Probing heavy Majorana neutrino pair production at ILC250 in a $U(1)_{B-L}$ extension of the Standard Model

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Motivation and introduction

The Right Handed Neutrino (RHN) can address the following big questions

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

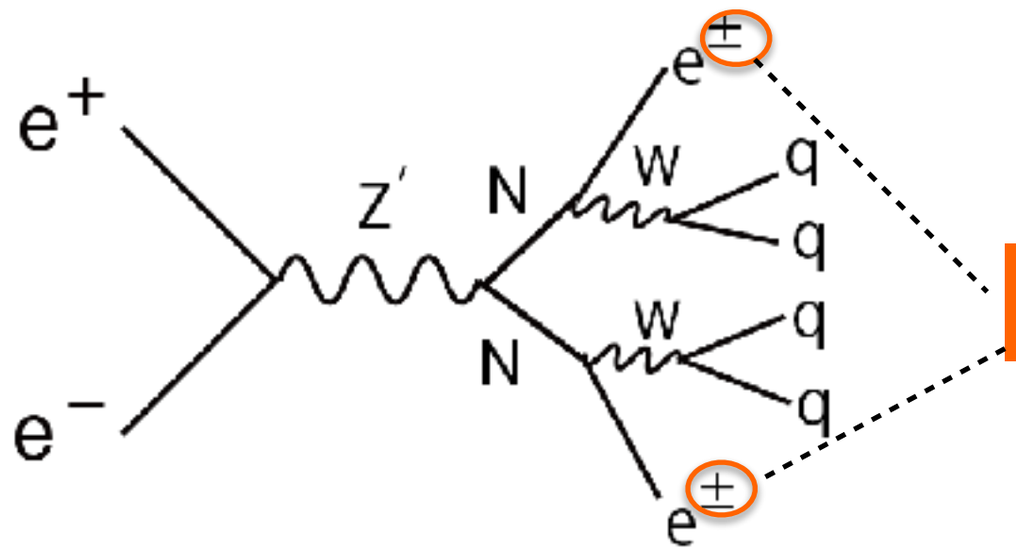
RHN is assumed to be

- a Majorana particle ($N = \bar{N}$)
- minimal $U(1)_{B\text{-}L}$ model

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

gauge boson : Z'

→ RHN **pair** production



Lepton # violation is possible!

↓

Same sign leptons possible

↓

Very small SM BG!

Benchmark points with $M_N = 85, 95, 100, 110, 120$ GeV

Benchmark points

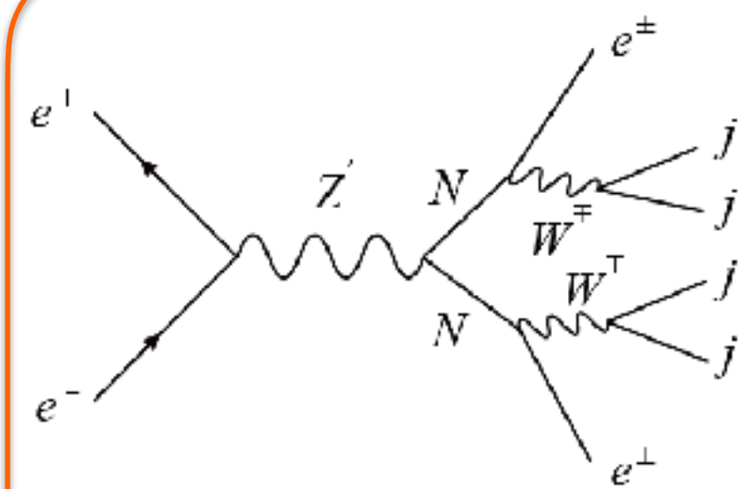
$$\mathrm{Pol}\,(e^+,e^-) = (-0.8,+0.3),(+0.8,-0.3) : \mathcal{L} = 900\,[\mathrm{fb}^{-1}]$$
$$\mathrm{Pol}\,(e^+,e^-) = (-0.8,-0.3),(+0.8,+0.3) : \mathcal{L} = 100\,[\mathrm{fb}^{-1}]$$

M_N [GeV] RHN mass	$M_{Z'}$ [TeV] Z' mass	g1' $U(1)_{B-L}$ coupling	$\lvert V_{eN}\rvert$ mixing angle	$BR(N \to eW)$	σ_{LR} [fb] 100% polarisation	σ_{RL}
85	7	1	0.003	0.50	0.048	0.089
95	7	1	0.003	0.48	0.033	0.060
100	7	1	0.003	0.44	0.026	0.046
110	7	1	0.003	0.40	0.012	0.021
120	7	1	0.003	0.37	0.0021	0.0035

- minimal $U(1)_{B-L}$ model
- ILC 250 with initial state radiation (ISR) and beamstrahlung (BS)

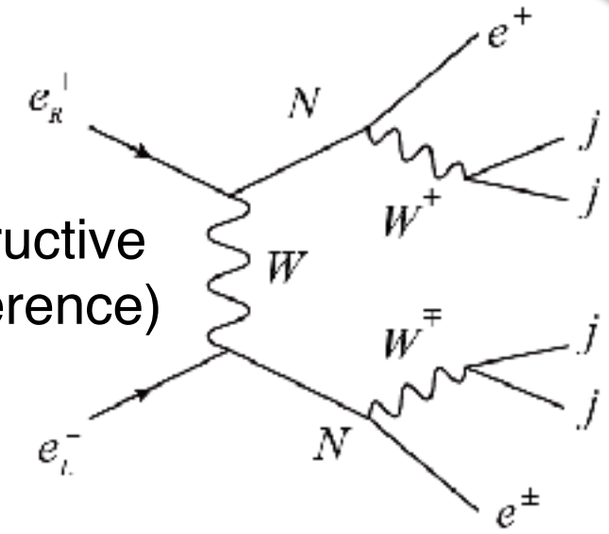
Analysis tool and backgrounds

ILC250 Signal process:



