Searches for cosmic ray anisotropies at ultra-high energies

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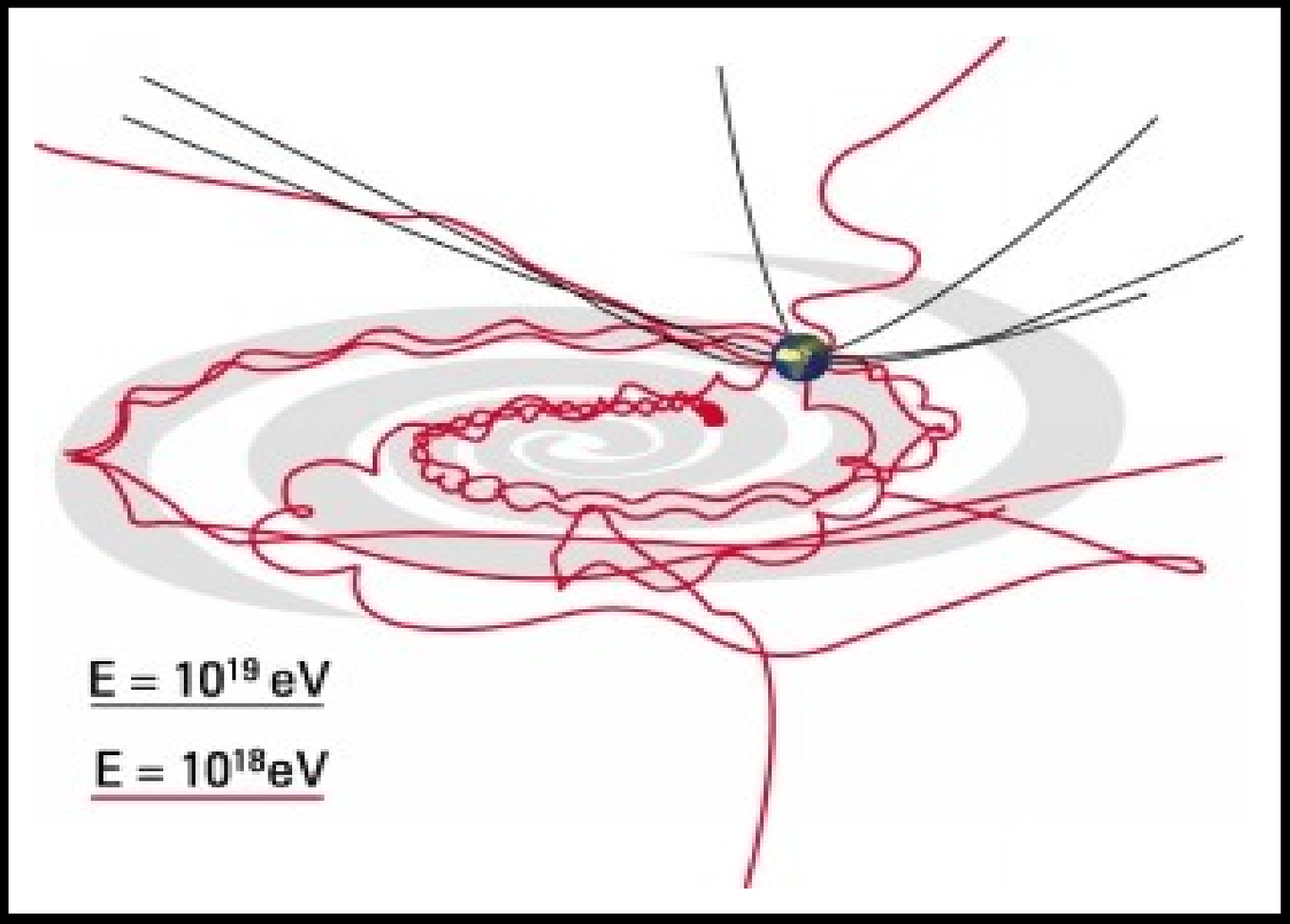
Searches for large scale modulations in right-ascension

The Pierre Auger Coll.,
Astropart. Phys. 34 (2011) 627-639

Large scale anisotropies at EeV energies ?

The galactic magnetic field «isotropises» EeV CRs



Dipolar anisotropies due to :

propagation effects:

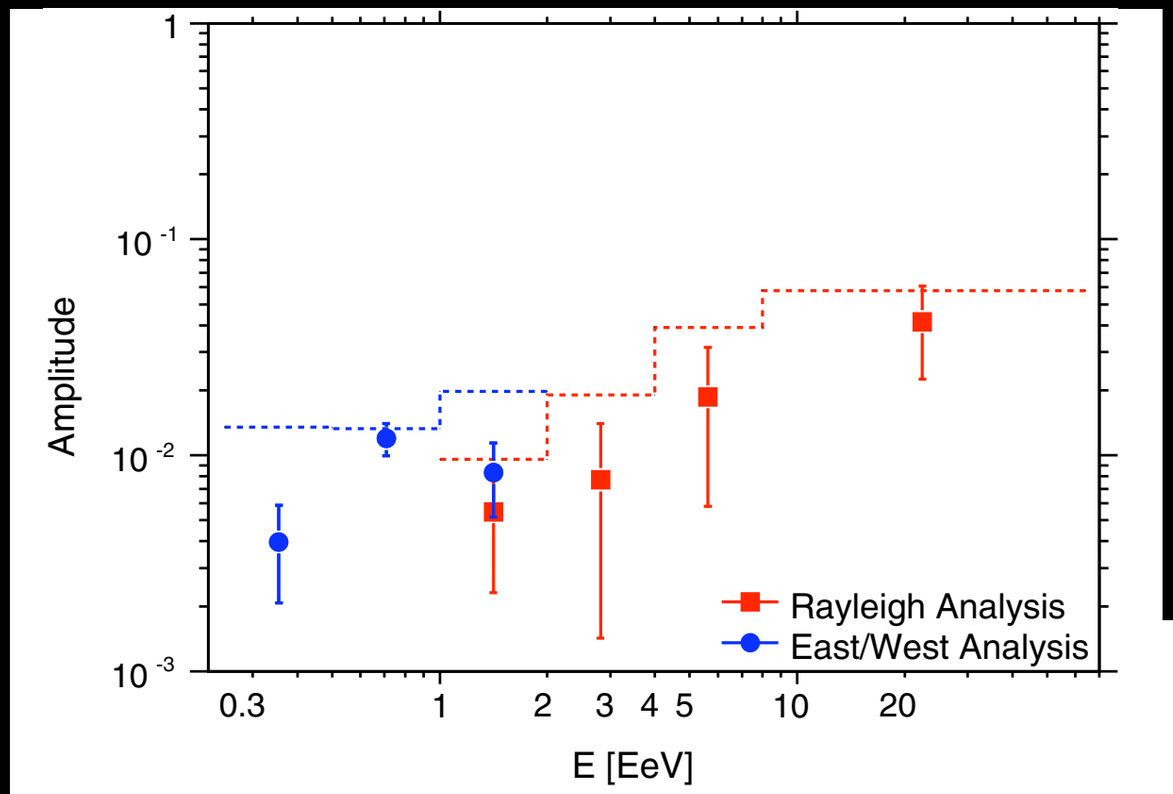
dipolar anisotropies at the % level could be left by diffusion/drift of galactic CRs

Compton-Getting effect:

if extragalactic, a small anisotropy may exist due to our motion with respect to the frame of extragalactic isotropy

