Probing LFV in an effective theory at ep colliders

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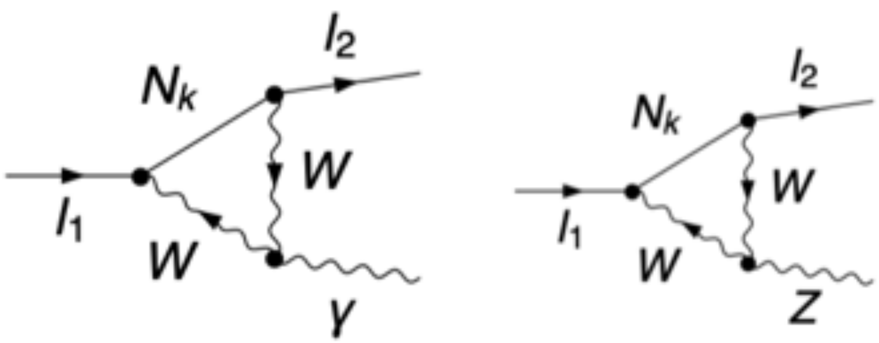
Talk based on
arXiv:2010.08907 and refs therein

XIX International Workshop on Neutrino Telescopes

LFV example



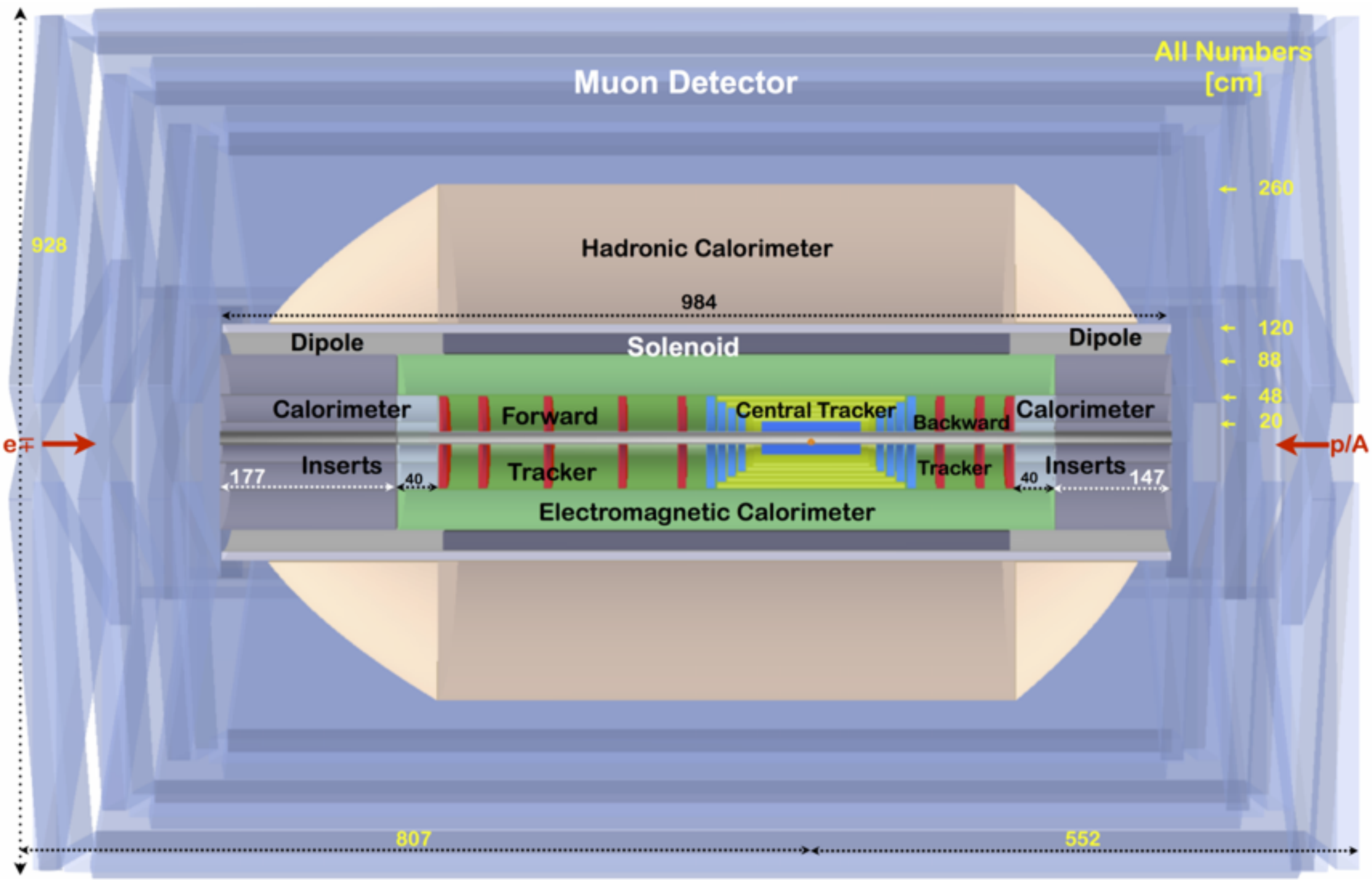
Indirect signature for heavy neutrino

Q: Which collider can give the best sensitivity, proton-proton, electron-electron or electron-proton collider?

