Universität Siegen

HEP Experimental High Energy Physics

CPPS Center for Particle Physics Siegen

Estimating the secondary photon flux produced during the propagation of primary cosmic rays

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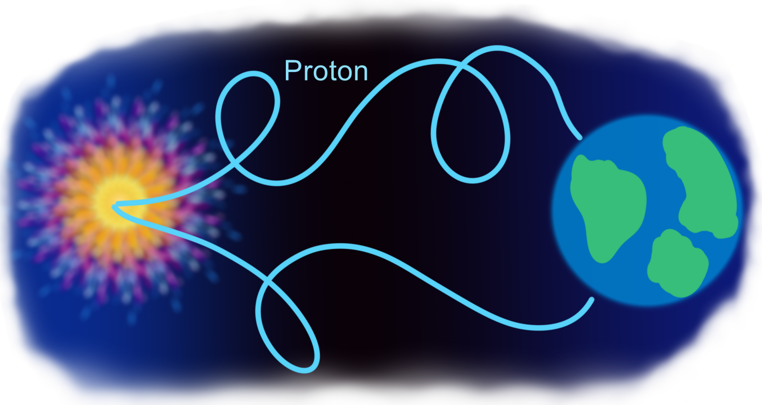
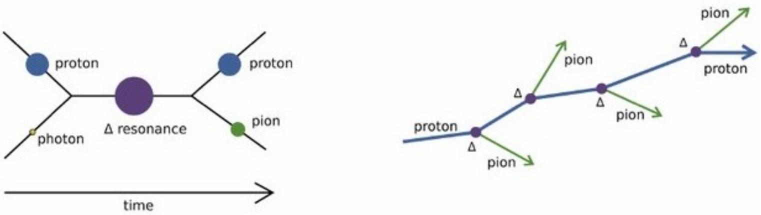
Cosmic Ray Propagation



- protons are affected by magnetic fields
- source identification difficult

Cosmic Ray Interaction

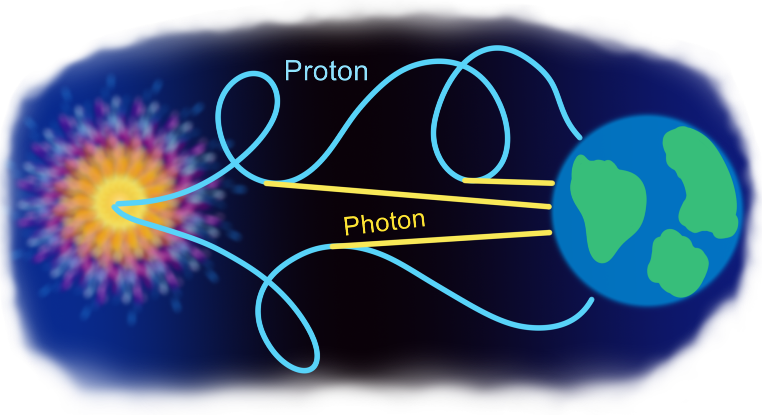
- Photo-pion-production via the Δ-resonance (above Greisen-Zatsepin-Kuzmin limit)
  $p + \gamma_b \rightarrow \Delta^+ \rightarrow p + \pi^0$ (K. Greisen (1966), G. T. Zatsepin, V. A. Kuz'min (1966))



(Bietenholz (2023))

- decay of neutral pions: $\pi^0 \rightarrow 2\gamma$
- further photon interactions: Pair-Production, inverse Compton-scattering, etc.

Photon Production during Cosmic Ray Propagation



- protons are affected by magnetic fields
- energetic protons produce secondary photons via photo-pion production

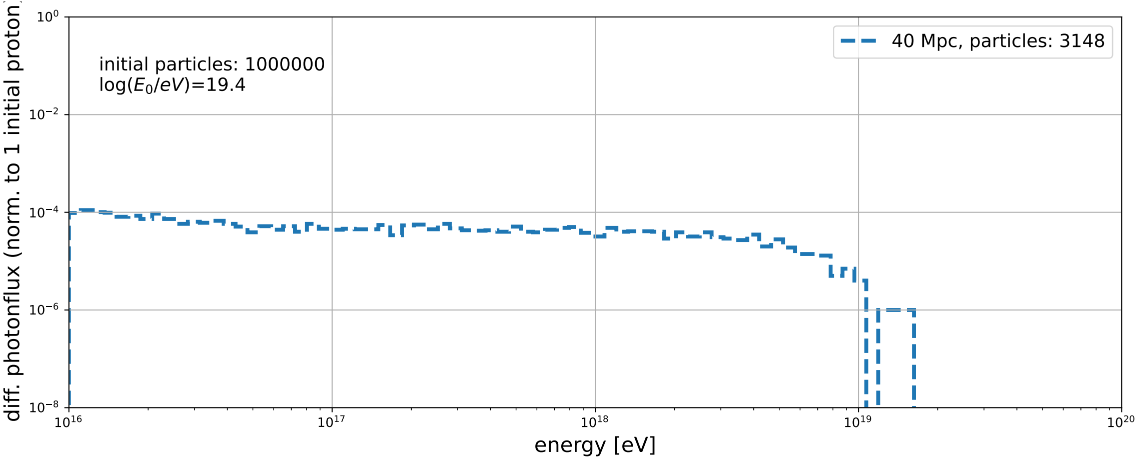
Simulation Framework: CRPropa

- Monte Carlo code for simulating the propagation of high-energy particles in the Universe

