

# Charge excess signature in the CODALEMA data

## Interpretation with SEFAS2

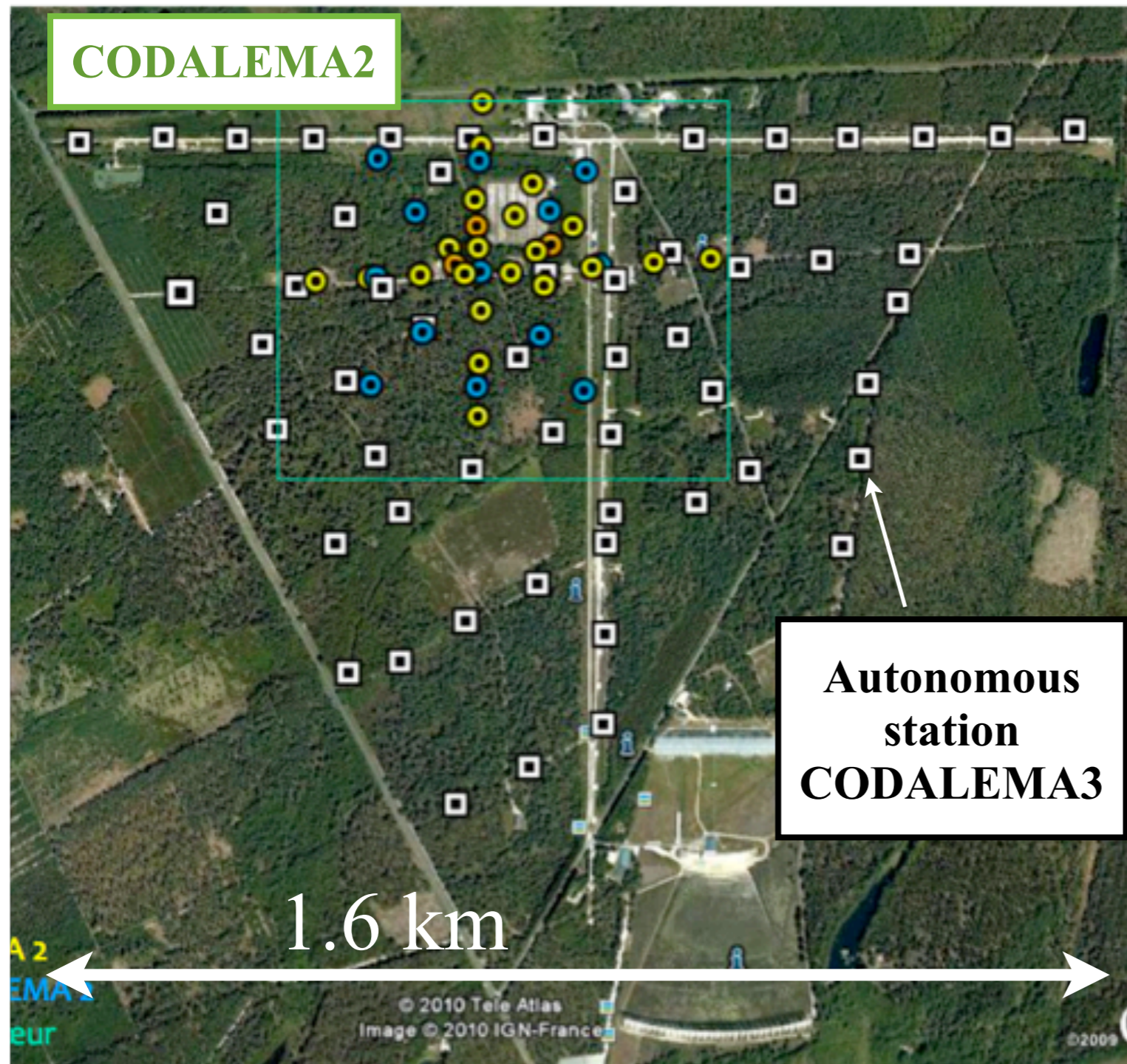
**Vincent Marin**  
*for the CODALEMA collaboration*  
**SUBATECH**  
*Nantes France*

**ICRC 2011 Beijing 12/08/2011**  
**China**



# CODALEMA, Nançay (France)

Radio detection of air showers above  $10^{16}$  eV



## CODALEMA2

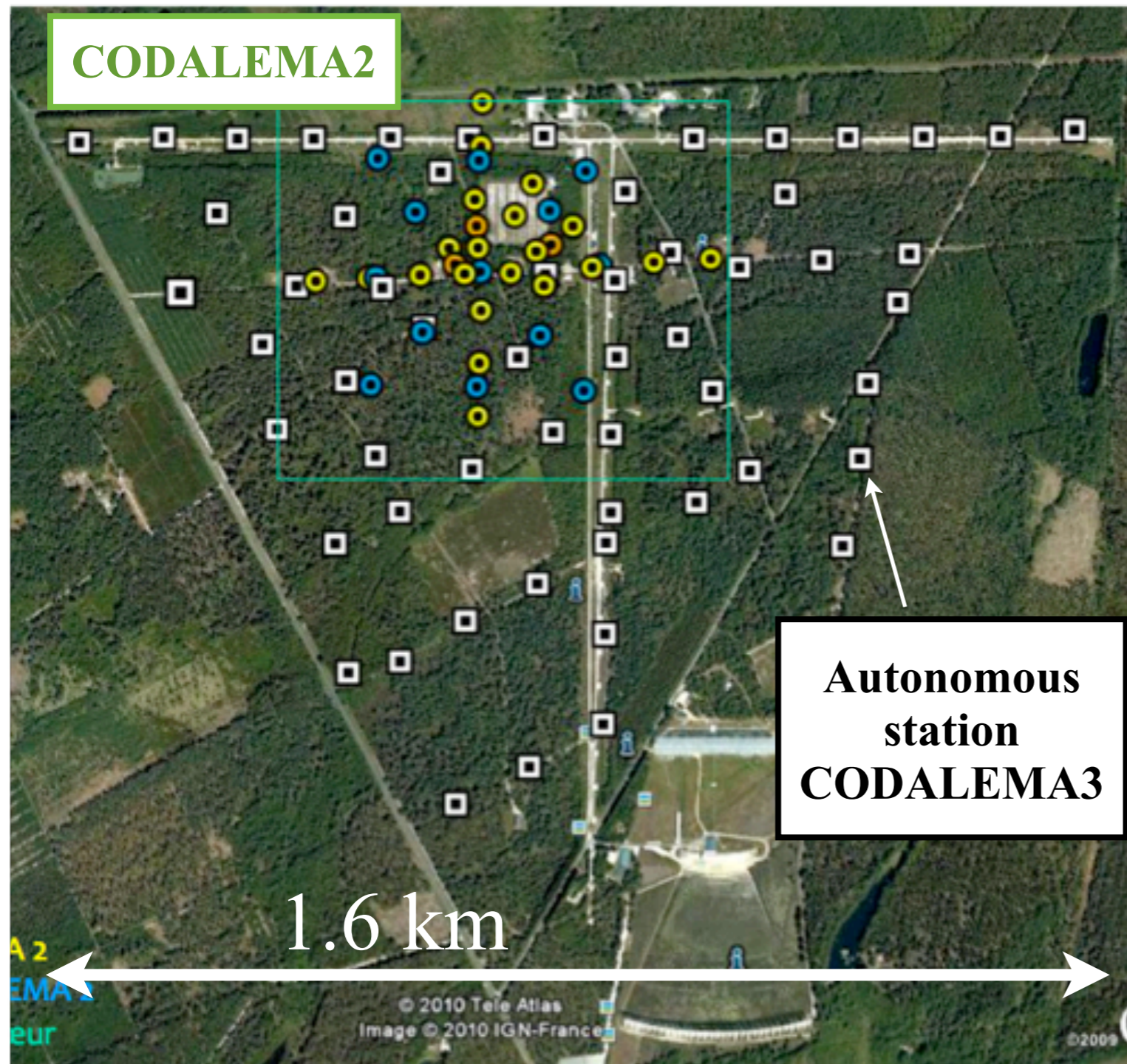
**24 antennas (EW polarization) triggered by an array of 13 scintillators**

## CODALEMA3

**60 dual polarization antennas, self-trigger, in acquisition and deployment**

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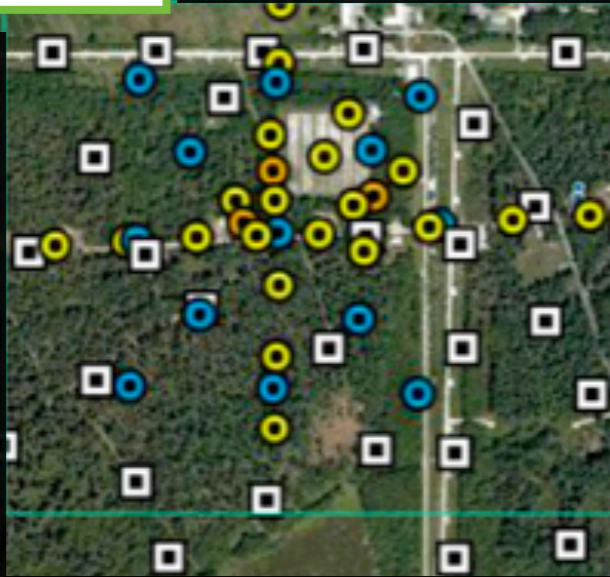
See A. Bellétoile's talk on August 15, Monday

**in acquisition and deployment**

# CODALEMA, Nançay (France)

Radio detection of air showers above  $10^{16}$  eV

CODALEMA2



**CODALEMA2**

**24 antennas (EW polarization)  
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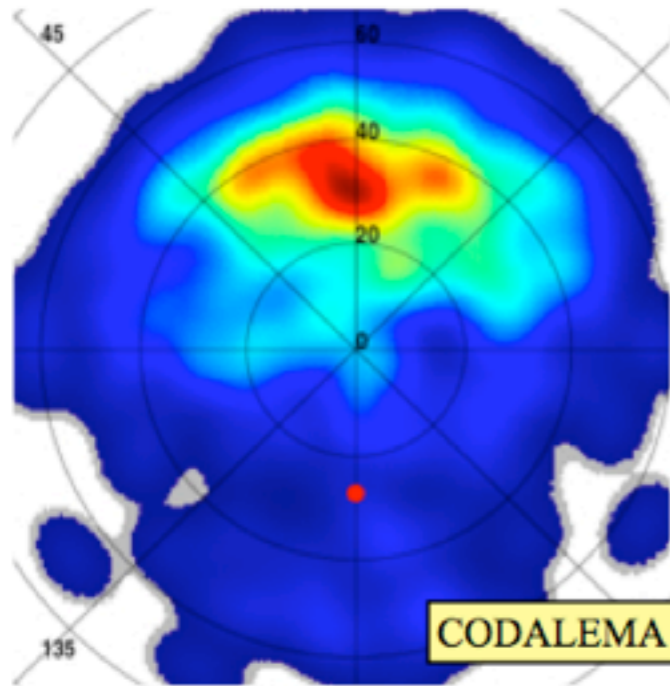
**This presentation  
focus only on CODALEMA2 data**

**CODALEMA3**

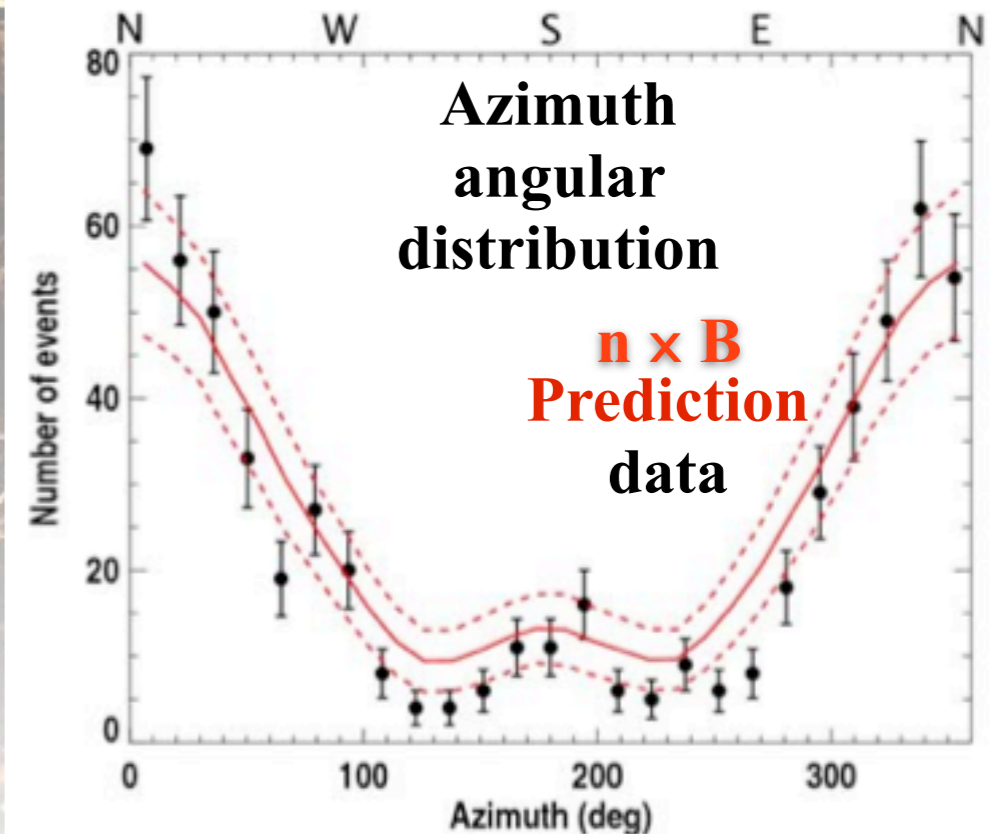
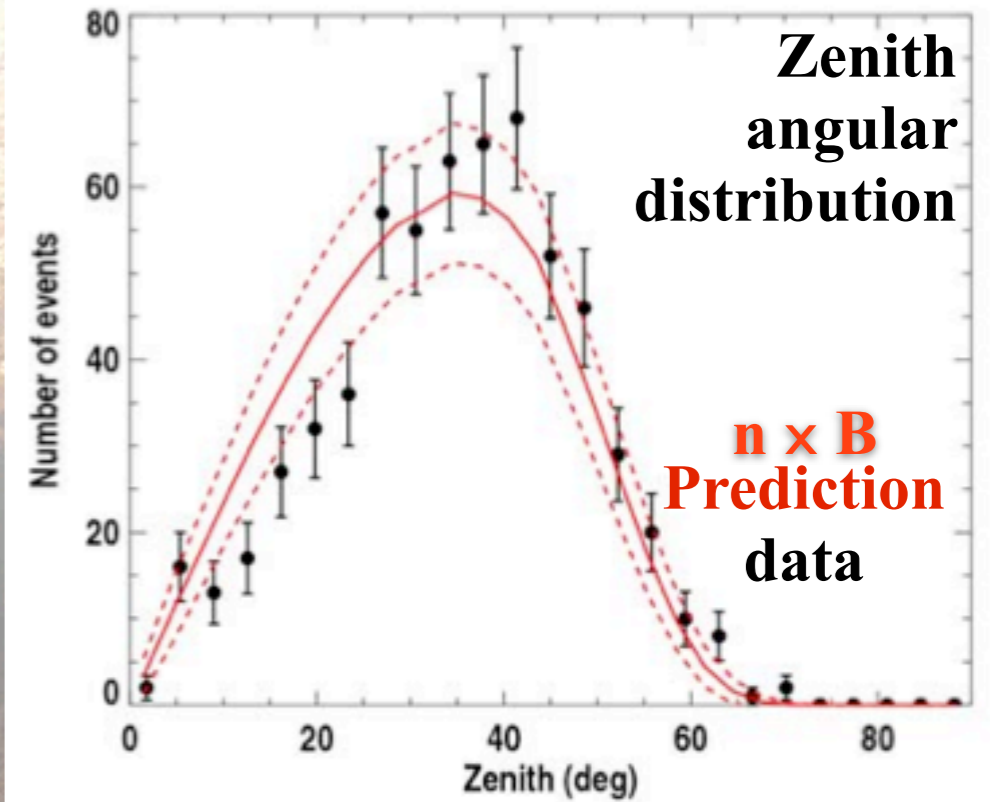
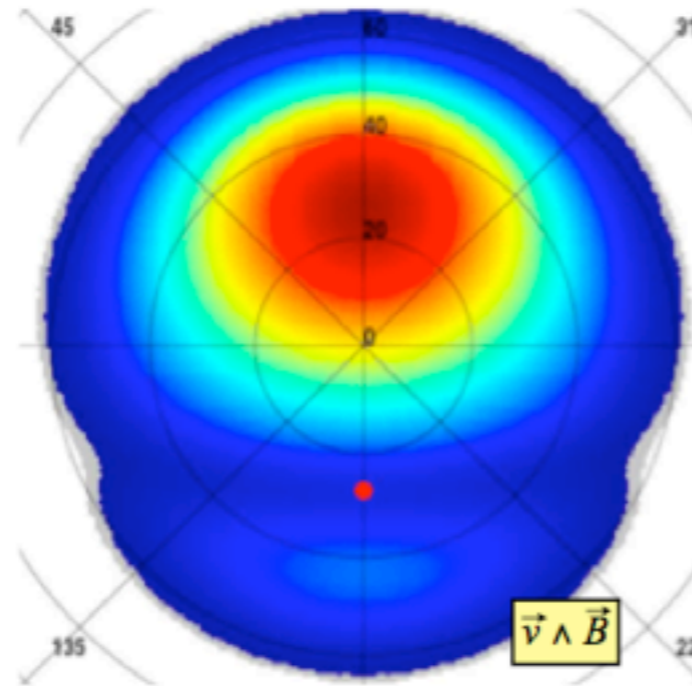
**dual polarization  
in acquisition and  
deployment**

# CODALEMA, Nançay (France)

Sky map of radio-detected events



EW component of  $\vec{n} \times \vec{B}$



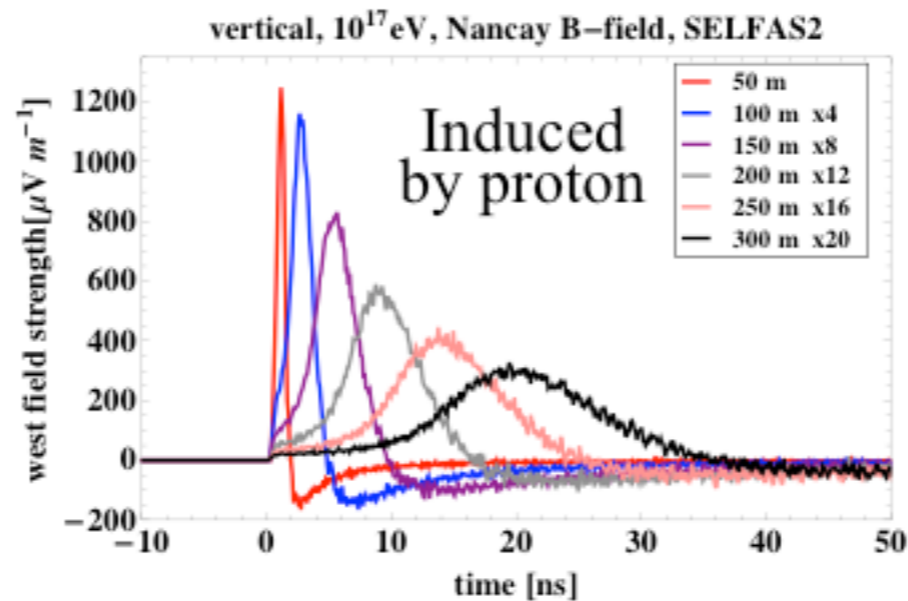
$$\vec{E} \propto \vec{n} \times \vec{B}$$

Direct confirmation of the  
**geomagnetic origin** of  
the air shower electric field

CODALEMA Collaboration, Astropart.Phys. 31 (2009)

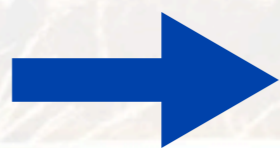
# SELFAS2

*Simulation of Electric Field from Air Shower*



- Geomagnetic mechanism contribution

Due to  
Lorentz Force

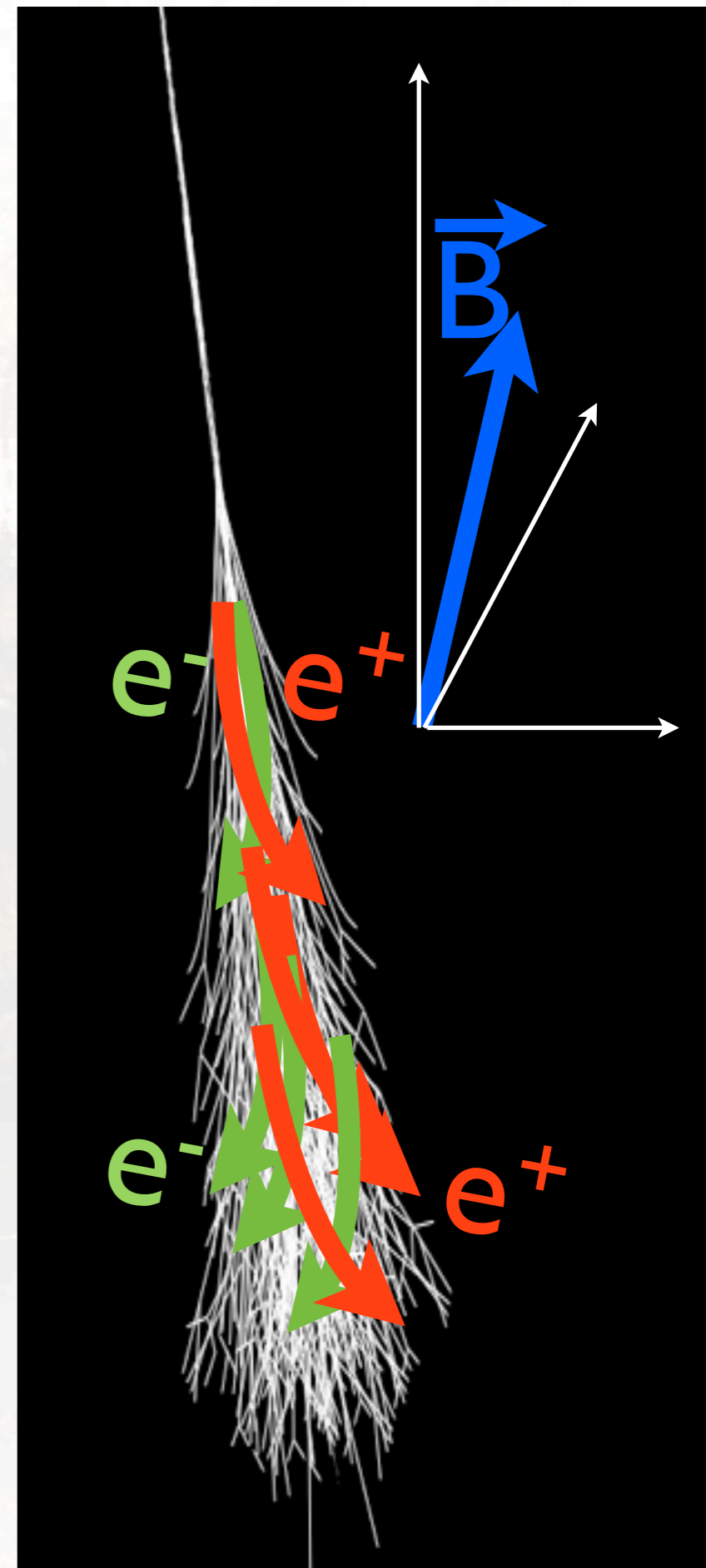


Charge  
separation

Transverse current  
variation

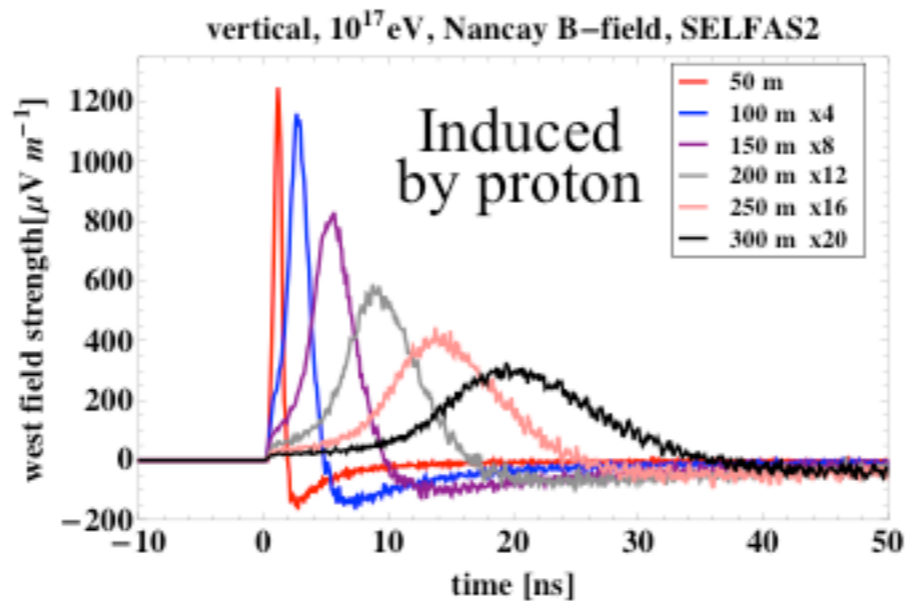


Maxwell equations  
Electric field



# SELFAS2

*Simulation of Electric Field from Air Shower*



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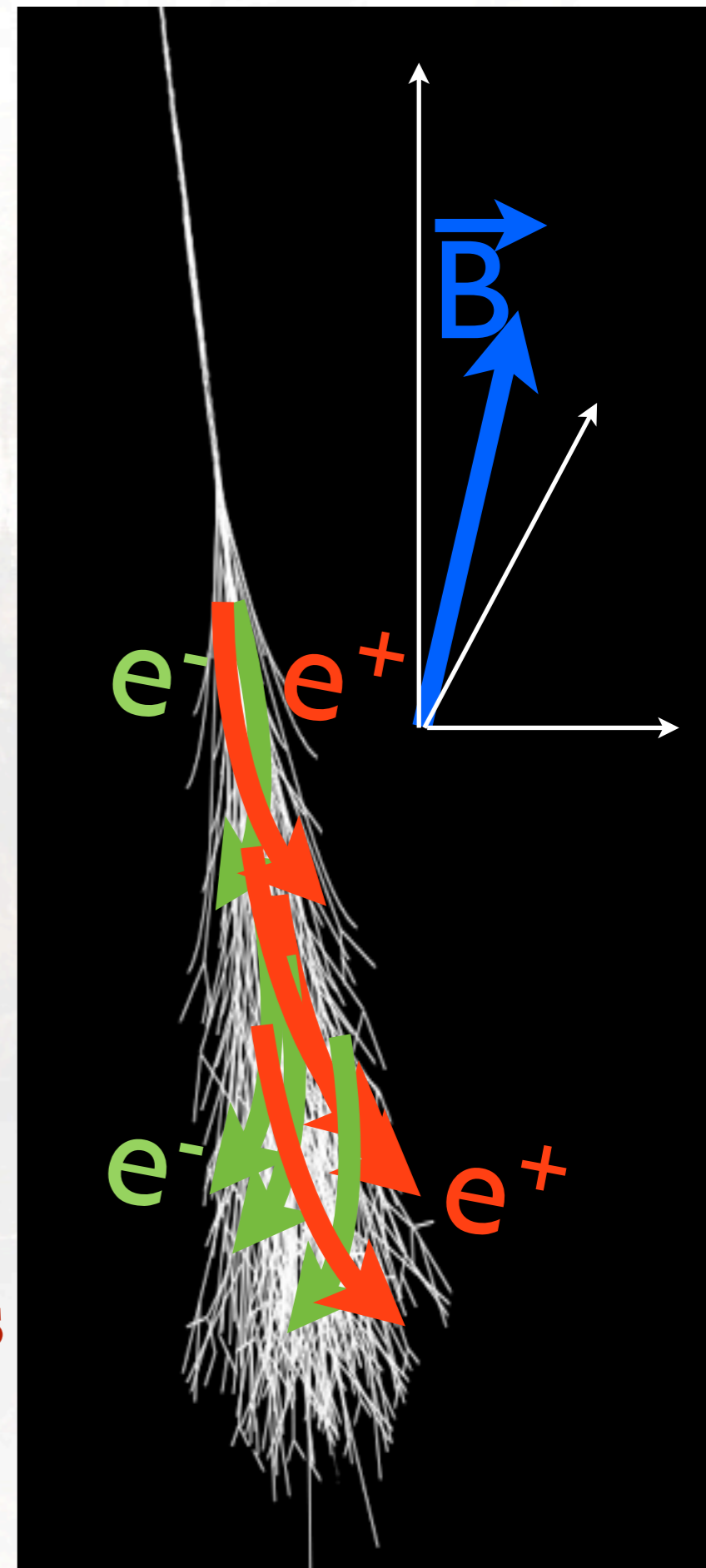
Due to Lorentz Force → Charge separation

