Electromagnetic Shower Simulation for CORSIKA 8

Jean-Marco Alameddine, Jaime Alvarez-Muñiz, Juan Ammerman-Yebra, Lars Bollmann, Wolfgang Rhode, Maximilian Sackel, Alexander Sandrock, Jan Soedingrekso, Enrique Zas

technische universität dortmund

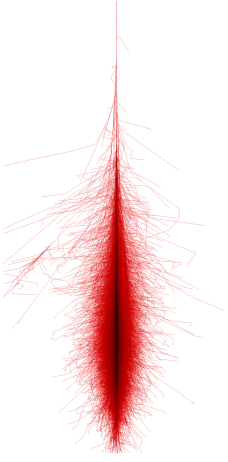
MEPhI National Research Nuclear University

IGFAE Instituto Galego de Física de Altas Enerxías

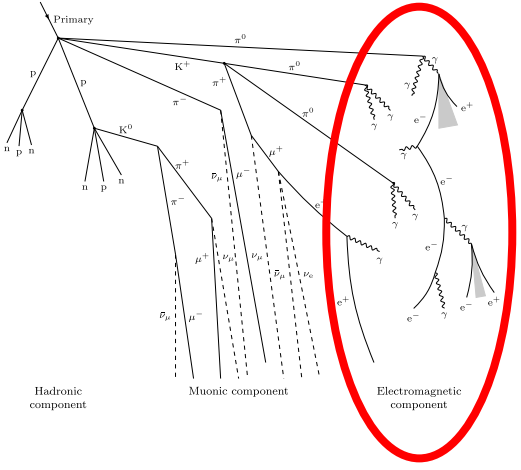
USC Universidade de Santiago de Compostela

XUNTA DE GALICIA

- **CORSIKA** is the leading framework used to simulate extensive air showers
- **CORSIKA 8:** Complete rewrite in C++17 which is currently under development
  - → flexibility
  - → modularity
  - → state-of-the art code base
  - → gitlab.ikp.kit.edu/AirShowerPhysics/corsika



→ For more about the development of CORSIKA 8, see for example the contribution "Status of the novel CORSIKA 8 air shower simulation framework"

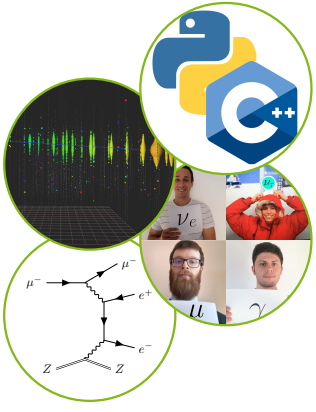


Source: PoS ICRC2015 (2016) 304

- In previous CORSIKA versions, the EM shower component is simulated using **EGS4**
  - → Fortran code released in early eighties
- Requirements for EM interaction model for CORSIKA 8:
  - → Modern and actively maintained code
  - → Up-to-date physics parametrizations
  - → Customizable

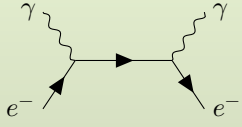
What is PROPOSAL?

- **PROPOSAL**: Software library to propagate high-energy leptons and photons
- Written in C++14, callable from Python as well
  - → Try: `pip install proposal`
- Customizable for wide range of applications
  - → Selection of different parametrizations for each physical process
- Actively maintained
  - → Visit our GitHub: `https://github.com/tudo-astroparticlephysics/PROPOSAL`



PROPOSAL

→ Provides cross sections



⇓

→ Provides propagation utilities

$$\lambda = \left(\int \frac{\mathrm{d}\sigma}{\mathrm{d}v} \, \mathrm{d}v \right)^{-1}$$

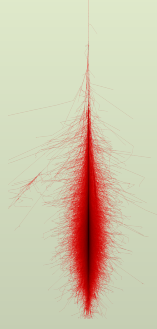
interaction lengths

stochastic losses

multiple scattering

CORSIKA 8

→ Provides shower simulation framework



→ For more about the modules in PROPOSAL, see J. Phys. Conf. Ser. 1690, 012021 (2020)

- Goal: Validate current status of CORSIKA 8 (version tagged `icrc-2021`)
  - → Compare electromagnetic shower component in CORSIKA 8 with other frameworks

