Exploring Right Handed Neutrinos at ILC

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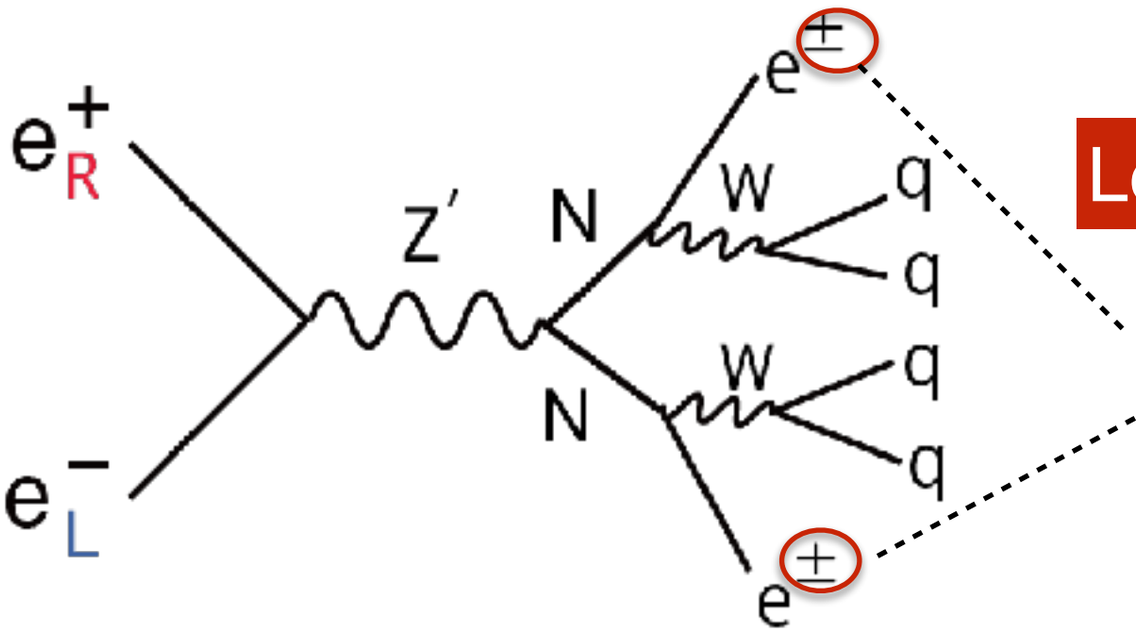
Motivation

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 unifiy?

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

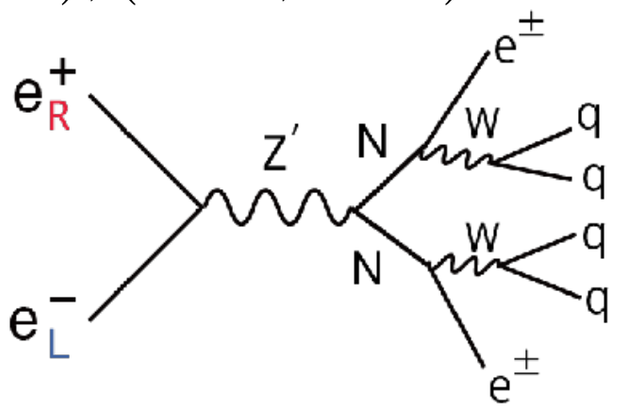
2 benchmark points

Not excluded by LHC

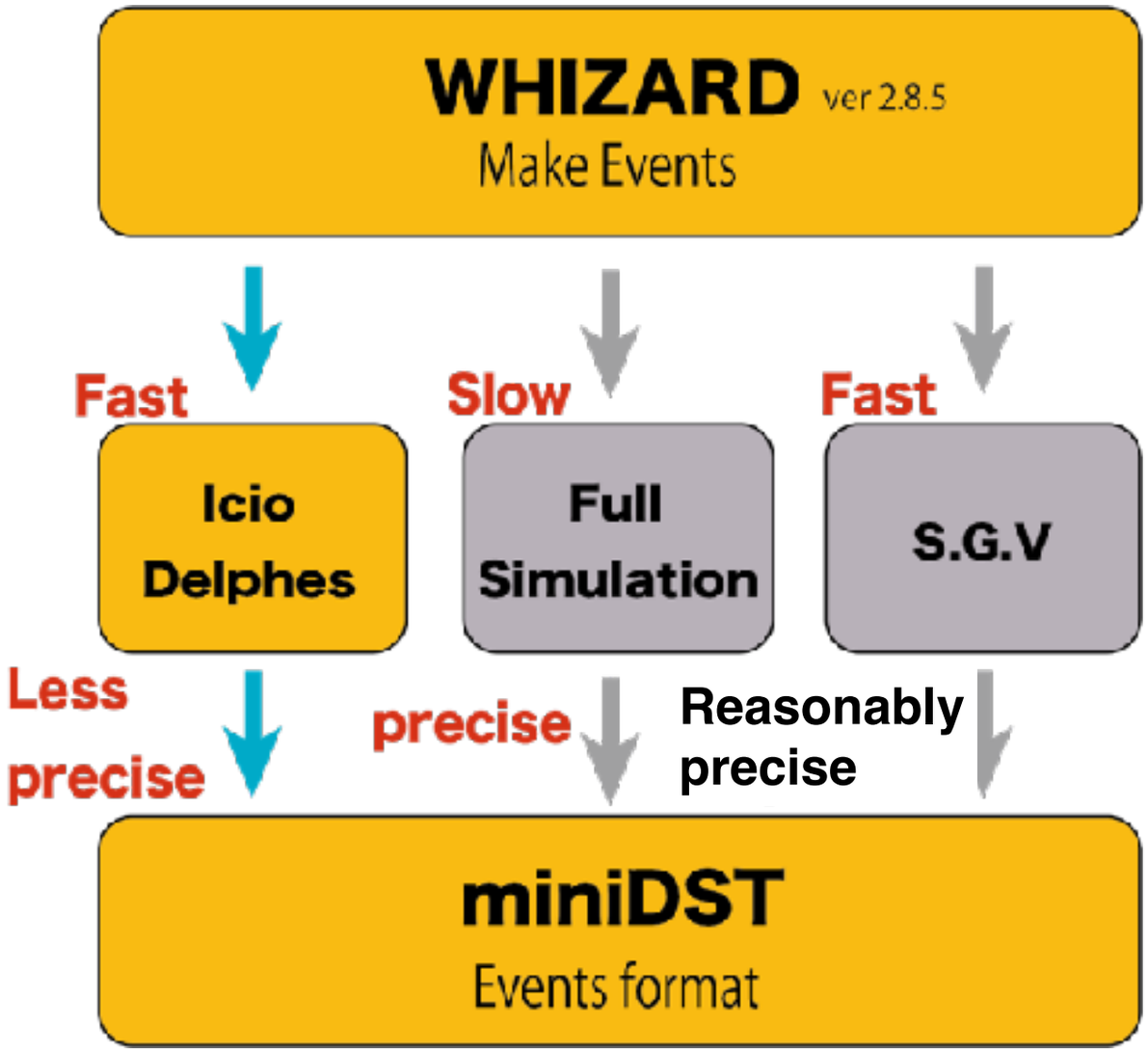
M_N [GeV]	$M_{Z'}$ [TeV]	g1'	$\lvert V_{eN}\rvert^2$	σ_{LR} (ee→NN) [fb]	Event # [4000fb-1]
100	7	1	0.001	7.08E-01	**1619**
200	7	1	0.005	1.63E-01	**372**

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

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



Analysis tool

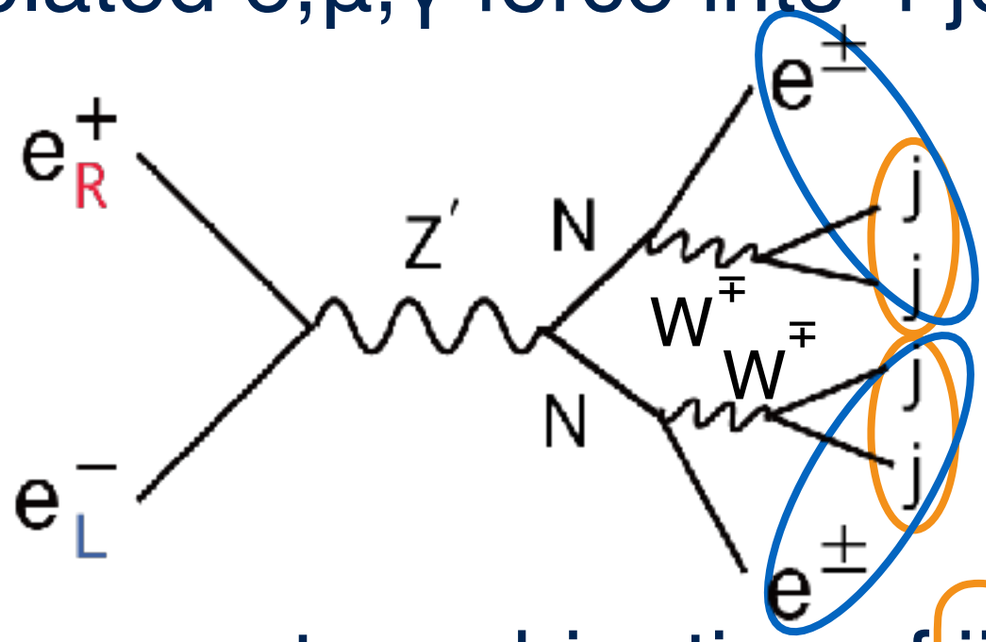


Fast simulation

- using Delphes with the "**generic ILC detector card**"
  recently prepared for the US Snowmass study
  → ***Friendly to newcomers***