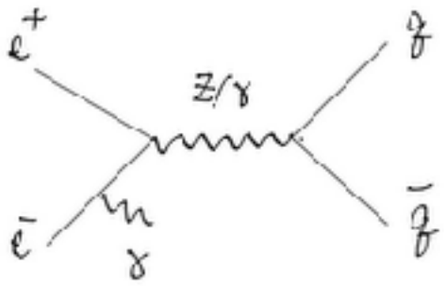
s-channel via Z'

\+ (Destructive interference)

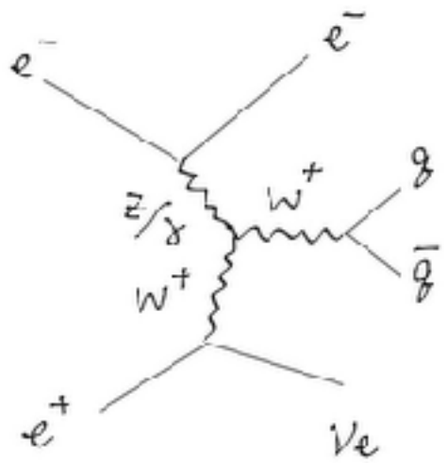


t-channel via W
(only e_L)

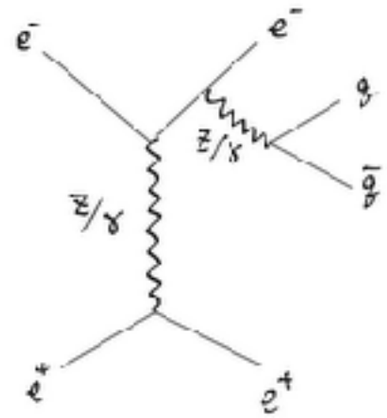
2 and 4 fermions major background processes:



2 fermions
hadronic



4 fermions singleW
semileptonic



4 fermions singleZee
semileptonic

WHIZARD ver 2.8.5
Make Events

↓

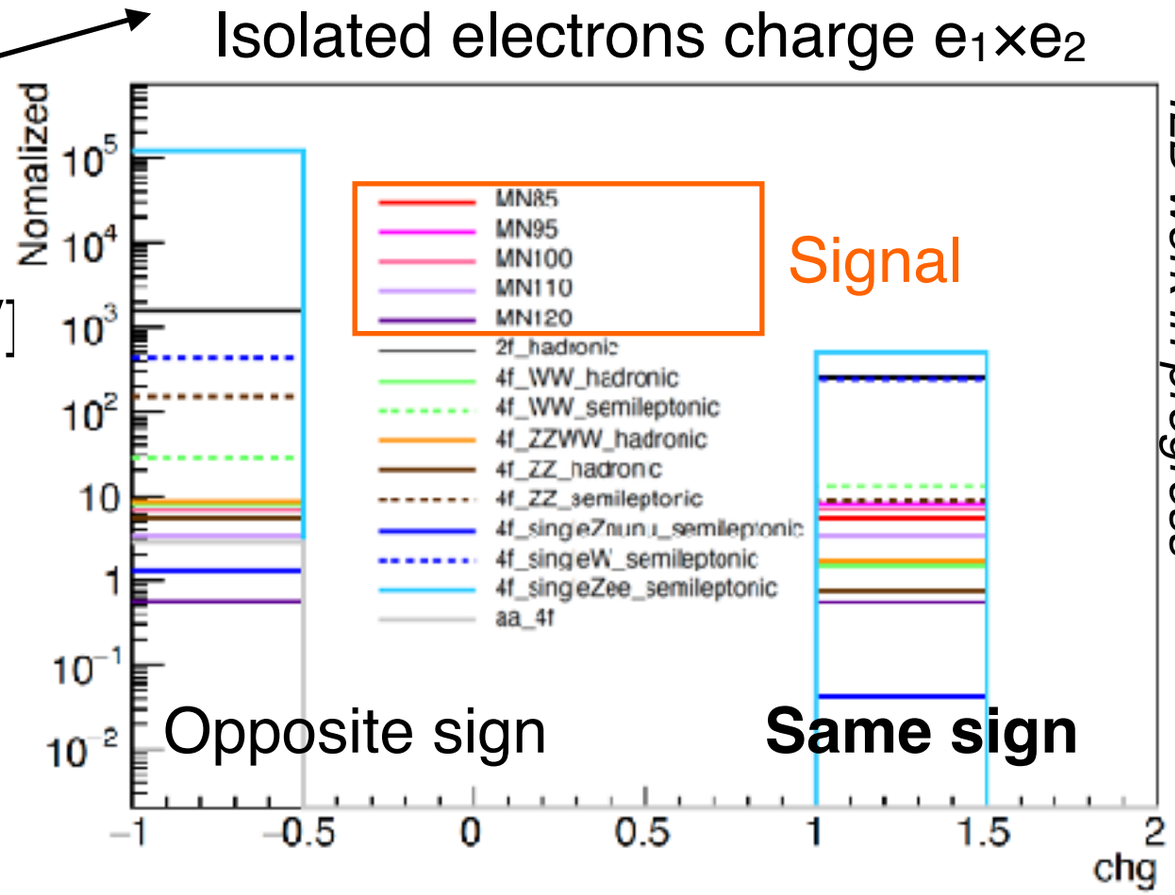
ILD Full Simulation
& (Geant4)
Reconstruction

