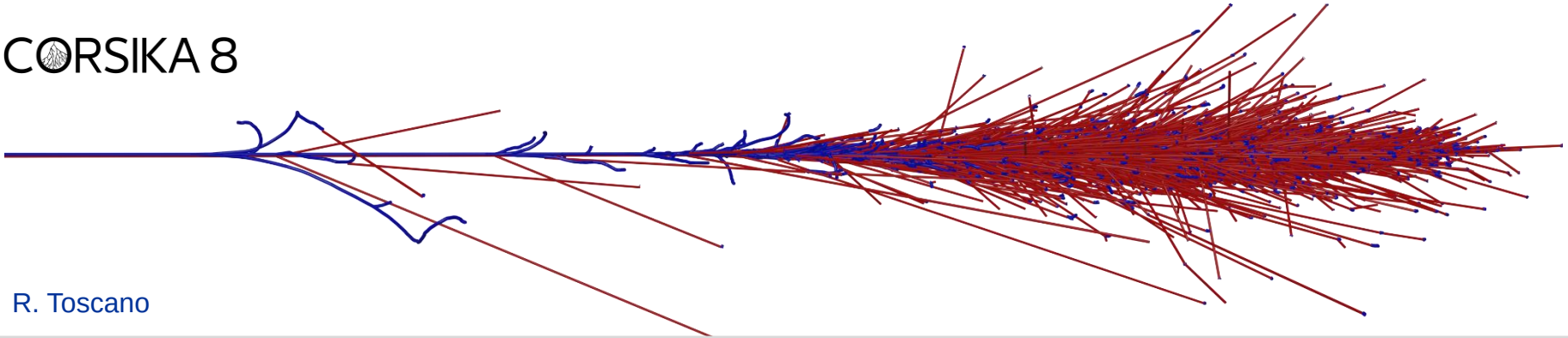
Karlsruhe Institute of Technology

VRIJE UNIVERSITEIT BRUSSEL

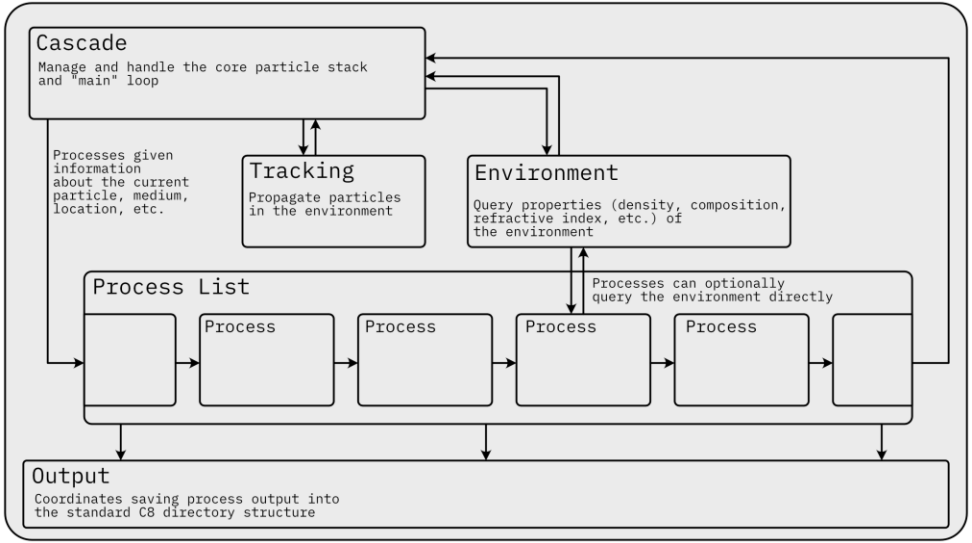
Validation of air-shower simulations with CORSIKA 8

Nikolaos Karastathis (KIT), Tim Huege (KIT & VUB)



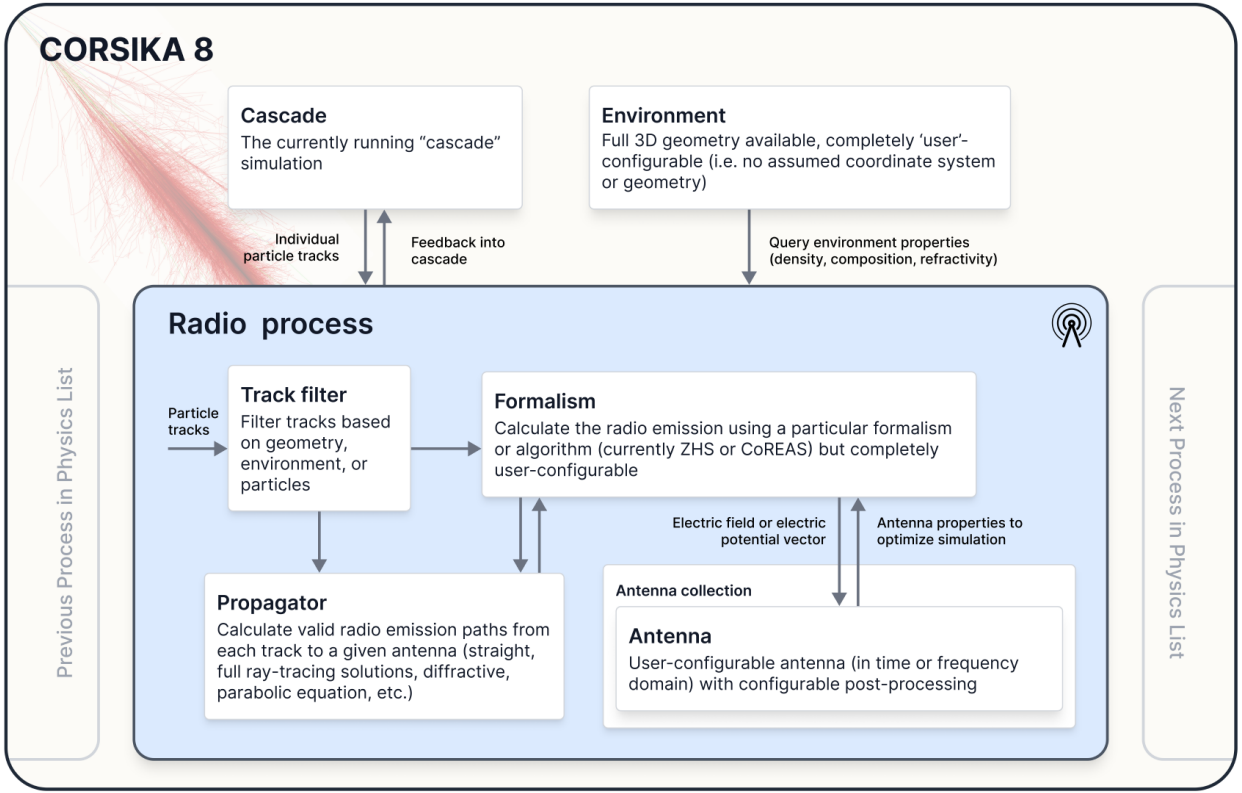
CORSIKA 8

- project started in 2018
- a modern reimplementation in C++, with focus on modularity
- designed with the needs of modern computing in mind
- coordinated by KIT, but as a true community effort

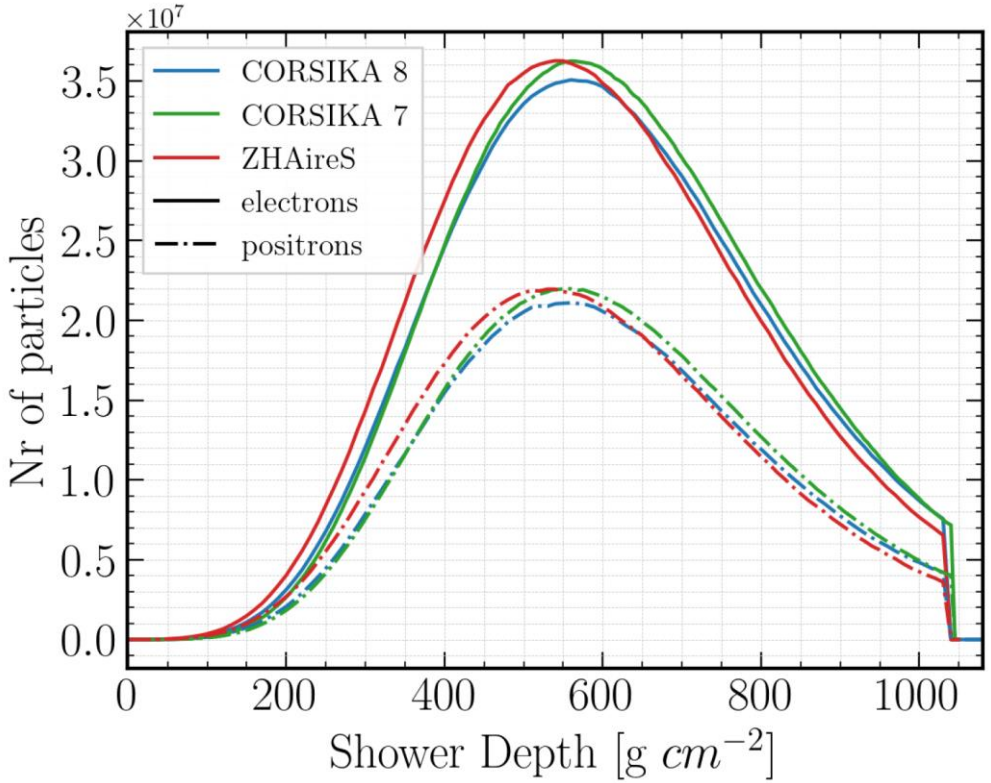


Radio-emission simulations

- radio emission from particle cascades fully implemented
- two formalisms: „CoREAS“ (endpoints) à la C7 and „ZHS“ à la ZHAireS
- generic structure
- powerful diagnostic

