The Fluorescence Telescopes of the Pierre Auger Observatory

Heiko Geenen for the Pierre Auger Collaboration

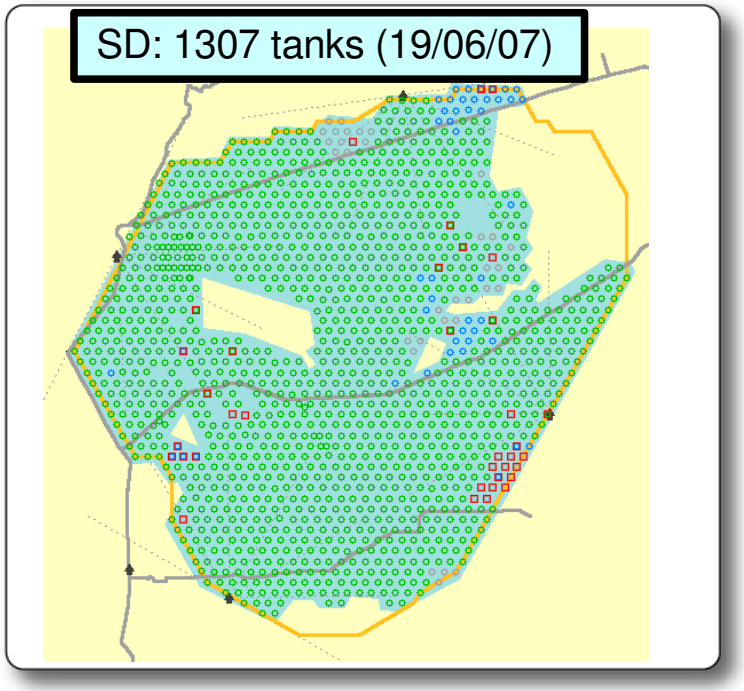
Bergische Universität Wuppertal

geenen@physik.uni-wuppertal.de

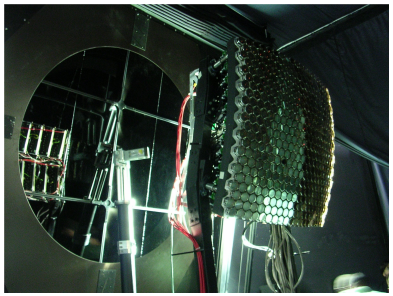
Outline:

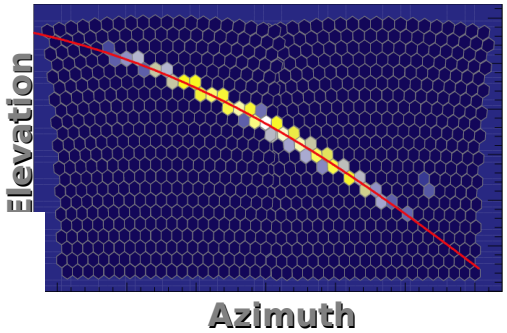
- Status
- Elongation Rate
- Energy Spectrum from FD
- Photon Limit from X_{max} Distribution

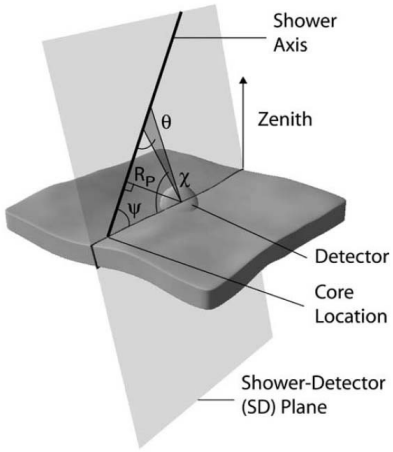
All Fluorescence Telecopes fully Operational

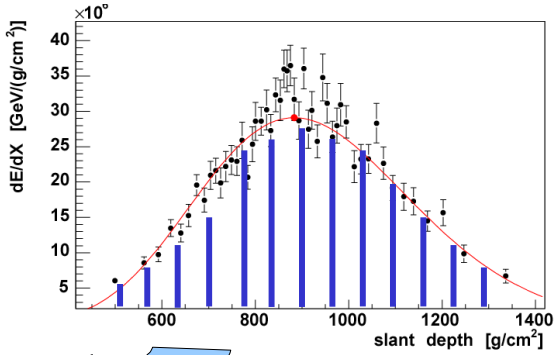


FD Reconstruction









$$\int \frac{dE}{dX} dX \sim E$$

Current systematics in energy reconstruction:

PMT response

Light collection: ± 5%
Detector calib.: ±10%

photons at telescope

Geometry reconst.: ± 2%
Aerosol contrib.: ±10%
Clouds: ± 5%

photons at shower

atm. density profile: ± 2%
Fluorescence yield: ±15%

charged particles at shower

Missing energy: ± 5%

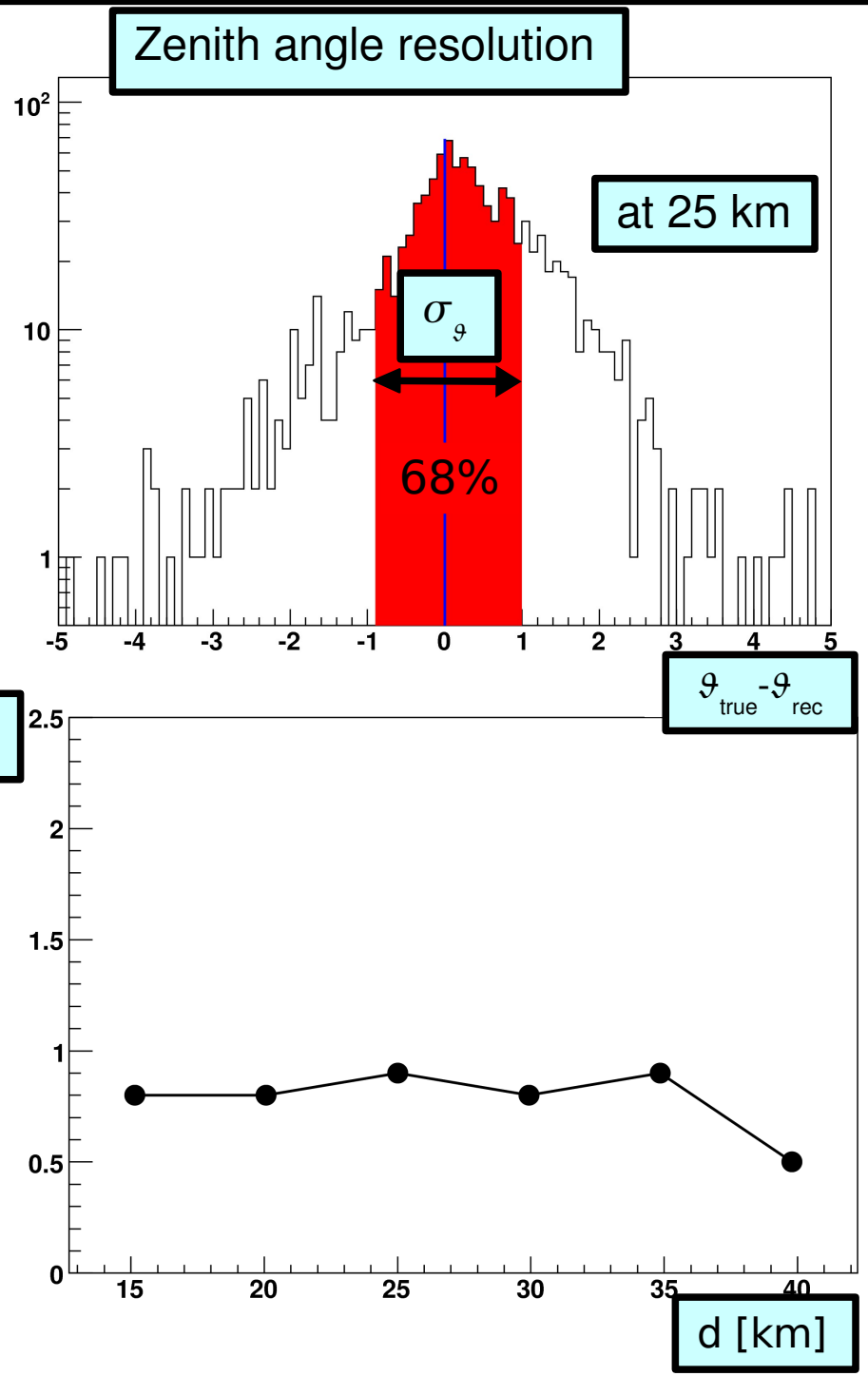
Energy of primary particle

±25%

Mono-Reconstruction Performance

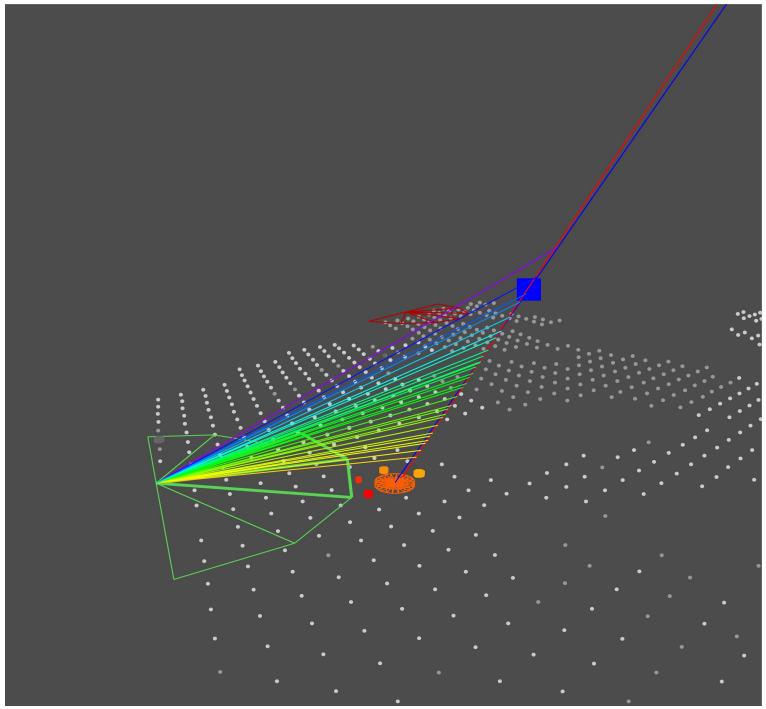
- Mono-energetic MC: $\log_{10}(E/eV)=17,17.5,18,...,21$
- Core position in field of view of one telescope (15km, 20km, ...40km)
- Zenith < 60°
- Full Simulation-Reconstruction chain
- Compare rec. and true observables

	$\sigma_{68\%}$
ϑ_{SDP}	0.3°
ϕ_{SDP}	0.2°
$\Delta\Psi_{SDP}$	0.35°
R_p	500-1000m
ϑ_{Axis}	1.°
ϕ_{Axis}	2-3°
$\Delta\Psi_{Axis}$	2-4°
X_{max}	15-40 g/cm²
Energy	20-25%

