DARK MATTER AT THE HIGGS RESONANCE

Daniele Massaro — in collaboration with M. Di Mauro, C. Arina, N. Fornengo, J. Heisig

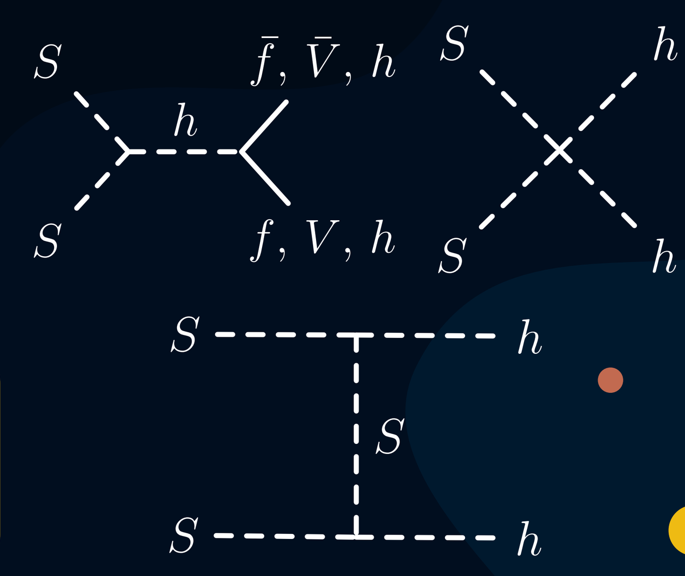
based on **arXiv:2305.11937**

Singlet scalar Higgs Portal model (SHP)

Scalar DM candidate S protected by a $\mathbb{Z}_2$ symmetry. After SSB:

$$\mathcal{L} \supset \frac{1}{2}\partial_\mu S \partial^\mu S - \frac{1}{2}m_S^2 S^2 - \frac{1}{4}\lambda_S S^4 - \frac{1}{4}\lambda_{HS} h^2 S^2 - \frac{1}{2} v_0 \lambda_{HS} h S^2$$

Solve the Boltzmann equation for the DM phase space density. The main annihilation channels are resonantly enhanced.



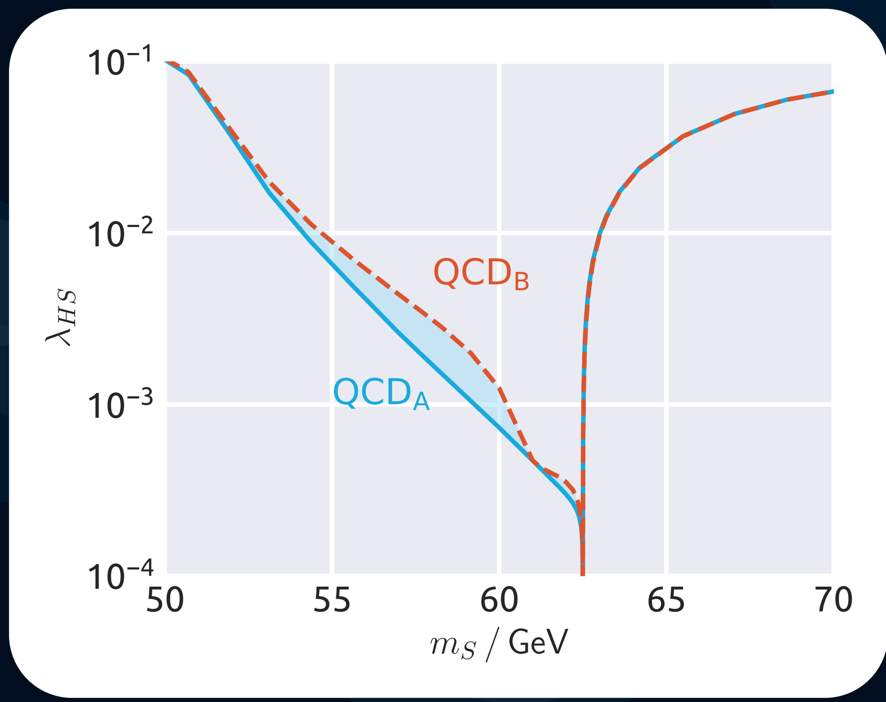
Kinetic equilibrium breaks down
Elastic scatterings are not resonantly enhanced. Coupling to SM particles depend on Yukawa: small.

