Prospects for observing charginos and neutralinos at 100 TeV

Kazuki Sakurai

(King's College London)

In collaboration with:
Bobby S. Acharya, Krzysztof Bożek, Chakrit Pongkitivanichkul

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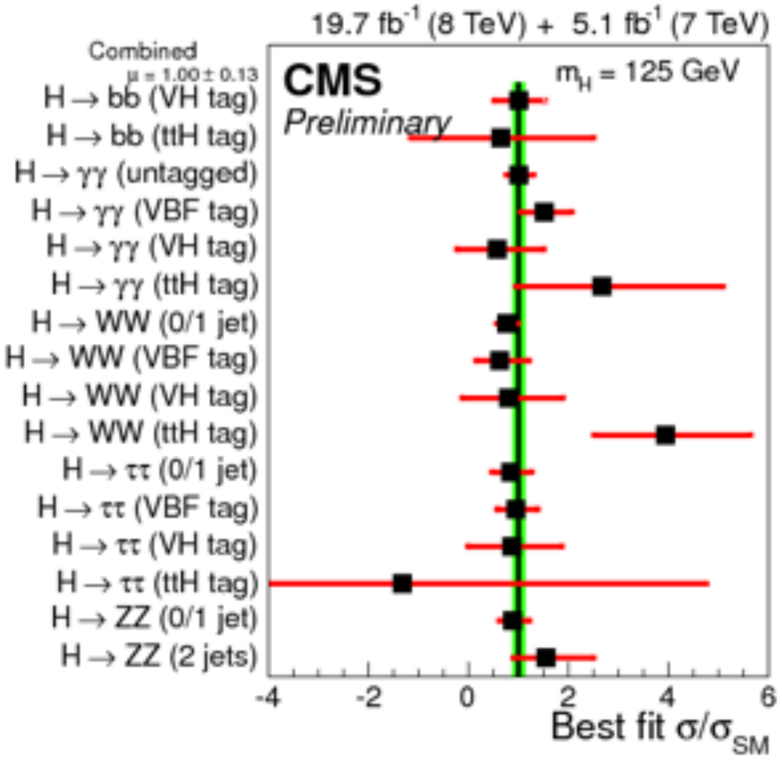
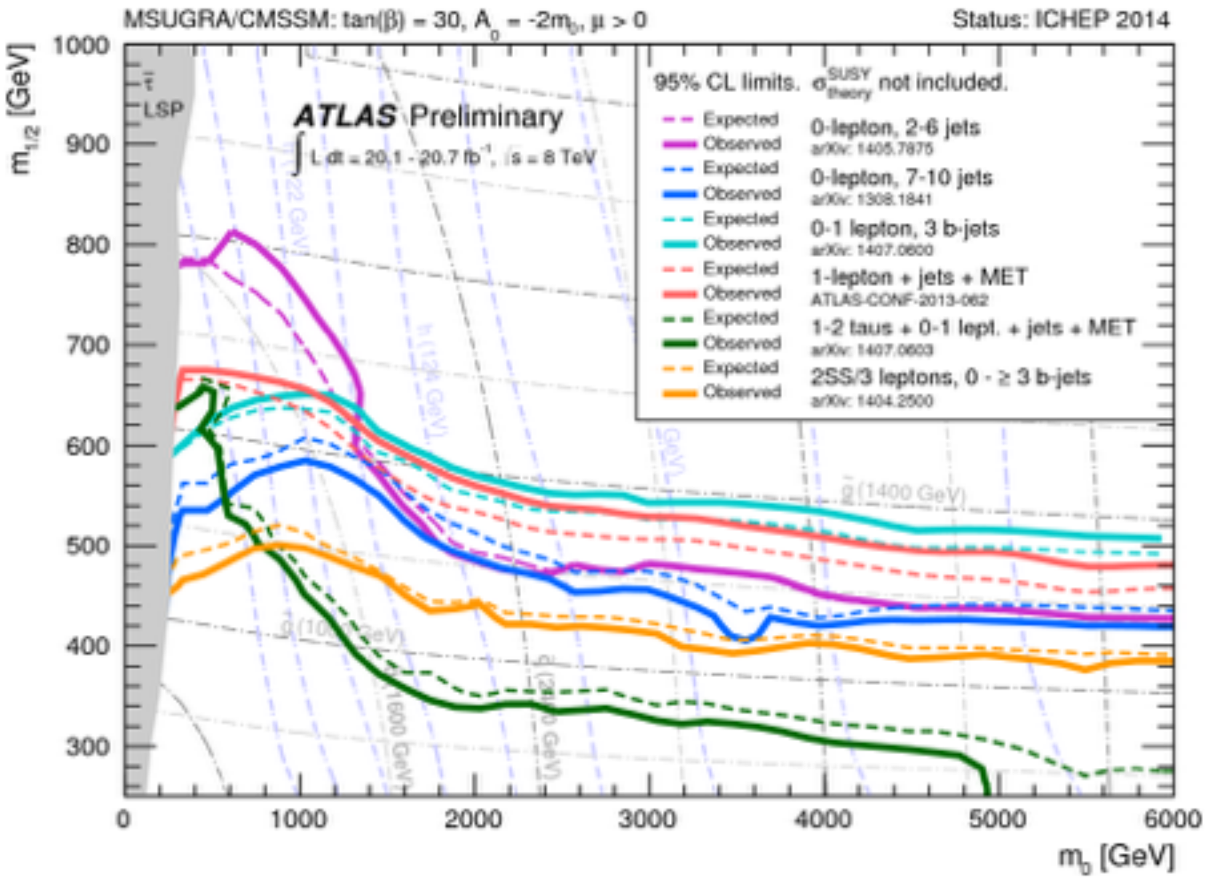
What we learned from LHC run1?

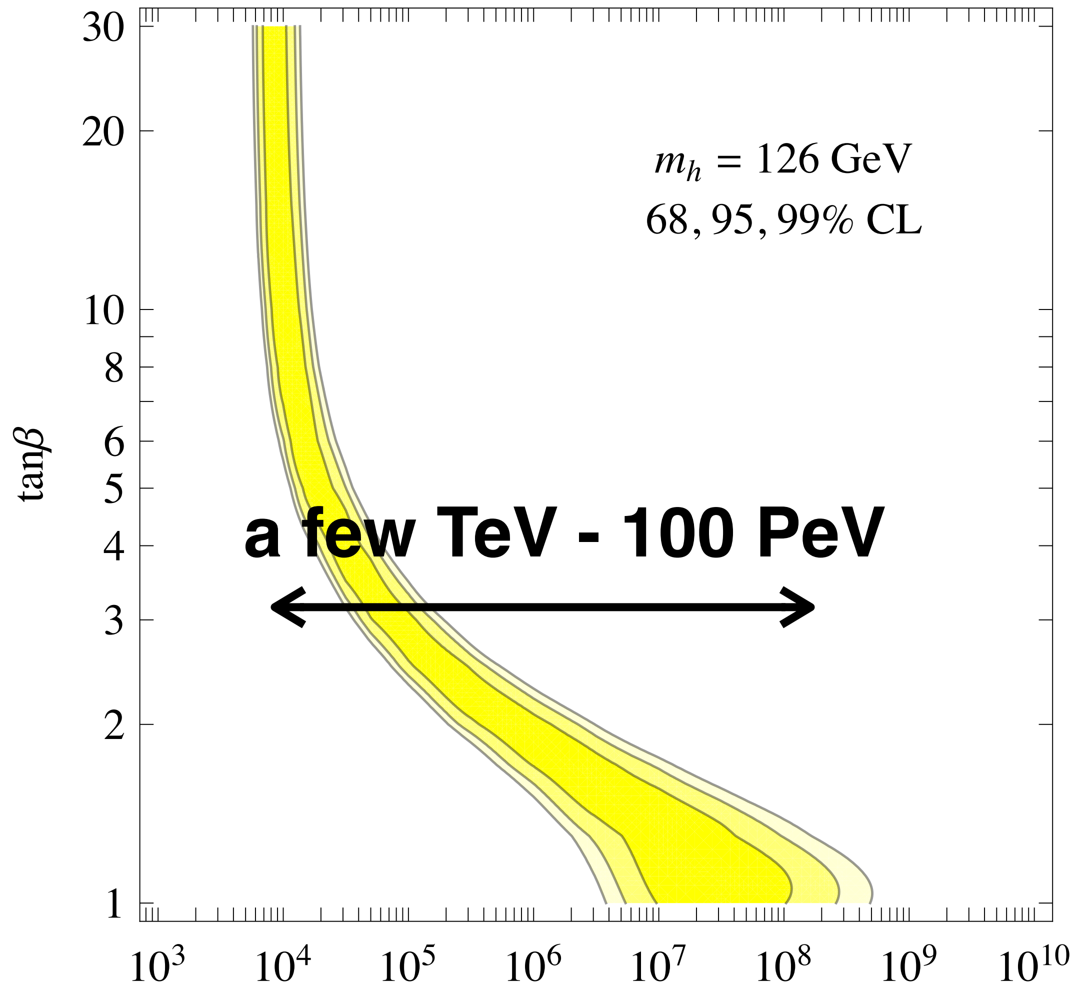
- The Higgs-like particle with mass 125GeV has been discovered.
- The property of the particle is consistent with the SM-Higgs.
- A number of SUSY searches, but no definitive excess has been observed.





Heavy Scalars?

[Giudice, Strumia '11]



scalar mass [GeV]

- The 126 GeV Higgs indicates heavy scalars with masses around a few TeV - 100 PeV.
- Consistent with null results in measurements of FCNIs and EDMs.

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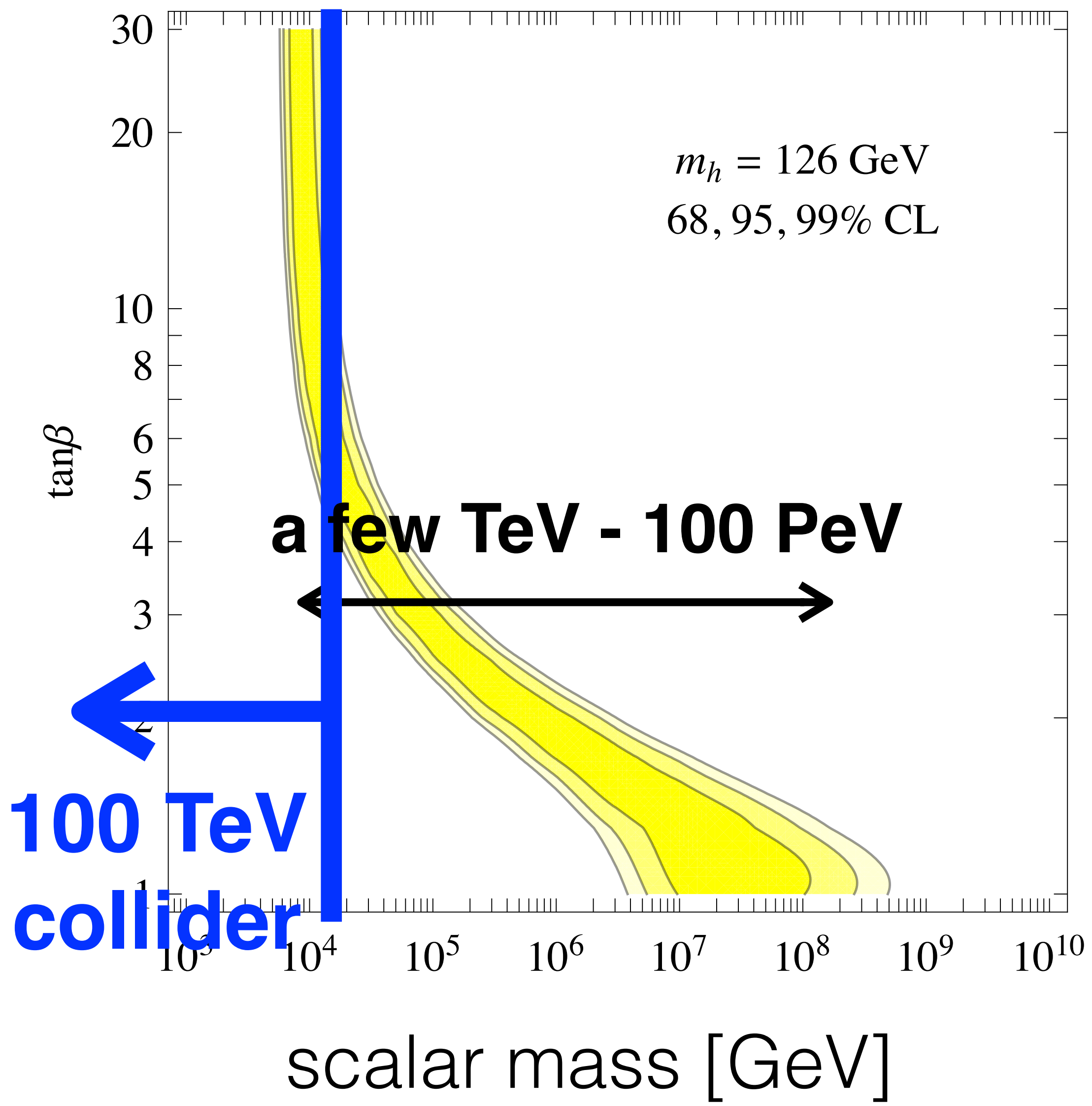
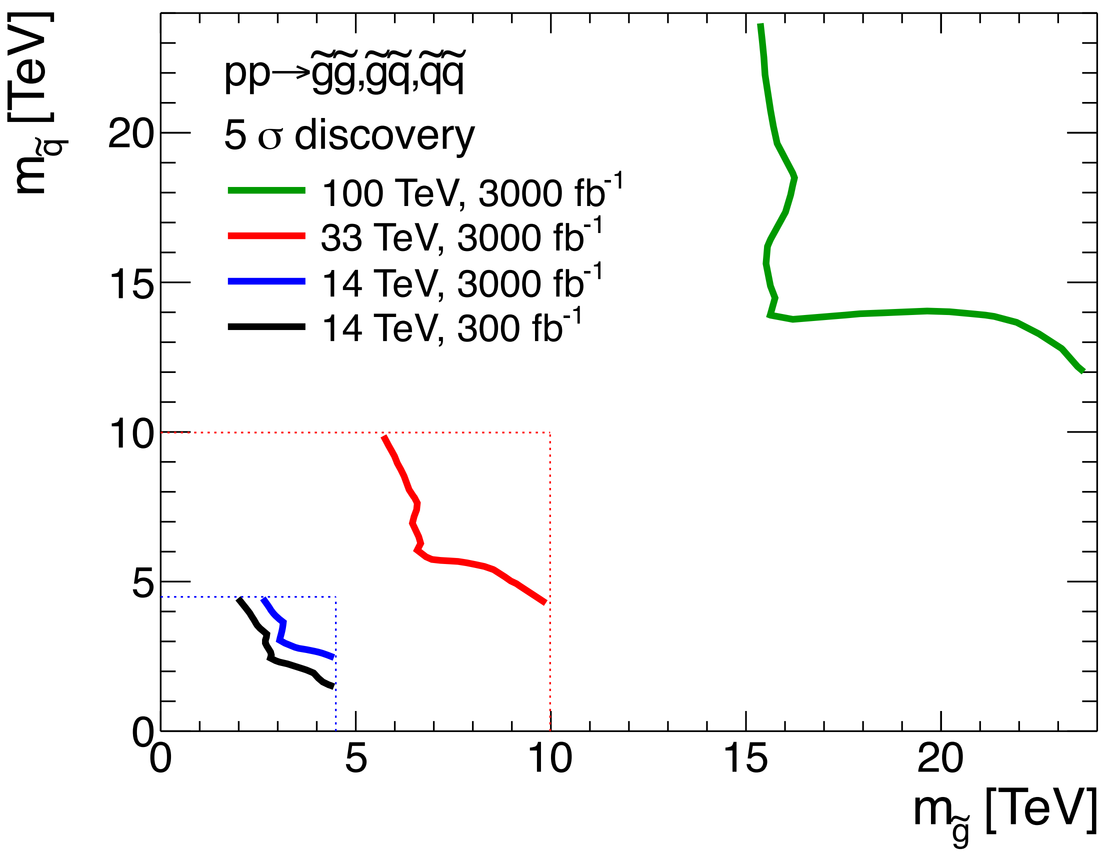


