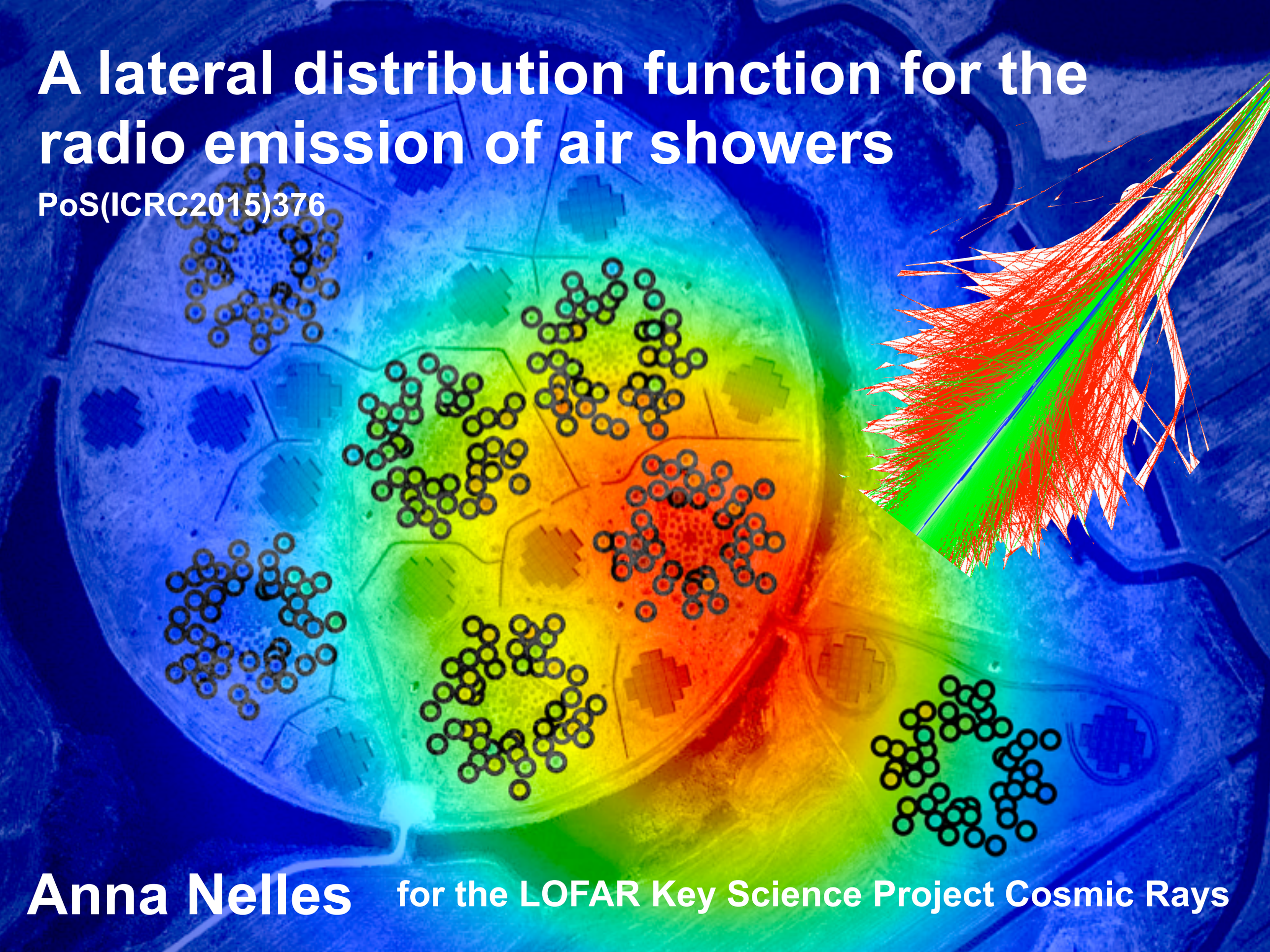
A lateral distribution function for the radio emission of air showers

PoS(ICRC2015)376



Anna Nelles for the LOFAR Key Science Project Cosmic Rays

LOFAR - LOw Frequency ARray

- large **distributed radio telescope** in Europe

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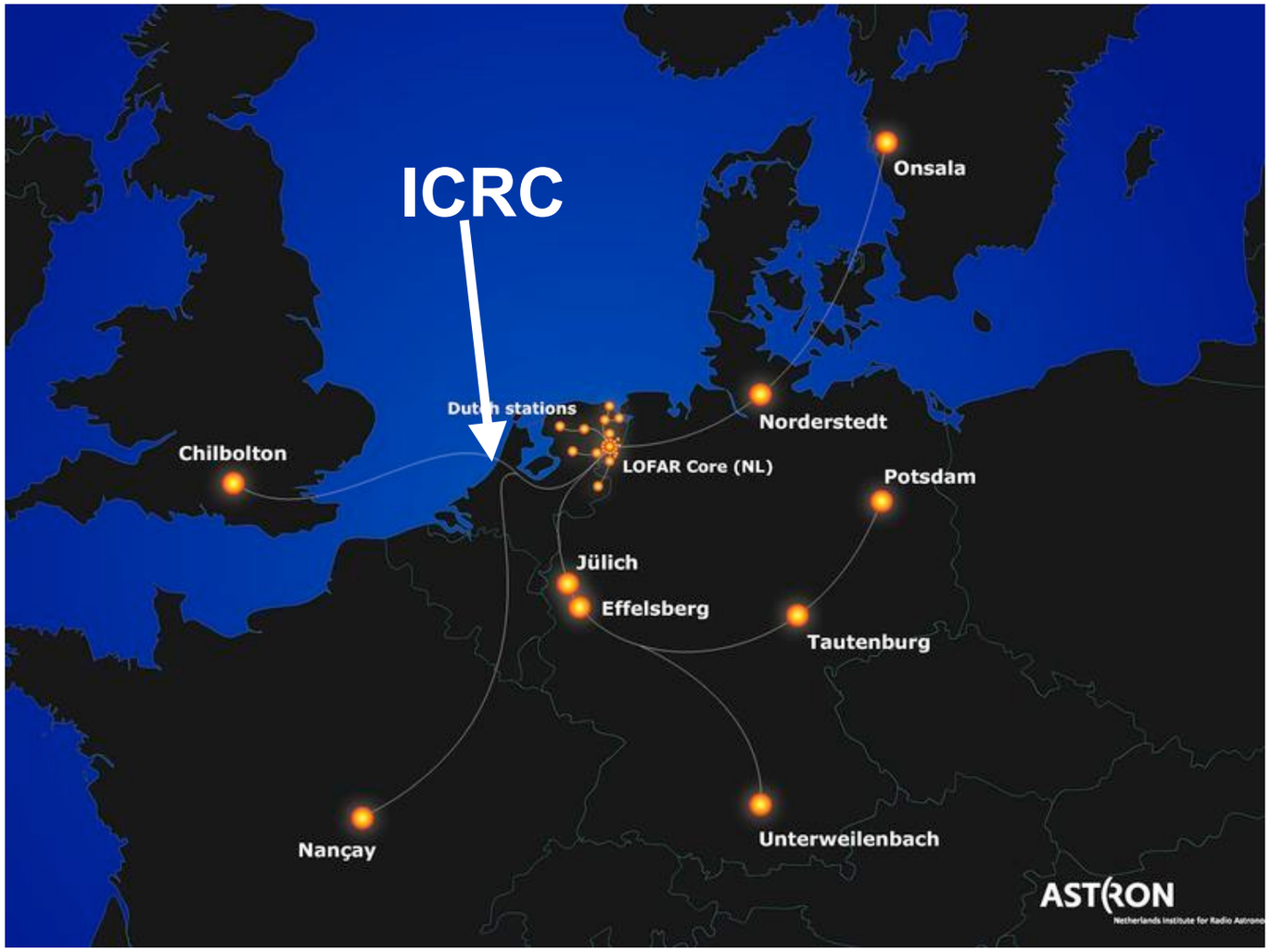

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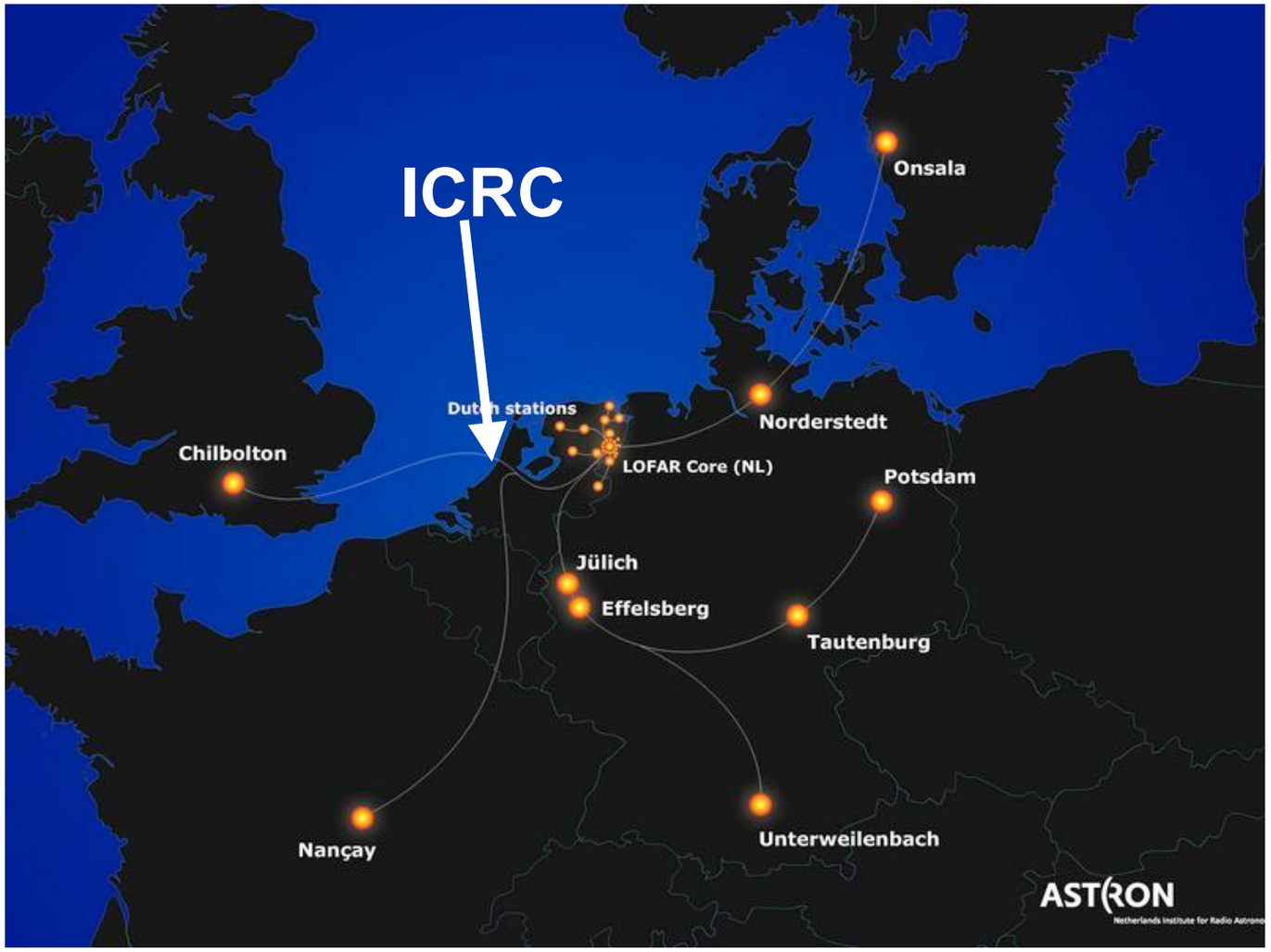

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- per station/location ~ 200 antennas
- two types of antennas **10 - 90 MHz** and **110 - 250 MHz**

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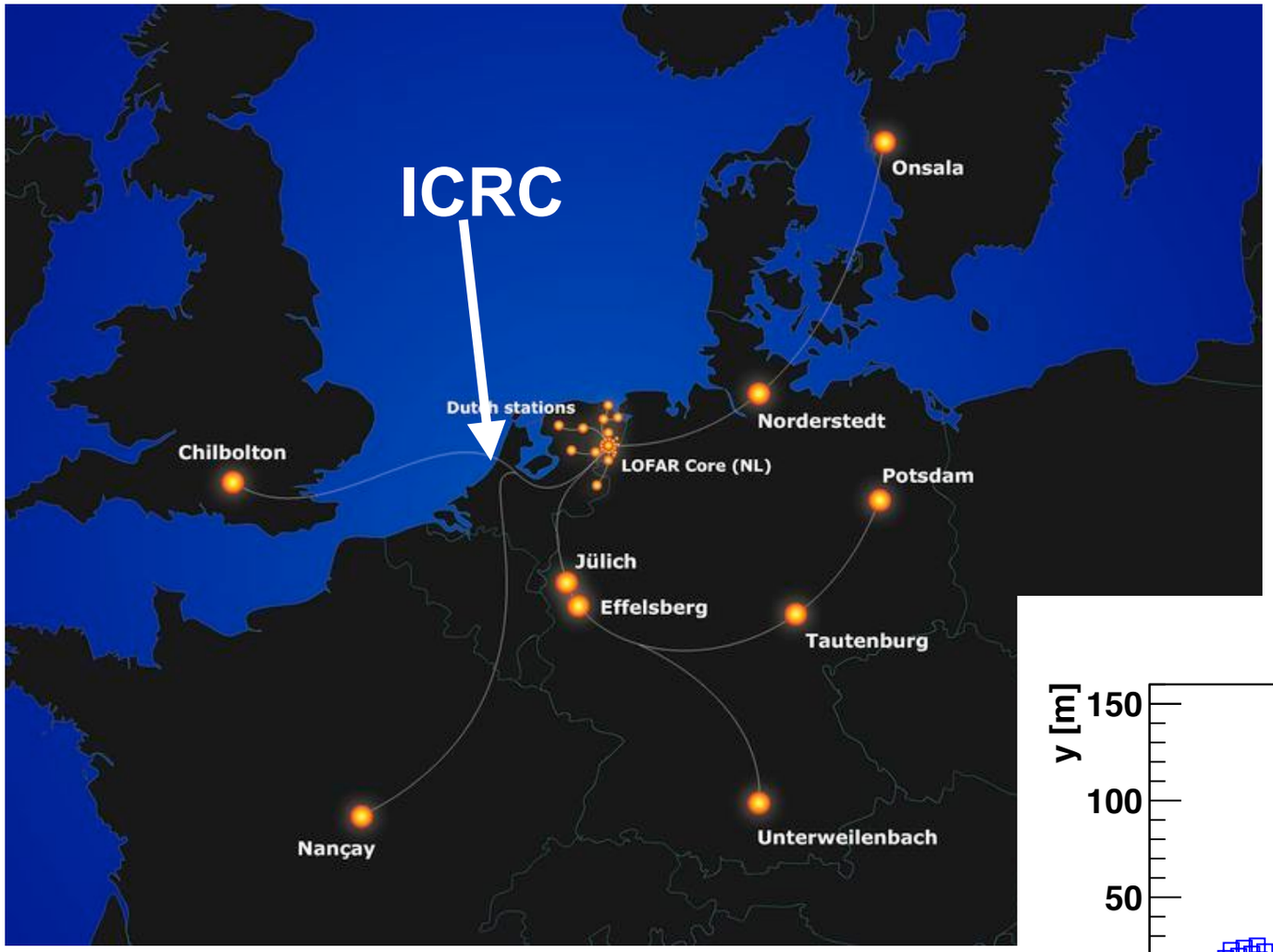

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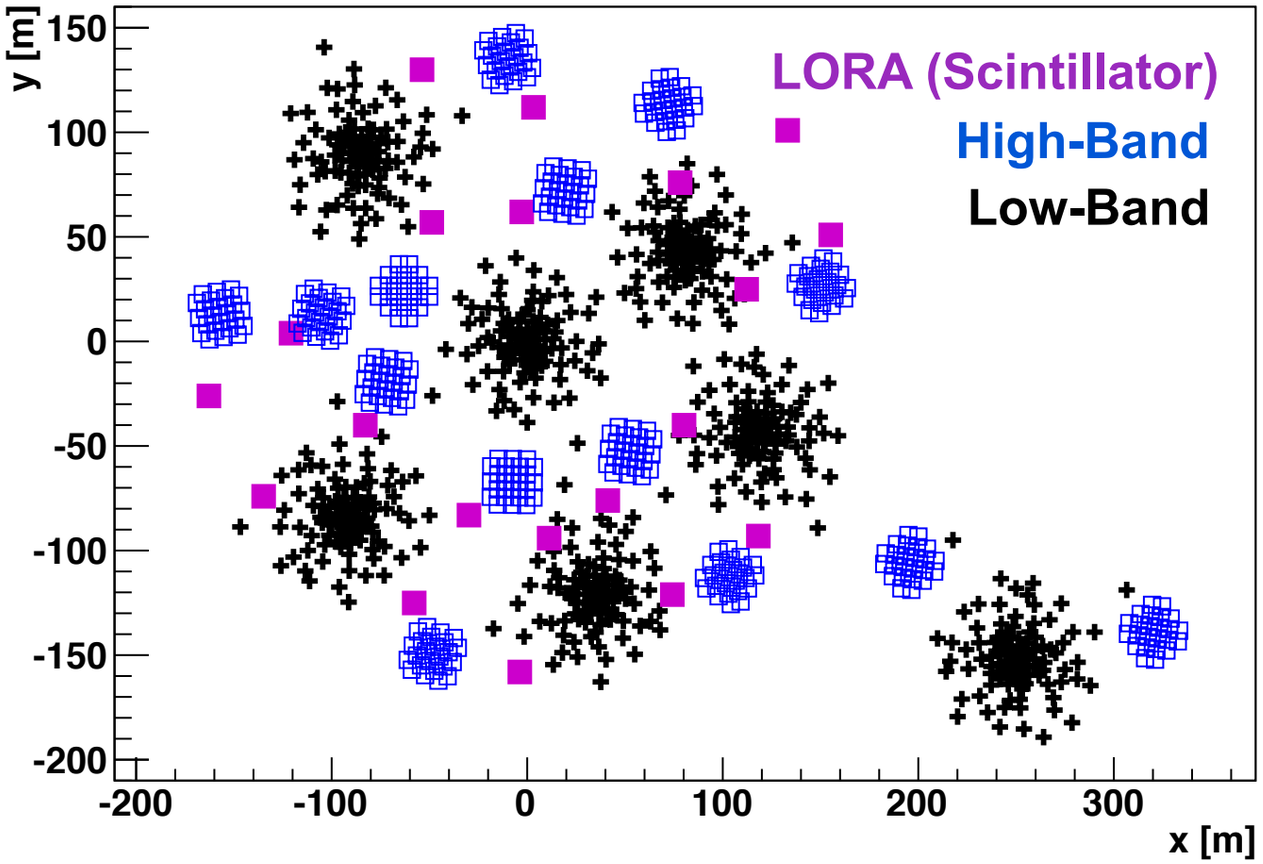

