Scalar vs Pseudoscalar Model

Direct Detection, Relic Density and Collider searches

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Outline

- DM is gauge singlet
- Additional Higgs doublet for gauge invariance
- A scalar gauge singlet, with either scalar or pseudoscalar couplings to DM
- Usual 2HDM potential[1]
- General singlet scalar potential $M_{SS}^2 S^2 + \lambda_s S^4$
- Interaction terms $\lambda_{xxs} \Phi_x^\dagger \Phi_x S^2$
- Mixing term: $\lambda_{12s} \Phi_1^\dagger \Phi_2 S^2$ or $i\mu_{12s} \Phi_1^\dagger \Phi_2 S$
- Singlet may or may not develop a vev
- Both approaches give very similar results
- Also possible mixed scalar/pseudoscalar couplings
- Different possible Yukawa Sectors: Type I, II, Inert. Generalization: aligned $y_u = \xi_u y_u^{SM}, y_d = \xi_d y_d^{SM}, y_l = \xi_l y_l^{SM}$

[1] We set the alignment limit condition $\lambda_3 + \lambda_4 + \lambda_5 = \lambda_1 = \lambda_2$.

- Particle content:
  - 1 Additional fermion (DM)
  - 1 additional charged scalar (Flavour constraints)
  - Either 1 additional Pseudoscalar (PS) and 2 additional scalars (S) or
  - 1 additional S and 2 additional PS
- Similar phenomenology at collider: Monojet, Mono-h/Z/W, $t\bar{t} + \not{E}_T$
- Different astroparticle phenomenology: DD, ID, relic density

Outline

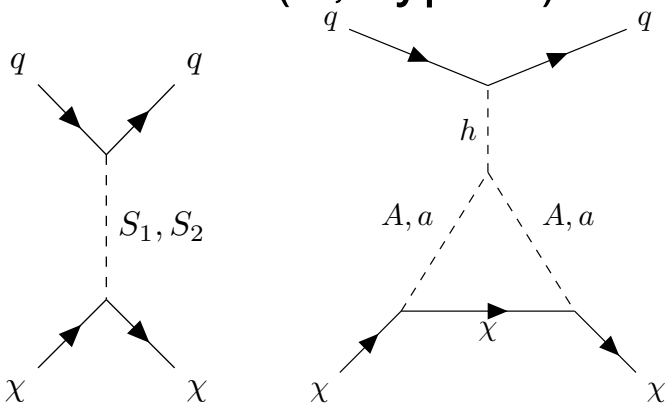
Comparison

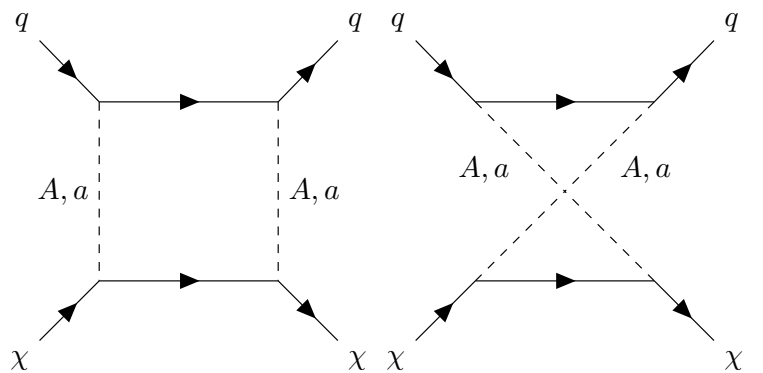
Direct Detection

Model	S	PS
Tree	SI	SD, q_{tr}^4
Loop	$\ll$ Tree	SI

- S generates SI cross section at tree level
- Tree level PS generated highly suppressed EFT operator
- Loop level operators dominate DD limits for PS by generating unsuppressed SI Cross section
- Triangle diagram wins over Box for $\tan\beta \lesssim 50$ [1404.3716]
- Triangle diagram limits do not depend on yukawa choice

