# Simulating radio emission from air showers with CORSIKA 8

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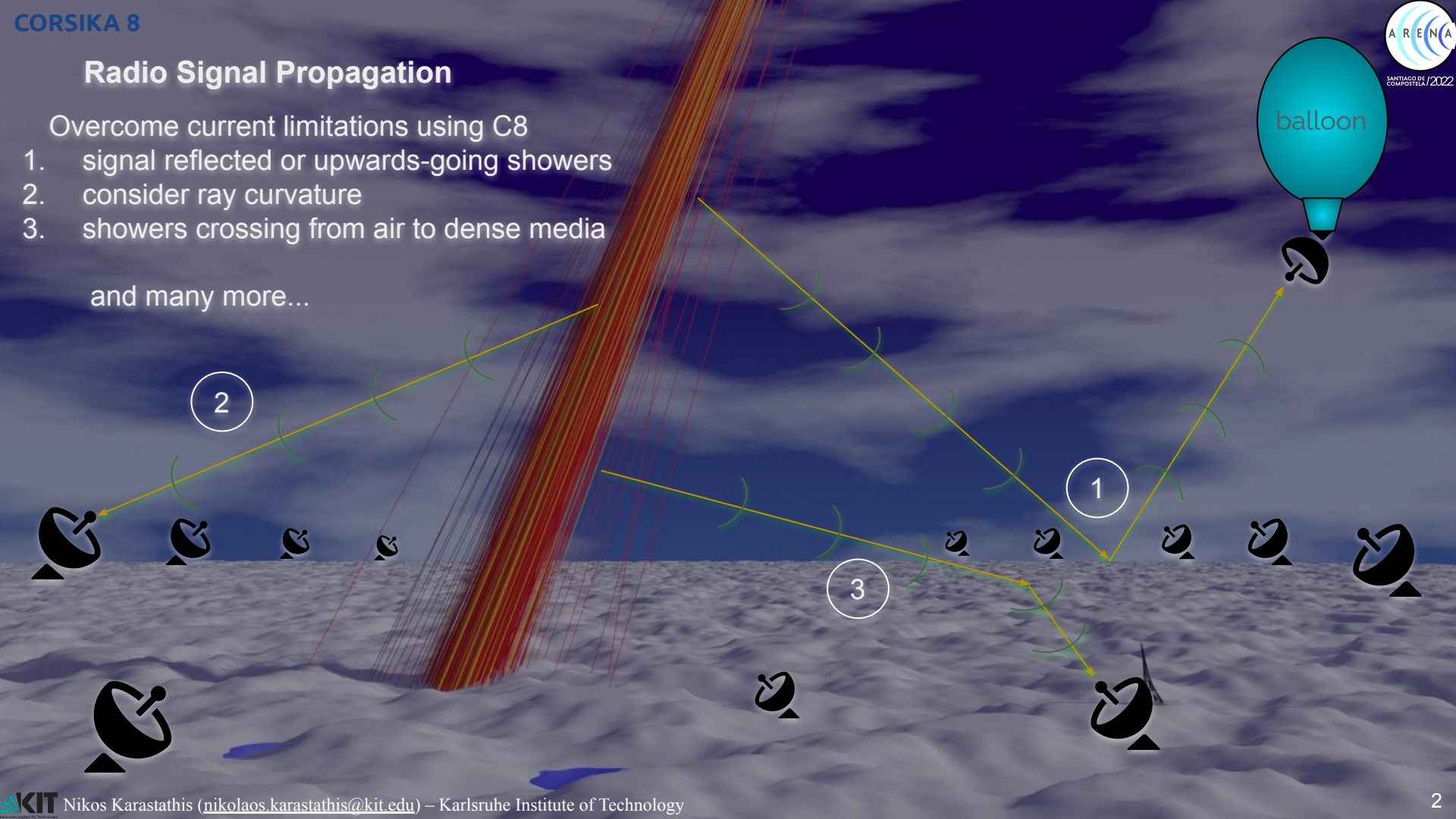
**for the CORSIKA 8 collaboration**

## Radio Signal Propagation

Overcome current limitations using C8

1. signal reflected or upwards-going showers
2. consider ray curvature
3. showers crossing from air to dense media

and many more...

