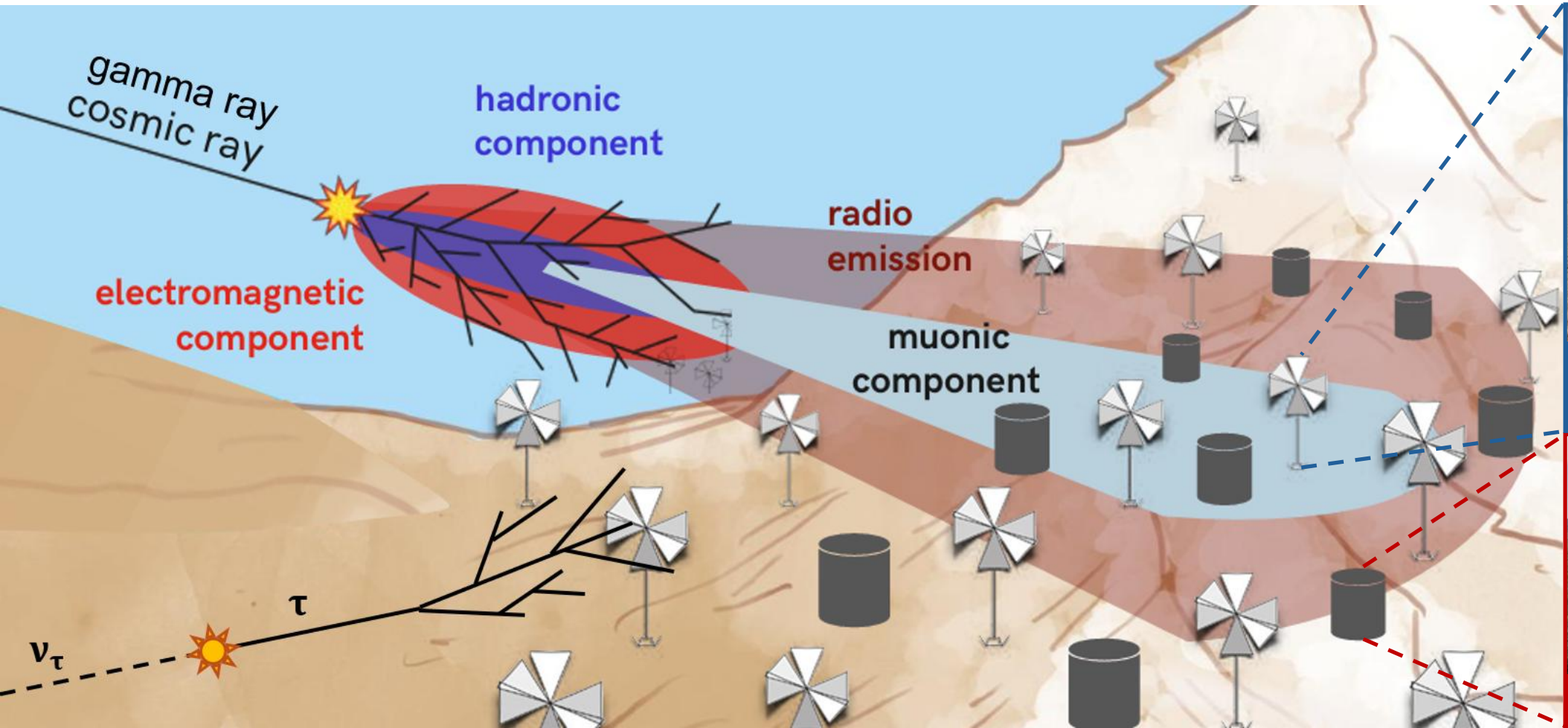
Hybrid detection of air showers

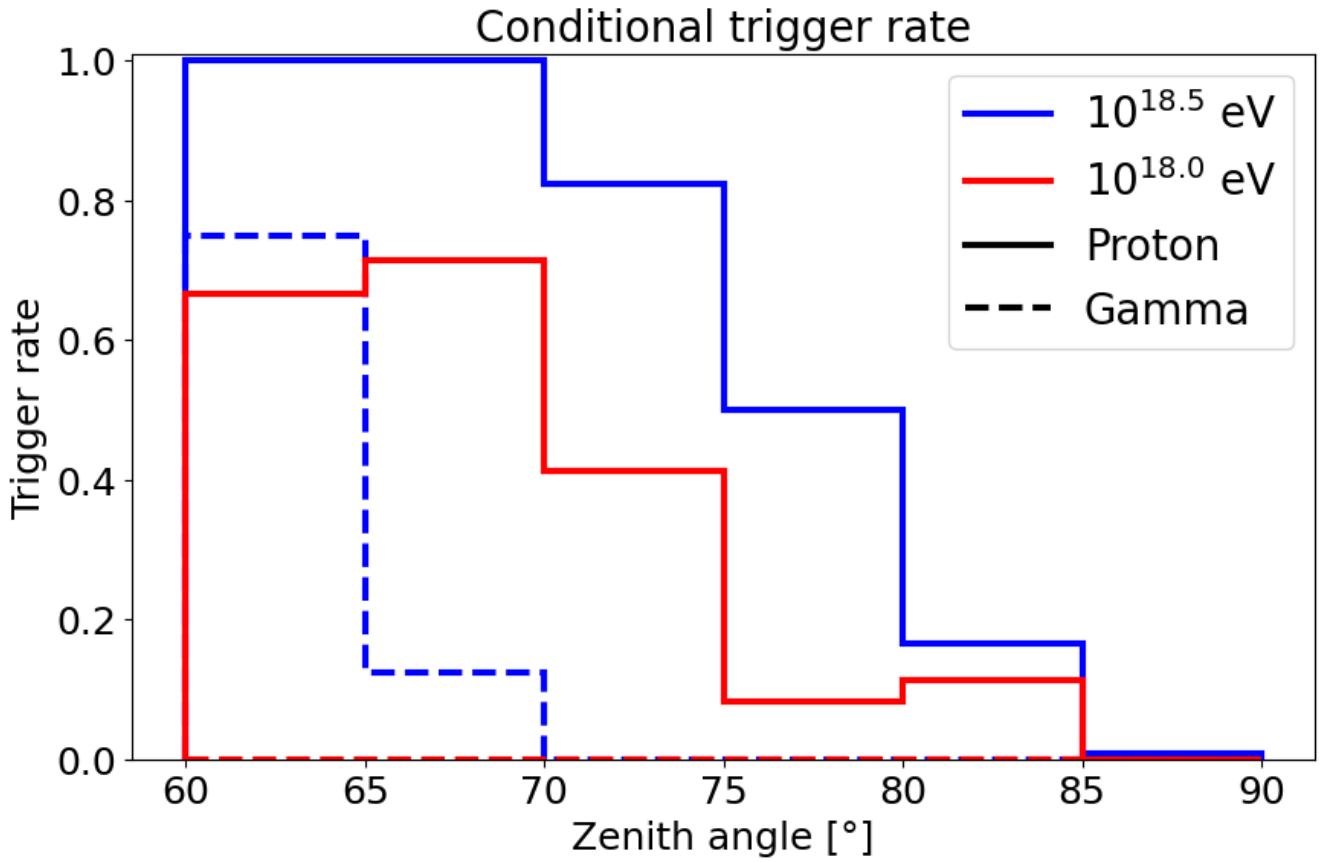
- Combine particle and radio information
- Differences in **muonic component**, between proton and gamma showers



GRAND radio antenna

TA scintillator

Proton – gamma discrimination with a hybrid array



Detector layout

- **Radio antennas** on **GP300** layout
- **Scintillators** on **infill** layout

Trigger parameters

Radio

- **4 antennas** with a signal higher than **75 μV/m**

Particles

- **3 scintillators** with a signal higher than **5 MIP**

- High potential for proton-gamma discrimination
- Interesting region between 70° and 85° for energies above $10^{18.0}$ eV

Limits and improvements

Limited statistics

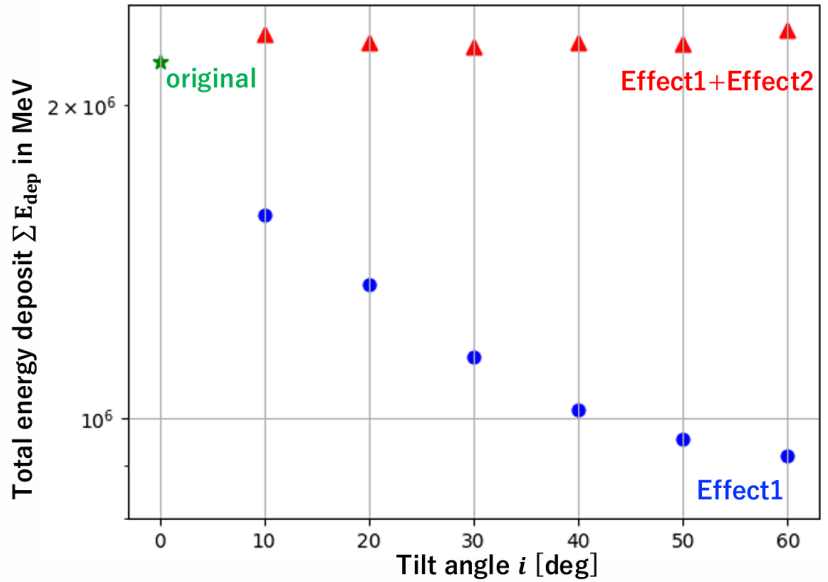
- Only 6000 events, and only 5 energy values
- New simulations (18000 events) with better sampling → to analyse

Size of the particle footprint

- Radius limited to 8.4km, smaller than GP300 layout
- Need to extend it by a factor 2.5, currently in progress

Inclining particle detectors ?

