Anisotropy of UHECR from extragalactic sources

Peter TINYAKOV
ULB, Brussels & INR, Moscow

Igor TKACHEV
CERN & INR, Moscow

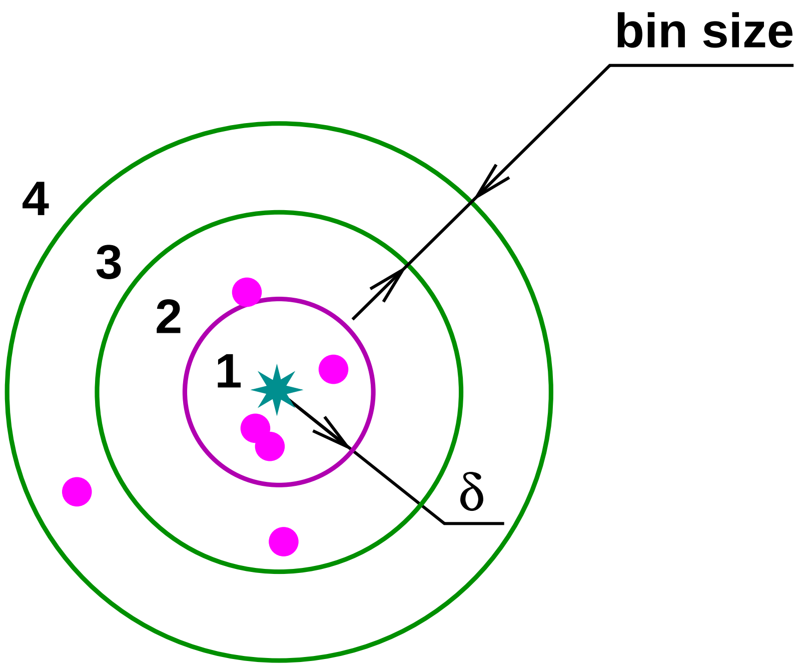
OUTLINE

- Searching for sources by statistical methods
- Correlations with BL Lacs in AGASA and Yakutsk data
- HiRes correlations and predictions for other experiments
- Trying to explain HiRes results by the standard physics

Searching for sources by correlation analysis

Algorithm ("source stacking"):

- Draw angular bins around all sources
- Count the total number of events N_i in the i-th bin
- Perform the same for many random sets and get $\bar{N}_i$, σ_i
- $f_i = (\bar{N}_i - N_i)/\sigma_i$ characterizes the value and significance of the excess/deficit in the corresponding bin



For point sources one may directly calculate the probability $P(\delta)$ of the excess in the first bin

Points to be careful about:

* Every independent trial reduces the significance (introduces a penalty factor)

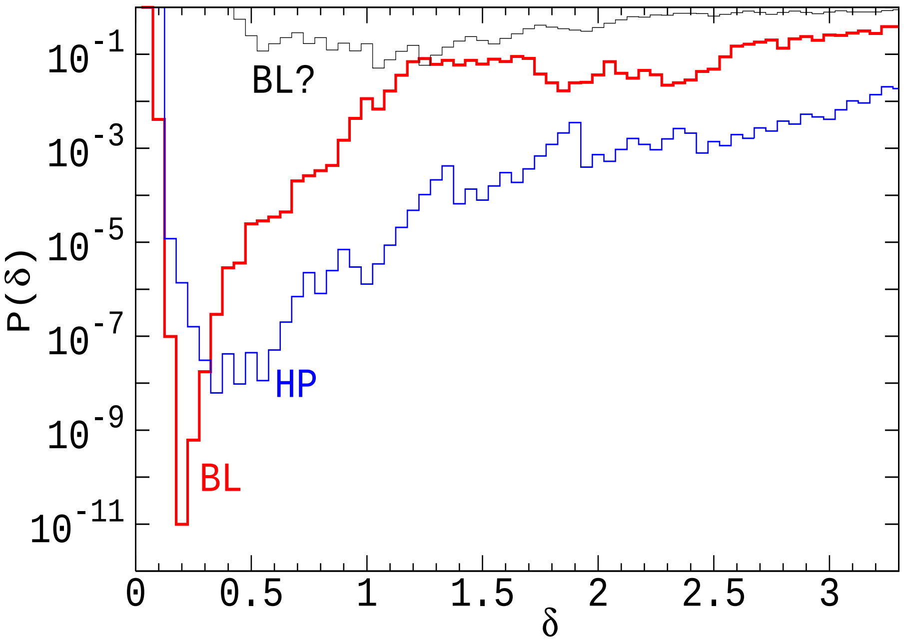
* Penalty introduced by adjustable cuts has to be simulated

