Investigating Gamma/Hadron Discrimination Features to Augment Gamma-Ray Observatory Physics Capabilities

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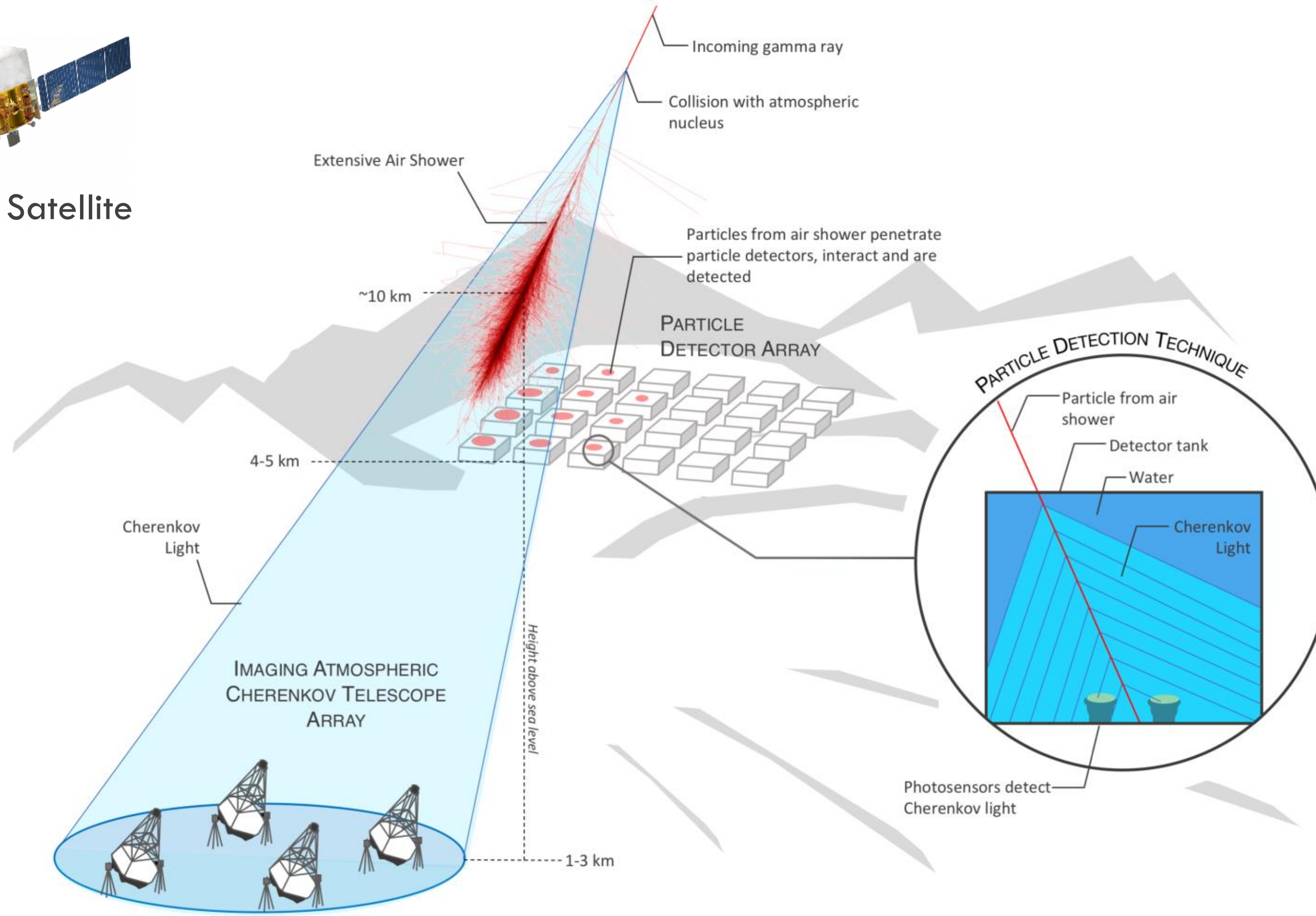
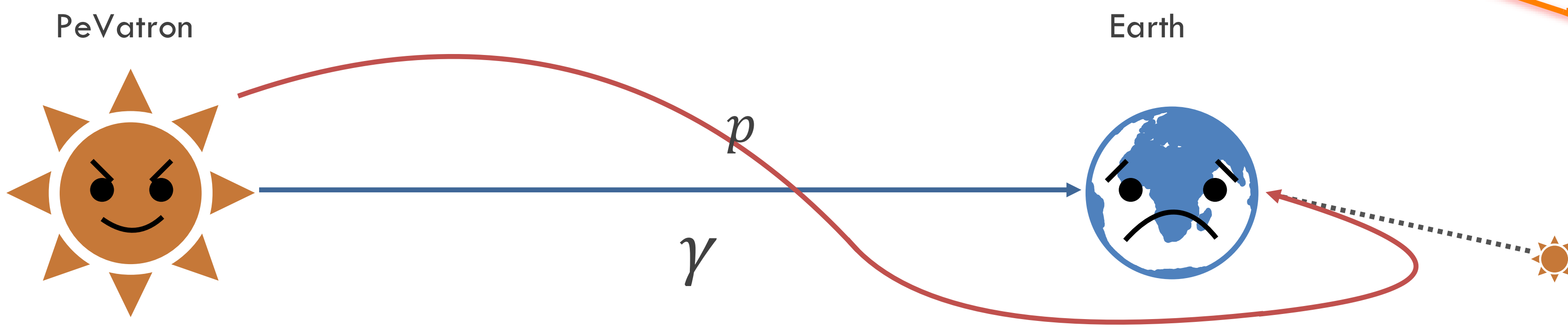
High-energy gamma-ray detection techniques

