Heavy neutral leptons in di-muon final states @ FCC-ee

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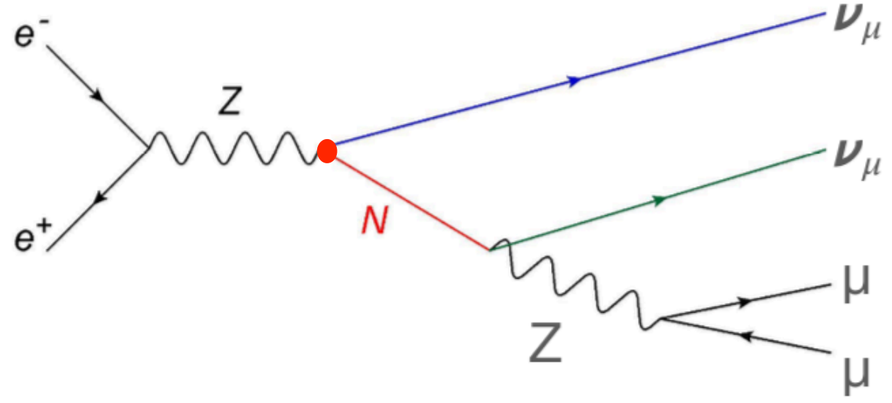
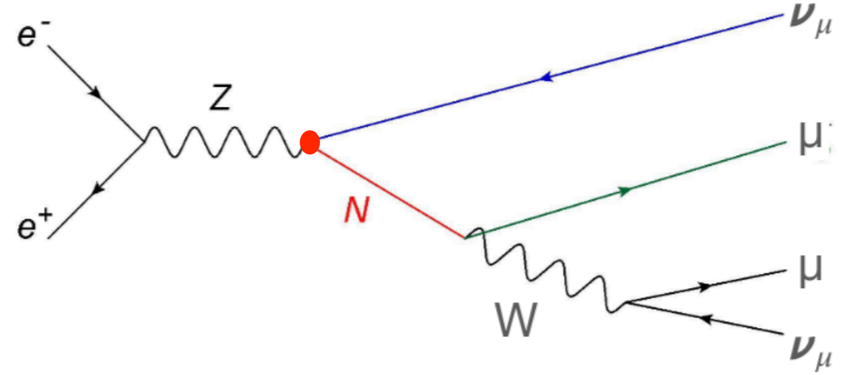
The simplest SM extension to account for the observation of ν oscillations would be RH partners of the LH νs allowing the νs to acquire a Dirac mass. Being EW and color singlet these new states also allow a Majorana mass which can also explain the lightness of the observed neutrino masses through the see-saw mechanism implying a large hierarchy between the EW scale and the masses of the new Majorana states N. The only way for the Ns to interact with the ordinary SM particles is via mixing with the ordinary νs.



For low values of the mixing coupling V_{mix} the Ns can have long decay length L (but also low cross-sections):

$$L \sim V_{mix}^{-2} \cdot m_N^{-5}$$



We assume that the Majorana Heavy Neutral Lepton (N) have mixing V_{mix} different from zero only with the ν_μ so that the only relevant decay modes are $N \to W\mu$ and $N \to Z\nu_\mu$ and we focus on final states with two muons and missing energy.

Signal samples

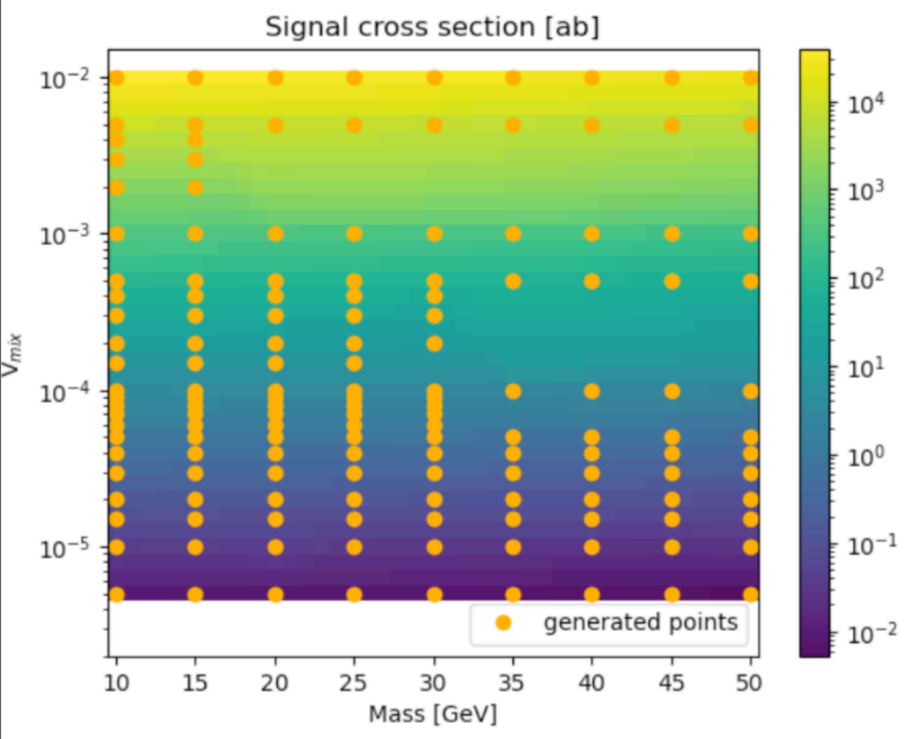
UFO model: SM_HeavyN_CKM_AllMasses_LO.tgz → https://feynrules.irmp.ucl.ac.be/wiki/HeavyN

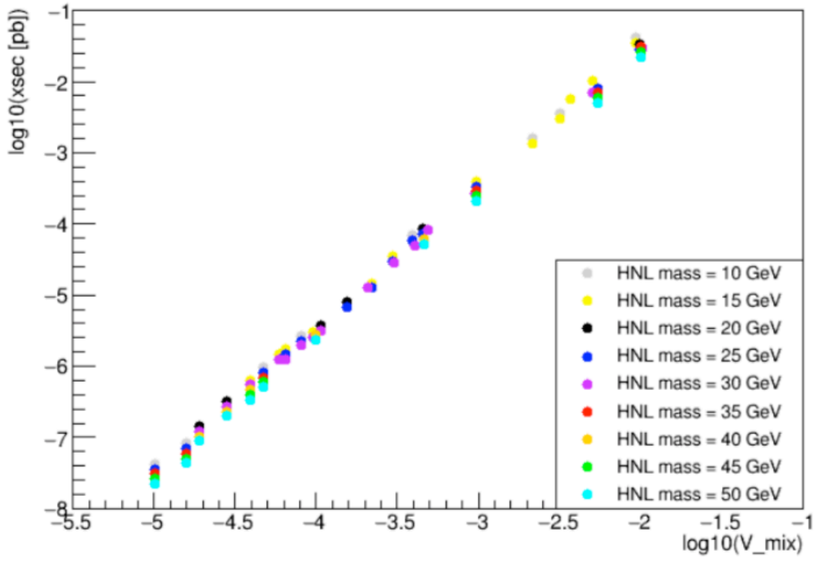
Samples of events (2000 events for each sample) in e+e- interactions at $\sqrt{s}$=91.6 GeV have been generated using MadGraph5_aMC@NLO v3.5.0. The samples have been generated for N masses in the range 10–50 GeV and V_{mix} in the range 10^{-2} – $5 \cdot 10^{-6}$.

