Cherenkov light in extensive air showers

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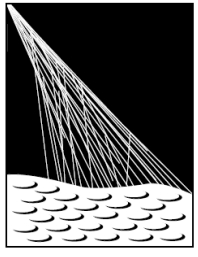


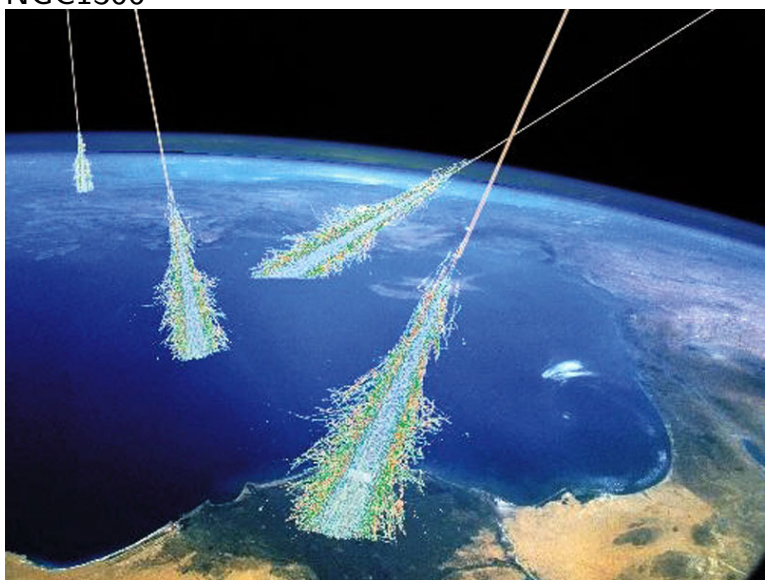
PIERRE AUGER OBSERVATORY

7. Oktober, 2011 - Astroparticle School - Obertrubach-Bärnfels

Outline

- Detection of Cosmic Rays
- Pierre Auger Observatory
- HEAT - low energy enhancement
- Simulation of extensive air showers
- Cherenkov light production
  - Effect of geomagnetic field
- Conclusion & Outlook

NGC1300

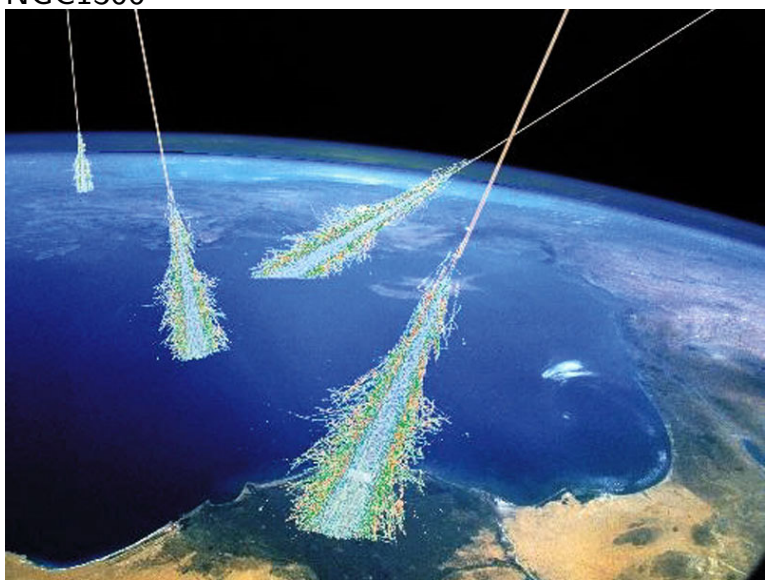


Motivation

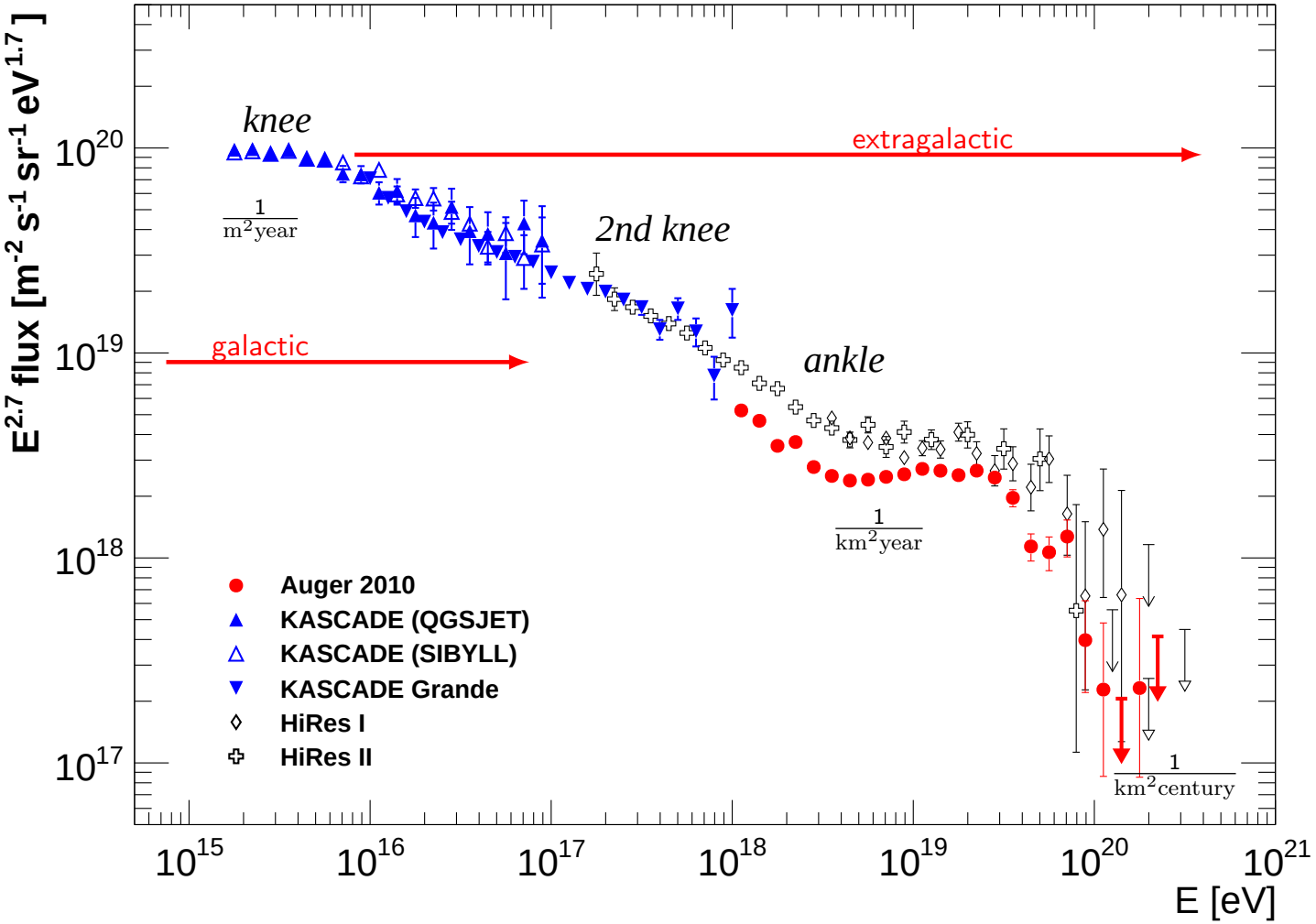
Cosmic Rays - open questions:

- Origin?
  - Galactic and extragalactic
- Composition?
  - From protons to heavy elements
- Energy?
  - Study shape of spectrum

