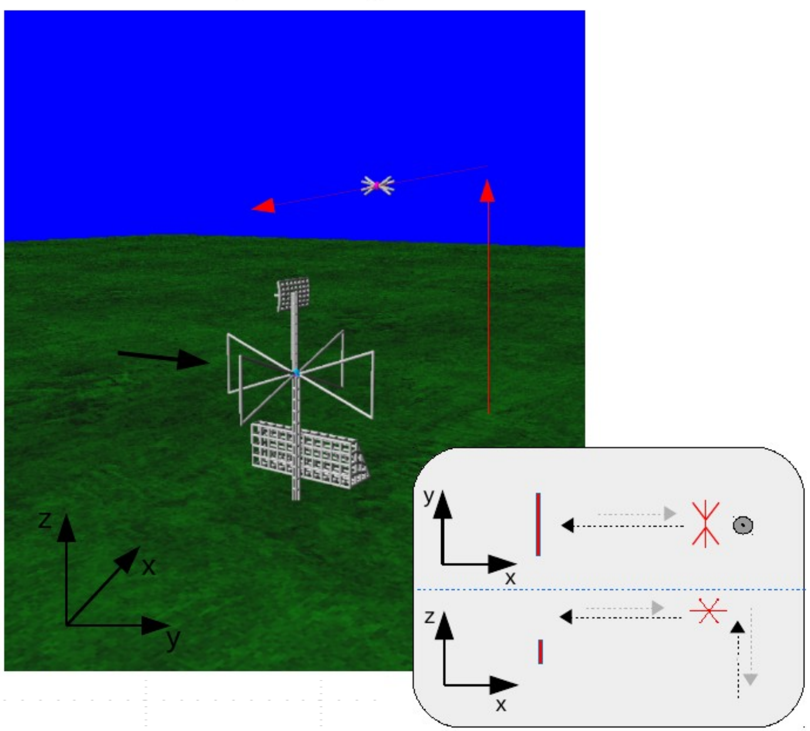
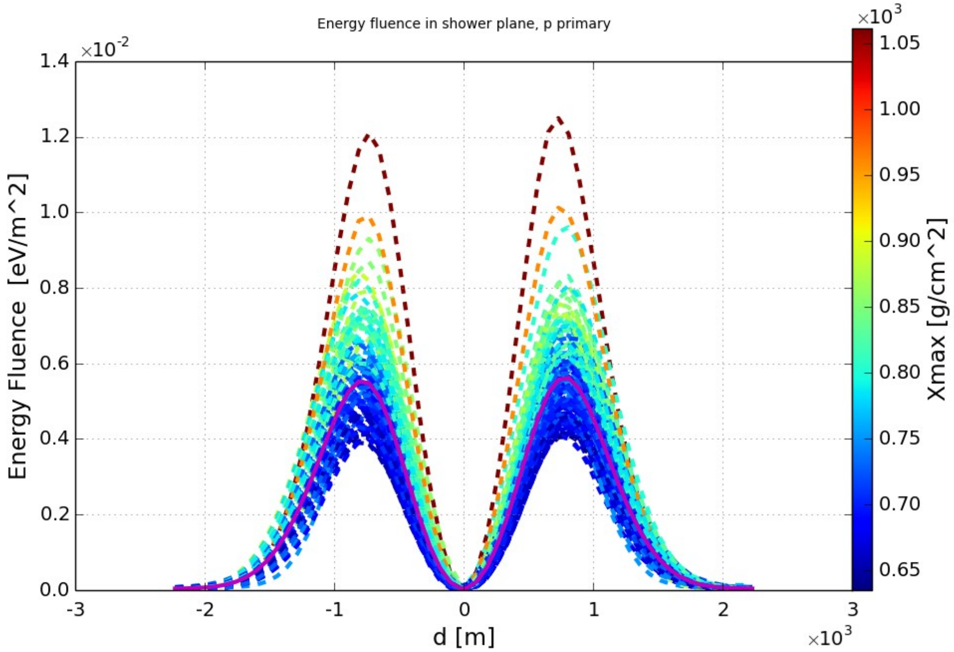
Measurement of radio emission induced by Ultra-high energy cosmic rays at energies above 1 EeV with the Pierre Auger Observatory

Horizontal component H_ϕ





<u>Florian Briechle</u>, Martin Erdmann, Felix Schlüter
for the Pierre Auger Collaboration

PIERRE AUGER OBSERVATORY

AERA Auger Engineering Radio Array

HELMHOLTZ | ASSOCIATION
Alliance for Astroparticle Physics

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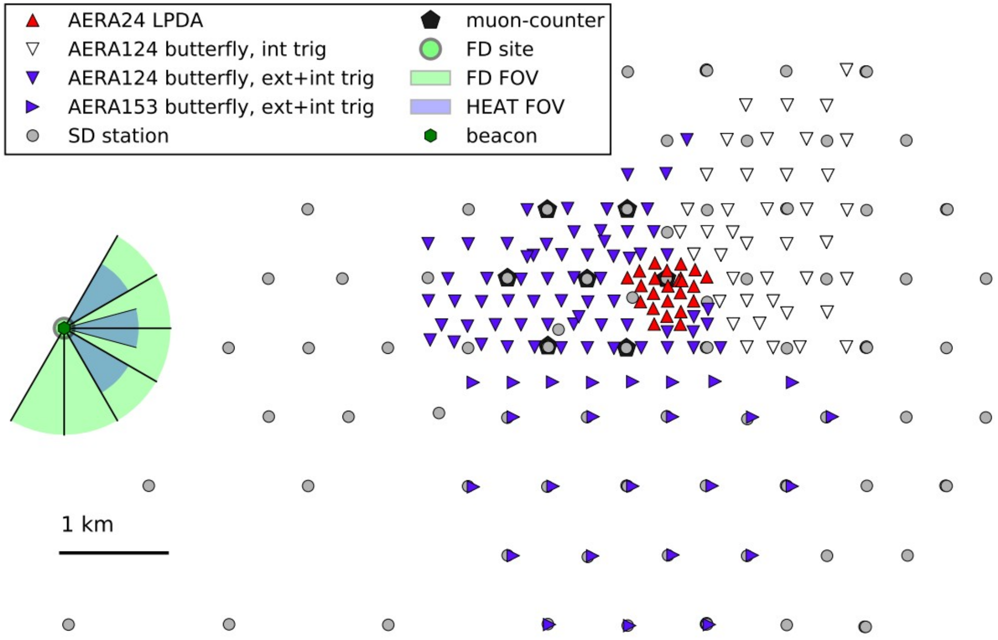
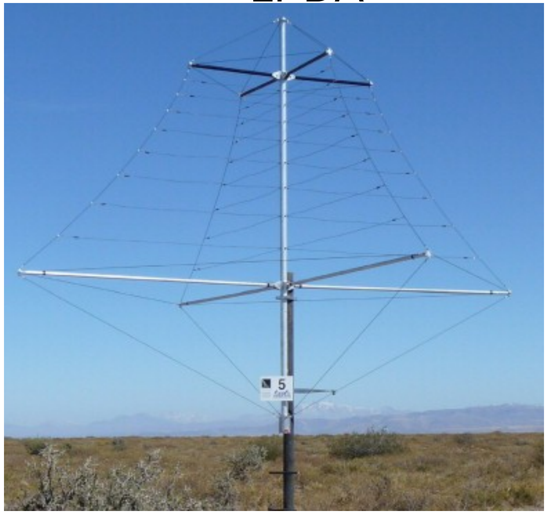
The Auger Engineering Radio Array

- World's largest radio detector for cosmic rays
- More than 150 autonomous radio stations on 17 km²
- Taking data since 2011
- Coincident measurements with SD and FD
- Two different antenna types
  - Log-periodic dipole antenna (LPDA)
  - Butterfly antenna
- Two polarizations
- Sensitive in the range of 30 – 80 MHz



