Gamma/hadron discrimination at high energies through the azimuthal fluctuations of the particle distributions at the ground

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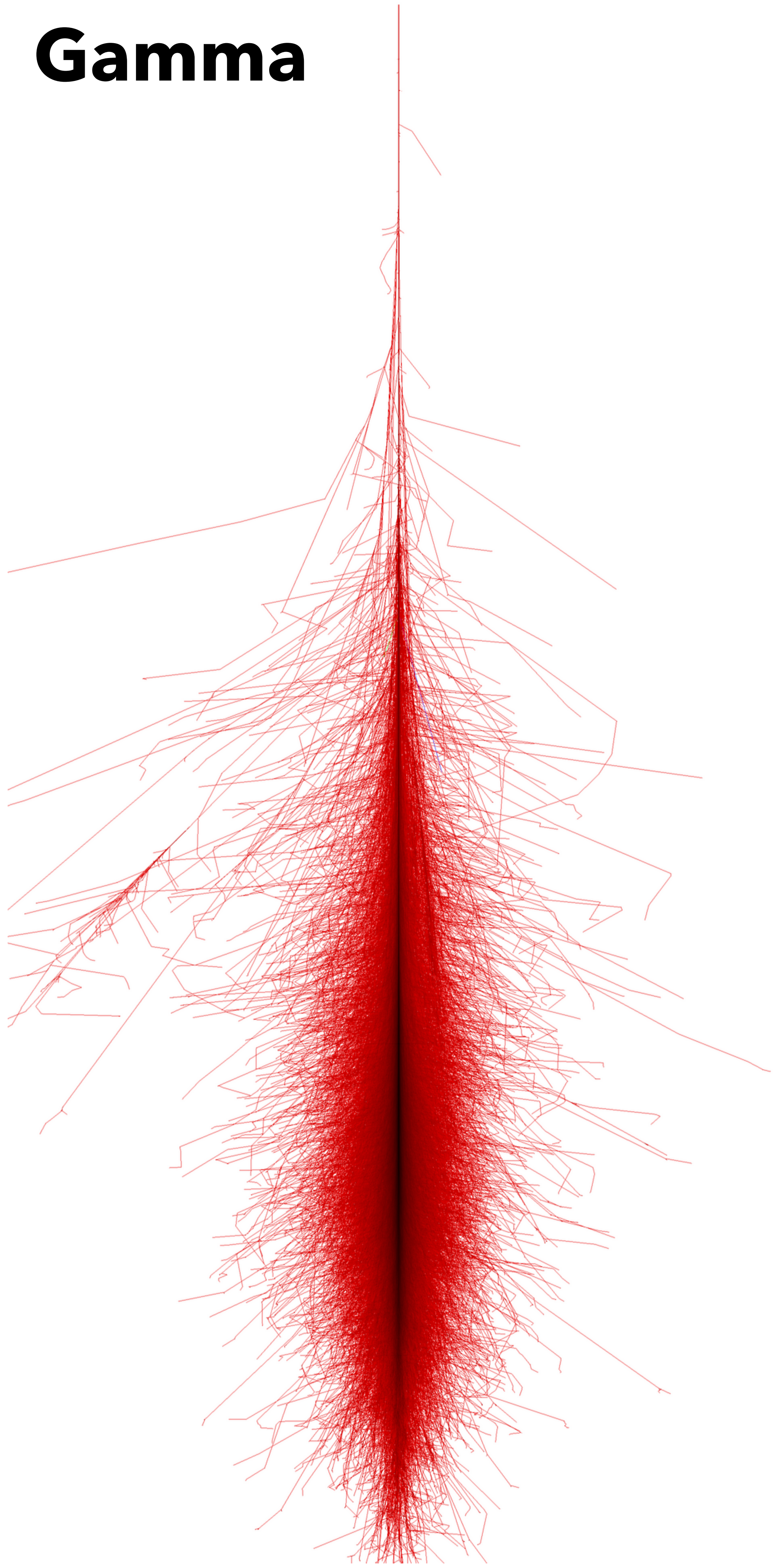
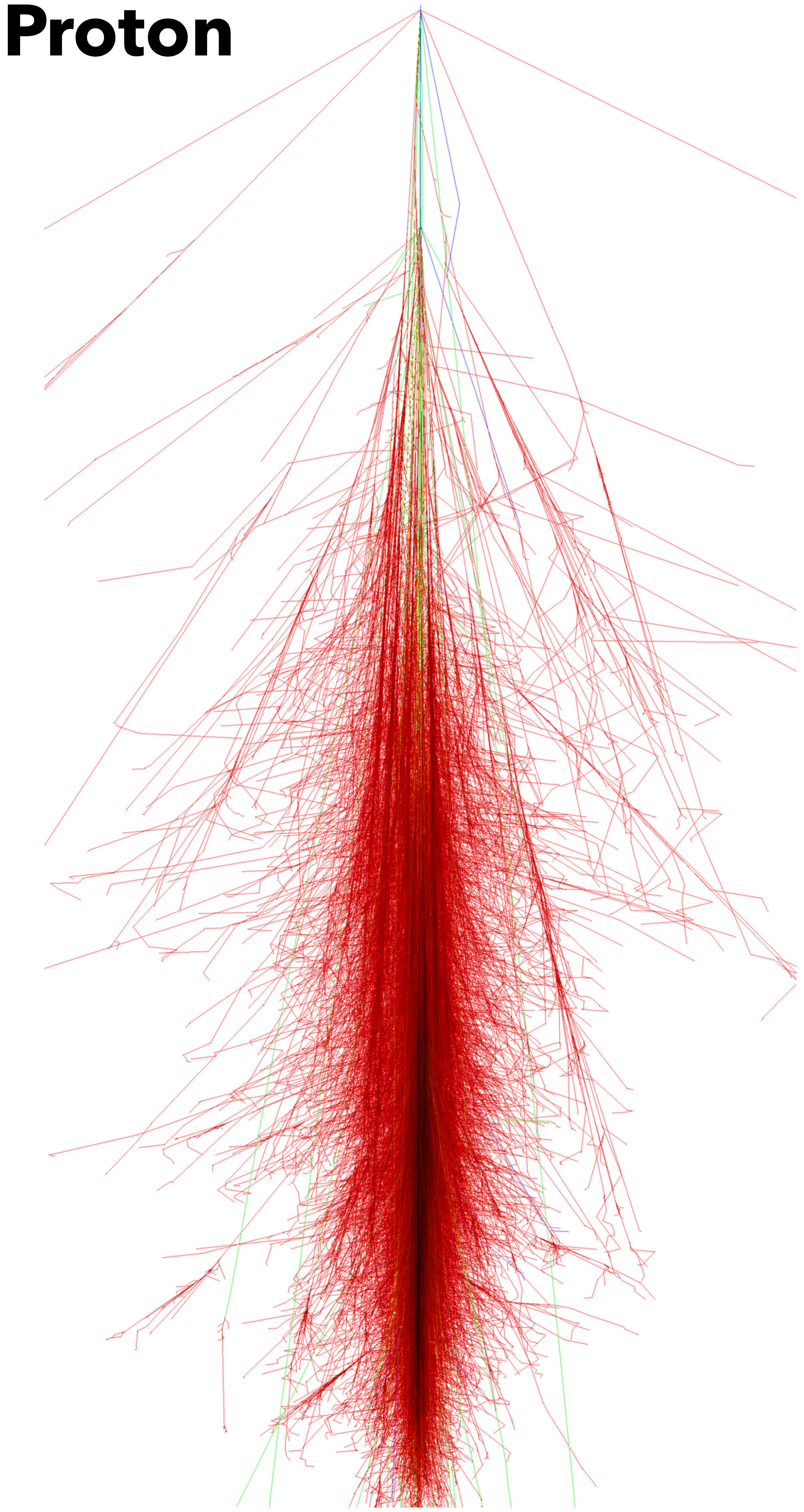
27th ECRS, Nijmegen, July 28th 2022

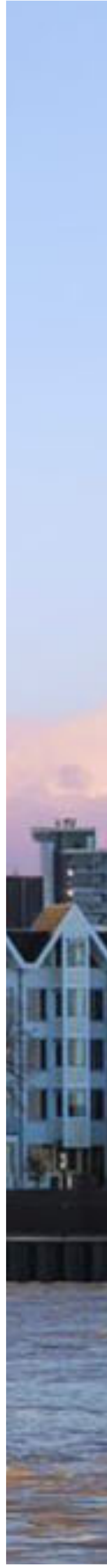
Gamma/hadron discrimination through the shower characteristics

Gamma **Proton**

$E = 1\,\mathrm{TeV}^*$







** This is just for illustration. In practice one should compare showers with same energy at the ground.*

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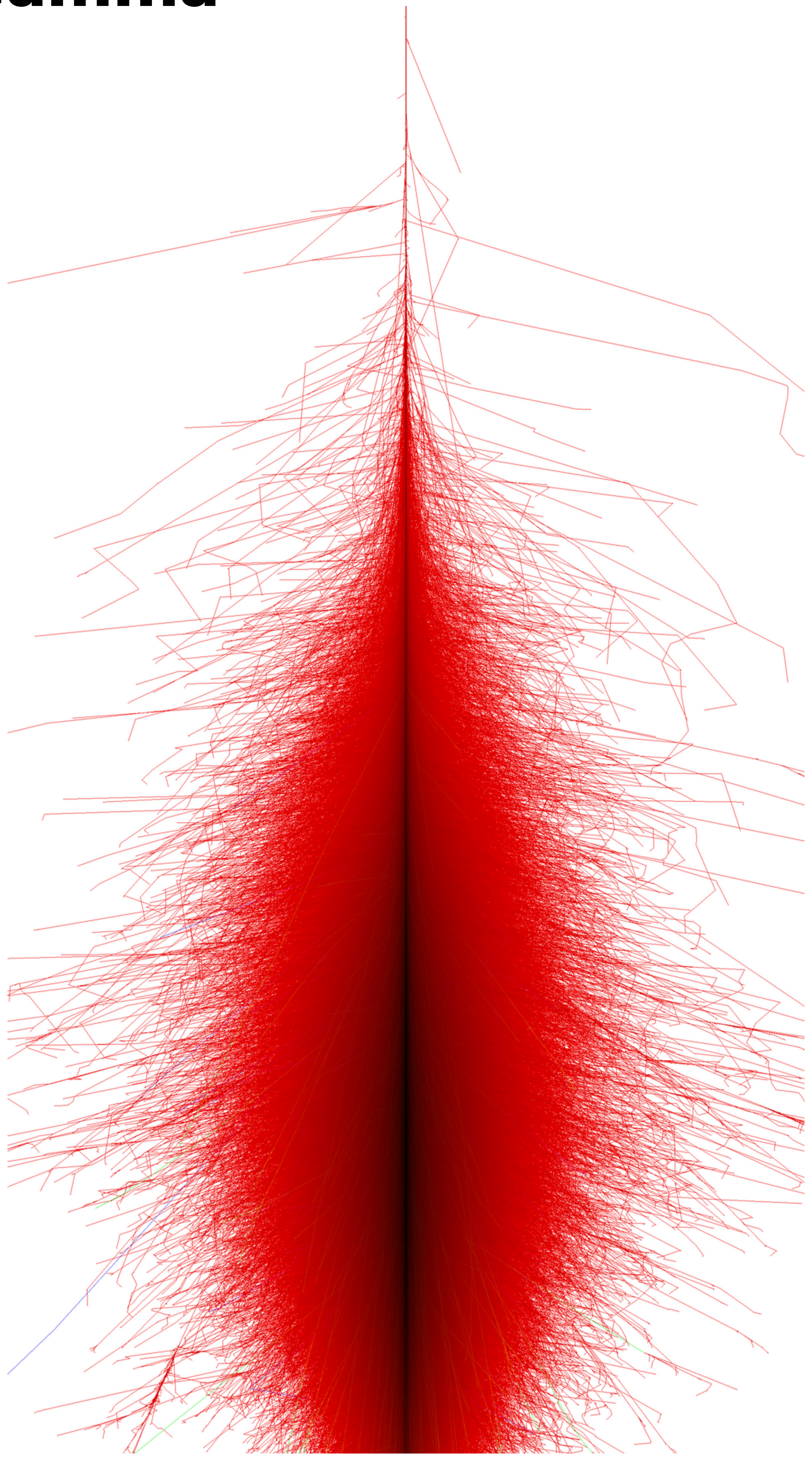
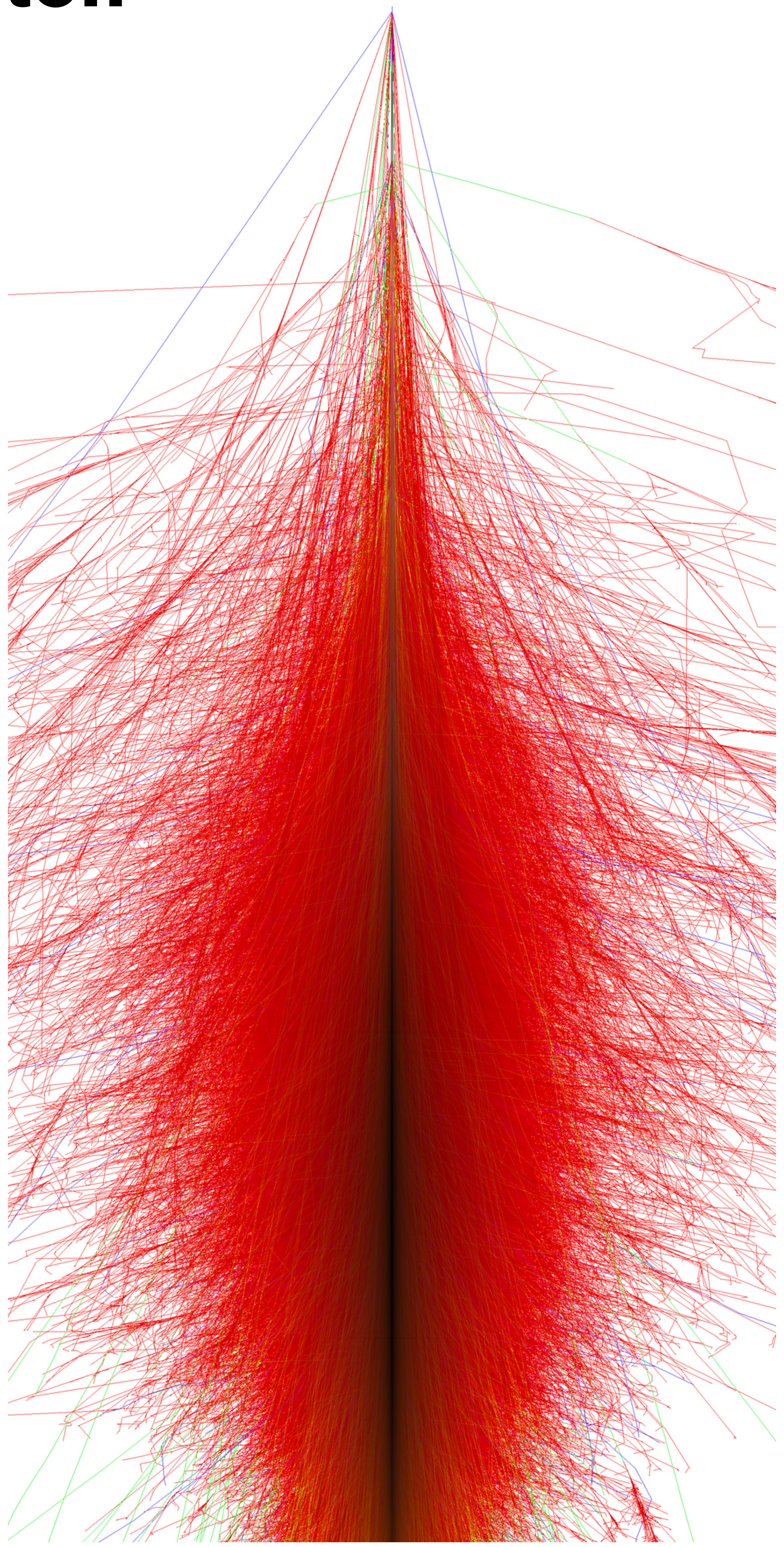
Gamma/hadron discrimination through the shower characteristics