Transverse current variation → Maxwell equations  
Electric field

- Charge excess contribution

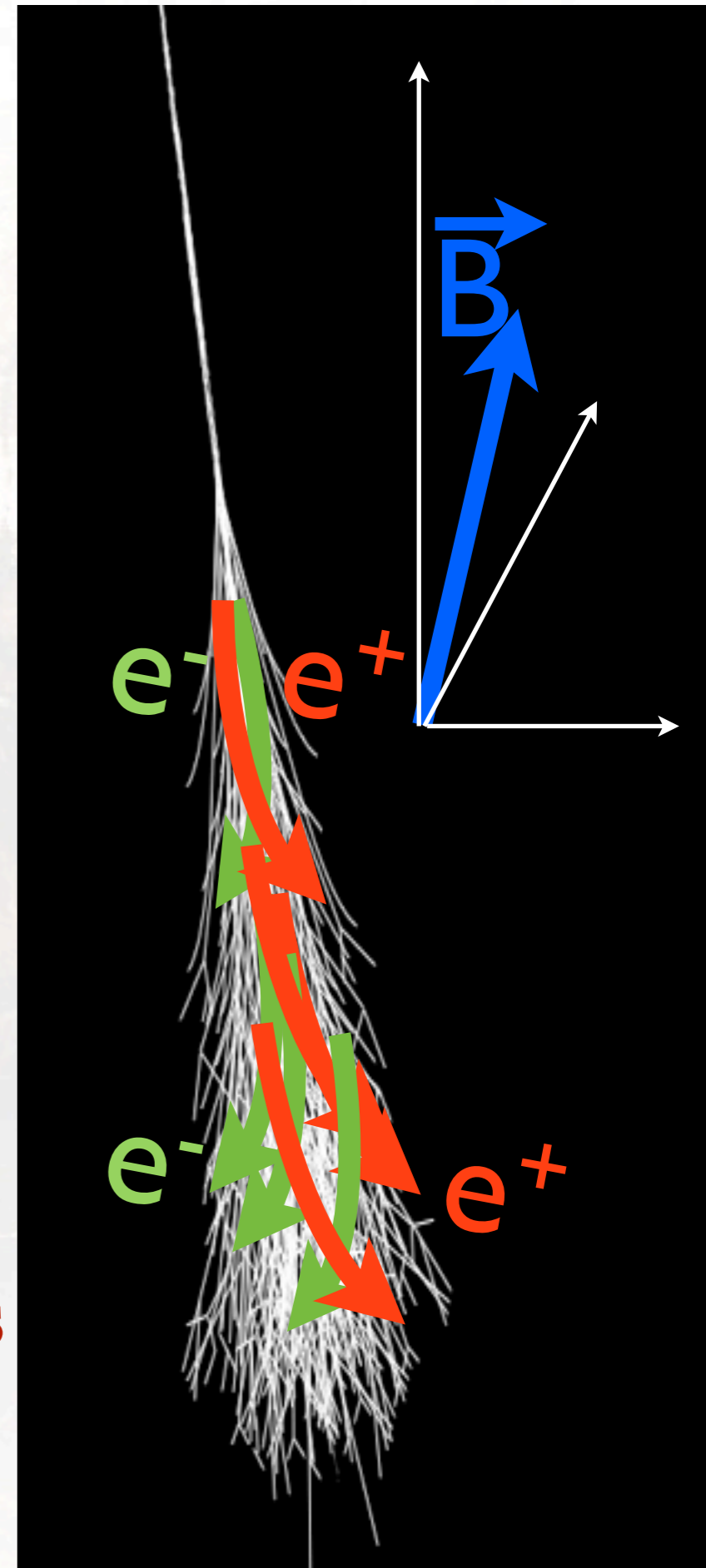
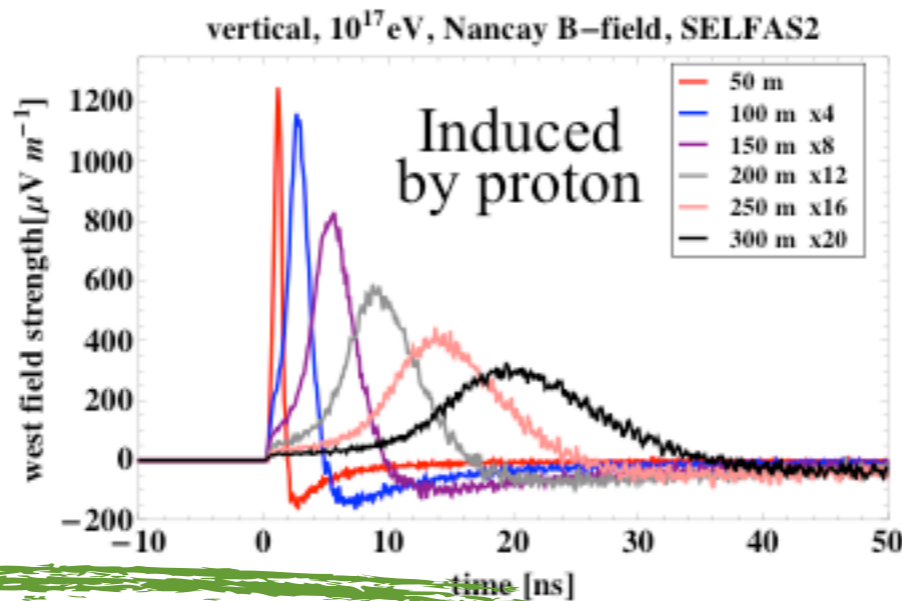
Electrons excess in the air shower → Residual negative charge

negative charge variation → Maxwell equations  
Electric field



# SELFAS2

*Simulation of Electric Field from Air Shower*



Geomagnetic mechanism contribution  
**Dominant, already**

**Due to observed charge separation**  
**Lorentz Force**

Transverse current variation → **Maxwell equations**  
**Electric field**

Charge excess contribution

**Second order contribution, search for its signature in our data**  
negative charge variation → **Maxwell equations**  
**Electric field**



# SEFAS2

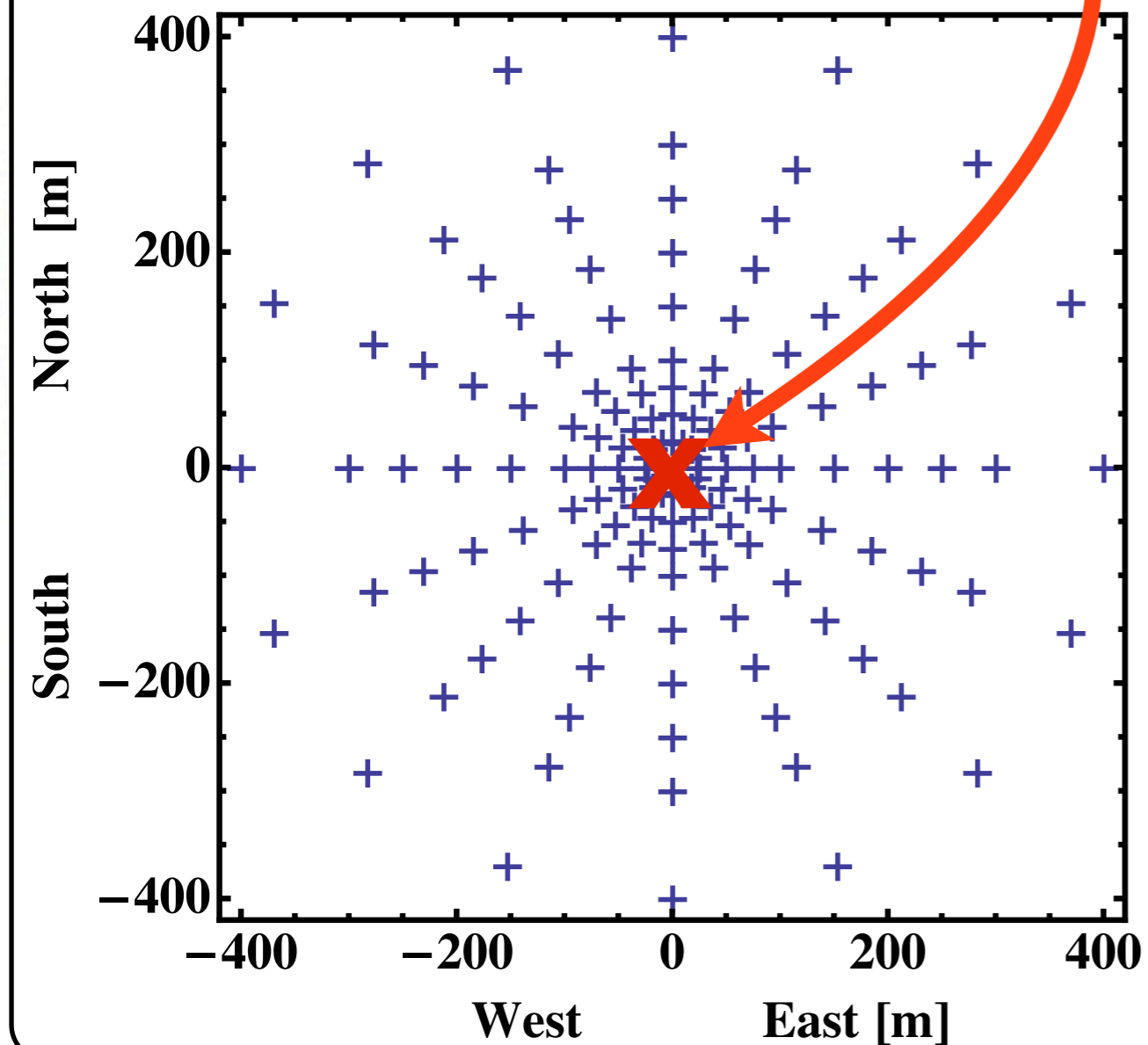
## Vertical event at CODALEMA

vertical shower,  $10^{17}$  eV,  
145 antennas

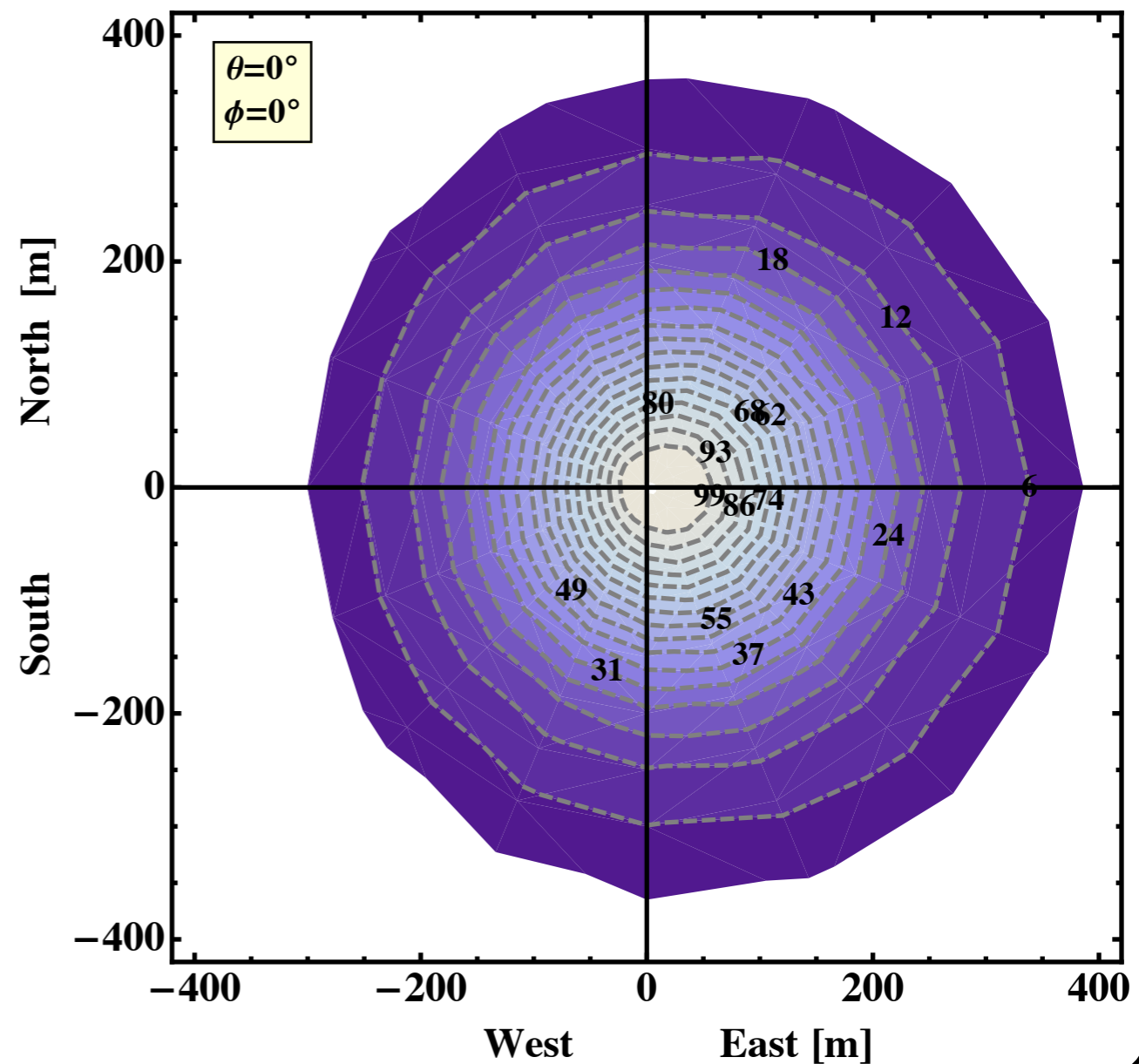
Ground core position in (0,0)

EW electric field absolute  
value on the ground

Antenna positions



East-west polarization



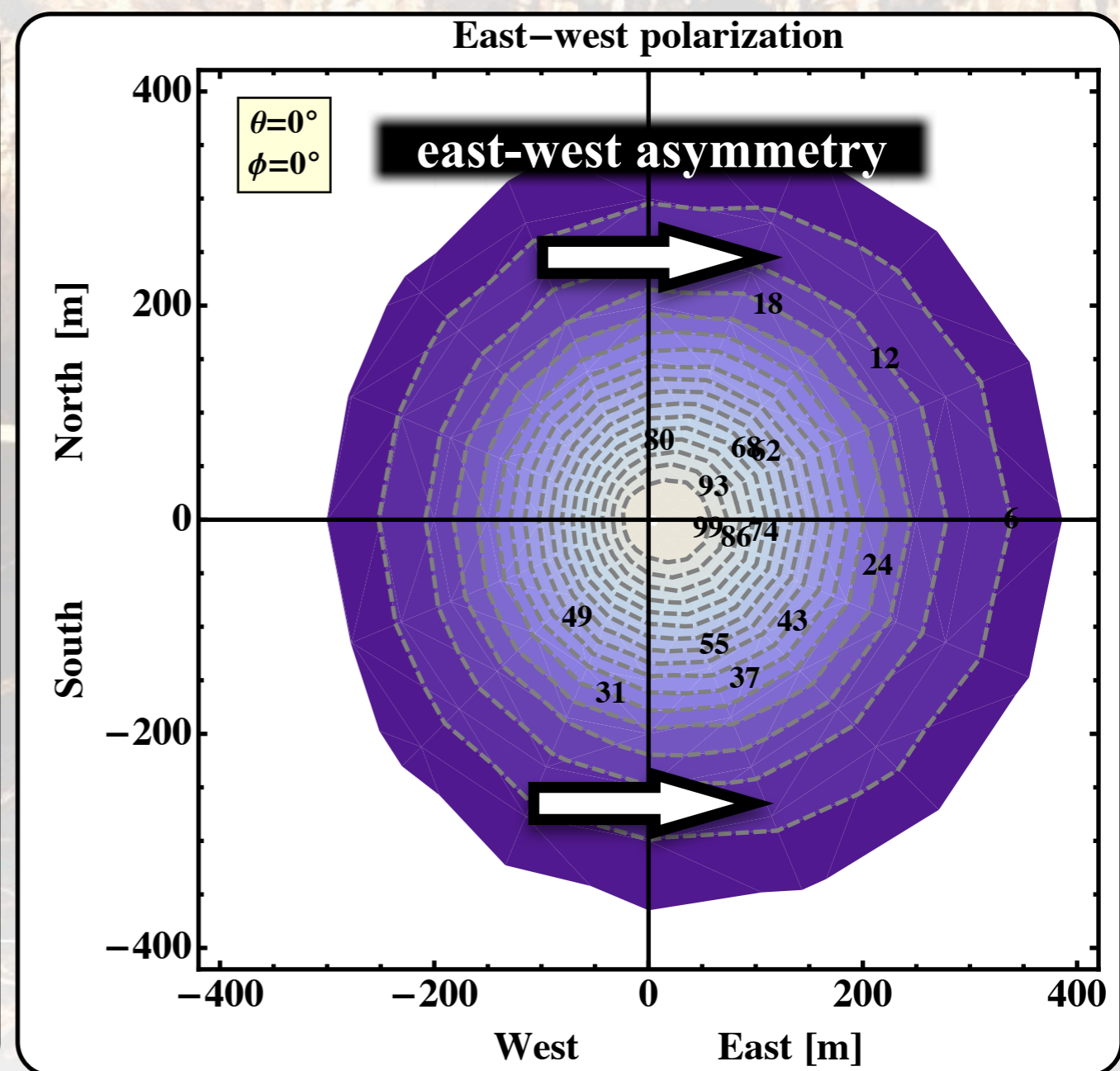
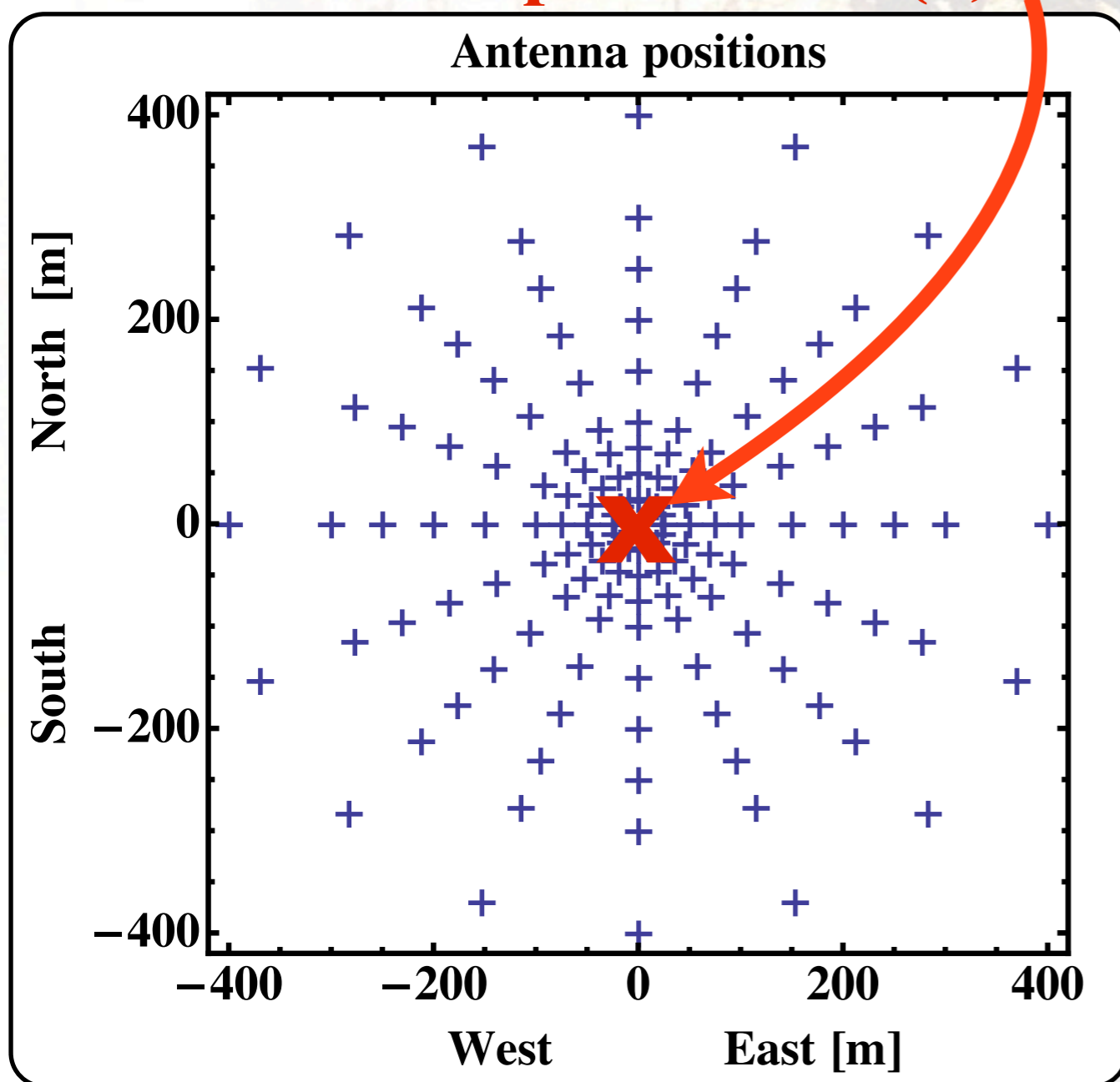
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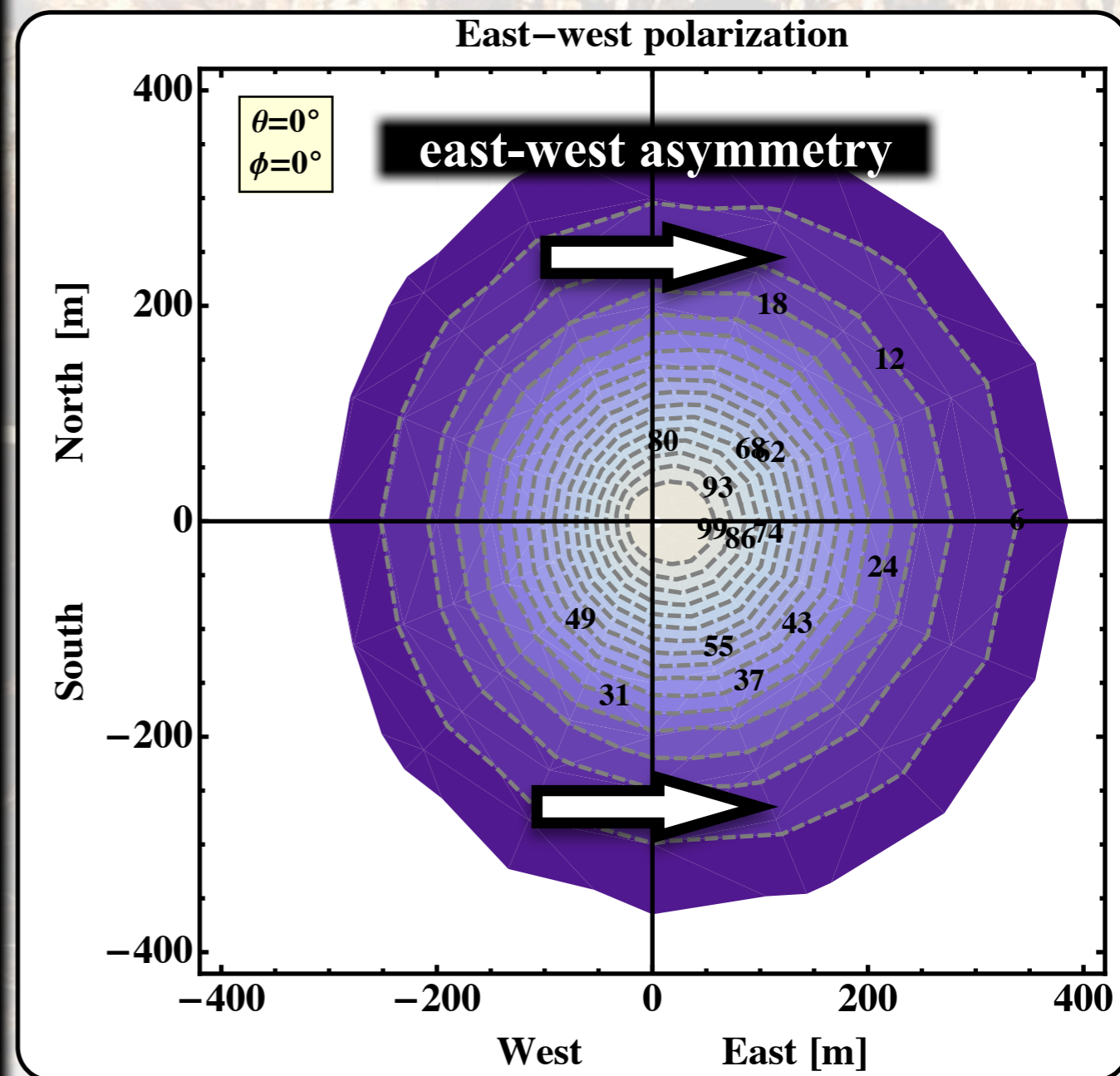
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EW electric field absolute  
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east-west asymmetry of  
the radio signal :

consequence of the  
charge excess  
contribution

Why?



