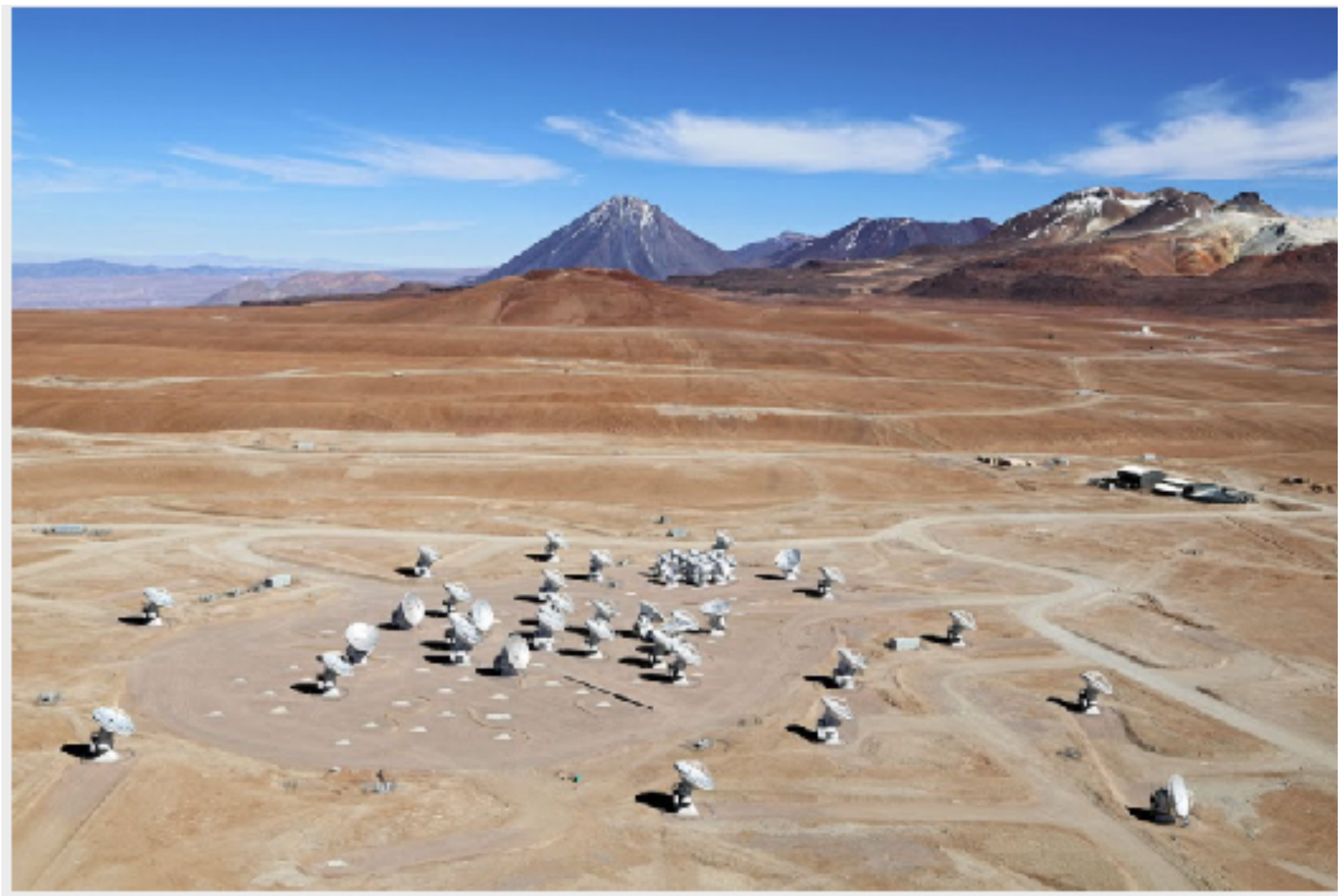
Fundamental drivers for the design of a ground-particle based gamma ray observatory



Harm Schoorlemmer, Ruben Lopez-Coto, Jim Hinton, Vikas Joshi, Armelle Jardin-Blicq, Pooja Surajbali, Werner Hoffman

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

Air shower physics

"Kicking in some open doors"

Detector design and performance choices

Recommendations / discussion

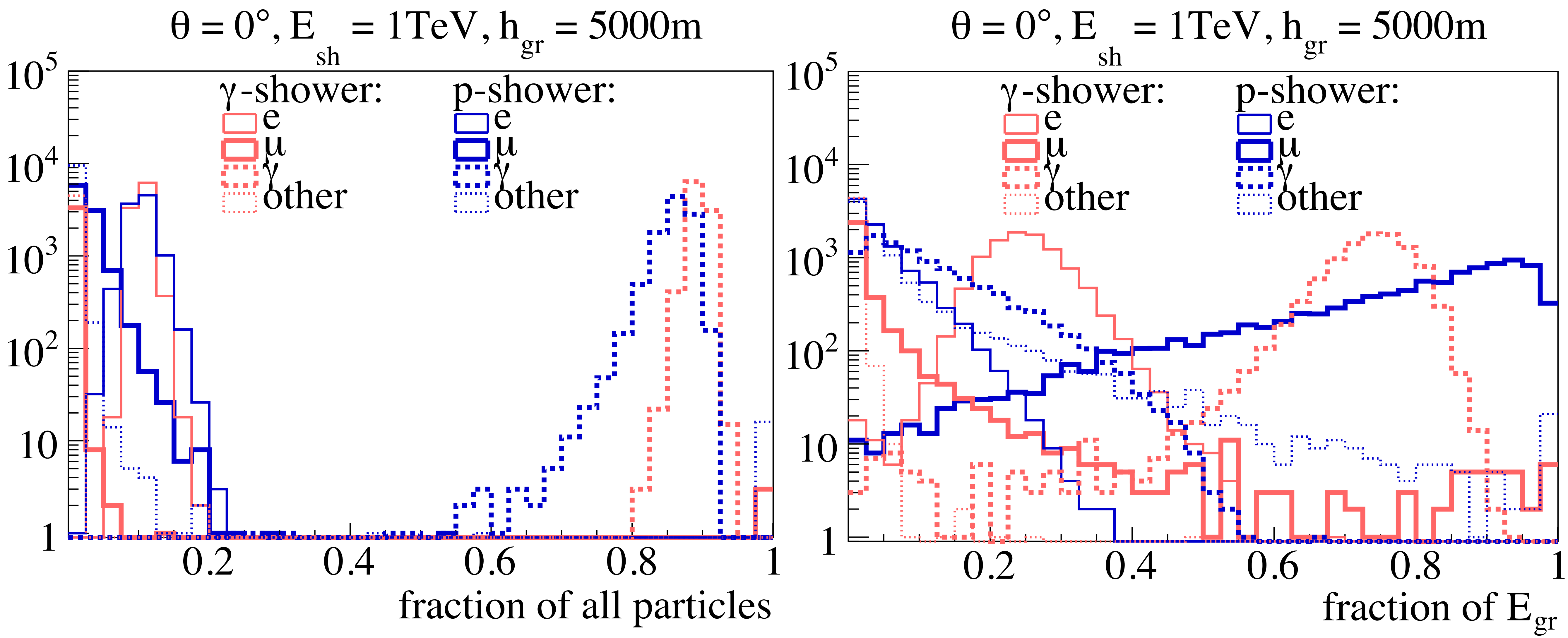
Air shower physics

Study based on CORSIKA simulations:

1) Ground altitudes 3900m - 6000m
2) Zenith angles: 0° - 50°
3) Energy range: 50 - 5000 GeV
4) Particles: **gammas** and **protons** (no B)

Air shower physics

What reaches the ground?



We only care about: e±, μ±,**γ**

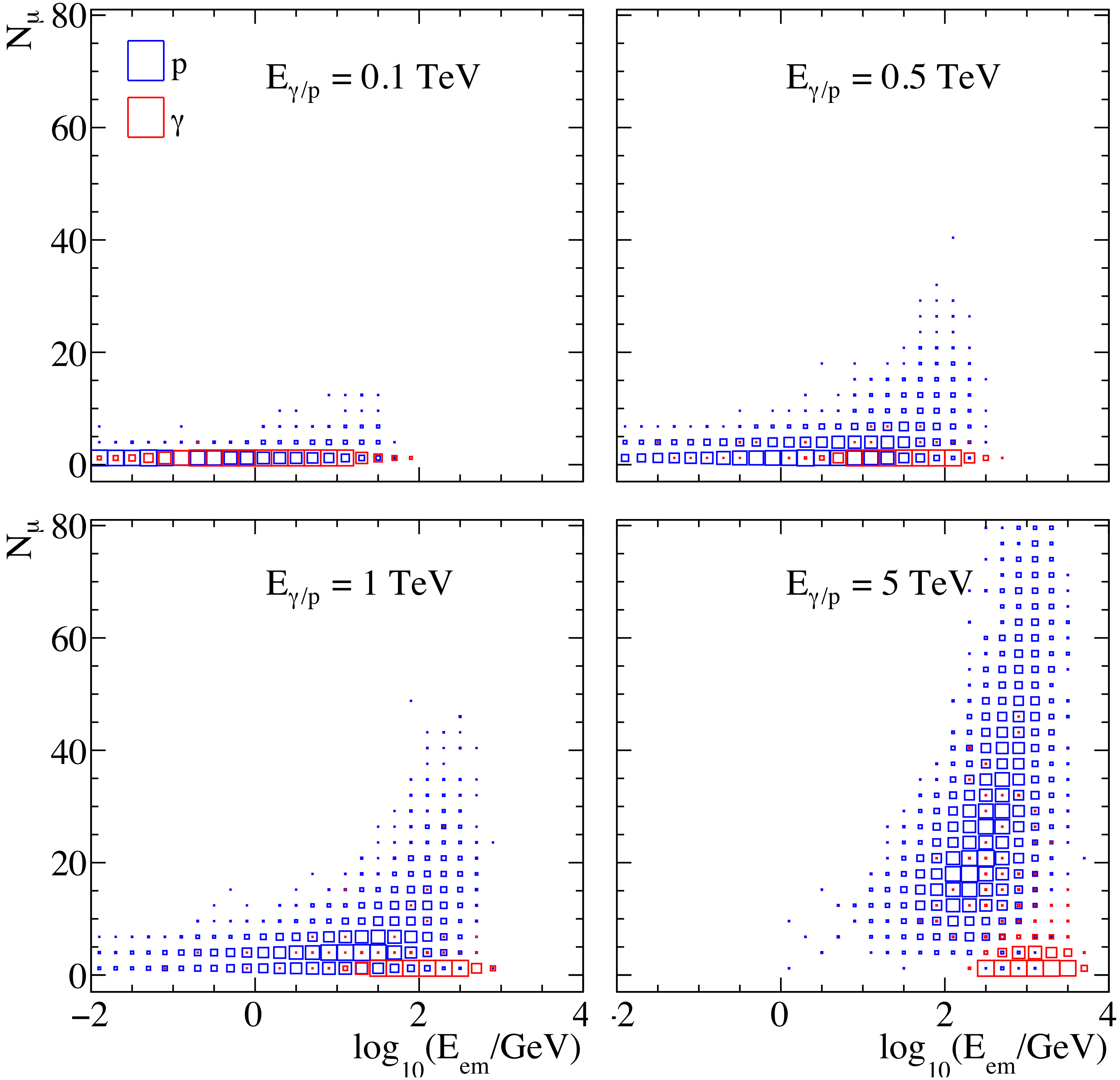
In **γ** induced showers ~80% of the energy goes into **γ**'s