Searches for small effects

Sidereal analysis - Amplitudes



Upper limits

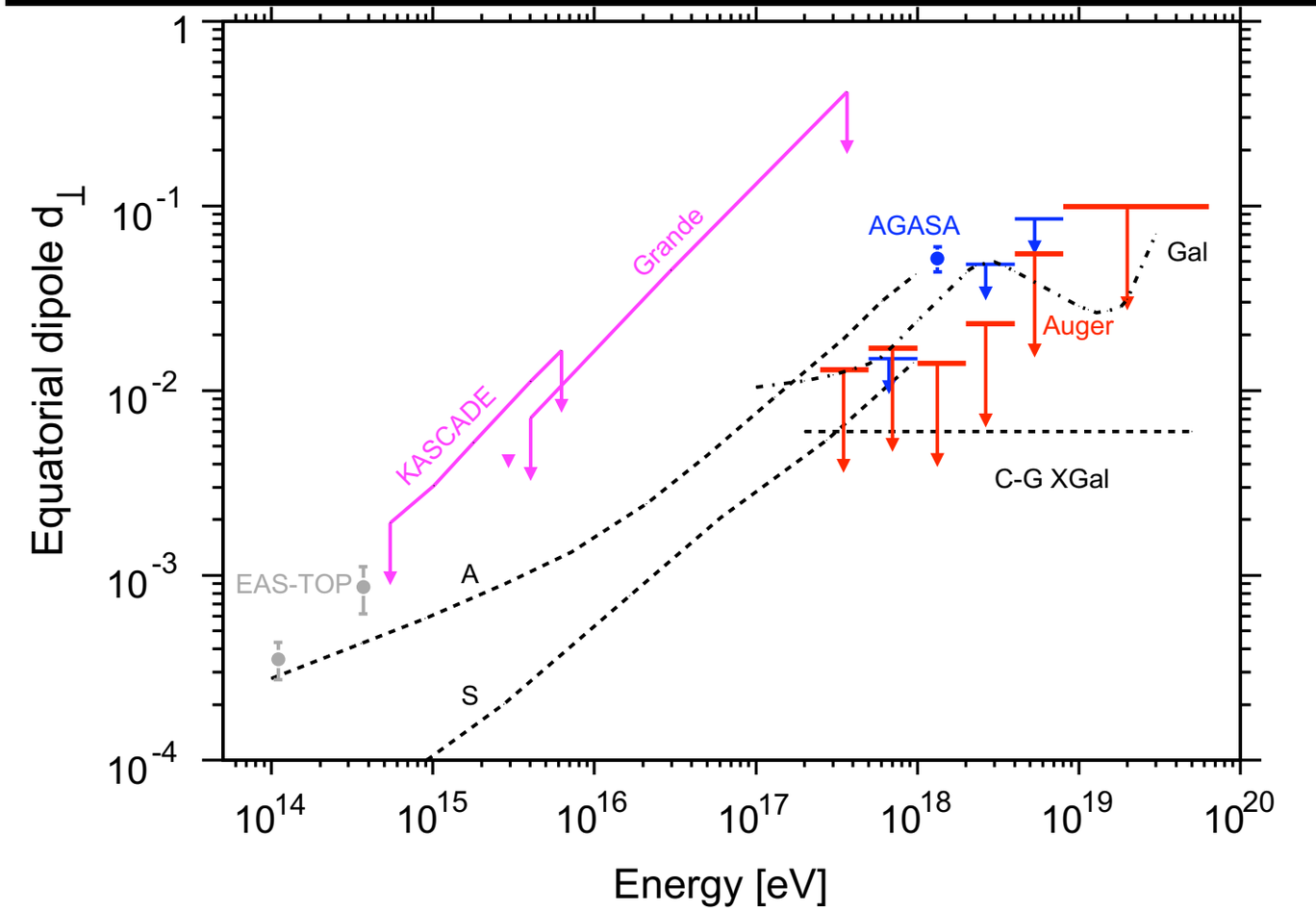
- competitive w.r.t. other experiments
- constrains on models

