Constraints on Majorana Dark Matter from LHC and IceCube

[based on arXiv:1509.07867; JH, Michael Krämer, Mathieu Pellen, Christopher Wiebusch]

Jan Heisig (RWTH Aachen University)

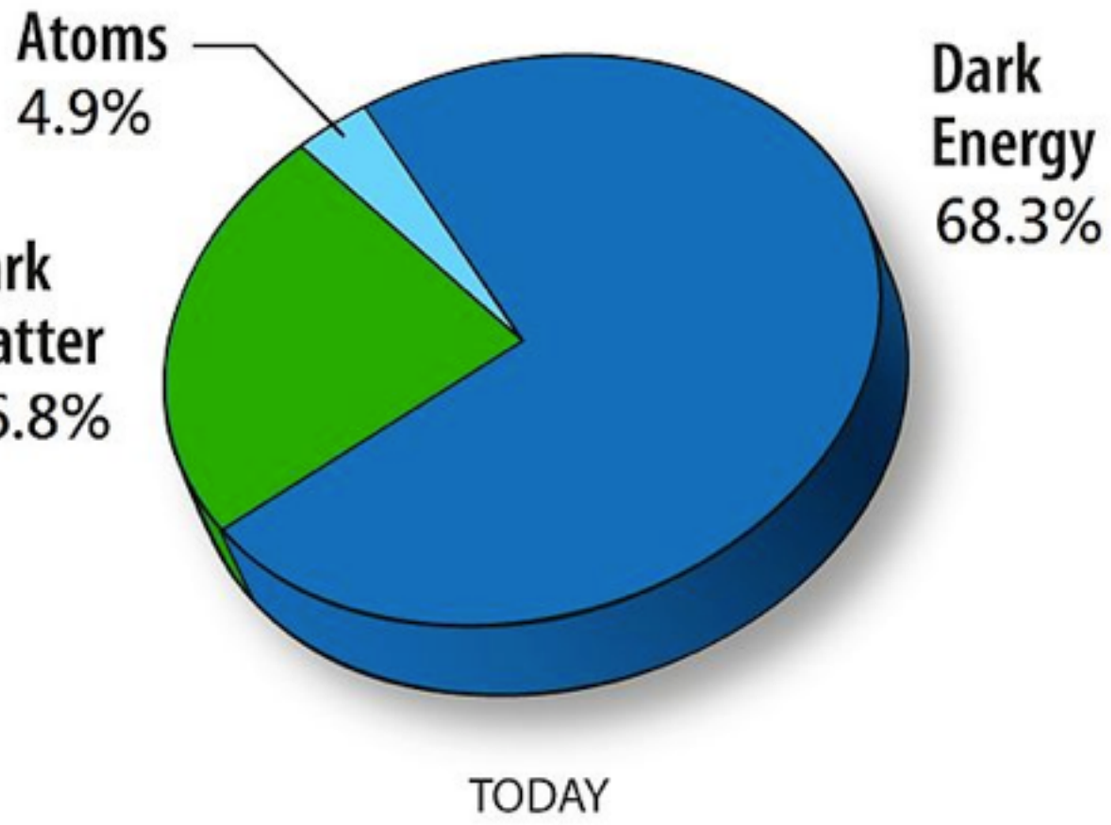
Institute for Theoretical Particle Physics and Cosmology | RWTH AACHEN UNIVERSITY

Aachen Bonn Heidelberg Mainz

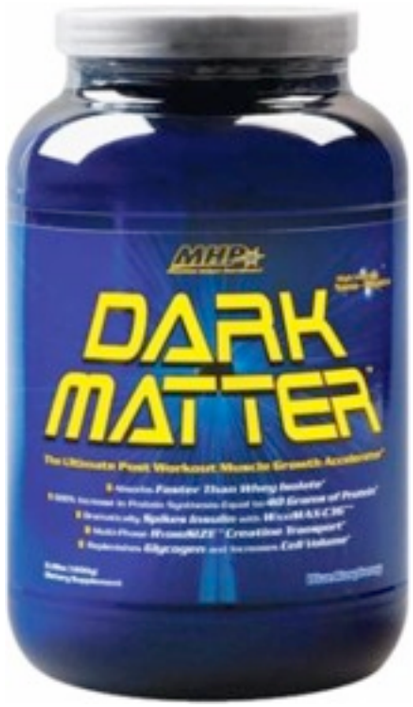
Meeting of Research Unit
New Physics at the LHC
Bonn, October 28th, 2015

Dark Matter → ?

Energy density of the universe:



Dark Matter → WIMP



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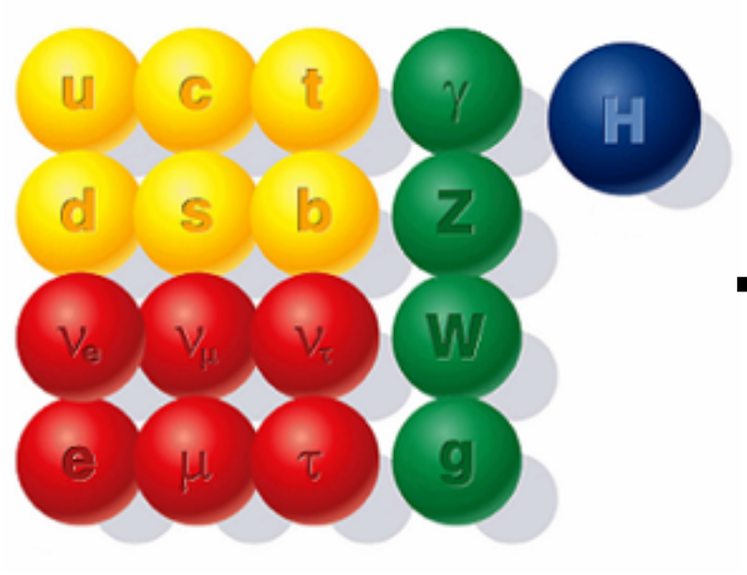