↓

miniDST
Events format

Cut conditions to select signal events

- Isolated e # = 2 && Isolated γ, μ # = 0
- Same sign isolated electrons
- Isolated electron energies $5 < E_{iso} < 200$ [GeV]
- Isolated electron angles $|\cos\theta_{isoe}| < 0.95$
- IsolatedLepTagging(min) > 0.9
- Thrust T < 0.9
- Jet clustering with Durham $\log_{10}(y12) > -1$
- Total visible transverse momentum $P_t < 80$ [GeV]



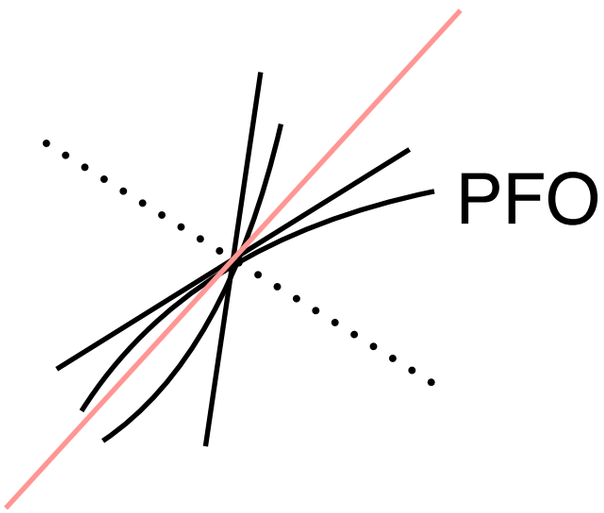
Thrust T

- ILC 250 with ISR / BS
- **Pol(e^-, e^+) = (+0.8, -0.3)**

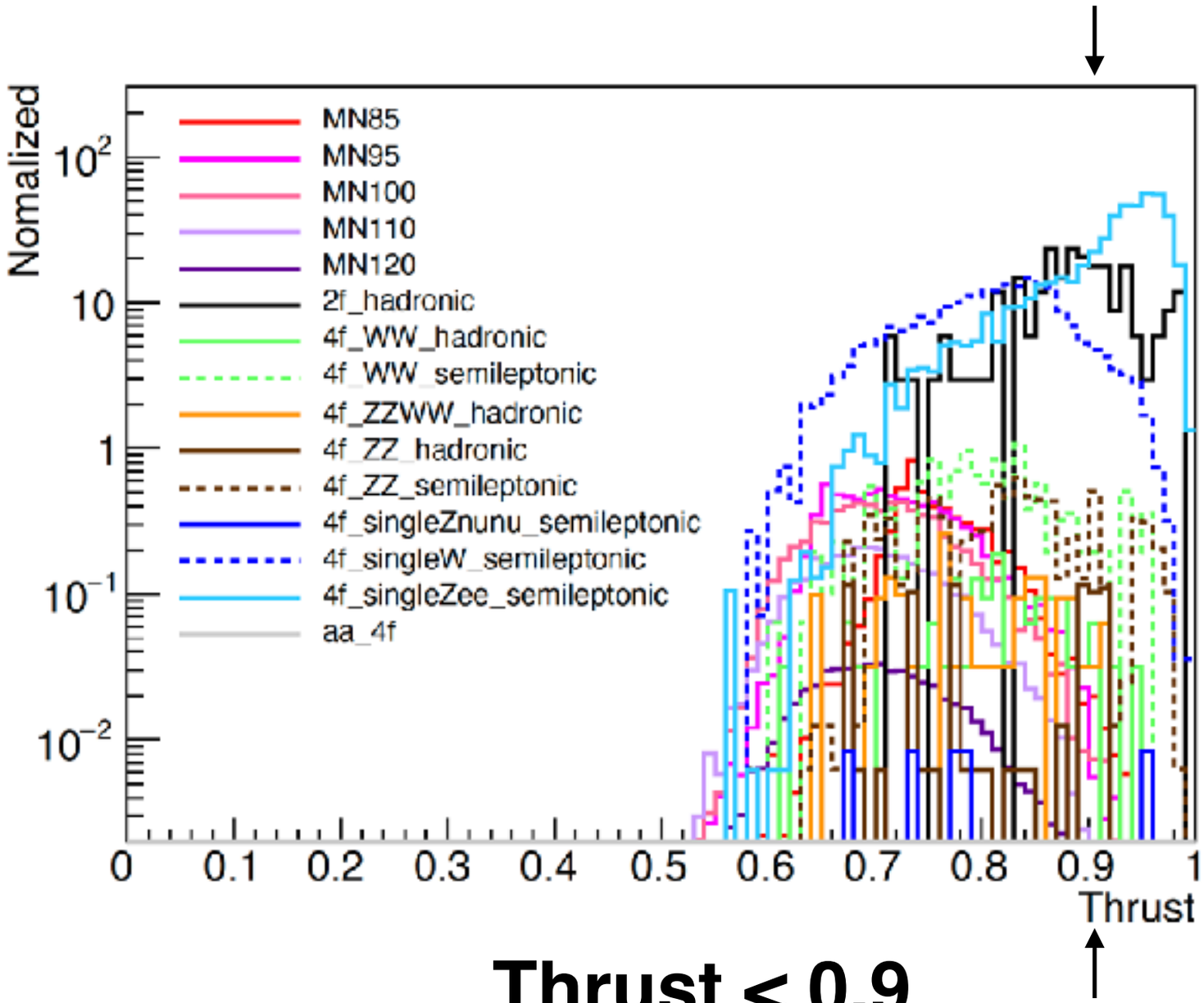
- Isolated e # = 2 && Isolated γ # = 0 && Isolated μ # = 0
- Isolated e is same sign ($e_1 \times e_2 = 1$)

