Four Year UniverseNet Activities on the Origin of Cosmic Rays

- Oxford: GZK neutrinos and gamma rays, galactic positrons from supernovae
- APC Paris: Ultra-High Energie Cosmic Ray Propagation and Acceleration and Dark Matter indirect detection
- Trieste and Annecy: Galactic positron, anti-proton and γ-ray fluxes from dark matter annihilation
- Kings College: Tests of D-foam models, Photon-Axion mixing
- Lancaster: Cosmic and gamma-rays from dark matter annihilation or decay
- Gran Sasso: Cosmic Rays, γ-rays and neutrinos from Supernova Remnants and ultra-high energy cosmic ray propagation

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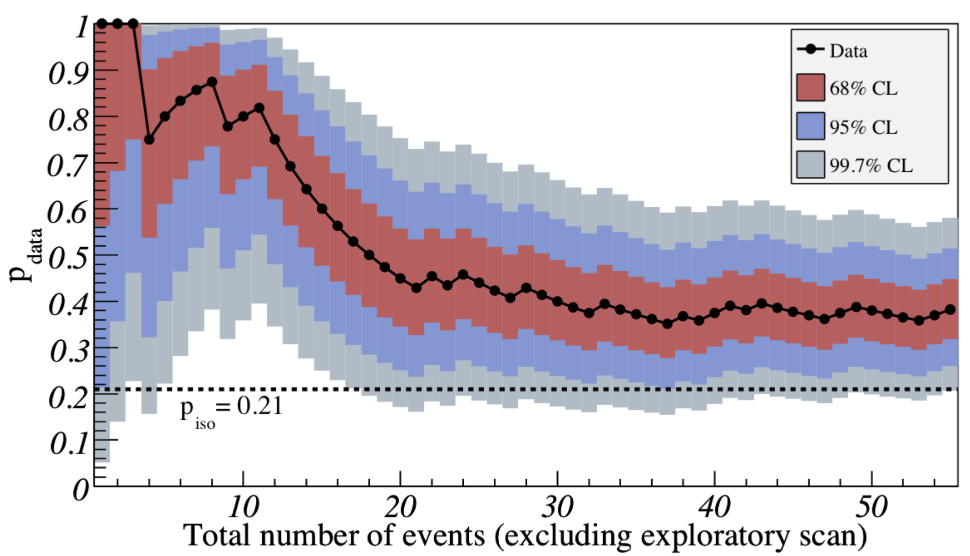
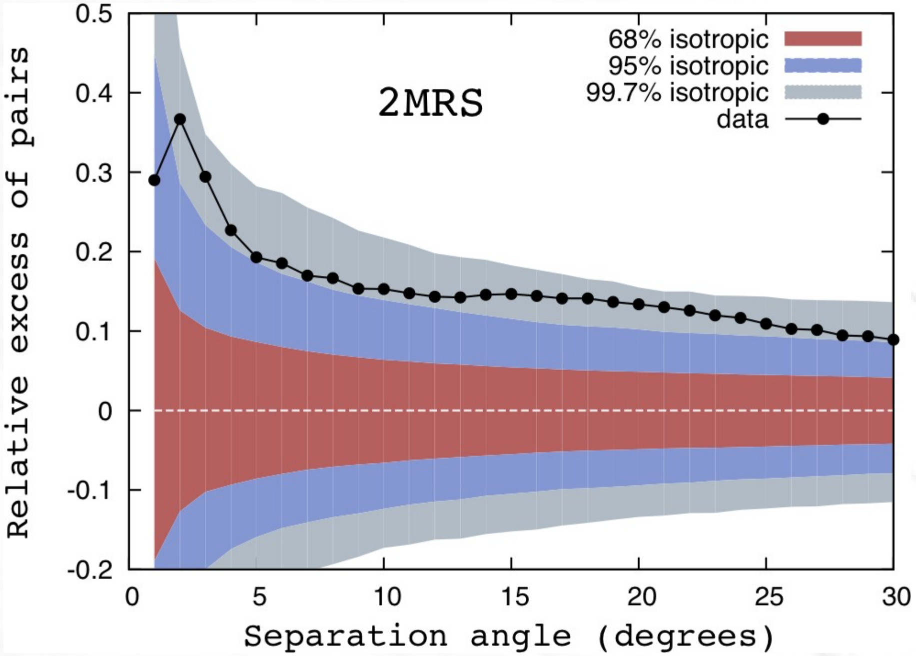
http://www2.iap.fr/users/sigl/homepage.html

Ultra-High Energy Cosmic Ray Sources and Composition

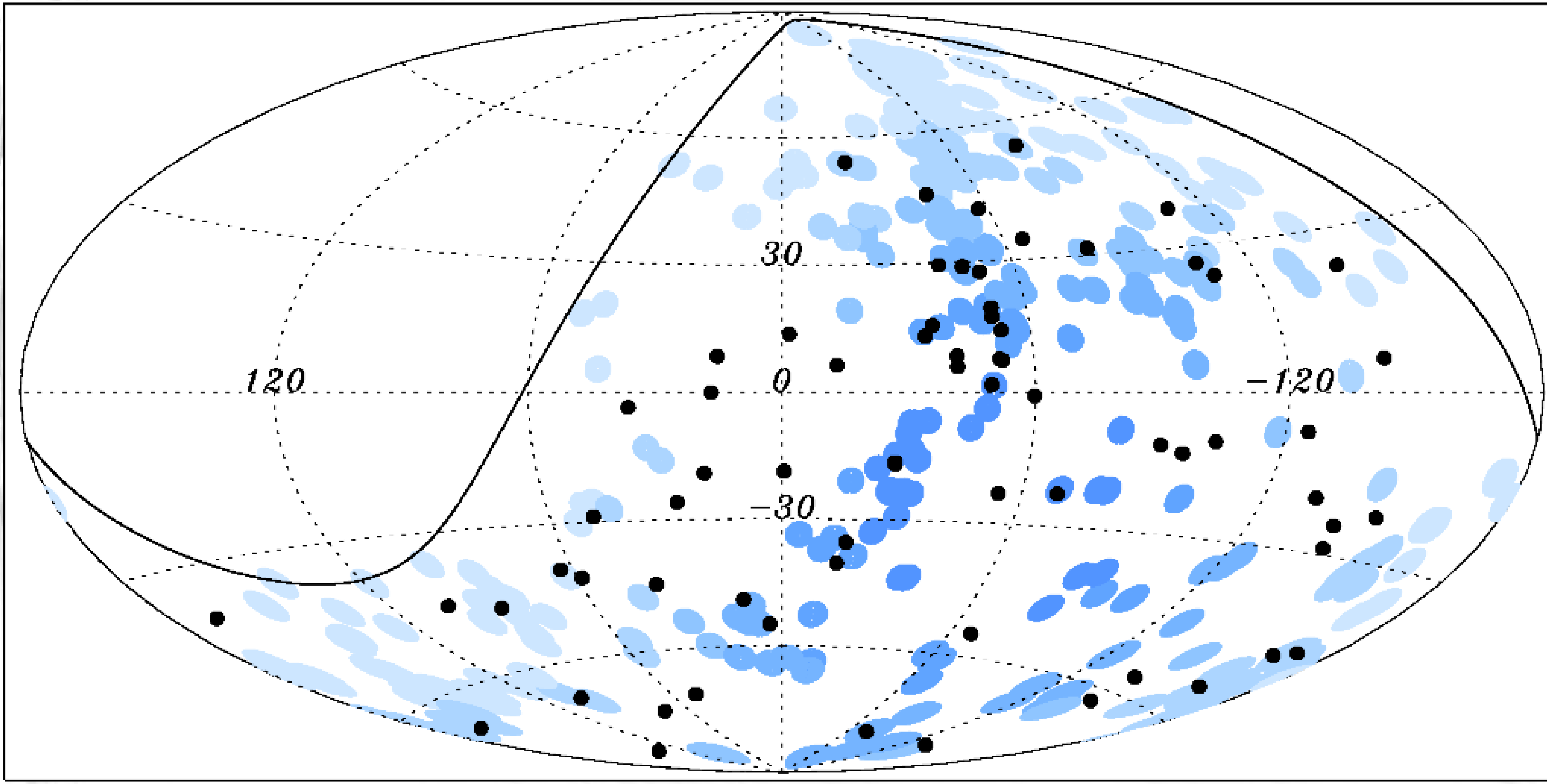
Pierre Auger Observatory update on correlations with nearby extragalactic matter: Pierre Auger Collaboration, arXiv:1009.1855





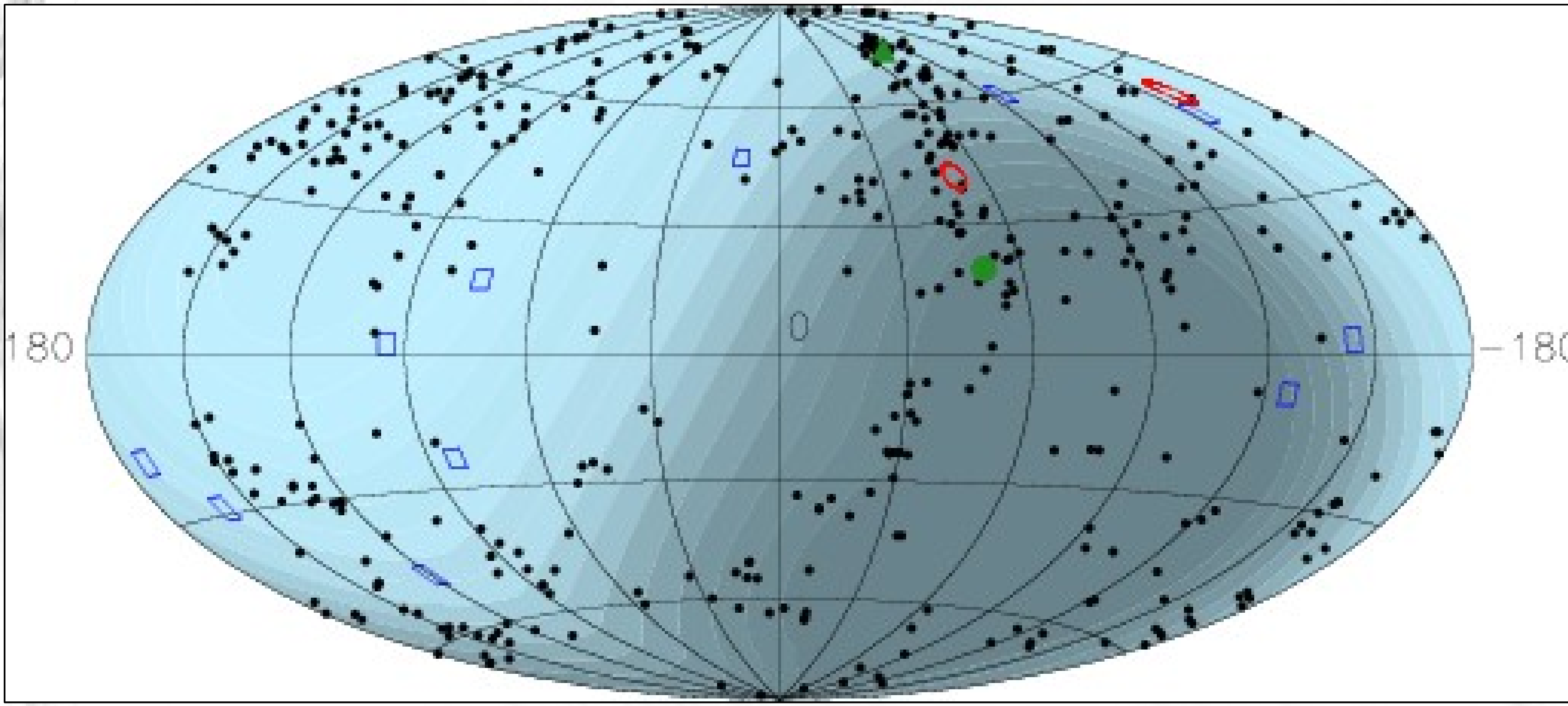
The case for anisotropy does not seem to have strengthened with more data: Fraction of events above 55 EeV correlating with the Veron Cetty Catalog has came down from 69+11-13% to 38+7-6% with 21% expected for isotropy. Excess of correlation also seen with 2MRS catalog at 95% CL.

