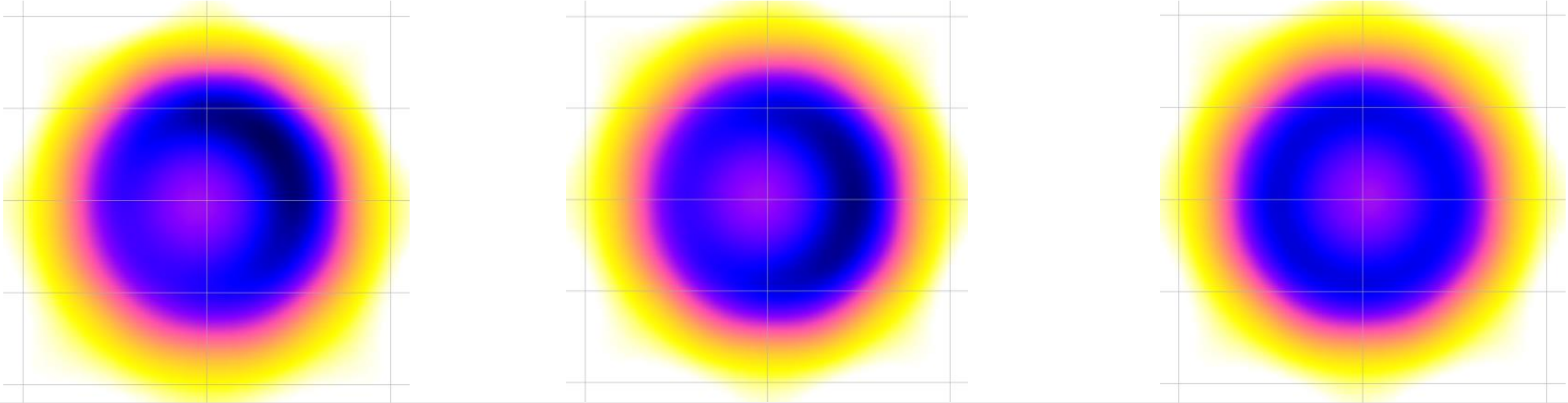
Karlsruhe Institute of Technology

VRIJE UNIVERSITEIT BRUSSEL

ICRC2019 36th International Cosmic Ray Conference · Madison, WI, USA
THE ASTROPARTICLE PHYSICS CONFERENCE
PoS(ICRC2019)294

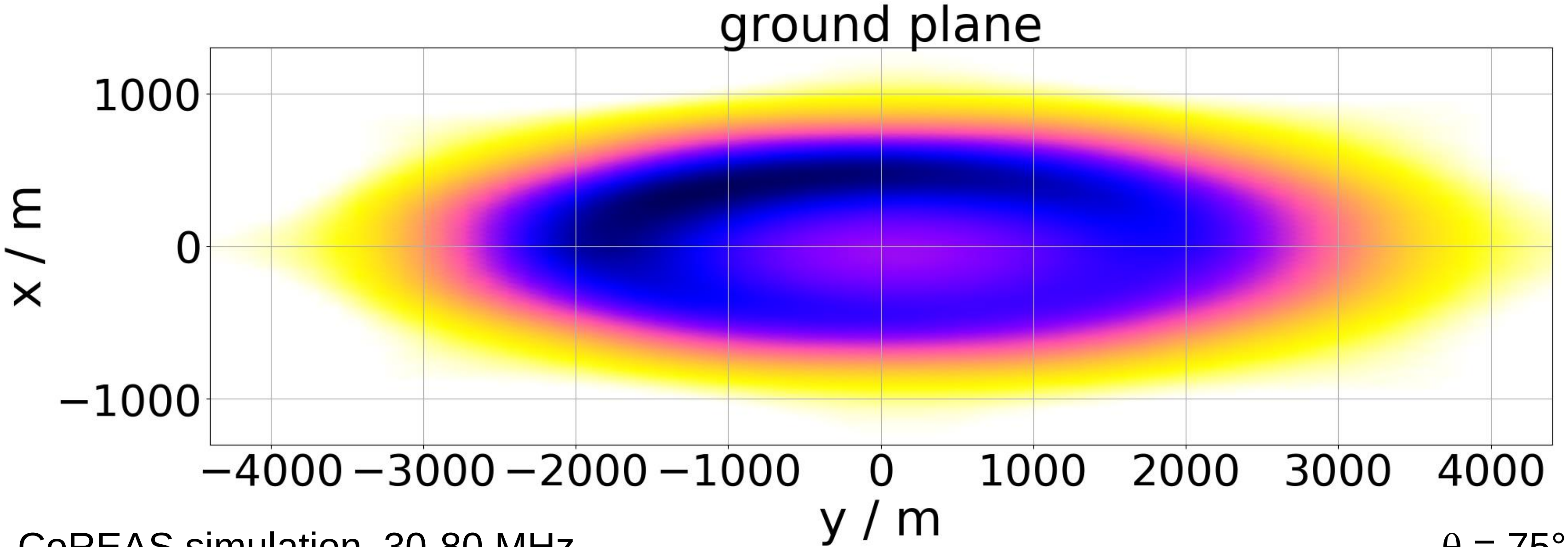
Symmetrizing the signal distribution of radio emission from inclined air showers

Tim Huege (KIT & VUB), Felix Schlüter (KIT) and Lukas Brenk (KIT)



The radio signal distribution of inclined showers

- inclined air showers illuminate elliptical area on the ground
- strong asymmetries in the distribution: geometrical, charge excess



