Effects of magnetic fields on anisotropies in a catalog based research

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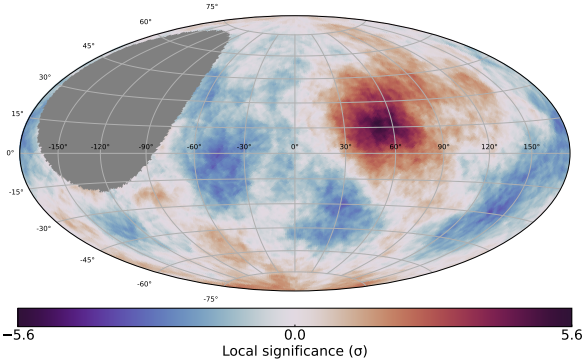
Current anisotropy studies

- LiMa significance:

$$S_{LM} = \sqrt{2}\left[N_{on} \cdot \ln\left(\frac{(1+\alpha)N_{on}}{\alpha(N_{on}+N_{off})}\right) + N_{off} \cdot \ln\left(\frac{(1+\alpha)N_{off}}{N_{on}+N_{off}}\right)\right]^{1/2}$$

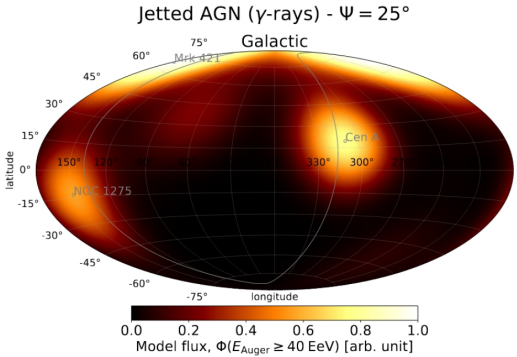
- Observed LiMa significance above 38 EeV

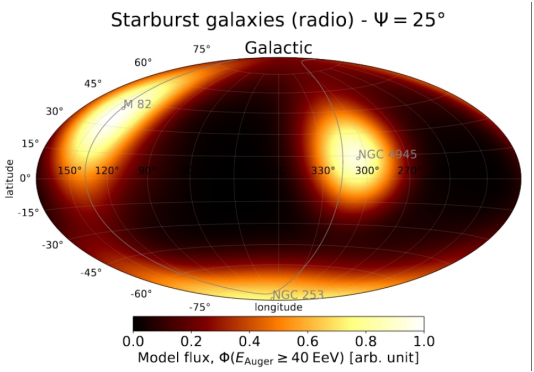


Source models

Source catalogs considered:

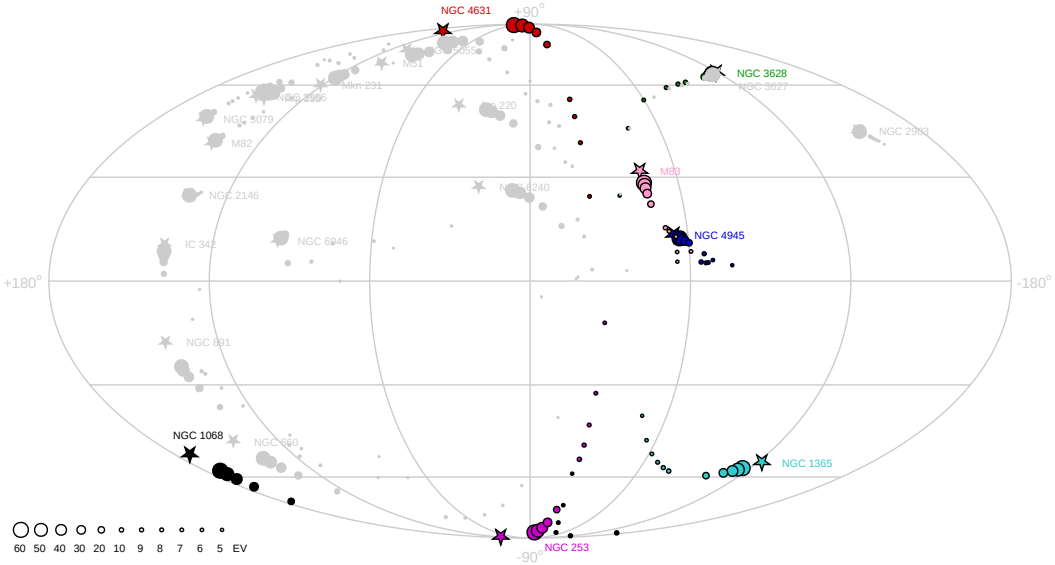
- SBG: 44 sources between 2.7 Mpc and 180 Mpc
- AGN: 26 sources between 3 Mpc and 250 Mpc
- Main contribution related to 3 sources in the SBG and AGN model





