# UPDATE ON HNLs AT FCC-ee

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18/03/2024

# CURRENT STATUS

- SIMULATION: update on $\ell\ell\nu\nu$ background and signals
- ANALYSIS: looked at a few cuts and related significance
- ARTICLE: drafted most of it

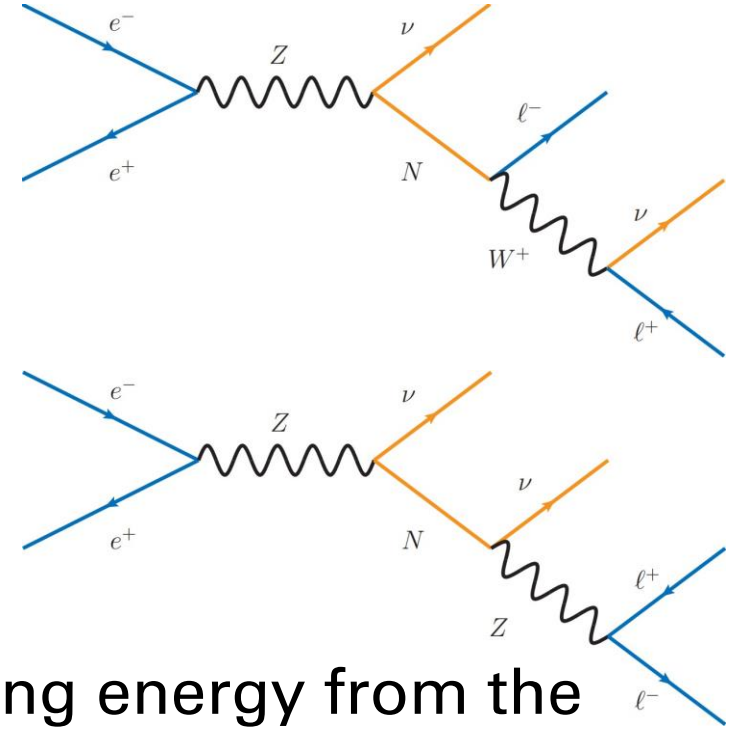
# HNLs SIGNAL

- 2 heavy neutral leptons (right-handed neutrinos) from the type I see-saw mechanism
- FCC-ee with IDEA detector, $\sqrt{s} \simeq 91.188\ GeV$

$$\boldsymbol{e^+e^- \rightarrow Z \rightarrow N_{1,2}\nu_\ell}$$

$$\boldsymbol{N_{1,2} \rightarrow \ell^+\ell^-\nu_\ell}$$

with $\ell = e, \mu, \tau$ and $\tau \rightarrow \nu_\tau \nu_e e$ or $\tau \rightarrow \nu_\tau \nu_\mu \mu$



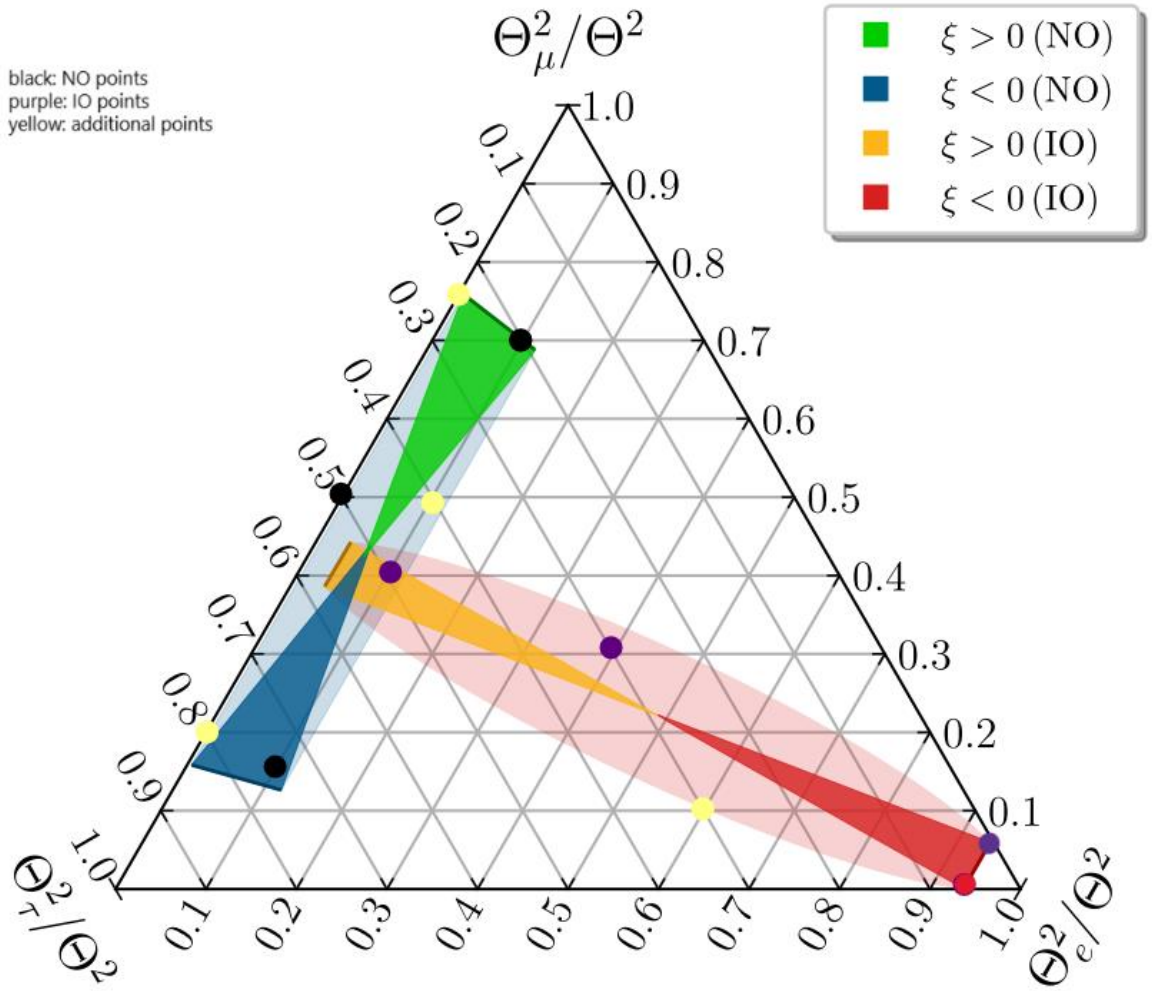

- Two leptons (e or $\mu$) are reconstructed with missing energy from the neutrinos (at least two)

# HNLs SIGNAL

- Parameters: two HNLs masses (10-80 GeV) and mixing matrix with the SM leptons
- The points chosen cover the areas compatible with oscillation data and leptogenesis
- Symmetry in type I see-saw:

$$\Delta M_{1,2} \ll \frac{M_1 + M_2}{2} = 1 \cdot 10^{-5}\ GeV \rightarrow U_{\ell 1} \simeq iU_{\ell 2}$$

- Set $U_{1,2\mu}$ to three values $(1 \cdot 10^{\{-4,-5,-6\}})$ in LLP range $(GenL_{xyz} > 10\ mm)$ then use the ratio to get the rest of the angles




https://arxiv.org/pdf/2307.07476.pdf

# SIMULATION

- Stage1 of FCCAnalyses (construction of variables) is done for all background samples available from Winter 23 campaign
- I wasn't able to produce a sufficient number of events for $\ell\ell\nu\nu$ in MadGraph but I was able to do $e\mu\nu\nu$ (ee, $\mu\mu, e\mu$) and $\tau\tau\nu\nu$ separately with 1M event each -> it doesn't take into consideration diagrams with $e\tau\nu\nu$ and $\mu\tau\nu\nu$
- It's not possible at the moment to use re-weighted samples in FCCAnalyses so the simulation of signals needs to happen after having figured out the cuts to see the least amount of samples needed