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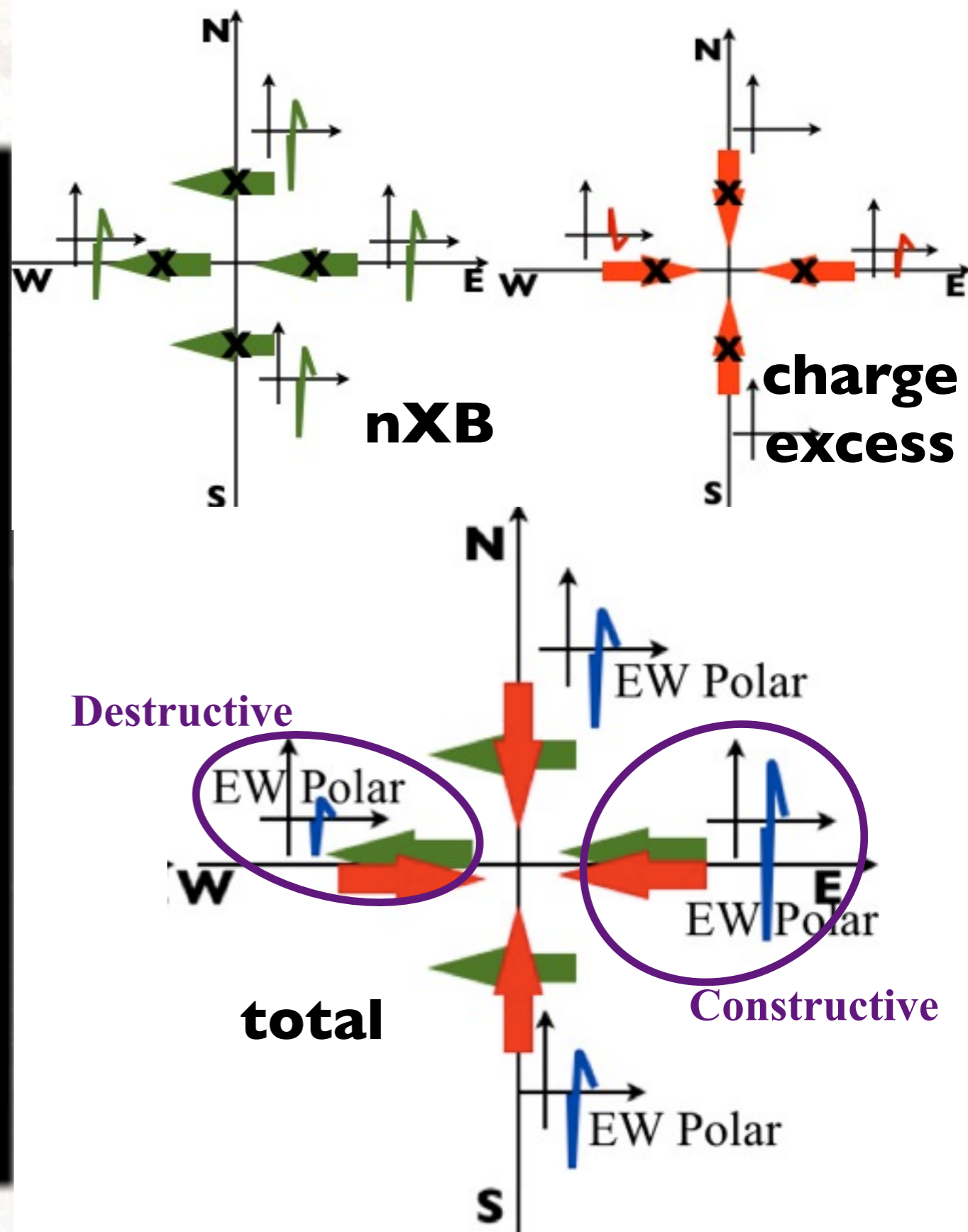
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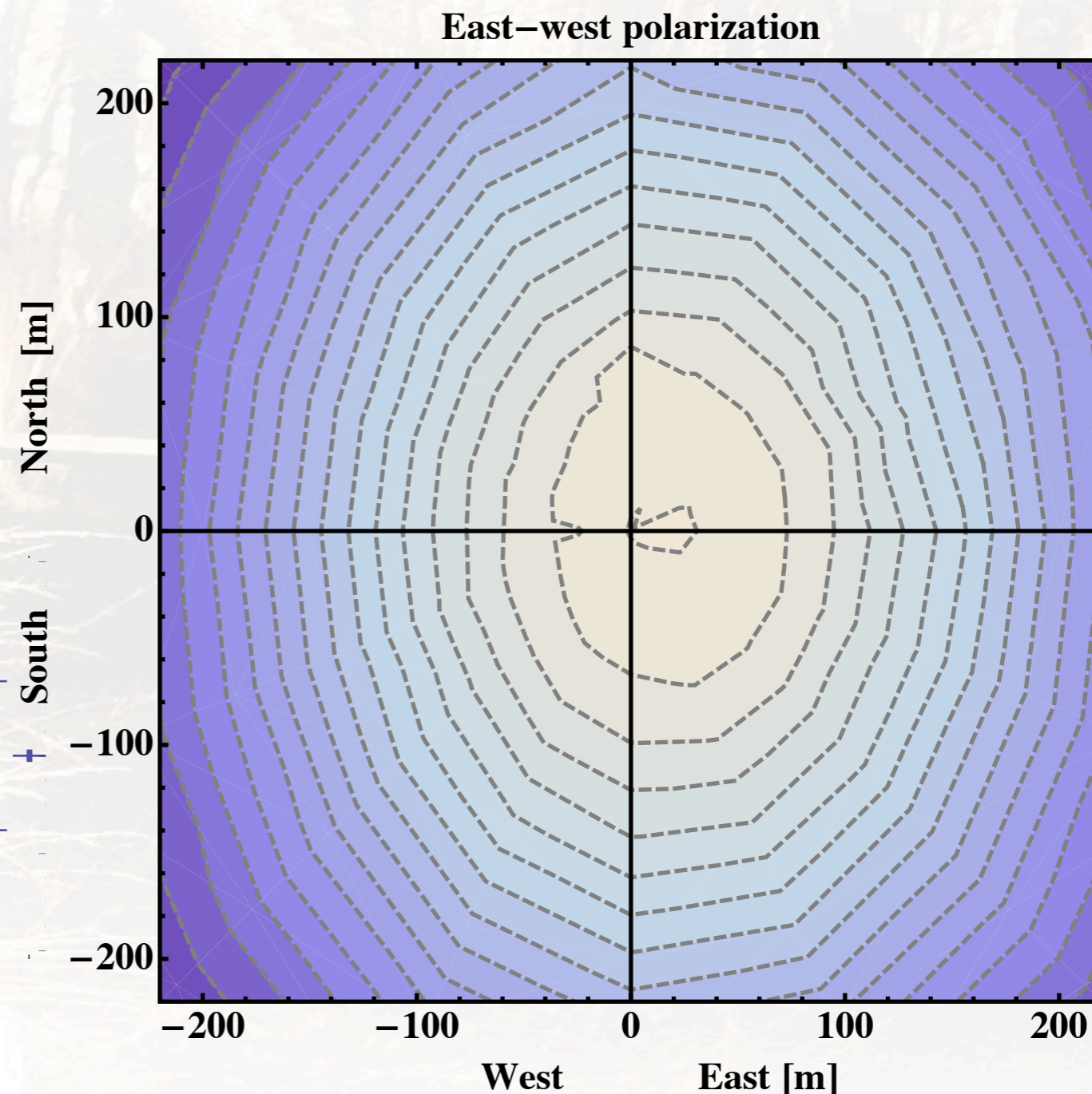
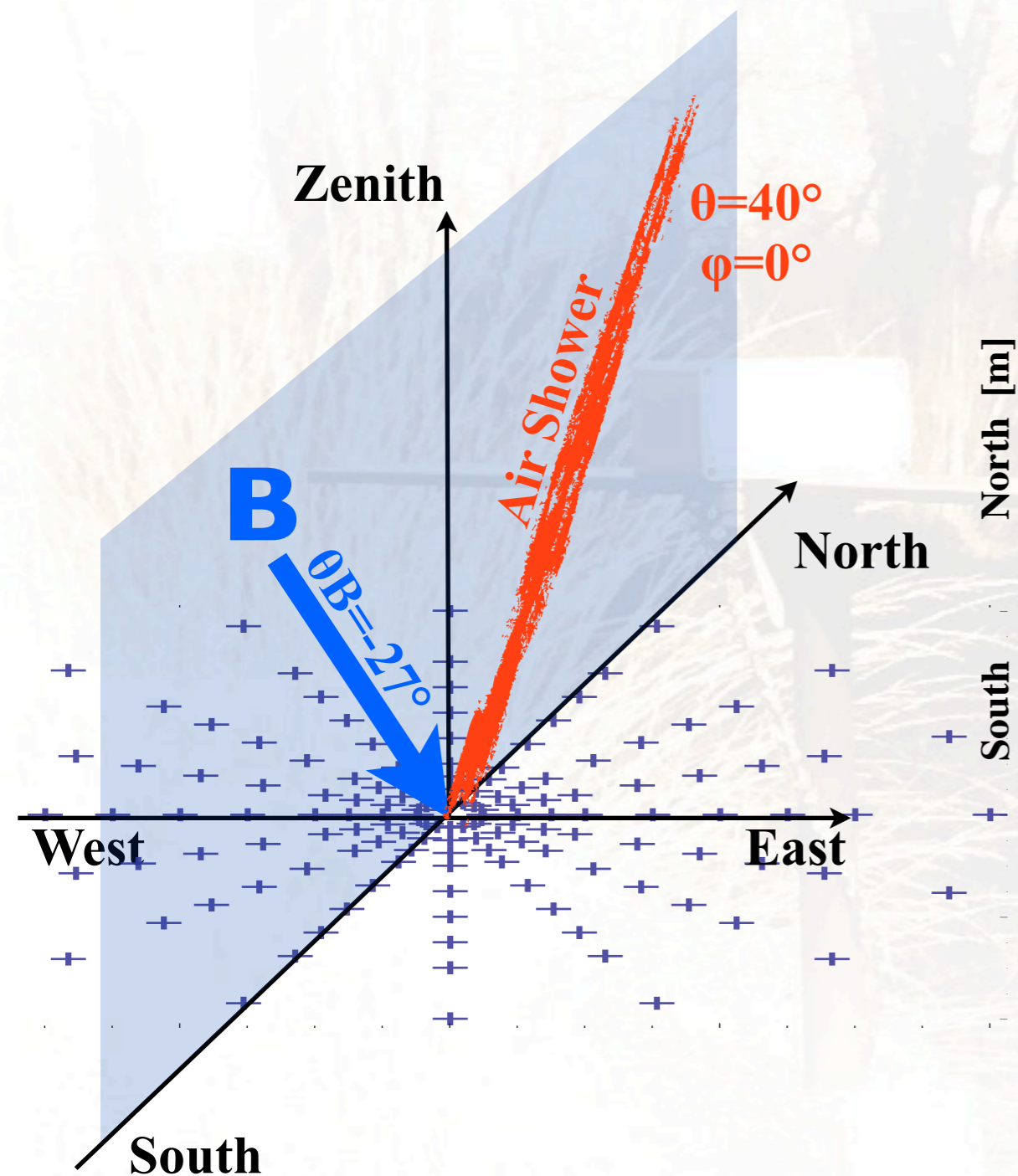


# SE/FAS2

## East-west asymmetry of the radio signal :

## Consequence of the charge excess contribution

### Dependence on arrival direction

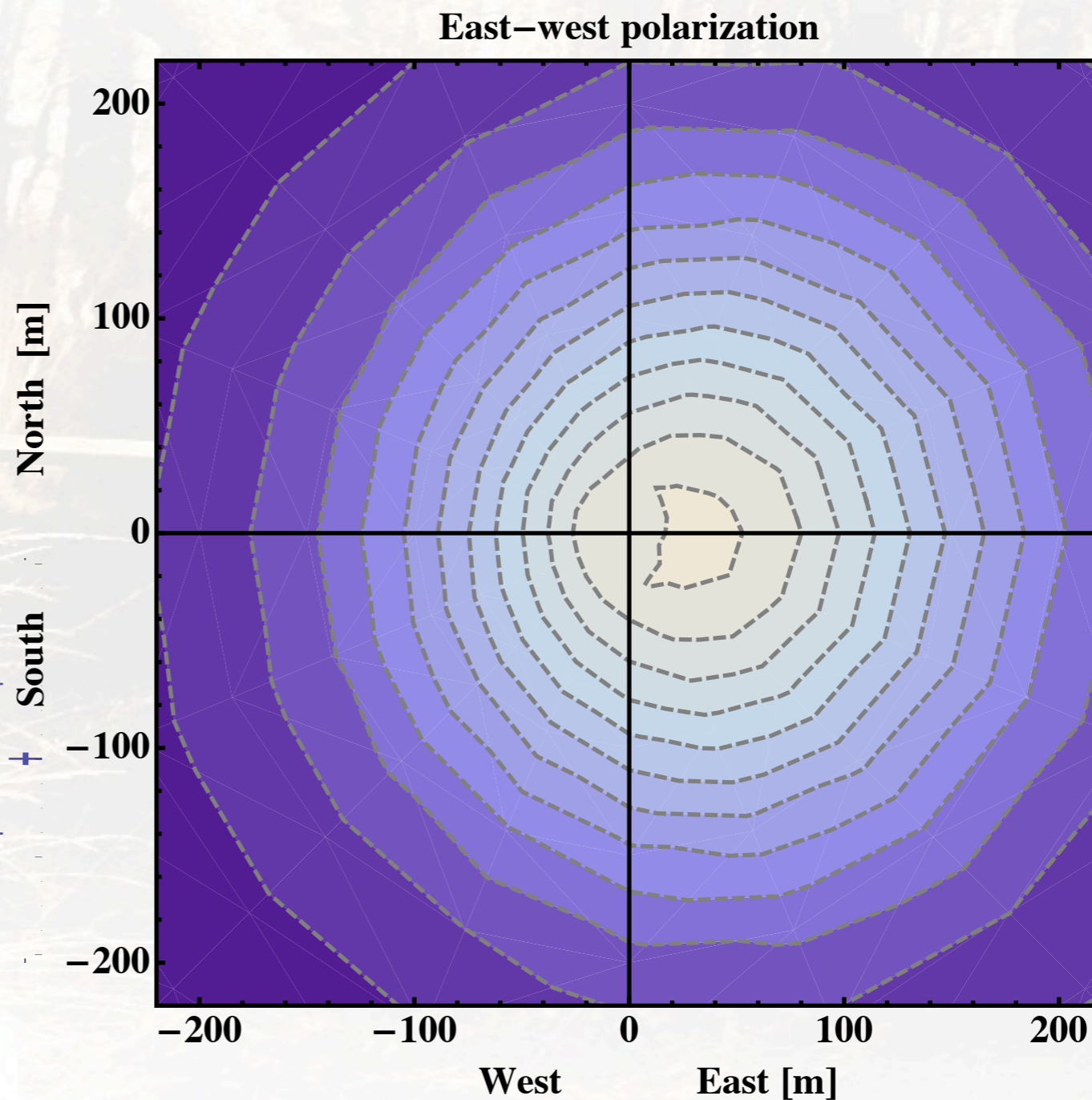
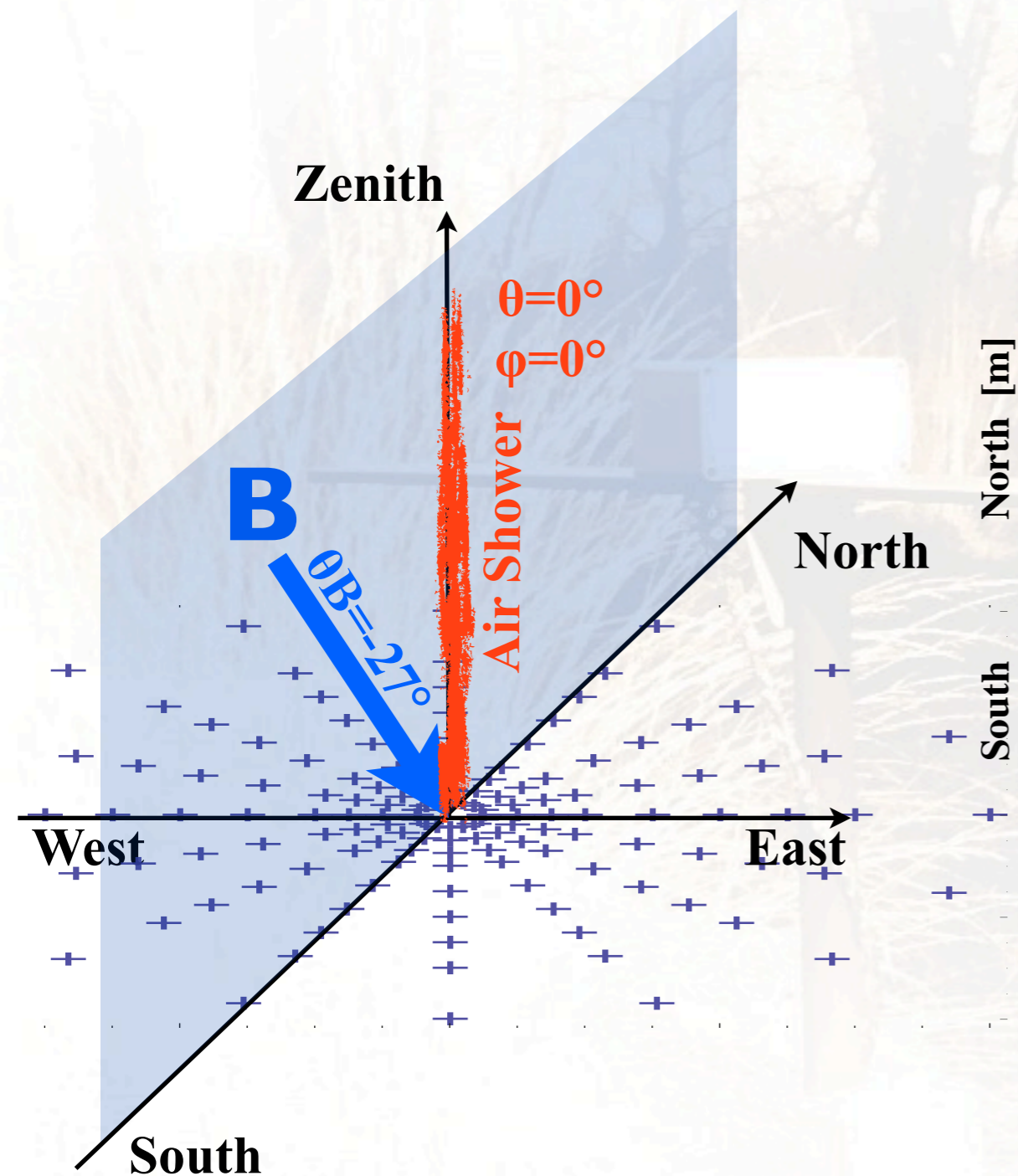


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East-west asymmetry of  
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## Effect on event for different arrival direction

