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

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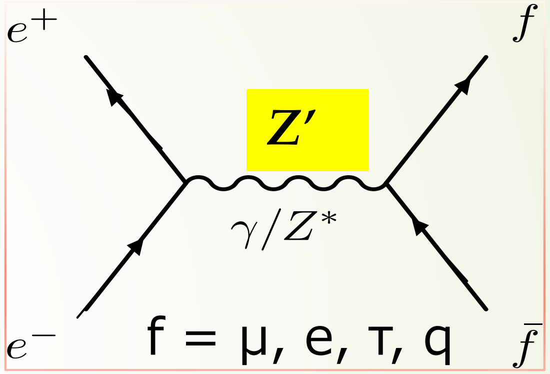
Purpose of 2-fermion process study

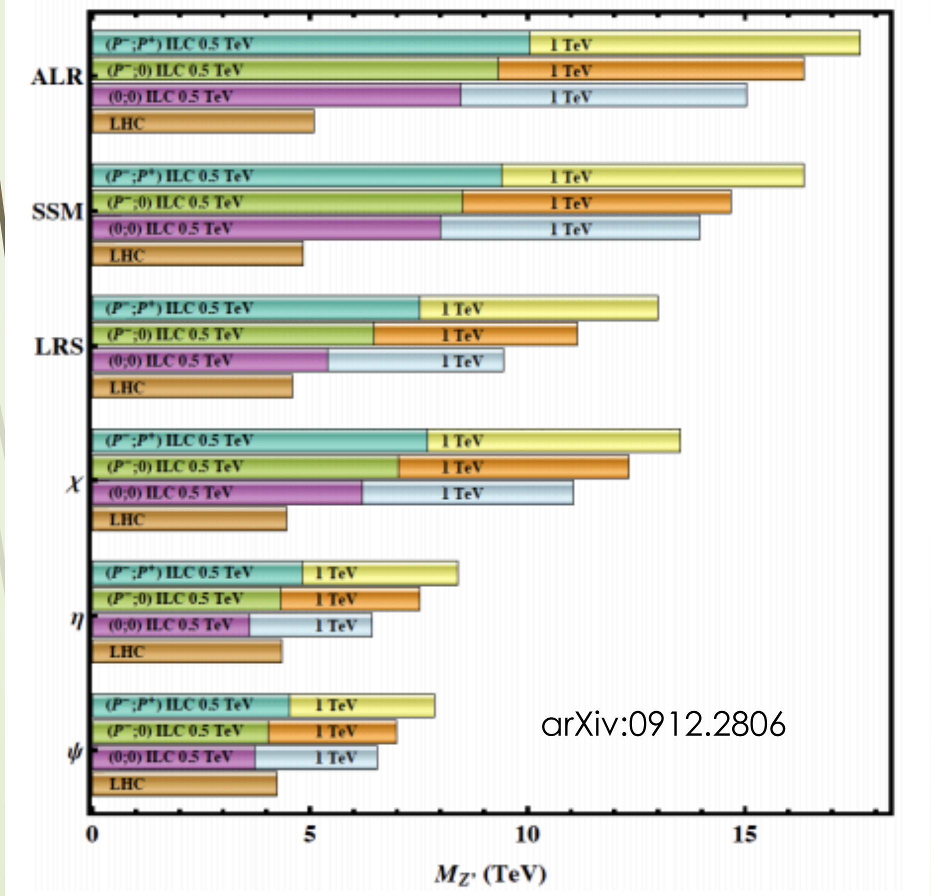
- Precise measurements of electroweak processes at the ILC will provide unique opportunities to explore new physics beyond the standard model.
- Fermion pair productions are sensitive to new contact interactions or a new heavy gauge boson



Z' by comparing cross-section and angular distribution with expectation of the model

Purpose of 2-fermion process study

Z' mass reach



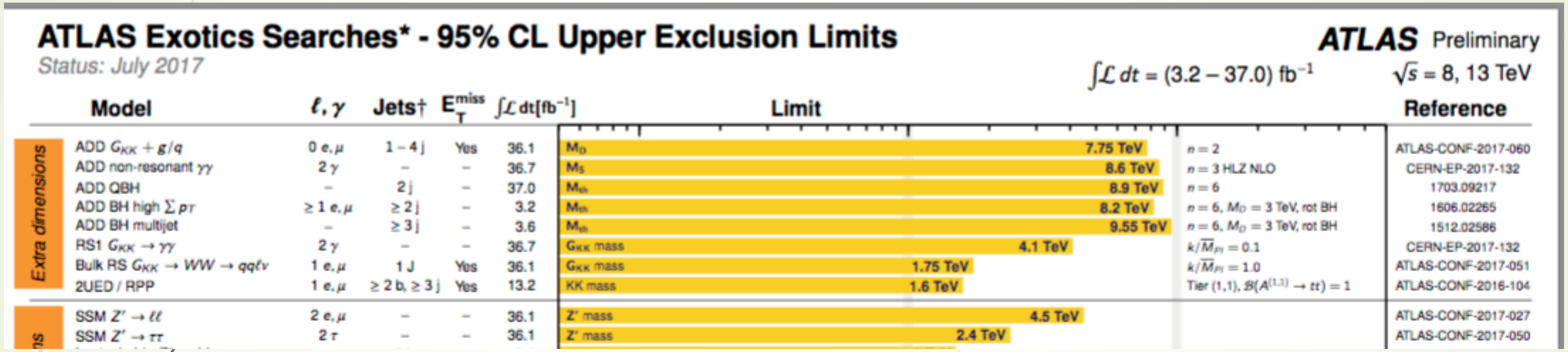
arXiv:0912.2806

- Studies at √s = 500 GeV or more energy exist.
  - The result is made without full simulation.
  - No result at √s = 250 GeV (the first-phase ILC: the Higgs factory)

We need to study by full detector simulation and √s = 250 GeV.