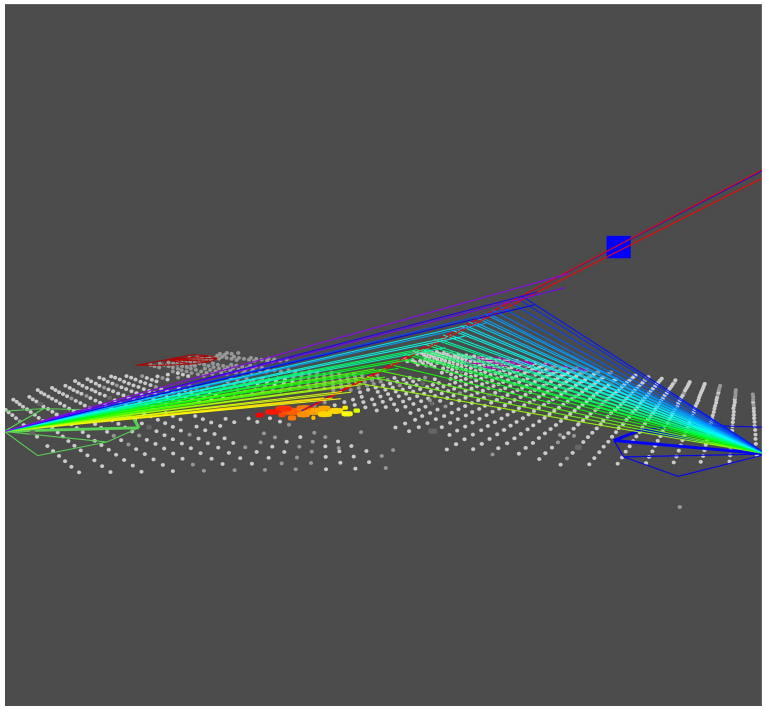


FD-Apertures

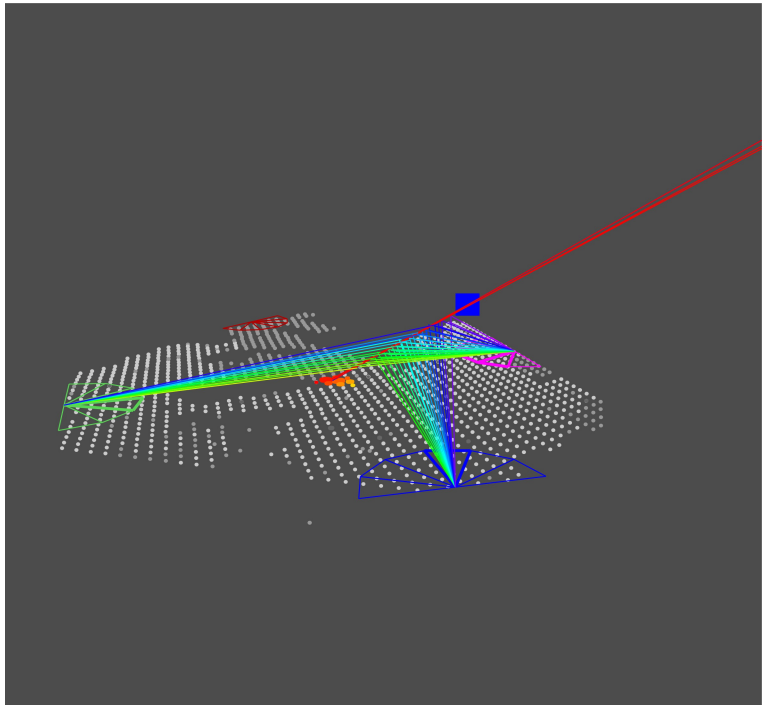
Mono



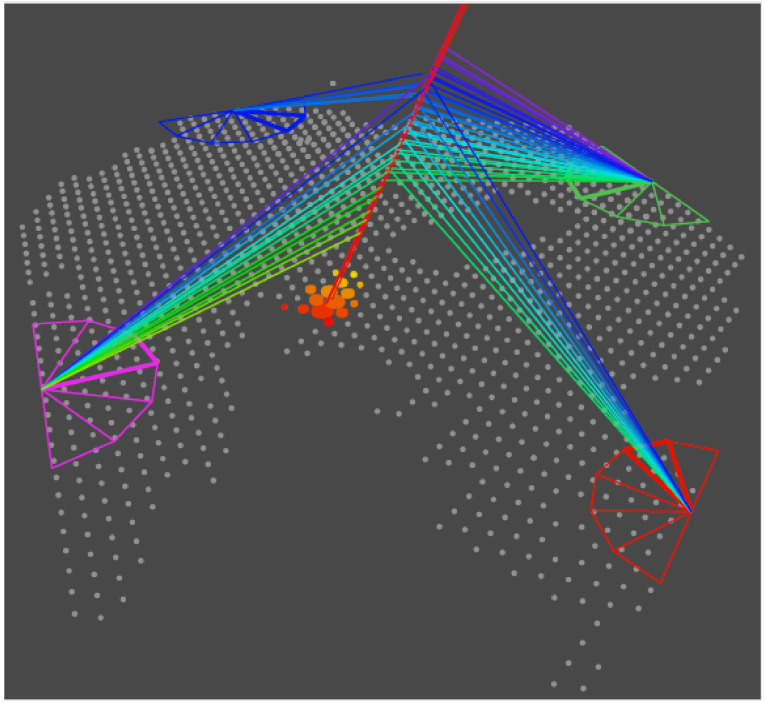
2-fold



3-fold

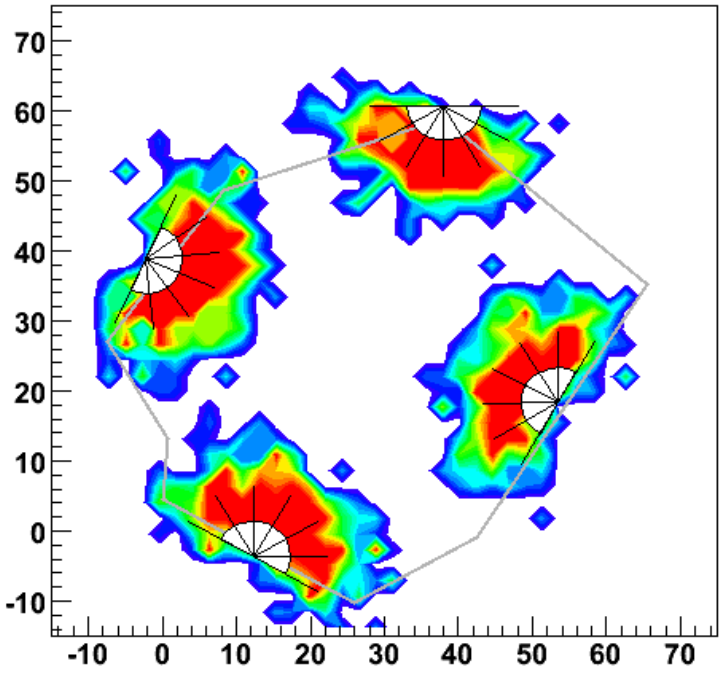


4-fold

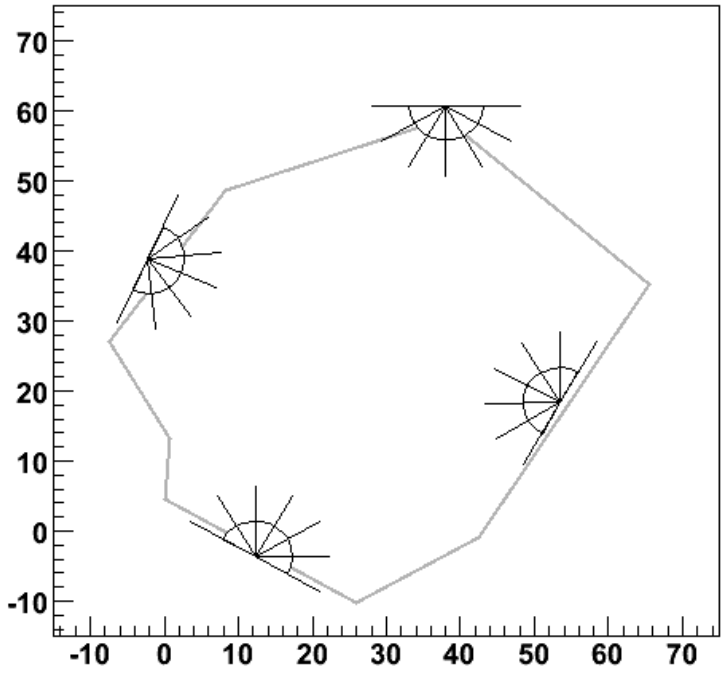


FD-Apertures (E=$10^{17.5}$eV)

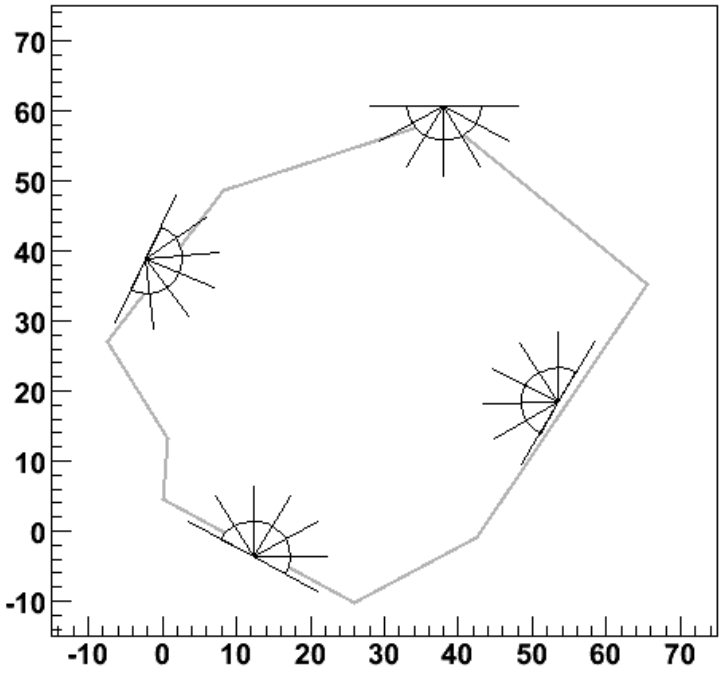
Mono



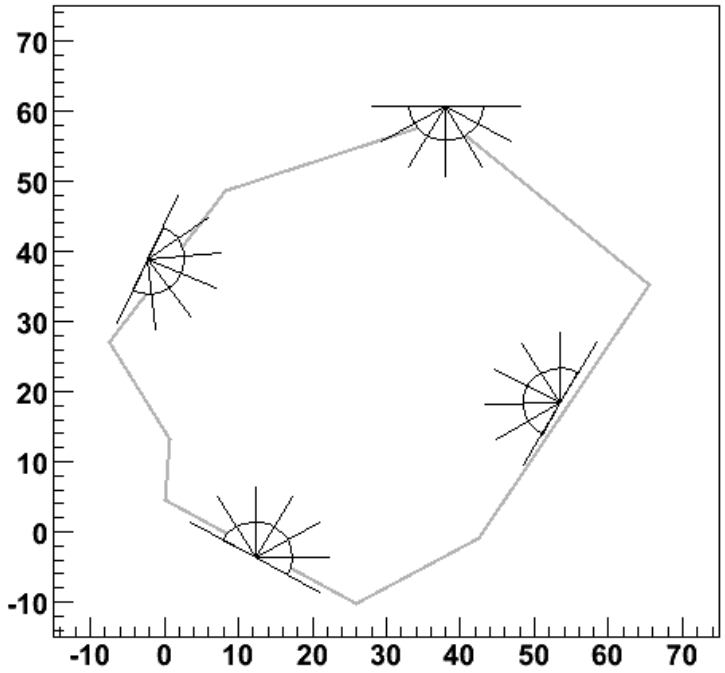
2-fold



3-fold

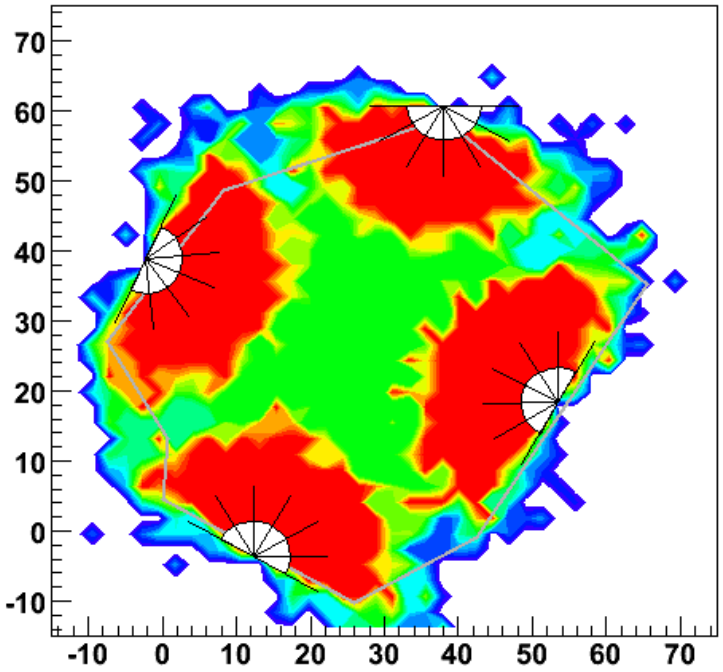


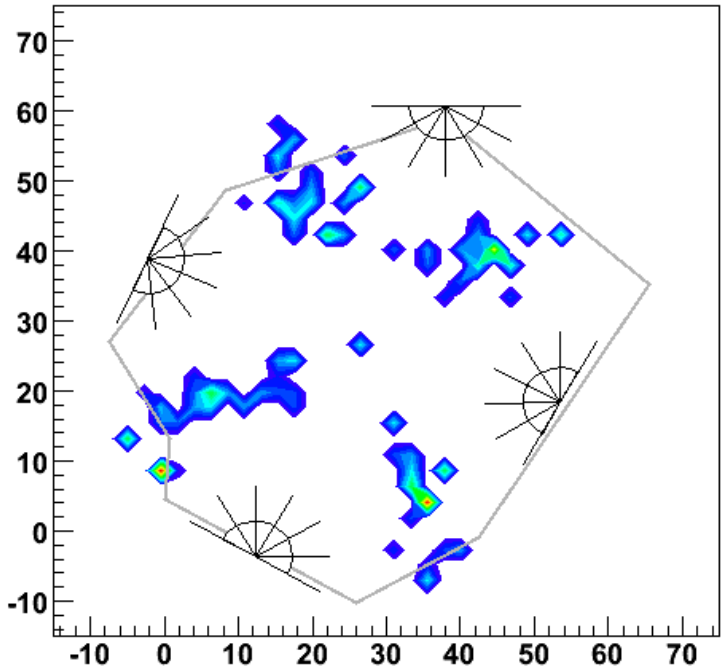
4-fold



FD-Apertures ($E=10^{18}$eV)