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 $\rightarrow M_{jje2}$

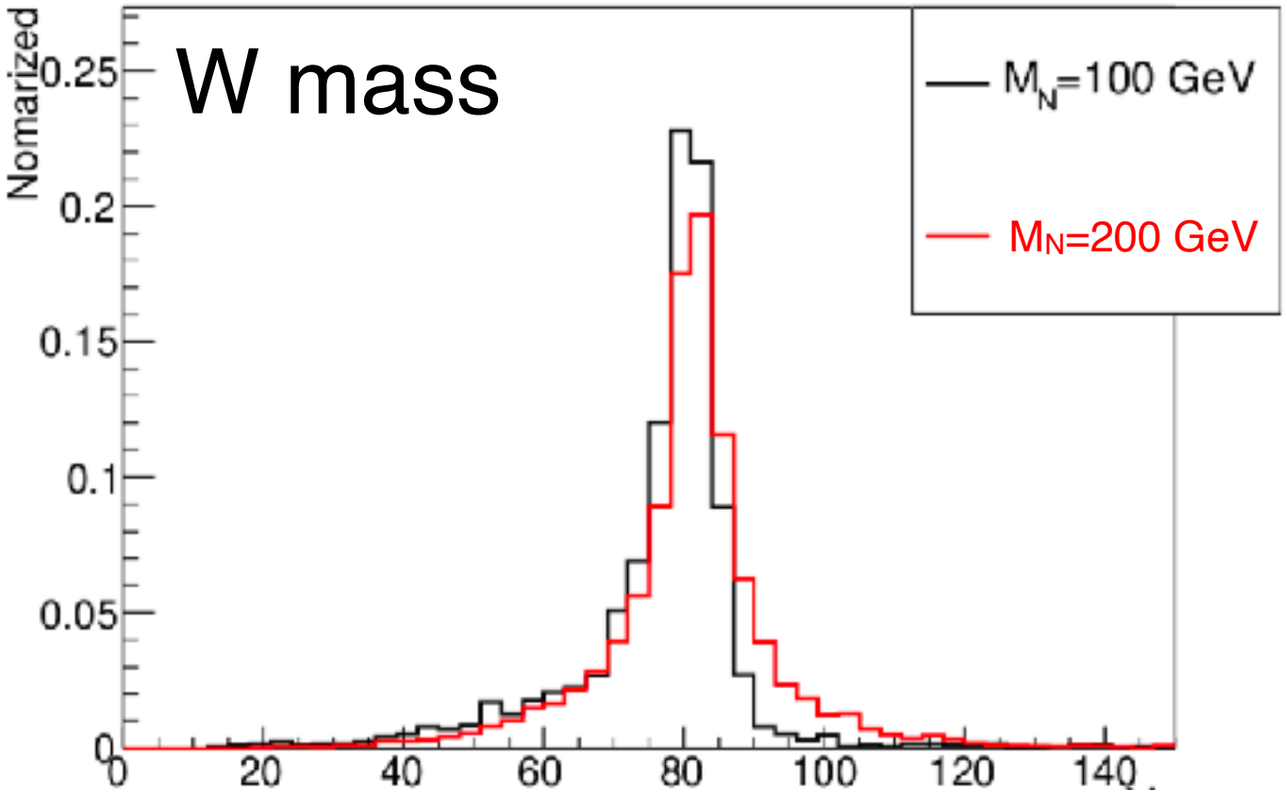
We expect for "$M_{jje1} = M_{jje2}$"

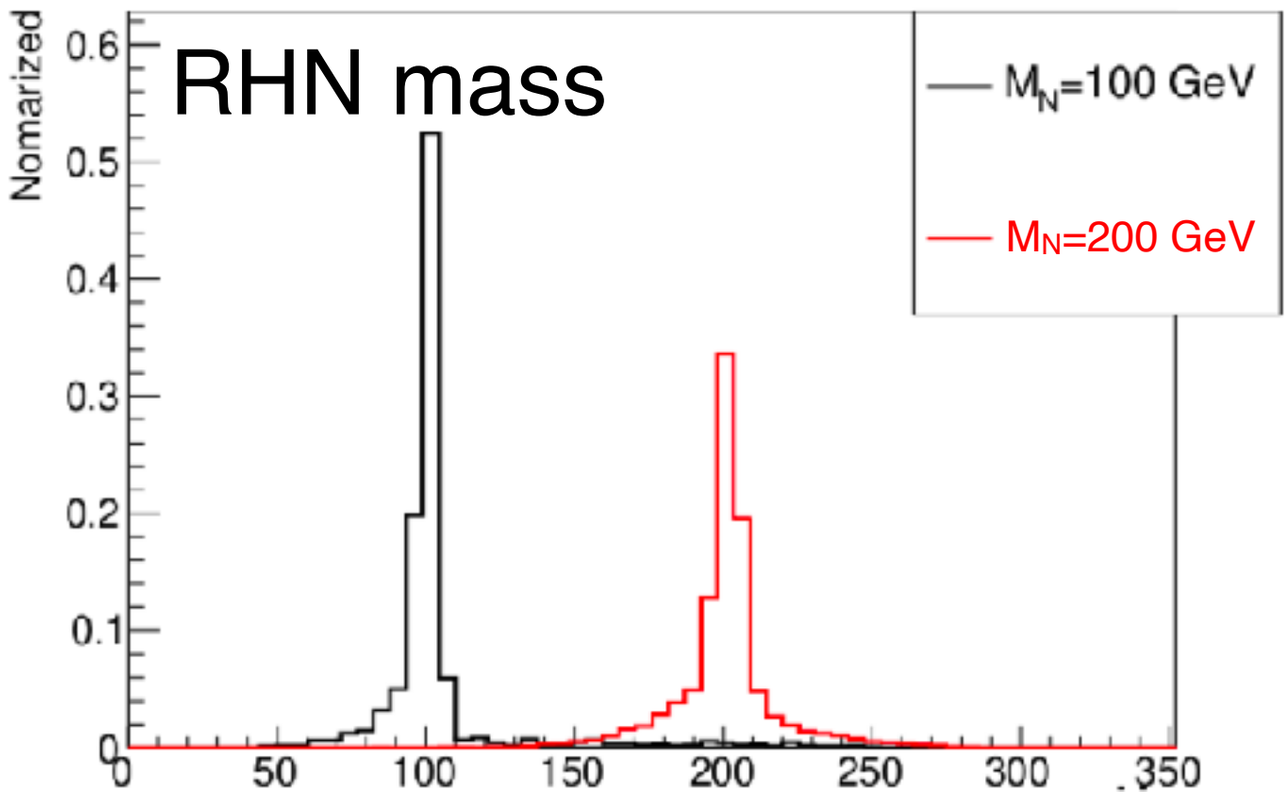
$$F = (M_{jje1} - M_{jje2})^2$$

Choose combination with minimum F

Reconstruction of W and RHN

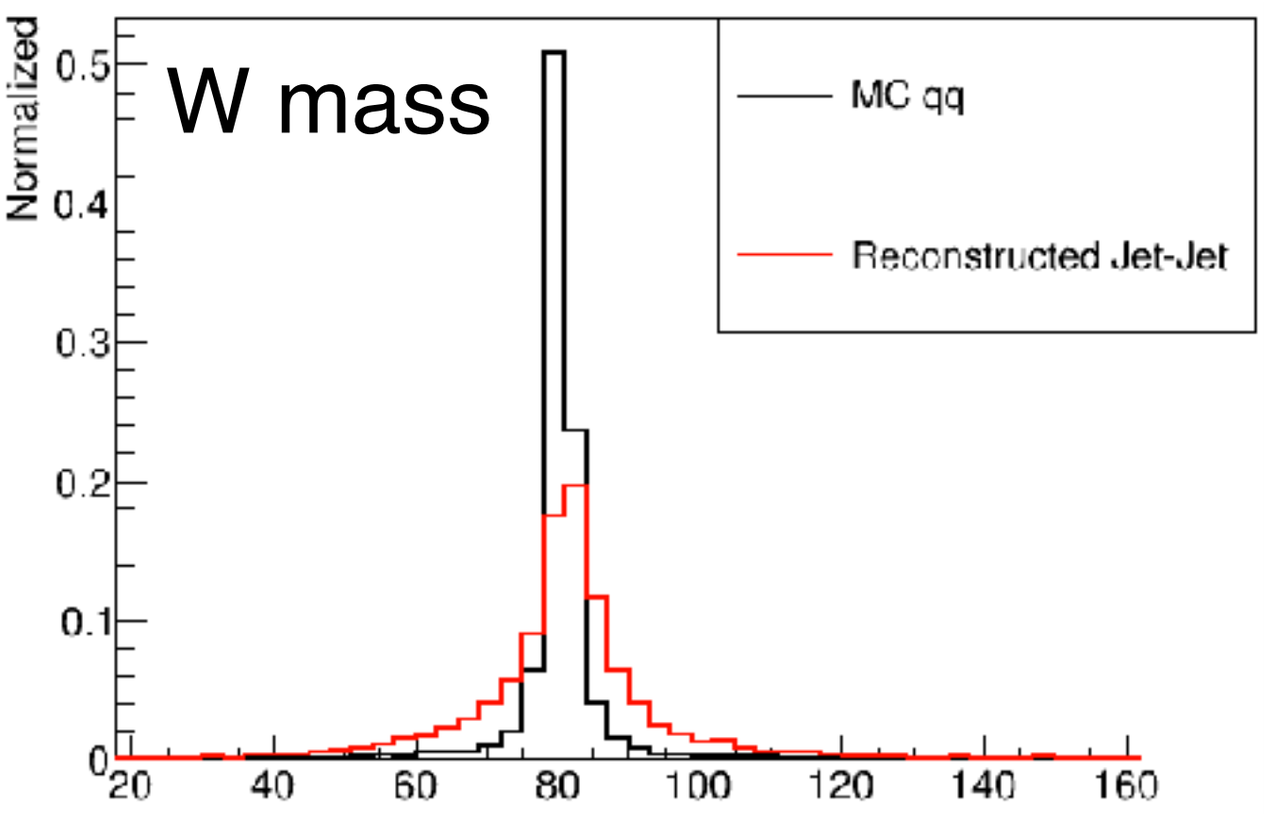
isolated electrons =2 && # isolated photons = 0
Choose the **best** combination



