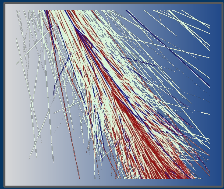
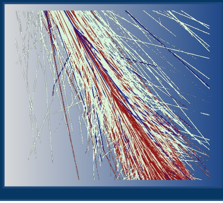


Overview and status of the CORSIKA 8 project

Ralf Ulrich

Scientific aim



A new framework for

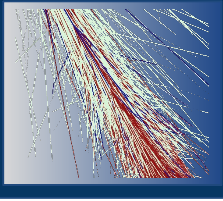
“particle transport with stochastic and continuous processes”,

as a stable and solid working horse for astroparticle physics for the next decades,

making most efficient use of expensive and limited scientific and computational resources in astroparticle physics,

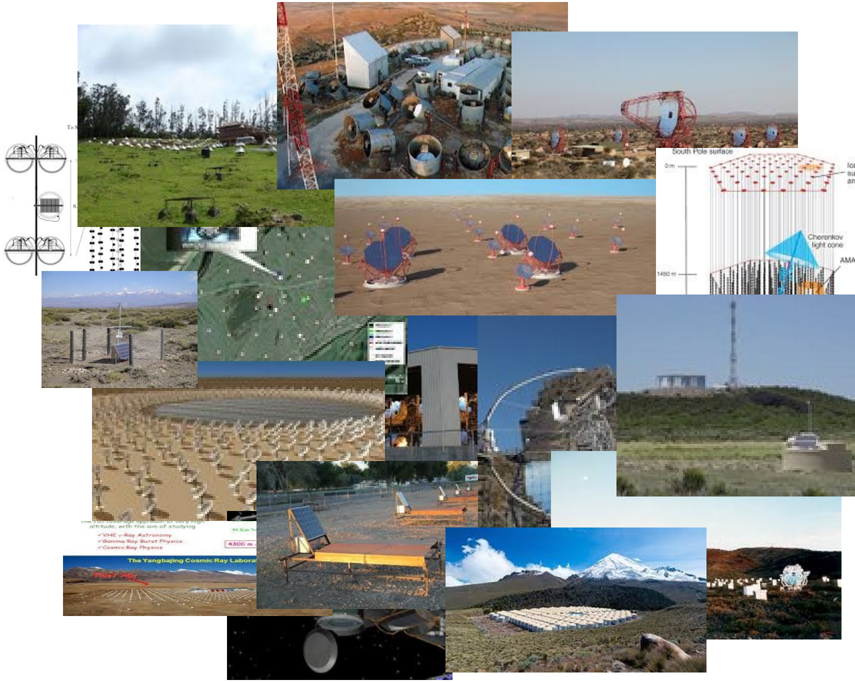
supporting experimental work, as well as physics advances.

Tasks for CORSIKA 8

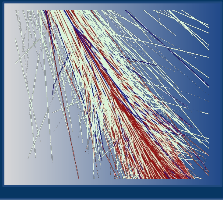


New framework as laboratory to investigate astroparticle physics problems related to secondary particle cascades

- Support future astroparticle physics experiments with solid foundation for simulations and research
- Further improve quality of simulations, and hadronic event generators, reduce and assess modeling uncertainties
- Research of air shower physics, i.e. muon production in air showers, etc.
    - Not enough muons in simulations
    - Spectrum of muons too soft in simulations
    - Closely linked to hadronic shower core



License: GPLv3

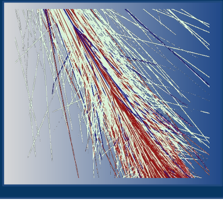


This is open source and all users are required to provide back their own fixes and improvements into the main development.

Thus, the main project and the complete community can benefit from all progress for a globally best result.

KIT is able and ready to defend license if needed.

Overview of CORSIKA 8 developments

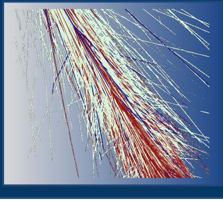


- First general workshop, layout of general plans, goal to involve the related physics community in development and research, setup of infrastructure: **25./26. June 2018**

- Start definition and formation of project as body of collaborating scientists, corsika-devel@lists.kit.edu
- Release of basic software framework definition on gitlab.ikp.kit.edu: **7. October 2018**
- 1st CORSIKA 8 Focus Week: **10. - 14. December 2019**
- Publication of white paper: https://doi.org/10.1007/s41781-018-0013-0 **18. December 2018**
- Release of first demonstration of shower simulation: **29. December 2018**
- 2nd CORSIKA 8 Focus Week: **18. - 22. February 2019**
- CORSIKA Air shower simulation workshop Karlsruhe: **17. - 20. June 2019**

Next release imminent: “physics demonstrator (hadron core) / ICRC2019”

CORSIKA 8 Project, current status



see file: SCIENTIFIC_AUTHORS

People:

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Hans Dembinski (3)
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Tim Huege (4,5)
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Darko Veberic (4)

