

Auger Milano

Lorenzo Caccianiga
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The Pierre Auger Observatory - Gruppo di Milano

Nome	Ruolo	FTE
Lorenzo Caccianiga	Ricercatore INFN	70%*
Lino Miramonti	PO Unimi	70%
Marco Giammarchi	Primo Ric. INFN	50%
Giovanni Consolati	PA Polimi	70%
Claudio Galelli	Dottorando Unimi	70%*
Francesco Cavaliere	Resp. officina meccanica Unimi	40%

Totale 3.7 FTE

- + **Federico Maria Mariani** Nuovo dottorando unimi da ottobre (già nella collaborazione da Aprile in quanto possessore di borsa post-laurea)
- + **Danelise Franco** Dottoranda Unicamp (Brasile) visiting Sett 2021-Feb 2022
- + **(Forse) Max Stadelmaier**: attualmente PhD student al KIT, ha applicato per una borsa post-doc finanziata dalla DAAD (Germania) per fare **12 mesi** fuori dalla Germania + 6 di nuovo al KIT. Buone probabilità di riuscita, nel caso viene da noi a partire da Giugno 2022-> Maggio 2023

*il 30% mancante è subordinato all'apertura della sigla SWGO

- Da luglio 2020 si sono laureati con noi 9 laureandi triennali e 4 magistrali + 2 triennali e 1 magistrale in corso

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- **Lorenzo Caccianiga** subentra a **Lino Miramonti** come **responsabile locale** da giugno 2021
- **Lorenzo Caccianiga** è da Gennaio 2021 **Task leader per le Arrival Directions** (Con G. Golup, Argentina)

- **Sottomesso PRIN 2020 - DEEPER**

Dark matter and other Exotic physics Explored

with Photons in Extreme-energy cosmic Rays using machine learning

PI: Lorenzo Caccianiga - INFN Milano

Denise Boncioli - Università degli Studi dell'AQUILA

Lorenzo Perrone - Università del SALENTO

in attesa dell'esito...

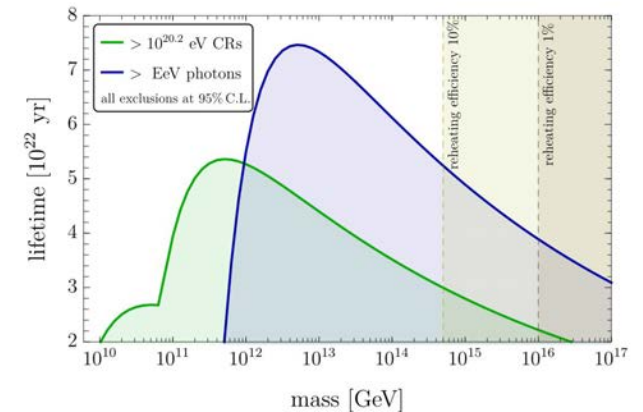


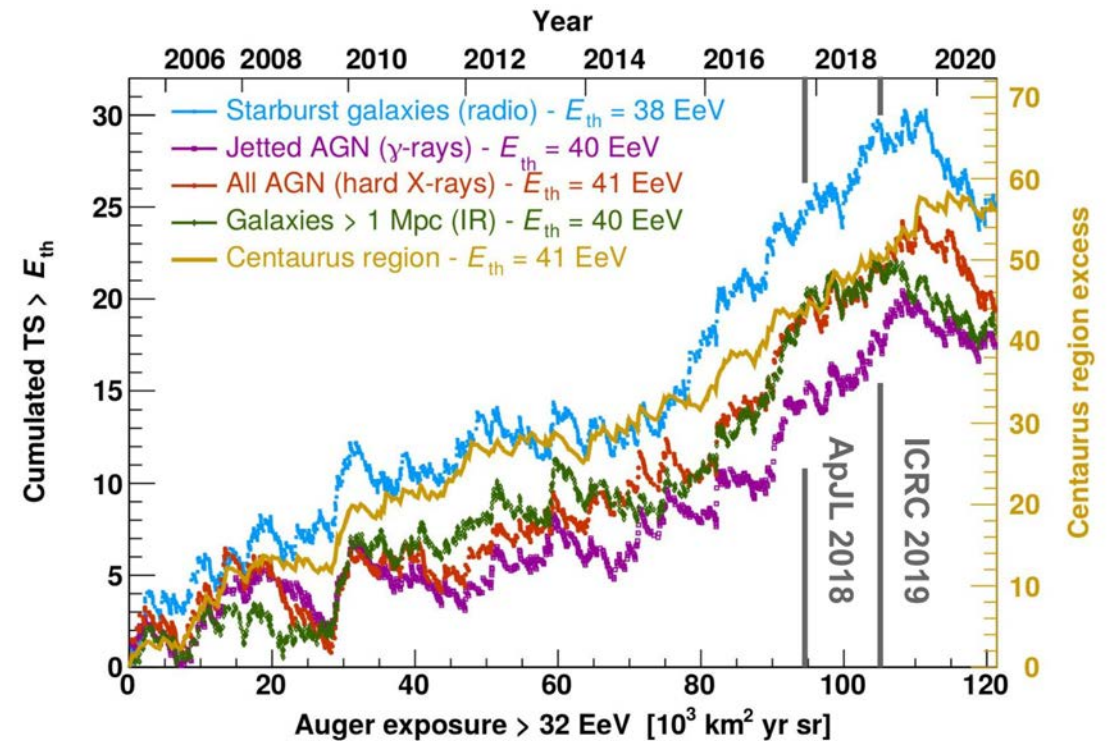
Figure 1: Constraints on the mass and lifetime of super-heavy DM particles from the absence of UHE photons (green) and from the absence of CR with energy above $10^{20.2}$ eV (blue). The allowed region lies above the curves. For illustration purpose, the 95% CL upper limit on mass obtained from the possible value of the Hubble rate at the end of inflation for a reheating efficiency of 1% (10%) is shown as the vertical dashed (dotted) line¹¹.

Risultati scientifici con contributo del gruppo

- **Lorenzo Caccianiga** (con il supporto di **Gianni Consolati** e **Marco Giammarchi**) si occupa del controllo del processo di **produzione dei dati** al centro di calcolo di Lione, contestualmente seguendo gli **SD Shift** che vengono svolti su base quindicinale.
- **Gianni Consolati, Lino Miramonti Marco Giammarchi e Francesco Cavaliere** sono stati coinvolti nella produzione di parti nuovi rivelatori (tubi di alloggio per il fototubo SSD) per **Auger Prime** e nella loro installazione nel campo.
- Creazione della task force “**MEAD**” (Mass estimators for arrival directions) per riunire esperti di diversi metodi di discriminazione di massa basati su SD con il preciso scopo di svolgere analisi di Arrival Directions con gli eventi più leggeri (= meno deflessi dai campi magnetici)
- Update della ricerca di **Neutroni** da sorgenti galattiche (nessun update dal 2014). Portata avanti da **Federico Mariani** con la supervisione di **LC**, Geraldina Golup e Paul Sommers (Penn State University) -> probabile paper l'anno prossimo
Possibile aggiunta di ricerca di **correlazione temporale** (e.g. con **Magnetar Outbursts**)

