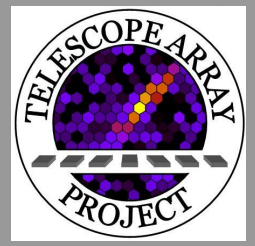
TA ANISOTROPY SUMMARY

P. Tinyakov,
for the **Telescope Array Collaboration**



TELESCOPE ARRAY COLLABORATION

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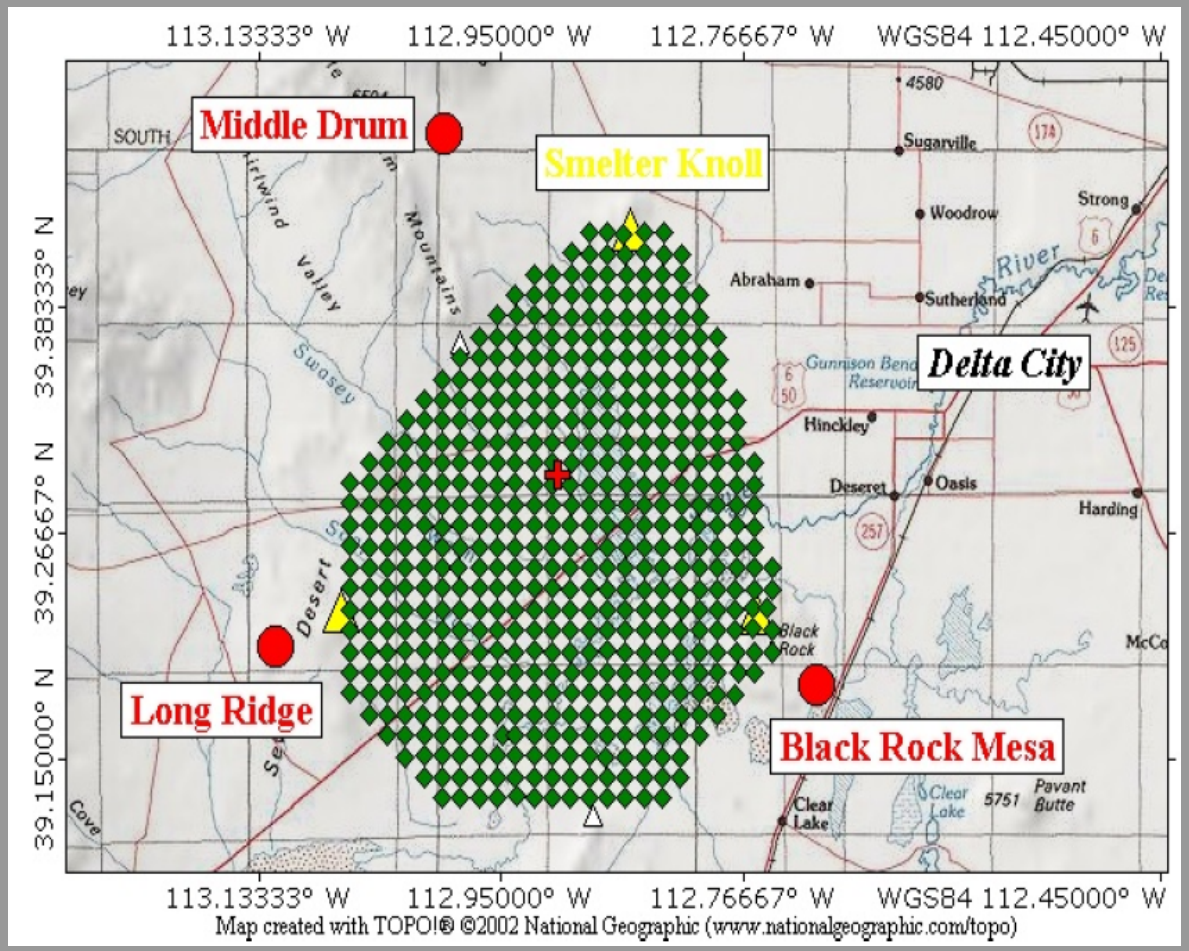
TA HYBRID DETECTOR

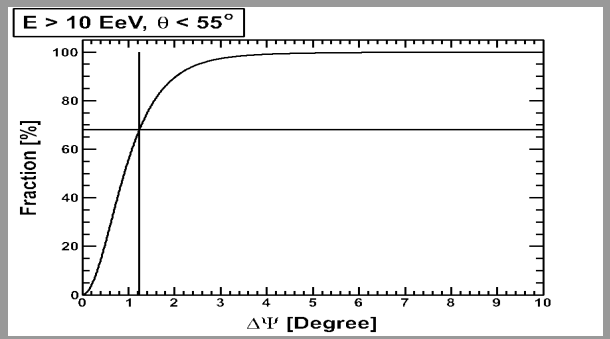


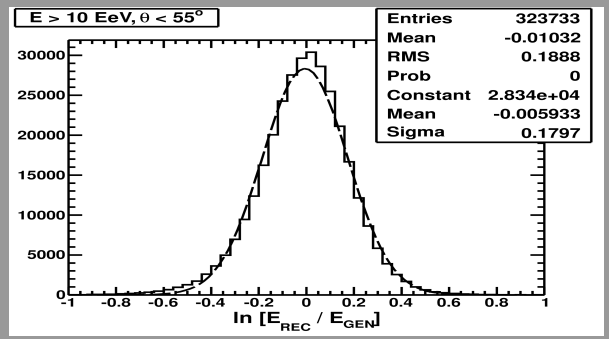
- 507 scintillator detectors covering 680 km^2
- 3 fluorescence sites, 38 telescopes
- SD fully operational from March 2008

TELESCOPE ARRAY PROJECT

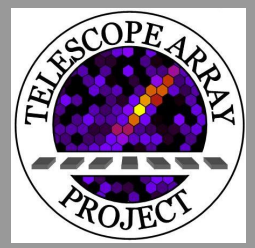
Anisotropy data set (SD)

- covers the period 12.05.2008 — 11.05.2015 (full 7 years)
- zenith angle up to 55°, loose border cut
- geometrical acceptance; exposure $\sim$ 8700 km^2 yr sr
- 2996 above 10 EeV
- 210 above 40 EeV
- 83 above 57 EeV
- angular resolution: better than 1.5°
- energy resolution: $\sim$ 20%





GLOBAL DISTRIBUTIONS



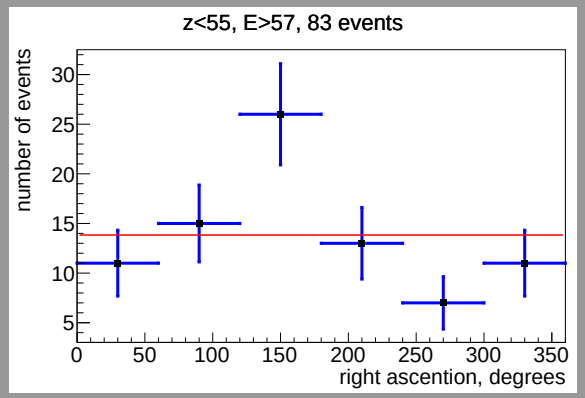
Comparison with isotropic distribution by KS test

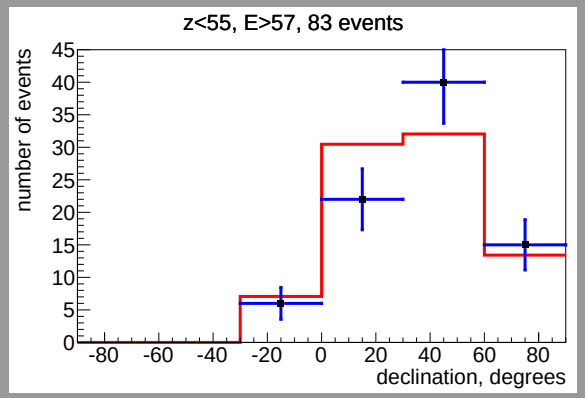
- Low energy sets $E > 10$ EeV and $E > 40$ EeV are compatible with isotropy; the smallest KS p-value is 0.12.