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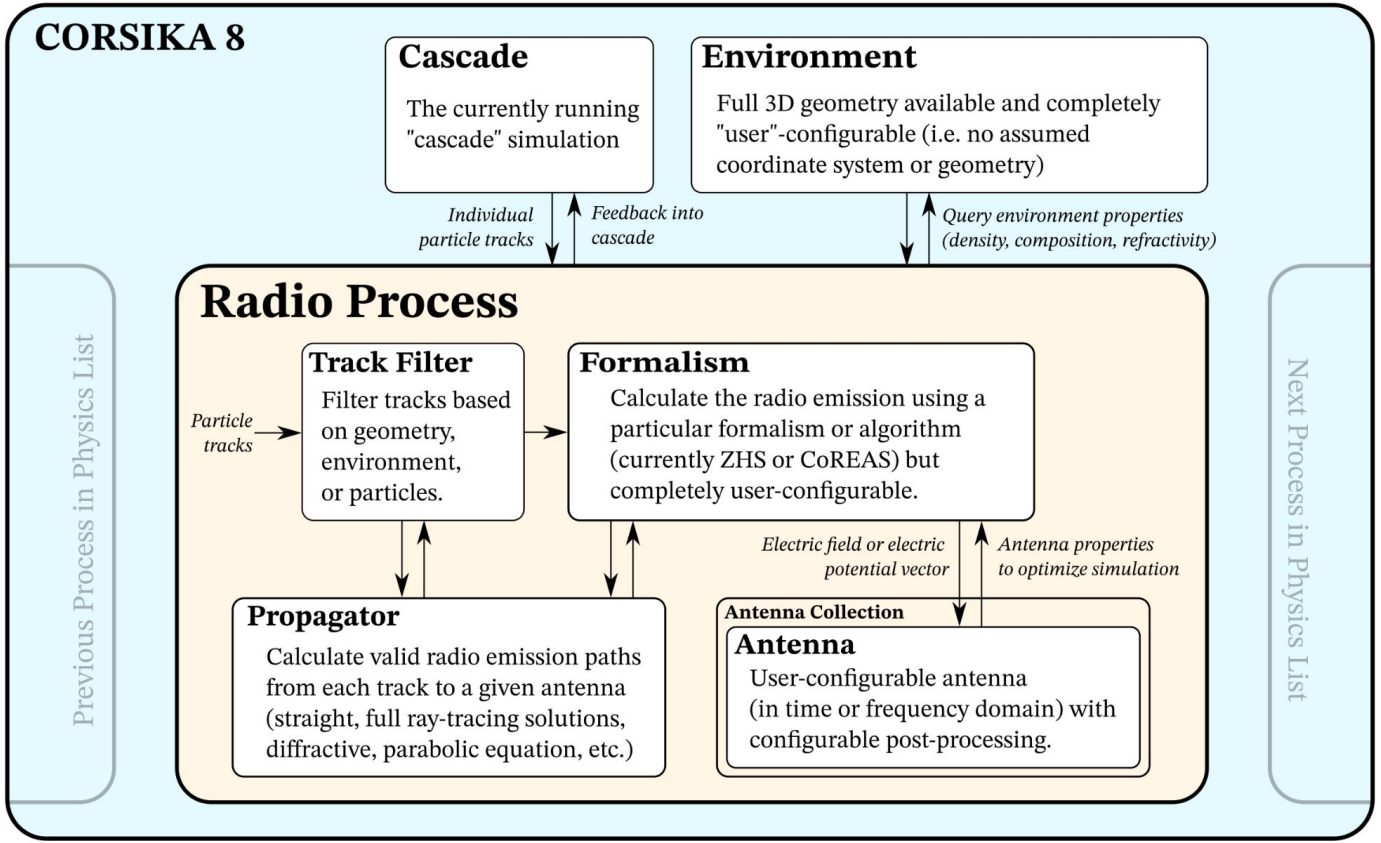
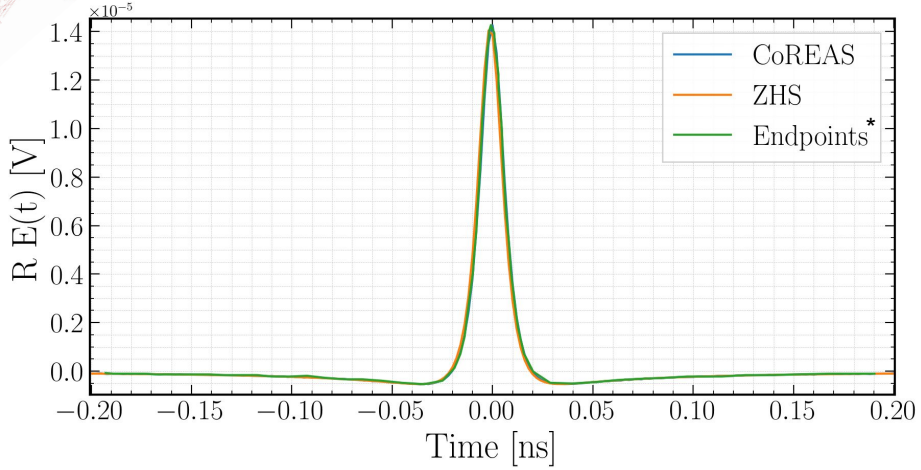
# Radio module architecture