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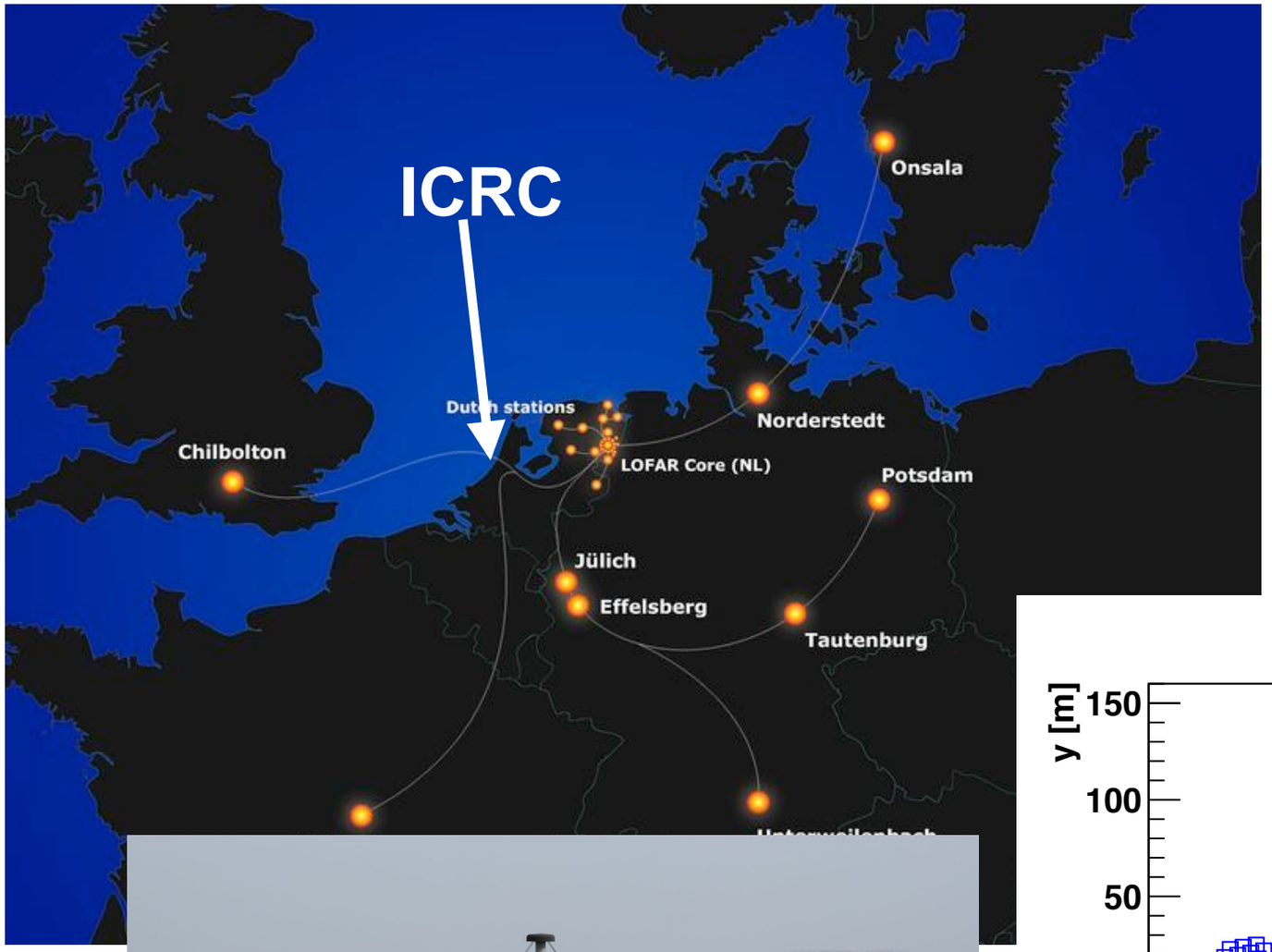

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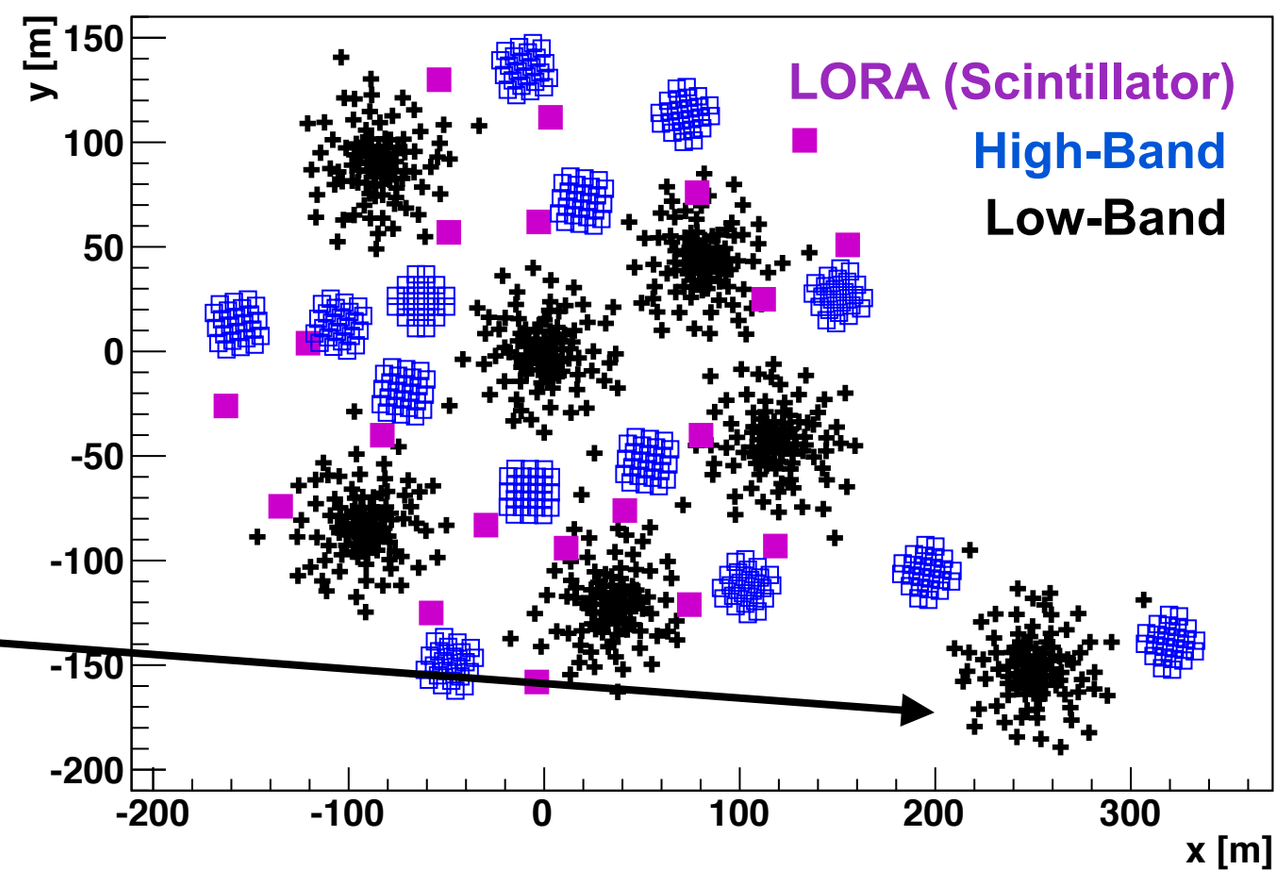
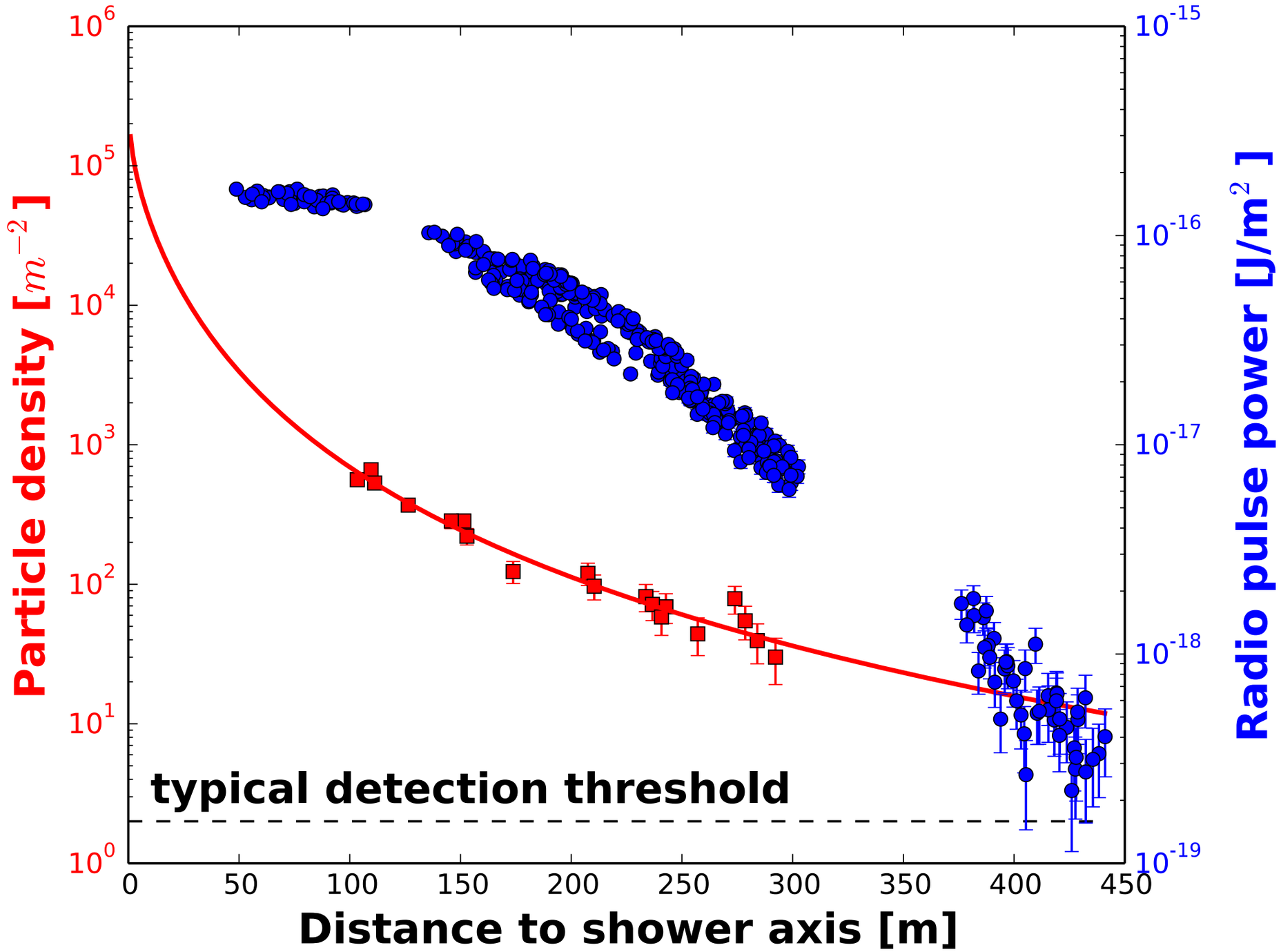


Radio and lateral distribution functions



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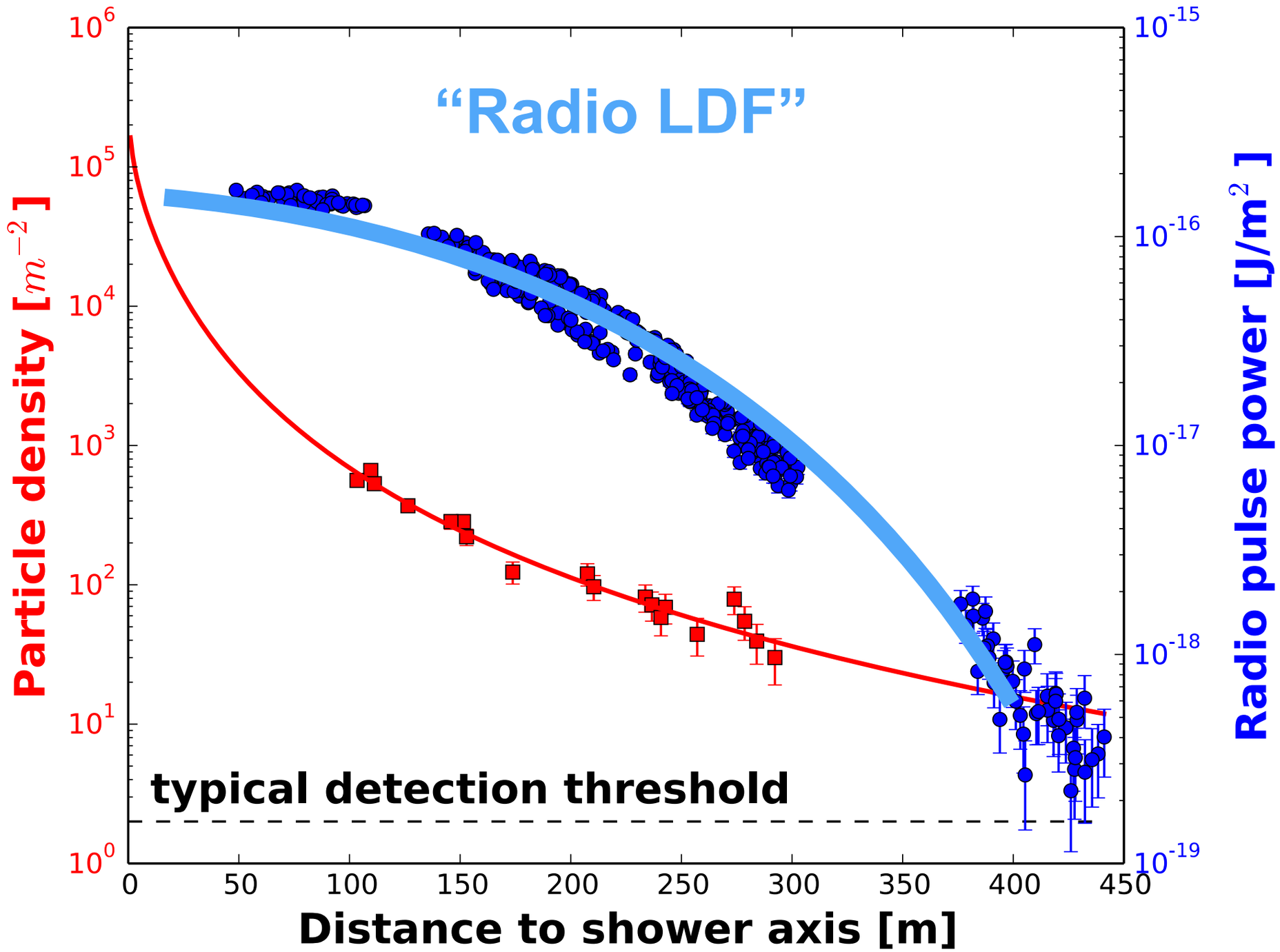