In **p** induced showers most of the energy in a few muons

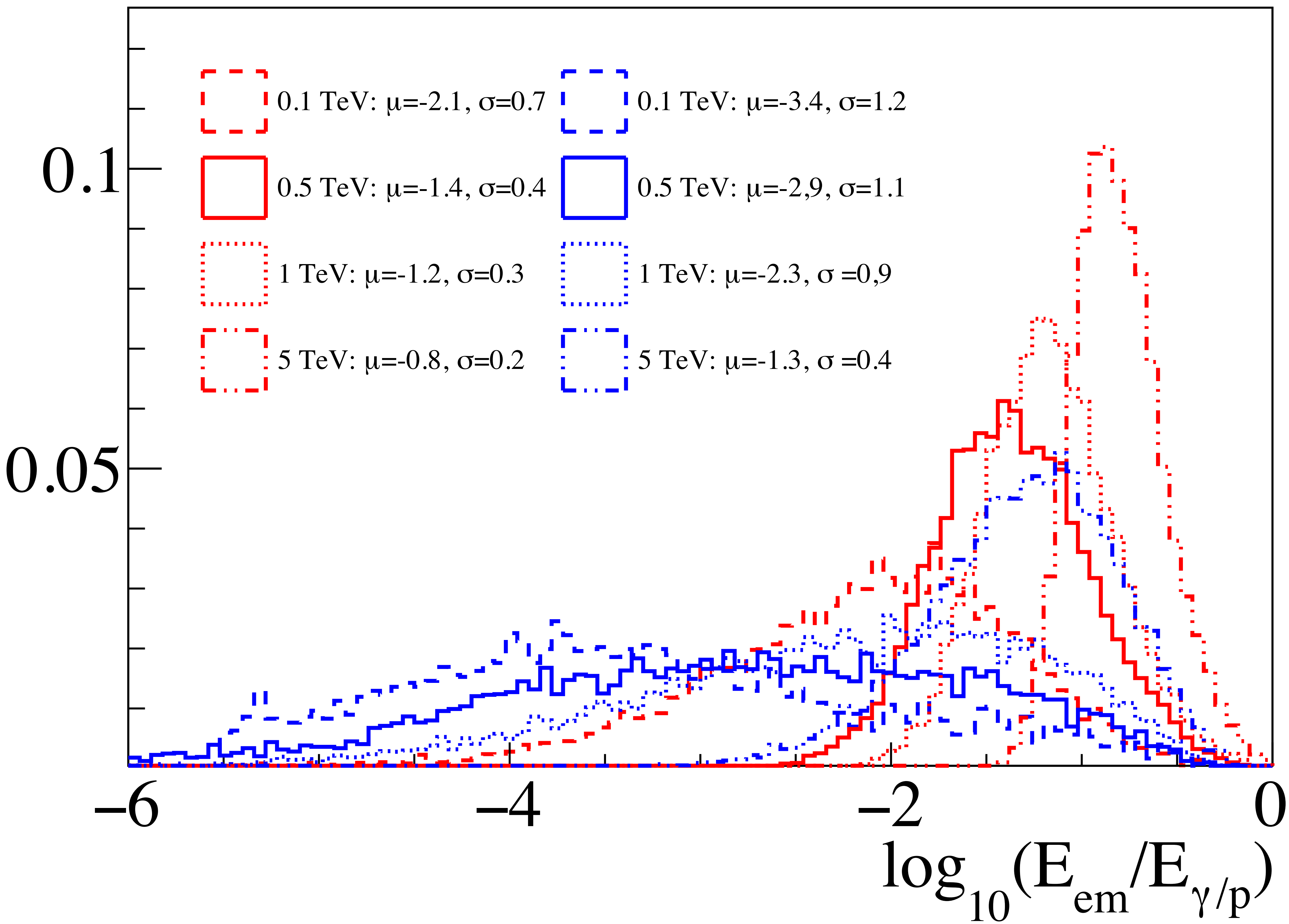
Air shower physics

Muons:
- Gamma / Hadron Separation

Electromagnetic Energy on ground:
- Is different for p/γ with the same energy

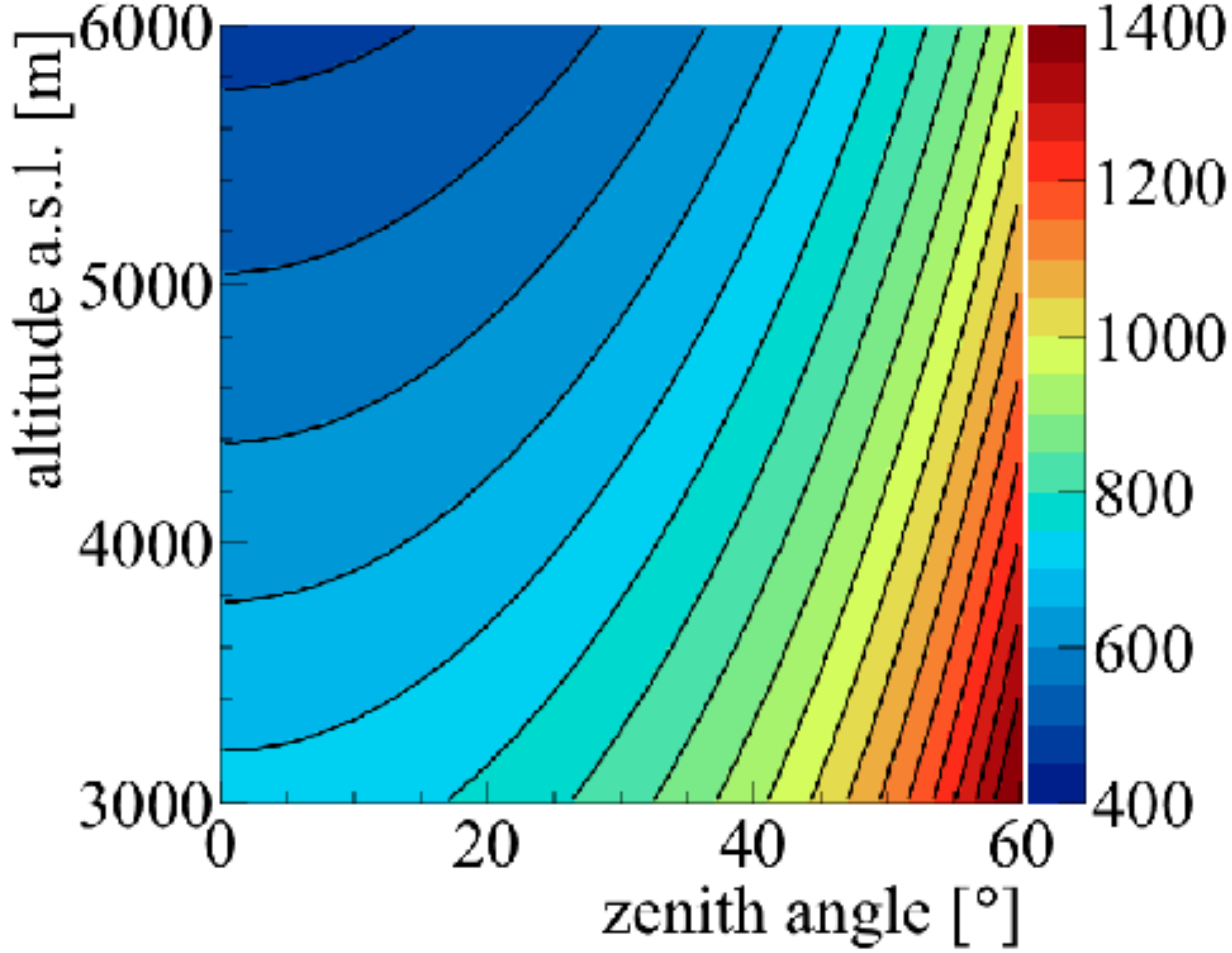


Air shower physics

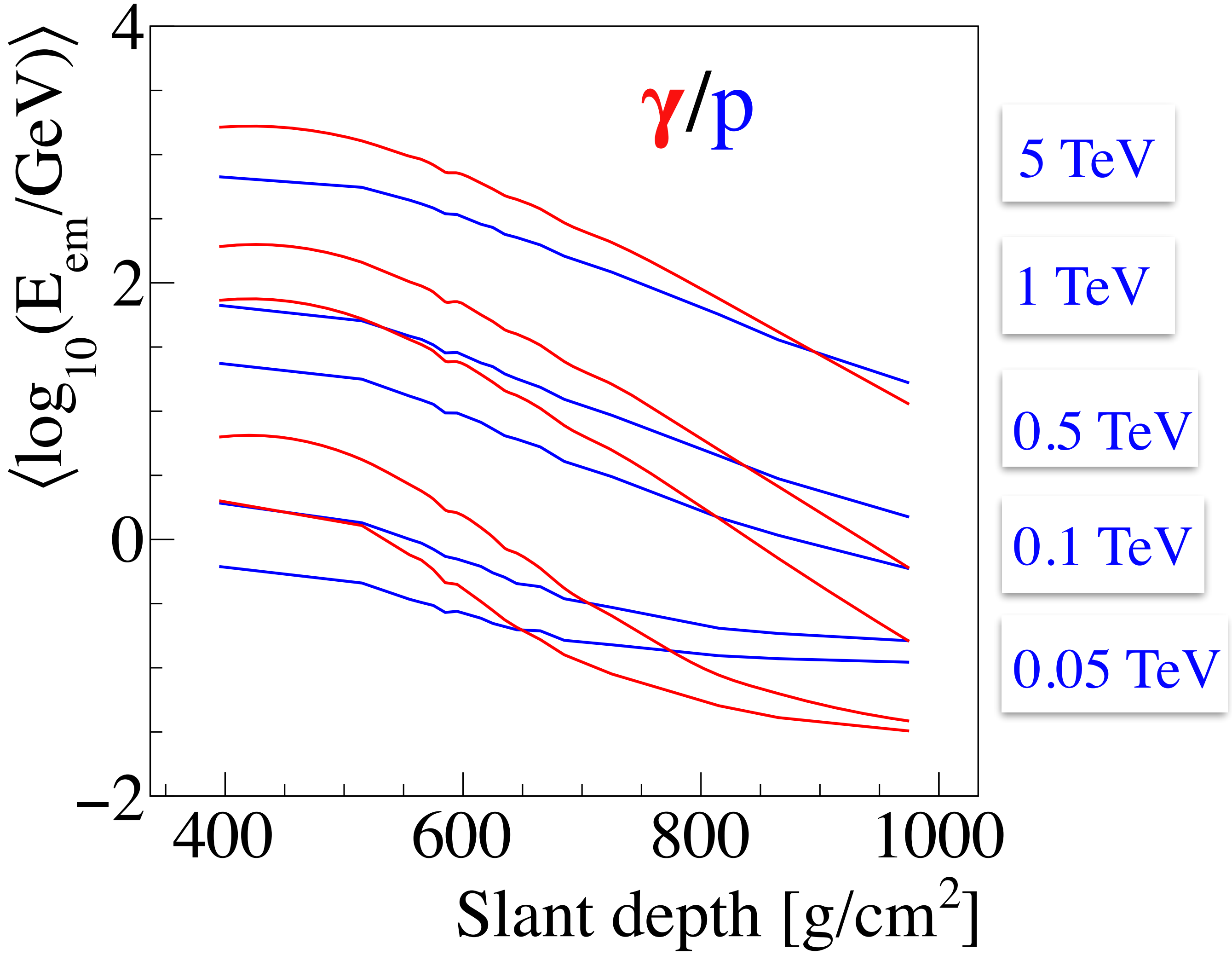


Air shower physics

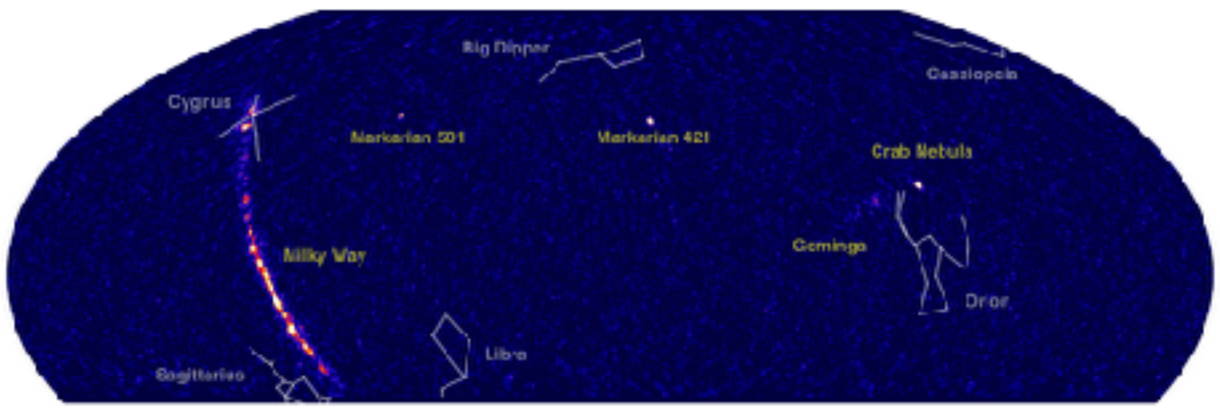
Slant depth [g / cm²]



Slant depth [g / cm²]

