

Dark Matter Searches in Heavy Quark Channels

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MRB, D. Gonçalves 1507.07926 & 1511.06451
MRB, D. Feld, D. Gonçalves 1410.6497

Scalar Simplified Models

- Dark matter interactions mediated by a (pseudo)scalar

$$\mathcal{L} \supseteq -g_\chi H \bar{\chi} \chi - g_v \frac{y_f}{\sqrt{2}} H \bar{f} f$$

$$\mathcal{L} \supseteq -g_\chi A \bar{\chi} \gamma^5 \chi - g_v \frac{y_f}{\sqrt{2}} A \bar{f} \gamma^5 f$$

see also Haisch *et al* 1208.4605, Harris *et al* 1411.0535 and others

- Minimal Flavor Violation: choose SM fermion couplings $\propto m_f$
- “Easy” to imagine this as part of extended Higgs sector
- Couplings to top quark dominate
 - But should keep in mind couplings to b -quarks
 - *e.g.* large $\tan \beta$ limit of 2-Higgs Doublet Models

Scalar Simplified Models

- Four parameter model:

$$m_\chi, m_{H/A}, g_\nu, g_\chi$$

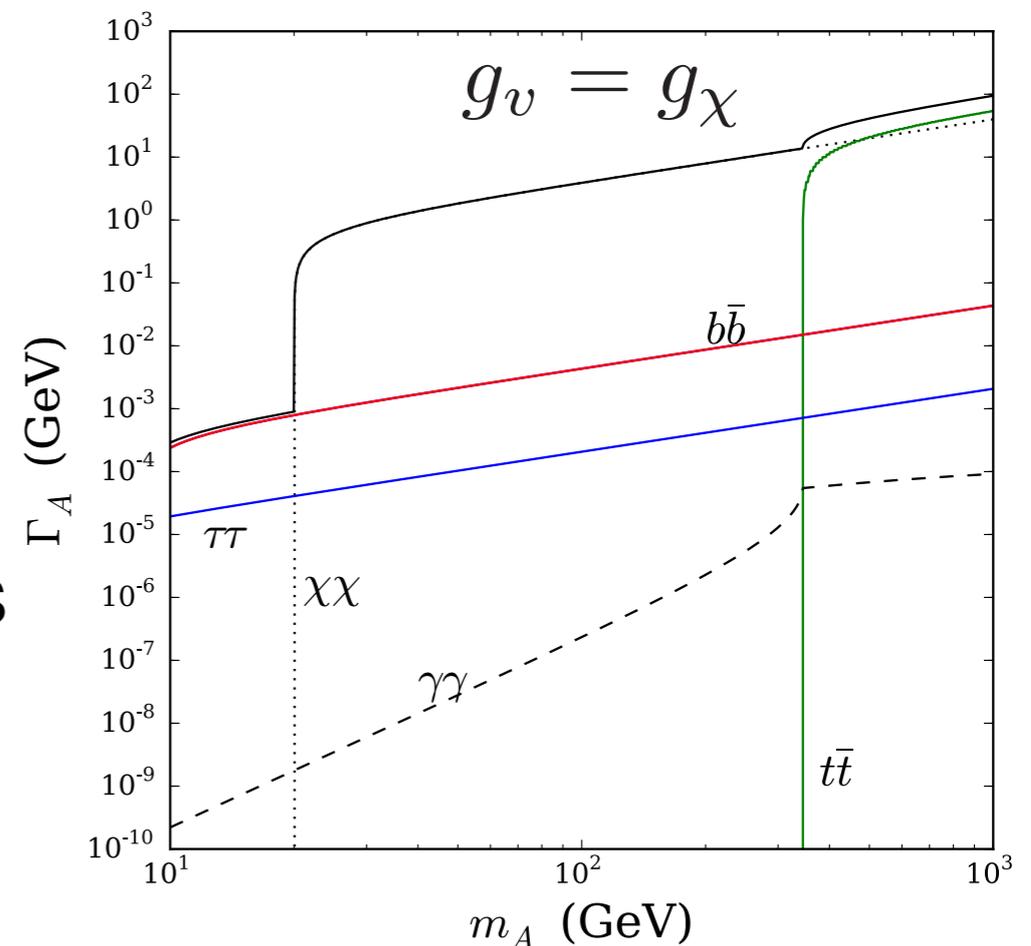
- Also need to specify additional decay channels: $\Gamma_{H/A}$

- For reasonable couplings

$$\Gamma_{H/A} \ll m_{H,A}$$

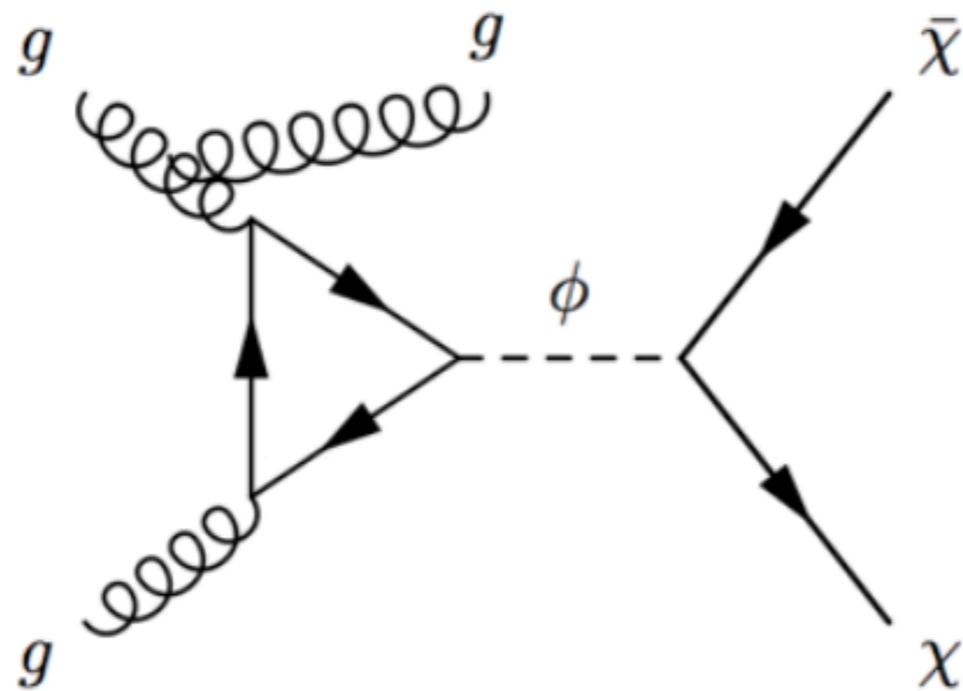
collider search efficiencies
independent of $\Gamma_{H/A}$

