New developments in CORSIKA 8 and EAS genealogy

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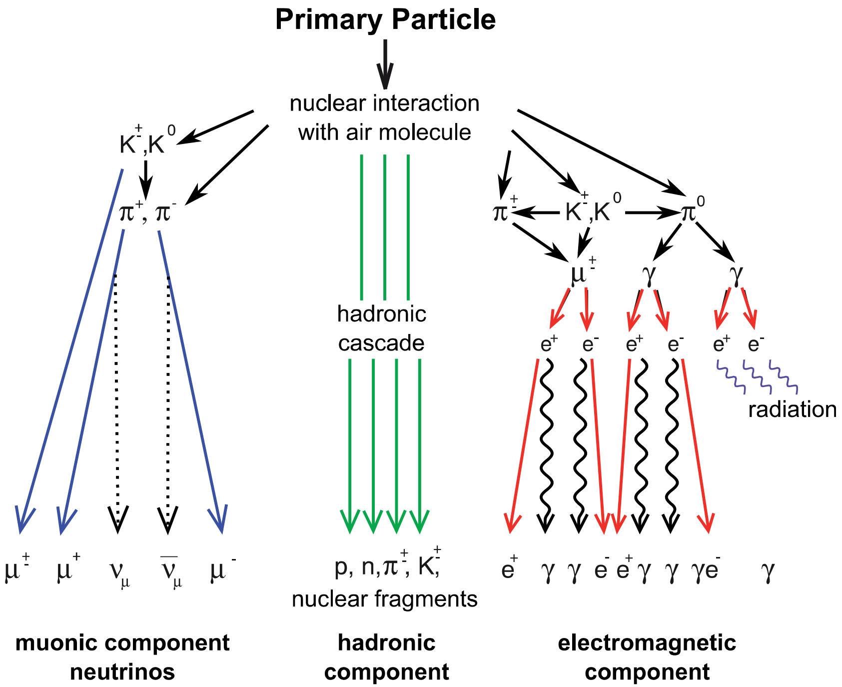
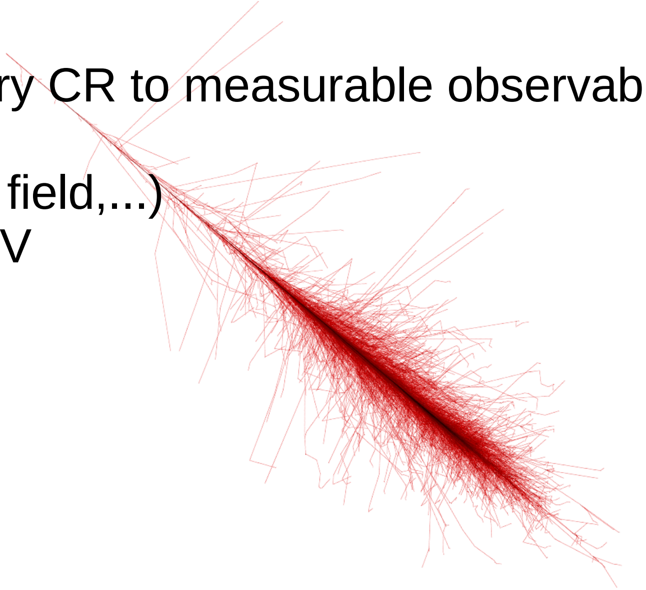
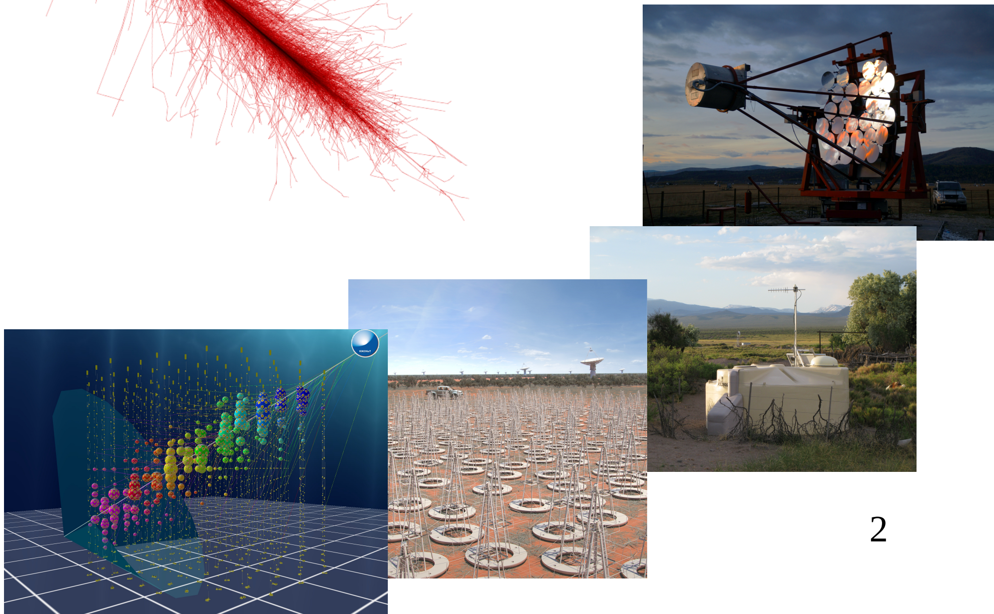
EAS simulations