- The 126 GeV Higgs indicates heavy scalars with masses around a few TeV - 100 PeV.
- Consistent with null results in measurements of FCNIs and EDMs.
- 100 TeV colliders have sensitivity to the scalars with masses below 15 TeV.

[Cohen et al. '13]

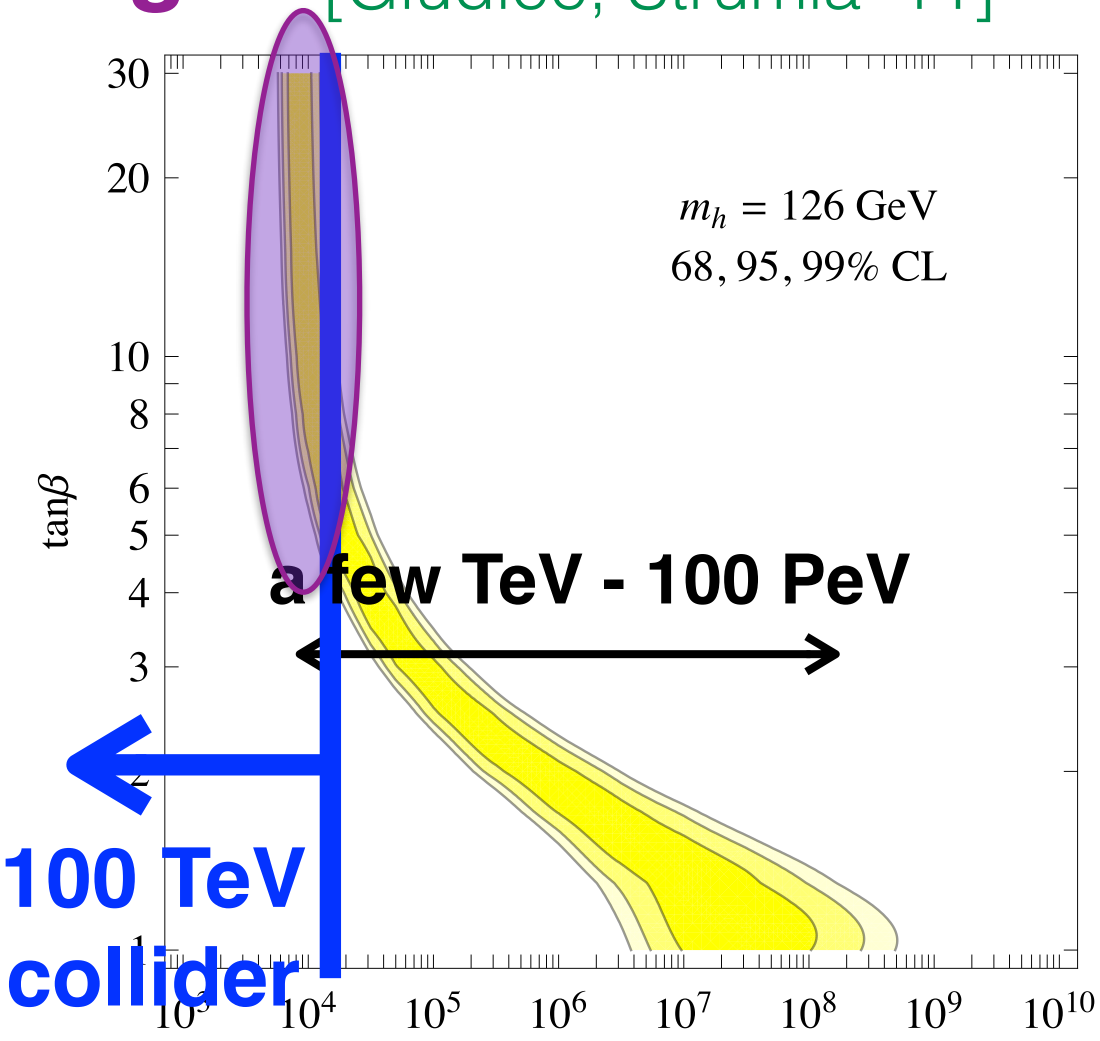


Heavy Scalars?

[Badziak et al. '14]

g-2

[Giudice, Strumia '11]



a few TeV - 100 PeV

100 TeV collider

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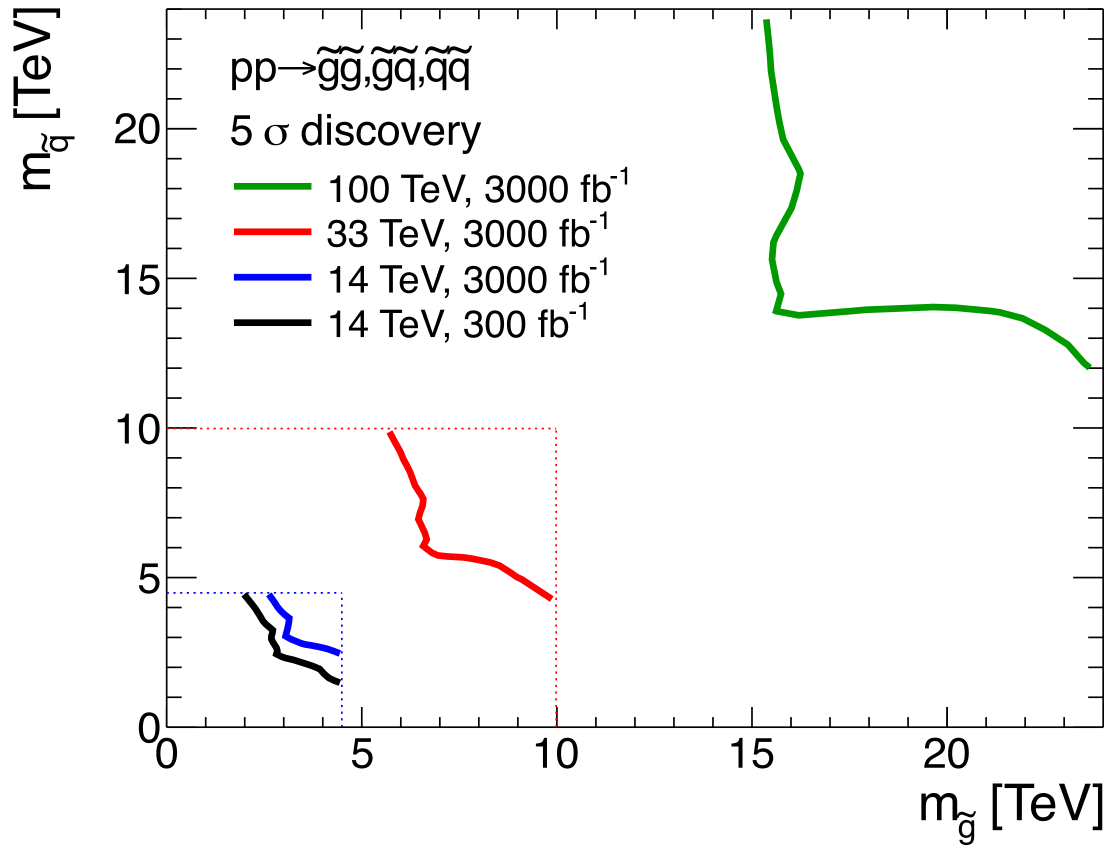

Light gauginos and higgsinos?

- Light gauginos and higgsinos are consistent with 126 GeV Higgs.
- Light gauginos and higgsinos with heavy scalars can achieve *gauge coupling unification*.

[Arkani-Hamed, Dimopoulos '04]

- The gauginos and higgsinos masses are often suppressed. (forbidden by R-symmetry and U(1)$_{PQ}$)

$$m_\phi^2 |\phi|^2 \leftarrow \left. \frac{X^\dagger X}{\Lambda^2} \Phi^\dagger \Phi \right|_{\theta^4}$$

$$M_\lambda \lambda^\alpha \lambda_\alpha \leftarrow \left. \frac{X}{\Lambda^2} W^\alpha W_\alpha \right|_{\theta^2}$$

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If X is charged, the gaugino masses are loop suppressed.

$$M_\lambda \lambda^\alpha \lambda_\alpha \leftarrow \left. \cancel{\frac{X}{\Lambda^2}} W^\alpha W_\alpha \right|_{\theta^2}$$