One of kind of event-shape variables

n_T:thrust axis



$$T \equiv \max \frac{\sum_j^n |p_j \cdot n_T|}{\sum_i^n |p_i|}$$



n_T:unit vector
P: momentum of each particle

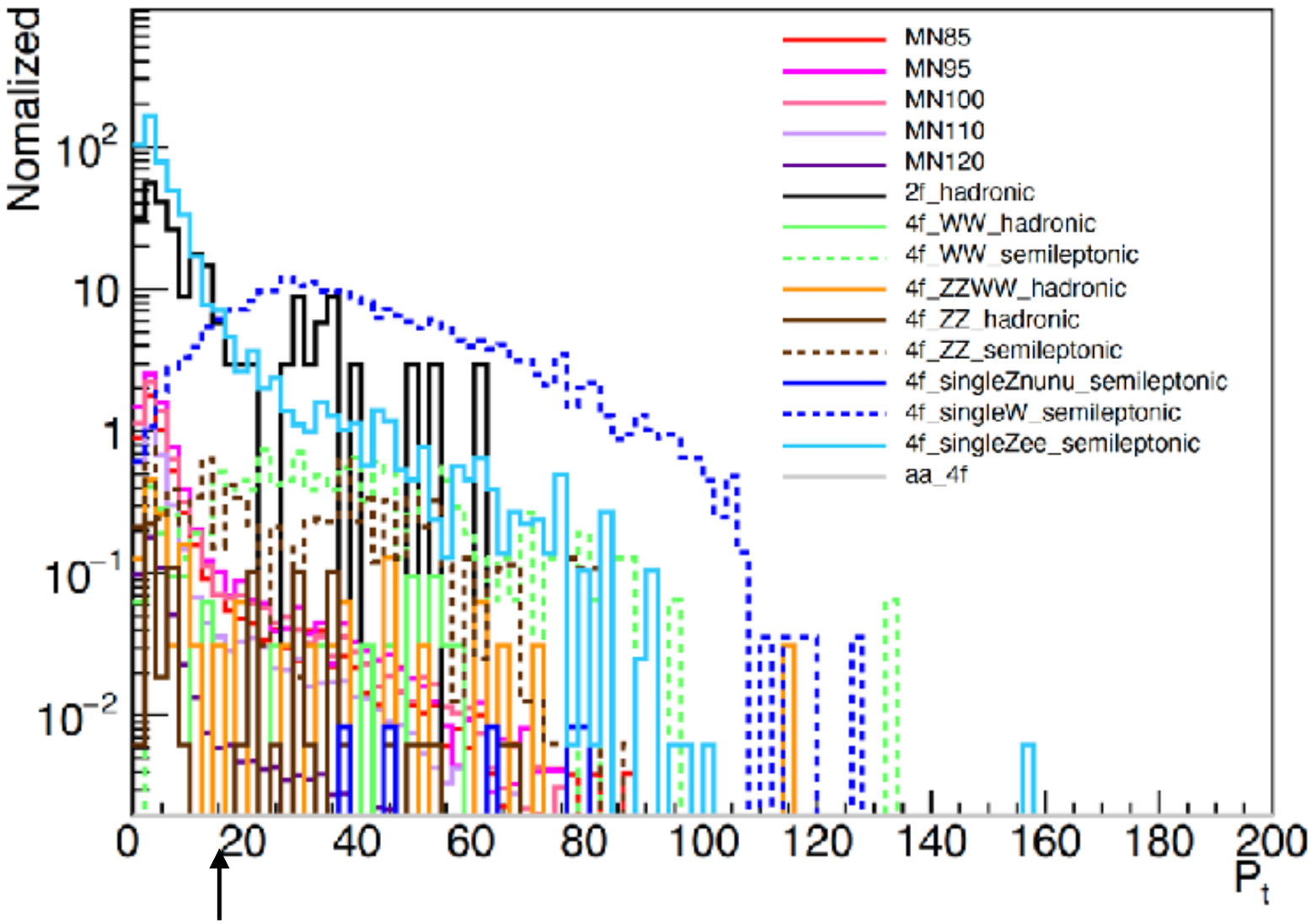
Thrust < 0.9
2f events exclude usefull

Total visible tansverse momentum

- ILC 250 with ISR / BS
- **Pol(e^-, e^+) = (+0.8, -0.3)**

- Isolated e # = 2 && Isolated γ # = 0 && Isolated μ # = 0
- Isolated e is same sign ($e_1 \times e_2 = 1$)

