Hadron Cascades in CORSIKA 8

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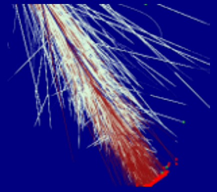
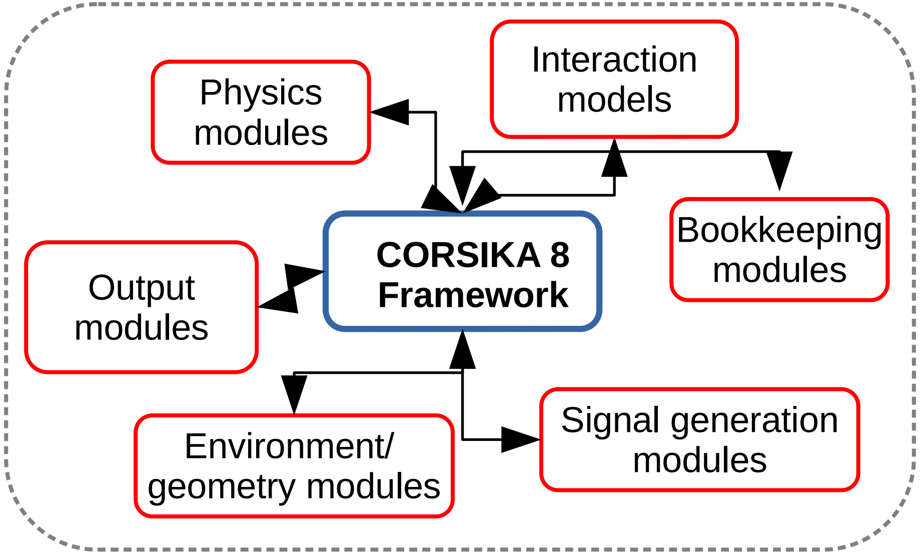
for the
CORSIKA 8 Project

ICRC 2021

Modularity and Cascade Physics

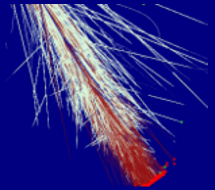




Cascade physics modules:
- Sibyll2.3d
- QGSJetII.4
- UrQMD1.3c
- PYTHIA8
- (next: EPOS-LHC, Hillas-Splitting)
- PROPOSAL
- BetheBlochPDG (3D dE/dX)
- CONEX (1D hybrid dE/dX)

Also used here:
- Geometry, Media package
- „parquet“ output
- Python analysis package

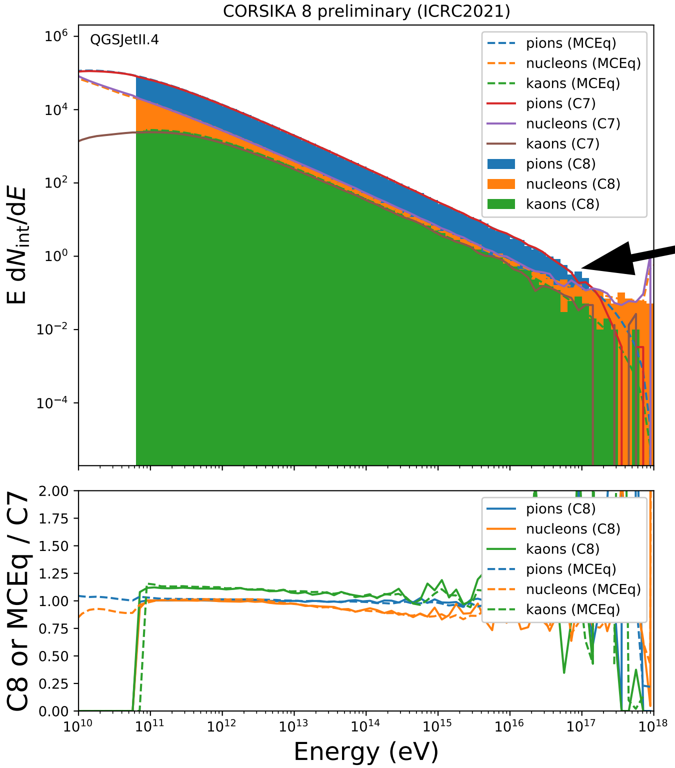
Hadron cascades validation



Each point of study:

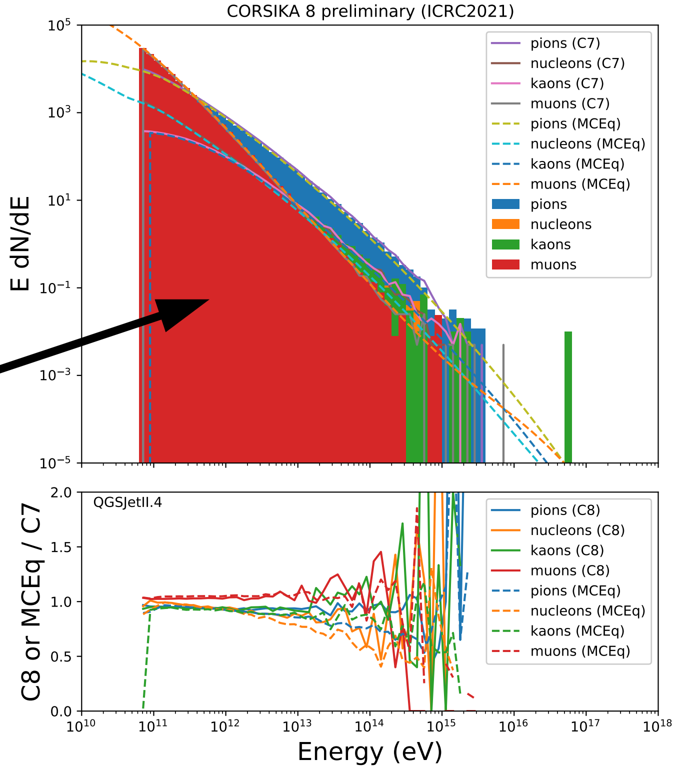
- 200 proton showers @ 1 EeV, vertical
- Secondary particle kinetic E-cut at 63.1 GeV
- Linsley US-std atmosphere, 50uT magnetic field, no e.m. cascade
- High-energy models: Sibyll2.3d and QGSJetII.4
- Observation level at 1400m a.s.l. (Malargüe)
- CORSIKA 8 release „icrc2021-b“
- CORSIKA 7.7440
- MCEq 1.2.1 (with Sibyll2.3c)

