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

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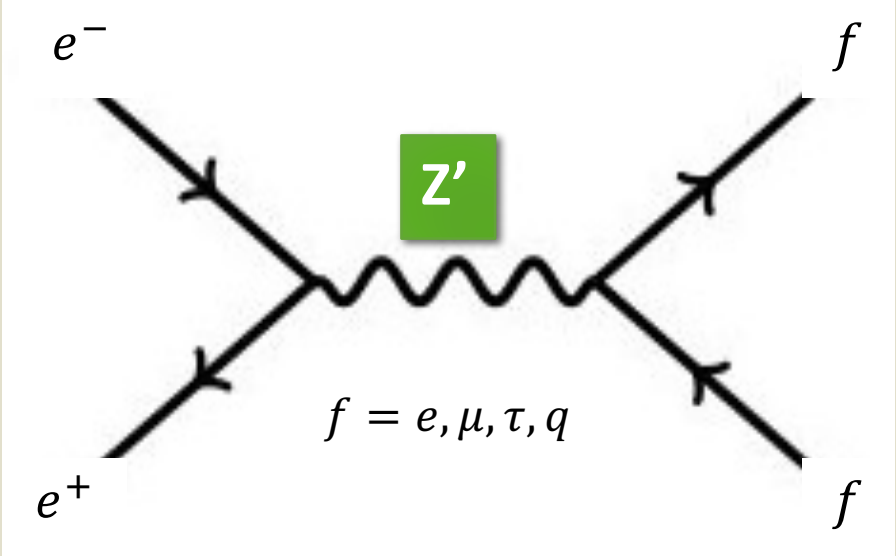
Purpose of 2-fermion process study

- 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 interactions or a new heavy gauge boson.

Z’ models

We consider 3 Z’ models in this analysis.

- SSM (Sequential Standard Model)

  A coupling constant between Z’ and fermion is same as Z and fermion’s one in Standard Model.

- E_6 group

  Focus on two extra *U(1)* which is occurred in decomposition of the E_6

  $$E_6 \rightarrow SO(10)\times U(1)_\psi \text{ and } SO(10) \rightarrow SU(5)\times U(1)_\chi$$

  Then, the composition of Z’ is $Z' = Z_\chi \cos\beta + Z_\psi \sin\beta$

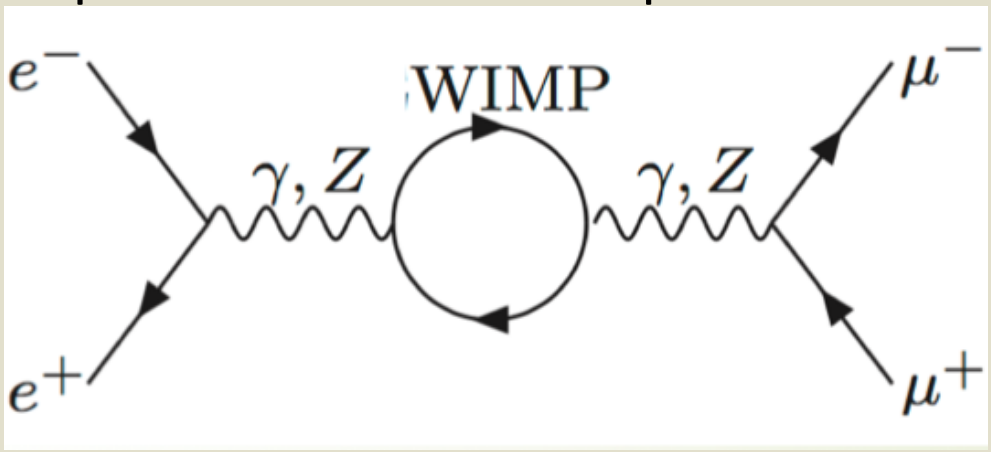
  ($\beta = 0$ … χ model , $\beta = \pi/2$ … ψ model , $\beta = \pi - \arctan\sqrt{3/5}$ … η model)

- ALR (Alternative Left-Right symmetry) **arXiv:0801.1345**

  Add $SU(2)_R$ to Standard Model

Electroweak WIMP search

- Precise measurements of electroweak processes can also search a EWIMP.
- The EWIMP is predicted to make loop interaction.



arXiv:1504.03402

WIMP model	$SU(2)_L$	$U(1)_Y$ hypercharge
MDM	$n = 3$, triplet	0
higgsino	$n = 2$, doublet	$\pm 1/2$
wino	$n = 5$, pentet	0

Simulation condition

- DBD ILD detector geometry : ILD_v1_05
- ILCSoft version : v01-16-p10
- H20-staging scenario with $\sqrt{s} = 250\ \mathrm{GeV}$

Total luminosity	e_L^-, e_R^+	e_R^-, e_L^+
2000 fb^{-1}	900 fb^{-1}	900 fb^{-1}

Polarization : (-0.8 , +0.3)

Analysis channel

channel	signal	background
$e^-e^+ \to e^-e^+$	2f-electron event	2f-muon, tau event 4f-leptonic event
$e^-e^+ \to \mu^-\mu^+$	2f-muon event	2f-tau event Bhabha 4f-leptonic event
$e^-e^+ \to \tau^-\tau^+$	2f-tau event	2f-muon event Bhabha 4f-leptonic event

Event selection

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

Cut terms

- Cut 1 : Both of the selected track has > 15 GeV energy
- Cut 2 : $E_{cal} / E_{track} < 0.3$

→High energy muons penetrate detectors, which give smaller energy deposit with respect to the track momentum

- Cut 3 : $E_{ECAL} /(E_{ECAL} + E_{HCAL}) < 0.45$

→Electrons deposit most of energy at ECAL , so it can distinguish muon events from electron events

Event selection

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

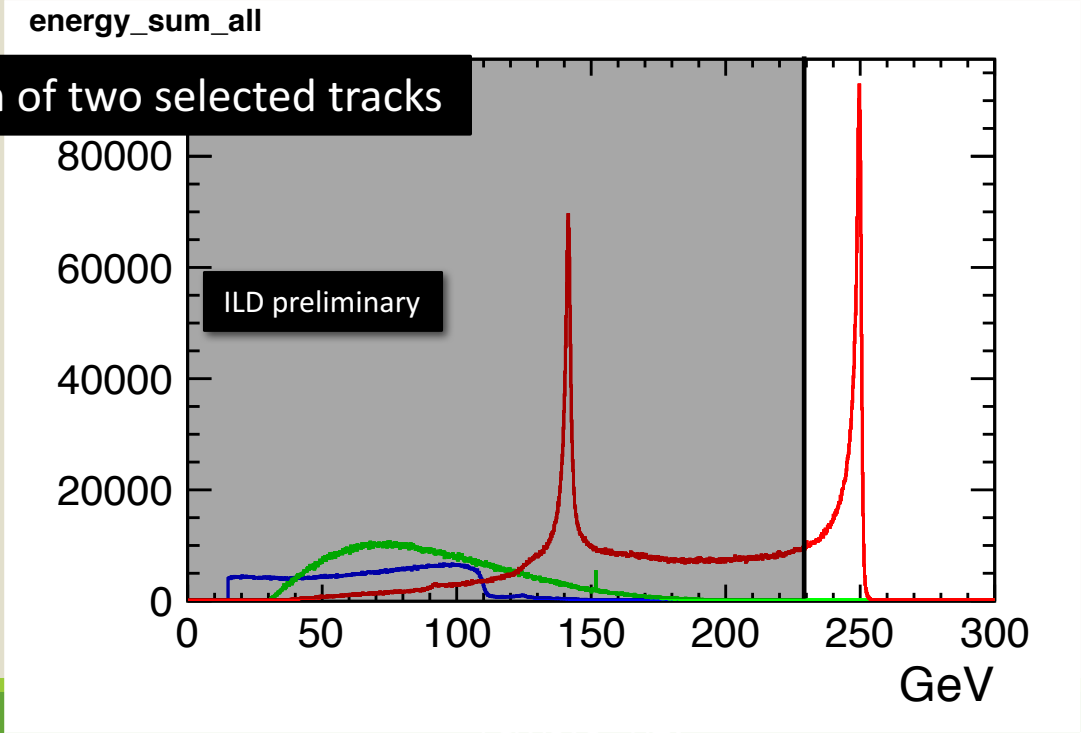
- Cut 4 : Energy sum of two selected tracks > 230 GeV