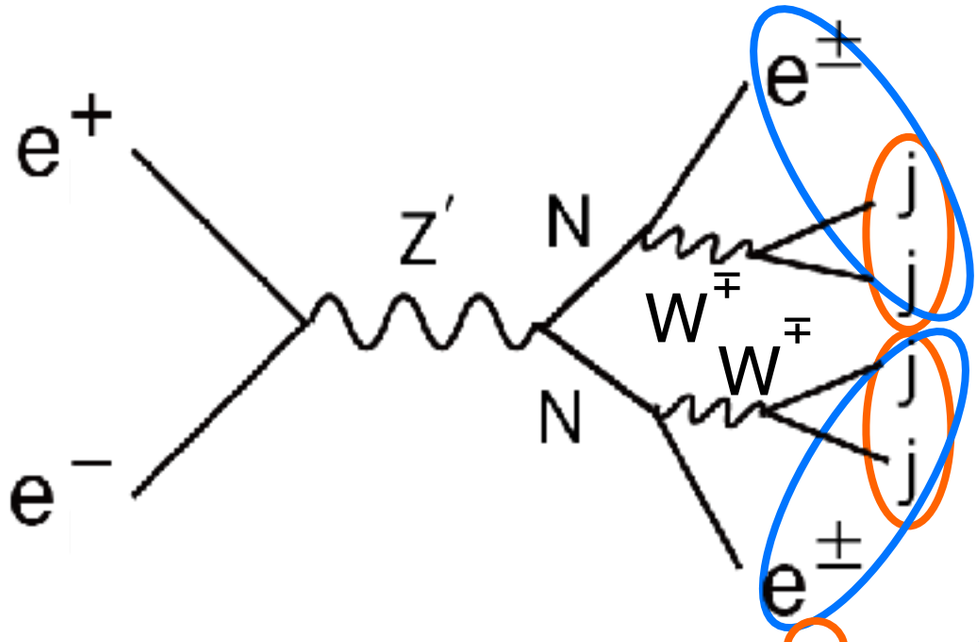
Total transverse momentum



P_t < 80 [GeV]

Reconstruction methods

After removing isolated electrons force into 4 jets (Durham)



Search for the correct combination of jj and jje

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

$$F_1 = (M_{jj1} - M_w)^2 + (M_{jj2} - M_w)^2$$

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

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

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

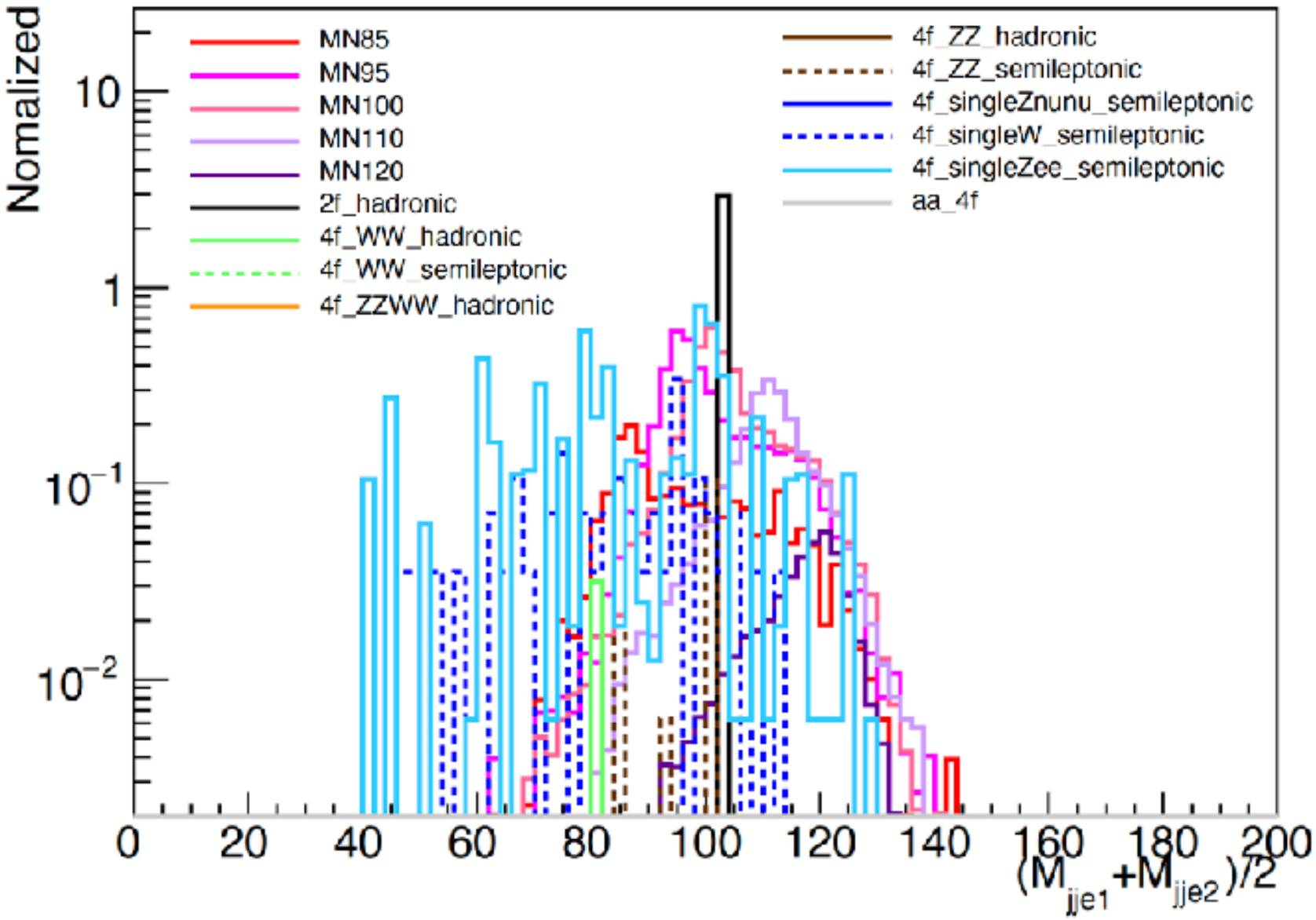
$$F_2 = (M_{jje1} - M_{jje2})^2$$

Choose combination with minimum F_1,F_2

Reconstructed RHN

- ILC 250 with ISR / BS
- **Pol(e^-, e^+) = (+0.8, -0.3)**

Reconstructed momentum



Remaing backgrounds ~ 8

Summary & Next Step

- Almost Backgrounds is removed
- Signal efficiency < 10%
- Just only applying cut -> neet to consider more