  (Batista et al. (2022))

- Simulation of a 1D-trajectory of N particles without magnetic fields
- initial particle: proton or heavier nucleon
- propagated distances and initial energy variable
- interactions: yes!

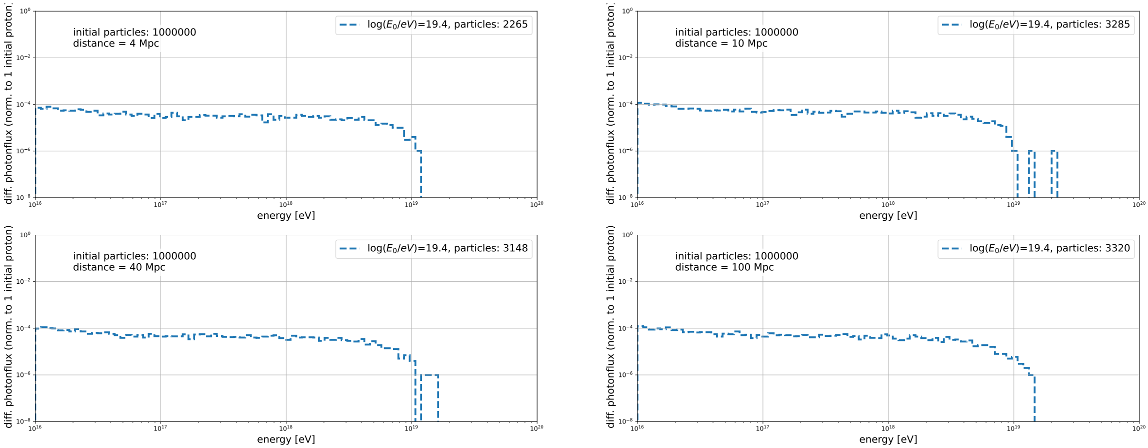
First Results



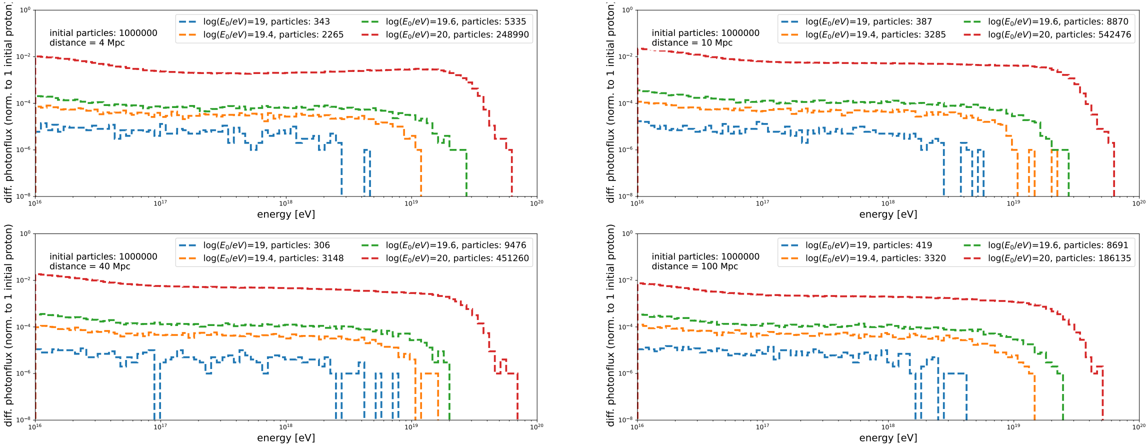
Potential Next Steps

- Varying the propagated distance: $4 - 400\,\mathrm{Mpc}$
- Varying the initial particle energy: $3 - 300\,\mathrm{EeV}$

