High-energy lepton and photon propagation with the simulation framework PROPOSAL

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Introduction to PROPOSAL

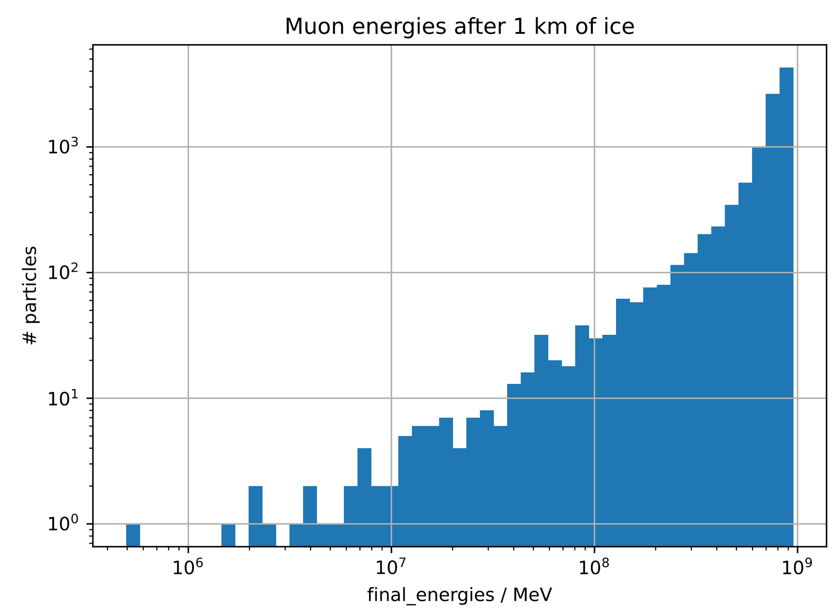
- Monte Carlo simulations are crucial to train machine learning algorithms
  - → The underlying tools need to be both precise and performant
- PROPOSAL is a simulation framework, providing 3D Monte Carlo simulations of high-energy electrons, positrons, muons, taus and photons
- Different parametrizations of physical processes, including up-to-date parametrizations, are available
- High-performance and high-precision simulations, optimized for large-scale particle propagation