QGSJetII.4



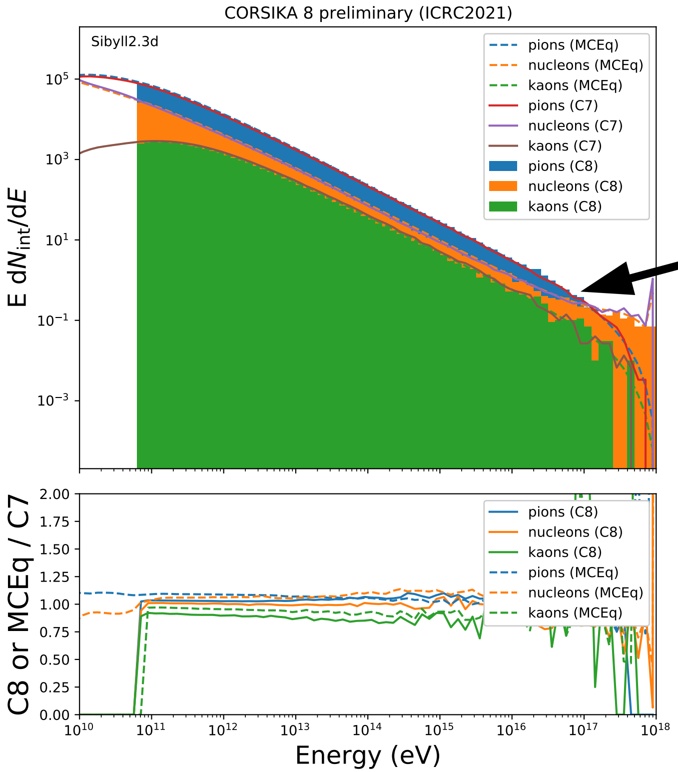
Interactions

At ground

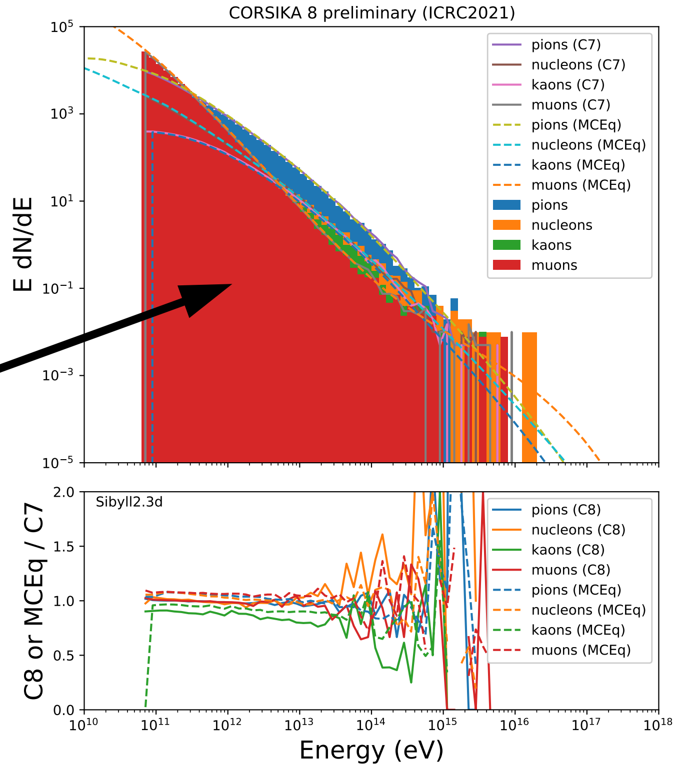


There is 5..10% of room for interpreation in the interface to a model like QGSJetII.

