# Neutrino Quantum Decoherence with KM3NeT/ARCA

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on behalf of the KM3NeT Collaboration

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# Neutrino Quantum Decoherence

- Beyond Standard Model effect predicted by quantum gravity.
- **Decoherence**: loss of coherence of the neutrino mass eigenstates due to the coupling of the neutrino quantum system to a larger environment.
- The time evolution of the neutrino density matrix ρ(t) is:

$$\rho \propto e^{-\left(\Gamma + i\frac{\Delta m_{ij}^2}{2E}\right)t}$$

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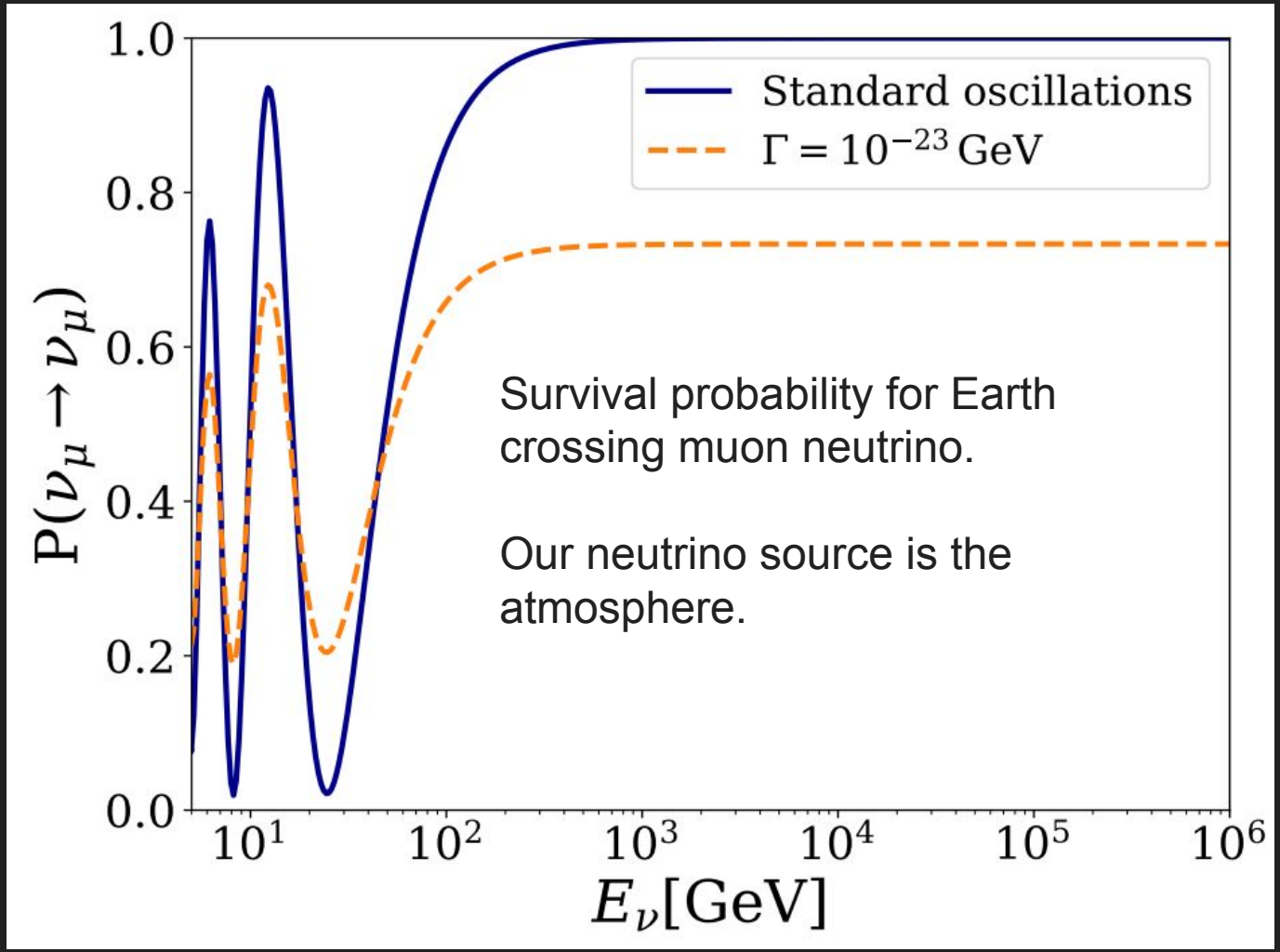
Decoherence parameter