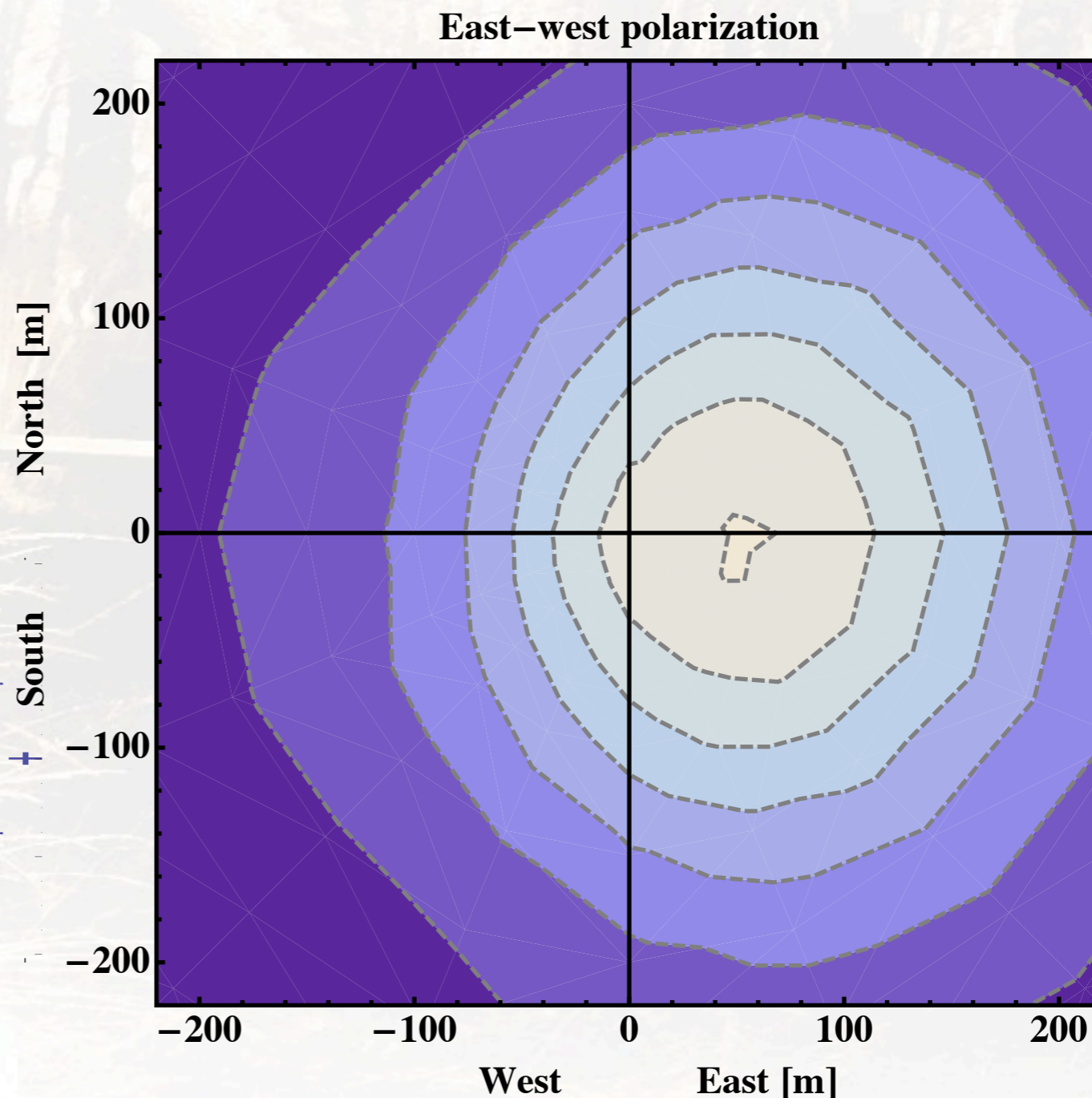
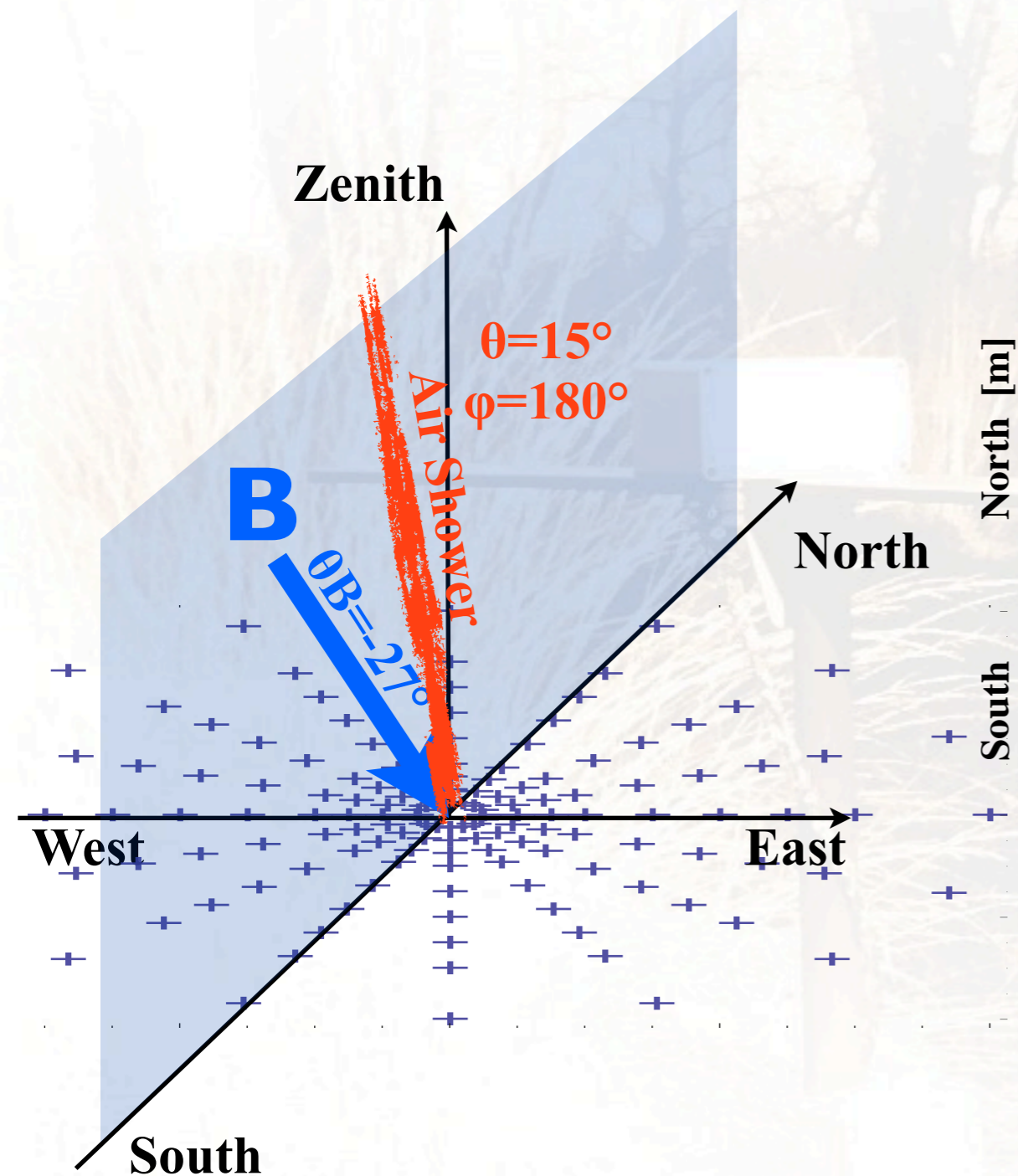


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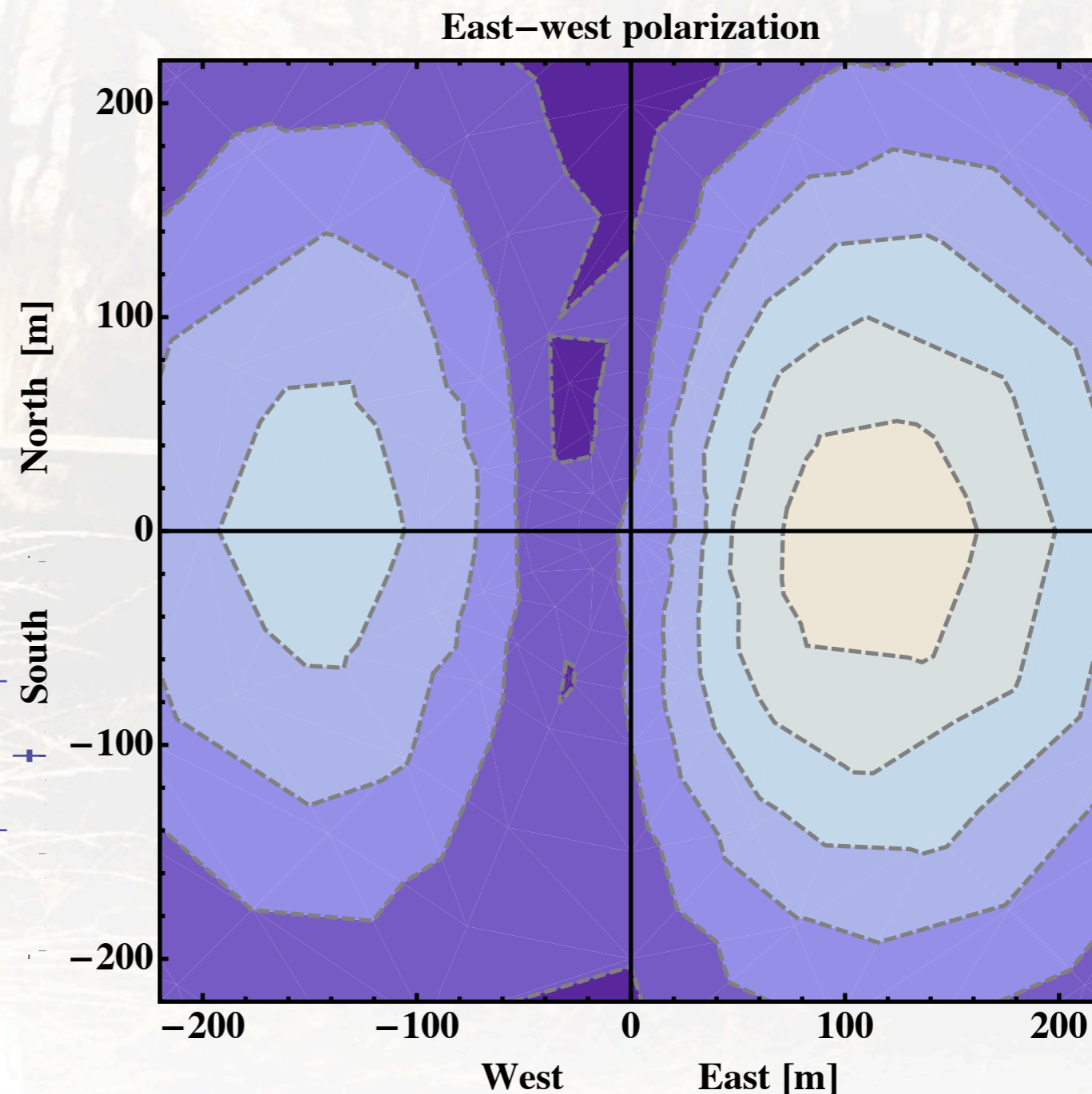
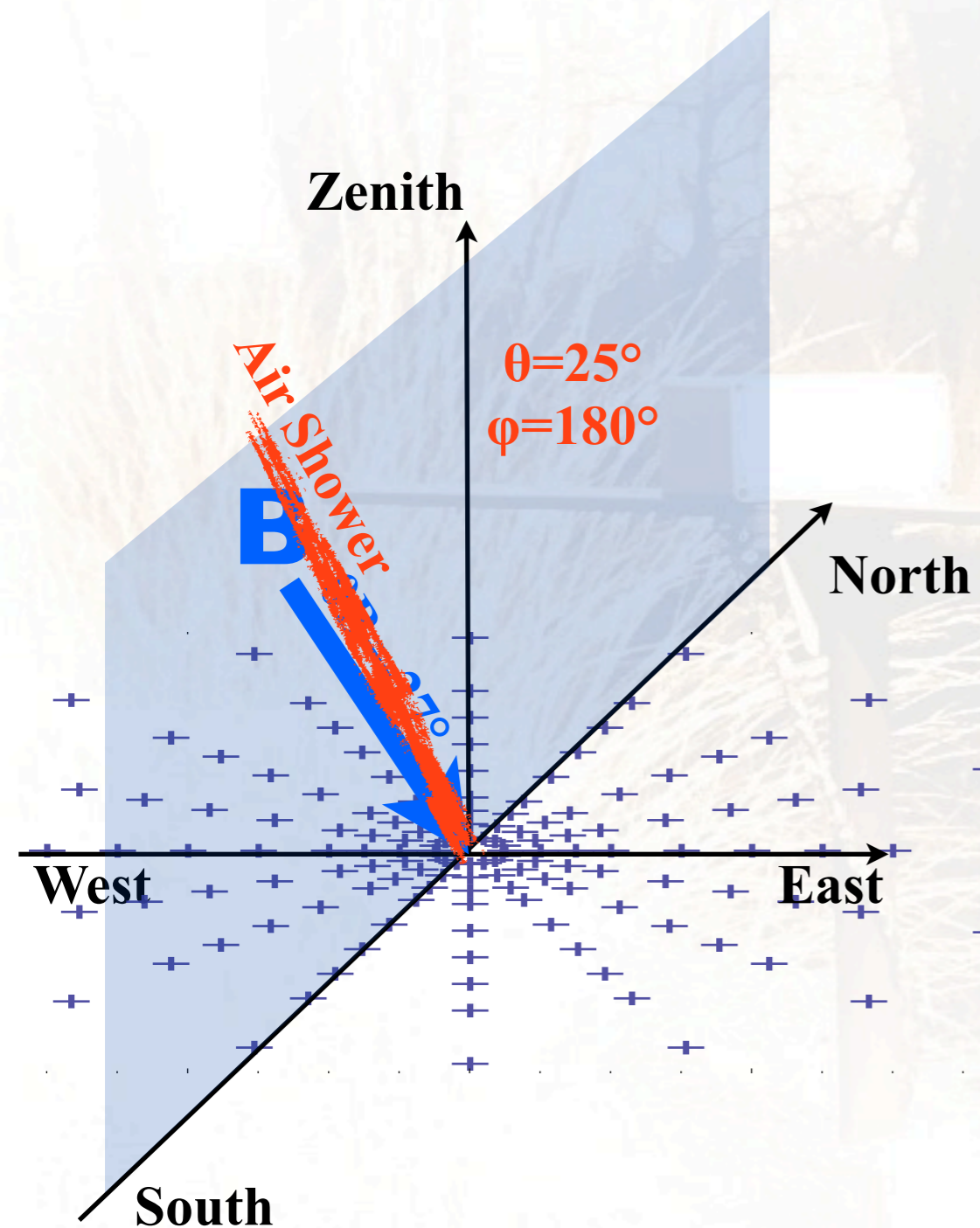


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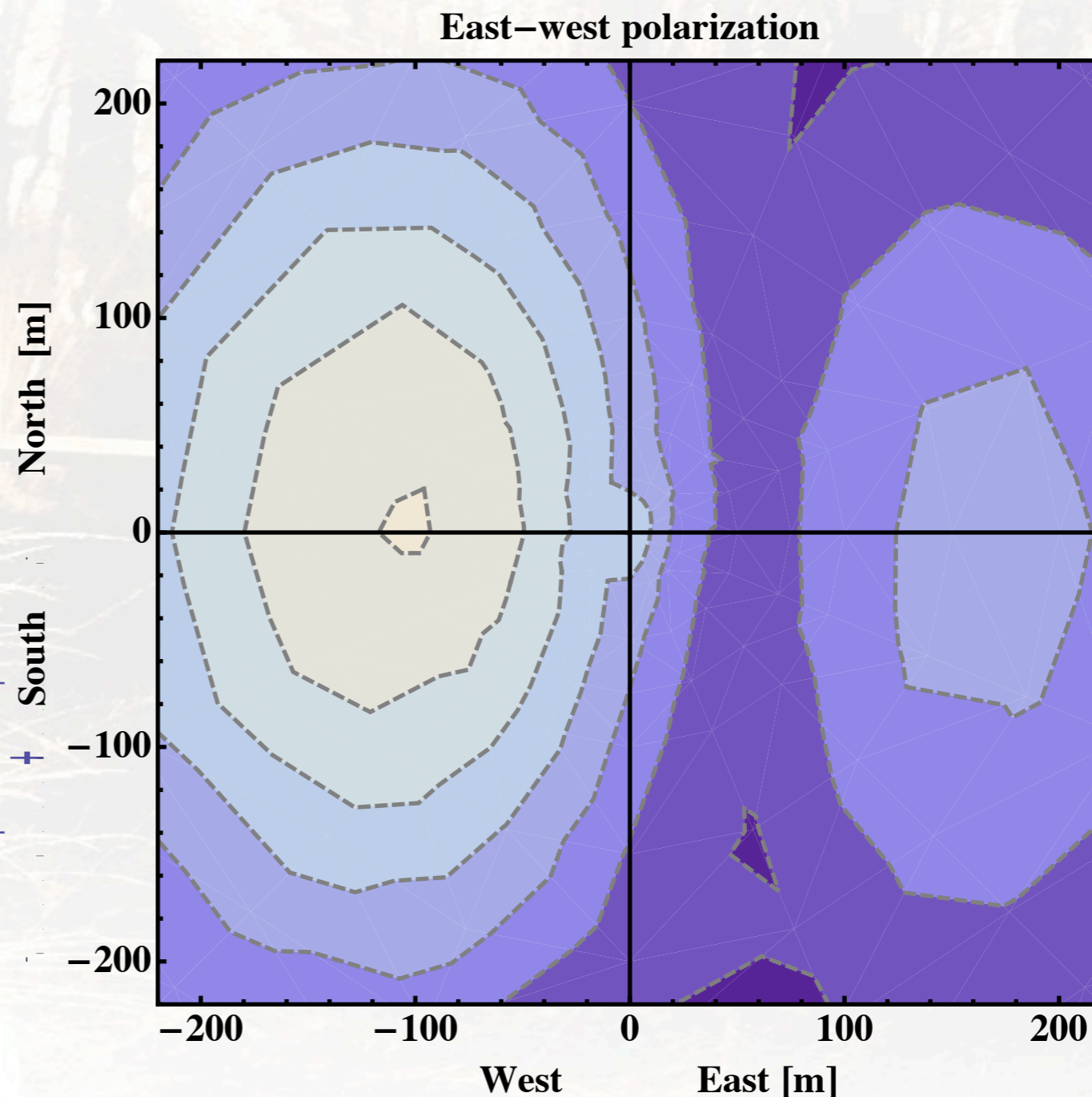
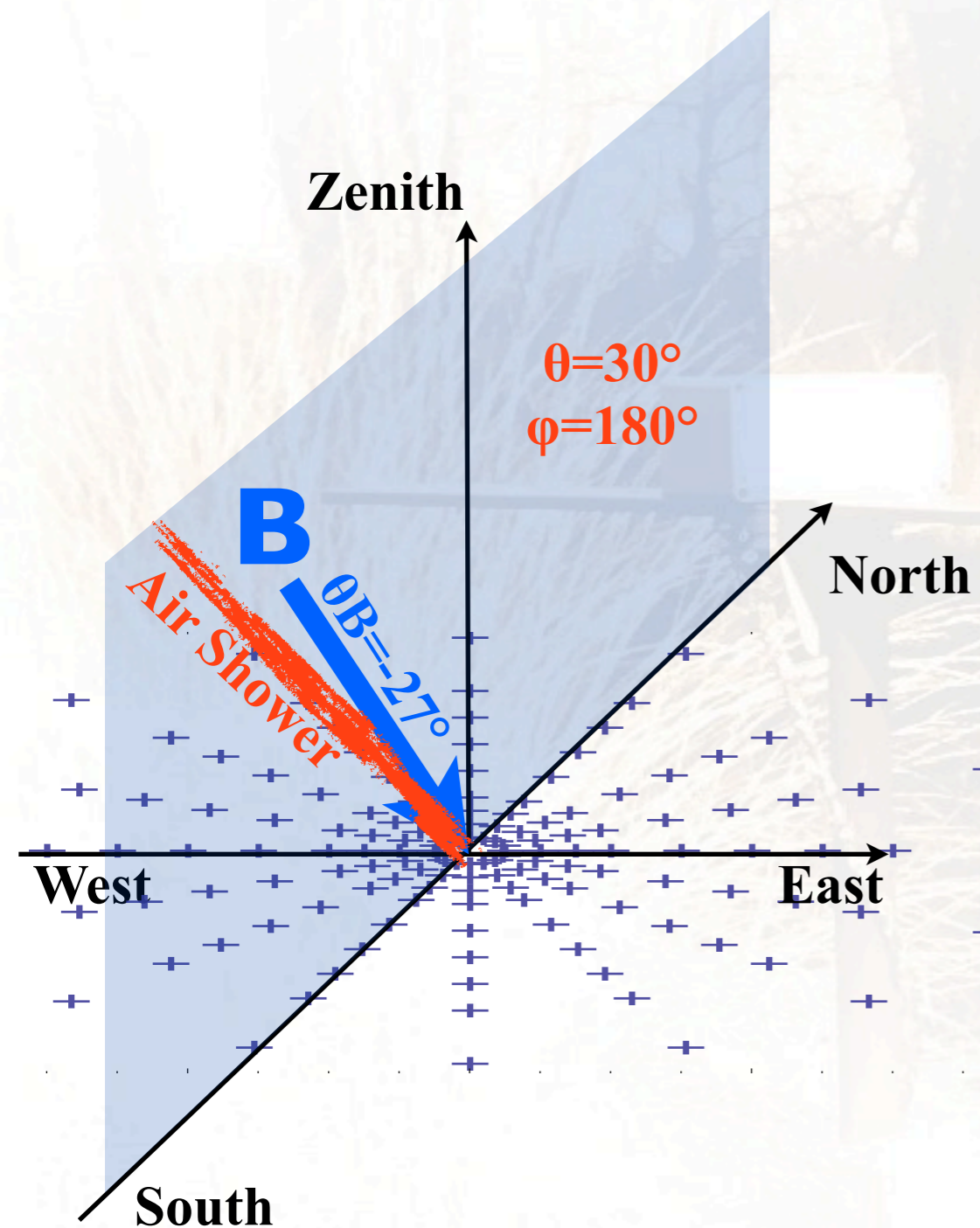


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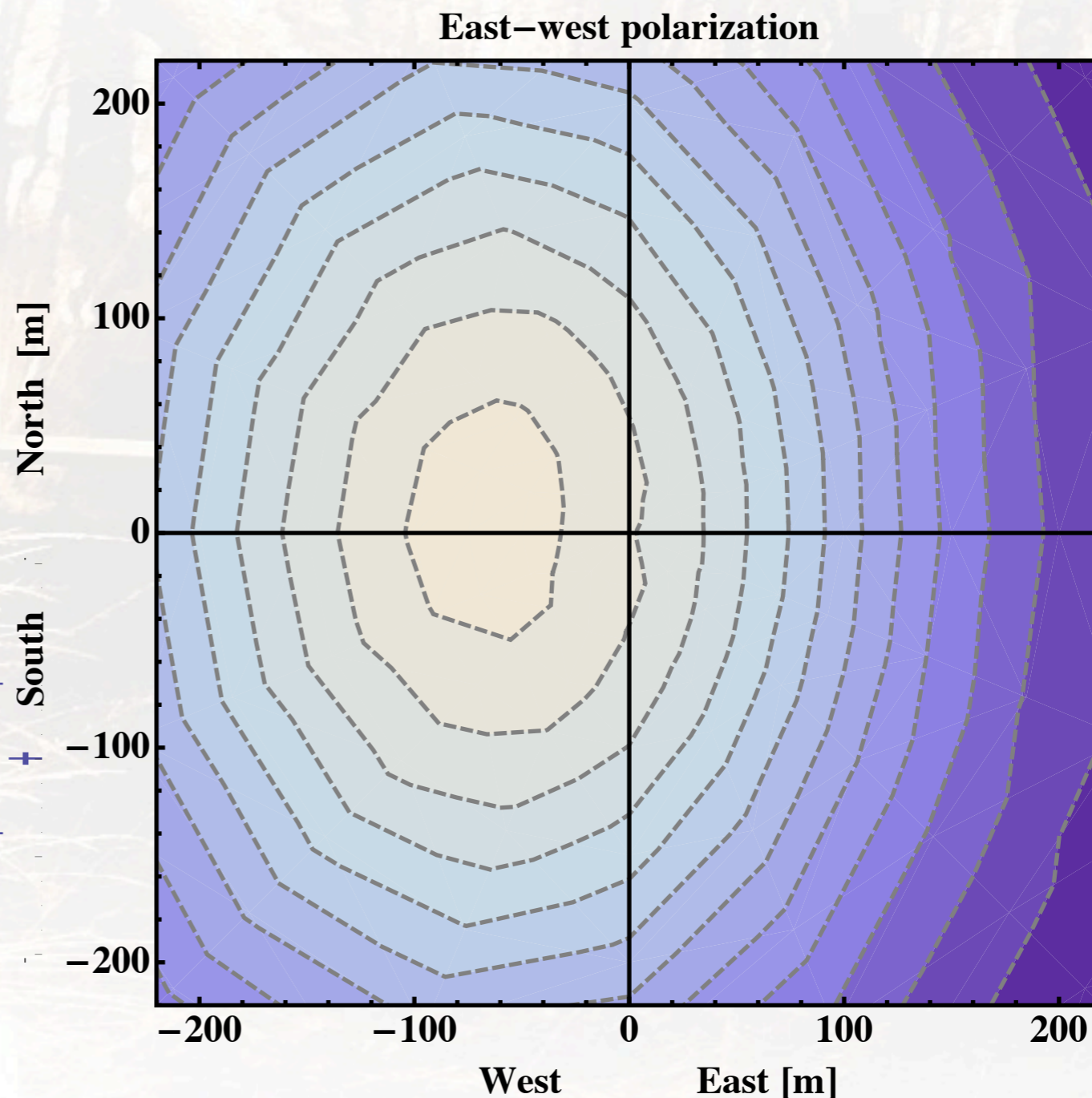
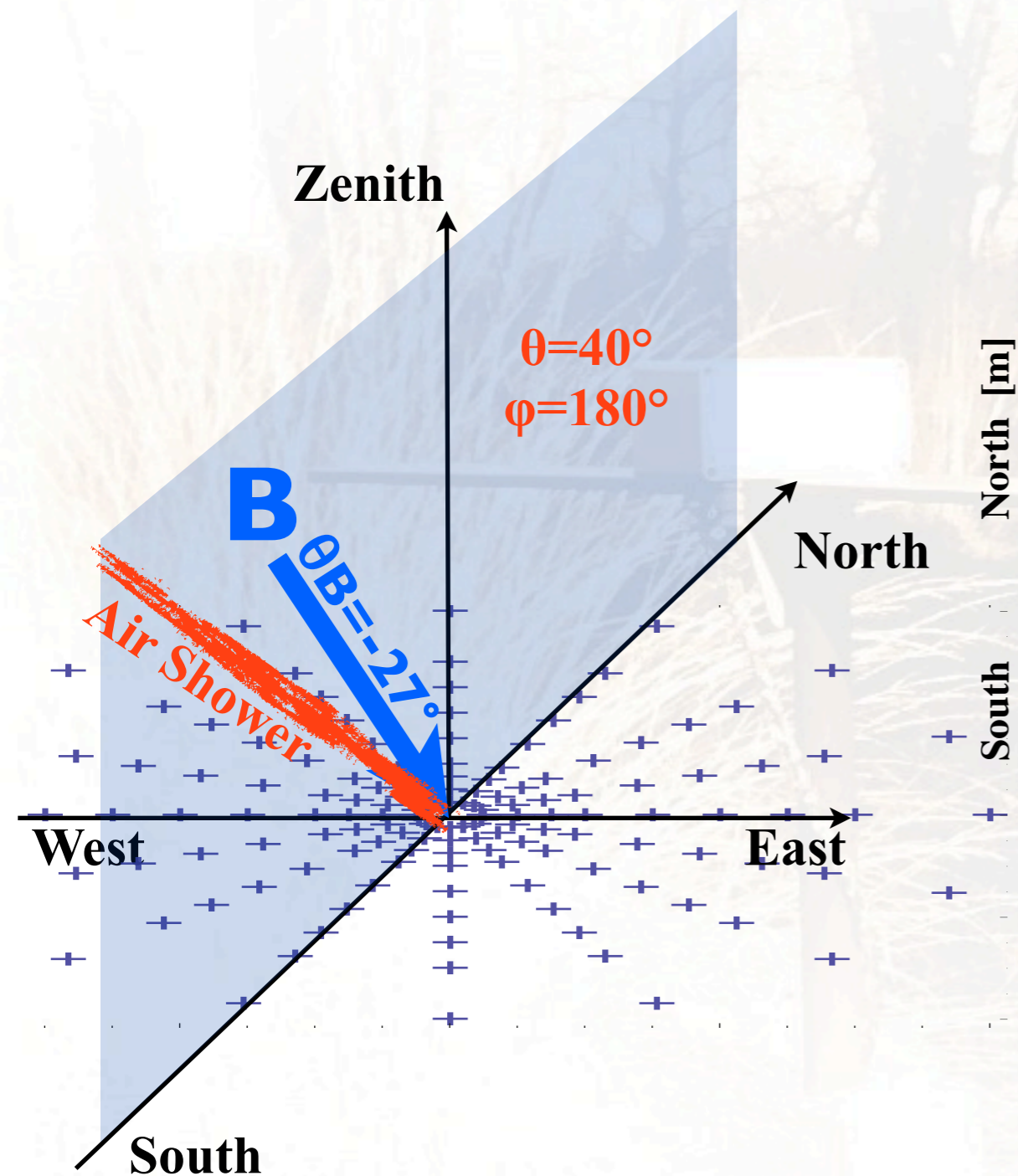