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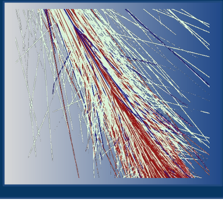
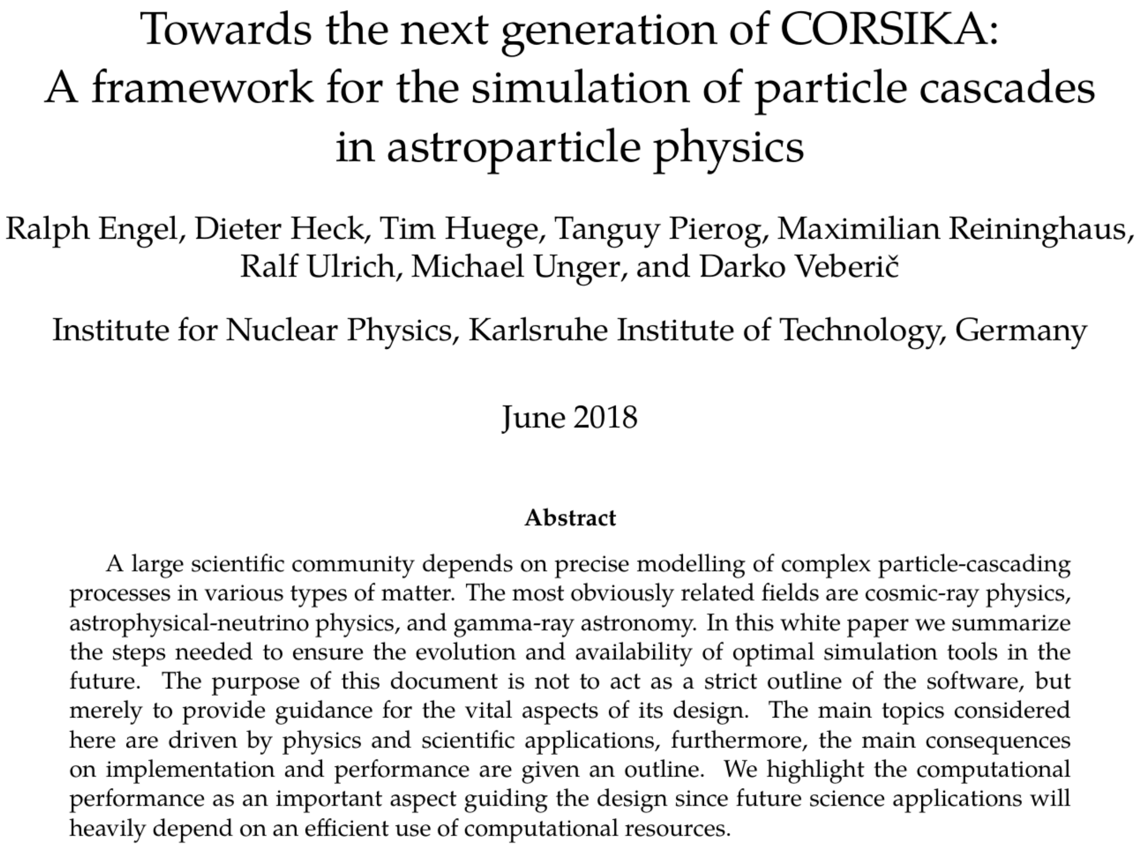
(1) University of Montpellier, France
(2) TU Dortmund University, Germany
(3) Max Planck Institute for Nuclear Physics, Heidelberg
(4) Karlsruhe Institute of Technology (KIT), Germany
(5) Vrije Universiteit Brussel, Belgium
(6) National Autonomous University of Mexico (UNAM)
(7) Laboratory of Instrumentation and Experimental Particles (LIP), Portugal

Several more colleagues have started to contribute
→ list will continue to increase. Don’t hesitate to get in contact.

Initial outline of the project





Towards the next generation of CORSIKA: A framework for the simulation of particle cascades in astroparticle physics

Ralph Engel, Dieter Heck, Tim Huege, Tanguy Pierog, Maximilian Reininghaus, Ralf Ulrich, Michael Unger, and Darko Veberič

Institute for Nuclear Physics, Karlsruhe Institute of Technology, Germany

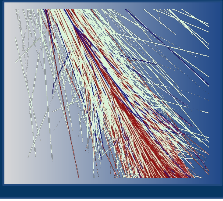
June 2018

Abstract

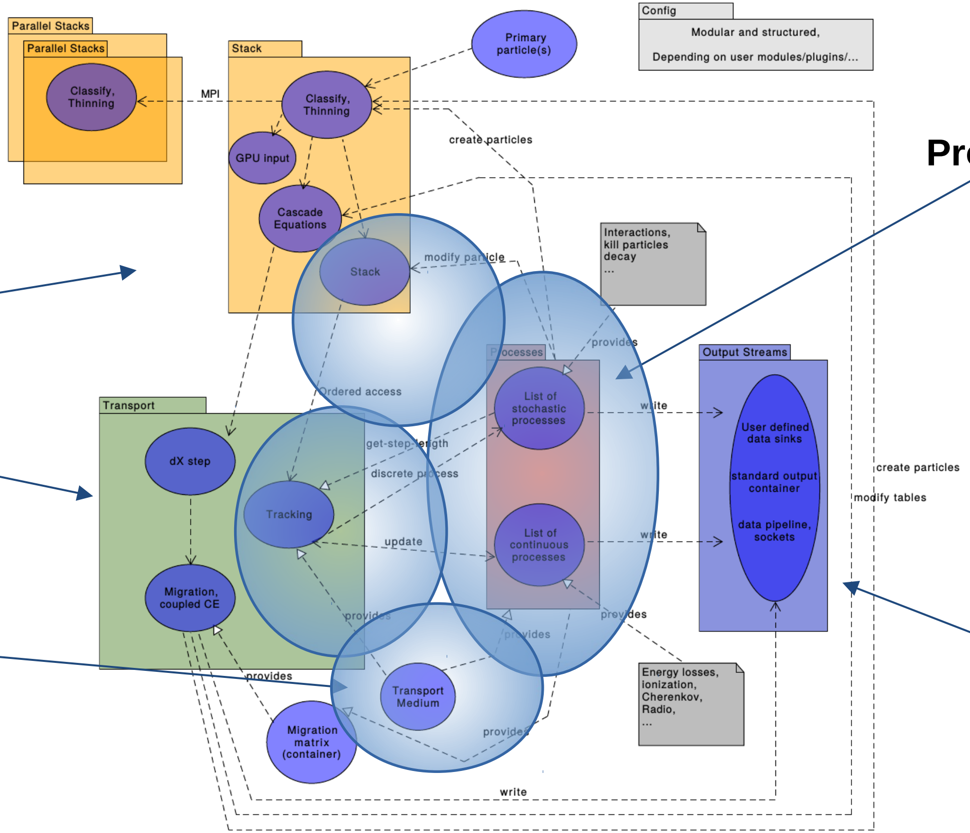
A large scientific community depends on precise modelling of complex particle-cascading processes in various types of matter. The most obviously related fields are cosmic-ray physics, astrophysical-neutrino physics, and gamma-ray astronomy. In this white paper we summarize the steps needed to ensure the evolution and availability of optimal simulation tools in the future. The purpose of this document is not to act as a strict outline of the software, but merely to provide guidance for the vital aspects of its design. The main topics considered here are driven by physics and scientific applications, furthermore, the main consequences on implementation and performance are given an outline. We highlight the computational performance as an important aspect guiding the design since future science applications will heavily depend on an efficient use of computational resources.

