The CORSIKA 8 cascade simulation framework

November 5, 2025

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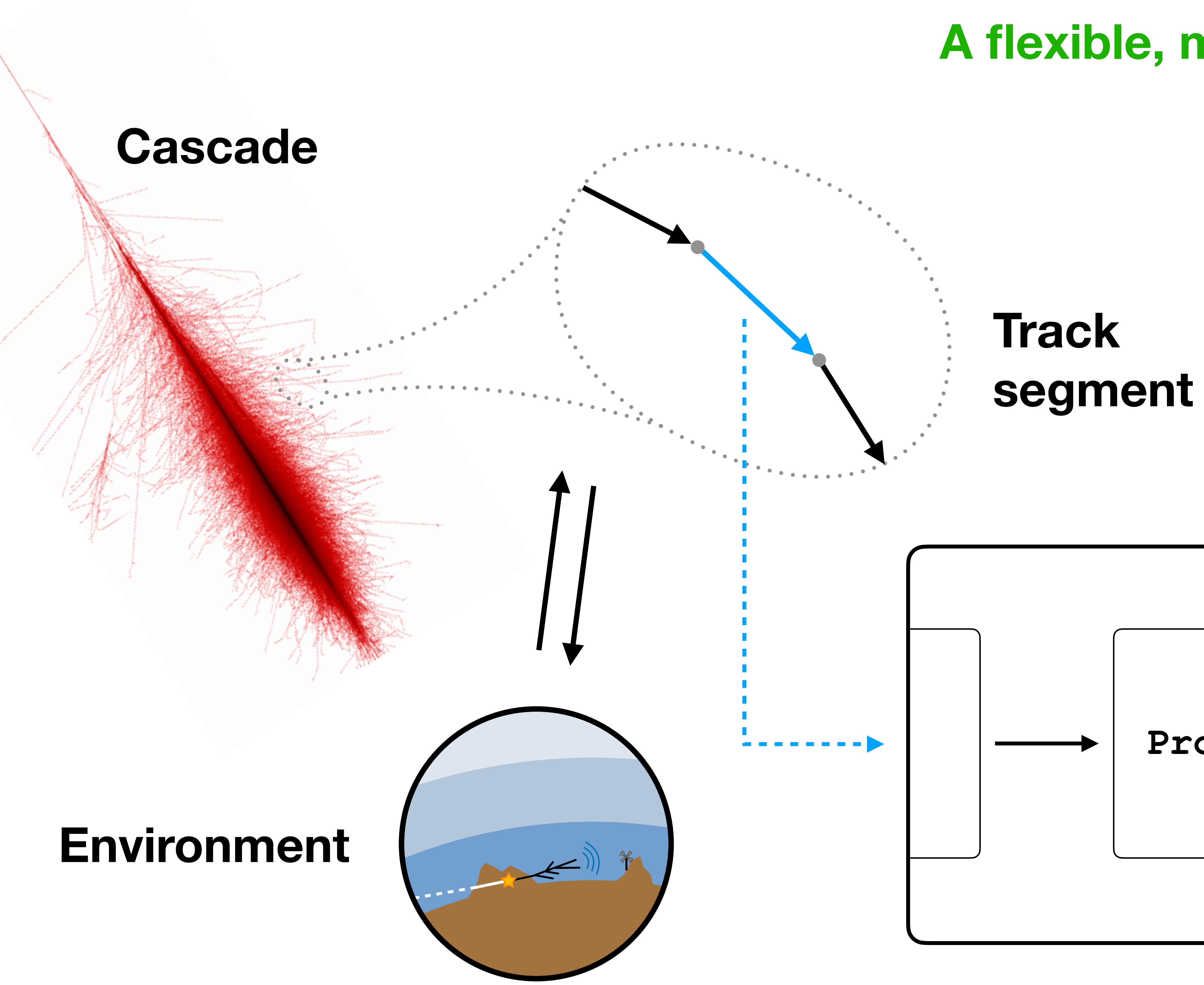
CORSIKA 8 at a glance

A general-purpose cascade simulation framework for the astroparticle community

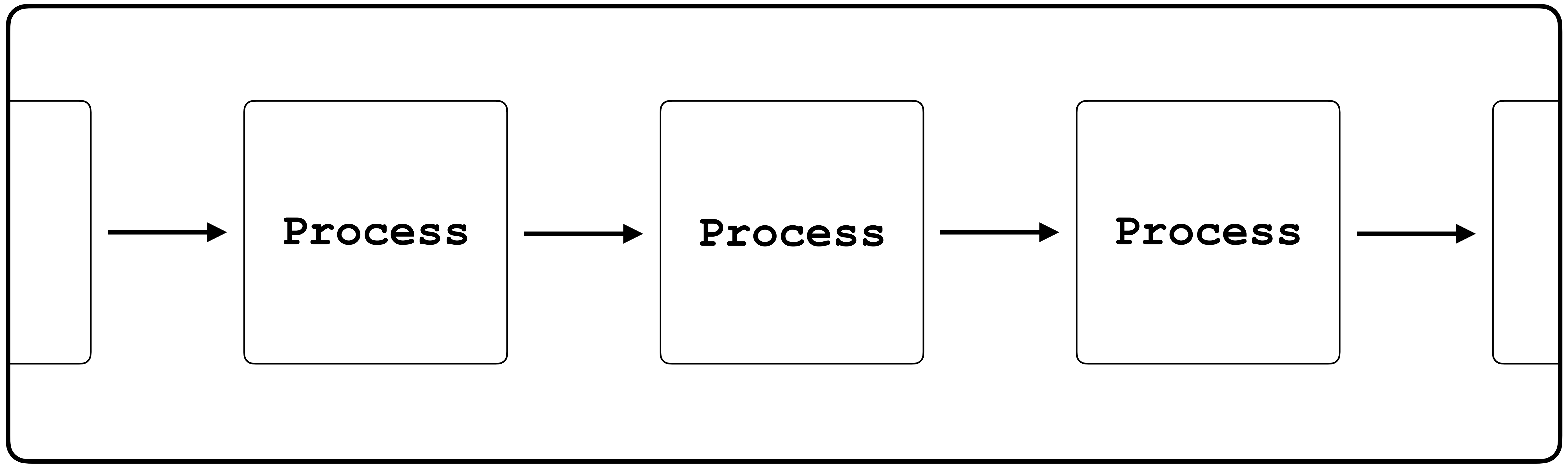
Design principles

A flexible, modular, and extensible particle-Monte Carlo code …



`Process`: user-defined (or provided) code to

→ Calculate observables *(e.g. radio emission)*, or
→ Modify cascade *(e.g. interaction models)*



… covers *typical use cases*, but also more *"exotic" applications*—**both discussed today!**

→ C8 will grow over time!

Current capabilities I

“Physics complete” for cascades from any primary *(ɣ, p, ν, nucleus)* **in air and dense media**

Available interaction models:

Sibyll 2.3d, EPOS-LHC, QGSJet-II04

(high-energy hadronic)

FLUKA, URQMD

(low-energy hadronic)

PROPOSAL

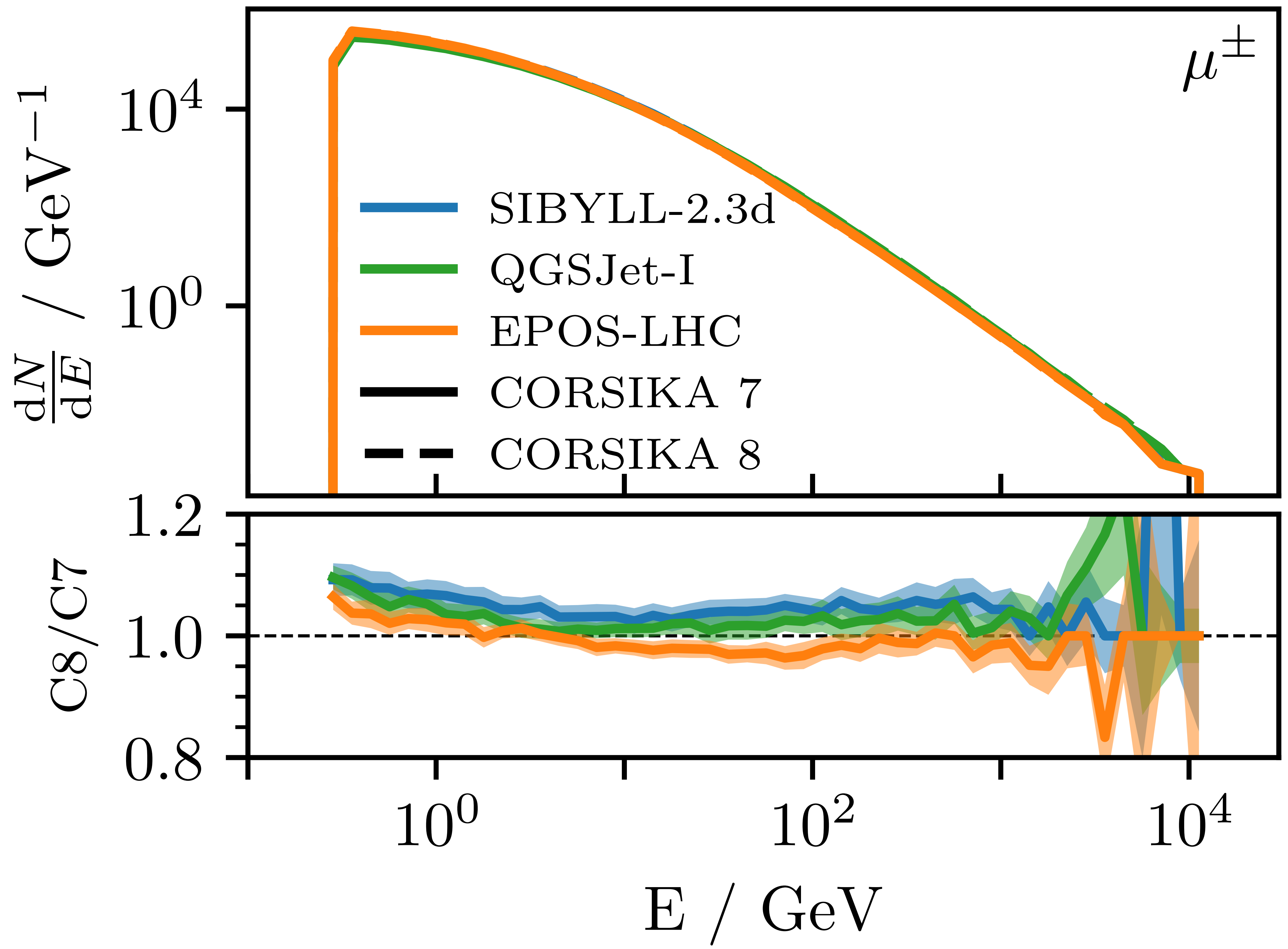
(EM interactions)

