Proposal for CR analysis from Brazil group

Bruno Lago[1], João Torres de Mello Neto[2], Marcio Müller[2], Rogerio Menezes de Almeida[3]

[1]Centro Federal de Educação Tecnológica Celso Suckow da Fonseca, [2]IF – Universidade Federal do Rio de Janeiro, [3]EEIMVR – Universidade Federal Fluminense.

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GRAND Collaboration Meeting, Dunhuang, China Apr 26, 2019

Outline

- Maximum likelihood method (M.Ahlers *et al.*,*ApJ* **823** (2016) 10);
- Ideas I;
- Xmax composition maps;
- Ideas II;

Motivation – Maximum likelihood method

- Perform multi-resolution analysis of lower energy events;
  - Requires coverage map estimation;
  - Acceptance not full;
  - Usual methods does not seem to work.
- Look for a method that takes into account detector effects;
- Candidate:
  - Iterative maximum likelihood method;

Maximum likelihood method

$i:$ local coordinate bin

$\tau:$ time bin

$\mathfrak{a}:$ eq. coordinate bin

- Estimate both the detector acceptance and the cosmic ray anisotropies.
- The number of cosmic rays expected from a given location bin *i*, at a given time bin τ is given by

$$\mu_{\tau i} \approx I_{\tau i} \mathcal{N}_\tau \mathcal{A}_i$$

Rel. intensity flux — Expected # of isotropic bkg evts. — Rel. Acceptance

Number of detected events

$$\mathcal{L}(n|I,\mathcal{N},\mathcal{A}) = \prod_{\tau i} \frac{(\mu_{\tau i})^{n_{\tau i}} e^{-\mu_{\tau i}}}{n_{\tau i}!} \, ,$$

$$\lambda = \frac{\mathcal{L}(n|I,\mathcal{N},\mathcal{A})}{\mathcal{L}(n|I^{(0)},\mathcal{N}^{(0)},\mathcal{A}^{(0)})}$$

Maximization

$$I^\star_{\mathfrak{a}} = \sum_\tau n_{\tau\mathfrak{a}} \Big/ \sum_\kappa \mathcal{A}^\star_{\kappa\mathfrak{a}} \mathcal{N}^\star_\kappa \, ,$$

$$\mathcal{N}^\star_\tau = \sum_i n_{\tau i} \Big/ \sum_j \mathcal{A}^\star_j I^\star_{\tau j} \, ,$$

$$\mathcal{A}_i = \sum_\tau n_{\tau i} \Big/ \sum_\kappa \mathcal{N}^\star_\kappa I^\star_{\kappa i} \, .$$