Ref: Arrival Directions of Cosmic Rays above 32 EeV from Phase One of the Pierre Auger Observatory

But


NGC 4631
+90°
NGC 3628
NGC 3627
M51
Mkn 231
NGC 2996
NGC 5079
M82
NGC 2983
M83
NGC 2146
NGC 6240
NGC 4945
IC 342
NGC 6946
+180°
-180°
NGC 891
NGC 1068
NGC 660
NGC 1365
NGC 253
-90°
60 50 40 30 20 10 9 8 7 6 5 EV

Role of the galactic magnetic field

- No coherent deflections have been considered
  $\rightarrow$ What is the meaning of the observed correlation?

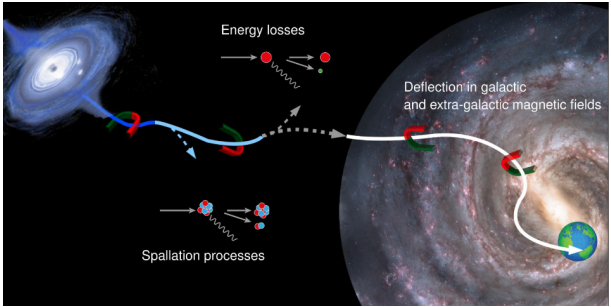
- $\theta^{\text{Auger}}_{\text{best fit}} \sim 15^\circ$
  $\rightarrow$ Is this an upper[1] (or lower[2]) limit to the EGMF?

[1] *An upper limit on the strenght of the extragalactic magnetic field from ultra-high-energy cosmic rays anisotropy,J. D. Bray1 et al,2018*

[2] *Extragalactic magnetic field constraints from ultra-high-energy cosmic rays from local galaxies,A. Van Vliet et al.,2021*

Simulation framework

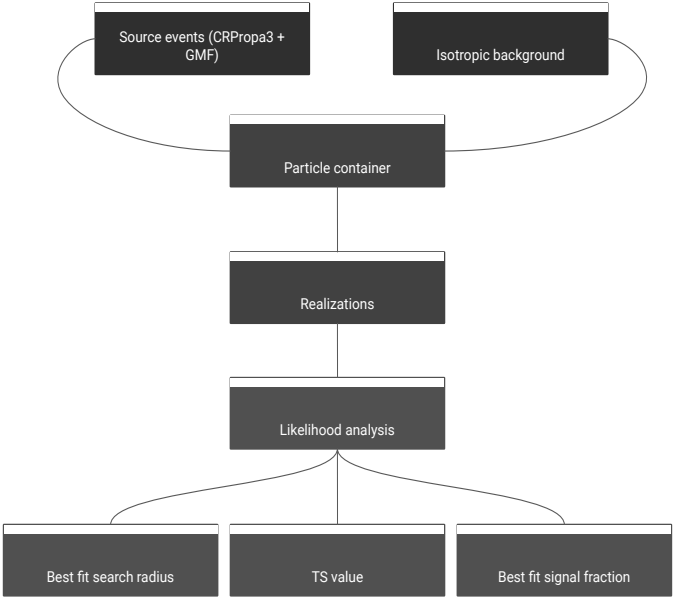
- Injected spectrum with mixed composition (*)
- Max rigidity cutoff (*)
- Extragalactic propagation: CRPropa3
- GMF model: Jansson&Farrar (2012)



