DarkBS Phenomenology

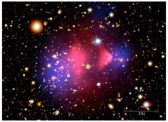
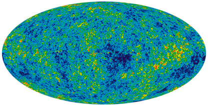
XIX Mexican Workshop on Particles and Fields, 2025

Gustavo Becerril Hernández
Dra. María Catalina Espinoza Hernández

IF-UNAM

October 22, 2025

Dark Matter as one of the main problems in physics

Dark Matter properties

What if DM is a fundamental particle?

1. It is NON-luminous
2. Very weak selft-interaction
3. It does NOT interact strongly with ordinary matter
4. NON-relativistic
5. It's LONG-lived

We need to **extend** the SM

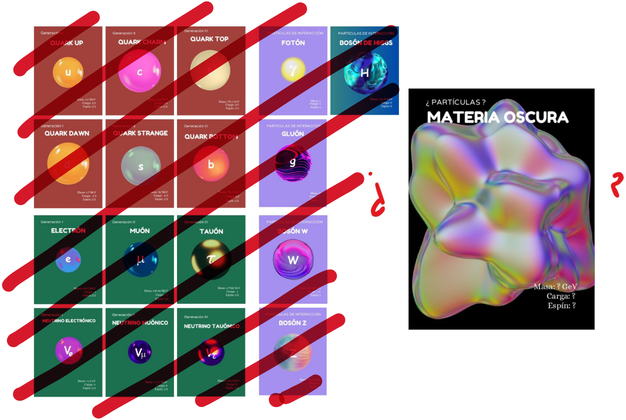


Figure: SM content with... DM?

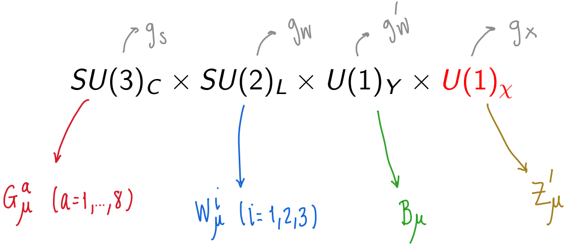
DarkBS

DarkBS (Sierra: Stub: Vicente, 2015), will be our election for the extention.

DarkBS

DarkBS (Sierra: Stub: Vicente, 2015), will be our election for the extention.

$$SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_\chi$$



DarkBS

It has...

Fields	$SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_\chi$
$Q_{L/R}$	$(\mathbf{3}, \mathbf{2}, \frac{1}{6}, 2)$
$L_{L/R}$	$(\mathbf{1}, \mathbf{2}, -\frac{1}{2}, 2)$
ϕ	$(\mathbf{1}, \mathbf{1}, 0, 2)$
χ	$(\mathbf{1}, \mathbf{1}, 0, -1)$

DM candidate

Table: New content of particles from DarkBS

The LHCb reported in 2014 an anomali in processes involving $b \to s$ transitions (LHCb Collab., PRL 113 (2014) 151601)

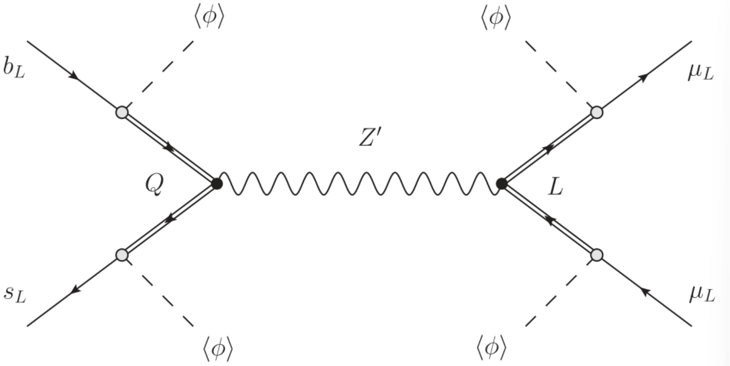
$$R_k = \frac{\mathrm{BR}(B \to K\mu^+\mu^-)}{\mathrm{BR}(B \to Ke^+e^-)} = 0.745^{+0.090}_{-0.074} \pm 0.036$$

The SM does predict

$$R_k^{SM} = \frac{\mathrm{BR}(B \to K\mu^+\mu^-)}{\mathrm{BR}(B \to Ke^+e^-)} = 1.0003 \pm 0.0001$$

