Improving the external trigger of AERA for extensive air showers at the Pierre Auger Observatory

Rukije Uzeiroska

University of Wuppertal

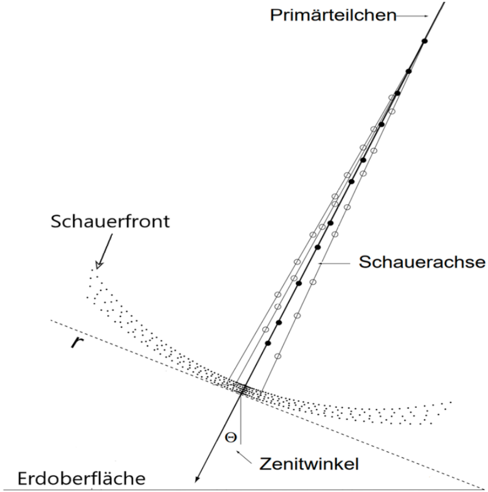
DPT 2022 - Karlsruhe

November 26, 2022

PIERRE AUGER OBSERVATORY

Bundesministerium für Bildung und Forschung

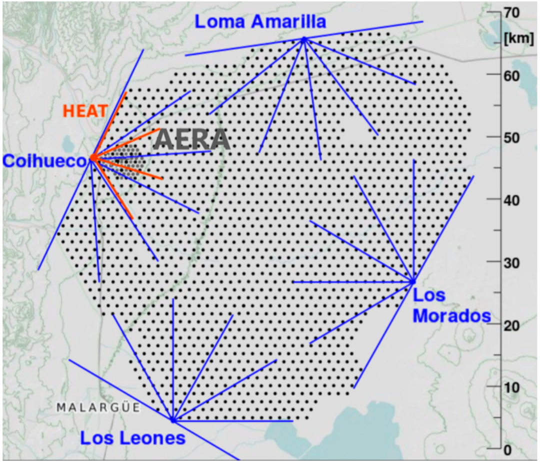
Characteristics of extensive air showers



- Shower axis: Direction of the primary particle
- Properties of the shower front:
  - longitudinal width $\approx 1\,\mathrm{m}$
  - lateral expansion $\approx$ few meters up to kilometers
- r: Distance to the shower axis
- θ: angle between the earth normal and the shower axis
- Shower core: intersection of the shower axis and the earth surface

Detection of extensive air showers with Pierre Auger Observatory

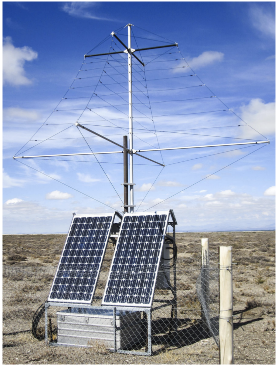
Pierre Auger Observatory



- World's largest observatory for the detection of high energy cosmic rays
- Located in Argentina
- Observatory: 3000 km^2
  Karlsruhe: 173 km^2
- Consists of several detector systems
- Relevant for this presentation:
  - Surface Detector (SD)
  - Auger Engineering Radio Array (AERA)

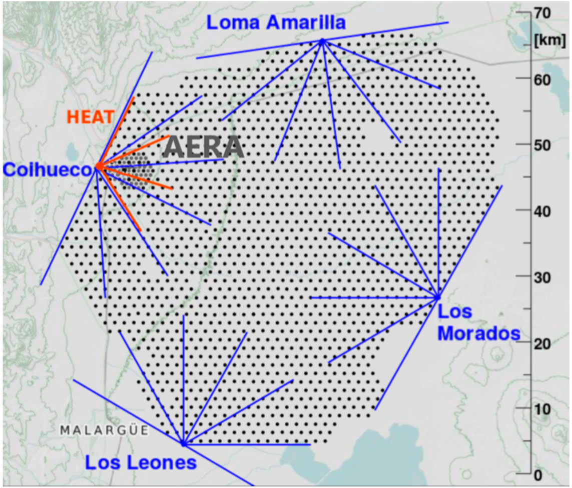
Pierre Auger Observatory

- Surface Detector:
  - Detection of charged particles
  - 1600 Measuring stations with water tanks
  - Surface of 3000 km^2



- Auger Engineering Radio Array:
  - Detection of radio radiation
  - 154 Measuring stations with antennas
  - Surface of 17 km^2