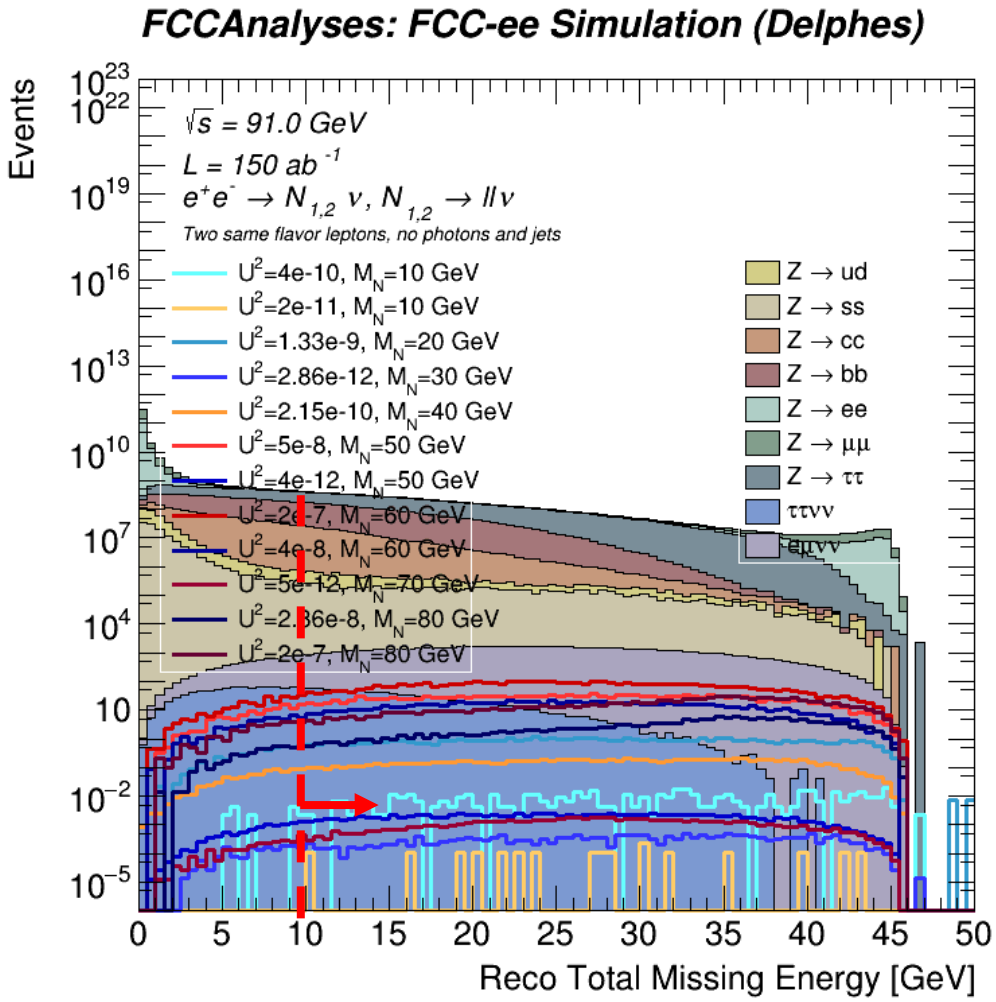
FCCAnalyses fork

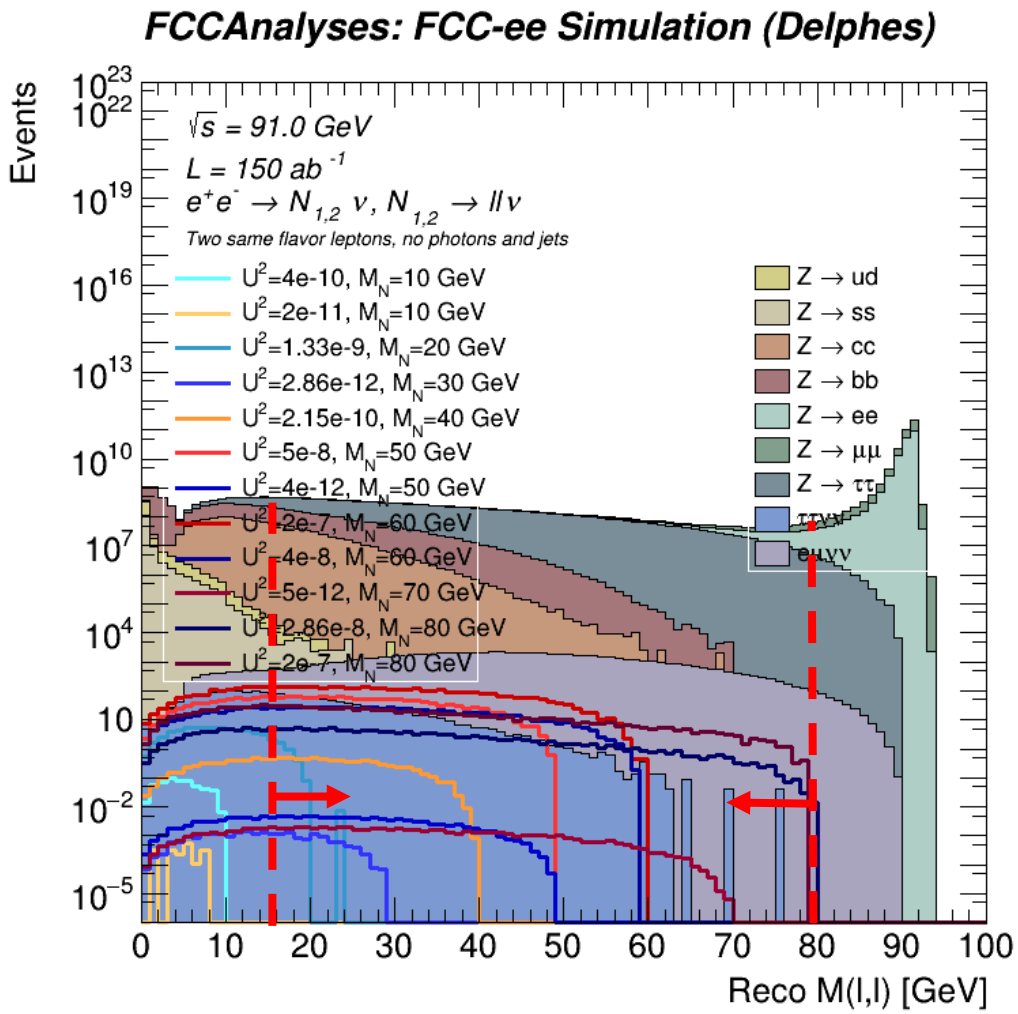
# ANALYSIS – SAME FLAVOR

These are the cuts that work better: more on spreadsheet and eos

1. Vetoes: two leptons (ee or $\mu\mu$), no photons, no jets (kt exclusive with n=0)
2. Invariant mass: $15 < M(\ell, \ell') < 80\ GeV$ (what we had in the thesis)
3. Missing energy: $ME > 10\ GeV$
4. Lepton momentum: $p < 42\ GeV$
5. Cosine of the angle between the leptons: $cos\theta > (-0.8)$
6. Missing theta (angle associated to the missing energy/momentum): $0.2 < \mathrm{ME}_{\theta} < 3$

# ANALYSIS – SAME FLAVOR



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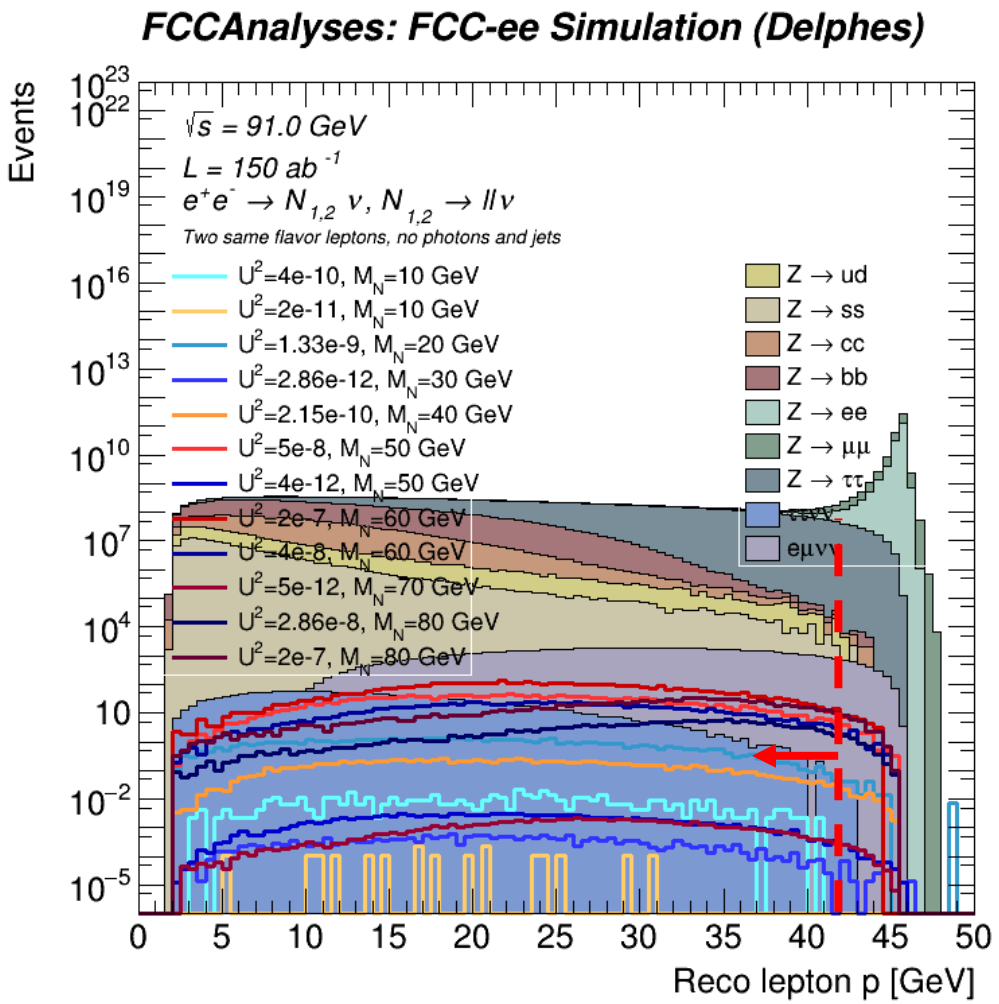