* Adjusting the bin size is an important source of penalty; for point sources this may be avoided by taking the optimum bin size from simulations

* Factors beyond control $\Longrightarrow$ the crucial check is the blind test

Example: proof that BL Lacs are surces of the high-energy EGRET photons

Gorbunov, PT, Tkachev, Troitsky
Mon.Not.R.Asrtron.Soc.(2005)

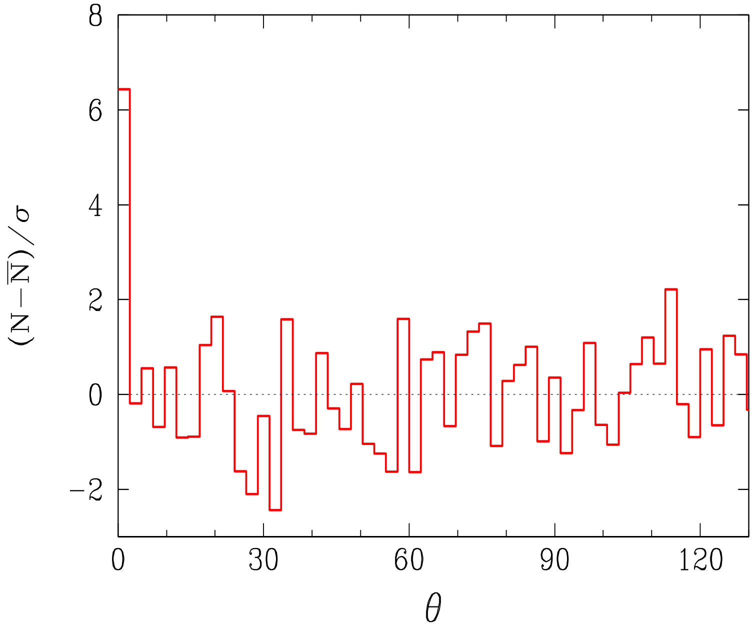


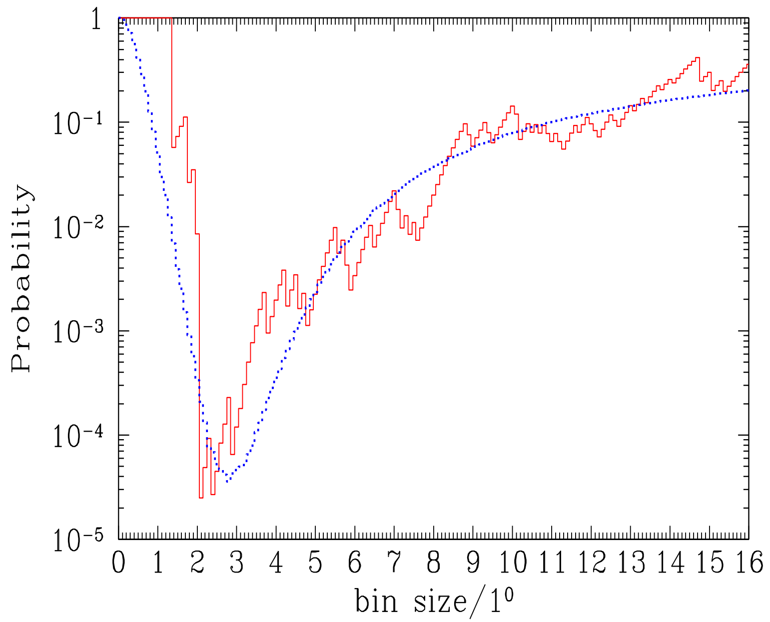
– 613 photons with $E > 10$ GeV (resolution $\sim 0.35°$)
– 178 confirmed BL Lacs
– 47 HP
– 81 unconfirmed BL Lacs