- $E > 57$ EeV

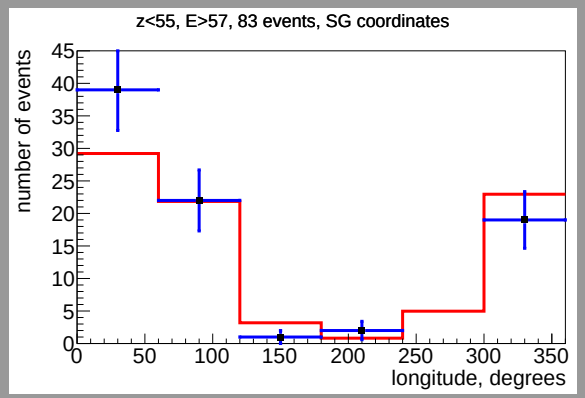
Frame	longitude	latitude
Equatorial:	0.07	0.04
Supergalactic:	0.01	0.03

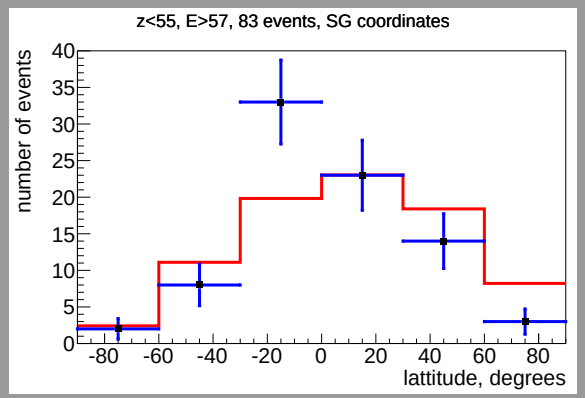
equatorial:

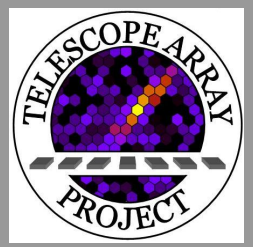




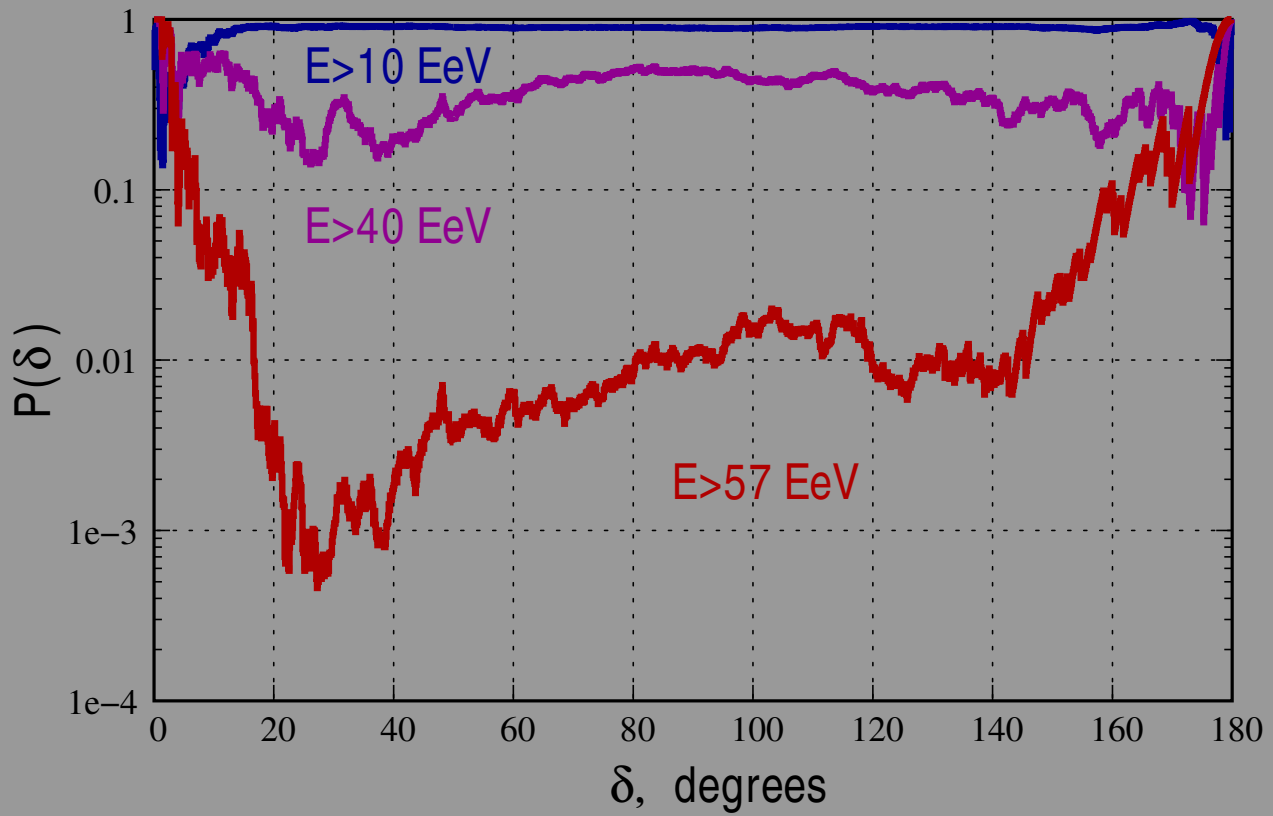
supergalactic:







AUTOCORRELATION FUNCTION

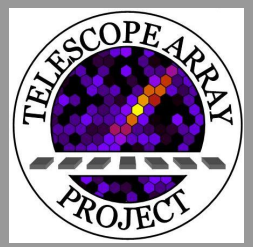


- count number of pairs separated by the angle δ
- compare to isotropic distribution; plot *p*-value as a function of the separation angle

- compatible with isotropy at $E > 10$ EeV and $E > 40$ EeV
- tension at $E > 57$ EeV

