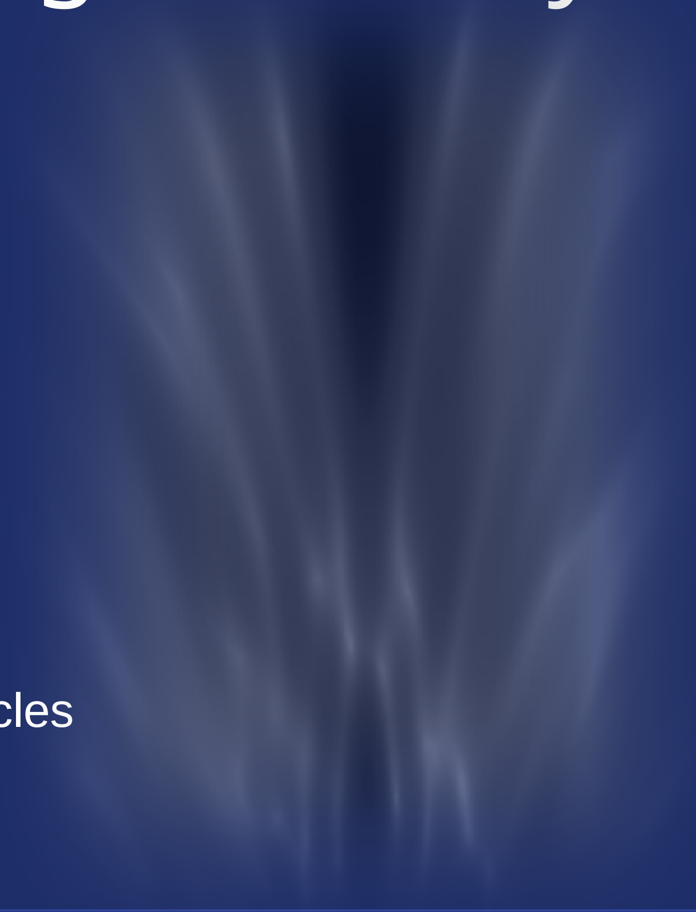
Prospects of detecting PeV gamma rays with SKA-Low



Philipp Laub* for the SKA SWG on High-Energy Cosmic Particles

ARENA 2026

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Science case

Radio detection of gamma-rays

- Galactic cosmic rays explored to the highest energies
- Gamma rays: smoking gun of the origin of charged cosmic rays

  → Hunt for ***PeVatrons***
- No gamma-ray detections identified above 2.48 PeV (LHAASO)
- No radio detection of gamma-ray-induced air showers yet
- Will this change with SKA-Low?