LPDA



Butterfly antenna

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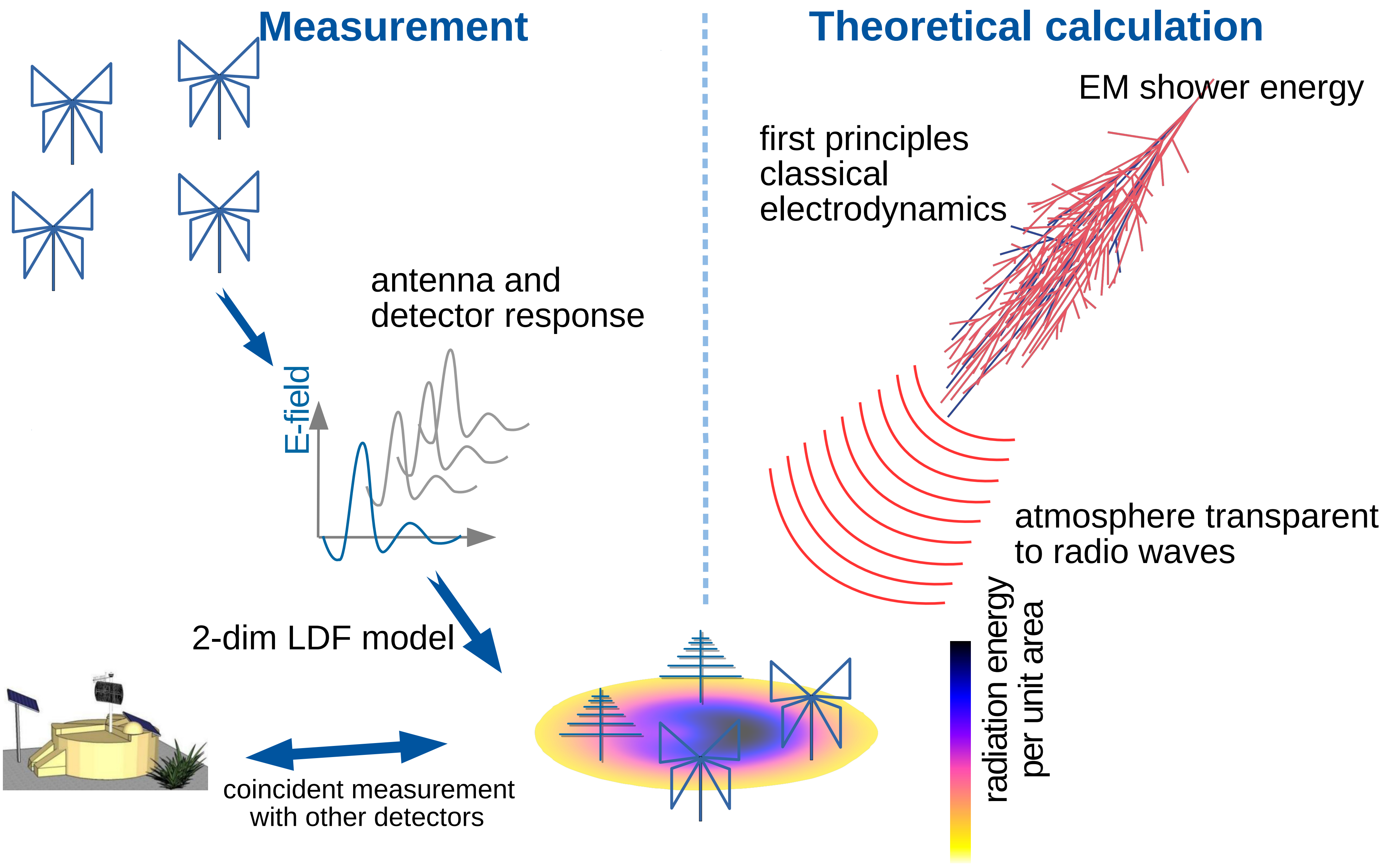
Independent Determination of Cosmic-Ray Energy Scale



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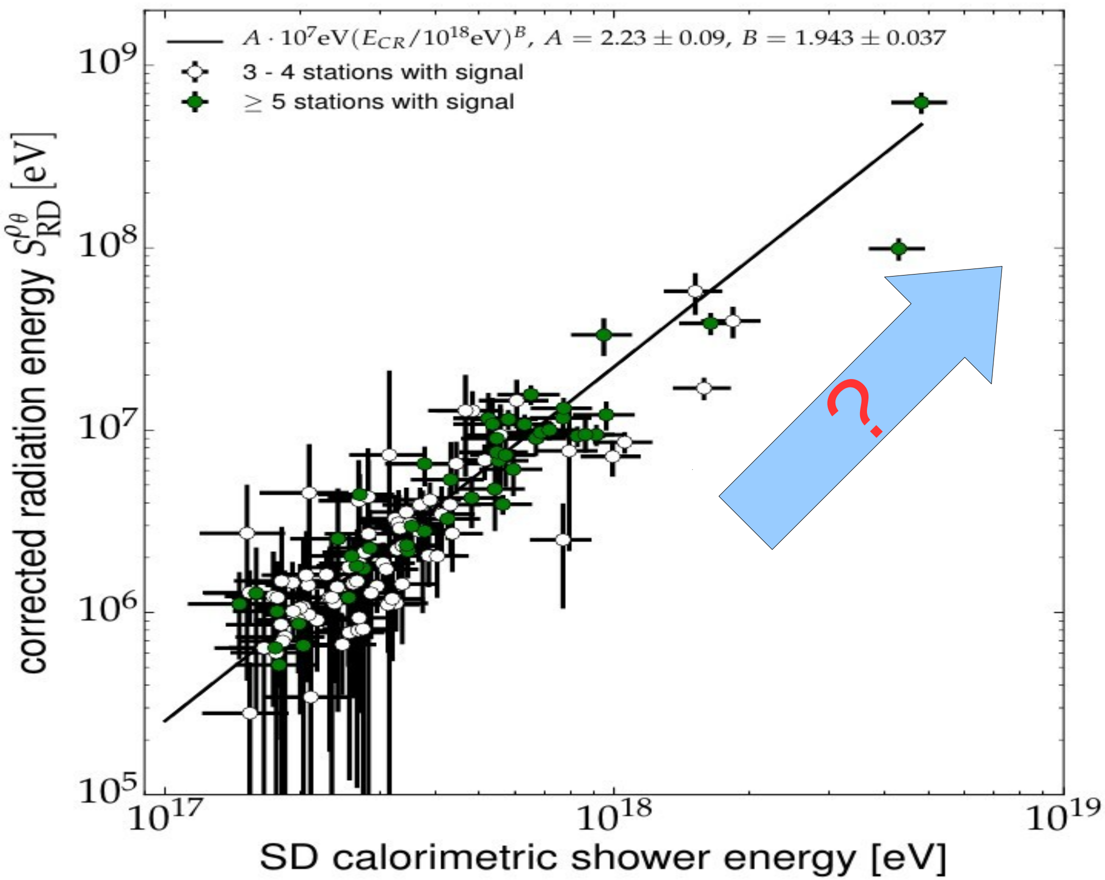
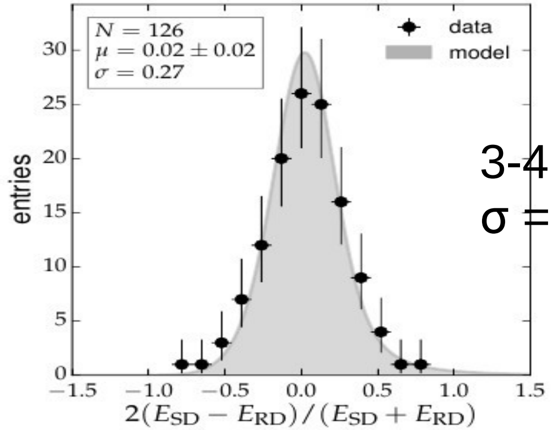
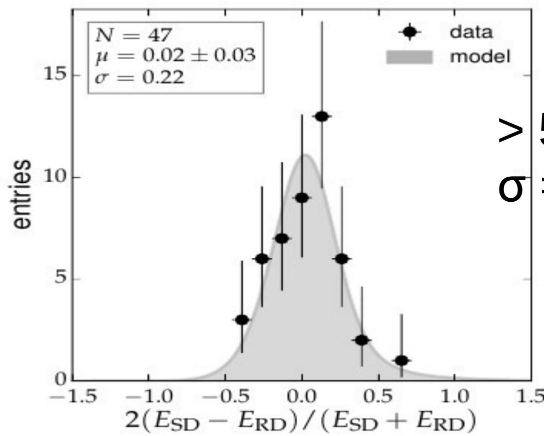
Measuring cosmic ray energy with Radio

- Cosmic rays energies determined by radio
- quadratic dependency of radio emission on cosmic ray energy
- Resolution of 14% for high-quality data set





