Light Studies and exotics events at Pierre Auger Observatory

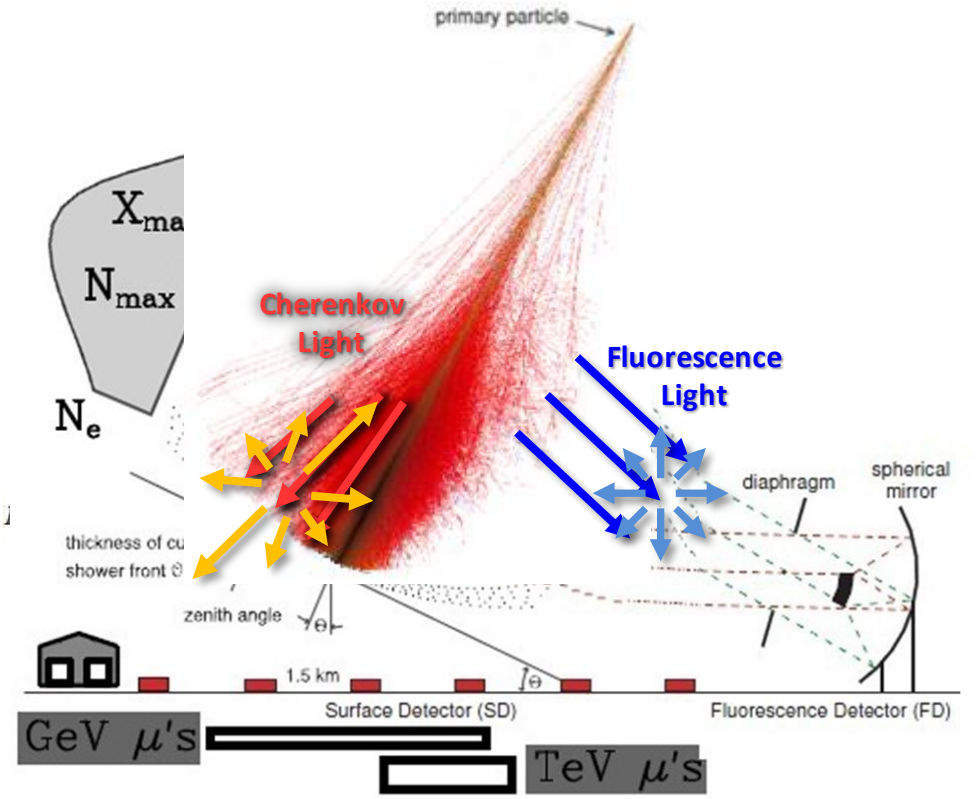
Jornadas do LIP 2012

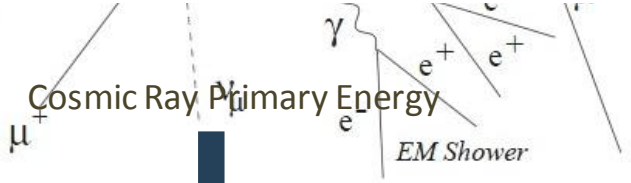
Auger LIP Group

João Pedro Espadanal

22-04-2012

How to detect the light emission of a shower?

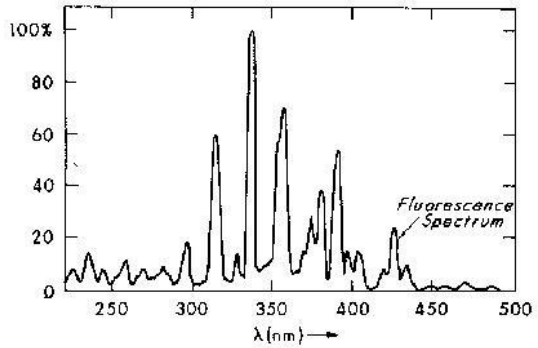




Cosmic Ray Primary Energy

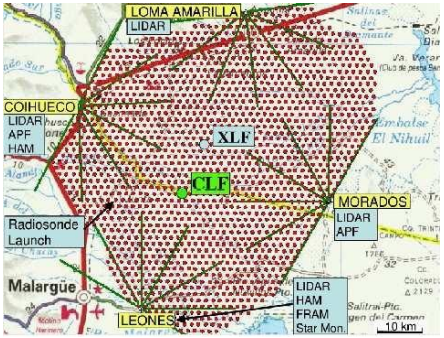
Quasi calorimetric energy measurement

- **Through the emitted light**
  1. Cherenkov Light
  2. Fluorescence Light in Nitrogen

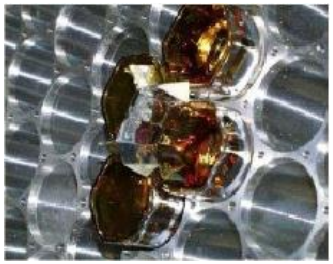


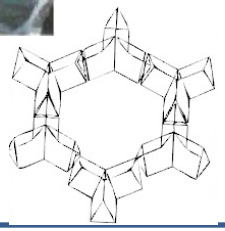
- **But we also have light scattering in the atmosphere that distort the shower image**
  1. **Rayleight Scattering**
  2. **Mie Scattering**

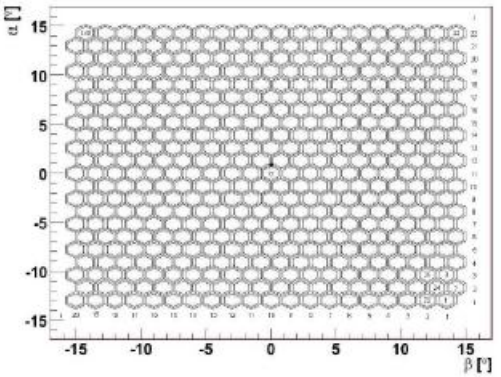
Fluorescence Detectors



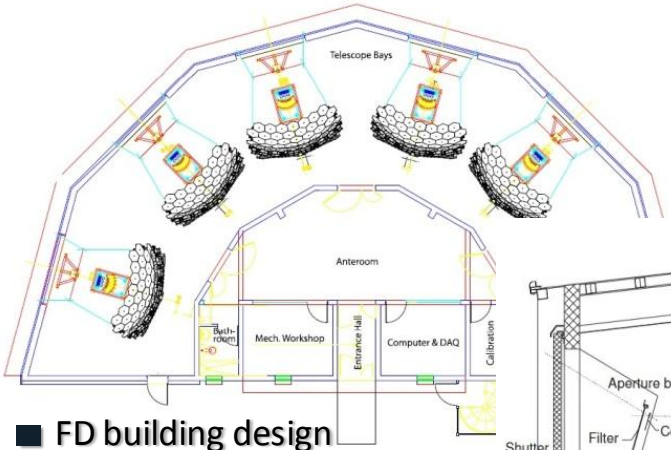
- **PMT Pixels**



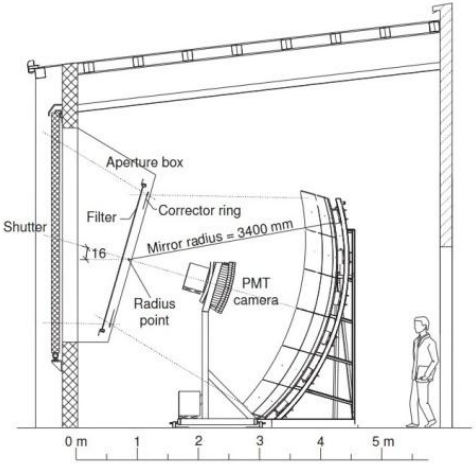




- FD Camera representation

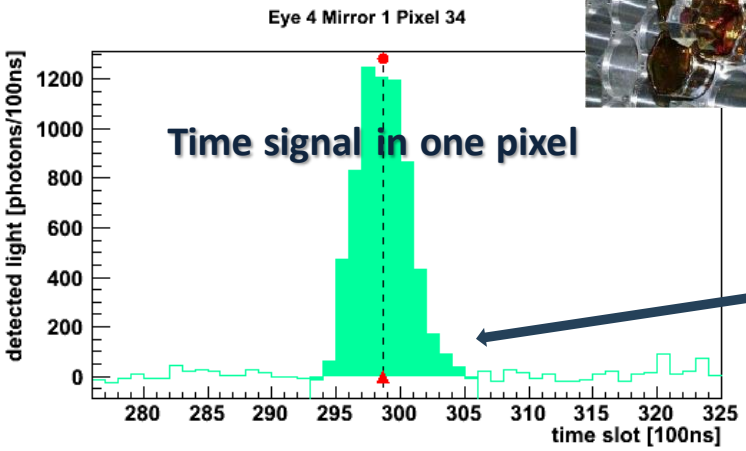


- FD building design

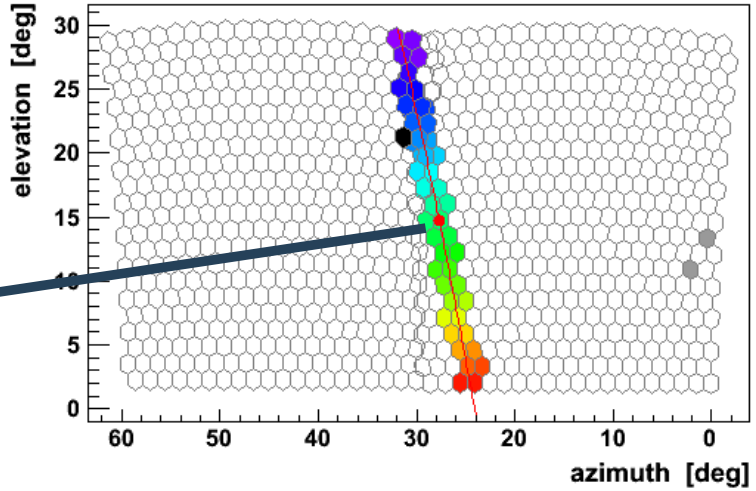


- FD Telescope design

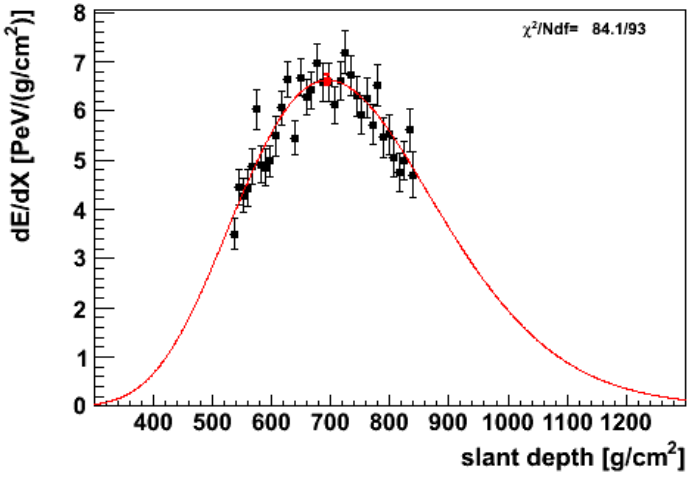
Light Detected



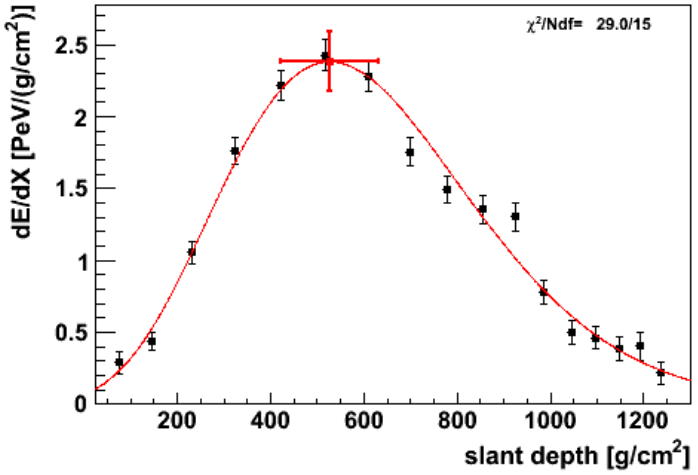
One typical event:



❑ Fluorescence rich event



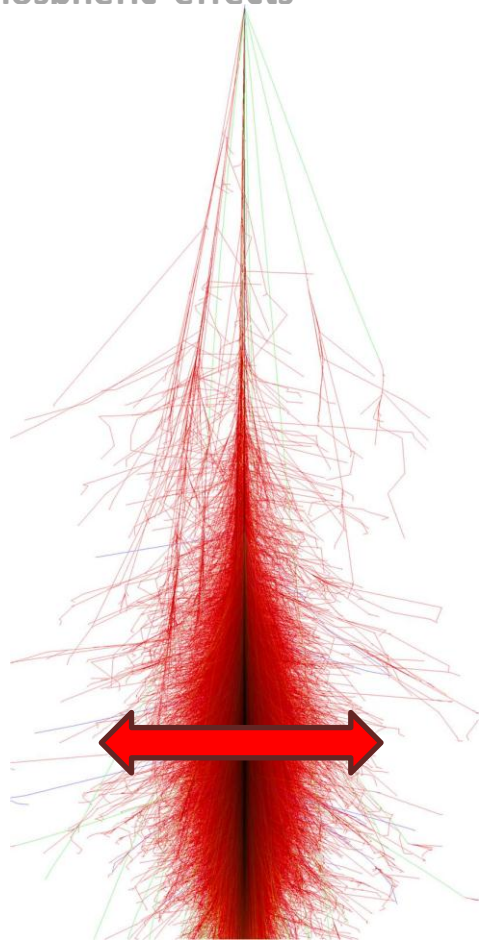
❑ Cherenkov rich event



Shower in 3 Dimensions

- **Shower in 3D space**
  - **Shower intrinsic width**
  - Detector effects
  - Atmospheric effects

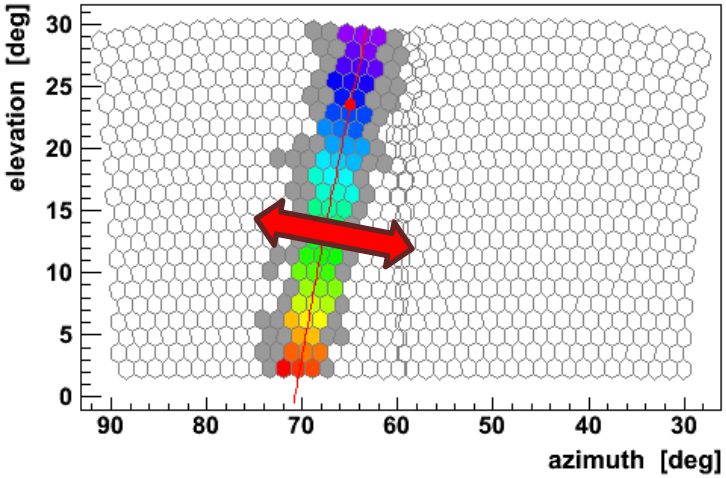
Shower Image width = **Shower intrinsic width** ⊗ **Atmosphere** ⊗ **Detector**