BL Lacs: 8 coincidences at 0.37 expected

Correlations with BL Lacs in AGASA and Yakutsk data

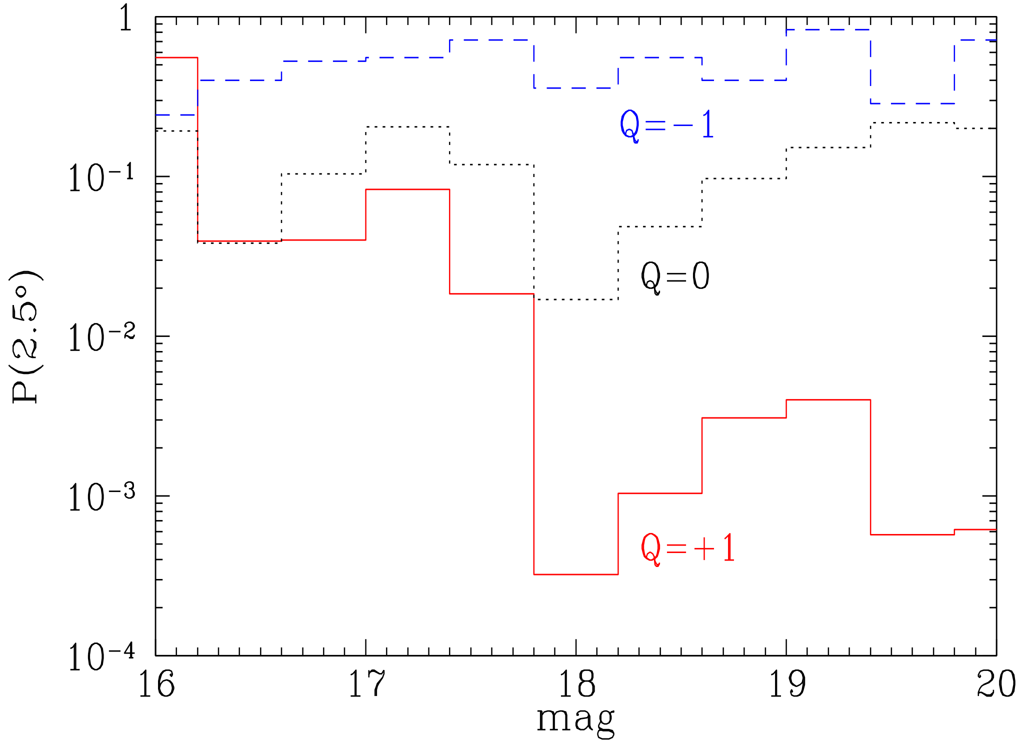
PT, Tkachev JETP Lett.(2001)





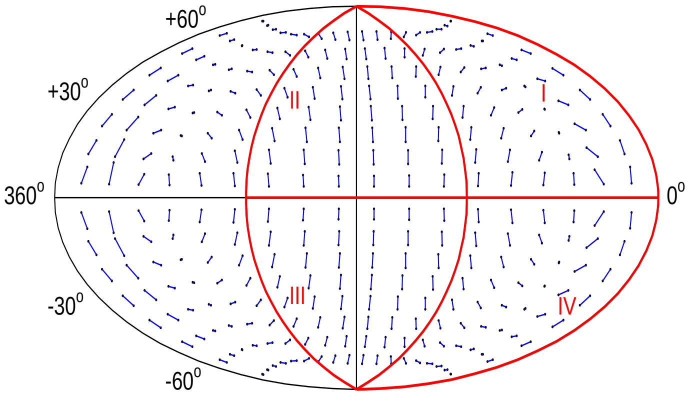
39 AGASA + 26 Yakutsk events vs. 22 brightest BL Lacs