Pythia8, TAUOLA

(particle decays, ν interactions)

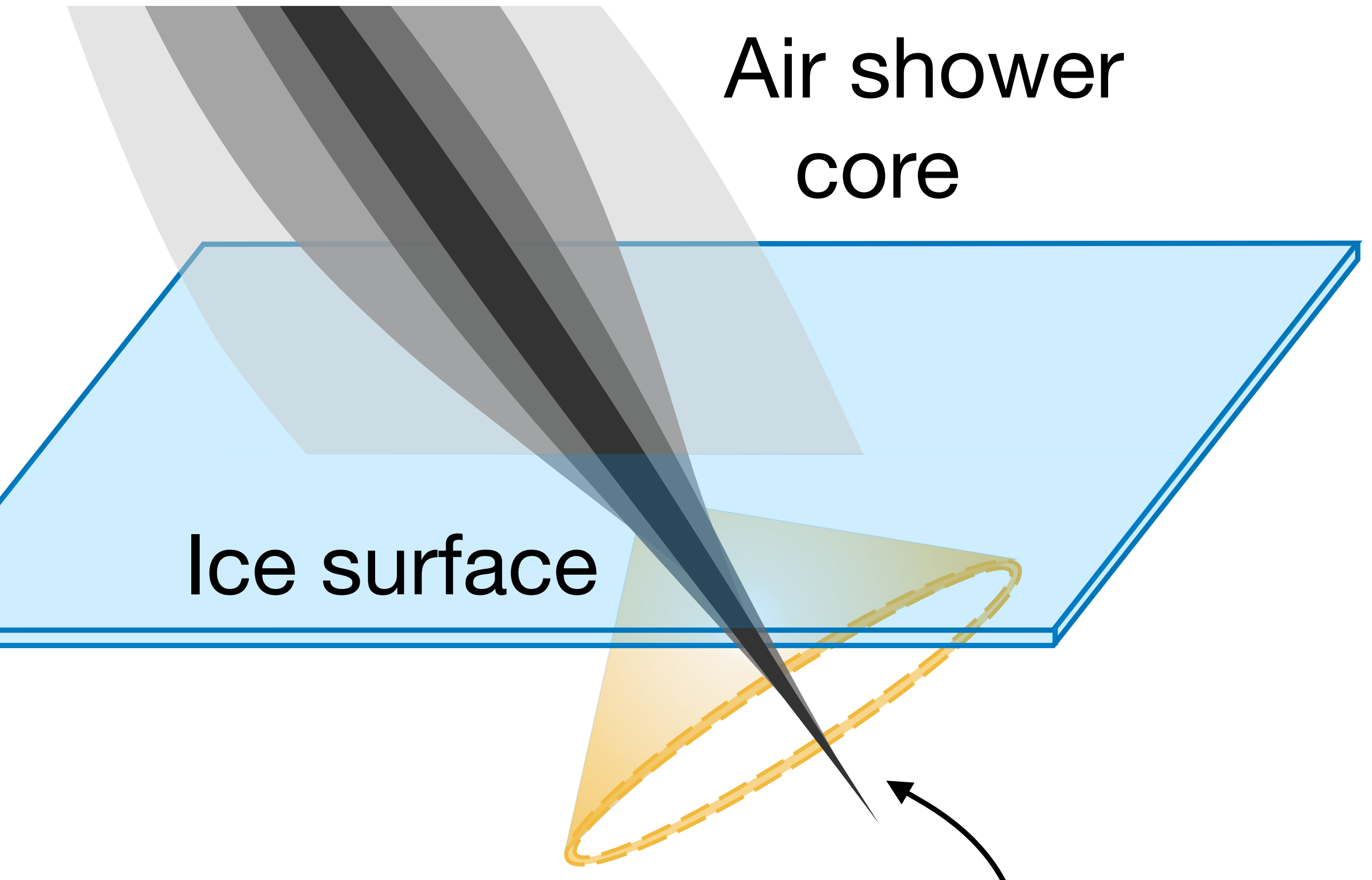
Comparison between CORSIKA 8 and CORSIKA 7: agreement at 10%-level for air showers

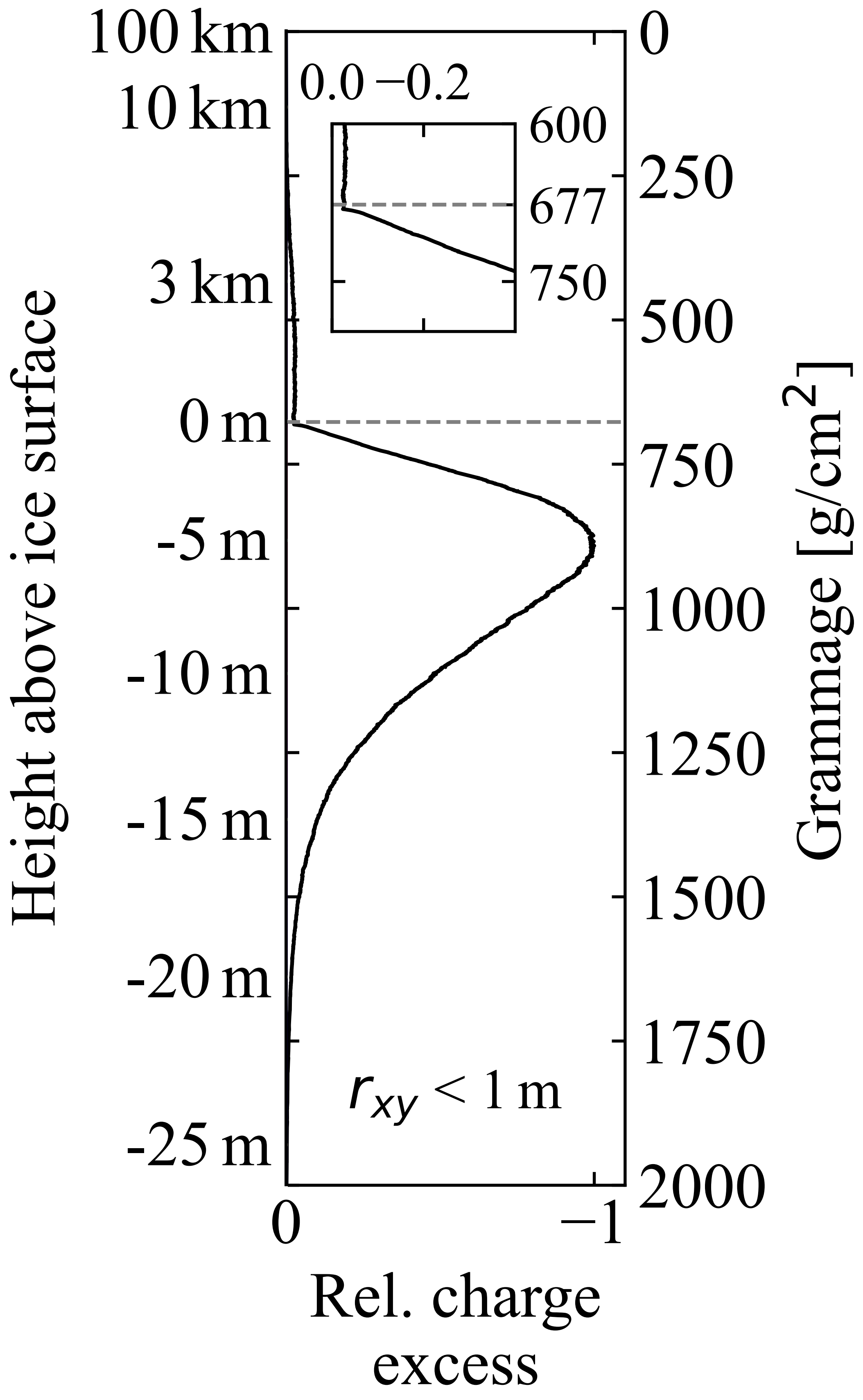
Vertical **100 PeV proton primary**: FLUKA, E > 0.1 MeV for EM, E > 1 GeV for muons and hadrons; different EM interaction models