$\Rightarrow$

$$M_1 = \frac{33}{5} \frac{\alpha_1}{4\pi} m_{3/2}$$

$$M_2 = \frac{\alpha_2}{4\pi} m_{3/2}$$

$$M_3 = -3 \frac{\alpha_3}{4\pi} m_{3/2}$$

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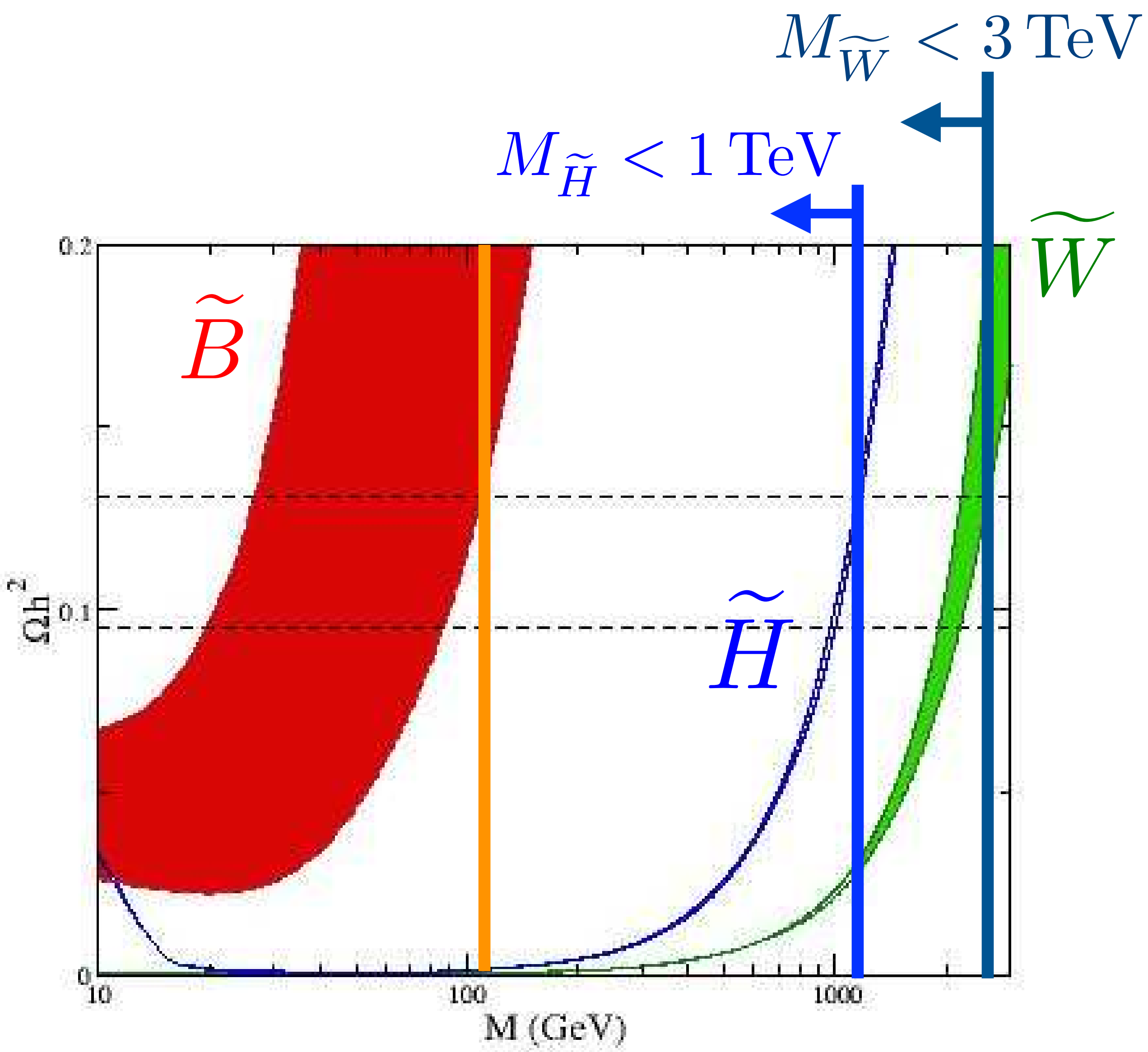
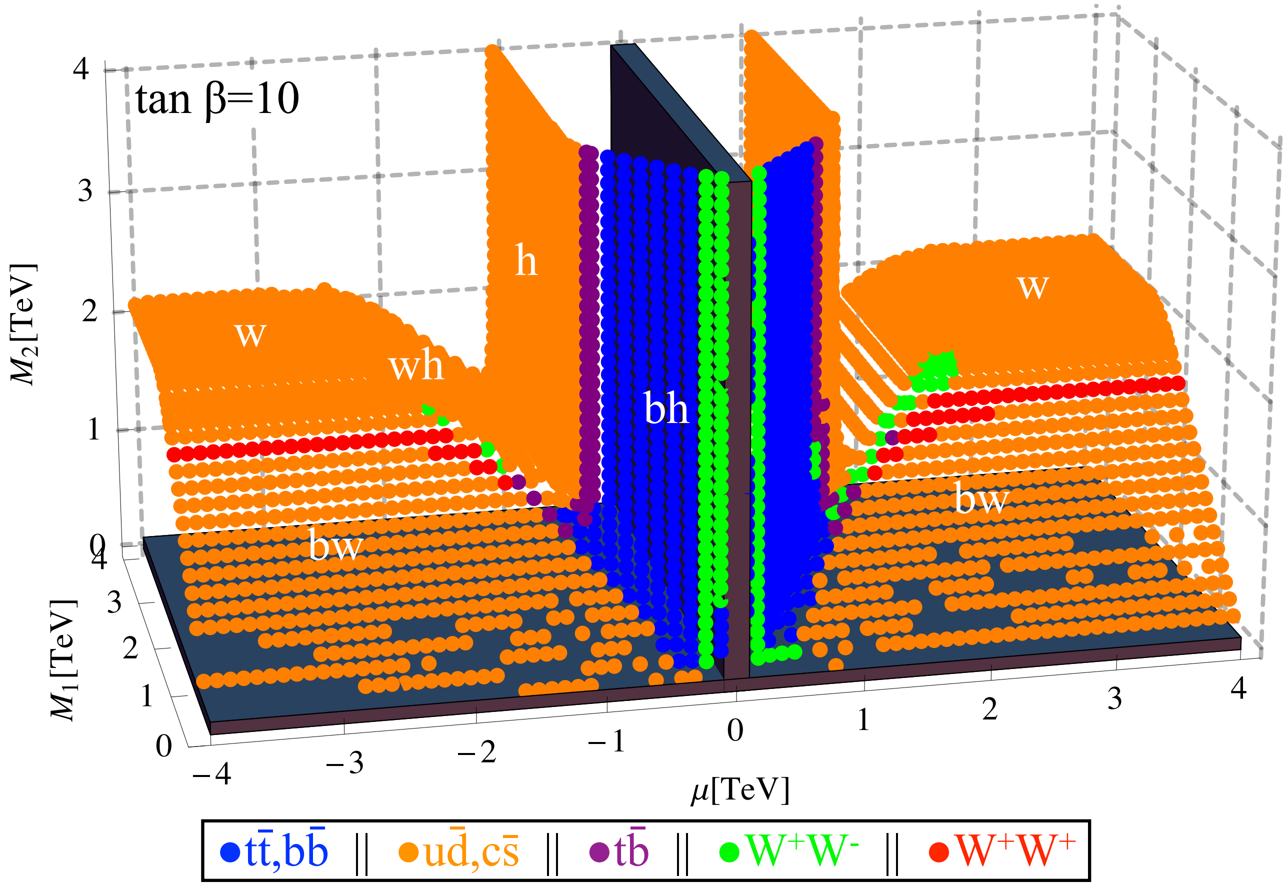
Wino becomes the lightest gaugino

Upper bound on the EWkino masses

- Heavy EWkinos tend to over produce the DM
- Assuming the MSSM and the standard thermal history of Universe, the LSP has to be lighter than 1-3 TeV. ➡ 100 TeV collider

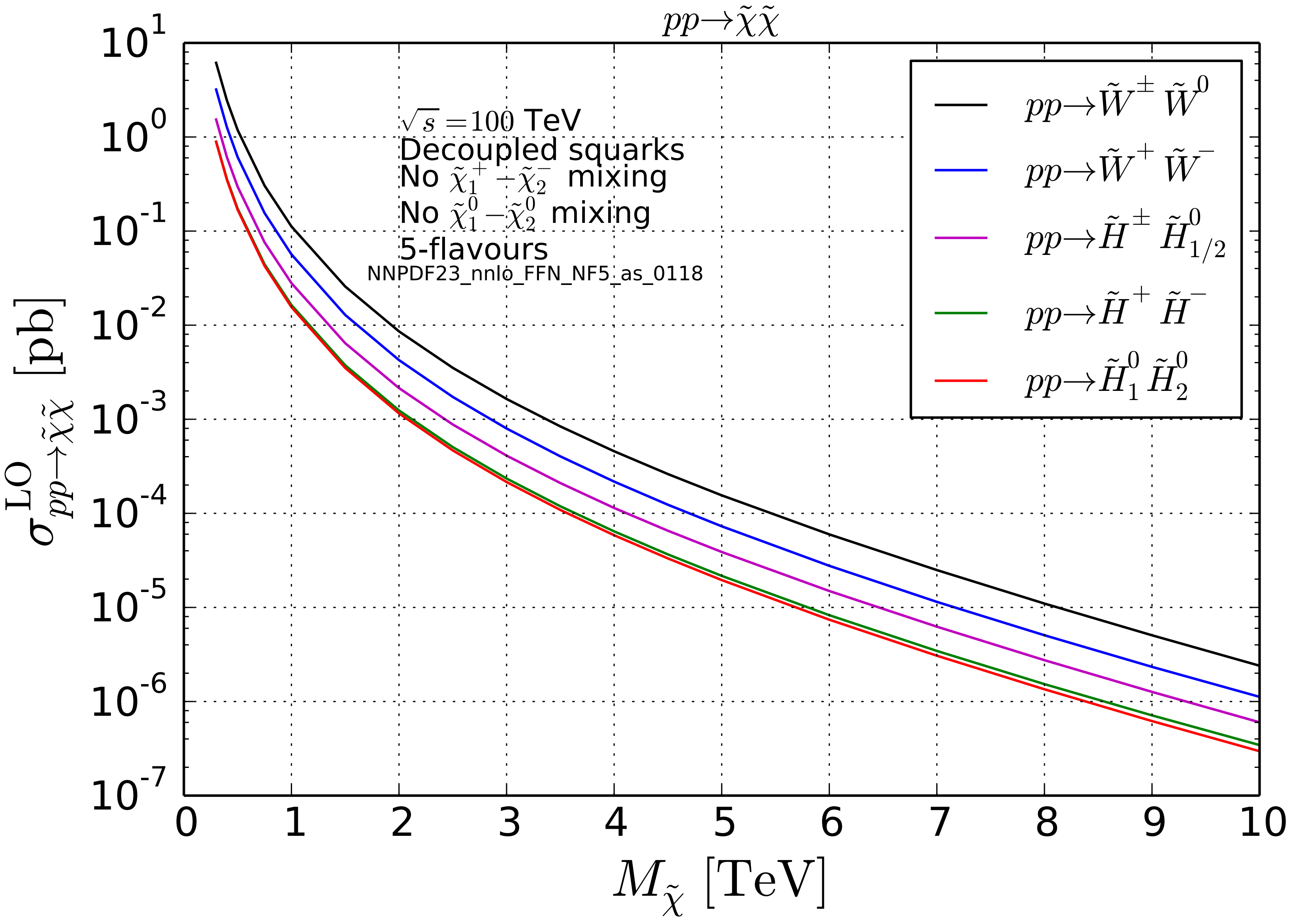


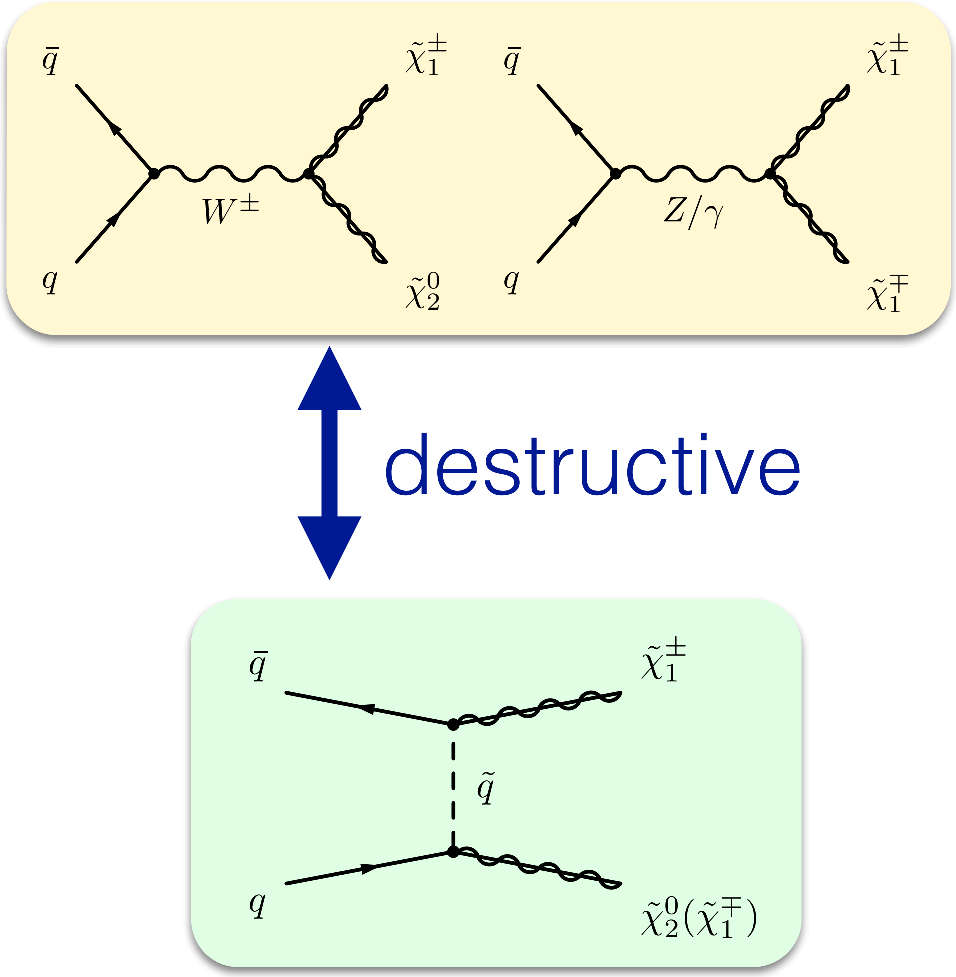
[Arkani-Hamed, Delgado, Giudice '06]



[Bramante, et al. '14]

Production Cross Section





destructive

$$\sigma(\tilde{W}^\pm\tilde{W}^0) > \sigma(\tilde{W}^+\tilde{W}^-) > \sigma(\tilde{H}^\pm\tilde{H}^0) > \sigma(\tilde{H}^+\tilde{W}^-) = \sigma(\tilde{H}^0_1\tilde{H}^0_2)$$

Other production modes and Bino production modes are negligible.