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

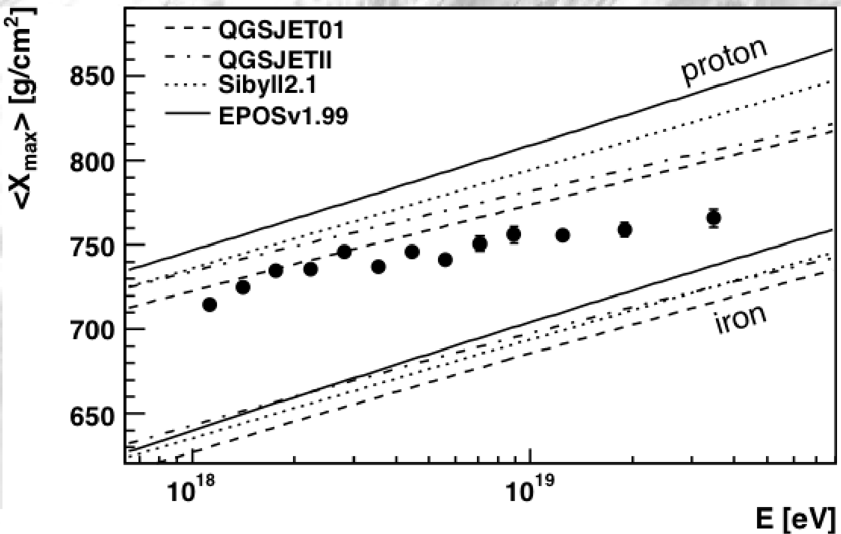
But HiRes sees no Correlations !

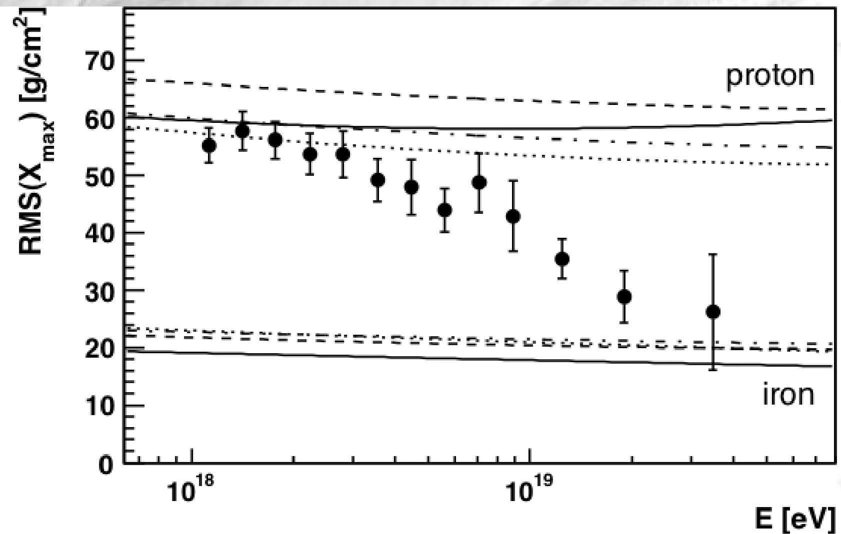


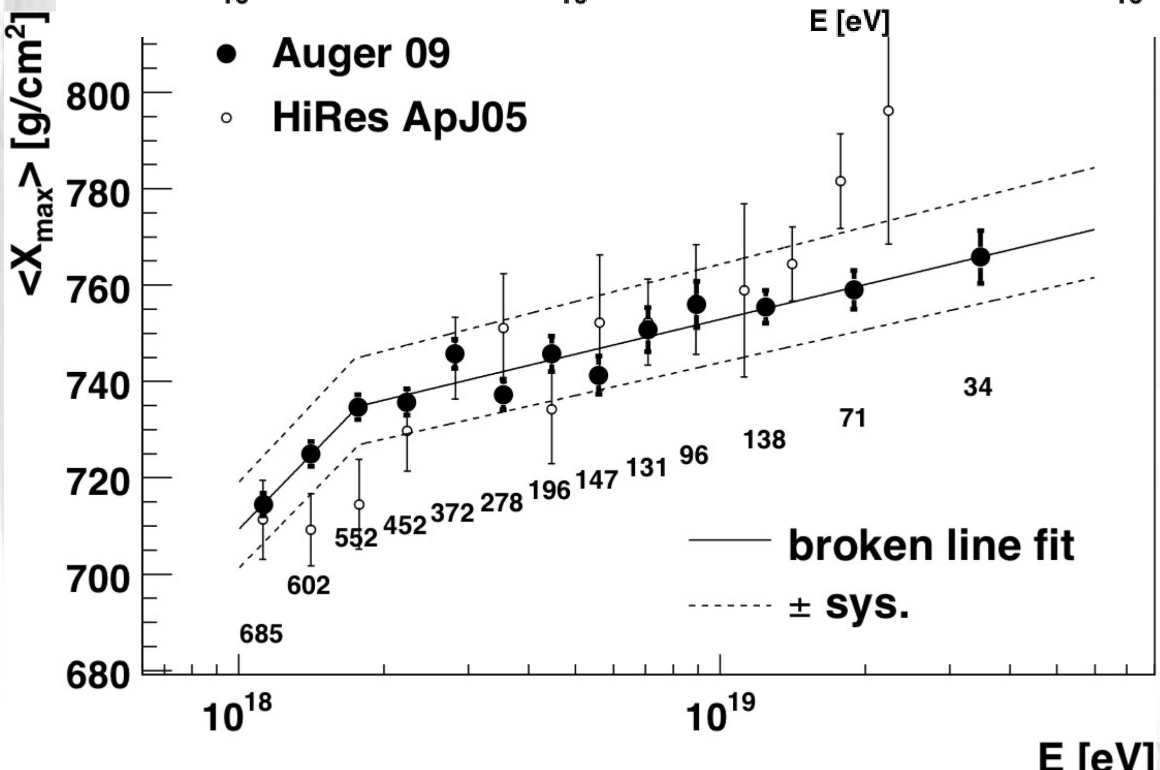
Black dots = 457 AGNs + 14 QSOs from the Veron Cetty catalogue for z < 0.018
red circles = 2 correlated events above 56 EeV within 3.1°,
blue squares = 11 uncorrelated events

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

There may be a significant heavy component at the highest energies:





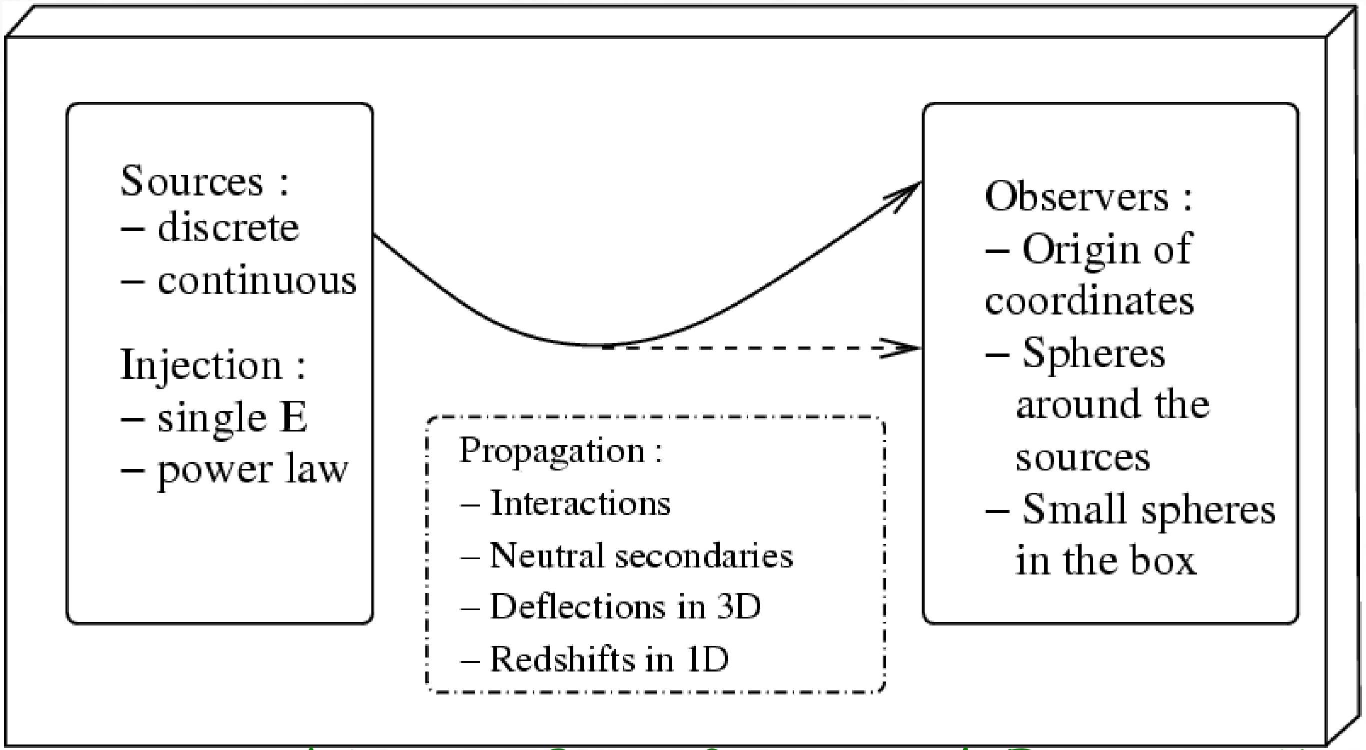


Auger data on composition seem to point to a quite heavy composition at the highest energies, whereas HiRes data seem consistent with a light composition.

