The Dark Sequential Z' Portal Collider and Direct Detection Experiments

Miguel Campos

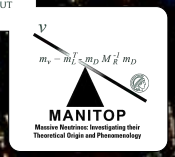
based on arXiv:1708.00890

work done in collaboration with

Giorgio Arcadi, Manfred Lindner, Antonio Masiero, Farinaldo S. Queiroz.

Max-Planck-Institut für Kernphysik & Heidelberg Universität

Hamburg, September 2017.



INTERNATIONAL MAX PLANCK RESEARCH SCHOOL PT FS

FOR PRECISION TESTS OF FUNDAMENTAL SYMMETRIES

UNIVERSITÄT HEIDELBERG
ZUKUNFT SEIT 1386

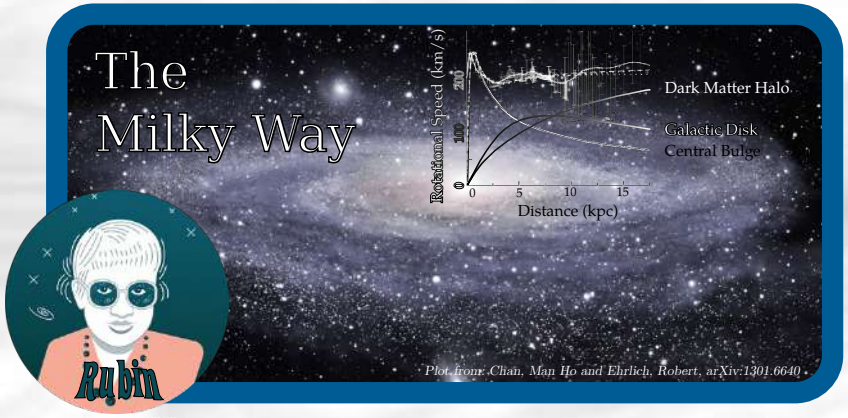
Introduction

Dark Matter

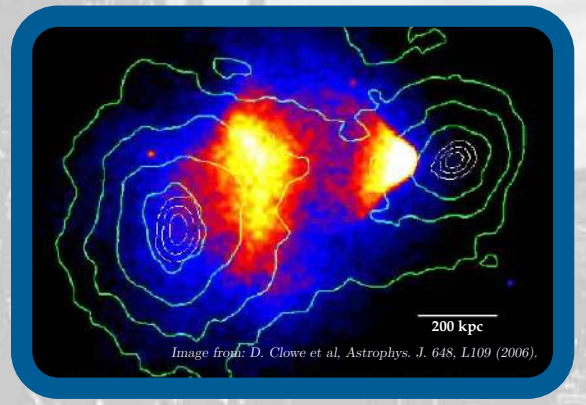
Evidence

The Coma Cluster

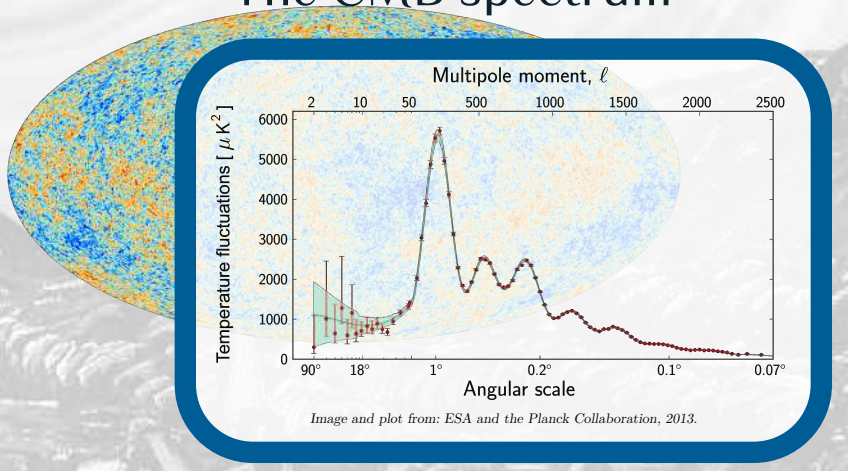
Galactic rotation curves



The Bullet cluster

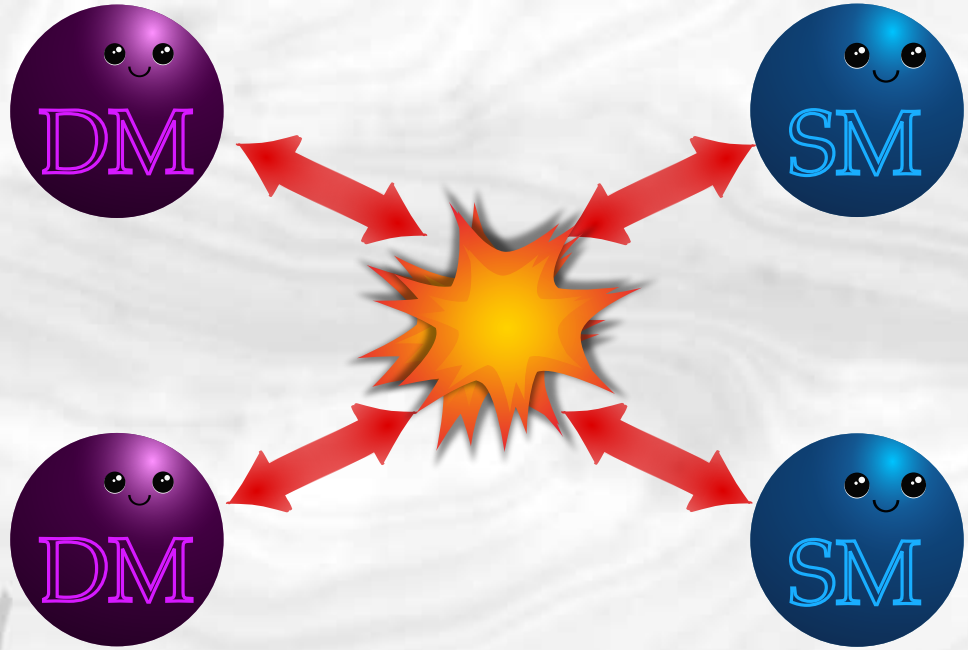


The CMB spectrum



Introduction

Methods of Detection



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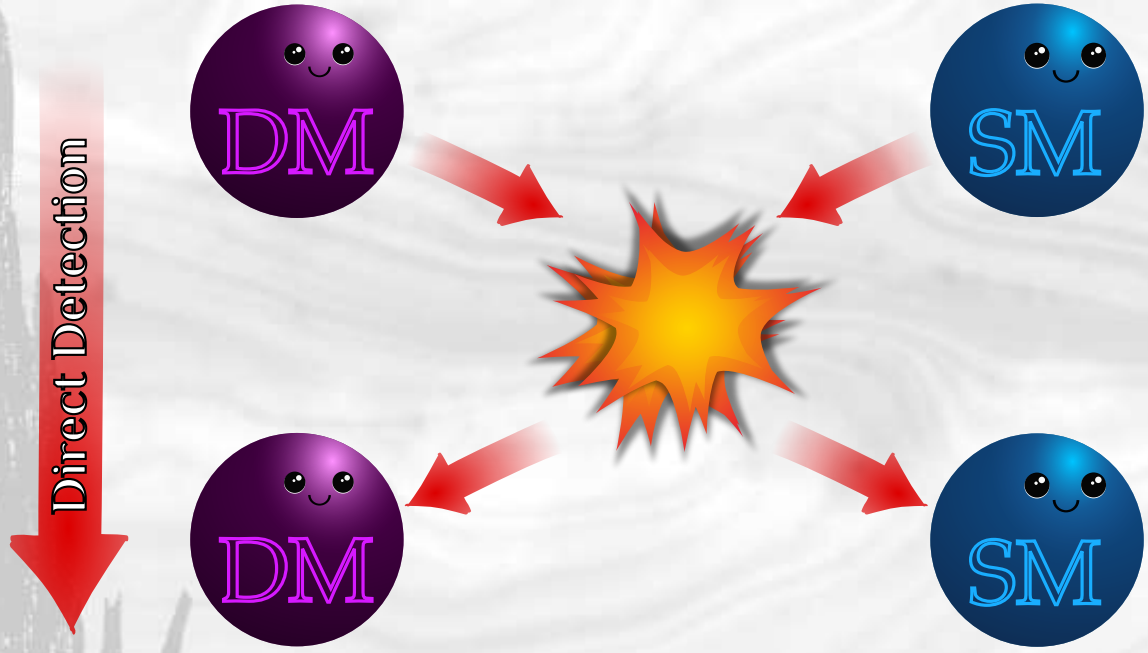
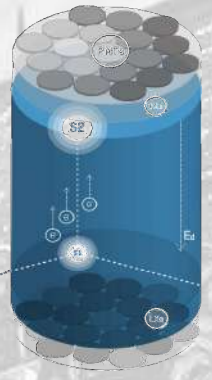
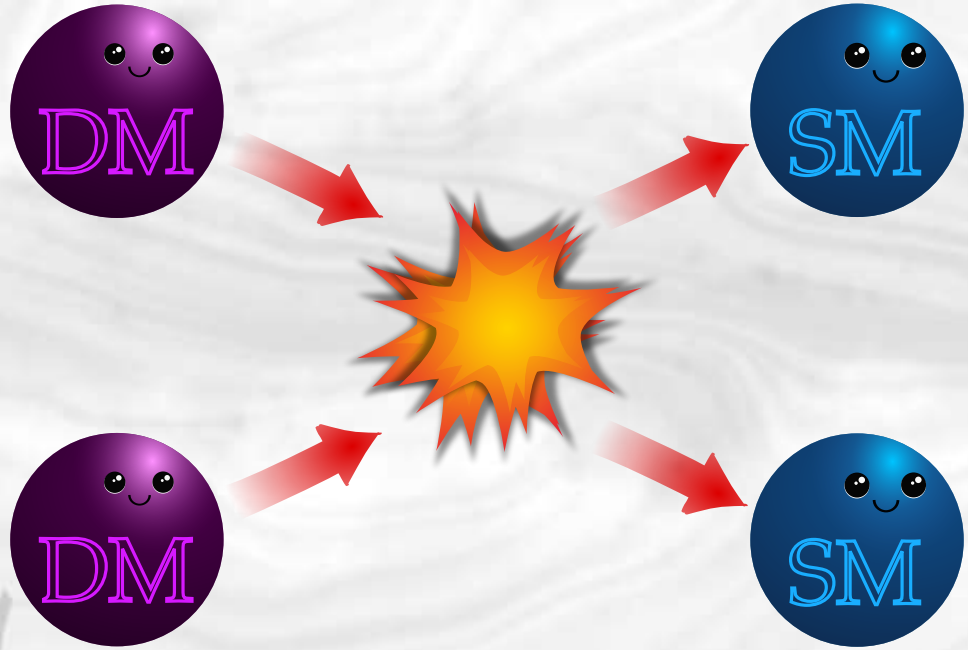