- key tool in astroparticle physics
- provide quantitative mapping from primary CR to measurable observables
- rely on accurate modeling of
  - environment (air density, geomagnetic field,...)
  - particle physics from ~100 TeV to ~MeV

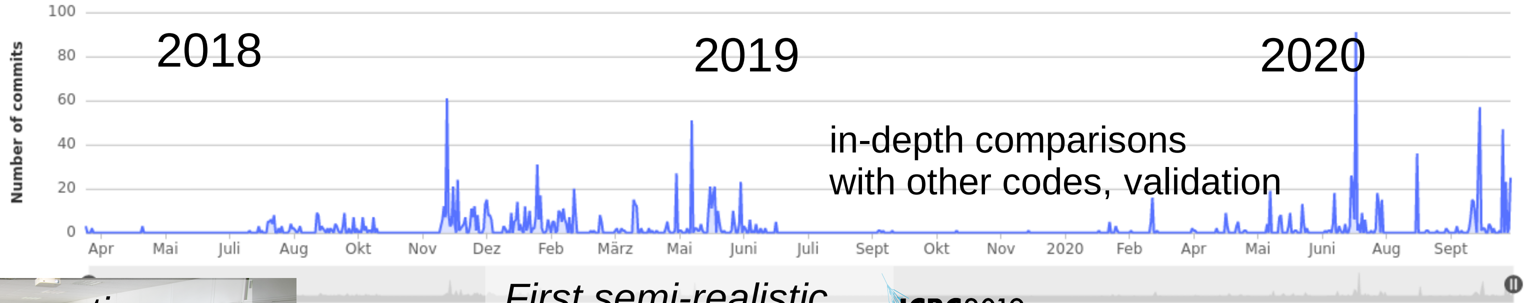






CORSIKA 8

- overcome limitations of existing codes
- combined efforts of specialists as international collaboration



2018

2019

2020

in-depth comparisons
with other codes, validation

Next Generation CORSIKA Workshop

Computing and Software for Big Science (2019) 3:2
https://doi.org/10.1007/s41781-018-0013-0

ORIGINAL ARTICLE

Towards A Next Generation of CORSIKA: A Framework for the Simulation of Particle Cascades in Astroparticle Physics

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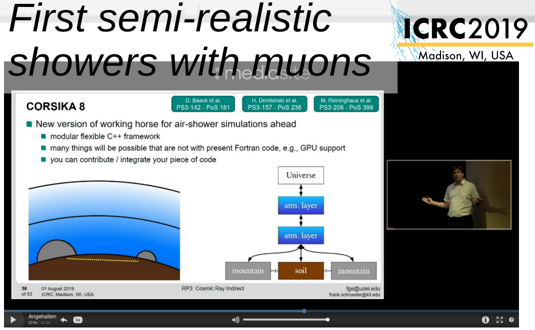
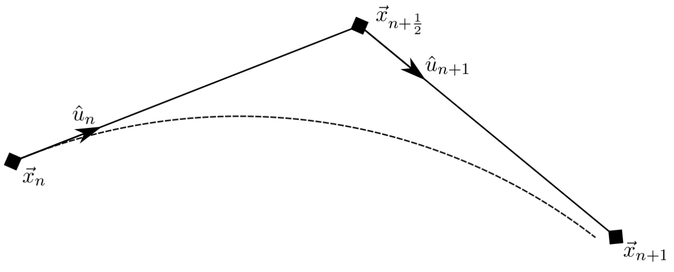
First semi-realistic showers with muons