Pierre Auger Collaboration, Phys.Rev.Lett., 104 (2010) 091101

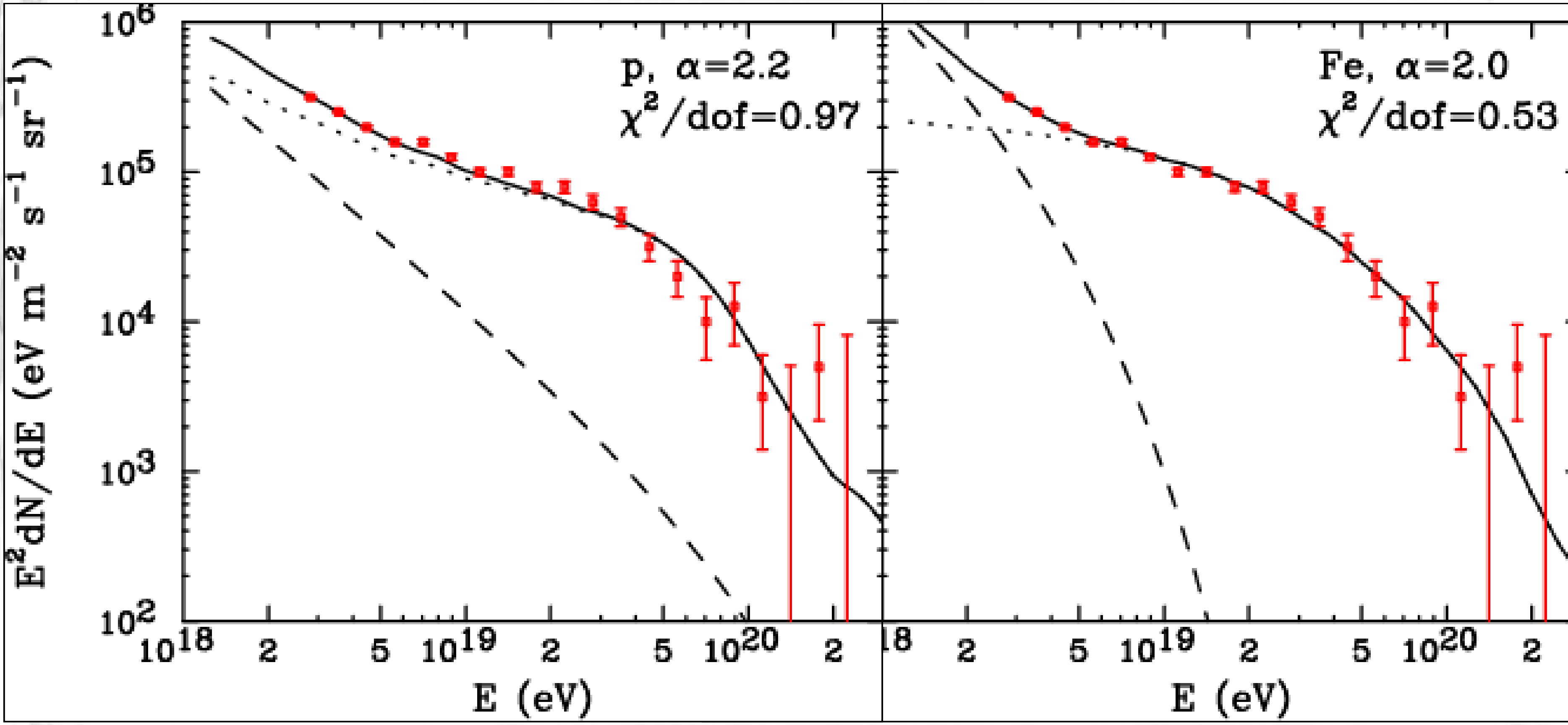
Ultra-High Energy Cosmic Ray Propagation

Many studies have been devoted to UHECR propagation.
For example, CRPropa is a public code for UHE cosmic rays, neutrinos and γ-rays being extended to heavy nuclei and hadronic interactions



Eric Armengaud, Tristan Beau, Günter Sigl, Francesco Miniati,
Astropart.Phys.28 (2007) 463.
http://apcauger.in2p3.fr/CRPropa/index.php
Now including: Jörg Kulbartz, Luca Maccione, Ricard Tomas, Mariam Tortola

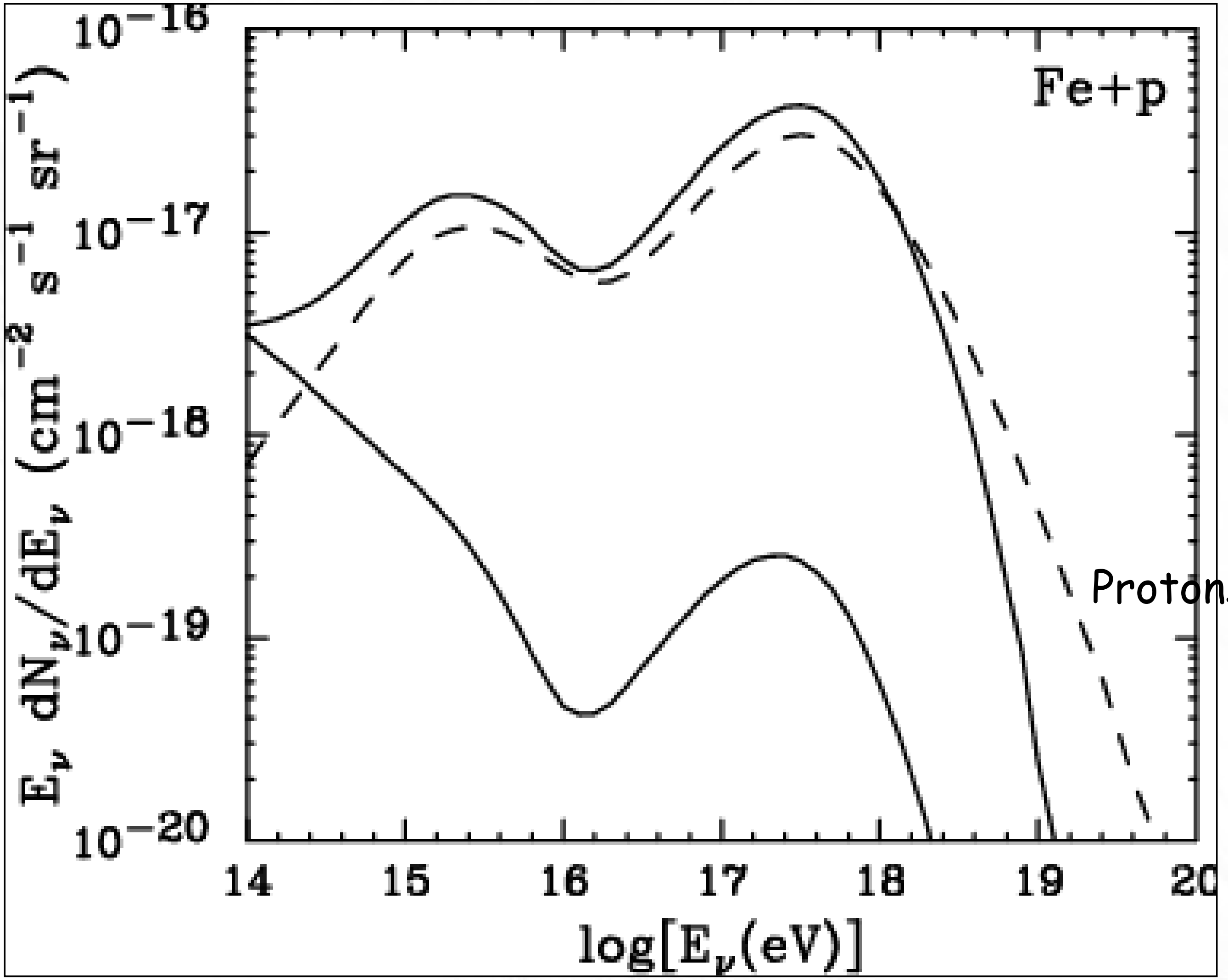
Chemical Composition and Cosmogenic Neutrino Flux



Best fits to Auger spectrum for proton and iron injection with $E_{max}=(Z/26)\times 10^{22}$ eV

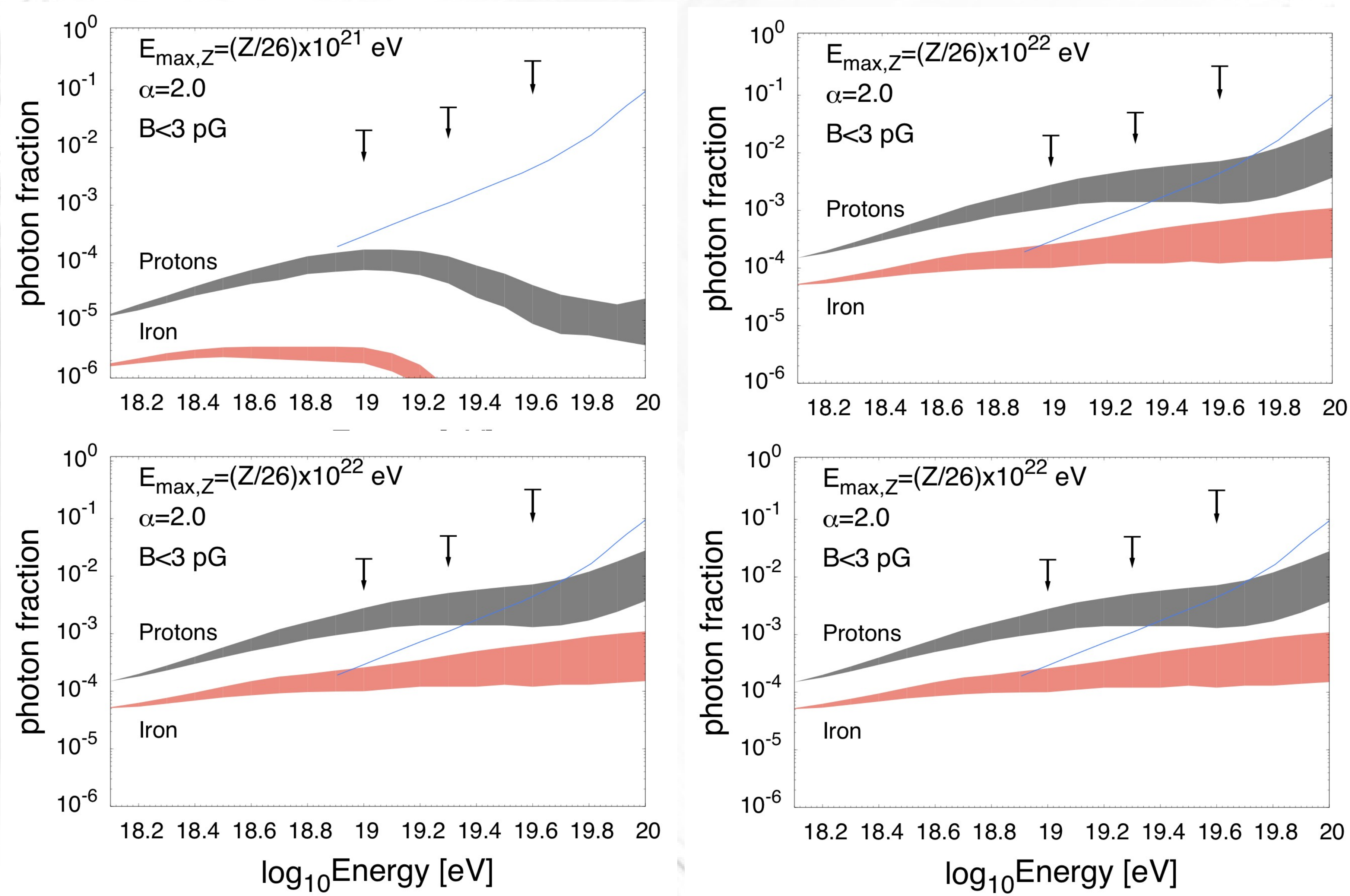
Anchordoqui, Hooper, Sarkar, Taylor, Astropart.Phys. 29 (2008) 1