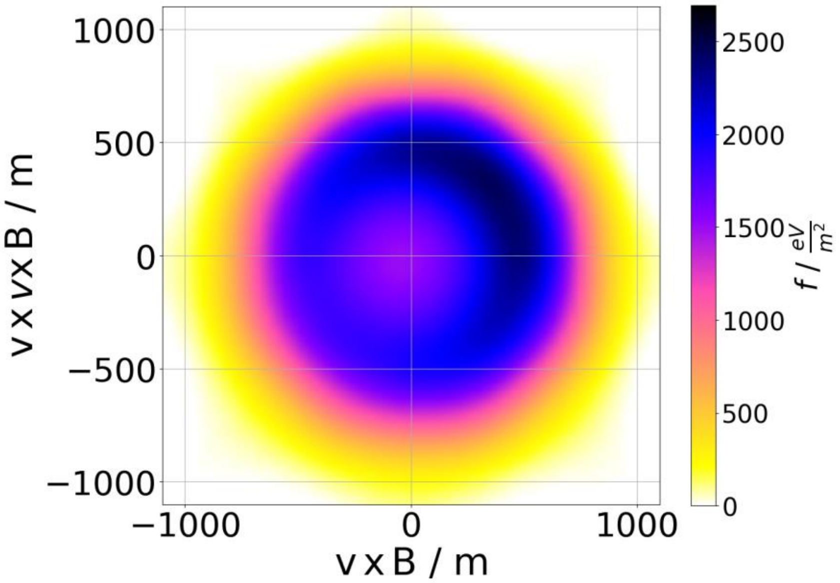
CoREAS simulation, 30-80 MHz

$\theta = 75°$

Symmetrizing the signal distribution

- goal: take out asymmetries, then apply simple 1d model LDF

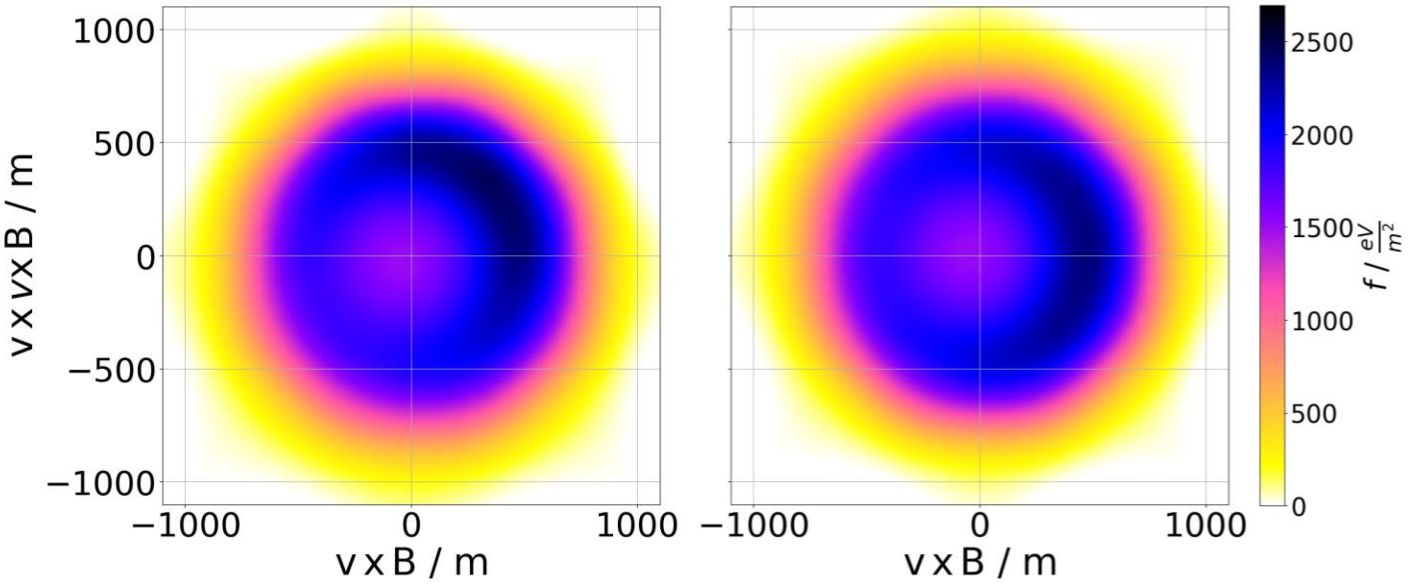
1: raw shower plane



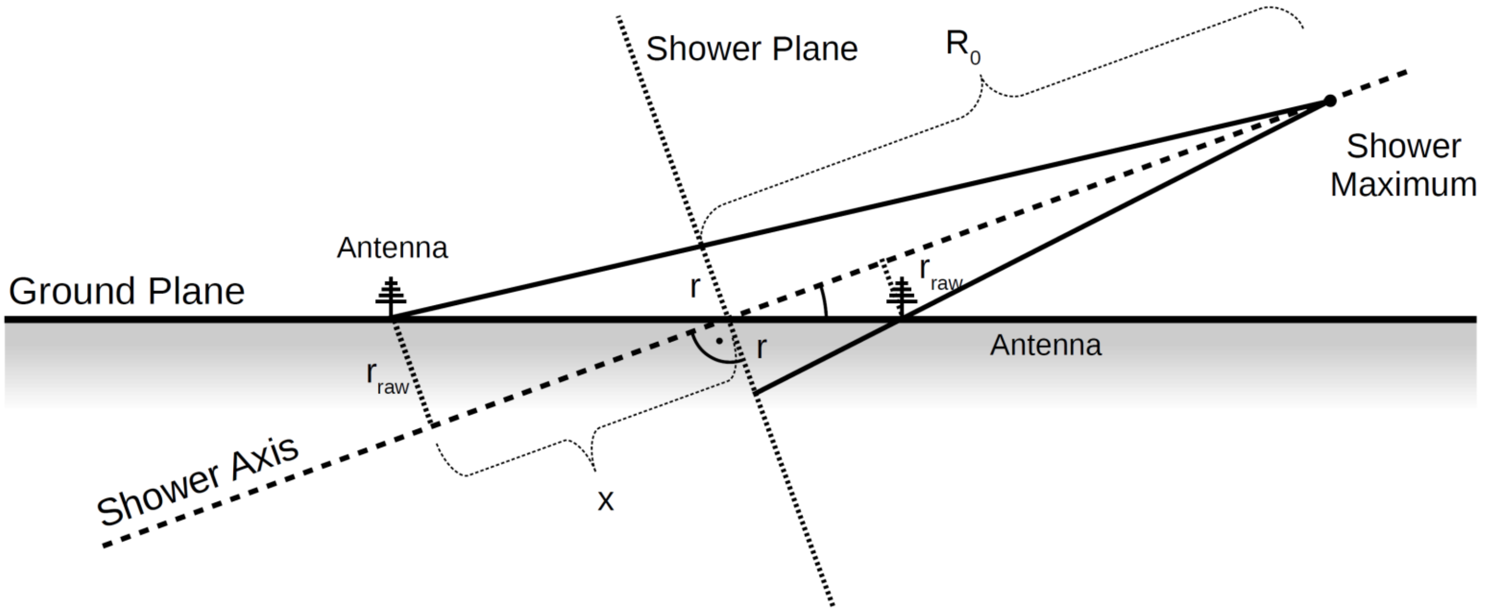
Symmetrizing the signal distribution

- goal: take out asymmetries, then apply simple 1d model LDF

1: raw shower plane　　2: early-late-corrected



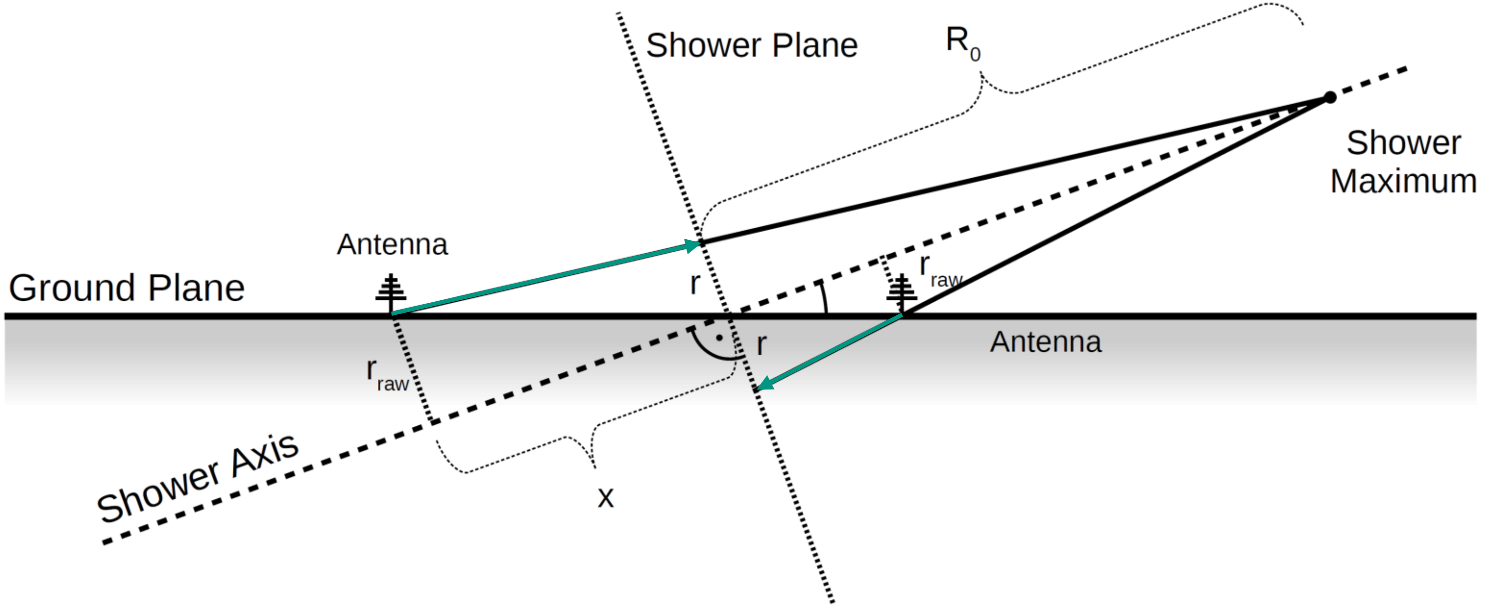
Correcting for early-late asymmetries



- correcting axis distances and energy fluences

$$f = f_{\mathrm{raw}} \cdot \left(\frac{R}{R_0}\right)^2 \qquad r = r_{\mathrm{raw}} \cdot \frac{R_0}{R} \qquad R \equiv R_0 + x$$

