Physics updates of the high-energy lepton and photon simulation tool PROPOSAL

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Introduction

PRopagator with **O**ptimal **P**recision and **O**ptimized **S**peed for **A**ll **L**eptons and photons

- 3D Monte Carlo simulation of individual particles [1, 2]
- Optimized for large-scale particle propagation
- Simulations of high-energy electrons, positrons, photons, muons, and taus

Installation

PROPOSAL is a C++14 library with Python bindings

→ Simple Python installation with `pip install proposal`

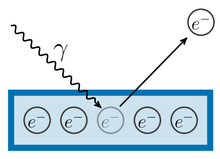
→ C++ installation via CMake, or with the package manager Conan

Physics improvements for photon interactions

Photoelectric absorption:

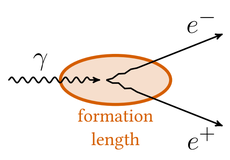
- Dominant interaction type for photon energies below $\approx 30\,\mathrm{keV}$
- Accurate description complicated, but not necessary for development of electromagnetic cascades

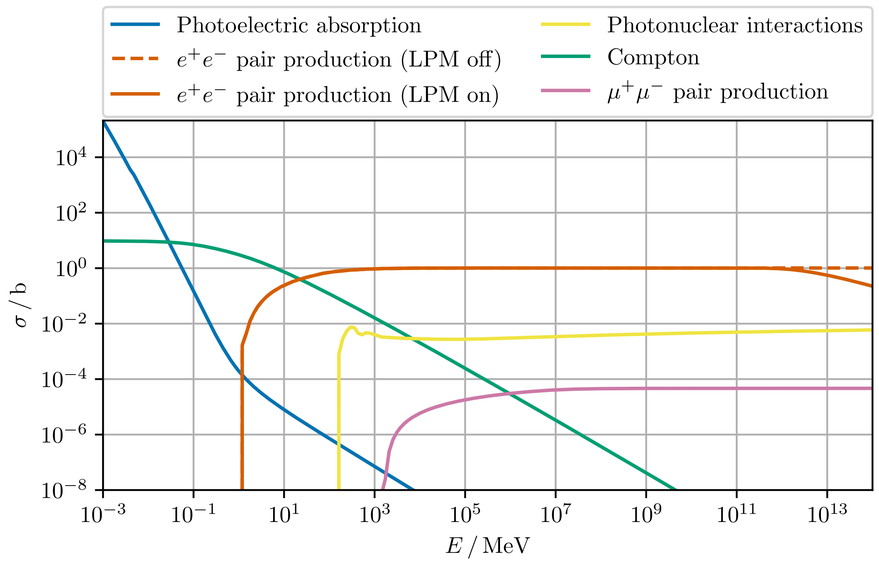
→ Implementation of an approximate description



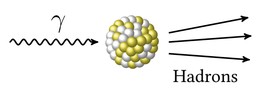
LPM effect:

- Suppression of small bremsstrahlung losses and symmetric pair production processes
- Relevant for high energies and/or dense media





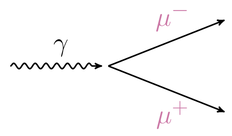
Photonuclear interactions:



- Absorption of photon by nucleus
- Source of hadrons (and consequently muons) from electromagnetic cascades
- Extrapolation to high energies has high uncertainties

→ Different parametrizations available

Muon pair production:



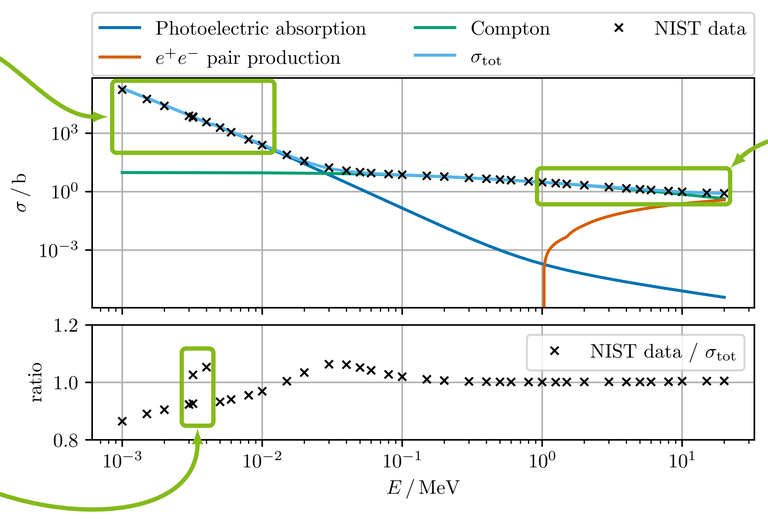
- Subdominant process compared to e^-e^+ pair production
- Source of muons from electromagnetic cascades

Validation of low-energy photon cross sections

Comparison of PROPOSAL implementation to calculations from NIST Standard Reference Database [3]

Agreement better than 10 % even at low energies where used parametrization is not expected to be exact

