Max-Planck-Institut für Kernphysik Heidelberg

Farinaldo Queiroz
Max Planck Institut fuer Kernphysik

Highlights on Dark Matter Complementarity

Based on arxiv: 1409.6301; 1407.4110; 1406.2424; 1404.1400; 1403.5027; 1403.2309; 1401.4253

MPI Kernphysik – April 24, 2015

What is the WIMP Miracle ?

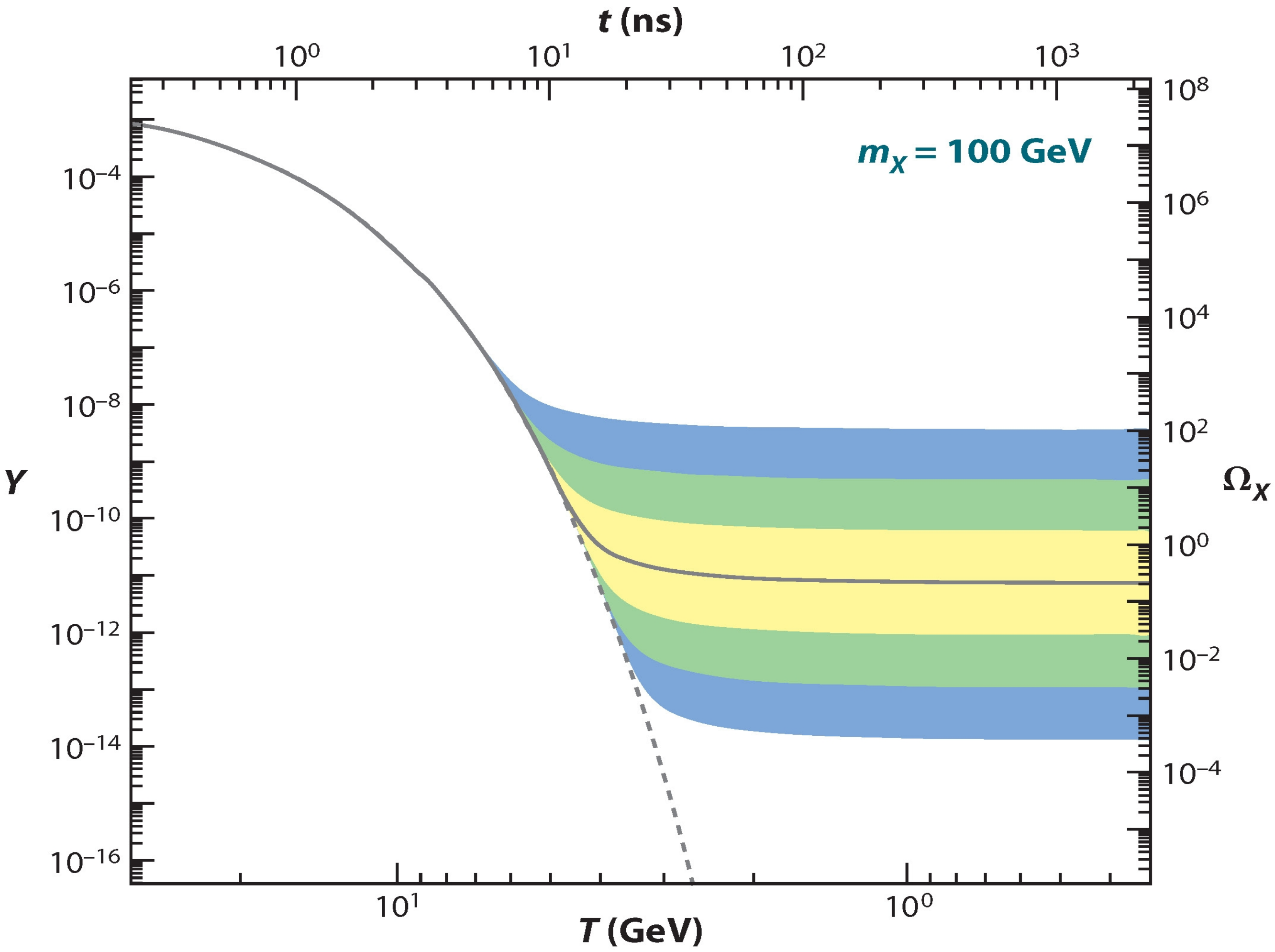
WIMPs yield the right relic abundance for a large mass range

WIMPs arise in many well motivated theories

WIMPs are fairly ease to stabilize from a model building perspective

WIMPs are within reach of the current and future experiments

WIMPs fill the bill regarding structure formation



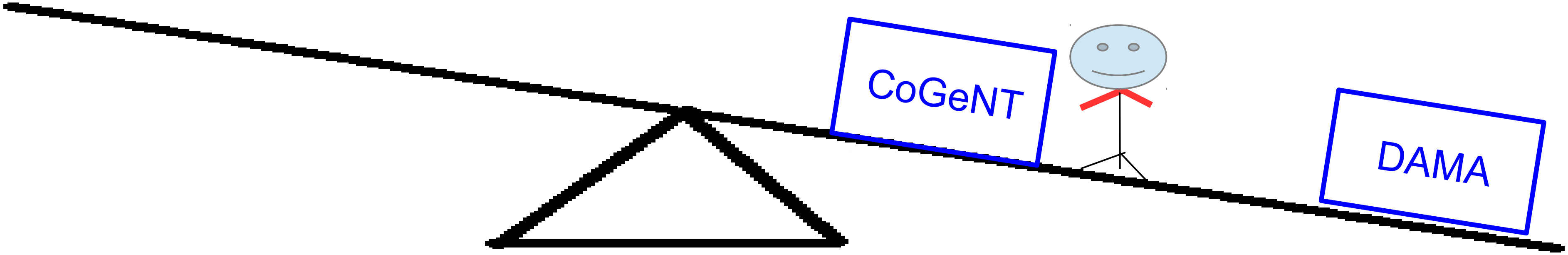
Dark Matter Signals or Unaccounted Backgrounds?

CRESST | **DAMA Modulation**

CDMS-Si | **CoGeNT Modulation**

Galactic Center | **AMS**

Woohoo we discovered DM!



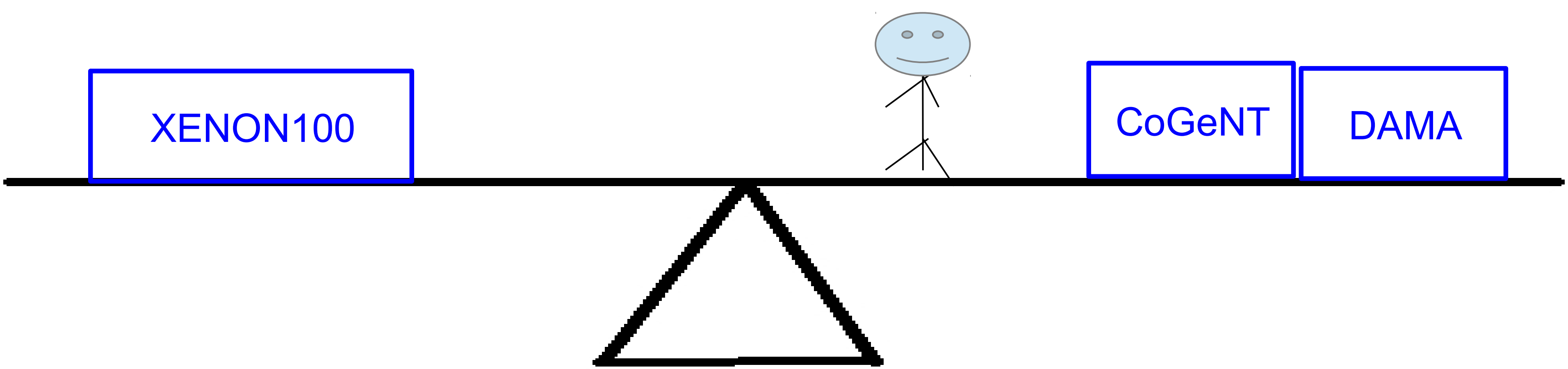
Dark Matter Signals or Unaccounted Backgrounds?

CRESST DAMA Modulation

CDMS-Si CoGeNT Modulation

Galactic Center AMS

This is still DM! Come on!



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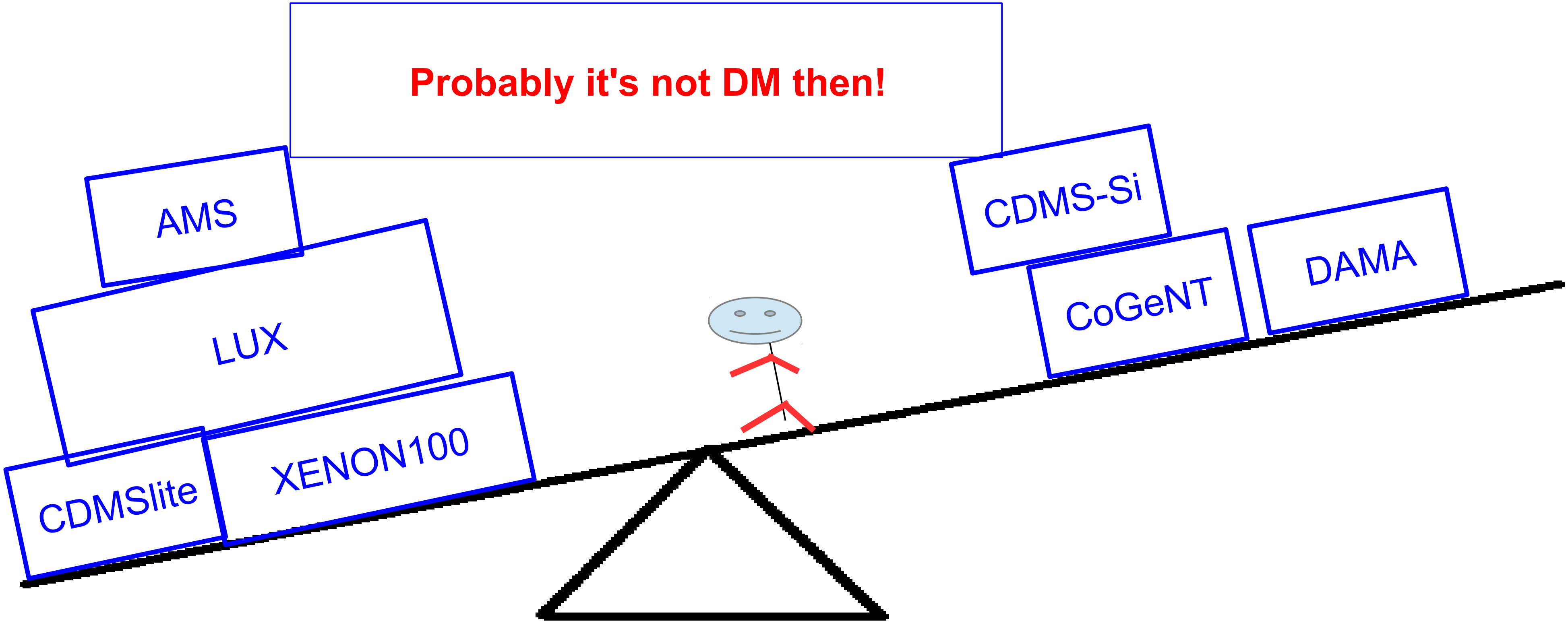
Dark Matter Signals or Unaccounted Backgrounds?

- CRESST
- CDMS-Si
- Galactic Center
- DAMA Modulation
- CoGeNT Modulation
- AMS



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Dark Matter Signals or Unaccounted Backgrounds?

CRESST

DAMA Modulation

CDMS-Si

CoGeNT Modulation

Galactic Center

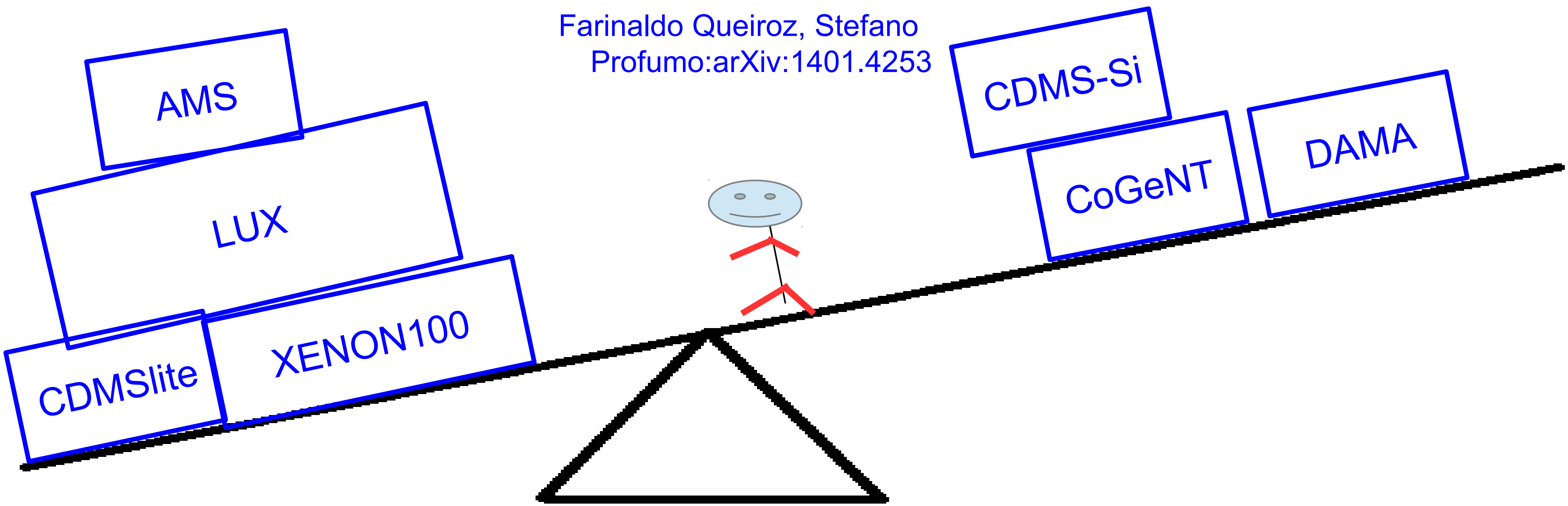
AMS

A New Possible Way to Explain DAMA Results ?

Jerry Ja'vra, arXiv:1401.0698

~GeV WIMP is not a way out!

Farinaldo Queiroz, Stefano Profumo:arXiv:1401.4253




BREAKING NEWS...

Hooper found a DM excess:
A Gamma-ray Excess in the Galactic Center!

Dark Matter Signals or Unaccounted Backgrounds?

CRESST

CDMS-Si

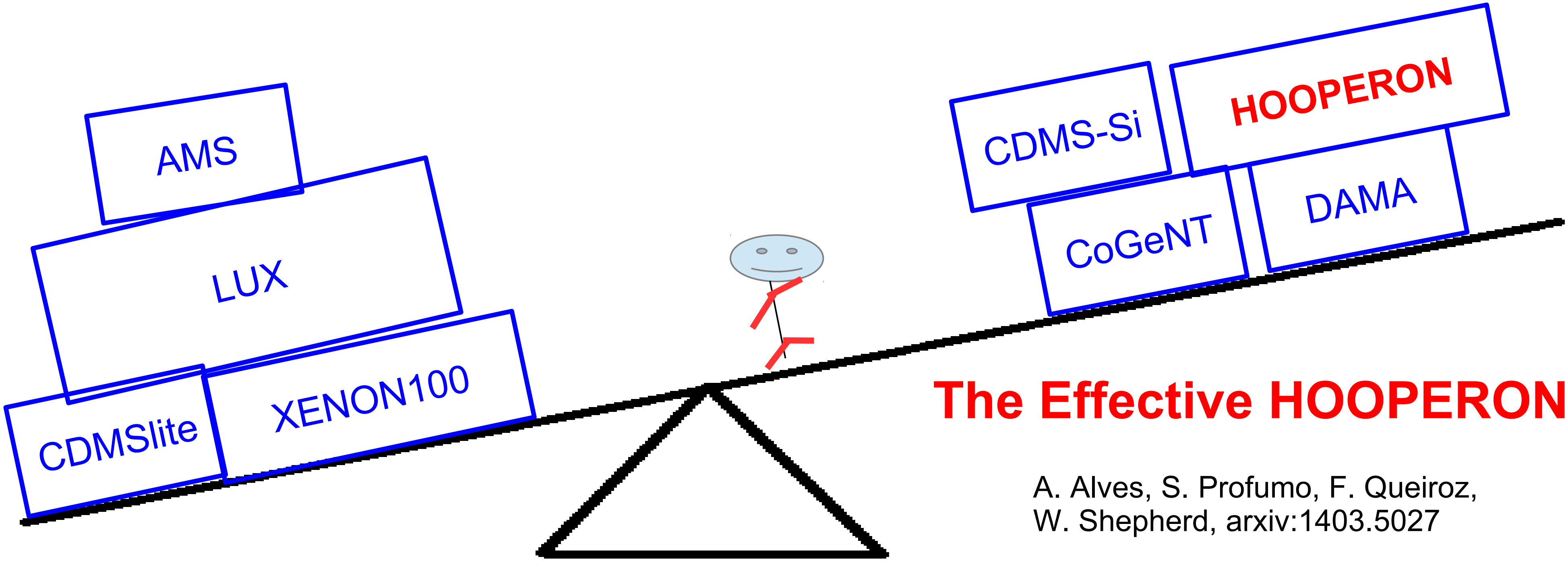
Galactic Center

DAMA Modulation

CoGeNT Modulation

AMS

Hooper keeps putting out papers regarding the GC excess on and on and on = Hooperon!