NGC1300

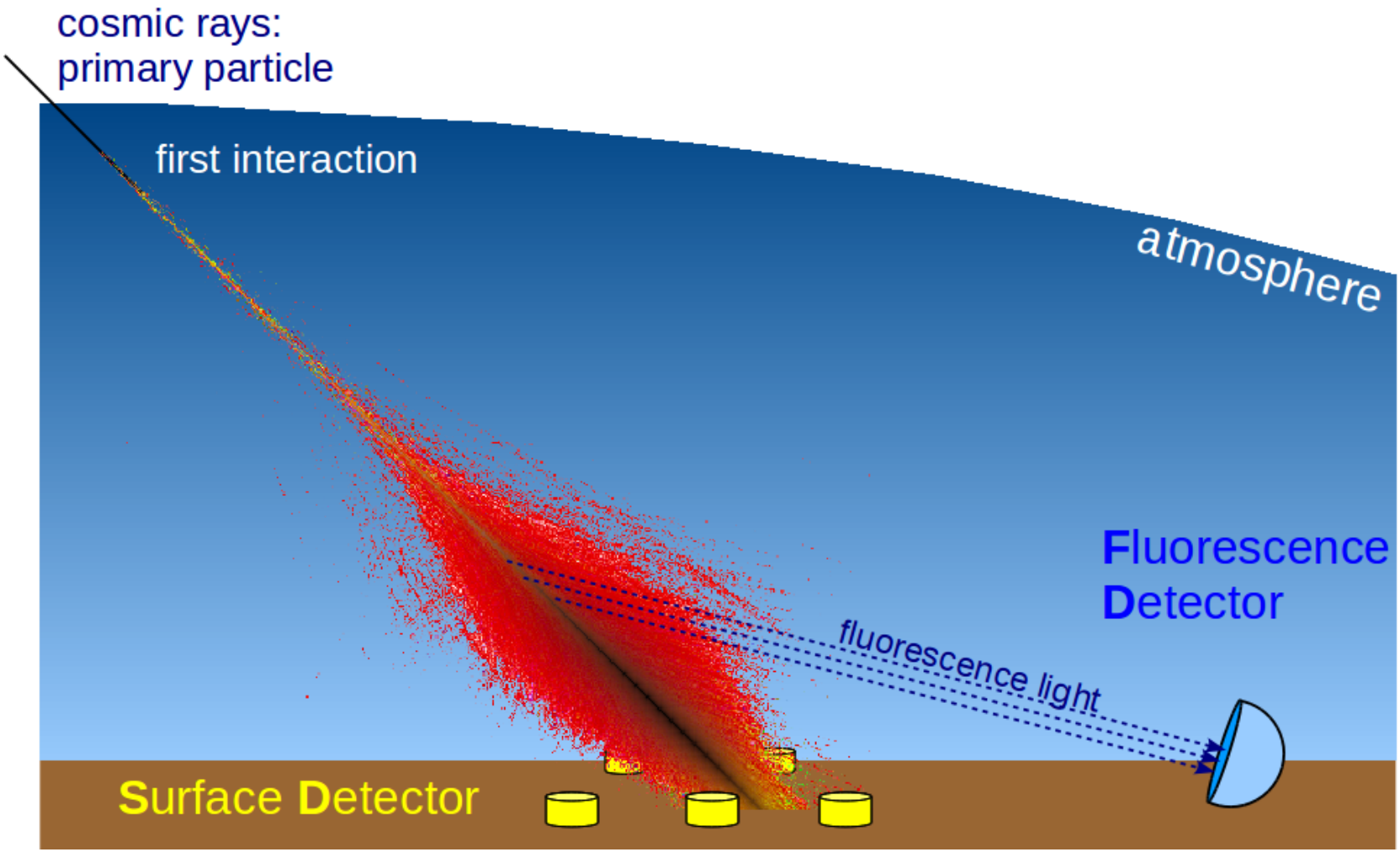


Cosmic rays energy spectrum



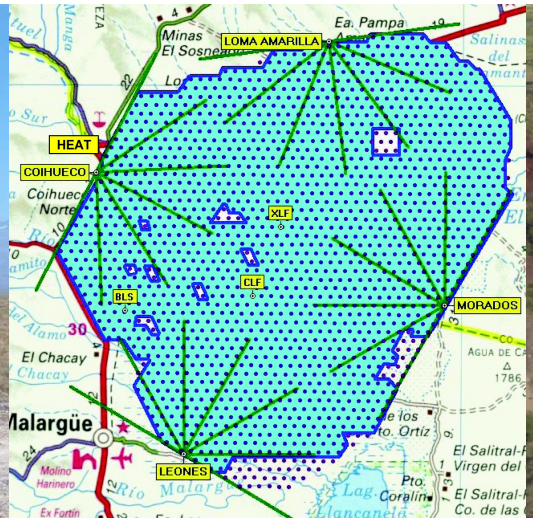
- very low flux at high energies $\Rightarrow$ large-area telescopes
- Pierre Auger Observatory: area 3000 km^2
- HEAT - enhancement for energy down to 10^{17} eV

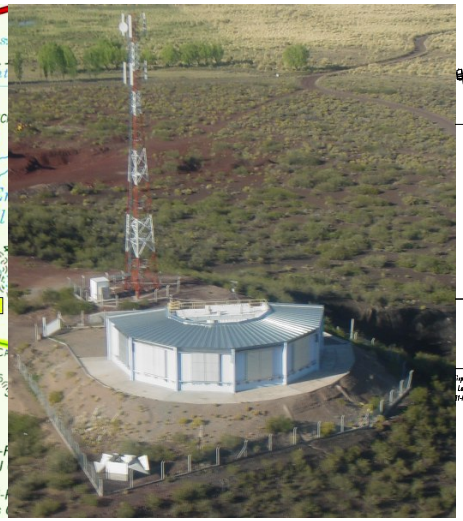
Detection of ultra high energy cosmic rays

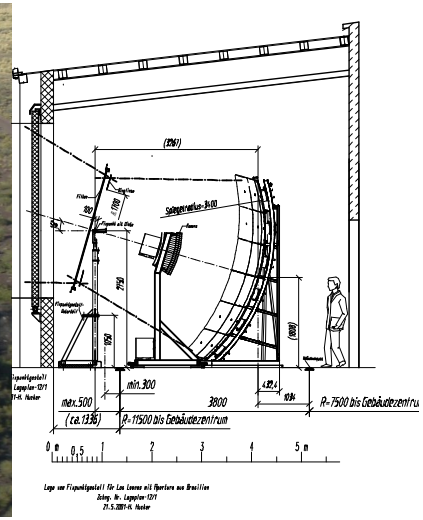


Hybrid detection technique

Pierre Auger Observatory: hybrid detector







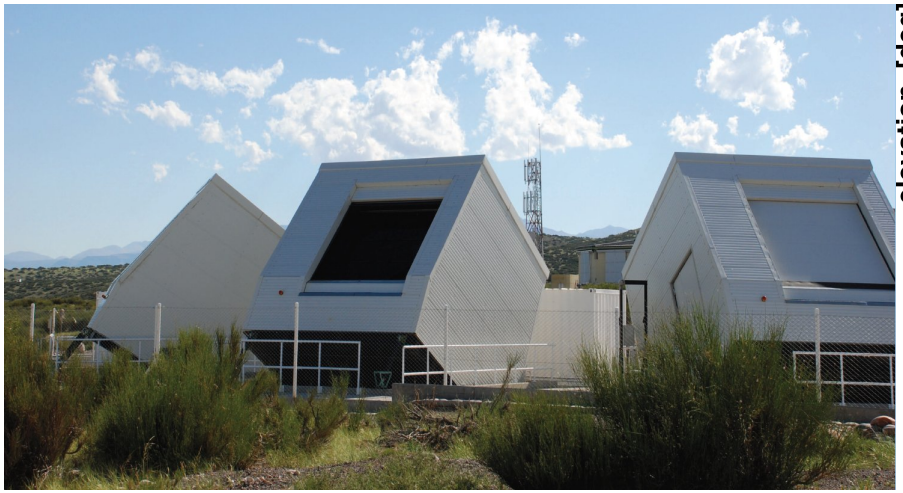
Surface Detector (SD)

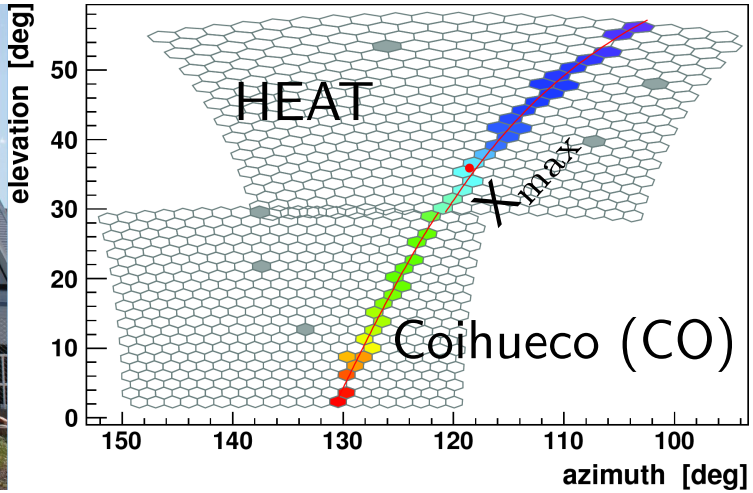
- 1660 detector stations
- Area 3000 km^2
- 1.5 km spacing
- water Cherenkov detectors

Fluorescence Detector (FD)

- 4 FD buildings (called eyes)
- each eye: 6 Schmidt-telescopes
- Field of view $30^\circ \times 30^\circ$
- Sensitive in $\lambda = 300..420$nm
- **H**igh **E**levation **A**uger **T**elescopes

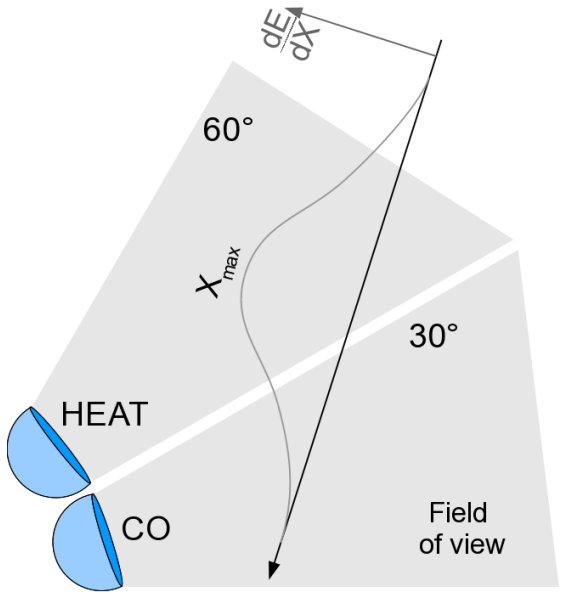
HEAT - **H**igh **E**levation **A**uger **T**elescopes



