# A new LDF parameterization for the air shower radio footprint applied to LOFAR data

Sud

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# A new LDF parametrization for the air shower radio footprint applied to LOFAR data

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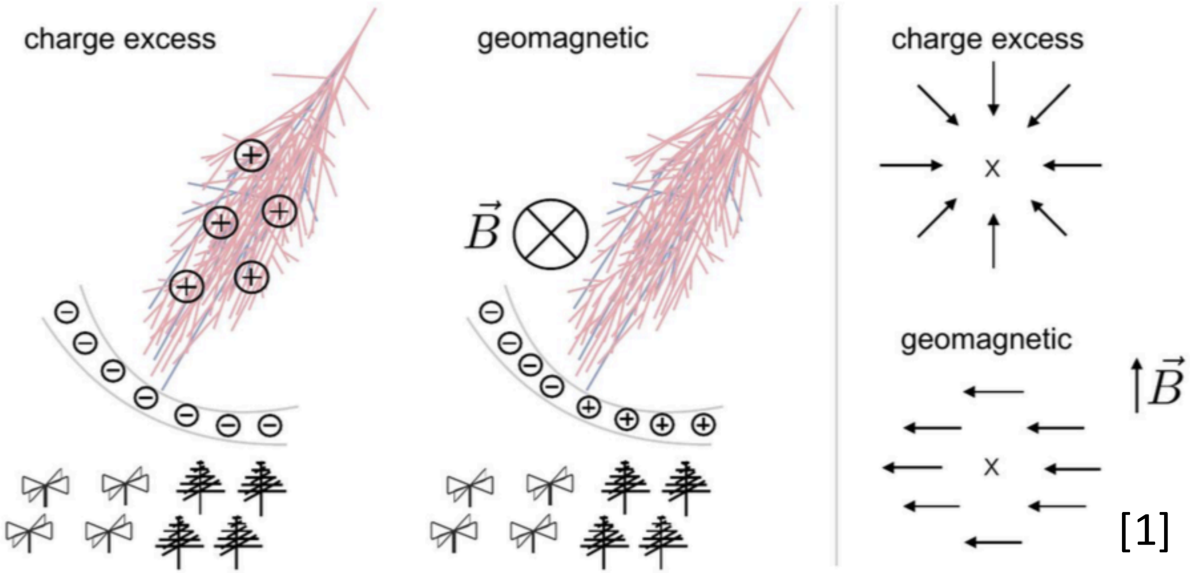
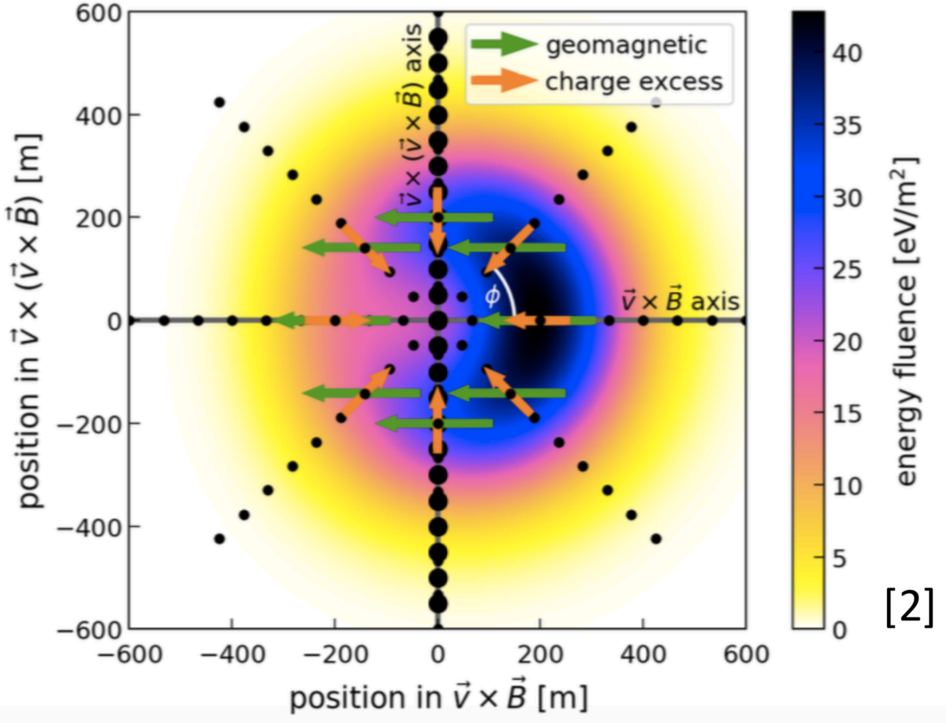
ARENA meeting 13th June

# Radio emission

## Radio emission mechanisms




## Shower plane




On the vxB = 0 axis, the geomagnetic and charge excess component can be seperated completely!

1. J. Schulz, "Cosmic Radiation – Reconstruction of Cosmic-Ray properties from Radio Emission of Extensive Air showers", In: PhD thesis Radboud University Nijmegen (2016)
2. C. Glaser, "Analytic description of the radio emission of air showers based on its emission mechanisms" (2018).

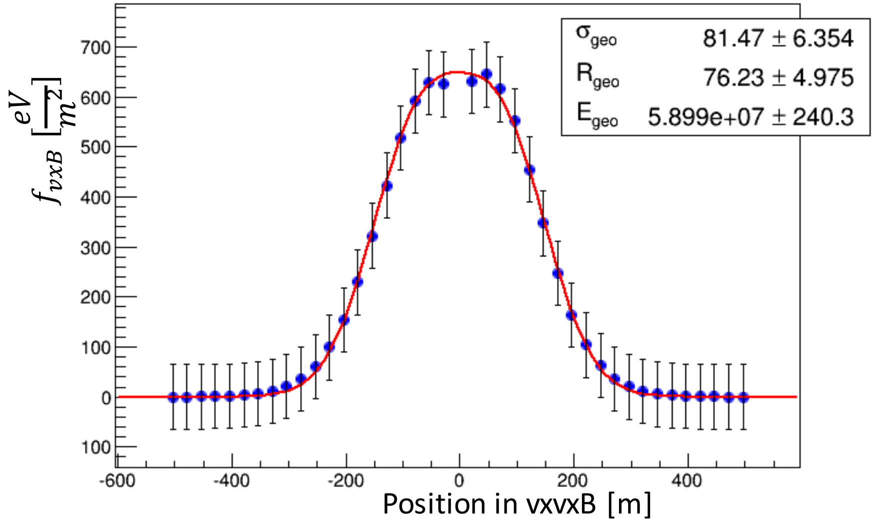
# A new LDF function

$$f_{geo} = \begin{cases} \frac{1}{N_{R-}} E_{geo} \exp(-(\frac{r-R_{geo}}{\sqrt{2}\sigma_{geo}})^2) & R_{geo} < 0 \\ \frac{1}{N_{R+}} E_{geo} [\exp(-(\frac{r-R_{geo}}{\sqrt{2}\sigma_{geo}})^2) + \exp(-(\frac{r+R_{geo}}{\sqrt{2}\sigma_{geo}})^2)] & R_{geo} \geq 0 \end{cases}$$

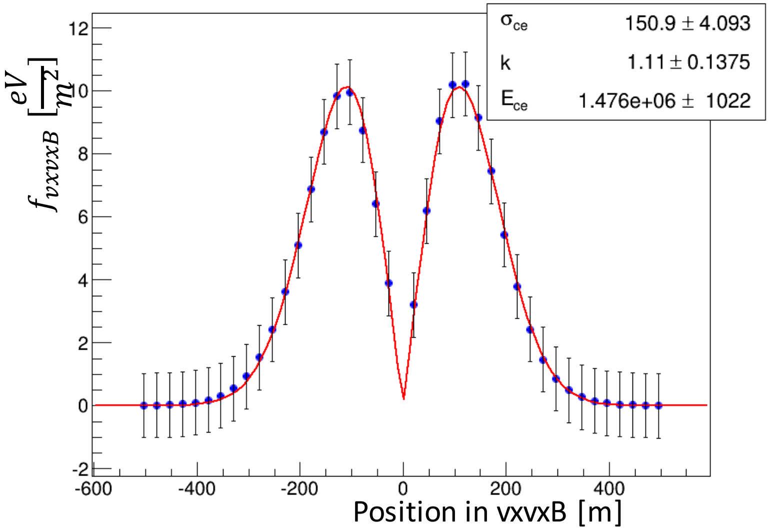
$$f_{ce} = \frac{1}{N_{ce}} E_{ce} r^k exp(-\frac{r^2(k+1)}{2\sigma_{ce}^2}) \qquad R_{ce} = \sigma_{ce}\frac{\sqrt{k}}{\sqrt{k+1}}$$

[2]

