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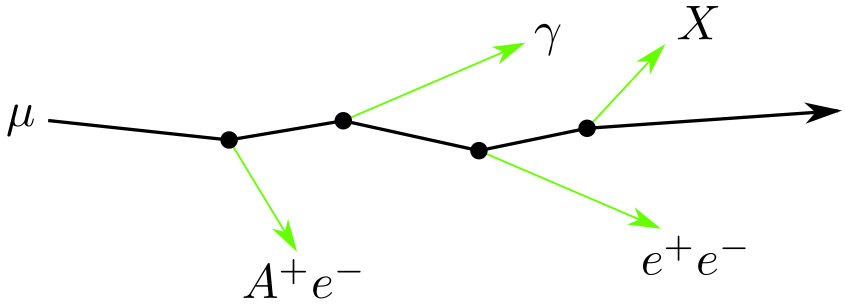

PROPOSAL: A library to propagate leptons and high energy photons

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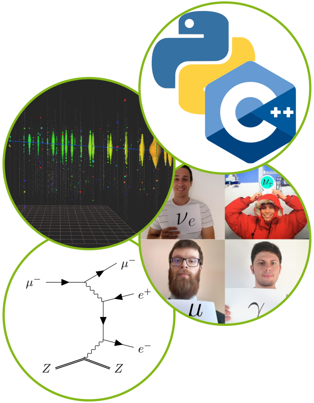
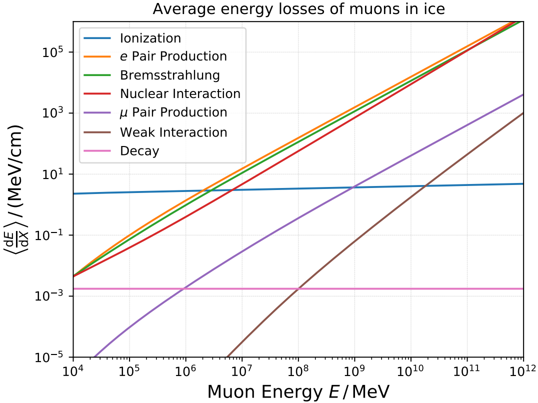
Technische Universität Dortmund

What is PROPOSAL?

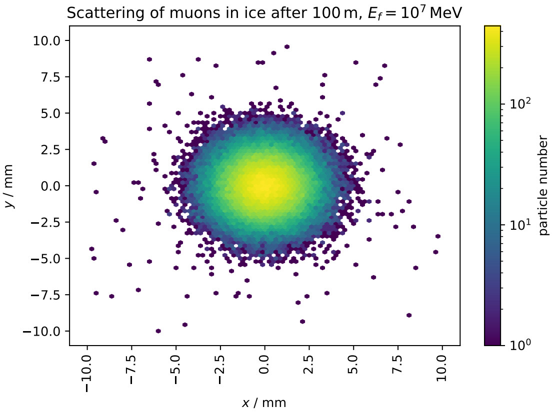
- PROPOSAL: Software library to propagate high-energy leptons and photons
- Written in C++11, callable from Python as well
  - Try: `pip install proposal`
- Easy-to-use, but still very customizable for different applications
- Actively maintained
  - Visit our GitHub: `https://github.com/tudo-astroparticlephysics/PROPOSAL`



- PROPOSAL originally specialized on μ and τ propagation
- Recently, γ propagation and an improved treatment of e^-/e^+ has been added
- Selection of different parametrizations for each process
  - → Several up-to-date parametrizations available
  - → Including effects such as LPM
  - → Rare processes can be included
  - → Easy to implement new parametrizations



- Next to energy losses, PROPOSAL can simulate...
  - → Multiple scattering effects
  - → Particle decays
  - → Creation of secondary particles



- Interaction are characterized by their relative energy loss v
- PROPOSAL differentiates continuous energy losses and stochastic enery losses:

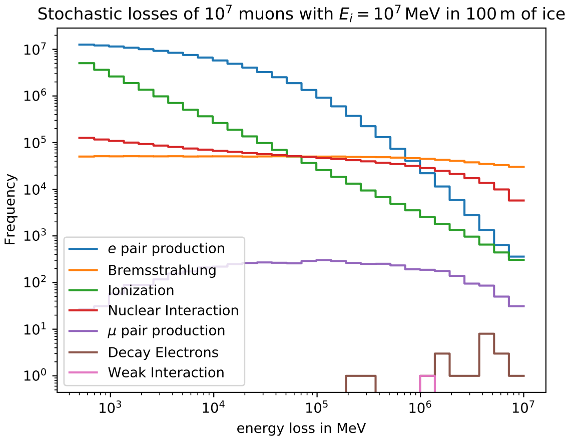
$v < v_{\text{cut}}$ continuous

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

with

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

→ Vary values for e_{cut} and ${v'}_{\text{cut}}$ to adjust precision



(Simplified) PROPOSAL propagation algorithm

Initial energy E_i

↓

Sample energy E_f where next stochastic loss occurs

↓

Calculate distance until next stochastic loss

↓

Sampling stochastic loss

↓

Repeat until fatal interaction, decay, $E < e_{\text{low}}$ or $d = d_{\text{max}}$