Risultati scientifici con contributo del gruppo

- **Lorenzo Caccianiga** è il responsabile per Auger dell'Editorial Board per il paper congiunto **Antares-IceCube-Auger-Telescope Array** sulla ricerca di **correlazioni tra neutrini e UHECR** -> sottomissione probabilmente entro fine anno
- **Lorenzo Caccianiga** (responsabile) e **Claudio Galelli** sono nell'Editorial Board per il nuovo paper sulle **anisotropie a piccola e intermedia scala** alle altissime energie (>32 EeV): verranno rilasciati i dati usati per l'analisi (prima volta dal 2015) -> sottomissione entro fine anno
- A seguire, verrà iniziata la stesura di un altro paper riguardo alla **connessione** tra anisotropie a **larga** e **piccola scala** da 4 EeV in su



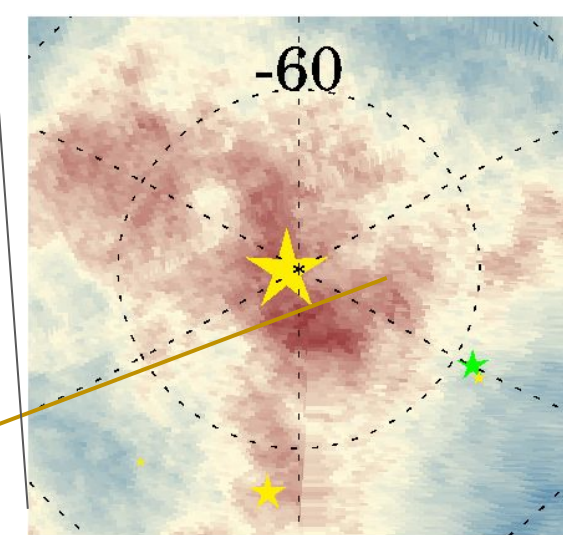
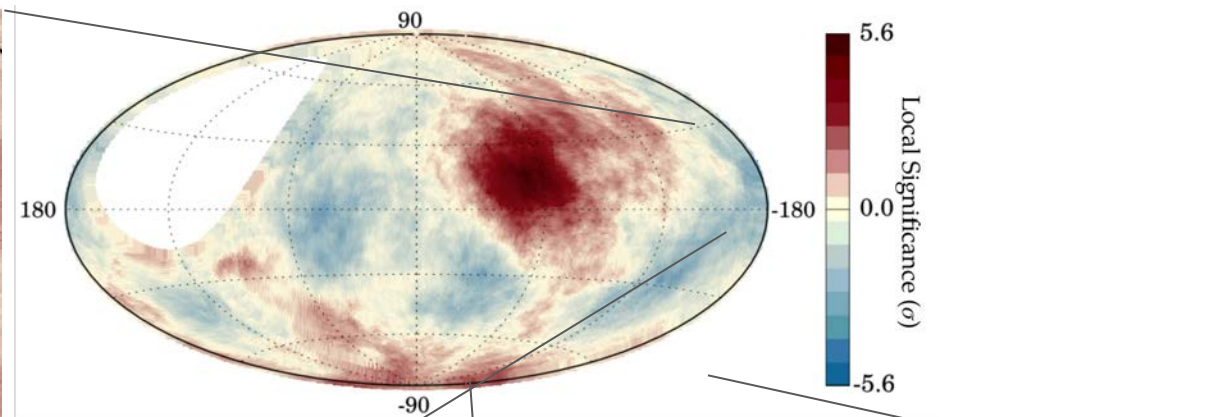
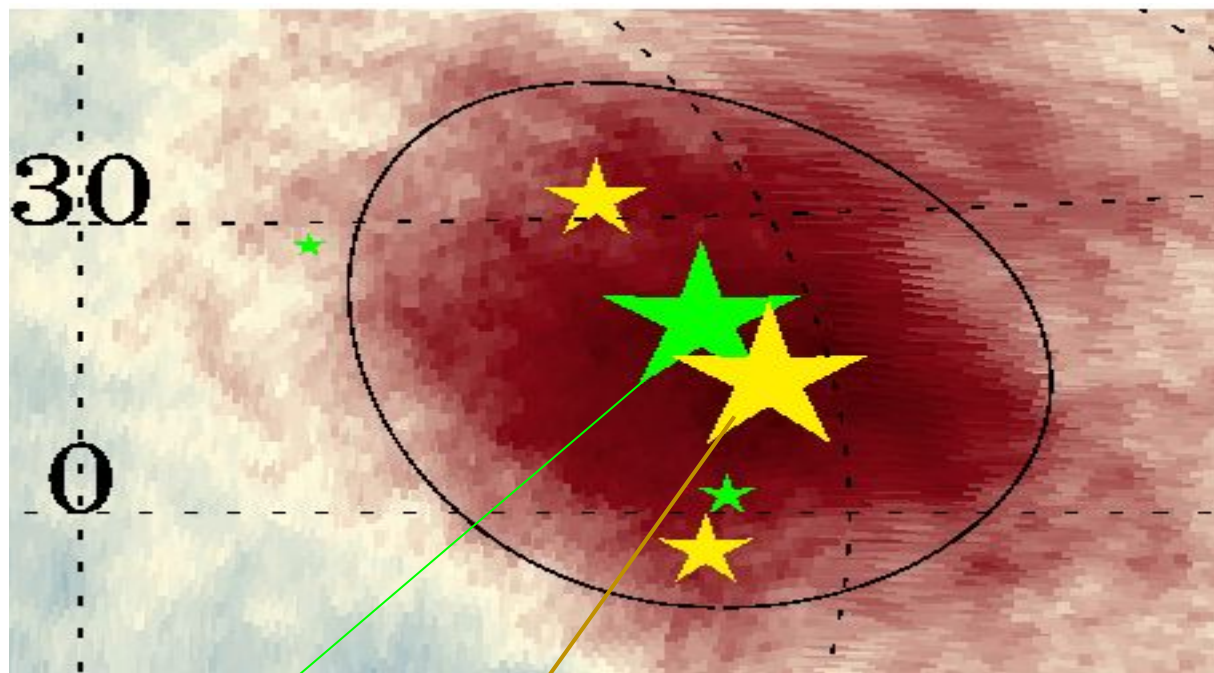
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Richieste economiche:

Capitolo	Motivazione	Richiesta
Missioni	Meeting di collaborazione a Malargue 5 persone totali su 2 meeting	15k€
	Installazione nuova elettronica turni tecnici	10k€
	Meeting Arrival Directions con gruppo di Parigi-Orsay per paper HEFD e Bariloche con Co-Task leader	2k€
	Conferenza UHECR 2022 x 2 persone	4k€
	Turno presa dati FD x2	8k€
	Meeting referee x1	1k€
	Meeting Collaborazione Italiana x2 persone	2k€
	Conferenze x2	3k€
Inventario	workstation per analisi dati	3k€
Trasporti	Auto a noleggio missioni Malargue	2k€