- Serves only to rescale
number of dark matter events

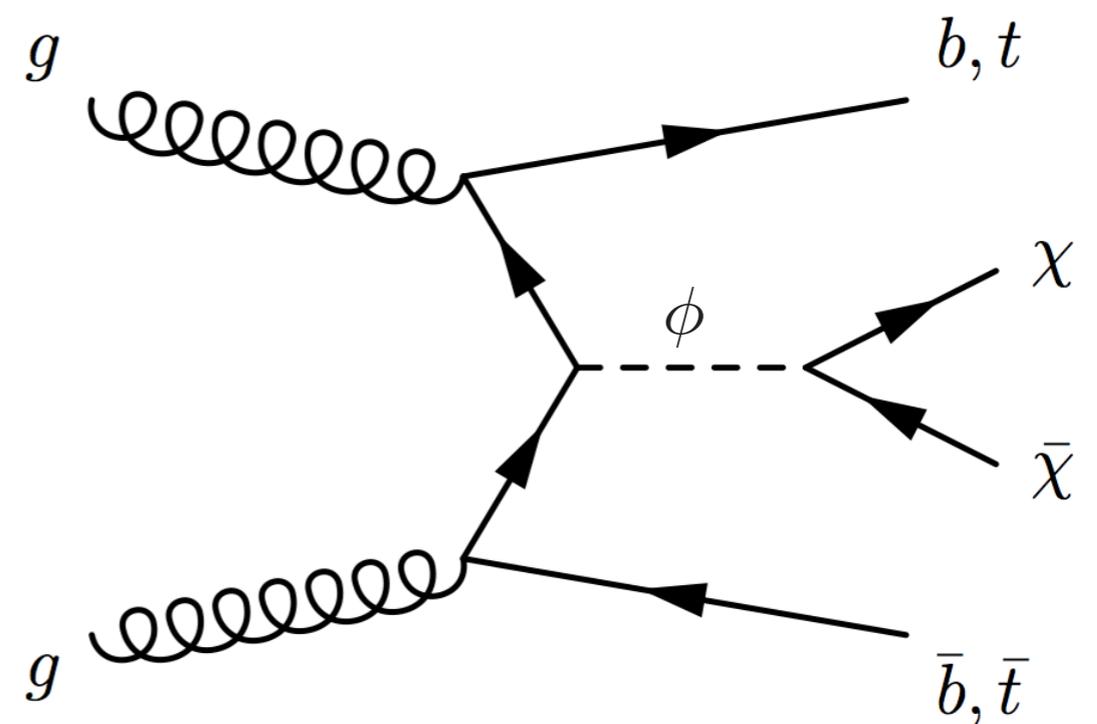


Scalar Production

- Two production modes:
 - gluon-fusion and associated heavy flavor



“loop”



“associated”