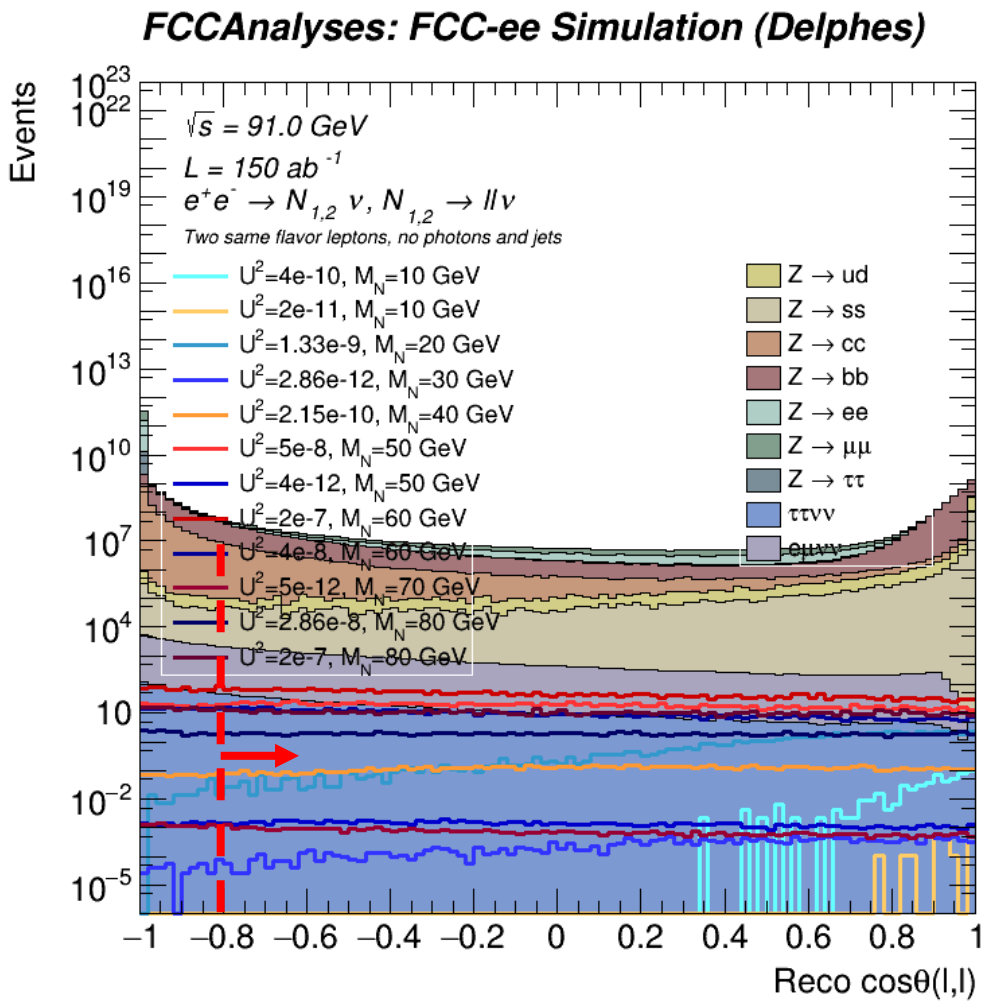


Shown only the leading lepton but the cut is on both leptons

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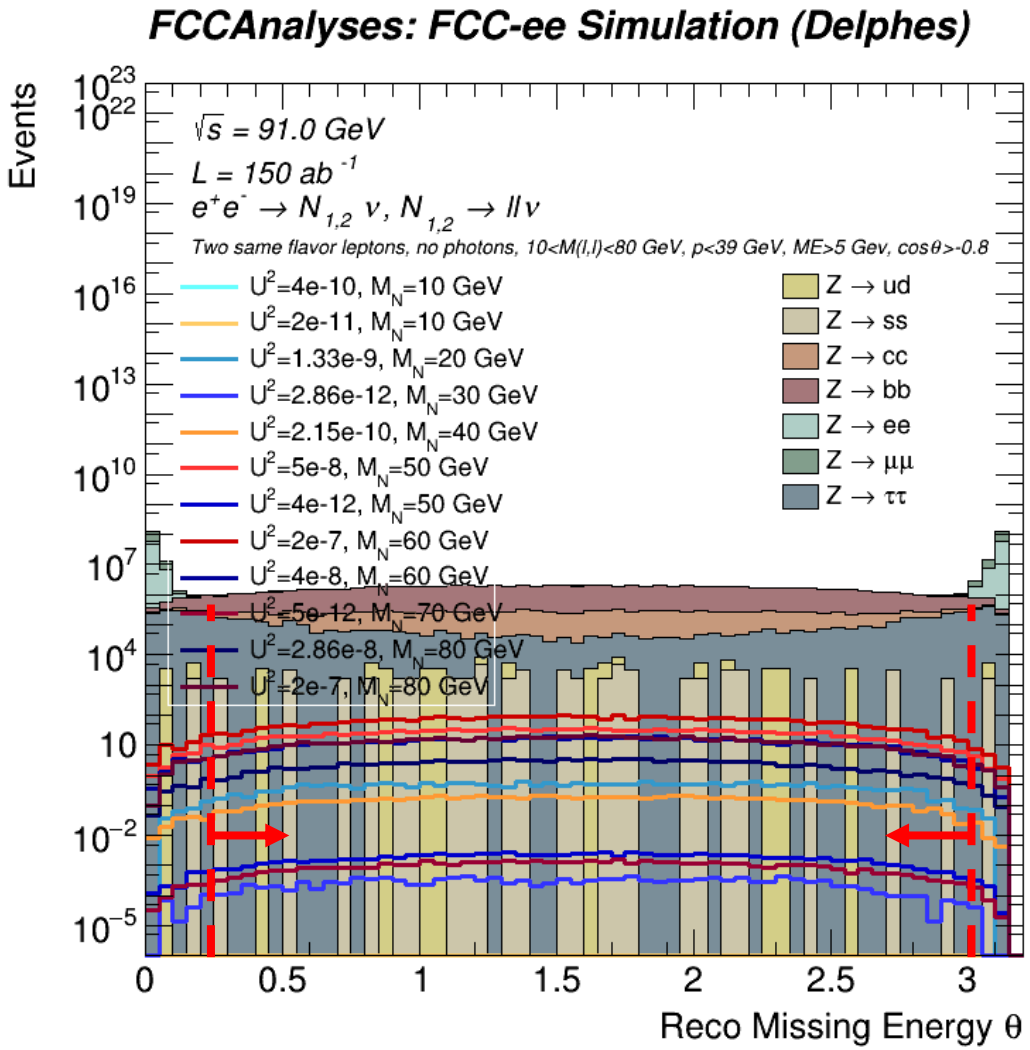
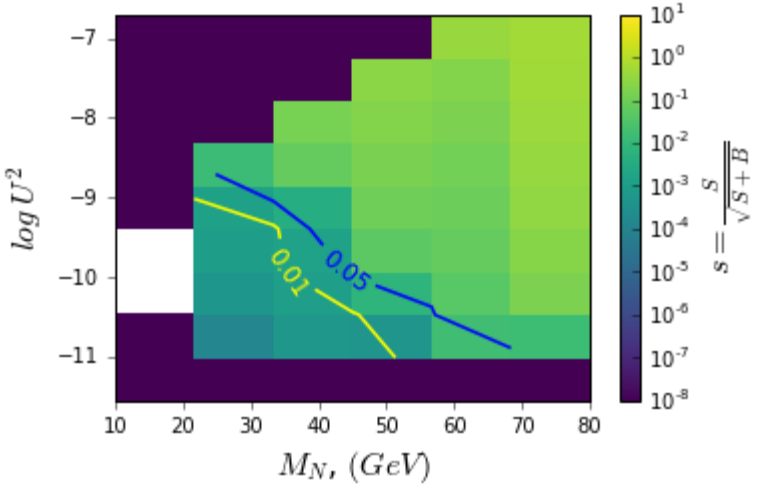



Older version with different cuts applied but it's very similar

# ANALYSIS – SAME FLAVOR

Significance $s = \frac{S}{\sqrt{S+B}}$ from these cuts:

SF $15 < M_{inv} < 80, ME > 10, p < 42, cos\theta > -0.8, 0.2 < ME_{\theta} < 3$

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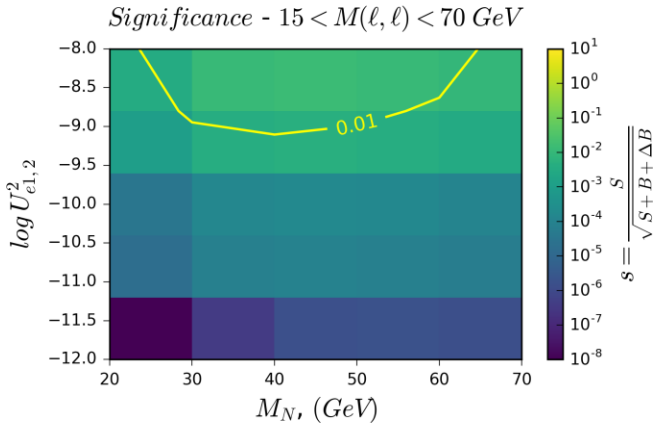


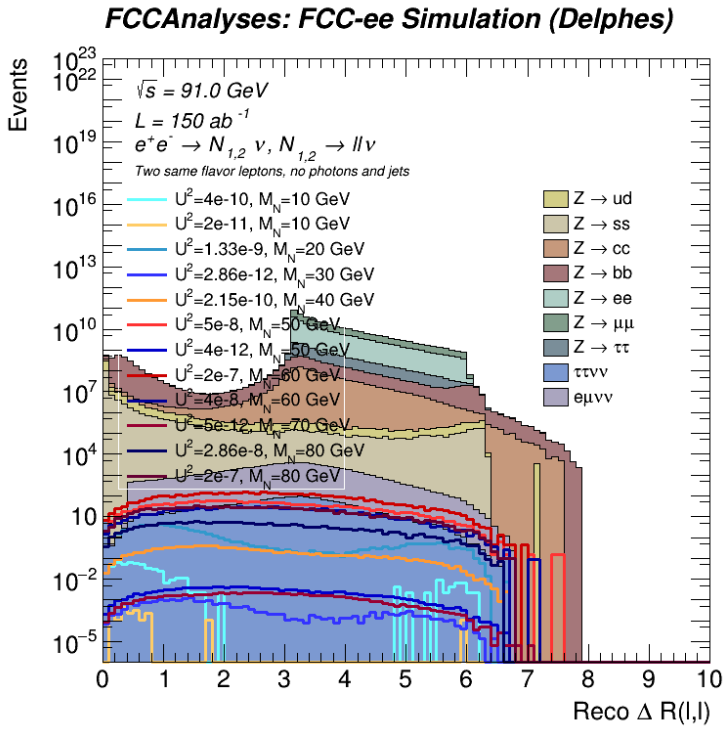


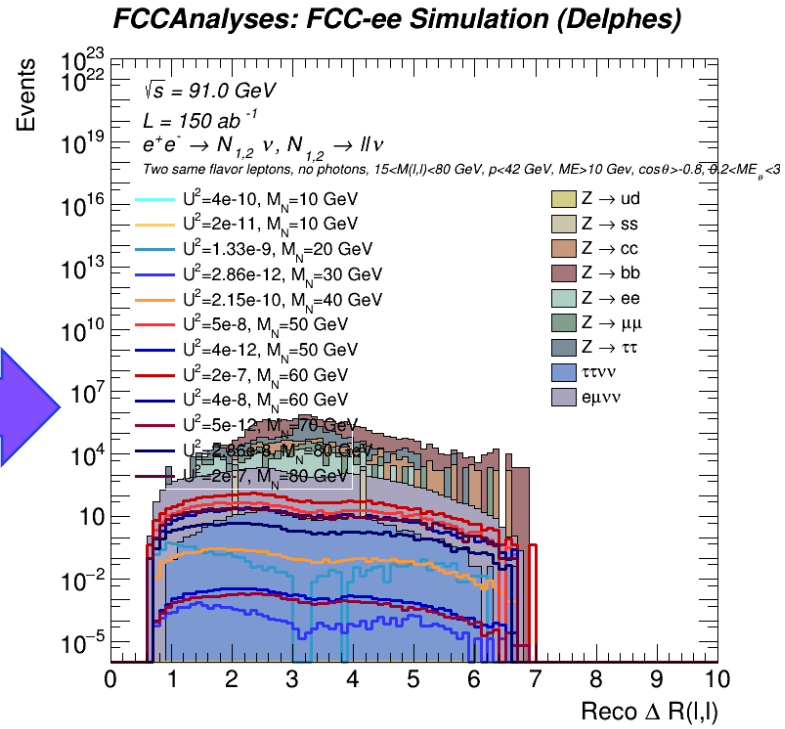

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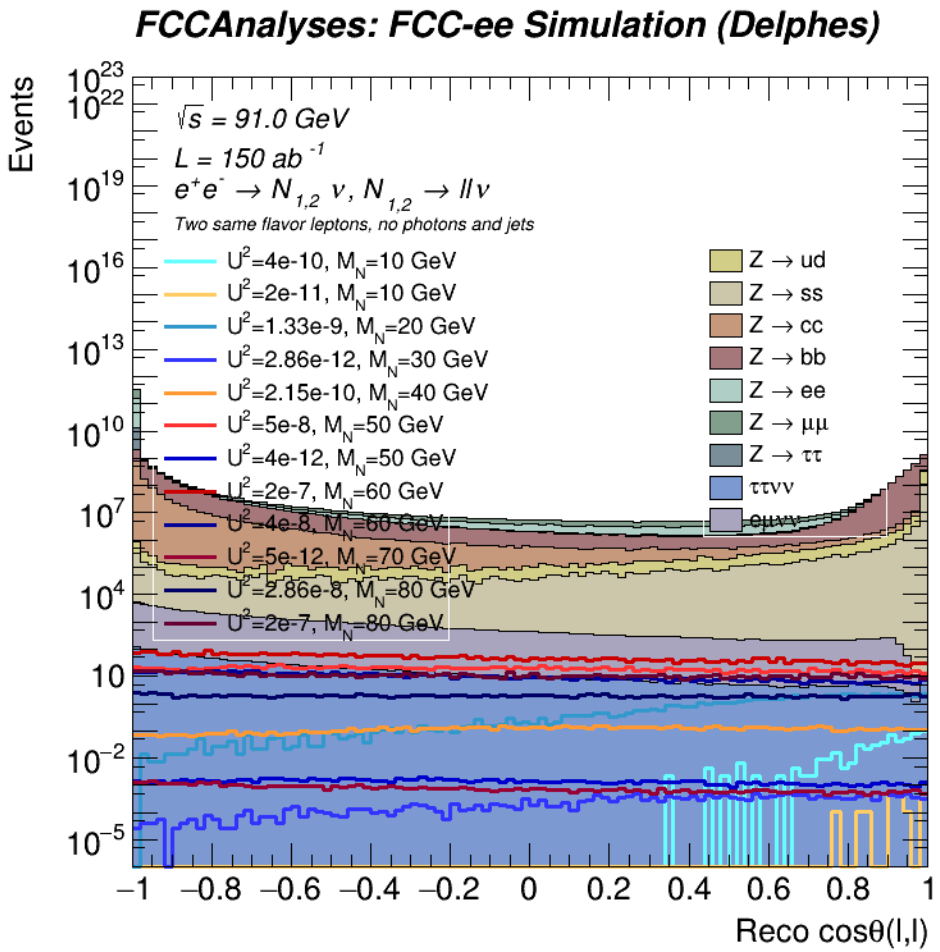