A: The collider that can provide a unique kinematics for the signal that can be easily distinguished from the relevant backgrounds

As a first guess, The electron-proton collider

The Large Hadron Electron Collider (LHeC)

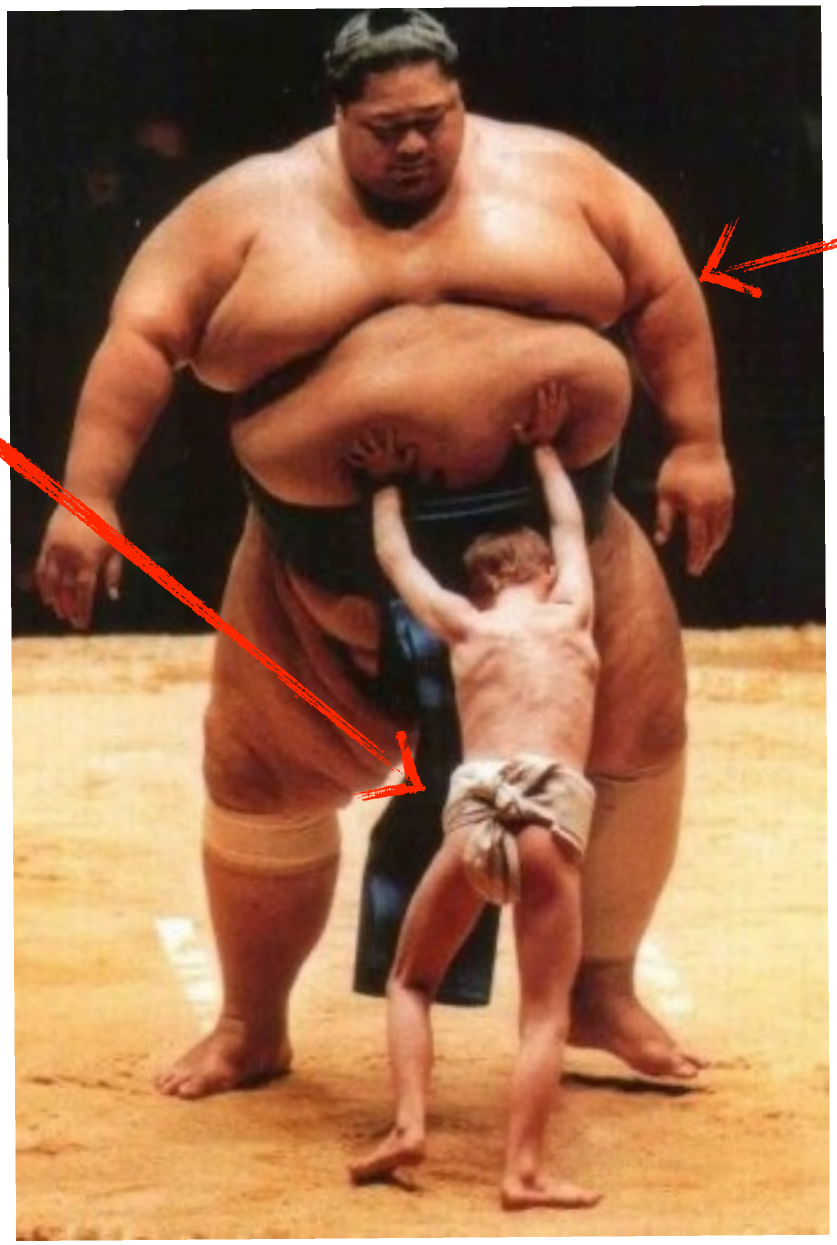


arXiv:1305.2090v1

As a first guess, The electron-proton collider

The LHeC is expected to provide a collision of proton beam with energy 7000 GeV and electron beam with energy 60 GeV

Electron beam



Proton beam

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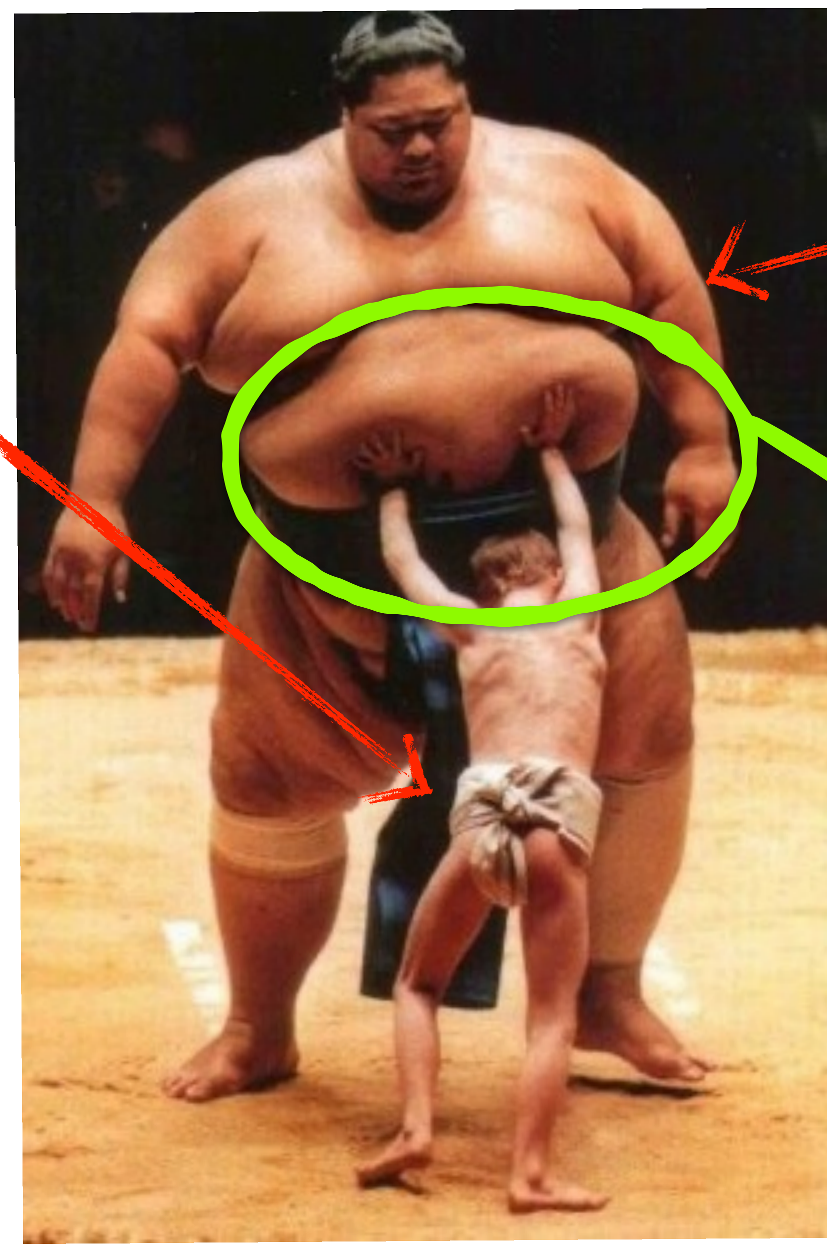
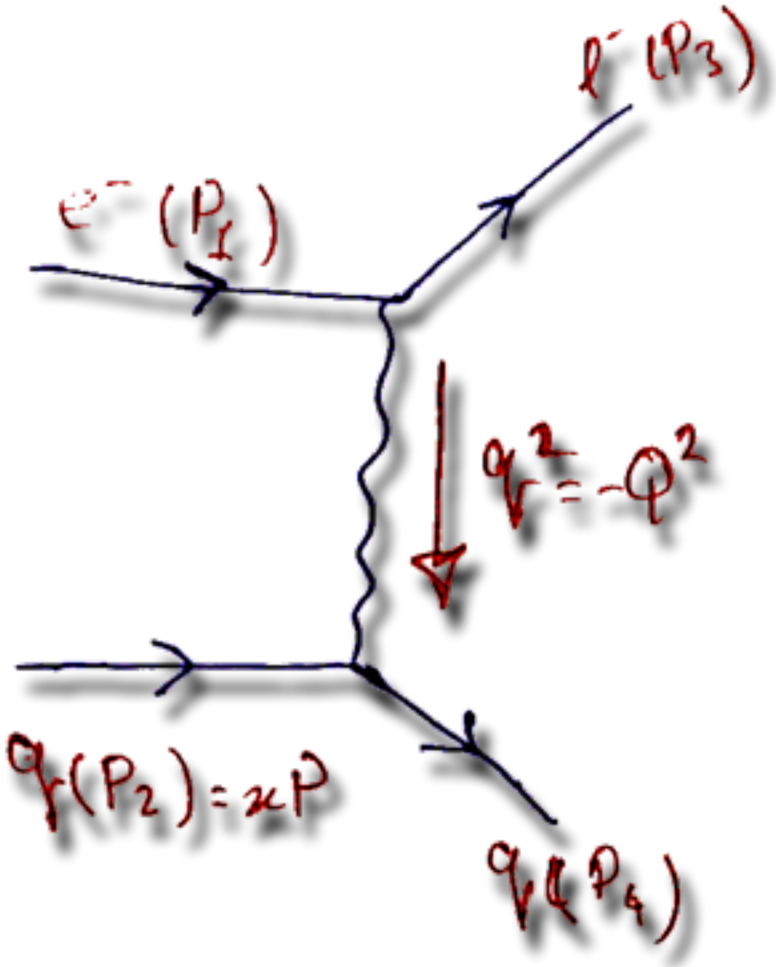
Electron beam