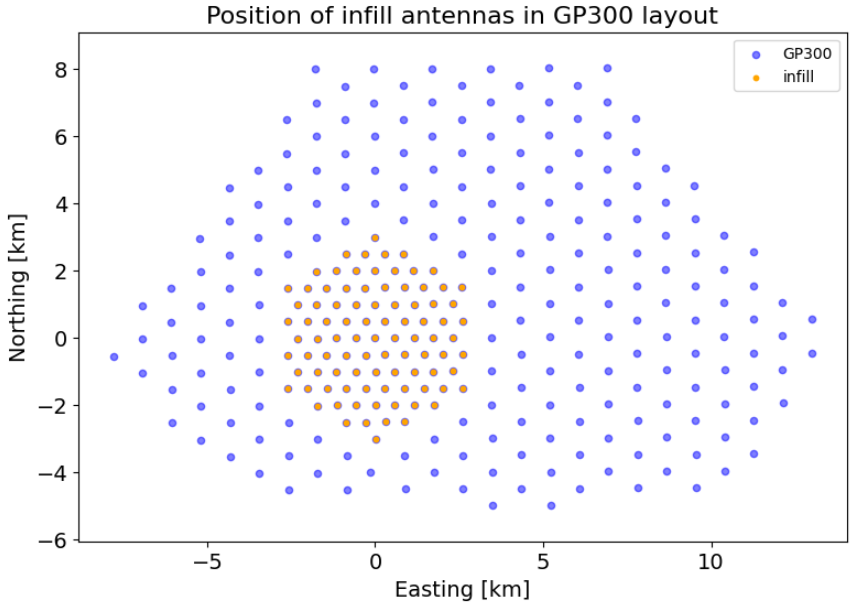
- Studied by Kaoru Takahashi
- Competition between length of particle path in detector (effect 1) and projected area (effect 2)

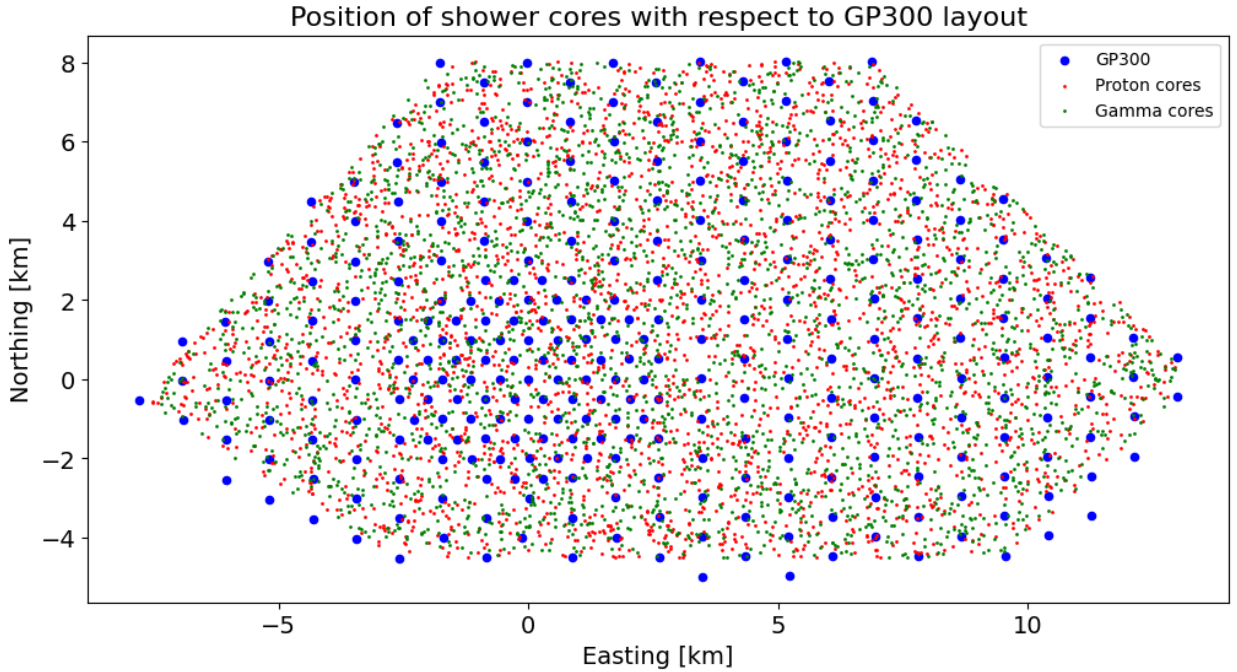


Back-up

Simulation library

- « Old » simulation library:
  - Proton and gamma primary : 3000 events for each primary
  - Energies : 16,5 17 17,5 18 18,5
  - Zenith between 60° and 87° with probability distribution in $1/\cos(\theta)$)
  - Random azimuth between 0° and 360°
  - Layout of GP300 (official) and GP13 (for radio antennas)
  - Random core contained





Simulation library

- « New » simulation library:
  - Proton and gamma primary : ~9000 events for each primary
  - Energies : between $10^{17.0}$ eV and $10^{18.5}$ eV, uniform
  - Zenith between 70° and 85° with uniform distribution
  - Random azimuth between 0° and 360°
  - Layout of GP300 (official) and GP13 (for radio antennas)
  - Random core contained

Particle footprint analysis: Methodology

- Aim: Calculate the energy deposits on scintillation detectors on the ground
- 1st step: DETHINNING
  - Undo the thinning from CORSIKA
- 2nd step: GEANT4 calculation of energy deposits
  - Calculate the energy deposited in a very dense layout of « imaginary » scintillation detectors, **around shower core** (with 6m spacing in a 8,4km radius around shower core)
- 3rd step: Calculate the energy deposited in the « real » layout considered
  - For each « real » detector, find the 4 closest « imaginary » detectors in the footprint (it depends on the shower core position) and average their energy deposits

Particle footprint analysis: Methodology

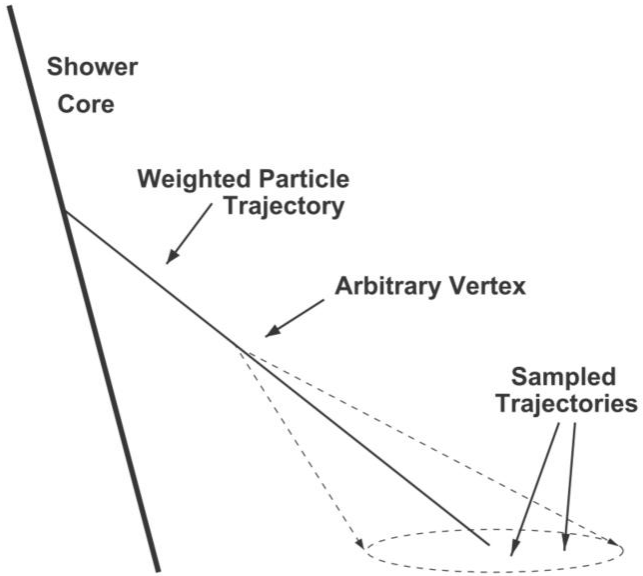
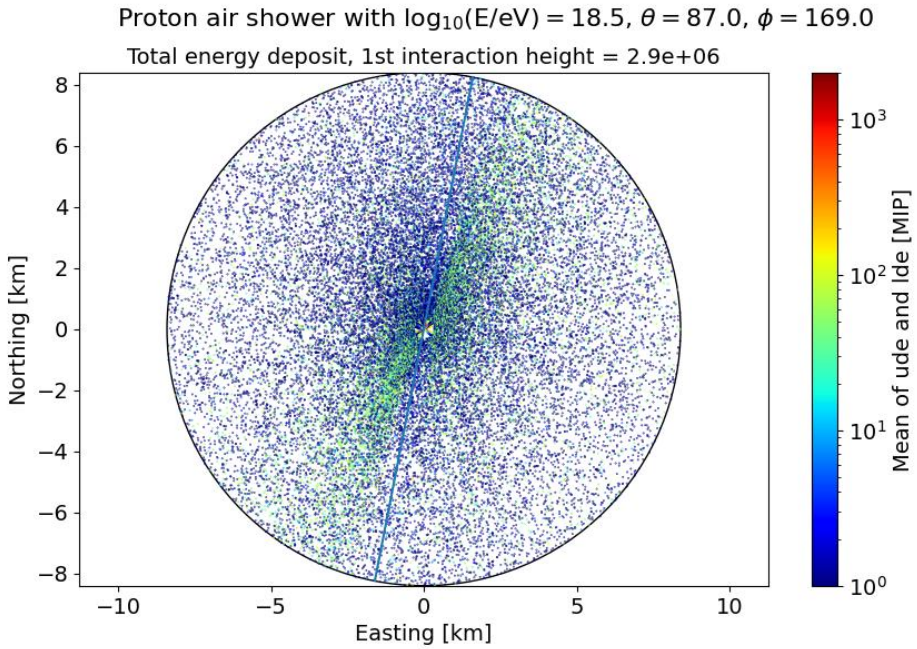
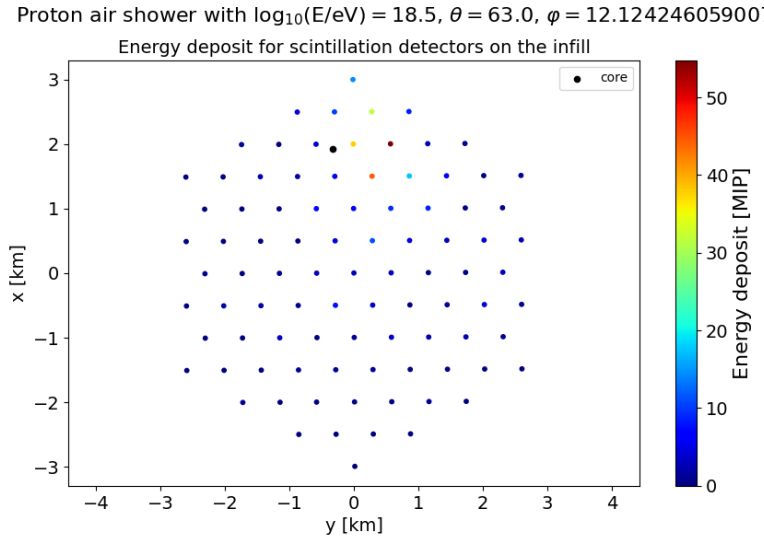


Fig. 1. Geometry for a "Gaussian cone" with a vertex placed at arbitrary position on the trajectory of the weighted particle.