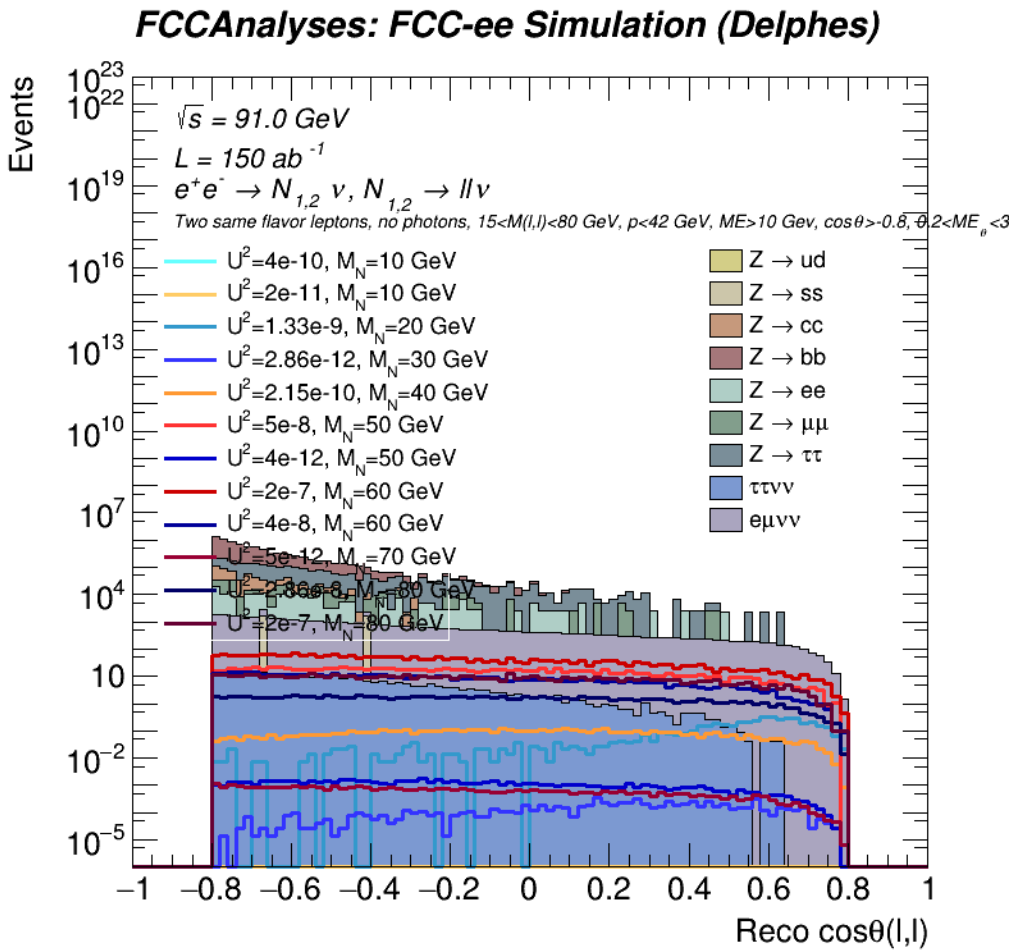

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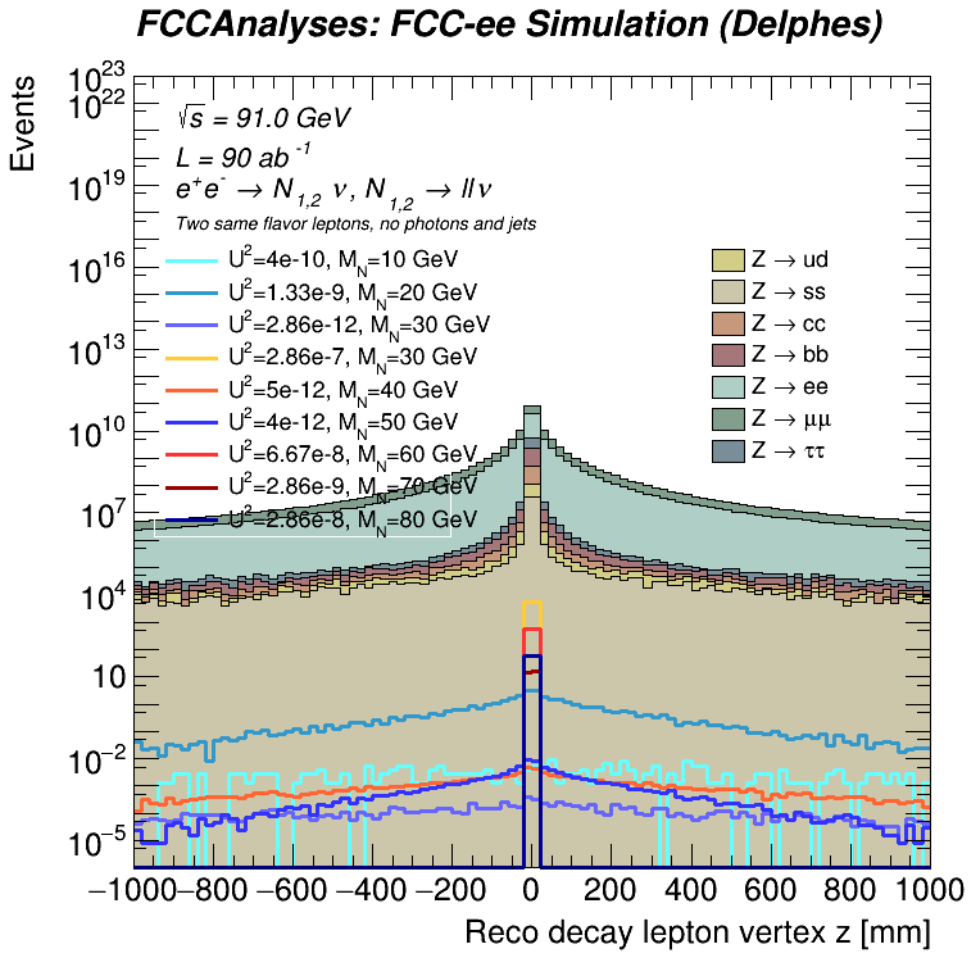


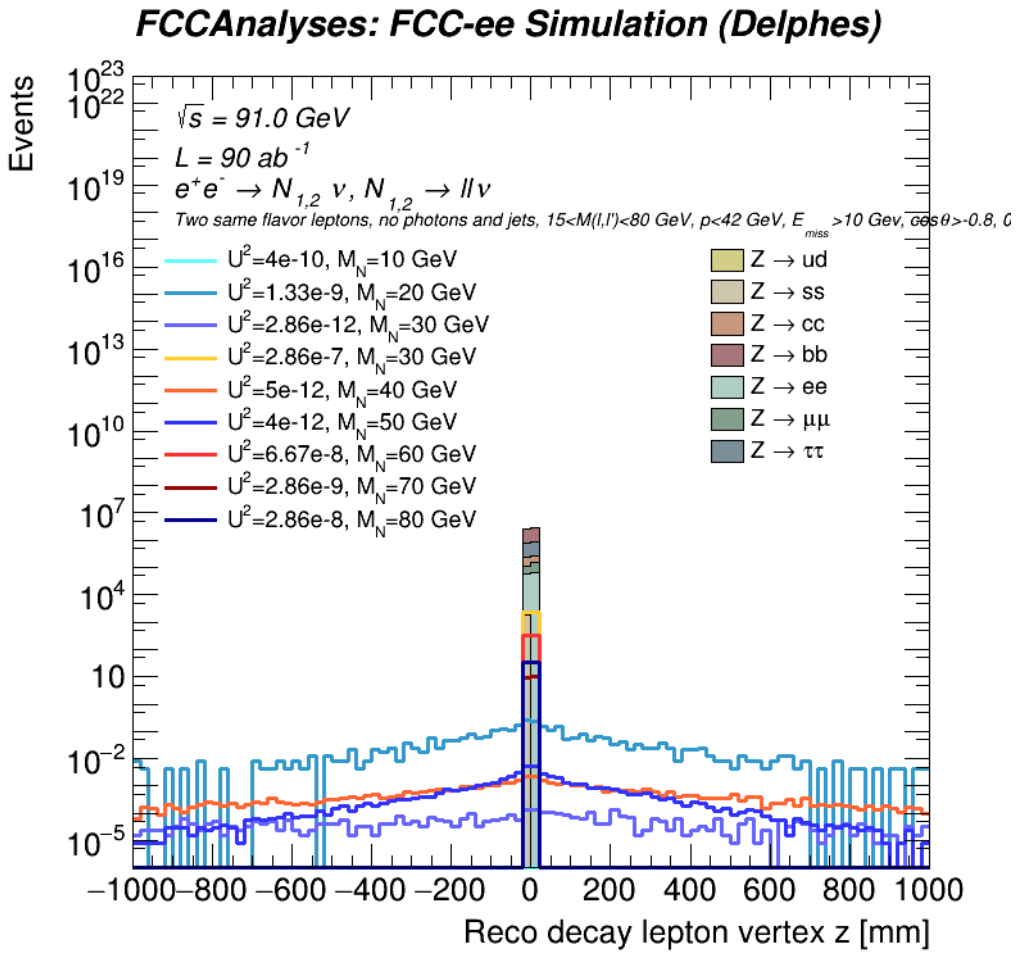

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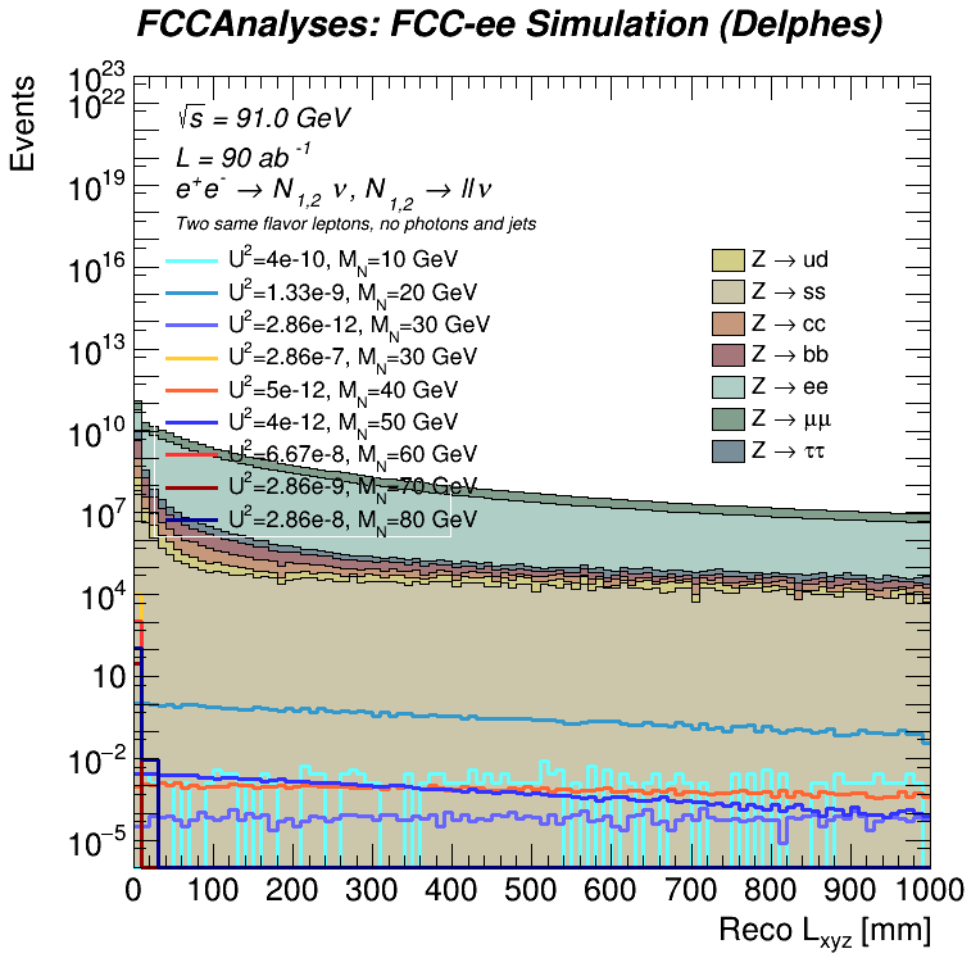