# SE/FAS2

## East-west asymmetry of the radio signal :

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SE/FAS2

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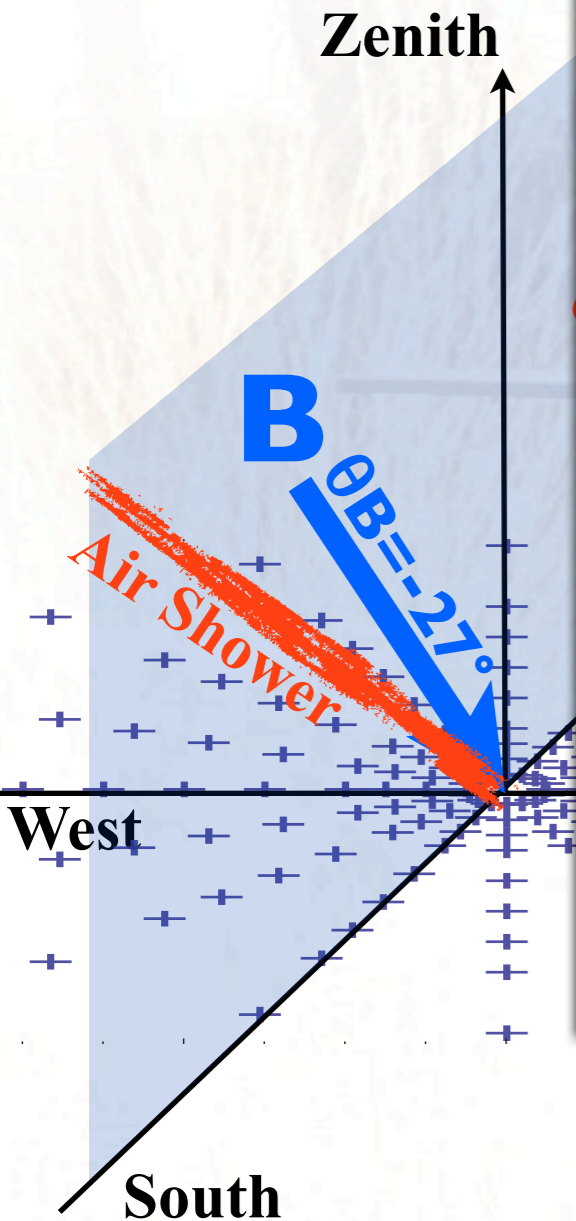
Consequence of the charge excess contribution

Effect on

SE/FAS2

direction

Simulation suggests that the east-west shift of the apparent radio core depends on the arrival direction of the shower



# Prediction for the CODALEMA statistics

Simulation with SELFAS2 of  
 $10^{17}$ eV proton air showers  
following the CODALEMA stat:

## We need:

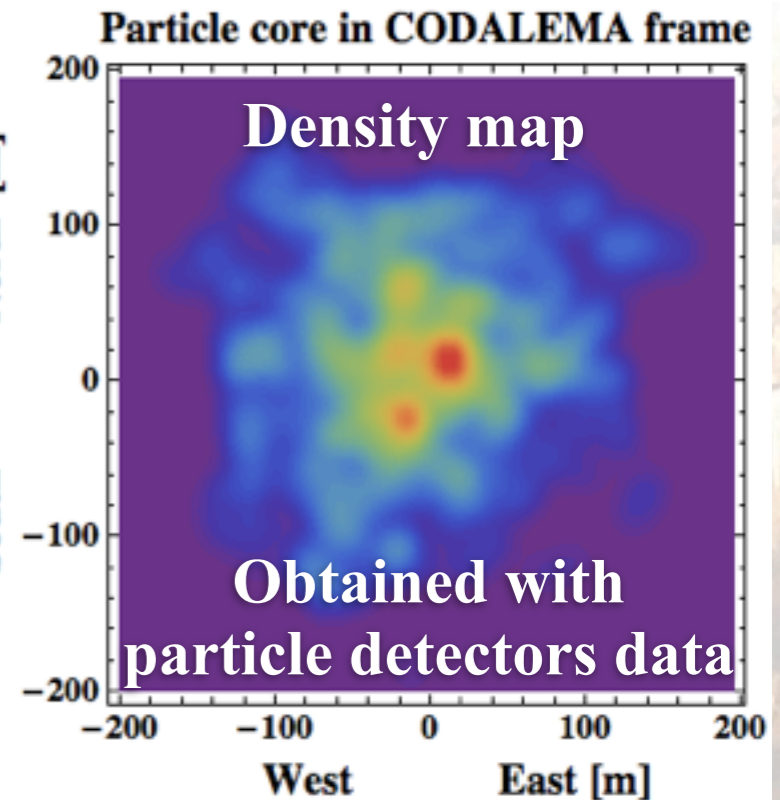
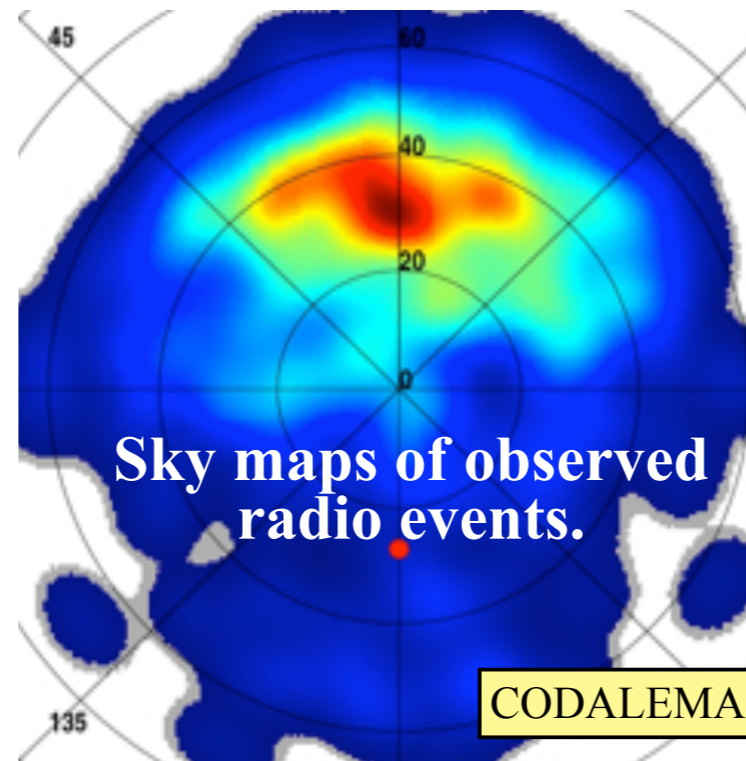
- arrival directions
- ground core positions

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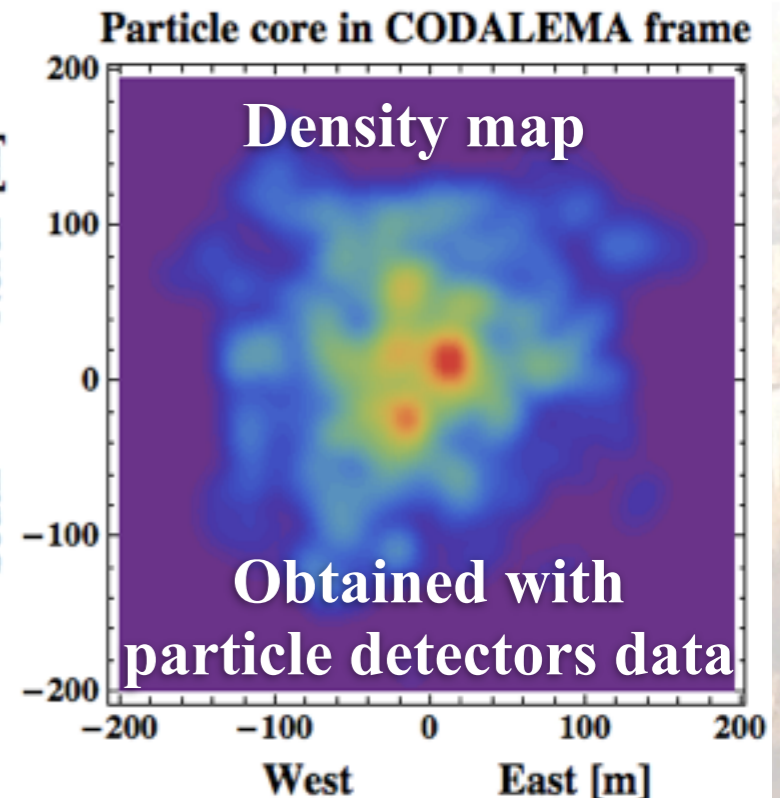
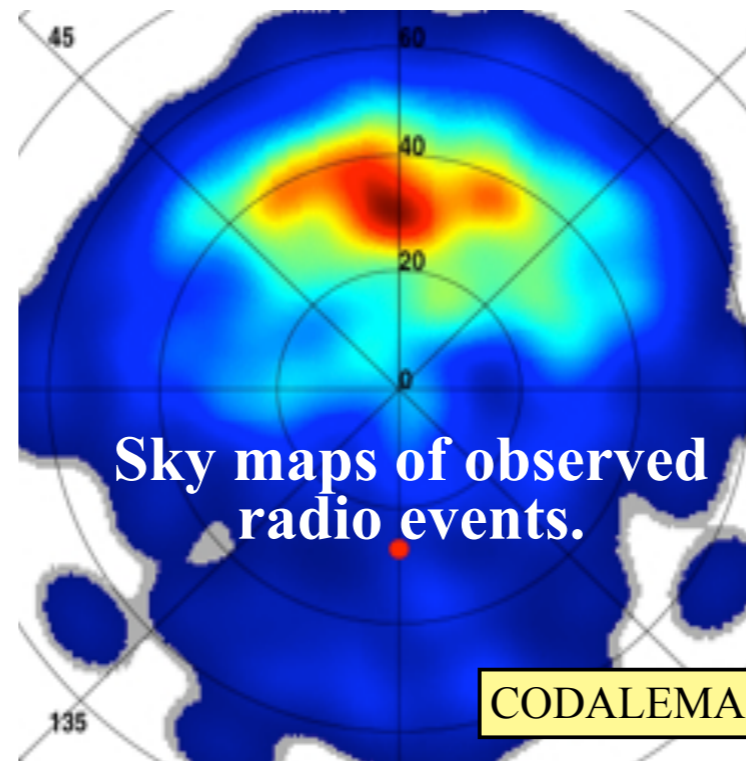
Monte Carlo sim. :  $(\theta, \varphi)$  and  $(X_{\text{core}}, Y_{\text{core}})$

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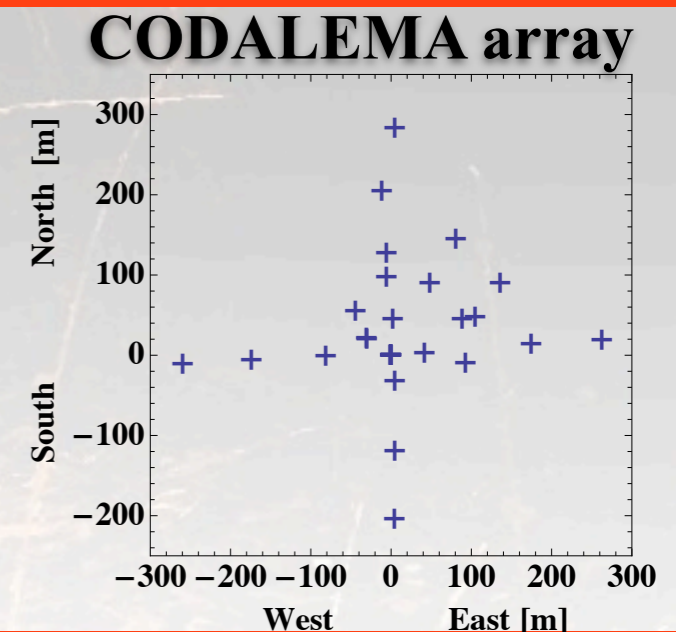
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Simulation  
with  
SELFAS2.2  
using

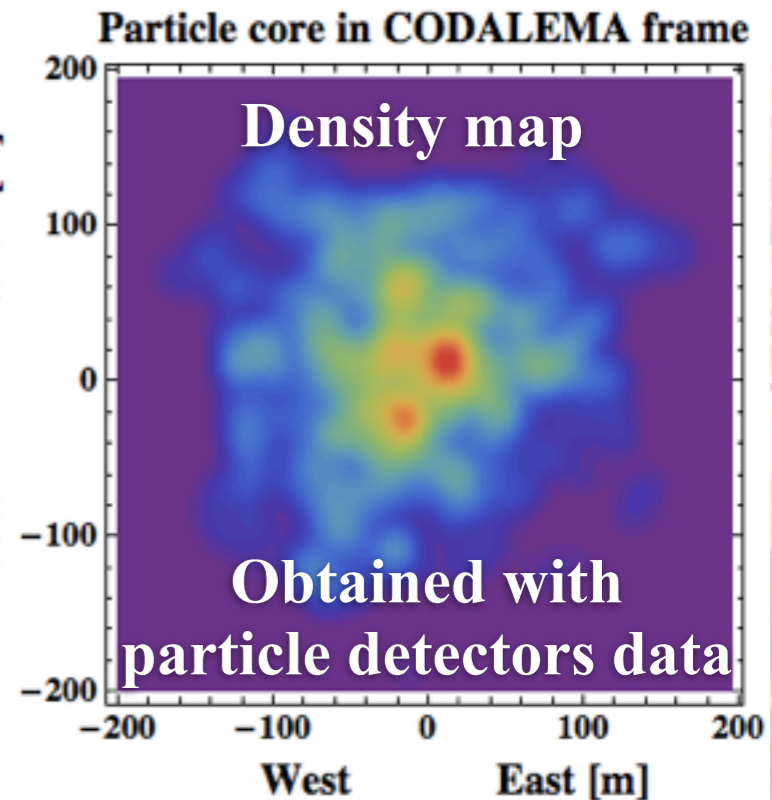
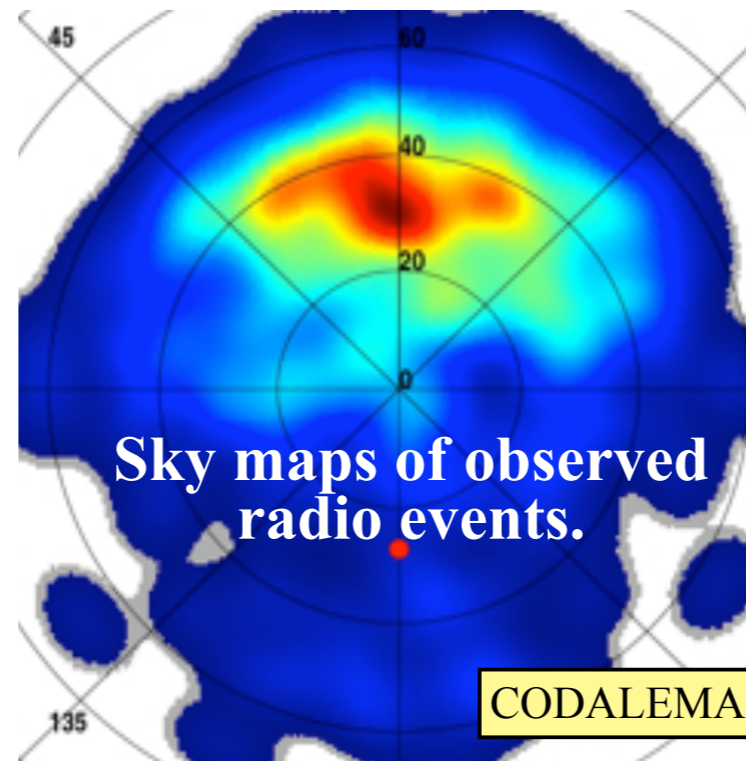


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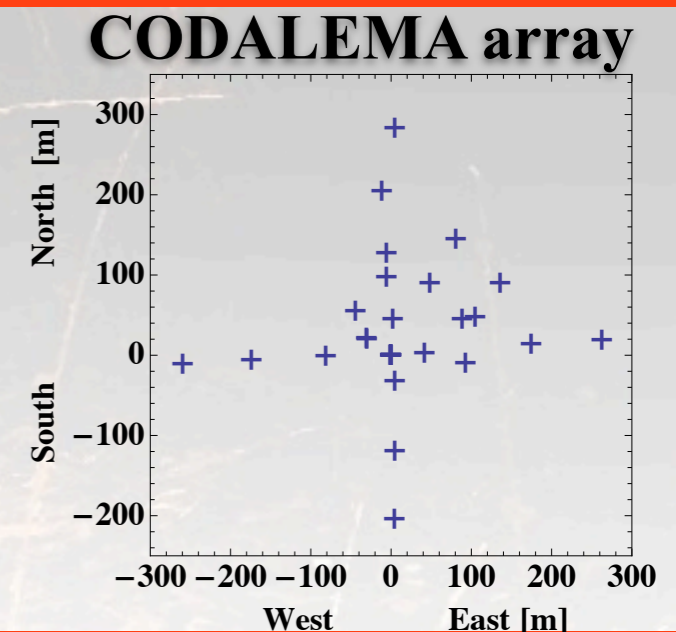
Event reconstruction with the CODALEMA analysis software

Lateral profile  $E_0 \cdot \exp(-d/d_0)$

4 free parameters:

$E_0, d_0, X_{\text{Rcore}}, Y_{\text{Rcore}}$

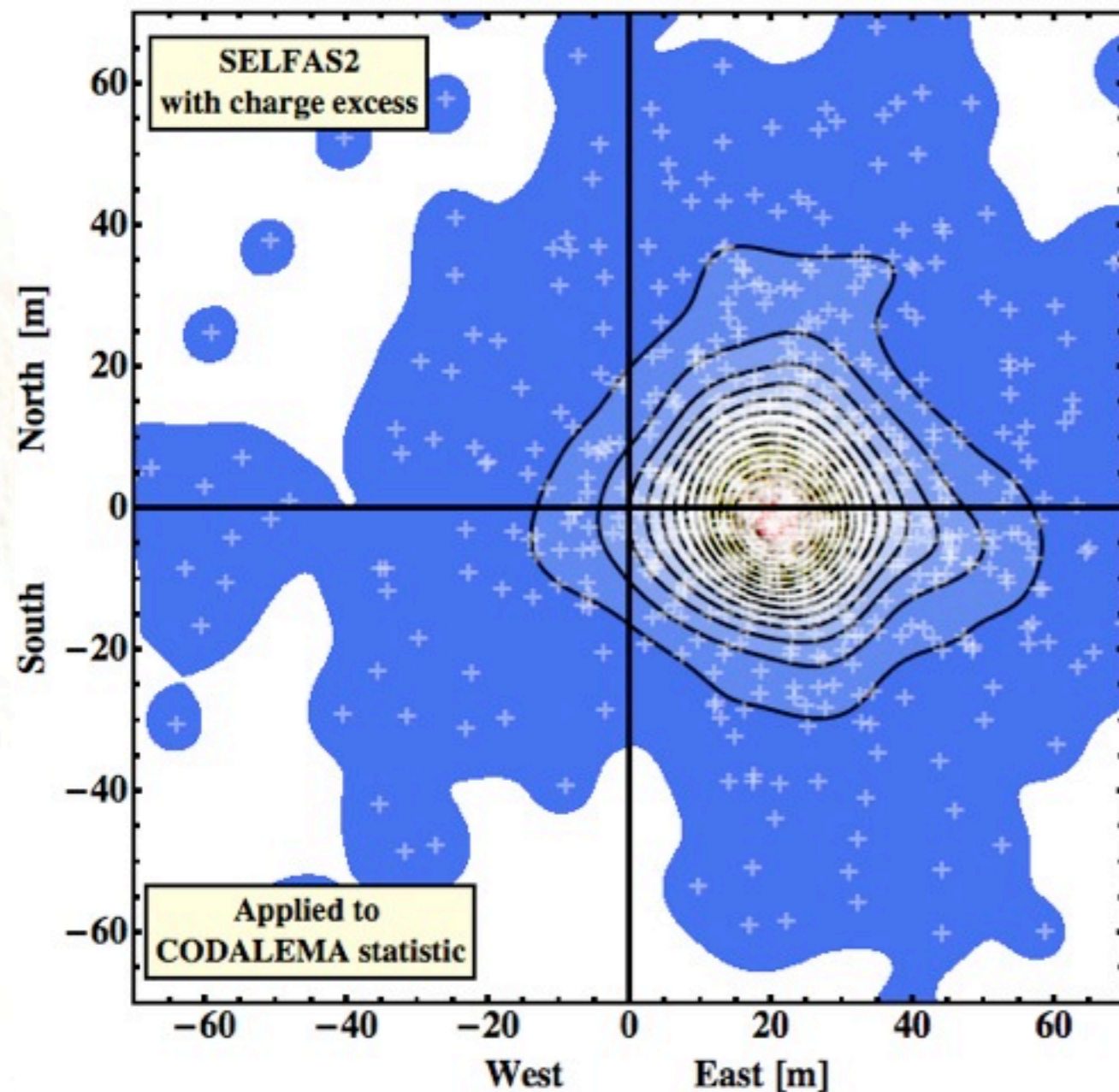
Simulation with SELFAS2.2 using



# SELFAS2 Reconstructed radio cores from simulation

For each **simulated** event, the reference frame is centered on the ground particles shower core