differential

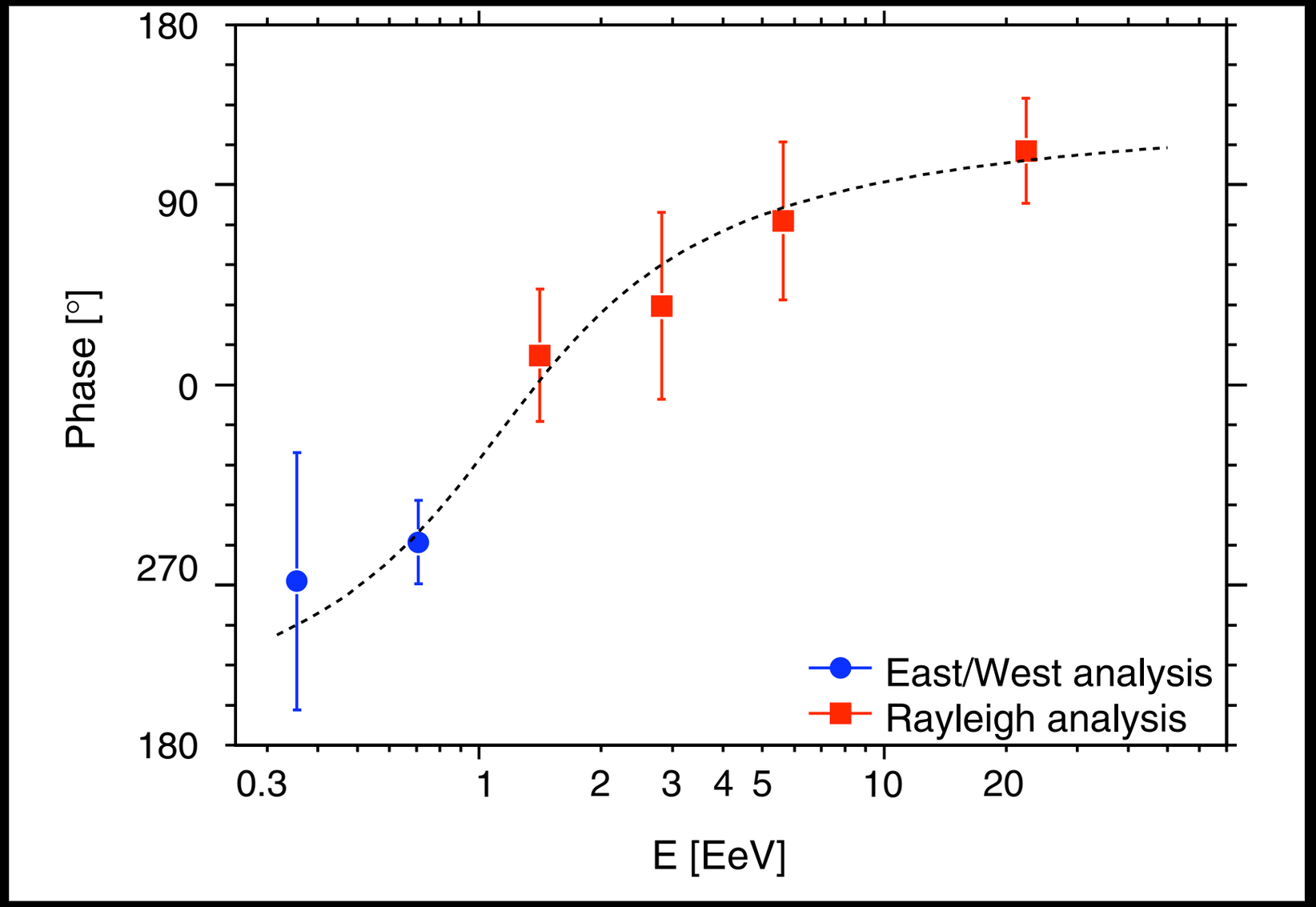
below the 2% detection level

Cumulative

no further evidence



Sidereal analysis - Phases

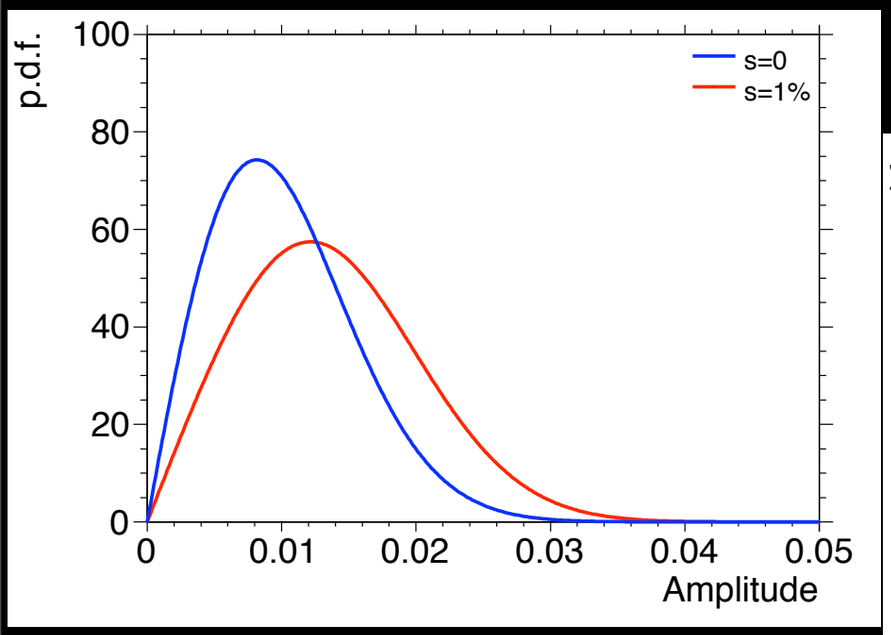


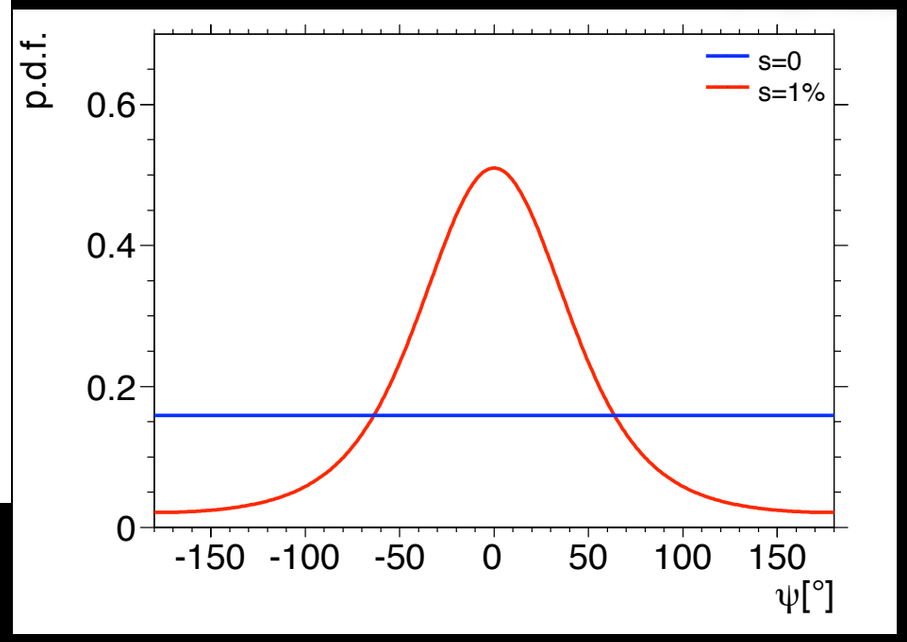
Not randomly distributed

Suggests a smooth transition around 1 EeV

Posterior probability: ~ 2×10^{-3}

Phases VS Amplitudes

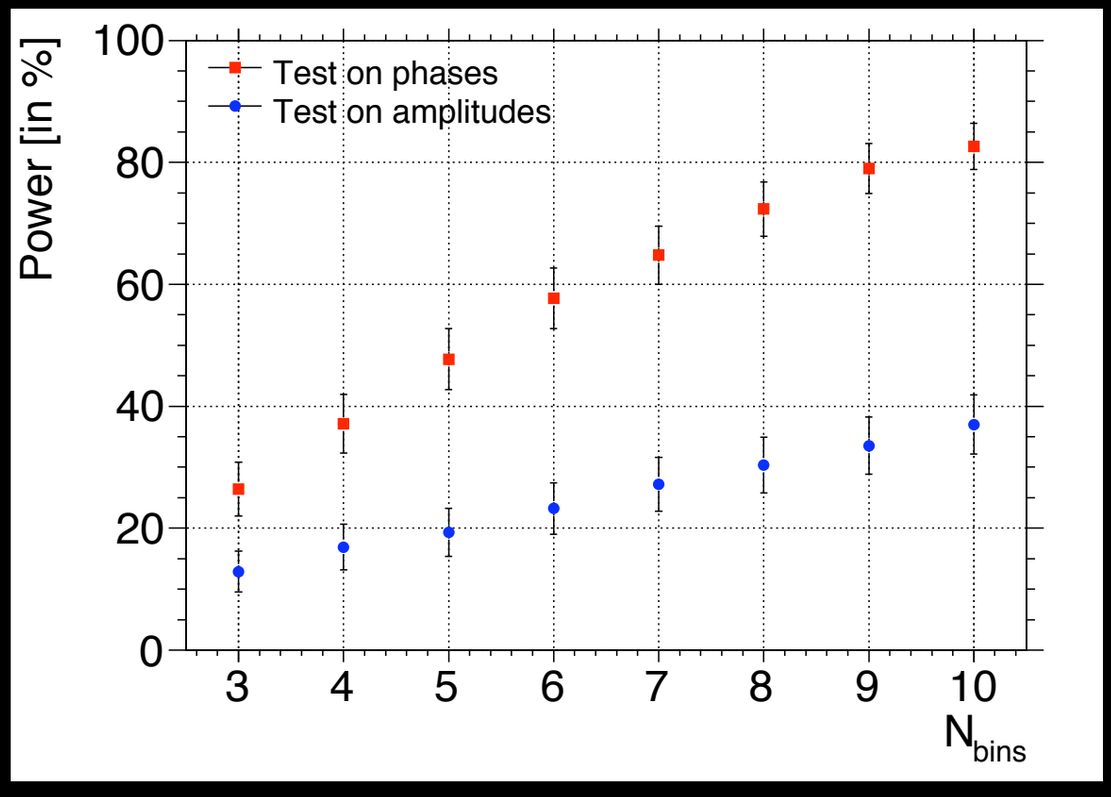




J. Linsley, Phys. Rev. Lett., 34 (1975)

In case of real signal:

phase consistency occur before the signal amplitude detection



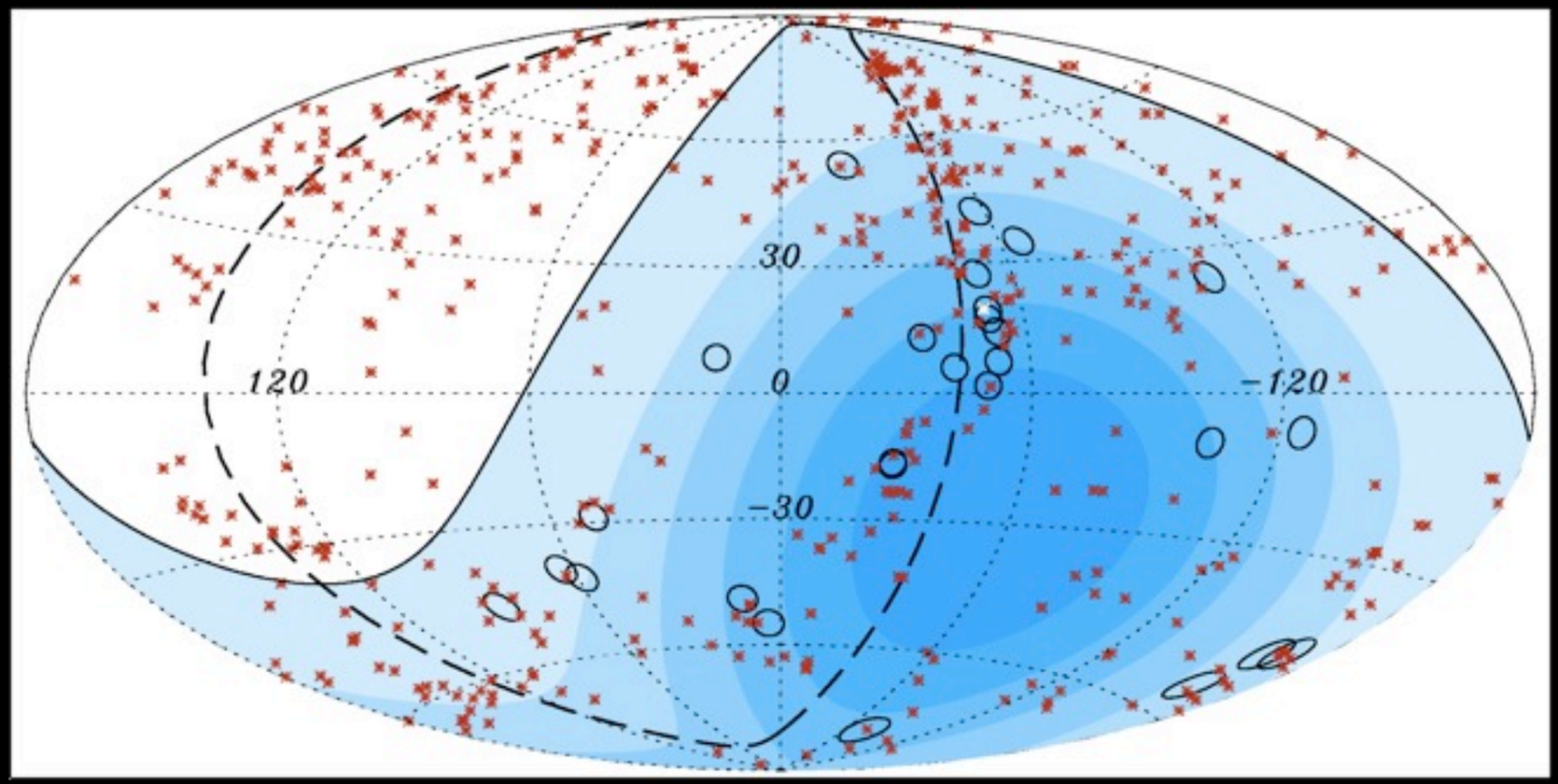
The phase test is ~2.5 more sensitive than the amplitude one to a genuine signal diluted within the background noise

Future work will profit from the lower energy threshold thanks to the low energy extension of the observatory

Searches for point sources at UHE

Reference papers:
The Pierre Auger Coll.,
Science 318 938 (2007),
Astropart. Phys. 29 (2008) 188-204,
Astropart. Phys. 34 (2010) 314-326

Angular distributions at UHE



Using 27 CR above 56 EeV

(01/01/04 - 31/08/07)

correlation with the positions of nearby extragalactic objects

(12th VCV)

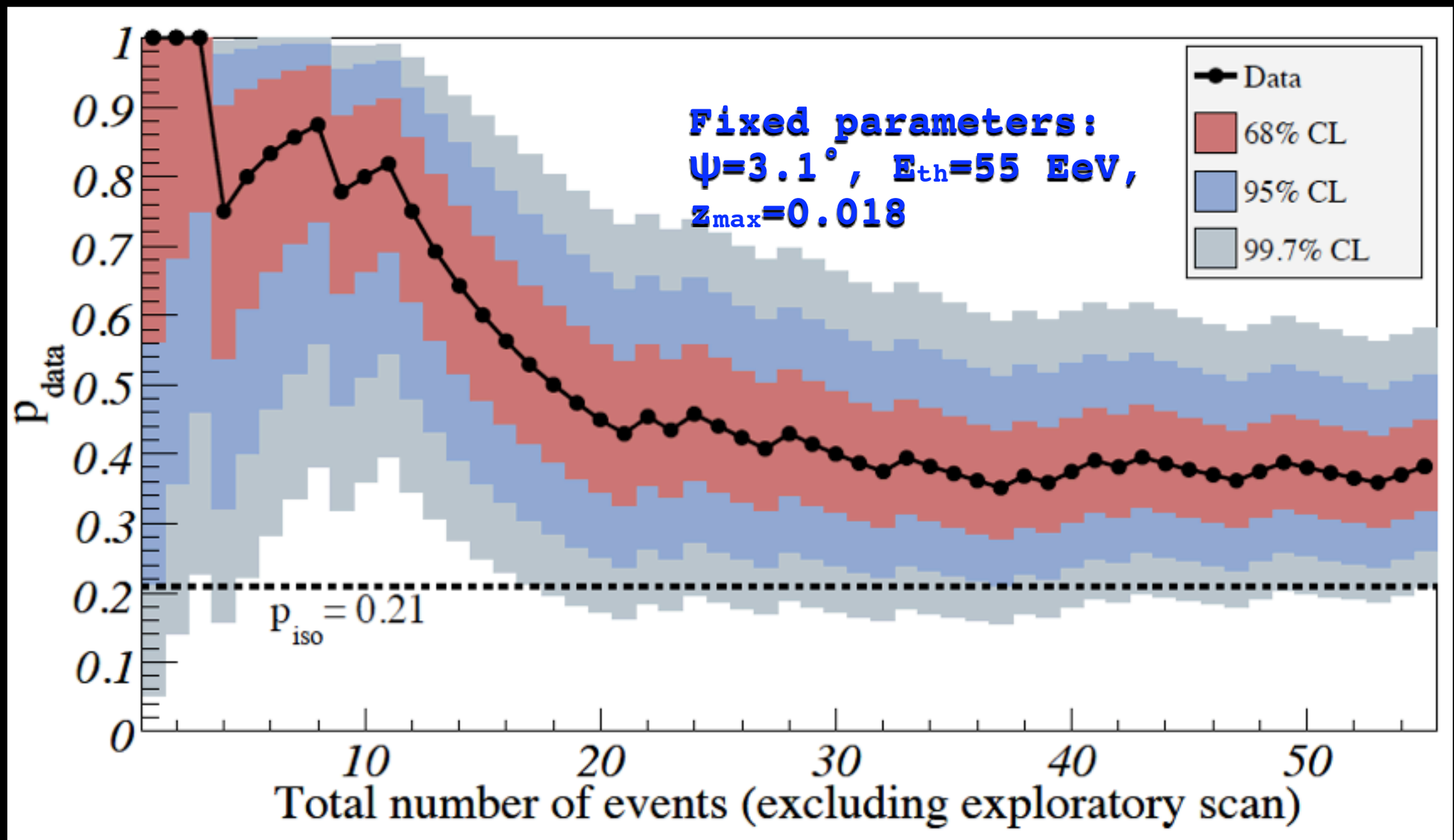
→ Correlation parameters fixed with early data:

- energy (55 EeV)
- angular separation (3.1°)
- distance (75 Mpc)

Test with later data, built to reject isotropy with 1% chance probability:
test passed with 6 correlated events out of 8

--> Isotropy rejected at 99% C.L.

Updated degree of correlation (31/12/2009)



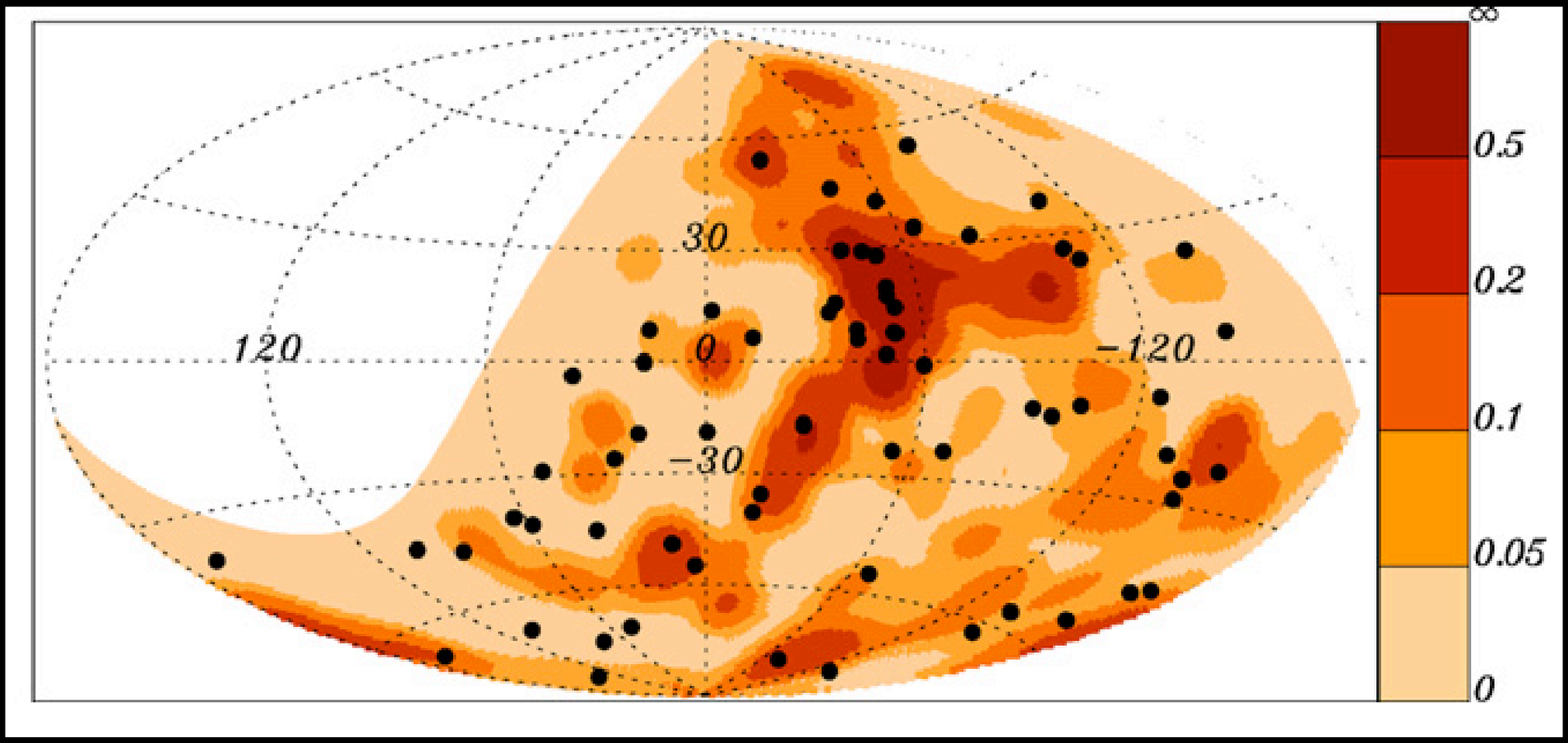
Correlation down: from (69±12)% to (38±7)%

(21% of random correlation from isotropic expectations)

Angular distributions at UHE

Search for correlations with other (more complete) catalogs of extra-galactic objects

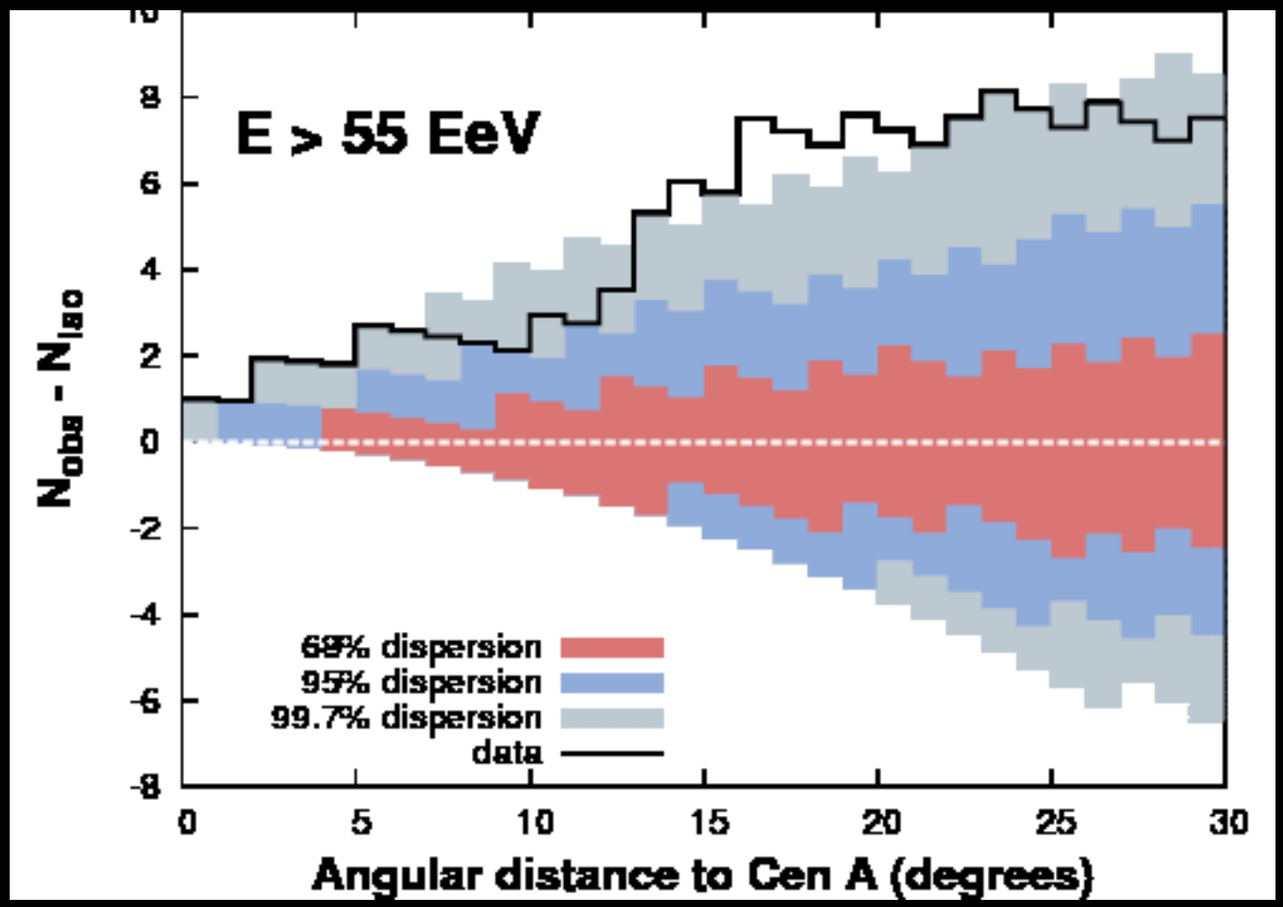
Fitting the 69 events on map densities built from source models based on 2MRS and Swift-BAT catalogs and including the GZK effect
2 free parameters : deflection angle (magnetic field) and «isotropic fraction» (incompleteness, heavier elements, ...)