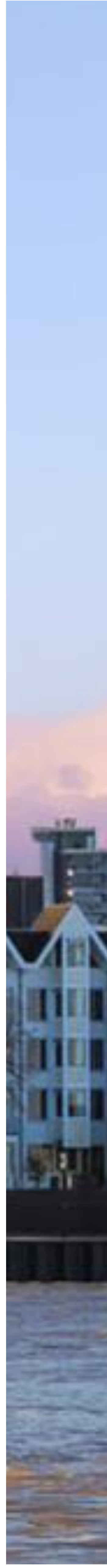
$E = 100\,\mathrm{TeV}$

Gamma



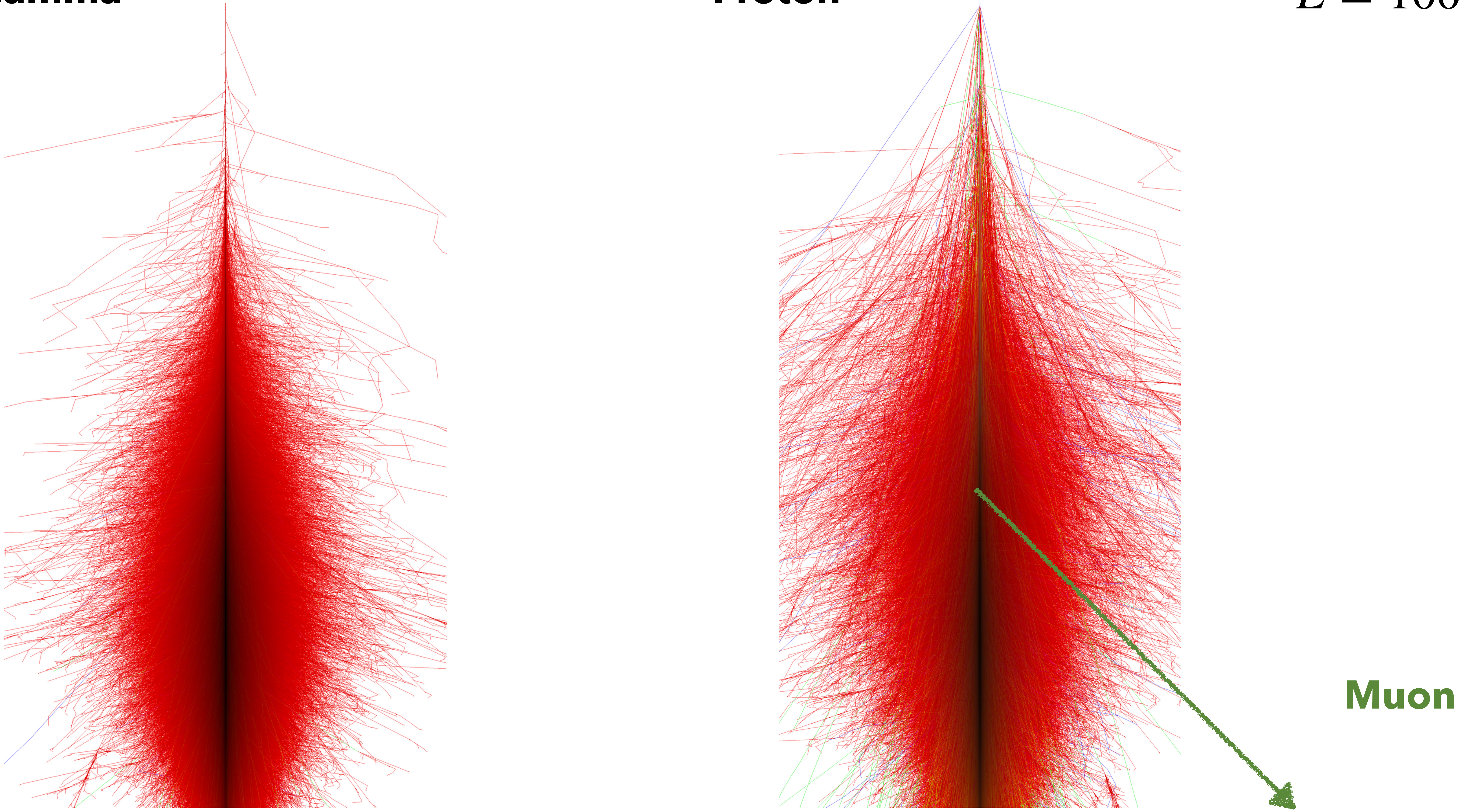
Proton

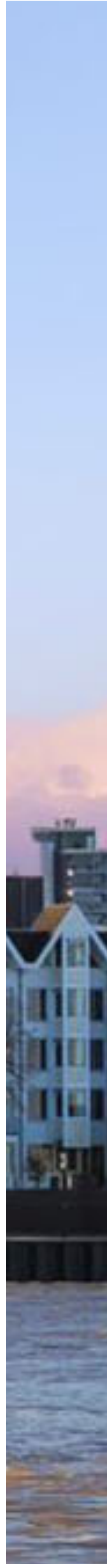




Gamma/hadron discrimination through the shower characteristics

Gamma **Proton** $E = 100\,\mathrm{TeV}$

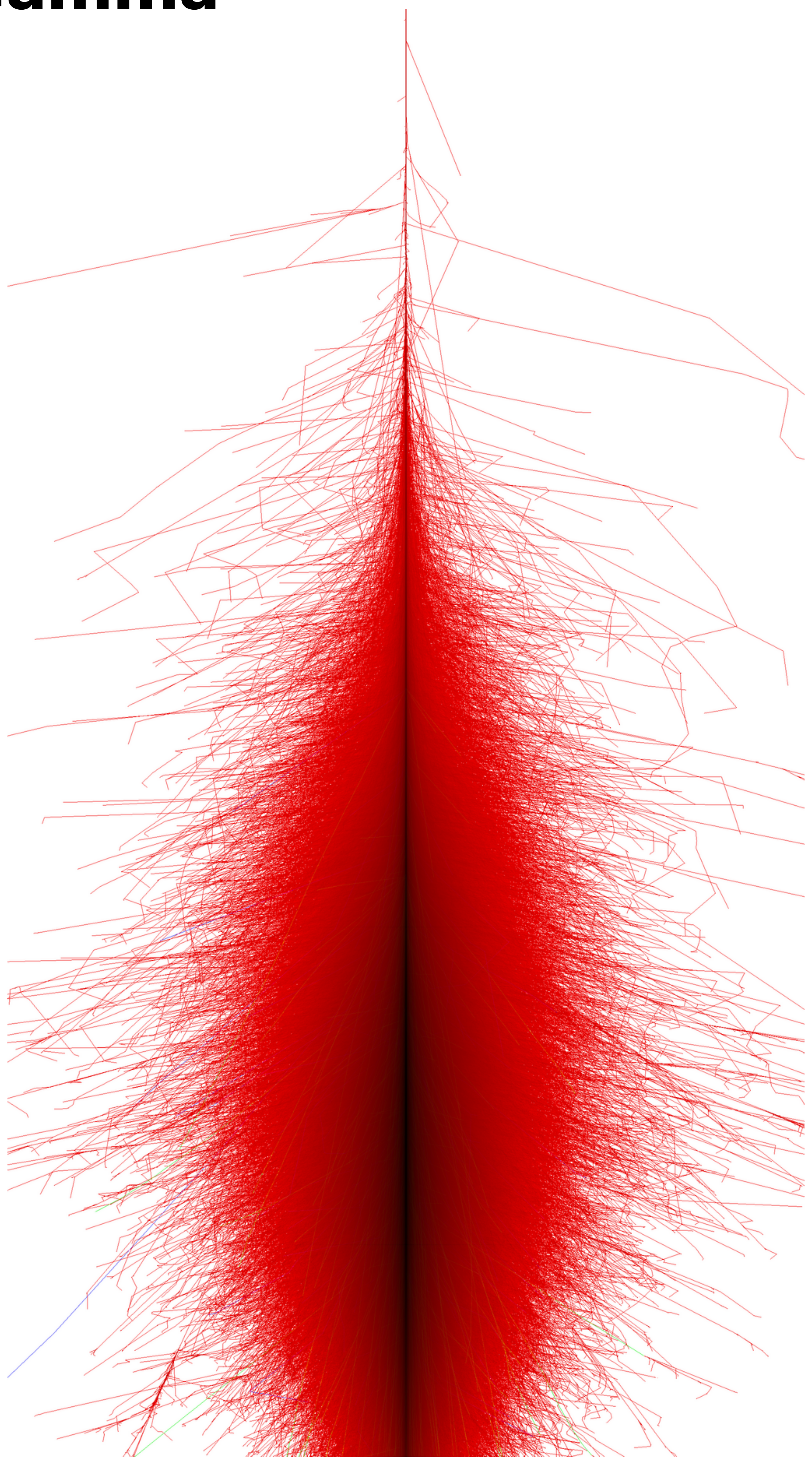




At the highest energies the number of muons are the viewed as the best g/h discriminant

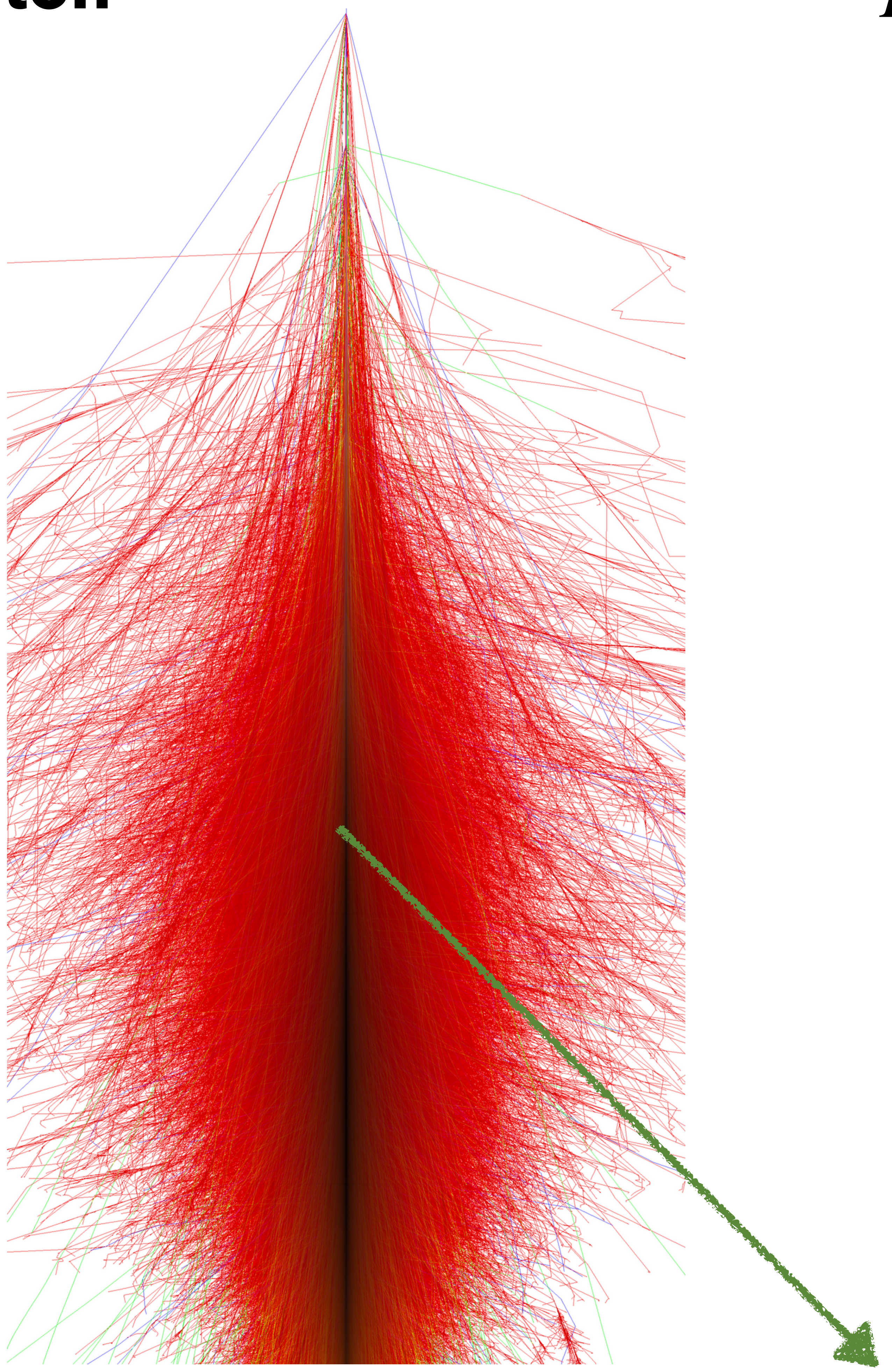
Gamma/hadron discrimination through the shower characteristics

Gamma

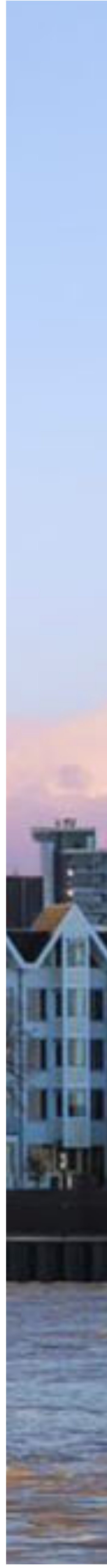


Proton

$E = 100\,\mathrm{TeV}$



Muon



Is there any information left on the shower footprint (azimuthal fluctuations)?