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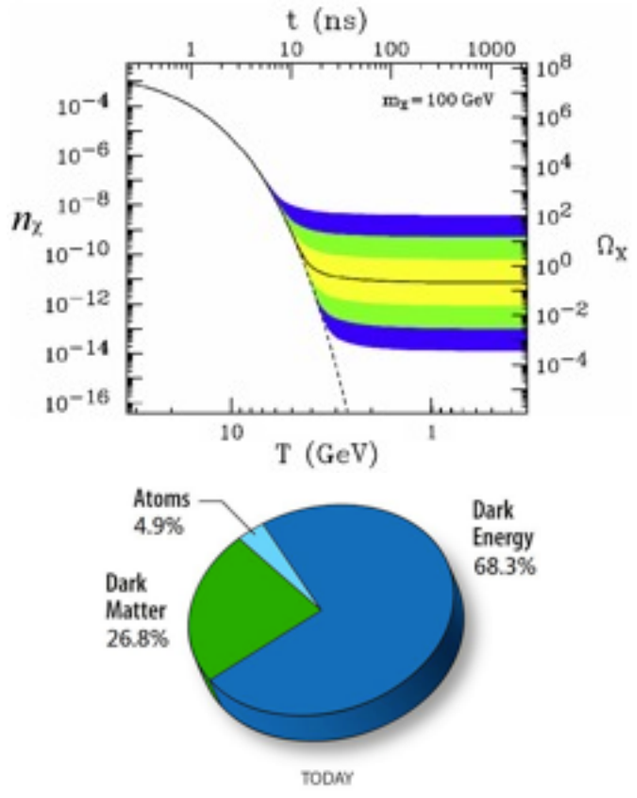

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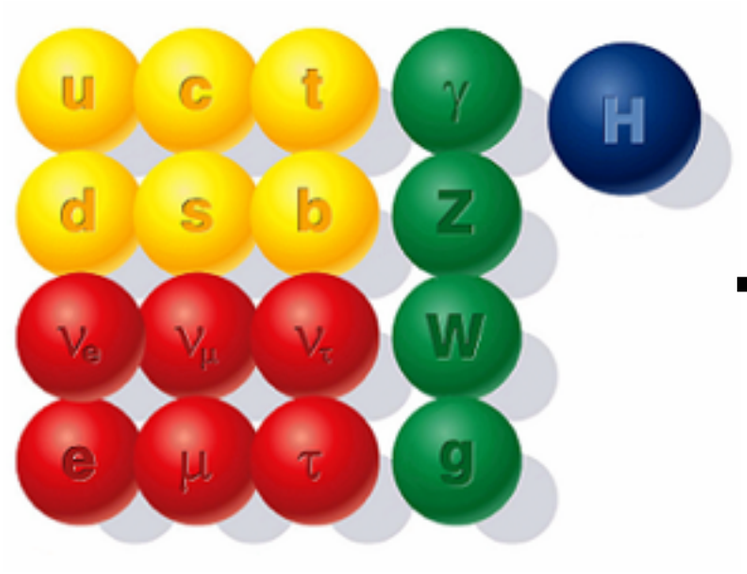

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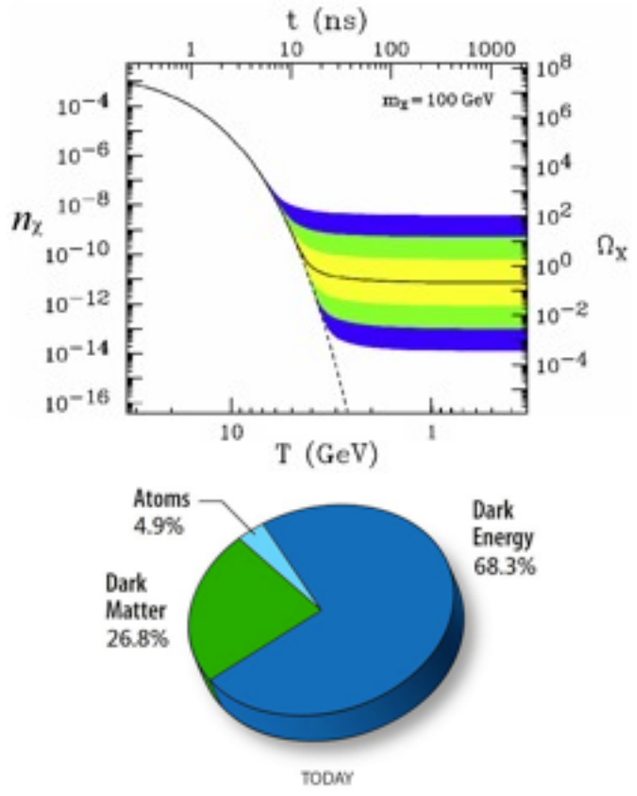

Pheno description

- Effective Operators
- Simplified Models

Probe

- Direct detection experiments
- Indirect detection (IceCube)
- Thermal relic density
- DM production@LHC