Reconstructed radio cores in shower core frames

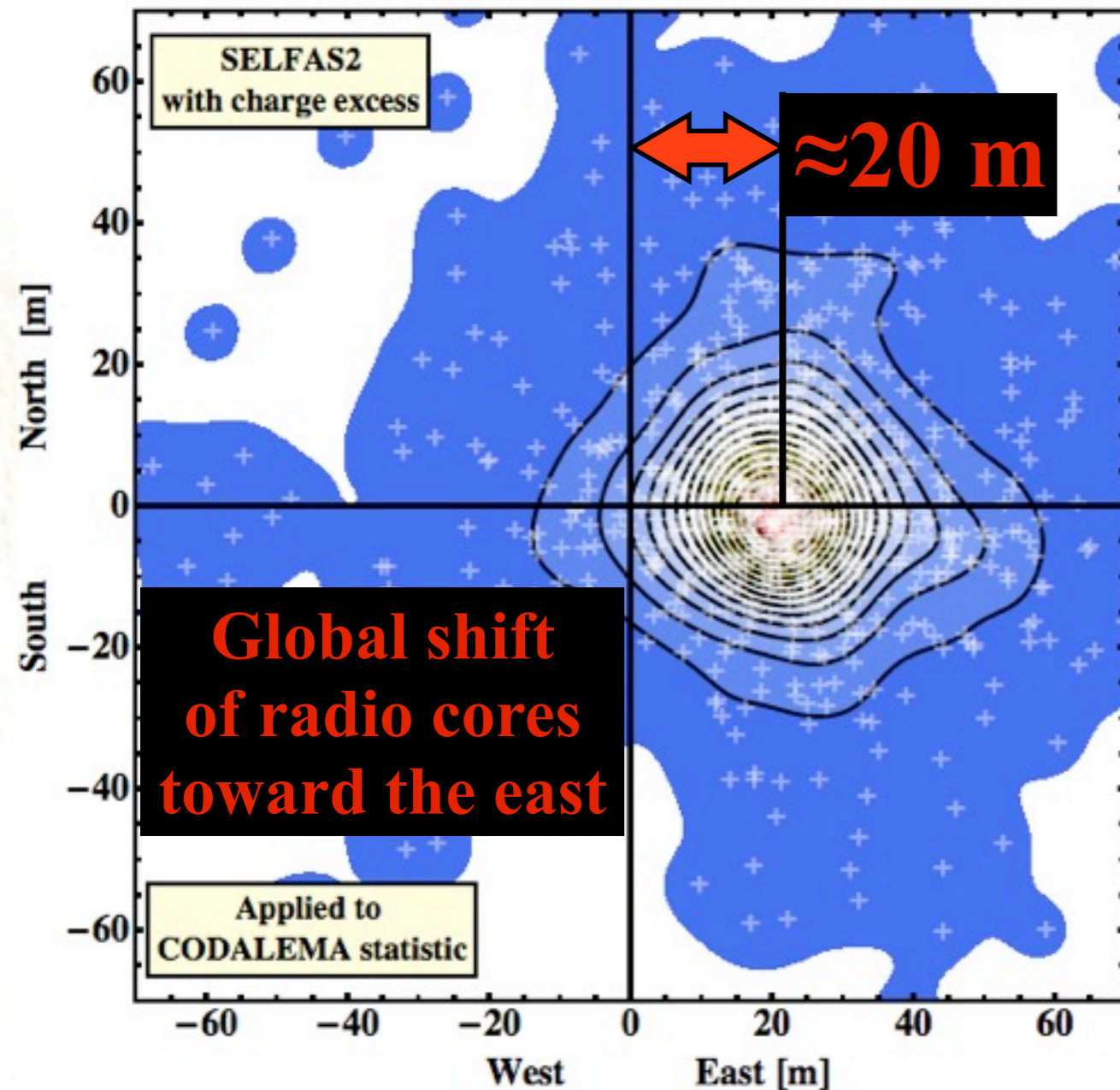




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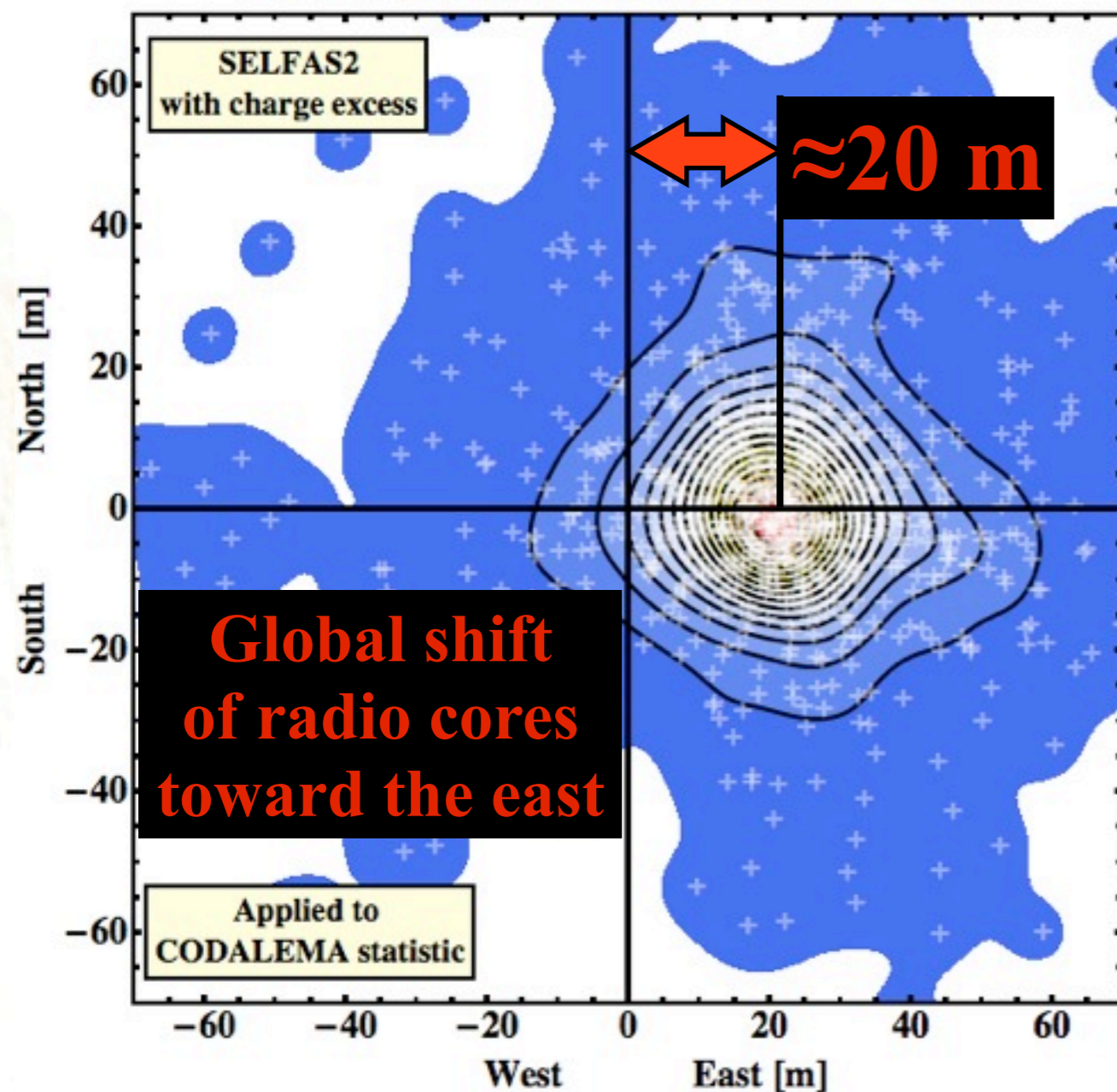
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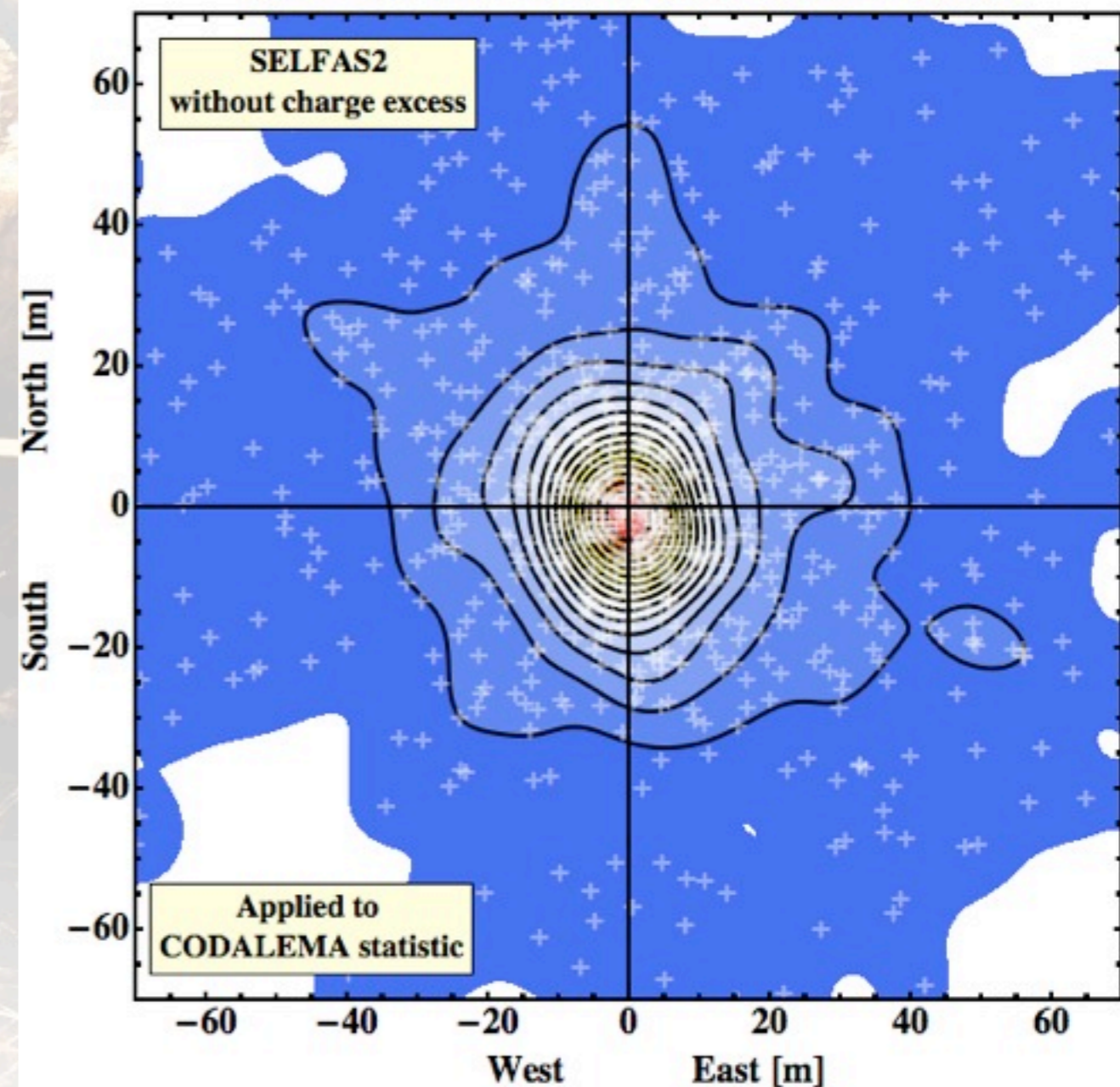
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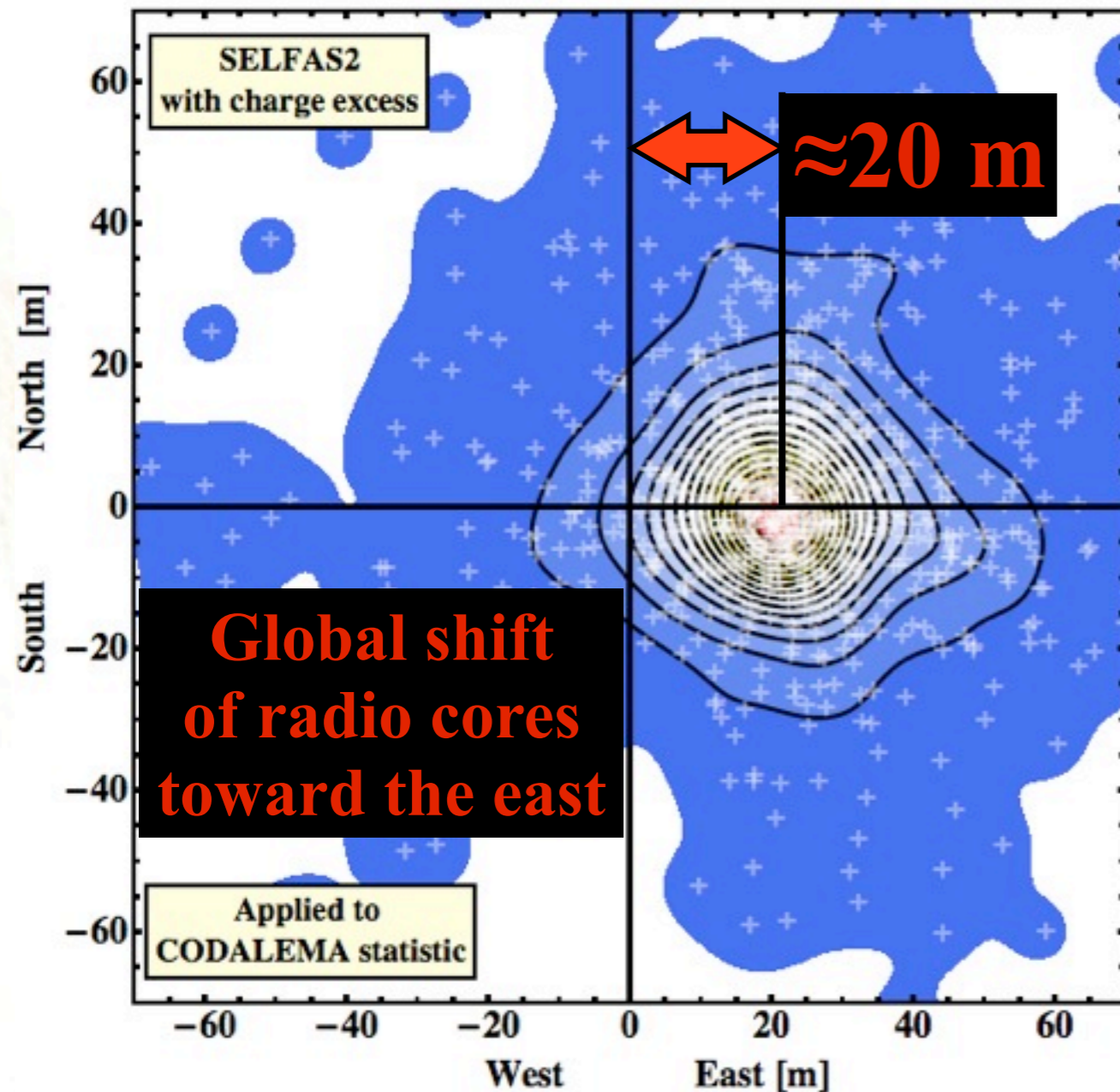
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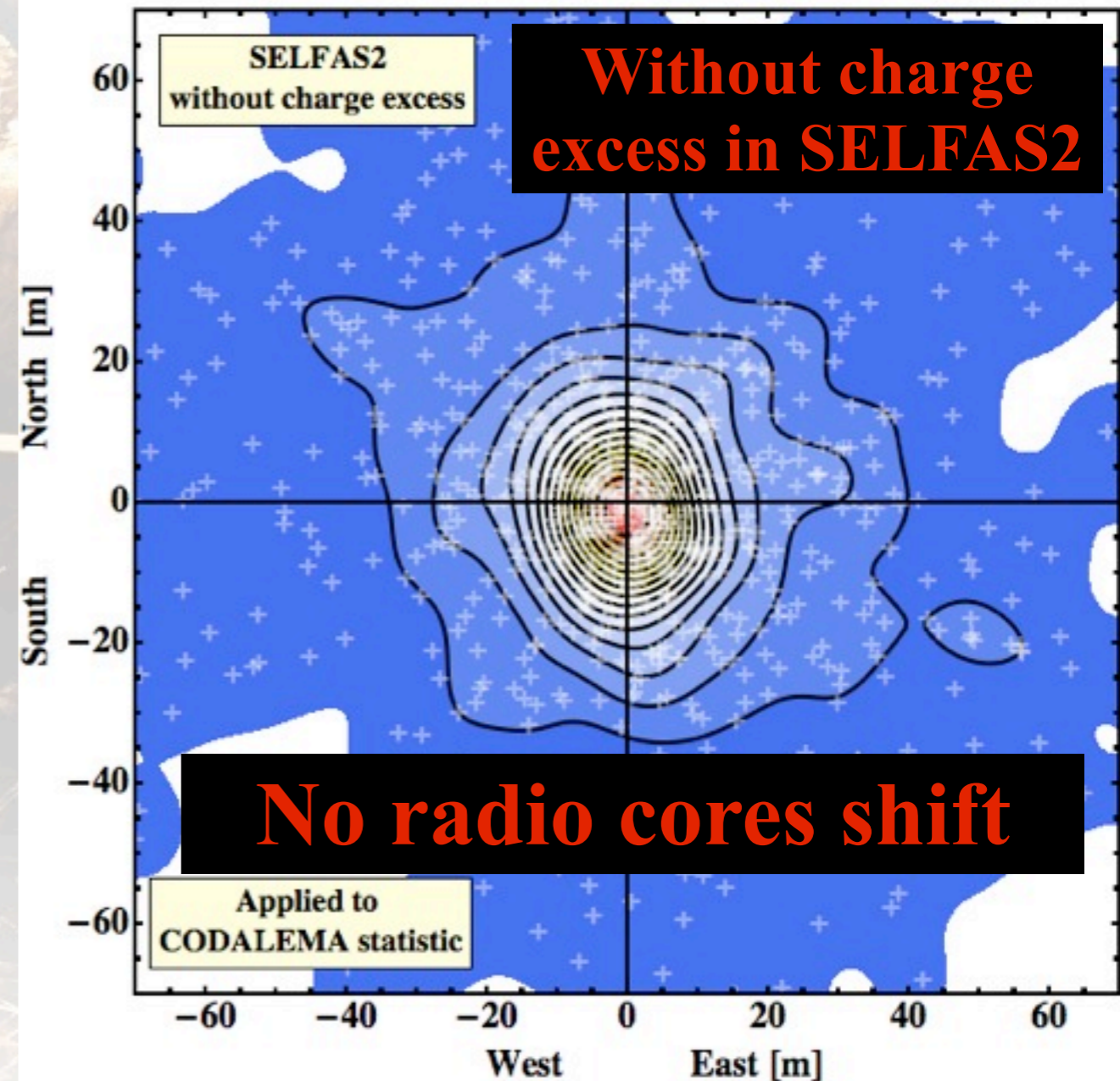
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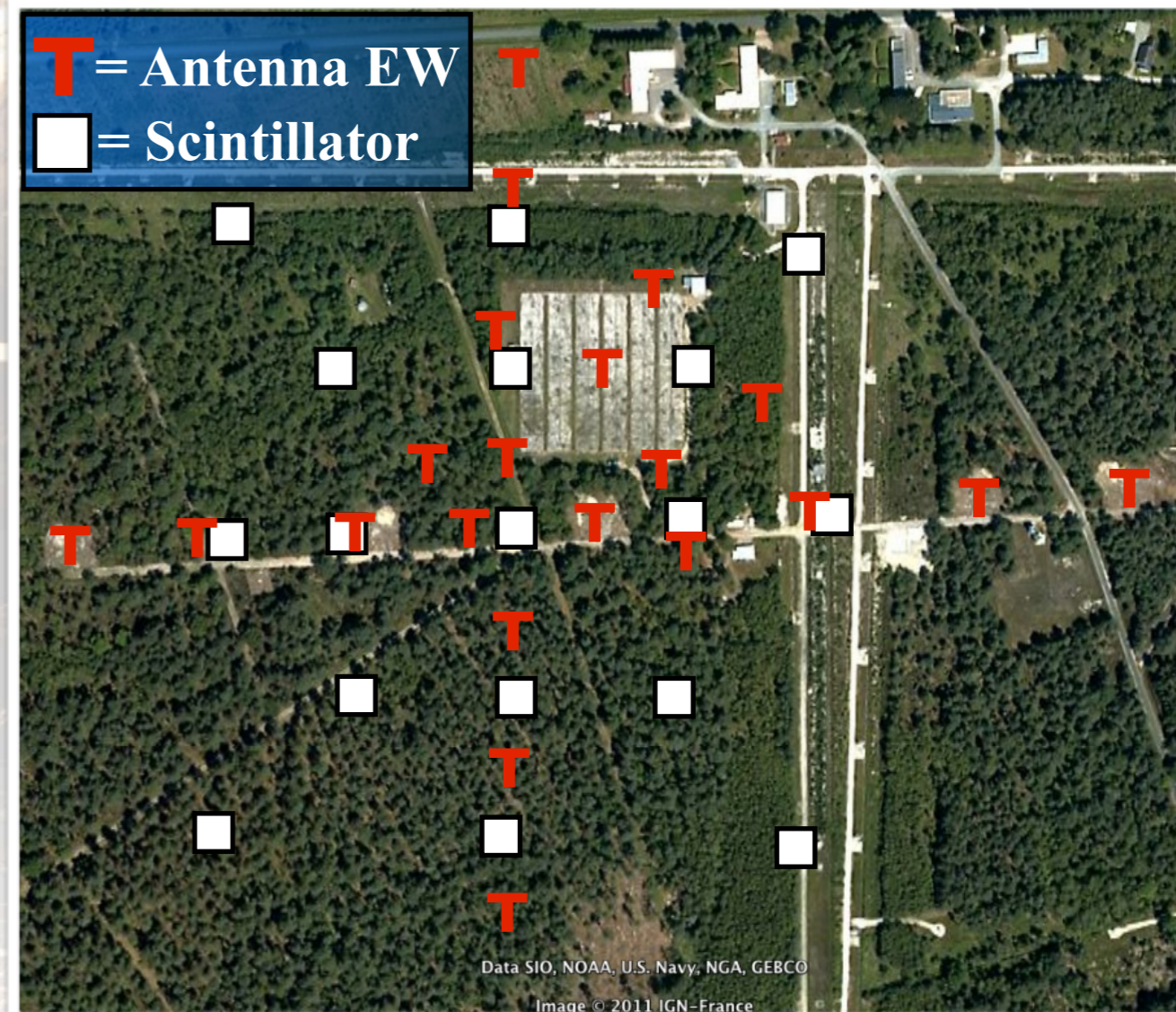
# What about the CODALEMA data...

For each event, the reference frame is centered on the ground particles shower core

Particle shower cores → Particle detector scintillators

Radio shower core → EW polarized antenna arrays

315 reconstructed radio cores with respect to the particle shower core



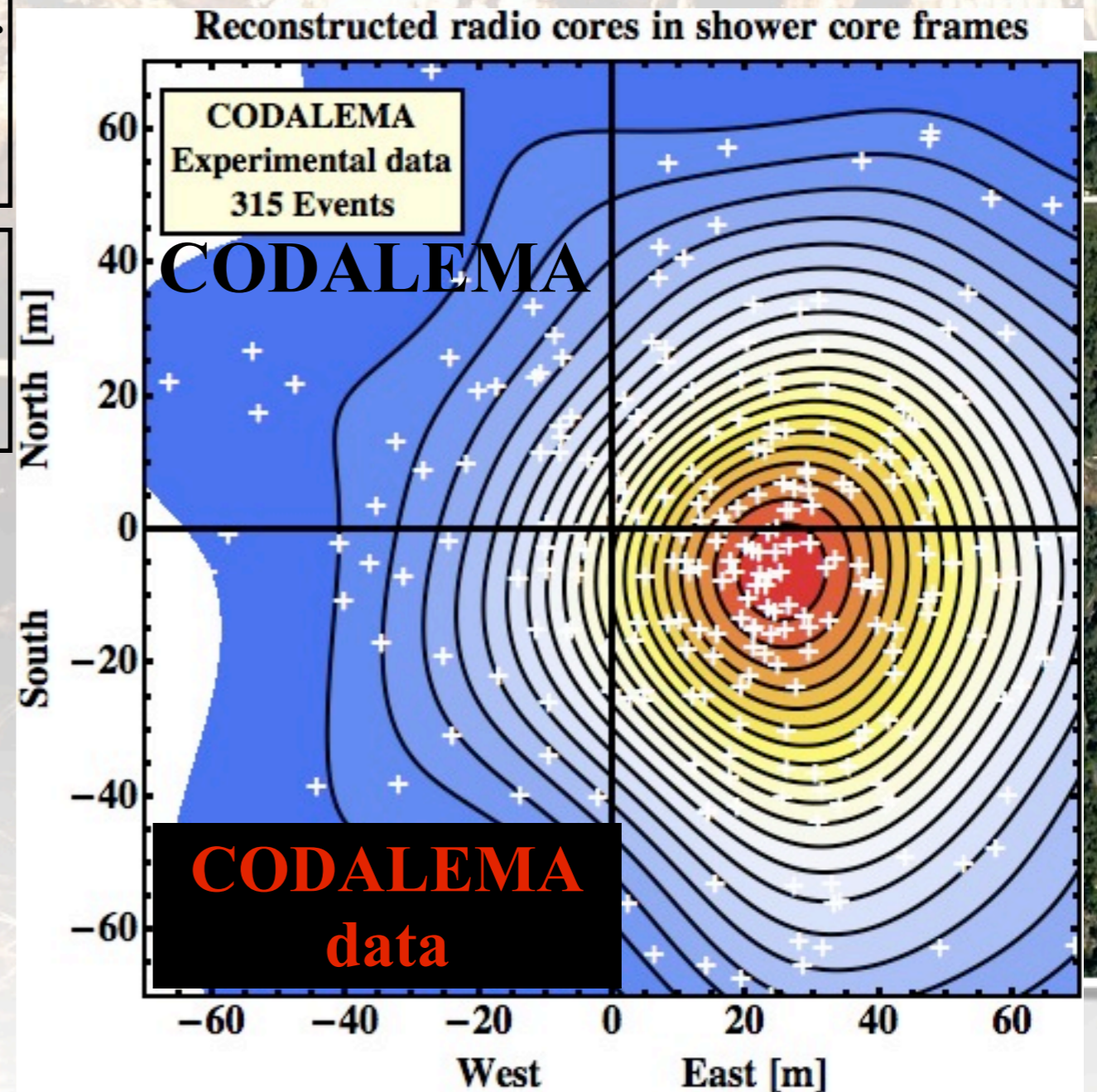
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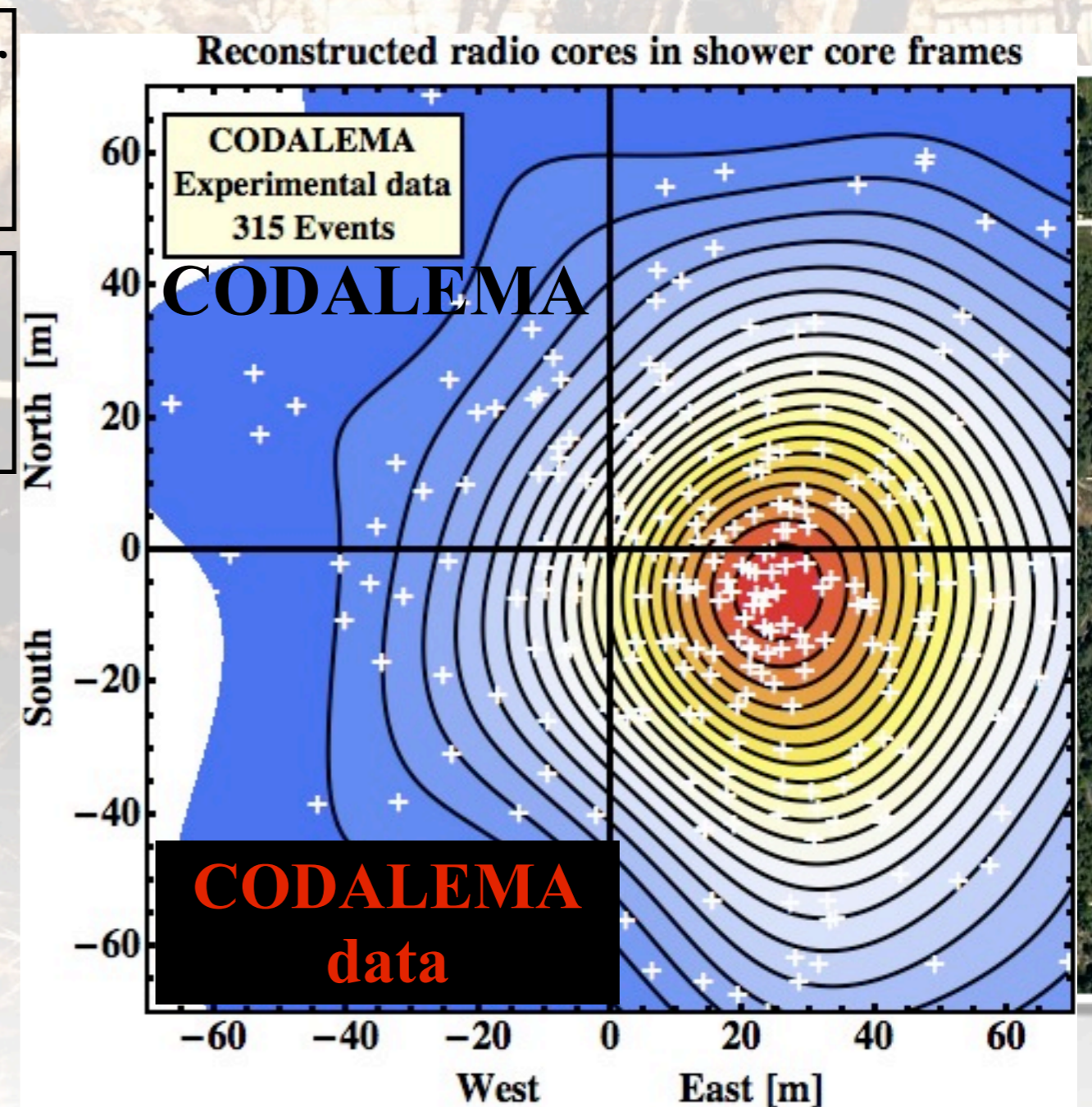
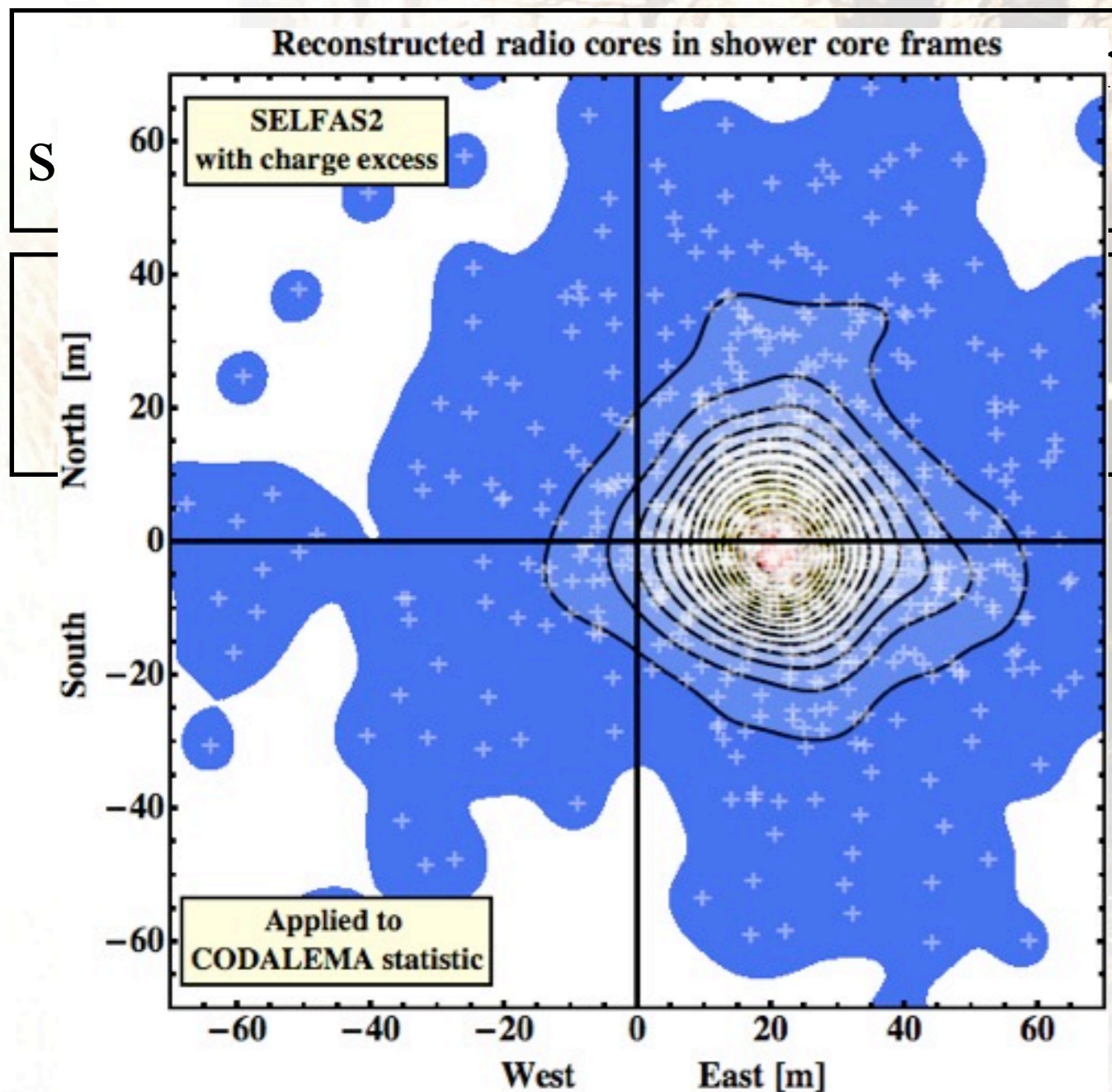
315 reconstructed radio cores with respect to the particle shower core