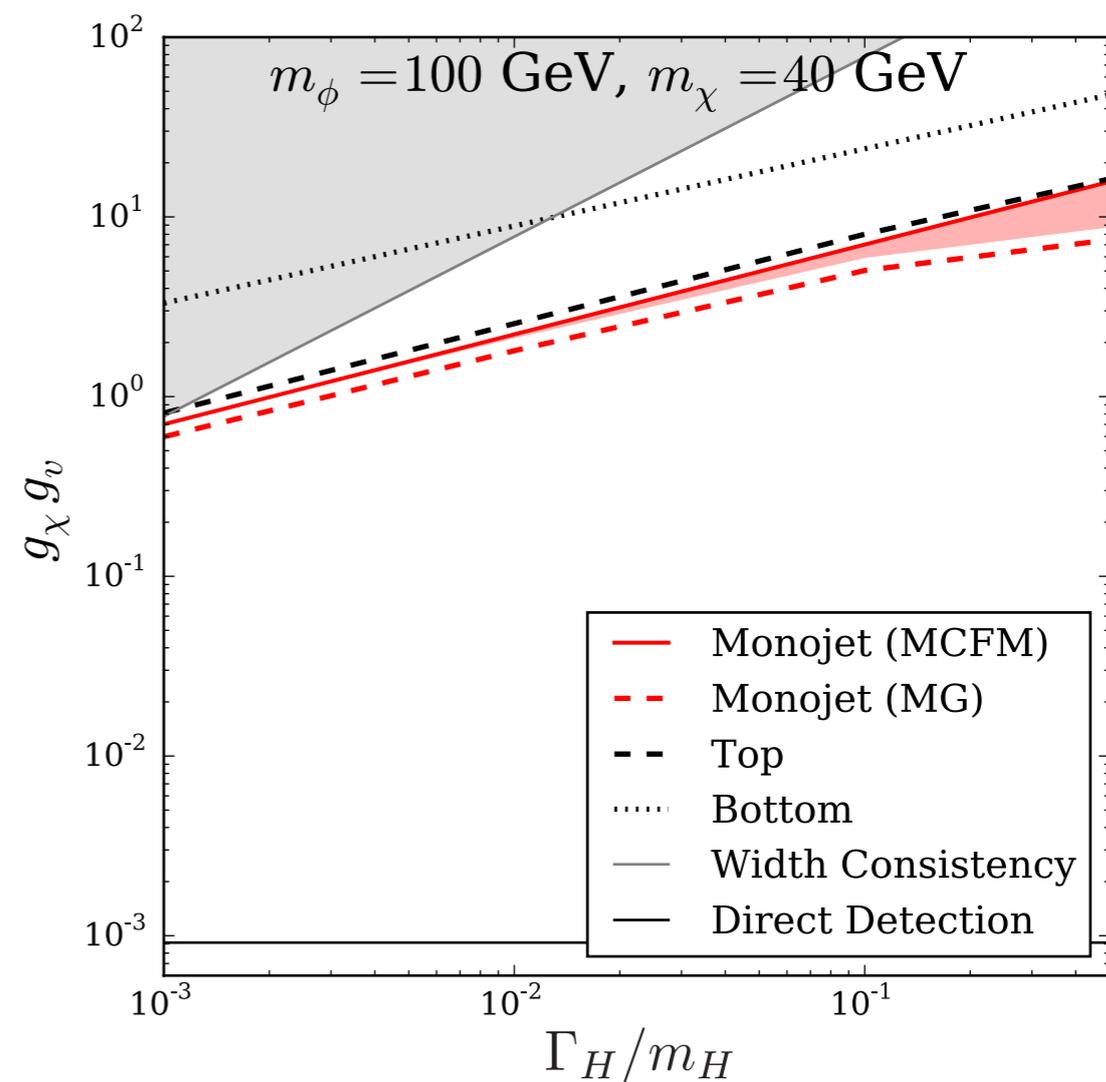
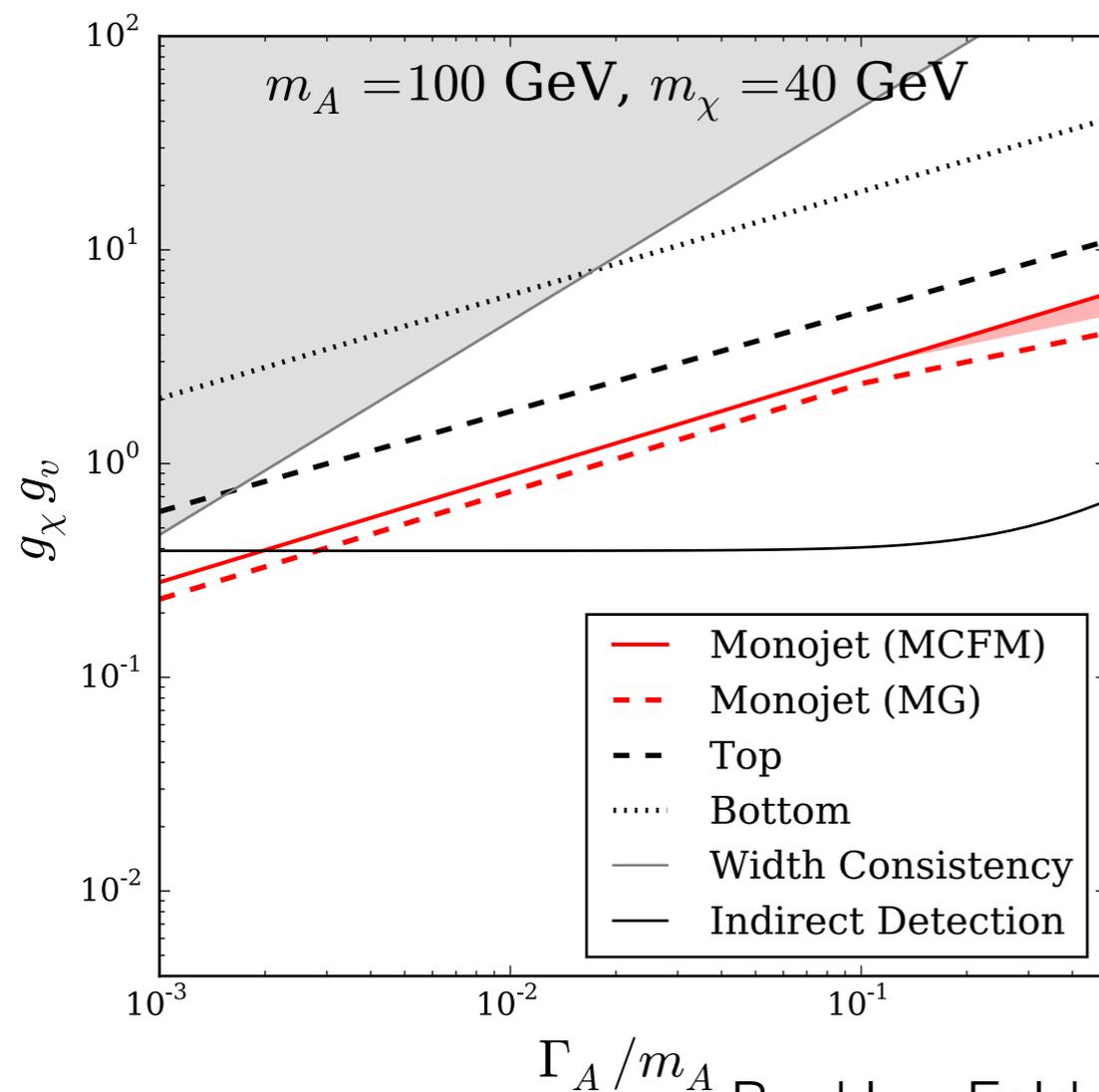
$$\phi = H/A$$

Associated Production

- CMS dileptonic tops: 2 leptons, no b -tag (B2G-13-004)
 - Signal region $\cancel{E}_T > 320$ GeV
 - semileptonic tops: 1 lepton (B2G-14-004)
- ATLAS b -tagged search. No leptons (1410.4031)
 - SR1: 2 jets (1+ b -tag) $pp \rightarrow b\bar{b} + (\phi \rightarrow \chi\bar{\chi})$
 - SR2: 3-4 jets (1+ b -tag) $pp \rightarrow t\bar{t} + (\phi \rightarrow \chi\bar{\chi})$
 - Both require $\cancel{E}_T > 300$ GeV