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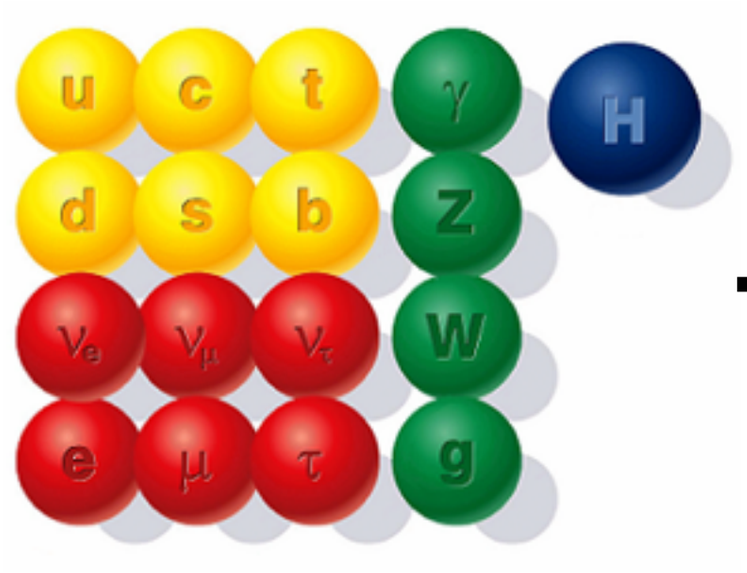

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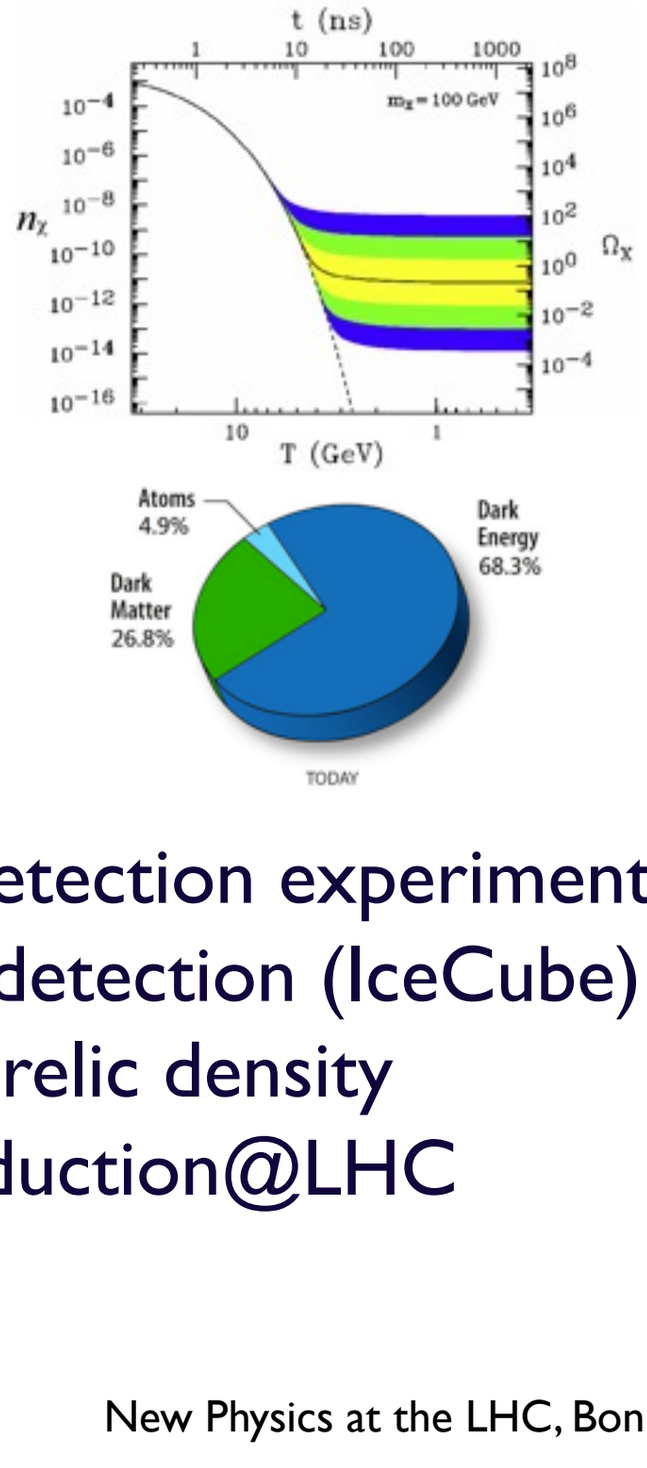

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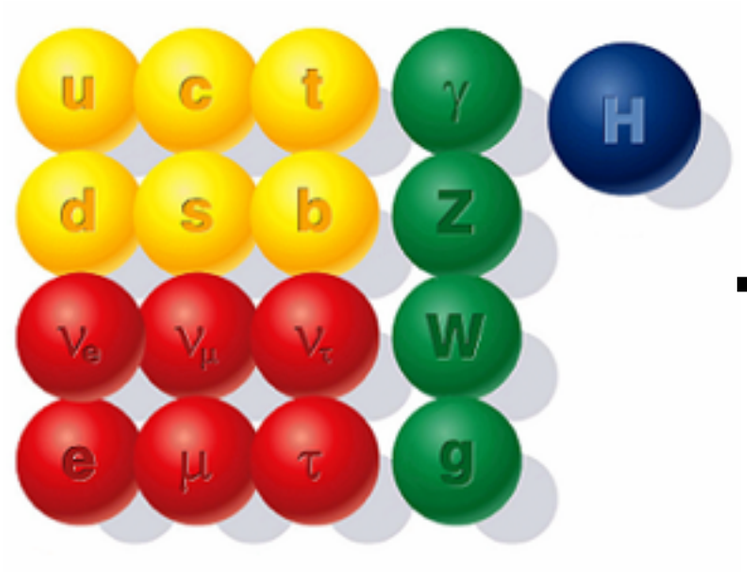