M.Ahlers *et al.*,*ApJ* **823** (2016) 10

Power spectrum

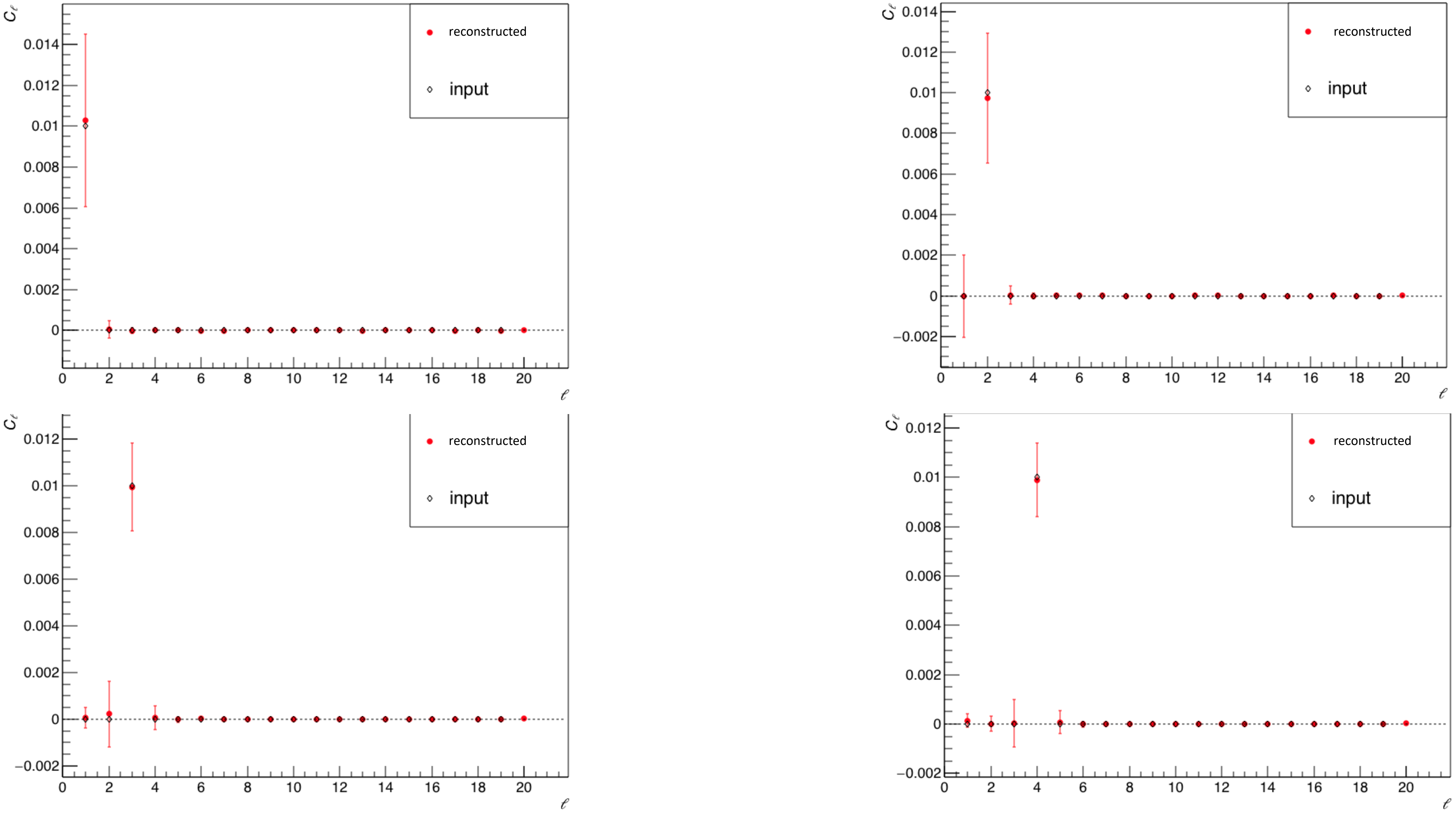
The true power spectrum C_l is related to the pseudo-one $\tilde{C}_l$ via

$$\tilde{C}_\ell = \frac{1}{2\ell+1}\sum_{m=-\ell}^{m=\ell} |\tilde{a}_{\ell m}|^2 \quad \Rightarrow \quad \left\langle \tilde{C}_\ell \right\rangle = \sum_{\ell_1} M_{\ell \ell_1} C_{\ell_1} + \frac{4\pi f_1^2}{N}$$

- The method is not able to capture a_{l0}:
  - $a_{l0}=0$. A correction has to be performed in $M_{ll'}$.