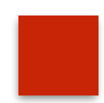


Funding = Science / Money

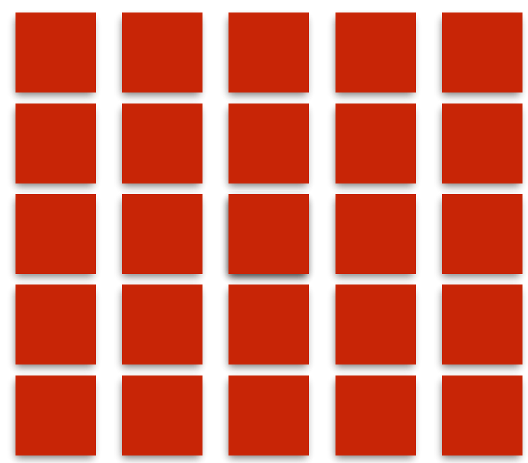


$$\propto \frac{N_s}{\sqrt{N_B \eta_B \delta_{68}^2}}$$

A detector unit

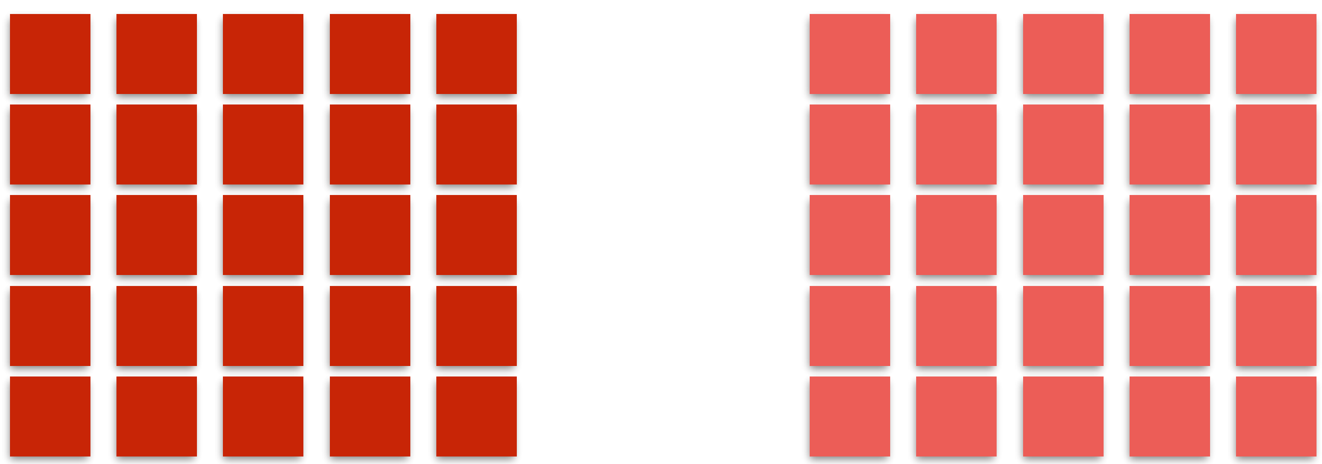


A detector array



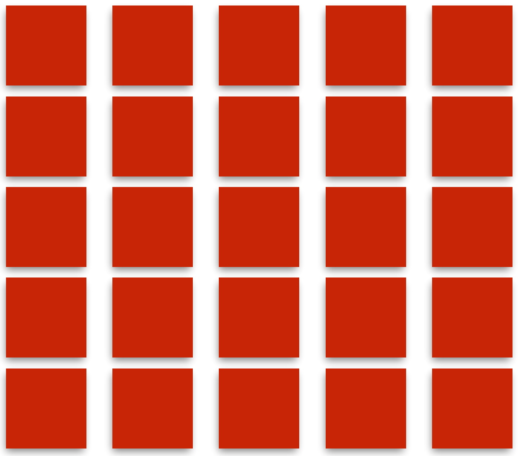
$$\propto \quad N$$

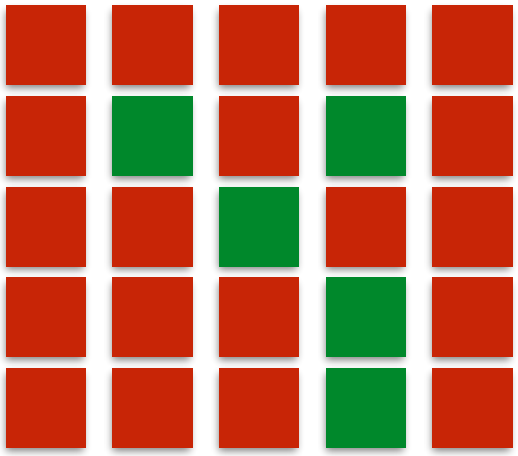
Energy threshold



$\propto$ sensor size, detection medium

Trigger multiplicity threshold

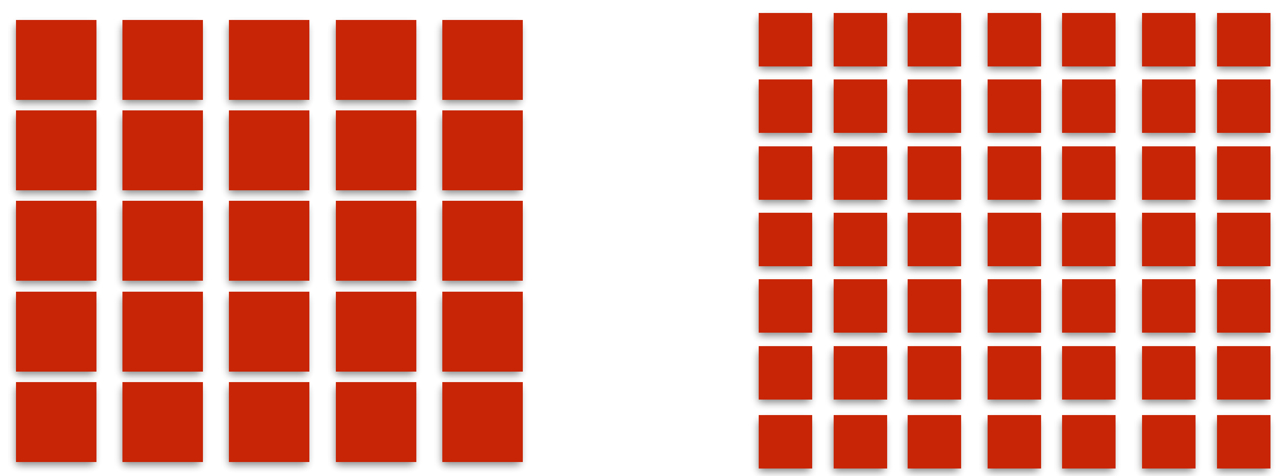




$\propto$

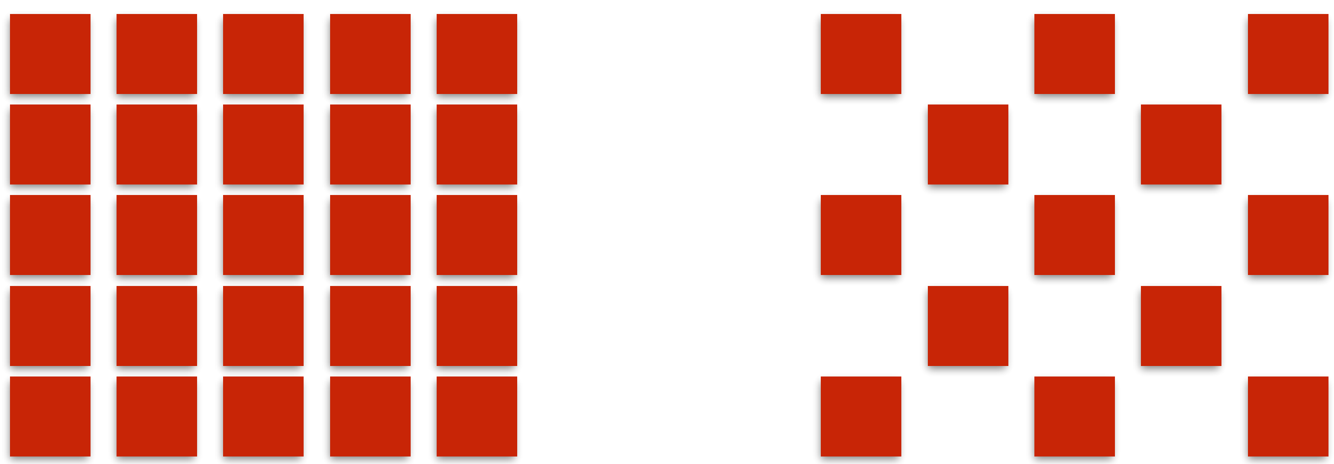
OR
AND

Unit size



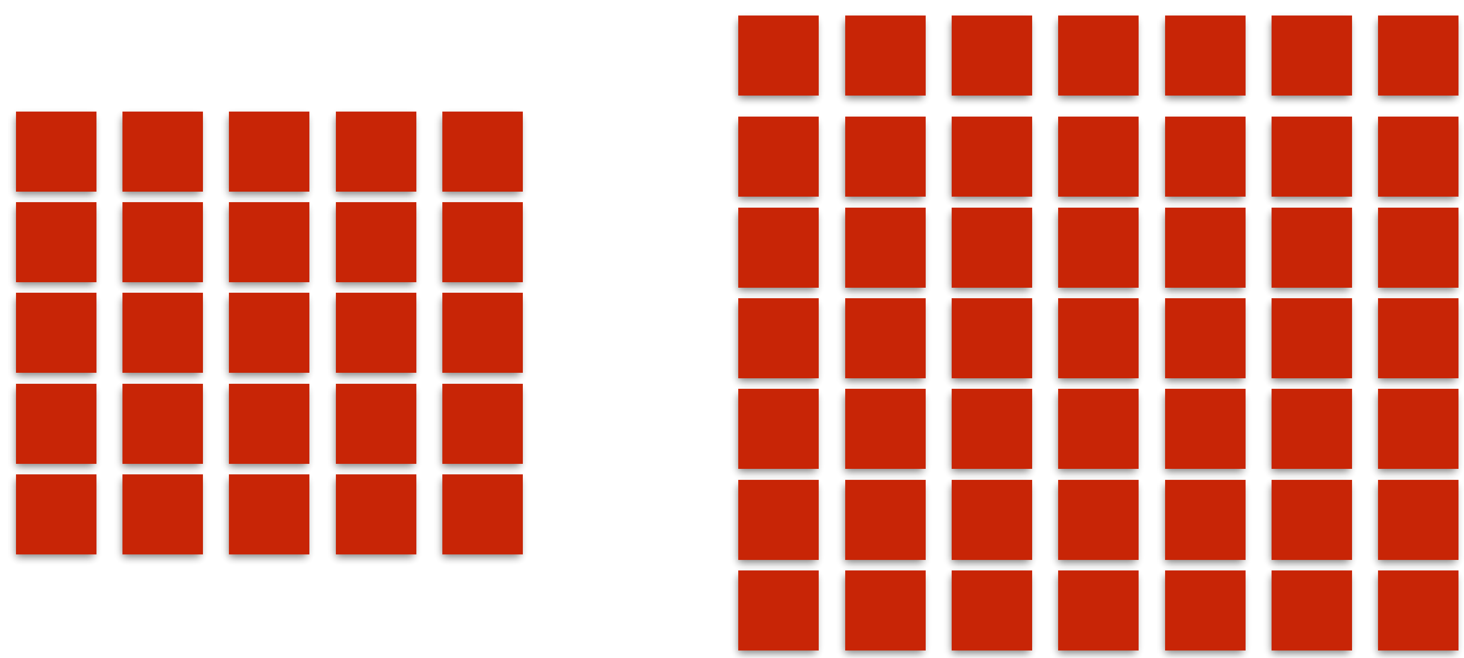
$$\propto \quad (1-\epsilon)N$$

Unit density



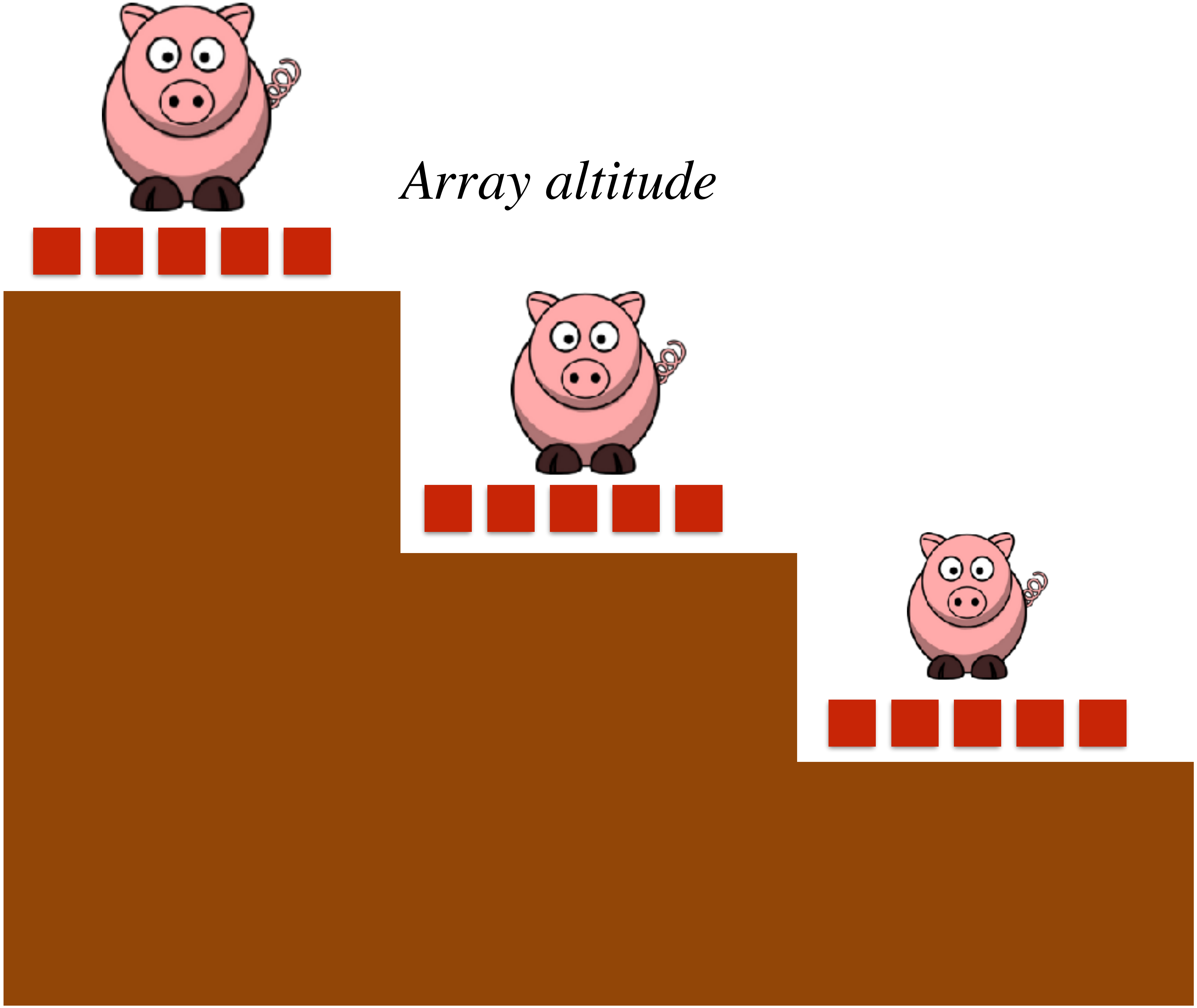
$$\propto \quad N$$

Array size



$$\propto \quad N$$

Array altitude



A reference observatory

Altitude = 5000m

Fill Factor = 1

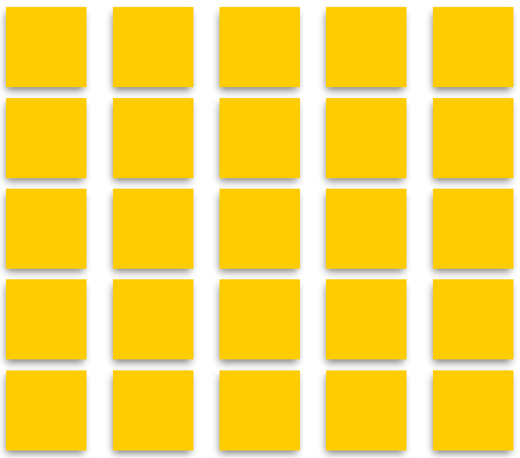
Unit size = 4m x 4m

Array size = 200m x 200m

Unit Energy Threshold = 10 MeV

Trigger Multiplicity > 3

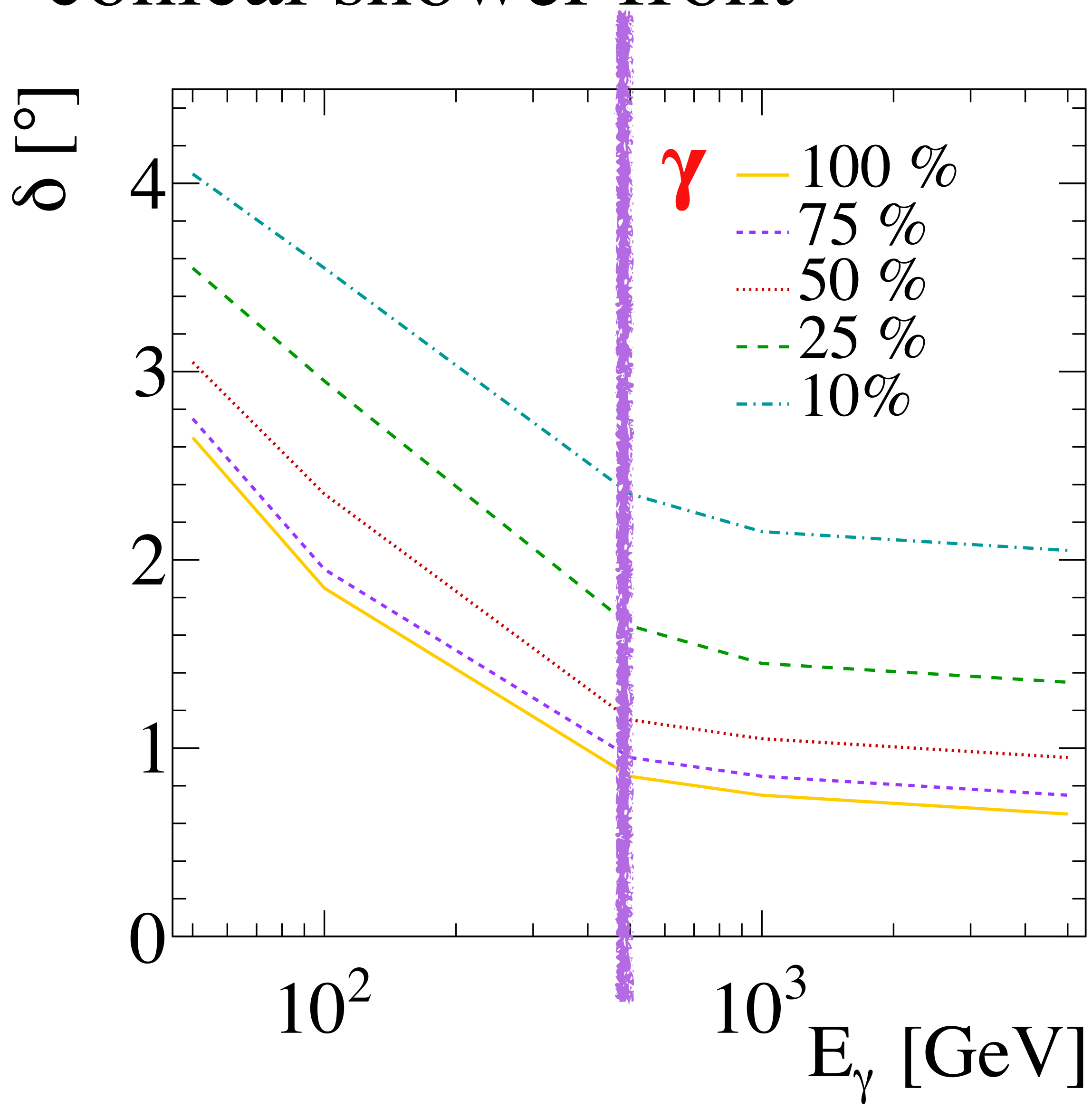
Events from zenith on the array and uniformly distributed on array



