UHECRs and Magnetic Fields

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2nd Snowmass UHECR Mini-Workshop
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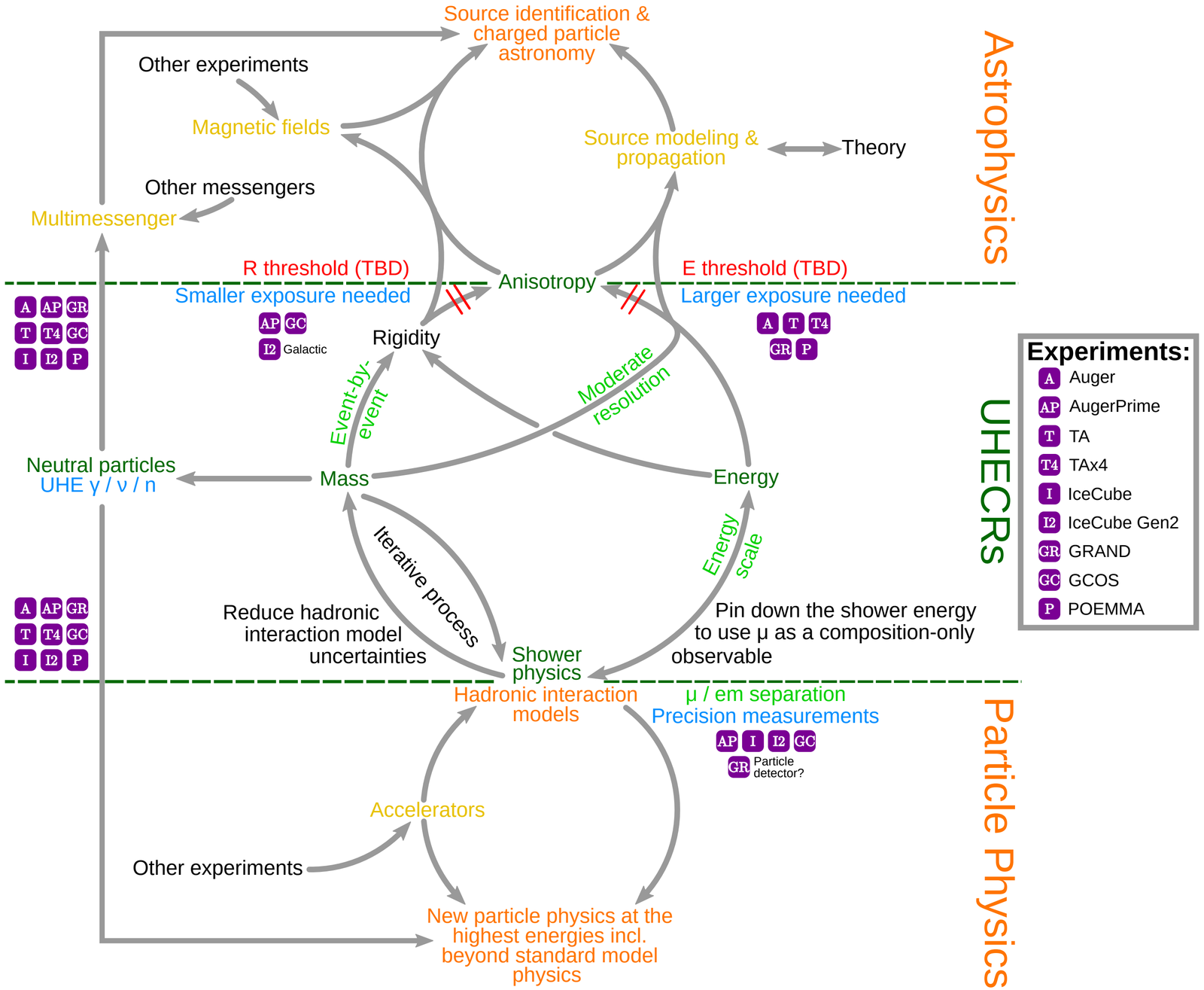
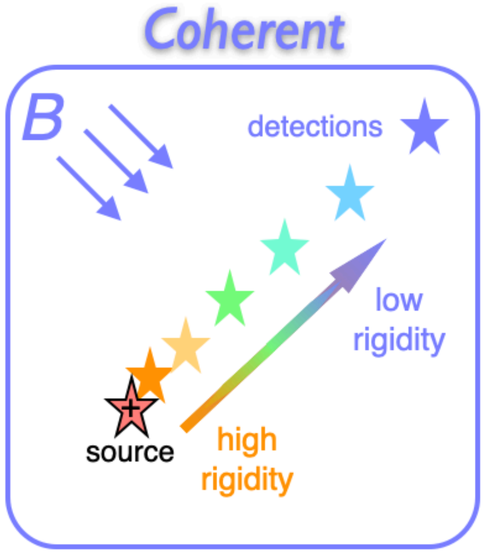
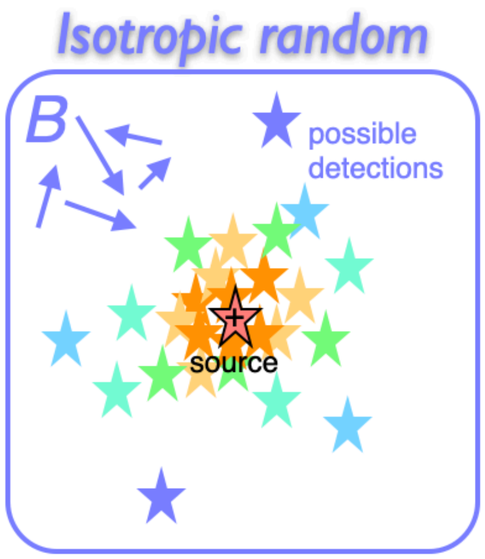
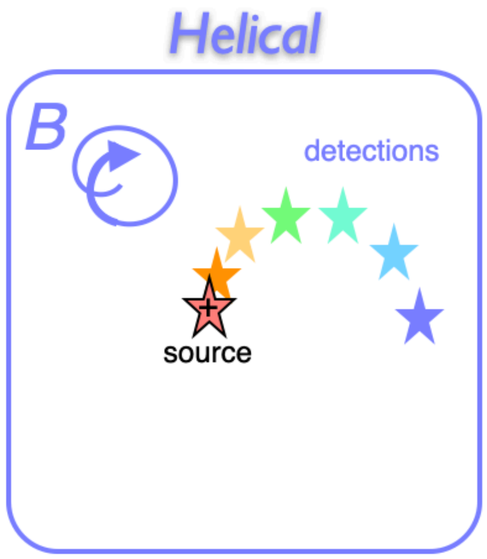
connections