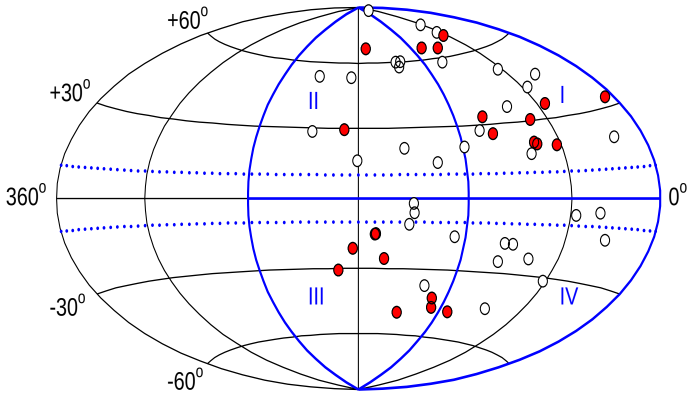
PT, Tkachev, Astropart.Phys.(2002)

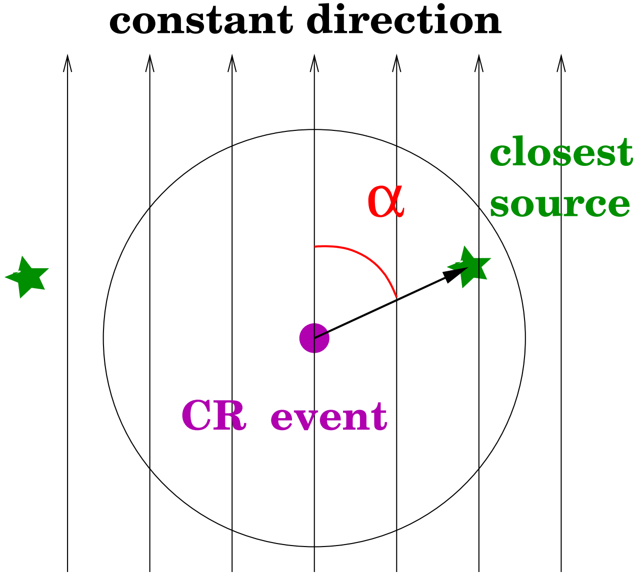


AGASA events $E > 4 \times 10^{19}$ vs. confirmed BL Lacs (with the correction for GMF)

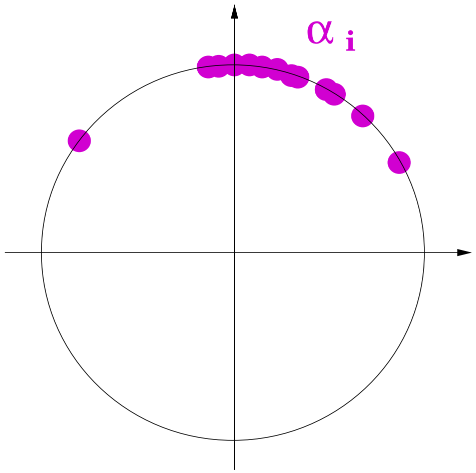
There are regions of coherent deflections:

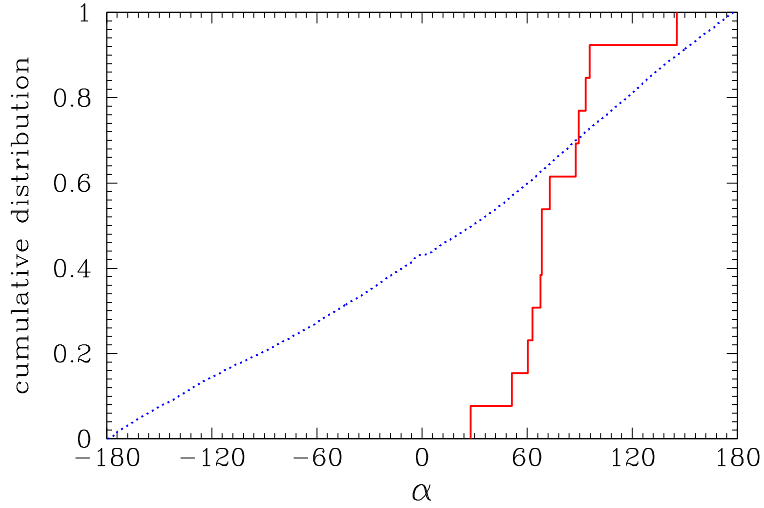






- Choose small patch on the sky (region where deflections due to GMF are expected to be coherent)
- For a given CR, find closest BL Lac within 10° (discard CR if there are none)
- Find angle α between direction CR$\rightarrow$BL and fixed direction
- Compare distribution of α's with that obtained for random CRs