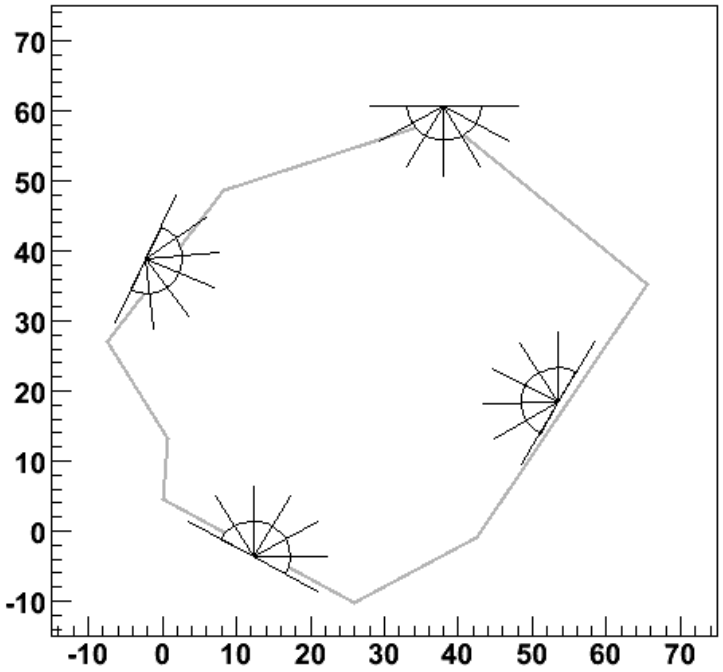
Mono

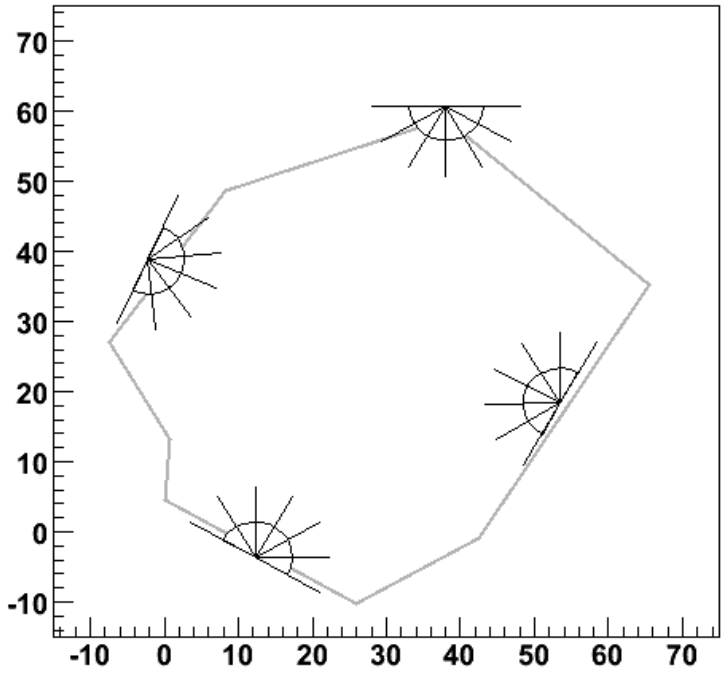




2-fold

3-fold

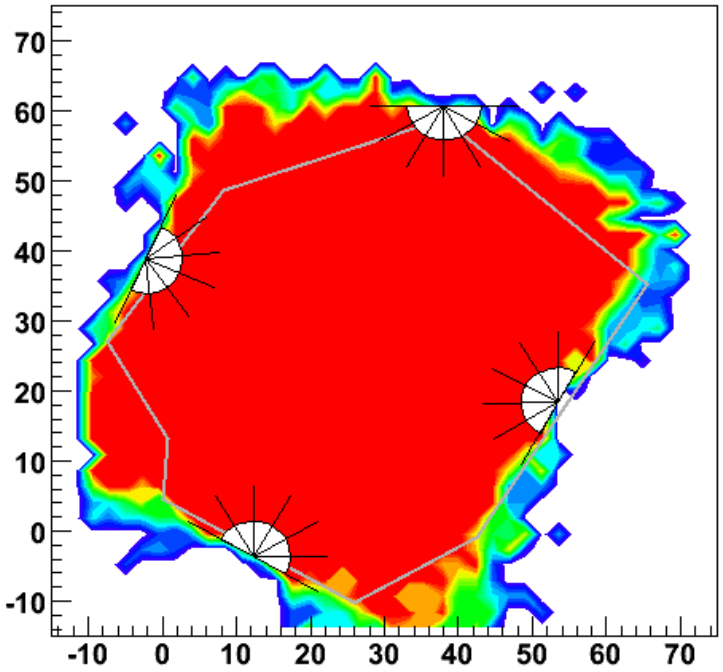




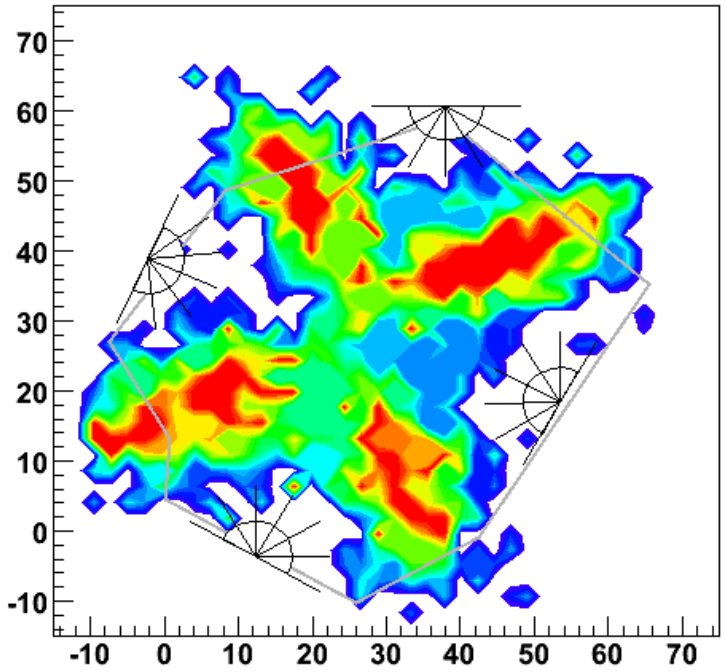
4-fold

FD-Apertures($E=10^{18.5}$eV)

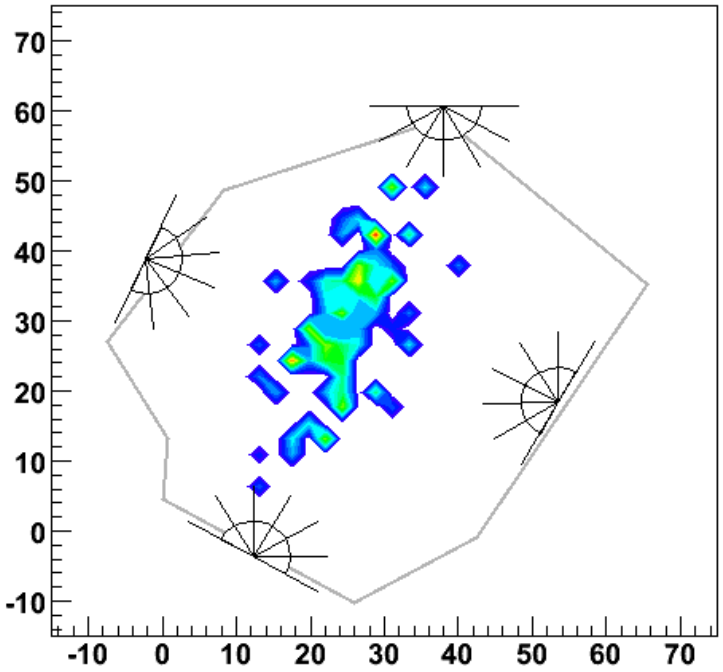
Mono



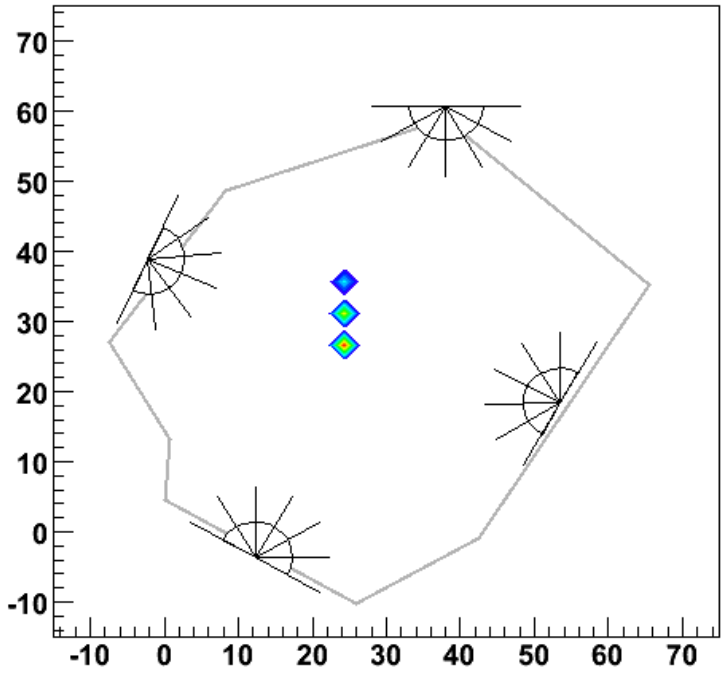
2-fold



3-fold

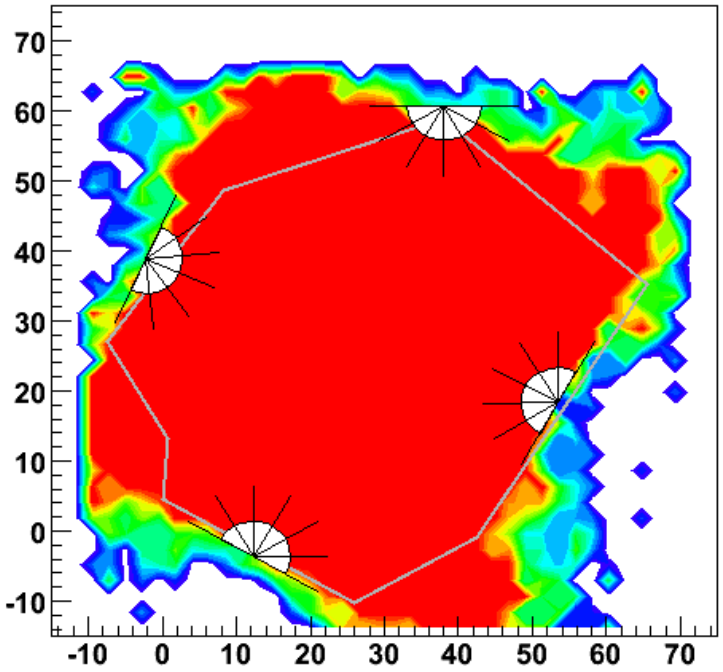


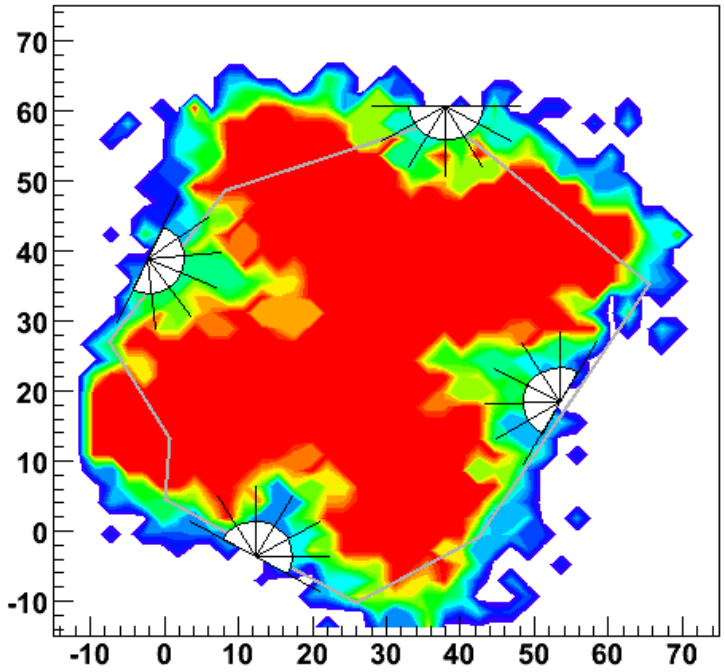
4-fold



FD-Apertures(E=10^{19}eV)