HOT SPOT

K. Kawata, ICRC-2015, CR3 0107

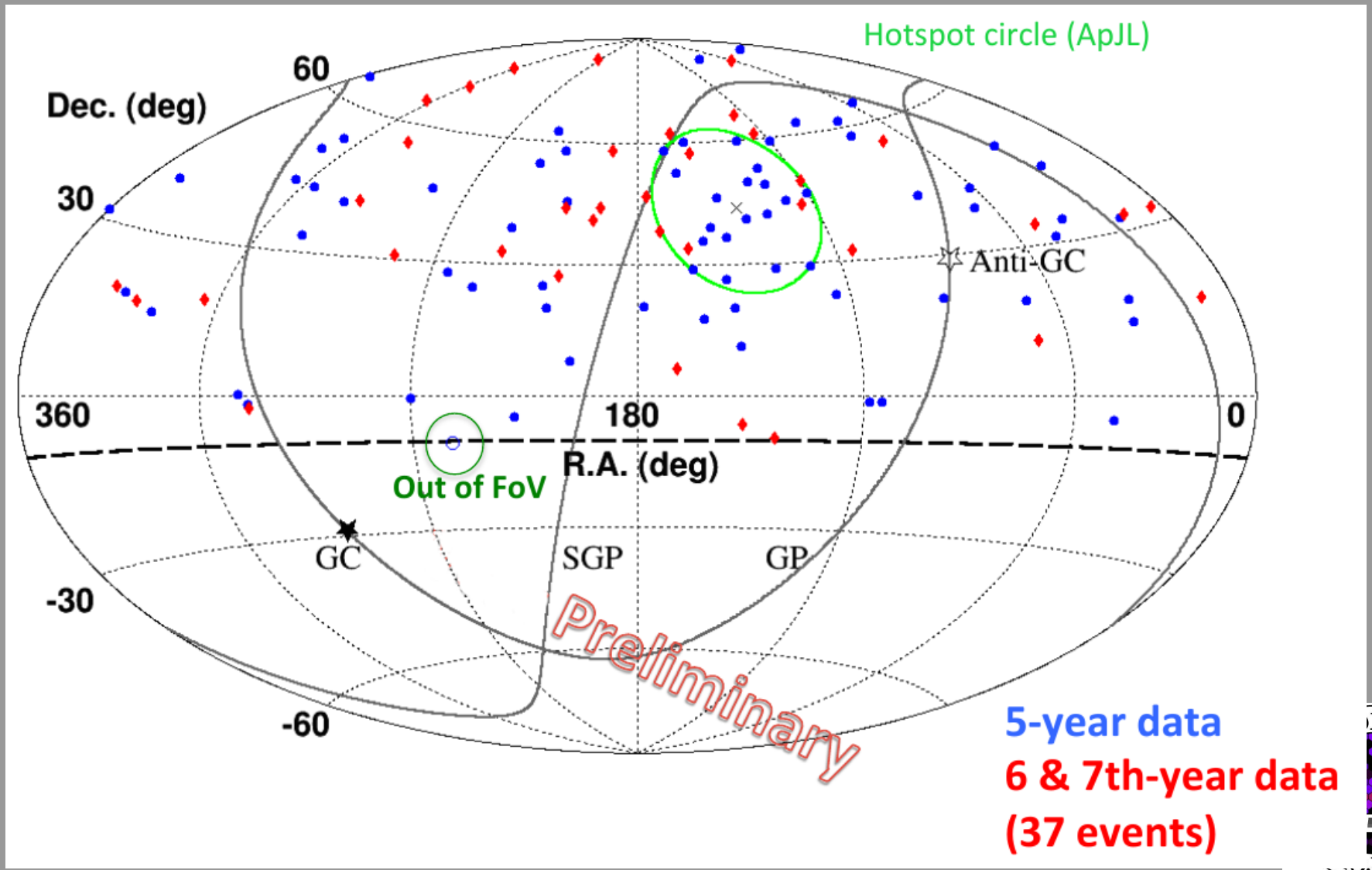


Hot spot in 5 yr data [ApJ 790:L21 (2014)]

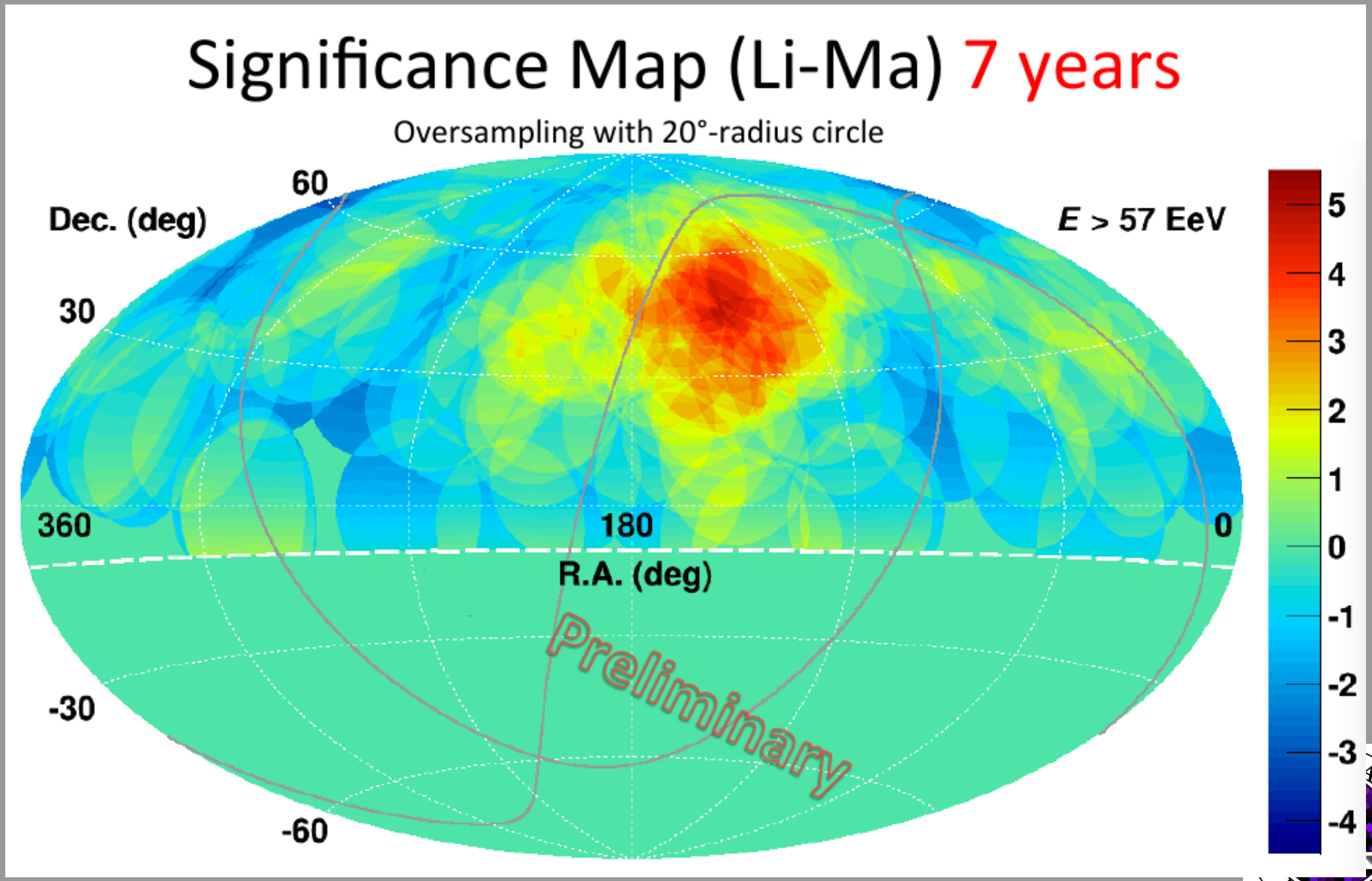
- Reconstruction with even looser cuts optimized for statistics (72 events above 57 EeV in 5 yr).
- "Hot spot" within the circle of radius 20° centered at $\mathrm{RA} = 146°$, $\mathrm{Dec.} = 43°$.
- After accounting for arbitrary position and opening angles 15°, 20°, 25°, 30°, 35° the significance is 3.4σ post-trial (5.1σ pre-trial).

