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Improvements in the high-energy lepton propagator PROPOSAL

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E5b

Introduction

- **PROPOSAL**: Tool to propagate charged leptons
  → MC simulations, multivariate statistics
- **Requirements:** Accuracy, performance
- **Processes:** Energy losses, scattering, decays
- Possibility to use **different parametrizations** → Study **systematic uncertainties**
- C++ library with Python bindings

Propagation

$$\frac{\mathrm{d}\sigma}{\mathrm{d}v} \quad \overbrace{\longrightarrow}^{?} \quad \text{energy losses}$$

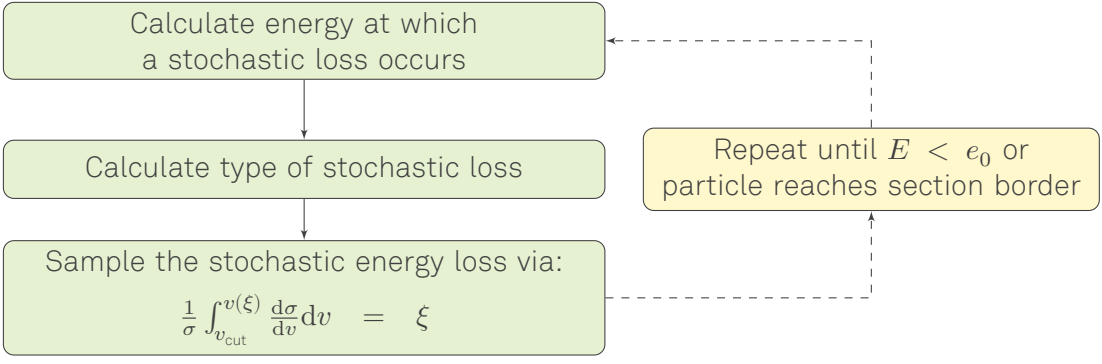
Propagation

$v < v_{\text{cut}}$ continuous losses

$v > v_{\text{cut}}$ stochastic losses

with $v_{\text{cut}} = \min\left[e_{\text{cut}}/E, v'_{\text{cut}}\right]$

Propagation



Standard interactions:

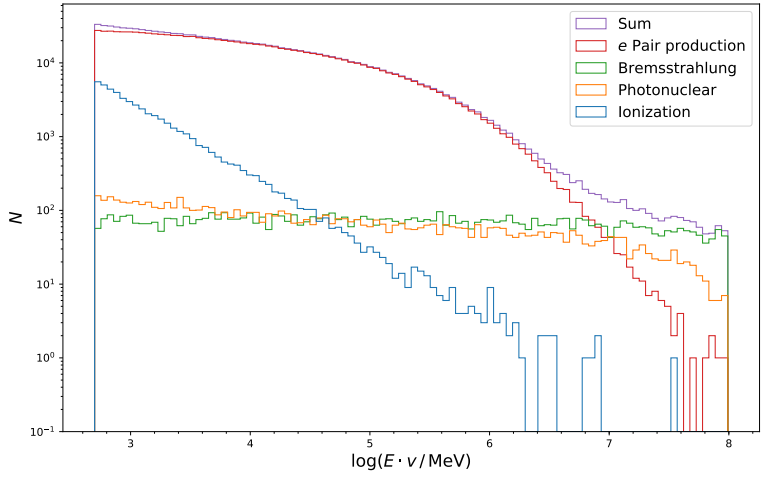
- e pair production
- Bremsstrahlung
- Photonuclear
- Ionization

Rare interactions:

- μ pair production
- Weak interaction

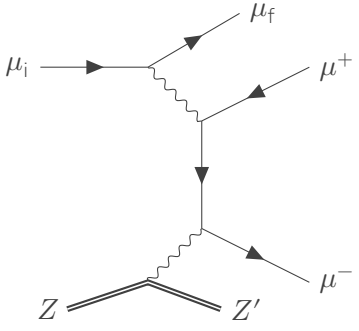
$\rightarrow$ Negligible contribution to overall energy loss

$\rightarrow$ Observable, interesting signature



Propagation of 10^4 muons with energy 10^8 MeV through 100 m of standard rock.

Direct Production of Muon Pairs



With the energy fraction transferred to the muon pair:

$$v = \frac{(\epsilon_+ + \epsilon_-)}{E}$$

With the asymmetry parameter:

$$\rho = \frac{(\epsilon_+ - \epsilon_-)}{(\epsilon_+ + \epsilon_-)}$$

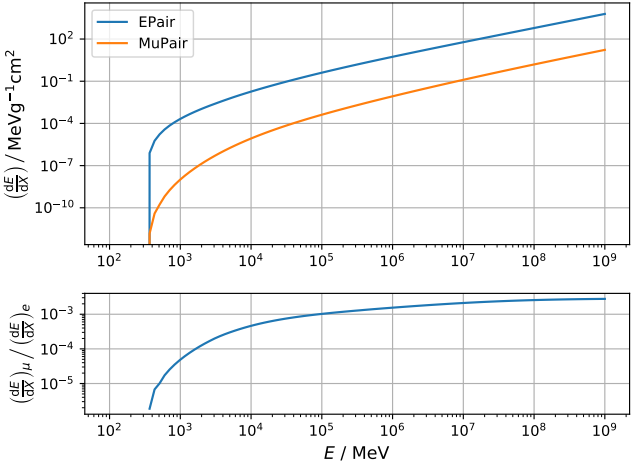
E: Initial energy of the incoming muon μ_i
$\epsilon_\pm$: Energy of the produced (anti)muon