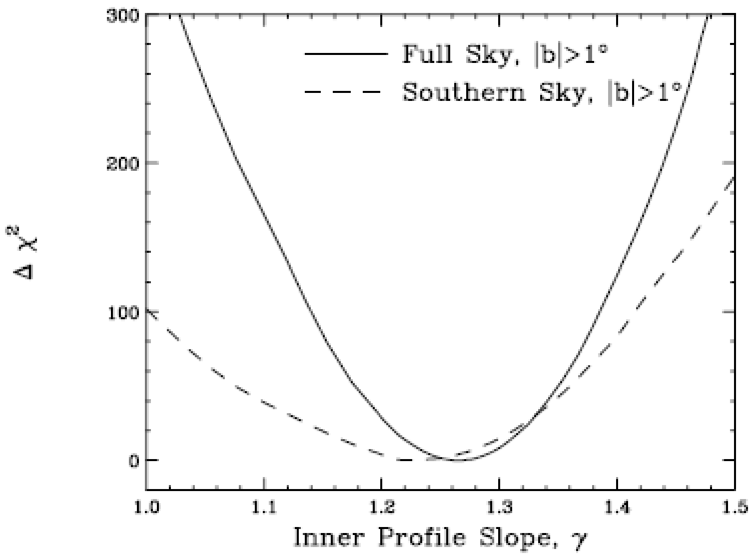


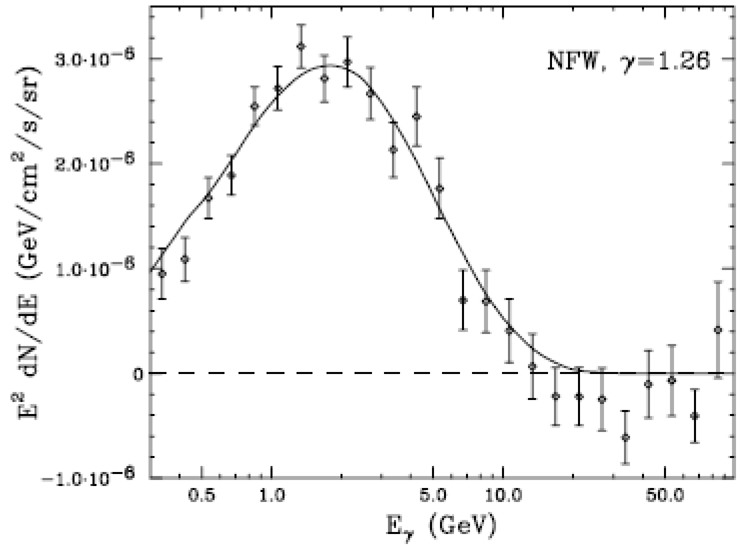
The Effective HOOPERON

A. Alves, S. Profumo, F. Queiroz, W. Shepherd, arxiv:1403.5027

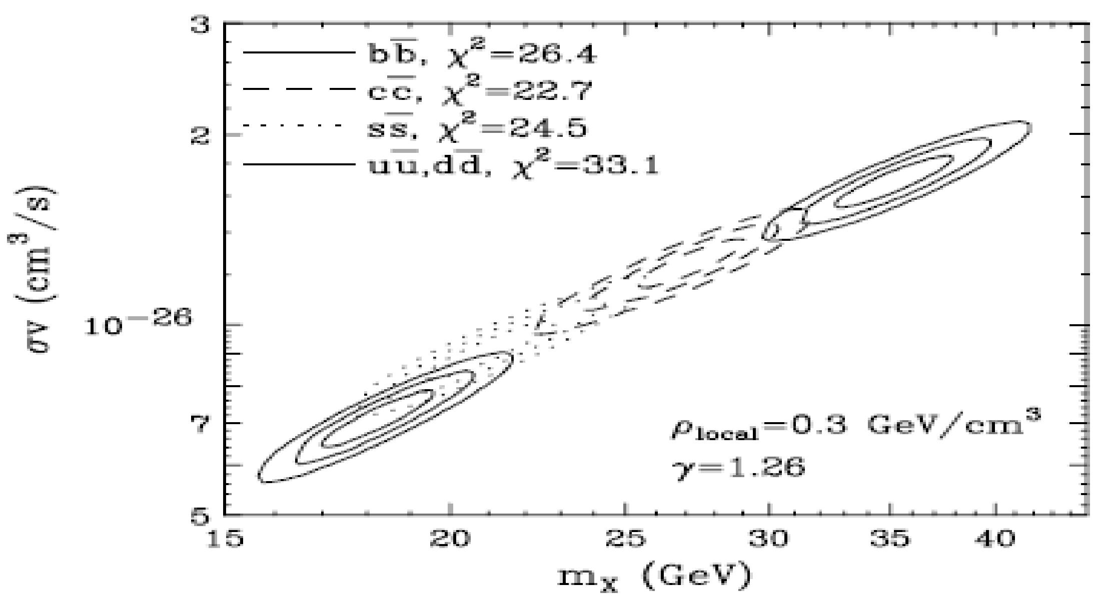
Galactic Center Excess

HOOPERON





DH et al
arxiv:1402.6703



This excess goes all the way back to L. Goodenough, DH, arXiv:0910.2998

Confirmed by several independent groups:

DH, T. Linden, PRD, arXiv:1110.0006
K. Abazajian, M. Kaplinghat, PRD, arXiv:1207.6047
DH, T. Slatyer, PDU, arXiv:1302.6589
C. Gordon, O. Macias, PRD, arXiv:1306.5725
W. Huang, A. Urbano, W. Xue, arXiv:1307.6862
K. Abazajian, N. Canac, S.Horiuchi, M. Kaplinghat, arXiv:1402.4090

Hooperon From a Particle Physics Perspective

Name	Operator	Dimension	SI/SD
D1	$\frac{m_q}{\Lambda^3}\bar{\chi}\chi\bar{q}q$	7	SI
D2	$\frac{im_q}{\Lambda^3}\bar{\chi}\gamma^5\chi\bar{q}q$	7	N/A
D3	$\frac{im_q}{\Lambda^3}\bar{\chi}\chi\bar{q}\gamma^5 q$	7	N/A
D4	$\frac{m_q}{\Lambda^3}\bar{\chi}\gamma^5\chi\bar{q}\gamma^5 q$	7	N/A
D5	$\frac{1}{\Lambda^2}\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$	6	SI
D6	$\frac{1}{\Lambda^2}\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu q$	6	N/A
D7	$\frac{1}{\Lambda^2}\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu\gamma^5 q$	6	N/A
D8	$\frac{1}{\Lambda^2}\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$	6	SD
D9	$\frac{1}{\Lambda^2}\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$	6	SD
D10	$\frac{i}{\Lambda^2}\bar{\chi}\sigma^{\mu\nu}\gamma^5\chi\bar{q}\sigma_{\mu\nu}q$	6	N/A
D11	$\frac{\alpha_s}{\Lambda^3}\bar{\chi}\chi G^{\mu\nu}G_{\mu\nu}$	7	SI
D12	$\frac{\alpha_s}{\Lambda^3}\bar{\chi}\gamma^5\chi G^{\mu\nu}G_{\mu\nu}$	7	N/A
D13	$\frac{\alpha_s}{\Lambda^3}\bar{\chi}\chi G^{\mu\nu}\tilde{G}_{\mu\nu}$	7	N/A
D14	$\frac{\alpha_s}{\Lambda^3}\bar{\chi}\gamma^5\chi G^{\mu\nu}\tilde{G}_{\mu\nu}$	7	N/A

The Effective HOOPERON

A. Alves, S. Profumo, F. Queiroz, W. Shepherd, arxiv:1403.5027

C1	$\frac{m_q}{\Lambda^2}\phi^\dagger\phi\bar{q}q$	6	SI
C2	$\frac{m_q}{\Lambda^2}\phi^\dagger\phi\bar{q}\gamma^5 q$	6	N/A
C3	$\frac{1}{\Lambda^2}\phi^\dagger\overleftrightarrow{\partial}_\mu\phi\bar{q}\gamma^\mu q$	6	SI
C4	$\frac{1}{\Lambda^2}\phi^\dagger\overleftrightarrow{\partial}_\mu\phi\bar{q}\gamma^\mu\gamma^5 q$	6	N/A
C5	$\frac{\alpha_s}{\Lambda^3}\phi^\dagger\phi G^{\mu\nu}G_{\mu\nu}$	6	SI
C6	$\frac{\alpha_s}{\Lambda^3}\phi^\dagger\phi G^{\mu\nu}\tilde{G}_{\mu\nu}$	6	N/A

~150 papers written

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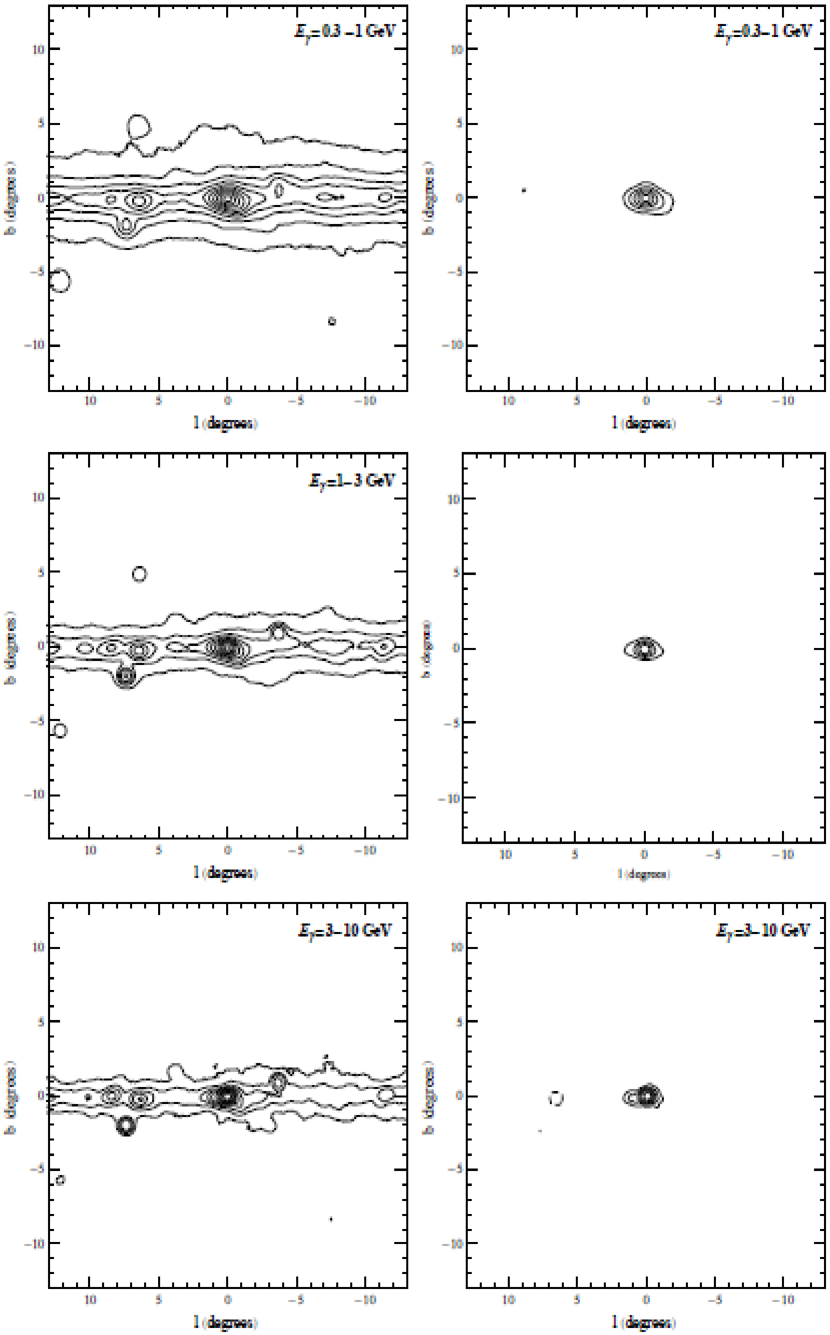
Hooperon From a Particle Physics Perspective

Berling, Hooper,McDermott
arxiv:1404.0022

Model Number	*DM*	*Mediator*	*Interactions*	Elastic Scattering	Near Future Reach? Direct	LHC
1	Dirac Fermion	Spin-0	$\bar{\chi}\gamma^5\chi$, $\bar{f}f$	$\sigma_{\rm SI} \sim (q/2m_\chi)^2$ (scalar)	No	Maybe
1	Majorana Fermion	Spin-0	$\bar{\chi}\gamma^5\chi$, $\bar{f}f$	$\sigma_{\rm SI} \sim (q/2m_\chi)^2$ (scalar)	No	Maybe
2	Dirac Fermion	Spin-0	$\bar{\chi}\gamma^5\chi$, $\bar{f}\gamma^5 f$	$\sigma_{\rm SD} \sim (q^2/4m_n m_\chi)^2$	Never	Maybe
2	Majorana Fermion	Spin-0	$\bar{\chi}\gamma^5\chi$, $\bar{f}\gamma^5 f$	$\sigma_{\rm SD} \sim (q^2/4m_n m_\chi)^2$	Never	Maybe
3	Dirac Fermion	Spin-1	$\bar{\chi}\gamma^\mu\chi$, $\bar{b}\gamma_\mu b$	$\sigma_{\rm SI} \sim$ loop (vector)	Yes	Maybe
4	Dirac Fermion	Spin-1	$\bar{\chi}\gamma^\mu\chi$, $\bar{f}\gamma_\mu\gamma^5 f$	$\sigma_{\rm SD} \sim (q/2m_n)^2$ or $\sigma_{\rm SD} \sim (q/2m_\chi)^2$	Never	Maybe
5	Dirac Fermion	Spin-1	$\bar{\chi}\gamma^\mu\gamma^5\chi$, $\bar{f}\gamma_\mu\gamma^5 f$	$\sigma_{\rm SD} \sim 1$	Yes	Maybe
5	Majorana Fermion	Spin-1	$\bar{\chi}\gamma^\mu\gamma^5\chi$, $\bar{f}\gamma_\mu\gamma^5 f$	$\sigma_{\rm SD} \sim 1$	Yes	Maybe
6	Complex Scalar	Spin-0	$\phi^\dagger\phi$, $\bar{f}\gamma^5 f$	$\sigma_{\rm SD} \sim (q/2m_n)^2$	No	Maybe
6	Real Scalar	Spin-0	ϕ^2, $\bar{f}\gamma^5 f$	$\sigma_{\rm SD} \sim (q/2m_n)^2$	No	Maybe
6	Complex Vector	Spin-0	$B^\dagger_\mu B^\mu$, $\bar{f}\gamma^5 f$	$\sigma_{\rm SD} \sim (q/2m_n)^2$	No	Maybe
6	Real Vector	Spin-0	$B_\mu B^\mu$, $\bar{f}\gamma^5 f$	$\sigma_{\rm SD} \sim (q/2m_n)^2$	No	Maybe
7	Dirac Fermion	Spin-0 (t-ch.)	$\bar{\chi}(1 \pm \gamma^5)b$	$\sigma_{\rm SI} \sim$ loop (vector)	Yes	Yes
7	Dirac Fermion	Spin-1 (t-ch.)	$\bar{\chi}\gamma^\mu(1 \pm \gamma^5)b$	$\sigma_{\rm SI} \sim$ loop (vector)	Yes	Yes
8	Complex Vector	Spin-1/2 (t-ch.)	$X^\dagger_\mu\gamma^\mu(1 \pm \gamma^5)b$	$\sigma_{\rm SI} \sim$ loop (vector)	Yes	Yes
8	Real Vector	Spin-1/2 (t-ch.)	$X_\mu\gamma^\mu(1 \pm \gamma^5)b$	$\sigma_{\rm SI} \sim$ loop (vector)	Yes	Yes

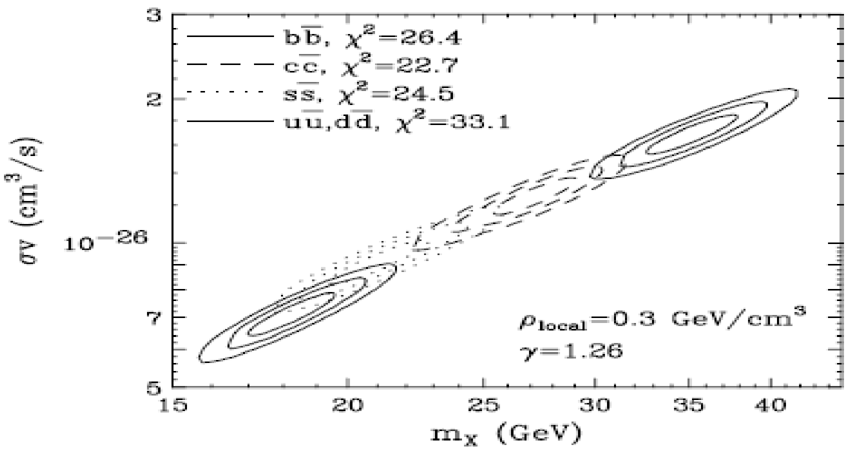
Just a reminder: Galactic Center Constraints



