Exploring Right Handed Neutrinos at ILC

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- Model — What is minimal B-L model?
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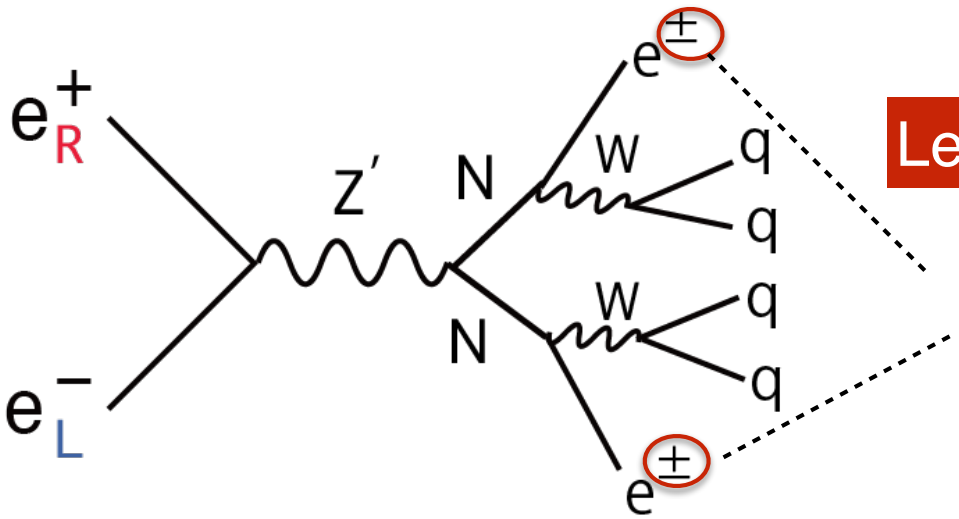
Motivation

The right handed neutrino(RHN) can address the following big questions

- Why does matter dominate anti-matter in our universe?
- Why is neutrino mass so small?
- Do quarks and leptons unify?

Right handed neutrino is assumed to be a Majorana particle.($\nu = \bar{\nu}$)

RHN **pair** production *OK!*



Lepton # violation is possible!

↓

Same sign leptons possible

↓

No SM BG!

Model

Gauged B-L extension of Standard Model(SM)

The unique anomaly free global symmetry in the SM

$$G_{B-L} \equiv SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_{B-L}$$

Gauge boson : Z'

- Anomaly free requirement → RHNs
- Seesaw mechanism ← automatically include

If B-L symmetry breaks spontaneously → Z' becomes **massive**

minimal B-L model

	$SU(3)_C$	$SU(2)_L$	$U(1)_Y$	$U(1)_{B-L}$
N_R^i	1	1	0	-1
Φ	1	1	0	2

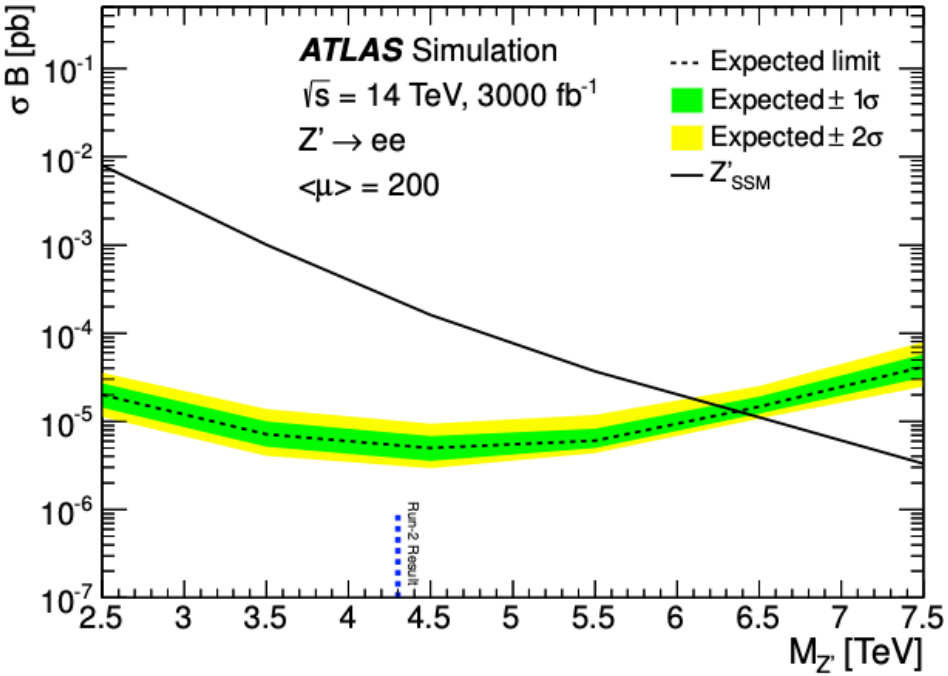
i=1,2,3

arXiV[1812.11931]