Scattering



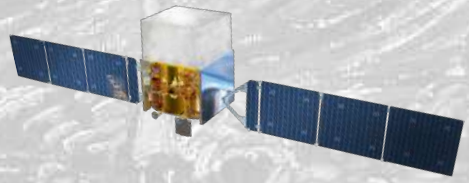
Introduction

Methods of Detection



Indirect Detection

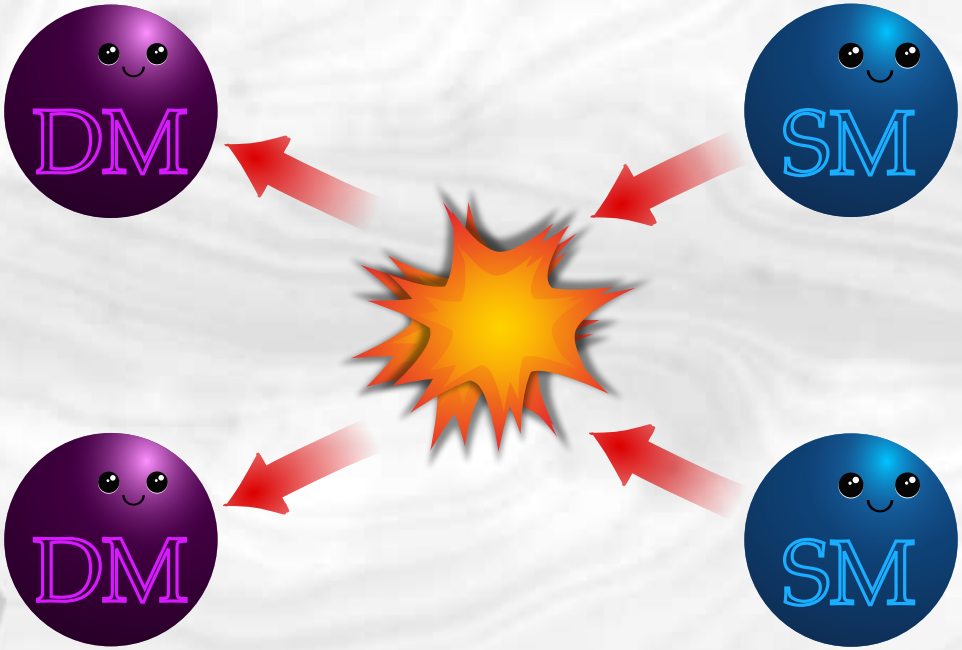
Annihilation



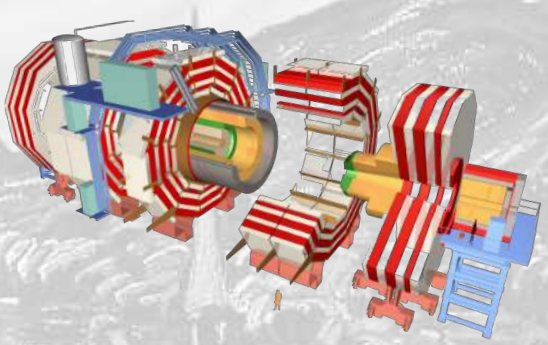
Introduction

Methods of Detection

Colliders



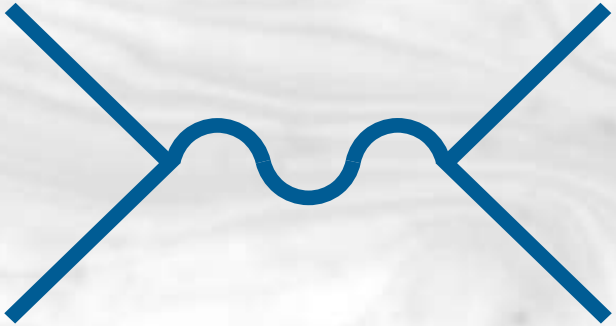
Production



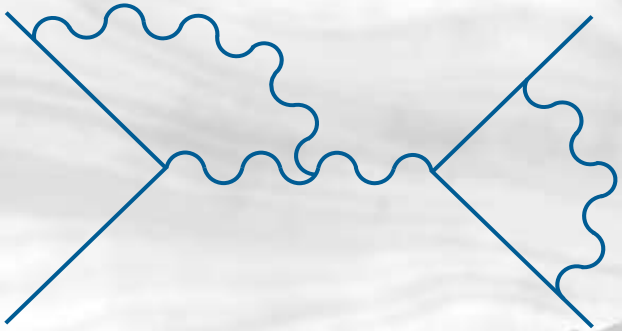
Introduction