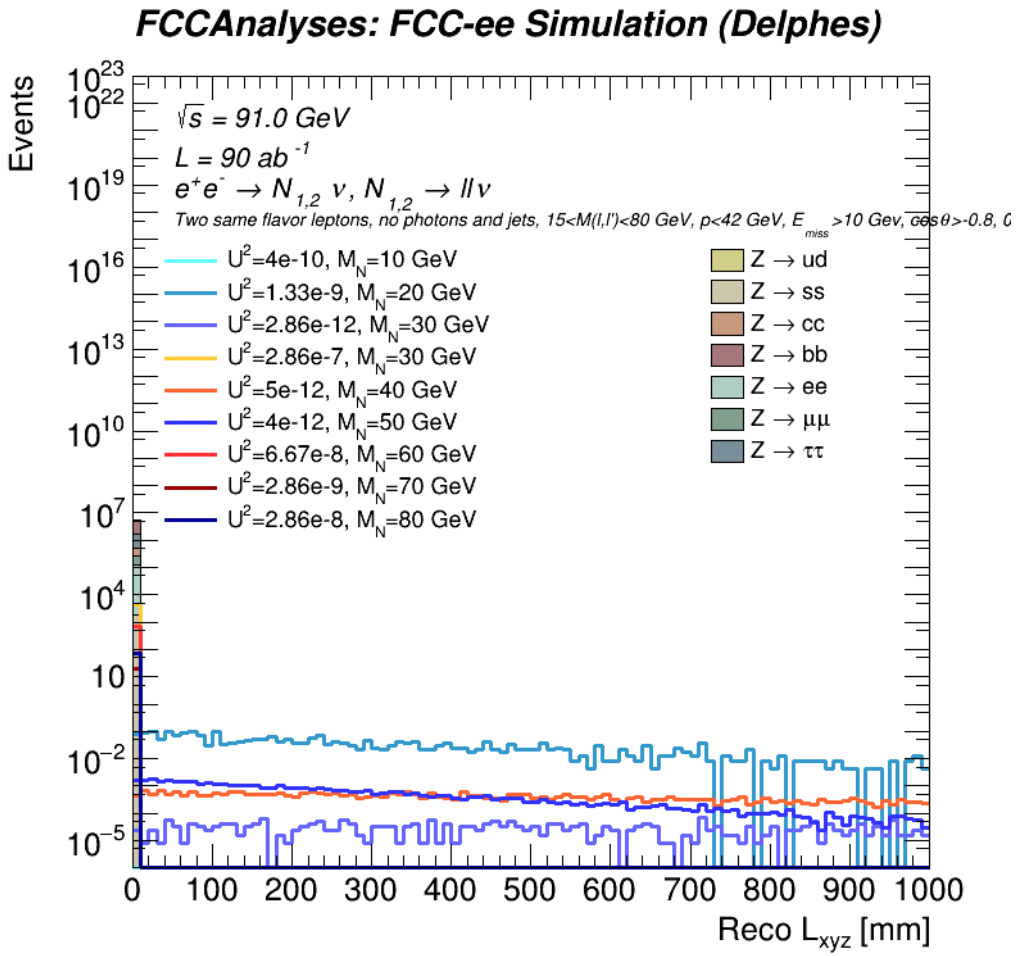

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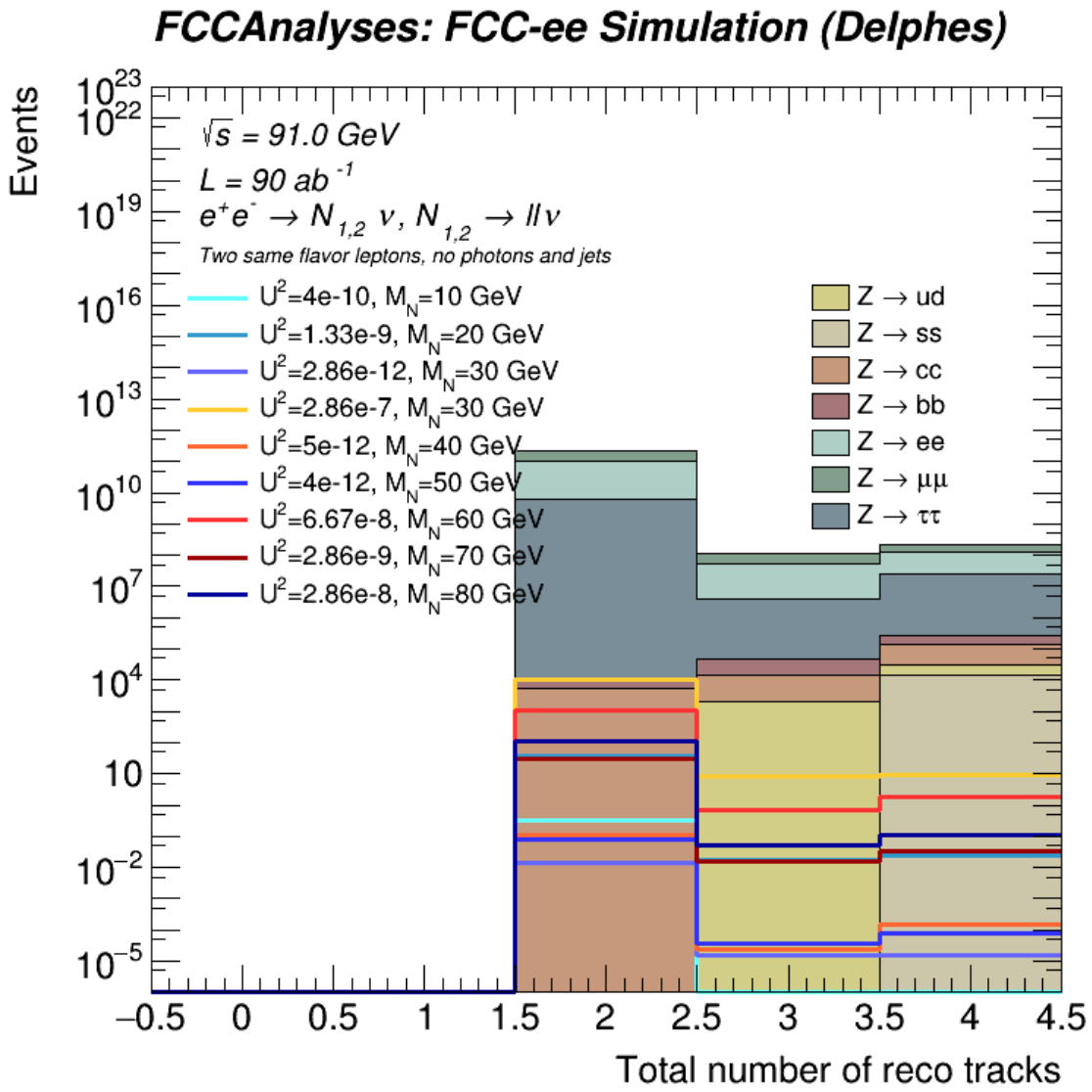

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2. Invariant mass: $15 < M(\ell, \ell') < 80\ GeV$ (what we had in the thesis)
3. Missing energy: $10 < ME < 43\ GeV$
4. Lepton momentum: $p < 39\ GeV$
5. Cosine of the angle between the leptons: $cos\theta > (-0.8)$

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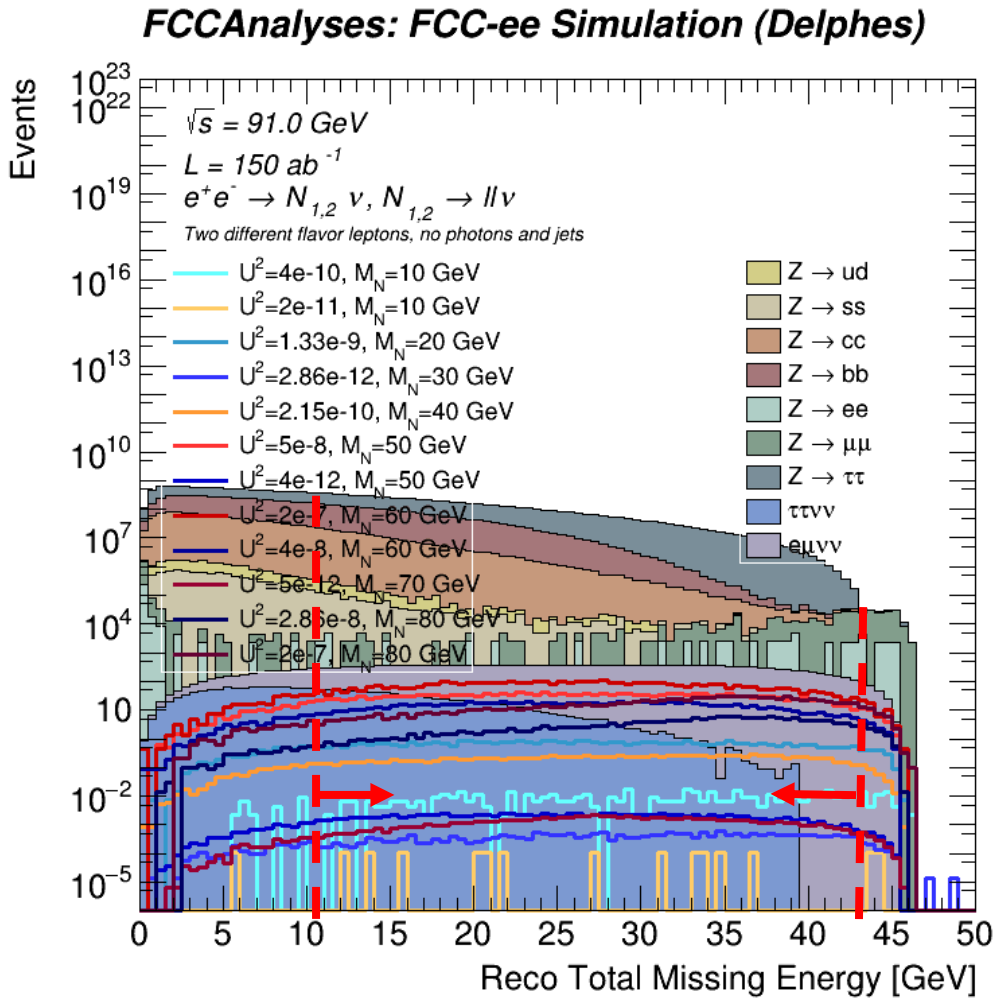