3-4 signal stations:
σ = 20 %



> 5 signal stations:
σ = 14 %

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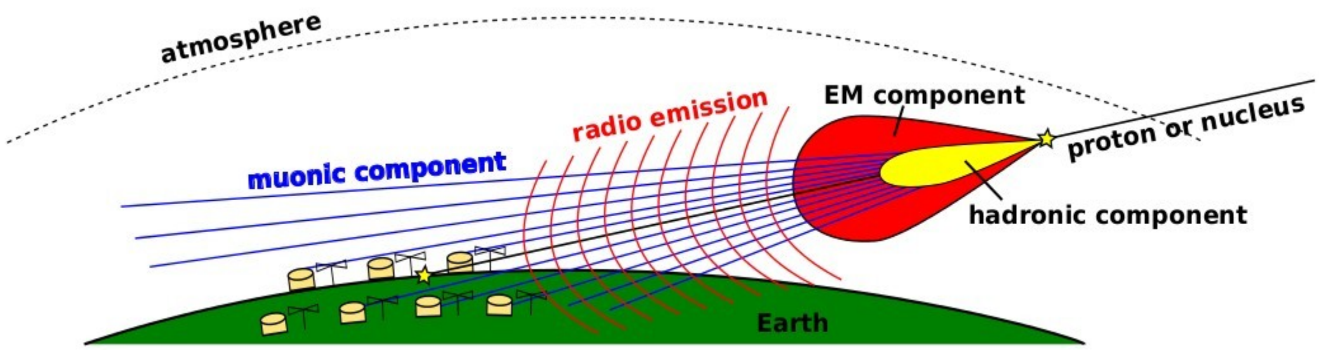
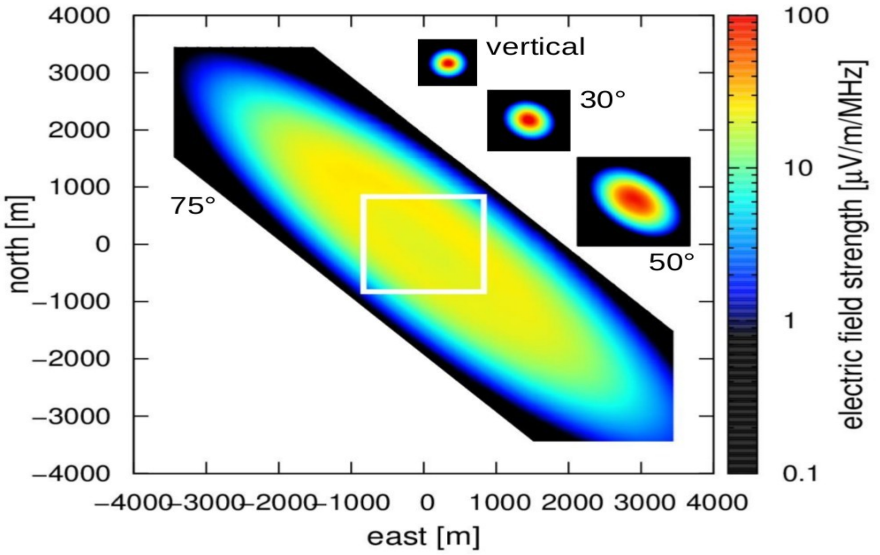
Horizontal air showers

- Extensive air showers with zenith angle θ > 60°



- Radio (and muons) reach ground
- EM and hadronic components die out earlier in atmosphere
- Inclined showers have larger footprint on ground
- Increase available phase space for detection of extensive air showers
  - ➔ Shower core can be further away
  - ➔ More stations triggered



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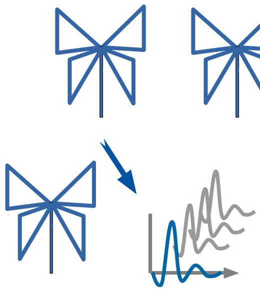
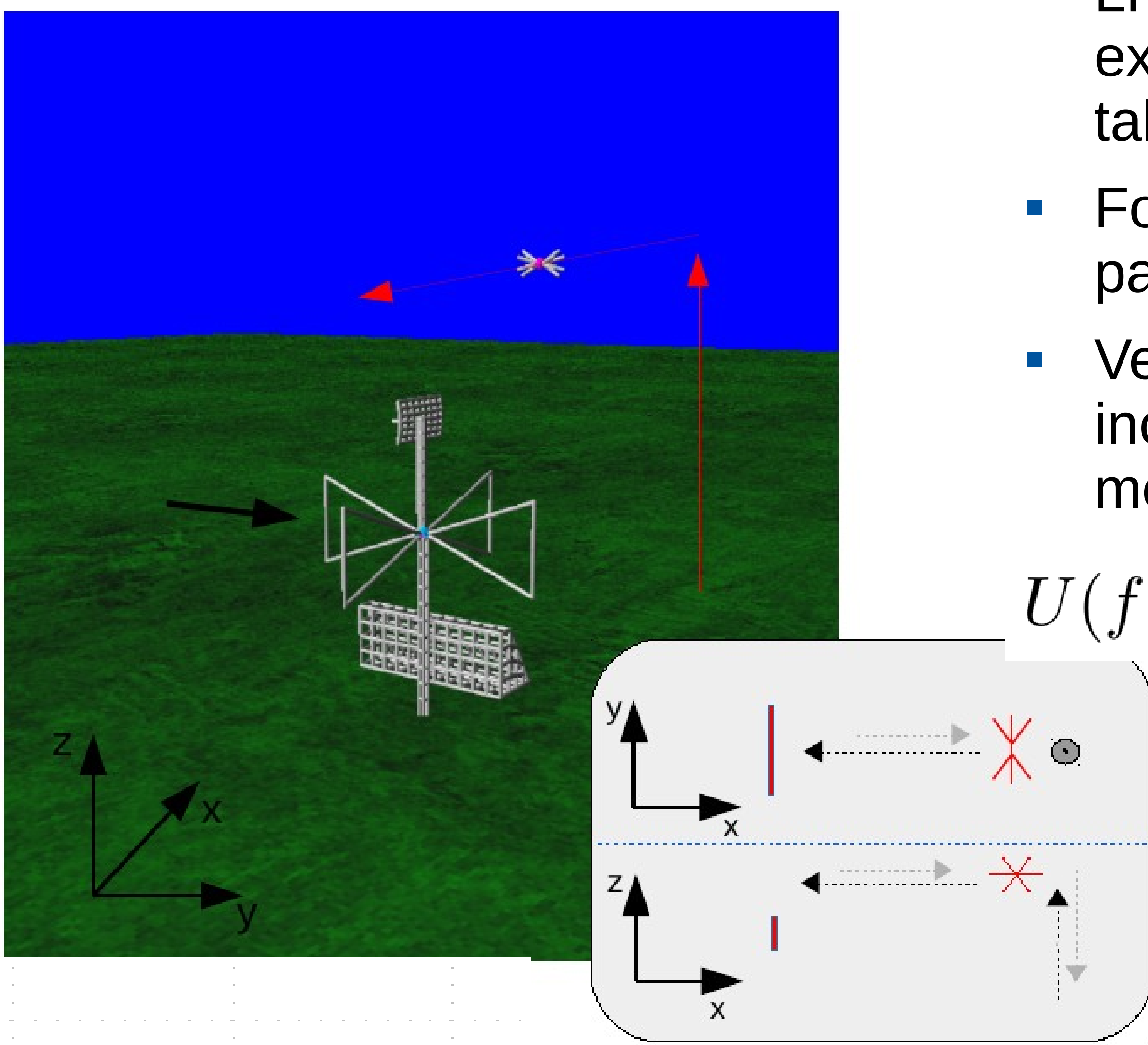


