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e5 experimentelle physik 5
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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

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

Propagation

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

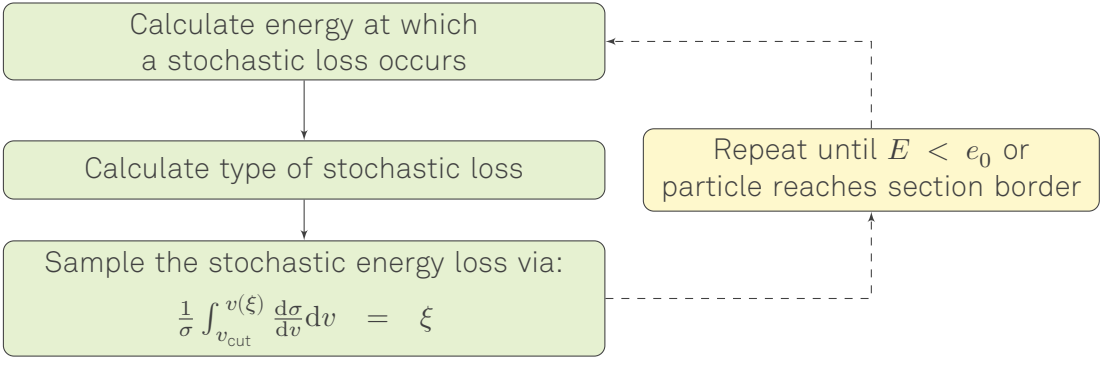
Propagation

$v < v_{\text{cut}}$
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:

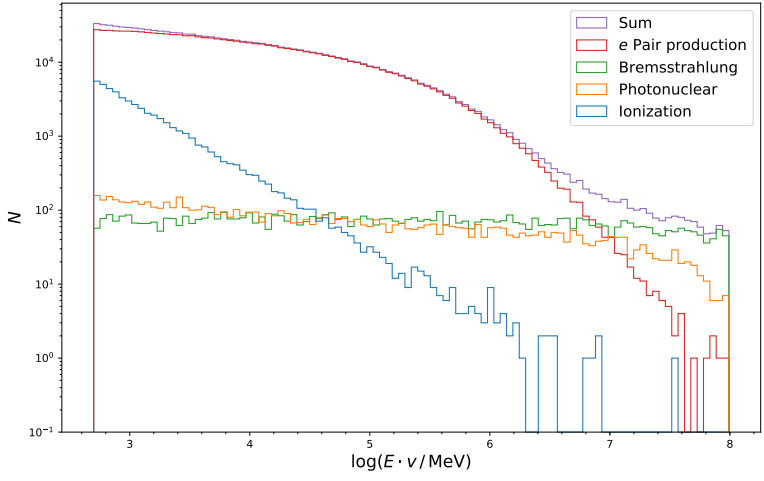
- e pair production
- Bremsstrahlung
- Photonuclear
- Ionization

Rare interactions:

- μ pair production
- Weak interaction

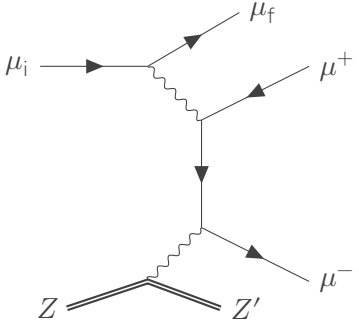
$\rightarrow$ Negligible contribution to overall energy loss

$\rightarrow$ Observable, interesting signature



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

Direct Production of Muon Pairs



Energy fraction transferred to the muon pair:

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

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

Double-differential cross section

For production of muon pairs [1]:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}v\mathrm{d}\rho} = \frac{2}{3\pi}(Z\alpha r_\mu)^2 \frac{1-v}{v} \Phi(v,\rho) \ln(X)$$

For production of electron positron pairs [2]:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}v\mathrm{d}\rho} = \frac{2}{3\pi} Z\left(Z+\xi\right)\left(\alpha r_e\right)^2 \frac{1-v}{v} \left(\Phi_e + \frac{m_e^2}{m_\mu^2}\Phi_\mu\right)$$

