Air shower simulations with CORSIKA 8

Maximilian Reininghaus

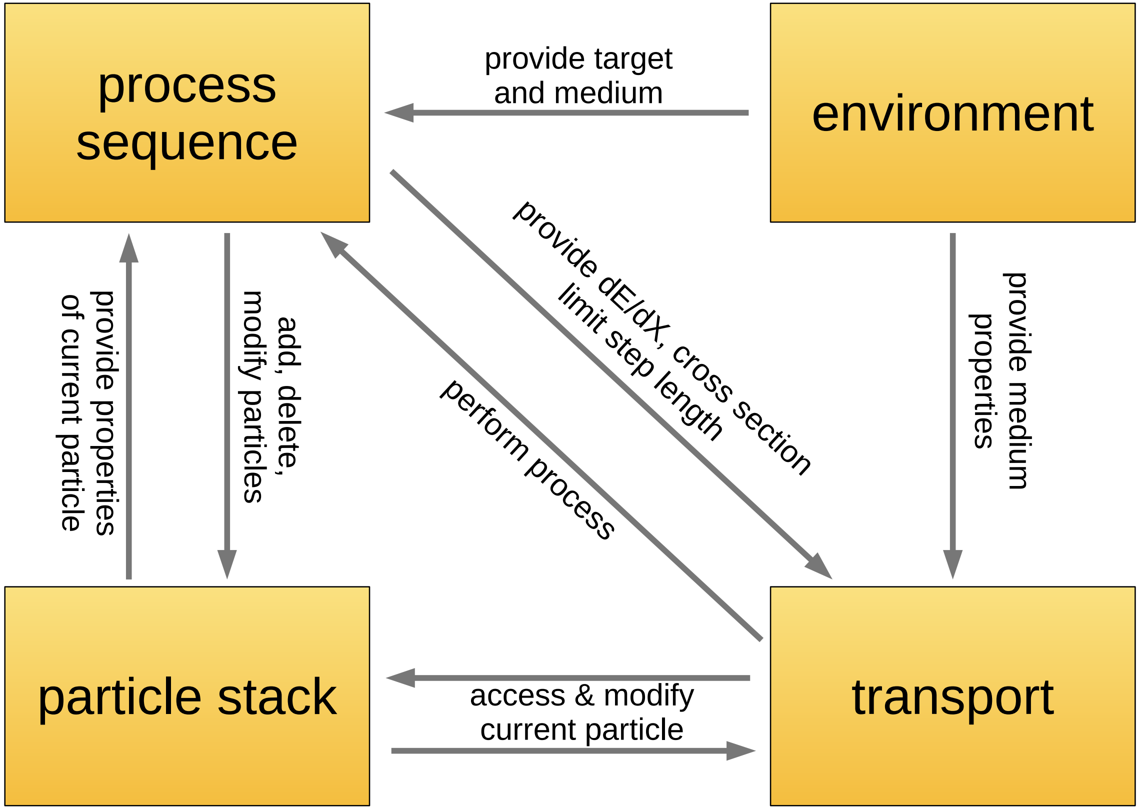
KIT Karlsruher Institut für Technologie

Double Doctoral degree in Astrophysics DDAp

ITeDA

Part I: Current status of the project

Building blocks of C8



process sequence

environment

particle stack

transport

provide target and medium

provide dE/dX, cross section limit step length

perform process

provide medium properties

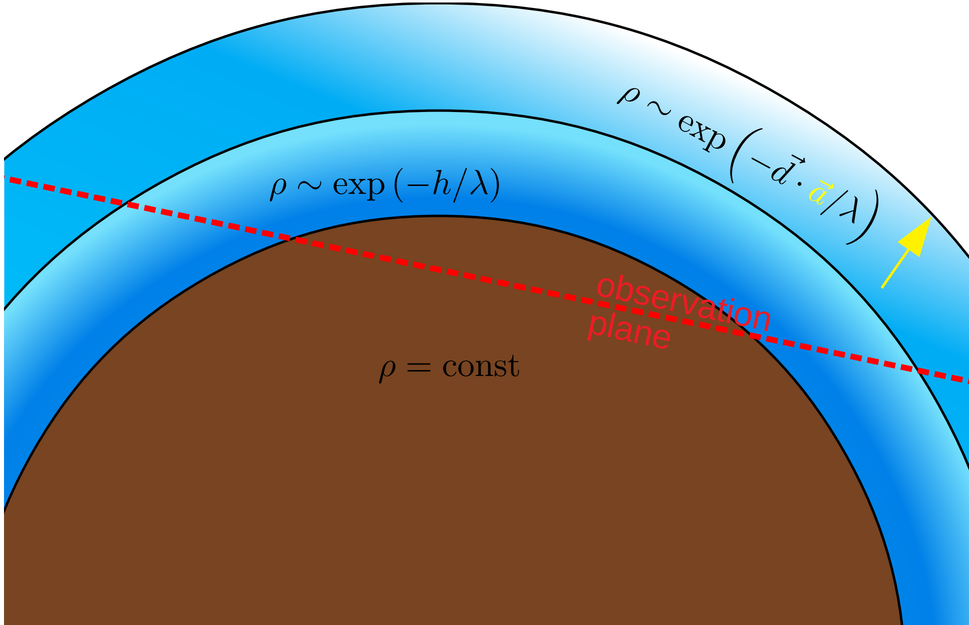
provide properties of current particle

add, delete, modify particles

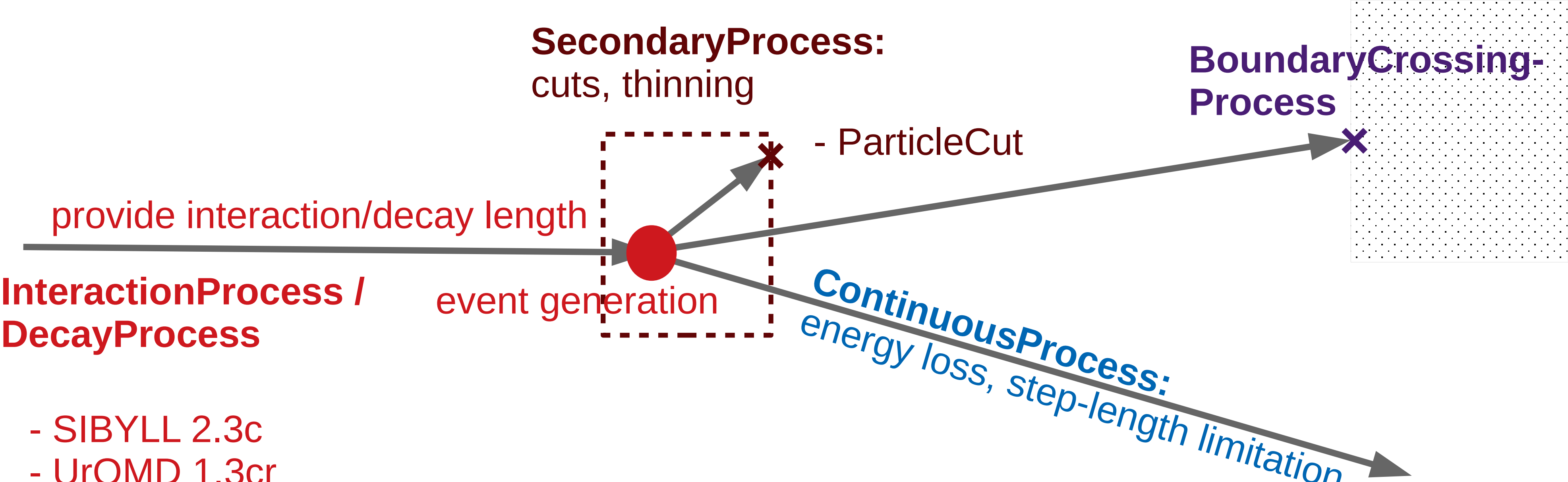
access & modify current particle

Worldbuilding

- world entirely composable by user
- different materials/density models in different regions of space
- currently available:
  - homogeneous