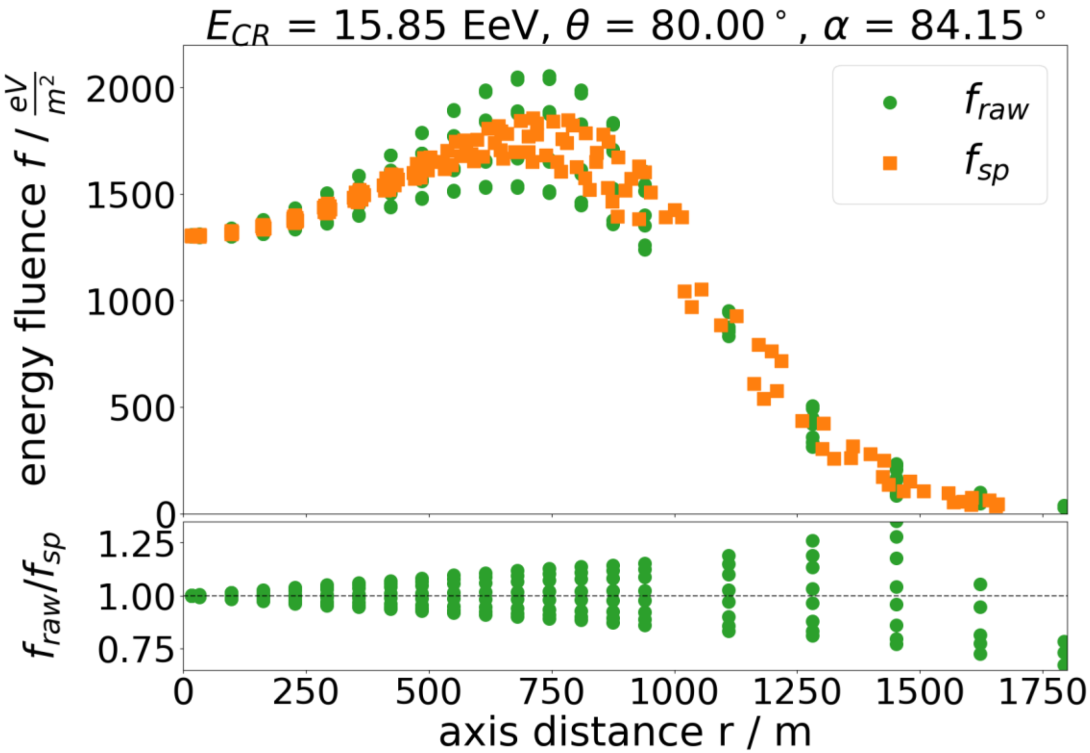
Correcting for early-late asymmetries



- correcting axis distances and energy fluences

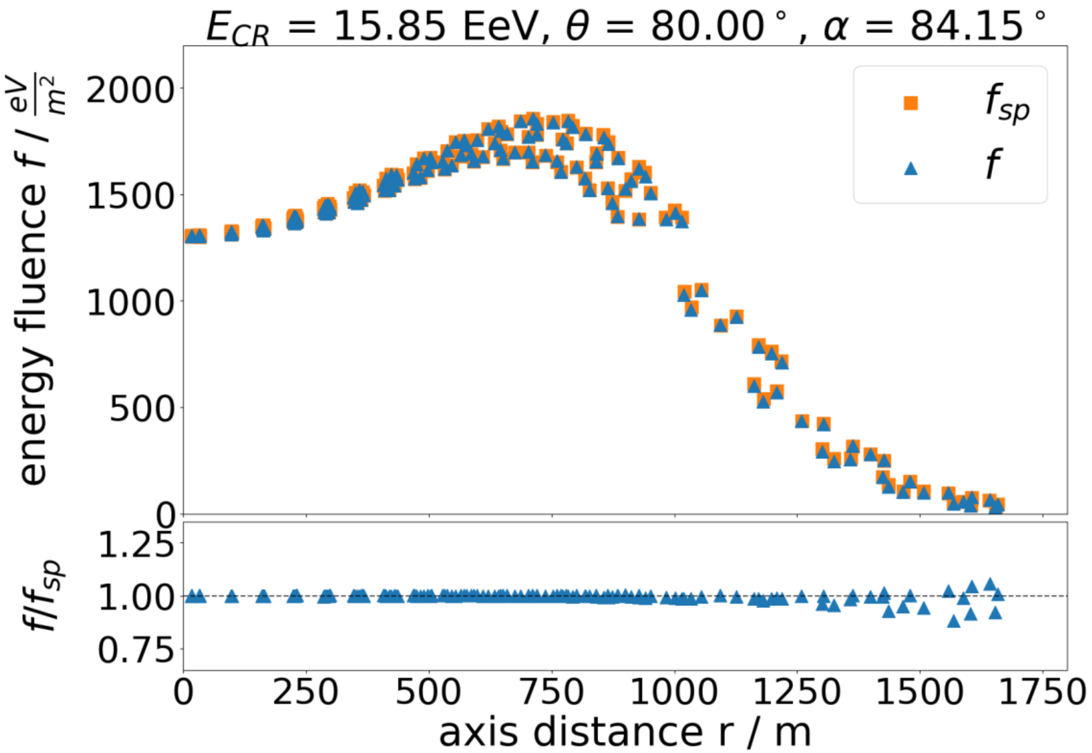
$$f = f_{\mathrm{raw}} \cdot \left(\frac{R}{R_0}\right)^2 \qquad r = r_{\mathrm{raw}} \cdot \frac{R_0}{R} \qquad R \equiv R_0 + x$$

Performance of early-late correction



- compare early-late corrected simulations with direct shower-plane sim.
- correction generally accurate to within 2%
- deviations possibly related to refractive index asymmetries? (see talk M. Gottowik)

Performance of early-late correction

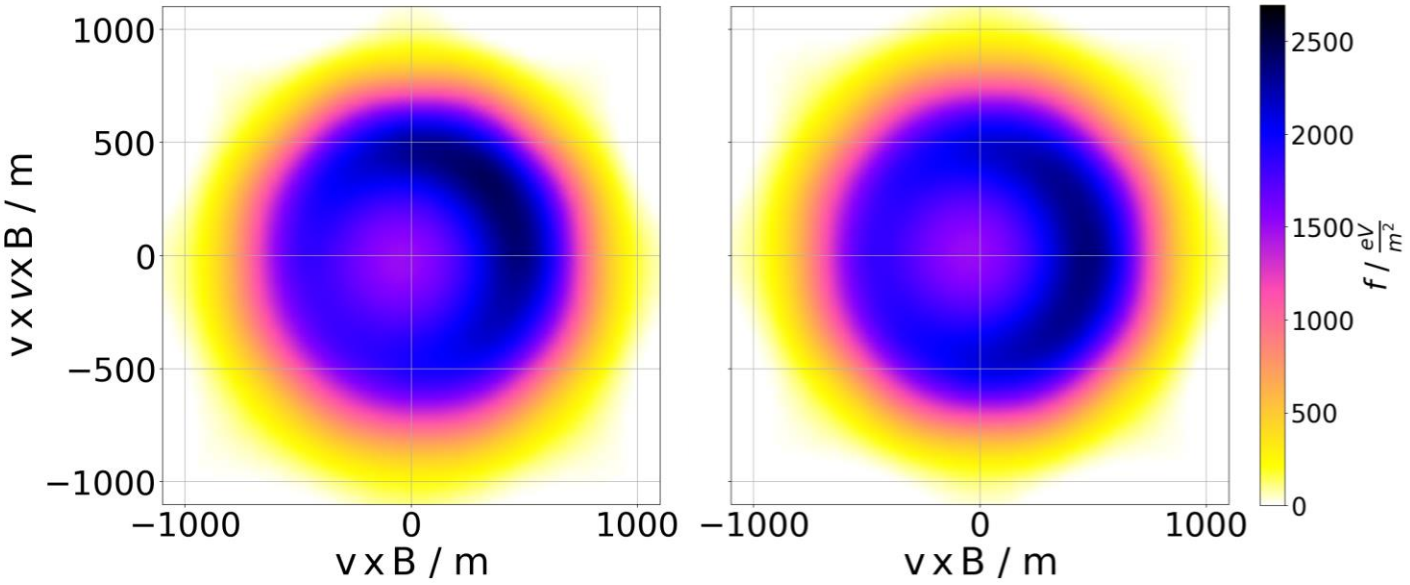


- compare early-late corrected simulations with direct shower-plane sim.
- correction generally accurate to within 2%
- deviations possibly related to refractive index asymmetries? (see talk M. Gottowik)

