# Dark matter (DM) gauge boson couplings

Uli Haisch, University of Oxford, 16th January 2015

based on Crivellin, UH & Hibbs, 1501.00907

[see also Cotta et al., 1210.0525; Carpenter et al., 1212.3352; Nelson et al., 1307.5064; Lopez et al.,1403.6734; ATLAS, 1404.0051]

# Motivation

"The weakness of interactions is often understood in field theory as a sign that the corresponding operators are irrelevant. Consequently, the "darkness" of DM may be naturally interpreted as a consequence of DM having only irrelevant interactions with light, and more generally with the electroweak gauge bosons."

[Liu et al., 1303.4404]

# Motivation

In fact, in case of Majorana DM, dimension-5 operators of dipole type are absent, so leading $SU(2)_L \times U(1)_Y$ invariant interactions of DM with photons are dimension 7:

$$\mathcal{L}_{\text{eff}} = \sum_{k=B,W,\tilde{B},\tilde{W}} \frac{C_k(\mu)}{\Lambda^3} O_k$$

$$O_B = \bar{\chi}\chi\, B_{\mu\nu}B^{\mu\nu}\,, \qquad O_W = \bar{\chi}\chi\, W^i_{\mu\nu}W^{i,\mu\nu}\,,$$

$$O_{\tilde{B}} = \bar{\chi}\chi\, B_{\mu\nu}\tilde{B}^{\mu\nu}\,, \qquad O_{\tilde{W}} = \bar{\chi}\chi\, W^i_{\mu\nu}\tilde{W}^{i,\mu\nu}$$

# Motivation

Latter operators special:

- annihilation into photon pairs velocity suppressed
  → indirect detection probably never provide limits
- DM-nucleon interactions loop suppressed
  → present direct detection bounds quite weak†
- for $m_\chi < O(100\ \text{GeV})$ relic density too large
  → additional operators or dark sector structure

†for future sensitivity see [Crivellin & UH, 1408.5046]

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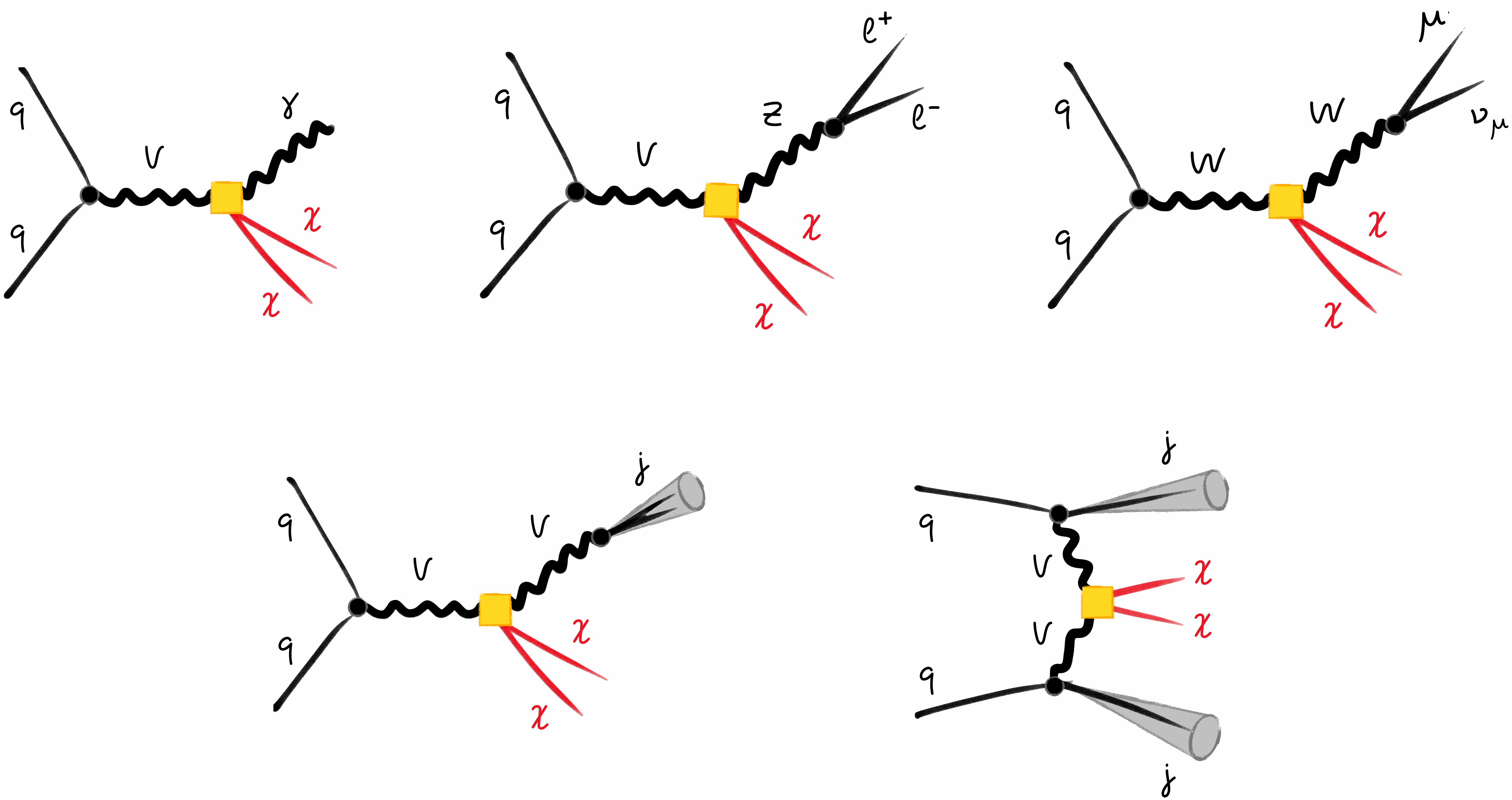
  → present direct detection bounds quite weak$^\dagger$