HOT SPOT: 7 yr update

Same cuts as for 5yr; 109 events with $E > 57$ EeV in 7yr set



HOT SPOT: 7 yr update



HOT SPOT: 7 yr update

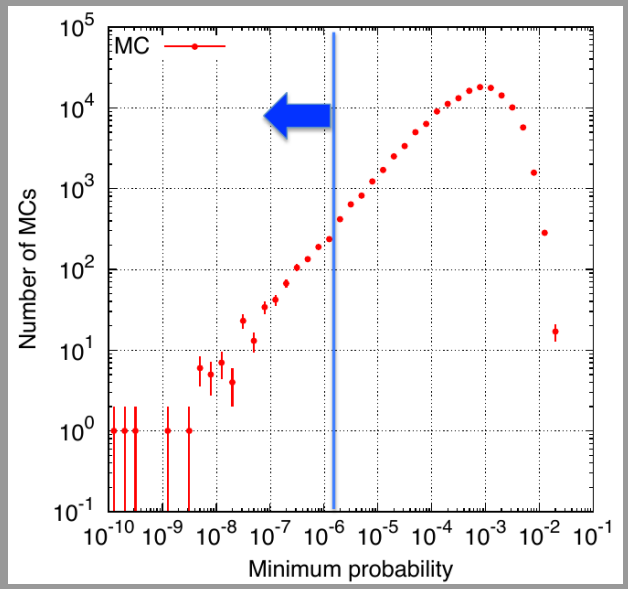
Significance (same procedure as for 5 yr):

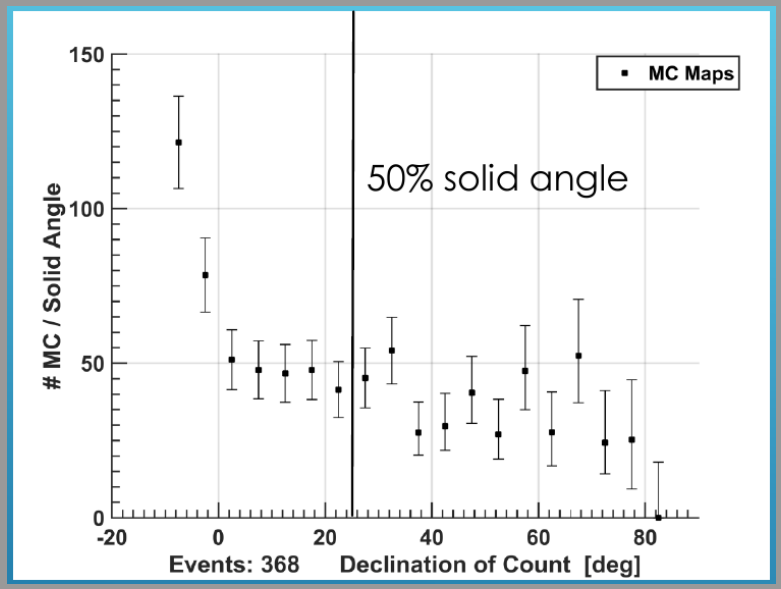
- oversampling at 15°, 20°, 25°, 30°, 35°, moving center
- Pre-trial: $P = 5.07\sigma$; $N_{\rm on} = 24$; $N_{\rm bg} = 6.88$;
  Post-trial $P = 3.7 \times 10^{-4}$ (3.4σ)
  $\Longrightarrow$ same as for 5 yr

- Blind search with 2yr data (6th and 7th yr):
  expected in the spot region 2.31, observed 4, $P = 0.2$

HOT SPOT: 8 yr update is on the way

- Increased statistics
- Improved significance estimate
  - A strange feature of penalty MC simulation is observed:



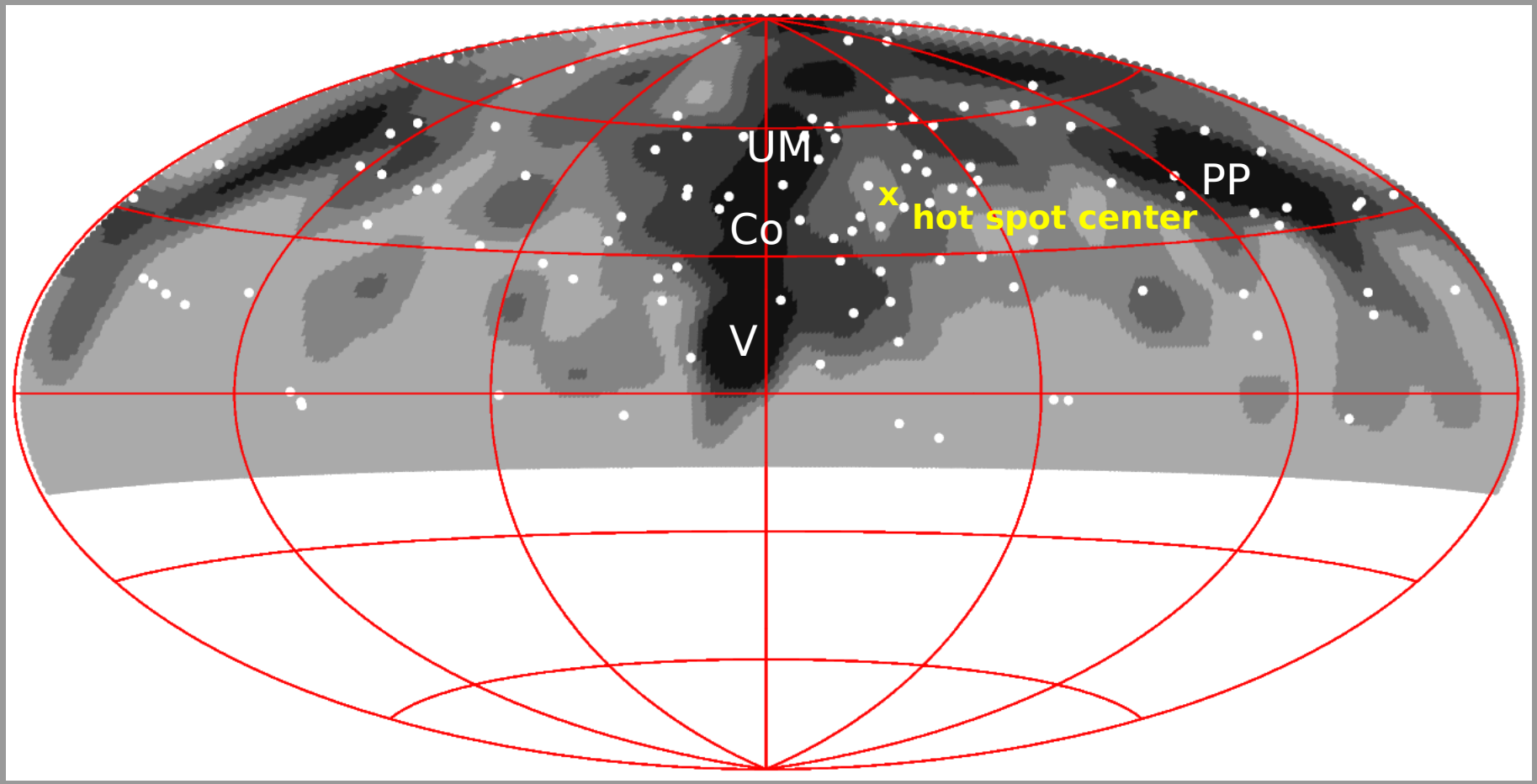


  - The math origin is understood and is harmless;
  - The p-value calculation is improved at small N_{ev}