Calibration of antennas

Horizontal component H_ϕ

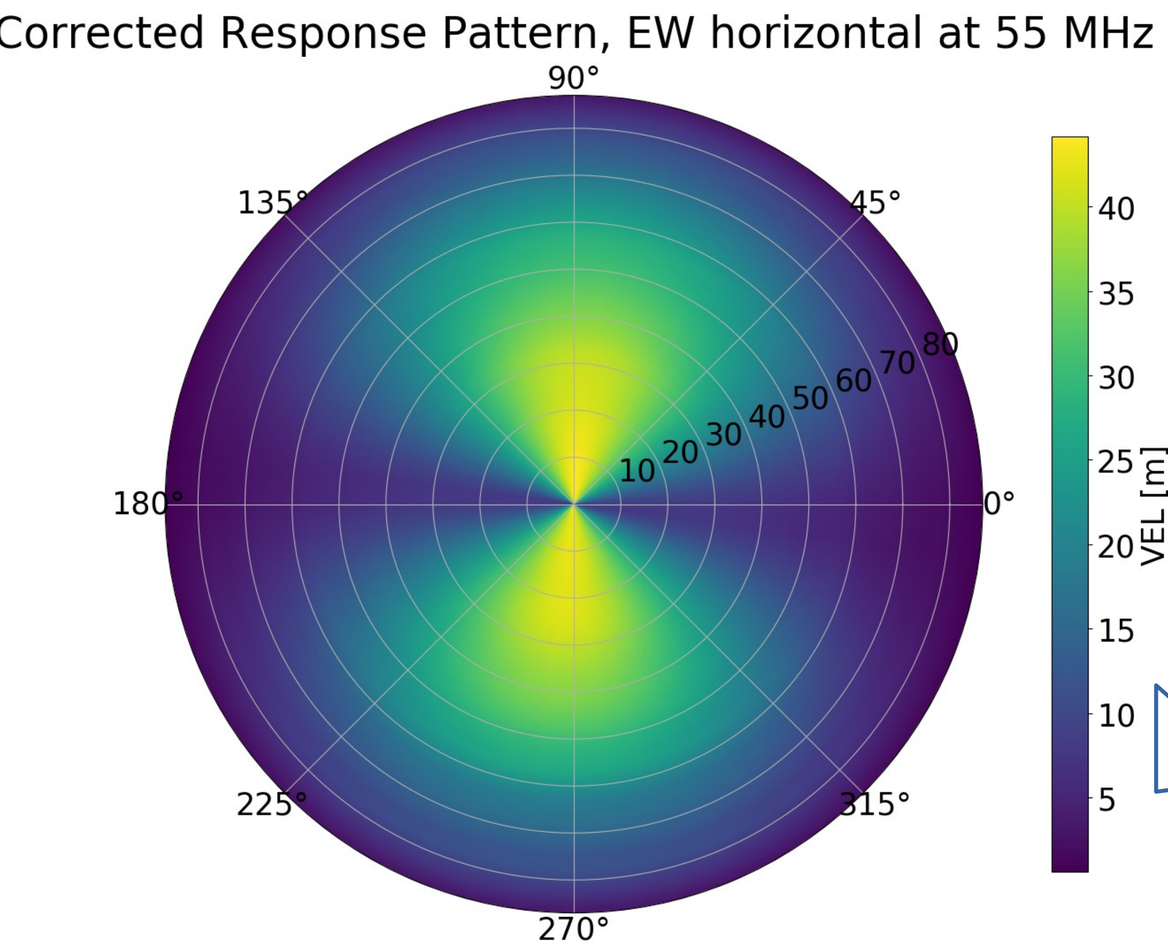


- Calibration campaign with an octocopter for both station types has been performed
- LPDA response pattern already extensively studied (see last years talks)
- For Butterfly: new response pattern established
- Vector effective length $\vec{H}$ relates incoming electric field and measured Voltage

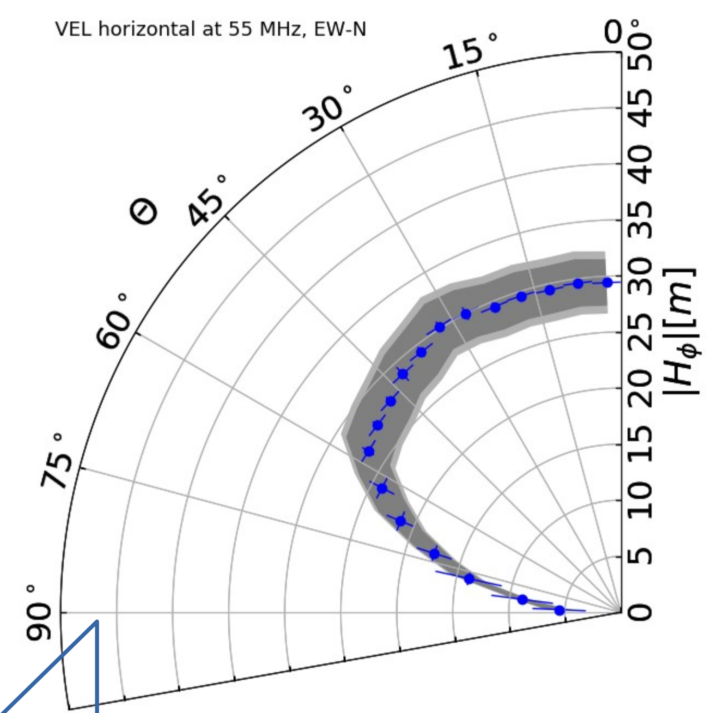
$$U(f,\theta,\phi) = \vec{H}(f,\theta,\phi) \cdot \vec{E}(f,\theta,\phi)$$

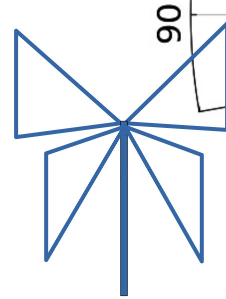
Butterfly Vector Effective Length

- Measurements from North, East, South, West, with 5 MHz spacing, full zenith range
- Use simulations for intermediate ranges in frequency and azimuth
- Precise description up to zenith angles of 80° with uncertainties on the order of 15%

