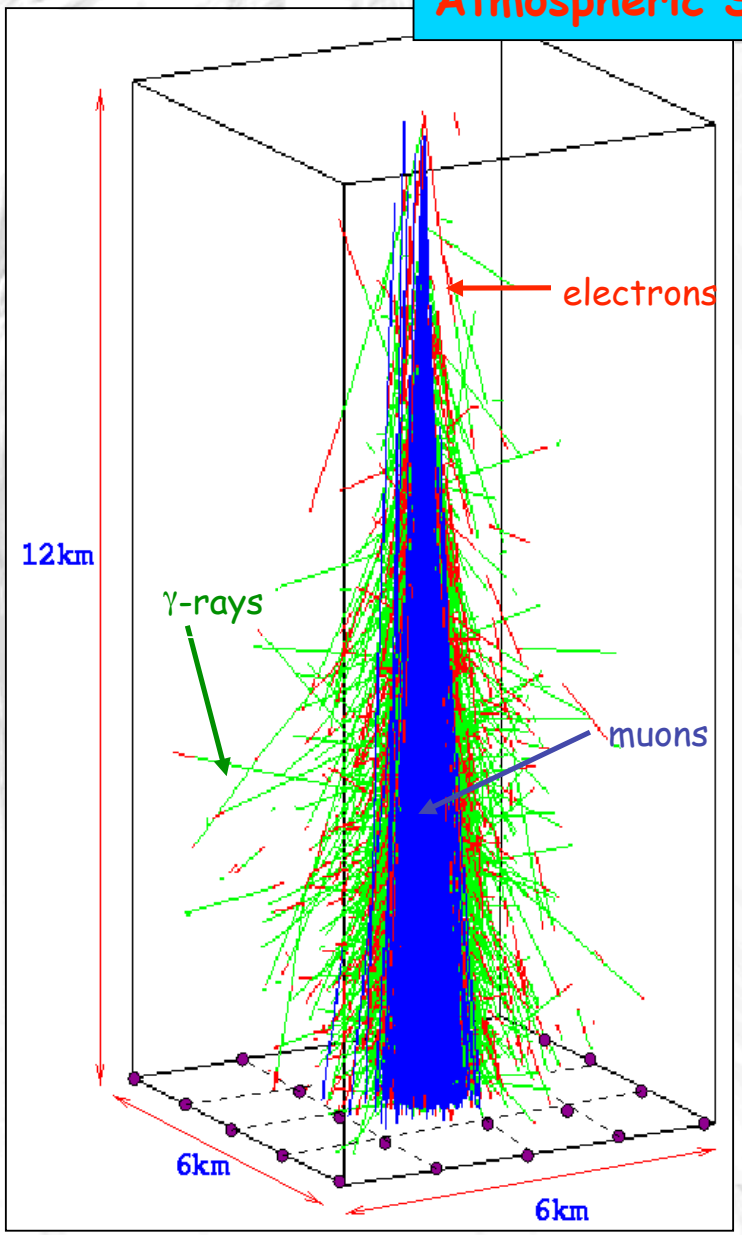
Auger exposure = 12,790 km^2 sr yr
up to December 2008

Pierre Auger Collaboration, PRL 101, 061101 (2008)
and Phys.Lett.B 685 (2010) 239





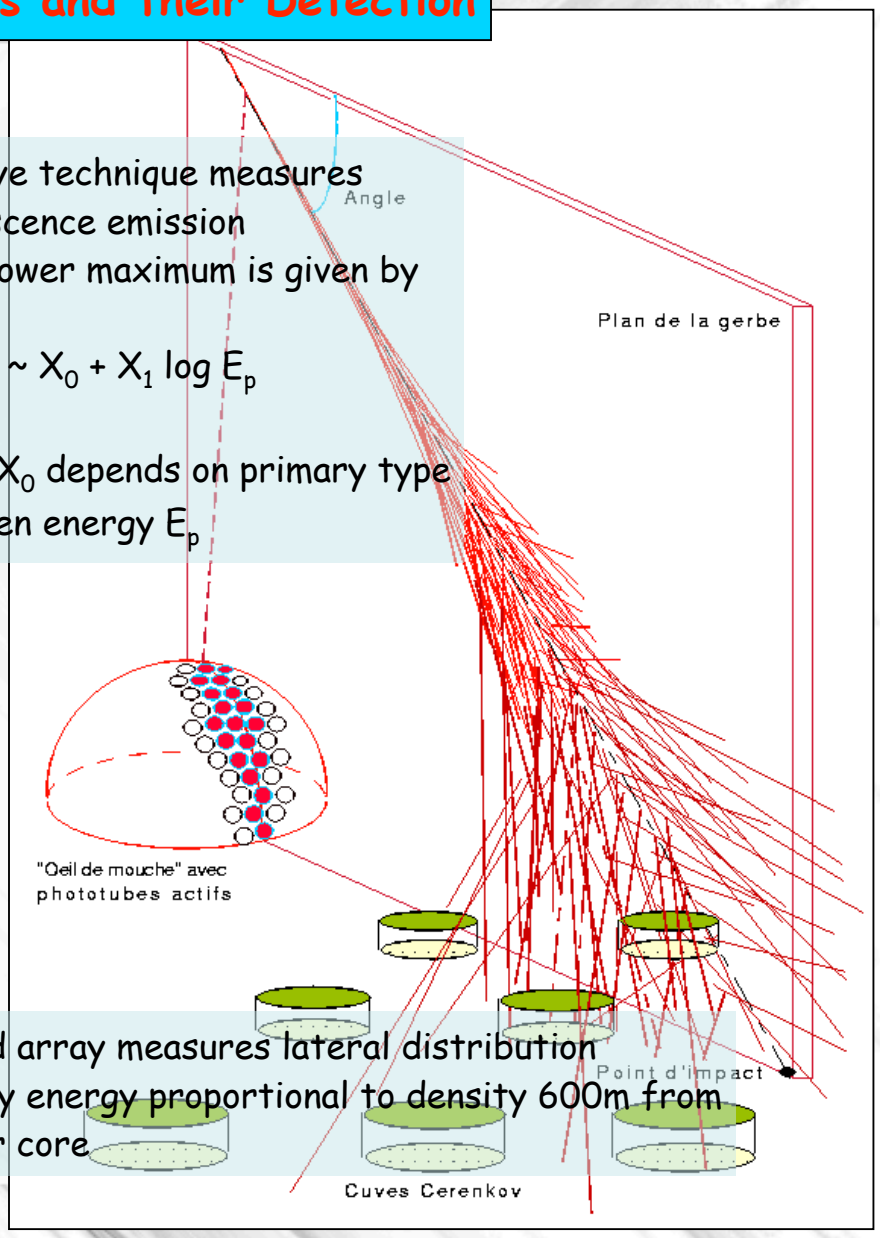
Atmospheric Showers and their Detection



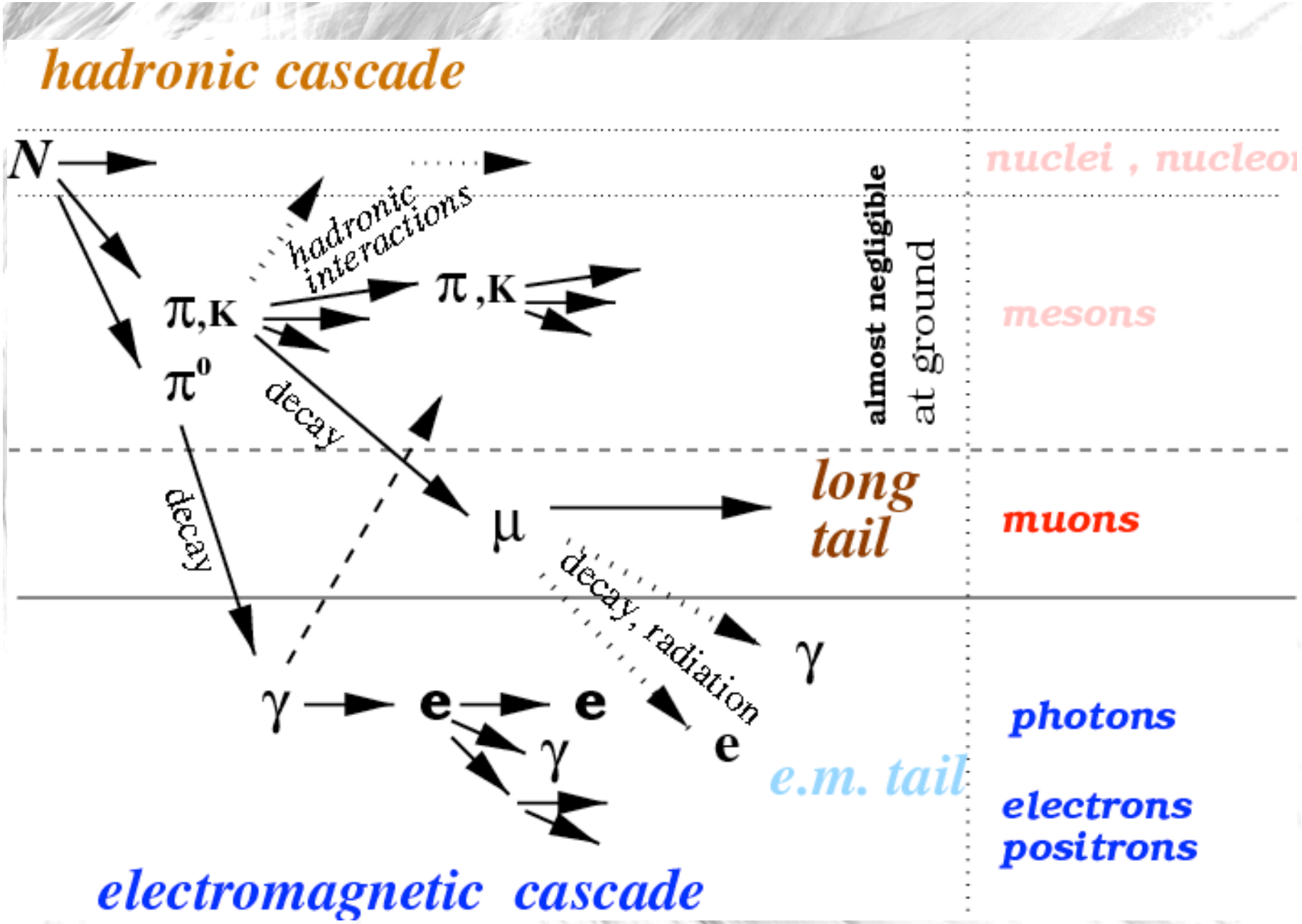
Fly's Eye technique measures fluorescence emission
The shower maximum is given by