Backup Slides

Ricerca di eccessi su piccola-intermedia scala



Cen A
Most contributing source to
2MRS, γ -AGNs and Swift-BAT

NGC 4945
Most contributing source to starburst

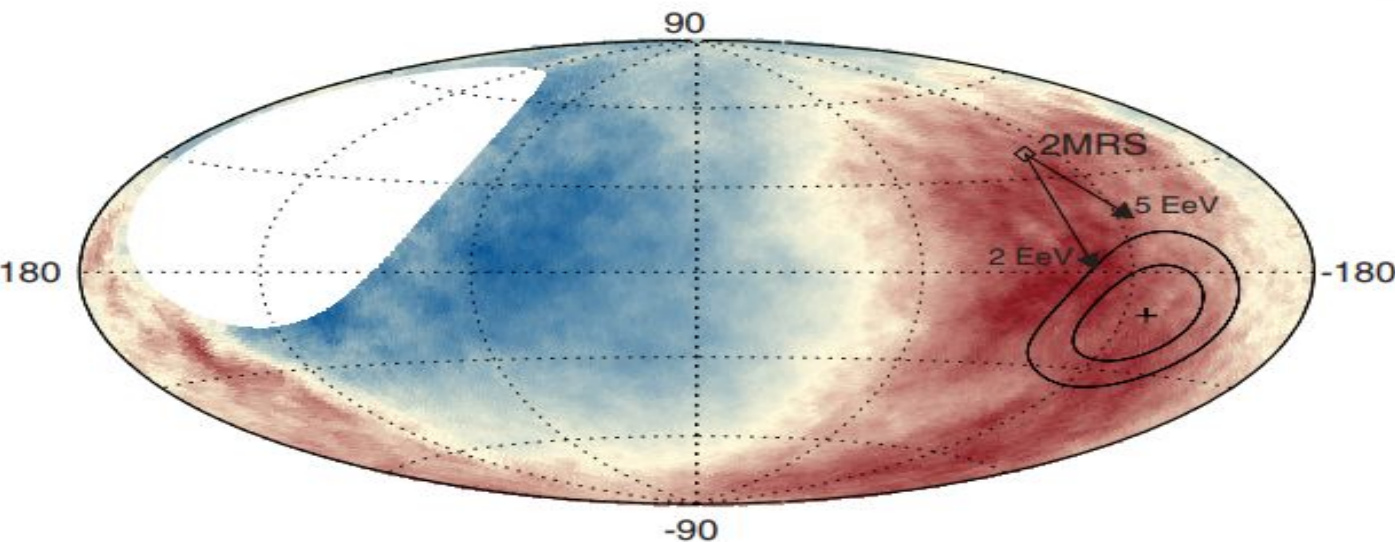
NGC 253
2nd-most contributing source
to starburst

Arrival directions - Large scale

Energy (EeV)	Number of events	Fourier coefficient a_α	Fourier coefficient b_α	Amplitude r_α	Phase φ_α (°)	Probability $P(\geq r_\alpha)$
4 to 8	81,701	0.001 ± 0.005	0.005 ± 0.005	$0.005^{+0.006}_{-0.002}$	80 ± 60	0.60
≥ 8	32,187	-0.008 ± 0.008	0.046 ± 0.008	$0.047^{+0.008}_{-0.007}$	100 ± 10	2.6×10^{-8}

No significant dipole in the 4-8 EeV energy range \mapsto Galactic origin disfavored

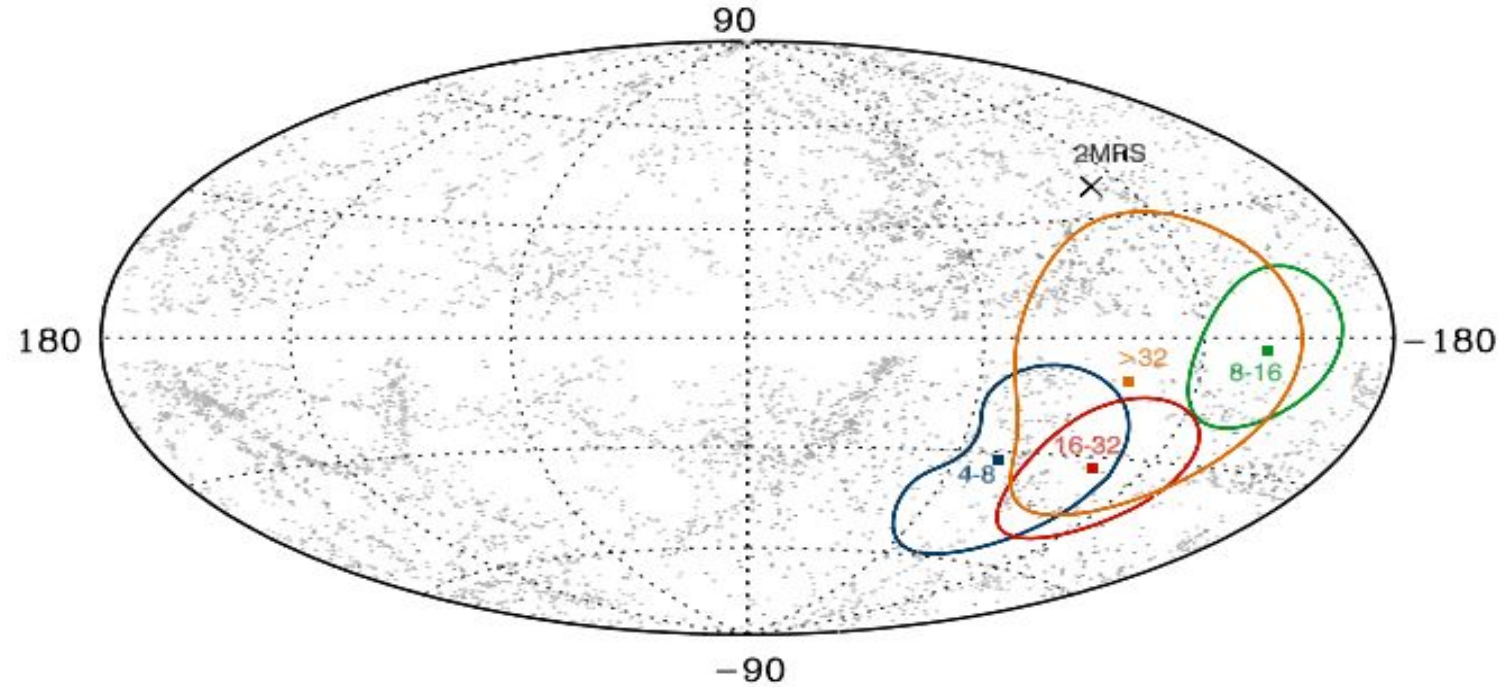
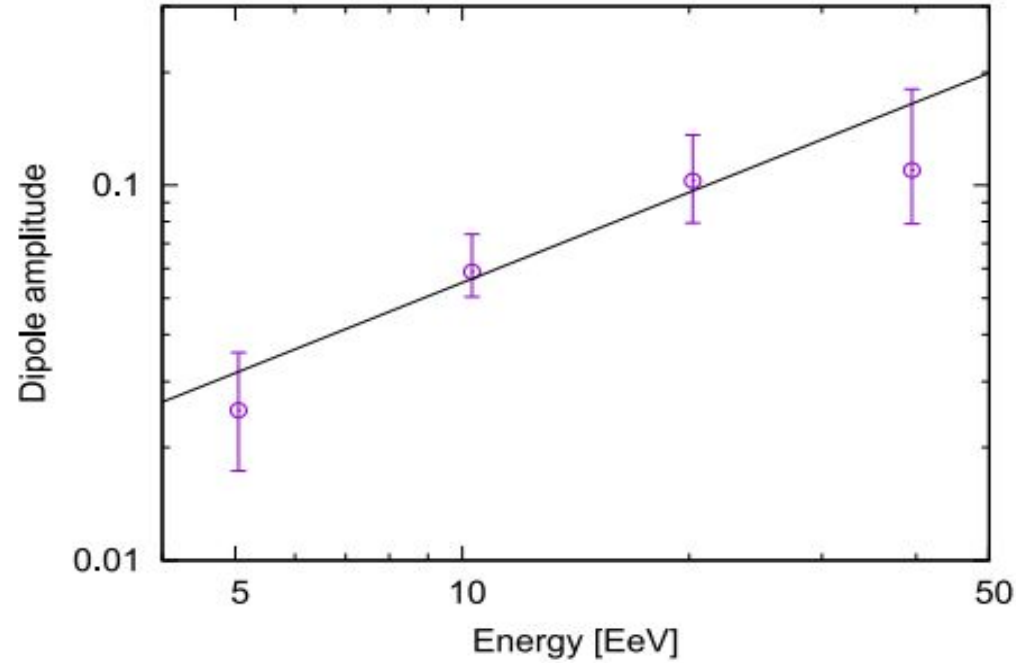
Significant dipole above 8 EeV \mapsto distribution of sources must be anisotropic (magnetic fields cannot anisotropize an isotropic distribution of CRs)