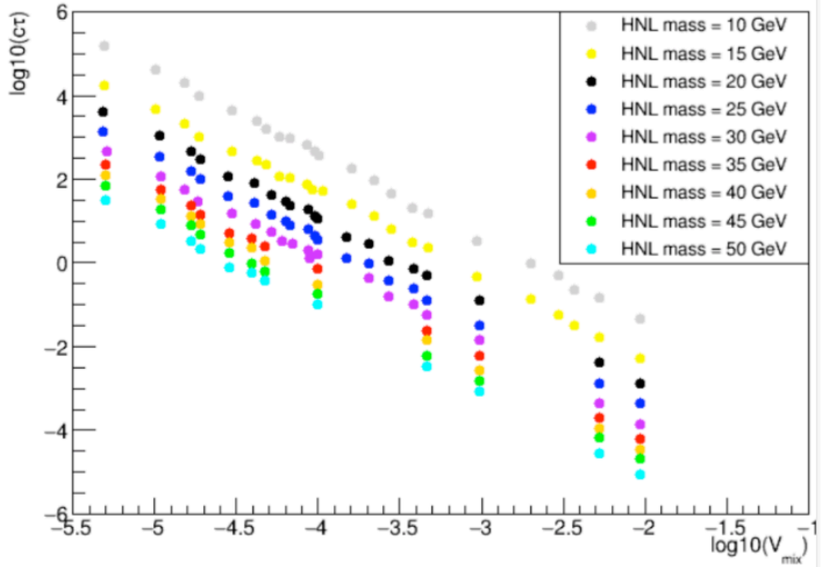
Standard EDM4HEP tools used:

- to process the LHE signal samples with Pythia8 (PS and hadronization) and Delphes (version Winter 2023)
- for the pre-selection and the production of the ntuples for the following analysis

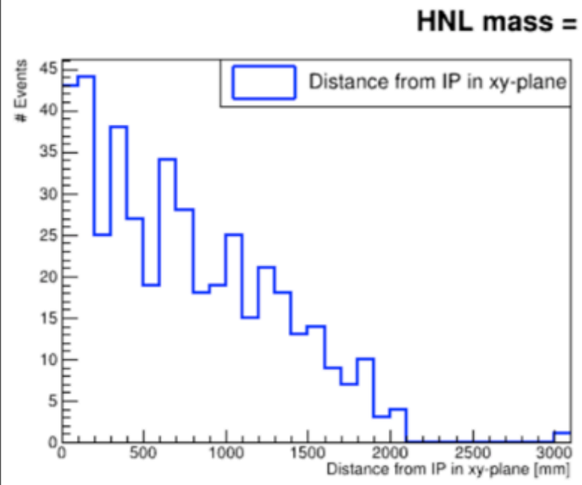
The minimal requests for the preselection are exactly two tracks in the central detector reconstructed as muons with p>3GeV.

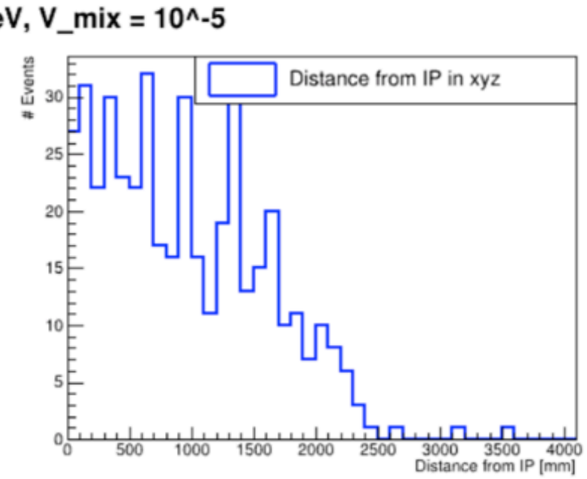


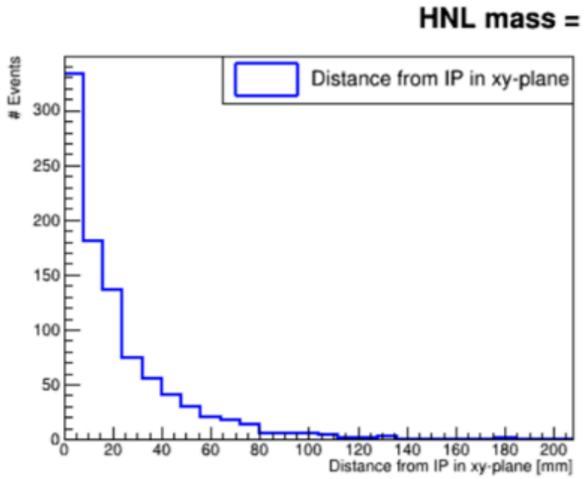


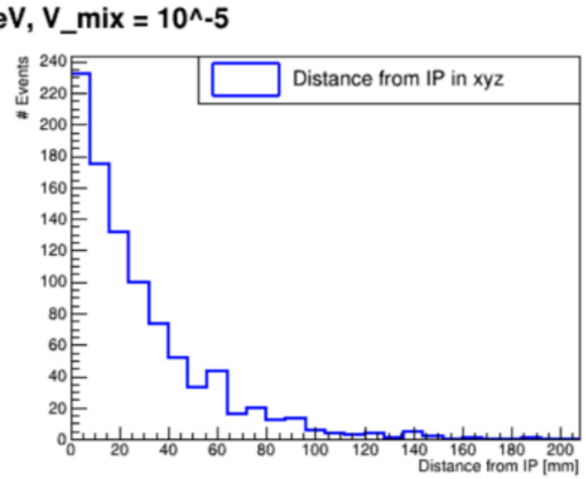


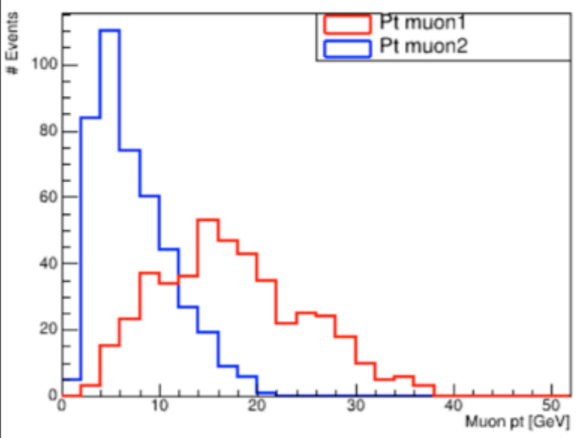
Distribution of few reconstructed variables for two generated points