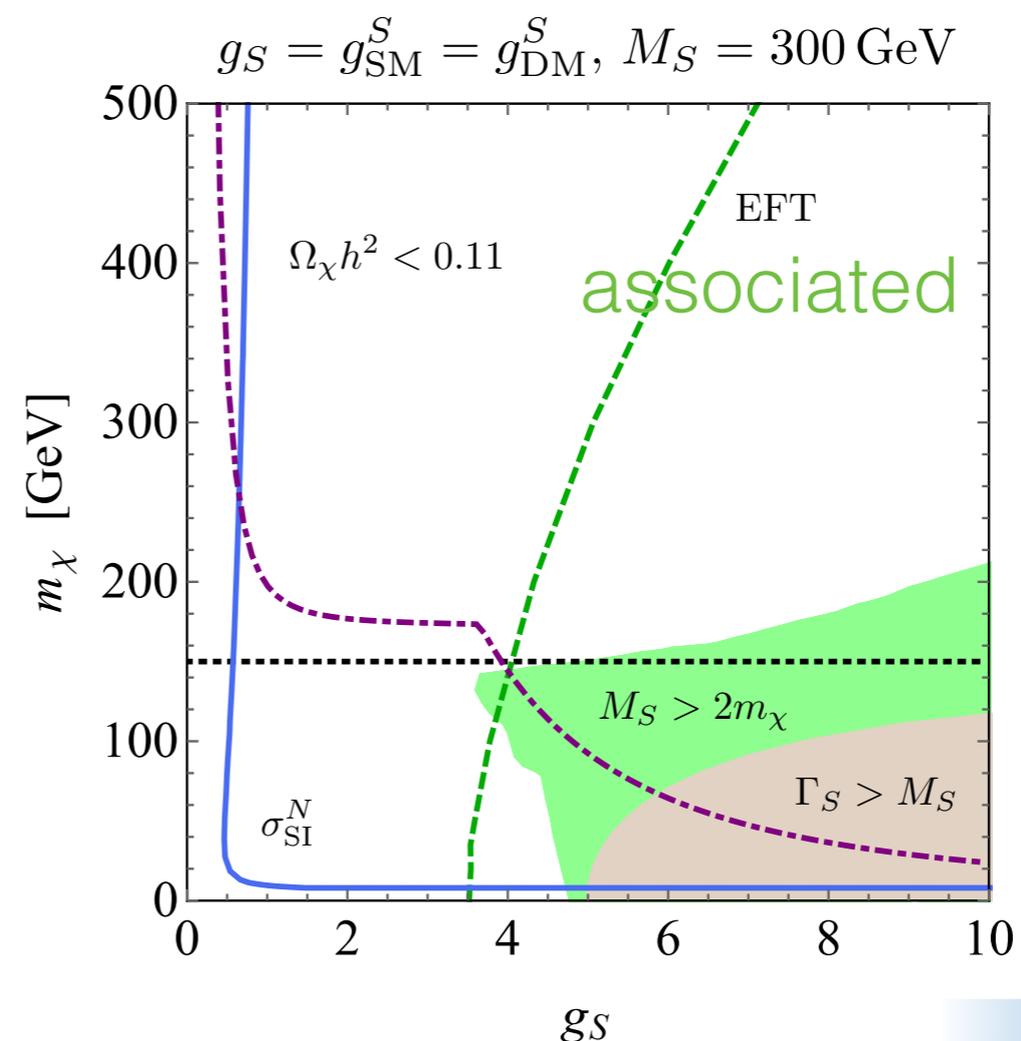
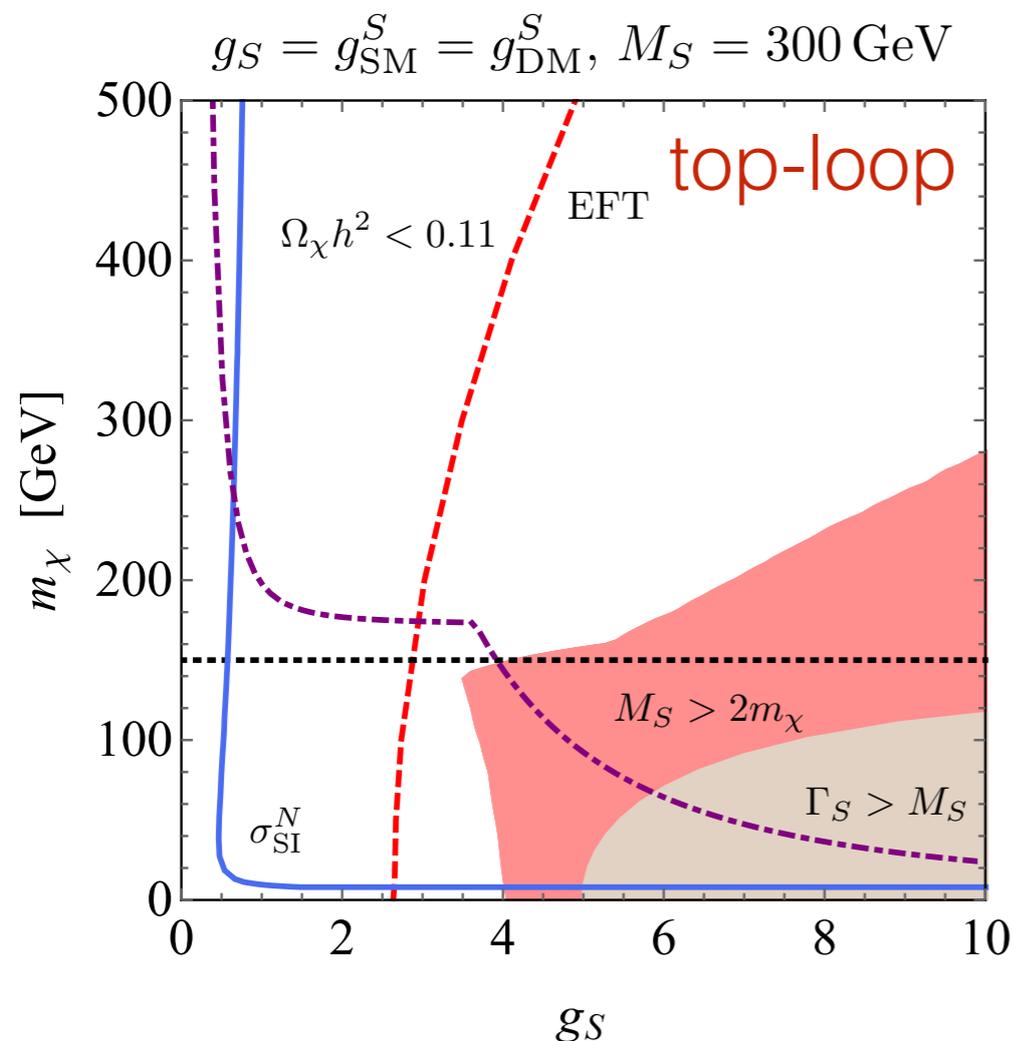
Loops vs. Associated Production

- At present, loop-induced gluon-fusion leads to stronger bounds than associated production
- Associated production measures tree-level couplings.



