

# Study of fermion pair productions at the ILC with center of mass energy of 250 GeV

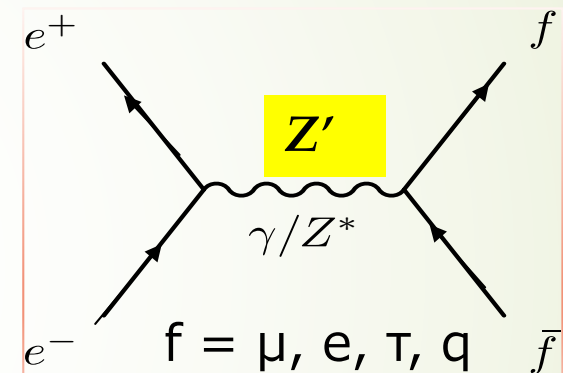
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Kiyotomo Kawagoe, Taikan Suehara, Tamaki Yoshioka (Kyushu University)

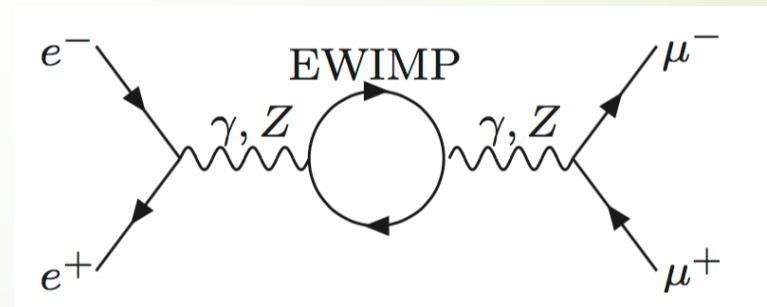
Keisuke Fujii, Akiya Miyamoto (KEK)

# Purpose of 2-fermion process study

- Precise measurements of electroweak processes at the ILC will provide unique opportunities to explore new physics beyond the standard model.



- (Traditional )  $Z'$  models (SSM, ALR, E6)
- correction by EWIMP (electroweak WIMP)
- $Z'$  with gauge Higgs unification



# (Traditional ) $Z'$ models

➤  $\sqrt{s} = 500 \text{ GeV} - 1 \text{ TeV}$  ILC have **10 -17 TeV** mass reach for heavy gauge boson. (in ALR model)

➤ LHC has **5 TeV** mass reach (arXiv : 0912.2806)

➤ No result at  $\sqrt{s} = 250 \text{ GeV}$

➤ We need to study by **precise simulation and** ( $\sqrt{s} = 250 \text{ GeV}$  as possible..)

➤ ATLAS (SSM model)

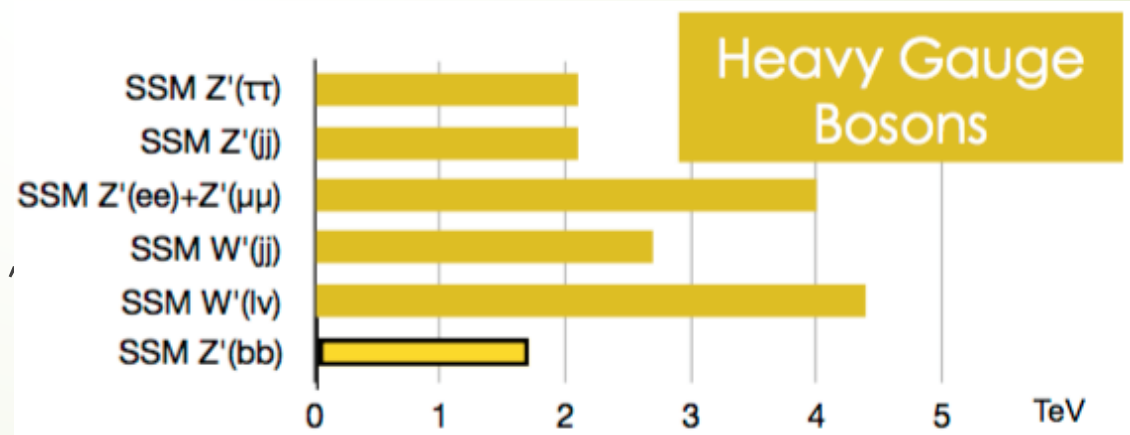
➤  $Z' \rightarrow ll$  ( $l = e, \mu$ ) : 4.5 TeV

➤  $Z' \rightarrow \tau\tau$  : 2.4 TeV  
( Lumi = 3.2 – 37.0 fb<sup>-1</sup> ,  
 $\sqrt{s} = 8,13 \text{ TeV}$  )

➤ CMS (SSM model)

➤  $Z' \rightarrow ll$  ( $l = e, \mu$ ) : 4 TeV

➤  $Z' \rightarrow \tau\tau$  : ~2.1 TeV

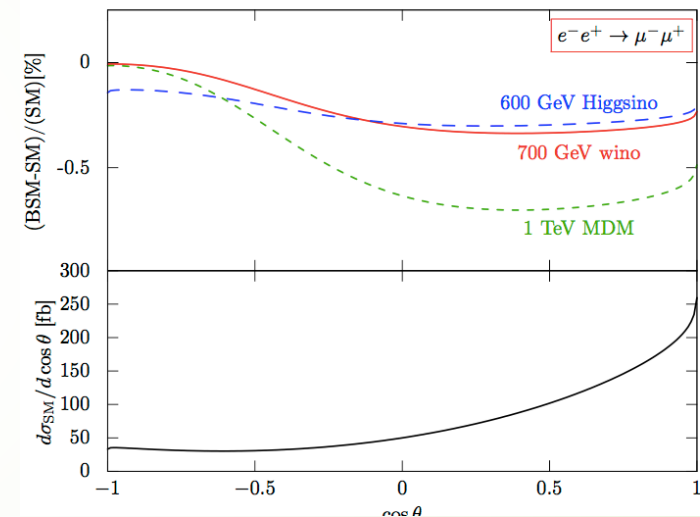
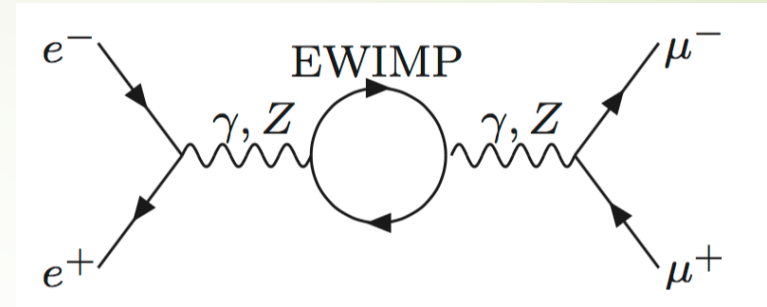


# Generic electroweak WIMP search

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by  $e^+e^- \rightarrow 2f$

- Indirect search of New physics(EWIMP)
- Direct search is limited  $\sqrt{s}/2$ . (125 GeV at ILC250)
- Mass and spin of WIMP are able to calculate deviation of  $2f$  for almost model independent. (arXiv:1504.03402 )
  - Example:
    - WINO ( $n=3, Y=0$ )
    - Higgsino ( $n=2, Y=\pm 1/2$ )
    - Minimal Dark Matter (MDM) ( $n=5, Y=0$ )
- Mass reach from  $2f$  is bigger than direct search.



Harigaya,  
Ichikawa,Kundu,  
Matsumoto,Shirai

arXiv:1504.03402

# Simulation condition

- DBD ILD detector geometry : ild-v1-05
- ILCSoft Version : v01-16-02-p1
- Using H-20 scenario at 250 GeV

Total Luminosity	$e^-_L e^+_R$	$e^-_R e^+_L$
2000 fb <sup>-1</sup>	900 fb <sup>-1</sup>	900 fb <sup>-1</sup>

- Polarization :  $|P(e^-)| = 80\%$ ,  $|P(e^+)| = 30\%$
- $e^-_L e^+_R$  and  $e^-_R e^+_L$  results are treated independently to investigate the deviation to SM

channel	Background
$e^-e^+ \rightarrow e^-e^+$	<ul style="list-style-type: none"> <li>• 2f - mumu, tautau event</li> <li>• 4f - Leptonic event</li> </ul>
$e^-e^+ \rightarrow \mu^- \mu^+$	<ul style="list-style-type: none"> <li>• 2f - tautau event ▪ <u>Bhabha</u></li> <li>• 4f - Leptonic event</li> </ul>
$e^-e^+ \rightarrow \tau^- \tau^+$	<ul style="list-style-type: none"> <li>• 2f - mumu event ▪ <u>Bhabha</u></li> <li>• 4f - Leptonic event ▪ 2f-hadronic</li> </ul>