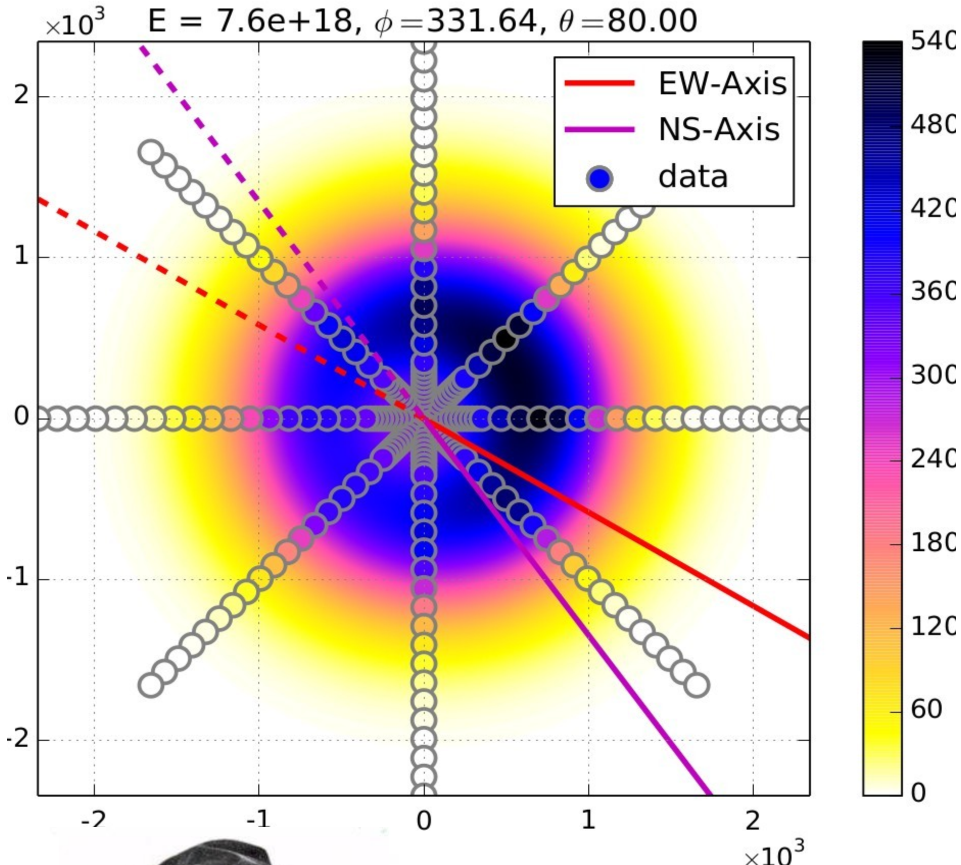


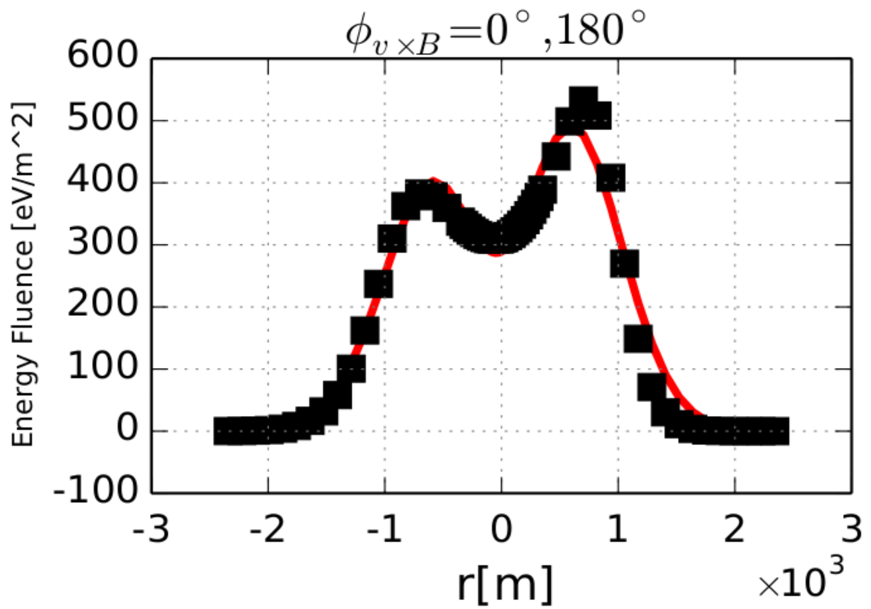
VEL horizontal at 55 MHz, EW-N

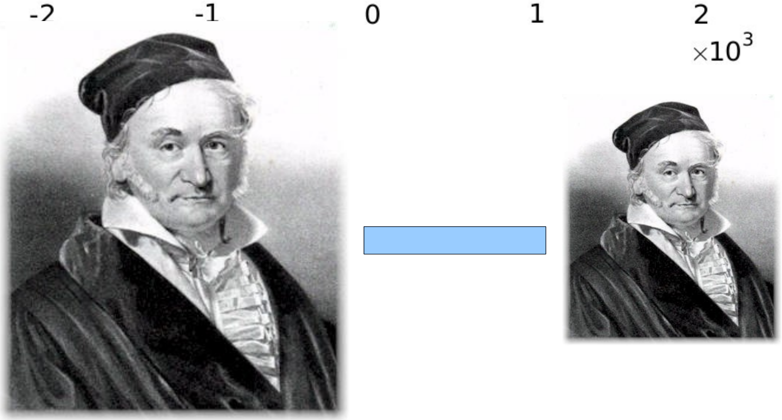


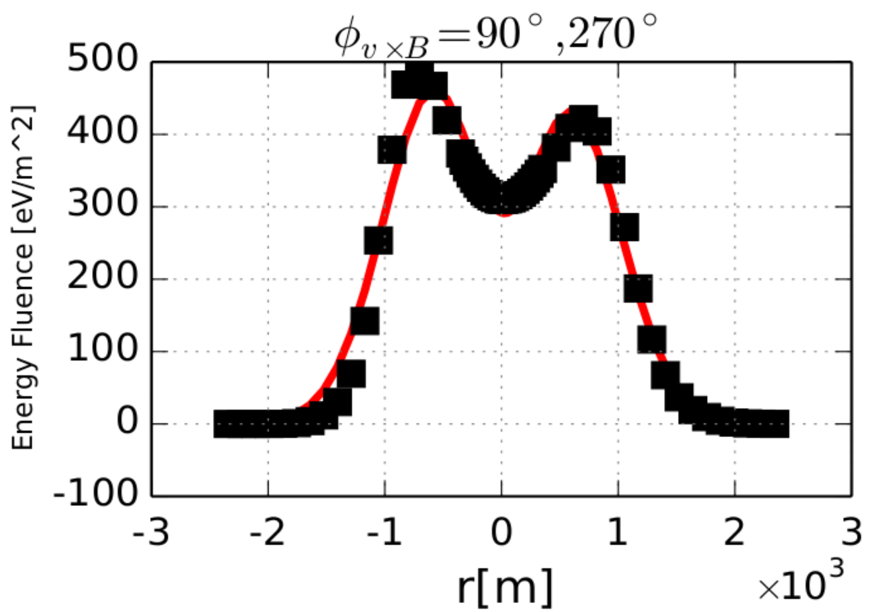


Lateral distribution fit is challenging









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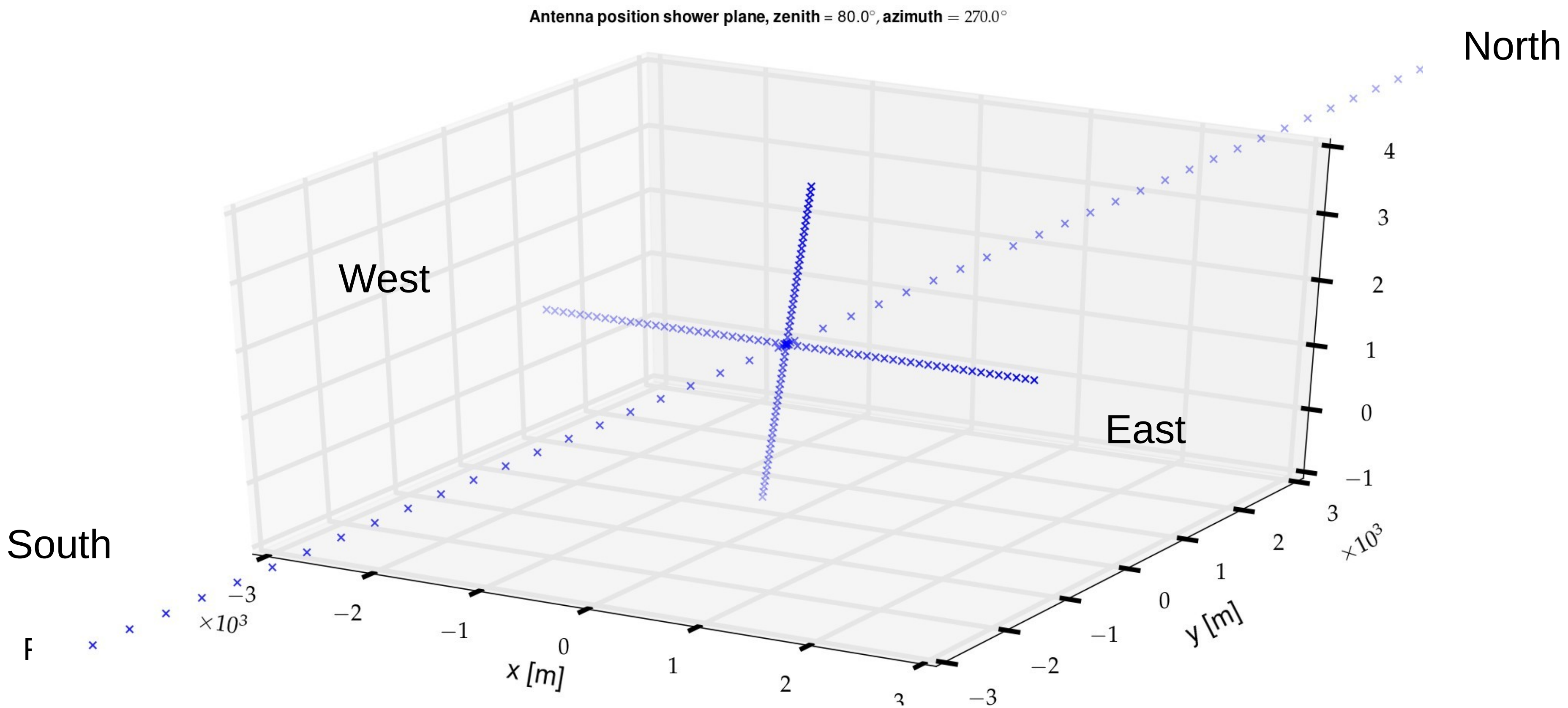
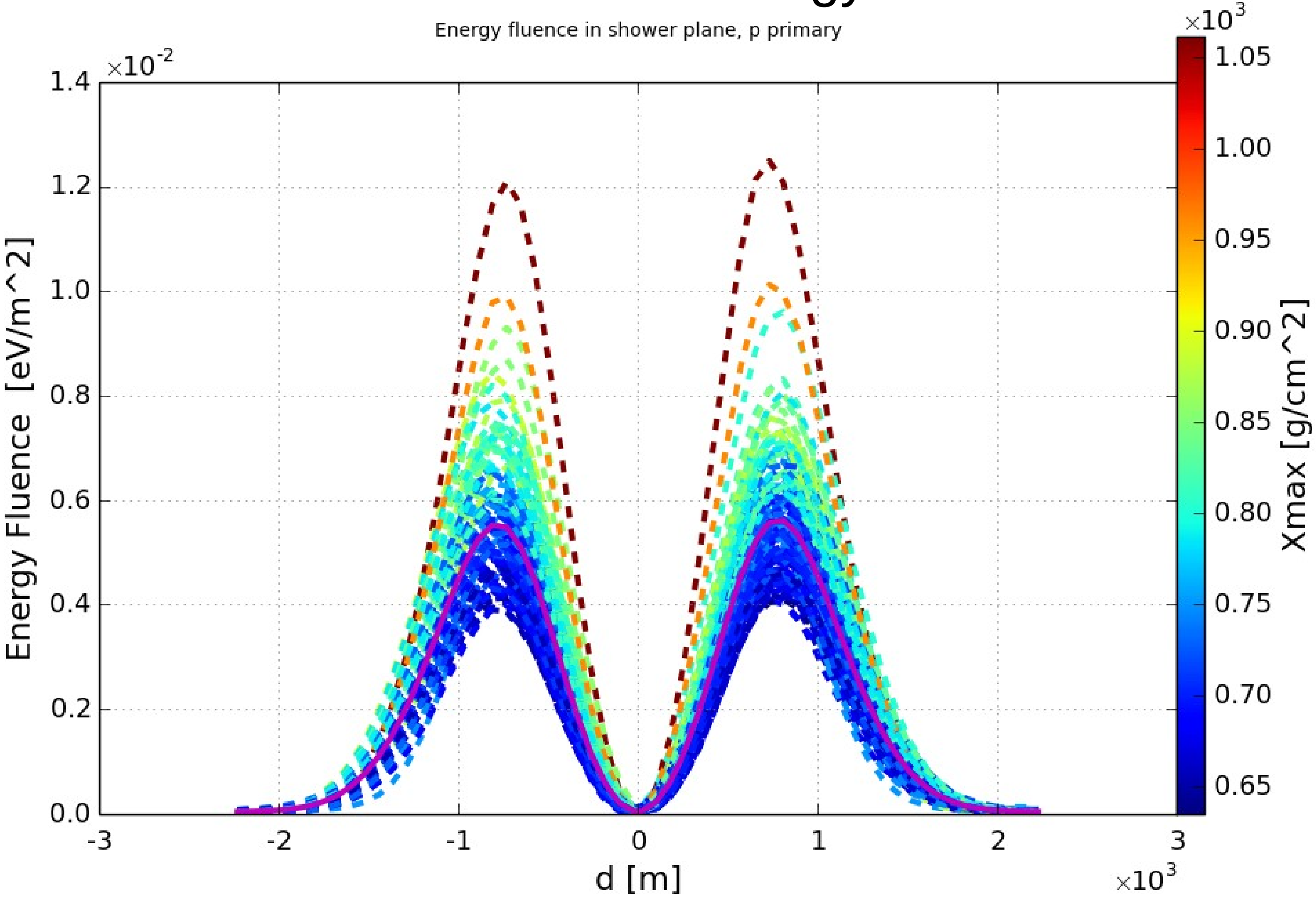
Simulations of charge excess emission