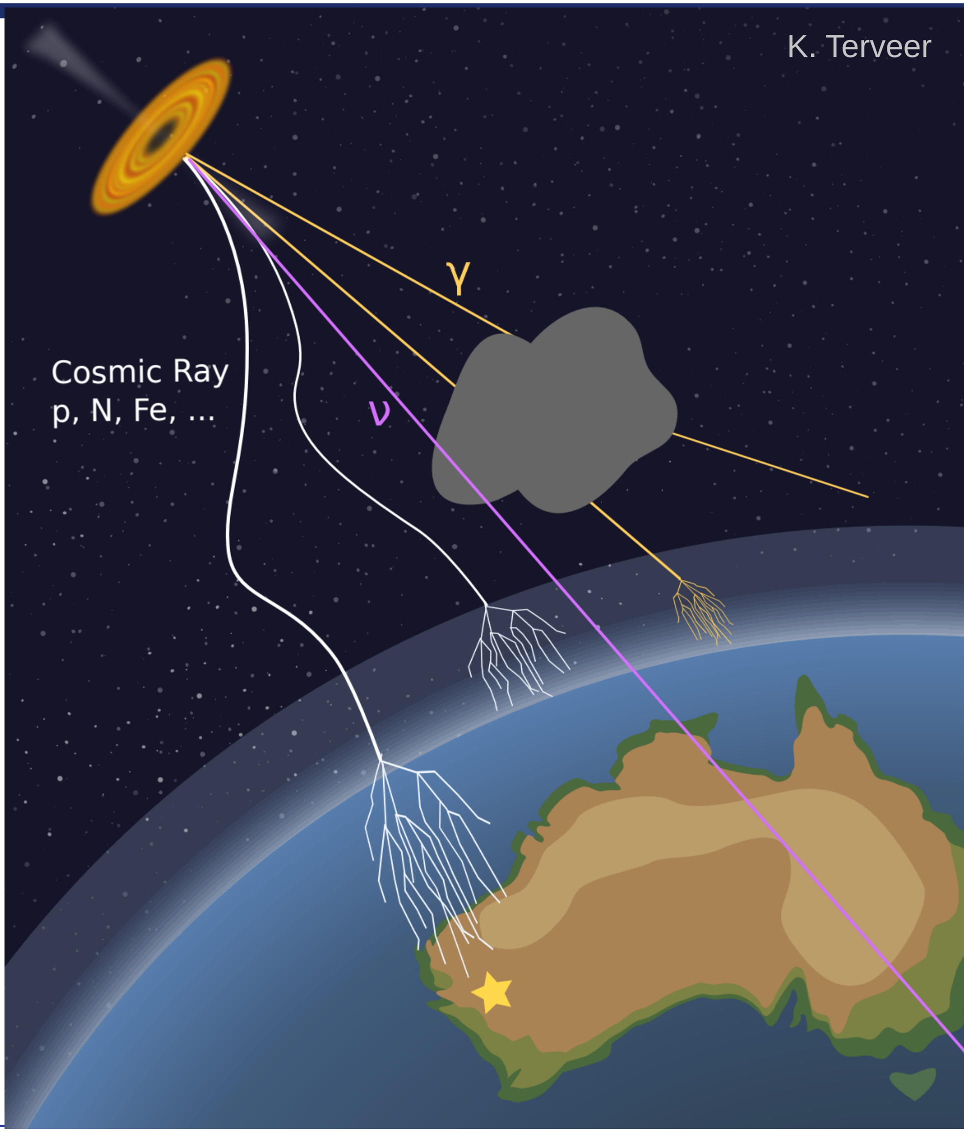
  → Southern hemisphere

  → Radio is weather-independent

  → Radio offers high duty-cycles

  → No mechanical pointing required with radio

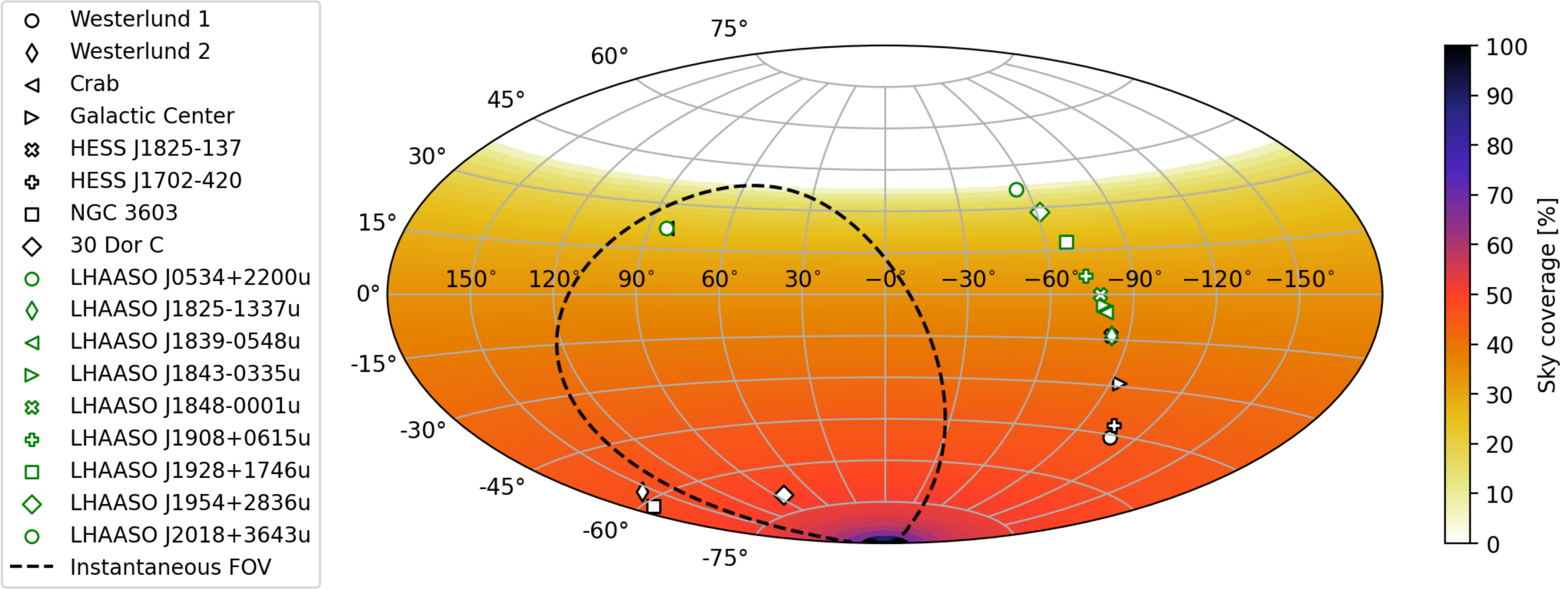
  → Large effective area



Field of view

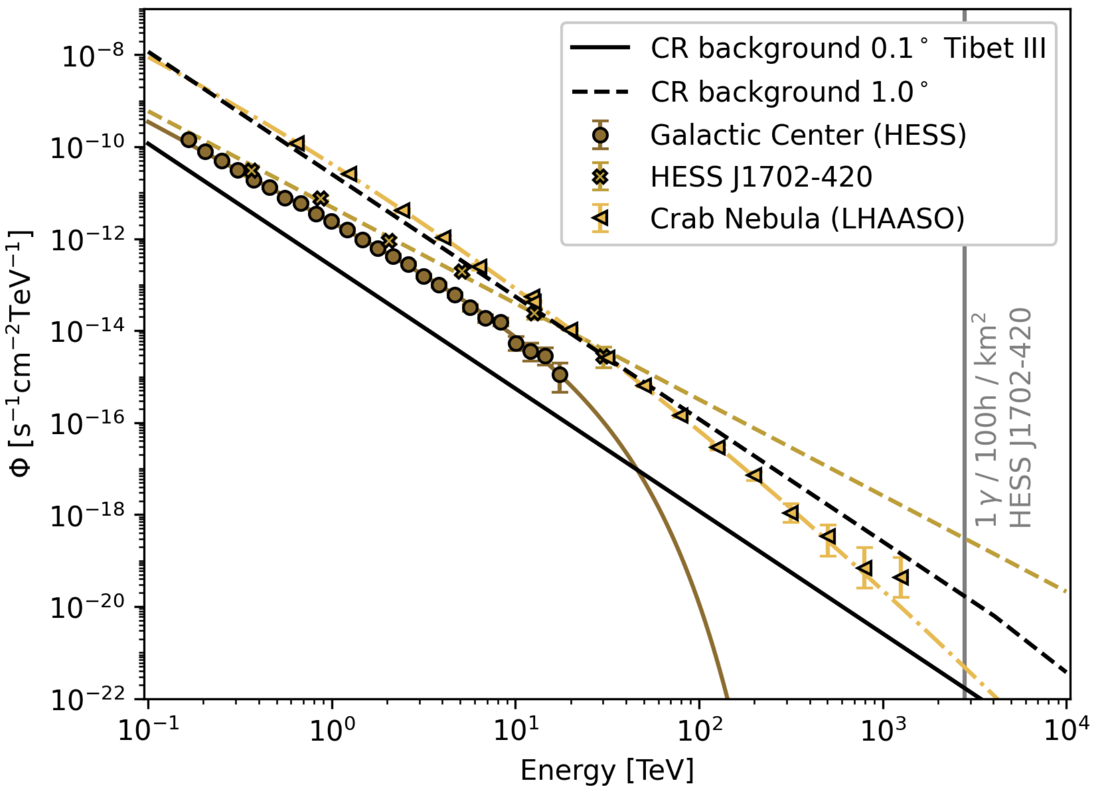
Radio detection of gamma-rays

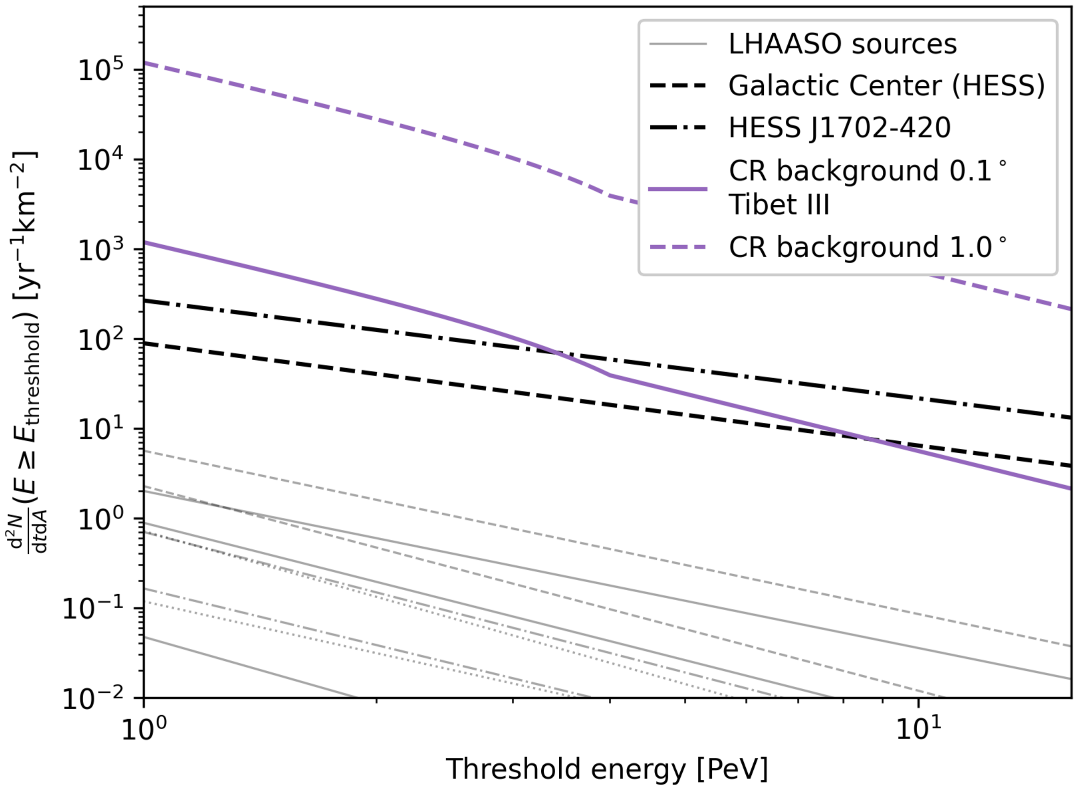
Integrated FOV of SKA-low (1 yr, zenith $\leq 65^{o}$)