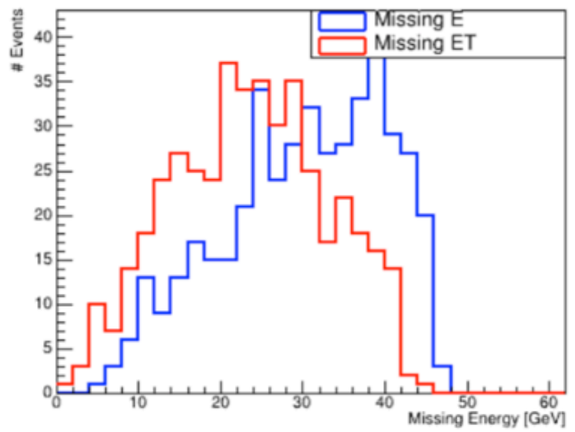


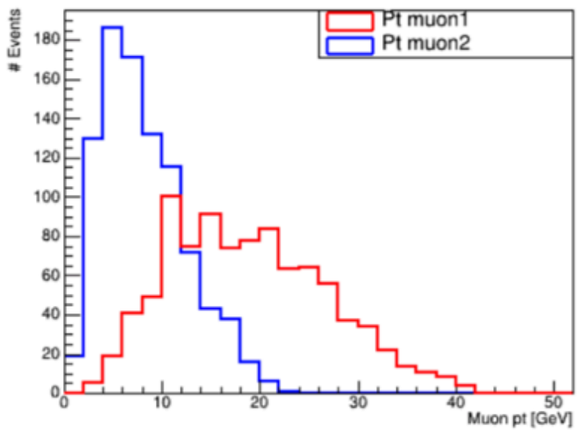


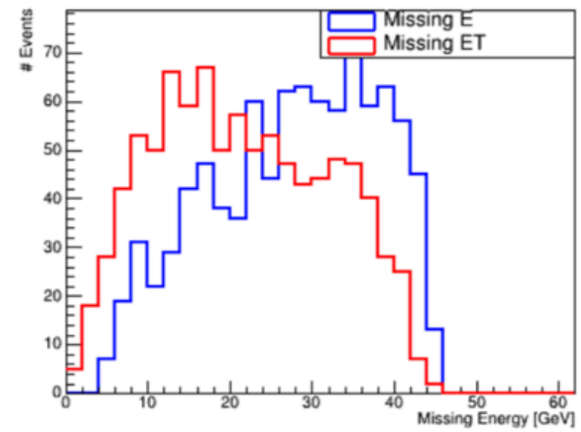






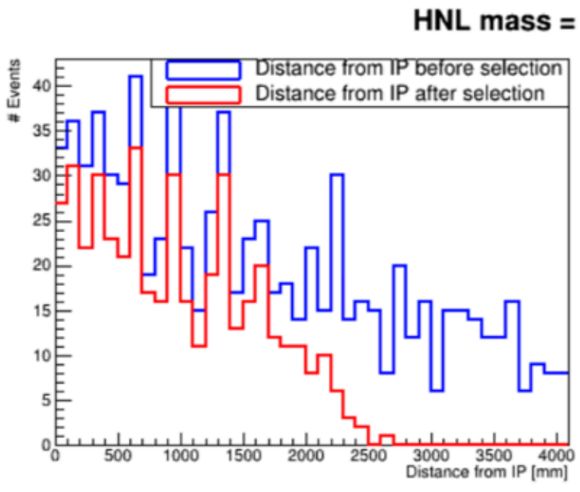


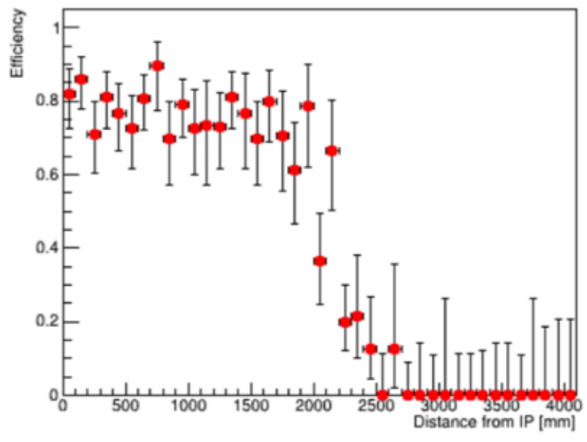


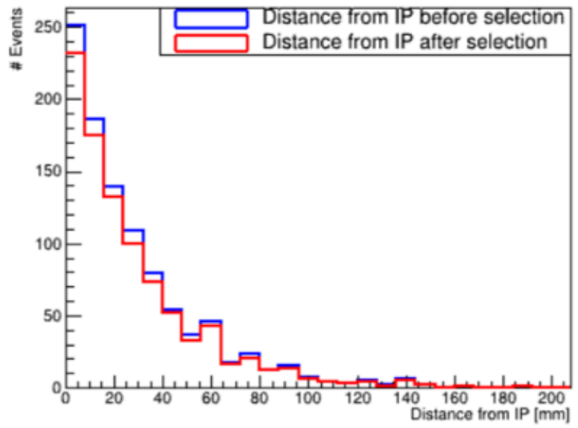


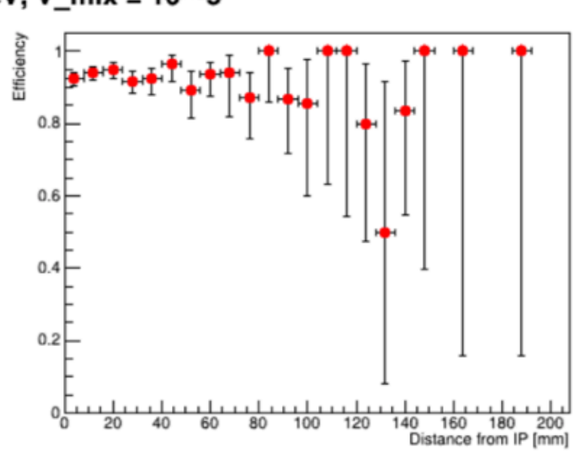
Displaced vertex → main selection cut for signal/bkg separation