Theoretical Approaches

Effective Field Theories



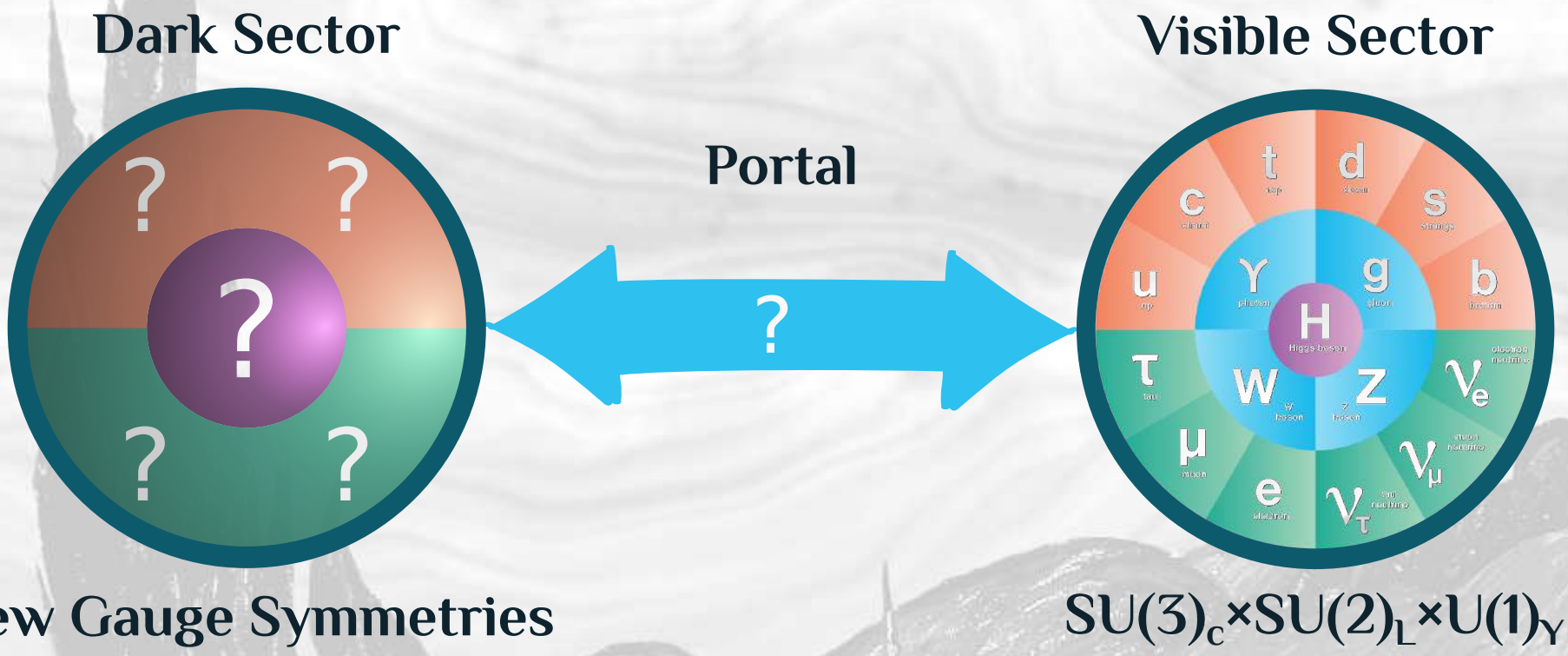
Simplified Models



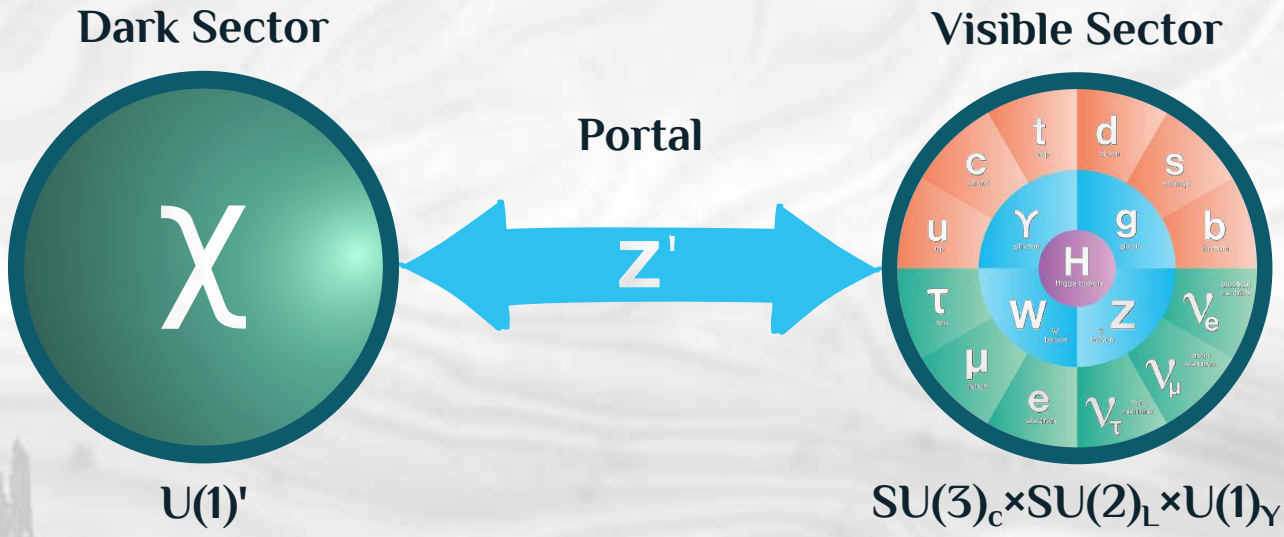
UV Complete Models

Introduction

Simplified Models



The Dark Sequential Z′ Portal



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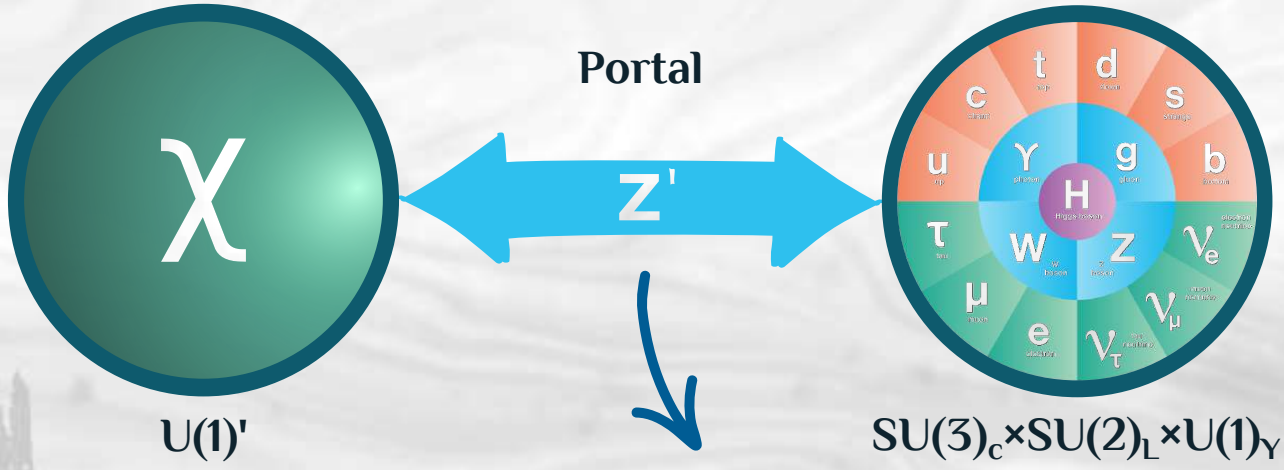
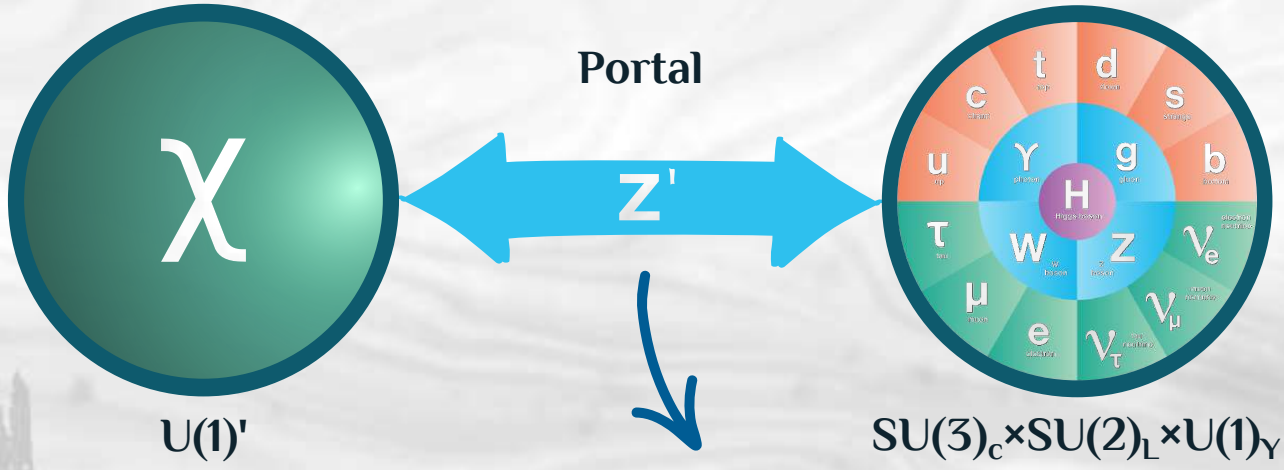