CORSIKA 7

- → Predecessor of CORSIKA 8
- → Version `7.7410`

ZHS MC

- → Code to simulate electromagnetic showers in homogeneous media (10.1103/PhysRevD.45.362)
- → Version `2006 Multimedia`

AIRES

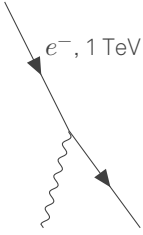
- → Tool to simulate full particle showers (10.13140/RG.2.2.12566.40002)
- → Version `19.04.00`

Comparison of theoretical descriptions

	CORSIKA 8	CORSIKA 7	ZHS MC	AIRES
bremsstrahlung	Koch & Motz	Koch & Motz	Stanev & Vankov	Rossi & Greisen
pair production	Tsai	Koch & Motz	Stanev & Vankov	Rossi & Greisen
ionization	Berger & Seltzer	Berger & Seltzer	Berger & Seltzer	(Fit to GEANT3)
photohadronic	✗	✓	✗	(✓)
scattering	Highland	Highland + Stochastic	Highland	Highland + Coulomb

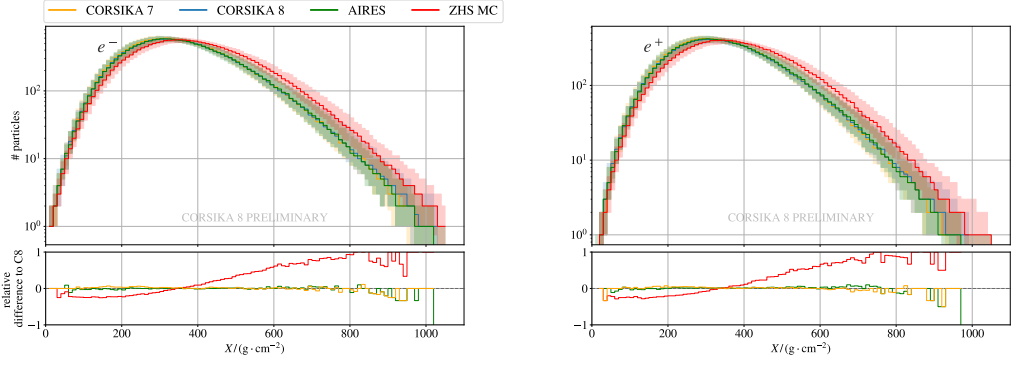
→ See our proceeding for all comparisons

Simulation parameters



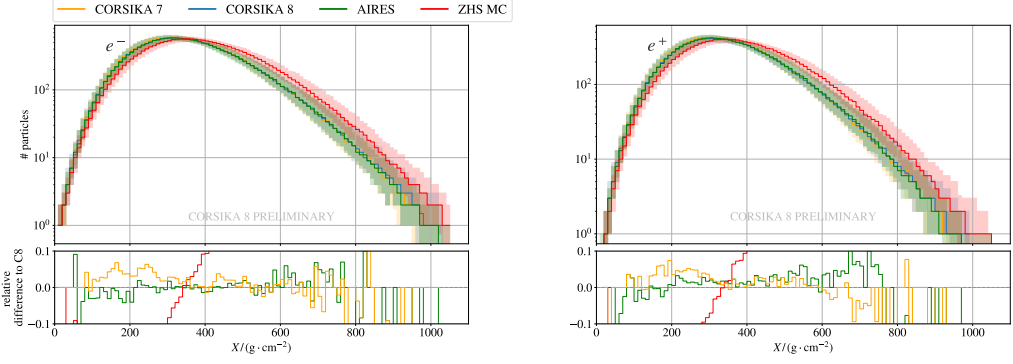
- → Statistics of 200 showers
- → Simulations in inhomogeneous air for CORSIKA 8, CORSIKA 7 and AIRES
- → Simulations in homogeneous air for CORSIKA 8, AIRES and ZHS
- → Particle threshold: 4 MeV
- → Energy loss cut: 2 MeV
  - ⇒ All frameworks have been adjusted to conform with these settings (except CORSIKA 7 energy loss cuts)

