Status and prospects of the CORSIKA 8 air shower simulation framework

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- Originally developed for the KASCADE experiment in the 1980s
- At the core of air shower simulations in many astroparticle physics experiments over the last 30 years
- Dedicated maintenance from KIT (D. Heck, T. Pierog, ...)
- Common reference frame for the community

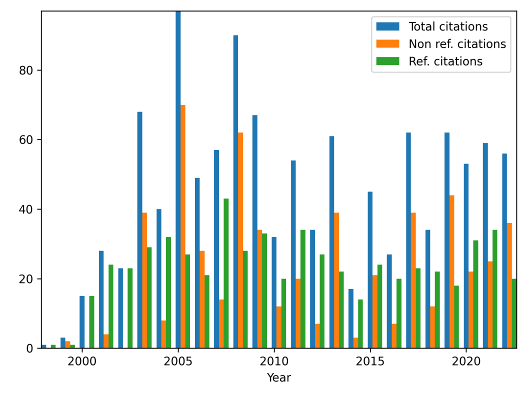

Figure 1: ADS citation metrics of FZKA-6019

Limitations of CORSIKA 7

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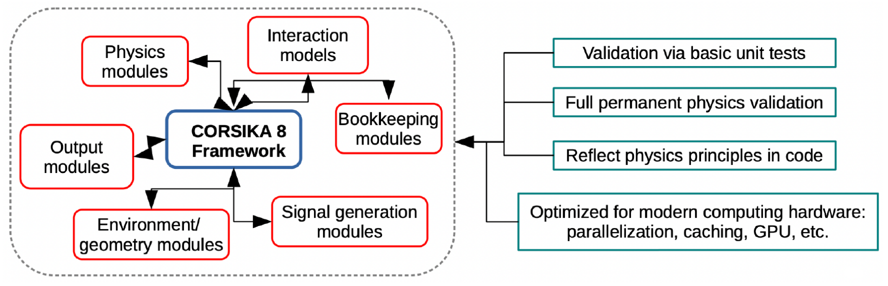
- Hand-optimized code: excellent performance, but incurs limitations
- Monolithic Fortran code (several dialects mixed)
- program options heavily intertwined in source code
- Maintainability increasingly difficult
- parallelization possibilities limited (MPI parallelized, but no multi-threading, no GPU parallelization, . . .)

- Since 2018: rewrite of CORSIKA in modern C++
- focus on modularity and the needs and possibilities of modern supercomputing
- coordinated by KIT, strong community integration



Status of CORSIKA 8

- hadronic and electromagnetic cascades are available
- extensive validation with CORSIKA 7 and other codes
    - actually found and fixed bugs in CORSIKA 7 this way
- already some possibilities go beyond what was possible in CORSIKA 7
- for experts: now is a great moment to engage in the development

- available hadronic interaction models
  - HE: QGSjet-II-04, EPOS-LHC, Sibyll 2.3d
  - LE: UrQMD
  - decay: Sibyll 2.3d, Pythia8
- new possibilities
  - genealogy of particles (beyond mother and grandmother particles)
  - much more flexible atmosphere
  - showers in different media (e. g. transiting from air to ice)

Comparison of particle spectra in C8, C7 & MCEq

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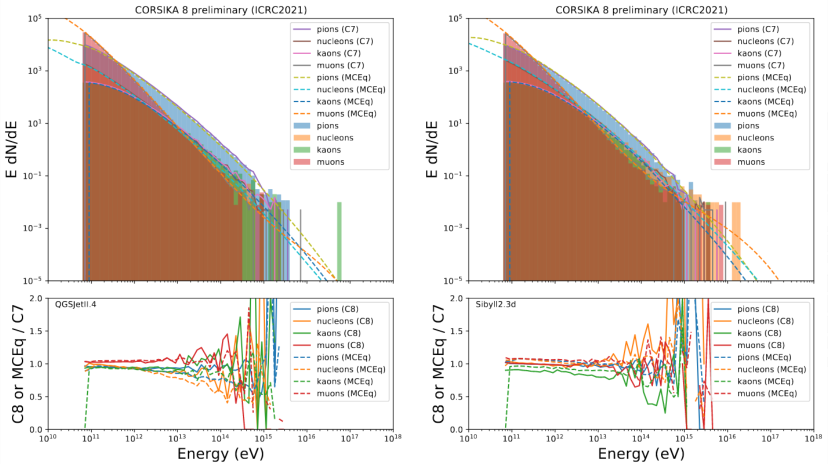