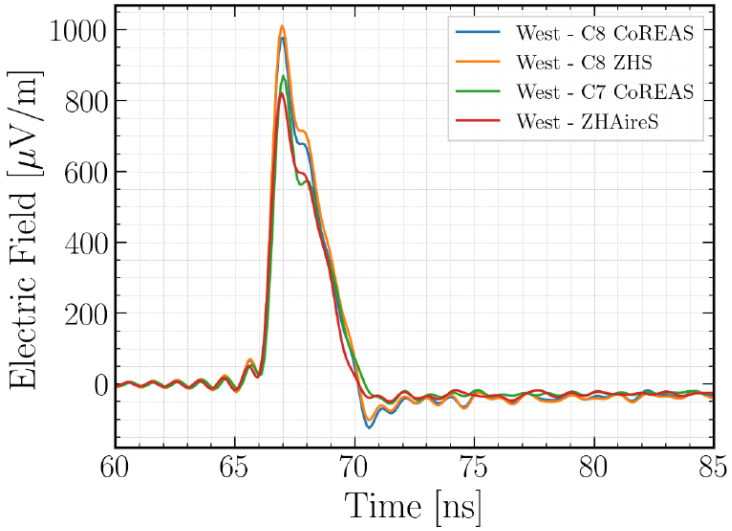


Comparison C8 vs C7 vs ZHAireS

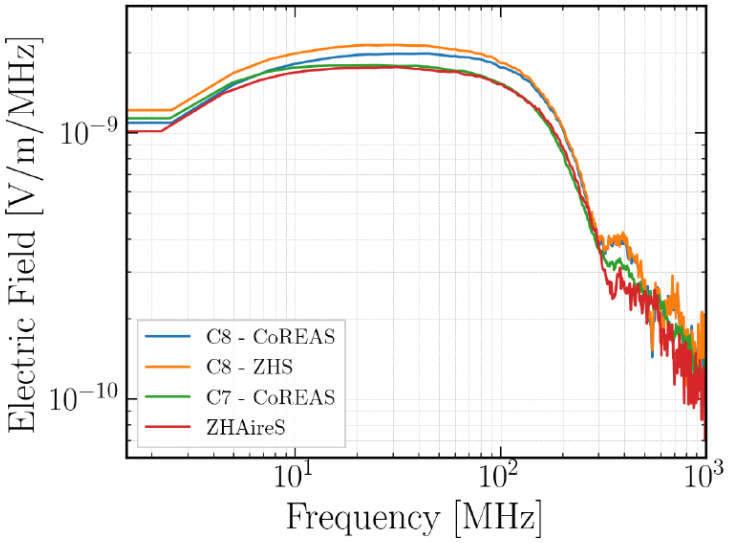


- Select „similar“ showers
- Standard setting for particle tracking
  - C8 max geomagnetic deflection angle 0.2 rad
  - C7 STEPFC 1.0 and max deflection 0.2 rad
- Vertical 10^{17} eV, 50 μT horizontal B-field, Sybill 2.3d & FLUKA, 0.5 MeV em particle cut, 10^{-6} opt. thinning, US standard atmo with n0=1.000327

Geomagnetic pulses 50 m from axis – 0-1 GHz

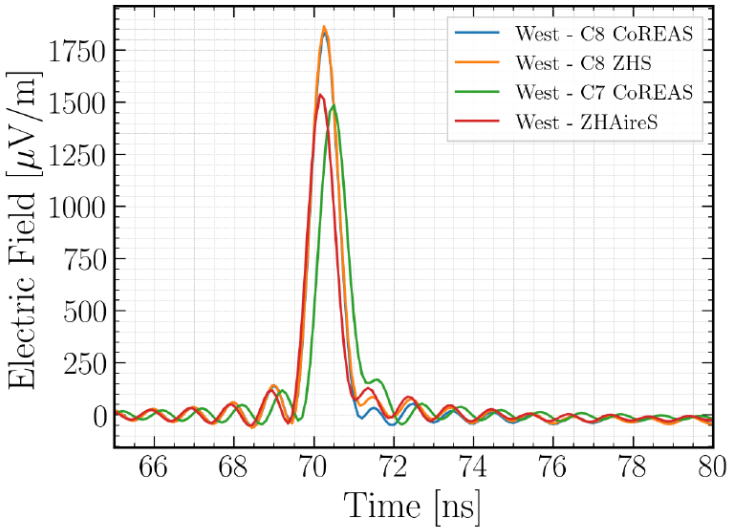


(a) 50 m.

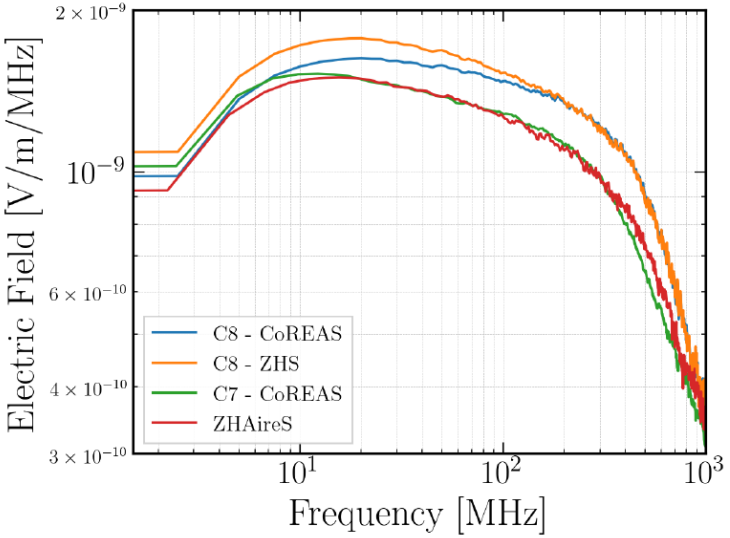


(b) 50 m.

Geomagnetic pulses 100 m from axis – 0-1 GHz

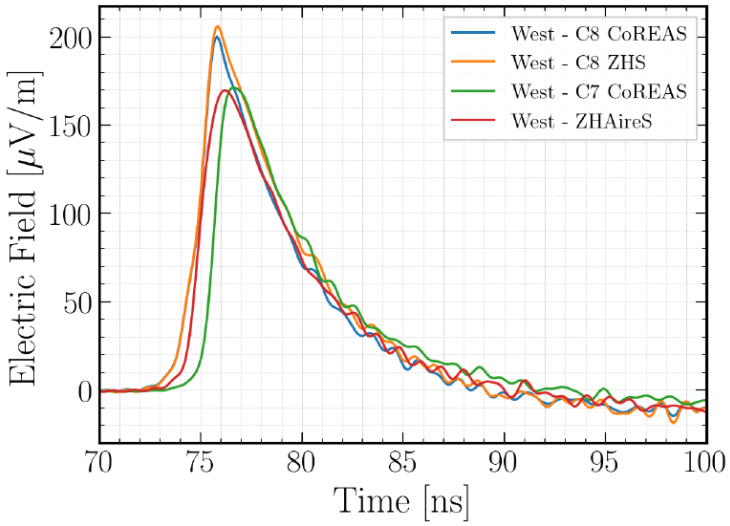


(c) 100 m.

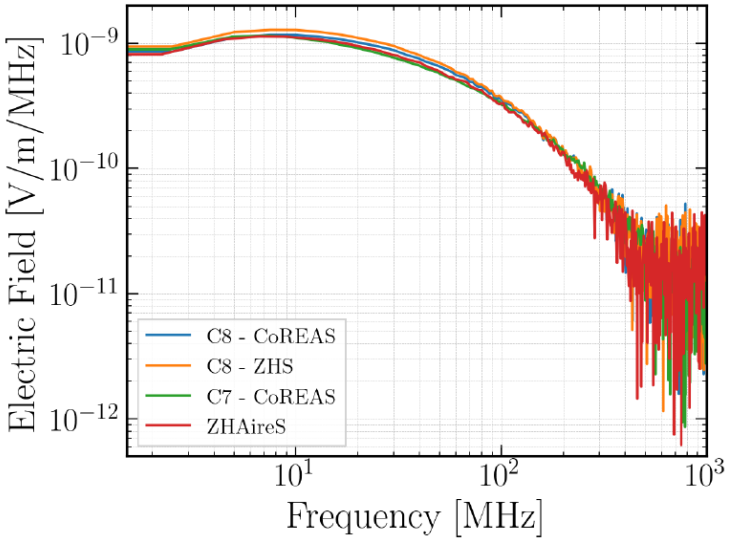


(d) 100 m.