- For study of projection effects: simulations without magnetic field and air density set to 1
  - All radio emission produced by charge excess
- Incoming shower at 80° Zenith angle, directly from south, E = 1 EeV
- Equal spacing of antennas in shower plane



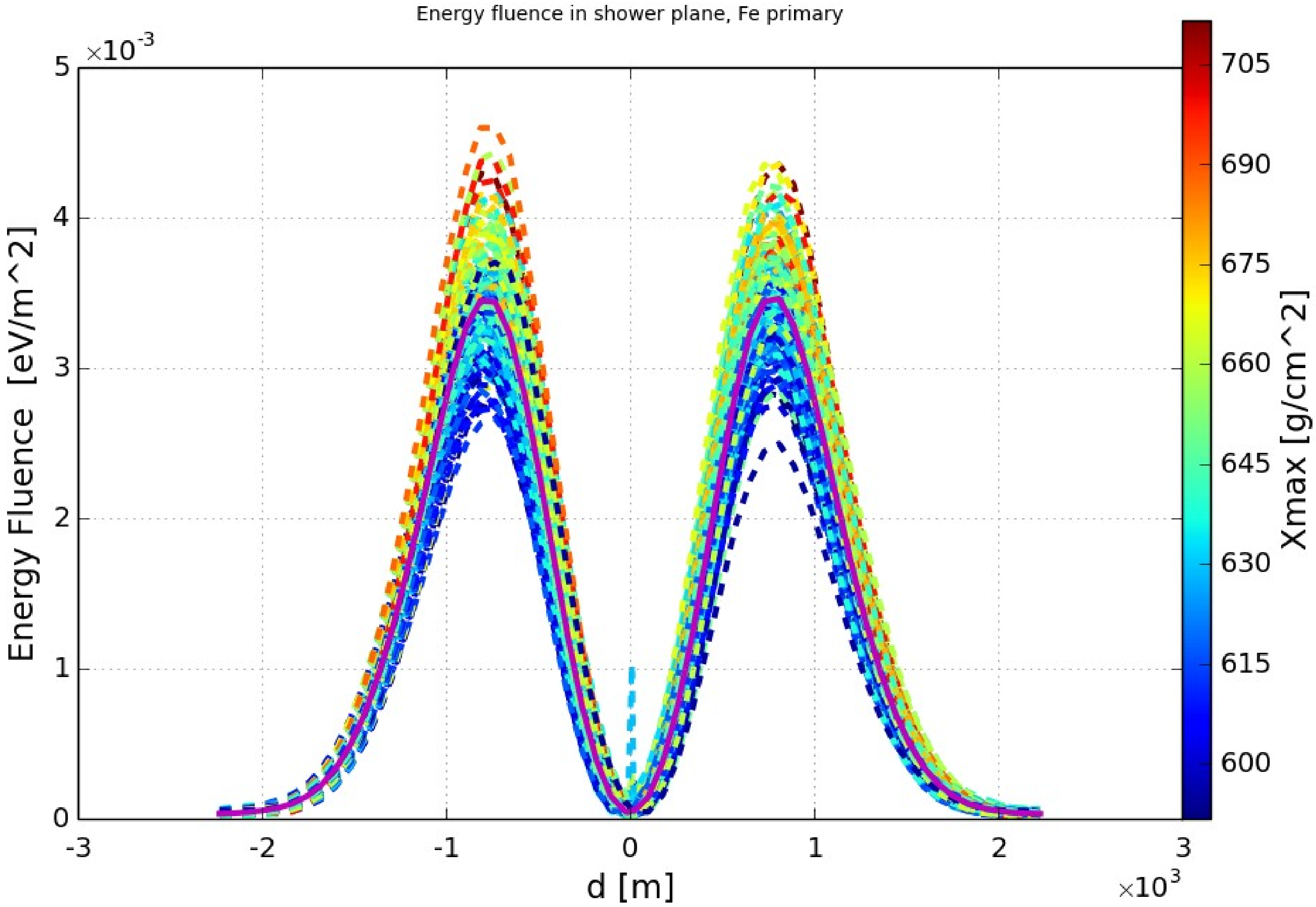
Simulation results

- Repeated simulation 200 times with proton, 200 with iron primary
- Left-right asymmetries from shower-to-shower fluctuations
  - In mean, asymmetries vanish
- Large absolute spread between simulations
- Strong Xmax correlation of absolute energy fluence