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Energy integral

$$\int_{E_i}^{E_f} \frac{\sigma(E)}{-f(E)} \cdot \mathrm{d}E = -\log(\xi)$$

- $\sigma(E) = \sigma_{\text{total, stochastic}}$
- $f(E) = \frac{\mathrm{d}E}{\mathrm{d}x}\Big|_{\text{cont}} \propto E \int_{v_{\text{min}}}^{v_{\text{cut}}} v \frac{\mathrm{d}\sigma}{\mathrm{d}v} \mathrm{d}v$
- $\xi \in [0, 1)$

Stochastic losses are all energy losses with a fractional energy loss $v > v_{\text{cut}}$!

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Displacement integral

$$x_f = x_i - \int_{E_i}^{E_f} \frac{\mathrm{d}E}{f(E)}$$

- $f(E) = \frac{\mathrm{d}E}{\mathrm{d}x}\Big|_{\text{cont.}} \propto E \int_{v_{\text{min}}}^{v_{\text{cut}}} v \frac{\mathrm{d}\sigma}{\mathrm{d}v} \mathrm{d}v$

(Simplified) PROPOSAL propagation algorithm

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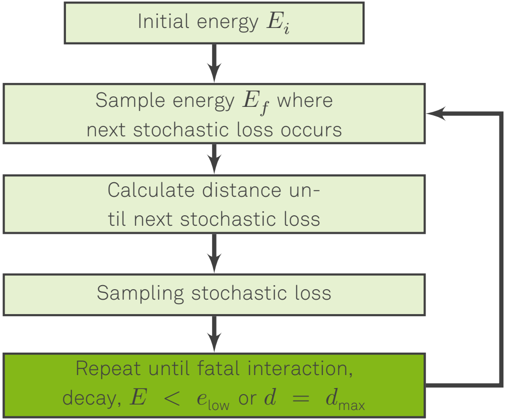
Stochastic loss

$$\frac{1}{\sigma_{\text{total}}} \int_{v_{\text{cut}}}^{v} \frac{\mathrm{d}\sigma}{\mathrm{d}v} = \xi$$

- $\xi \in [0, 1)$

(Simplified) PROPOSAL propagation algorithm



Interpolation

- Many integrals need to be calculated during propagation
  - → Usage of interpolation tables to decrease runtime
  - → Both cross section integrals (left) and integrals necessary for propagation steps (right) are interpolated

$$\int \frac{d\sigma}{d\nu} d\nu$$

$$\int \nu \frac{d\sigma}{d\nu} d\nu$$

$$\int_{E_i}^{E_f} \frac{\sigma(E)}{-f(E)} \cdot \mathrm{d}E = -\log(\xi)$$

$$x_f = x_i - \int_{E_i}^{E_f} \frac{\mathrm{d}E}{f(E)}$$

Minimal PROPOSAL code example

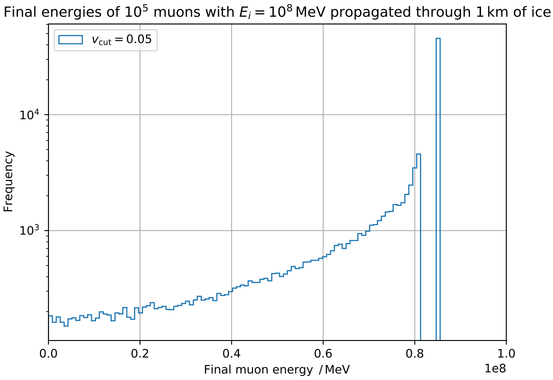
C++ Code

```
// read properties from config file
prop Propagator(MuMinusDef(), "config.json");

// define initial state
Vector3D position(0, 0, 0);
Vector3D direction(0, 0, 1);
auto energy = 1e8.f; // MeV
init_state DynamicData(position, direction, energy);

vector<double> energies;

for(int i = 0; i < 1e5; i++) {
    auto track = prop.Propagate(init_state, 1e5); // cm
    double E_final = track.back().GetEnergy();
    energies.push_back(E_final);
}
```

json file

```
"global":
{
  "cuts":
  {
        "e_cut": INF,
        "v_cut": 0.05,
        "cont_rand": false
  }
},

"sectors": [
{
  "medium": "ice",
  "geometries": [
        {
          "shape": "sphere",
          "origin": [0, 0, 0],
          "outer_radius": 6374134000000
        }
  ]
}
]
```