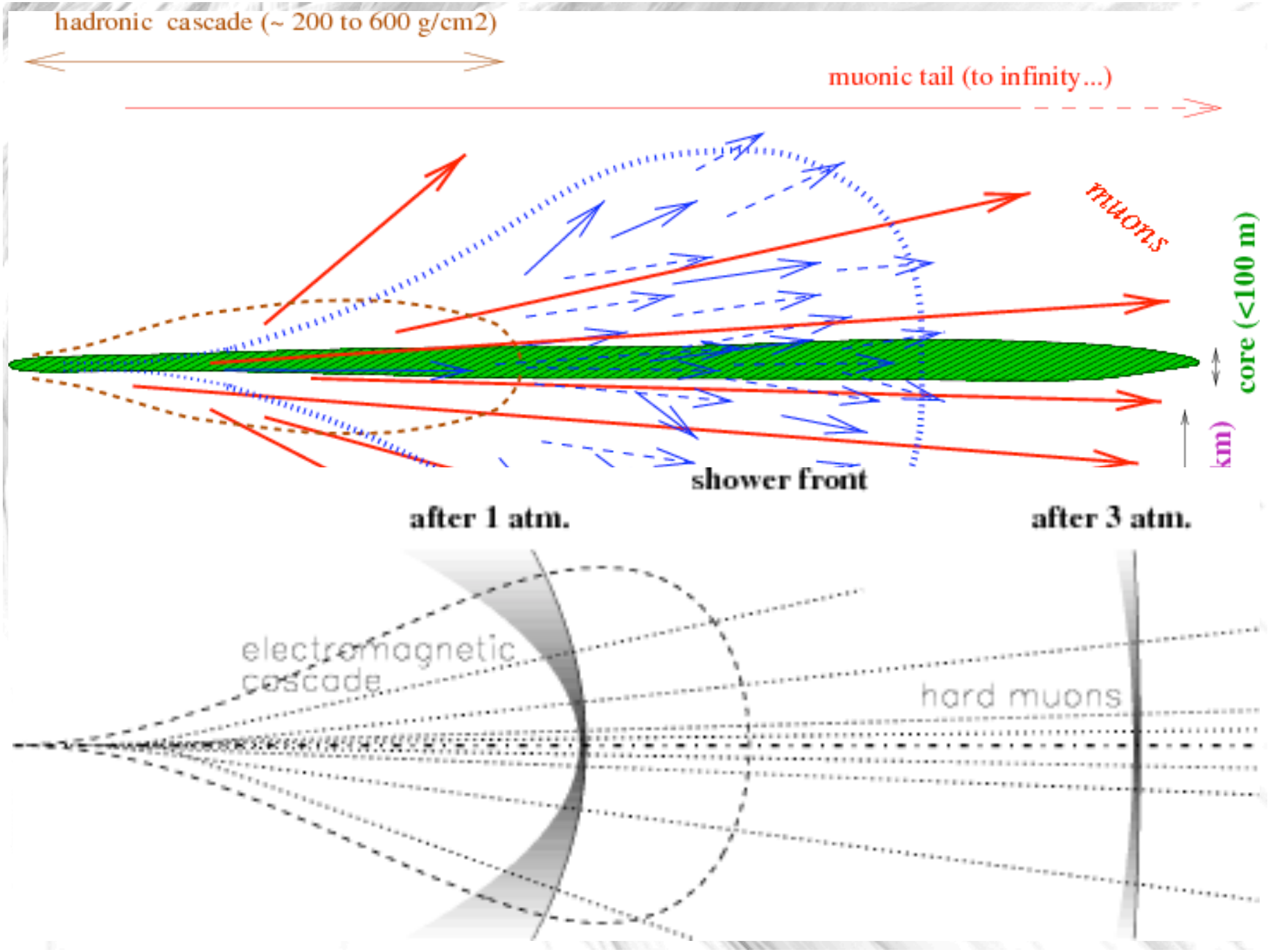
$$X_{max} \sim X_0 + X_1 \log E_p$$

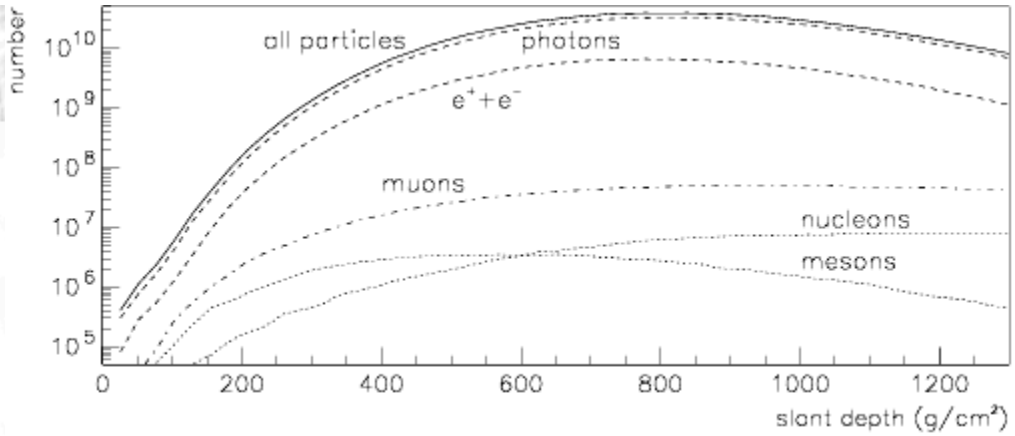
where X_0 depends on primary type for given energy E_p

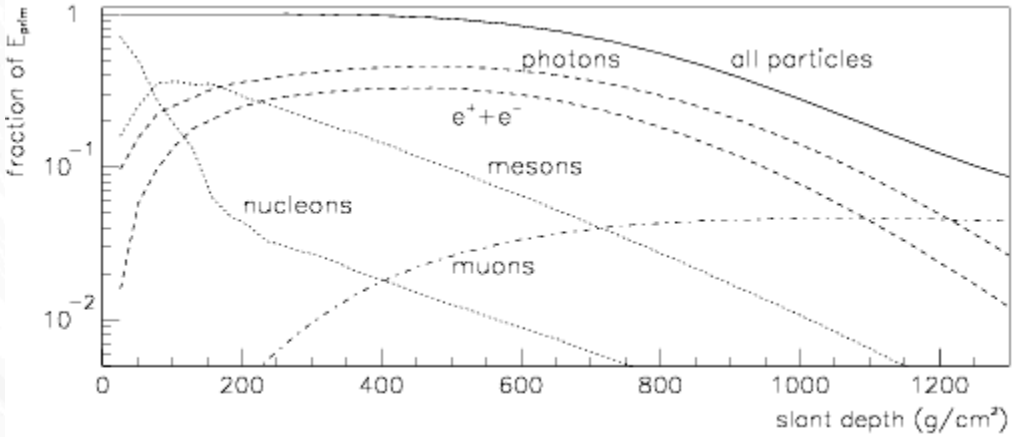


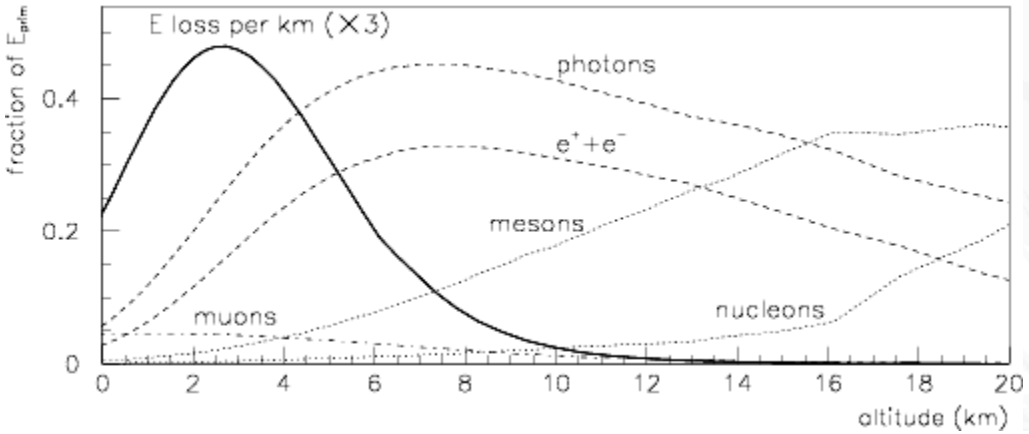
Ground array measures lateral distribution
Primary energy proportional to density 600m from shower core


hadronic cascade
N
hadronic interactions
π,K
π,K
π0
decay
decay
almost negligible
at ground
nuclei , nucleon
mesons
long tail
μ
muons
decay, radiation
γ
γ
e
e
γ
e
e.m. tail
photons
electrons
positrons
electromagnetic cascade

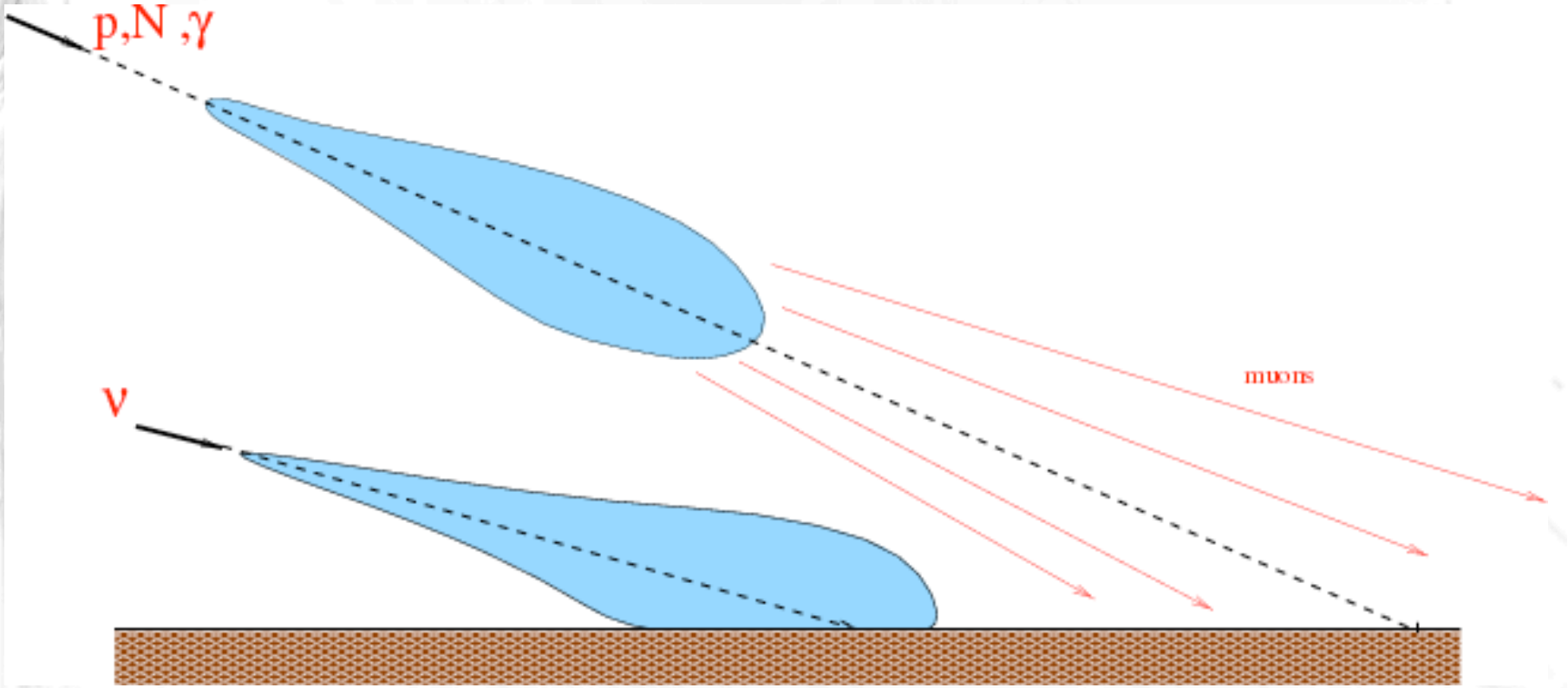

hadronic cascade (~ 200 to 600 g/cm2)
muonic tail (to infinity...)
muons
core (<100 m)
km)
shower front
after 1 atm.
after 3 atm.
electromagnetic cascade
hard muons

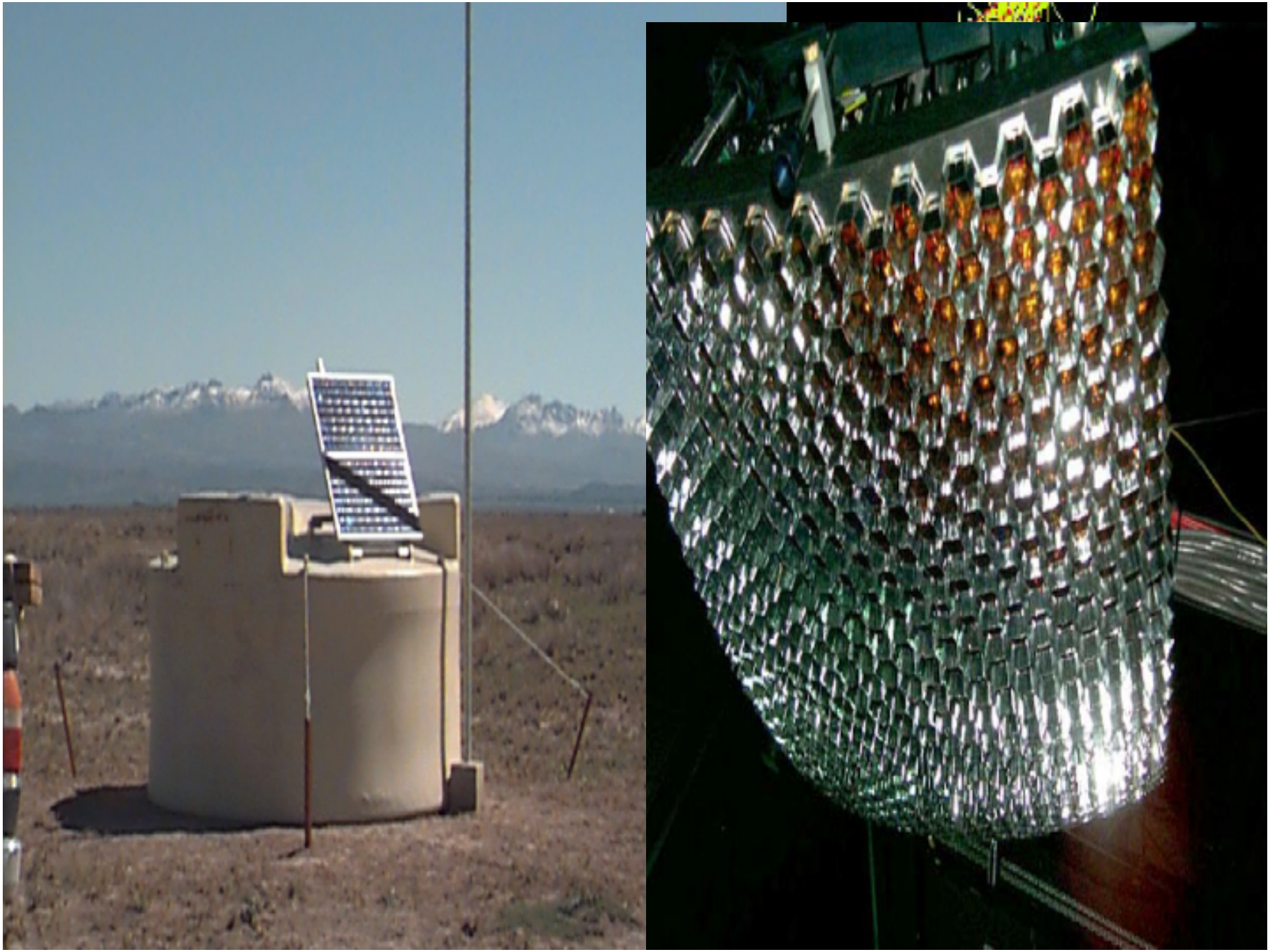

number
all particles
photons
$e^+ + e^-$
muons
nucleons
mesons
slant depth (g/cm²)