Direction of the dipole too far from the Galactic Center \mapsto Galactic origin disfavored
possible hint of correlation with the direction of the distribution of nearby matter, if shifted in (certain) magnetic field models

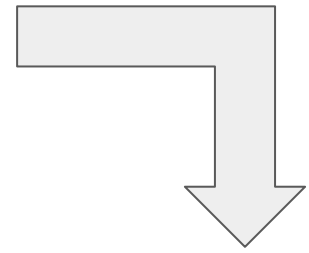
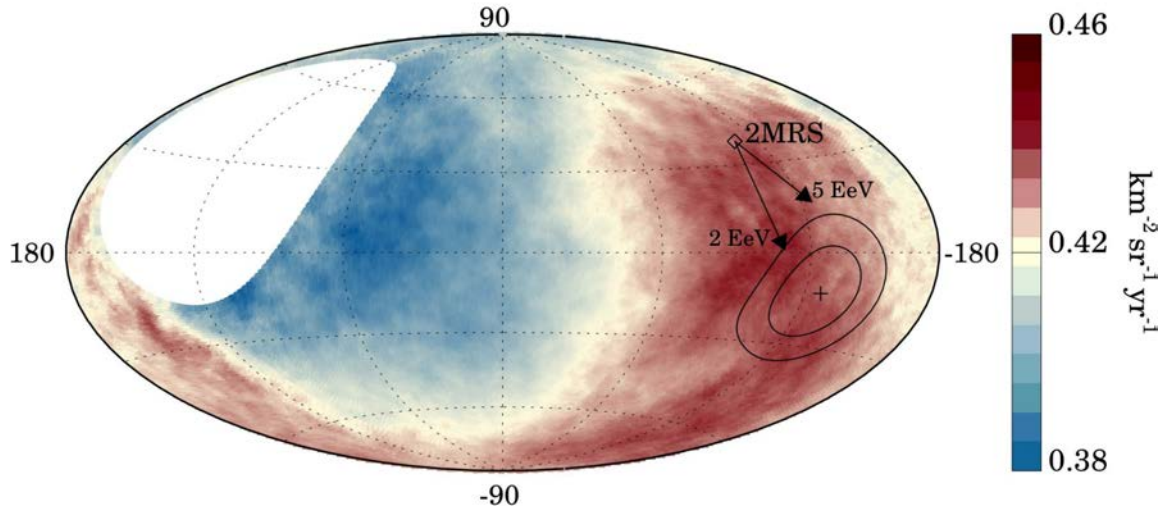
Arrival directions - Large scale

The Astrophysical Journal, Volume 868, Number 1 (2018)



Dipole amplitude seems to increase with energy
(but too few events at high energies)

Eccessi su larga scala -> transizione a piccola/intermedia



“Fisher analysis”

Anisotropia a larga scala - “bassa” energia

Distribuzione **dipolare** con significatività 6σ per eventi con energia >8 EeV

Esclusa provenienza galattica - in linea con la distribuzione della materia nell’universo locale (2MRS)

GAP 2017- 039 Likelihood-ratio test against isotropy of:

$$\frac{1}{N} \frac{dN}{d \cos \theta} = \frac{1}{2} \left[i + (1 - i) \frac{\kappa \exp(\kappa \cos \theta)}{\sinh \kappa} \right]$$