Comput. Softw. Big Sci. 3 (2019) 1

Proposed program flow



○ → exists now



Stack

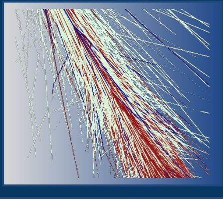
Tracking and stepping

Environment

Processes

Output

Some notes on the stack



The stack is where particle data is stored.

We need no particle object class, just a reference on the stack.

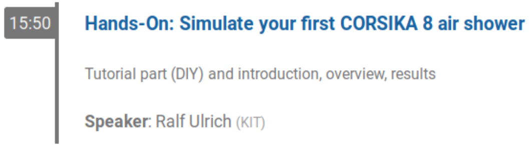
Stack can be anything internally (fortran, std::vector, std::map, file, combination of everything), only the interface must be well defined.

For physicist and users this must look like:

Plan 2018

```
for (auto particle : stack) {
   particle.GetEnergy(showerFrame);
   ...
}
```

Actual Code 06/2019

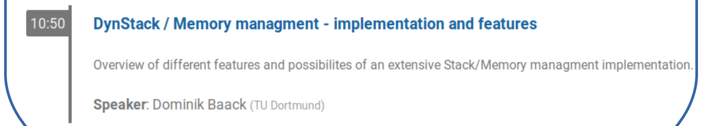


15:50 **Hands-On: Simulate your first CORSIKA 8 air shower**

Tutorial part (DIY) and introduction, overview, results

Speaker: Ralf Ulrich (KIT)

See also, Thursday

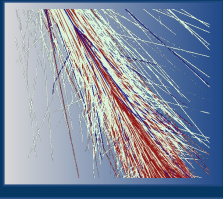


10:50 **DynStack / Memory managment - implementation and features**

Overview of different features and possibilites of an extensive Stack/Memory managment implementation.

Speaker: Dominik Baack (TU Dortmund)

The main program loop

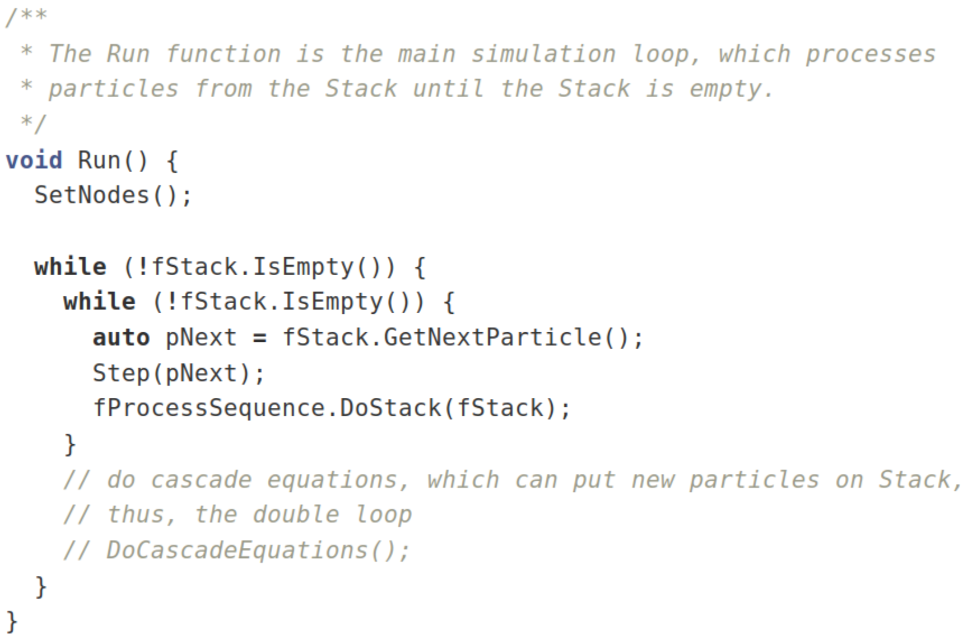


Task: empty the stack → then finished

Plan 2018

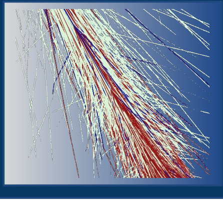
```
stack.add(primaryParticle);
while (!stack.Empty()) {
  while (!stack.Empty()) {
    auto particle = stack.Get();
    Step(particle);
  }
  cascadeEquations.Solve();
}
```

Actual Code 06/2019



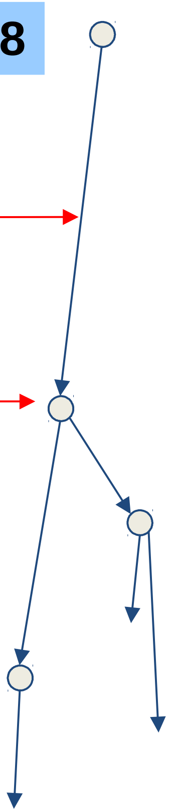
```
/**
 * The Run function is the main simulation loop, which processes
 * particles from the Stack until the Stack is empty.
 */
void Run() {
  SetNodes();

  while (!fStack.IsEmpty()) {
    while (!fStack.IsEmpty()) {
      auto pNext = fStack.GetNextParticle();
      Step(pNext);
      fProcessSequence.DoStack(fStack);
    }
    // do cascade equations, which can put new particles on Stack,
    // thus, the double loop
    // DoCascadeEquations();
  }
}
```

Tracking through medium, and processes



Plan 2018

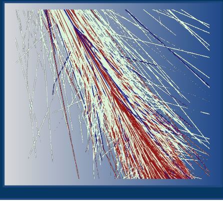
- Continuous processes occur on a scale much below the transport step-length, e.g. ionization, multiple scattering, radio emission, Cherenkov production, and thus an effective treatment can be used.
- Discrete processes typically lead to the disappearance of a particle and to production of new particles (typically for, but not limited to, collisions or decays).