2MRS : (1.5°, 64%)

Swift : (7.8°, 56%)

Centaurus A



→ More significant excess at 18° (13/69) above E_z = 55 EeV

NB : it is an a posteriori results

no C.L. can be given

Anisotropies and chemical composition

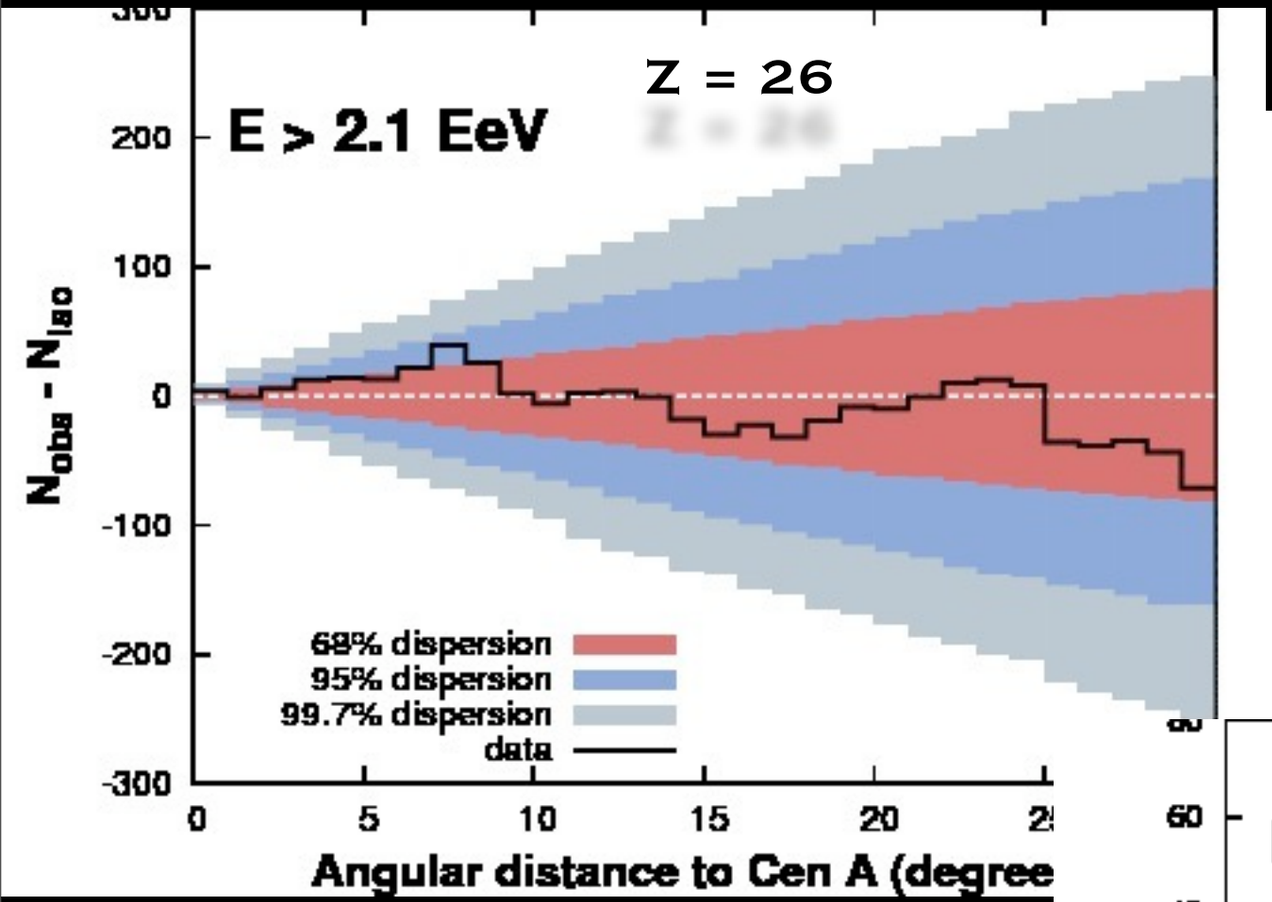
Reference paper:
The Pierre Auger Coll.,
JCAP06 (2011) 022

