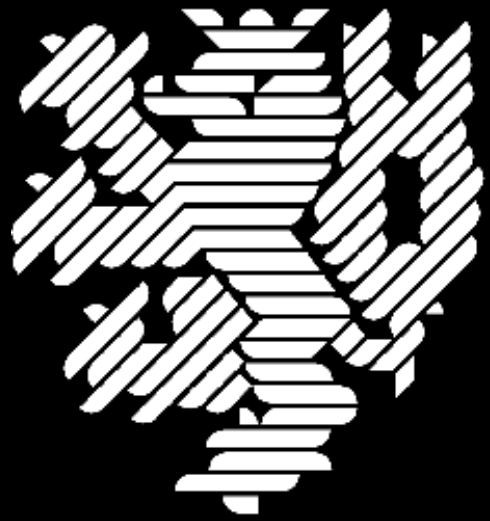
Simulation Studies on creation and propagation of UHE-γ with CRPropa



Schule für Astroteilchenphysik
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Biswajit Sarkar
Bergische Universität Wuppertal

Outline

- Motivation
- How are UHE - γ generated?
- Some information on CRPropa
- What I have done till now:
  - Propagation of primary γ
  - Propagation of primary protons
- Outlook

Motivation

- No UHE - γ ($>10^{18}$ eV) observed yet
  - photons measured with energies up to 10^{14} eV
- UHE - γ could be used as probe for nearby extragalactic UHECR sources
- Detection would open a new window to the universe
- Aim of my studies: making predictions on number of UHE - γ accompanying UHECR, for different source scenarios

How are UHE $-\gamma$ generated?

- photo-pion production (GZK-effect):

$$p_{UHE} + \gamma_{EBL} \rightarrow \Delta^{+}(1232) \rightarrow p + \pi^{0} \searrow \gamma_{UHE}\,\gamma_{UHE}$$

$$p_{UHE} + \gamma_{EBL} \rightarrow \Delta^{+}(1232) \rightarrow n + \pi^{+} \searrow \mu^{+} + \nu_{UHE}$$

- proton-pair production: (PPP)

$$p_{UHE} + \gamma_{EBL} \rightarrow p + e^{+} + e^{-}$$

- development of em-cascades:(ICS,PP,DPP,TPP):