SDId 3599086

Energy = 1.58×10^{19}

Distance $_{\text{to eye}}$ = 3.87 km



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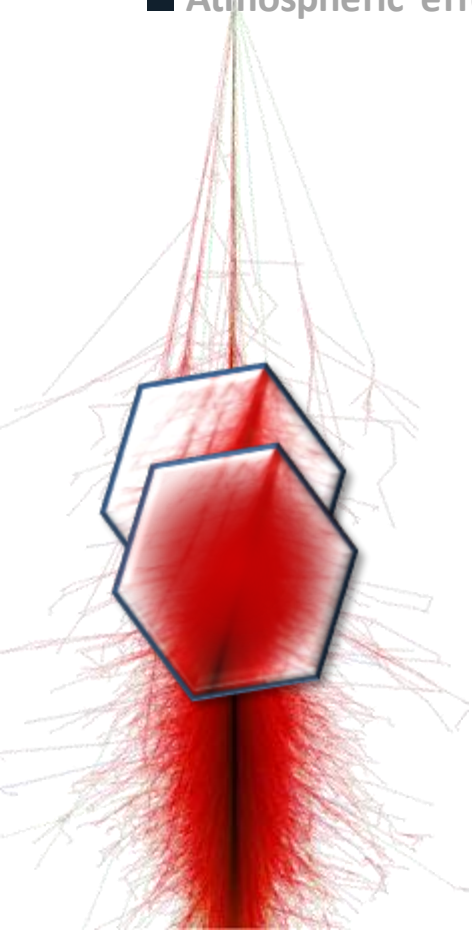
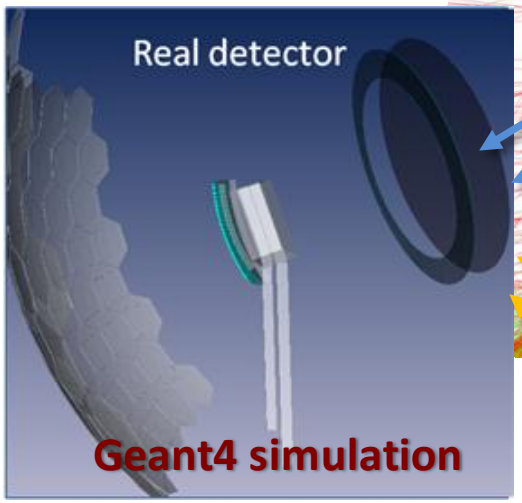
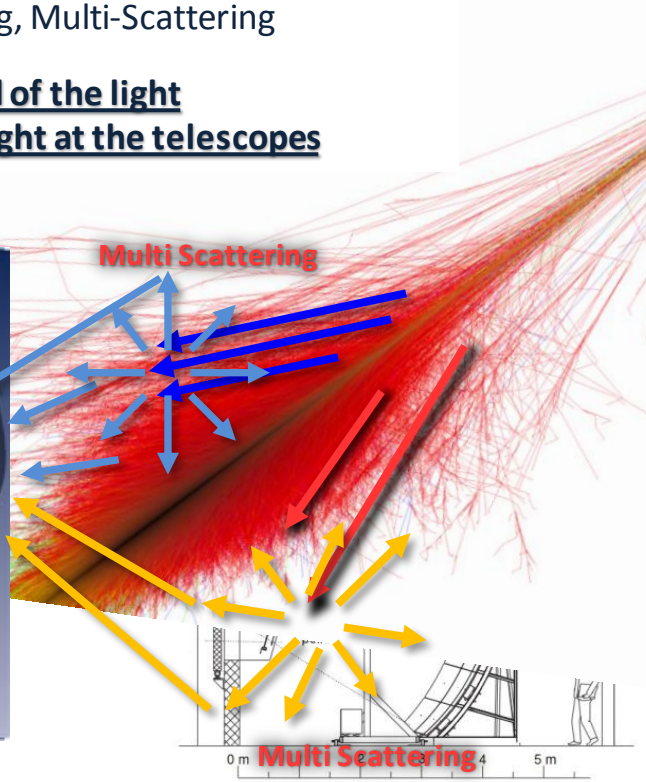
Shower Image width = **Shower intrinsic width** ⊗ **Atmosphere** ⊗ **Detector**

- Rayleigh Scattering of Fluorescence Light
- Mie and Rayleigh Cherenkov Scattering, Multi-Scattering

- **Spread of the light**
- **Less light at the telescopes**







3D Shower Simulation

- We generate the air showers

❑ Shower in 3D space

- Shower intrinsic width
- Detector effects
- Atmospheric effects

We are working in a shower simulation
Within the intrinsic shower

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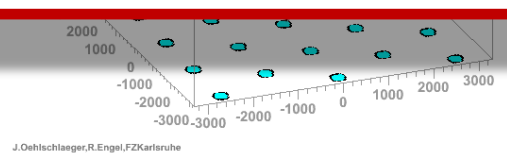
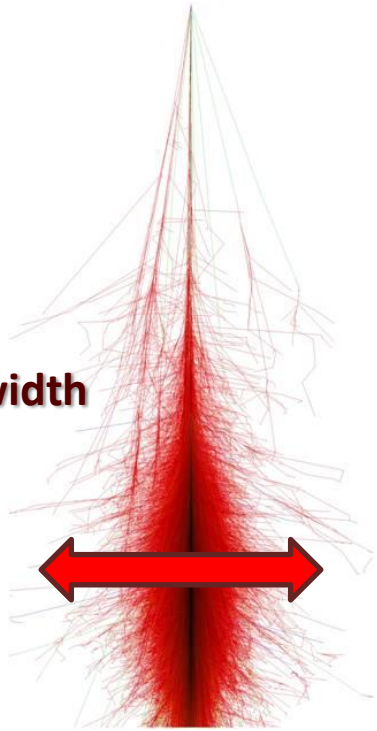


3D Simulation: Offline Framework Intervention

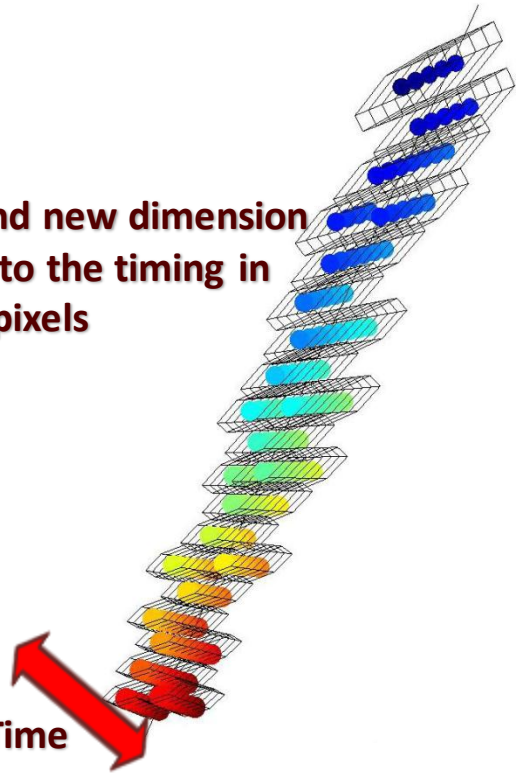
- Offline Framework Intervention

- More two dimensions for analysis



- Lateral width

- And new dimension due to the timing in the pixels



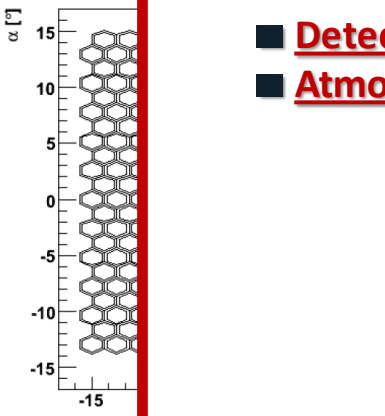
CLF and Roving Laser

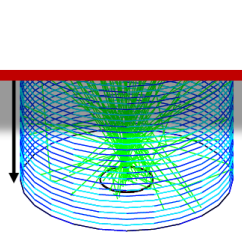
- The best way of study the detector and atmosphere effects is using laser

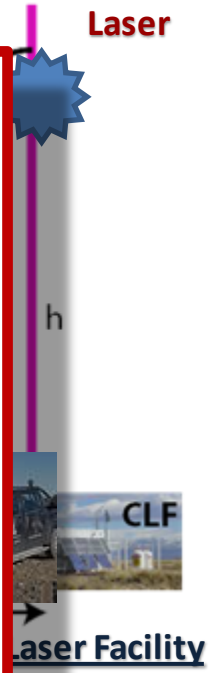
- Shower in 3D space
  - Shower intrinsic width
  - Detector effects
  - Atmospheric effects

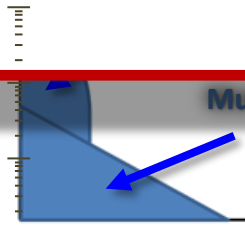
How to study the distortion of the detector + atmosphere?

Geant4 s
and laser in order to understand the effects







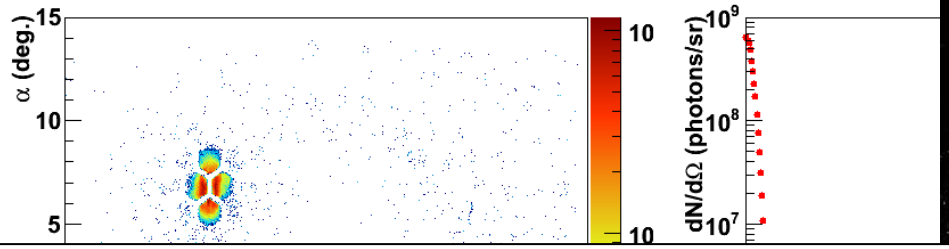


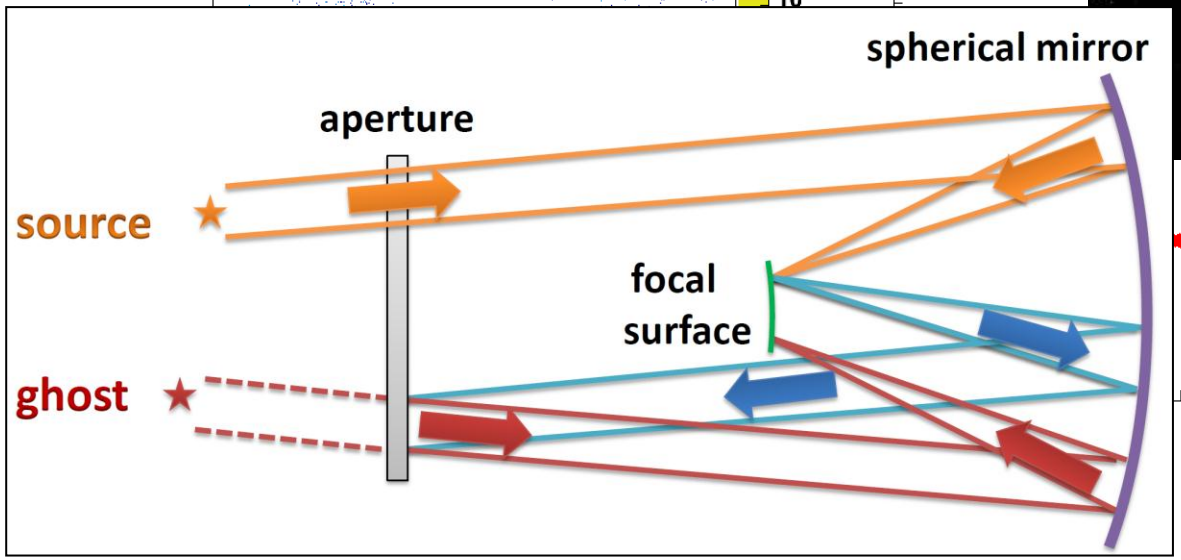
Distance in the camera to the laser pulse center

CLF and Roving Laser

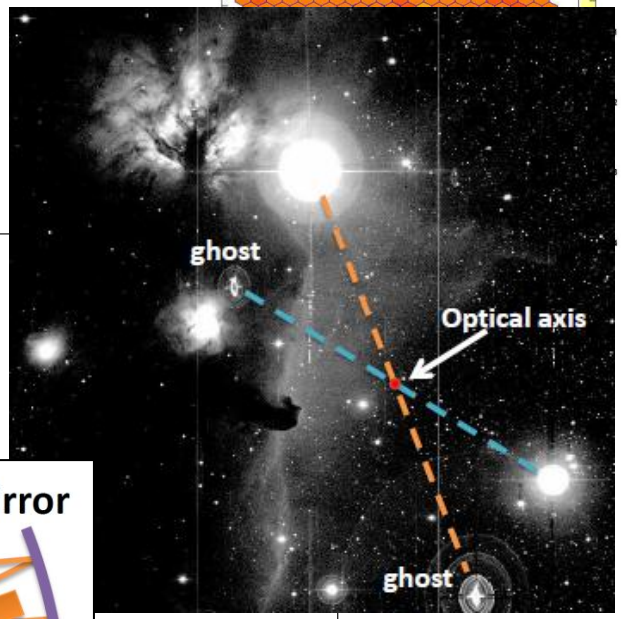
- Internal reflections of in the detector

