Dark Matter in Vector Boson Fusion

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THE UNIVERSITY OF CHICAGO

Pittsburgh Invisible Higgs Workshop,
August 25, 2016

Outline

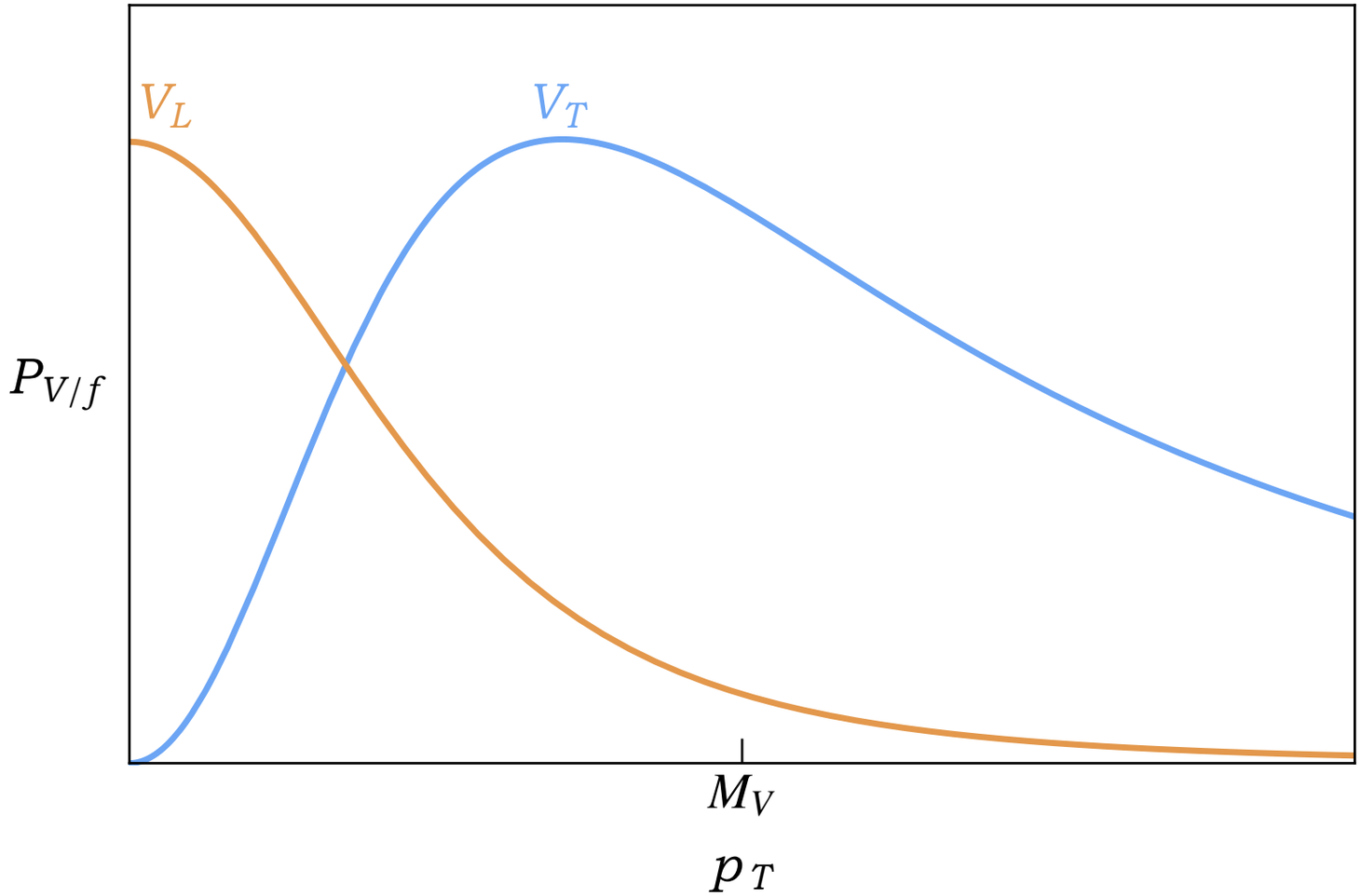
I. General VBF Overview

II. EFTs and the Higgs Portal

III. Electroweakinos

I. General VBF Overview

VBF Topology (q→V+j)



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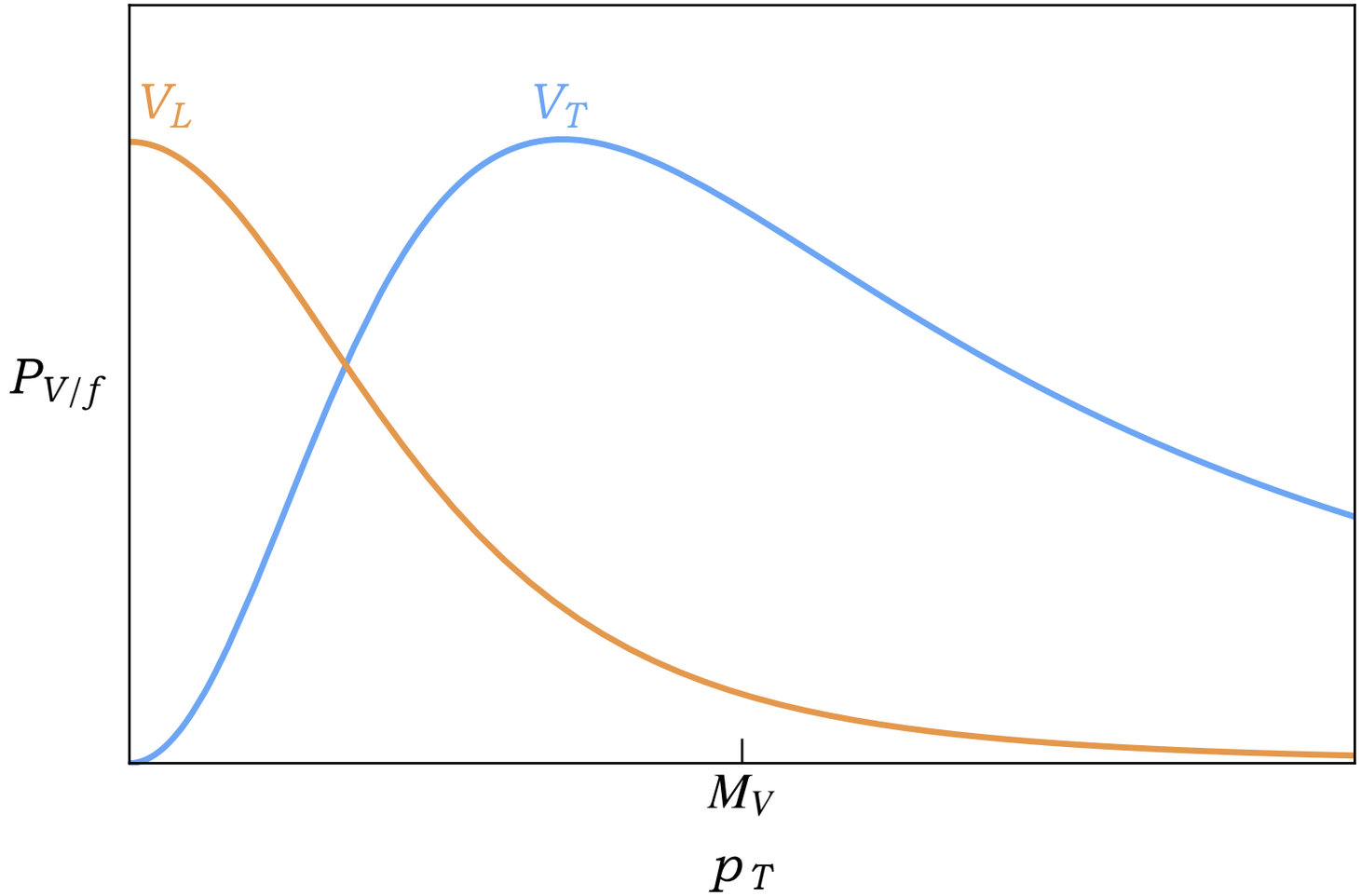

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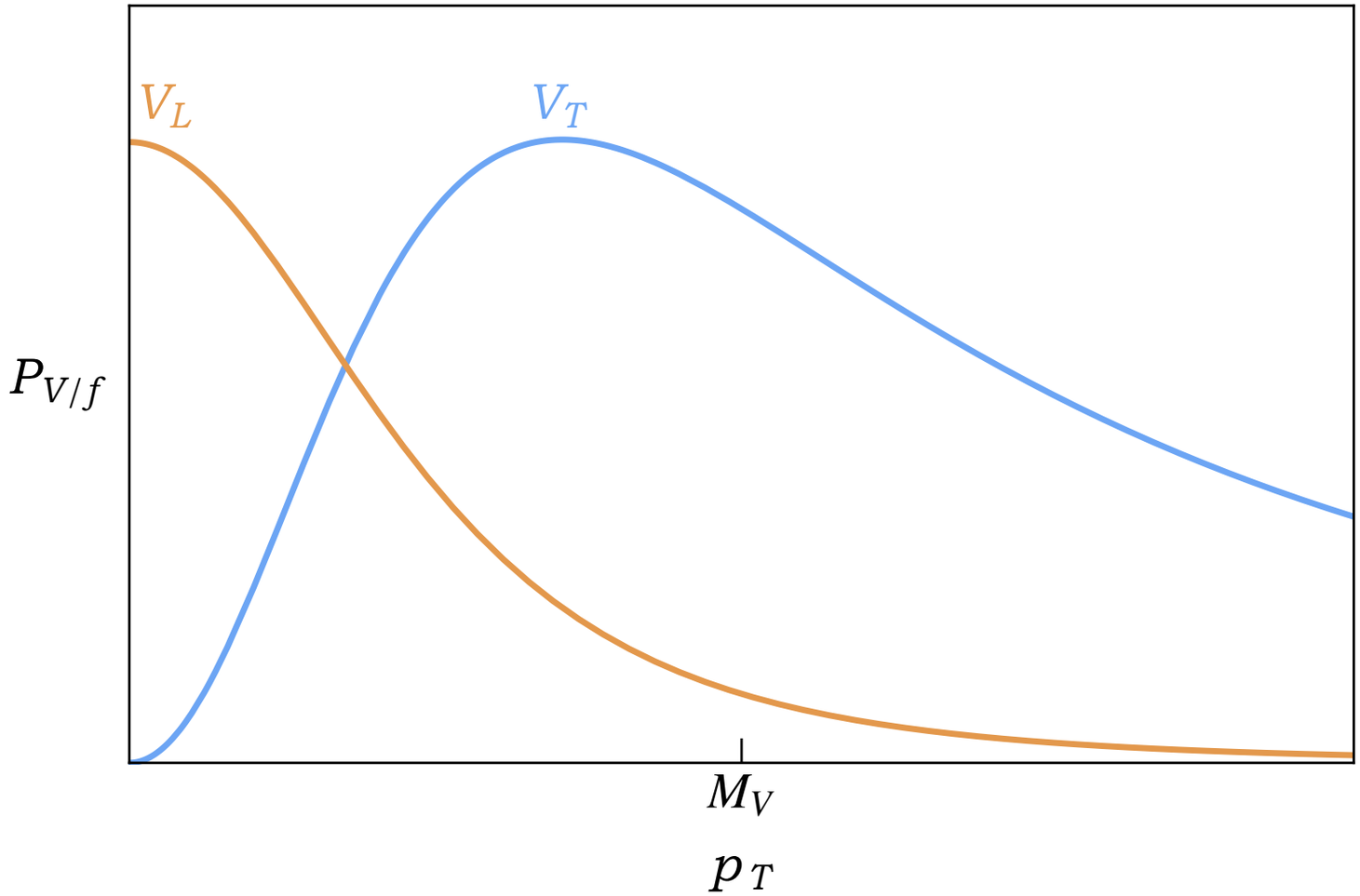

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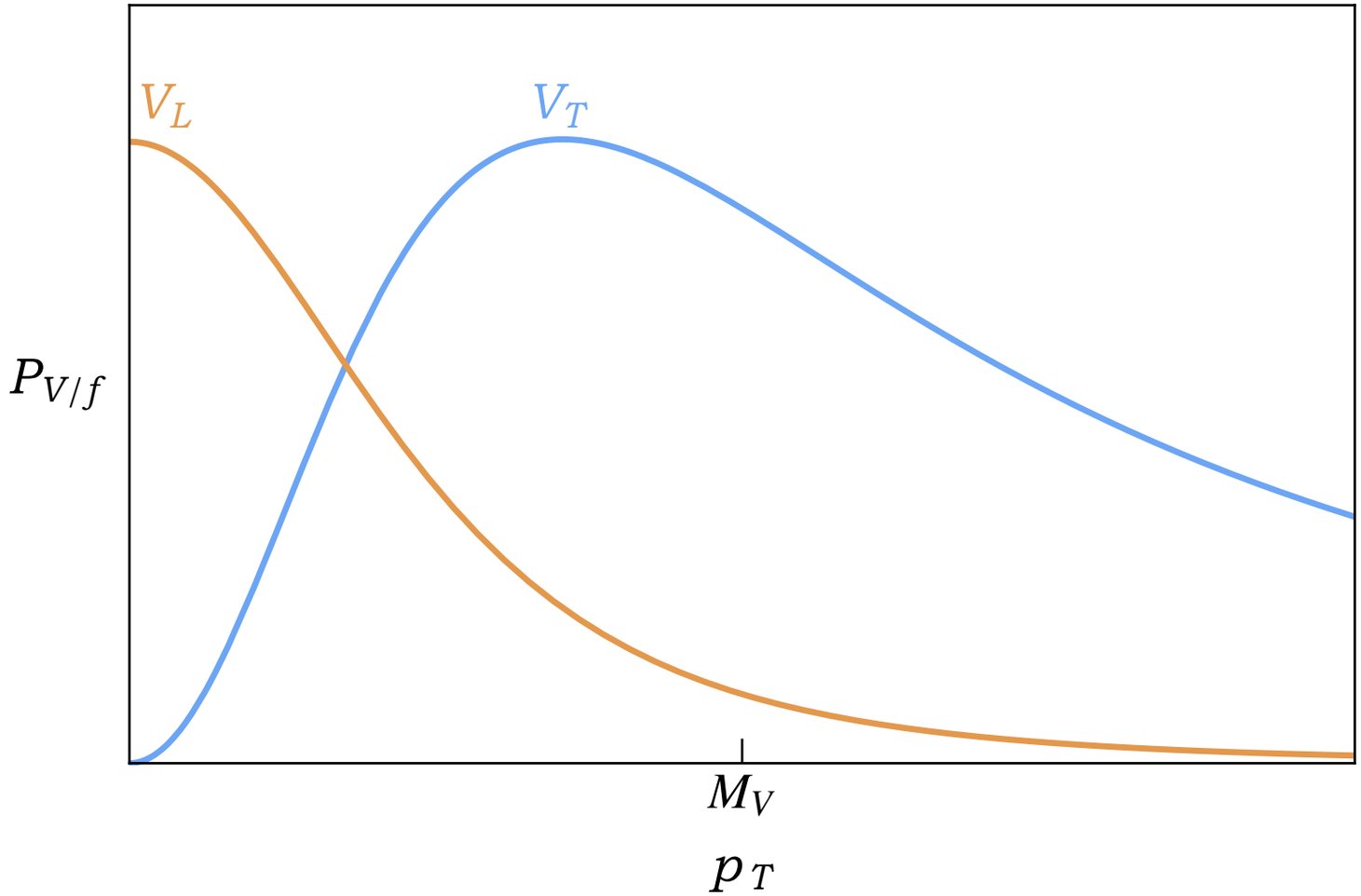