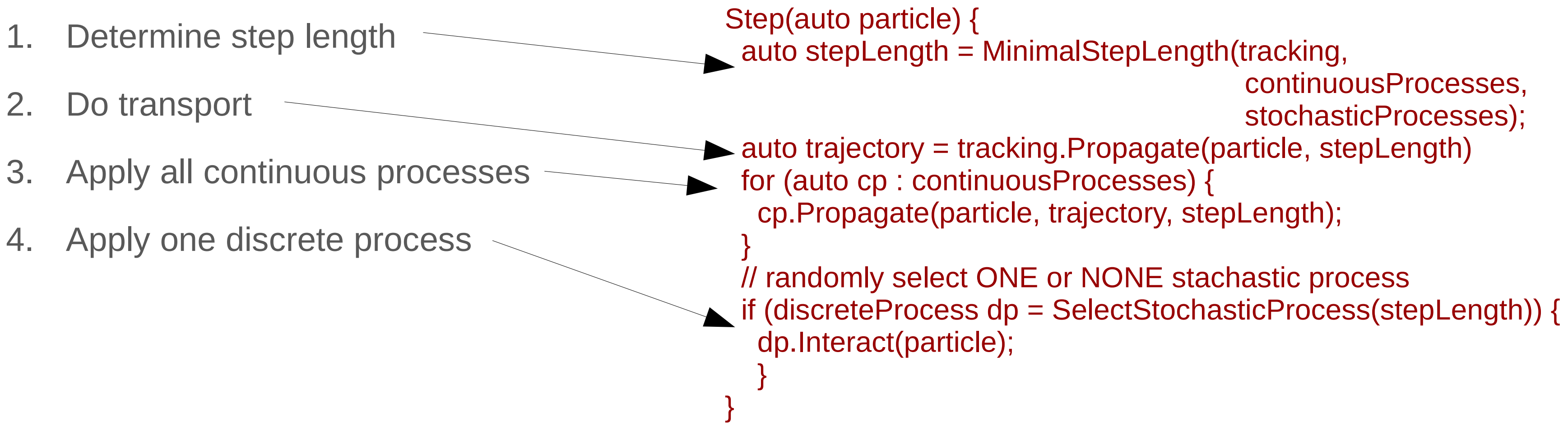
Actual Code 06/2019

- DiscreteProcess → DecayProcess, InteractionProcess
- ContinuousProcess
- SecondariesProcess
- StackProcess

One simulation step



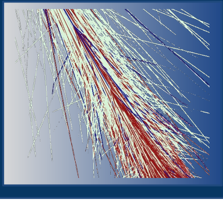
Plan 2018



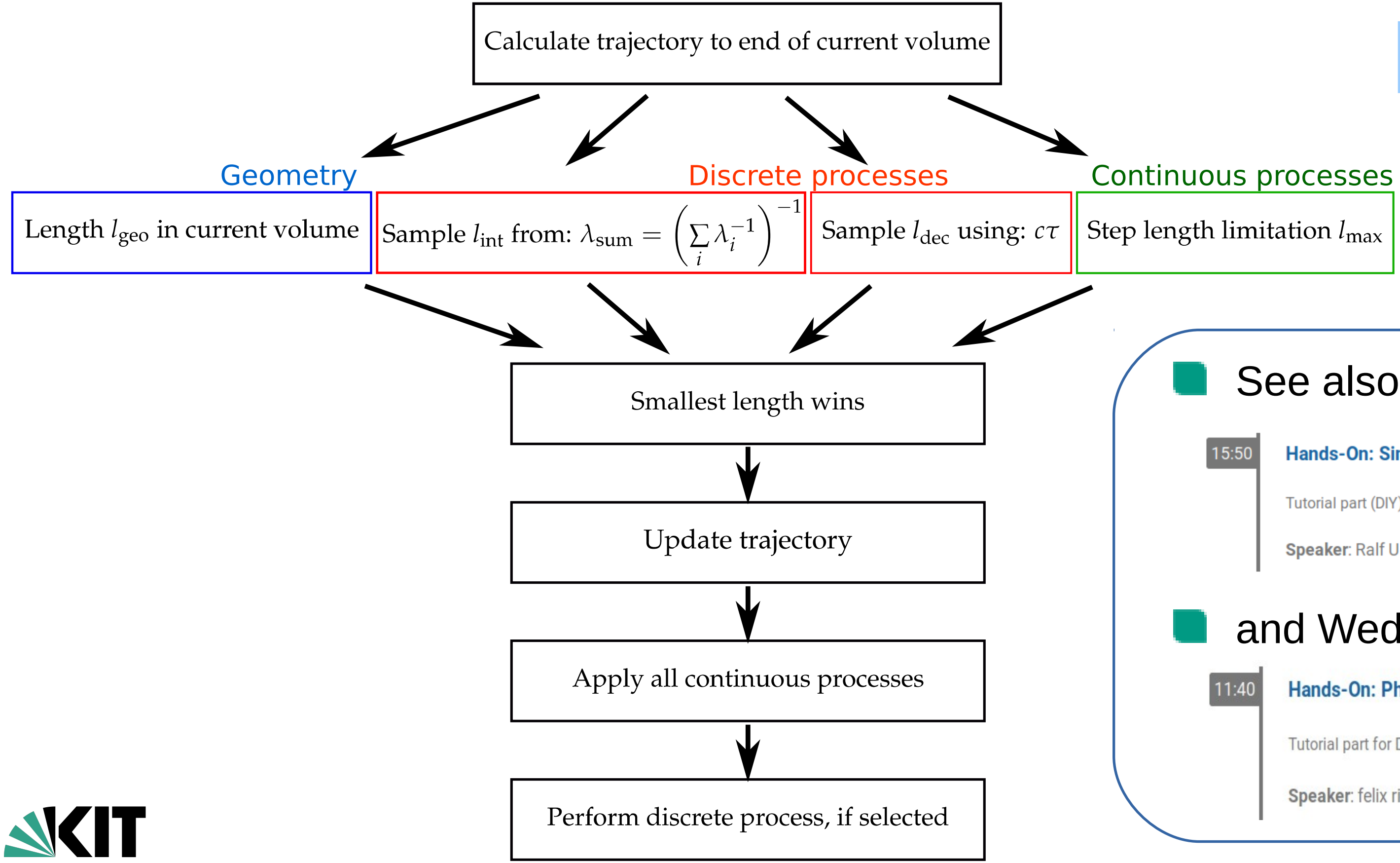
1. Determine step length
2. Do transport
3. Apply all continuous processes
4. Apply one discrete process

```
Step(auto particle) {
  auto stepLength = MinimalStepLength(tracking,
                                      continuousProcesses,
                                      stochasticProcesses);
  auto trajectory = tracking.Propagate(particle, stepLength)
  for (auto cp : continuousProcesses) {
    cp.Propagate(particle, trajectory, stepLength);
  }
  // randomly select ONE or NONE stachastic process
  if (discreteProcess dp = SelectStochasticProcess(stepLength)) {
    dp.Interact(particle);
    }
}
```