# Event Selection (1/2)

$$e^-e^+ \rightarrow e^-e^+$$

$$e^-e^+ \rightarrow \mu^- \mu^+$$

- Track Selection
  - The track with the highest energy is selected from each positive and negative tracks.
- Cut 1: Both of the selected tracks has  $> 10$  GeV energy
- Cut 2 :  $E_{\text{cluster}} / E_{\text{track}} < 0.6$  (mu),  $> 0.6$  (electron)
  - High energy muons penetrate detectors, which give smaller energy deposit with respect to the track momentum'
- Cut3:  $E_{\text{ECAL}} / (E_{\text{ECAL}} + E_{\text{HCAL}}) < 0.5$  (mu),  $> 0.9$  (electron)
  - Electrons deposit most of energy at ECAL  
(This cut aims to cut Bhabha events)



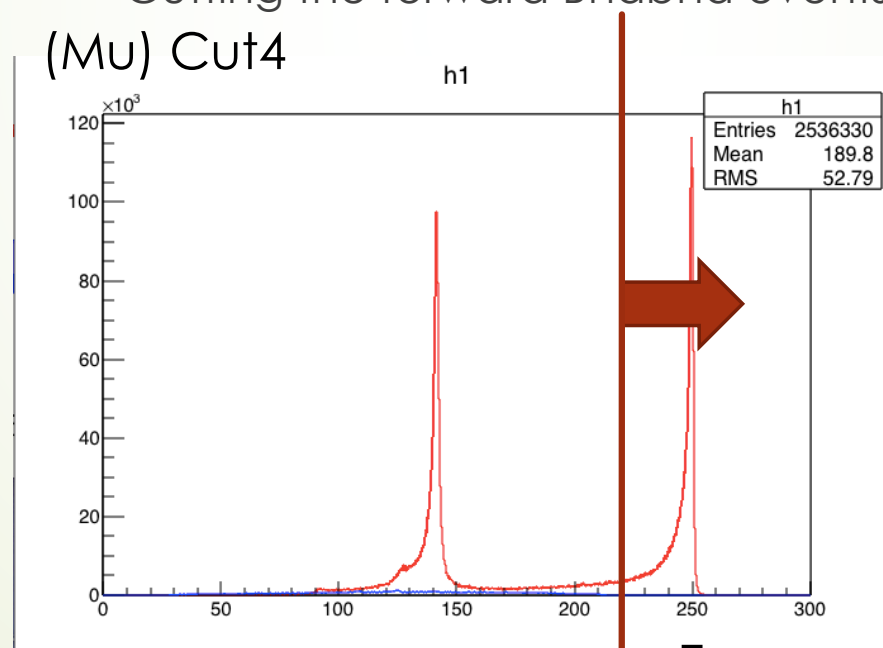
# Event Selection (2/2) $\cos \theta = \frac{P_z}{E}$

$$e^-e^+ \rightarrow e^-e^+$$

$$e^-e^+ \rightarrow \mu^- \mu^+$$

- Cut4 : Energy sum of two selected tracks > 230 GeV
  - Cutting most of 4f/tautau background and radiative return events .
- Cut 5:  $|\cos\theta| < 0.95$ 
  - Cutting the forward Bhabha events

(Mu) Cut4



Red :  $\mu^+\mu^-$

Blue : SM  
background

Energy sum [GeV]

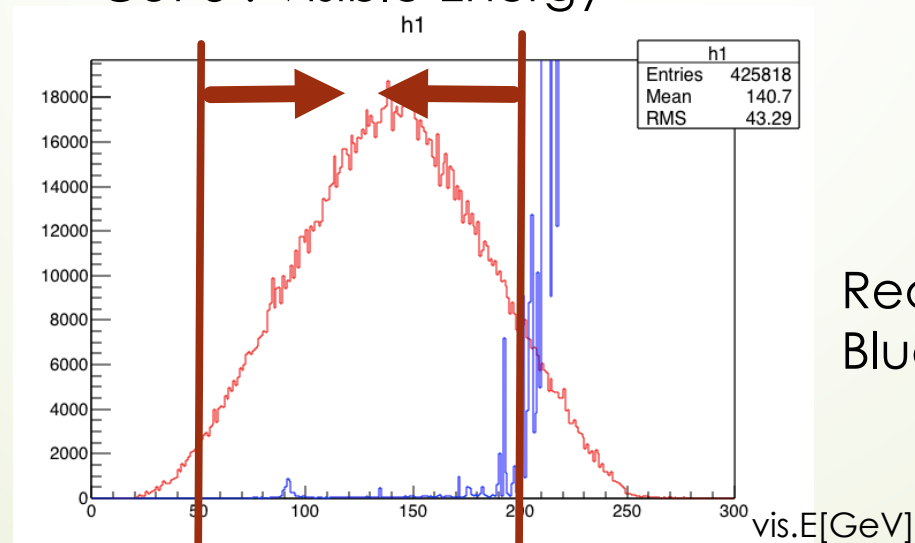
# Event Selection

$$e^-e^+ \rightarrow \tau^- \tau^+$$

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- Jet clustering (TaJet)
- Selection : 2 jets
- Cut 1: Energy > 10 GeV
- Cut 2: Opening angle > 178 degree
- Cut 3: 50 GeV < Visible Energy < 200 GeV
  - To cut mumu events
- Cut 4 :  $|\cos\theta| < 0.95$ 
  - To cut bhabha

Cut 3 : Visible Energy



Red : TauTau(signal)  
Blue : Background



# Cut Table

After preselection of  $|\cos\theta| < 0.97$   
and  $E_{e^+} + E_{e^-} > 200 \text{ GeV}$

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e eL.pR	Signal (Bhabha)		All BG
No cut	2.16E+08		2.79E+07
$E > 10 \text{ GeV}$	2.12E+08	98%	2.11E+07
Clu./Tra.	2.10E+08	97%	6.91E+06
$E/(E+H)$	2.09E+08	97%	1.67E+06
$E1 + E2 > 230 \text{ GeV}$	1.05E+08	49%	4.01E+04
$ \cos\theta  < 0.95$	5.58E+07	26%	9.99E+03

e eR.pL	Signal (Bhabha)		All BG
No cut	2.10E+08		1.06E+07
$E > 10 \text{ GeV}$	2.07E+08	98%	7.21E+06
Clu./Tra.	2.04E+08	97%	4.87E+06
$E/(E+H)$	2.04E+08	97%	1.18E+06
$E1 + E2 > 230 \text{ GeV}$	1.02E+08	48%	3.88E+04
$ \cos\theta  < 0.95$	5.45E+07	26%	9.58E+03

Mu eL.pR	Signal (MuMu)		All BG
No cut	1.23E+07		2.31E+08
$E > 10 \text{ GeV}$	1.01E+07	82%	2.23E+08
Clu./Tra.	8.11E+06	66%	7.50E+05
$E/(E+H)$	7.93E+06	65%	7.10E+05
$E1 + E2 > 230 \text{ GeV}$	3.21E+06	26%	7.64E+02
$ \cos\theta  < 0.95$	3.03E+06	25%	7.34E+02

Mu eR.pL	Signal (MuMu)		All BG
No cut	1.00E+07		2.20E+08
$E > 10 \text{ GeV}$	7.89E+06	79%	2.13E+08
Clu./Tra.	6.36E+06	63%	2.09E+05
$E/(E+H)$	6.22E+06	62%	1.86E+05
$E1 + E2 > 230 \text{ GeV}$	2.68E+06	27%	5.98E+02
$ \cos\theta  < 0.95$	2.53E+06	25%	5.79E+02

Tau eL.pR	Signal (TauTau)		All BG
No cut	1.11E+07		3.14E+08
$E > 10 \text{ GeV}$	3.77E+06	34%	1.37E+08
angle $> 178 \text{ deg.}$	1.41E+06	13%	1.17E+08
Visible energy $> 200$	1.32E+06	12%	6.21E+07
$ \cos\theta  < 0.95$	1.17E+06	11%	1.86E+04

Tau eR.pL	Signal (TauTau)		All BG
No cut	8.66E+06		2.67E+08
$E > 10 \text{ GeV}$	2.87E+06	33%	1.30E+08
angle $> 178 \text{ deg.}$	1.14E+06	13%	1.13E+08
Visible energy $> 200$	1.06E+06	12%	6.01E+07
$ \cos\theta  < 0.95$	909406	11%	1.54E+04