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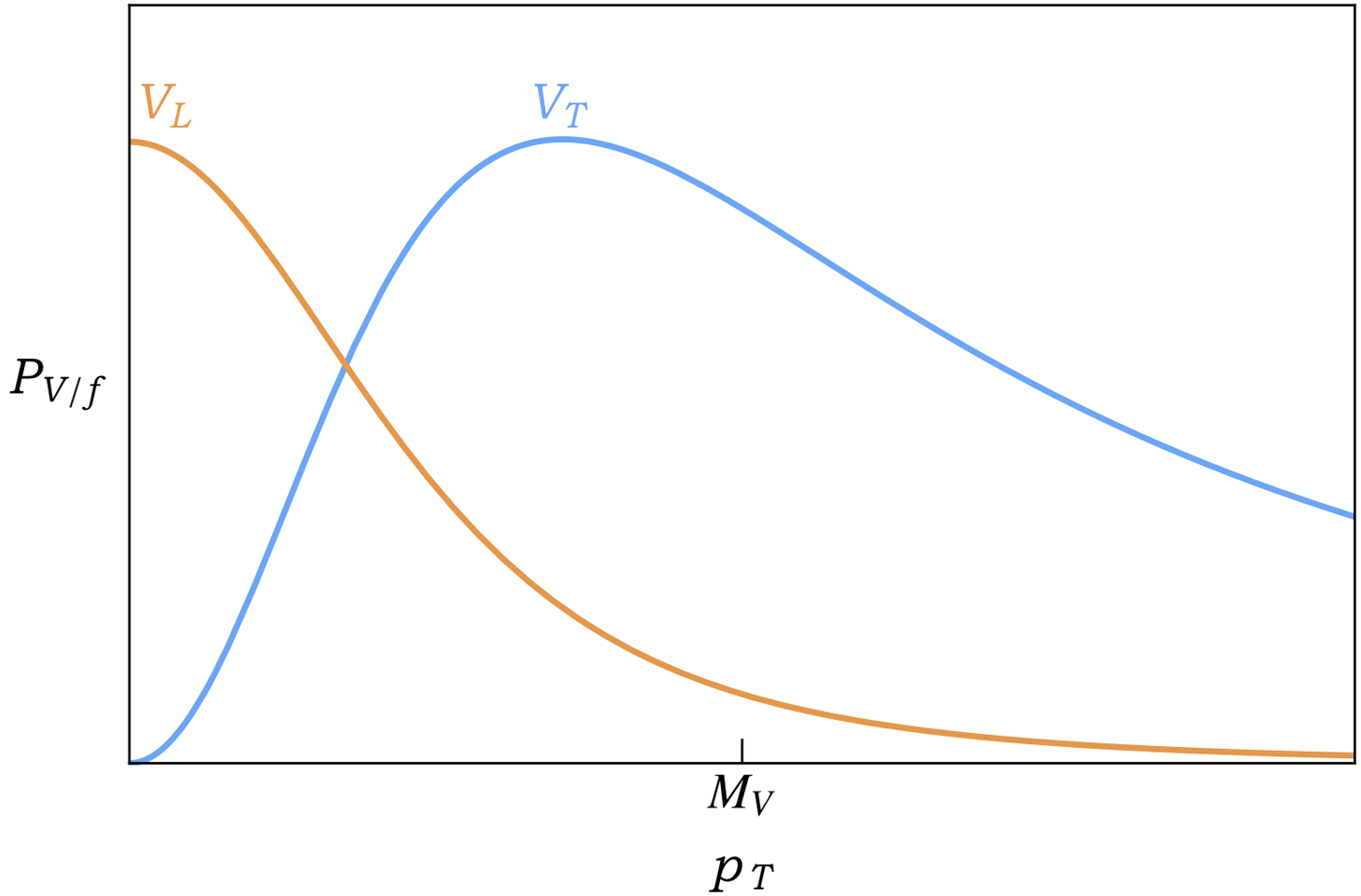

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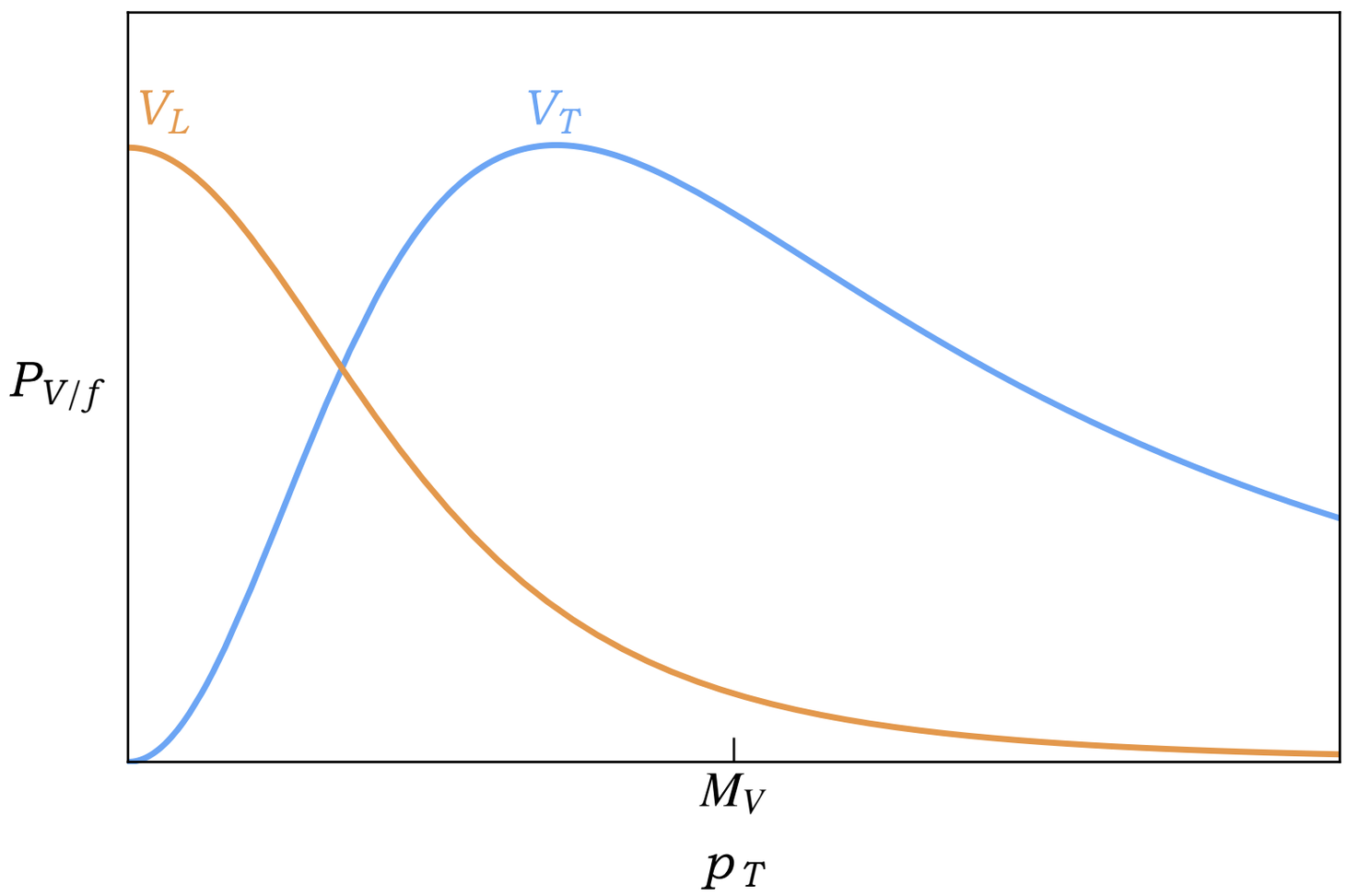
VBF kinematics
+ MET



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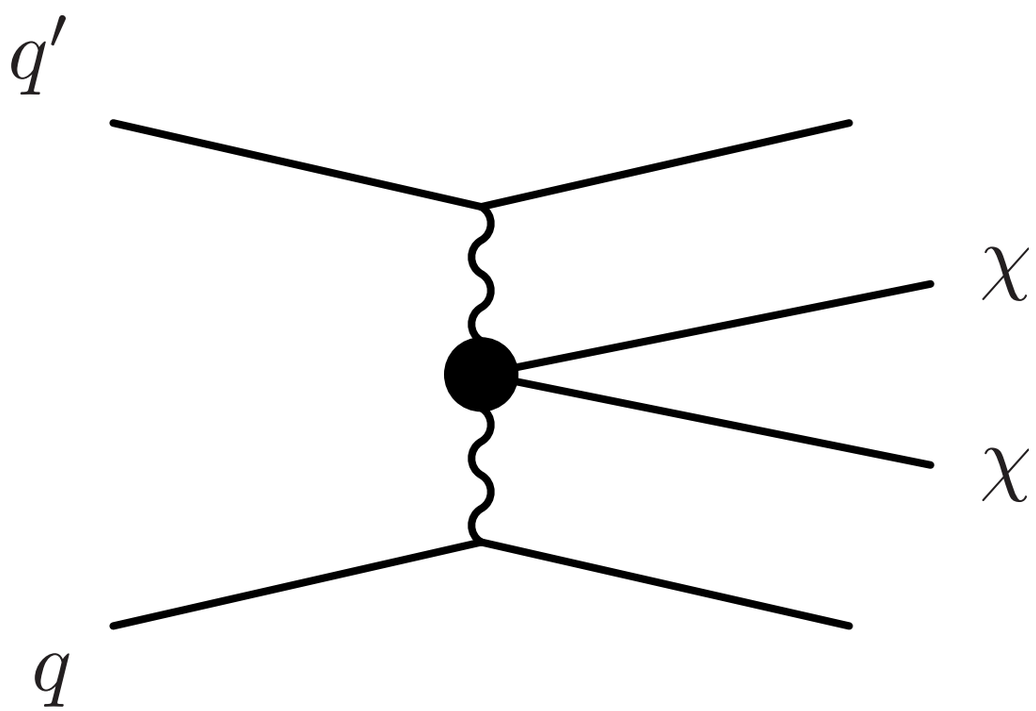
- Without Higgs, $V_L V_L \to V_L V_L$ violates unitarity at ~ TeV.
- *SM-ish* Higgs gives E^2 behavior in amplitudes.
- 2nd largest production channel for Higgs.