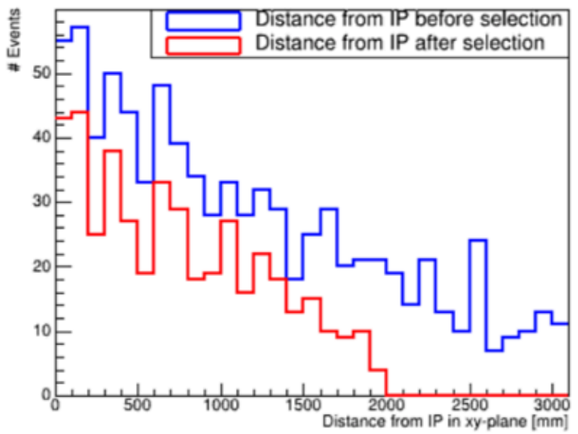
Pre-selection efficiency as a function of the distance of the displaced vertex from the interaction point

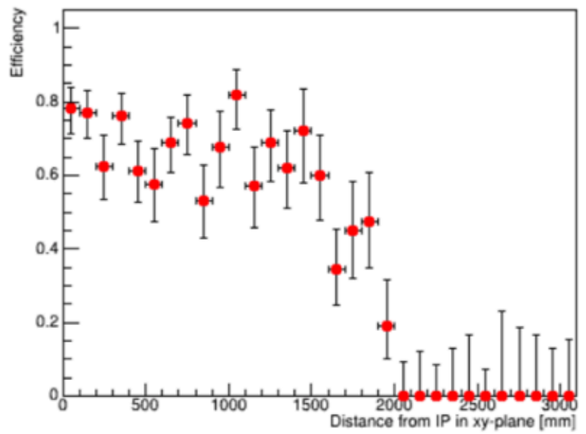


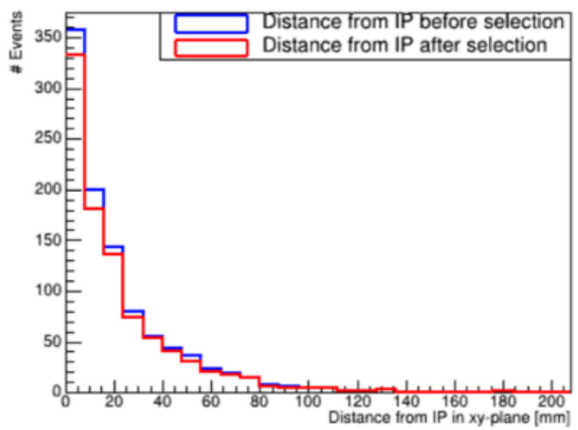


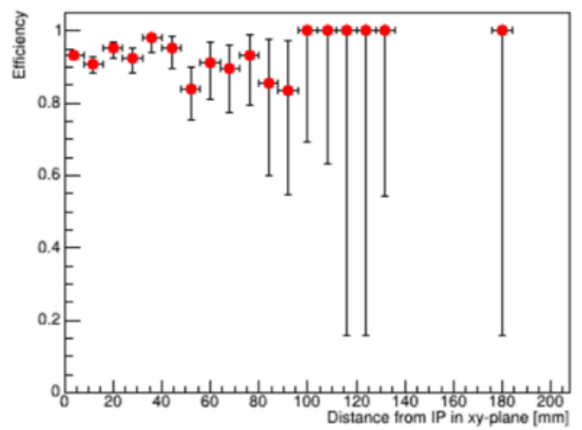












Background samples

Central production → Spring 2021

Process	Number of events	Cross section [pb]	Integrated luminosity [fb^{-1}]
$Z \to \mu\mu$	10^7	1462.8	6.836
$Z \to \tau\tau$	10^7	1476.58	6.772
$Z \to bb$	10^9	6645.46	150.47
$Z \to cc$	10^9	5215.46	191.74

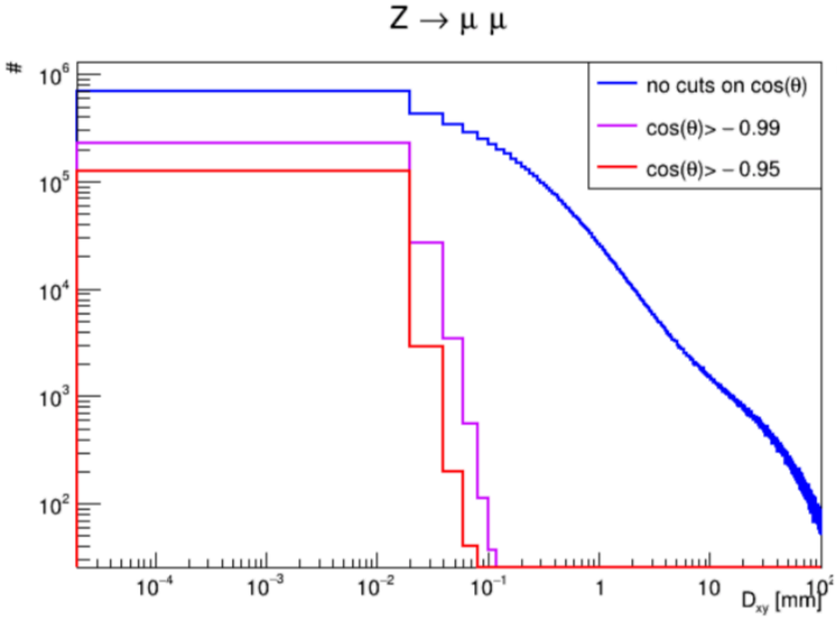
several orders of magnitude less than needed