1st step: DETHINNING

2nd step: GEANT4 energy deposits





3rd step: « real » particle footprint

Trigger criteria

- Detector triggered = energy deposit above a certain threshold
- Thresholds used: 1, 3, 5, 10, 30 Minimum Ionising Particles (MIP)

- Event triggered = more than 3 detectors triggered
- Two interesting quantities:
  - Trigger rate
  - (Differential) Event rate

Number of triggered events

- Ratio of total triggered events for proton with respect to gamma:
  - 1 MIP: 5,4
  - 3 MIP: 10,3
  - 5 MIP: 15,7
  - 10 MIP: 14,7
  - 30 MIP: no gamma events triggered
- Optimum at 5 MIP ? Best compromise between number of events and ratio

```
Proton events:

Total events: 3000

Triggered events, 3 scintillators with signal:
Above 1 MIP: 390
Above 3 MIP: 196
Above 5 MIP: 110
Above 10 MIP: 44
Above 30 MIP: 4


Gamma events:

Total events: 3000

Triggered events:

Triggered events, 3 scintillators with signal:
Above 1 MIP: 72
Above 3 MIP: 19
Above 5 MIP: 7
Above 10 MIP: 3
Above 30 MIP: 0
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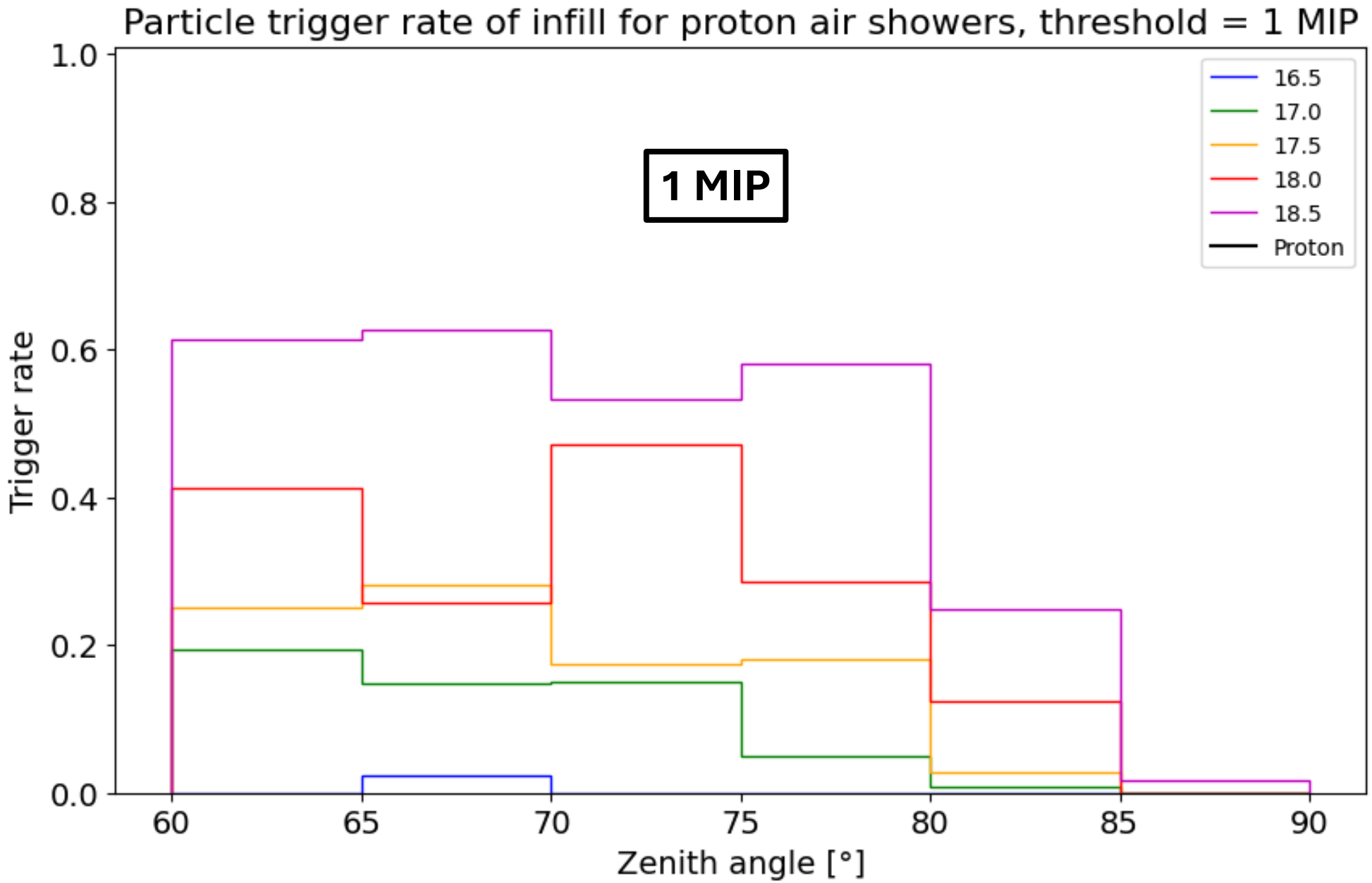
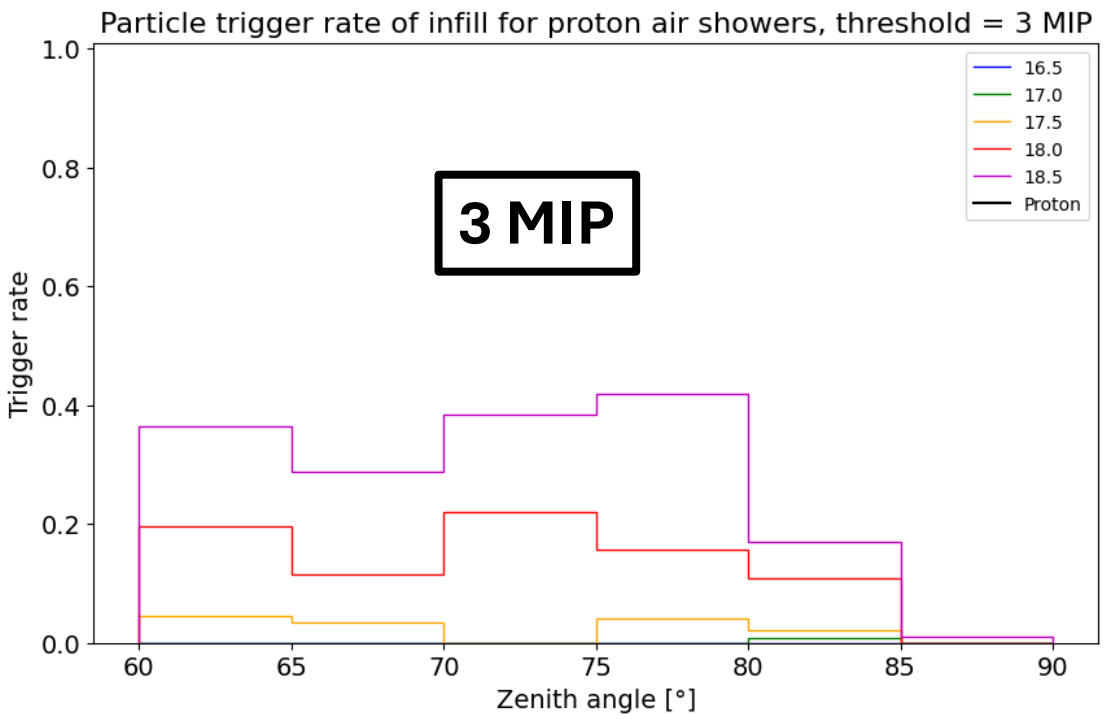
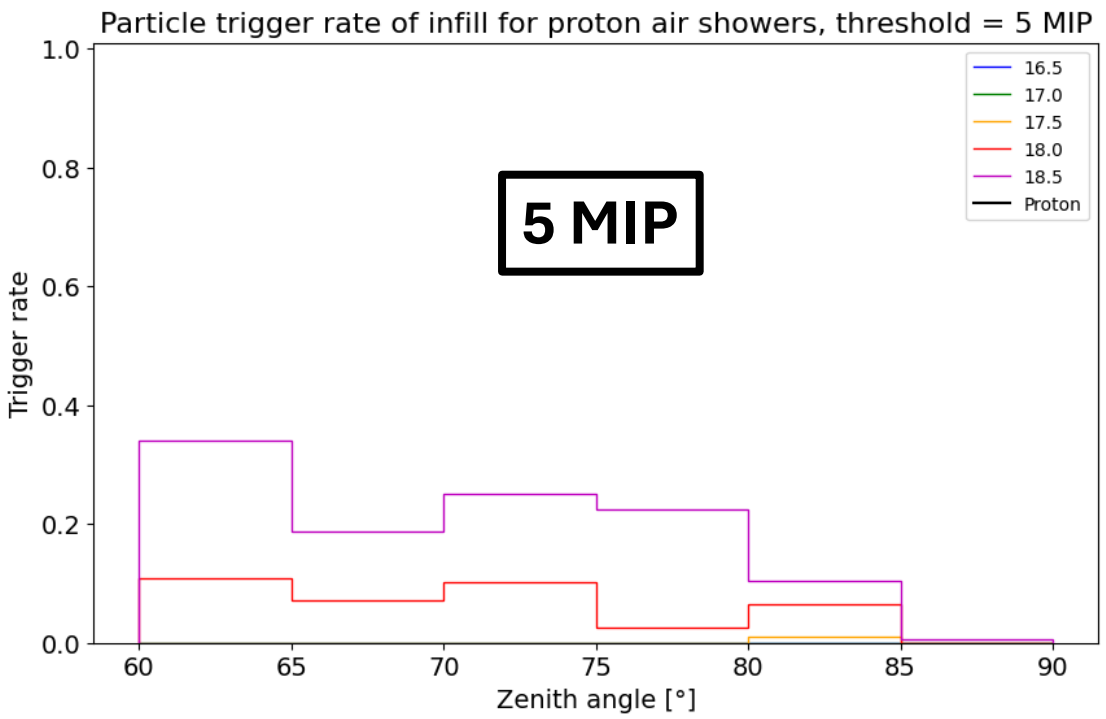
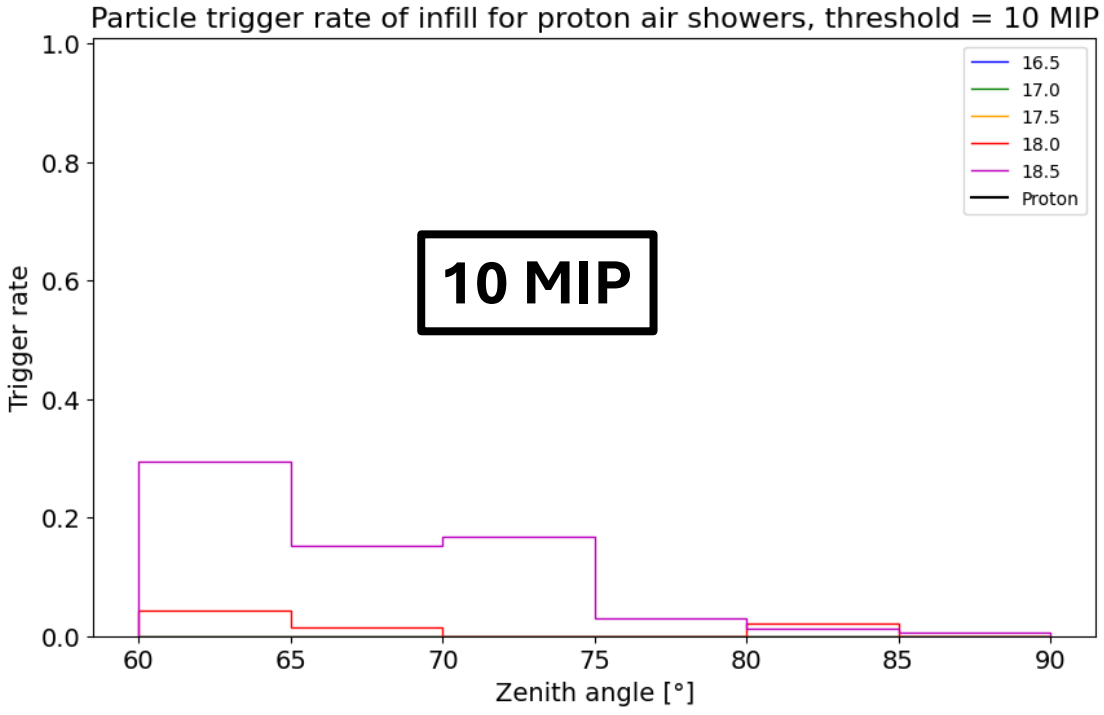
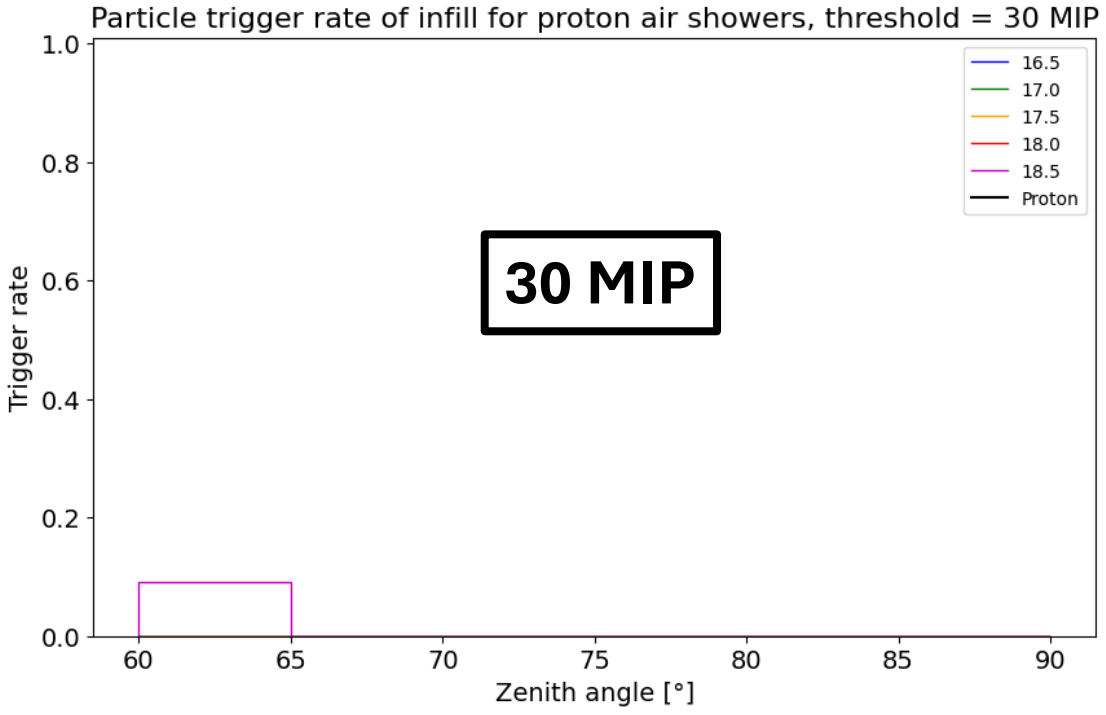
Proton trigger rate



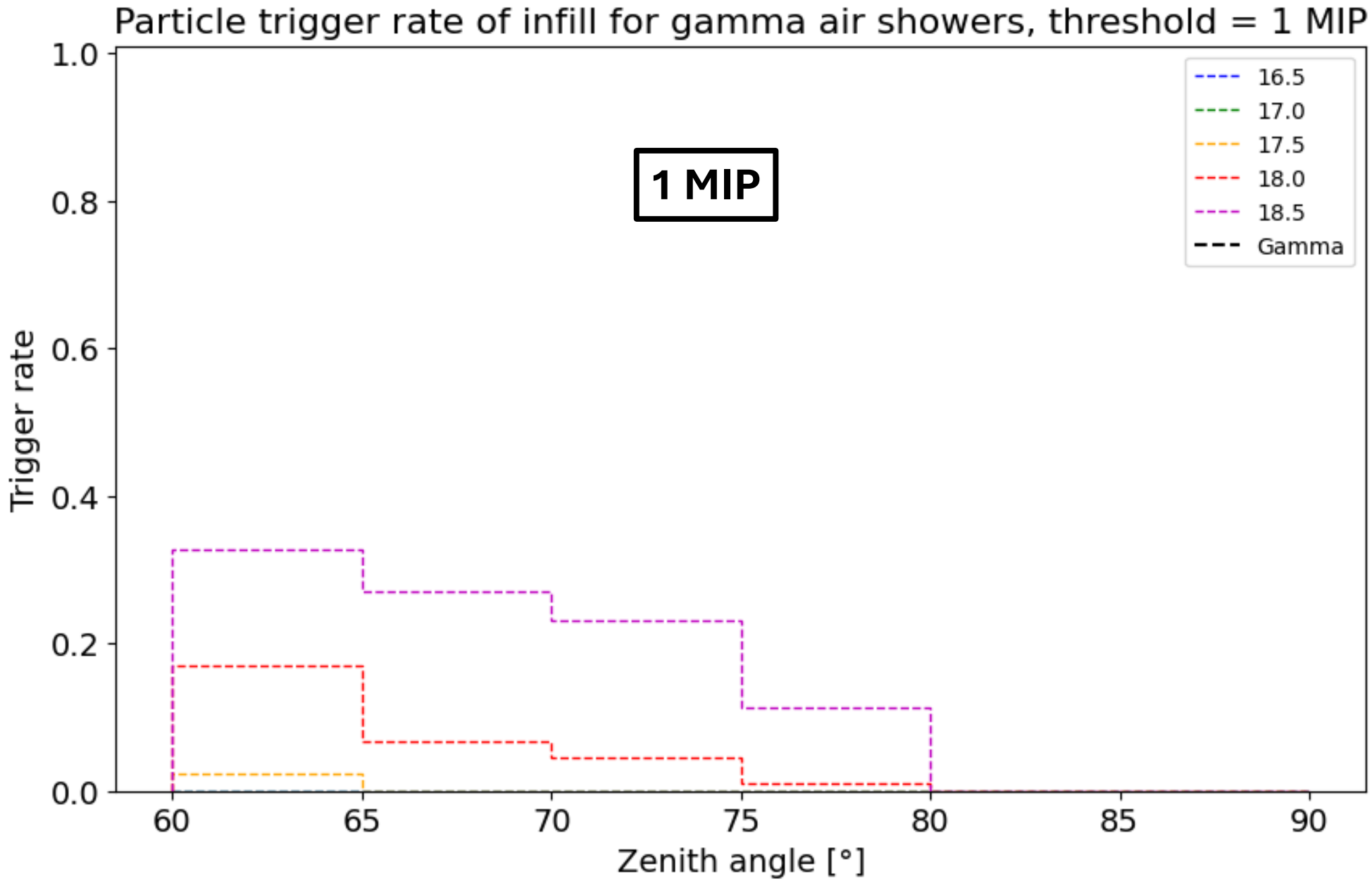

Particle trigger rate of infill for proton air showers, threshold = 3 MIP
3 MIP