  - exponential flat & curved ("sliding planar approximation")
- easily extensible by own models


$\rho \sim \exp\left(-\vec{d}\cdot\vec{a}/\lambda\right)$
$\rho \sim \exp\left(-h/\lambda\right)$
observation plane
$\rho = \mathrm{const}$

Process classes



SecondaryProcess:
cuts, thinning

- ParticleCut

BoundaryCrossing-Process

provide interaction/decay length

InteractionProcess / DecayProcess

event generation

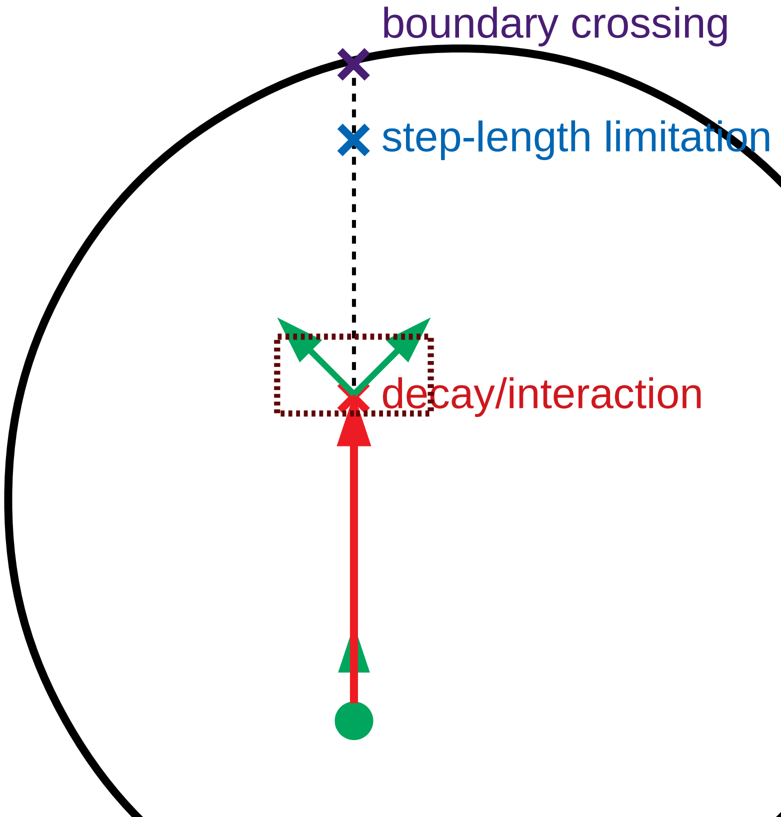
ContinuousProcess:
energy loss, step-length limitation,...

- SIBYLL 2.3c
- UrQMD 1.3cr
- PYTHIA 8.235 (for decays & p target interactions)
- SwitchProcess(LEModel, HEModel, E_{th})

- EnergyLoss
- TrackWriter
- ObservationPlane

Cascade step

- determine step-length
- apply continuous processes
- perform interaction/decay
- apply secondary processes



