Particle Dark Matter Constraints:
The Effect of Galactic Uncertainties

Based on:
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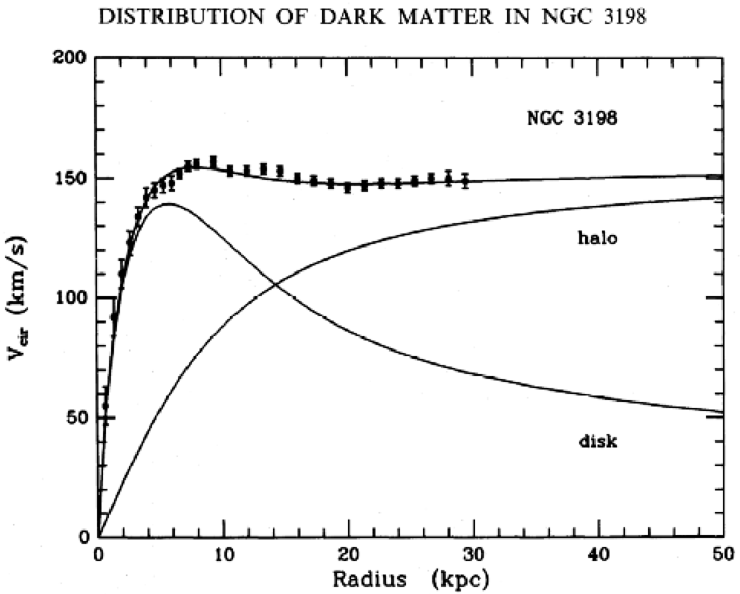
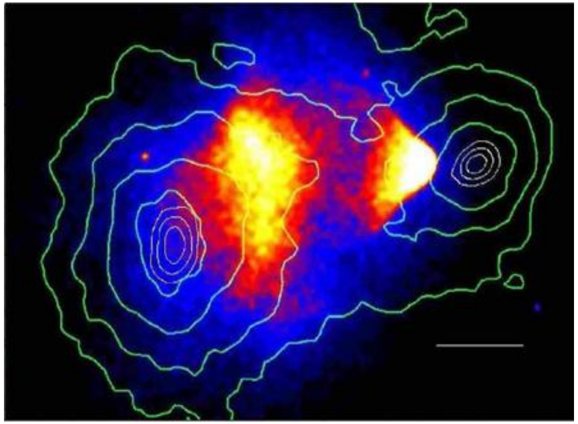
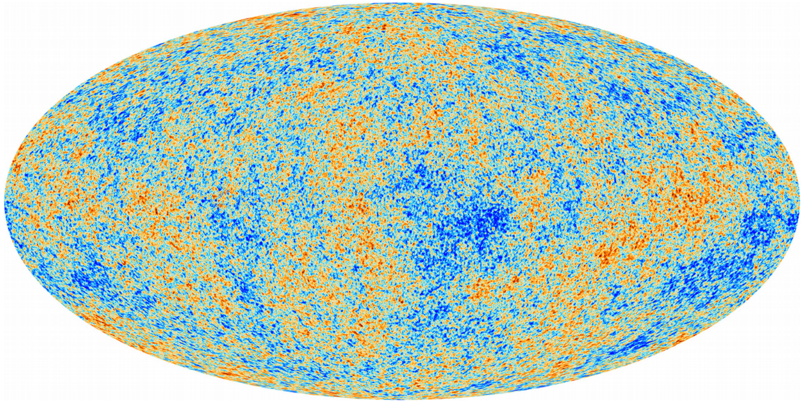
Evidences for Dark Matter

Several observations indicate existence of non-luminous Dark Matter (missing force) at very different scales!

* Galactic rotation curves
* Clusters of galaxies
* CMB anisotropies







Direct Detection

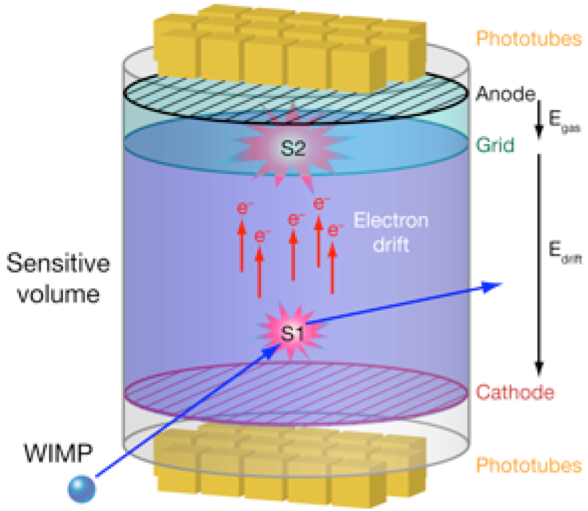
Direct detection experiments aim to measure the recoil energy of a nucleus in a detector after the collision with a DM from the halo of the MW.

Differential event rate

$$\frac{dR}{dE} = \frac{\rho_0}{m_\chi} \frac{1}{m_N} \int d^3v \, \frac{d\sigma}{dE} \, v \, f(v)$$

Particle physics: m_χ and σ

Astrophysics: ρ_0 and $f(v)$

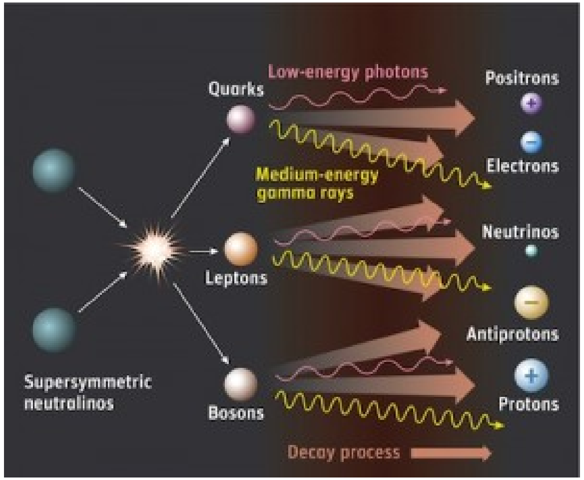


Indirect Detection

Indirect detection aims at detecting the flux of final stable particles produced by DM annihilation or decay.