  → Cutting most of 4-fermion/tau events

  → The peak at 130 GeV is not sensitive of new physics

- Cut 5 : $|\cos\theta| < 0.95$ → Cutting the bhabha events

Cut 4 , Energy sum of two selected tracks



Cut Table (muon channel)

	signal(μ^+, μ^-)	e^+, e^-	τ^+, τ^-	4-fermion
all events	9729276	826420806	11715161	7727579
E_{tr} > 15 GeV	9358109	817956421	11715084	6390250
E_{cal}/E_{tr} < 0.3	9260263	1491299	896920	3348735
$E_{ecal}/(E_{eca}l+E_{hcal})$<0.45	2914017	1491187	780722	1329145
E_{sum} > 230 GeV	748977	56	4522	32
$\lvert \cos\theta \rvert$ < 0.95	747716	56	4477	32

Finally, this cut term is

E > 15 GeV & E_{cal}/E_{tr} < 0.3 & $E_{ecal}/(E_{eca}l+E_{hcal})$<0.45 & E_{sum} > 230 GeV & $\lvert \cos\theta \rvert$ < 0.95 & charge= -1,1

We can cut the most of background events by 5 cut terms.

Cut Table (electron channel)

	signal(e^+, e^-)	μ^+, μ^-	τ^+, τ^-	4-fermion
all events	826420806	9729276	11715161	7727579
E_{tr} > 15 GeV	817956421	9358109	11715084	6390250
E_{cal}/E_{tr} > 0.8	817741169	29091	11714881	2595257
$E_{ecal}/(E_{eca}l+E_{hcal})$>0.85	817468884	12182	11714841	1661159
E_{sum} > 230 GeV	368324206	14	21	11448
$\mid \cos\theta \mid$ < 0.95	25705598	14	21	11448

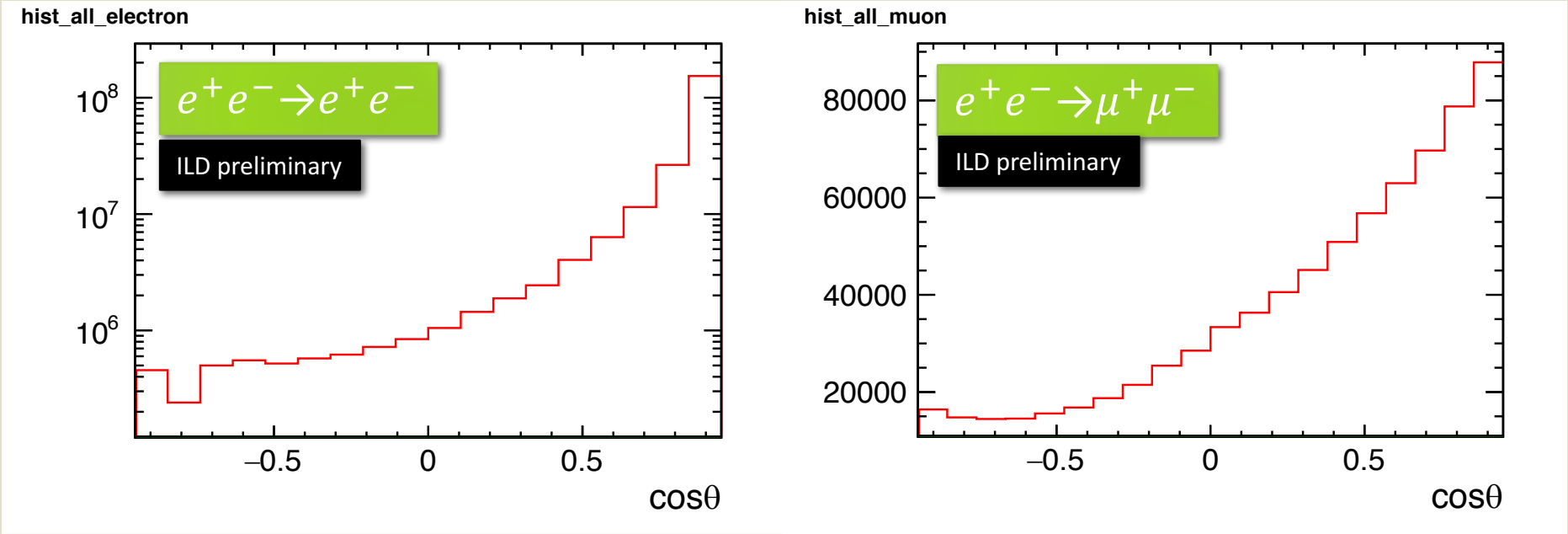
Finally, this cut term is

E > 15 GeV & E_{cal}/E_{tr} > 0.8 & $E_{ecal}/(E_{eca}l+E_{hcal})$>0.85 & E_{sum} > 230 GeV & $\mid \cos\theta \mid$ < 0.95 & charge= -1,1

We can also cut the most of background events by 5 cut terms.

Angular distribution

These figures are the angular distribution of each channel after event selections.



angle distribution with 20 bins

Toy Monte Carlo

Procedure

Make a pseudo experiment using SM angular distribution.

↓

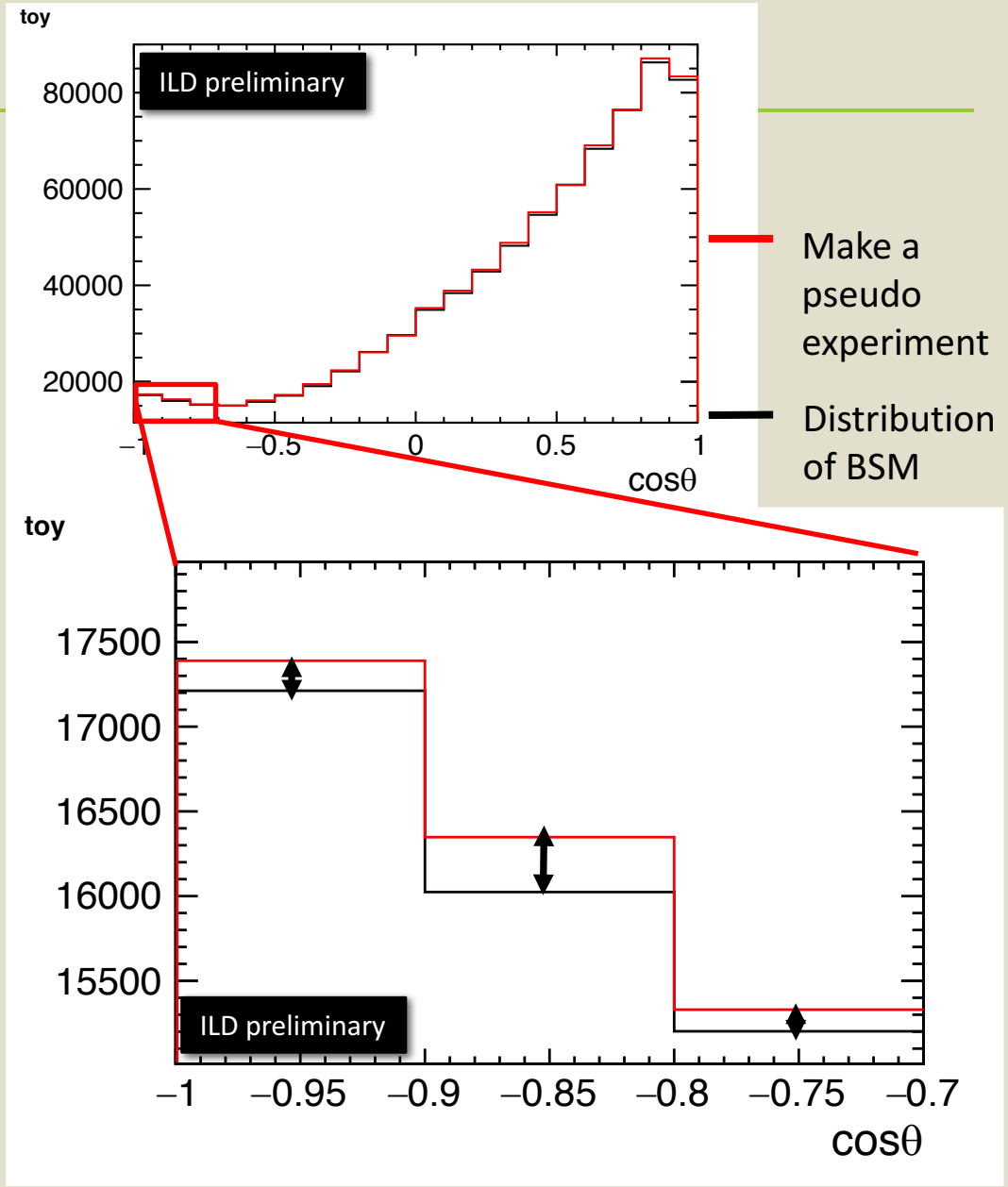
Calculate χ^2 to each BSM. (0.1% systematics assumed for each bin)