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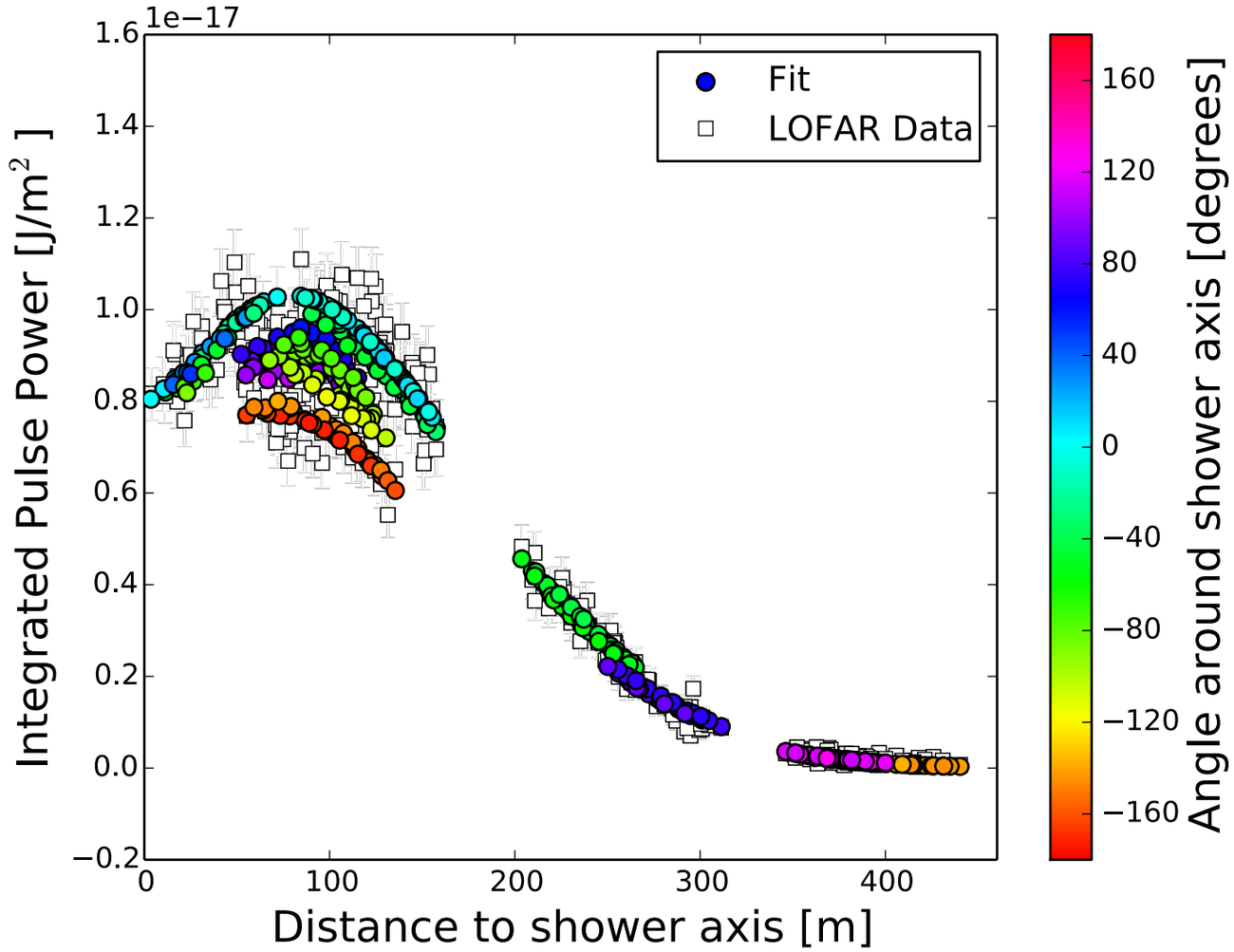

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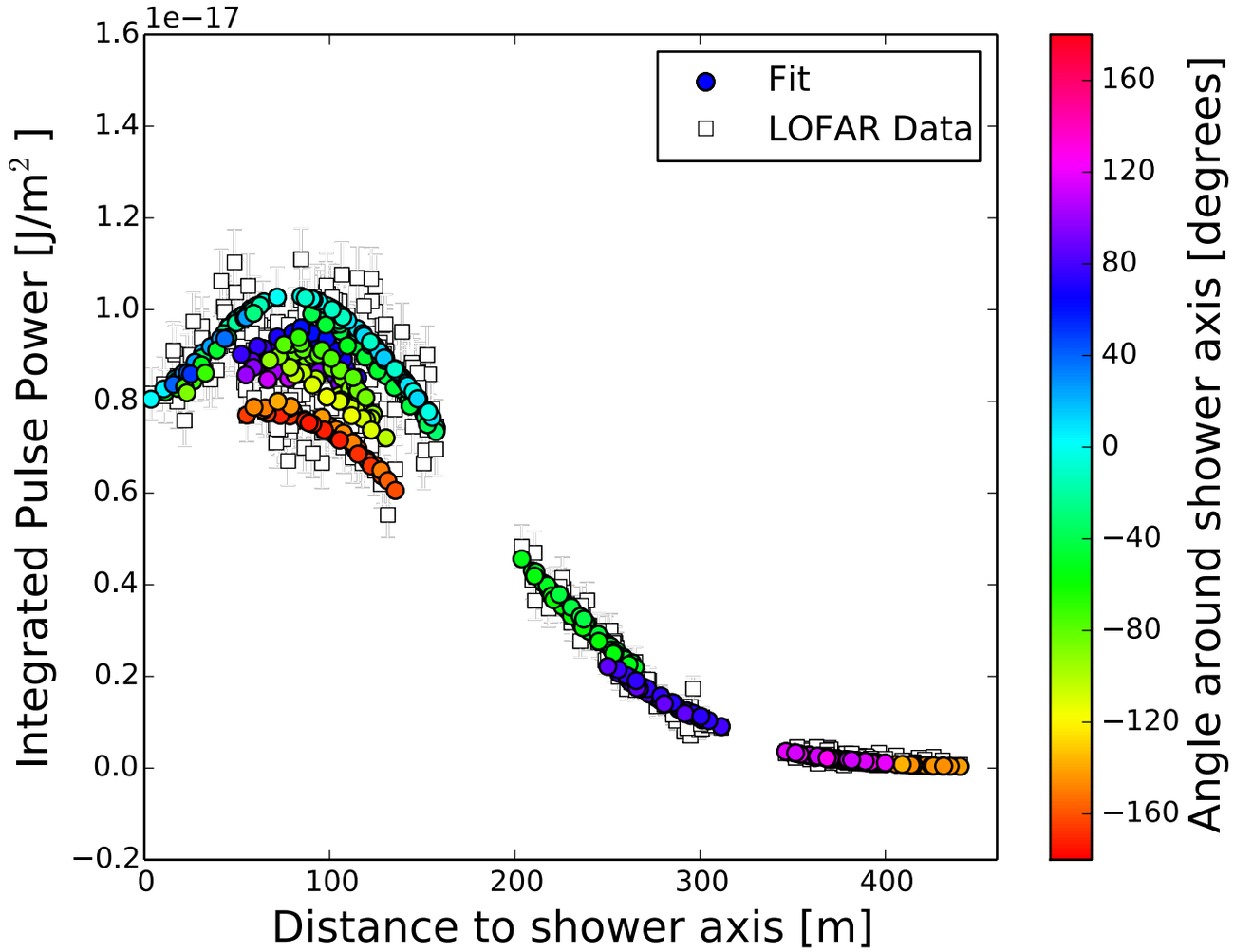
- “Features” in LDF are real

Radio and lateral distribution functions



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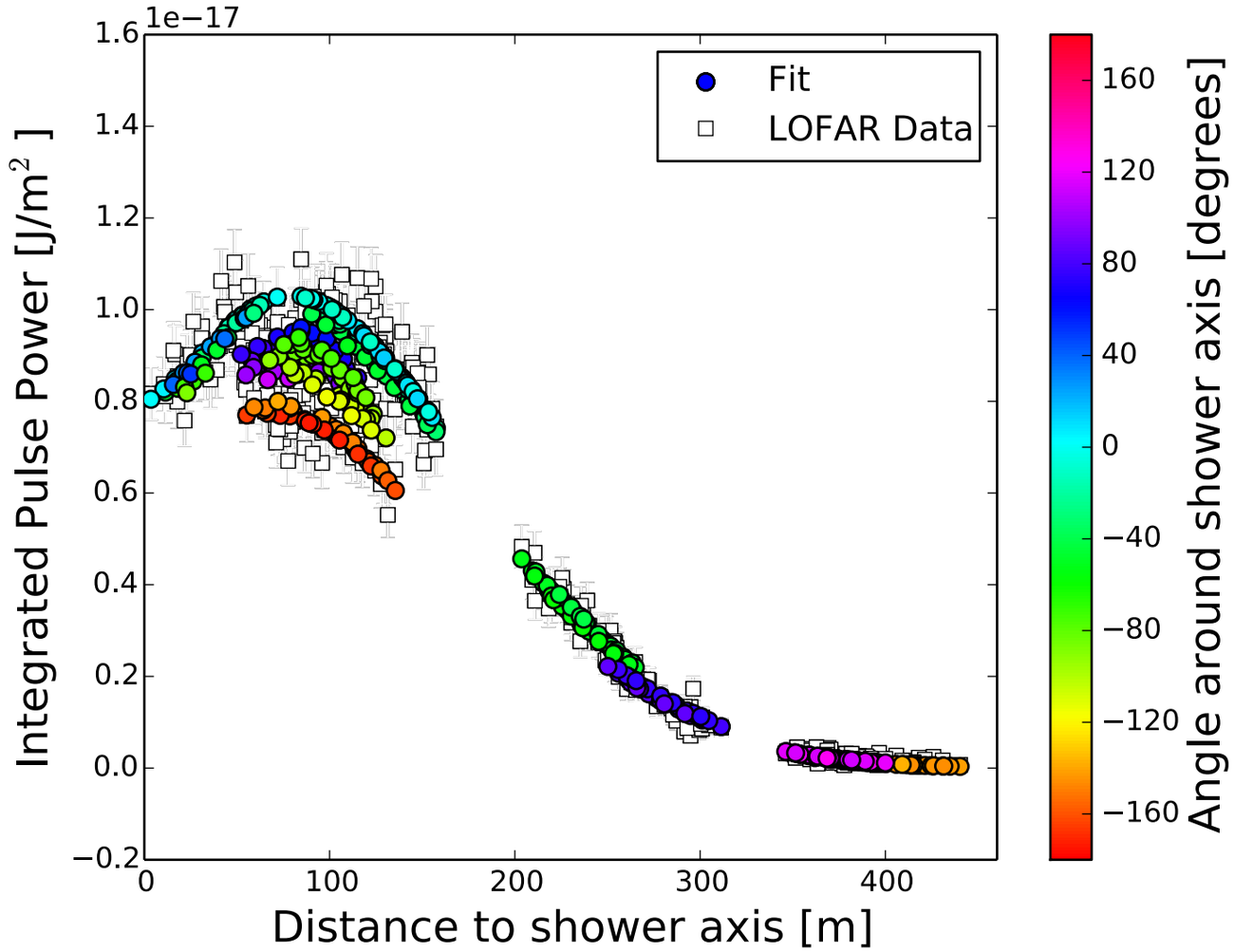

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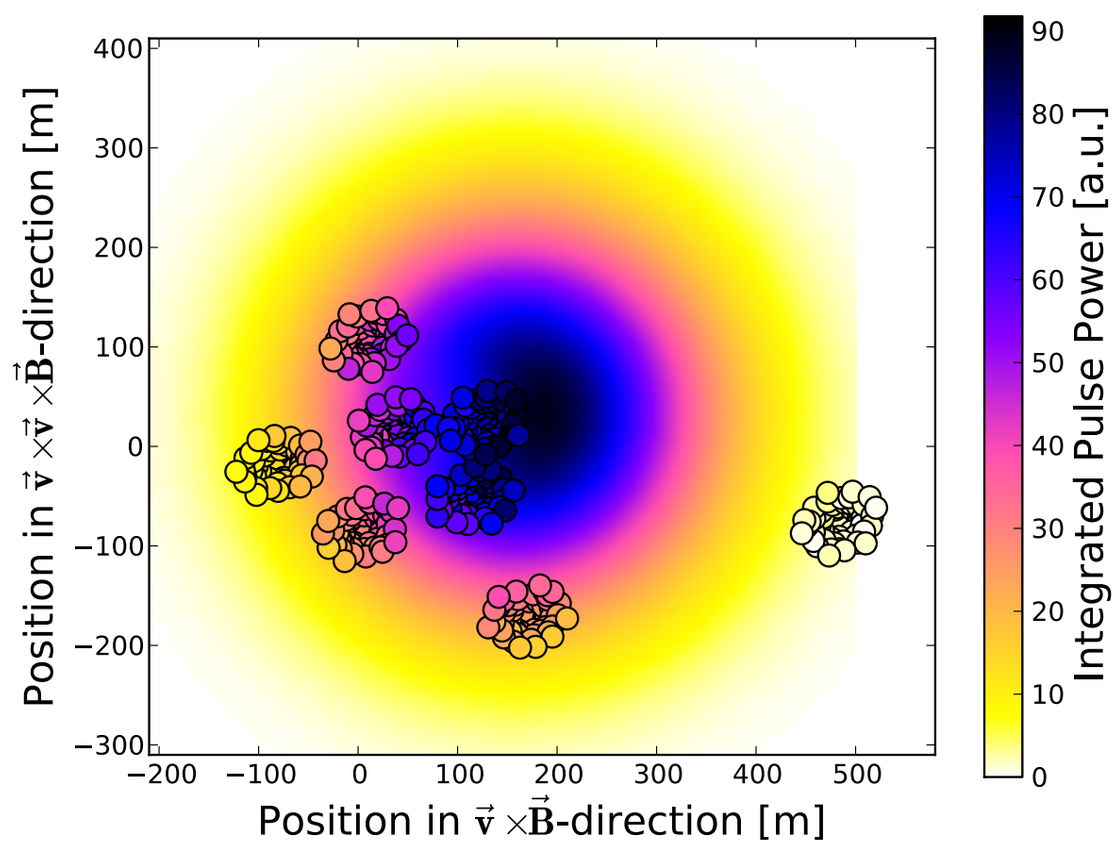
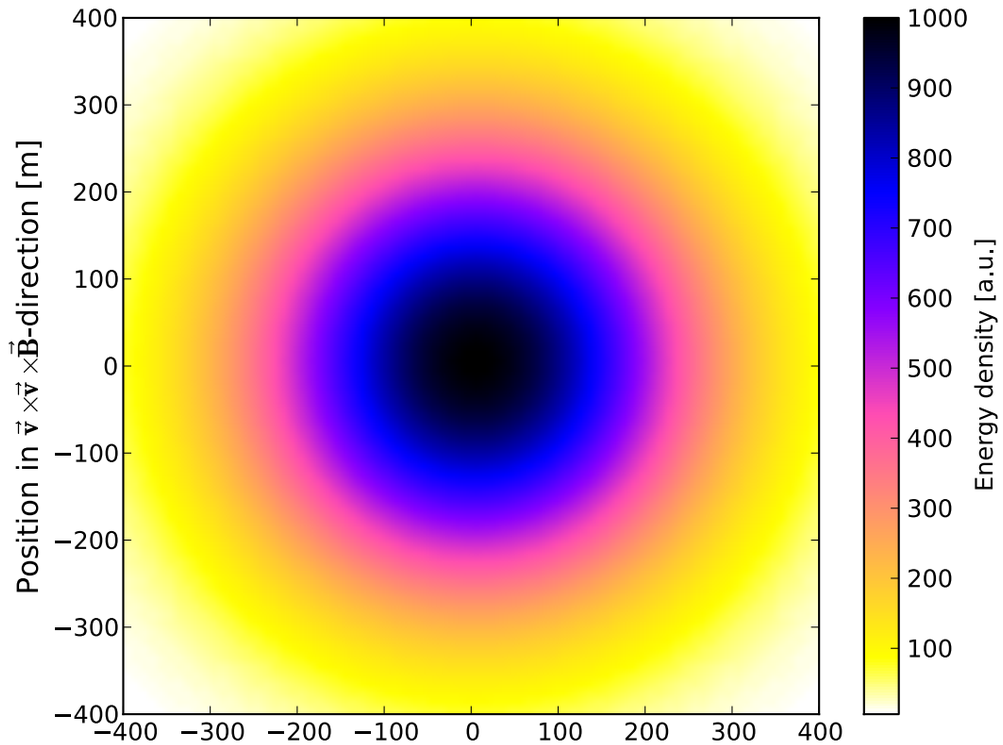
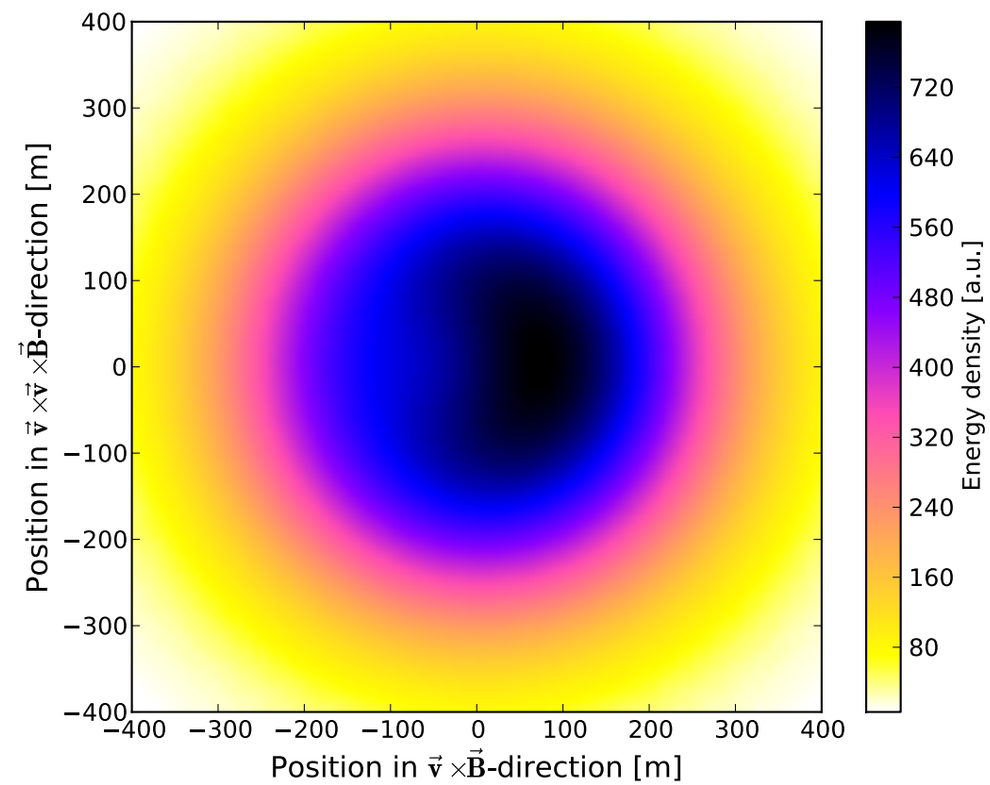
- Characteristic bean-shaped form