Figure 2: Vertical proton shower at 10^{18} eV. From PoS(ICRC2021)474.

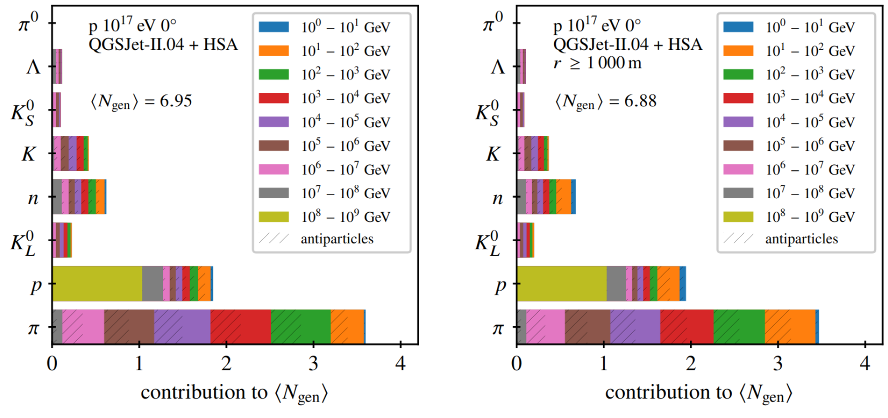


Figure 3: Muon ancestor particle distributions by species and energy. From PoS(ICRC2021)463.

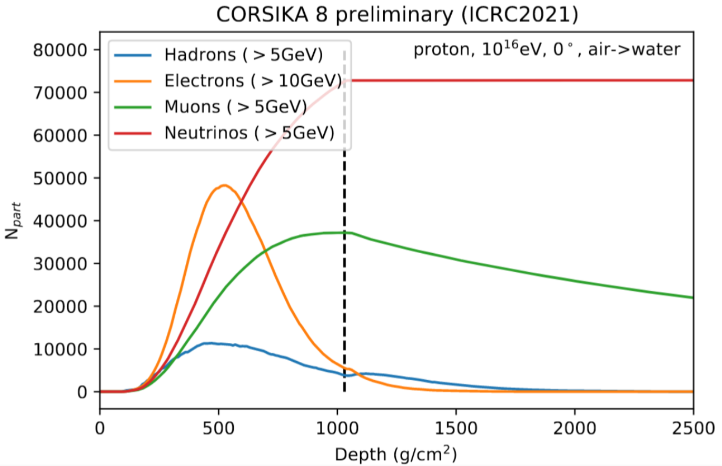


Figure 4: Vertical 10^{16} eV proton shower across media. From PoS(ICRC2021)474.

Electromagnetic cascades

- in CORSIKA 7: modified version of EGS 4
  - deeply integrated into the CORSIKA source code
  - Mortran code
  - added $\gamma \to \mu\mu$, $\gamma N \to X$ and (optionally) LPM effect
- in CORSIKA 8: lepton propagator PROPOSAL
  - modular C++14 library with Python bindings
  - propagation of electrons, positrons, and photons as well as muons
  - LPM effect available in media with homogeneous density (for inhomogeneous density work in progress)

