# Lepton portal dark matter, gravitational waves, and collider phenomenology

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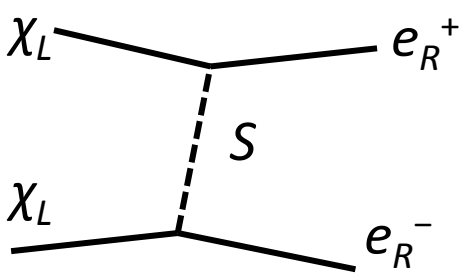
- # The lepton portal dark matter

The model[Y. Bai and J. Berger, 1402.6696]:

- One scalar ($S$) and one fermion ($\chi$) in the dark sector (i.e. $Z_2$);
- Portal coupling $y_l \chi_L e_R S$ (lepton can be $e$ $\mu$ $\tau$);
- Three possibilities: Dirac fermion DM, Majorana fermion DM, scalar DM

The scenario we are interested in: Majorana fermion DM

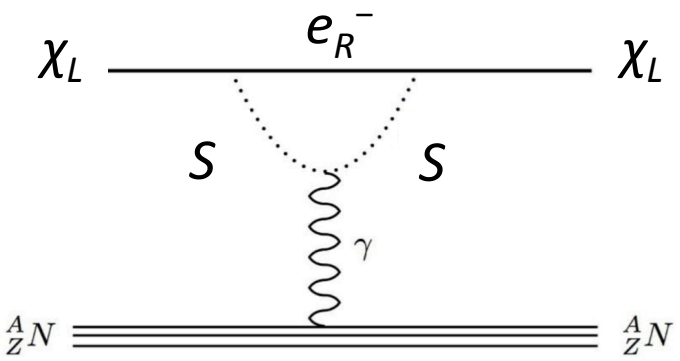
- $M_\chi < M_S$ ;
- $\chi$ is a gauge singlet, while $S$ has the same quantum number with $e_R$ ;
- Freeze-out: t-channel S exchange ($p$-wave)




Coupling $y_l$ = O(1) and $M_\chi$ , $M_S$ = O(100 GeV) gives the correct DM abundance.

- # Direct and indirect searches for Majorana DM

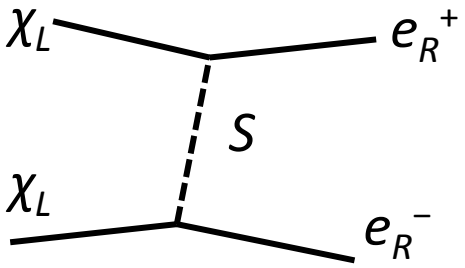
Direct: one-loop level induced operator




$$\mathcal{O}_1^{\text{Majorana}} = \left[-\overline{\chi}\gamma^\mu\gamma^5\partial^\nu\chi + \text{h.c.}\right] F_{\mu\nu}$$

*p*-wave suppressed, $\sigma \approx 10^{-49}$ cm$^2$, no hope to detect

Indirect: also *p*-wave suppressed and hence negligible.




No direct or indirect signals for Majorana case!

- # Gravitational waves and collider searches

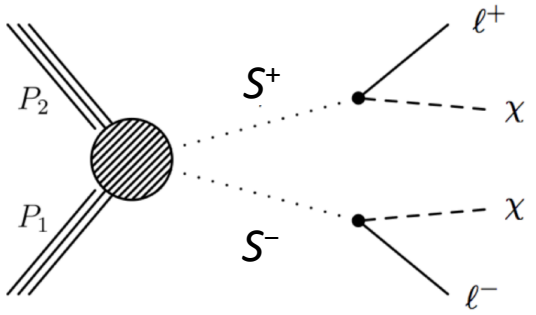
The relevant Lagrangian

$$\mathcal{L}_\chi = y_\ell \bar{\chi}_L S^\dagger \ell_R + \text{h.c.},$$
$$\mathcal{L}_S = \left(D^\mu S\right)^\dagger D_\mu S - V\left(S, H\right),$$
$$V(H,S) = \mu_H^2 |H|^2 + \mu_S^2 |S|^2 + \lambda_H |H|^4 + \lambda_S |S|^4 + 2\lambda_{HS} |H|^2 |S|^2,$$

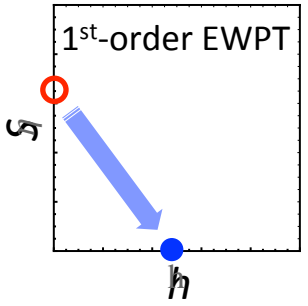
Pair produced $S^+S^-$ (and 100% to lepton + DM final state)

At the LHC: two channels:

- $qq > Z^*/\gamma^* > S^+S^-$
- $gg > h^* > S^+S^-$ [via the coupling $\lambda_{HS}$]




If $\mu_S^2 < 0$ and $\lambda_{HS}$ is siezable, the potential $V(H,S)$ might triger a 1st-order EW phase transition and provide detectable GWs



- Collider searches

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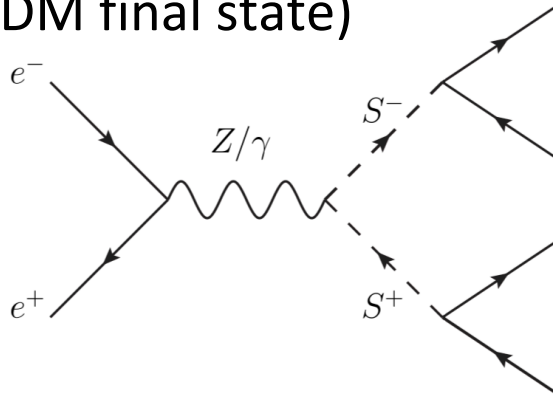
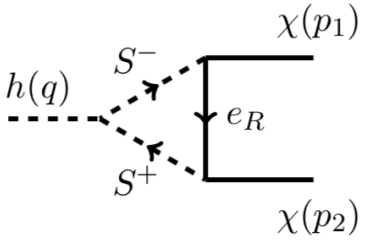