Fermi Satellite

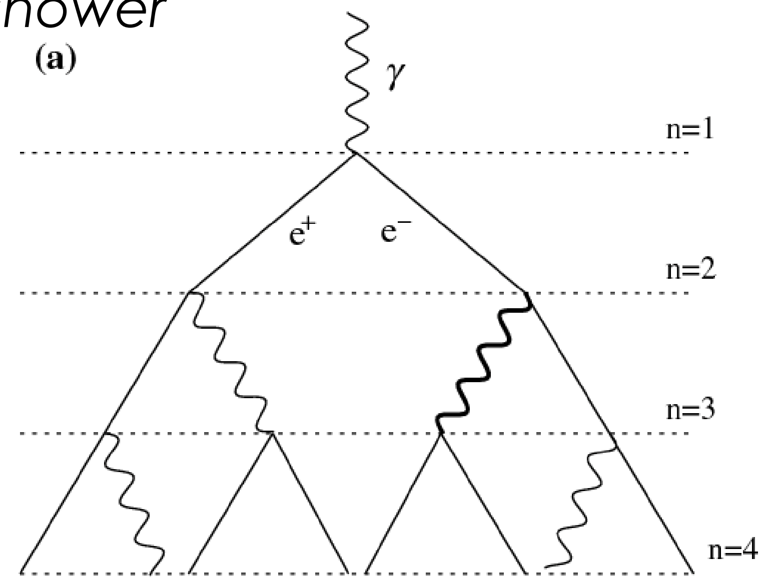


LHAASO experiment

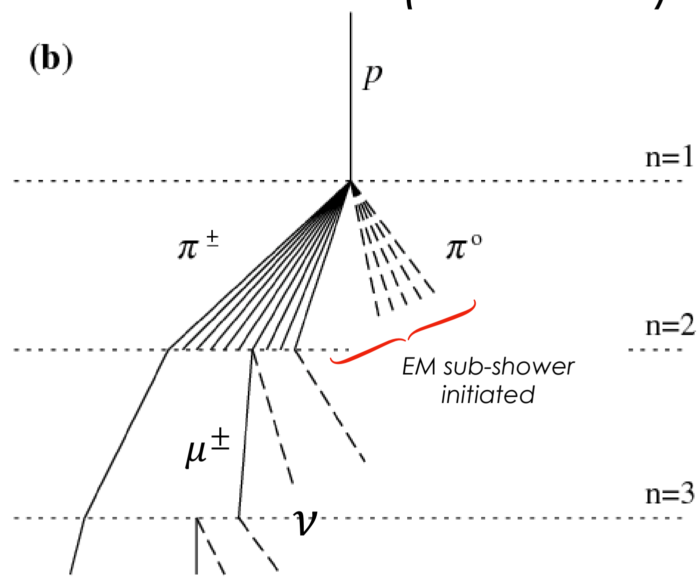
Gamma Rays vs Cosmic Rays



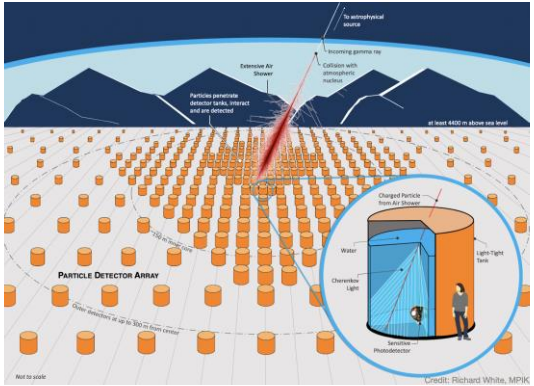
Gamma-initiated (EM) shower



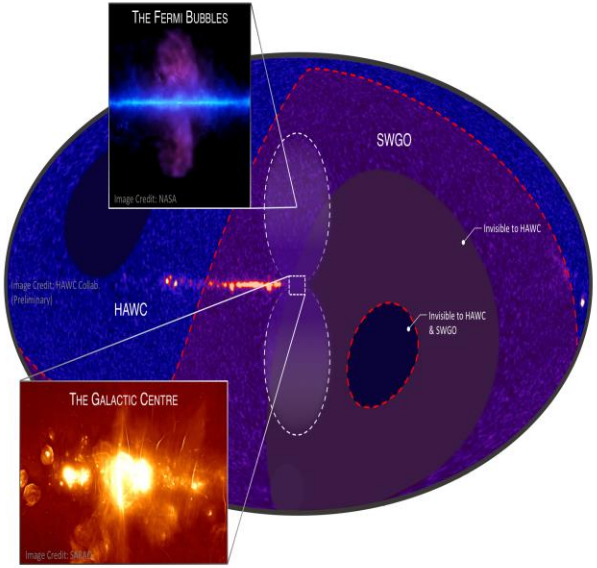
Proton-initiated (hadronic) shower



The Southern Wide-field Gamma-ray Observatory



- 15-countries collaboration.
- Next generation gamma-ray observatory currently in R&D phase.
- To be built at high altitude in Atacama Astronomical Park, Chile.
- Large ground array based on Water Cherenkov Detectors.
- Able to observe the galactic center.

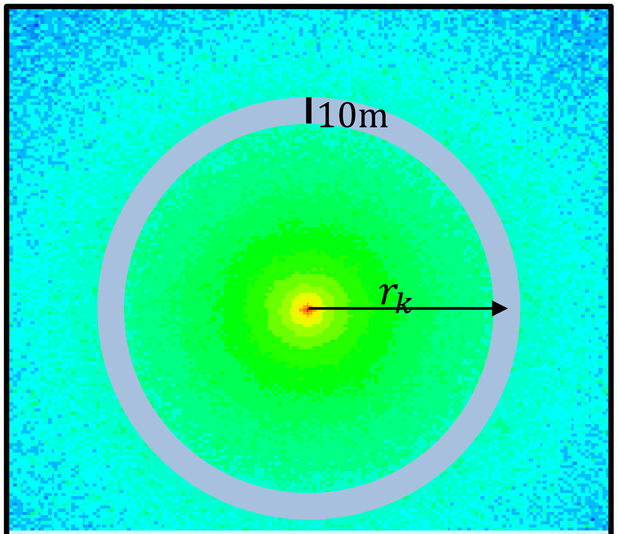


But enormous background to be dealt with!