Trigger rate
Zenith angle [°]
16.5
17.0
17.5
18.0
18.5
Proton

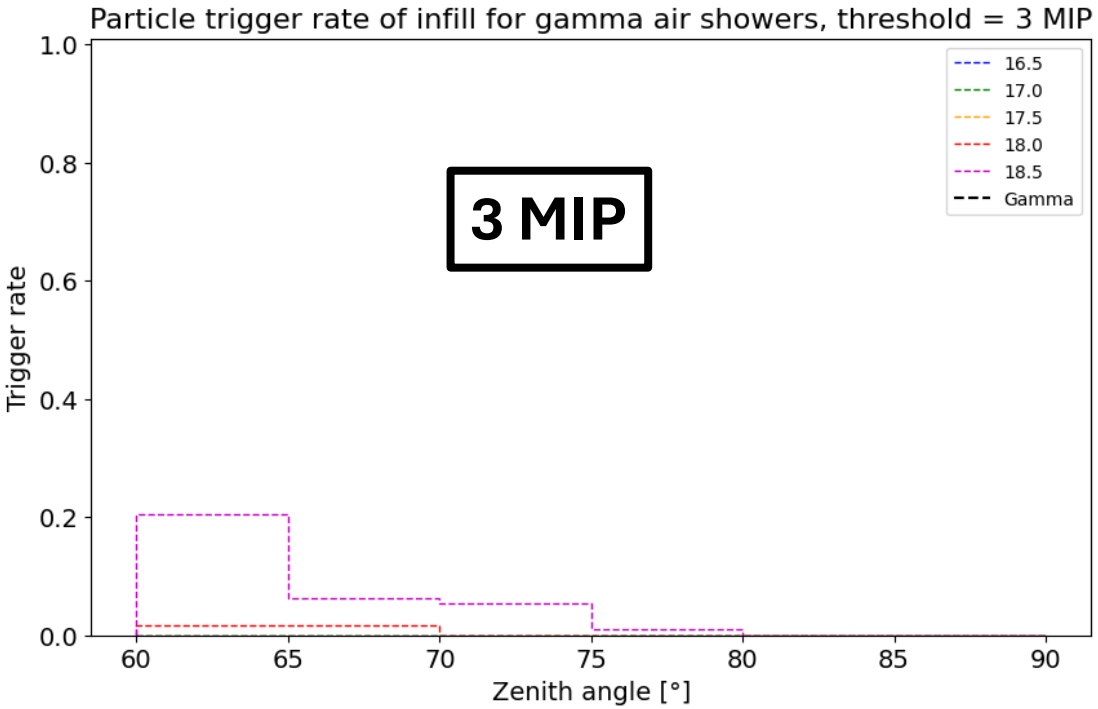

Particle trigger rate of infill for proton air showers, threshold = 5 MIP
5 MIP
Trigger rate
Zenith angle [°]
16.5
17.0
17.5
18.0
18.5
Proton

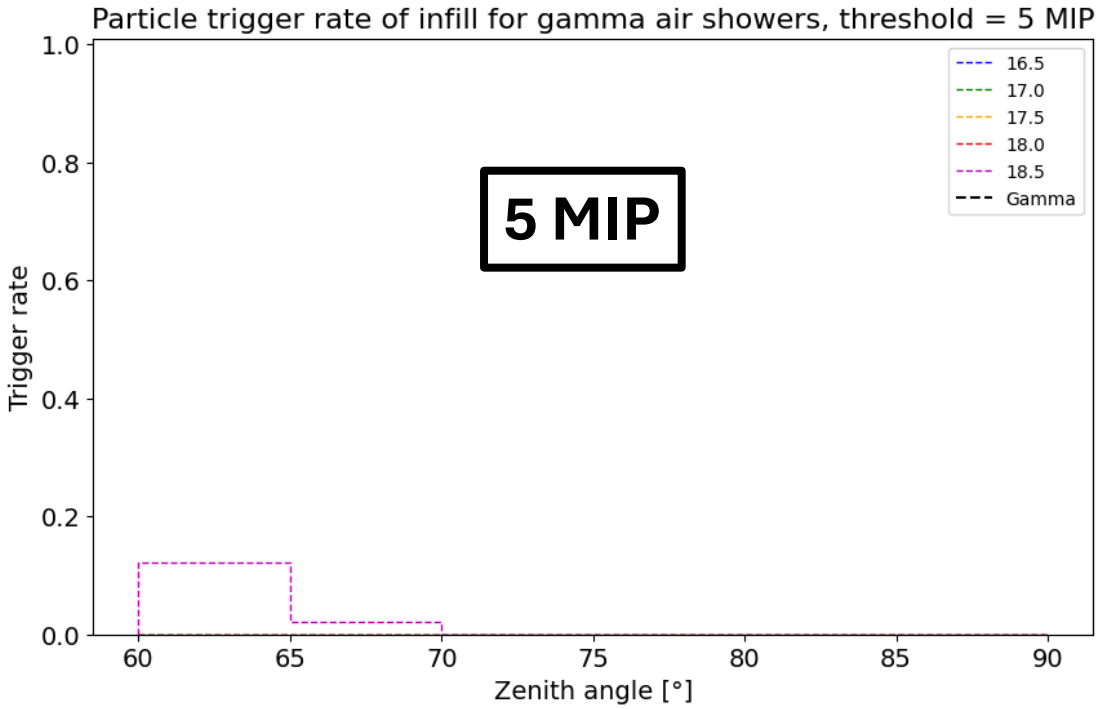

Particle trigger rate of infill for proton air showers, threshold = 10 MIP
10 MIP
Trigger rate
Zenith angle [°]
16.5
17.0
17.5
18.0
18.5
Proton

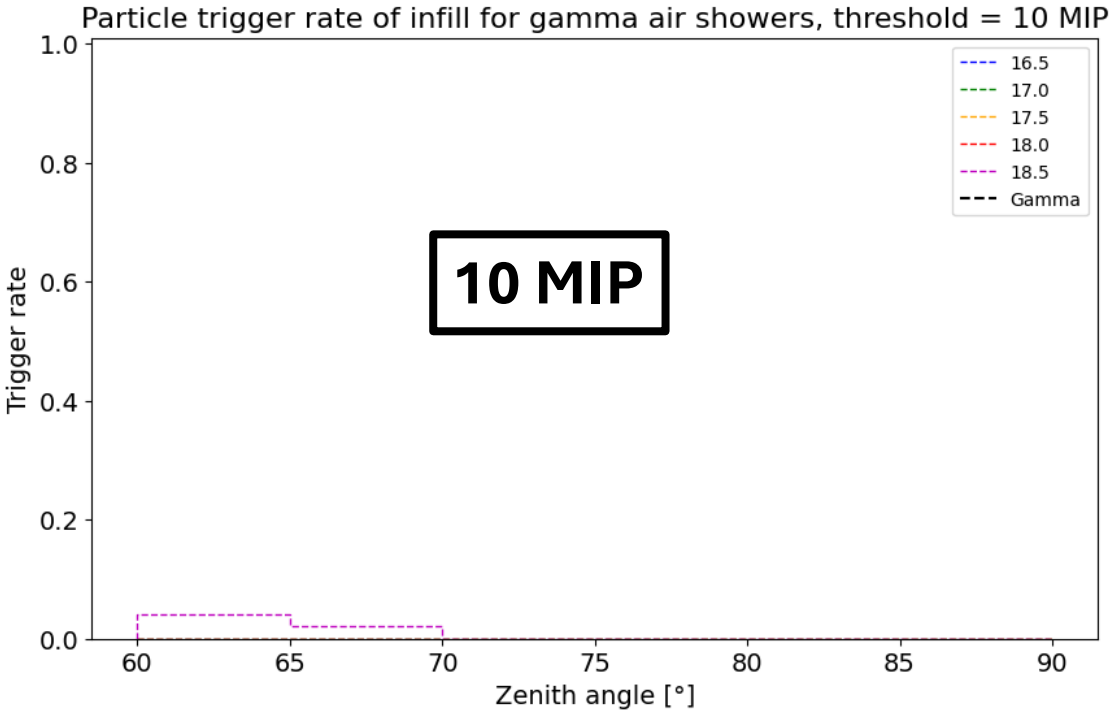

Particle trigger rate of infill for proton air showers, threshold = 30 MIP
30 MIP
Trigger rate
Zenith angle [°]
16.5
17.0
17.5
18.0
18.5
Proton

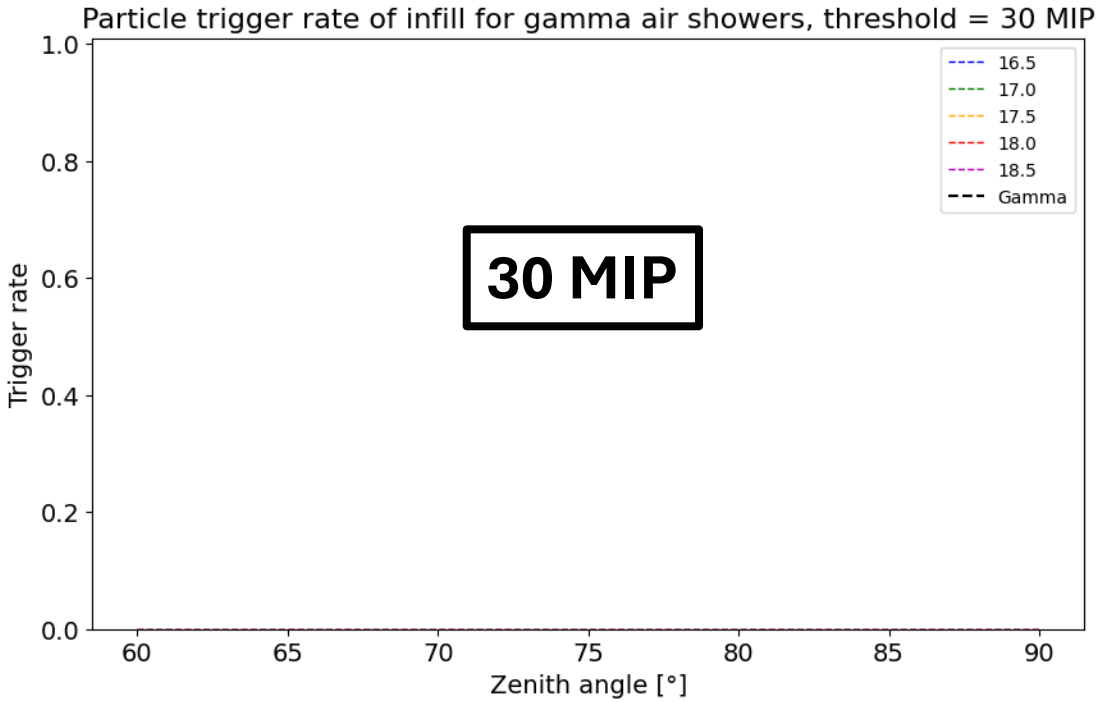
Gamma trigger rate