Symmetrizing the signal distribution

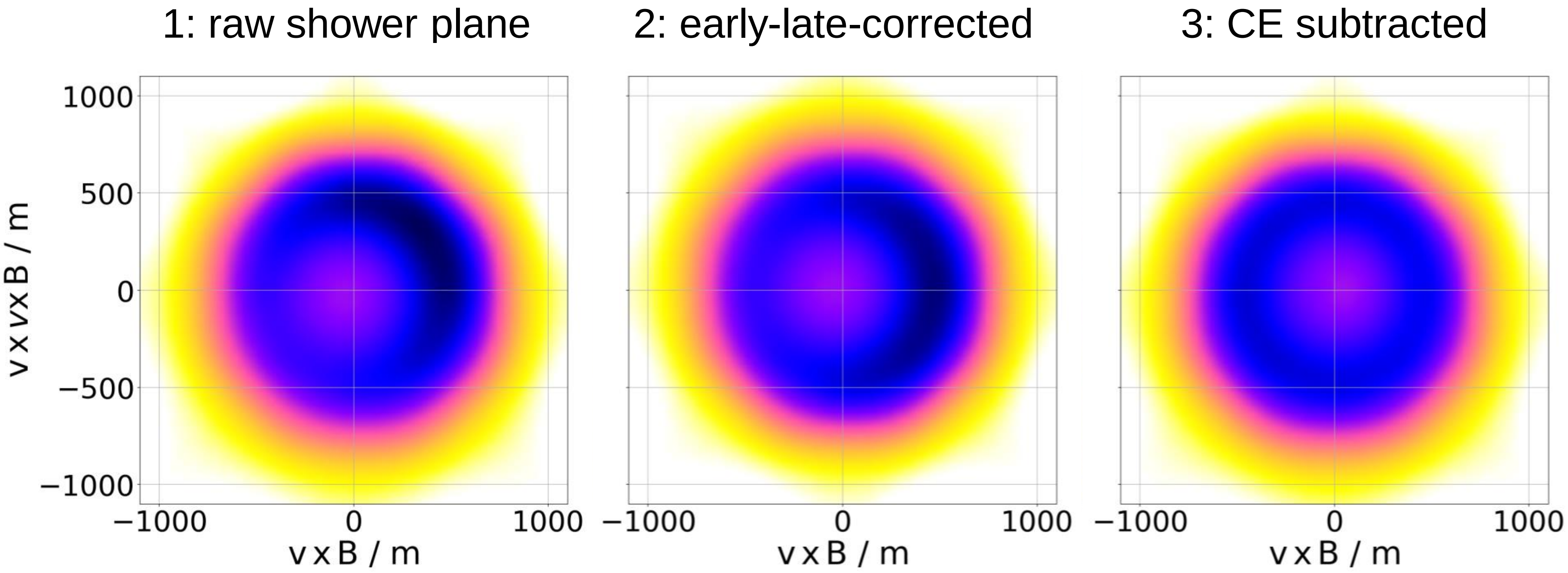
- goal: take out asymmetries, then apply simple 1d model LDF

1: raw shower plane   2: early-late-corrected

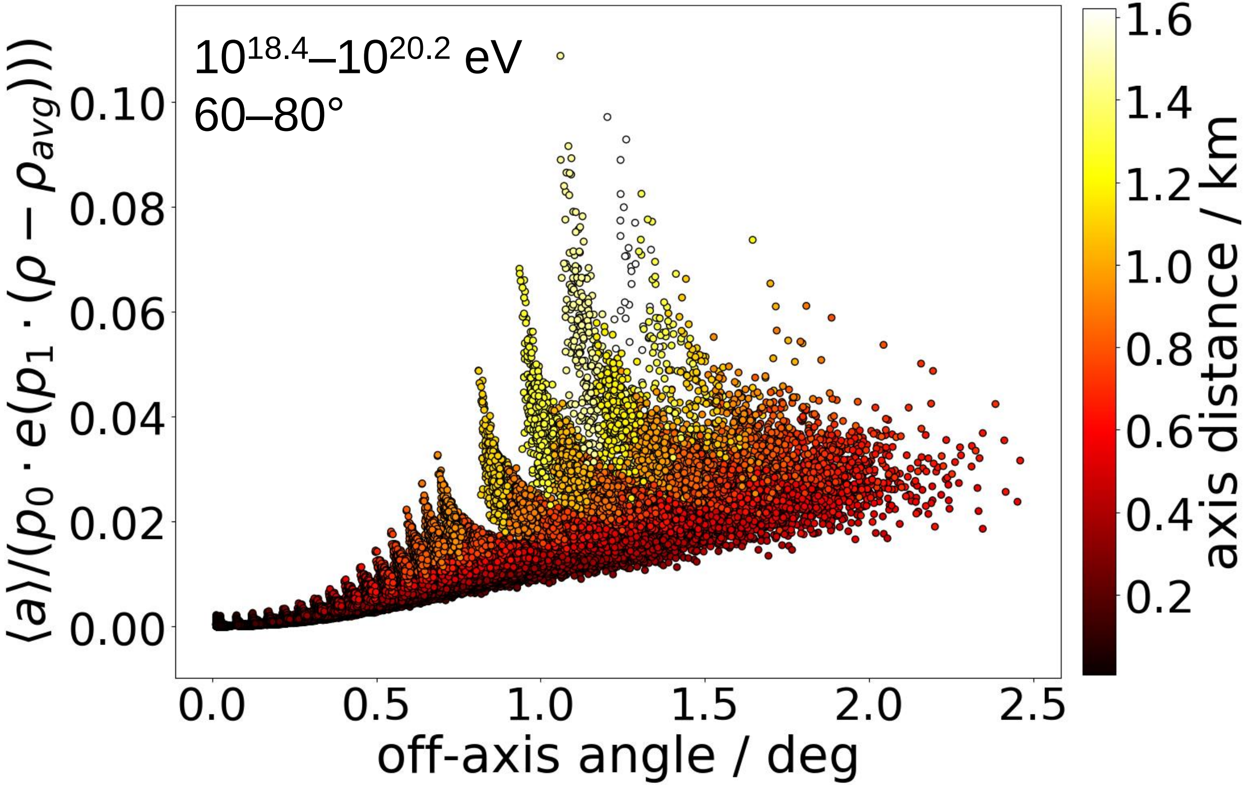


Symmetrizing the signal distribution

- goal: take out asymmetries, then apply simple 1d model LDF



The charge-excess fraction in the energy fluence



- charge-excess fraction

$$a \equiv \sin^2(\alpha) \cdot \frac{f_{ce}}{f_{geo}}$$

depends on off-axis angle, lateral sdistance and density at Xmax

Parameterisation of charge-excess fraction

Karlsruhe Institute of Technology

- analytic parameterization optimized for universal applicability

$$a(r, d_{\max}, \rho_{\max}) = 0.373 \cdot \frac{r}{d_{\max}} \cdot \exp\left(\frac{r}{762.6\ \mathrm{m}}\right) \cdot \left[\exp\left(\frac{\rho_{\max} - \langle\rho_{\max}\rangle}{0.149\ \mathrm{kg/m^3}}\right) - 0.189\right]$$