Differential event rate

$$\frac{dN}{dA\,dt\,d\Omega\,dE} = \frac{\langle\sigma v\rangle}{2\,m_\chi^2}\,\frac{dN}{dE}\,\frac{1}{4\pi}\int_{\rm los}\rho_\chi^2\,dl$$



Particle physics: m_χ, $\langle\sigma v\rangle$ and the ann. channel

Astrophysics: $\rho_\chi(l,\Omega)$

Our Aim

- The determination of Particle Physics quantities is highly affected by *astrophysical uncertainties*
- The latter, especially those for our own MW, are ill-known, and often not fully accounted for when analyzing the pheno of particle physics models

- Systematic analysis of how the uncertainties on the DM structure in our Galaxy affect the determination of New Physics
- Estimate the effects of the Galactic Uncertainties in the *particle physics parameter space*, by varying different sources of uncertainty one at a time
- Treat uncertainties (direct & indirect) in a self-consistent way

Galactic Dynamics

- Dynamical Method:
  Rotation curves track *total* gravitiational potential
  compared to the expected velocity due to visible matter
  Mismatch → fit DM density profile
- Compilation of observed RC data (Iocco, Pato & Bertone '15)
  Milky Way morphology: 70 baryonic models
  Stellar bulge + Stellar disk + Gaseous disk (Pato, Iocco & Bertone '15)
- gNFW DM density profile: $$\rho_\chi = \rho_0 \left(\frac{R_0}{R}\right)^\gamma \left(\frac{R_s + R_0}{R_s + R}\right)^{3-\gamma}$$
- Fit → (ρ_0, γ)
  R_S = 20 kpc

$$\chi^2 = \sum_{i=1}^{N} d_i^2 \equiv \sum_{i=1}^{N} \left[\frac{(y_i - y_{t,i})^2}{\sigma_{y,i}^2 + \sigma_{b,i}^2} + \frac{(x_i - x_{t,i})^2}{\sigma_{x,i}^2} \right]$$

Galactic Dynamics

- **Reference** Morphology of the baryonic component (BjX)
  R_0 = 8 kpc and v_0 = 230 km/s
  → γ = 1.11 and ρ_0 = 0.466 GeV/cm^3

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- Uncertainties on **Galactic Parameters** R_0 and v_0 (Reference morphology)
  R_0 = [7.5, 8.5] kpc and v_0 = [200±20, 279±33] km/s

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- Uncertainties on the **Morphology** of the baryonic component (R_0 = 8 kpc and v_0 = 230 km/s)
  Different morphologies in order to minimize/maximize γ and ρ_0

Galactic Dynamics

Reference morphology

Morphology	R_0 (kpc)	v_0 (km/s)	M_* ($\times 10^{10}\, M_\odot$)	γ	ρ_0 (GeV/cm^3)	χ^2/dof
BjX	8	230	2.4 ± 0.5	1.11	0.466	1.22

Galactic Dynamics

Statistical uncertainties

Reference morphology

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BjX	7.5	312	1.52 ± 0.19	$0.633^{+0.019}_{-0.020}$	1.762 ± 0.017	1.35
BjX	8.5	180	2.4 ± 0.5	2.02 ± 0.07	0.055 ± 0.004	0.90