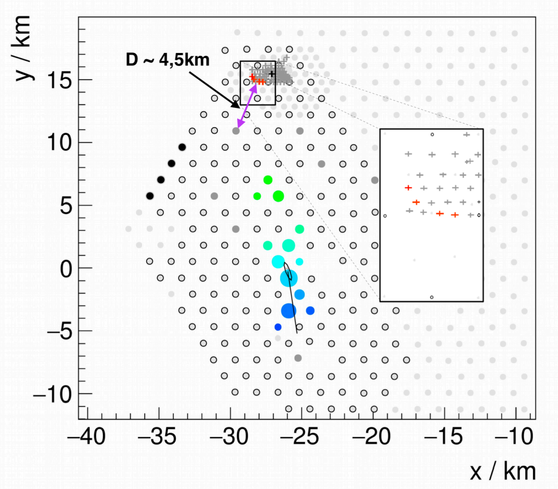
Pierre Auger Observatory



Current SD trigger of AERA

- Data taking of AERA with different internal and external trigger modes
- Relevant: external SD-trigger
- Trigger condition: $D < 5\,\text{km}$
  - ⇒ Data rate too high
  - ⇒ Low purity (approx. 10 of 8000 events reconstructable)
  - ⇒ Limited efficiency

(Adopted from M. Gottowik)



Reconstruction of the shower axis and the distance to AERA

The online reconstruction method

Offline reconstruction method:

- Used in the Auger analysis software
- More information necessary than given at trigger level
- Takes an indefinite amount of time

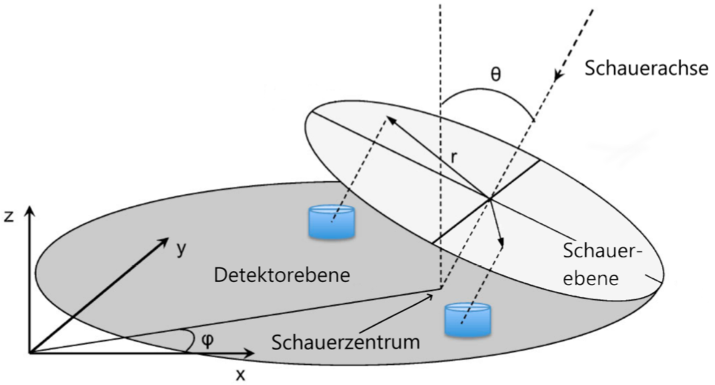
Online reconstruction method requirements:

- Should take place at trigger level
- Only coordinates and time stamps of the SD stations known
- Only a few seconds available

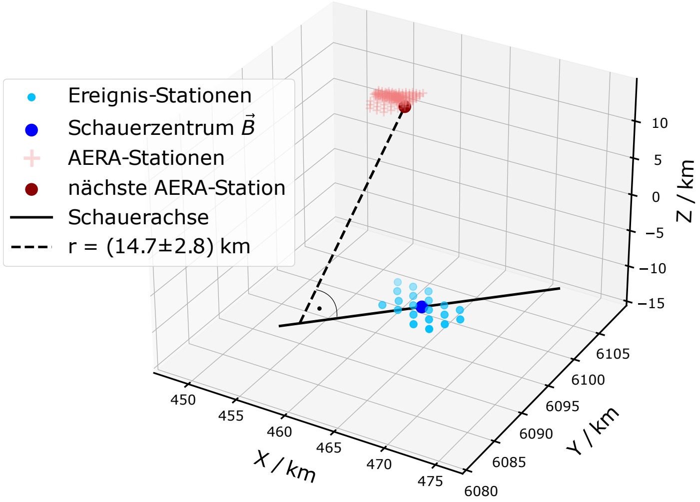
$\Rightarrow$ Offline reconstruction unsuitable for the ext. SD trigger
$\Rightarrow$ Development of a fast reconstruction method with sufficient accuracy

Geometric relationships

- Definition of a shower axis
  - Direction vector
  - Shower core
- Inclination of the shower axis
  - ⇒ Shower front reaches the stations with a **time delay**
- Direction vector
  - ⇒ Zenith angle θ
  - ⇒ Azimuth angle φ



Reconstruction of the distance r



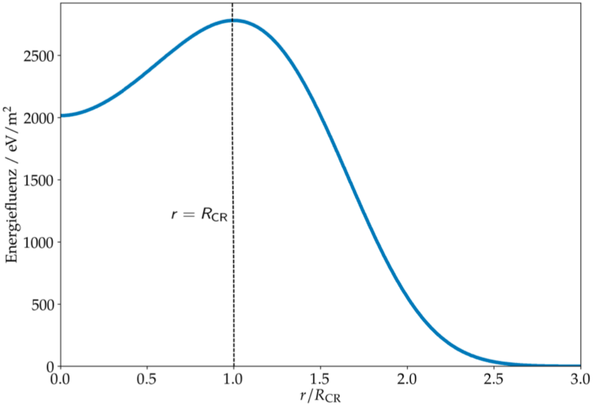
- Shower core: median $\vec{B}$ of the coordinates of the triggered SD stations
- r: shortest distance between the shower axis and AERA