- Gamma rays buried in hadronic background.
- Excellent gamma/hadron discrimination capabilities needed.
- Muon counting → commonly used strategy, but expensive and with high environmental impact.
- Talks of grouping tanks to save on costs.
- Alternative based on the total signal collected by the WCDs desirable.

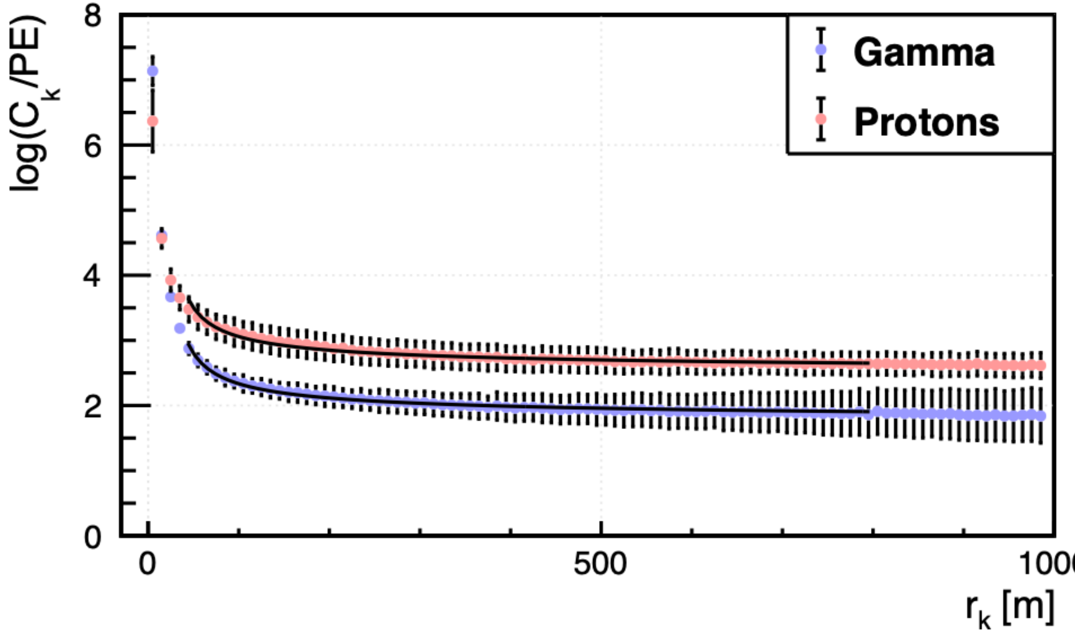
Exploring the shower footprint - the C_k variable

- Idea: quantifying the complex structure of hadronic showers through the azimuthal asymmetries of their footprint.



Ring with n_k stations and mean signal $\langle S_k \rangle$

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



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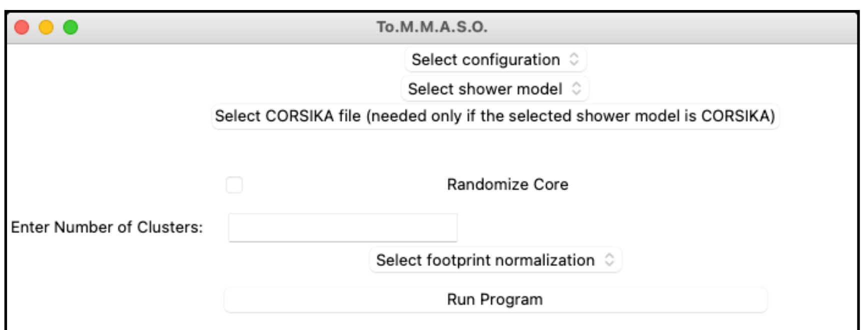
To.M.M.A.S.O.