Arindam Das, Nobuchika Okada, Satomi Okada, Digesh Raut

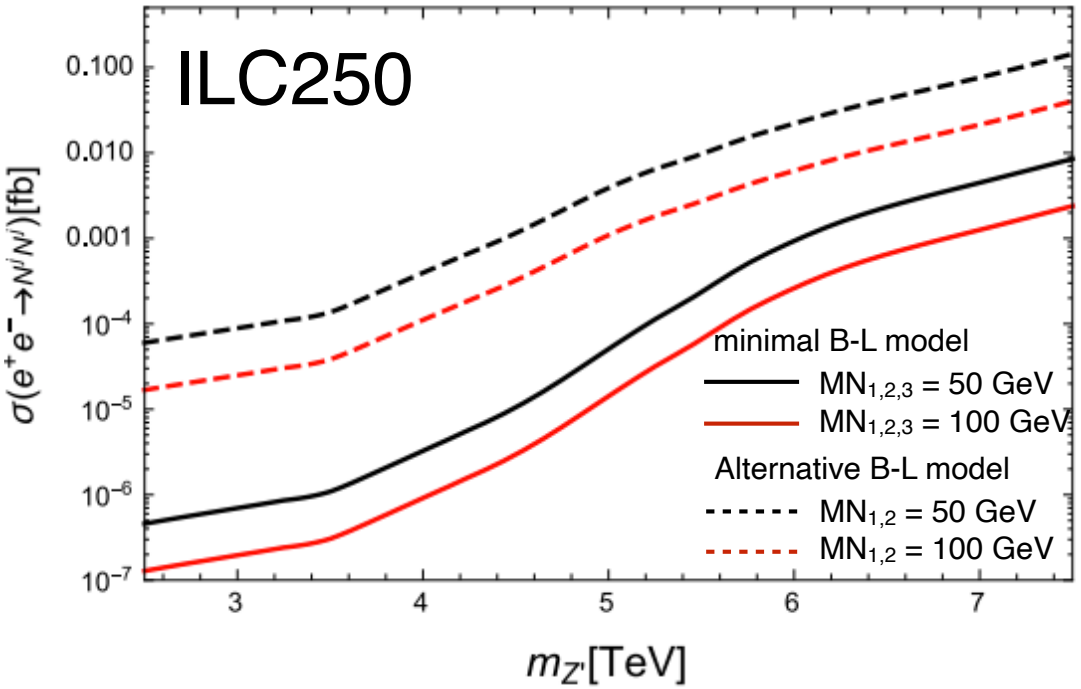
Current limits - Z’ mass

SM like Z’ coupling



ATLAS-TDR-LHCC2017-2018

HL-LHC prospects limit for $U(1)_{B-L}$ model



arXiV[1812.11931]

The heavier Z’ mass less constrained by LHC

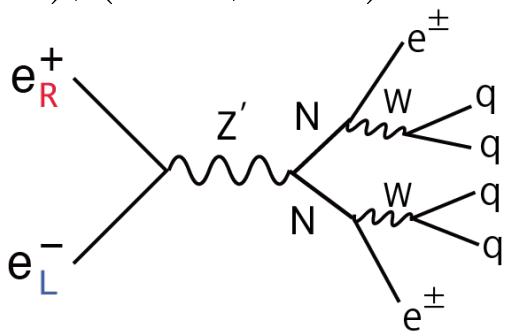
2 benchmark points

Not excluded by LHC

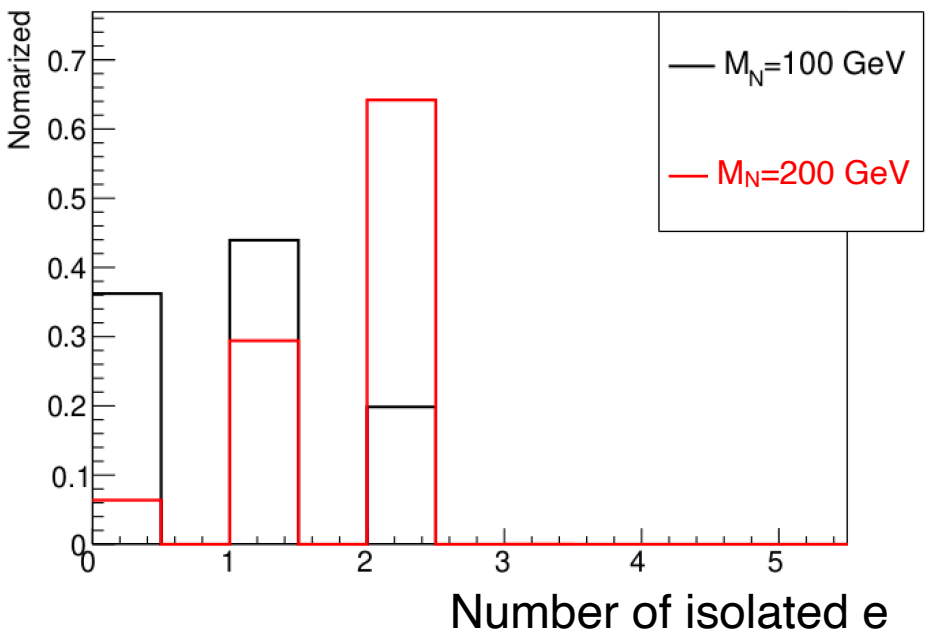
M_N [GeV]	$M_{Z'}$ [TeV]	g1'	$\lvert V_{eN}\rvert^2$	σ_{LR} (ee→NN)	Event # [4000fb-1]
100	7	1	0.001	7.05E-01	**1613**
200	7	1	0.005	1.61E-01	**368**
100	3	0.05	0.001	1.34E-04	0.3
200	3	0.05	0.005	2.66E-05	0.06

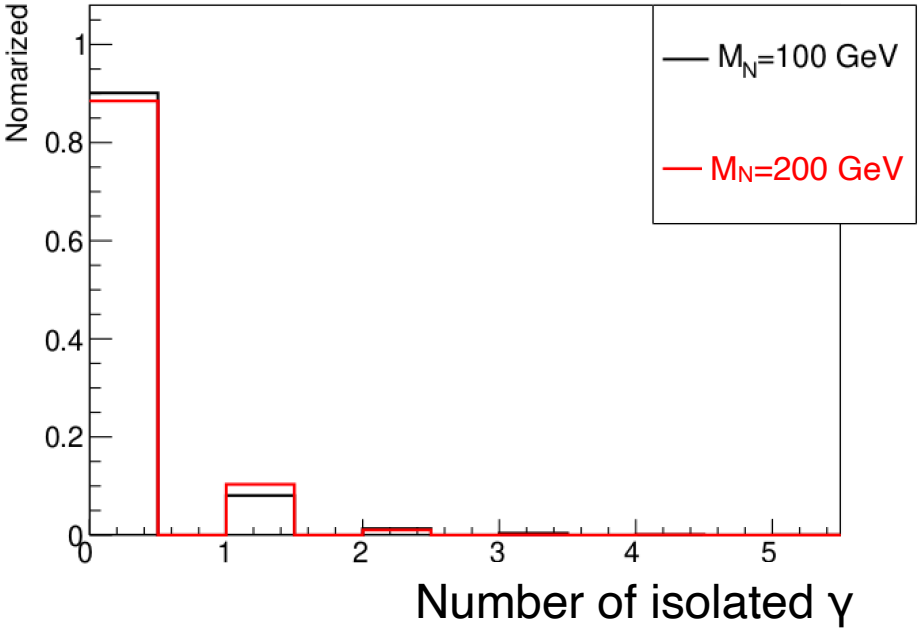
- minimal $U(1)_{B-L}$ model
  - ✦$\sigma_{LR} = \sigma_{RL}$(100%)
- ILC 500 with ISR / BS
- Generated event # = 5000