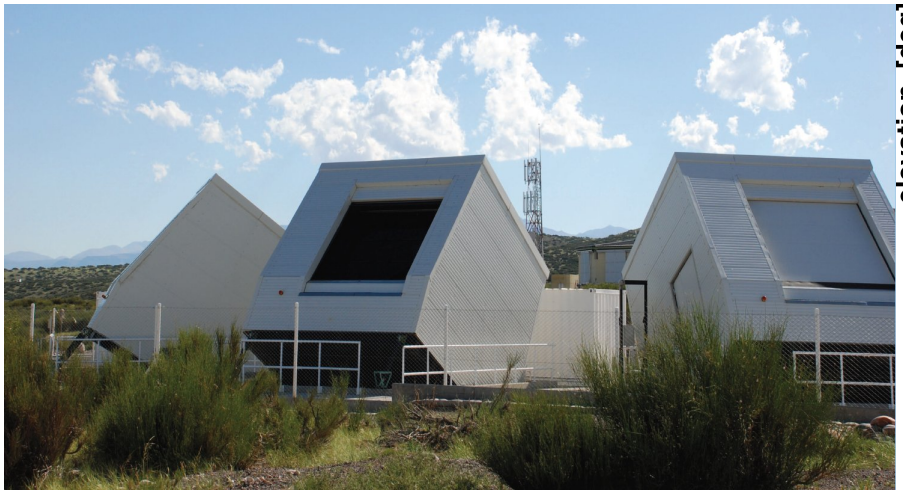


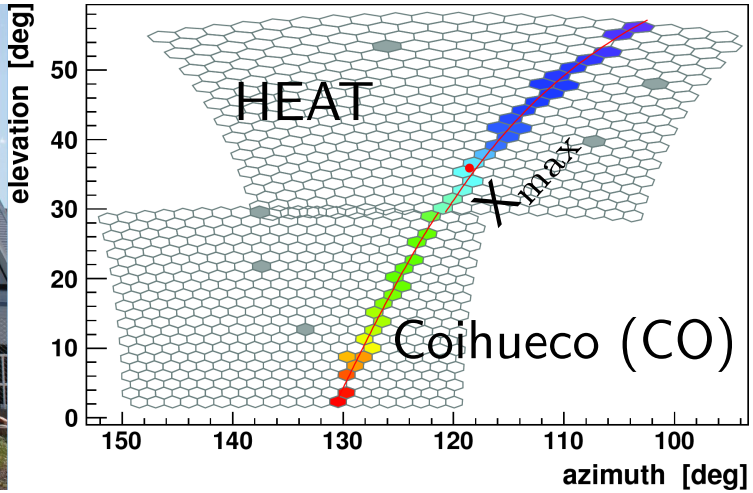
- 3 telescopes extending field of view of FD
- Looking at elevations between 30° and 60°

→ $X_{\max}$:= maximum of secondary particle energy deposit



HEAT - **H**igh **E**levation **A**uger **T**elescopes



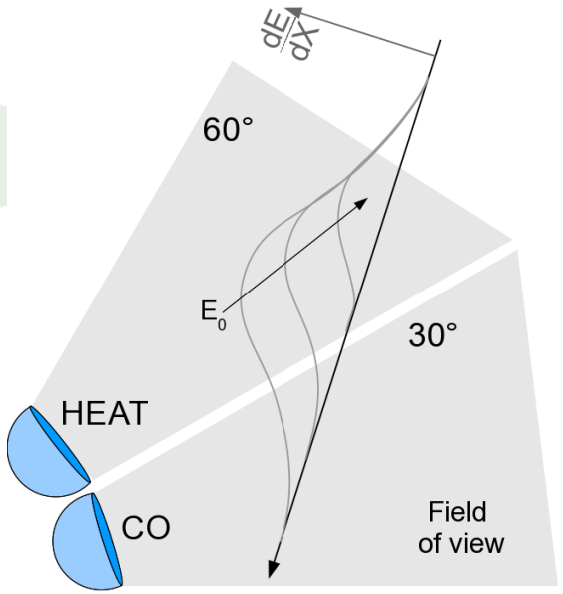


Extension for lower energy showers:

- Less energy deposited in the atmosphere

→ Only near showers detectable

- X_{max} at higher elevations → field of view



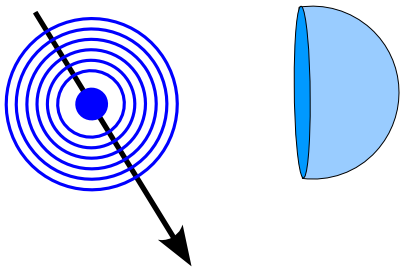
Light production mechanisms

Fluorescence and Cherenkov light in extensive air showers

Fluorescence light in atmosphere

- Excitation of nitrogen molecules by shower particles
- Emission of light with discrete spectrum in UV
- Photons are emitted uniformly

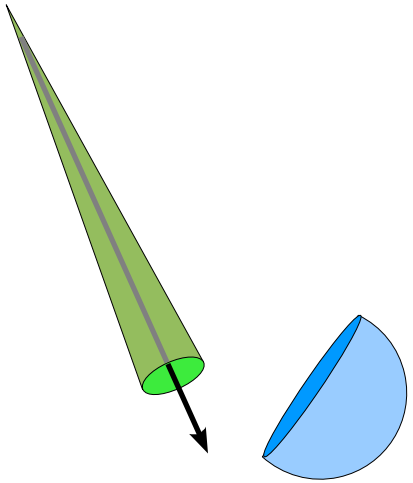
→ Visible at every viewing angle of the detector



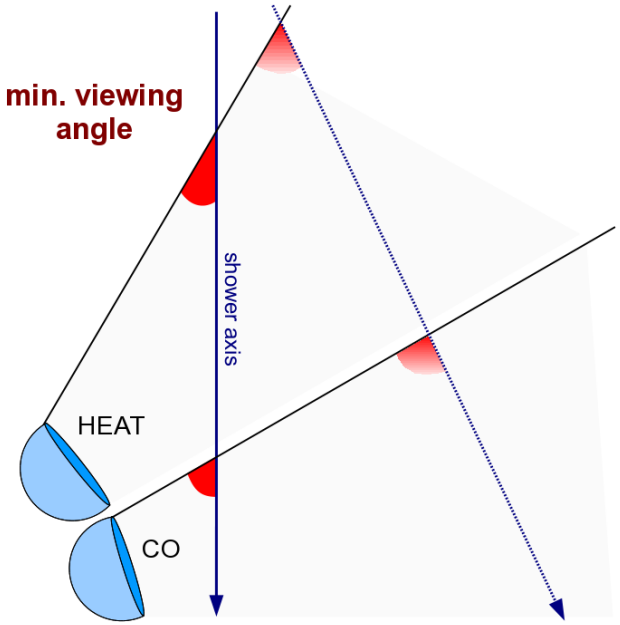
Cherenkov light in atmosphere

- Charged particles traveling faster than medium speed of light polarize medium atoms
- Cherenkov light is then emitted under angle $\cos(\theta_{Ch}) = \frac{1}{\beta n}$
- Continuous spectrum, mainly in UV
- Cherenkov light is beamed along particle track

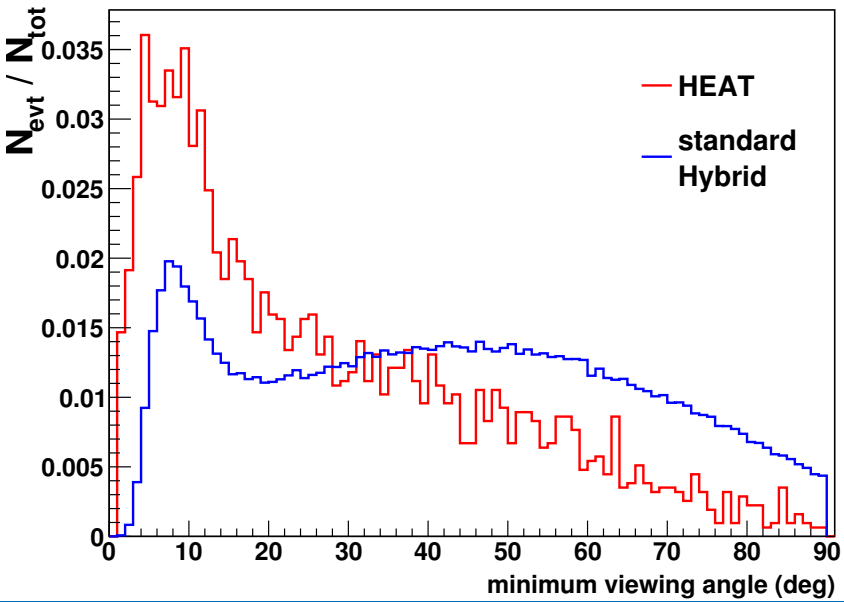
→ Superposed light cone in the direction of the shower

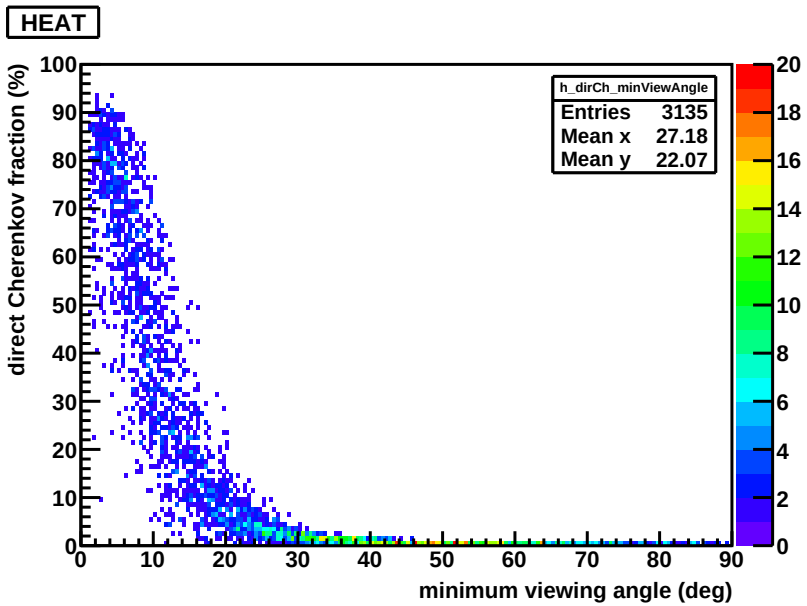


Effect of geometry on detected shower light



- More acute minimum viewing angle for HEAT showers
- HEAT is looking into the Cherenkov cone
- Fraction of direct Cherenkov light twice as high in HEAT events than in standard FD