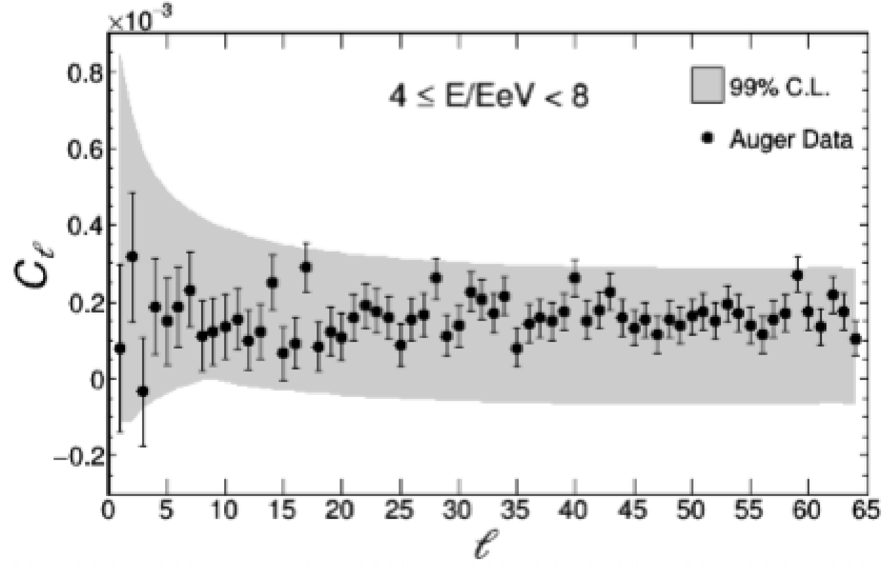
$$\tilde{M}_{ll'} = M_{ll'} - \frac{1}{2l+1}\sum_{m'=-l'}^{l'} |K_{l0l'm'}|^2 \, ,$$

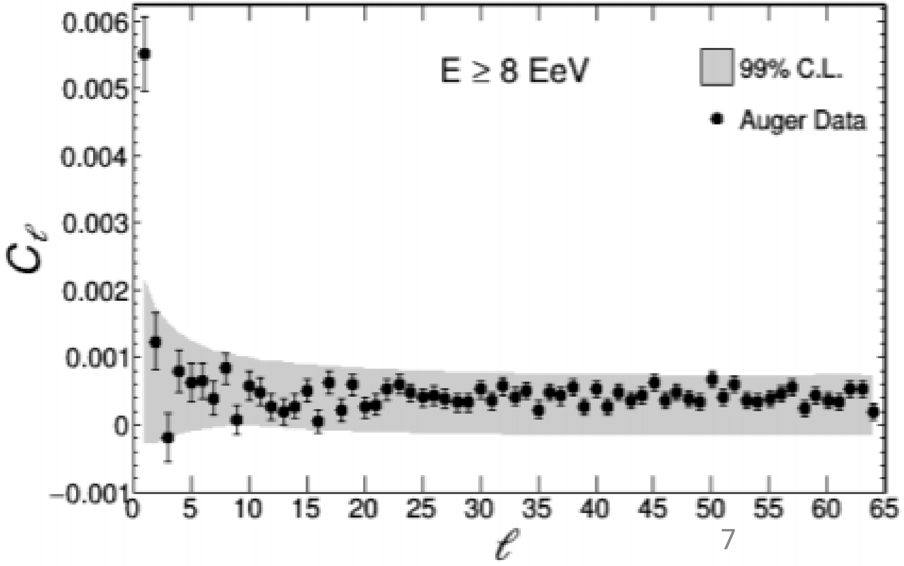
Accurate anisotropy reconstruction.