Standard Oscillations

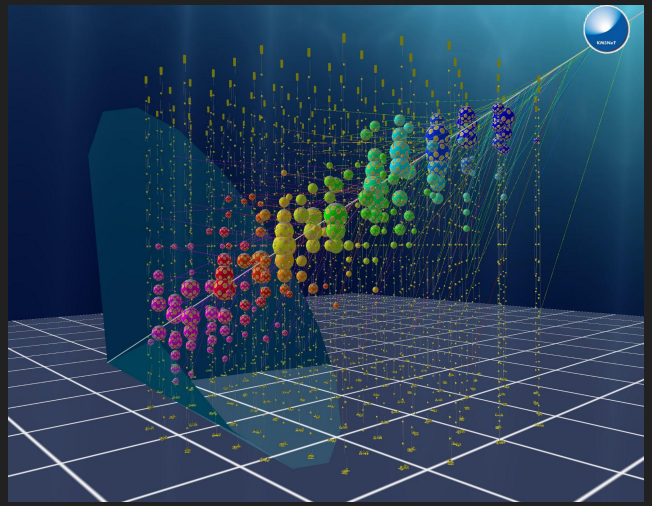
- **Decoherence** leads to a damping of the oscillation amplitude.


1.0
0.8
0.6
0.4
0.2
0.0
$P(\nu_\mu \to \nu_\mu)$
$10^1$
$10^2$
$10^3$
$10^4$
$10^5$
$10^6$
$E_\nu$[GeV]
Standard oscillations
$\Gamma = 10^{-23}$ GeV
Survival probability for Earth crossing muon neutrino.
Our neutrino source is the atmosphere.

# How can we probe this beyond Standard Model effect with KM3NeT?

# KM3NeT detectors

Water Cherenkov detectors in the Mediterranean Sea




The amount of expected muon neutrinos is different between the standard oscillations and decoherence hypothesis.