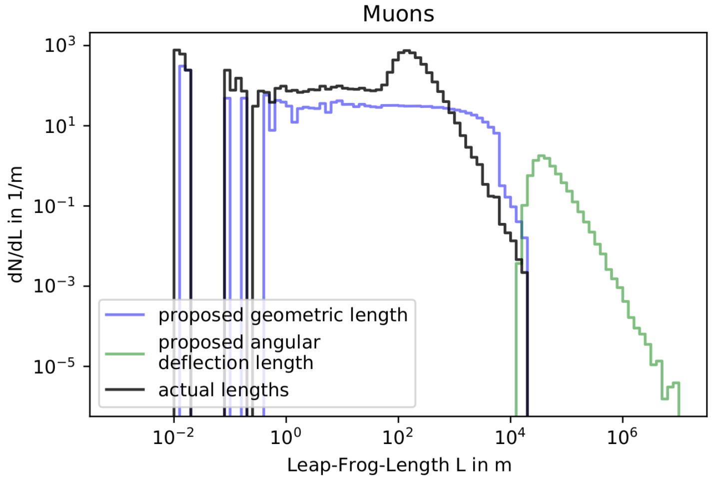
- CONEX e.m. CE
- PROPOSAL for e.m.
- **magnetic fields**
- **full shower history**

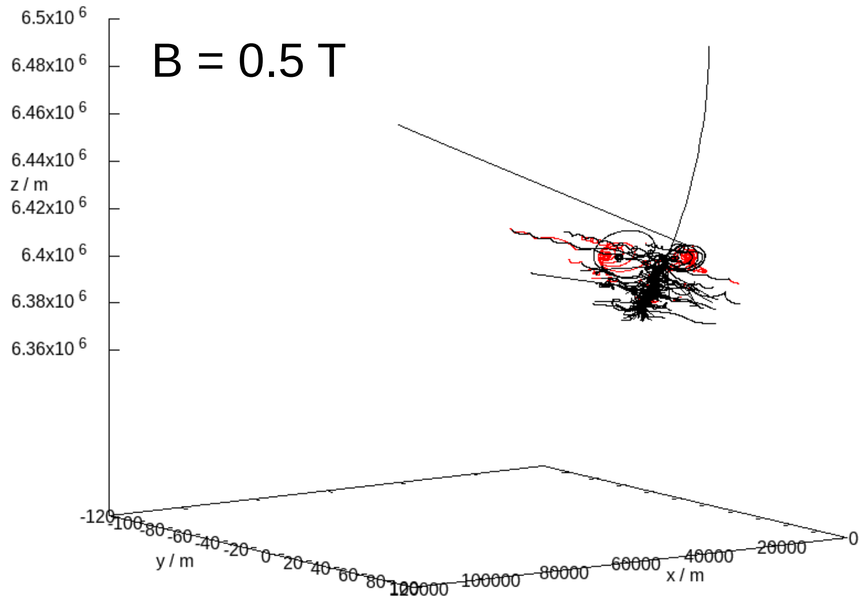
Magnetic fields

- B.Sc. thesis project of André Schmidt
- leapfrog algorithm inspired by AIRES



- step-length limitation to avoid large curvature per step
- almost no impact on actual step-length *(under certain simulation conditions)*