## User-configurable parameters

- Filter
- Formalism
- Propagator
- Antenna



# Electron in a uniform magnetic field

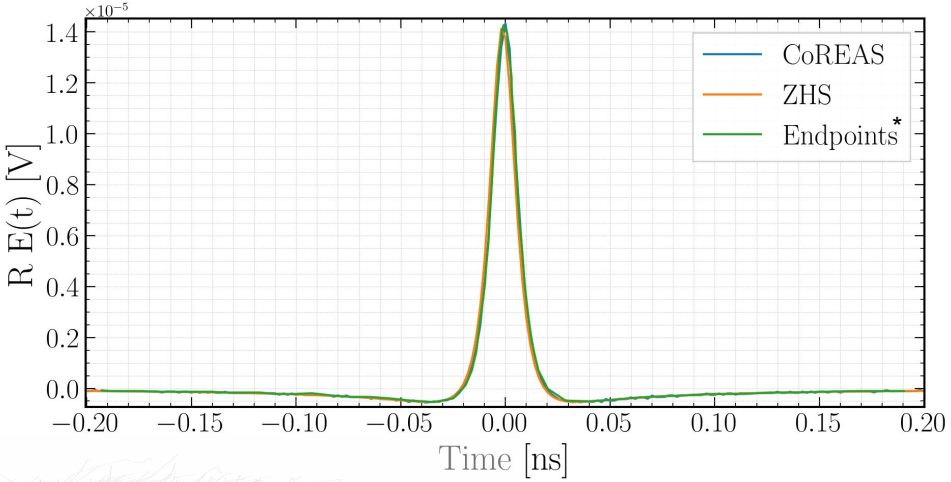



→ CORSIKA 8 tracking algorithm

Used C8's LeapFrog magnetic field tracking algorithm. Created a suitable environment with the corresponding values for magnetic field and gyrofrequency of the relativistic electron.

→ Manual tracking algorithm

100.000 points on a circle (L = 100m) connected by straight track segments. The relativistic electron of fixed energy, is allowed to travel on these tracks.






* C.W. James, H. Falcke, T. Huege and M. Ludwig, doi: 10.1103/PhysRevE.84.056602

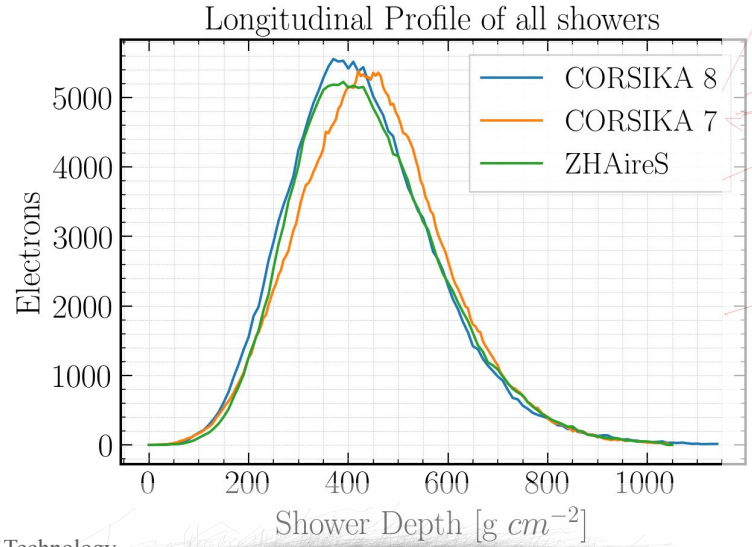
# Simulation of an extensive air shower

- 10 TeV electron-induced vertical shower
- US Standard atmosphere – uniform refractive index (n=1.000327)
- Horizontal geomagnetic field B = 50 μT aligned in the x direction
- $X_{\max} \approx 430\, g\, cm^{-2}$
- Star-shaped grid of antennas – 20 concentric rings (25m - 500m)