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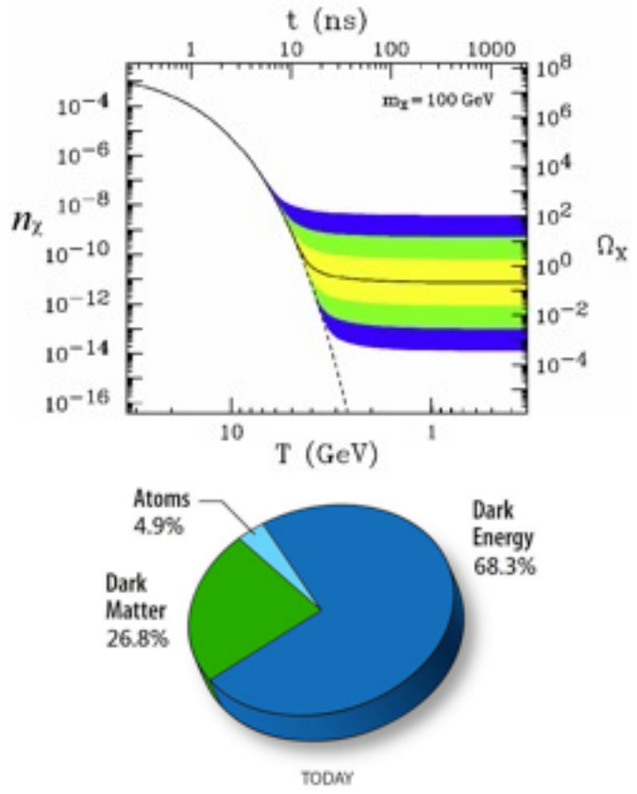

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Simplified Models for Dark Matter

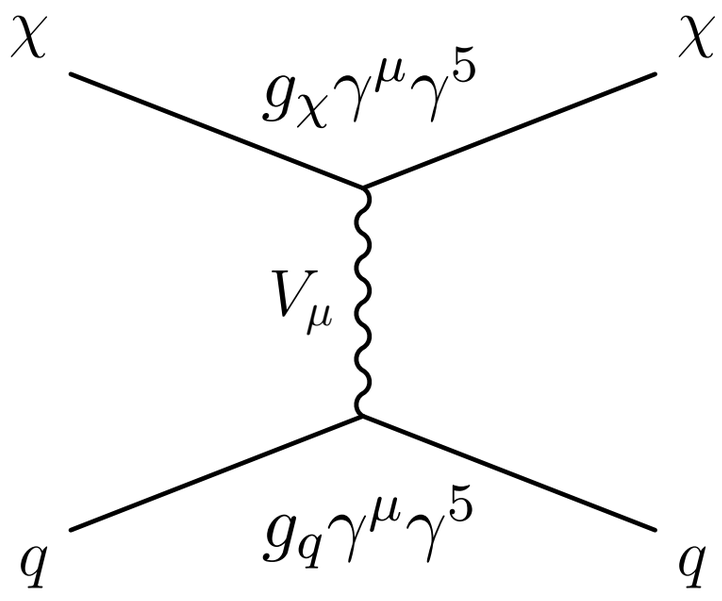
Busoni, De Simone, Morgante, Riotto: 1307.2253
Buchmueller, Dolan, McCabe: 1308.6799
Busoni,De Simone, Jacques, Morgante, Riotto: 1405.3101
Buchmueller, Dolan, Malik, McCabe: 1407.8257
Harris, Khoze, Spannowsky, Williams: 1411.0535
Chala, Kahlhoefer, McCullough, Nardini, Schmidt-Hoberg: 1503.05916
Backović, Krämer, Maltoni, Martini, Mawatari, Pellen: 1508.05327
Baker, Brod, Hedri, Kaminska, Kopp, Liu, Thamm, Vries, Wang, Yu, Zurita: 1510.03434
...

This Talk

- Explore complementarity new Limits from LHC and IceCube
- Discuss EFT↔ Simplified Model

A "direct-detection-phobic" model

- Model where LHC and IceCube are competitive
  → No spin-independent WIMP-nucleon scattering



- Vector-boson *s*-channel messenger
- Majorana DM
- Axial couplings to quarks and DM (no couplings to leptons)
- Four parameters: M_V, m_χ, g_q, g_χ

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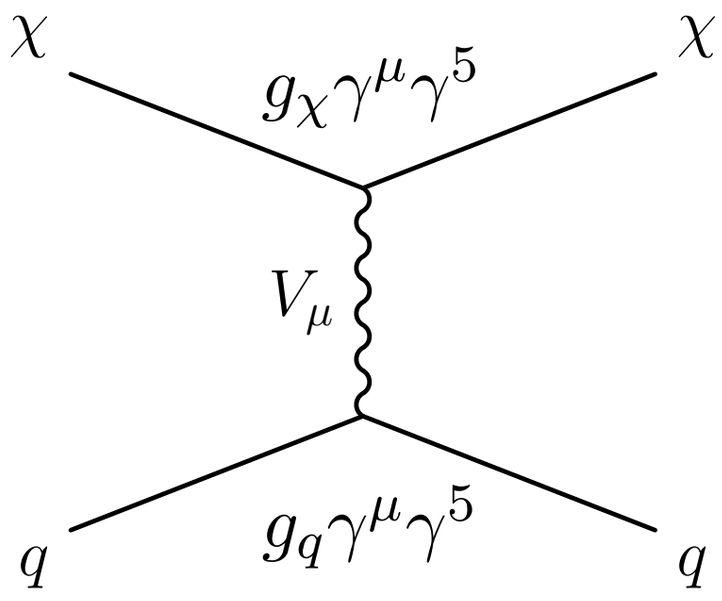

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- Here: choose $M_V, m_\chi, (g_q g_\chi), \Gamma_V$ $\quad (\Rightarrow\ g_q, g_\chi)$

  Note: not all values allowed!