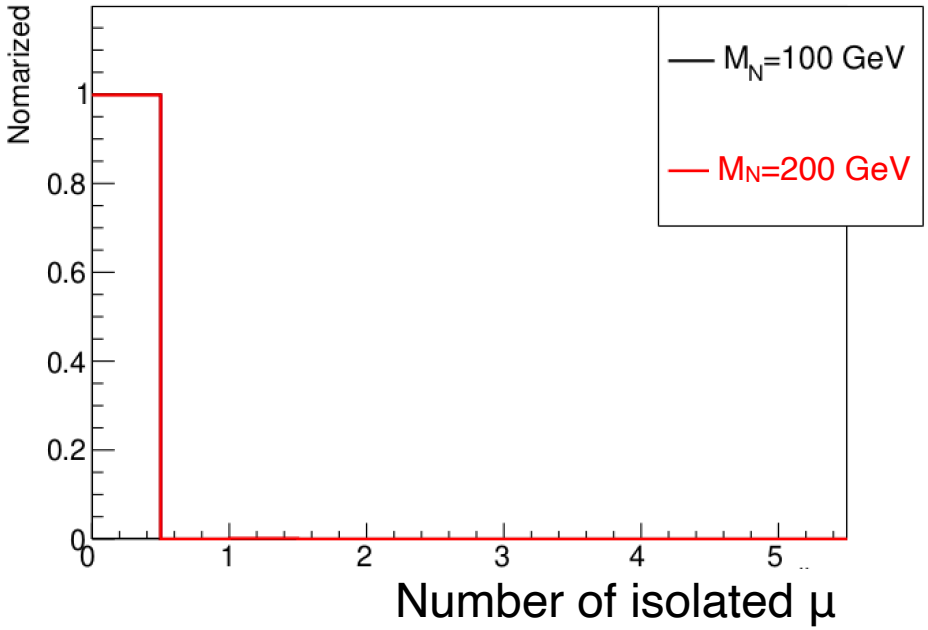
$$\mathrm{Pol}(-0.8,+0.3),(+0.8,-0.3) : \mathcal{L} = 1600\,[\mathrm{fb}^{-1}]$$
$$\mathrm{Pol}(+0.8,+0.3),(-0.8,-0.3) : \mathcal{L} = 400\,[\mathrm{fb}^{-1}]$$



Reconstructed particles - Isolated e,γ,μ



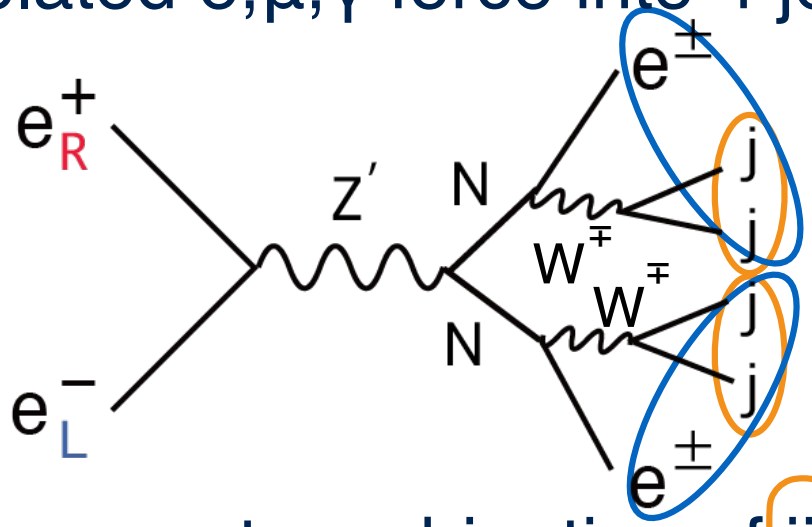




isolated electrons = 2
isolated photons = 0

Reconstruction methods

After removing isolated e,μ,γ force into 4 jets (Durham)



Search for the correct combination of jj and jje

Jet pair 1 $\rightarrow M_{jj1}$, Jet pair 2 $\rightarrow M_{jj2}$

$$F = (M_{jj1} - M_w)^2 + (M_{jj2} - M_w)^2$$

Best jet pair 1 + iso e $\rightarrow M_{jje1}$

Best jet pair 2 + iso e $\rightarrow M_{jje2}$

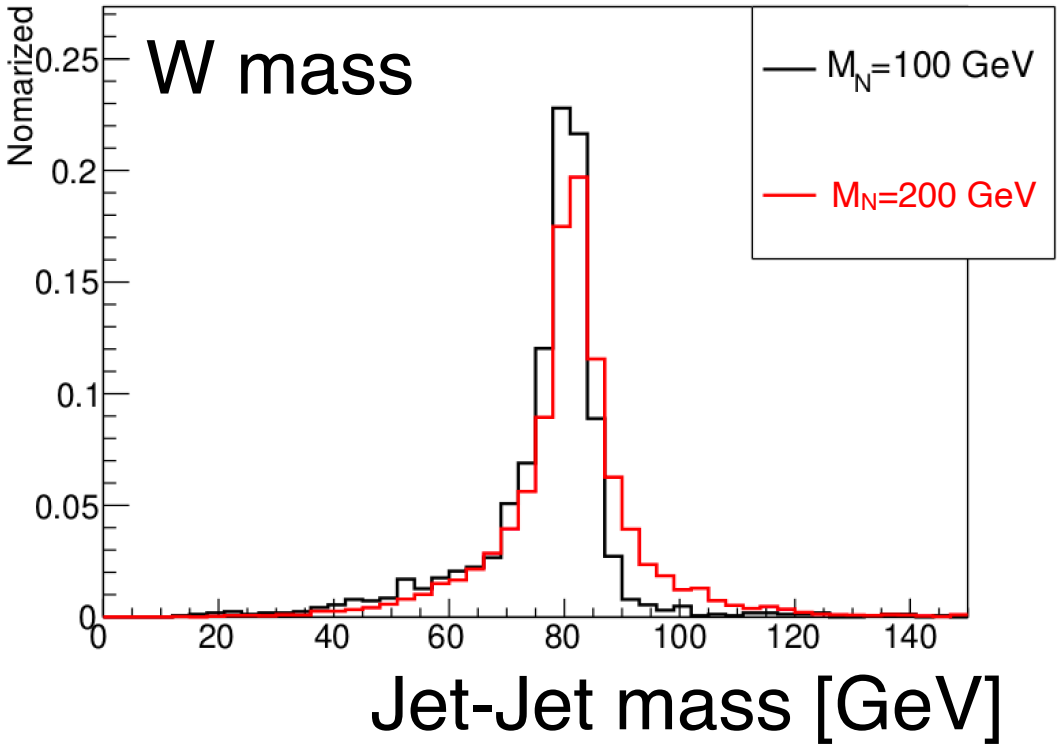
We expect for "$M_{jje1} = M_{jje2}$"