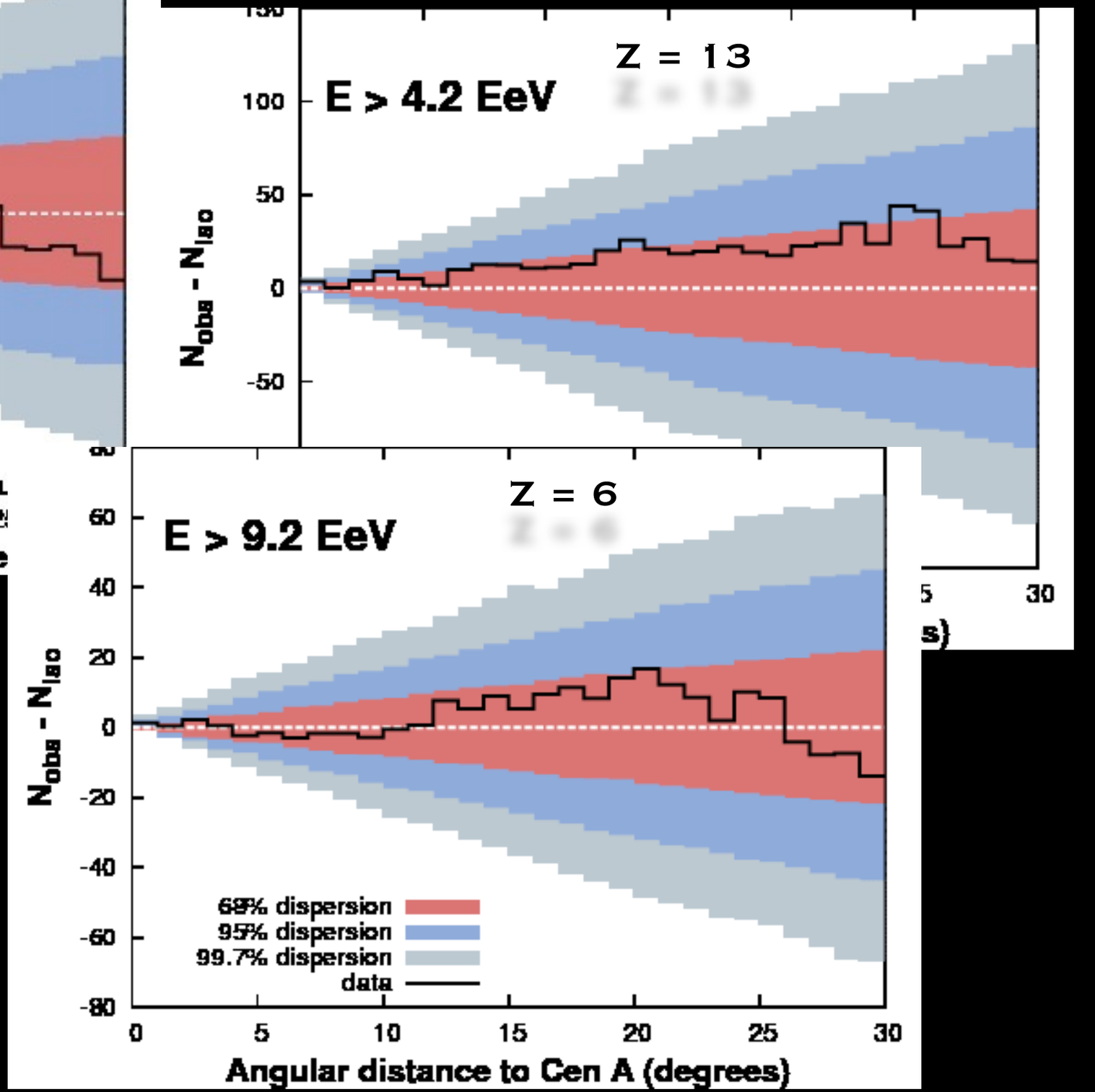
Anisotropy at lower energy threshold

We have detected some excesses above E_z = 55 EeV

→ we can search for excesses to occur at lower energies ($E : E_z/Z$)

Anisotropy at lower energy threshold





Cen A : distributions consistent with isotropy

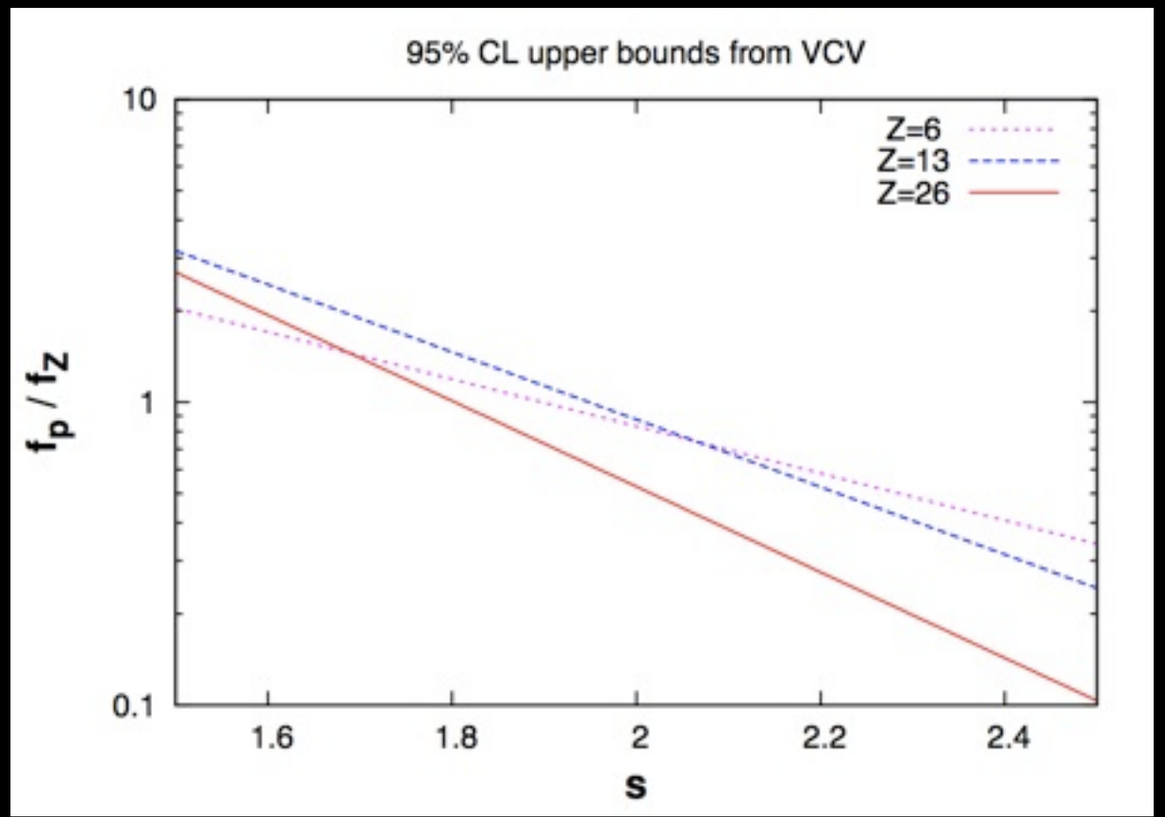
The results are similar for the VCV catalogue