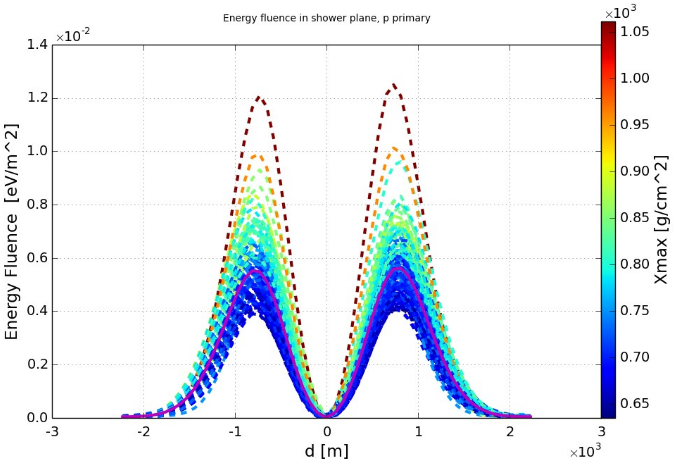
Simulation Iron

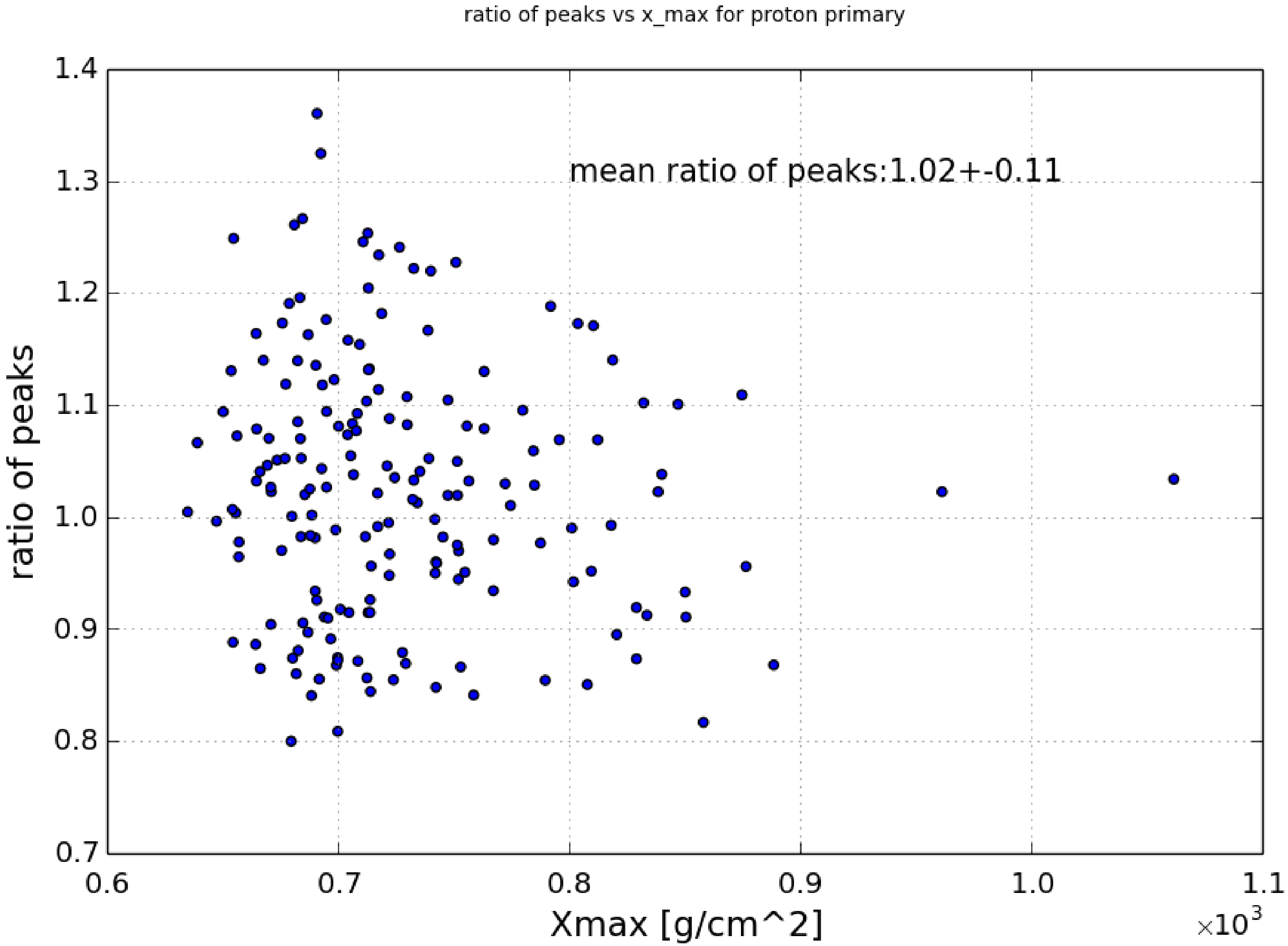
- Smaller spread for iron primaries
- As expected: Shower-to-shower fluctuations smaller for heavy primaries



Ratio of peaks

- Take ratio of right peak and left peak
- 1 in mean, but large scatter
- No Xmax dependance





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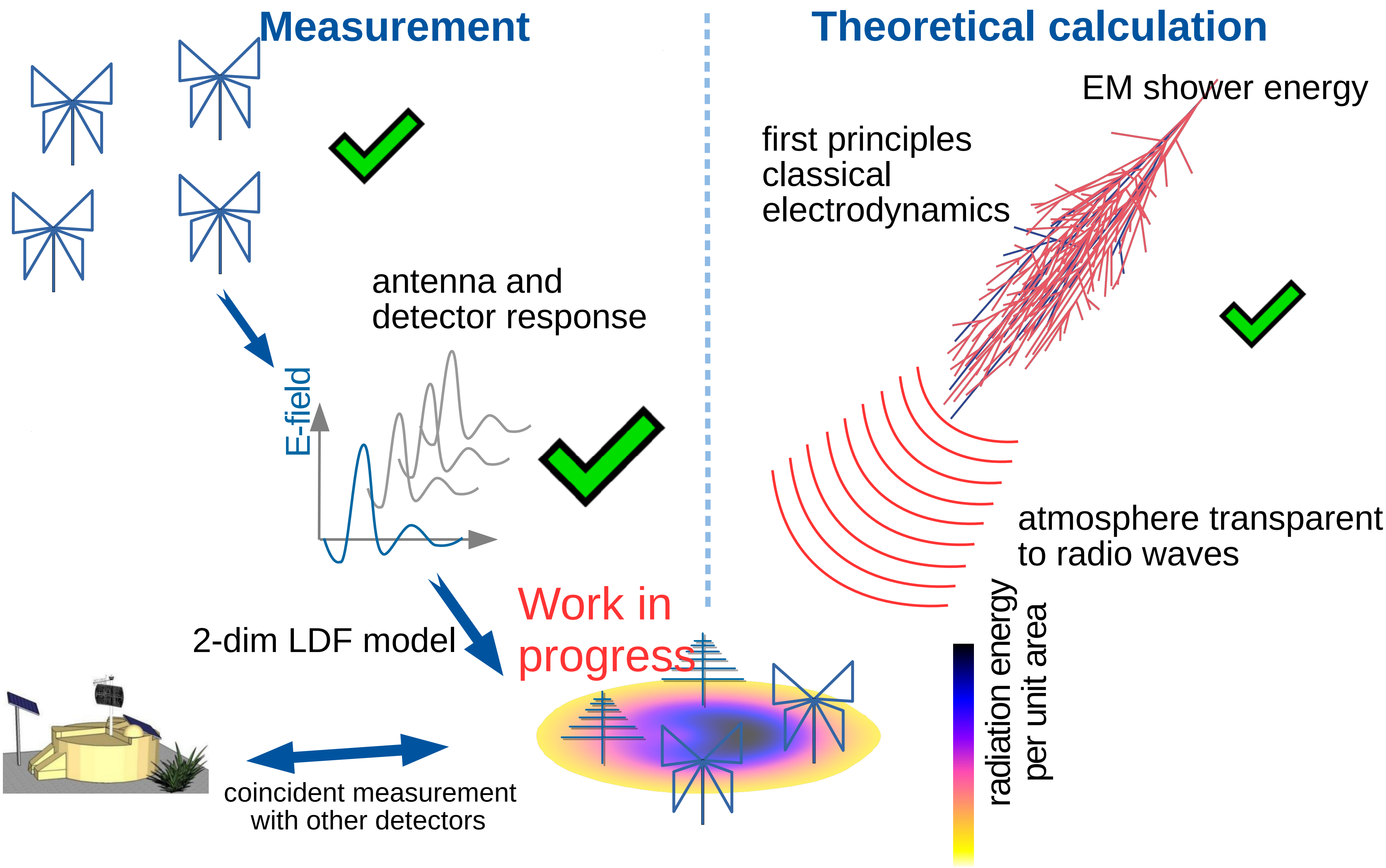

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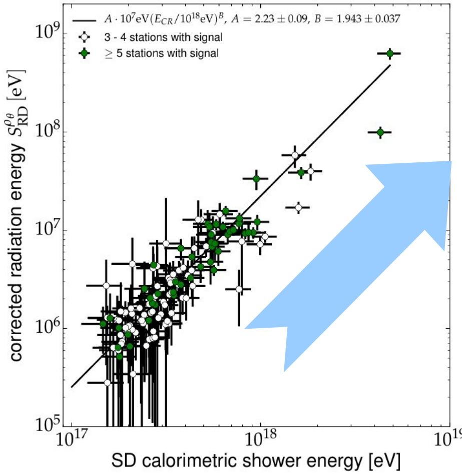
Summary and Outlook

- Extensive air showers induced by Ultra-High Energy Cosmic Rays hot topic in current research
  - Usable for energy calibration of whole Pierre Auger Observatory
- AERA well suited for study of these showers
- Well understood detector
  - Calibration campaign performed
  - Response pattern of antennas well described
- Need reconstruction of horizontal air showers
  - Asymmetries in charge excess emission found
  - Have to adapt reconstruction fit for horizontal showers
- In future: Energy calibration up to highest energies possible



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Uncertainties Calibration

Uncertainties @ 55MHz, $\theta = 42.5°$	Horizontal sys [%]	 stat [%]	Meridional sys [%]	 stat [%]
Global uncertainties:	**6.9**		**6.9**	
Injected power	2.5		2.5	
Transmitter gain	5.8		5.8	
Temp. drift signal generator & LNA	3.0		3.0	
Cable attenuation	0.5		0.5	
Flight dependent uncertainties:	**7.7**		**11.1**	
Transmitter position	4.8		5.4	
Ground height	1.1		0.8	
Antenna height	0.7		0.8	
Electric field twist	0.9		6.9	
Received power	5.8		6.7	
all	**10.2**	2.8	**12.8**	10.1