Sibyll2.3d



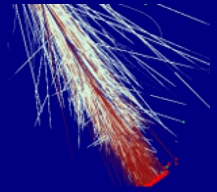
Interactions

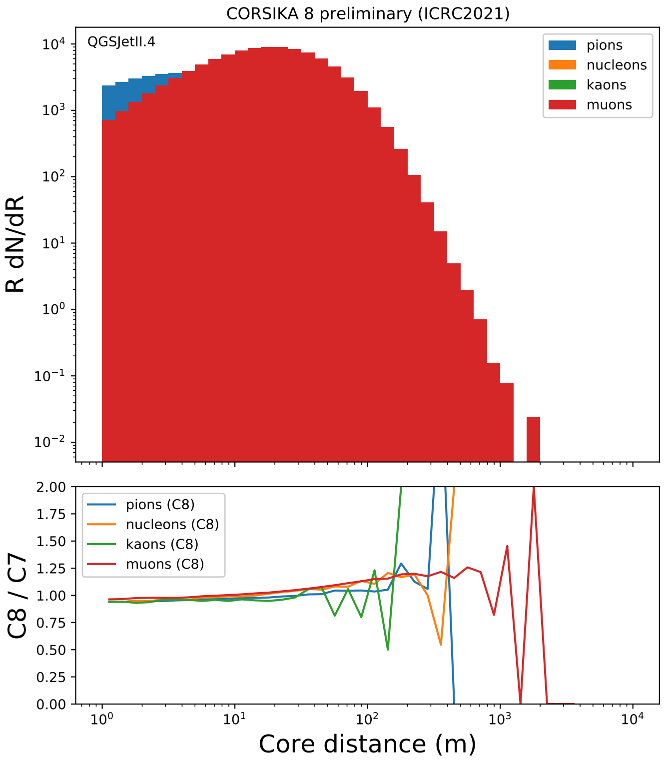


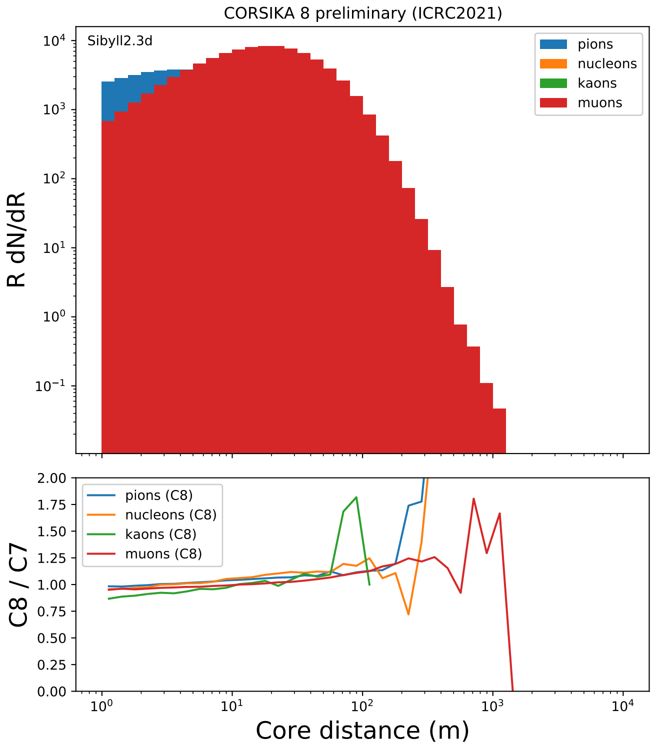
At ground

Difference Sibyll2.3c (MCEq) to Sibyll2.3d visible. Kaons slightly off.