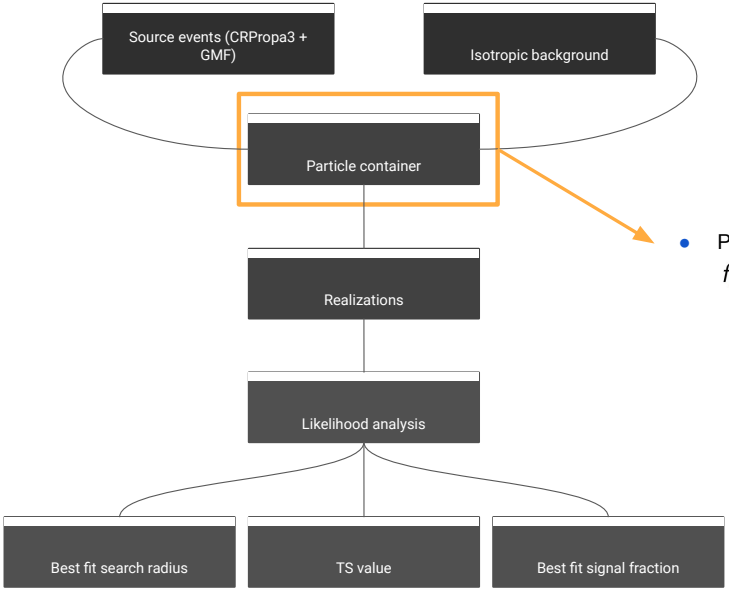
Credit:H. Wilczyski

*: Combined fit paper:JCAP 04 (2017) 038

Analysis method

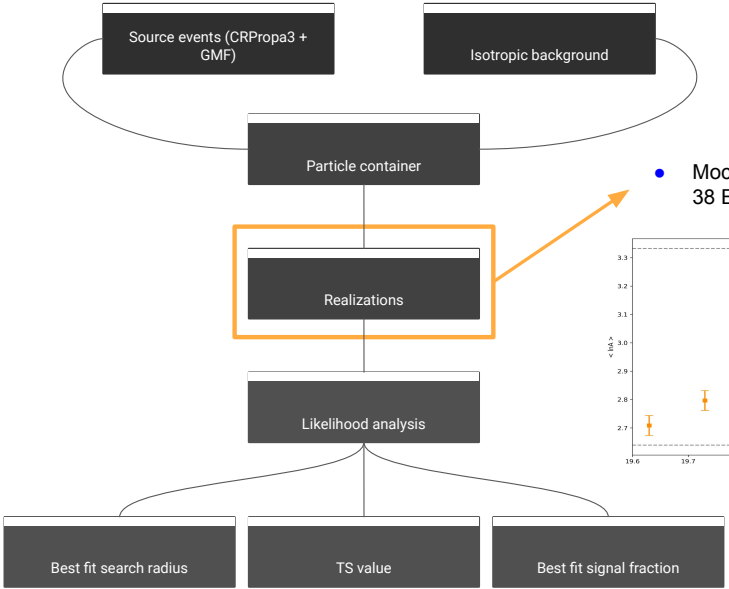


Analysis method

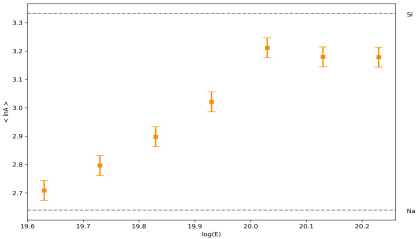


- Particle container:
  $f_{srcs} \cdot N_{tot} + (1 - f_{srcs}) \cdot N_{tot}$

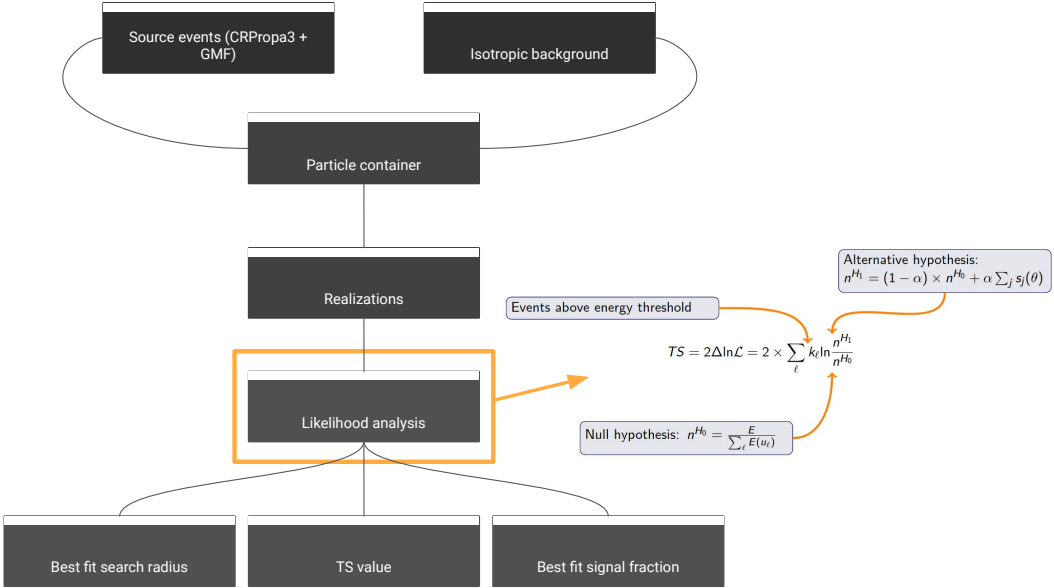
Analysis method



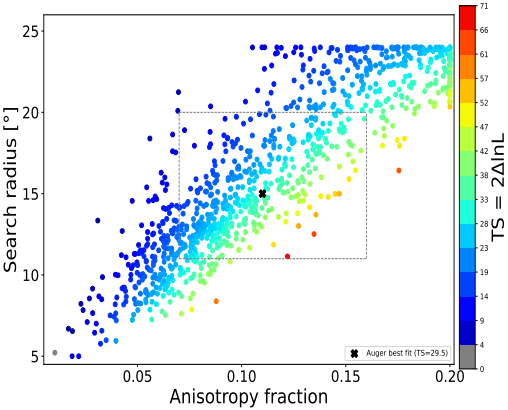
- Mock dataset: 1309 events above 38 EeV