→ PP

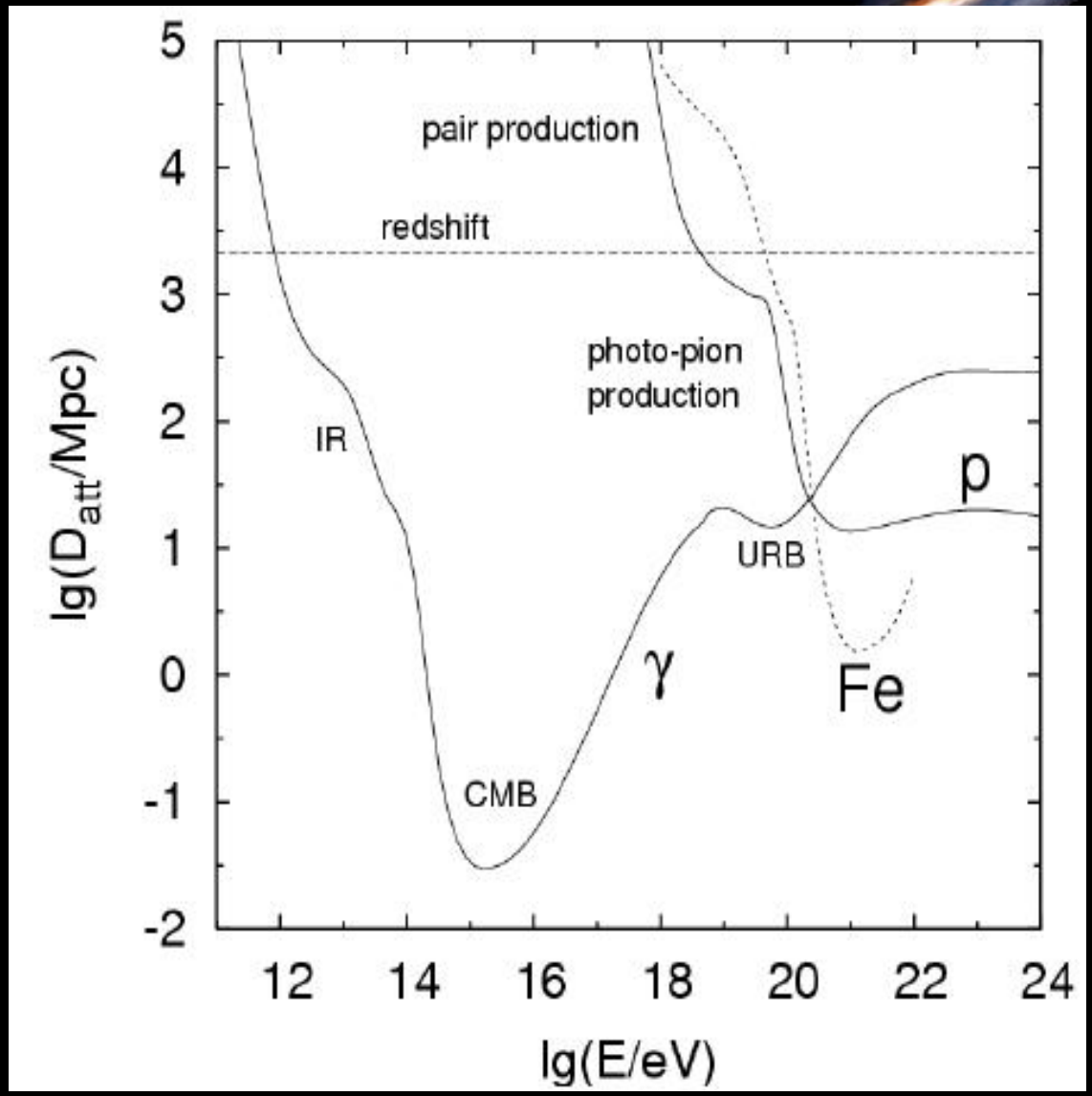
→ ICS

$$\gamma_{UHE} + \gamma_{EBL} \rightarrow e^{+} + e^{-}$$

$$e^{\pm} + \gamma_{EBL} \rightarrow e^{\pm} + \gamma_{UHE}$$

Energy loss length

- Energy dependence for p and γ
- Universe becomes transparent for "lower" energies for both

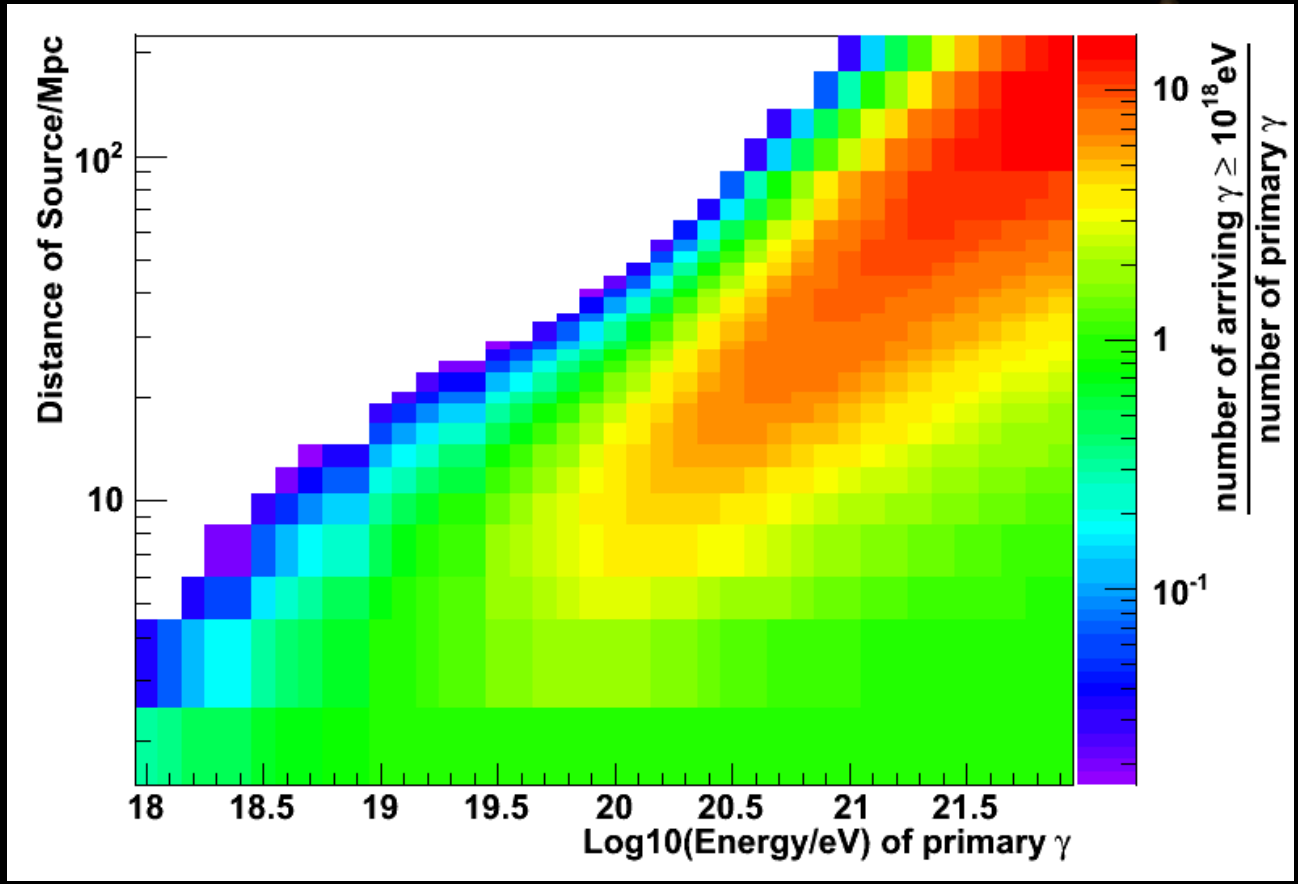


Some information on CRPropa

- Only nucleons and their secondary particles are considered
- Secondary particles:
  - photons from em-cascades (no monte carlo)
  - neutrinos
- Four different simulation modes
  - trajectories
  - events at observer
  - each of them in 1d and 3d
- Also implemented
  - Cosmological red-shift (only 1d)
  - Deflection in magnetic fields (only in 3d)