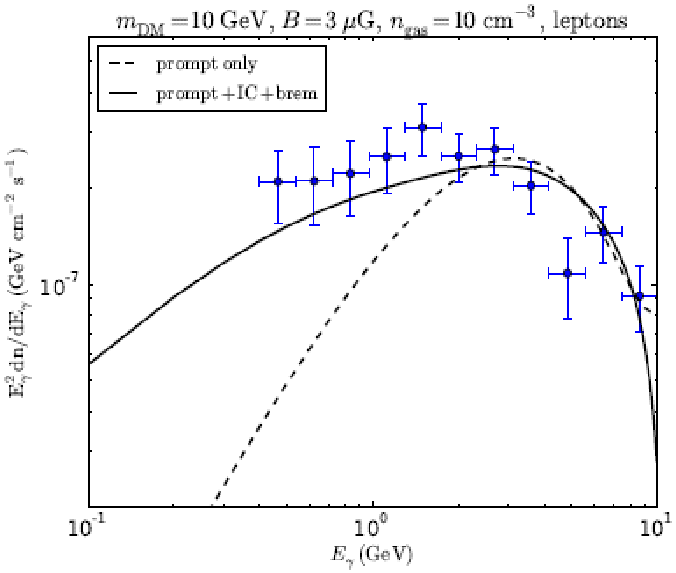
Halo Model	Energy Range	$\frac{\sigma v}{m_{\rm DM}^2}\int dE_\gamma \frac{dN_\gamma}{dE_\gamma}$ (U.L.)
NFW	0.3-1 GeV	1.8×10^{-28} cm^3 s^{-1} GeV^{-2}
NFW	1-3 GeV	6.4×10^{-29} cm^3 s^{-1} GeV^{-2}
NFW	3-10 GeV	1.4×10^{-29} cm^3 s^{-1} GeV^{-2}
NFW	10-100 GeV	1.7×10^{-30} cm^3 s^{-1} GeV^{-2}
Einasto	0.3-1 GeV	1.0×10^{-28} cm^3 s^{-1} GeV^{-2}
Einasto	1-3 GeV	4.1×10^{-29} cm^3 s^{-1} GeV^{-2}
Einasto	3-10 GeV	9.2×10^{-30} cm^3 s^{-1} GeV^{-2}
Einasto	10-100 GeV	9.2×10^{-31} cm^3 s^{-1} GeV^{-2}
Contracted (γ=1.2)	0.3-1 GeV	8.2×10^{-29} cm^3 s^{-1} GeV^{-2}
Contracted (γ=1.2)	1-3 GeV	2.8×10^{-29} cm^3 s^{-1} GeV^{-2}
Contracted (γ=1.2)	3-10 GeV	5.0×10^{-30} cm^3 s^{-1} GeV^{-2}
Contracted (γ=1.2)	10-100 GeV	6.0×10^{-31} cm^3 s^{-1} GeV^{-2}
Contracted (γ=1.4)	0.3-1 GeV	1.6×10^{-29} cm^3 s^{-1} GeV^{-2}
Contracted (γ=1.4)	1-3 GeV	4.3×10^{-30} cm^3 s^{-1} GeV^{-2}
Contracted (γ=1.4)	3-10 GeV	7.5×10^{-31} cm^3 s^{-1} GeV^{-2}
Contracted (γ=1.4)	10-100 GeV	1.1×10^{-31} cm^3 s^{-1} GeV^{-2}
Cored (R_C=100 pc)	0.3-1 GeV	2.0×10^{-28} cm^3 s^{-1} GeV^{-2}
Cored (R_C=100 pc)	1-3 GeV	6.8×10^{-29} cm^3 s^{-1} GeV^{-2}
Cored (R_C=100 pc)	3-10 GeV	1.5×10^{-29} cm^3 s^{-1} GeV^{-2}
Cored (R_C=100 pc)	10-100 GeV	1.7×10^{-30} cm^3 s^{-1} GeV^{-2}
Cored (R_C=1 kpc)	0.3-1 GeV	3.7×10^{-28} cm^3 s^{-1} GeV^{-2}
Cored (R_C=1 kpc)	1-3 GeV	2.0×10^{-28} cm^3 s^{-1} GeV^{-2}
Cored (R_C=1 kpc)	3-10 GeV	5.3×10^{-29} cm^3 s^{-1} GeV^{-2}
Cored (R_C=1 kpc)	10-100 GeV	5.3×10^{-29} cm^3 s^{-1} GeV^{-2}

Dan Hooper, Farinaldo Queiroz, Chris Kelso, arxiv:1209.3015

Hooperon From an Astrophysics Perspective



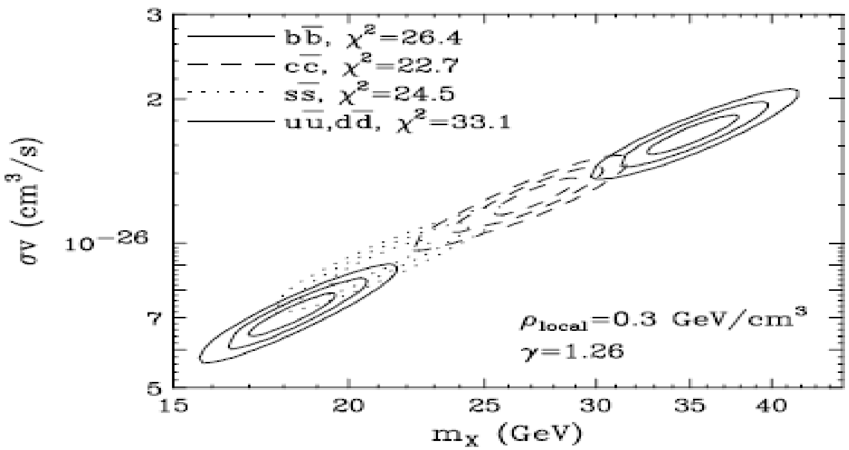
Dan Hooper, Tim Linden et al
arxiv:1402.6703



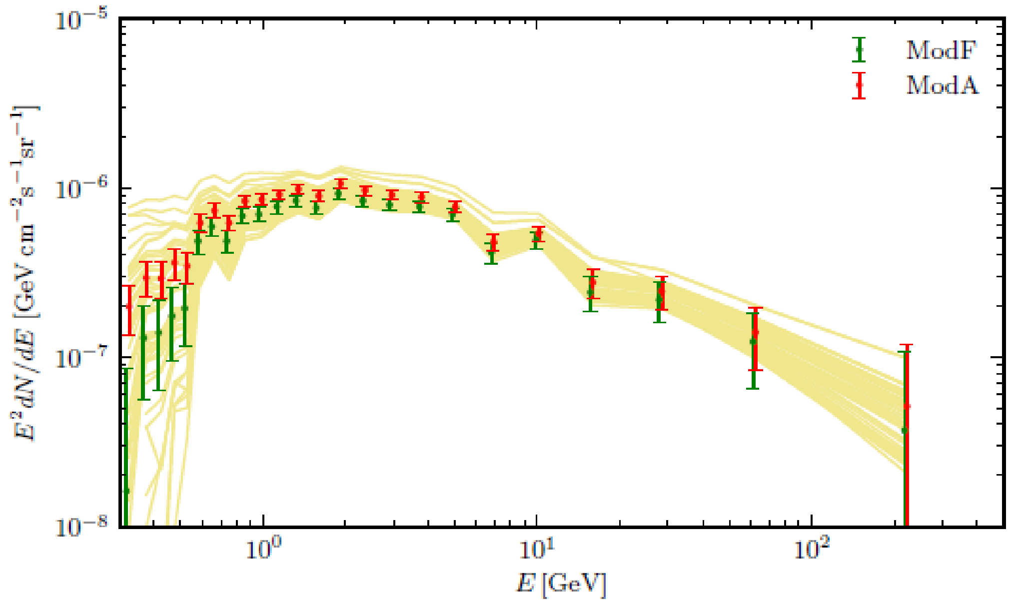
Leptons provide a better fit with the inclusion of Brem. and IC , Joseph Silk et, al arxiv:1403.1987

Hadrons vs **Leptons**

Hooperon From an Astrophysics Perspective



Dan Hooper, Tim Linden et al
arxiv:1402.6703

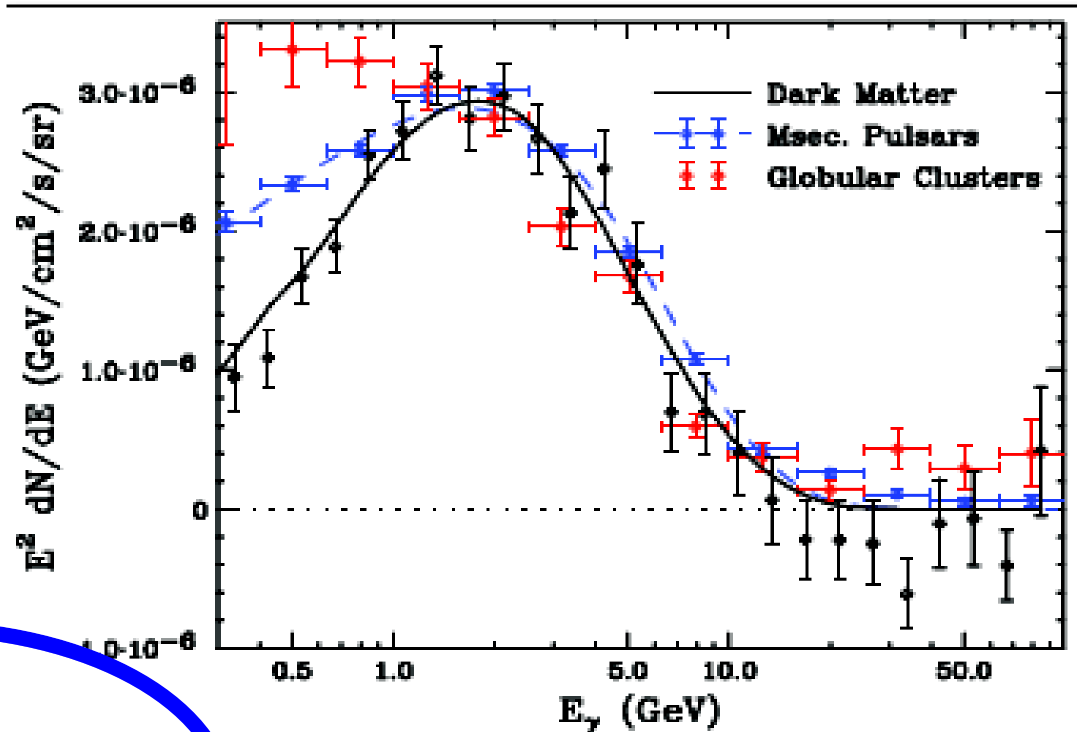


Considered several models propagation models...

The Excess still persists

What Could produce the Excess ?

Hooperon From an Astrophysics Perspective



Dark Matter **vs** **Pulsars**

See: E. Carlson, S. Profumo 1405.7685 for a supernova remnant interpretation.

The Excess extends to ~10 degrees

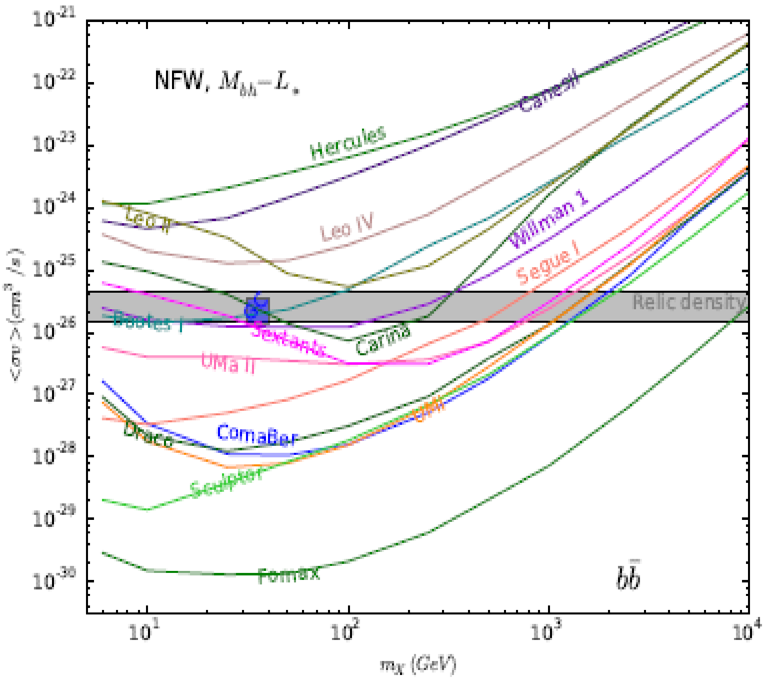
The Excess is centered around Sgr A

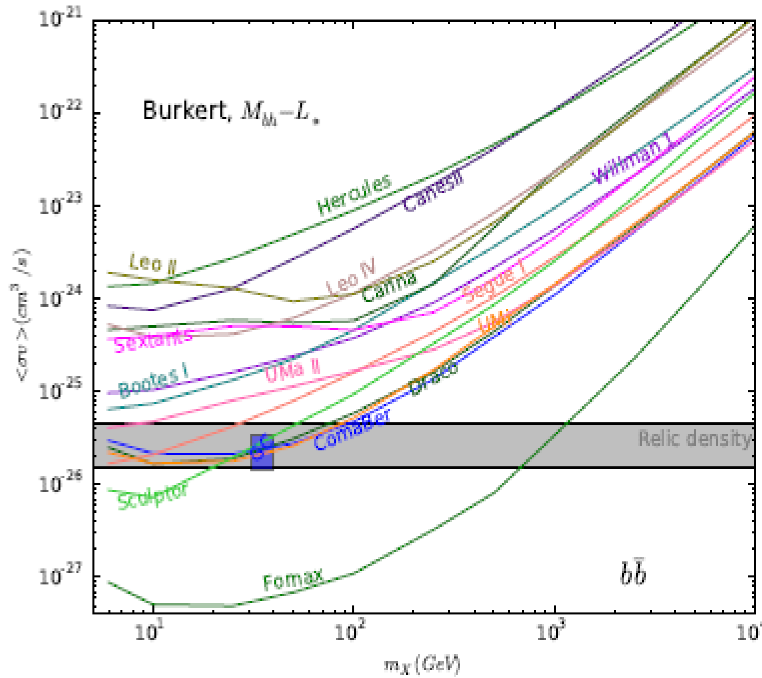
Using the luminosity function of current Fermi's observations of MSPs: ~2 000 MSPs would be needed

Is the HOOPERON Excluded by Dwarf Galaxies Data ?

YES IF THERE WERE Black Holes in Dwarf Galaxies

NEW Stringent Dwarf Galaxies Constraints : Farinaldo, Profumo, Alma arxiv:1406.2424





Black Hole Mass

$$M_{\rm bh} = 0.0013 L_*$$

OR

$$\frac{M_{\rm bh}}{{\rm M}_\odot} = \begin{cases} 10^{6.91}\left(\frac{\sigma_*}{100\,{\rm km/s}}\right)^4 & (\sigma_* \geq 6\,{\rm kms}) \\ 100 & (\sigma_* < 6\,{\rm km/s}) \end{cases}$$

OR

$$\frac{M_{\rm bh}}{{\rm M}_\odot} = \begin{cases} 10^{8.32}\left(\frac{\sigma_*}{200\,{\rm kms}^{-1}}\right)^{5.64} & (\sigma_* \geq 15\,{\rm kms}) \\ 100 & (\sigma_* < 15\,{\rm km/s}). \end{cases}$$

Is the HOOPERON Excluded by Dwarf Galaxies Data ?

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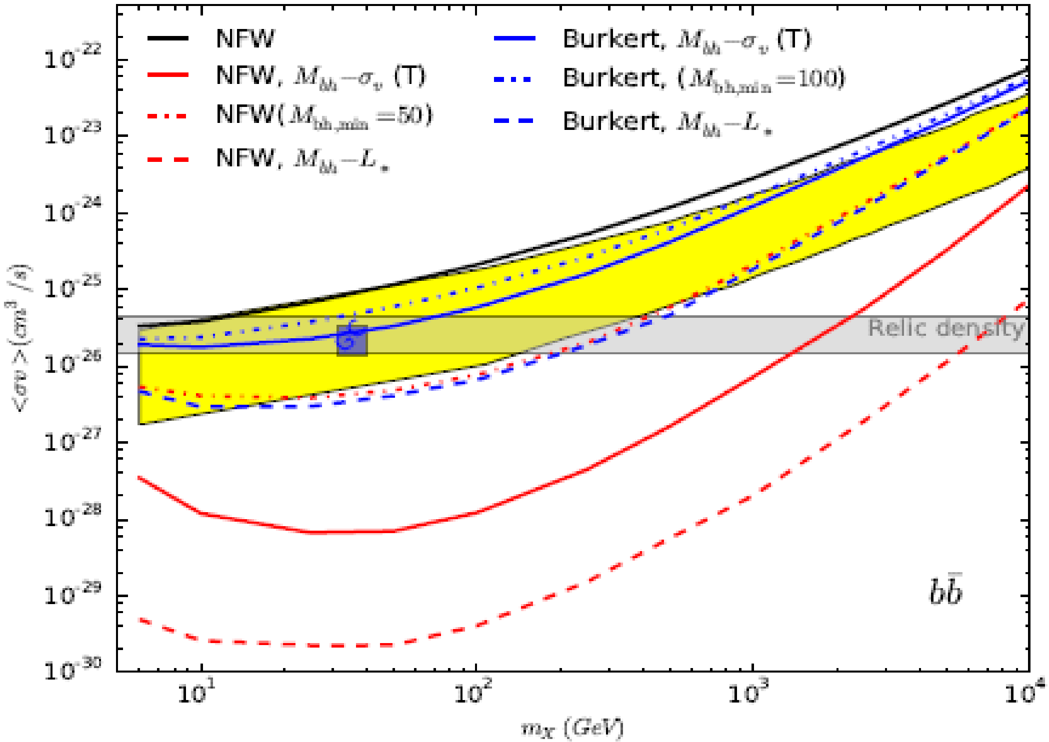
NEW Stringent Dwarf Galaxies Constraints : Farinaldo, Profumo, Alma arxiv:1406.2424



Black Hole Mass

$M_{bh} = 0.0013 L_*$ **OR** $\frac{M_{bh}}{M_\odot} = \begin{cases} 10^{6.91}\left(\frac{\sigma_*}{100\,\mathrm{km/s}}\right)^4 & (\sigma_* \geq 6\,\mathrm{kms}) \\ 100 & (\sigma_* < 6\,\mathrm{km/s}) \end{cases}$ **OR** $\frac{M_{bh}}{M_\odot} = \begin{cases} 10^{8.32}\left(\frac{\sigma_*}{200\,\mathrm{kms}^{-1}}\right)^{5.64} & (\sigma_* \geq 15\,\mathrm{kms}) \\ 100 & (\sigma_* < 15\,\mathrm{km/s}). \end{cases}$