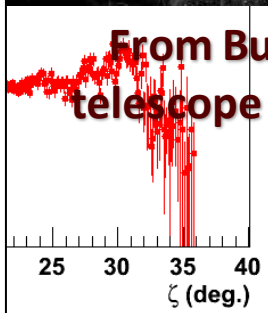
With roving laser





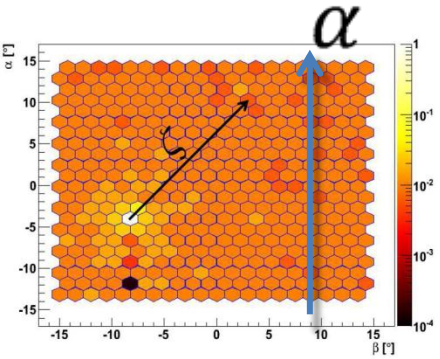
The Horsehead Nebula



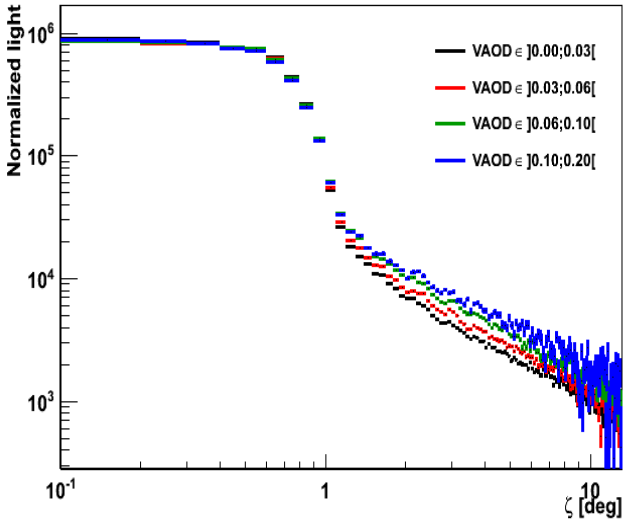


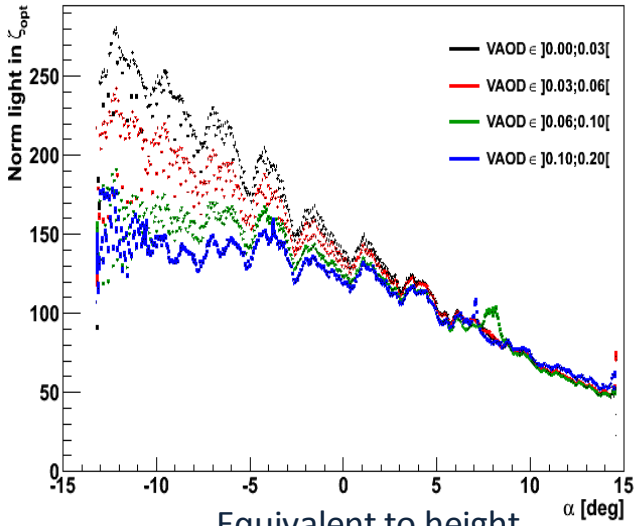
From Burrell Schmidt telescope at Kitt Peak

CLF and Roving Laser



- **CLF Data -> Far away from telescopes (atmosphere effects)**

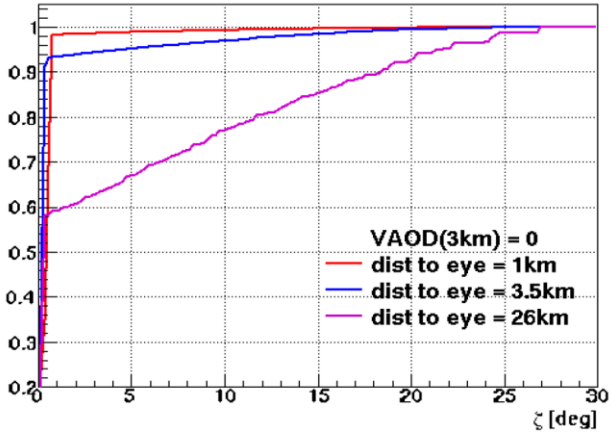


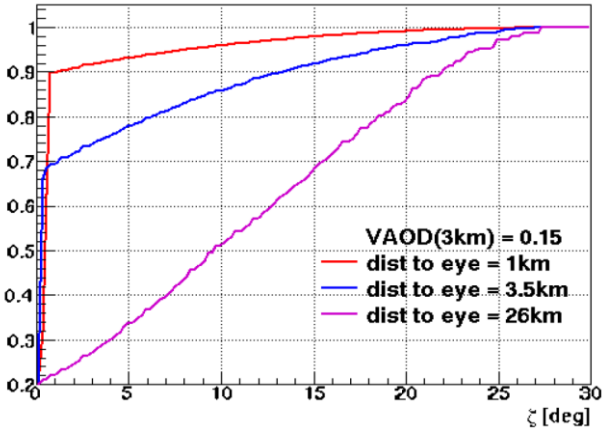


Equivalent to height → Top atm

VAOD
Proportional to the amount of aerosols

Which cause more multi scattering by Mie





Roving Laser Campaign - Photos

Campaign July 2010

Campaign April 2011

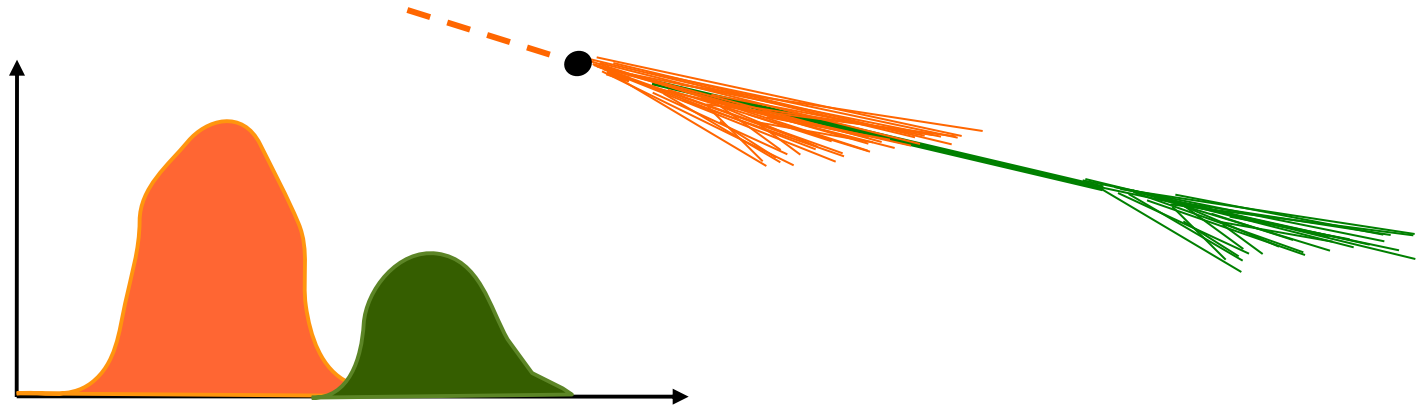
Outlook

- ***Detailed understanding of the detector behavior and atmospheric effects***
- ***Shower physics studies with new spatial dimensions***
- ***After understanding the atmosphere and detector, we can disentangle strange and exotics events***

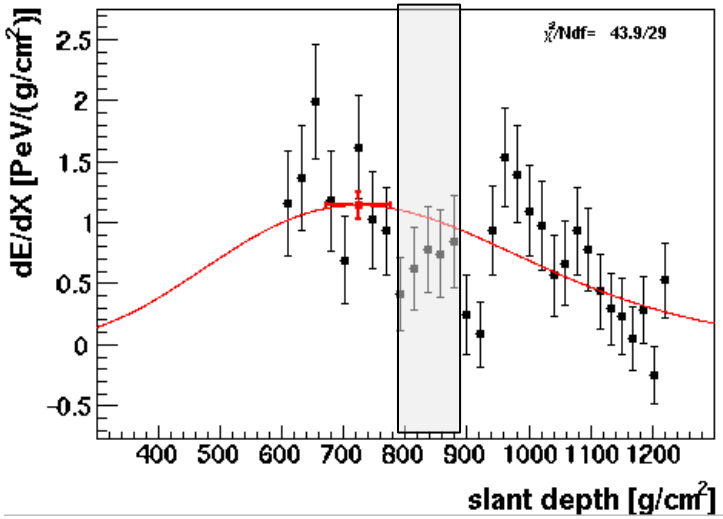
Exotics Events

Example:

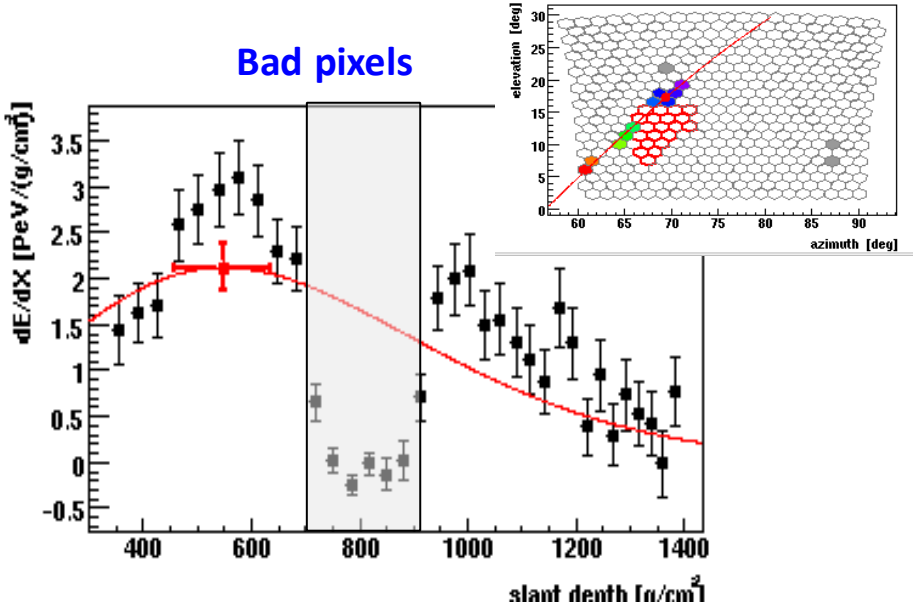
Double Bangs



Cloudy day



Bad pixels



Exotics Events

Low flux

Limited detector capabilities

} **But a unique energy window!**

- New physics

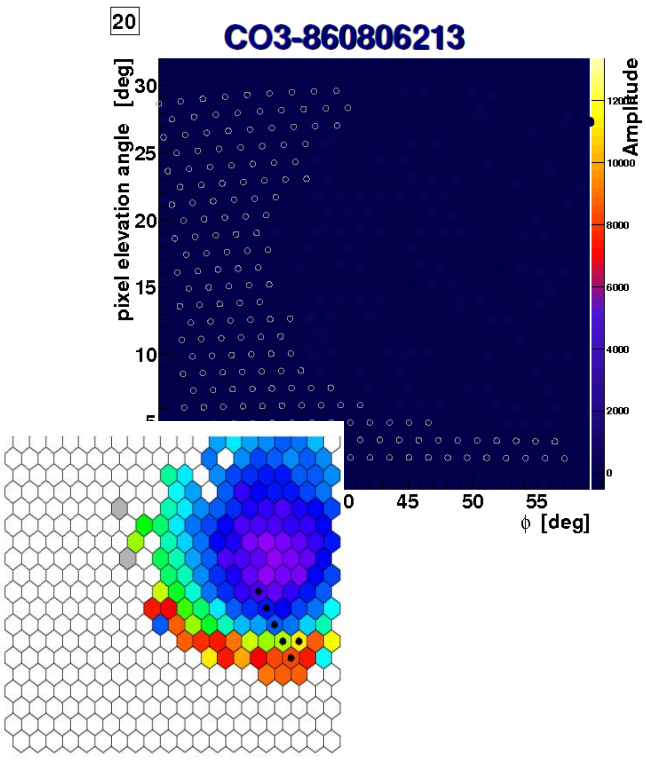
  at primary or in shower development

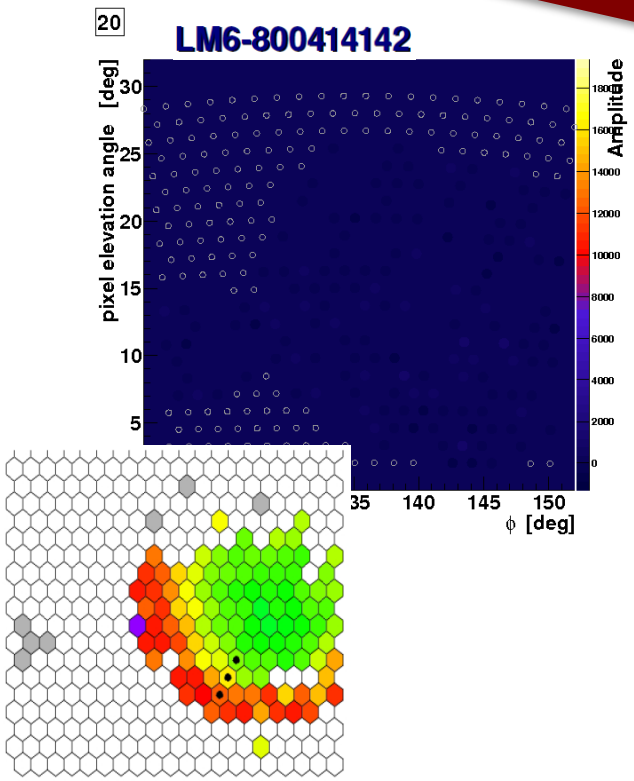
- Neutrino channel: low background

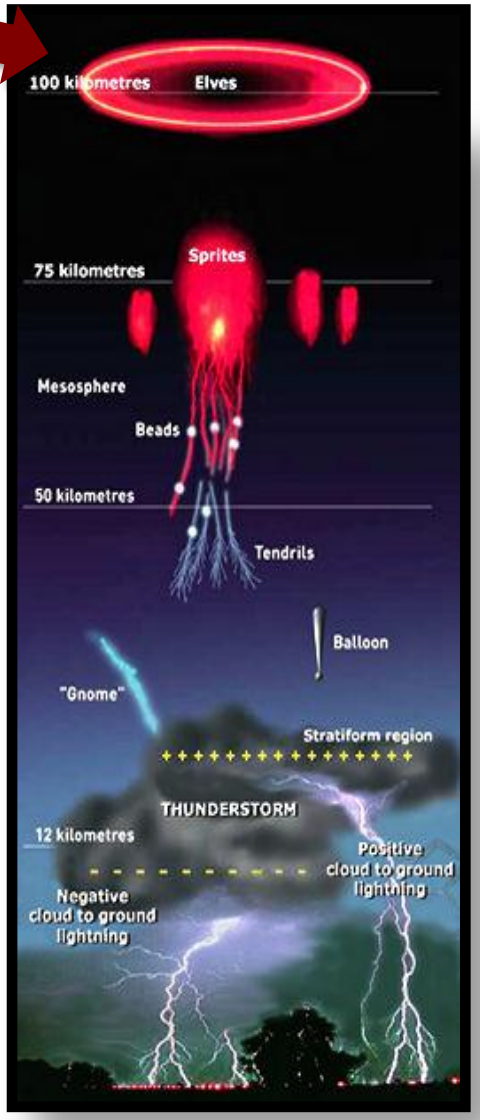
- Looking for distinctive signatures

Candidate Particle	Properties	Xmax	RMS	SD
Magnetic Monopole	Mass of ~10^5 GeV, created in SU(4)xSU(2)xSU(2) symmetry breaking, primary particle	Deep X_{max}	High RMS	Very small SD signal from muon-poor showers
MBH	Neutrino-induced secondary, near instantaneous decay to an "explosion" of Hawking Radiation	Proton-like X_{max} moving to deep	Low RMS	Hadronic SD signal
UHECRONs	Strongly interacting, heavy, conceived as a possibility for super-GZK events	Deep X_{max}	High RMS	Hadronic SD signal
Strangelet	Bag of up, down and strange quarks in roughly equal proportions, high mass (~500 GeV)	Iron-like X_{max}	Moderate RMS	High muon content, and large SD signal
Q-Ball	Bose-Einstein condensate of a SUSY strangelet, proton-decay inducing	Very Deep X_{max}	Proton-like RMS	Low muon content and small SD signal