Injection of UHE-γ with discrete energy at the source

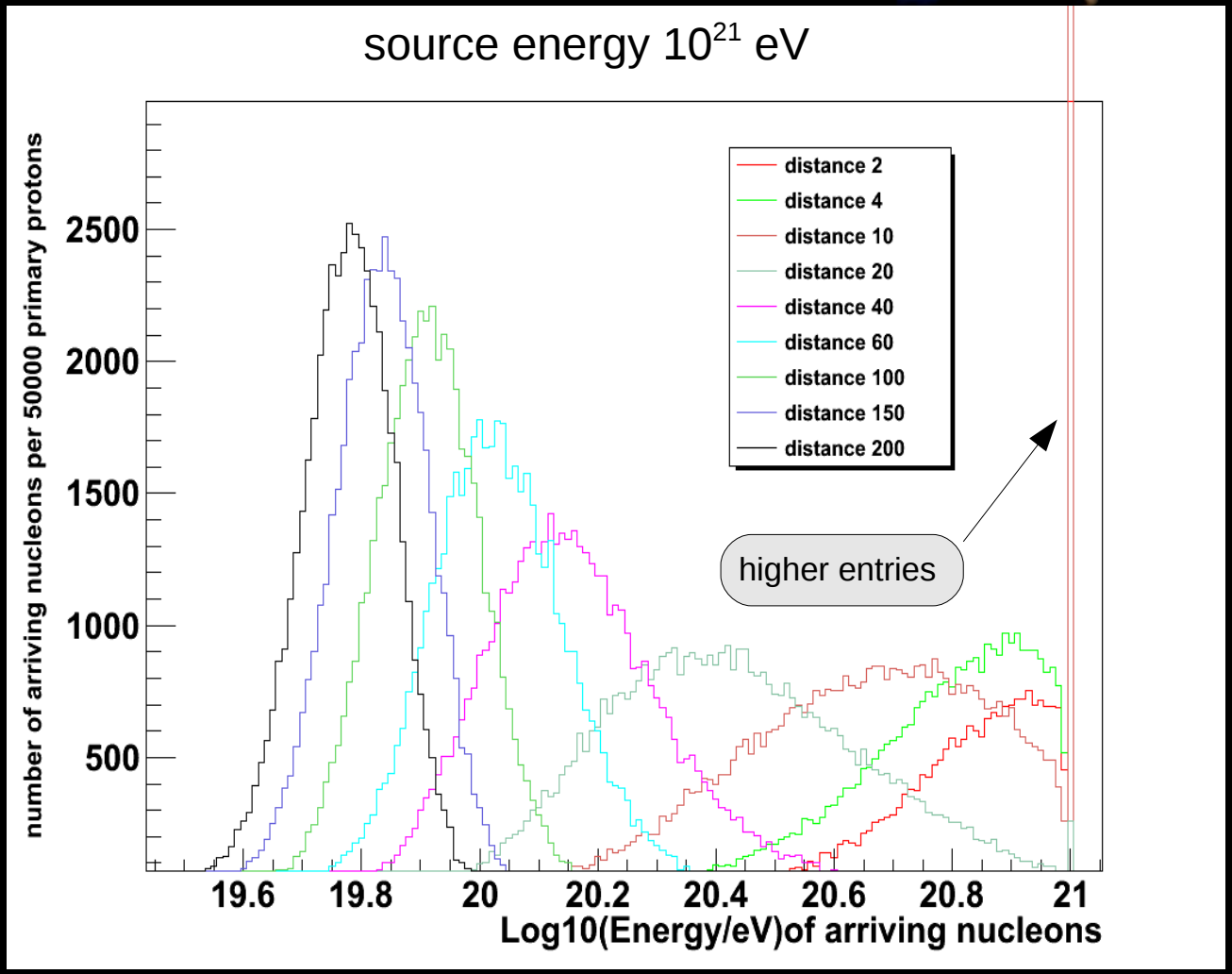
- Study of different source distance and energy
- Observing only photons above a threshold-energy (10^{18}eV)
  - ➔ There is a maximum
  - ➔ Maximum is moving to higher distances with higher source energies