θ : angle with respect to direction under test

Isotropic fraction

Fisher distribution

$\kappa \gg 1$

$\kappa \ll 1$

$$e^{-\kappa \theta^2 / 2}$$

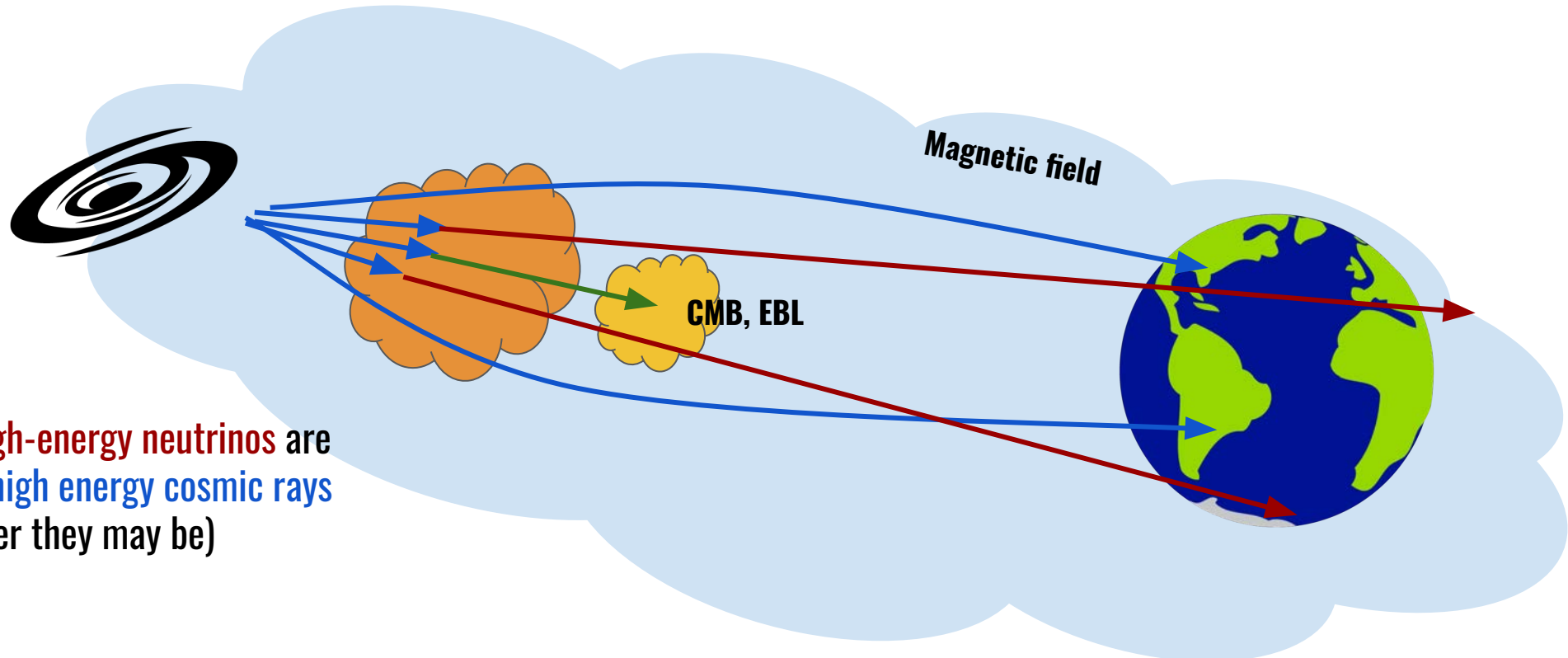
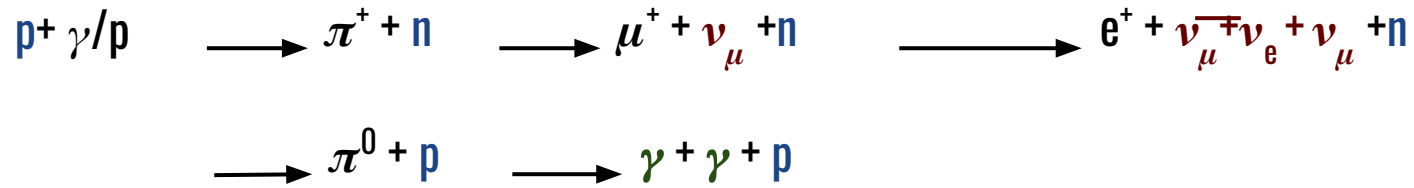
Gaussian

$$(1-i)\kappa \cos \theta$$

Dipole

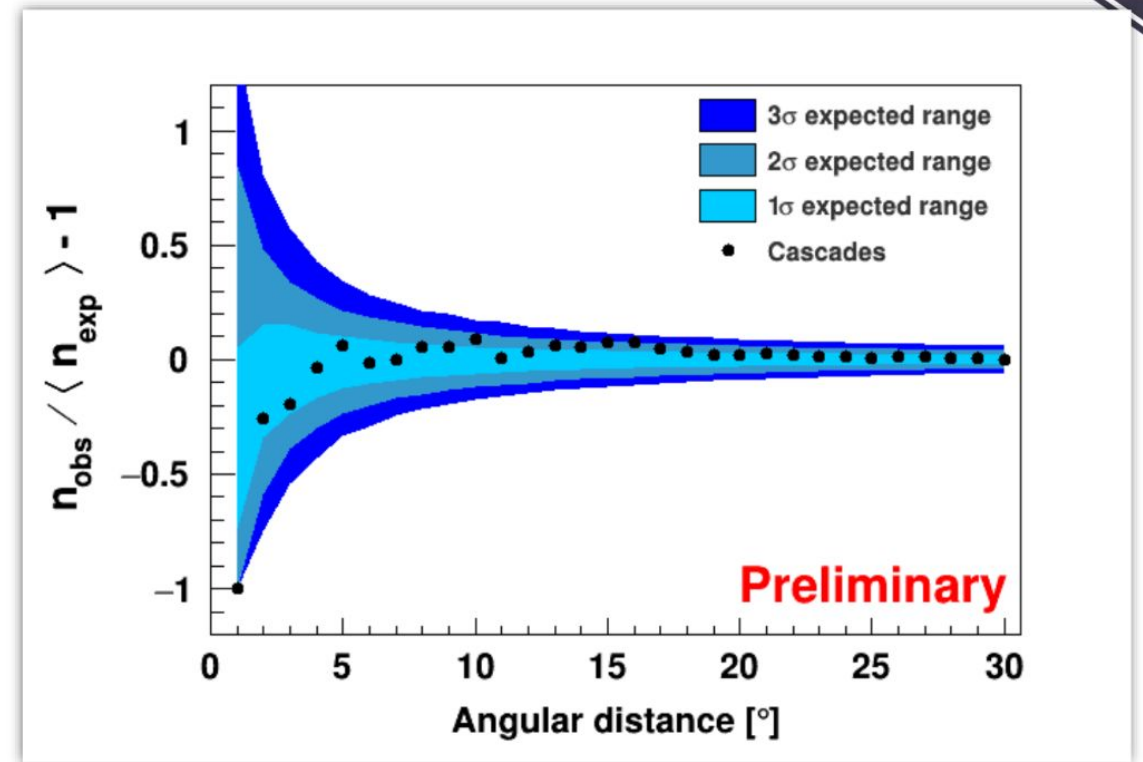
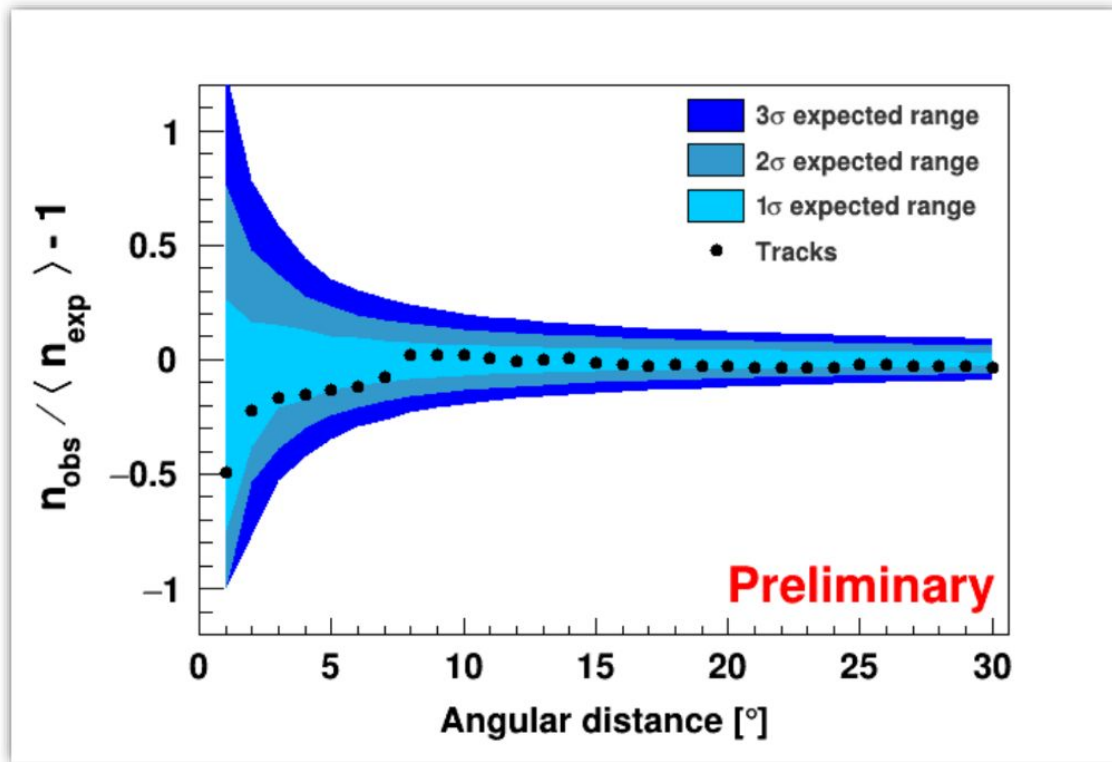
Arrival directions - Multimessenger