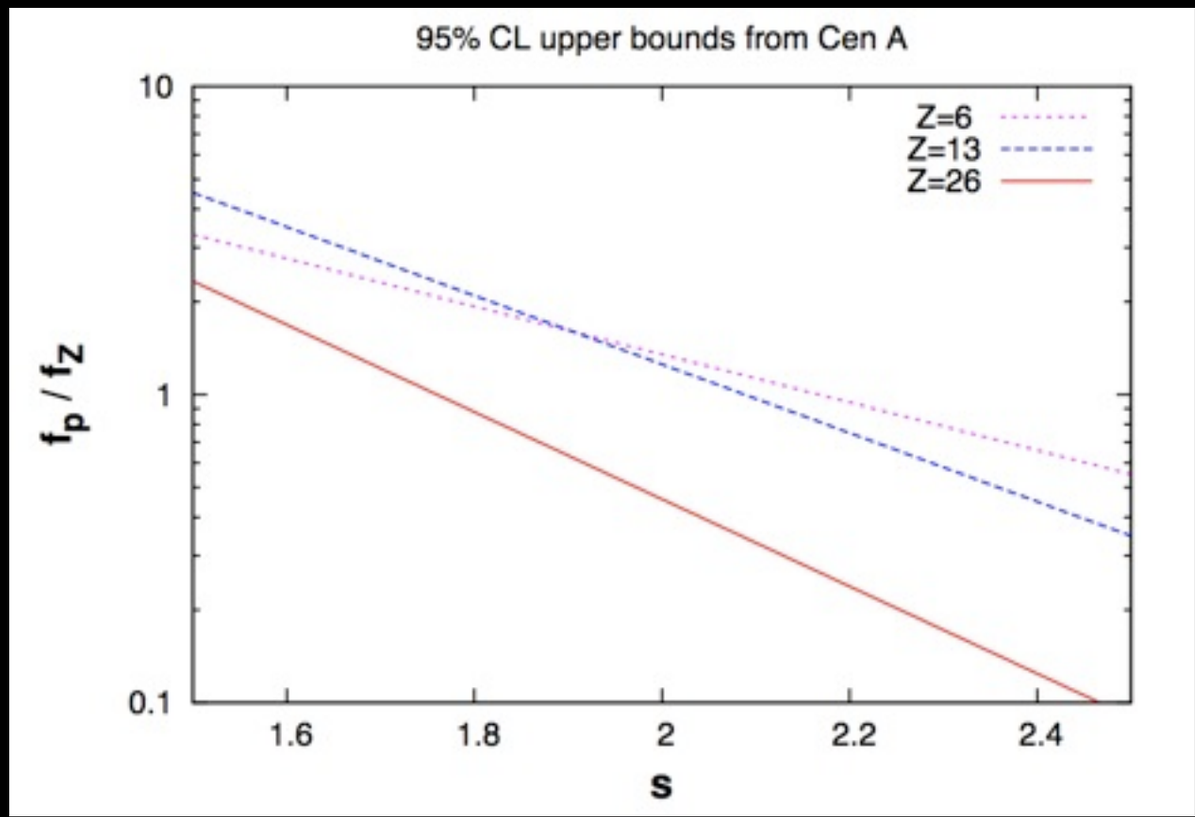
Constrains on the composition

Main hypothesis :

M. Lemoine & E. Waxman, JCAP 11 (2009)

- these excesses at high energy are due to heavy nuclei (Z)
- CR acceleration depends only on the rigidity (E/Z) of the particle
- No propagation effects
- power law for the spectral shape below E_{TH} : $\Phi \propto (E/Z)^{-s}$





The constrains on the p-fraction are getting weaker as «s» is harder

obtained independently of the X_{MAX} measurements

Conclusions

Conclusion

Large scale modulation in RA

- Amplitude : no evidences, still at the level of
- Only upper limits
- Smooth transition in the phase of the dipole (evidence for anisotropy ?)

Point source searches

- Compare the arrival directions with catalogues (VCV/2MRS/SWIFT)
- Cen A : the excess is still present (a posteriori: no c.l.)

Constrain on the composition

- No indication of overdensities in the lower energy bins
- → Limit on the relative proton fraction
- independent of X_{max} measurements

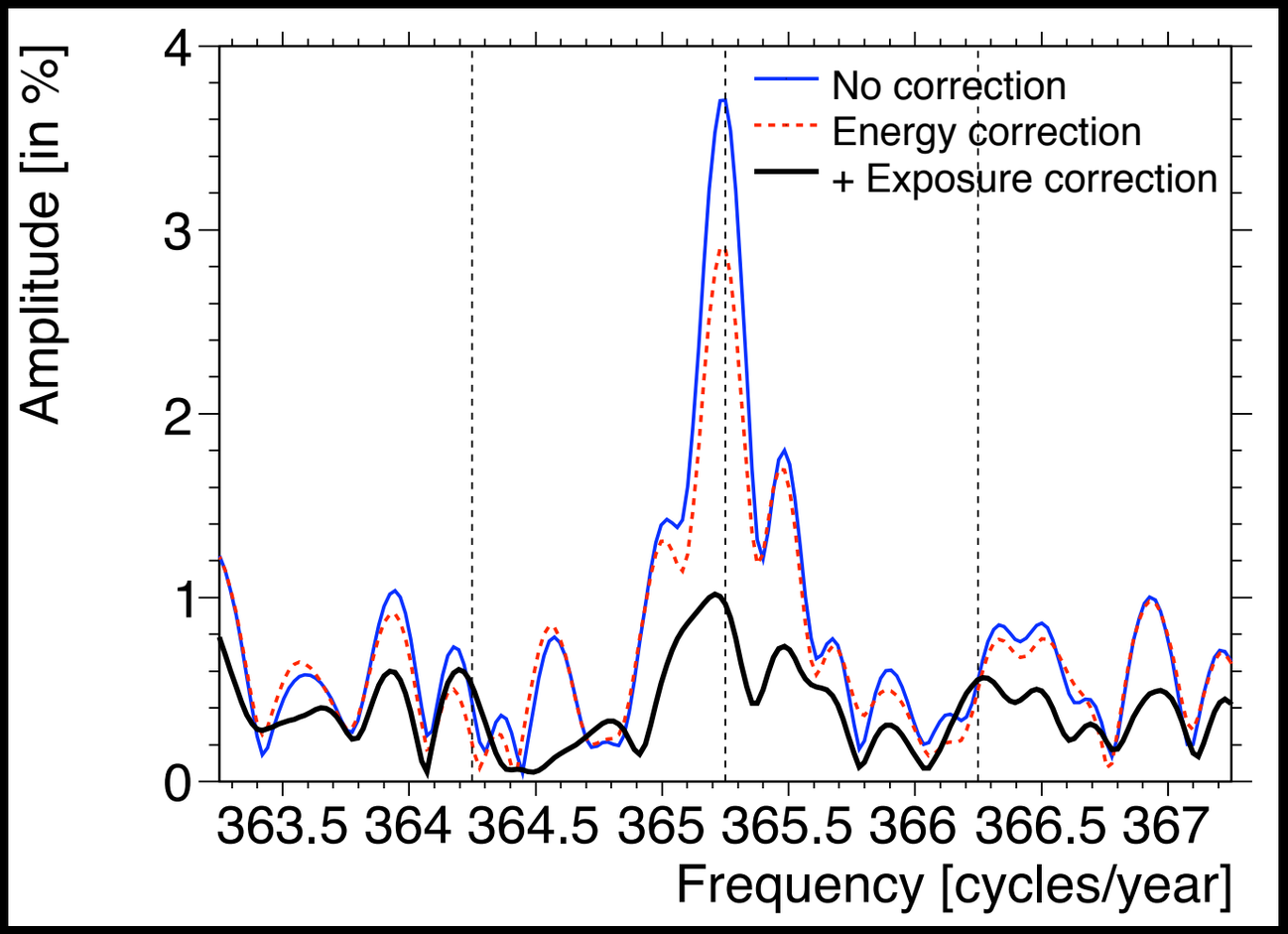
Back Up

Accounting for experimental effects

Challenge: estimation of the exposure with high accuracy

1- Monitoring of the number of elementar cells => geometrical exposure calculation in each direction

2- Energy corrections as a function of atmospheric pressure and density



2 possible sources of spurious modulations at the sidereal freq.:

1- Pollution by the solar frequency (=> canceled by the 6-yrs exposure time)

2- Sideband mechanism due to any annual variation of the daily

N.B.: Well below the energy saturation threshold, use of the «East/West» method to remove spurious effects [Bonino et al., ApJ, 2011]

Composition study with at the Auger Observatory

measured X_{MAX} and RMS(X_{MAX})

vs

MC simulations of EAS

as far as models are correct:

gradual increase in the

average mass with the

energy