Part II: First results & comparison

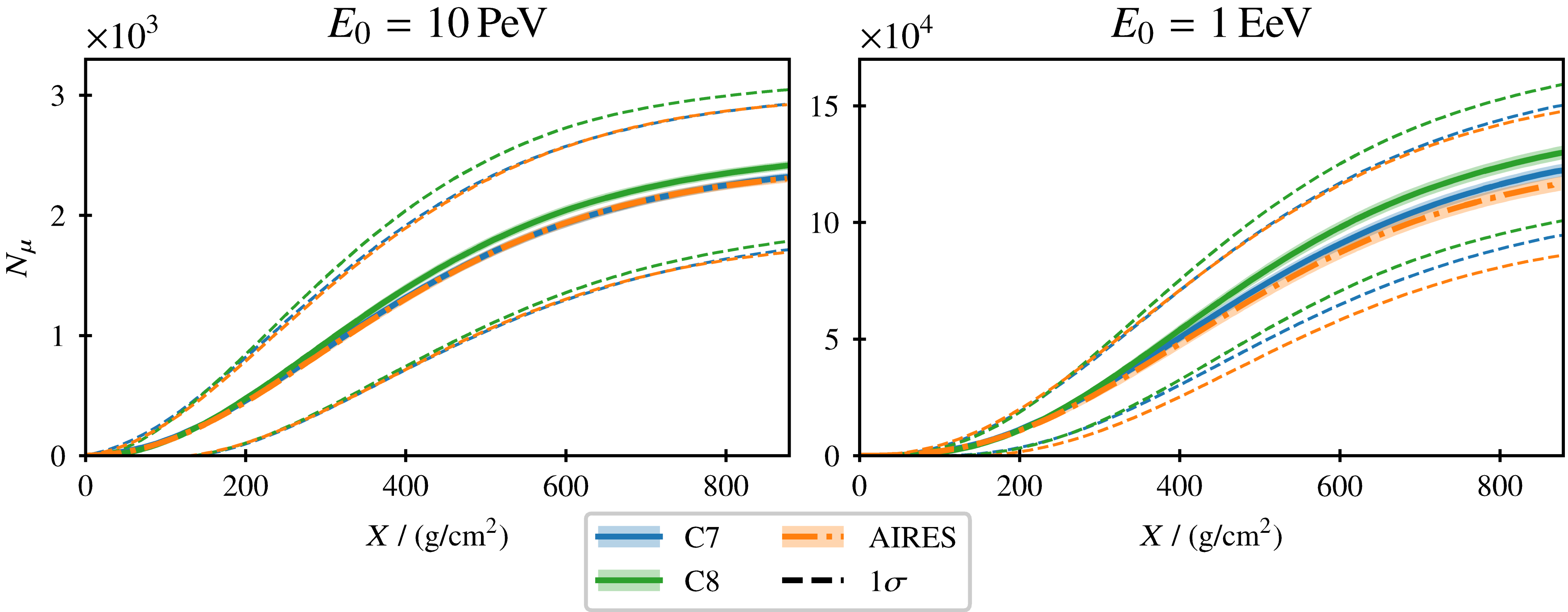
see D. Melo, MR, F. Riehn, R. Ulrich, PoS ICRC2019, 399

Setup

- mostly equivalent setups for C8, C7.64, AIRES 19.04
- flat exponential atmosphere 878 g/cm^2
- propagation of hadrons & muons
- vertical proton showers @ 10 PeV & 1 EeV

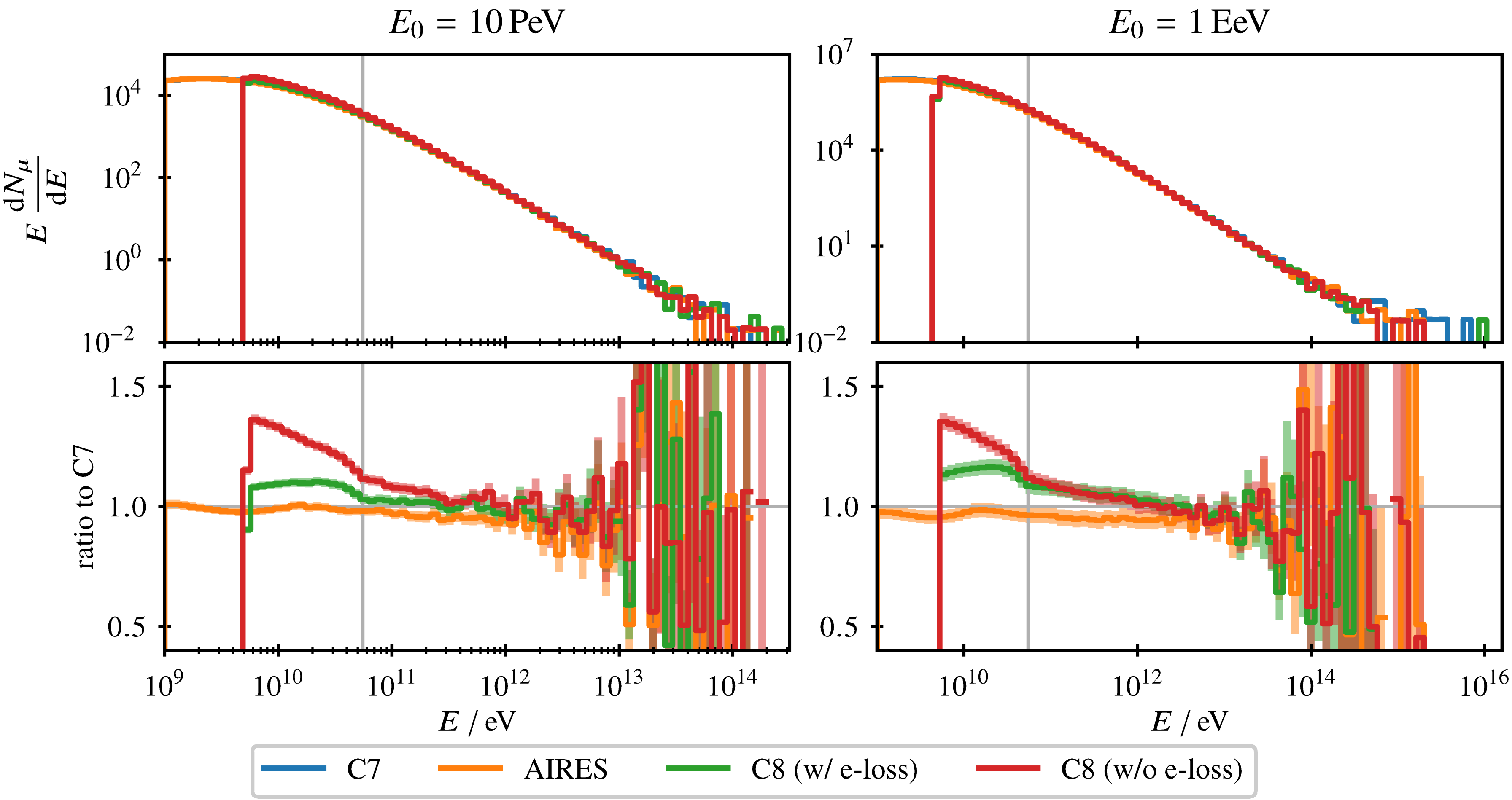
	HE model	**LE model**
CORSIKA 8	SIBYLL 2.3c	UrQMD 1.3
CORSIKA 7		
AIRES 18.10		Hillas Splitting Algorithm
	transition at **55 GeV**	