Next steps

- Removing overlay events (= making all process again)
- Evaluating cut conditions
- Making exclusion plots
- (Parameter serach near 125 GeV)

Cut flow (eRpL)

- ILC 250 with ISR / BS
- $\mathrm{Pol}\,(e^+, e^-) = (+0.8, -0.3) : \mathcal{L} = 900\,[\mathrm{fb}^{-1}]$

ILD work in progress

	Signal Entries				
	M_N=85	M_N=95	M_N=100	M_N=110	M_N=120
No cut	48	48	39	19	3
e_{iso} #=2 && γ_{iso} #=0 && μ_{iso} #=0	10	16	13	6	1
Same sign ($e_{iso1} \times e_{iso2} = 1$)	5	8	6	3	0
$5 < E_{isoe} < 100$	5	8	6	3	0
$\lvert\cos\theta_{isoe}\rvert < 0.95$	4	7	6	3	0
Isolated $\mathrm{Tagging}_{min} > 0.9$	2	4	4	2	0
Thrust $T < 0.9$	2	4	4	4	0
log(y12) > -1	2	4	4	2	0
$P_T > 80$	1	4	4	2	0

Cut flow (eRpL)

- ILC 250 with ISR / BS
- $\mathrm{Pol}\,(e^+, e^-) = (+0.8, -0.3) : \mathcal{L} = 900\,[\mathrm{fb}^{-1}]$