Longitudinal shower development



- shower maximum for ZHS shifted towards larger depths

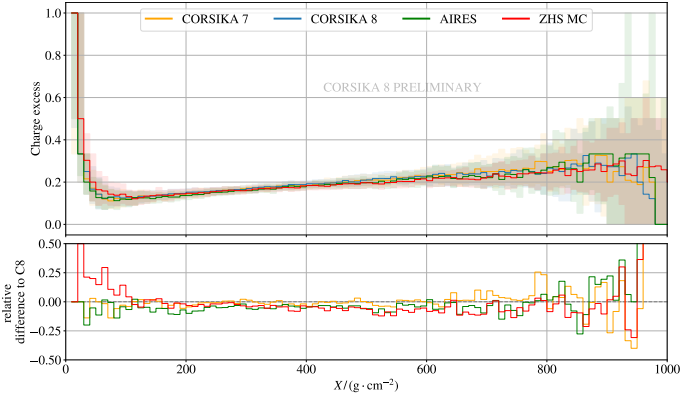
Longitudinal shower development



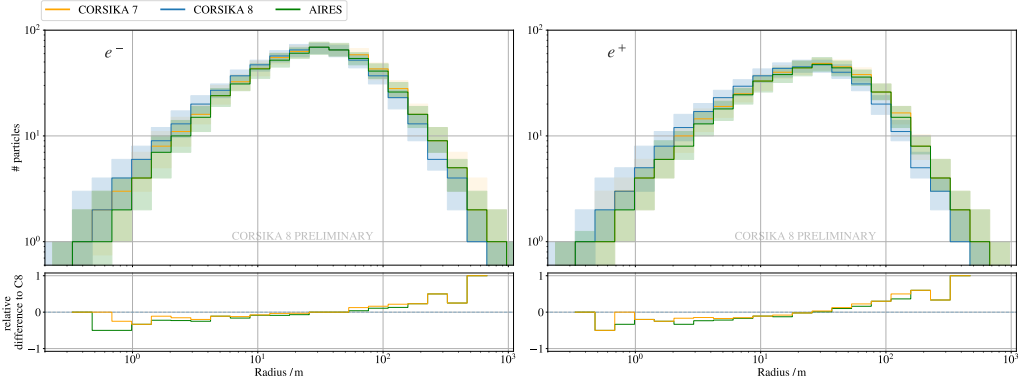
- agreement of C7, C8 and AIRES within 5 % at the shower maximum
- Possible differences in cross sections

Longitudinal development of the charge excess

- Charge excess: $\frac{N_{e^-} - N_{e^+}}{N_{e^-} + N_{e^+}}$
- Effect caused by ionization, annihilation and Compton scattering
- Relevant for radio emission in air showers
- Effect clearly visible and consistent for all frameworks

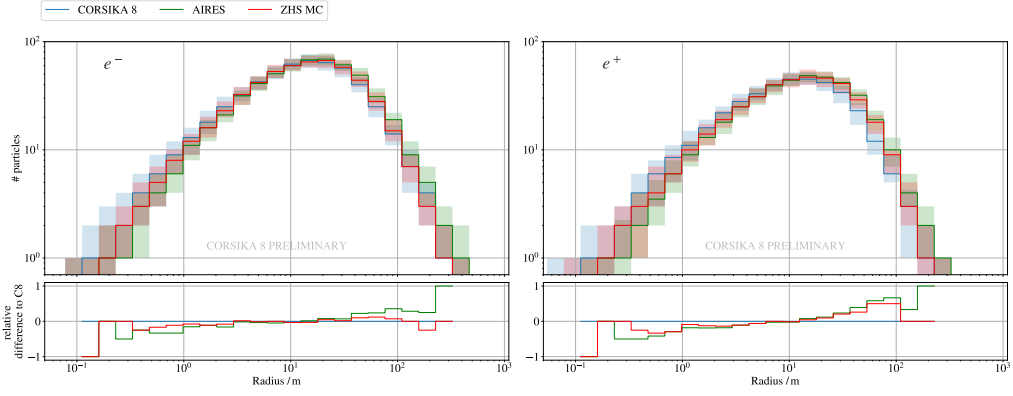


Lateral shower development



- Simulation in **inhomogeneous** atmosphere, observation level set to X_{max} (8600 m)
- Distribution for CORSIKA 8 shifted towards the shower axis