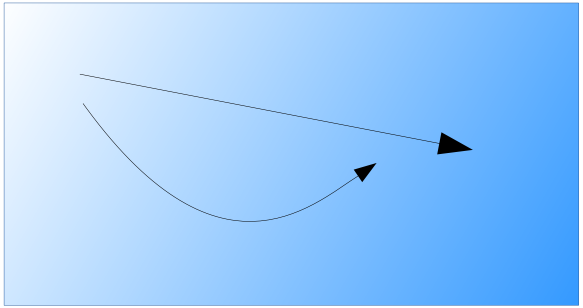




Interlude: new sampling algorithm

grammage integration

$$X(l) = \int_0^l \rho(x) \mathrm{d}x$$



- already impossible analytically for curved atmosphere
- what if path is curved?

distribution of interaction points

$$p(X) = \frac{1}{\lambda} \exp(-X/\lambda)$$ only if λ = const.

in general: *survival function* fulfills

$$\frac{\mathrm{d}P_{\mathrm{int}}}{\mathrm{d}t} = -\alpha(t) P_{\mathrm{int}}(t)$$

how can we sample from $p(t) = -\frac{\mathrm{d}P_{int}}{\mathrm{d}t}$?

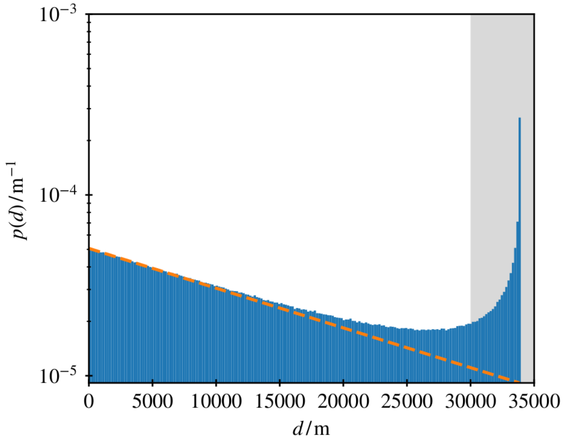
Interlude: new sampling algorithm

use direct sampling with *u* ~ uniform:

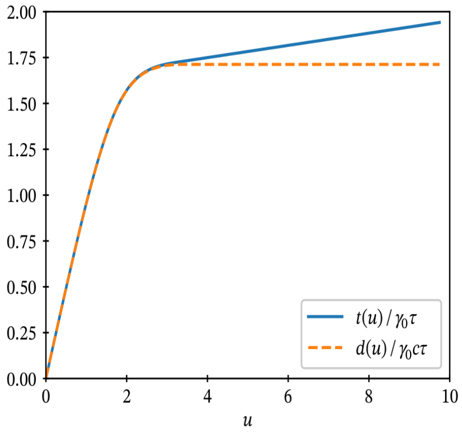
$$\frac{\mathrm{d}t}{\mathrm{d}u} = \frac{1}{\alpha(t(u))P(t(u))} = \frac{1}{\alpha(t(u))(1-u)}$$

solve this ODE numerically together with equations of motions (Lorentz force, energy losses,…) with *u as independent variable*
→ no *X* integration necessary

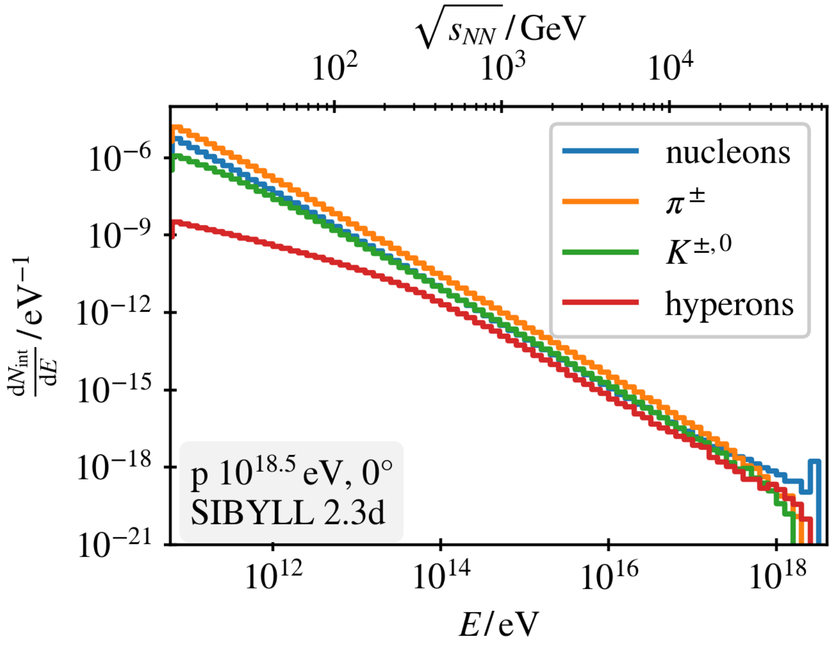
example:
minimum-ionizing muons
in exp. atmosphere