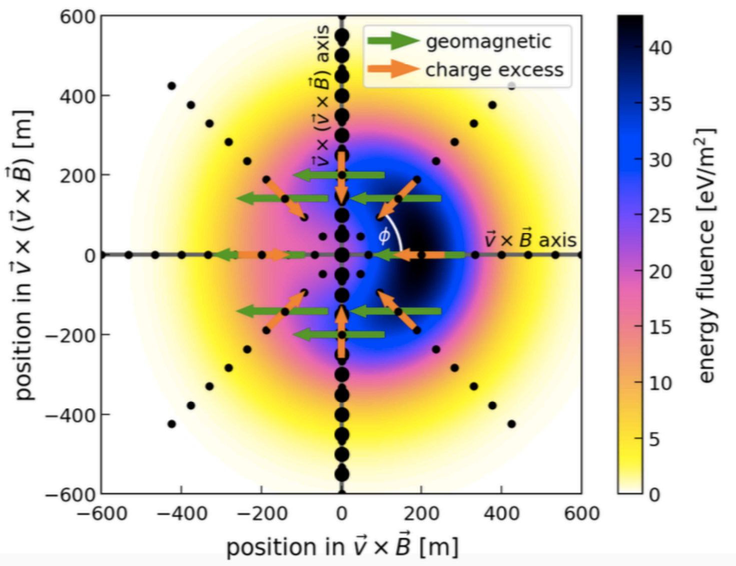
## Geomagnetic on vxB = 0 arm




## Charge excess on vxB = 0 arm




## Shower plane




$$f_{v\times B}(r) = (\sqrt{f_{geo}(r)} + cos\phi\sqrt{f_{ce}(r)})^2$$

$$f_{v\times(v\times B)}(r) = sin^2\phi f_{ce}(r)$$

$$f = f_{v\times B} + f_{v\times(v\times B)}$$

[2]

# CoREAS simulations

Footprint of radio emission on the ground

$$f(E_{geo}, E_{ce}, R_{geo}, R_{ce}, \sigma_{geo}, \sigma_{ce}, x, y)$$

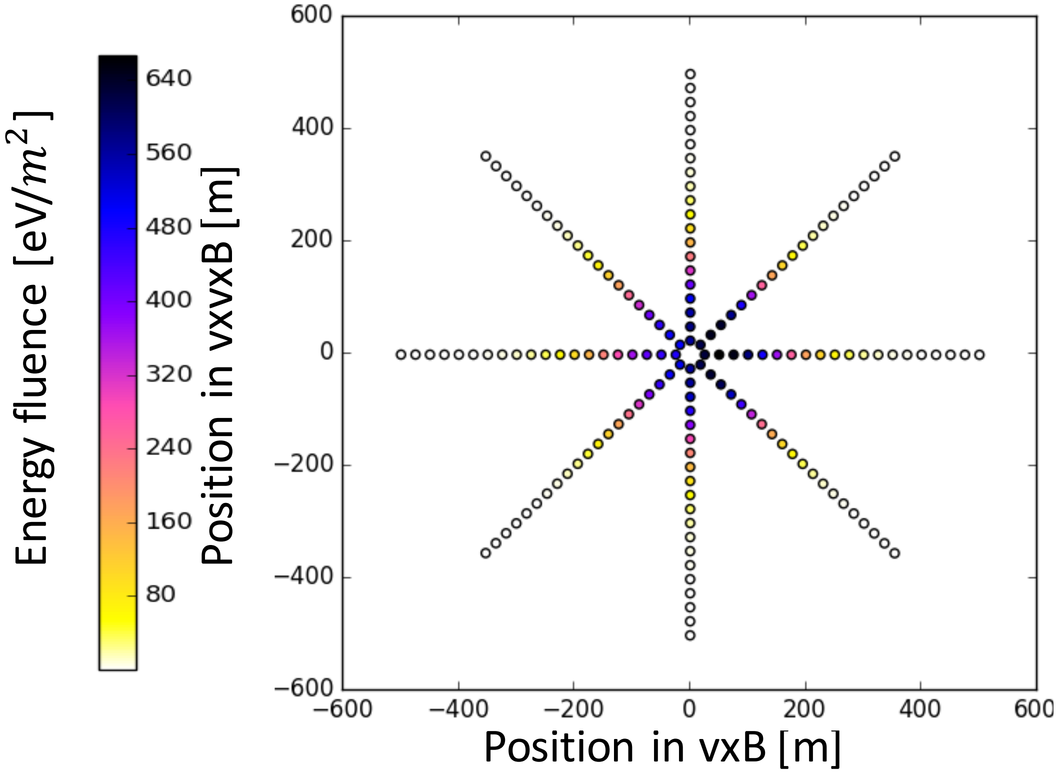
$$\downarrow$$

$$f(E(E_{geo}, E_{ce}), D_{xmax}(R_{geo}, R_{ce}, \sigma_{geo}, \sigma_{ce}), x, y)$$

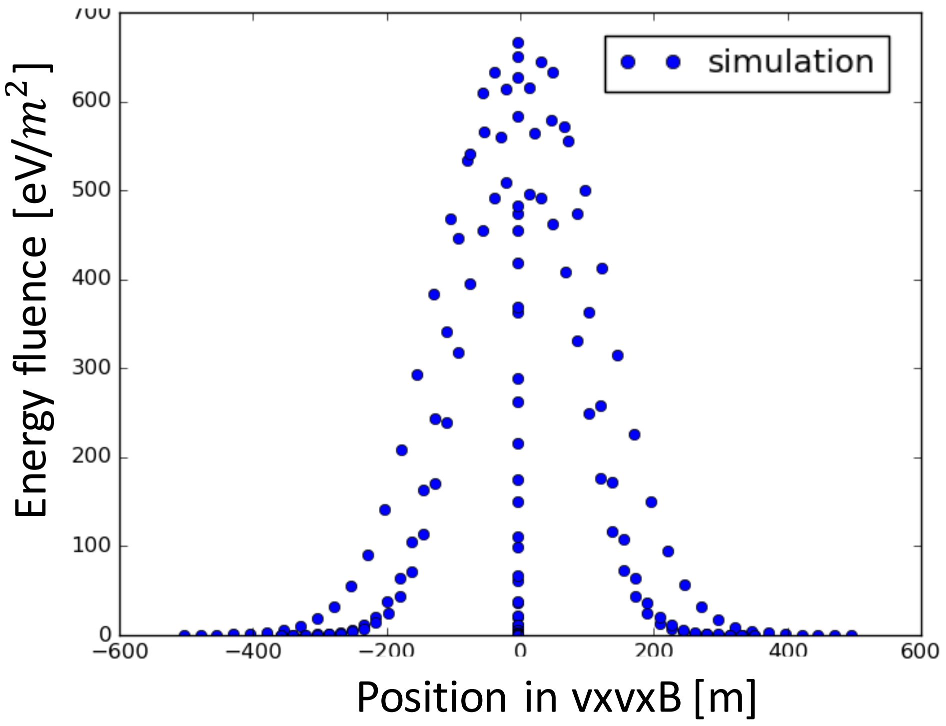
- CoREAS simulations are used to parametrize the function
- New function has only 4 parameters
- Just dependent on shower properties