See also:
A. Nelles et al,. Astr. Part. Phys. 60, 13-24 (2014)
C. Glaser et al. (Auger Coll.), this session

The function





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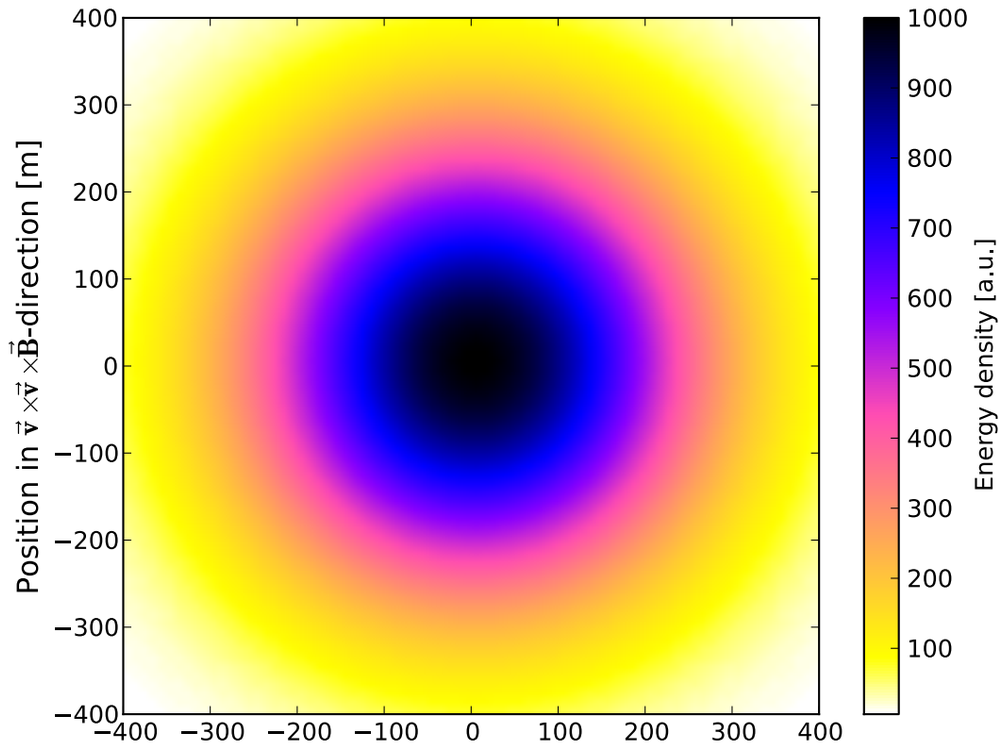

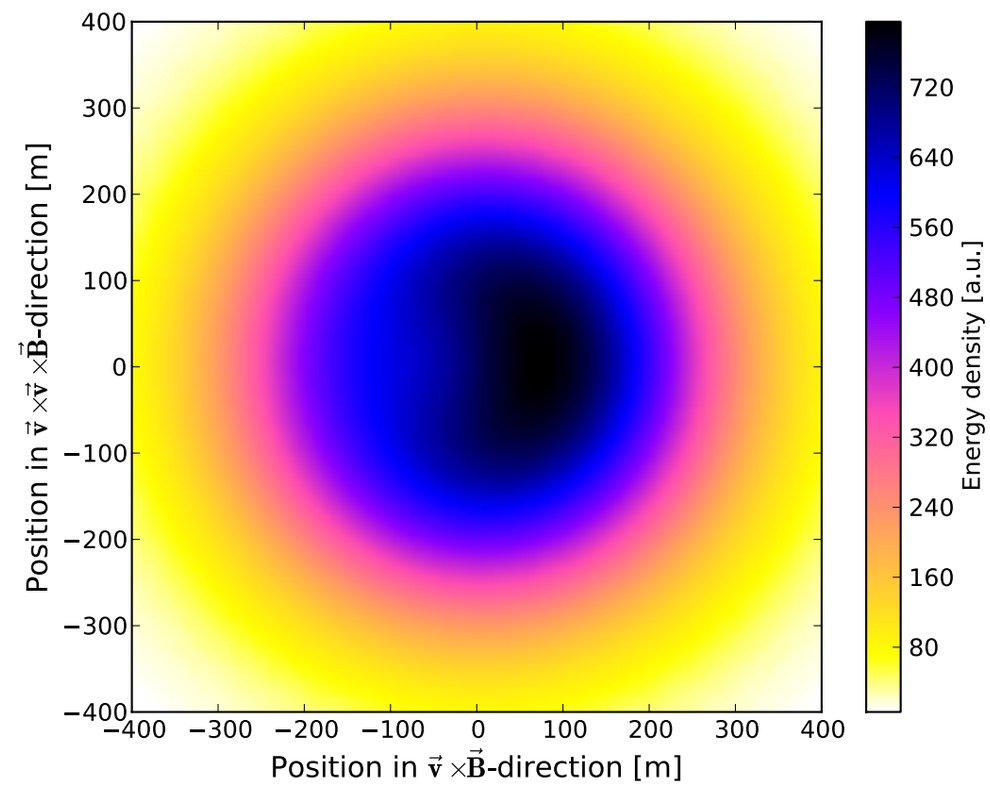

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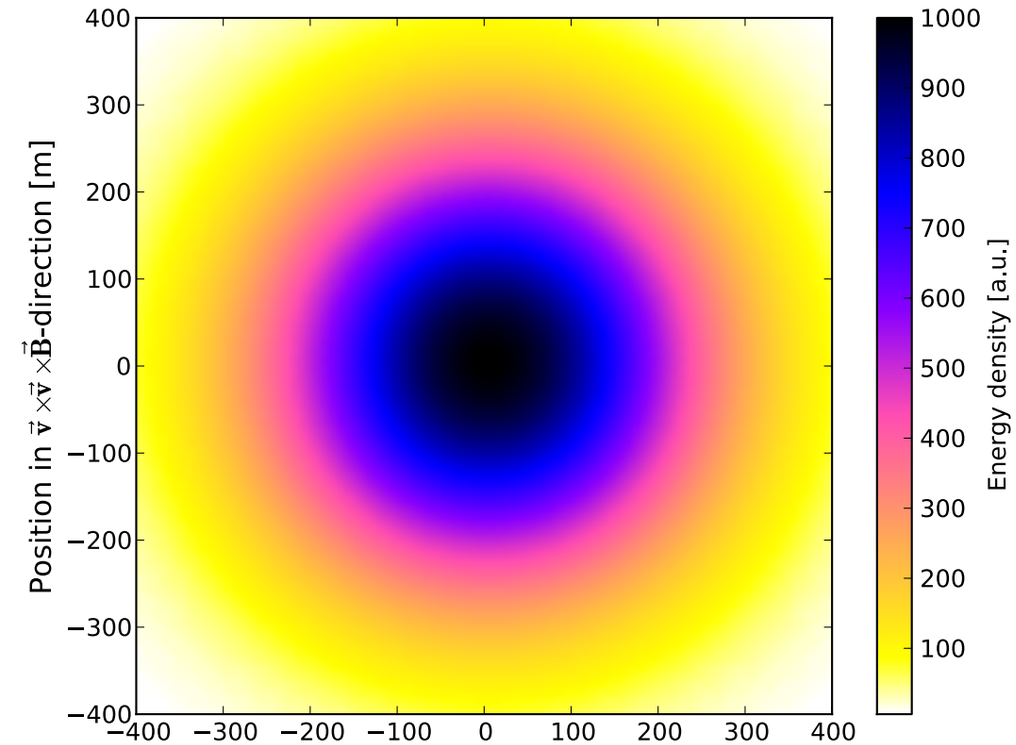
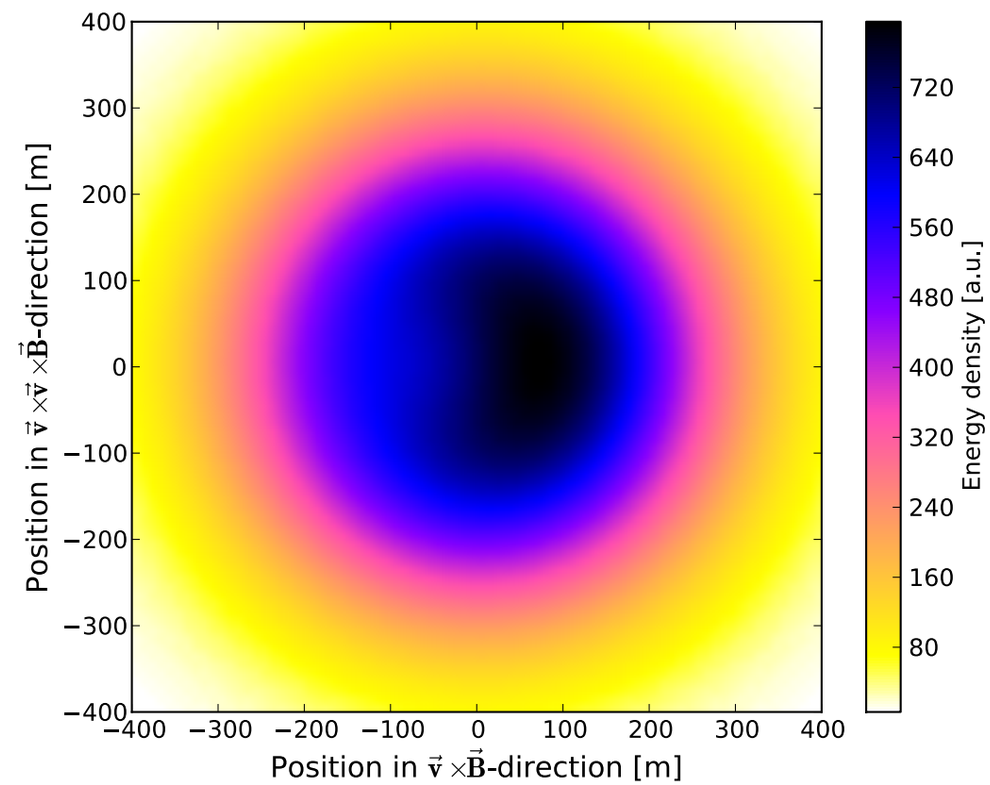
- Subtract second Gaussian, offset from first to obtain asymmetry





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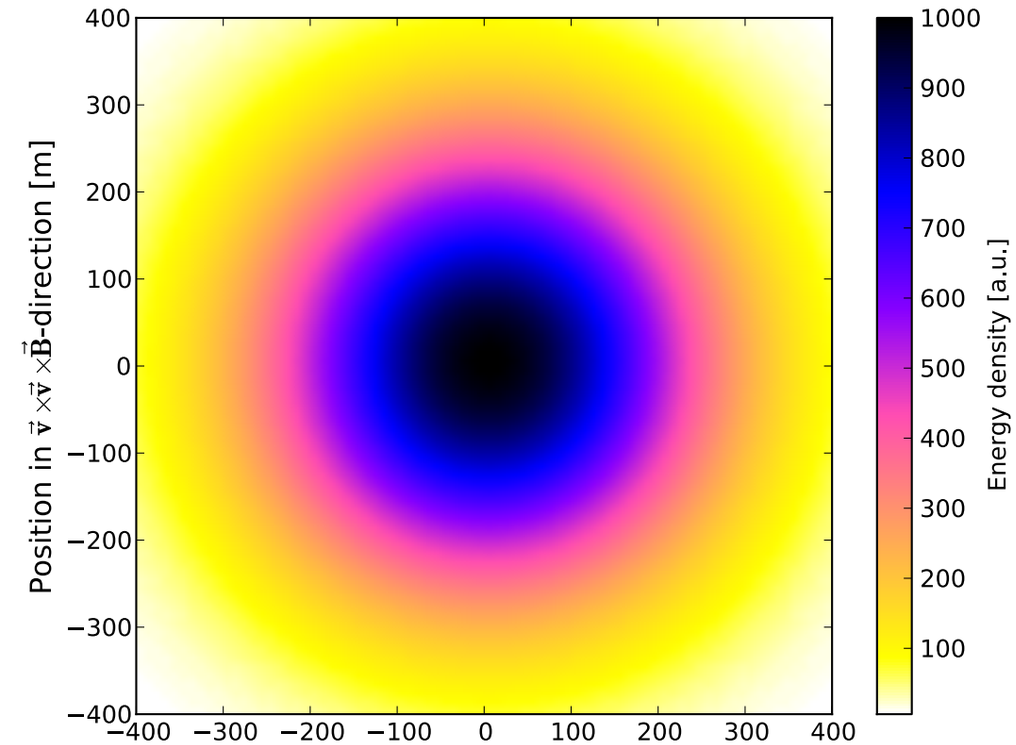