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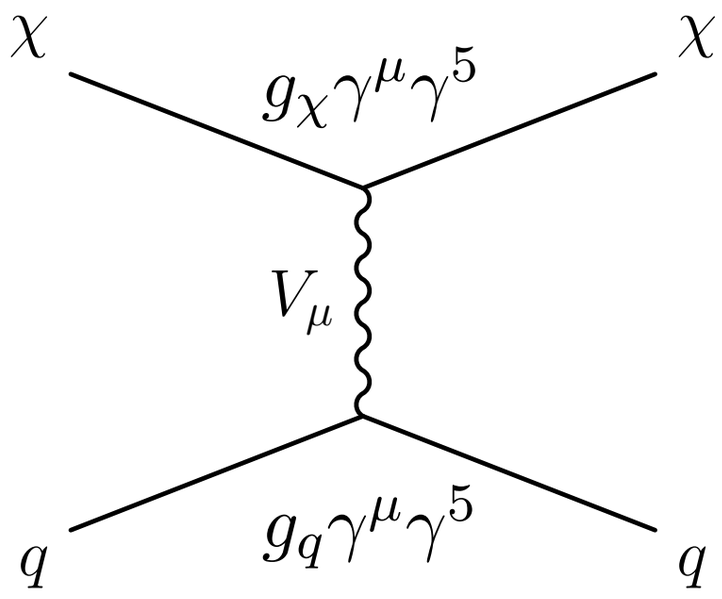

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EFT: $m_\chi, (g_q g_\chi / M_V^2)$

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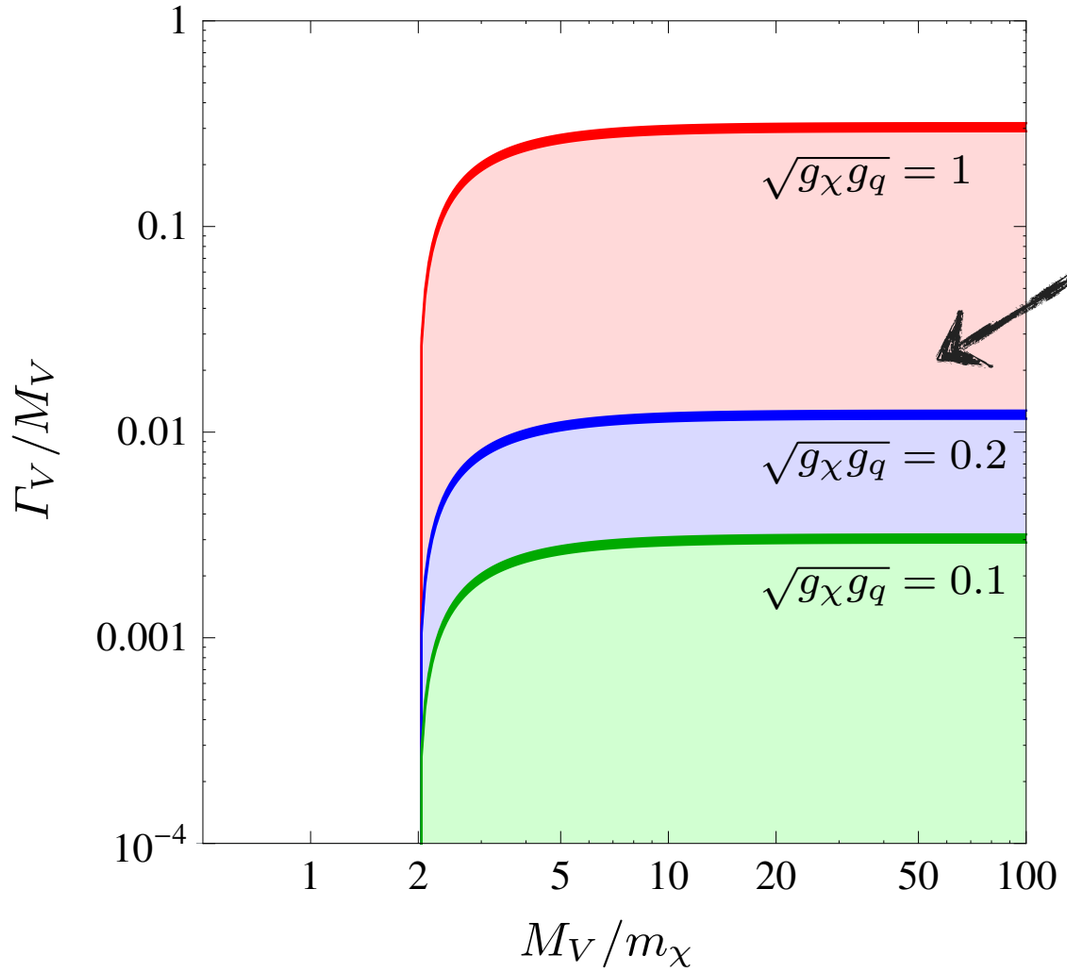

Inaccessible regions

- Here: choose $M_V, m_\chi, (g_q g_\chi), \Gamma_V \quad (\Rightarrow \; g_q, g_\chi)$