Majorana fermion

Natural consequence of a symmetry breaking chain in GUTs and other extended groups.

If the SM Higgs is not charged under U(1)', there is no mass mixing and Z' is the only ***portal***. Here, Z' couples to the SM exactly as Z does, hence ***Sequential***.

The Dark Sequential Z' Portal



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$$\mathcal{L} \supset \left[g_\chi \chi \gamma^\mu \gamma^5 \chi + \sum_{f \in \mathrm{SM}} \bar{f} \gamma^\mu (g_{fv} + g_{fa} \gamma^5) f \right] Z'_\mu$$

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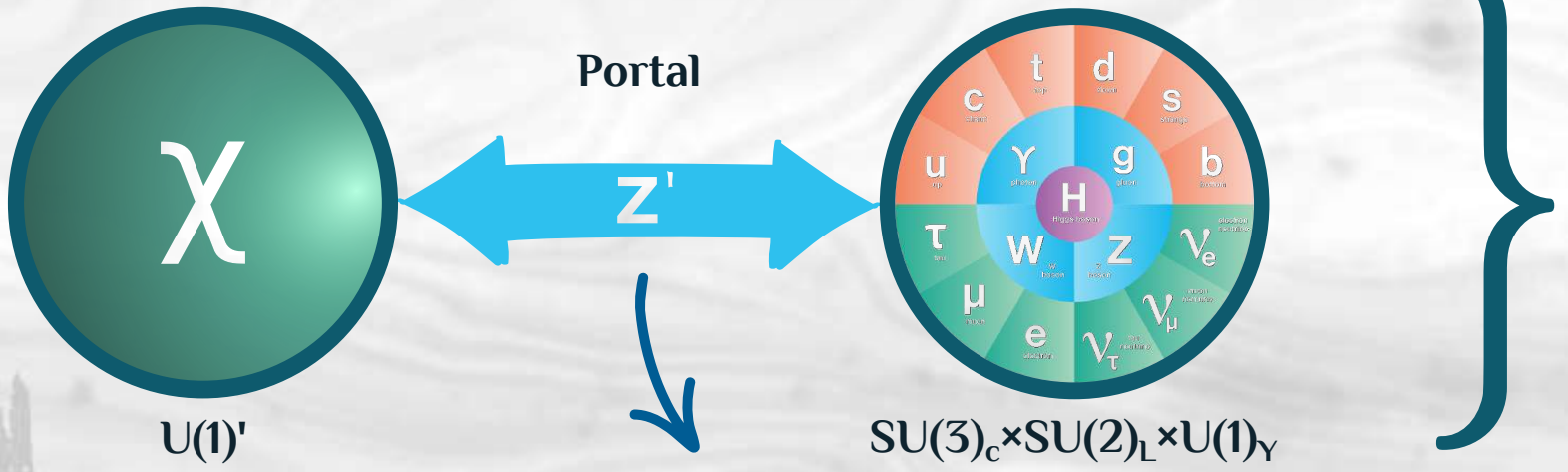

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$\bar{f}\gamma^\mu f \chi \gamma_\mu \gamma_5 \chi$ → SI → velocity suppressed → ✗

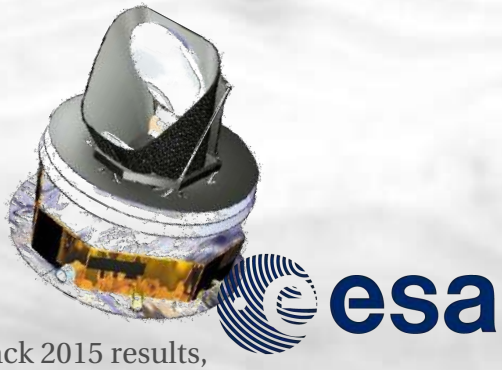
$\bar{f}\gamma^\mu \gamma_5 f \chi \gamma_\mu \gamma_5 \chi$ → SD → ✓

Constraints

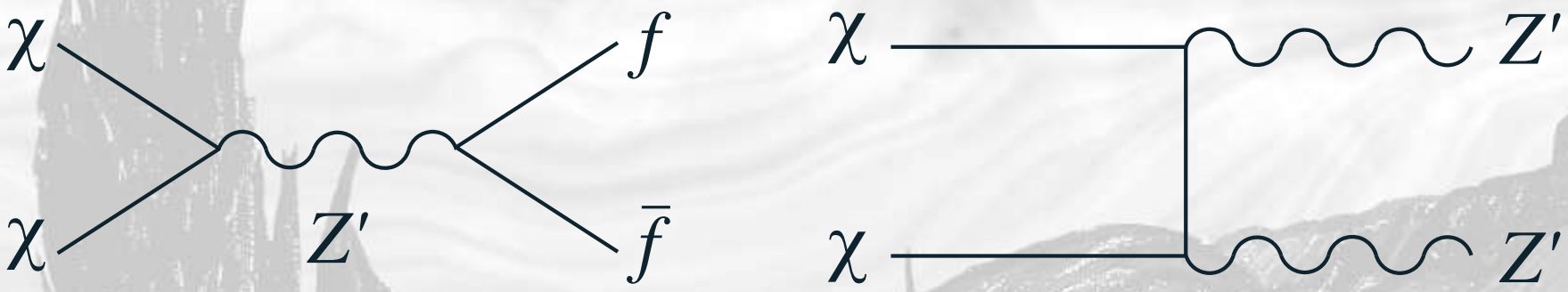
Relic Density

$$\Omega h^2 = 0.1199 \pm 0.012$$

(through thermal production)



[Planck 2015 results,
Astron. Astrophys. 594 (2016) A13]



Calculated using **`MicrOmegas 4.3.2.`**

Constraints

Direct Detection

$$\sigma^{\mathrm{SD}}_{\chi N} = \frac{12\mu^2_{\chi N}}{\pi}\frac{g^2_\chi}{M^4_{Z'}}\left[g_{ua}\Delta^N_u + g_{da}\left(\Delta^N_d + \Delta^N_s\right)\right]^2,\ N = p, n$$