# CoREAS simulations

Shower plane event 118956923

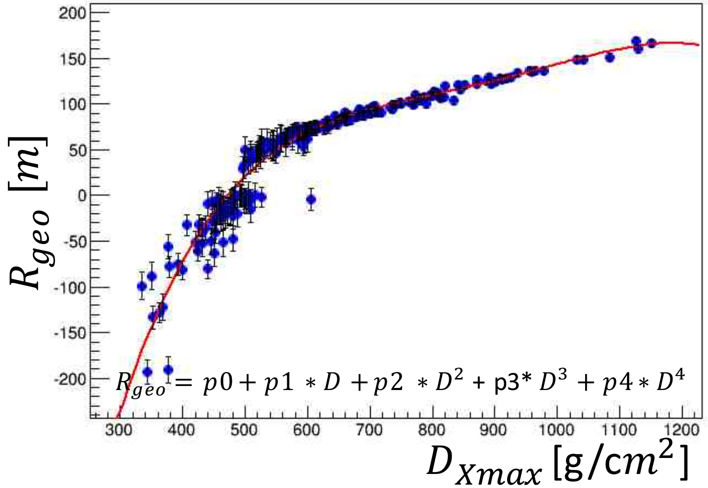


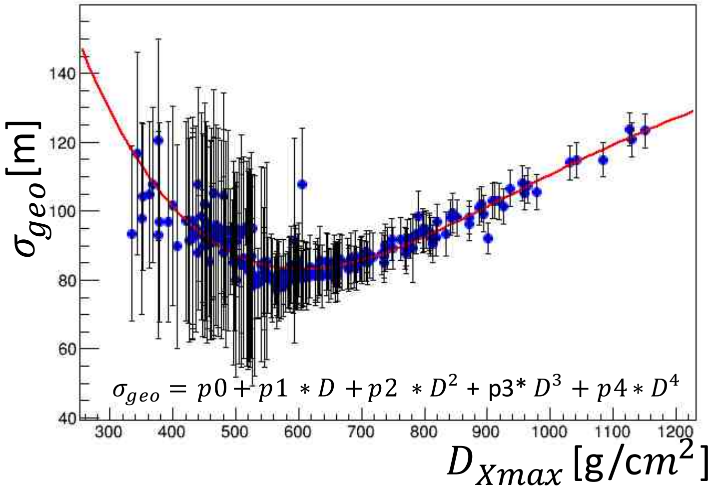

Energy fluence event 118956923

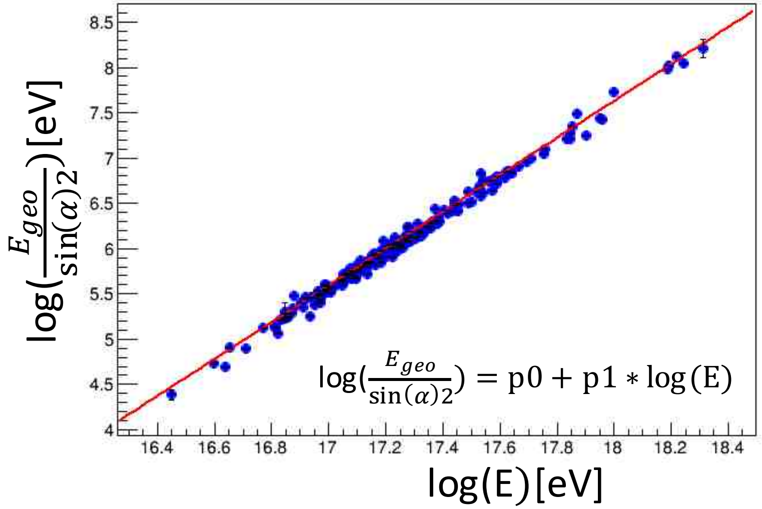


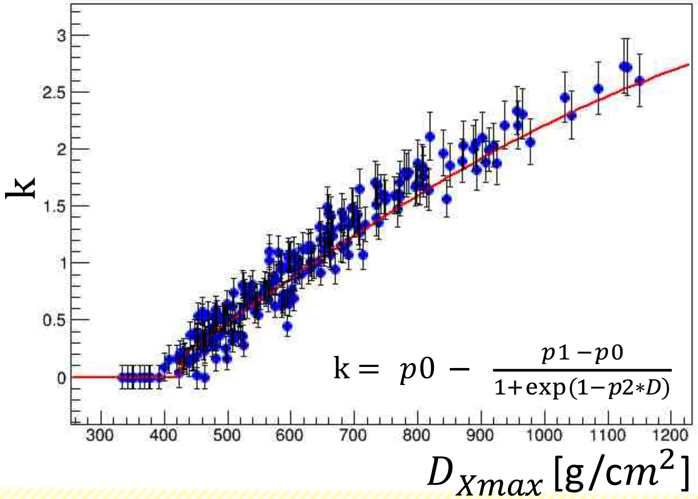
# CoREAS simulations

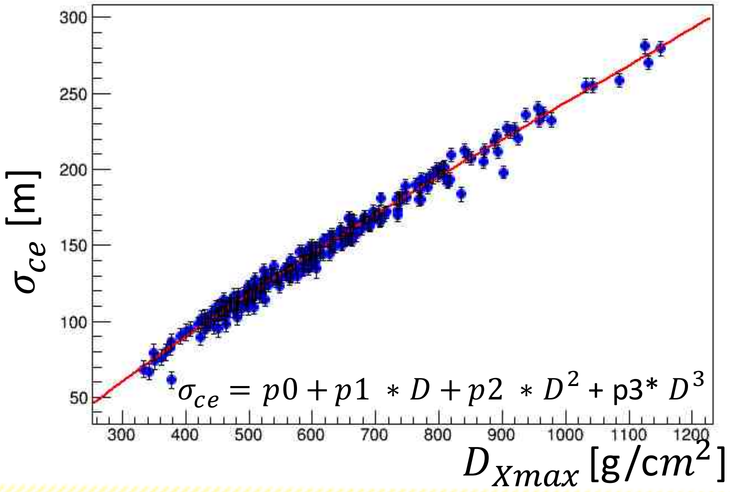
## Parametrizations

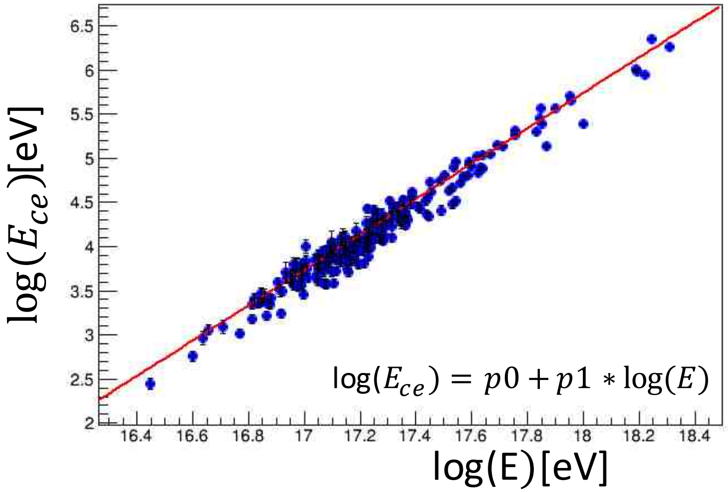


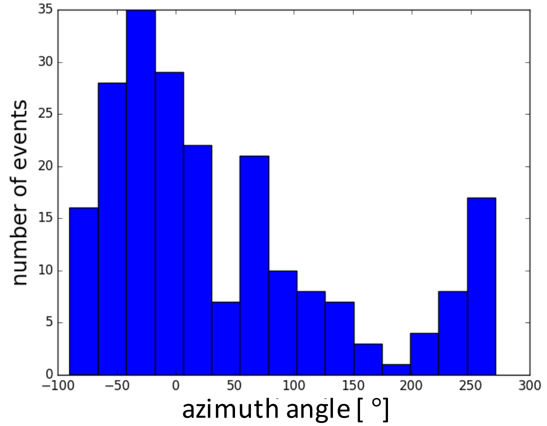



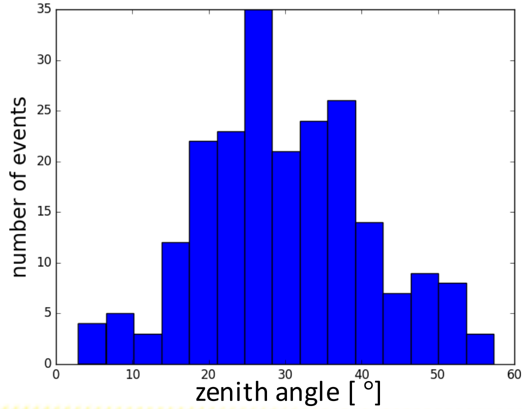



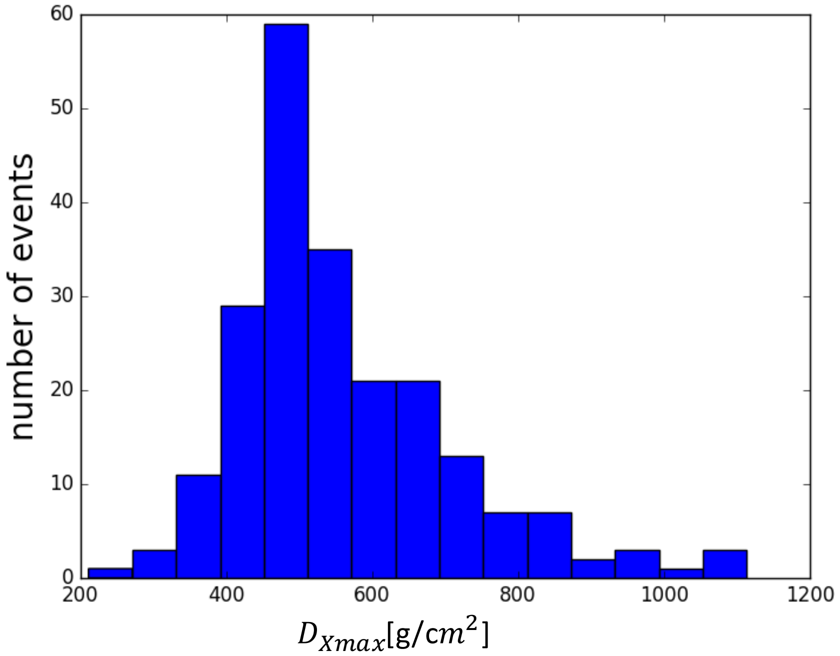
# CoREAS simulations

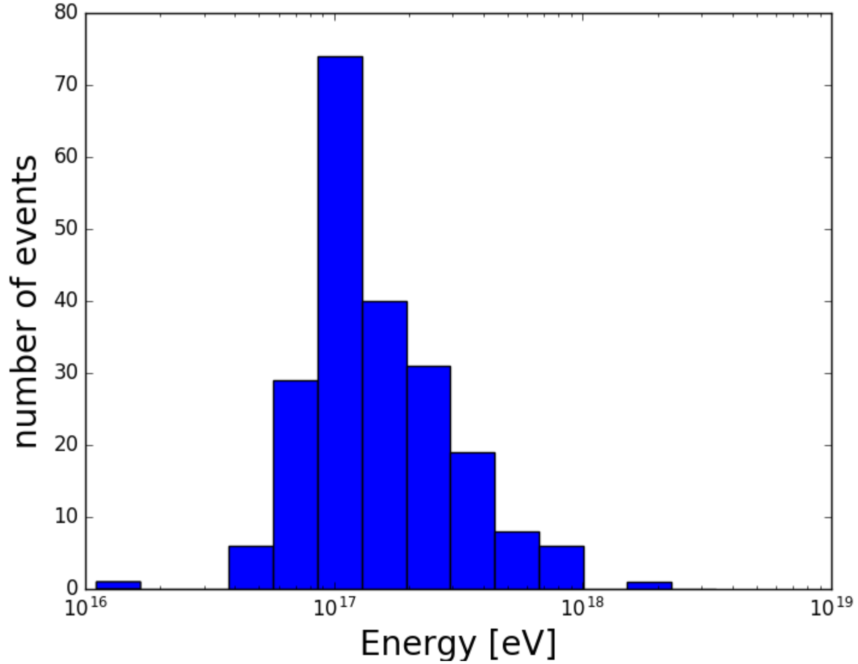
- 250 showers based on real LOFAR events are used for analysis
- Simulations with realistic atmospheric model