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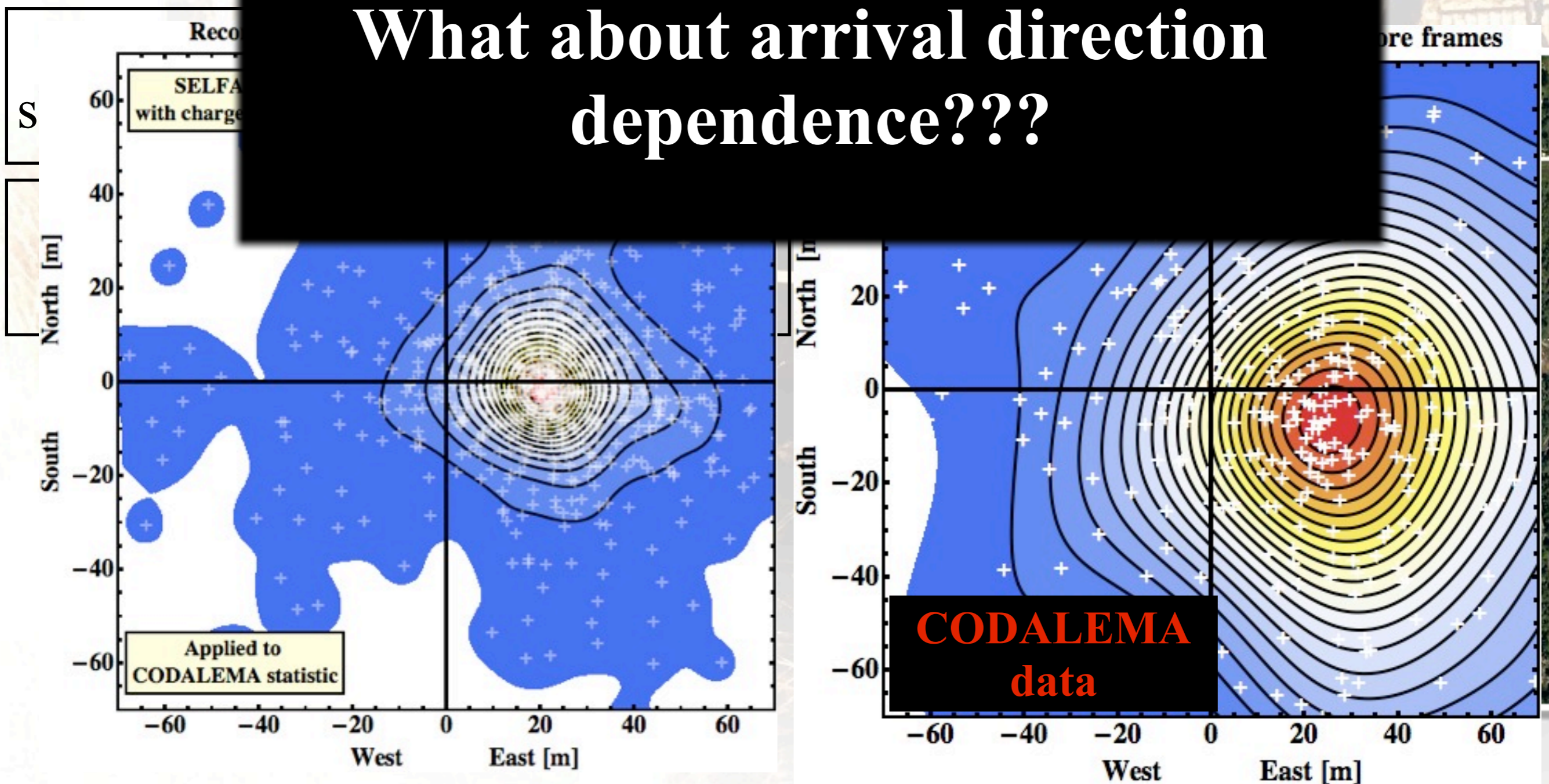
**good agreement!!!**



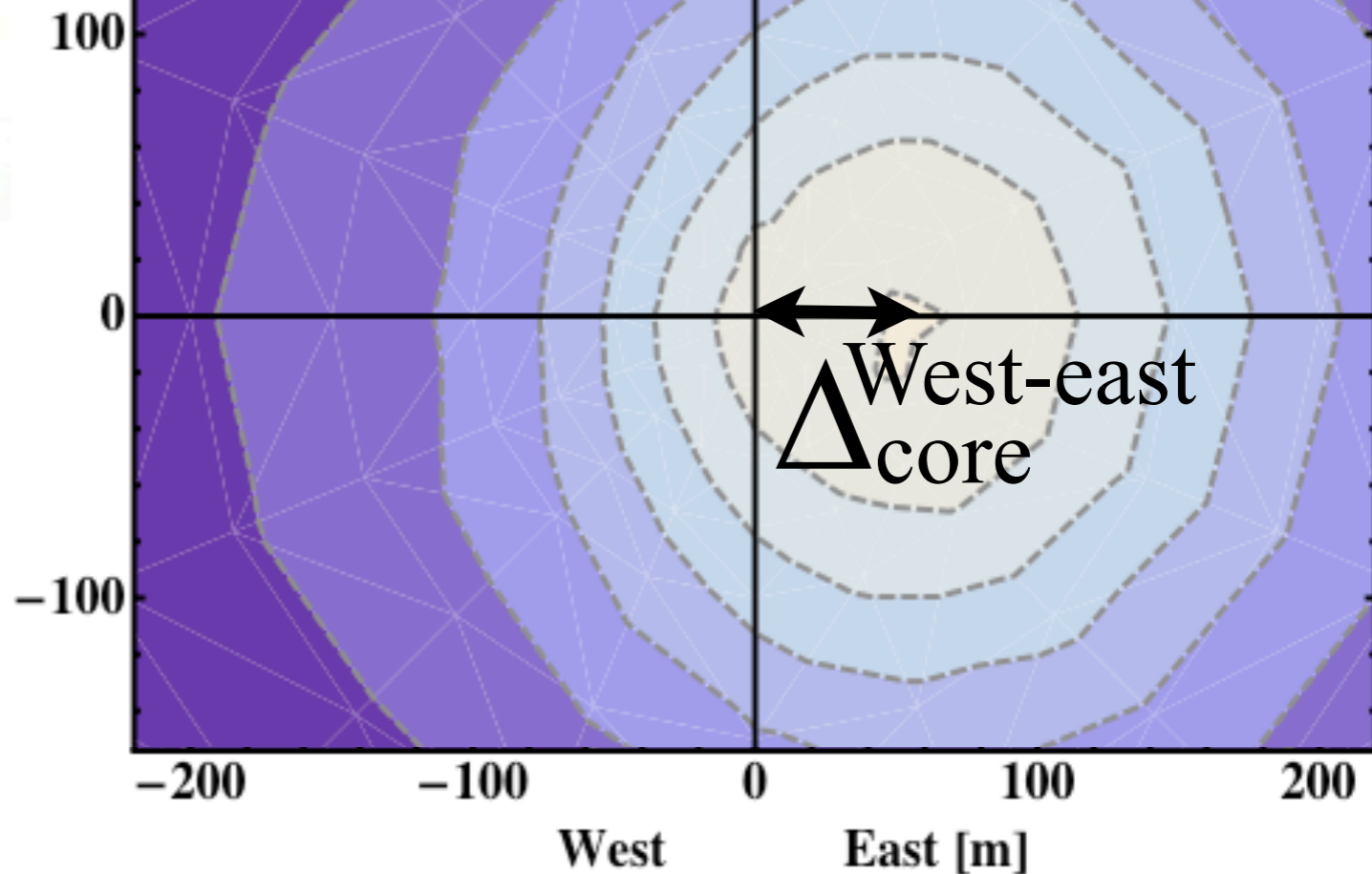
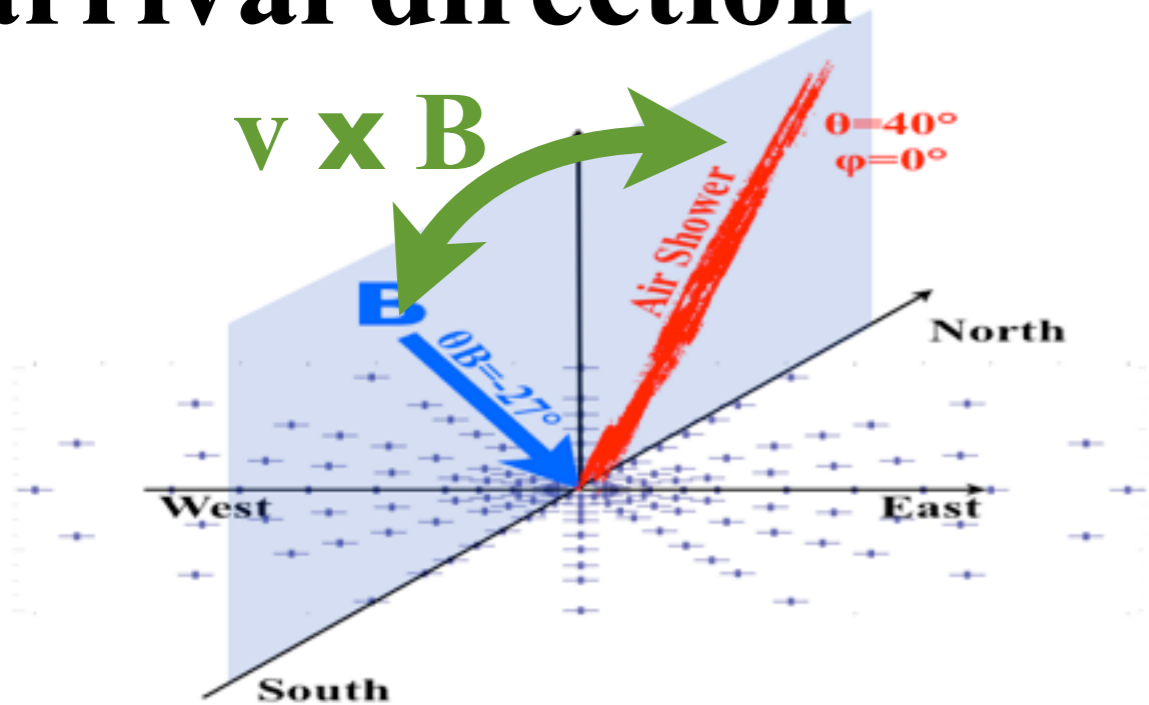
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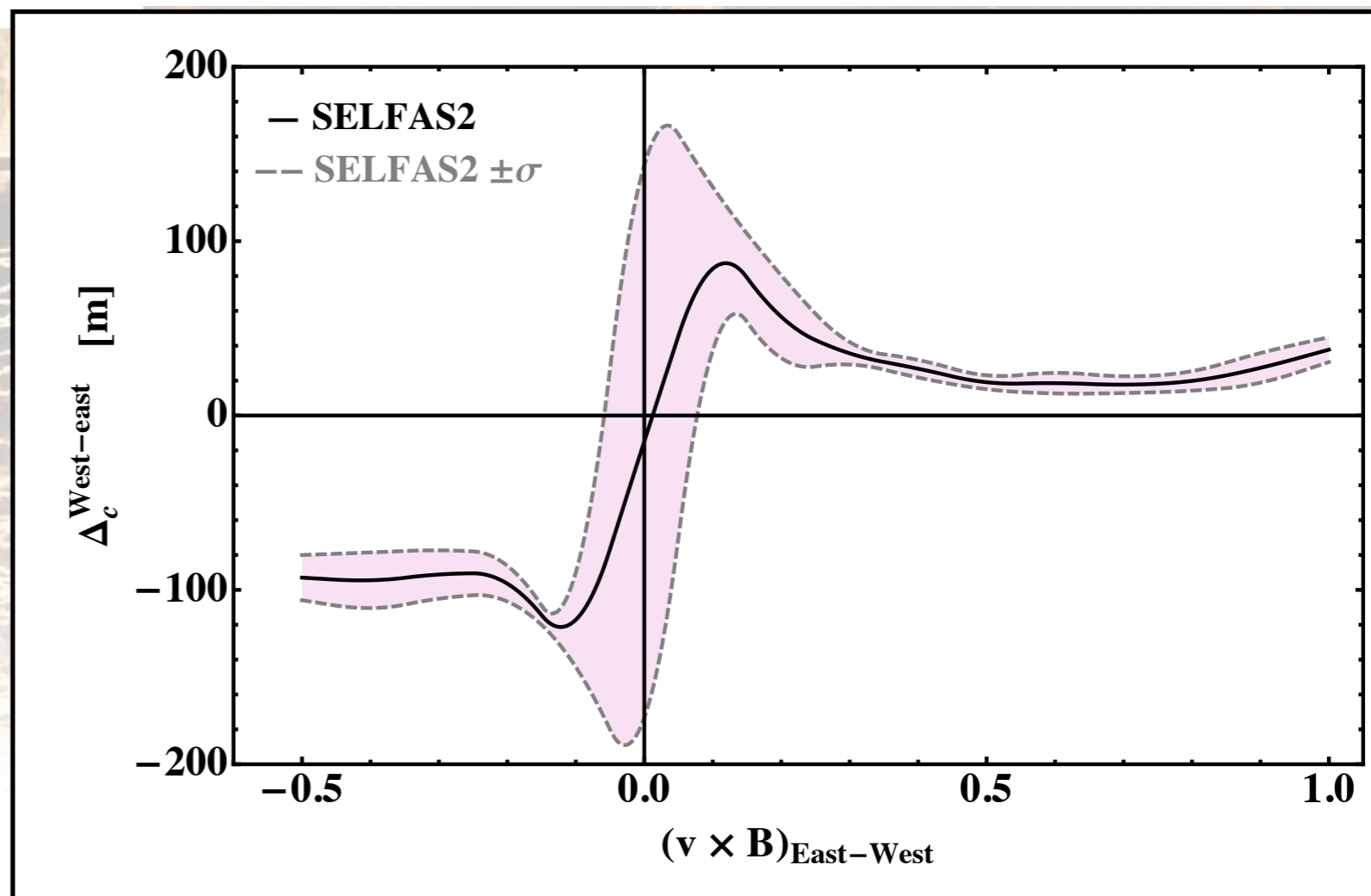
What about arrival direction dependence???



# Dependence on arrival direction

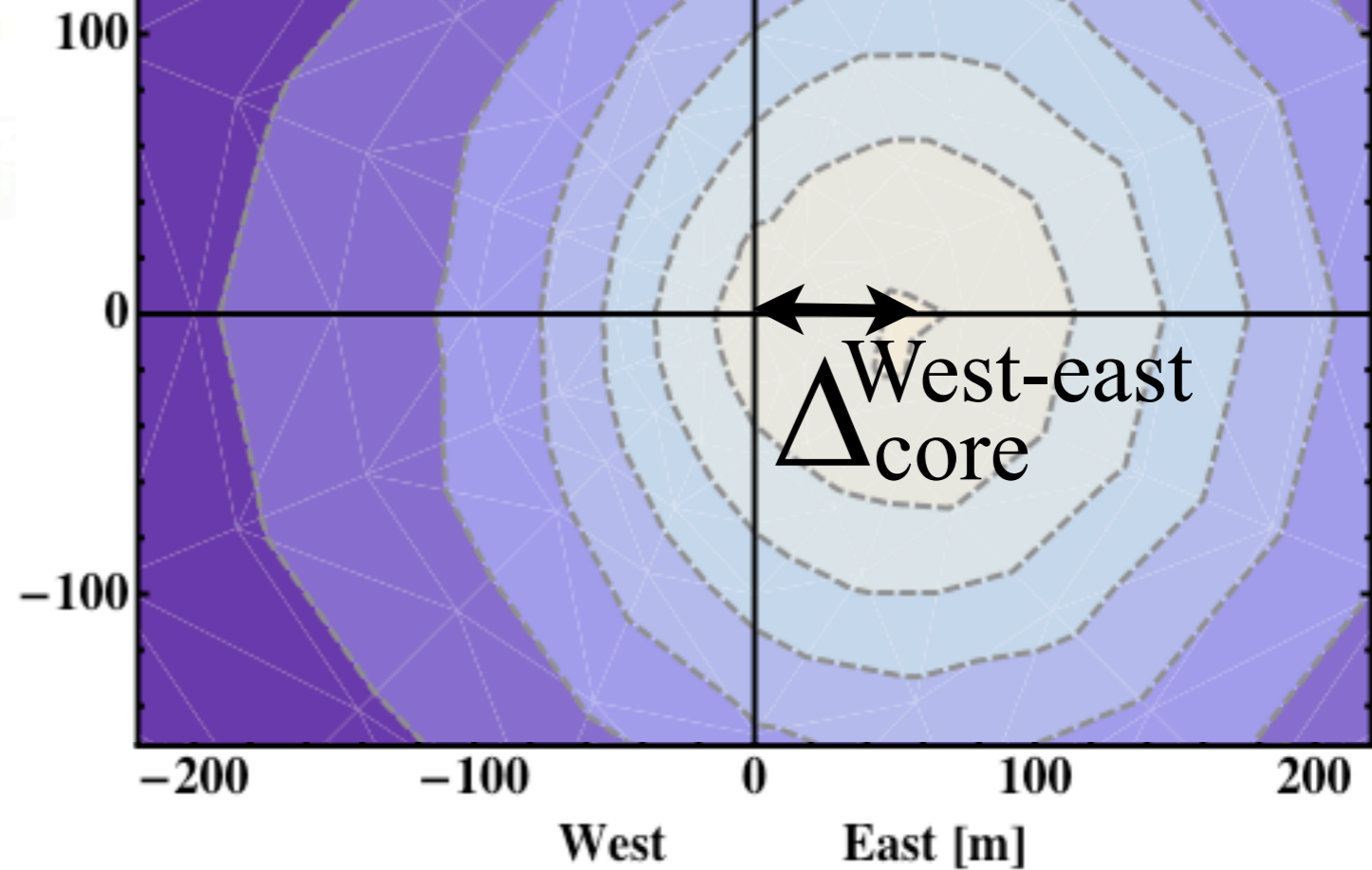
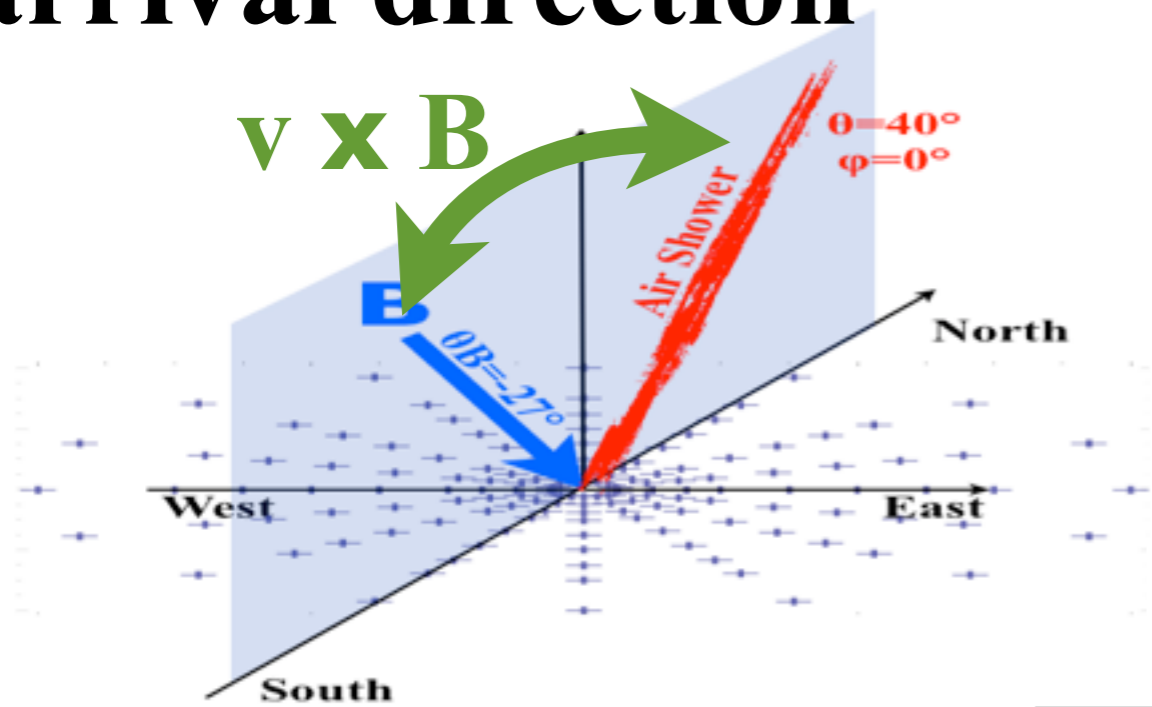