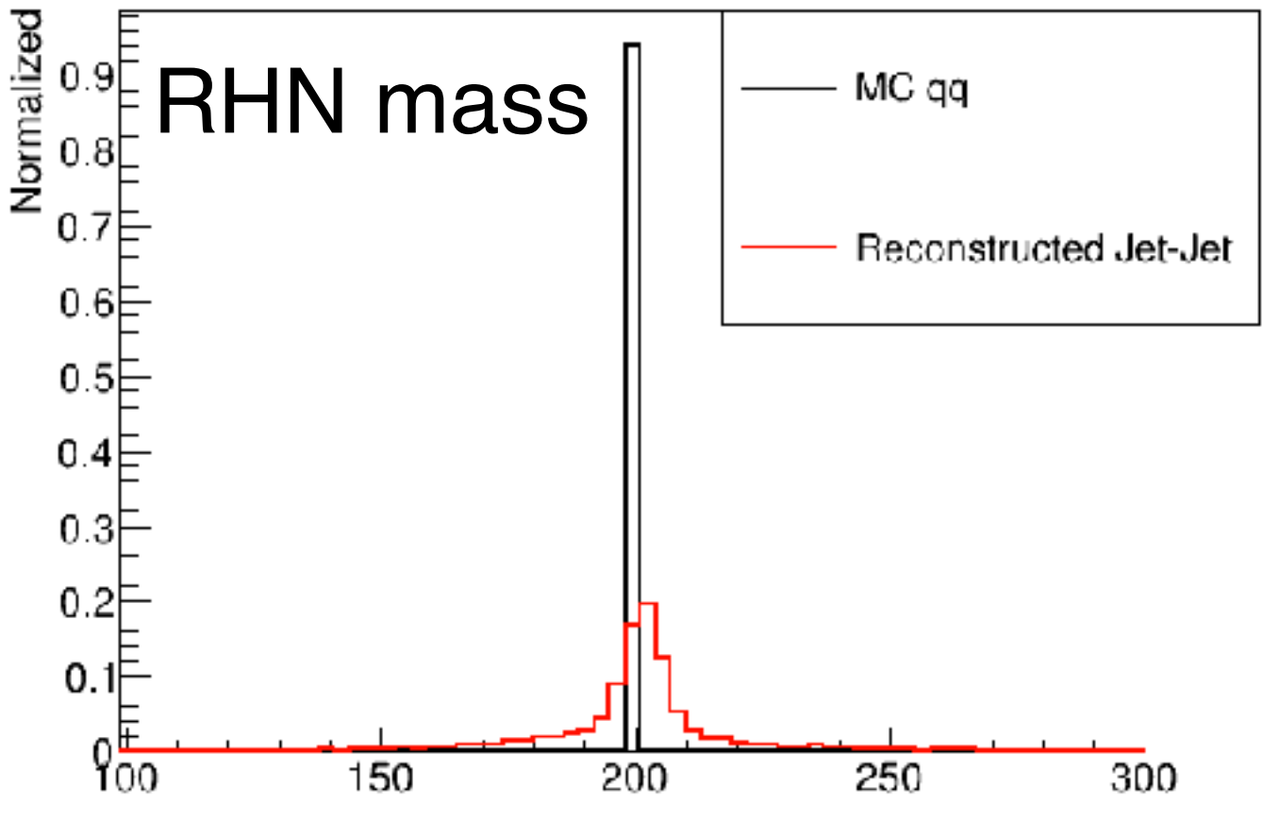


Comparison between MC and Reconstructed W Bosons and RHN

- M_N =200 GeV

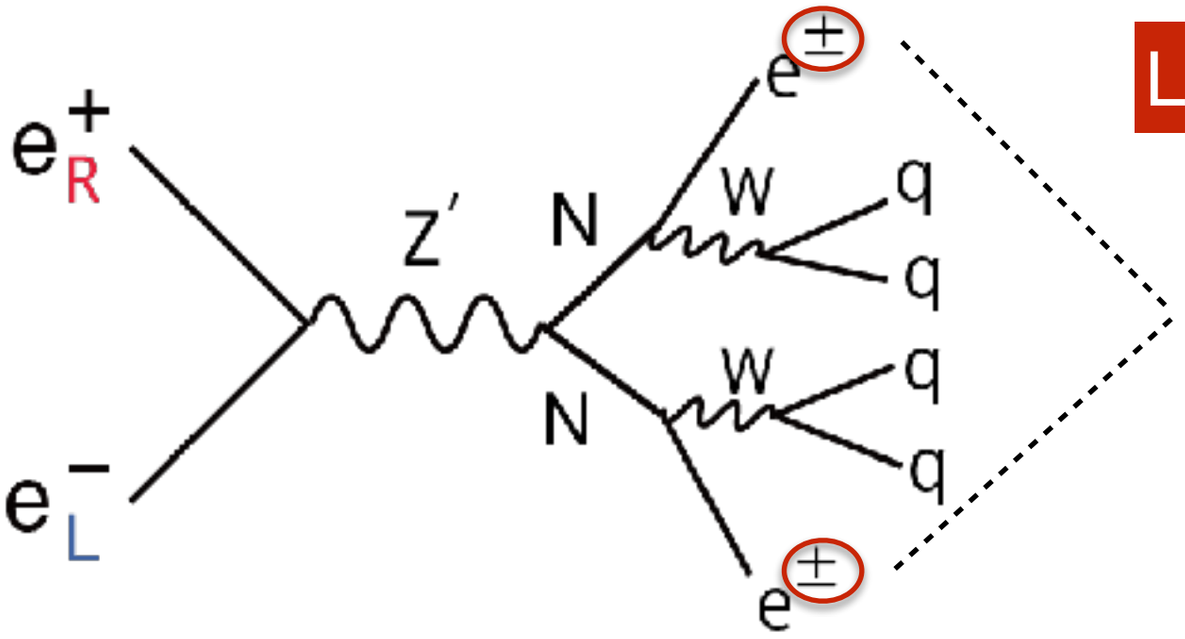


Jet-Jet / qq mass [GeV]



Jet-Jet-e mass [GeV]

Back grounds



Lepton # violation is possible!

↓

Same sign leptons possible

↓

No SM BG!

However… We need to consider as the follow.

Charge misidentification

Add to full simulation back ground samples.

eexyyx, xxxxee, yyyyee
(All polarization)