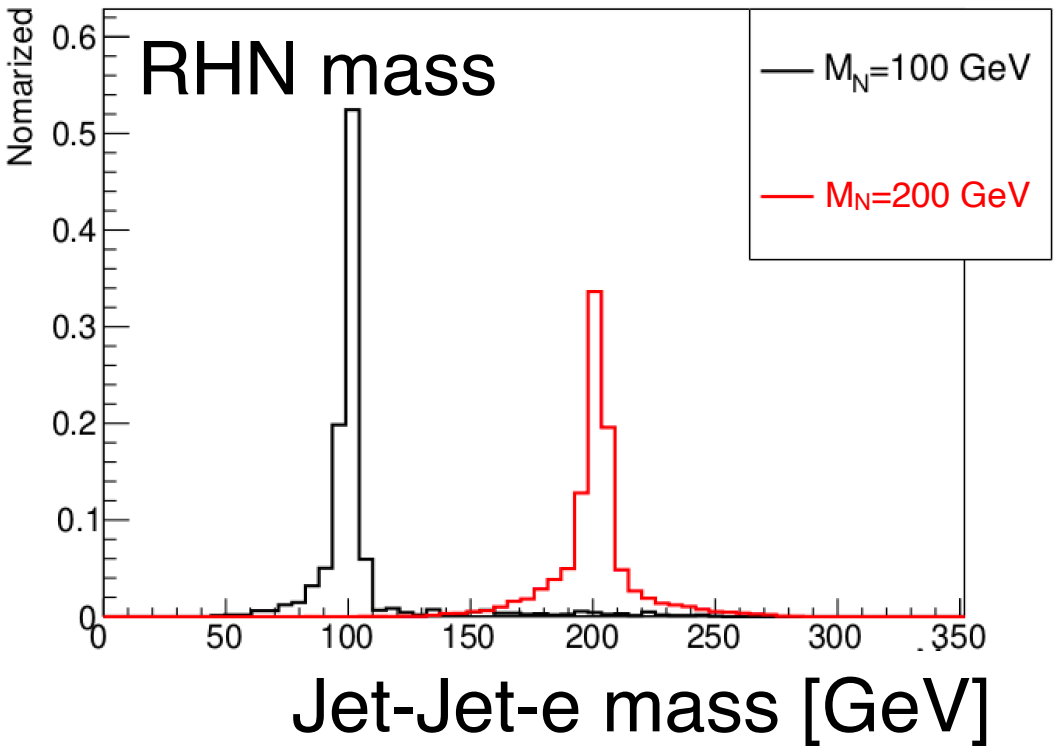
$$F = (M_{jje1} - M_{jje2})^2$$

Choose combination with minimum F

Reconstruction of W and RHN

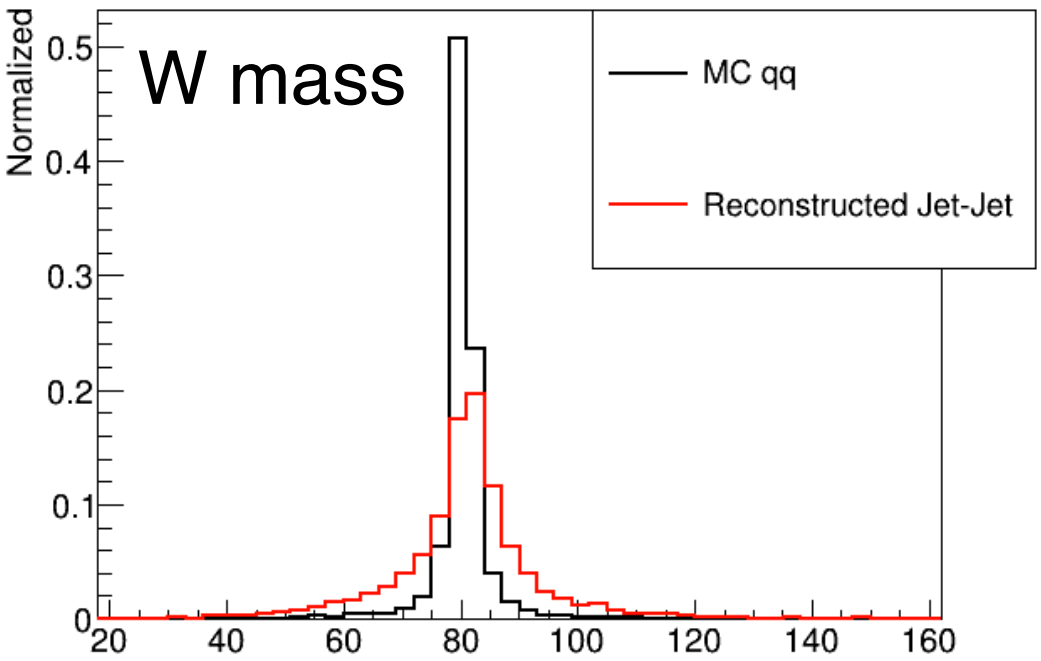
- # isolated electrons =2 && # isolated photons = 0
- Choose the **best** combination