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

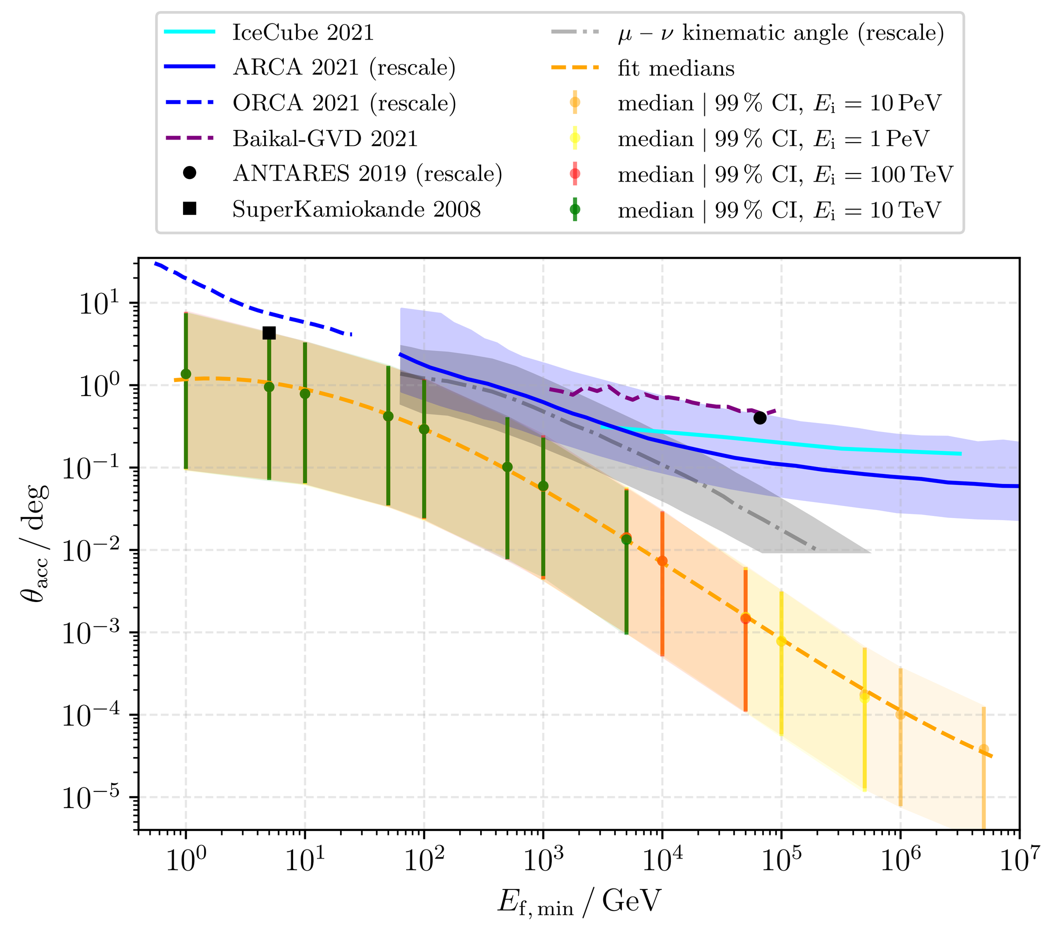
How to use PROPOSAL

- PROPOSAL can be used as a C++ or a Python library
  - → Simple Python installation with `pip install proposal`
  - → C++ installation using the package manager Conan and CMake
- Information about the configuration environment can be read using a JSON file

```
import proposal as pp

# read properties from config file
particle = pp.particle.MuMinusDef()
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 = 1e9 # MeV

# propagation
final_energies = []
for i in range(10000):
    output = prop.propagate(init_state,
                            max_distance = 1e5) # cm
    E_f = output.final_state().energy
    final_energies.append(E_f)
```

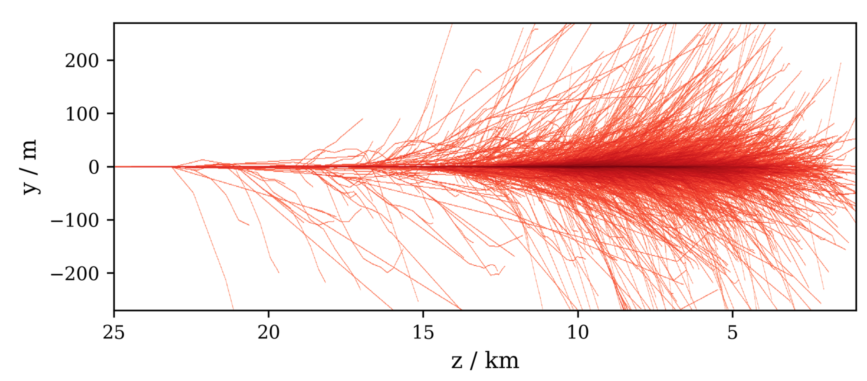


Simulation of Deflection Uncertainties on Direction Reconstructions of Muons Using PROPOSAL