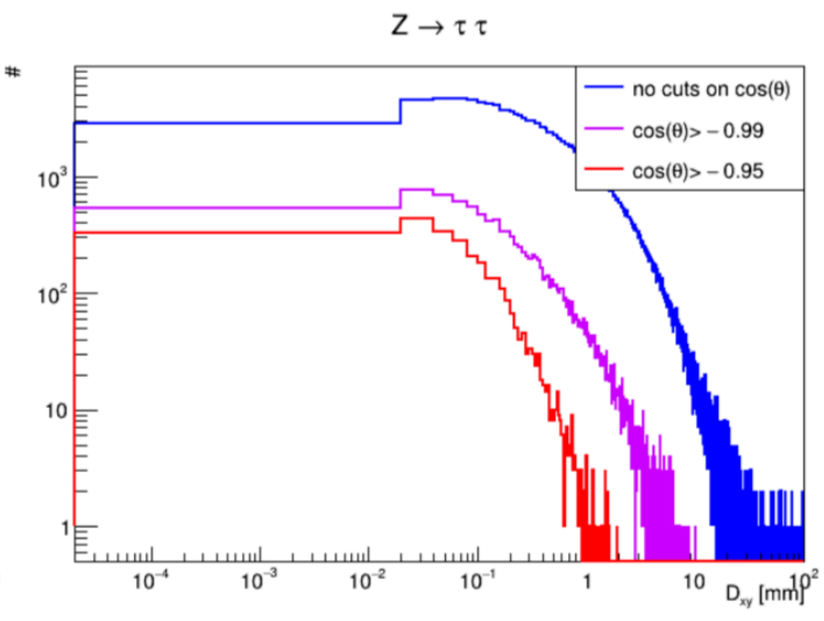
Same pre-selection as the signal samples:
exactly two tracks in the central detector reconstructed as muons with p>3GeV

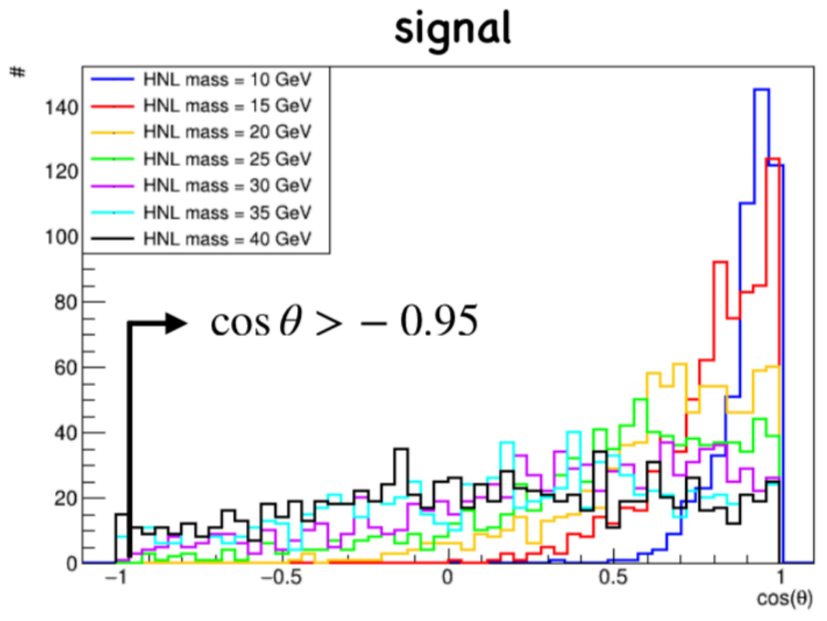
D_{xy}= distance reconstructed 2μ-vertex - interaction point

large tails towards high values due to bad vertex reconstruction for back-to-back tracks