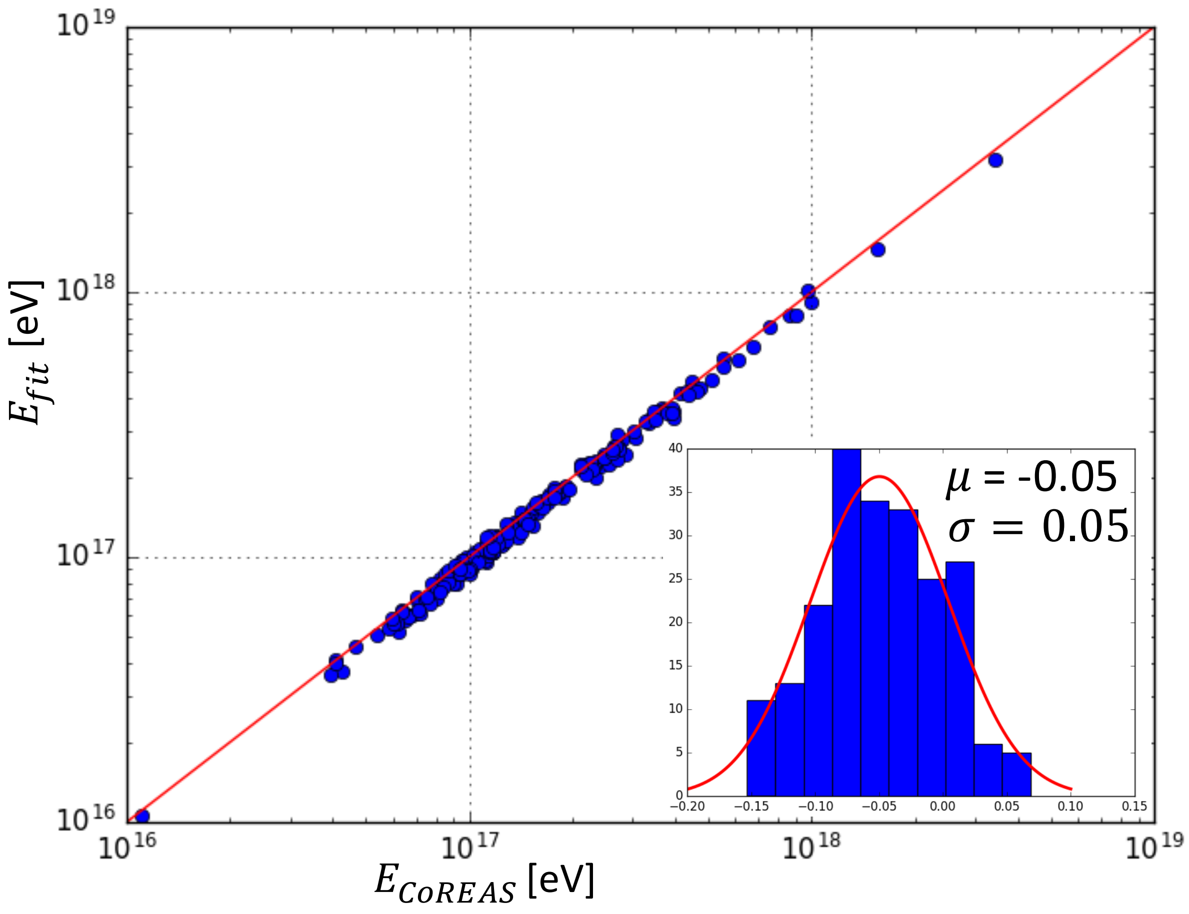

Parameters of simulated showers



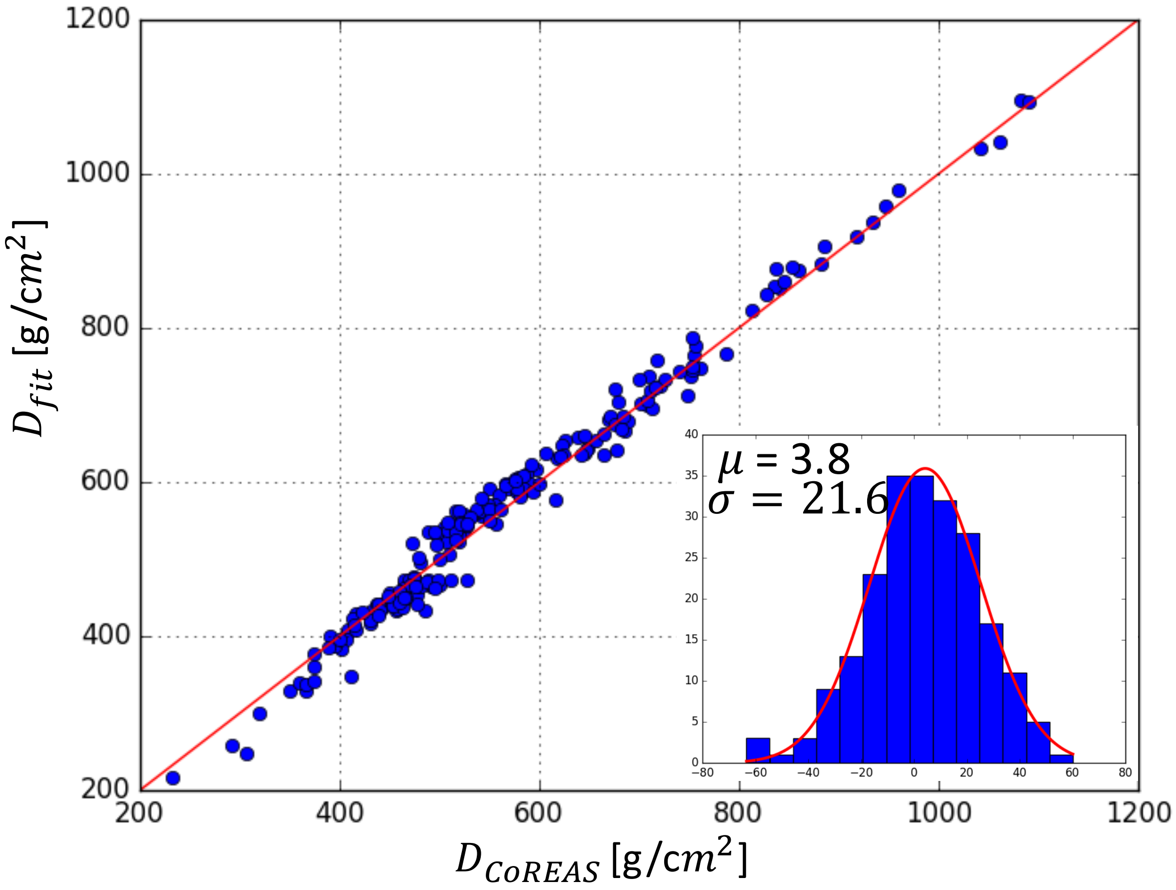



# CoREAS simulations

Reconstructed versus true energy

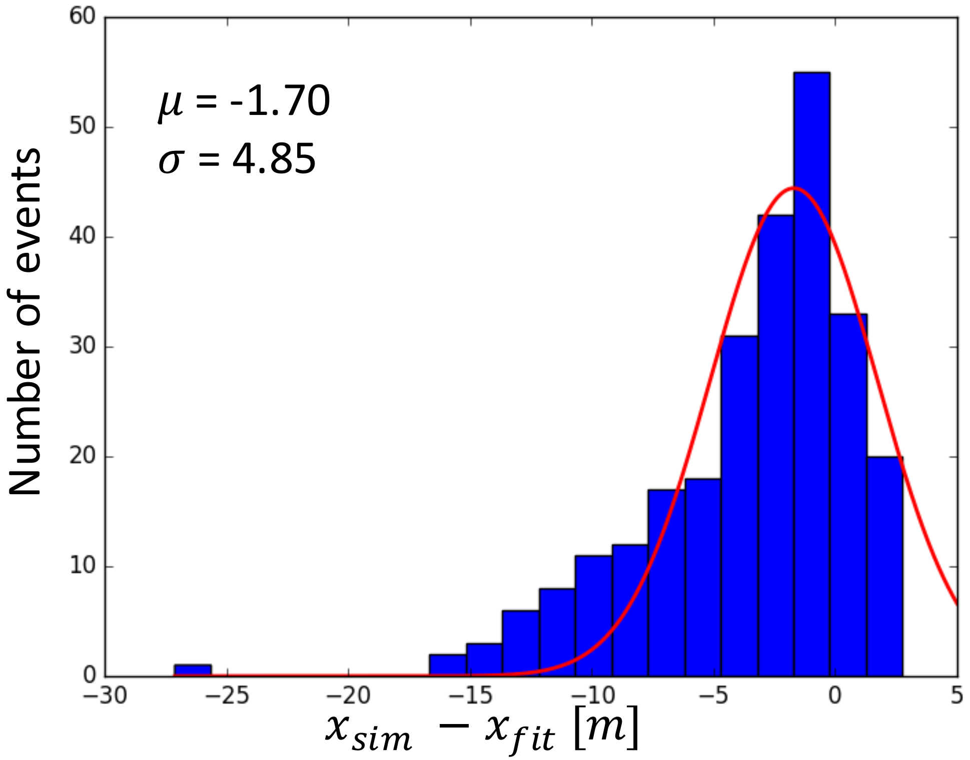



Reconstructed versus true distance to $X_{max}$

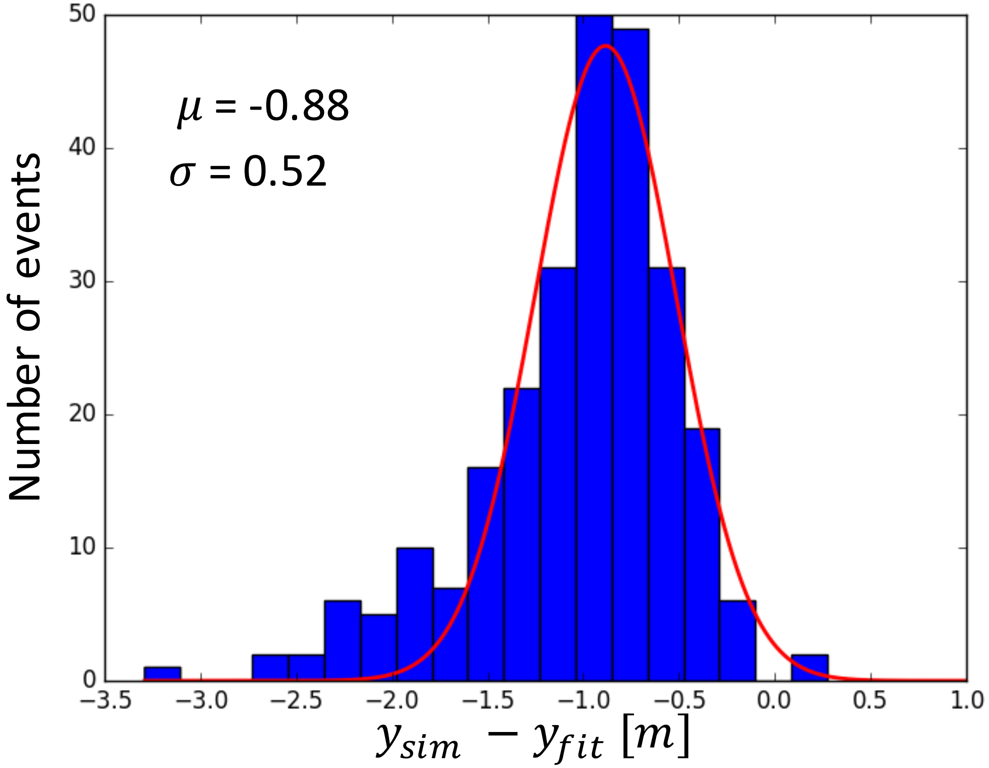


# CoREAS simulations

Difference reconstructed and true x-coordinate of shower axis

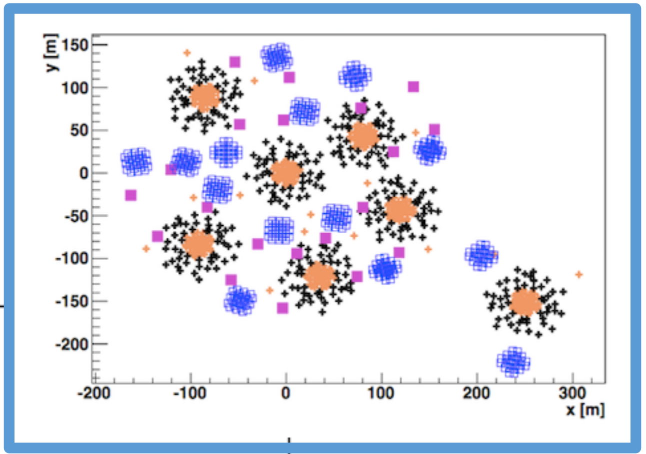