Use the **full Boltzmann equation**, solved w/ the code DRAKE [T. Binder, T. Bringmann, M. Gustafsson, A. Hryczuk. EPJ C 81, p. 577].

The freeze-out temperature results $T_{\rm fo} \approx \mathcal{O}(1)$ GeV which is close to the QCD phase transition.

QCD_A
All quarks are free and present in the plasma. Maximize elastic scattering.

QCD_B
Only light quarks (u, d, s) can contribute. Minimize elastic scattering.



Direct detection

Cross section DM-nucleon is spin-independent:

$$\sigma_{\rm SI} = \frac{\lambda_{HS}^2}{4\pi m_h^4}\frac{m_N^4 f_N^2}{(m_S+m_N)^2}$$

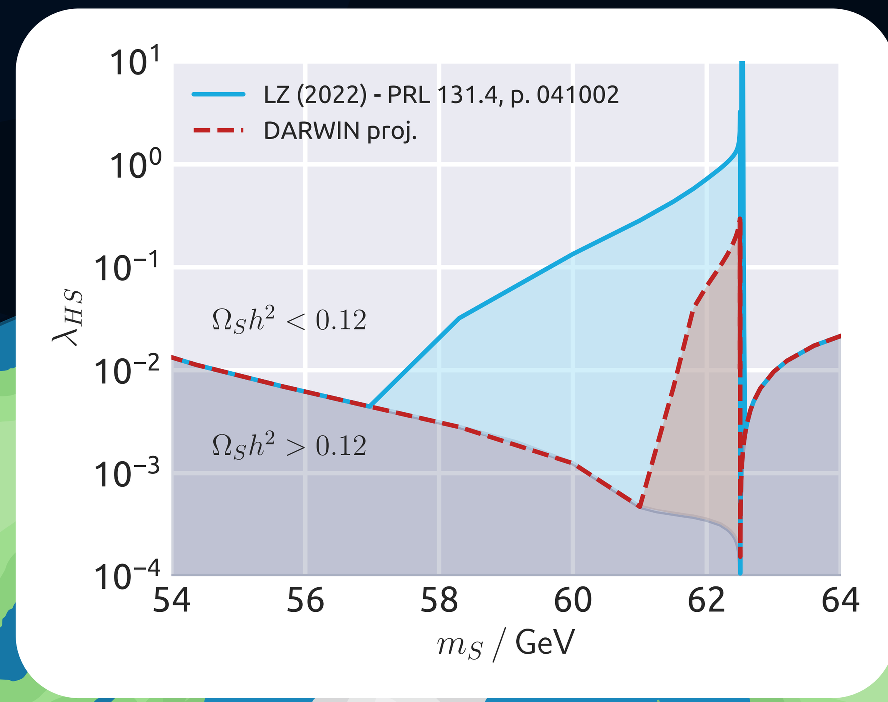
90% CL upper bounds from **LZ** and projections from **DARWIN**.