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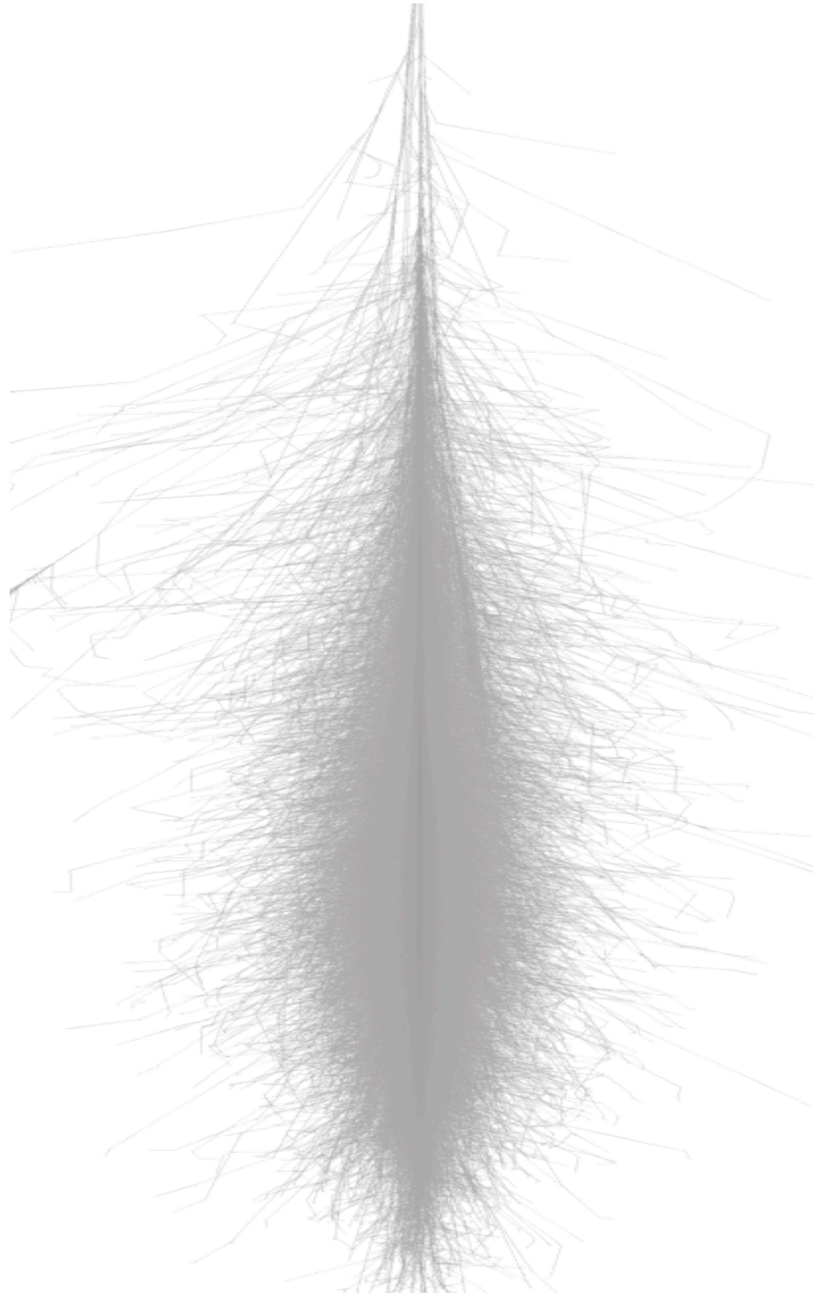
Simulation strategy

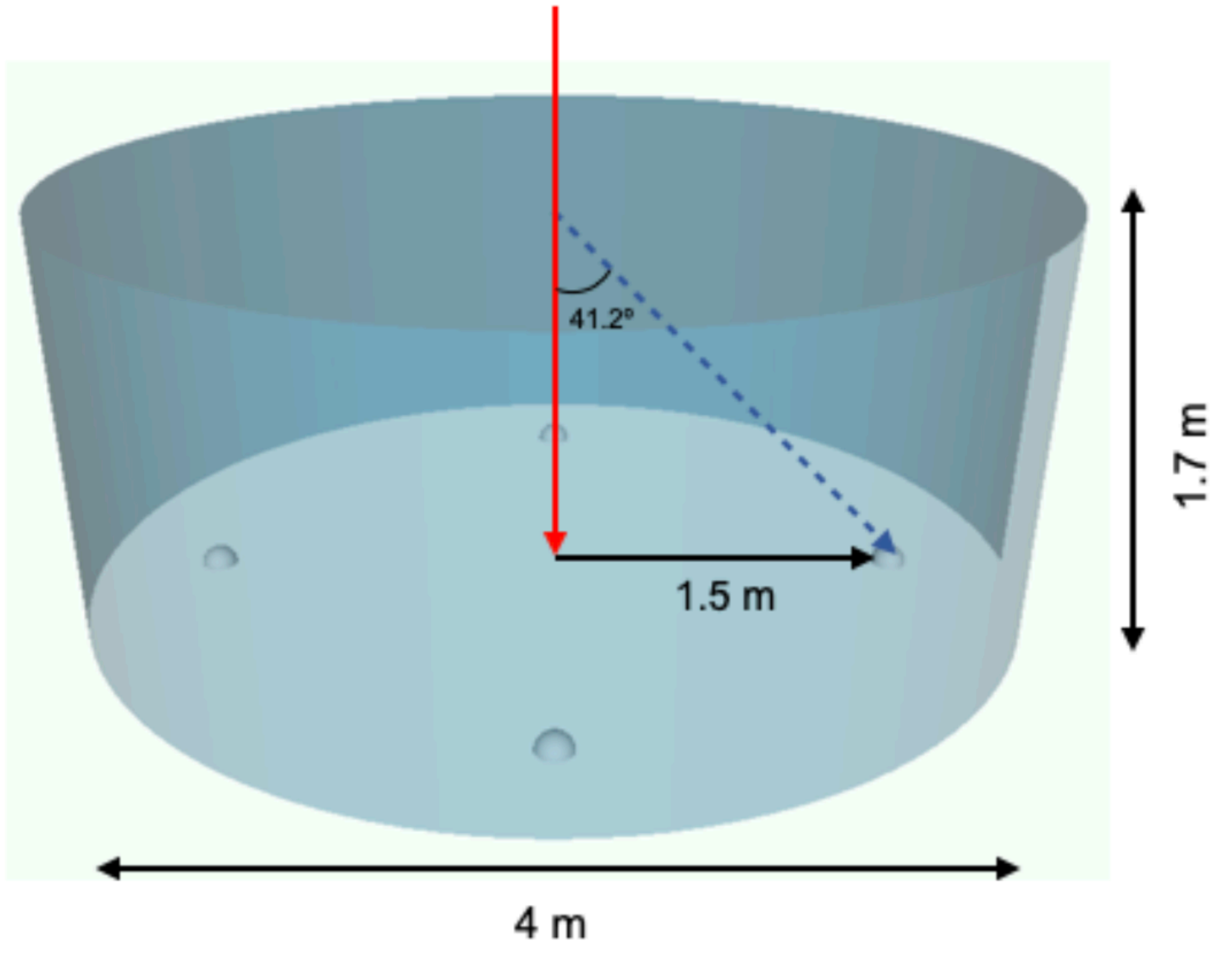
CORSIKA simulations
Collect particles at the ground (5000 m)



Square grid to emulate stations
Detection area of $1\,\mathrm{km}^2$
Cell area of $\sim 12\,\mathrm{m}^2$

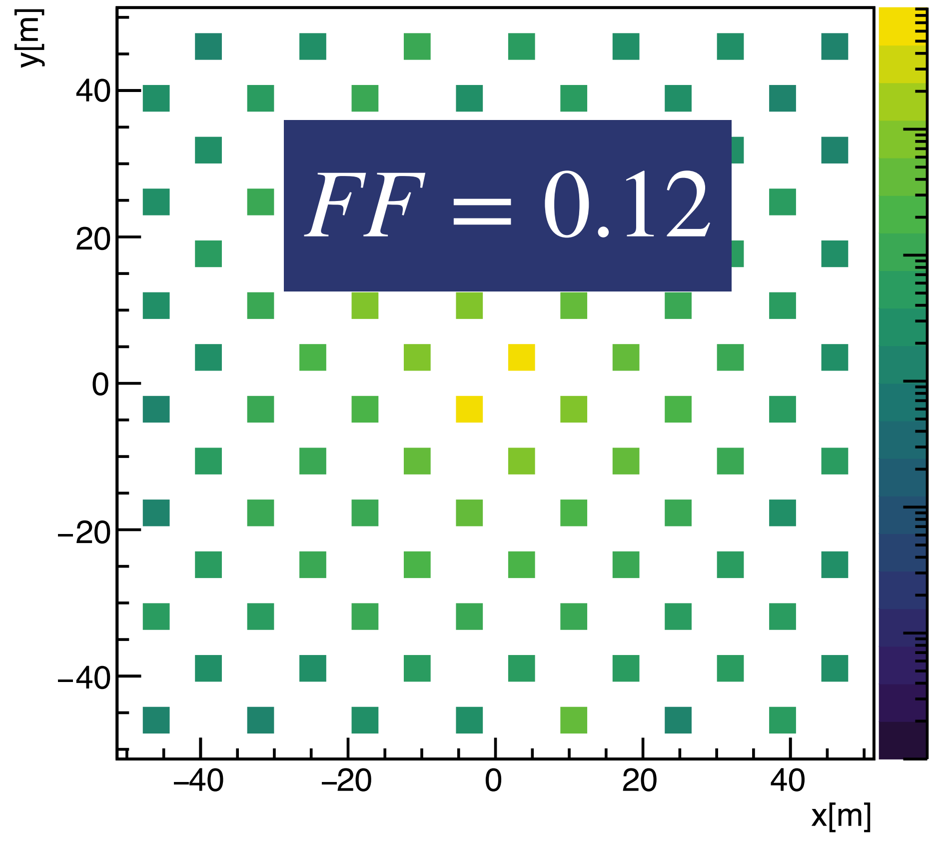
Convert energy of particles into signal collected by a water Cherenkov detector

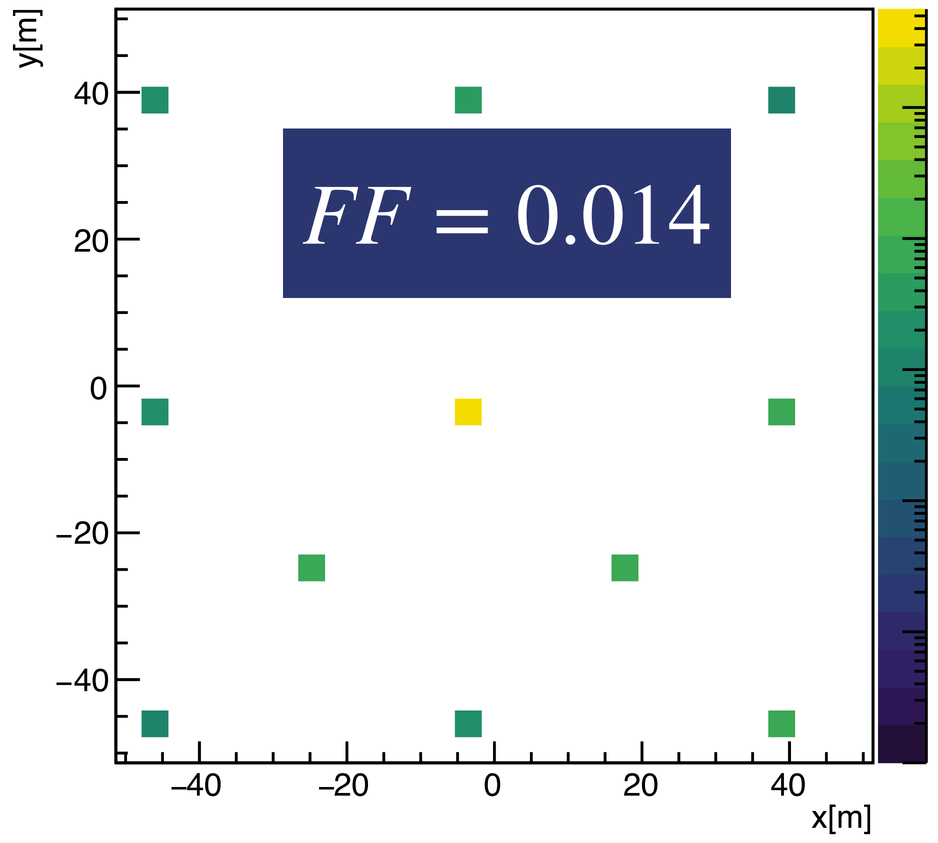
R. C. et al, Eur.Phys.J.C 81 (2021) 6, 542

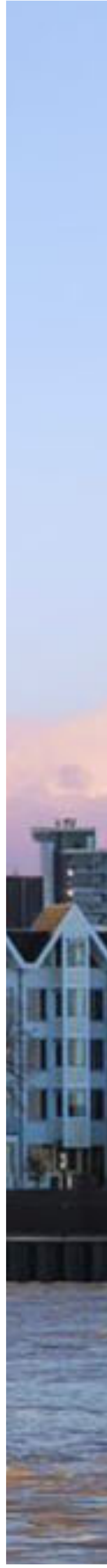


Parameterisation created injecting vertical particles in a Geant4 simulation

Consider arrays with different instrumented areas (Fill Factor - FF)