The simulation step



Version 06/2019



Calculate trajectory to end of current volume

Geometry

Discrete processes

Continuous processes

Length l_{geo} in current volume

Sample l_{int} from: $\lambda_{\text{sum}} = \left(\sum_i \lambda_i^{-1}\right)^{-1}$

Sample l_{dec} using: $c\tau$

Step length limitation $l_{\max}$

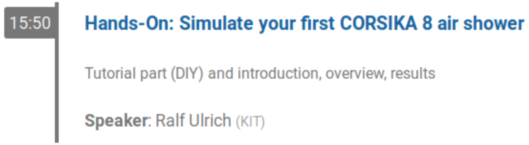
Smallest length wins

Update trajectory

Apply all continuous processes

Perform discrete process, if selected

- See also later today:



15:50 **Hands-On: Simulate your first CORSIKA 8 air shower**

Tutorial part (DIY) and introduction, overview, results

Speaker: Ralf Ulrich (KIT)

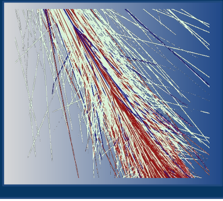
- and Wednesday:

11:40 **Hands-On: Physics processes** 50m

Tutorial part for DIY, introduction and concepts

Speaker: felix riehn (LIP, Lisbon)

Atmosphere → Environment

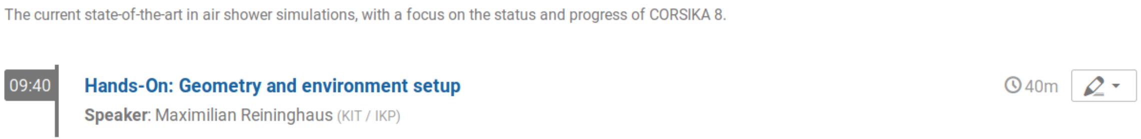


We need to supply a lot more information on the environment compared to before. The environment must be a plug-and-play object, where functionality can be provided for whatever is needed for the scientific application. The interface could include that, but this is not exclusive:

Plan 2018

Environment::GetVolumeId(point)
Environment::GetVolumeBoundary(trajectory)
Environment::GetTargetParticle(point)
Environment::GetDensity(point)
Environment::GetIntegratedDensity(trajectory)
Environment::GetRefractiveIndex(point)
Environment::GetTemperature(point)
Environment::GetHumidity(point)
Environment::GetMagneticField(point)
Environment::GetElectricField(point)

Status today, see Thursday:

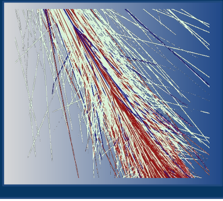


The current state-of-the-art in air shower simulations, with a focus on the status and progress of CORSIKA 8.

09:40 **Hands-On: Geometry and environment setup**
Speaker: Maximilian Reininghaus (KIT / IKP)

40m

Programming considerations



Physicists should never be forced to know in what values of parameters in a specific “reference frame”, they work with variables explicitly in the correct frame:

- Coordinate systems
- Lorentz transformation
- Particle IDs
- Physical units

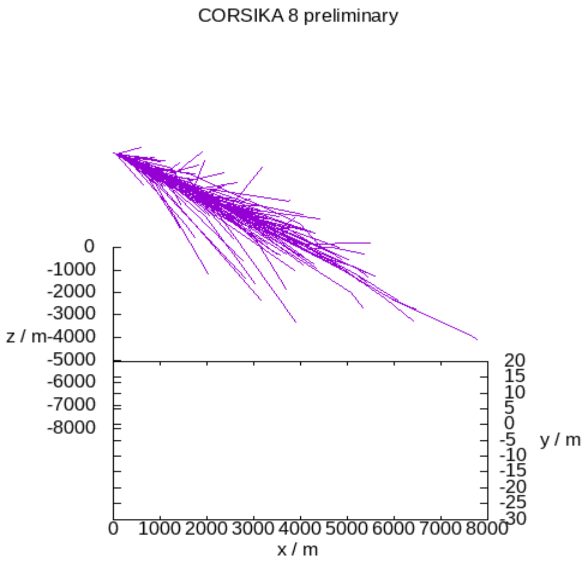
Plan 2018

Actual Code 06/2019

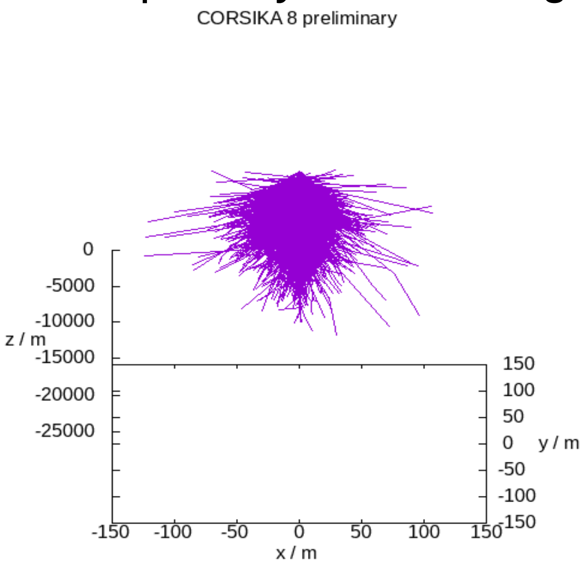
Some considerations are not yet final, but the general ideas are at work and do exactly what they were designed for.