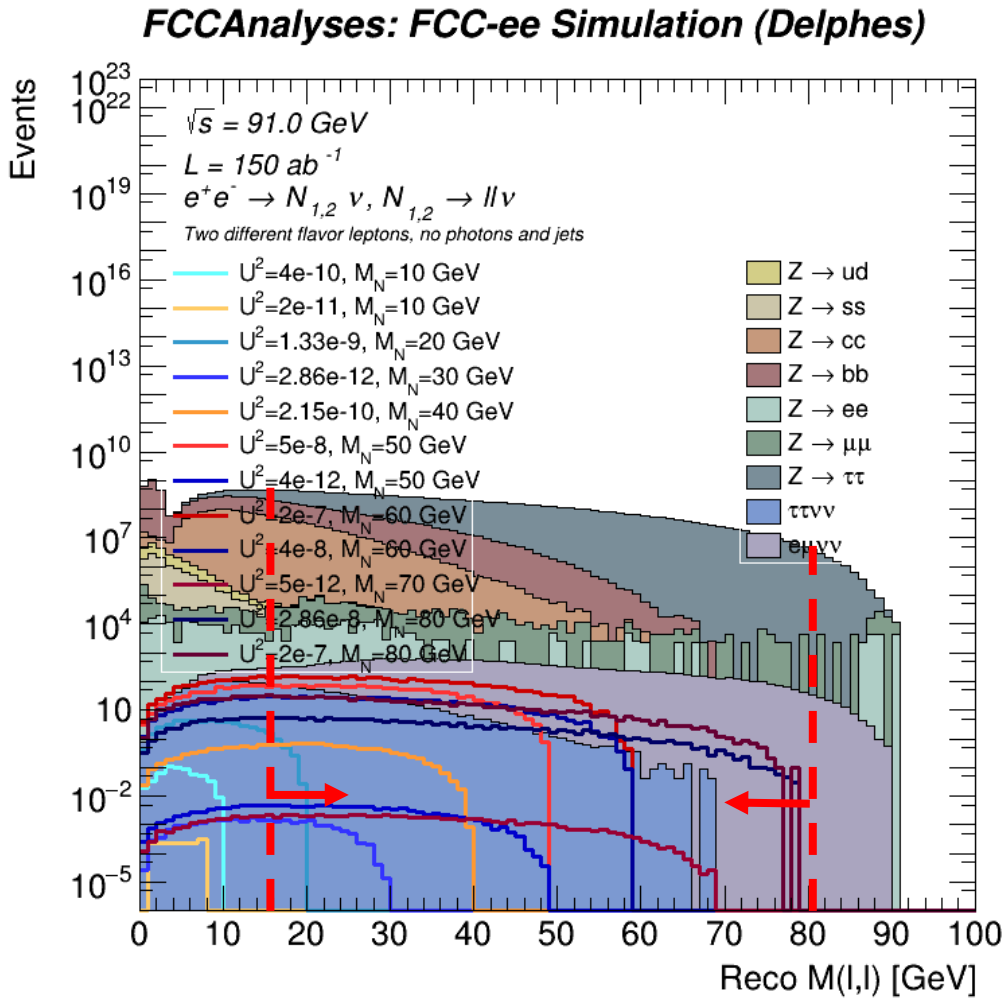

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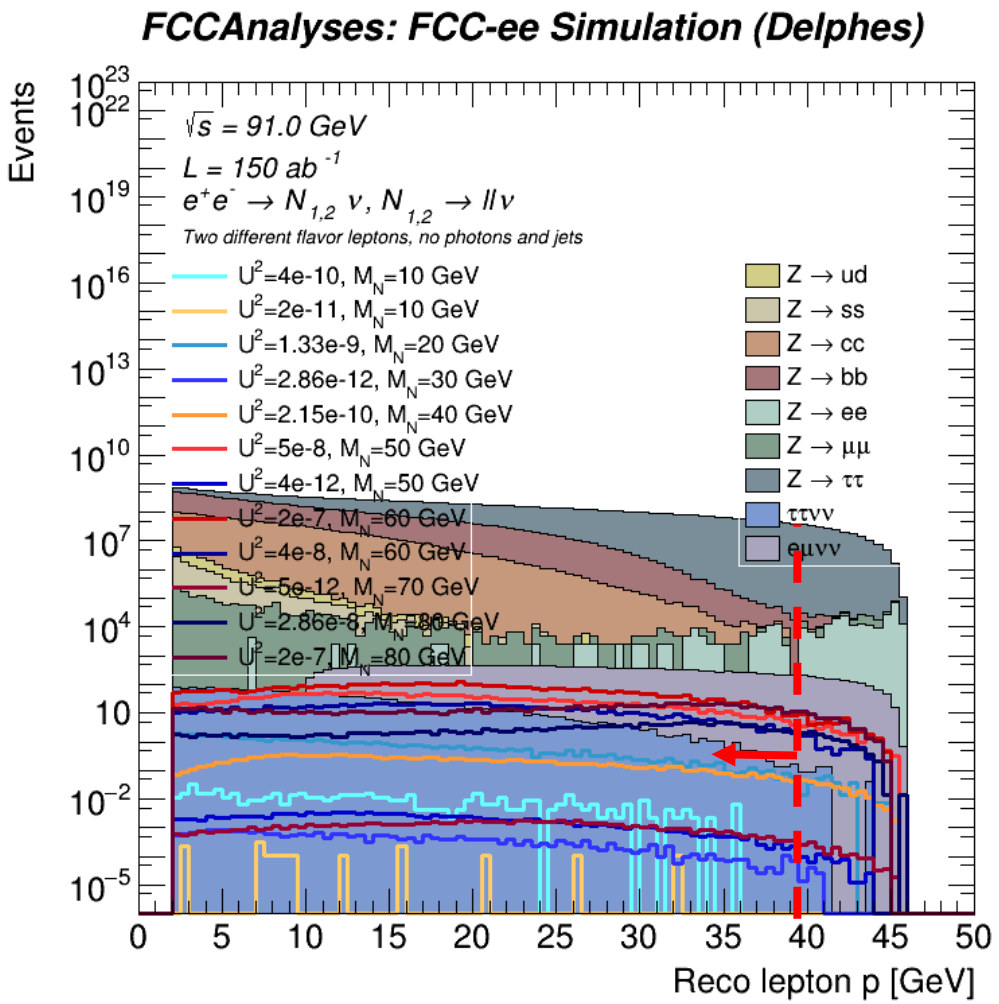


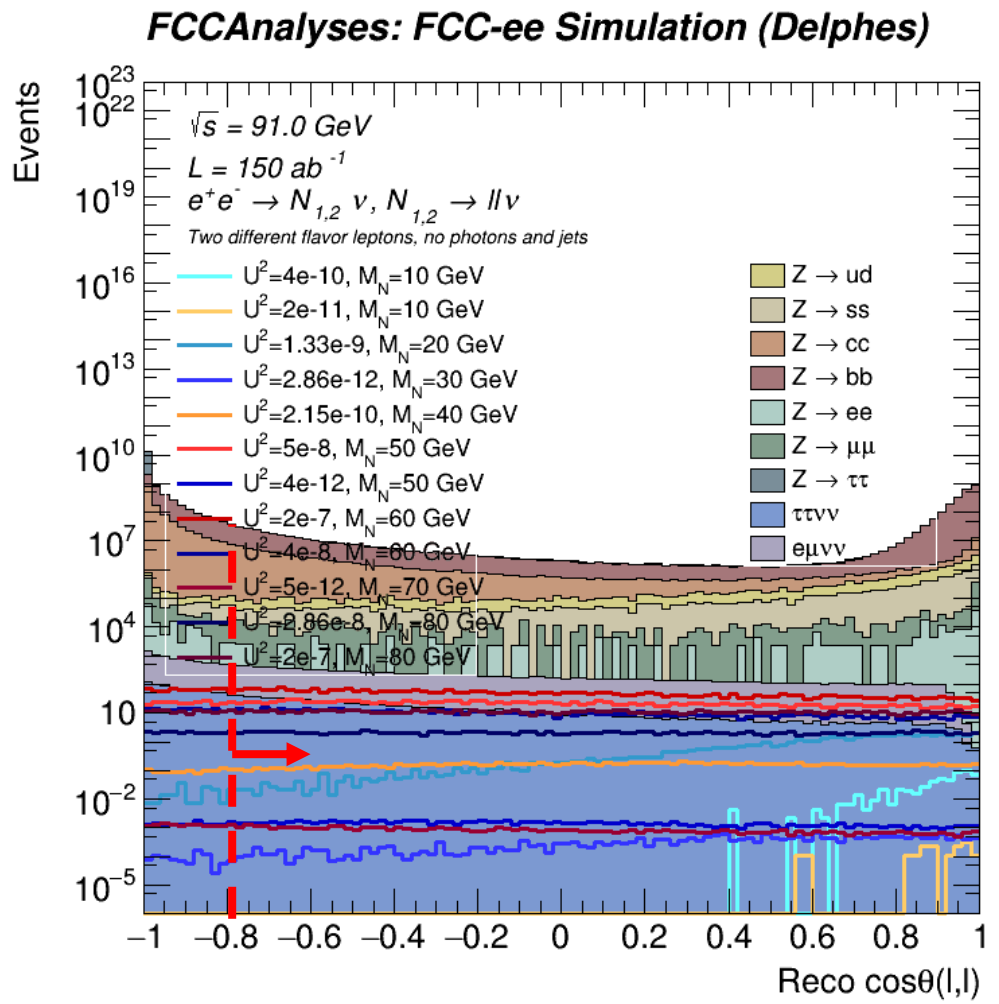


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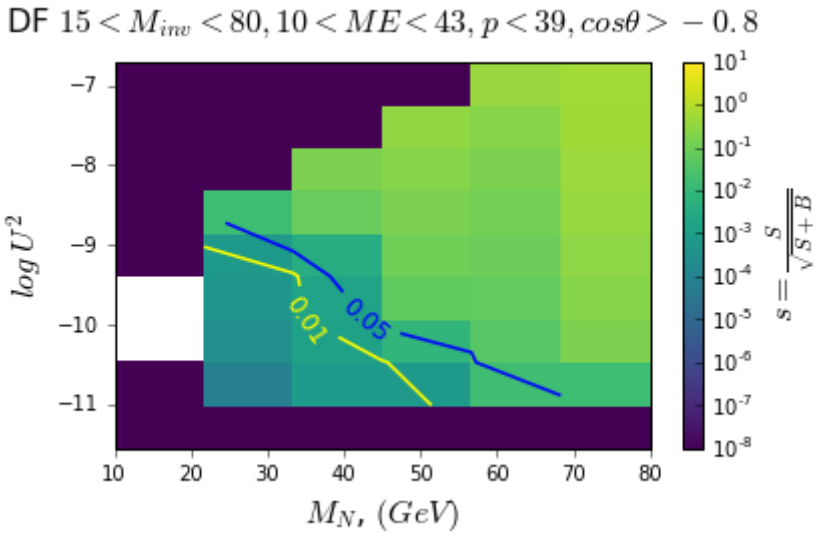
Significance from these cuts:

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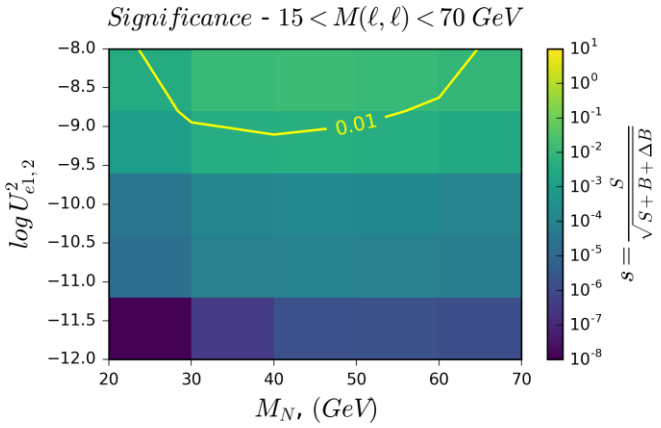