Search for correlations between UHECRS detected by **Auger** and **Telescope Array**, and High-Energy neutrinos as detected by **IceCube** and **ANTARES** (since 2018).



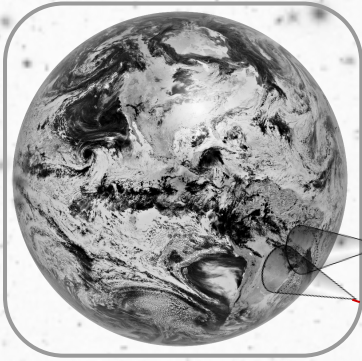
It is expected that **high-energy neutrinos** are produced near **ultra-high energy cosmic rays** accelerators (whatever they may be)

Arrival directions - Multimessenger



- In the first publication, potentially interesting results were found in the analyses done between UHECR and high-energy cascades. *These p-values have become larger with more statistics.*
- Updated cross-correlation results was presented by me at UHECR 2018 with new data from Auger, TA and data from ANTARES for the first time. The p-values are now of the order of $\sim 2.7 \times 10^{-2}$

Which sources, which galaxies?

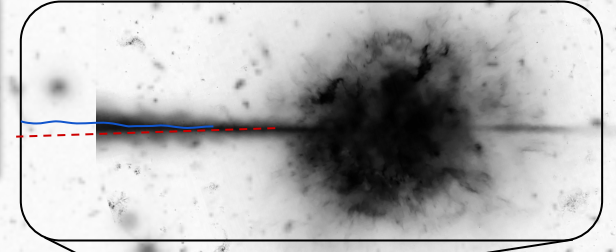


EBL
eV photons

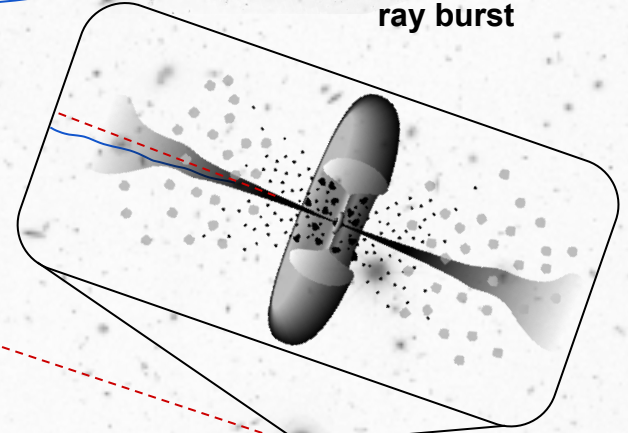
Attenuation weights:
from best-fit escape spectrum
of Auger spectral-composition
modeling

CMB
meV photons

EeV-ZeV
cosmic rays



Long gamma-ray burst



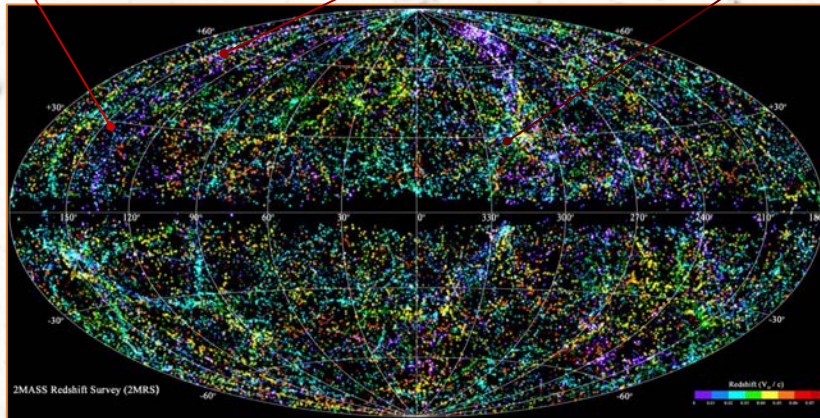
Radio galaxy

electromagnetic
emission

M82, starburst

NGC 4151,
non-jetted AGN

Cen A, jetted AGN



UHECR flux \propto star formation / AGN activity?

Star formation (e.g. long GRB):

- integral = **stellar mass: infrared** from revised 2MRS (44,113 gal. at 2.2 μm)
- **instantaneous: radio** based on Lunardini+ 19 (44 gal. at 1.4 GHz)

Jetted / non-jetted **AGN** (e.g. radio galaxies, blazars / Seyferts):

- **accretion** w. or w./o. jets: **X-rays** *Swift*-BAT 105 months (523 gal. at 14-195 keV)
- **jets: γ -rays** from *Fermi*-LAT 3FHL (26 gal. at 10 GeV - 1 TeV)

Cosmic ray propagation

Interaction with photon backgrounds

$$p + \gamma_{CMB} \rightarrow p + \pi^0 \quad E_{th} \approx 10^{19} \text{ eV}$$

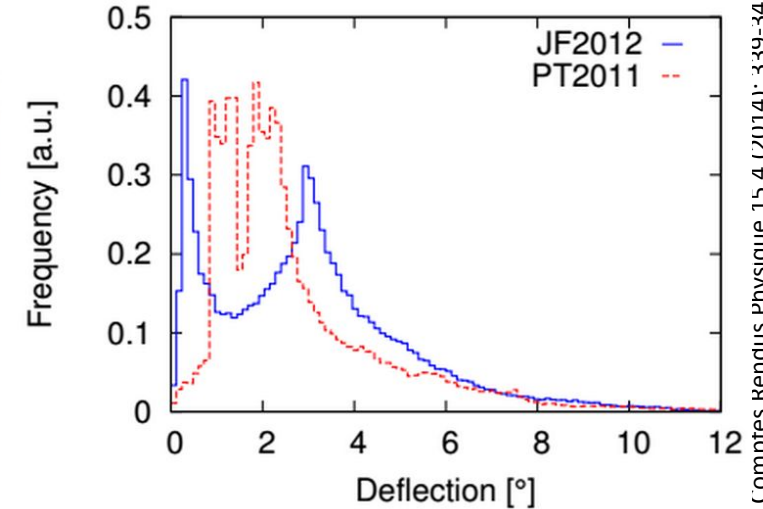
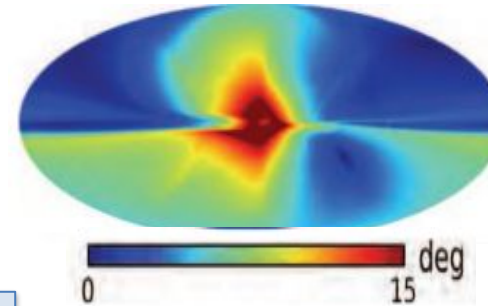
$$A + \gamma_{CMB} \rightarrow (A-1) + n$$