Flux

Radio detection of gamma-rays



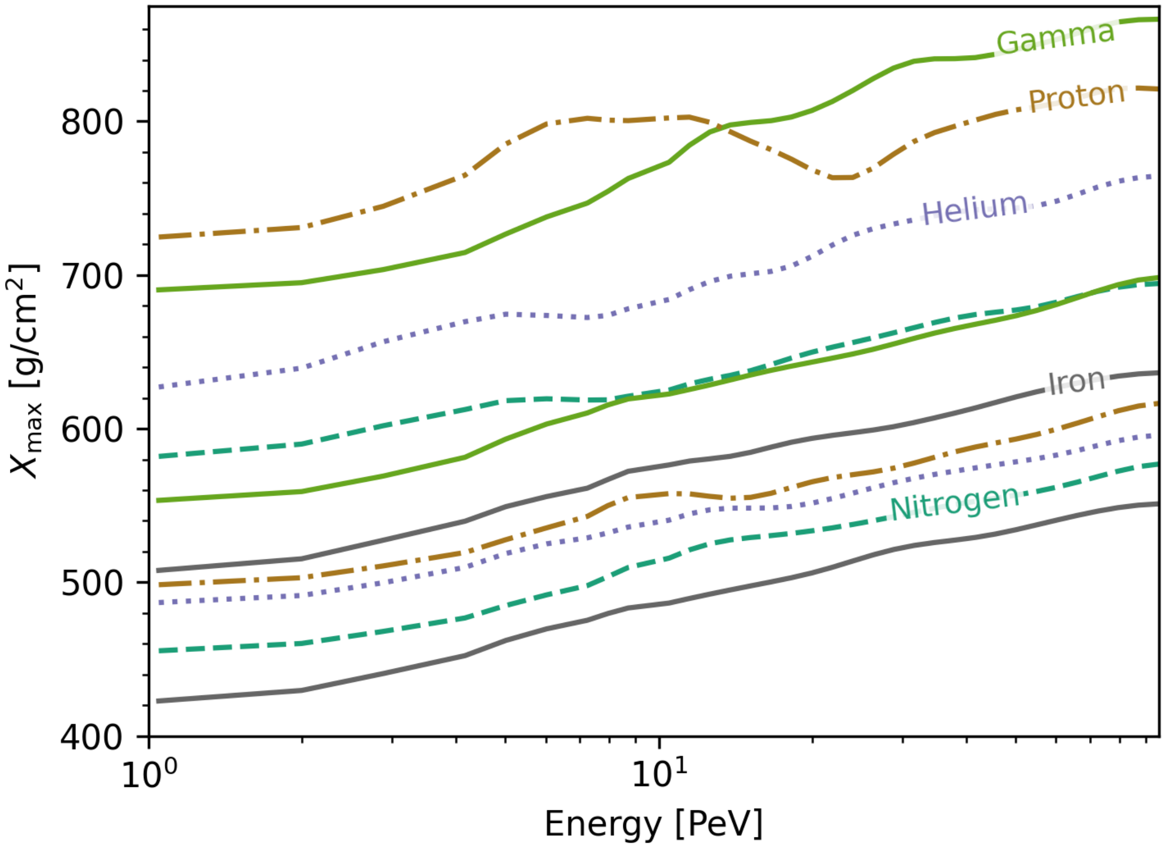


Source spectra extrapolated (power law)
Sky coverage included

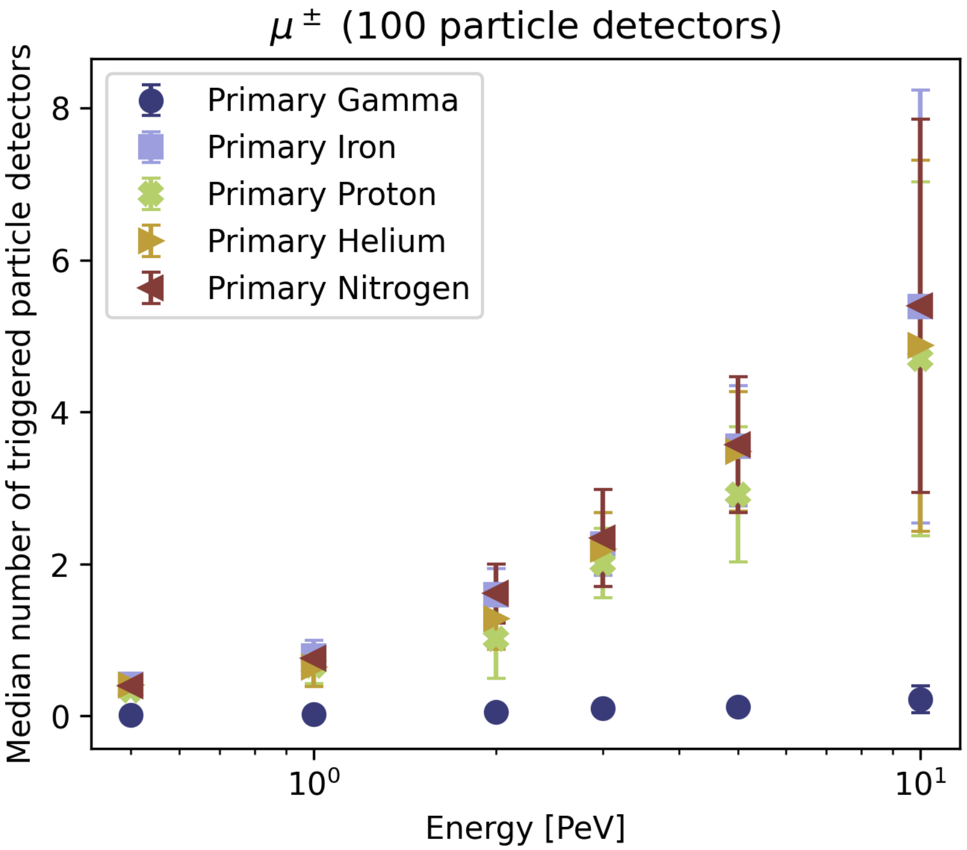
Gamma-hadron separation

Radio detection of gamma-rays

Preliminary, based on CORSIKA+CONEX simulations:



100 flat particle detectors (1 m^2), randomly distributed

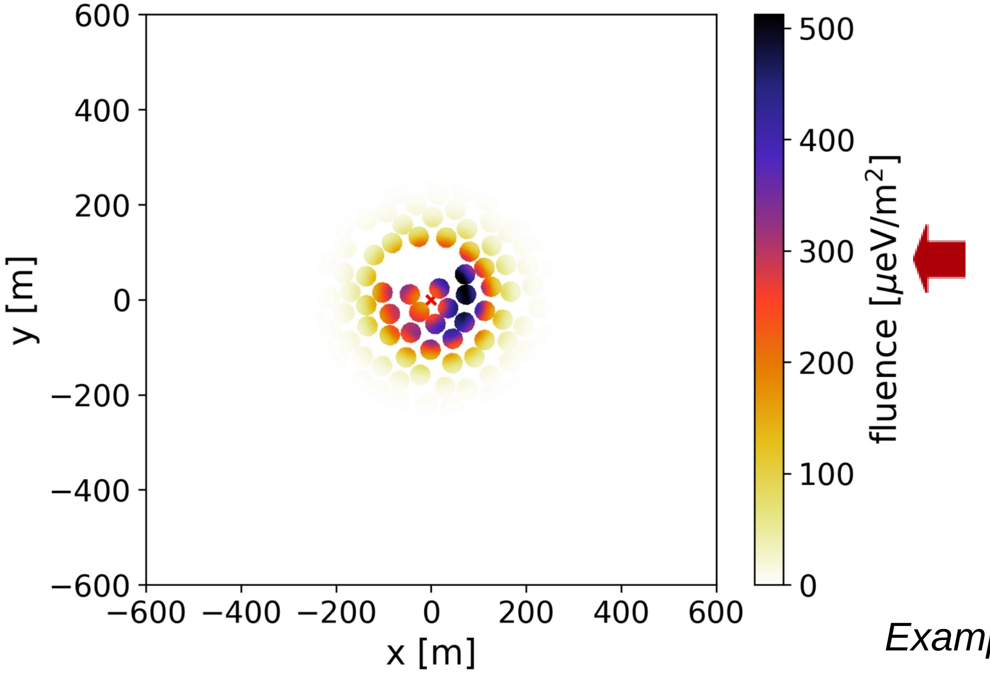


Simulations

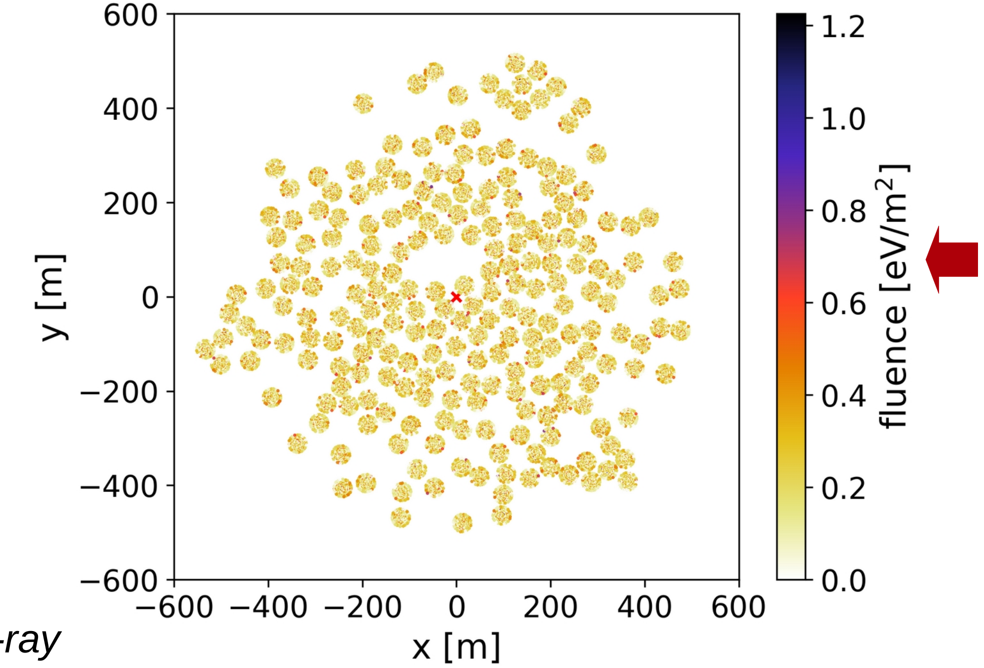
Radio detection of gamma-rays

- CORSIKA + CoREAS star-shape simulations
- Interpolated to SKA-low antenna positions (*A. Corstanje et al. 2023, JINST 18 P09005*)
- Galactic noise added