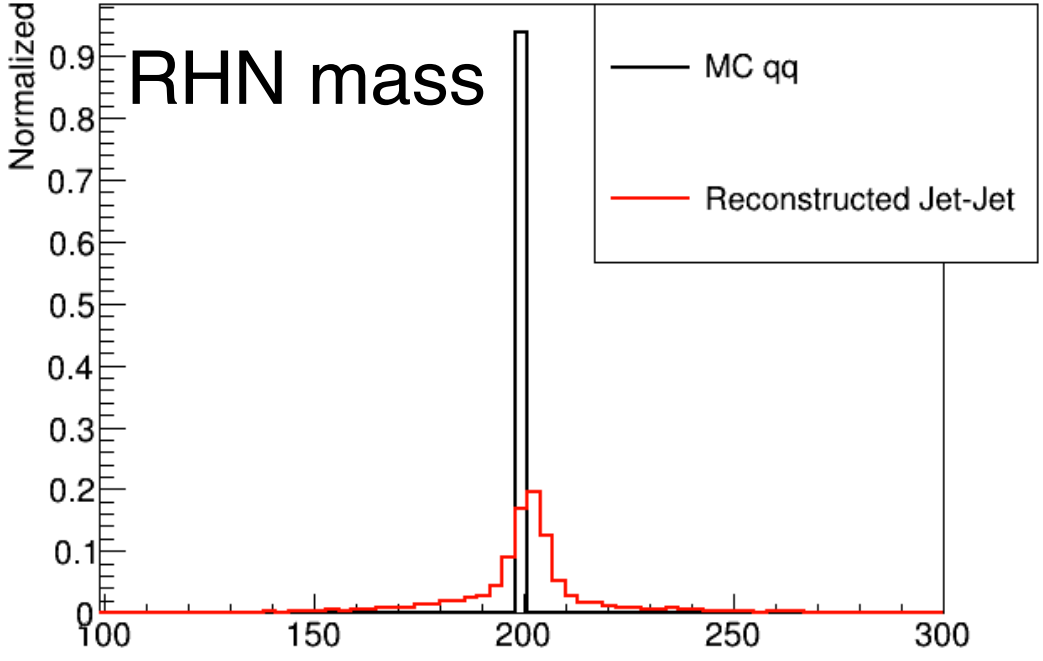


Comparison between MC and Reconstructed W Bosons and RHN

- M_N =200 GeV



Jet-Jet / qq mass [GeV]



Jet-Jet-e mass [GeV]

Summary in the case of minimal B-L

- RHN pair production has a distinctive signature of same sign leptons in the final state
  →Expected to be **almost background free**
- Carried out **fast simulation** for RHN pair production using **Delphes miniDST** framework
- Analyzed detector-simulated particles and tried to reconstruct RHNs → **Looks promising!**

My plan for the next step

1. Include potential background processes ←Now

   - Impose new conditions

   - Update our signal samples
     - Consider the polarization

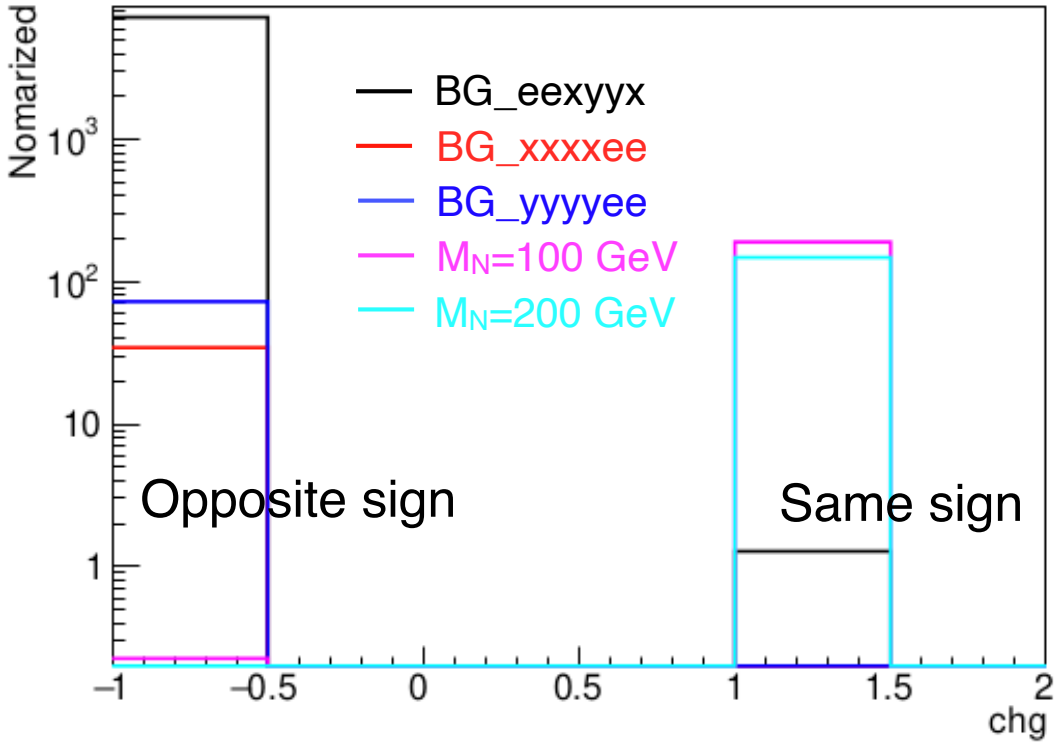
   → Look at the full simulation.