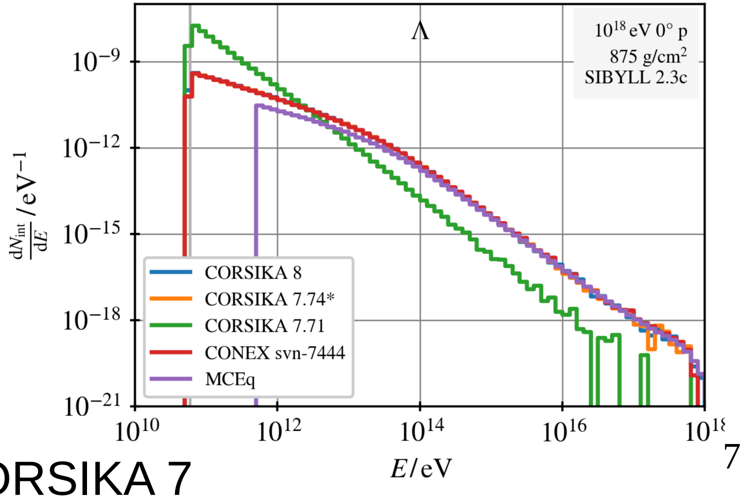
propagation distance



Counting interactions

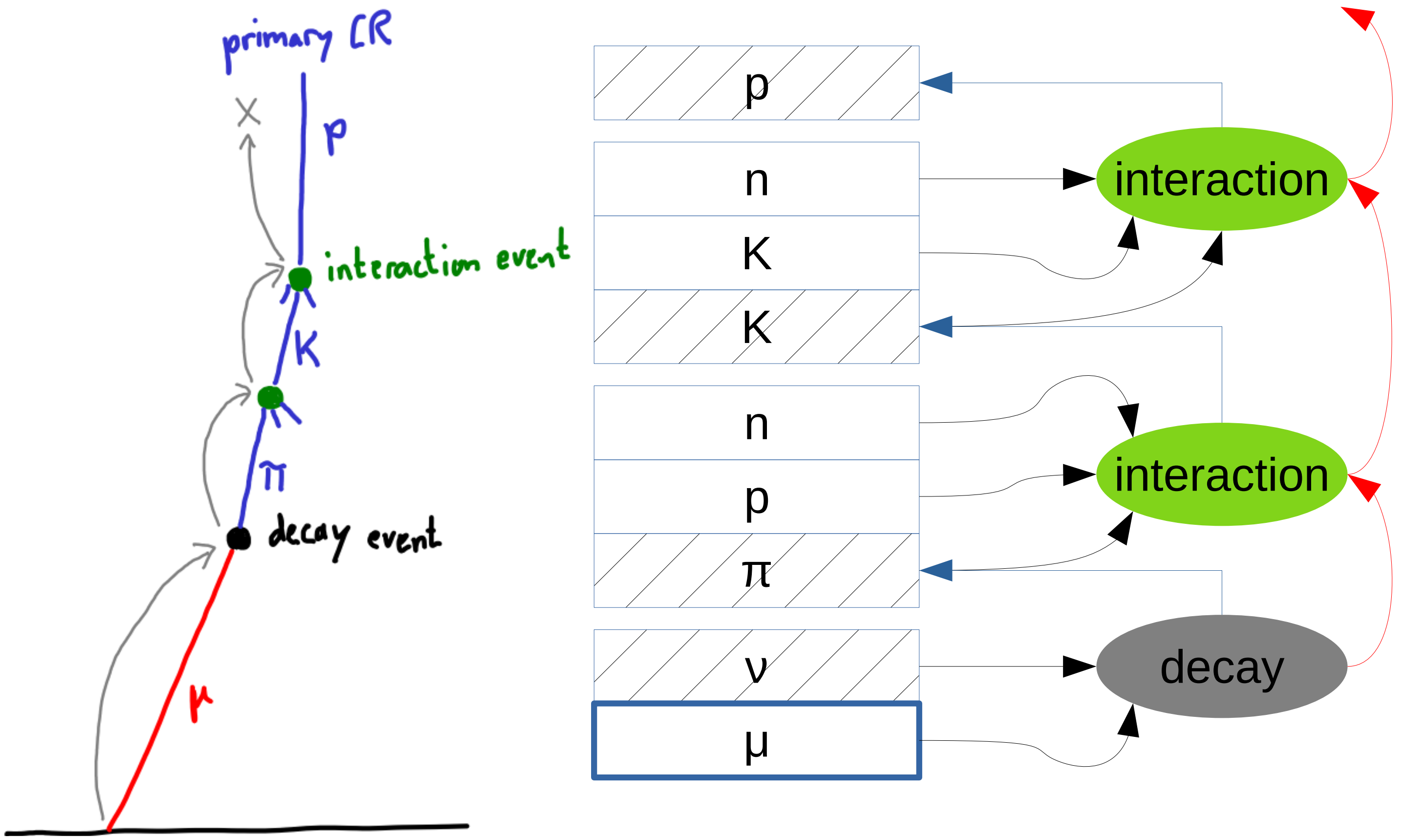


- very close to primary energy dominated by nucleons (→ leading baryon effect)
- pions take over at ~ E_0 / 10
- power law with index α ≈ -2



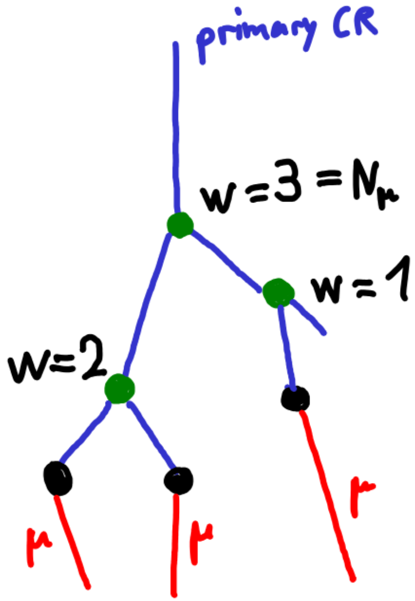
also useful for cross-validation with other codes, revealed bug regarding hyperon decay in CORSIKA 7