Cosmic rays at high energy can interact with cosmic photon backgrounds, losing energy

→ Cosmic rays above ~40 EeV cannot arrive from further than **few hundreds of Mpc** (GZK Horizon)

Looking at the highest energies allows us to reduce the number of candidate sources and magnetic deflections

Magnetic Fields



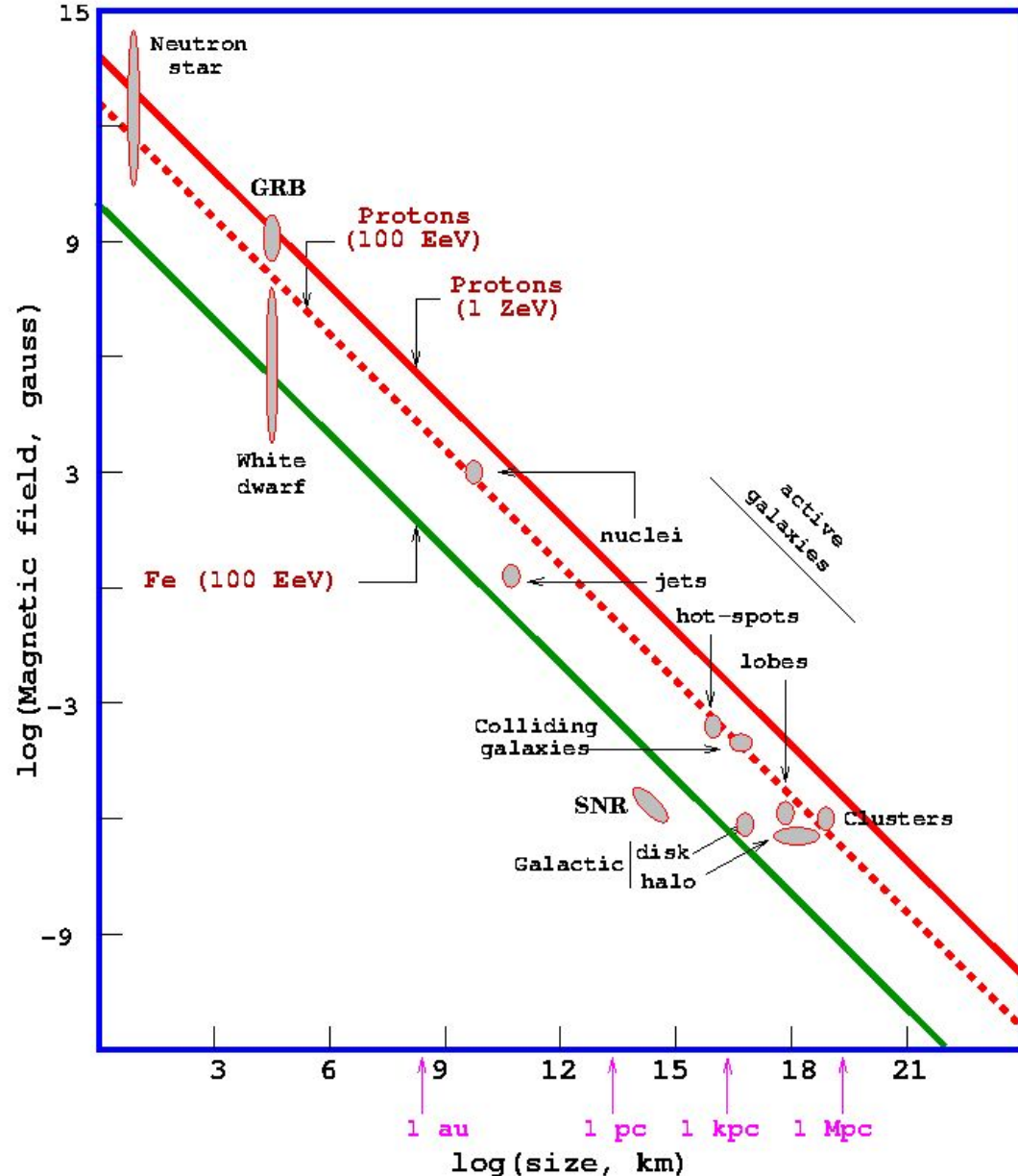
Distribution of deflections for a 100 EeV proton in two different models for the Galactic Magnetic Field

Magnetic fields deflections are

$$\delta \propto Z \times E^{-1}$$

Candidate sources

A.M. Hillas Ann.Rev:Astron.Astrophys.,22:425,1984

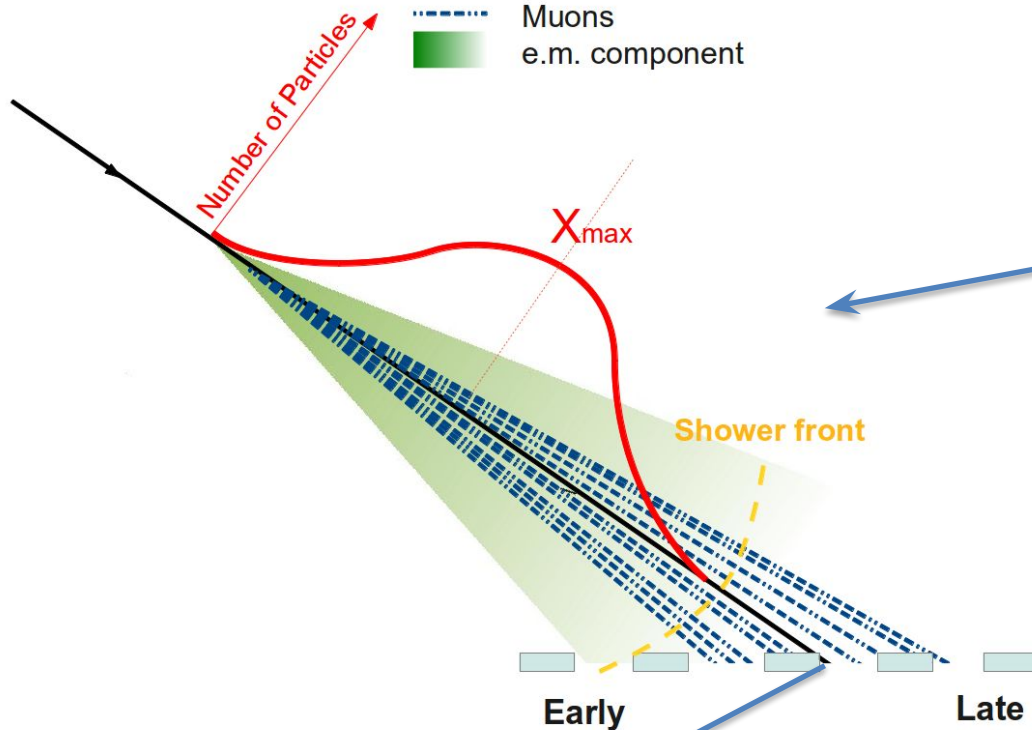


All acceleration models require the cosmic ray to be confined into the source.
 → stringent conditions on the magnetic fields of the candidate sources

$$E_{\max}^{\text{Limit}} \propto Z \cdot L \cdot B$$

Extensive Air Showers (1)

When a UHECR interact with the high atmosphere, it creates a cascade of secondary particles: an extensive air shower (EAS)



Observing the longitudinal profile of the shower (e.g. with fluorescence telescopes) the **total calorimetric energy** can be estimated

The number of particles at ground at a reference distance from the shower axis is a good **energy** estimator.