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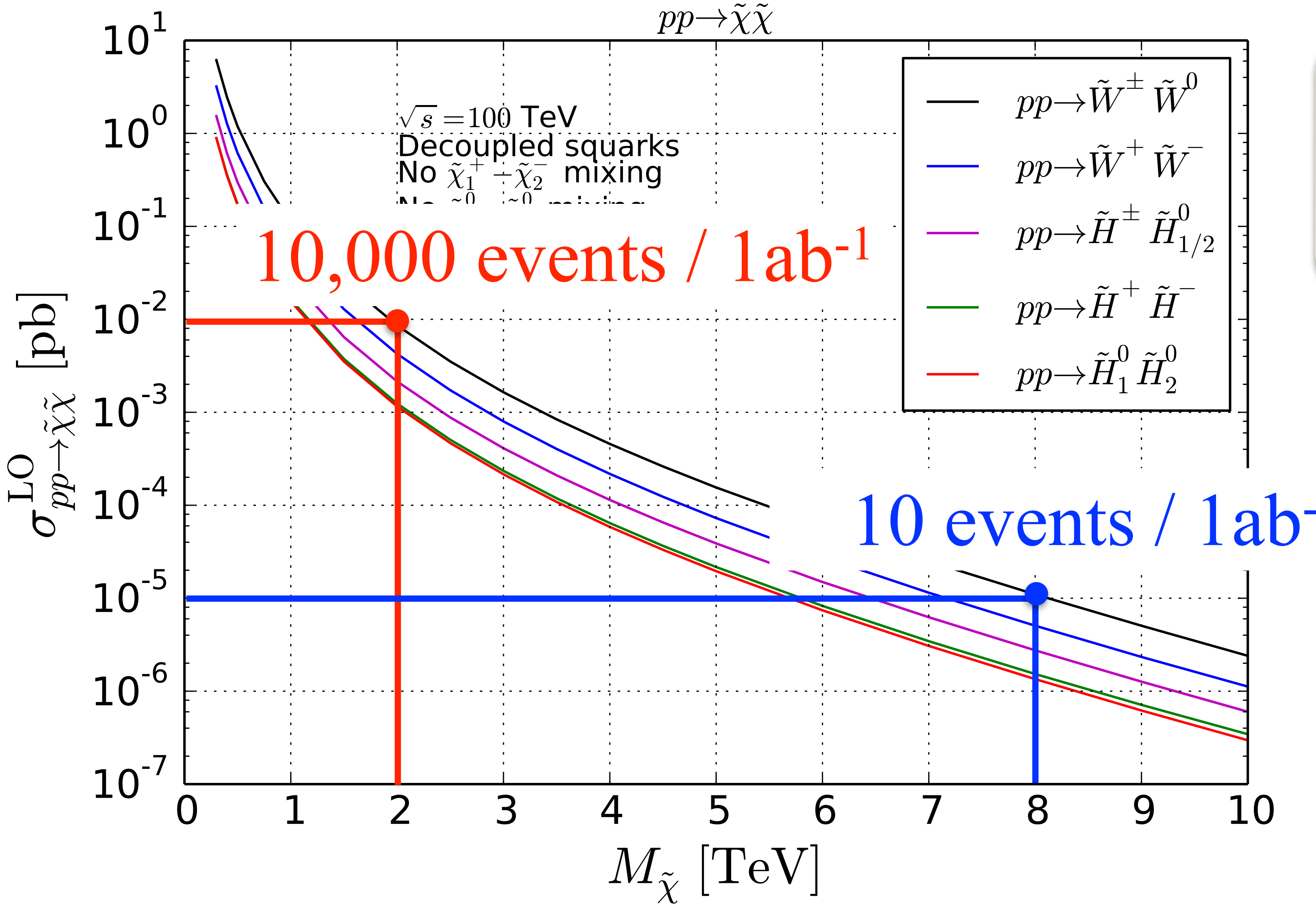
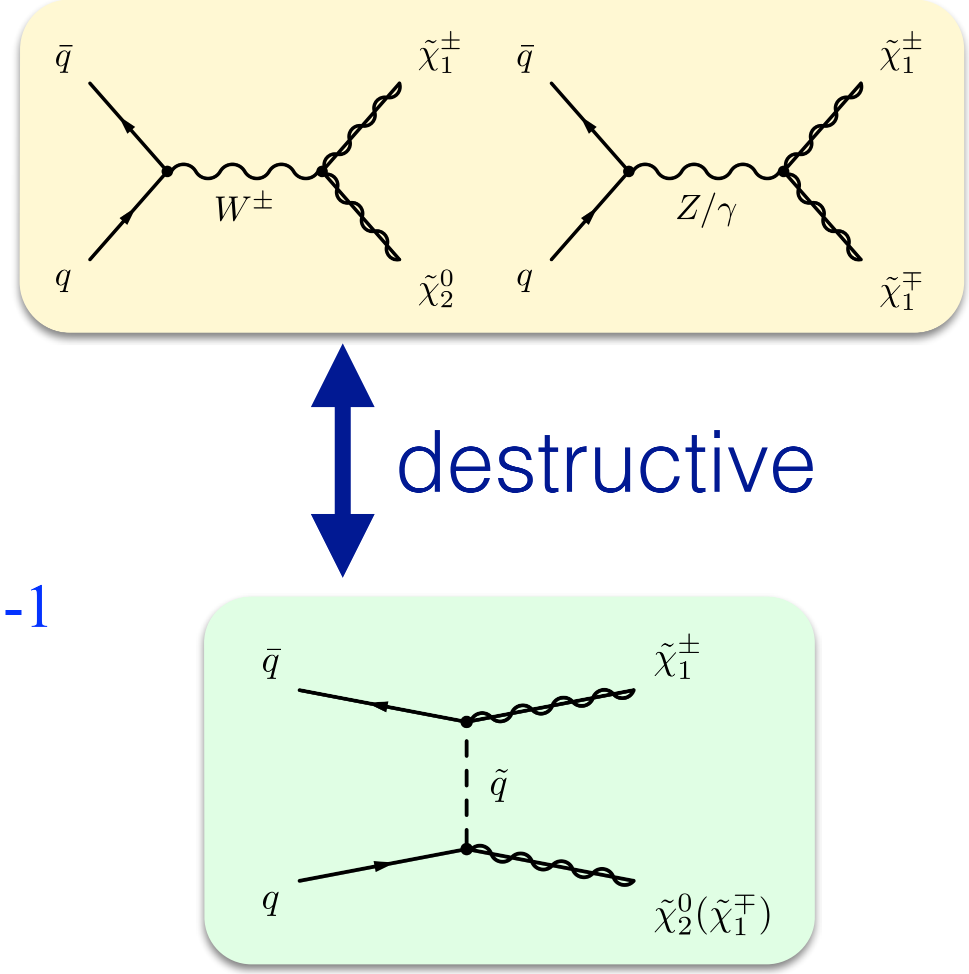


10,000 events / 1ab^{-1}

10 events / 1ab^{-1}



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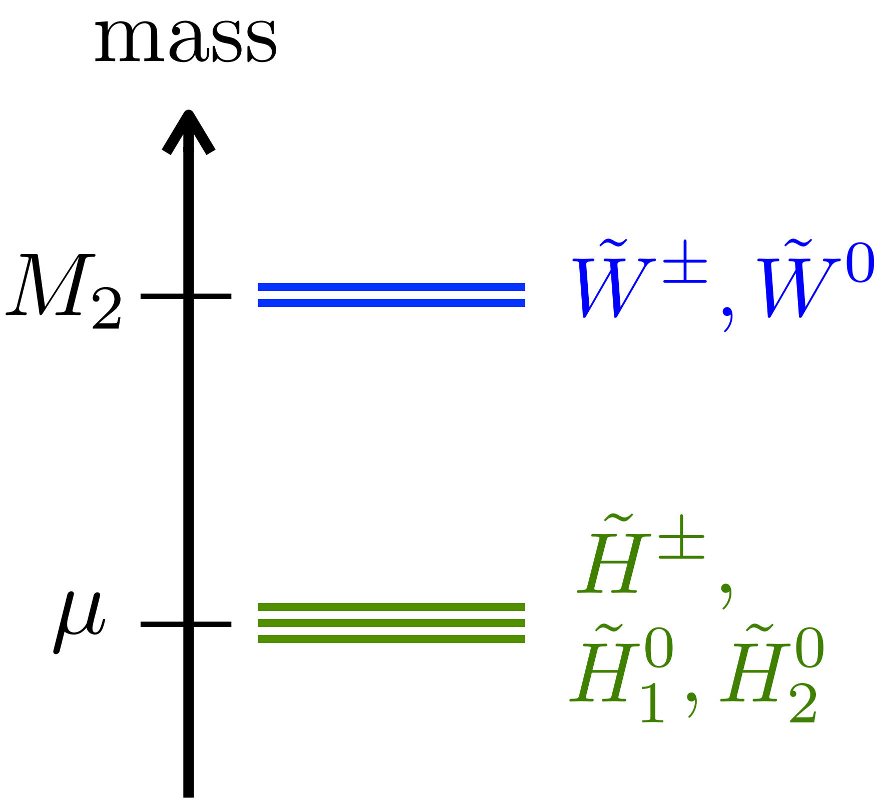
Decay Modes



- How does Winos decay to Higgsinos?

$$\mathcal{L} \supset \left[H_u^\dagger e^V H_u + H_d^\dagger e^V H_d\right]_{\theta^4}$$

$$\supset \sqrt{2}g(H_u^* \widetilde{W}^a T^a \widetilde{H}_u - H_d^* \widetilde{W}^a T^a \widetilde{H}_d) + \text{h.c.}$$

$$\begin{pmatrix} H_u^+ \\ H_u^0 \end{pmatrix} = \begin{pmatrix} \sin\beta \cdot \phi^+ + \cdots \\ \frac{1}{\sqrt{2}}(\cos\alpha \cdot h + i \sin\beta \cdot \phi^0) + \cdots \end{pmatrix}$$

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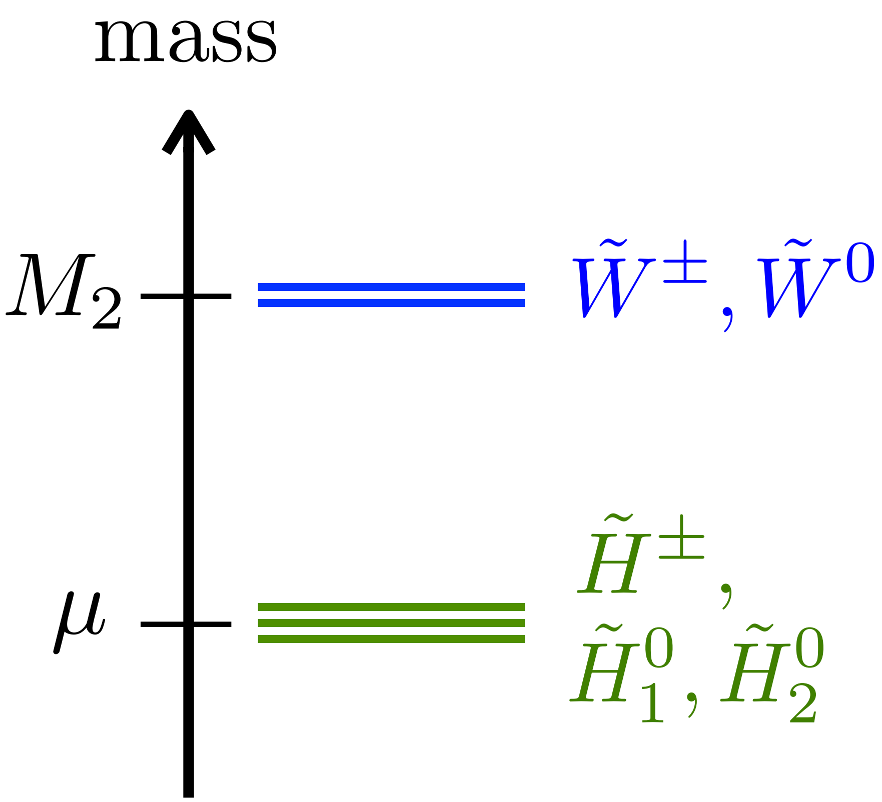

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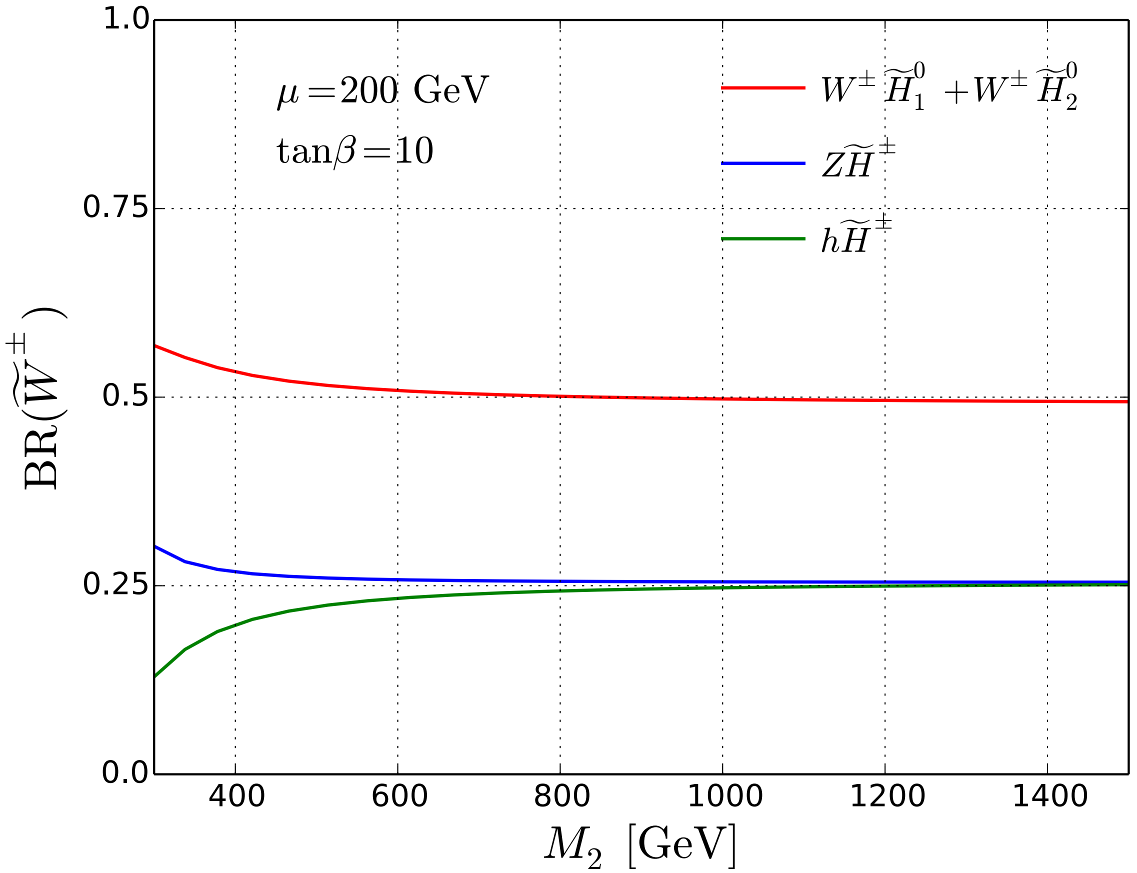
[Goldstone boson equivalence theorem]