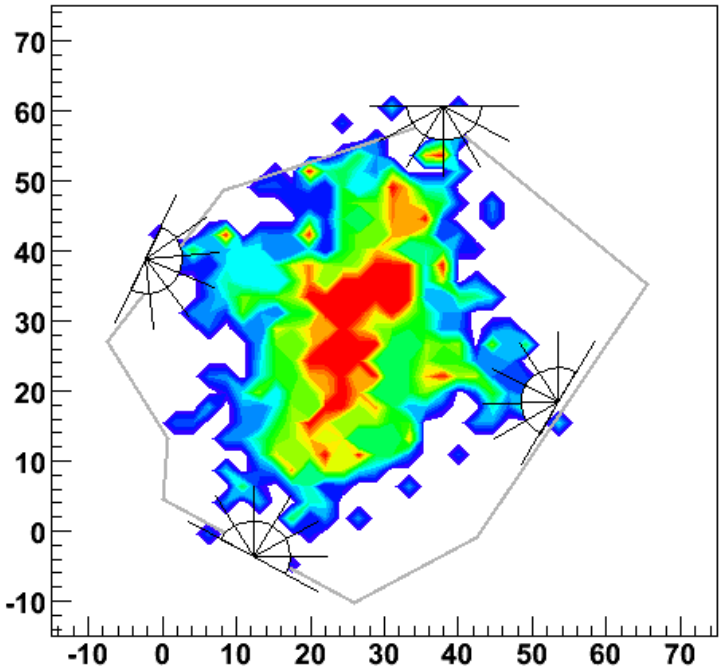
Mono

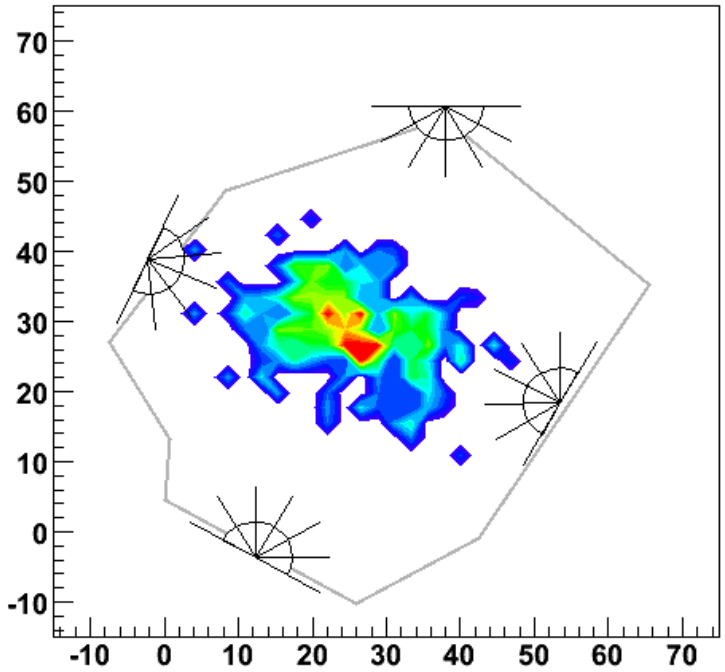




2-fold

3-fold

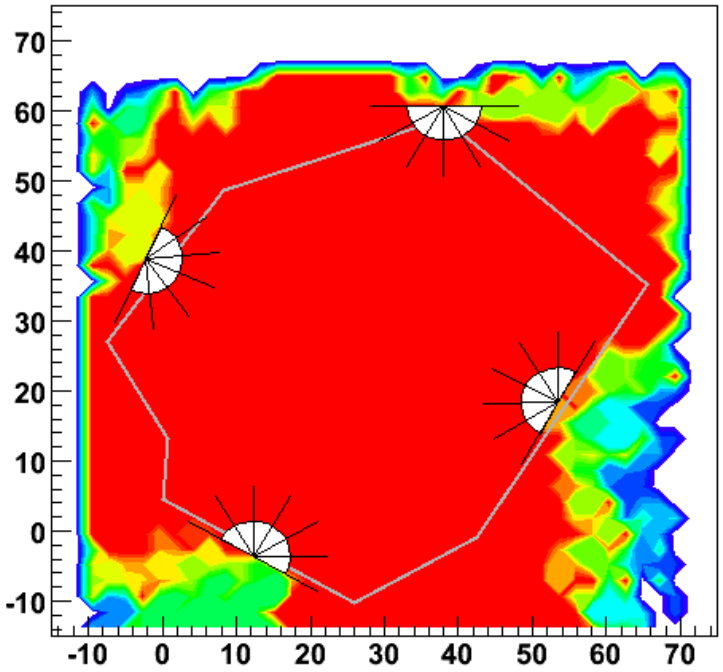


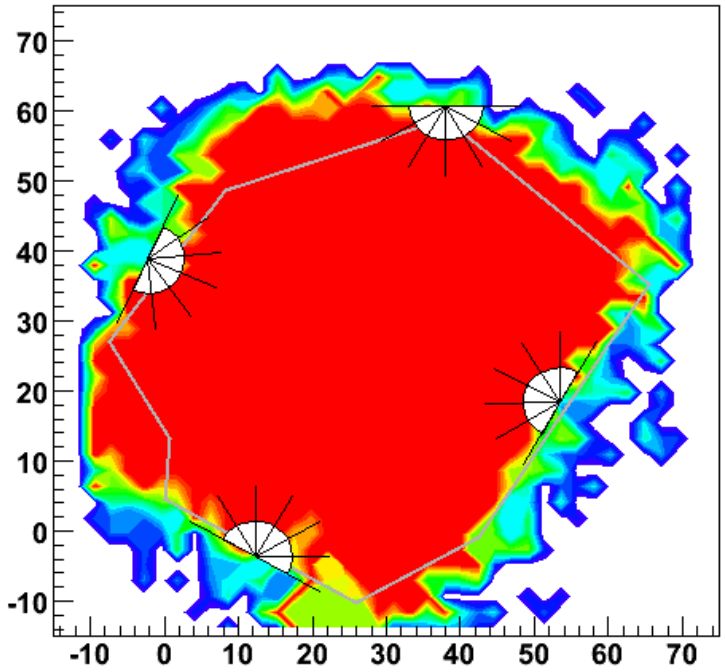


4-fold

FD-Apertures(E=$10^{19.5}$eV)

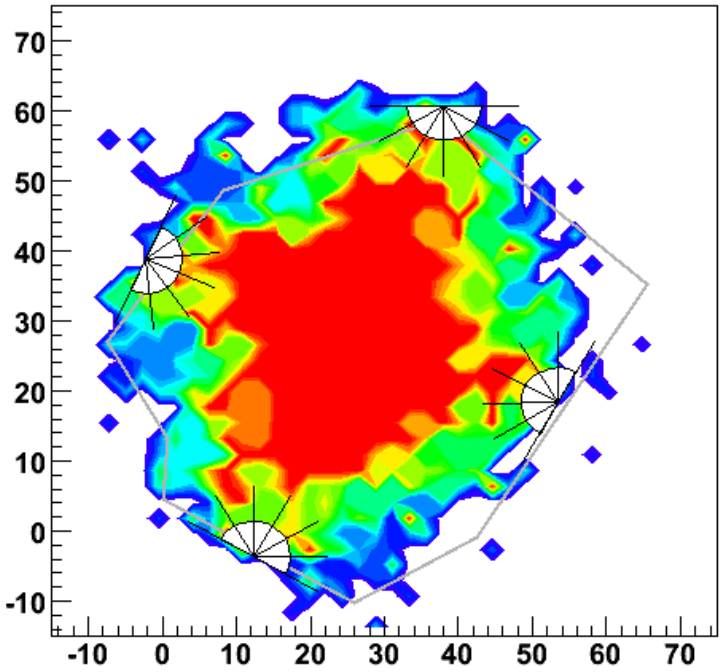
Mono

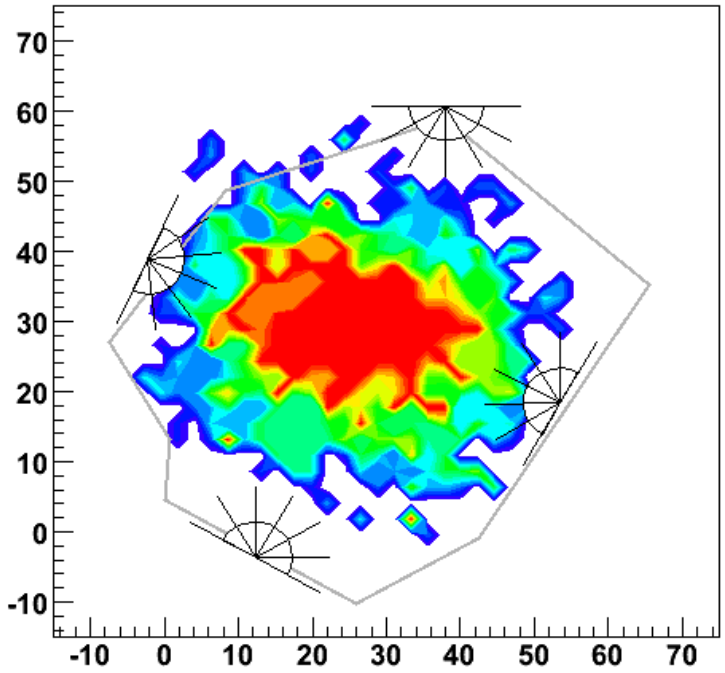




2-fold

3-fold

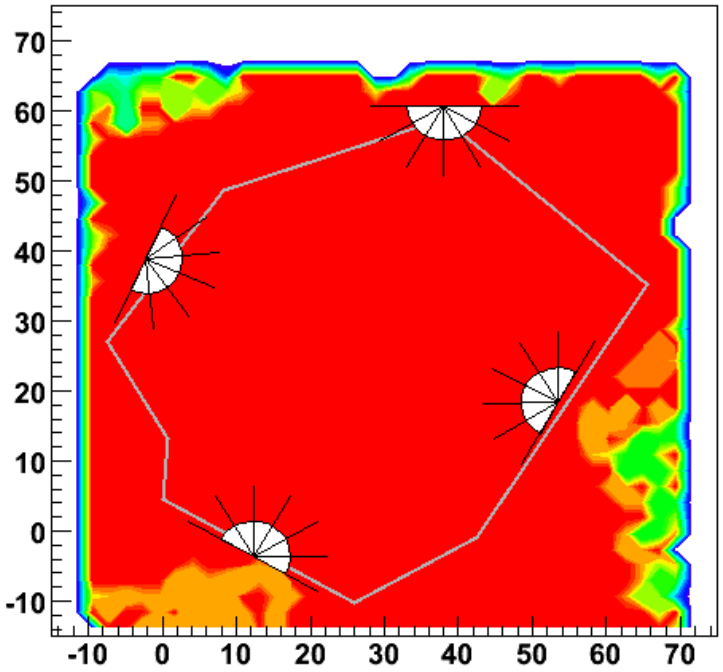


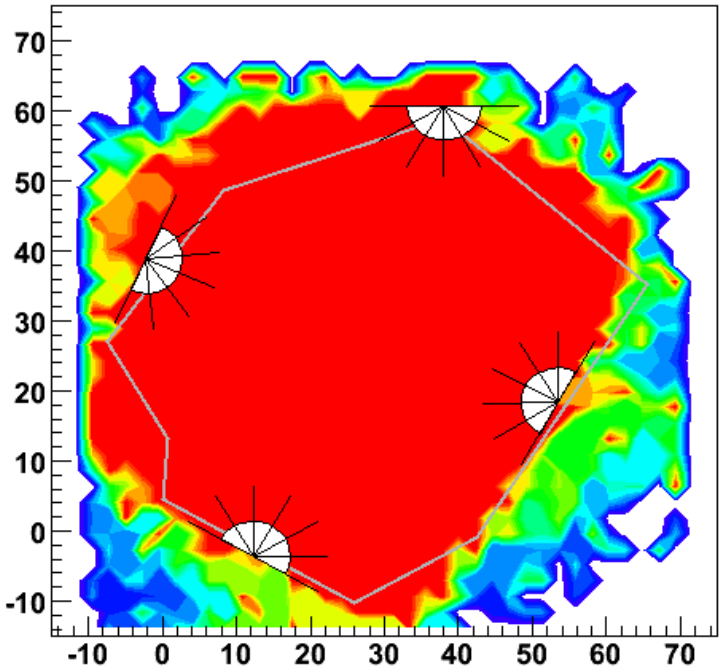


4-fold

FD-Apertures(E=10^{20}eV)