Z' at LHC (SSM model)

- ATLAS
  - Z′ →ll (l = e, μ) : 4.5 TeV Z′ →τ τ : 2.4 TeV



ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

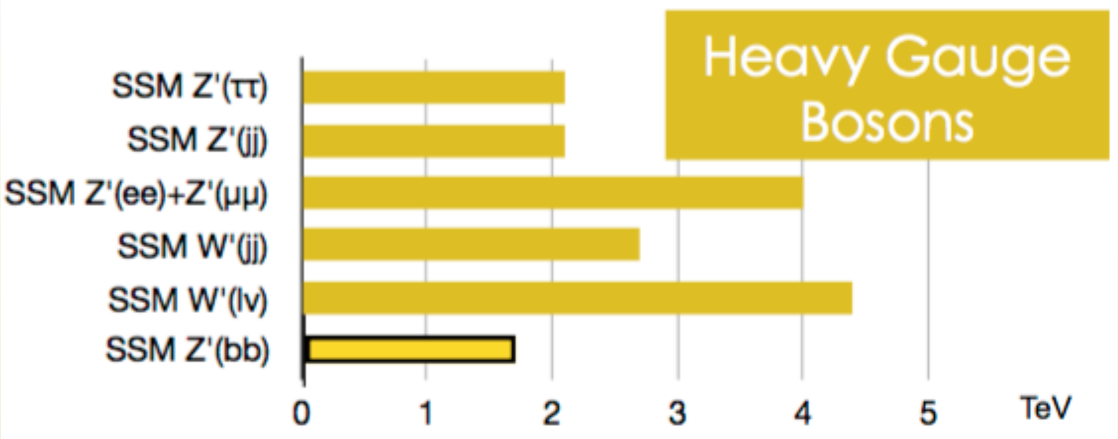
Status: July 2017

ATLAS Preliminary

$\int\mathcal{L}\,dt = (3.2 - 37.0)\ \mathrm{fb}^{-1}$ $\sqrt{s} = 8, 13$ TeV

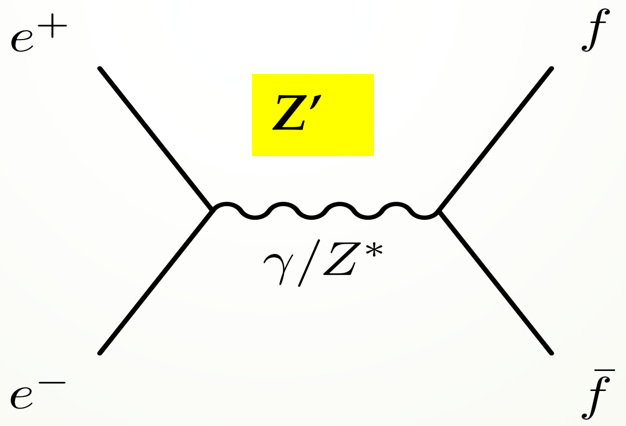
	Model	ℓ, γ	Jets†	E_T^{miss}	$\int\mathcal{L}\,dt[\mathrm{fb}^{-1}]$	Limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	0 e, μ	1 − 4 j	Yes	36.1	M_D 7.75 TeV	$n = 2$	ATLAS-CONF-2017-060
	ADD non-resonant $\gamma\gamma$	2 γ	–	–	36.7	M_S 8.6 TeV	$n = 3$ HLZ NLO	CERN-EP-2017-132
	ADD QBH	–	2 j	–	37.0	M_{th} 8.9 TeV	$n = 6$	1703.09217
	ADD BH high $\sum p_T$	≥ 1 e, μ	≥ 2 j	–	3.2	M_{th} 8.2 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1606.02265
	ADD BH multijet	–	≥ 3 j	–	3.6	M_{th} 9.55 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1512.02586
	RS1 $G_{KK} \to \gamma\gamma$	2 γ	–	–	36.7	G_{KK} mass 4.1 TeV	$k/\overline{M}_{Pl} = 0.1$	CERN-EP-2017-132
	Bulk RS $G_{KK} \to WW \to qq\ell\nu$	1 e, μ	1 J	Yes	36.1	G_{KK} mass 1.75 TeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2017-051
	2UED / RPP	1 e, μ	≥ 2 b, ≥ 3 j	Yes	13.2	KK mass 1.6 TeV	Tier (1,1), $\mathcal{B}(A^{(1,1)} \to tt) = 1$	ATLAS-CONF-2016-104
ns	SSM $Z' \to \ell\ell$	2 e, μ	–	–	36.1	Z' mass 4.5 TeV		ATLAS-CONF-2017-027
	SSM $Z' \to \tau\tau$	2 τ	–	–	36.1	Z' mass 2.4 TeV		ATLAS-CONF-2017-050

- CMS
  - Z′ →ll (l = e, μ) : 4 TeV Z′ →τ τ : ˜2.1 TeV



Today's Talk

- report on a new simulation study of fermion pair productions at 250 GeV
- demonstrate the potential of the first-phase ILC (the Higgs factory).



f = e, μ, τ, c, b

focus on lepton pairs in this talk

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^{-1}	1350 fb^{-1}	425 fb^{-1}

  - 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	Signal	Background
$e^-e^+ \rightarrow e^-e^+$	• 2f - ee event	• 2f - mumu, tautau event • 4f - Leptonic event
$e^-e^+ \rightarrow \mu^-\mu^+$	• 2f - mumu event	• 2f - tautau event ▪ Bhabha • 4f - Leptonic event
$e^-e^+ \rightarrow \tau^-\tau^+$	• 2f - tautau event	• 2f - mumu event ▪ Bhabha • 4f - Leptonic event ▪ 2f-hadronic

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 : $E_{cluster}$ / E_{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_{ECAL} /(E_{ECAL} +E_{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)