↓

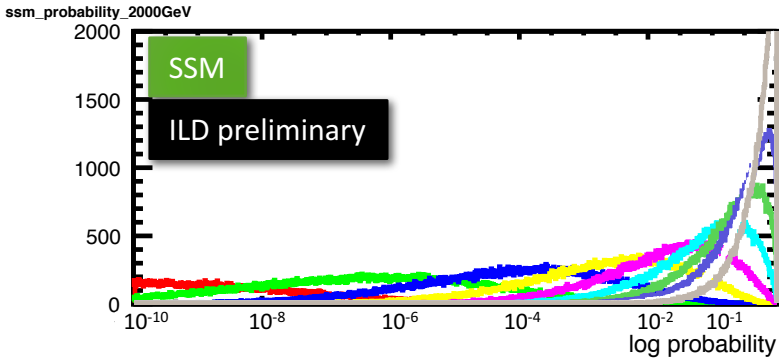
repeat 100,000 times

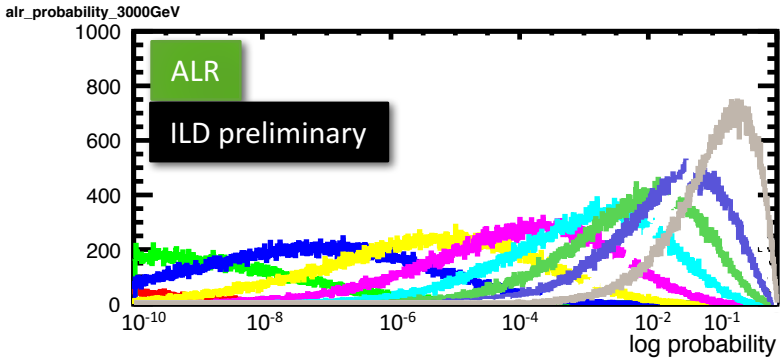
↓

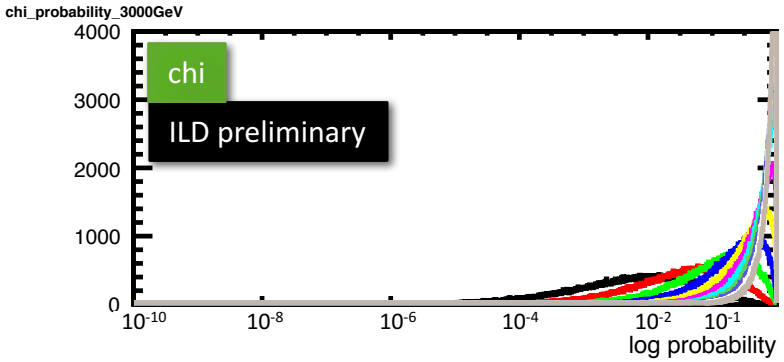
Obtain median of χ^2 distribution and calculate probability

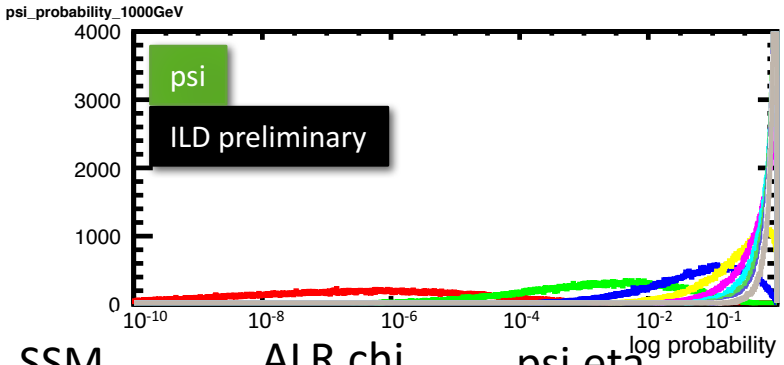


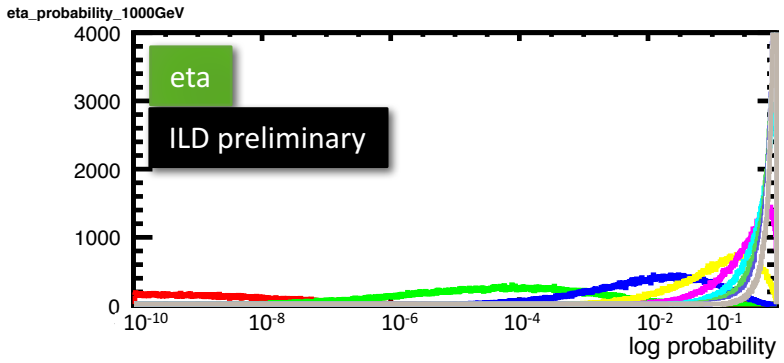
Probability distribution with Toy MC (only e channel)