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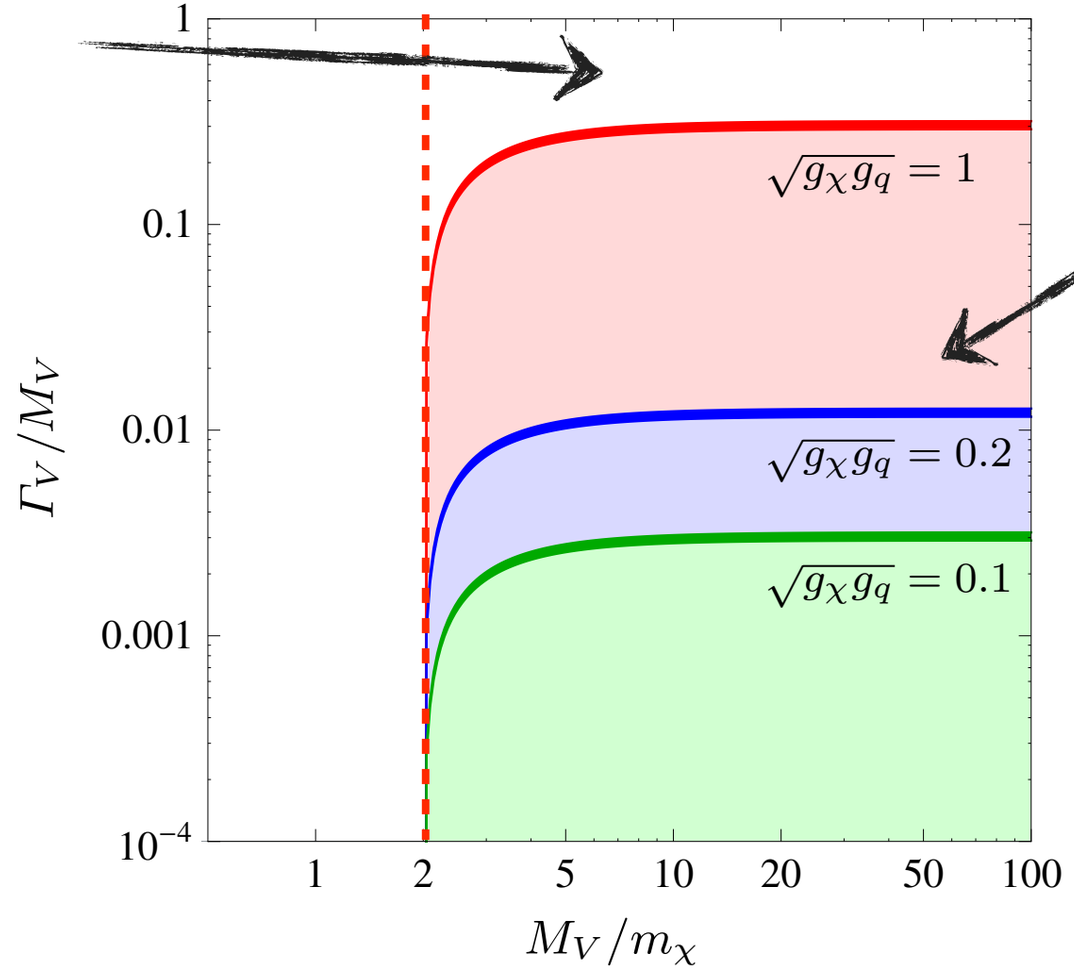
A "direct-detection-phobic" model

Two-fold ambiguity regarding g_q/g_χ

→ Choose smaller g_q/g_χ unless $g_\chi > 4\pi$



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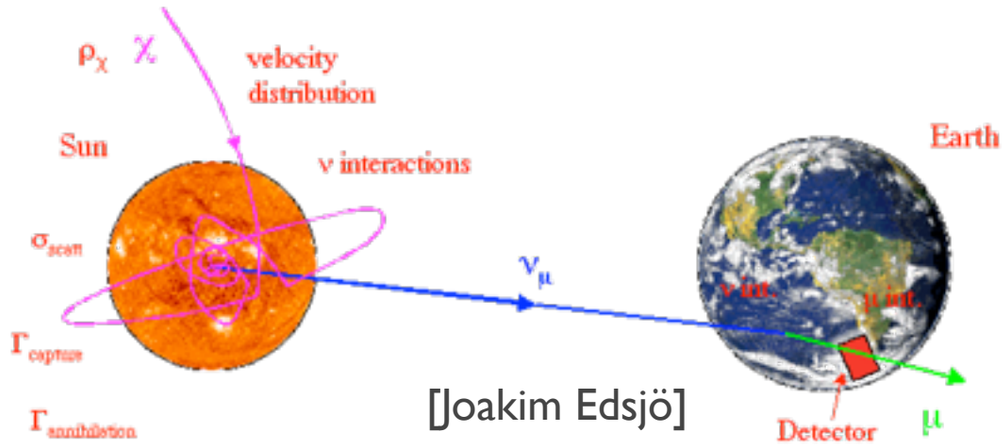
IceCube limits from Dark Matter annihilation in the Sun

Indirect DM detection: annihilation in the Sun

- Sun: Giant DM trap via WIMP-nucleon scattering ("direct detection")
- Sensitive to spin-dependent scattering



[Joakim Edsjö]