Galactic Dynamics

Statistical uncertainties

Reference morphology

Galactic parameters

Morphology variation

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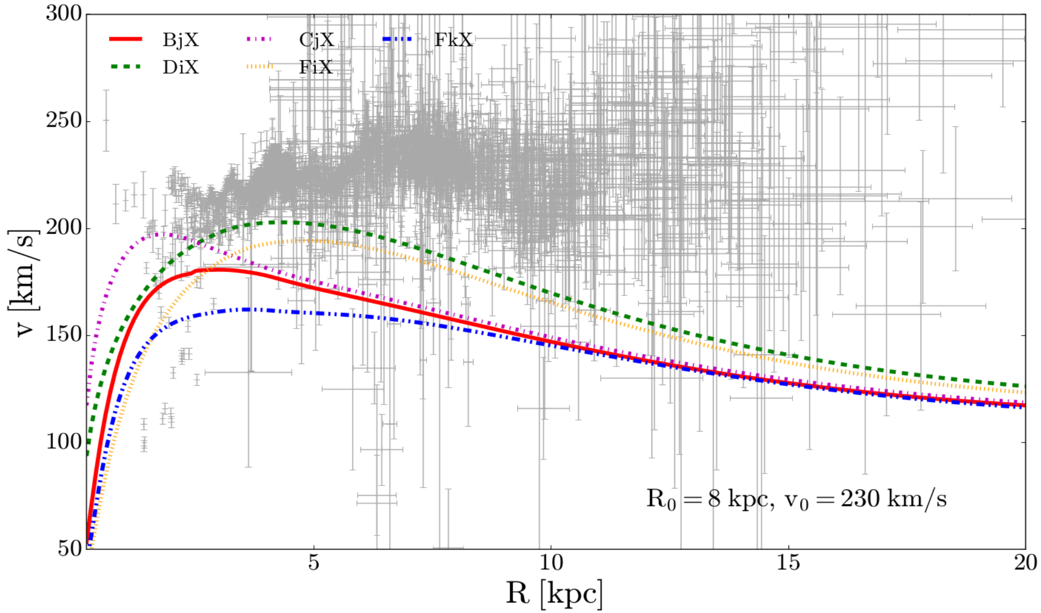
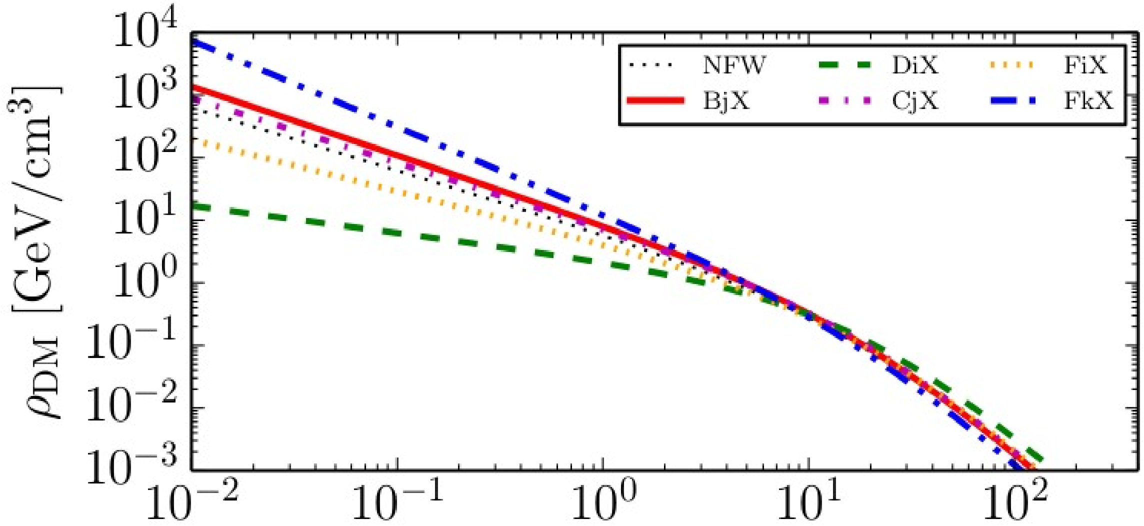
BjX	8.5	180	2.4 ± 0.5	2.02 ± 0.07	0.055 ± 0.004	0.90
FkX	8	230	2.0 ± 0.4	$1.38^{+0.03}_{-0.02}$	$0.427^{+0.007}_{-0.008}$	1.05
DiX	8	230	3.0 ± 0.6	$0.43^{+0.07}_{-0.06}$	0.405 ± 0.011	0.99
CjX	8	230	2.5 ± 0.6	1.03 ± 0.04	$0.471^{+0.010}_{-0.011}$	1.13
FiX	8	230	2.6 ± 0.4	0.82 ± 0.05	0.387 ± 0.010	1.16



Galkin

(Pato & Iocco '17)



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Impact on Particle Physics Models

Singlet Scalar DM

McDonald '07

S is a scalar singlet, protected by a Z_2

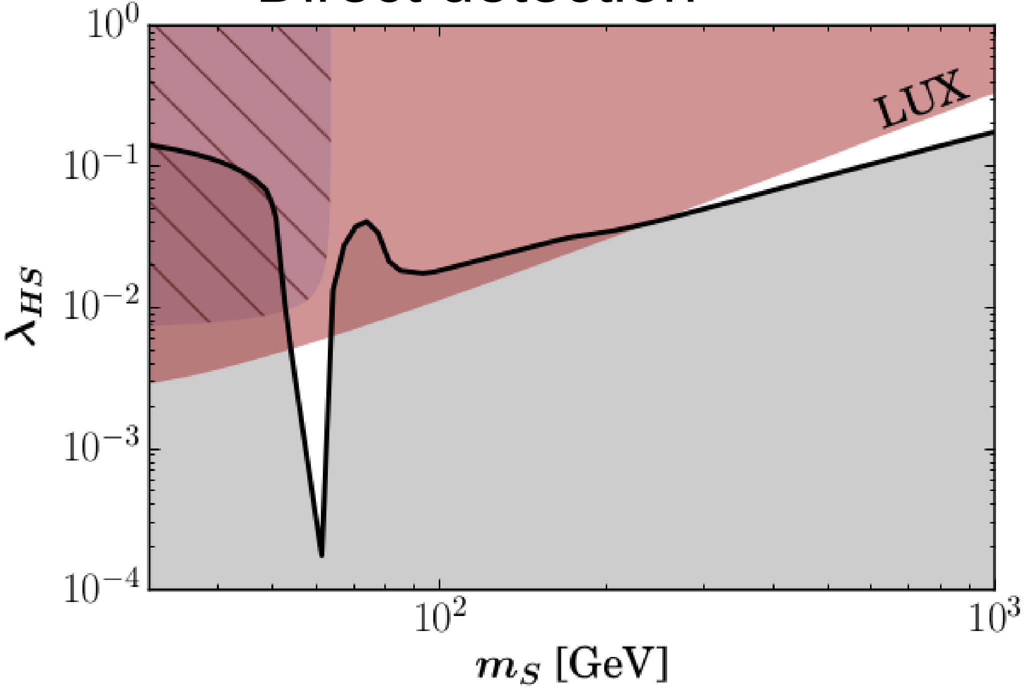
$$V \supset \mu_S^2\, S^2 + \lambda_S\, S^4 + \lambda_{HS} |H|^2\, S^2$$

3 free parameters:

* m_S DM mass
* λ_{HS} Higgs portal
* λ_S DM quartic coupling

Singlet Scalar DM: Reference morphology

Direct detection



BjX with R_0 = 8 kpc and v_0 = 230 km/s

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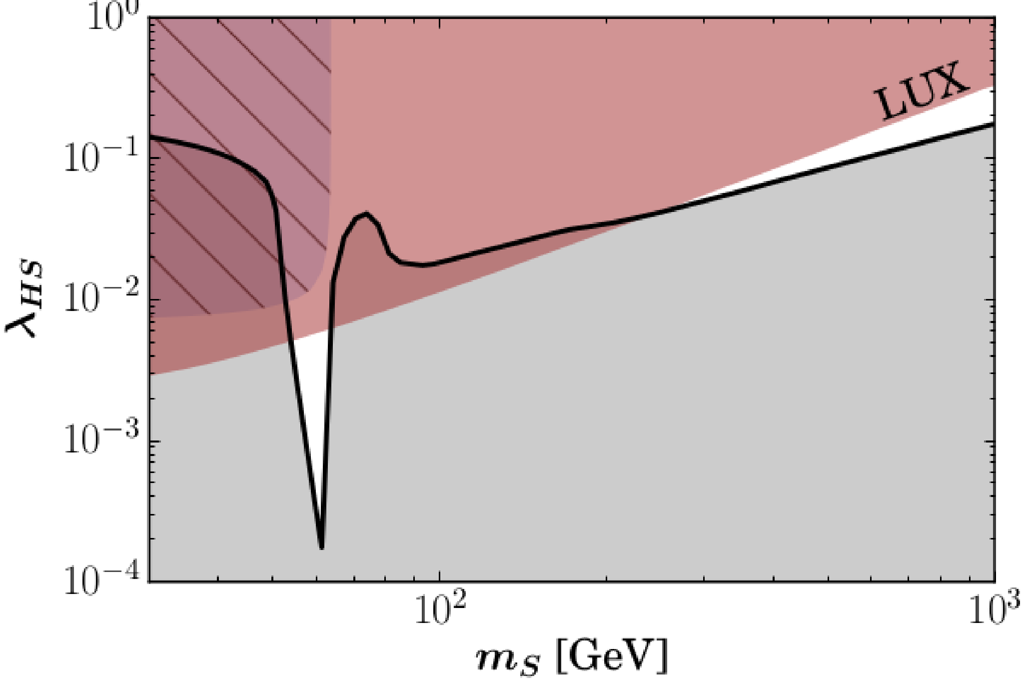

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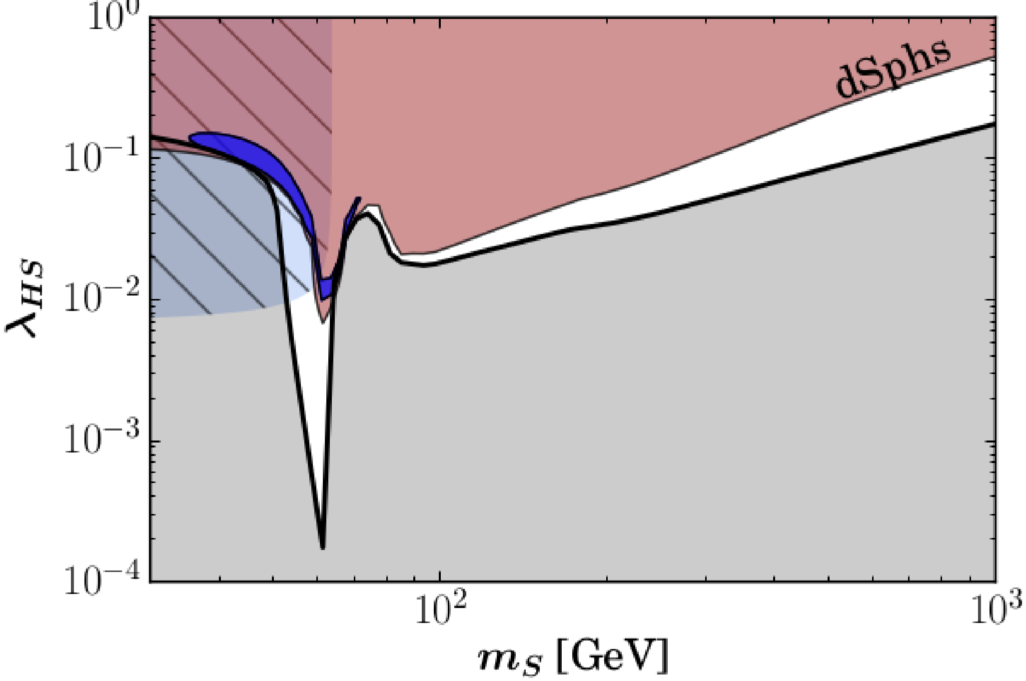

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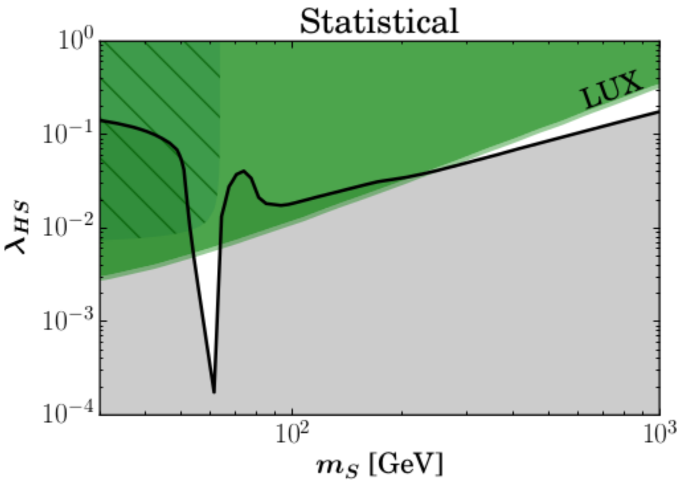