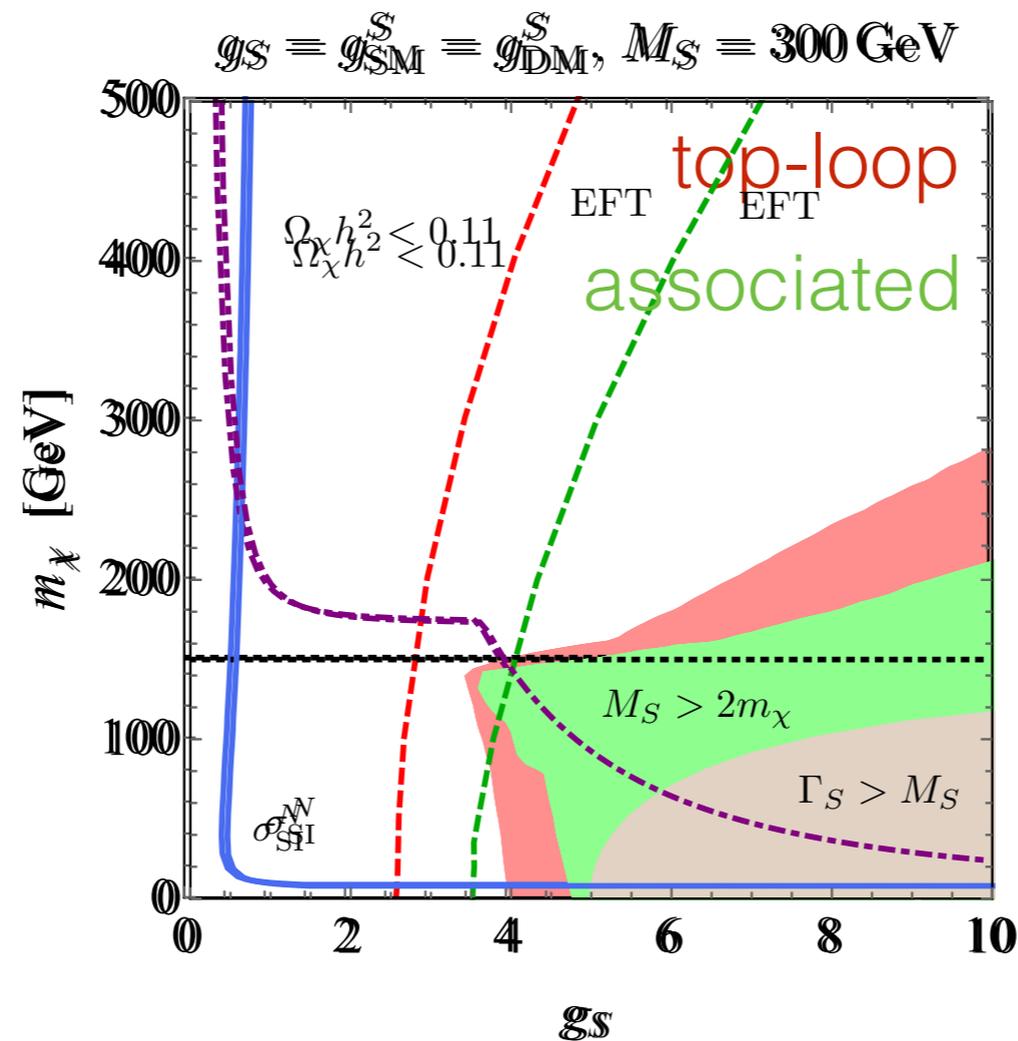
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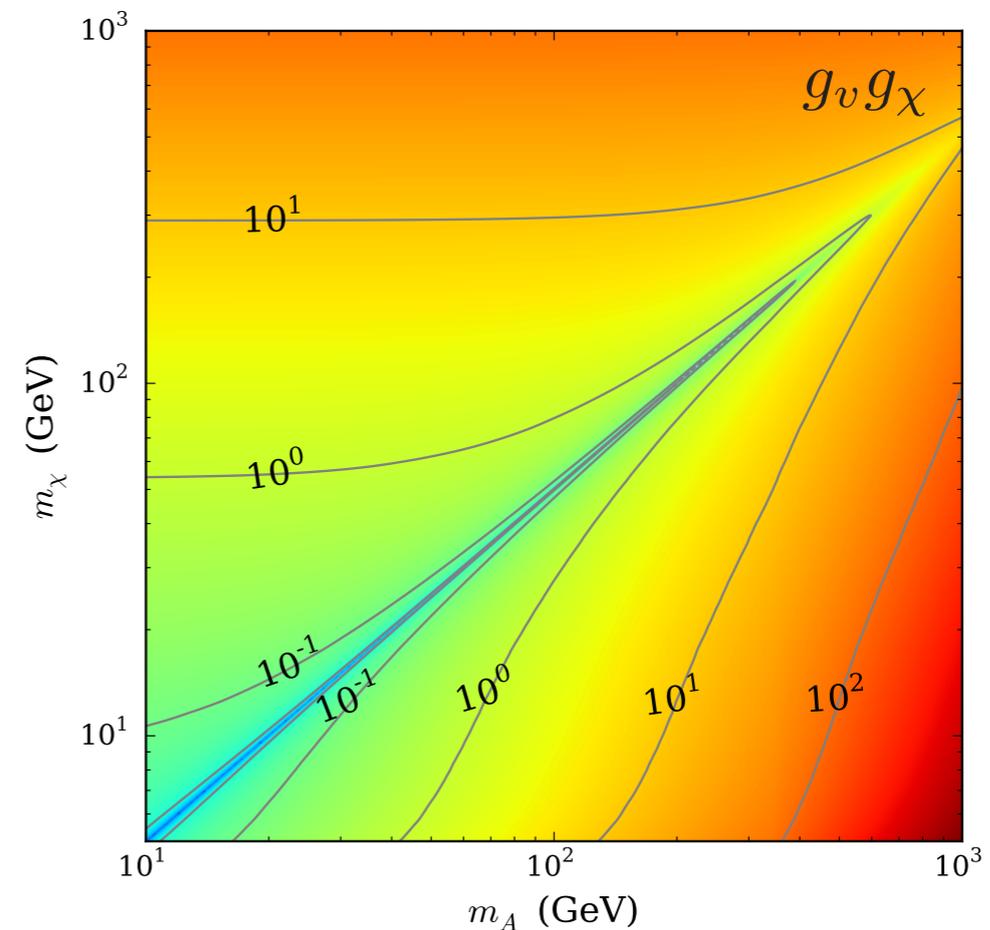
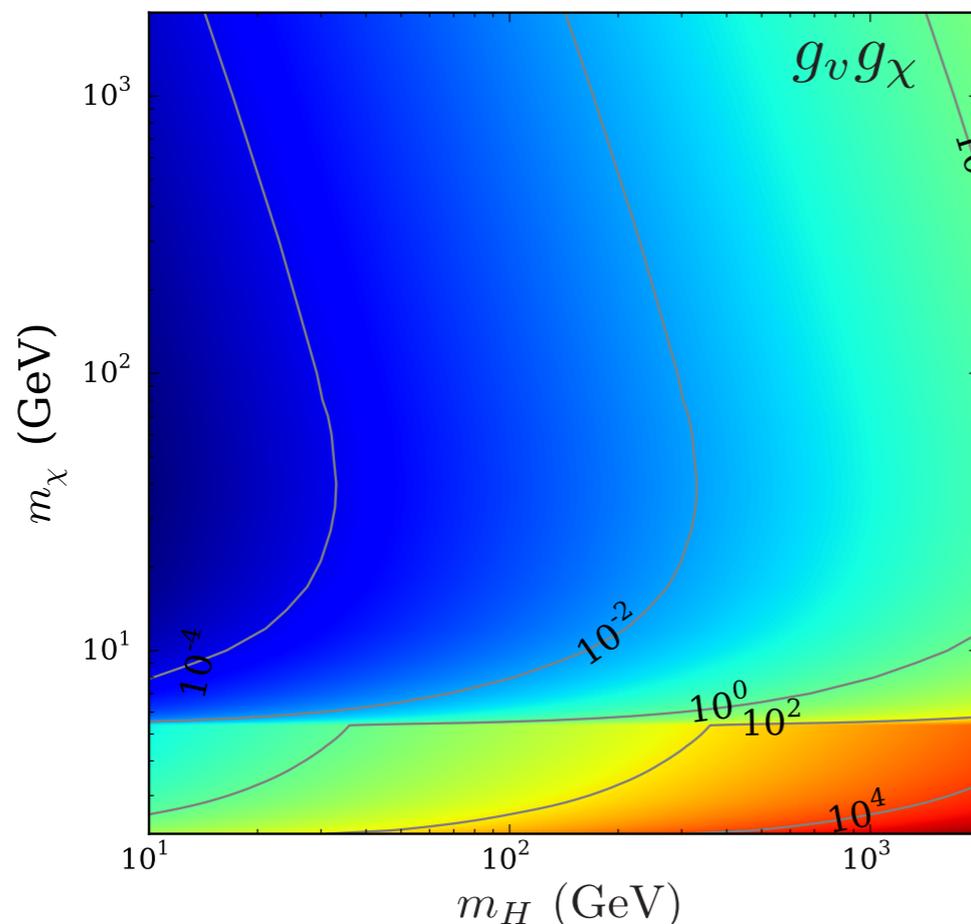
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Non-Collider Searches