CR Power Spectrum in the literature

The Pierre Auger Collaboration, *JCAP* **06** (2017) 026

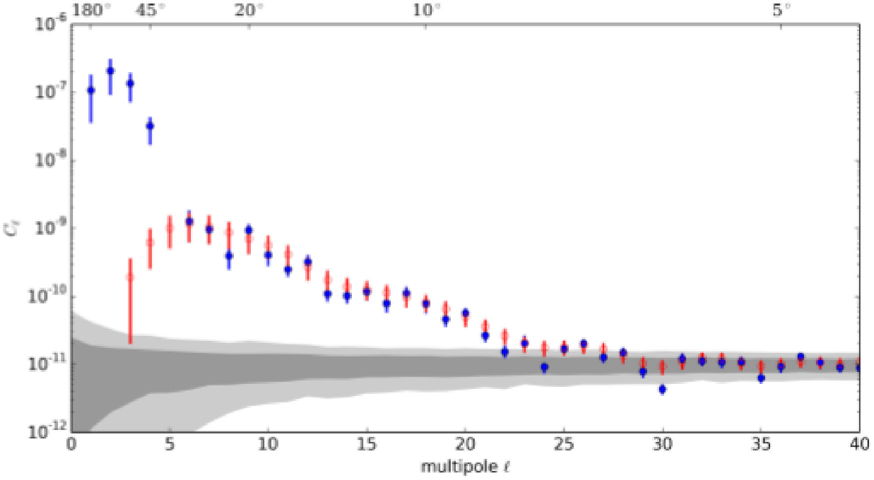




- As far as we are concerned:
  - No power spectrum analysis for GRANDProto300 energy range.

Room for contributions by GRAND

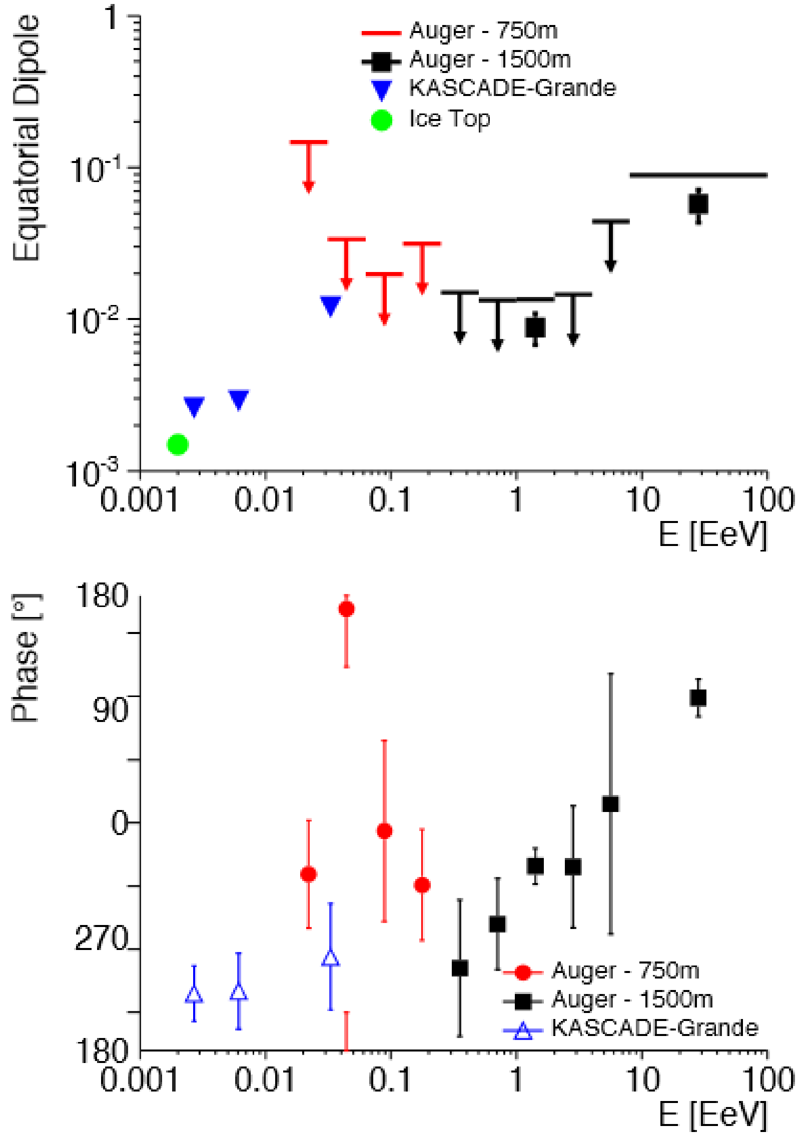
Deligny, O., *Astroparticle Physics* **104** (2019) 13-41



IceCube data (median energy of 20 TeV)
Blue – Power Spectrum, red – the same with large scale contribution subtracted.
Bands: light – 68% C.L. And dark – 95% C.L.