BjX with R_0 = 8 kpc and v_0 = 230 km/s

γ = 1.11±0.03

ρ_0 = 0.466±0.01 GeV/cm^3

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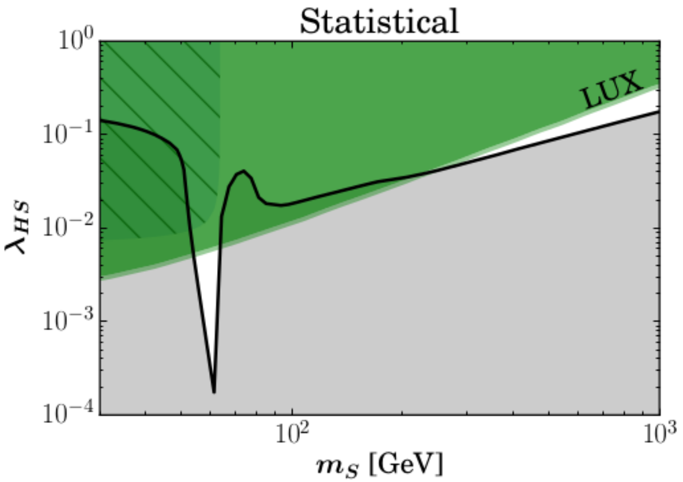

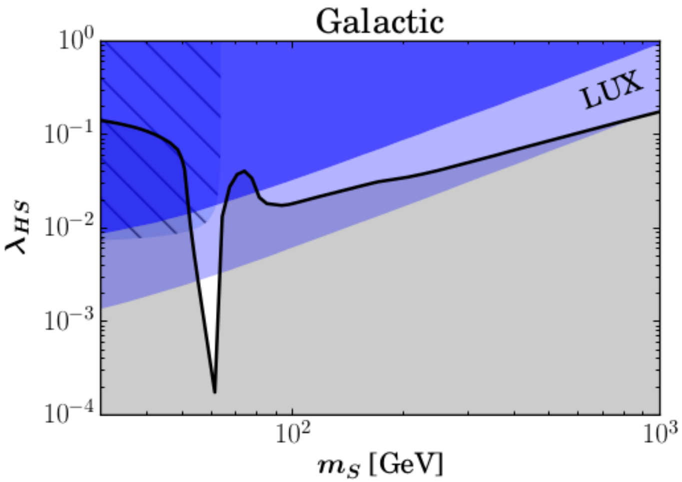

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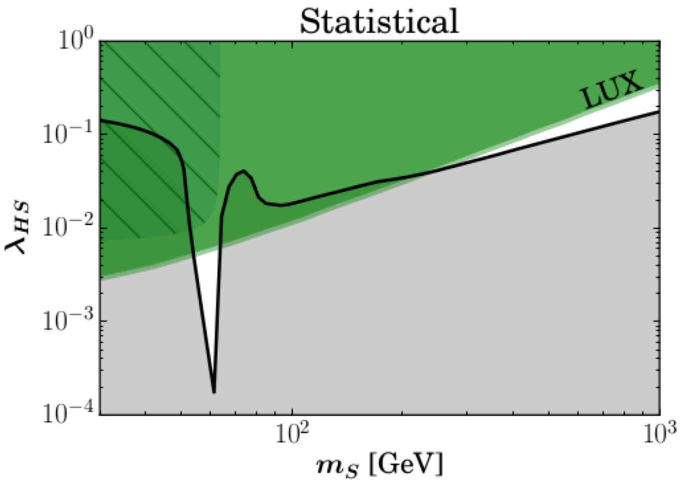
BjX with
R_0 = [7.5, 8.5] kpc
v_0 = [180, 312] km/s

Singlet Scalar DM: Direct Detection



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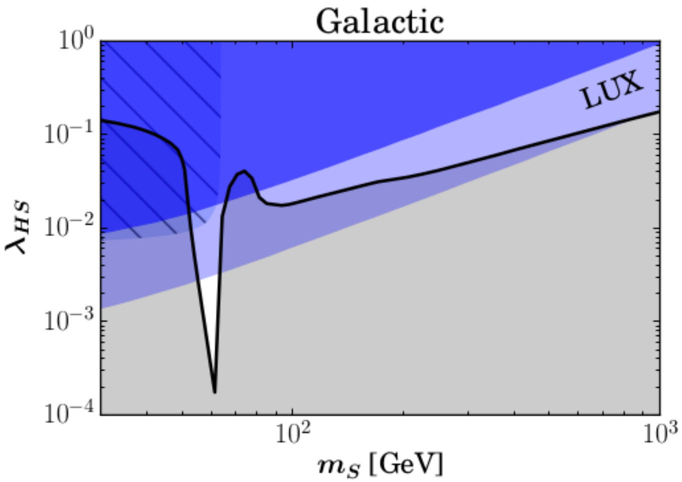