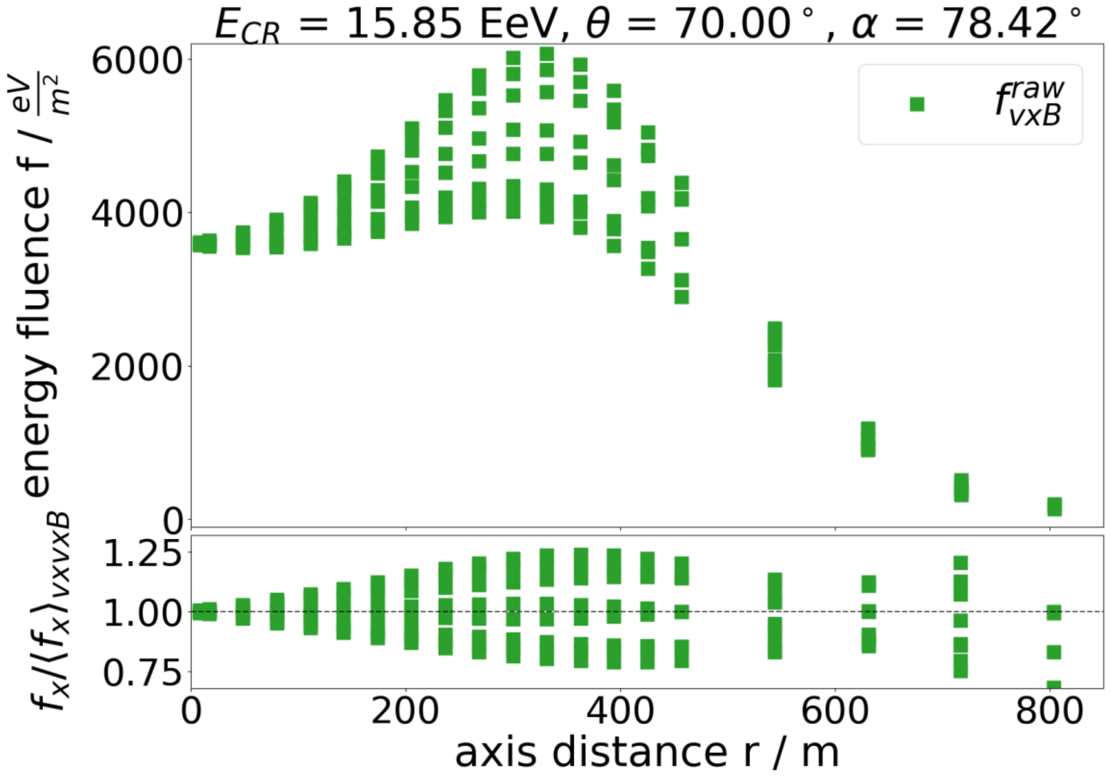
off-axis angle — axis distance — atmospheric density correction

- with this, we can calculate geomagnetic energy fluence at any location by subtraction of charge-excess fluence from ***v*** x ***B*** measurement

$$f_{\mathrm{geo}}^{\mathrm{par}} = \frac{f_{\mathbf{v}\times\mathbf{B}}}{\left(1 + \frac{\cos(\phi)}{|\sin(\alpha)|} \cdot \sqrt{a(r, d_{\max}, \rho_{\max})}\right)^2}$$

cf. Glaser et al. JCAP 09 (2016) 024 and Astroparticle Physics 104 (2019) 64-77

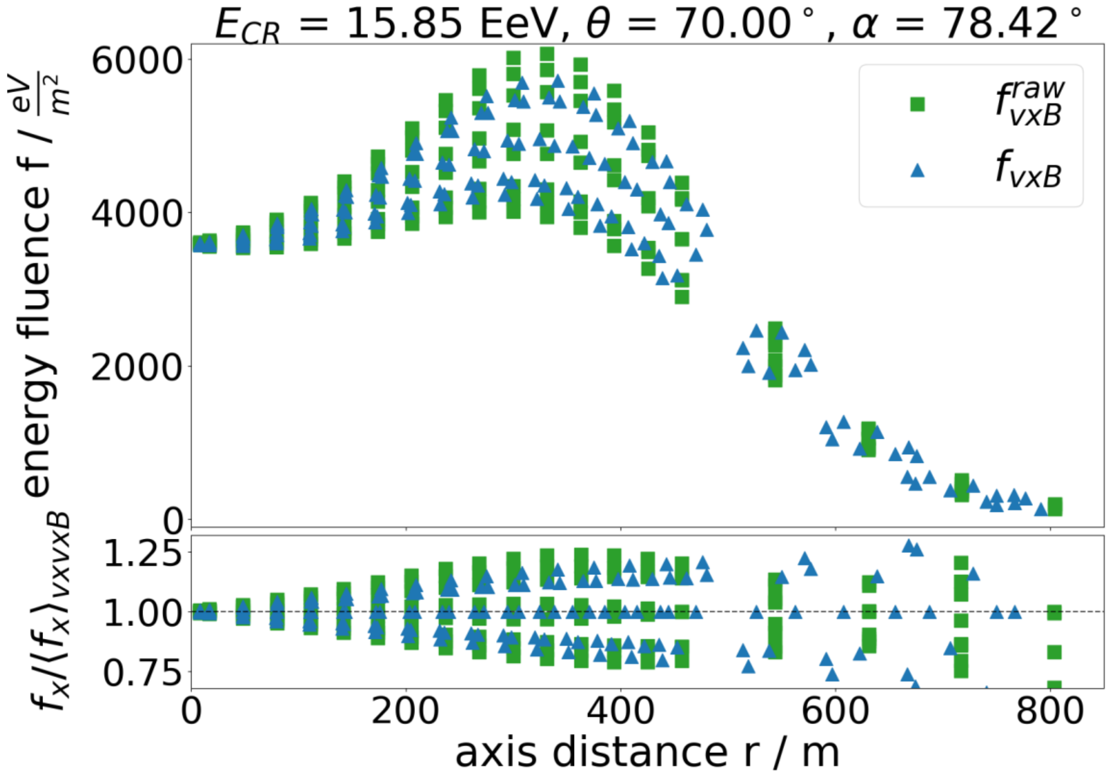
Performance of charge-excess correction



- application of early-late correction and charge-excess correction results in a mostly symmetric LDF
- some scatter remains, arising from deviations from circular symmetry of charge-excess fraction