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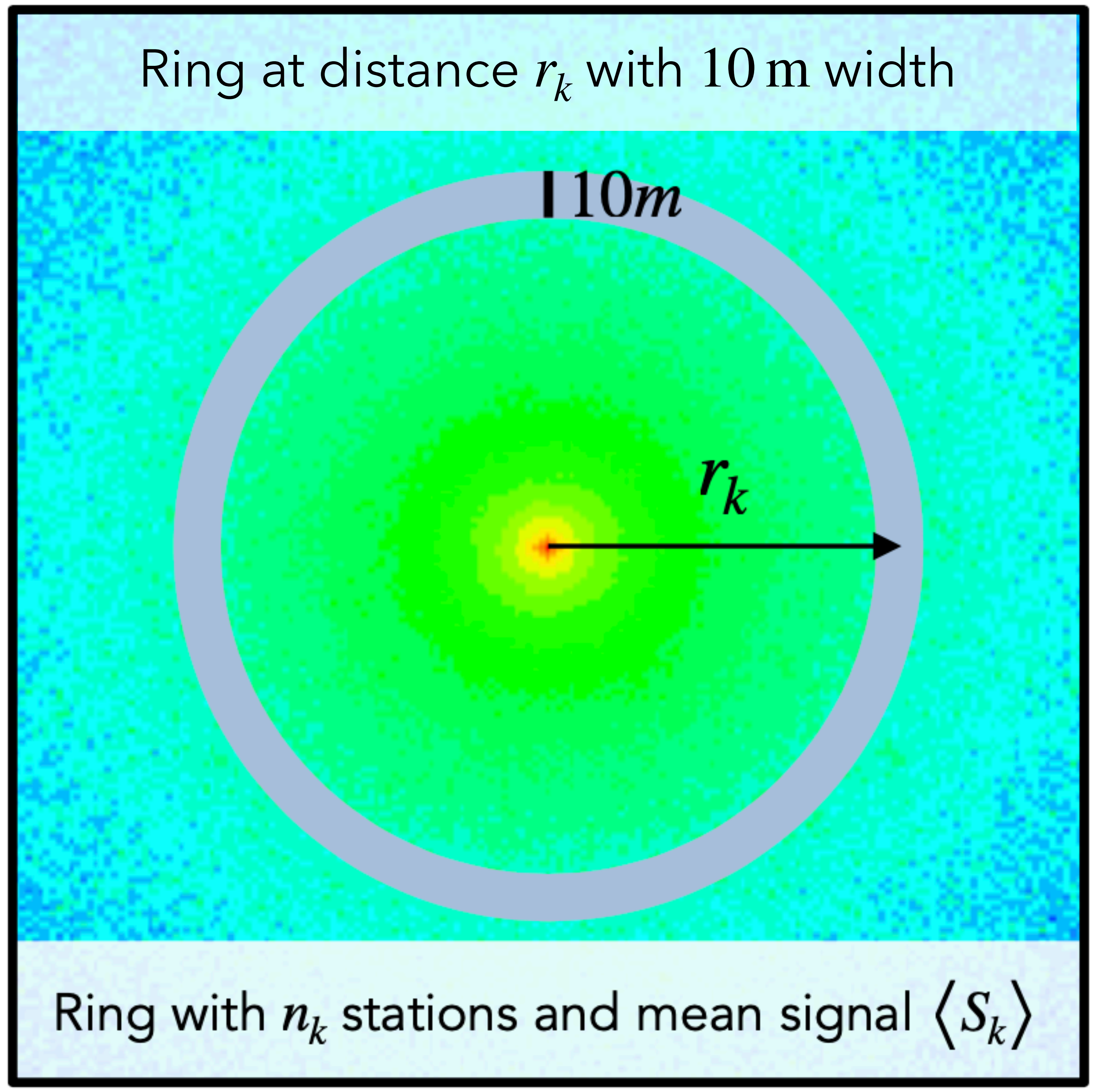
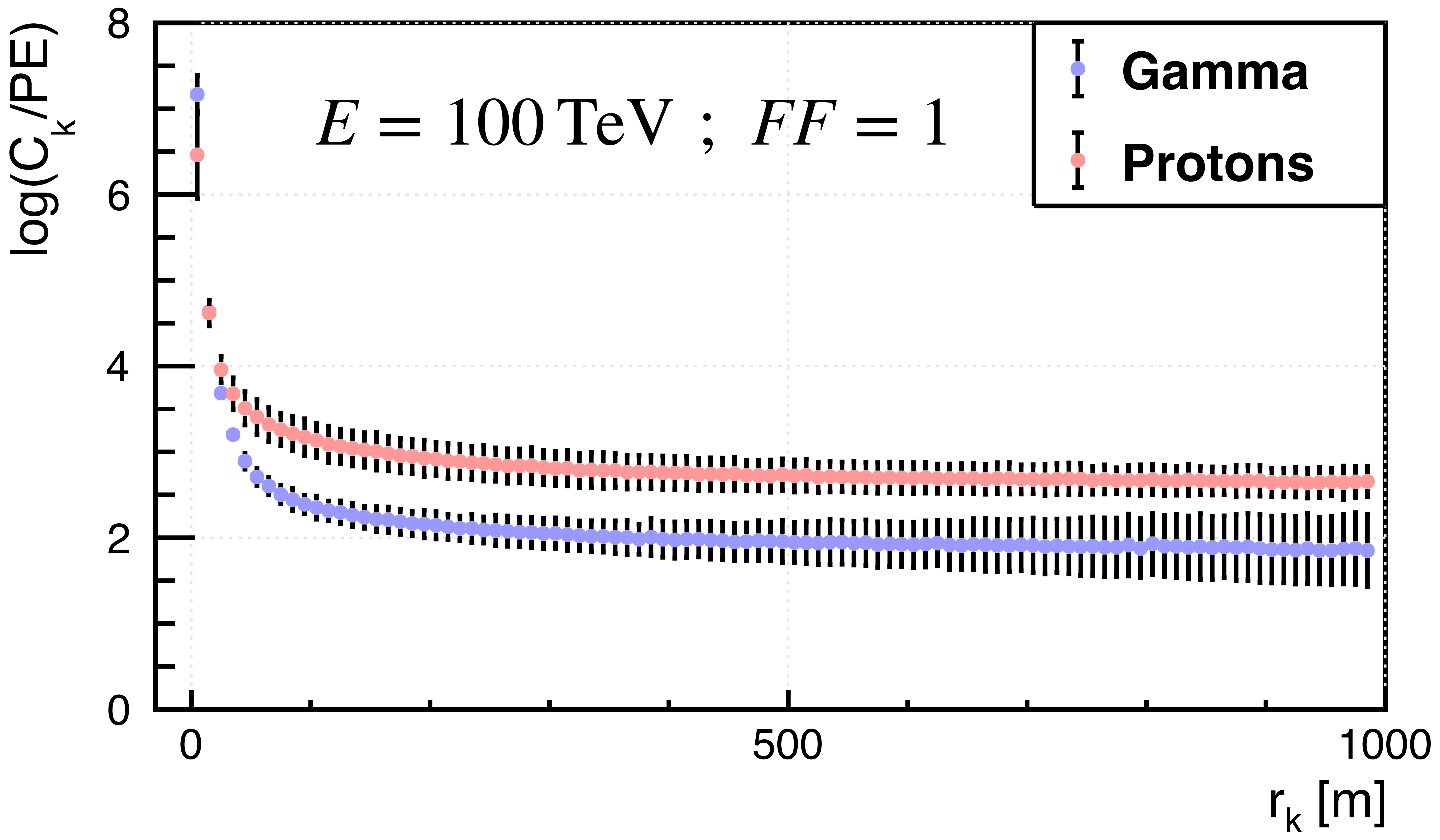
Exploring the shower azimuthal asymmetries

$$C_k = \frac{2}{n_k(n_k-1)} \frac{1}{\langle S_k \rangle} \sum_{i=1}^{n_k-1} \sum_{j=i+1}^{n_k} \left(S_{ik} - S_{jk}\right)^2$$





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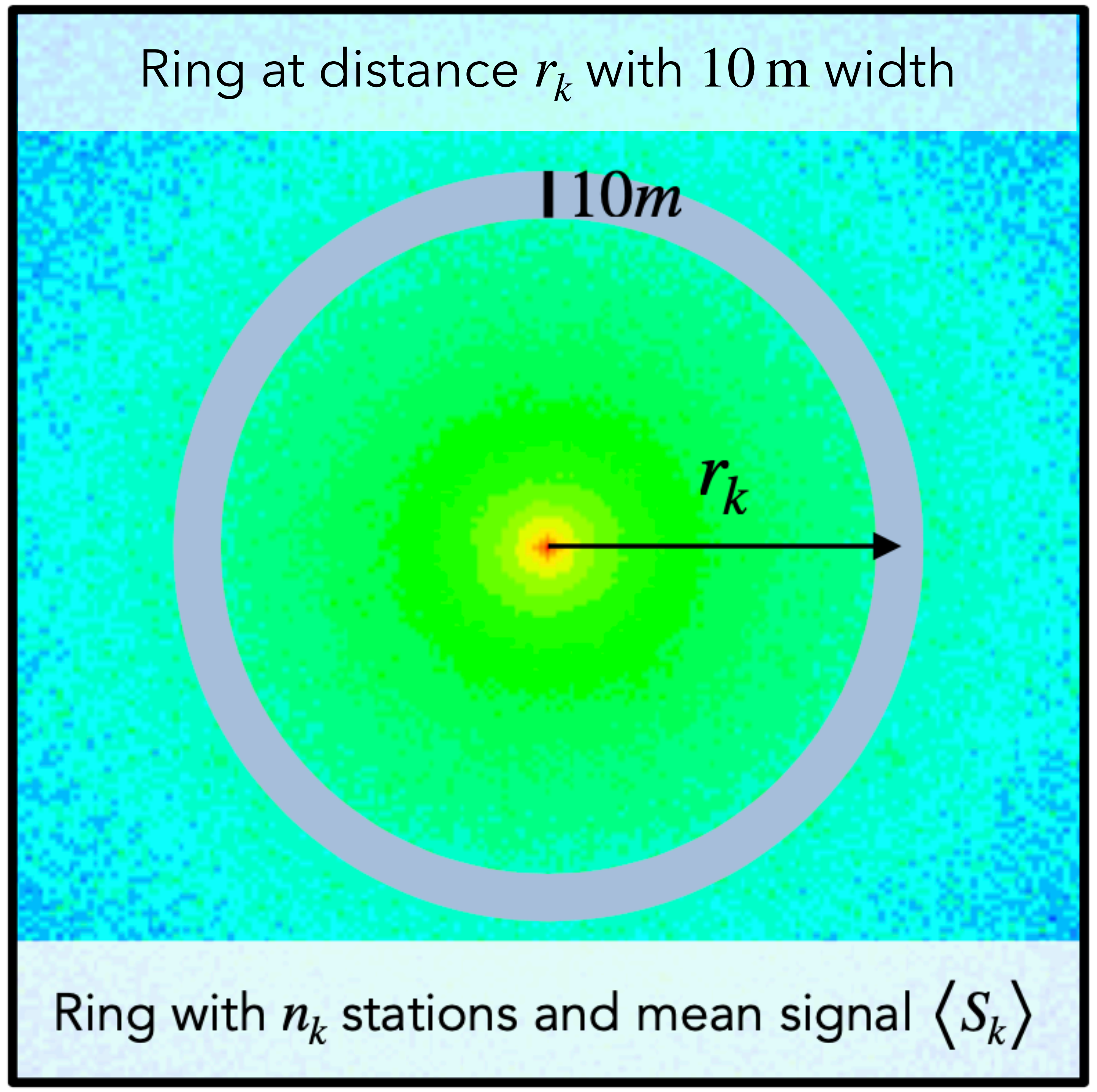
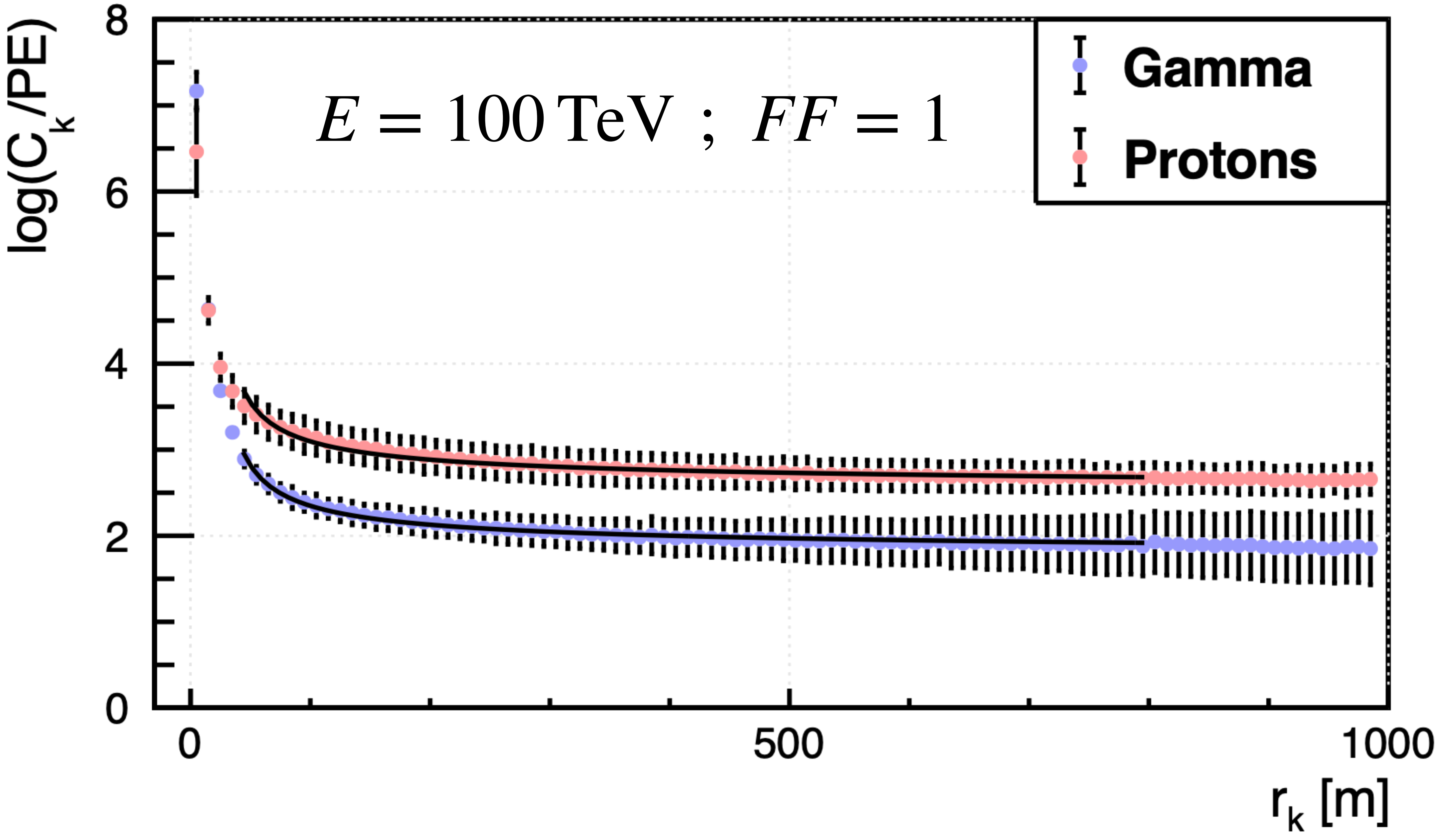
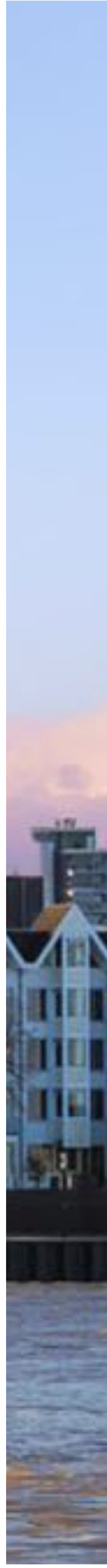
Exploring the shower azimuthal asymmetries

$$\log\left(C_k\right) = a + \frac{b}{\log\left(\frac{r_k}{40\,\mathrm{m}} + 1\right)}$$

