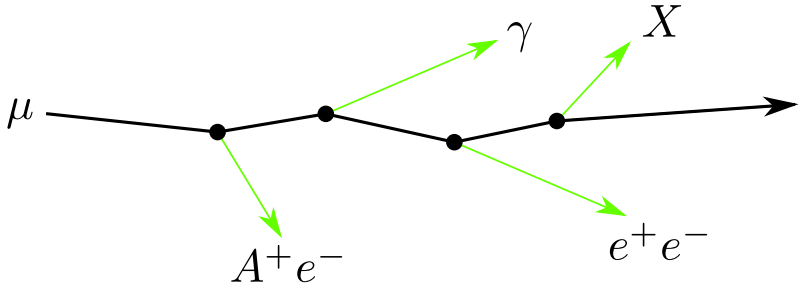
technische universität dortmund

BERGISCHE UNIVERSITÄT WUPPERTAL



Applications of the high-energy lepton and photon propagator PROPOSAL

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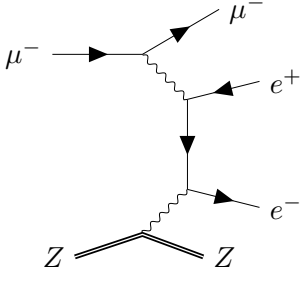
University of Wuppertal[2]

Introduction to PROPOSAL

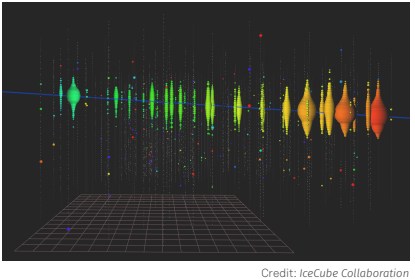
Motivation behind PROPOSAL

(and many other Monte Carlo Simulation tools...)

Theory:



Event signatures:



Credit: *IceCube Collaboration*

PROPOSAL → Propagator with Optimal Precision and Optimized Speed for All Leptons

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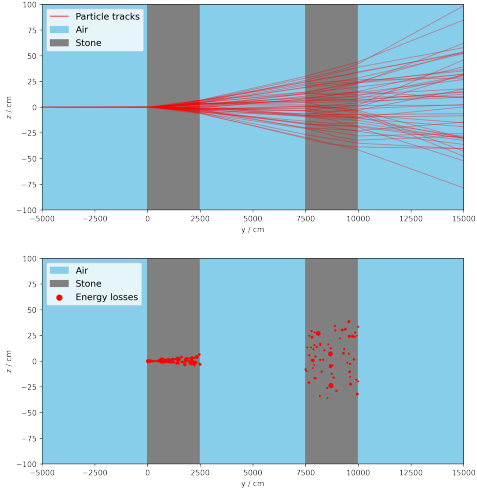
- 3D Monte Carlo simulation of individual particles, considering ...
  - ... energy losses
  - ... scattering effects
  - ... particle decays
  - → **Customizable:** Selection of different parametrizations available for each process
- **Input:** Initial particle state
- **Output:** Information on particle track, including ...
  - ... Final particle state
  - ... Energy losses
  - ... Intermediate particle states
- C++14/Python library



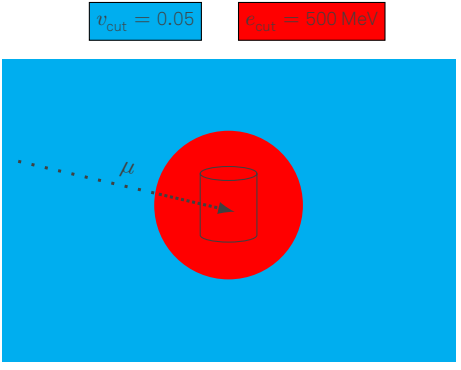
PROPOSAL → Propagator with Optimal Precision and Optimized Speed for All Leptons

Interpolation tables:

- Cross sections and results of propagation integrals are stored as interpolation tables
  - → Crucial for the performance of PROPOSAL

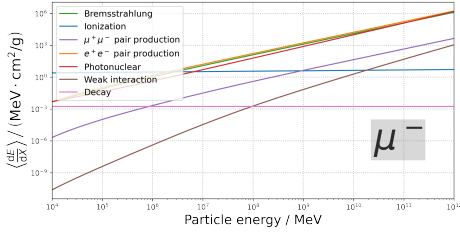
Energy loss cuts:

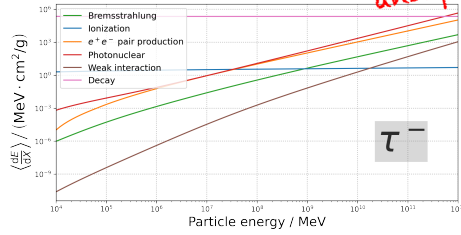
- PROPOSAL differentiates between continuous and stochastic energy losses
- Energy losses can be defined by their relative size v_{loss} and their absolute size e_{loss}
- The energy cut settings ($v_{\text{cut}}, e_{\text{cut}}$) define which interactions are treated stochastically/continuously

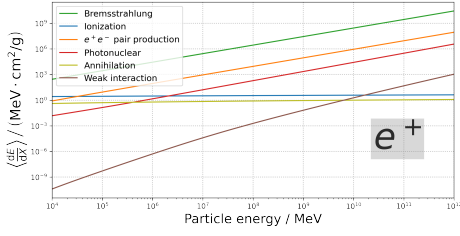


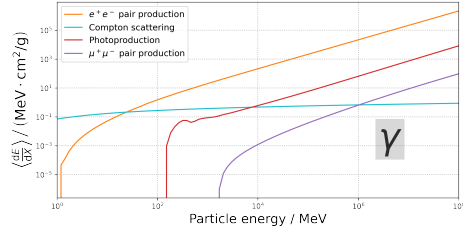
→ Adjust energy cut settings to find ideal trade-off between precision and performance!

PROPOSAL → Propagator with Optimal Precision and Optimized Speed for All Leptons and photons





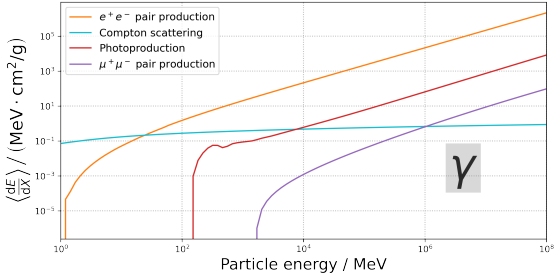


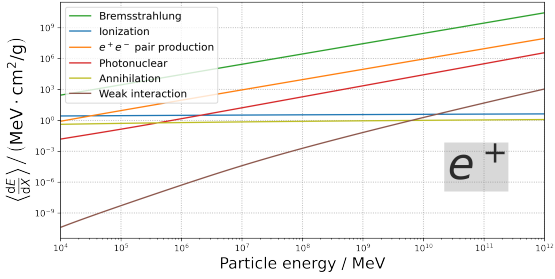


Recent updates in PROPOSAL

Improvements for electromagnetic interactions:

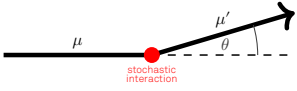
- Inclusion of $\gamma \rightarrow \mu^+\mu^-$
- Inclusion of $\gamma \rightarrow$ Hadrons (Photohadronic interaction)
  - $\rightarrow$ Relevant for very-high energies
- Sampling of deflection angles for bremsstrahlung photons

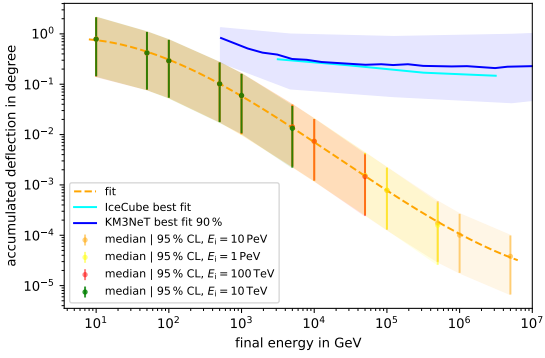




Stochastic deflections

- PROPOSAL considers multiple scattering (continuous losses)
- Deflections may also occur in (very) stochastic interactions
  - → Possible influence on directional reconstructions?
- Stochastic deflections for muon interactions have been added to PROPOSAL



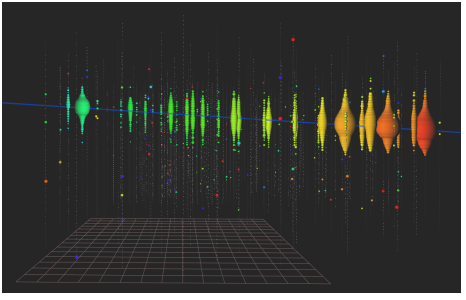


"NN-based parametrization of muon deflections simulated by PROPOSAL"
⇒ Talk **T46.6** by Pascal Gutjahr

Applications of PROPOSAL

IceCube Neutrino Observatory

- PROPOSAL is used in the IceCube simulation chain
  - → Simulation of muons and taus in ice
  - → PROPOSAL provides the energy losses along the particle track
  - → Energy losses are further processed by other tools to simulate Cherenkov photons