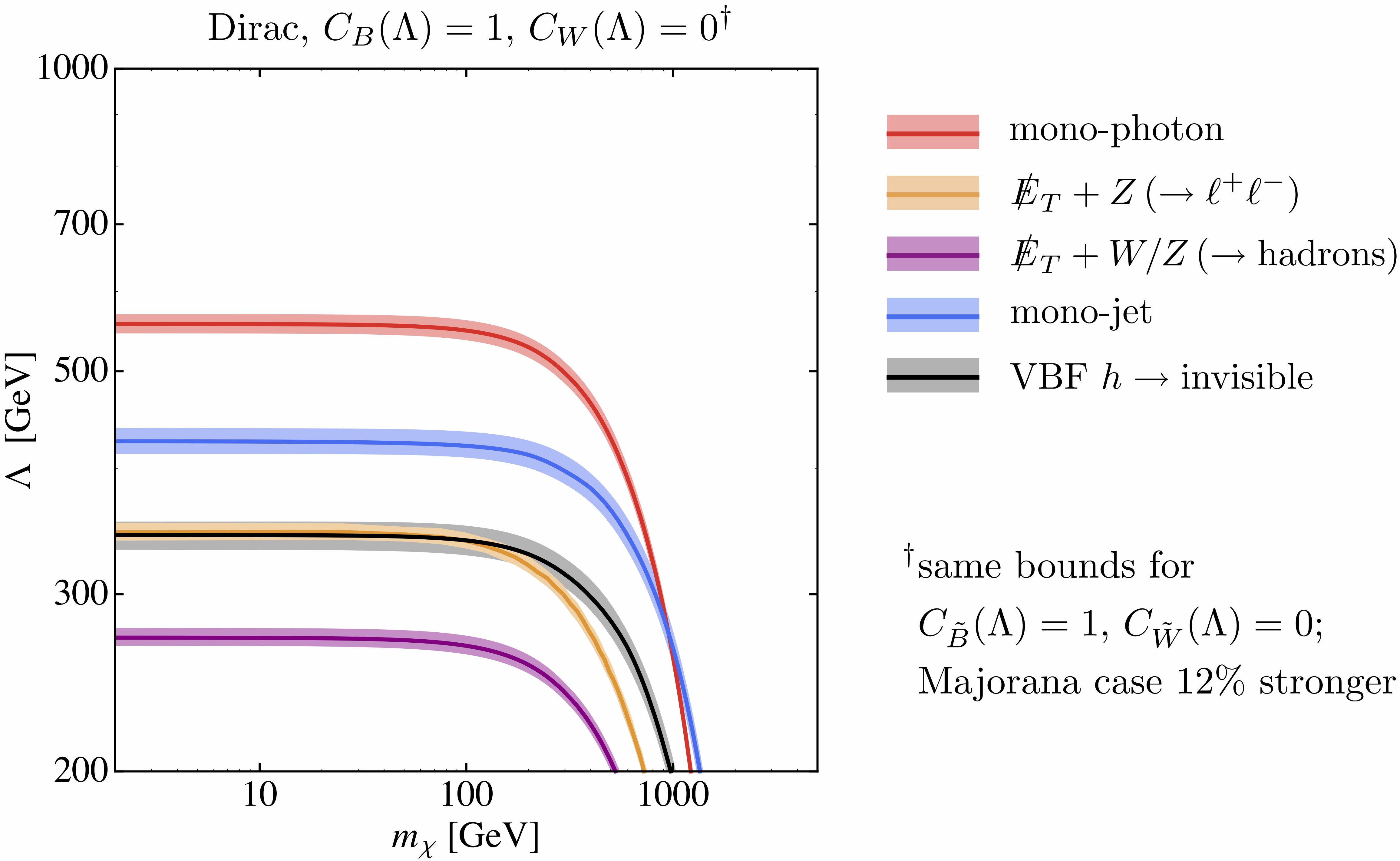
**Attractive DM scenario with room to be explored by LHC**