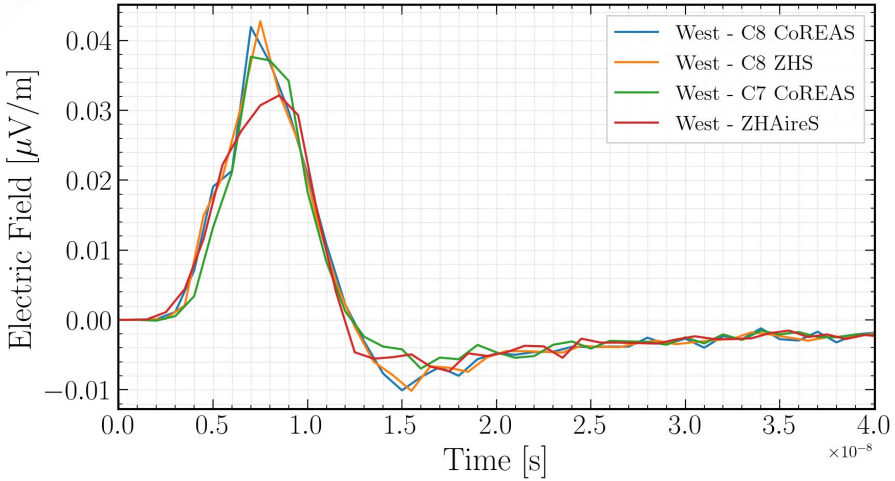
## Comparison

- CORSIKA 8 – CoREAS
- CORSIKA 8 – ZHS
- CORSIKA 7 – CoREAS
- ZHAireS

PROPOSAL v. 7.2.1 for C8 simulations



# Pulses comparison

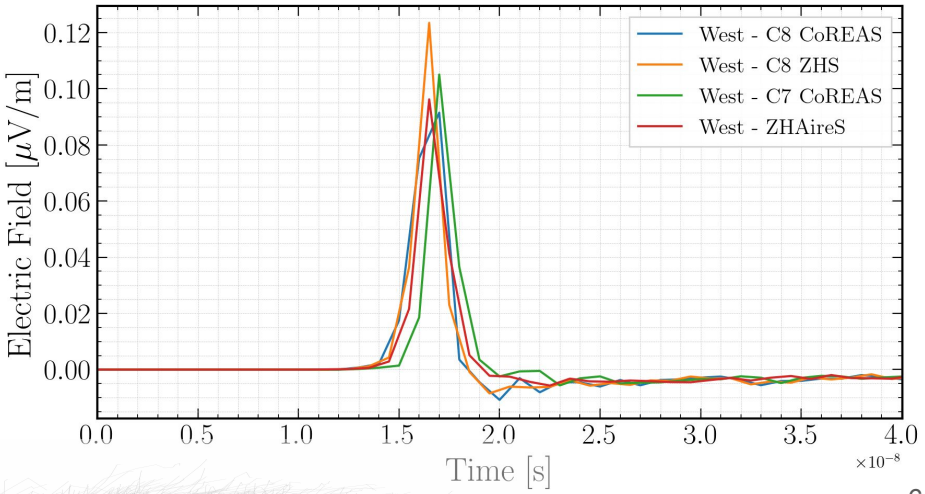



Antenna at 200m from the shower core

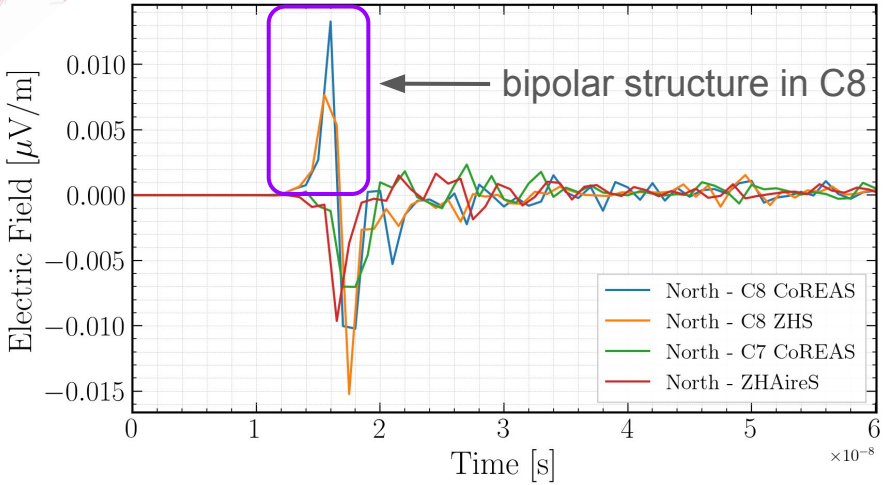
- Very good agreement between C7, ZHAireS and C8 CoREAS in pulse amplitude
- C8 ZHS is a bit higher