Ideas I

- 2D anisotropy analysis:
  - Data (in the future);
- Detection efficiency x time;
  - Simulation:
    - Dipole according KASCADE-Grande results;
  - Realistic detector effects (João and Márcio);
  - Others.

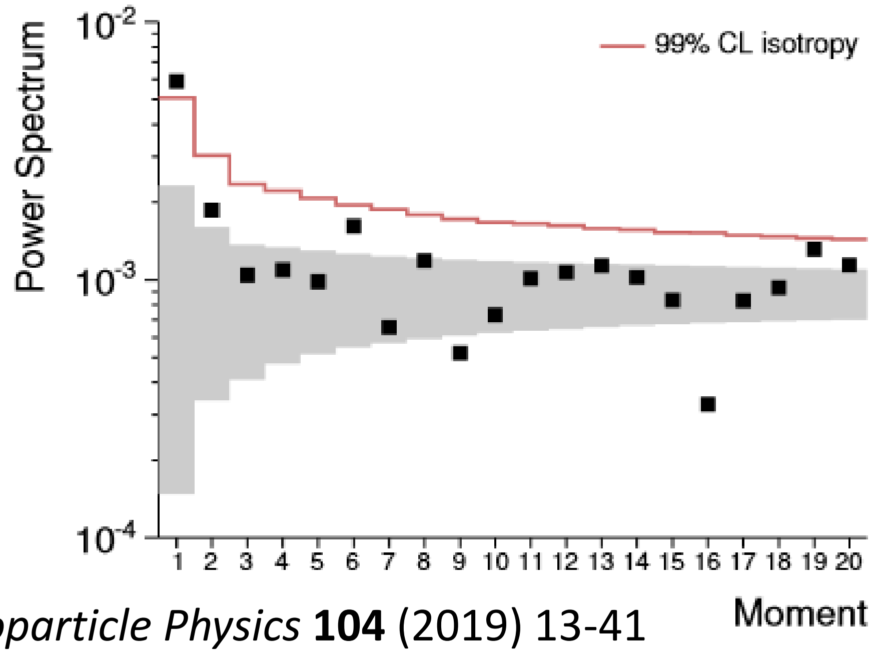


Deligny, O., *XXV ECRS 2016 Proceedings*

FIG. 4: First harmonic amplitude (top) and phase (bottom) as a function of energy above 1 PeV, as collected in [32].

Full Sky Coverage

- Current CR experiments have partial sky coverage;
  - Joint analysis encouraged;
  - Careful treatment of calibration/normalization.
  - Auger + TA Power Spectrum (E>10 EeV);
    - Gray band: rms;
    - Solid line: 99% C.L.



Deligny, O., *Astroparticle Physics* **104** (2019) 13-41

- GRAND antennas around the world would enable Full Sky coverage;
  - Great for anisotropy analysis!

Xmax composition maps I

- Studies of composition maps are recent:
  - Also in the Pierre Auger Observatory.

- Our group is highly involved in this task;

- Main idea:
  - Build composition (Xmax) maps;
  - Correction due to energy bin width.
  - Study the significance of the maps obtained.