x…up type quark
y…down type quark

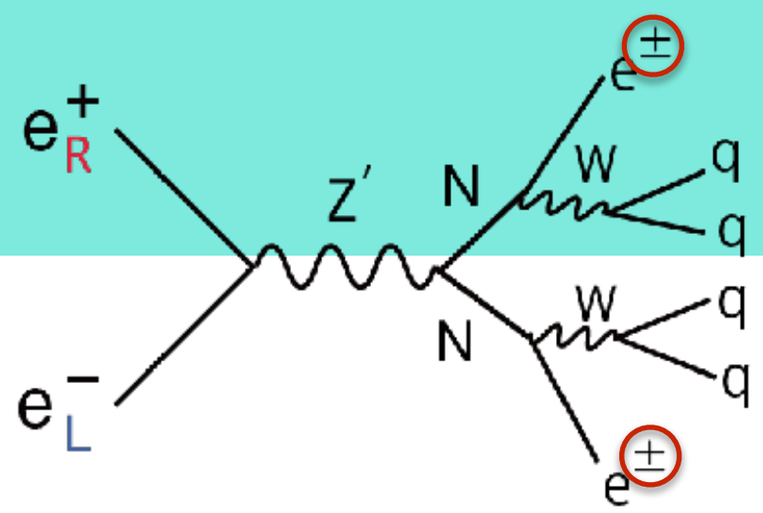
Cross section — BG

x…up type quark
y…down type quark

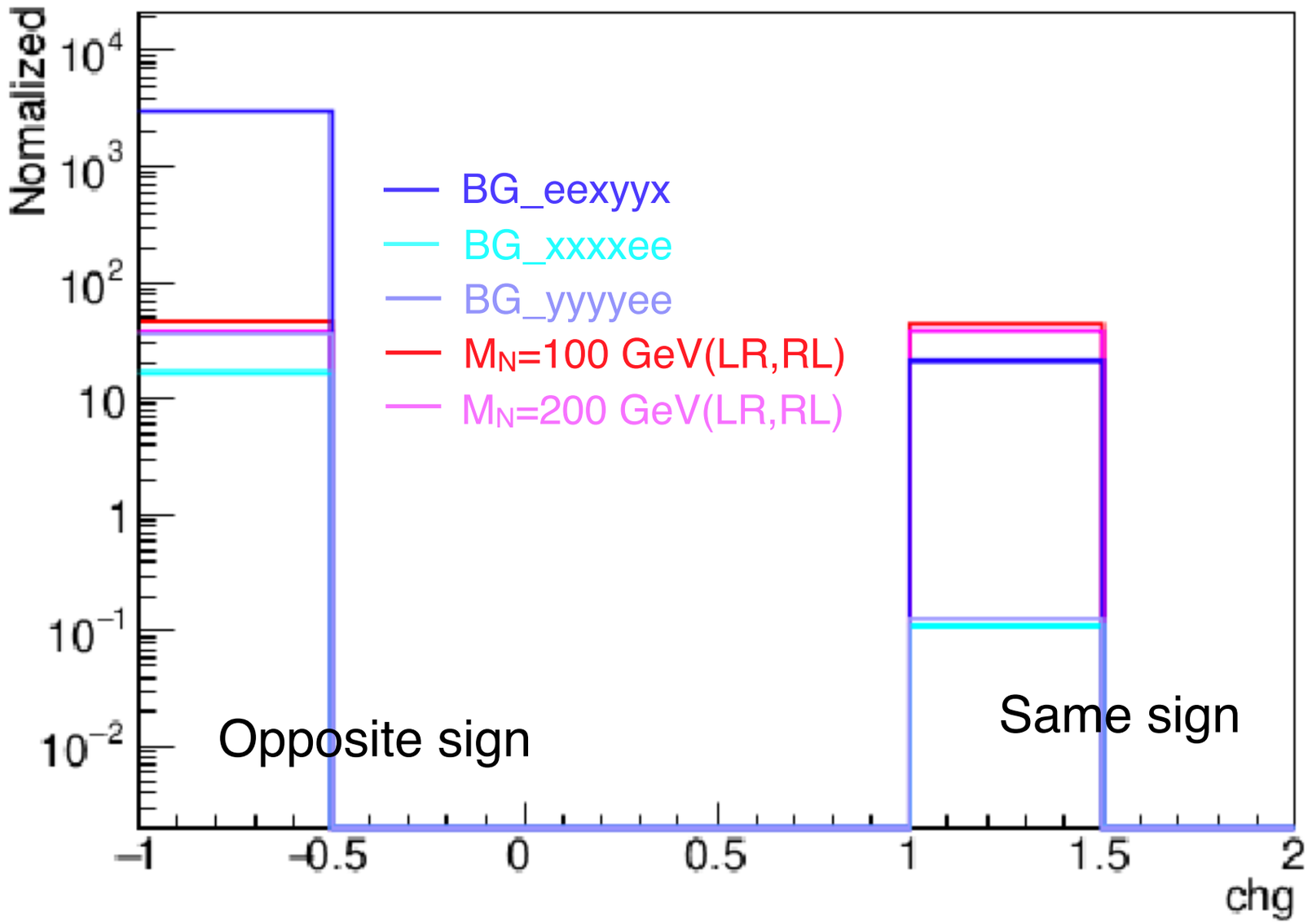
(100%,100%)	eexyyx	xxxxee	yyyyee
eLpR	1.64E+01	8.71E-02	1.45E-01
eRpL	3.64	4.62E-02	5.31E-02
eLpL	6.63	3.38E-02	2.20E-02
eRpR	6.61	3.30E-02	1.97E-02

Electron Charge

ILC 500 with ISR / BS (80,30)



Isolated electrons charge

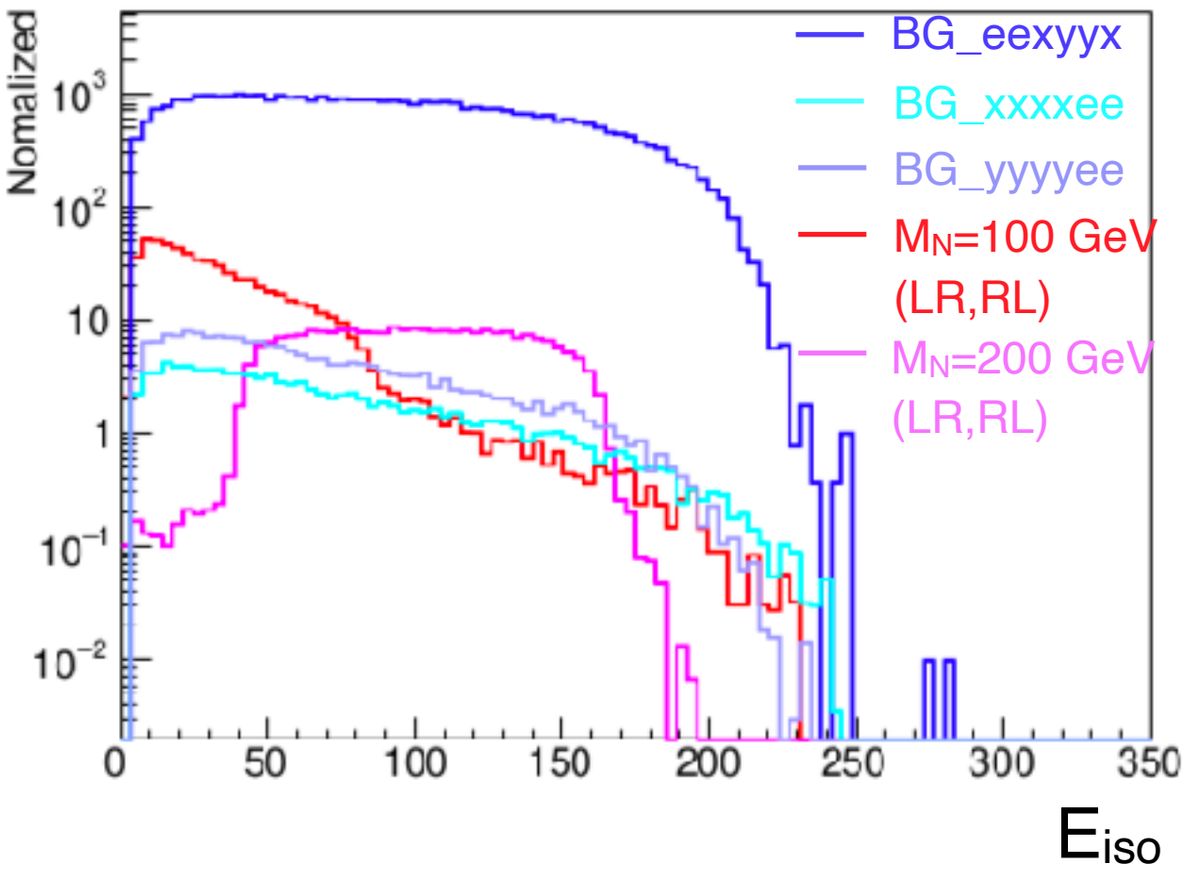


We use only same sign samples (Charge == 1)

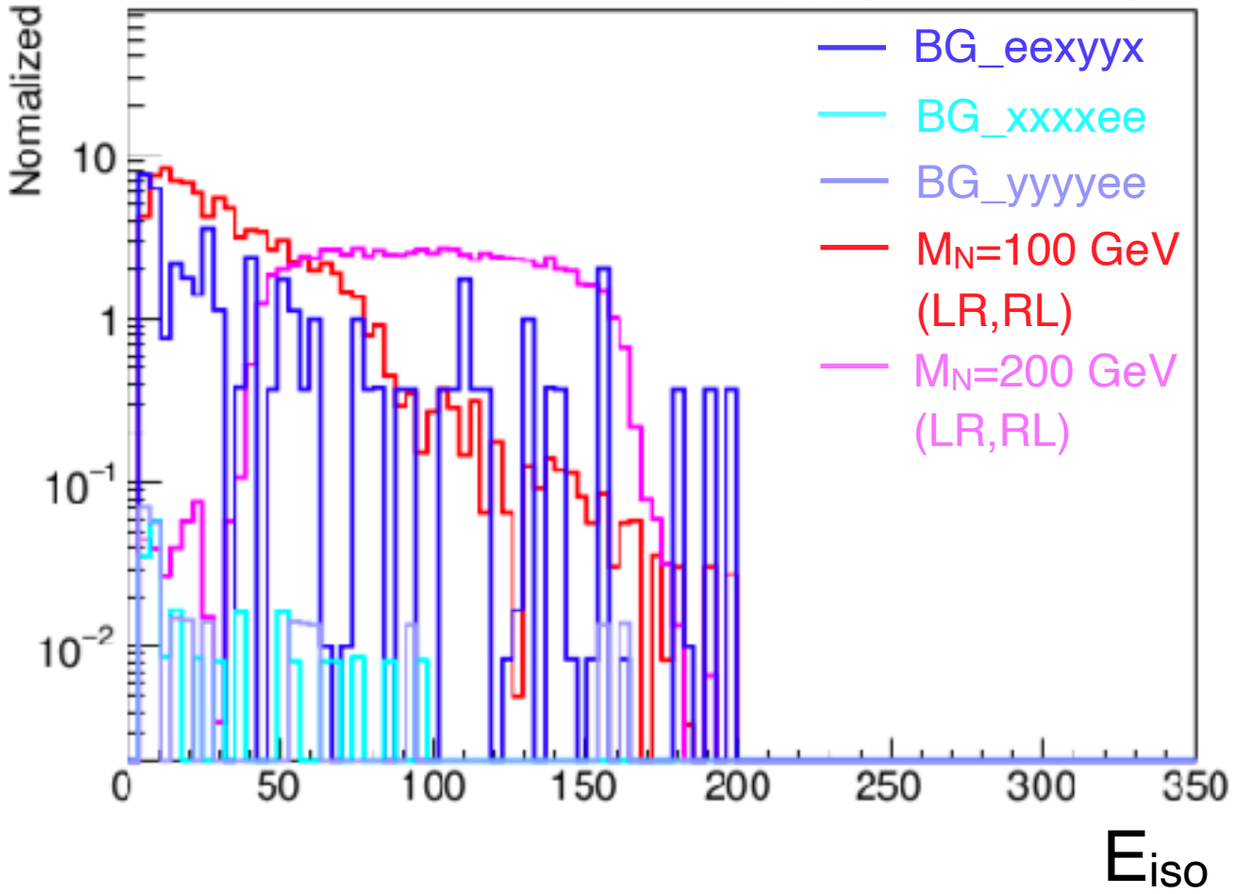
Isolated electron energy

ILC 500 with ISR / BS (80,30)