Antenna at 50m from the shower core

- Very good agreement between C8 (both formalisms) and C7 in pulse amplitude
- ZHAireS seems slightly off



# Polarization properties

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- Polarization behaviour matches
- C8 pulses have a bipolar structure instead of a unipolar pulse
- This affects the symmetry

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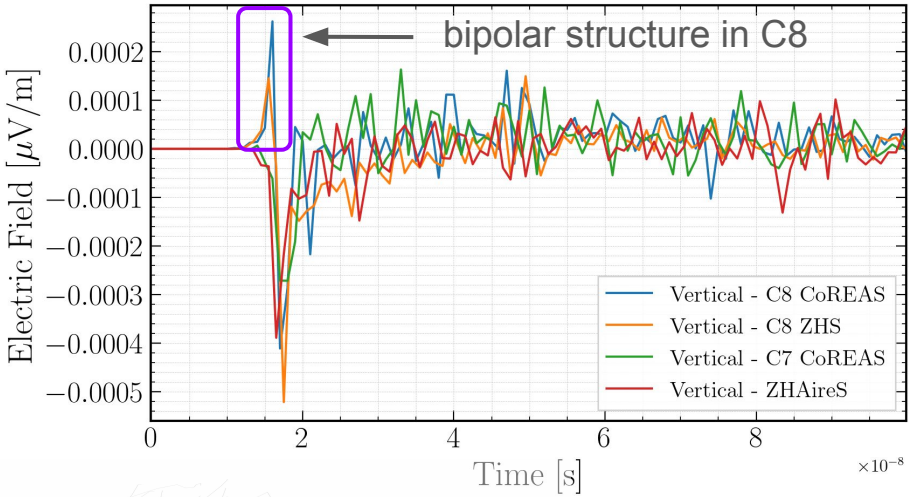
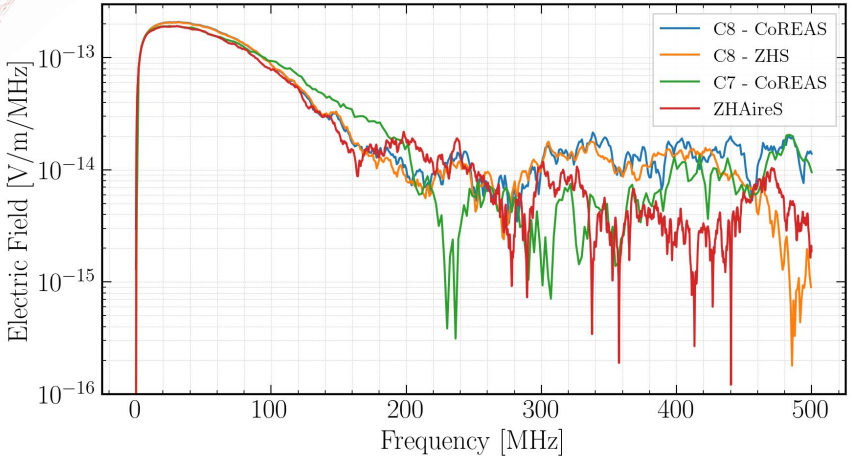


# Frequency spectra comparison

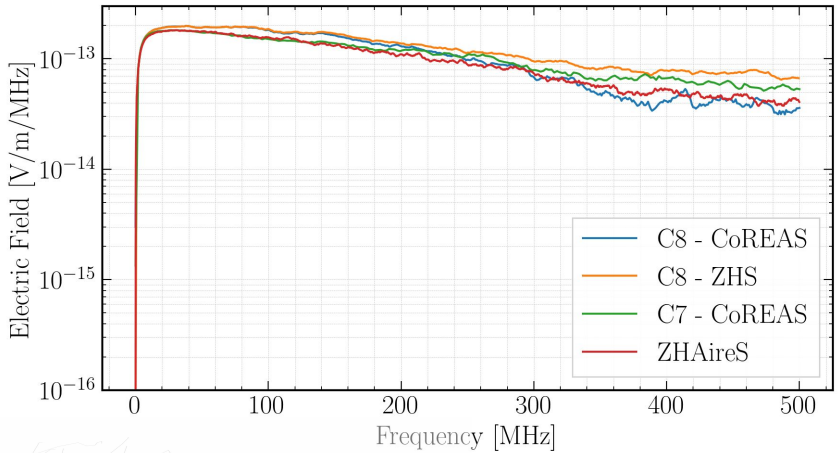



Antenna at 50m from the shower core

- Increase in power below 80 MHz for C8 spectra
- Increase in power between 300 and 400 MHz for C8 spectra
- C8 CoREAS and C8 ZHS diverge after 420 MHz
- Overall decent agreement