At the 240 GeV CEPC: two kinematics:

- On-shell: $M_S < 120$ GeV;
- Semi-off-shell: $120 < M_S < 240$ GeV;

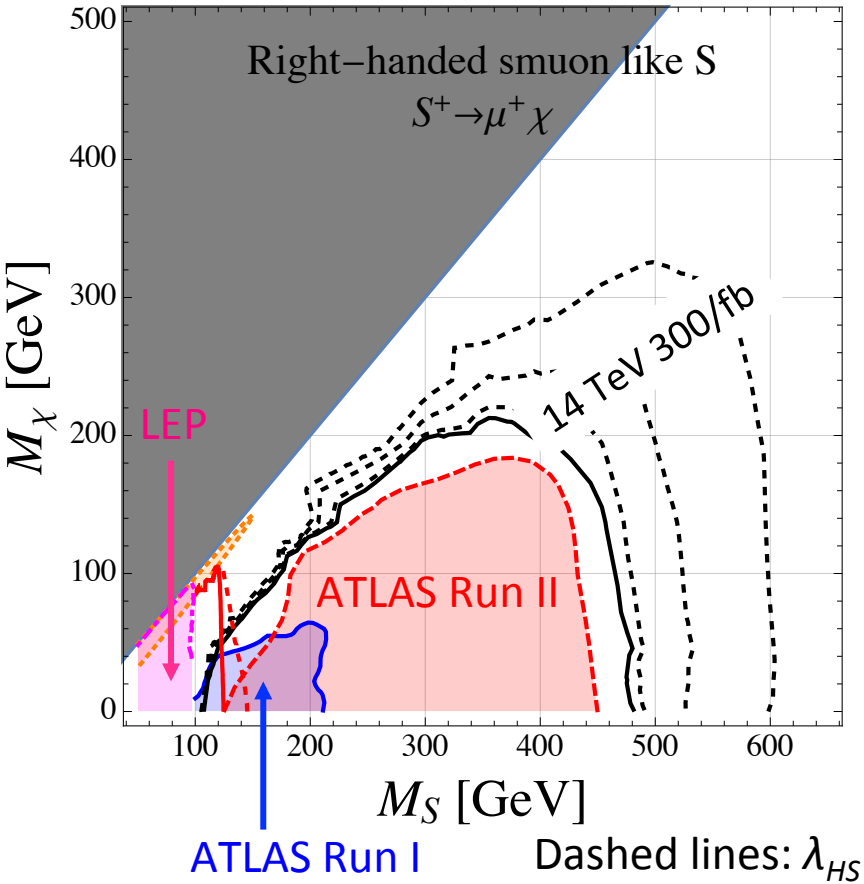
The semi-off-shell region: also probe the size of $y_l$ (portal coupling)

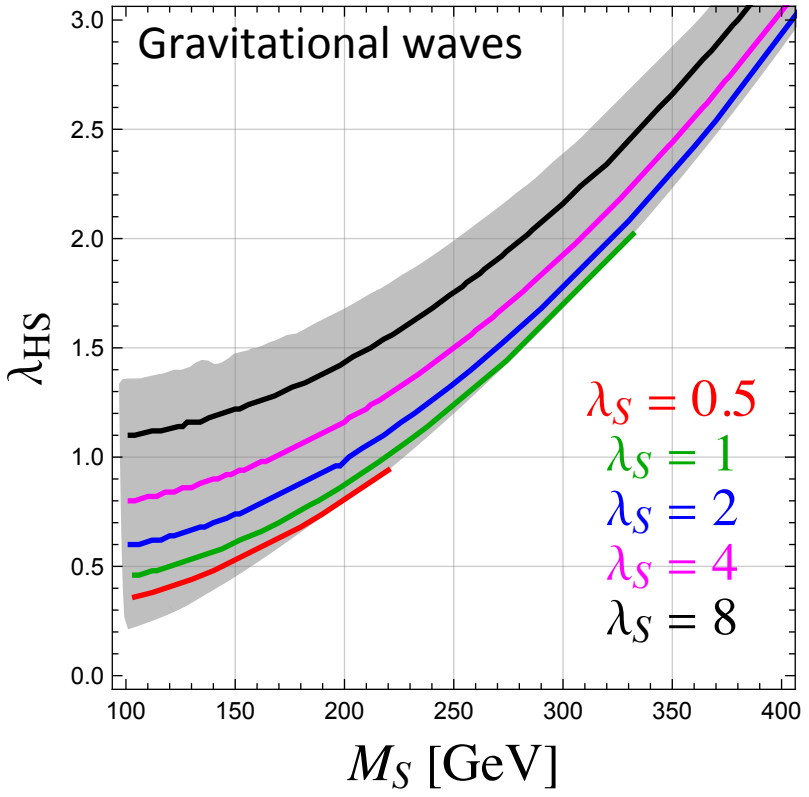
The Higgs/$Z$ exotic decay: another probe for $y_l$ .



- Preliminary results

The shaded regions: existing bounds; lines: projections




Dashed lines: $\lambda_{HS}$ = 2, 5, 10

Next step: the exotic decay bounds for $y_l$.