In case S makes up the fraction $\xi = \frac{\Omega_S h^2}{\Omega_{\rm DM} h^2}$ of DM density,

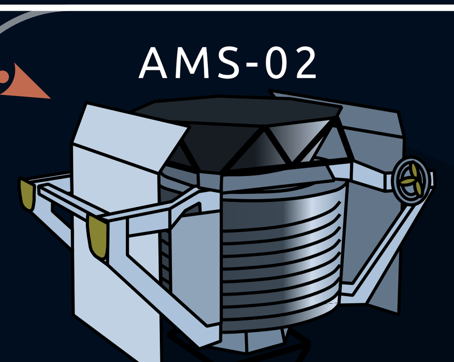
then we can relax the bounds by rescaling $\sigma_{\rm SI}$ appropriately:

$$\xi \sigma_{\rm SI}(m_S, \lambda_{HS}) \leq \sigma_{\rm UL}$$

LZ @ SURF



Indirect detection



ANTIPROTONS

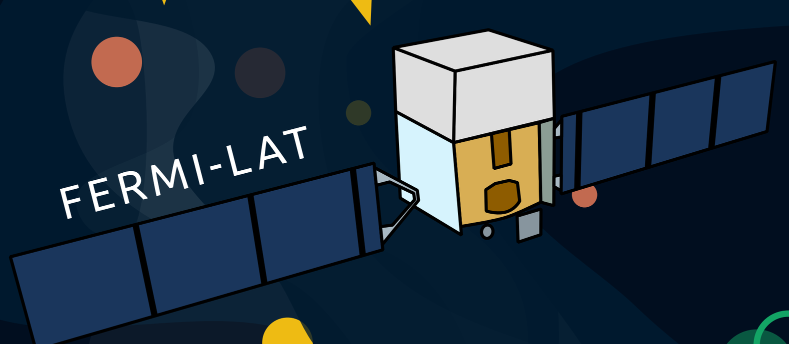
PHOTONS

Primary flux of $\bar{p}$ from dark matter annihilation. Differential production per volume, time and energy:

$$\mathcal{Q}(E, \boldsymbol{r}) = \left(\frac{\rho(\boldsymbol{r})}{\rho_\odot}\right)^2 \sum_f \mathcal{B}_f \left(\frac{dN_{\bar{p}}}{dE}\right)_f$$

Flux of secondary DM $\bar{p}$: tune the propagation parameters so the primary emission is compatible with AMS-02 observations. Propagation model includes diffusion, reacceleration, energy losses, secondary production/fragmentation, solar modulation.

Obtain a χ^2 profile for antiprotons data from AMS-02 [F. Kahlhöfer, M. Korsmeier, M. Krämer et al. JCAP 12.12, p. 37].