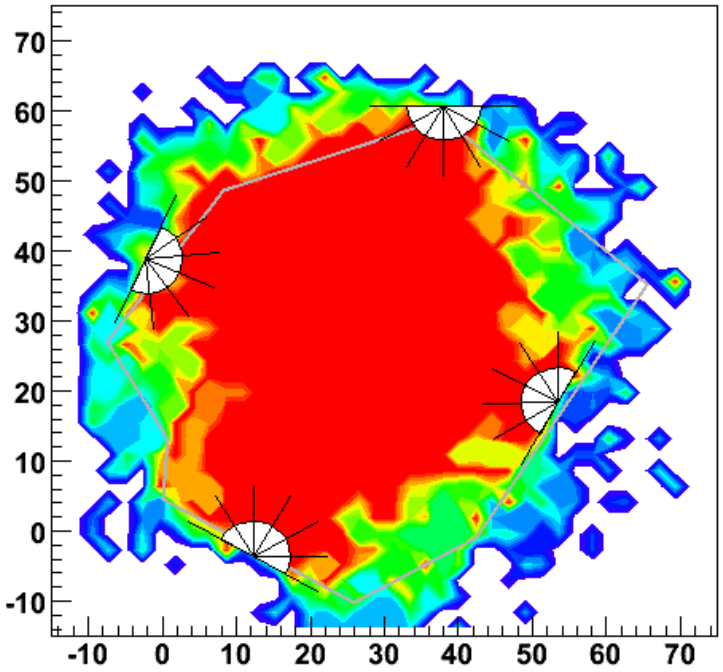
Mono

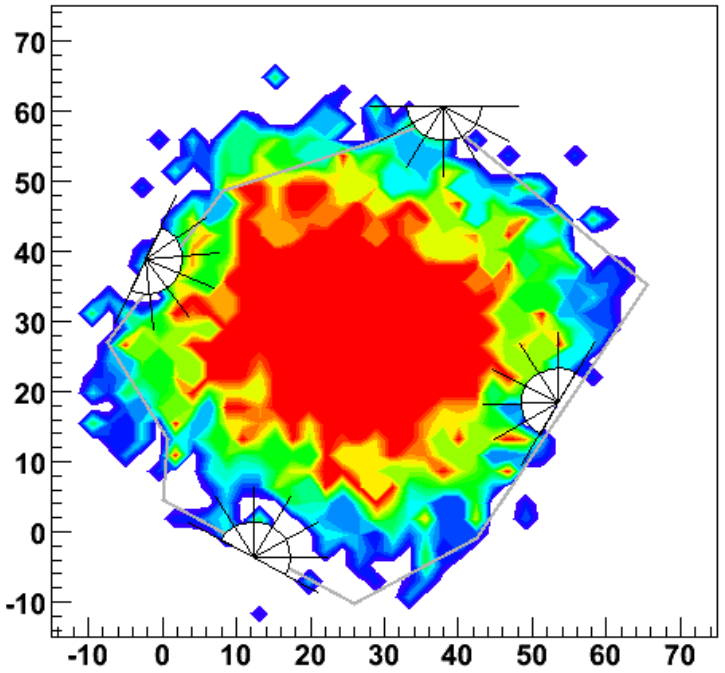




2-fold

3-fold





4-fold

Simulation

Corsika showers:

- Using oversampling (7-11x):
  - p-showers (330k)
  - Fe-showers (618k)

Energy spectrum

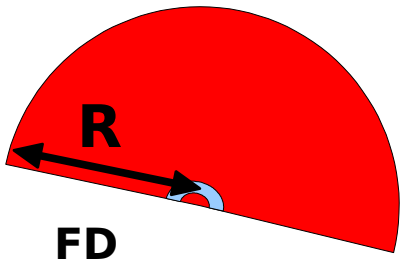
$$\frac{dN}{dE} \propto E^{-2}$$

Angular distribution:

- isotropic:
  $dN \propto \cos\theta \; d\cos\theta d\phi$

Core positions

- homogeneous, $R_{cut}(E)$



$$R = \begin{cases} 6\ km & \log_{10}E < 17. \\ 15\ km & 17. < \log_{10} < 17.5 \\ 32\ km & 17.5 < \log_{10} < 18 \\ 50\ km & 18. < \log_{10} < 18.5 \\ 60\ km & 18.5 < \log_{10} \end{cases}$$

Importance sampling

$$\left\{\frac{dN}{dE}\right\}_{phys} = \underbrace{\frac{\left\{\frac{dN}{dE}\right\}_{phys}}{\left\{\frac{dN}{dE}\right\}_{MC}}}_{w} \times \left\{\frac{dN}{dE}\right\}_{MC}$$

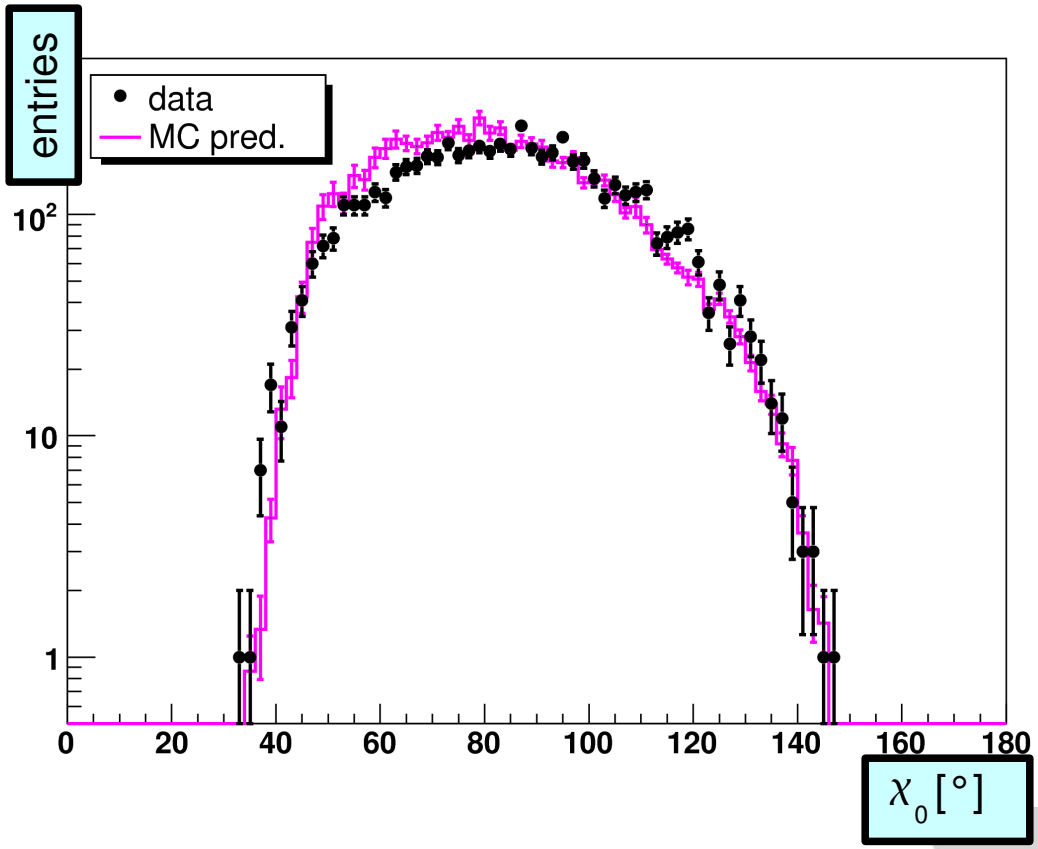
Assumed physical spectrum

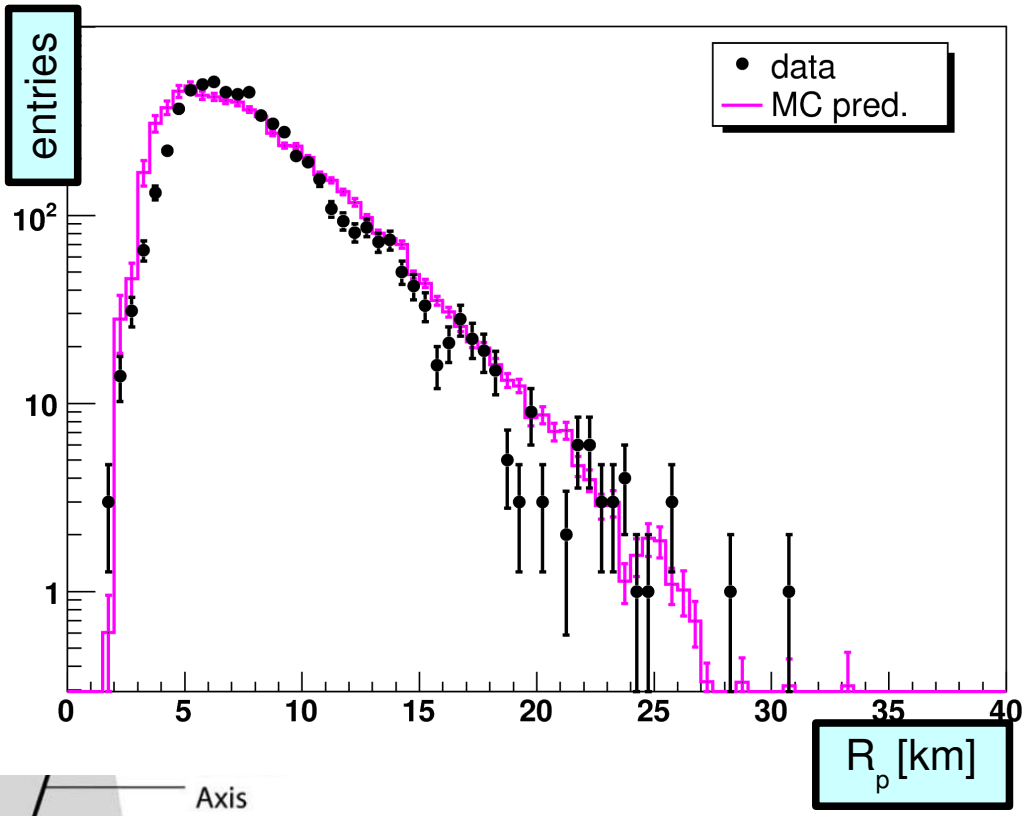
- E^{-3} spectrum with kink

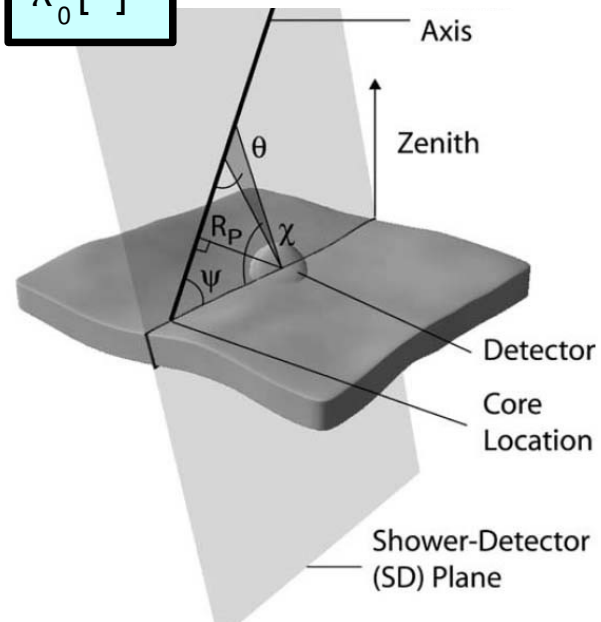
$$\phi = \begin{cases} \phi_1 E^{-3.3} & E < 10^{18.5} eV \\ \phi_2 E^{-3} & E \geqslant 10^{18.5} eV \end{cases}$$