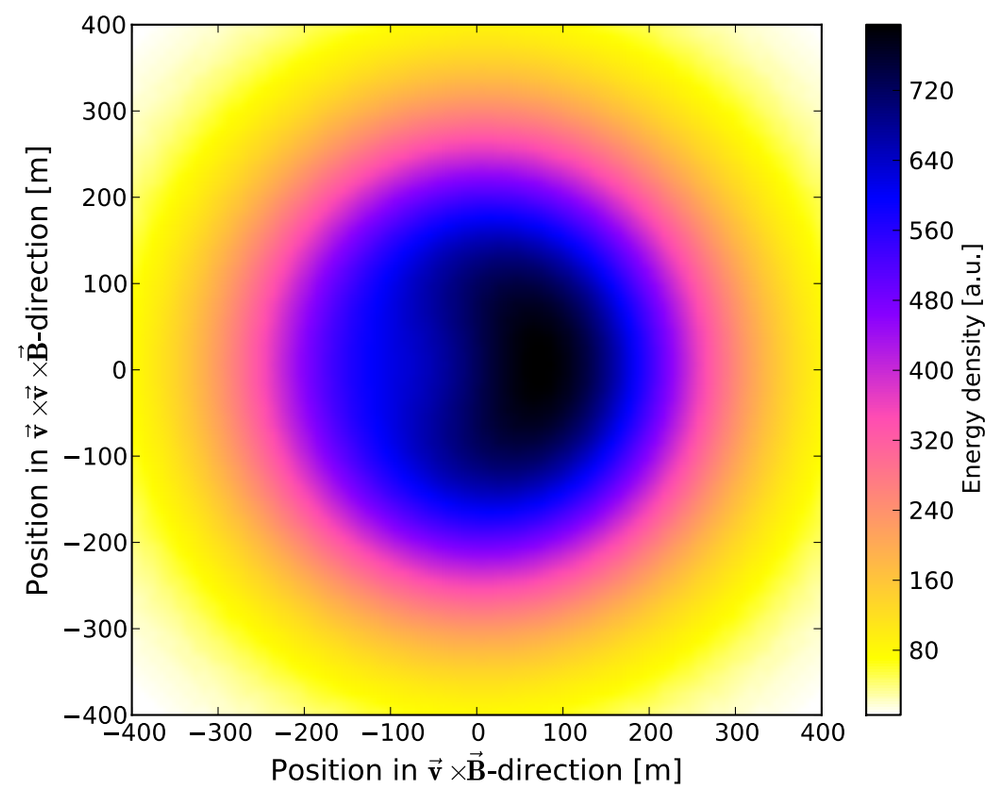

The function

- Eight free parameters too many for stable fit
- Physical free parameters
  - **Shower direction** (two parameters, determined from arrival timing)
  - **Shower axis position** (two parameters)
  - **Height of shower maximum** (one parameter)
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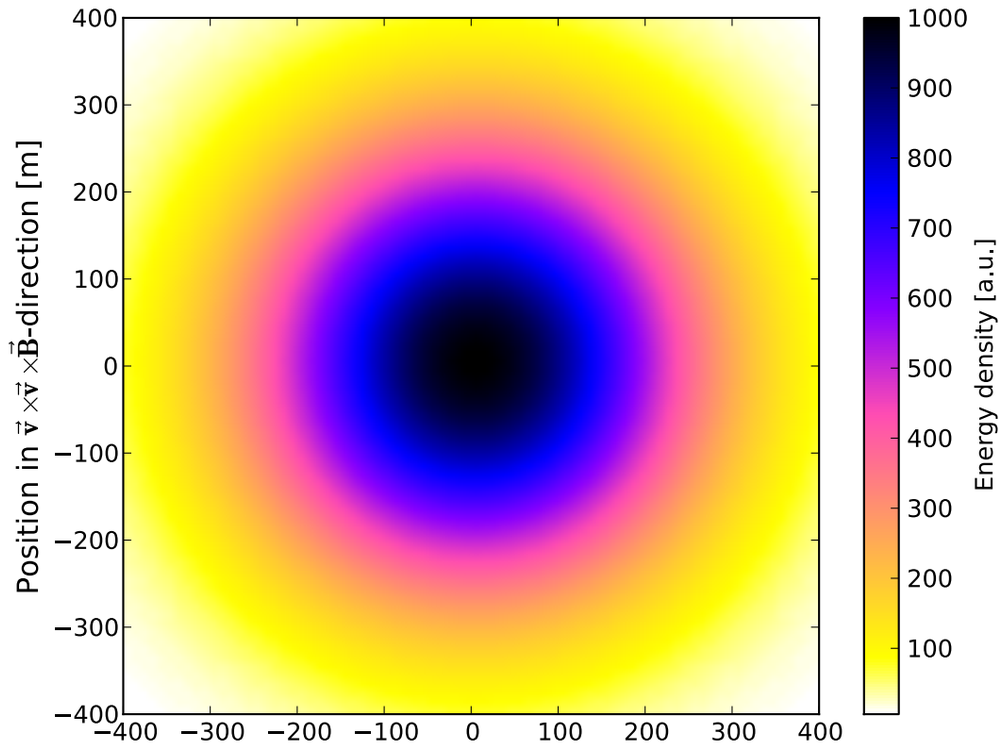
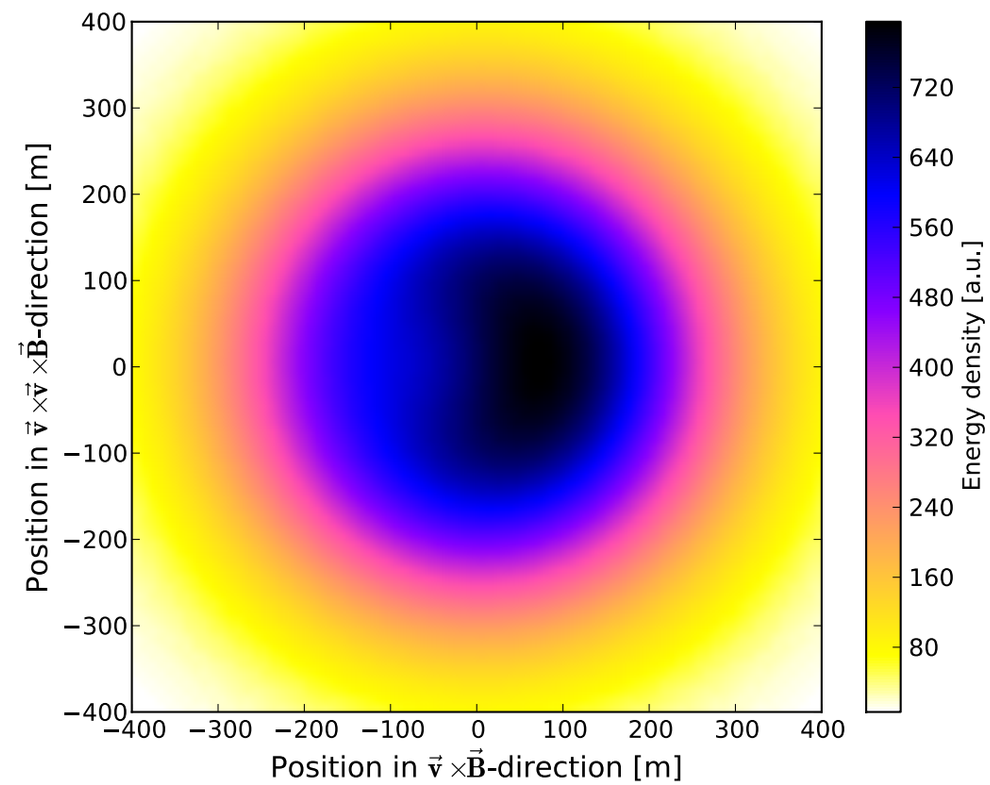
= four parameters for function





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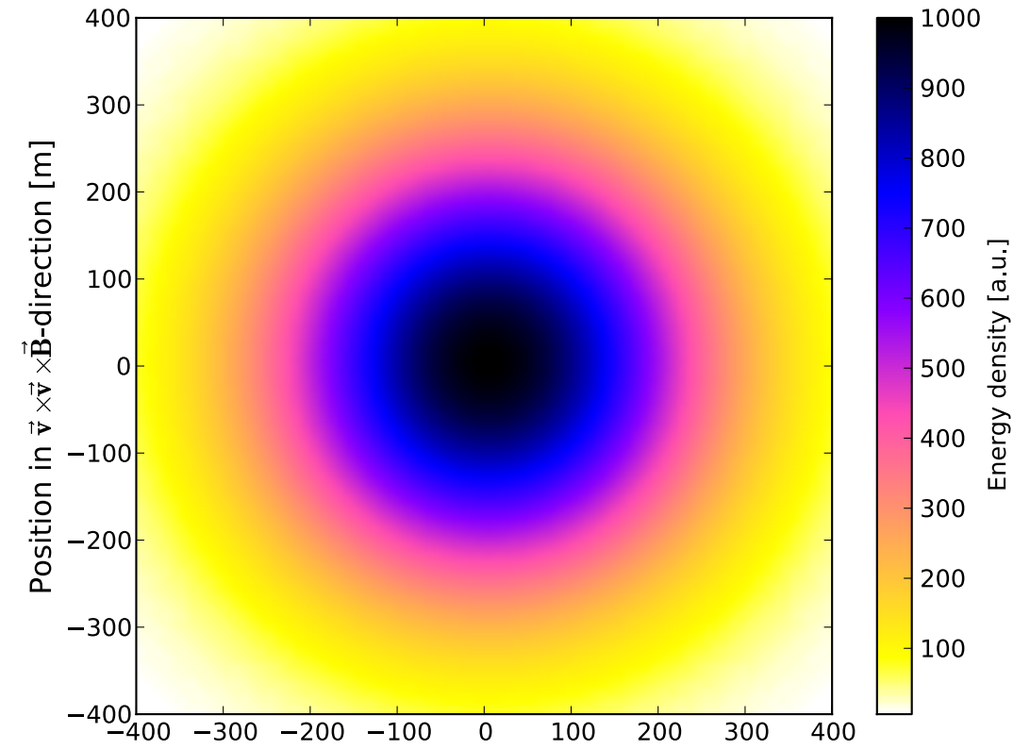

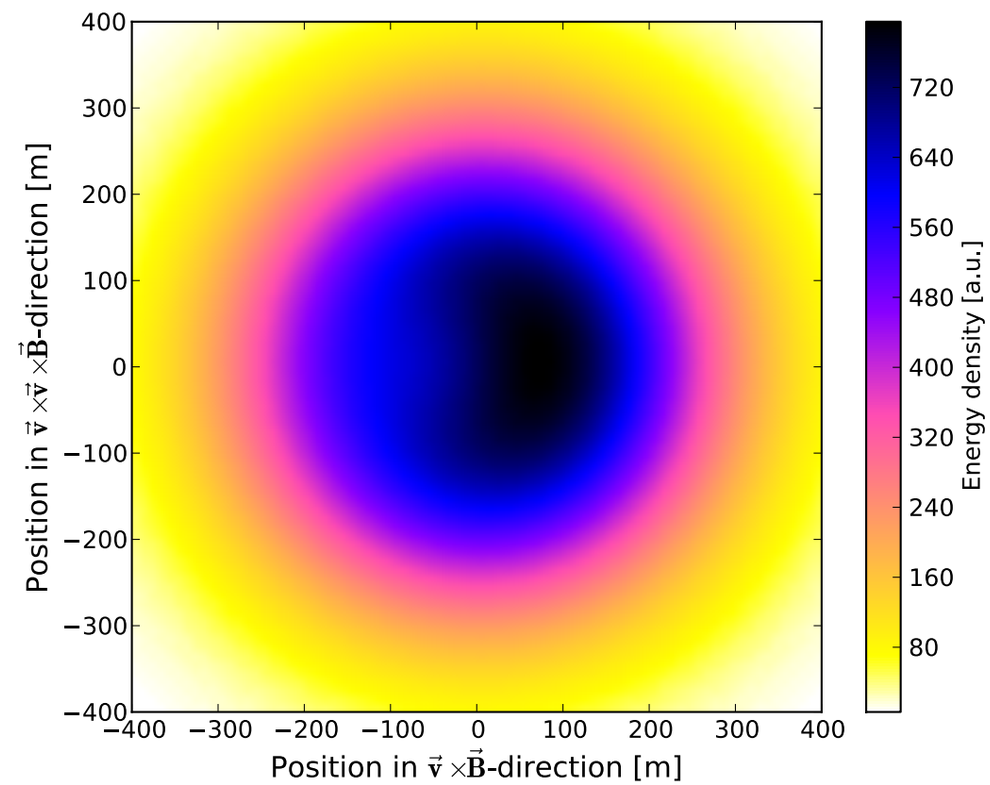

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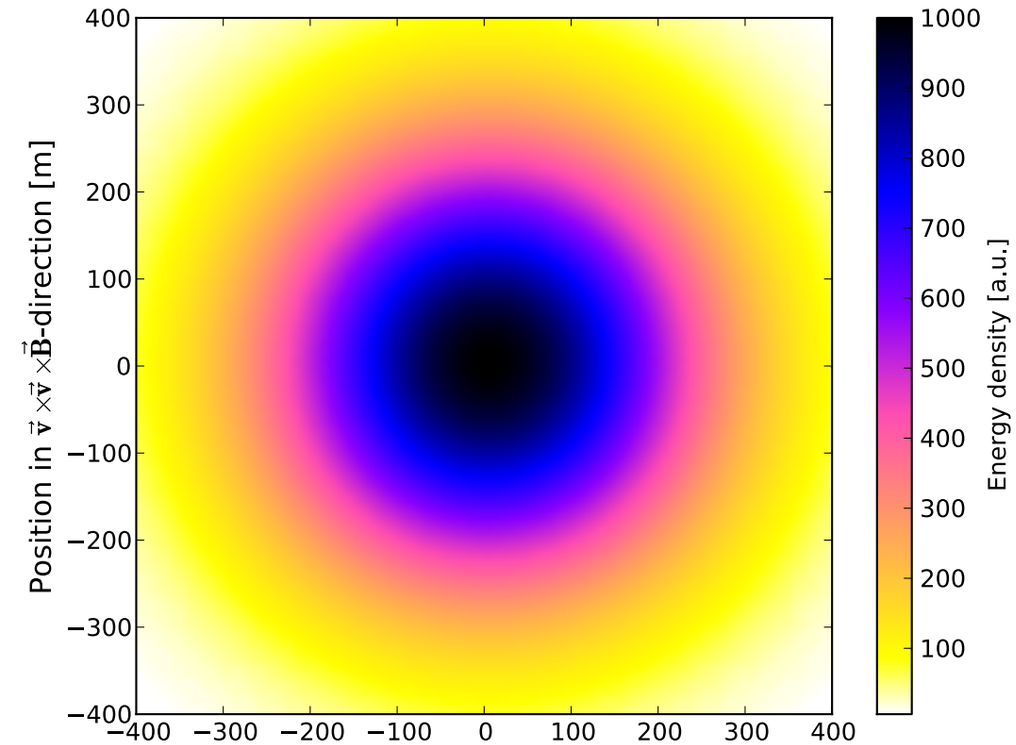

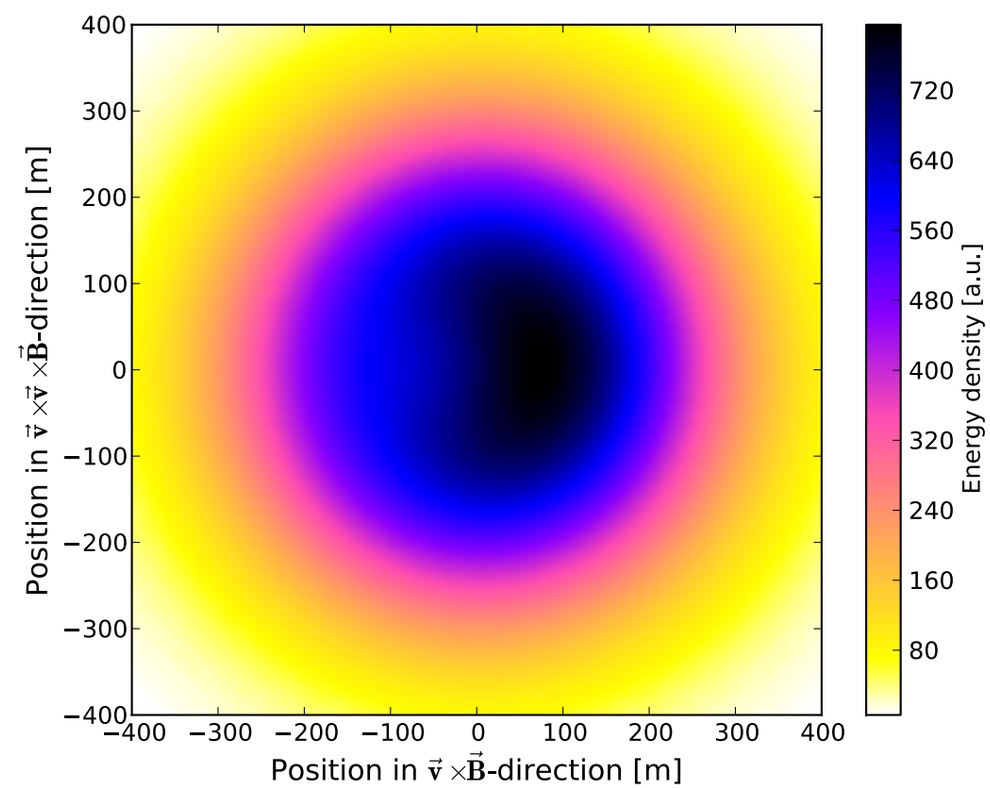

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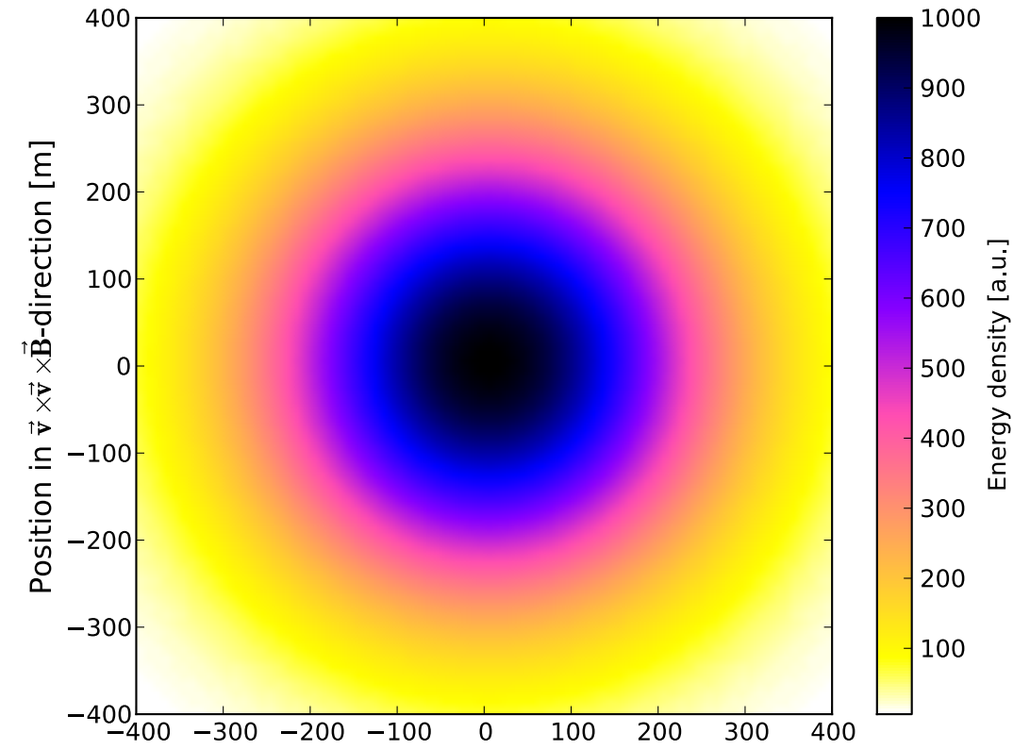