# Angular distribution

$$\cos \theta = \frac{P_z}{E}$$

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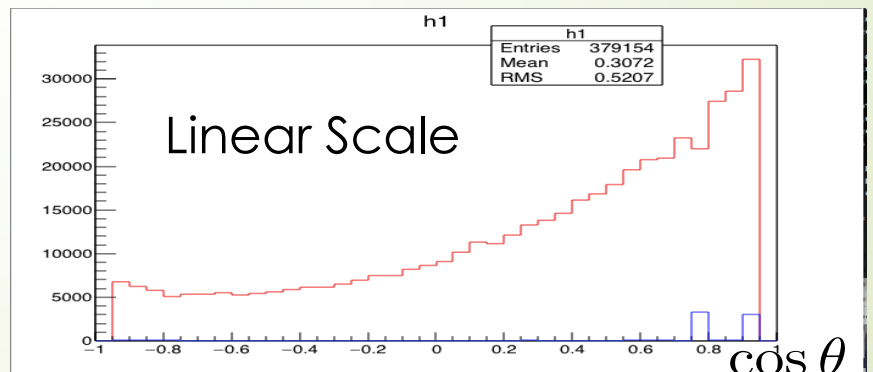
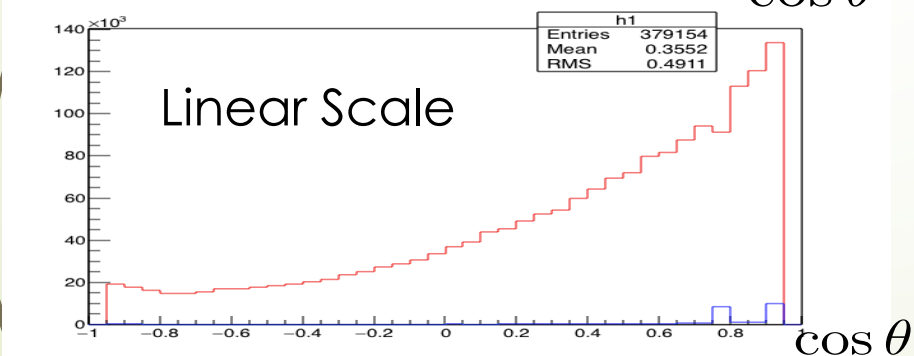
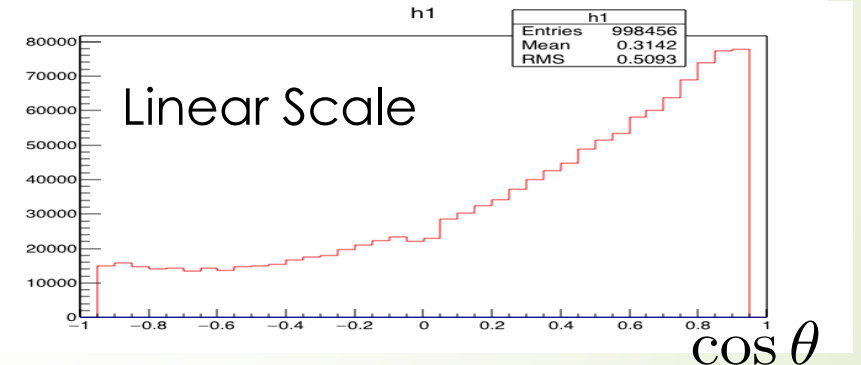
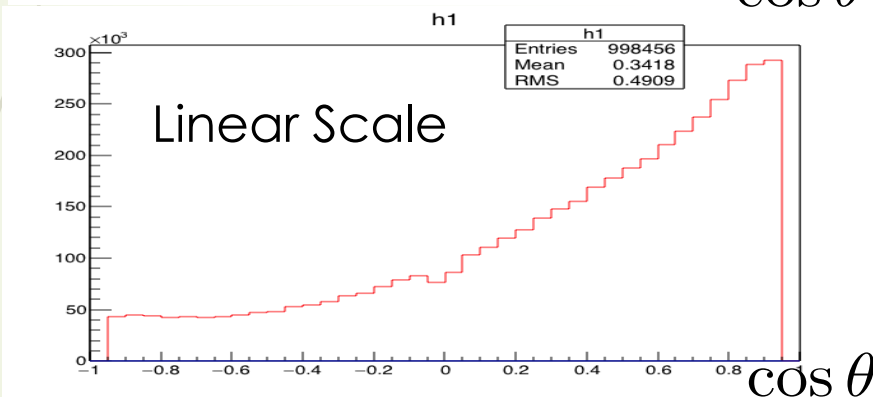
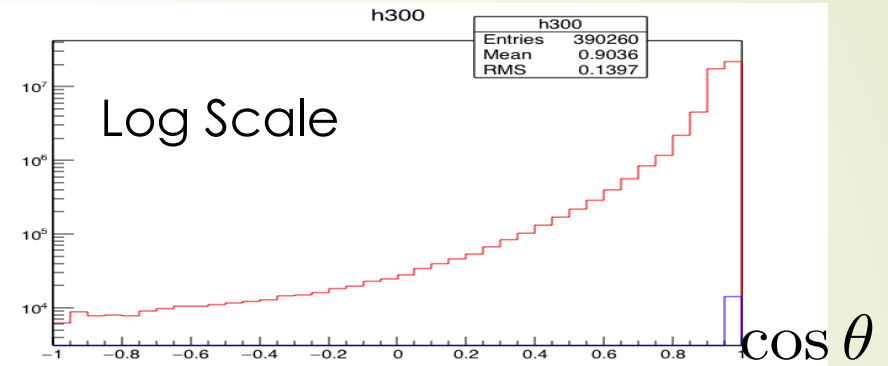
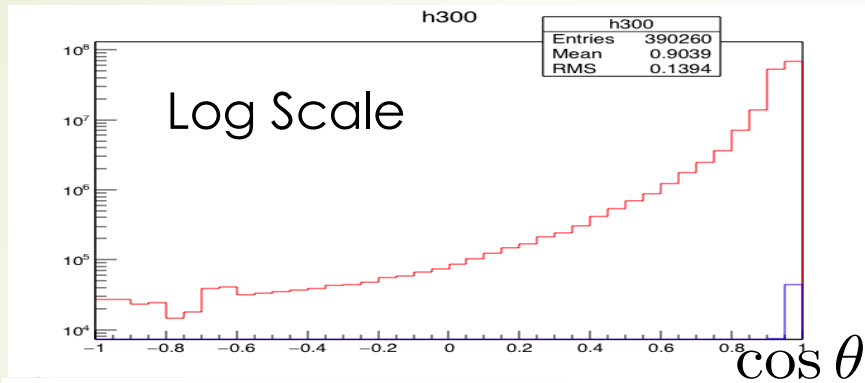
$e^-_L e^+_R$

$e^-_R e^+_L$

$e^-$

$\mu^-$

$\tau^-$



Identify  $Z'$  models based on the statistics of these distribution

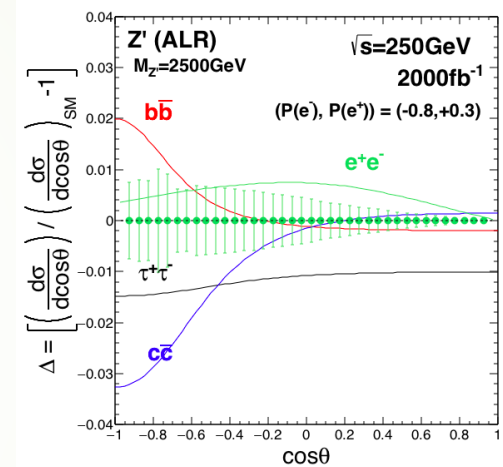
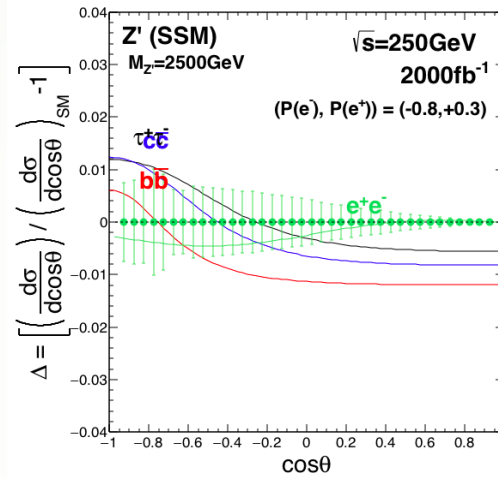
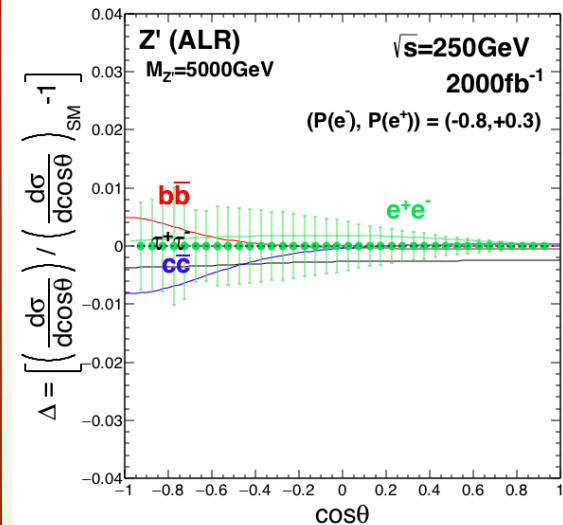
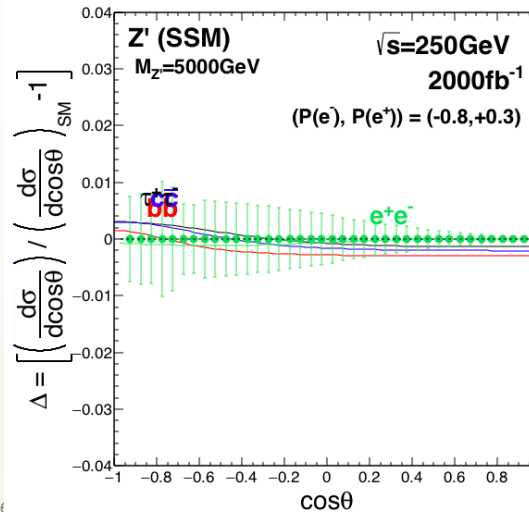
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# investigation the deviation to SM