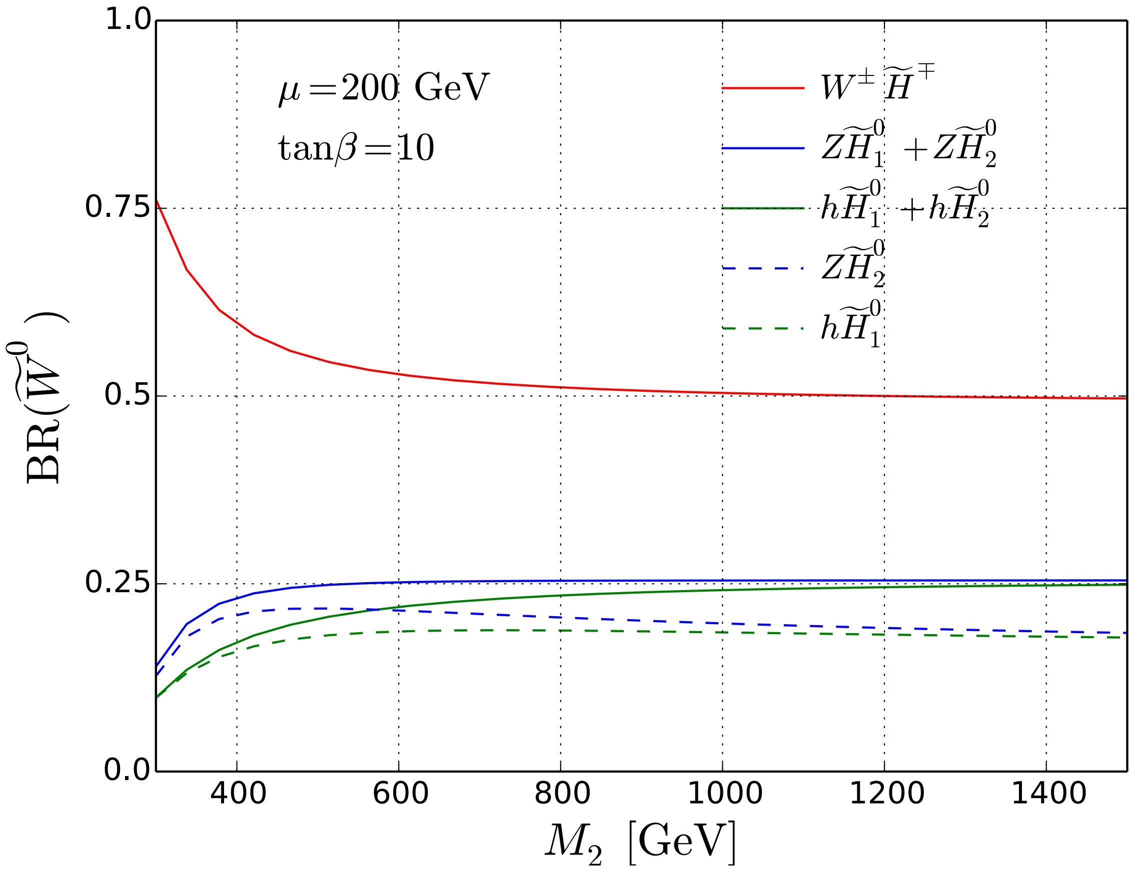
$$M_2 - \mu \gg m_W$$

$$W_L^+ \to \phi^+, Z_L^0 \to \phi^0$$

Decay Modes

Acharya, Bożek,
Pongkitivanichkul, KS ’14





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Golden Channel

$$\widetilde{H}^{\pm}/\widetilde{H}^{0} \to \widetilde{H}^{0}_{1} + \underline{X_{\text{soft}}}$$ *not reconstructed*

- This introduces the degeneracy of the processes.

(e.g.)

$$\left.\begin{aligned} \widetilde{W}^{+}\widetilde{W}^{-} &\to (W^{+}\widetilde{H}^{0}_{1/2})(Z\widetilde{H}^{-}) \\ \widetilde{W}^{+}\widetilde{W}^{0} &\to (W^{+}\widetilde{H}^{0}_{1/2})(Z\widetilde{H}^{0}_{1/2}) \\ &\to (Z\widetilde{H}^{+})(W^{+}\widetilde{H}^{-}) \end{aligned}\right\} \quad \boxed{W^{+}Z + E_{T}^{\text{miss}} + X_{\text{soft}}}$$

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---

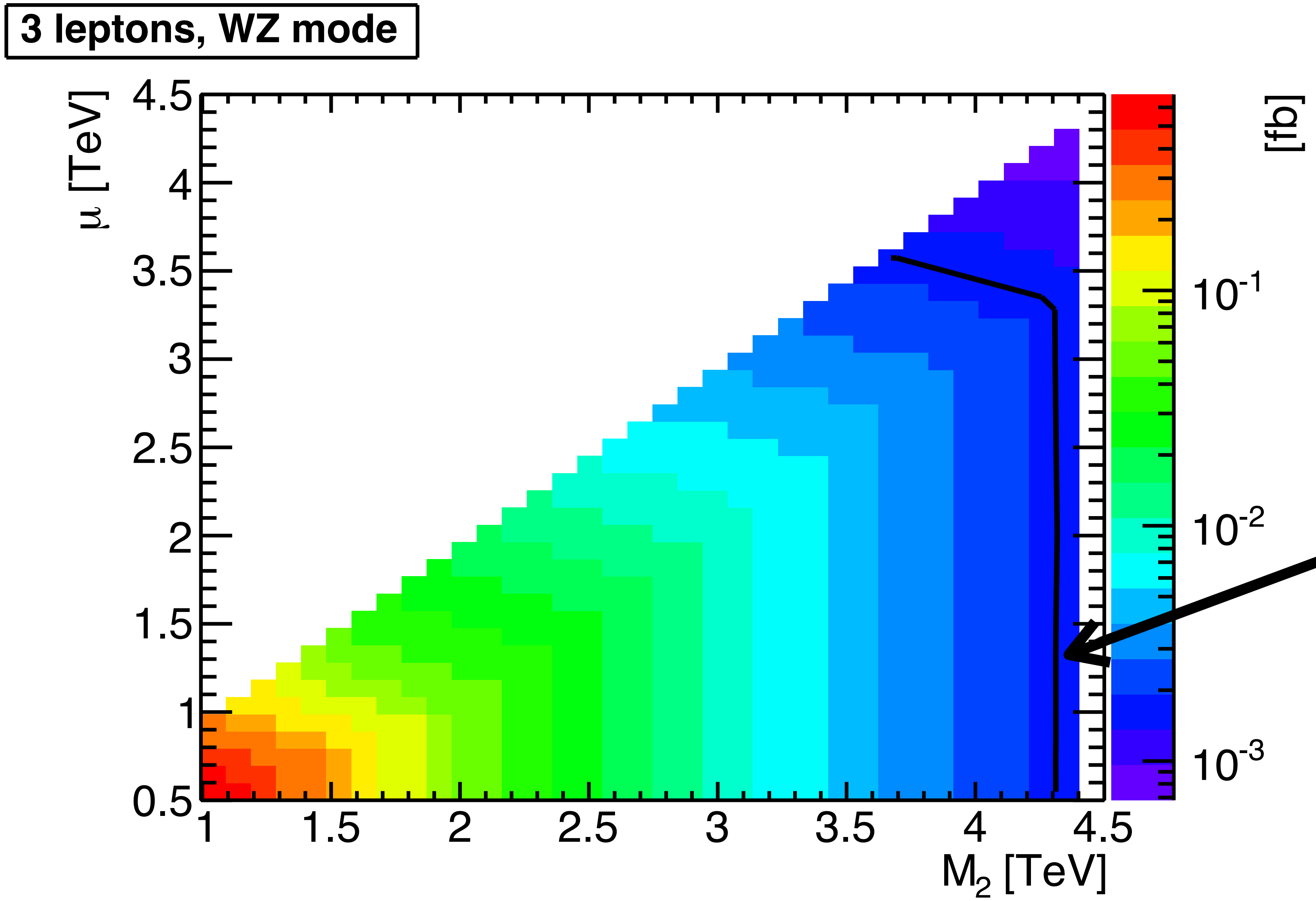
	mode		rate
$\widetilde{W}^{\pm}\widetilde{W}^{0}, \widetilde{W}^{+}\widetilde{W}^{-} \to$	$W^{\pm}Z$	$+\not{E}_T + X_{\rm soft}$	1/4
	$W^{+}W^{-}$	$+\not{E}_T + X_{\rm soft}$	1/4
	$W^{\pm}h$	$+\not{E}_T + X_{\rm soft}$	1/4
	Zh	$+\not{E}_T + X_{\rm soft}$	1/8
	ZZ	$+\not{E}_T + X_{\rm soft}$	1/16
	hh	$+\not{E}_T + X_{\rm soft}$	1/16

Golden Channel

$$\boxed{\widetilde{W}^{\pm}\widetilde{W}^{0}, \widetilde{W}^{+}\widetilde{W}^{-} \to W^{+}Z + \not{E}_T + X_{\rm soft} \to (\ell\nu)(\ell_i^{+}\ell_i^{-}) + \not{E}_T + X_{\rm soft}}$$

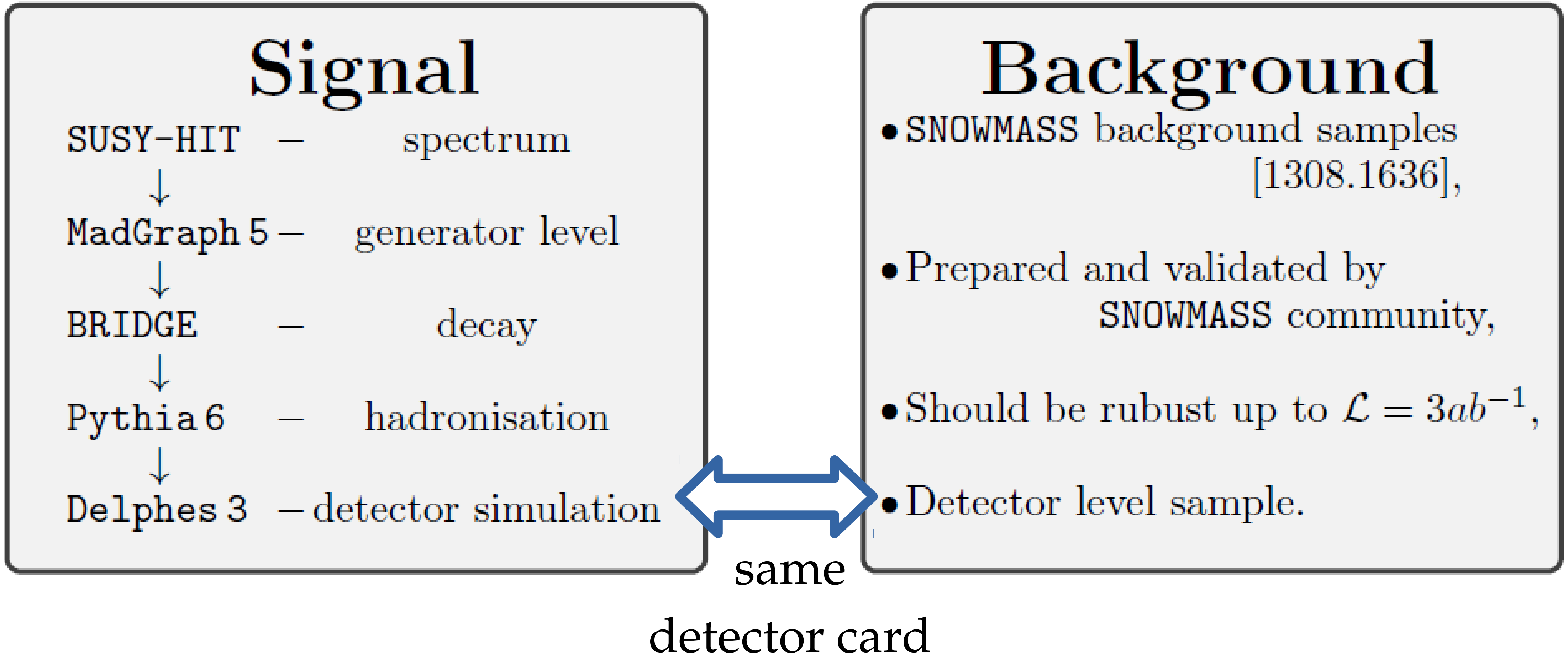
3 lepton channel

$$\widetilde{W}^{\pm}\widetilde{W}^{0}, \widetilde{W}^{+}\widetilde{W}^{-} \to \ W^{+}Z + \not{E}_T + X_{\rm soft} \to (\ell\nu)(\ell_i^+\ell_i^-) + \not{E}_T + X_{\rm soft}$$



5 signal events @ 3ab^{-1}

Simulation



Signal

`SUSY-HIT` – spectrum
↓
`MadGraph 5` – generator level
↓
`BRIDGE` – decay
↓
`Pythia 6` – hadronisation
↓
`Delphes 3` – detector simulation

Background

- `SNOWMASS` background samples [1308.1636],
- Prepared and validated by `SNOWMASS` community,
- Should be rubust up to $\mathcal{L} = 3ab^{-1}$,
- Detector level sample.

same
detector card

Background cross-section

Process	σ [pb]
VV	3.0×10^{6}
ttV	2.2×10^{5}
tV	2.7×10^{6}
VVV	3.6×10^{4}
BG total	6.0×10^{6}

Preselection

- exactly three isolated leptons with $p_T > 10$ GeV and $|\eta| < 2.5$
- a same-flavour opposite-sign (SFOS) lepton pair with $|m_{\ell\ell}^{\rm SFOS} - m_Z| < 10$ GeV
- no b-tagged jet