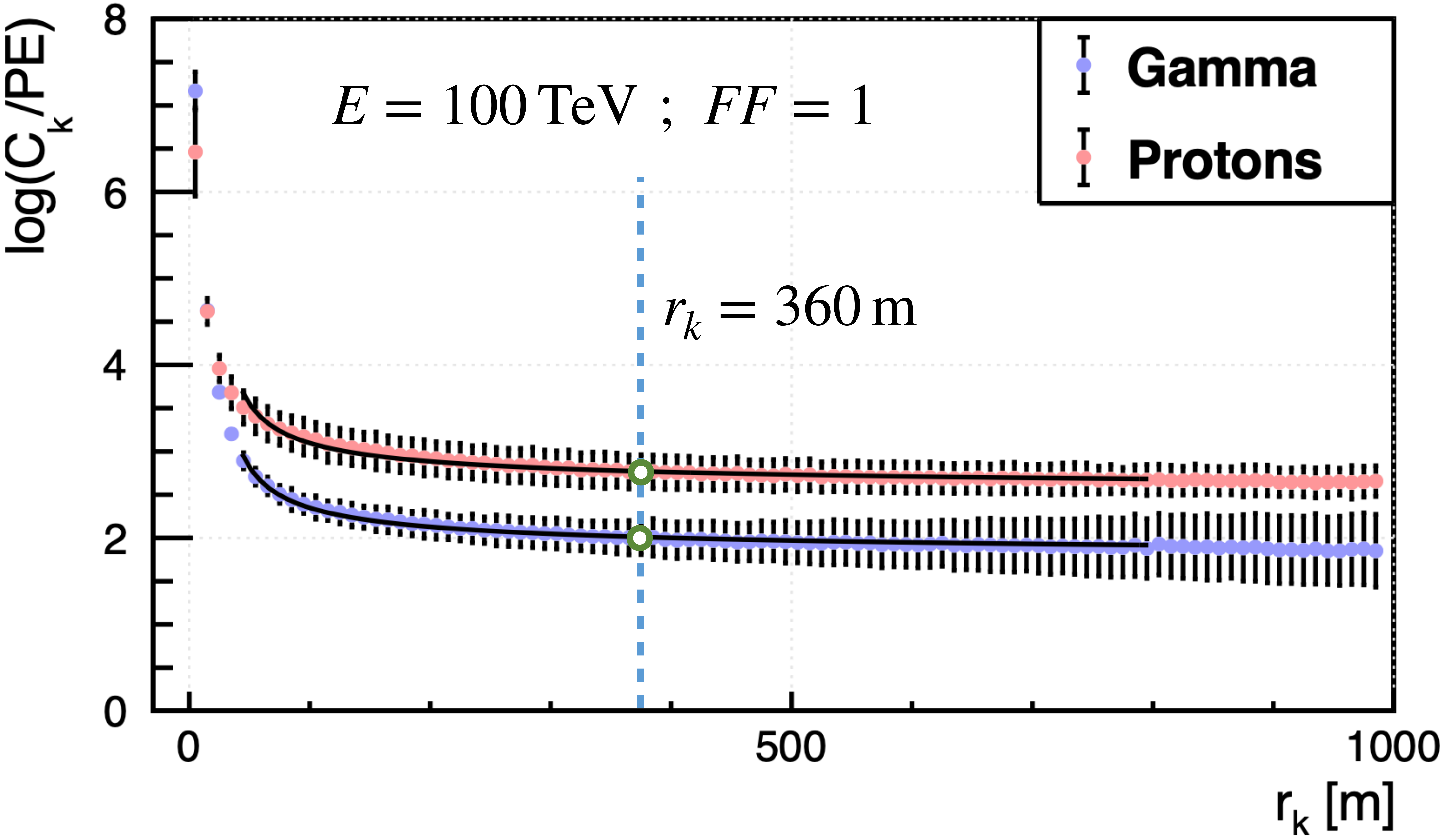


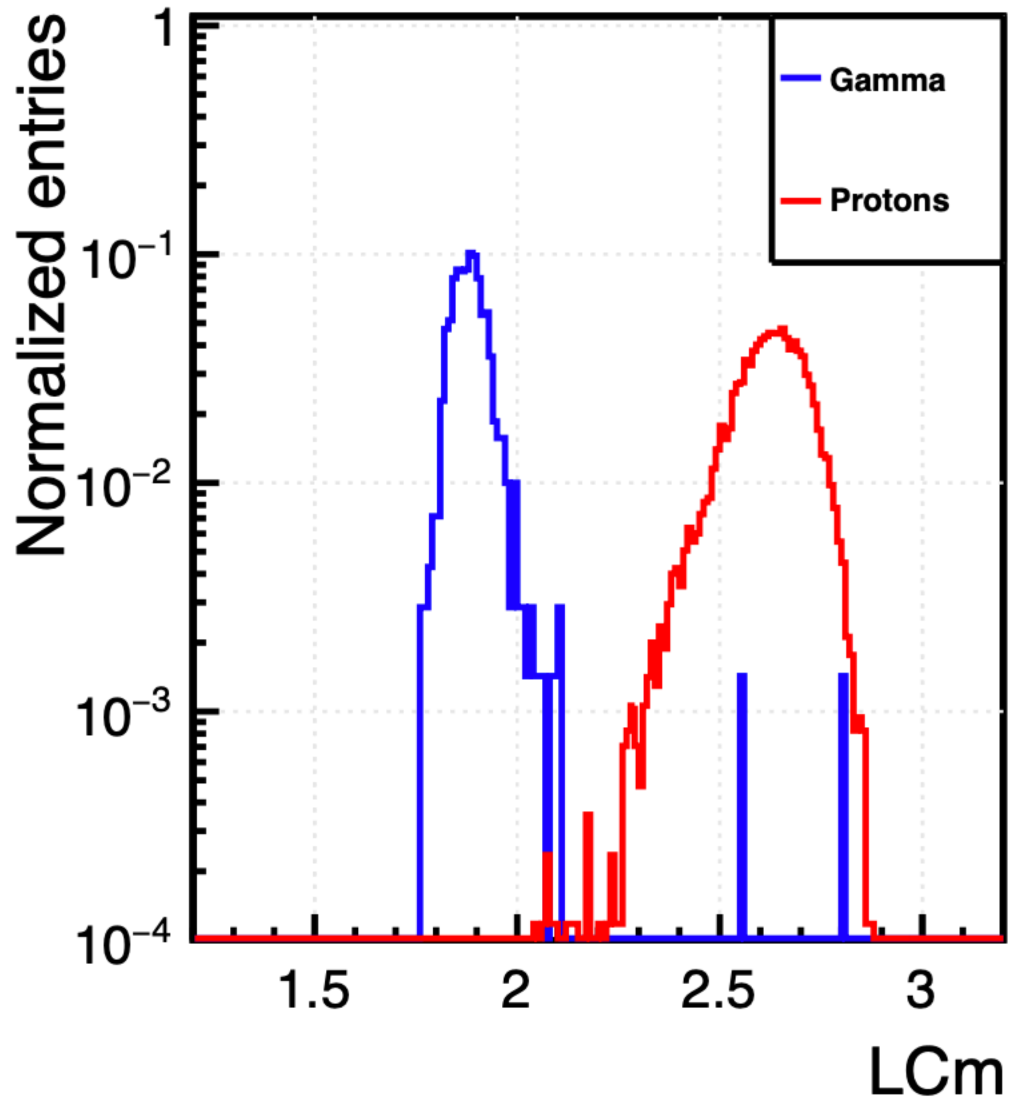


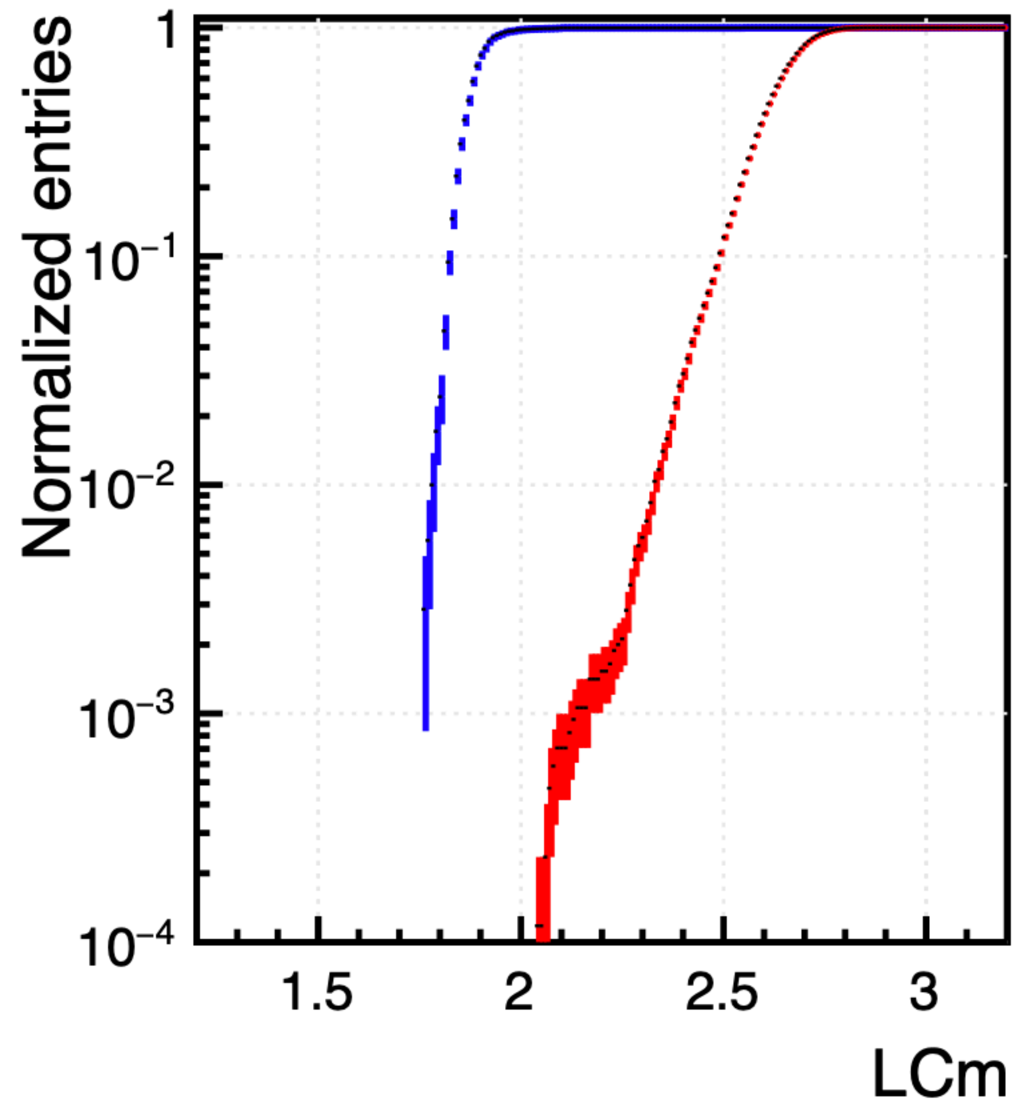


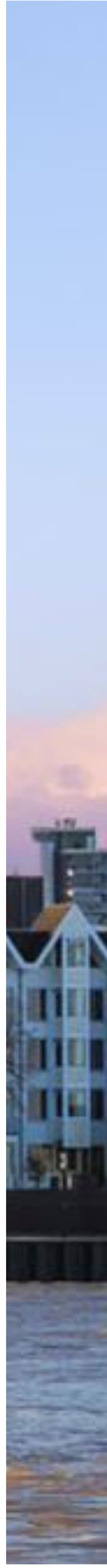
Gamma/hadron discriminator: *LCm*

$$\boxed{LCm \equiv \log\left(C_k\right)\big|_{r_k=360\,\mathrm{m}}}$$



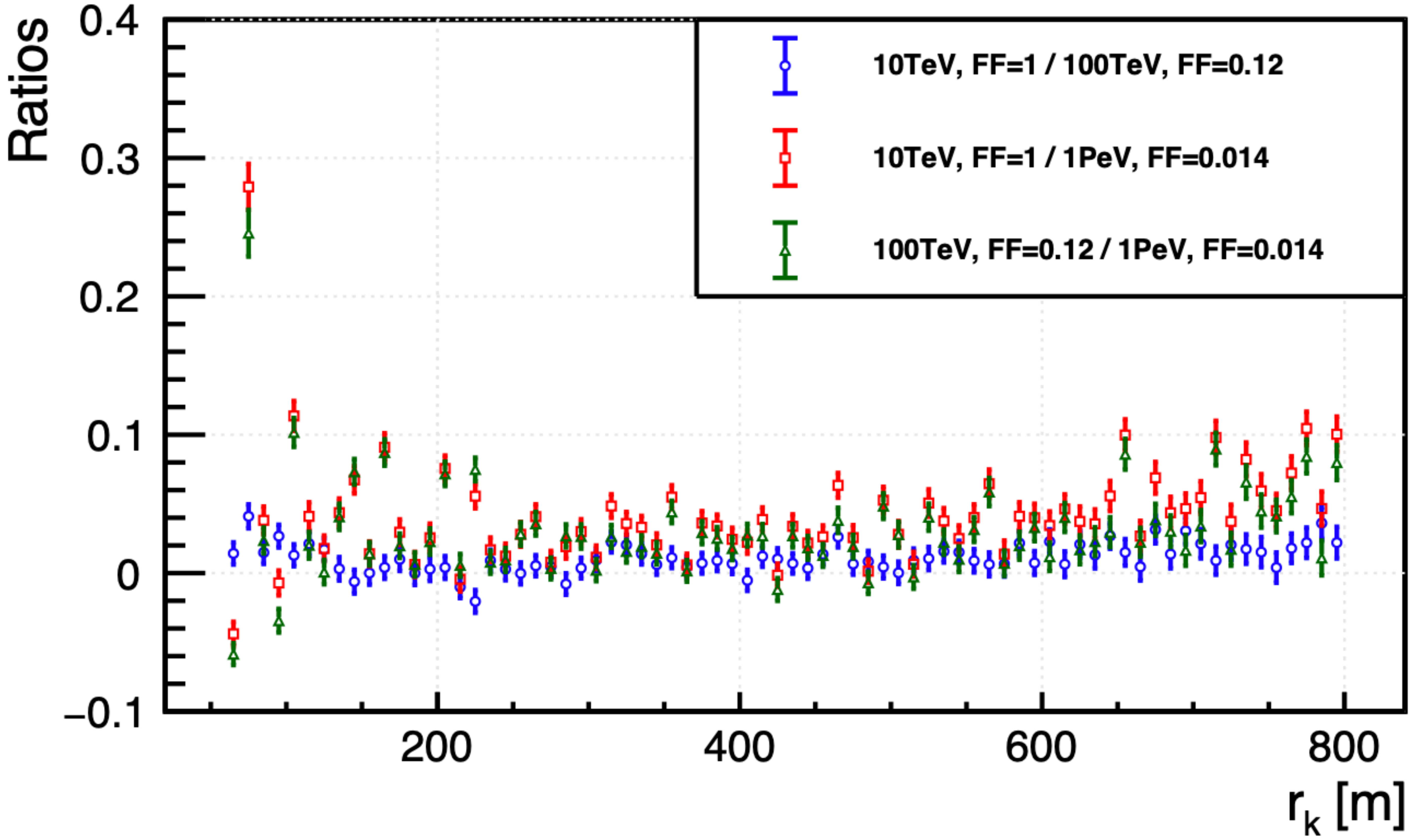






The scaling quantity K

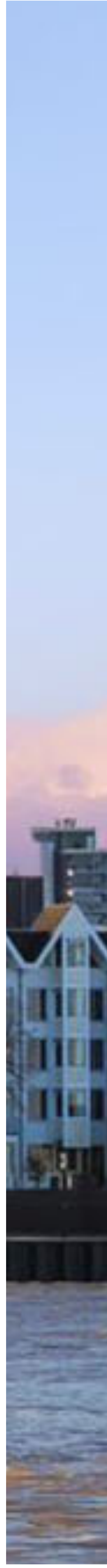
Proton C_k profiles with $\boxed{K \sim 10.6}$



$$\boxed{K = E^{\beta} \times FF}$$

- E is the primary energy [TeV]
- $\beta = 0.925$ is a parameter relating number of muons at ground with the shower energy : $N_{\mu} \propto E^{\beta}$
- FF is the fill factor $\in]0; 1]$

The azimuthal fluctuations are invariant for primary energy and arrays where K is the same



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Modelling the array fill factor