$\Longrightarrow$ Very small changes in the final answer

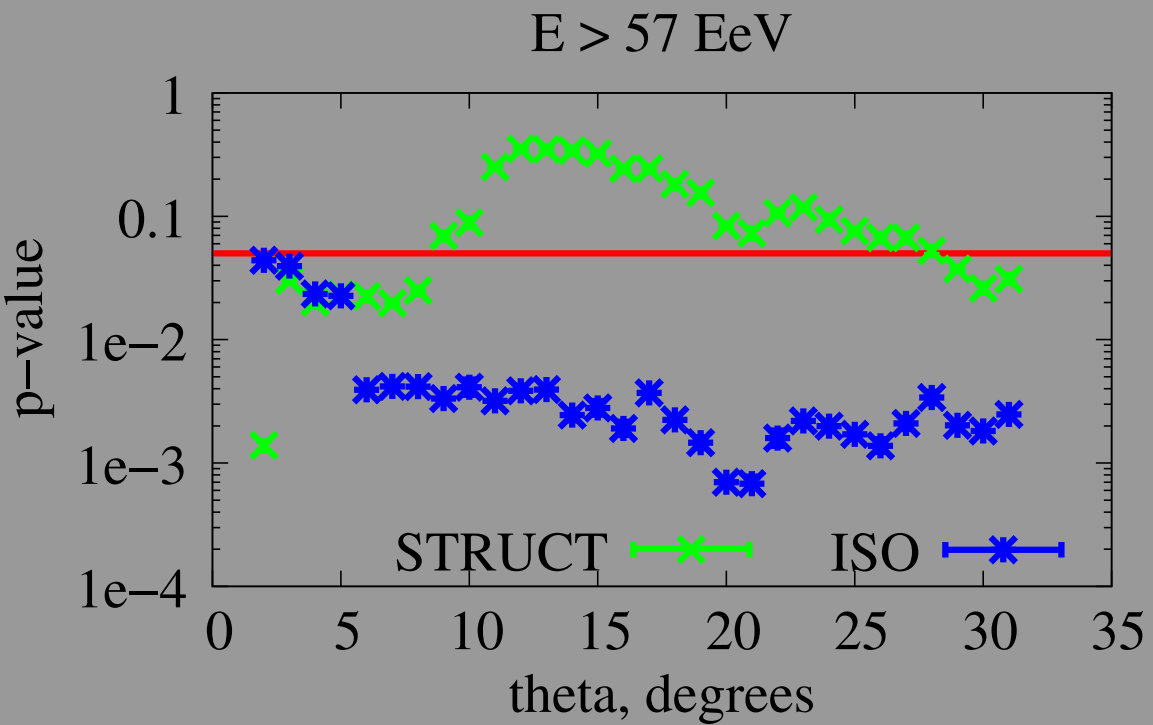
CORRELATION WITH LSS

7 yr events vs. LSS expectation (protons of 57 EeV)



Equatorial coordinates. Darker color represents larger flux. UM — Ursa Major; Co — Coma; V — Virgo; PP — Perseus-Pisces

Statistical test for compatibility with LSS & isotropy

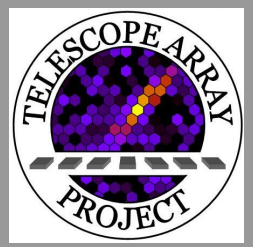


$E > 57$ EeV events are:

- COMPATIBLE with LSS
- IN TENSION with isotropy

Compatibility as a function of smearing angle theta (low p-values = incompatible).

OTHER SEARCHES



Anisotropy in energy spectrum [method 1]

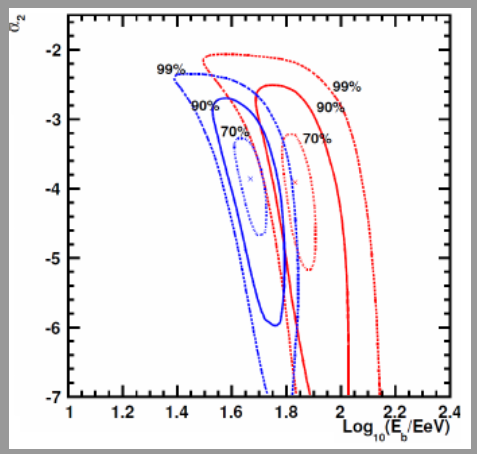
Details & update: see talk by T. Nonaka at this conference.

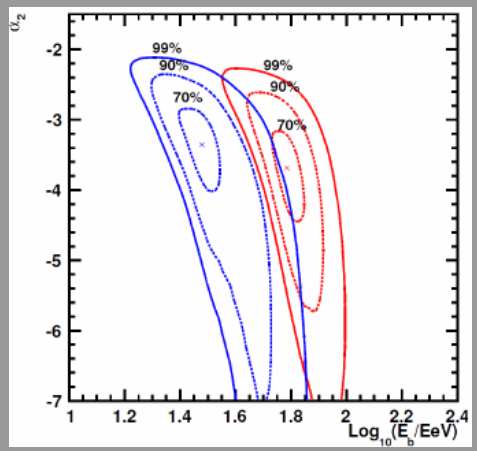
Strategy: *T. Nonaka, ICRC-2015, P1CR 233*

- Split the event set into “on-source” and “off-source” parts
- compare the “on-source” and “off-source” energy spectra

Two analyses:

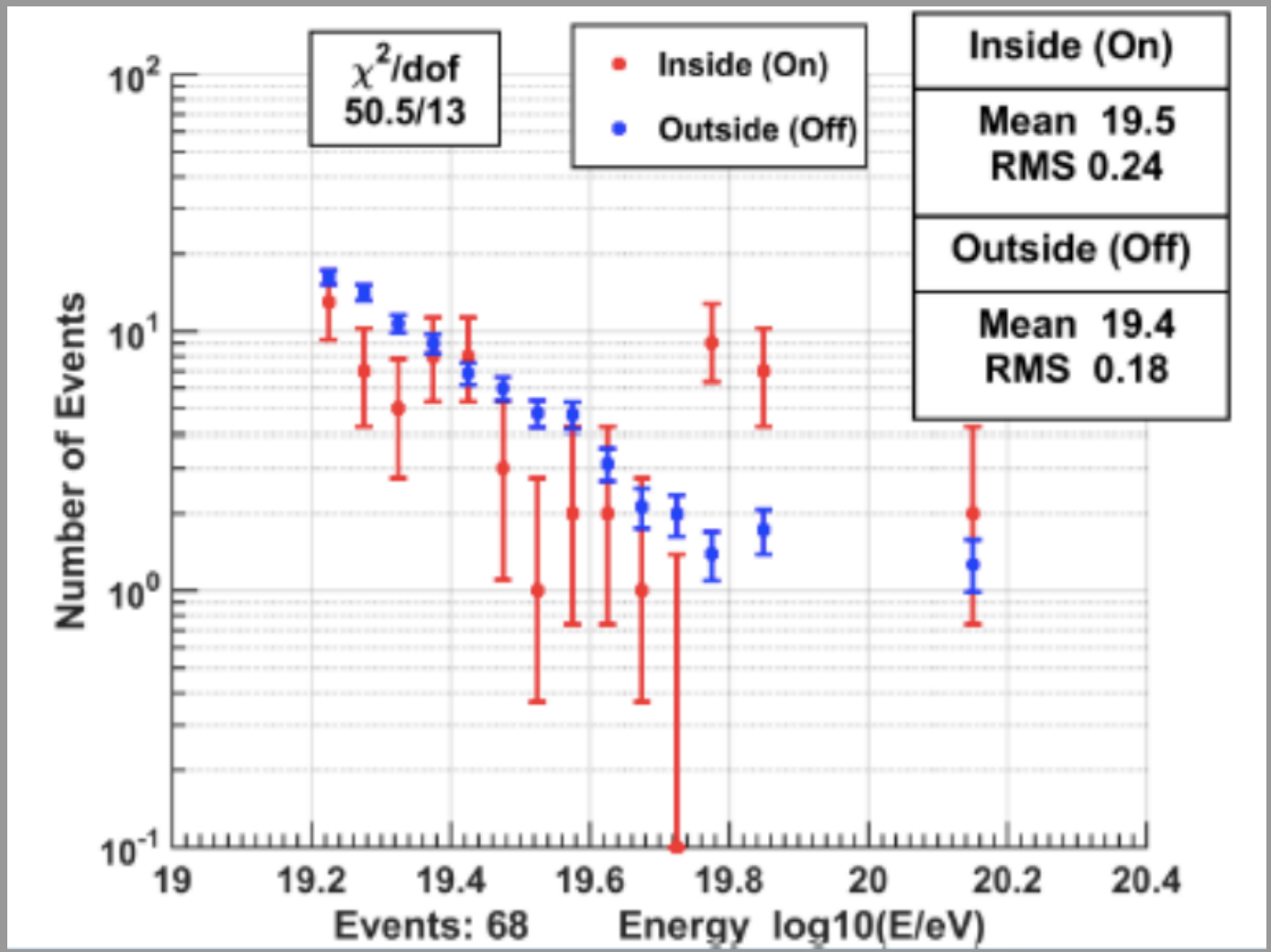
- “On-source” = within 30° from Supergalactic plane
  $\Longrightarrow \sim 3.2\sigma$ difference (post-trial)
- “On-source” = within 11° from VCV AGNs
  $\Longrightarrow \sim 2.4\sigma$ difference (post-trial)



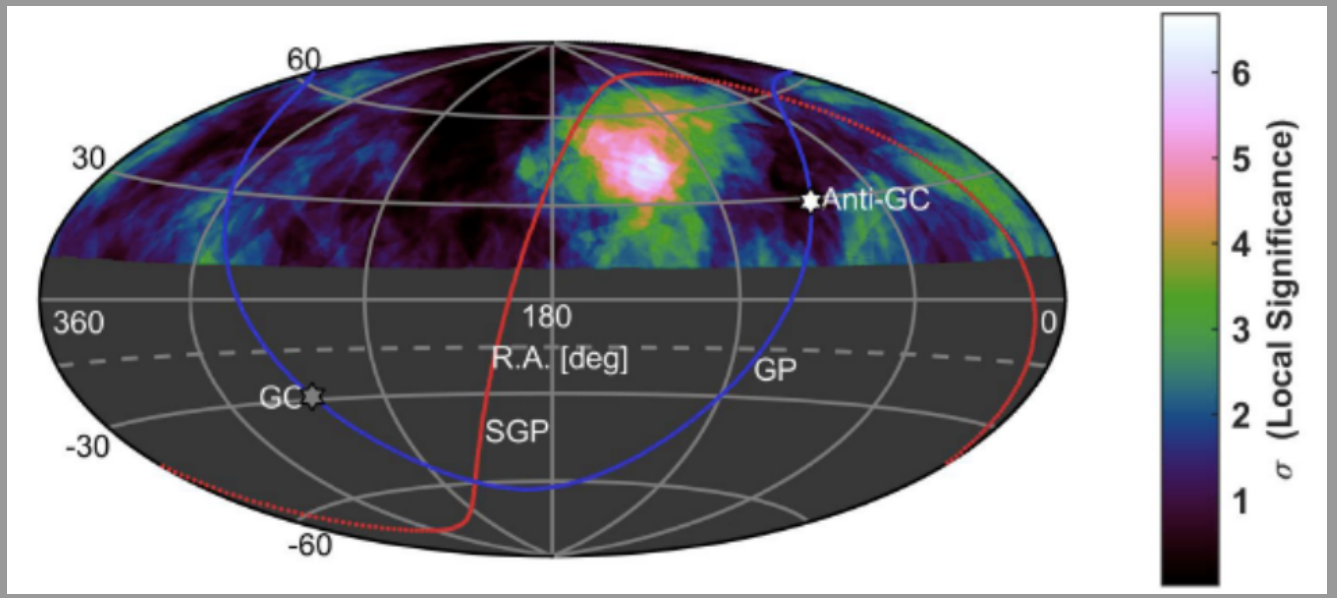


Anisotropy in energy spectrum [method 2]

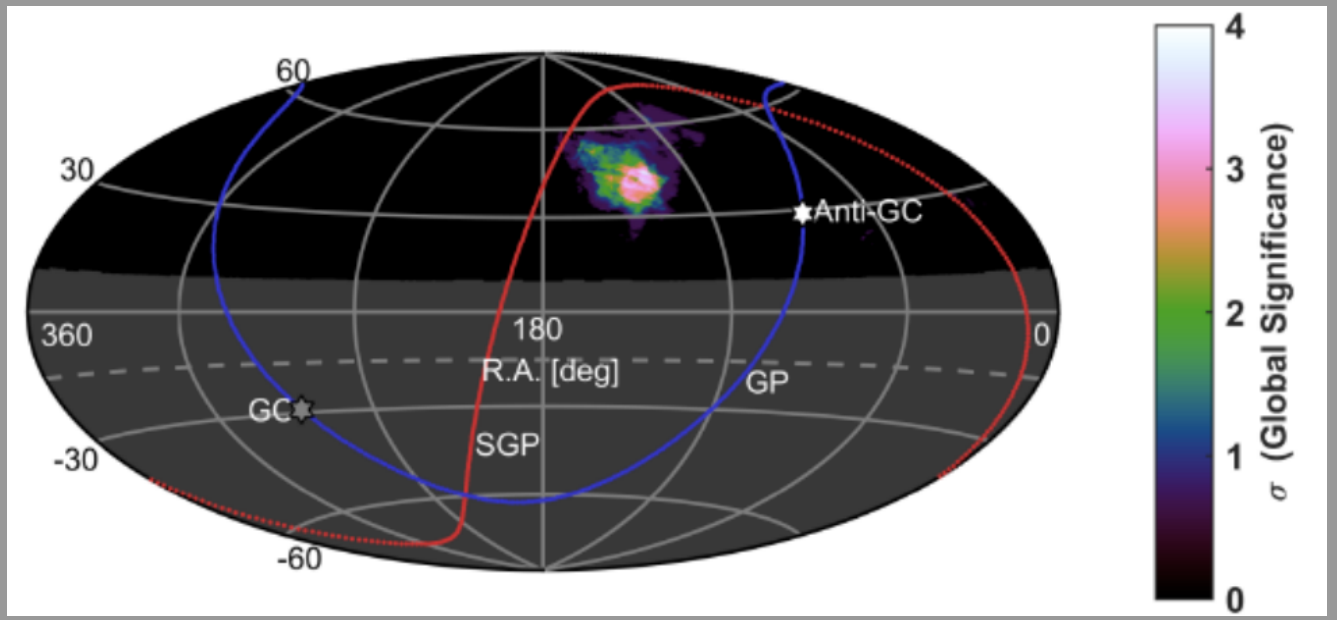
Spectral differences “on” and “off” the hot-spot region