- Scalar mediators give spin-independent direct detection cross sections
- Pseudoscalars give velocity-independent indirect detection cross sections
- Keep in mind these have astrophysical assumptions

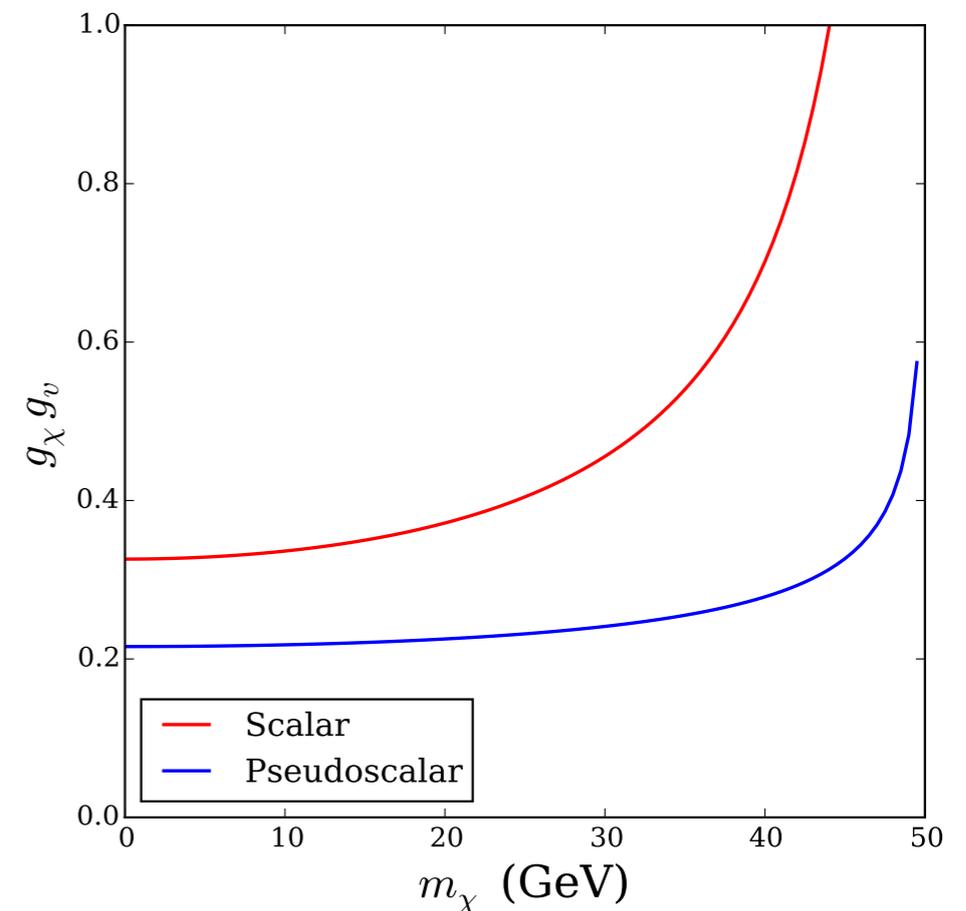


Scalar vs. Pseudoscalar

- Constraints on CP-even and CP-odd mediators are not the same (for otherwise identical parameters)
 - Larger production cross section for pseudoscalars
- Also have orthogonal predictions for non-collider searches.

	CP-even	CP-odd
Direct Det.	YES	NO
Indirect Det.	NO	YES

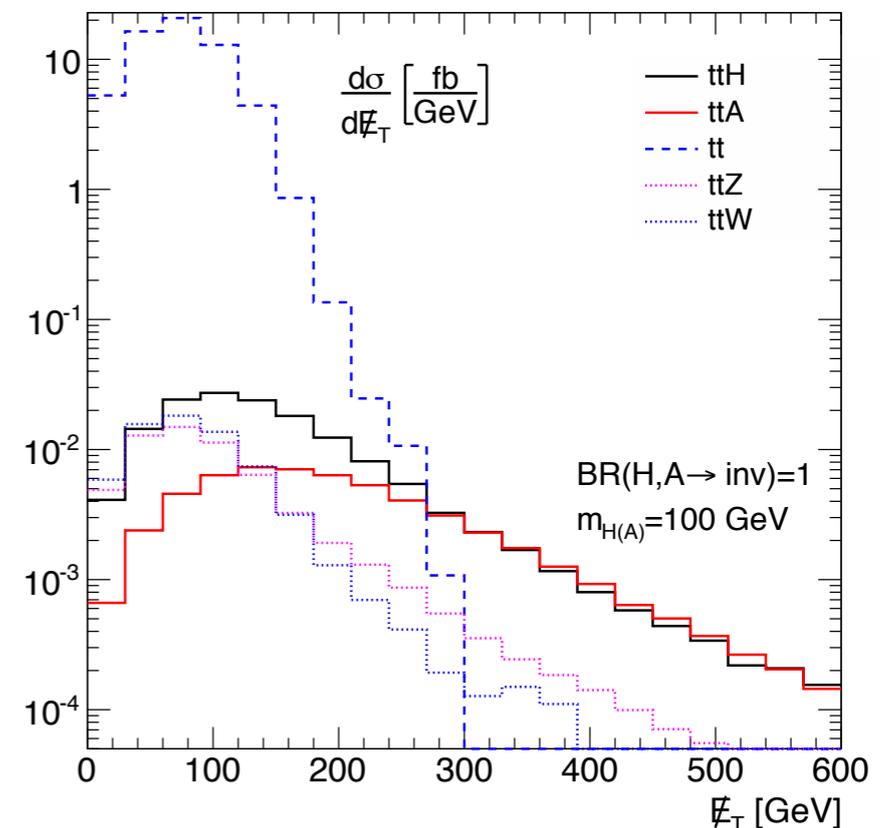
- But can we measure this directly?