Antenna at 200m from the shower core

- Slight increase in power below 200 MHz for C8
- C8 CoREAS and C8 ZHS diverge slightly after 200 MHz
- Overall decent agreement



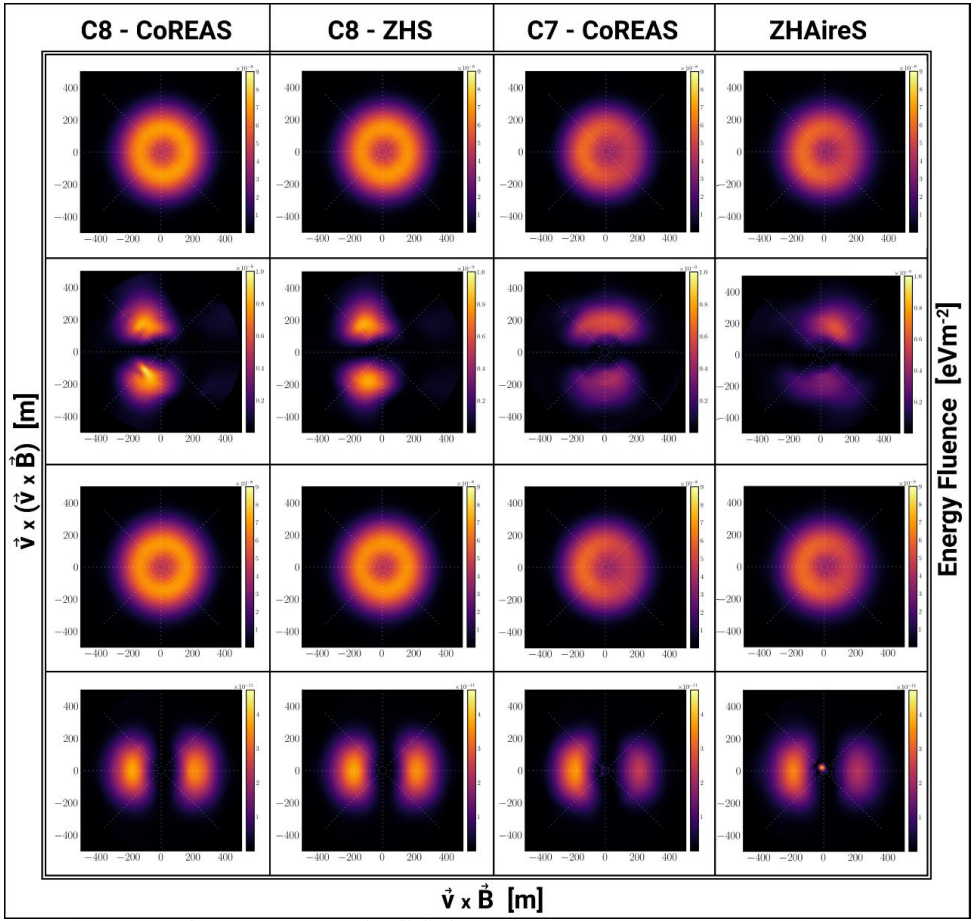
# Energy fluence 2D maps (30 - 80 MHz)