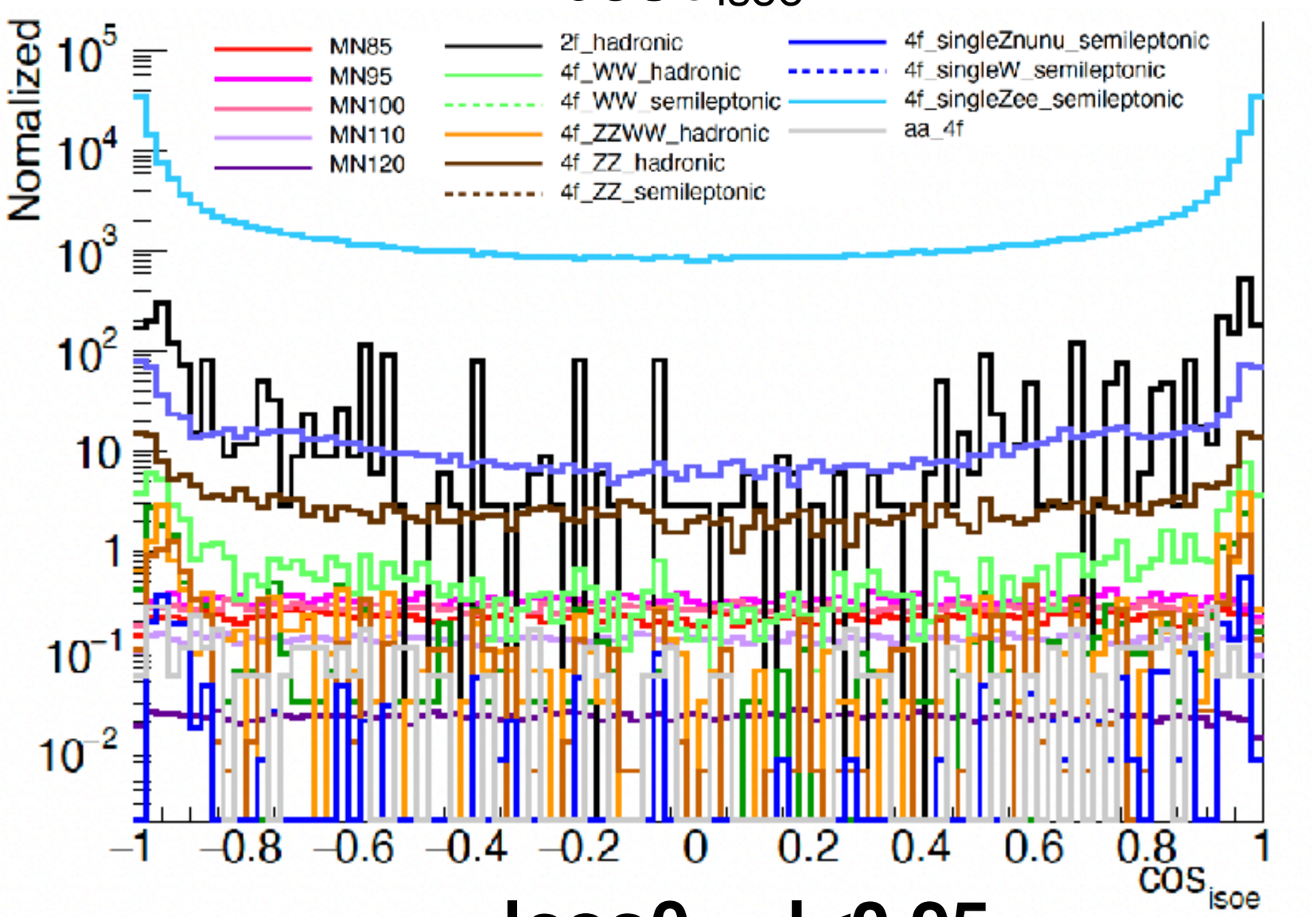
ILD work in progress

	BG Entries									
	2f_hadronic	4f_WW_hadronic	4f_WW_semileptonic	4f_ZZWW_hadroni	4f_ZZ_hadronic	4f_ZZ_semileptonic	4f_ZZnunu_semileptonic	4f_singleW_semileptonic	4f_singleZee_semileptonic	aa_4f_zz_sl
No cut	304775	1795	20893	1673	1359	8836	89	380120	778343	26
e_{iso} #=2 && γ_{iso} #=0 && μ_{iso} #=0	1766	9	41	10	6	157	1	667	120939	0
Same sign ($e_{iso1} \times e_{iso2} = 1$)	252	1	12	1	0	8	0	240	496	0
$5 < E_{isoe} < 100$	252	1	12	1	0	8	0	239	474	0
$\lvert\cos\theta_{isoe}\rvert < 0.95$	47	0	4	0	0	3	0	93	43	0
Isolated $\mathrm{Tagging}_{min} > 0.9$	8	0	0	0	0	0	0	16	11	0
Thrust T < 0.9	5	0	0	0	0	0	0	14	8	0
log(y12) > -1	2	0	0	0	0	0	0	11	6	0
$P_T > 80$	2	0	0	0	0	0	0	1	5	0

$\cos\theta_{isoe}$

- ILC 250 with ISR / BS
- **Pol(e^-, e^+) = (+0.8, -0.3)**

- Isolated e # = 2 && Isolated γ # = 0 && Isolated μ # = 0
- Isolated e is same sign ($e_1 \times e_2 = 1$)



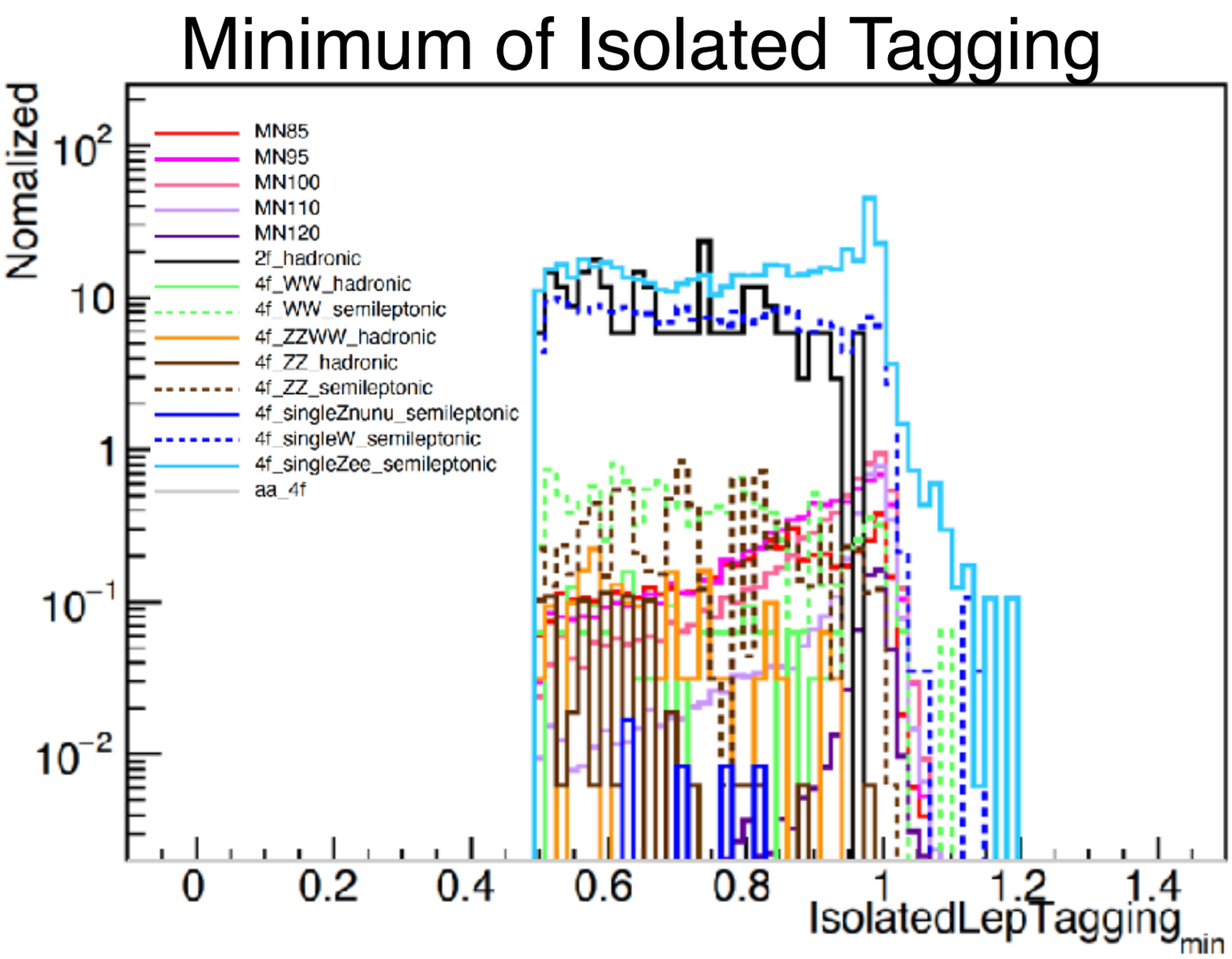
Almost bg is
back to back events

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

Isolated Leptagging

- ILC 250 with ISR / BS
- **Pol(e^-, e^+) = (+0.8, -0.3)**

- Isolated e # = 2 && Isolated γ # = 0 && Isolated μ # = 0
- Isolated e is same sign ($e_1 \times e_2 = 1$)