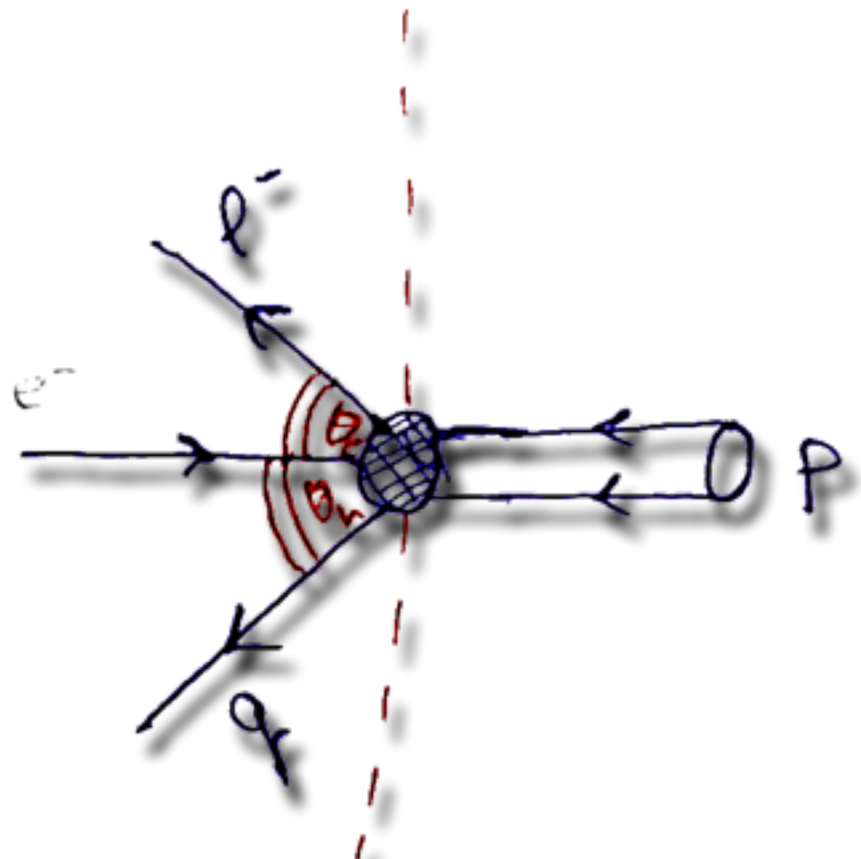


Proton beam

Interaction takes place in the Lab frame and physics is expected to be boosted in the forward proton beam direction