  → Radio signal much smaller than noise



+ Noise



Example: 0.5 PeV gamma-ray

Beamforming

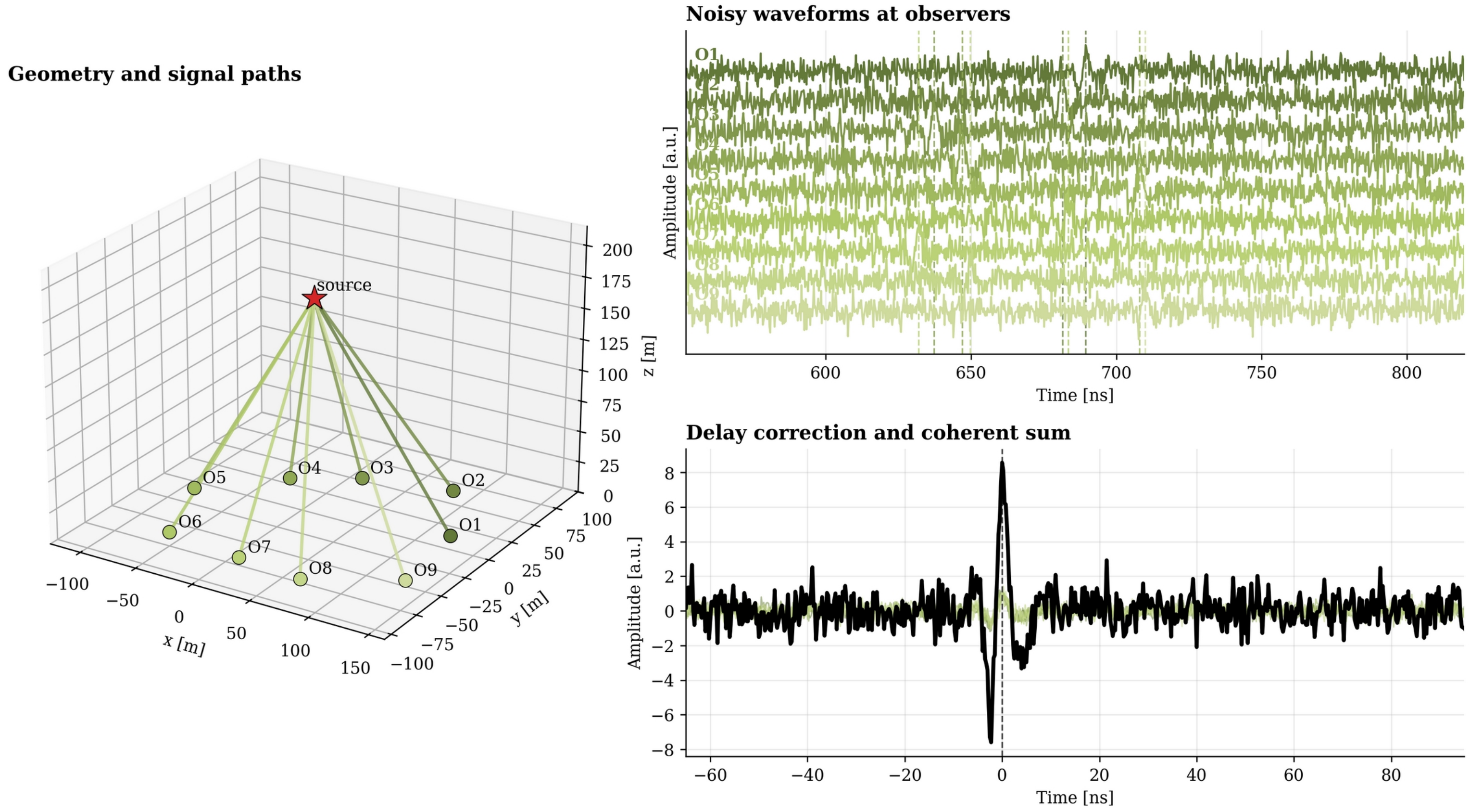
Radio detection of gamma-rays

→ lower energy threshold via beamforming
(see Schoorlemmer and Carvalho, 2021) .

Algorithm:

- Choose a potential point of emission in 3D space
- Calculate time delays between antennas
- Build coherent sum of waveforms of multiple antennas and calculate a score (e.g. power in the beamformed waveform)
  - Signal ideally scales with $N_{antennas}$
  - Noise ideally scales with $\sqrt{N_{antennas}}$

    → SNR scales with $\sqrt{N_{antennas}}$



Beamforming

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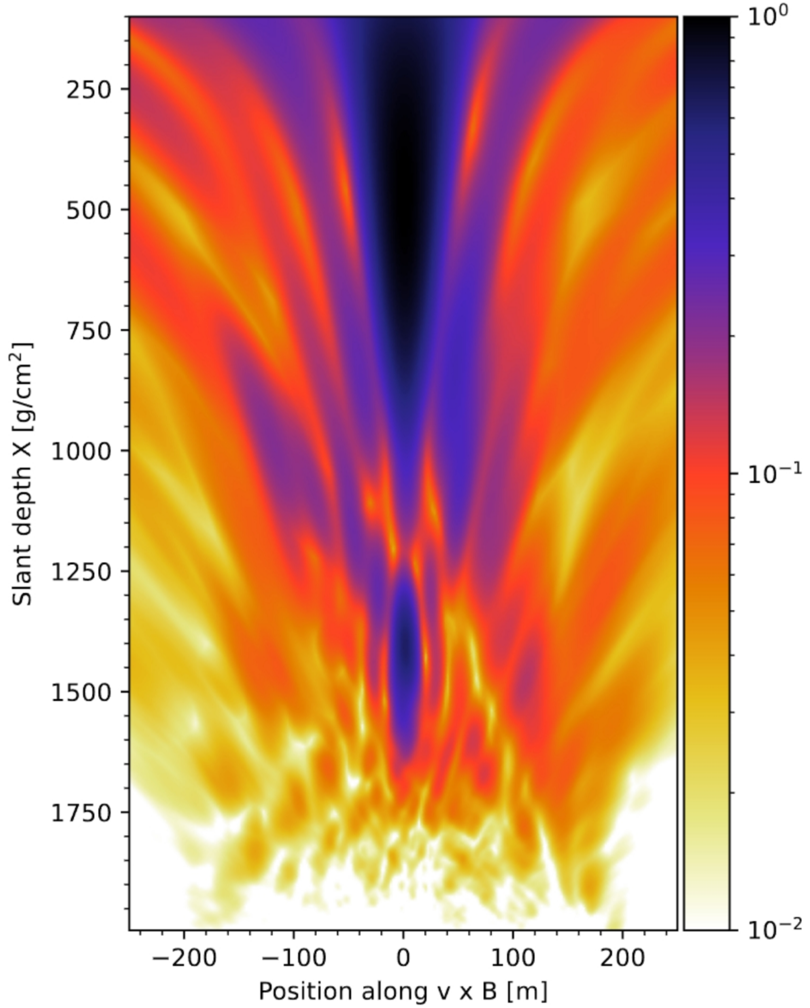
- Repeat for many points in 3D space