Geomagnetic pulses 200 m from axis – 0-1 GHz

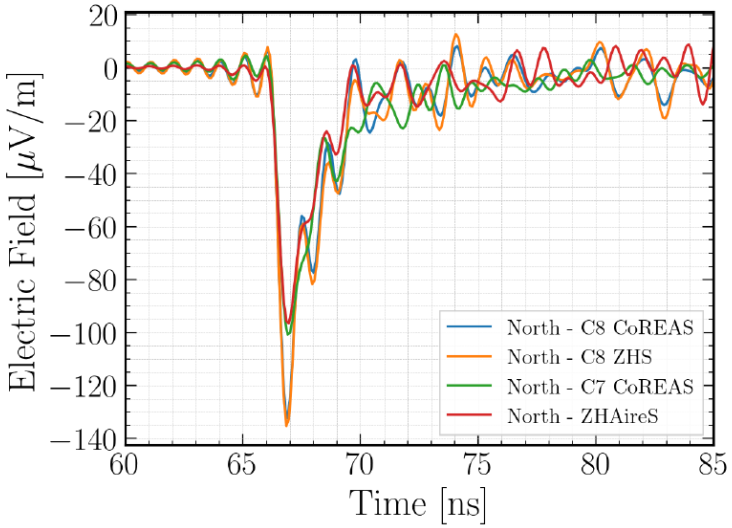


(e) 200 m.

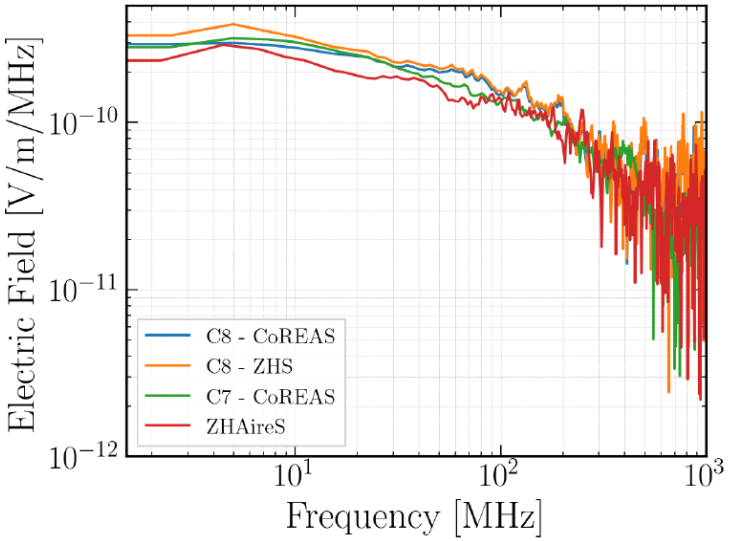


(f) 200 m.

Askaryan pulses 50 m from axis – 0-1 GHz

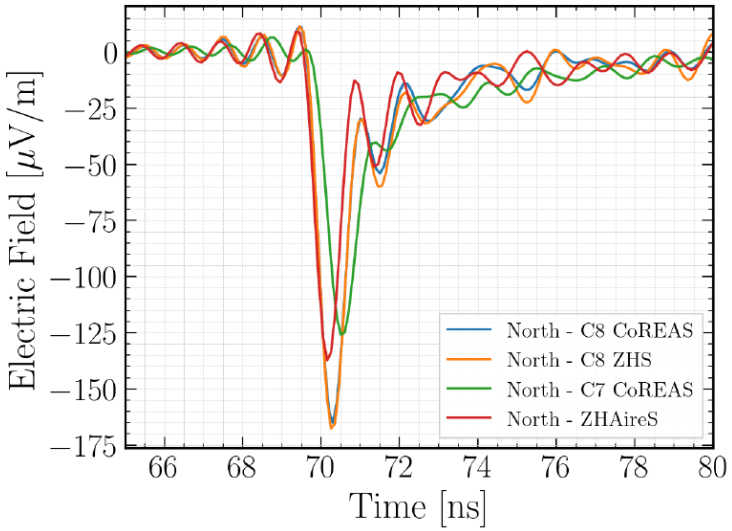


(a) 50 m.

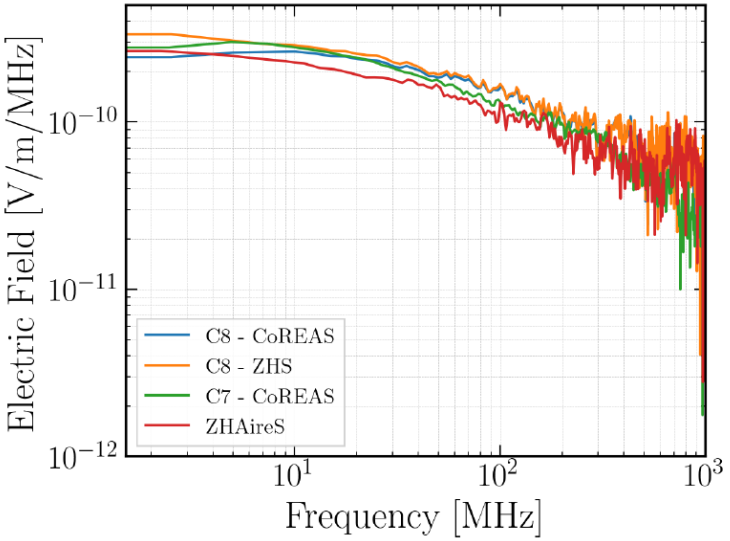


(b) 50 m.

Askaryan pulses 100 m from axis – 0-1 GHz

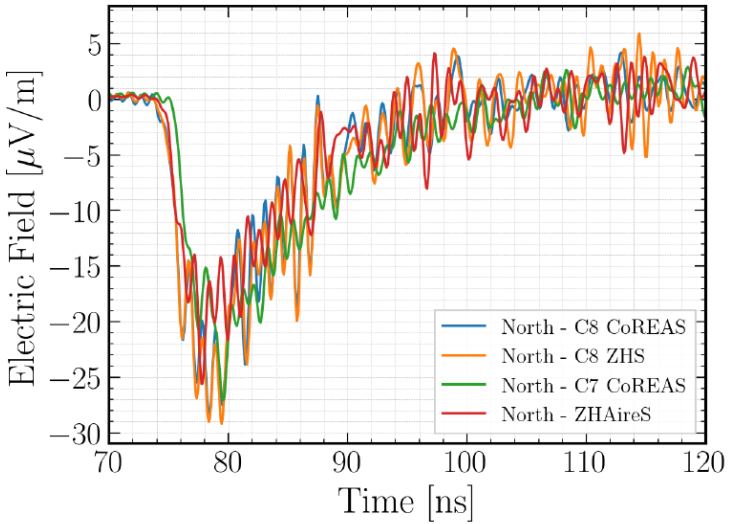


(c) 100 m.

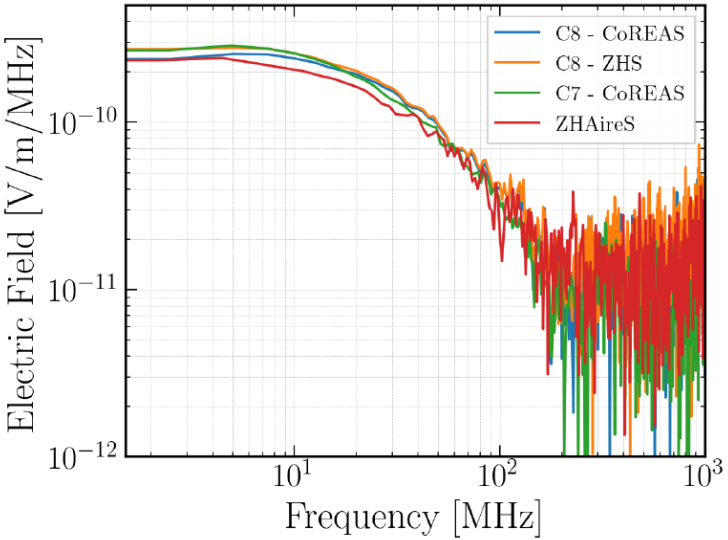


(d) 100 m.

Askaryan pulses 200 m from axis – 0-1 GHz



(e) 200 m.



(f) 200 m.

