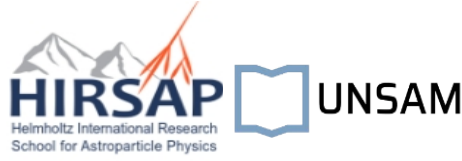
Studies on the effects of magnetic fields on anisotropies in a catalog based search

L. Deval, R. Engel, T.Fitoussi, M.Unger

Astroparticle school - Obertrubach-Bärnfels

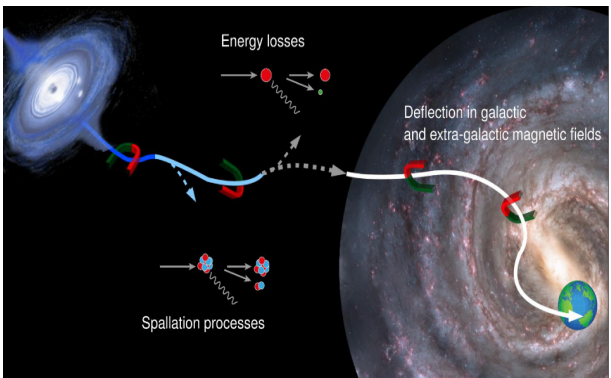
10 October 2023



Brief introduction on cosmic ray propagation

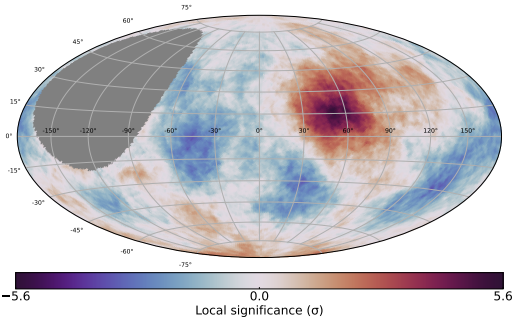
- Cosmic rays are charged particles which origin is an open question
- Focus of this work: Ultra High Energy Cosmic Rays (UHECRs) $\rightarrow$ CRs above 38 EeV
- Extragalactic propagation and galactic magnetic field influence their arrival direction at Earth

- What do we observe?



Current anisotropy studies in Auger

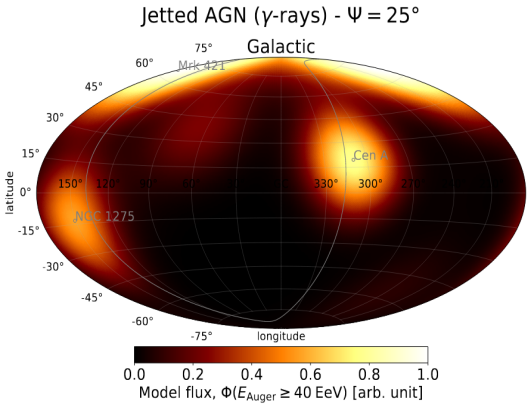
- Observed overdensity (excess of events) in Centaurus region
- Results obtained with a blind search where:
  - N_{on} = events inside given radius
  - N_{off} = events outside given radius
  - Top hat smearing = 27°



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

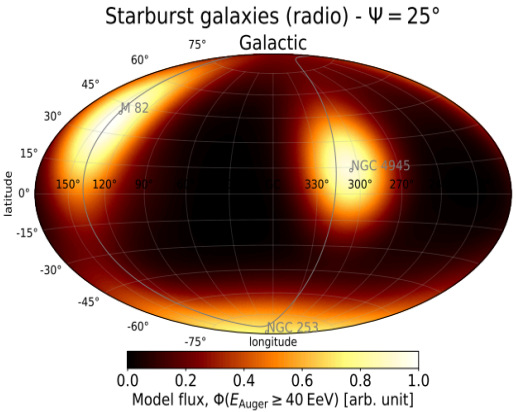
Source catalogs considered:

- Jetted Active Galactic Nuclei (AGN): 26 sources with distances between 3 Mpc and 250 Mpc
- Main contribution related to 3 sources

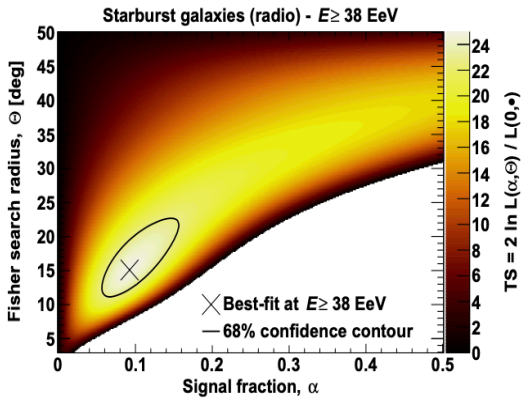


Source catalogs considered:

- Starburst Galaxies (SBG): 44 sources with distances between 2.7 Mpc and 180 Mpc
- Main contribution related to 3 sources

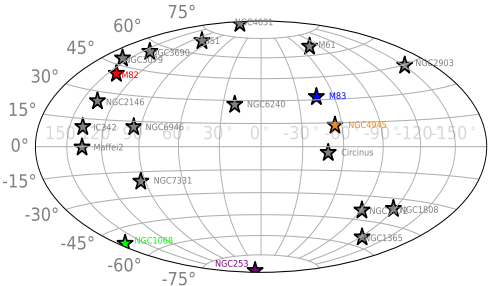


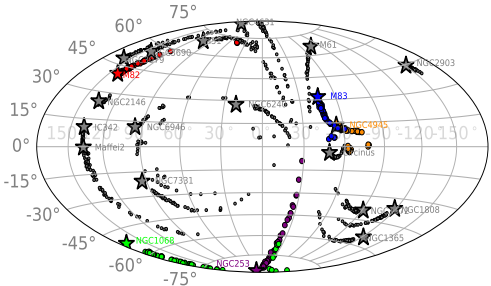
- Model constructed with:
  - Fisher distribution around every source with a search radius θ
  - contribution from the source (anisotrpoy fraction α)
  - Model is tested against isotropy throught a likelihood analysis
- Highest significance found for Starburst Galaxies with:
  - Test statistic (TS) $= 25$
  - Best fit parameters:
    - Search radius (θ) $\sim 15^{\circ}$
    - Anisotropy fraction (α) $\sim 10\%$
- Galactic magnetic field **not** considered



Role of the galactic magnetic field

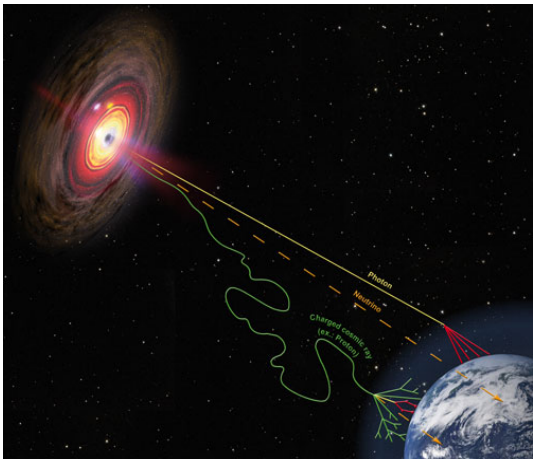
- No coherent deflections have been considered in the flux model
  $\rightarrow$ What is the meaning of the observed correlation?