$^\dagger$for future sensitivity see [Crivellin & UH, 1408.5046]

# LHC signals & searches

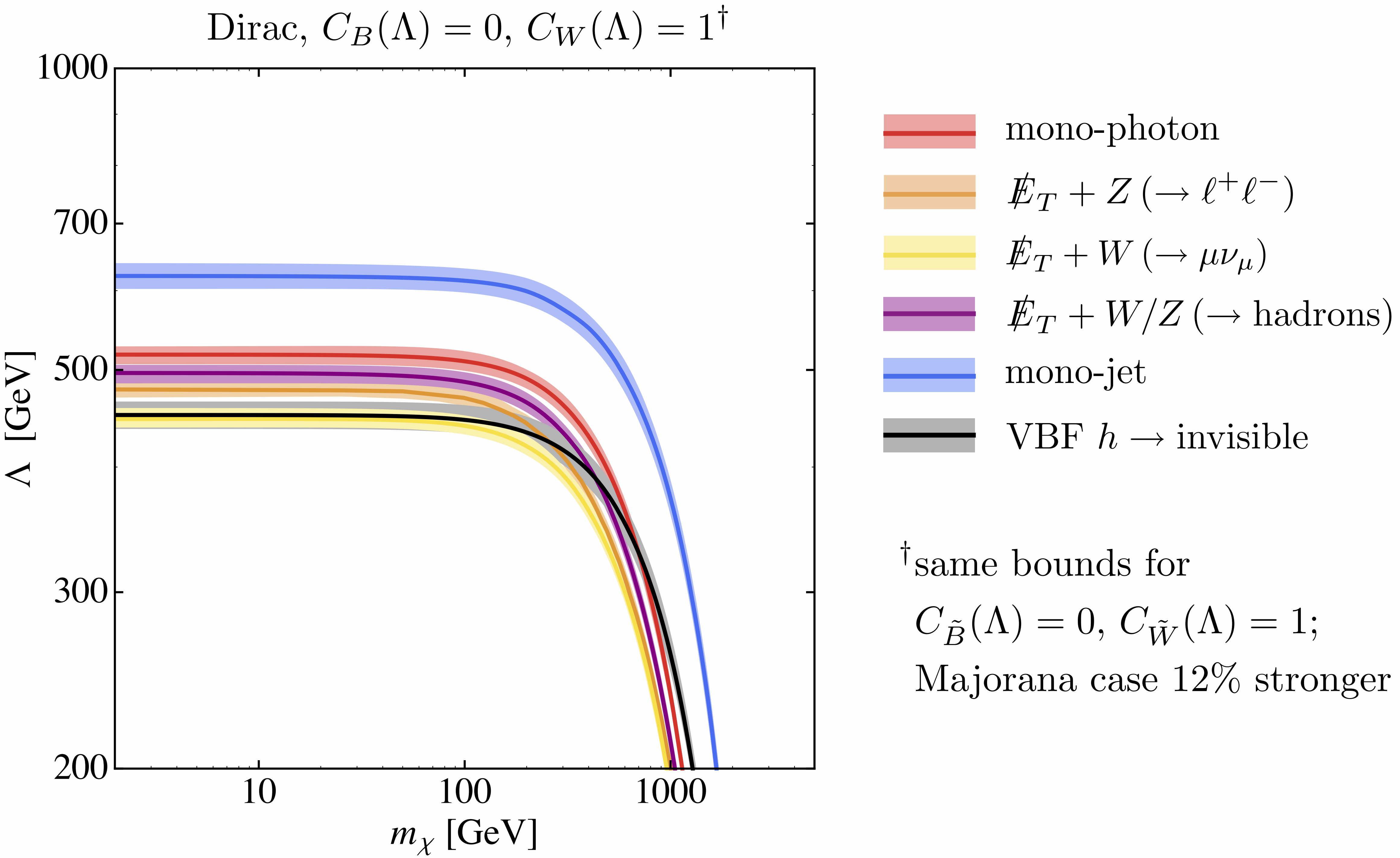


# Bounds on new-physics scale




$^\dagger$same bounds for $C_{\tilde{B}}(\Lambda) = 1$, $C_{\tilde{W}}(\Lambda) = 0$; Majorana case 12% stronger

# Bounds on new-physics scale




$^\dagger$same bounds for $C_{\tilde{B}}(\Lambda) = 0$, $C_{\tilde{W}}(\Lambda) = 1$; Majorana case 12% stronger

# LHC 14 TeV forecast

Limits improve by factor of at least 2 in first year. Then progress slows down given imperfect understanding of SM background (assumed to be known to 5% accuracy)†

†findings agree with [ATL-COM-PHYS-2014-549]

$8\,\mathrm{TeV\ LHC},\ 20\,\mathrm{fb}^{-1}:$
$\Lambda \gtrsim 600\,\mathrm{GeV}$

↓

$14\,\mathrm{TeV\ LHC},\ 25\,\mathrm{fb}^{-1}:$
$\Lambda \gtrsim 1.3\,\mathrm{TeV}$

↓

$14\,\mathrm{TeV\ LHC},\ 300\,\mathrm{fb}^{-1}:$
$\Lambda \gtrsim 1.5\,\mathrm{TeV}$

# Jet-jet angular correlations

Imposed VBF cuts :