- **But we found Elves!!!**







Thank You

Back up slides

New approach: 3D Simulation

In Corsika:

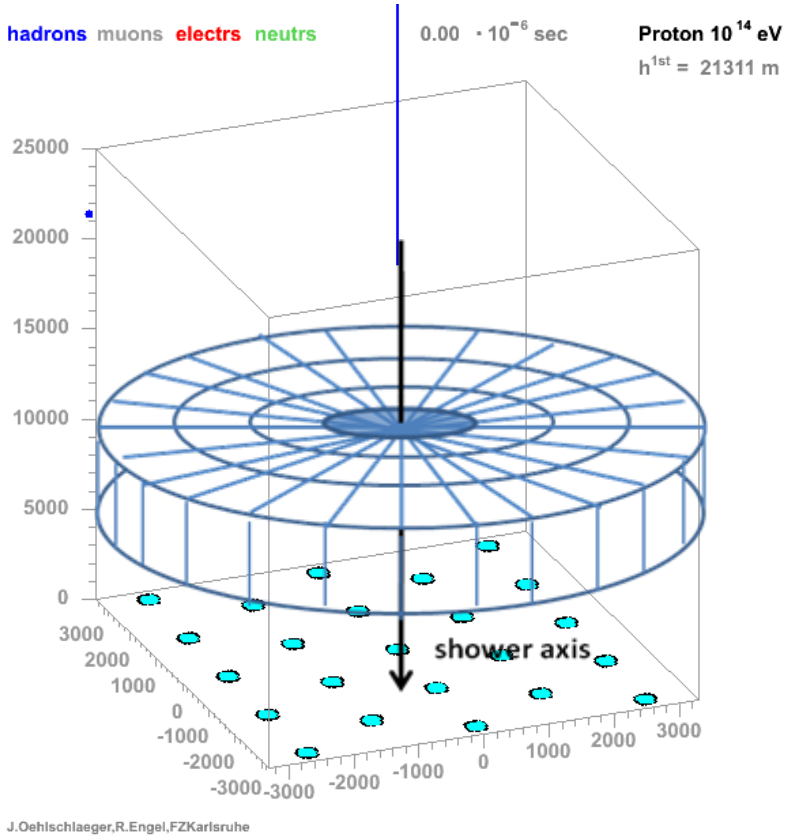
- ***The energy deposited and other relevant variables are saved for each sky bin***

Physical Geometry

- ***Shower has azimuthal symmetry***
- ***Bins with smaller volume in denser shower region (small r)***

Cylindrical geometry (r, ϕ, z):

- ***r : 50 x 20m***
- ***ϕ : 24 x 15 deg*** ***24 x 50 x 300 = 6 x 10^5 bins***
- ***z : 500 x 100 m***
- ***(max size: 1000m x 360 deg x 50000 m)***



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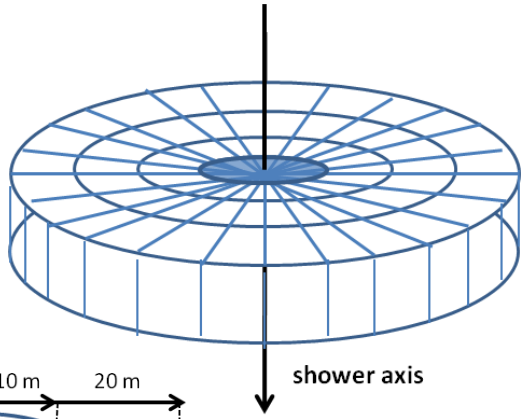
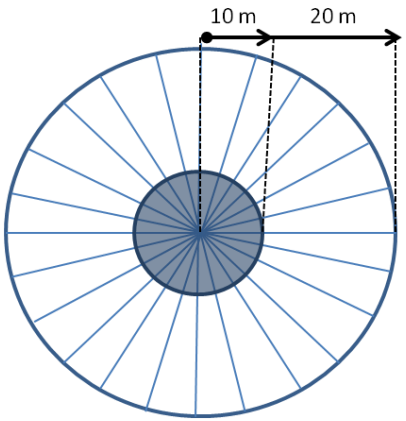
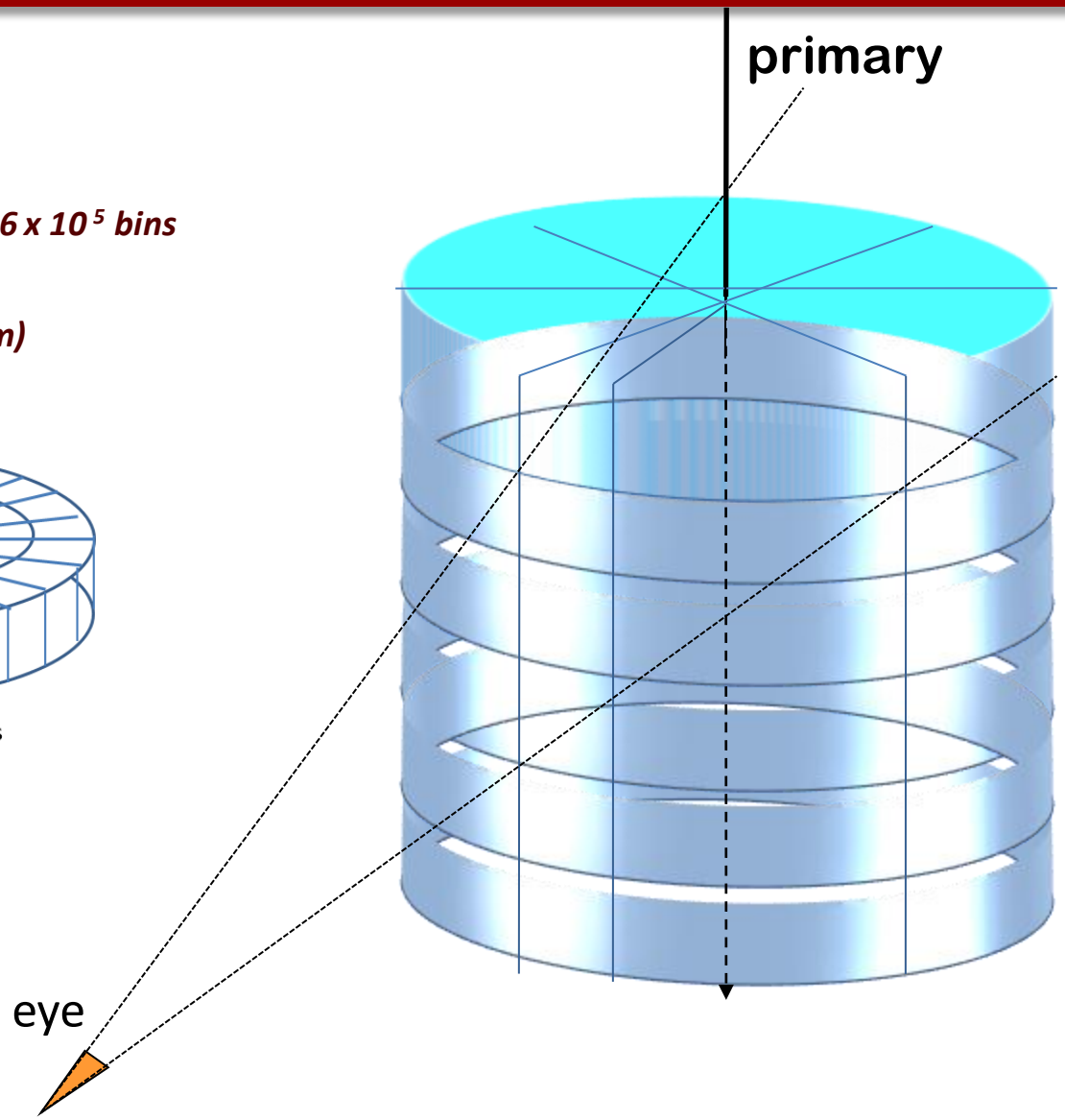
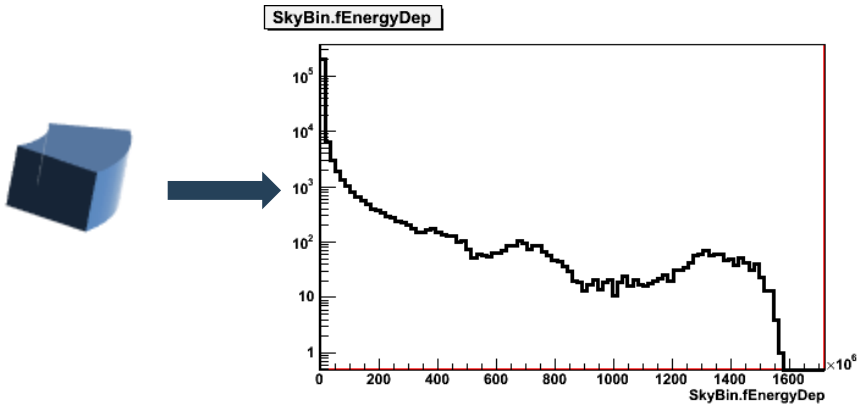






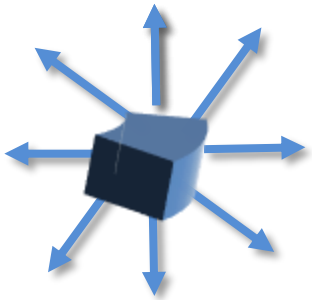
Sky Bins Information

- **For fluorescence:**

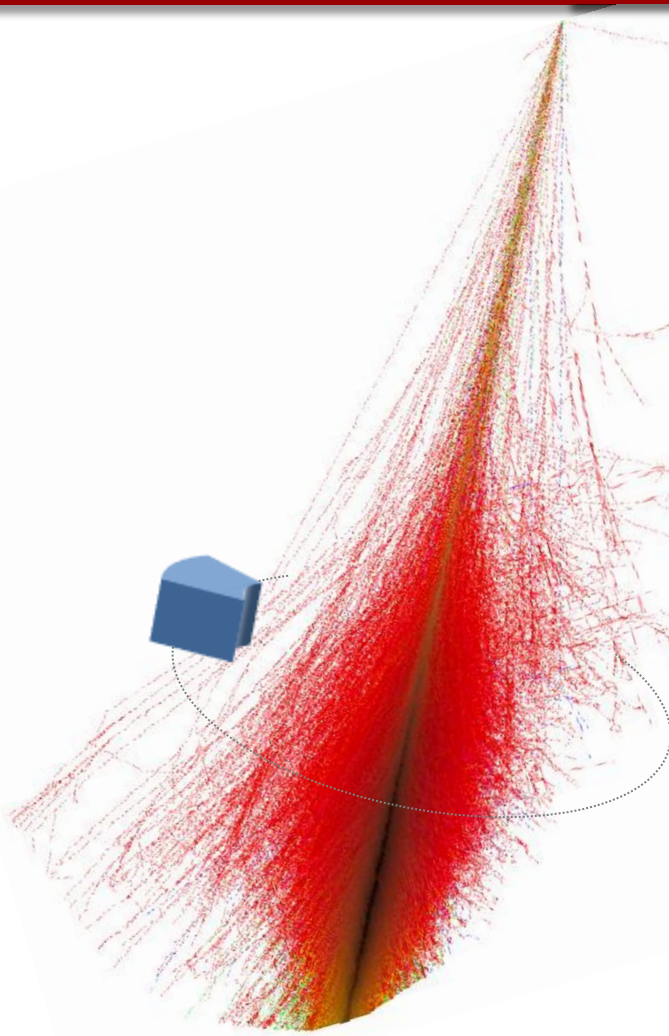


- Energy Deposited in each SkyBin

$$N^{\gamma\,fluo}_{emitted}(i,\Delta\lambda) = \frac{E_{dep}(i)}{E_0} Y_e^{fluo}(i,\Delta\lambda)$$

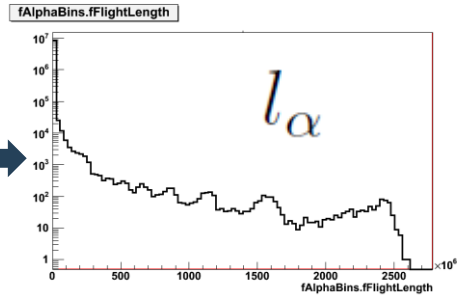


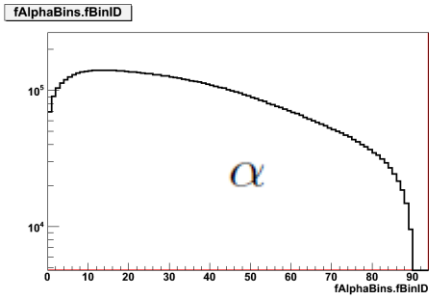
- Isotropic Emission

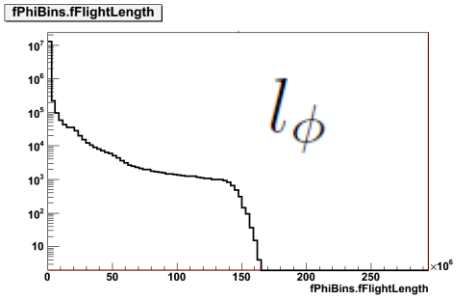


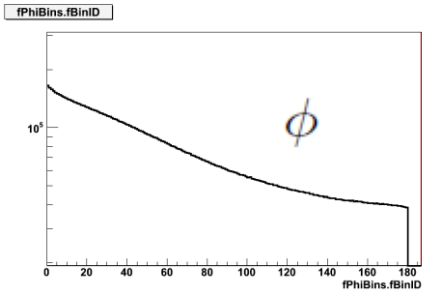
Sky Bins Information

For Cherenkov:



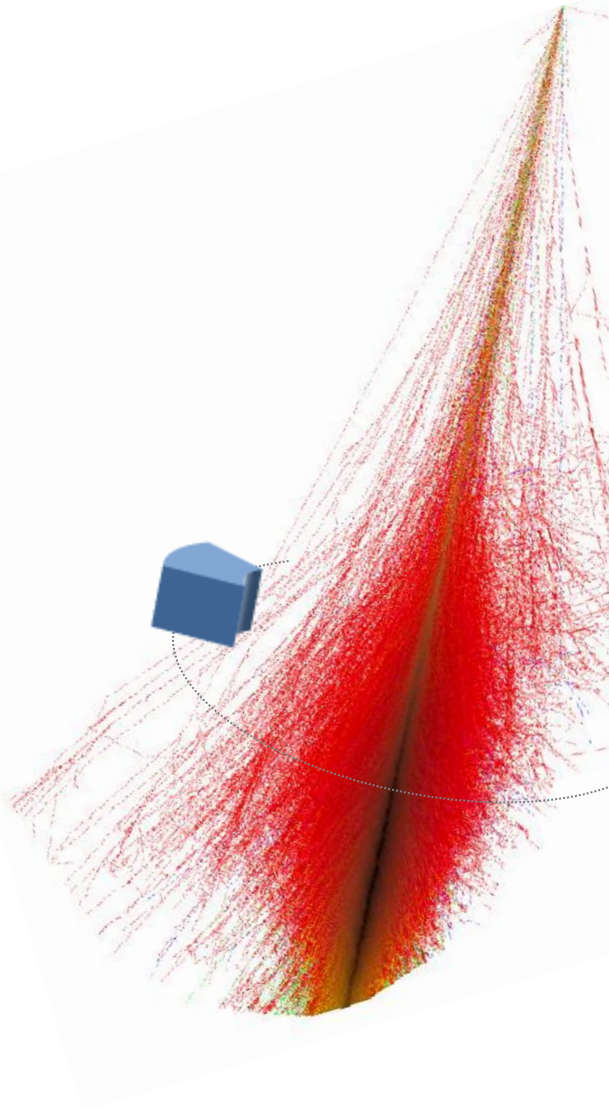






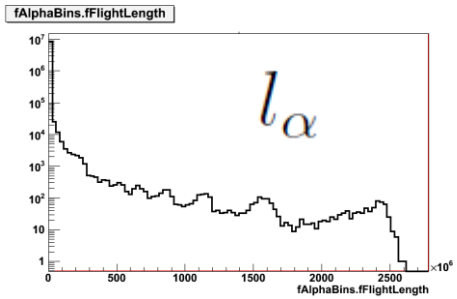
- Electron Length distribution
- Electrons angle distribution

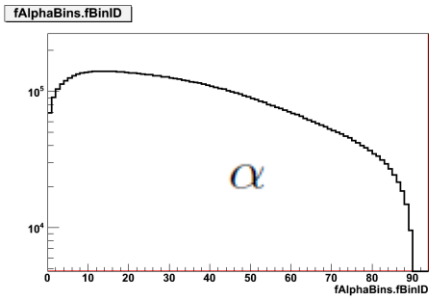
$$N_{ph} = n_{Electons} \cdot < l_\alpha > . \frac{l_\phi}{< l_\phi >} \quad 2\pi(1 - \tfrac{1}{n^2}) \quad (\frac{1}{\lambda_2} - \frac{1}{\lambda_1})$$

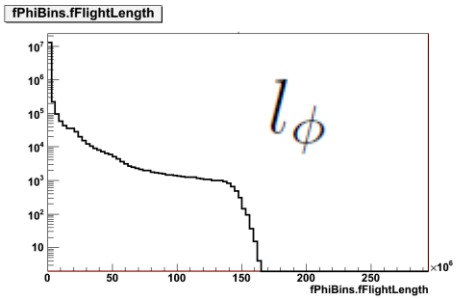


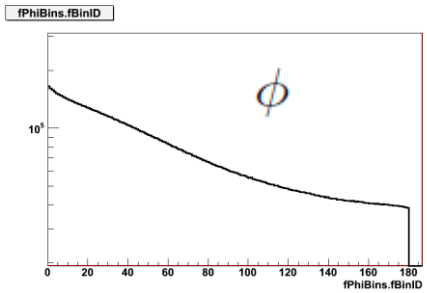
Sky Bins Information

For Cherenkov:

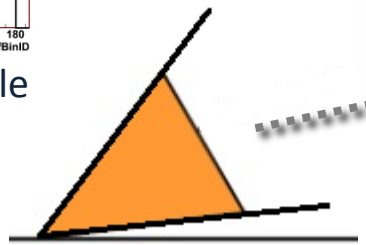


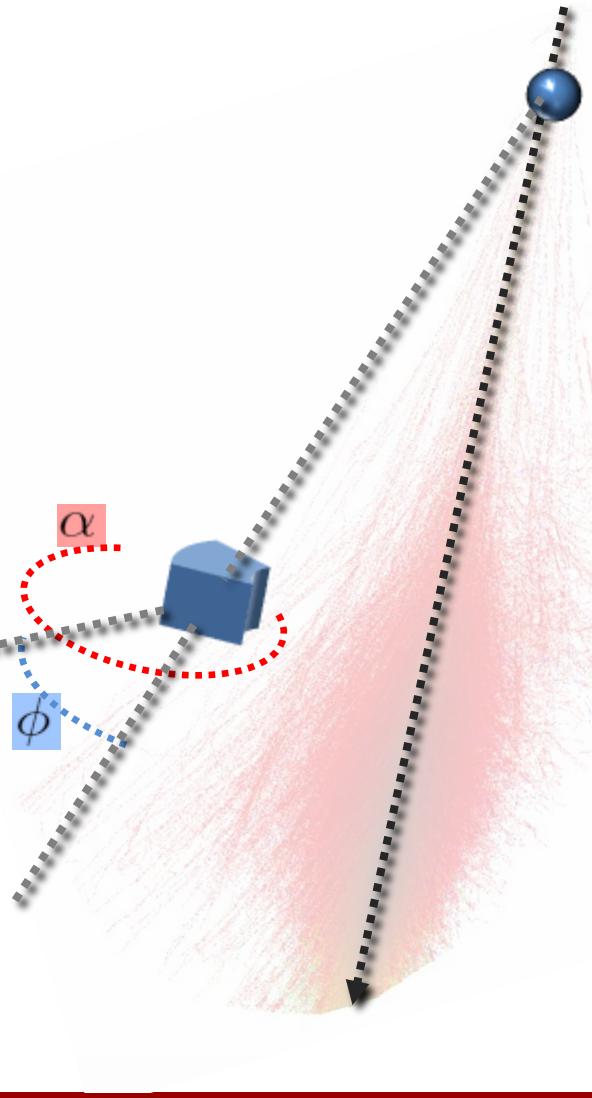






- Electron Length distribution
- Electrons angle distribution





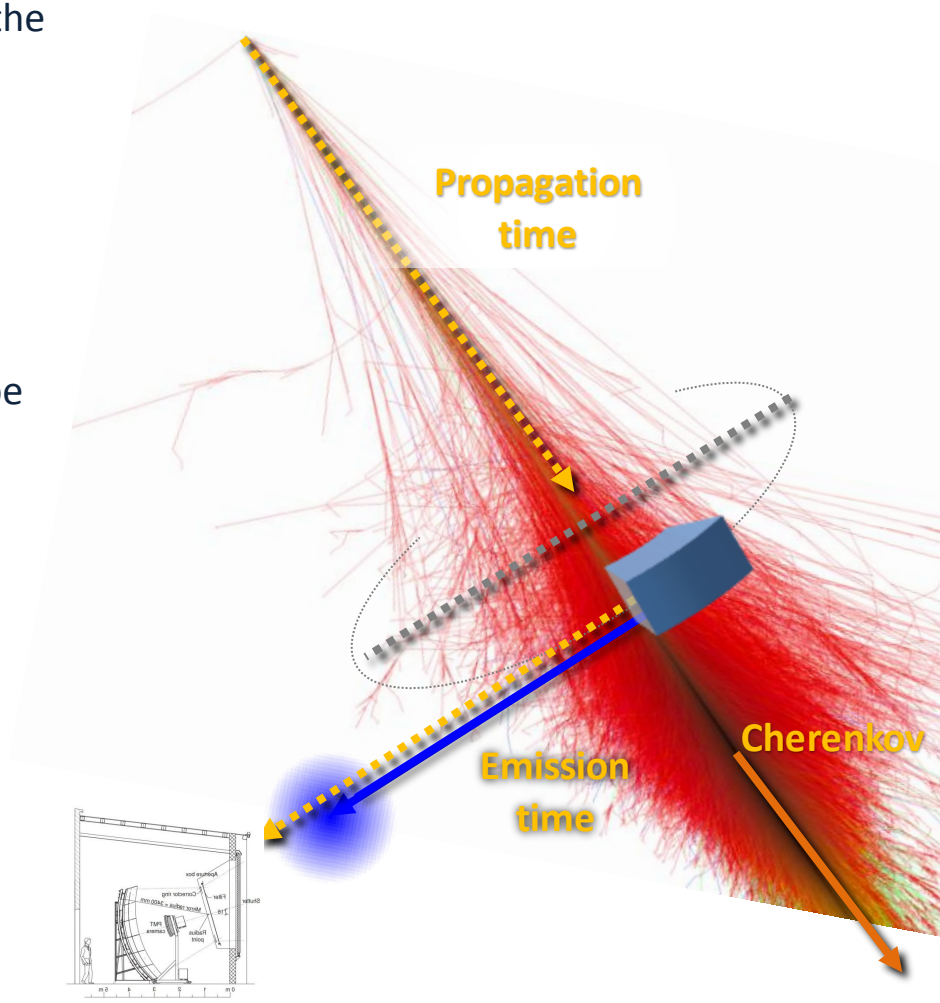
$$N_{ph} = n_{Electons} . < l_\alpha > . \frac{l_\phi}{< l_\phi >} \quad 2\pi(1 - \tfrac{1}{n^2}) \quad (\frac{1}{\lambda_2} - \frac{1}{\lambda_1})$$

3D Simulation: Offline Framework Intervention

Offline Framework Intervention

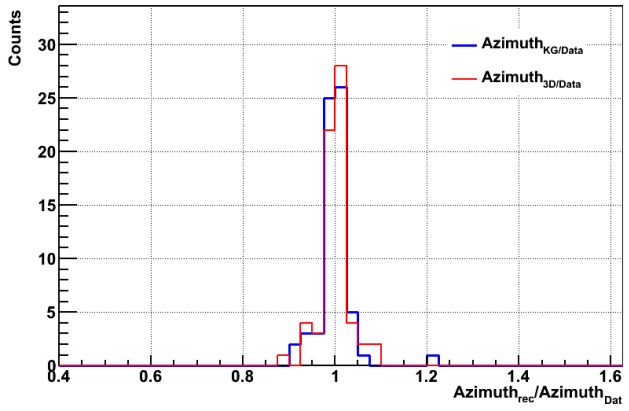
- Offline Framework simulates and reconstructs the events after Monte Carlo generation:
  - Simulate the event
  - Simulate the detector
  - Add backgrounds and simulate efficiencies
  - Reconstruct the event

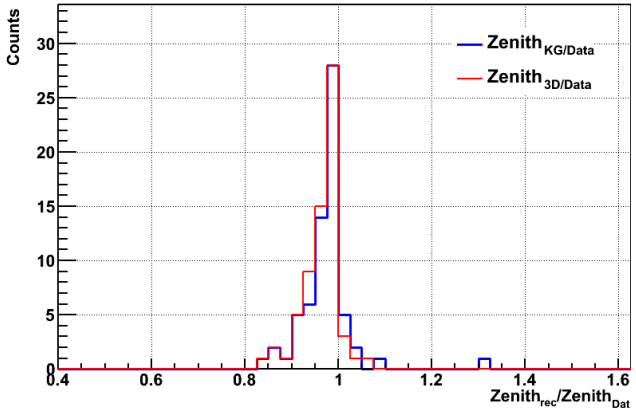
- Change and create a few modules, in order to be able to simulate in the framework
  - Produce photons: Fluorescence emission
    Cherenkov emission
  - Propagate to detector using geometrical information :
    - solid angle
    - emission angle
    - distance to telescope
  - Attenuate and scatter photons
    - Cherenkov scattered
    - Multiple-scattering