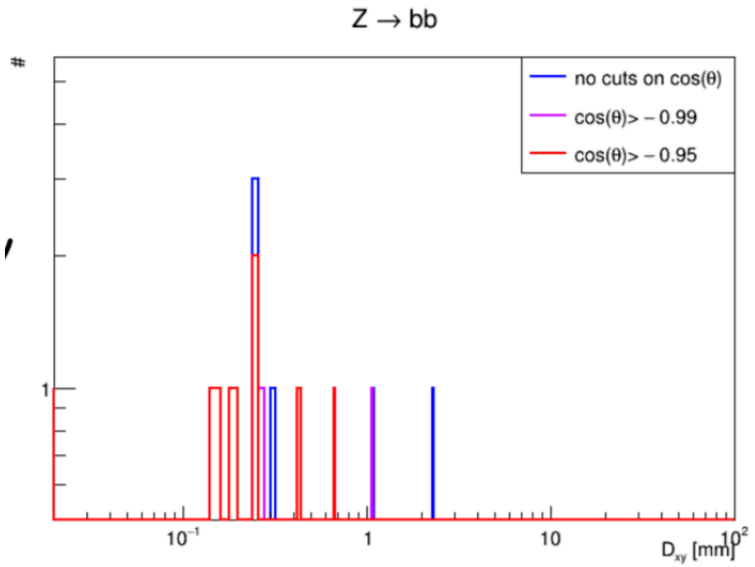
→ introduced a cut on $\cos\theta$

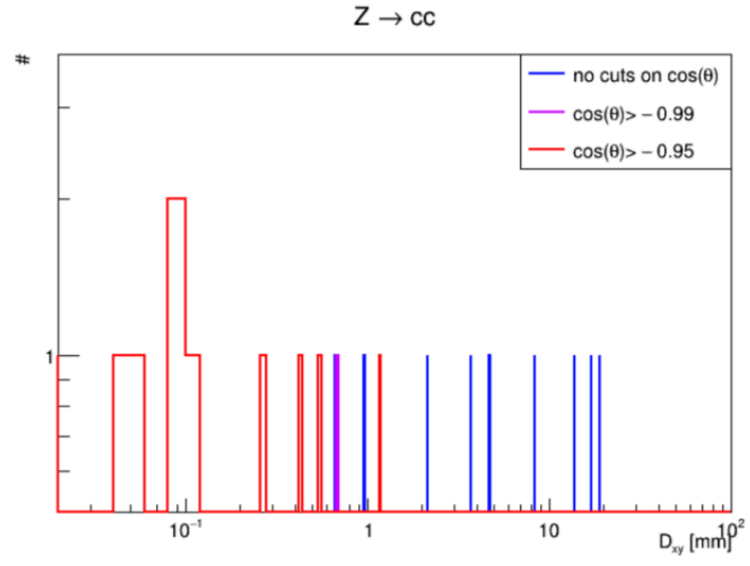


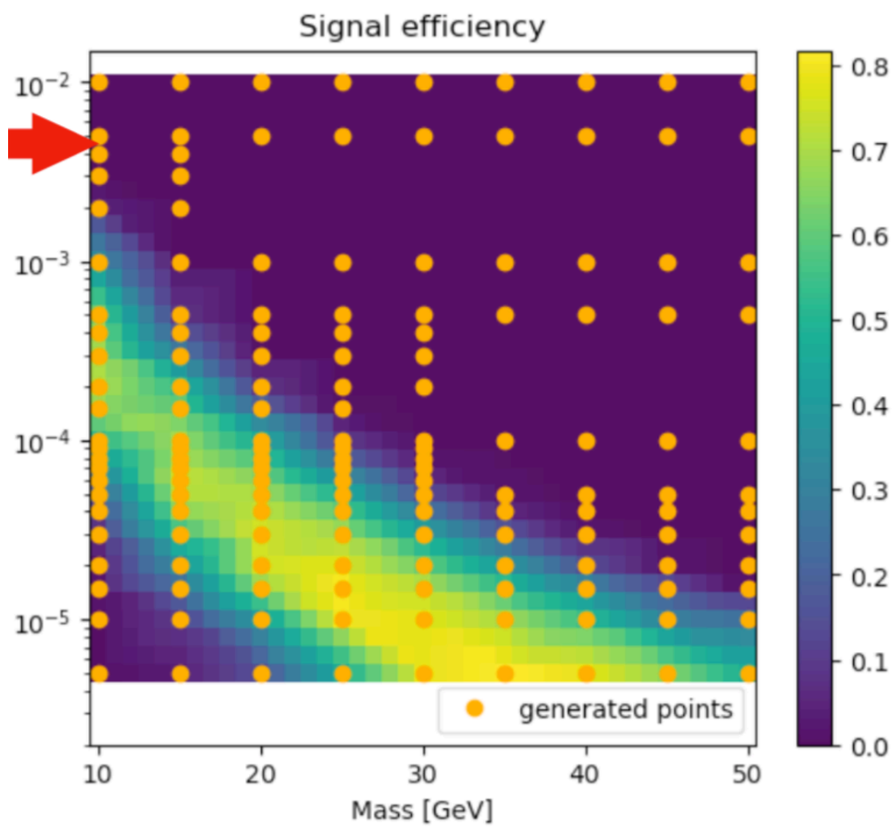


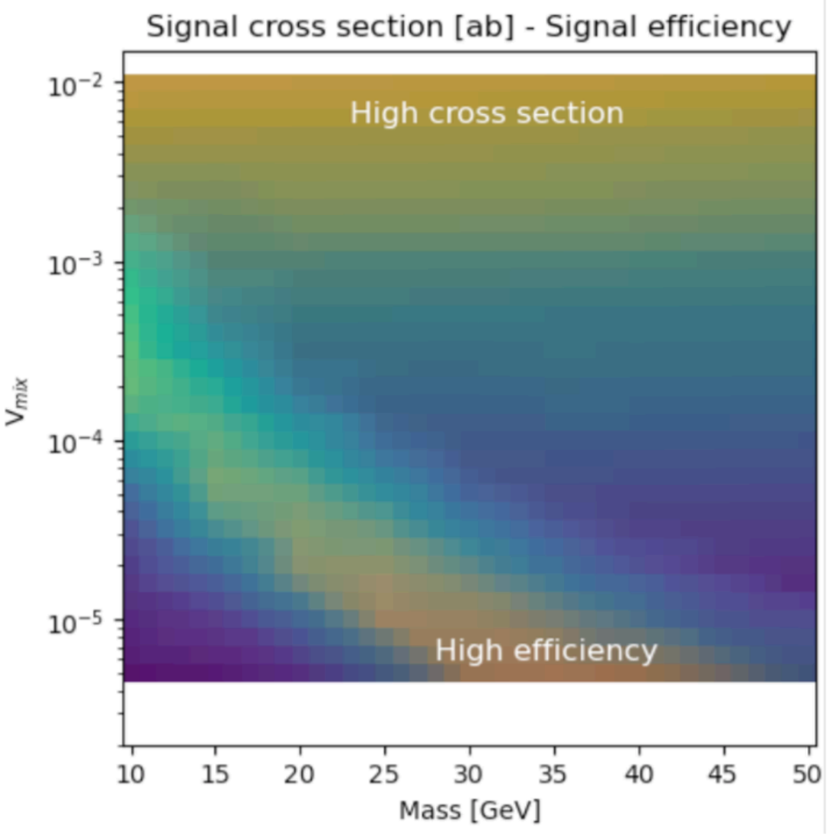


Optimization of D_{xy} cut requires a reliable background estimation with larger samples. At the moment the estimated sensitivity was evaluated for D_{xy} > 1/3/10 cm assuming negligible background.