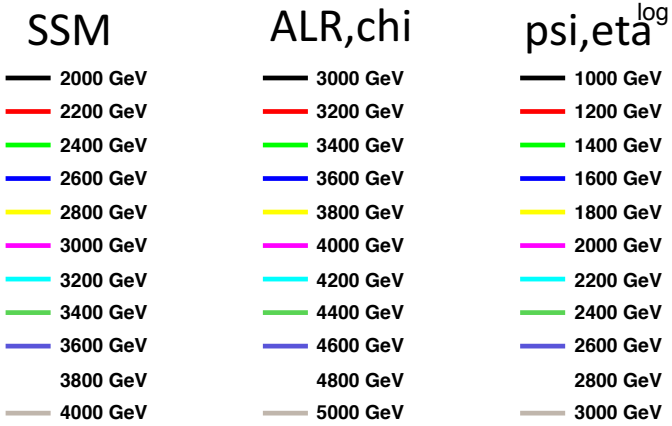




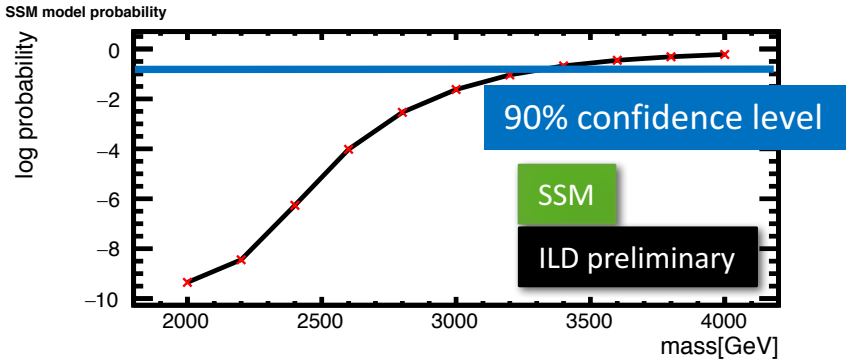


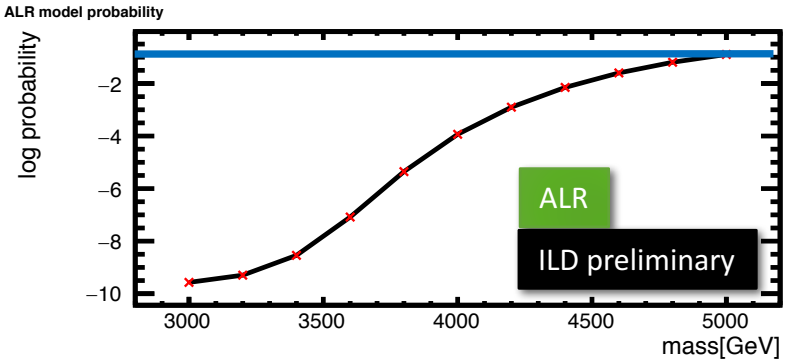


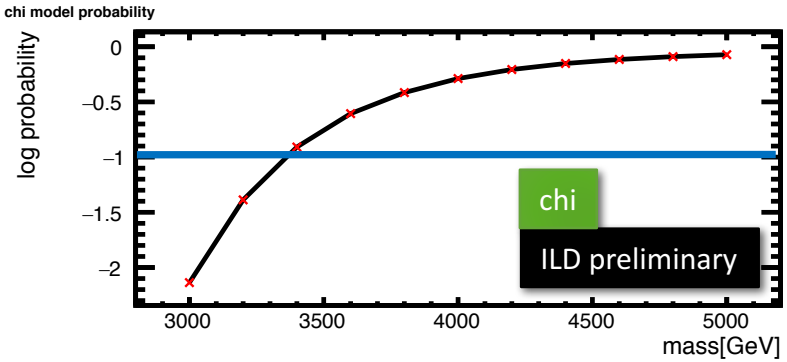


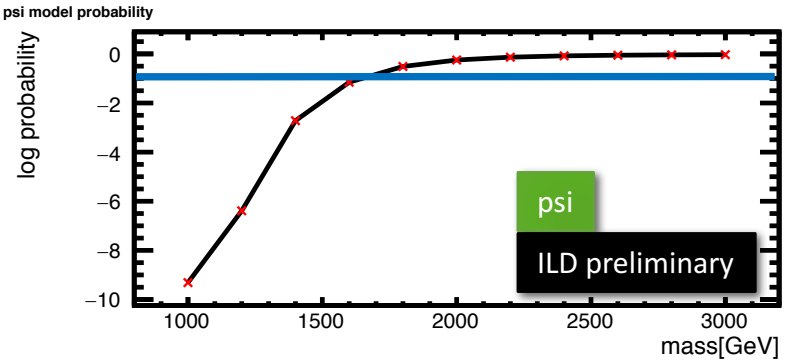


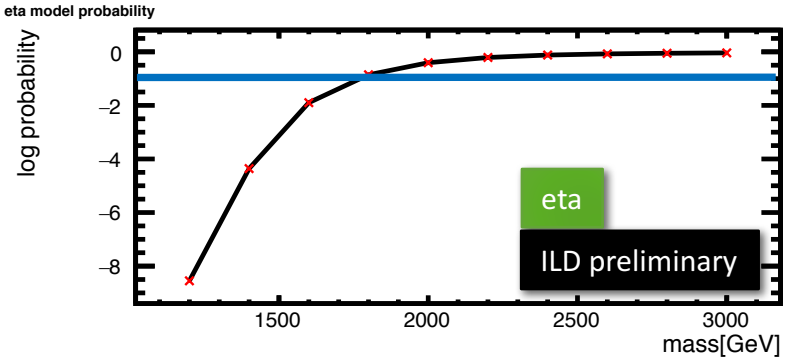
Mass dependence of probability in Z' models (only e)





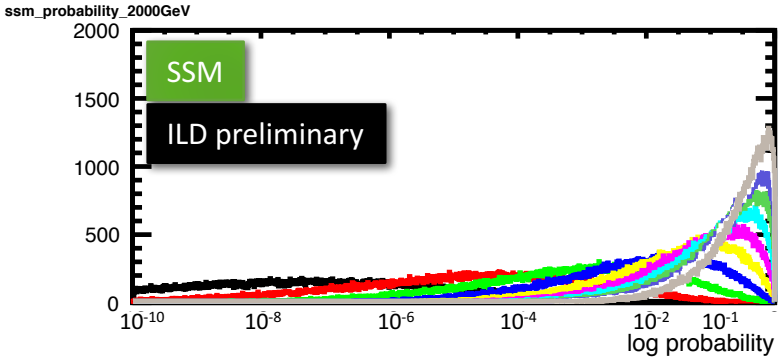


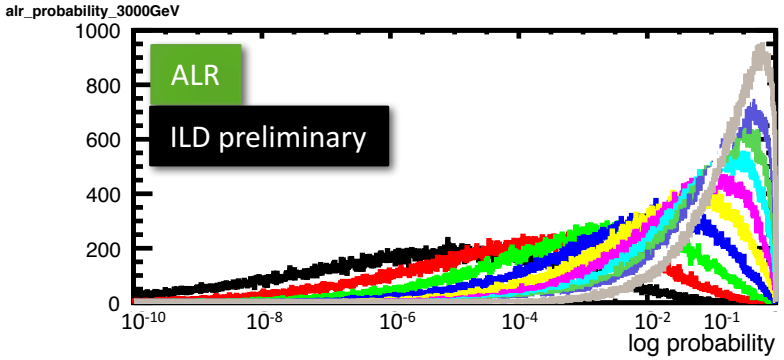


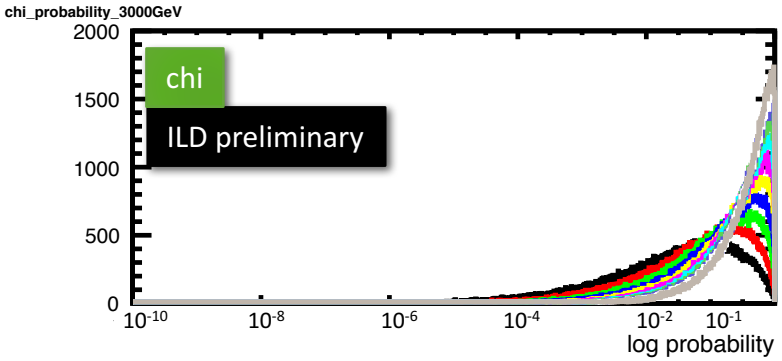


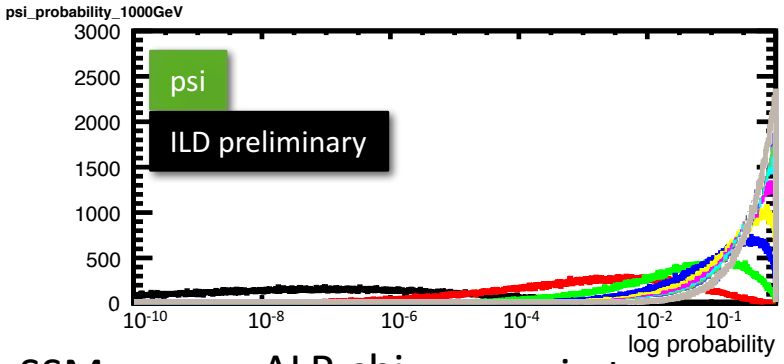
BSM model	mass reach (90% confidence level)
SSM	3.2 TeV
ALR	4.9 TeV
χ	3.4 TeV
ψ	1.6 TeV
η	1.7 TeV