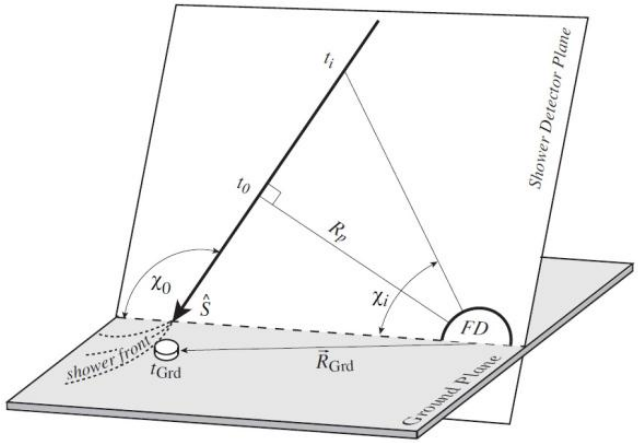


Validation of 3D Simulation

Geometry reconstruction

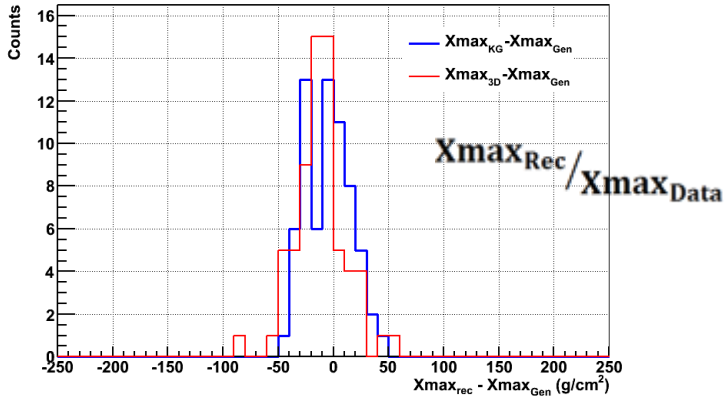


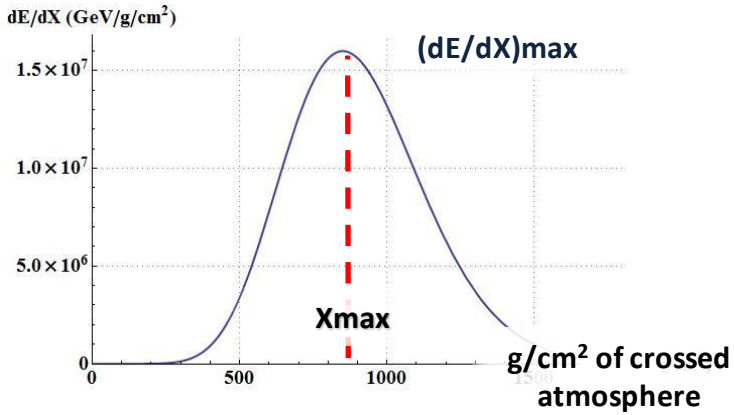




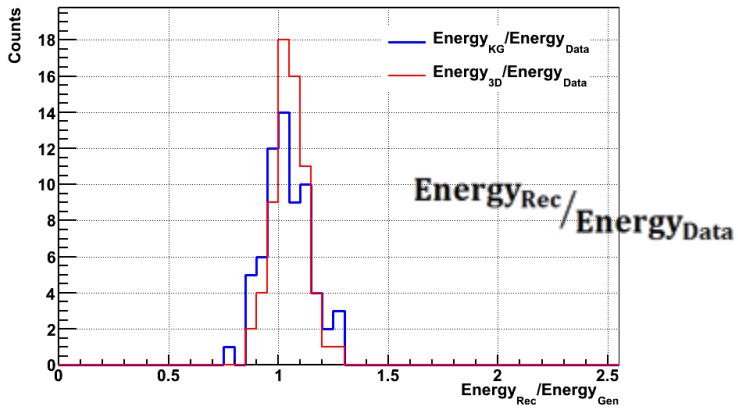
Validation of 3D Simulation

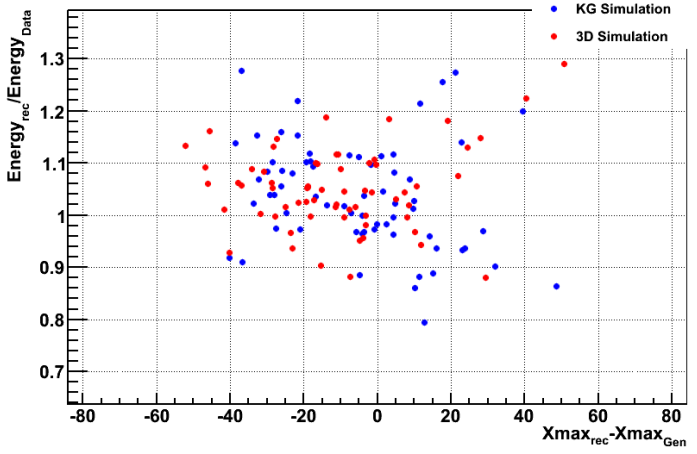
Xmax reconstruction



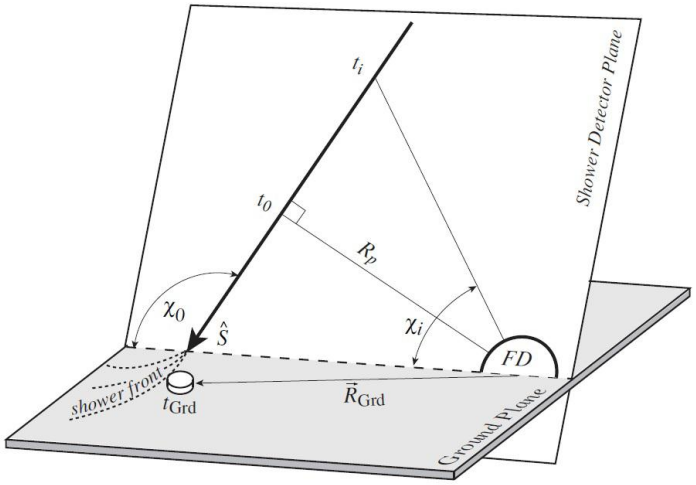


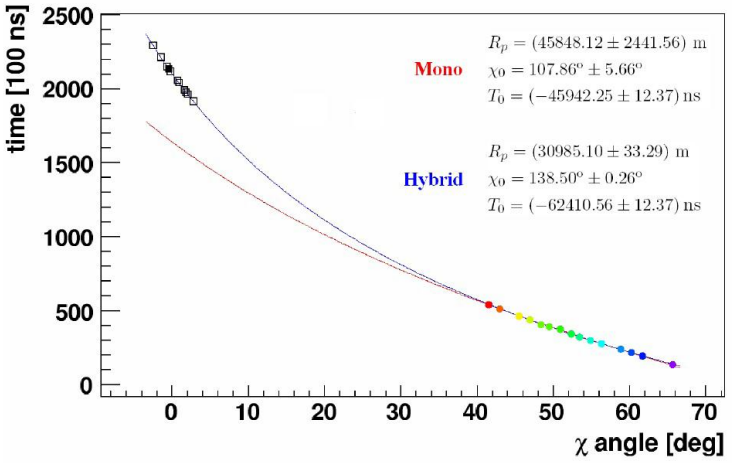
Energy reconstruction





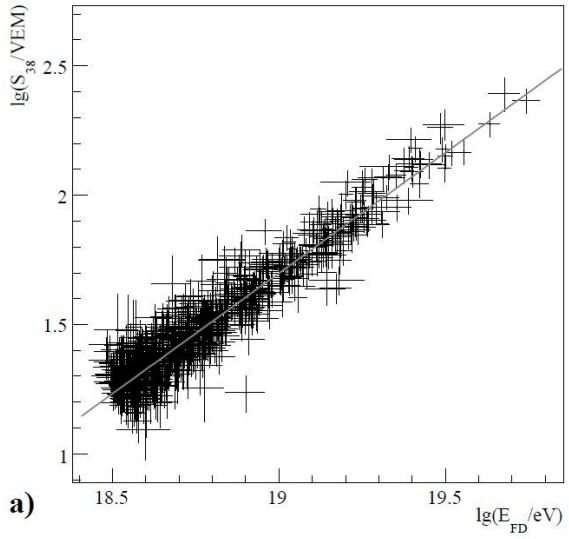
Reconstruction



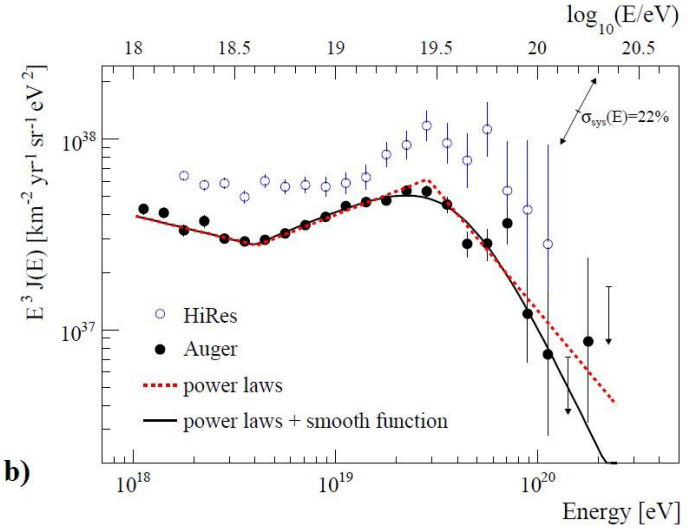


$$t_i = t_0 + \frac{R_p}{c}\tan[(\chi_0 - \chi_i)/2]$$

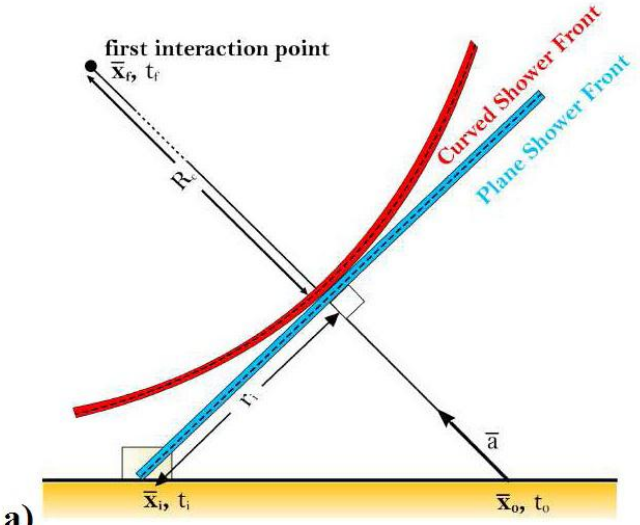
$$y = Cx \qquad C = \begin{cases} 0, & \text{if } i < j \\ c_i^d + c_{ii}^s, & \text{if } i = j \\ c_{ij}^s, & \text{if } i > j \end{cases}$$


lg(S38/VEM)
2.5
2
1.5
1
18.5
19
19.5
lg(EFD/eV)

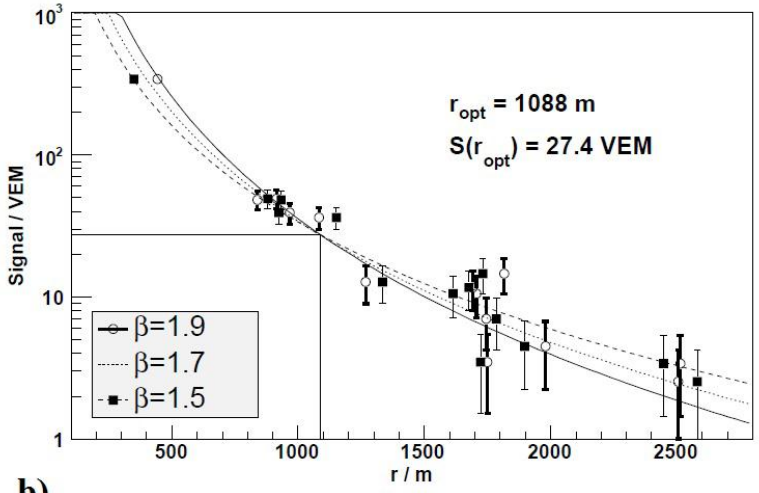
a)


log10(E/eV)
18
18.5
19
19.5
20
20.5
E3 J(E) [km-2 yr-1 sr-1 eV2]
10^38
10^37
σsys(E)=22%
HiRes
Auger
power laws
power laws + smooth function
10^18
10^19
10^20
Energy [eV]

b)


first interaction point
x̄f, tf
Curved Shower Front
Plane Shower Front
R
ri
ā
x̄i, ti
x̄0, t0

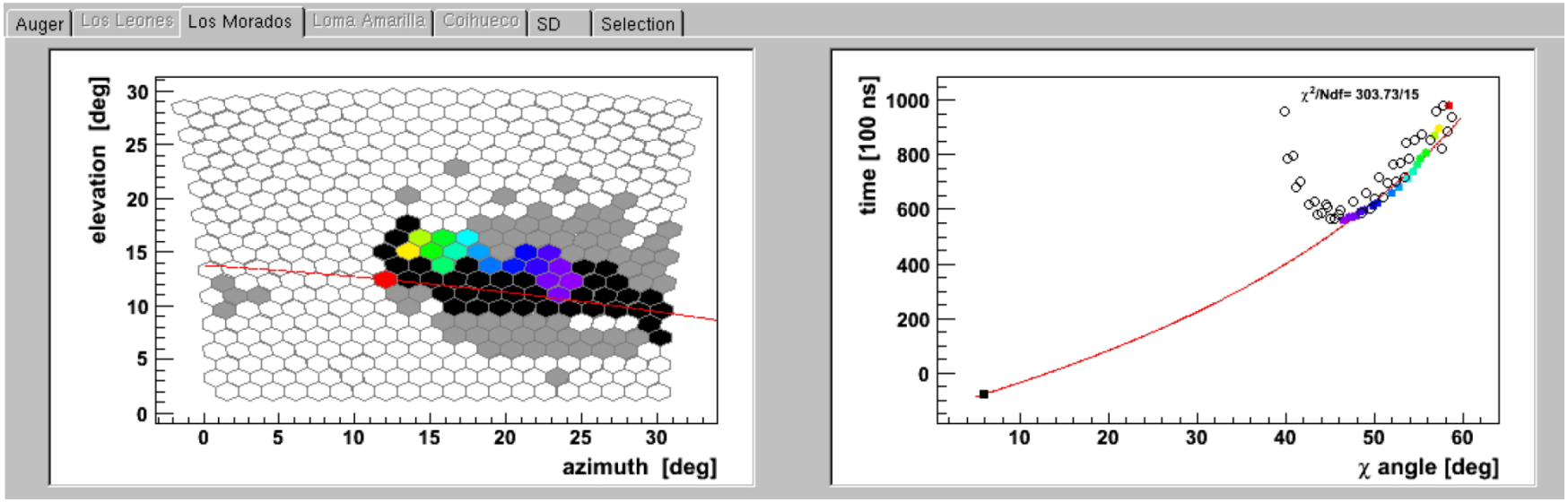
a)


10^3
10^2
10
1
Signal / VEM
ropt = 1088 m
S(ropt) = 27.4 VEM
β=1.9
β=1.7
β=1.5
500
1000
1500
2000
2500
r / m

b)

Atmosphere

LM6-800414142 in ADSTs (EventBrowser)