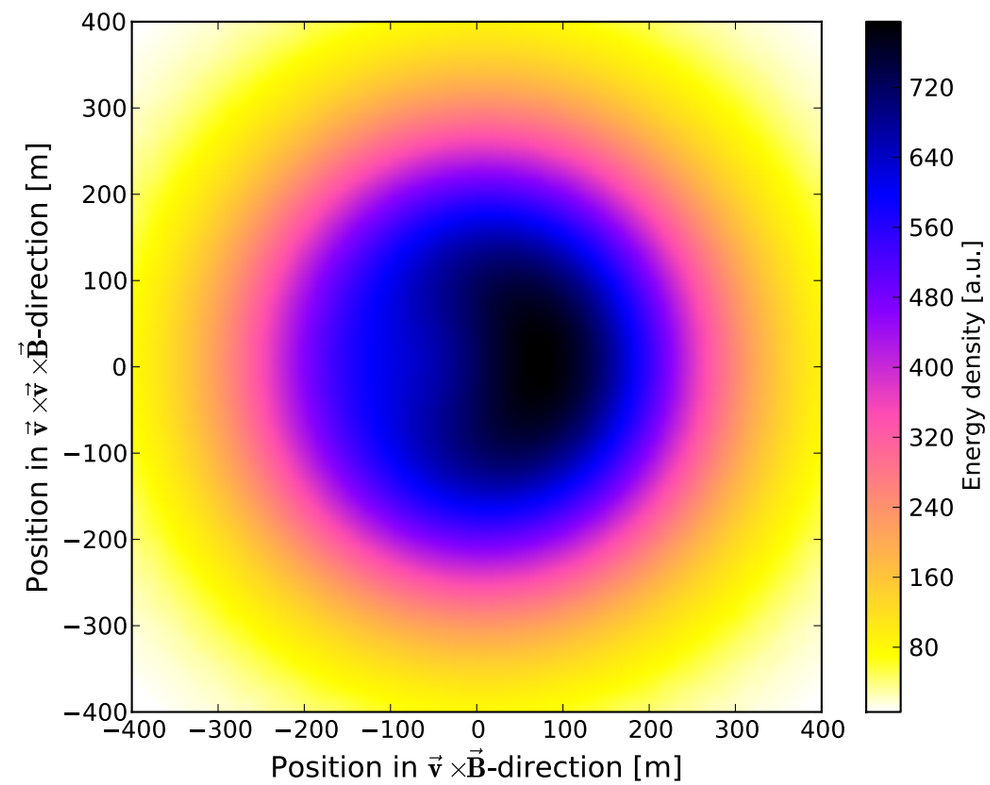

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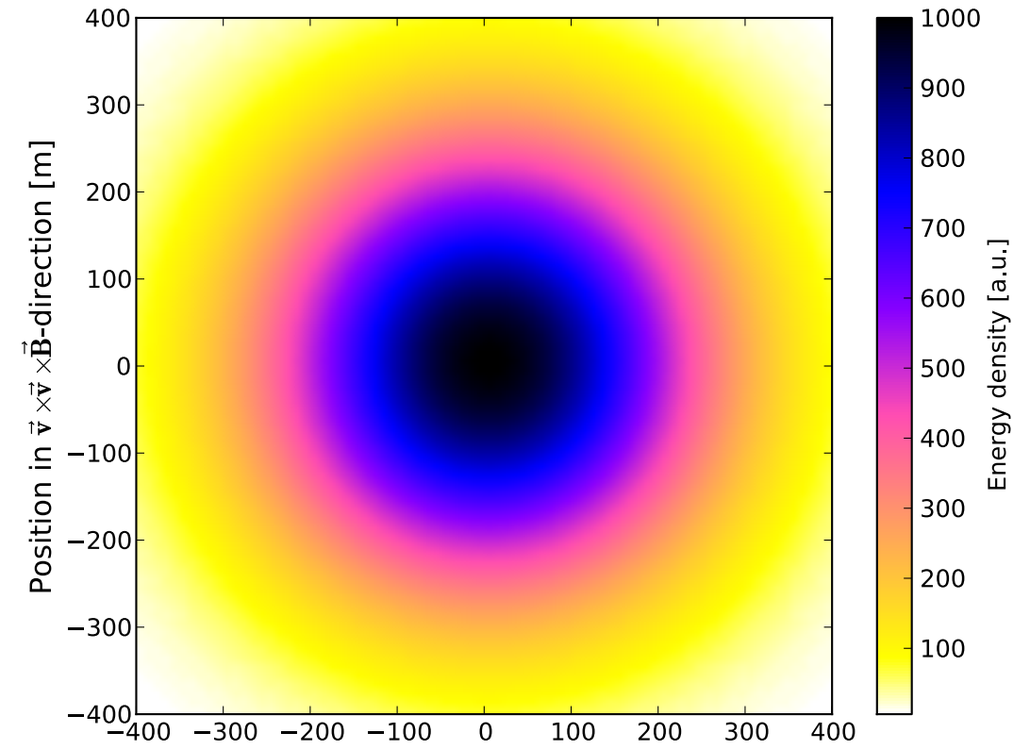

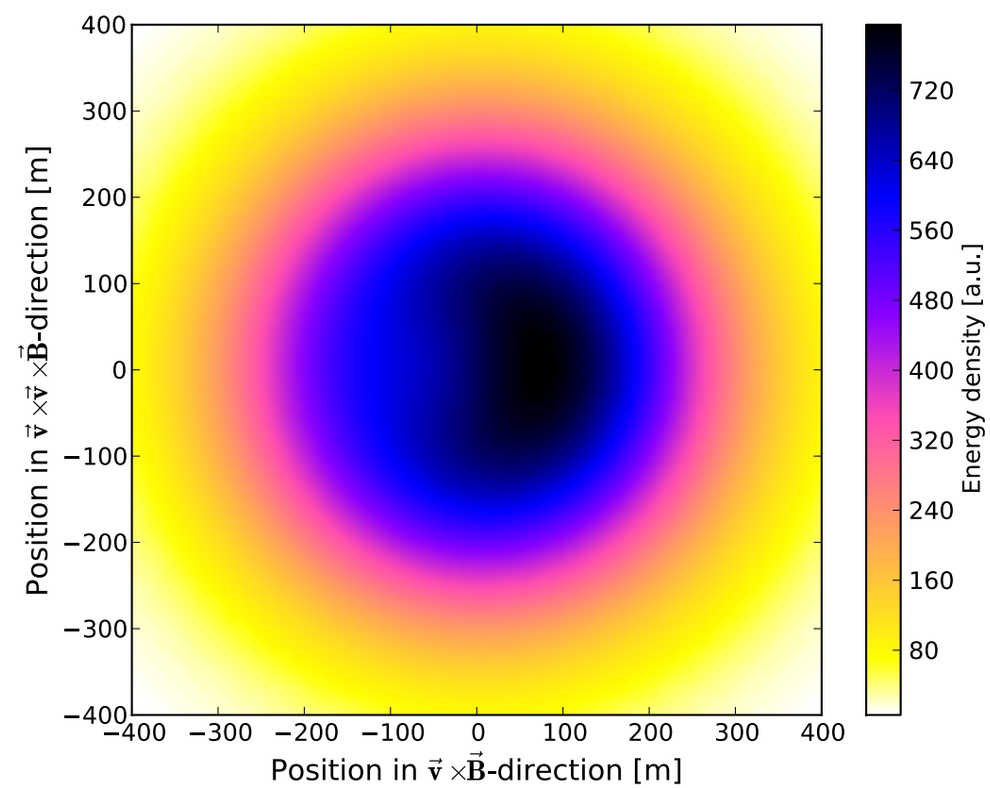

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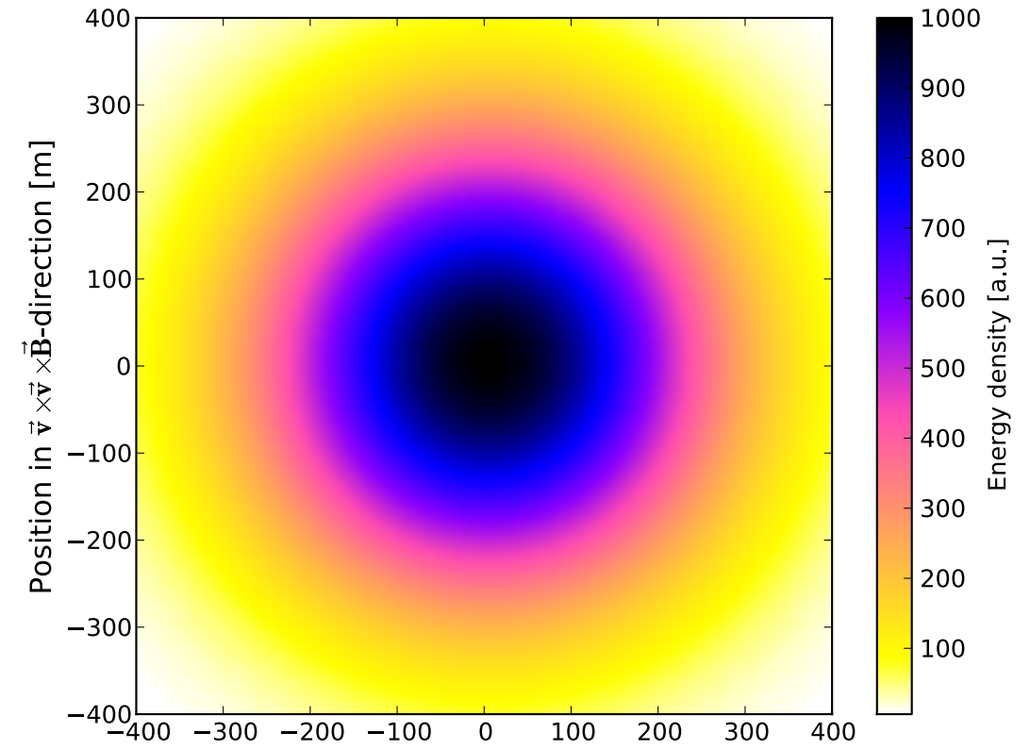

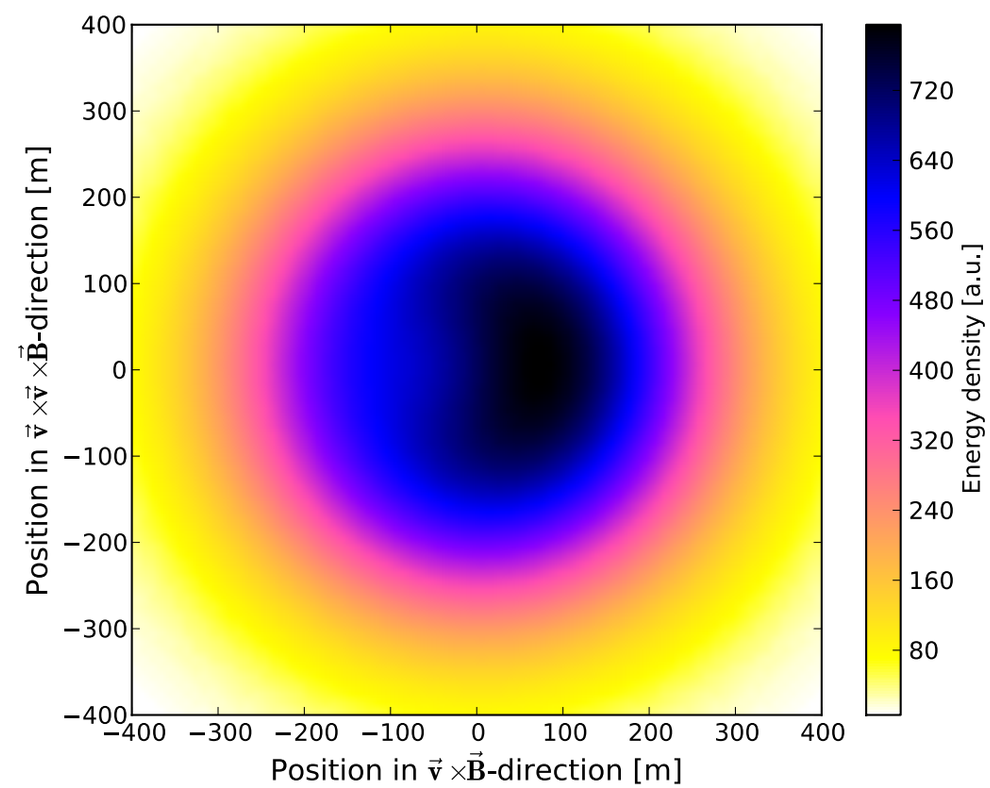

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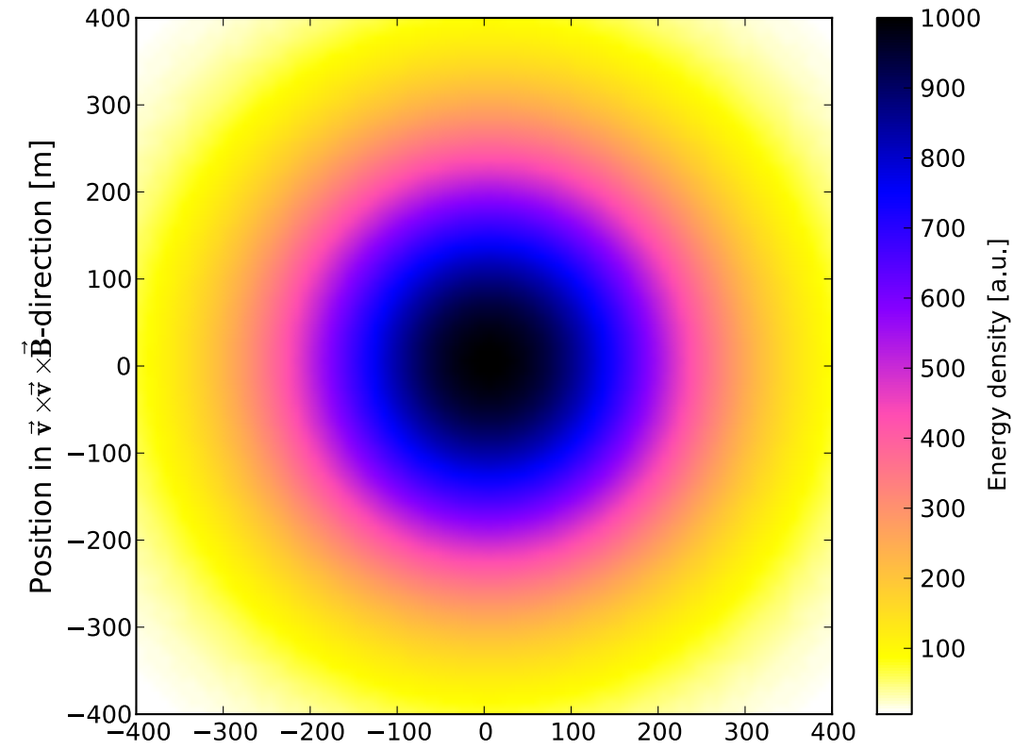
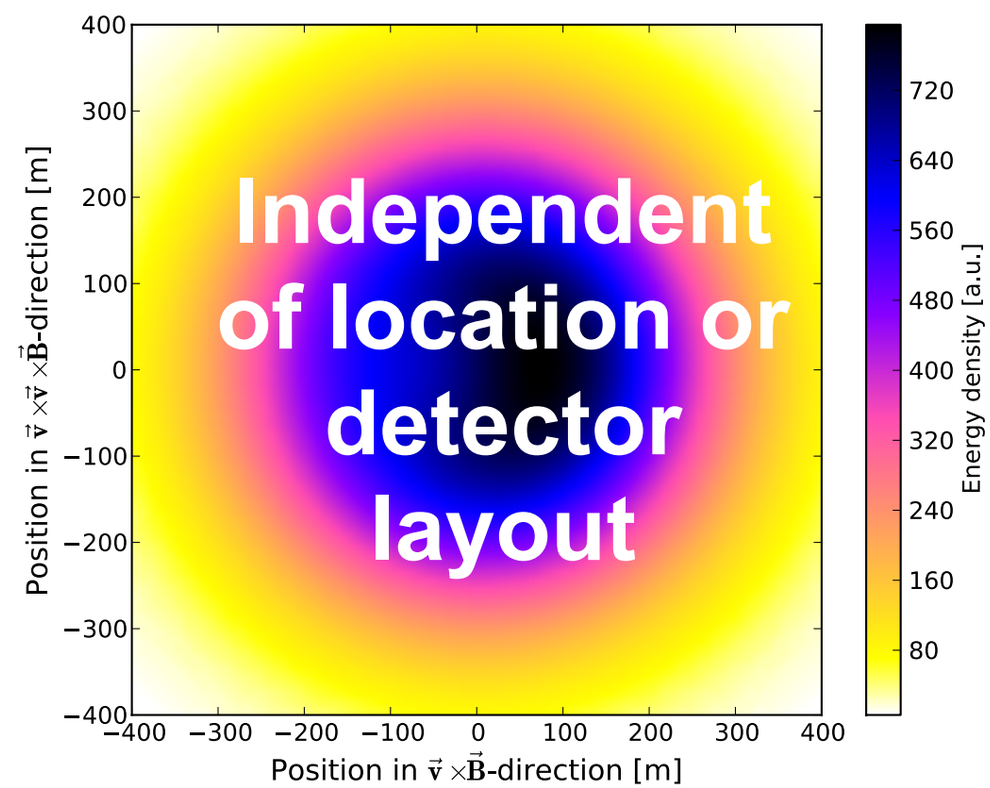
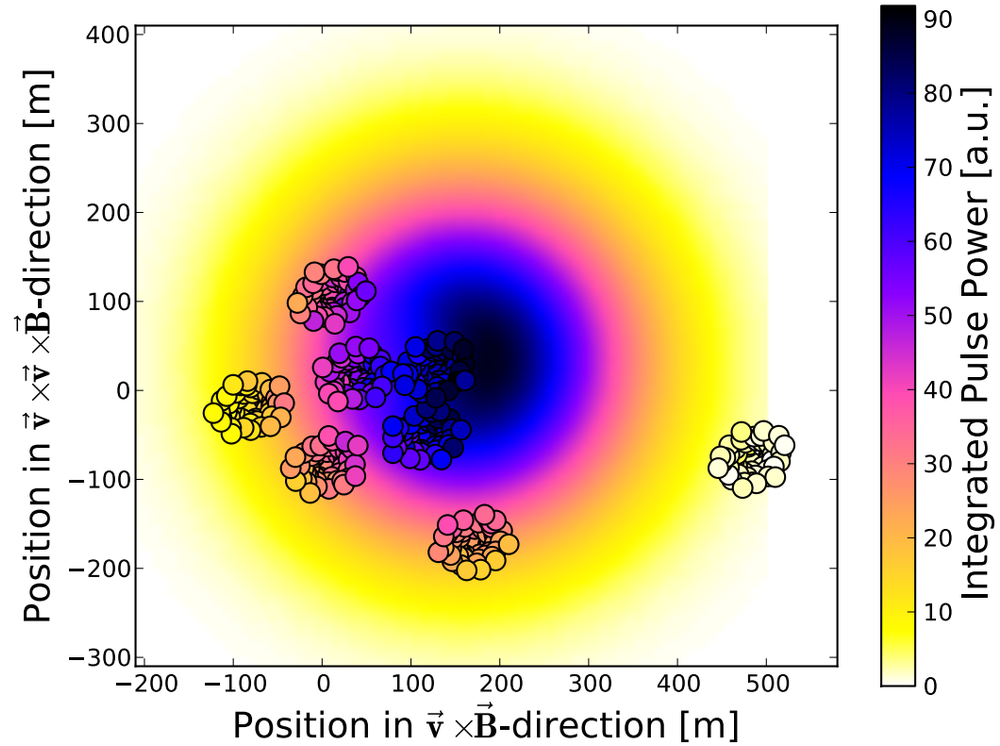