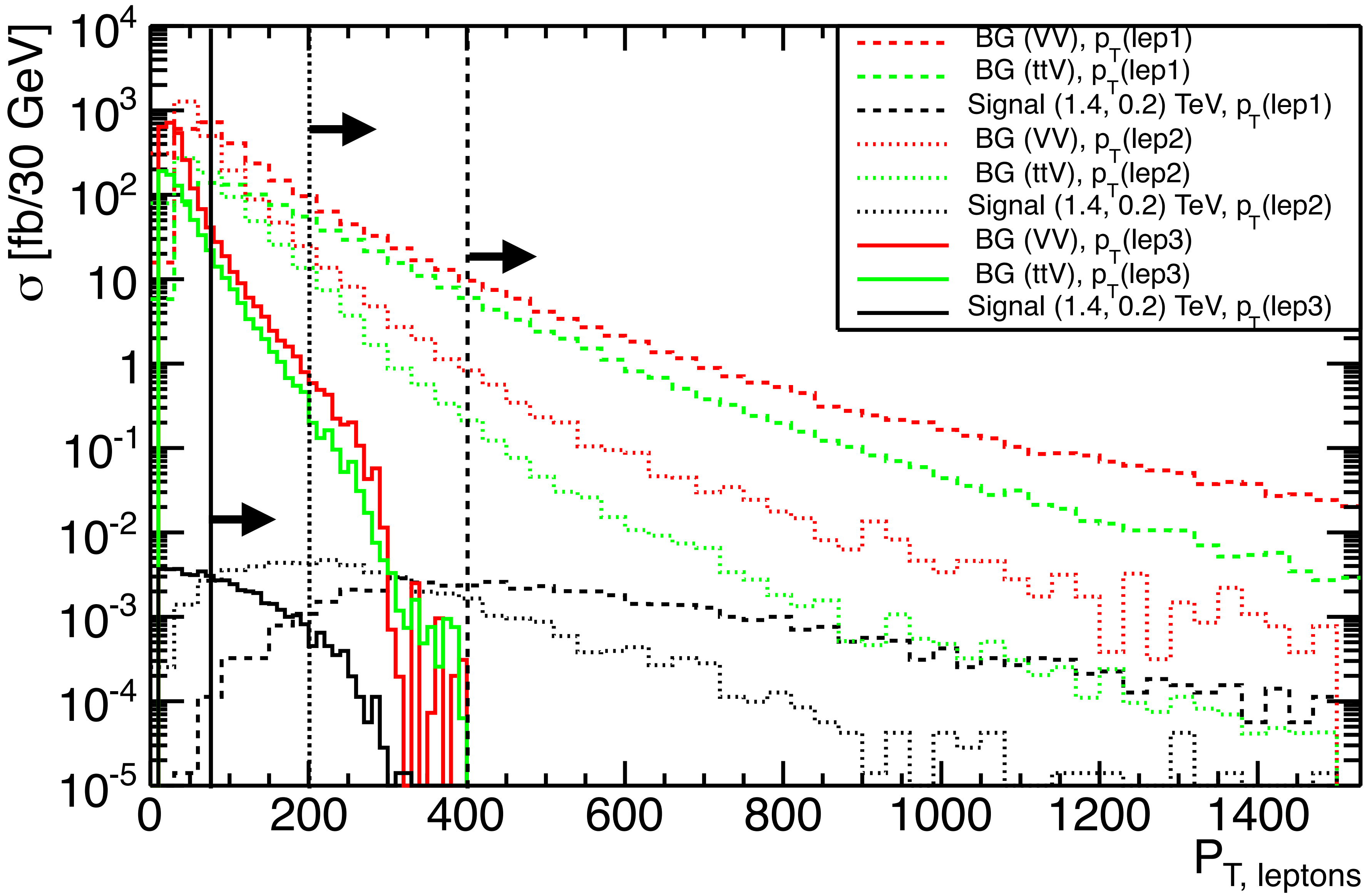
Background Cross-Section in [pb]

Process	No cut	$= 3$ lepton	$\|m_{\ell\ell}^{\rm SFOS} - m_Z\| < 10$	no-b jet
VV	3025348	2487	2338	2176
ttV	220161	792	552	318
tV	2764638	68.9	6.07	4.12
VVV	36276	76.1	56.2	56.2
BG total	6046422	3424	2952	2554
$(M_2, \mu) = (800, 200)$	1.640	0.588	0.565	0.534
$(M_2, \mu) = (1200, 200)$	0.397	0.124	0.119	0.111
$(M_2, \mu) = (1800, 200)$	0.0863	0.0190	0.0179	0.0170

Signal Regions

Signal Region	3 lepton p_T [GeV]	E_T^{miss} [GeV]	m_T [GeV]
Loose	$> 100, 50, 10$	> 150	> 150
Medium	$> 250, 150, 50$	> 350	> 300
Tight	$> 400, 200, 75$	> 800	> 1100

$(M_2, \mu) = (1.2, 0.2)$ TeV



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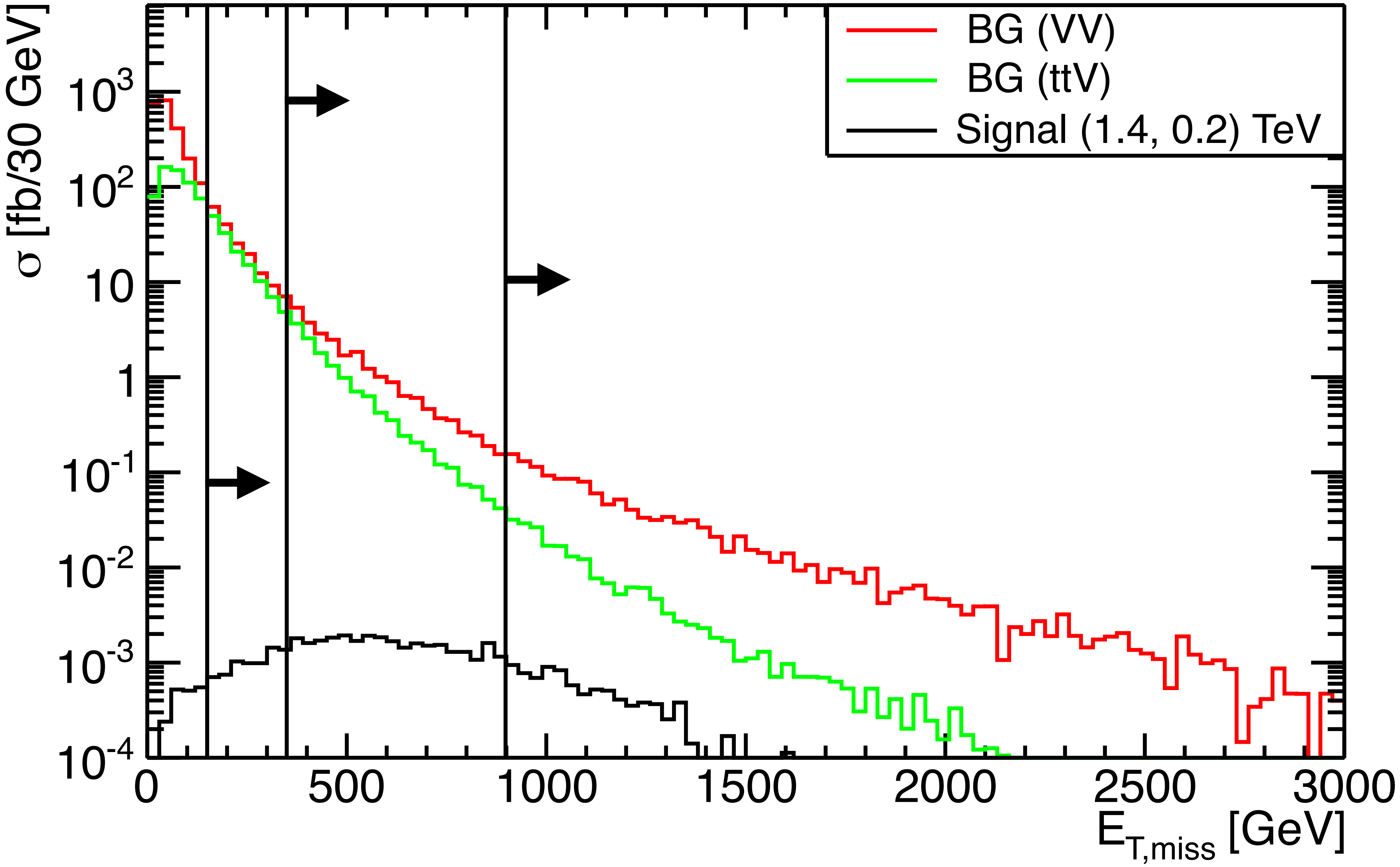

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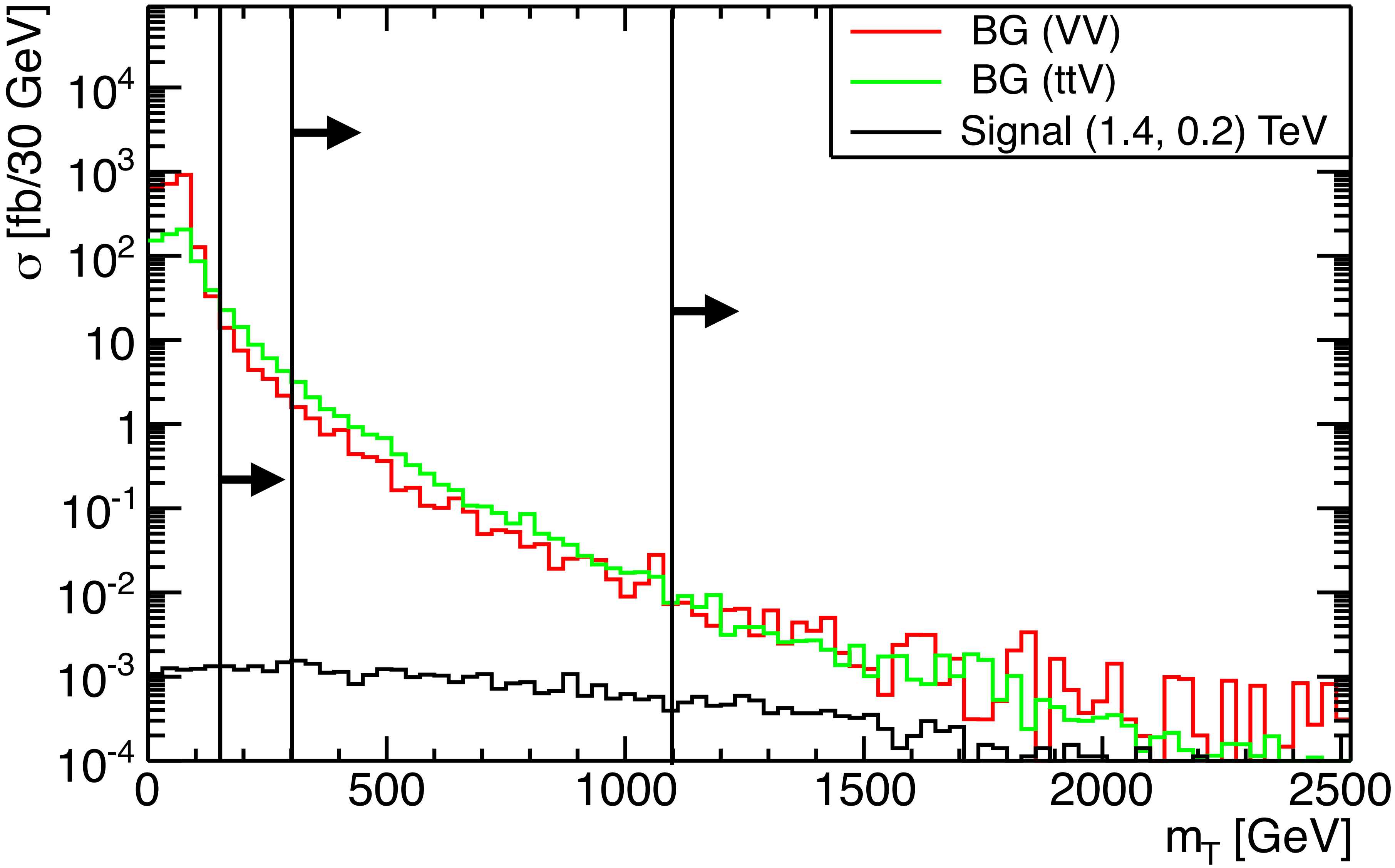
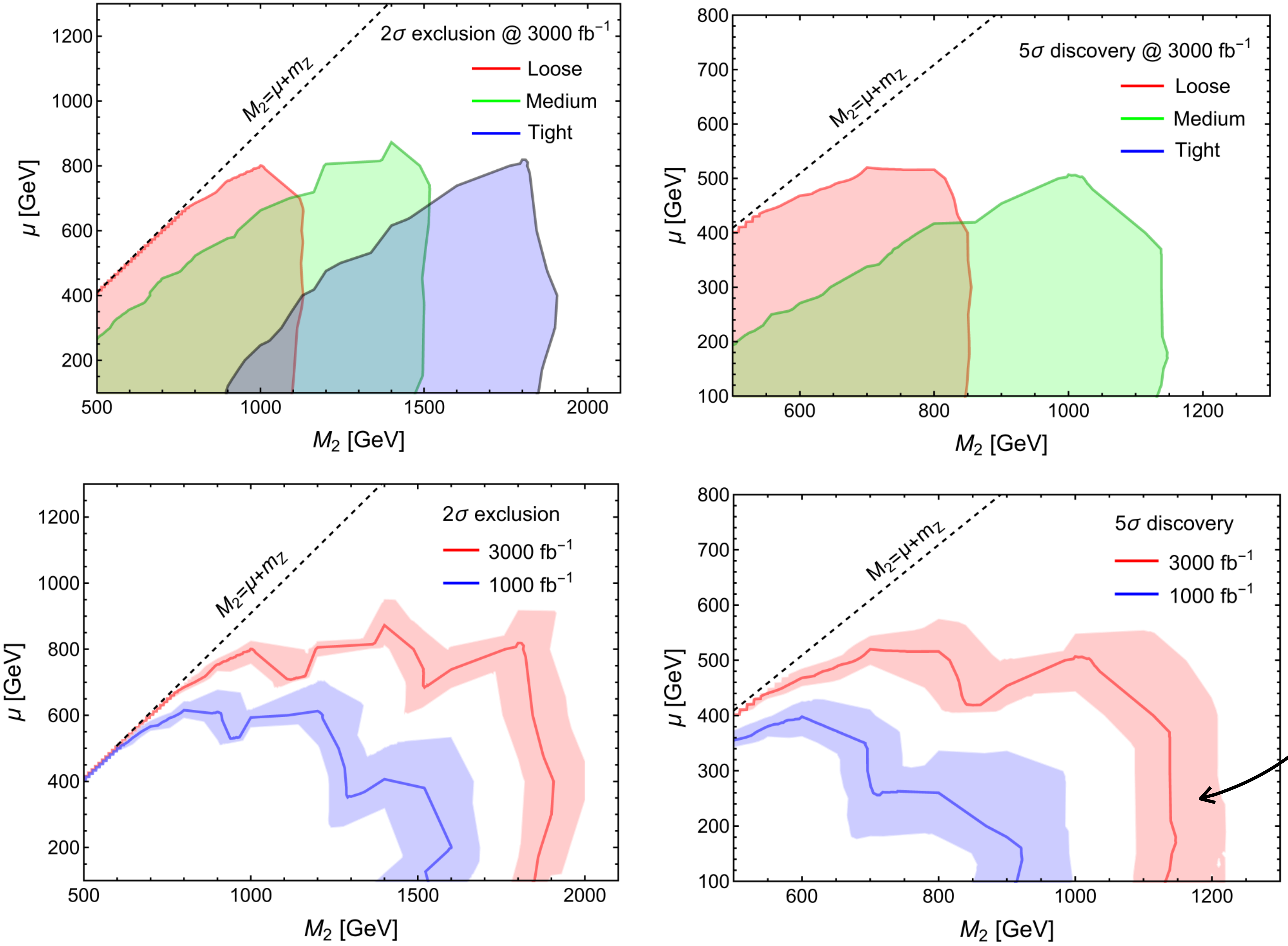