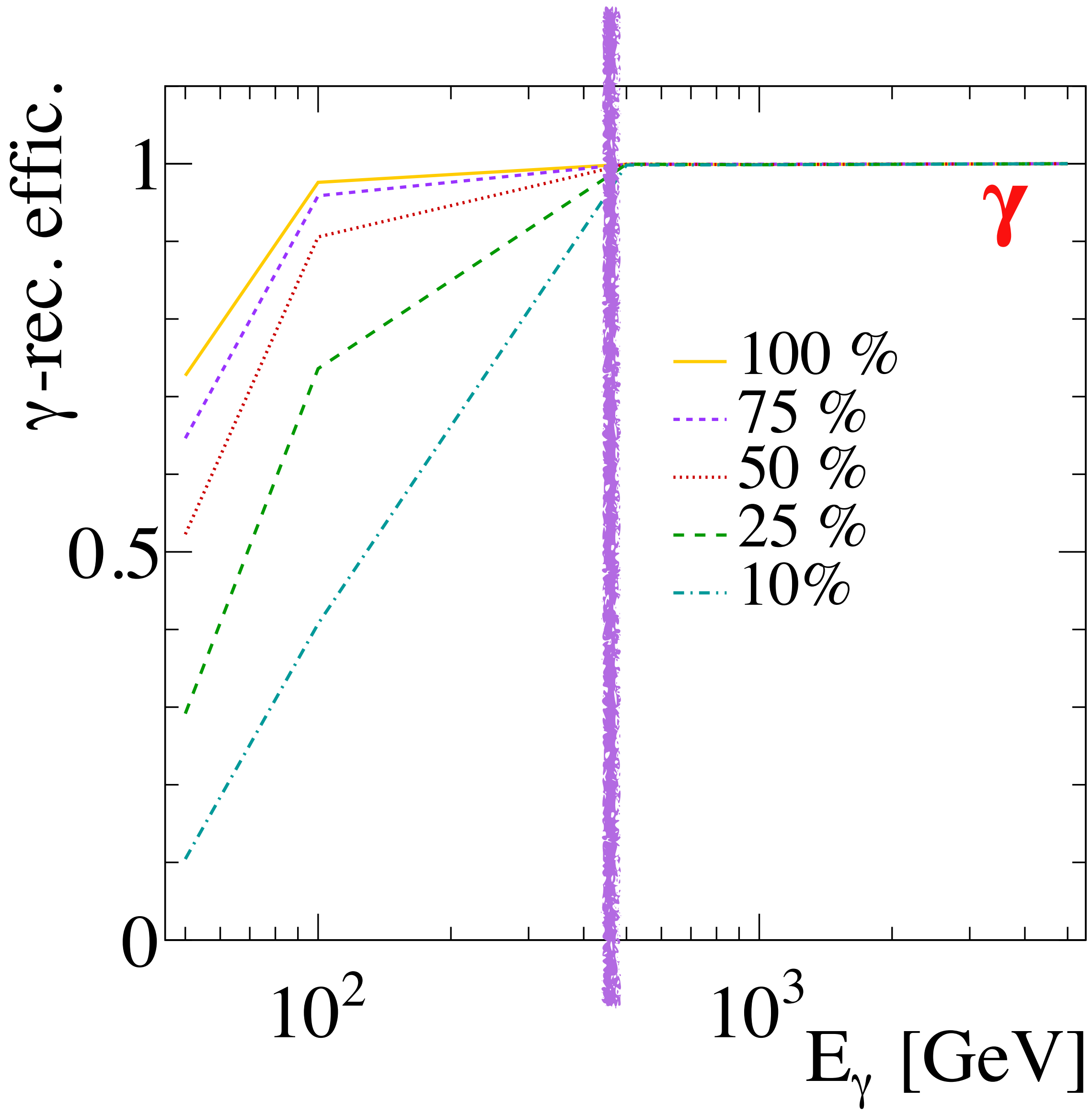
Assumed: Muon counter array + perfect EM-calorimeter of same dimensions

Unit density

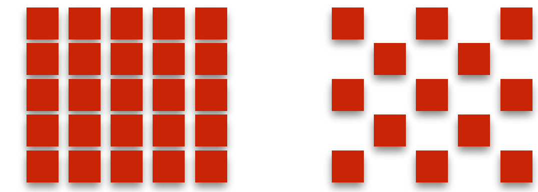
“Simple Angular reconstruction” conical shower front

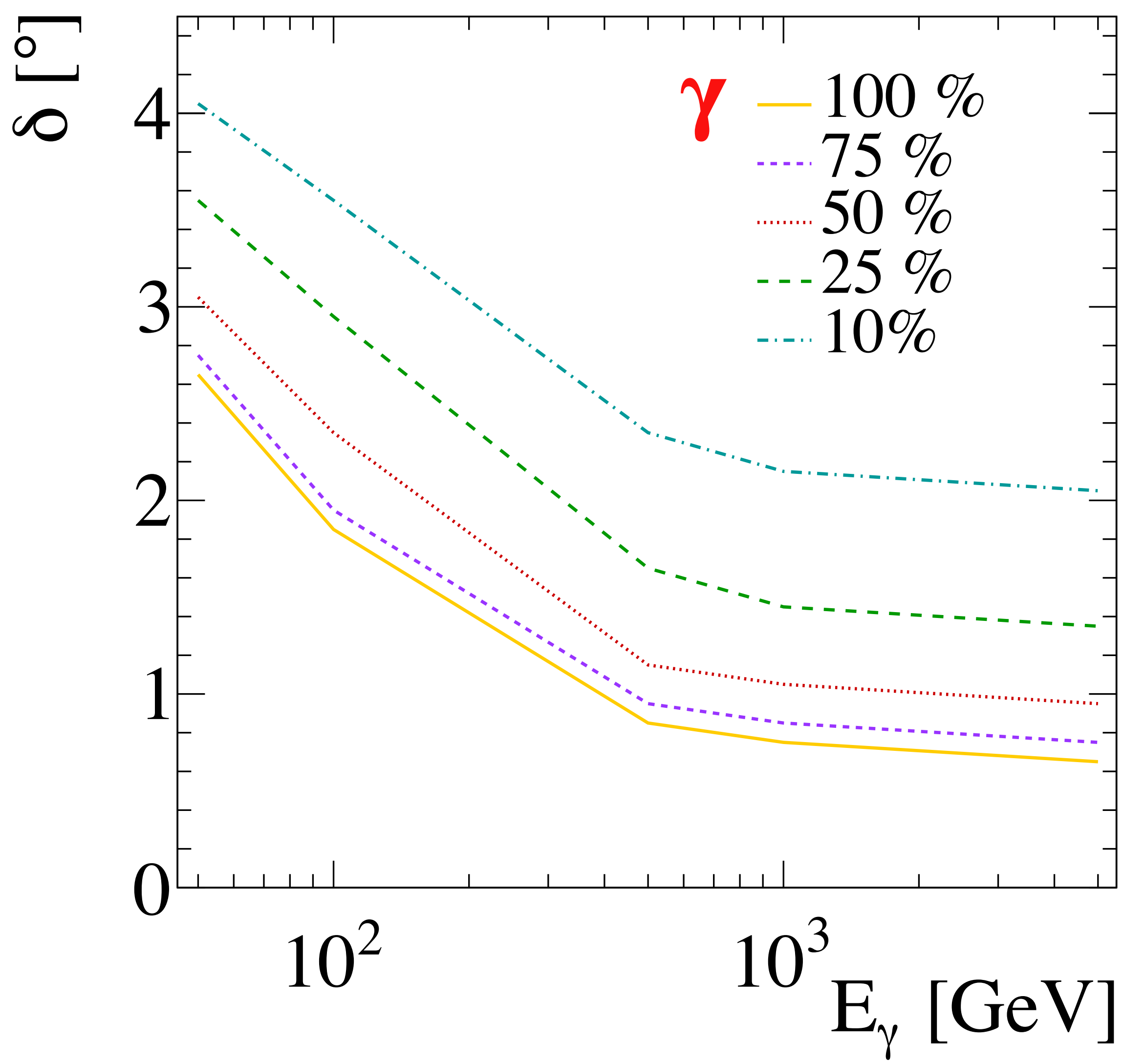


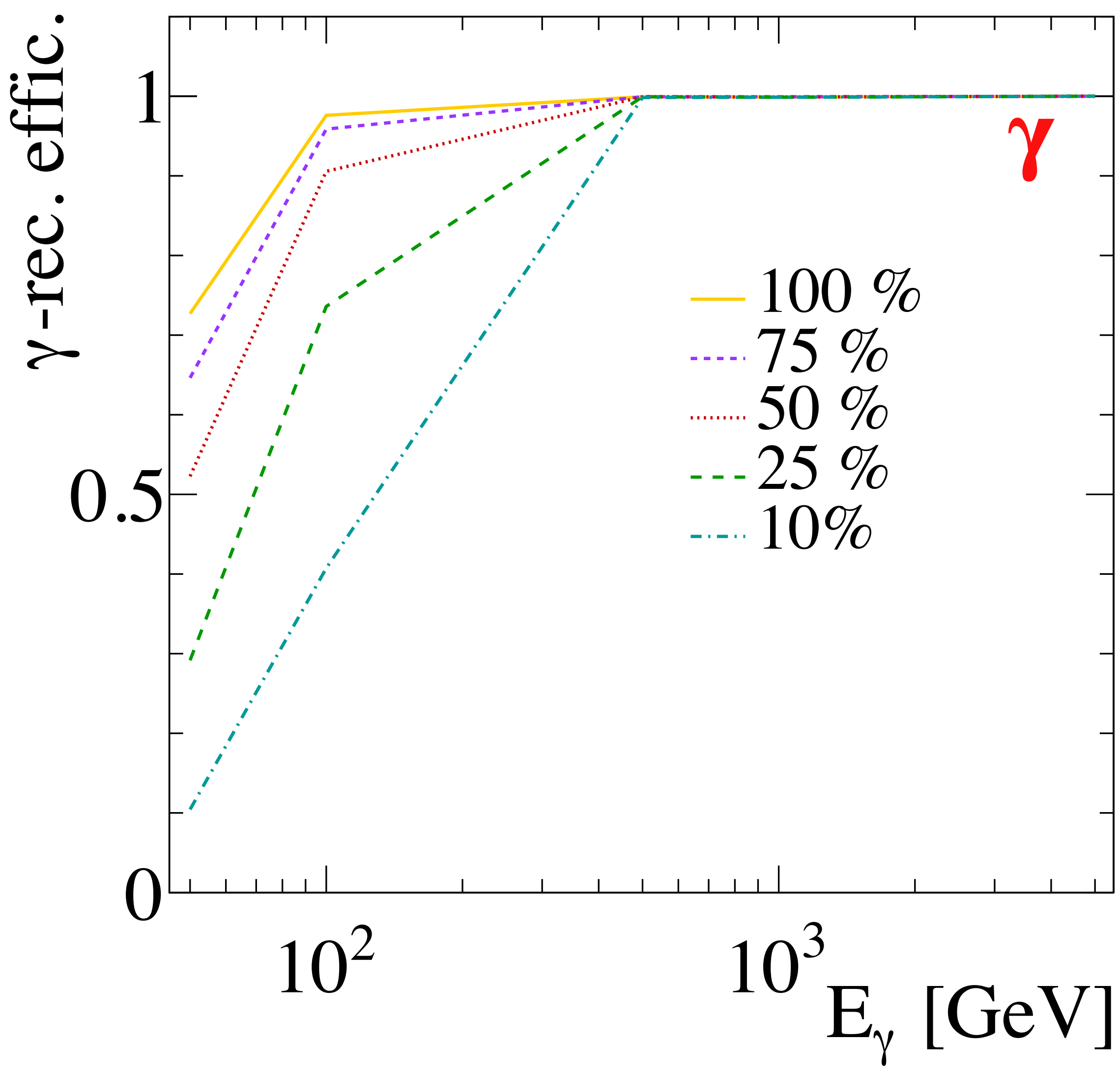
“Events failing simple fit…”



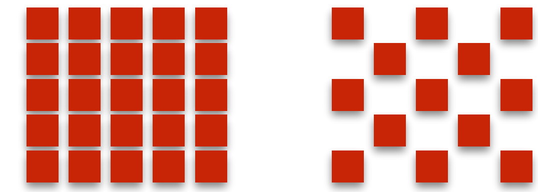
Unit density







Unit density

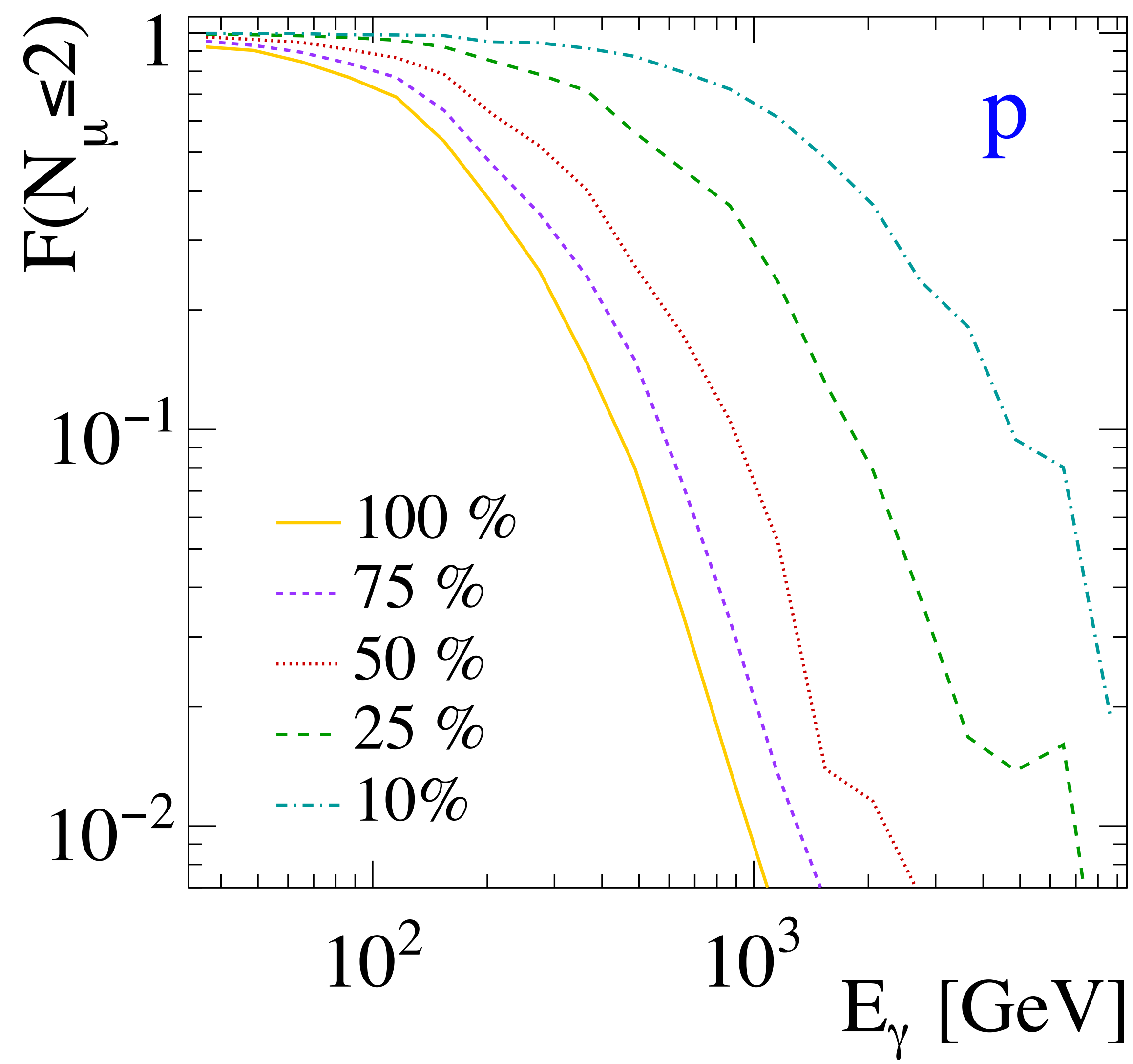


"Naive Gamma hadron separation": $N_\mu \geq 2$

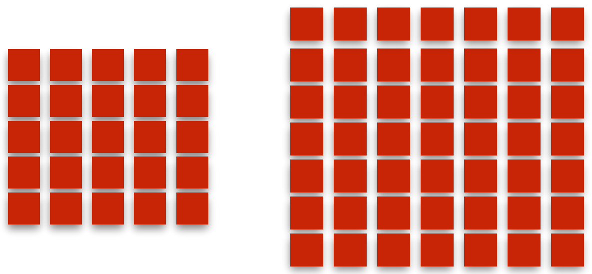
$$\frac{N_s}{\sqrt{N_B \eta_B \delta_{68}^2}}$$