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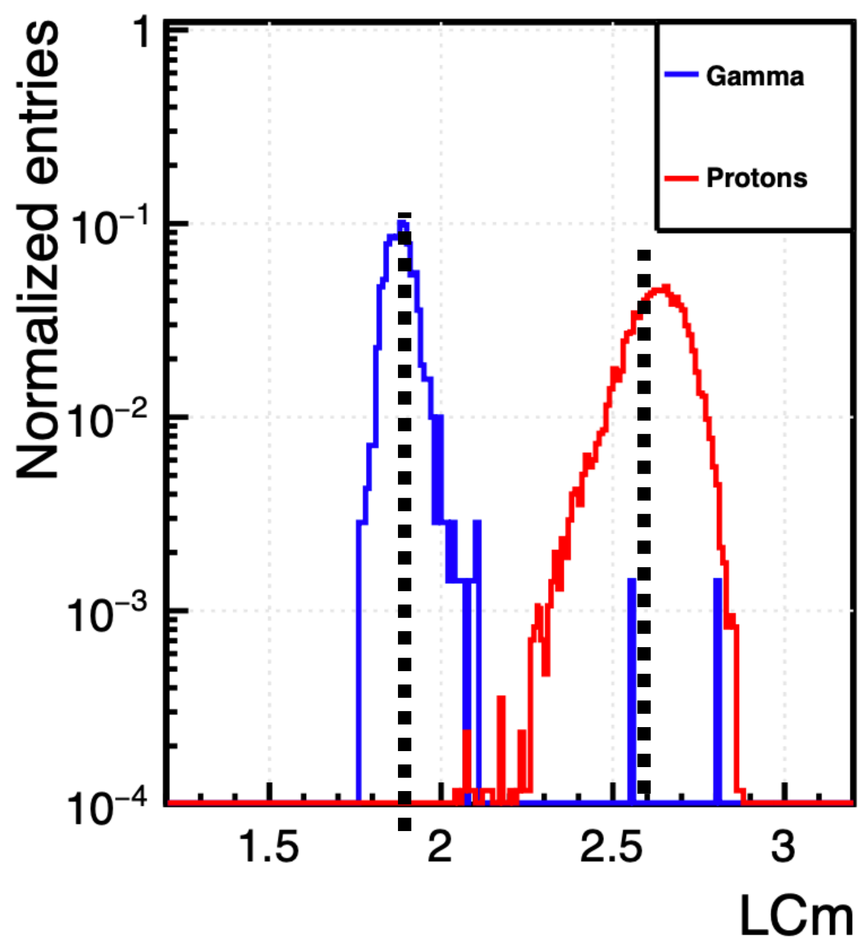
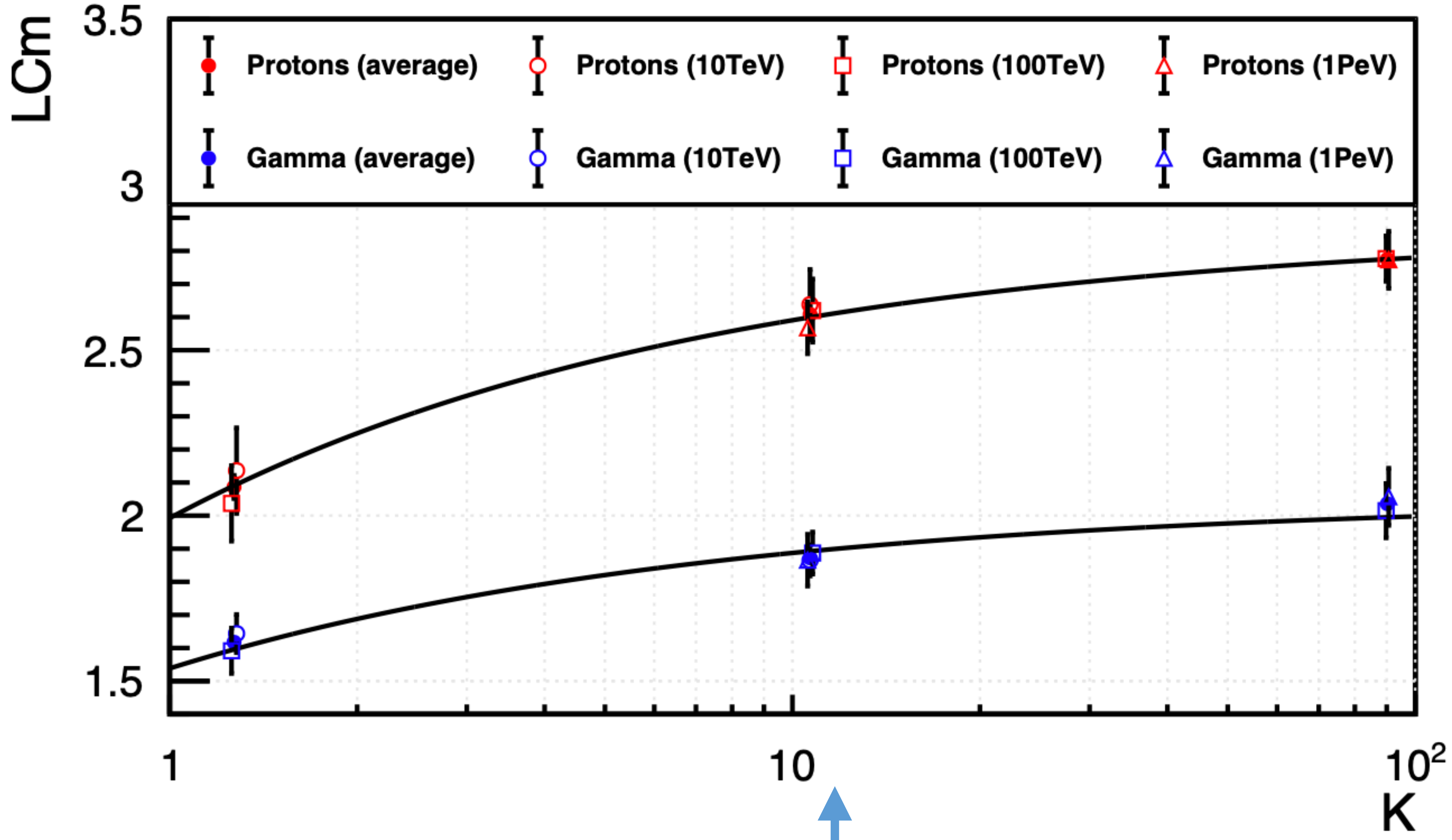
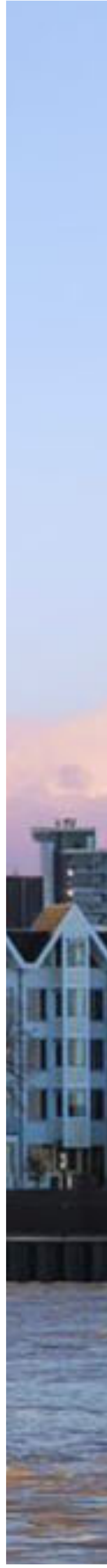




$$\langle LCm_i \rangle (K) \sim A_i + \frac{B_i}{\sqrt{K}}$$



Modelling the array fill factor

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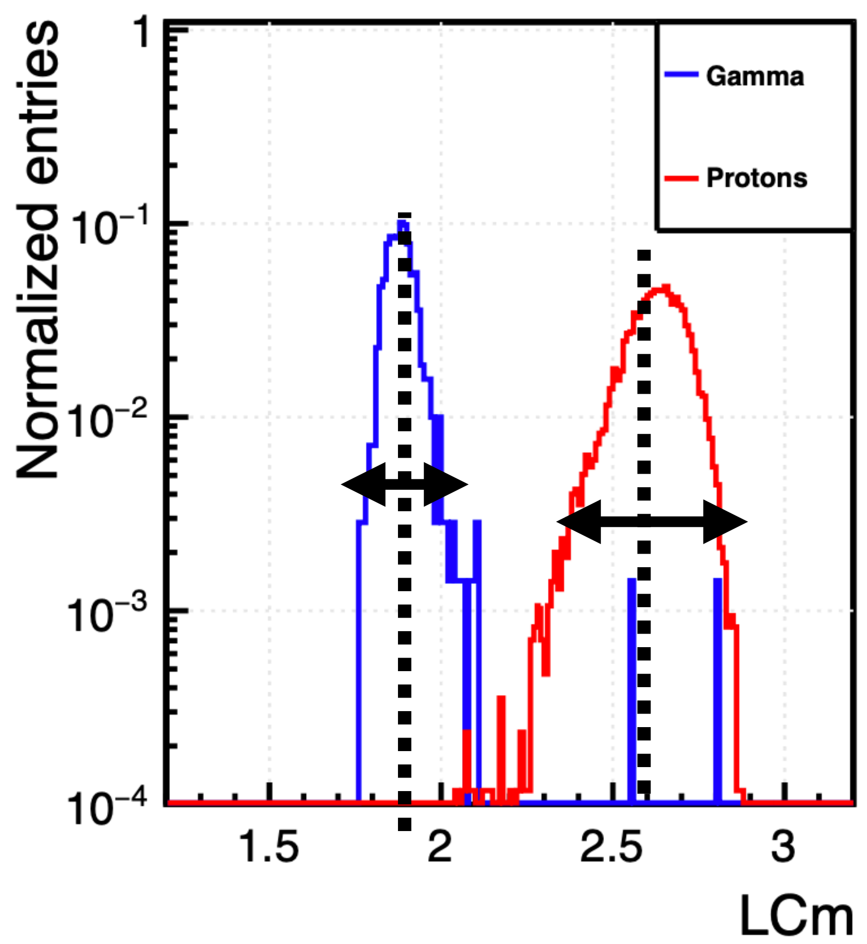
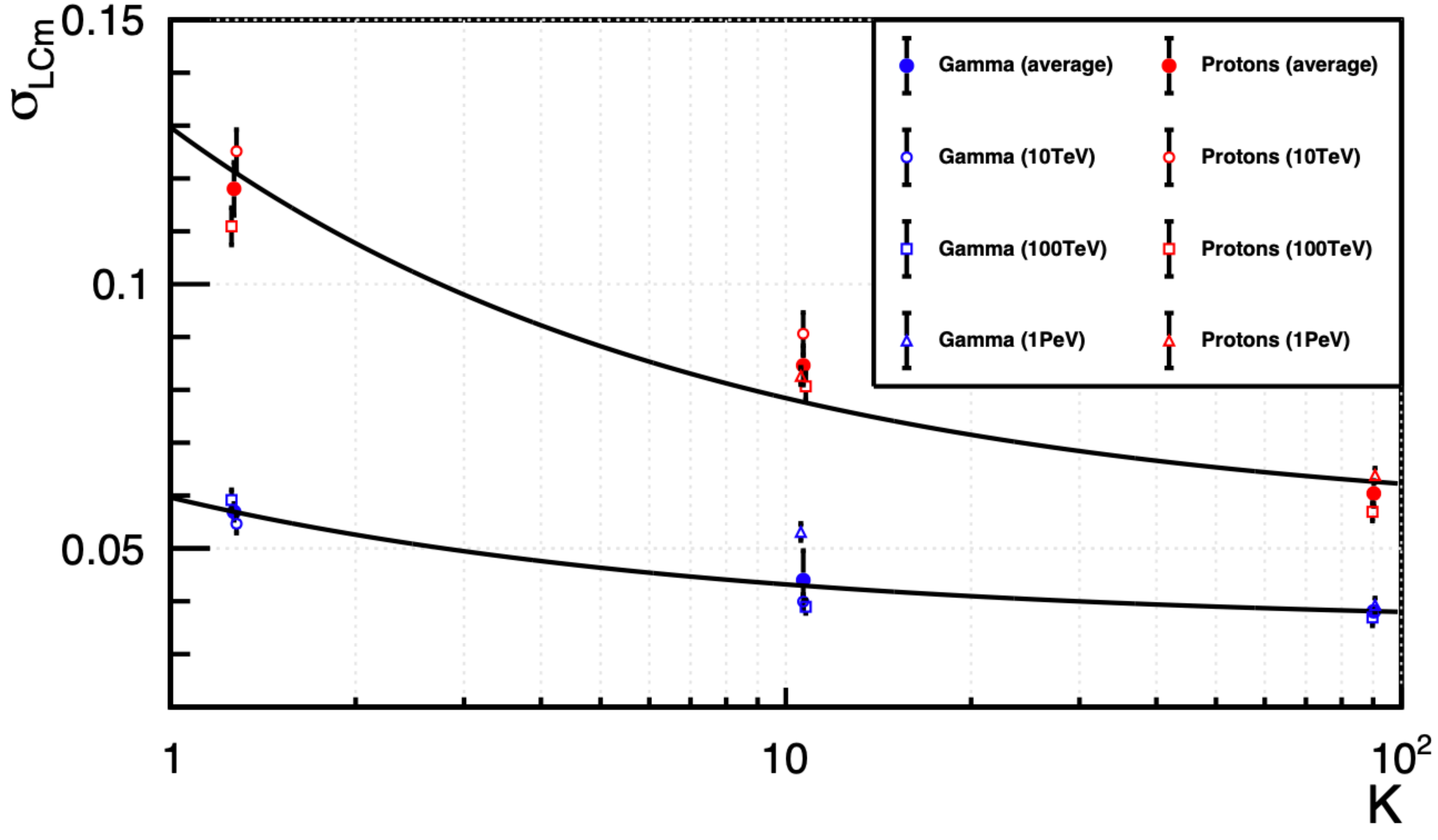
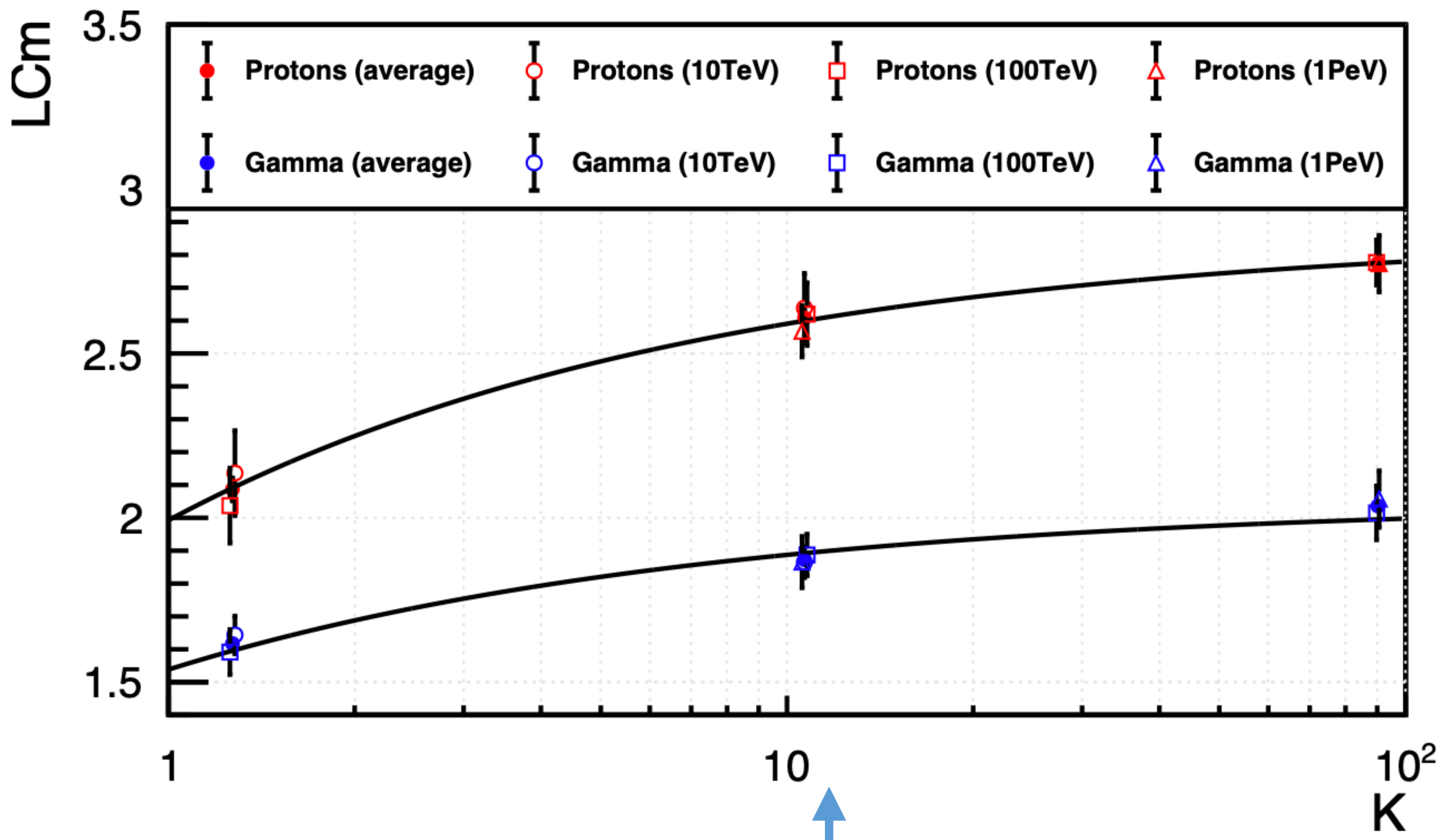
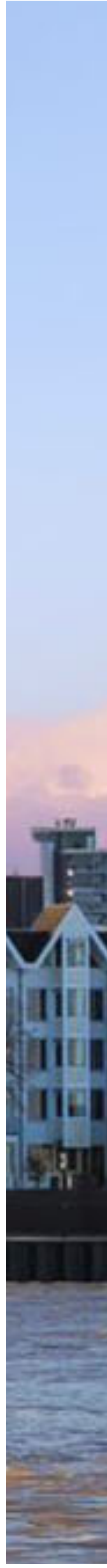






