Next Generation Instrumentation for Ultra-High-Energy Cosmic Rays (UHECR)

UNIVERSITY OF DELAWARE
BARTOL RESEARCH INSTITUTE

based on the Snowmass CF7 Whitepaper on UHECR with about 100 authors and 200+ endorsers → arxiv: 2205.05845

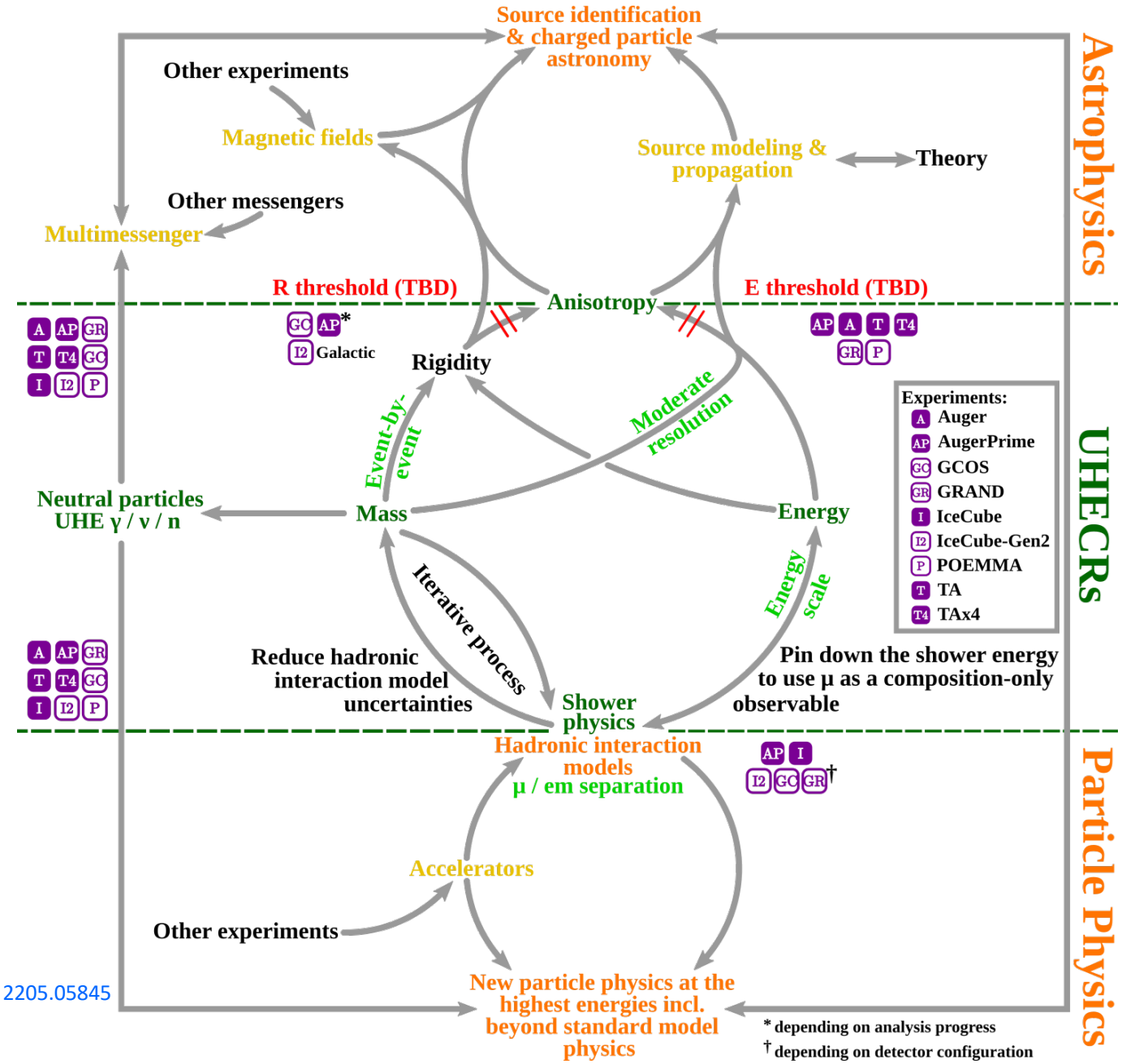
Presenter:
Frank G. Schroeder

Summary Table: Major experiments for UHECR astrophysics *and* particle physics at 10^{17} – 10^{21} eV.