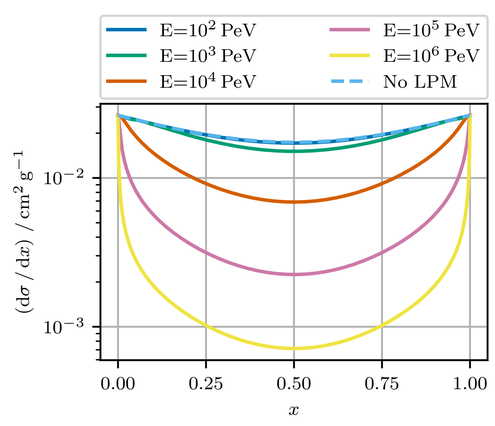
Expected discrepancies around absorption lines (here: K-line of Ar)



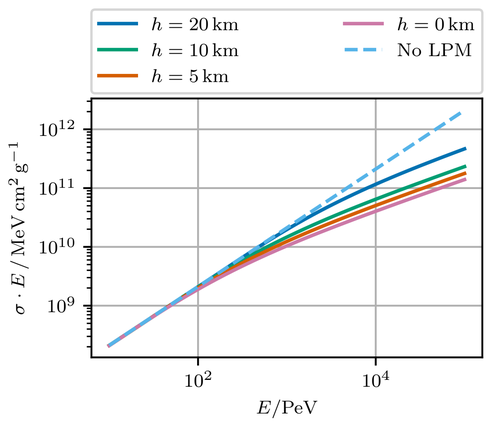
Good agreement for energies where pair production and Compton are dominant processes

Impact of LPM effect on air showers

Influence of the LPM effect on pair production processes in air



- For air at sea level, suppression of symmetric pair production processes at energies above $1 \times 10^2\,\mathrm{PeV}$



- LPM suppression is density dependent, and therefore dependent on height in atmosphere

How to use PROPOSAL

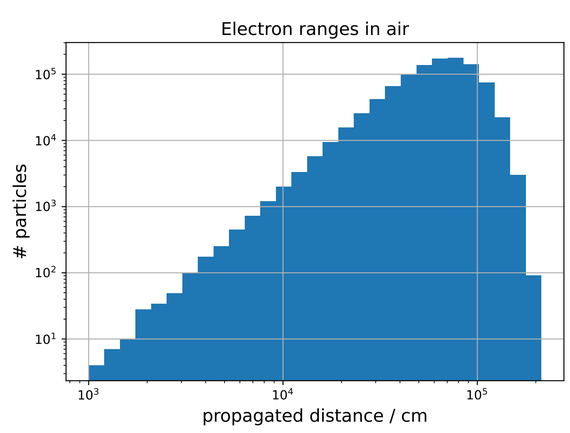
```python
import proposal as pp

# define propagator
particle = pp.particle.EMinusDef()
prop = pp.Propagator(particle, "config.json")

# define initial particle state
init_state = pp.particle.ParticleState()
init_state.position = pp.Cartesian3D(0, 0, 0)
init_state.direction = pp.Cartesian3D(0, 0, 1)
init_state.energy = 1e3 # energy in MeV

# propagation
particle_ranges = []
for i in range(int(1e6)):
    output = prop.propagate(init_state)
    x_f = output.final_state().propagated_distance
    particle_ranges.append(x_f)
```

Information about environment in json configuration file



Application: CORSIKA 8

PROPOSAL is used to simulate the electromagnetic and muonic shower component in the new particle-shower simulation code CORSIKA 8 [4]

→ For more details, see talks by A. Sandrock [CRI19-06] and T. Huege [CRI20-08] on Wednesday

Summary

- Implementation of new photon processes relevant at low and high energies

→ Complete description of electrons, positrons, and photons in the regime relevant for electromagnetic cascades

- PROPOSAL is a highly flexible framework for lepton and photon simulations

Contact

Find the PROPOSAL repository under:
`github.com/tudo-astroparticlephysics/PROPOSAL`

Contact via mail:
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References

[1] J.-H. Koehne et al. *PROPOSAL: A tool for propagation of charged leptons.* In: *Comput. Phys. Commun.* 184.9 (2013), pp. 2070–2090. DOI: 10.1016/j.cpc.2013.04.001. [2] M. Dunsch et al. *Recent Improvements for the Lepton Propagator PROPOSAL.* In: *Comput. Phys. Commun.* 242 (2019), pp. 132–144. DOI: 10.1016/j.cpc.2019.03.021. arXiv: 1809.07740 [hep-ph]. [3] J. M. Hubbell and S. M. Seltzer. *Tables of X-Ray Mass Attenuation Coefficients and Mass Energy-Absorption Coefficients from 1 keV to 20 MeV for Elements Z = 1 to 92 and 48 Additional Substances of Dosimetric Interest.* Tech. rep. NISTIR 5632. National Institute of Standards and Technology, May 1995. [4] R. Engel et al. *Towards A Next Generation of CORSIKA: A Framework for the Simulation of Particle Cascades in Astroparticle Physics.* In: *Computing and Software for Big Science* 3.1 (Dec. 2018), p. 2. ISSN: 2510-2044. DOI: 10.1007/s41781-018-0013-0.

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