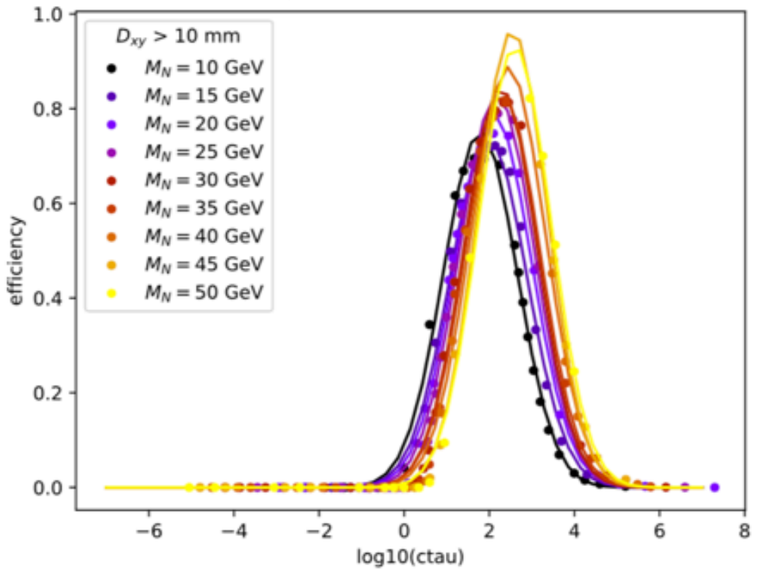


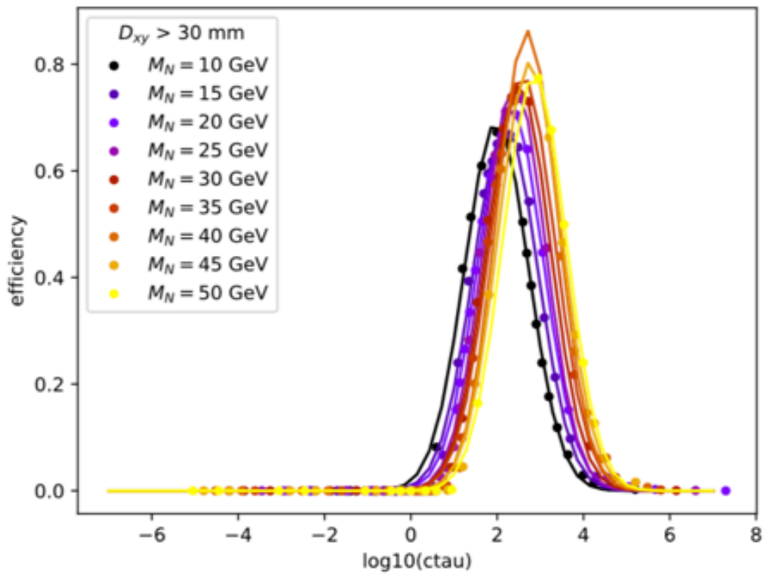


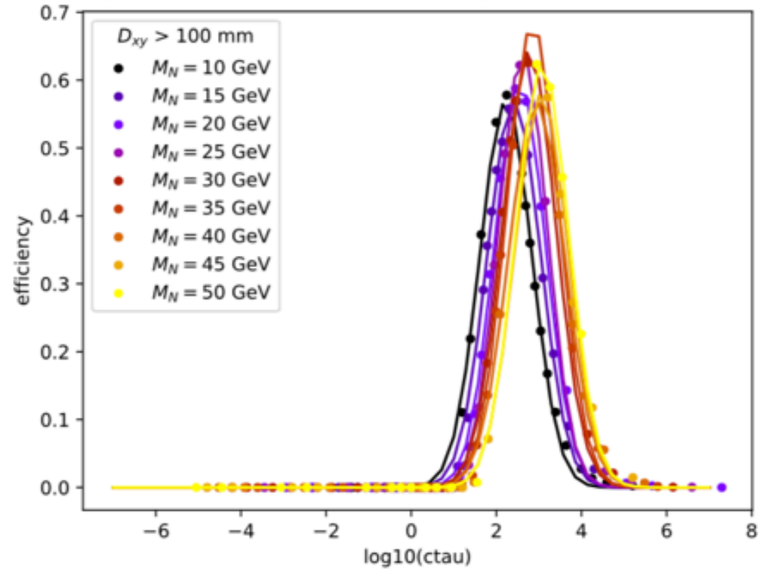
Final selection:

- preselection
- cos(θ) > -0.95
- D_{xy} > 1 cm

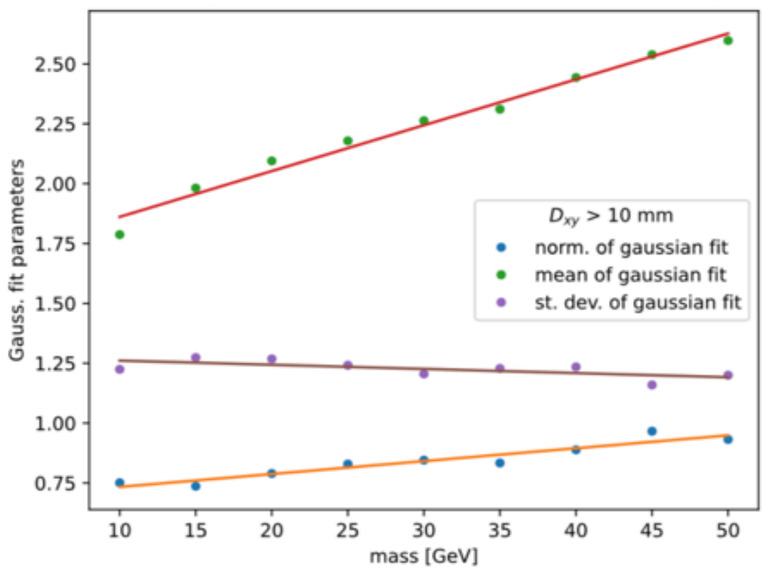
efficiency parametrized for each mass sample as a function of the decay length by means of gaussian fits

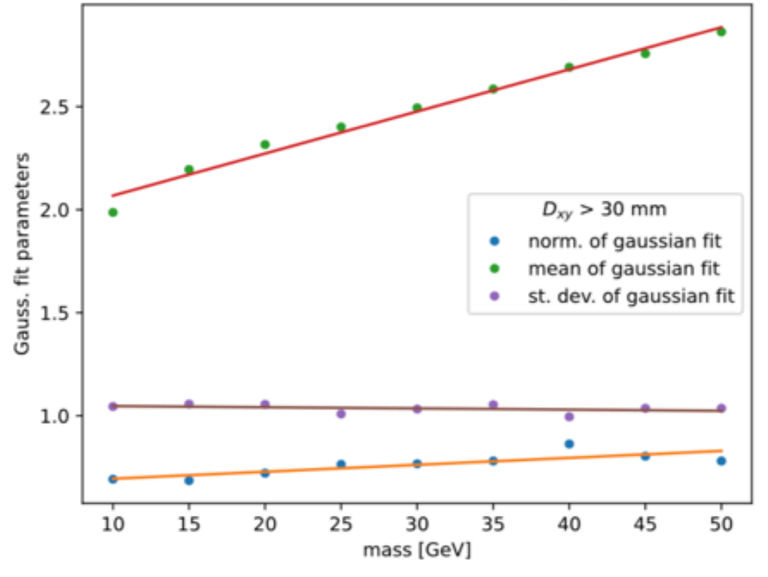


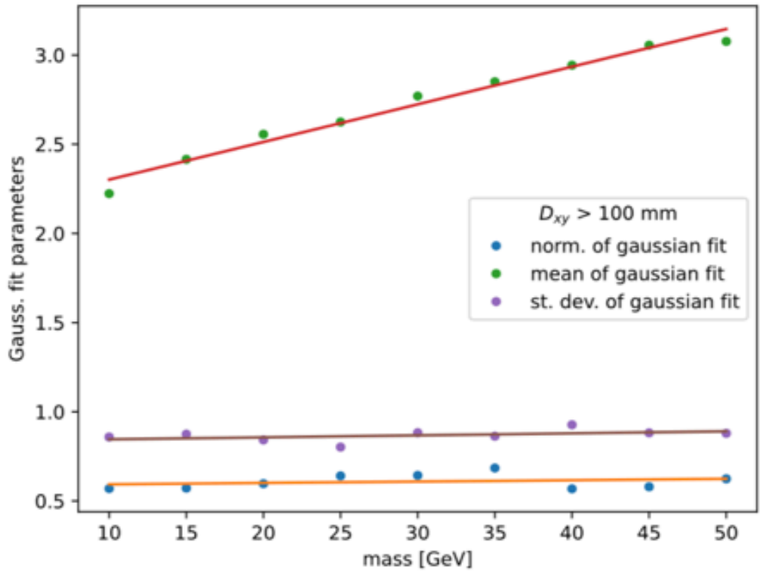




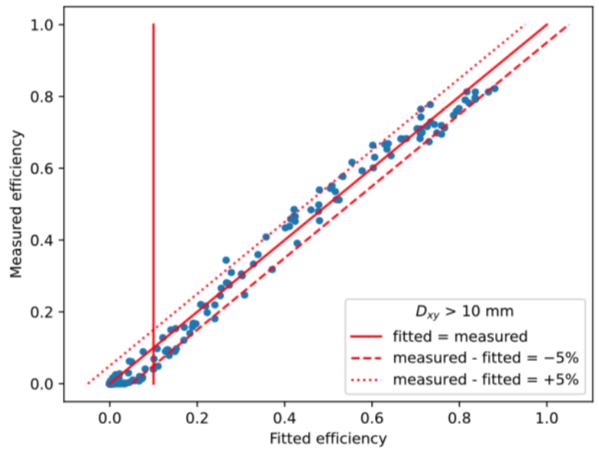
interpolation between mass points using linear fits on the gaussian fit parameters