Lateral particle densities at ground

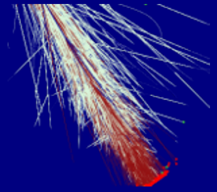


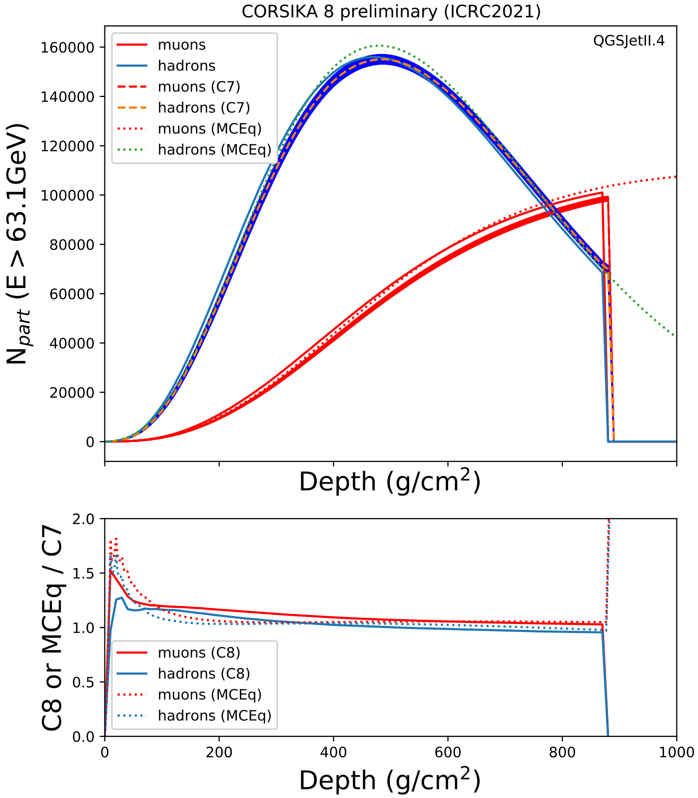


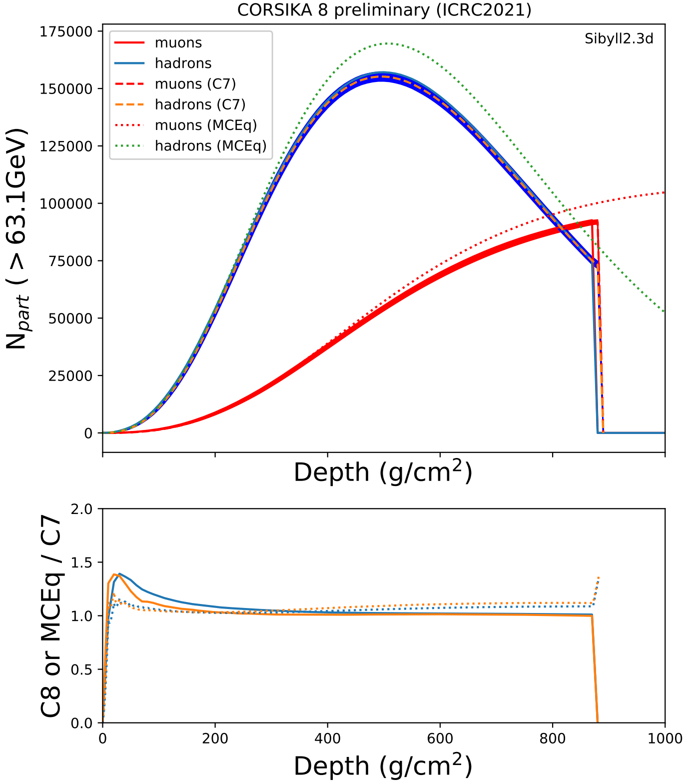


CORSIKA 8 slightly wider than CORSIKA 7

Longitudinal particle number profile



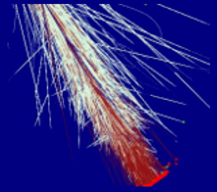




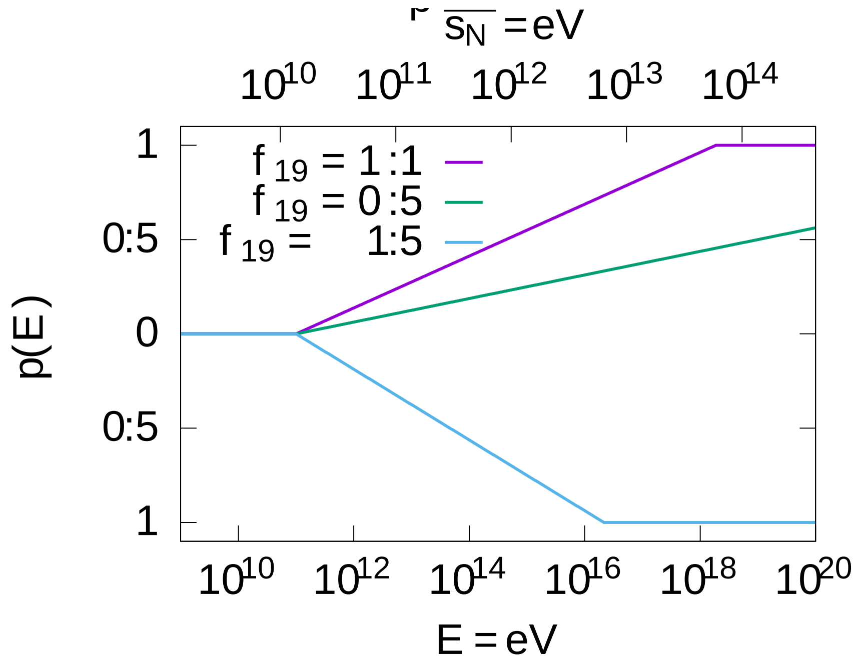
Sibyll2.3c/d difference seen.

CORSIKA 7 has slightly „slower“ profiles.