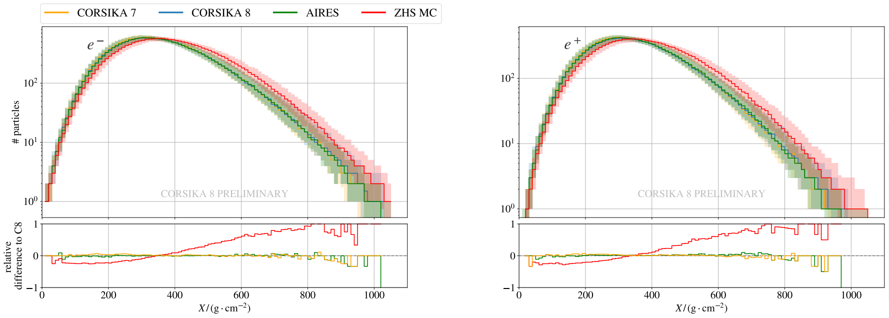


Figure 5: Longitudinal profile of 1 TeV electromagnetic showers in C7, C8, AIRES, and ZHS. From PoS(ICRC2021)428.

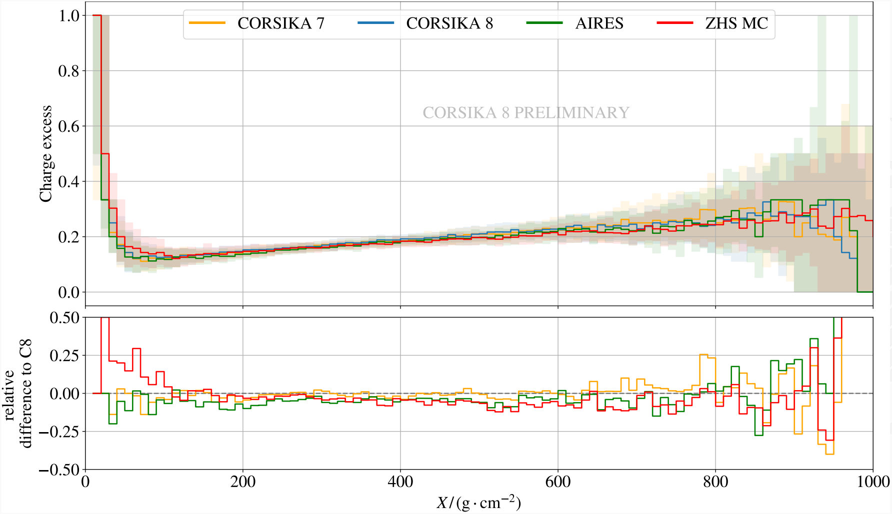
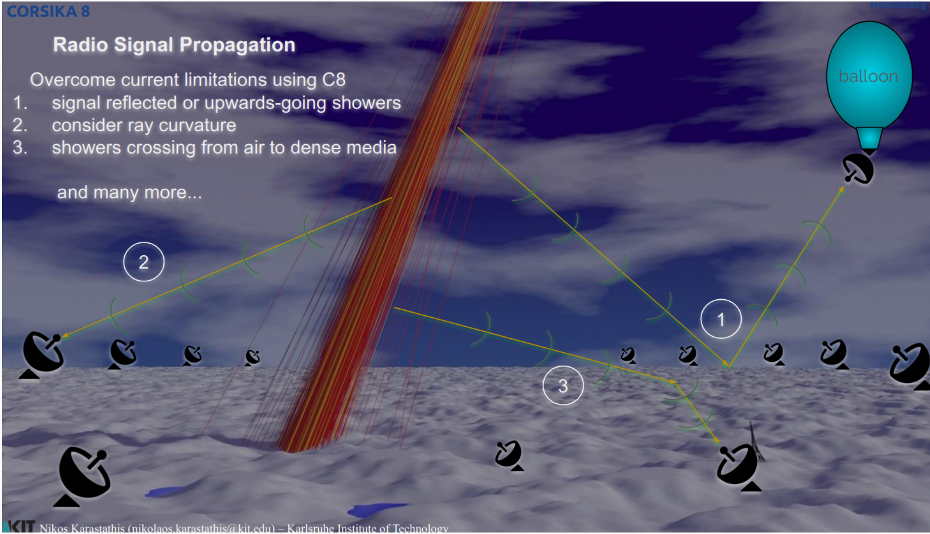


Figure 6: Charge excess of 1 TeV electromagnetic showers in C7, C8, AIRES, and ZHS. From PoS(ICRC2021)428.