Injection of UHE protons with discrete energy at source

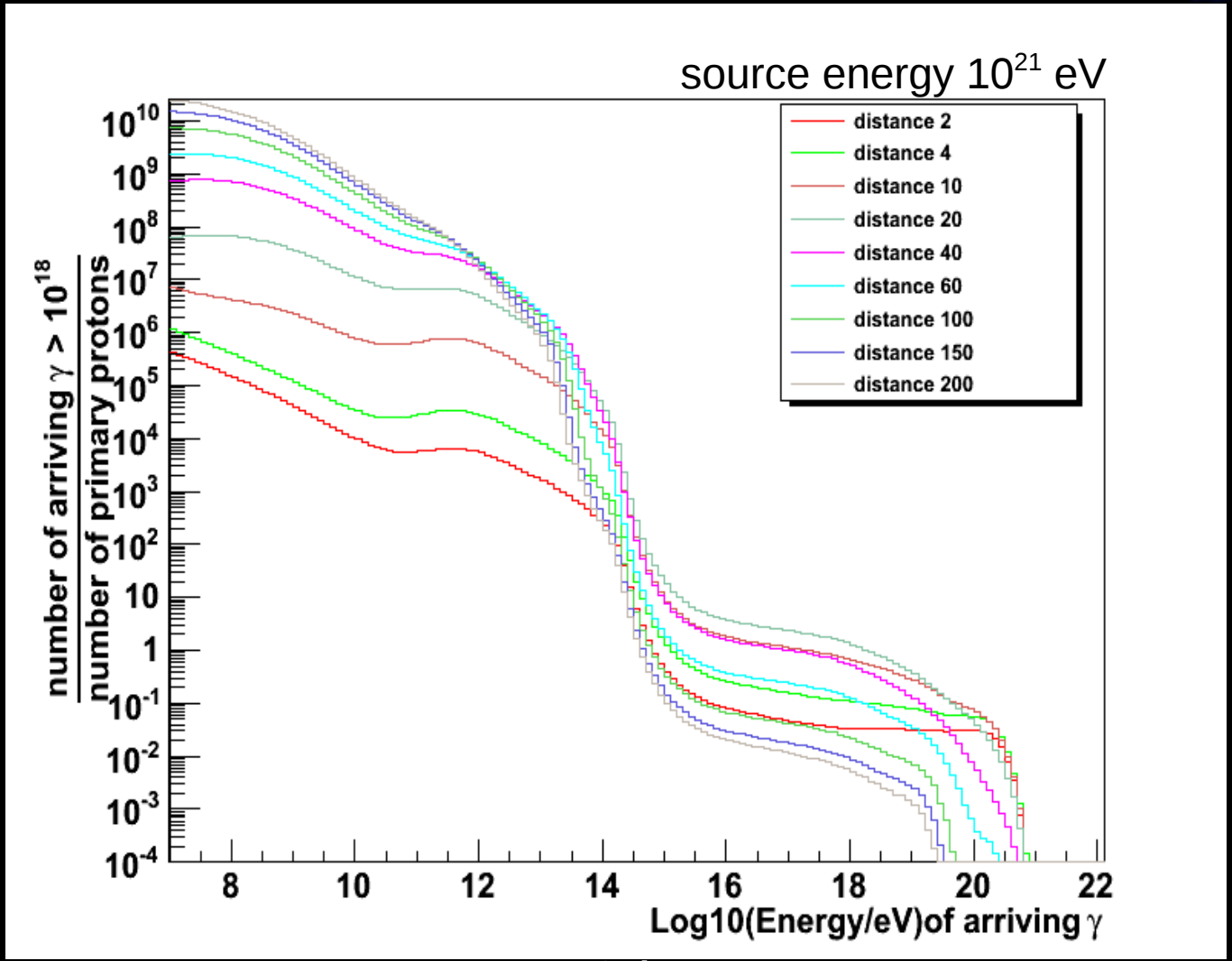
- Nucleon spectra
- Mean energy decreases with increasing distance until universe becomes transparent to protons