Current capabilities II

Simulation of cross-media cascades
↔ *"impacting" air shower cores*





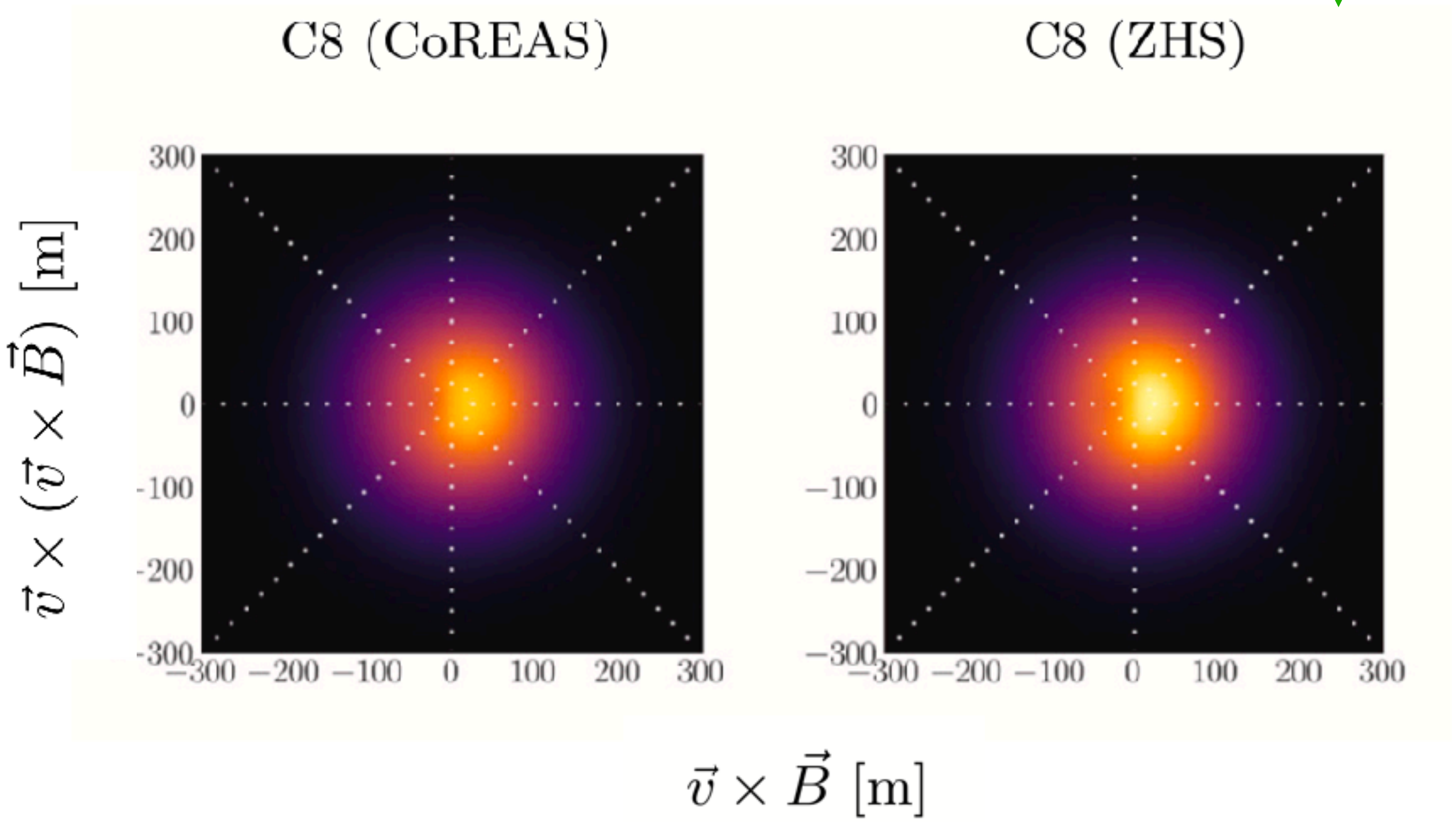
→ **Charge-excess** *(Askaryan)* **emission in dense media**

→ ***See talk by N. Alden (ARA)***
(Thursday afternoon)

In-air radio emission through endpoint formalism *(CoREAS)* **and ZHS**

Comparison of different emission (and propagation) algorithms on the same shower!

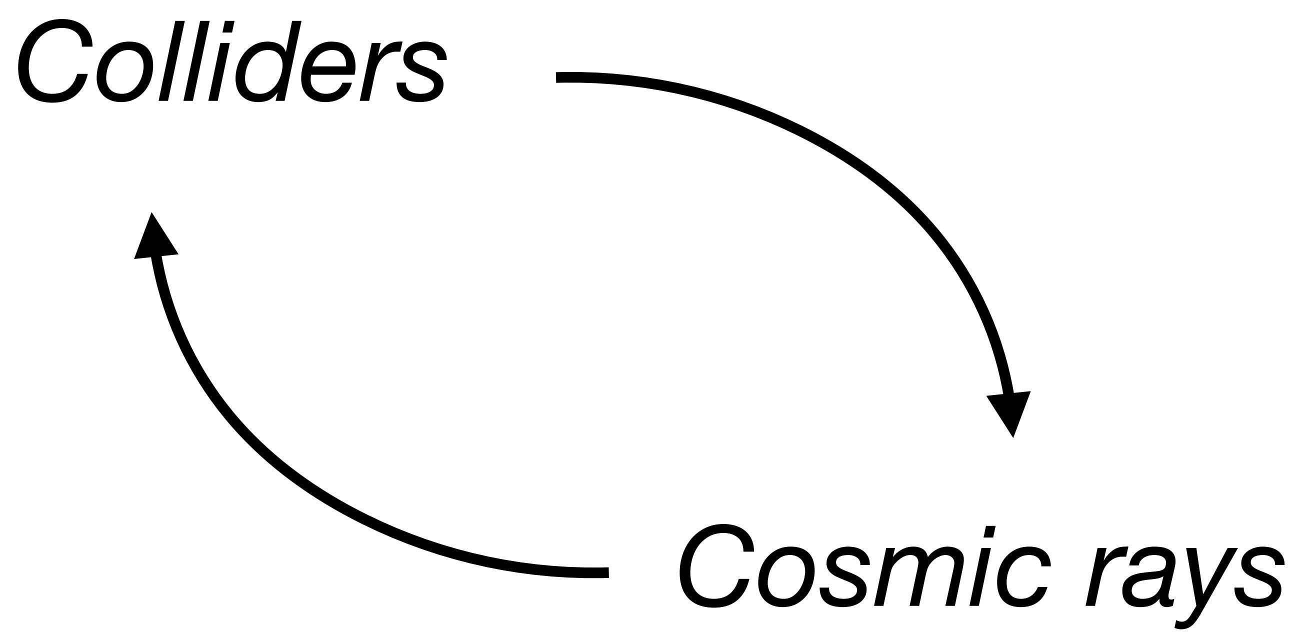
|Energy fluence|, 30 MHz—80 MHz



[Astropart. Phys. 166, 103072 (2025)]

2025 developments: new interaction models

Pythia 8 / Angantyr:
general-purpose event generator for colliders; available in C8 as hadronic interaction model