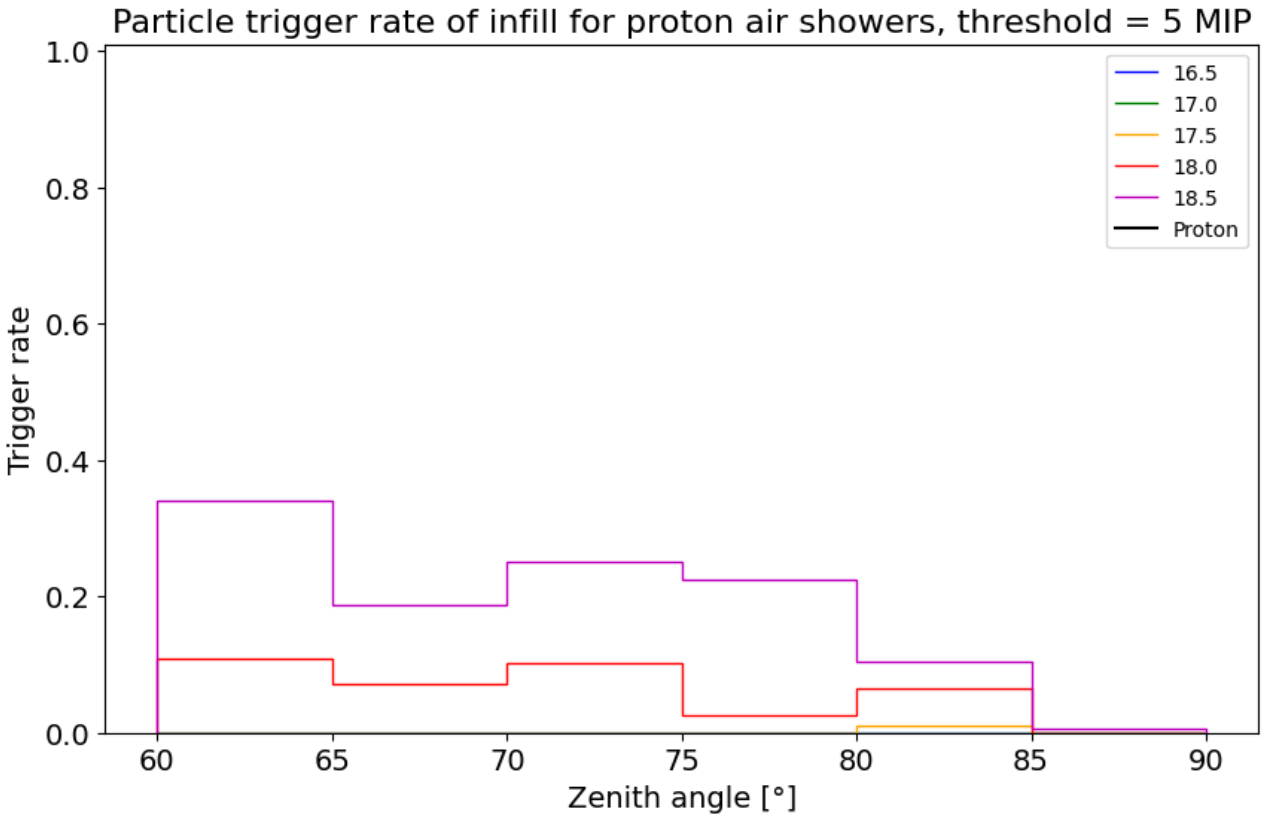

Particle trigger rate of infill for gamma air showers, threshold = 3 MIP
3 MIP
16.5
17.0
17.5
18.0
18.5
Gamma
Trigger rate
Zenith angle [°]

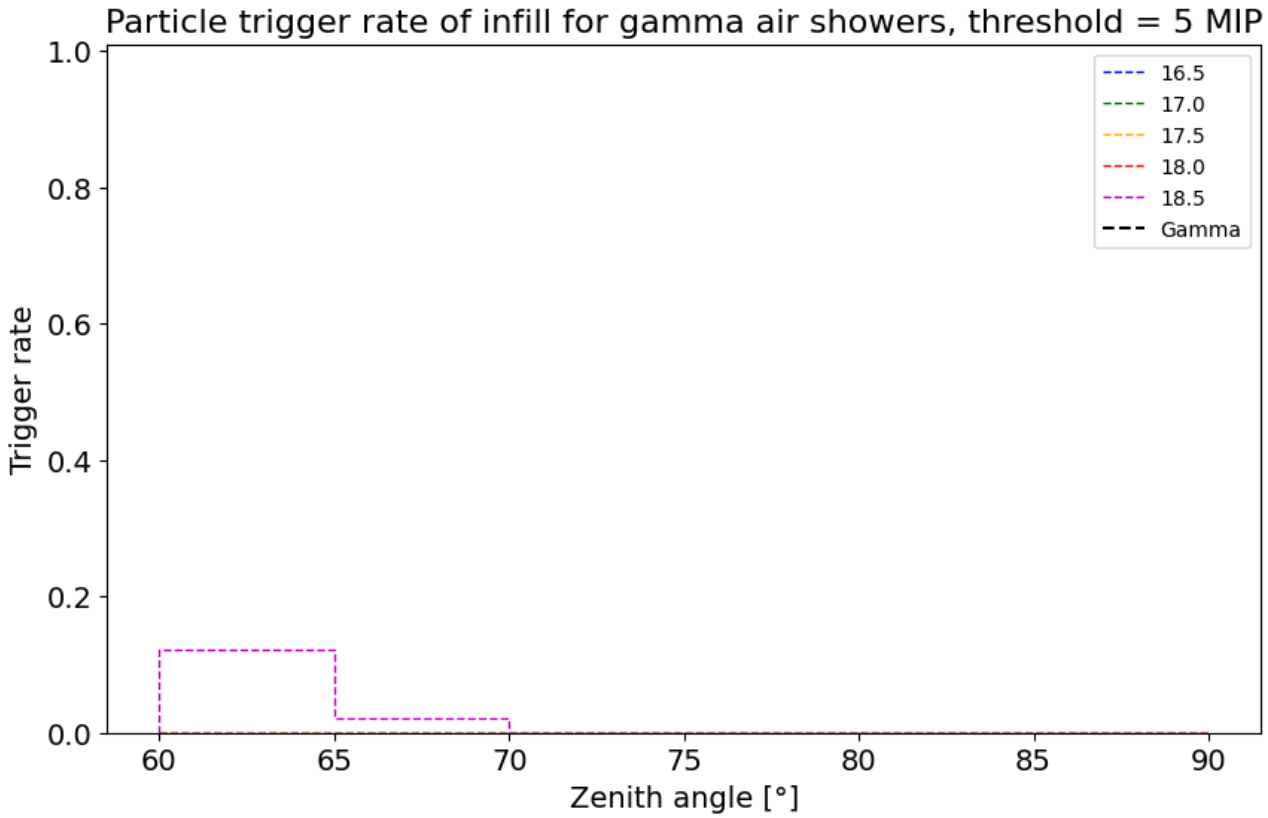

Particle trigger rate of infill for gamma air showers, threshold = 5 MIP
5 MIP
16.5
17.0
17.5
18.0
18.5
Gamma
Trigger rate
Zenith angle [°]


Particle trigger rate of infill for gamma air showers, threshold = 10 MIP
10 MIP
16.5
17.0
17.5
18.0
18.5
Gamma
Trigger rate
Zenith angle [°]


Particle trigger rate of infill for gamma air showers, threshold = 30 MIP
30 MIP
16.5
17.0
17.5
18.0
18.5
Gamma
Trigger rate
Zenith angle [°]

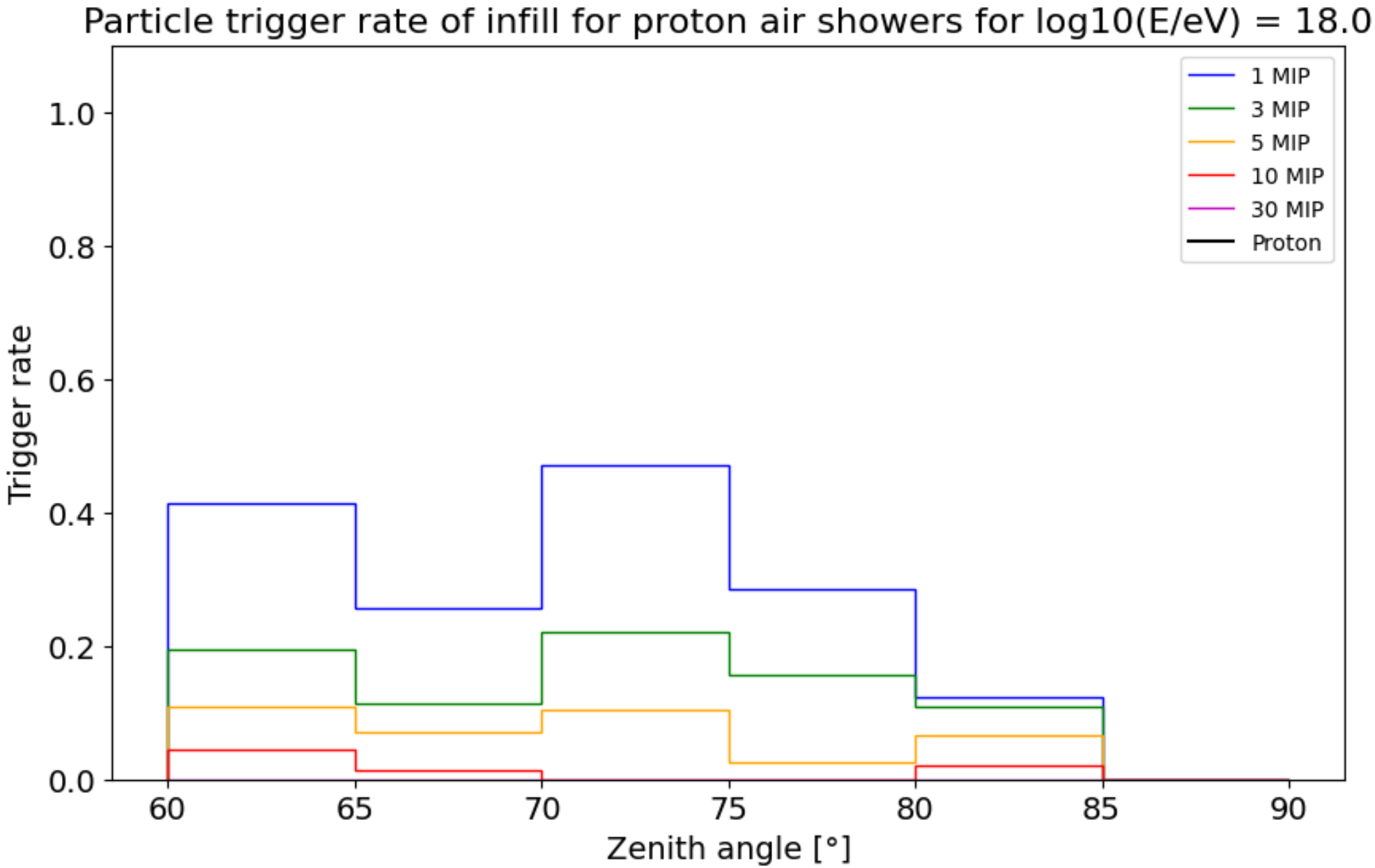
Comparison proton-gamma