UHECR deflections

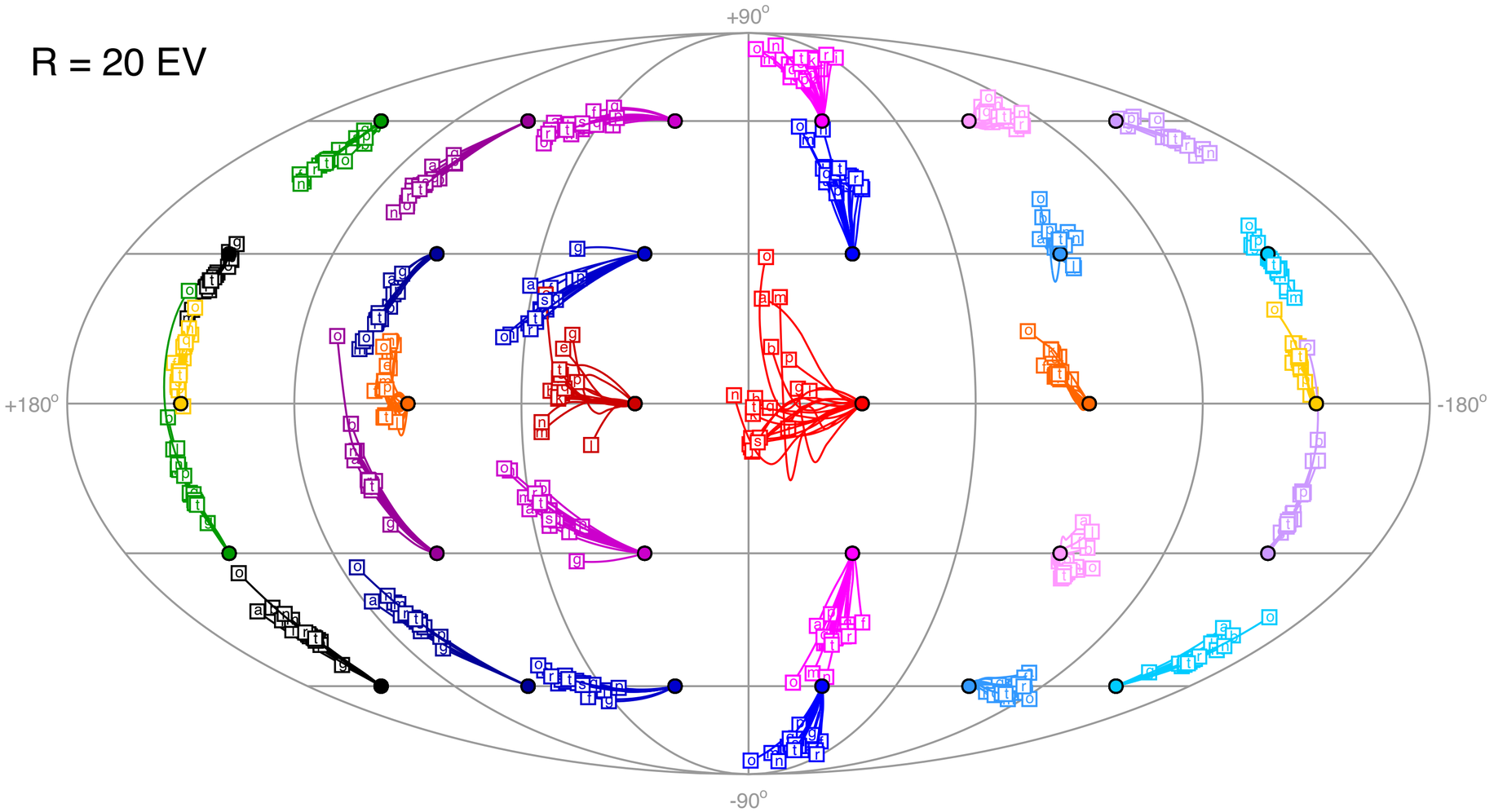






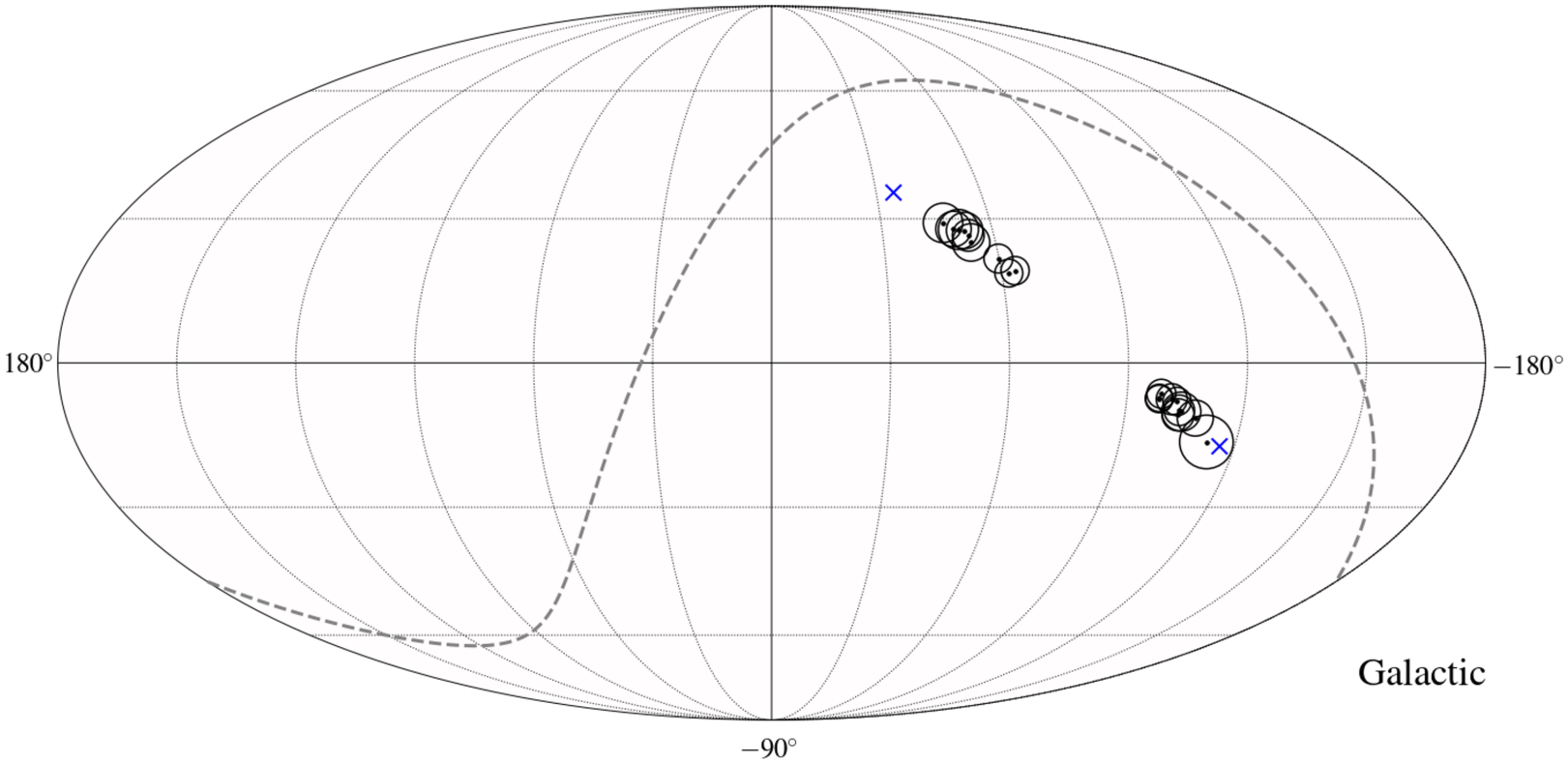
- to first-order, deflections depend on CR rigidity
- different types of field structures act differently
- to interpret UHECR arrival directions, each type of structure have to be understood
- conversely, UHECR deflections can provide information about magnetic fields