➔ Energy is given to secondary particles

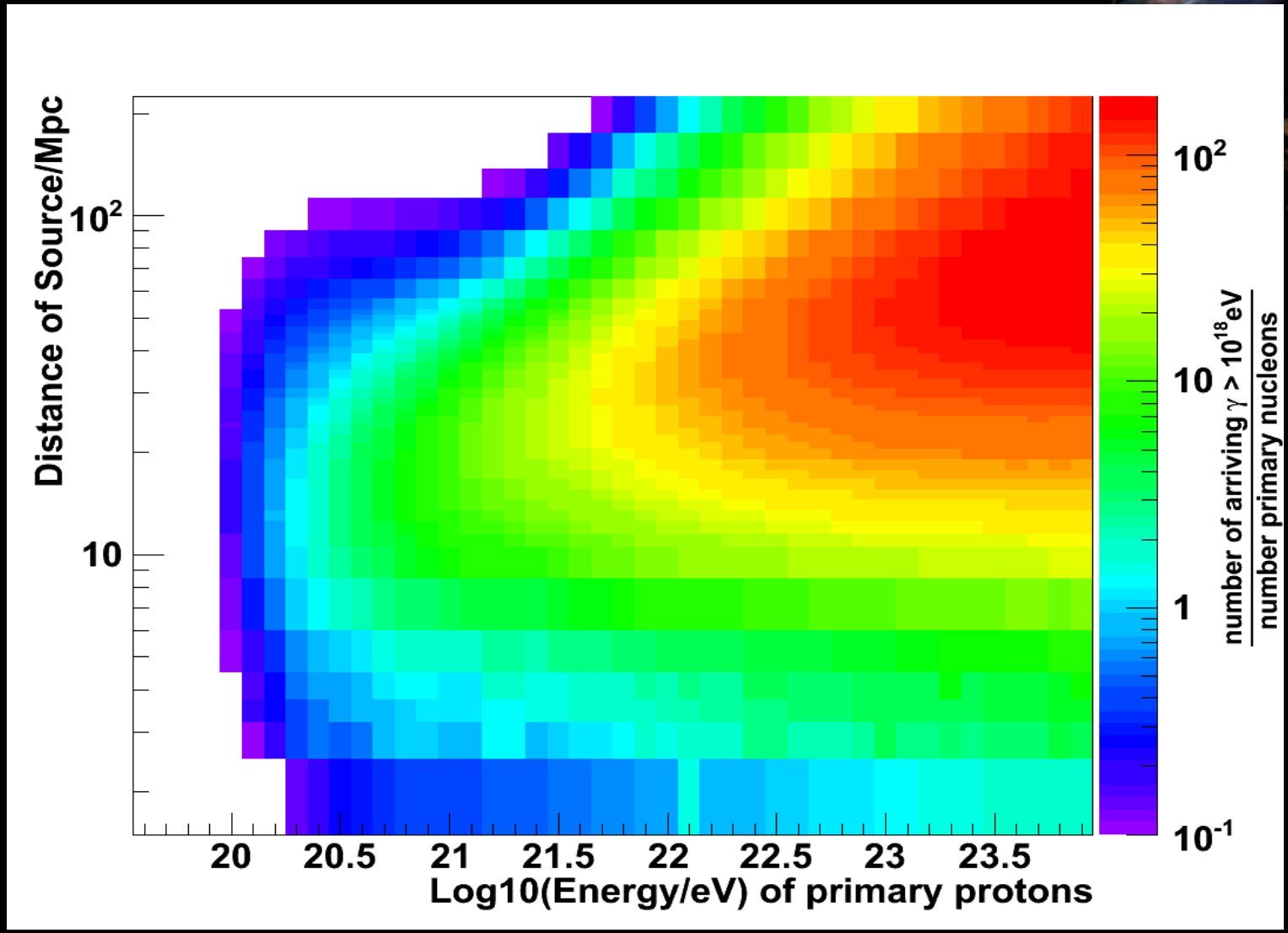


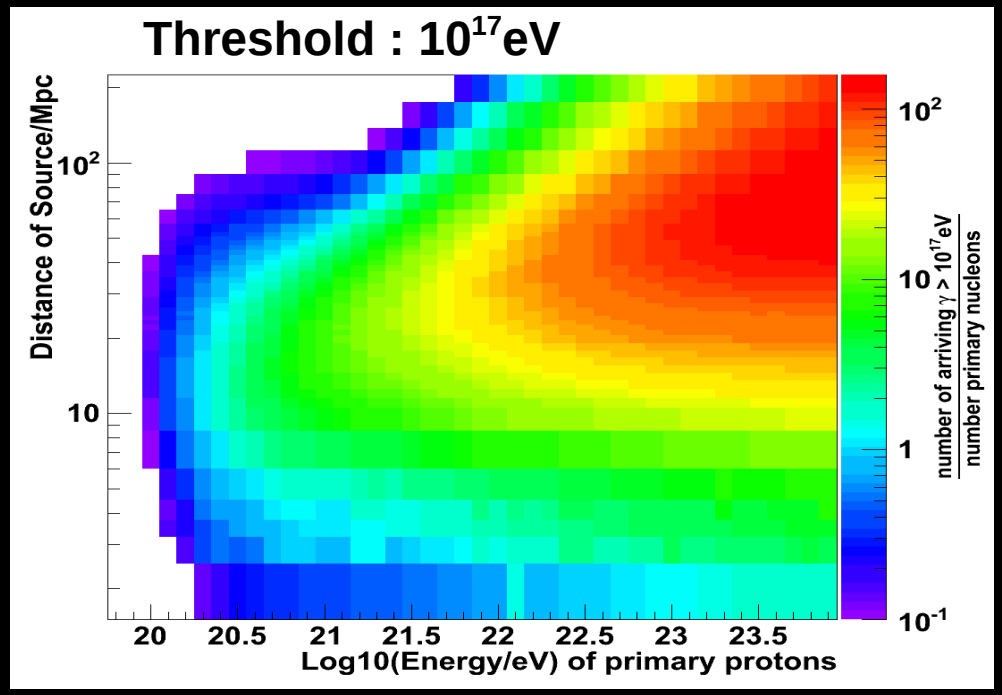
Injection of UHE protons with discrete energy at source