Trigger conditions

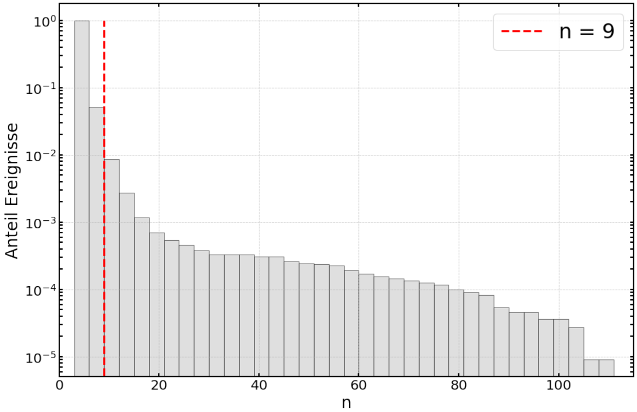
Lateral energy distribution of radio radiation

- Fit to the lateral energy distribution of the radio radiation of a real air shower
- R_{CR}: Cherenkov radius
- $r \geq 3 \cdot R_{\mathrm{CR}} \Rightarrow$ Energy flux = 0
- Examination of $r < 3 \cdot R_{\mathrm{CR}}(\theta)$ as trigger condition, since the radio emission is hardly measurable outside

(cf. M. Gottowik)



Trigger studies on the number of stations n



- Reconstruction time strongly dependent on number of SD stations n

  $\Rightarrow$ Limitation of n necessary
- Left: normalized cumulative distribution of n for 131 310 real events
- Less than 1 % of the events with $n > 9$
- Trigger condition: events with $n > 9$ are going to be saved without reconstruction

Summary

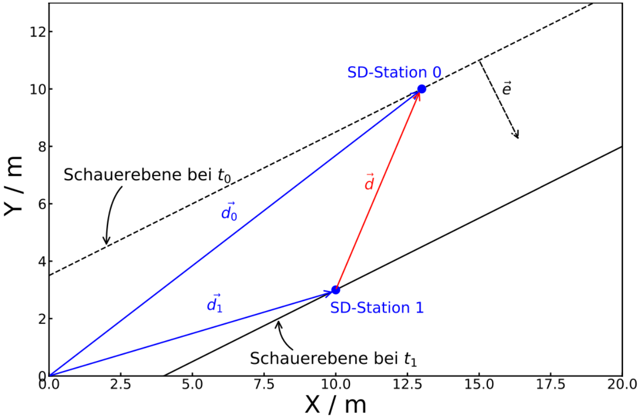
Summary

- Goal: Optimization of the external SD trigger of AERA
- Online reconstruction method:
  - Little information necessary
  - Good agreement with the results of the offline reconstruction method
  - Very fast
- Trigger condition $r < 3 \cdot R_{\mathrm{CR}}(\theta)$:
  - Increases the efficiency of the trigger
  - Doubles the purity of the data
- Trigger studies on n
  - Less than 1 % of all events with $n > 9$

$\Rightarrow$ Newly developed trigger condition: $n > 9$ or $r < 3 \cdot R_{\mathrm{CR}}(\theta)$

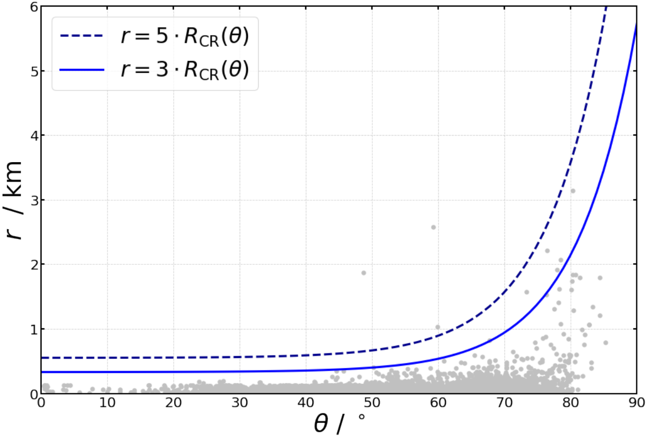
Backup

Reconstruction of the direction vector



- Direction vector of an air shower: $\vec{e} = (e_x, e_y, e_z)$
- From geometric relationships follows:
  - $\Rightarrow \; -v \cdot (t_i - t_j) = -\vec{e} \cdot (\vec{d}_i - \vec{d}_j)$
- v: Propagation velocity
  - $\Rightarrow$ In this case: $v \approx c$
- $\vec{d}_i, \vec{d}_j$ Location vectors of two SD stations with their trigger times $\vec{t}_i, \vec{t}_j$