2. Consider other models

New Conditions

1. Include potential background processes
   - Impose new conditions

Isolated electrons charge



Isolated electron # = 2 && Isolated photon # =0

+

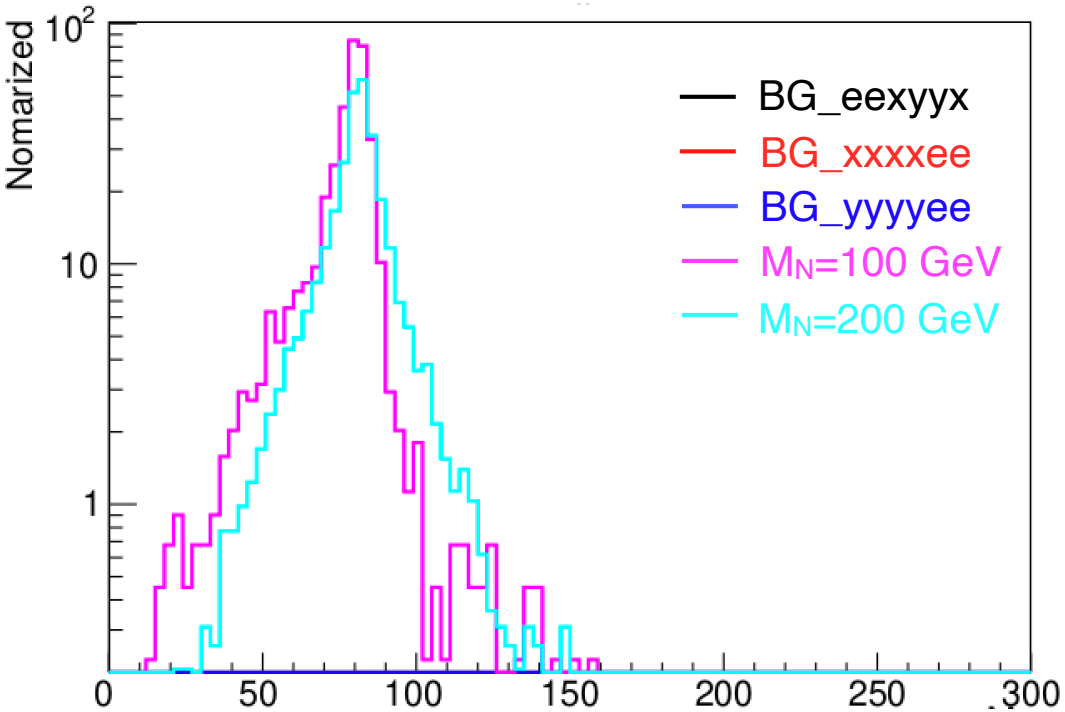
Charge = 1

After conditions

1. Include potential background processes
   - Impose new conditions

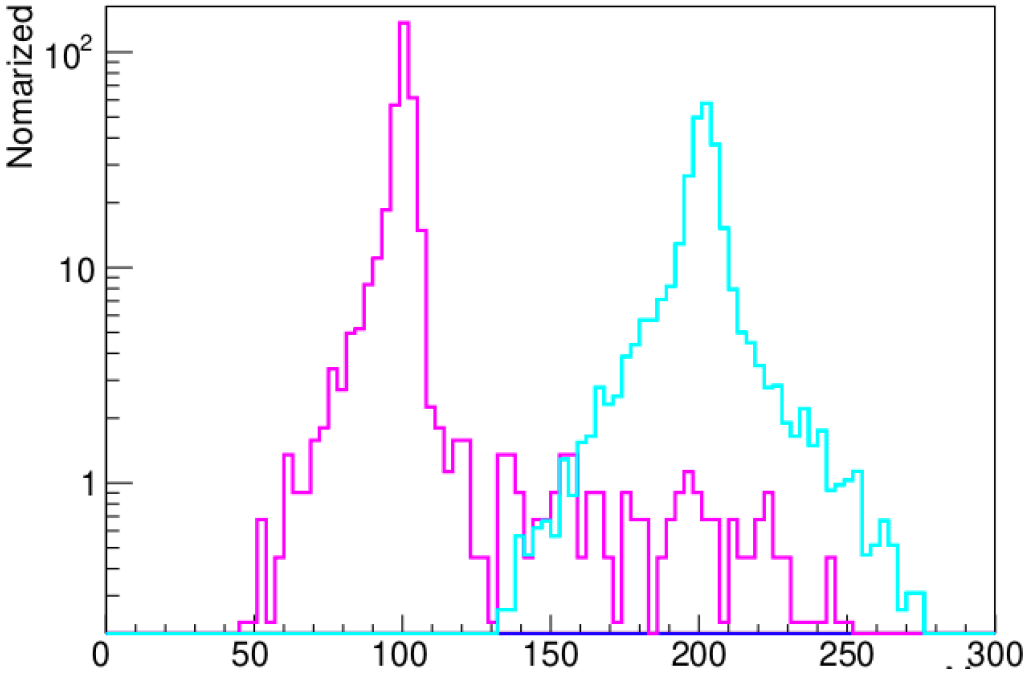
Isolated electron # = 2 && Isolated photon # =0 && charge = 1

W mass



Jet-Jet / qq mass [GeV]

RHN mass



Jet-Jet-e mass [GeV]

My plan

1. Include potential background processes
   - Update our signal samples
     - Consider the polarization

Before

- Only W^-
- "e-" , "e+" => "u", "d~", "e-", "c", "s~", "e-"

{ $restrictions = "3+4+5~n1 && 6+7+8~n1 && 3+4~'W+' && 6+7~'W+' "}

- eLpR(100,100)

After

- Including both probability W^+ and W^-
- "e-" , "e+" => quark, antiquark, electron, quark, antiquark, electron

{ $restrictions = "3+4+5~n1 && 6+7+8~n1 && 3+4~'W+:W-' && 6+7~'W+:W-' "}

- eLpR,eRpL,eLpL,eRpR (80,30)

Current status

- Make new samples (eRpL, eLpL, eRpR, eLpR)

  Problems in .sin file

  ・process time is too long and kicked out of KEKcc.

  →try “mpi option”
  (Advised by Junpin-san and Daniel-san)