$$\Delta\eta_{j_1 j_2} > 2\,,$$

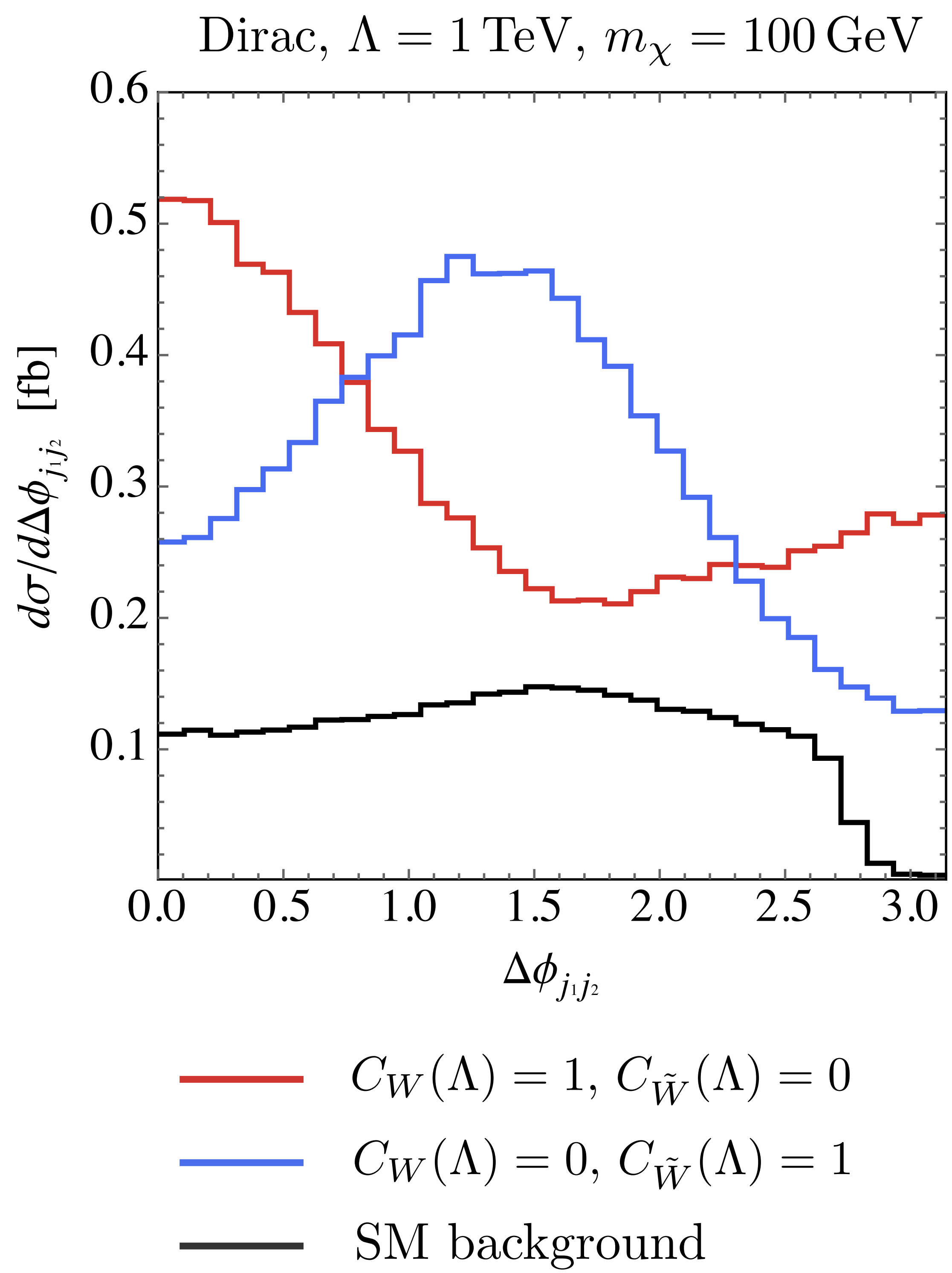
$$m_{j_1 j_2} > 1100\,\mathrm{GeV}$$

$$\sigma_{\mathrm{fid}}\left(pp \to \not{E}_T + 2j\right) = 1.0\,\mathrm{fb}$$

$$\sigma_{\mathrm{fid}}\left(pp \to Z\left(\to \bar{\nu}\nu\right) + 2j\right) = 0.35\,\mathrm{fb}$$