Muon longitudinal profle



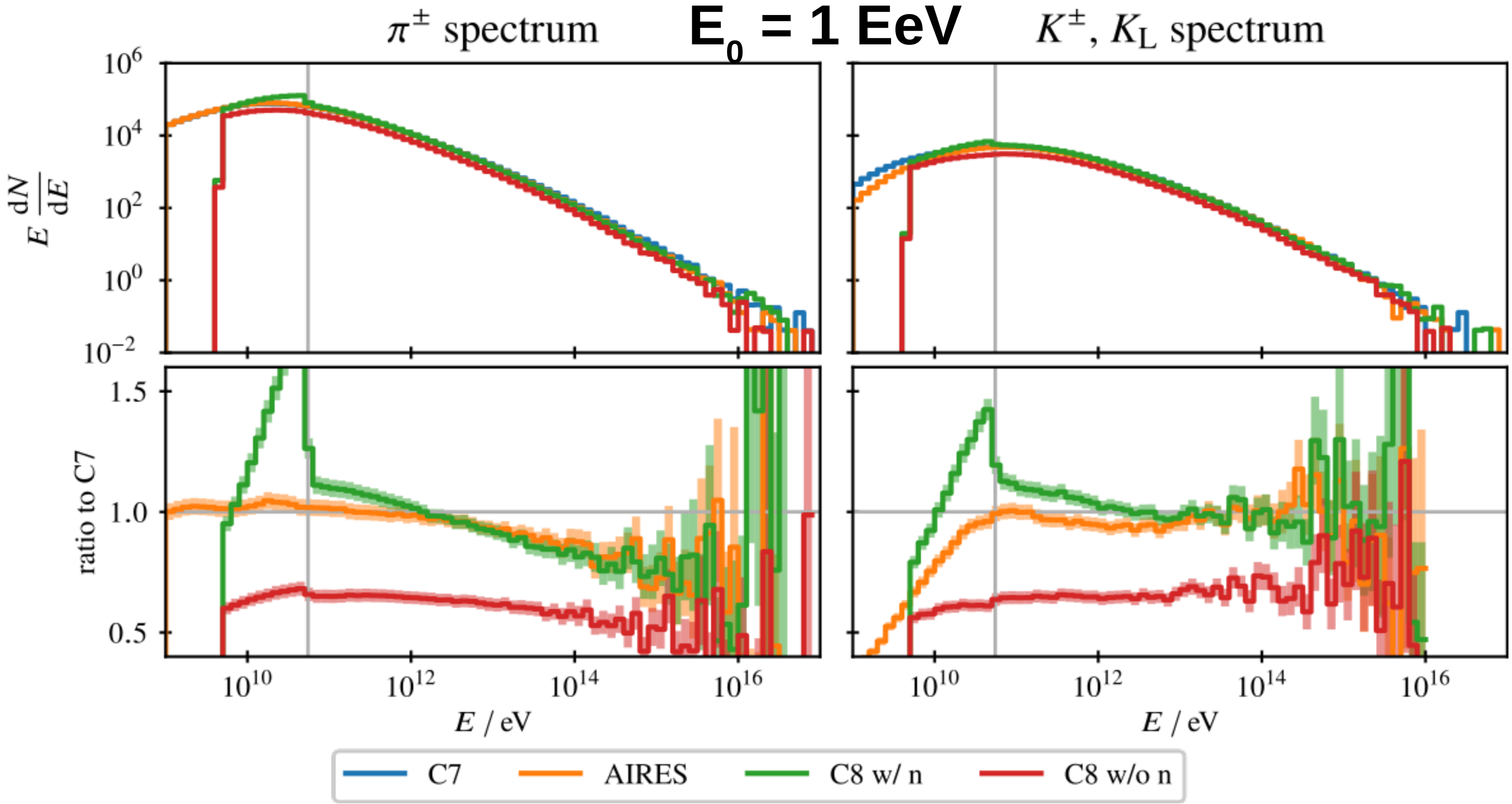
$E_\mu \geq 55$ GeV

Muon energy spectrum

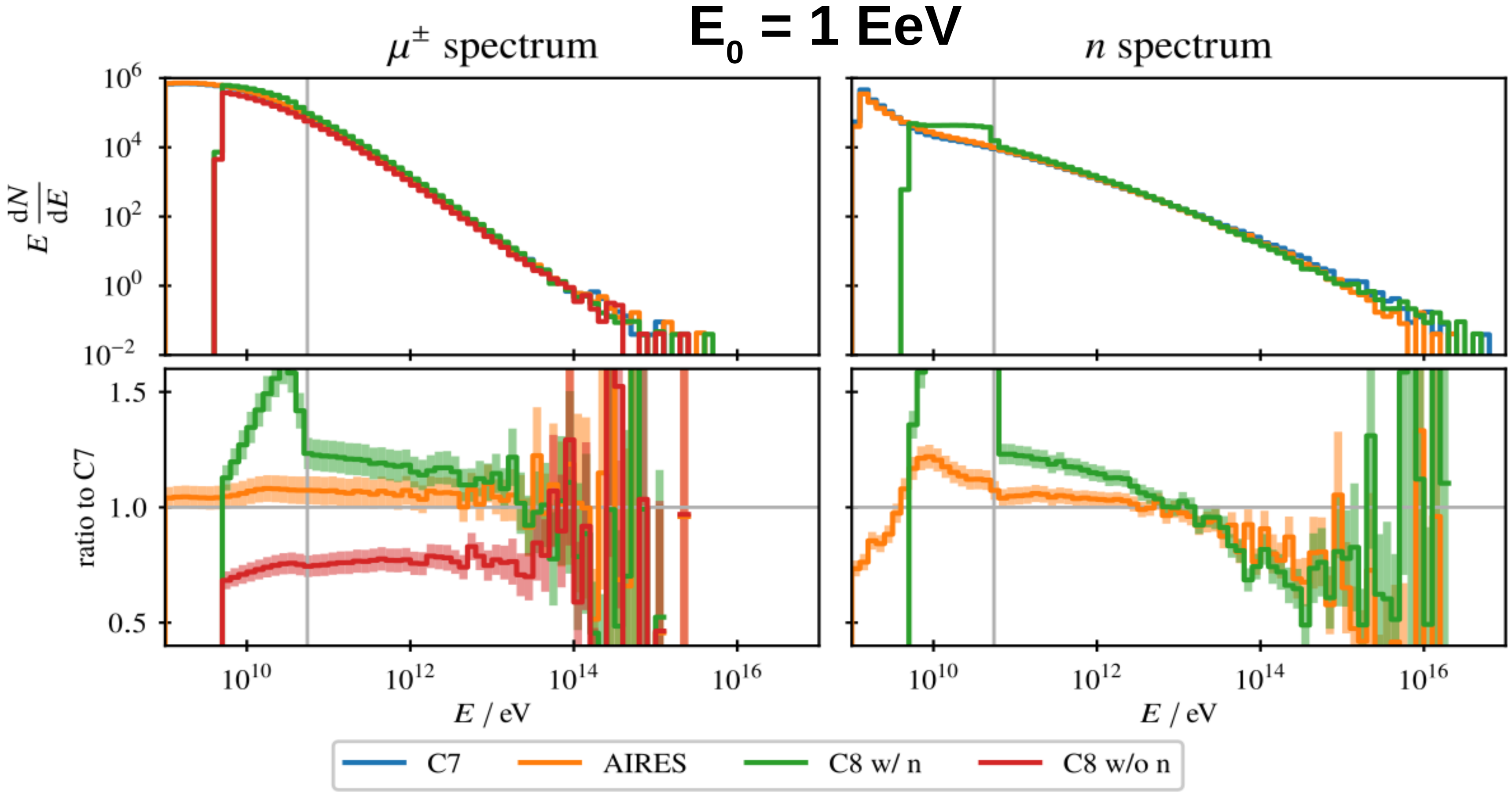


Energy spectra at 7 km