Difference reconstructed and true y-coordinate of shower axis

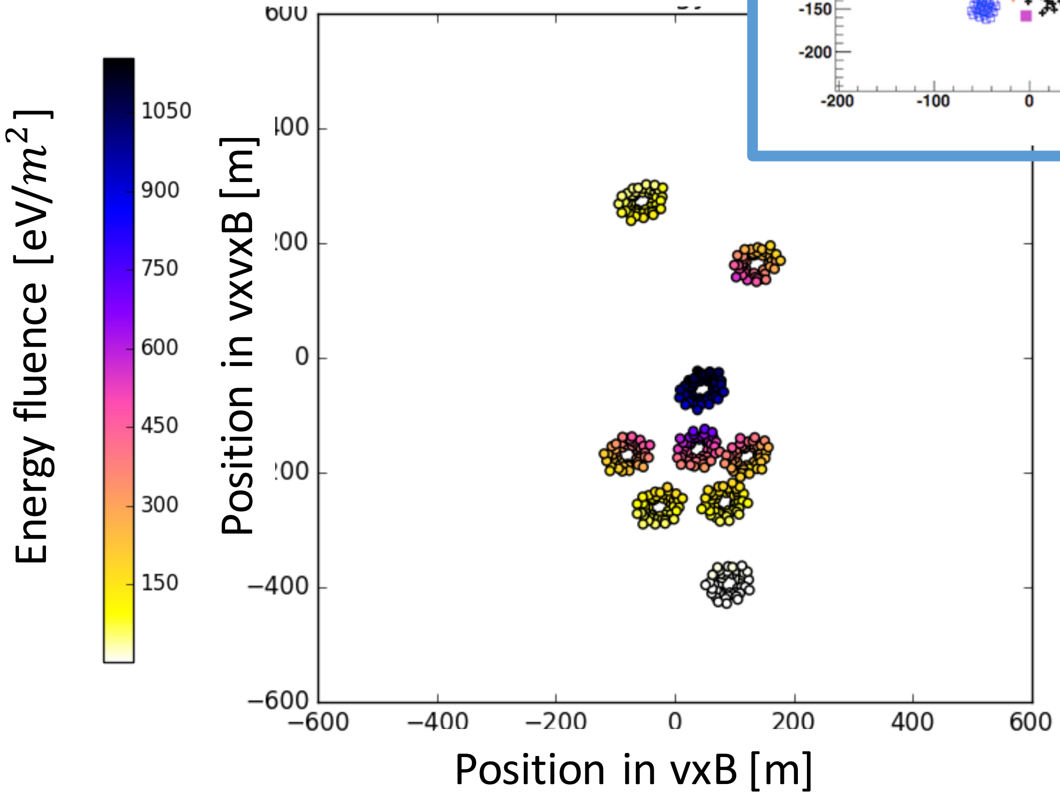


# LOFAR data

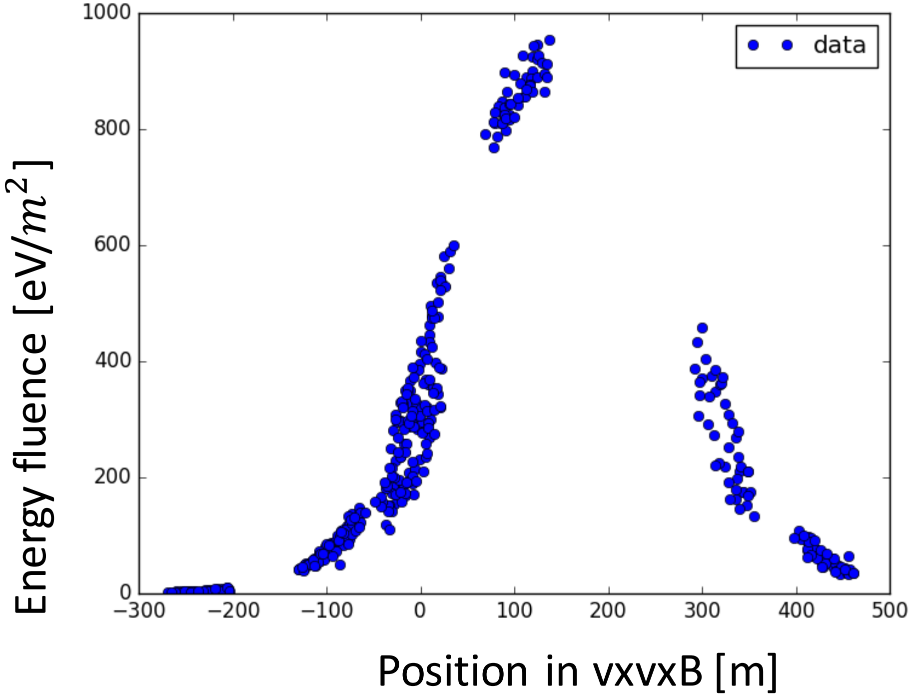
Superterp




Shower plane event 118956923

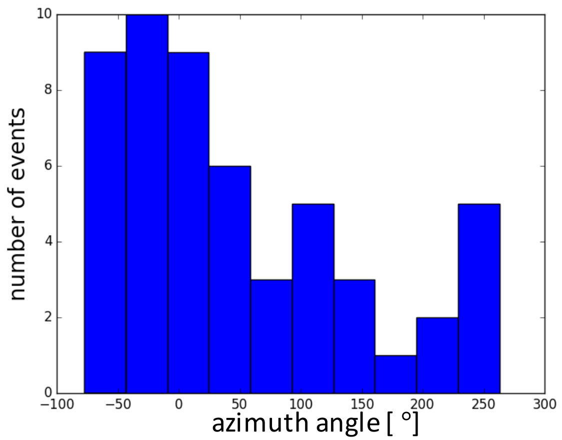


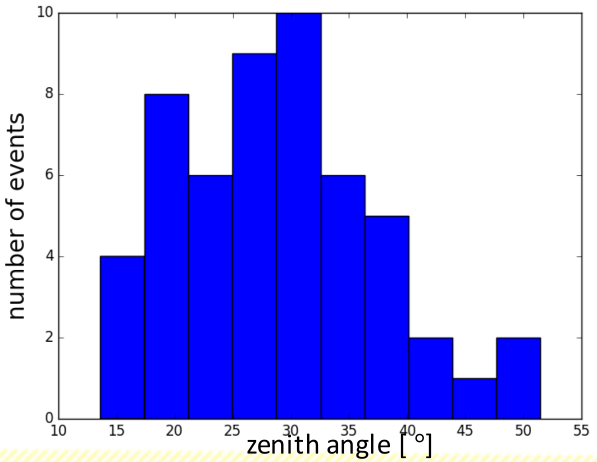

Energy fluence event 118956923



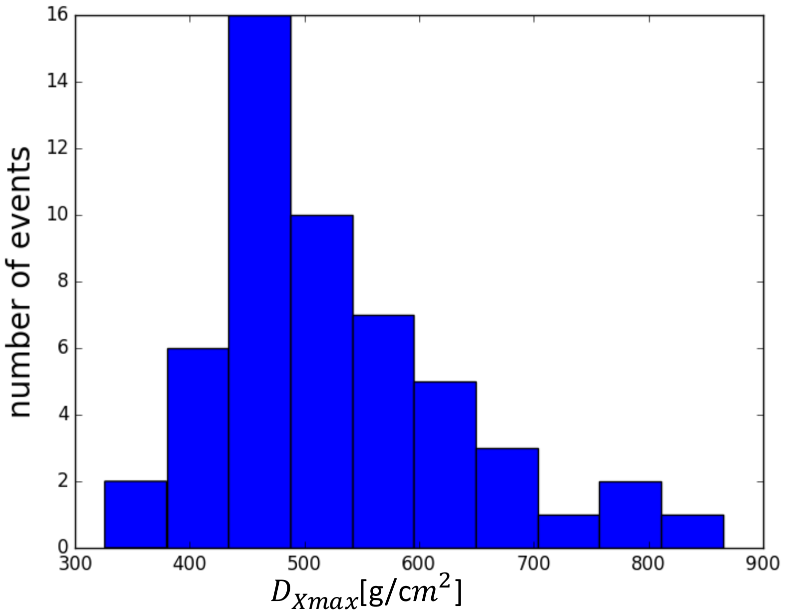
# LOFAR data

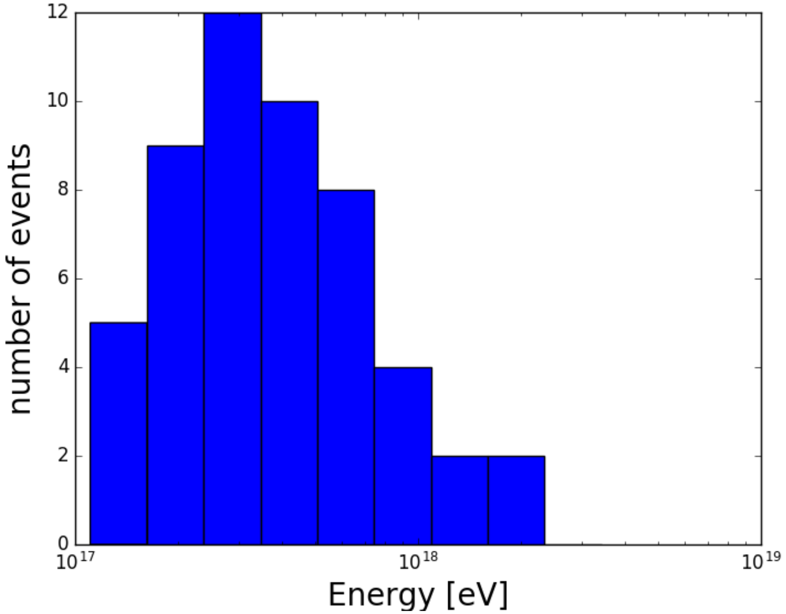
- 60 showers with at least 3 stations triggered are used for analysis



