Reconstruction of the Muon Production Distance in Air Showers at the Pierre Auger Observatory

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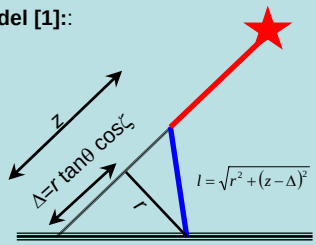
Motivation: In an Extensive Air Shower, particles arrive at ground at different times with respect to the shower plane front. Muons are of special interest.

Muon Time Model [1]::

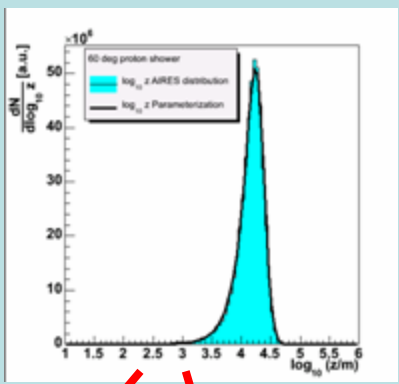


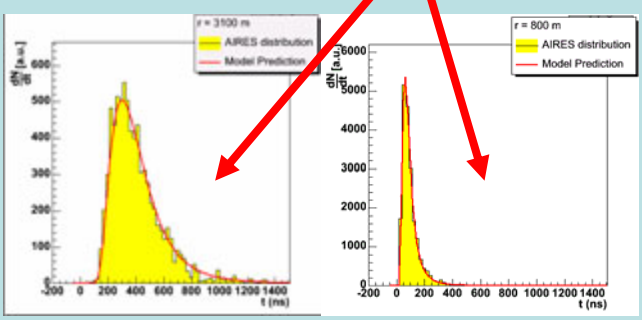
This muon arrival time structure is mainly due to geometry effects. Muons are produced approximately within the shower axis, Then, the delay can be approximated by:

$$ct_g = \frac{1}{2}\frac{r^2}{z-\Delta} \qquad (1)$$

There is a second order contribution to the delay, due to the different muon velocities: the *kinematical delay*.

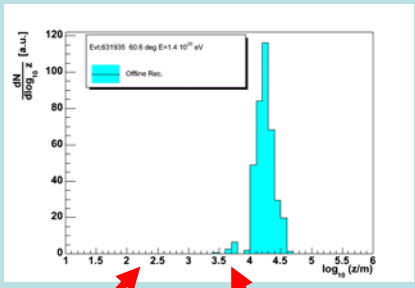
The arrival time distribution is a direct transformation of the production distance distribution.

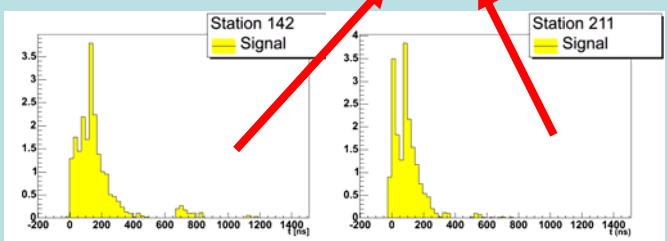




Method [2]**:** The Pierre Auger Observatory is made out of 4 fluorescence telescopes (FD) and 1600 Cerenkov tanks deployed in an area of 3000 km² (SD) that record the arrival time information of the particles at ground.

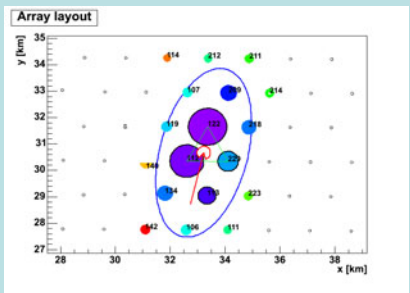
Inverting *eq.* 1 we can obtain the production distance distribution.



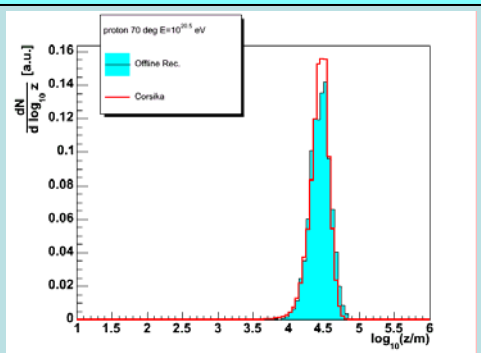


Limitations [2]**:** We can use all tanks except those close to the central region, because:

- They introduce a larger uncertainty.
- In vertical showers, electrons and photons shadow the muon signal.
- *Kinematical delay* dominates.



Test: The method has been tested using the full Auger detector simulations.



References:

[1] L. Cazon, R.A. Vazquez, A.A. Watson, E. Zas, Astropart.Phys.**21**:71-86 (2004)

[2] L. Cazon, R.A. Vazquez, E. Zas, Astropart.Phys.**23**:393-409 (2005)

Applications of the technique:

- Mass composition studies.
- Neutrino discrimination.
- Comparison with the Fluorescence measurements (Hybrids):Hadronic Models Validation.
- Core and Angle reconstruction.