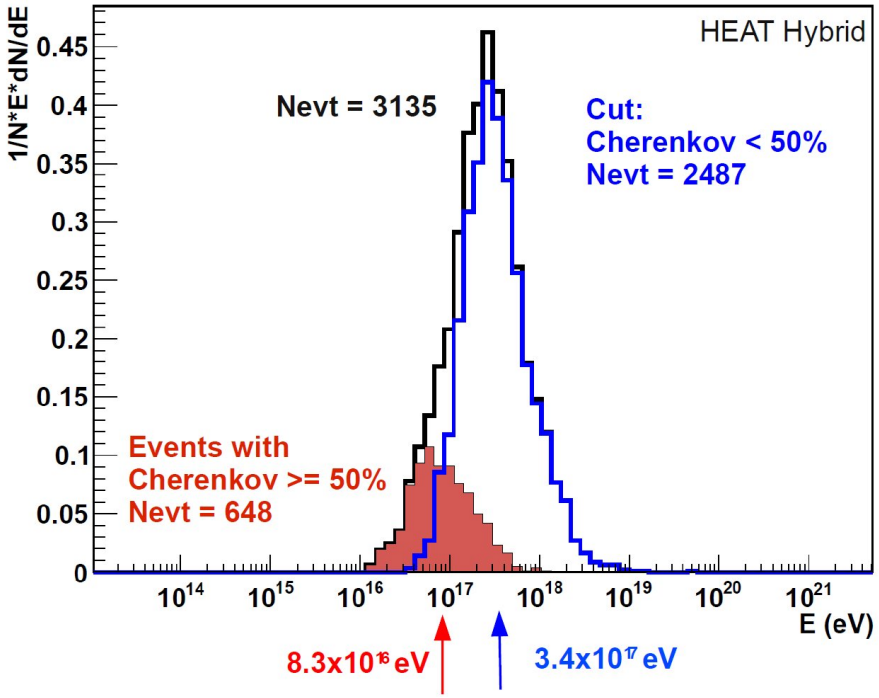




Cherenkov ⇔ Energy

- Cherenkov light allows triggering of low energy showers, otherwise not seen by standard FD

BUT Reconstruction chain not developed for high Cherenkov fraction - such showers are rejected by present data cuts for high level analysis



- It is important to consider Cherenkov-rich showers to extend Auger spectrum towards lower energy
- Understand influence of Cherenkov light for shower reconstruction

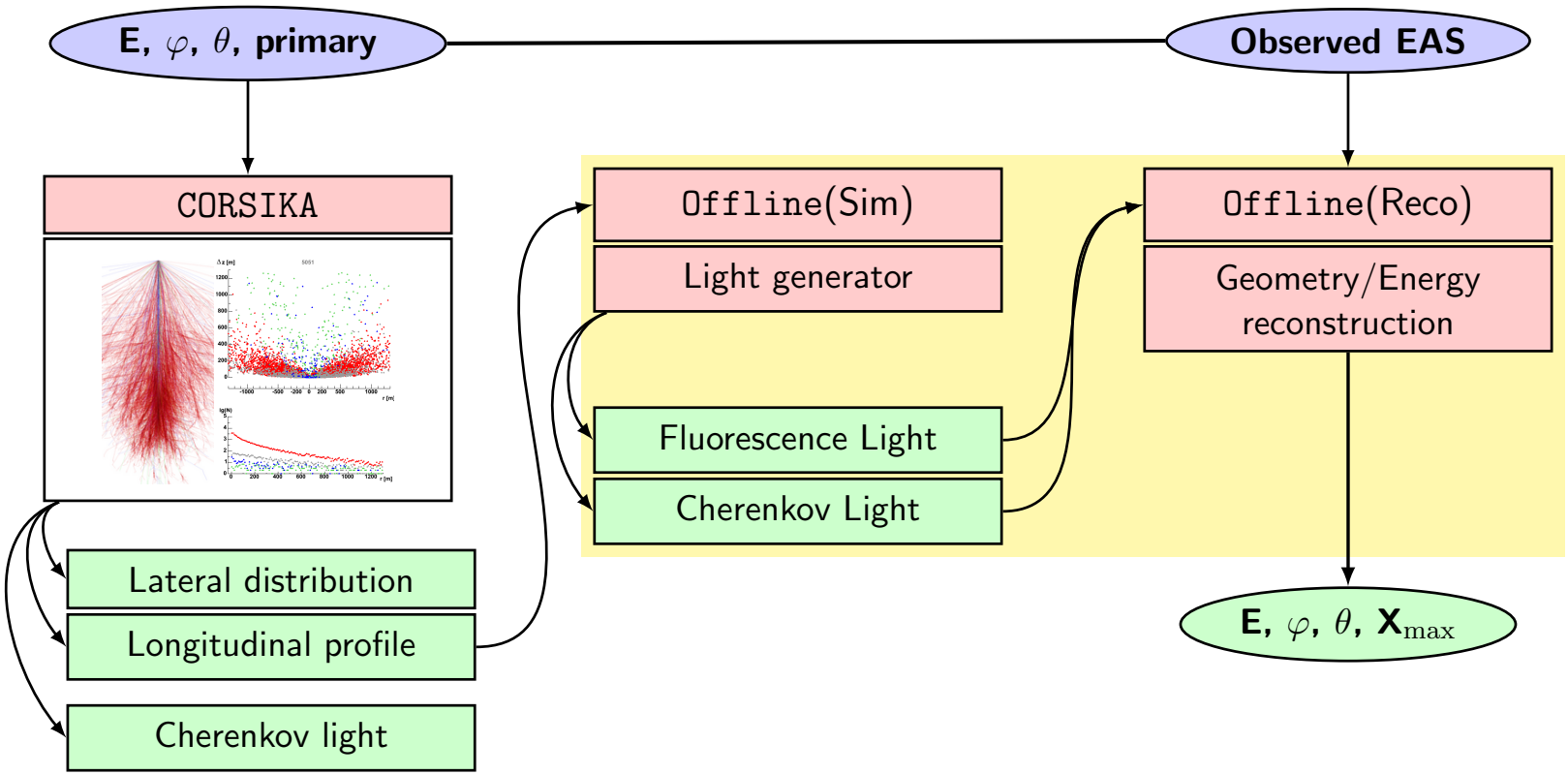
Simulation and reconstruction of extensive air showers

CORSIKA

Standard tool for full air shower simulation

Offline

Modular tool for air shower reconstruction developed by Pierre Auger Collaboration



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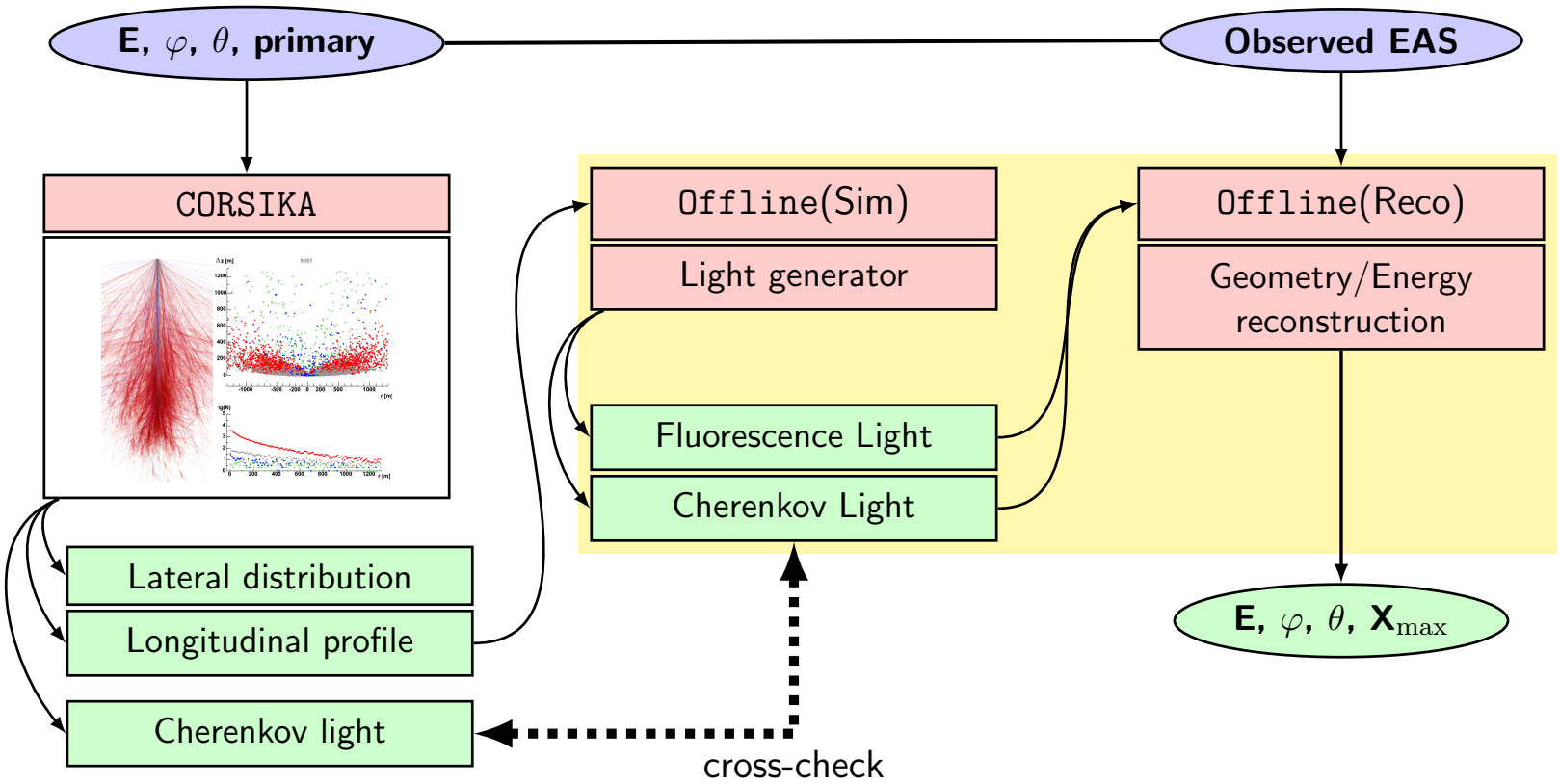
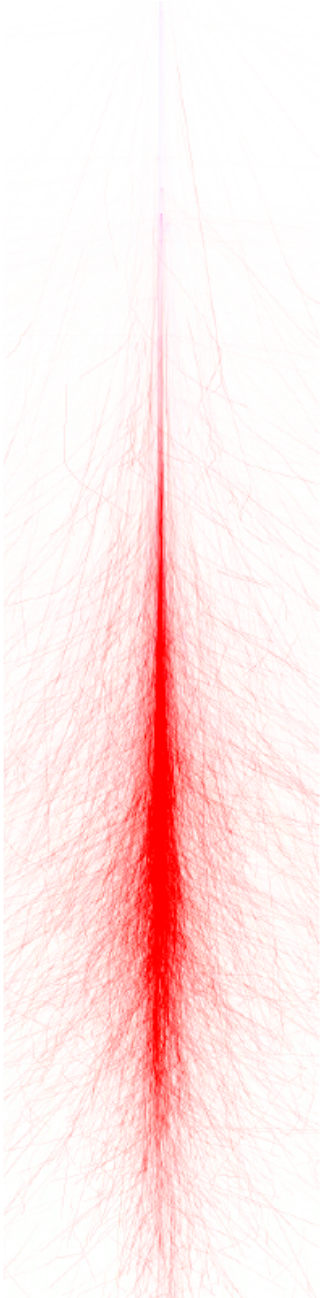