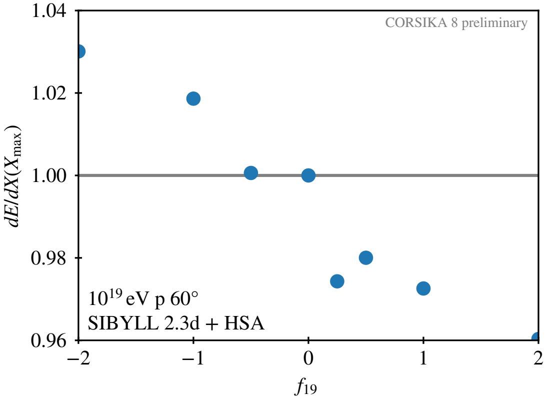
Study rho0 in air showers

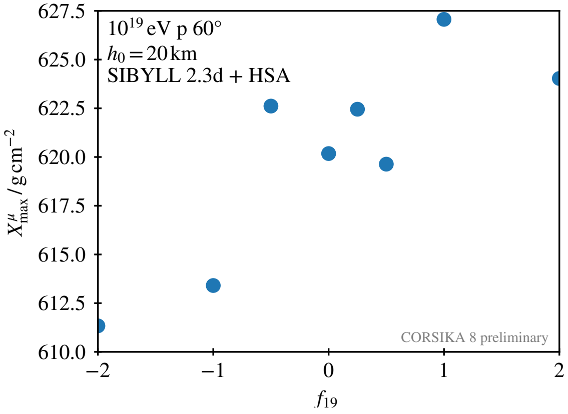


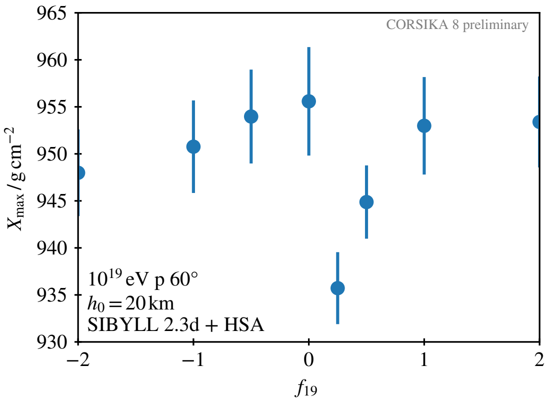
- Add extra module for ad-hoc rho0 ↔ pi0 conversion in the cascade
- Invent energy-dependent conversion probability
- Simulate proton showers at 10 EeV
- Seconday particles down to 1GeV
- Use CONEX 1D dE/dX for Xmax

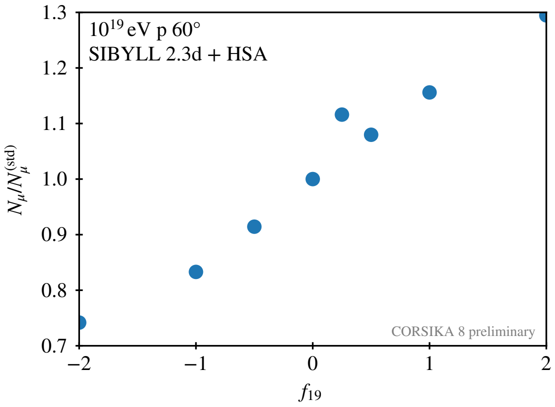


Impact of rho0







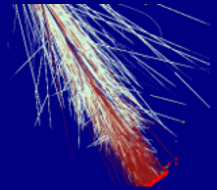


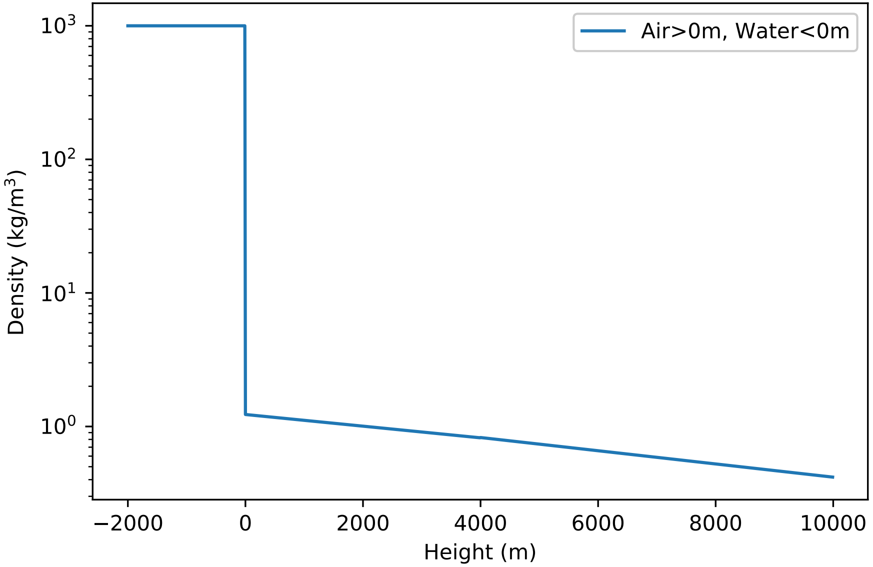
- Very minor impact on Xmumax and Xmax and dE/dX|max
- Muon number changes very clearly