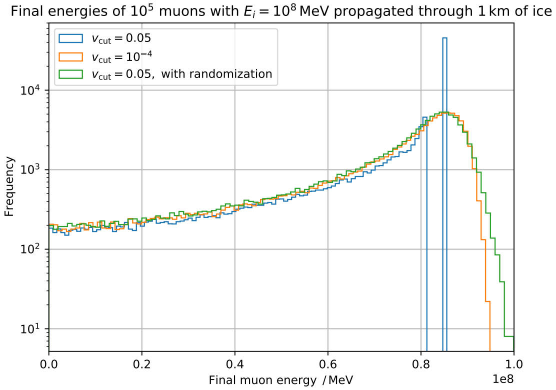
Continuous randomization



- Simulating muons with identical initial energies causes a peak in the energy distribution

→ All particles with zero stochastic losses will have the same final energy

Continuous randomization

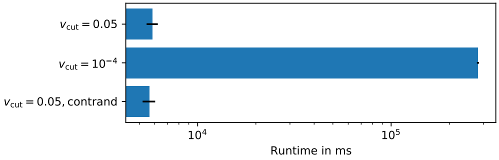


- Simulating muons with identical initial energies causes a peak in the energy distribution

→ All particles with zero stochastic losses will have the same final energy

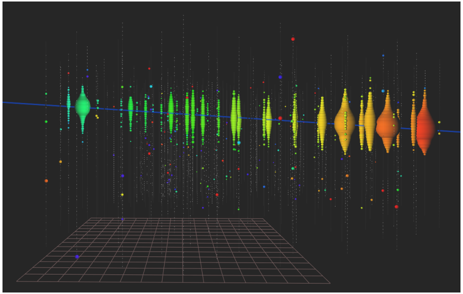
- PROPOSAL provides the feature *continuous randomization*

→ This adds random fluctuations to the continuous losses



IceCube Neutrino Observatory

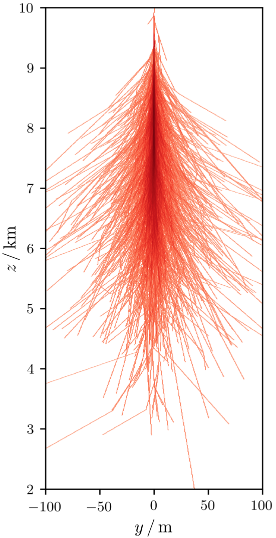
- PROPOSAL used in IceCube simulation chain
  - → Interested in energy losses along a particle track, provided by the PROPOSAL propagator
  - → Energy losses are further processed by other tools to simulate Cherenkov photons
- Adjustable precision important for all large-scale detectors
  - High precision inside detector (small v_{cut})
  - High performance in front of detector (higher v_{cut} with continuous randomization)



Credit: IceCube Collaboration

CORSIKA 8

- Up to CORSIKA7: Electromagnetic shower component simulated by EGS4
- CORSIKA 8: Inclusion of PROPOSAL as an EM shower model (see CORSIKA GitLab)
- CORSIKA is interested in single propagation steps for e^+, e^- and γ
  - $\rightarrow$ Modular structure of PROPOSAL allows to extract individual components of the propagation routine



ICECUBE
SOUTH POLE NEUTRINO OBSERVATORY

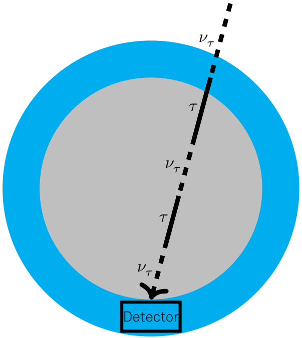
NuRadioMC

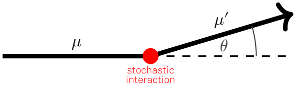
BAIKAL-GVD

CORSIKA 8

Future developments

- Neutrino propagation in PROPOSAL
  - → Can be used for tau regeneration studies
- Stochastic deflections
  - → Deflections may occur in (very) stochastic interactions (especially for bremsstrahlung and photonuclear interactions)
  - → Can be used to examine the influences, e.g. on direction reconstructions
- Backward Monte Carlo simulations [1705.05636]
  - → Can be used to increase statistics for relevant event signatures





Current developments

- Current developments on GitHub branch `restructure_parametrization`
  - → Several improvements, both internally as well as for users
  - → Preparations for inclusion in CORSIKA 8
  - → Will be merged soon with our master branch
- If you are interested in using PROPOSAL ...

  ...use `pip install proposal` to try it out

  ...look at our GitHub page for more information

  ...contact us directly! jean-marco.alameddine@udo.edu