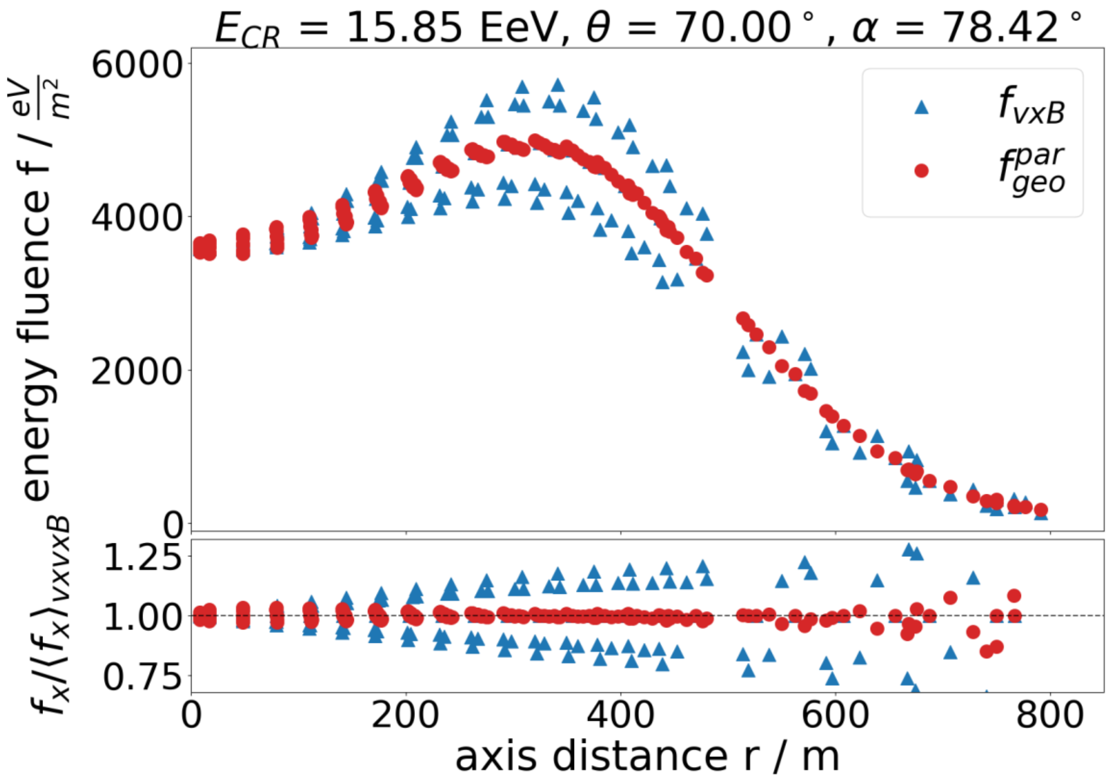
Tim Huege <tim.huege@kit.edu>

Performance of charge-excess correction



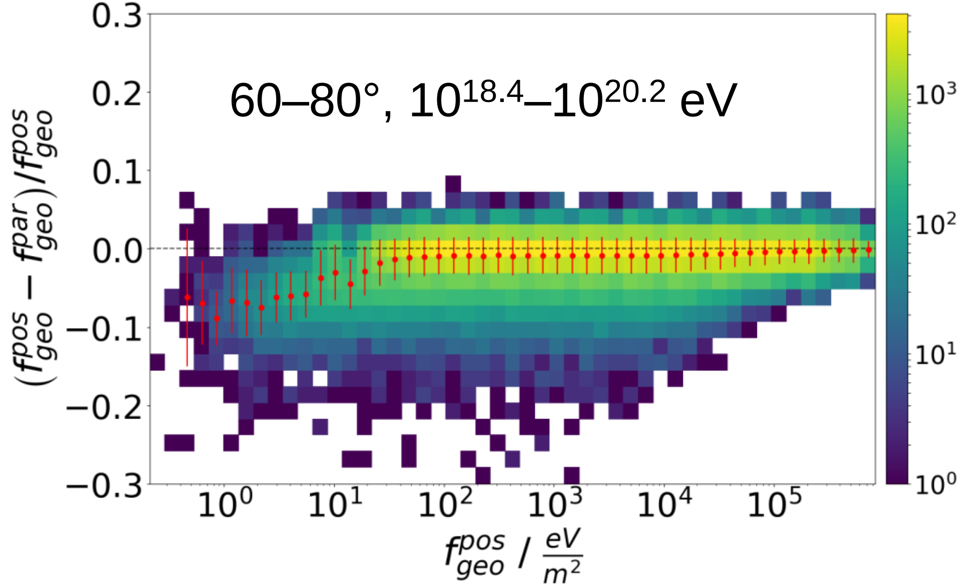
- application of early-late correction and charge-excess correction results in a mostly symmetric LDF
- some scatter remains, arising from deviations from circular symmetry of charge-excess fraction

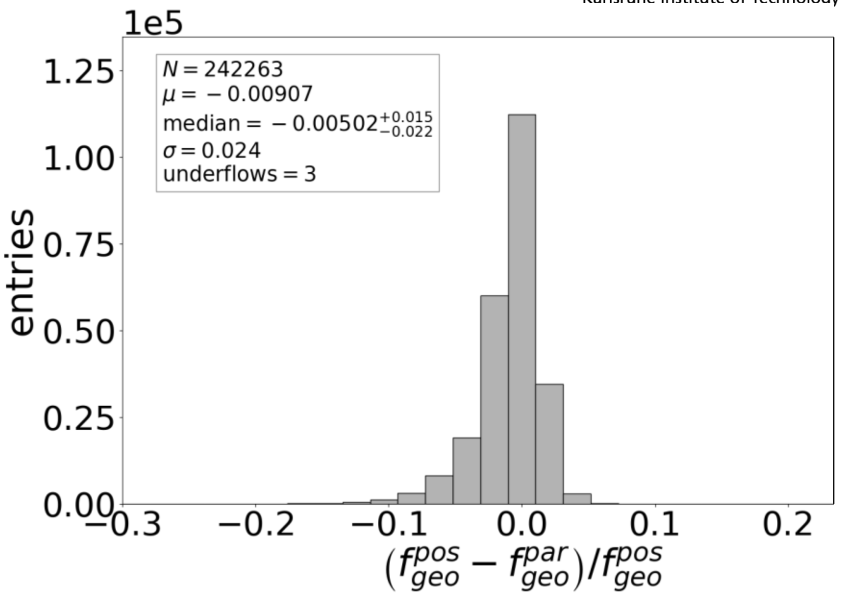
Performance of charge-excess correction



- application of early-late correction and charge-excess correction results in a mostly symmetric LDF
- some scatter remains, arising from deviations from circular symmetry of charge-excess fraction

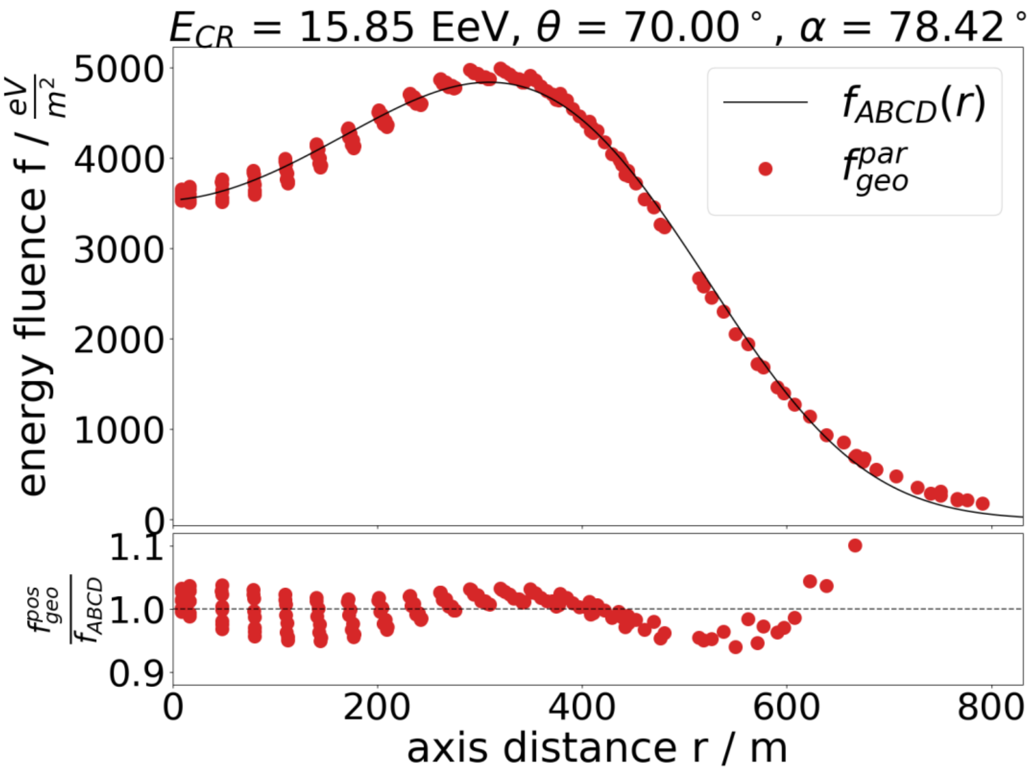
Overall performance of symmetrization





- average bias for all showers is below 1%, spread below 2.5%
- deviations from true geomagnetic energy fluence only at small values (not relevant for the radiation energy integration)