$$e^-e^+ \rightarrow e^-e^+$$

SSM model

ALR model

 $M_{Z'} = 2.5 \text{ TeV}$ 

 $M_{Z'} = 5.0 \text{ TeV}$ 


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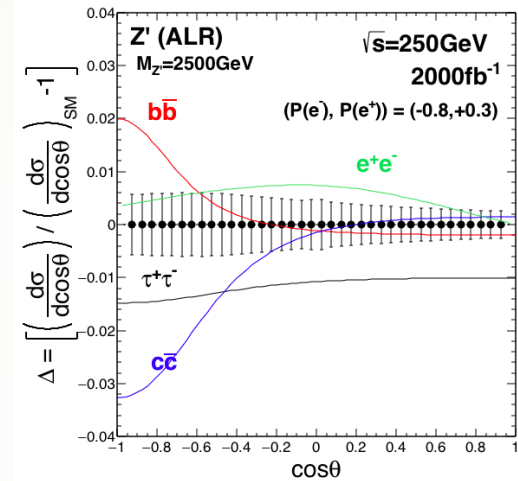
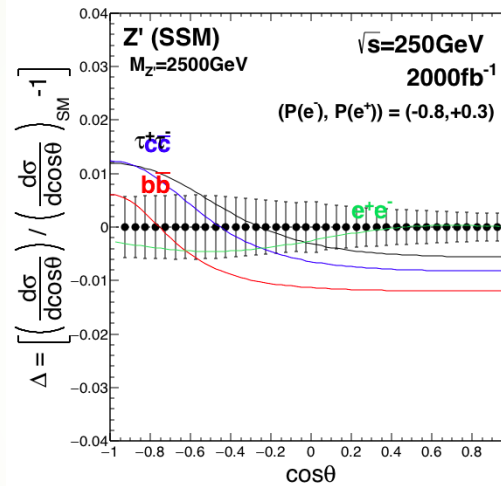
# investigation the deviation to SM

$$e^-e^+ \rightarrow \mu^- \mu^+$$

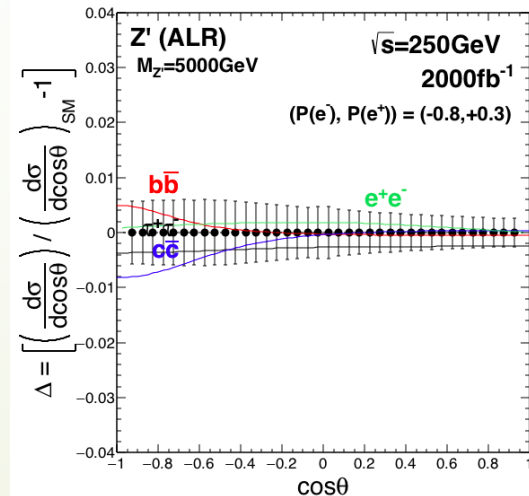
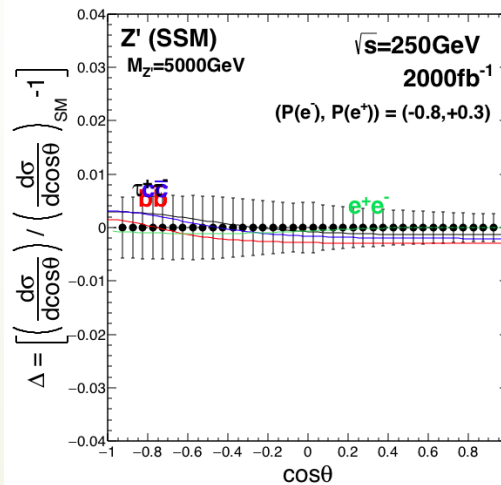
SSM model

ALR model

$$M_{Z'} = 2.5 \text{ TeV}$$



$$M_{Z'} = 5.0 \text{ TeV}$$



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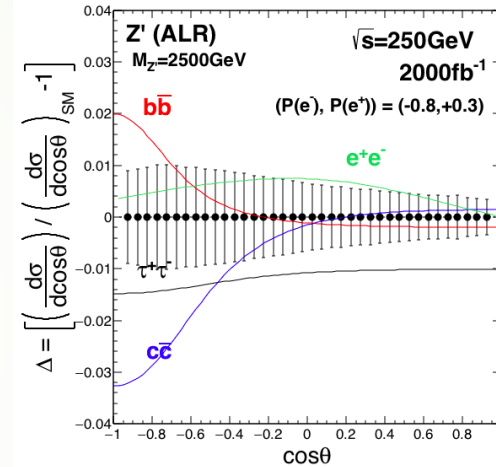
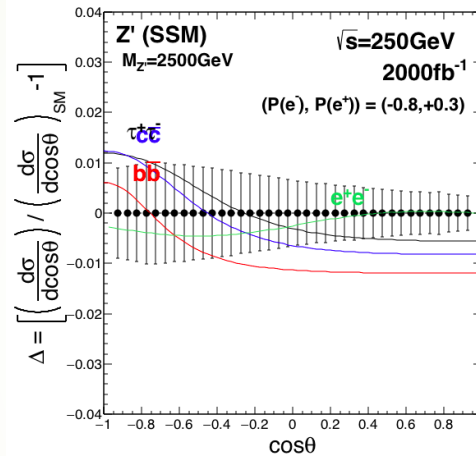
# investigation the deviation to SM

$$e^-e^+ \rightarrow \tau^- \tau^+$$

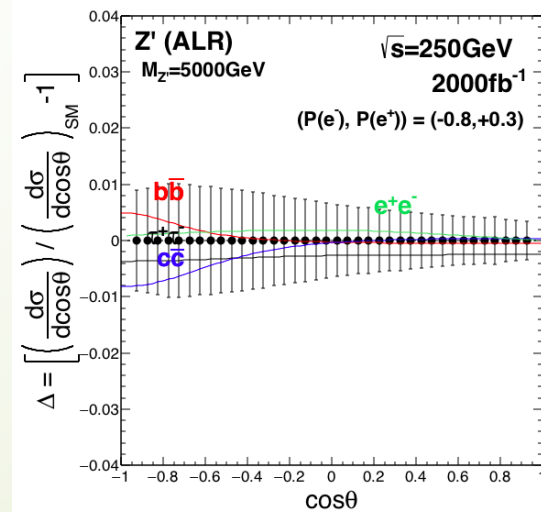
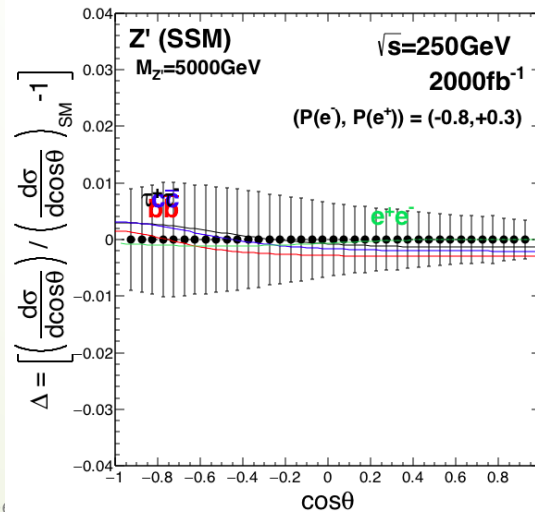
SSM model