Radio-emission 30-80 MHz

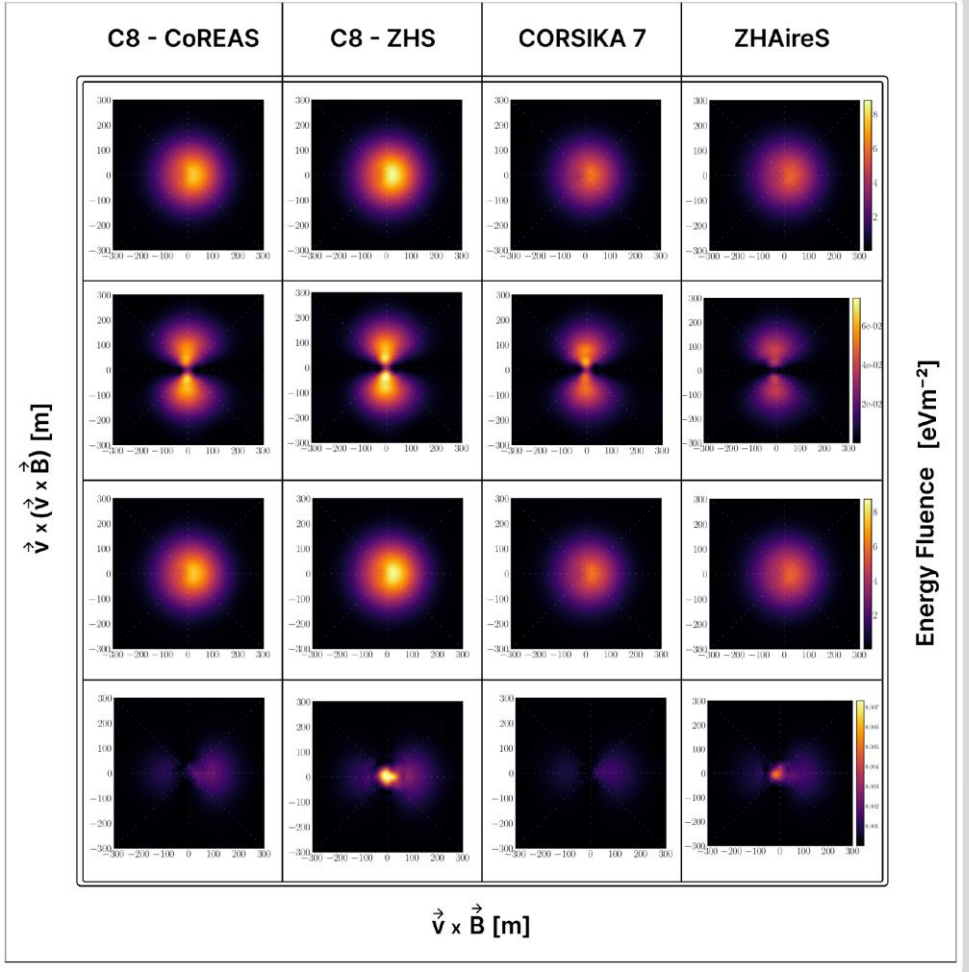
- patterns and polarizations match
- C8 produces slightly more signal
- to be studied in more detail

modulus

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

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

$$\vec{v}$$



N. Karastathis for C8
PoS(ICRC2023)425

Radio-emission 50-350 MHz

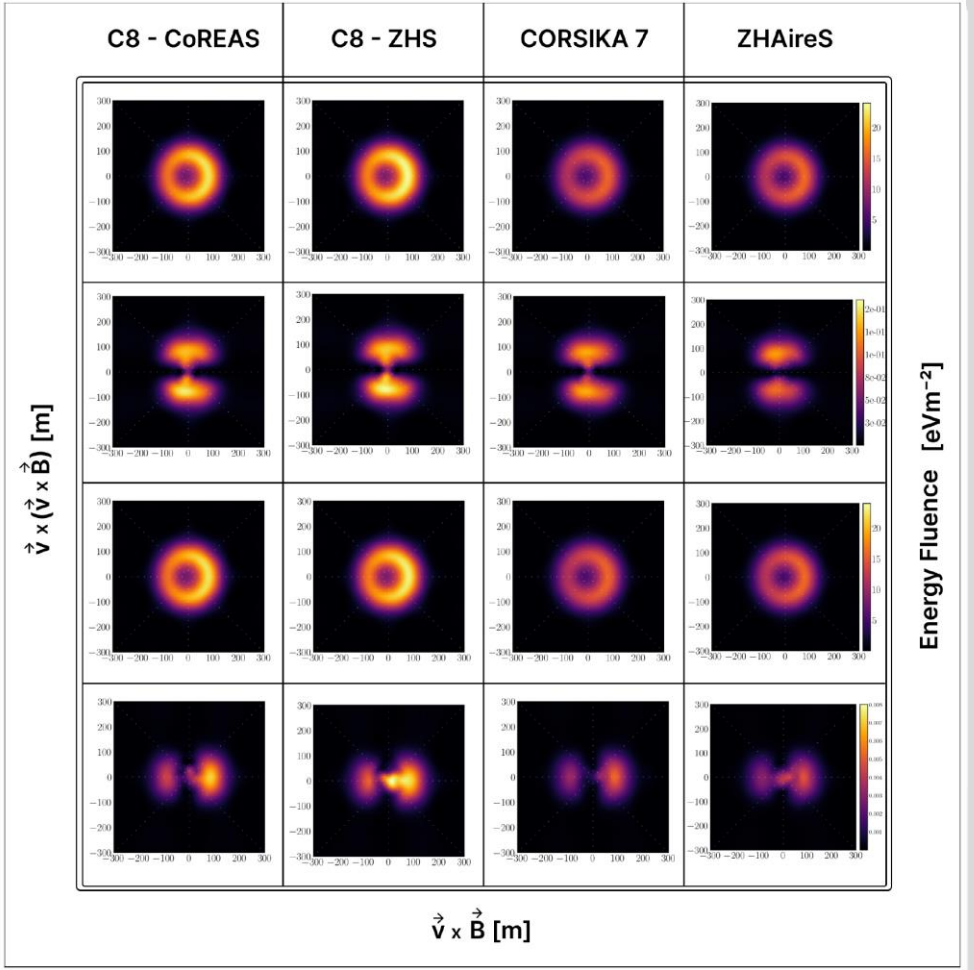
- patterns and polarizations match
- C8 produces slightly more signal
- to be studied in more detail