	Experiment	Feature	Cosmic Ray Science*	Timeline
current	Pierre Auger Observatory	Hybrid array: fluorescence, surface e/μ + radio, 3000 km^2	Hadronic interactions, search for BSM, UHECR source populations, $\sigma_{\text{p-Air}}$	AugerPrime upgrade
current	Telescope Array (TA)	Hybrid array: fluorescence, surface scintillators, up to 3000 km^2	UHECR source populations proton-air cross section ($\sigma_{\text{p-Air}}$)	TAx4 upgrade
≤ EeV	IceCube / IceCube-Gen2	Hybrid array: surface + deep, up to 6 km^2	Hadronic interactions, prompt decays, Galactic to extragalactic transition	Upgrade + surface enhancement → IceCube-Gen2 deployment → IceCube-Gen2 operation
> EeV	GRAND	Radio array for inclined events, up to 200,000 km^2	UHECR sources via huge exposure, search for ZeV particles, $\sigma_{\text{p-Air}}$	GRANDProto 300 → GRAND 10k → GRAND 200k multiple sites, step by step
> EeV	POEMMA	Space fluorescence and Cherenkov detector	UHECR sources via huge exposure, search for ZeV particles, $\sigma_{\text{p-Air}}$	JEM-EUSO program → POEMMA
> EeV	GCOS	Hybrid array with $X_{\max}$ + e/μ over 40,000 km^2	UHECR sources via event-by-event rigidity, forward particle physics, search for BSM, $\sigma_{\text{p-Air}}$	GCOS R&D + first site → GCOS further sites

2025 2030 2035 2040

*All experiments contribute to multi-messenger astrophysics also by searches for UHE neutrinos and photons; several experiments (IceCube, GRAND, POEMMA) have astrophysical neutrinos as primary science case.



2205.05845

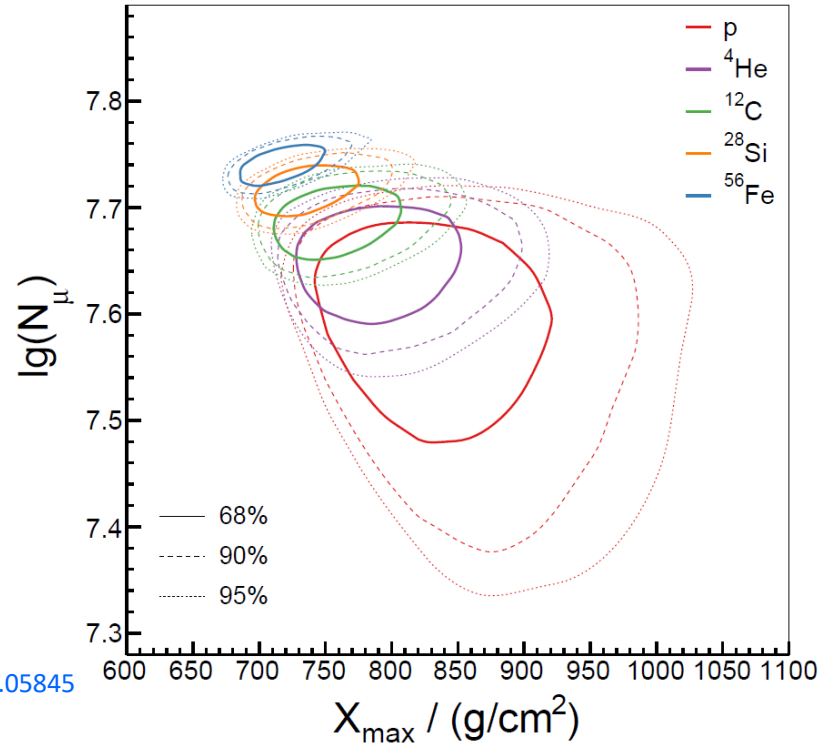
Complementary Approaches

Two types of next-generation instruments needed to for future UHECR science

1. huge exposure combined with accurate knowledge of average mass composition
   - space-based stereo observation (P) POEMMA
     → see remarks by Tonia Venters
   - ground-based multi-site international radio array for neutrinos and UHECR (GR) GRAND
2. event-by-event rigidity through high accuracy air-shower detection (GC) GCOS
   - particle astrophysics by back-tracing through magnetic fields when rigidity is known
   - more stringent tests of hadronic interaction model to investigate, e.g., muon puzzle
   - better identification of primary particle type also helps BSM searches, such as SHDM

Global Cosmic-Ray Observatory (GCOS)

- GCOS will be a 40,000 km² ground array of hybrid detectors distributed among several sites
  - joint sites with GRAND radio arrays possible: huge statistics, but no event-by-event mass separation
- Event-by-event mass separation requires simultaneous detection of muons + em. shower maximum (X_{max})
- U.S. participation requires **R&D during this decade**, preparing for a **possible U.S. site in the next decade**



2205.05845

Left:
Complementary mass sensitivity of muons and X_{max} is needed for event-by-event rigidity estimate

Right:
Possible particle detector of the GCOS array. Next steps: prototypes, optimizations and cross-calibration