fraction of E_{prim}
photons
all particles
$e^+ + e^-$
mesons
nucleons
muons
slant depth (g/cm²)

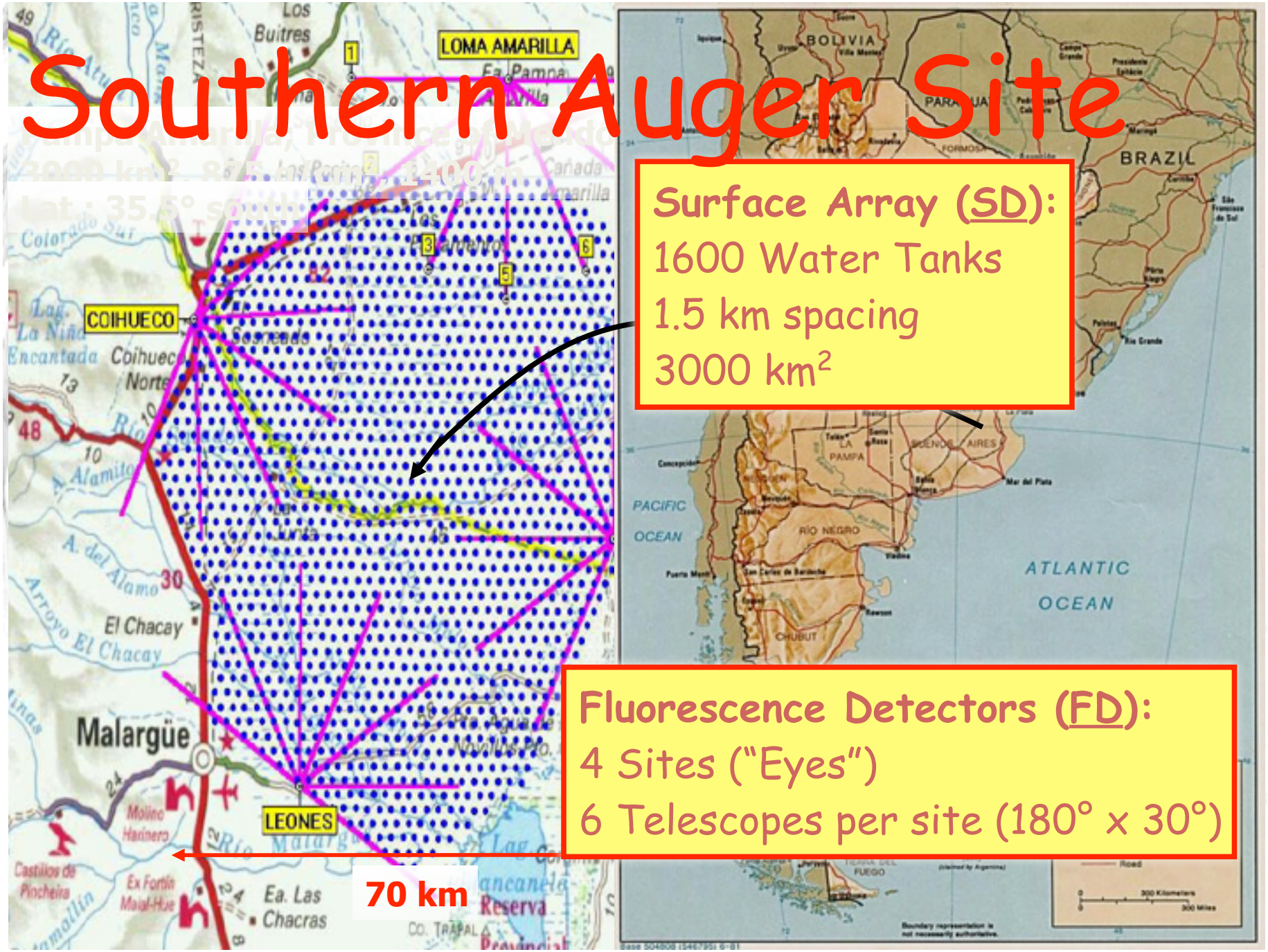

fraction of E_{prim}
E loss per km (X3)
photons
$e^+ + e^-$
mesons
muons
nucleons
altitude (km)

Cosmic ray versus neutrino induced air showers





Southern Auger Site



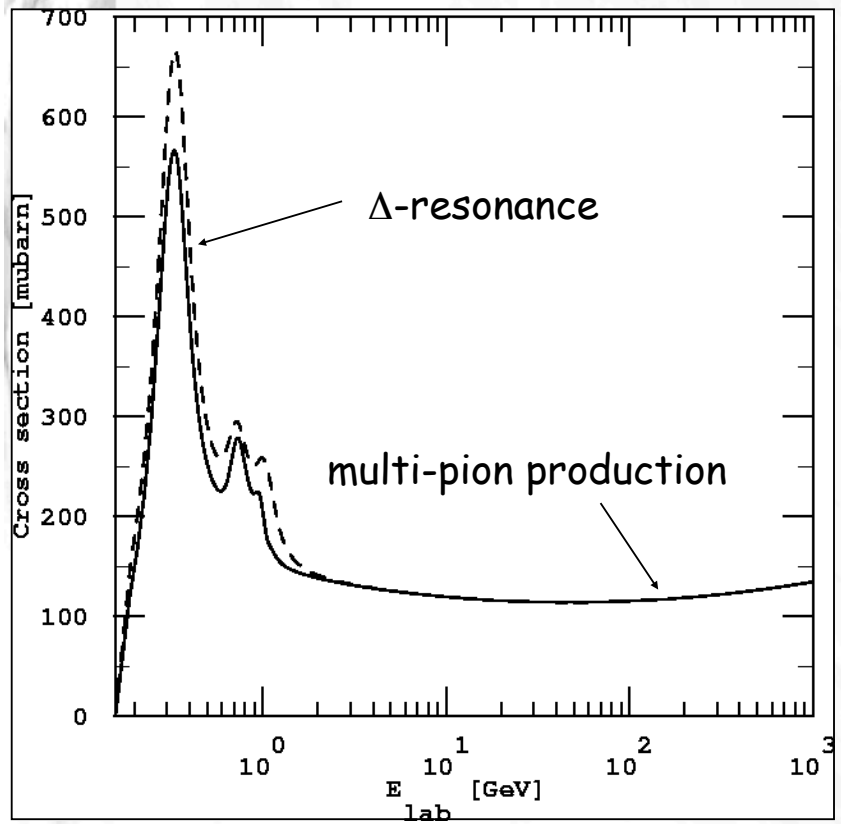
Surface Array (SD):
1600 Water Tanks
1.5 km spacing
3000 km^2

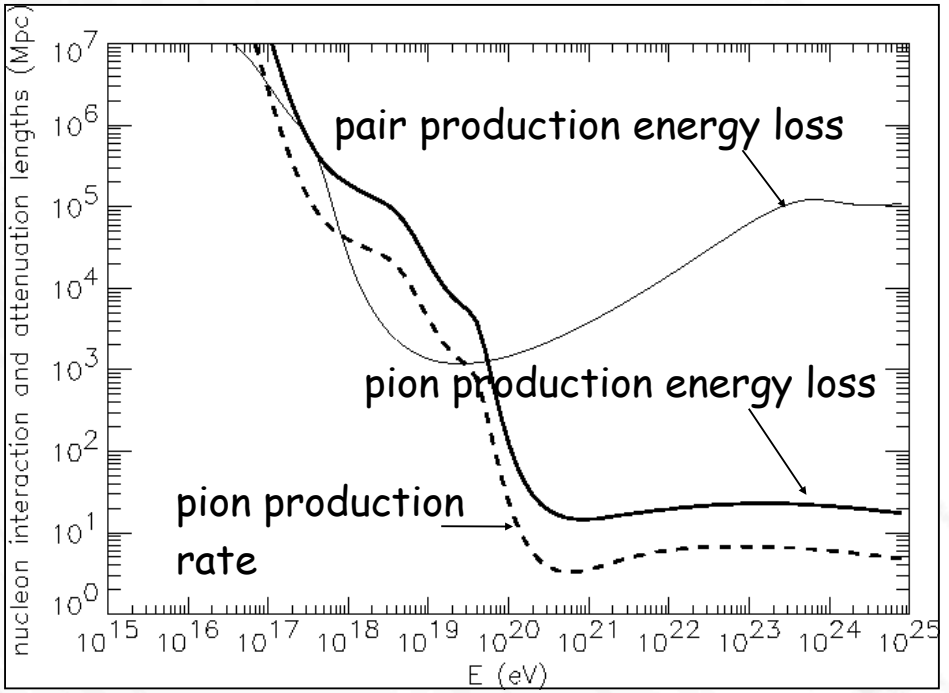
Fluorescence Detectors (FD):
4 Sites ("Eyes")
6 Telescopes per site (180° x 30°)

The Greisen-Zatsepin-Kuzmin (GZK) effect

Nucleons can produce pions on the cosmic microwave background

$$E_{\rm th} = \frac{2m_N m_\pi + m_\pi^2}{4\varepsilon} \simeq 4 \times 10^{19}\,{\rm eV}$$





sources must be in cosmological backyard
Only Lorentz symmetry breaking at $\Gamma > 10^{11}$ could avoid this conclusion.