Beamforming

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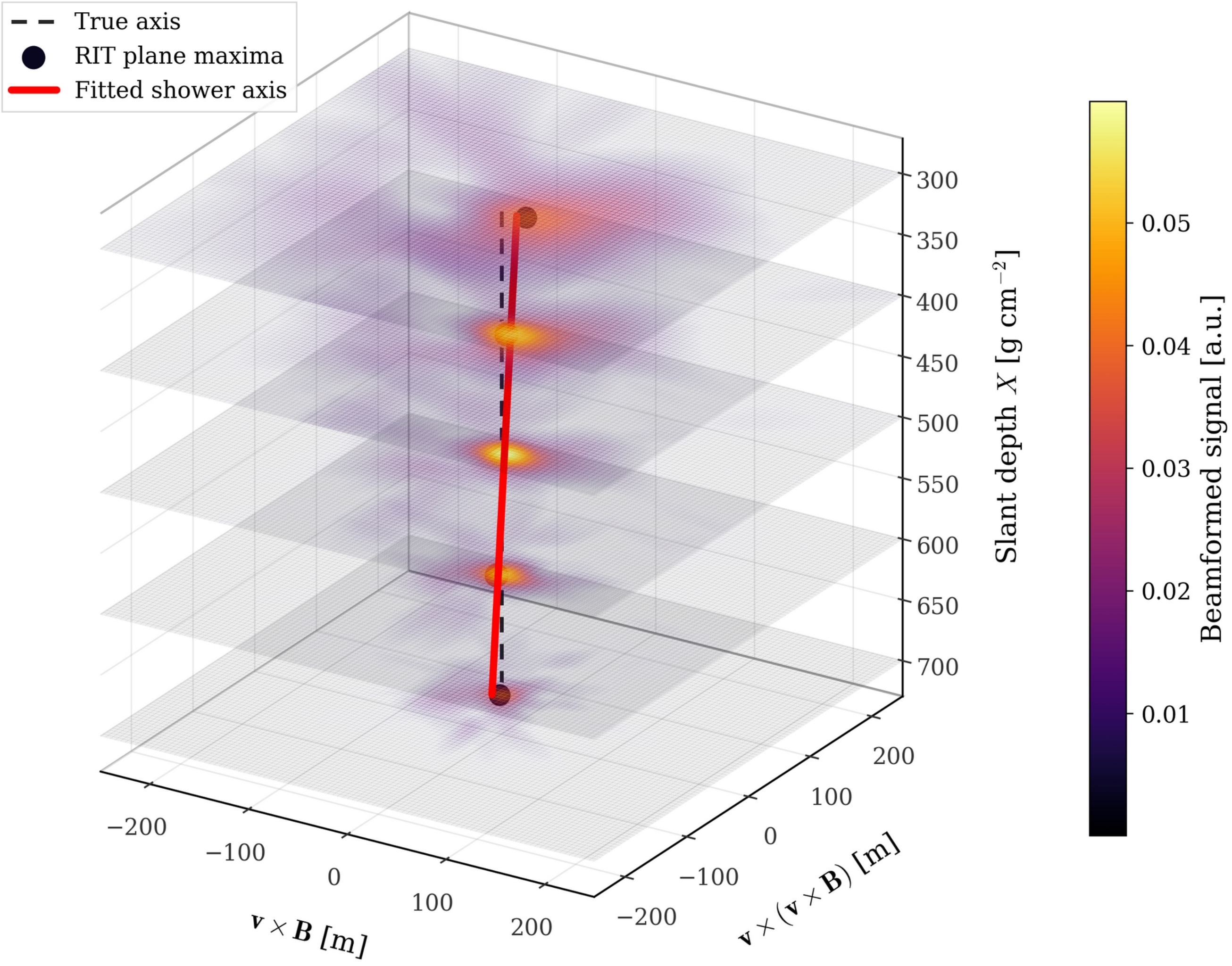
- Repeat for many points in 3D space
- Determine shower axis



Triggering

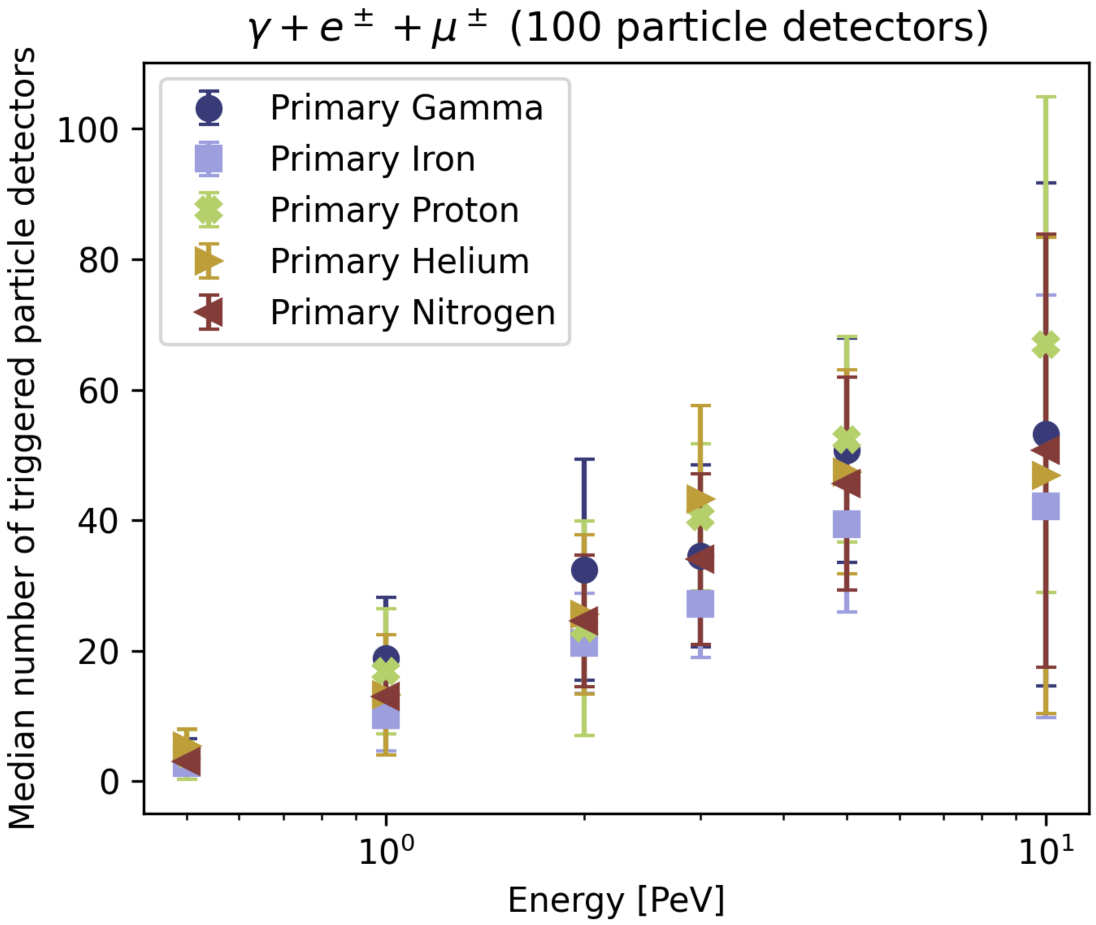
Radio detection of gamma-rays

Particles:

- Particle detector array planned and in progress
- Energy threshold?
- Direction and core initial guess?

→ Hard at low energies

→ Beamforming trigger?



CORSIKA simulations

Beamforming trigger?