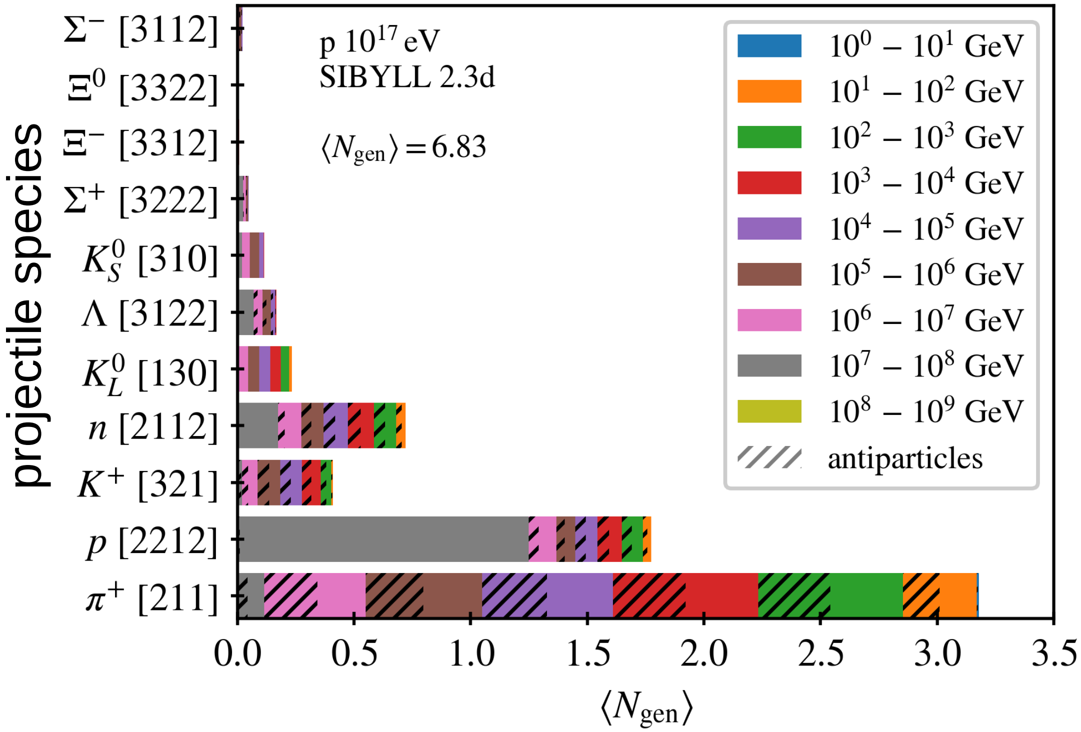
Preserving the shower history



- Last in – first out
- keep “dead” particles in the middle of the stack
- delete “dead” particles at the end of the stack
- store *event* as well, including copy of secondaries at *production state*