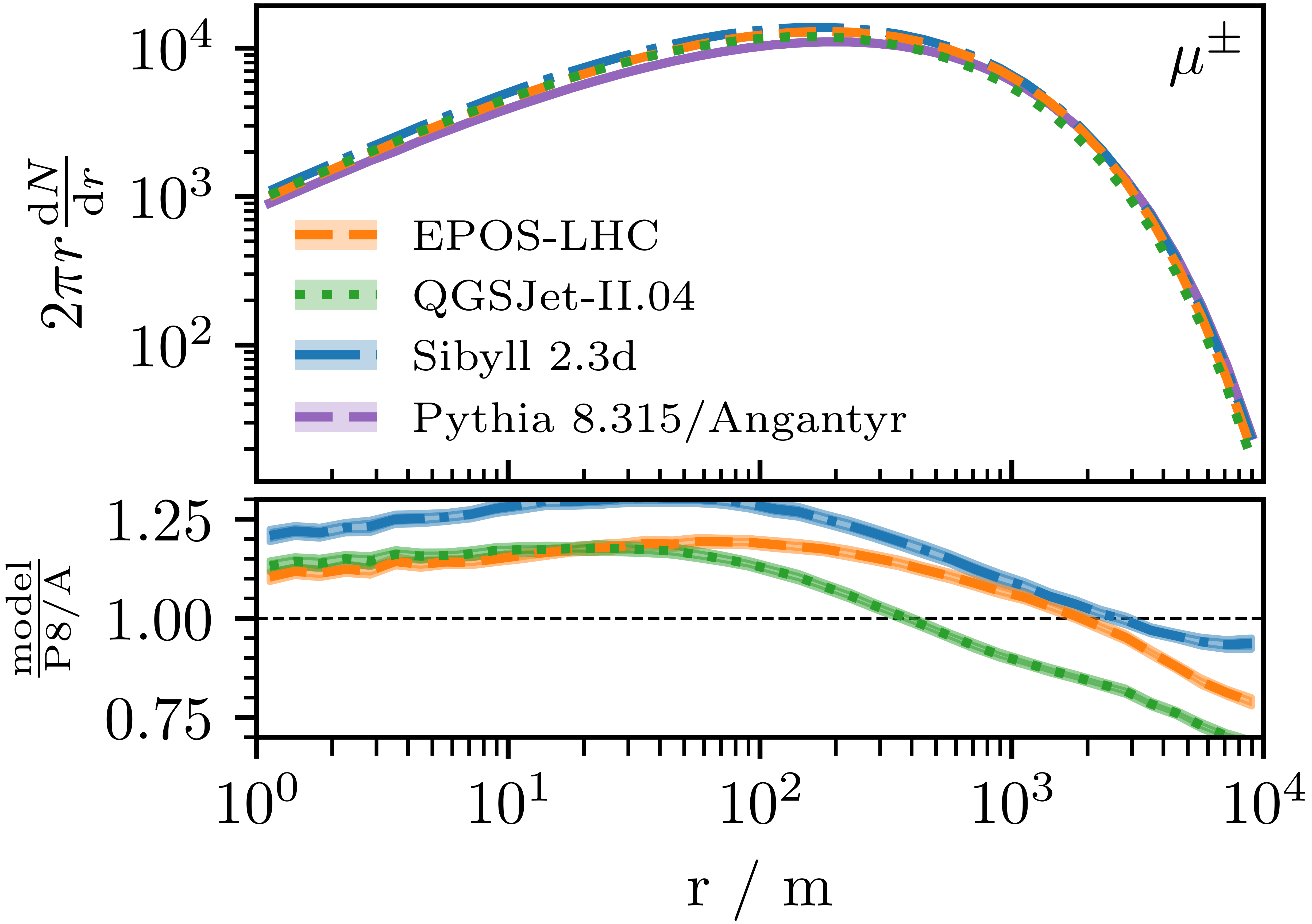


Can begin to use air shower data to tune Pythia 8 / Angantyr

→ QGSJet-III, EPOS-LHC-R
also being integrated

Differences in muon lateral distributions w.r.t. other models

Inclined 10 EeV iron primary, θ = 67



2025 developments: event viewer

Simulation output readable with provided `python` package

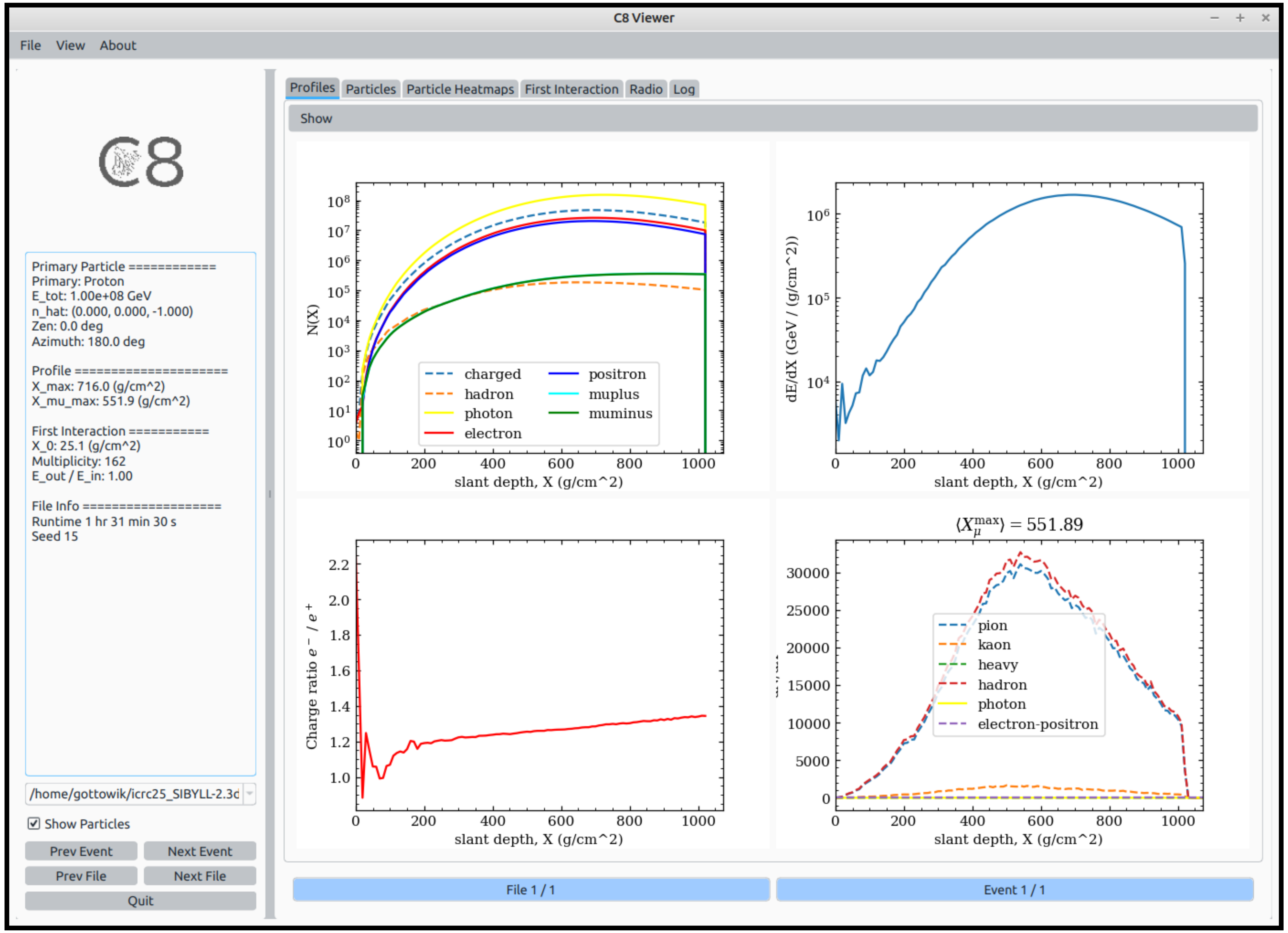
CORSIKA 8

↓

Shower library

No user knowledge of file format required;
easy to perform custom analyses

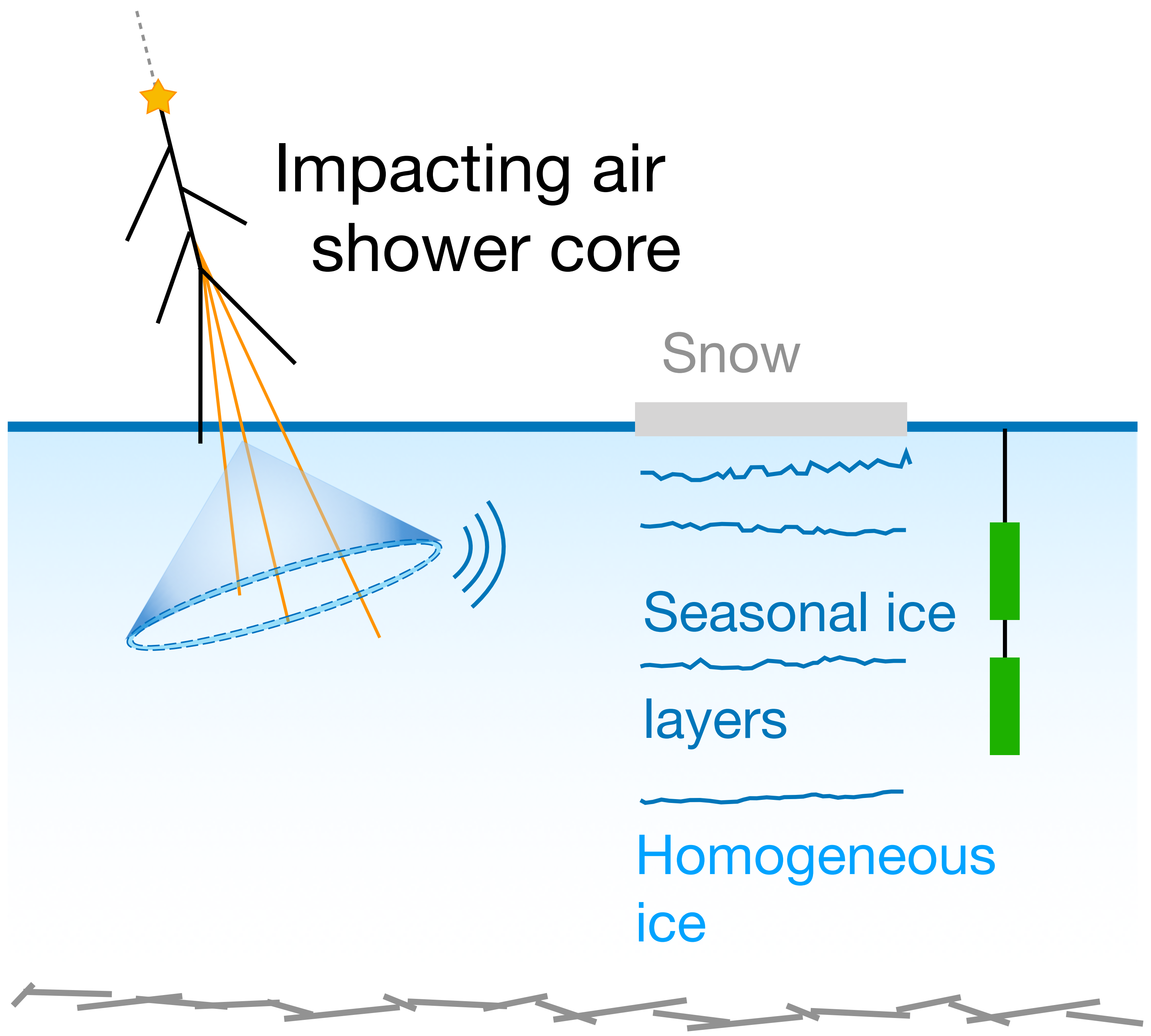
Graphical interface for quick inspection of shower content →