Toy Montecarlo Model of an Air Shower Observatory

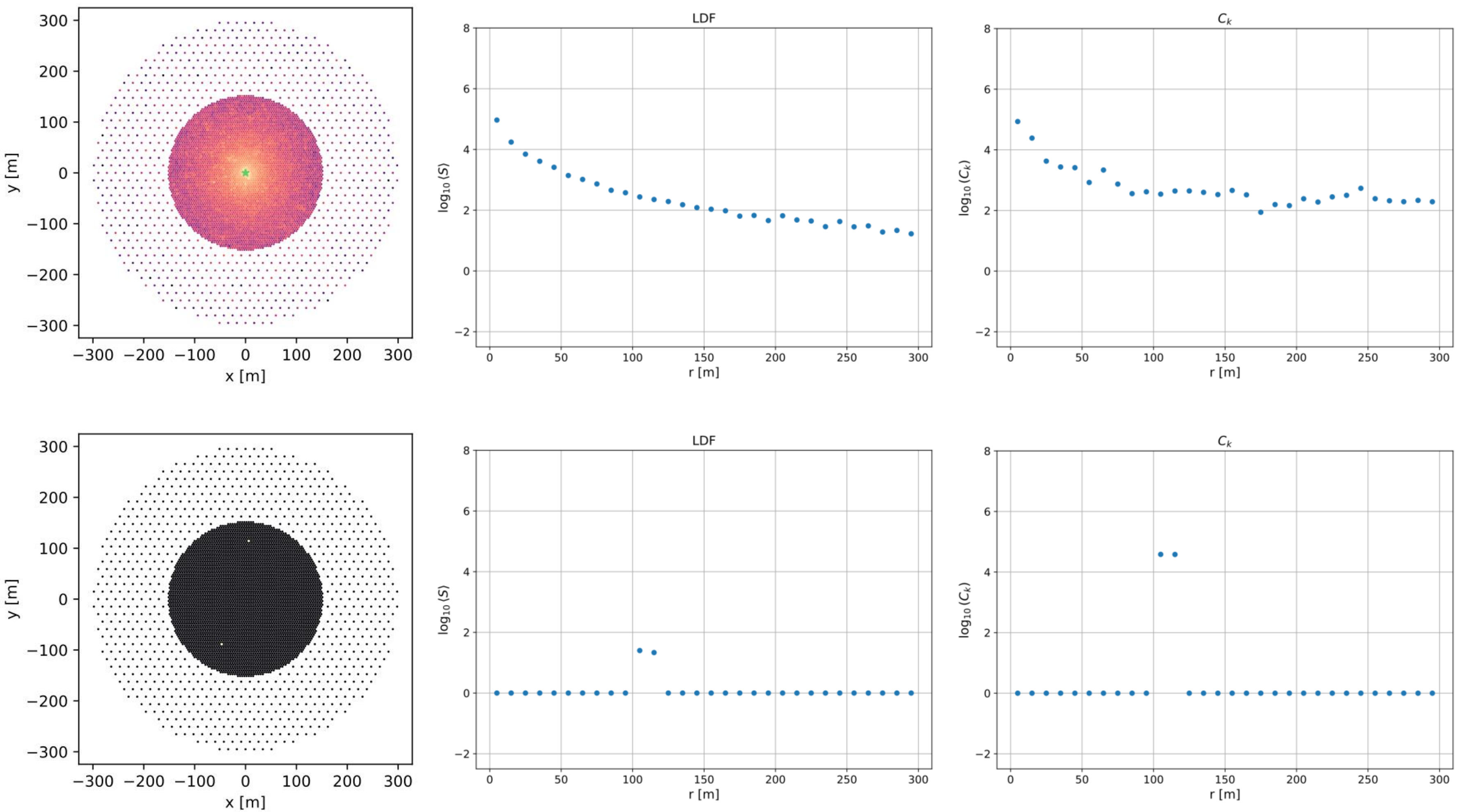
- A Python framework for the emulation of gamma-ray ground array aimed at studying shower variables in a controlled environment.
- Using array layouts designed by the SWGO collaboration and custom layouts.
- Emulating showers injecting known signal distributions (uniform, NKG, …) into the array.
- Compatible with CORSIKA showers.

```
class Shower:

    def __init__(self, tanks, randomizeCore):

        self.nRings = 30
        self.ringWidth = 10. #[m]
        self.rings = []
        self.init_rings()

        centralTank = random.choice(tanks)
        centralTank : Tank

        self.core_x = 0.0
        self.core_y = 0.0
        #or I can have the core in any random tank
        if randomizeCore:
            self.core_x = centralTank.x
            self.core_y = centralTank.y

        for tank in tanks:
            tank : Tank #this just to have autocompletion
            tank.find_core_distance(self.core_x, self.core_y)
            tank.find_ring(self.nRings, self.ringWidth)
```

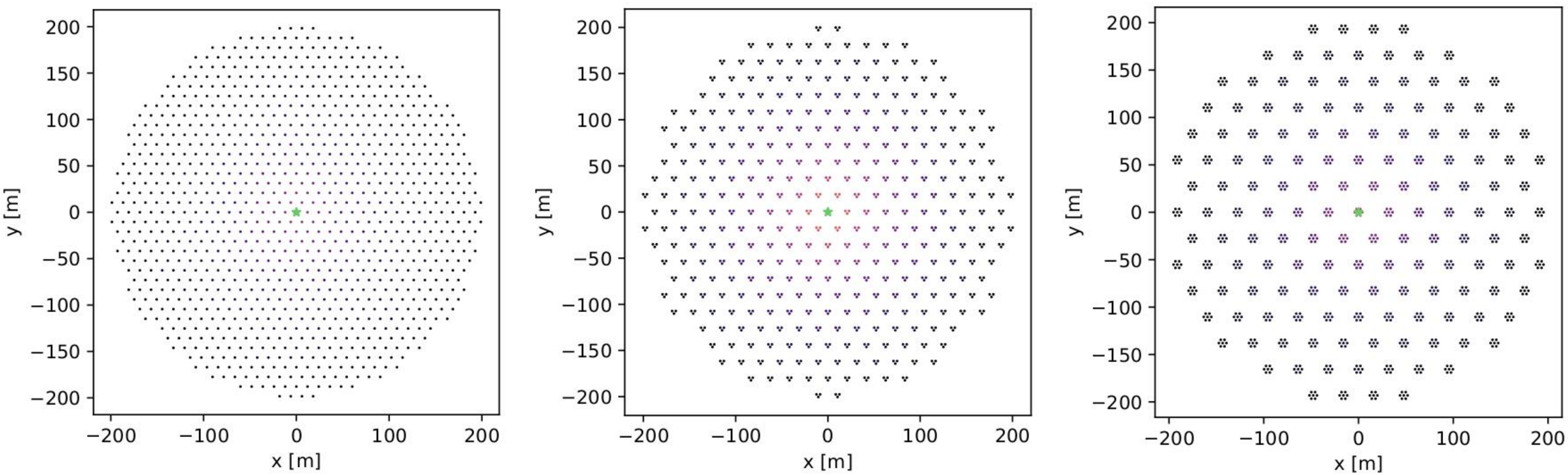



```
obs = Observatory(config_header_file)
shower = Shower(obs.tanks, randomizeCore)

if shower_model == "NKG":
    shower.generate_nkg(obs.tanks)
elif shower_model == "Uniform":
    shower.generate_uniform(obs.tanks)
elif shower_model == "CORSIKA":
    corRead = CorsikaReader(corsika_file, obs.tanks)
    shower.inject_corsika_particles(obs.tanks, corRead.particles)
```