All polarizations

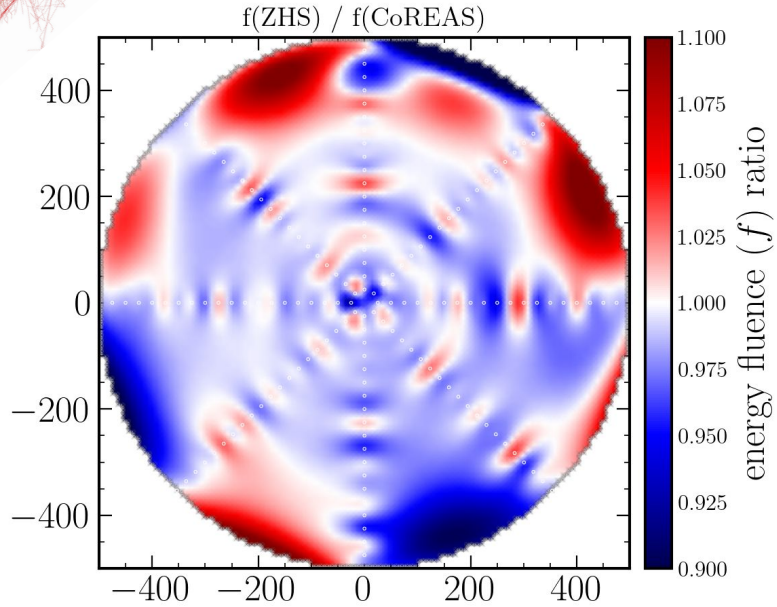
$\vec{v} \times \left(\vec{v} \times \vec{B}\right)$

$\vec{v} \times \vec{B}$

$\vec{v}$



# CoREAS / ZHS fluence comparisons

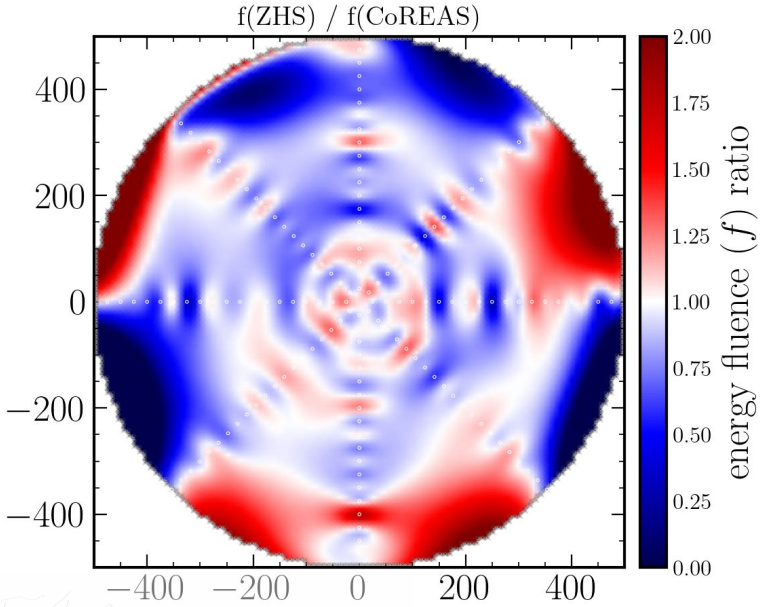



$\vec{v} \times \vec{B}$

- Agreement within 10%

- Good agreement as well
- Biggest differences can be seen in positions where the signal weaker
- Interpolation artifacts

$\vec{v} \times \left(\vec{v} \times \vec{B}\right)$



# Summary

- Radio module is designed to support next generation experiments
- Tested and validated in simple scenarios
- Electron showers simulations show good agreement between C8 with C7 and ZHAireS in absolute amplitude of the pulse
- Agreement of polarization characteristics between C8 with C7 and ZHAireS
- 2D fluence maps provide interesting observations and point us to investigate further
- Very good agreement between CoREAS and ZHS algorithms in C8

Radio module in C8 is capable of calculating the radio emission like C7 and ZHAireS. Our project is open source and under development so we welcome you to join us and implement more sophisticated signal propagation scenarios tailored to your needs.