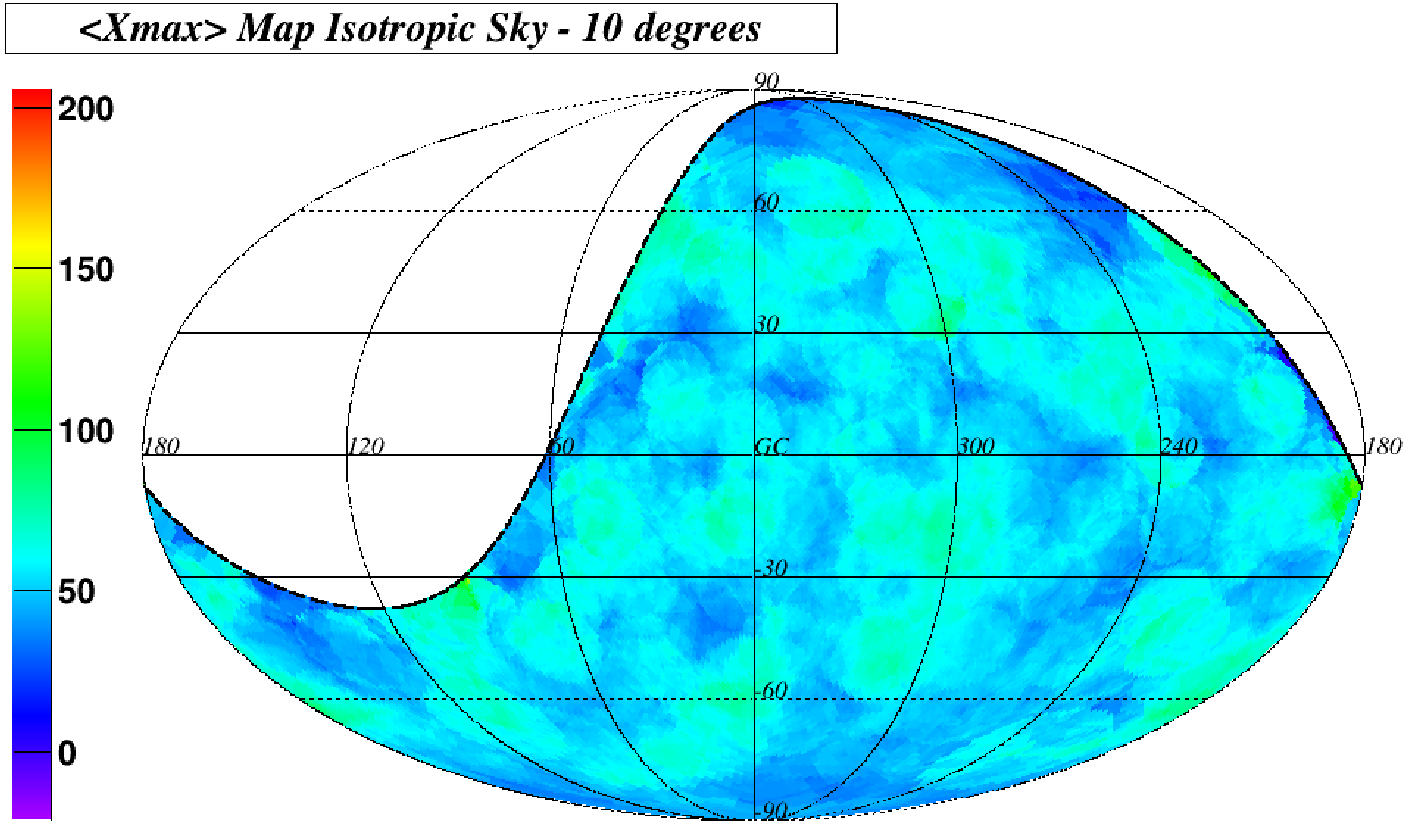
Xmax composition maps II

- Xmax correction for elongation rate according energy using EPOS-LHC Iron nucleus, via conex;