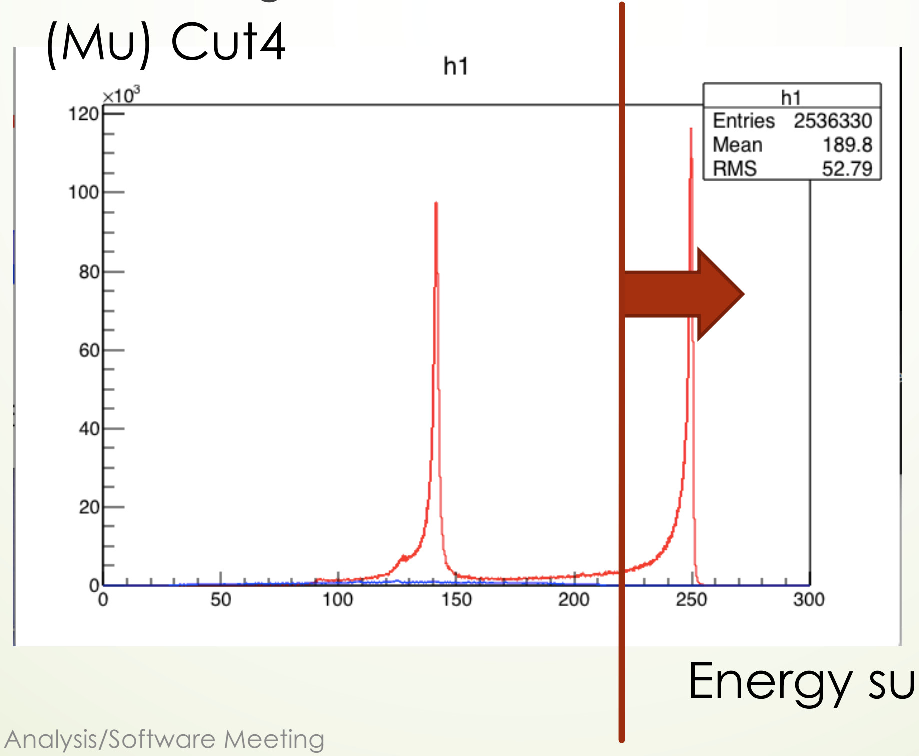
$$\cos\theta = \frac{P_z}{E}$$

$e^- e^+ \longrightarrow e^- e^+$

$e^- e^+ \longrightarrow \mu^- \mu^+$

- Cut4 : Energy sum of two selected tracks > 230 GeV
  - Cutting most of 4f/tautau background and radiative return events .
- Cut 5: |cosθ| < 0.95 (mu only)
  - Cutting the forward Bhabha events (mu only)

(Mu) Cut4



Red : μ⁺μ⁻

Blue : SM background

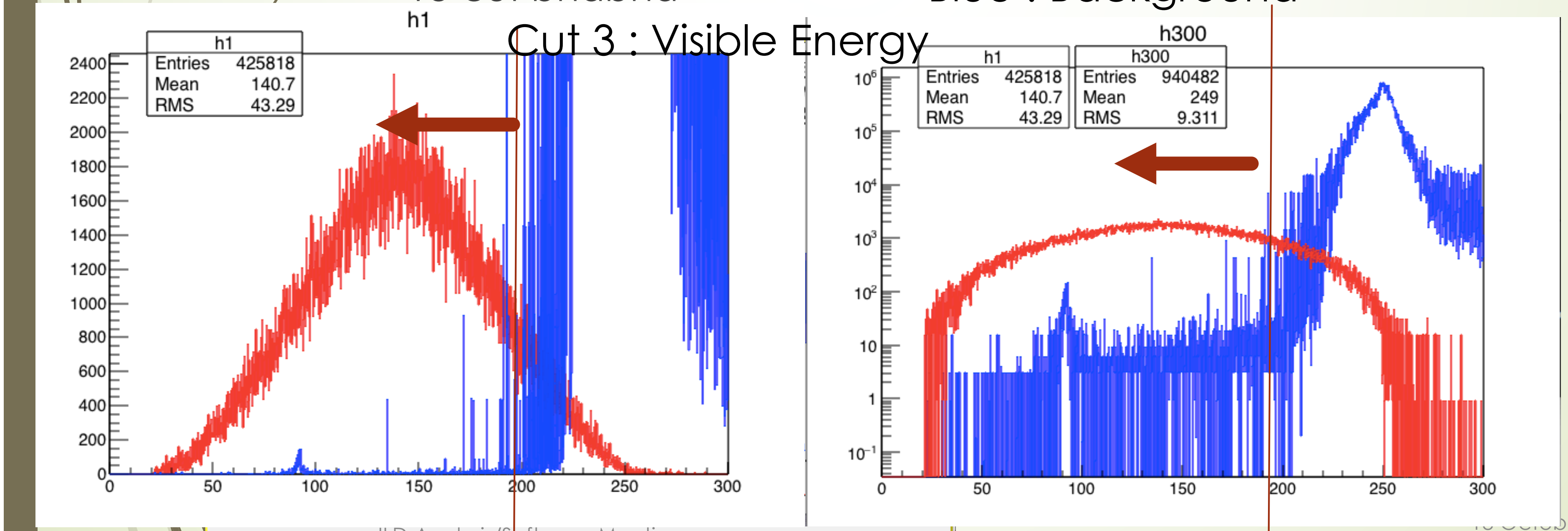
Event Selection

$e^-e^+ \longrightarrow \tau^-\tau^+$

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

Red : TauTau(signal)
Blue : Background

Cut 3 : Visible Energy



Cut Table (Electron)

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

e eL.pR2000	Signal(Bhabha)		BG(MuMu)		BG(TauTau)		BG(WW/ZZ)		BG(single W/Z)	
No cut	3.24E+08		1.84E+07		1.67E+07		2.66E+06		4.08E+06	
E > 10 GeV	3.18E+08	98%	1.51E+07	82%	1.12E+07	67%	2.07E+06	78%	3.41E+06	84%
Clu./Tra.	3.14E+08	97%	15157.1	0%	8.26E+06	49%	333426	13%	1.76E+06	43%
E/(E+H)	3.14E+08	97%	9803.09	0%	1.22E+06	7%	42080.6	2%	1.23E+06	30%
E1 +E2 > 230 GeV	1.57E+08	49%	0	0%	1.31E+02	0%	0	0%	59952.2	1%

e eR.pL2000	Signal(Bhabha)		BG(MuMu)		BG(TauTau)		BG(WW/ZZ)		BG(single W/Z)	
No cut	1.05E+08		5.01E+06		4.33E+06		97158.2		522975	
E > 10 GeV	1.03E+08	98%	3.94E+06	79%	2.84E+06	65%	70070.9	72%	412702	79%
Clu./Tra.	1.02E+08	97%	4253.19	0%	2.12E+06	49%	11989.5	12%	307563	59%
E/(E+H)	1.02E+08	97%	2876.66	0%	307045	7%	1564.29	2%	280929	54%
E1 +E2 > 230 GeV	5.08E+07	48%	0	0%	28.8447	0%	0	0%	19362.8	4%