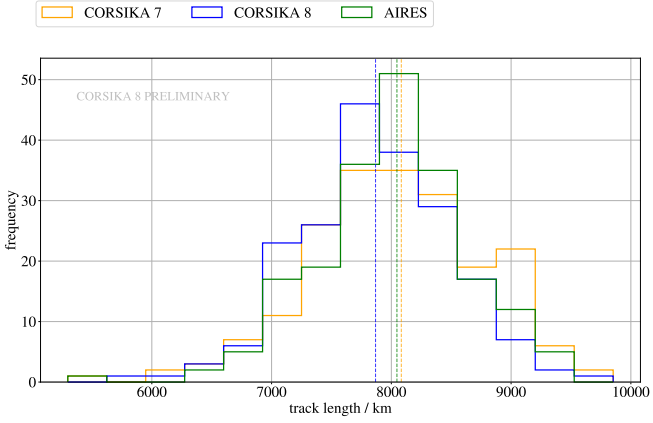
Lateral shower development



- Simulation in **homogeneous** atmosphere, observation level set to X_{max}
- Distribution for CORSIKA 8 shifted towards the shower axis
  - → Scattering description in CORSIKA 8 not yet complete

Track lengths

- Observable: Summed length of all e^- and e^+ tracks
- Shapes of distributions agree

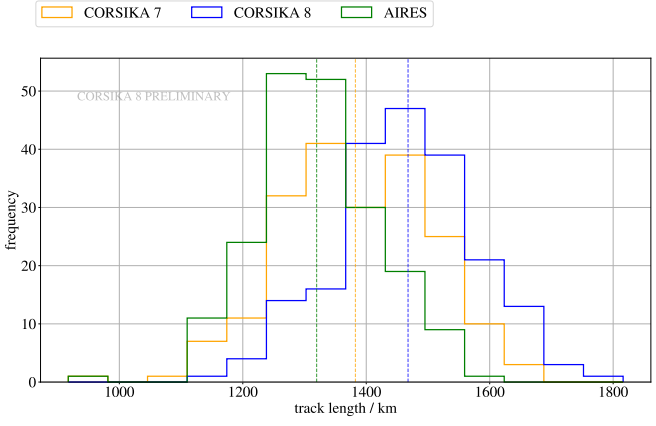


Track lengths

- Observable: Projected excess track length

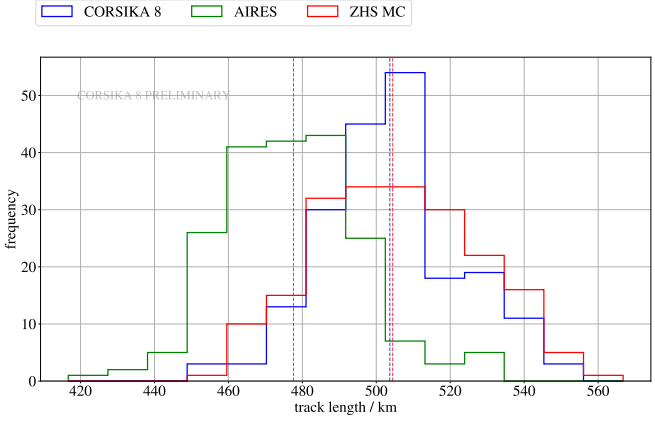
→ Sum of e^- track lengths minus sum of e^+ track lengths, each projected onto shower axis

- Important quantity for radio emission in air showers
- Displacement of distributions visible



Track lengths

- Observable: Projected excess track length
- Simulation in homogeneous air



Summary

- First systematic comparisons of the EM shower component simulated in CORSIKA 8
  - → First results are promising
  - → Most observed differences are within a 10 % range

Outlook

- Investigations of the observed differences
- Improvements for the electromagnetic interaction model in CORSIKA 8
  - → Photohadronic interactions
  - → LPM effect in inhomogeneous media
  - → Scattering and deflections
- Further cross checks with other frameworks, also under different conditions (energies, media, cuts, ...)
- Runtime comparisons and optimizations