Continous energy loss per distance

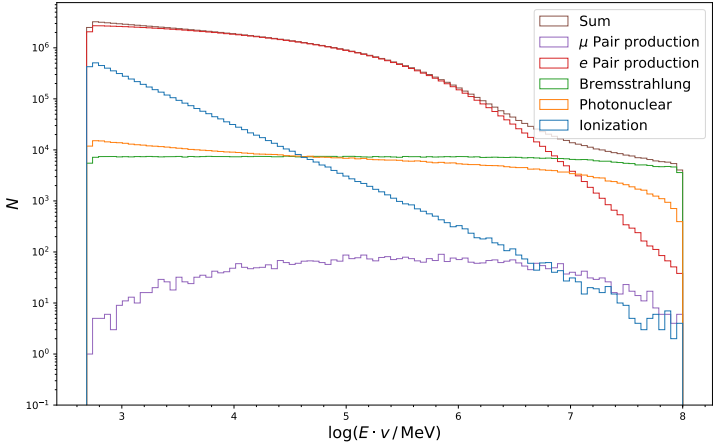
$$-\left\langle \frac{\mathrm{d}E}{\mathrm{d}x} \right\rangle = E \frac{N_\mathrm{A}}{A} \int_{v_\mathrm{min}}^{v_\mathrm{cut}} v \frac{\mathrm{d}\sigma}{\mathrm{d}v} \mathrm{d}v$$

with

$$v_\mathrm{min} = \frac{2m_\mu}{E},$$
$$v_\mathrm{max} = 1 - \frac{m_\mu}{E}.$$

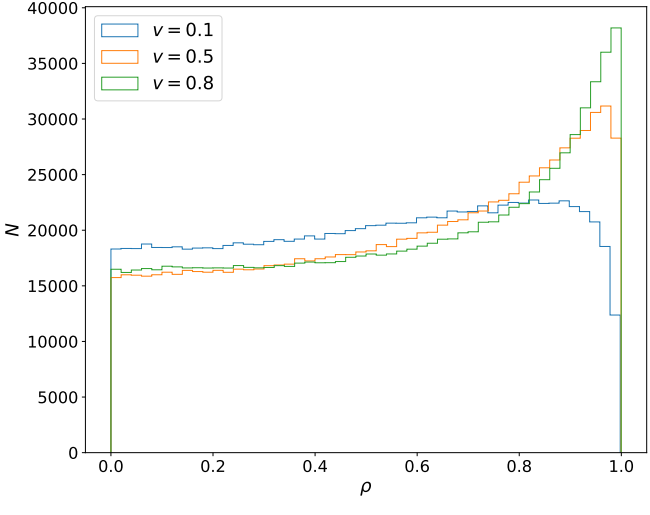


Comparion of e-pair and μ-pair production, only continous losses (i.e. $v_\mathrm{cut} = v_\mathrm{max}$).



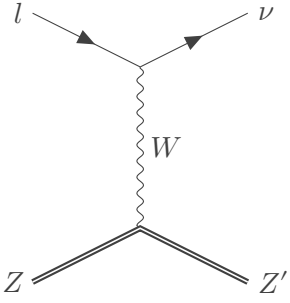
process	N / N_{ges}	E / E_{ges}
e pairp.	0,94	0,94
loniz.	$4 \cdot 10^{-2}$	$5 \cdot 10^{-2}$
Brems.	$1 \cdot 10^{-2}$	$7 \cdot 10^{-3}$
Photon.	$8 \cdot 10^{-3}$	$6 \cdot 10^{-3}$
μ pairp.	$6 \cdot 10^{-5}$	$5 \cdot 10^{-5}$

Stochastic losses in standard rock of 10^6 muons with $E = 10^8$ MeV, $e_{\text{cut}} = 500$ MeV, $v_{\text{cut}} = 5 \cdot 10^{-2}$.



Sampling of ρ for muons with $E = 1 \cdot 10^6$ MeV and different v in standard rock.

Weak interaction



- Highly suppressed process
- Similarities with "lollipop" signature in τ-events
- Crossing symmetry [3]:

$$\mathrm{d}\sigma\left(\mu Z \to \nu_\mu Z\right) = \frac{1}{2}\mathrm{d}\sigma\left(\nu_\mu Z \to \mu Z\right)$$

[3] Sandrock, Alexander: Higher-order corrections to the energy loss cross sections of high-energy muons, 2018, pp. 38-40

Future: Physical improvements in PROPOSAL

- Improvement of electron propagation
- Propagation of high-energy photons
- Deflection of particles in magnetic fields
- Propagation through media with non-homogenous density

https://github.com/tudo-astroparticlephysics/PROPOSAL

https://arxiv.org/abs/1809.07740

PROPOSAL may be modified and distrubuted under terms of a modified LGPL license.
More information on our GitHub page.