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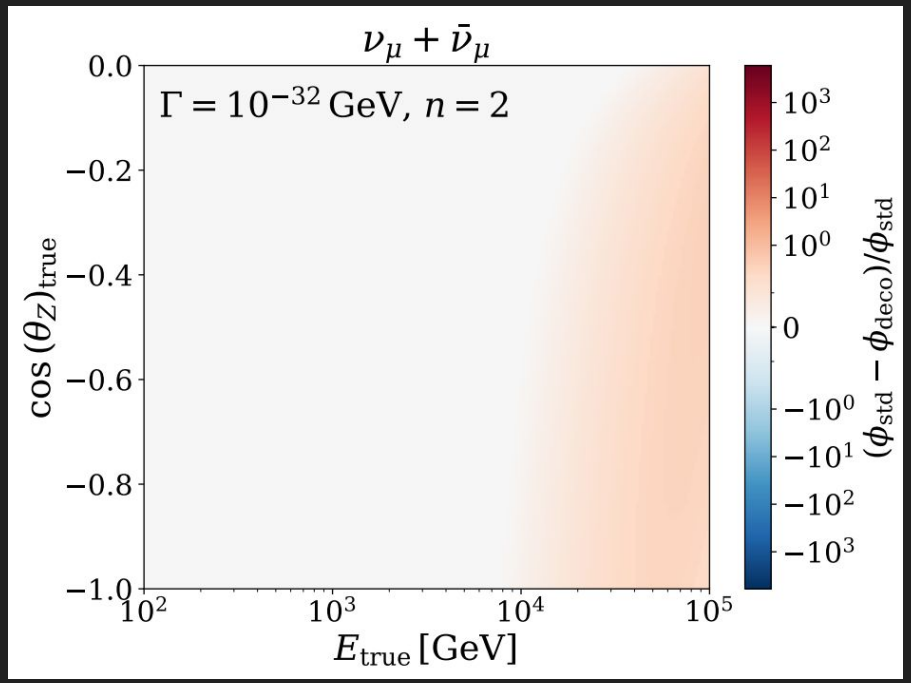
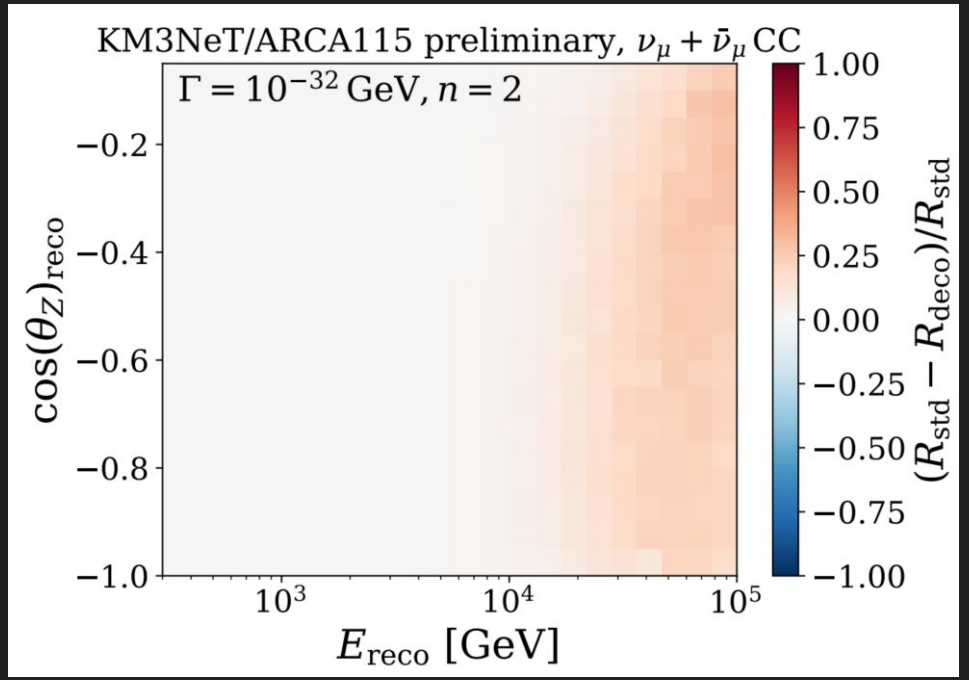
# Difference between standard oscillations and decoherence:




Difference in muon neutrino flux (**true** zenith angle, true energy). Theory!