CORSIKA 8
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...
balloon
2
1
3
KIT Nikos Karastathis (nikolaos.karastathis@kit.edu) – Karlsruhe Institute of Technology

- two algorithms for radio emission calculation
    - CoREAS as in CORSIKA 7
    - ZHS as in ZHAires
    - both formalisms in good agreement
- fully implemented as process
- filter, formalism, propagator, and antenna configurable by user

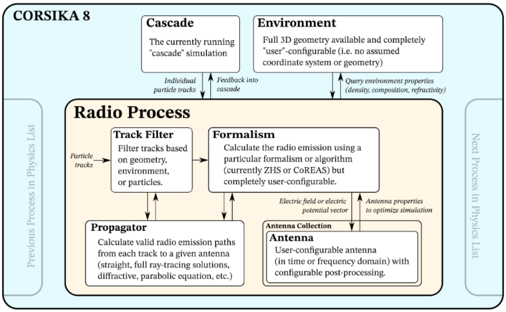
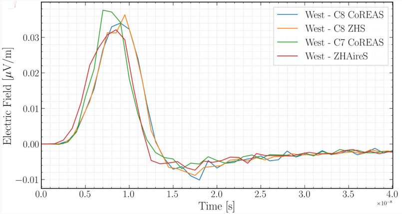


Figure 7: Schema of radio emission calculation. From PoS(ICRC2021)427.

Comparison of radio pulses



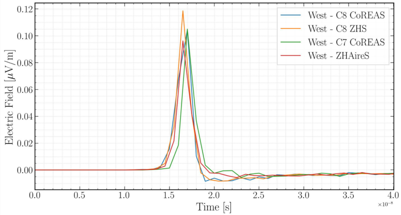


Figure 8: 10 TeV electromagnetic shower at 50 m (left) and 200 m (right) distance from shower core. From Heidelberg C8 Workshop 2022.

Comparison of radio frequency spectra

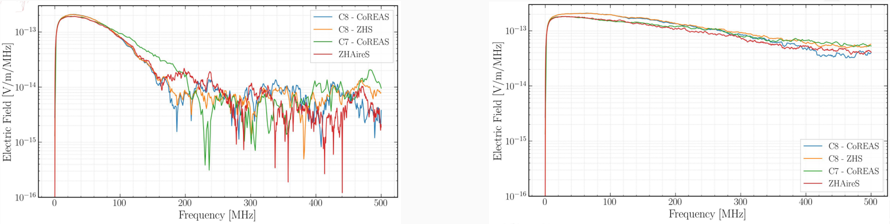


Figure 9: 10 TeV electromagnetic shower at 50 m (left) and 200 m (right) distance from shower core. From Heidelberg C8 Workshop 2022.

- Two implementations of Cherenkov emission available
- in good agreement with each other and CORSIKA 7
- one vectorized, the other uses GPU parallelization

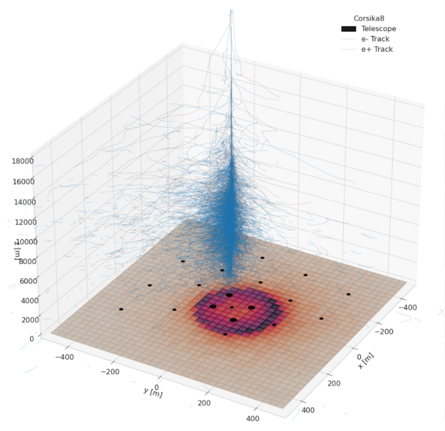


Figure 10: 1 TeV shower with ground level distribution of Cherenkov light. From PoS(ICRC2021)705.