2025 developments: radio in complex media

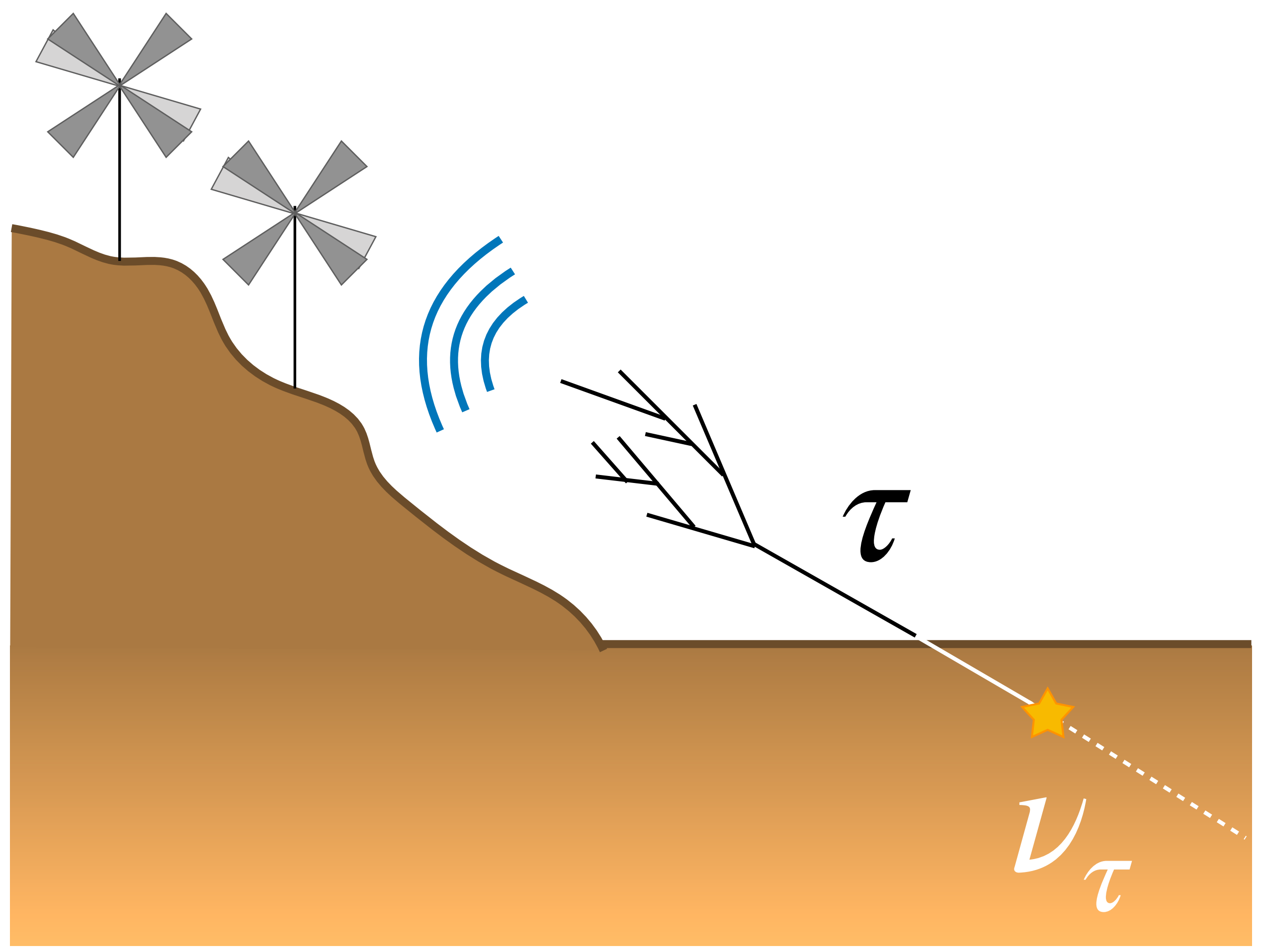
Many current (or proposed) radio experiments operate in complex environments

→ *Medium feature scale size L can be comparable to the radiation wavelength λ!*



In-ice radio neutrino observatories
(e.g. ARA @ South Pole, RNO-G in Greenland)

→ *Seasonal density fluctuations in near-surface ice*



Tau-neutrino detection experiments
(e.g. BEACON, TAMBO, GRAND)

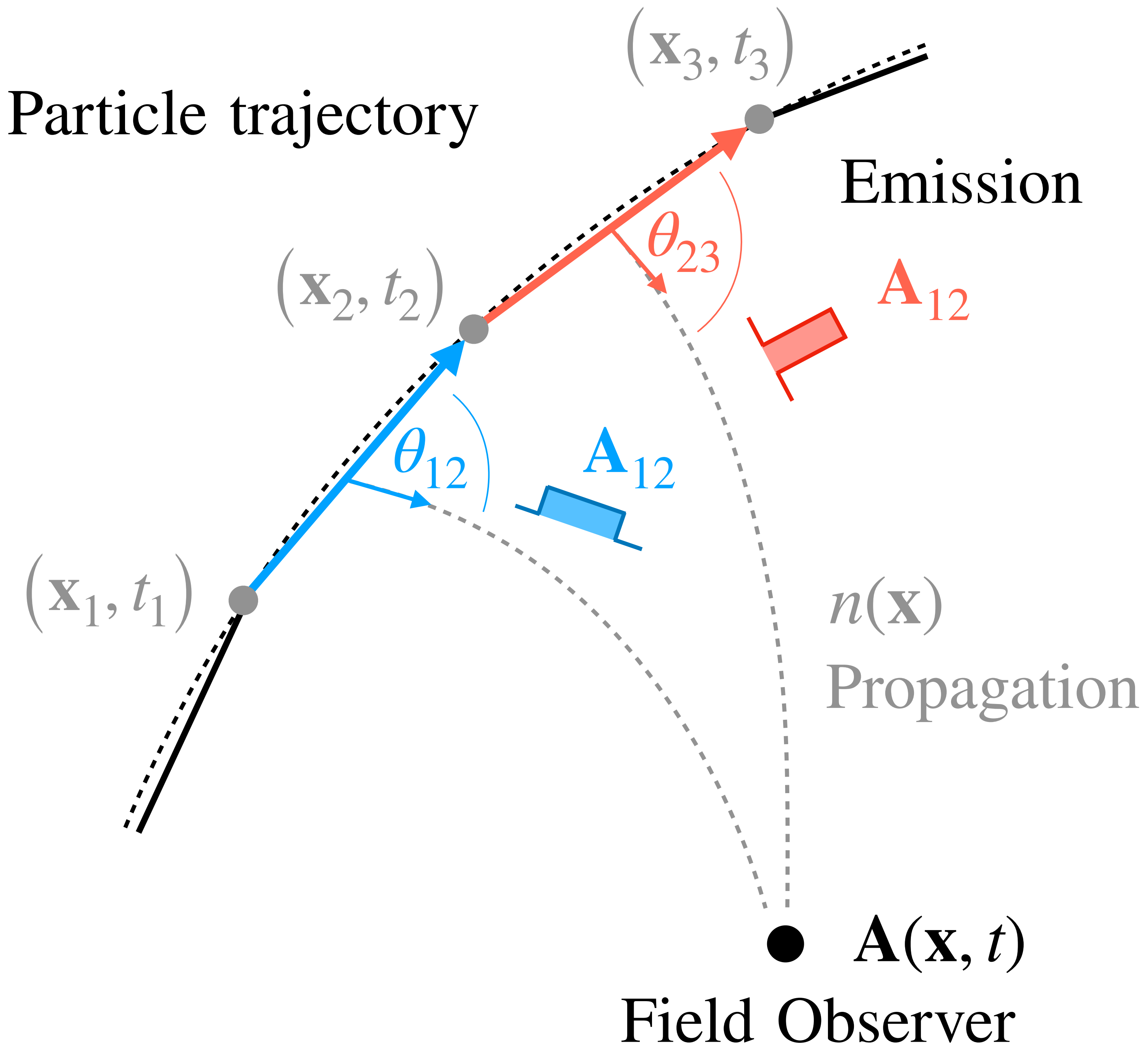
→ *Near-surface radiation propagation*

2025 developments: radio in complex media

Two complementary radio simulation approaches available in C8

Geometric optics: $\lambda/L \ll 1$

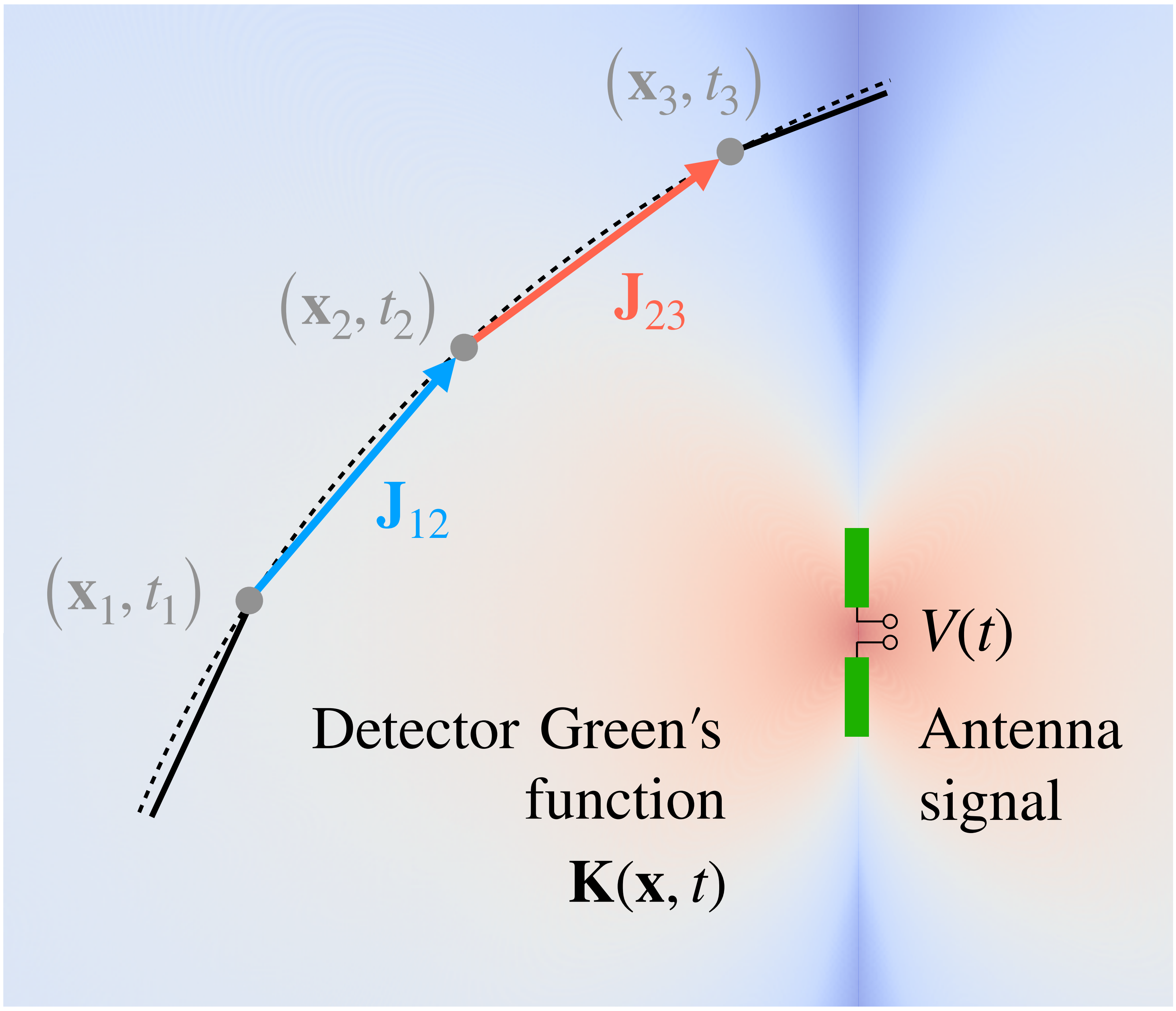
Ray optics is valid—often *assumed* to be the case