Cut Table (Mu)

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

Mu eL.pR2000	Signal(Mu Mu)		BG(TauTau)		BG(WW/ZZ)		BG(single W/Z)		BG(Bhabha)	
No cut	1.84E+07		1.67E+07		2.66E+06		4.08E+06		3.24E+08	
E > 10 GeV	1.51E+07	82%	1.12E+07	67%	2.07E+06	78%	3.41E+06	84%	3.18E+08	98%
Clu./Tra.	1.22E+07	66%	257860	2%	838126	32%	8230.03	0%	8230.03	0%
E/(E+H)	1.19E+07	65%	238879	1%	817000	31%	8716.42	0%	0	0%
E1 +E2 > 230 GeV	4.82E+06	26%	31.5402	0%	1112.73	0%	1.7544	0%	0	0%
$\lvert\cos\theta\rvert < 0.95$	4.55E+06	25%	31.5402	0%	1067.63	0%	1.40352	0%	0	0%

Mu eR.pL2000	Signal(Mu Mu)		BG(TauTau)		BG(WW/ZZ)		BG(single W/Z)		BG(Bhabha)	
No cut	5.01E+06		4.33E+06		97158.2		522975		1.05E+08	
E > 10 GeV	3.94E+06	79%	2.84E+06	65%	70070.9	72%	412702	79%	1.03E+08	98%
Clu./Tra.	3.18E+06	63%	62501.5	1%	33612.5	35%	3756.74	1%	4450.65	0%
E/(E+H)	3.11E+06	62%	57867.7	1%	32819.7	34%	2341.34	0%	0	0%
E1 +E2 > 230 GeV	1.34E+06	27%	0.629007	0%	295.384	0%	2.83403	0%	0	0%
$\lvert\cos\theta\rvert < 0.95$	1.27E+06	25%	0.629007	0%	286.654	0%	2.26723	0%	0	0%

Cut Table (Tau)

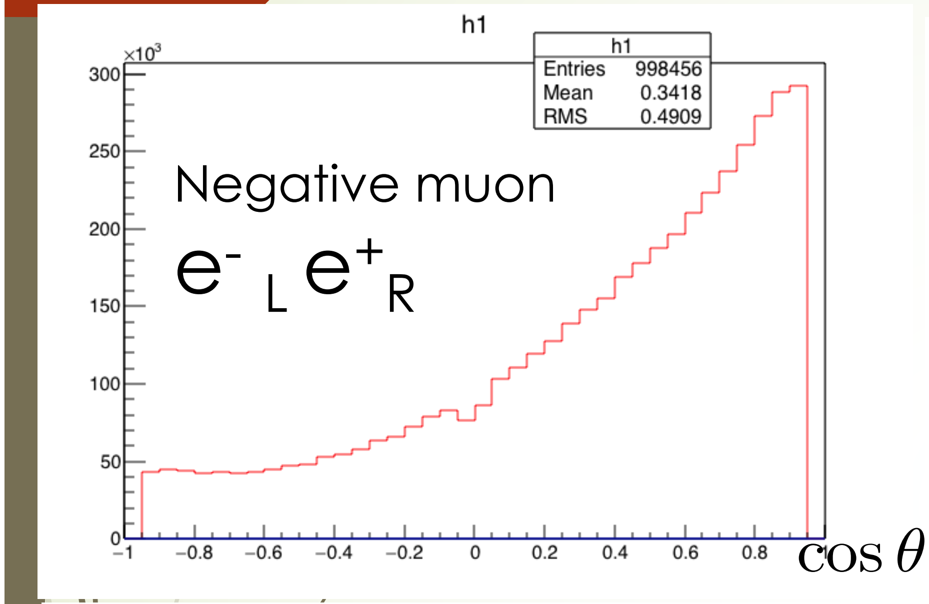
$e^-e^+\to \tau^-\tau^+$

Tau eL.pR 2000 fb	Signal (TauTau)		BG (MuMu)		BG (WW/ZZ)		BG (single W/Z)		BG (Bhabha)		BG (hadron)	
No cut	1.67E+07		1.84E+07		2.66E+06		4.08E+06		3.24E+08		1.22E+08	
E > 10 GeV	5.66E+06	34%	7.55E+06	41%	1.36E+06	51%	1.66E+06	41%	1.95E+08	60%	51522	0%
angle > 178 deg.	2.12E+06	13%	2.92E+06	16%	3.52E+03	0%	6.64E+04	2%	1.73E+08	53%	70.422	0%
Visible energy > 200	1.97E+06	12%	2.72E+06	15%	3.20E+03	0%	9.25E+03	0%	9.04E+07	28%	67.9	0%
$\|\cos\theta\|$ < 0.95	1.79E+06	11%	6258.87	0%	2.75E+03	0%	2.63E+03	0%	1.63E+04	0%	0	0%

Tau eR.pL 2000 fb	Signal (TauTau)		BG (MuMu)		BG (WW/ZZ)		BG (single W/Z)		BG (Bhabha)		BG (hadron)	
No cut	4.33E+06		5.01E+06		97158		522975		1.05E+08		2.26E+07	
E > 10 GeV	1.44E+06	33%	1.97E+06	39%	37168	38%	81779	16%	6.28E+07	60%	16885	0%
angle > 178 deg.	568321	13%	813061	16%	102	0%	20252	4%	5.58E+07	53%	16	0%
Visible energy > 200	529530	12%	758292	15%	89	0%	1962	0%	2.93E+07	28%	1	0%
$\|\cos\theta\|$ < 0.95	461034	11%	1515.25	0%	70	0%	84	0%	6.03E+03	0%	0	0%