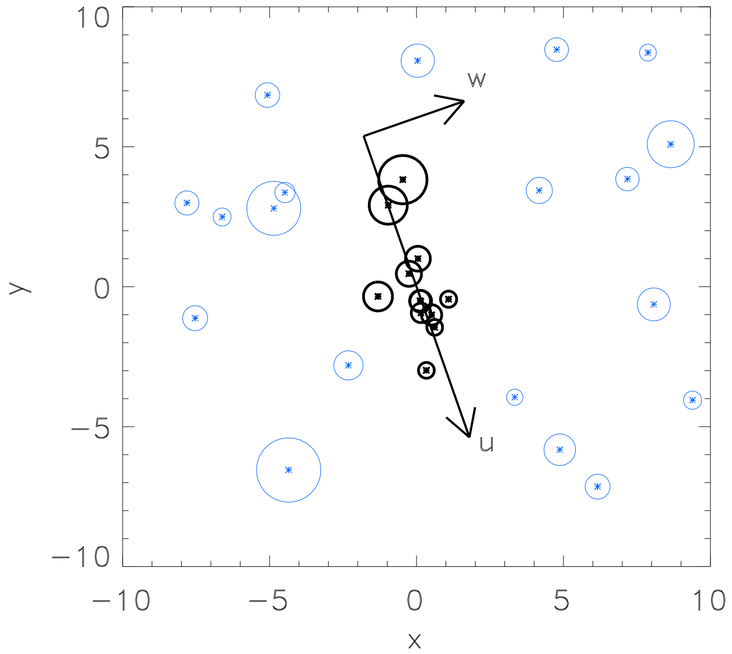
the galactic magnetic field (GMF)

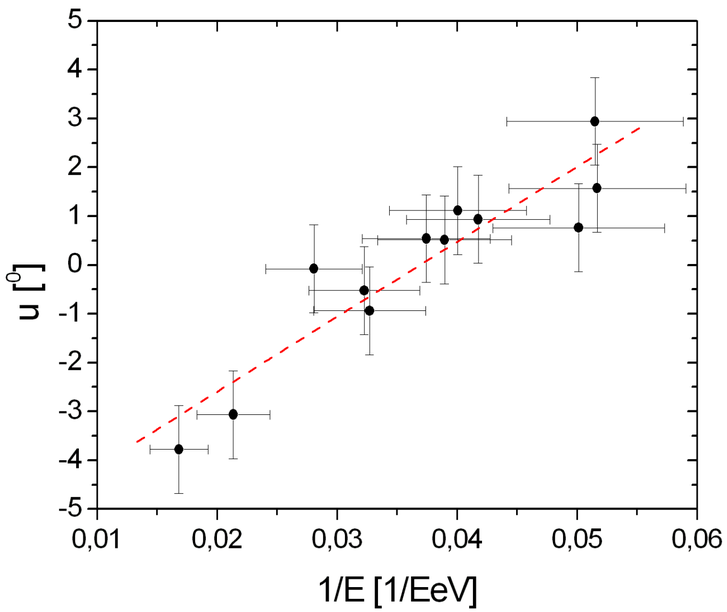


- CRs are backtracked from the circles
- they end up in the indicated squares for each different GMF model
- deflections are rigidity-dependent