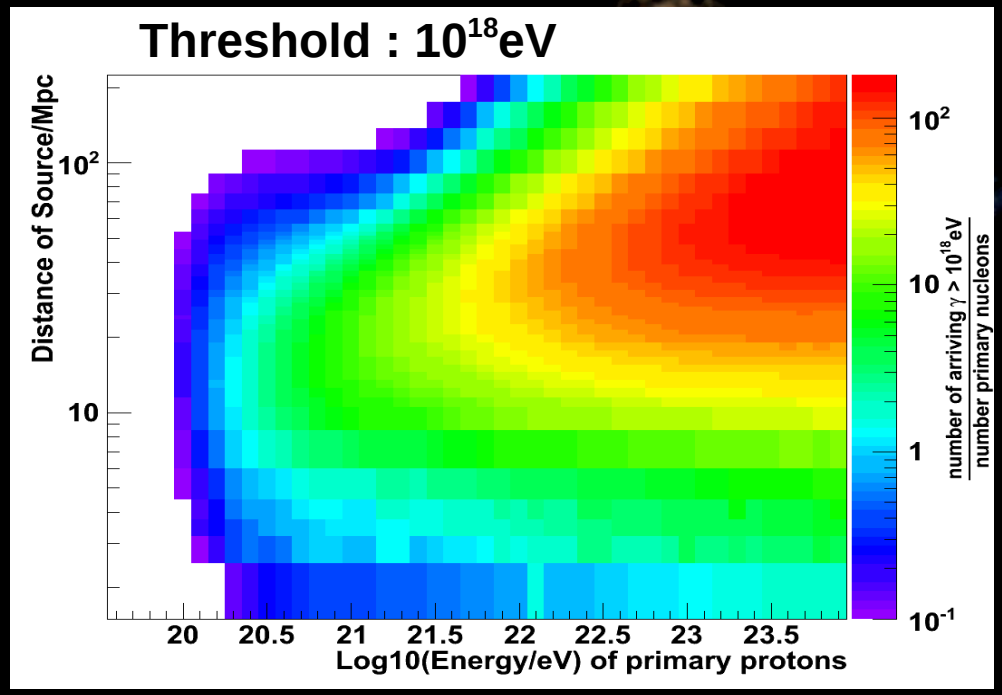
- Resulting photon spectra:



Photons above the threshold energy 10^{18} eV from primary UHE protons




Threshold : 10^{17}eV
Distance of Source/Mpc
10^2
10
20
20.5
21
21.5
22
22.5
23
23.5
Log10(Energy/eV) of primary protons
10^2
10
1
10^{-1}
number of arriving $\gamma > 10^{17}$eV / number primary nucleons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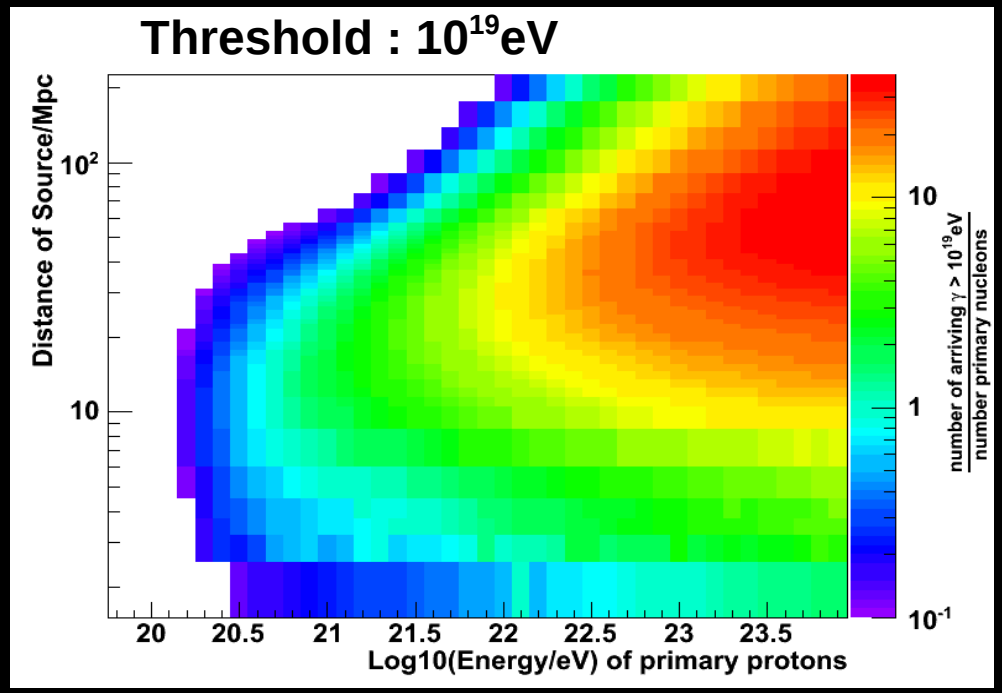
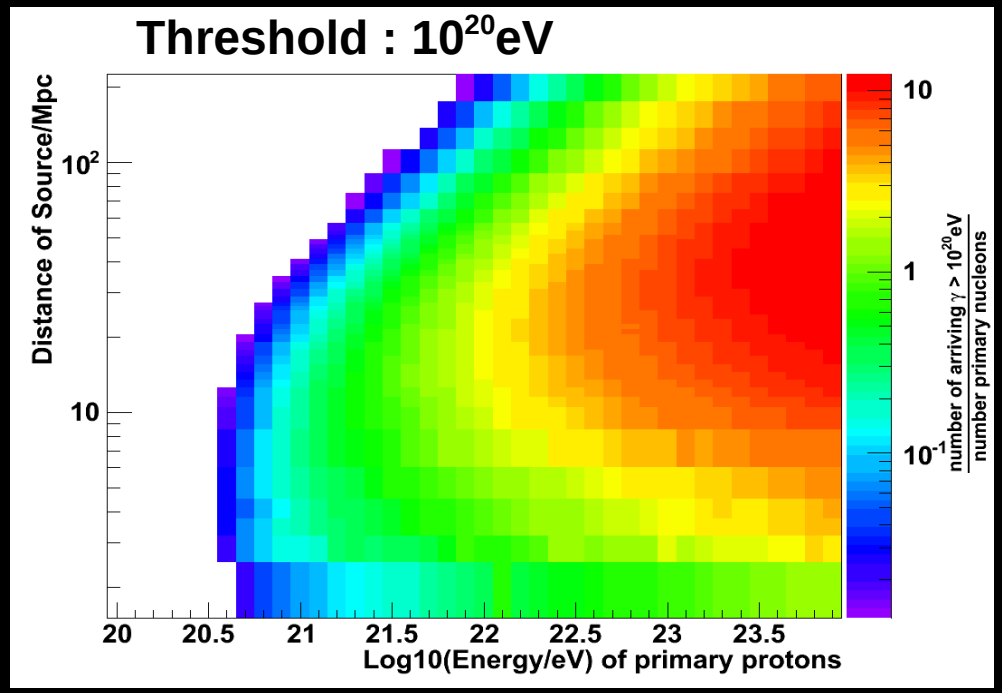