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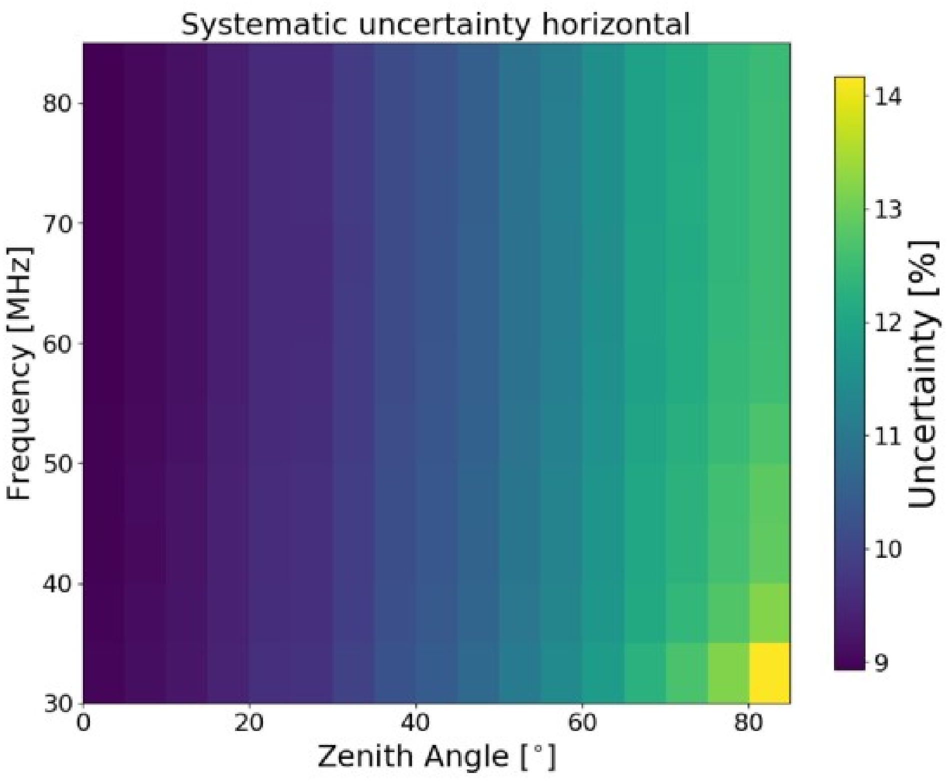
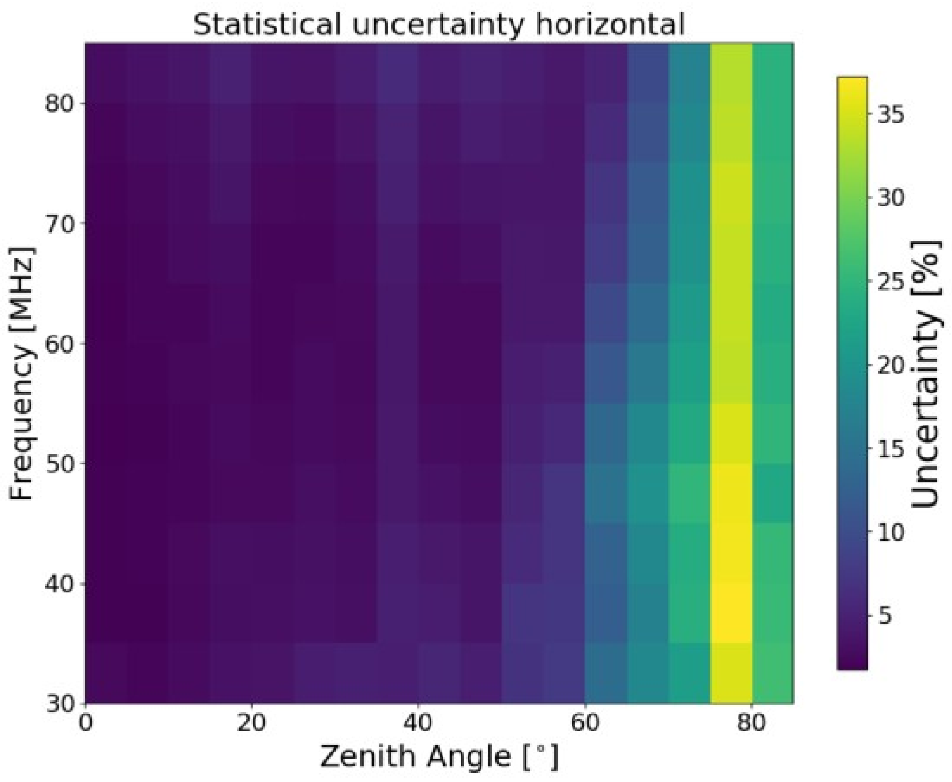
Uncertainties Calibration





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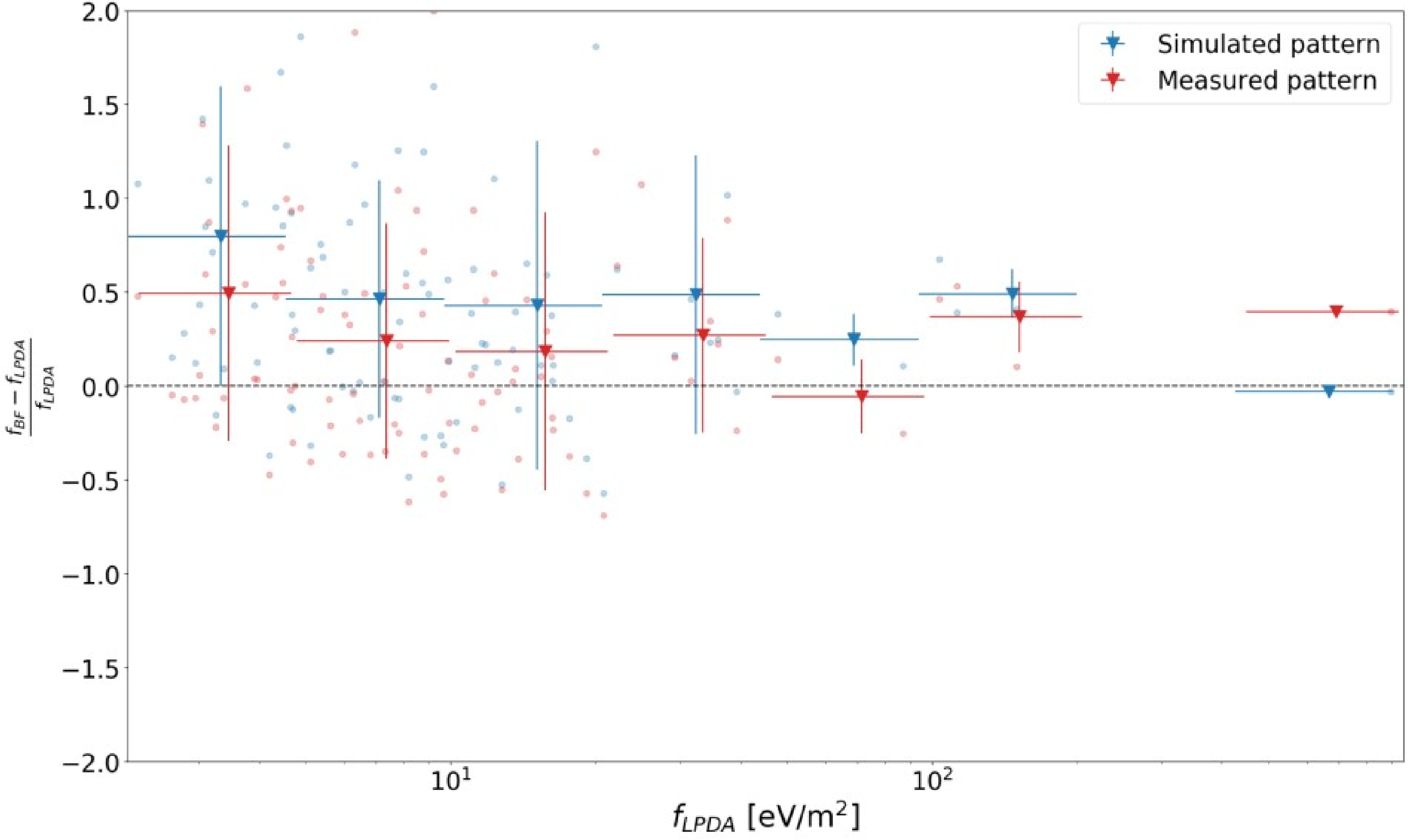
Comparison old/new pattern



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