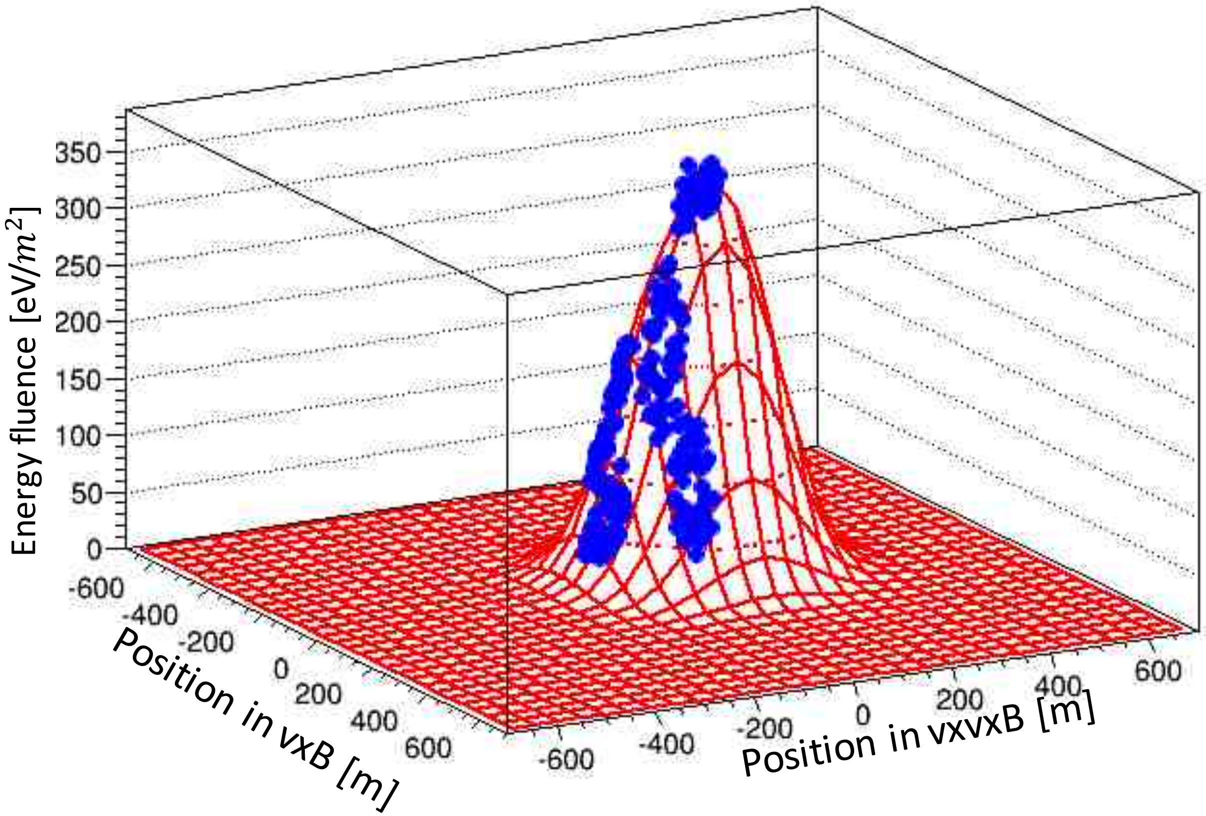

Parameters of measured showers



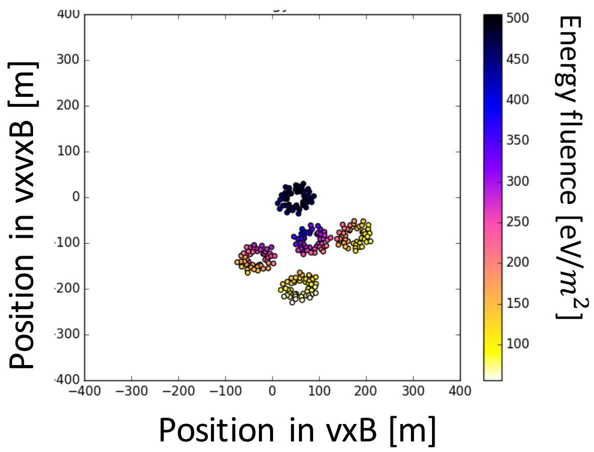



# LOFAR data

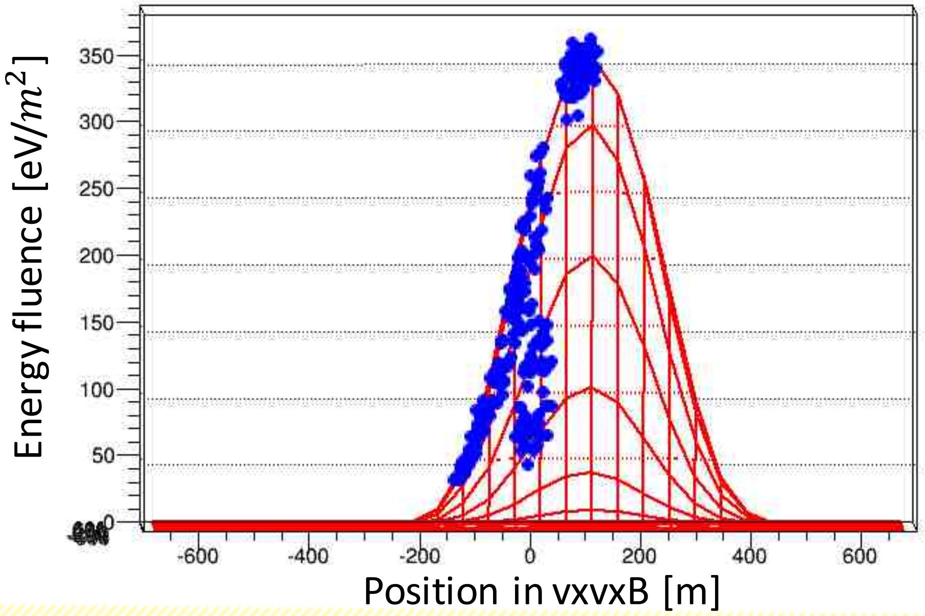
Example fit of data for event 48361669




Shower plane 48361669

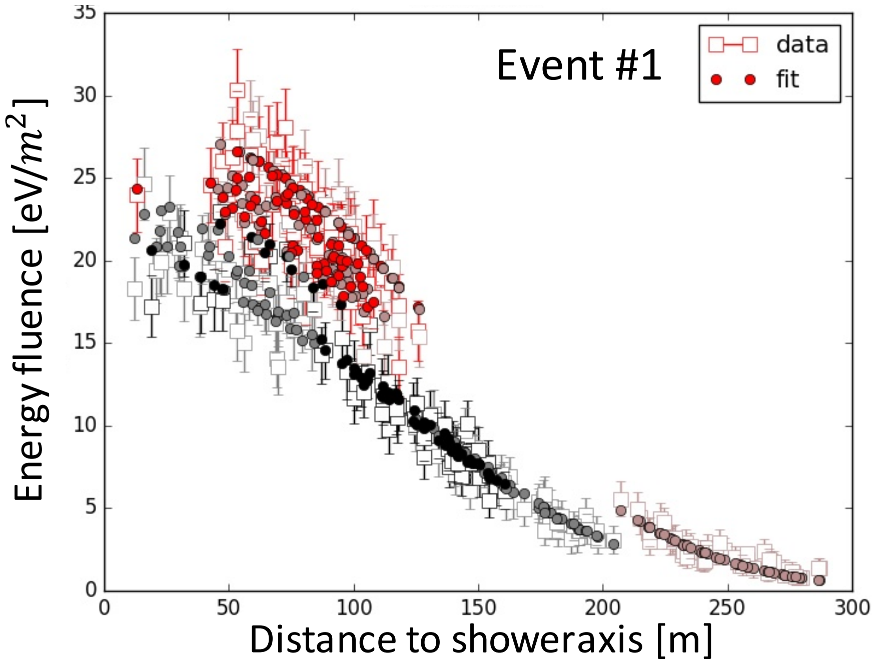


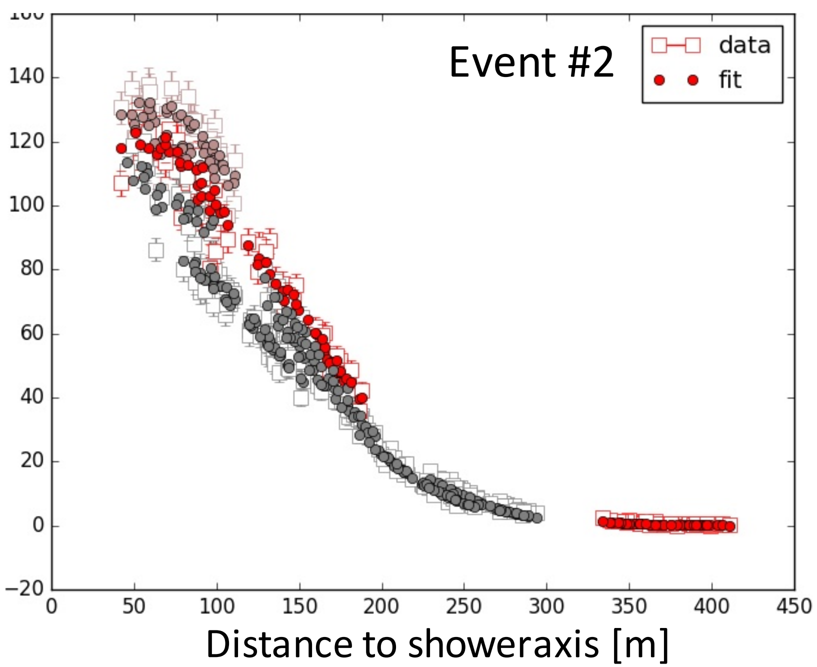

Example fit of data for event 48361669

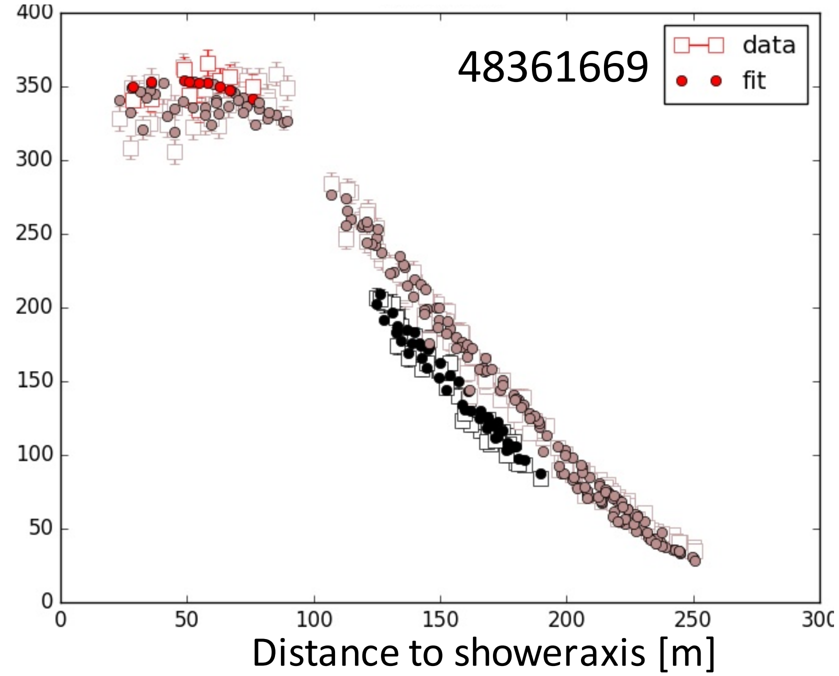


# LOFAR data

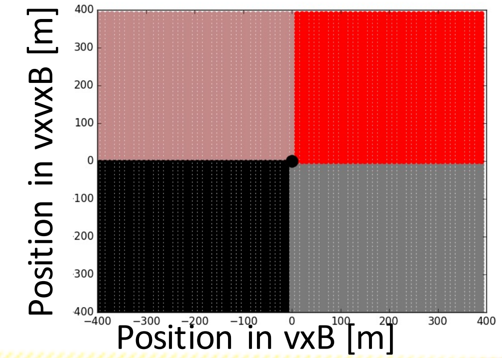
Fit result examples