multiplets and the galactic magnetic field

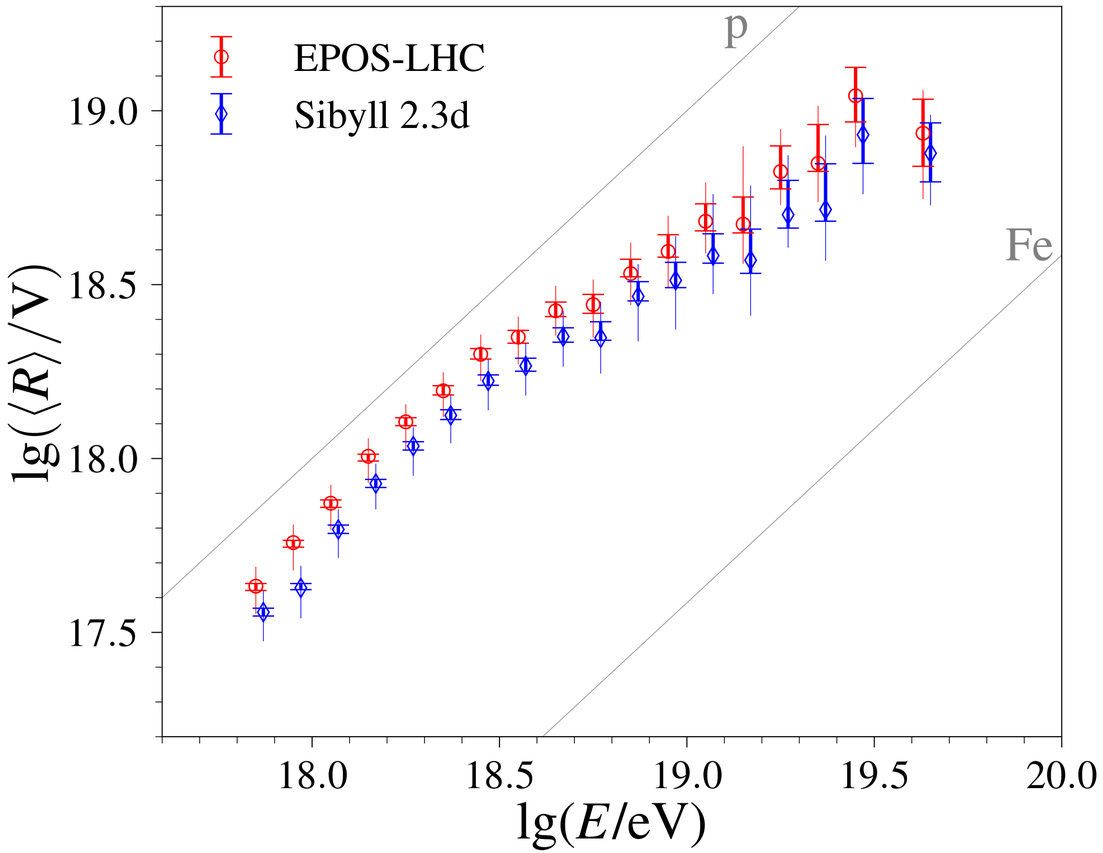


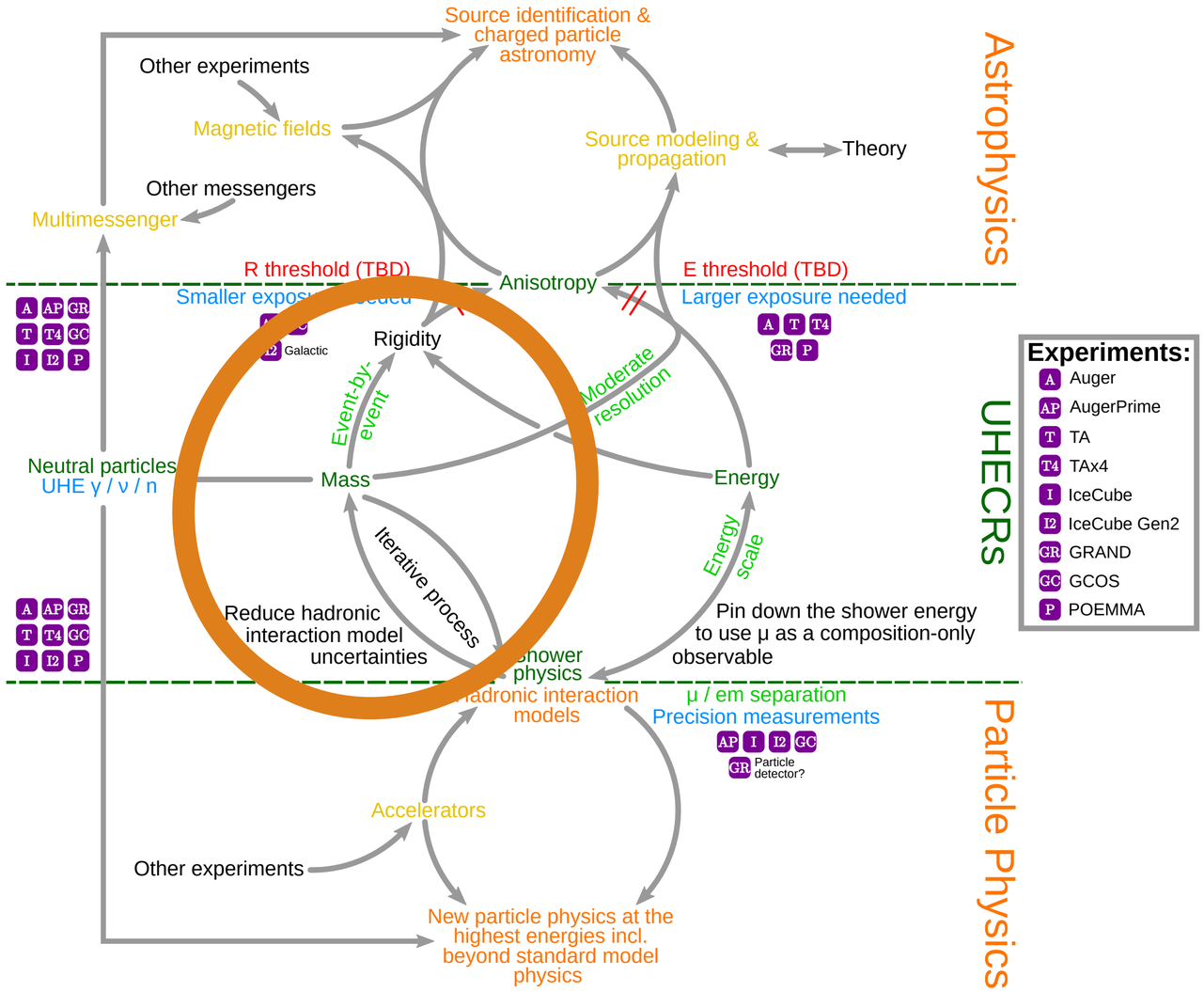




- magnetically-induced alignment of CRs
- two candidates observed so far
- multiplets are energy-ordered
- rigidity-dependent

connections: mass composition





GMF: looking into the future

next decade

- SKA: pulsar observations + parallax measurements
- PASIPHAE survey (starlight polarisation) + GAIA distance measurements (up to ~2 kpc)