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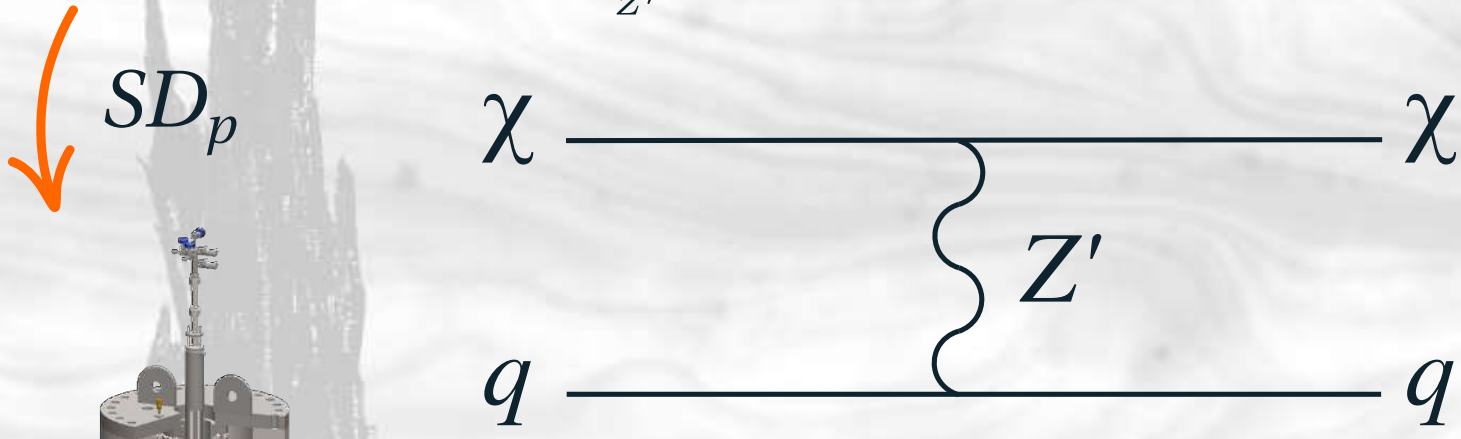
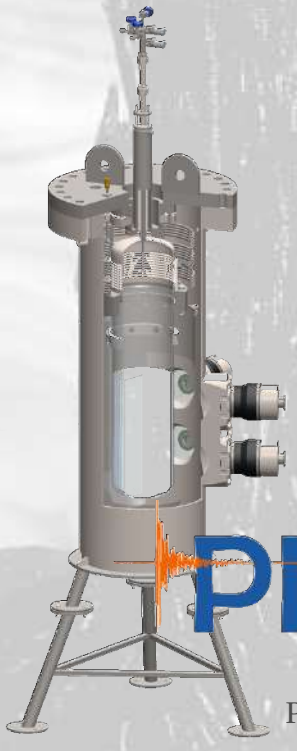
SD_p



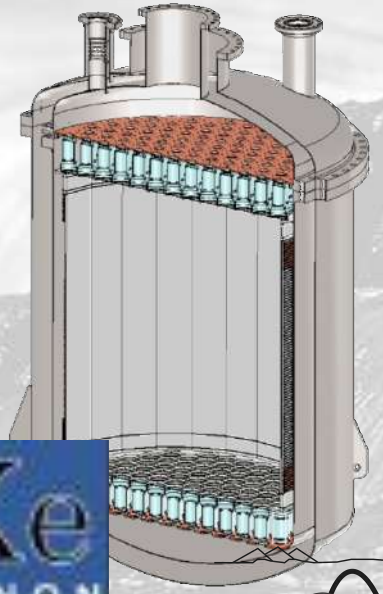
SD_n



(One unpaired proton in C_3F_8)

PICO

[PICO Collaboration, Phys. Rev. Lett. 118, 251301 (2017)]



(One unpaired neutron in Xe)

[XENON Collaboration, arXiv:1705.06655]

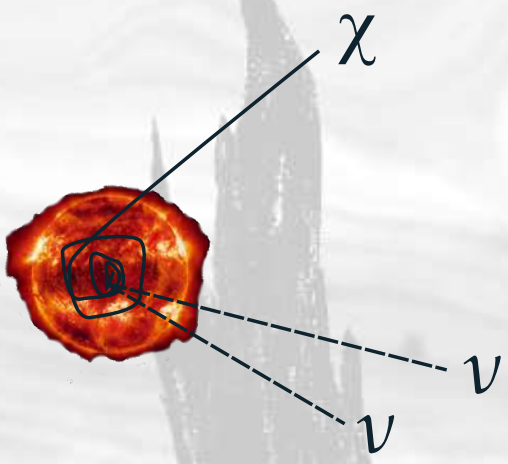
[XENON Collaboration, JCAP 1604 (2016) no.04, 027]

[LUX Collaboration, Phys. Rev. Lett. 118, 251302 (2017)]

XENON Dark Matter Project + LUX

Constraints

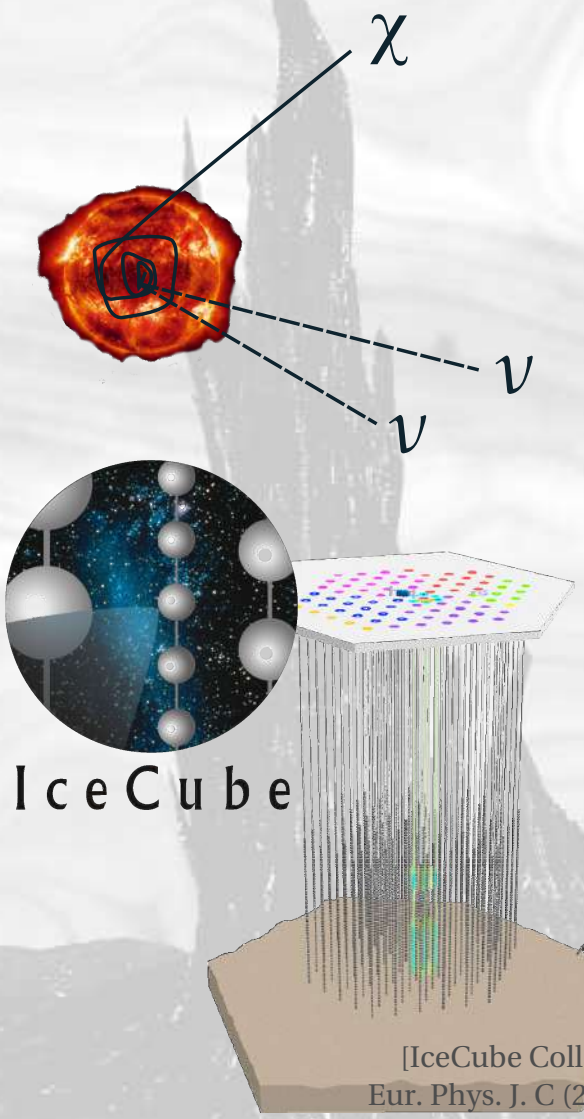
Direct Detection 2



- Neutrino flux is connected to DM capture and annihilation.
- Once the equilibrium is reached the annihilation can be removed and limits can be imposed on the capture rate.