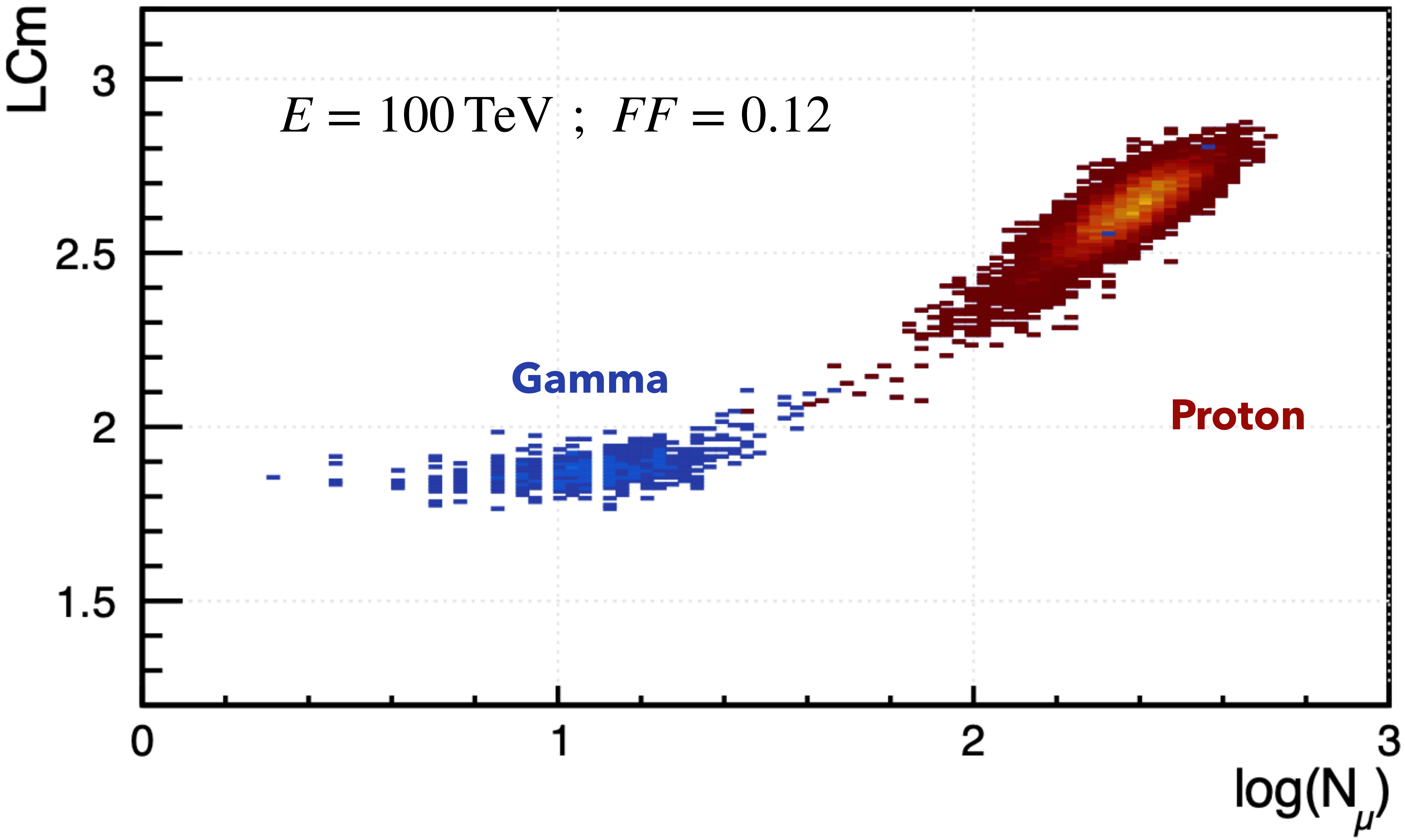
$$\langle LCm_i \rangle(K) \sim A_i + \frac{B_i}{\sqrt{K}}$$

$$\sigma_{LCm_i}(K) \sim \Delta_i + \frac{C_i}{\sqrt{K}}$$



LCm vs N_μ

(Total signal at ground : e.m. + muons + hadrons)



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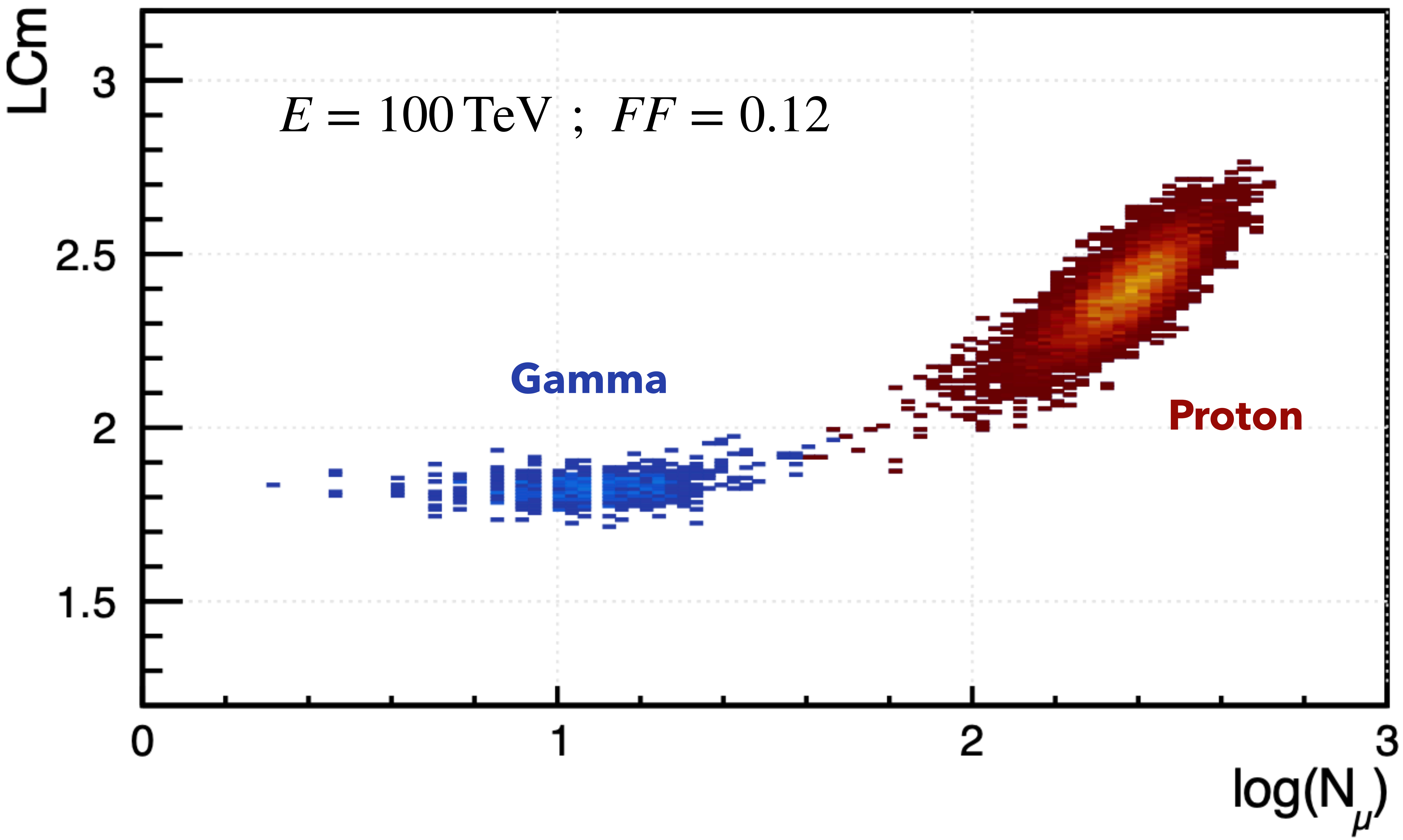
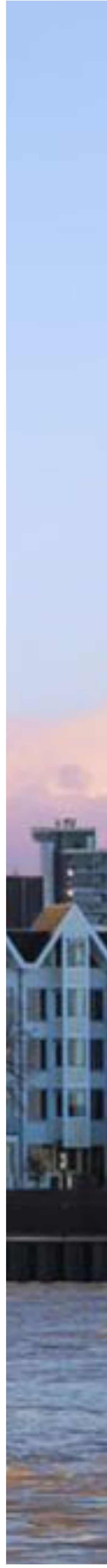
LCm vs N_μ

(Electromagnetic signal at ground : e.m. + ~~muons~~ + ~~hadrons~~)



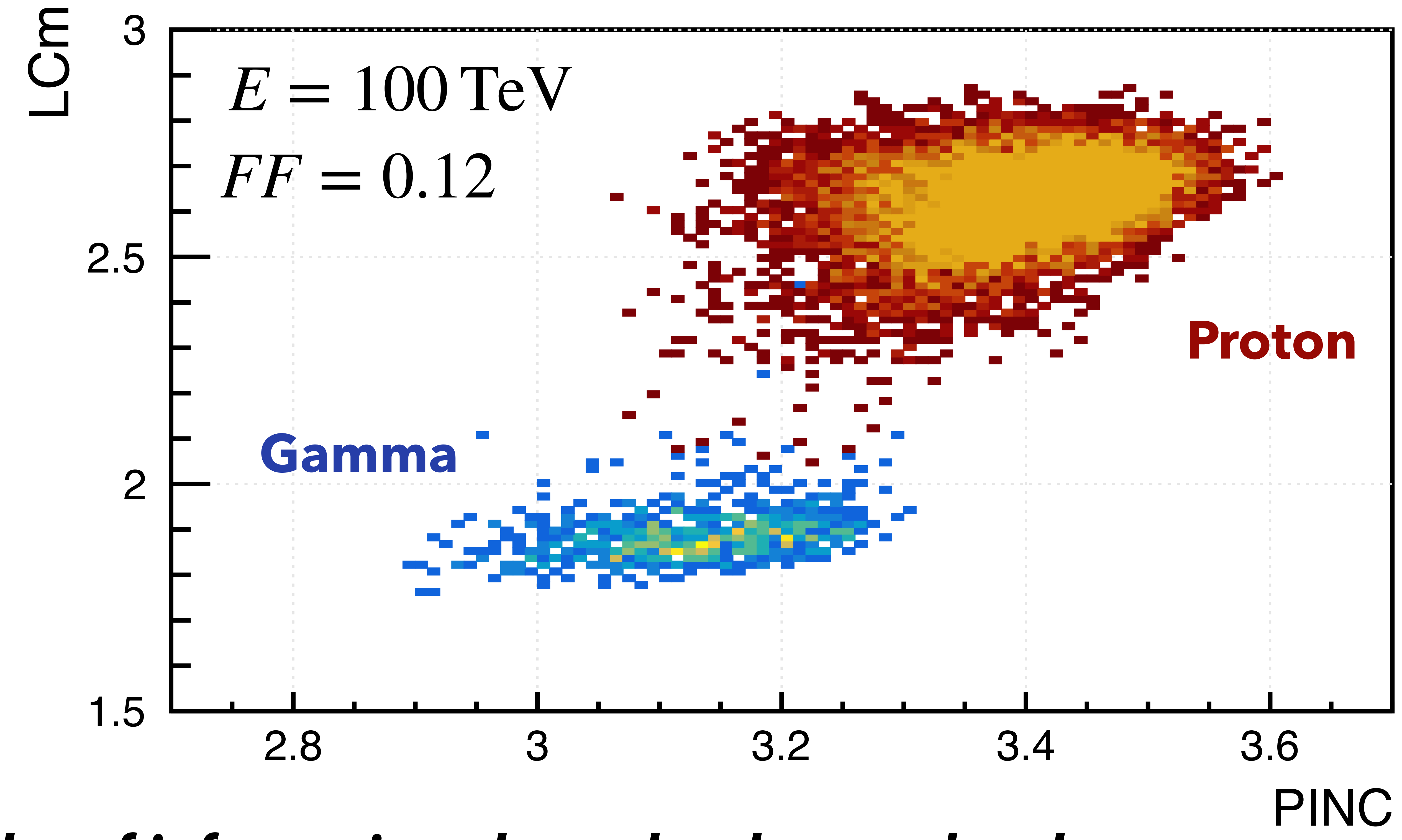


LCm vs PINCness

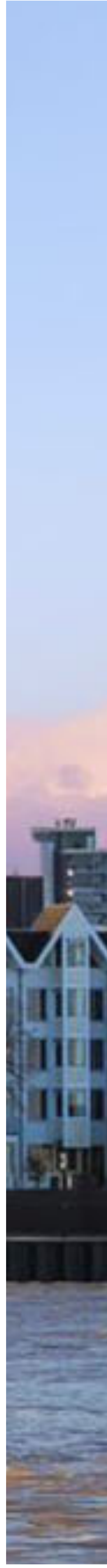
(Total signal at ground : e.m. + muons + hadrons)

- Check potential comparing with other known similar g/h discriminators
- PINC (Parameter for IdeNtifying Cosmic rays)
  - HAWC collaboration
  - [arXiv:2205.12188](https://arxiv.org/abs/2205.12188)
  - Explores the fluctuations along the lateral profile

$$PINC = \frac{1}{N}\sum_{i=0}^{N}\frac{\left[\log_{10}(q_i) - \langle \log_{10}(q_i)\rangle\right]^2}{\sigma^2}$$



The azimuthal distributions contain a lot of information about the shower development



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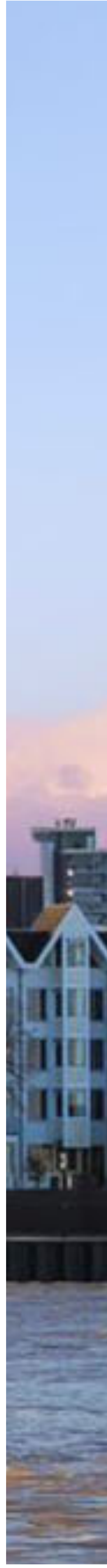
Summary

- A new variable (C_k) has been introduced to evaluate the shower azimuthal fluctuation level and a new gamma/hadron discriminator (LCm) based on this analysis is proposed

- It has been shown that excellent gamma/hadron discrimination is possible through the assessment of the shower azimuthal fluctuations (even analysing solely the electromagnetic shower component at the ground!)