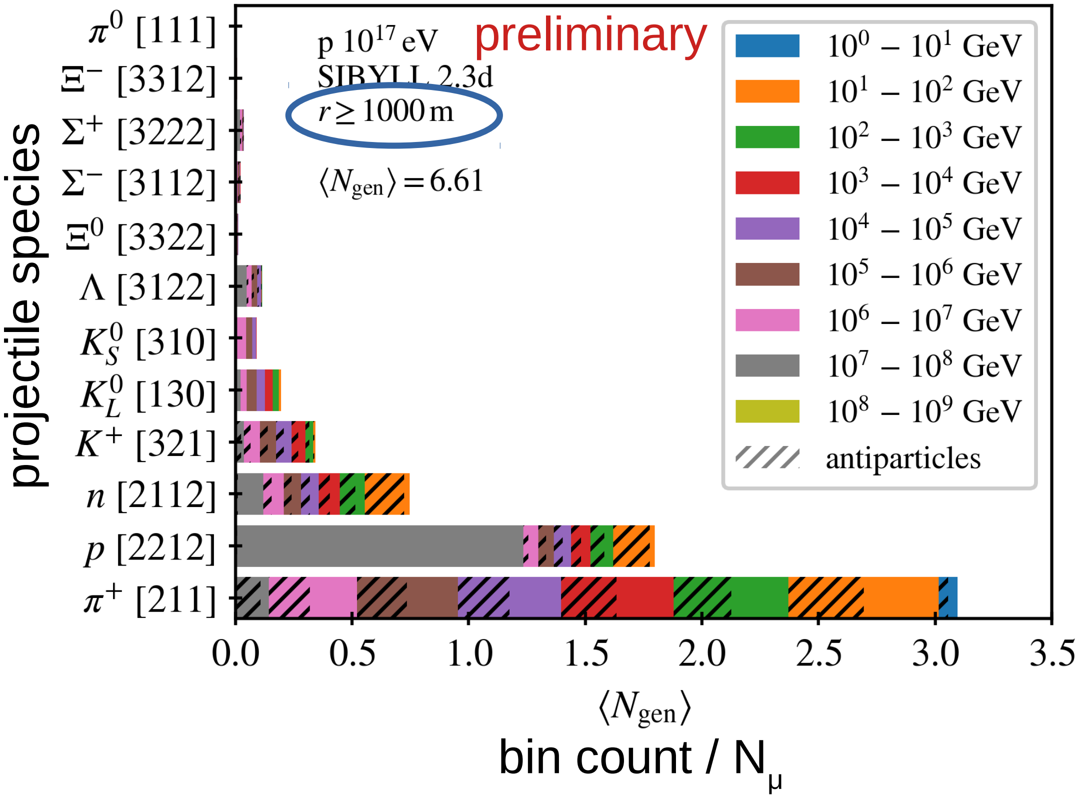
Muon interaction history





bin count / N_μ

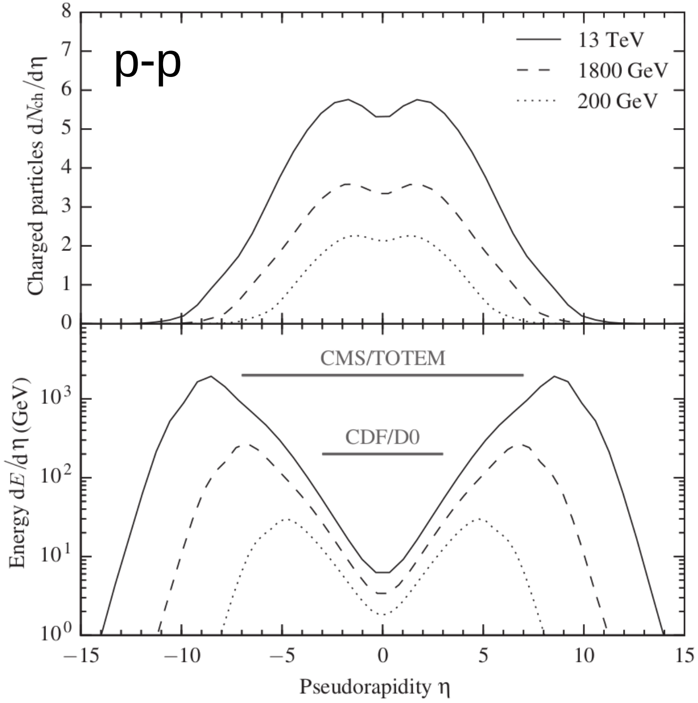
Muon interaction history



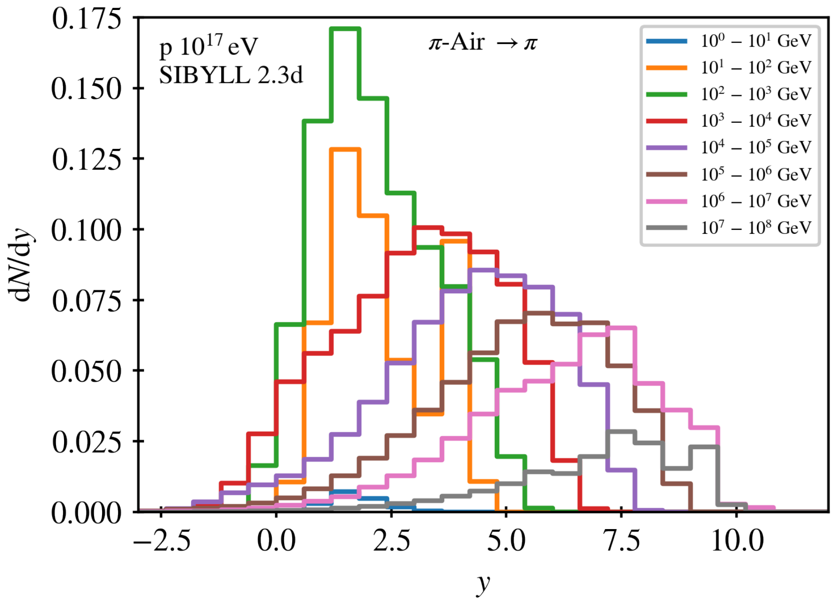
- shift to lower energies for pions
- overabundance of antinucleons?

Rapidity

Which phase space is relevant for muon production?



Gaisser, Engel, Resconi 2016



$$y = \frac{1}{2} \ln \frac{E + p_{\|}}{E - p_{\|}}$$

Summary

- CORSIKA 8 is gaining momentum
- cross-validation of hadronic cascade lead to improvements/bugfixes in several codes
- magnetic fields, e.m. interactions almost complete
- insight into full shower history for the first time
- *ongoing work:* studies of muon production phase space