modulus

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

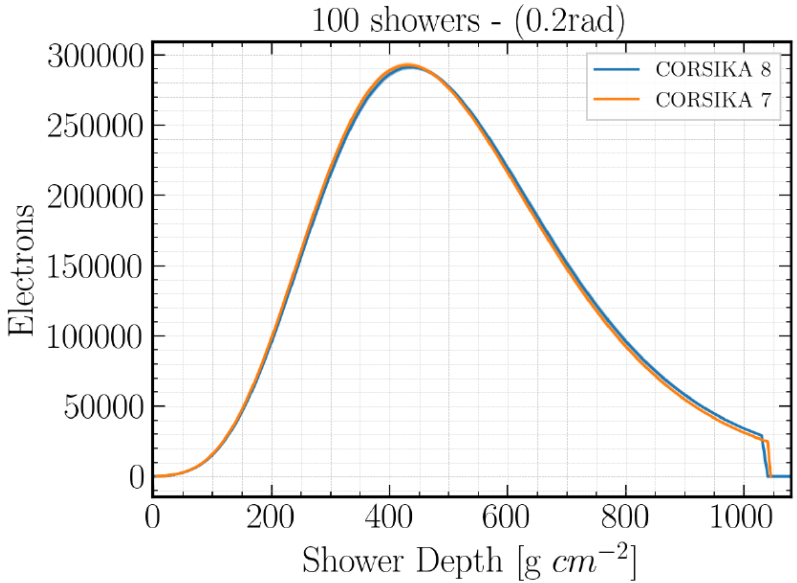
$$\vec{v} \times \vec{B}$$

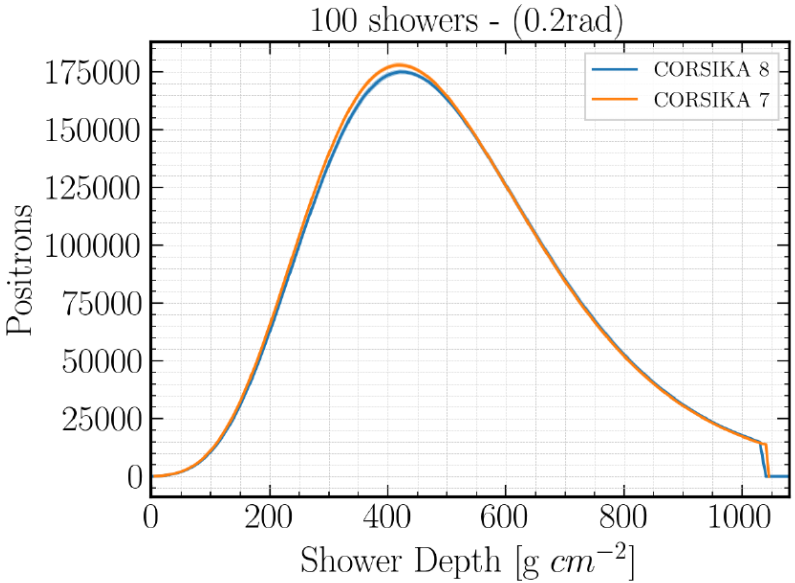
$$\vec{v}$$



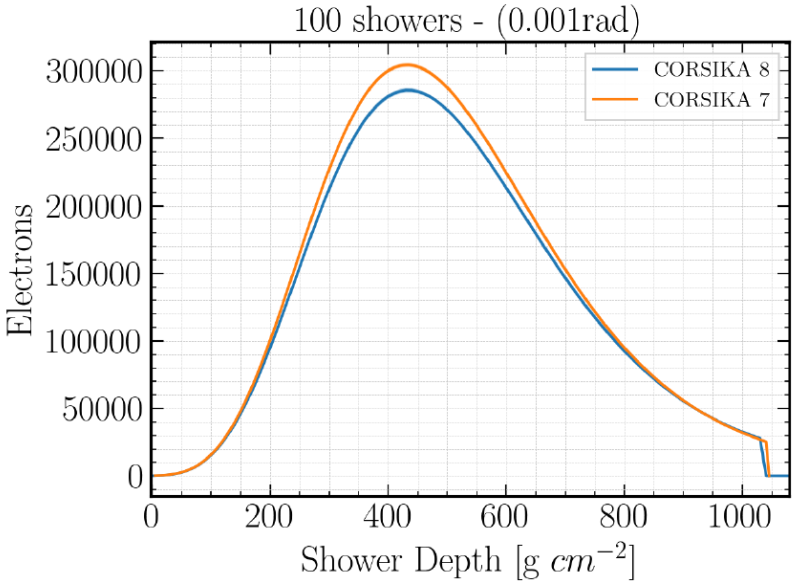
N. Karastathis for C8
PoS(ICRC2023)425

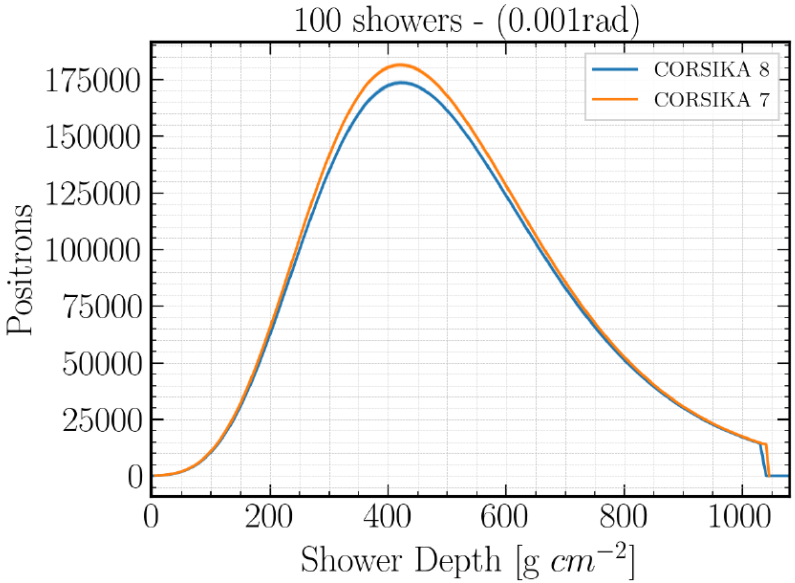
Comparing 100 showers (1 PeV, iron) – 0.2 rad





Comparing 100 showers (1 PeV, iron) – 0.001 rad



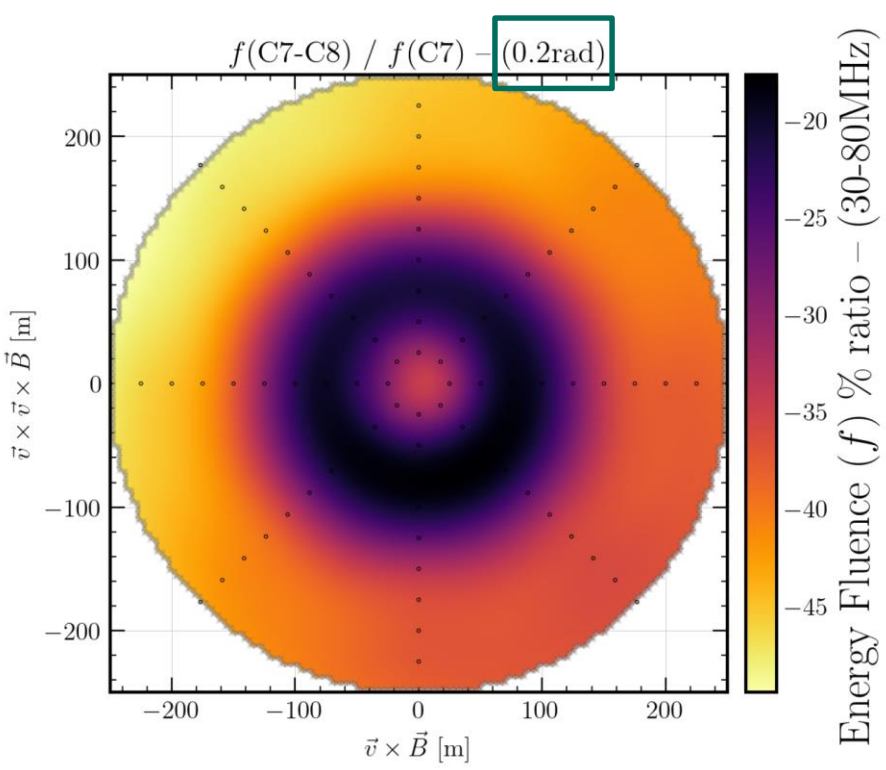


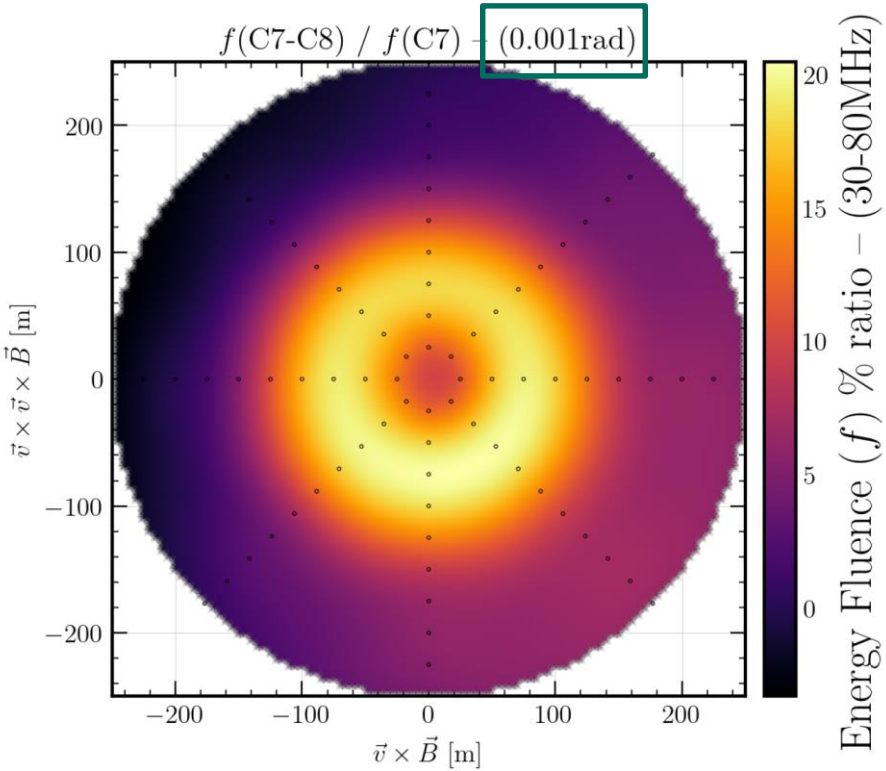
Comparison radiation energy C8/C7

CORSIKA 8 vs CORSIKA 7 – mean difference in terms of % (0.2rad)		
Radiation Energy	30 MHz to 80 MHz	50 MHz to 350 MHz
Total Radiation Energy	-31.9%	-53.6%
Geomagnetic Contribution	-31.8%	-53.5%
Charge Excess	-46.1%	-31.2%

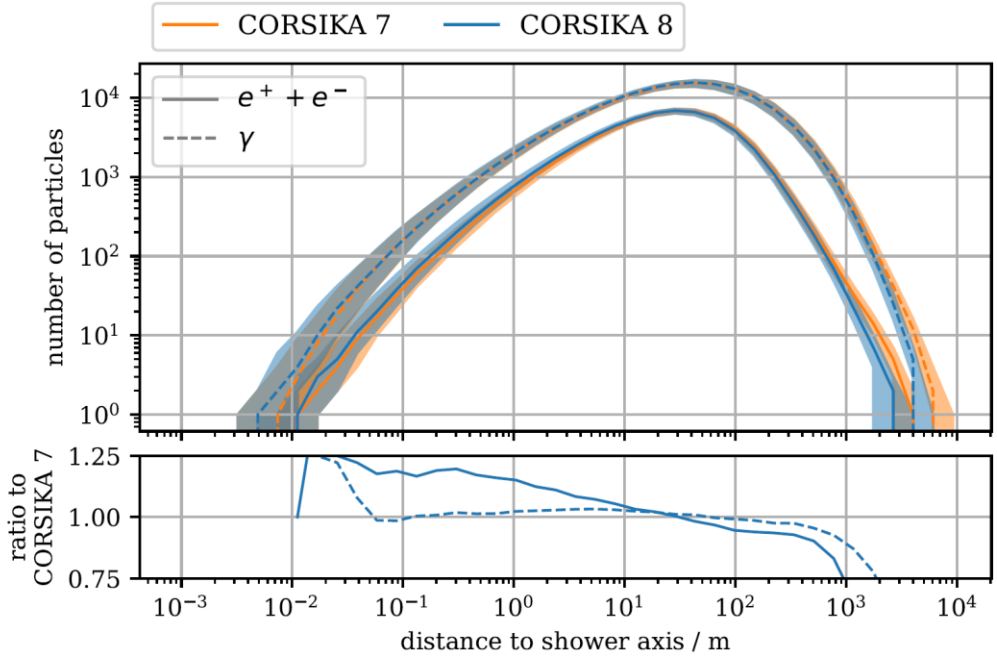
CORSIKA 8 vs CORSIKA 7 – mean difference in terms of % (0.001rad)		
Radiation Energy	30 MHz to 80 MHz	50 MHz to 350 MHz
Total Radiation Energy	10.2%	0.2%
Geomagnetic Contribution	10.1%	-0.2%
Charge Excess	4.6%	7.8%

