Magnetic field in CORSIKA8

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- Addition of a freely selectable magnetic field $\vec{B}(\vec{x})$
- Implementation of Lorentz force (with $\hat{u} = \frac{\vec{v}}{|\vec{v}|}$)

$$\vec{F}_L = \frac{d\vec{p}}{dt} = q \cdot (\vec{v}(t) \times \vec{B}(\vec{x})) \tag{1}$$

$$\vec{p} = \int q \cdot (\hat{u} \times \vec{B}(\vec{x}))dx \tag{2}$$

- Particle movement changes

Objectives

Most important issues for the particle propagation:

- Time efficient, simple
- Accuracy of the new particle position $\vec{x}_1$
- Absolute value of the momentum is not changed by Lorentz force $|\vec{p}_0| = |\vec{p}_1|$

Leap Frog Algorithm

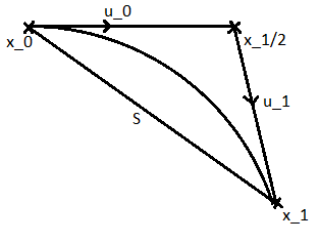


Figure: Schematic sketch of the function of the algorithm

- Direction $\vec{u}$ gets updated after a half step
- The particle moves on the direct path S to the endpoint $\vec{x}_1$

Leap Frog Algorithm

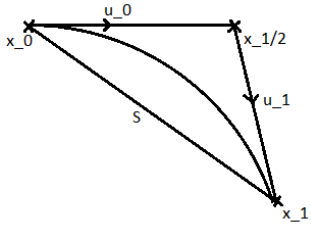


Figure: Schematic sketch of the function of the Algorithm

$$\vec{x}_{\frac{1}{2}} = \vec{x}_0 + \frac{\Delta l}{2}\hat{u}_0 \tag{3}$$

$$\hat{u}_1 = \hat{u}_0 + \Delta l \frac{q}{|\vec{p}|}\left(\hat{u}_0 \times \vec{B}(\vec{x}_{\frac{1}{2}})\right) \tag{4}$$

$$\vec{x}_1 = \vec{x}_{\frac{1}{2}} + \frac{\Delta l}{2}\hat{u}_1 \tag{5}$$

Leap Frog Algorithm

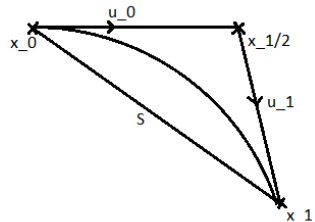


Figure: Schematic sketch of the function of the Algorithm

- $\vec{B}$ is only used on a few points along the way
  $\rightarrow \vec{B}$ shall not change much between those points
- other algorithms are more complicated and not so much more accurate

Steplength Δl

- the steplength is not predetermined
- number of steps is the most important factor for efficiency
- use the largest possible steplength
  $\rightarrow$ the distance to the next event

Events

- possible events are for example:
  interaction, decay, energy loss of 1%, geometric limitation, angular deflection of 0.1 rad
- distance to every event is calculated in every step
- the event with the shortest distance happens

Steplength

Changes of the distance calculation after adding the magnetic field:

- For interactions and decays the calculation stays the same
- Calculations more complex for geometric limitations
  example: boundary of an atmospheric layer
- A limitation is added for angular deflection of 0.1 rad

Steplength - All particles

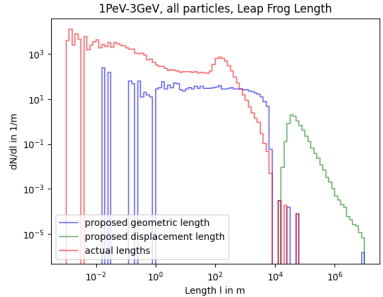
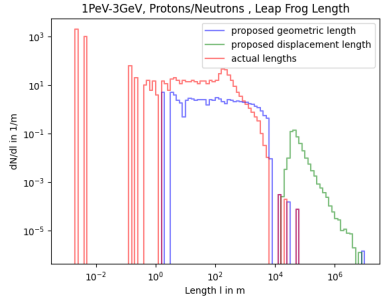