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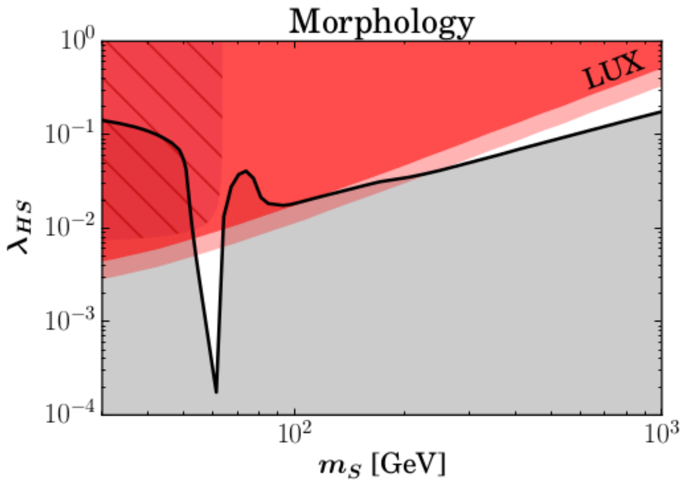
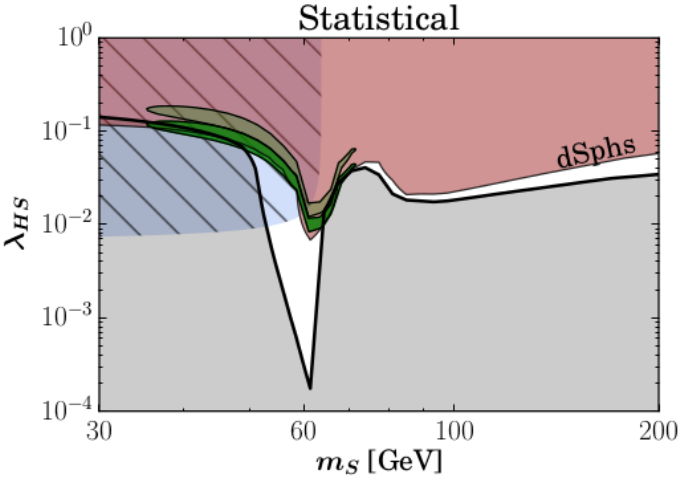
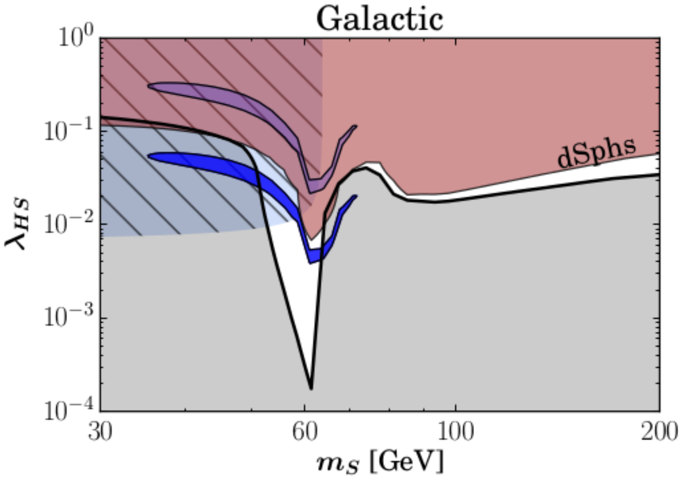
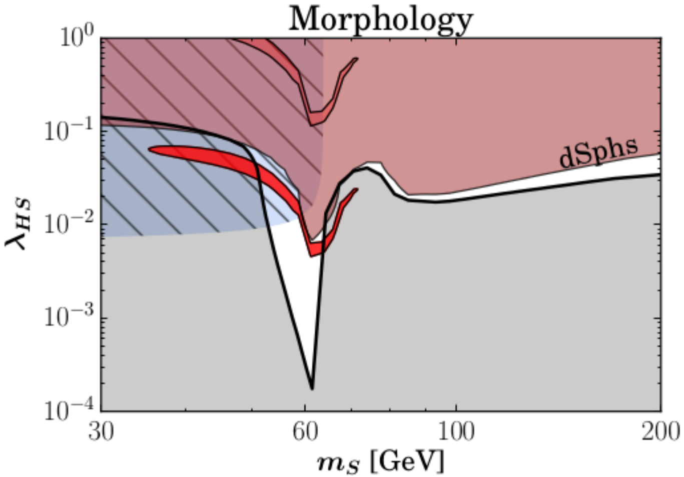


Different morphologies
for the baryons
R_0 = 8 kpc and v_0 = 230 km/s

Singlet Scalar DM: Indirect Detection







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R_0 = 8 kpc and v_0 = 230 km/s

Inert Doublet Model

Barbieri et al '06

Φ is an inert doublet, protected by a Z_2

$$V \supset \mu_2^2\,|\Phi|^2 + \lambda_2\,|\Phi|^4 + \lambda_3|H|^2\,|\Phi|^2 + \lambda_4|H^\dagger\,\Phi|^2 + \frac{\lambda_5}{2}\,\left[(H^\dagger\,\Phi)^2 + \mathrm{H.c.}\right]$$

4 new states: H^0, A^0, $H^\pm$

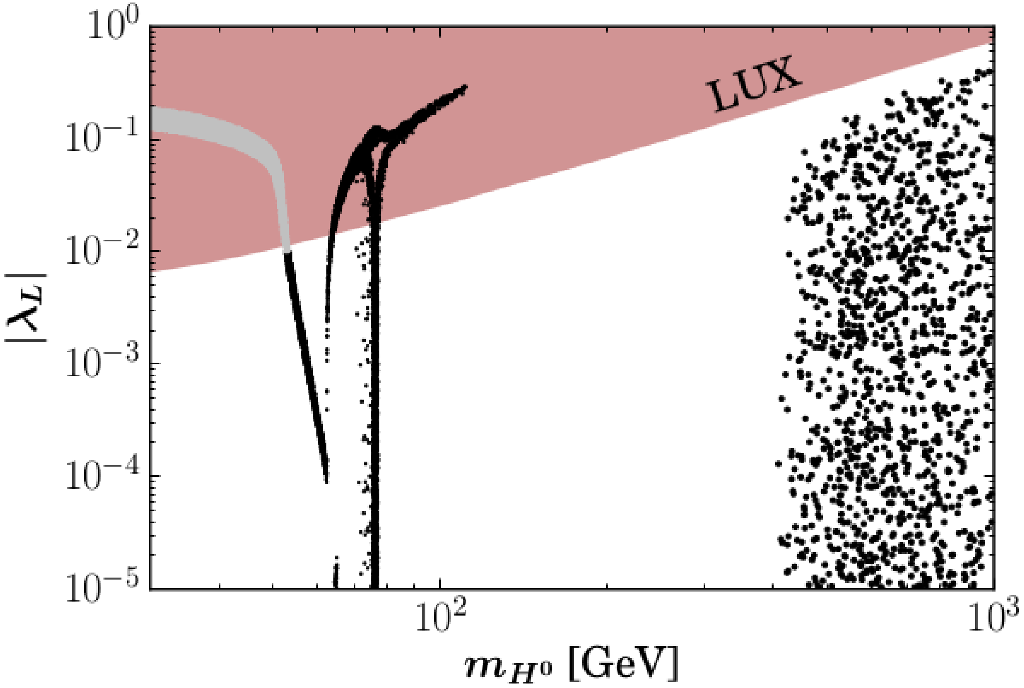
→ The lightest neutral state can play the role of DM