The Ultra-High Energy Cosmic Ray Mystery consists of (at least) Three Interrelated Challenges

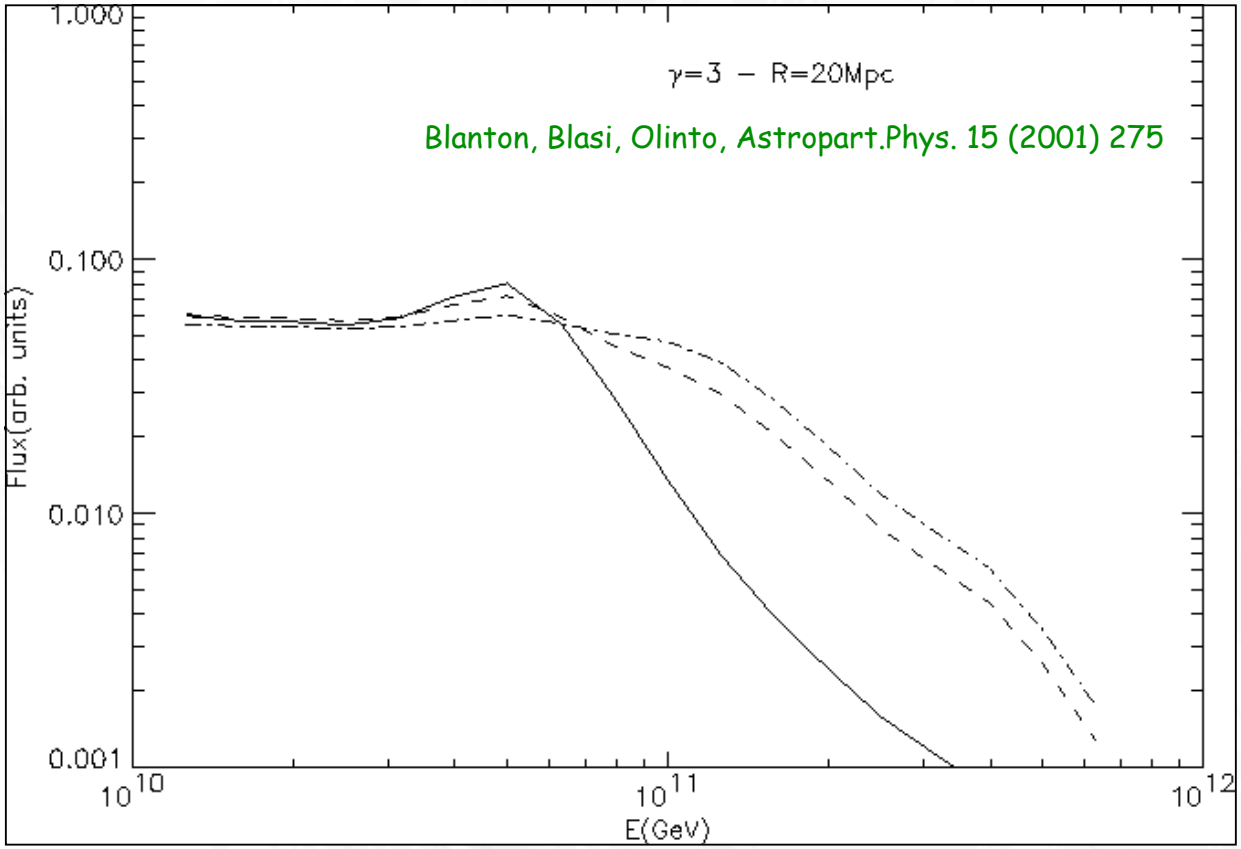
1.) electromagnetically or strongly interacting particles above 10^{20} eV loose energy within less than about 50 Mpc.

2.) in most conventional scenarios exceptionally powerful acceleration sources within that distance are needed.

3.) The observed distribution does not yet reveal unambiguously the sources, although there is some correlation with local large scale structure

GZK "cut-off" is a misnomer because "conventional" astrophysics can create events above the "cut-off"

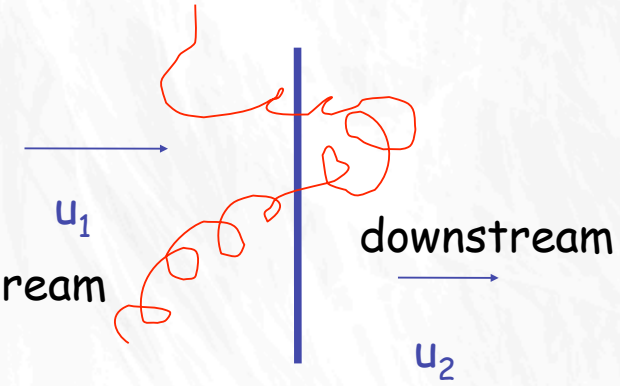
The GZK effect may tell us about the source distribution (in the absence of strong magnetic deflection)



Observable spectrum for an E^{-3} injection spectrum for a distribution of sources with overdensities of 1, 10, 30 (bottom to top) within 20 Mpc, and otherwise homogeneous.

1st Order Fermi Shock Acceleration

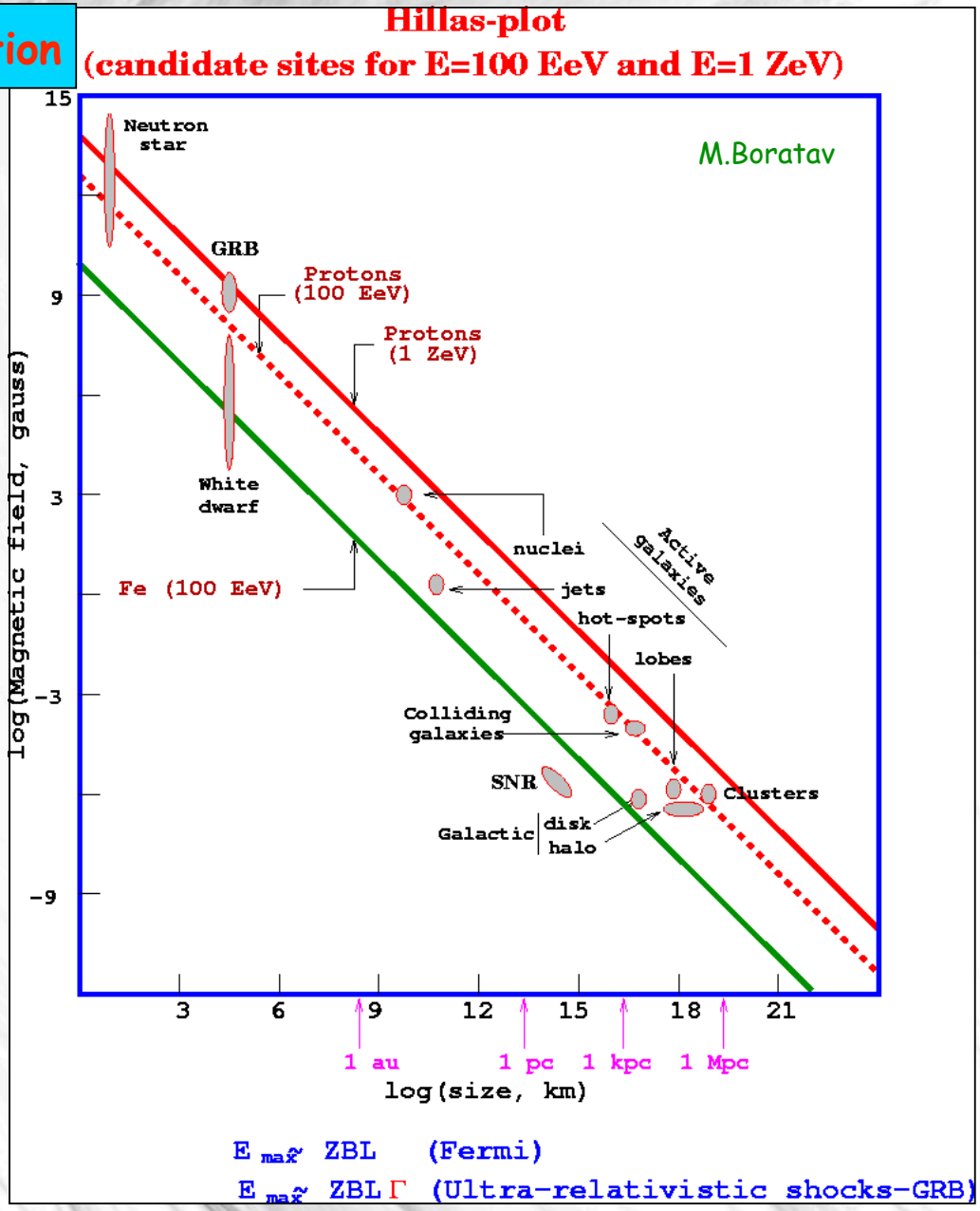
The most widely accepted scenario of cosmic ray acceleration



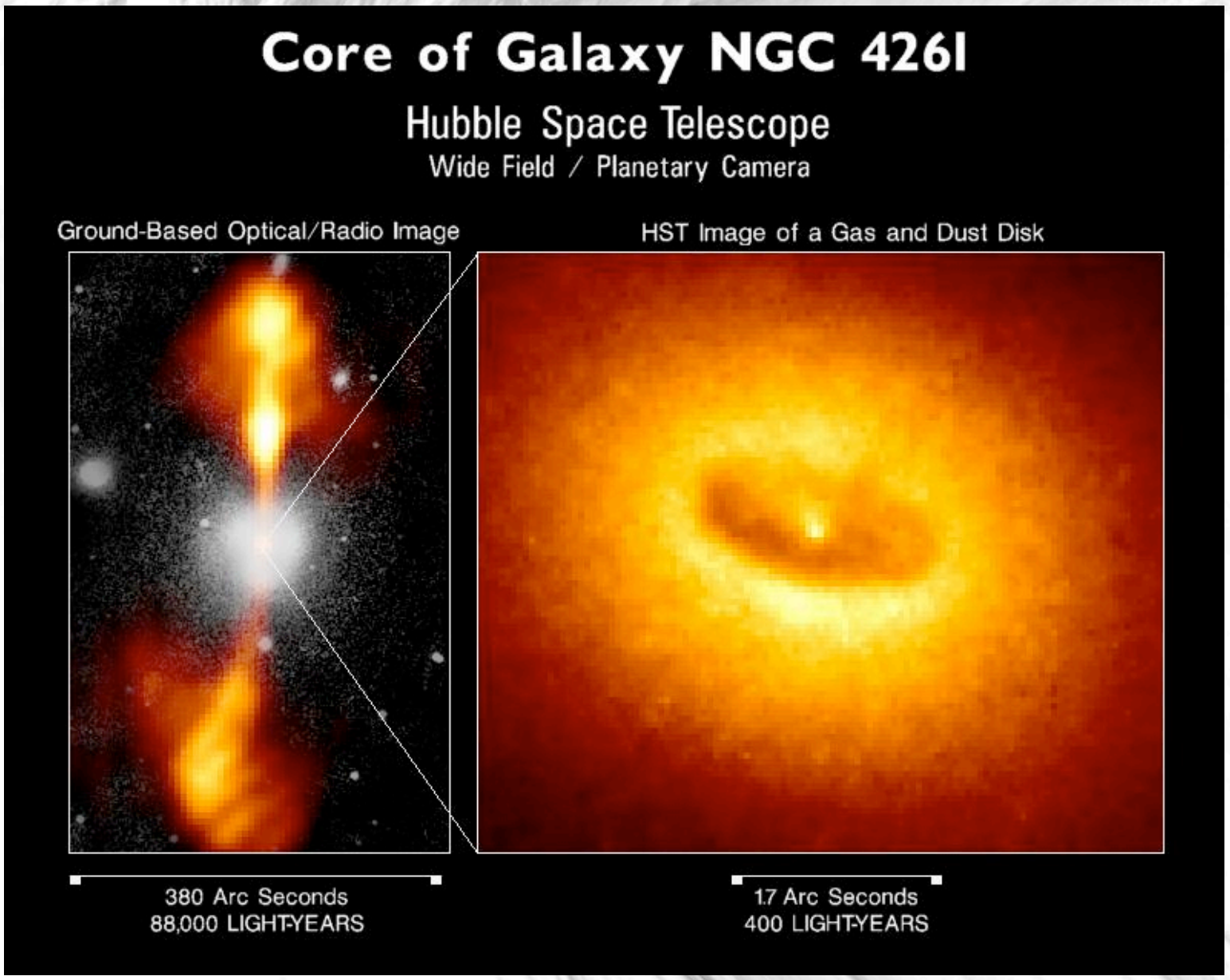
Fractional energy gain per shock crossing $\propto u_1 - u_2$ on a time scale r_L/u_2 .

Together with downstream losses this leads to a spectrum E^{-q} with $q > 2$ typically.