Isolated electron energy(before cut)



Isolated electron energy(after cut)

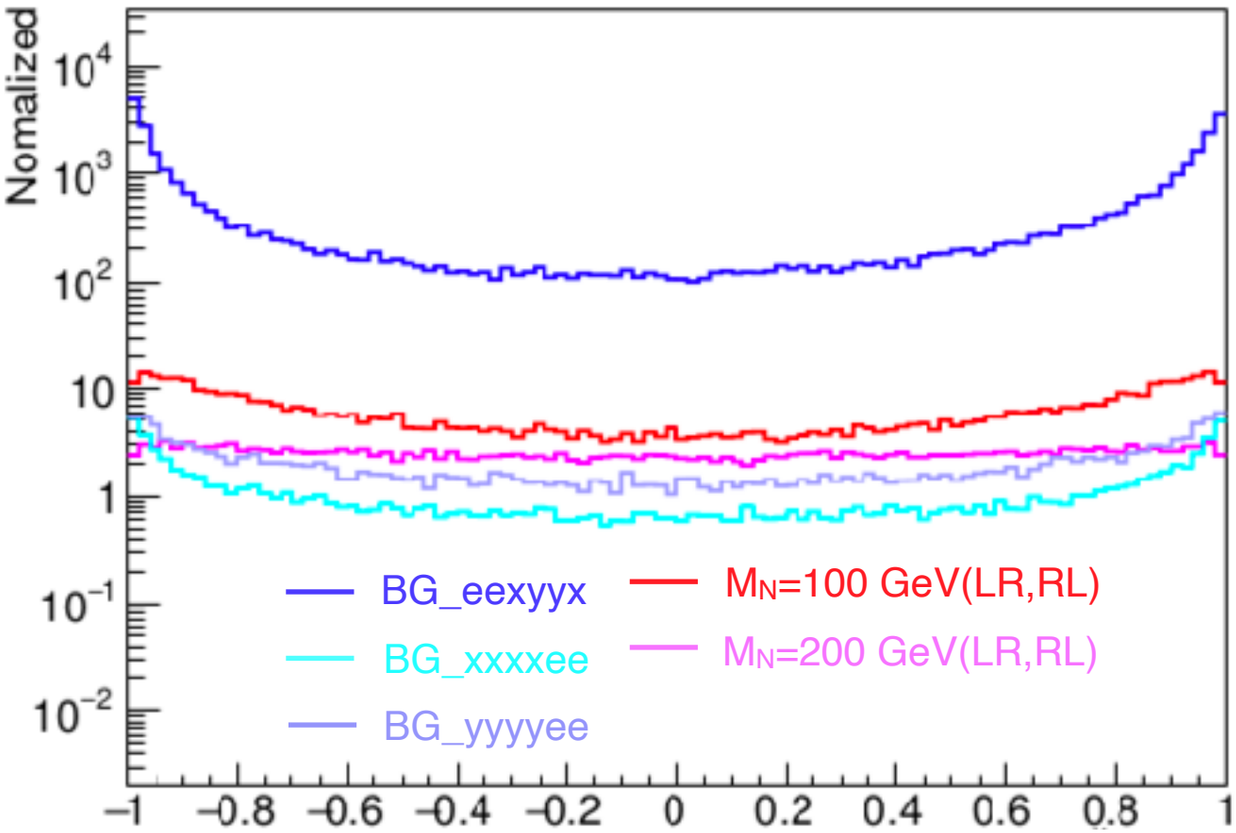


$E_{iso} < 200$ [GeV]

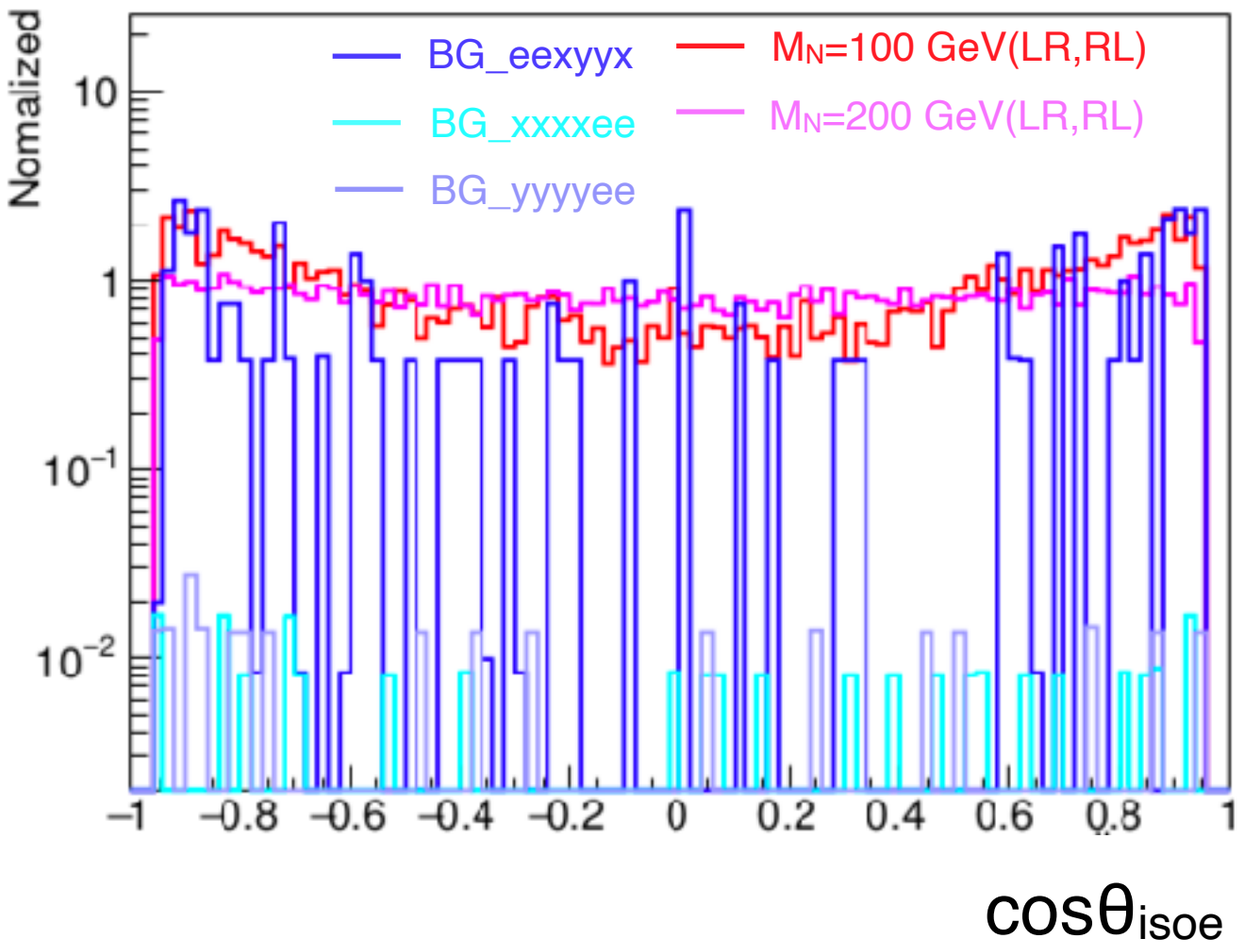
$\cos\theta_{isoe}$

ILC 500 with ISR / BS(80,30)

$\cos\theta_{isoe}$ (before cut)



$\cos\theta_{isoe}$ (after cut)