ZHS / CoREAS + raytracing

Full electrodynamics: $\lambda/L \gtrsim 1$

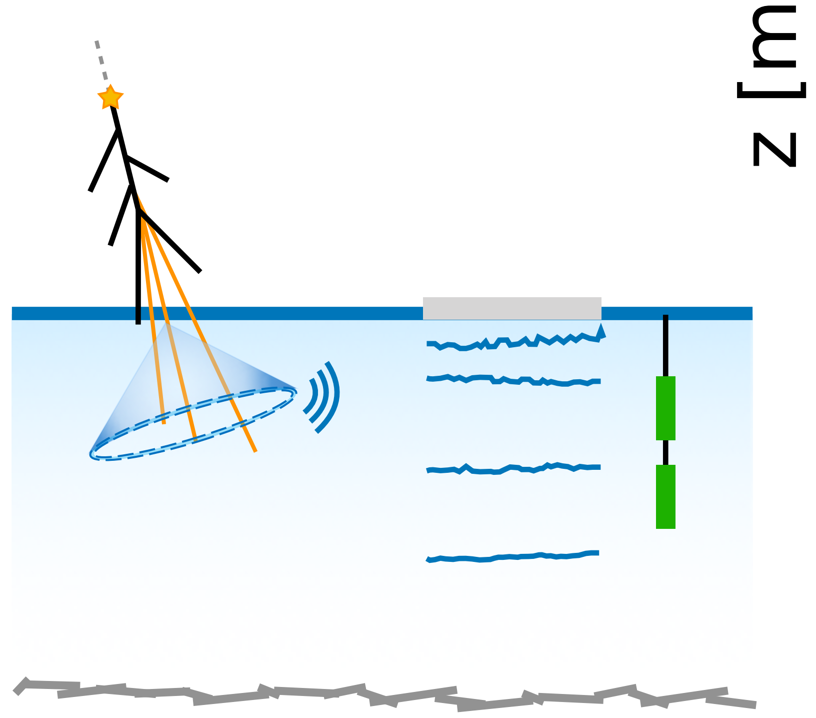
Wave-optics propagation effects are important; handled by external *Eisvogel* package