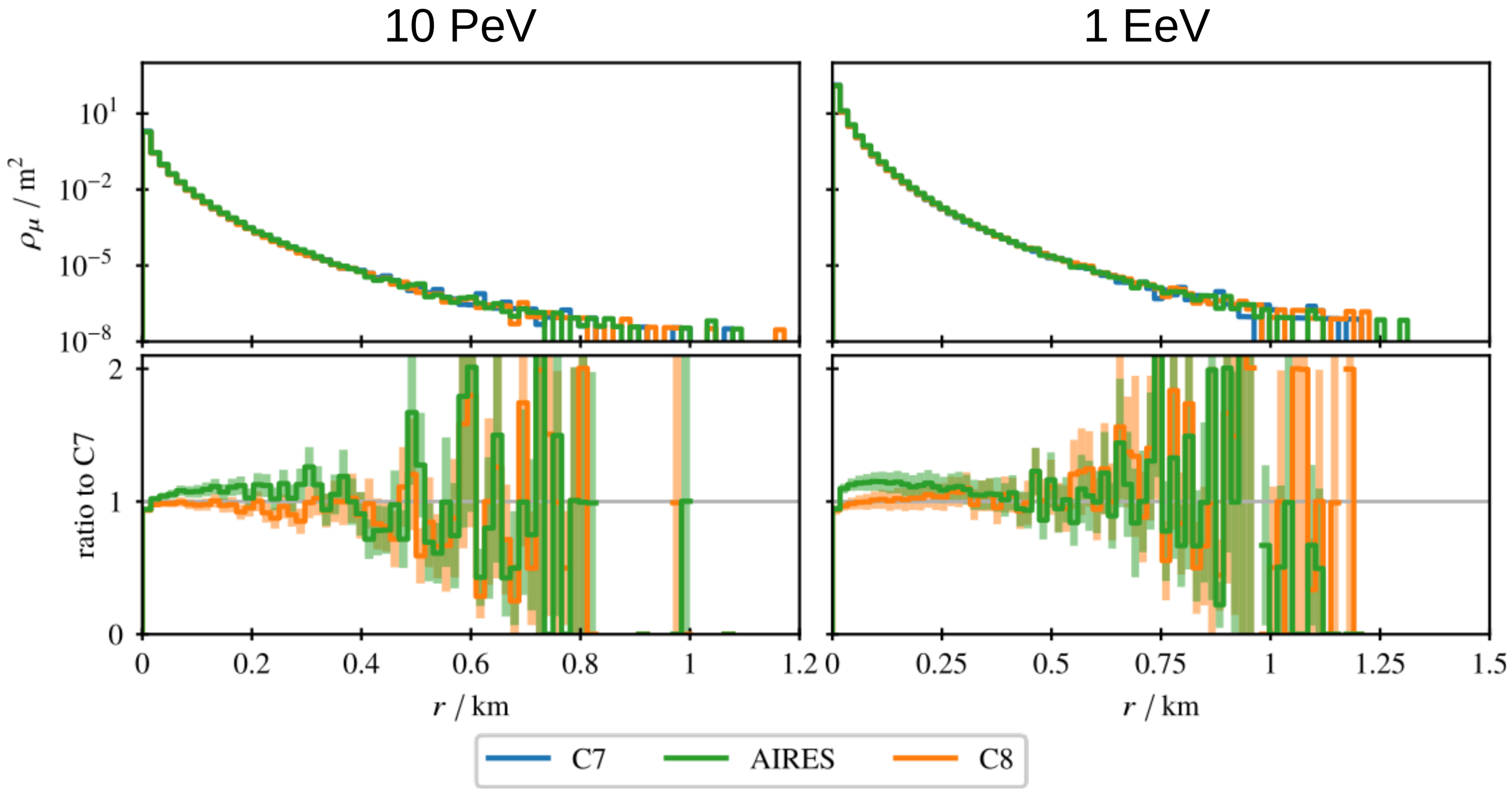
E_0 = 1 EeV



Energy spectra at 7 km



Muon LDF



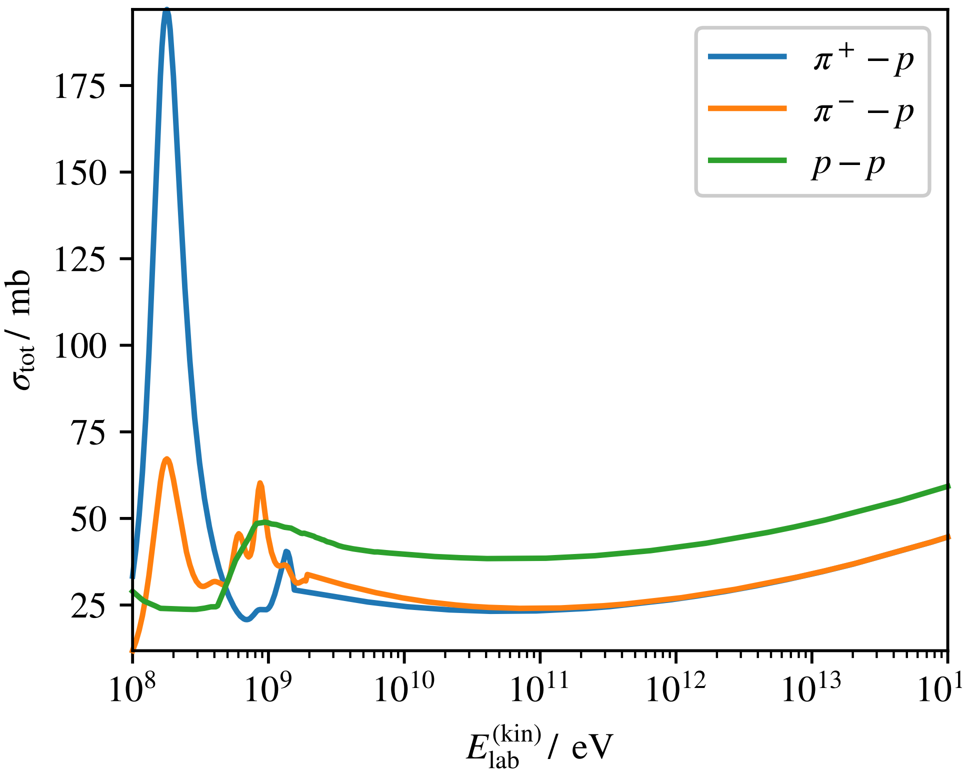
$E_\mu \geq 55$ GeV

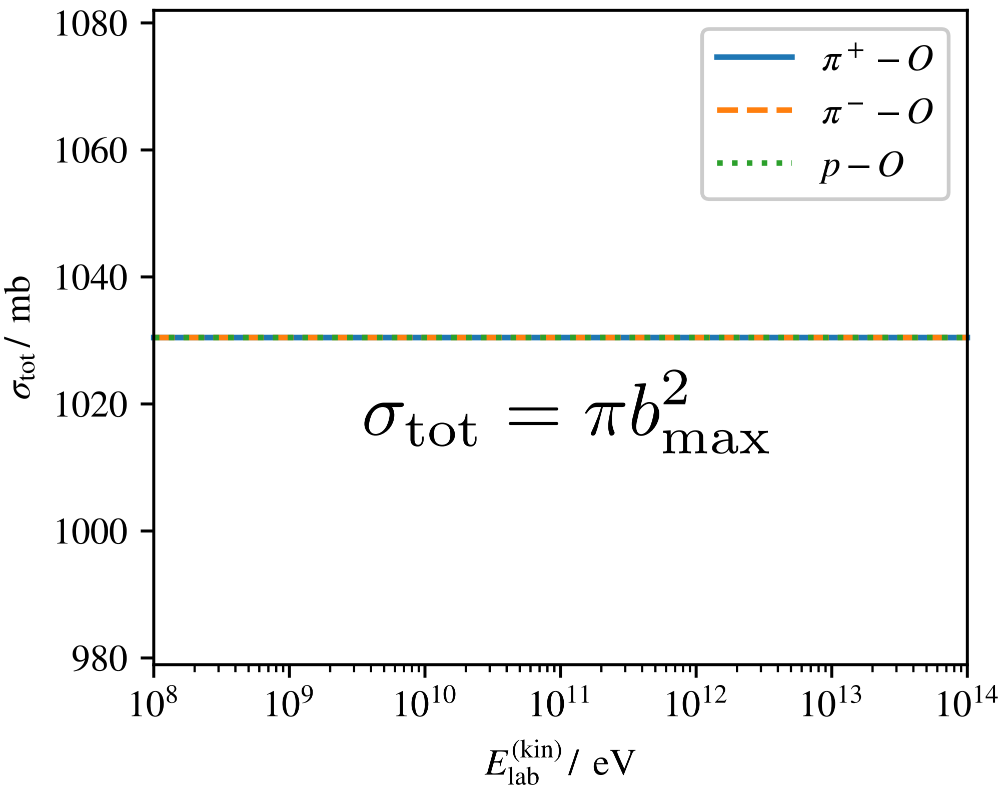
Summary

- CORSIKA 8 is alive and kicking
- hadrons and muons in air already possible
- first results are comparable to other codes
- discrepancies will likely shed light on muon production