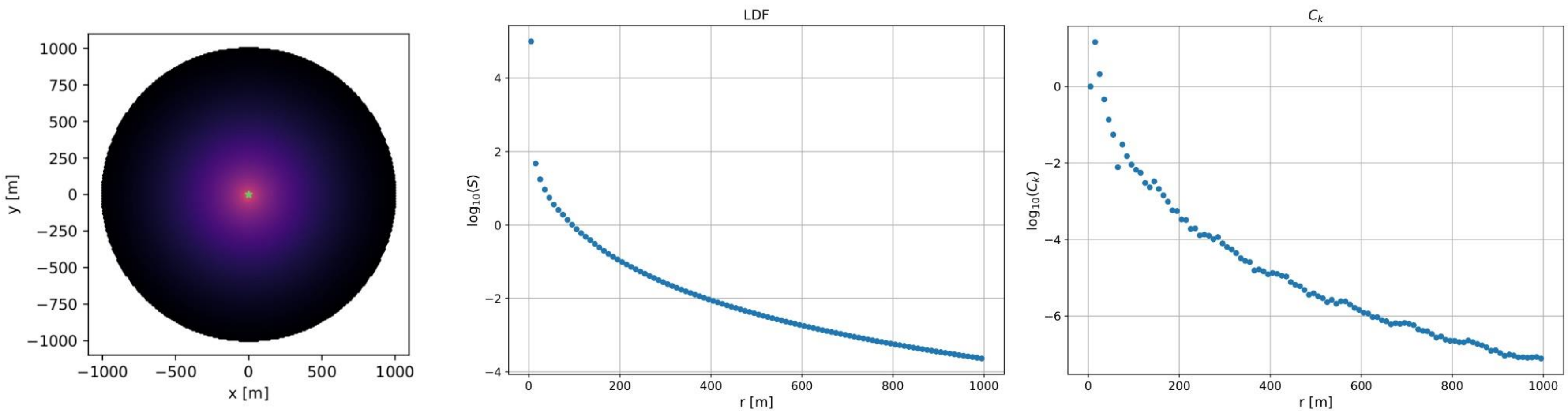
To.M.M.A.S.O.


y [m]
x [m]
LDF
log10 (S)
r [m]
C_k
log10 (C_k)
r [m]
y [m]
x [m]
LDF
log10 (S)
r [m]
C_k
log10 (C_k)
r [m]