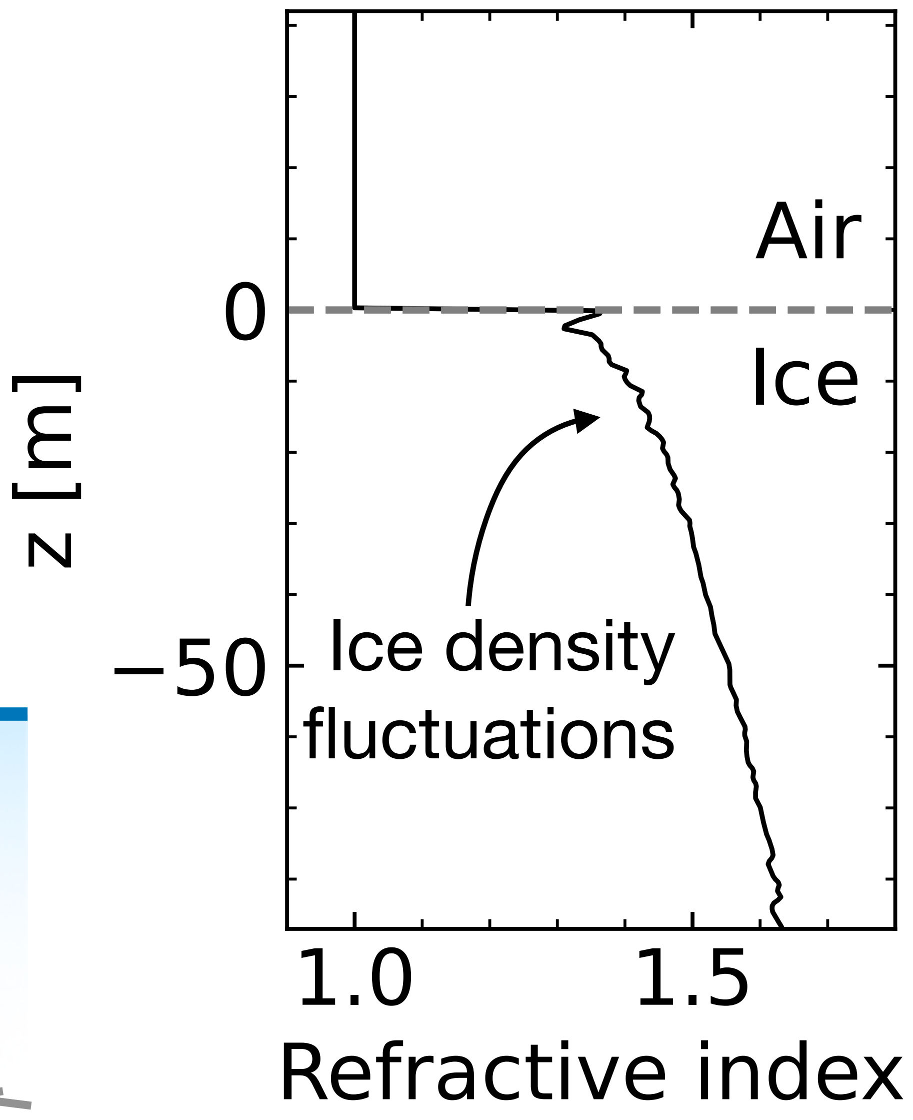


Medium → Green's function → antenna signal

2025 developments: radio in complex media

In-ice radio detectors are the perfect testbed to study radio propagation



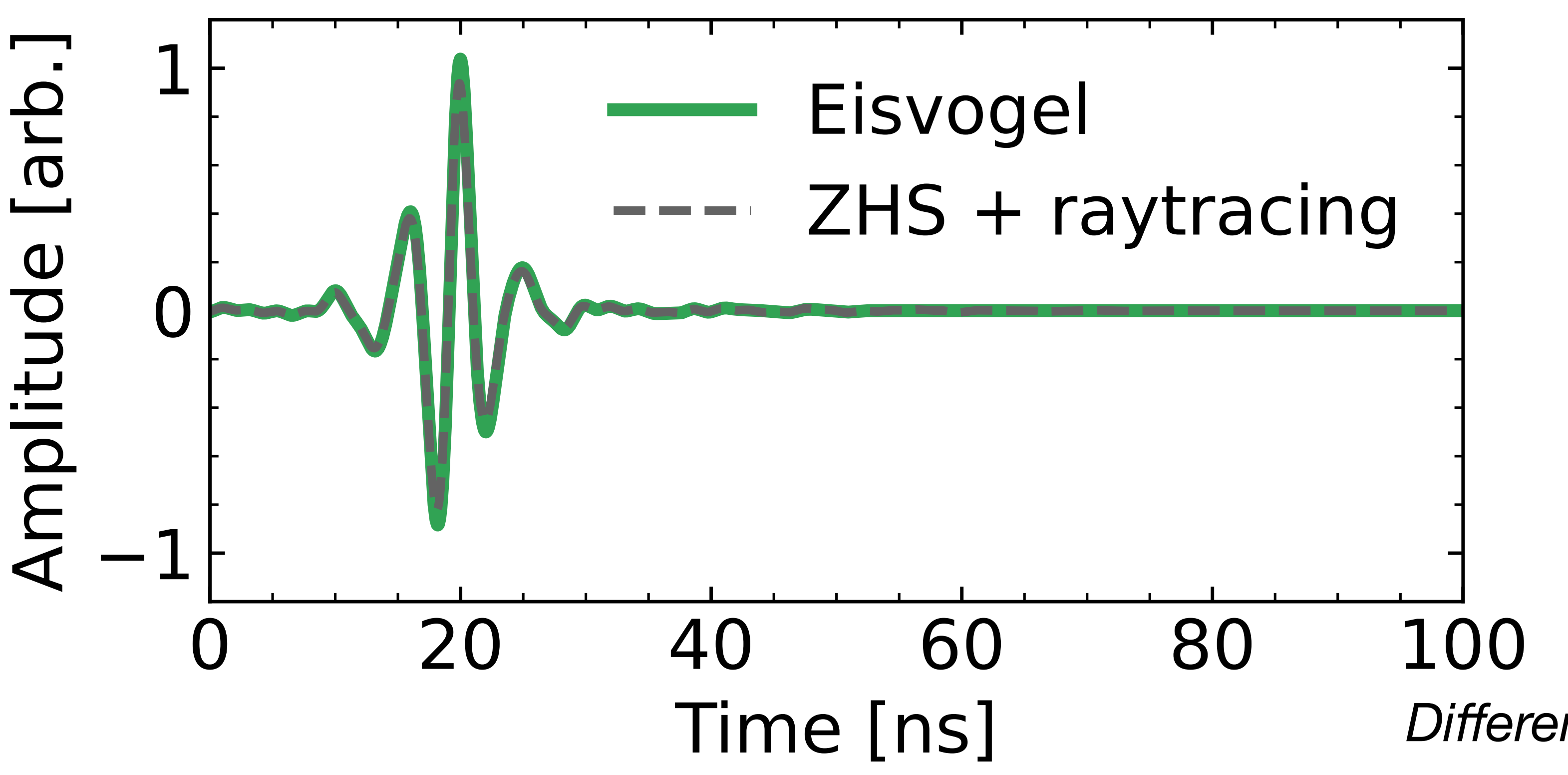


2025 developments: radio in complex media

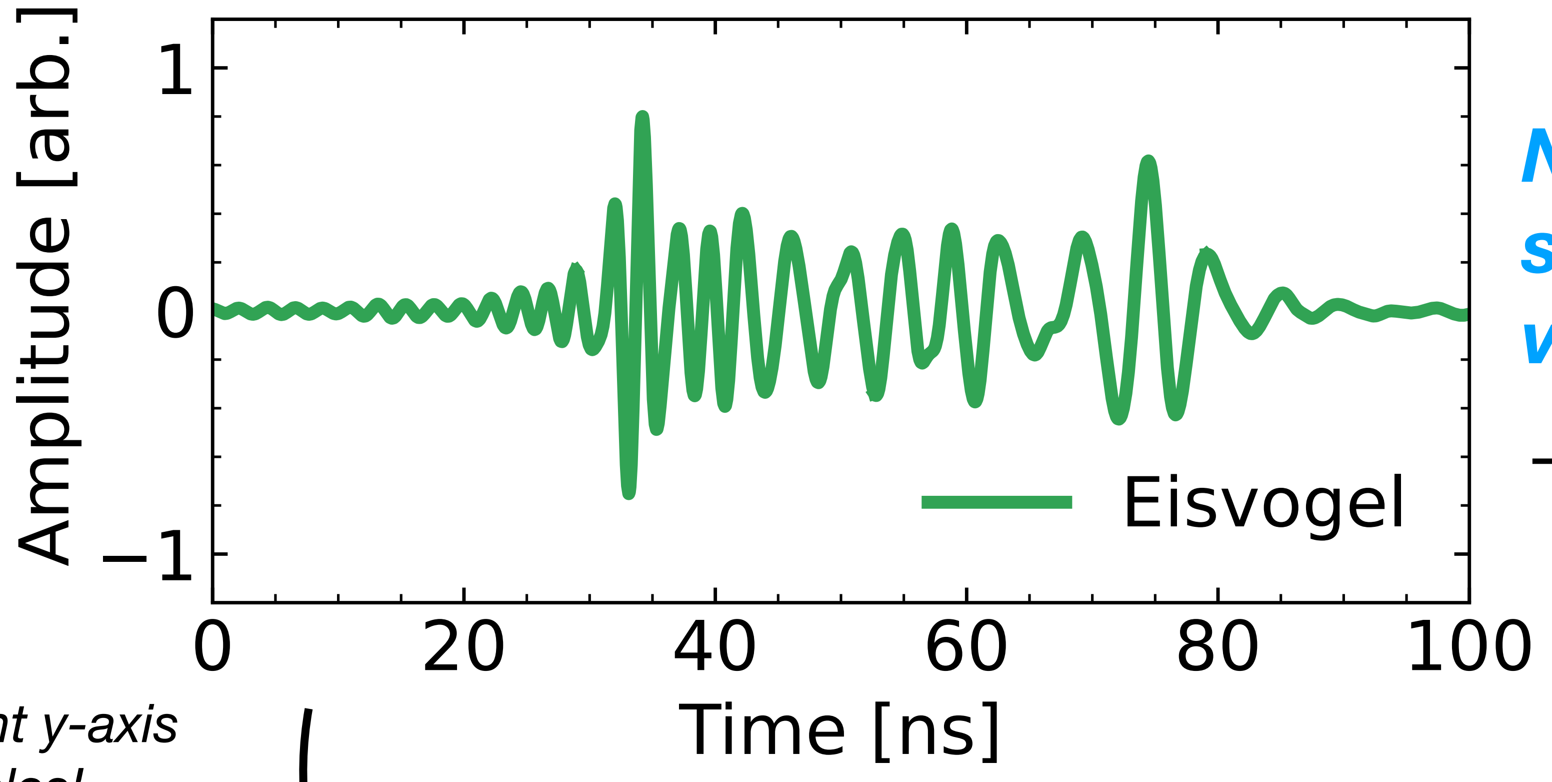
In-ice radio detectors are the perfect testbed to study radio propagation

*Both **approaches agree** if **ray optics** describes the **"leading-order" propagation***

→ *Impulsive radio signal!*

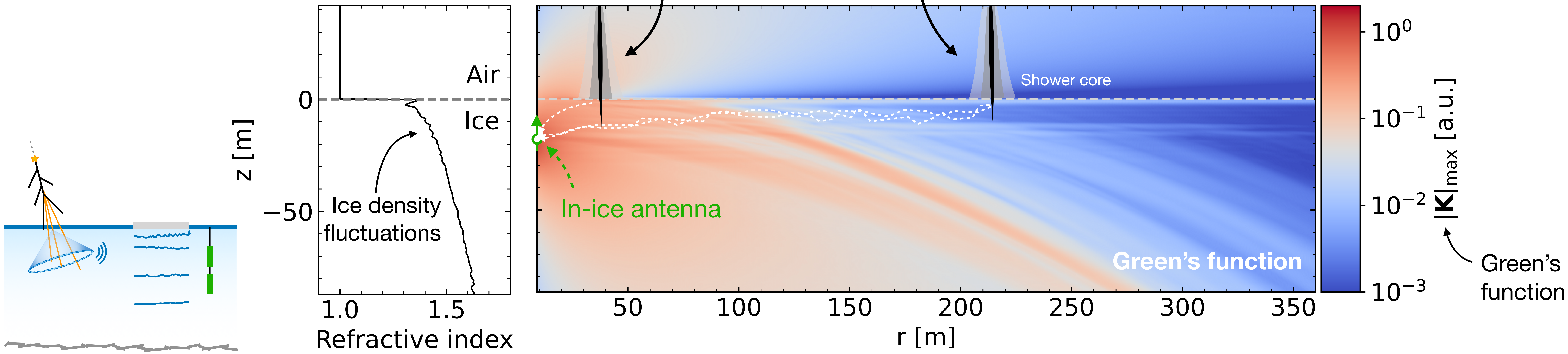


Different y-axis scales!



No ray optics solution: signal character very different

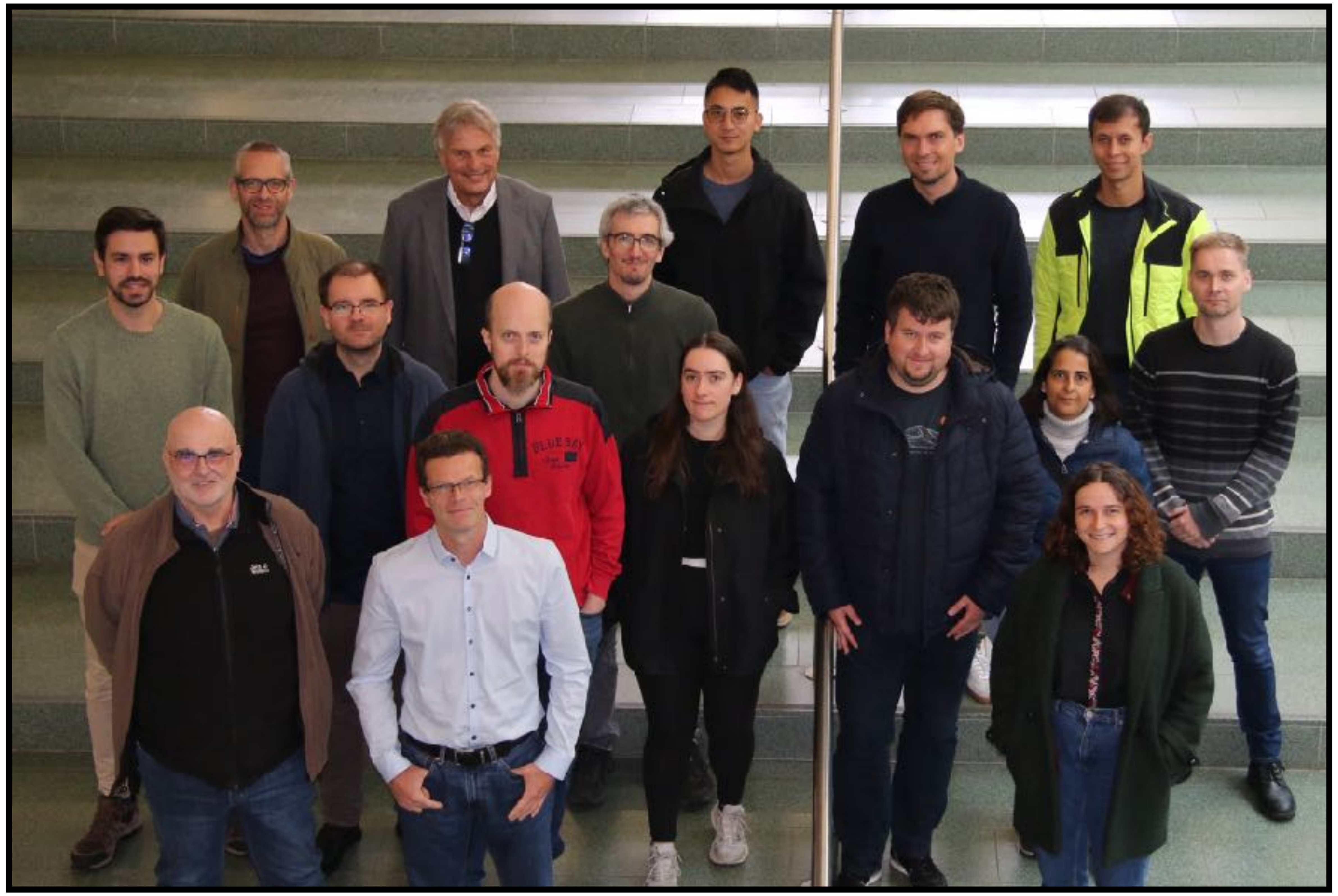
→ *Multi-path propagation disperses signal*