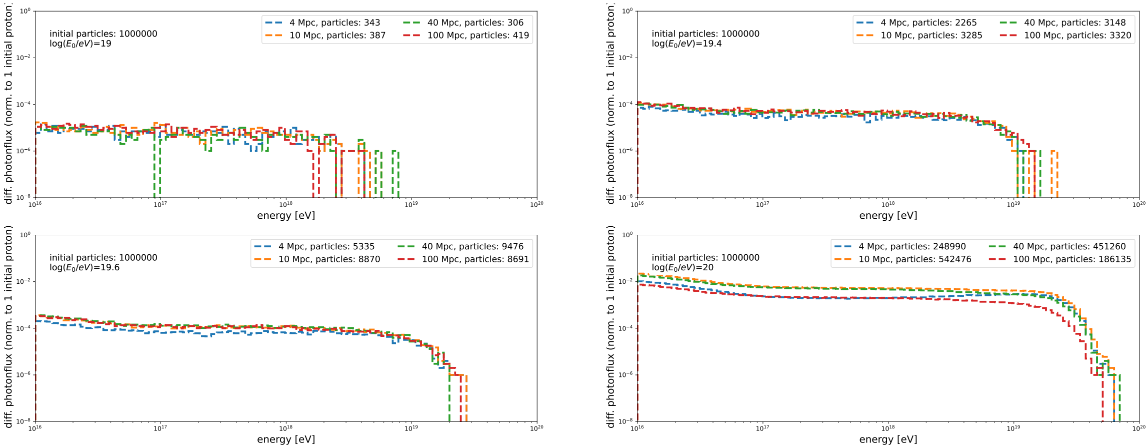
Varying the Propagated Distance



Varying the Initial Energy

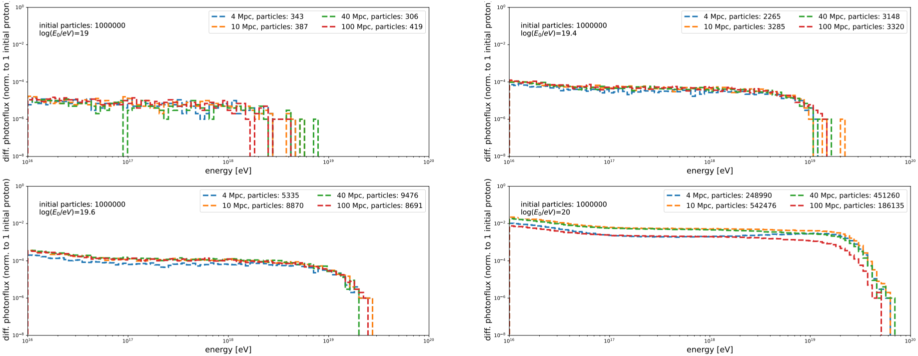


Sorting the plots the other way around

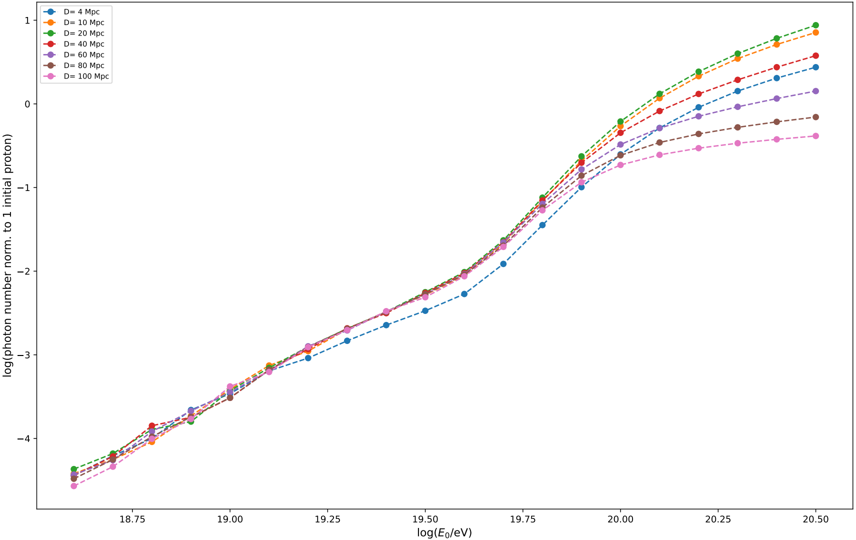


Optimum Source Distance

- determine the total photon number generated for each energy-distance combination
- plot photon-number against initial energy for each simulated distance



Optimum Source Distance



Current Results: Optimum Source Distance

- up to $E \sim 10^{19.7}\,\mathrm{eV} \approx 50\,\mathrm{EeV}$: little variation of flux (except for very close sources)
  - Photon production and reduction are similarly efficient over larger distances
  - at very close distances photon reduction (pair-production) is more efficient
- above $E \sim 50\,\mathrm{EeV}$: larger distance-dependant variation, optimum distance of $\sim 20\,\mathrm{Mpc}$ increase of photon flux from close sources
  - variation due larger interaction length of photo-pion production
  - almost constant interaction length of pair-production

Current Work in Progress

- Simulating initial particles with energies distributed over a spectrum
- Combining fixed-energy simulations to mimic initial energy spectrum
- Combining fixed-distance simulations to mimic source distribution
- Running and combining simulations for other initial nuclei

Goal of this Project

- Estimate how variables like source distance, initial energies and cosmic ray composition affect secondary photon flux
- Estimate scenarios resulting in maximum or minimum photon flux