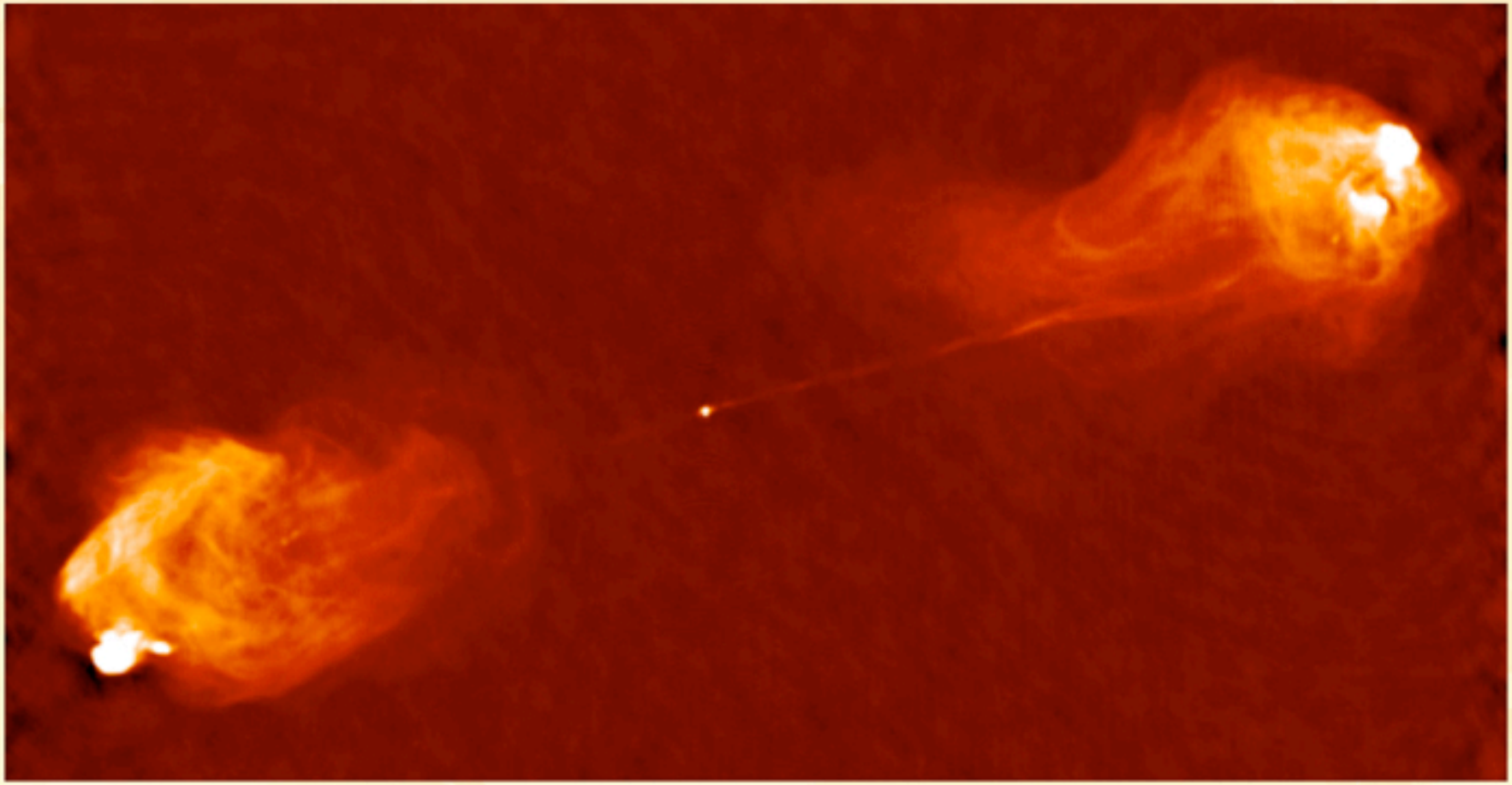
When the gyro-radius r_L becomes comparable to the shock size L, the spectrum cuts off.



A possible acceleration site associated with shocks in hot spots of active galaxies

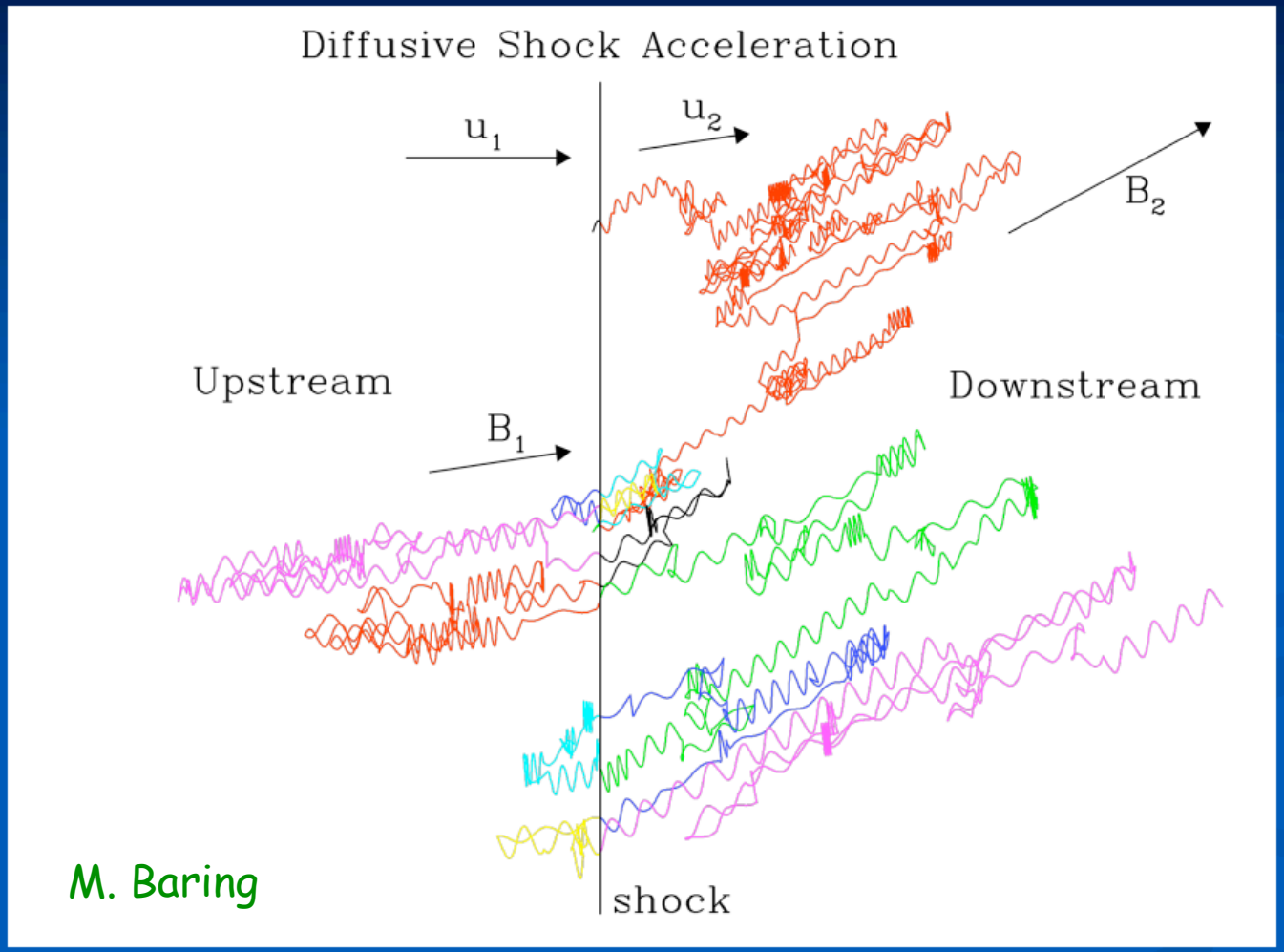


Or Cygnus A



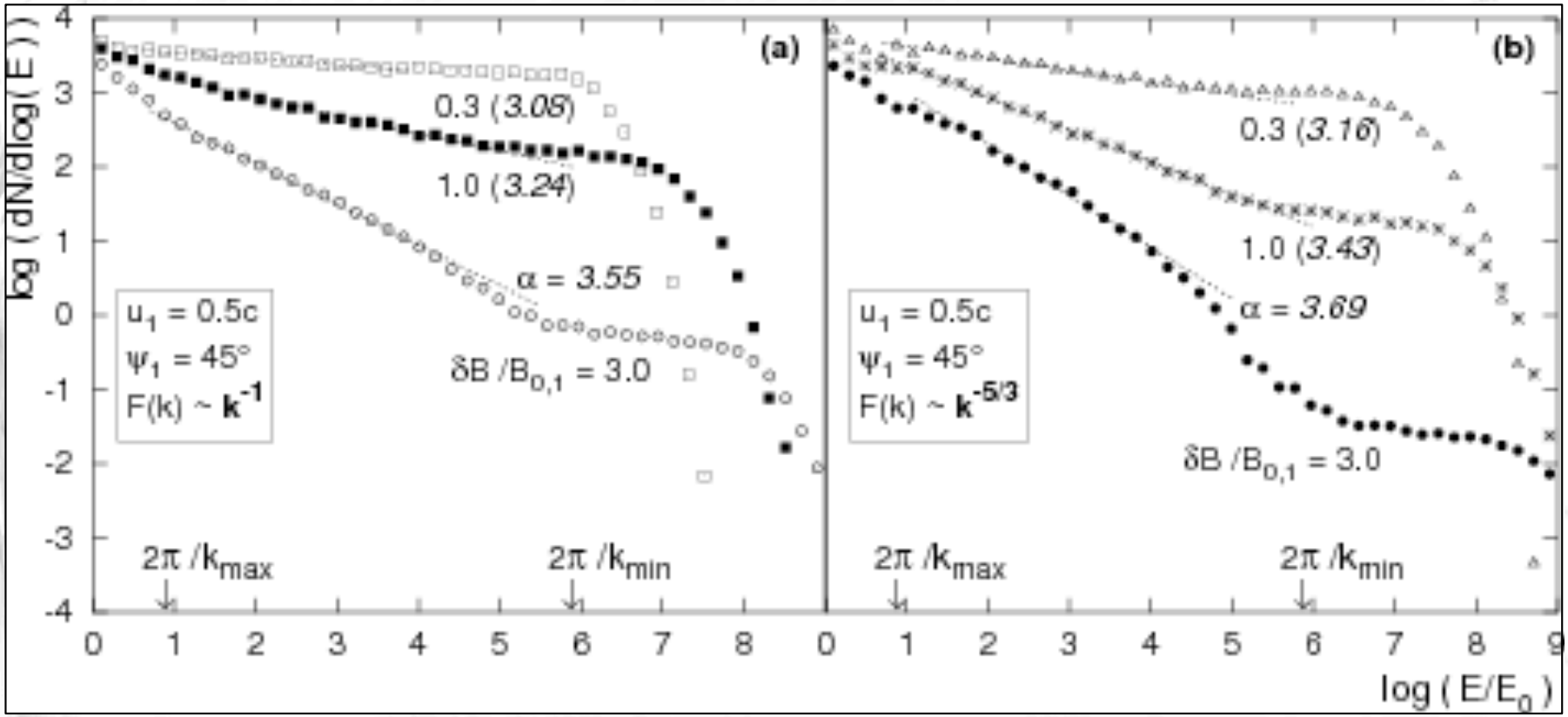
Shock Acceleration Theory

Monte Carlo Simulation Particle Trajectories



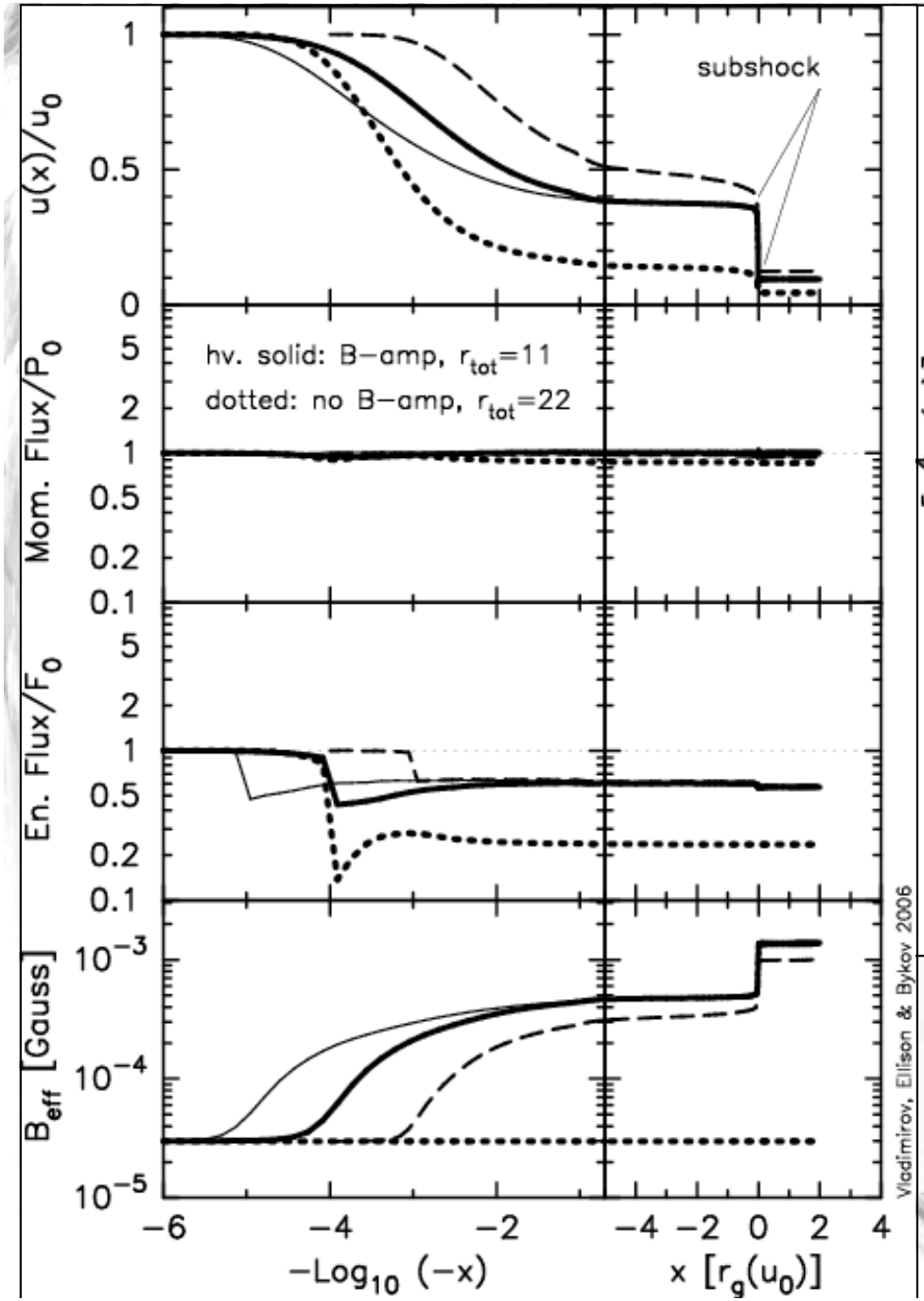
- Gyration in B-fields and diffusive transport modeled by a Monte Carlo technique; color-coded in Figure according to fluid frame energy.
- Shock crossings produce net energy gains (evident in the increase of gyroradii) according to principle of first-order Fermi mechanism.