DarkBS

a solution to the $b \to s$ anomalies



DarkBS

The potential is extended by the following terms:

$$\mathcal{V} = V_{SM} + \mathcal{V}(\Phi, \phi, \chi) + \mathcal{V}(\Phi, \chi),$$

DarkBS

The potential is extended by the following terms:

$$\mathcal{V} = V_{SM} + \mathcal{V}(\Phi, \phi, \chi) + \mathcal{V}(\Phi, \chi),$$

where V_{SM} correspond to the SM potential. Besides,

$$\mathcal{V}(\Phi, \phi, \chi) = \lambda_{\Phi\phi}|\Phi|^2|\phi|^2 + \lambda_{\Phi\chi}|\Phi|^2|\chi|^2$$

and

$$\mathcal{V}(\phi, \chi) = m_\phi^2|\phi|^2 + \frac{\lambda_\phi}{2}|\phi|^4 + m_\chi^2|\chi|^2 + \frac{\lambda_\chi}{2}|\chi|^4 + \cdots$$
$$\cdots + \lambda_{\phi\chi}|\phi|^2|\chi|^2 + \left(\mu\phi\chi^2 + h.c.\right).$$

DarkBS

If we assume:

$$\langle \phi^0 \rangle = \frac{v}{\sqrt{2}}, \quad \langle \phi \rangle = \frac{v_\phi}{\sqrt{2}}.$$

DarkBS

If we assume:

$$\langle \phi^0 \rangle = \frac{v}{\sqrt{2}}, \quad \langle \phi \rangle = \frac{v_\phi}{\sqrt{2}}.$$

Implies that...

- ϕ breaks spontaneously $U(1)_\chi \to \mathbb{Z}_2$, giving mass to the boson Z', $m_{Z'} = 2 g_X v_\phi$.

DarkBS

If we assume:

$$\langle \phi^0 \rangle = \frac{v}{\sqrt{2}}, \quad \langle \phi \rangle = \frac{v_\phi}{\sqrt{2}}.$$

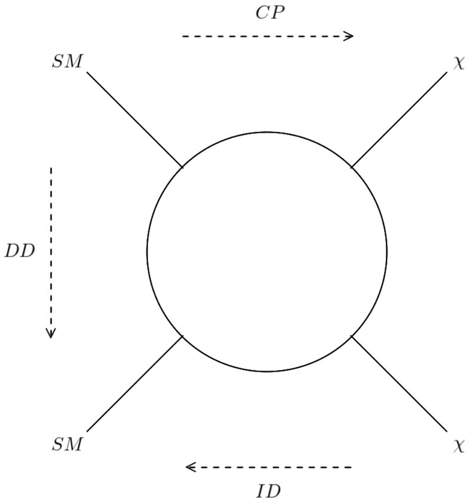
Implies that...

- ϕ breaks spontaneously $U(1)_\chi \to \mathbb{Z}_2$, giving mass to the boson Z', $m_{Z'} = 2g_X v_\phi$.

Also χ is a scalar field, neutral and stable.

and now... we make phenomenology!

Detection Methods



A little bit of Numerical Analysis

A little bit of Numerical Analysis

To simulate the experiments we need several computational tools for high energy physics:

★ *SARAH* (arXiv:0806.0538 [hep-ph])

A little bit of Numerical Analysis

To simulate the experiments we need several computational tools for high energy physics:

- ★ *SARAH* (arXiv:0806.0538 [hep-ph])
- ★ *SPheno* (arXiv:hep-ph/0301101, arXiv:1104.1573)
- ★ *MicrOmegas* (arXiv:2312.14894 [hep-ph])
- ★ *DDCalc* (arXiv:1705.07920, arXiv:1808.10465)
- ★ *Diver* (arXiv:1705.07959)

A little bit of Numerical Analysis

To simulate the experiments we need several computational tools for high energy physics:

- ★ *SARAH* (arXiv:0806.0538 [hep-ph])
- ★ *SPheno* (arXiv:hep-ph/0301101, arXiv:1104.1573)
- ★ *MicrOmegas* (arXiv:2312.14894 [hep-ph])
- ★ *DDCalc* (arXiv:1705.07920, arXiv:1808.10465)
- ★ *Diver* (arXiv:1705.07959)
- ★ *MadGraph* (arXiv:1405.0301 [hep-ph])
- ★ *MadAnalysis* (arXiv:1206.1599 [hep-ph])

For some observables it is necessary to first calculate the likelihood function (LF),

$$\triangle\chi^2 = \chi^2 - \chi^2_{min} = -2log(\mathcal{L}/\mathcal{L}_{max}).$$

The sweep for the parameter space was divided into two parts:

1. conditions of unitarity and stability of the vacuum.
2. construct the functions χ^2_i for each observable i.