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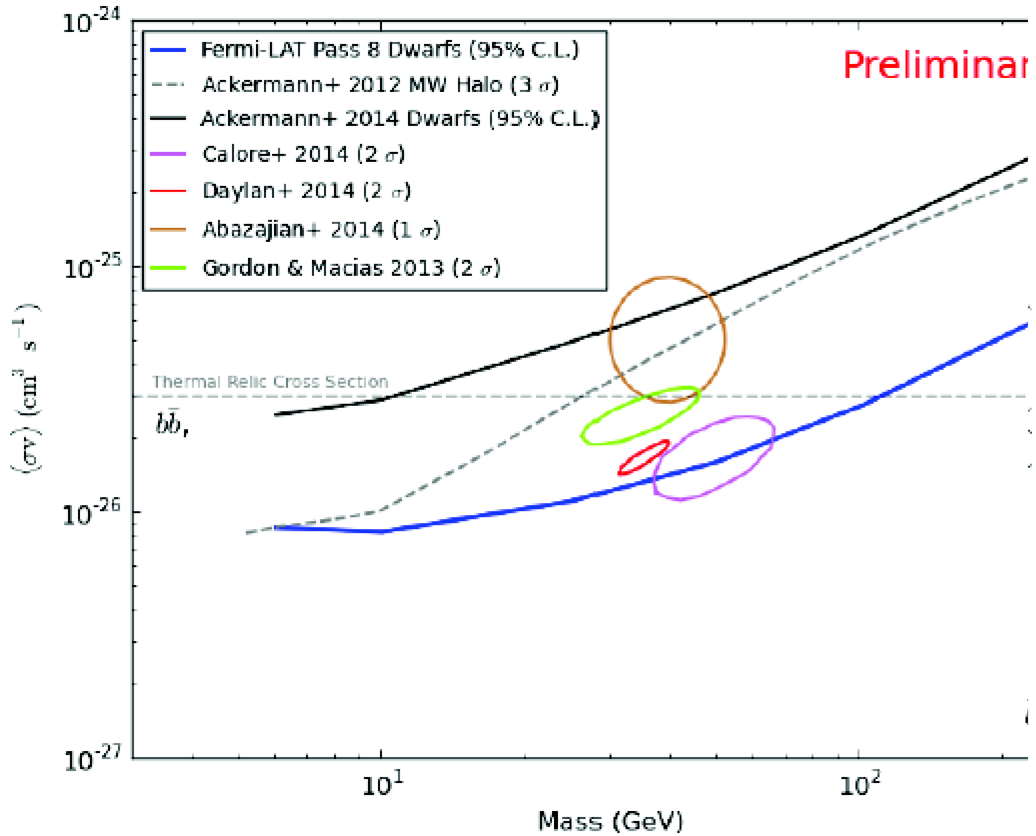
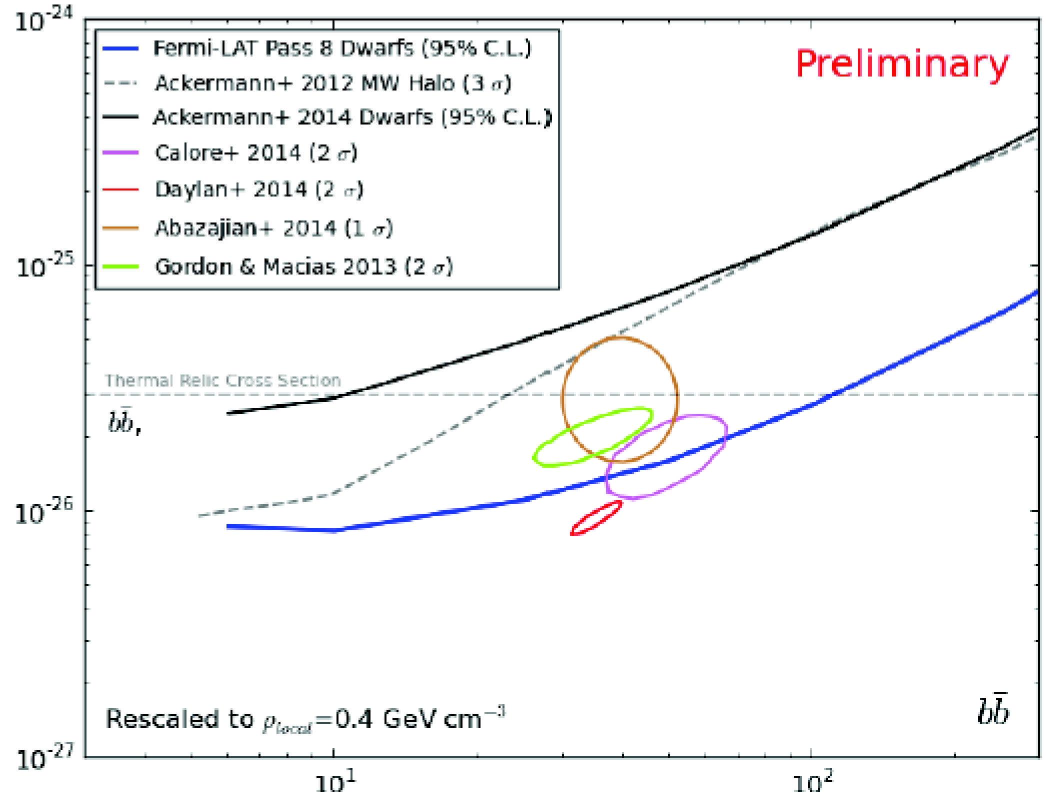
Is the HOOPERON Excluded by Dwarf Galaxies Data ?

NO, IF THERE WERE NOT Black Holes in Dwarf Galaxies and we had a stepper DM profile



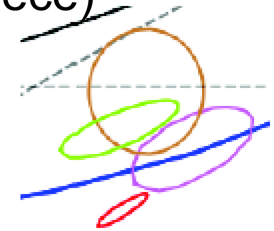


Indirect Detection Olympics: Fits performed by different groups

Hooper,Linden,Abazajian et al (US)

Cholis et al (Greece)

Weniger et al (Germany)



Gordon et al (South Africa)

Calore et al (Italy)

Space Available!

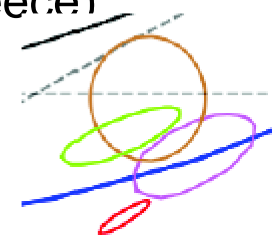
Call 630-840-8195

Indirect Detection Olympics: Fits performed by different groups

Hooper,Linden,Abazajian et al (US)

Cholis et al (Greece)

Weniger et al (Germany)



Sorry !Taken!

Gordon et al (South Africa)

Calore et al (Italy)

Patreek et al (India)

Galactic Center Excess
HOOPERON

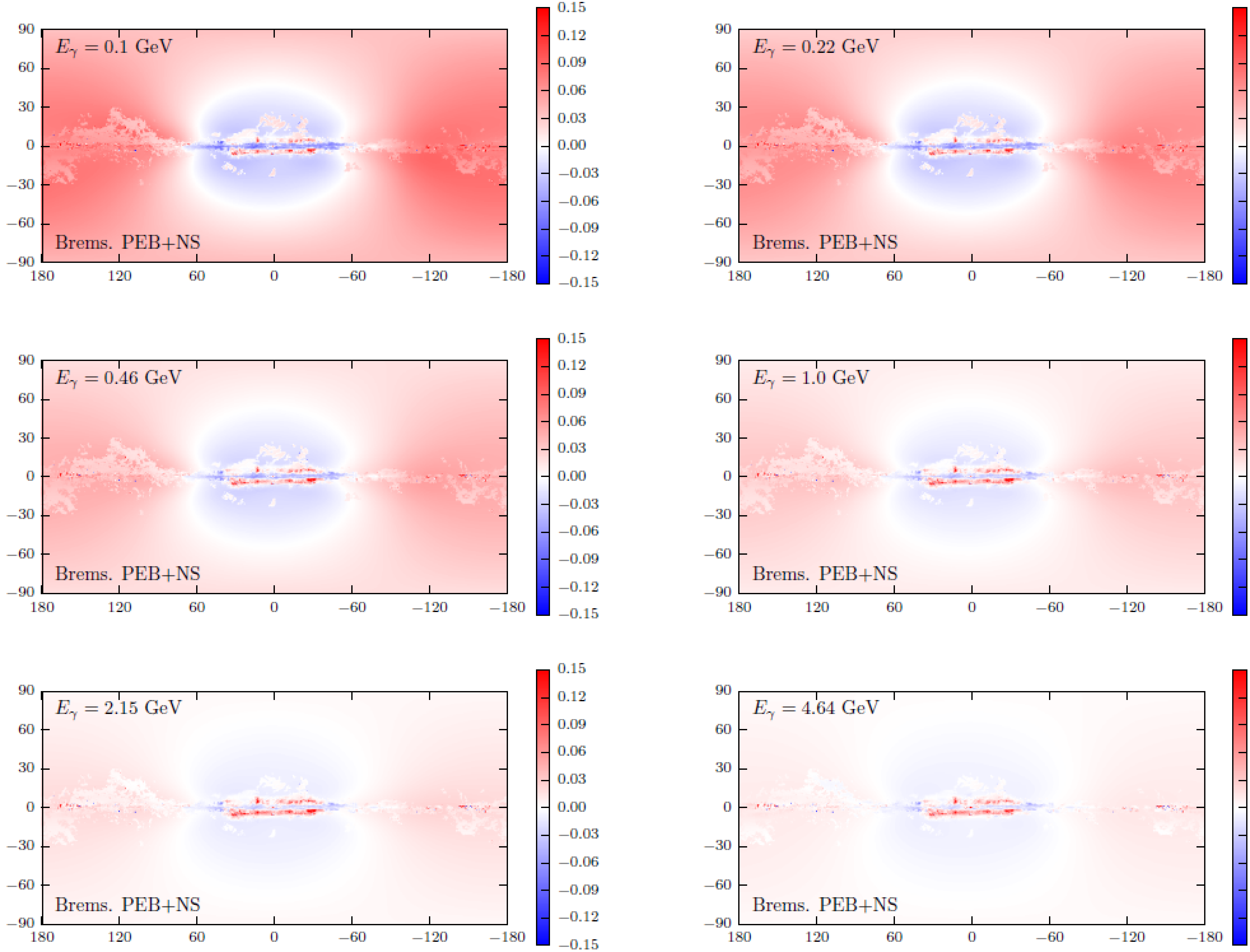
→ **Systematics**

→ **Gas Model**

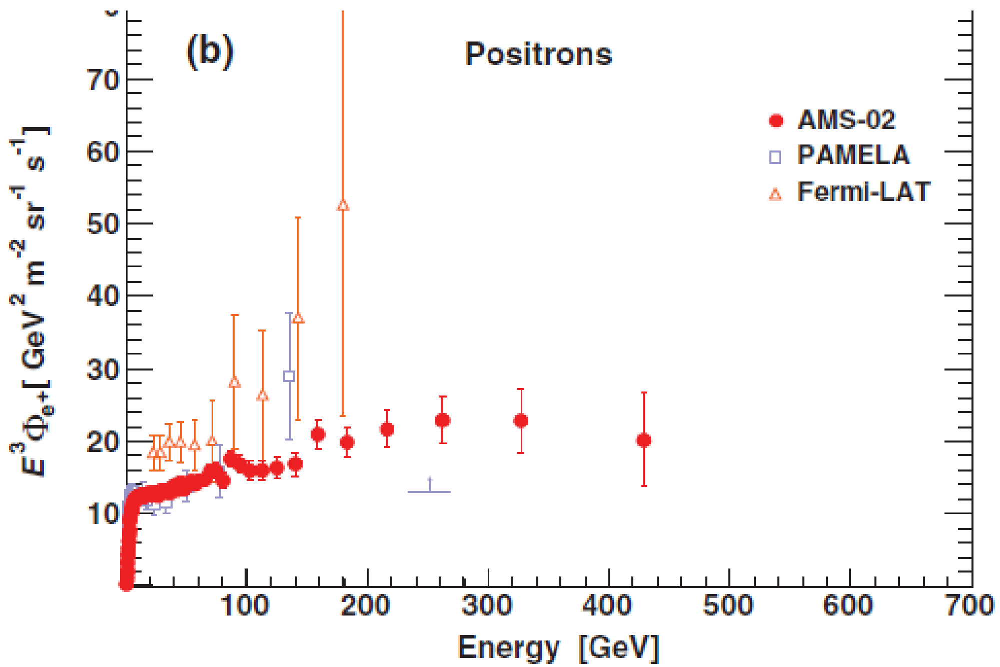
→ **Data-drive background models**

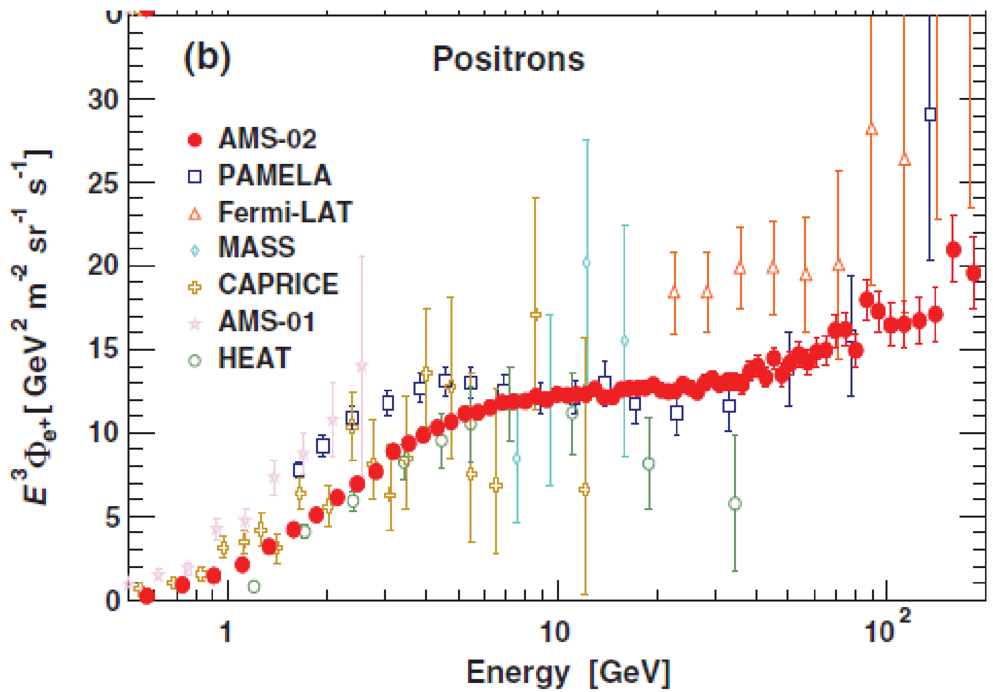
In preparation in collaboration w/ Tim Linden, Stefano Profumo, Eric Carlson

See: Calore, Cholis, Weniger : arXiv:1404.0042


$E_\gamma = 0.1$ GeV
Brems. PEB+NS
$E_\gamma = 0.22$ GeV
Brems. PEB+NS
$E_\gamma = 0.46$ GeV
Brems. PEB+NS
$E_\gamma = 1.0$ GeV
Brems. PEB+NS
$E_\gamma = 2.15$ GeV
Brems. PEB+NS
$E_\gamma = 4.64$ GeV
Brems. PEB+NS

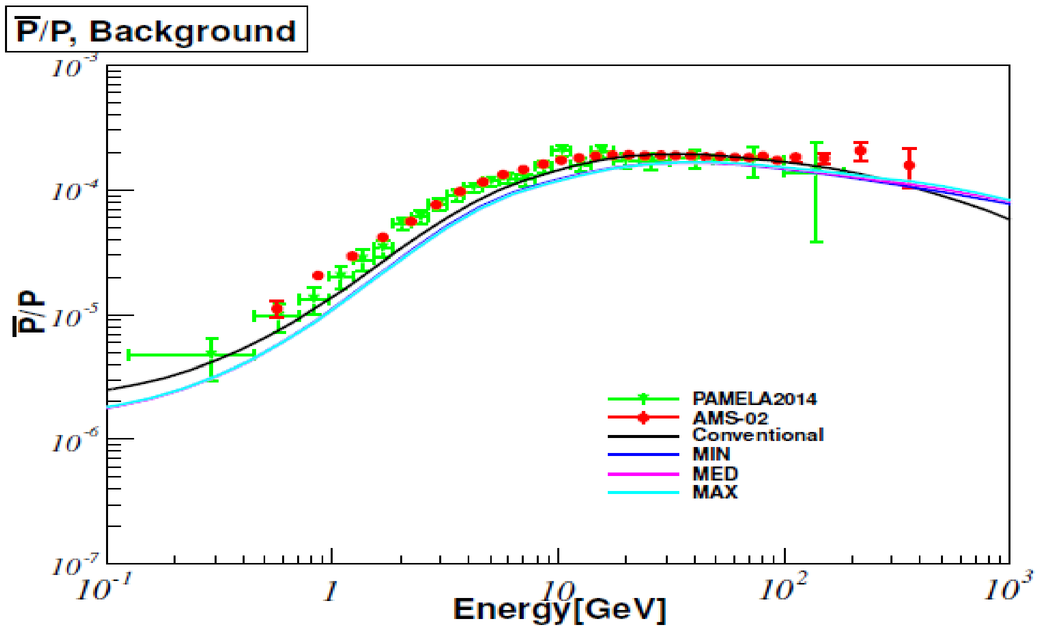
AMS: Positron Excess ?