Results

Acharya, Bożek,
Pongkitivanichkul, KS '14

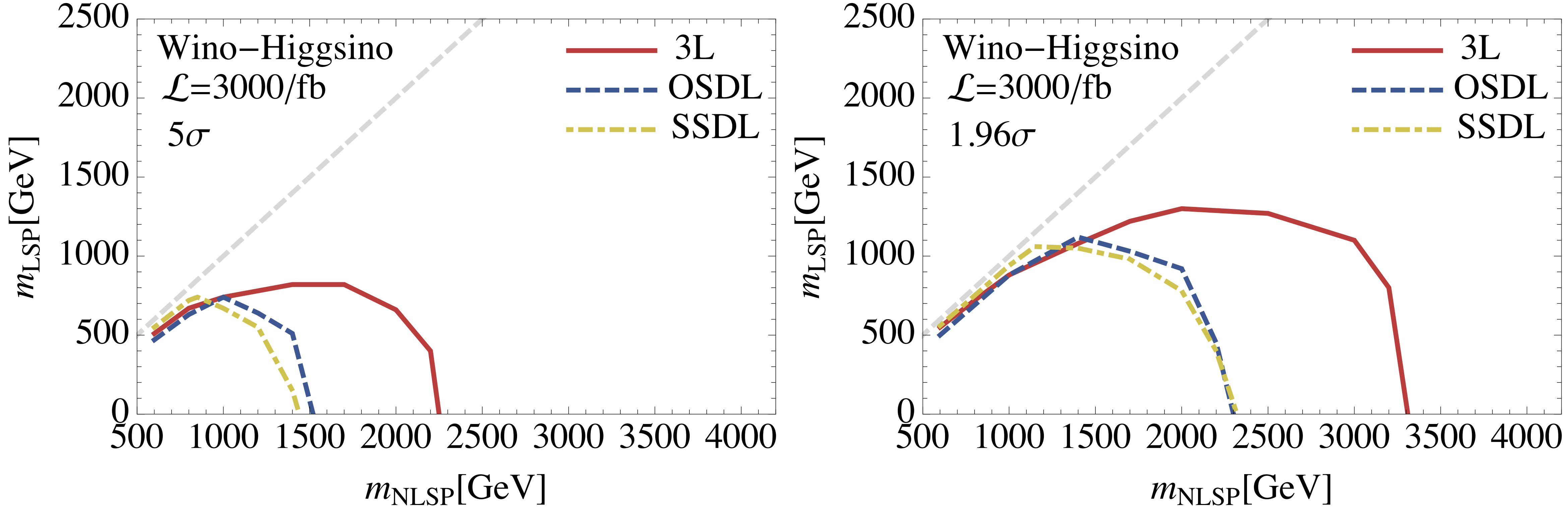


$B \rightarrow (1 \pm 0.3)B$

Wino can be discovered (excluded) up to 1.1 (1.8) TeV @ 3ab^{-1}

Discussion

Gori, Jung, Wang, Wells ‘14



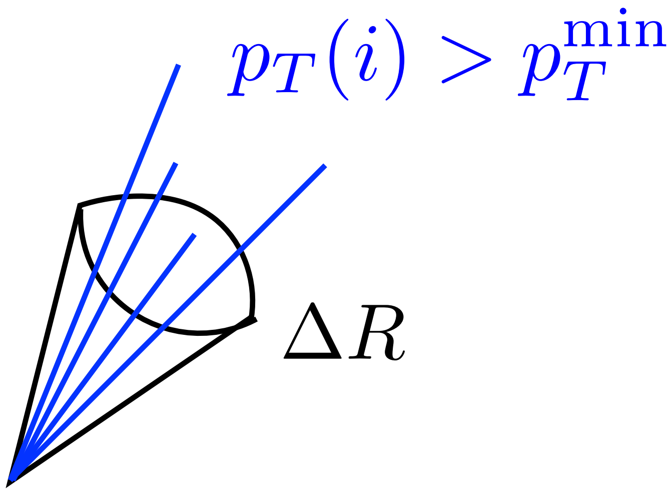
- The authors of ‘1410.6287’ found much better reach (2.1 (3.2) TeV for discovery (exclusion)).

- One main difference is they use particle-level analysis and allow the lepton separation of ΔR > 0.05.

Delphes lepton isolation

The lepton isolation parameter:

$$I(\ell) = \frac{\sum_{i\neq\ell}^{\Delta R<R,\ p_T(i)>p_T^{\min}} p_T(i)}{p_T(\ell)}$$



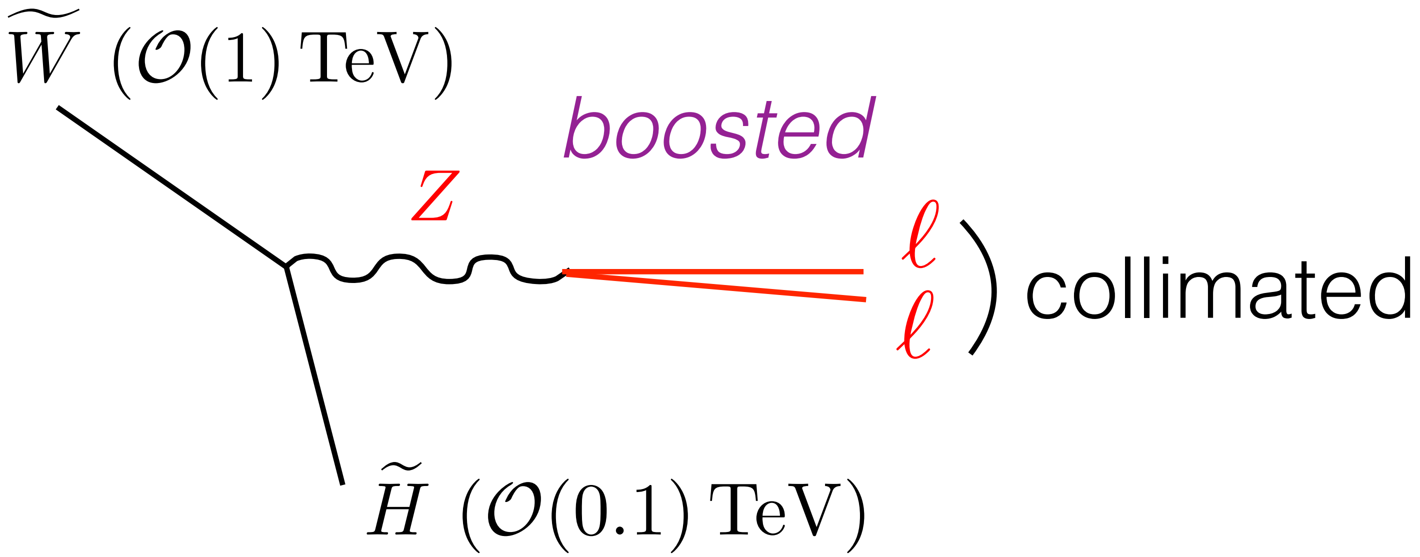
[Snowmass card]

$\Delta R = \boxed{0.3}$

$p_T^{\min} = 0.5\,\mathrm{GeV}$

$\underline{I(\ell) < 0.1}$

isolation criteria



The lepton reco-efficiency can be significantly degraded.

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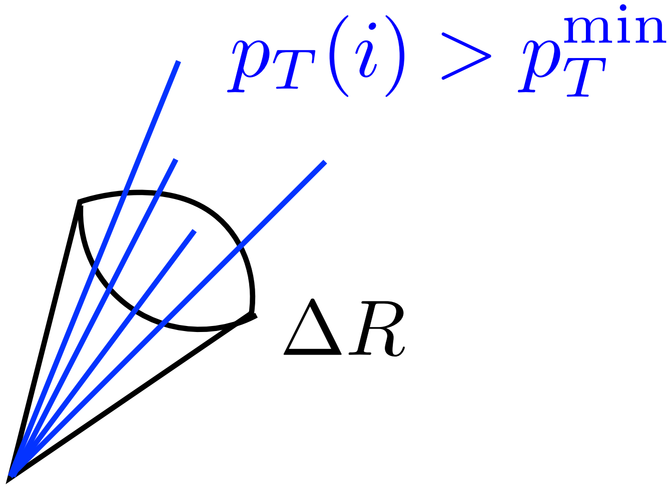

[Snowmass card]

$$\Delta R = \boxed{0.3}$$

$$p_T^{\mathrm{min}} = 0.5\,\mathrm{GeV}$$

$$\underline{I(\ell) < 0.1}$$

isolation criteria

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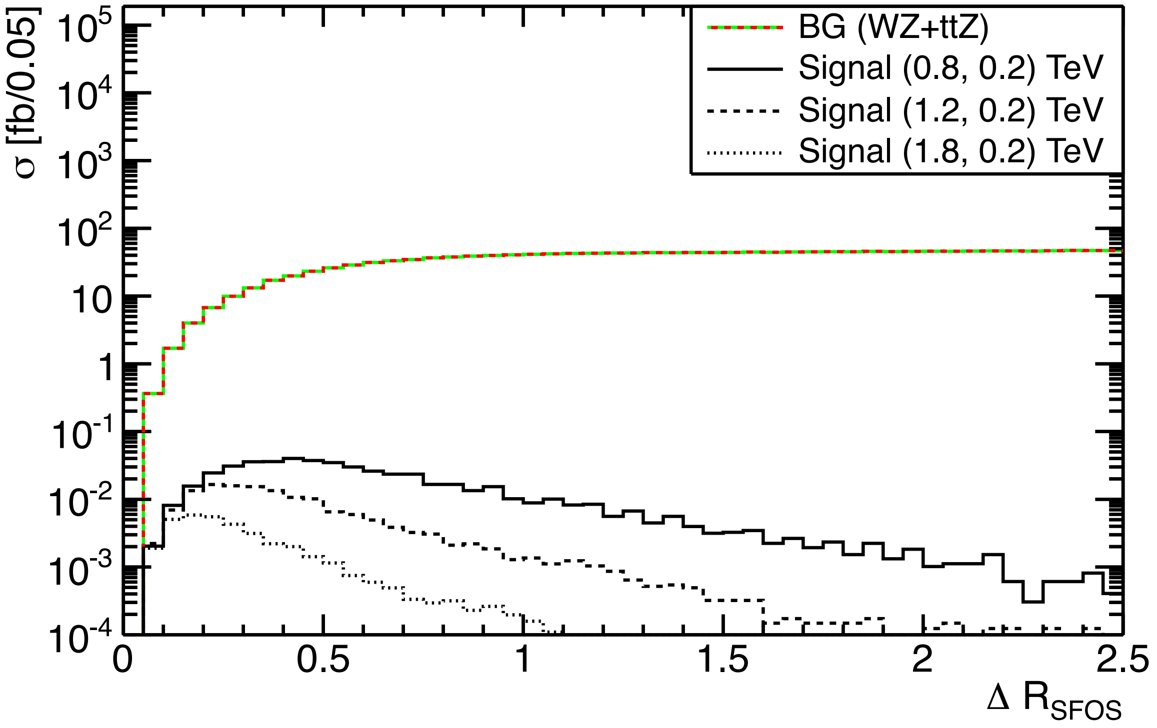
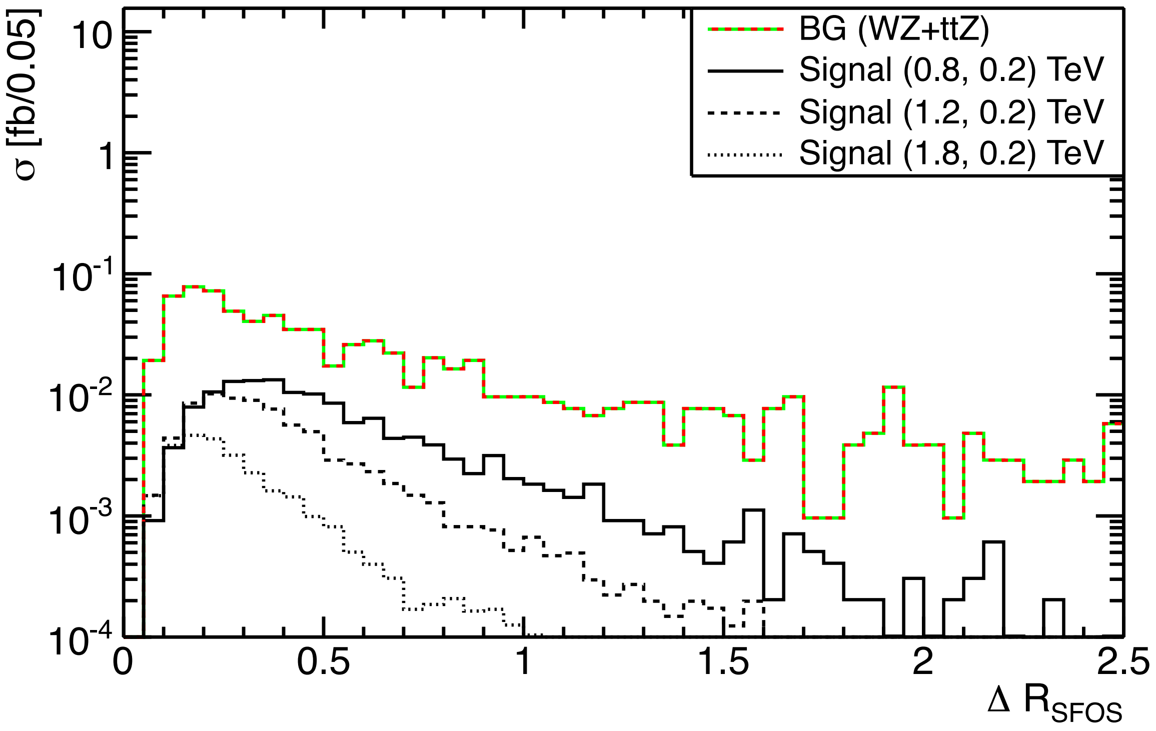
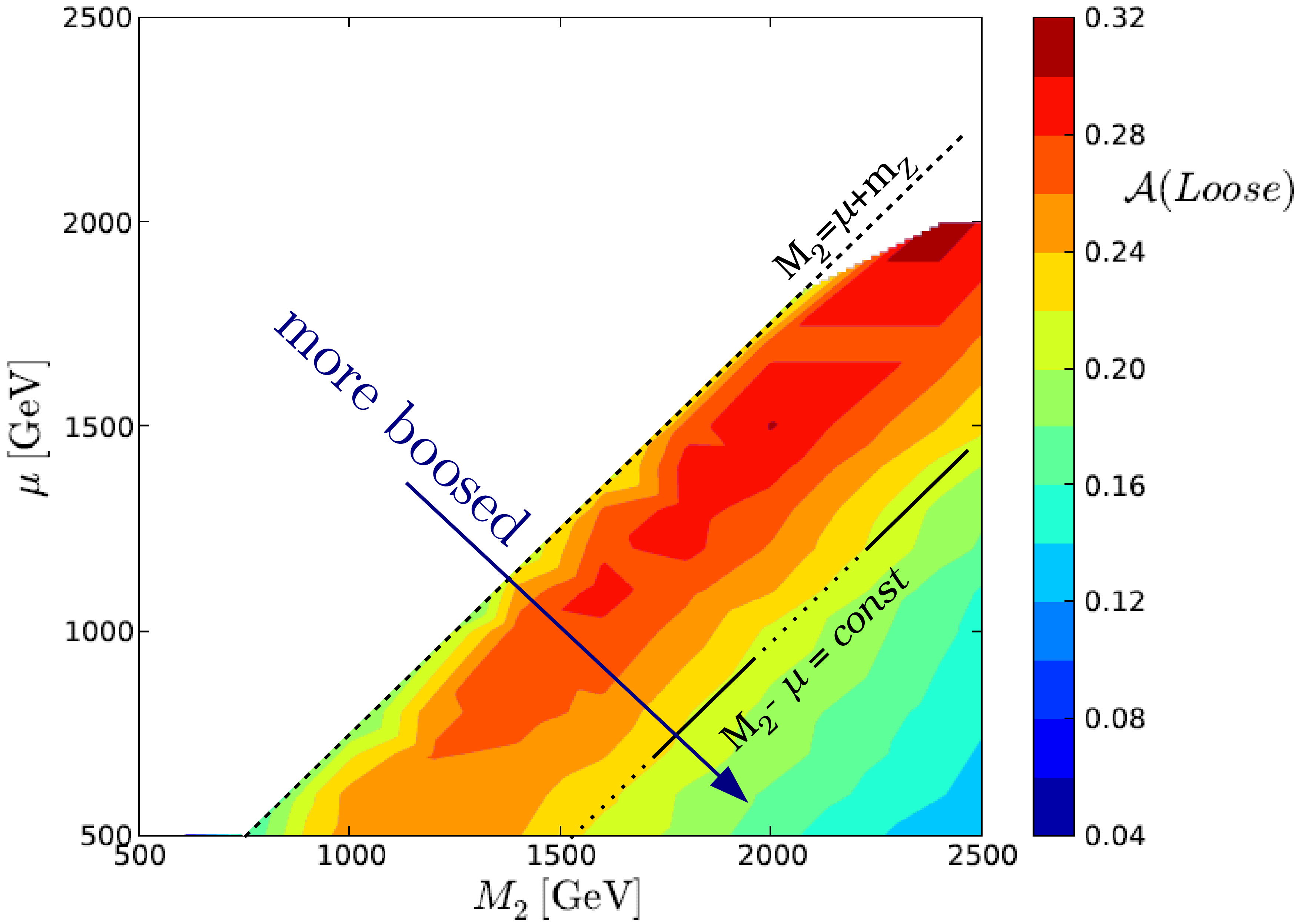
after preselection