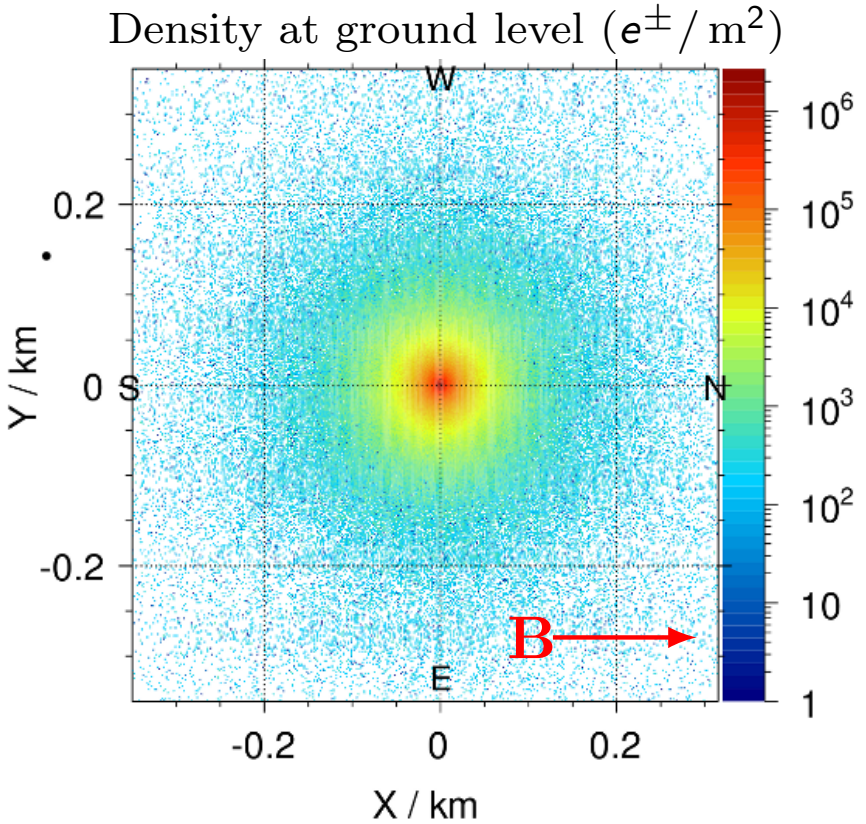
Effect of the geomagnetic field on particle showers



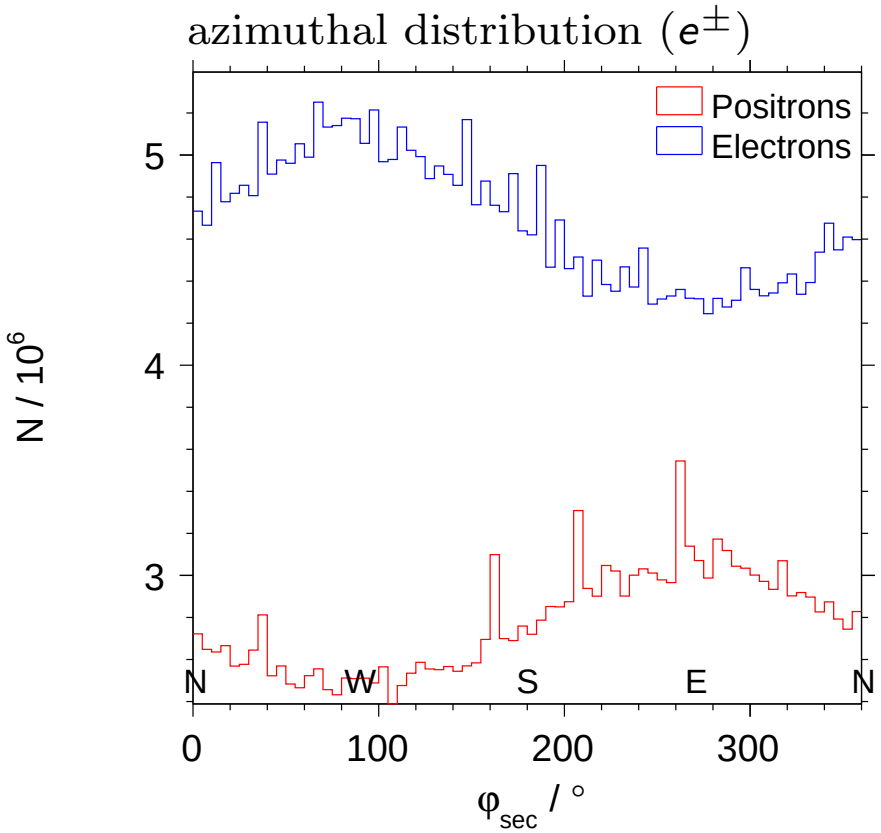
- Cherenkov light is mainly caused by electrons and positrons
- Interested in effects on electromagnetic shower component