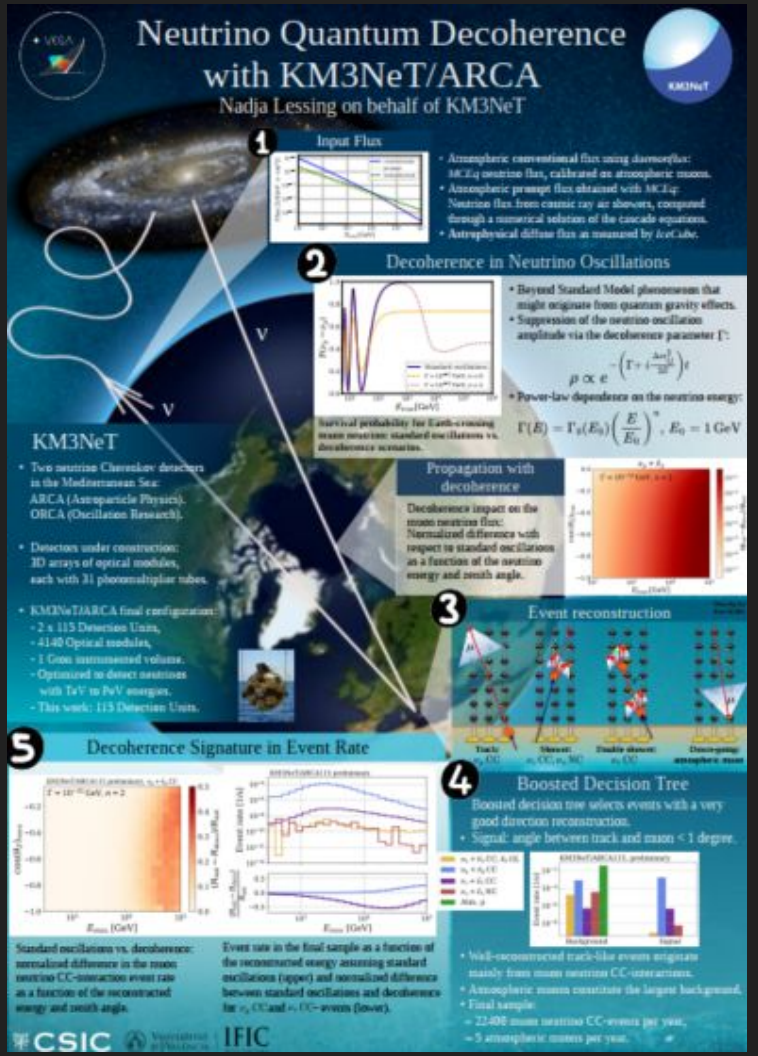

Difference in muon neutrino event rate (**reconstructed** zenith angle and energy) With detector effects and background!

# Conclusions

- This is how (most) beyond Standard Model searches in neutrino oscillations are performed in KM3NeT (ORCA).
- This work is the first analysis of this type with KM3NeT/ARCA.
  -> sensitivities to be published soon.

- For ORCA, results were already obtained :
  The KM3NeT Collaboration, *Search for quantum decoherence in neutrino oscillations with six detection units of KM3NeT/ORCA,* JCAP 10.1088/1475-7516/2025/03/039
  -> Upper limits on the decoherence parameter Γ.

Thank you for your attention!



# Backup

# Theory of decoherence

Thomas Stuttard and Mikkel Jensen,
*Neutrino decoherence from quantum gravitational stochastic perturbations*
10.1103/PhysRevD.102.115003

$$\frac{d}{dt}\rho(t) = -i[H, \rho(t)] - \mathcal{D}[\rho(t)]\,,$$

$$\mathcal{D}[\rho(t)] = -\frac{1}{2}\sum_{k=1}^{N^2-1}\left(\left[V_k, \rho(t)V_k^\dagger\right] + \left[V_k\rho(t), V_k^\dagger\right]\right)$$