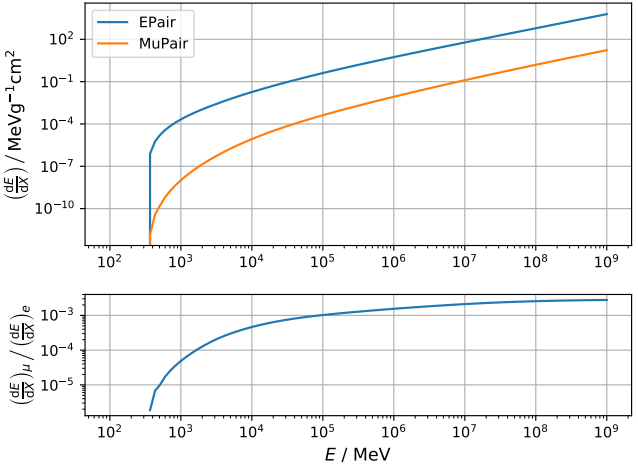
[1] Kelner, Kokoulin, Petrukhin: Phys. of Atomic Nuclei, Vol. 63, No. 9, 2000, pp. 1603-1611
[2] Kokoulin, Petrukhin: Proceedings of 12th ICCR, 1971, p. 2436

Continous energy loss per distance

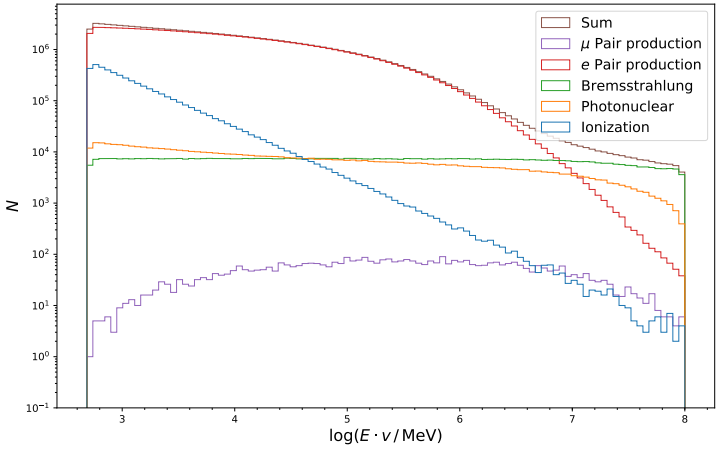
$$-\left\langle \frac{\mathrm{d}E}{\mathrm{d}x} \right\rangle = E \frac{N_\mathrm{A}}{A} \int_{v_\mathrm{min}}^{v_\mathrm{cut}} v \frac{\mathrm{d}\sigma}{\mathrm{d}v} \mathrm{d}v$$

with

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

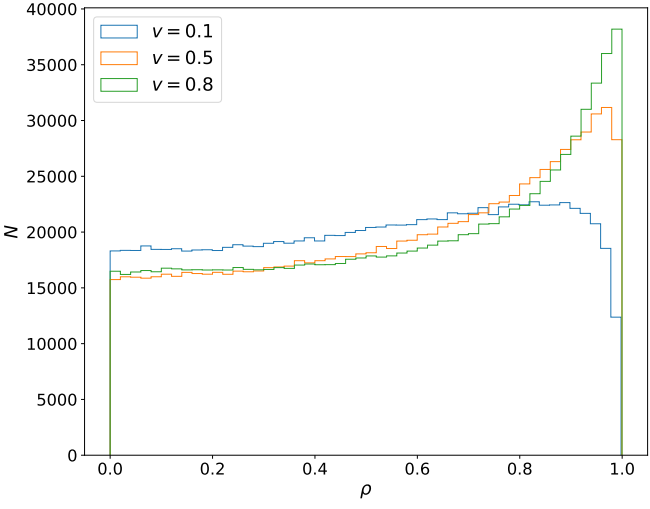


Comparion of e-pair and μ-pair production, only continous losses (i.e. $v_\mathrm{cut} = v_\mathrm{max}$).



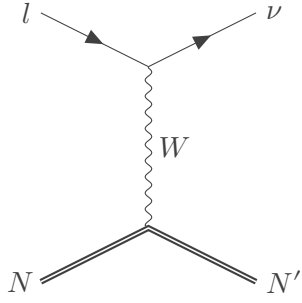
process	N / N_{ges}	E / E_{ges}
e pairp.	0,94	0,94
loniz.	$4 \cdot 10^{-2}$	$5 \cdot 10^{-2}$
Brems.	$1 \cdot 10^{-2}$	$7 \cdot 10^{-3}$
Photon.	$8 \cdot 10^{-3}$	$6 \cdot 10^{-3}$
μ pairp.	$6 \cdot 10^{-5}$	$5 \cdot 10^{-5}$

Stochastic losses, standard rock, 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

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https://arxiv.org/abs/1809.07740