LHeC Kinematics





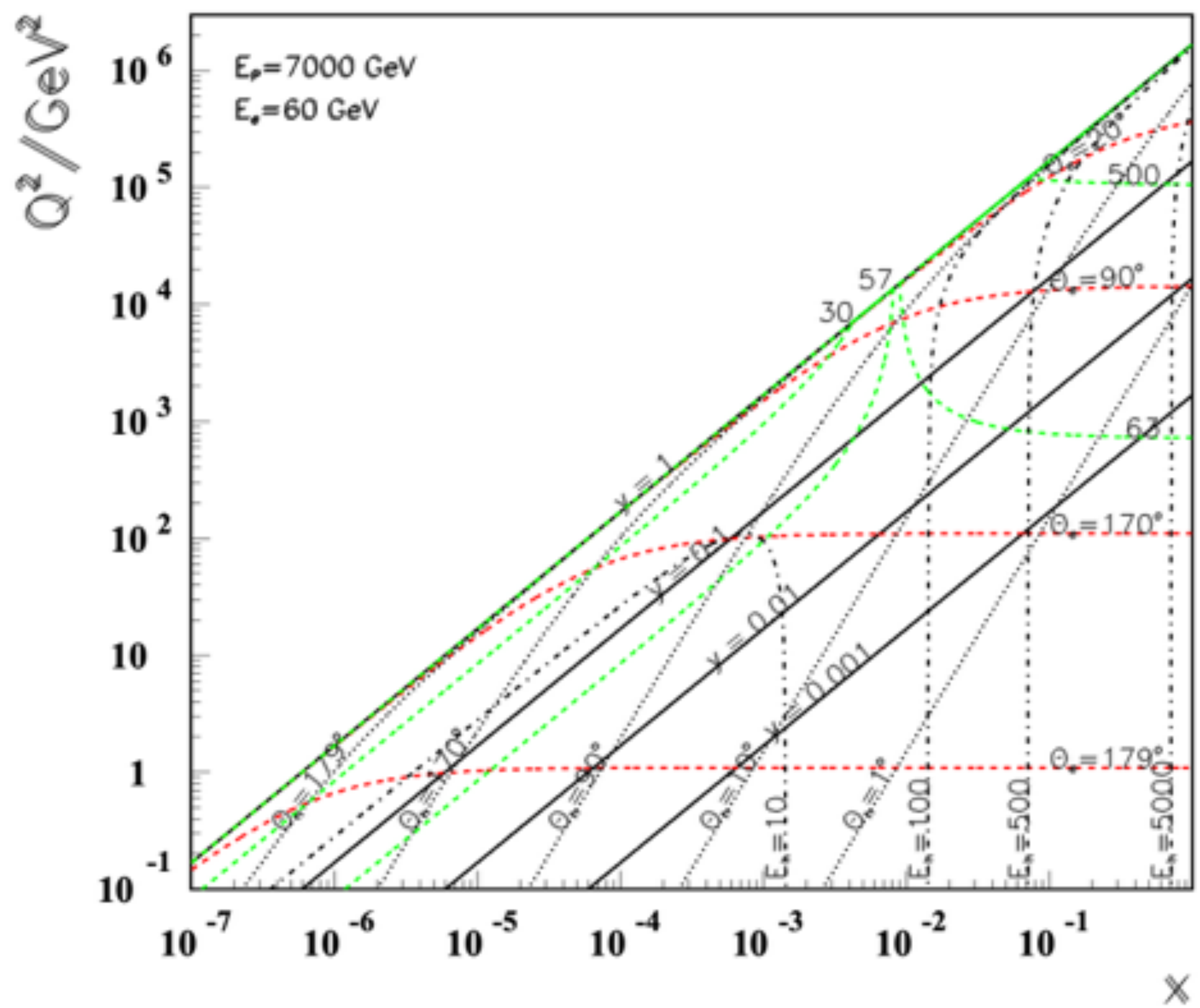
Couple of equations that control the whole kinematics

$$x = \frac{q^2}{s\ y_e}, \quad \text{with} \quad y_e = 1 - \frac{E_l}{2E_e}\left(1 - \cos\theta_e\right)$$