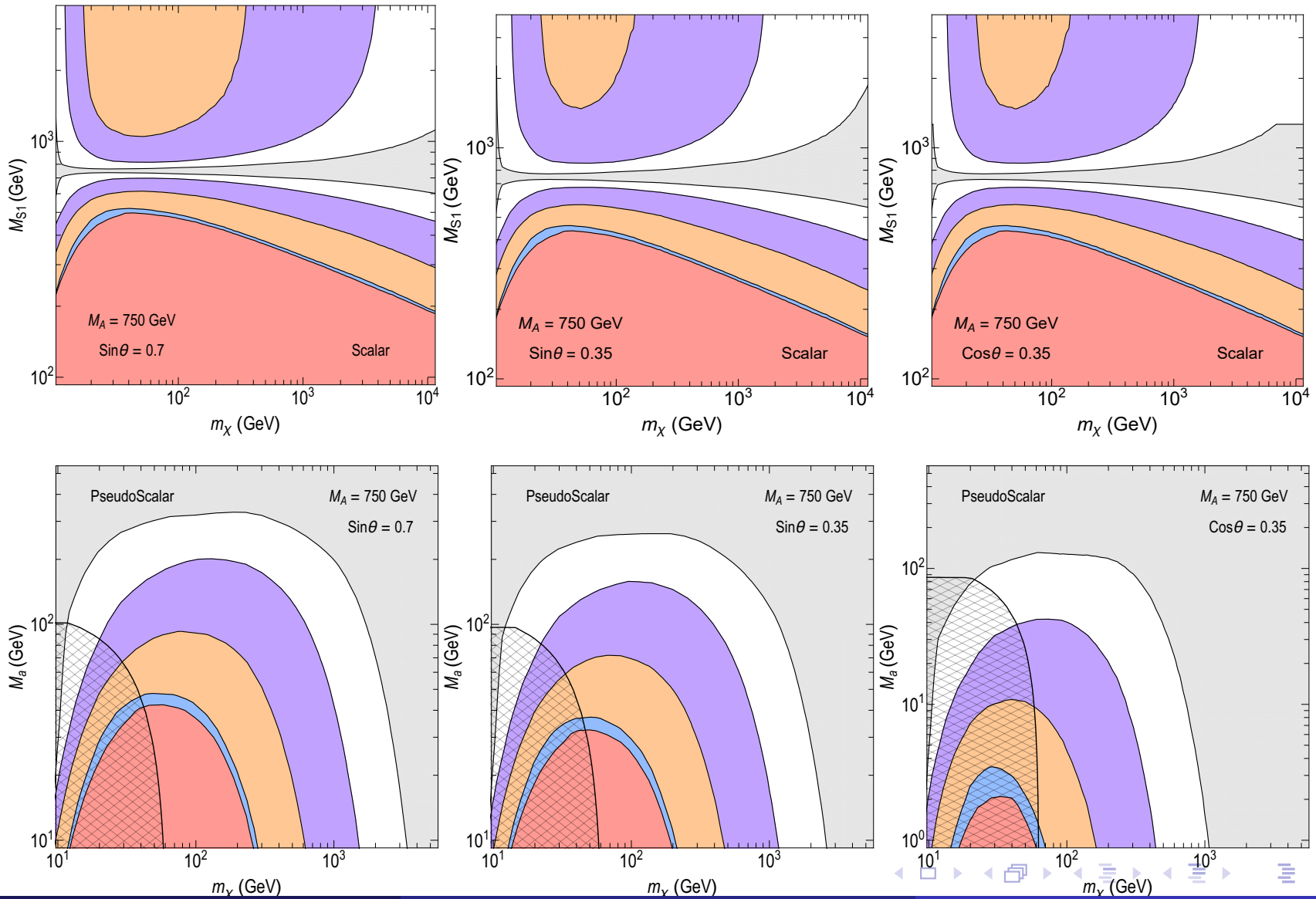
- Intereference: propagators (S, PS), flavours (S, Type II)