$\rightarrow$ Study geomagnetic field

Electrons and positrons at ground level

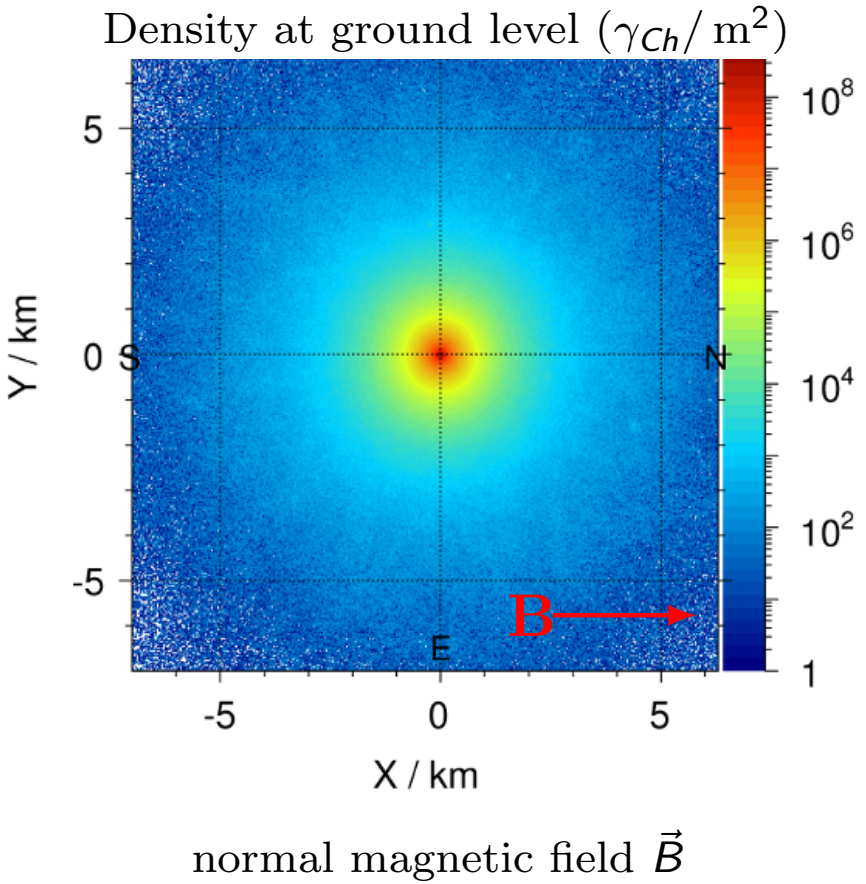


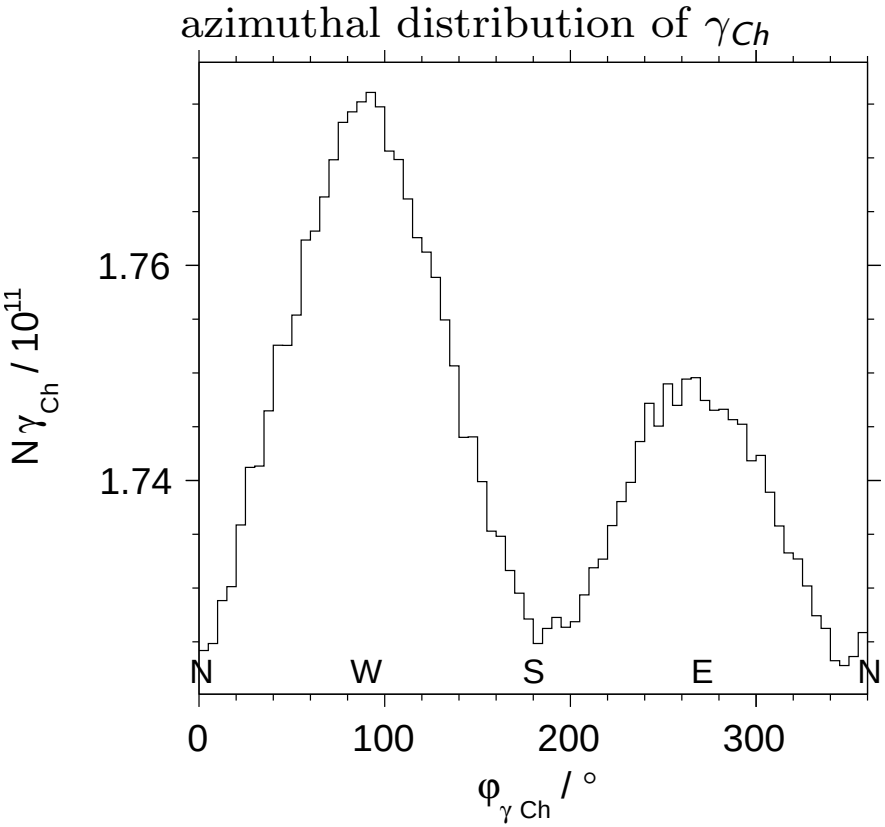
Earth magnetic field $\vec{B}$



- Electrons and positrons are deflected by the geomagnetic field
- Asymmetry in azimuthal distribution of secondary particles

Cherenkov photons at ground level



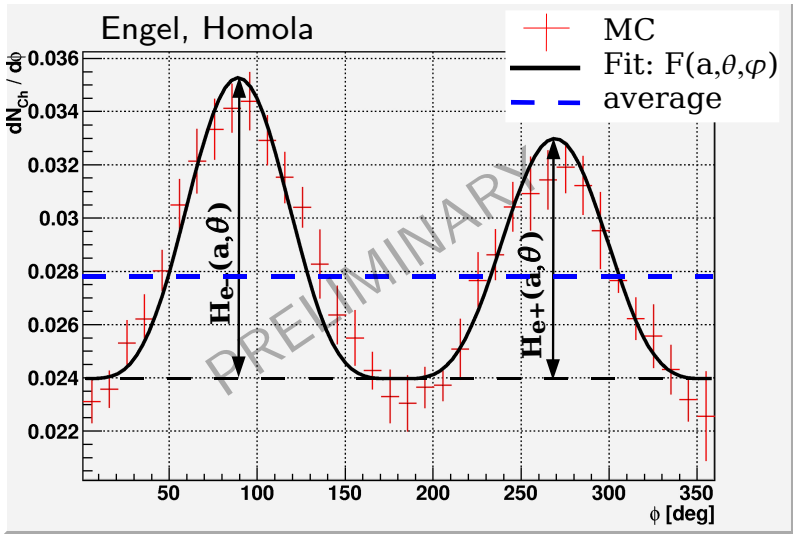


- Cherenkov photons follow the distribution of charged particles
- Asymmetry in azimuthal distribution of Cherenkov light due to geomagnetic field

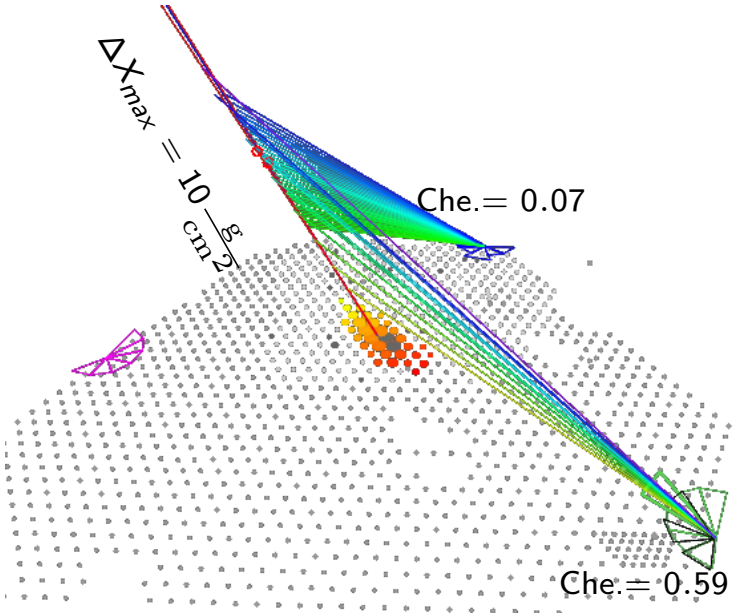
Parametrization of azimuthal asymmetry

- Consider influence of the geomagnetic field on azimuthal distribution of Cherenkov light in Auger data

→ Provides better reconstruction



- Test with stereo events as seen by 2 telescopes
- Correction of expected Cherenkov light for azimuthal asymmetry provides better reconstruction in E and $X_{\max}$



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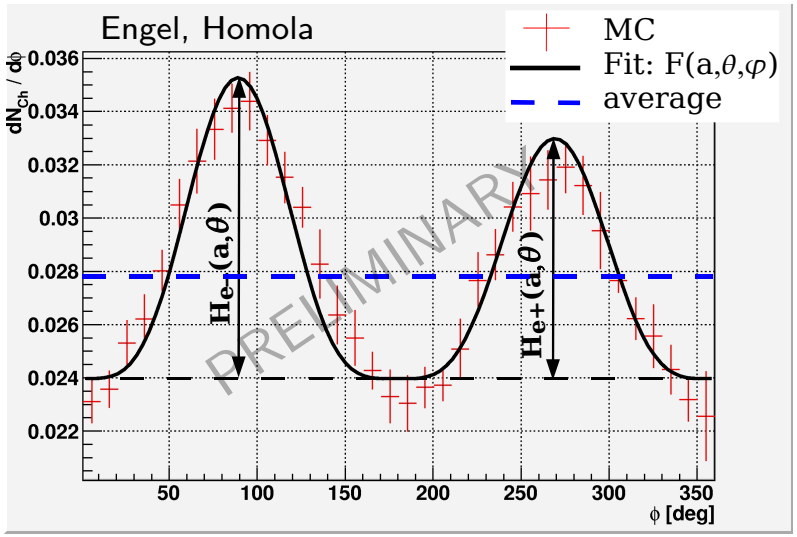
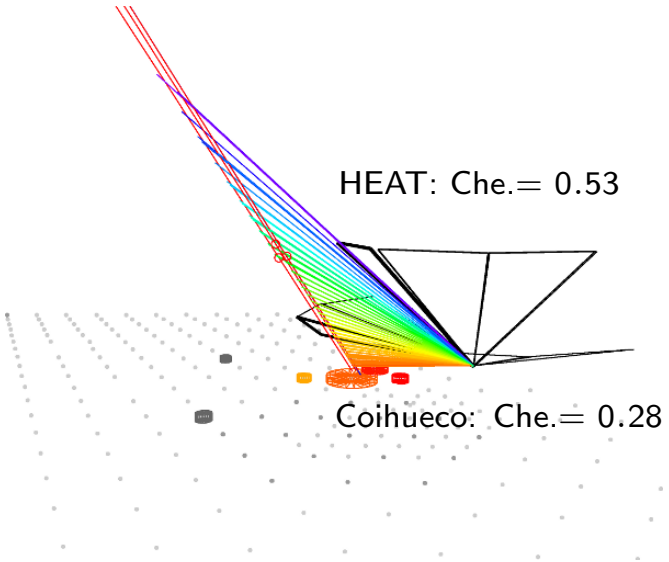


- HEAT and Coihueco stereo events also have different Cherenkov fractions

→ Estimate and apply correction for HEAT reconstruction



Conclusion & Outlook

Conclusion

- HEAT - low energy enhancement
- Higher Cherenkov light fraction in HEAT data
- Cherenkov light becomes important for reconstruction of air showers in $\overline{\text{Off}}\underline{\text{line}}$
- `CORSIKA` simulation study of secondary particles and Cherenkov light
- Asymmetry in azimuthal distribution caused by geomagnetic field