II. EFTs and the Higgs Portal

Effective Field Theories

Brooke et al., arXiv:1603.07739

Effective Field Theories



$$
\begin{aligned}
\mathcal{L}_{\mathrm{D5a}} &\supseteq \frac{1}{\Lambda}\left[\bar{\chi}\chi\right]\left[\frac{Z_\mu Z^\mu}{2} + W^+_\mu W^{-\mu}\right], \\
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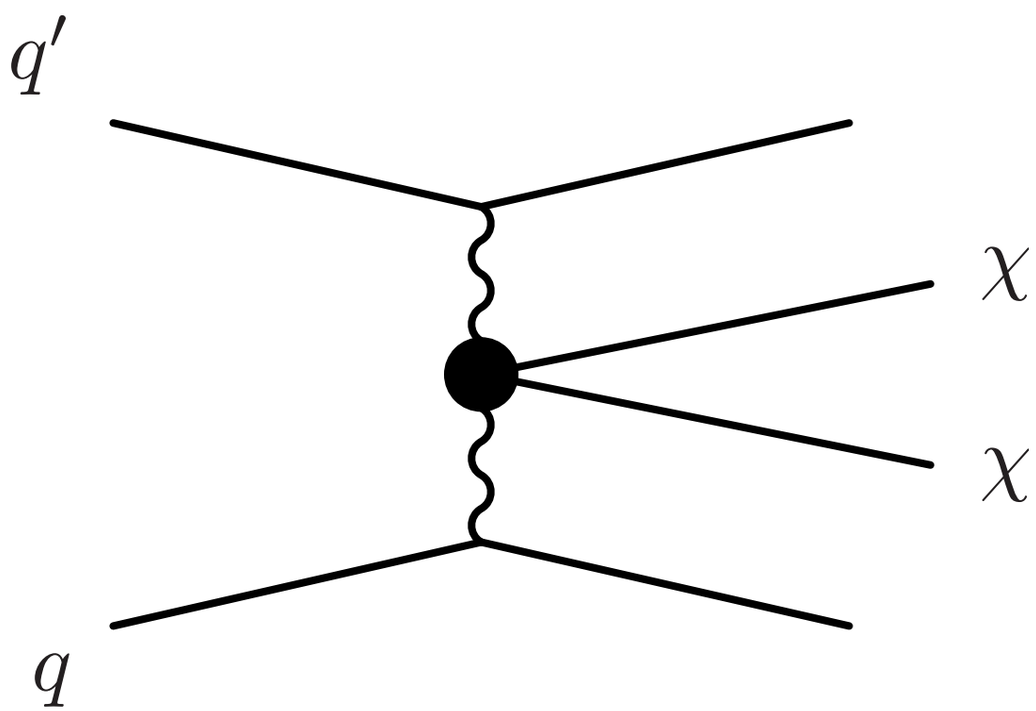
Effective Field Theories

VBF requires lower MET thresholds compared to Mono-X
$\Rightarrow$ EFT formalism is valid



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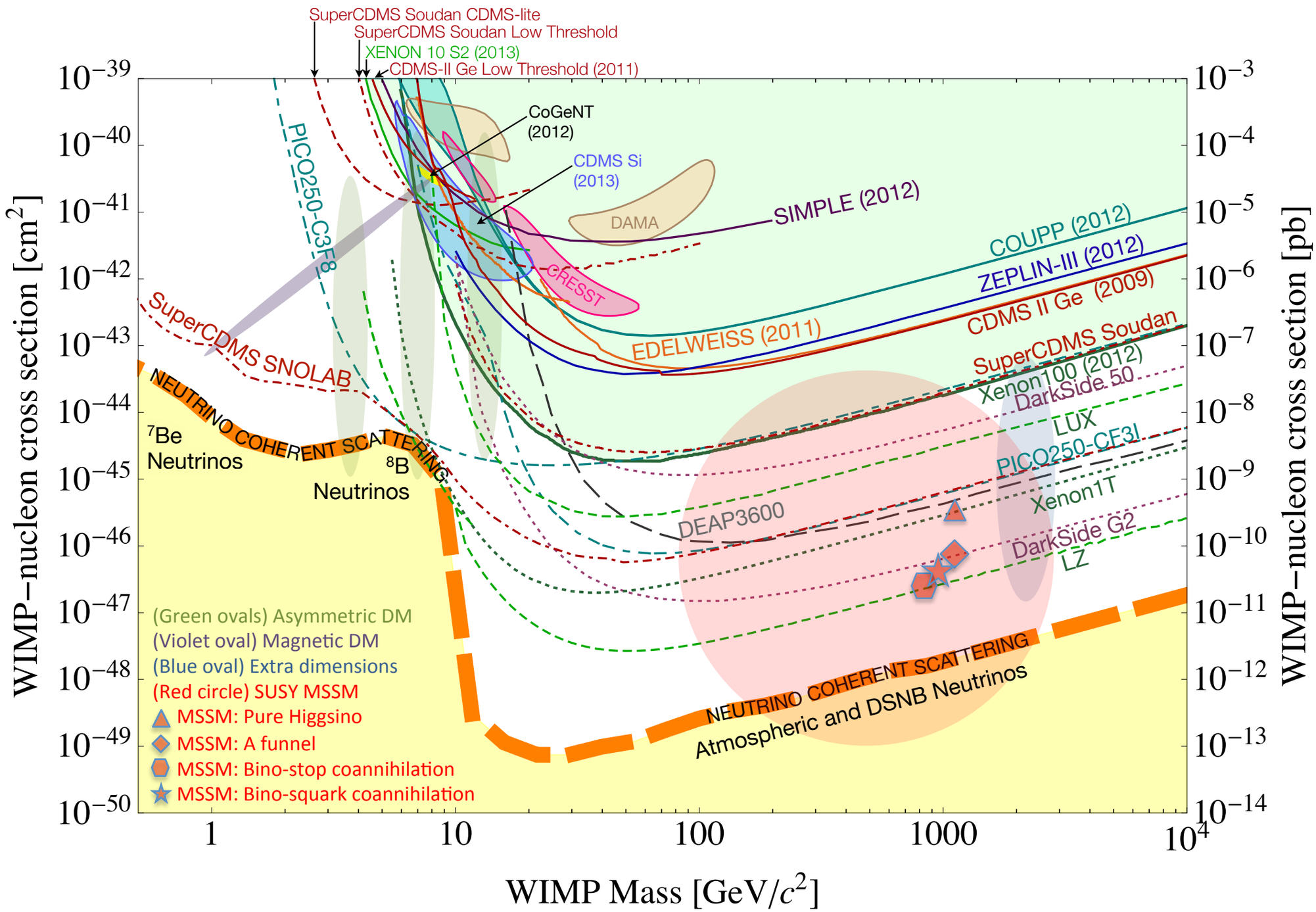
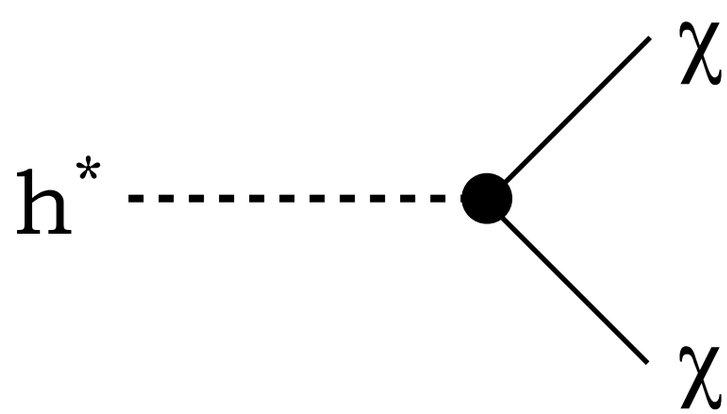
“Moore’s Law” of Direct Detection



arXiv:1310.8327

Off-Shell Production



The Simplest DM Model

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- $c_\phi \sim 1$ motivated from EW baryogenesis, naturalness.
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- VBF has good balance of signal rate and background separation.

Craig et al., arXiv:1412.0258

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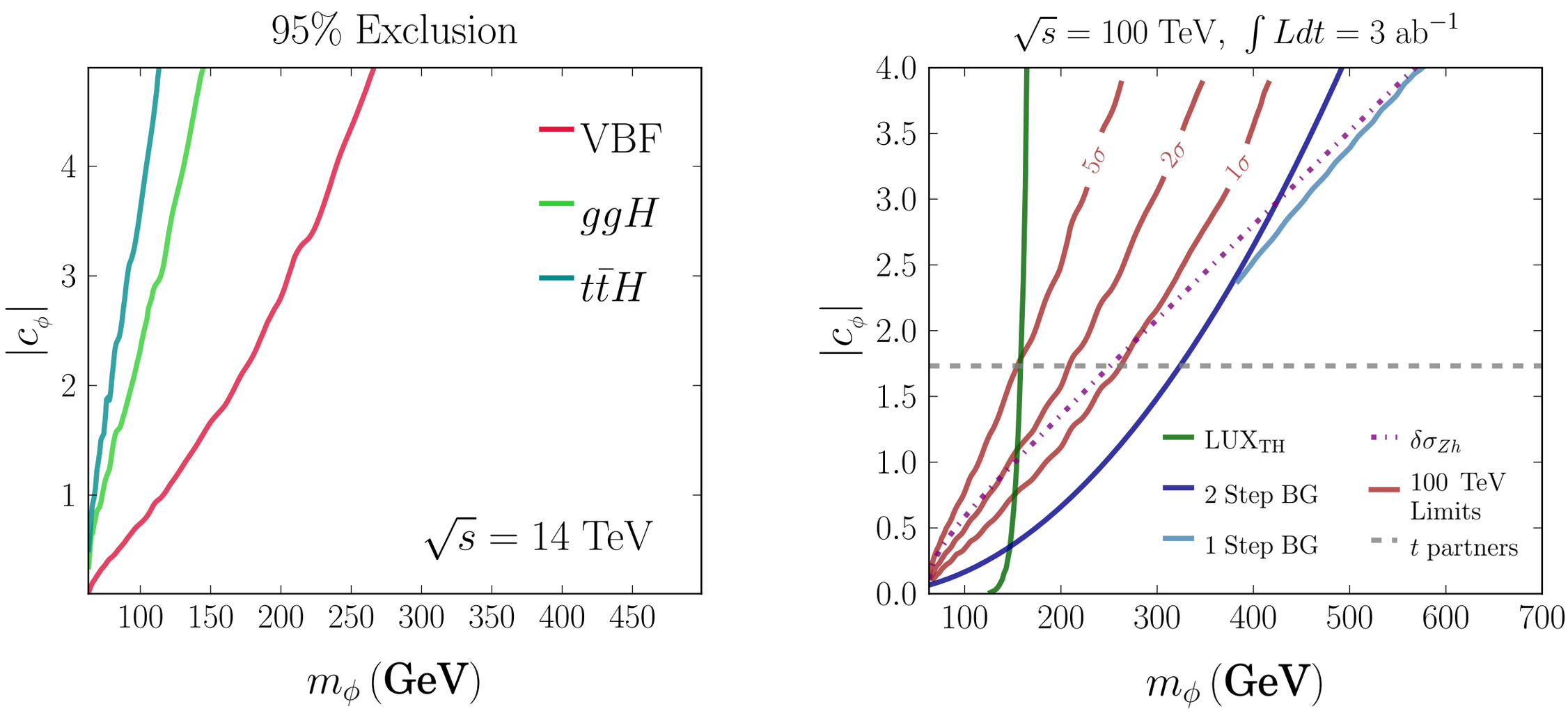

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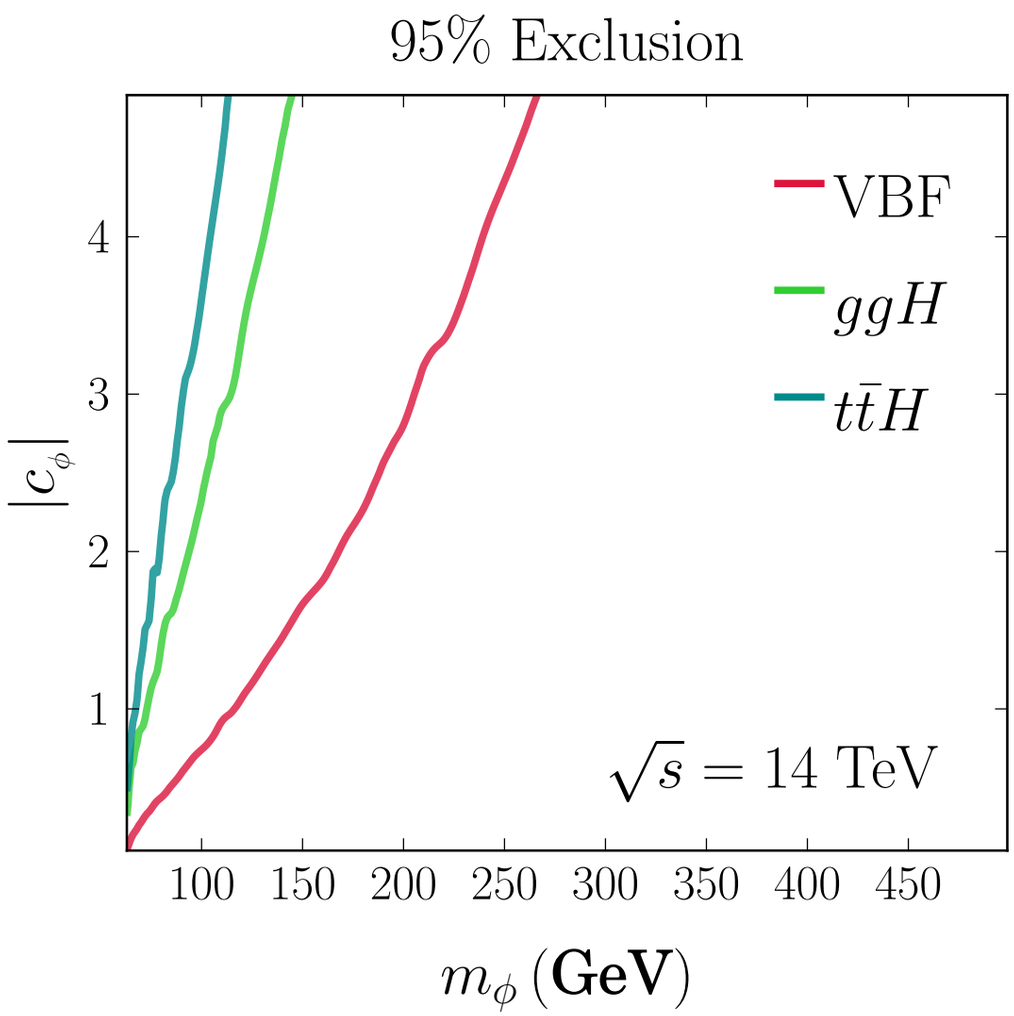