Constraints

Direct Detection 2



[IceCube Collaboration,
Eur. Phys. J. C (2017) 77: 146]

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$$C_{\mathrm{DM}} = 10^{20} s^{-1} \left(\frac{1\ \mathrm{TeV}}{m_\chi} \right)^2 \frac{2.77\,\sigma_{SD_p} + 4270\,\sigma_{SI_p}}{10^{-40} cm^{-2}}$$

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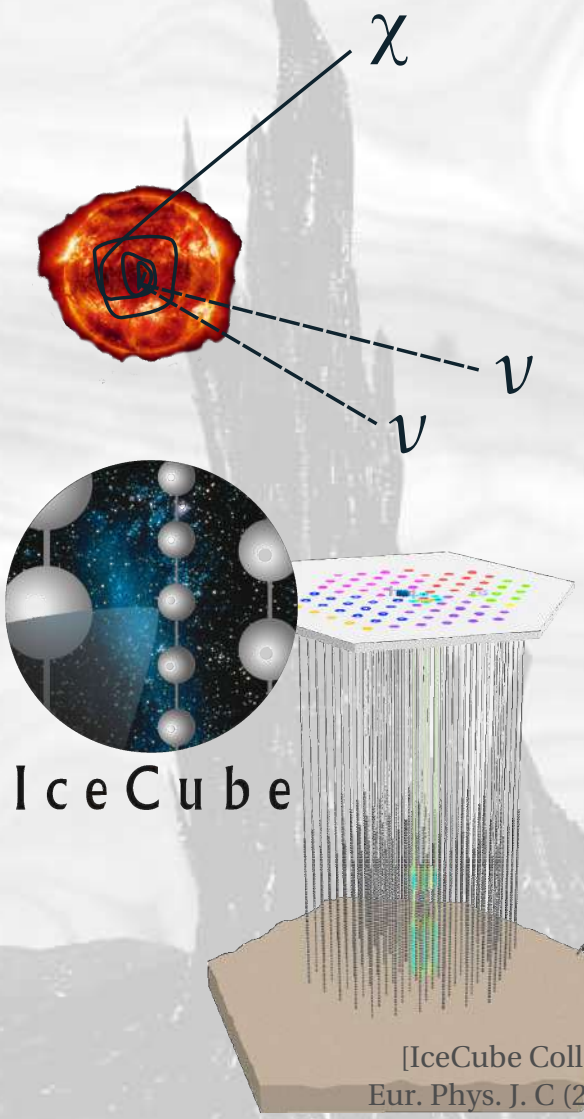
Direct Detection 2



[IceCube Collaboration, Eur. Phys. J. C (2017) 77: 146]

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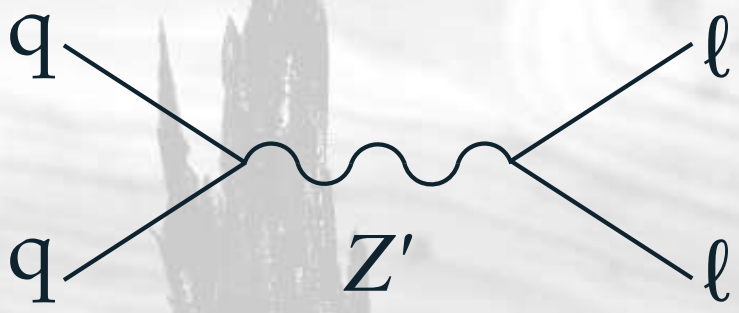
Subdominant, but limits closer to those of DD Experiments (PICO-60).

Dominant, but limits coming from DD Experiments (XENON1T, LUX) are several orders of magnitude stronger.

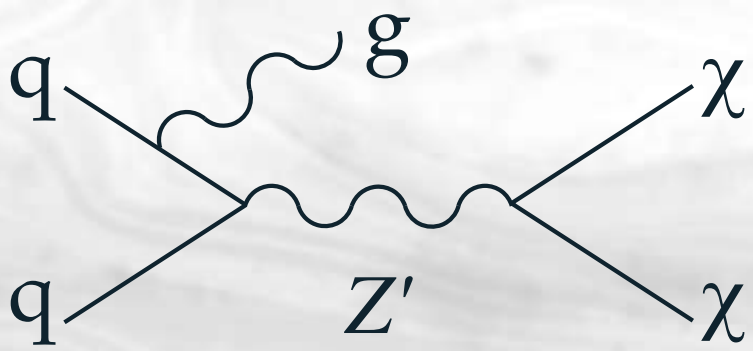
Constraints

Colliders

Dileptons



Monojet



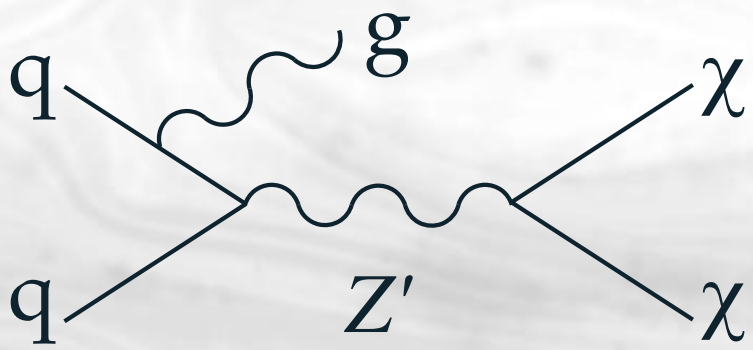
[ATLAS Collaboration, arXiv:1707.02424]

Constraints

Colliders

Dileptons

Monojet



Monojet searches are based on events with missing energy peaking at DM pairs, hence the limits are for

$$M_\chi < M_{Z'}/2$$

For 13 TeV and 36.1 fb^{-1}, it roughly excludes

$$M_{Z'} \approx 4 \text{ TeV}.$$

The limit weakens for $M_\chi < M_{Z'}$

$$\frac{\Gamma(Z' \to \ell\ell)}{\Gamma(Z' \to ff)} \Rightarrow \text{Br}(Z'_{\text{SSM}} \to \ell\ell)\,[1 - \text{Br}(Z' \to \chi\chi)]$$

[ATLAS Collaboration, arXiv:1707.02424]

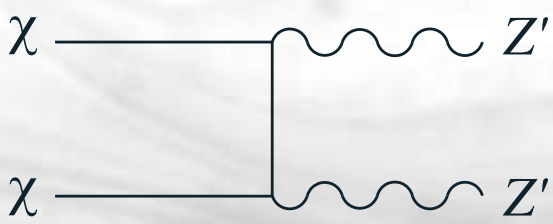
ATLAS EXPERIMENT

Constraints

Perturbativity

As this is ***not*** a UV complete theory, the model exhibits an odd behavior in the process $\chi\chi \to Z'Z'$

$$\sigma(\chi\chi \to Z'Z') \propto \frac{\sqrt{s}M_\chi}{M_{Z'}}$$



This is due to the contribution from Z'_L to the diagram. Unitarity can be restored once the scalar that breaks U(1)' is introduced.

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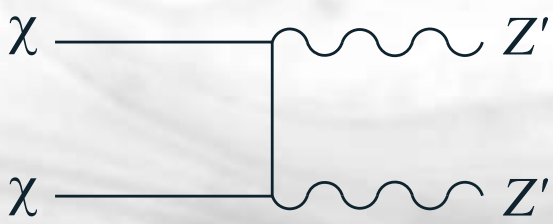


This is due to the contribution from Z'_L to the diagram. Unitarity can be restored once the scalar that breaks U(1)' is introduced.

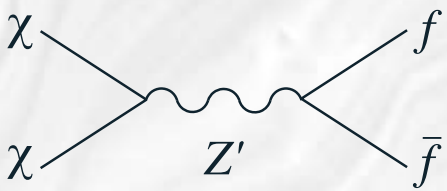
Hence, a limit on the validity of our results can be translated as

$$M_\chi > \sqrt{\frac{\pi M_{Z'}}{2g_\chi^2}}$$

[F. Kahlhoefer, K. Schmidt-Hoberg, T. Schwetz, and S. Vogl, *JHEP* **02** (2016) 016]

Small Digression

Why not Indirect Detection?