Range of cosmogenic neutrino fluxes consistent with PAO spectrum and composition

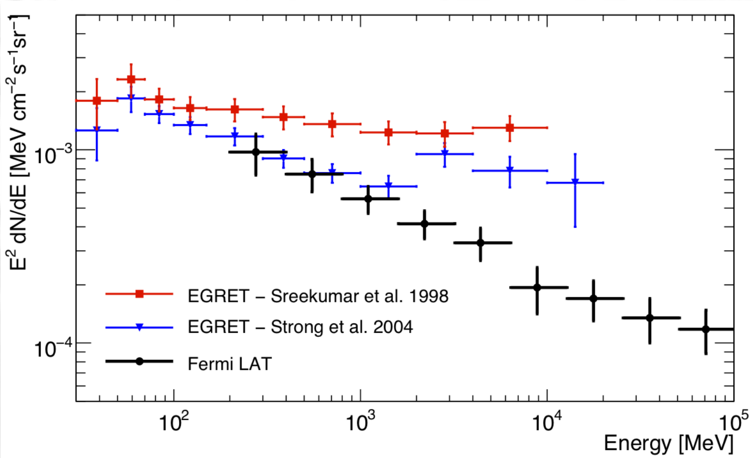


Anchordoqui, Hooper, Sarkar, Taylor, Phys.Rev.D 76 (2007) 123008

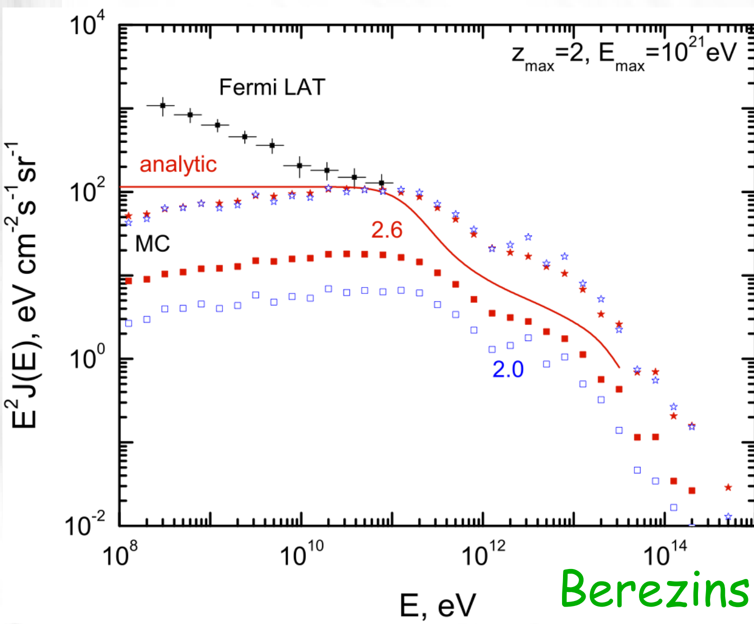
Also UHE gamma ray fluxes depend not only on maximal primary energy, but also on composition, see e.g. Hooper, Taylor, Sarkar, arXiv:1007.1306

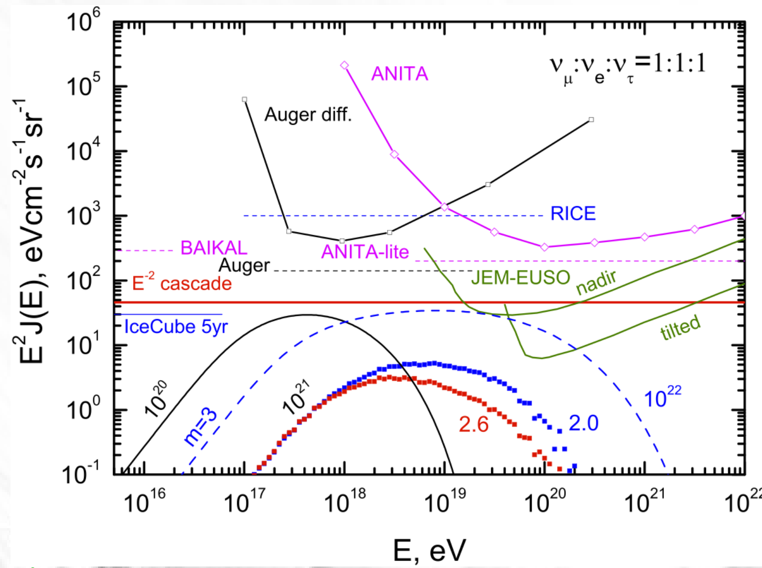


Fermi LAT has established a reduced diffuse extragalactic GeV gamma-ray flux [Phys. Rev. Lett. 104, 101101 (2010)] compared to EGRET:



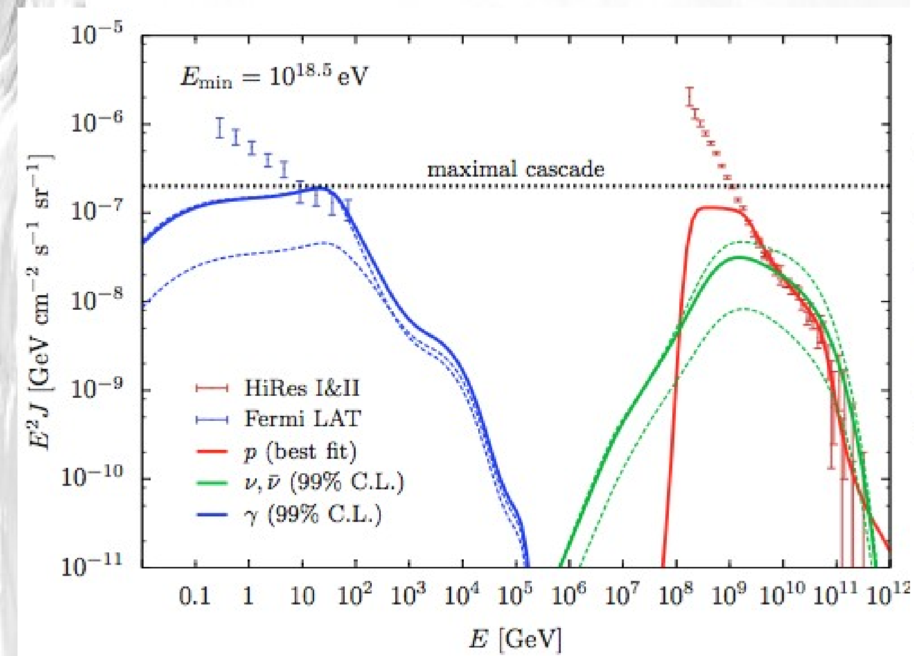
Due to the relation between gamma- and neutrino fluxes, this has reduced the maximal GZK neutrino flux to values requiring next generation experiments:

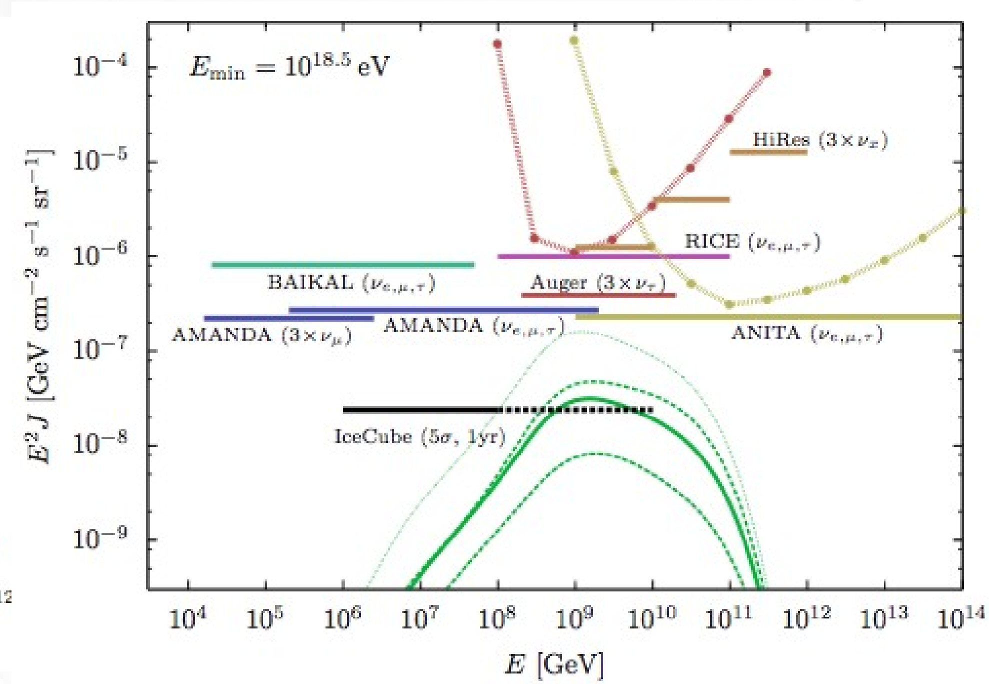




Berezinsky et al, arXiv:1003.1496

Fluxes higher by factor ~30 for given parameters but similar GZK
Neutrino limits after scan over parameters have been obtained by
Ahlers et al., arXiv:1005.2620:



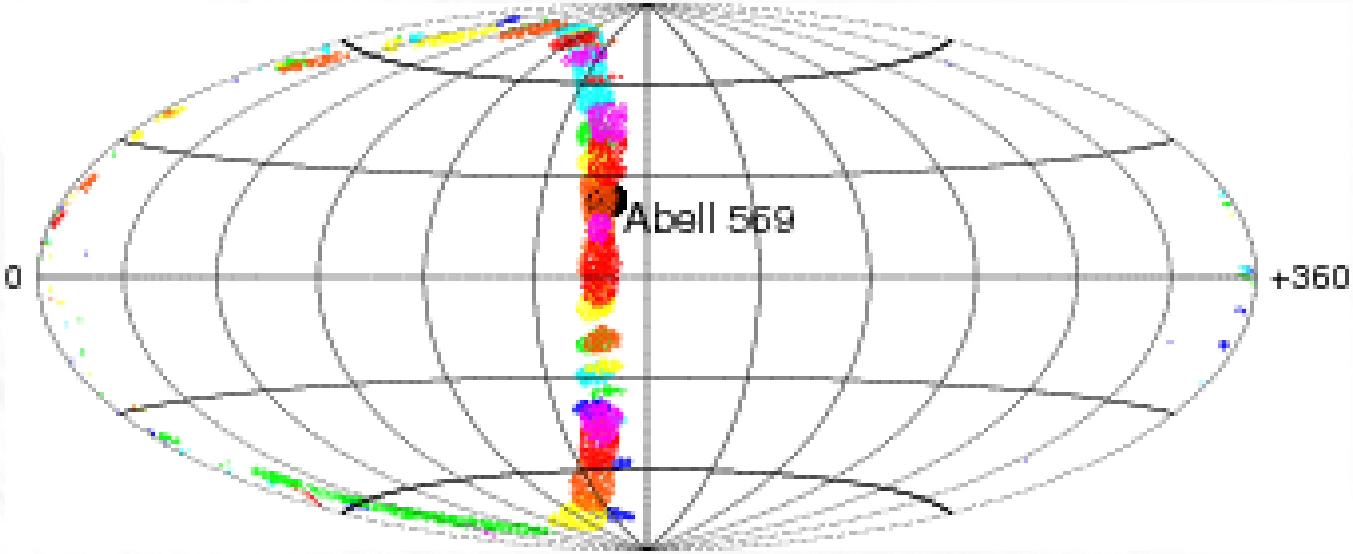


Chemical Composition and Galactic Deflection

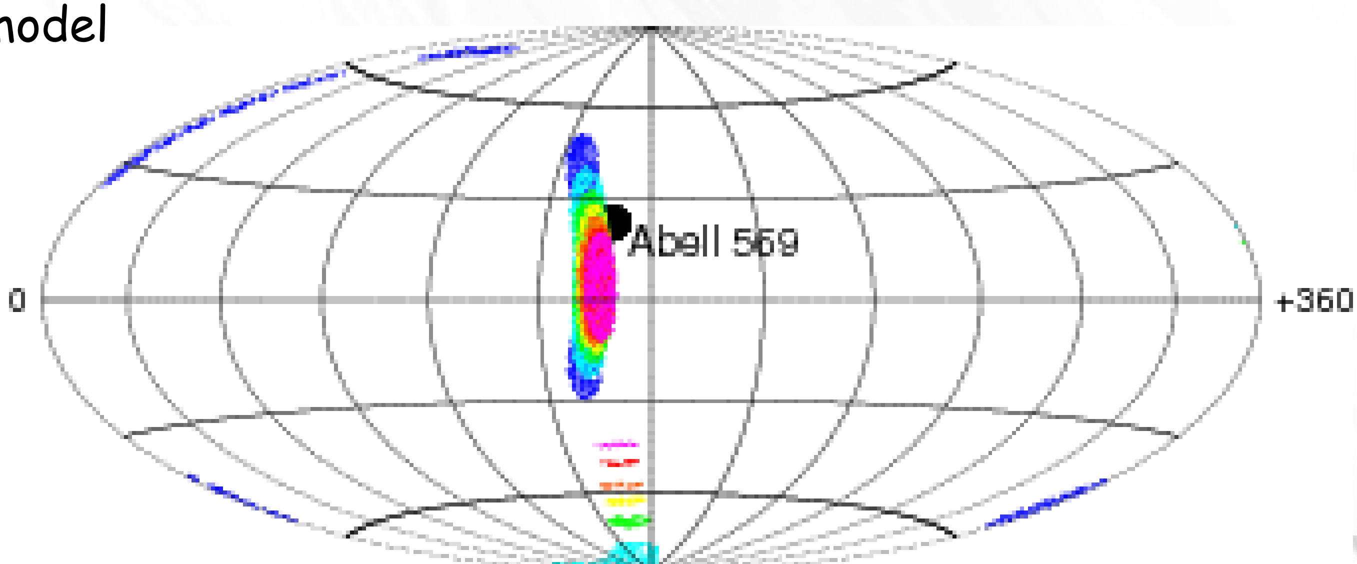
Deflection in **galactic magnetic field** is rather model dependent,
but can reach dozens of degrees for iron at GZK energies in models of
Tinyakov, Tkachev, Harrari, Mollerach, Roulet and Prouza, Smida

"Iron Image" of galaxy cluster Abell0569 in two galactic field models

Energy range from 60 to 140 EeV



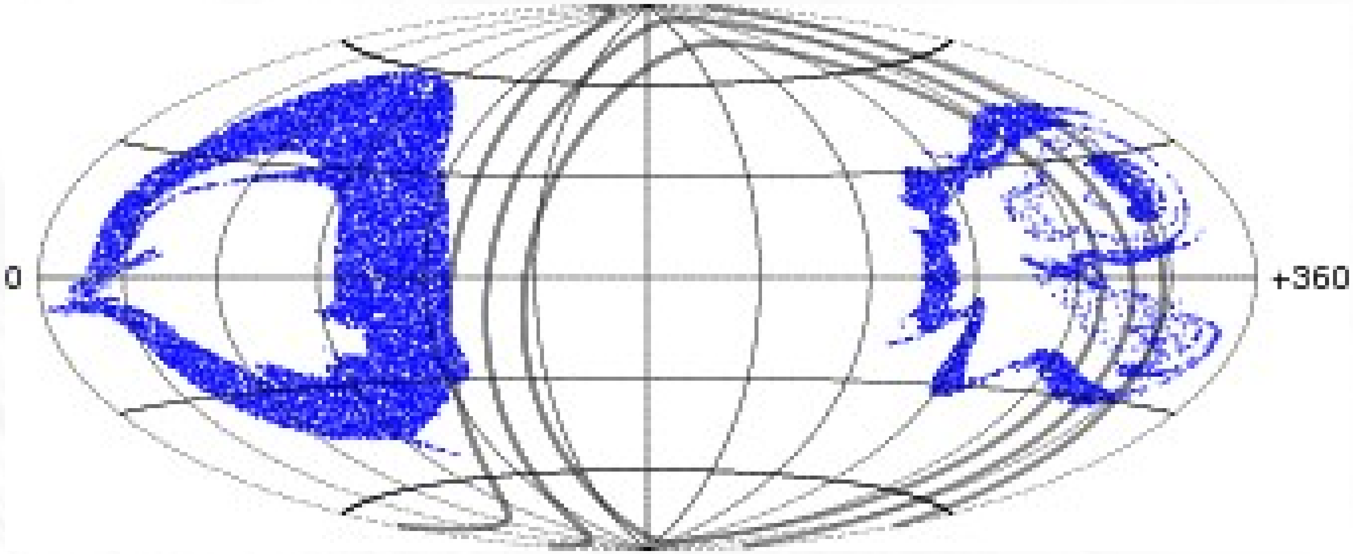
Sun08 model



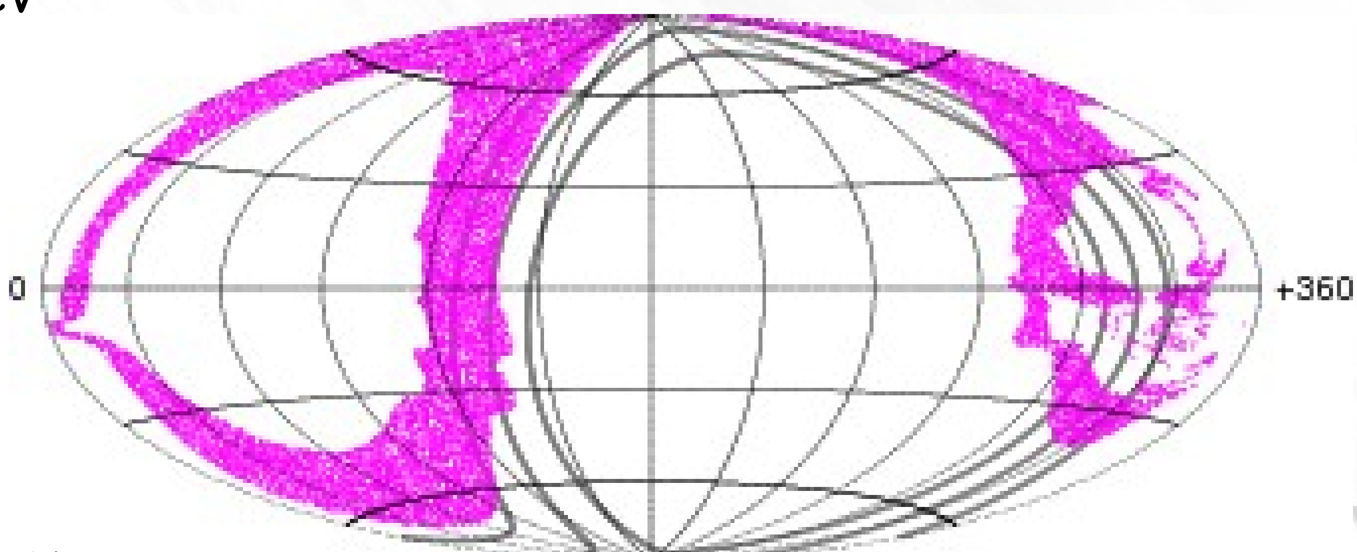
Sun08 modified halo model

Giacinti, Kachelriess, Semikoz, Sigl, arXiv:1006.5416

"Iron image" of supergalactic plane in galactic magnetic field model of Prouza&Smida



E=60 EeV



E=140 EeV

Giacinti, Kachelriess, Semikoz, Sigl, arXiv:1006.5416

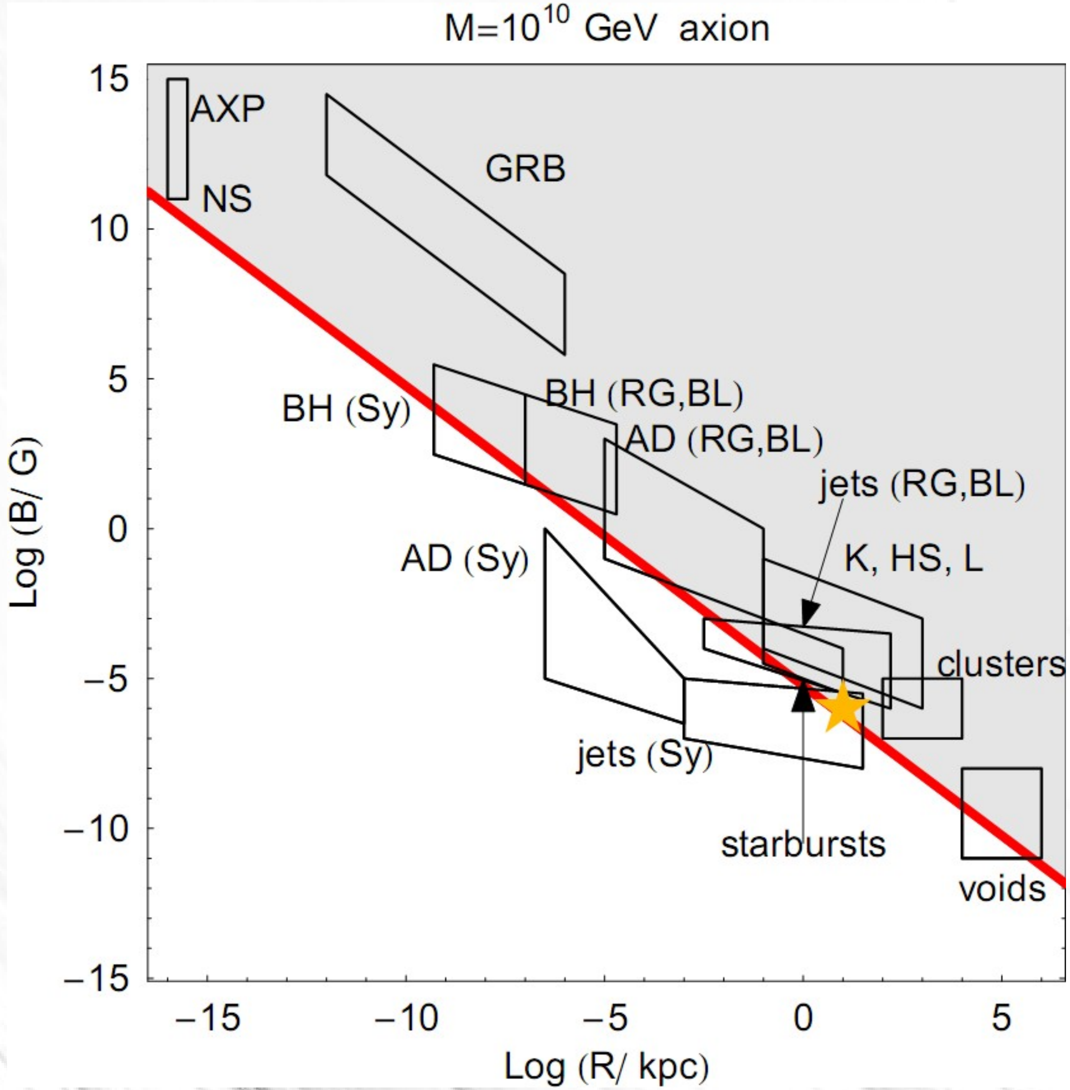
Open Question (and task for the future): Reconcile following observational indications:

a) If correlated AGN are sources, primaries should be protons to avoid too much deflection in galactic field

b) air shower measurements indicate mixed or heavy composition

c) Theory of AGN acceleration seem to favor heavier nuclei to reach observed energy

Photon-Axion Mixing has been suggested as a way to propagate neutrals over GZK-distances ("shining light through the Universe") and explain possible correlations with extragalactic sources in
Fairbairn, Rashba and Troitsky, arXiv:0901.4085:



Size versus magnetic field
Strength of source to convert
photons into axions to be
back-converted to photons
in the Galactic magnetic field