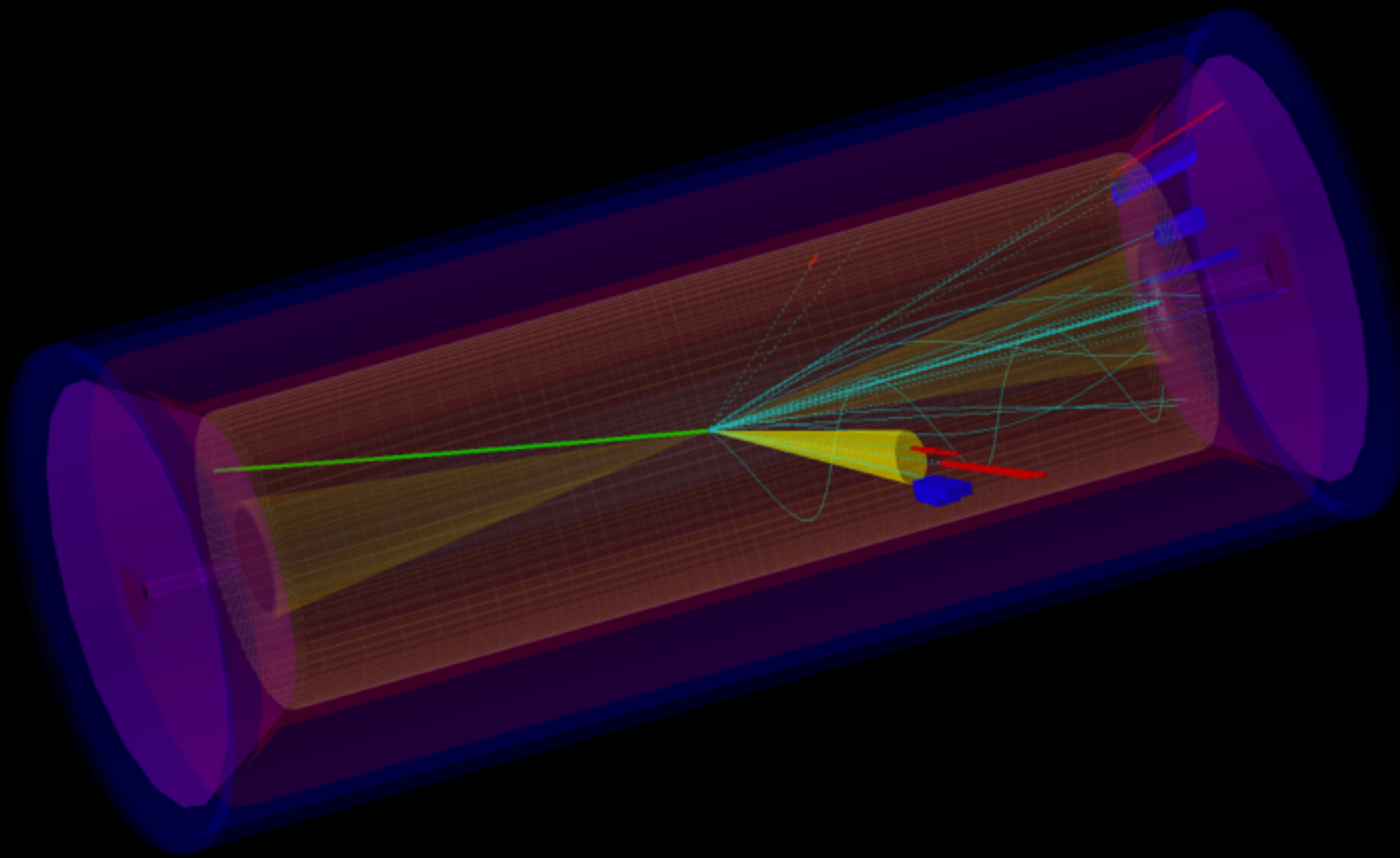
LHeC Kinematics

At the LHeC, Bjorken variable suppress the incoming quark energy and most of the parameter space the energy of the incoming electron and quark energies are nearly equal

For Small energy transfer, the final state lepton scatter in the backward direction of the detector such phenomena called "Lepton back scattering at ep colliders"



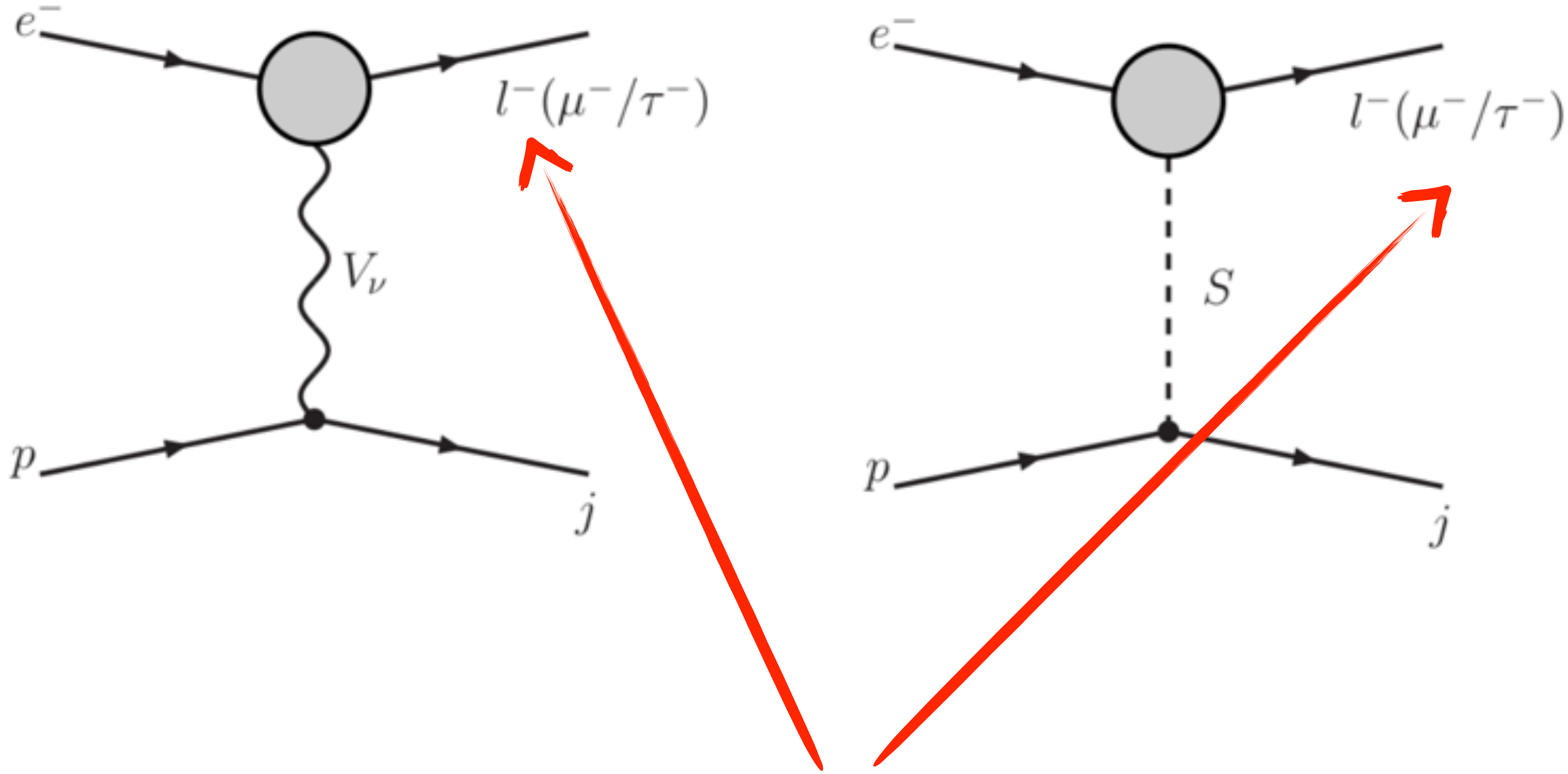
LHeC and FCC-he Study Group
arXiv:2007.14491