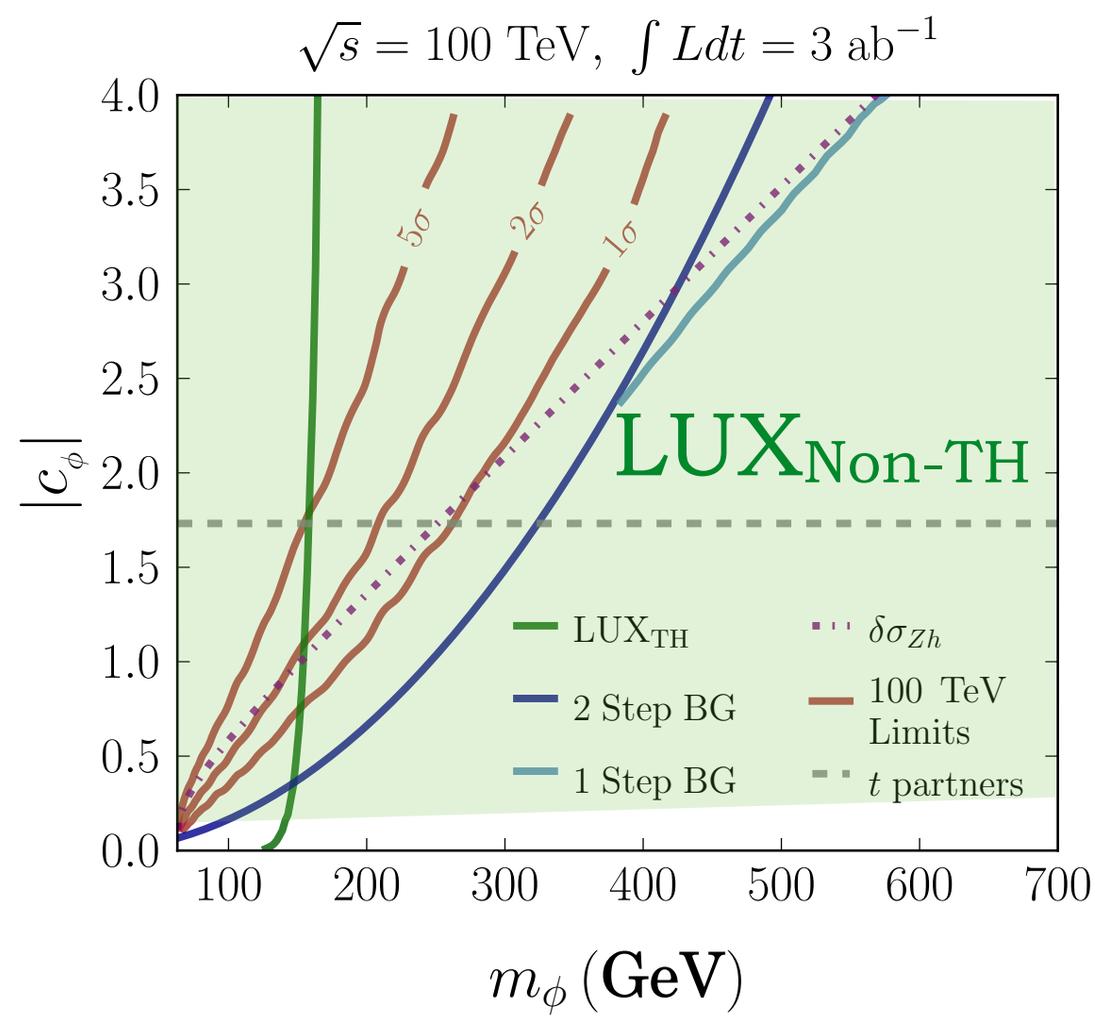

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III. Electroweakinos

Neutralinos

$$
M_{\tilde{\chi}} = \begin{array}{c}
\begin{array}{cccc} \tilde{H}_u \quad , & \tilde{H}_d \quad , & \tilde{W} \quad , & \tilde{B} \end{array} \\
\begin{pmatrix}
0 & \mu & -g_2\, v_u\,/\sqrt{2} & g_1\, v_u\,/\sqrt{2} \\
\mu & 0 & g_2\, v_d\,/\sqrt{2} & -g_1\, v_d\,/\sqrt{2} \\
-g_2\, v_u\,/\sqrt{2} & g_2\, v_d\,/\sqrt{2} & M_2 & 0 \\
g_1\, v_u\,/\sqrt{2} & -g_1\, v_d\,/\sqrt{2} & 0 & M_1
\end{pmatrix}
\end{array}
$$

1. Winos and Higgsinos

Minimal Dark Matter

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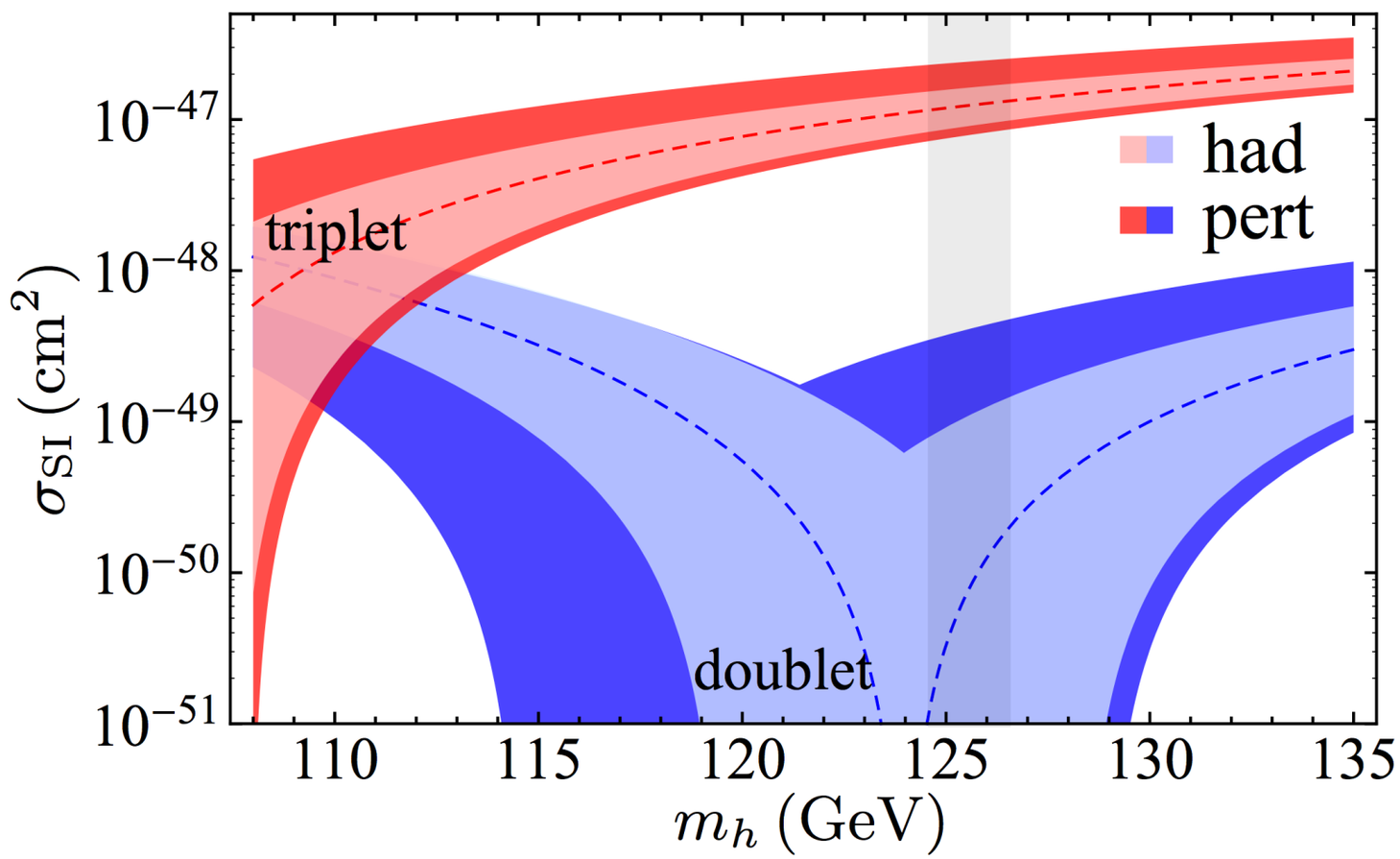
- Prospects for direct detection solely dependent on known parameters.

Direct Detection



Solon, Hill, arXiv:1309.4092

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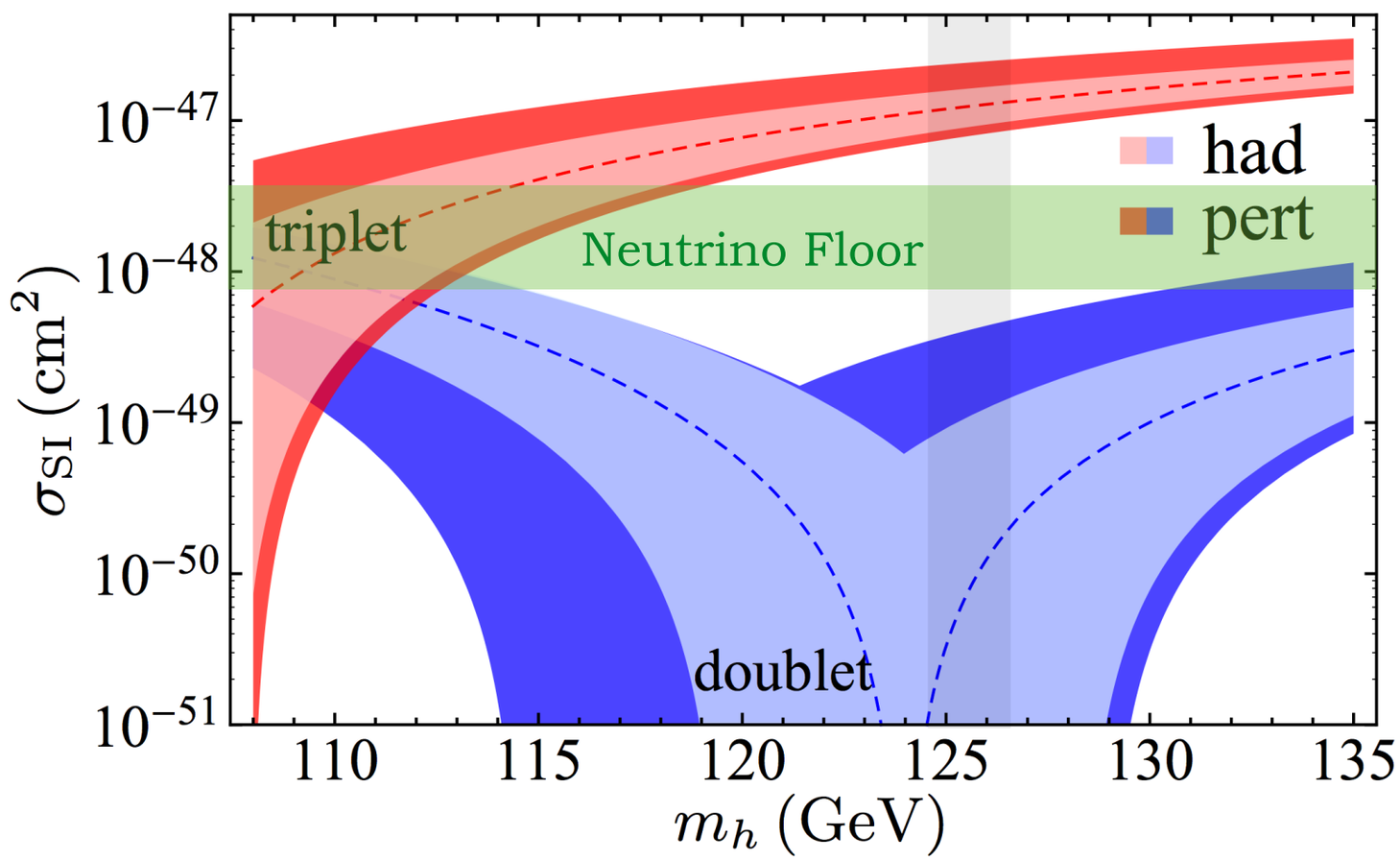

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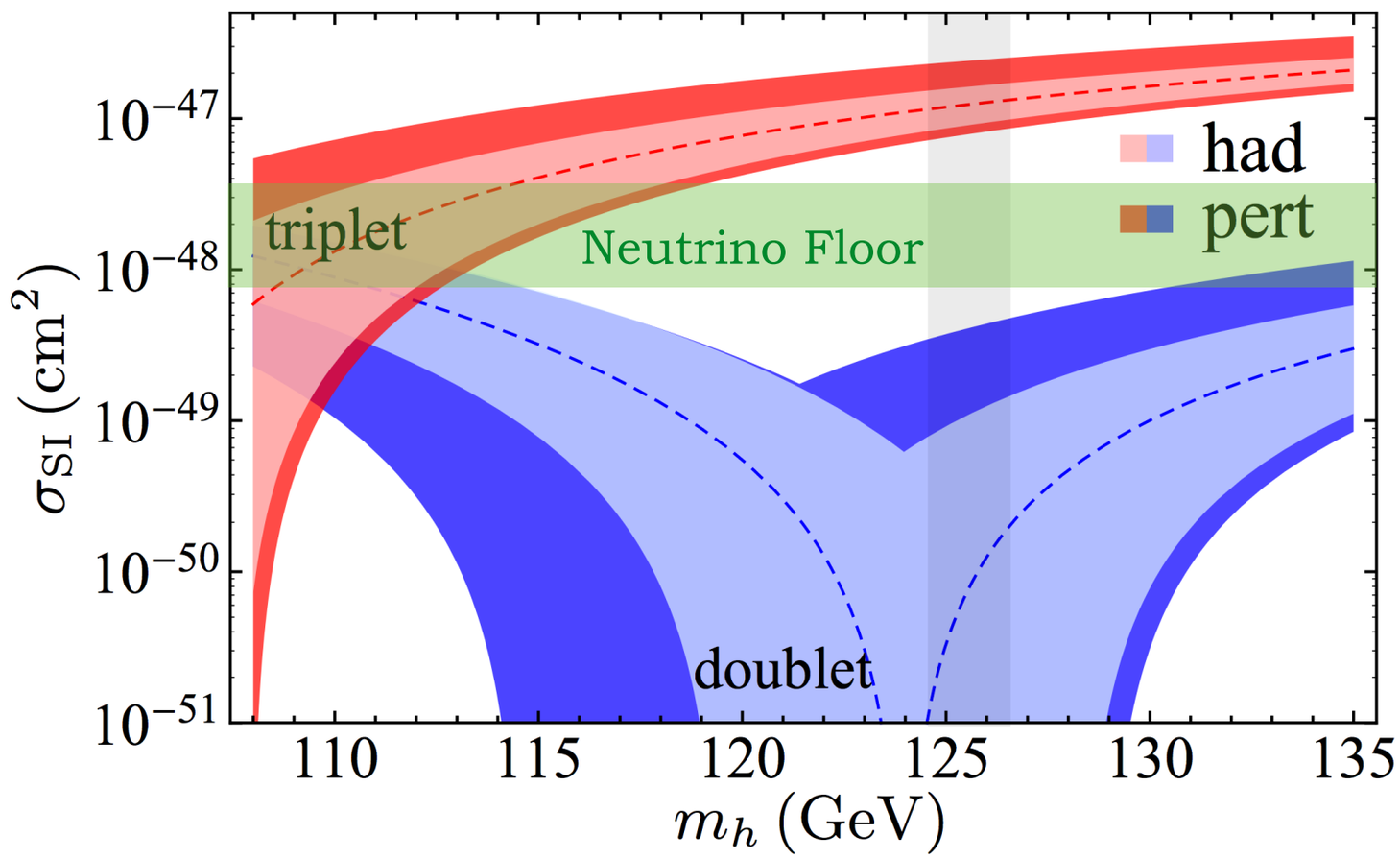
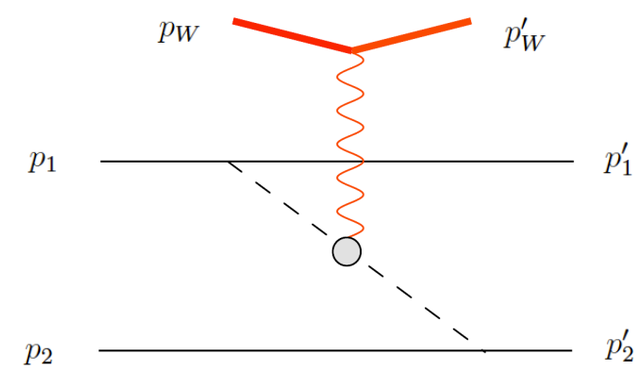


Multi-Nucleon?