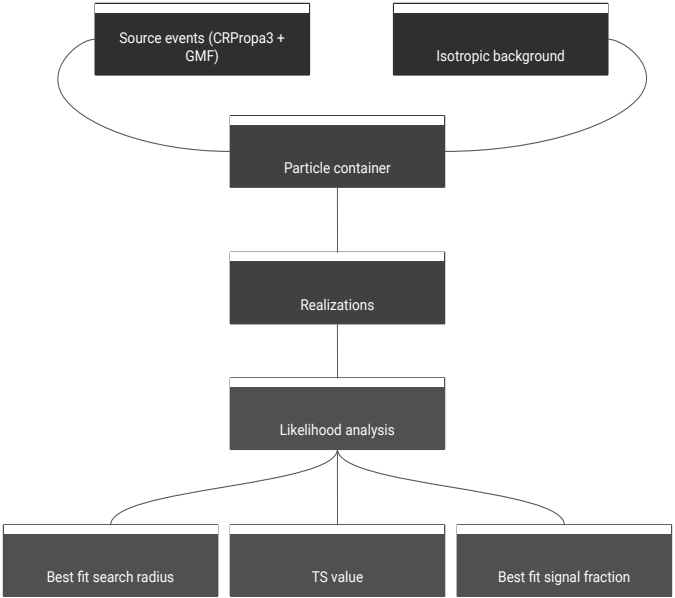
Simulation framework

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

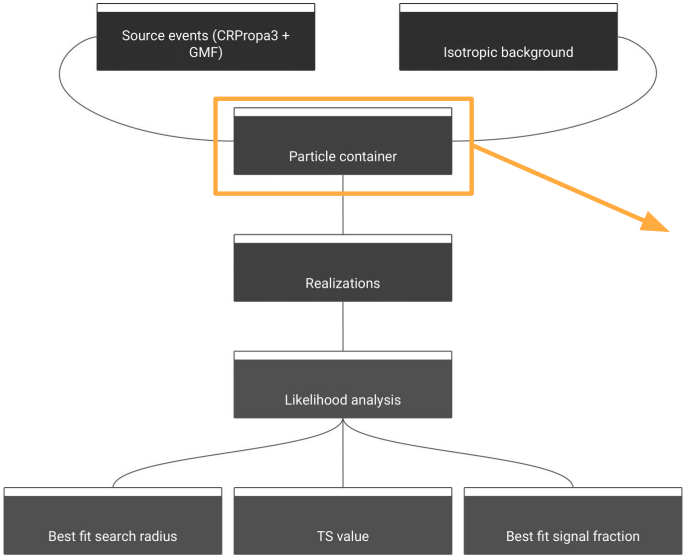


*: JCAP 04 (2017) 038

Analysis method

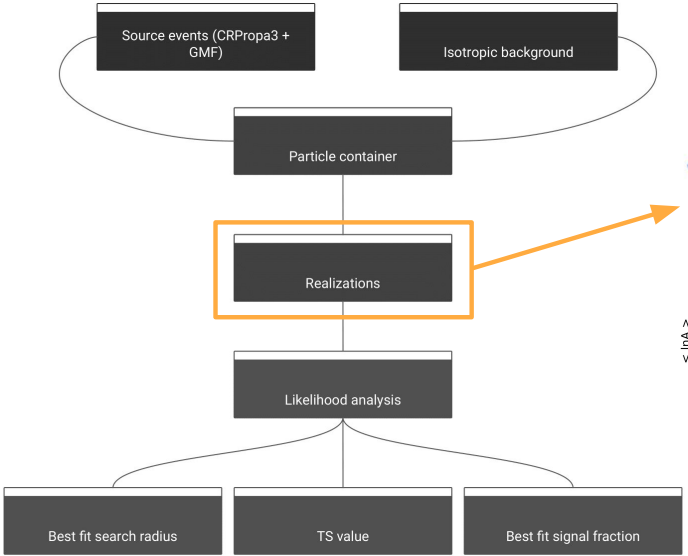


Analysis method

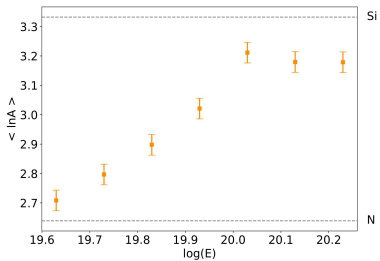


- Particle container:
  $f_{srcs} \cdot N_{tot} + (1 - f_{srcs}) \cdot N_{tot}$

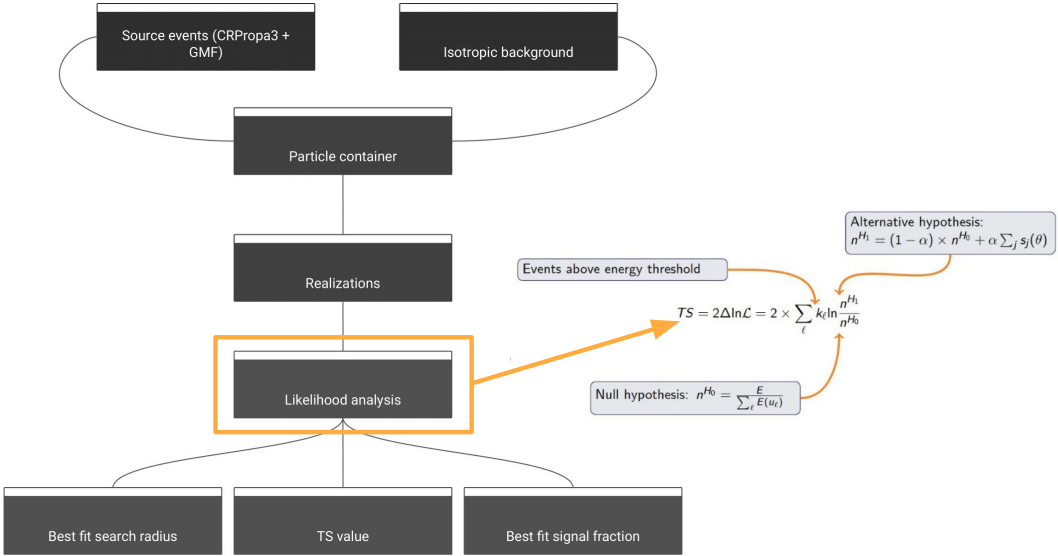
Analysis method



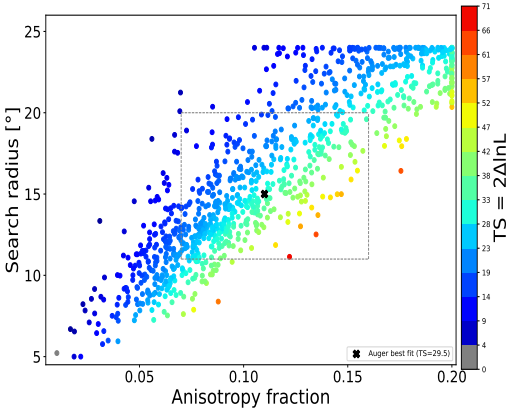
- Mock dataset: 1309 events above 38 EeV



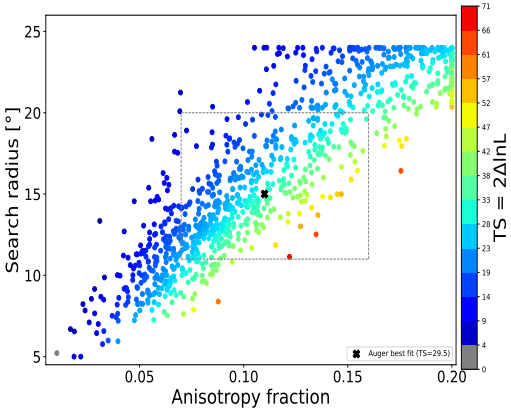
Analysis method

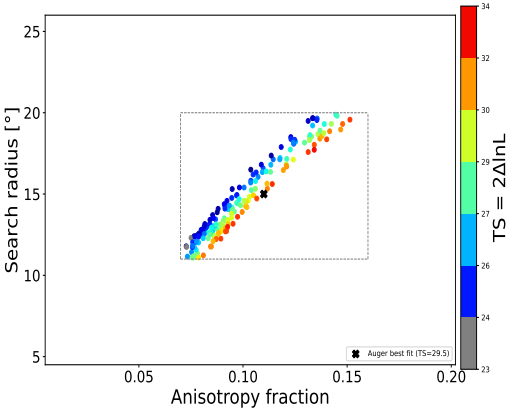


Fit results for mock data sets



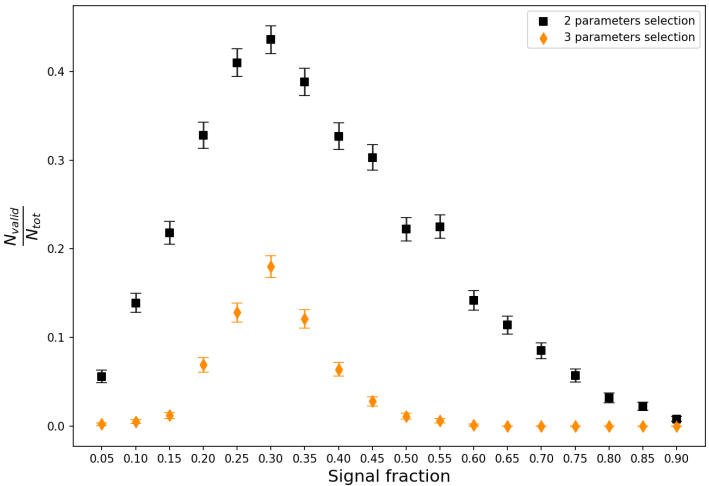
Fit results for mock data sets





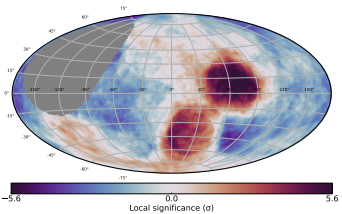
Signal fraction scan SBG hypothesis

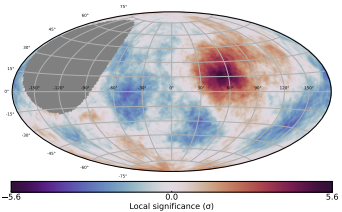
- Best scenario: $f_{src} = 0.3$
- Source contribution is increased ($f_{src} > \alpha^{Auger}$)
- Parameters:
  - 2 parameters selection: α, θ
  - 3 parameters selection: α, θ, TS



A 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 (?)





- Catalog based analysis (ApJ 2022): no coherent deflections included
- This study: simulated realizations (CRPropa3+JF12)
- Results:
  Meaning of the observed correlation?
  - $\sim 20\%$ of the realizations returns compatible parameters in agreement with the Auger analysis
  - Source signal fraction 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