- normalized to uptime
- 50% iron, 50% proton induced showers

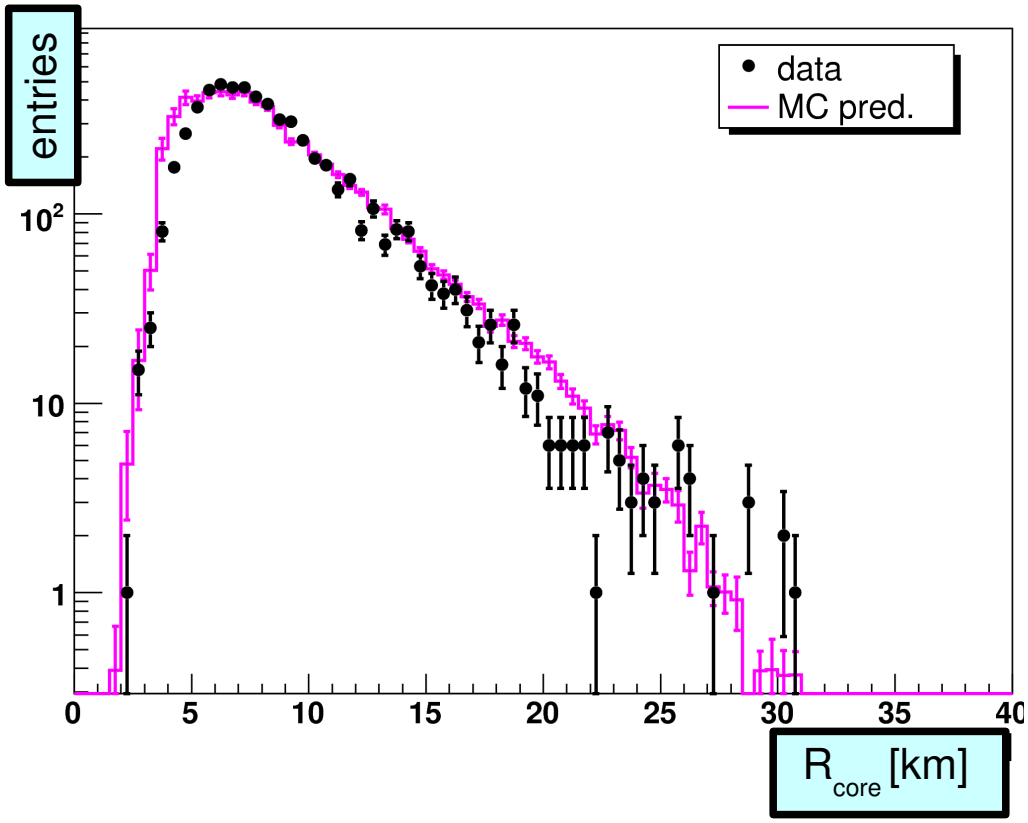
Data-MC Comparison

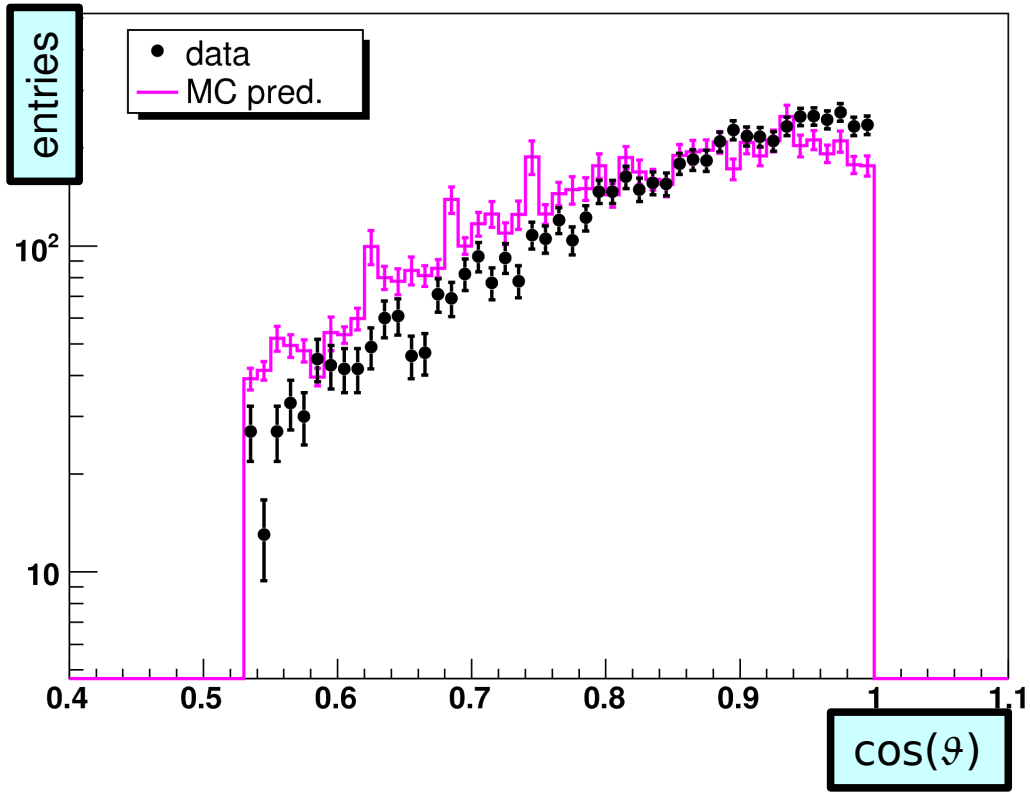






Data-MC Comparison

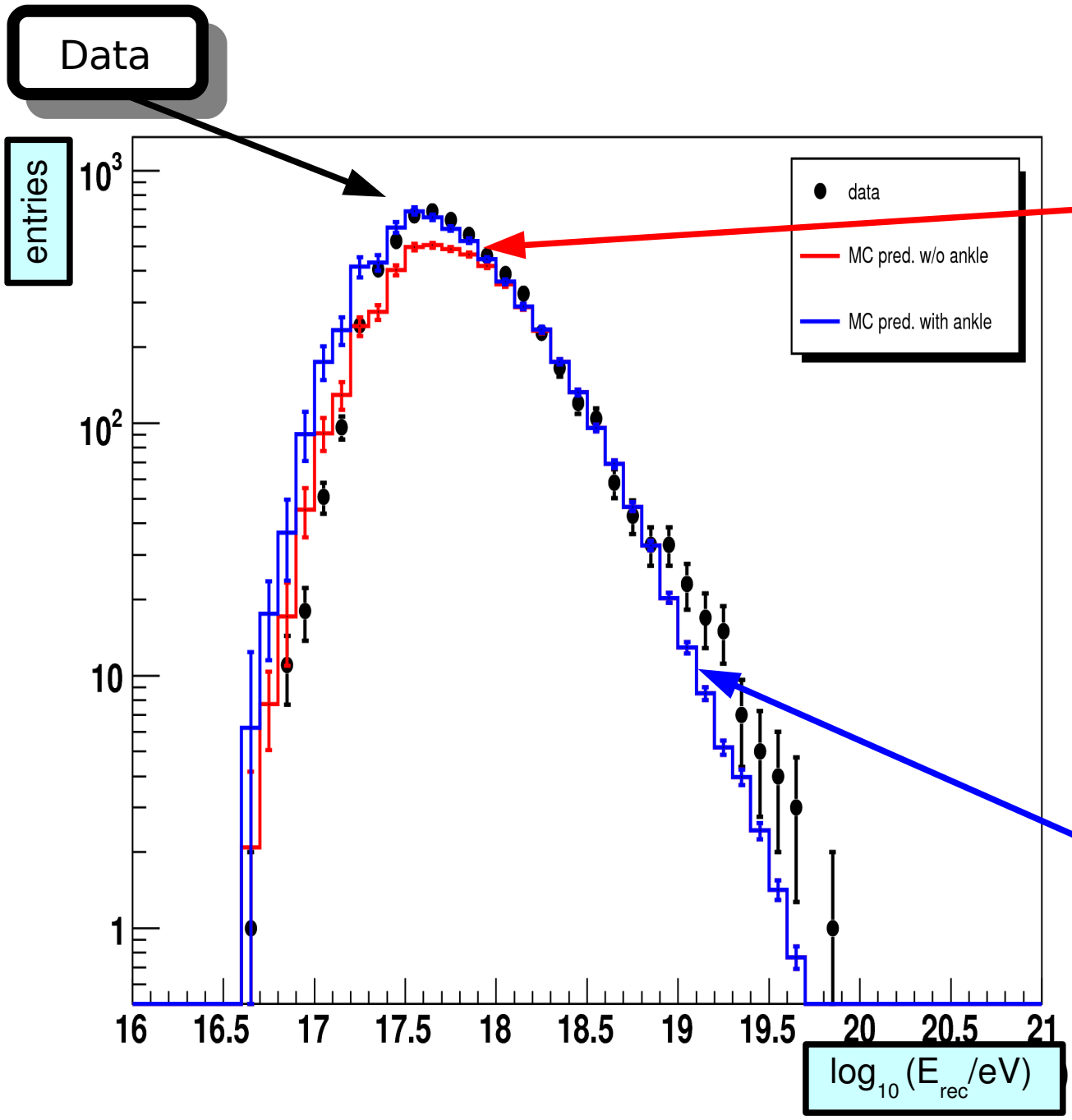




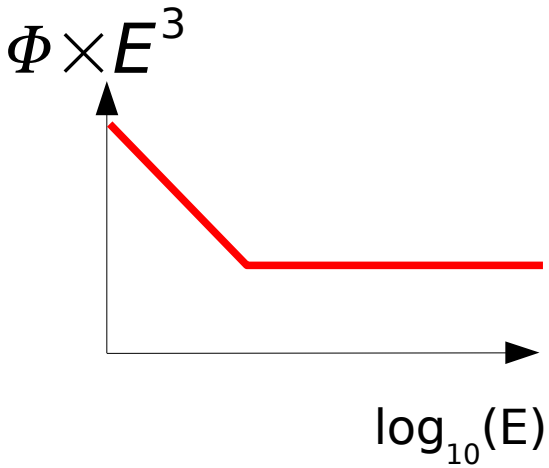
Good agreement in:

- shape
- normalization

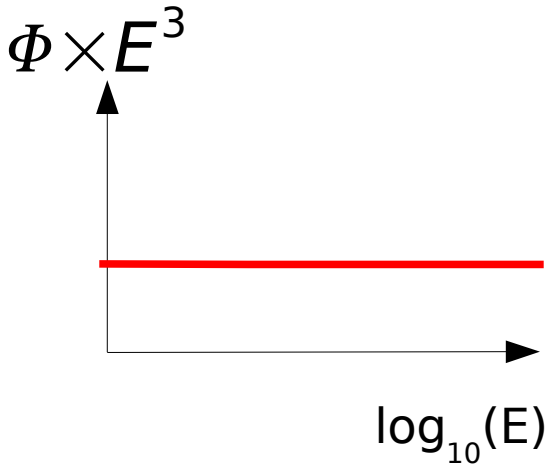
Sensitivity on Input Spectrum



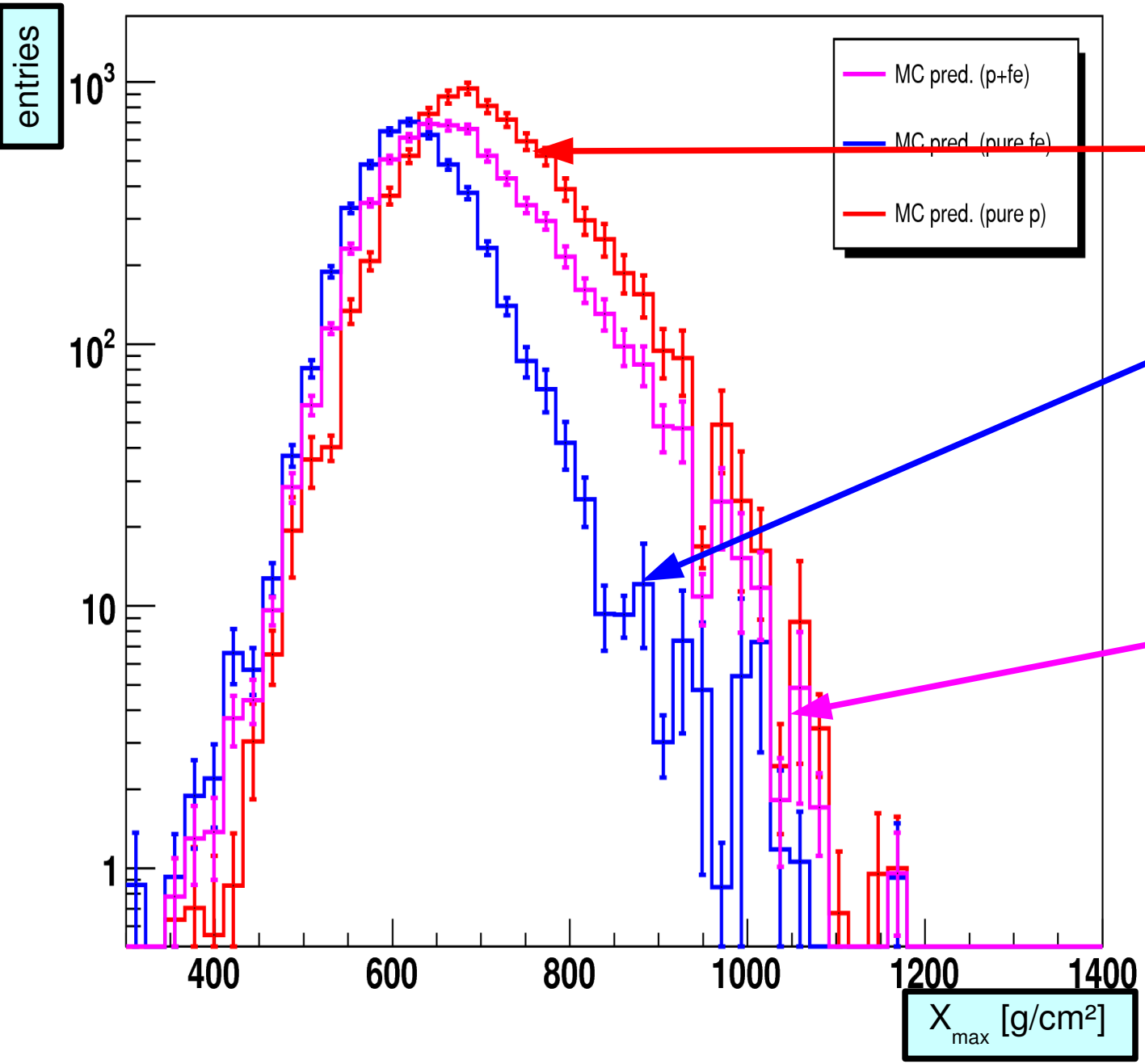
Standard



For comparison



Sensitivity on Composition

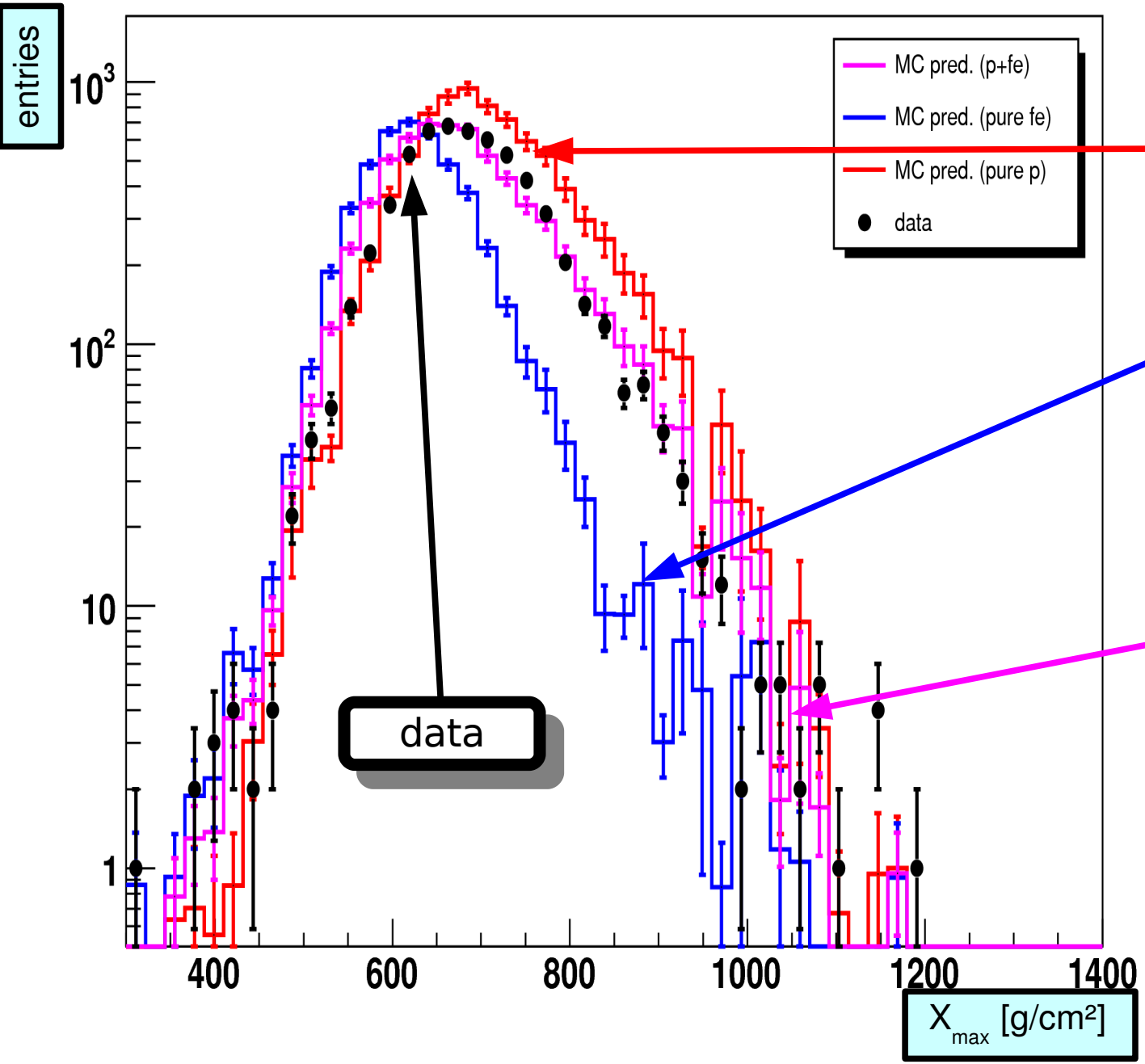


pure proton composition

pure iron composition

standard composition:
50% proton
50% iron

Sensitivity on Composition

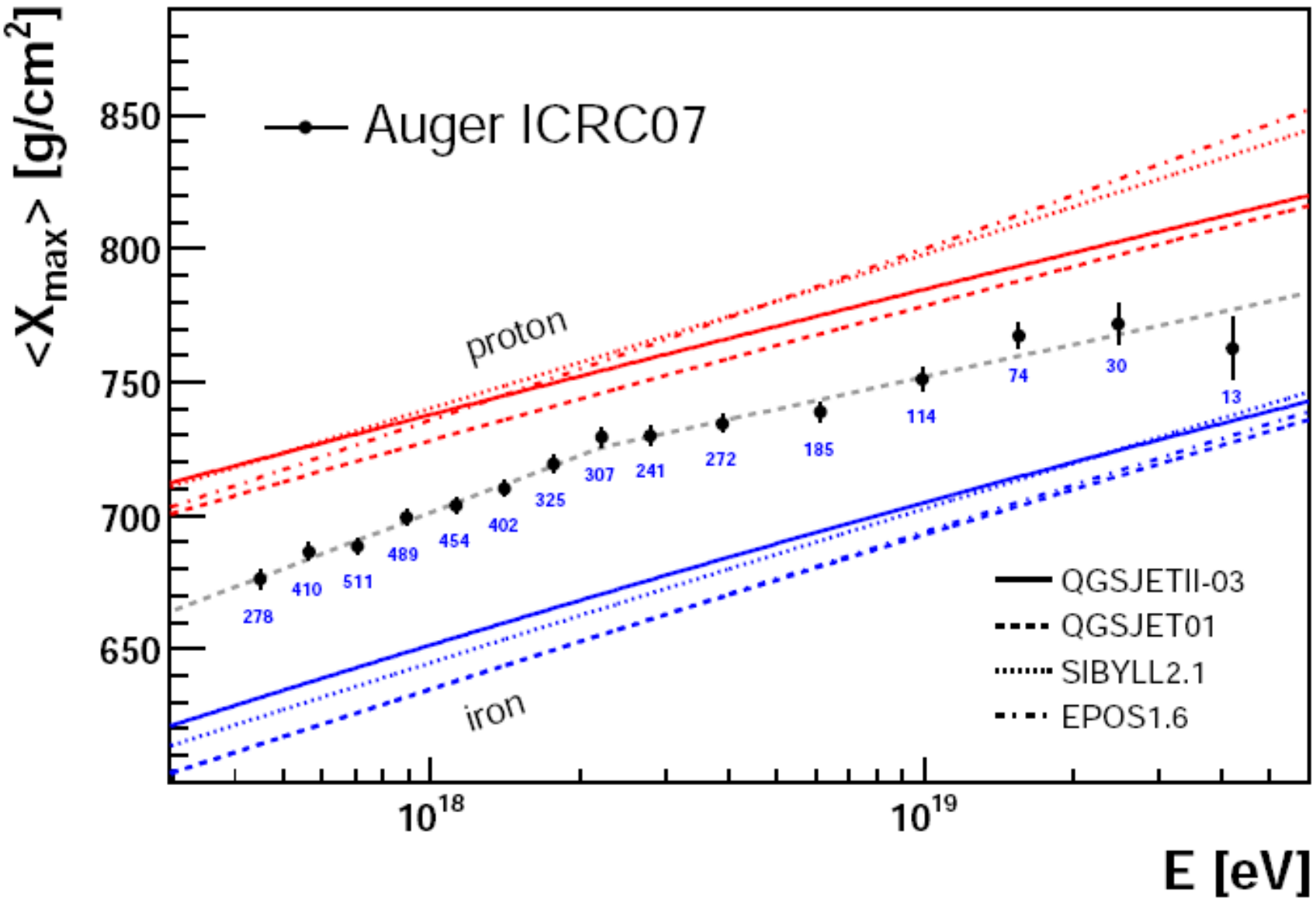


pure proton composition

pure iron composition

standard composition:
50% proton
50% iron

Elongation Rate



Unfolding the FD-Mono Spectrum

$$\left\{\frac{dN}{dE}\right\}_{obs} = \int_{E_{phys}} dE_{phys}\, P(E_{obs}|E_{true})\,\epsilon(E_{true}) \left\{\frac{dN}{dE}\right\}_{true}$$

Limited resolution due to:
- EAS fluctuations
- measurement and reconstruction uncertainties

leads to smearing of energy
=non-diagonal process

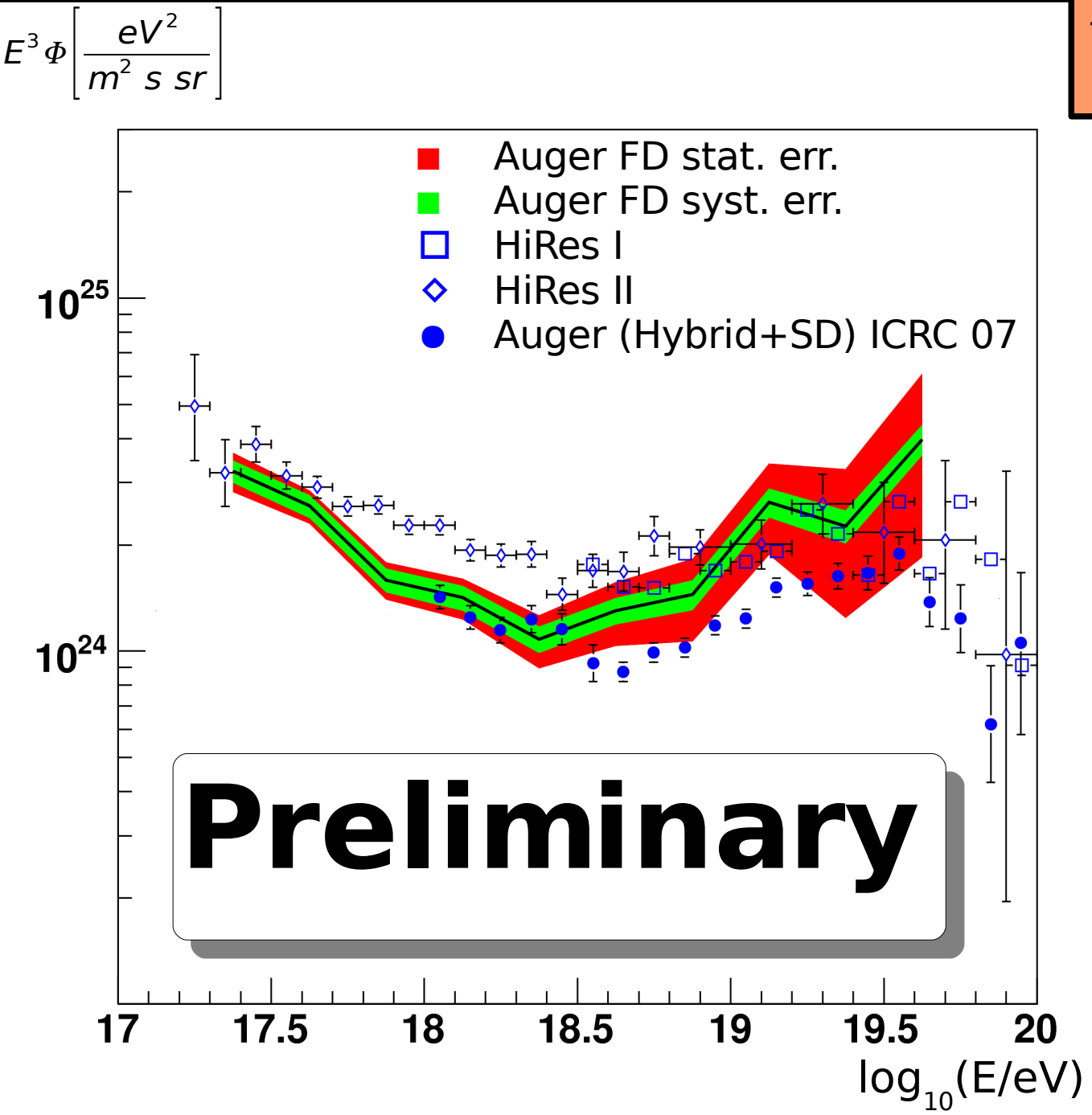
Limited acceptance due to:
- detector efficiency
- event geometry

=diagonal process

Deconvolution of Fredholm integral equation using Gold Unfolding (parametrize acceptance and resolution from MC)