Figure: Comparison of proposed geometric and displacement events to the actual lengths used

red: distance to the next event (shortest distance)
blue: proposed distance to the next atmospheric layer
green: proposed distance after which the particle is deflected by 0.1 rad

Steplength - Protons/Neutrons



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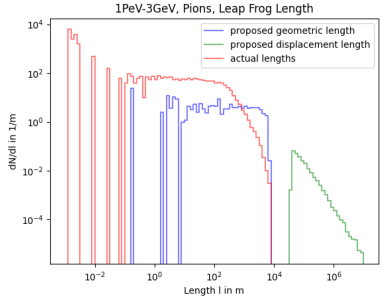
Steplength - Pions



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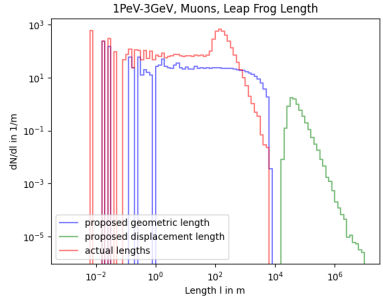
Steplength - Muons



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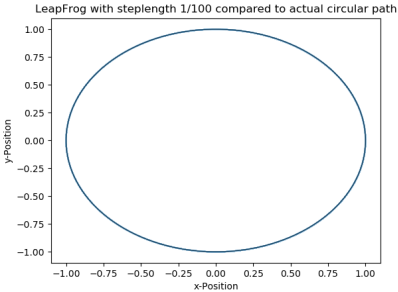
Accuracy

Accuracy test

- initial velocity perpendicular to magnetic field
- homogeneous magnetic field
- circular motion with a gyroradius r_g of 1
- steplength $\Delta l = 0.01$

Accuracy



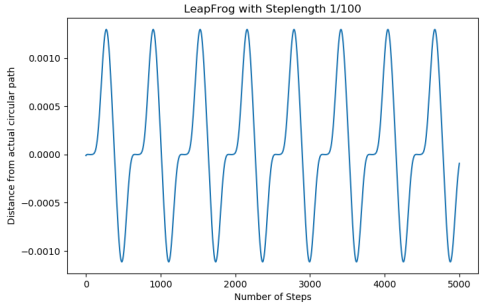


Figure: Accuracy test with a steplength of 0.01

- algorithm is stable
- max. error of 0.13%

Accuracy

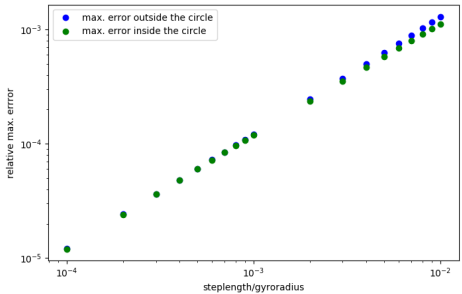


Figure: max. errors of the accuracy test for different steplengths

- error linear dependent on the steplength
- average $\frac{steplength}{gyroradius} \sim 7 \cdot 10^{-4}$

Momentum

- absolute momentum and energy shall be preserved
- momentum increases, because $|\vec{u}_1| > 1$
  $\rightarrow$ particles with superluminal velocity could occur
- trivial solution:

$$\vec{p}_1 = |\vec{p}_0| \cdot \frac{\vec{u}_1}{|\vec{u}_1|} \tag{6}$$

- continuous processes, such as energy loss, are applied afterwards

Steplength - All particles

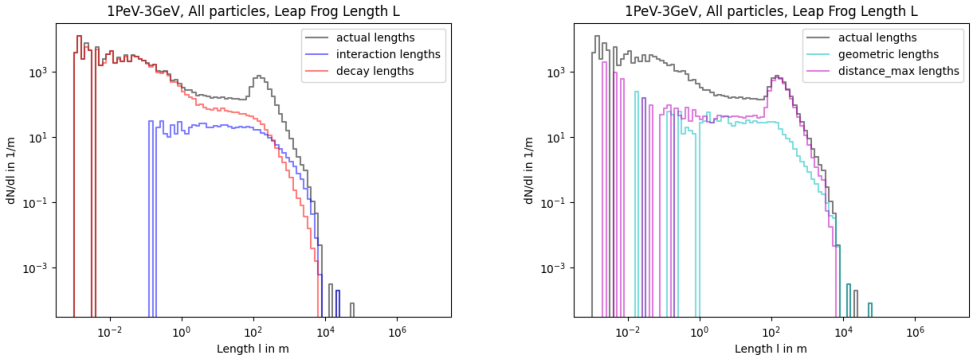
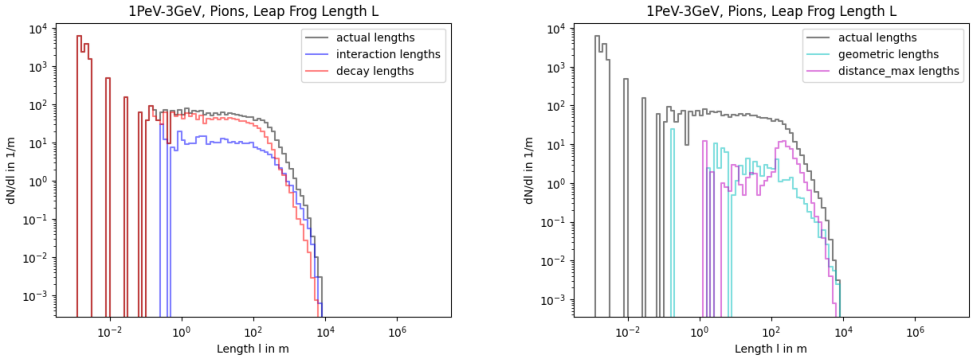


Figure: Event types, that are causing the actual length

distance max: energy loss, observation plane, ...

Steplength - Pions



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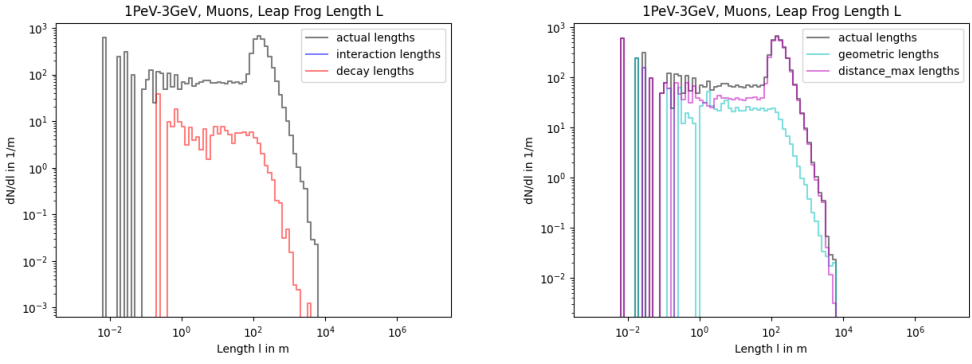
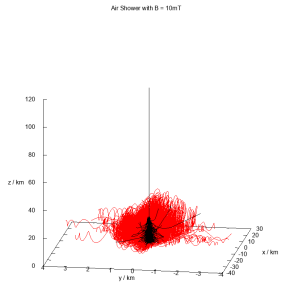


Figure: Event types, that are causing the actual length

distance max: energy loss, observation plane, ...

End

Thanks for listening.
Are there any questions or suggestions?



B = 10 mT
red: muons
black: hadrons

Figure: Air shower with ca. 200 times the earth magnetic field in y-direction