Clusterization



Example Simulation

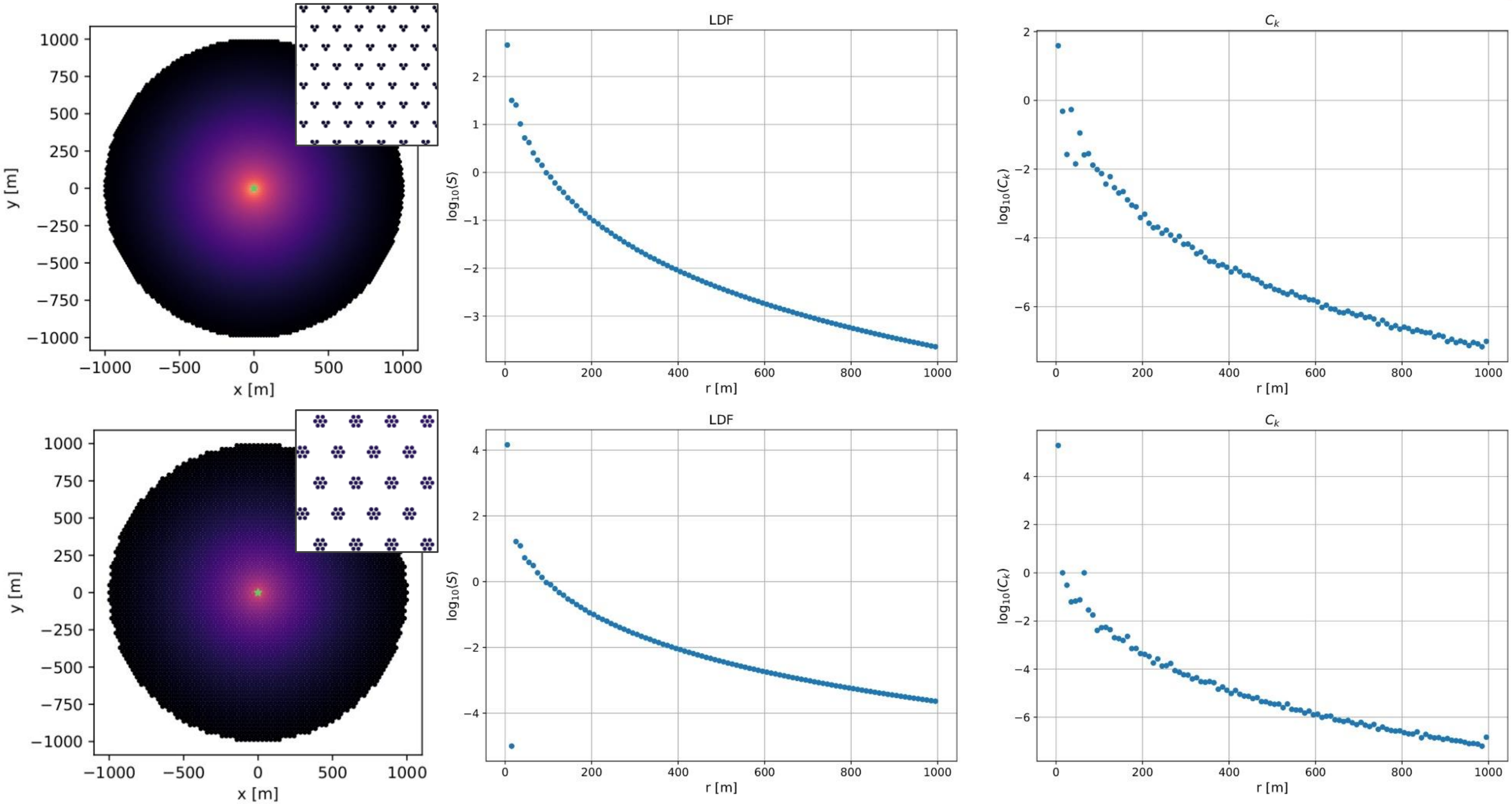


- Radius: 1Km
- Fill Factor: 12.5%
- Applied Signal: NKG

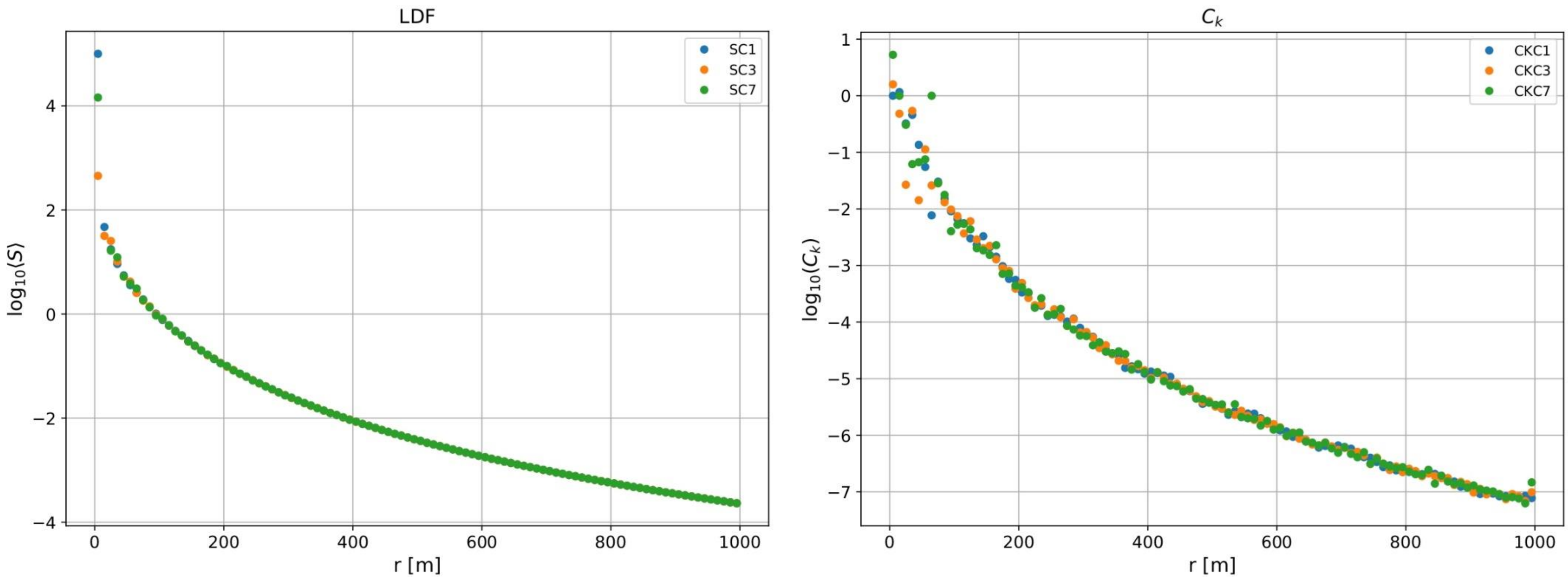
$$S_{\text{tank}} = C\left(\frac{d_{\text{tank}} + 0.01}{r_{\text{M}}}\right)^{s-2}\left(\frac{d_{\text{tank}} + 0.01}{r_{\text{M}}} + 1\right)^{s-4.5}$$

$$C = 1000, r_{\text{M}} = 100, s = 1$$

Clusters of 3 and 7

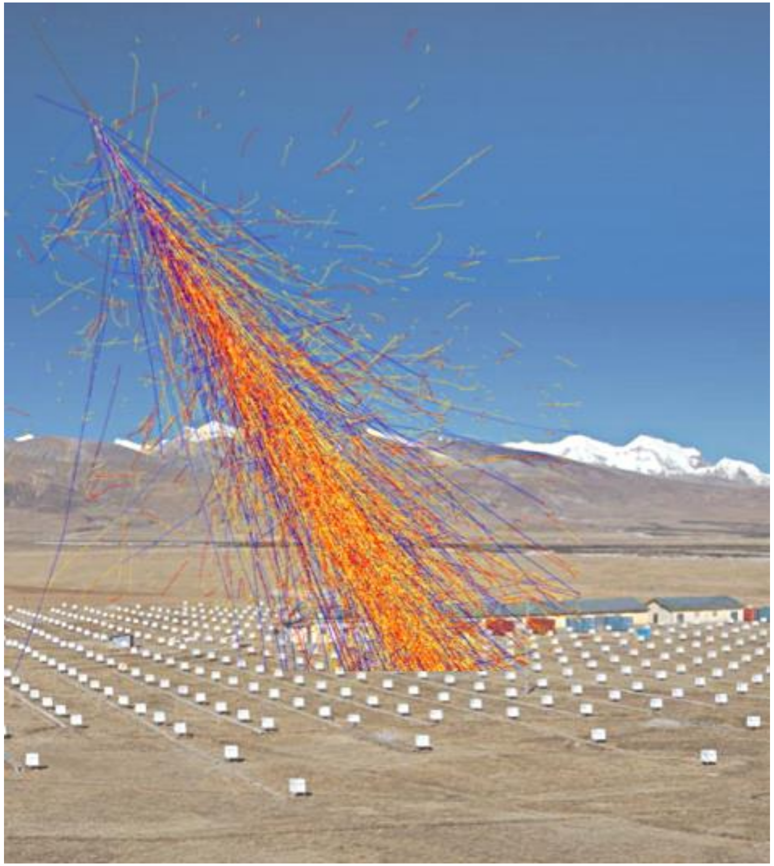


Comparison


LDF
SC1
SC3
SC7
$\log_{10}\langle S \rangle$
4
2
0
−2
−4
0
200
400
600
800
1000
r [m]
C_k
CKC1
CKC3
CKC7
$\log_{10}(C_k)$
1
0
−1
−2
−3
−4
−5
−6
−7
0
200
400
600
800
1000
r [m]