ALR model

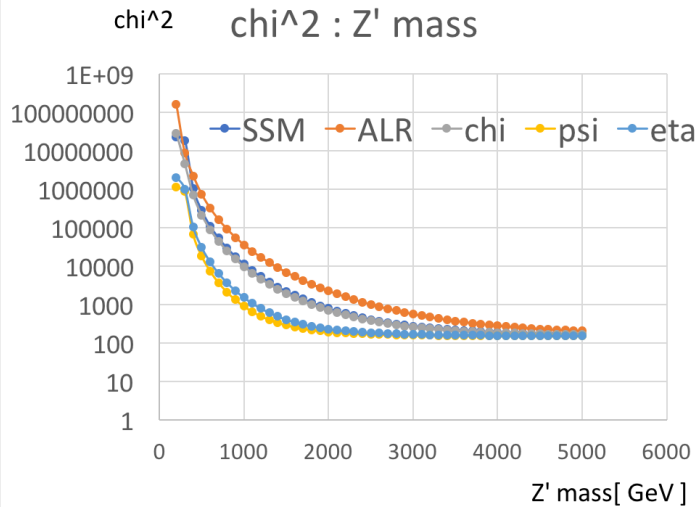
$$M_{Z'} = 2.5 \text{ TeV}$$



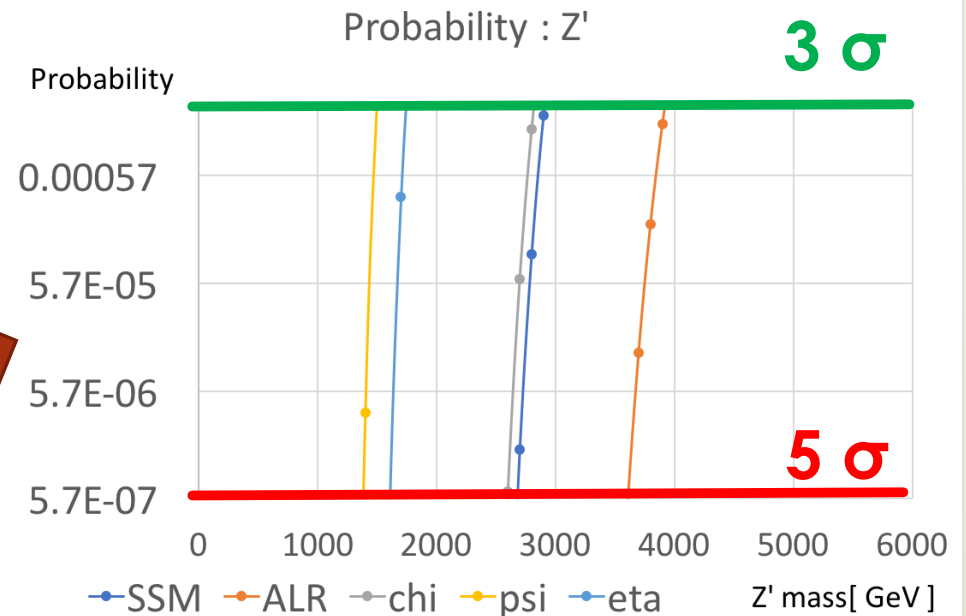
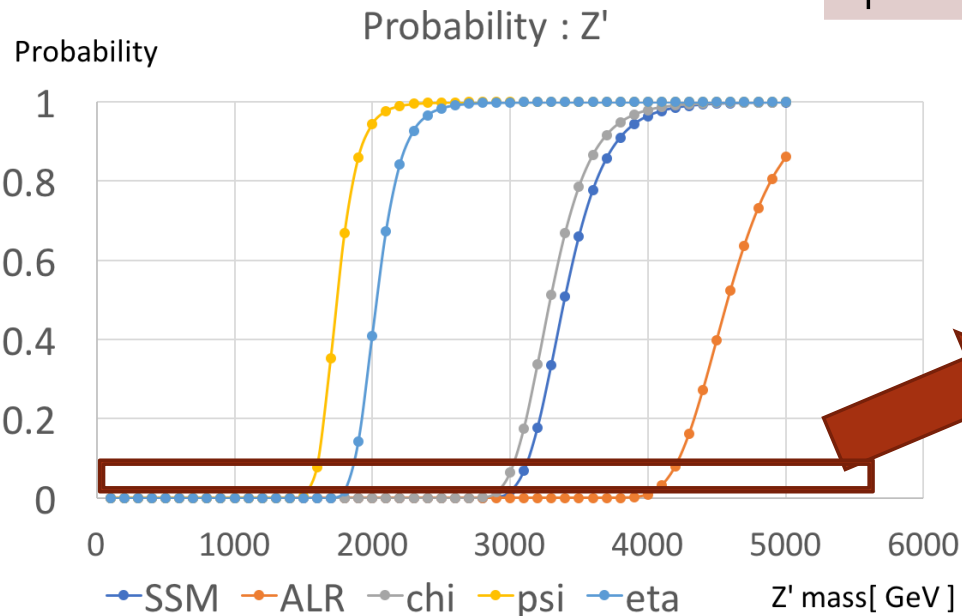
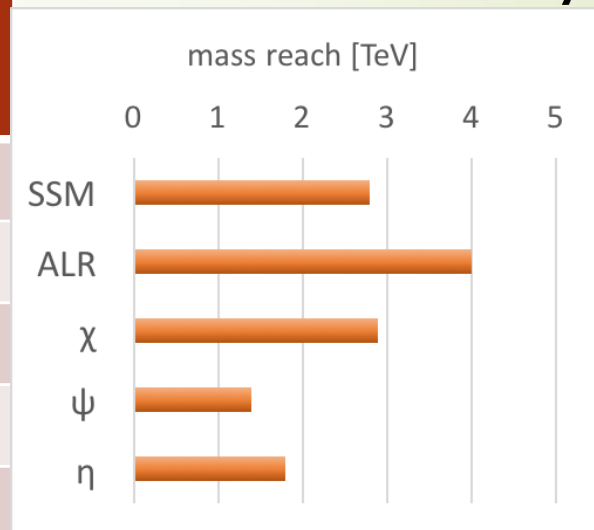
$$M_{Z'} = 5.0 \text{ TeV}$$



# Result (Traditional $Z'$ ) (probability) ( $e^-e^+ \rightarrow l^-l^+$ combined)



BSM model	mass reach ( $3\sigma$ )
SSM	$\sim 2.8$ TeV
ALR	$\sim 4.0$ TeV
$\chi$	$\sim 2.9$ TeV
$\psi$	$\sim 1.4$ TeV
$\eta$	$\sim 1.8$ TeV



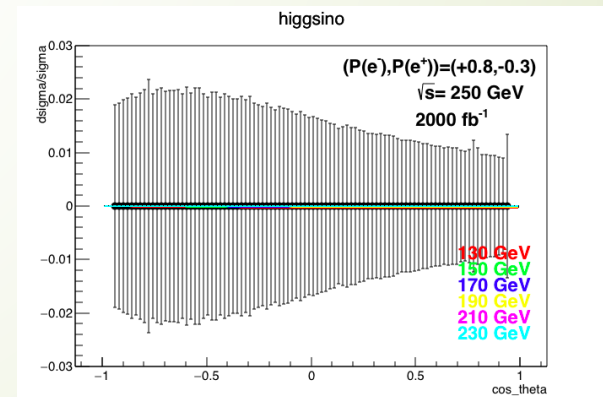
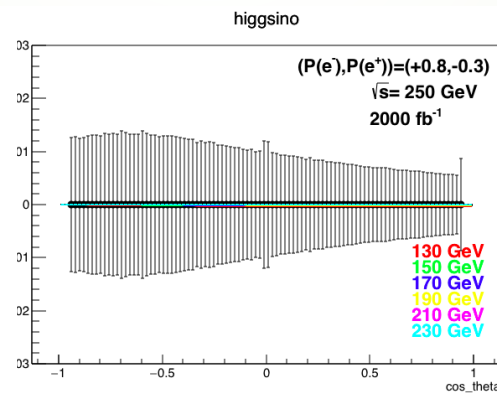
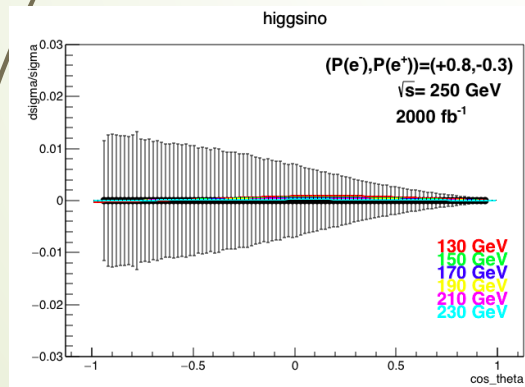
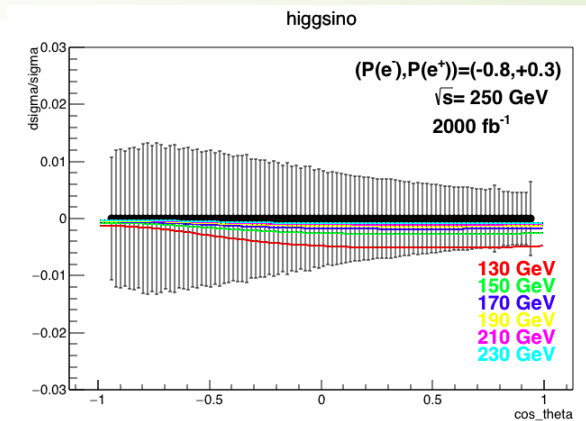
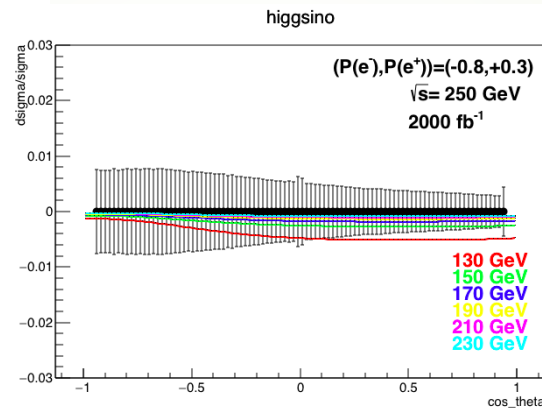
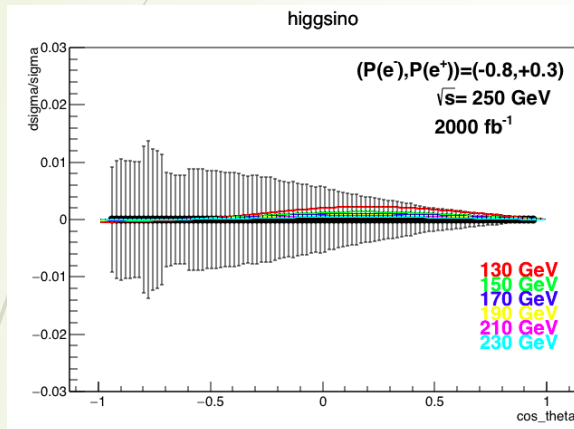