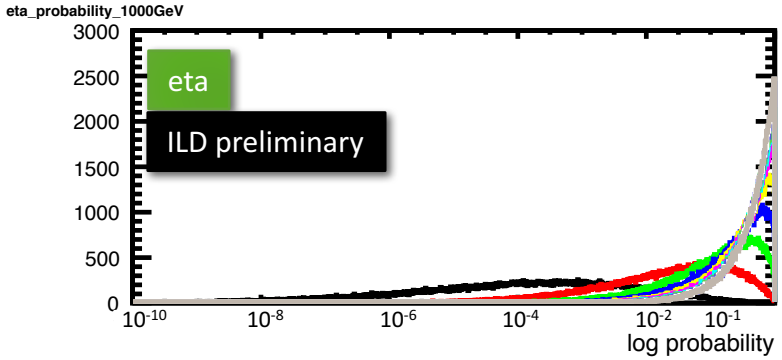
Probability distribution with Toy MC (only μ channel)

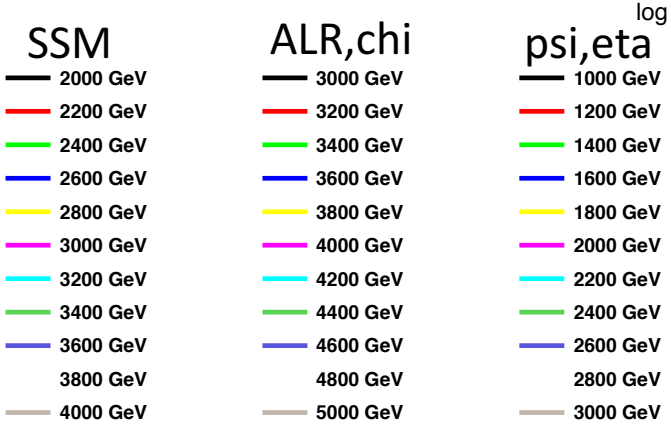




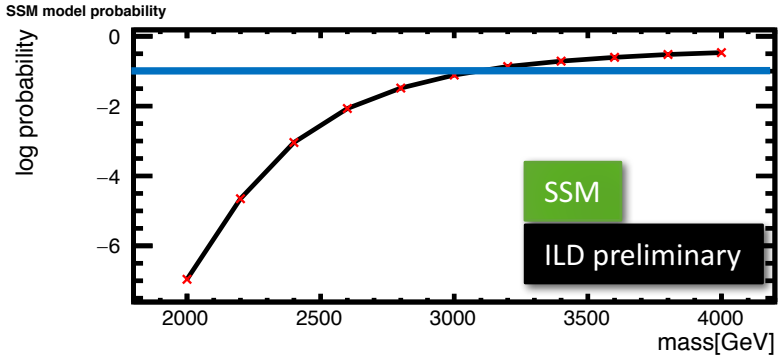


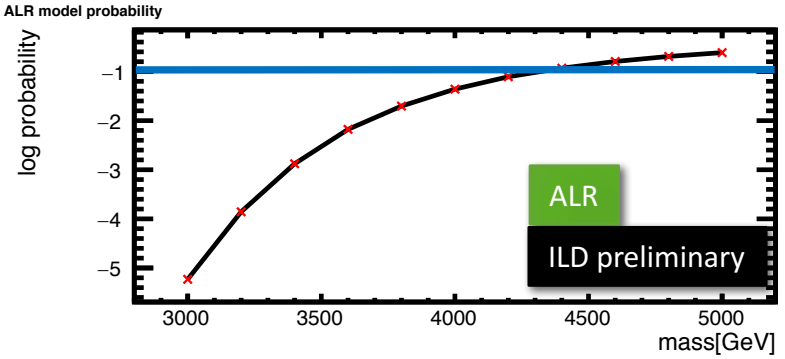


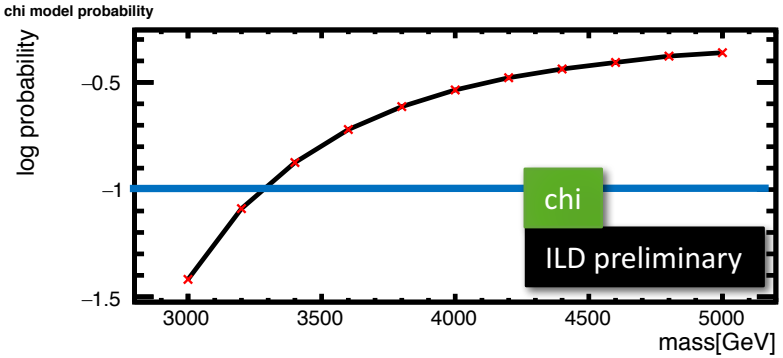


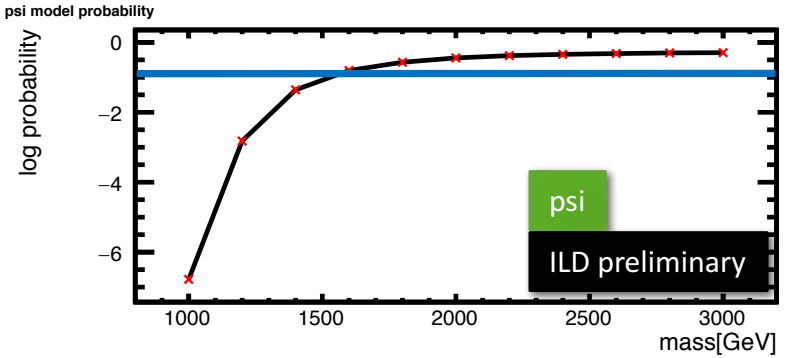


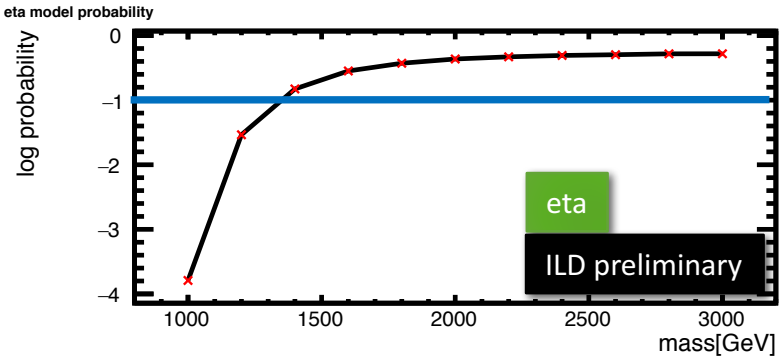
Mass dependence of probability in Z' models (only μ)