Total fluence 30-80 MHz comparison C8/C7





Electromagnetic showers in C8 vs. C7

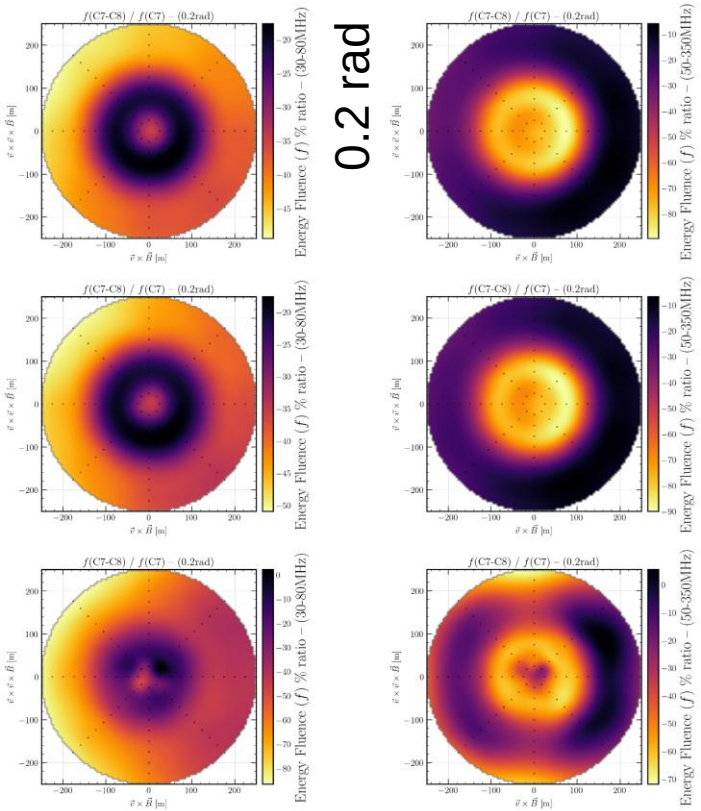


EM cascade in C8 based on PROPOSAL 7.6.2 (CORSIKA 7 uses modified EGS)

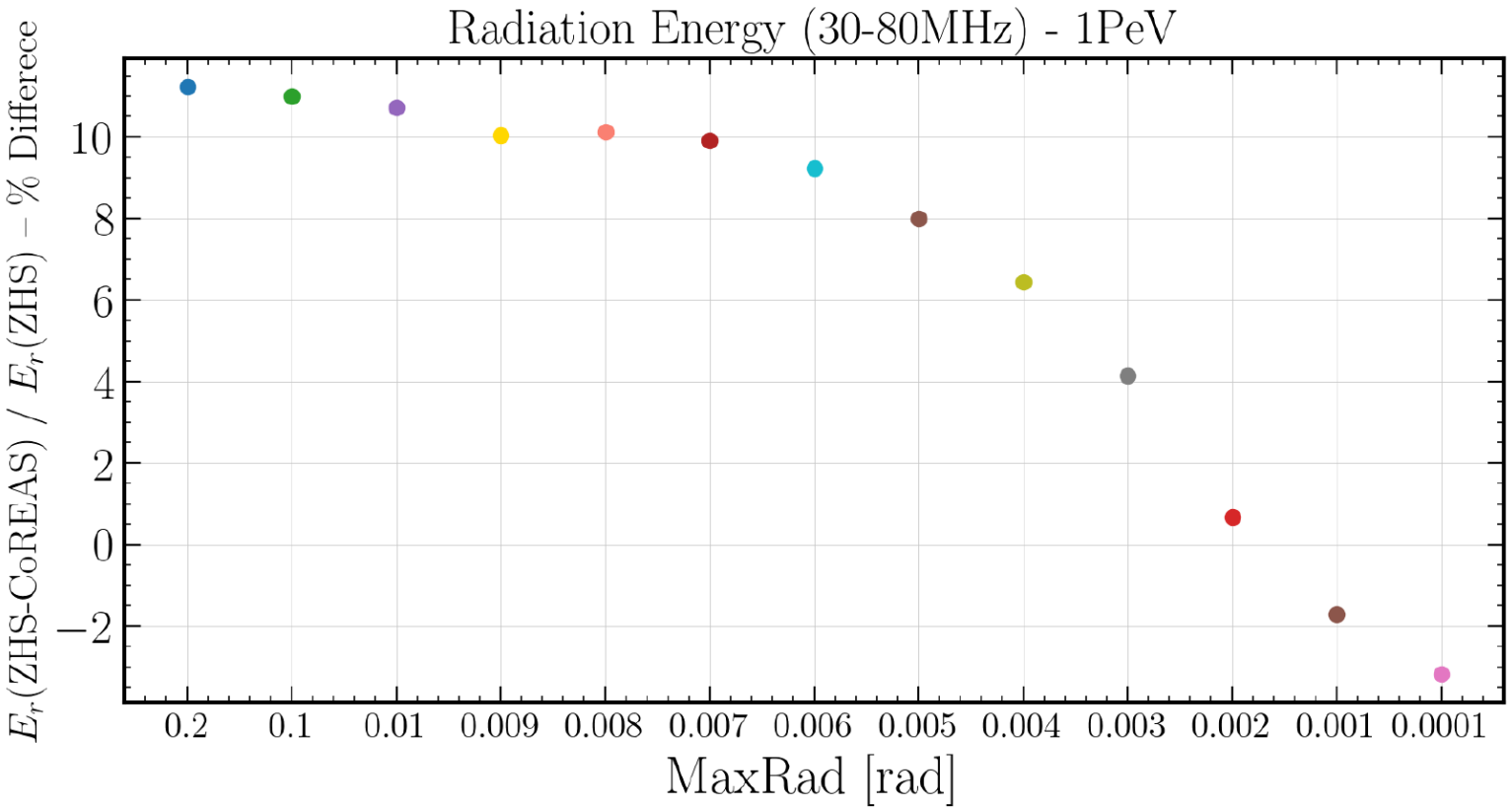
Figure 47: Median values of lateral profiles of electrons, positrons and photons for 100 TeV photon induced showers. Observation height for the evaluation is set to 5800 m, corresponding to $X_{\max} = 497\,\mathrm{g\,cm^{-2}}$. This plot was provided by Jean-Marco Alameddine [75].

J.-M. Alameddine

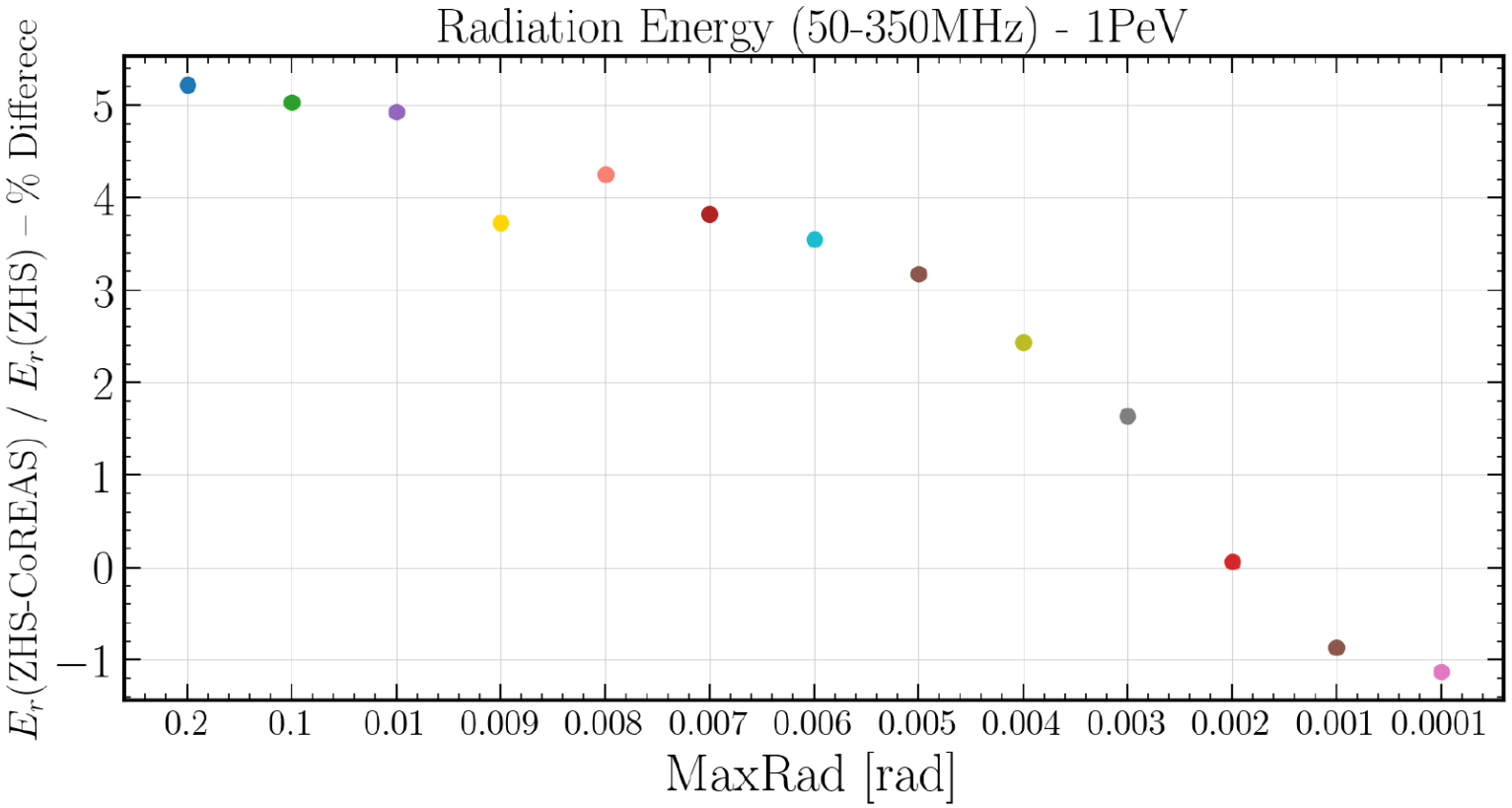
Comparing 100 showers (1 PeV, iron)