Delphes event display

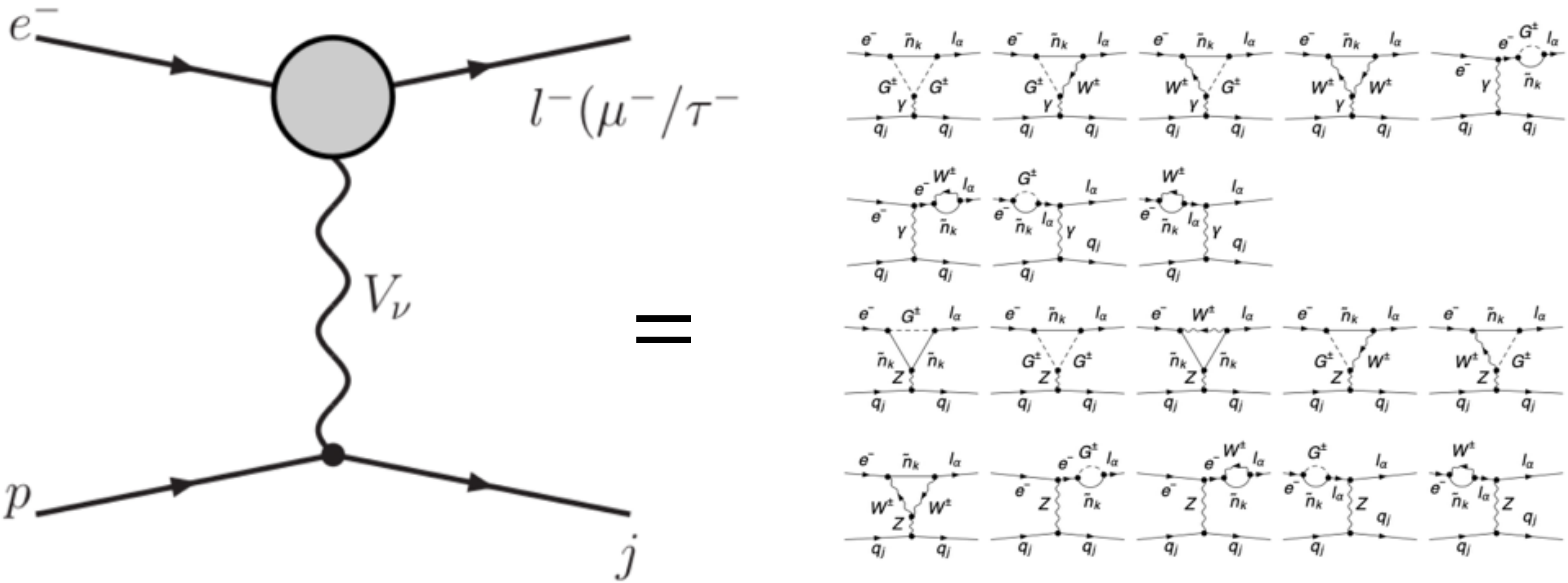
Q: Well, we have found the collider. Which theory shall we consider ?

A: Effective theory is a generic framework that can be fitted to any specific model



The SM has no source for LFV. Effective models with LFV can provide a clean signal at the LHeC

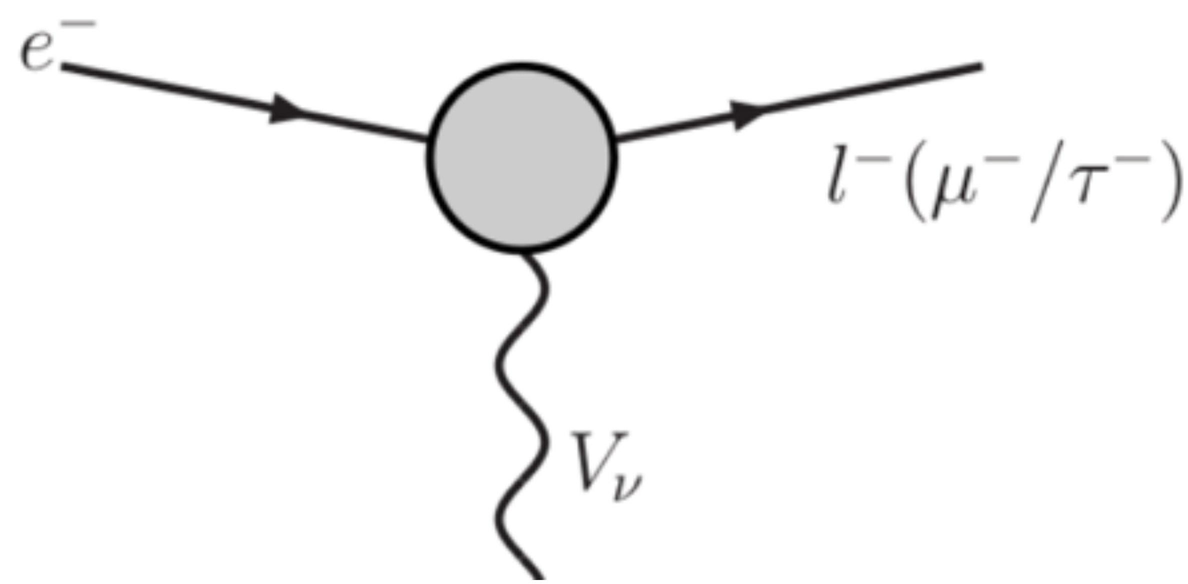
Effective low scale seesaw model



processes are UV finite !!

Generic Form Factors

Vector mediated processes



Monopole operator

$$\mathcal{L}_{\text{eff}}^{\text{monopole}} = \bar{\ell}_\alpha \gamma_\mu P_{L,R} \ell_\beta \left[A_{L,R}\, g^{\mu\nu} + B_{L,R}(g^{\mu\nu} q^2 - q^\mu q^\nu)\right] V_\nu,$$

Dipole operator

$$\mathcal{L}_{\text{eff}}^{\text{dipole}} = \bar{\ell}_\alpha \sigma^{\mu\nu} P_{L,R} \ell_\beta \; q_\mu V_\nu \; D_{L,R},$$

Analysis at RECO level

1- Calculate the FF numerically

2- Calculate the total cross section as $\mathcal{M}_{LHeC} = \mathcal{M}_{\gamma^*} + \mathcal{M}_{Z}$, by implementing the effective vertex with the right Lorentz structure