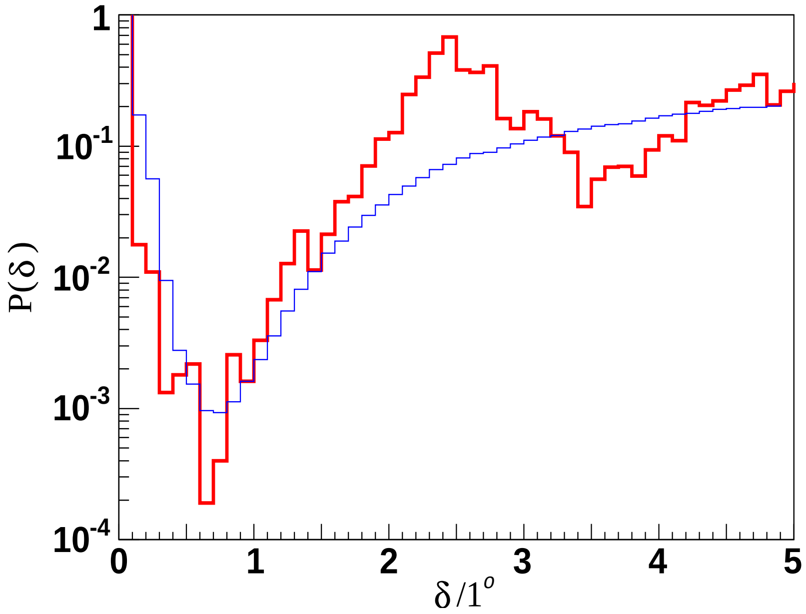




KS test: observed (red) and random (blue) distributions of angles α_i differ significantly, $p_{\rm chance} \sim 10^{-4}$

Correlations in HiRes stereo data & predictions for future experiments

Gorbunov, PT, Tkachev, Troitsky JETP Lett.(2004)
Abbasi et al. Astrophys.J.(2006)