Threshold : 10^{19}eV
Distance of Source/Mpc
10^2
10
20
20.5
21
21.5
22
22.5
23
23.5
Log10(Energy/eV) of primary protons
10
1
10^{-1}
number of arriving $\gamma > 10^{19}$eV / number primary nucleons


Threshold : 10^{20}eV
Distance of Source/Mpc
10^2
10
20
20.5
21
21.5
22
22.5
23
23.5
Log10(Energy/eV) of primary protons
10
1
10^{-1}
number of arriving $\gamma > 10^{20}$eV / number primary nucleons

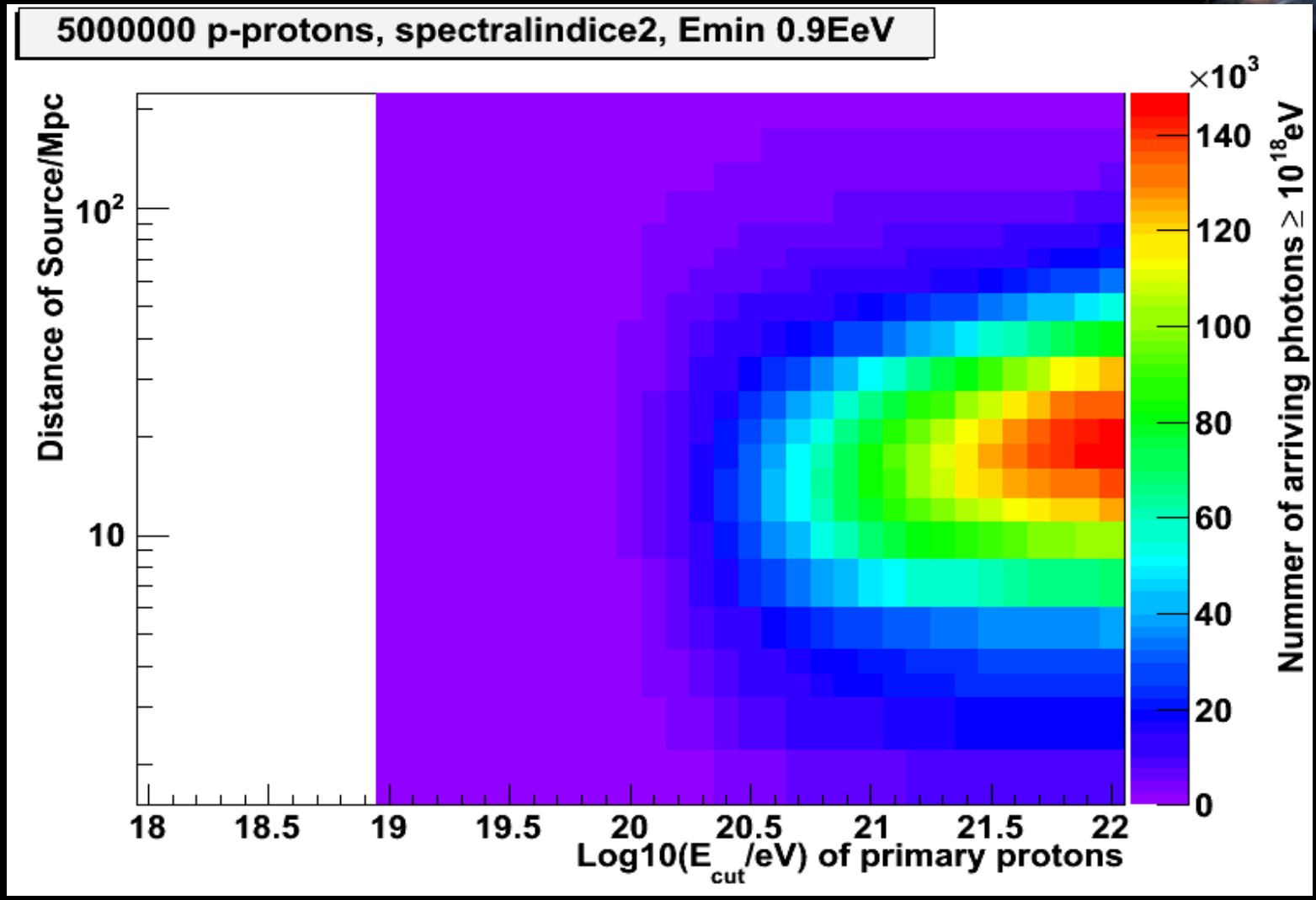
Outlook