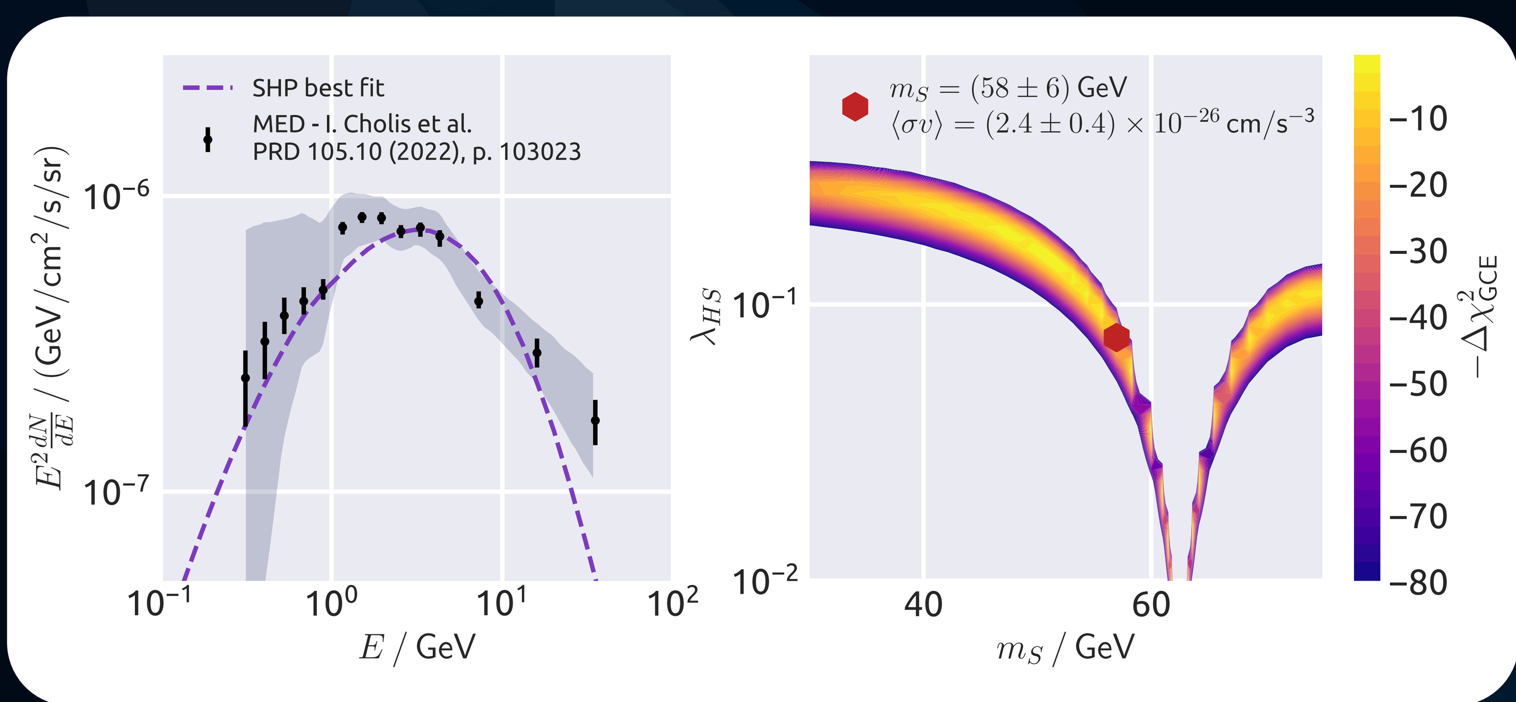


Consider only prompt emission of γ-rays

$$\frac{dN}{dE d\Omega} = \frac{r_\odot}{8\pi}\left(\frac{\rho_\odot}{m_S}\right)^2 J \times \langle\sigma v\rangle \sum_f \mathcal{B}_f \left(\frac{dN_\gamma}{dE}\right)_f$$

secondary emissions are negligible, because they are relevant mainly for $\mathcal{O}(1)$ GeV photon energies, where GCE flux uncertainties are high.

Fit GCE spectral energy distribution assuming SHP, obtaining χ^2 profile.



$$J = \frac{1}{\Delta\Omega}\int_{\Delta\Omega} d\Omega \int_{\rm l.o.s} \frac{dl}{r_\odot}\frac{\rho^2[r(l,\Omega)]}{\rho_\odot^2}$$

Uncertainties on DM distribution affect J-factor.

MIN	MED	MAX
J	⟷	$7\,J$

Perform study of **photons from dSph** (48 galaxies) and obtain a χ^2 profile.