Outlook

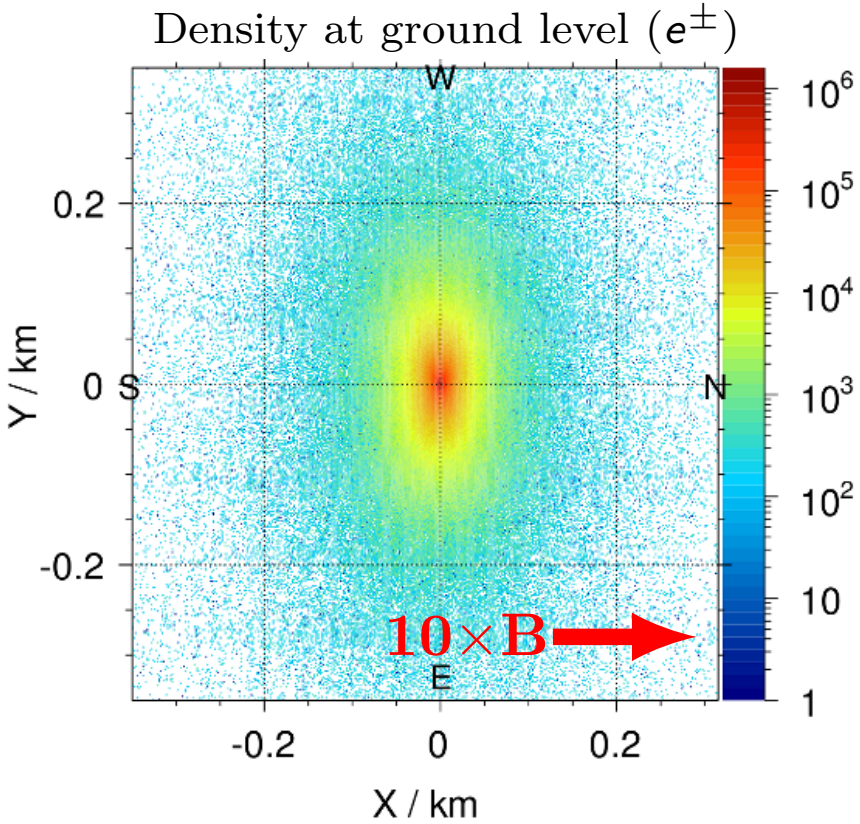
- Apply azimuthal asymmetry parametrization to HEAT and Coihueco stereo events
- Verify/optimize Offline Cherenkov simulation and reconstruction routines

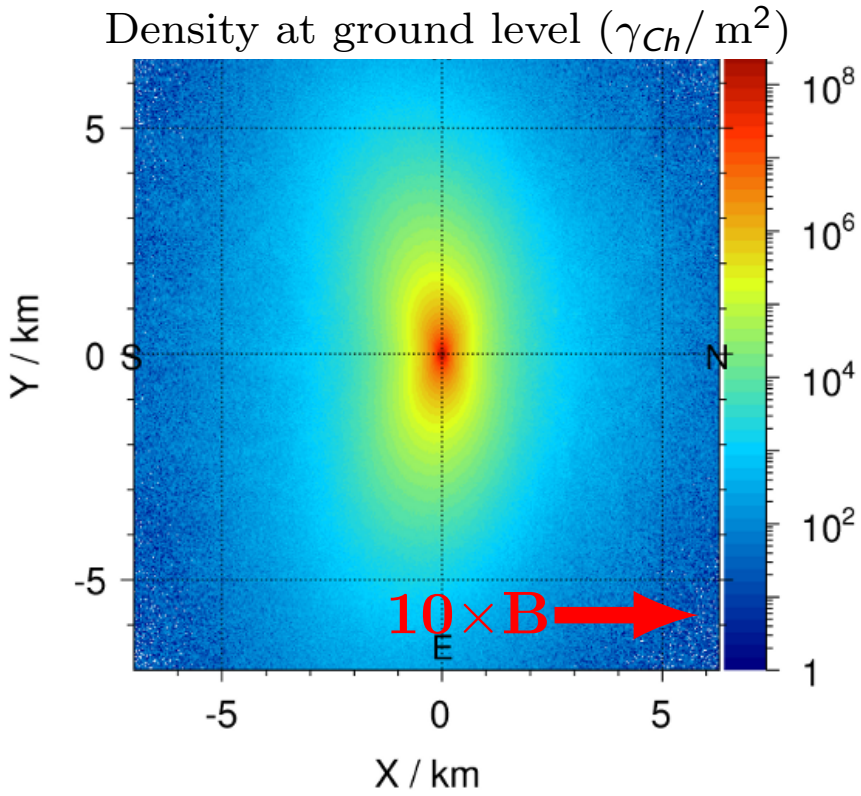
$\rightarrow$ Use Cherenkov-rich HEAT showers for high level analysis

Thank You!

Backup

Cherenkov photons at ground level



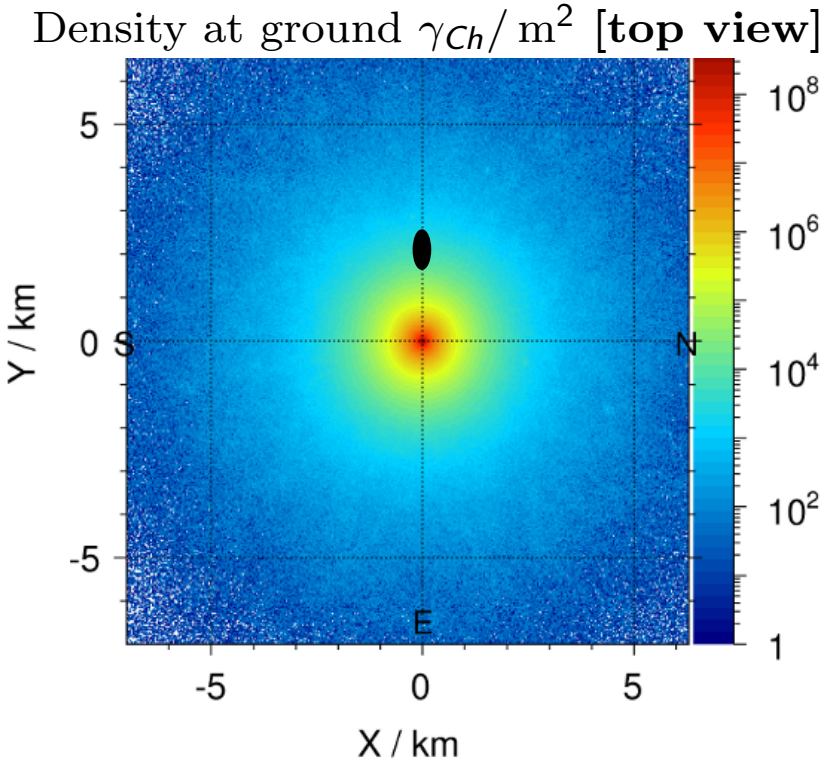


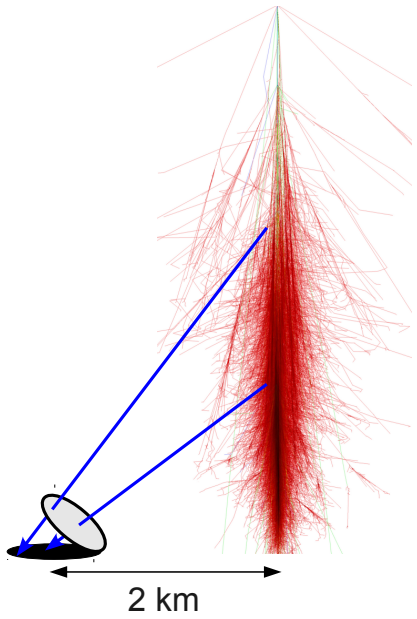
tenfold magnetic field $10 \times \vec{B}$

- Cherenkov photons follow the distribution of charged particles
- Asymmetry due to geomagnetic field inducted into Cherenkov light distribution

Simulation of Cherenkov photons arriving at the ground

- `CORSIKA` proton shower, $E = 10^{18}\,\mathrm{eV}, \varphi = 0°, \theta = 0°, \lambda = 300..420\,\mathrm{nm}$

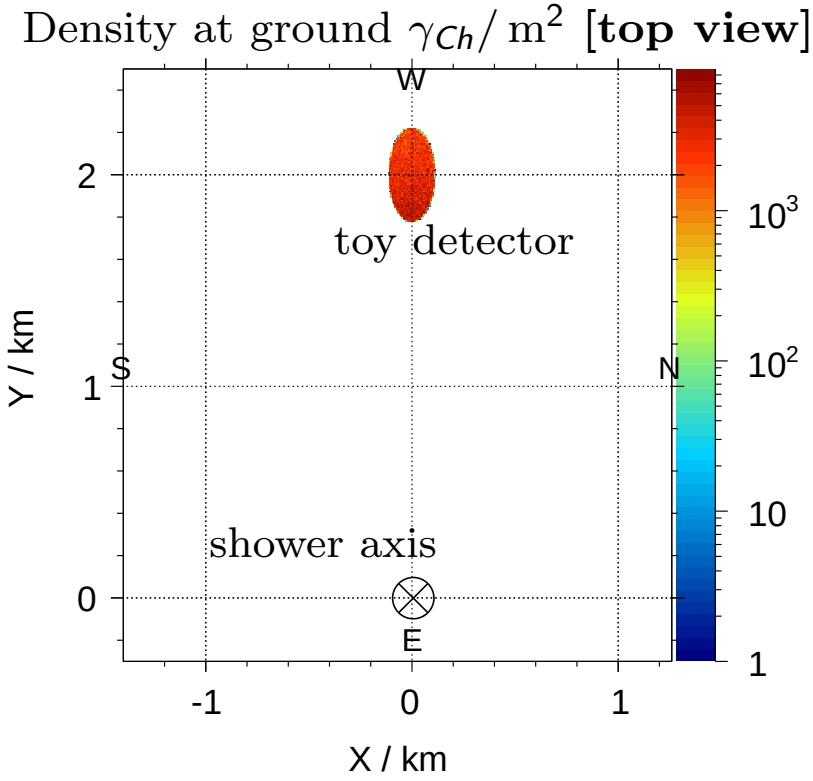


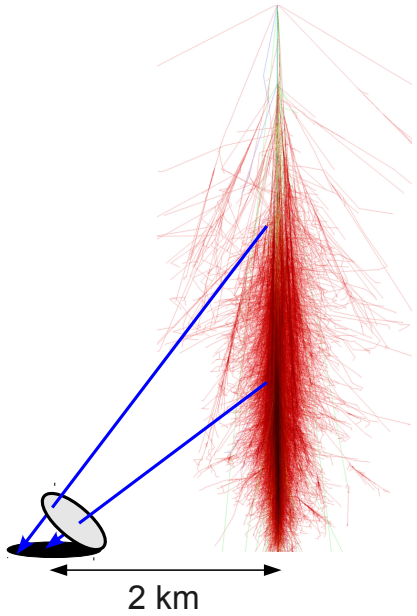


- Define toy detector at ground level, 110m radius, 2km distance

Cherenkov photons at toy detector

- CORSIKA proton shower, $E = 10^{18}\,\mathrm{eV}, \varphi = 0°, \theta = 0°, \lambda = 300..420\,\mathrm{nm}$