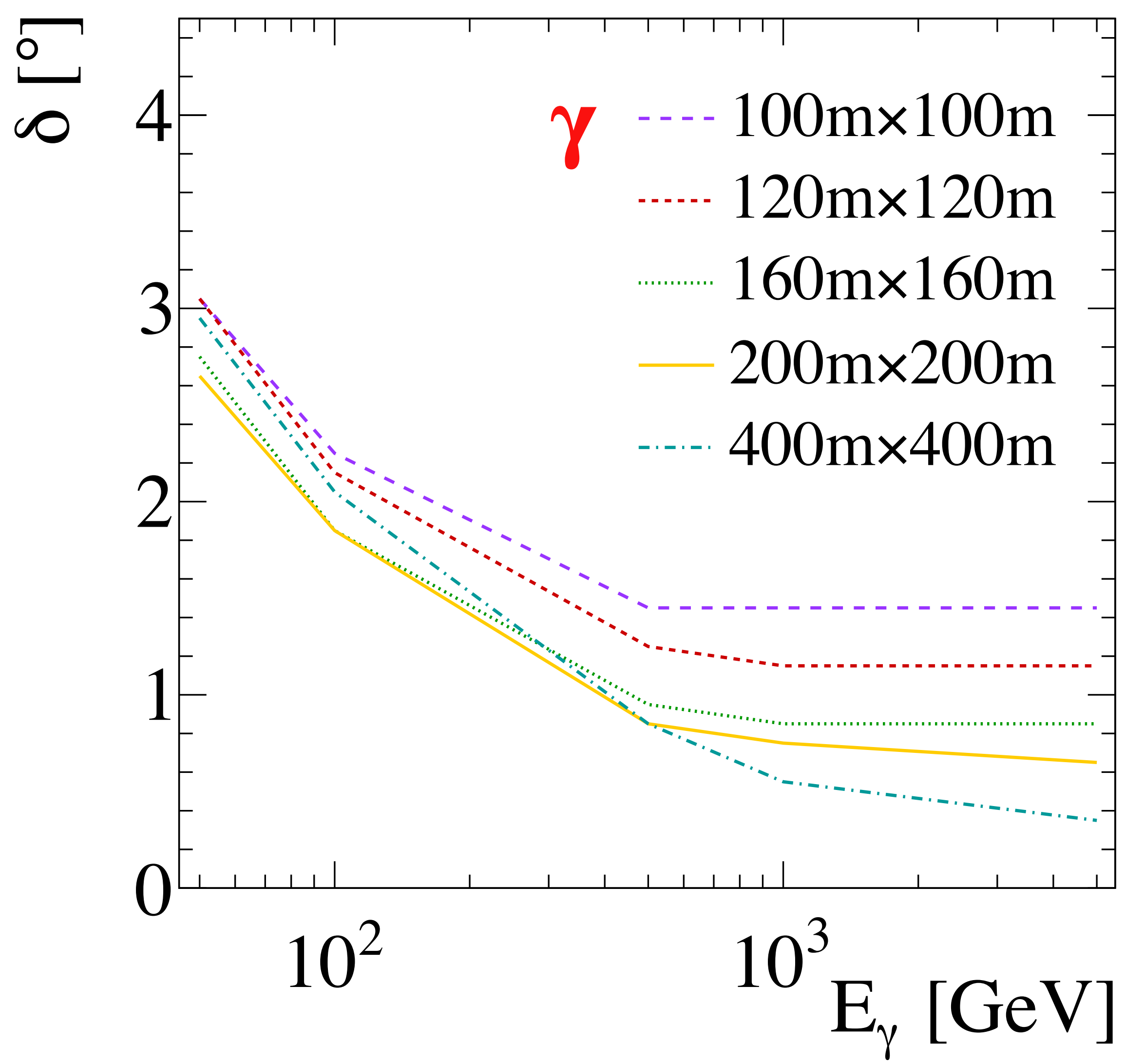
Comparing fill factor 50% at 500 GeV to **reference** you gain:

0.375

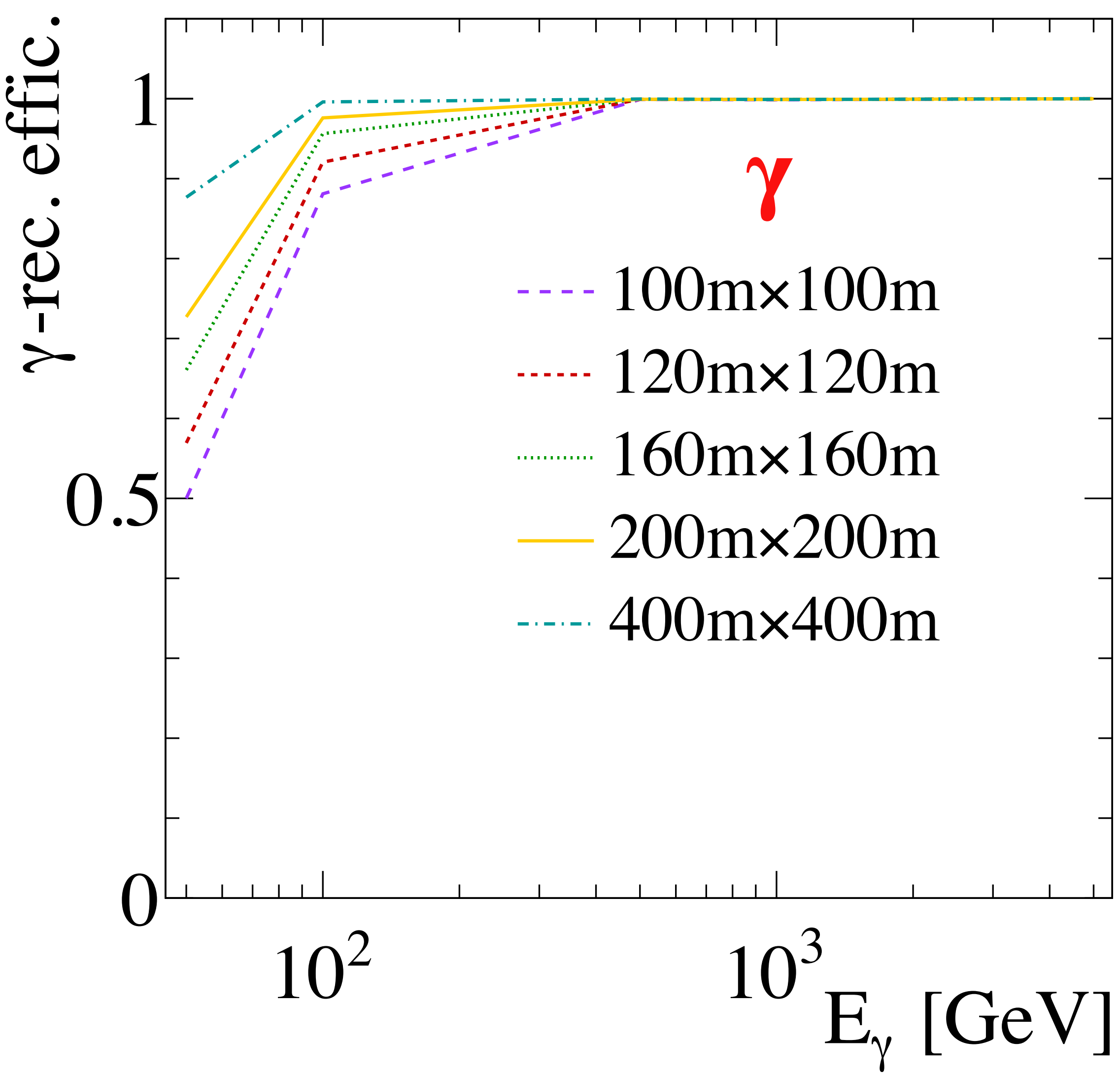


Array size



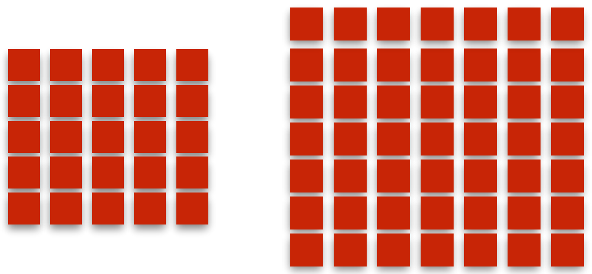


δ [°]
γ
100m×100m
120m×120m
160m×160m
200m×200m
400m×400m
0
1
2
3
4
10^2
10^3
E_γ [GeV]



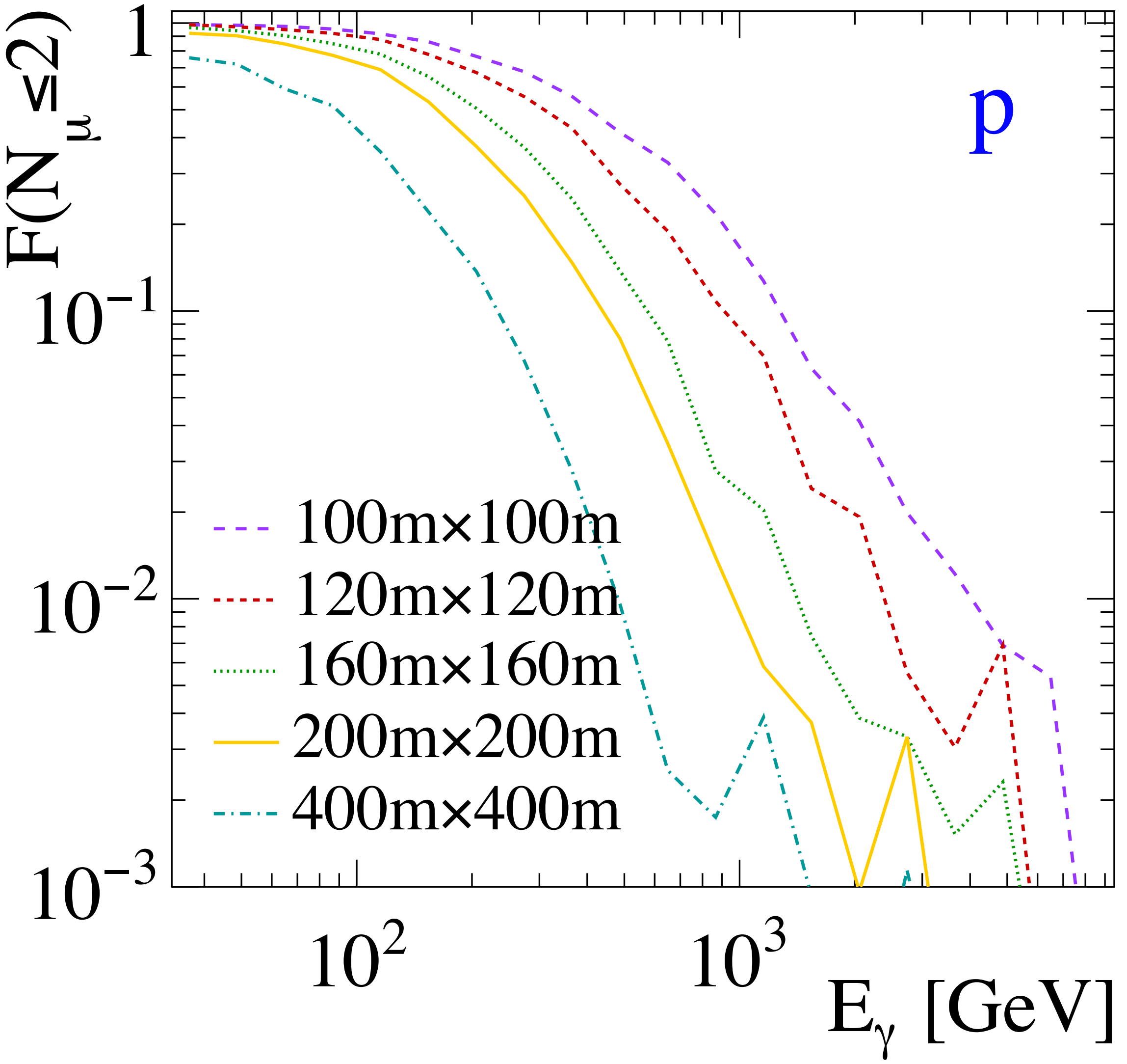
γ-rec. effic.
γ
100m×100m
120m×120m
160m×160m
200m×200m
400m×400m
0
0.5
1
10^2
10^3
E_γ [GeV]