Constraints for Relic Density

The relic density measured by the Planck satellite;
$\Omega h^2 = 0.120 \pm 0.001$ (arXiv:1807.06209 [astro-ph.CO])

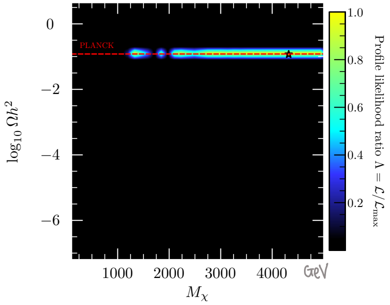


Figure: DM abundance

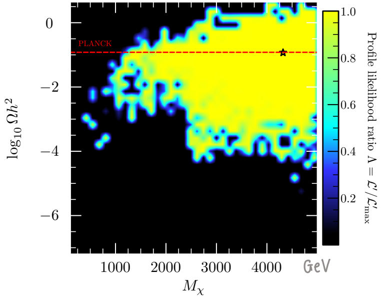


Figure: Abundance with respect to the LF of DD

Constraints for Direct Detection

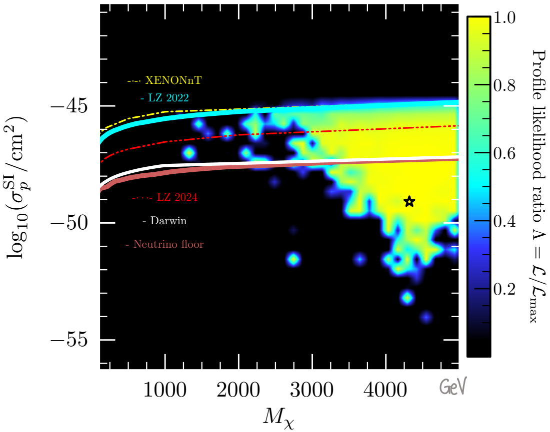


Figure: Likelihood profile with respect to the DD + PLANCK LF. Comparison with limits from several DD experiments is included.

LHC Constraints

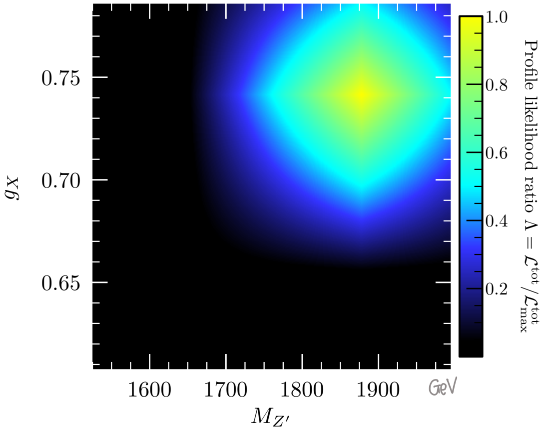


Figure: Likelihood profile relative to the DD + PLANCK + LHC LF. The LHC LF takes into account searches for the Z' boson.

Conclusions

- DarkBS contains a DM candidate on the WIMP scale; χ.

Conclusions

- DarkBS contains a DM candidate on the WIMP scale; χ.
- The best-fit point replicates the relic density.

Conclusions

- DarkBS contains a DM candidate on the WIMP scale; χ.
- The best-fit point replicates the relic density.
- Without any experiments capable of detecting this candidate... there will be future problems.

Conclusions

- DarkBS contains a DM candidate on the WIMP scale; χ.
- The best-fit point replicates the relic density.
- Without any experiments capable of detecting this candidate... there will be future problems.
- The model is viable for very massive DM and Z'.

Conclusions

- DarkBS contains a DM candidate on the WIMP scale; χ.
- The best-fit point replicates the relic density.
- Without any experiments capable of detecting this candidate... there will be future problems.
- The model is viable for very massive DM and Z'.

¡Gracias!

:)