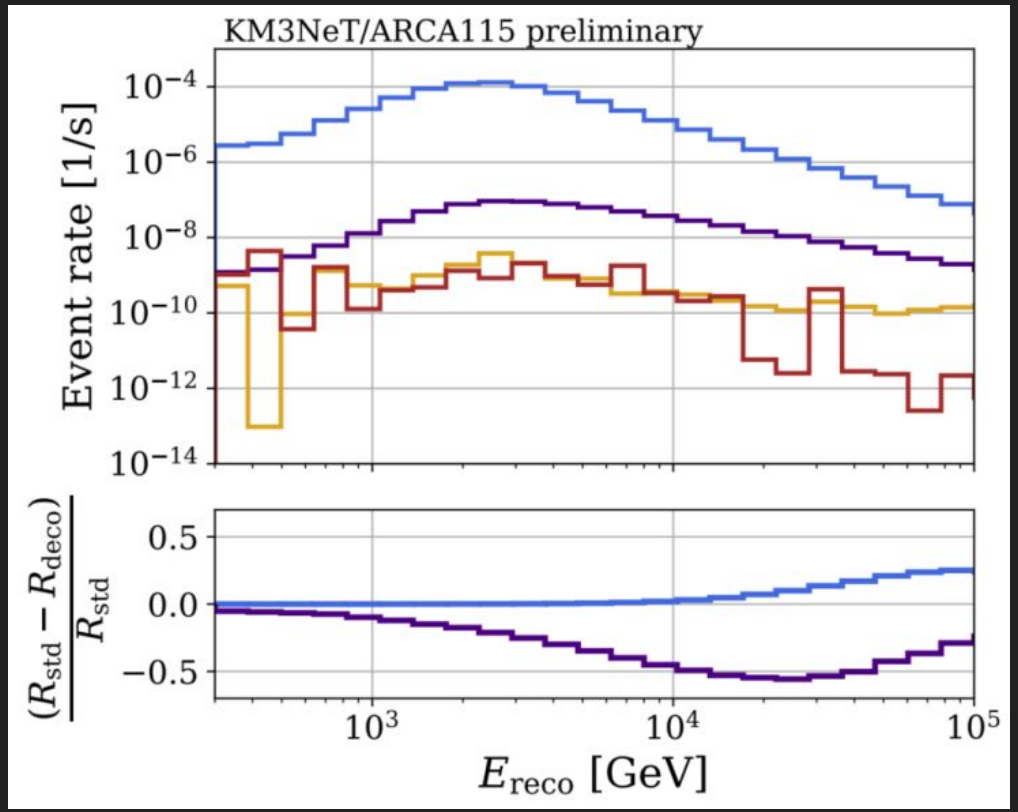
↓ SU(3) basis

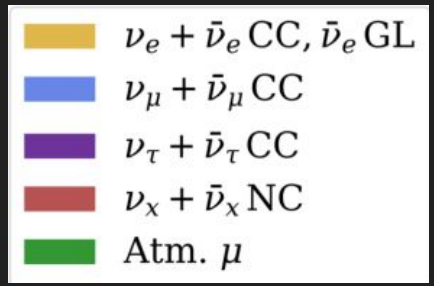
$$\mathcal{D}[\rho(t)] = (D_{\mu\nu}\rho^\nu)\lambda^\mu$$

$$D_{\text{phase perturbation}} = \text{diag}(0, \Gamma, \Gamma, 0, \Gamma, \Gamma, \Gamma, \Gamma, 0)$$