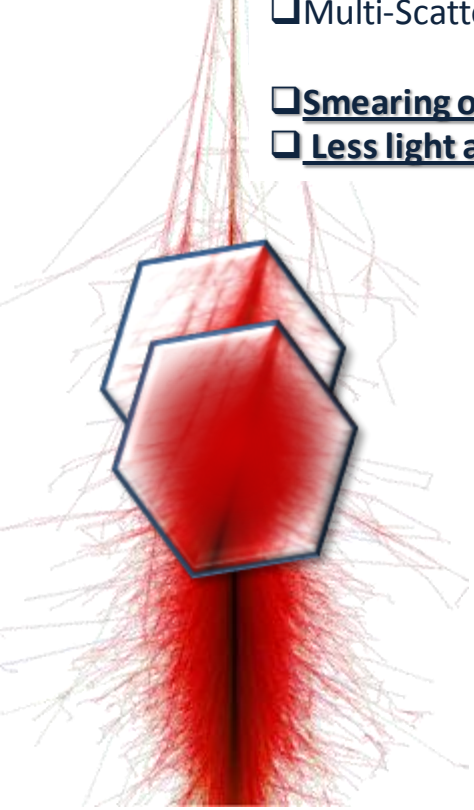


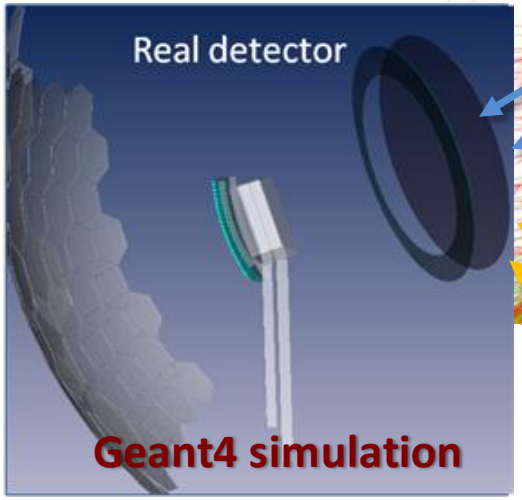
Challenging Effects

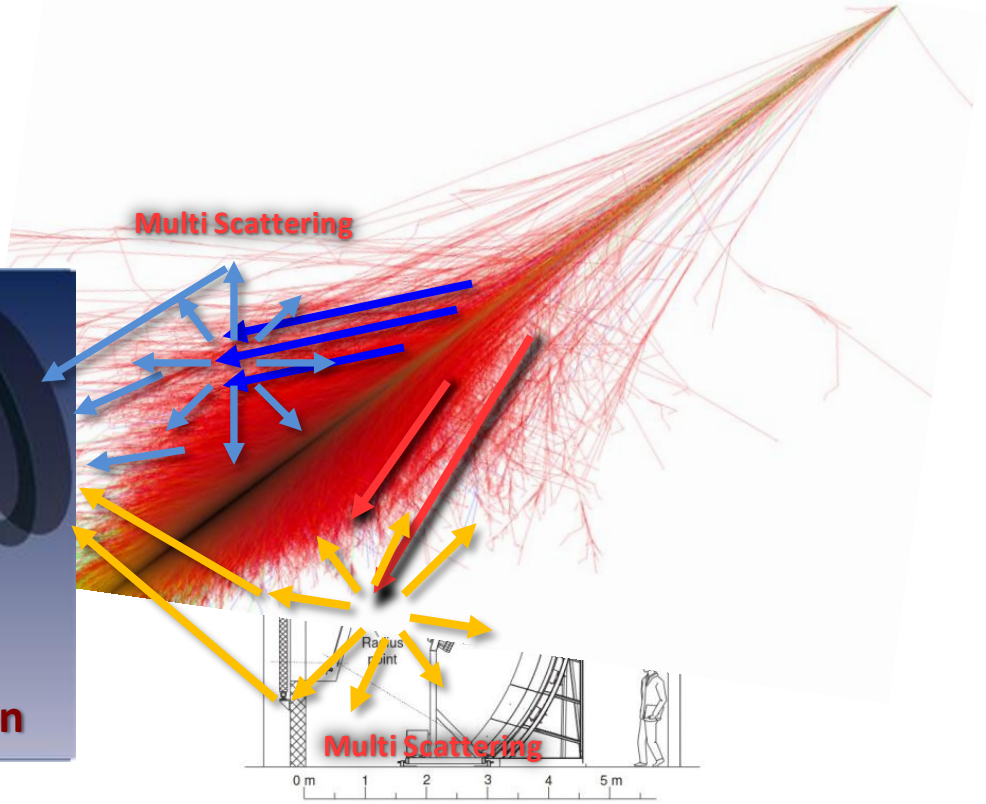
- Challenging Effects
  - Shower width
  - Detector effects
  - Atmospheric effects

- Rayleigh Scattering of Fluorescence Light
- Mie and Rayleigh Cherenkov Scattering
- Multi-Scattering

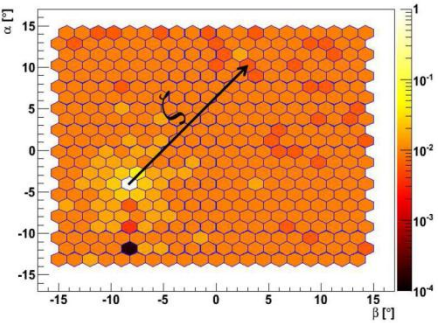
- **Smearing of the light**
- **Less light at the telescopes**





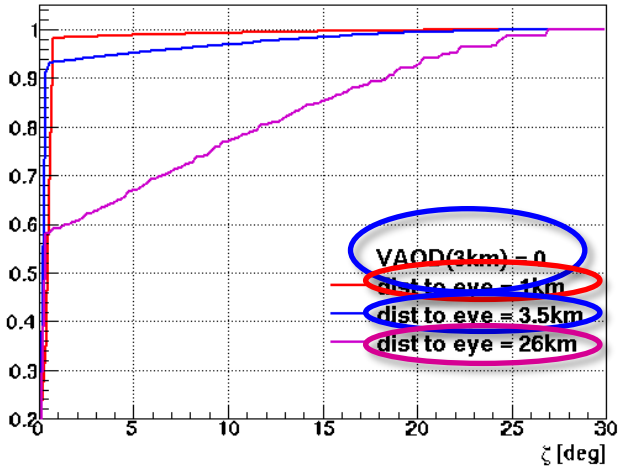


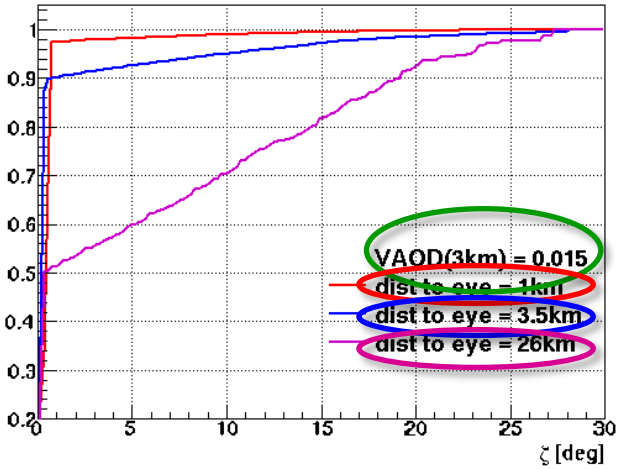
CLF and Roving Laser

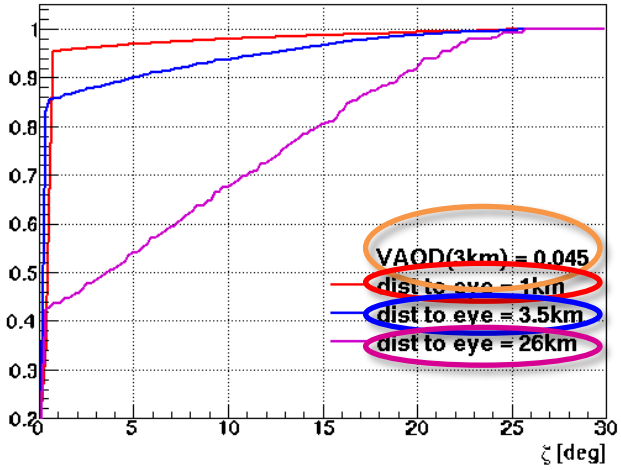


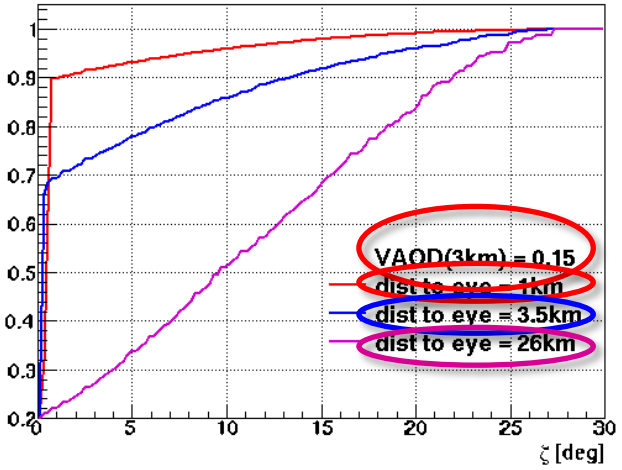
VAOD
Proportional to the amount of aerosols

Which cause more multi scattering by Mie









Geant4

Physics

Rayleigh scattering:

Phase function (**G4OpRayleigh** class in Geant4 kernel)

$$\frac{d\sigma}{d\Omega} = \sigma \frac{3}{16\pi}\left(1+\cos^2\theta\right)$$

Implemented
(dependence on depolarization factor tbd)

Mie scattering:

Phase function (**G4OpMie** class in Geant4 kernel)

$$\frac{d\sigma}{d\Omega} = \frac{1-g^2}{4\pi}\left(\frac{1}{\left(1+g^2-2g\cos\theta\right)^{3/2}}\right)$$

Implemented
(g is the average value of cosθ
and depends the on aerosol type)

$$\frac{d\sigma}{d\Omega} = \frac{1-g^2}{4\pi}\left(\frac{1}{\left(1+g^2-2g\cos\theta\right)^{3/2}} + f\frac{3\cos^2\theta - 1}{2(1+g^2)^{3/2}}\right)$$

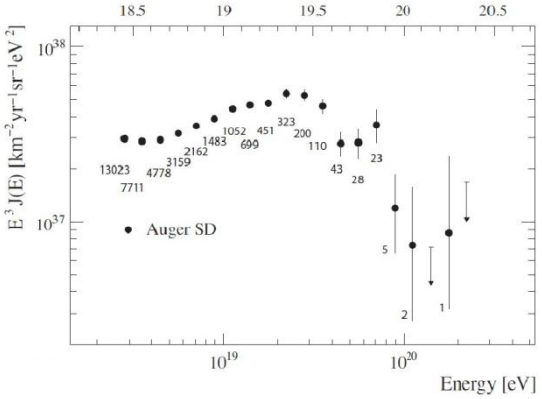
backscattering component
To be implemented

Ruben Conceição

AUGER

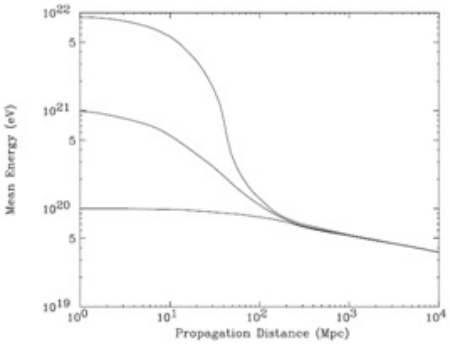
Cosmic Rays spectrum and propagation

Energy Spectrum

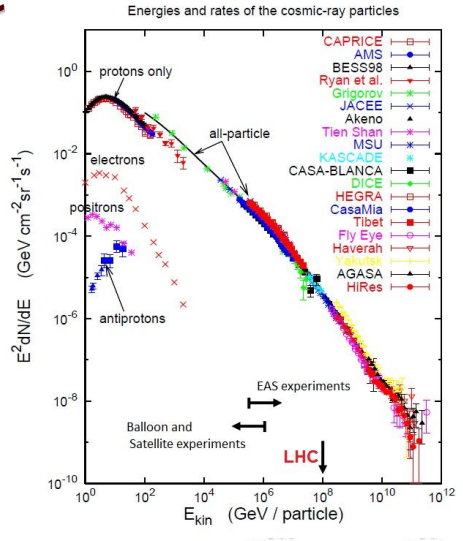


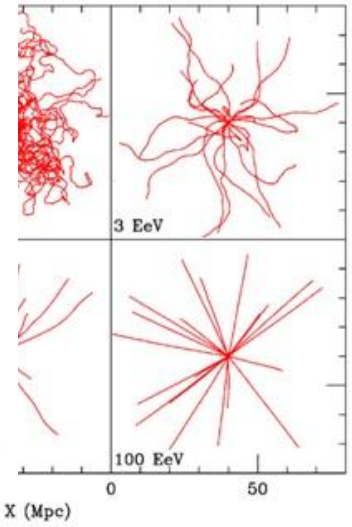
- Strong evidences for the GZK effect

$$p + \gamma_{CMB} \longrightarrow p + \pi^0$$
$$\longrightarrow p + \pi^+ + \pi^-$$
$$\longrightarrow p + e^- + e^+$$



Cosmic Ray Propagation





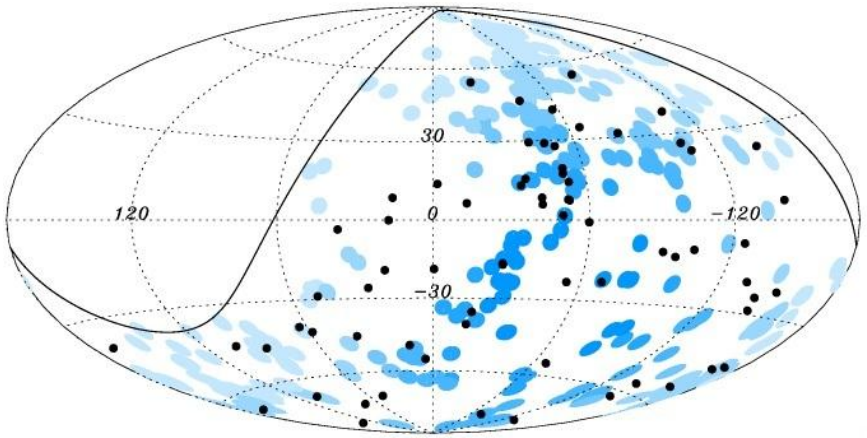
- Assuming magnetic field 1μG
- Proton with ~10^{19}eV corresponds to a Larmor radius of ~10kpc

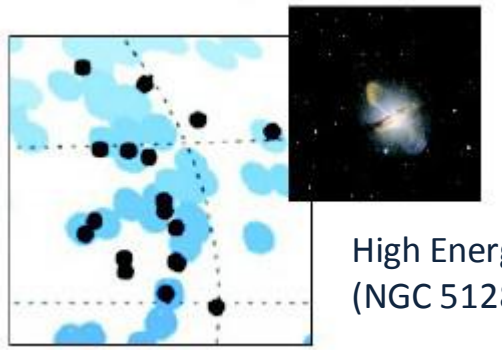
*The Pierre Auger Collaboration, Phys. Lett. B685:239-246,2010