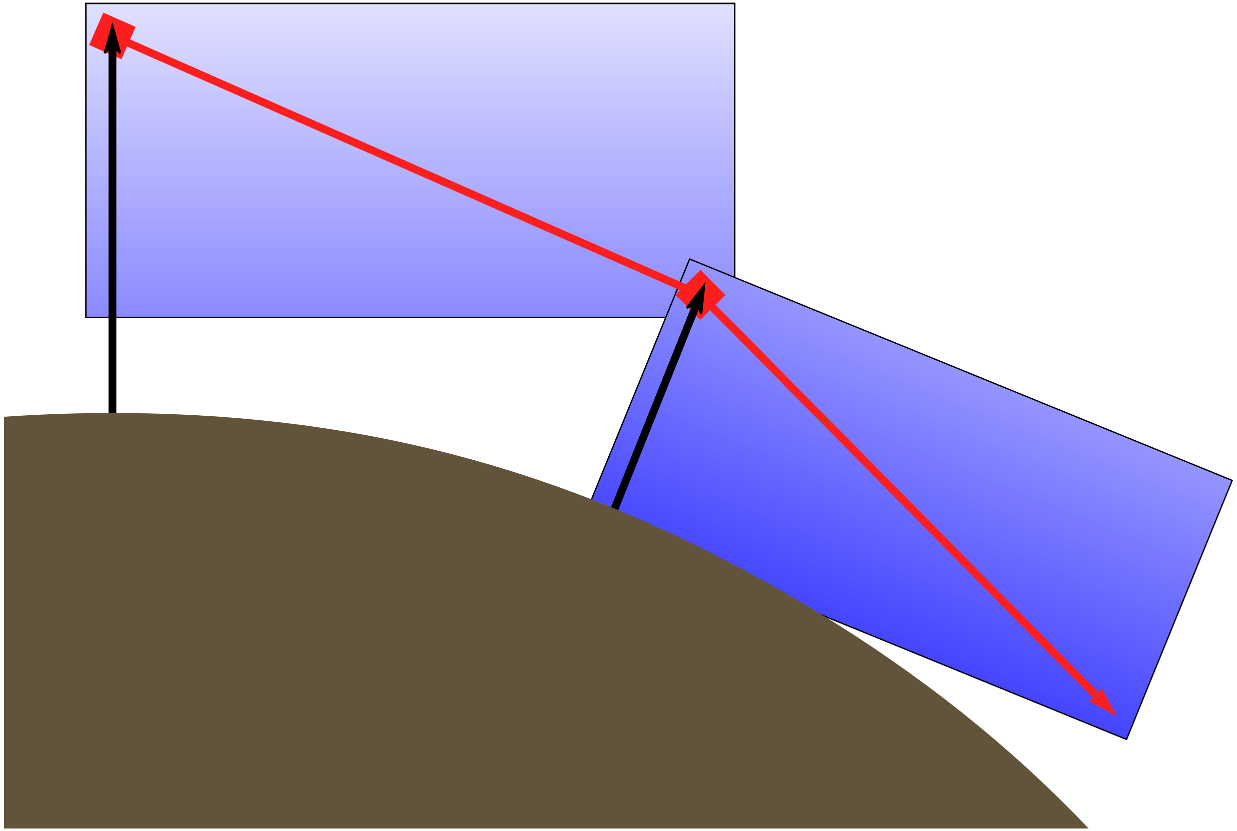
Backup

UrQMD cross-sections



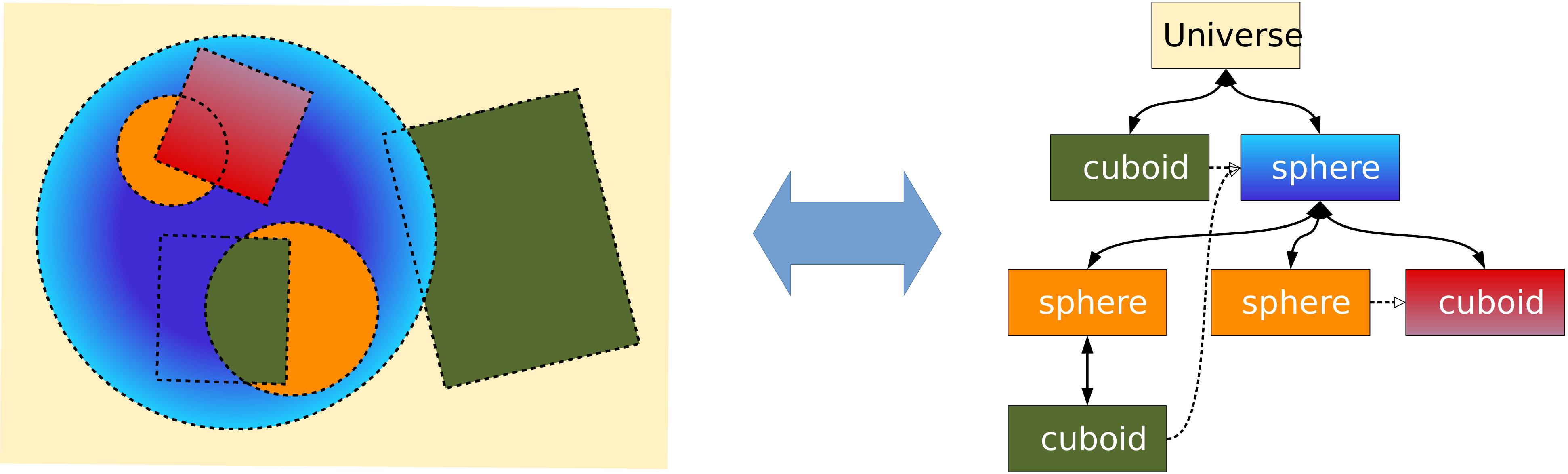


Sliding planar approximation



Worldbuilding

- geometric primitives furnished with material properties
- assembled in a tree representing containment



under the hood

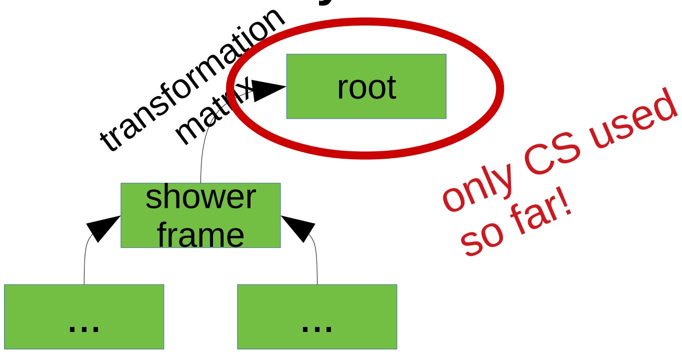
statically typed units

→ compile-time dimensional analysis

```
MassDensityType rho = 4_g /
                      cube(cm);
auto length = 5.4_m;
auto X = length * rho
// → GrammageType
```