https://gitlab.iap.kit.edu/AirShowerPhysics/corsika

# Thank you!

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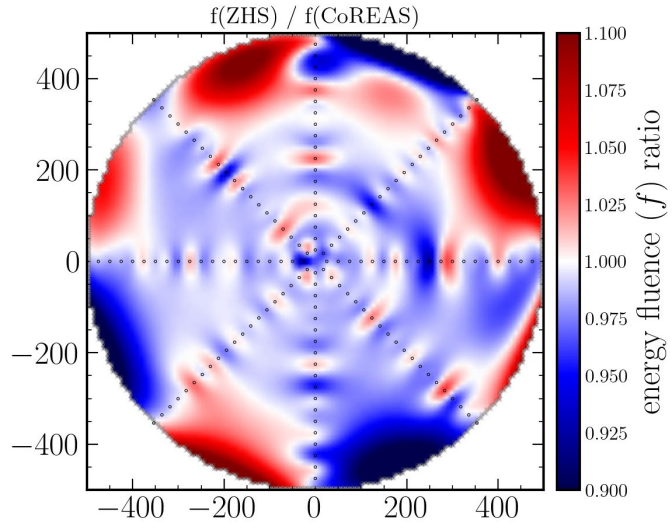
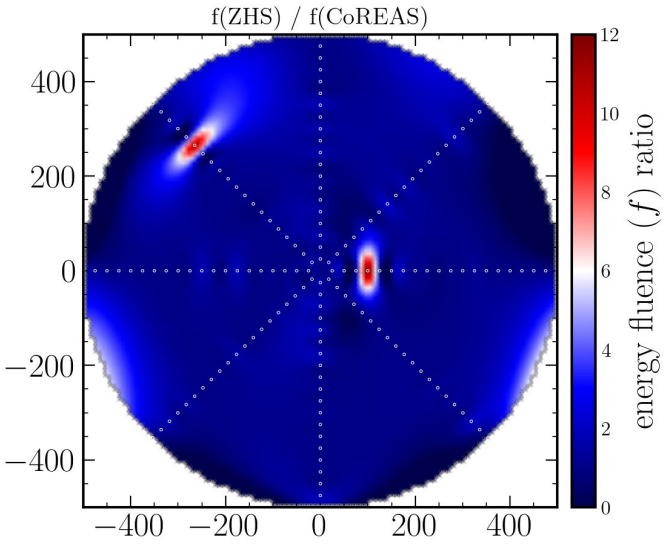
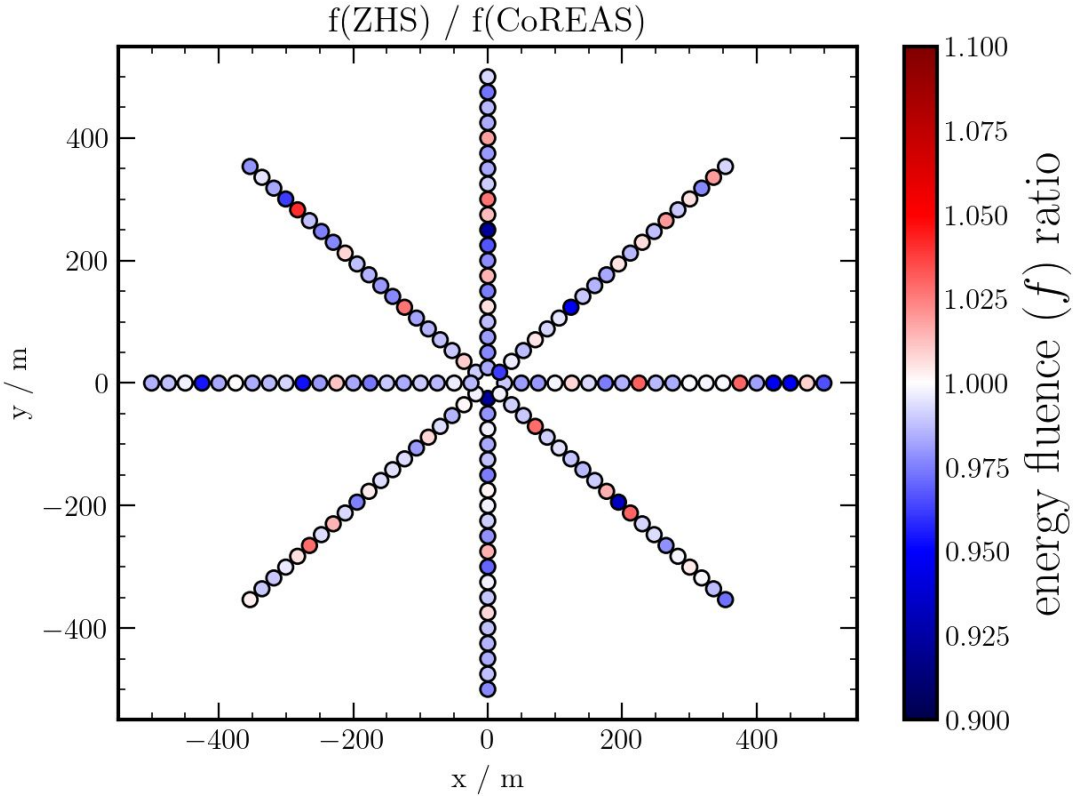
# Bonus slides

# CoREAS / ZHS fluence comparisons




- In **all polarizations** they agree within 0.92 and 1.04
- In **v** they agree within 0.71 and 11.85
- The big differences are due to numerical reasons in positions with very weak signal



# CoREAS / ZHS without interpolation

**All polarizations**