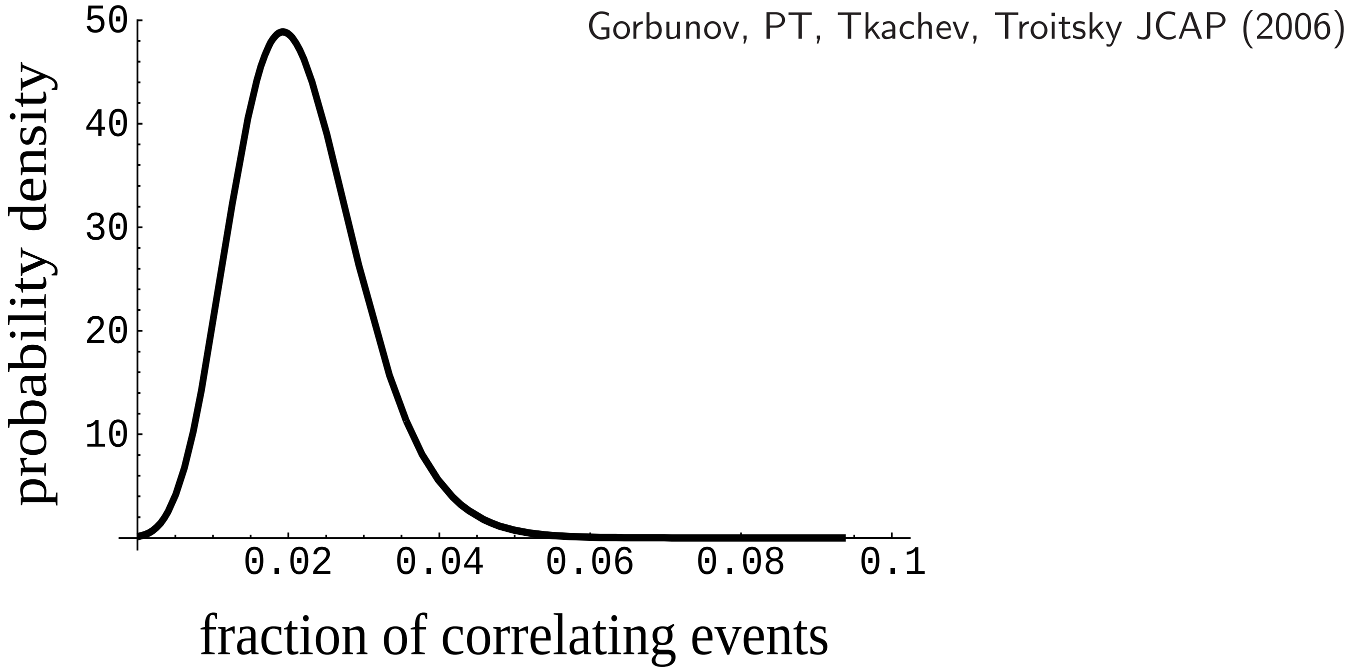
156 confirmed BL Lacs with mag < 18

271 HiRes stereo event with angular resolution of $0.6°$

red: data
blue: MC simulation

At $0.8°$: 11 coincidences at ~ 3 expected $\Longrightarrow P \sim 4 \times 10^{-4}$

Estimate of the signal



At 95% C.L. the fraction η of correlating events is

$$1.5\% < \eta < 3.5\%$$

Predictions

Assume: set of 156 BL Lacs is uniform (this may not be the case!)

$$\left.\begin{array}{r}\text{angular resolution}\\ \text{acceptance}\\ \text{number of events}\end{array}\right\} \Longrightarrow \text{expected number of correlating events}$$

Experiment	σ	F
HiRes (stereo)	$0.6°$	1.38
AGASA	$2.4°$	1.37
PAO (surface)	$1.4°$	0.53
PAO (hybrid)	$0.6°$	0.48
TA (surface)	$1.55°$	1.41
TA (hybrid)	$0.62°$	1.51

Experiment	$\sqrt{2}\sigma$	N	S	B	$\Delta n_{95\%}$	N_0
HiRes, original	$0.85°$	271	7.46	3.54		
HiRes (stereo)	$0.85°$	190	5.23	2.48	1-17	271
AGASA	$3.39°$	1500	43.4	310	308-417	3870
PAO (surface)	$1.98°$	8000	87.9	216	239-413	3517
PAO (hybrid)	$0.85°$	2000	24.8	9.10	15-66	467
TA (surface)	$2.19°$	8000	239	710	785-1235	1560
TA (hybrid)	$0.88°$	2000	58.6	30.3	47-161	277