Lorentz Symmetry Violation in the Photon Sector

For a photon dispersion relation

$$\omega_{\pm}^{2}=k^{2}+\xi_{n}^{\pm}k^{2}\left(\frac{k}{M_{Pl}}\right)^{n},\quad n\geq 1,$$

time delays can result, as sometimes observed in GRBs or AGN flares. At the same time **pair production may become inhibited, increasing GZK photon fluxes above observed upper limits: In the absence of LIV in pairs for n=1, this yields:**

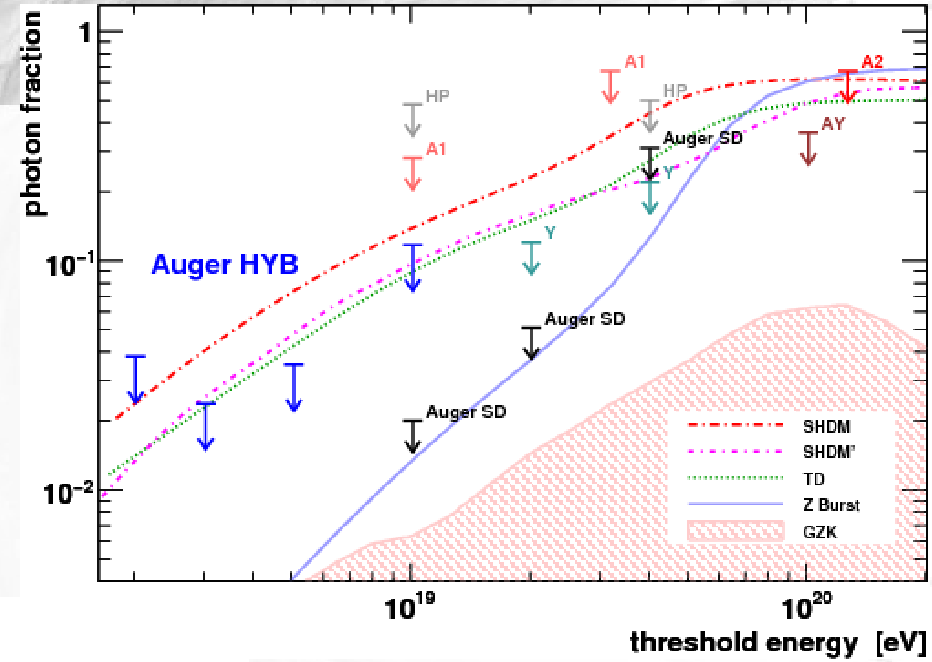
$$\xi_{1}\leq 10^{-12}$$

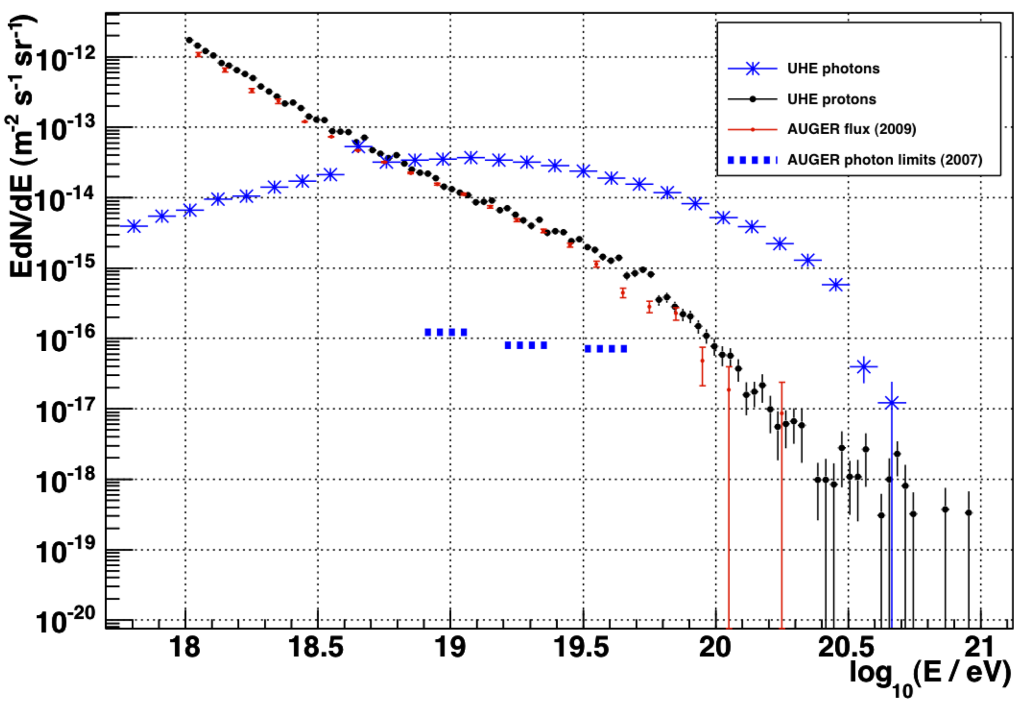
Such strong limits may indicate that Lorentz invariance violations are completely absent !

These limits are also inconsistent with interpretations of time delays of high energy gamma-rays from GRBs within quantum gravity secanrios based on effective field theory
Maccione, Liberati, Sigl, PRL 105 (2010) 021101

Possible exception in space-time foam models,
Ellis, Mavromatos, Nanopoulos, arXiv:1004.4167

Pierre Auger Collaboration,
Astropart. Phys. 31 (2009) 399





Maccione, Liberati, Sigl,
PRL 105 (2010) 021101

Galactic Cosmic Ray Propagation and Signatures of Dark Matter Annihilation

Much theoretical activity was triggered by several observed „anomalies" and „excesses", among them an excess of the positron to electron ratio observed by PAMELA between 10 and 100 GeV and of the electron + positron flux observed by ATIC, FERMI LAT and H.E.S.S between 30 and 1000 GeV.

This has been interpreted as due to annihilating or decaying dark matter, but also in terms of astrophysical processes.

A central role in these studies is played by the modelling of the propagation of galactic cosmic rays.

Galactic Cosmic Ray Propagation

Galactic propagation of charged cosmic rays is described by solving the diffusion-convection-energy loss equation:

$$\partial_t n = \nabla \left(D_{xx} \nabla n - \mathbf{v}_c n \right) + \partial_p \left(p^2 D_{pp} \partial_p \frac{n}{p^2} \right) - \partial_p \left[\dot{p}\, n - \frac{p}{3} \left(\nabla \cdot \mathbf{v}_c n \right) \right] + Q(\mathbf{r}, p)$$

spatial diffusion | convection | reacceleration | energy loss | adiabatic compression/ expansion | source term

Each of possibly several species would be governed by this type of equation. The source term includes primaries originating in astrophysical sources or through dark matter decay or annihilation, but also terms proportional to the product of a primary species with the relevant cross section in case of production through interactions. Uncertainties in these cross sections have been studied by Delahaye et al., arXiv:0809.5268

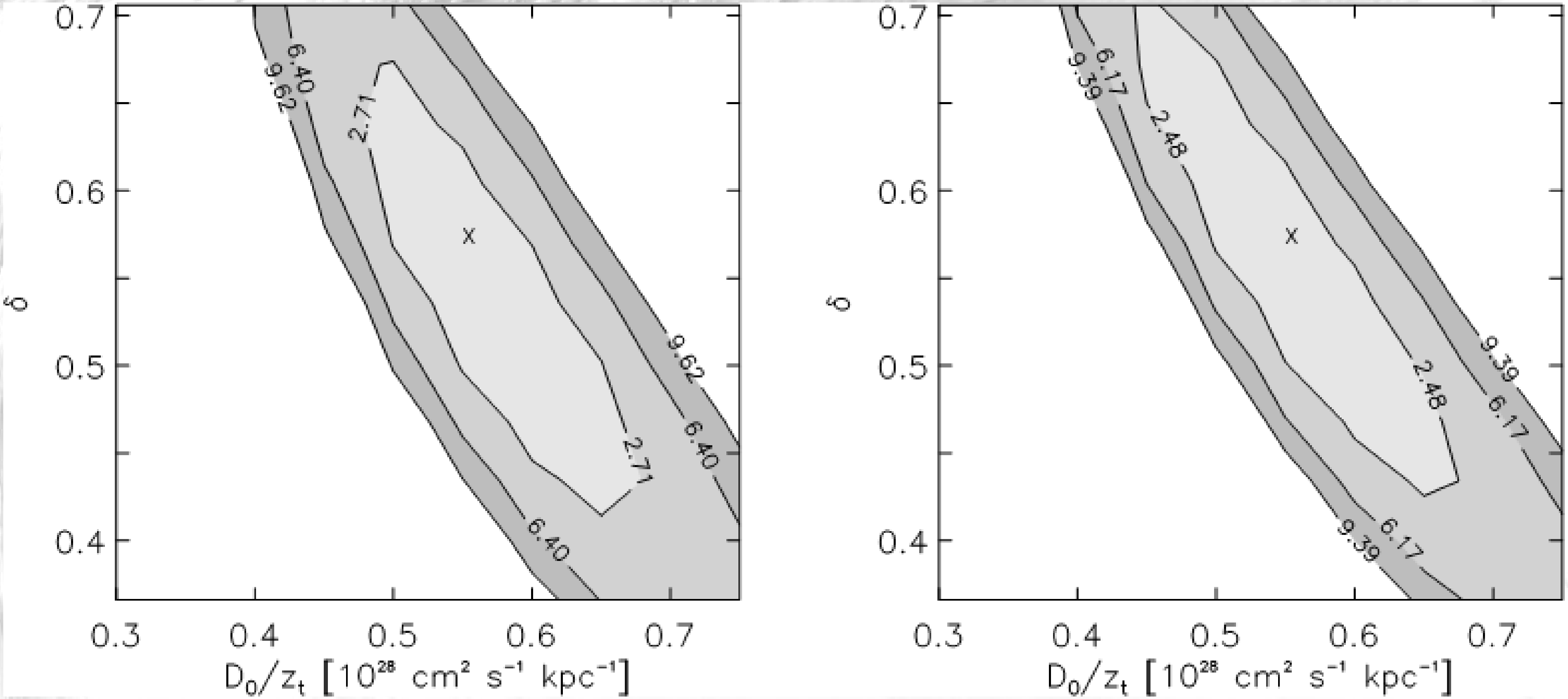
This equation can be solved numerically in a cylindrical slab geometry with suitable boundary conditions.

DRAGON, a new numerical tool for solving the propagation equation has been developed in Evoli, Gaggero, Grasso, Maccione, JCAP 0810, 018 (2008) and ArXiv:0907.3289, 0909.4548.

Analytical Greens function approaches have also been used, e.g. by Delahaye et al., arXiv:0809.5268.

Out of the resulting electron/positron distribution one can compute synchrotron emission (and also inverse Compton scattering) along any line of sight.

Parameter values in propagation equation are partially constrained by nuclear abundances and lead to different propagation models that lead to flux predictions in a given source scenario.