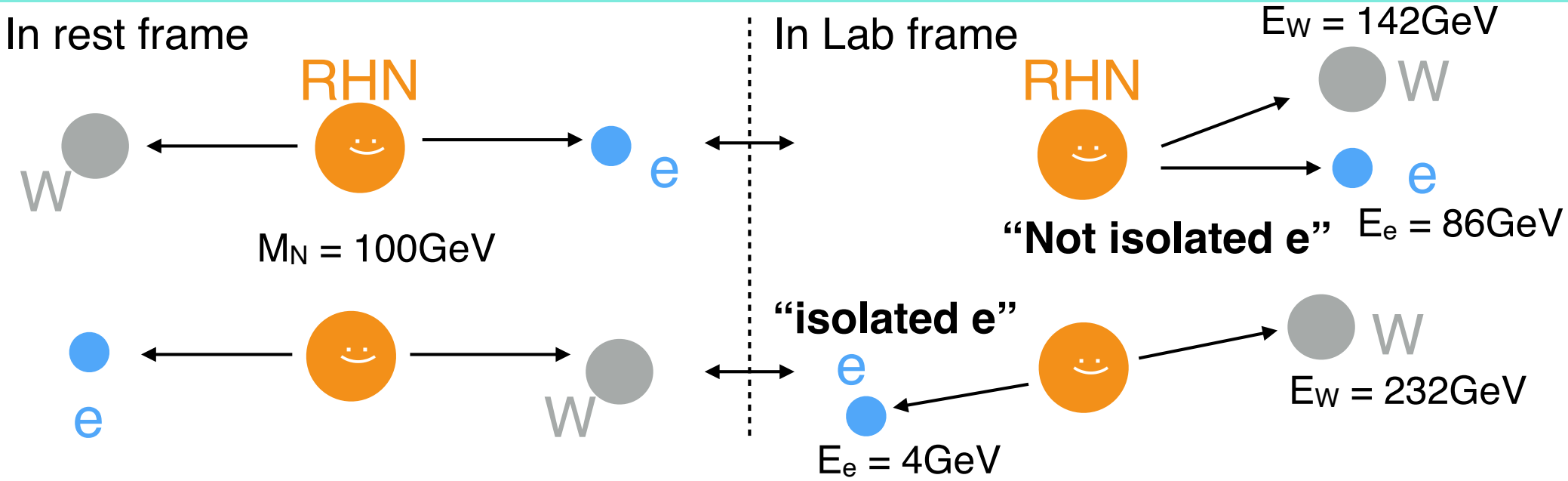
  Maybe work

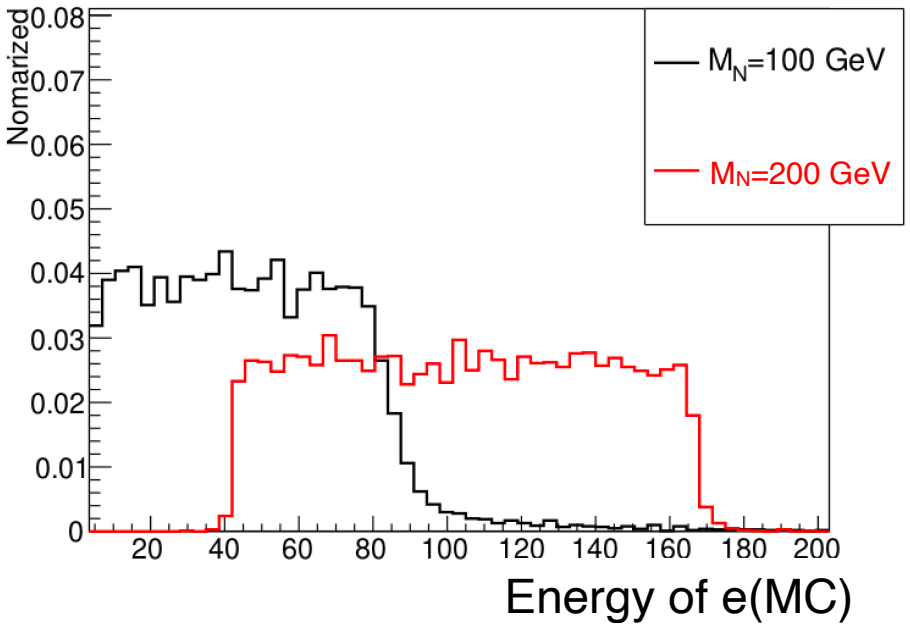
  →try to using “bsub”
  But we have problems and bsub doesn’t work well

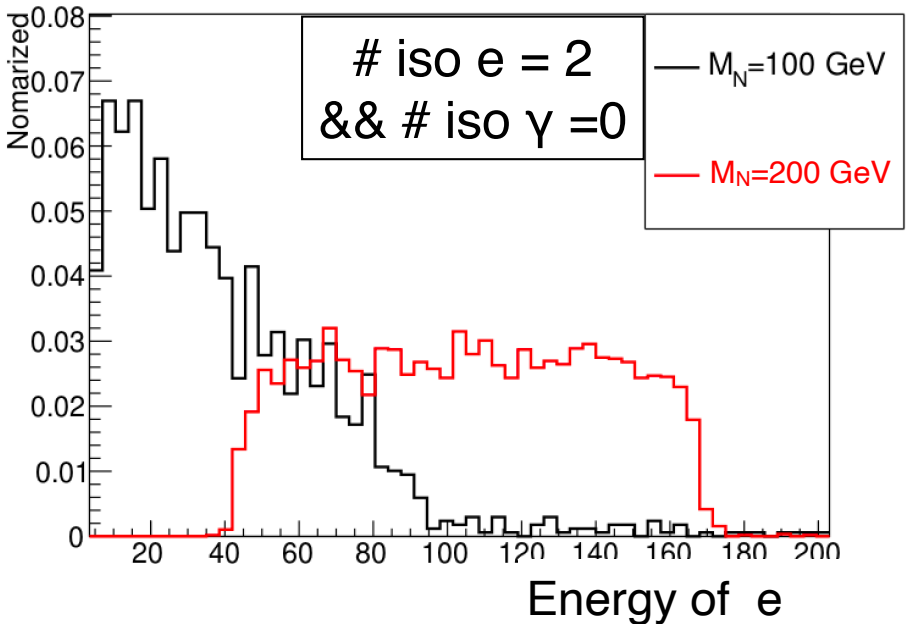
  → Fixed it today….

Backup

Why is an about half of # isolated electrons 1 in M_N=100 GeV?







ILC250

M_N [GeV]	$M_{Z'}$ [TeV]	g1'	$\|V_{eN}\|^2$	σ_{LR} (ee→NN)	Event # [2000fb-1]
100	7	1	0.001	4.53E-02	50