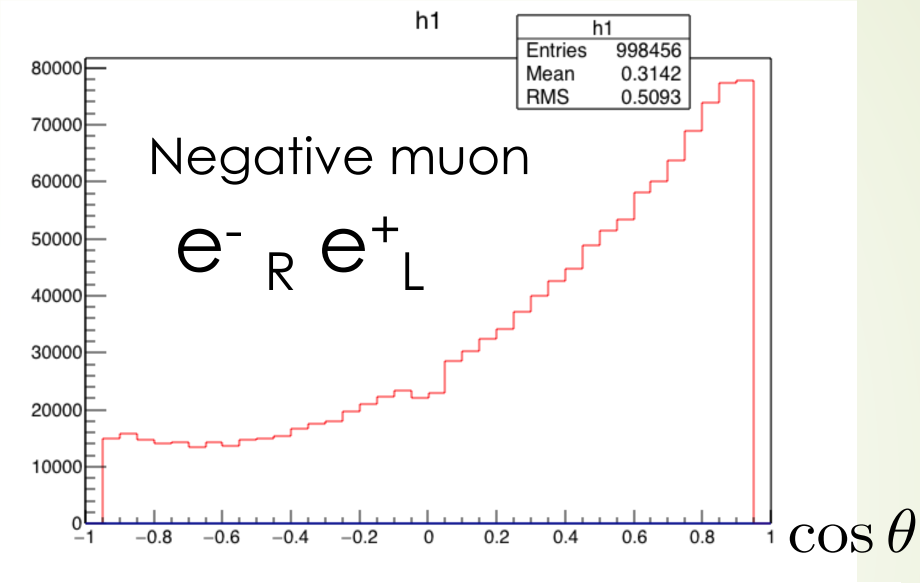
Angular distribution

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



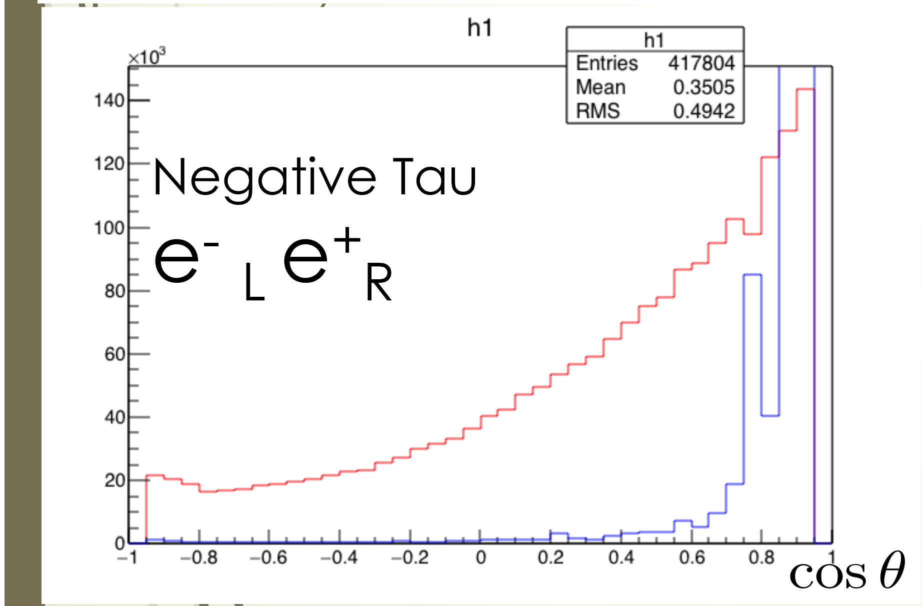
Negative muon

$e^-_L \, e^+_R$



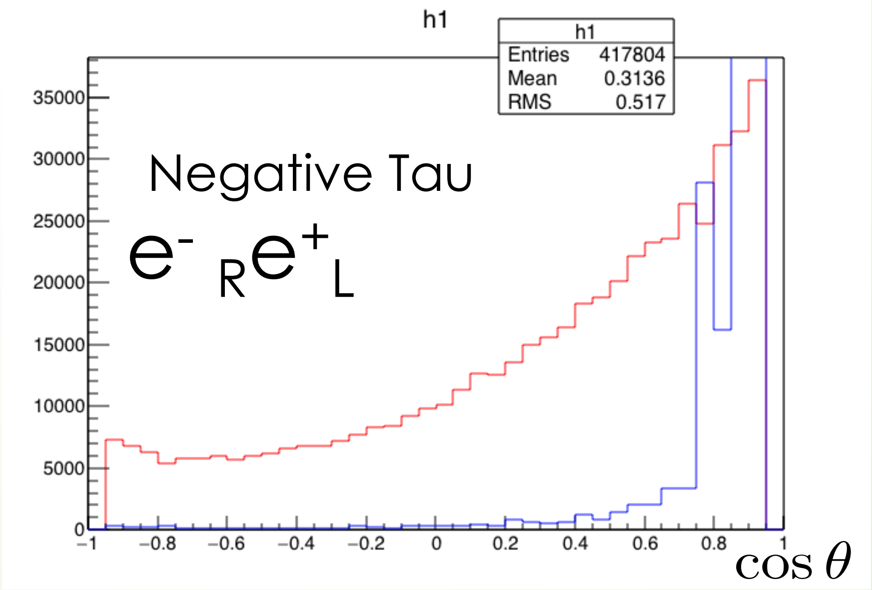
Negative muon

$e^-_R \, e^+_L$



Negative Tau

$e^-_L \, e^+_R$