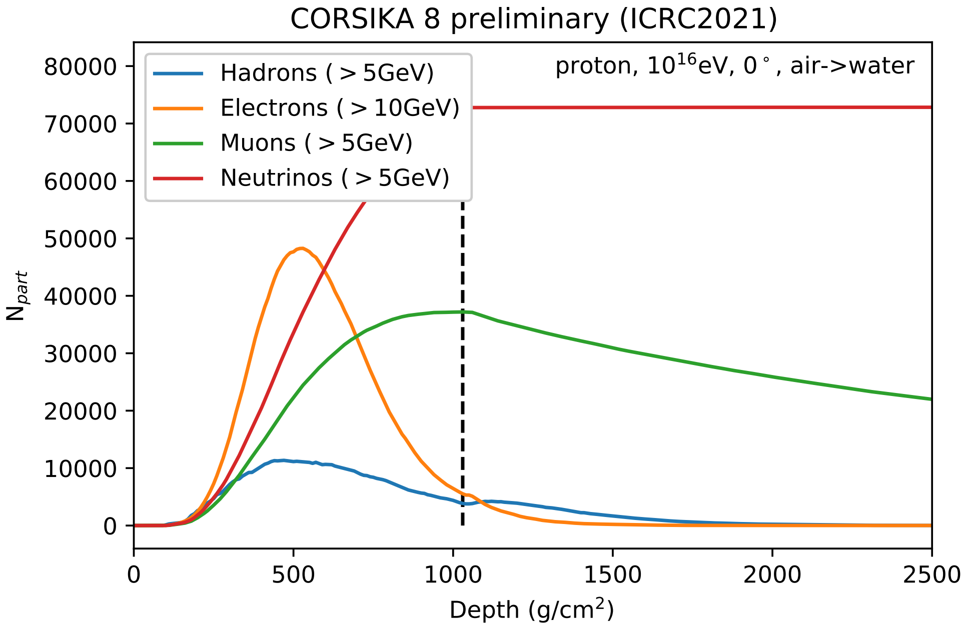
Non-air showers

- CORSIKA 8 supports by design arbitrary geometry and media
- Restrictions imposed only by the used physics modules, right now e.g. Sibyll targets A<20, UrQMD targets only N, O, Ar.
- Media transitions can be simulated
- Entirely non-earth (exo) scenarios can be simulated

Air-showers hitting water



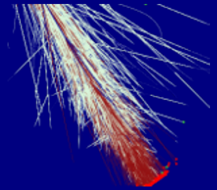


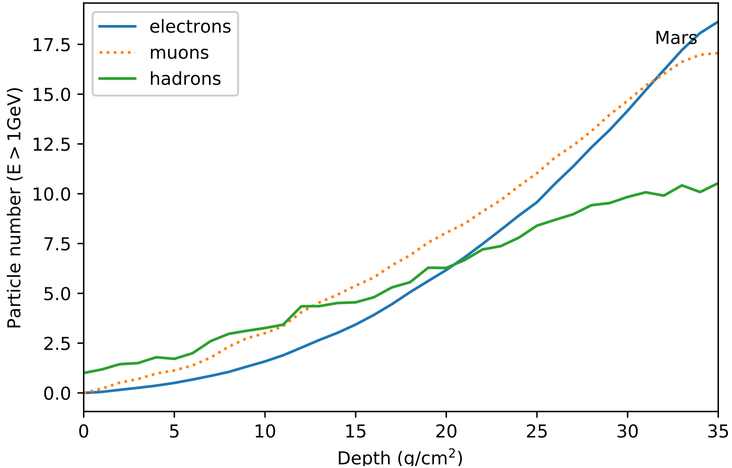


Particles are tracked to interface air/water. Shower continues in water.

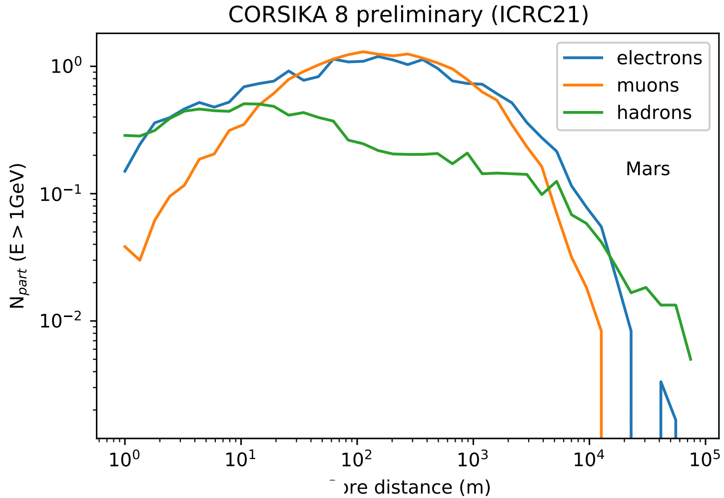
Energy losses in water are large, particles drop below cuts fast.