$$S/\sqrt{B} = 8.4\ \ (25\,\mathrm{fb}^{-1})\,,$$

$$S/\sqrt{B} = 29\ \ (300\,\mathrm{fb}^{-1})$$



# Jet-jet angular correlations

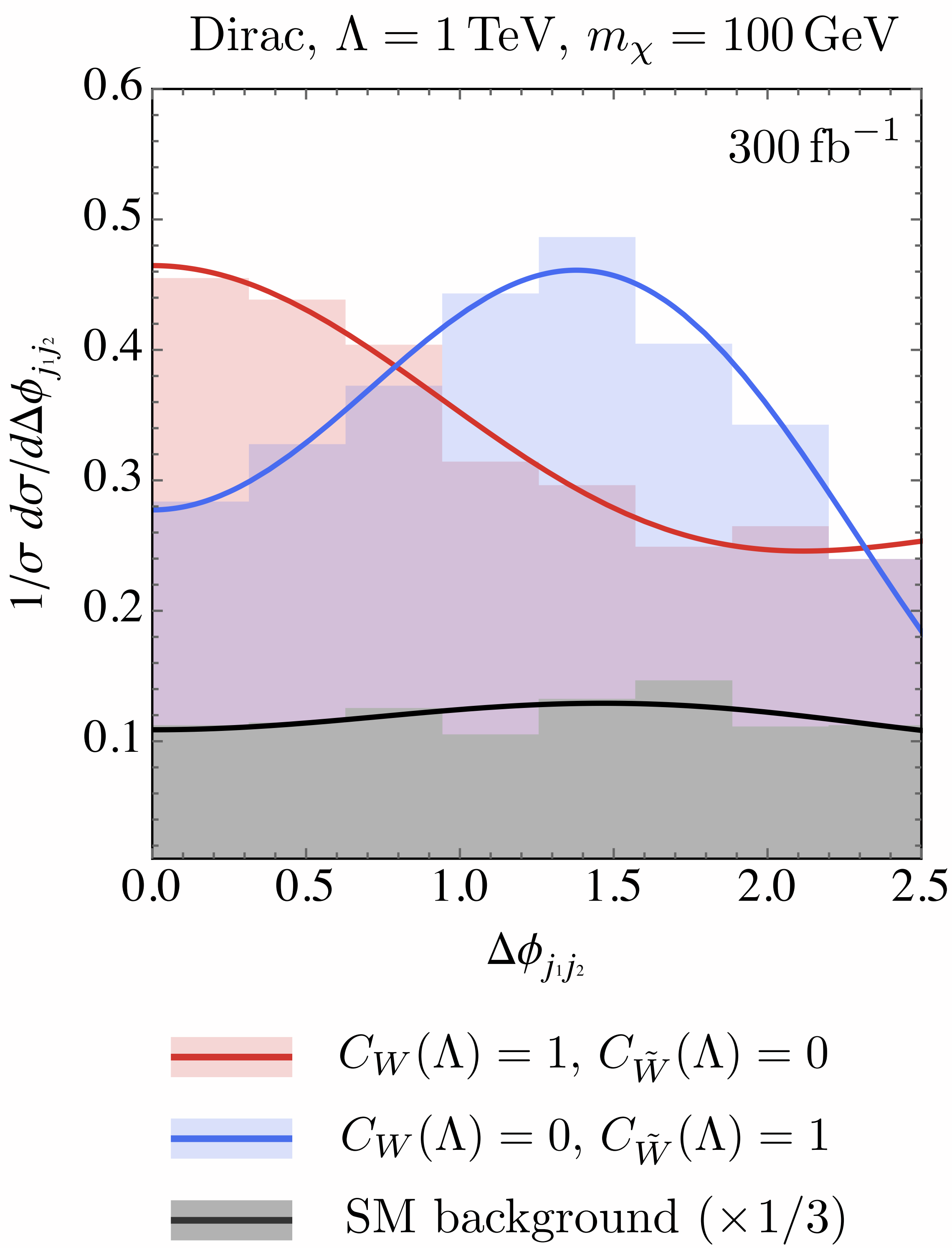
Angular decomposition :

$$\frac{1}{\sigma}\frac{d\sigma}{d\Delta\phi_{j_1 j_2}} = \sum_{n=0}^{2} a_n \cos\left(n\Delta\phi_{j_1 j_2}\right)$$