5 free parameters:

→ m_{H0}, m_{A0}, $m_{H\pm}$, λ_2 and $\lambda_L \equiv \frac{1}{2}(\lambda_3 + \lambda_4 - \lambda_5)$

Inert Doublet Model: Reference morphology

Direct detection



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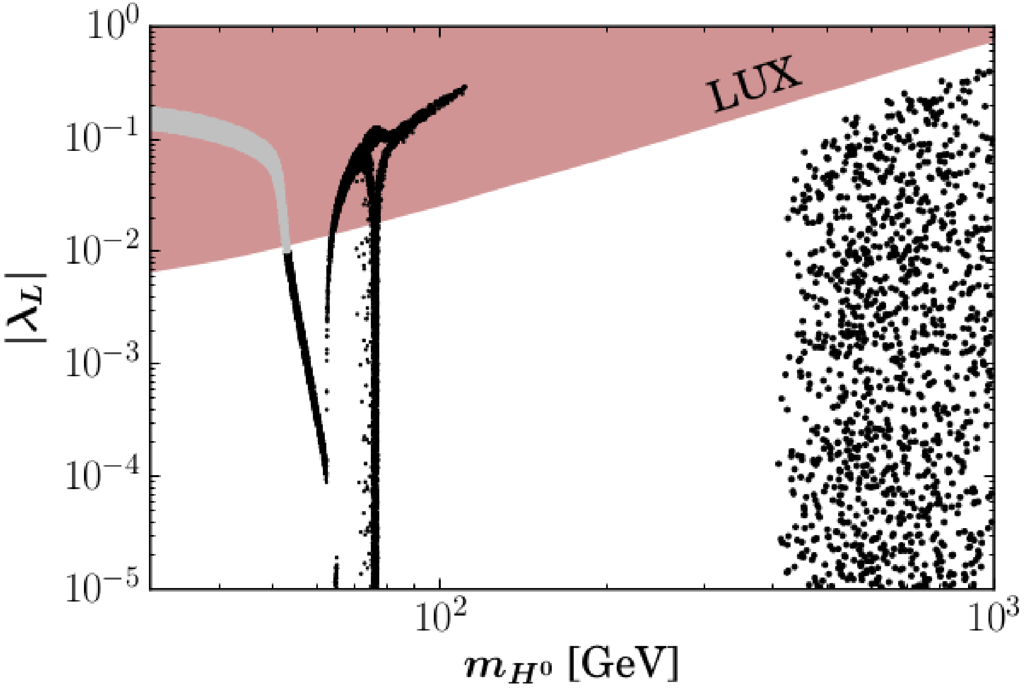

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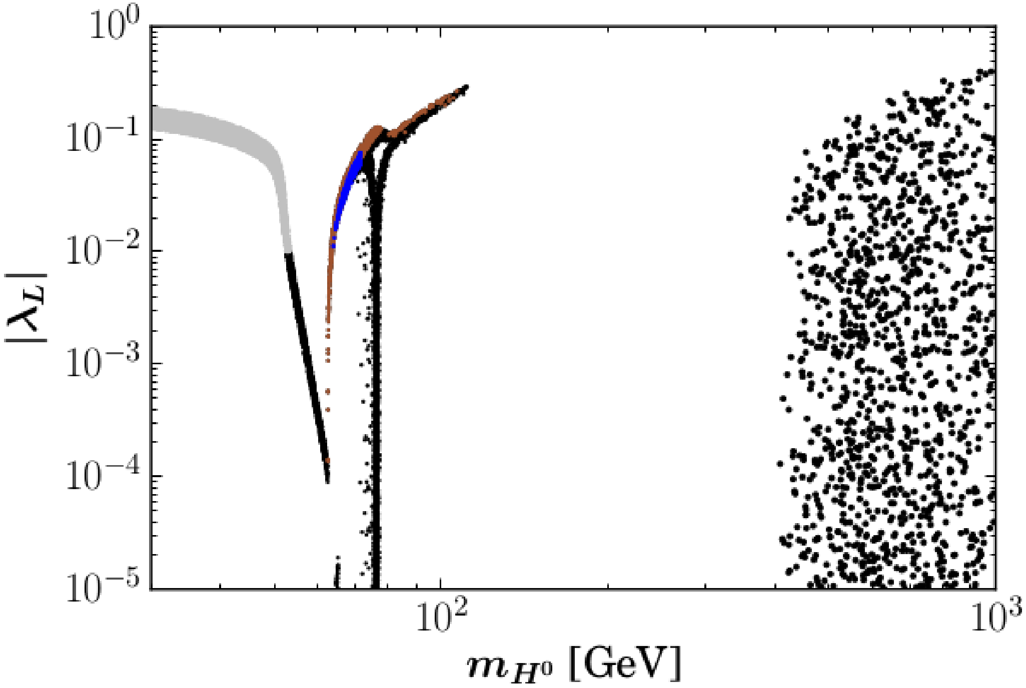

