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

Lorenzo Cazon, Markus Roth
Forschungszentrum and Universität Karlsruhe

**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.

**Method:**

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:**

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.

**Applications of the technique:**

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

**Muon Time Model [1]:**

\[ t_g = \frac{1}{2} \frac{r^2}{z - \Delta} \]

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:

\[ ct_g = \frac{1}{2} \frac{r^2}{z - \Delta} \]

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

**References:**