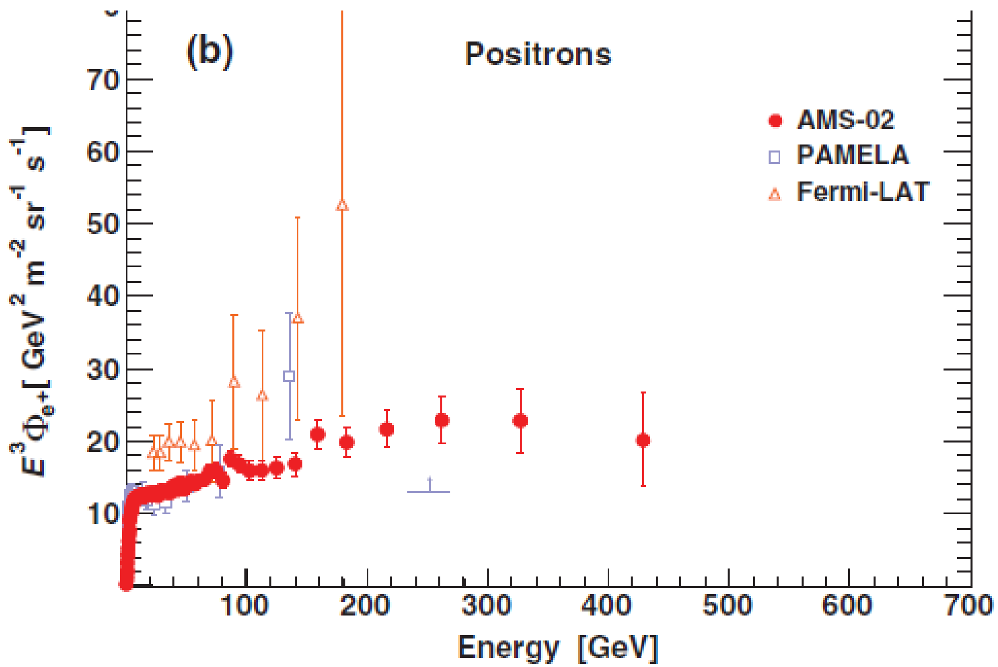


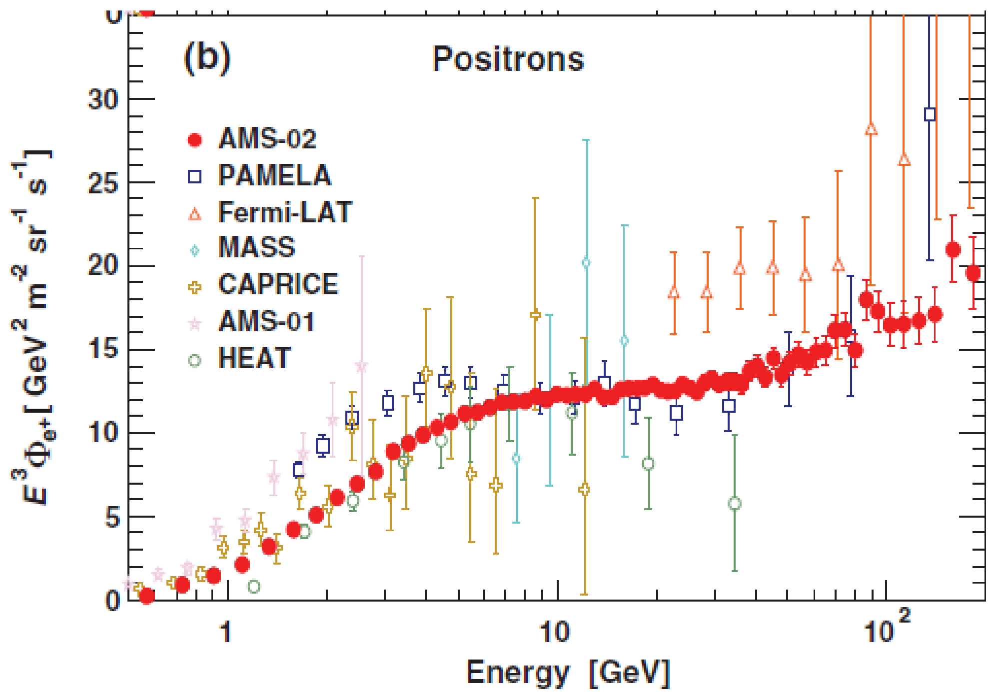
AMS Collab:

arxiv:1504.04604



AMS: Positron Excess ?



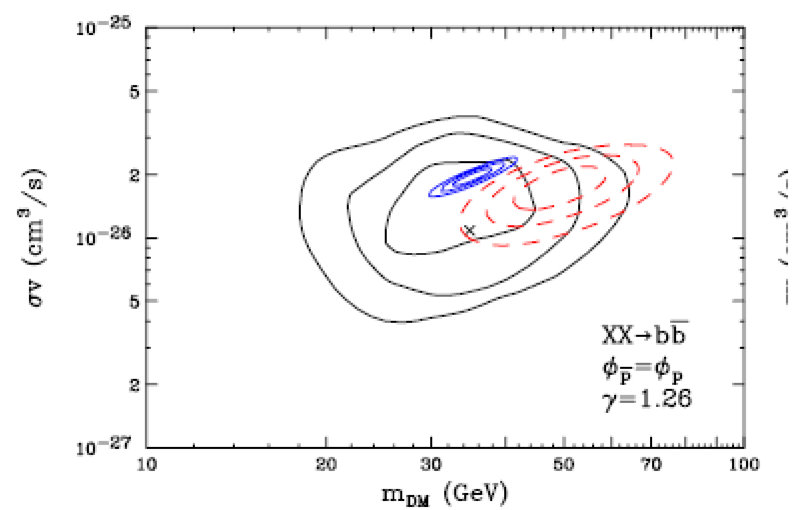


AMS Collab:

PAMELA: Anti-Proton Excess ?

KeV Line ?

See: Carlson, Jeltema,Profumo, arxiv:1411.1758



Hooper,Linden,Mertsch
Arxiv: 1410.1527

Given this mess, we will exploit dark matter complementarity in the context of simplified dark matter models

→ Collider

→ Direct Detection

→ Indirect Detection

Z' Portal

Z'

Dark Sector ⟷ Visible Sector

Different Setups

1. **Leptophilic**
   g-2 Public Code: Farinaldo Queiroz and Will Shepherd
   PRD, arxiv:1403.2309

2. **Leptophobic** : next slides

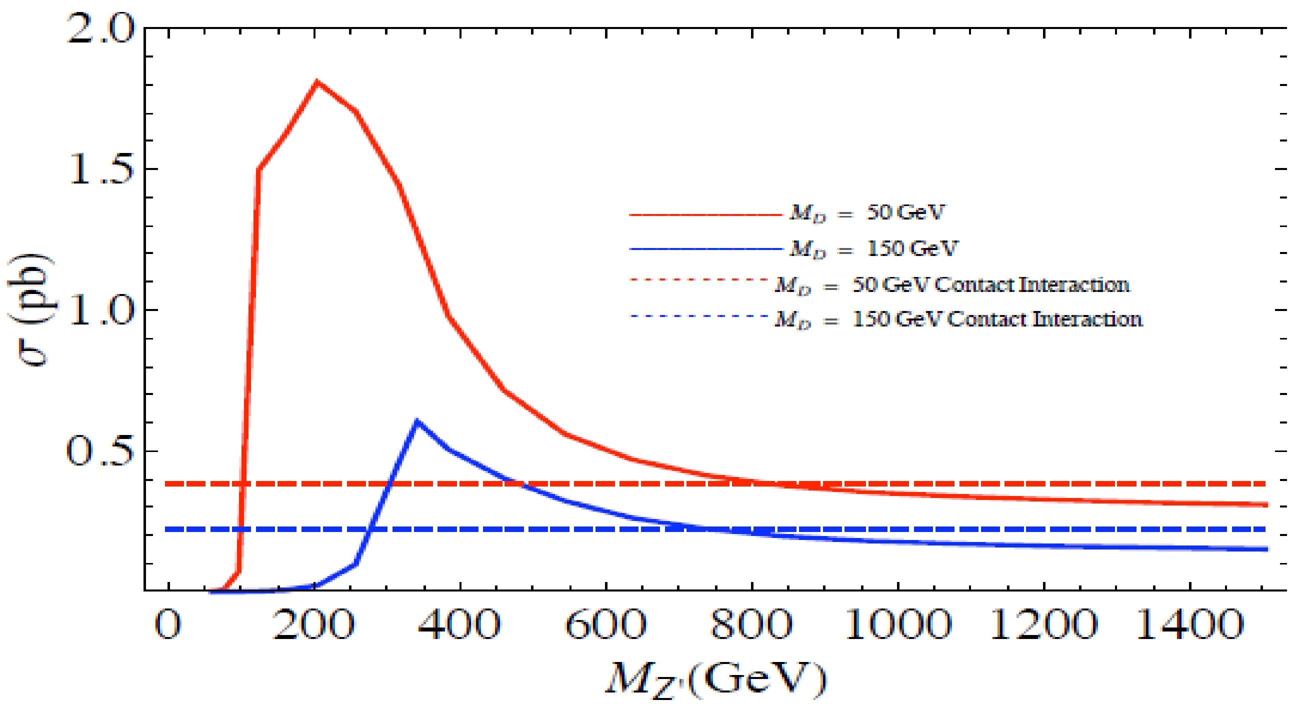
3. **General**

   Hooper, Queiroz, Berlin, Profumo, Alves, arxiv:1501.03490

Z' Portal: Leptophobic

$$\mathcal{L} = -\frac{g}{2C_W}\left[\sum_i \bar{q}_i\gamma^\mu(a\cdot g_V^i - b\cdot g_A^i\gamma_5)q_i\right]Z'_\mu + g_\chi\left[\bar{\chi}\gamma^\mu(1\pm\gamma_5)\chi\right]Z'_\mu$$

Effective Operators x **Simplified Model**



Z' Portal: Leptophobic

A. Alves, Stefano Profumo, Farinaldo Queiroz and Will Shepherd, JHEP 1404 (2014) 063 arXiv:1312.5281

$$\mathcal{L} = -\frac{g}{2C_W}\left[\sum_i \bar{q}_i\gamma^\mu(a\cdot g_V^i - b\cdot g_A^i\gamma_5)q_i\right]Z'_\mu + g_\chi\left[\bar{\chi}\gamma^\mu(1\pm\gamma_5)\chi\right]Z'_\mu$$

We are not interested in the U(1)x where the Z' comes from

This U(1)x might be anomalous and new fermions should be introduced.

Free Parameters

↓

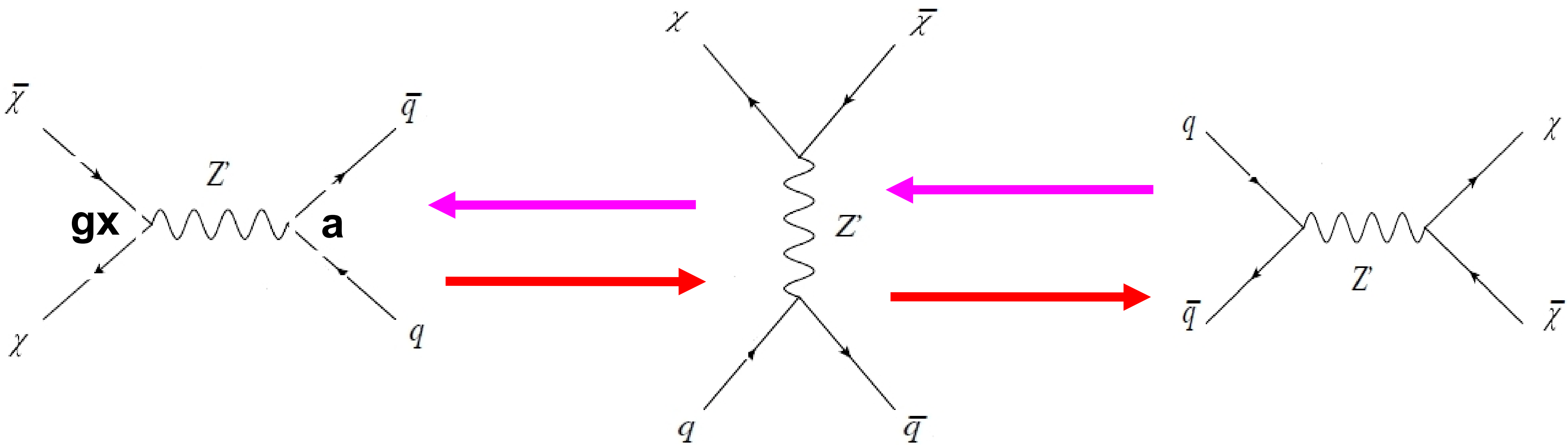
a b gx Mz' Mwimp

We will investigate a=b=1 → Z' = Z and a=b=0.5 (suppressed couplings)

Z' Portal: Leptophobic

Complementariy

A. Alves, Stefano Profumo, Farinaldo Queiroz and Will Shepherd, JHEP 1404 (2014) 063
arXiv:1312.5281



Indirect Detection **Direct Detection** **Collider**

Z' Portal: Leptophobic

$$\mathcal{L} = -\frac{g}{2C_W}\left[\sum_i \bar{q}_i\gamma^\mu(a\cdot g_V^i - b\cdot g_A^i\gamma_5)q_i\right]Z'_\mu + g_\chi\left[\bar{\chi}\gamma^\mu(1\pm\gamma_5)\chi\right]Z'_\mu$$

Dirac WIMP – Quarks Interactions

The Leptophobic Dark Z' Portal

	Operator	Structure	Scattering Cross Section
O_1	$\bar{q}\gamma^\mu q\bar{\chi}\gamma_\mu\chi$	Spin Independent	$\frac{9g_V^2 g_\chi^2 M_n^2 M_\chi^2}{\pi M_{Z'}^4 (M_n+M_\chi)^2}$
O_2	$\bar{q}\gamma^\mu q\bar{\chi}\gamma_\mu\gamma_5\chi$	Spin Independent	$\sim v^2$
O_3	$\bar{q}\gamma^\mu\gamma_5 q\bar{\chi}\gamma_\mu\chi$	Spin Dependent	$\sim v^2$
O_4	$\bar{q}\gamma^\mu\gamma_5 q\bar{\chi}\gamma_\mu\gamma_5\chi$	Spin Dependent	$\frac{3g_A^2 g_\chi^2(\Delta\Sigma)^2 M_n^2 M_\chi^2}{\pi M_{Z'}^4 (M_n+M_\chi)^2}$

Farinaldo Queiroz et al, arXiv:1312.5281

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Z' Portal: Leptophobic

The Leptophobic Dark Z' Portal

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O_1	$\bar{q}\gamma^\mu q\bar{\chi}\gamma_\mu\chi$	Spin Independent	$\frac{9g_V^2 g_\chi^2 M_n^2 M_\chi^2}{\pi M_{Z'}^4 (M_n+M_\chi)^2}$
O_2	$\bar{q}\gamma^\mu q\bar{\chi}\gamma_\mu\gamma_5\chi$	Spin Independent	$\sim v^2$
O_3	$\bar{q}\gamma^\mu\gamma_5 q\bar{\chi}\gamma_\mu\chi$	Spin Dependent	$\sim v^2$
O_4	$\bar{q}\gamma^\mu\gamma_5 q\bar{\chi}\gamma_\mu\gamma_5\chi$	Spin Dependent	$\frac{3g_A^2 g_\chi^2 (\Delta\Sigma)^2 M_n^2 M_\chi^2}{\pi M_{Z'}^4 (M_n+M_\chi)^2}$

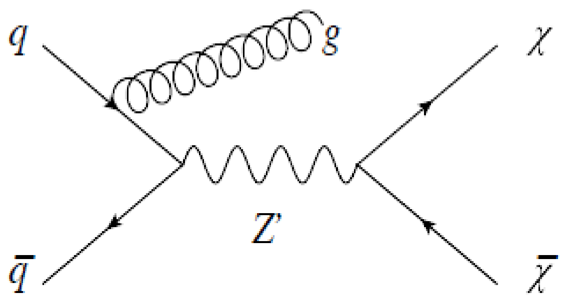
Underlying Physics

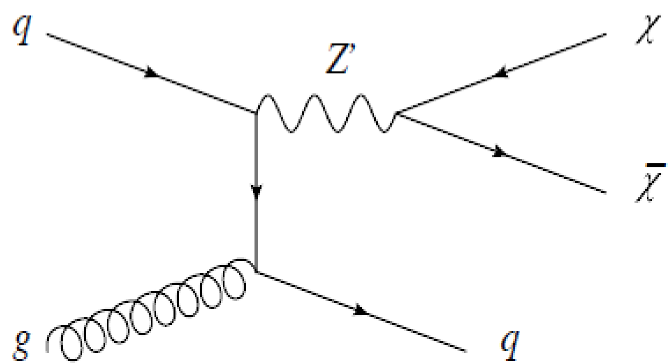
	$\mathcal{L}_{\rm int}^j$	Nonrelativistic Reduction
O1	$\bar{\chi}\gamma^\mu\chi\bar{N}\gamma_\mu N$	$1_\chi 1_N$
O2	$\bar{\chi}\gamma^\mu\gamma^5\chi\bar{N}\gamma_\mu N$	$2\vec{v}^\perp\cdot\vec{S}_\chi + 2i\vec{S}_\chi\cdot\left(\vec{S}_N\times\frac{\vec{q}}{m_N}\right)$
O3	$\bar{\chi}\gamma^\mu\chi\bar{N}\gamma_\mu\gamma^5 N$	$-2\vec{S}_N\cdot\vec{v}^\perp + \frac{2}{m_\chi}i\vec{S}_\chi\cdot(\vec{S}_N\times\vec{q})$
O4	$\bar{\chi}\gamma^\mu\gamma^5\chi\bar{N}\gamma^\mu\gamma^5 N$	$-4\vec{S}_\chi\cdot\vec{S}_N$

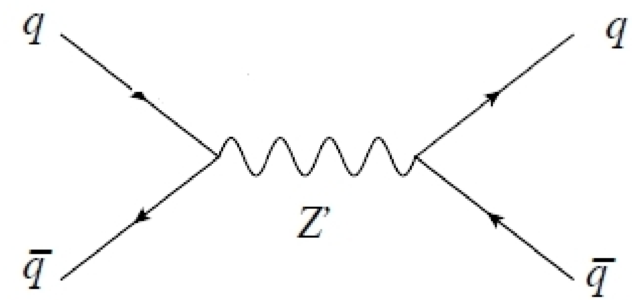
Misconception in the Z' portal!

Z' Portal: Leptophobic

Mono-Jet / Di-jet / Missing Energy







$p\bar{p} \to Z' \to jj$

$pp \to Z' \to jj$

$pp \to Z' + j \to \chi\bar{\chi} + j \to \not{E}_T + j$

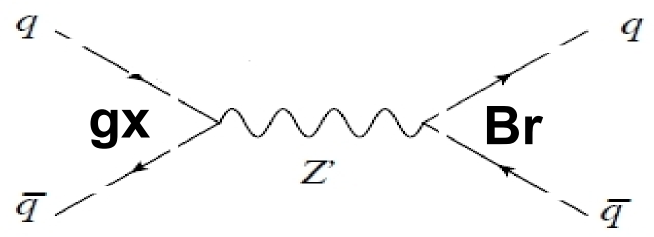
A new heavy neutral gauge boson such Z' may lead to a resonance in jj.