Fitting a rotationally symmetric LDF

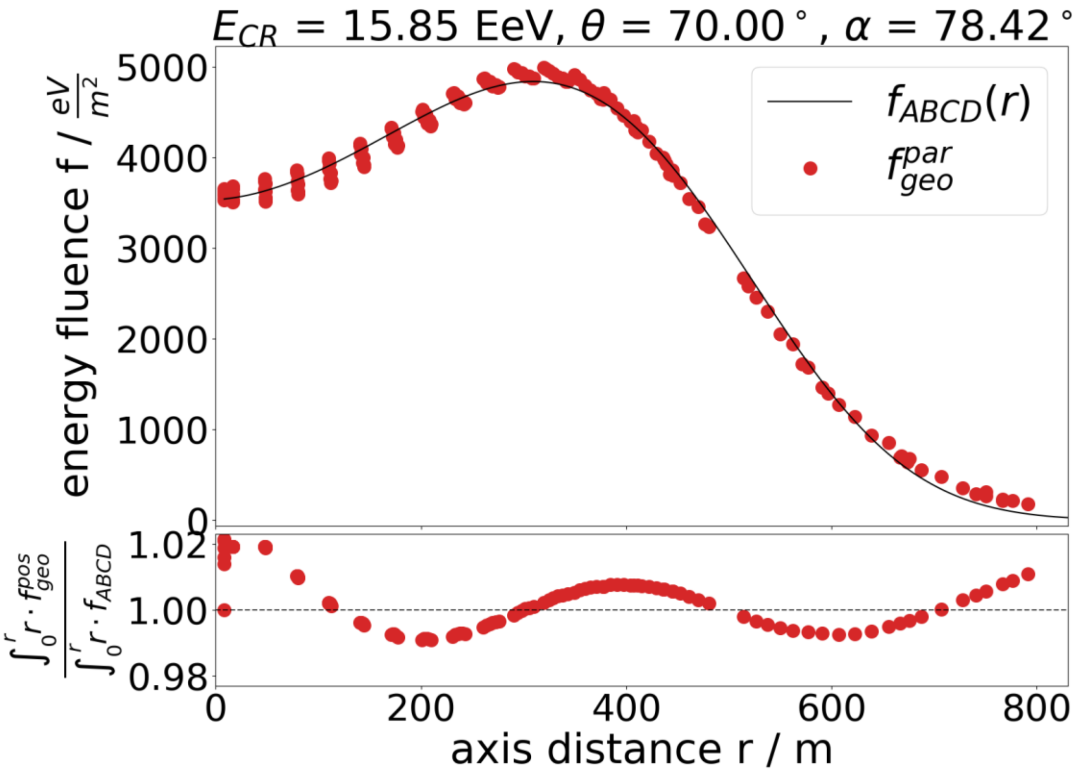


- canonical exponential of a cubic polynomial works well

$$f_{\mathrm{ABCD}}(r) = A \cdot \exp\left[-B \cdot r - C \cdot r^2 - D \cdot r^3\right]$$

- some deviations at large lateral distances, but minor influence on radiation energy integration

Fitting a rotationally symmetric LDF

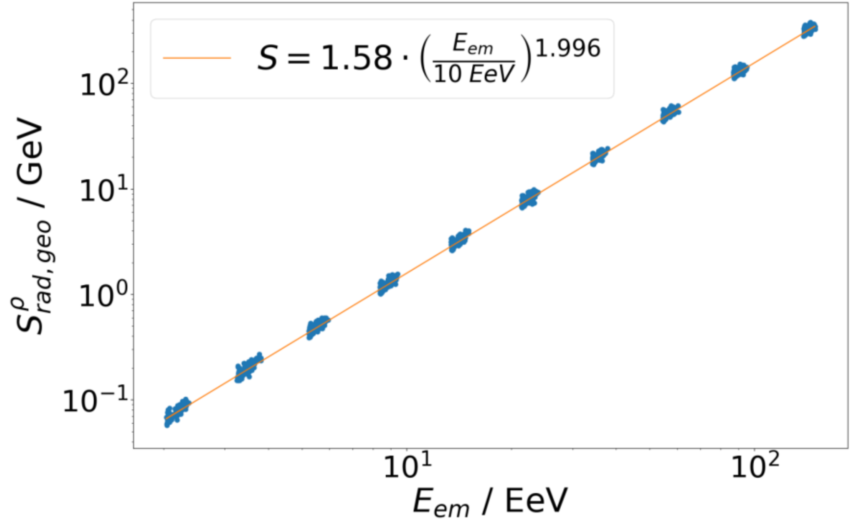


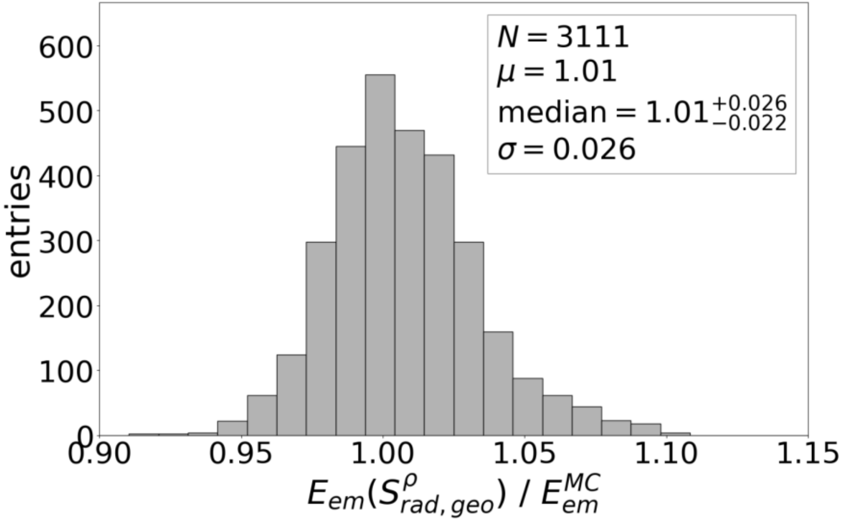
- canonical exponential of a cubic polynomial works well

$$f_{\mathrm{ABCD}}(r) = A \cdot \exp\left[-B \cdot r - C \cdot r^2 - D \cdot r^3\right]$$

- some deviations at large lateral distances, but minor influence on radiation energy integration

Radiation energy integration via fitted LDF



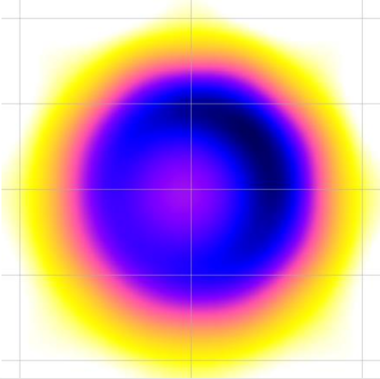


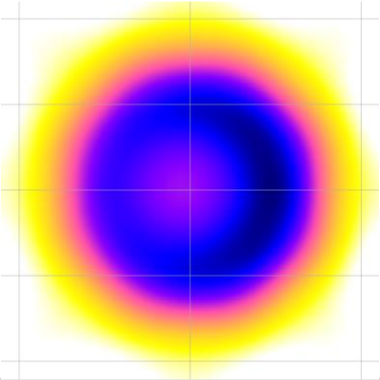
- density-corrected geomagnetic radiation energy correlates well with energy in the electromagnetic cascade, spread smaller than 3%