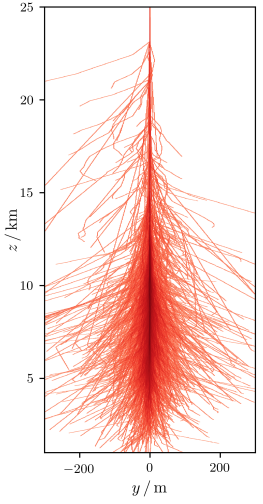


Credit: *IceCube Collaboration*

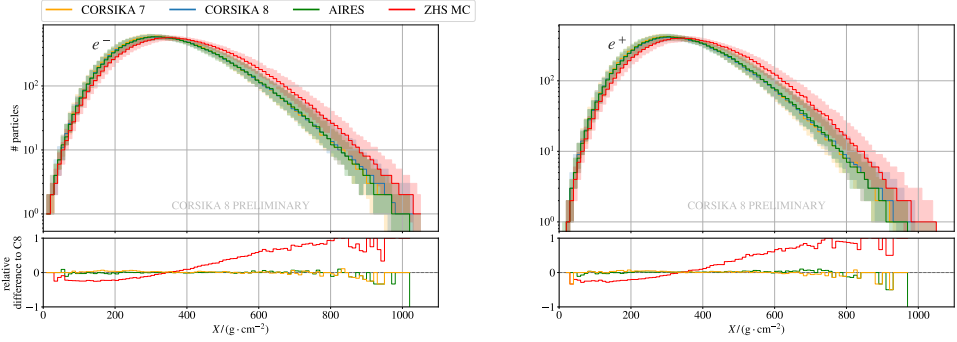
CORSIKA 8

- CORSIKA 8: Newest version of the air shower simulation framework CORSIKA (currently under development)
  - → see: `gitlab.iap.kit.edu/AirShowerPhysics/corsika`
- PROPOSAL is used in CORSIKA 8 as an electromagnetic shower model
  - → CORSIKA uses propagation steps provided by PROPOSAL modules

⇒ Talks dedicated to CORSIKA 8: T47.8, T72.5, T72.7, AKPIK1.7



1 TeV e^- shower simulated with CORSIKA 8



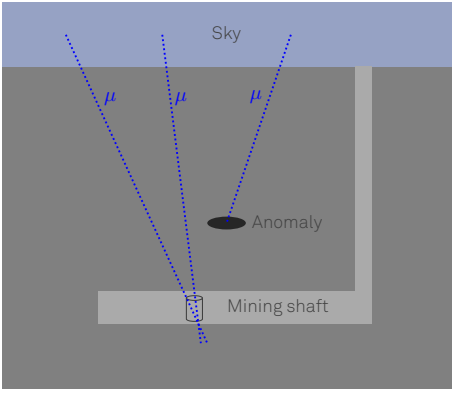
Longitudinal profile for 200 electromagnetic showers, initiated by 1 TeV e^-

- First comparisons of CORSIKA 8 results with other simulation frameworks are promising

  ⇒ See PoS(ICRC2021)428

Muography:

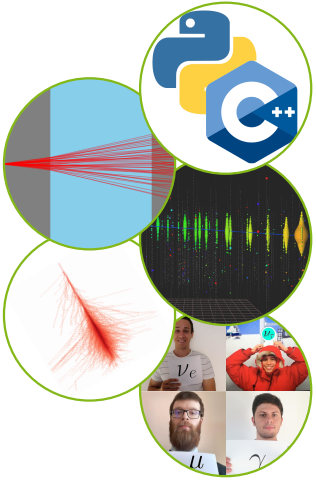
- Non-invasive imaging technique using Cosmic Ray muons
  - → Trace muon number to observe density anomalies
- PROPOSAL is a well-suited tool to provide the necessary muon simulations
  - → Currently analyzing the possibilities to use muography in mining with PROPOSAL simulations



Summary and outlook

Summary

- C++/Python framework to propagate high-energy leptons and photons
  - → Easy python installation: Try: `pip install proposal`
- PROPOSAL is adaptable for different use cases
  - → EnergyCuts: Adjustable trade-off between precision and performance
  - → All interaction processes are modular and customizable
- Recent updates in PROPOSAL ...
  - ... for high-energy photon propagation
  - ... in the description of muon scattering
- Actively maintained and developed as an open-source project
  - → Visit us on GitHub: `github.com/tudo-astroparticlephysics/PROPOSAL`



Outlook

- Version `7.3.0` of PROPOSAL has been released today!
- Planned improvements for the next versions include:
  - → Description of the LPM effect in inhomogeneous media
  - → Inclusion of photoelectric interactions of γ