First impressions, January 2019

Proton primary, 100TeV, 45deg

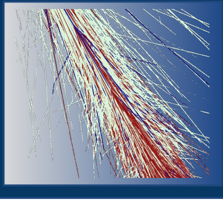


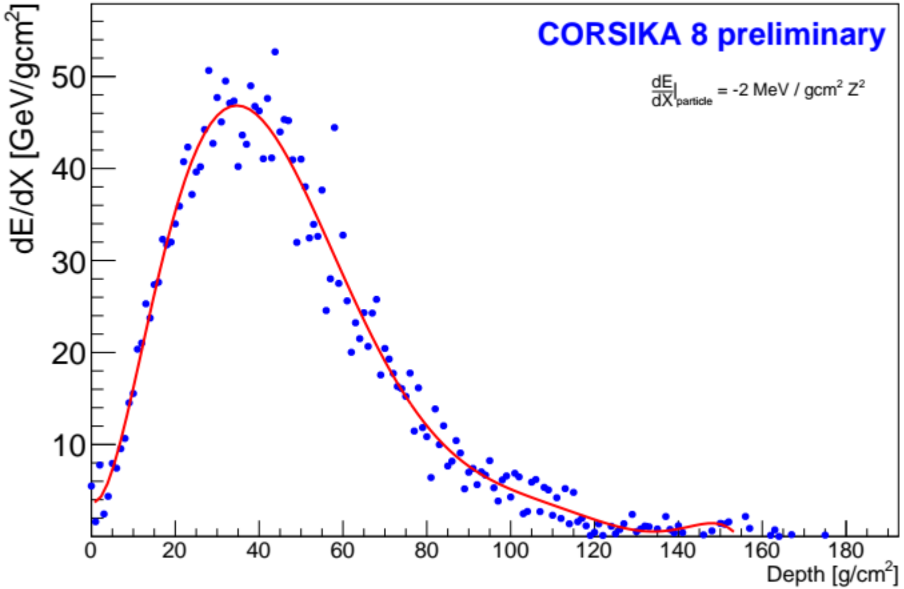
Iron primary, 1PeV, 0deg



```
…
auto sequence = sibyll << sibyllNuc << decay << cut << trackWriter;
cascade::Cascade EAS(environment, tracking, sequence, stack);
EAS.Init();
EAS.Run();
```

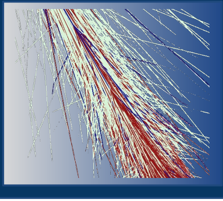
First ~longitudinal profile, February 2019





```
…
auto sequence = sibyll << sibyllNuc << decay << EnergyLoss(2_MeV/1_g*square(1_cm)) << cut;
cascade::Cascade EAS(env, tracking, sequence, stack);
EAS.Init();
EAS.Run();
```

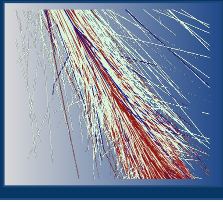
Main challenges ahead



- Continue to build a worldwide collaboration around CORSIKA 8
  - Plan next technical journal articles, think about first physics articles
- Run-time configuration infrastructure
- Particle data output interface and definition
- Logging, also for parallel runs etc.
- Full physics implementation: hadrons plus nu/mu/e/gamma etc.
- Physics validation
- Seamless integration of cascade equations
- Profiling, optimization, vectorization and multi-threading solutions where useful
- Radio, Cherenkov
- Documentation

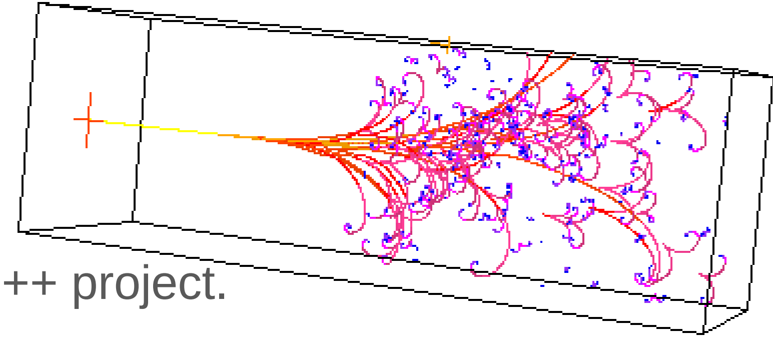
…. and many more

Electron gamma cascades



The electron gamma cascade is a very important part of the shower

- We assume we can model it accurately
- It needs most of the computation resources
- It is directly responsible for most: Cherenkov, Radio emission

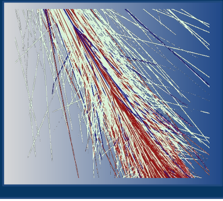


Currently:
customized EGS4 code, there is special physics in CORSIKA that is missing in essentially all other similar projects, e.g. LPM effect.
However, basically impossible to port into a new C++ project.

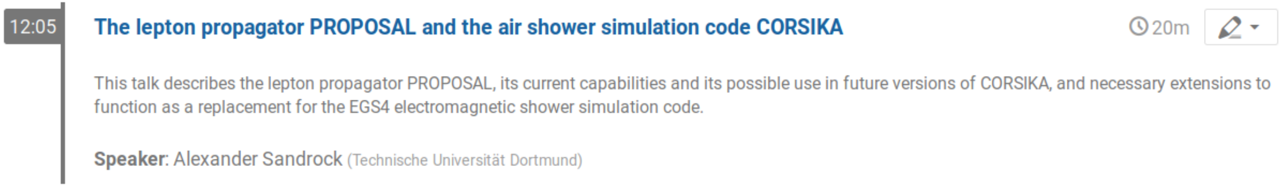
→ We need new C++ version of modern EG cascades

plus smart solutions for speedup: CE, GANs, parameterizations, GPU, ...