Radio detection of gamma-rays

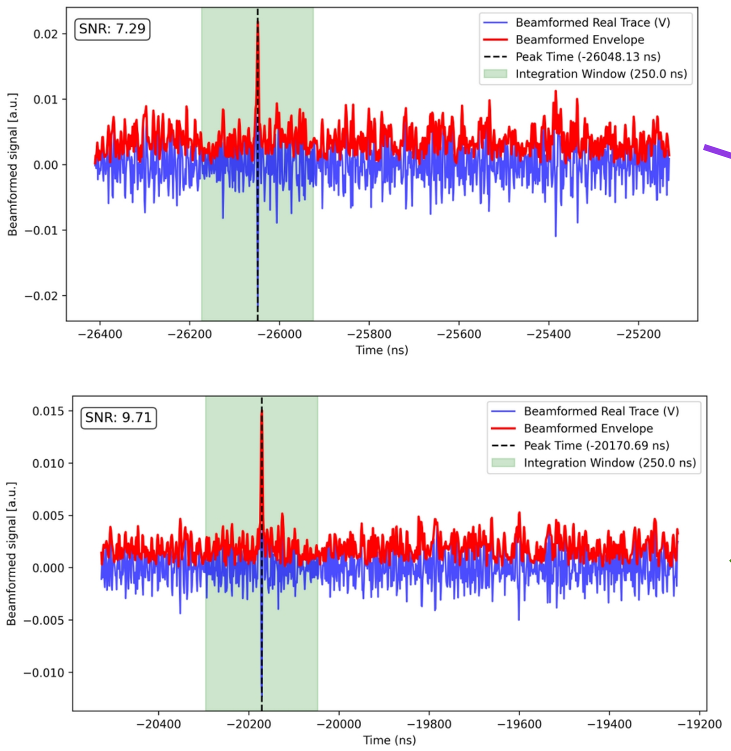
Trigger via constant beamforming?

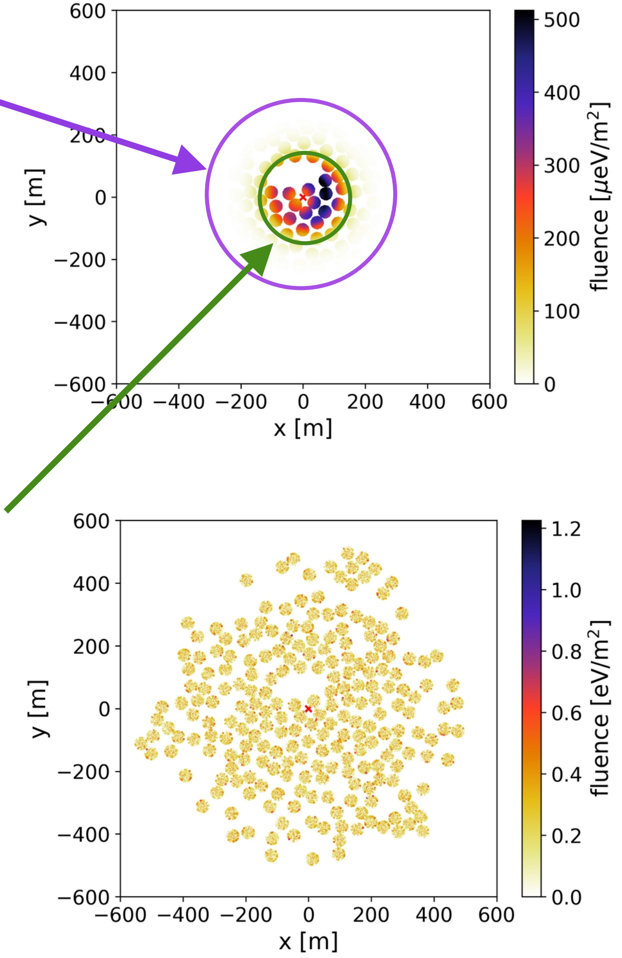
- Choose potential source(s)
- Assume direction known (gamma-rays: straight trajectory)
- Determine shower axis using beamforming

Problem:

- Good antenna selection required for low energies, otherwise too much noise
- Depends on core location (unknown)

→ Brute-force scan for core locations





Beamforming trigger?

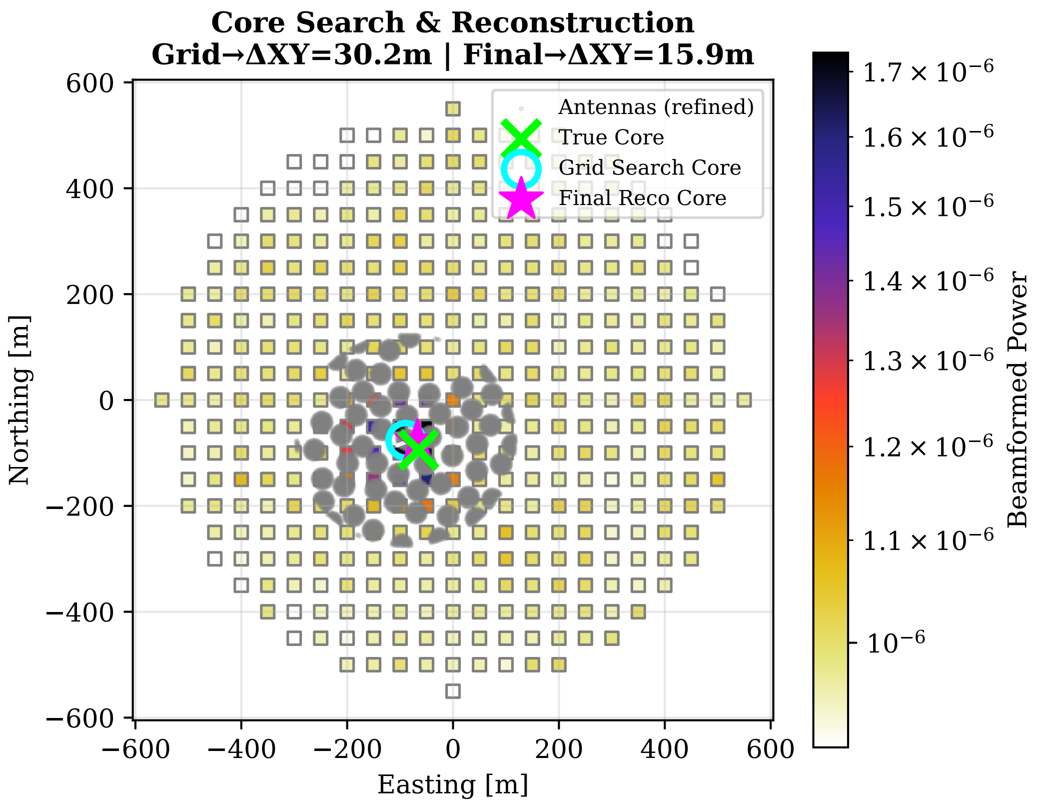
Radio detection of gamma-rays

Blind core search:

- Fast beamforming analysis on grid of possible core locations with antenna selection
- Determine best core („center of mass“)
- Finer beamforming shower axis reconstruction for best core

    → Final core and direction

- **GPUs** for performance speedup (CuPy + CUDA kernel, full reconstruction takes ***~ 1 minute***)
- Compare best beamformed SNR of reconstruction to best SNR from true shower geometry