* Cronin, J. W. 2005, Nuclear Physics B (Proc. Suppl.), 138, 2005

Cosmic Rays directions

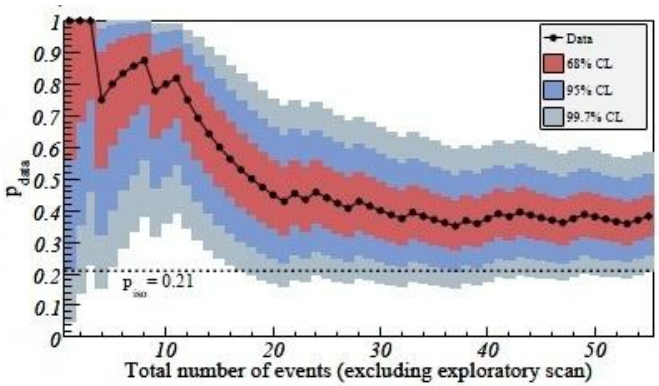
❑ Anisotropy

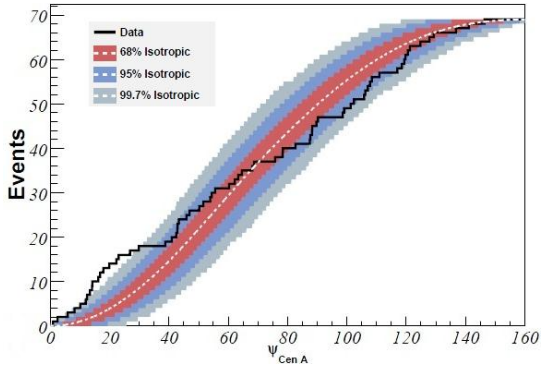




High Energy Centaurus A (NGC 5128) excess

■ Analysing the 57 more energetic events (>10^{19} eV), we have anisotropy, but more statistic is needed for better conclusions

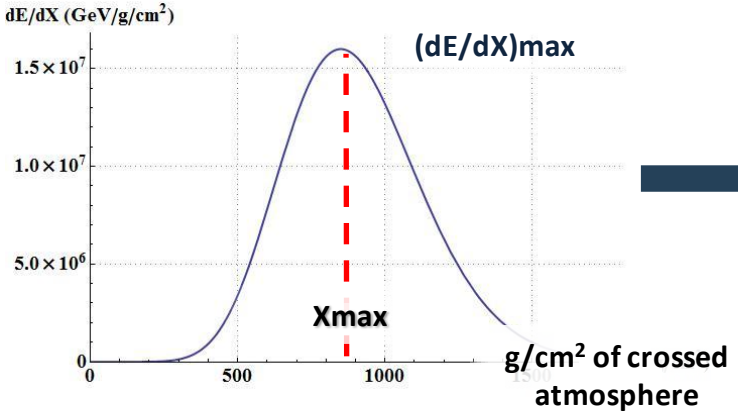


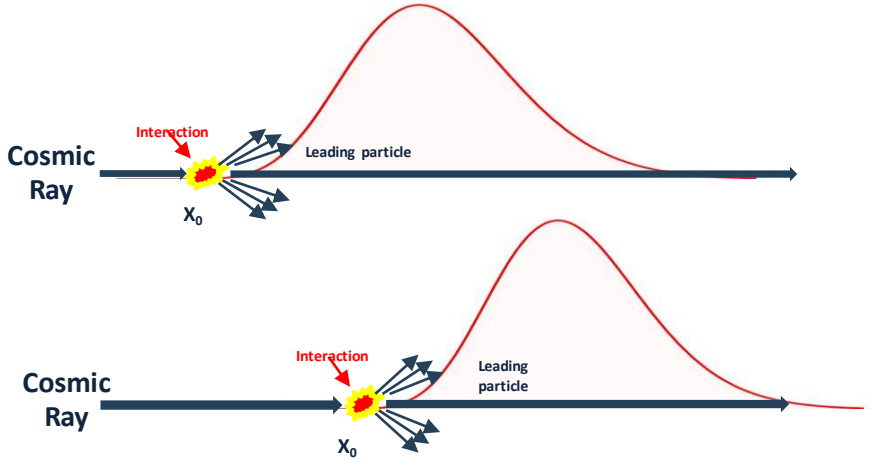


*The Pierre Auger Collaboration, arXiv:1009.1855v2 [astro-ph.HE]

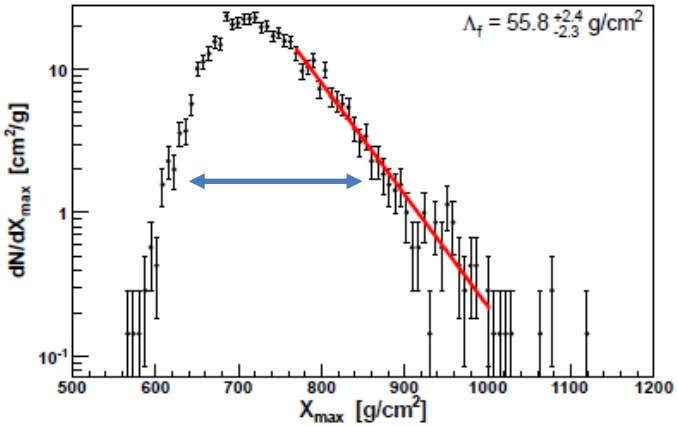
Xmax results

Xmax remind





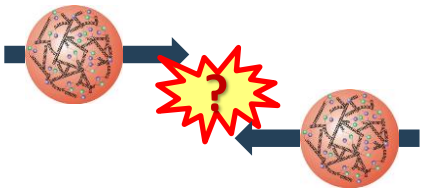
RMS Xmax

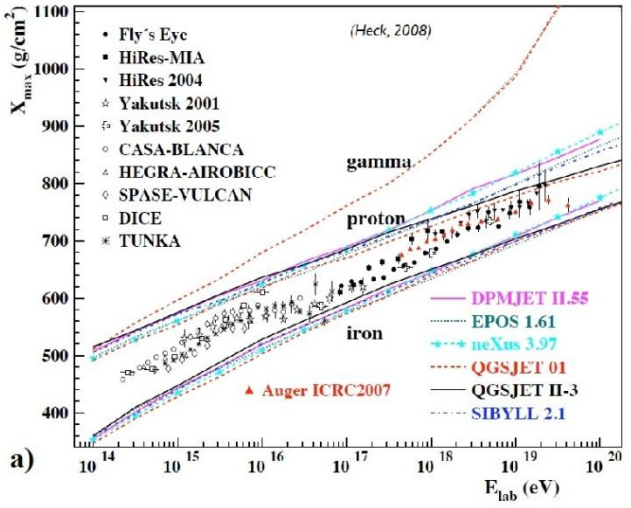


3. Xmax results

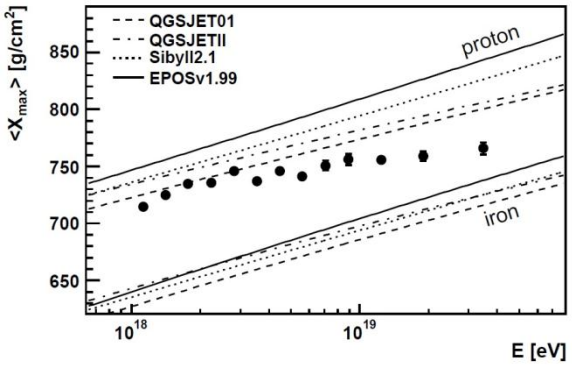
Xmax evolution with energy

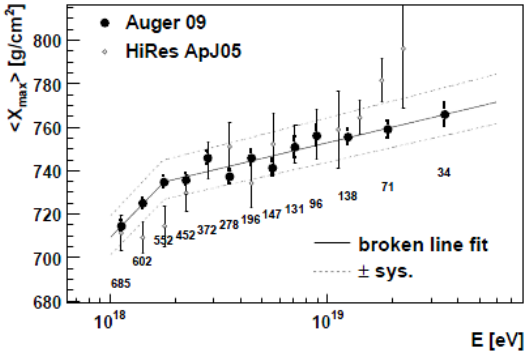
- Xmax goes from iron to proton, and then seems to returns to heavier nuclei again (at ultra high energies)
- Are cosmic rays really becoming heavier?
  - Astrophysical Challenges
  - Or problems with model predictions
  - Are there **new interactions**?

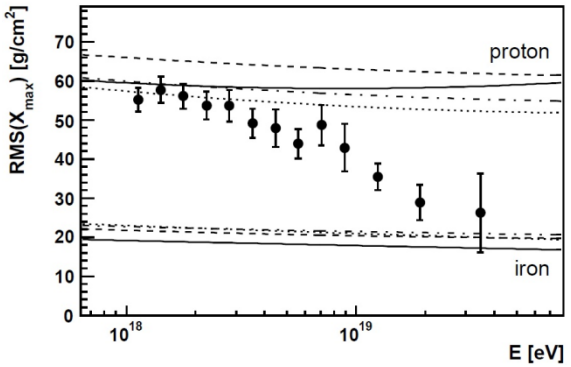




Recent results





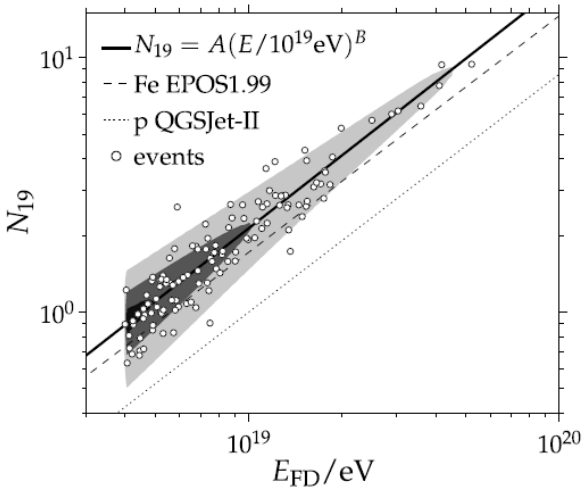


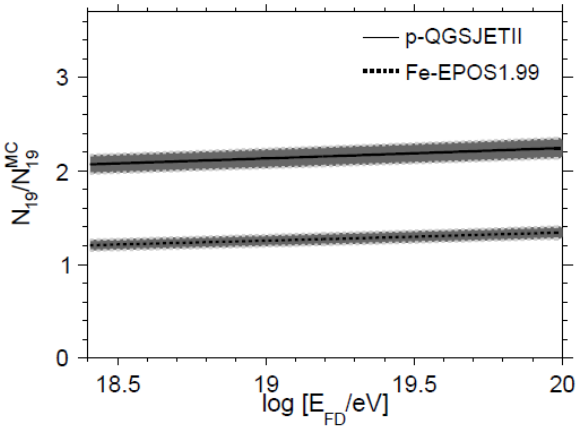
data until March 2010

*The Pierre Auger Collaboration, Phys. Rev. Lett. 104, 2010.

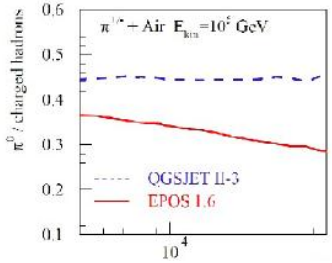
Muon Number

Larger Muon number

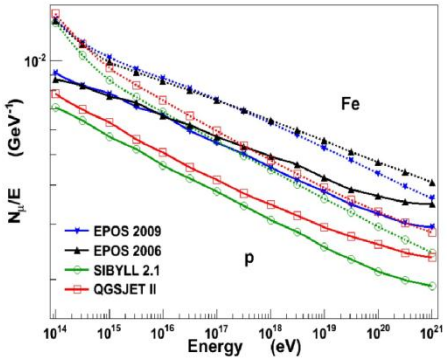




- More muons than possible
- Standard physics can not reproduce it
- May be new kinds of interactions
  - Non-perturbative QCD is not understood
  - Problems in the hadronization

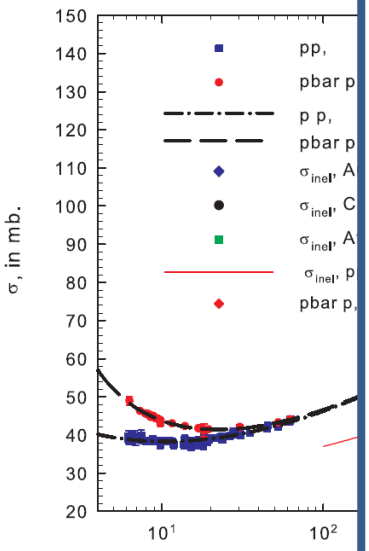


- Energy reconstruction?



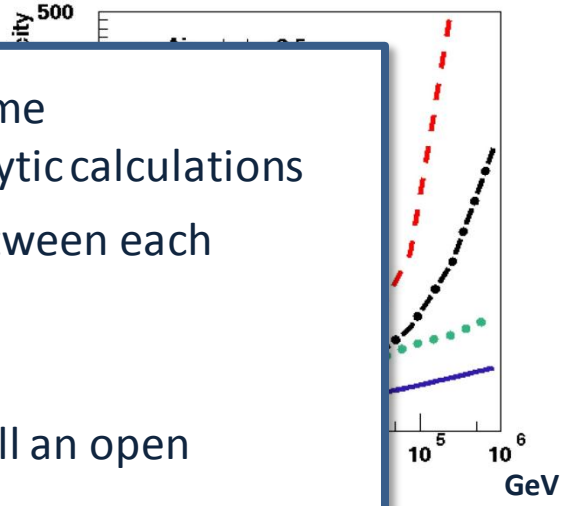
Hadronic Models

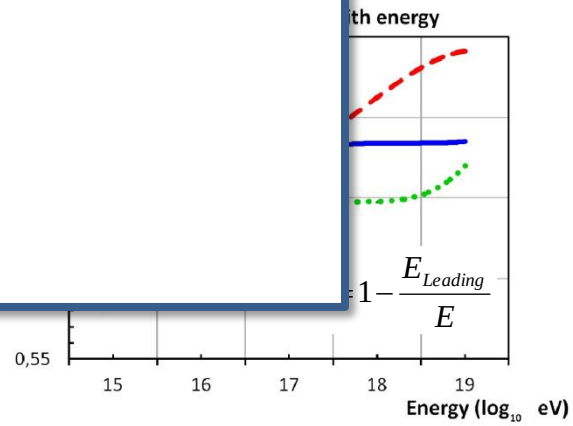
❑ Cross section



■ The models can not des
consistently

❑ Multiplicity





■ Non-perturbative QCD regime
so we can not make analytic calculations

■ Models are inconsistent between each other and with the data

■ Cosmic rays composition still an open question

■ Challenges for new Data

■ Challenge for news models