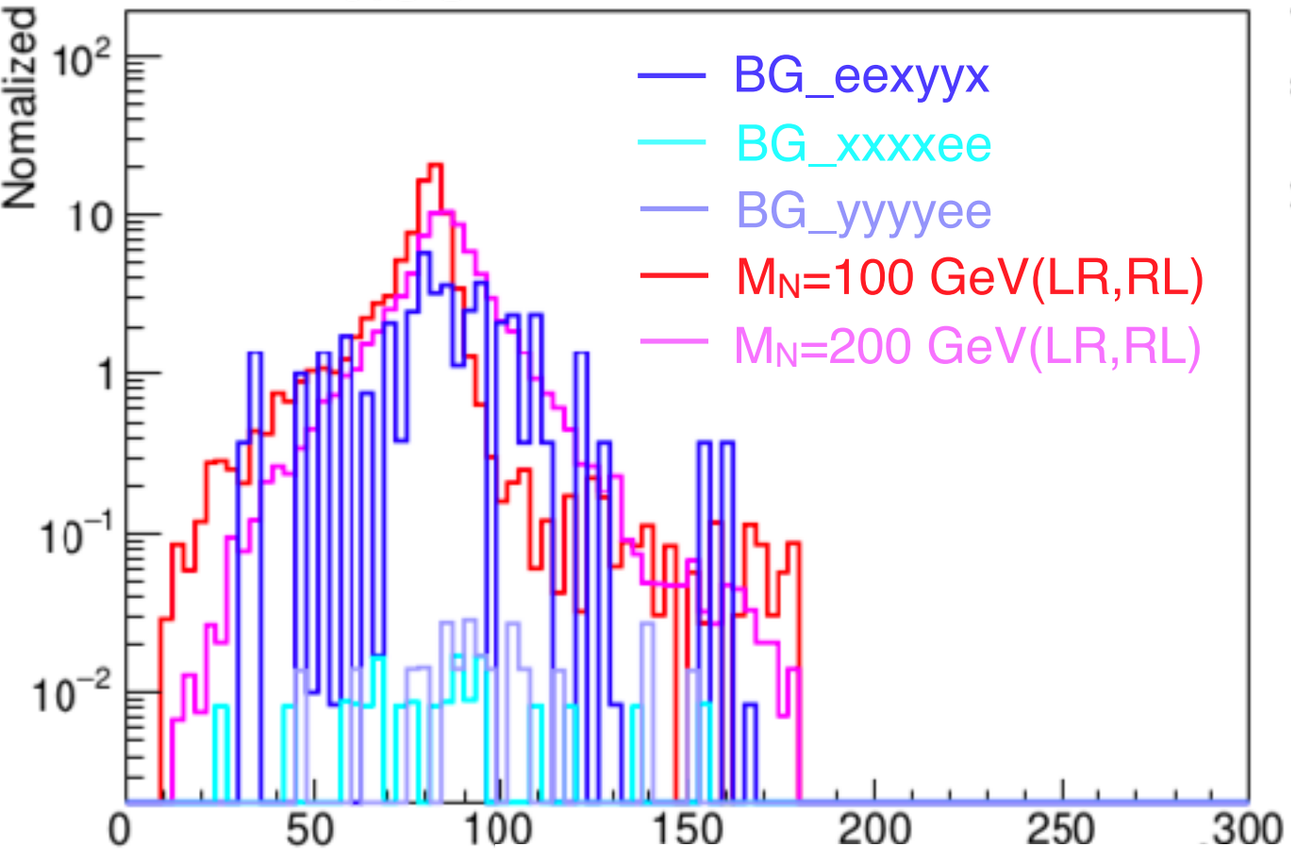


$-0.95 < \cos\theta_{isoe} < 0.95$

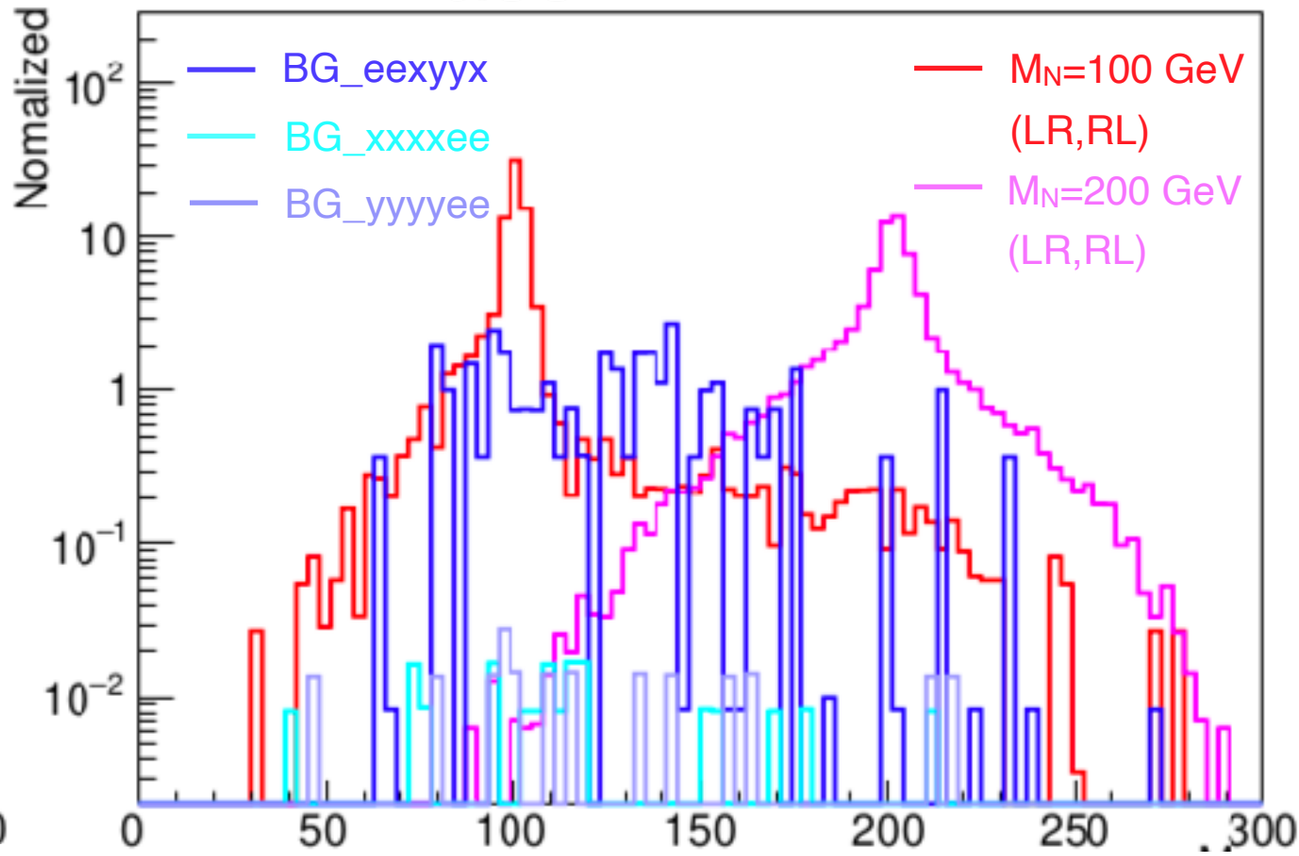
Reconstructed

isolated electrons =2 && # isolated photons = 0
$E_{iso} < 200$ [GeV] && $-0.95 < \cos\theta_{isoe} < 0.95$

W mass



RHN mass



BG is not quite free but we can remove

Summary & Future work

- Carried out **fast simulation** for RHN pair production using **Delphes miniDST** framework
- Consider the **charge misidentification** in the backgrounds process

  ⟶ BG is not quite free but we can remove these.

Event # [4000fb^{-1}]