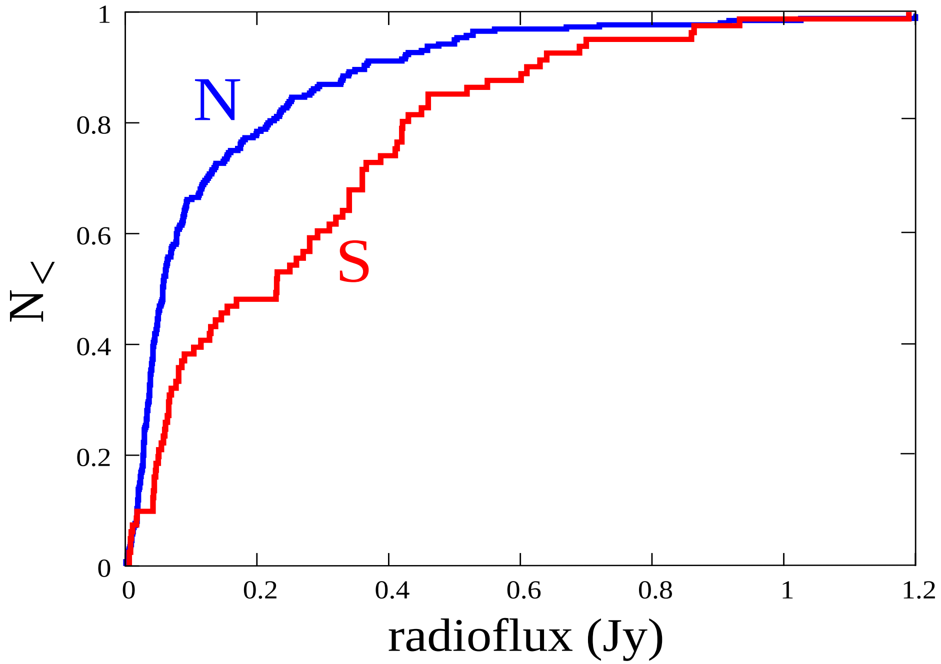
S — events from sources

B — chance coincidences

$\Delta n_{95\%}$ — 95% interval for the number of coincidences

N_0 — number of events needed to match sensitivity of HiRes

Caveat (in case of PAO):
Southern and Northern BL Lacs may be different!



Distributions in radio flux are different: $P_{KS} \sim 10^{-6}$

Searching for SM explanation of HiRes correlations

PT, Tkachev astro-ph/0612359

Assume:

- Energies are measured correctly
- Primary particles are neutral

  (at $E = 10^{19}$ eV, $B = 1\ \mu\text{G}$, $L = 1$ kpc deflection is $\theta \sim 5^\circ$)
- their fraction η is of order 1%
- Sources are at $\gtrsim 400$ Mpc

To cross the Galactic magnetic field a particle must be long-living

$$\tau > 10\,\mathrm{s}\left(\frac{m}{1\mathrm{GeV}}\right)\left(\frac{10^{19}\mathrm{eV}}{E}\right)$$

SM candidates:

— neutrino
— photon
— neutron
— atoms

Photons do not reach the Earth from 400 Mpc at $E \sim 10^{19}$ eV

Neutrinos as primaries are excluded by shower development

Atoms form slowly and disintegrate fast $\Longrightarrow$ their fraction is small

$$R_{\rm formation} \sim 10^{-5} \frac{1}{\rm Mpc}.$$

$$R_{\rm decay} \sim 100 \frac{1}{\rm Mpc}.$$

Neutron

* Weak reaction $p + \bar{\nu} \to n + e^+$ on neutrino background is too weak,

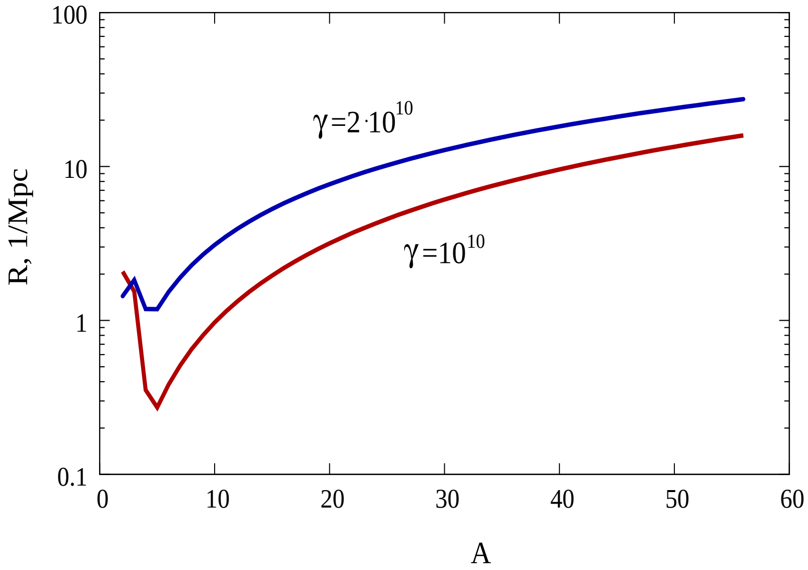
$$R \sim 3 \times 10^{-12} \frac{1}{\text{Mpc}}$$