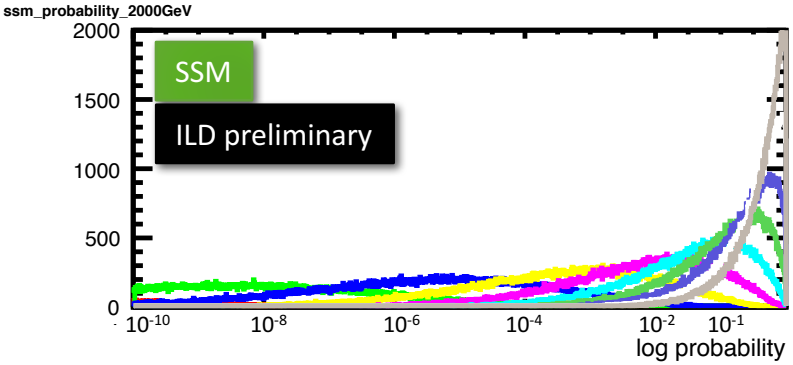


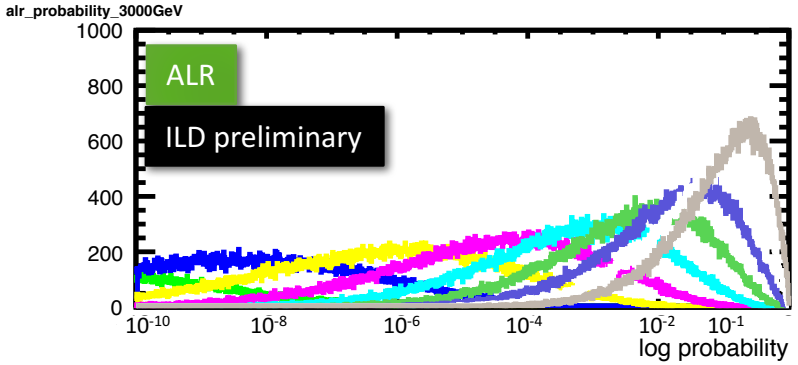


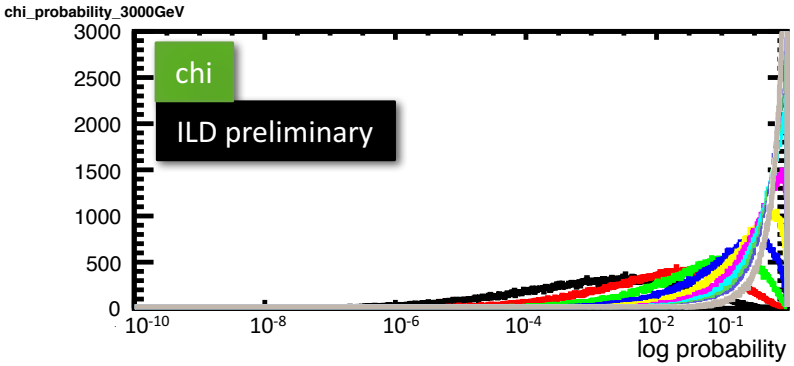


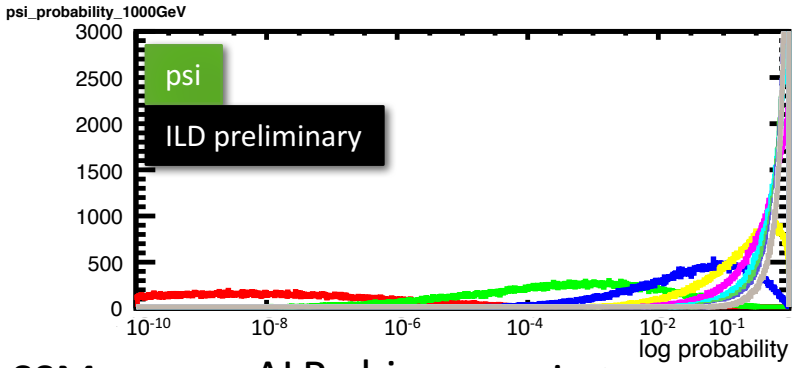
BSM model	mass reach (90% confidence level)
SSM	3.0 TeV
ALR	4.4 TeV
χ	3.3 TeV
ψ	1.5 TeV
η	1.3 TeV

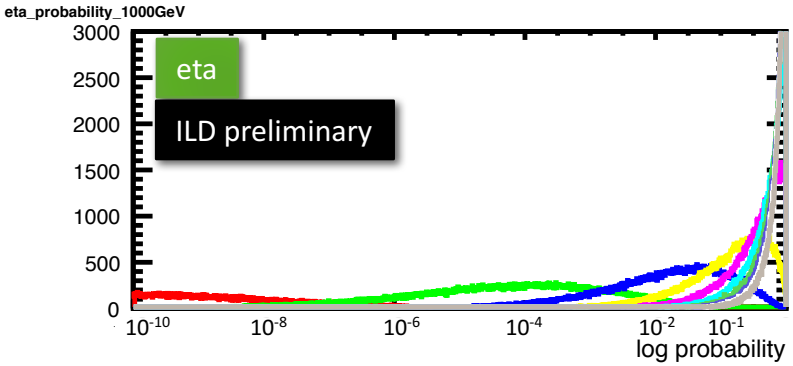
Probability distribution with Toy MC (with e, μ)