$$\langle \sigma v \rangle_{ff} = \sum_f n_c^f \frac{2\sqrt{m_\chi^2 - m_f^2}}{\pi m_\chi M_{Z'}^4 \left(M_{Z'}^2 - 4m_\chi^2\right)^2} \left[(g_{fa})^2 g_\chi^2 m_f^2 \left(M_{Z'}^2 - 4m_\chi^2\right)^2 \right]$$

$$- \frac{v^2}{6\pi m_\chi M_{Z'}^4 \sqrt{m_\chi^2 - m_f^2} \left(M_{Z'}^2 - 4m_\chi^2\right)^3} \left[(g_{fa})^2 \left\{ -g_\chi^2 \left(M_{Z'}^2 - 4m_\chi^2\right) \right.\right.$$

$$\times \left(23 m_f^4 M_{Z'}^4 - 192 m_f^2 m_\chi^6 - 4 m_f^2 m_\chi^2 M_{Z'}^2 \left(30 m_f^2 + 7 M_{Z'}^2\right)\right.$$

$$\left.\left. + 8 m_\chi^4 \left(30 m_f^4 + 12 m_f^2 M_{Z'}^2 + M_{Z'}^4\right)\right)\right\}$$

$$\left. + M_{Z'}^4 (g_{fv})^2 \left\{ 4 g_\chi^2 \left(m_f^4 + m_f^2 m_\chi^2 - 2 m_\chi^4\right) \left(M_{Z'}^2 - 4 m_\chi^2\right) \right\} \right]$$

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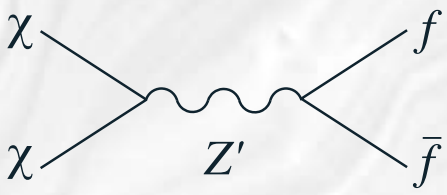

helicity suppressed $\propto \frac{m_f^2}{M_{Z'}^4}$

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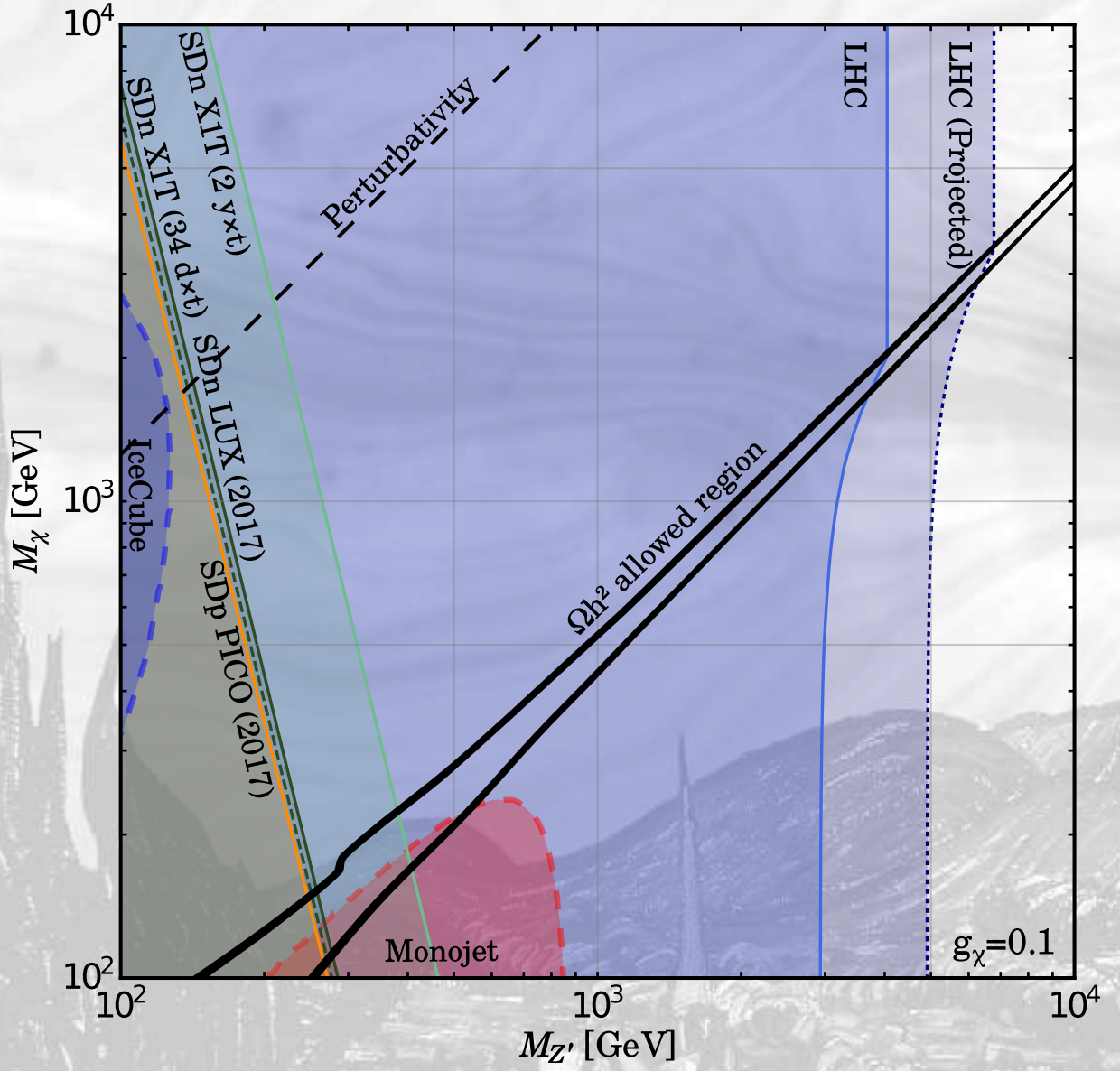
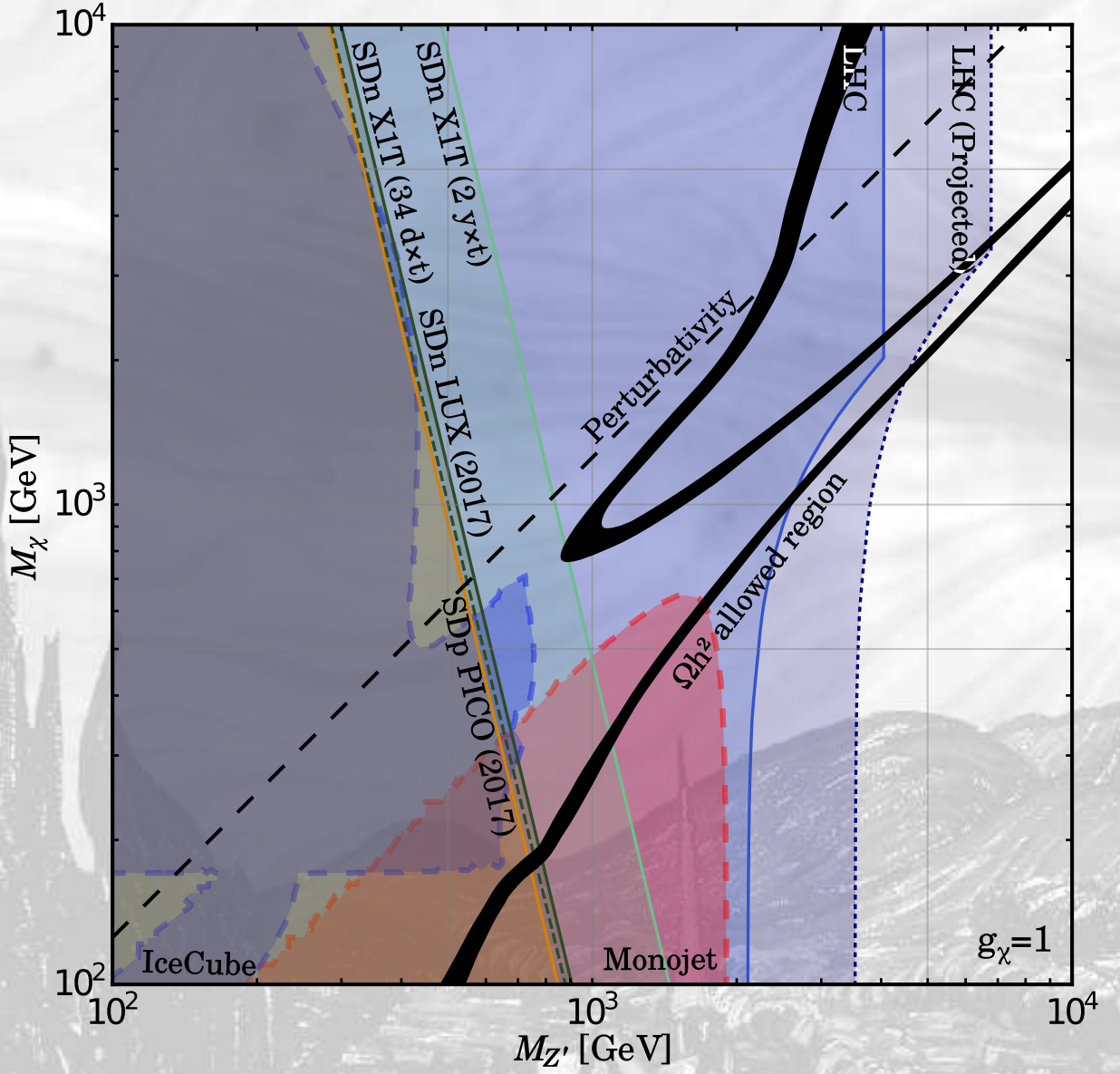
$$+ M_{Z'}^4 (g_{fv})^2 \left\{ 4 g_\chi^2 \left(m_f^4 + m_f^2 m_\chi^2 - 2 m_\chi^4\right) \left(M_{Z'}^2 - 4 m_\chi^2\right) \right\} \Big]$$