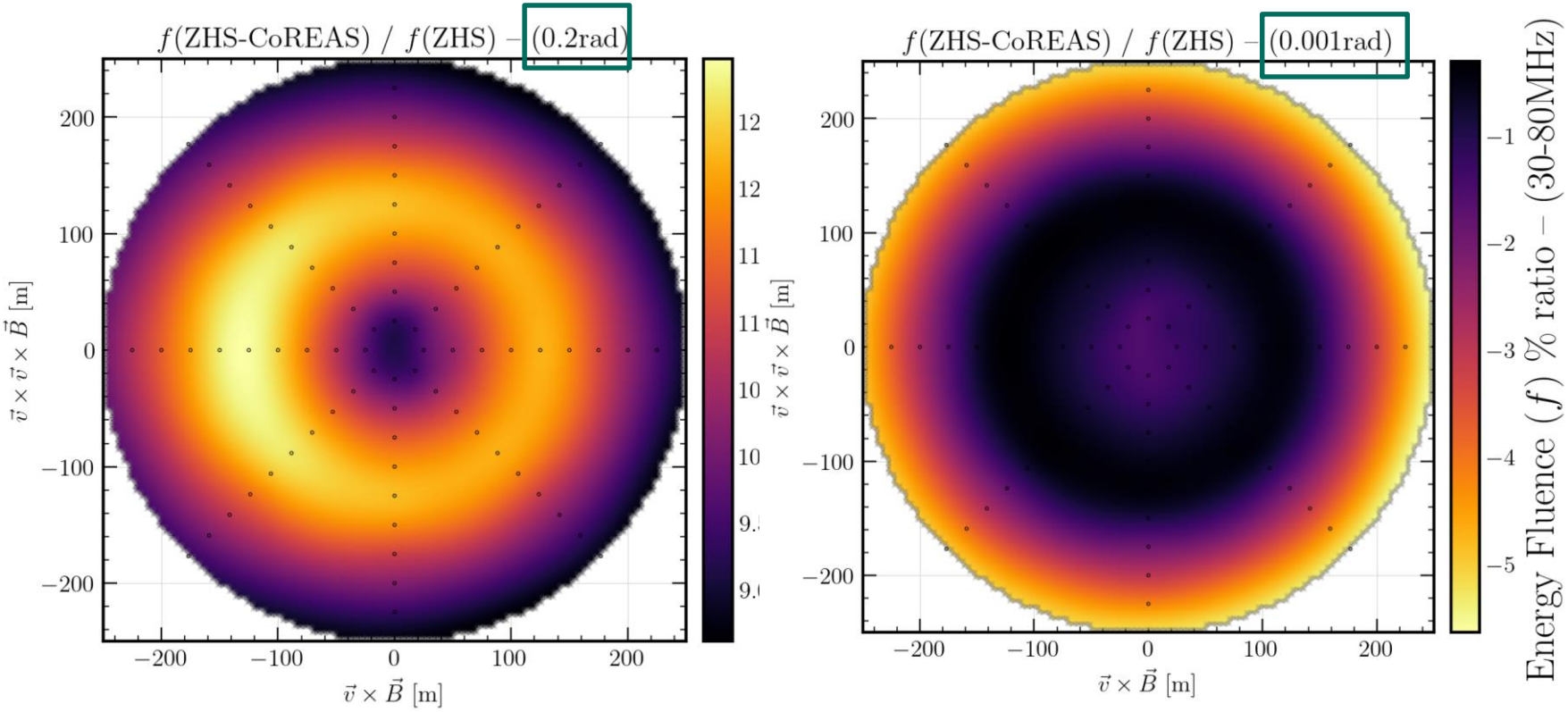
ZHS and endpoints converge 30-80 MHz



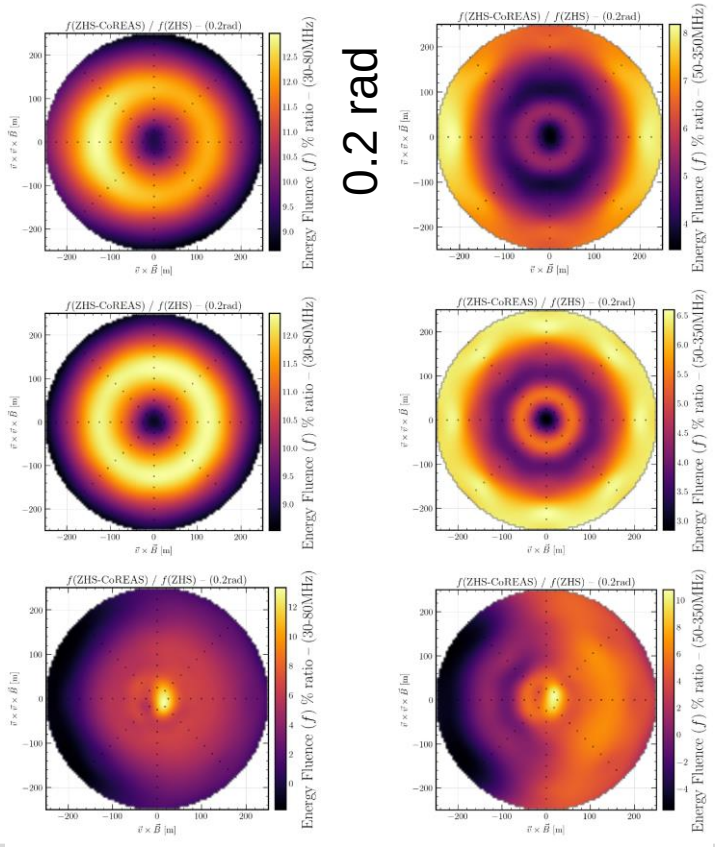
ZHS and endpoints converge 50-350 MHz



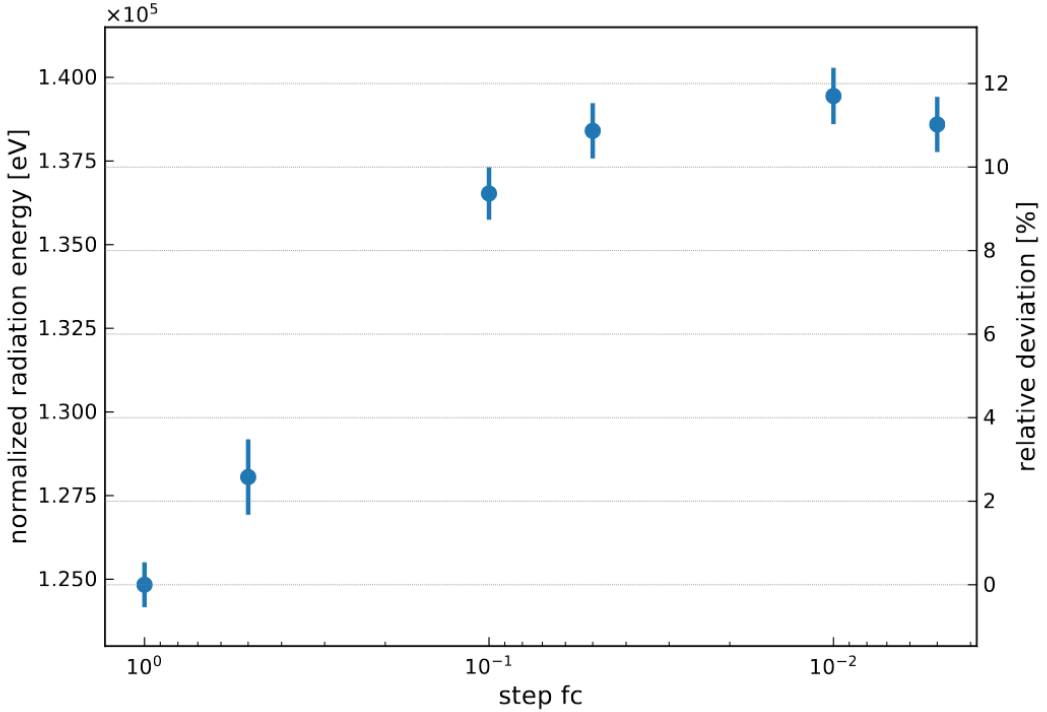
Total fluence 30-80 MHz comparison ZHS/endp.