# WIMP search : Higgsino

$$e^-e^+ \rightarrow e^-e^+$$

$$e^-e^+ \rightarrow \mu^- \mu^+$$

$$e^-e^+ \rightarrow \tau^- \tau^+$$



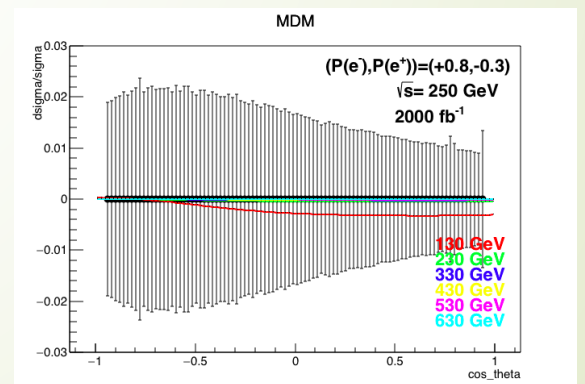
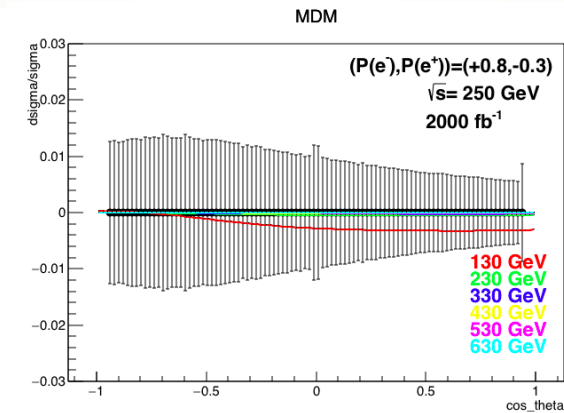
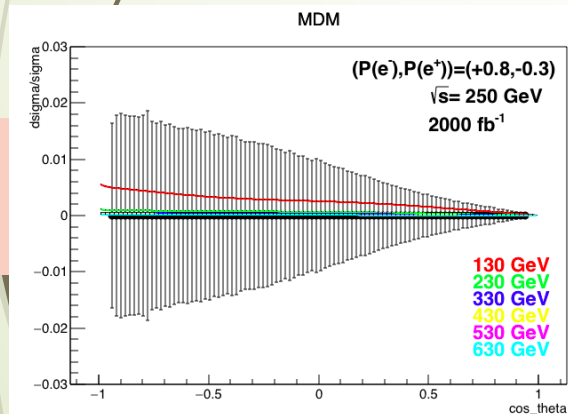
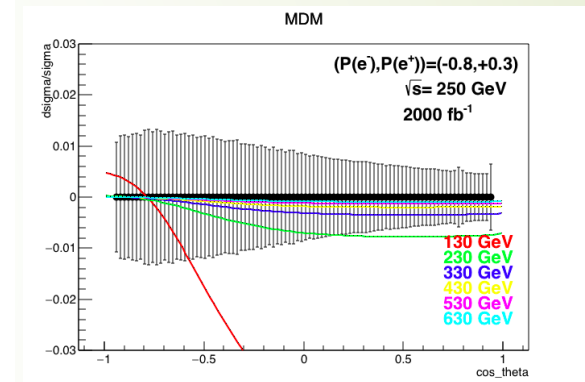
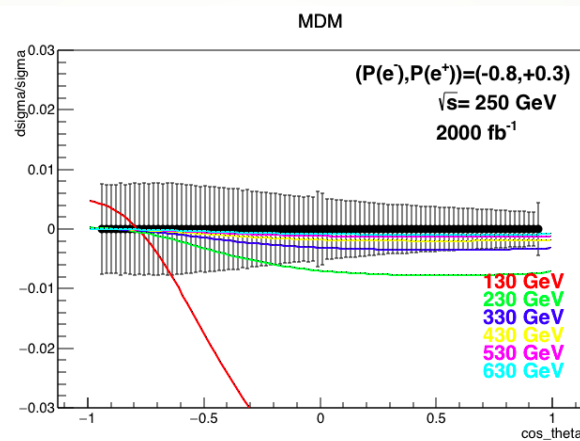
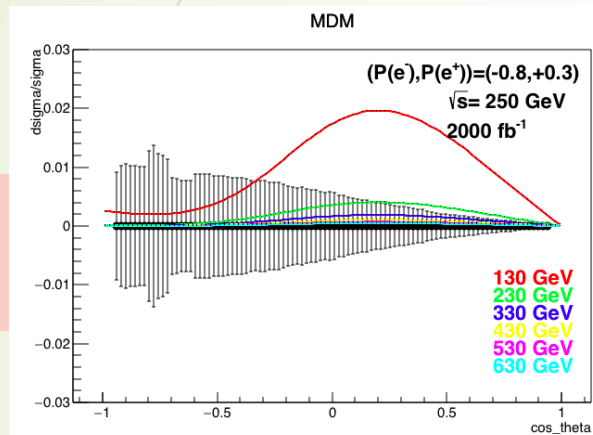