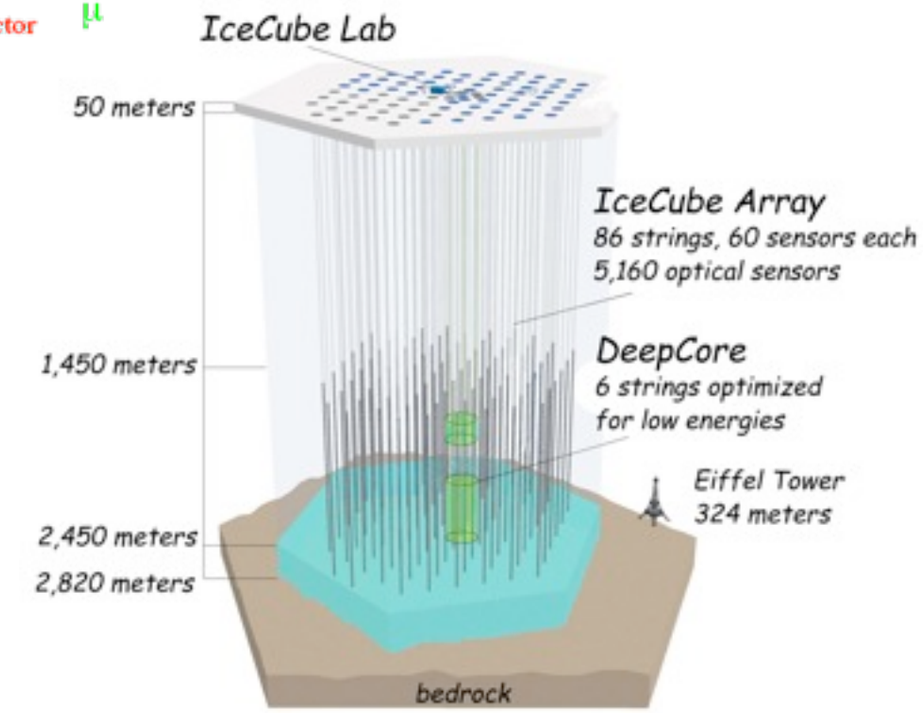
Detect neutrinos from DM annihilation with IceCube

$$\dot{N} = C_\odot - C_\mathrm{A} N^2$$

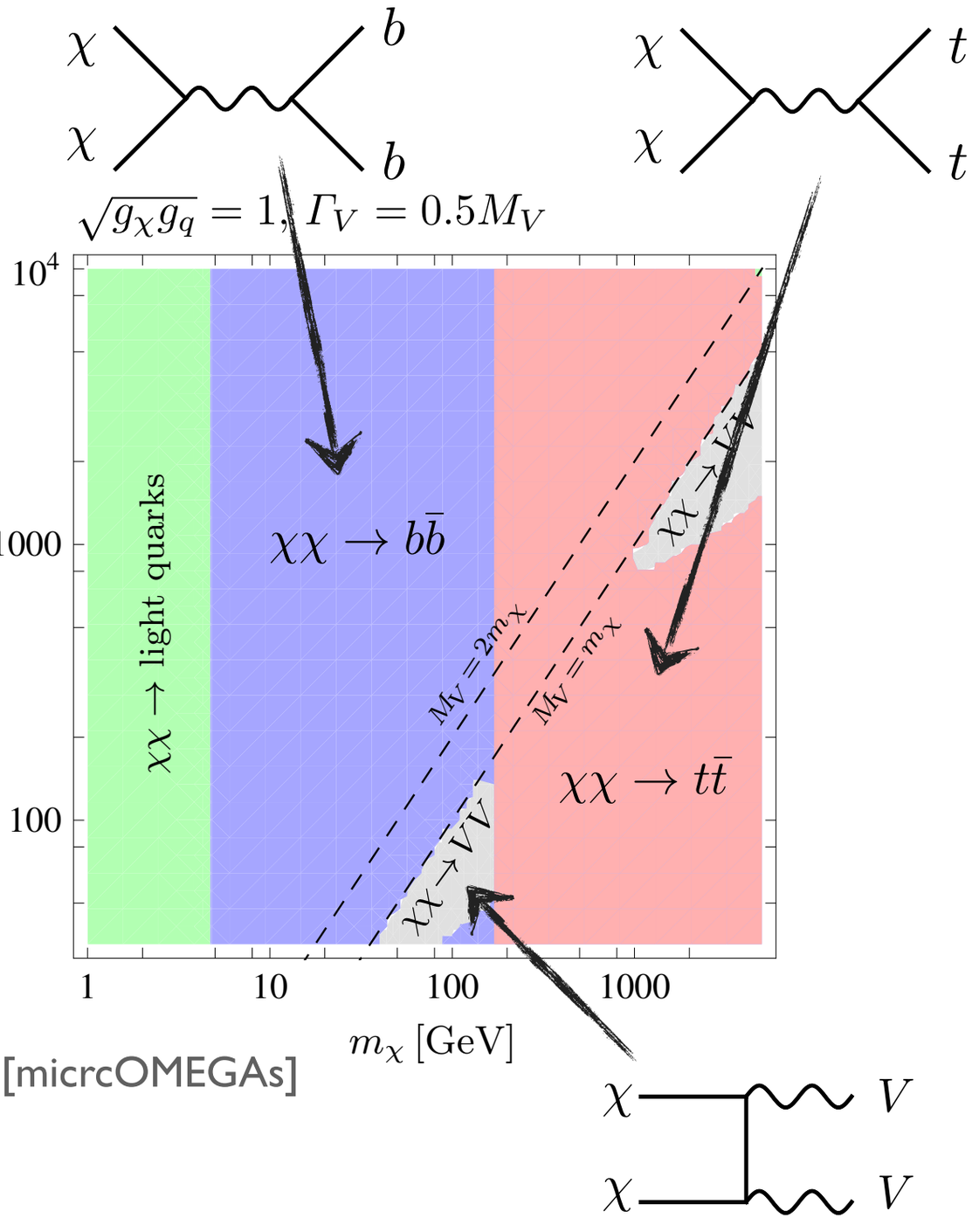
Capture rate: WIMP-nucleon scattering σ_{SD} in the Sun