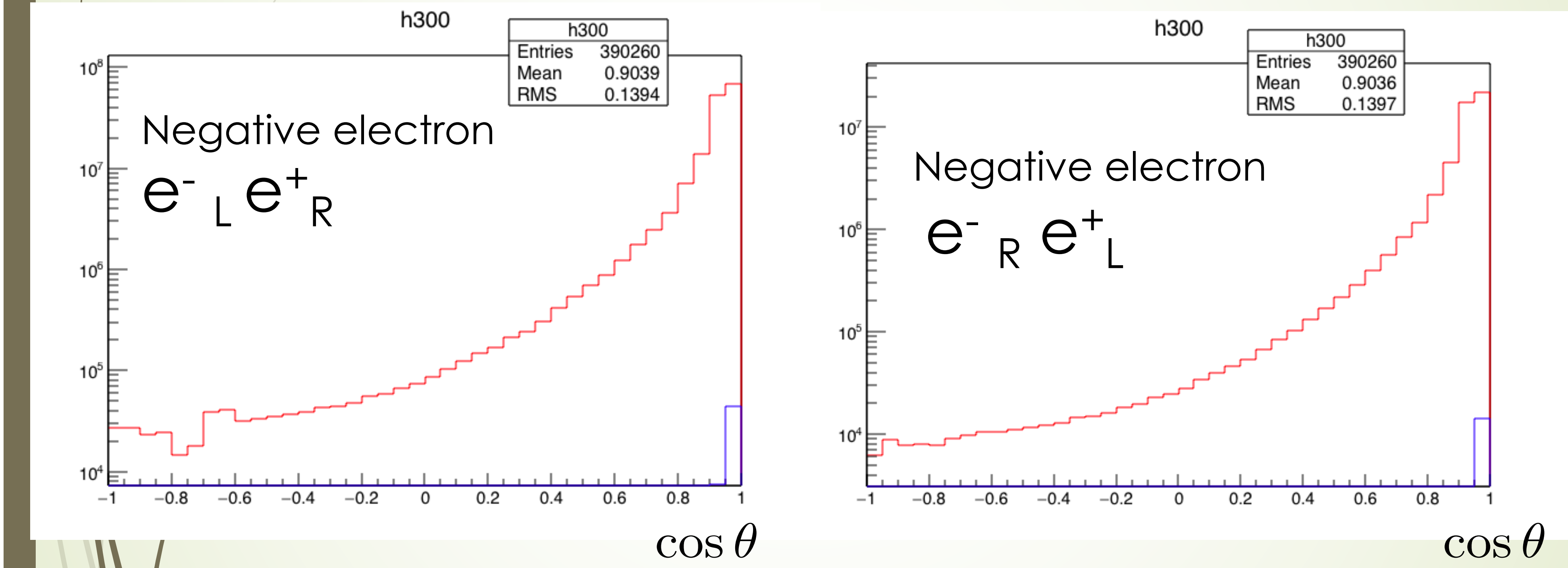


Negative Tau

$e^-_R e^+_L$

Angular distribution

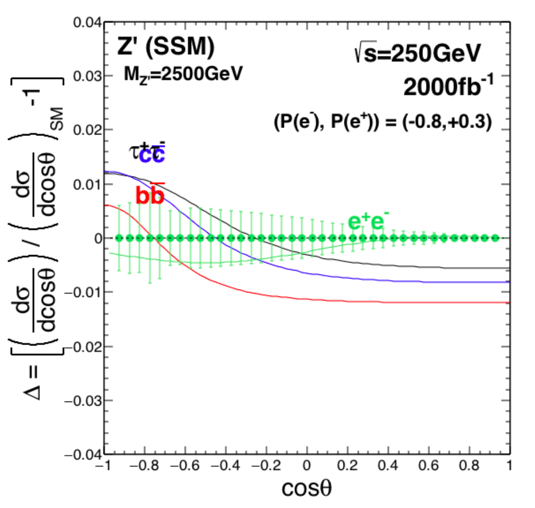
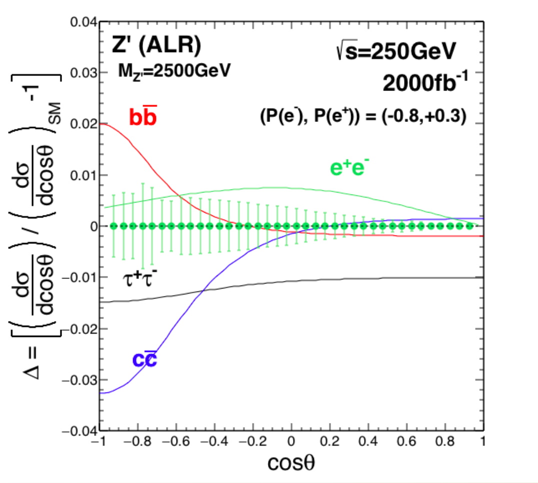
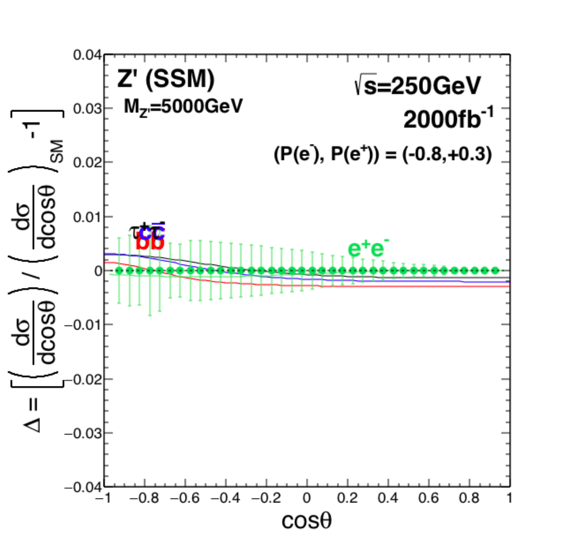
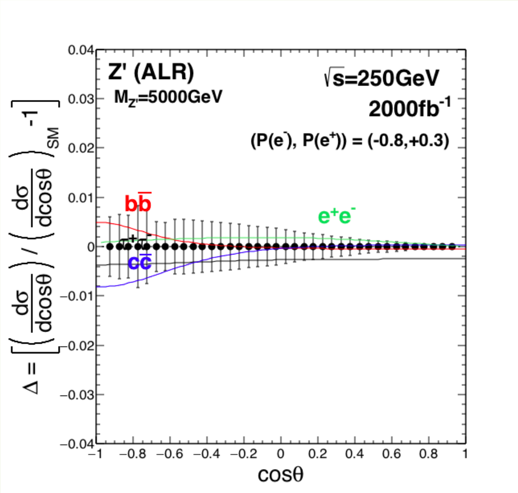
$$\cos\theta = \frac{P_z}{E}$$