velocity suppressed $\propto v^2$

Results


SDn X1T (2 y×t)
Perturbativity
LHC
LHC (Projected)
SDn X1T (34 d×t)
SDn LUX (2017)
IceCube
SDp PICO (2017)
Ωh² allowed region
Monojet
g_χ=0.1
M_χ [GeV]
M_Z' [GeV]
10^2
10^3
10^4

Results


SDn X1T (2 y×t)
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LHC
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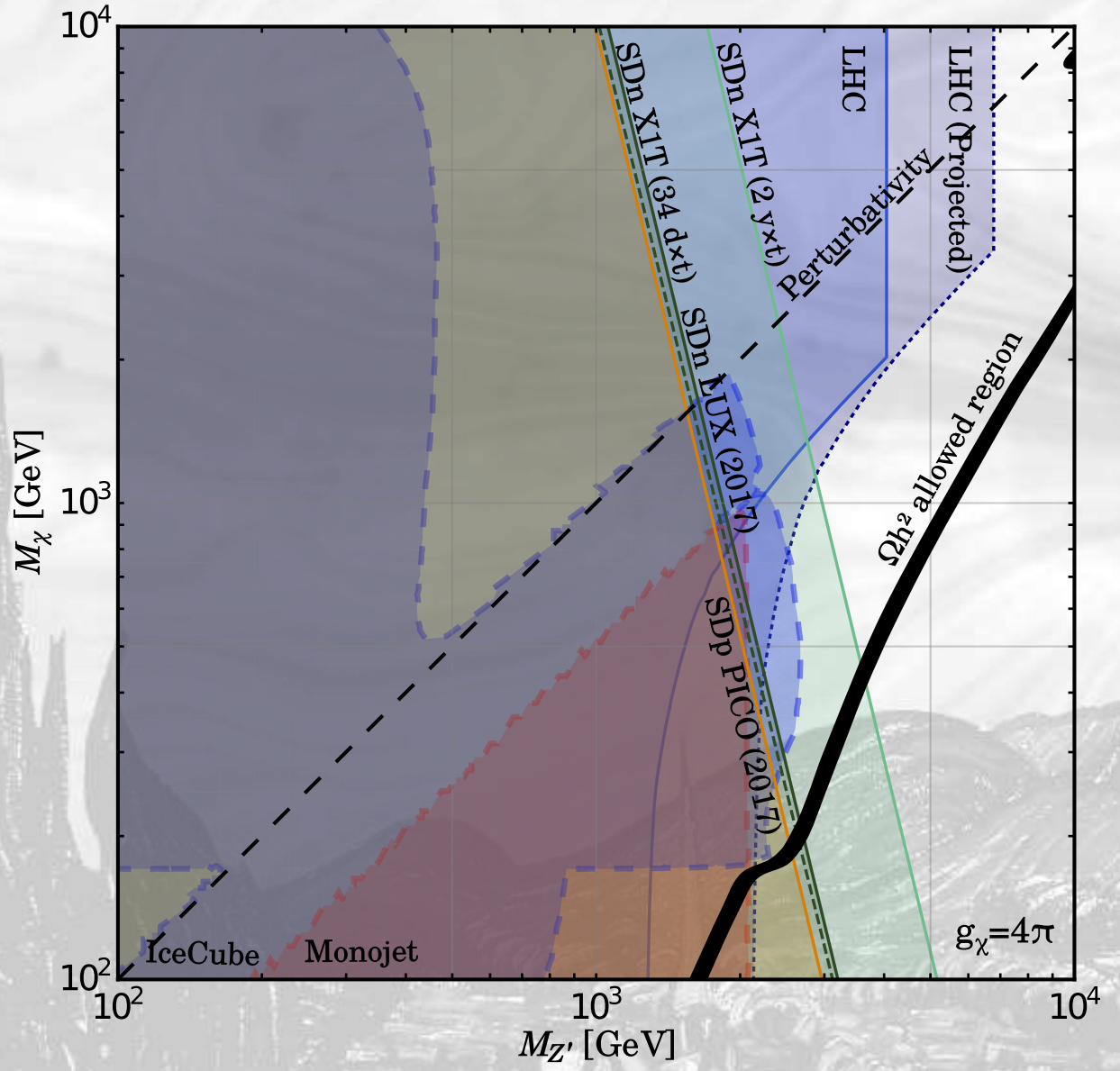
Perturbativity
Ωh² allowed region
IceCube
Monojet
g_χ=1
M_χ [GeV]
M_Z' [GeV]
10^2
10^3
10^4

Results


10^4
10^3
10^2
M_χ [GeV]
10^2
10^3
10^4
$M_{Z'}$ [GeV]
SDn X1T (34 d×t)
SDn X1T (2 y×t)
LHC
LHC (Projected)
Perturbativity
SDn LUX (2017)
SDp PICO (2017)
Ωh^2 allowed region
IceCube
Monojet
$g_\chi=4\pi$

Conclusions

- We have investigated the Majorana DM model in the context of a Z' portal.
- The DM phenomenology is dictated by fixed gauge interactions, due to the fact that we adopted the Sequential Z' framework.
- Direct detection experiments based on bubble chambers and liquid xenon, as well as neutrino telescopes provide important constraints.
- LHC searches for dilepton and monojet+missing energy provide orthogonal bounds, the former being the strongests.
- We computed the relic density curves, defining the region of the parameter space where one can successfully have a Majorana DM particle.
- We varied the DM coupling to Z' to asses the impact on the constraints and highlight the importance of complementary probes.


Thank you!

Backup Slides

Dark Matter Decay Channels

$$\langle \sigma v \rangle_{Z'Z'} = \frac{g_\chi^4}{\pi m_\chi^2}\left(1-\frac{M_{Z'}^2}{m_\chi^2}\right)^{\frac{3}{2}}\left(1-\frac{M_{Z'}^2}{2m_\chi^2}\right)^{-2} + \frac{g_\chi^4 v^2}{3\pi m_\chi^2}\sqrt{1-\frac{M_{Z'}^2}{m_\chi^2}}\left(1-\frac{M_{Z'}^2}{2m_\chi^2}\right)^{-4}\left(\frac{23}{16}\frac{M_{Z'}^6}{m_\chi^6}-\frac{59}{8}\frac{M_{Z'}^4}{m_\chi^4}+\frac{43}{4}\frac{M_{Z'}^2}{m_\chi^2}+2-12\frac{m_\chi^2}{M_{Z'}^2}+8\frac{m_\chi^4}{M_{Z'}^4}\right).$$