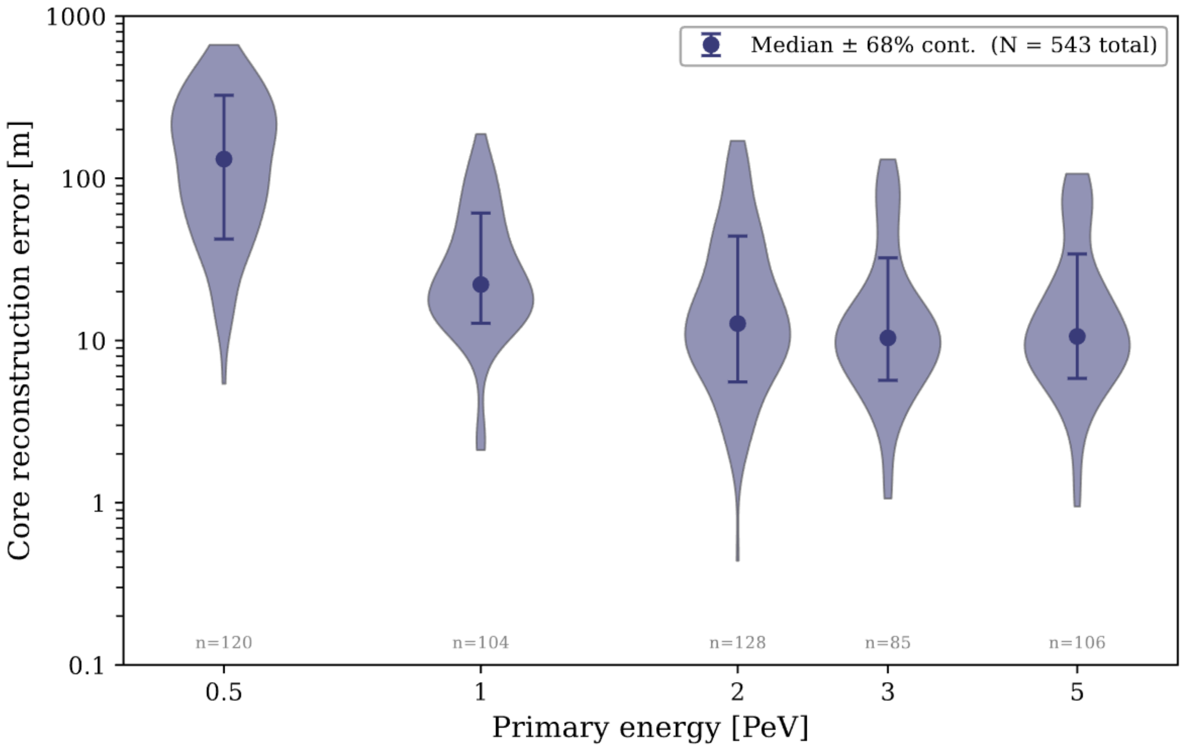


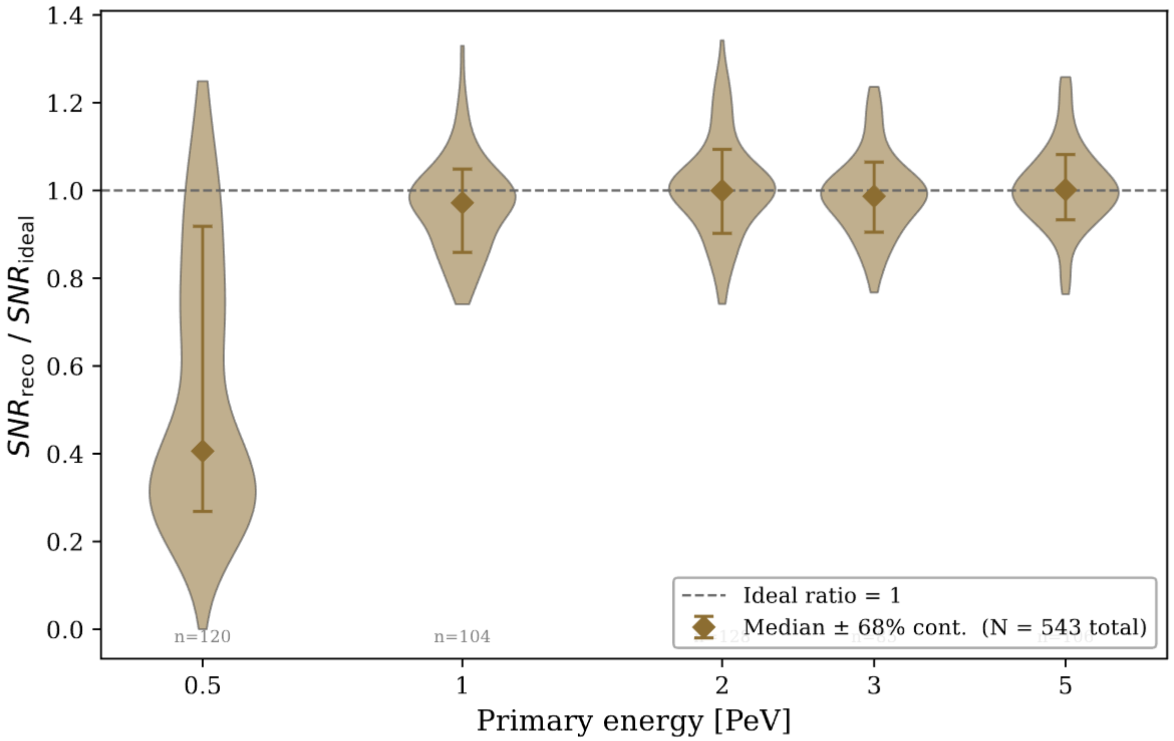
Blind core reconstruction

Radio detection of gamma-rays

With quality cuts:

- Shower core $\leq$ 300m away from array core
- Zenith $\leq$ 55°

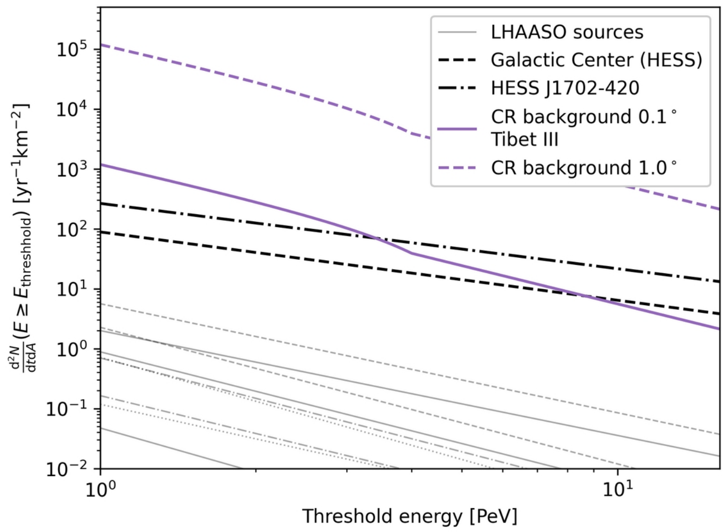




Summary and outlook

Radio detection of gamma-rays

- Enough gamma rays at low PeV energies
- Lower radio energy threshold using beamforming
- GPU-accelerated beamforming
- Triggering and gamma-hadron separation challenging
- Blind core reconstruction promising



TODOs:

- Effective gamma-hadron separation
- Effective area simulation