3D map of the GMF

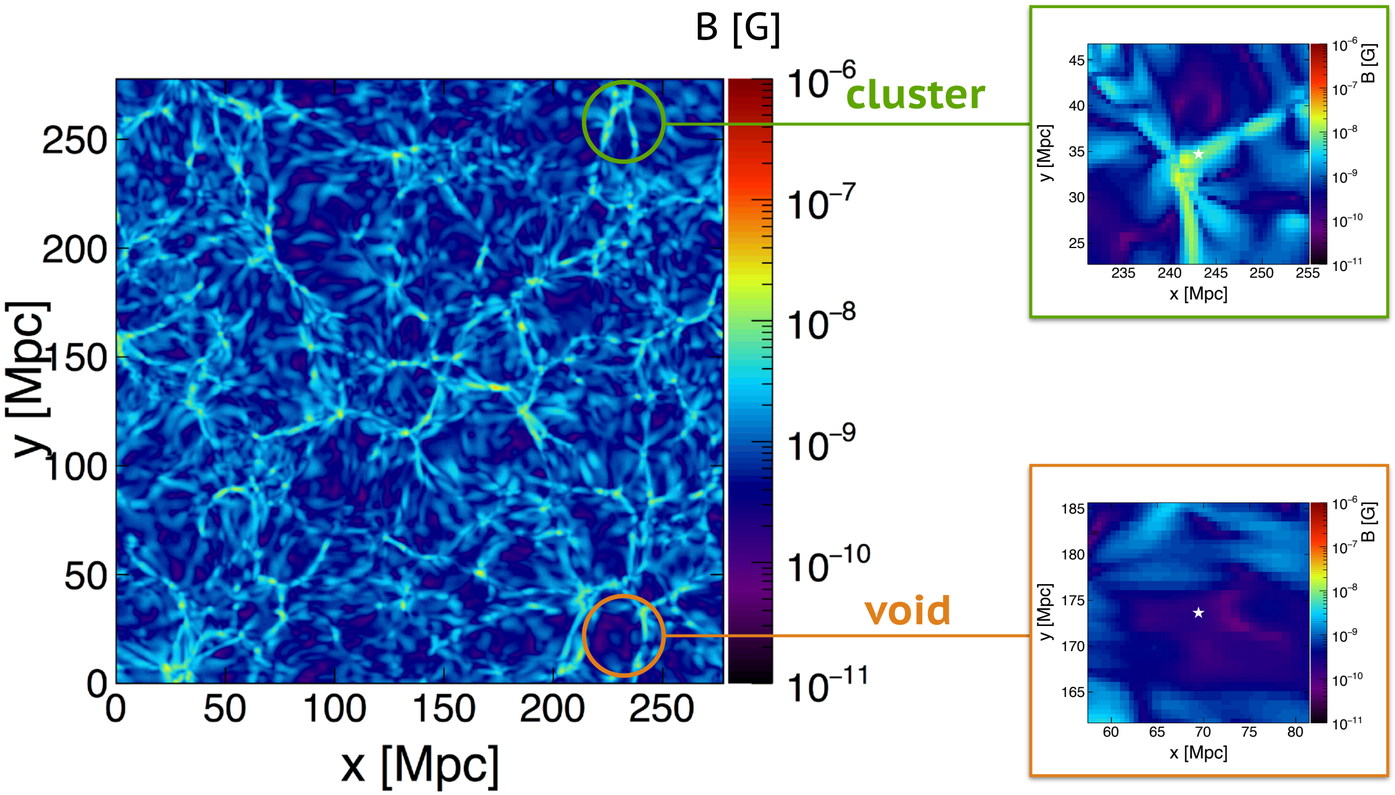
what will we most likely have

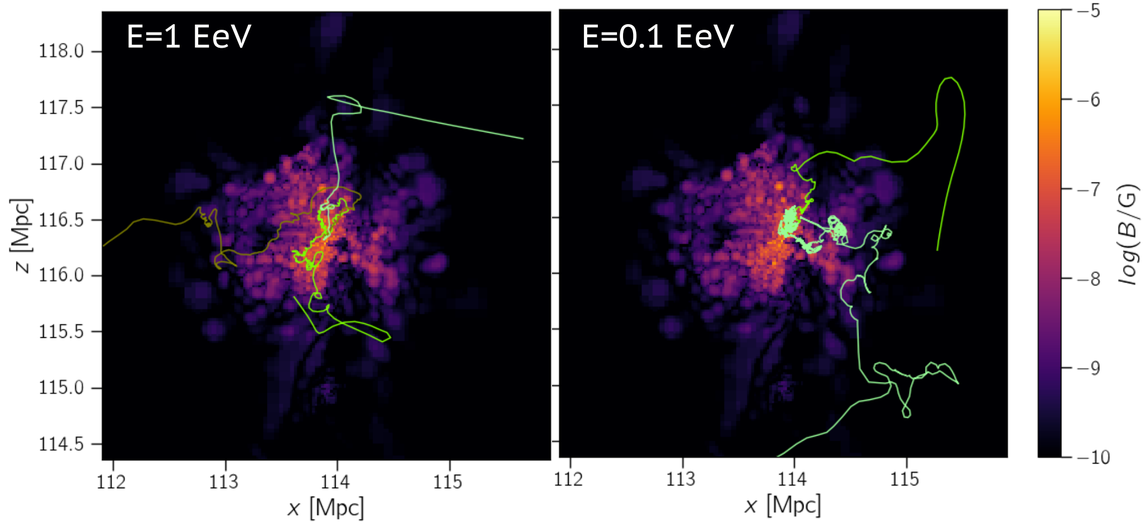
- measurements of coherent component of GMF
- measurements of random component of GMF
- better understanding of the field reversals

beyond the next decade

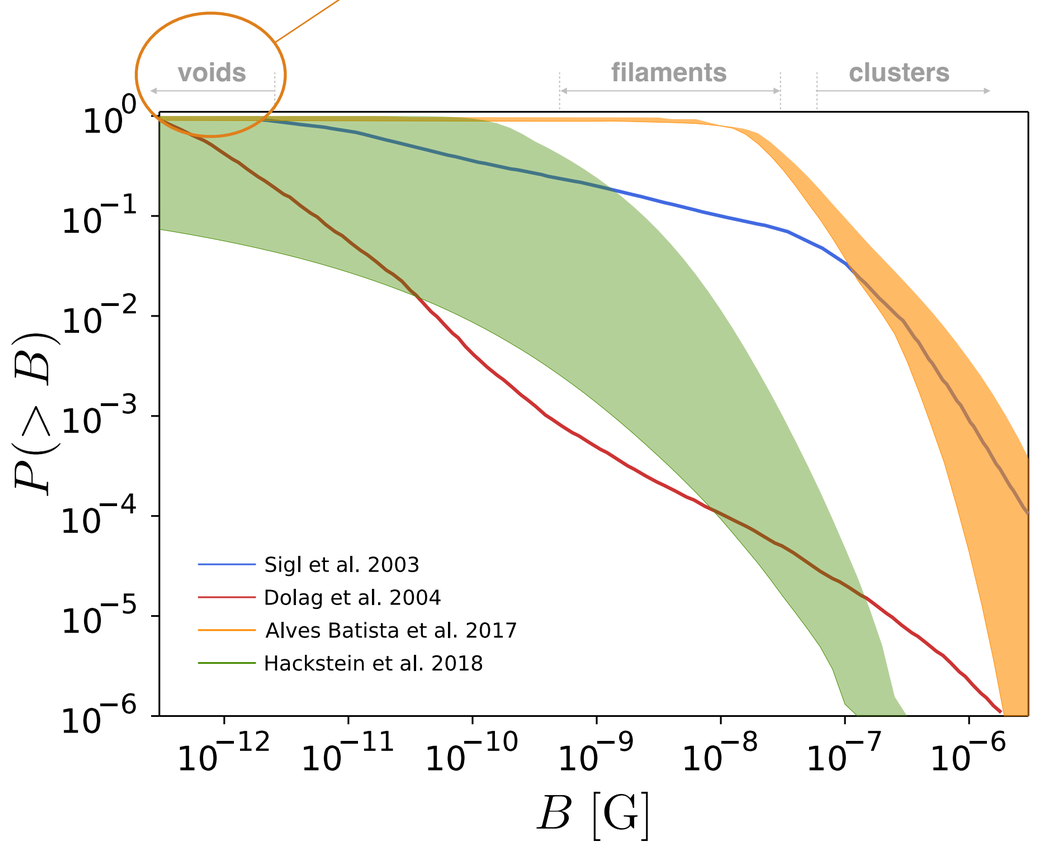
- GMF in the halo will likely *not* be measured
- but we will have better estimates of the field in the halo in external galaxies
- we will be able to build better models for the halo component of the GMF