- open source project, source code available on KIT gitlab server
- bi-weekly Zoom calls
- communication via mailing list and Slack channel

Prospects

- performance optimization
- improved treatment of multiple scattering
- Landau-Pomeranchuk-Migdal effect in inhomogeneous media
- interfaces to PYTHIA 8, FLUKA, and SOPHIA
- photohadronic interactions at low energies

Conclusion

- developers: now is a great time to join the effort
- end users: please have a little more patience
- CORSIKA 8 is capable of simulating complete showers
- already some capabilities go beyond what is possible with CORSIKA 7

Backup

Air showers on Earth and on Mars

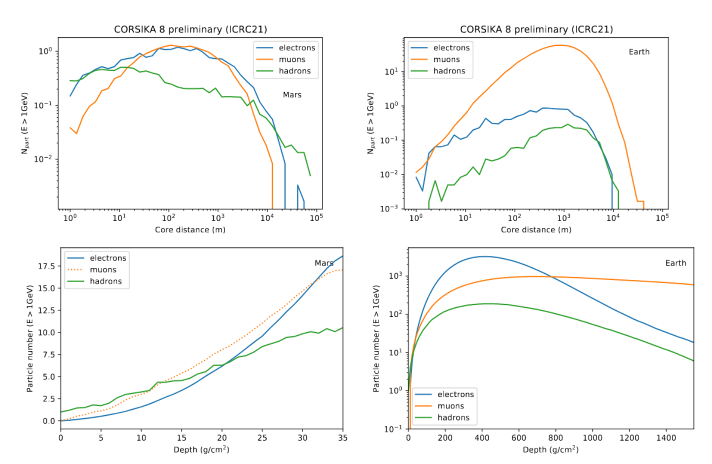
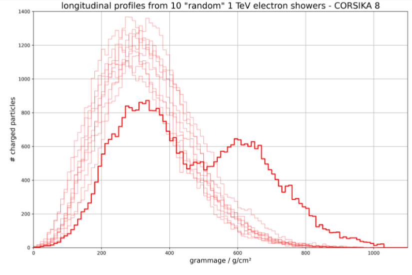


Figure 11: 100 TeV proton showers at 60° zenith angle. From PoS(ICRC2021)474.

Example electromagnetic cascades



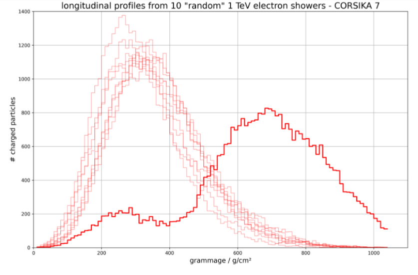


Figure 12: Longitudinal profiles of electromagnetic showers in CORSIKA 7 and CORSIKA 8.

Radio fluence from a $10\,\mathrm{TeV}$ EM shower

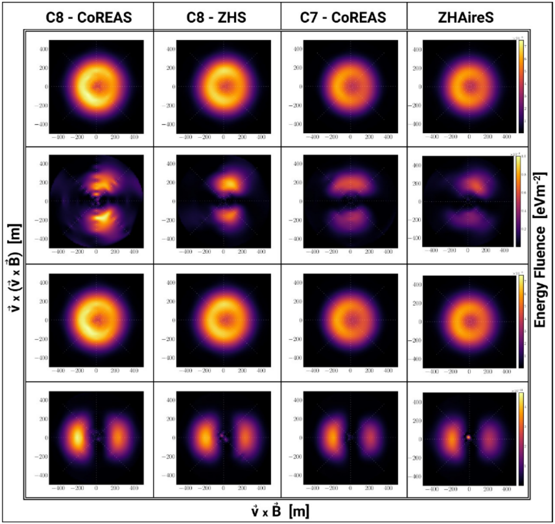


Figure 13: Energy fluence in different electric field polarizations. From PoS(ICRC2021)427.