Lepton Spin Correlations

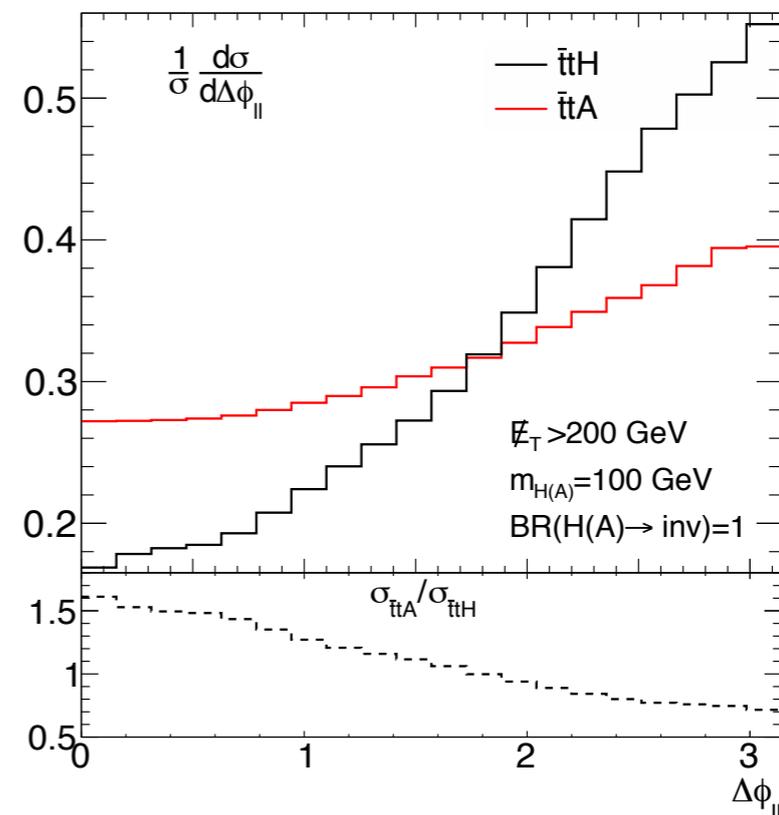
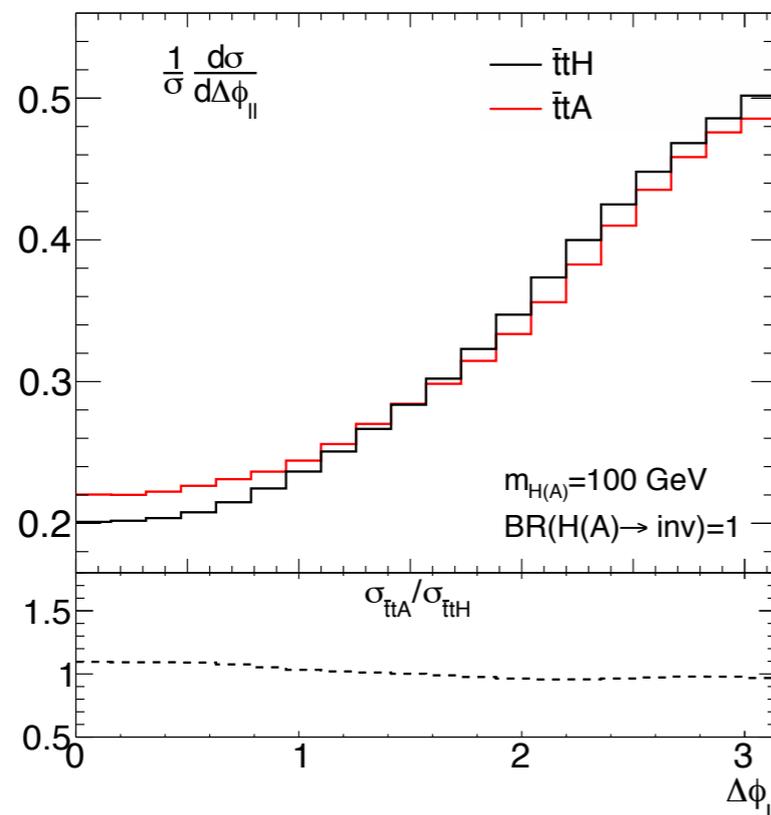
- Background reduction via cuts on MET.
- Additional useful information in other distributions.
- Example: Direct measurement of the CP of H/A in associated top channel similar to measurement of Higgs-top CP-structure

- Lots of work done in this area.
- Variables tend to have low sensitivity when integrated over all phase space.
- But we're already in a restricted phase-space: large $p_{T,H/A} \sim \cancel{E}_T$