Unfolded Data

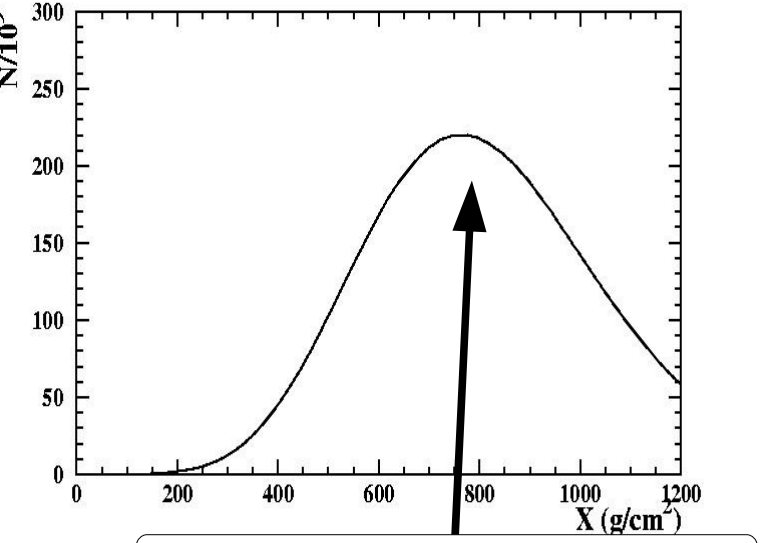
for Hybrid spectrum, see presentation F. Salamida



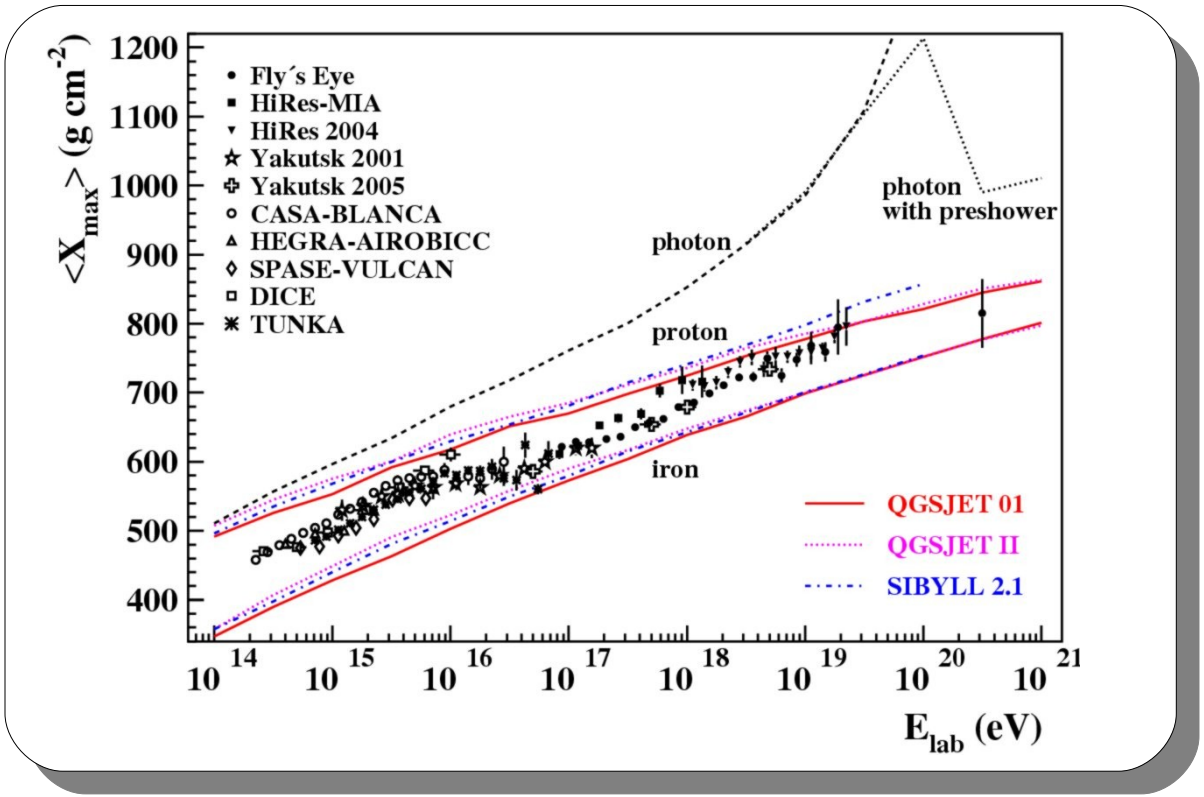
- Ankle clearly visible at ~$10^{18.5}$ eV
- good agreement in normalization
- No conclusion about GZK-Cutoff yet possible with FD-data

Photon Discrimination with X_{max}

Auger, Astropart. Phys. 27 (2007)



X_{max}
(depth of shower maximum)

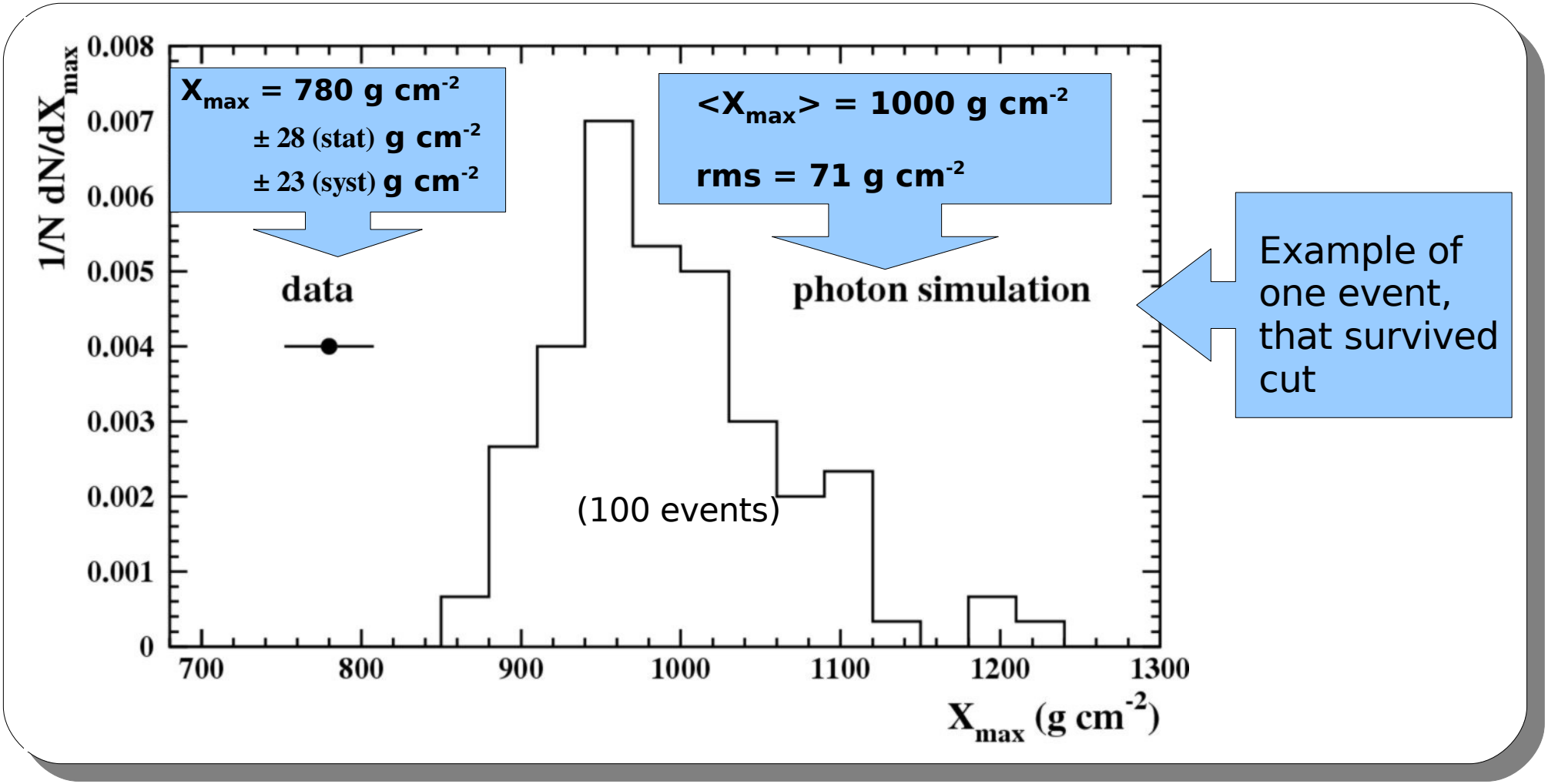


- Photon induced EAS develop deeper in the atmosphere than hadron induced showers
- Use hybrid data, quality and fiducial volume cuts

Photon Limit-Example

Auger, Astropart. Phys. 27 (2007)

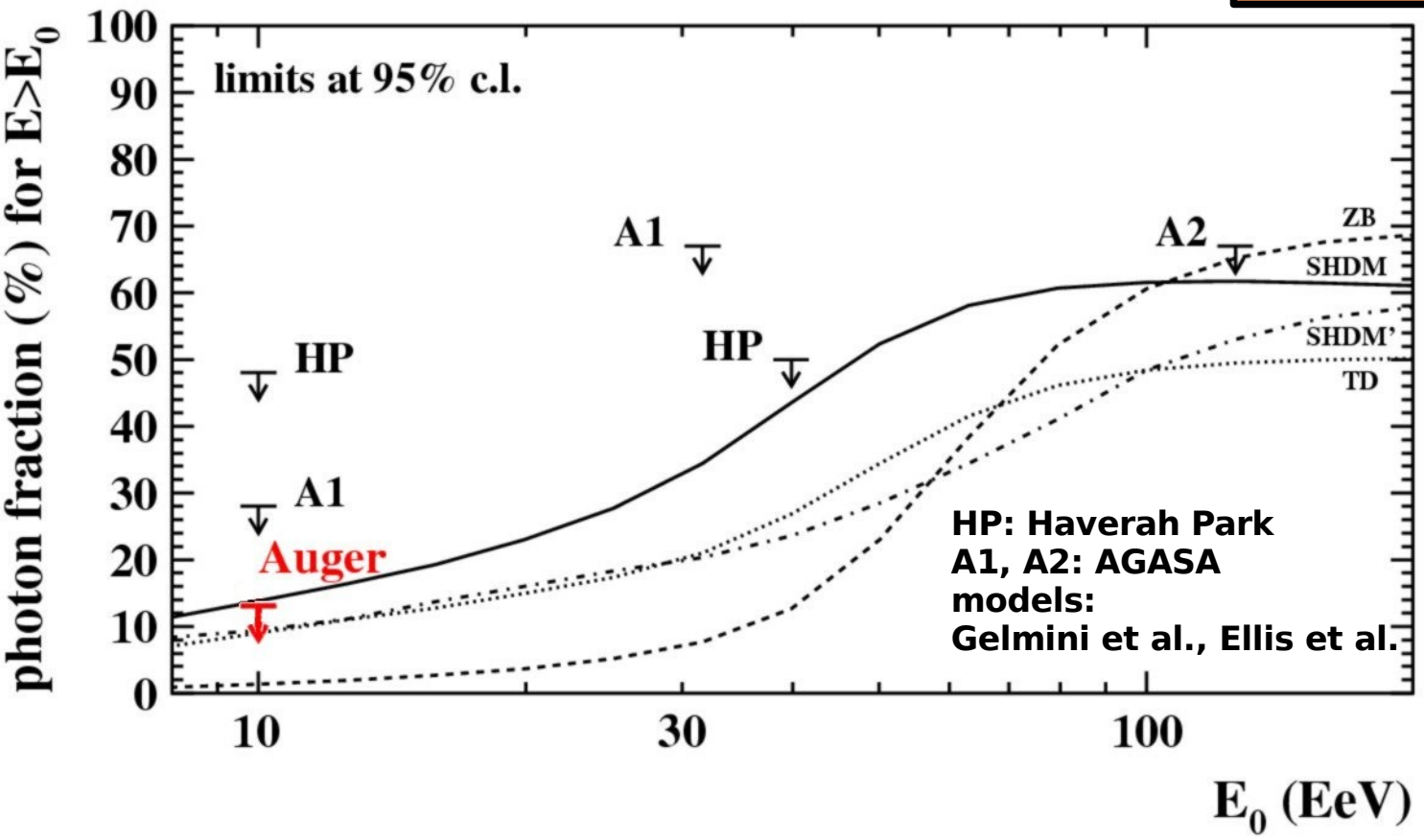
- For each event: simulate photon X_{max} distribution (PRESHOWER+CORSIKA)



- Compare data & simulation => (statistical method:) photon limit
- Correction of limit for detector acceptance

Auger Photon Limit

Auger, ICRC (2007)



- **13% upper limit** (95% c.l.) to cosmic-ray photon fraction
- confirms and improves on previous limits above 10^{19} eV

Summary

- FD fully operational since Feb. 2007 (first 4-fold event observed)
- Simulation validated:
  - Comparison in good agreement (shape and normalization)
  - MC-data comparison sensitive to energy spectrum
  - Mixed composition suggested by data
- FD-mono spectrum unfolded:
  - Good agreement in normalization
  - Ankle clearly visible at $\sim 10^{18.5}$ eV
  - Conclusion about GZK-cutoff not yet possible with FD-data
- Photon limit derived from X_{max}-distribution using hybrid data:
  - 13% upper limit (95% c.l.) to cosmic-ray photon fraction