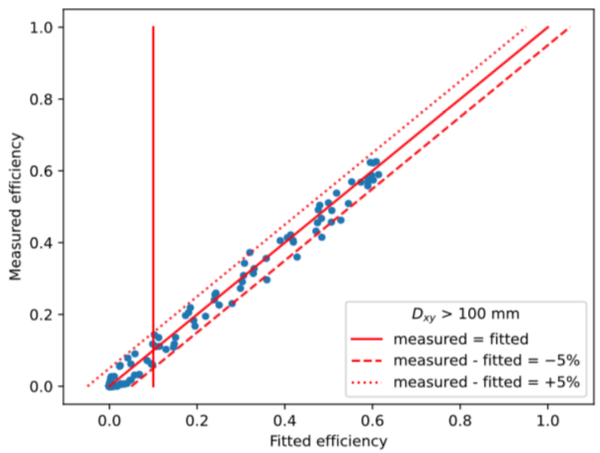


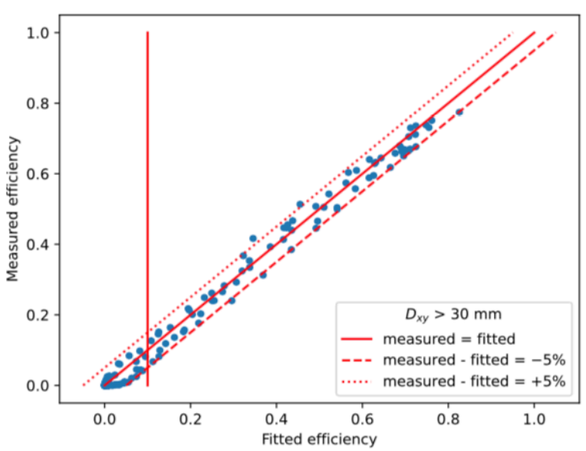




fitted vs measured efficiency



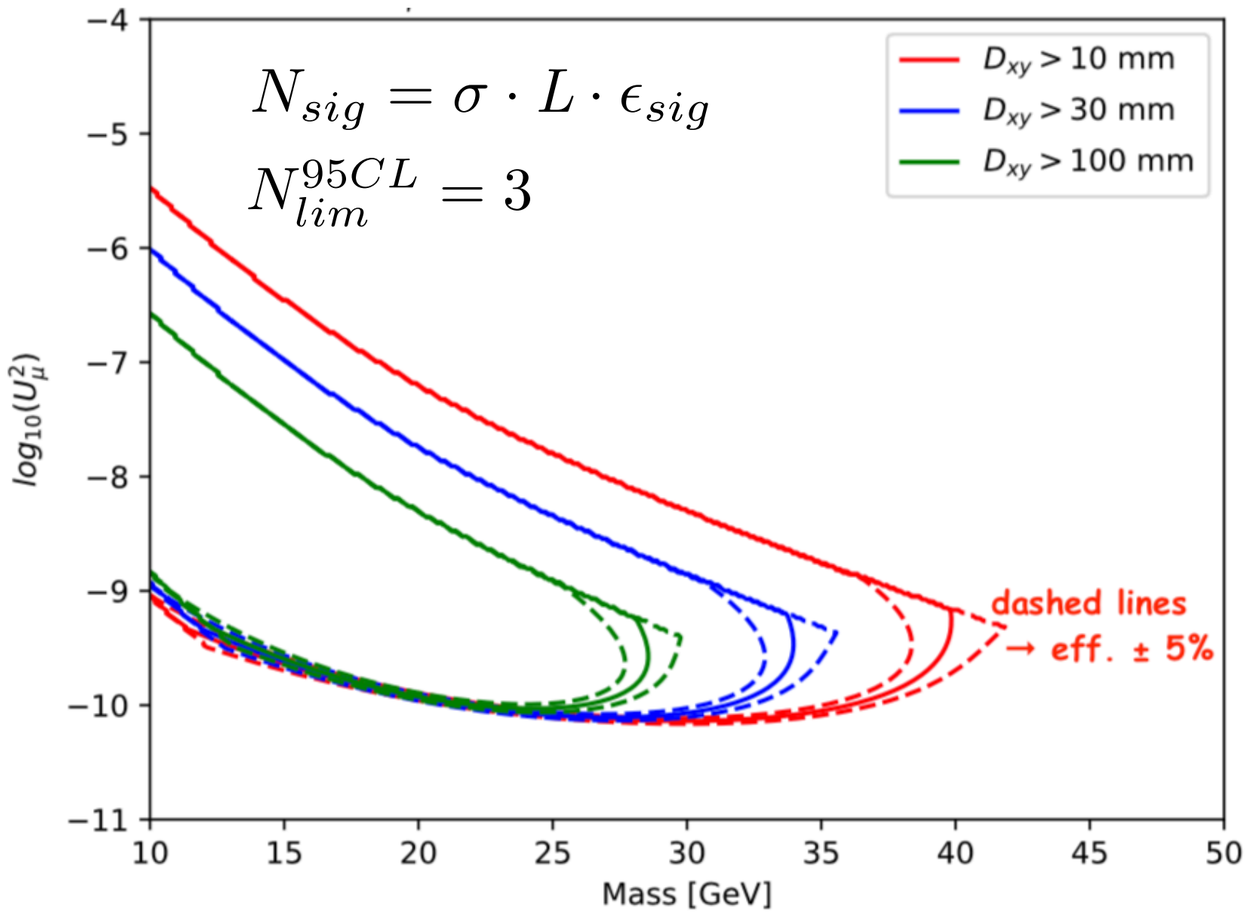




parametrization not reliable for very low efficiencies

efficiency set to 0 if < 0.1

95% CL limits (L = 150 ab^{-1})



Future plans

The LLP WG aims for a publication by the end of the year
Other ongoing analysis:
HNL→ejj
HNL→eenu
HNL→mujj

Still under discussion if one single paper or two (one for the electron and one for the muon channels)

Next step: summarize the work done so far in a document and then consider whether it is feasible to join the effort