Identify Z' models based on the statistics of these distribution

investigation the deviation to SM

$e^-e^+ \longrightarrow e^-e^+$

	SSM model	ALR model
Mz' = 2.5 TeV		
Mz' = 5.0 TeV		

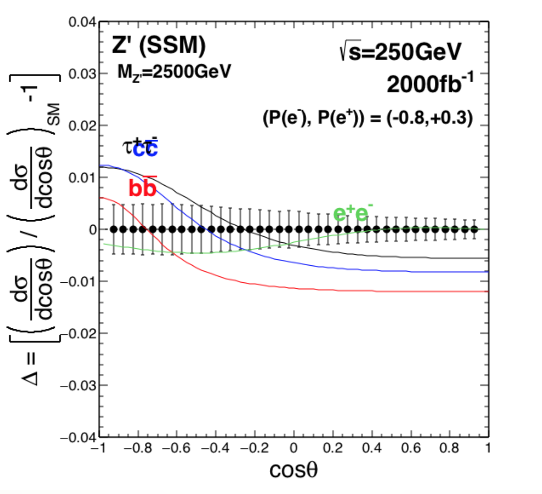
investigation the deviation to SM

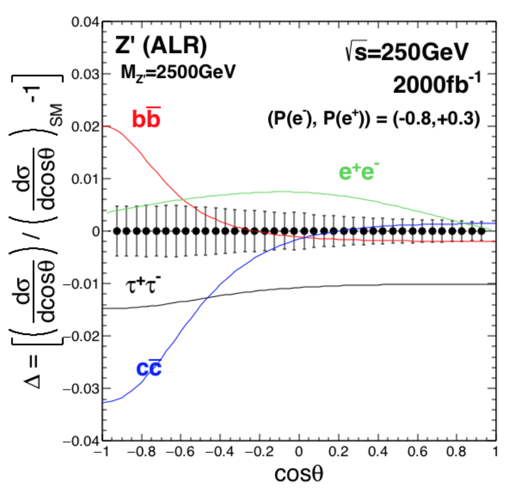
$e^-e^+\longrightarrow \mu^-\mu^+$

SSM model

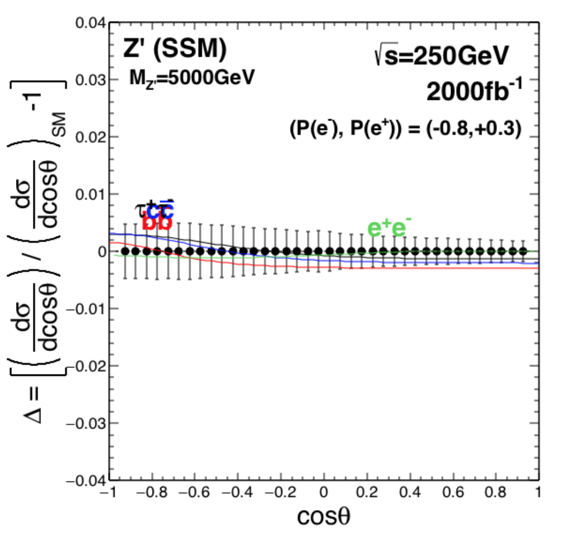
ALR model

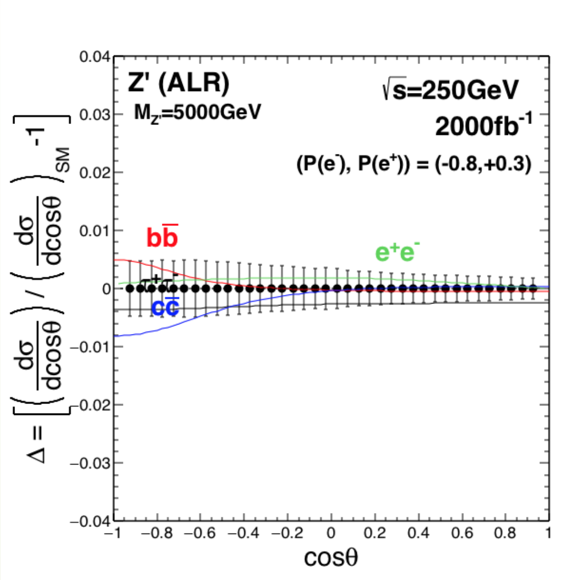
Mz’ = 2.5 TeV





Mz’ = 5.0 TeV





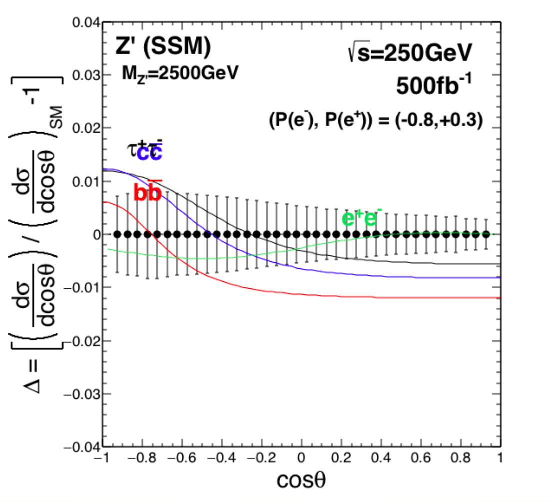
investigation the deviation to SM

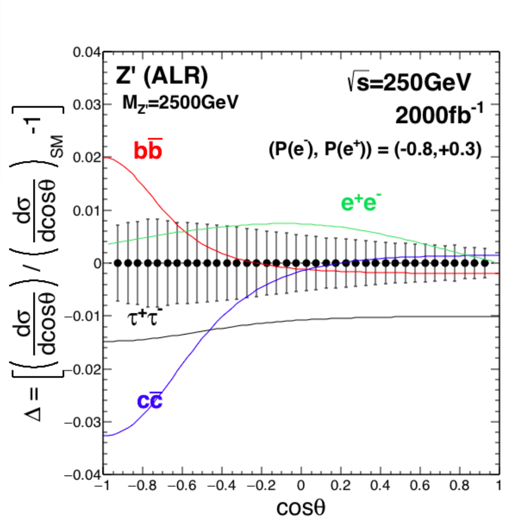
$e^-e^+ \to \tau^-\tau^+$

SSM model

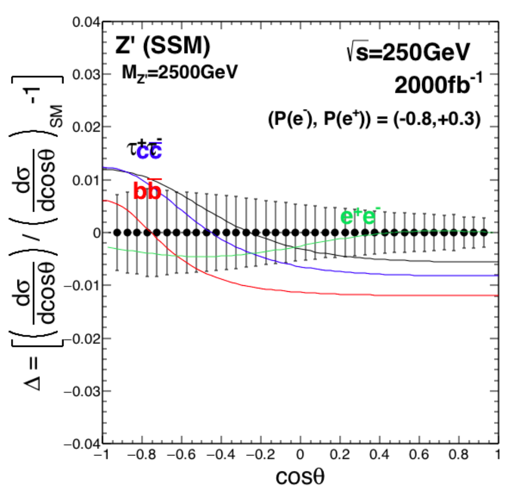
ALR model

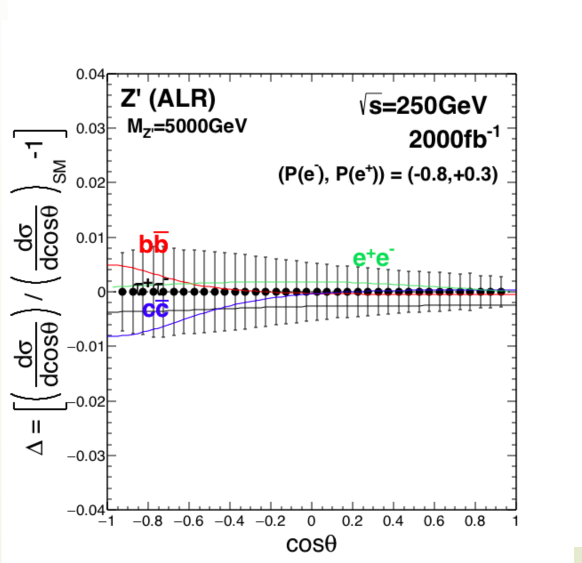
Mz' = 2.5 TeV





Mz' = 5.0 TeV





Results

preliminary

Mz’ = 2.5 TeV

e

Z' = 2.5 TeV	eL.pR			eR.pL		
BSM model	χ^2	ndf	probability	χ^2	ndf	probability
SSM	14.2	38	0.999	4.66	38	1
ALR	226	38	1.39E-28	73.4	38	4.92E-03
χ	59.9	38	0.0131	19.4	38	0.995
Ψ	0.945	38	1	0.312	38	1
η	2.61	38	1	0.851	38	1

μ

Z' = 2.5 TeV	eL.pR			eR.pL		
BSM model	χ^2	ndf	probability	χ^2	ndf	probability
SSM	169	38	1.35E-18	67.9416	38	2.01E-03
ALR	569	38	6.84E-96	93.0471	38	1.62E-06
χ	216	38	6.97E-27	44.3083	38	0.222
Ψ	45.1	38	1.99E-01	40.3235	38	0.368
η	42.1	38	2.98E-01	43.7011	38	0.242

τ