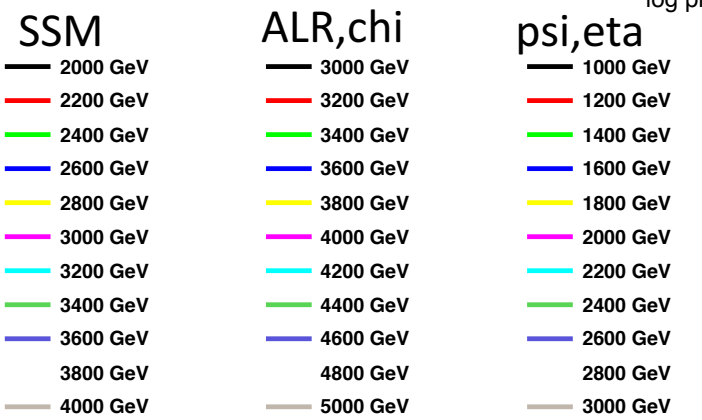




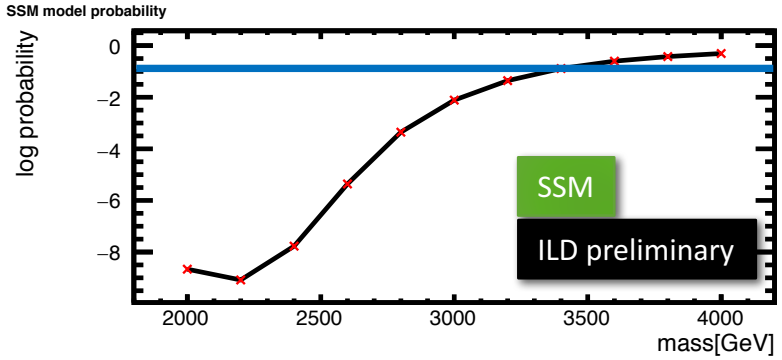


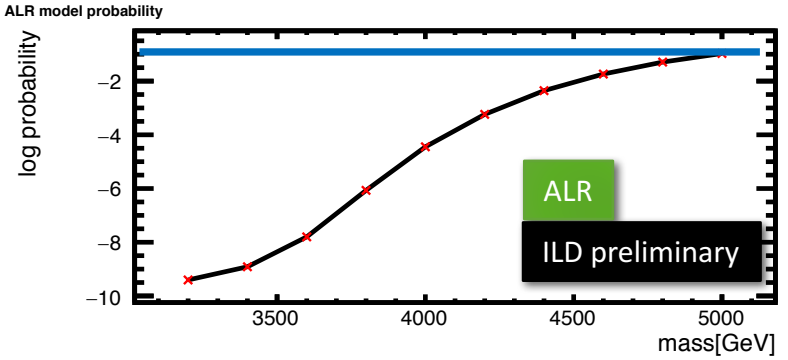


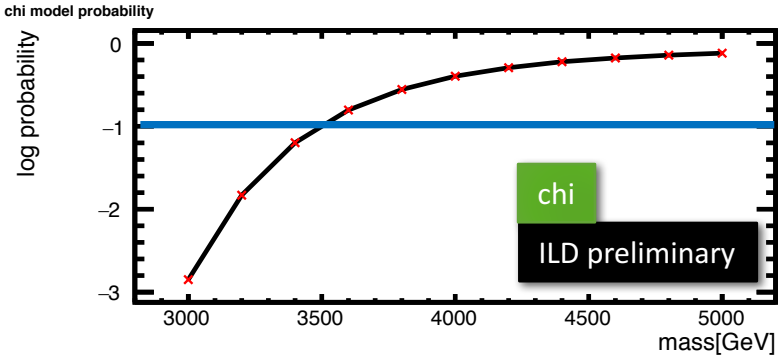


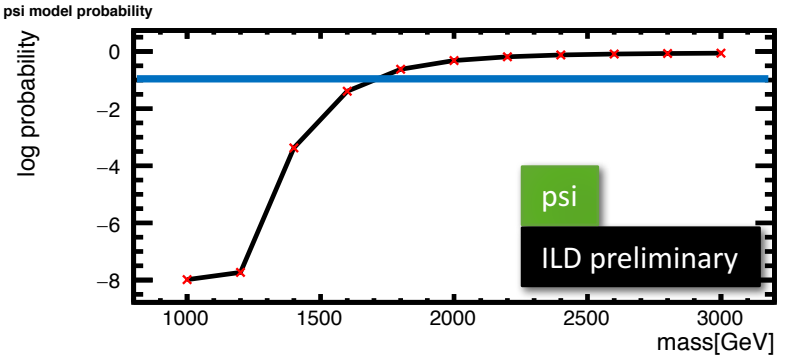


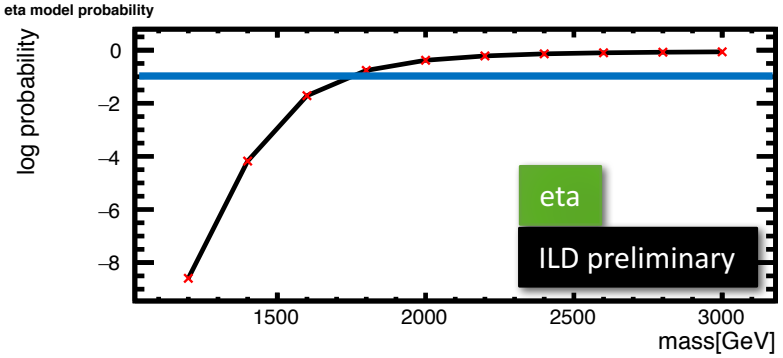
Mass dependence of probability in Z' models (e, μ)







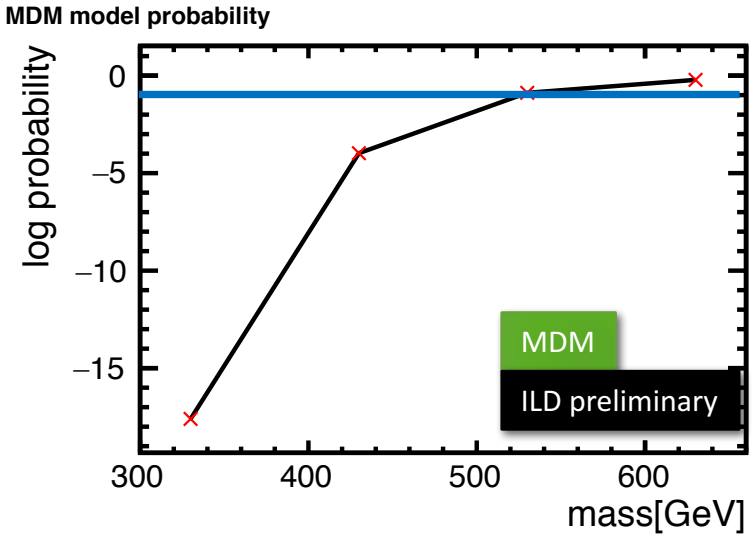


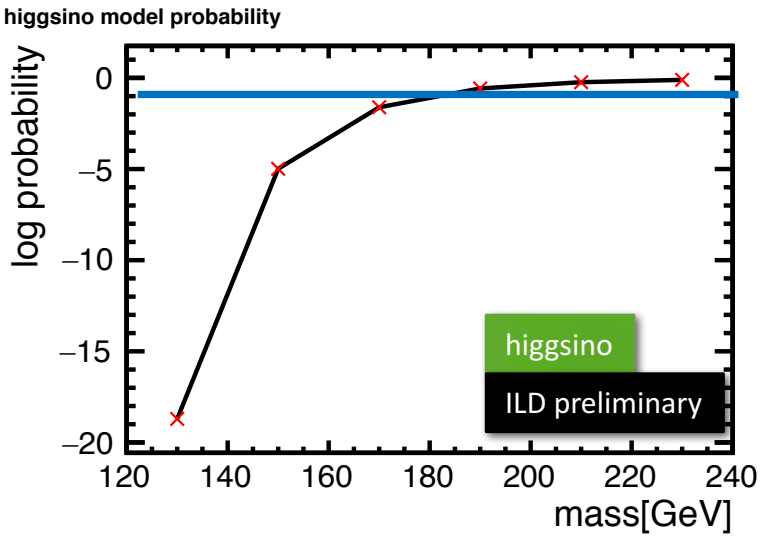


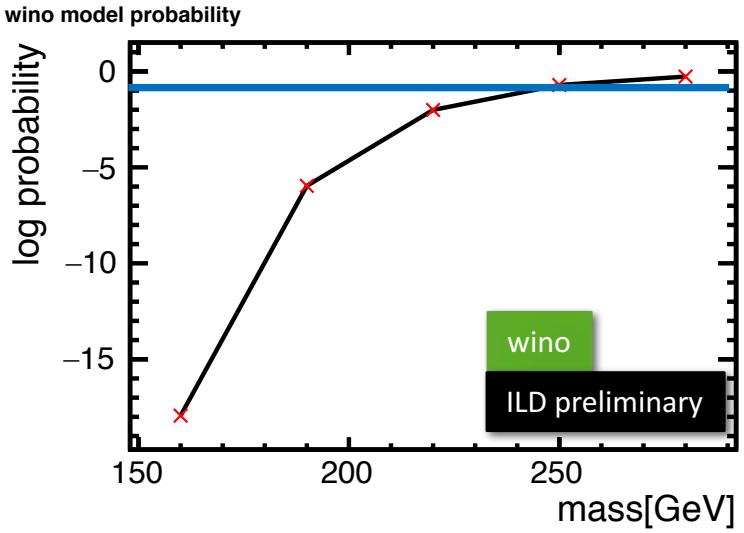
BSM model	mass reach (90% confidence level)
SSM	3.4 TeV
ALR	5.0 TeV
χ	3.5 TeV
ψ	1.7 TeV
η	1.7 TeV

Mass dependence of probability in EWIMP models (only e)