- Quantify this studies by finding a approximative formulas for the photon number
- Regarding proton sources with energy-distribution
- Taking magnet fields into account
- Implementing parts of the Véron-Cetty AGN catalog in 1d- and 3d-simulations for some source scenarios

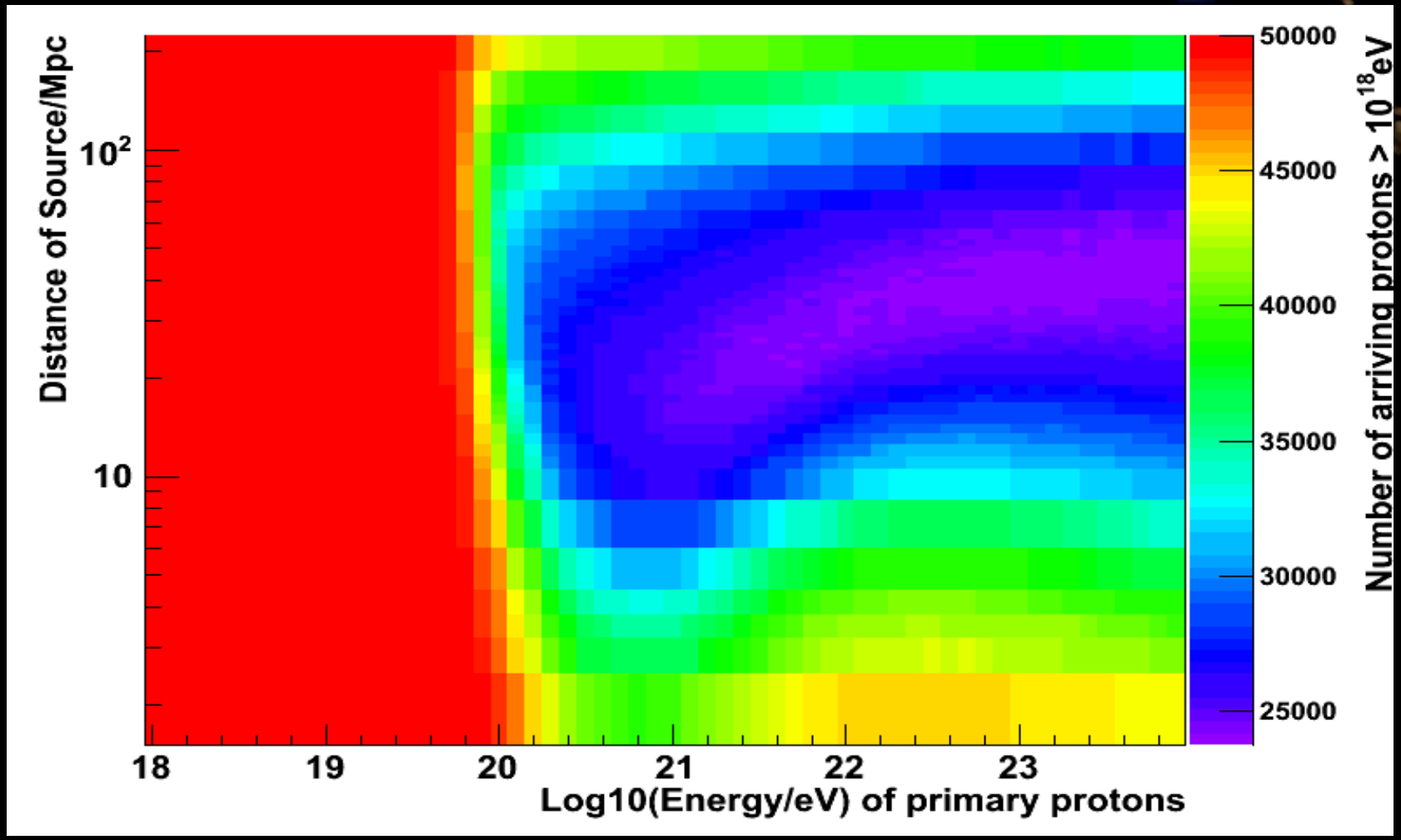
Thank you for your attention

BACKUP

Injection of primary protons with



Injection of UHE protons with discrete energy at source



Injection of UHE protons with discrete energy at source