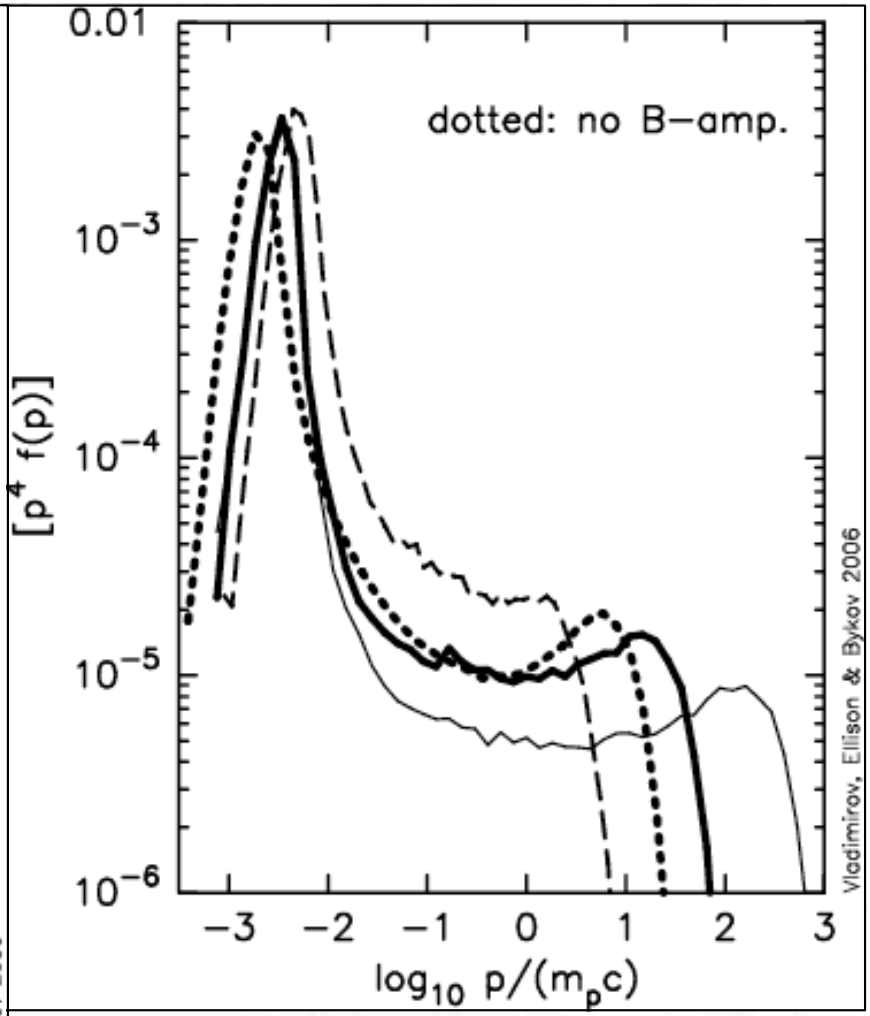
Monte Carlo simulations of particle spectra for oblique mildly relativistic shocks



No "universal" spectral index a~4.2 as sometimes claimed

Niemiec and Ostrowski, e.g. arXiv:0801.1339

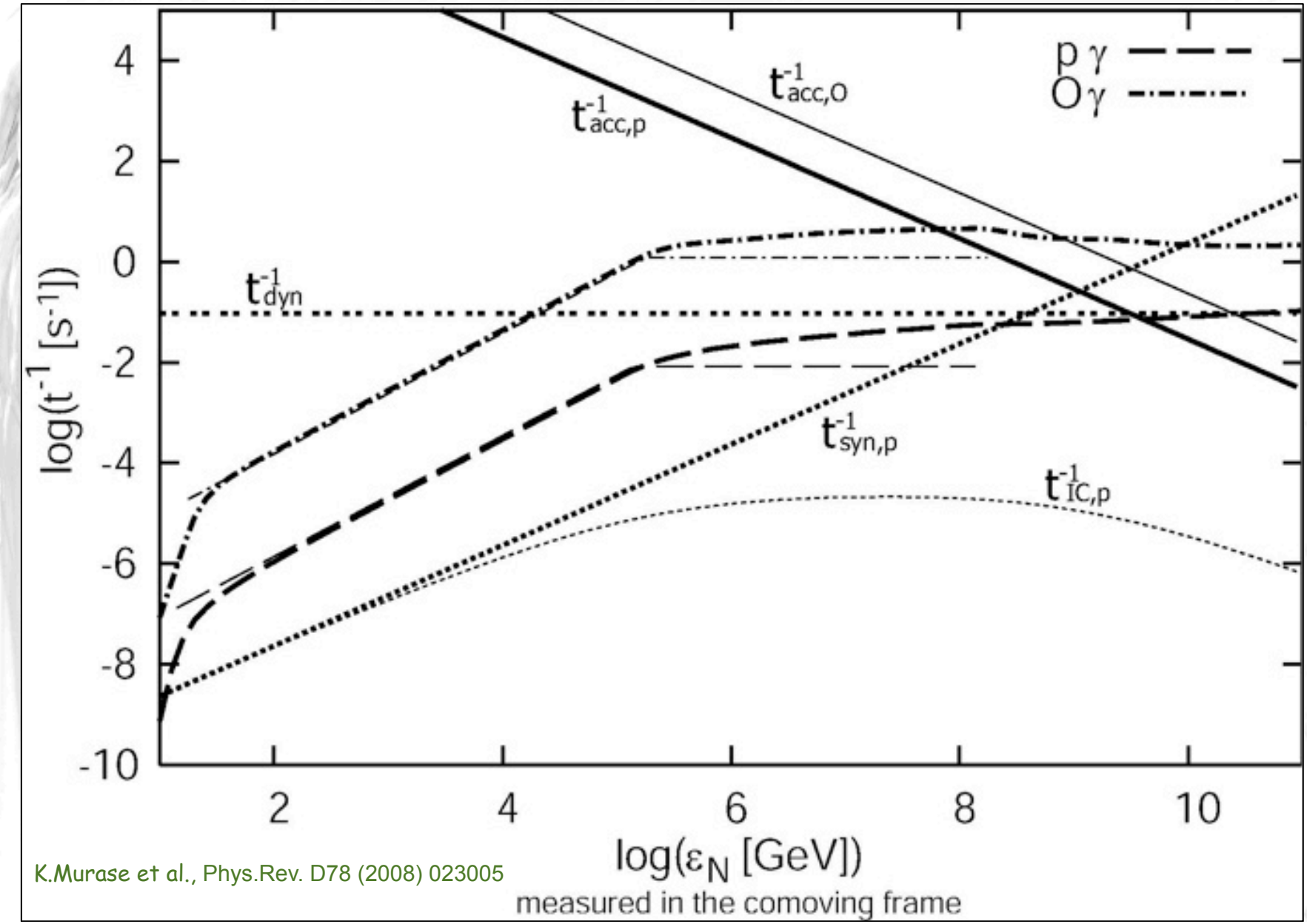




Vladimirov, Ellison, Bykov, Astrophys.J. 652 (2006) 1246

Monte Carlo simulations with backreaction on magnetic turbulence

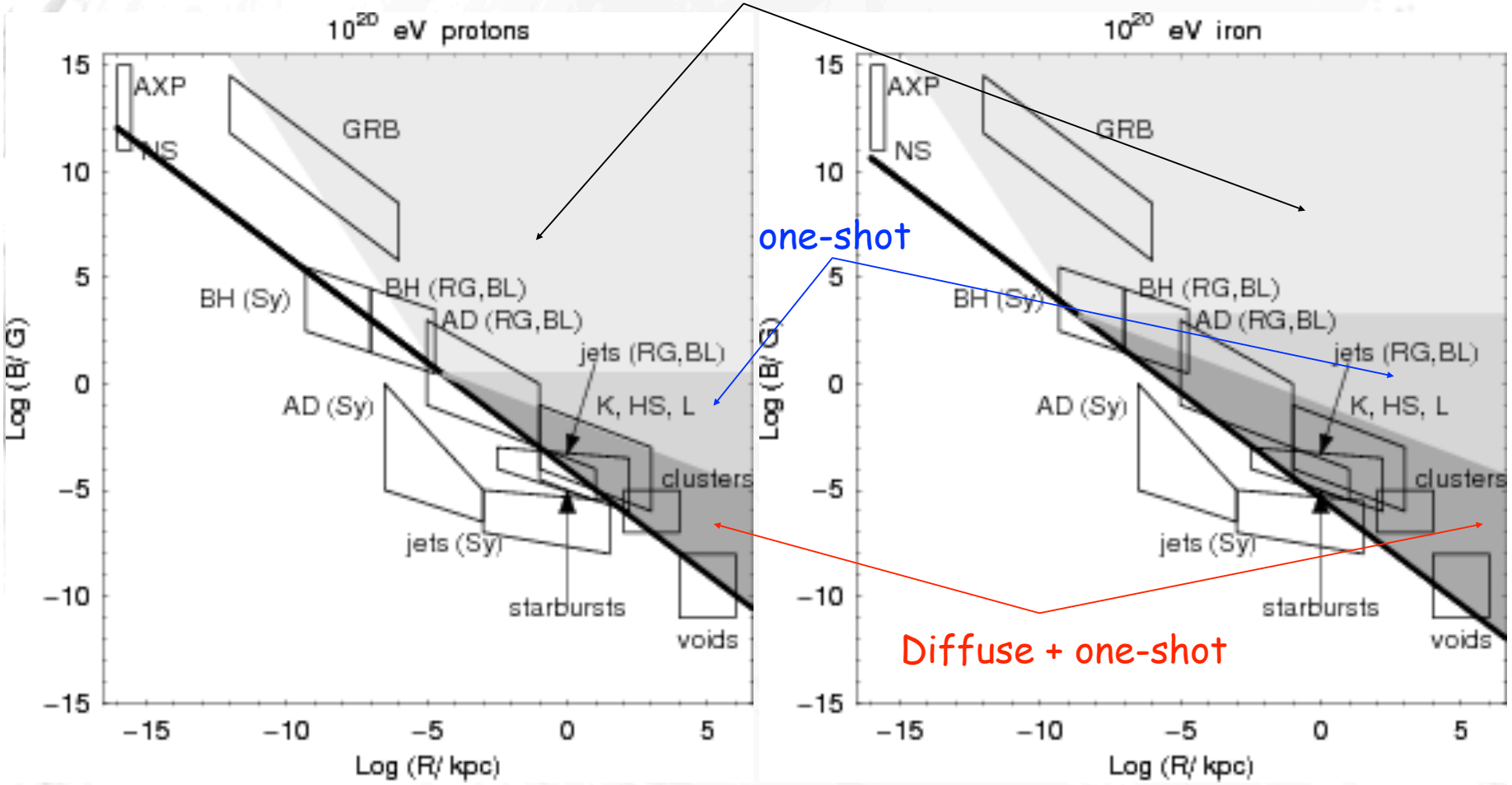
Acceleration and energy loss rates for protons and oxygen nuclei in model for high luminosity gamma-ray bursts