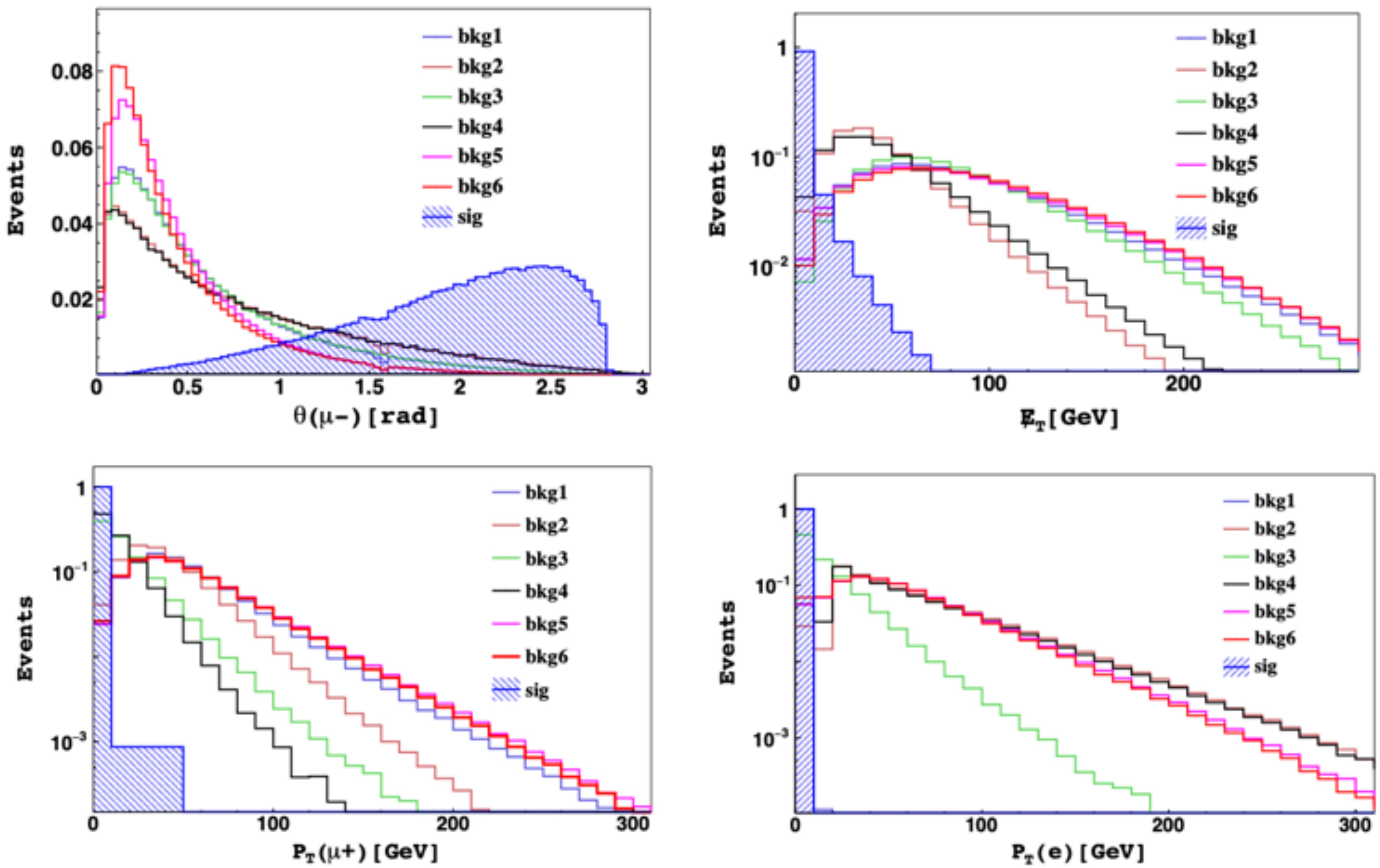
$$\mathcal{M}_{\gamma^*} = \bar{u}_{l_\alpha} \left[B^{\gamma}_{L,R} P_{L,R}\, q^2\, \gamma^{\nu} - i\sigma^{\mu\nu} q_{\mu}\, D^{\gamma}_{L,R} P_{L,R} \right] u_e \left(\frac{-ie\ g_{\mu\nu}}{q^2} \right) \bar{u}_q(-ieQ_q\gamma^{\mu}) v_q\ ,$$

$$\mathcal{M}_Z = \bar{u}_{l_\alpha} \left[A^{Z}_{L,R} P_{L,R} \gamma^{\nu} + B^{Z}_{L,R} P_{L,R} q^2 \gamma^{\nu} - i\sigma^{\mu\nu} q_{\mu} D^{Z}_{L,R} P_{L,R} \right] u_e \left(\frac{-ig_{\mu\nu}}{q^2 - M_Z^2} \right) \bar{u}_q(\gamma^{\mu}\, g_{L,R} P_{L,R}) v_q.$$

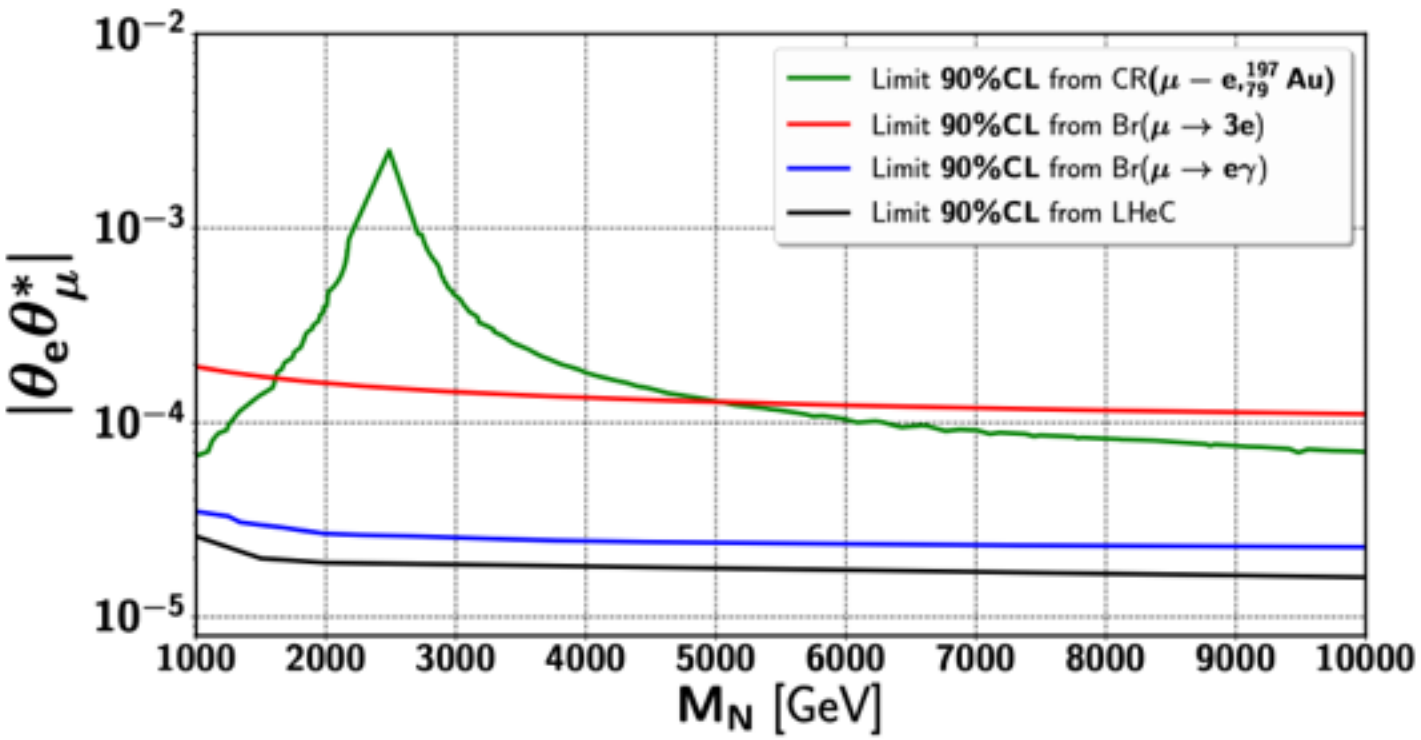
3- Generate the events + Hadronization + detector effect