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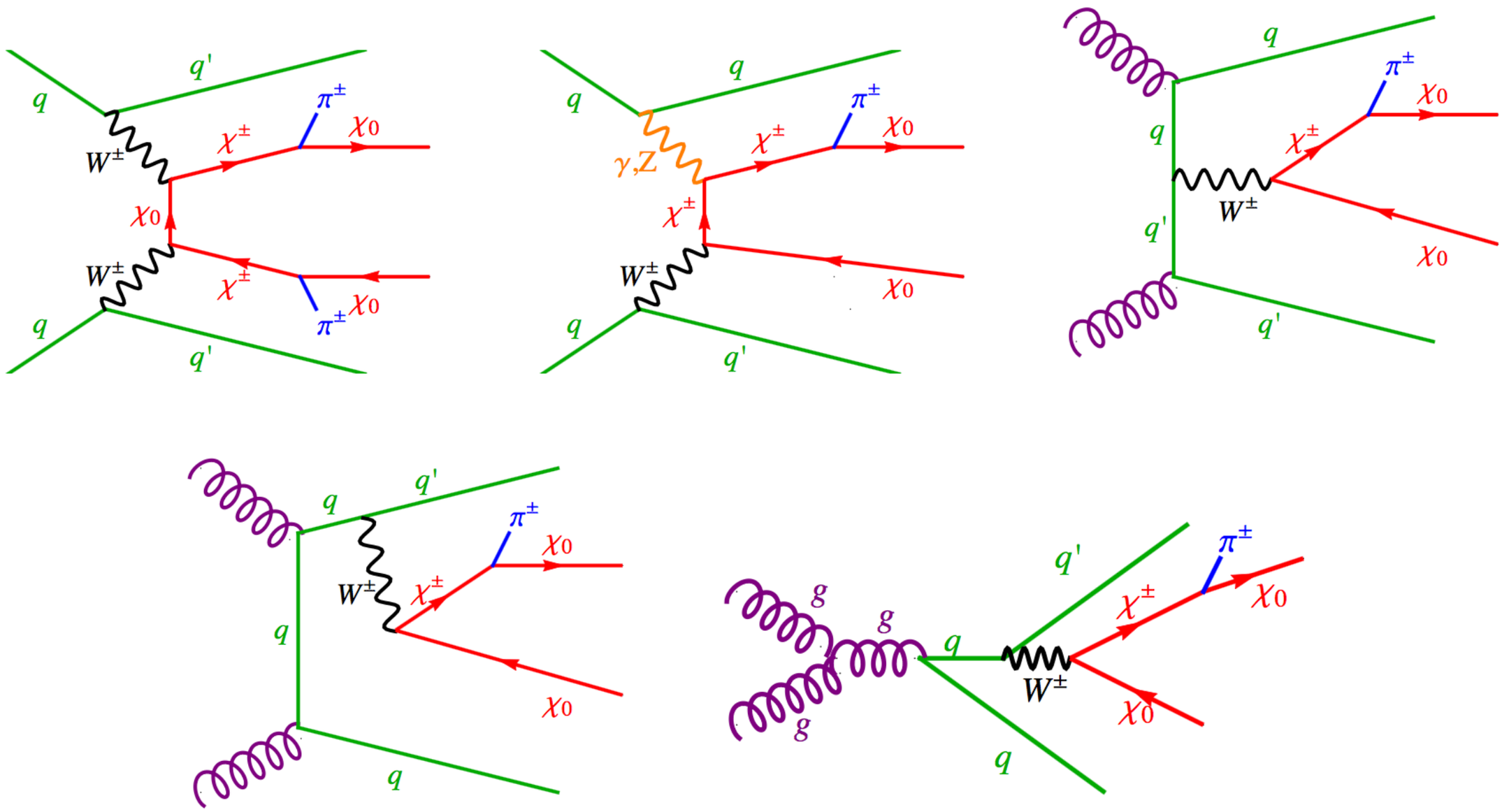
VBF Signal



Berlin, Lin, Low, Wang, arXiv:1502.05044

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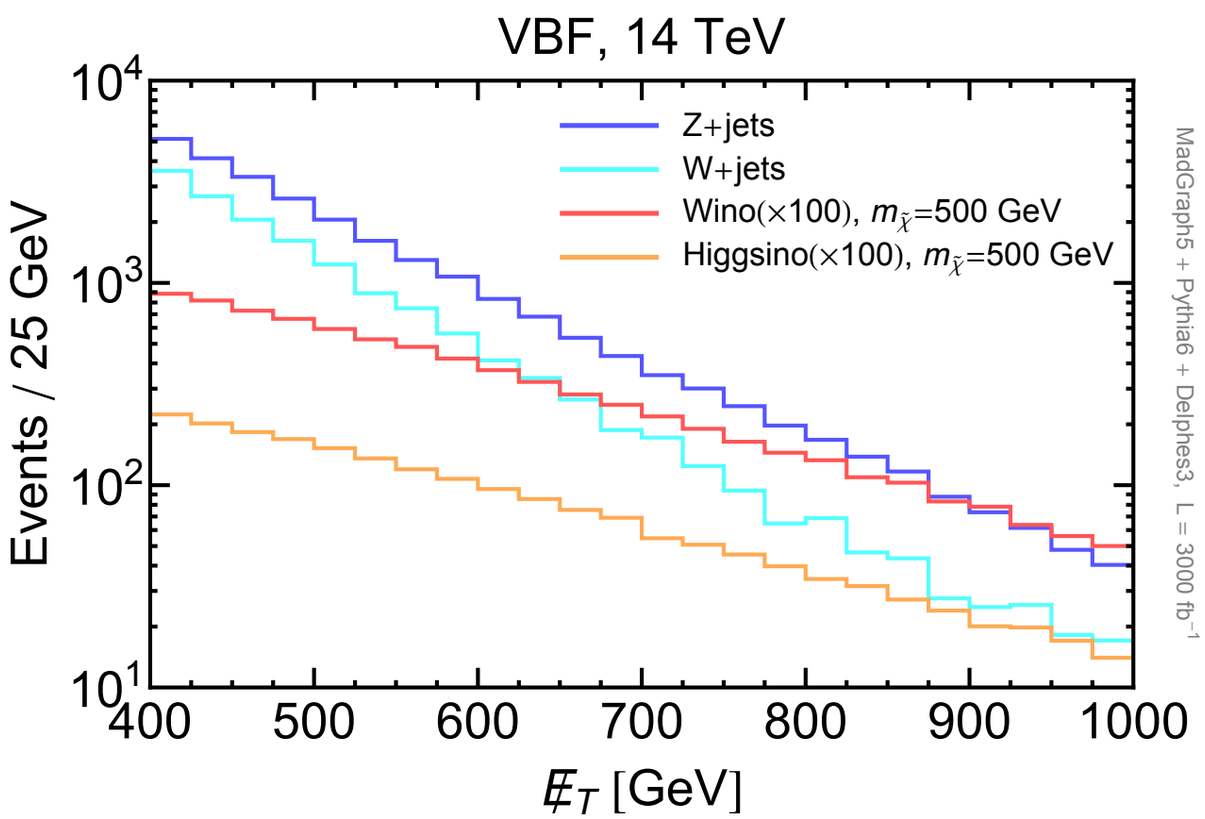