e_L^- , e_R^+



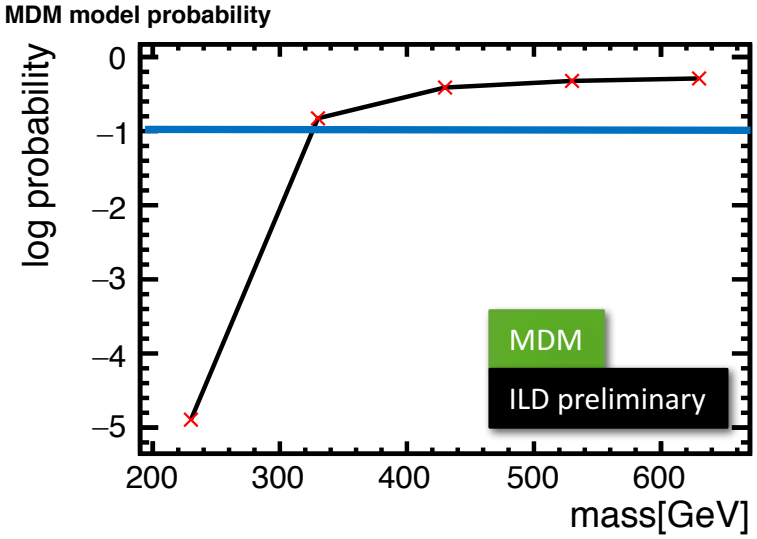


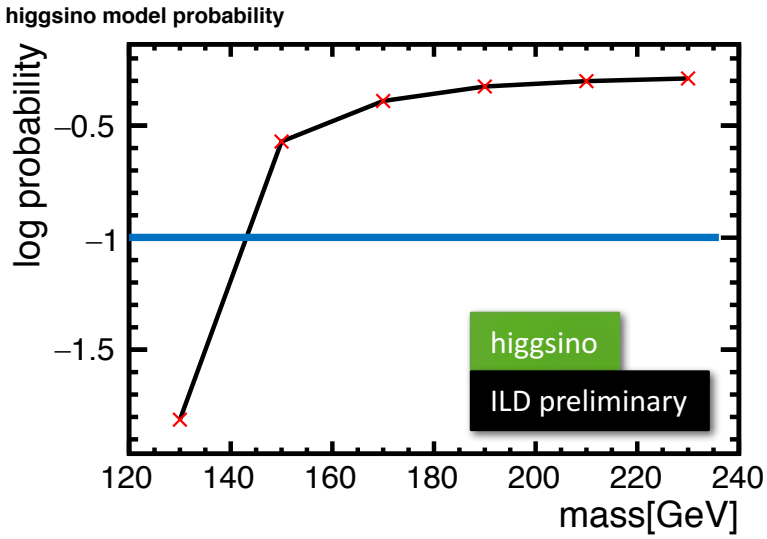


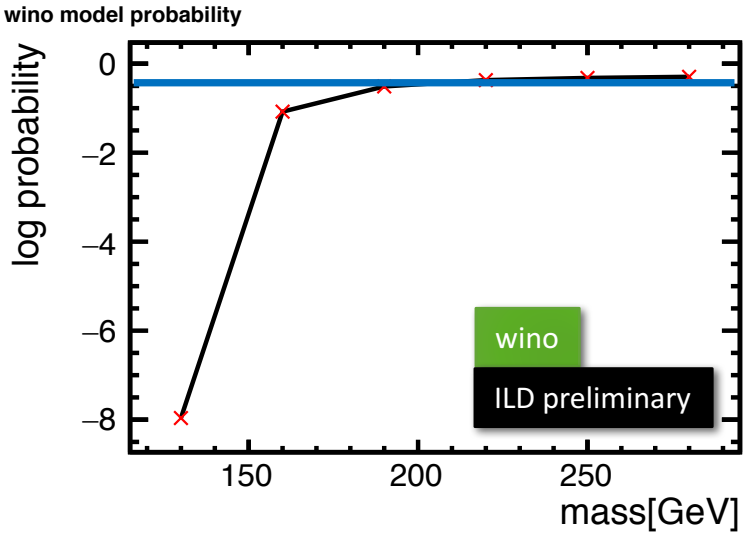
BSM model	mass reach (90% confidence level)
MDM	520 GeV
higgsino	180 GeV
wino	250 GeV

Mass dependence of probability in EWIMP models (only μ)

e_L^-, e_R^+



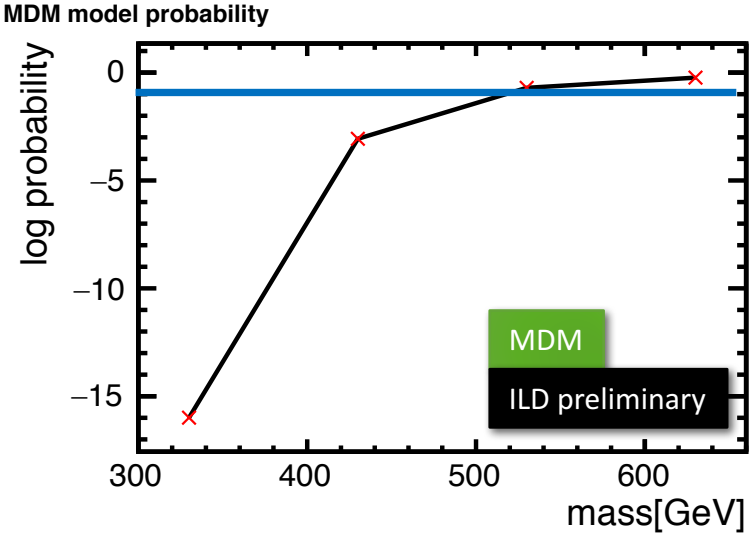


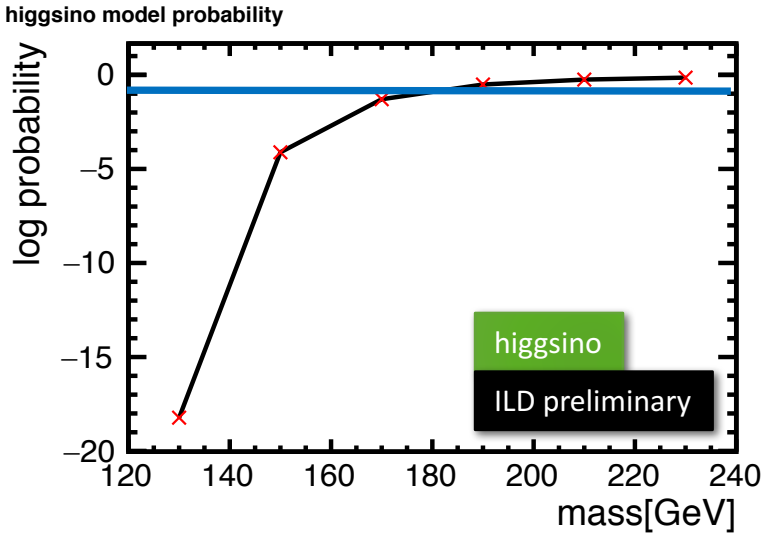


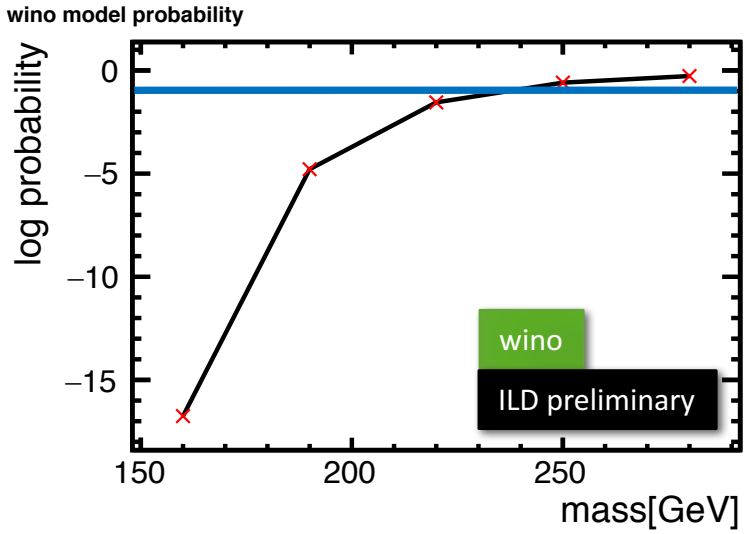
BSM model	mass reach (90% confidence level)
MDM	320 GeV
higgsino	145 GeV
wino	170 GeV

Mass dependence of probability in EWIMP models (with e, μ)

e_L^- , e_R^+







BSM model	mass reach (90% confidence level)
MDM	520 GeV
higgsino	180 GeV
wino	240 GeV

Summary

- We get a 90% confidence level for each BSM model

BSM model	mass reach (90% confidence level)
SSM	3.4 TeV
ALR	5.0 TeV
χ	3.5 TeV
ψ	1.7 TeV
η	1.7 TeV

BSM model	mass reach (90% confidence level)
MDM	500 GeV
higgsino	180 GeV
wino	240 GeV

To Do

- Find a mass reach including tau channel
- Include GHU model and other BSM
- Consider systematic effect in more detail

back up

Comparison with previous results

Our results (With e, μ)		Previous results (With e, μ, τ)	
BSM model	**mass reach (3 sigma)**	**BSM model**	**mass reach (3 sigma)**
SSM	3.1 TeV	SSM	2.8 TeV
ALR	4.8 TeV	ALR	4.0 TeV
χ	3.3 TeV	χ	2.9 TeV
ψ	1.6 TeV	ψ	1.4 TeV
η	1.6 TeV	η	1.8 TeV

- In the most of BSM models, mass reach(3 sigma) is bigger than previous one.
- This results is including electron and muon channels.

Comparison with previous results

Our results (With e, μ)		Previous results (With e, μ, τ)	
BSM model	**mass reach (3 sigma)**	**BSM model**	**mass reach (3 sigma)**
MDM	460 GeV	MDM	330 GeV
higgsino	165 GeV	higgsino	150 GeV
wino	220 GeV	wino	150 GeV

- The results of WIMP model are similar to previous one.
- But these are including electron and muon channels, so the mass reach will extend (will be better than previous results)