Comparison

Direct Detection: Results

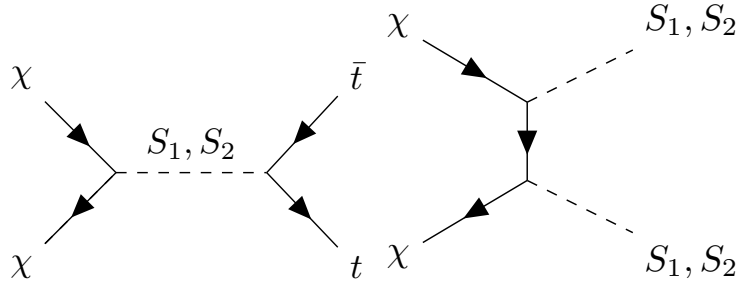


Outline

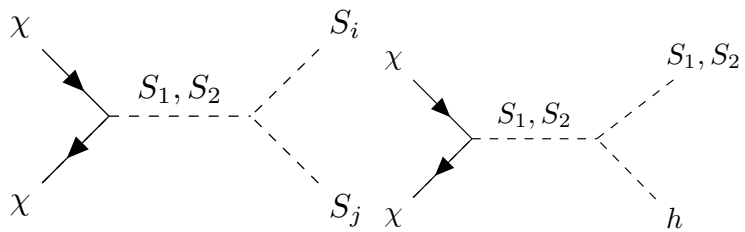
Comparison

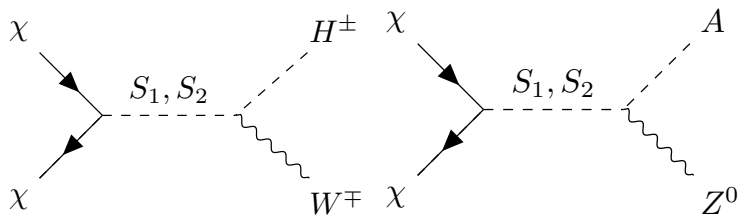
ID and relic Density

Model	S	PS
Suppression	p	s
RD	0.3	-
ID	10^{-6}	-



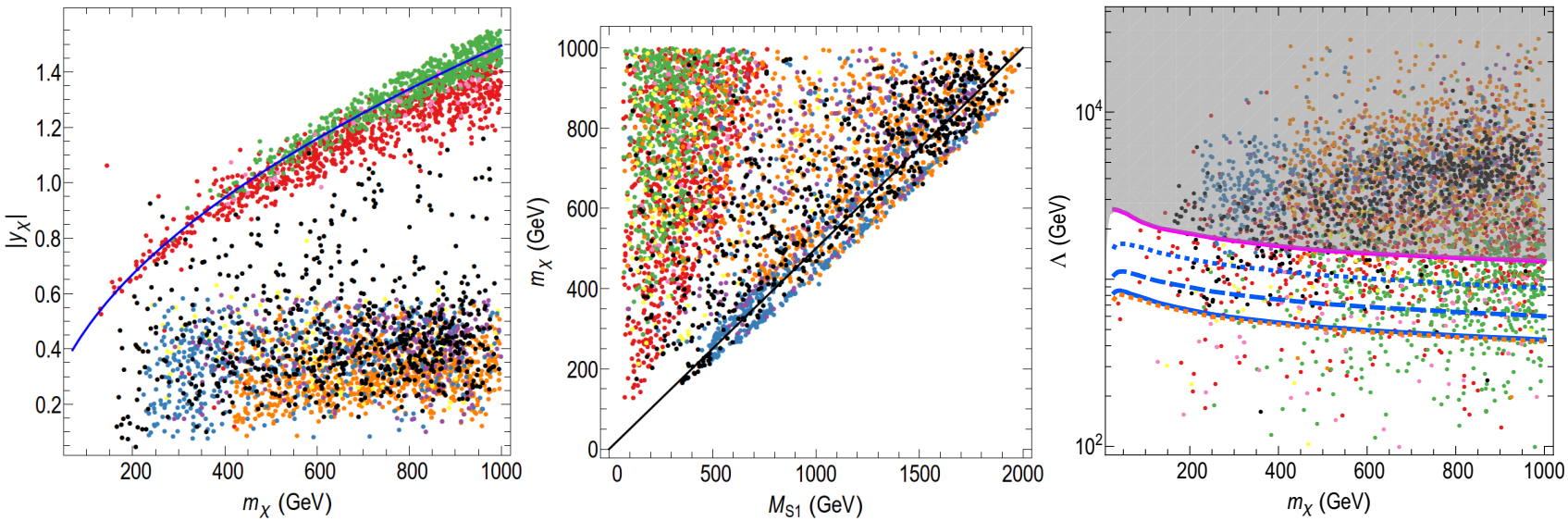
- S annihilations are p-wave suppressed
- No ID signal expected
- RD can still be achieved
- RD naturally of the right size for $\mathcal{O}(1)$ couplings
- Several exotic annihilation channels comparing to non-gauge invariant version, including some EW channels