Stay tuned



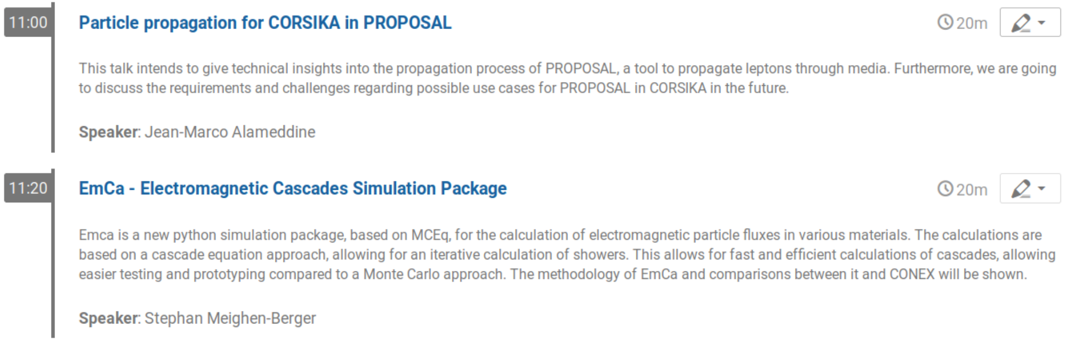
Monday



12:05 **The lepton propagator PROPOSAL and the air shower simulation code CORSIKA** 20m

This talk describes the lepton propagator PROPOSAL, its current capabilities and its possible use in future versions of CORSIKA, and necessary extensions to function as a replacement for the EGS4 electromagnetic shower simulation code.

Speaker: Alexander Sandrock (Technische Universität Dortmund)



11:00 **Particle propagation for CORSIKA in PROPOSAL** 20m

This talk intends to give technical insights into the propagation process of PROPOSAL, a tool to propagate leptons through media. Furthermore, we are going to discuss the requirements and challenges regarding possible use cases for PROPOSAL in CORSIKA in the future.

Speaker: Jean-Marco Alameddine

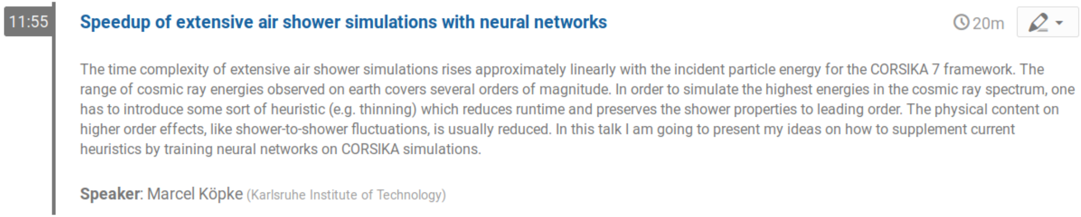
11:20 **EmCa - Electromagnetic Cascades Simulation Package** 20m

Emca is a new python simulation package, based on MCEq, for the calculation of electromagnetic particle fluxes in various materials. The calculations are based on a cascade equation approach, allowing for an iterative calculation of showers. This allows for fast and efficient calculations of cascades, allowing easier testing and prototyping compared to a Monte Carlo approach. The methodology of EmCa and comparisons between it and CONEX will be shown.

Speaker: Stephan Meighen-Berger

Wednesday

Thursday

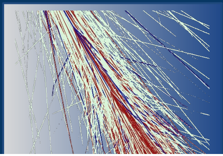


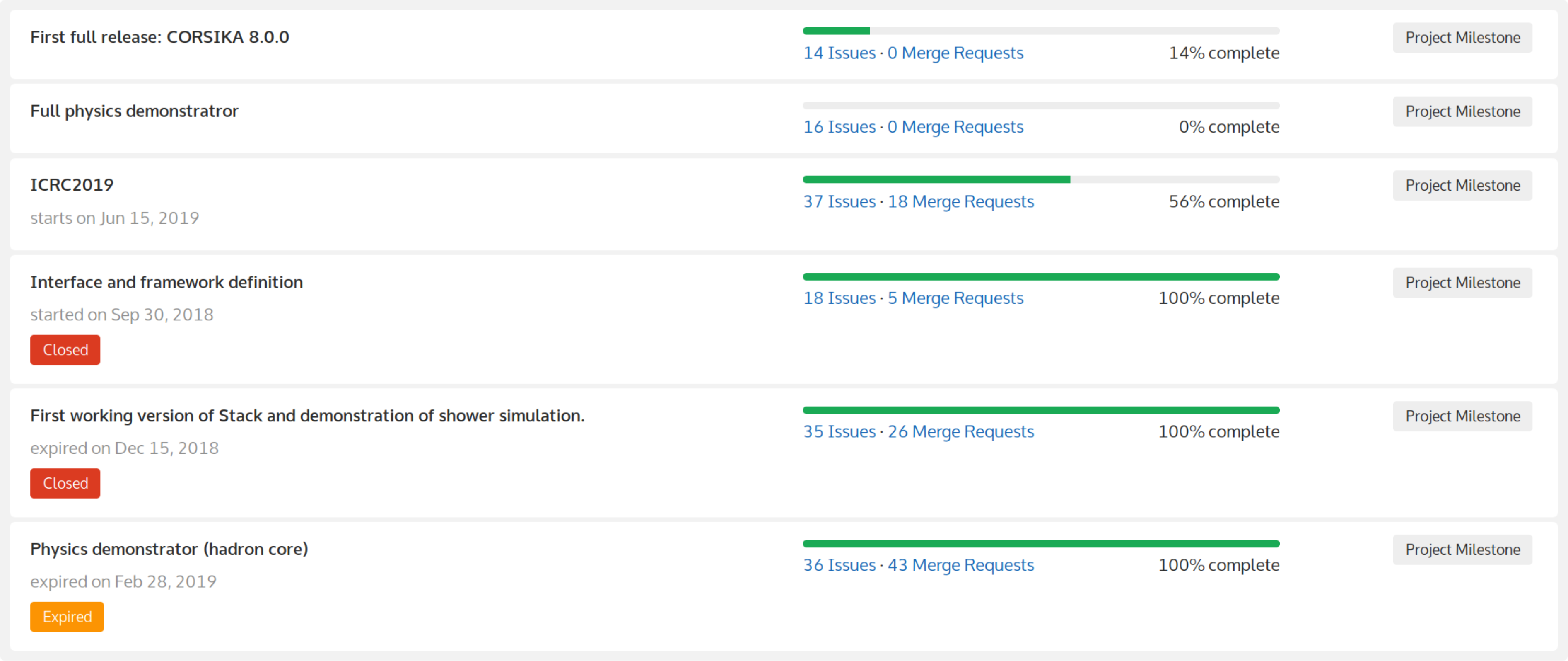
11:55 **Speedup of extensive air shower simulations with neural networks** 20m

The time complexity of extensive air shower simulations rises approximately linearly with the incident particle energy for the CORSIKA 7 framework. The range of cosmic ray energies observed on earth covers several orders of magnitude. In order to simulate the highest energies in the cosmic ray spectrum, one has to introduce some sort of heuristic (e.g. thinning) which reduces runtime and preserves the shower properties to leading order. The physical content on higher order effects, like shower-to-shower fluctuations, is usually reduced. In this talk I am going to present my ideas on how to supplement current heuristics by training neural networks on CORSIKA simulations.