magnetic fields in the large-scale structure of the universe

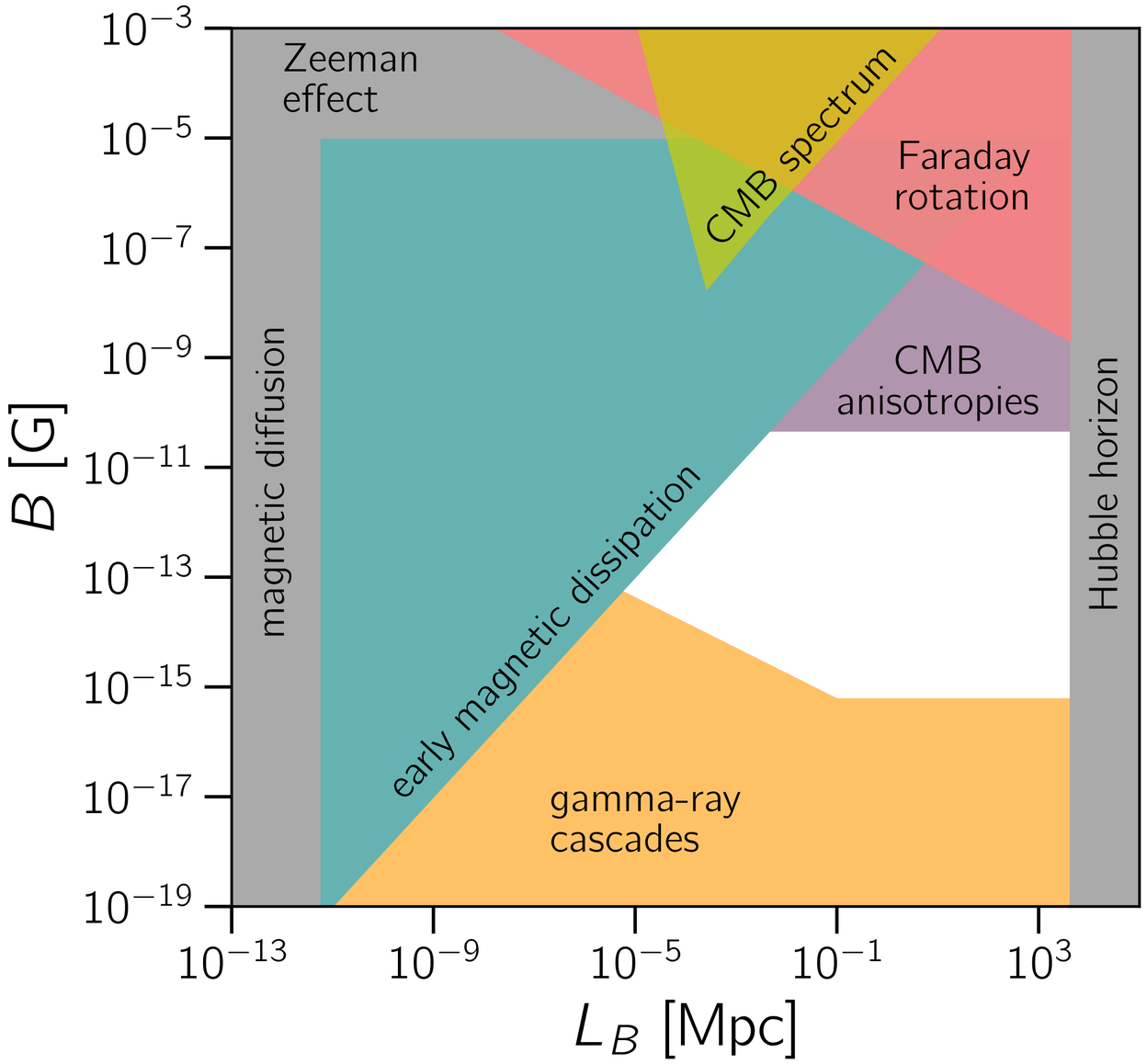




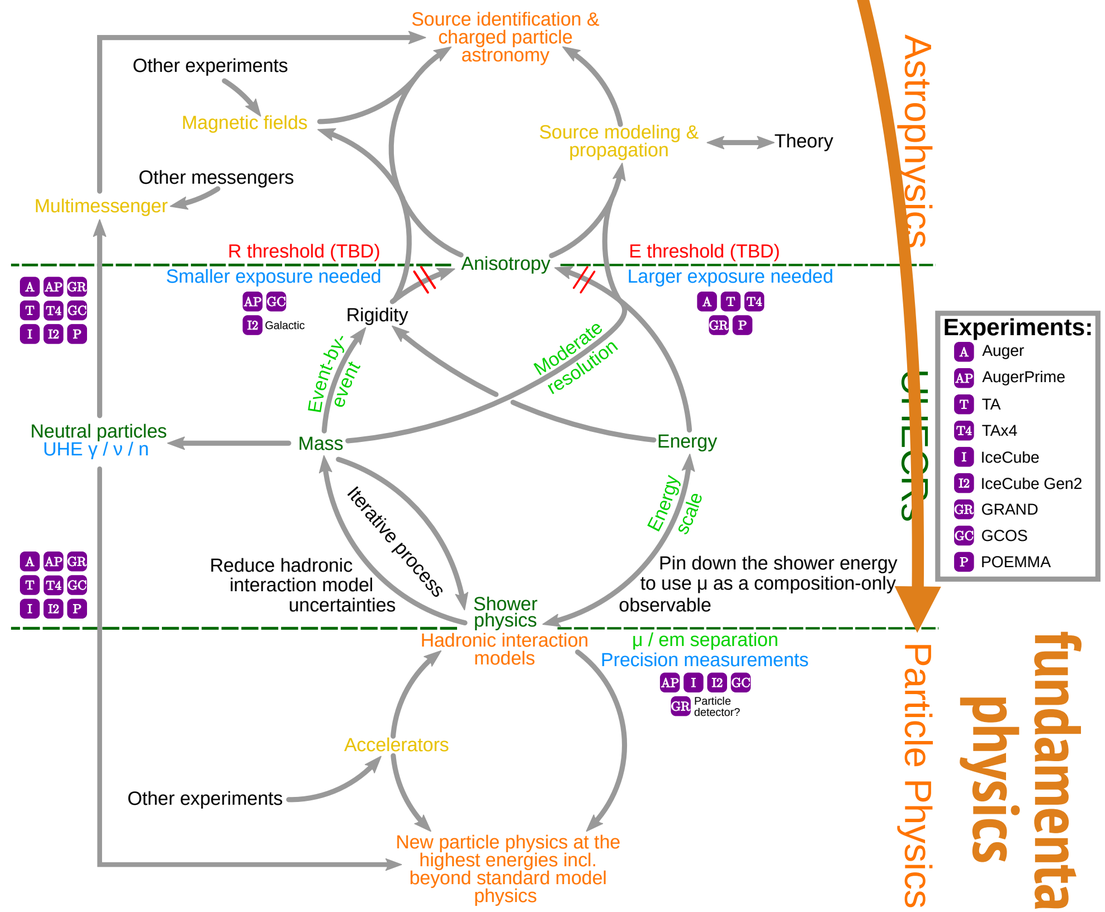
dominant for UHECR propagation over tens of Mpc



intergalactic magnetic fields (IGMFs)



- how were they produced?
- what is their role in the evolution of the universe?
- how strong are they?
- what is their power spectrum?
- what are their topological properties?