$$X_{max,i}^{norm} = X_{max,i} - X_{max}^{EPOS,Fe}(E_i)$$

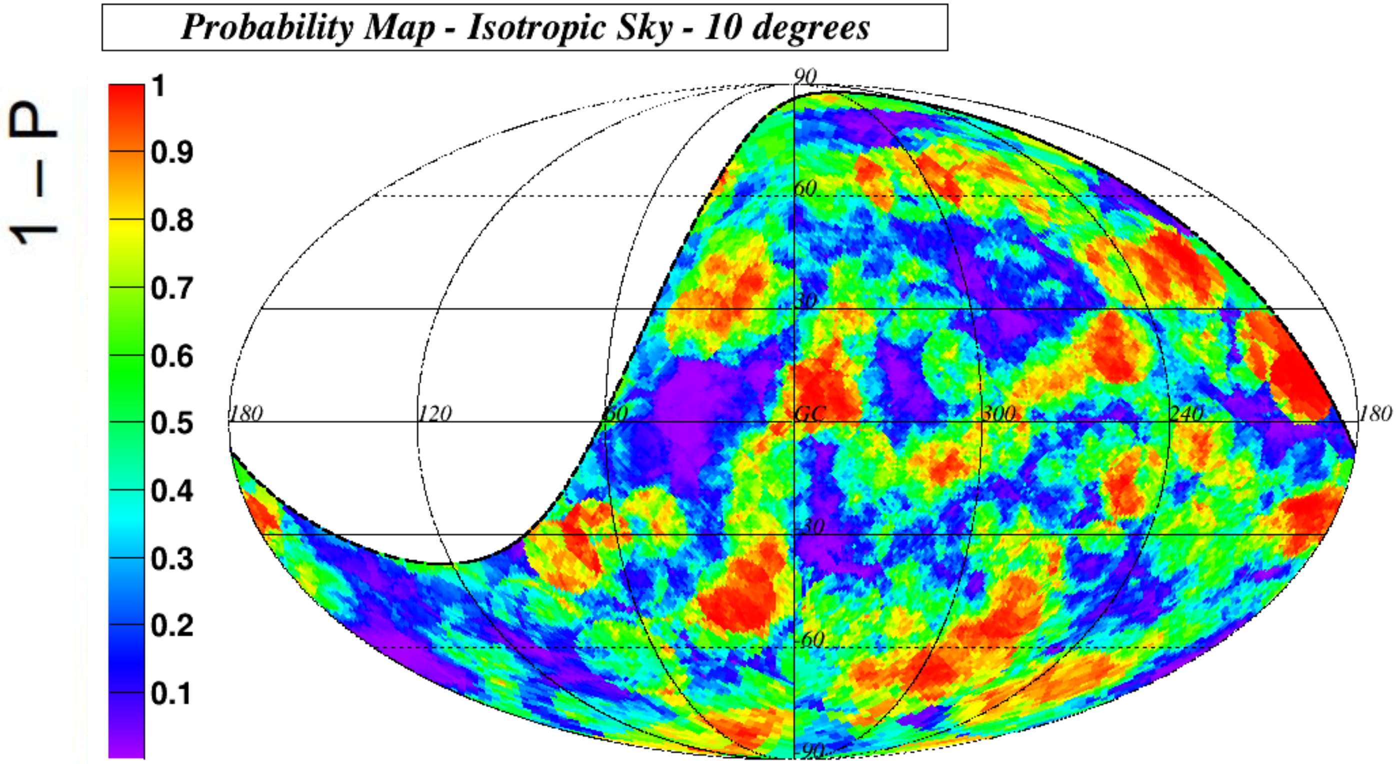
- Evaluate the mean Xmax using top-hat windows over the celestial sphere;

- Pierre Auger Observatory simulation --------------------->



Xmax composition maps III

Probability Map $P_i = \frac{N\left(\left\langle X_{max}^{in-shuff}\right\rangle > \left\langle X_{max}^{in-data}\right\rangle\right)}{N_{shuff}}$



1 - P close to zero indicates heavy composition, close to 1 indicates light composition

Ideas II

- Given the goal Xmax resolution and exposure from GRANDProto300

  Use MC simulation in order to study the power of Xmax maps to constrain astrophysical and magnetic field models.

- Example:
  - Simulate events according the 2MRS catalog;
  - Emission spectra $E^{-\gamma}$ (exponential broken - rigidity dependent);
  - Nuclei (H, He, N, Si and Fe, for instance);
  - Evaluate the composition maps for each nuclei.
    - Including GRAND specifications;

Summary

- Our group is very excited with the GRAND experiment;

- We can contribute with anisotropy analysis;
  - Multi resolution;
  - Full sky coverage would be great!
  - As well as full acceptance!

- Xmax studies under development;
  - Very promising.

Thank you!