	Before cut	After cut
M_N=100[GeV]	1619	43
M_N=200[GeV]	372	38

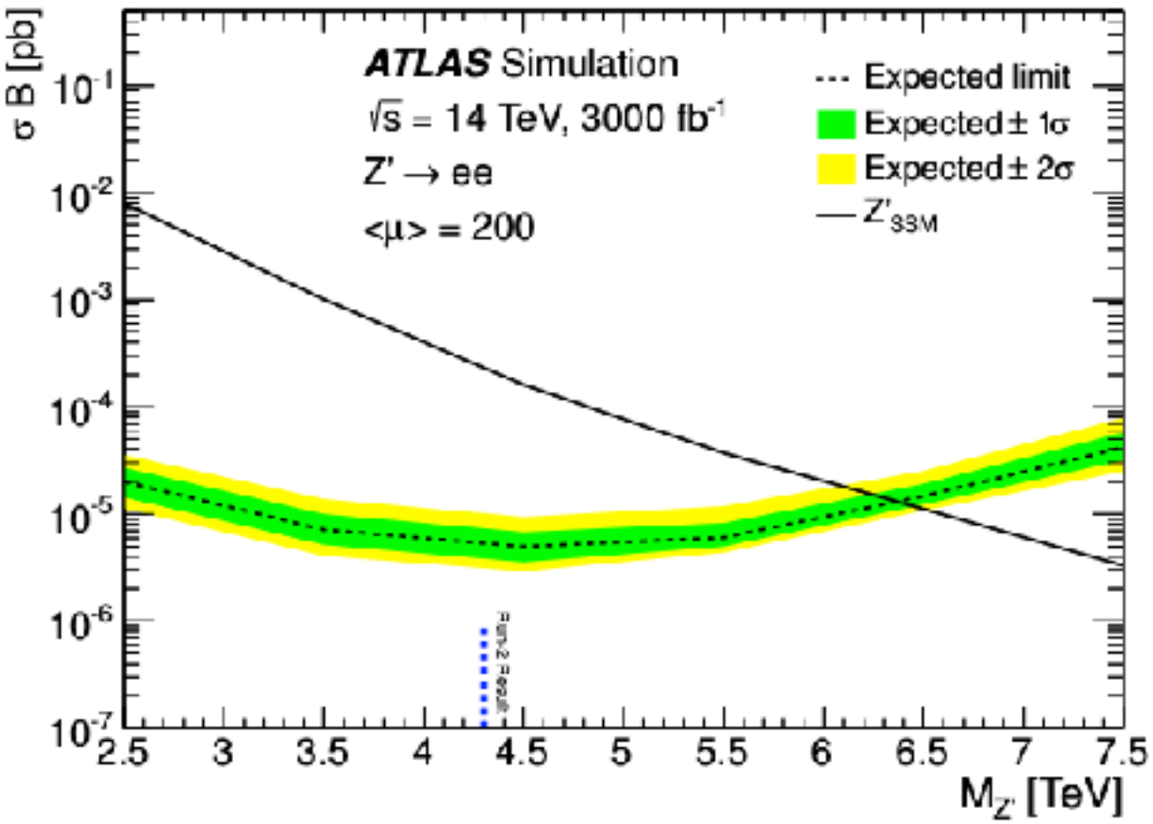
Preliminary

Consider more cut condition

Backup

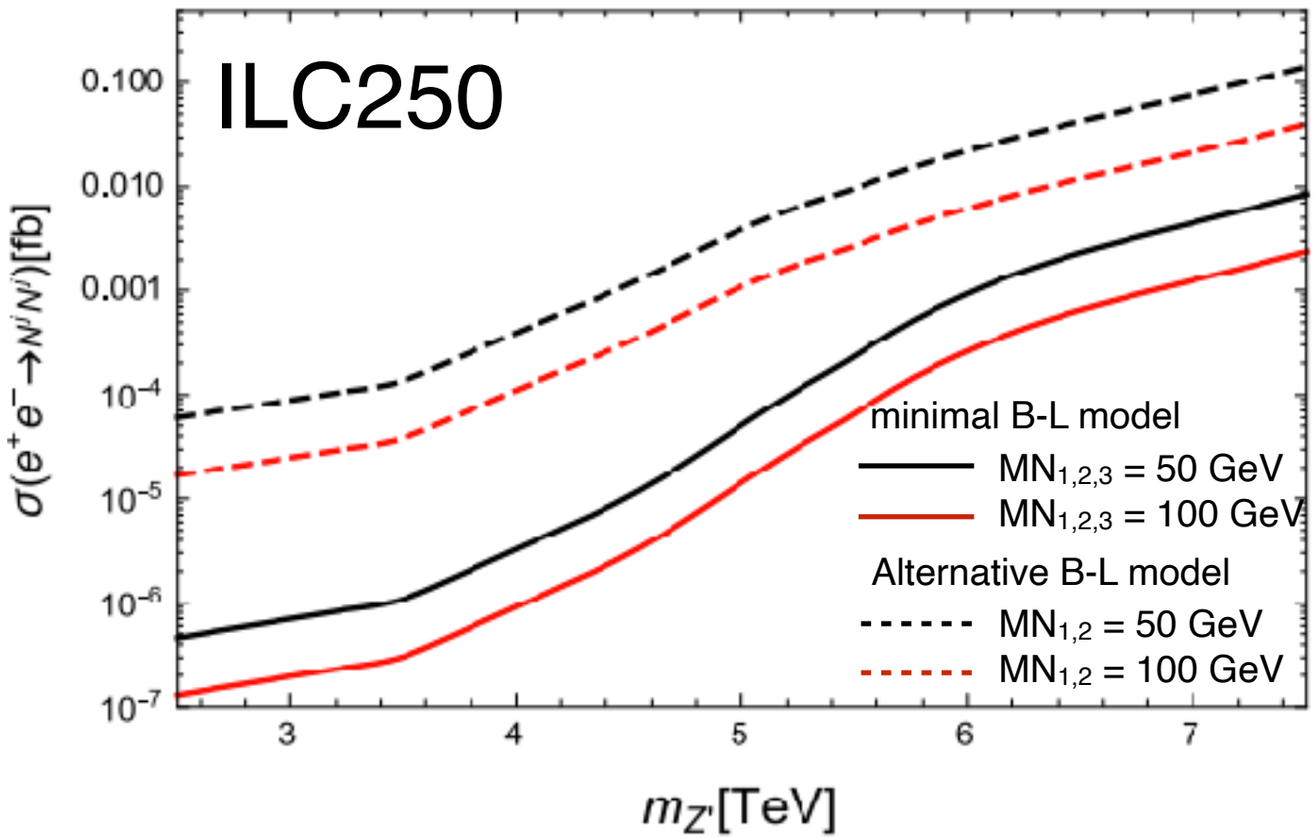
Current limits - Z' mass

SM like Z' coupling



ATLAS-TDR-LHCC2017-2018

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

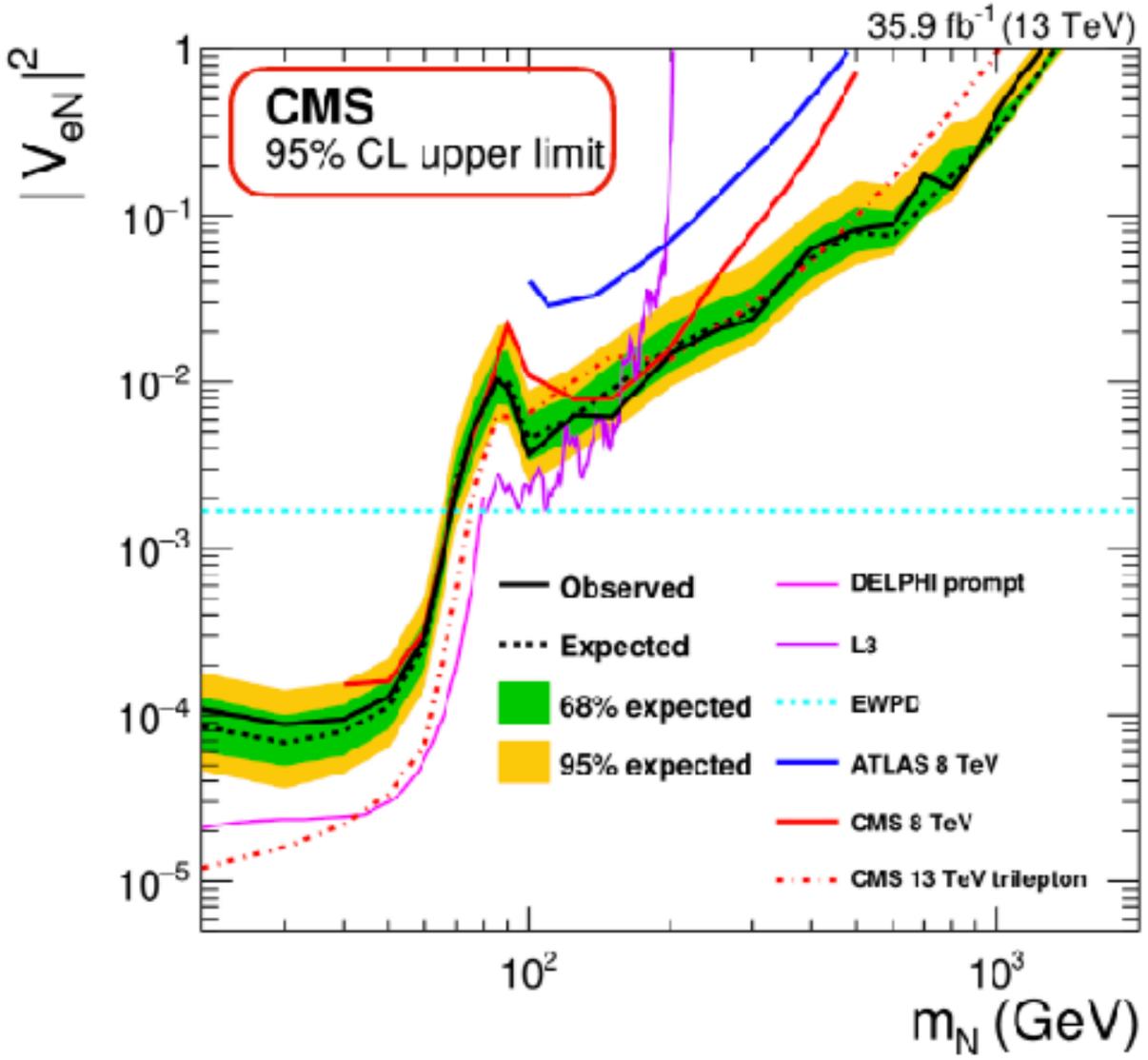


arXiV[1812.11931]

The heavier Z' mass less constrained by LHC

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

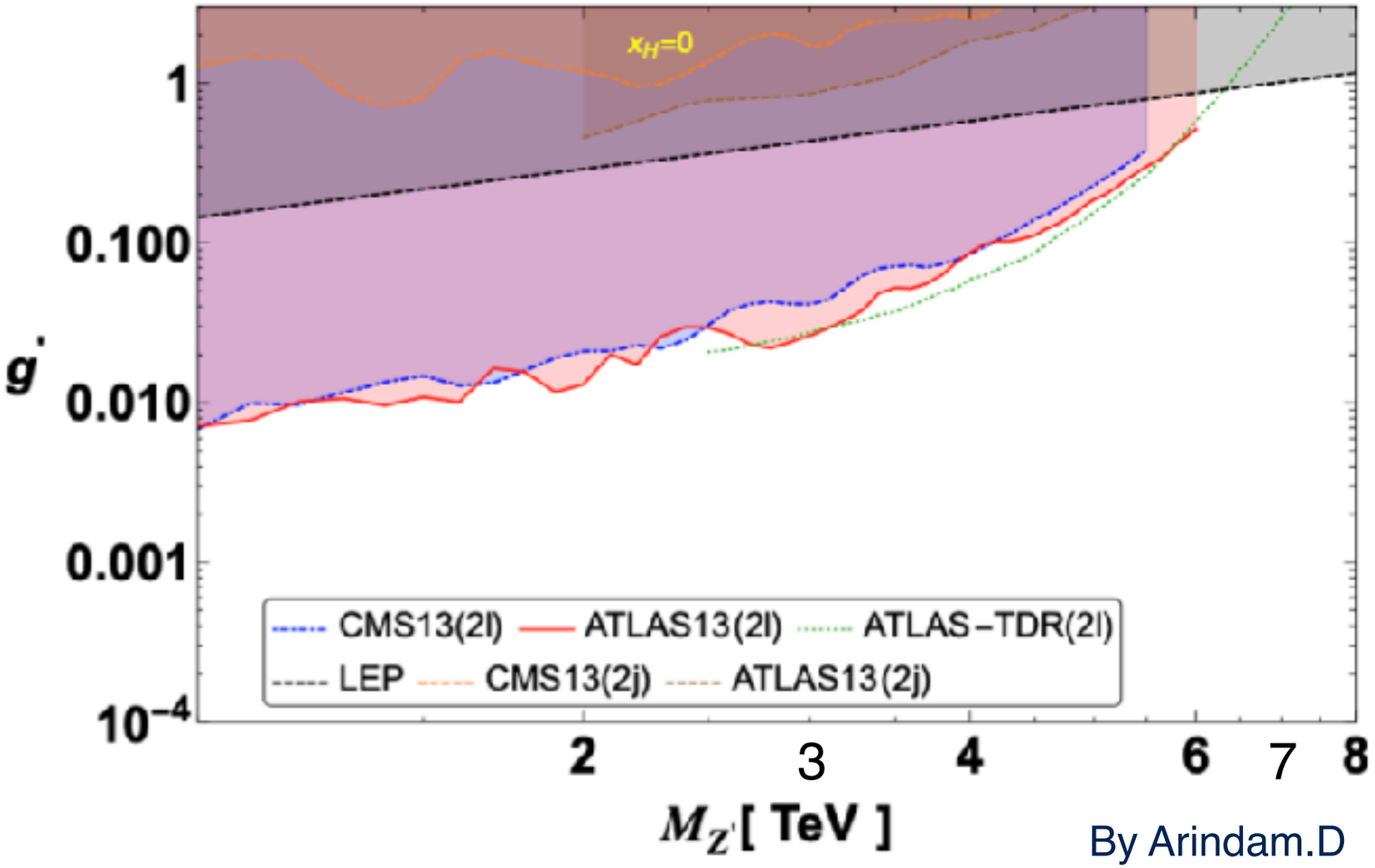
$|V_{eN}|^2$: the "light-heavy" neutrino mixing matrix