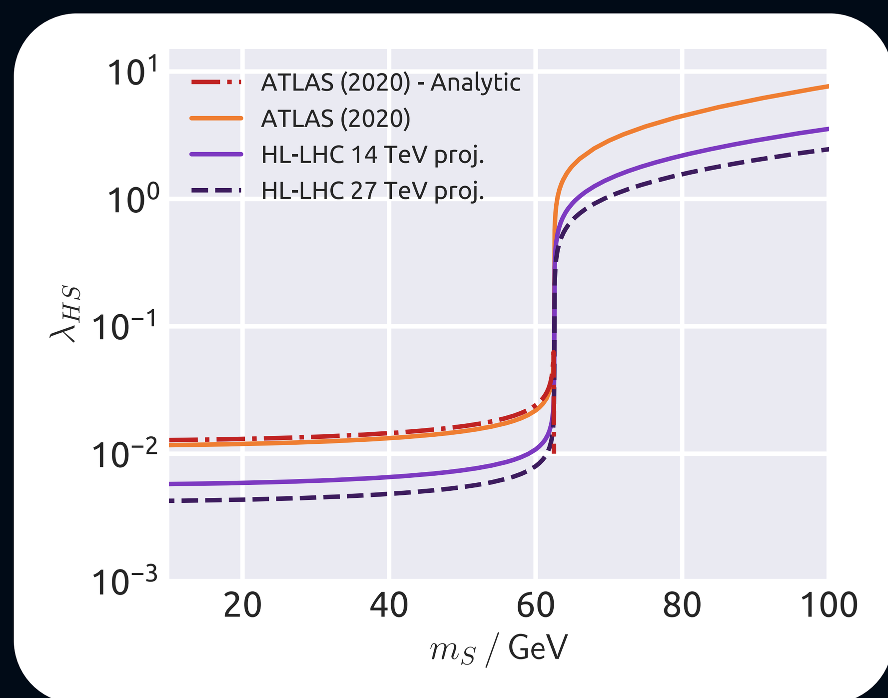
Collider searches

ATLAS @ LHC

Higgs **invisible width** to S (ATLAS):

$$\mathcal{B}_{h,\rm inv} = \frac{\Gamma_{h,\rm inv}}{\Gamma_{h,\rm inv} + \Gamma_{h,\rm SM}} < 0.13 \text{ at 95\% CL.}$$

Off-shell Higgs contribution relevant. Find the constraints using general DM pair-production formula with off-shell Higgs-like s-channel mediator.