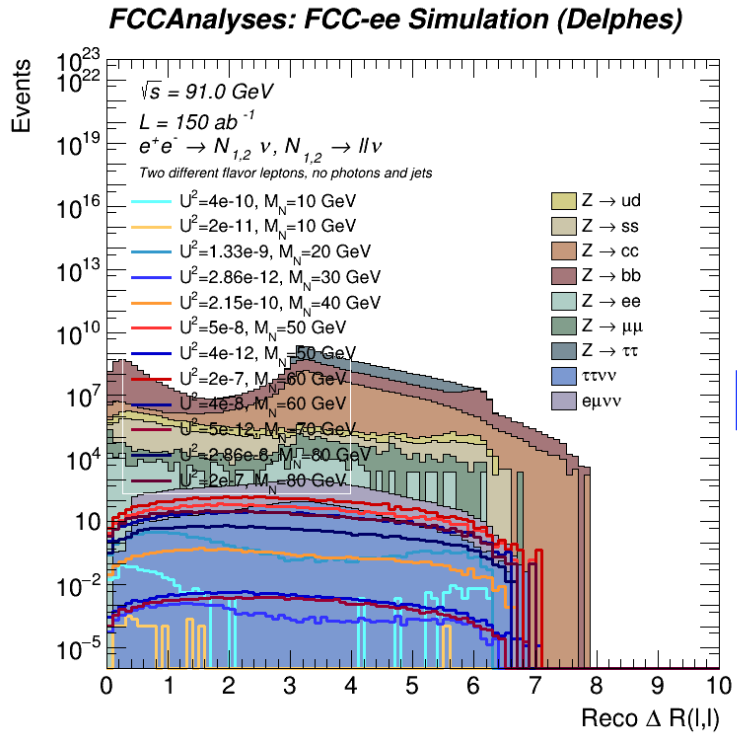


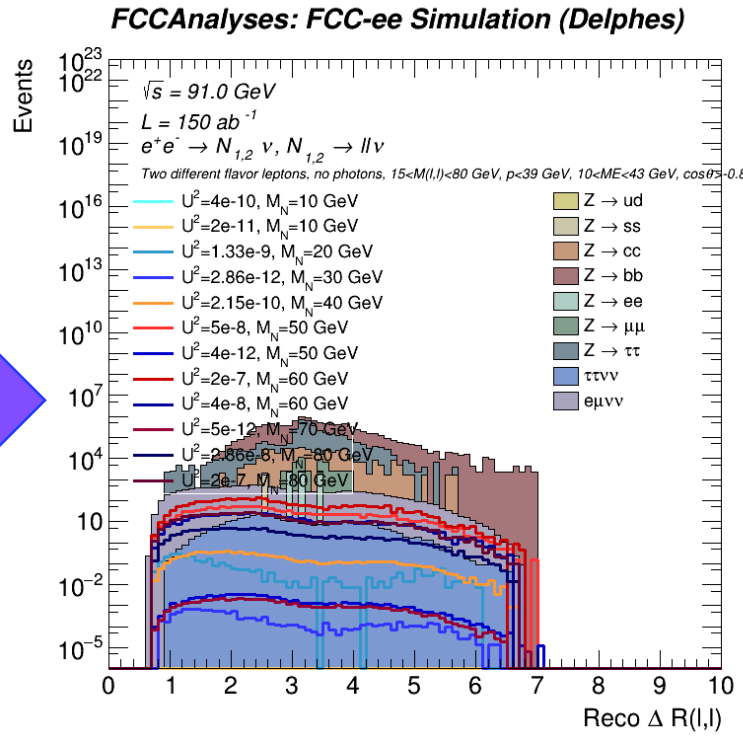

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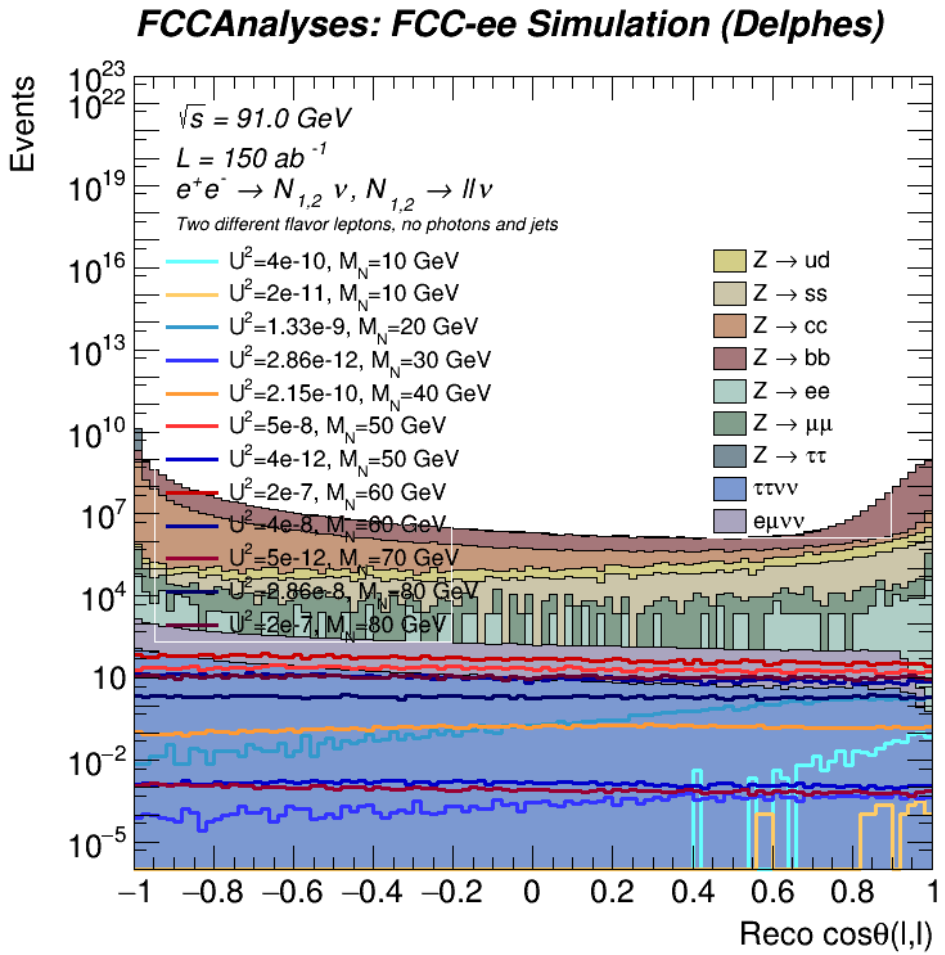


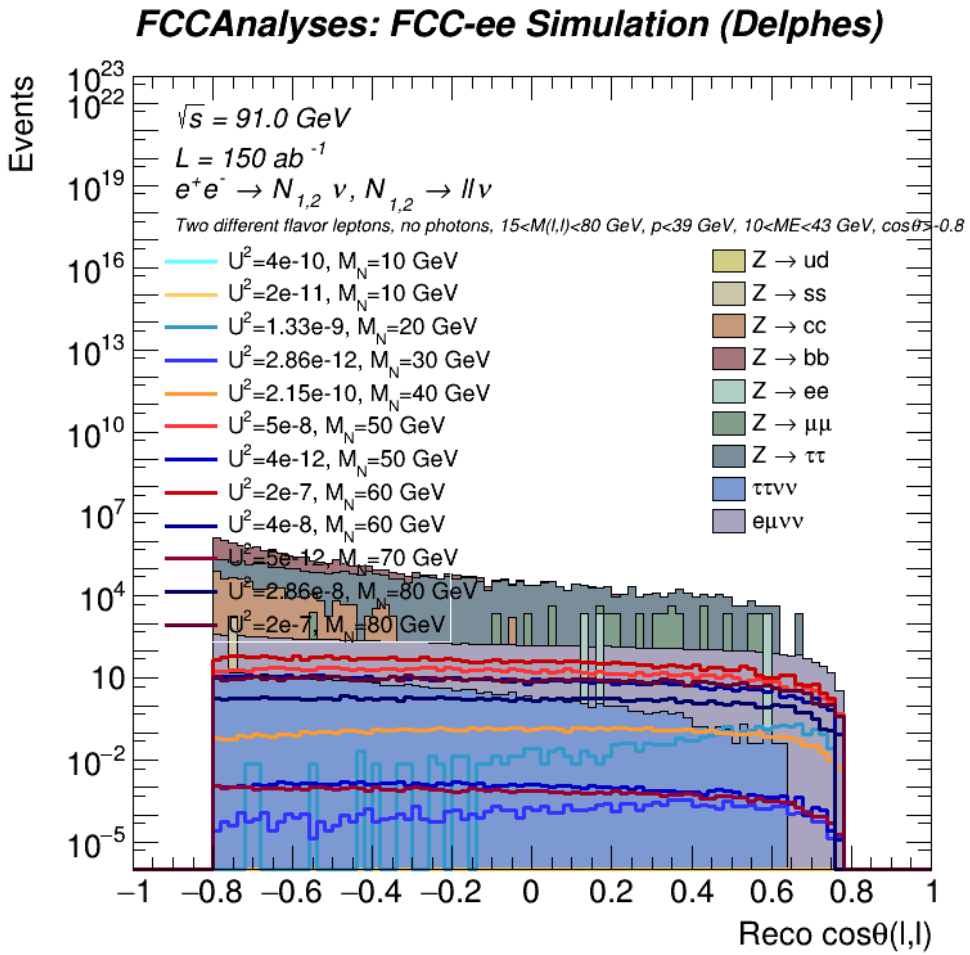

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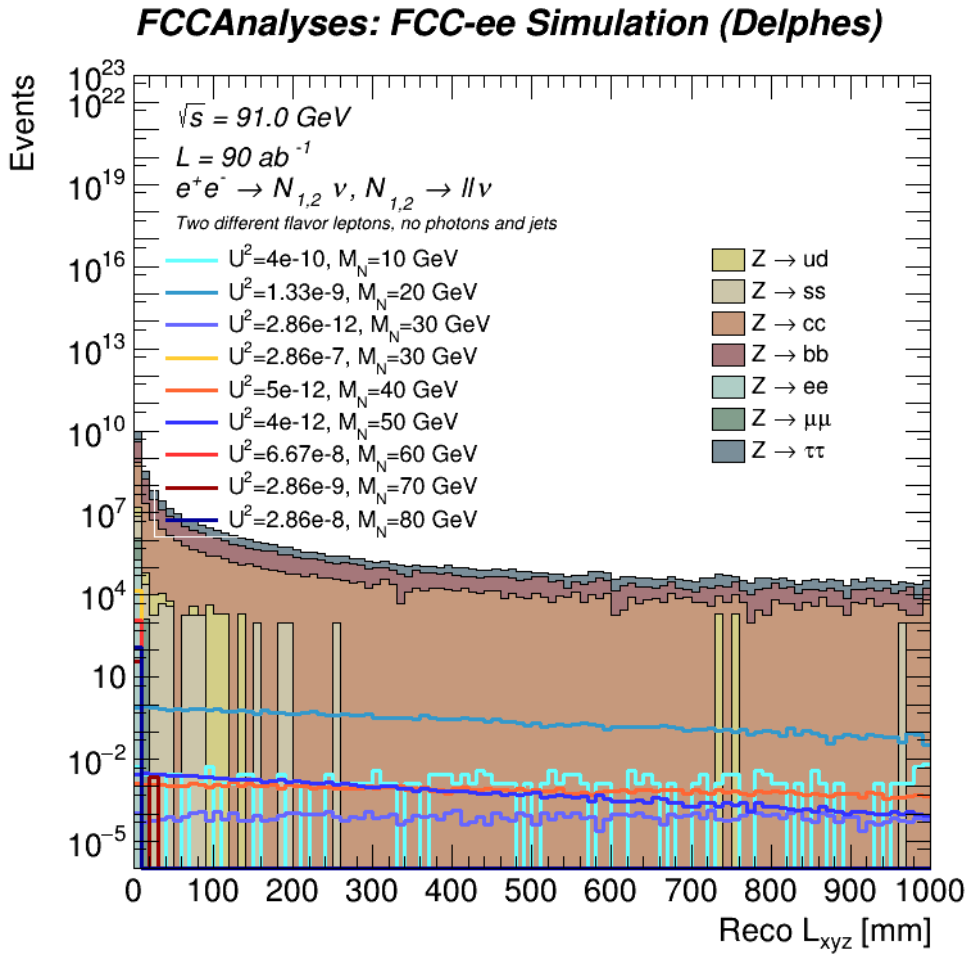