Comparison

ID and relic Density



- Results for the scan of the scalar model. [1710.10764]
- DM Yukawa y_χ of $\mathcal{O}(1)$ or on-resonance annihilations.
- PS expected to give similar results with slightly smaller DM yukawas y_χ.

Outline

Comparison

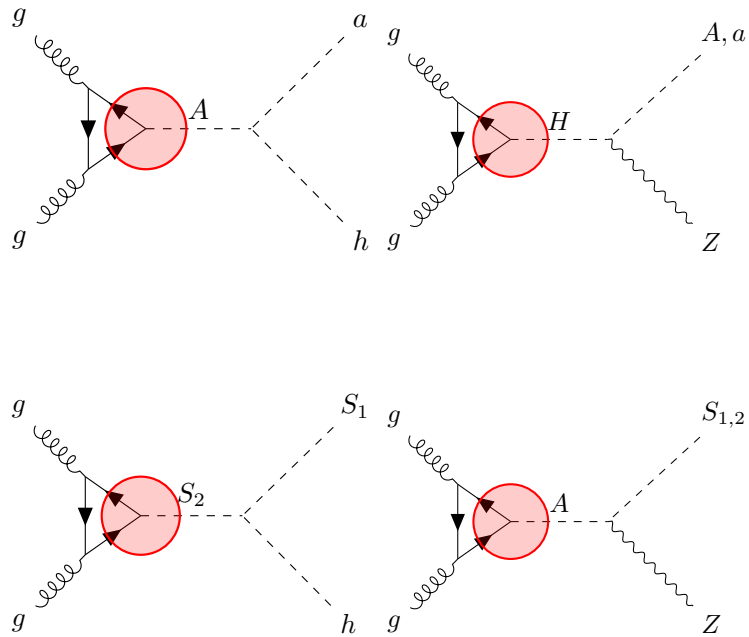
LHC searches

- Very similar phenomenology
- Main difference: structure of quark-scalar couplings
- This translates in different production cross sections for the scalars
- PS production enhanced over the scalar at low masses $M_{a,S_1} \gtrsim 2m_t$

Comparison

LHC searches

- Same topologies
- Resonant production [1509.01110], [1701.07427]
- Different $\bar{q}qS$ coupling structure
- PS model produces Mono-h through A production, Mono-Z through H production
- S model produces Mono-h through S_2 production, Mono-Z through A production
- PS should be more sensitive to Mono-h, S to Mono-Z



Outline

Conclusions

Models Summary

Model	S	PS
DD Tree	SI	SD, q_{tr}^4
DD Loop	$\ll$ Tree	SI
DD LO	Tree	Loop
DD limits (M_{S_1}, M_a)	$\lesssim 400\,\mathrm{GeV}$	$< 50\,\mathrm{GeV}$
DD propagators interf.	Yes	Yes
DD flavour interference	Type II	No
Annihilations	p	s
RD	Yes, p-wave	Yes
ID signals	No	Yes
Mono-X enhancement	Mono-Z	Mono-h

Conclusions

Summary

- Scalar and pseudoscalar very similar models, but different limits especially in Astro-ph searches
- Both producing SI DD, but PS has loop suppression
- Both models have interference between propagators in DD, Scalar Type II has also flavour interference at $\tan\beta \sim 0.9$
- Both producing right RD, but scalars is p-wave suppressed, thus requiring slightly larger couplings
- ID highly suppressed for scalar
- Similar topologies at LHC
- Different production rates, with scalar usually featuring lower cross sections. Exception: mono-Z