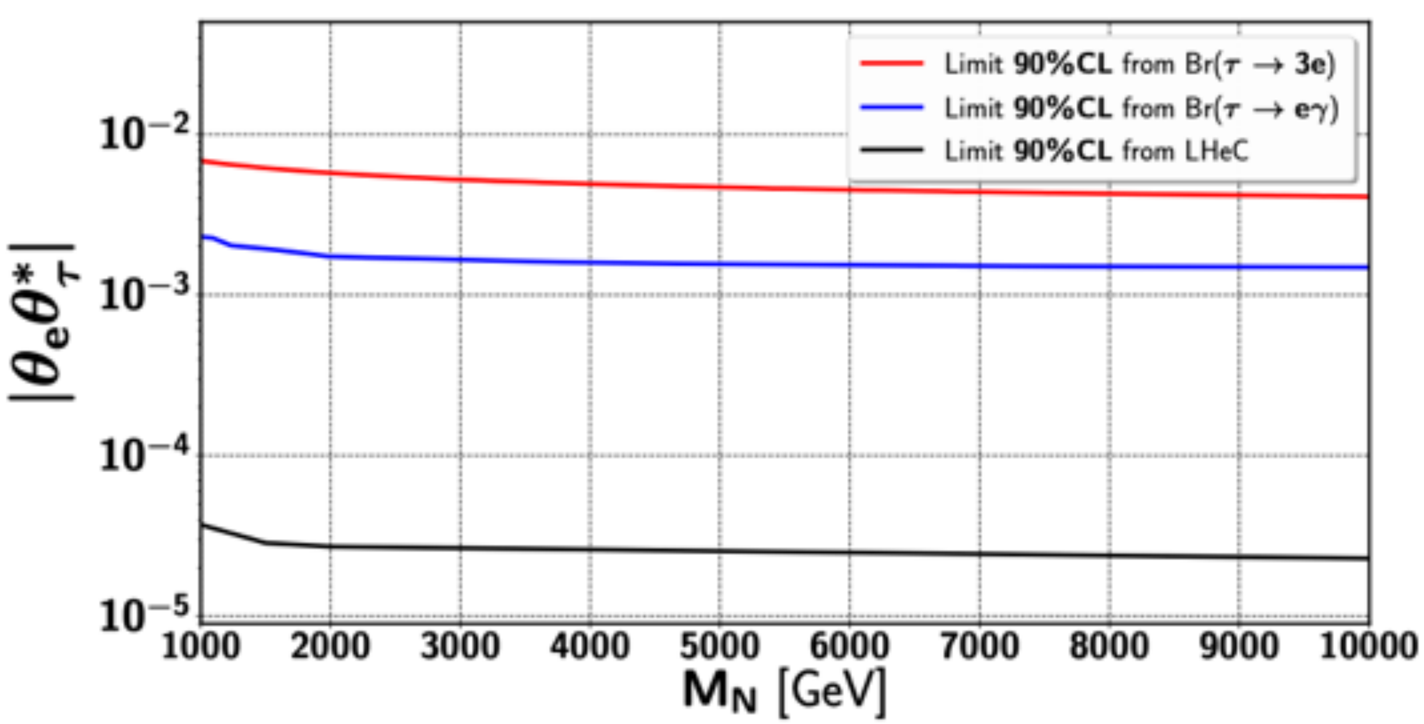
Analysis at RECO level

Signal Vs bkgs



LHeC can provide the better sensitivity for LFV search than all the existing searches





Current limit from different experiments

$$Br(\mu \to e\gamma) \leq 4.2 \times 10^{-13}$$

$$Br(\tau \to e\gamma) \leq 3.3 \times 10^{-8}$$

$$Br(\mu \to e^- e^+ e^-) \leq 1. \times 10^{-12}$$

$$Br(\tau \to e^- e^+ e^-) \leq 2.7 \times 10^{-8}$$

$$Cr(\mu - e,\ {}^{197}_{79}\mathrm{Au}) \leq 7 \times 10^{-13}$$

Summary

1- The backward direction of the LHeC is a clean area which is very sensitive to LFV searches

2- LFV search at the LHeC in an effective theory can provide a characteristic features for the signal events that can be distinguished from all relevant background

3- For low energy transfer, muon/tau leptons back scattering can provide a good discrimination between the signal and the backgrounds

4- For low scale linear seesaw model the LHeC can provide better sensitivity than all existing experiments

5- For scattering tau lepton the LHeC can still provide a better sensitivity than the future upgrade of BELLE and BABAR experiments

THANK
YOU