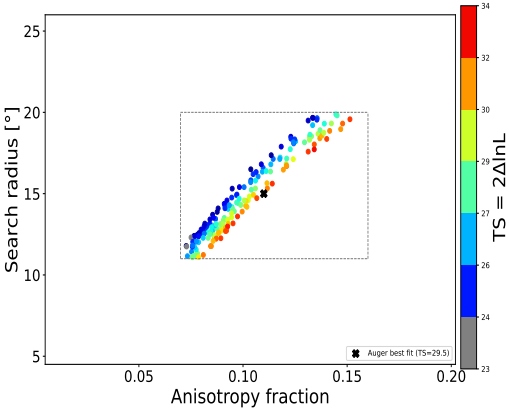


Analysis method



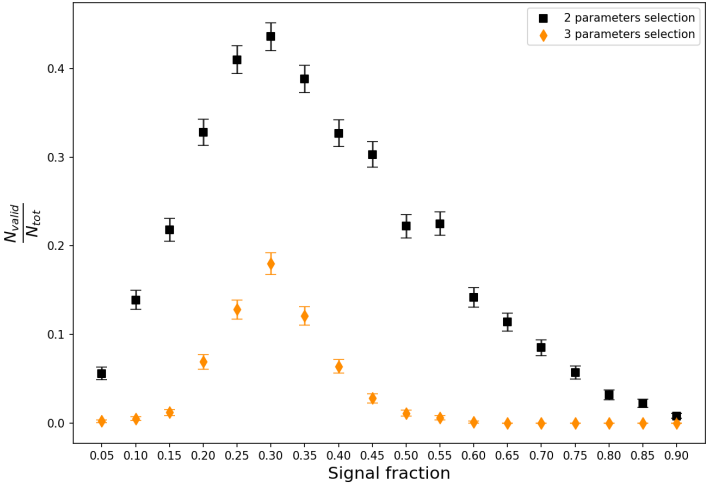
Fit results for mock data sets





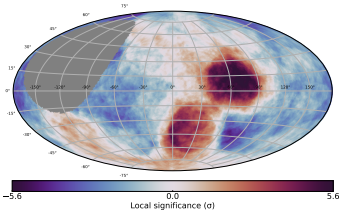
Signal fraction scan SBG hypothesis

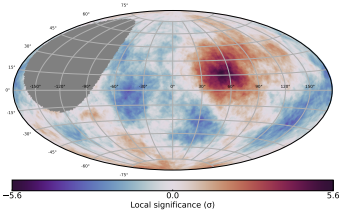
- Best scenario: $f_{src} = 0.3$
- Source contribution is increased in order to recover compatible results ($\alpha^{Auger} = 0.1$)



Closer look: overdensity maps SBG sample

- Overdensity in CenA region preserved
- CenA region amplified by M83 events deflected to NGC4945 region
- NGC253 overdensity $\rightarrow$ not seen in data ($\omega^{\phi}_{NGC253} = 13.6$, $\omega^{\phi}_{NGC4945} = 16$)
- NGC1068 deflections with a different flux weight (?)





Conclusions

- Current analysis: no coherent deflection $\rightarrow$ simulated realizations (CRPropa3+GMF) return compatible parameters due to an increased source contribution
- What is the meaning of the observed correlation?
  - In $\sim 20\%$ of the realizations (considering a 3 parameters selection) it is possible to recover compatible parameters in agreement with the Auger analysis
  - Source signal fraction needs to be increased ($f_{src}^{best\ fit} = 0.3$, $f_{signal}^{Auger} = 0.1$)
  - The extra contribution is seen as background due to the isotropic distribution of the heavy elements which dominate the spectrum at high energy and some signal is lost outside of the search radius.
- Is $\theta_{best\ fit}^{Auger} \sim 15^\circ$ related to a limit for the EGMF?
  - In order to obtain comparable results in term of search radius, signal fraction and TS no contribution from the EGMF is needed

Next steps

- Analysis with different mock datasets to impose limits to the EGMF
- Further studies on behavior of NGC253
- New definition of Likelihood (rigidity dependence)
- Behavior of the analysis with different lenses