Anisotropy in energy spectrum [method 2]



local: 6.7σ



global: $\sim 4.0\sigma$

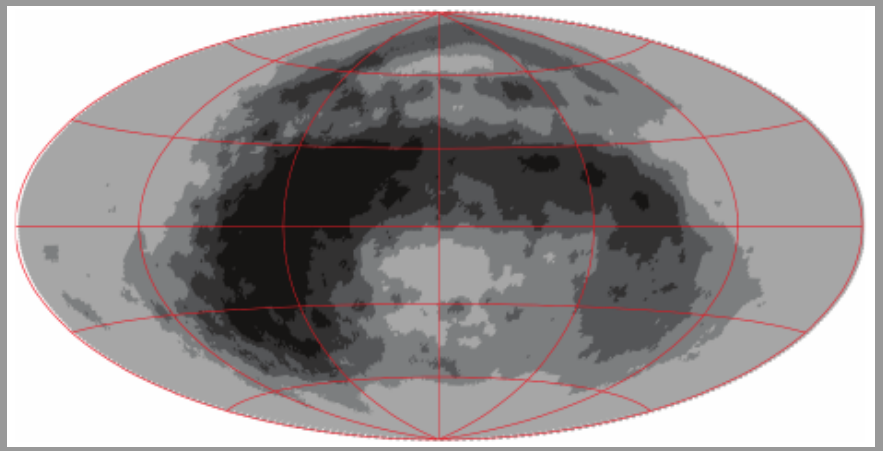
Search for EeV protons of Galactic origin

D. Ivanov et al, arXiv:1608.06306

Details & update: see poster by D.Ivanov at this conference.

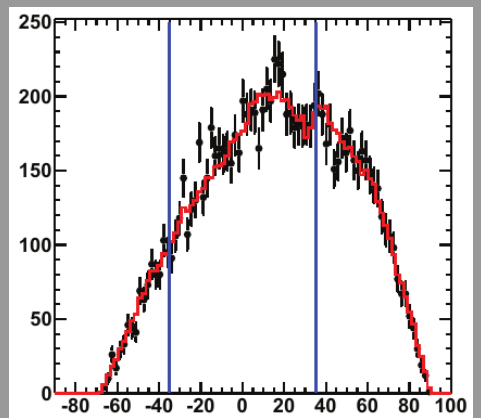
Motivation:

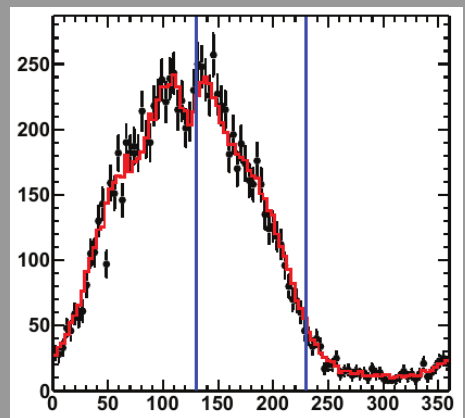
- At the transition from ballistic to diffusive regime ($E \sim 1$ EeV), one can predict the proton flux from galactic sources. It is *strongly anisotropic*.
- Comparing to observed flux, the proton component may be constrained.



Results:

- fraction of Galactic protons in ~ 1 EeV UHECR is $\lesssim 1\%$ at 90% CL.





COMBINED ANALYSES

- Auger + TA: Large-Scale Distribution of Arrival Directions of Cosmic Rays Detected at the Pierre Auger Observatory and the Telescope Array above 10^{19} eV

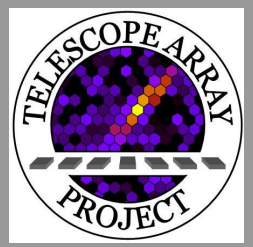
  Astrophys.J. 794 (2014) 172

  - update on harmonic analysis of combined data set at $E > 10^{19}$ eV
    $\Longrightarrow$ non-zero dipole @ 2.8σ

- IceCube + Auger + TA: Correlation between the UHECRs measured by the Pierre Auger Observatory and Telescope Array and neutrino candidate events from IceCube

  JCAP 1601 (2016) 037

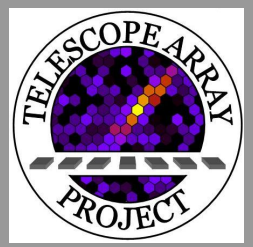
  - highest energy $E > 57$ EeV Auger + TA events vs. neutrinos
    $\Longrightarrow$ correlation @ 3.4σ



CONCLUSIONS

- Some hints on anisotropy of UHECR start to emerge:
  - dipole at low energies
  - “hot spot” in the GZK region
  - spectral variations over the sky