Evoli, Gaggero, Grasso, Maccione, JCAP 0810, 018 (2008)

χ^2 distribution in the diffusion coefficient normalization D_0, its scale height z_t, and the slope δ of its energy dependence resulting from B/C, C/O and N/O data

Propagation parameters have been studied in much detail also in the context of a Markov chain Monte Carlo by Putze et al., arXiv:0808.2437

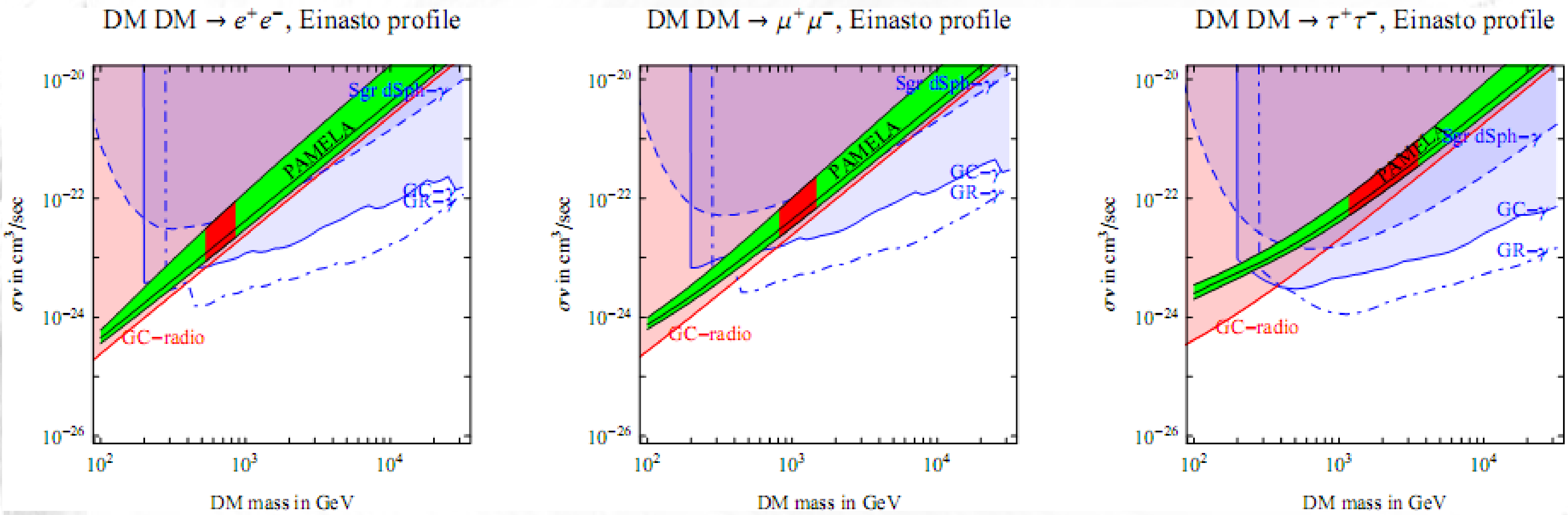
Main Points and Results:

Annihilating Dark Matter with the standard thermal relic annihilation cross section needs a “boost factor” of a few hundred in order to reproduce the positron data. This could be either a velocity-dependent resonance in the cross section (e.g. Sommerfeld enhancement) or increased annihilation rates due to dark matter “clumps”

In order not to overproduce at the same time the anti-proton fluxes requires “leptophilic” dark matter.

The produced leptons can in turn lead to other constraints from synchrotron emission and inverse Compton scattering.

Radio and Gamma-Ray Constraints

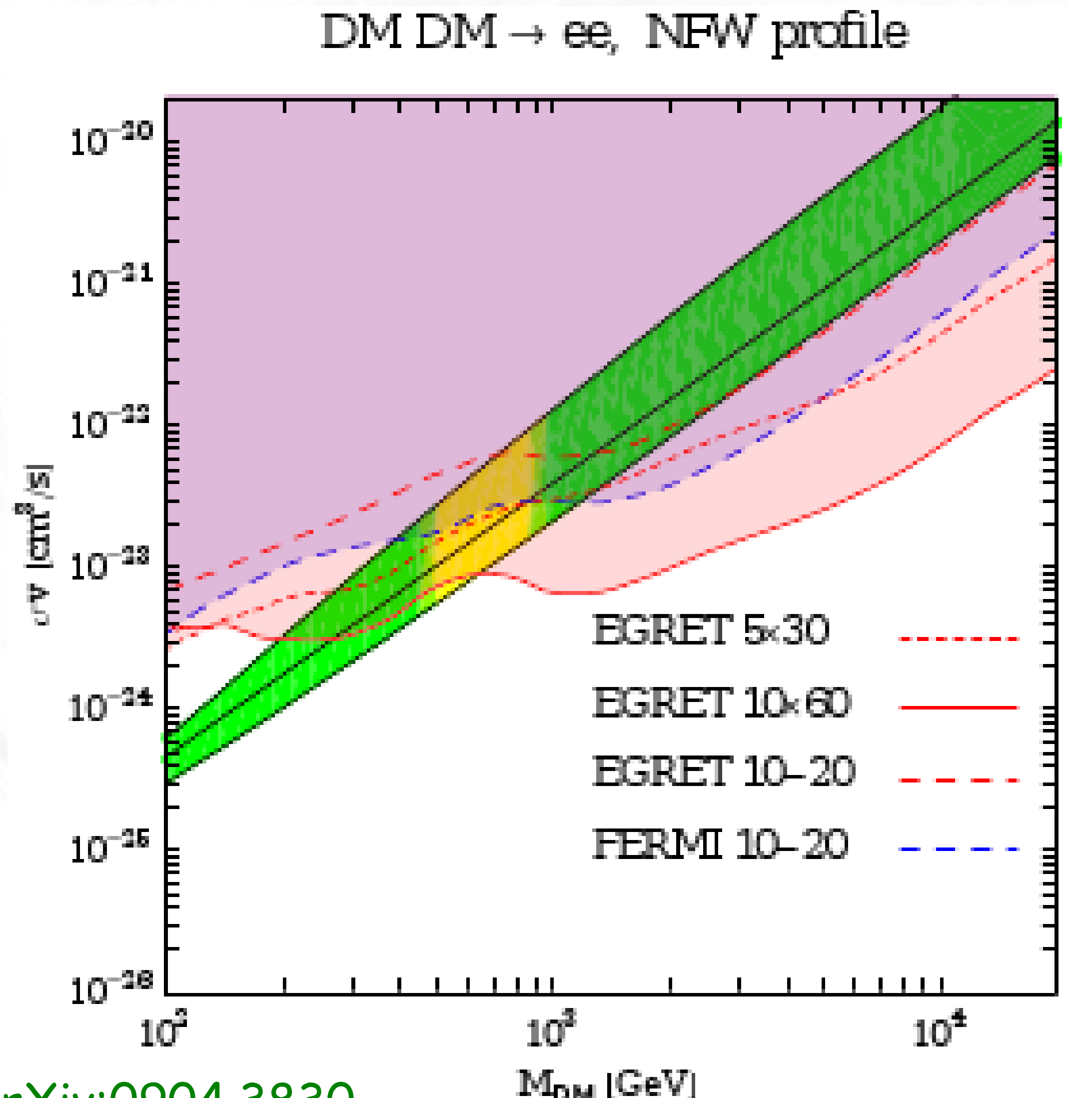


Bertone, Cirelli, Strumia, Taoso,JCAP 0903, 009 (2009)

Comparison of region favored by PAMELA (greenbands) and ATIC (red regions) with the bounds from HESS observations of the Galactic Center (blue continuous line), Galactic Ridge (blue dot-dashed), and SgrDwarf (blue dashed) and of observations of the Galactic Center at 408GHz (red lines) Dark matter annihilation channels as indicated at top, unit boost and Sommerfeld factors assumed.

Extragalactic constraints have been considered in
Kawasaki, Kohri, Nakayama, Phys.Rev.D80, 023517 (2009)

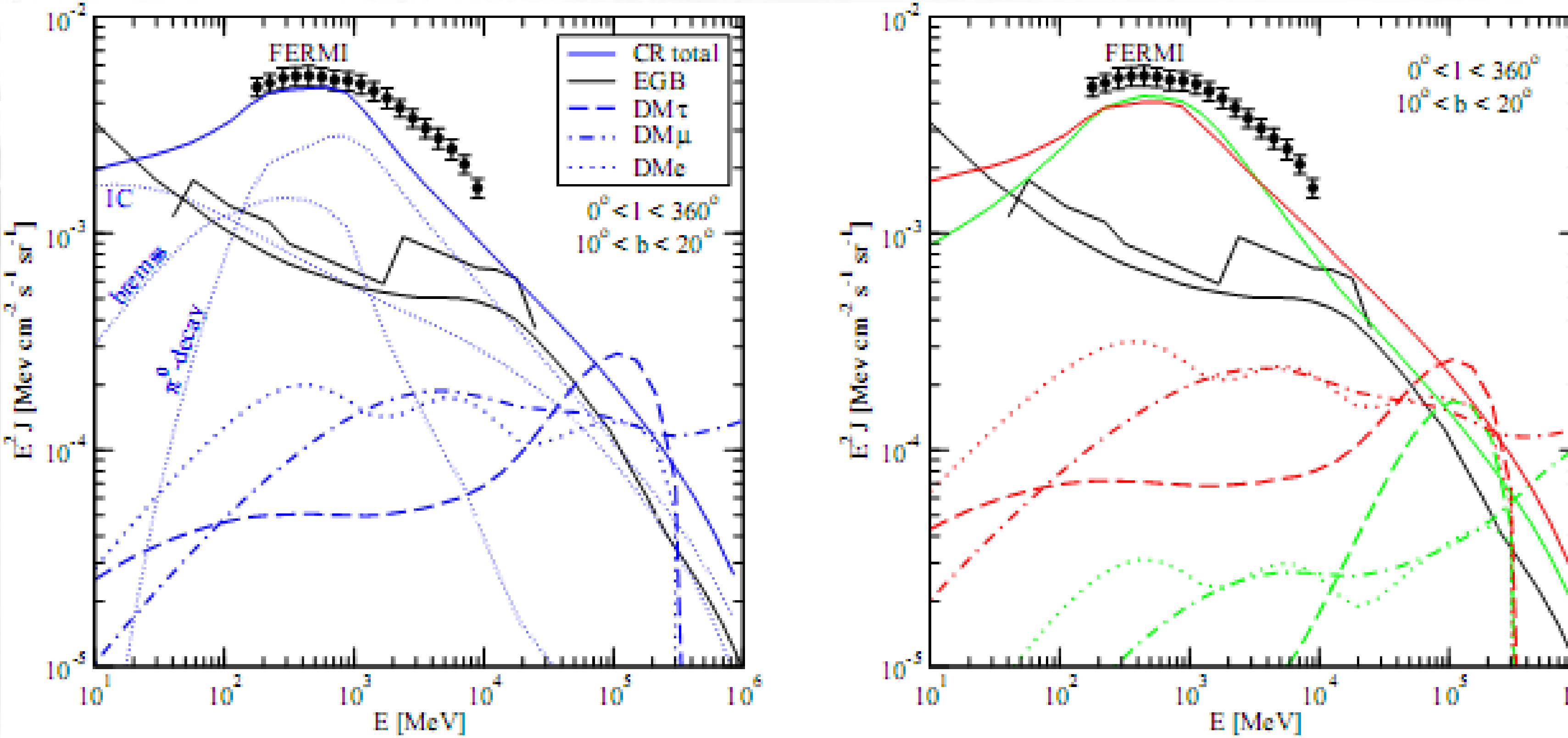
Constraints from Inverse Compton Scattering



Cirelli, Panci, arXiv:0904.3830

Significant constraints result from comparing inverse Compton scattering fluxes with EGRET and FERMI data on **Galactic Fluxes**.