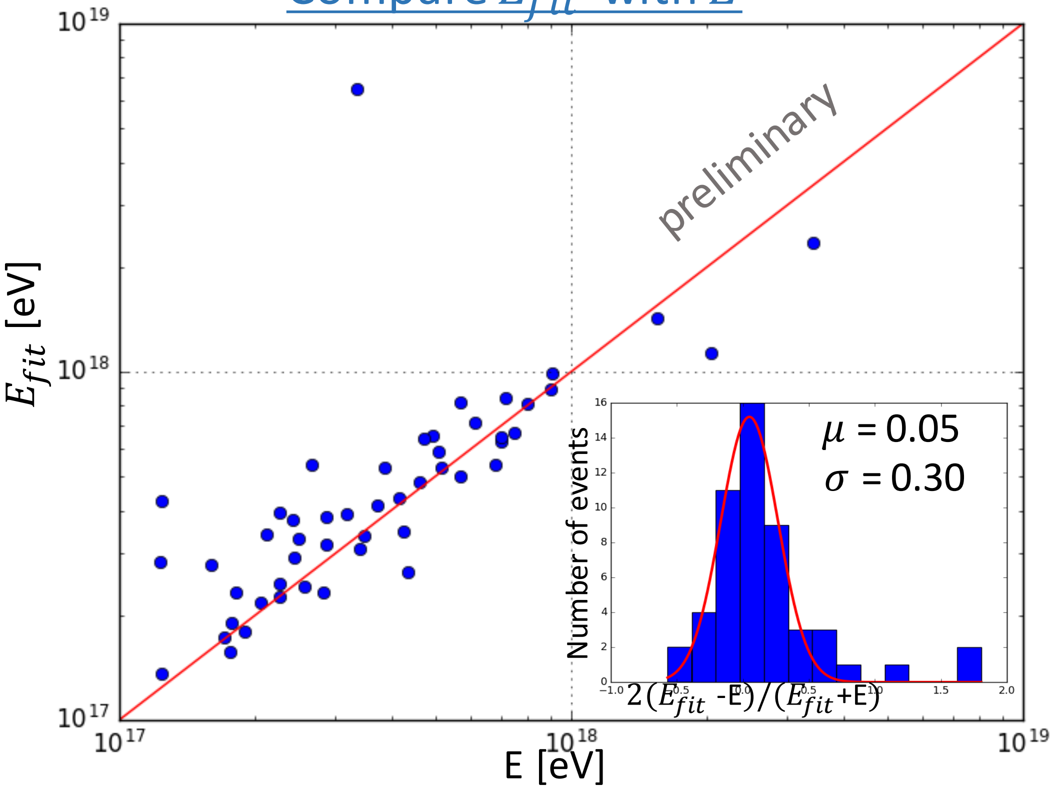




Shower plane

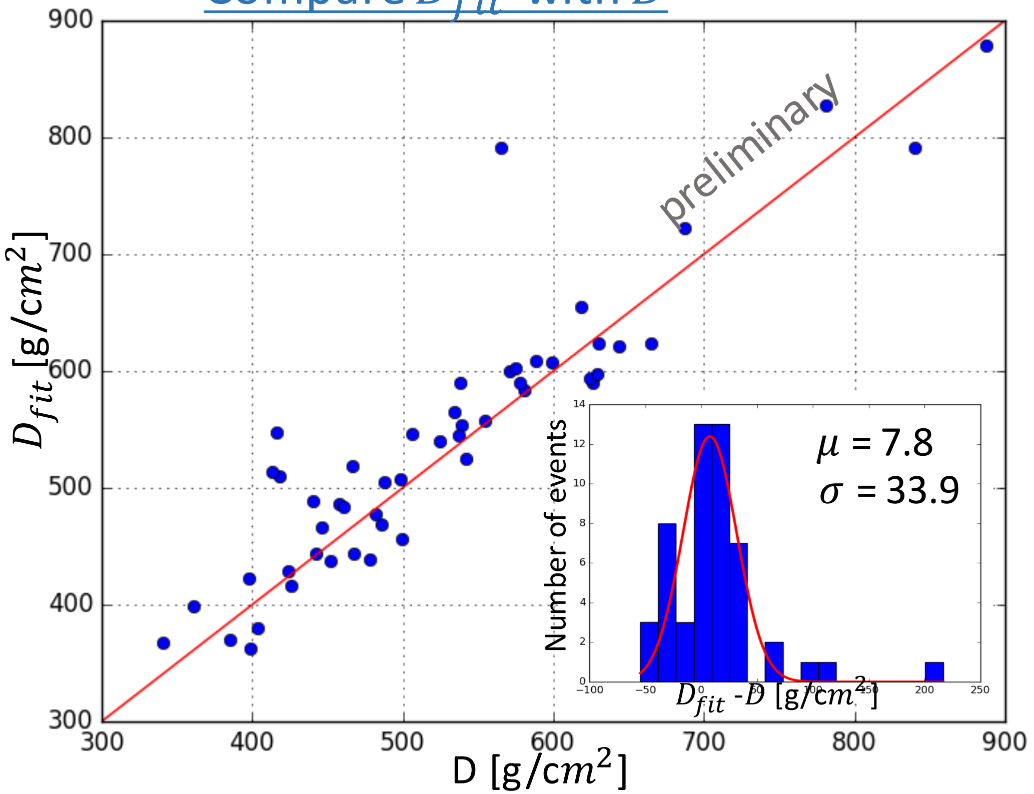


# LOFAR data

Compare $E_{fit}$ with $E$



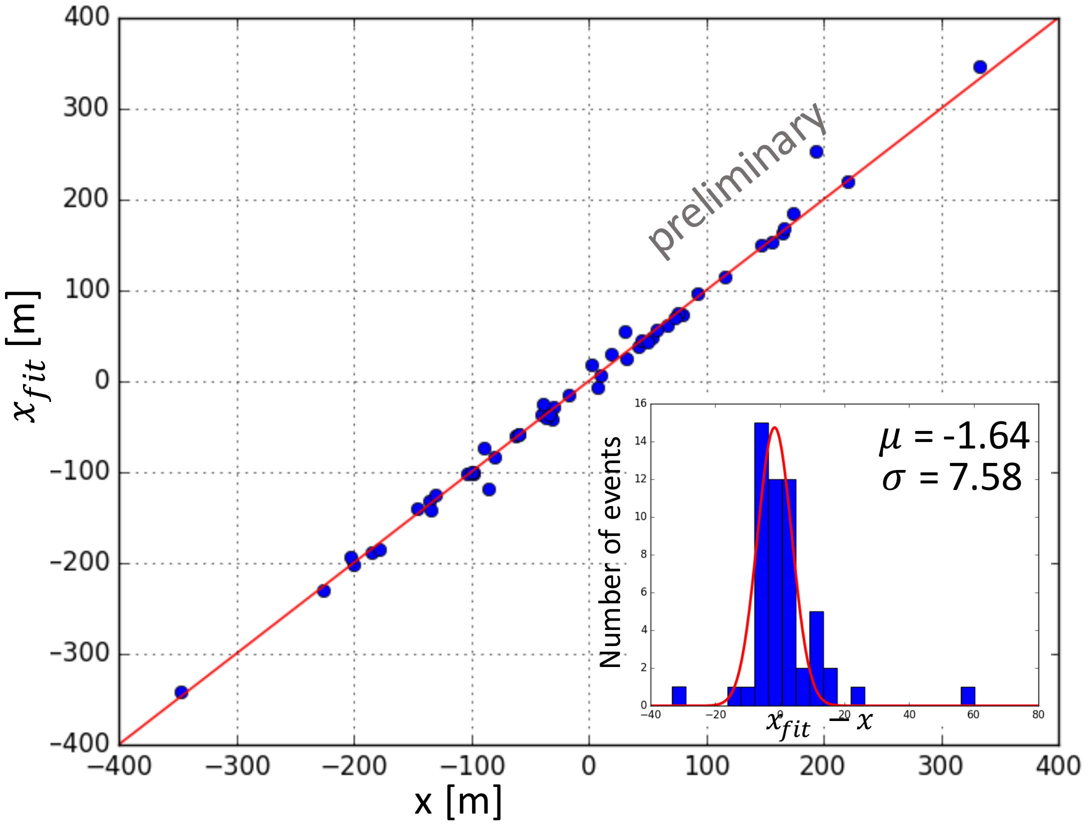

Compare $D_{fit}$ with $D$



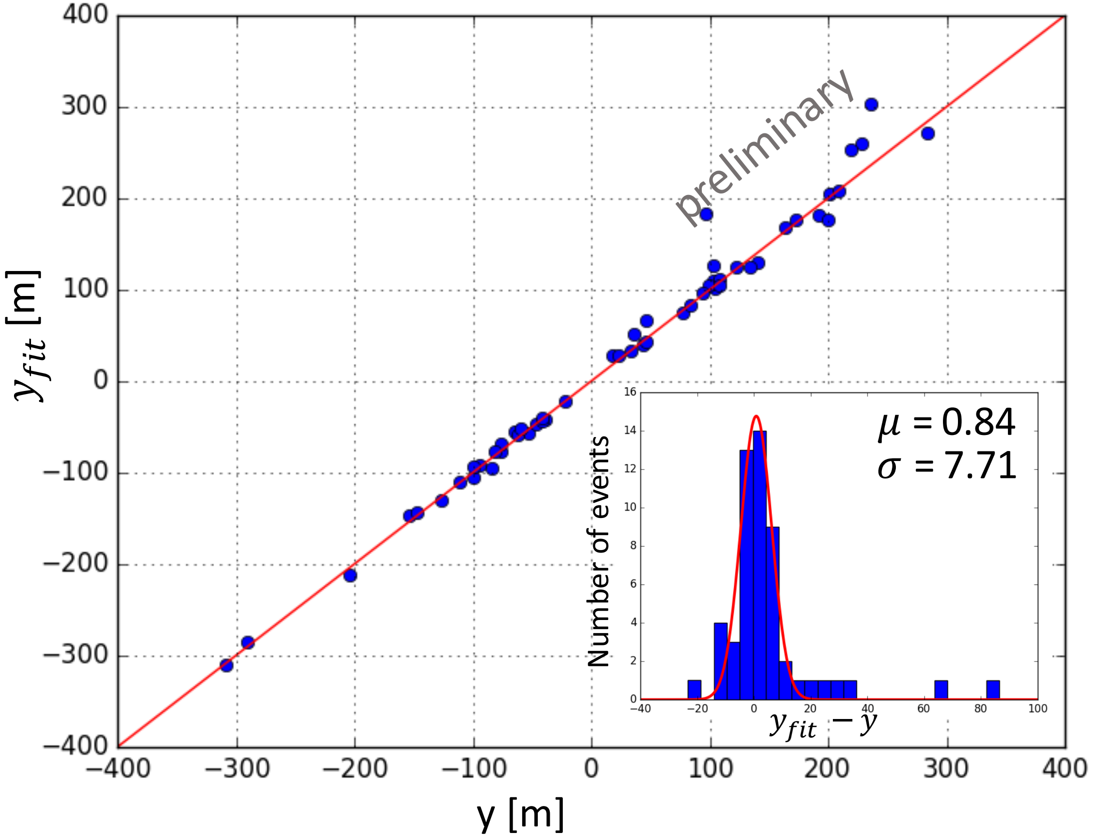

- $E_{fit}$ values are compared with $E$ from particles detector or with E from old LDF
- $D_{Xmax}$ values are compared with $D_{Xmax}$ from computational intensive method, which uses old LDF as starting values

# LOFAR data

## Compare $x_{fit}$ with $x$




## Compare $y_{fit}$ with $y$



# Conclusions

- New analytic function to describe radio footprint on the ground
- Successfully applied to LOFAR data
- Function used to reconstruct properties of simulated shower with $\sigma_{E=}$ 5 %, $\sigma_{Dxmax} = 29.51\ g/cm^2$, $\sigma_x = 4.85$ m, $\sigma_{y=}$ 0.52 m
- Function used to reconstruct properties of measured events with $\sigma_{E=}$ 30 %, $\sigma_{Dxmax} = 33.9\ g/cm^2$, $\sigma_x = 7.58$ m, $\sigma_{y=}$ 7.71 m