Comparing ZHS vs. ‚endpoints' (1 PeV, iron)



CORSIKA 7 radiation energy as f(track size)



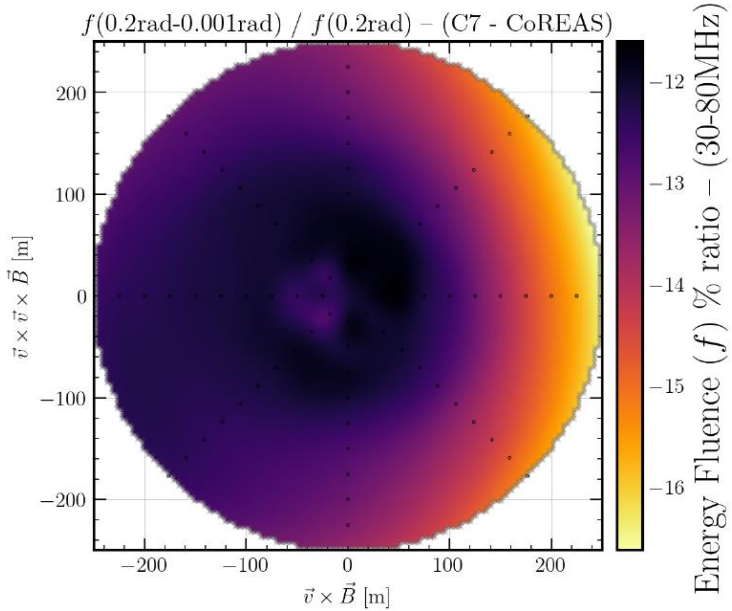
- See Gottowik et al., *Astropart.Phys.* 103 (2018) 87-93

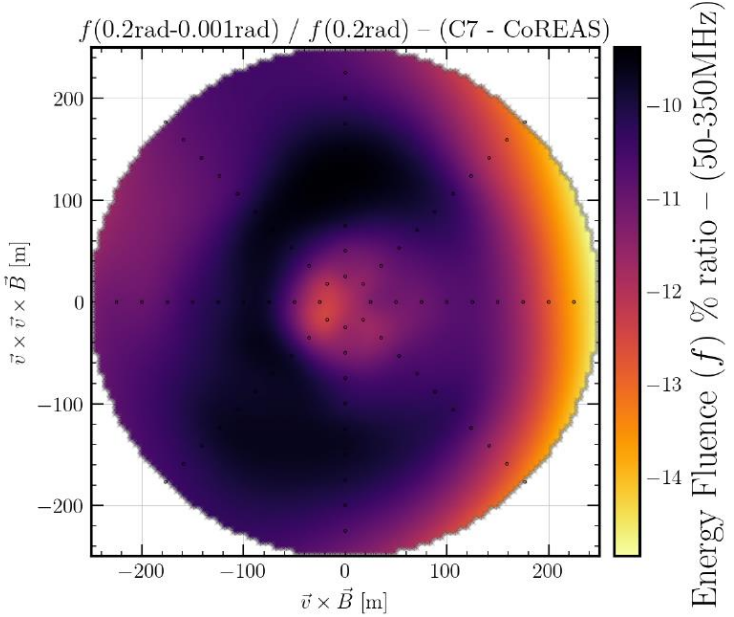
CORSIKA 7 default versus fine tracks

0.2rad vs 0.001rad – mean difference in terms of % (C7 CoREAS)		
Radiation Energy	30 MHz to 80 MHz	50 MHz to 350 MHz
Total Radiation Energy	-12.3%	-10.0%
Geomagnetic Contribution	-12.7%	-10.4%
Charge Excess	-12.9%	-12.4%

- Consistent with Gottowik et al. result that STEPFC = 0.05 gives ~11% more radiation energy

CORSIKA 7 default versus very fine tracks



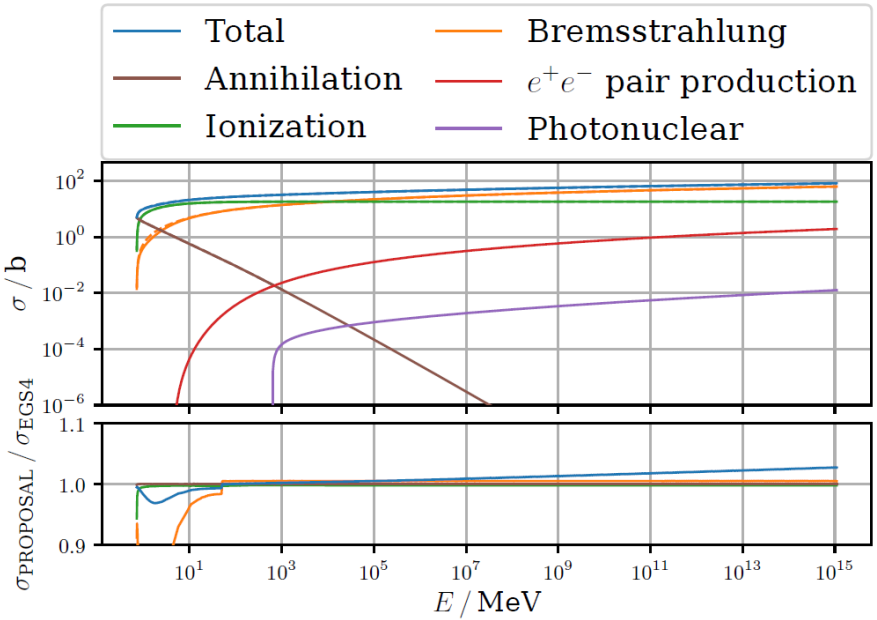


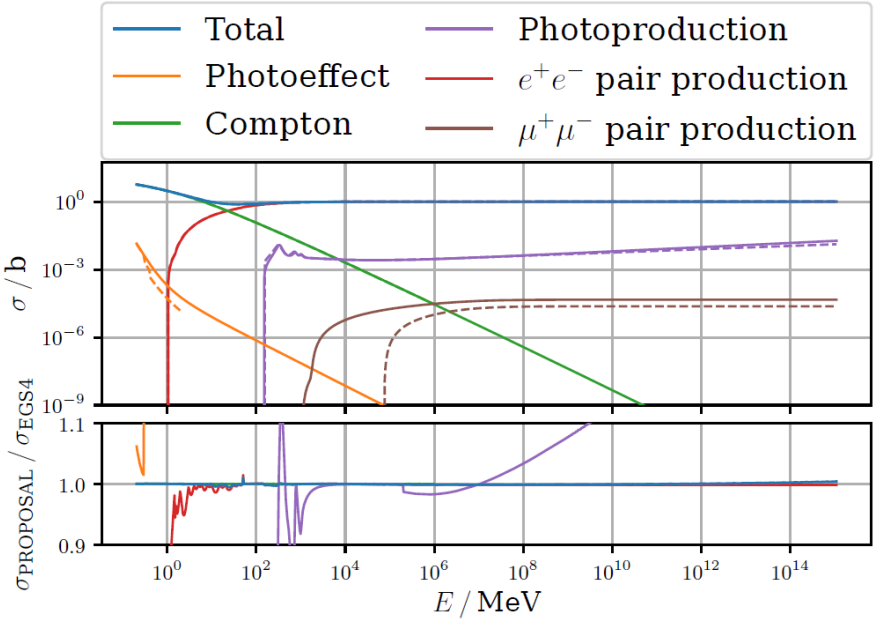
- Fluence distribution in footprint changes on „few %“ level
- Should check influence on Xmax reconstruction (Auger <-> LOFAR)

Conclusions

- Results depend on particle tracking details, both in C7 and C8
- ZHS and CoREAS formalisms change differently with track length, but they converge at the *same* result within 2-3%
- C8 and C7 with very short tracks agree within 10% in radiation energy (5% in energy scale), but footprint looks somewhat different
- C7 with very fine tracks has 11-12% more radiation energy, was known before, footprint shape changes on „few %“ level
  - Potential cause of LOFAR/AERA Xmax discrepancy in case changes are stronger for one than the other? At least run some tests!

Differences between PROPOSAL and EGS4





- Electromagnetic cascade „well understood“, but worth studying in detail as it sets the energy scale for many cosmic-ray detectors