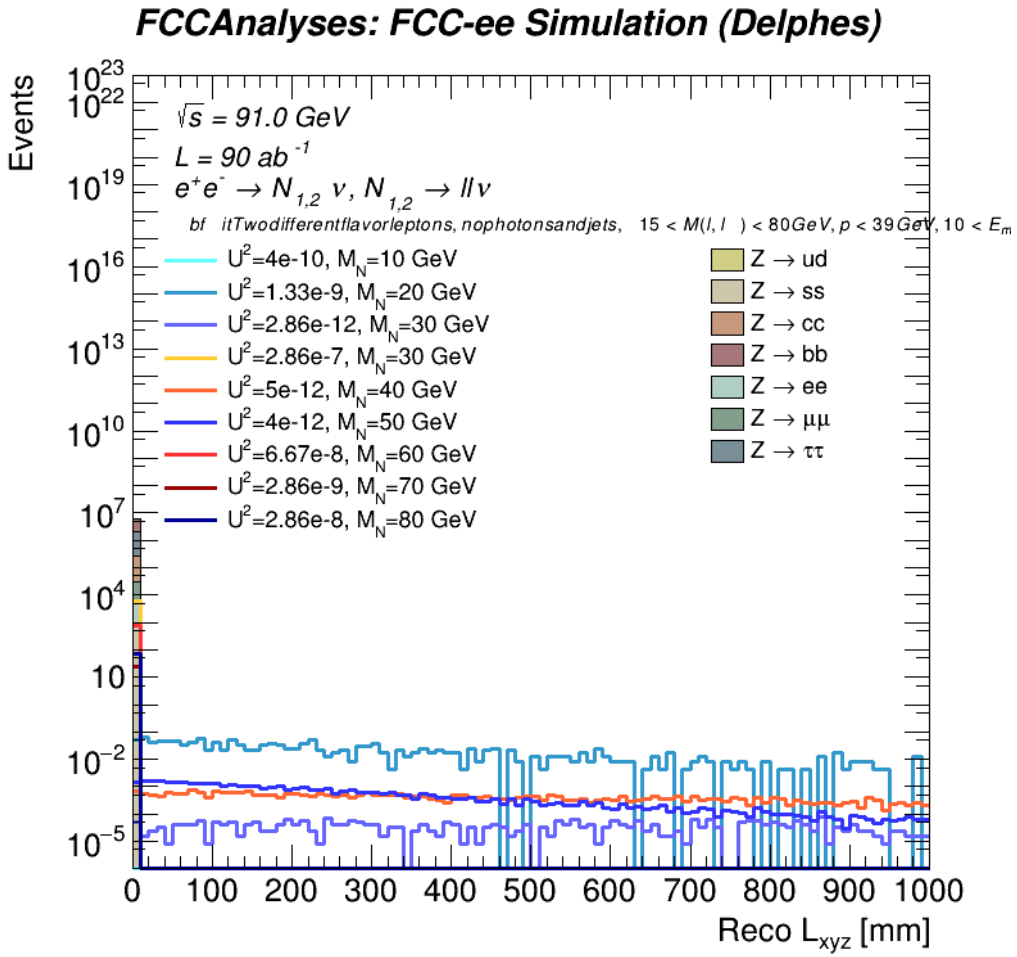

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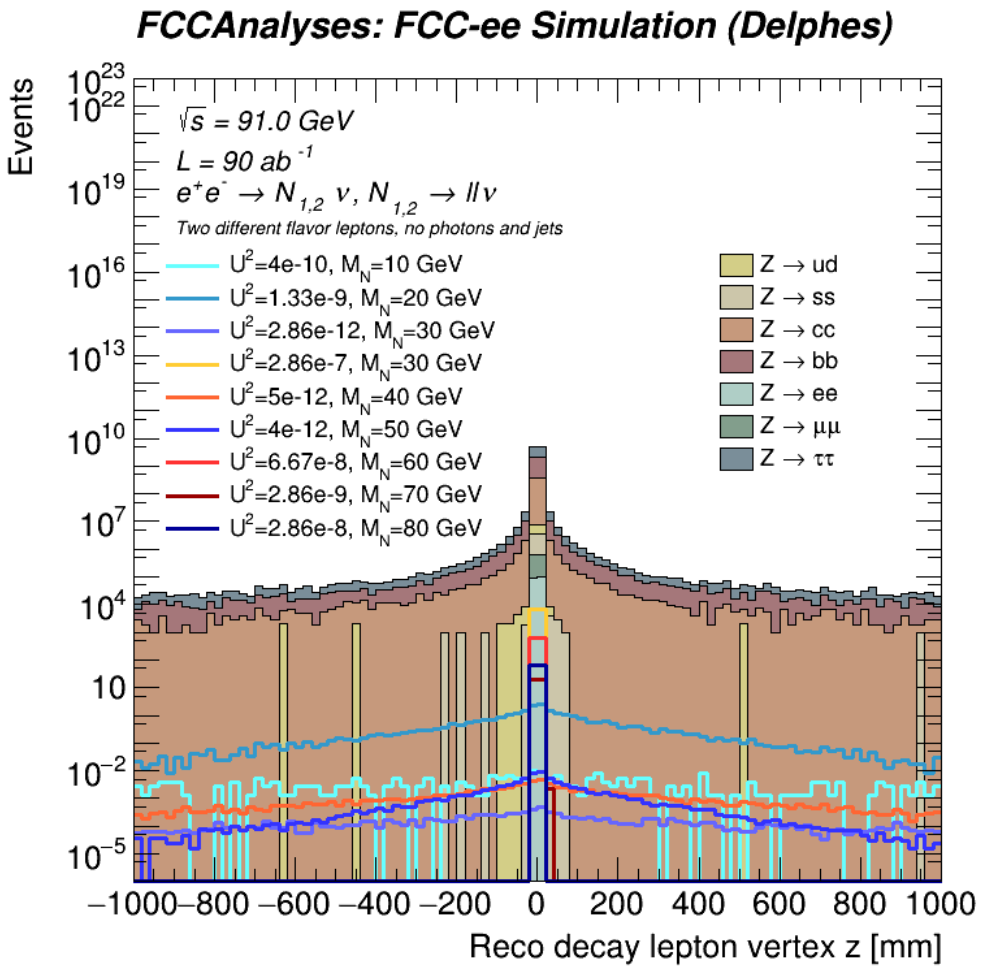


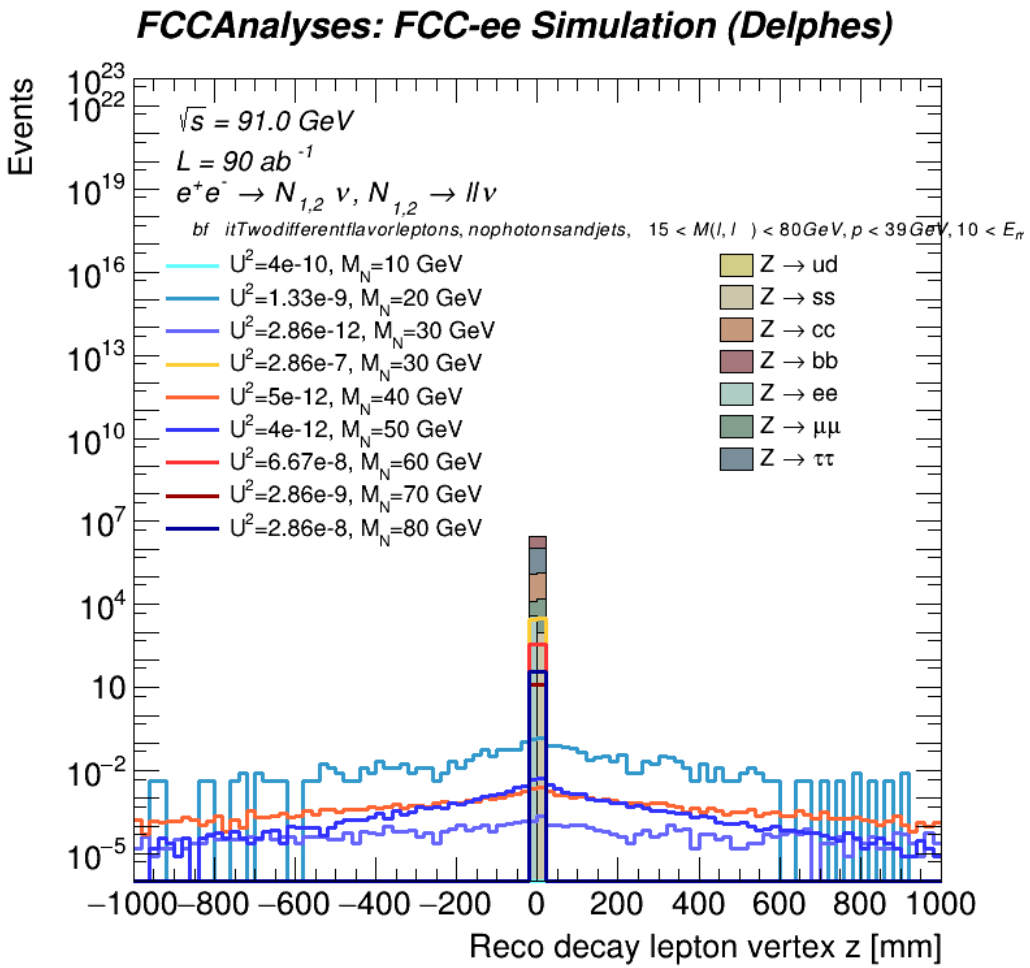

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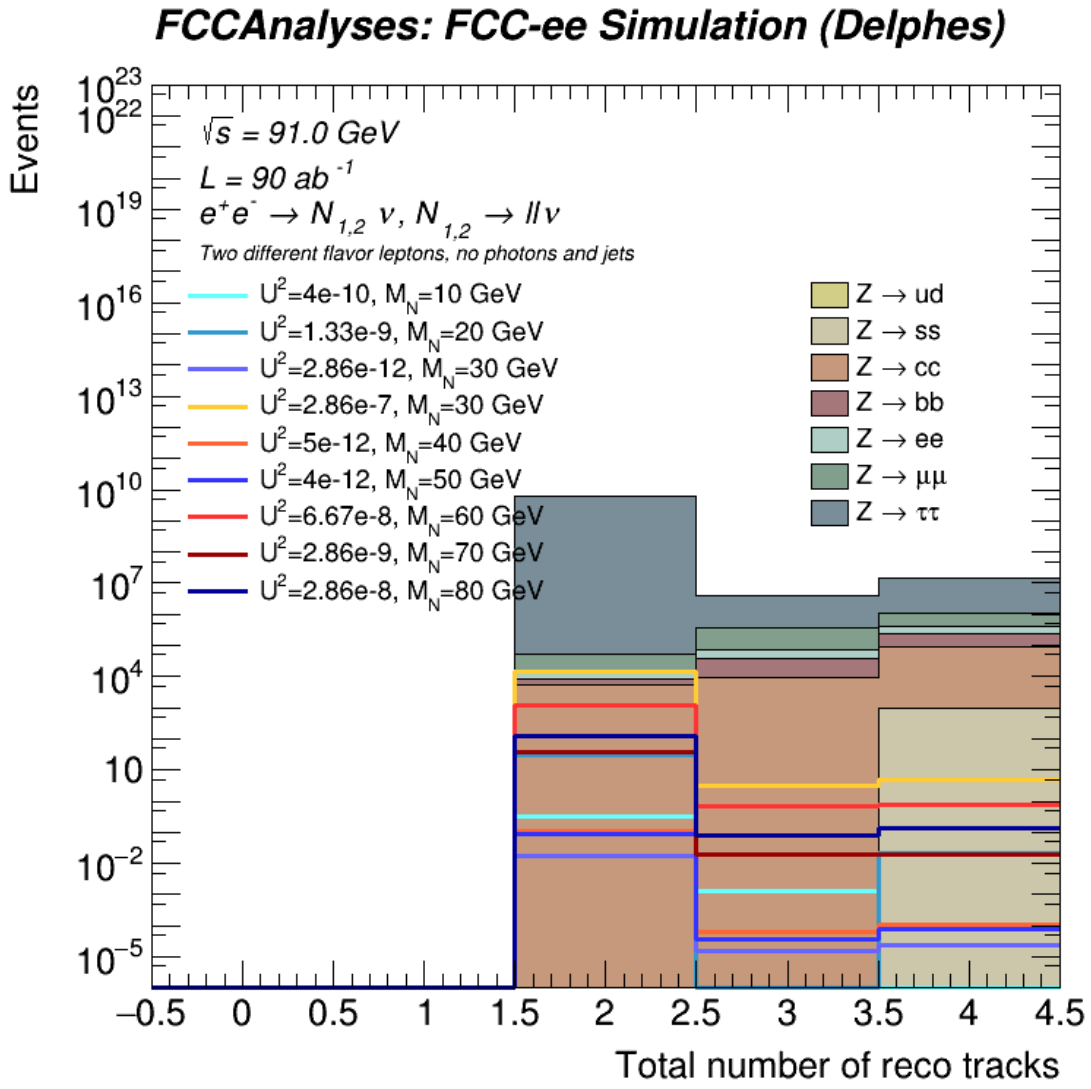

# ANALYSIS - DISCUSSION

- We started producing signals with high-medium-small mixing angle and 20-80 mass range for each hierarchy (42 individual files) then let python linearly extrapolate the rest
- More points can be added later to see in more detail some specific region

# ARTICLE

- The first three sections are fully written (adapted from the thesis, added more references)
- Section 4 can only be written after having the results
- Revision can already happen to speed things up
- In one-two months at most it should be ready for publication with about 20 pages of content

Contents

# FUTURE DEVELOPMENTS

- There are still a few things that can exapand the project:
  - $\ell jj$ decay
  - Prompt decay
  - FCC-hh
- These could be bachelor/master theses as most of the code is already set up and just needs to be adapted to the specific case