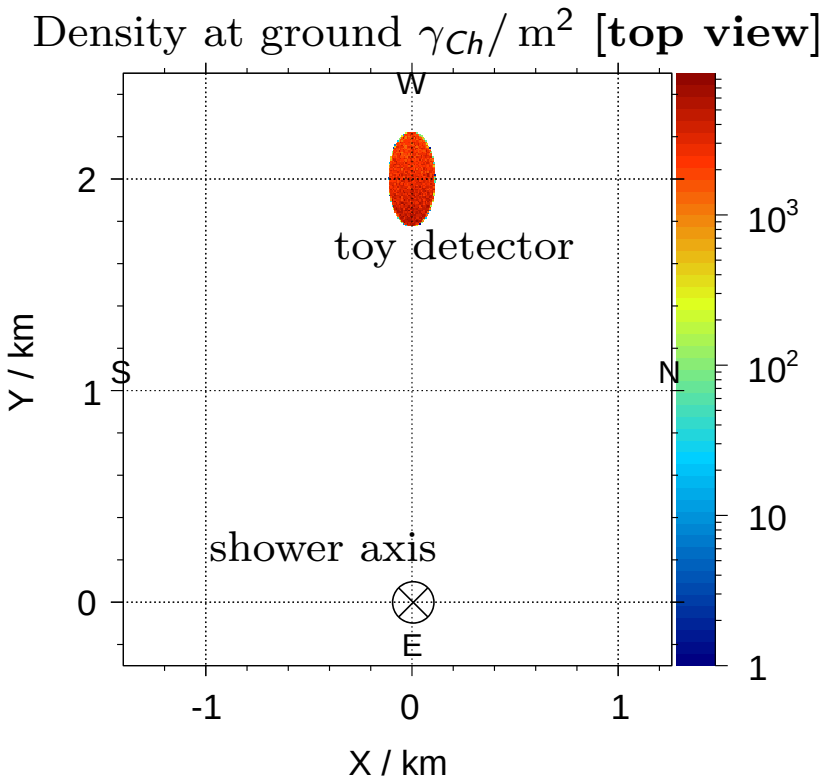


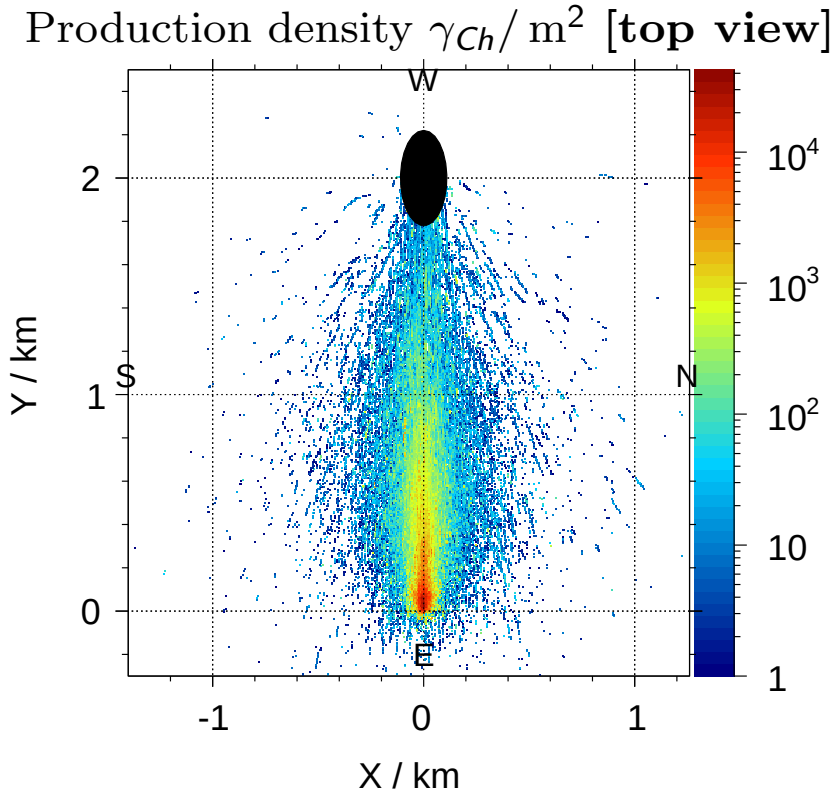


- Define toy detector at ground level, 110m radius, 2km distance
- Backtrack photons to their emission point

Cherenkov photons production

- CORSIKA proton shower, $E = 10^{18}\,\mathrm{eV}, \varphi = 0°, \theta = 0°, \lambda = 300..420\,\mathrm{nm}$

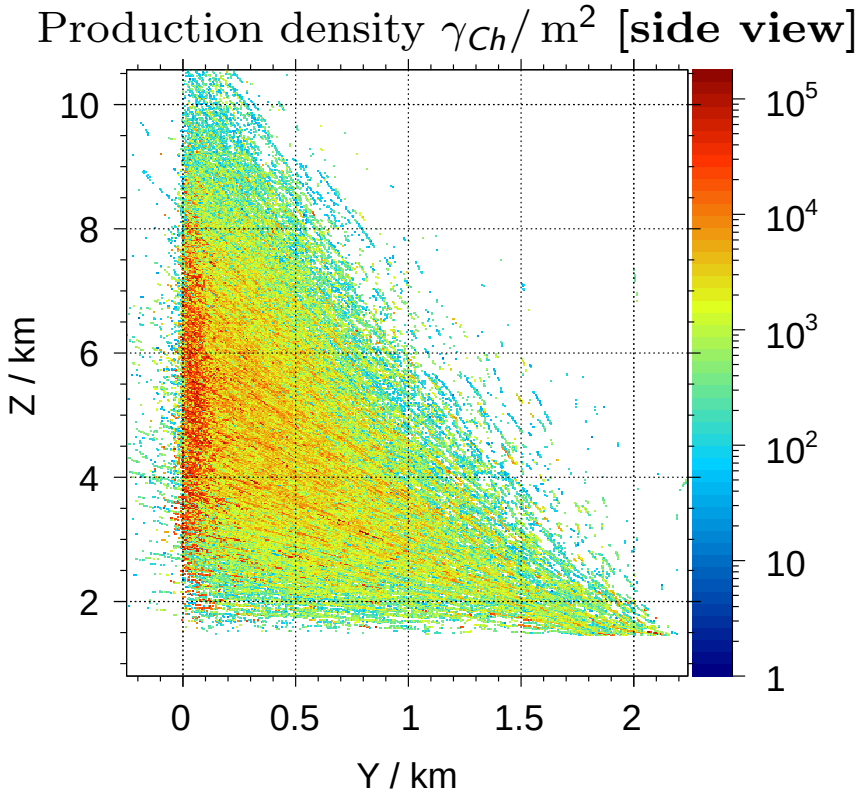


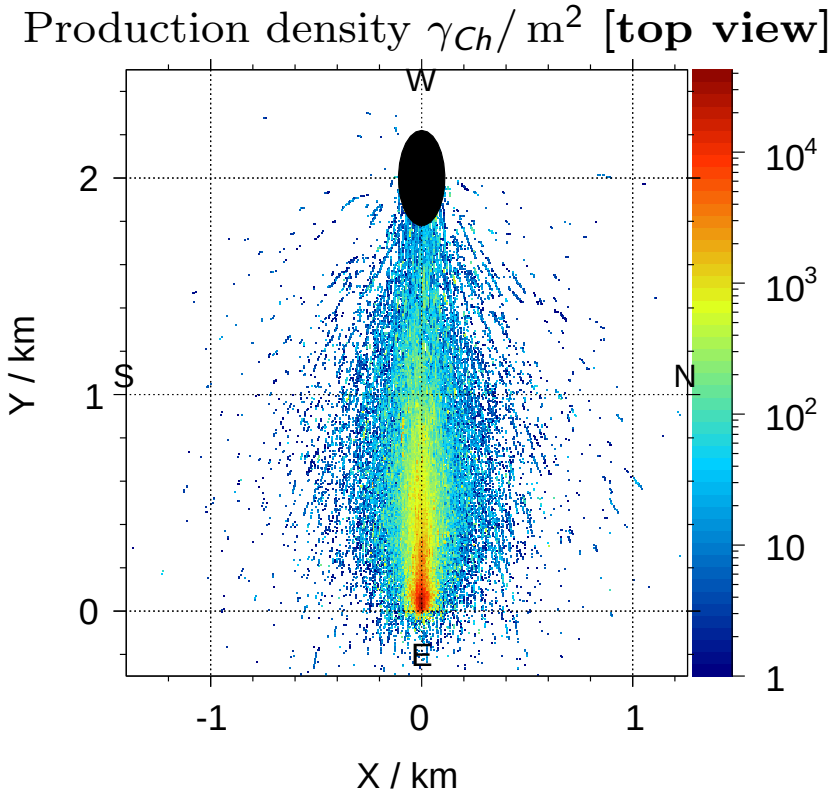


- Production density for photons hitting the aperture
- Photons produced off the shower axis

Cherenkov photons production

- CORSIKA proton shower, $E = 10^{18}\,\mathrm{eV}, \varphi = 0°, \theta = 0°, \lambda = 300..420\,\mathrm{nm}$





- Production density for photons hitting the aperture
- Photons produced off the shower axis

→ Estimate effect on geometry reconstruction