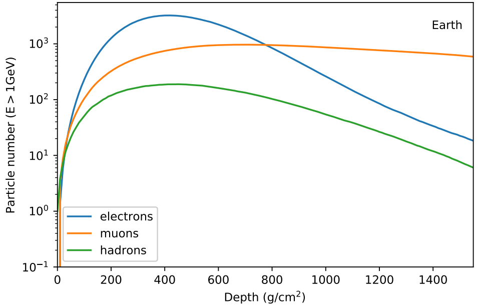
Exo showers on Mars



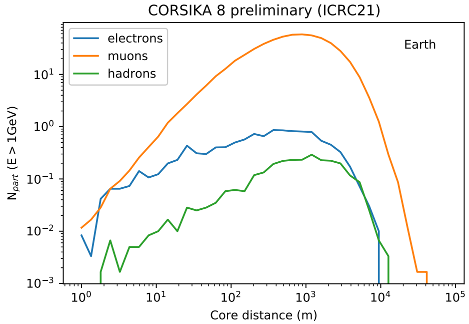


Mars





Earth

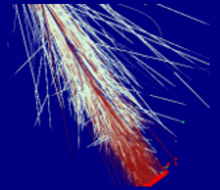


Very different showers on Mars compared to Earth (work in progress)

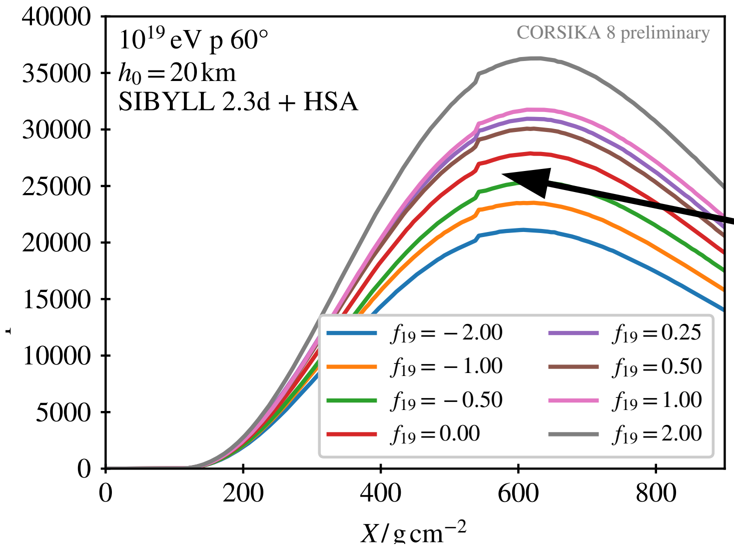
Summary

- A lot of progress, but still major work ahead.
- Physics validation started and ongoing.
- Rho0 was studied again, illustrating the clear impact on muon numbers.
- Non-air showers are directly possible (work-in-progress).
- Framework already useful, but careful: expect further larger changes and updates during the next months.

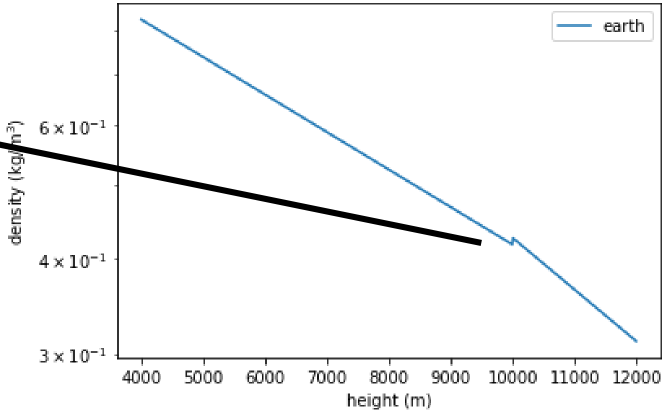
Additional materials



Muon production profile (apparent)



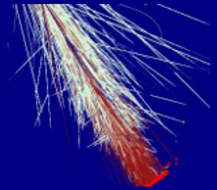
Linsley, US std. model:



High resolution MPD:

- MPD very sensitive to even small features of density model.
- Problematic due to proximity to maximum

Mars vs. Earth density model



- Comparing Linsley US std. atmosphere with the NASA Mars density model

  as implemented in CORSIKA 8