IGMFs: looking into the future

next decade

- better measurements of IGMFs in structures (clusters and filaments)
- new IGMF constraints from gamma-ray observatories such as CTA
- possibility of multimessenger constraints using gamma-ray cascades and, e.g., neutrinos
- IGMF in voids will likely remain mostly unknown

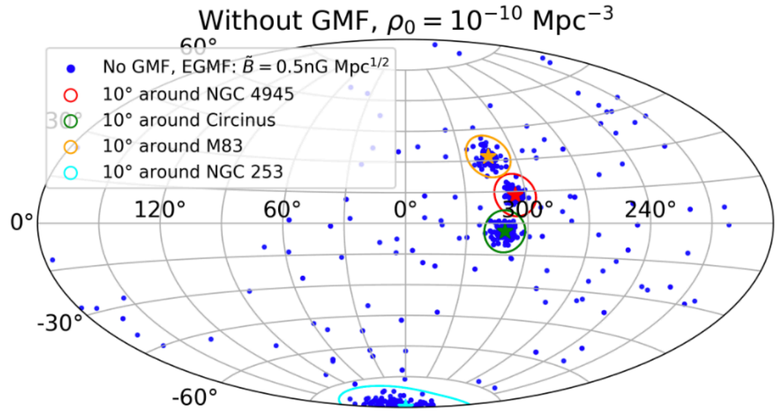
beyond the next decade

- SKA + ngVLA → Faraday tomography of extragalactic magnetic fields?
- gamma-ray observatories at ~MeV-GeV energies (AMEGO, GAMMA-400, AMS-100) + TeV observatories (e.g. CTA) → better constraints

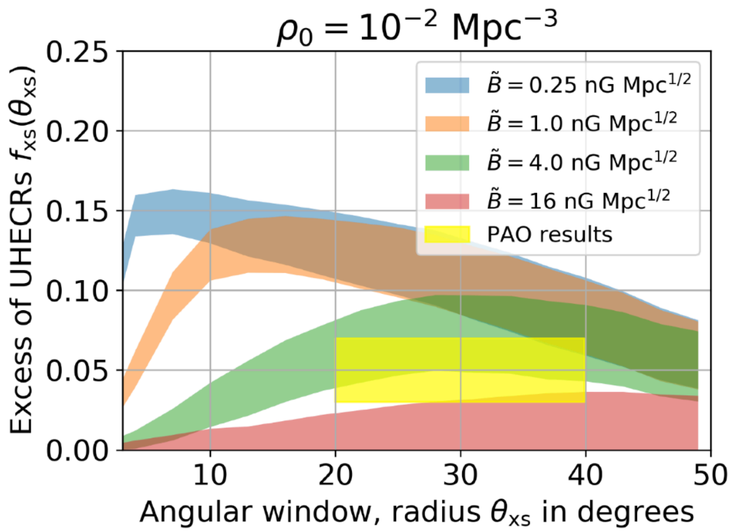
wishlist: 3D map of extragalactic fields