# Simulation SELFAS2





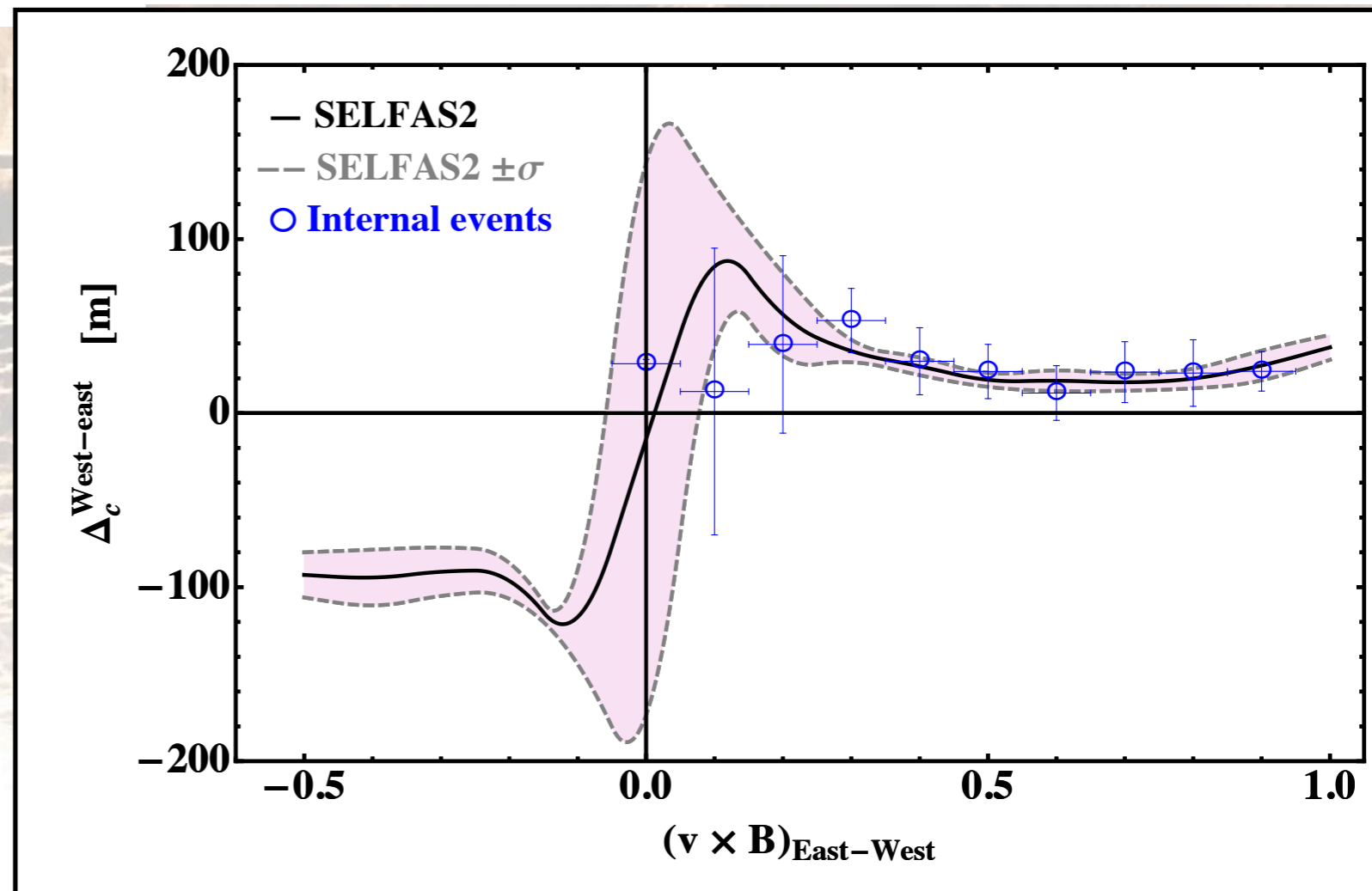
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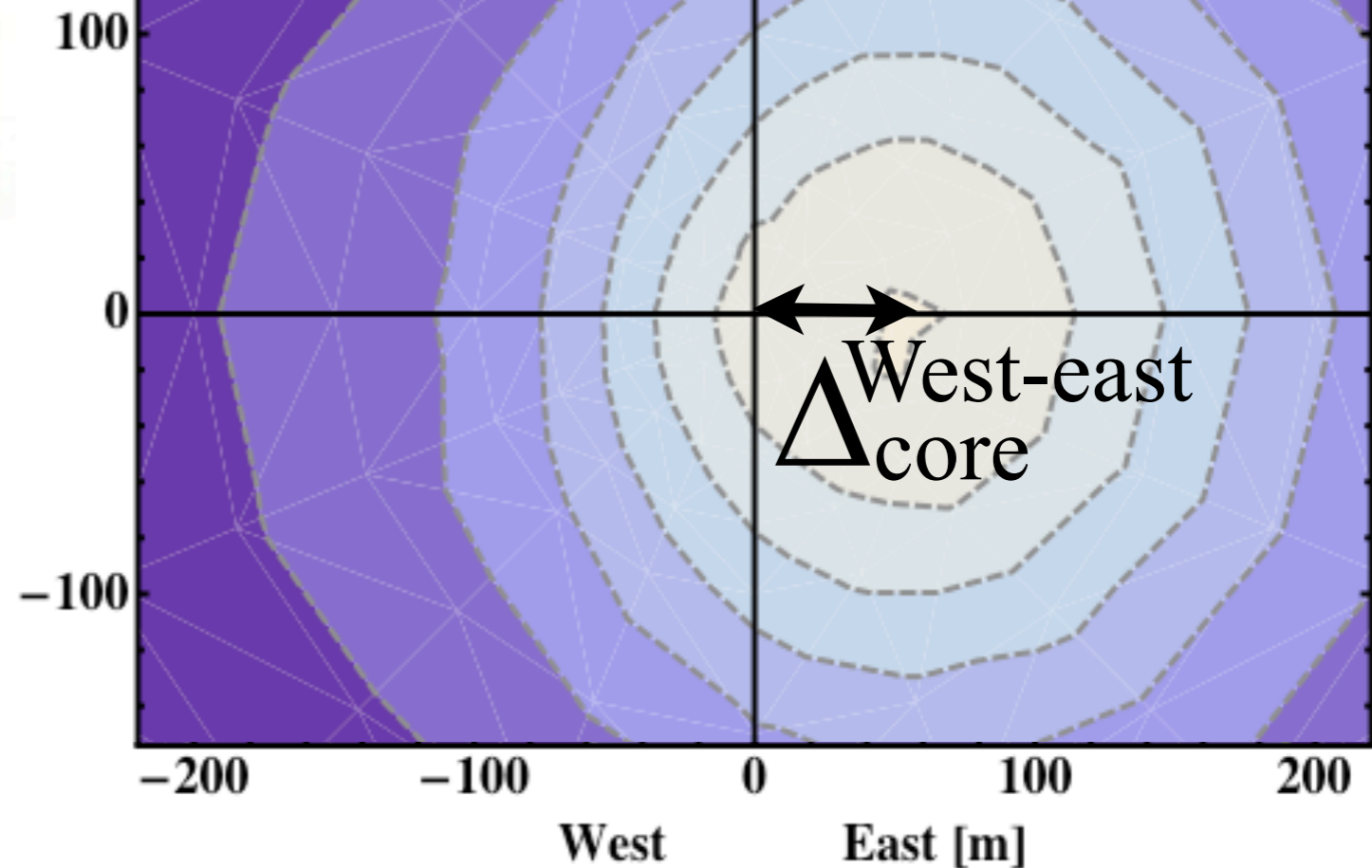
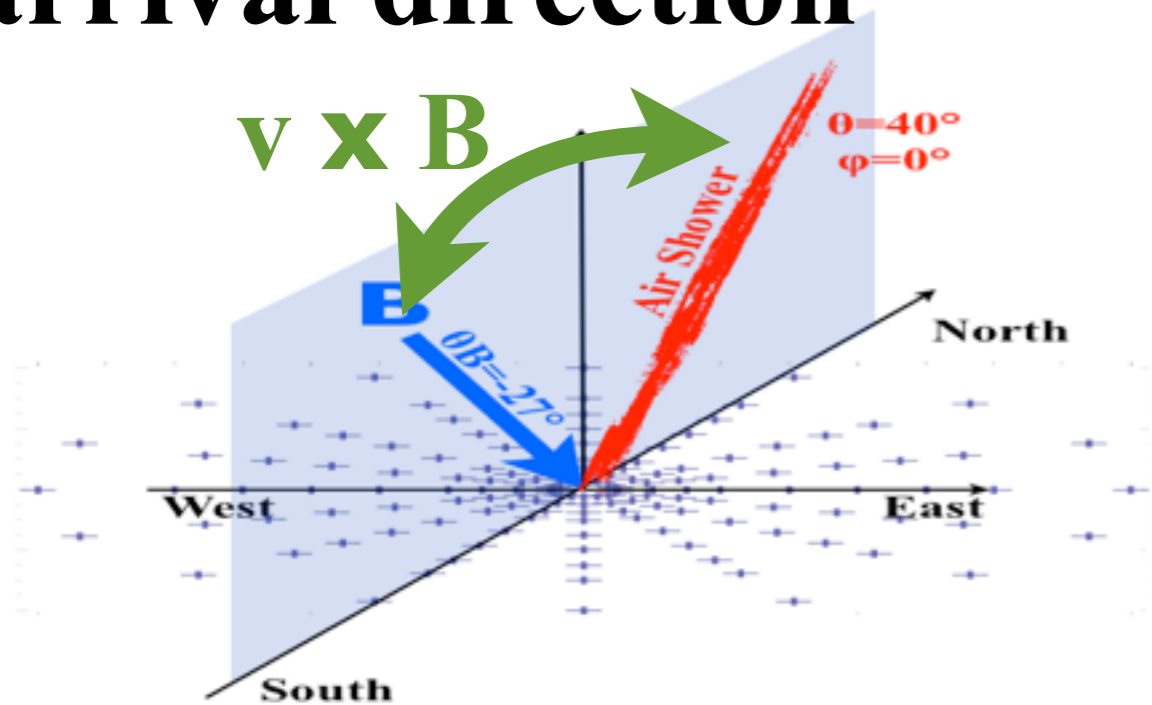
## Simulation SELFAS2 vs CODALEMA data

### Internal events

- Passing usual quality cuts
- Internal to radio and particles array



# Dependence on arrival direction



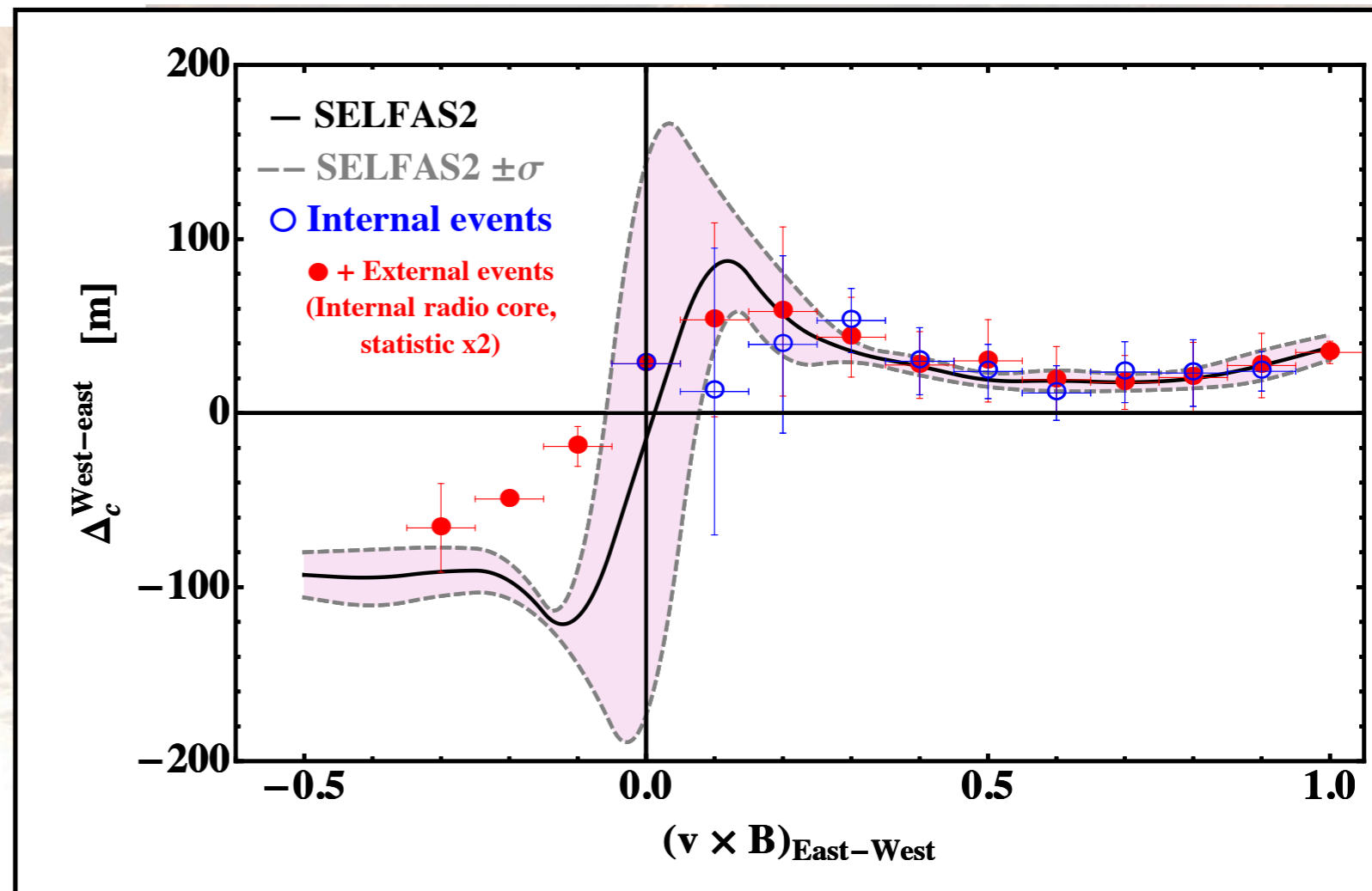
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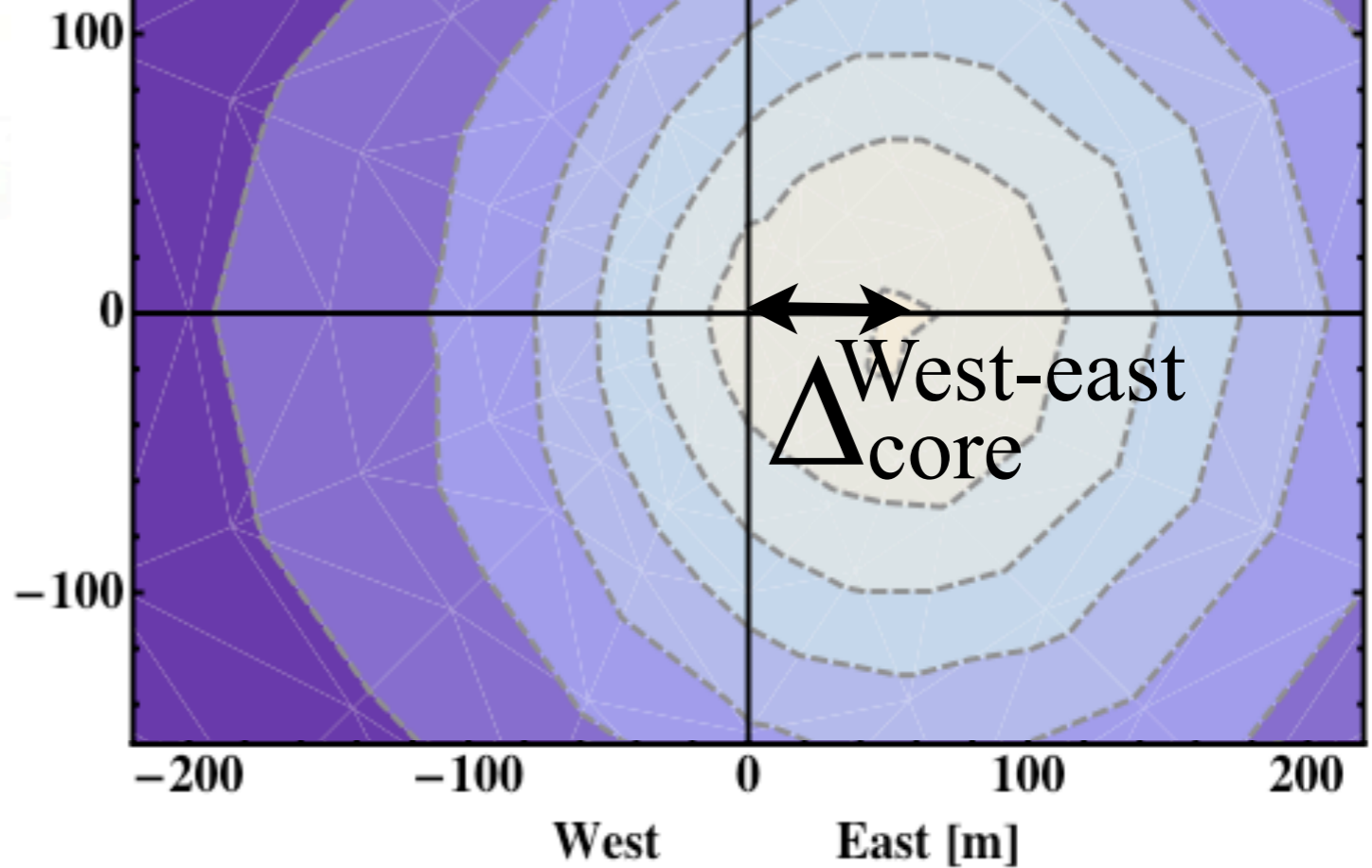
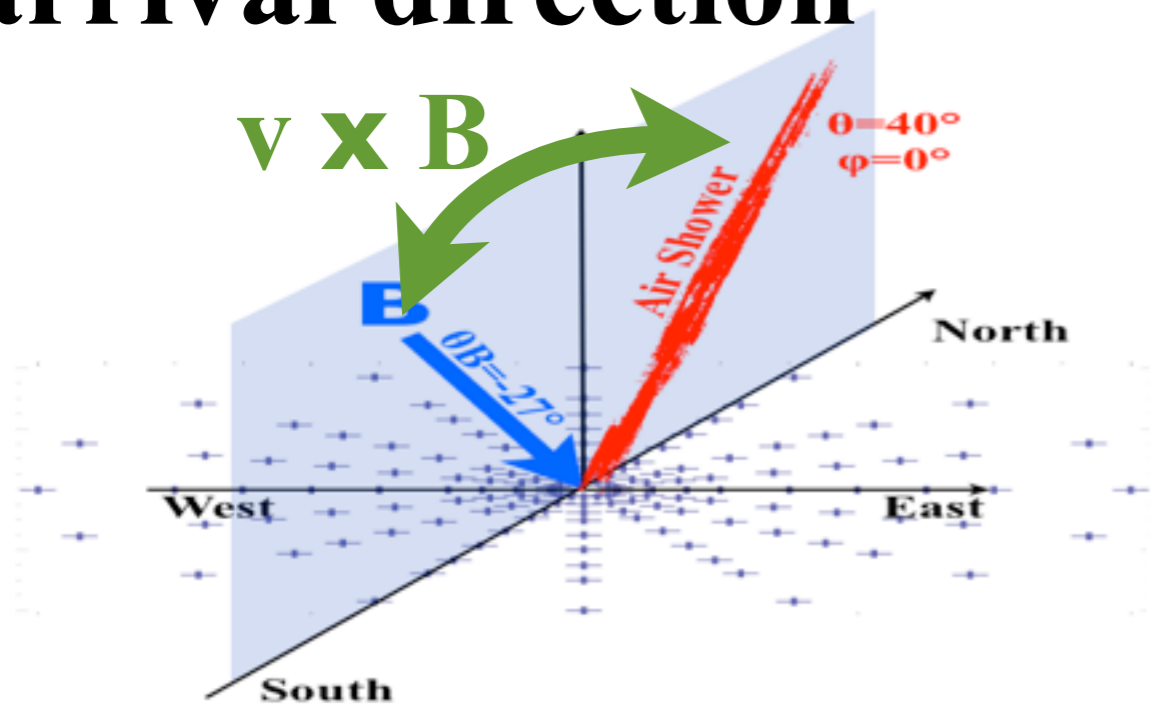
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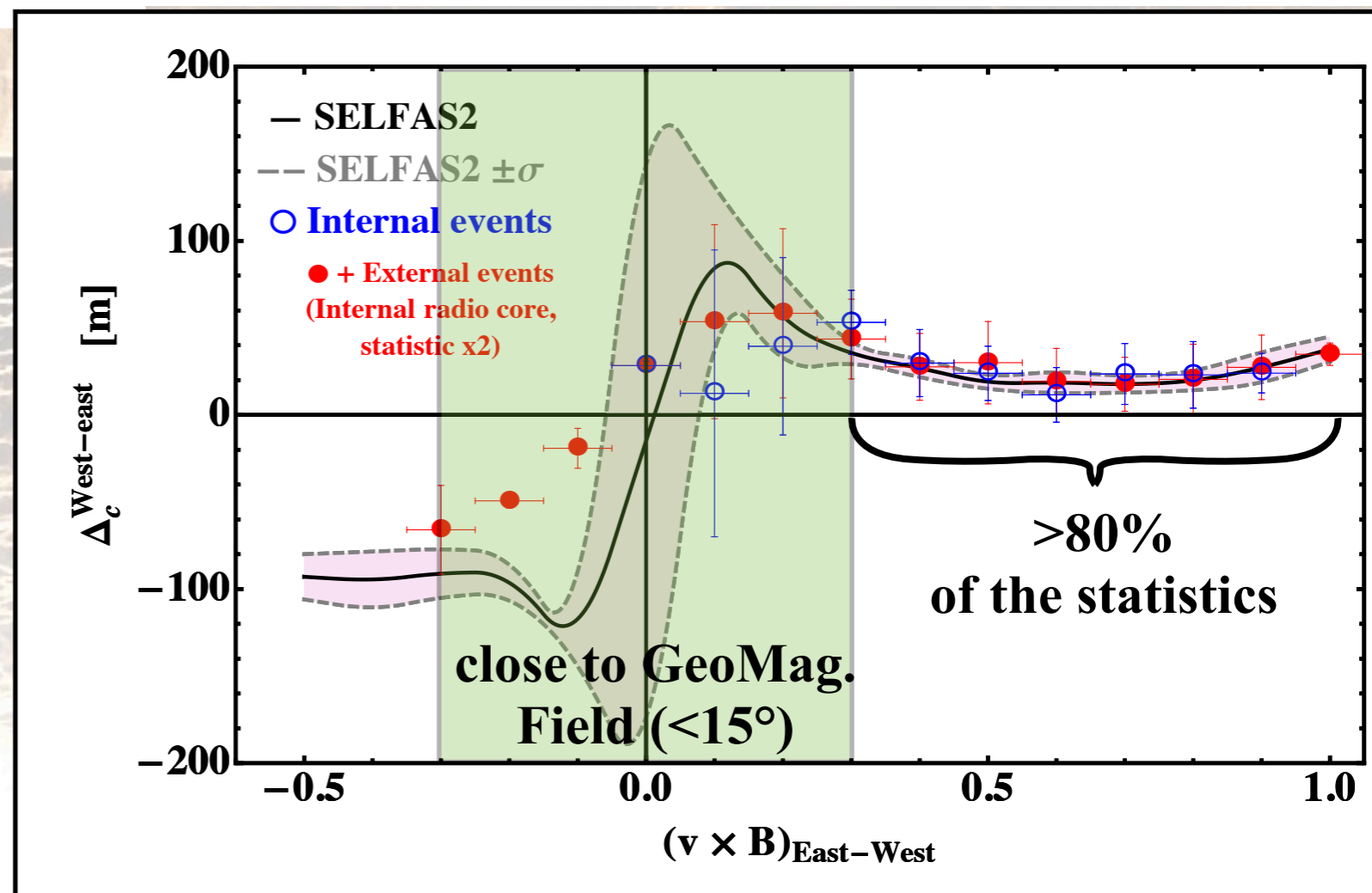
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### Internal events

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### External events

- Passing usual quality cuts
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# Conclusion

CODALEMA  
SELFAS2

- a **new observable** has been identified as being an evidence of the charge excess mechanism in the air showers electric field in the MHz frequency domain
- two different mechanisms  $\rightarrow$  two different polarization patterns  $\rightarrow$  interferences  $\rightarrow$  displacement  $\Delta_c$  at the ground level of the maximum electric field location with respect to the maximum particle density location
- $\Delta_c$  depends on the shower arrival direction (checked for the EW polarization): good agreement between simulations with SELFAS2 and the CODALEMA data
- this new observable should be measurable in AERA at the Pierre Auger observatory.
- the charge excess fraction depends on the arrival direction and on the antenna location; for instance, for a vertical shower, the charge excess signal represents 20% of the total electric field