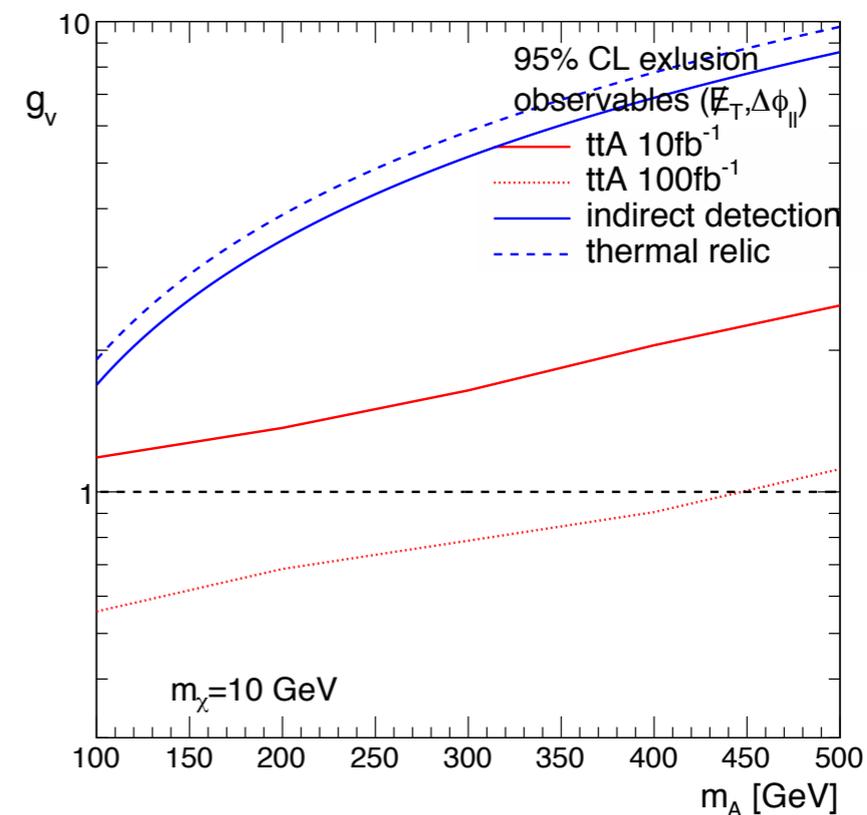
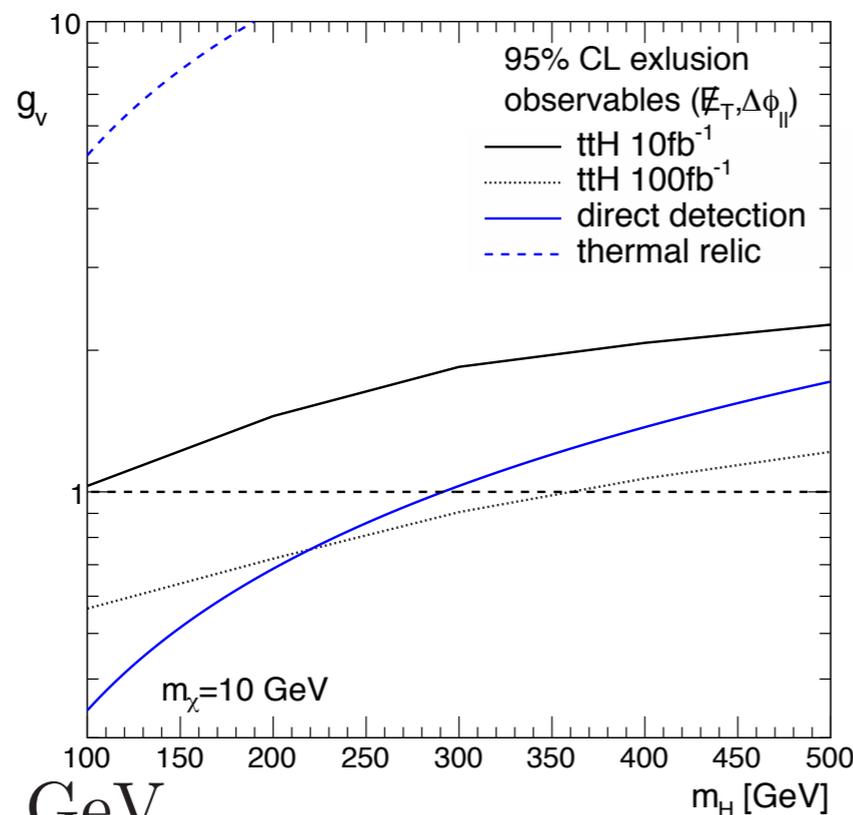
CP-Sensitive Leptons

- In dileptonic $pp \rightarrow t\bar{t}(H/A \rightarrow \chi\bar{\chi})$ events, $\Delta\phi_{\ell\ell}$ is a proxy for $\Delta\phi_{tt}$, and sensitive to CP of H/A at large \cancel{E}_T
- (see 1507.07926 for applications to Higgs)



Distinguishing CP

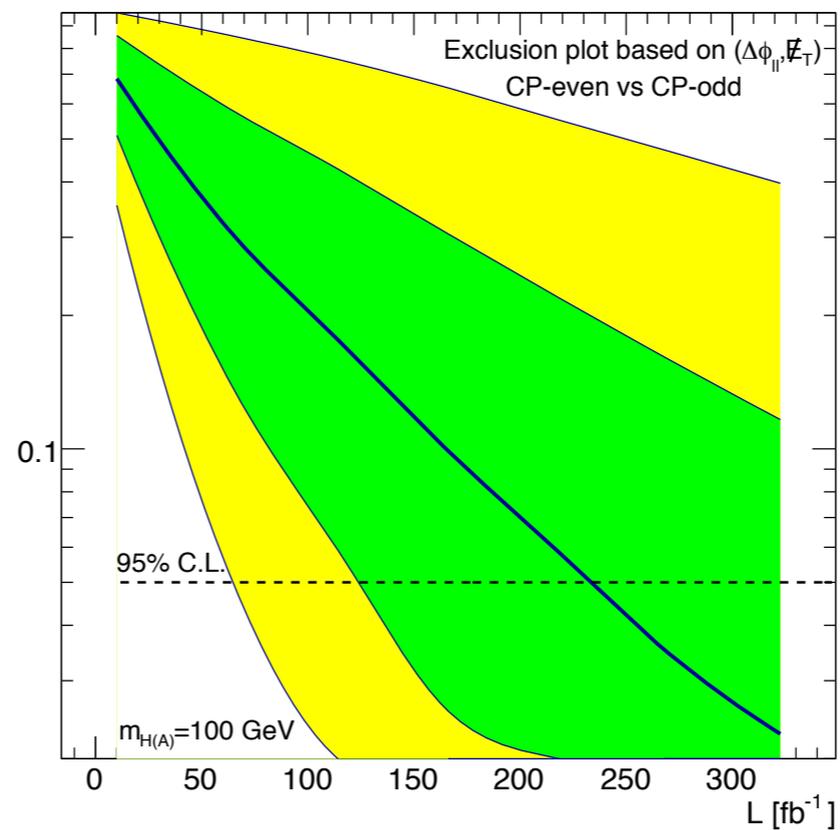
- Mild improvements on discovery of dark matter in scalar/pseudoscalar Simplified Model with $\Delta\phi_{\ell\ell}$
 - Here we assume $BR(H/A \rightarrow \chi\bar{\chi}) = 1$
- But if we find a signal, we can use that to measure CP



$m_{H/A} = 100\text{ GeV}$

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$$m_{H/A} = 100 \text{ GeV}$$

Conclusions

- Associated heavy flavor production in general slightly less constraining than loop-production.
 - This should not deprioritize associated searches.
 - Measures tree-level couplings to variety of fermions, rather than loop-level interaction.
- Multiparameter space. Would suggest scans of $m_{H/A}, m_\chi$
- Kinematic effects of width minimal
- Combine with non-collider experiments to begin to understand the full theory.