Detailed tests of the dark matter hypothesis with the galactic diffuse γ-ray emission, have been performed also by
Regis and Ullio, Phys.Rev.D80, 043525 (2009):

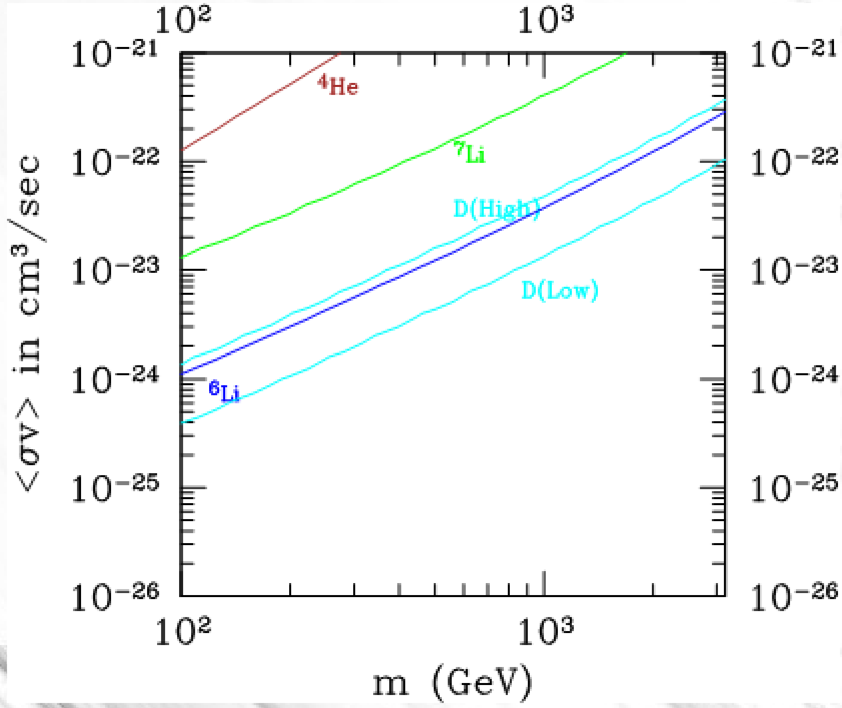


Diffuse γ-spectrum at galactic latitudes between 10° and 20° compared to FERMI LAT data. Left: Cosmic ray primary and secondary contributions of different channels (dotted) and sum (solid). Black=extragalactic from model and EGRET. Other lines: various dark matter annihilation channels Right: dependence on propagation model for charged primaries

Furthermore, neutrinos produced in dark matter annihilation or decay start to become constrained by Super-Kamiokande and may be Detected by kilometer-scale future neutrino experiments, as pointed out in
Hisano, Kawasaki, Kohri, Nakayama, Phys.Rev.D79, 043516 (2009).

Dark matter annihilation cross sections can also be constrained by their effects on BBN and light element abundances, see
Hisano, Kawasaki, Kohri, Moroi, Nakayama, Phys.Rev.D79, 083522 (2009):

For annihilation into W^+W^- pairs

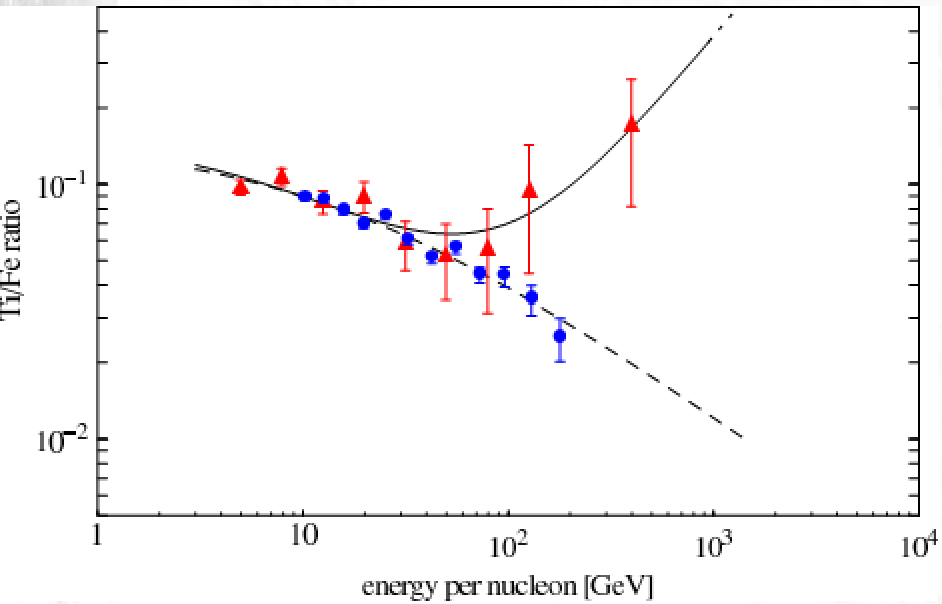


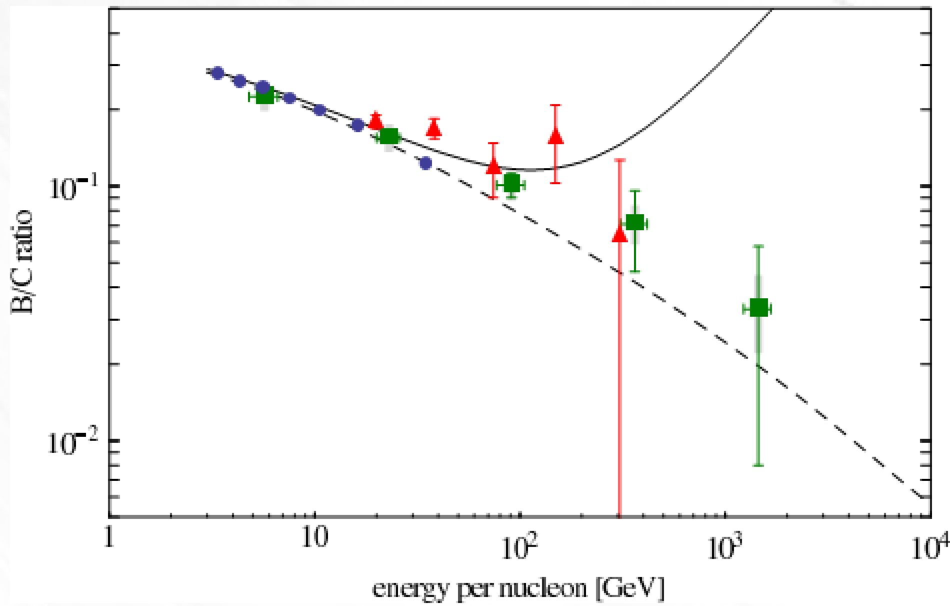
Astrophysical Interpretations of PAMELA positron excess

Possibility 1: Direct production of positrons by nearby pulsars

Possibility 2: Indirect production from pion decay during acceleration of hadronic cosmic rays

Abundances of secondary hadronic cosmic rays could distinguish between Dark matter and astrophysical origin,
e.g. Mertsch and Sarkar, Phys.Rev.Lett.103, 081104 (2009)

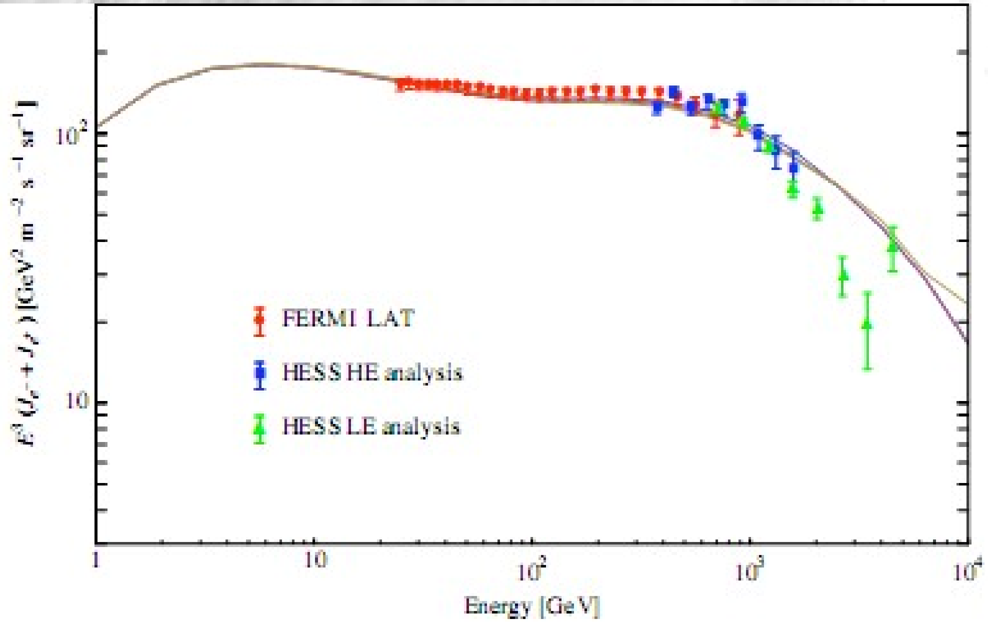




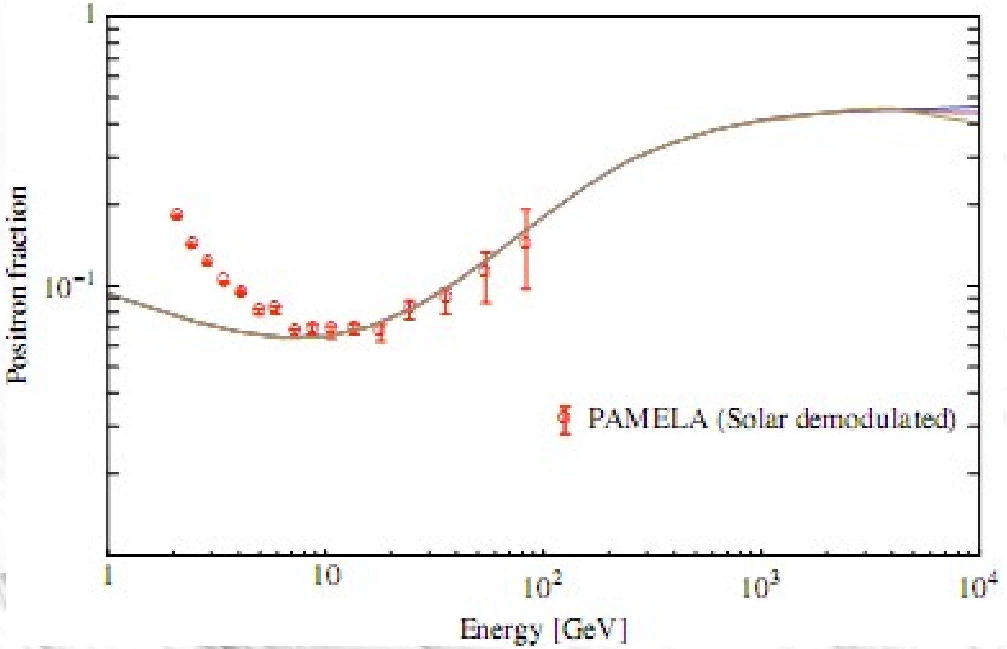
Secondary nuclei from propagation only (dashed) versus including production and acceleration in sources (solid)

Primary electrons and secondary positrons accelerated in galactic supernova remnants can fit electron and positron data:

Ahlers, Mertsch, Sarkar arXiv:0909.4060



Secondary production rate in supernova remnants was normalized to γ-ray fluxes and diffusion rate parameter normalized to FERMI LAT and HESS observation of electron+ positron flux



Conclusions

1.) Many activities on the origin of cosmic rays and related topics at several participant labs.

2.) Cross-connections to dark matter activities via indirect detection by annihilation products, many activities triggered by recent PAMELA, ATIC and FERMI LAT data

3.) ESR Philipp Mertsch at Oxford was working on astrophysical origin of positron excess observed by PAMELA.