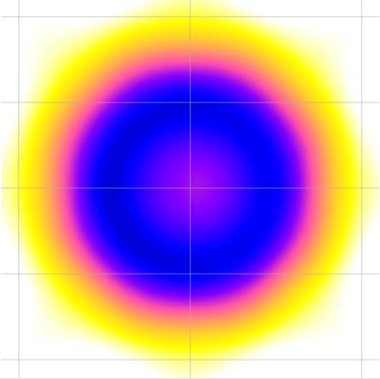
$$S^{\rho}_{\text{rad,geo}} = \frac{E^{\text{geo}}_{\text{rad}}}{\sin^2(\alpha)} \cdot \frac{1}{1 - p_0 + p_0 \cdot \exp\left[p_1 \cdot (\rho - \langle\rho\rangle)\right]}$$

Conclusion

- radio signal distribution of inclined air showers is highly asymmetric
- have developed analytic model to symmetrize the distribution
- symmetrized distribution can be fit with simple 1d LDF
- integration over 1d LDF yields *geomagnetic radiation energy*
- 3% intrinsic energy resolution in 30-80 MHz band and for θ = 60-80°
- will develop event reconstruction on this basis



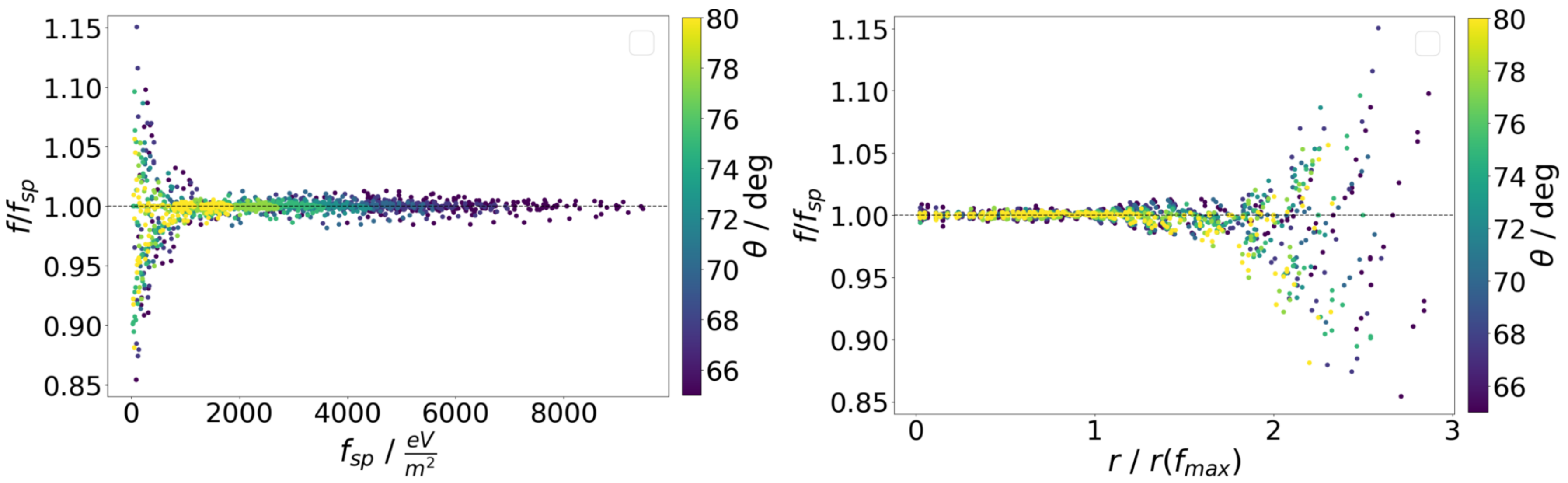




Tim Huege <tim.huege@kit.edu>

Backup

Performance of early-late correction



- most significant deviations are at large lateral distances and small energy fluences

Determining charge-excess fraction directly

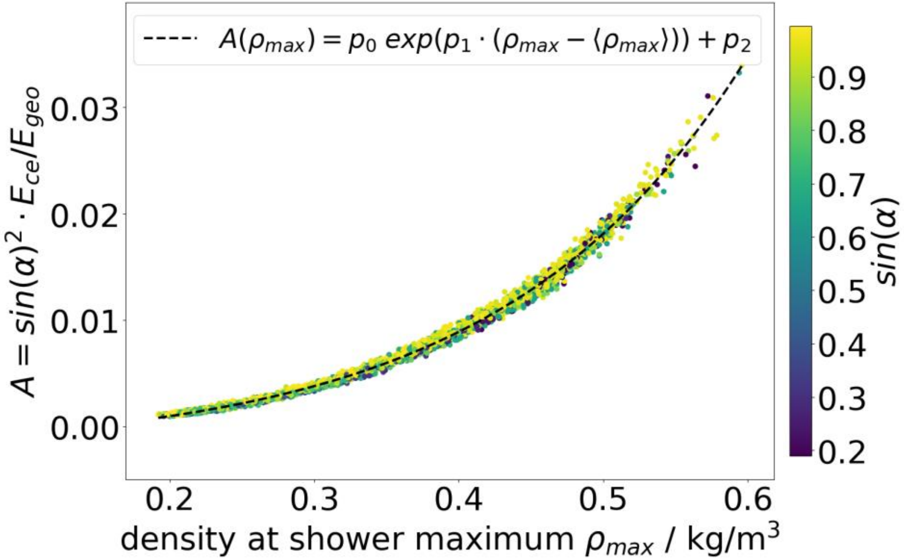
Karlsruhe Institute of Technology

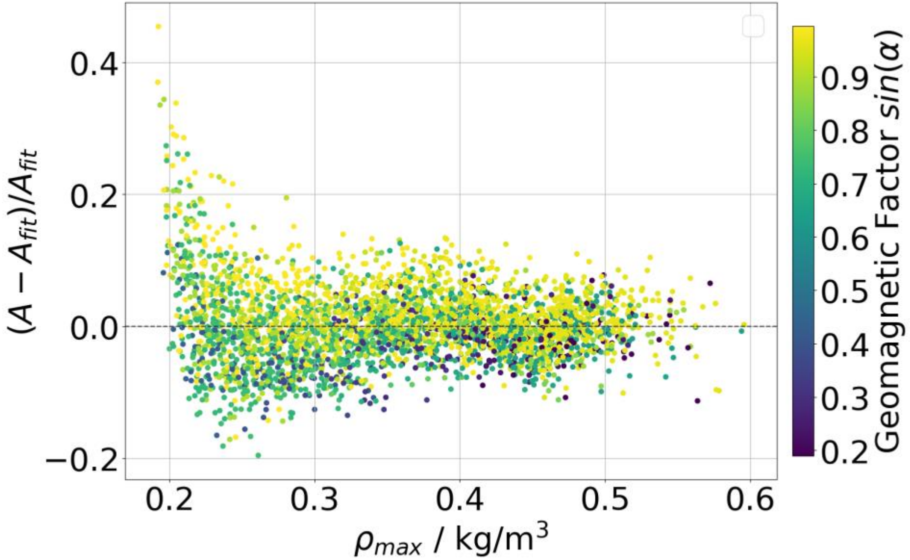
$$f_{\text{geo}}^{\text{pos}} = \left(\sqrt{f_{\mathbf{v}\times\mathbf{B}}} - \frac{\cos(\phi)}{|\sin(\phi)|} \cdot \sqrt{f_{\mathbf{v}\times\mathbf{v}\times\mathbf{B}}} \right)^2$$

$$f_{\text{ce}}^{\text{pos}} = \frac{1}{\sin^2(\phi)} \cdot f_{\mathbf{v}\times\mathbf{v}\times\mathbf{B}}.$$

- for a given observation position, the charge-excess fraction can be determined directly via the known polarisation characteristics of the geomagnetic and charge-excess contributions, cf. Glaser et al., Astroparticle Physics 104 (2019) 64-77

Total CE fraction and density at Xmax





- *total* charge-excess fraction correlates with density at Xmax, see Glaser, Erdmann, Hörandel, Huege, Schulz, JCAP 09 (2016) 024