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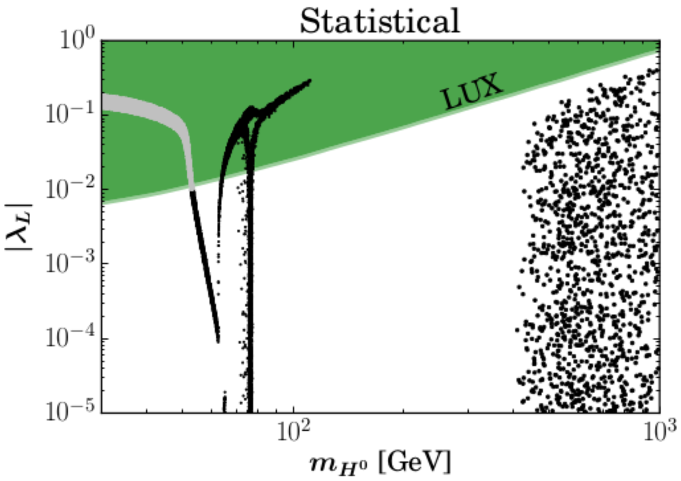

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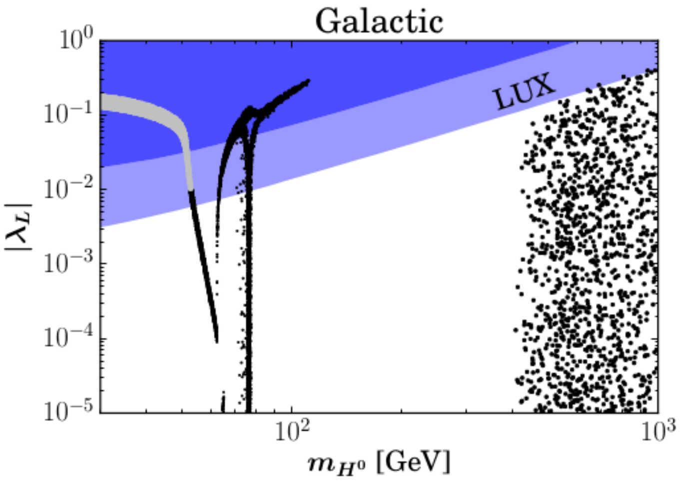

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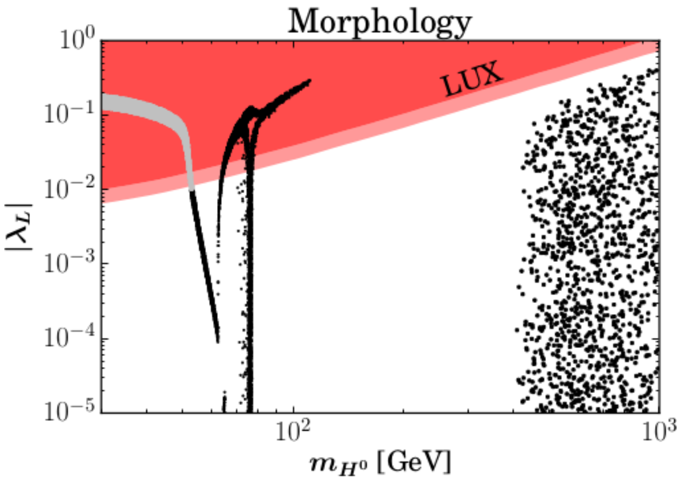

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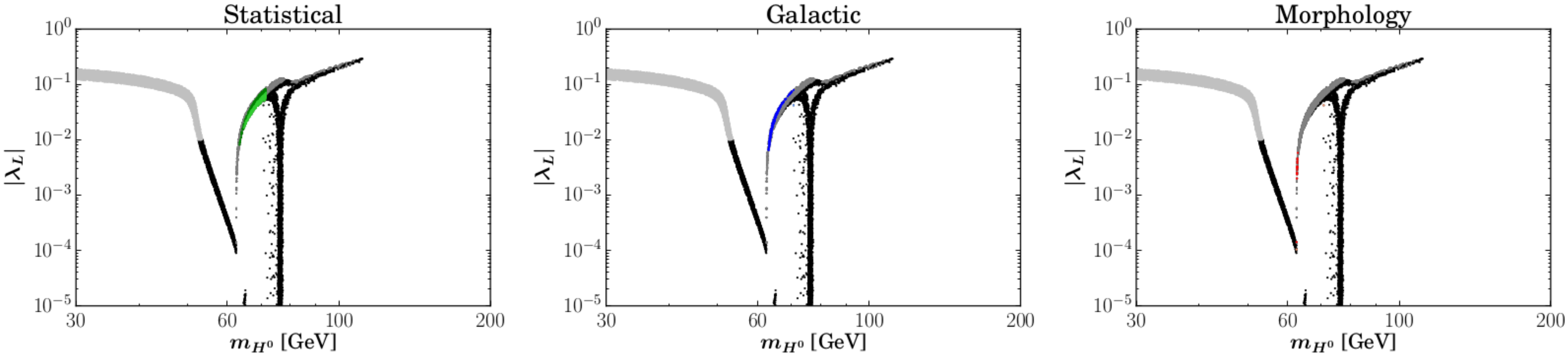

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Conclusions

- Galactic uncertainties affect the determination of the DM distribution and propagate when constraining New Physics
- Galactic uncertainties have to be under control in order to extract particle physics obsevables (m_χ, $<\sigma v>$, σ, Br)
- Systematic scan of major sources of uncertainties:
  * Statistical
  * Galactic Parameters
  * Baryonic Morphology
- Galactic uncertainties play a mayor role, but too ofter overlooked!
- Gaia mission expected to improve the determiantion of R_0 and ρ_0