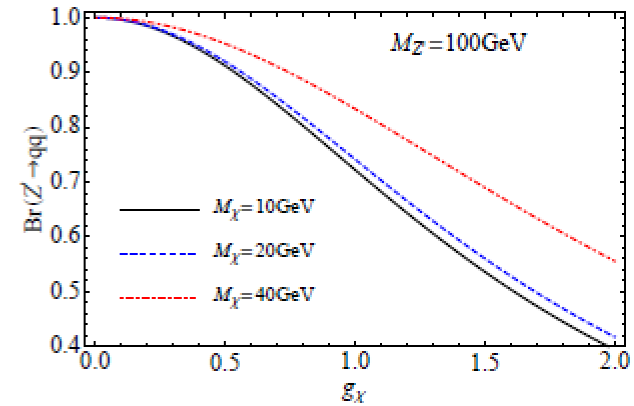
The Tevatron and LHC collaborations have been searching for resonances in dijet events with null results until now

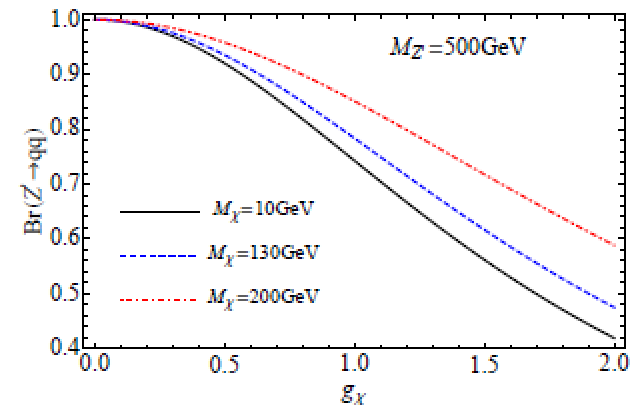
No evidence for DM in colliders

Z' Portal: Leptophobic- Based on Dijet Data

$p\bar{p} \rightarrow Z' \rightarrow jj \quad pp \rightarrow Z' \rightarrow jj$







A new heavy neutral gauge boson such Z' may lead to a resonance in jj.

No resonance has been found

The effect of the mass and couplings of the DM particle on the dijet bounds is indirect.

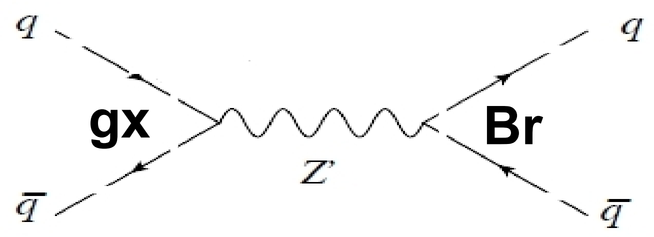
For a fixed Z'mass, the branching ratio BR(Z' → q q) increases as Mχ approaches MZ' /2, up until

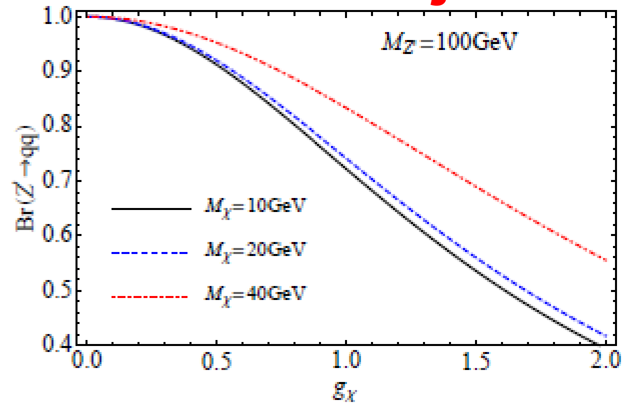
$$BR(Z' \rightarrow q\bar{q}) + BR(Z' \rightarrow \chi\bar{\chi}) = 1$$

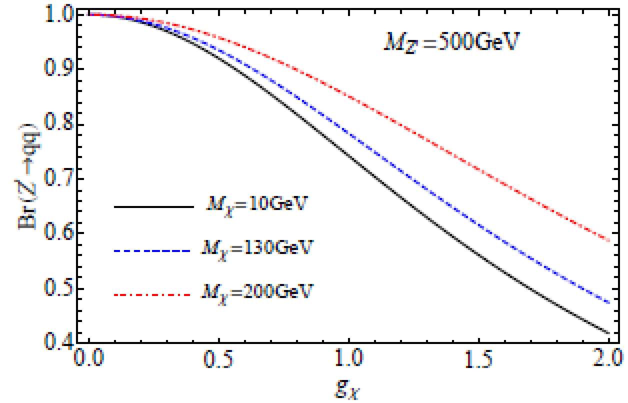
Decreasing the coupling between the DM and Z' increases the branching faction into quarks.

Z' Portal: Leptophobic- Based on Dijet Data

$p\bar{p} \to Z' \to jj \quad pp \to Z' \to jj$







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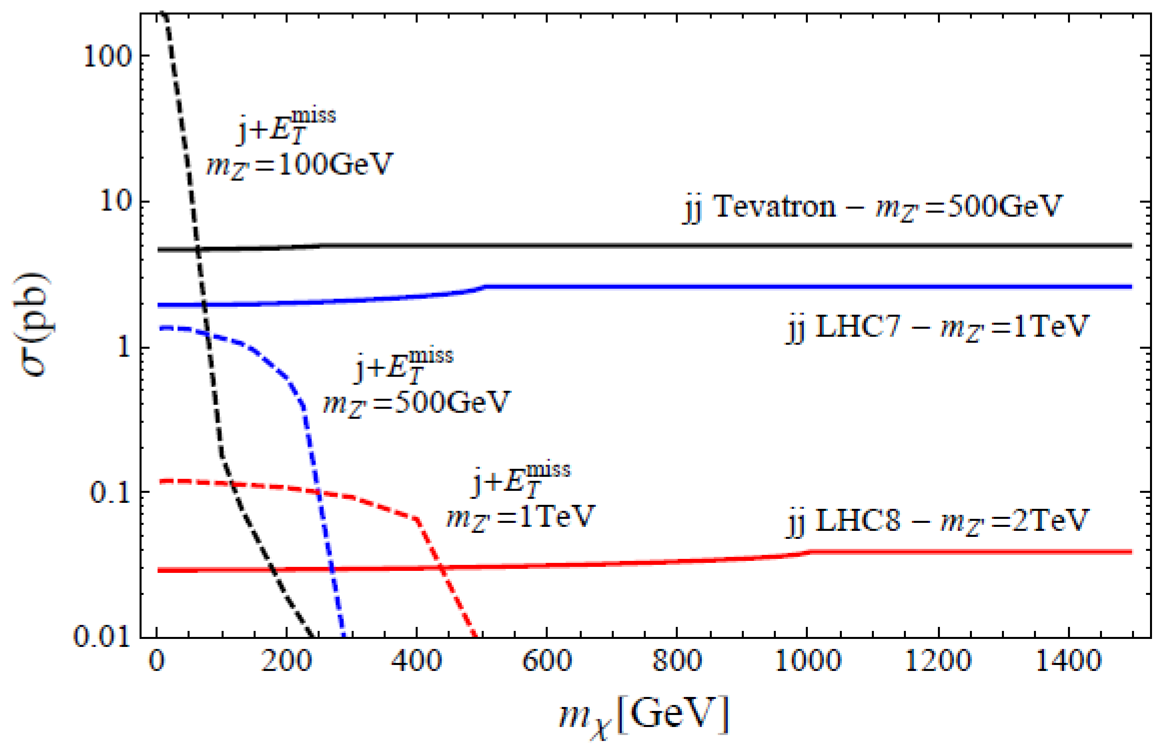
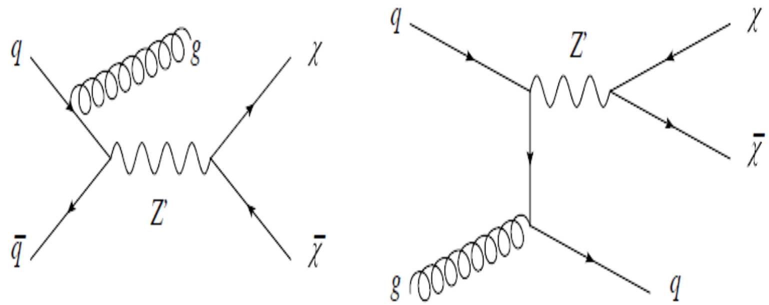
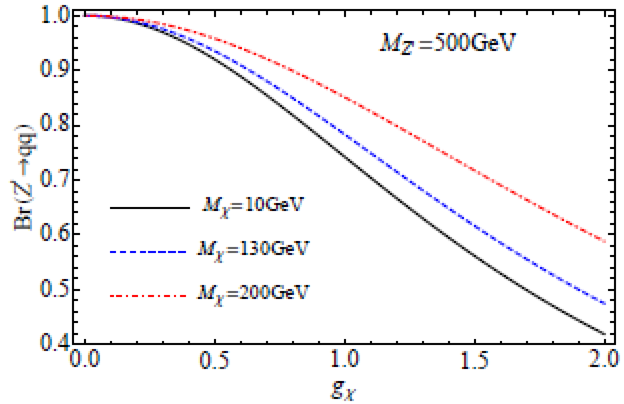


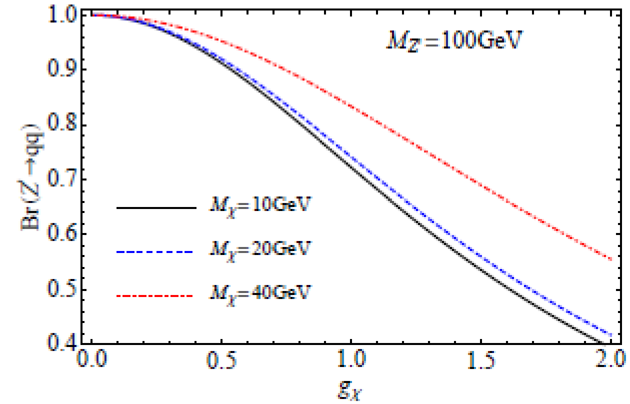
Max-Planck-Institut für Kernphysik Heidelberg

Z' Portal: Leptophobic- Based on Mono-jet Data

$$pp \to Z' + j \to \chi\bar{\chi} + j \to \not{E}_T + j$$



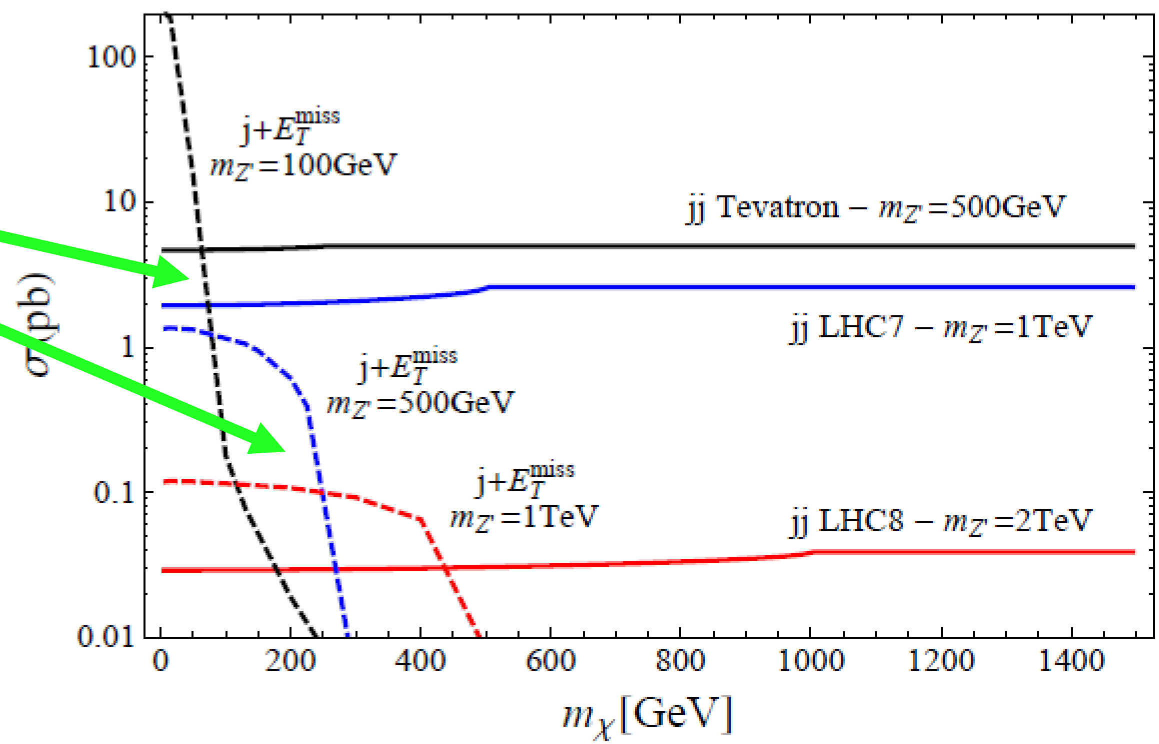




The dark matter mass and couplings are important

For a fixed Z'mass, the branching ratio BR(Z' → q q) increases as Mχ approaches MZ' /2, up until

$$BR(Z' \to q\bar{q}) + BR(Z' \to \chi\bar{\chi}) = 1$$



Decreasing the coupling between the DM and Z' increases the branching faction into quarks.

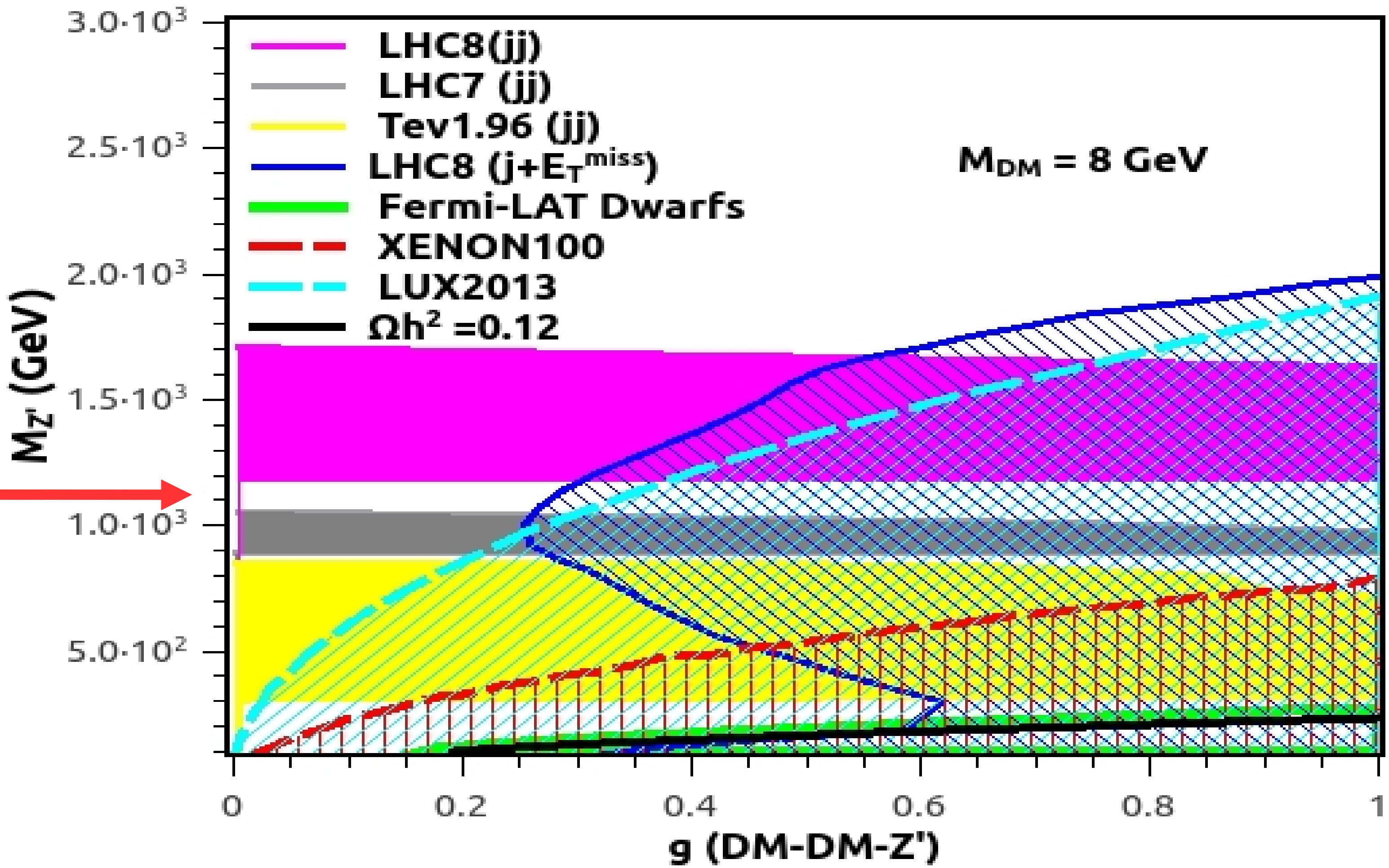
Z' Portal: Leptophobic- Dark Matter Complementarity