Conclusions

- SWGO will be the first high altitude large ground array based on Water Cherenkov Detectors in the Southern hemisphere.
- There's a need for new Gamma/Hadron Discrimination techniques
- The C_k variable is a good discriminator between cosmic and gamma rays
- Clustering the tanks has a negligeable impact on the C_k variable

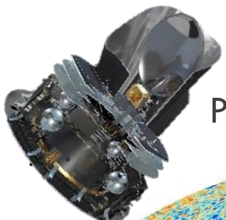


SWGO
The Southern Wide-field Gamma-ray Observatory

Backup slides

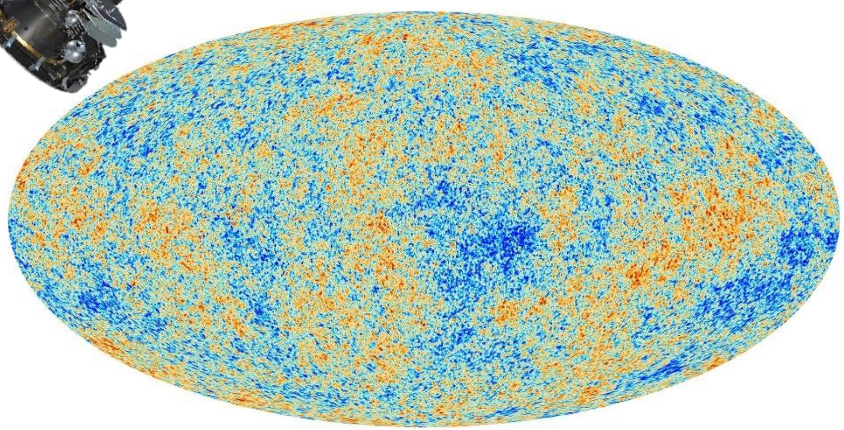
Gamma Rays

- Universe has sources of charged and uncharged particles (cosmic rays and gamma rays)
- Cosmic rays are predominant and form background cosmic radiation
- Gamma rays travel in a straight line (don’t interact with magnetic fields)

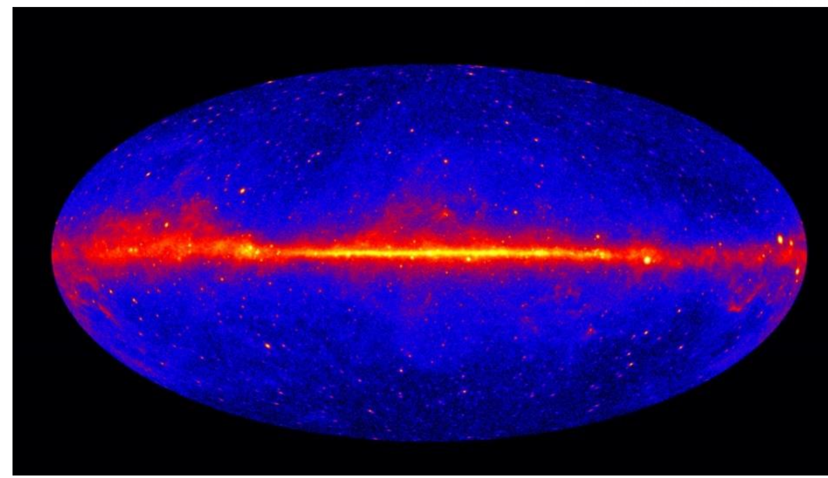


Planck Satellite

Fermi Satellite



Cosmic microwave background sky map



Gamma ray sky map

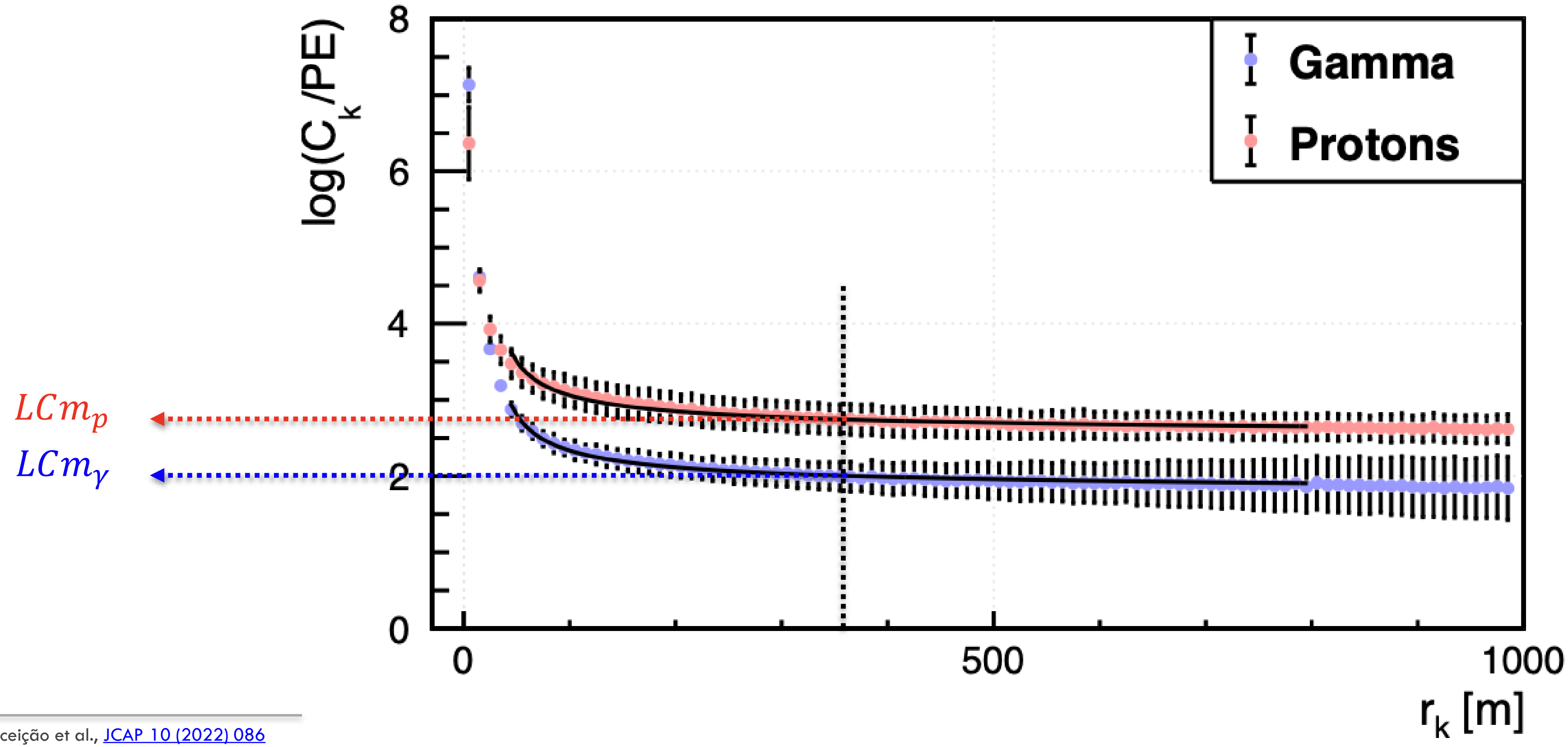
Sky maps looking at diferente wave lenghts