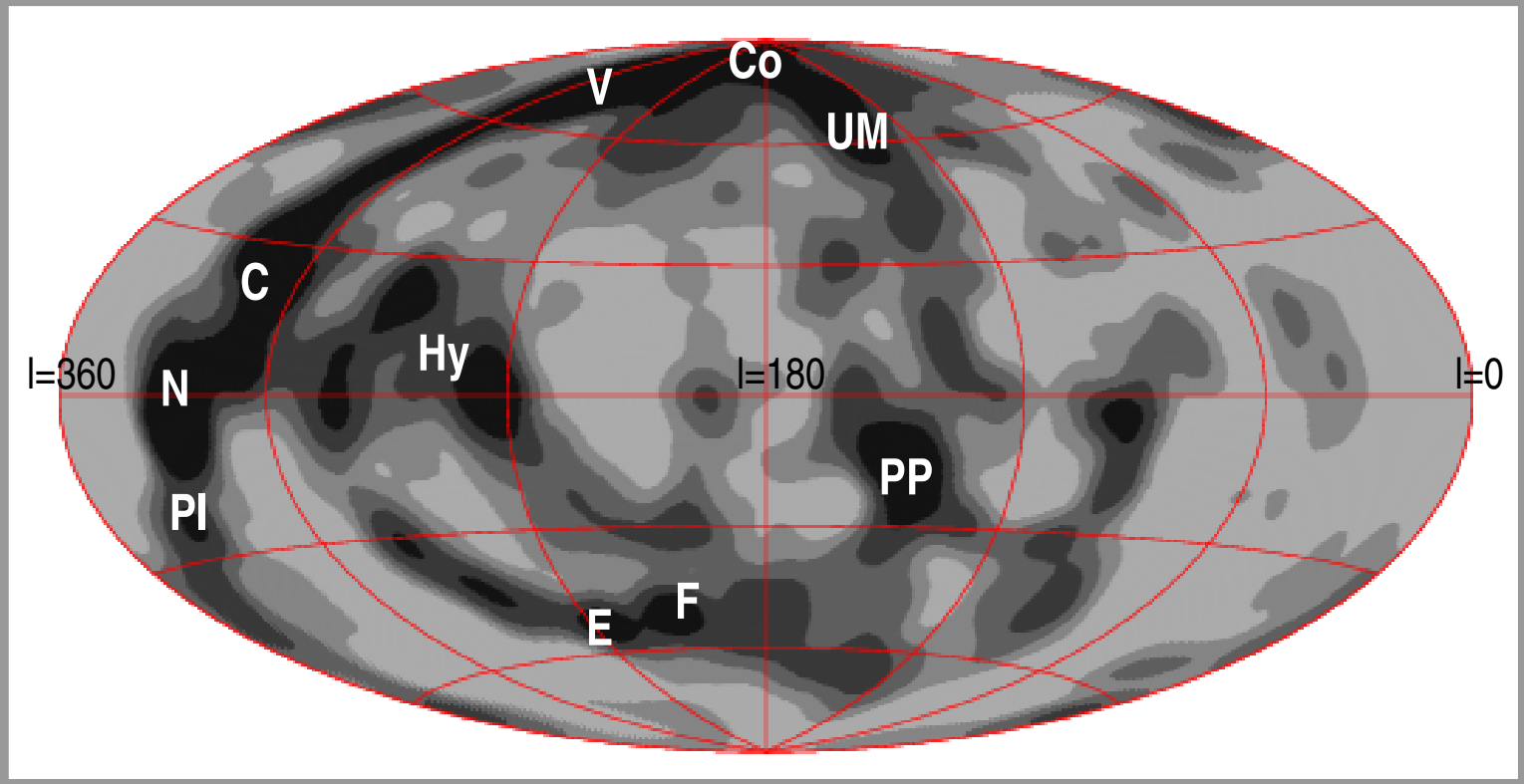
- HOWEVER: in all cases the significance is yet insufficient for a definite conclusion



BACKUP SLIDES

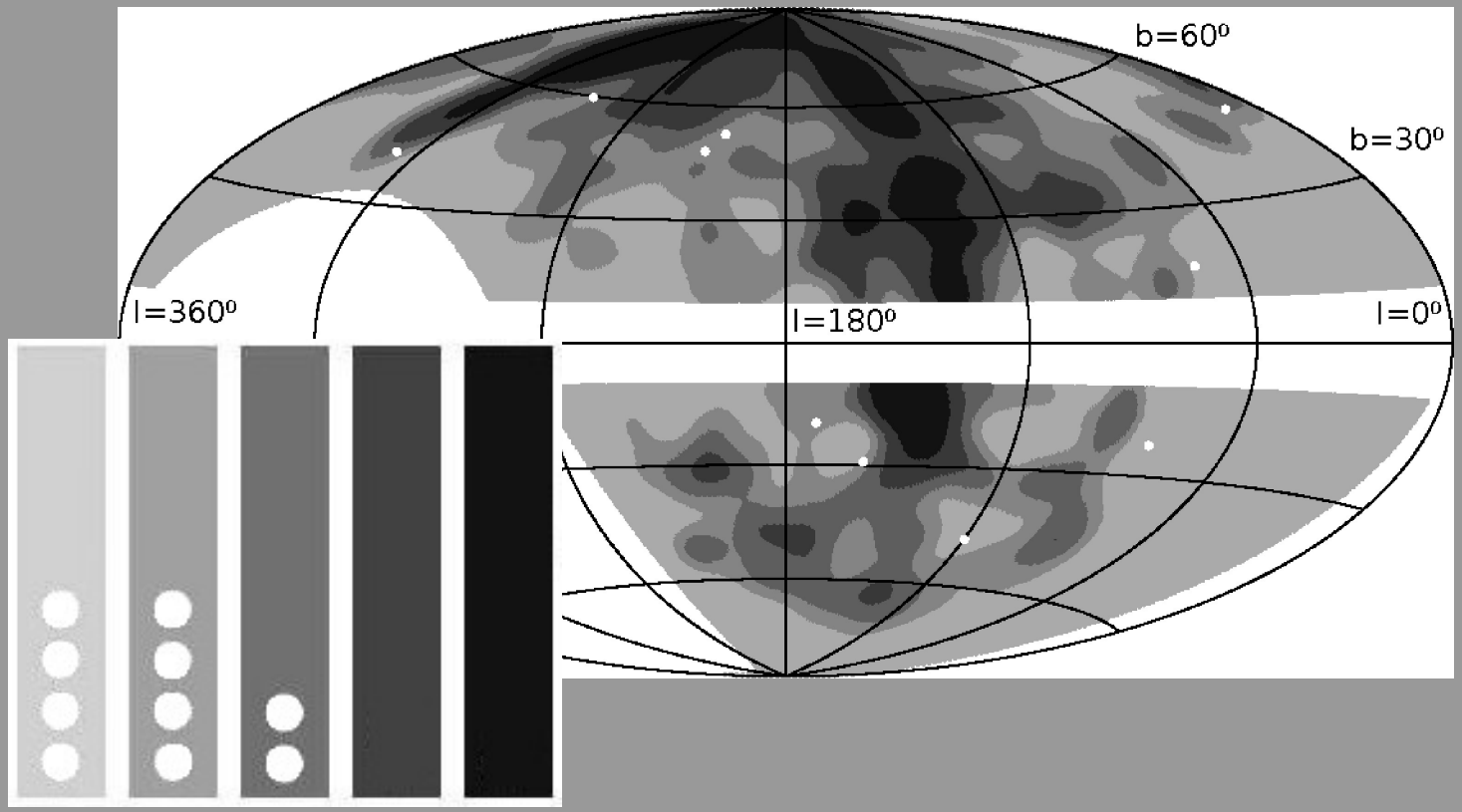
CR flux expected in LSS model

Example: $E > 57$ EeV, $\theta = 6°$, Galactic coordinates



C: Centaurus supercluster (60 Mpc); Co: Coma cluster (90 Mpc); E: Eridanus cluster (30 Mpc); F: Fornax cluster (20 Mpc); Hy: Hydra supercluster (50 Mpc); N: Norma supercluster (65 Mpc); PI: Pavo-Indus supercluster (70 Mpc); PP: Perseus-Pisces supercluster (70 Mpc); Ursa Major North group (20 Mpc) South group (20 Mpc); V: Virgo cluster (20 Mpc).

THE FLUX SAMPLING STATISTICAL TEST



- Events following the model would produce uniform distribution over the bands
- No binning is needed (on the picture it is for illustration only): two distributions may be compared by the KS test