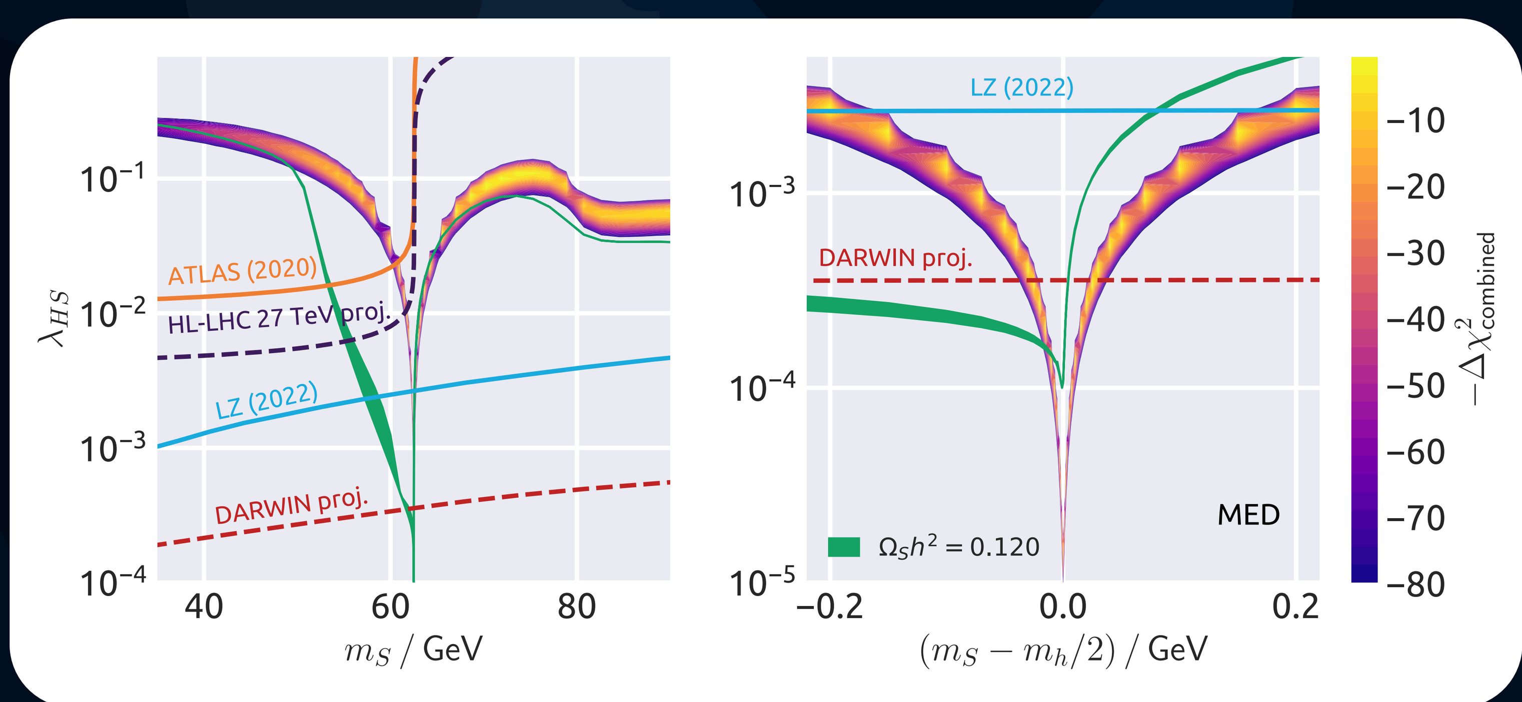
Putting it all together

Best fit point of MED model that satisfies all constraints is:

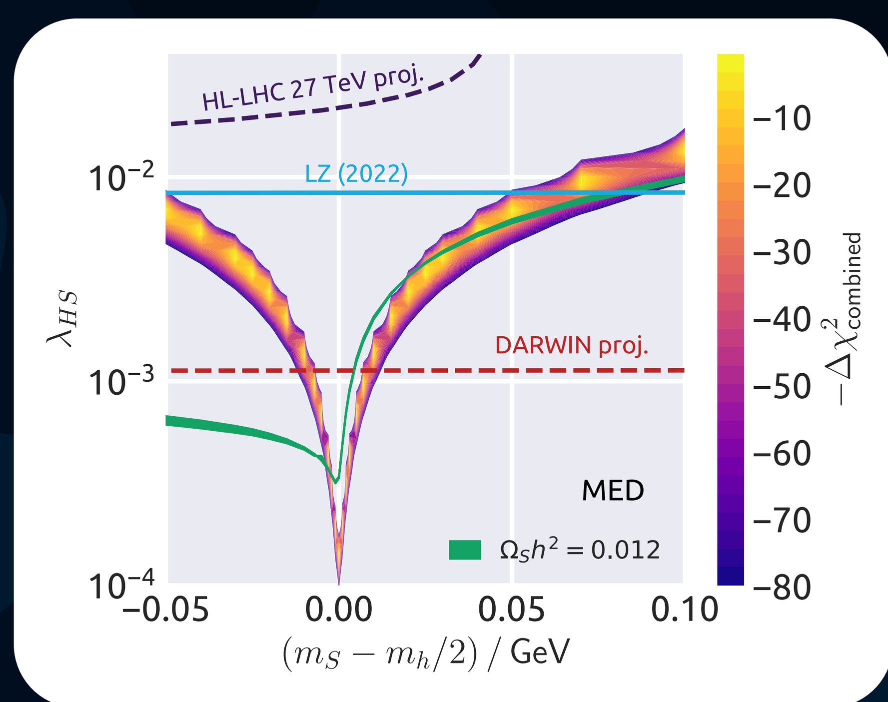
$$m_S = m_h/2 - (10 \div 20) \text{ MeV}$$
$$\lambda_{HS} = (1.4 \div 1.7) \times 10^{-4}$$

Assuming MIN and MAX, best fit does not change, while the coupling becomes:

$$\lambda_{HS} = (1.2 \div 2.0) \times 10^{-4}$$



What if $\xi = 0.1$?



ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

Theory and Phenomenology of Fundamental Interactions — UNIVERSITY AND INFN · BOLOGNA

INFN

UCLouvain