K.Murase et al., Phys.Rev. D78 (2008) 023005

Hillas plot with energy losses

one-shot, curvature-dominated only

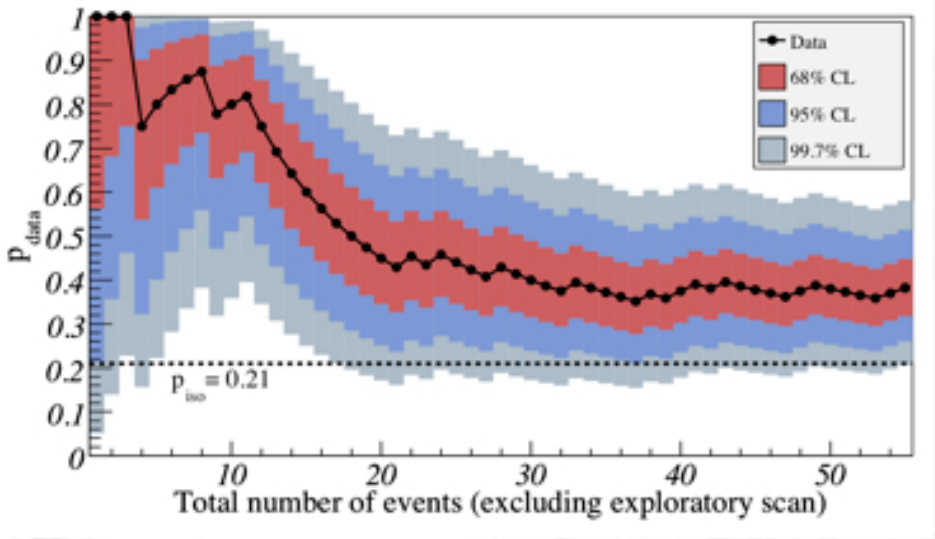


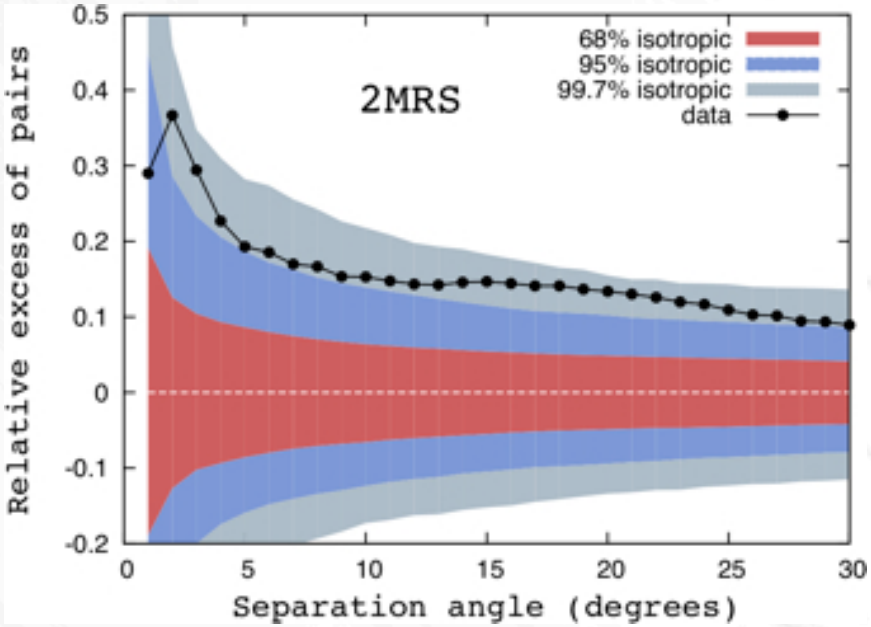
Observed events consistent with constraints on correlated sources for heavy primaries !

Ptitsyna, Troitsky., arXiv:0808.0367

Ultra-High Energy Cosmic Ray Sky Distribution

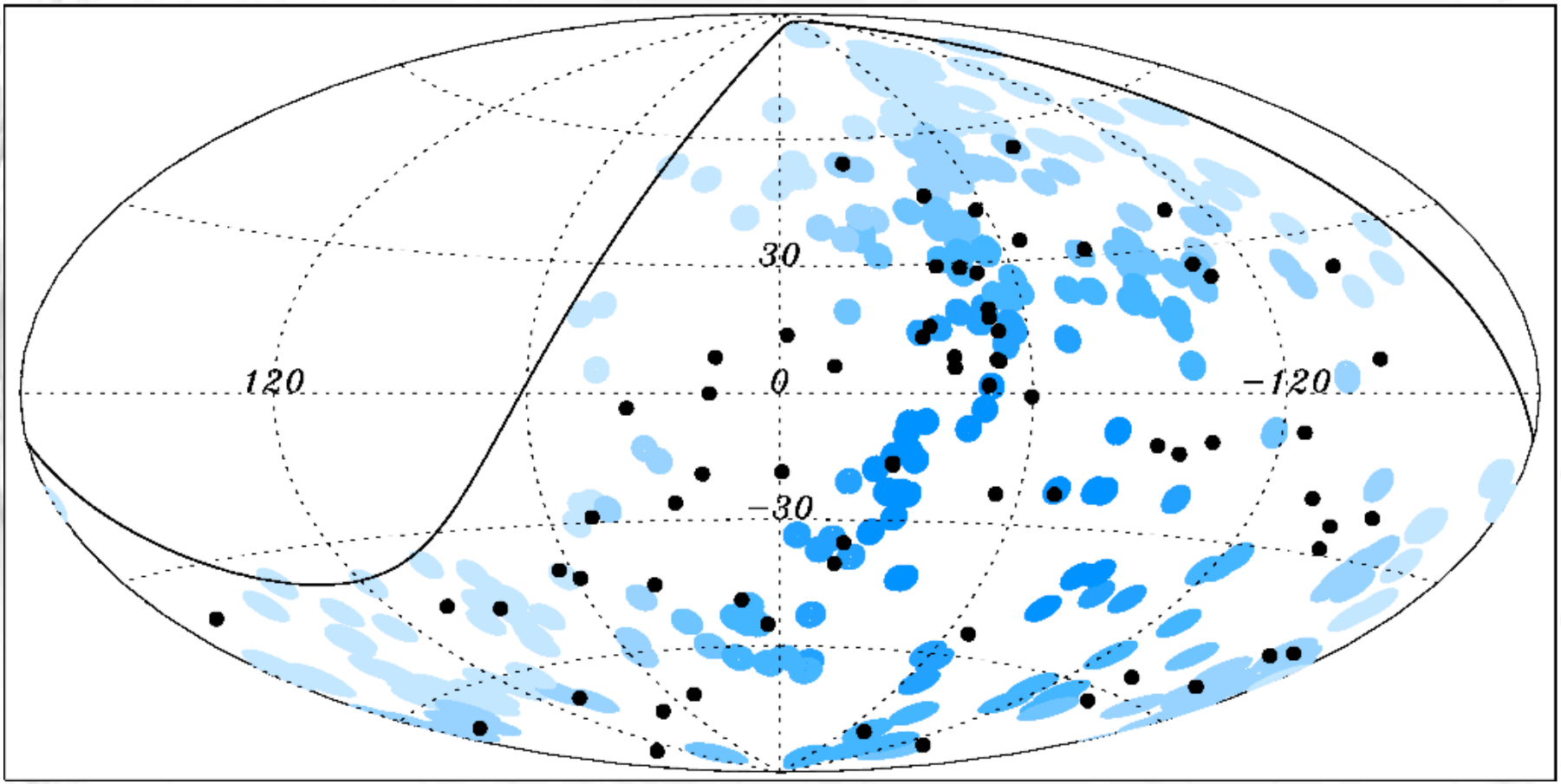
Pierre Auger Observatory update on correlations with nearby extragalactic matter: Pierre Auger Collaboration, arXiv:1009.1855





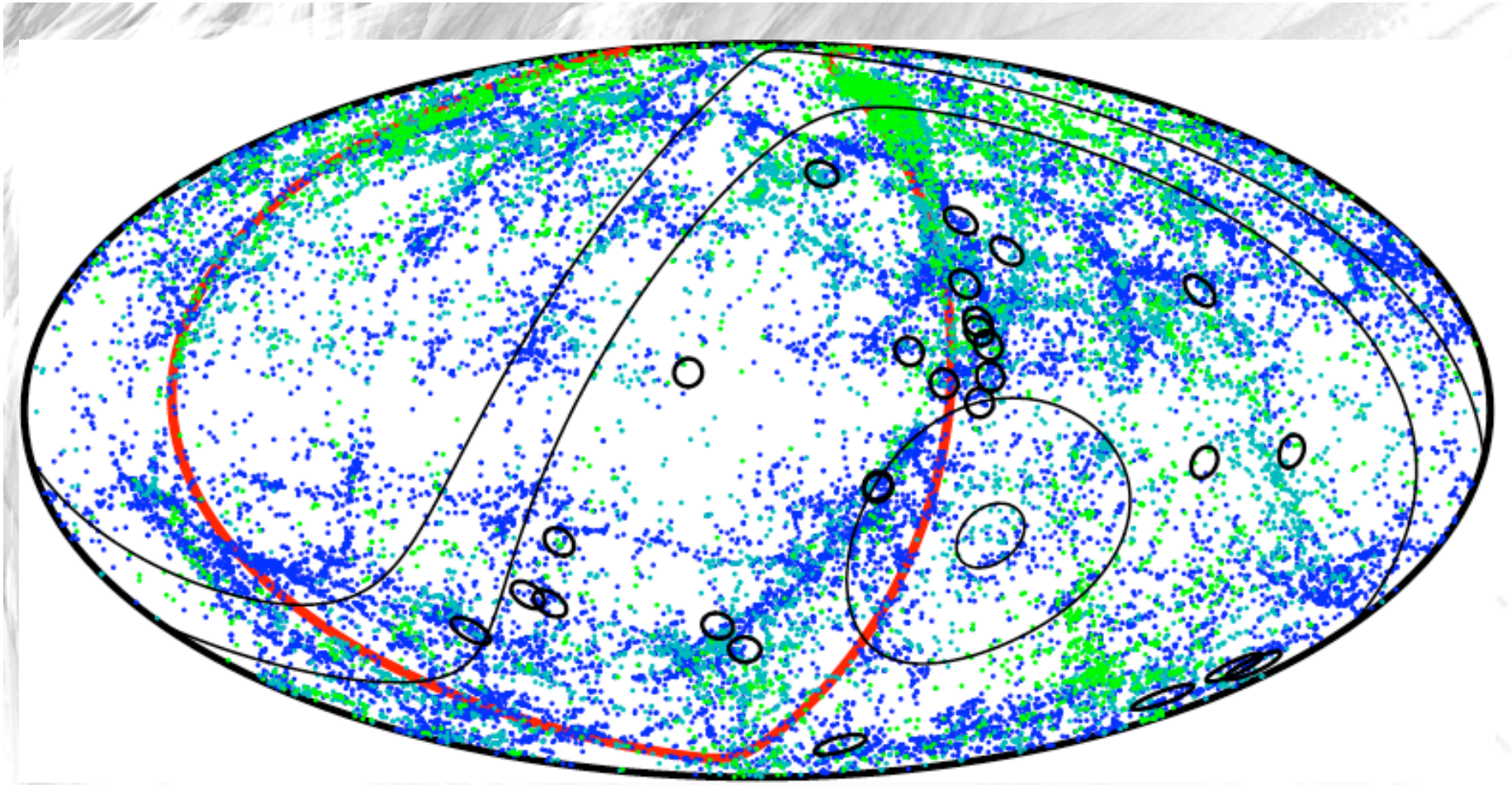
The case for anisotropy does not seem to have strengthened with more data: Fraction of events above 55 EeV correlating with the Veron Cetty Catalog has came down from 69+11-13% to 38+7-6% with 21% expected for isotropy. Excess of correlation also seen with 2MRS catalog at 95% CL.

Auger sees Correlations with AGNs !