The path forward

Future development of C8 is driven by physics!

Developers from collaborations working on air-showers, in-ice radio detectors, tau neutrino detectors



C8 development workshop @ Dortmund, October 2025

C8 beta release, incl. container image w/ all dependencies: [download]

Upcoming end-of-year release with performance improvements & further features

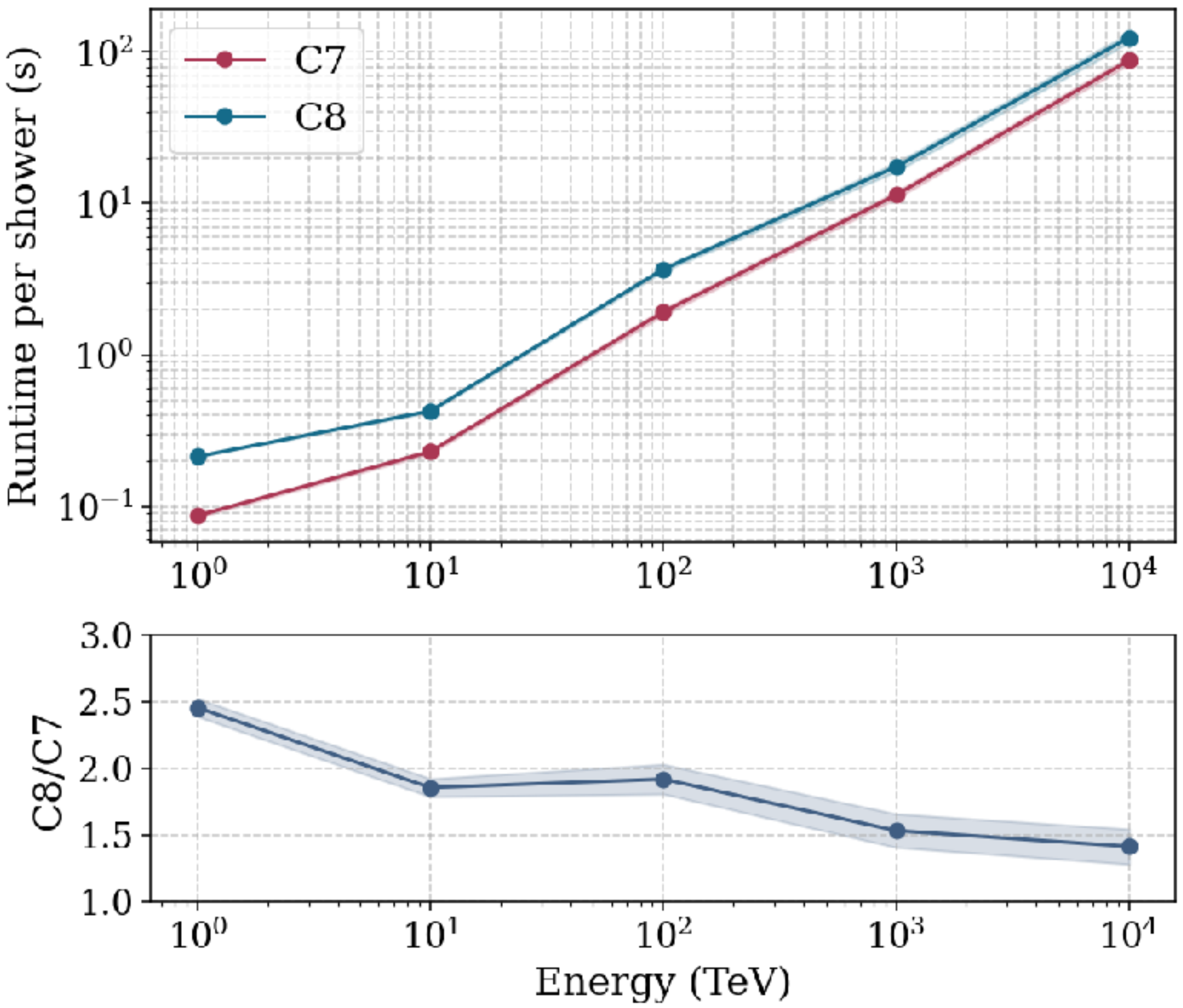
Backup

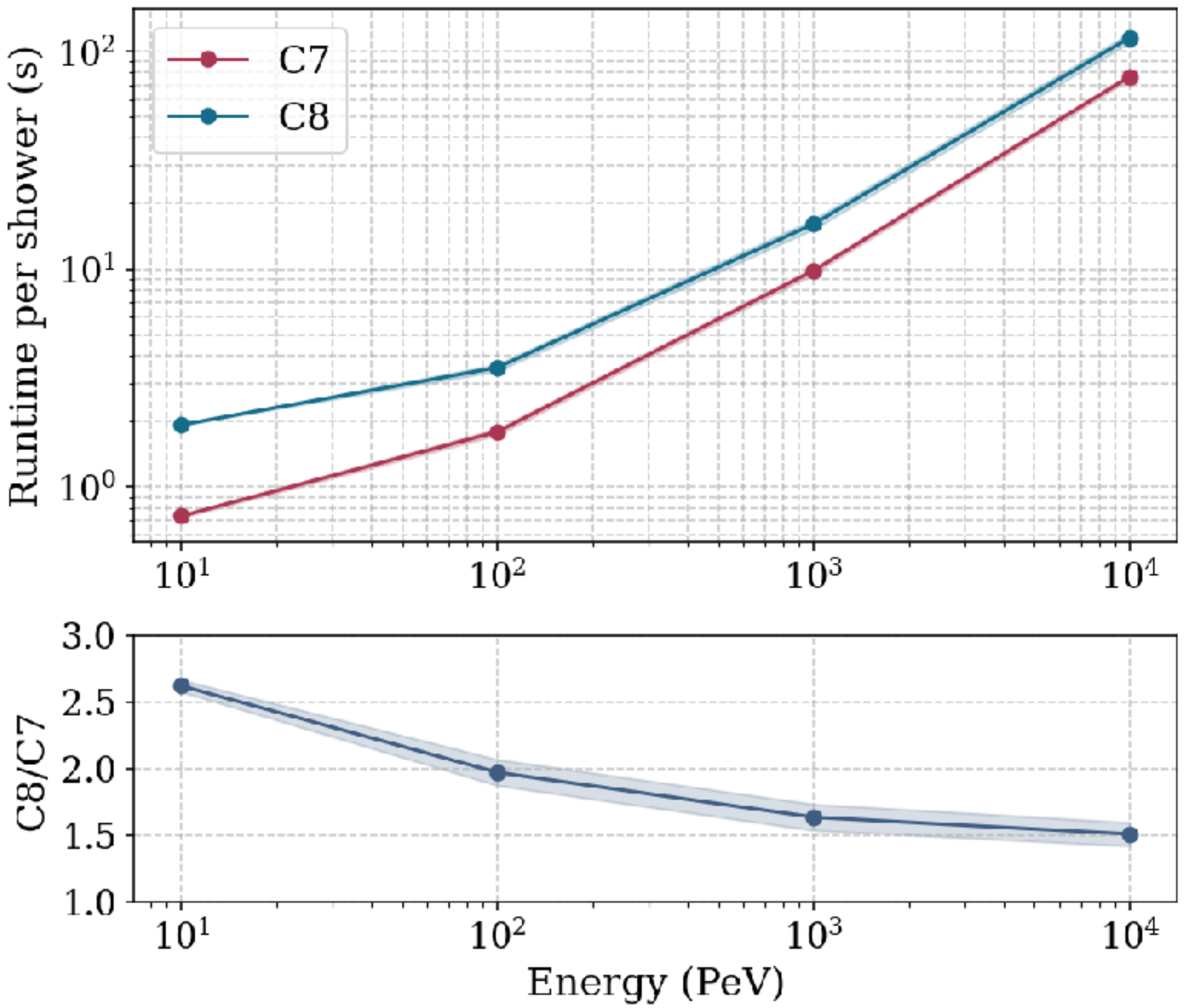
Performance in comparison to C7

C7: *hand-optimized, monolithic Fortran*

C8: *flexible, modularized C++*

Comparable performance for **hadronic** cascades *(C8 1.5-3x slower compared to C7)*





(Equivalent settings in both codes)