Array size

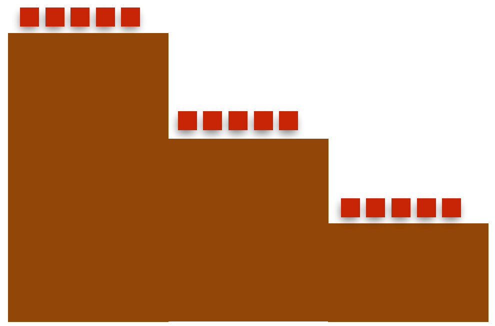


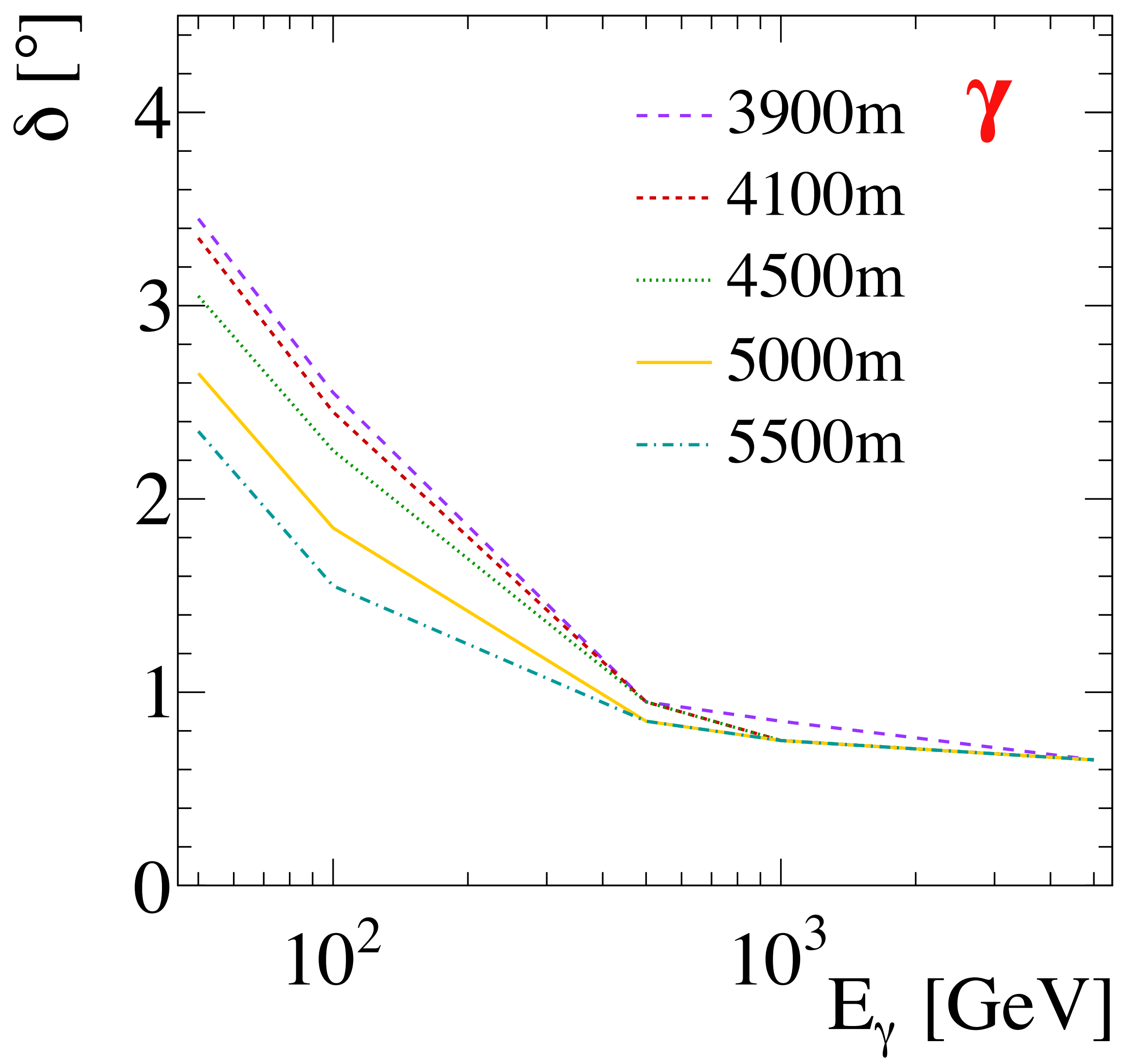
Comparing area of 120mx120m at 500 GeV to reference you gain:

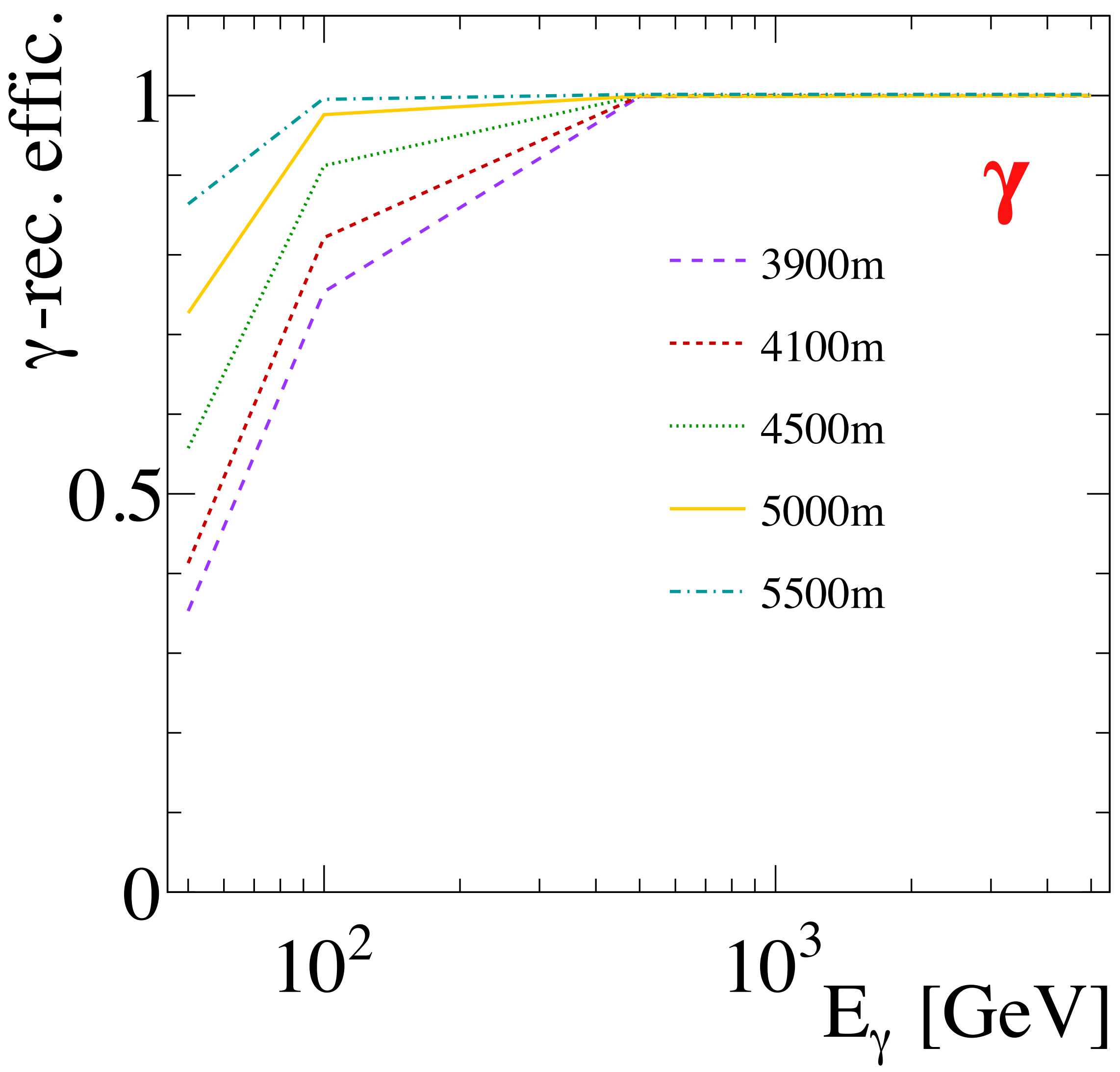
0.375



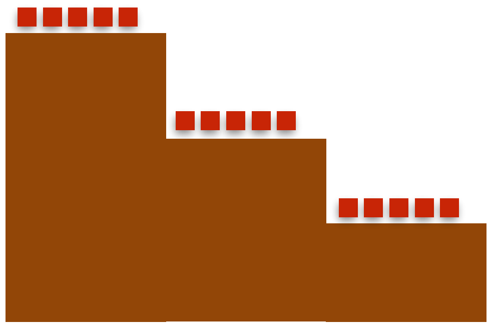
Array altitude





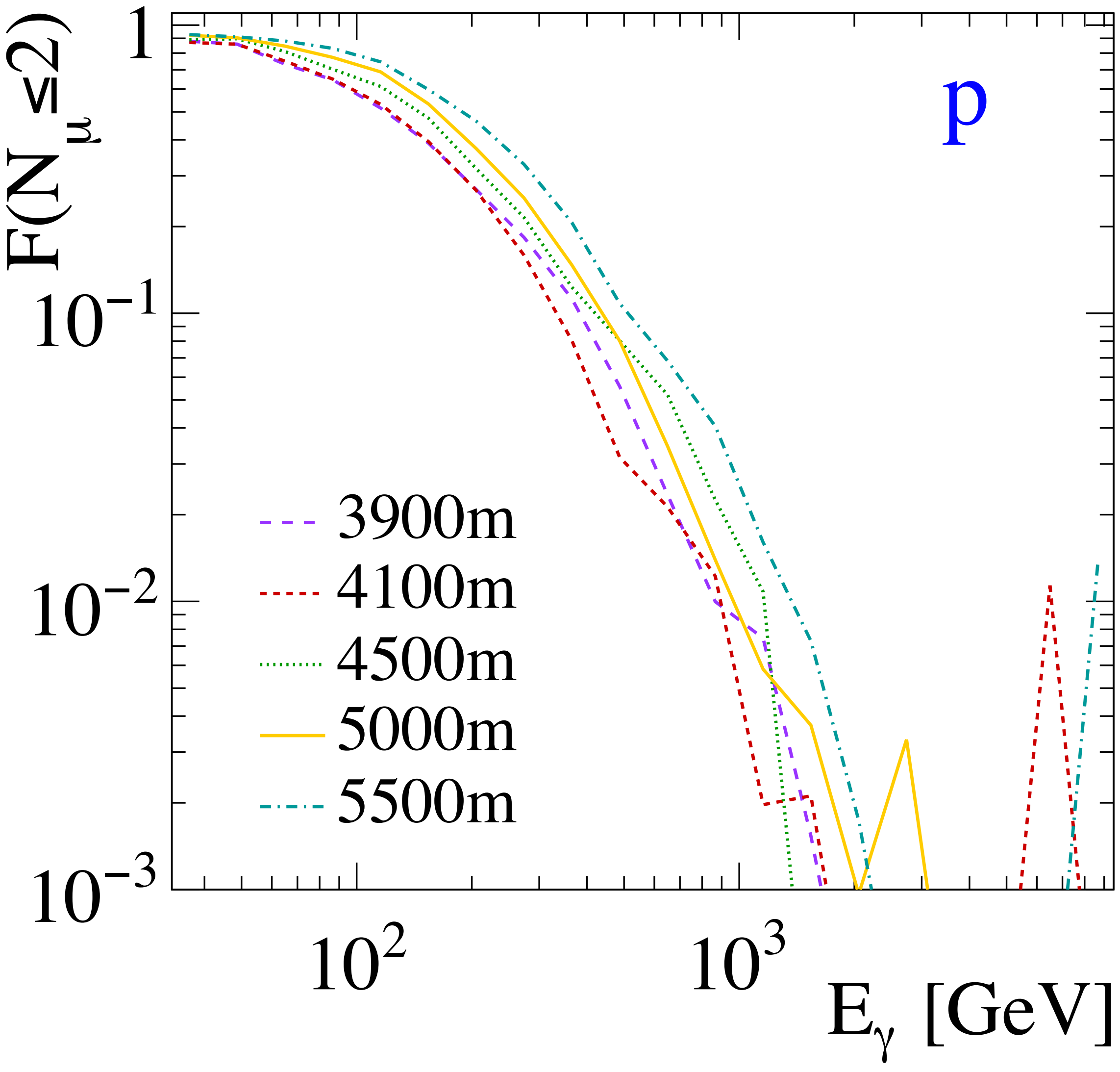


Array altitude

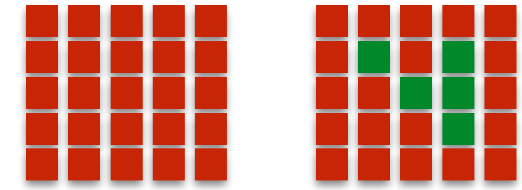


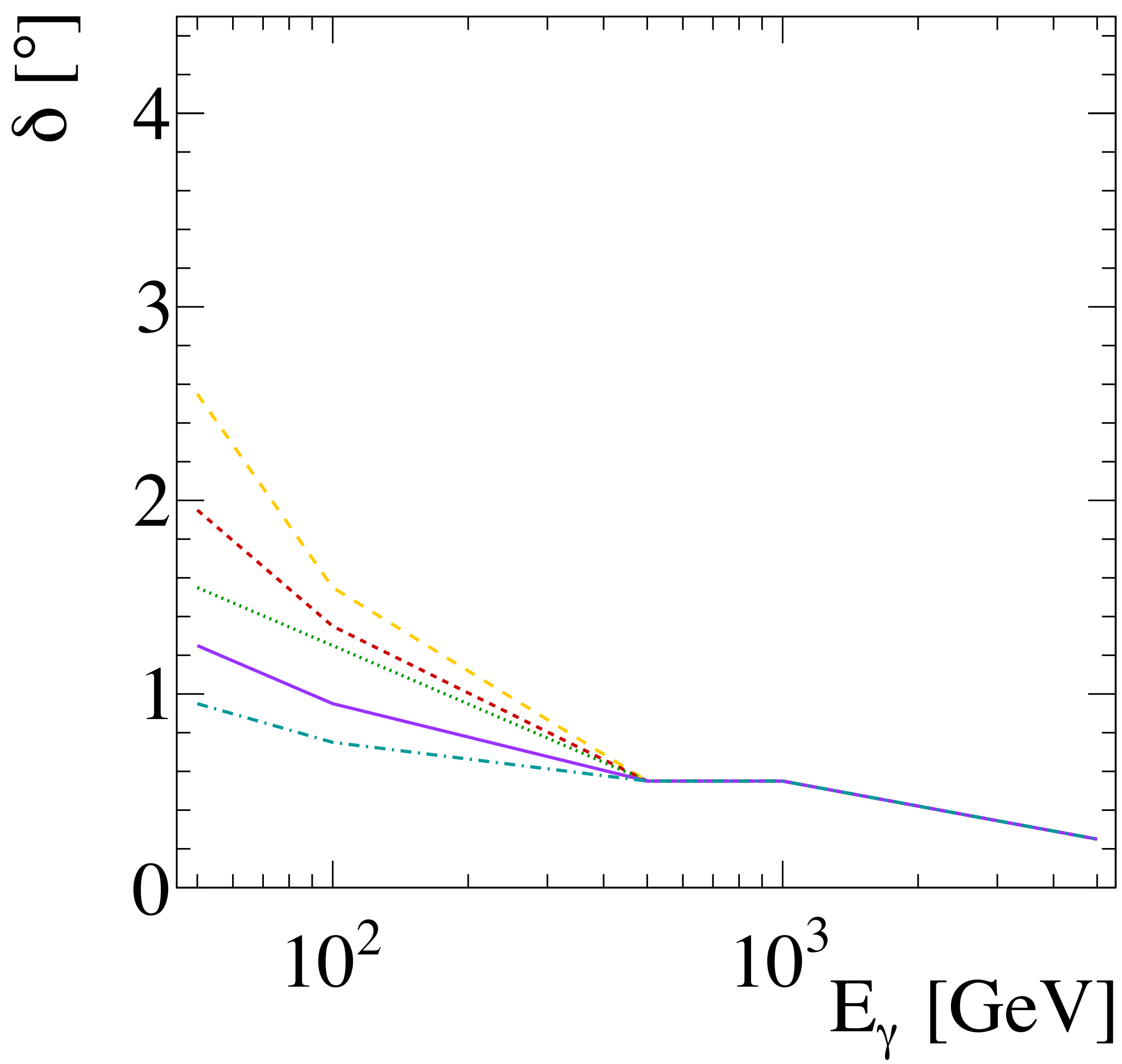
Comparing altitude of 4100 at 500 GeV to **reference** you gain:

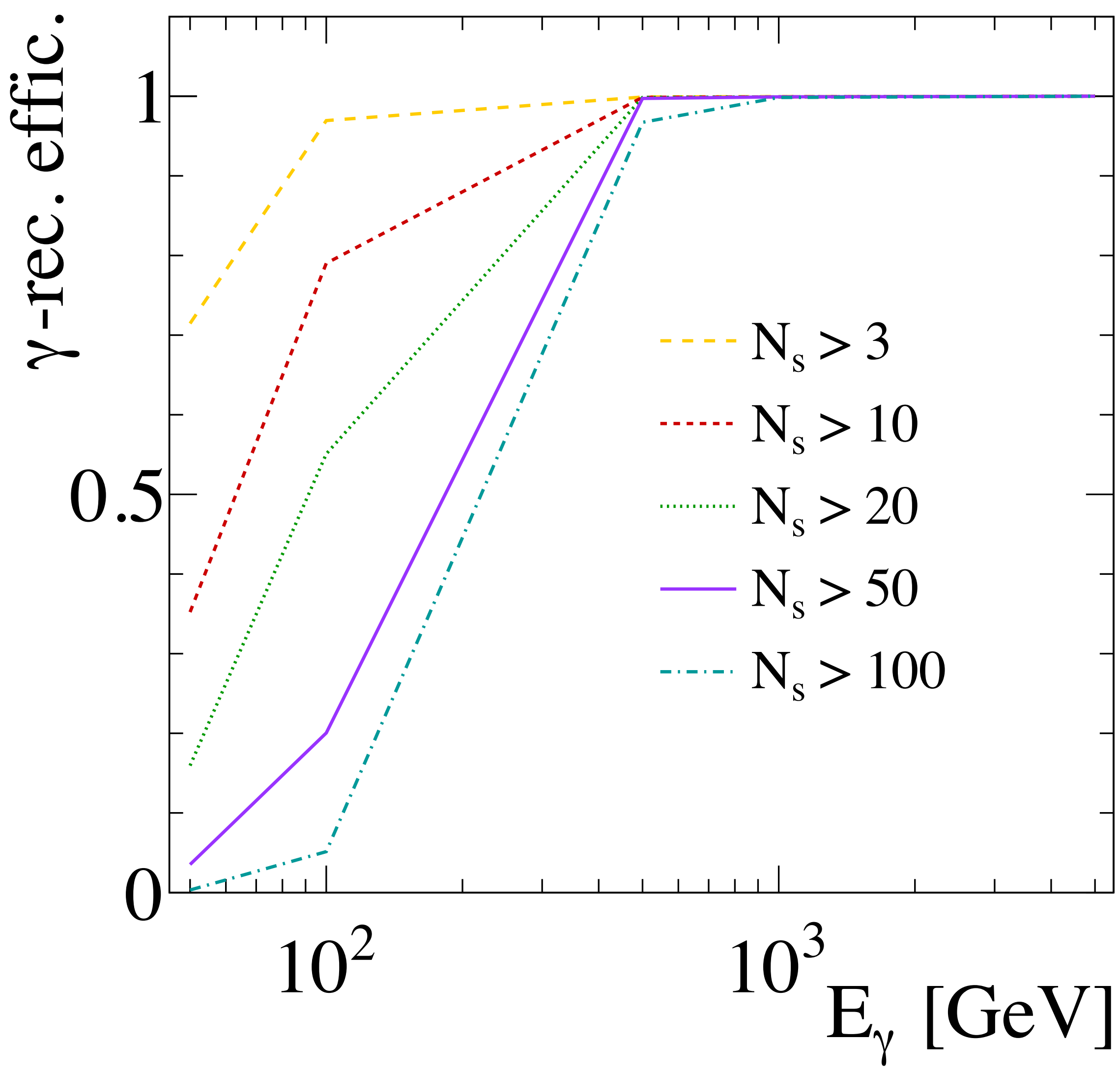
1.45 ????



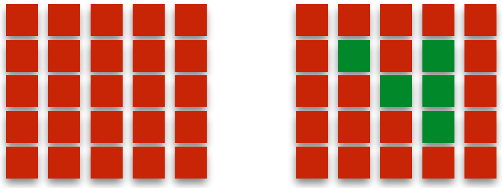
Trigger multiplicity threshold





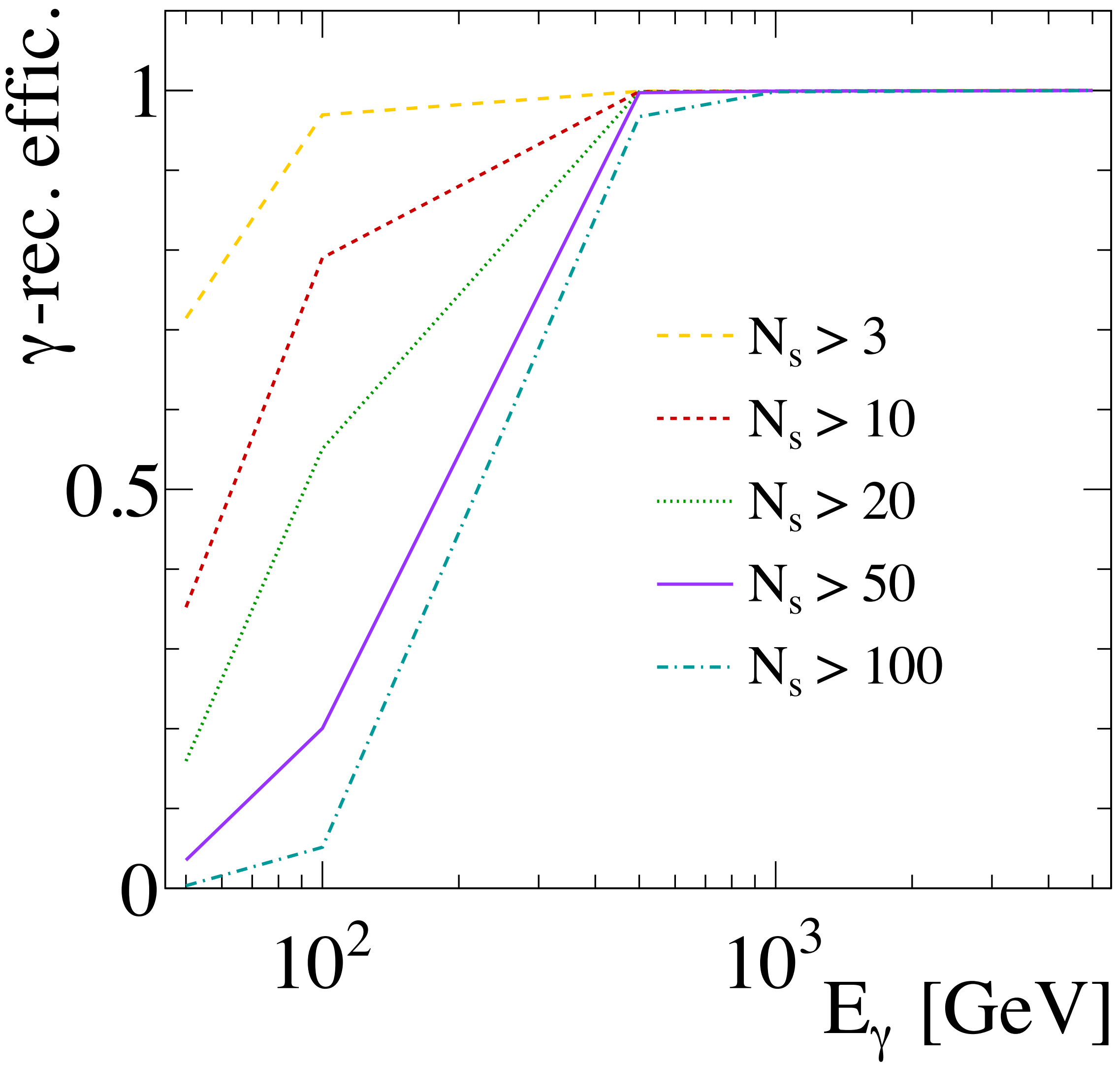


Trigger multiplicity threshold

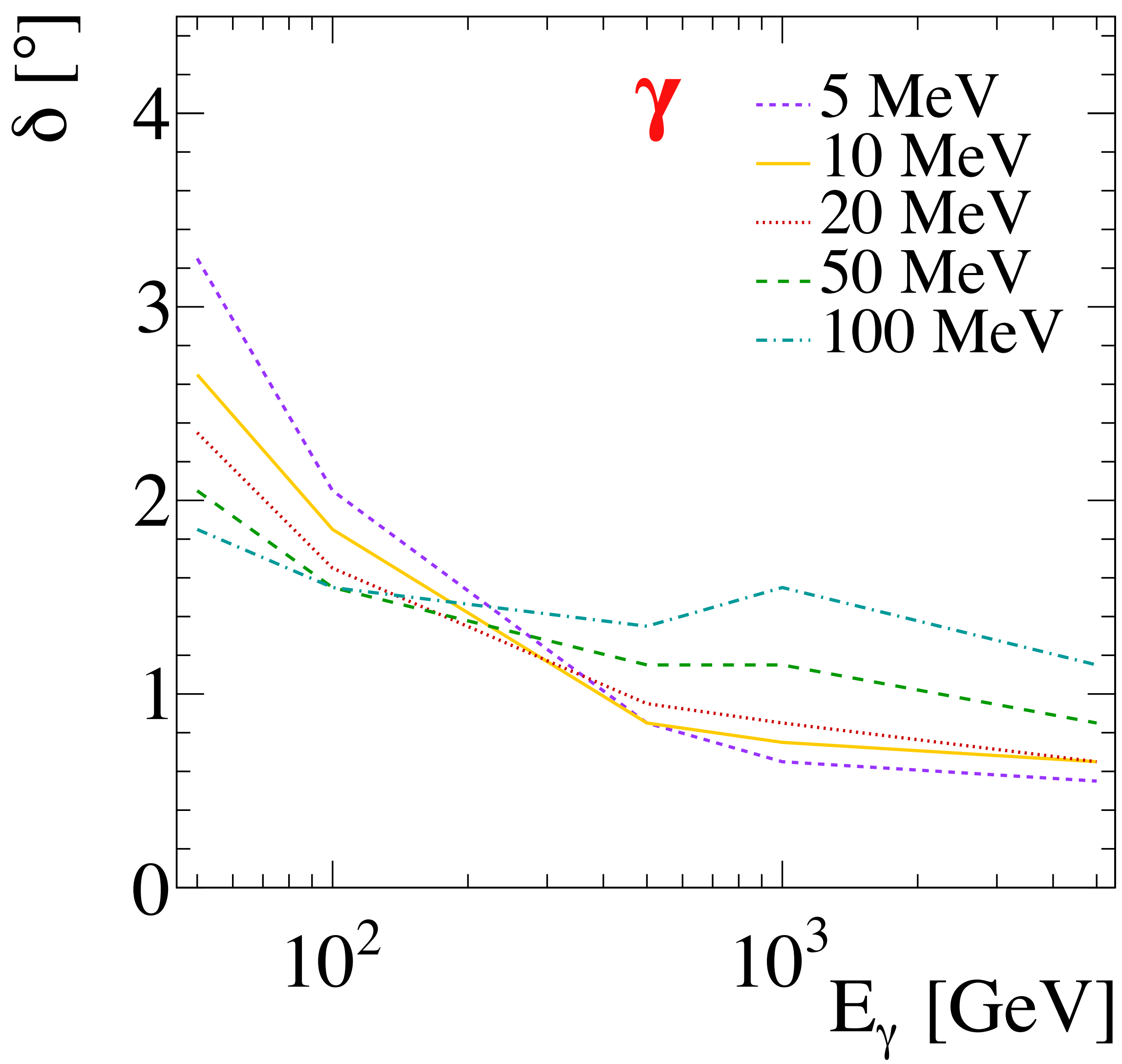


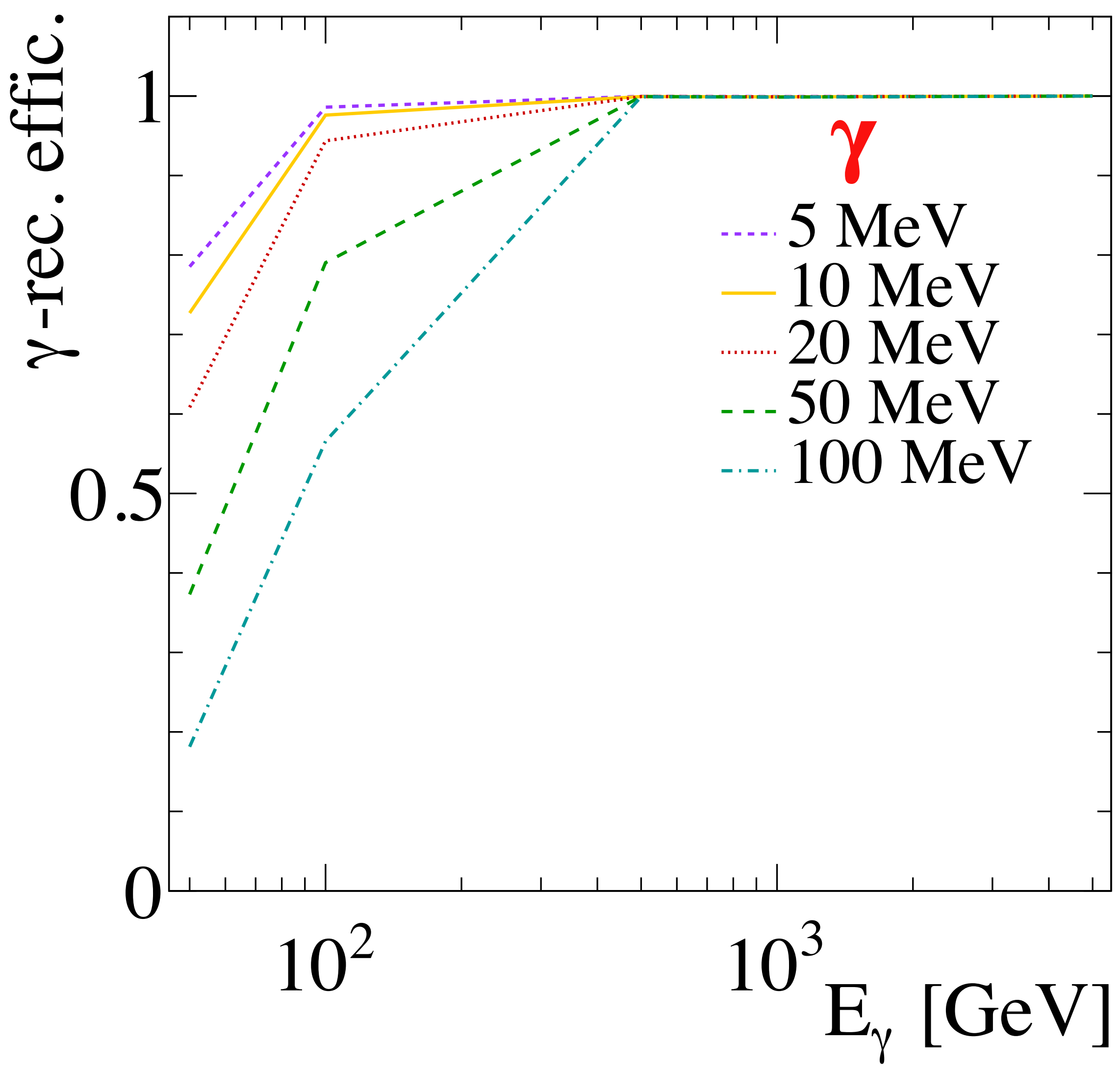
Comparing multiplity N > 20 at 500 GeV to **reference** you gain:

1.00

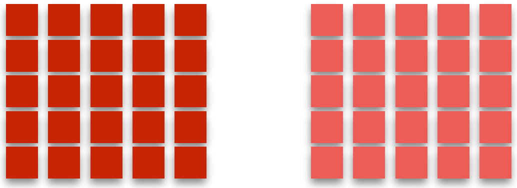


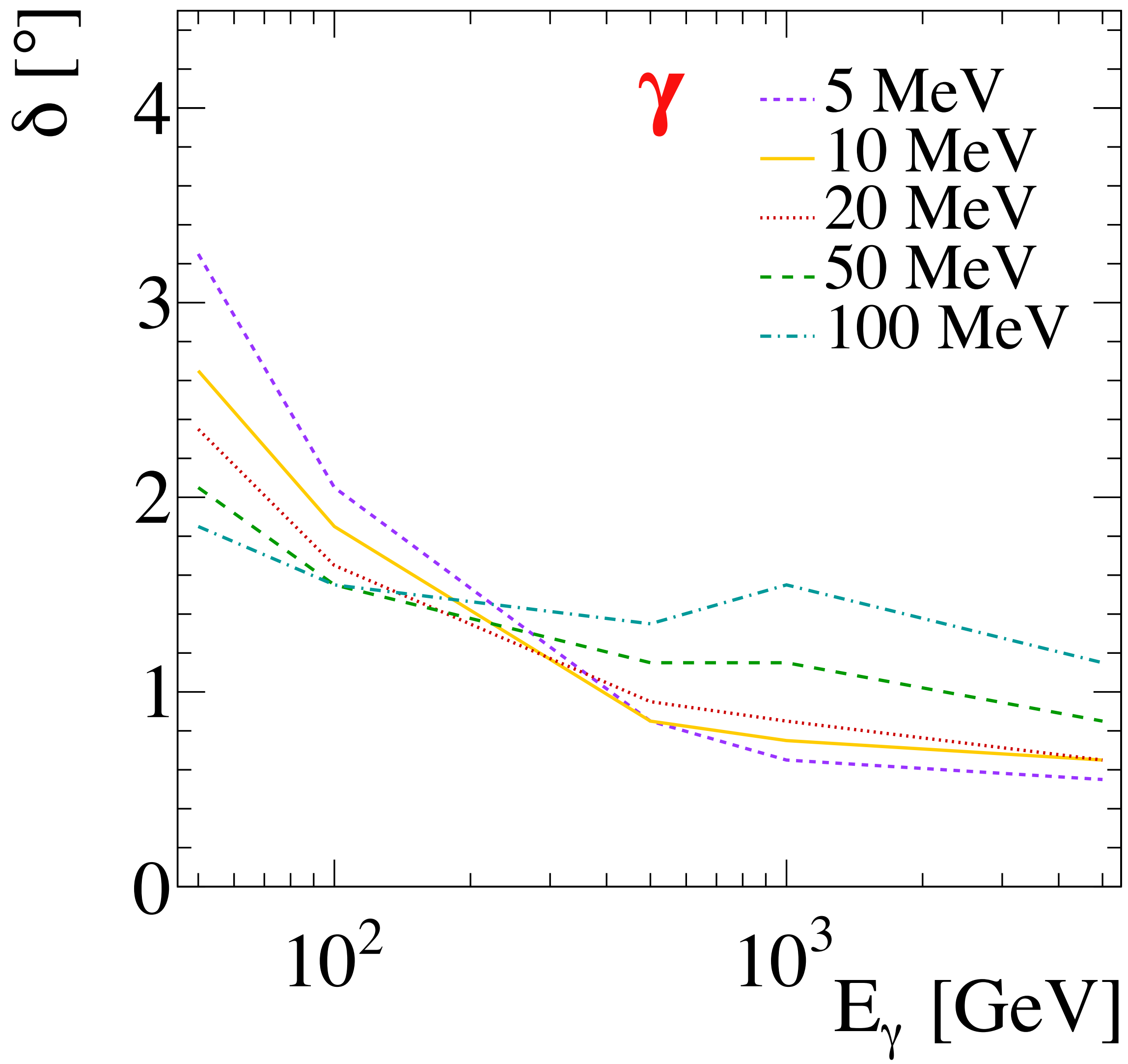
Energy threshold





Energy threshold

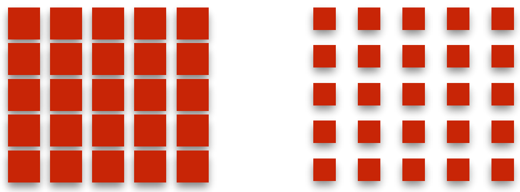


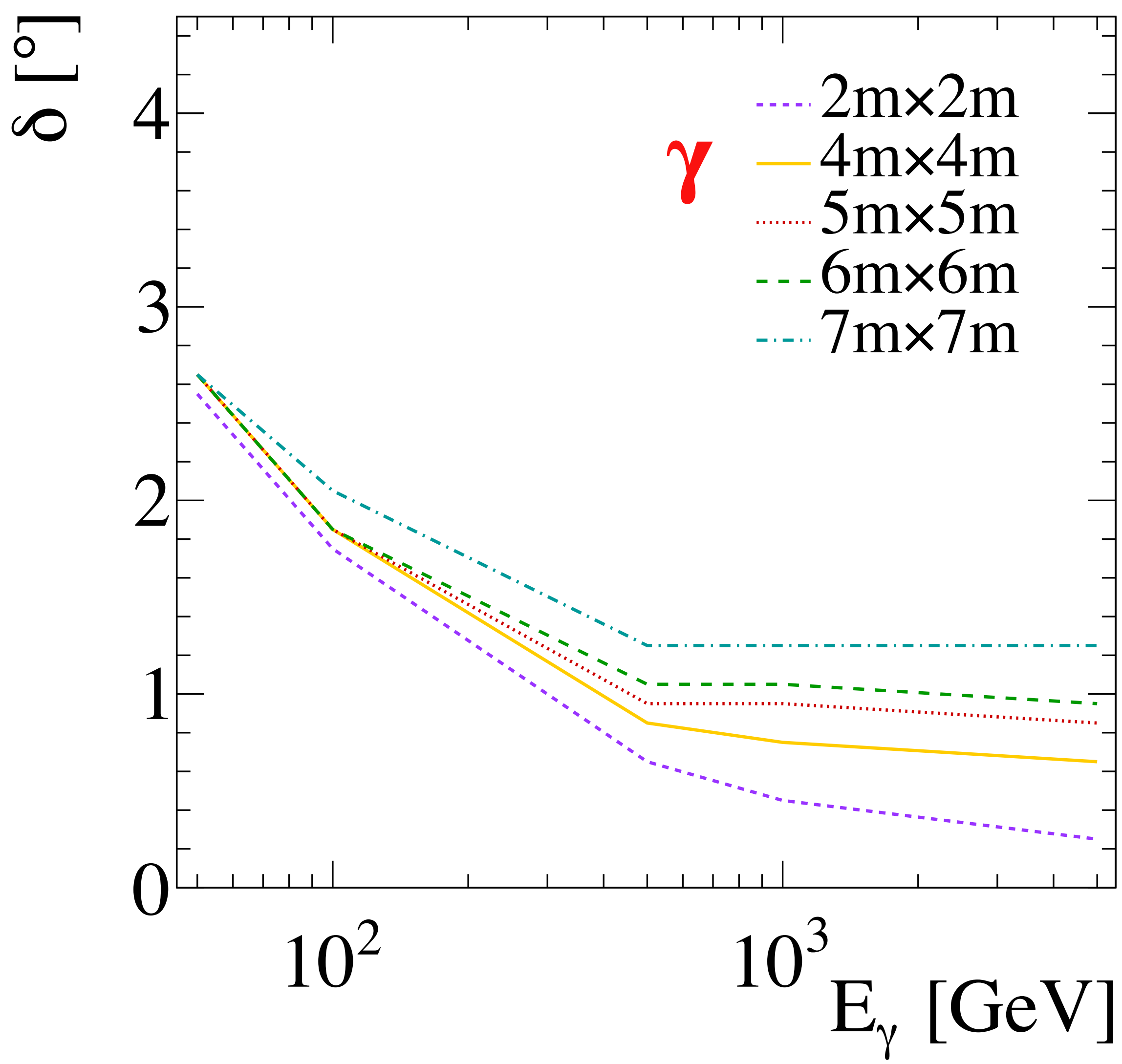


Comparing unit energy threshold of 50 MeV at 500 GeV to reference you gain:

0.75

Unit size





Comparing unit size of 6m x 6m at 500 GeV to **reference** you gain:

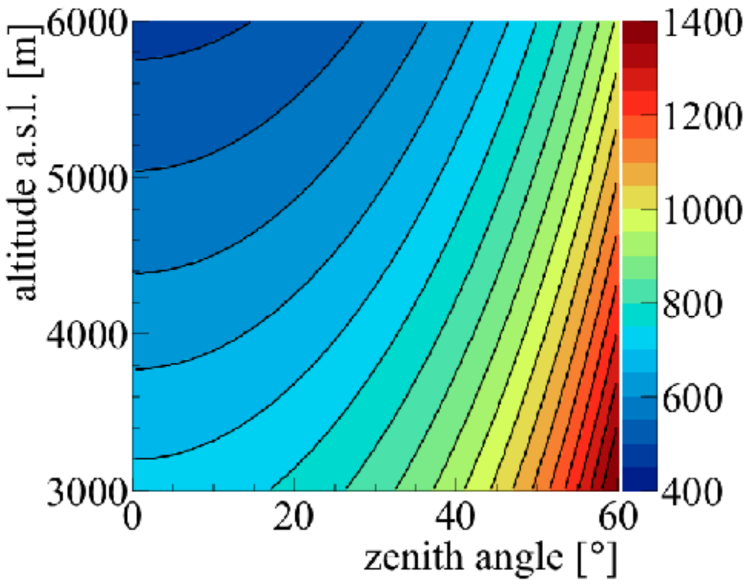
0.81

Aperture

the fraction of events that you collect

$$\mathcal{A}(E_{\gamma,p}) = 2\pi \int_0^{\theta_{\max}} A_\perp \mathcal{E}(\theta, E_{\gamma,p}) \cos(\theta) \sin(\theta) d\theta$$

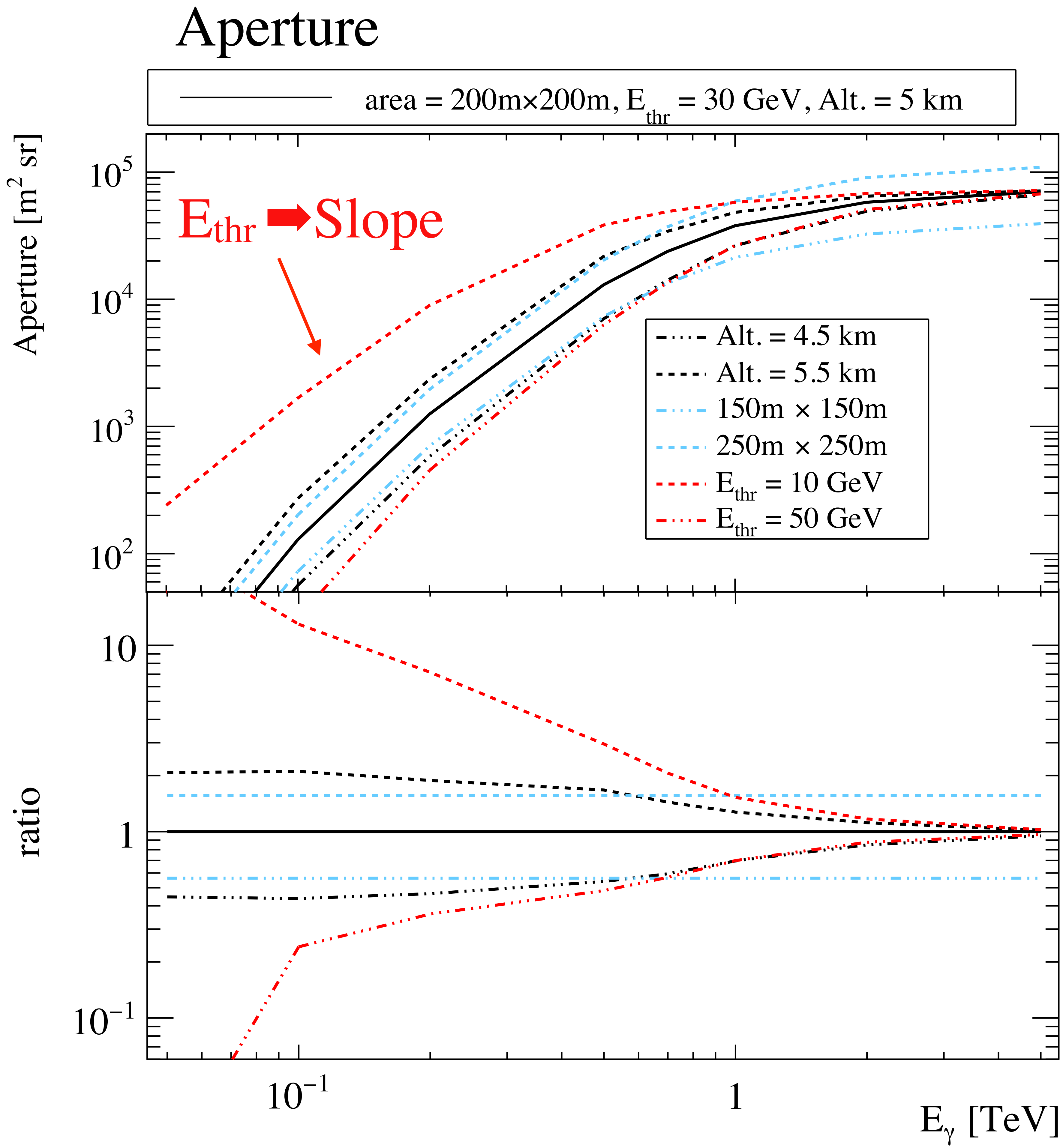
the size of your array



Some numbers at 500 GeV:

4.5km -> 5.5 km you gain a factor of 3

You achieve the same by going from 150m x150m array to a 250mx250m (2.7 in size) at 5000m



Recommendations

Muon detector: Pretty straight forward G/H separation above 200 GeV (in addition it should help reducing accidental CR background)

Find physical sensible parameters before designing an array (not necessary the ones presented here)

Simulate more (to me/us/everybody):

- Background & Trigger concepts
- Science cases + sensitivity curves
- Work together :), slack channel https://southerngamma.slack.com/

Recommendations

Sensitivity

$$N_*(E_i) = \int_0^t \int_0^{\Omega*} \int_{E_l}^{E_h} \frac{d\Phi_*(E,\Omega_*)}{dE} A_\perp \cos\theta \mathcal{E}(\theta, E, \mathcal{F}_\gamma) dE d\Omega dt$$

source spectrum and morphology/*angular resolution*

effective size of array

fraction of events that remain after *gamma selection*

$$N_B(E_i) = \int_0^t \int_0^{\Omega*} \int_{E_l}^{E_h} \frac{d\Phi_B(E,\Omega_*)}{dE} A_\perp \cos\theta \mathcal{E}(\theta, E, \mathcal{F}_\mathcal{B}) dE d\Omega dt$$

$$\frac{N_*}{\sqrt{N_B}}$$