$$\Gamma(E_\nu) = \Gamma_0\left(\frac{E_\nu}{E_0}\right)^n$$

# Final sample

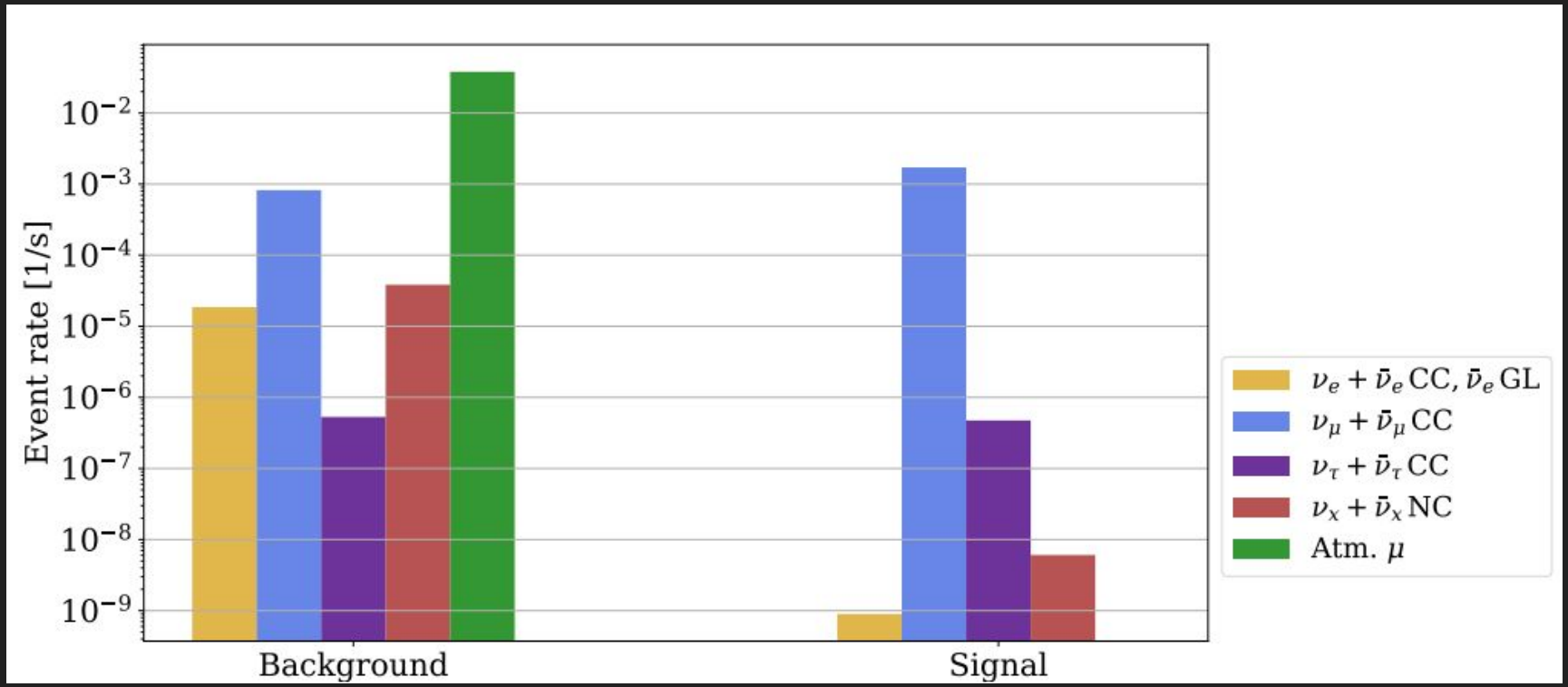


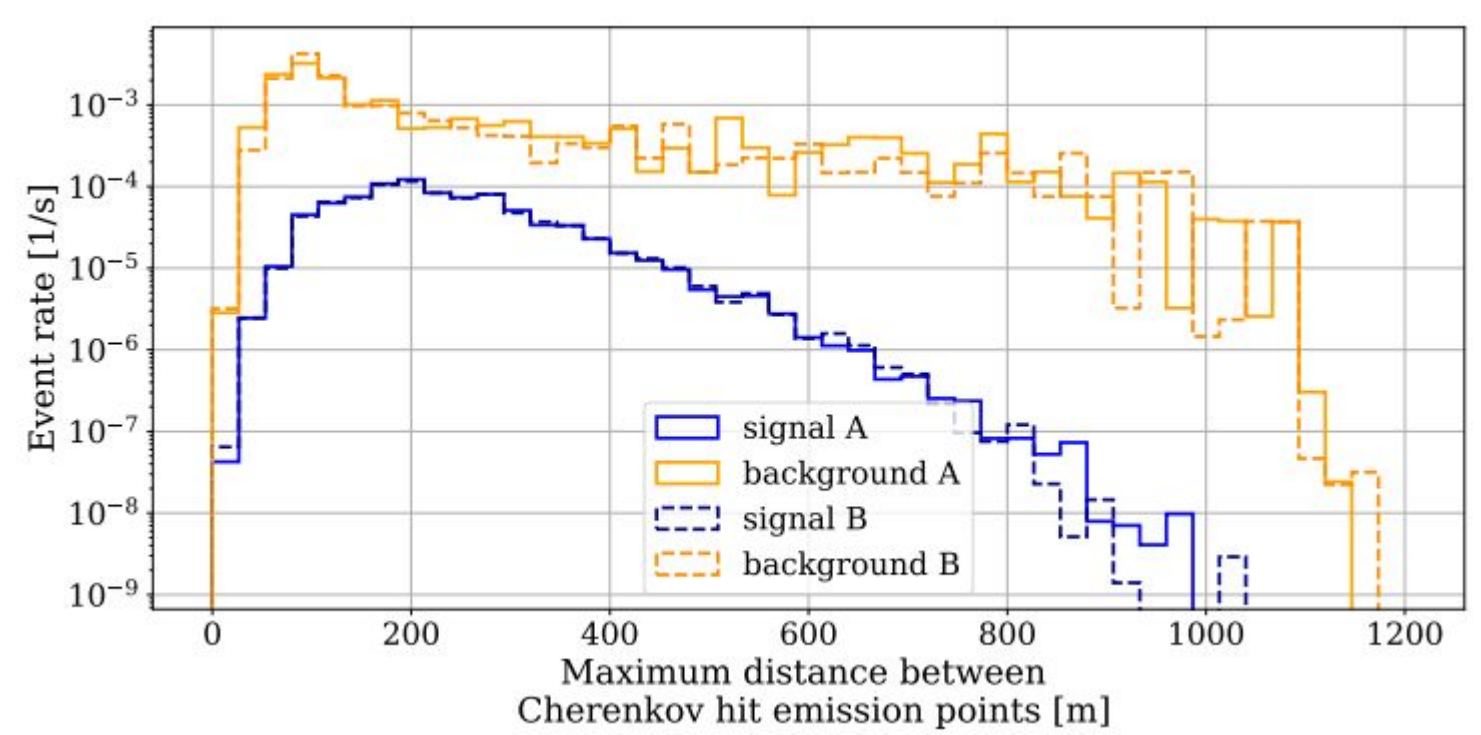

Before Boosted Decision Tree (BDT):
~ 800000 atm. muons/year

After cut BDT score:
~ 5 atm. muons/year

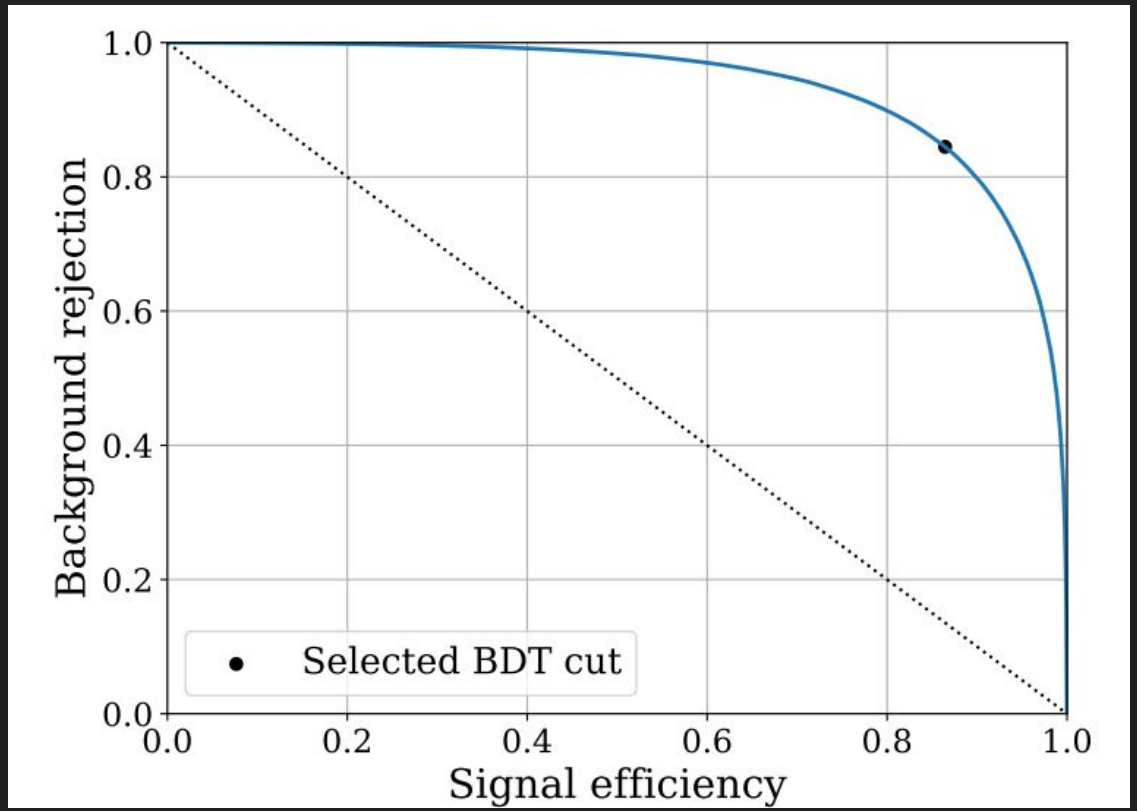
# Boosted Decision Tree training sample



# Boosted decision tree variables (example)



# Boosted decision tree performance



# Inside the Earth: attenuation and tau-regeneration