# WIMP search : MDM

$$e^-e^+ \rightarrow e^-e^+$$

$$e^-e^+ \rightarrow \mu^- \mu^+$$

$$e^-e^+ \rightarrow \tau^- \tau^+$$

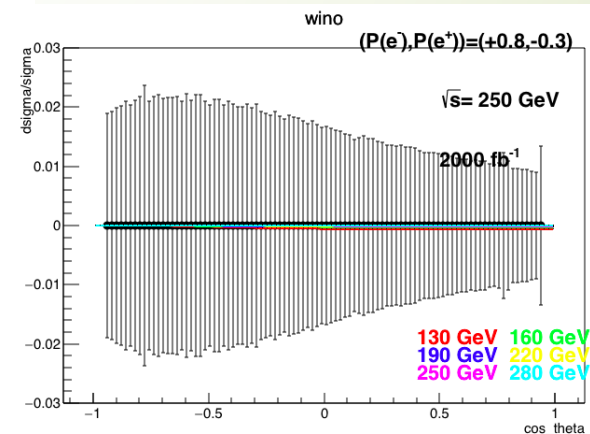
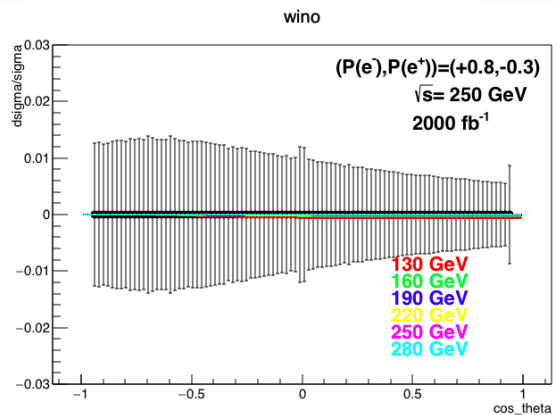
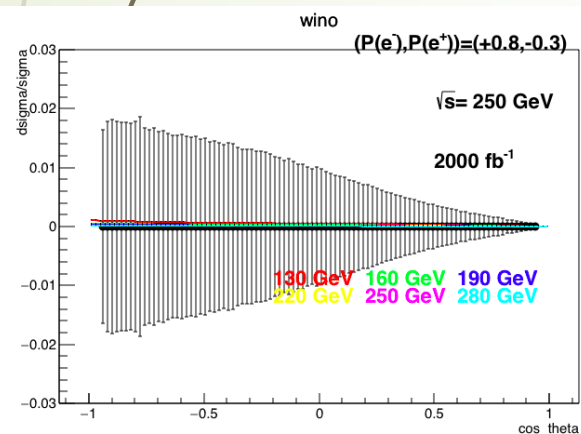
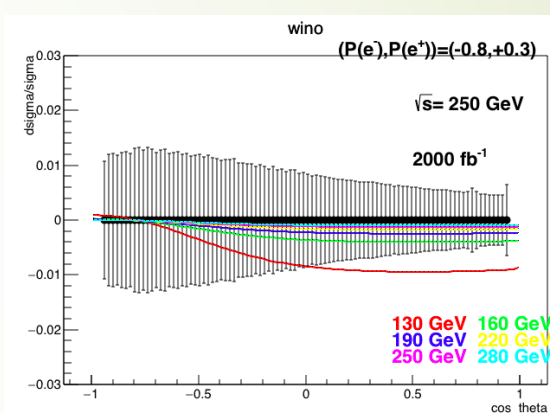
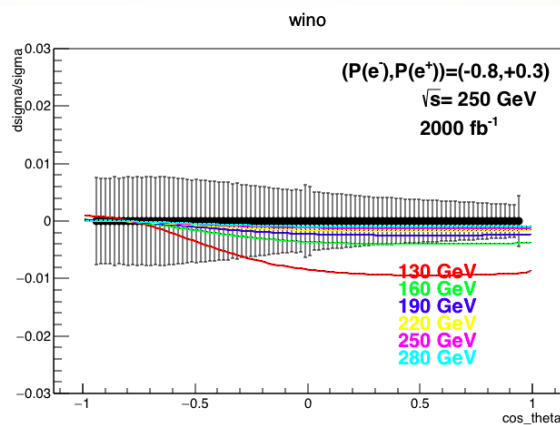
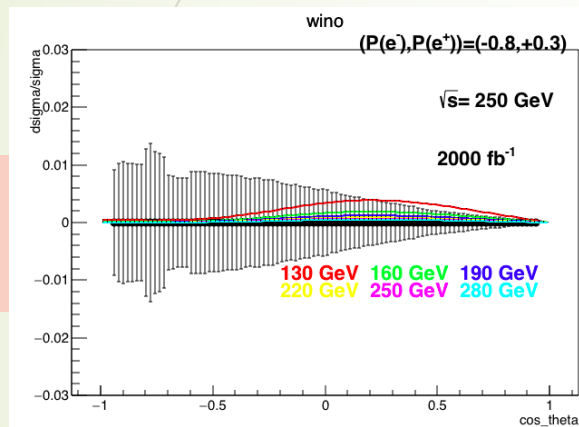


# WIMP search : wino

$$e^-e^+ \rightarrow e^-e^+$$

$$e^-e^+ \rightarrow \mu^- \mu^+$$

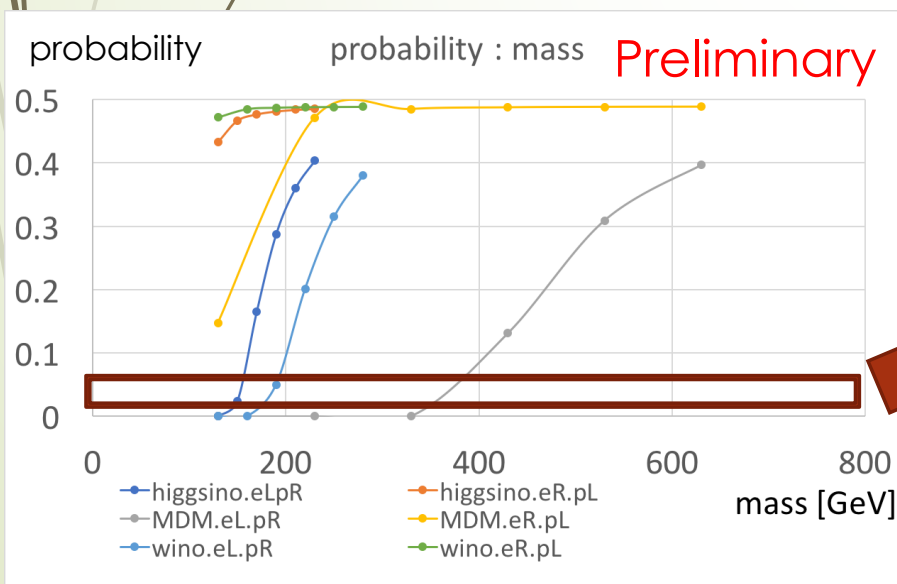
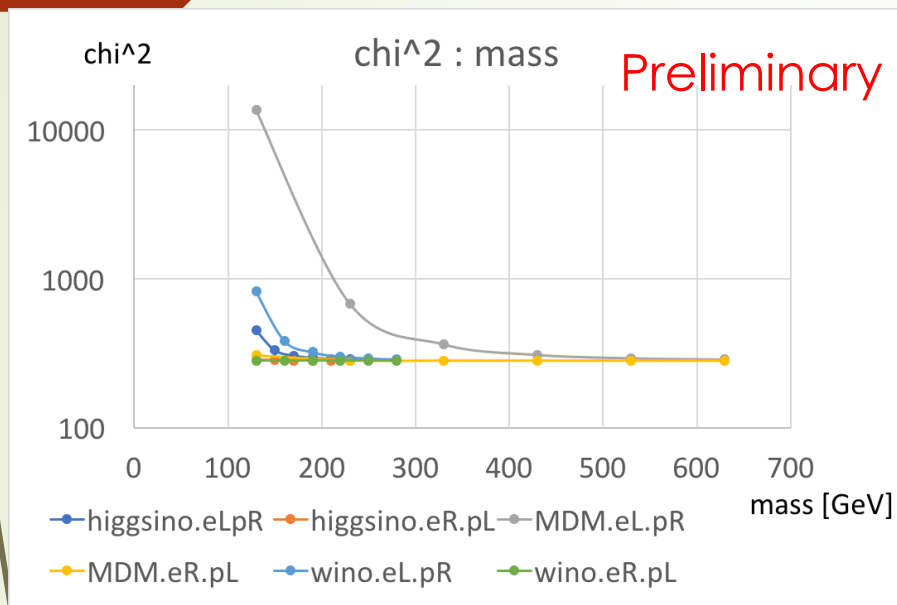
$$e^-e^+ \rightarrow \tau^- \tau^+$$



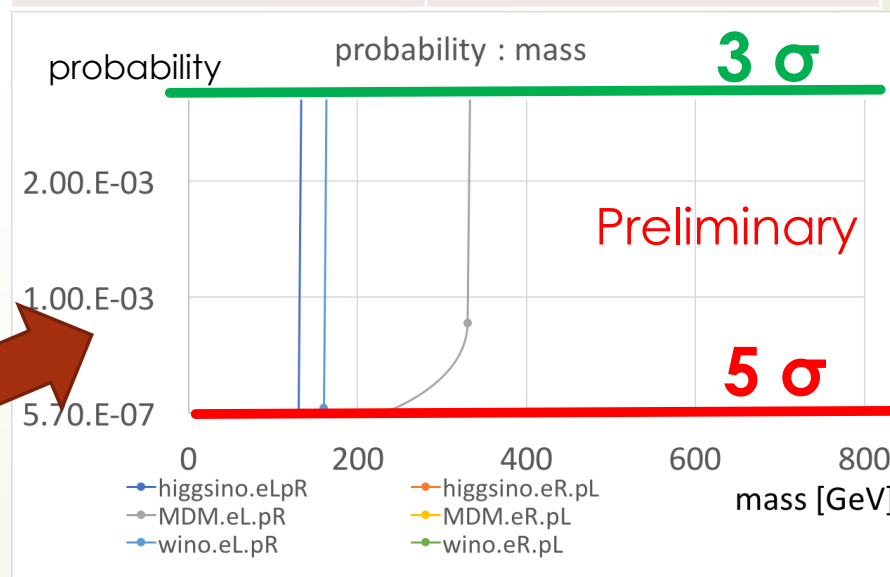
# Result (WIMP search)