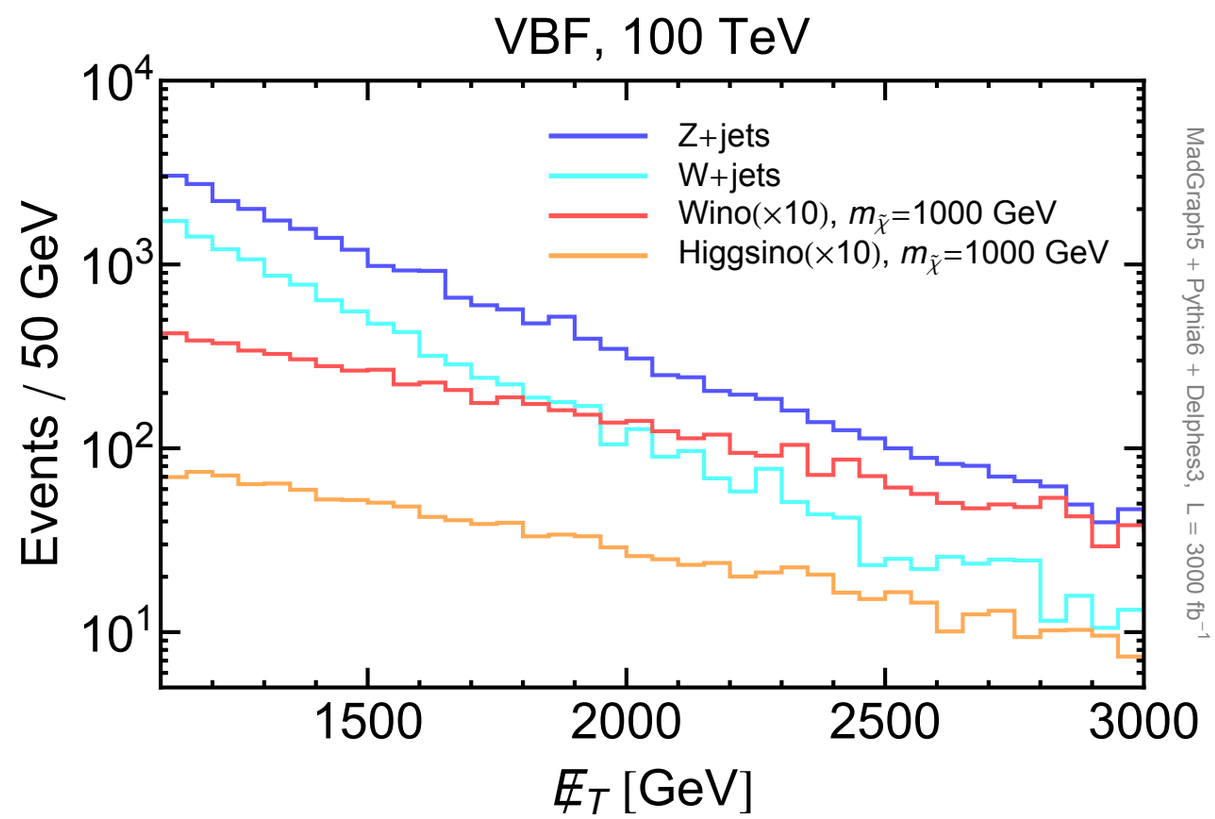

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VBF Cuts

- Backgrounds: Z+jets, W+jets, tt, QCD multijet

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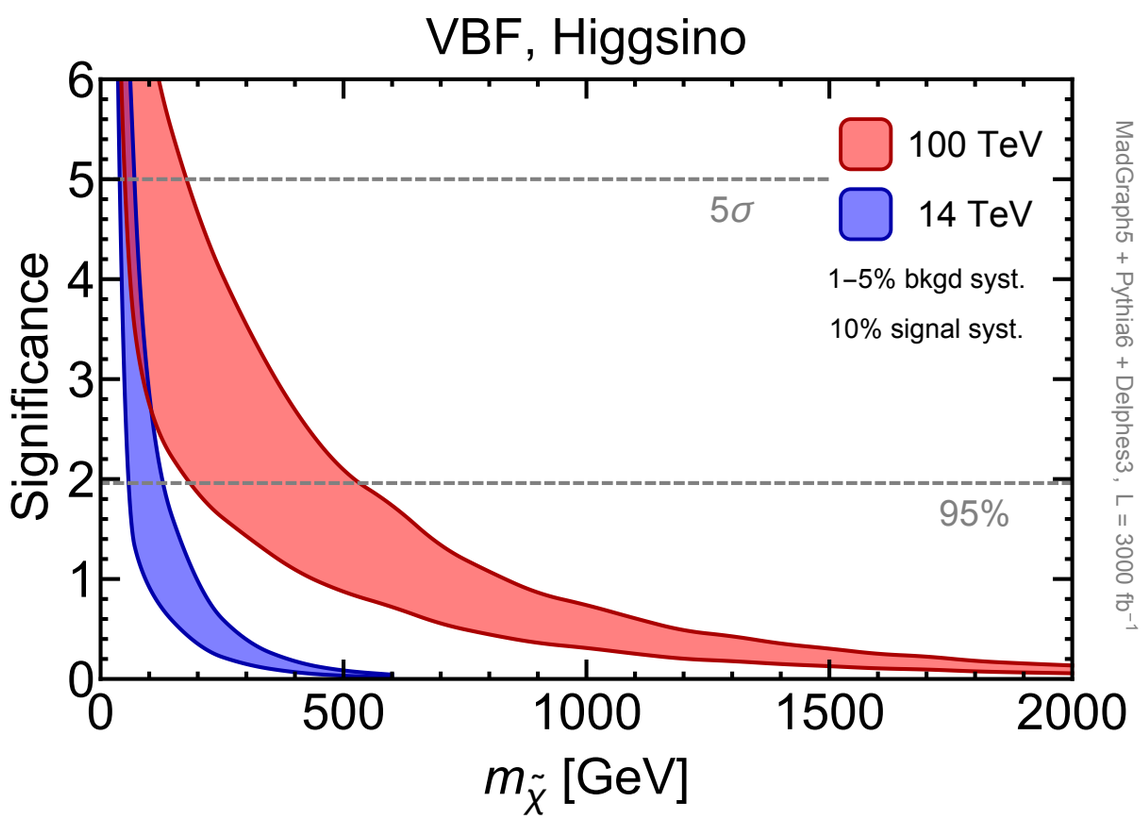
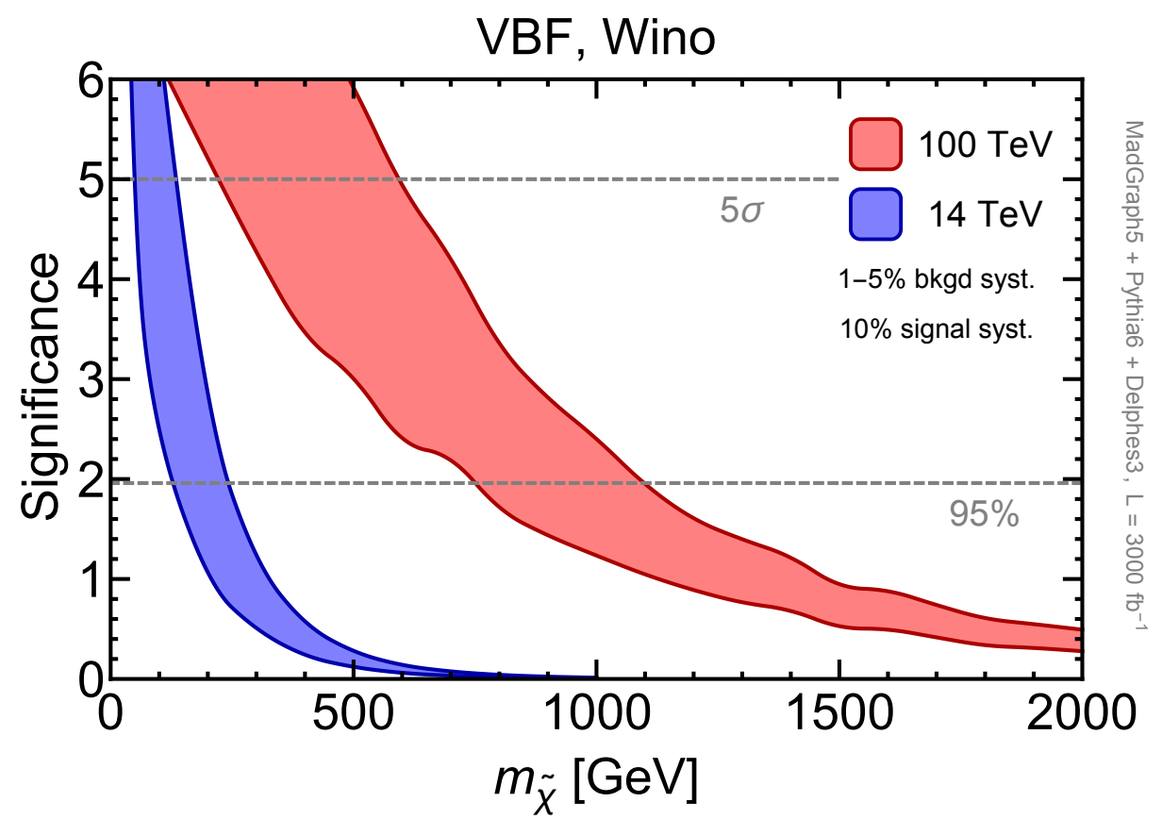
- Backgrounds: Z+jets, W+jets, tt, QCD multijet

Cut	14 TeV		100 TeV	
	Wino	Higgsino	Wino	Higgsino
n_{jet}	2	2	2	2
$\lvert\eta(j)\rvert$	5	5	7	7
$p_T(j_{\text{tag}})$ (GeV)	45	45	75	50
$\Delta\eta(j_1, j_2)$	3.75	3.75	4.25	4.25
$\Delta\phi(j_1, j_2)$	2	2	2	3
$M(j_1, j_2)$ (TeV)	2	1	10	5
$\not{E}_T$ (GeV)	400 – 700		1100 – 2500	
$p_T(j_{\text{veto}})$ (GeV)	45	45	50	50
$p_T(e, \mu)$ (GeV)	20	20	20	20
$p_T(\tau)$ (GeV)	30	30	40	40
$\eta(e)$	2.5	2.5	2.5	2.5
$\eta(\mu)$	2.1	2.1	2.1	2.1
$\eta(\tau)$	2.3	2.3	2.3	2.3