Application: CORSIKA 8

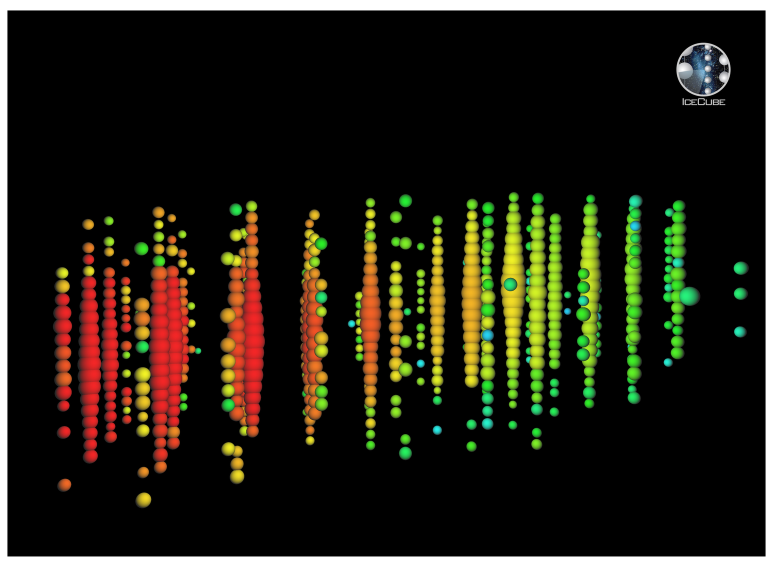
- New version of the air shower simulation framework CORSIKA
  - → Entirely new code structure, based on modern C++
  - → Focus on flexibility, modularity, efficiency and reliability [1]
- PROPOSAL is used to simulate the electromagnetic and muonic shower component
  - → PROPOSAL provides individual modules, where each module solves specific physical tasks [2]
  - → CORSIKA 8 uses these modules to calculate interaction lengths, energy losses, multiple scattering and secondary particles
- First comparisons of CORSIKA 8 and CORSIKA 7: Good agreement for simulations of electromagnetic showers [3]



1 TeV e^- shower simulated with CORSIKA 8

Application: Neutrino telescopes

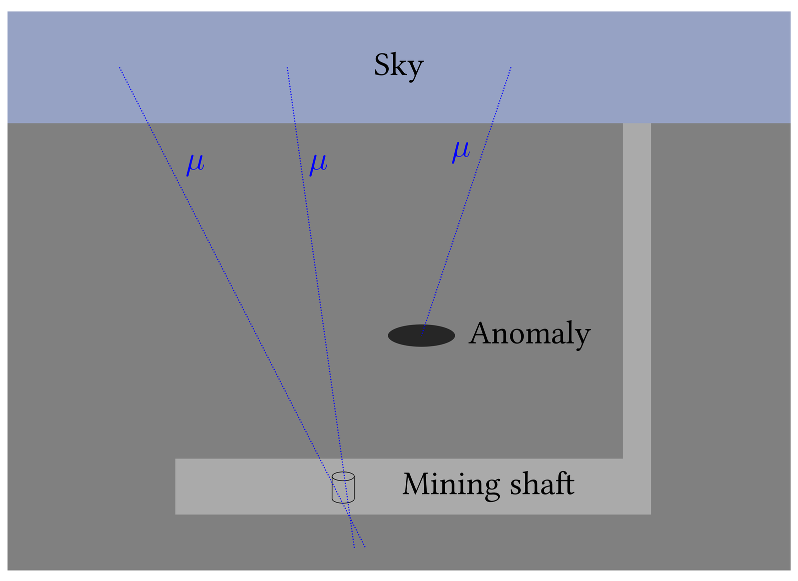
- PROPOSAL is used by neutrino telescopes, for example in the IceCube Neutrino observatory or in RNO-G
- Simulation of muon and tau energy losses in ice
  - → Precise simulations and an accurate description of cross sections are crucial



Muon track in the IceCube detector
(*Source: IceCube Collaboration*)

Application: Muography

- Non-invasive imaging technique using Cosmic Ray muons
- Tracing muon number along trajectories: Provides information, for example on density anomalies
- PROPOSAL is a well-suited tool to provide the necessary muon simulations
  - → Currently analyzing the possibilities to use muography in mining with PROPOSAL simulations



Visualization of the muography technique

Outlook

- Implementation of the LPM effect for inhomogeneous media
  - → Important for very-high-energy air showers
- Implementation of only-stochastic propagation
  - → Allows for neutrino propagation with PROPOSAL

Contact

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References

[1] 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.

[2] J.-M. Alameddine et al. *PROPOSAL: A library to propagate leptons and high energy photons*. In: *J. Phys. Conf. Ser.* 1690.1 (Dec. 2020), p. 012021. DOI: 10.1088/1742-6596/1690/1/012021.

[3] J.-M. Alameddine et al. *Electromagnetic Shower Simulation for CORSIKA 8*. In: *PoS* ICRC2021 (2021), p. 428. DOI: 10.22323/1.395.0428.

Acknowledgements

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