Blue 3.1 deg. circles = 318 AGNs from the Veron Cetty catalogue within 75 Mpc (exposure weighted color); black dots = 69 events above 55 EeV.
29 events correlated within 3.1°, 14.5 expected for isotropy

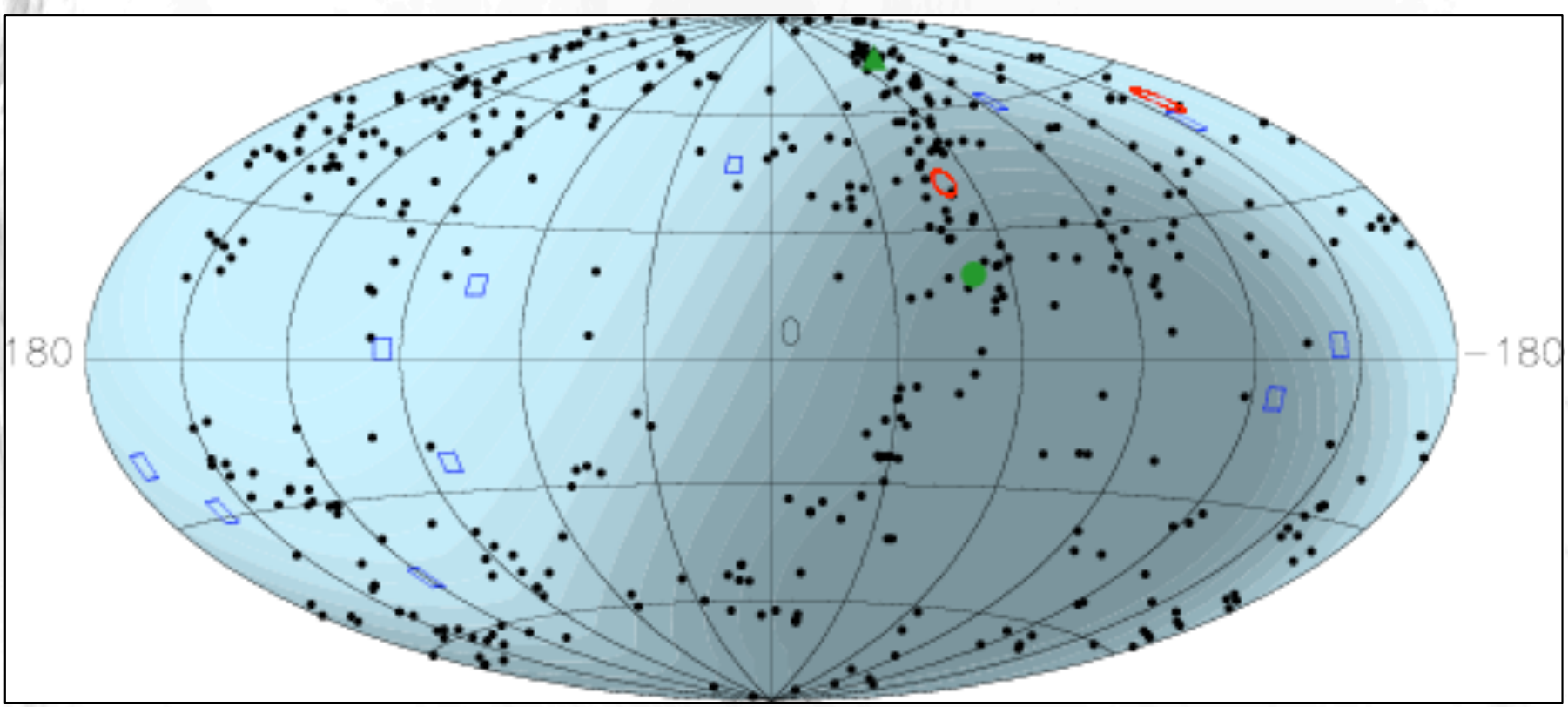
Pierre Auger Collaboration, arXiv:1009.1855



Points = galaxies with z < 0.015
Black circles = Auger events above 60 EeV.
Black lines = equal exposure contours
red line= supergalactic plane

Lipari, arXiv:0808.0417

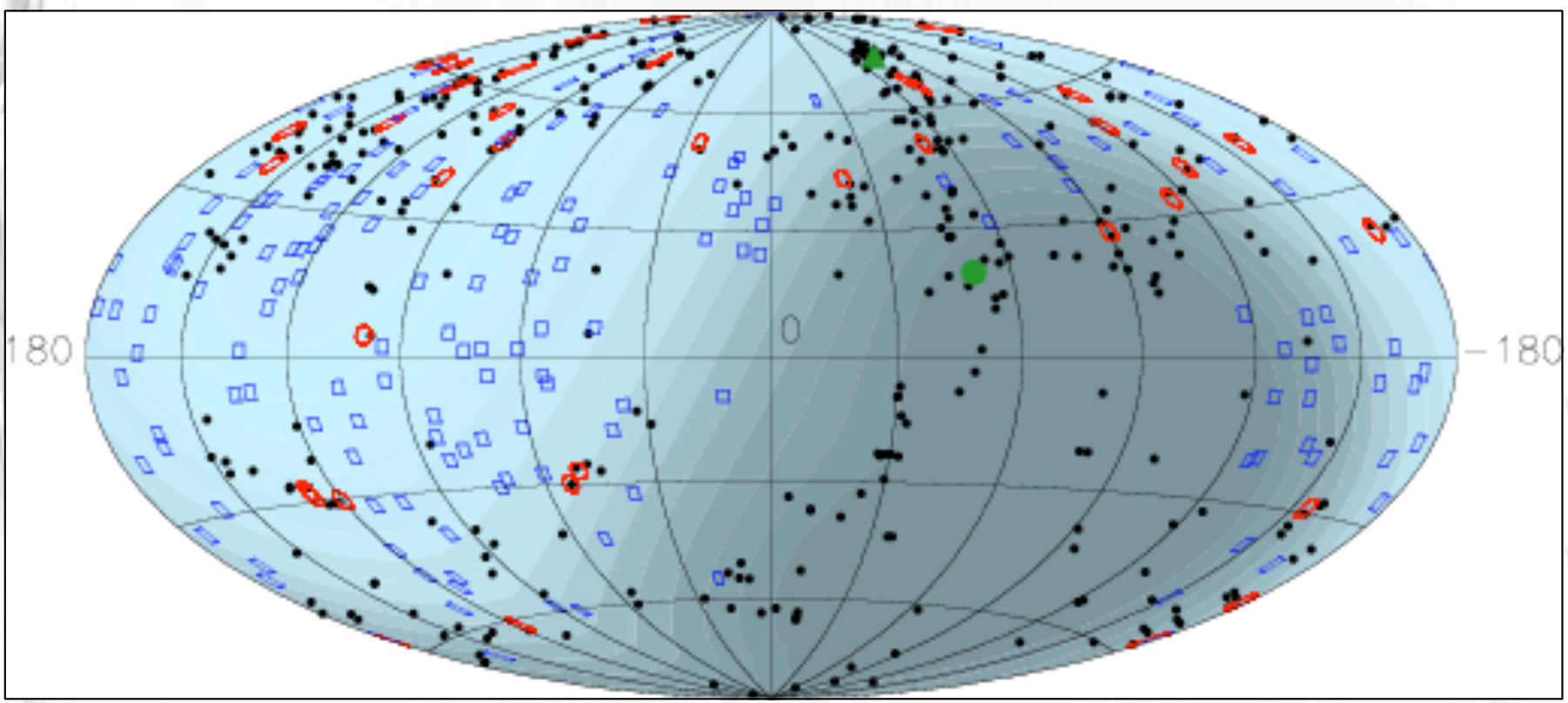
But HiRes sees no Correlations !



Black dots = 457 AGNs + 14 QSOs from the Veron Cetty catalogue for z < 0.018
red circles = 2 correlated events above 56 EeV within 3.1°,
blue squares = 11 uncorrelated events

HiRes Collaboration, Astropart.Phys. 30 (2008) 175

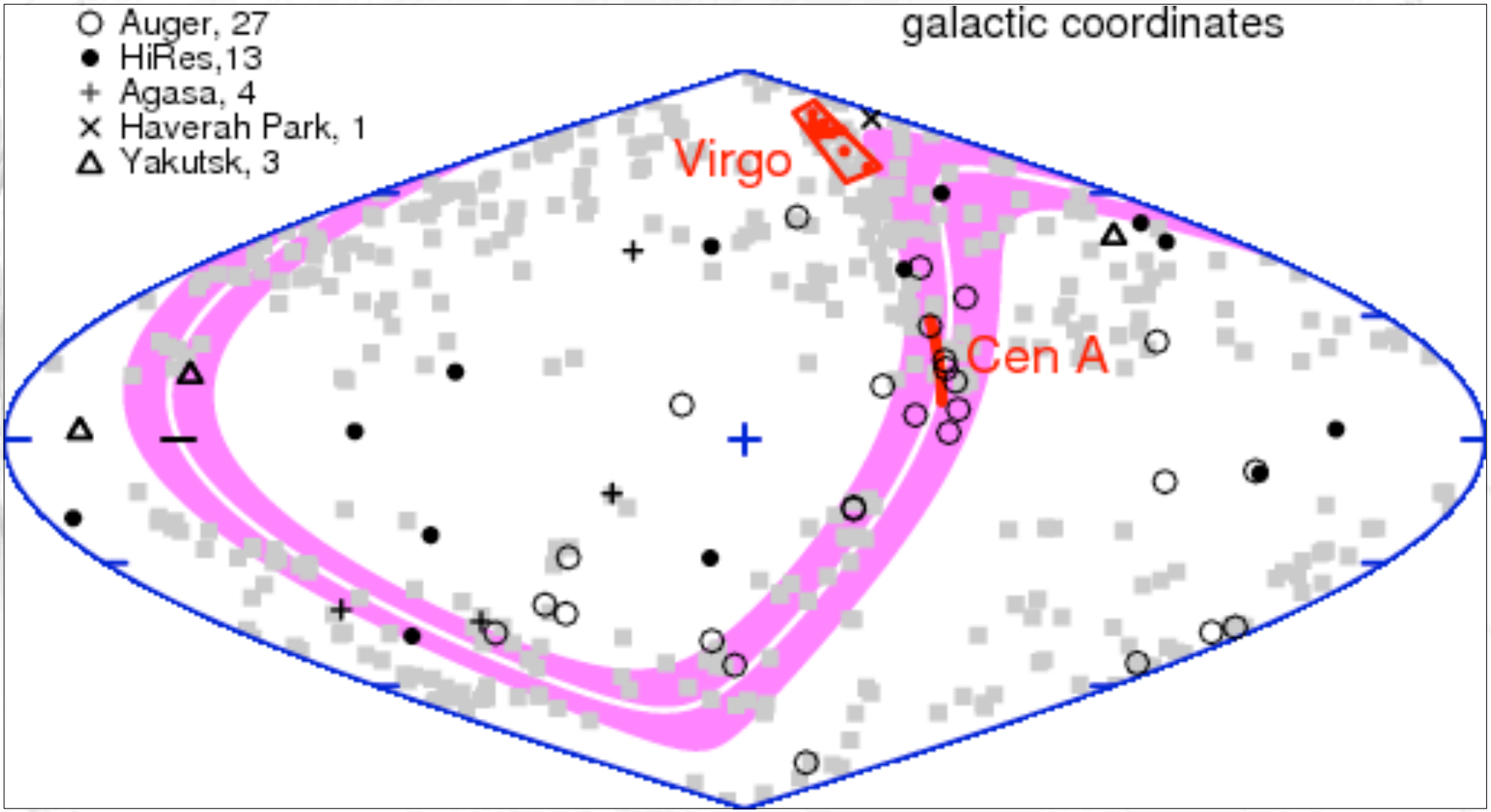
But HiRes sees no Correlations !



Black dots = 389 AGNs + 14 QSOs from the Veron Cetty catalogue for z < 0.016
red circles = 36 correlated events above 15.8 EeV within 2.0°,
blue squares = 162 uncorrelated events

HiRes Collaboration, Astropart.Phys. 30 (2008) 175

Correlation with supergalactic plane



Correlation with supergalactic plane within 10° (15°) is improved from 2.0 (2.4) sigma to 3.6 (3.2) sigma when definition relates to structure within 70 Mpc.

Stanev, arXiv:0805.1746

Further Curiosities in the Sky Distributions

too few events from Virgo cluster, see
Gorbunov et al., JETP Lett. 87 (2007) 461

too many events from Centaurus A, e.g. Moskalenko et al., arXiv:0805.1260; Rachen, arXiv:0808.0348.

The AGNs with which Auger events correlate are not thought to be strong enough, see Moskalenko et al., arXiv:0805.1260; Zaw, Farrar, Greene, arXiv: 0806.3470 (the latter arguing for flares)

According to Gureev and Troitsky, arXiv:0808.0481, the correlation of Auger events with AGNs is stronger when nearest neighbor sources only are counted, than when all AGN within given off-set are counted. According to them, this reveals individual sources rather than the population.