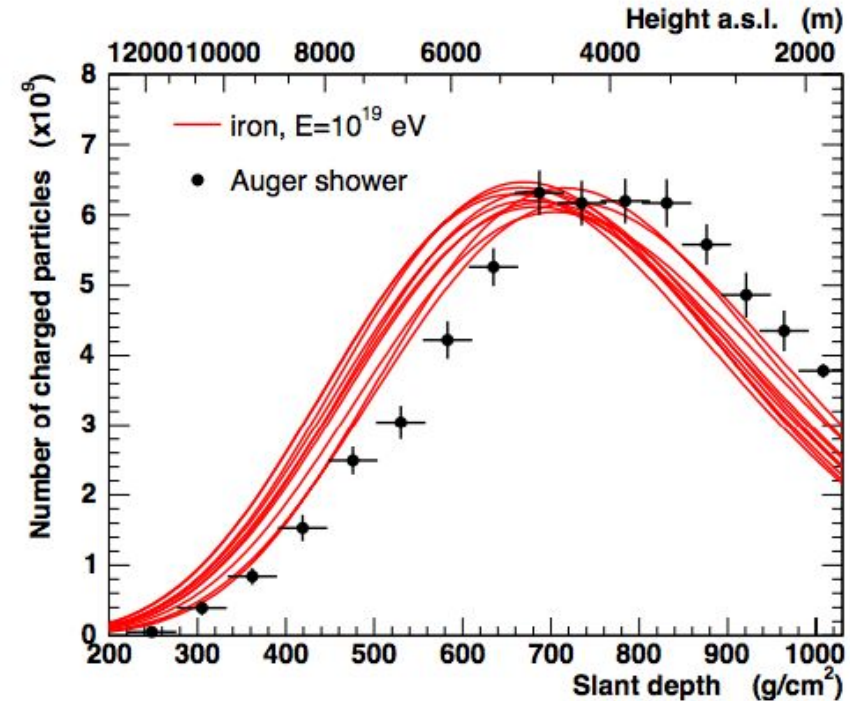
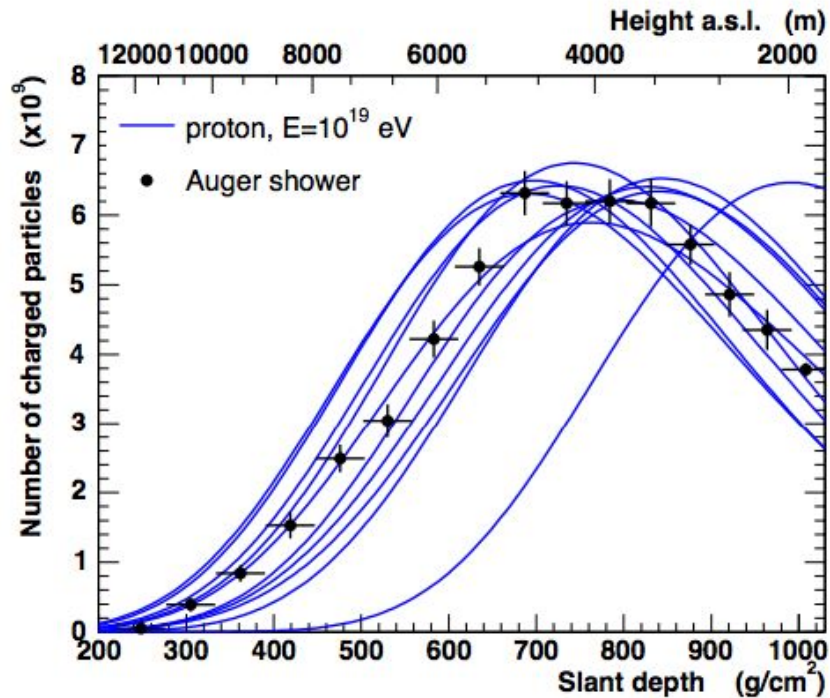
Needs to be absolutely calibrated:

- Monte Carlo
- Calorimetric measurements

From the arrival time of the shower at ground it is possible to reconstruct the **arrival direction** of the primary

Extensive Air Showers (2)

To infer the primary **mass**, the most interesting observables are the depth of the shower maximum (X_{\max}) and its RMS



To simulate EAS we use **hadronic interaction models**. The latest models are tuned on LHC data but the first interaction for cosmic rays at the highest energies are beyond the energy reached by LHC.

Courtesy of R. Engel

The update of the analysis

- Catalogs update: (more details on the wiki page)
 - more sources to test (now **+282** compared to the past work (2014))
 - **extended** catalog (dec. $\leq 45^\circ$): **Crab is included!**
 - there is any strong candidate that it would make sense to prioritize the search for it? Crab, 12 PeV γ -ray Galactic sources (Lhaaso), ..?
- Study 3 datasets:
 - Vertical full array ($E > 1$ EeV) and **field of view up to 25°**
 - Inclined full array ($E > 1$ EeV) and **field of view up to 45°**
 - Infill (0.1 EeV $< E < 1$ EeV) and **field of view up to 20°**
 - possibility to study better nearby sources

Summary of catalogs update

SOURCES Dec. < 20°	542 (357 in the work of 2014)
SOURCES 20° < Dec. < 45°	96 (not included in past work)
SOURCES dist. < 1kpc & Dec. < 20°	66 (43 in the work of 2014)

Target sets (plus plane and galactic center)	ApJ2014 sources (up to 20° of declination)	This work sources (up to 45° of declination)
millisecond pulsars	68	125
gamma-ray pulsars	77	215
LMXB	87	99
HMXB	48	60
TeV PWN	17 (observed only by H.E.S.S.)	28 (observed by H.E.S.S., MAGIC, VERITAS and HAWC)
TeV other	16 (observed only by H.E.S.S.)	34 (observed by H.E.S.S., MAGIC, VERITAS and HAWC)
TeV UNIDentified	15 (observed only by H.E.S.S.)	44 (observed by H.E.S.S., MAGIC, VERITAS and HAWC)
Microquasars	13	13
Magnetars	16	20

Ricerca eccessi spazio-temporali da oggetti galattici

Test di algoritmi (e.g. MEPSA) per ricerca di correlazioni spazio-temporali in serie di dati