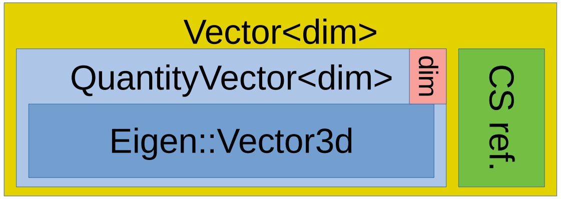
conversion between
SI & natural units provided!

coordinate systems



Definition of new CS by:
- rotation and/or translation
- reference CS

Vectors & points



automatic transformations into common CS when necessary:

```
Vector<length> v(cs1,…),
               w(cs2,…);
auto u = v + w;
```

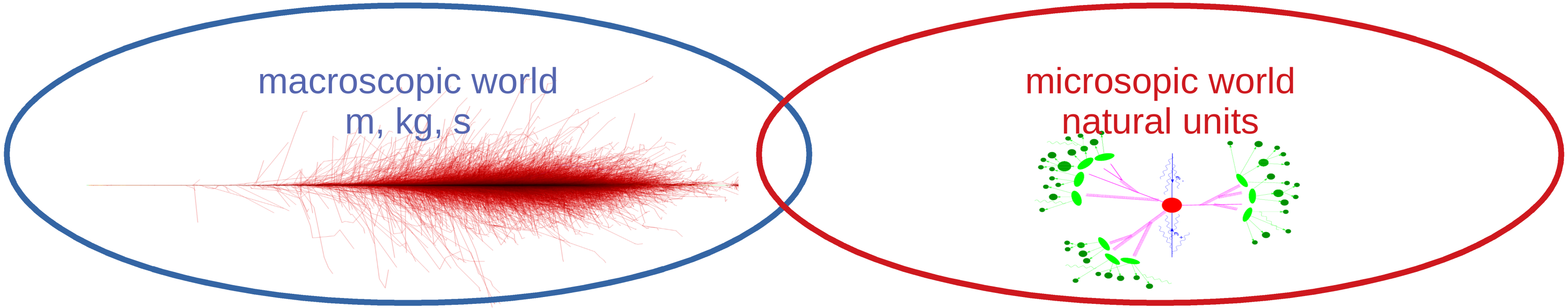
Units

- Compile-time dimensional analysis based on *PhysUnits C++11*
- Example:

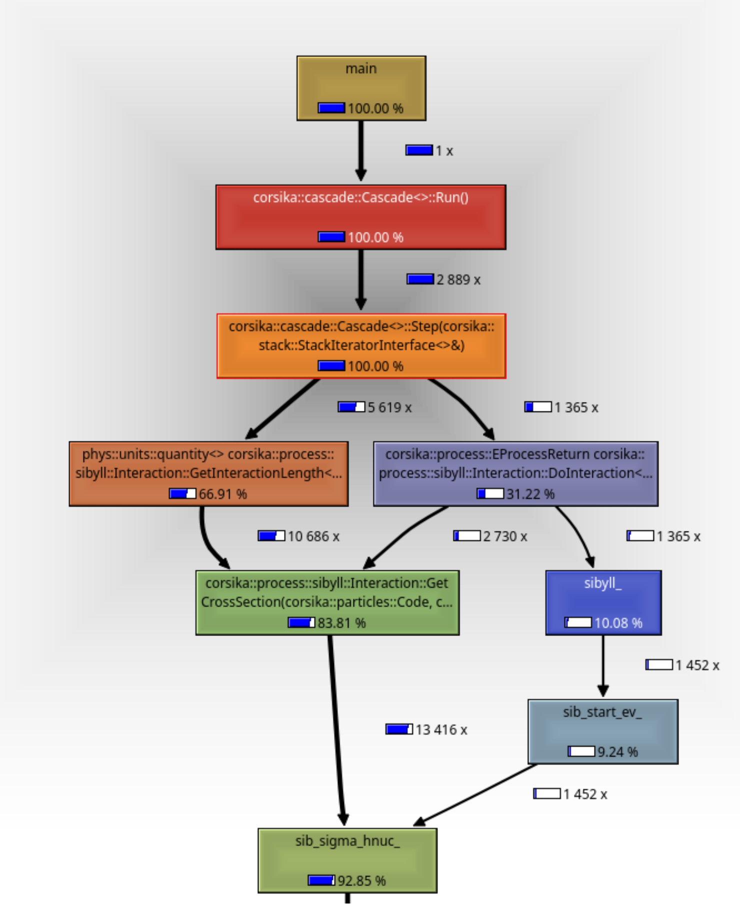
```
MassDensityType rho = 4_g / cube(cm);
auto length = 5.4_m;
auto X = length * rho // -> GrammageType
```

fully integrated into geometry framework: Vector<speed_d>, ...

- conversion between SI & natural units provided!



Profiling


main
100.00 %
1 x
corsika::cascade::Cascade<>::Run()
100.00 %
2 889 x
corsika::cascade::Cascade<>::Step(corsika::stack::StackIteratorInterface<>&)
100.00 %
5 619 x
1 365 x
phys::units::quantity<> corsika::process::sibyll::Interaction::GetInteractionLength<...
66.91 %
corsika::process::EProcessReturn corsika::process::sibyll::Interaction::DoInteraction<...
31.22 %
10 686 x
2 730 x
1 365 x
corsika::process::sibyll::Interaction::GetCrossSection(corsika::particles::Code, c...
83.81 %
sibyll_
10.08 %
1 452 x
13 416 x
sib_start_ev_
9.24 %
1 452 x
sib_sigma_hnuc_
92.85 %