Trigger studies on angle θ and distance r



- R_{CR} depends on the zenith angle θ of a shower
- 5528 real events are reconstructed with the online method
  - SD and RD data were reconstructed offline by Auger
  - As many of them as possible should be triggered
- Trigger efficiencies:
  - $r < 3 \cdot R_{CR}(\theta)$: 99.87 %
  - $r < 5 \cdot R_{CR}(\theta)$: 99.96 %

Determination of a clear shower direction

Aufstellung des Gleichungssystems

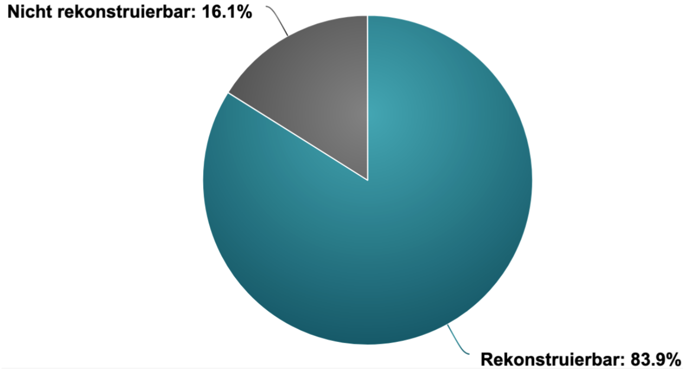
$$
\begin{aligned}
\text{I)} \quad & -c(t_1 - t_0) = e_x \cdot (d_1 - d_0)_x + e_y \cdot (d_1 - d_0)_y + e_z \cdot (d_1 - d_0)_z \\
\text{II)} \quad & -c(t_2 - t_0) = e_x \cdot (d_2 - d_0)_x + e_y \cdot (d_2 - d_0)_y + e_z \cdot (d_2 - d_0)_z \\
\text{III)} \quad & e_x^2 + e_y^2 + e_z^2 = 1
\end{aligned}
$$

- All possible three-station combinations are run through
- Number of combinations for n triggered SD stations:

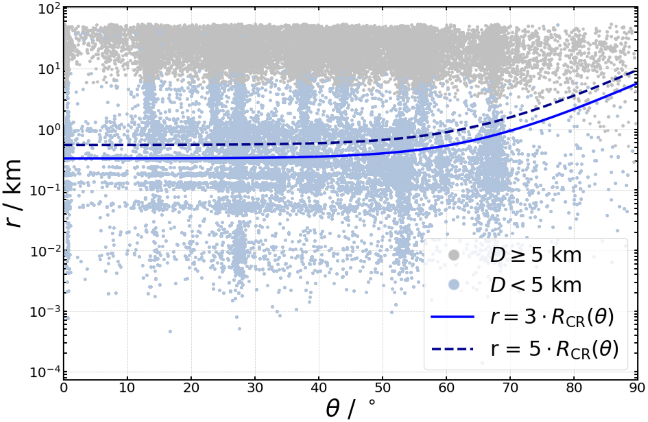
$$M = \frac{n!}{(n-3)! \cdot 3!} \underset{n=14}{\overset{\text{Beispielereignis}}{=}} 364$$

Test the trigger condition

- Analysis of 131 310 additional events with the online reconstruction method
- Nearly all reconstructable events triggered by more than 3 or 4 SD stations
  - $\Rightarrow$ Others are background
- $D < 5\,\mathrm{km}$: no shower reconstruction
  - $\Rightarrow$ Triggers events that cannot be reconstructed
  - $\Rightarrow$ Many background events



Comparison of the trigger conditions



- With $D < 5\,\text{km}$:
  - Some triggered events not measurable for AERA
  - Some events measurable for AERA are not triggered
- Proportion of triggered events:
  - $D < 5\,\text{km}$: 36.24 %
  - $r < 3 \cdot R_{CR}(\theta)$: 18.13 %
- Purity of the data increases by a factor of two!