Combining colliders, direct and indirect detection bounds

Assuming the Z' = Z

Viable region

Otherwise Mz' >1.7 TeV



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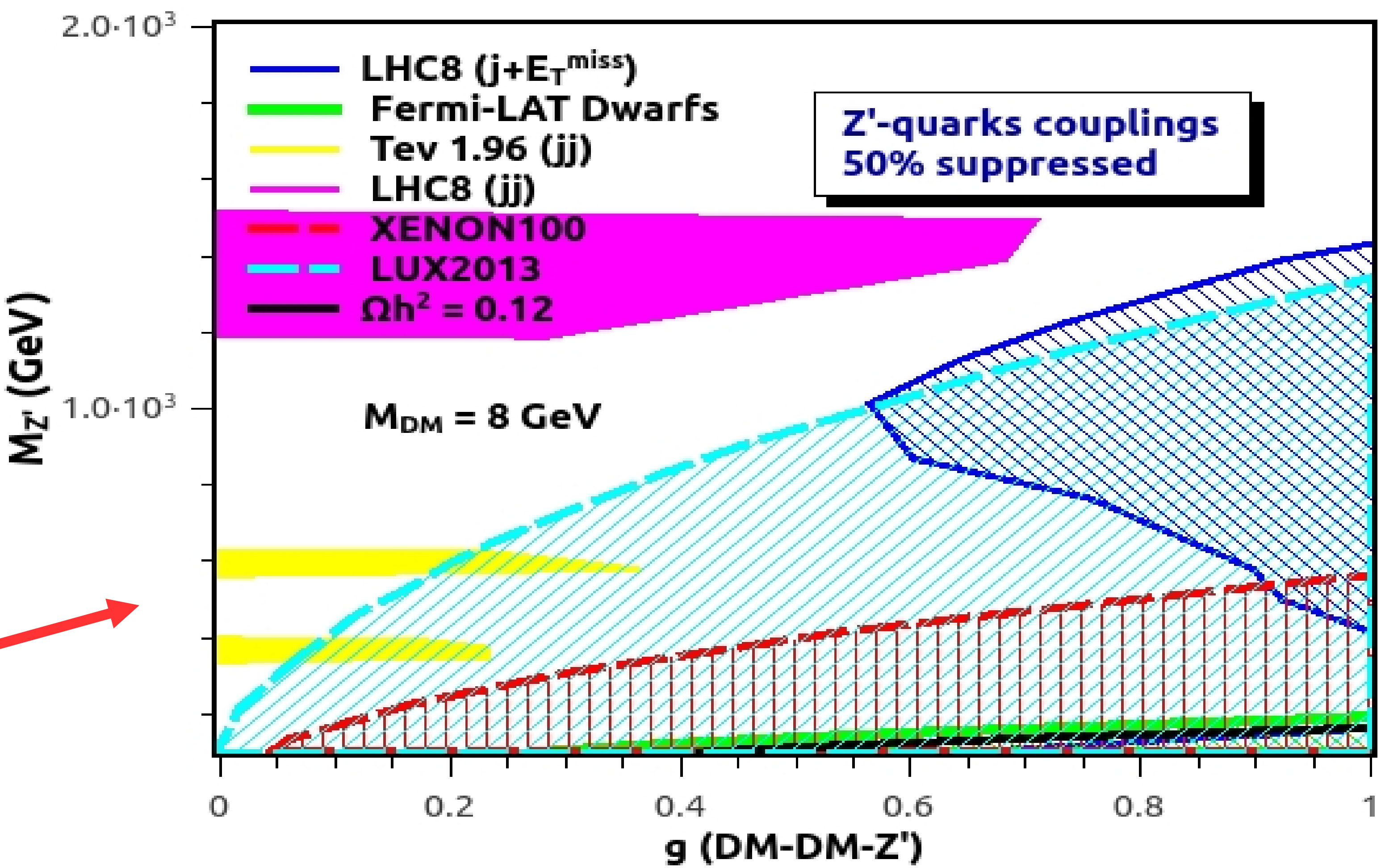
Z' Portal: Leptophobic- Dark Matter Complementarity

Assuming the couplings are suppressed in 50% compared to the Z quarks ones

Note how significant the impact of suppressing the Z'-quarks couplings in 50% is

Combining colliders, direct and indirect detection bounds



Viable region

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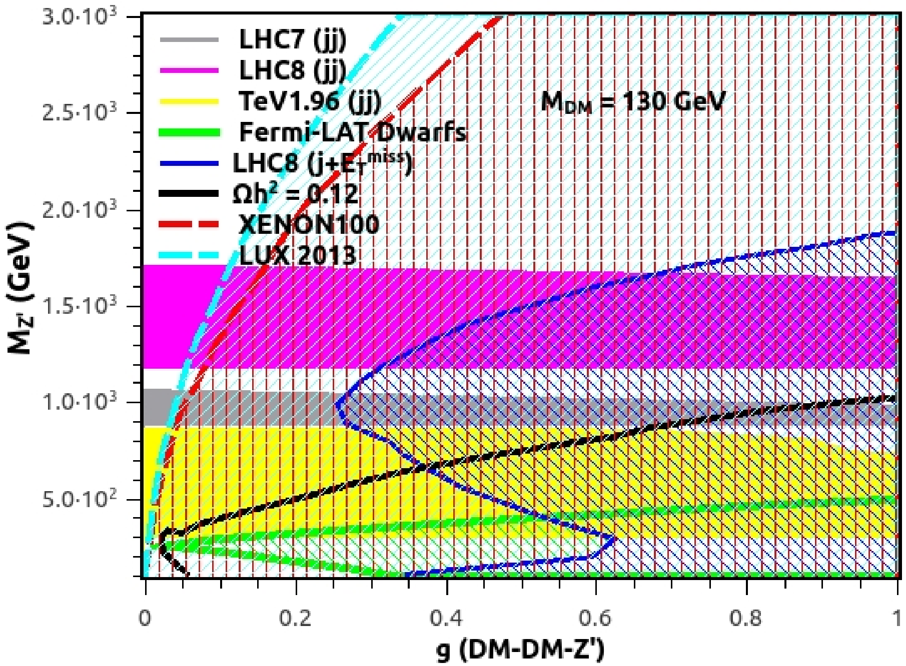
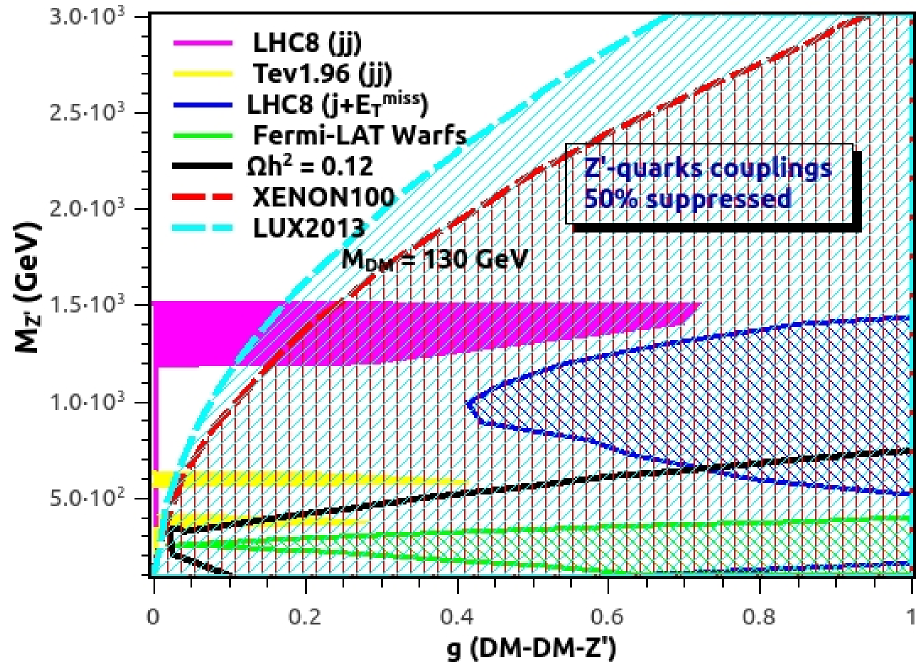
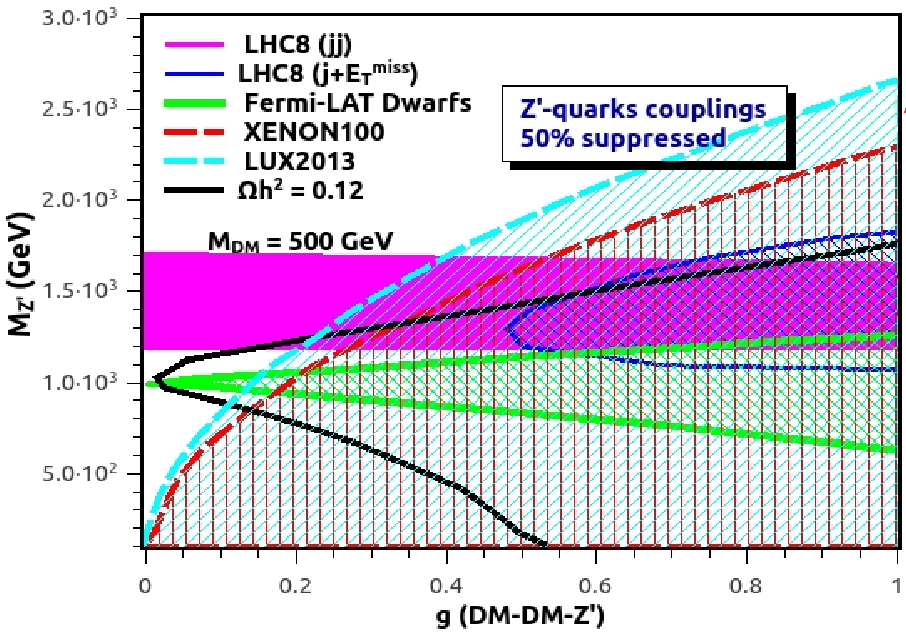
Z' Portal: Leptophobic- Dark Matter Complementarity

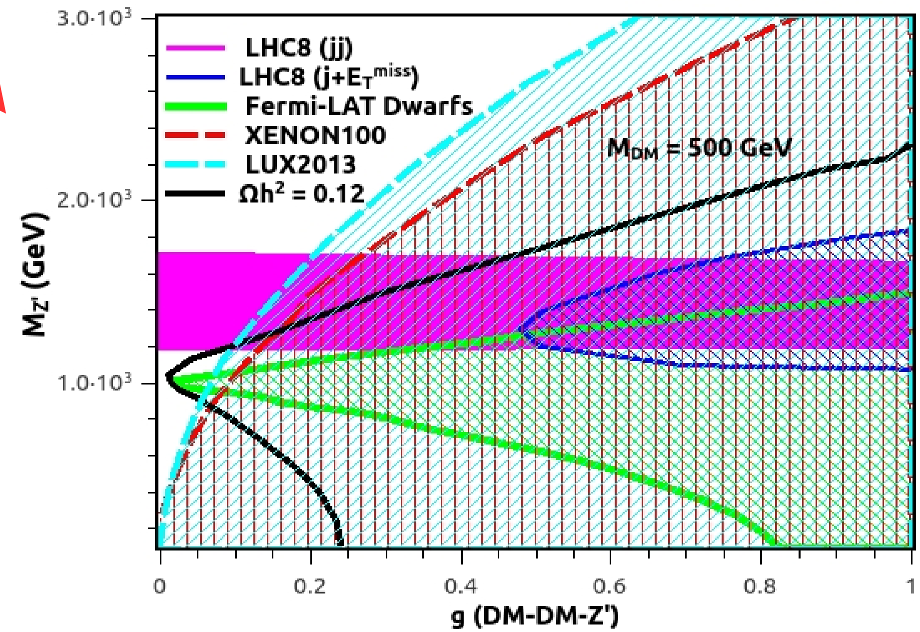
130 GeV WIMP



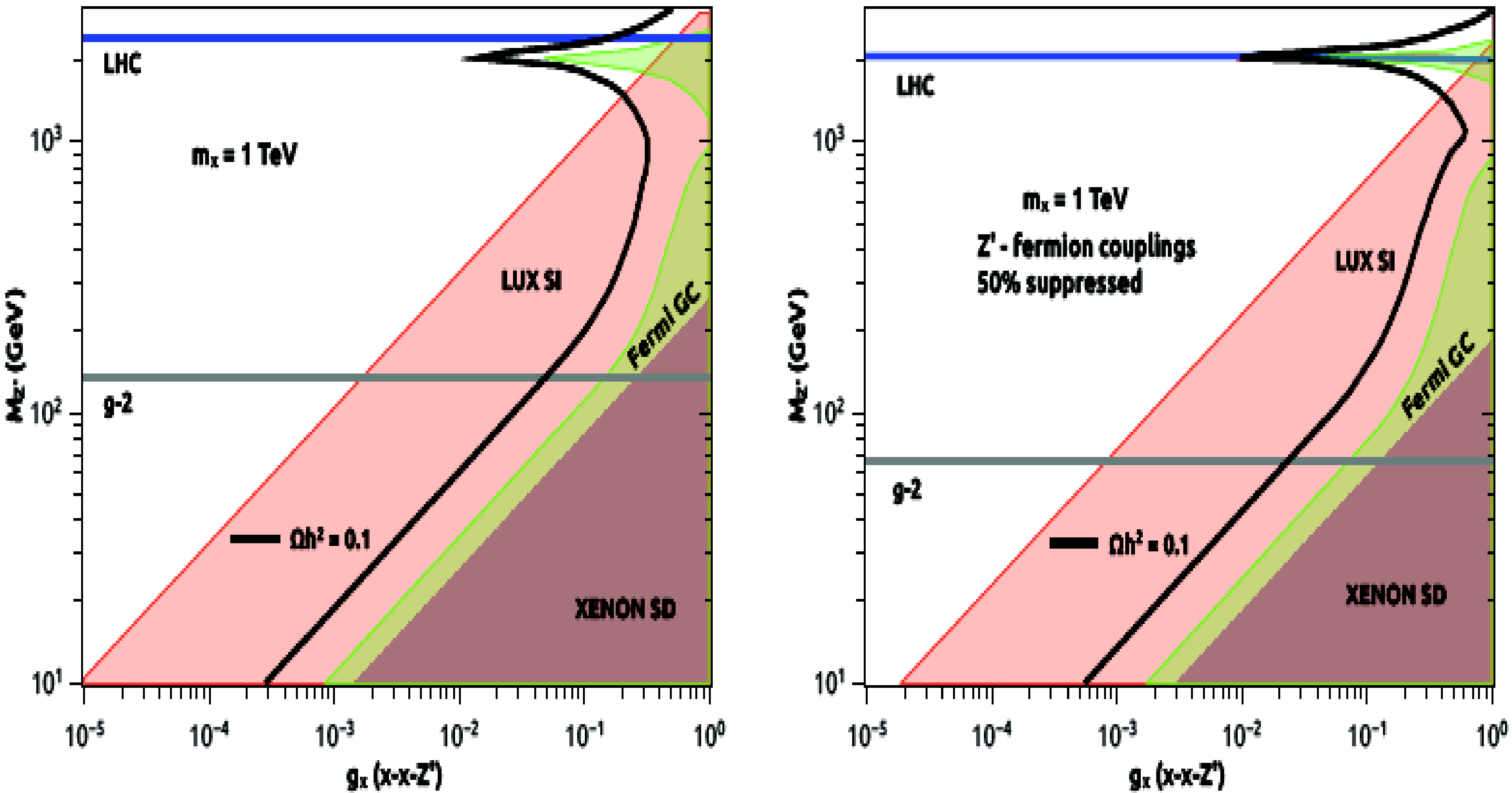


500 GeV WIMP



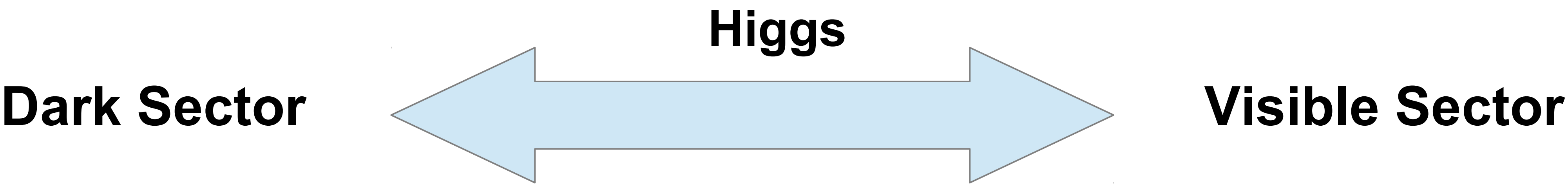


Z' Portal: General



Conclusion: MZ' > 2.1 TeV regardless of the DM mass

Higgs Portal:



Simplified Model

$$\mathcal{L}_S = -\frac{\mu_S^2}{2} S^2 - \frac{\lambda_{hs}}{2} S^2 H^\dagger H - \frac{1}{2}\partial_\mu S \partial^\mu S - \frac{\lambda_S}{4}\lambda_S S^4$$

Farinaldo Queiroz, Kuver Sinha, arxiv: 1404.1400

Higgs Portal:

Dark Sector ⟷ **Higgs** ⟷ **Visible Sector**

Simplified Model

$$\mathcal{L}_S = -\frac{\mu_S^2}{2} S^2 - \frac{\lambda_{hs}}{2} S^2 H^\dagger H - \frac{1}{2}\partial_\mu S \partial^\mu S - \frac{\lambda_S}{4}\lambda_S S^4$$

Relevant for DM phenomenology

Impose a Z2 symmetry to stabilize S

Prohibits S H H

Free Parameters : mS and λhs

$$m_S = \sqrt{\mu_S^2 + \frac{\lambda_{hs} v_0^2}{2}}$$

Farinaldo Queiroz, Kuver Sinha, arxiv: 1404.1400

Higgs Portal:

Higgs

Dark Sector ⟷ **Visible Sector**

Simplified Model

$$\mathcal{L}_S = -\frac{\mu_S^2}{2}S^2 - \frac{\lambda_{hs}}{2}S^2 H^\dagger H - \frac{1}{2}\partial_\mu S \partial^\mu S - \frac{\lambda_S}{4}\lambda_S S^4$$