CMS PAS EXO-19-019

Current Limits and prospects - Z' mass,g1'

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



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

By Arindam.D

ILC250

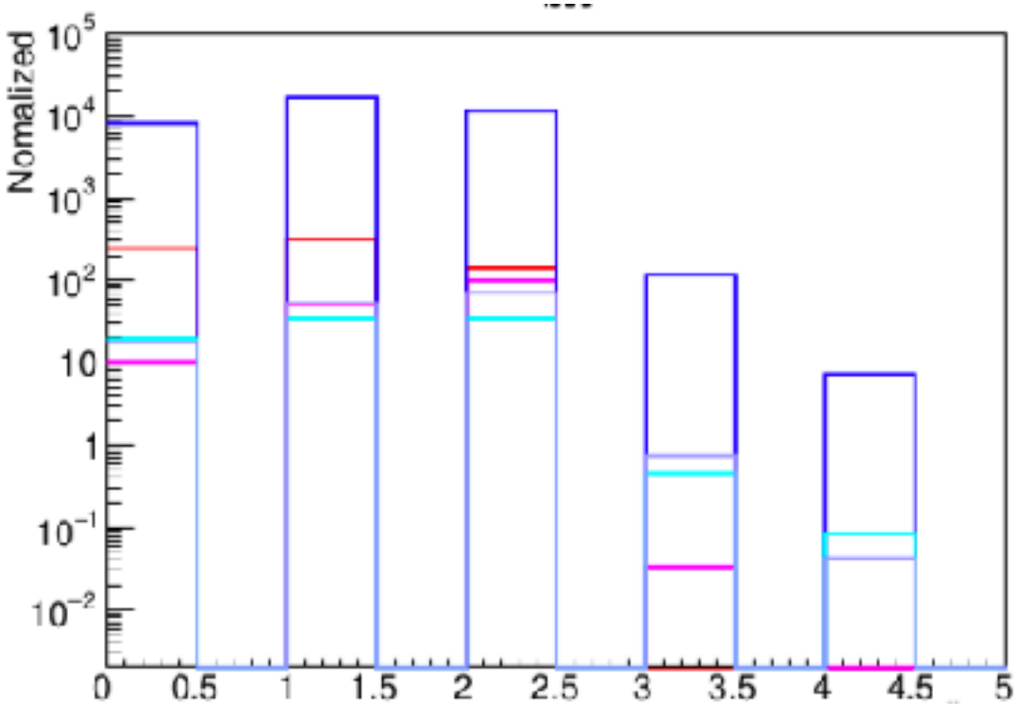
M_N [GeV]	$M_{Z'}$ [TeV]	g1'	$\lvert V_{eN}\rvert^2$	σ_{LR} (ee→NN)	Event # [2000fb-1]
100	7	1	0.001	4.53E-02	50

Cross section with the beam polarization

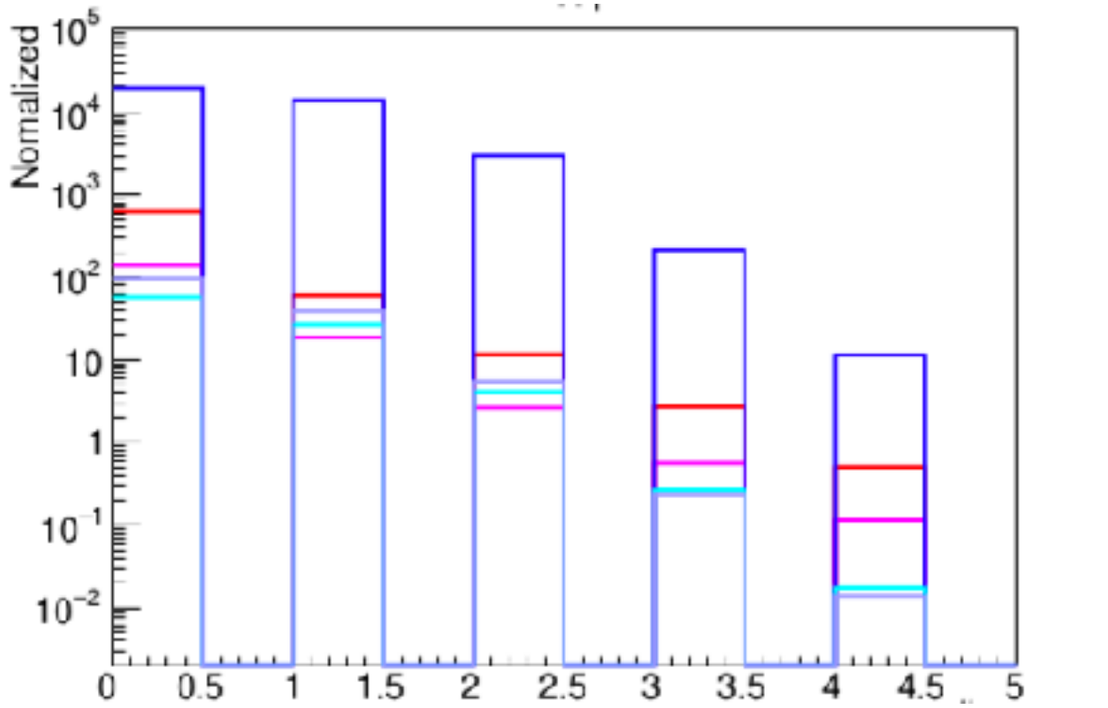
$$\sigma(P_-, P_+) = \left(\frac{1-P_-}{2}\right)\left(\frac{1+P_+}{2}\right)\sigma_L + \left(\frac{1+P_-}{2}\right)\left(\frac{1-P_+}{2}\right)\sigma_R \ (\sigma_L = \sigma_R)$$

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

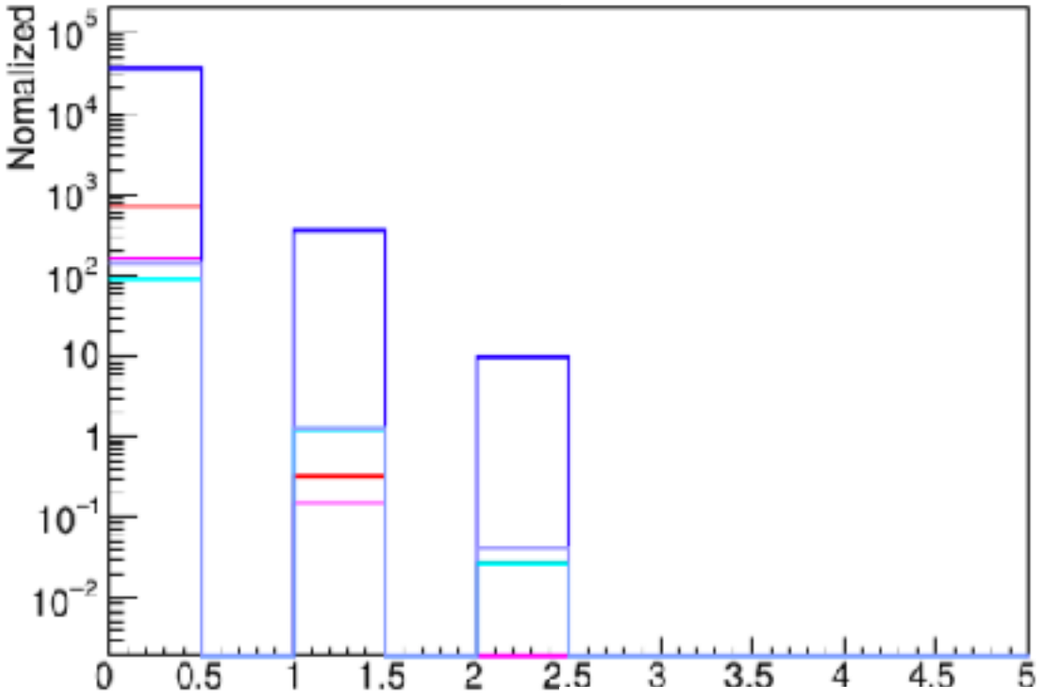
Isolated particles (Signal + Backgrounds)



Number of isolated e



Number of isolated γ



Number of isolated μ