Z' = 2.5 TeV	eL.pR			eR.pL		
BSM model	χ^2	ndf	probability	χ^2	ndf	probability
SSM	89.1	38	5.52E-06	51.87	38	0.0662
ALR	242.9	38	1.07E-31	92.21	38	2.11E-06
χ	107.2	38	1.62E-08	55.71	38	0.0318
Ψ	40.8	38	3.50E-01	38.76	38	0.4350
η	39.6	38	4.00E-01	38.46	38	0.4484

Mz’ = 5.0 TeV

Z' = 5 TeV	eL.pR			eR.pL		
BSM model	χ^2	ndf	probability	χ^2	ndf	probability
SSM	0.904	38	1	2.98	38	1
ALR	14.08	38	0.999	4.56	38	1
χ	3.73	38	1	1.21	38	1
Ψ	0.0602	38	1	0.0199	38	1
η	0.164	38	1	0.0534	38	1

Z' = 5 TeV	eL.pR			eR.pL		
BSM model	χ^2	ndf	probability	χ^2	ndf	probability
SSM	46.1	38	0.171	39.8413	38	0.388
ALR	70.8	38	9.67E-04	41.4027	38	0.324
χ	49.0	38	0.108	38.3891	38	0.452
Ψ	38.43	38	0.450	38.143	38	0.463
η	38.3	38	0.458	38.3513	38	0.454

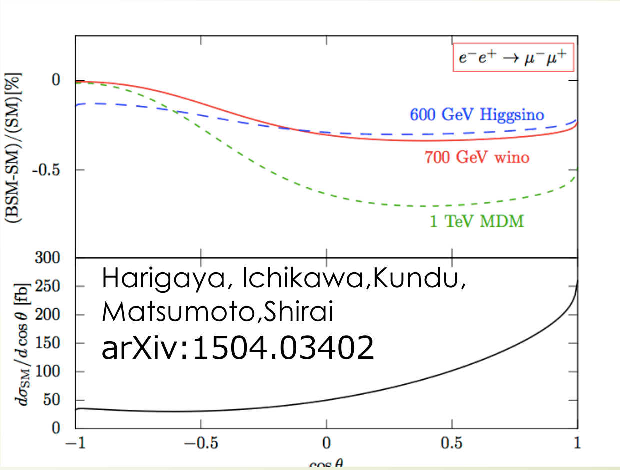
Z' = 5 TeV	eL.pR			eR.pL		
BSM model	χ^2	ndf	probability	χ^2	ndf	probability
SSM	41.1	38	0.335	38.9	38	0.431
ALR	50.7	38	0.082	41.4	38	0.326
χ	42.3	38	0.292	39.1	38	0.421
Ψ	38.2	38	0.462	38.0	38	0.467
η	38.1	38	0.465	38.0	38	0.468

Summary

- Fermion pair productions are sensitive to new contact interactions or a new heavy gauge boson.
- We use e+ e- -> 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 costheta distributuon.

Plan

- To study hadronic analysis
- Study indirect search WIMP



Harigaya, Ichikawa,Kundu, Matsumoto,Shirai arXiv:1504.03402