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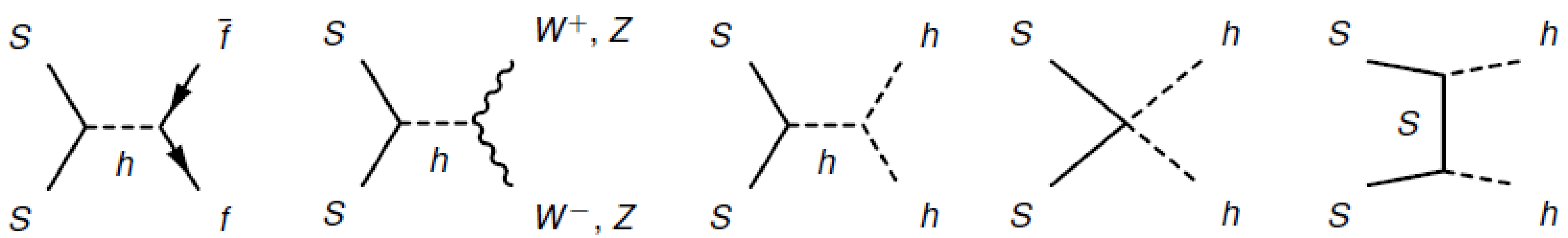
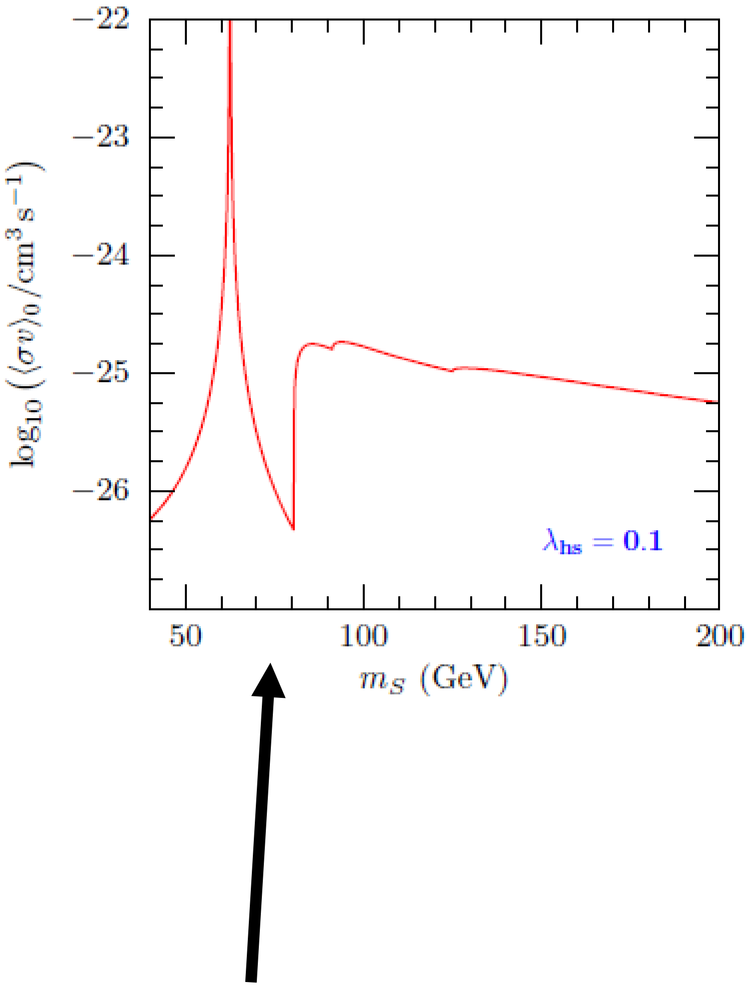


Higgs Portal:

Abundance

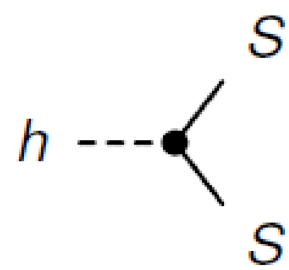


Higgs Resonance

Higgs Portal:

Invisible Width

Latest 95% CL combined LHC+Tevatron limit across all production and decay channels is $BF_{SS} < 23\%$ (Belanger et al.



$$\Gamma_{h\to SS} = \frac{\lambda_{hs}^2 v_0^2}{32\pi m_h^2}\left(m_h^2 - 4m_S^2\right)^{1/2}$$

Straightforward

$$\Gamma_{SS} = \frac{\lambda_3^2 v^2}{32\pi M_h}\left(1 - \frac{4M_S^2}{M_h^2}\right)$$

$$\Gamma_{vis} = 4.07 \text{ MeV for } M_h = 125 \text{ GeV}$$

$$\mathrm{BR}_{\mathrm{JJ}} = \frac{\Gamma_{SS}}{\Gamma_{vis} + \Gamma_{SS}}$$

Uncertainty in the total Higgs width is quite large!

We still have the LUX and Fermi-LAT bounds

We are not focused on the Hooperon!

Real scalars are excluded by direct Detection.

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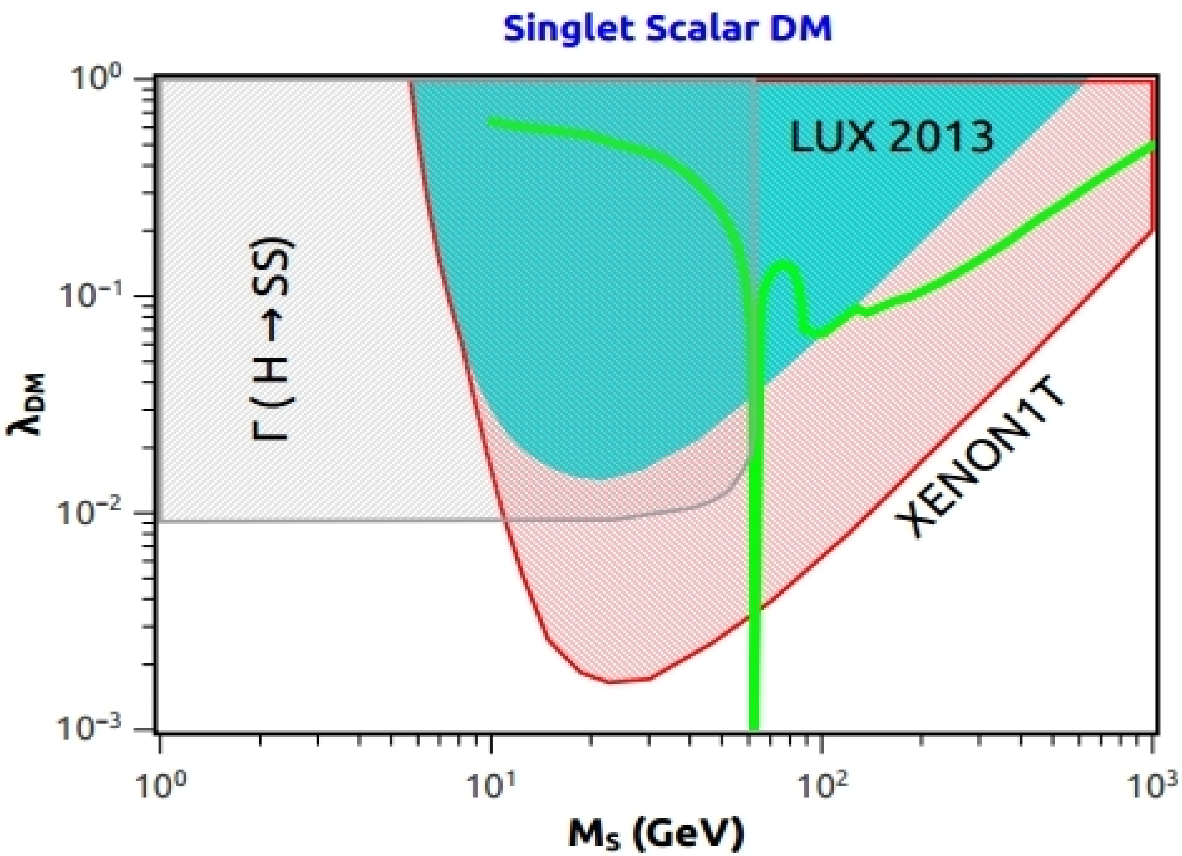
Higgs Portal: Direct and Indirect Detection



Farinaldo Queiroz, Kuver Sinha, arxiv: 1404.1400
Farinaldo. Queiroz, K. Sinha, A. Strumia, arxiv:1409.6301

Indirect detection excludes masses < 70 GeV

Direct detection excludes masses < 100 GeV

Final Remarks

The Higgs and Z' portals are still consistent with current constraints in the WIMP mass range

Near resonances the Z' portal is compatible with other searches/bounds.

Only dark matter masses larger than ~ 100GeV are allowed in the Higgs Portal for couplings of oder one.

There are many viable WIMP - DM portals in the literature.
Less explored: Axion Portal ...in preparation with William Wester

Footnote:

Leptoquarks tied to dark matter is a plausible explanation for the eejj nue jj excess, F. Queiroz, K.Sinha, A. Strumia arxiv:1409.6301

Conclusions

Hooperon, AMS Excess, Gamma-ray Line, CDMS-Si Excess, DAMA Modulation, CoGeNT Excess/Modulation, CRESST excess, CMS Leptoquark Excess, KeV Line

Is this all "chasing ambulances"?

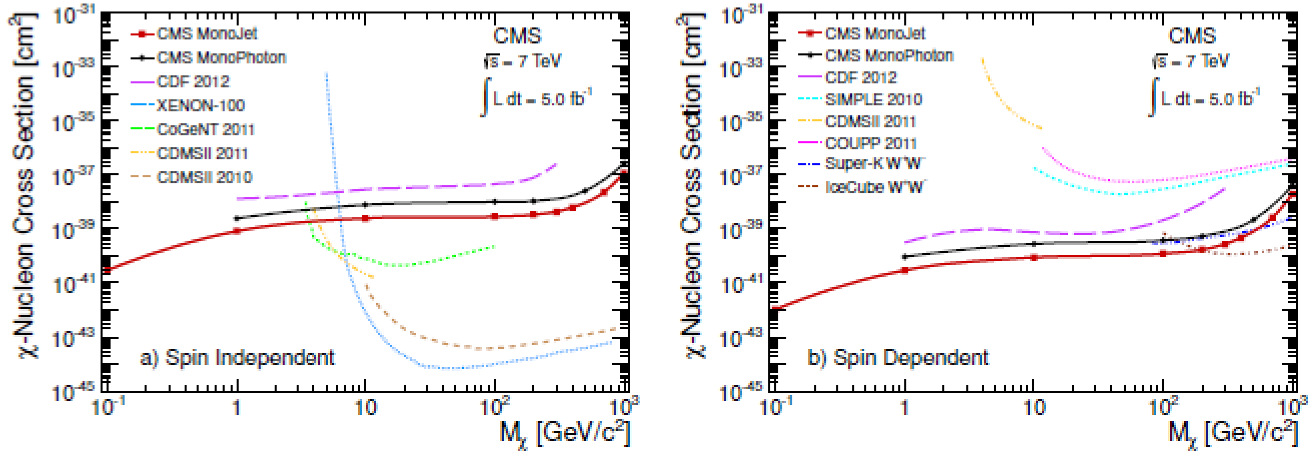
"Ambulance chasing OK,
as long as the **patient is not dead**"

Anyways, dark matter complementarity is the way to go, and VANILLA WIMPs will be put to the test in the next decade

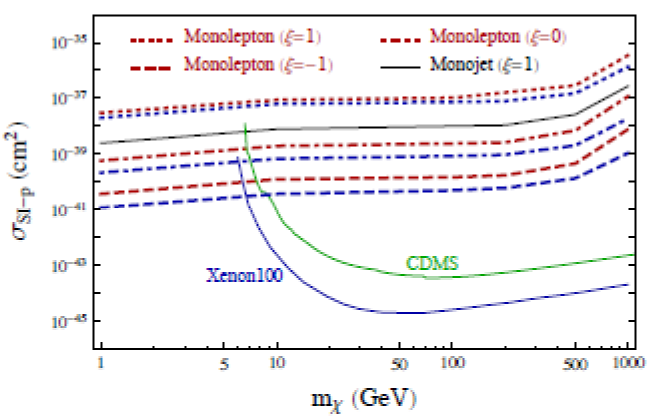
Thank you

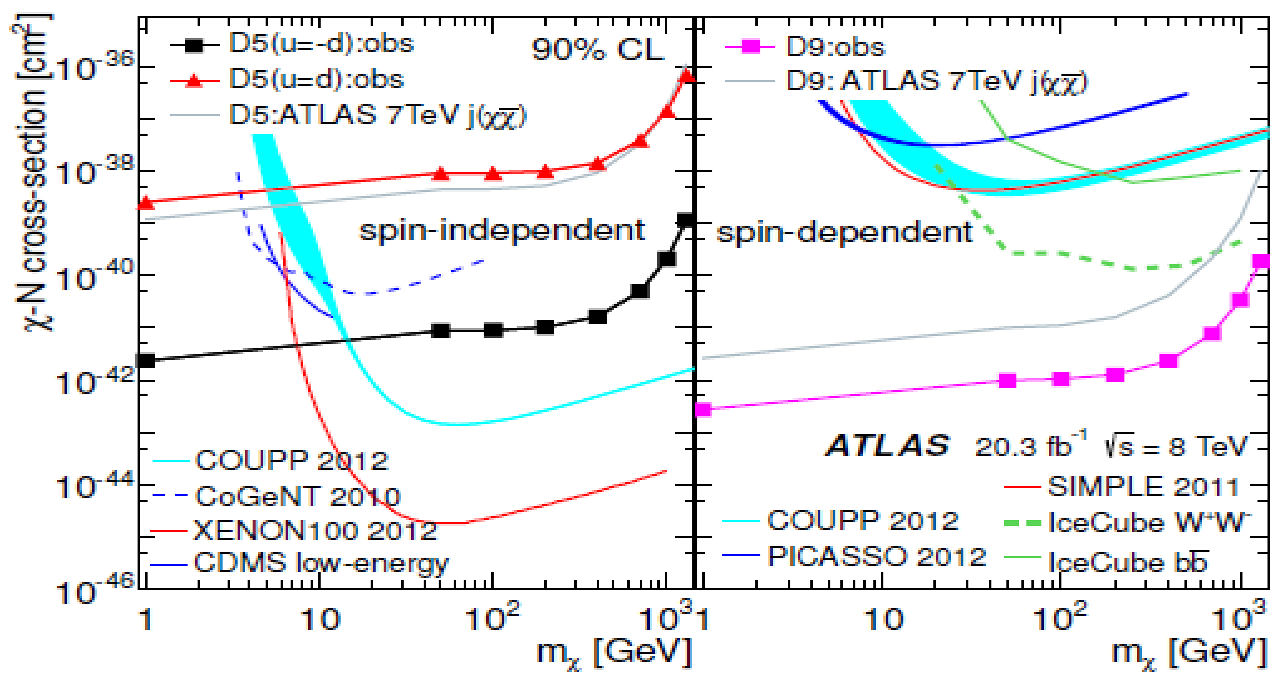
Mono-X Searches

Mono-photon

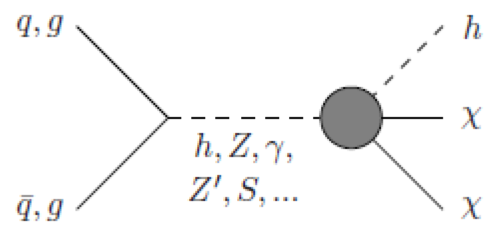


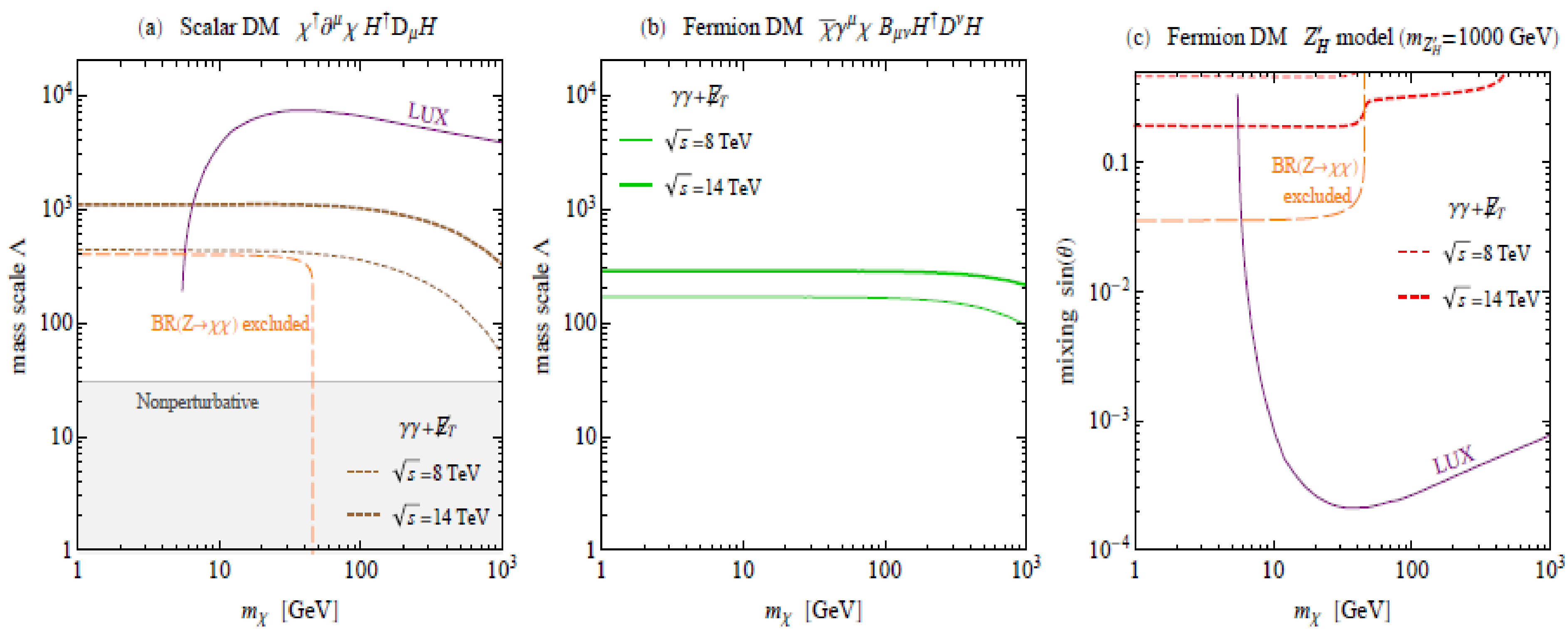
Mono-Z/W





Mono-H





Michael Mulhearn,Daniel Whiteson et al, arxiv:1312.2592