Reconstructing shower axis

- Shower axis determines location in array
- Center (NOT location at strongest signal) corresponds to shower axis
- Offset only in **vxB** direction



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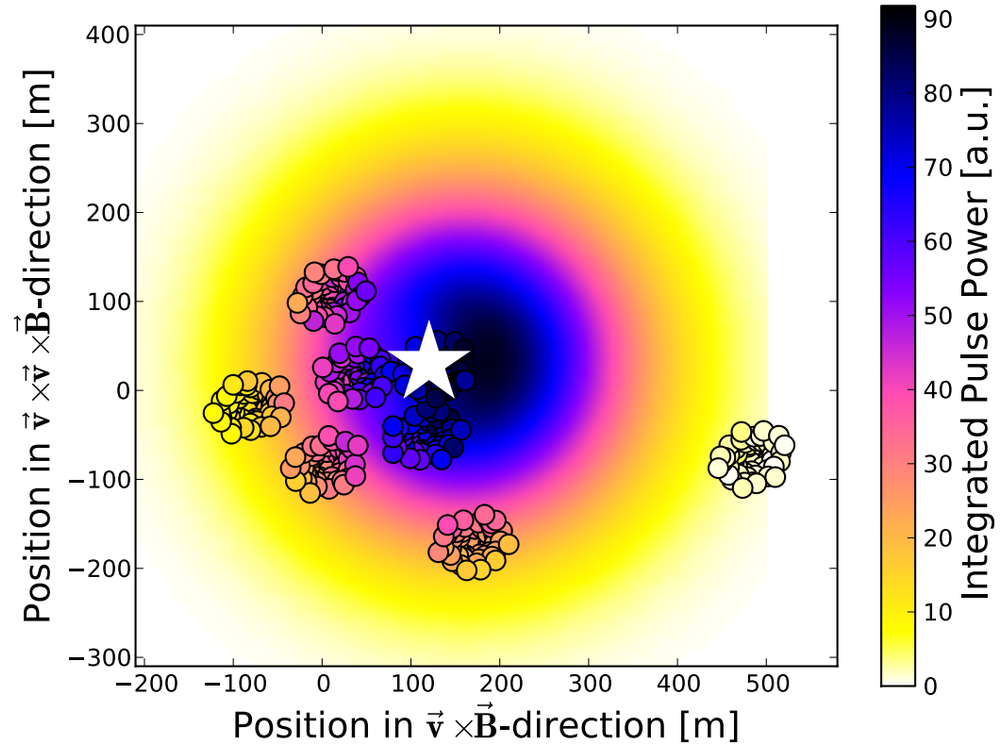

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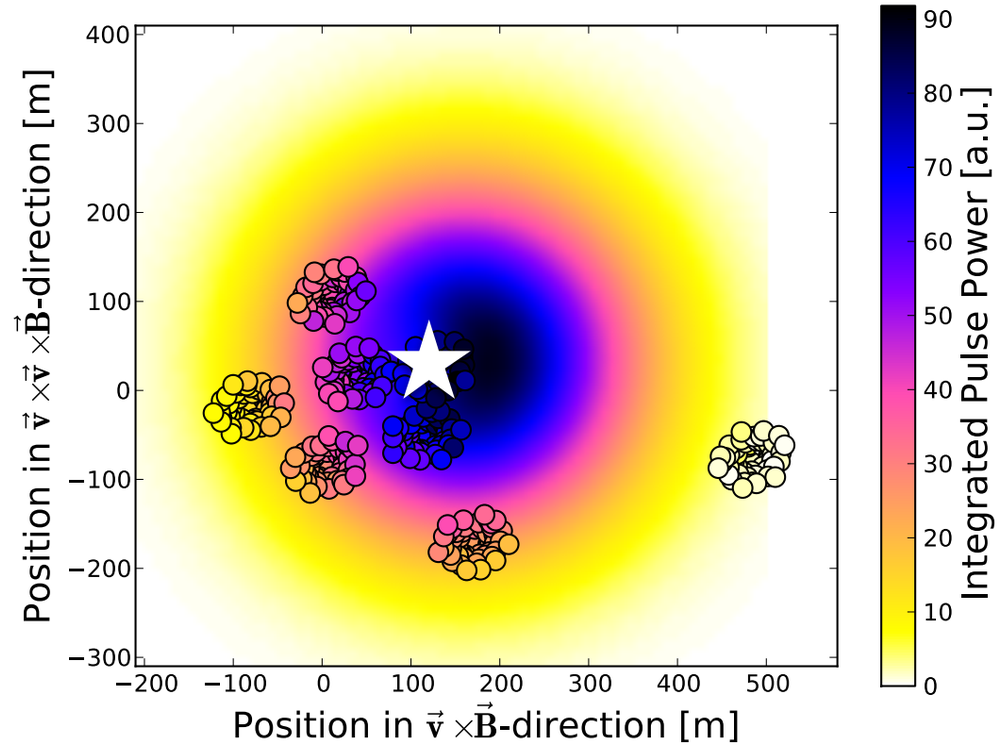
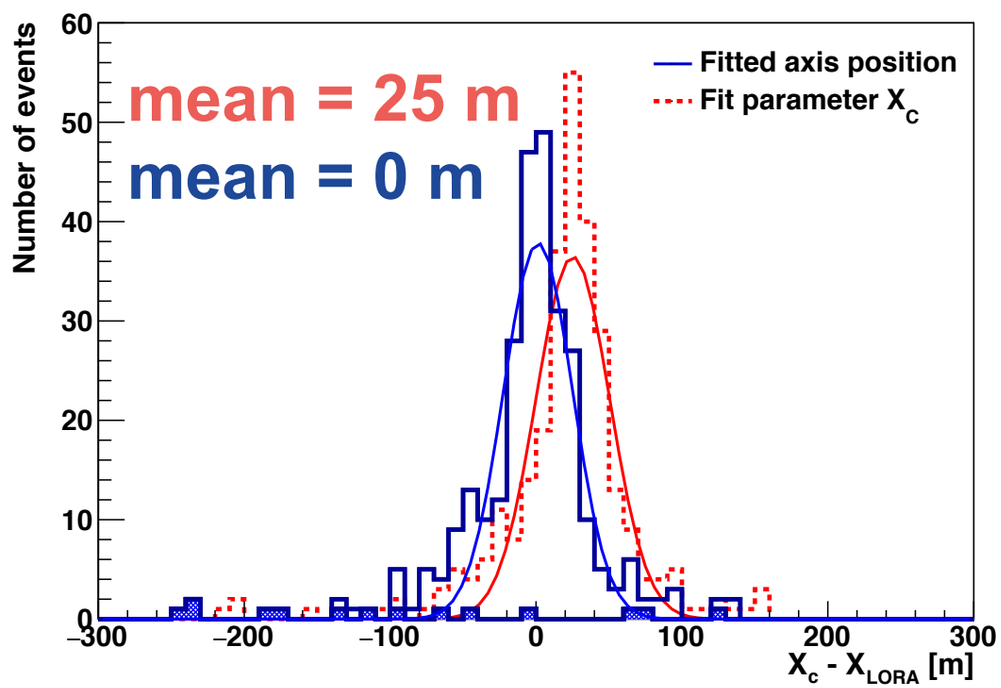
- Resolution of 15 meters for LOFAR with respect to scintillator array



Position in **v**x**B** direction



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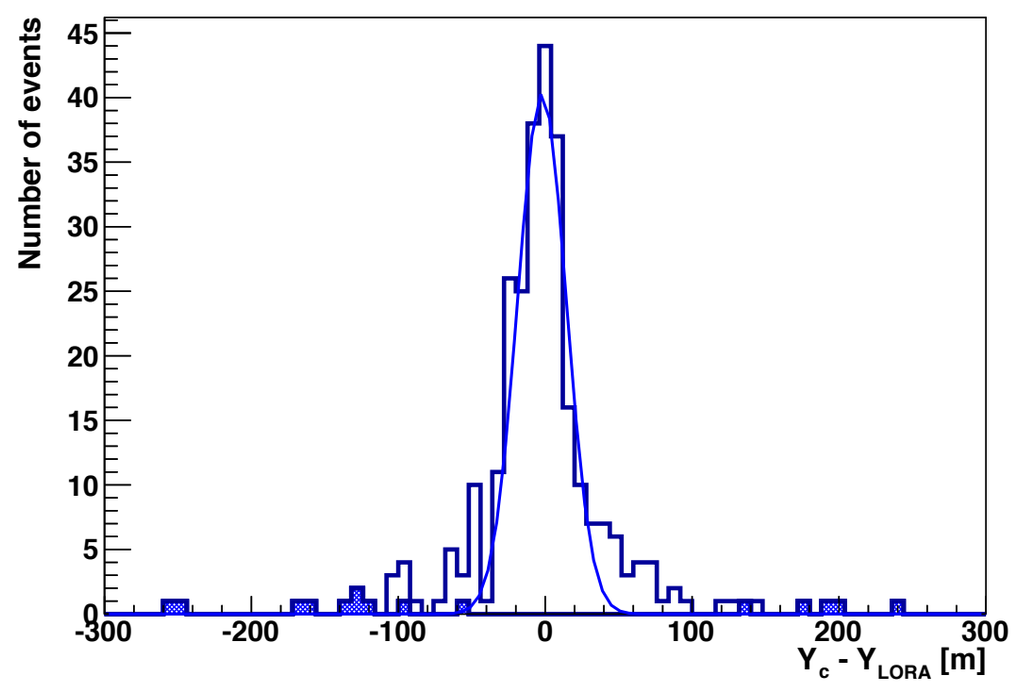

A. Nelles et al. JCAP05(2015)018

Reconstruction of the Energy

- Radio signal is coherent
  = amplitude scales with
  number of particles
  = scales with energy

*see **many** papers before this*

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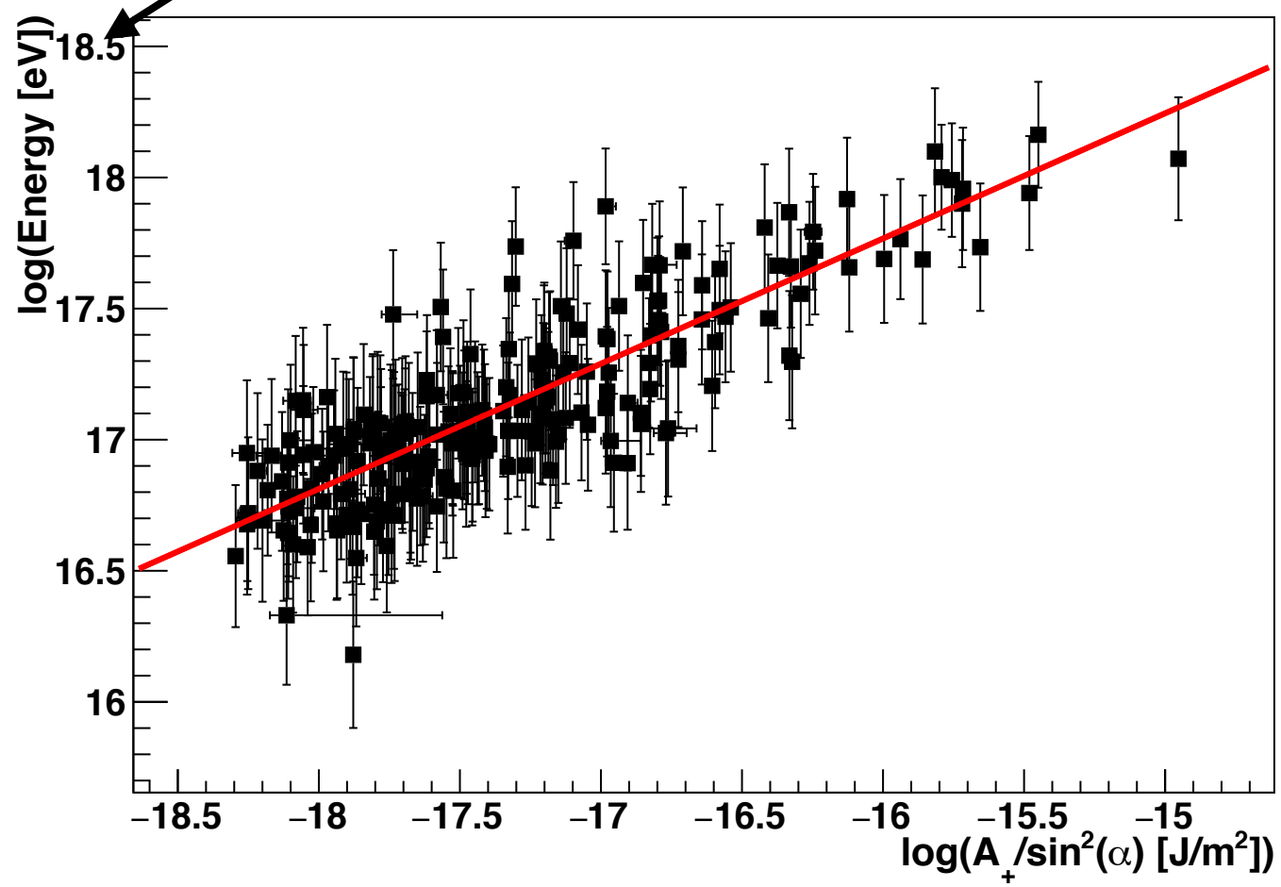
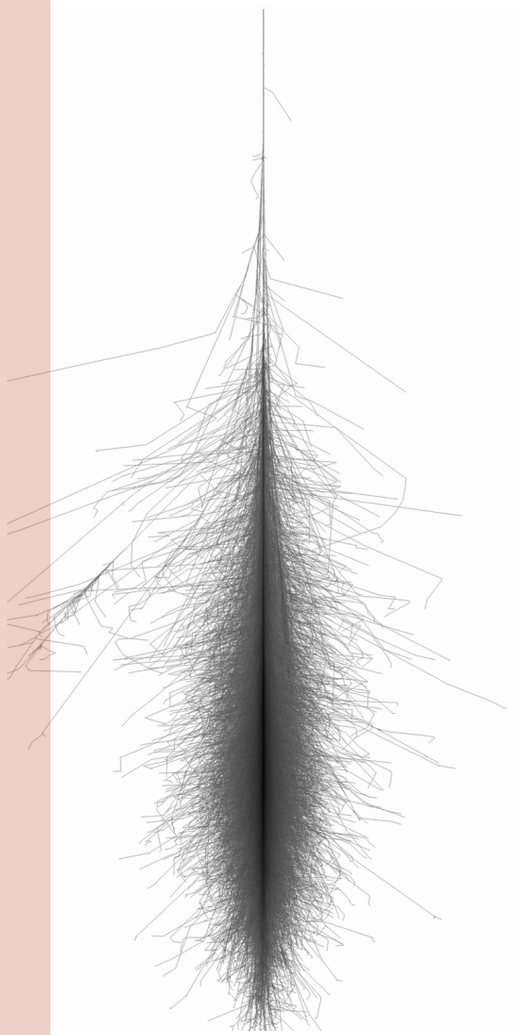
- e.g. scaling parameter A_+ of function shows clear correlation with energy
- Resolution of ~30%, dominated by resolution of particle array at LOFAR