Speaker: Marcel Köpke (Karlsruhe Institute of Technology)

Milestones

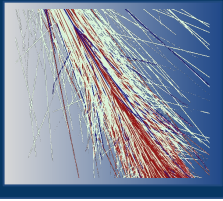




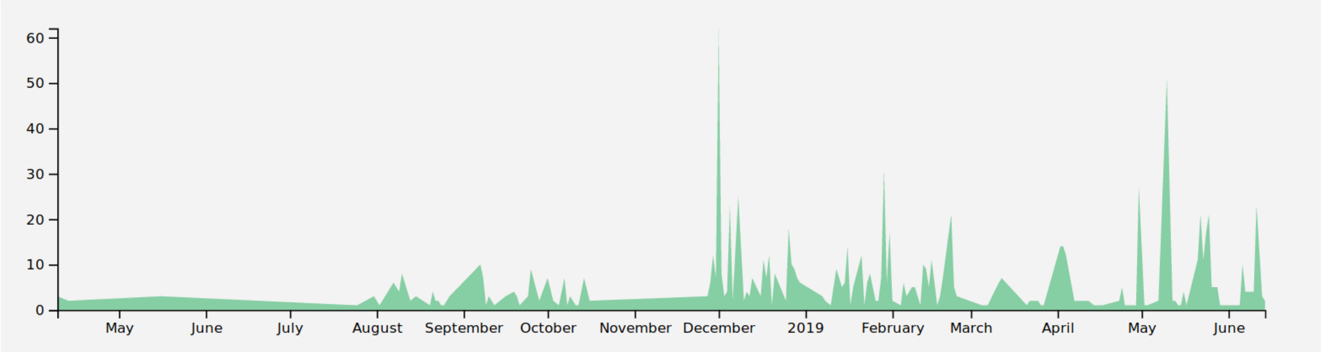
First full release: CORSIKA 8.0.0	14 Issues · 0 Merge Requests	14% complete	Project Milestone
Full physics demonstratror	16 Issues · 0 Merge Requests	0% complete	Project Milestone
ICRC2019 starts on Jun 15, 2019	37 Issues · 18 Merge Requests	56% complete	Project Milestone
Interface and framework definition started on Sep 30, 2018 Closed	18 Issues · 5 Merge Requests	100% complete	Project Milestone
First working version of Stack and demonstration of shower simulation. expired on Dec 15, 2018 Closed	35 Issues · 26 Merge Requests	100% complete	Project Milestone
Physics demonstrator (hadron core) expired on Feb 28, 2019 Expired	36 Issues · 43 Merge Requests	100% complete	Project Milestone

Review milestone planning for 2019/2020 during next two weeks!

Development activity

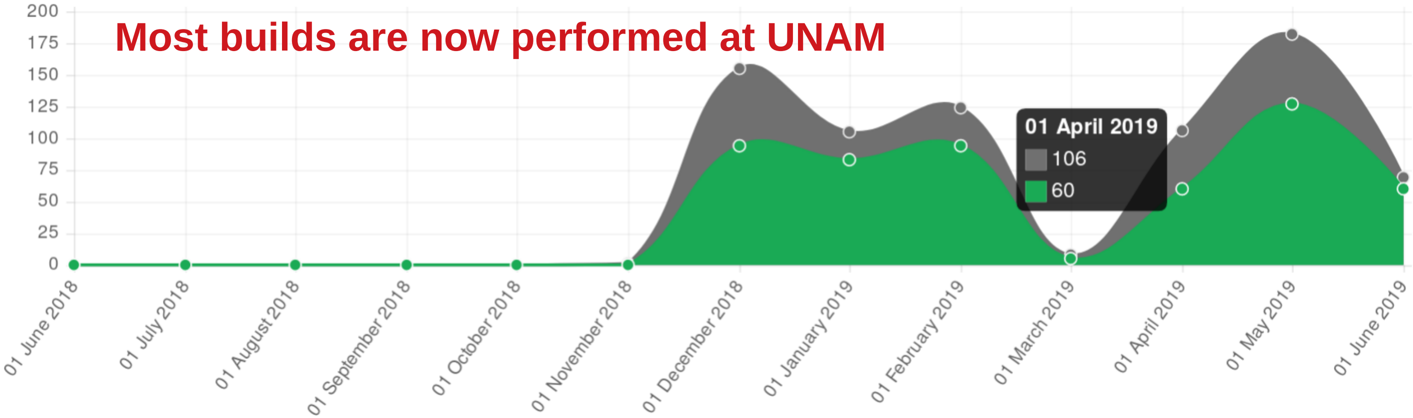


Commits to master, excluding merge commits. Limited to 6,000 commits.



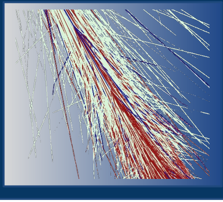
No. of contributions on gitlab.ikp.kit.edu

Automatic builds triggered by changes on gitlab



Most builds are now performed at UNAM

Summary



CORSIKA 8 has started as a new and major collaborative project

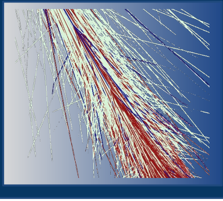
- So far well on track with original planning and ideas
- Basic software framework, and development infrastructure in place
- First hadron/muon physics implemented

There are still many very critical developments and obstacles in the future.

CORSIKA 8 still has to present itself to become the improved replacement of CORSIKA 7 within the next ~12 months

At this workshop a complete picture of the current CORSIKA 8 is presented, the status should be critically reviewed and steered into the optimal direction.

Final remark



CORSIKA –

COsmic Ray Simulations for Kascade

will become

CORSICA

COsmic Ray SImualtions of Cascades