Berlin, Lin, Low, Wang, arXiv:1502.05044

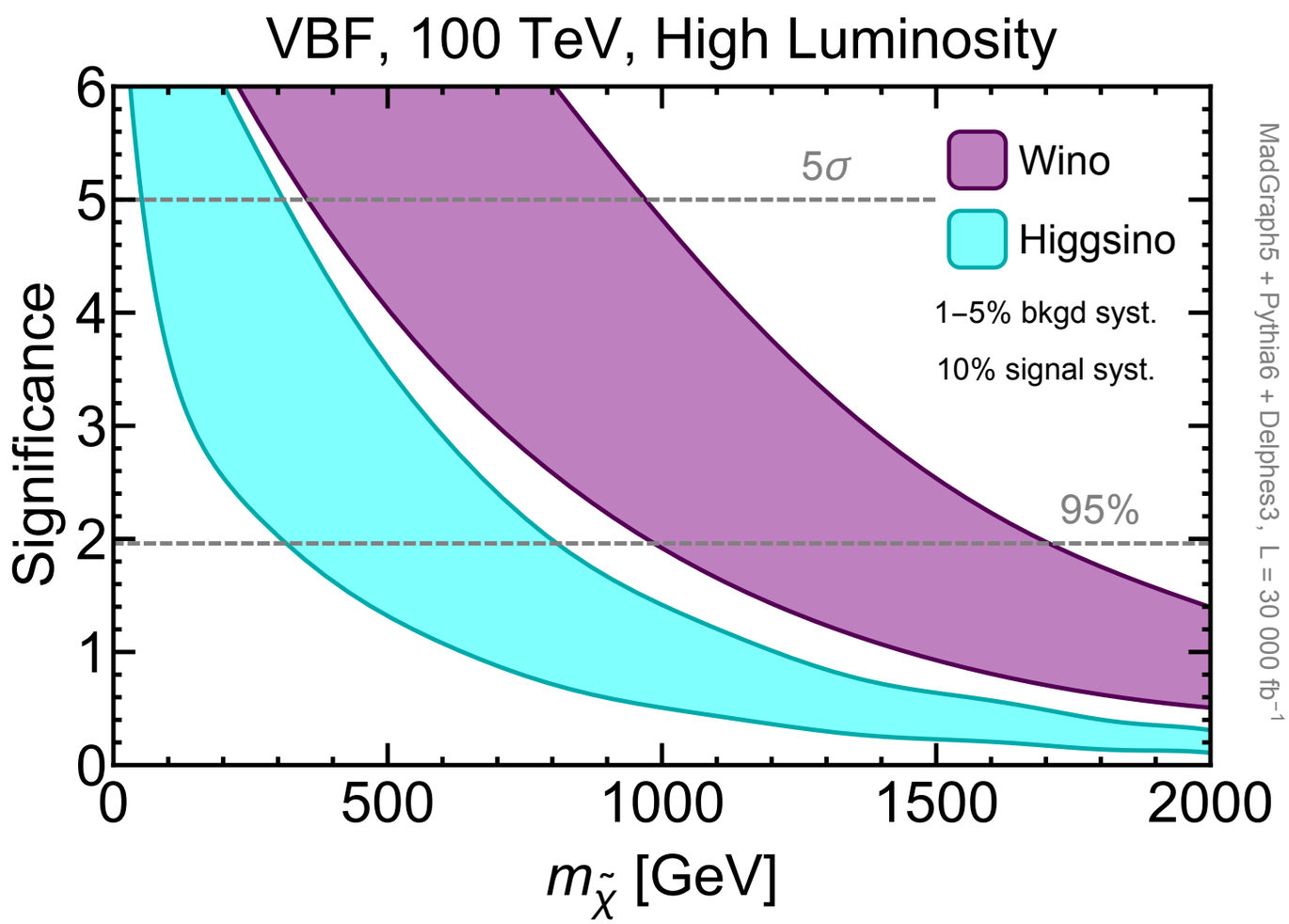
Results





Berlin, Lin, Low, Wang, arXiv:1502.05044

High Luminosity

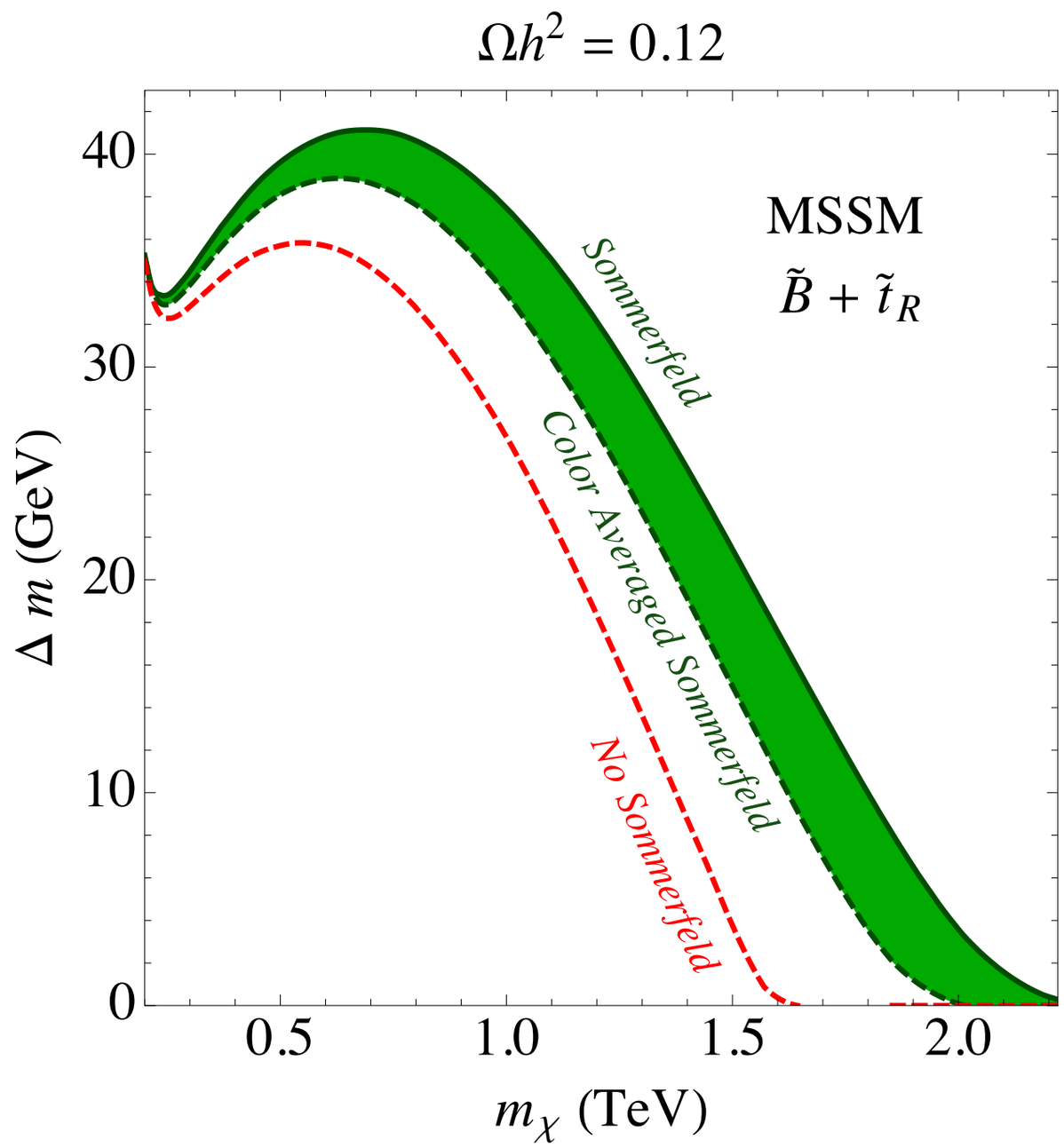


Berlin, Lin, Low, Wang, arXiv:1502.05044

2. Binos

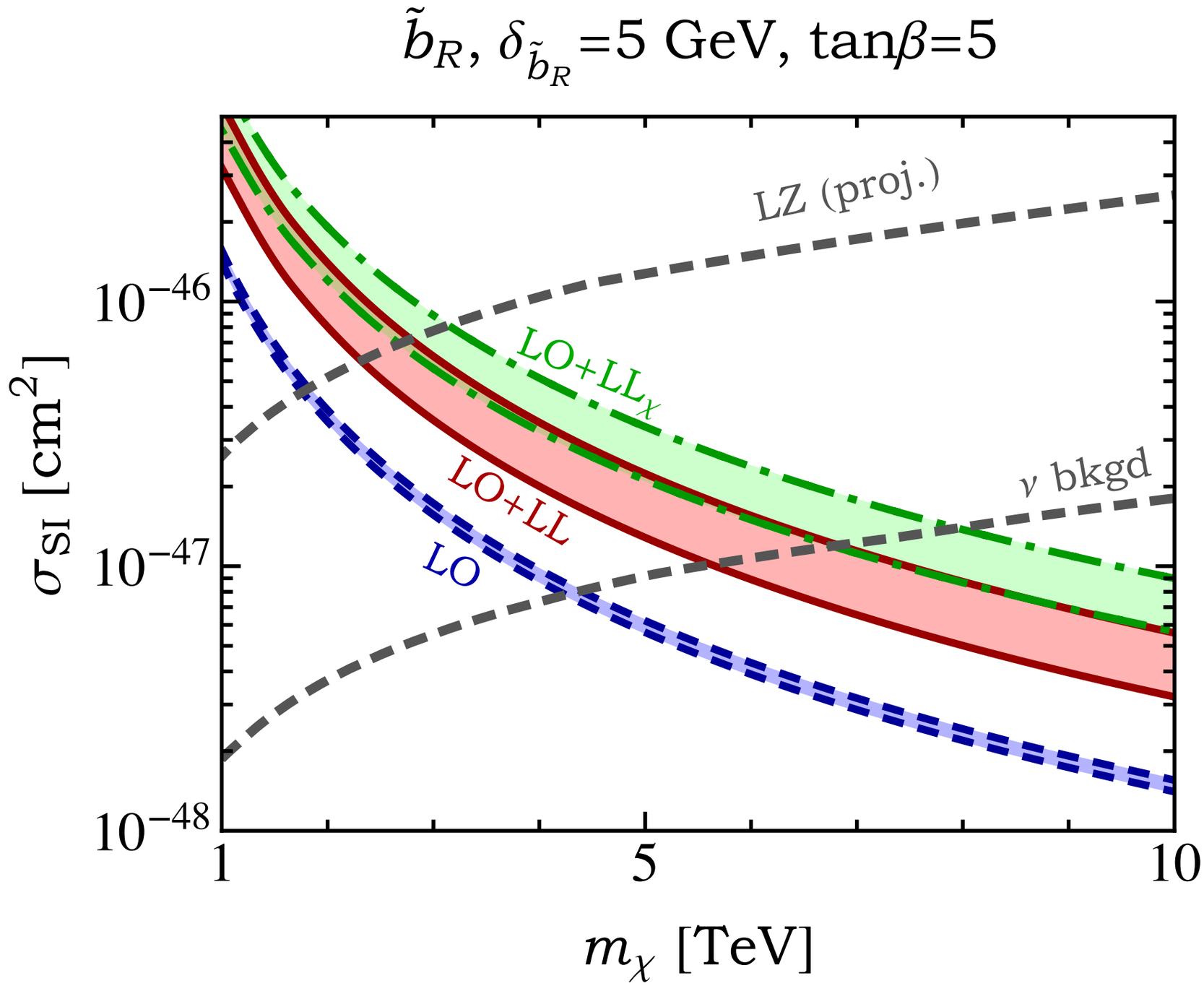
Cosmology

Motivates small mass splittings.



Ibarra, Pierce, Shah, Vogl, arXiv:1501.03164

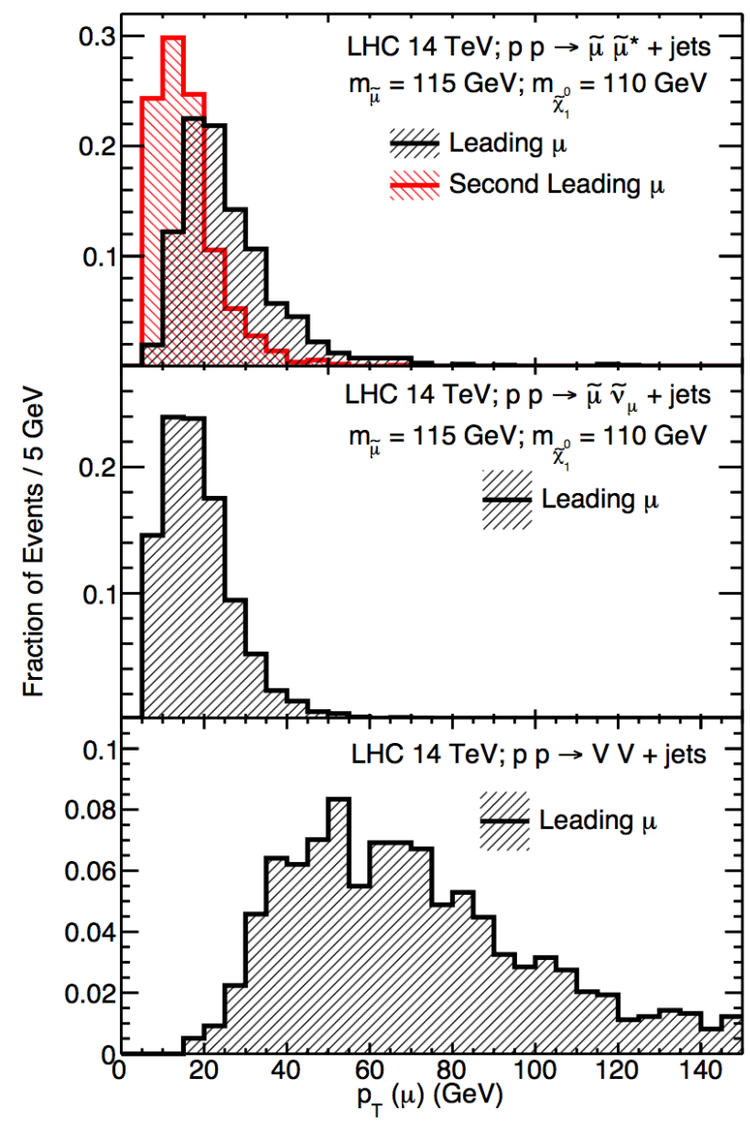
Direct Detection



AB, D. Robertson, M. Solon, K. Zurek, arXiv:1511.05964

VBF Signal

- Compressed bino-slepton spectra difficult to probe with direct searches.
- VBF jets + MET + central leptons
- Mass reach of O(100) GeV binos



Dutta et al. arXiv:1411.6043

Conclusions

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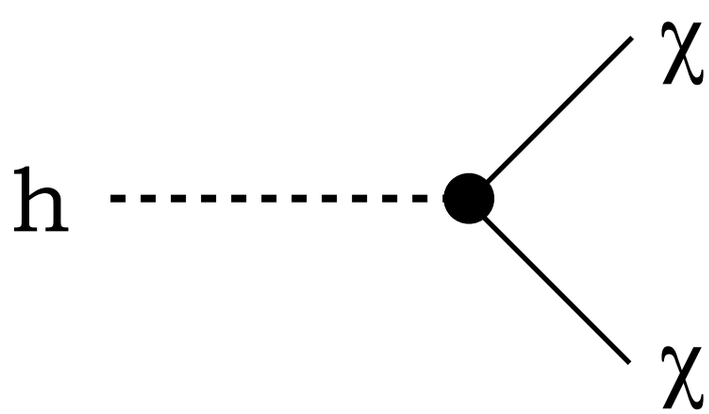
- Most powerful direct probe for off-shell production.
- Consistent EFT models of dark matter at Run 2.
- Complementary (but not most sensitive) channel for electroweakinos.
- Tagging additional central activity is an interesting alternative.

Backup Slides

On-Shell Production



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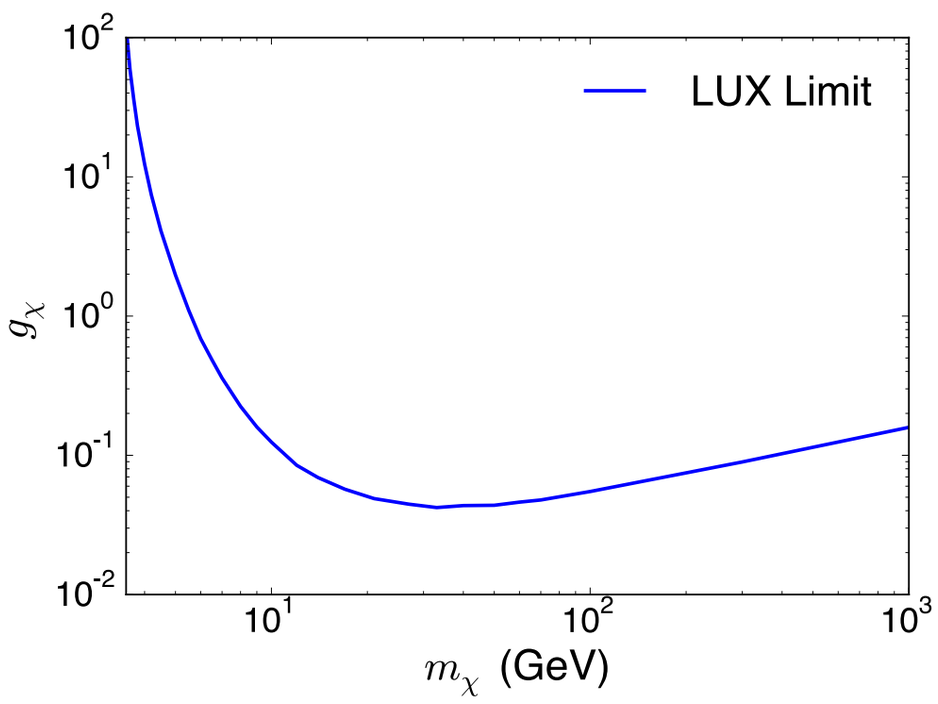

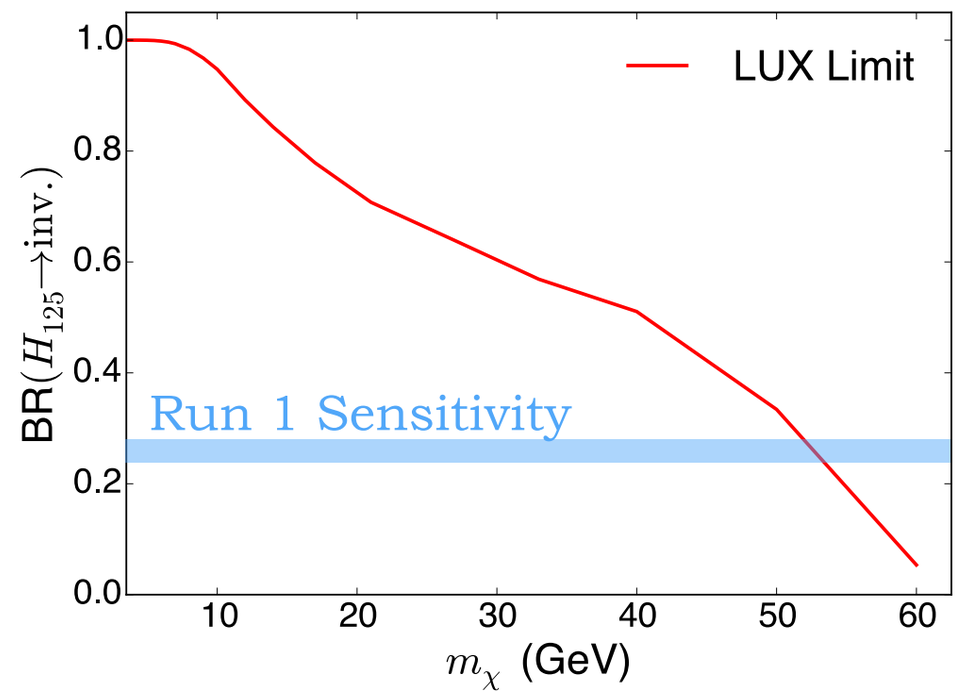

Brooke et al., arXiv:1603.07739

VBF Production On-Shell

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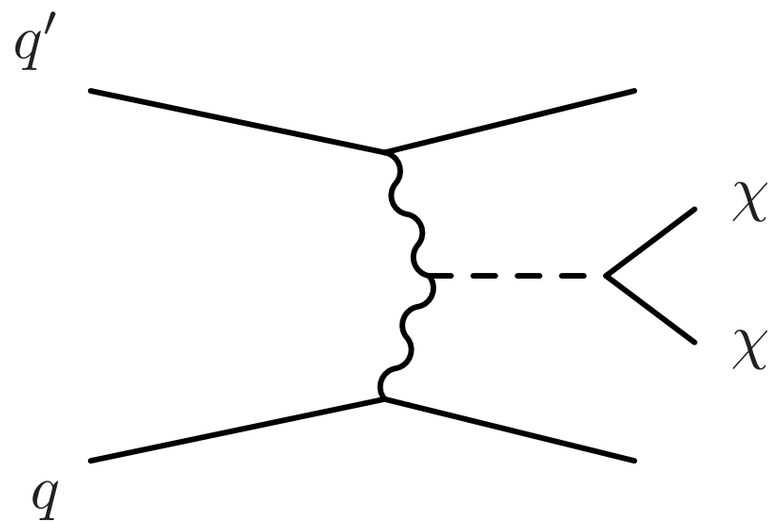
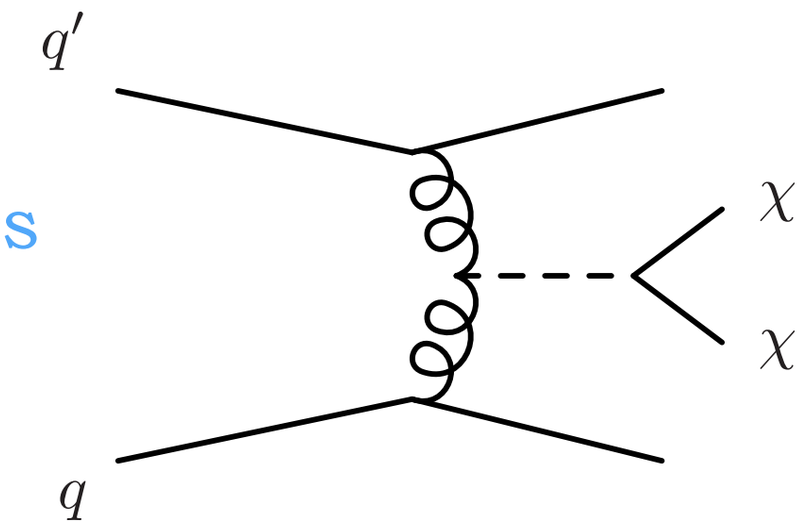
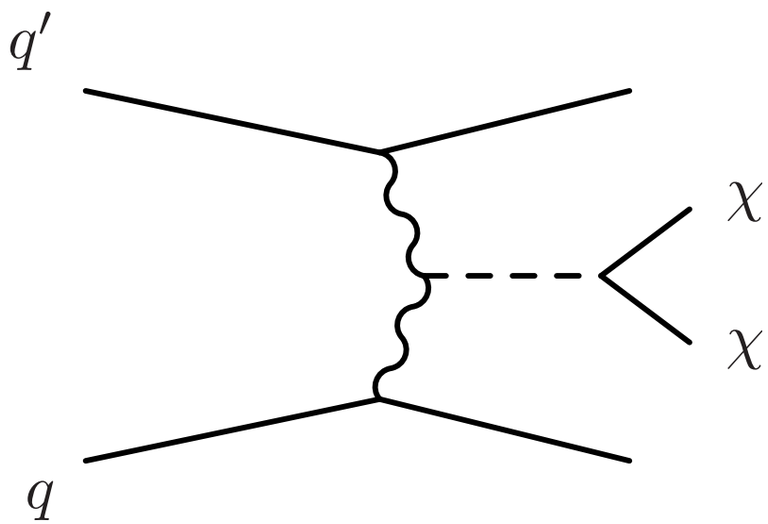