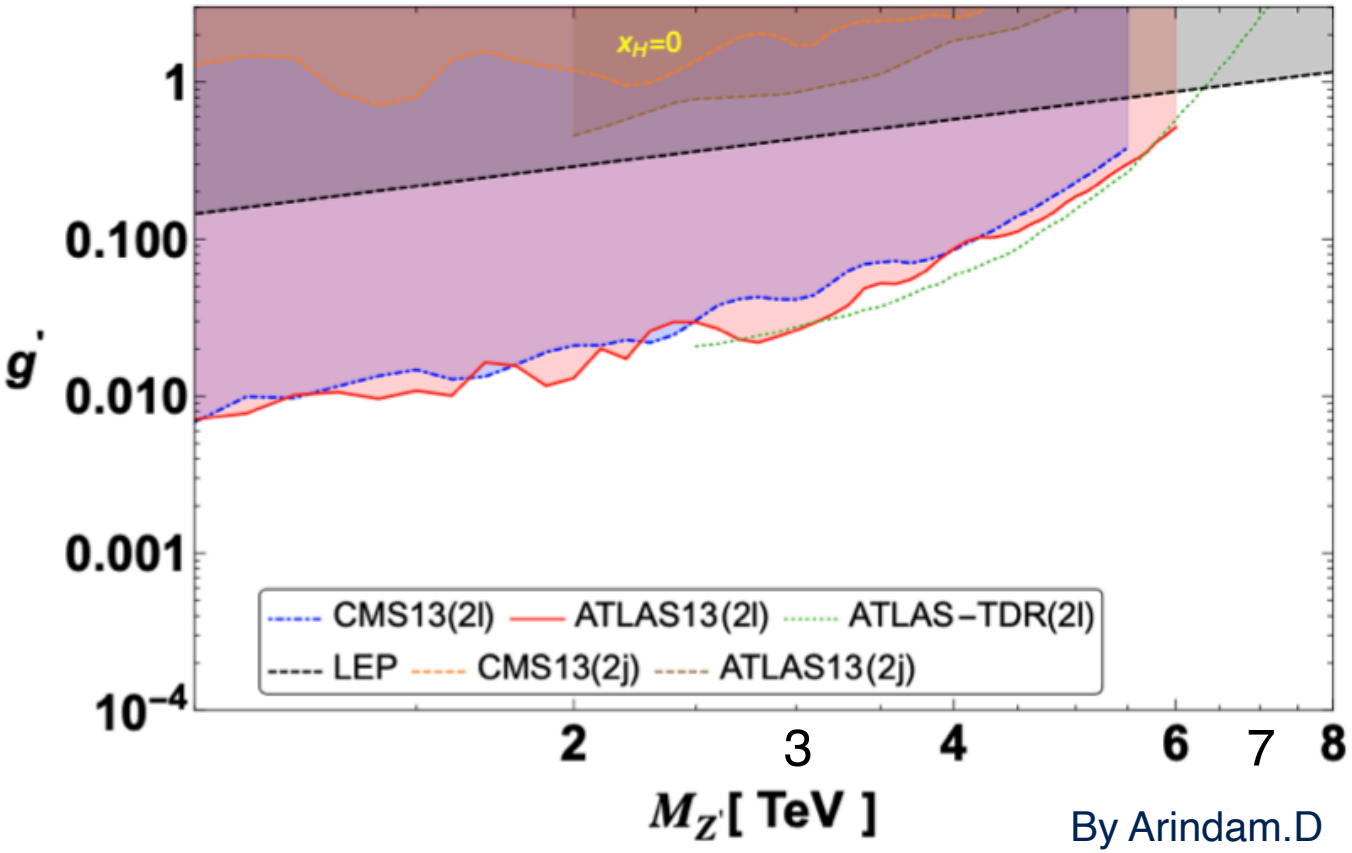
Cross section with the beam polarization

$$\sigma(P_-, P_+) = \left(\frac{1-P_-}{2}\right)\left(\frac{1+P_+}{2}\right)\sigma_L + \left(\frac{1+P_-}{2}\right)\left(\frac{1-P_+}{2}\right)\sigma_R \ (\sigma_L = \sigma_R)$$

$$\mathrm{Pol}(-0.8, +0.3), \mathrm{Pol}(+0.8, -0.3) : \mathcal{L} = 900\,[\mathrm{fb}^{-1}]$$
$$\mathrm{Pol}(+0.8, +0.3), \mathrm{Pol}(-0.8, -0.3) : \mathcal{L} = 100\,[\mathrm{fb}^{-1}]$$

Current Limits and prospects - Z' mass,g1'

G1' :$U(1)_{B-L}$ gauge coupling constant

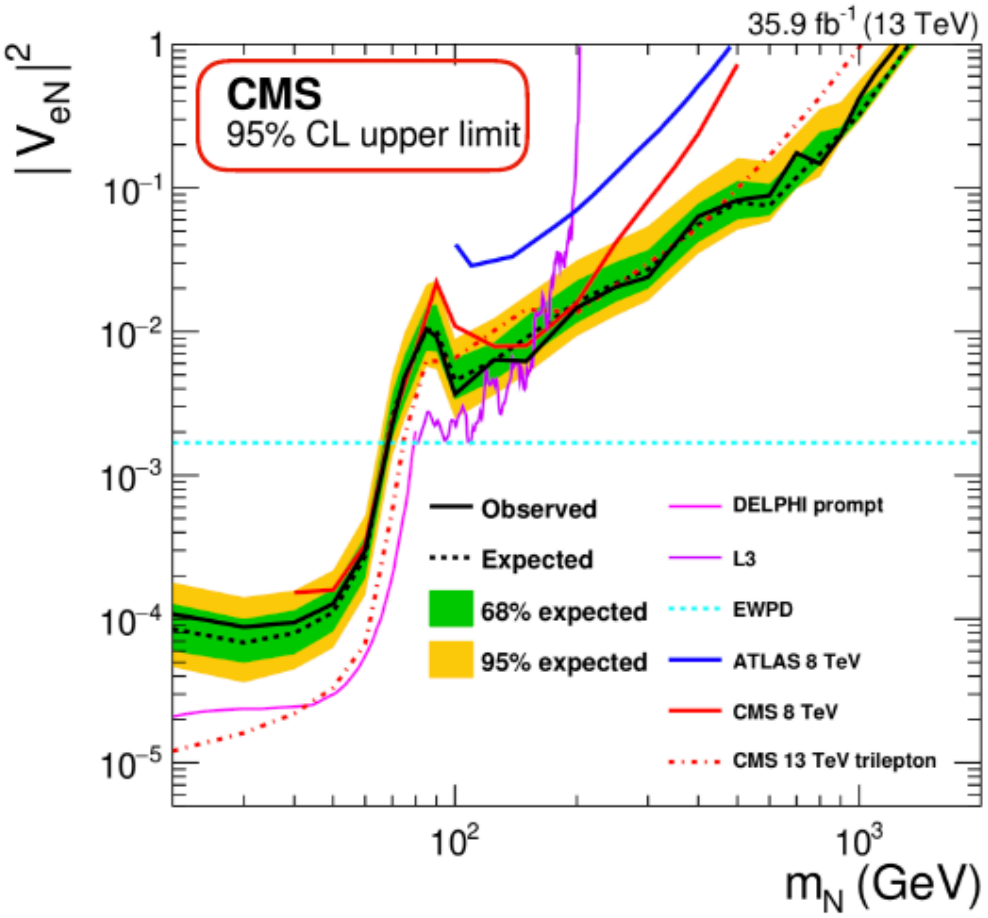


By Arindam.D

M_N [GeV]	$M_{Z'}$ [TeV]	g1'
100	7	1
200	7	1

Current limits $|V_{eN}|^2$

$|V_{eN}|^2$: the "light-heavy" neutrino mixing matrix



CMS PAS EXO-19-019