⬇ $300\,\mathrm{fb}^{-1}$

$$(a_2/a_0)_{W+\mathrm{SM}} = 0.15 \pm 0.10,$$
$$(a_2/a_0)_{\tilde{W}+\mathrm{SM}} = -0.45 \pm 0.14,$$
$$(a_2/a_0)_{\mathrm{SM}} = -0.12 \pm 0.22$$

significance : 2.7, 2.4, 5.1




# A $295K backup

# Jet-jet angular correlations

Angular decomposition :

$$\frac{1}{\sigma}\frac{d\sigma}{d\Delta\phi_{j_1 j_2}} = \sum_{n=0}^{2} a_n \cos\left(n\Delta\phi_{j_1 j_2}\right)$$

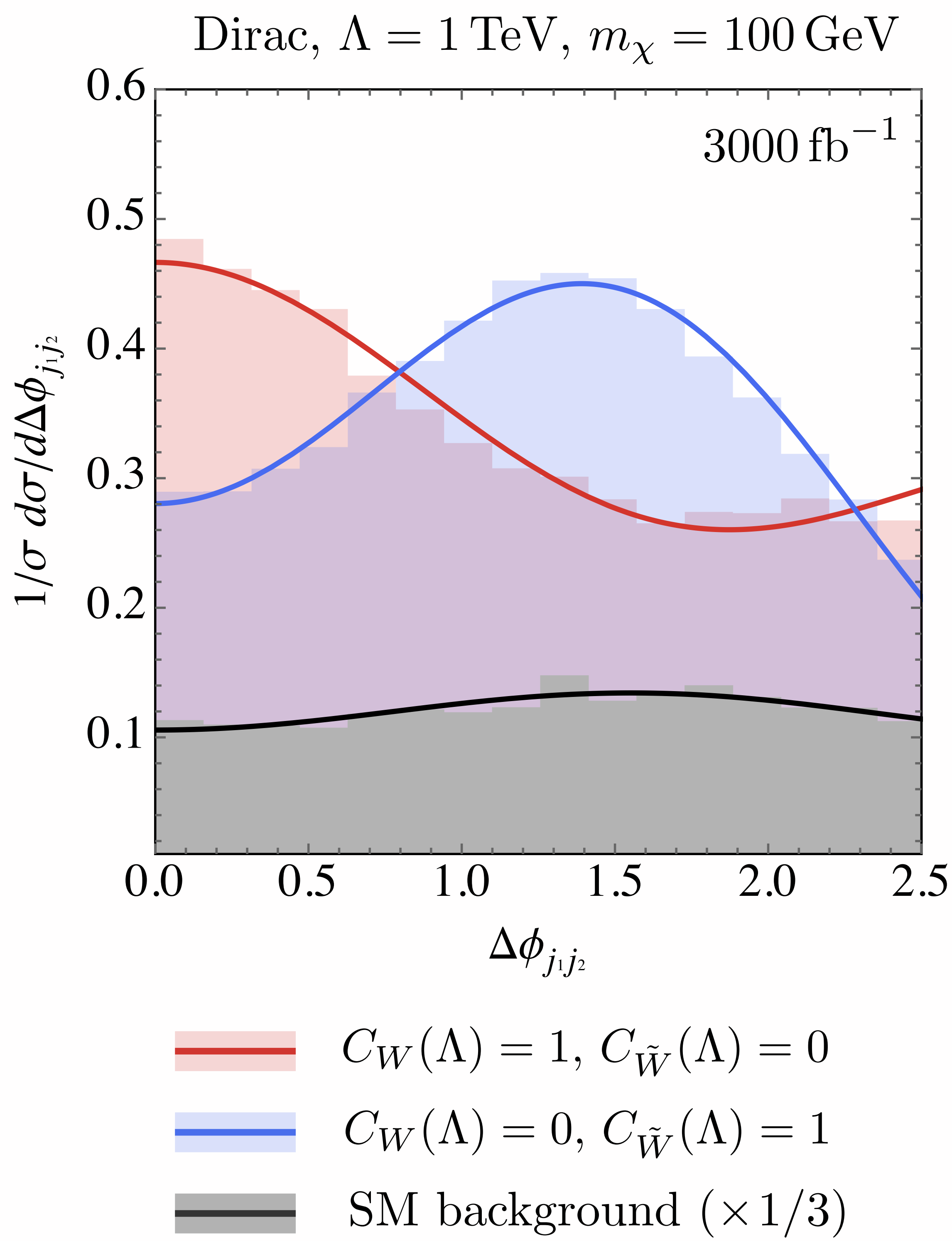
$3000\,\mathrm{fb}^{-1}$

$$(a_2/a_0)_{W+\mathrm{SM}} = 0.18 \pm 0.03,$$

$$(a_2/a_0)_{\tilde{W}+\mathrm{SM}} = -0.40 \pm 0.04,$$

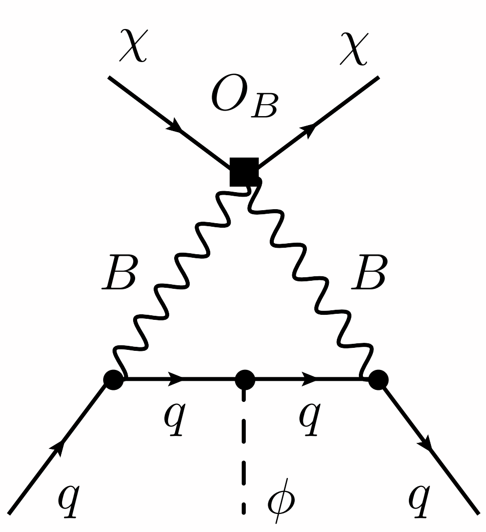
$$(a_2/a_0)_{\mathrm{SM}} = -0.13 \pm 0.07$$

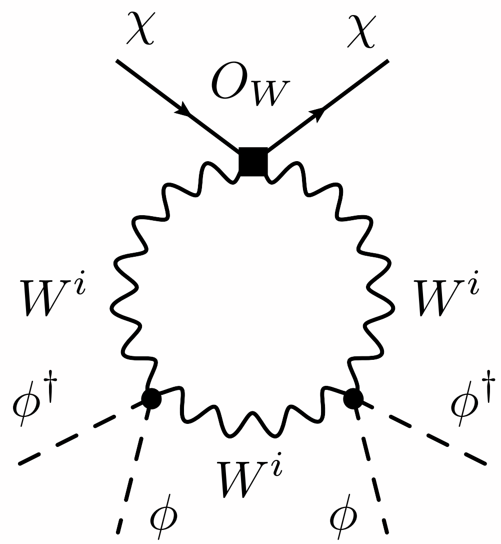
significance : 10.3, 6.8, 17.1




B1/B3

# Loop-induced direct detection




$$O_B \overset{\text{mixing}}{\longrightarrow} O_q = y_q \, \bar\chi\chi \, \bar q \phi q \,,$$