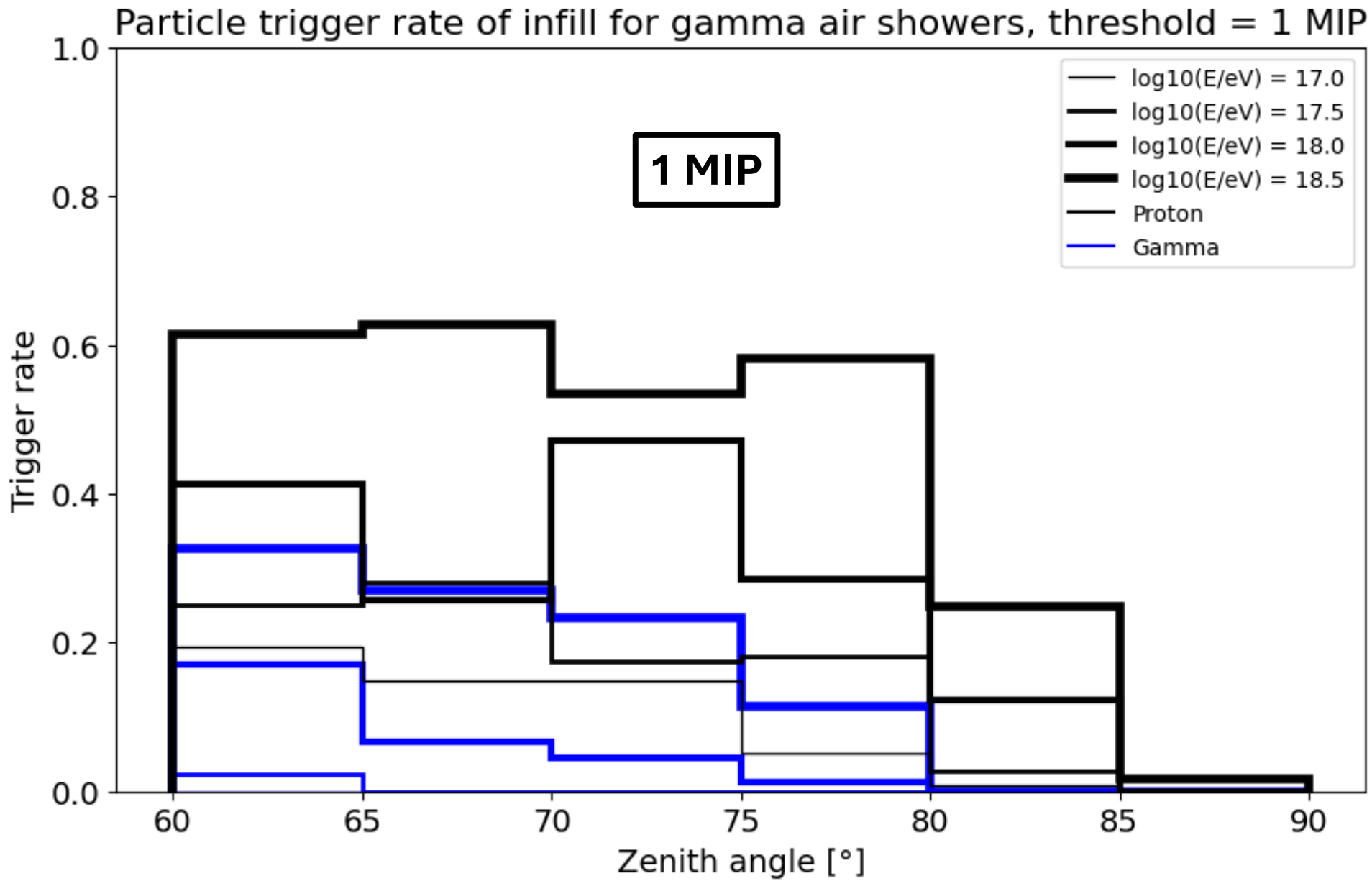


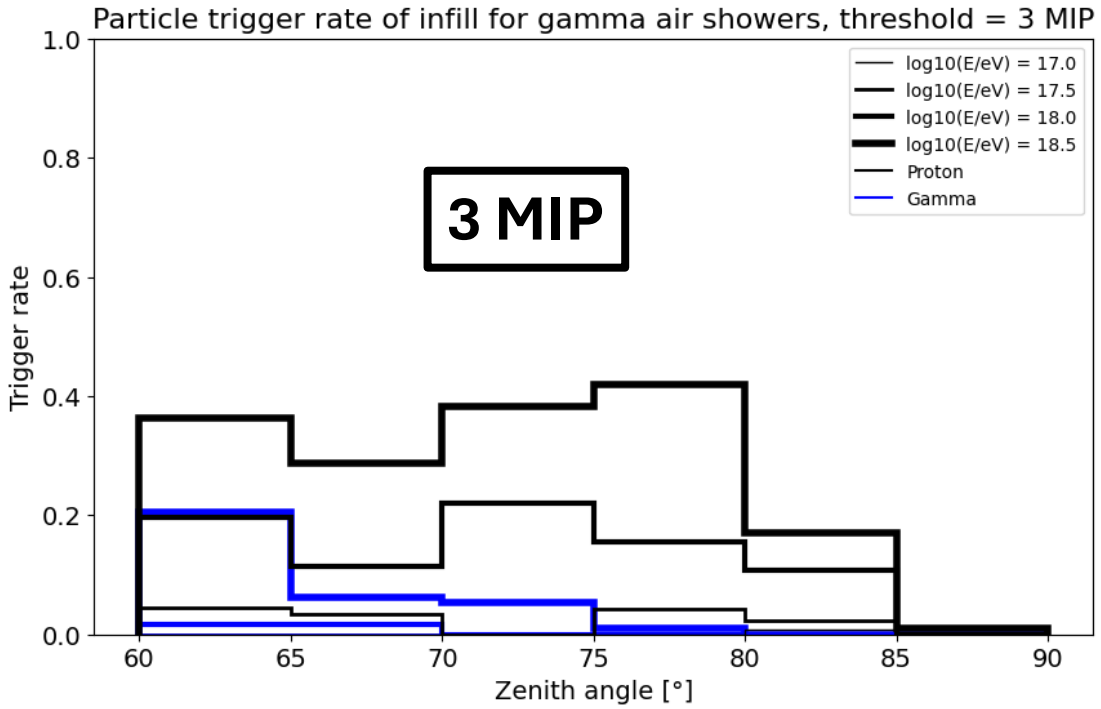
Optimal distinction between proton and gamma primaries seems to be for 5 MIP threshold for energies above 1 Eev and zenith angles between 70° and 85°.

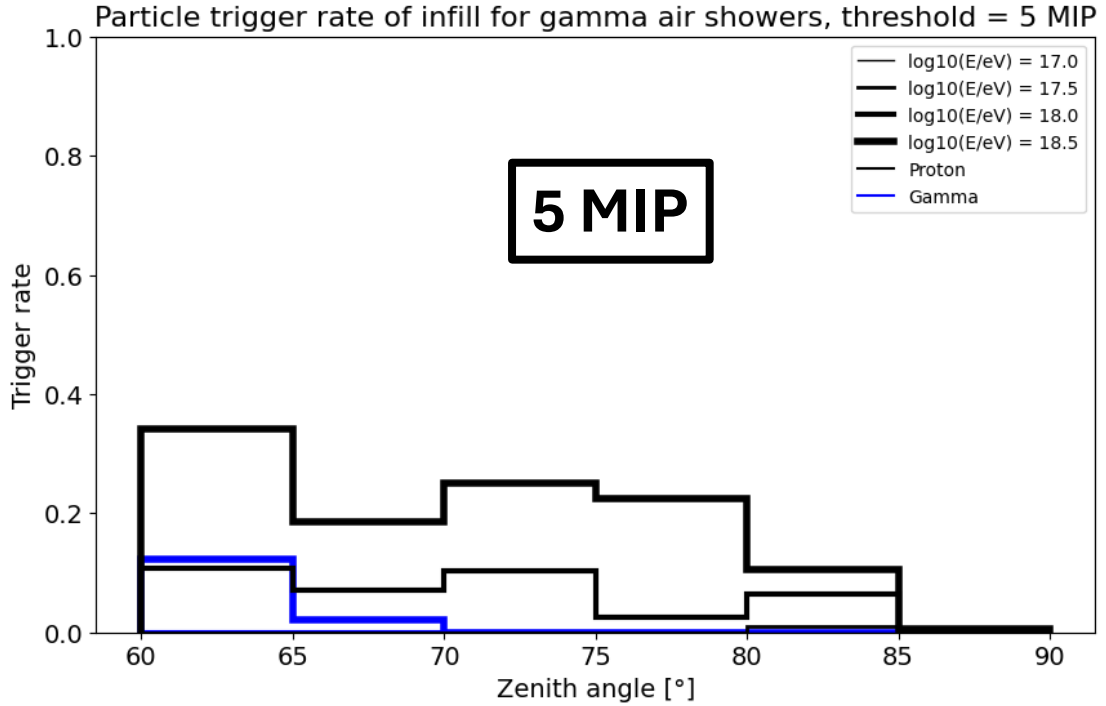
Variation of trigger rate with threshold (at E = 1EeV)

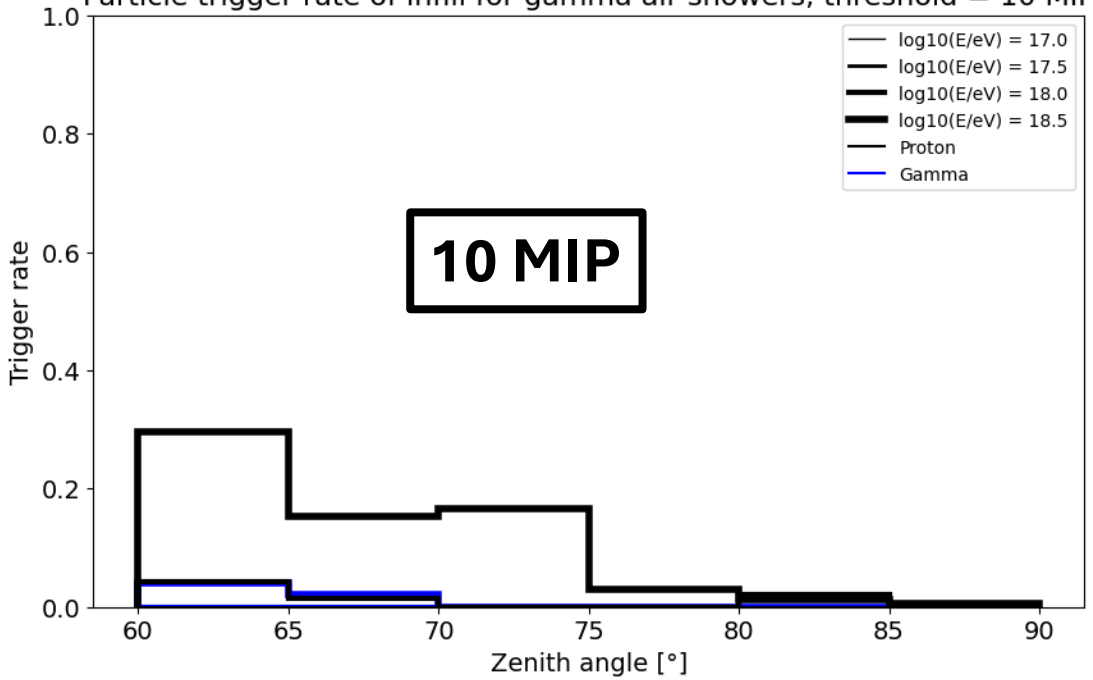


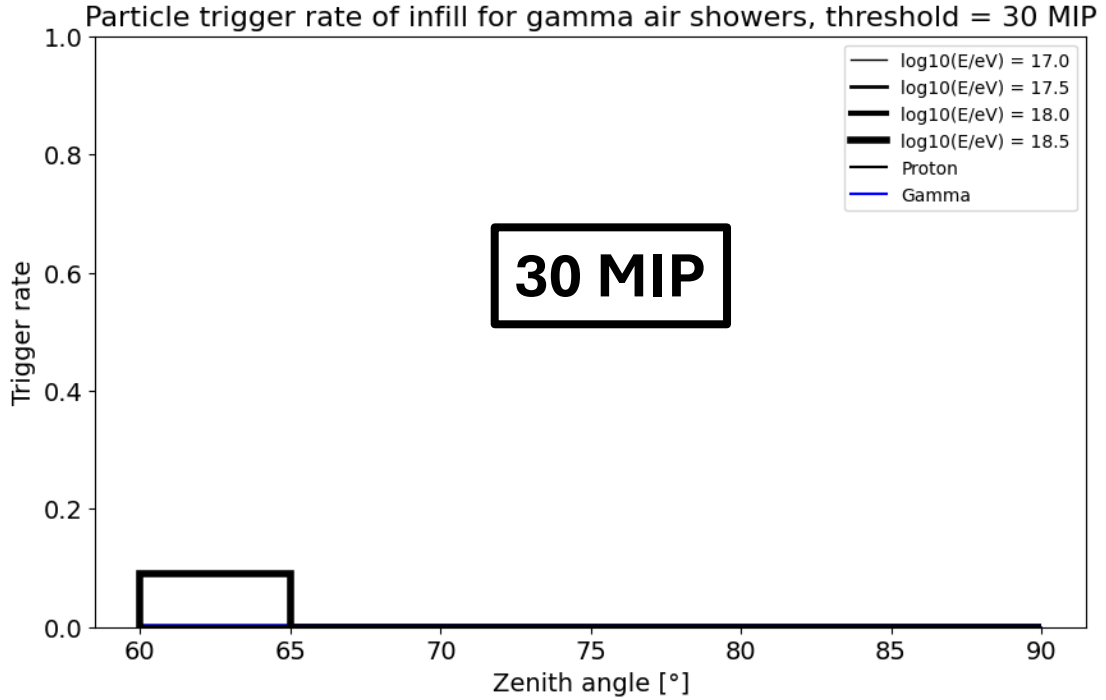
Comparison proton-gamma (2)



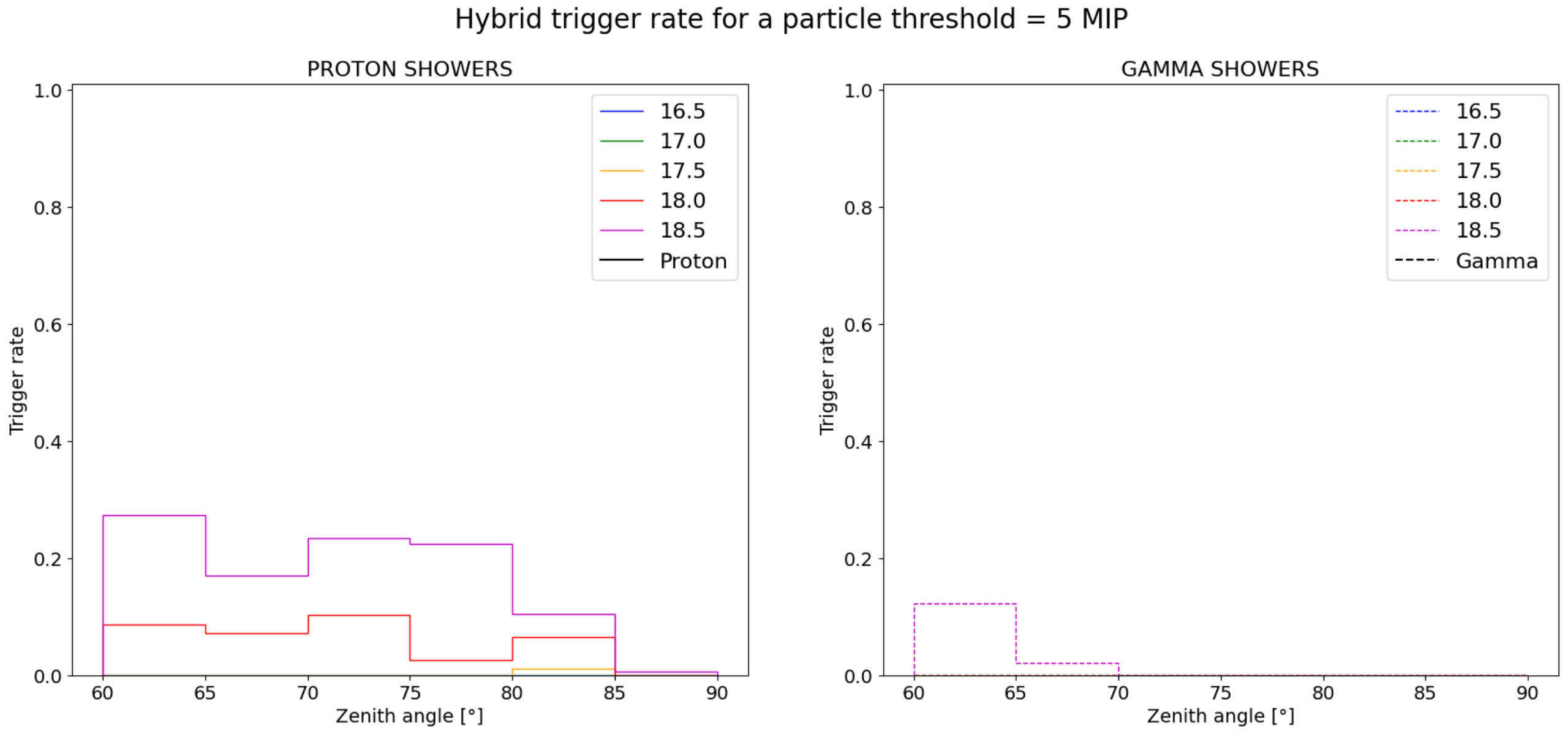

Particle trigger rate of infill for gamma air showers, threshold = 3 MIP
3 MIP
log10(E/eV) = 17.0
log10(E/eV) = 17.5
log10(E/eV) = 18.0
log10(E/eV) = 18.5
Proton
Gamma
Trigger rate
Zenith angle [°]


Particle trigger rate of infill for gamma air showers, threshold = 5 MIP
5 MIP
log10(E/eV) = 17.0
log10(E/eV) = 17.5
log10(E/eV) = 18.0
log10(E/eV) = 18.5
Proton
Gamma
Trigger rate
Zenith angle [°]


Particle trigger rate of infill for gamma air showers, threshold = 10 MIP
10 MIP
log10(E/eV) = 17.0
log10(E/eV) = 17.5
log10(E/eV) = 18.0
log10(E/eV) = 18.5
Proton
Gamma
Trigger rate
Zenith angle [°]


Particle trigger rate of infill for gamma air showers, threshold = 30 MIP
30 MIP
log10(E/eV) = 17.0
log10(E/eV) = 17.5
log10(E/eV) = 18.0
log10(E/eV) = 18.5
Proton
Gamma
Trigger rate
Zenith angle [°]

New plots: hybrid trigger rate with MIP threshold



New plots: conditional trigger rate with MIP threshold