and MET>0.5TeV, mT>0.2TeV



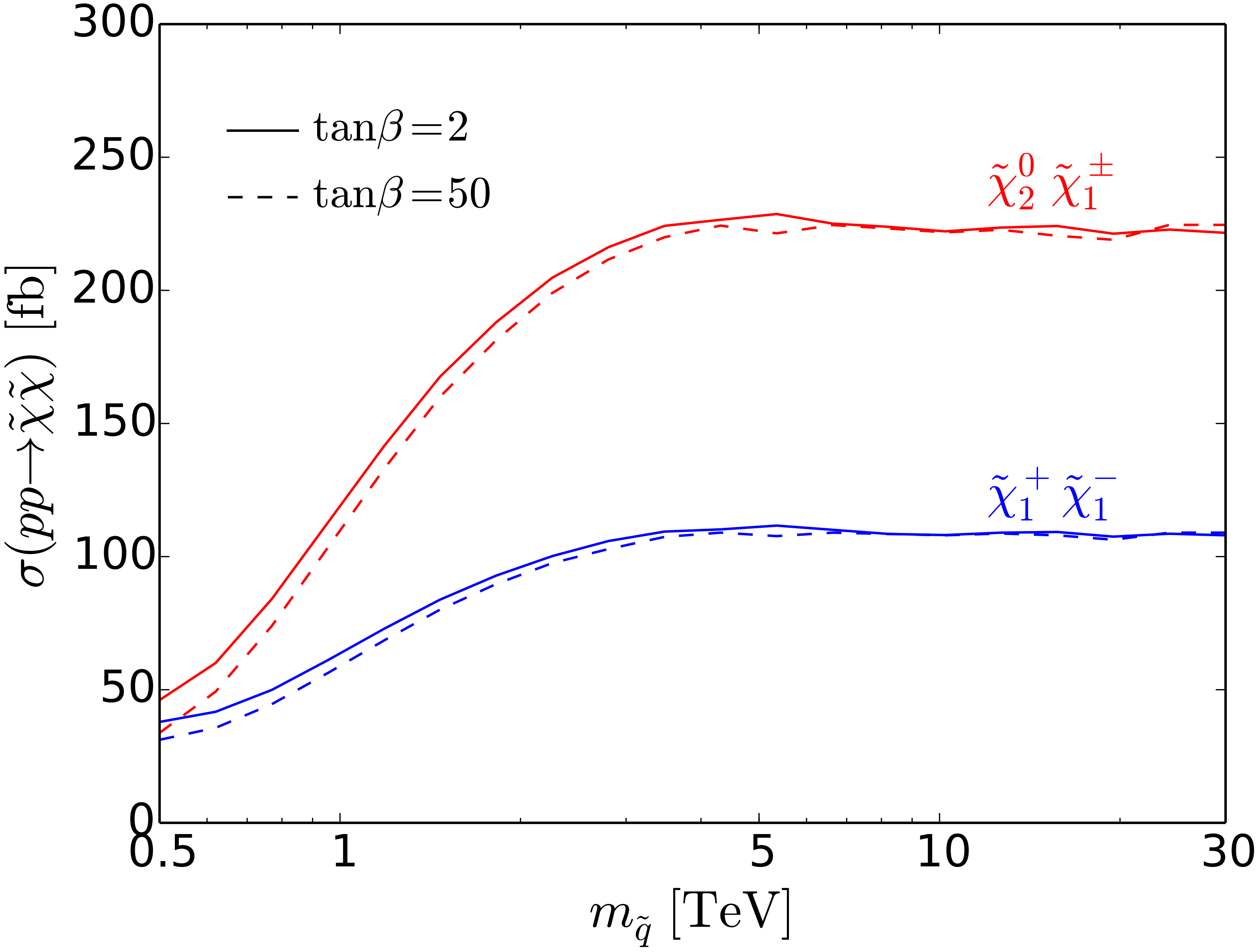
Acceptance Map



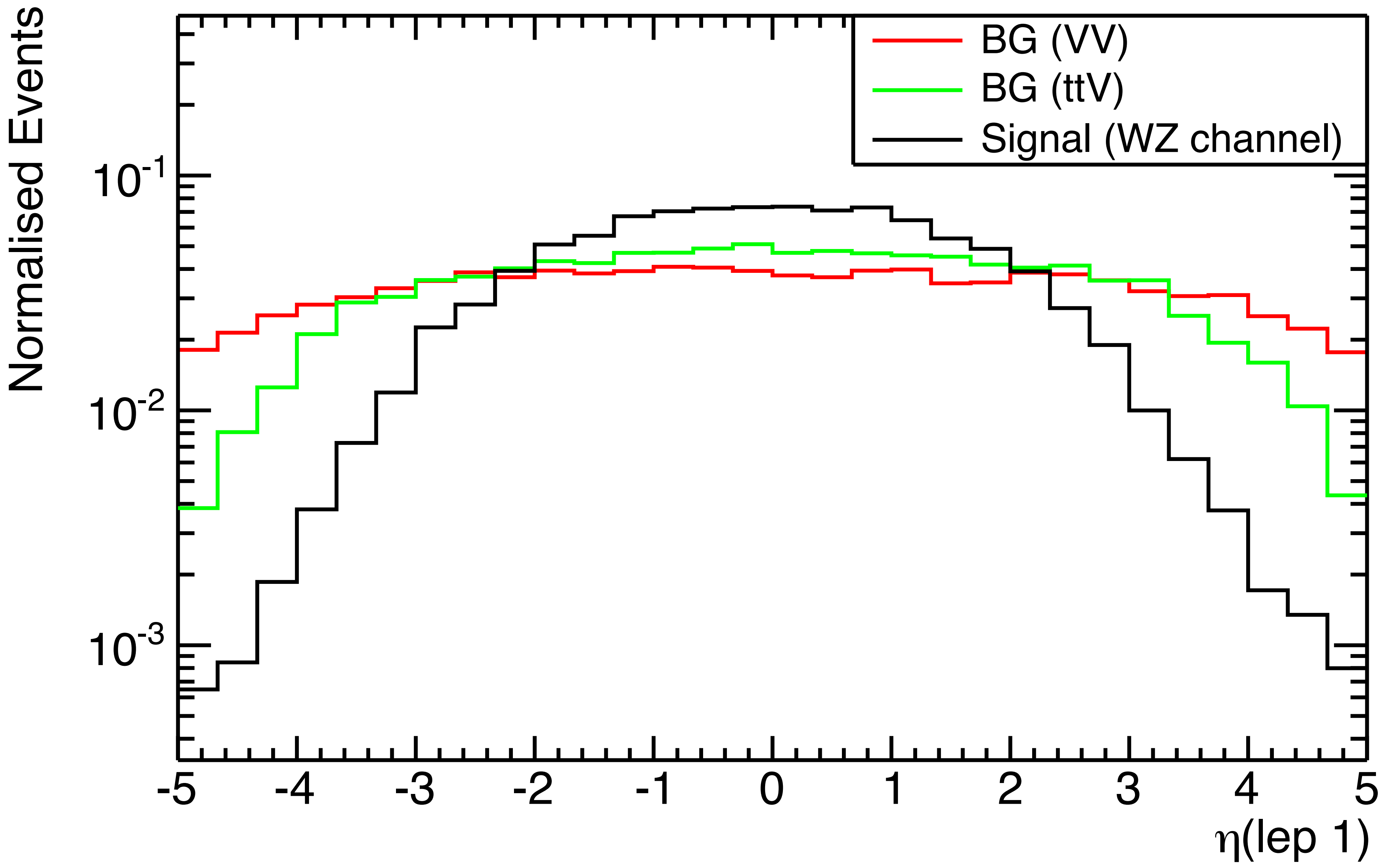
- The lepton separation is a limiting factor for the 3-lepton analysis.
- A better mass reach can be obtained if a smaller lepton separation can be achieved at a 100 TeV collider.

Summary

- Light EWkinos are well motivated: GCU, DM, …
- A 100 TeV collider is important to constrain (discover) the EWkino sector.
- If scalars are decoupled (and Higgsinos are light), the heavier EWkinos decay universally to W, Z and h, which can be understood by Goldstone equivalence theorem.
- A simple 3-lepton analysis shows the Wino mass reach is 1.1 (1.8) TeV for discovery (exclusion).
- A good lepton separation is important to constrain the EWkinos using the 3-lepton channel.



$\sigma(pp\to\tilde{\chi}\tilde{\chi})$ [fb]
$m_{\tilde{q}}$ [TeV]
300
250
200
150
100
50
0
0.5
1
5
10
30
tanβ=2
tanβ=50
$\tilde{\chi}_2^0\,\tilde{\chi}_1^\pm$
$\tilde{\chi}_1^+\,\tilde{\chi}_1^-$


BG (VV)
BG (ttV)
Signal (WZ channel)
Normalised Events
10^{-1}
10^{-2}
10^{-3}
-5
-4
-3
-2
-1
0
1
2
3
4
5
η(lep 1)

Process	No cut	= 3 lepton	$\lvert m_{\ell\ell}^{\mathrm{SFOS}} - m_Z \rvert < 10$	no-b jet	$p_T^{\ell} > (100, 50, 10)$	$E_T^{\mathrm{miss}} > 150$	$m_T > 150$	$S/\sqrt{B}$
VV	3025348	2487	2338	2176	647	106	5.1	
ttV	220161	792	552	318	176	41.2	6.6	
tV	2764638	68.9	6.07	4.12	0.665	0.391	0.0793	
VVV	36276	76.1	56.2	56.2	23.4	6.0	1.06	
BG total	6046422	3424	2952	2554	847	153	12.8	
$(M_2, \mu) = (800, 200)$	1.640	0.588	0.565	0.534	0.506	0.465	0.381	5.82
$(M_2, \mu) = (1200, 200)$	0.397	0.124	0.119	0.111	0.109	0.103	0.090	1.38
$(M_2, \mu) = (1800, 200)$	0.0863	0.0190	0.0179	0.0170	0.0168	0.0164	0.0150	0.234

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