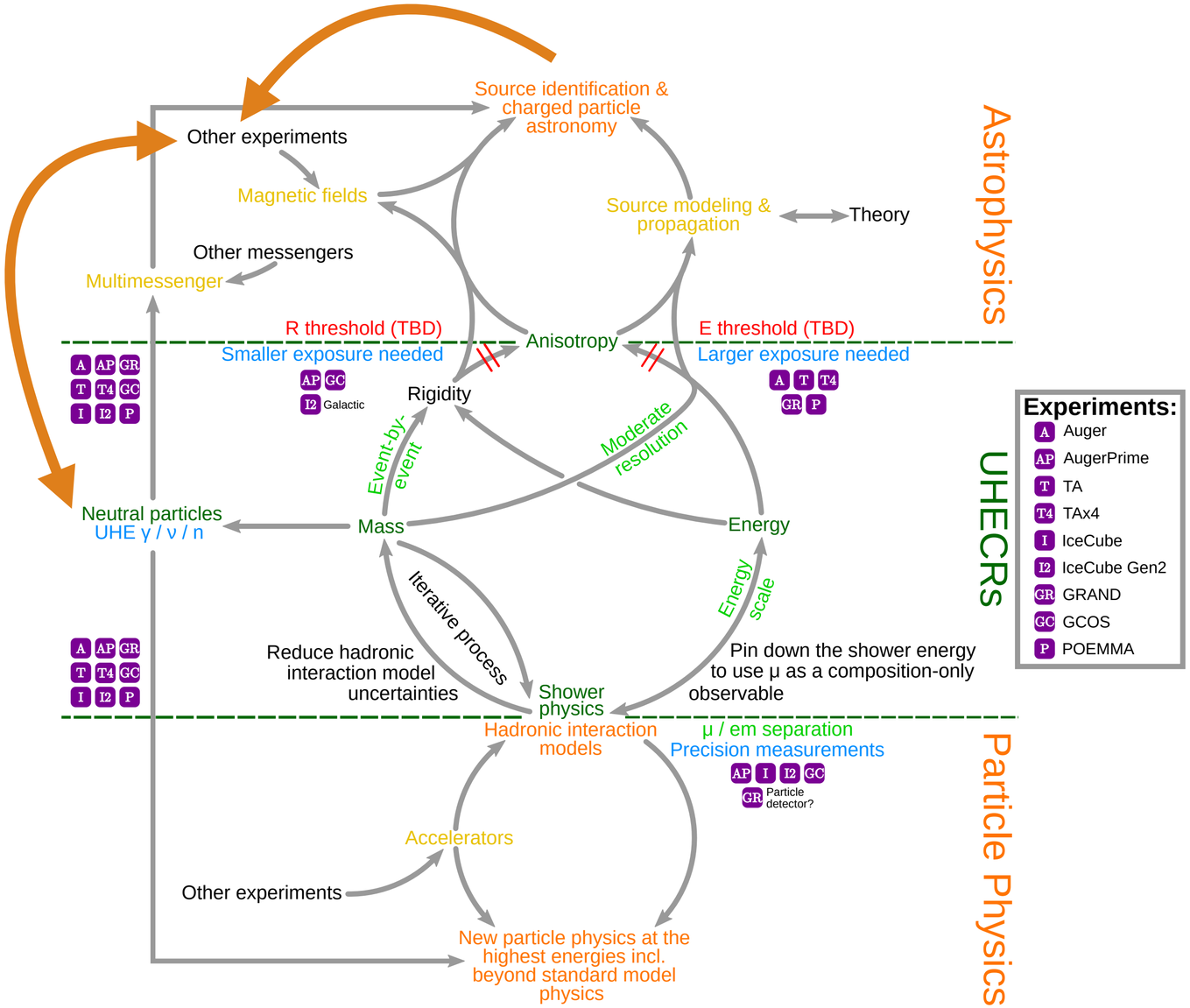
constraining magnetic fields

- in principle, it is possible to constrain magnetic fields using UHECRs
- **UHECR sources have to be known**
- **UHECR composition must be known**
- opportunities for multimessenger constraints



van Vliet et al. 2021

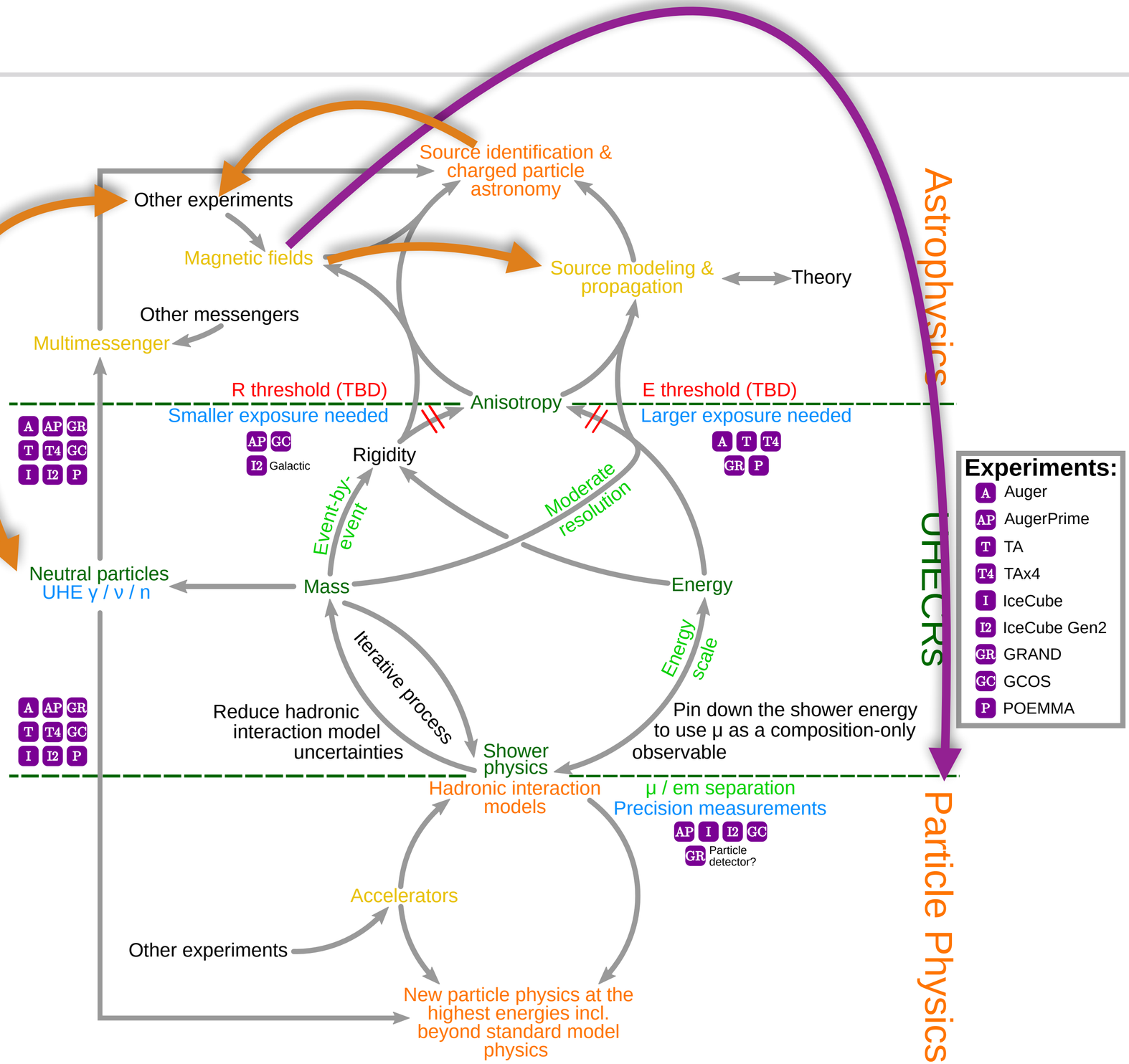




summary & outlook

- substantial progress in the modelling of the GMF will be made in the next decade
- *either* IGMFs have to be shown to be weak *OR* they must be understood and modelled
- even if they are strong, UHECR astronomy is still be possible (but more difficult)
- substantial magnetic-field uncertainties will still be present in UHECR measurements in the near and mid-future
- ability to scan the parameter space of magnetic-field uncertainties → computational developments
- next-generation observatories should measure composition on an event-by-event basis
- identification of UHECR multiplets can strongly constrain GMF
- UHECRs could be used to constrain IGMFs, especially combined with other messengers

summary


Source identification & charged particle astronomy
Other experiments
Magnetic fields
Source modeling & propagation
Theory
Other messengers
Multimessenger
R threshold (TBD)
Smaller exposure needed
Anisotropy
E threshold (TBD)
Larger exposure needed
A AP GR T T4 GC I I2 P
AP GC I2 Galactic
A T T4 GR P
Rigidity
Event-by-event
Moderate resolution
Neutral particles
UHE γ / ν / n
Mass
Energy
Iterative process
Energy scale
A AP GR T T4 GC I I2 P
Reduce hadronic interaction model uncertainties
Shower physics
Pin down the shower energy to use μ as a composition-only observable
Hadronic interaction models
μ / em separation
Precision measurements
AP I I2 GC GR Particle detector?
Accelerators
Other experiments
New particle physics at the highest energies incl. beyond standard model physics
Astrophysics of UHECRS
Particle Physics
Experiments:
A Auger
AP AugerPrime
T TA
T4 TAx4
I IceCube
I2 IceCube Gen2
GR GRAND
GC GCOS
P POEMMA