arXiv:2205.12188



Acknowledgements

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Lisb@20^20

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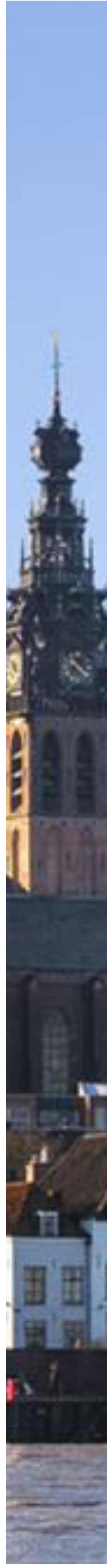
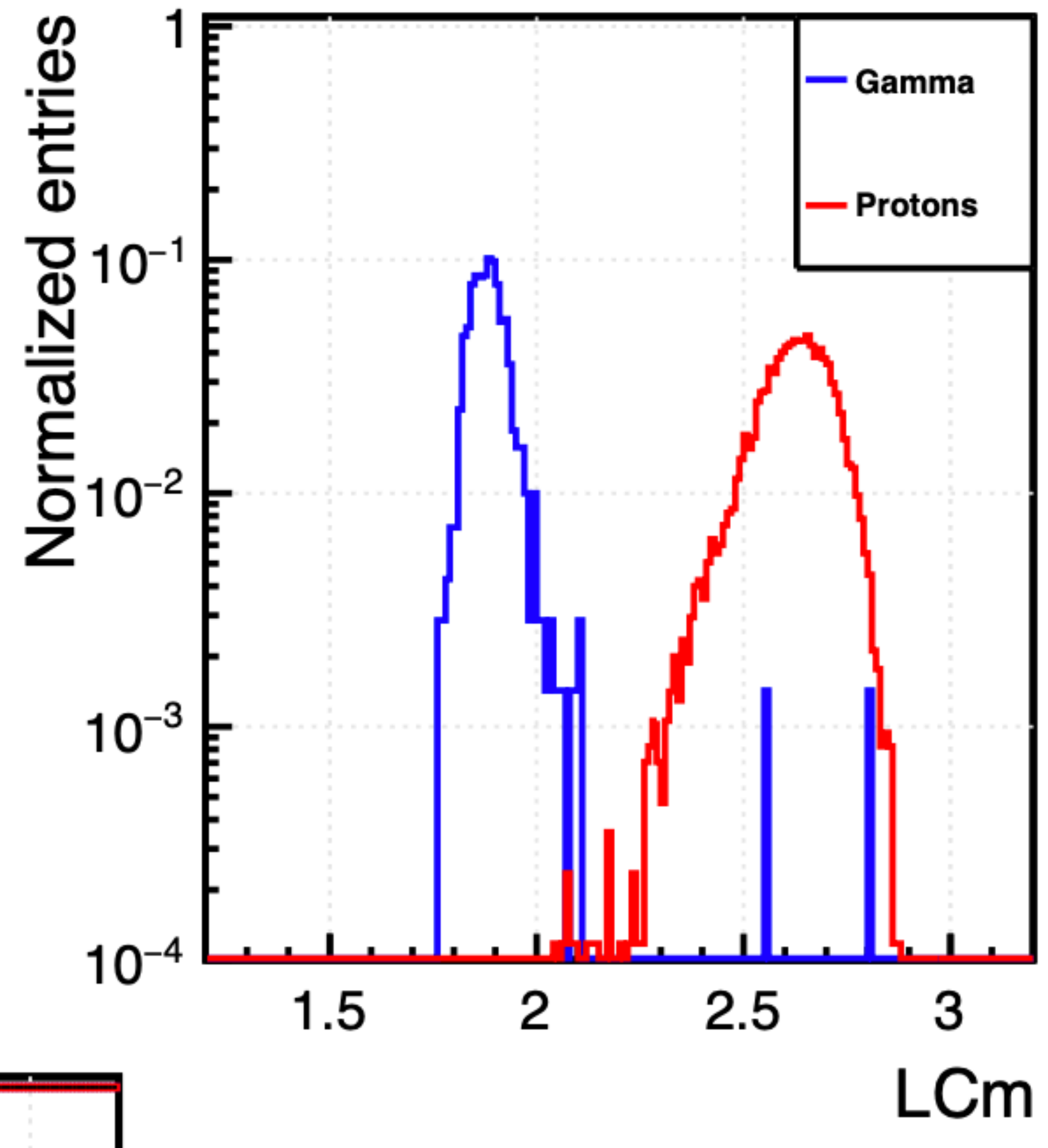
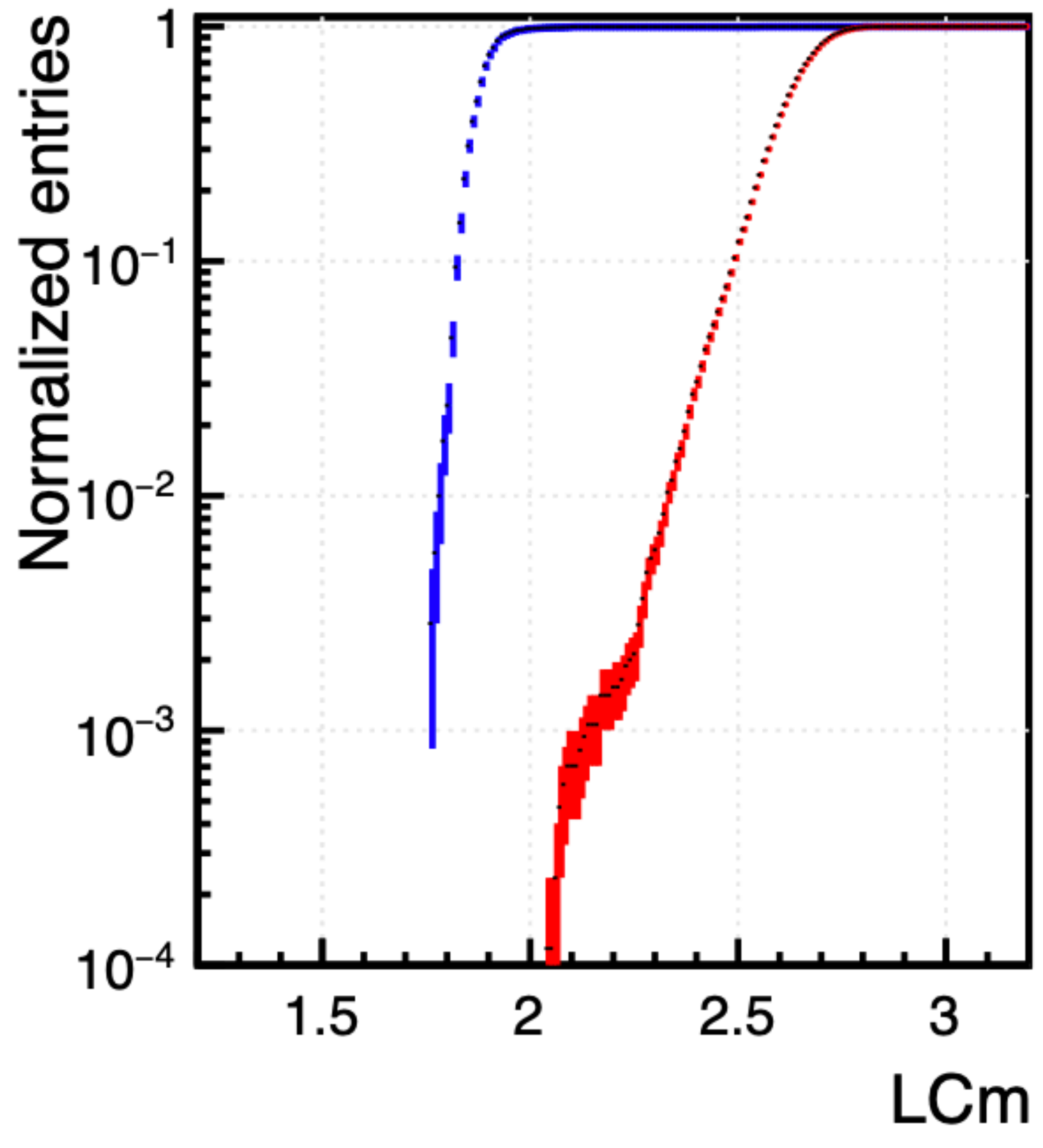


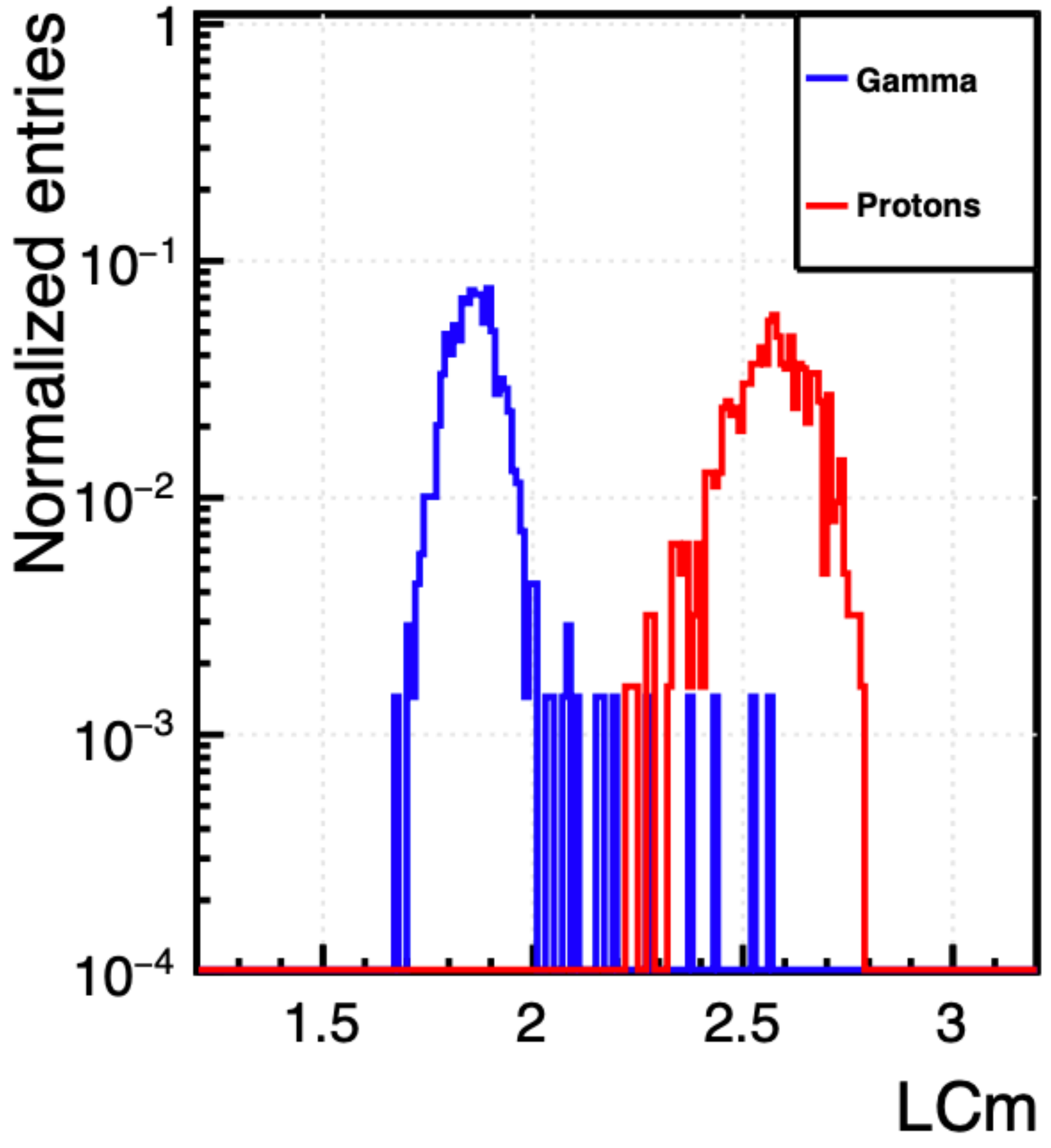
BACKUP SLIDES

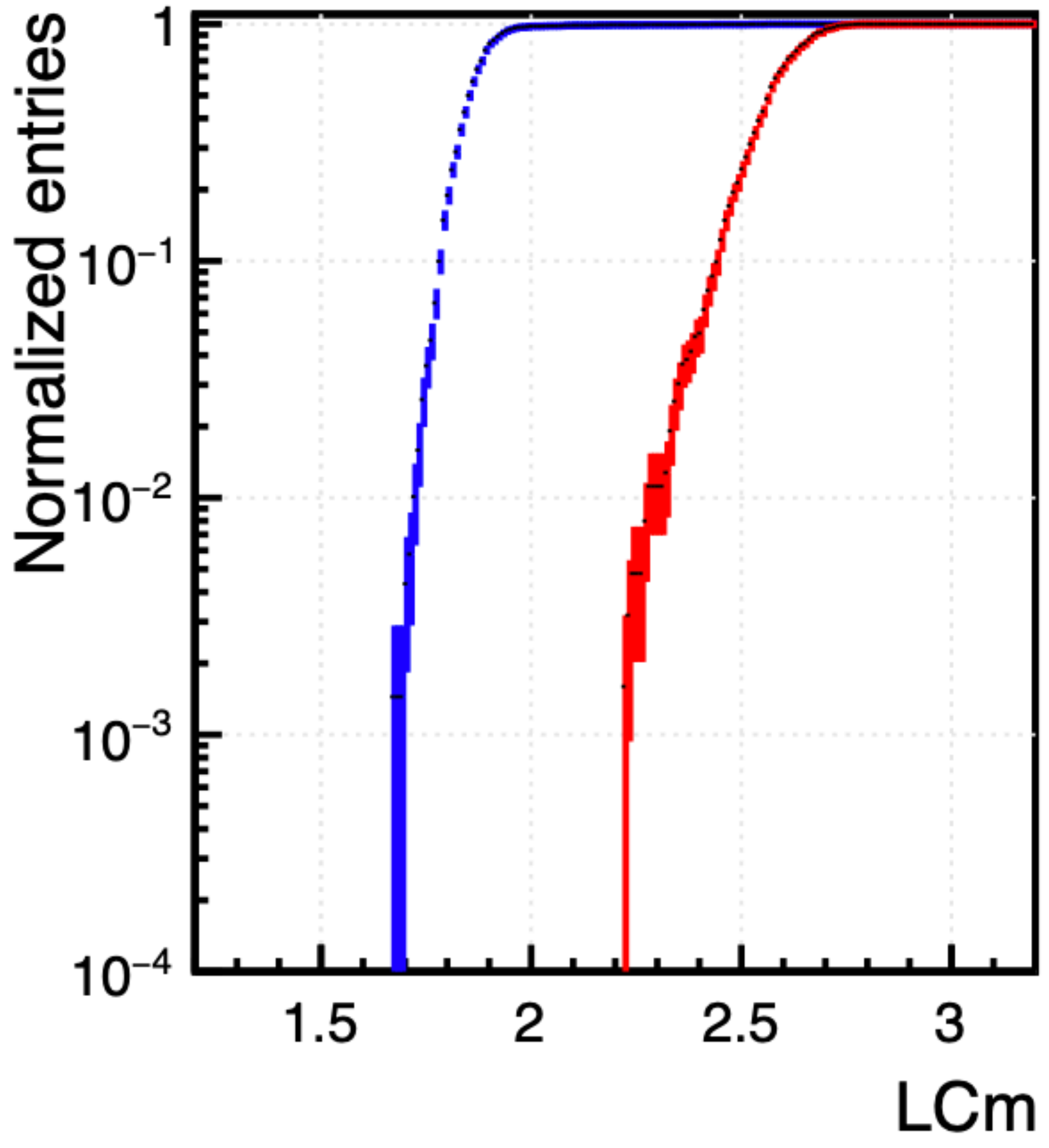
Gamma/hadron discrimination

$E = 100\,\mathrm{TeV}\ ;\ \ FF = 0.12$

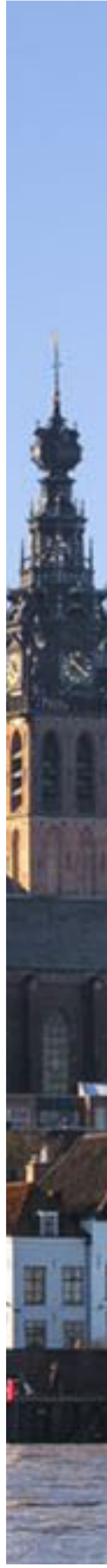








$E = 1\,\mathrm{PeV}\ ;\ \ FF = 0.014$



WCD signal fluctuations