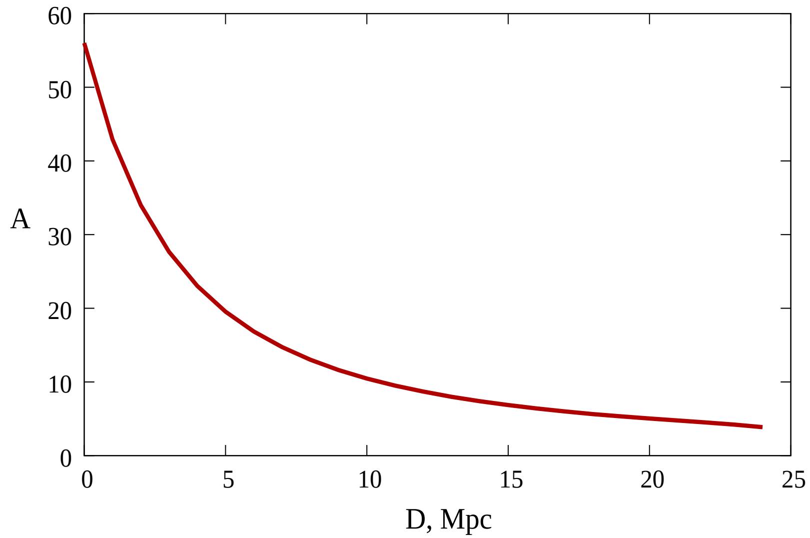
* Nuclei photodisintegration

$$A \to A' + \#n + ...$$

could produce neutrons if it occurs within 100kpc from Earth ...

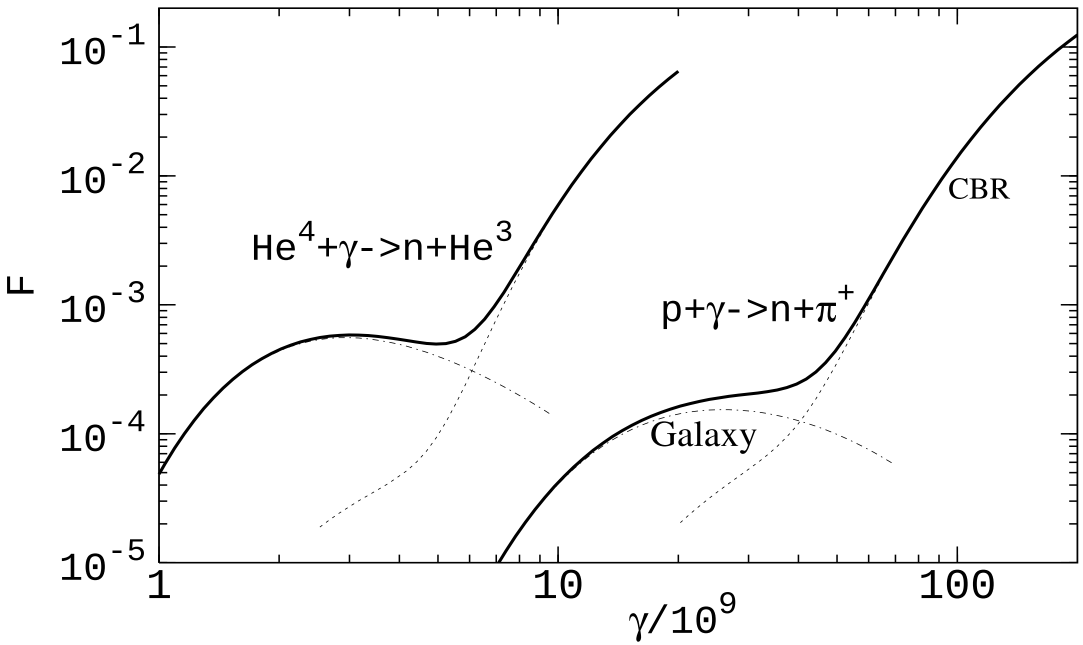
… but the problem is the distance to the source: nuclei cannot reach us





Neutrons by pion photoproduction on Galactic IR

$$p + \gamma_{\rm IR} \to n + \pi^+$$



$\Longrightarrow$ nearly two orders of magnitude too small

CONCLUSIONS

- Statistical methods of source identification do work
- BL Lac correlations: blind test is needed
- If confirmed, correlations in HiRes data will be a problem for the Standard Model physics