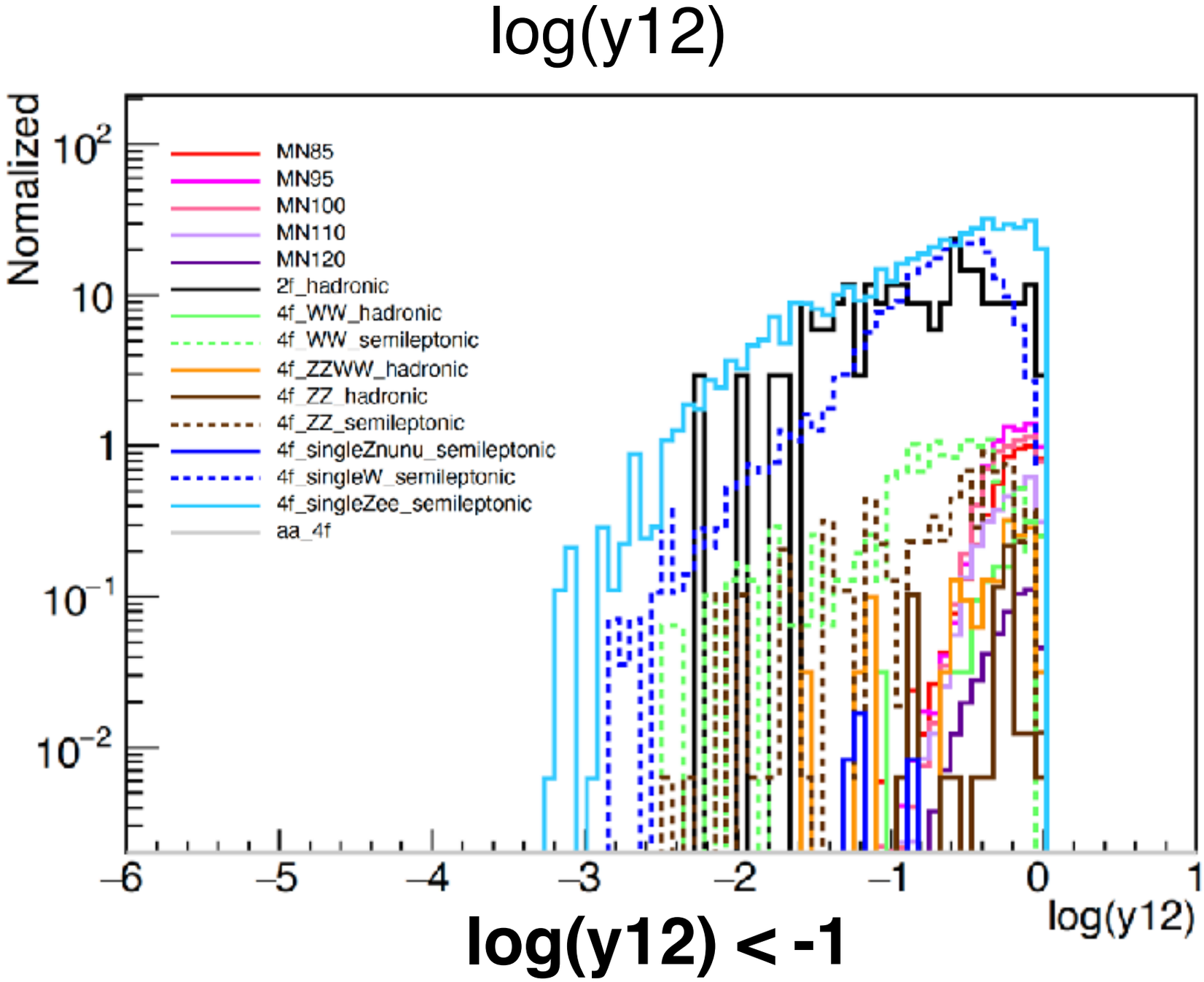


IsolatedLepTagging > 0.9

log(y12)

- ILC 250 with ISR / BS
- **Pol(e^-, e^+) = (+0.8, -0.3)**

- Isolated e # = 2 && Isolated γ # = 0 && Isolated μ # = 0
- Isolated e is same sign ($e_1 \times e_2 = 1$)



log(y12) < -1

Cross section — BG

(100%,100%)	2f_hadronic	4f_WW_hadronic	4f_WW_semileptonic	4f_ZZWW_hadroni	4f_ZZ_hadronic	4f_ZZ_semileptonic	4f_ZZnunu_semileptonic	4f_singleW_semileptonic	4f_singleZee_semileptonic	aa_4f_zz_sl
eLpR	1.28E+05	1.49E+04	1.88E+04	1.24E+04	1.41E+03	8.38E+02	6.10E+02	1.03E+04	1.42E+03	4.93E-01
eRpL	7.04E+04	1.37E+02	1.73E+02	2.25E+02	6.07E+02	4.67E+02	2.62E+02	8.67E+01	1.22E+03	
eLpL								1.91E+02	1.16E+03	
eRpR								1.91E+02	1.16E+03	