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( $e^-e^+ \rightarrow \ell\ell^+$  combined)



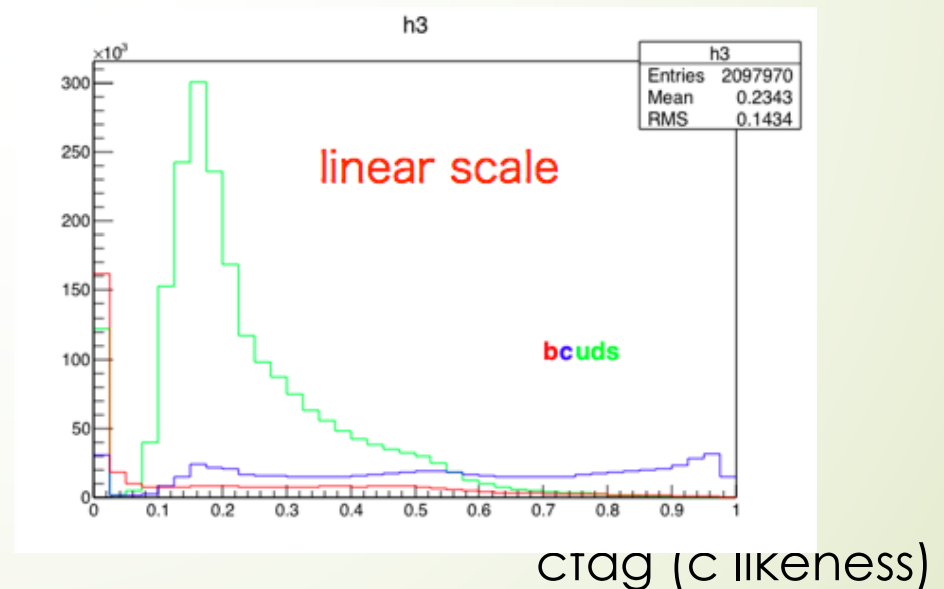
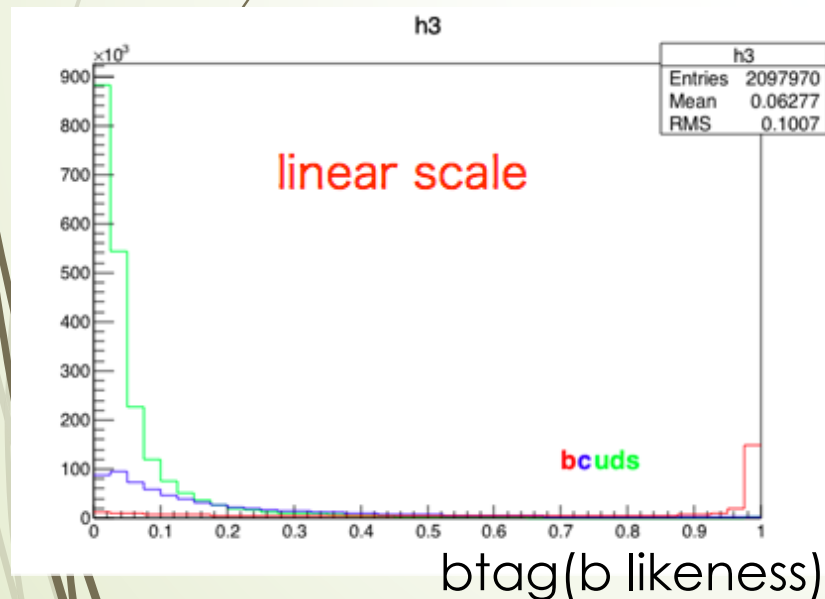
	mass reach ( $3\sigma$ )
higgsino.eL.pR	$\sim 150$ GeV
higgsino.eR.pL	$< 130$ GeV
MDM.eL.pR	$\sim 330$ GeV
MDM.eR.pL	$< 130$ GeV
wino.eL.pR	$\sim 190$ GeV
wino.eR.pL	$< 130$ GeV



# Ongoing study (traditional Z') $ee \rightarrow bb$

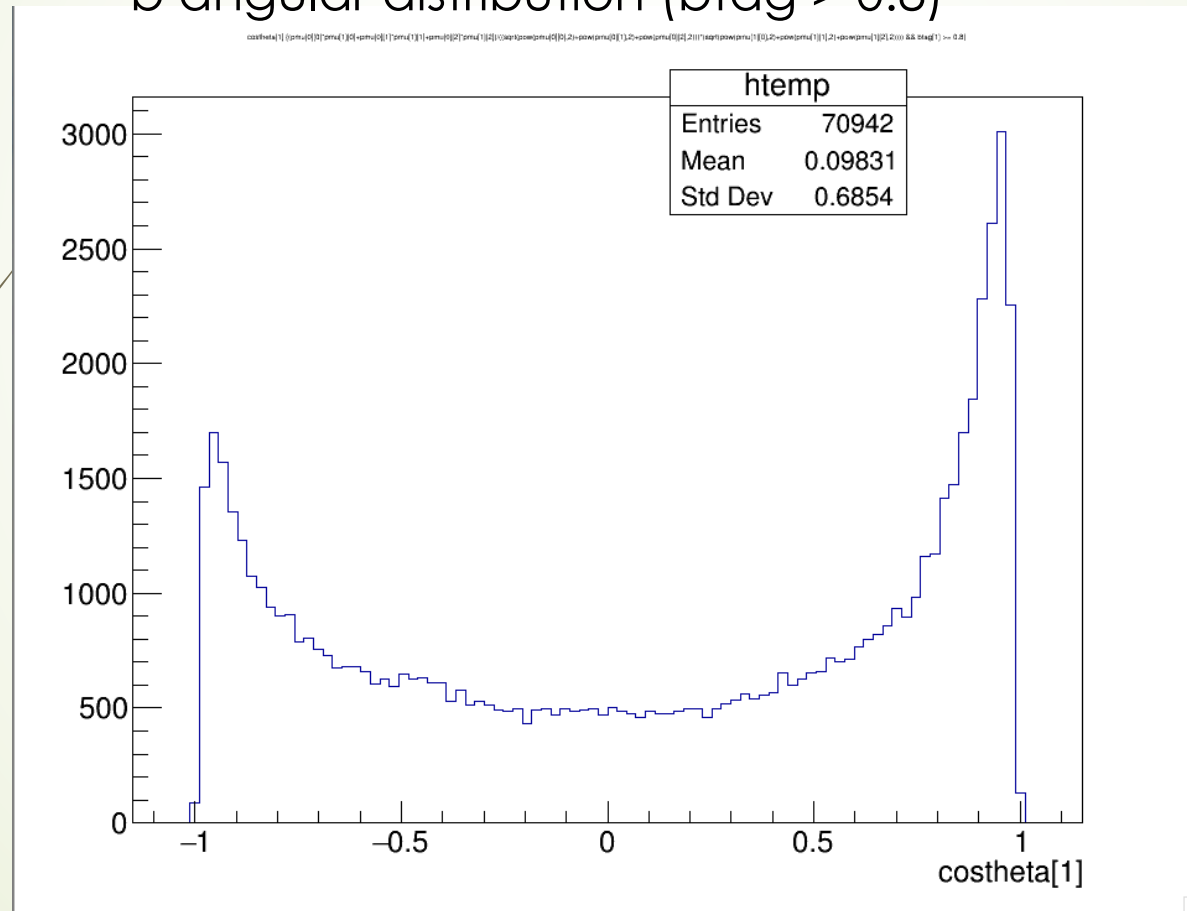
channel	Background
$e^-e^+ \rightarrow b\bar{b}$	<ul style="list-style-type: none"> <li>4f - semiLeptonic event</li> <li>4f - hadronic event</li> </ul>

flavor tagging from 2f\_hadronic



# Ongoing study (traditional Z') $ee \rightarrow bb$

b angular distribution ( $b_{\text{tag}} > 0.8$ )



# Summary

- ▶ Fermion pair productions are sensitive to new contact interactions or a new heavy gauge boson.
- ▶ We use  $e^+ e^- \rightarrow 2l$  process in 250 GeV to investigate the possibility to find the  $Z'$  models.
- ▶  $Z'$  models of SSM and ALR with 2.5 TeV mass can be discovered in the  $\cos\theta$  distribution.
- ▶ Electroweak WIMPs with mass of higher than direct search can be probed by  $2f$  measurement.

## Plan

- ▶ Analysis on hadronic channels to be combined