LCm - a high-resolution gamma/hadron discriminator

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

$$LCm \equiv \log(C_k)|_{r_k = r_m}$$

$$r_m = 360m$$



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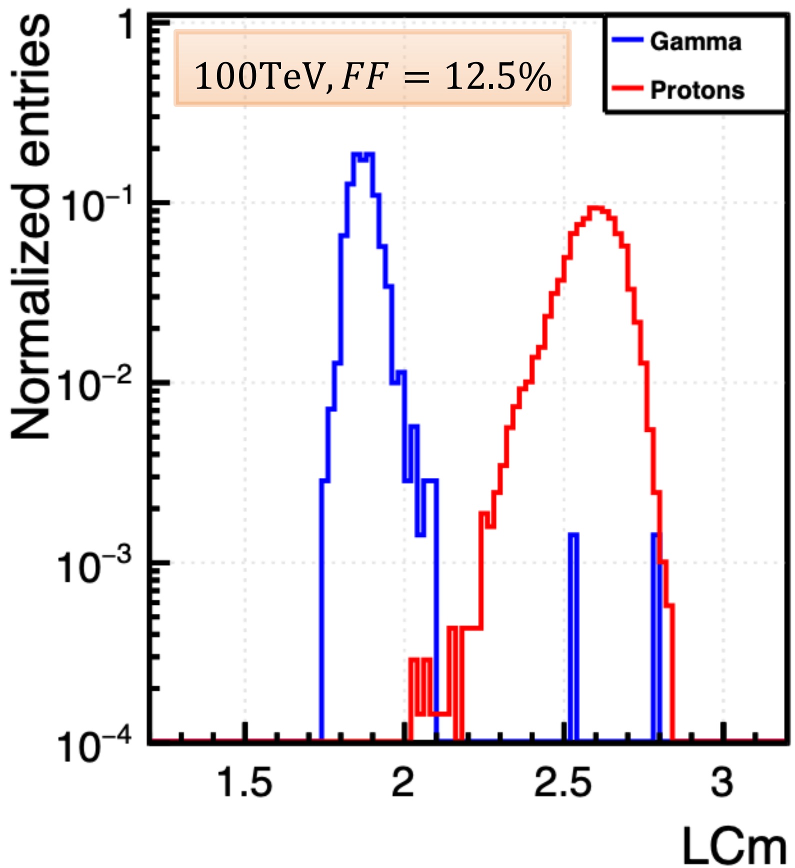
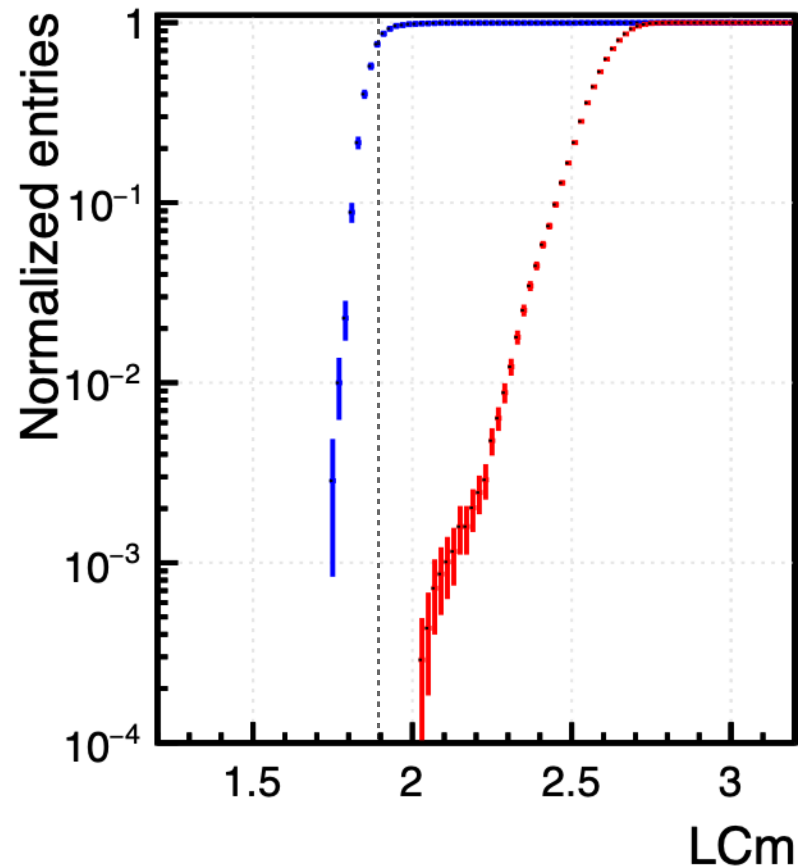
LCm - a high-resolution gamma/hadron discriminator





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