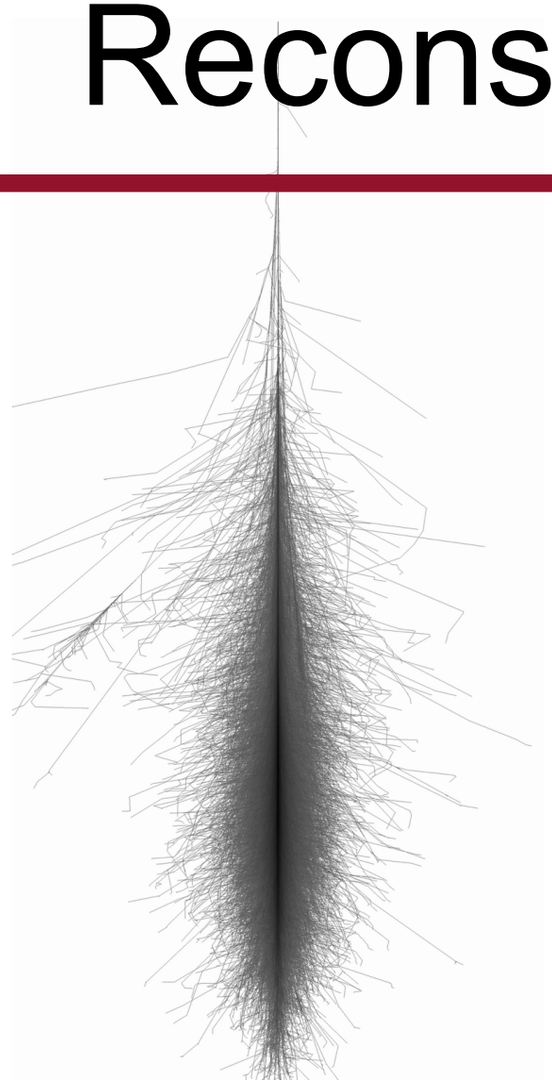
Energy from particle detectors

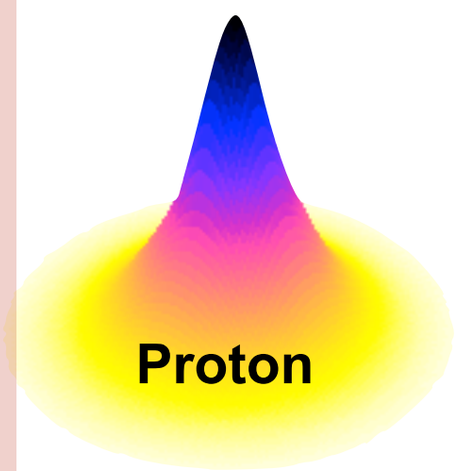


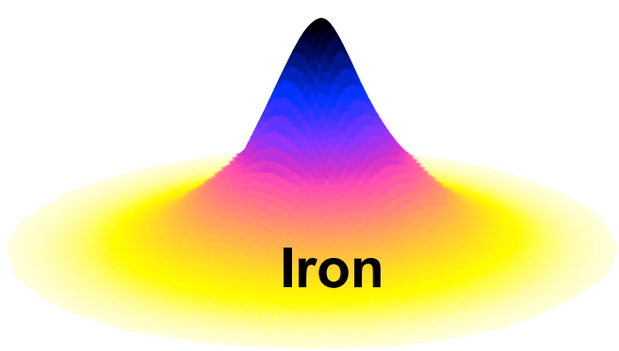
Fit parameter corrected for magnetic field angle
now calibrated, see Hörandel et al. PoS(ICRC2015)662

Reconstruction of X_{max}

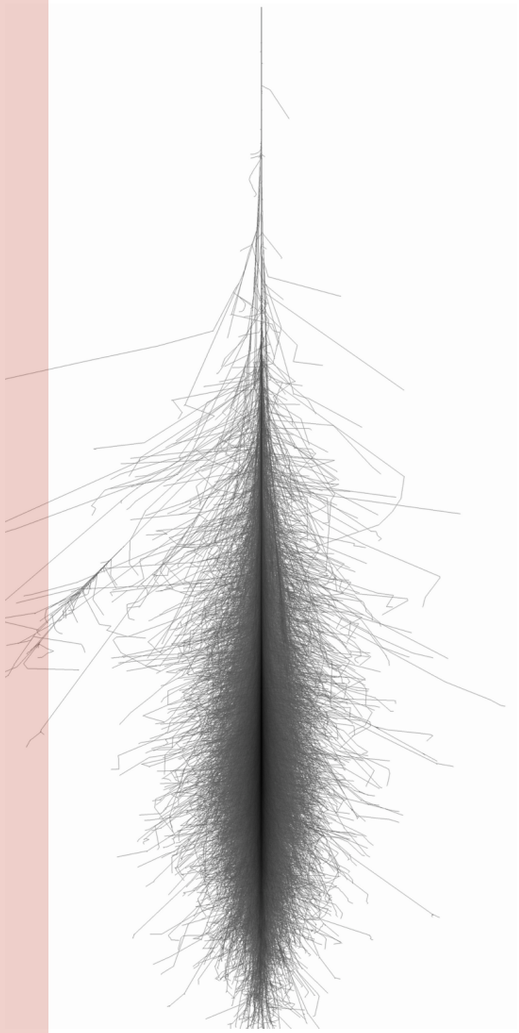


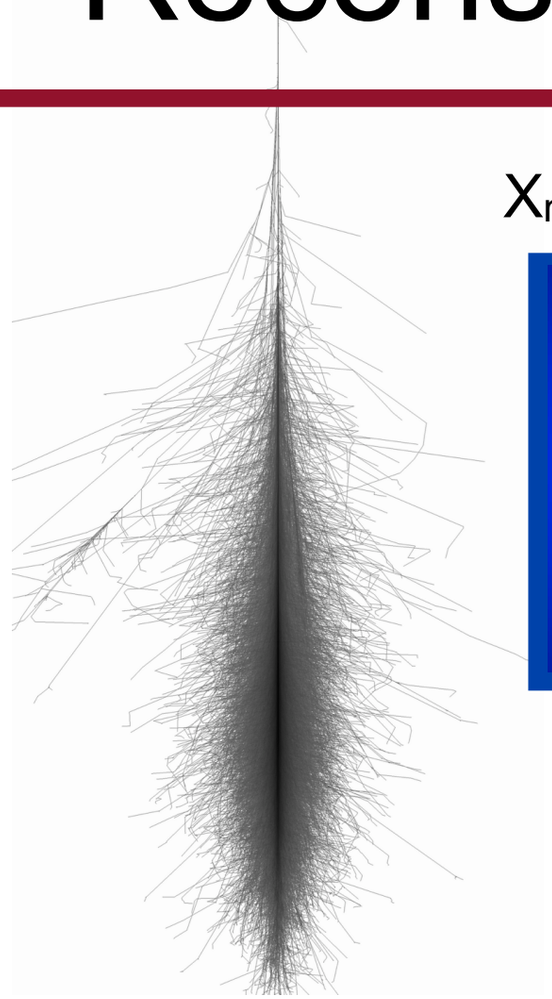




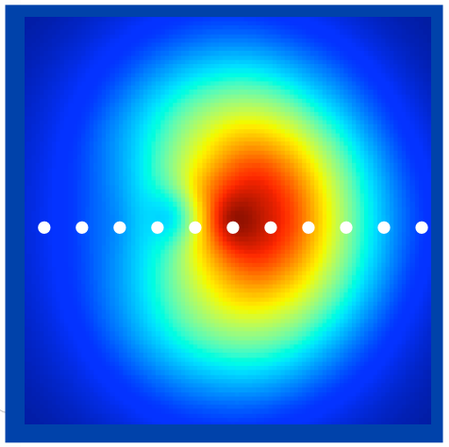


Reconstruction of X_{max}

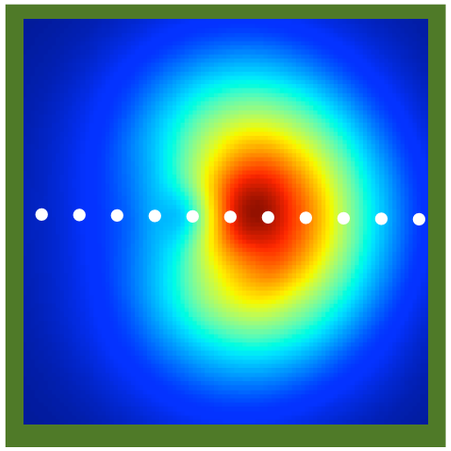




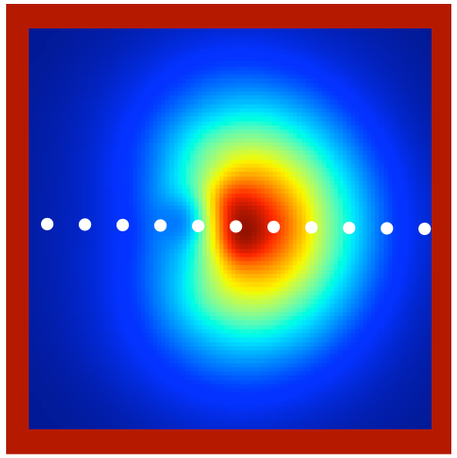
X_{max} ~ 600 g/cm^2

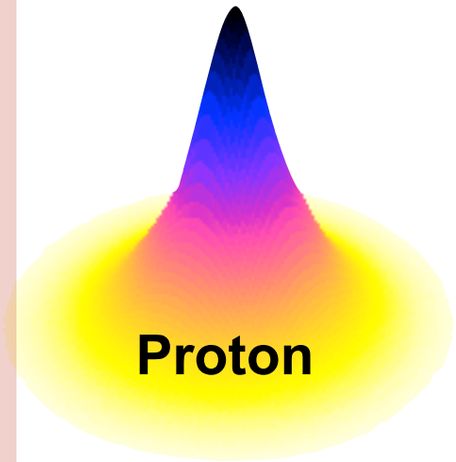


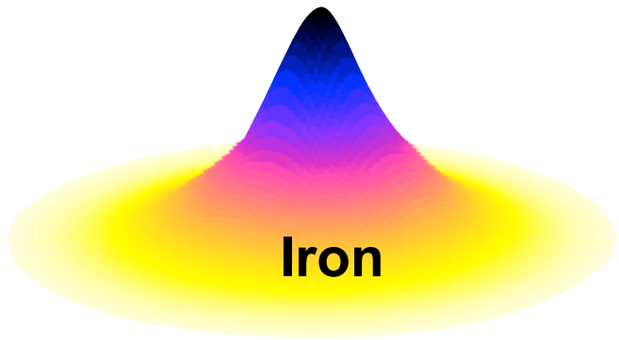
650 g/cm^2



700 g/cm^2







- Size of footprint is determined by distance to the emission point since radio signals are not attenuated in the atmosphere
- Correlation with **distance to X_{max}**

$$D(X_{\max})[\mathrm{g/cm^2}] = X_{\mathrm{atm}}[\mathrm{g/cm^2}]/\cos(\theta) - X_{\max}[\mathrm{g/cm^2}]$$

Reconstruction of X_{max}

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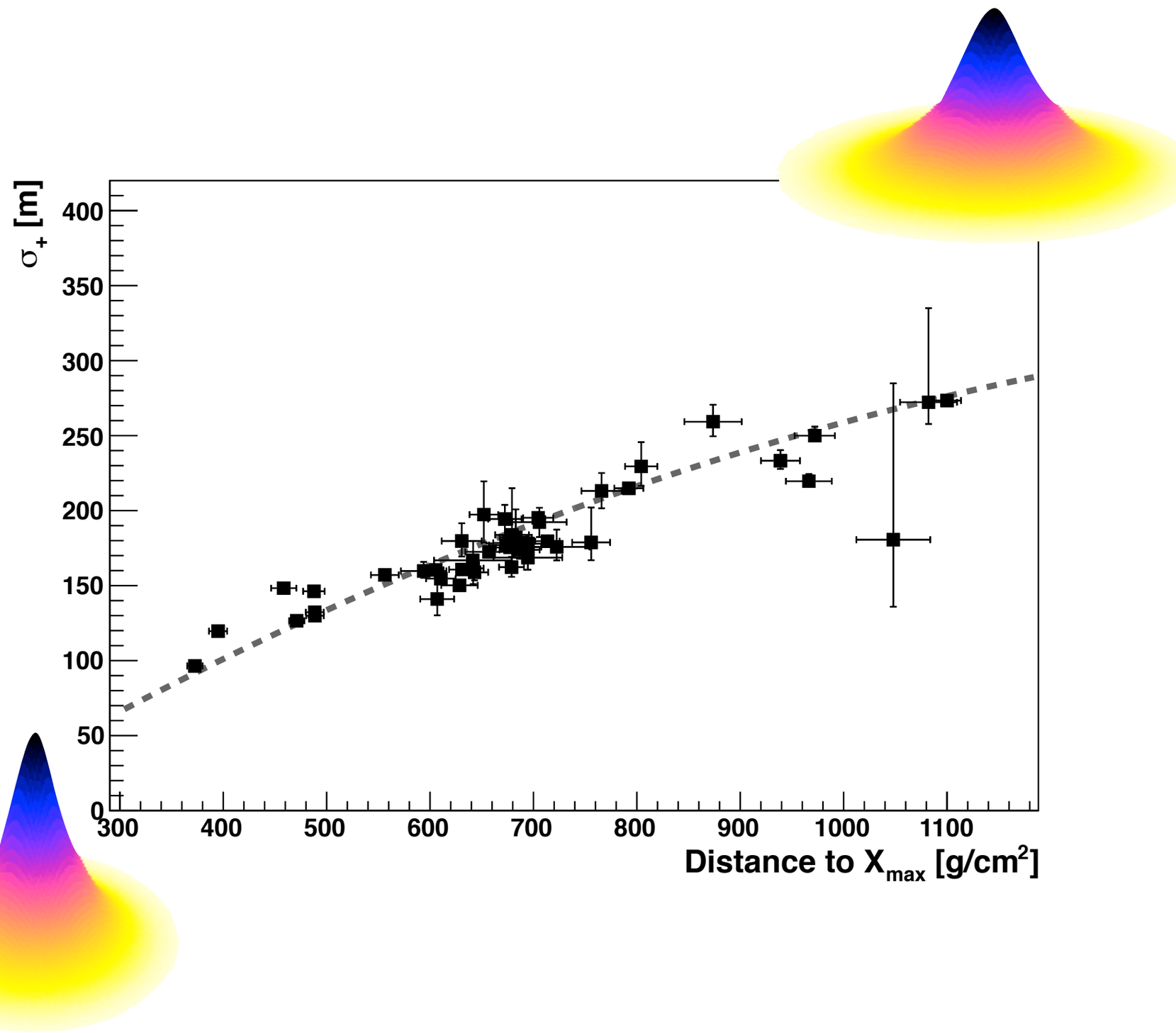

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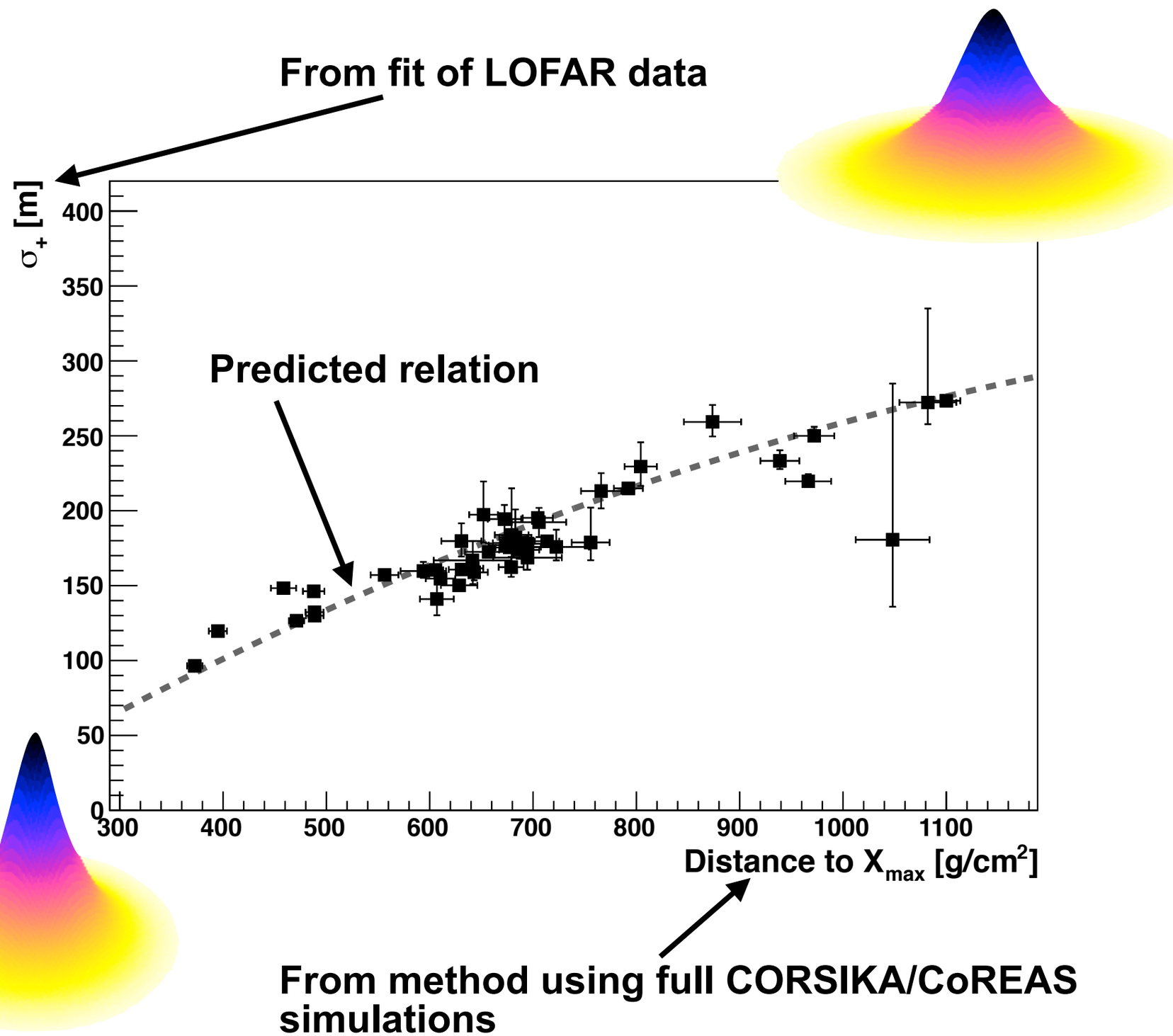

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Conclusions

General radio lateral distribution function

- Based on CoREAS simulations:
- Four free parameters: **energy, X_{max}, shower axis position**
- Shape parameters dependent on magnetic field and height above sea-level

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General radio lateral distribution function

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Function is easy to use and suitable for all radio arrays

- Shape is found at all locations
- Best correlating quantity to energy and constants a function of location of experiment
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Application shown for LOFAR air shower data

- ~ 15 meter resolution of axis position, no bias
- ~ 30 % energy resolution, limited by comparison to particle array
- ~ 35 g/cm^2 X_{max} resolution against full Monte Carlo simulations, no independent detector at LOFAR