VBF kinematics
+ MET

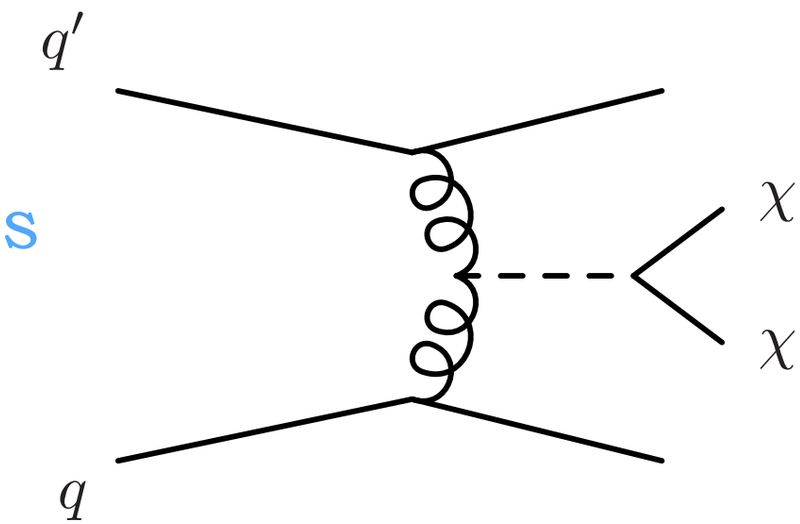


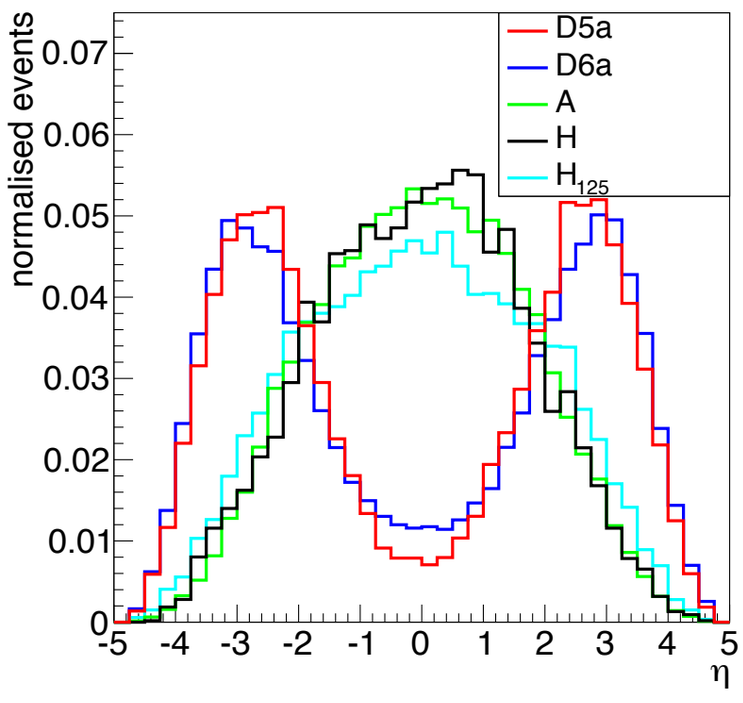
Brooke et al., arXiv:1603.07739

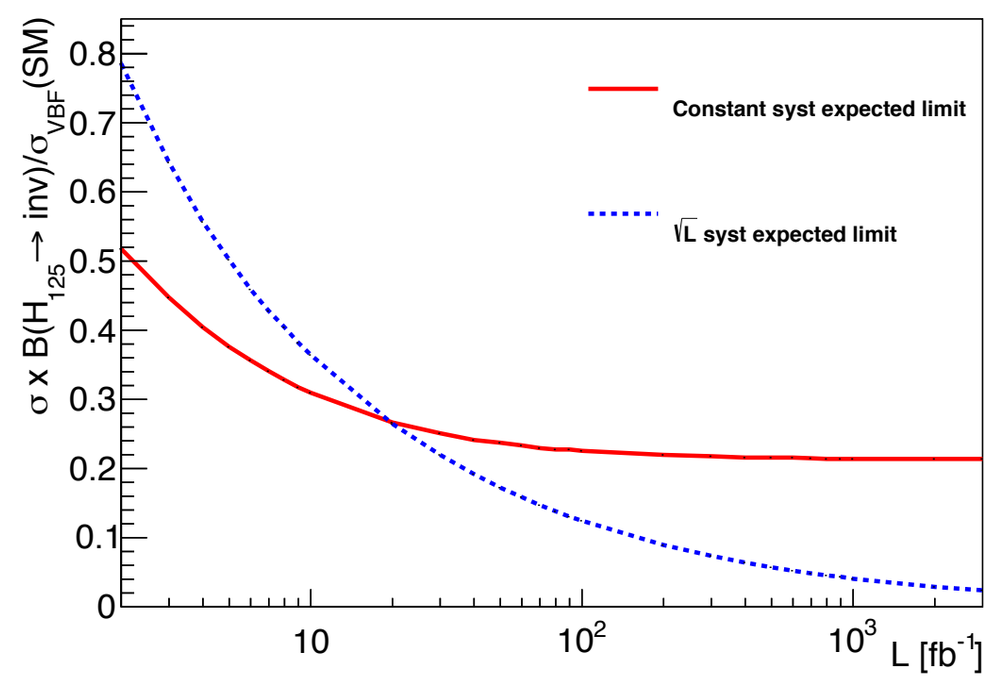
VBF Production On-Shell



VBF kinematics
+ MET







Brooke et al., arXiv:1603.07739

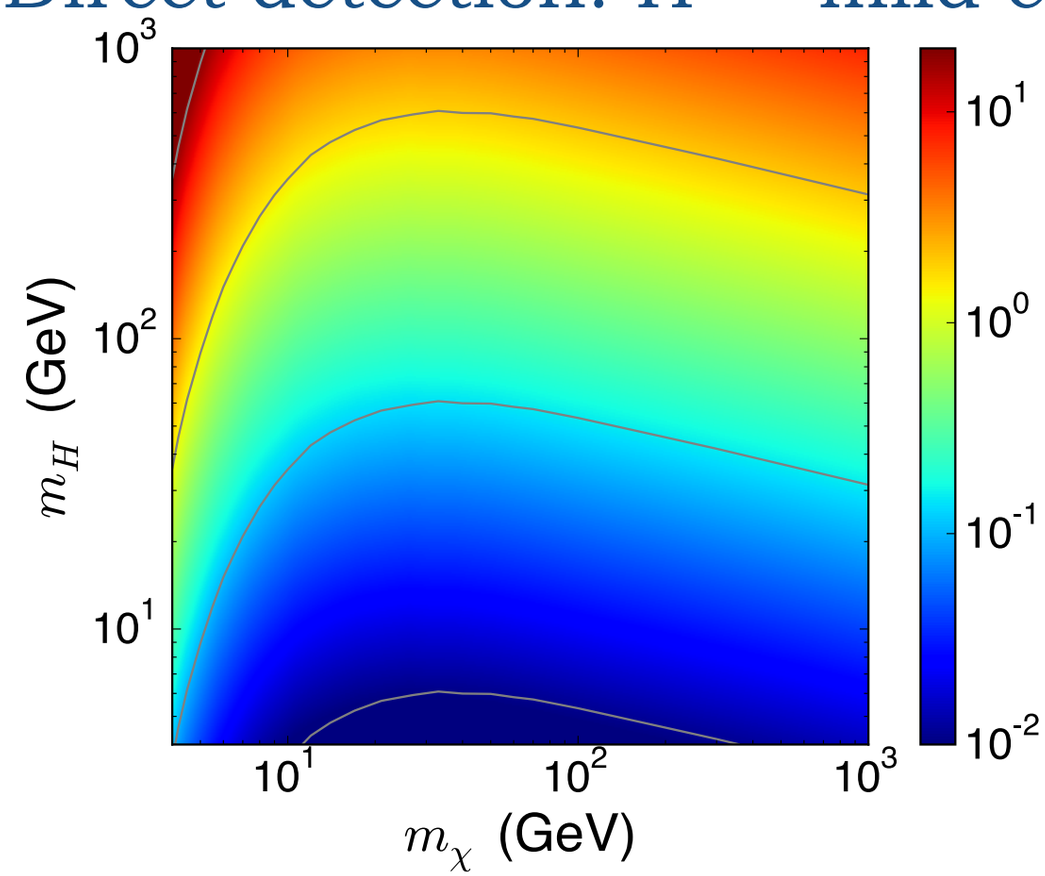
(non-SM) Higgs Portal Dark Matter

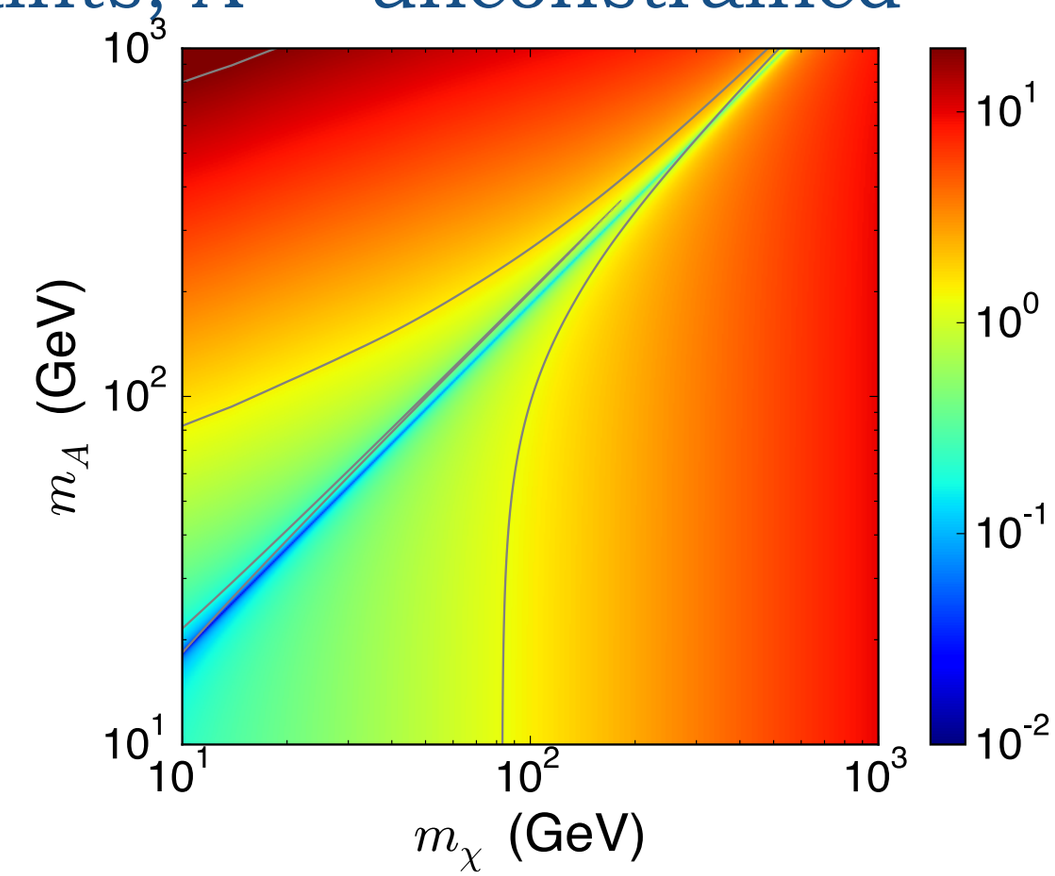
- Simplified Models: $\mathcal{L} \supset g_\chi \, H \, \overline{\chi} \chi + g_\chi \, H \sum_f y_f \, \bar{f} f$

No couplings to W,Z

$$\mathcal{L} \supset g_\chi \, A \, \overline{\chi} i\gamma^5 \chi + g_\chi \, A \sum_f y_f \, \bar{f} i\gamma^5 f$$

- Indirect detection: H → unconstrained, A → mild constraints
- Direct detection: H → mild constraints, A → unconstrained





Brooke et al., arXiv:1603.07739