$$O_W \overset{\text{mixing}}{\longrightarrow} O_\phi = \bar\chi\chi \left(\phi^\dagger \phi\right)^2$$

$$C_q(\mu_l) \simeq \left( \frac{3 Y_{q_L} Y_{q_R} \alpha_1}{\pi} \, C_B(\Lambda) + \frac{9 \alpha_2^2}{2} \frac{v^2}{m_h^2} \, C_W(\Lambda) \right) \ln \left( \frac{m_W^2}{\Lambda^2} \right) + \ldots \,,$$

$$C_G(\mu_l) \simeq -\frac{1}{12\pi} \left\{ \left( \frac{\alpha_1}{2\pi} \, C_B(\Lambda) + \frac{27 \alpha_2^2}{2} \frac{v^2}{m_h^2} \, C_W(\Lambda) \right) \ln \left( \frac{m_W^2}{\Lambda^2} \right) + \ldots \right\}$$

$$\sigma_N^{\rm SI} \simeq \frac{m_{\rm red}^2 m_N^2}{\pi \Lambda^6} \left| \sum_{q=u,d,s} f_q^N \, C_q(\mu_l) - \frac{8\pi}{9} f_G^N \, C_G(\mu_l) + \ldots \right|^2$$

[Crivellin & UH, 1408.5046]

# Bounds on $O_B$ & $O_W$

[Crivellin & UH, 1408.5046]