Annihilation rate: $C_\mathrm{A} N^2 = 2\Gamma_A$

Equilibrium: $C_\odot = C_\mathrm{A} N^2 \propto$ neutrino flux



Dominant annihilation channels



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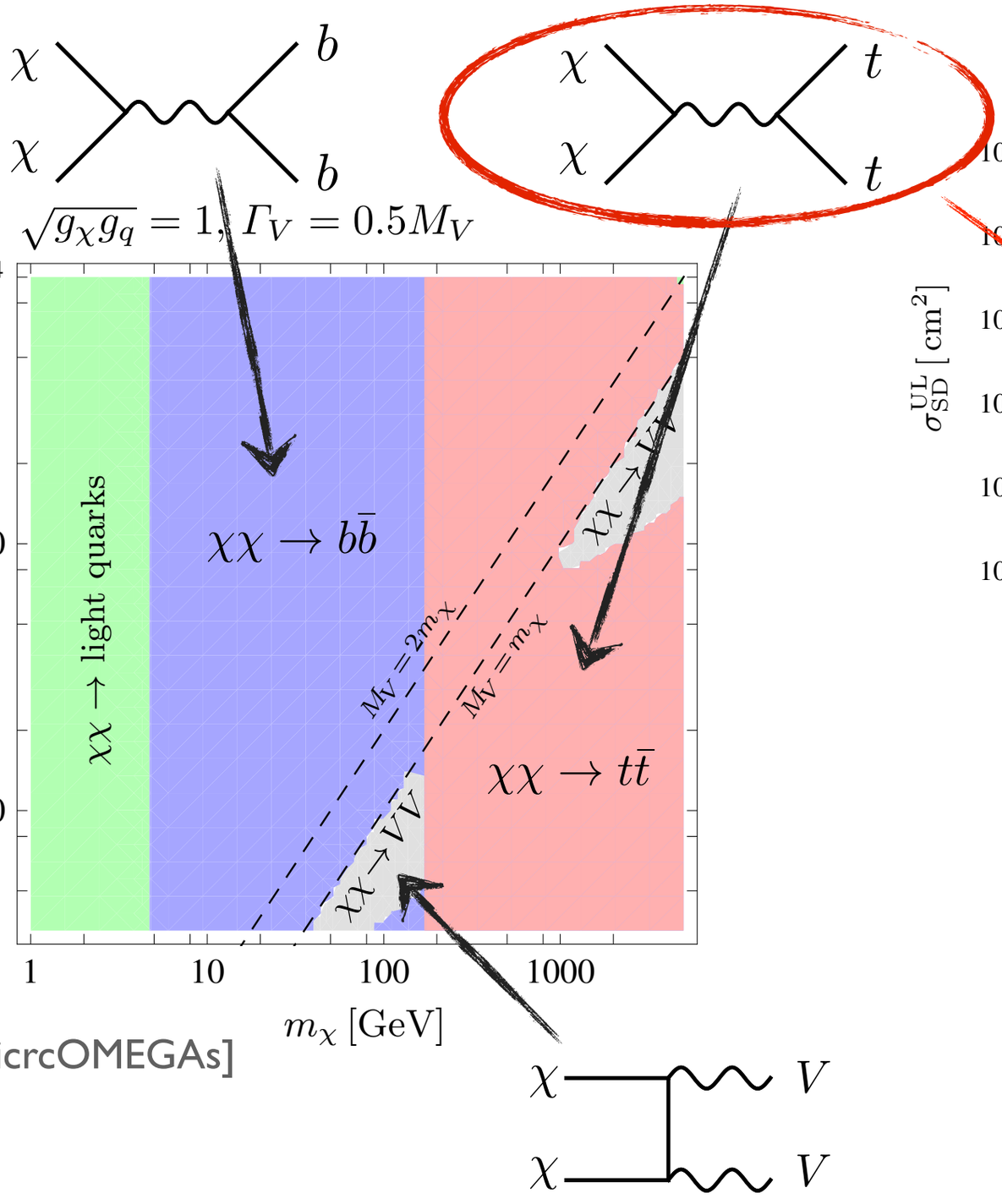
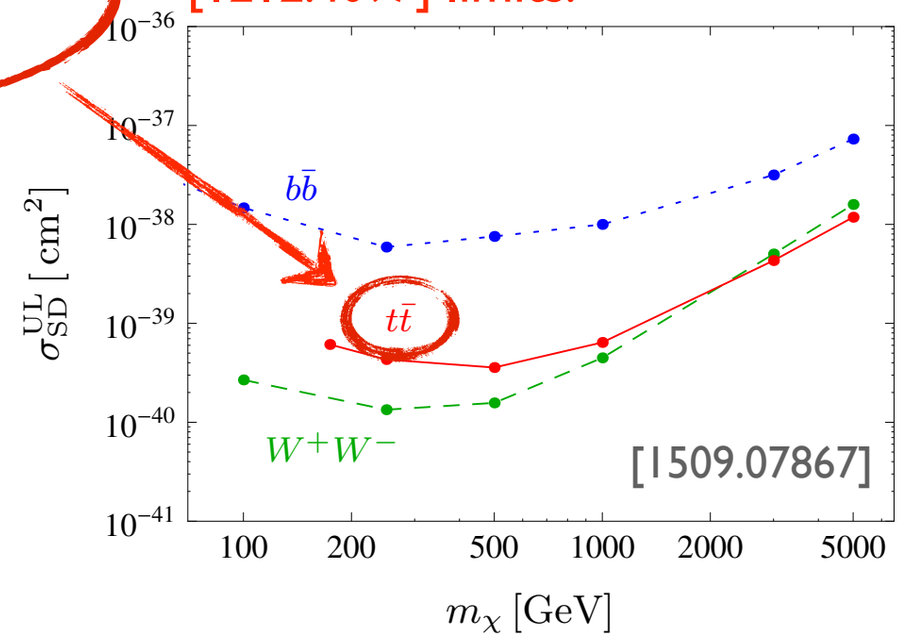


Re-interpretstion of IceCube-79 [1212.4097] limits:



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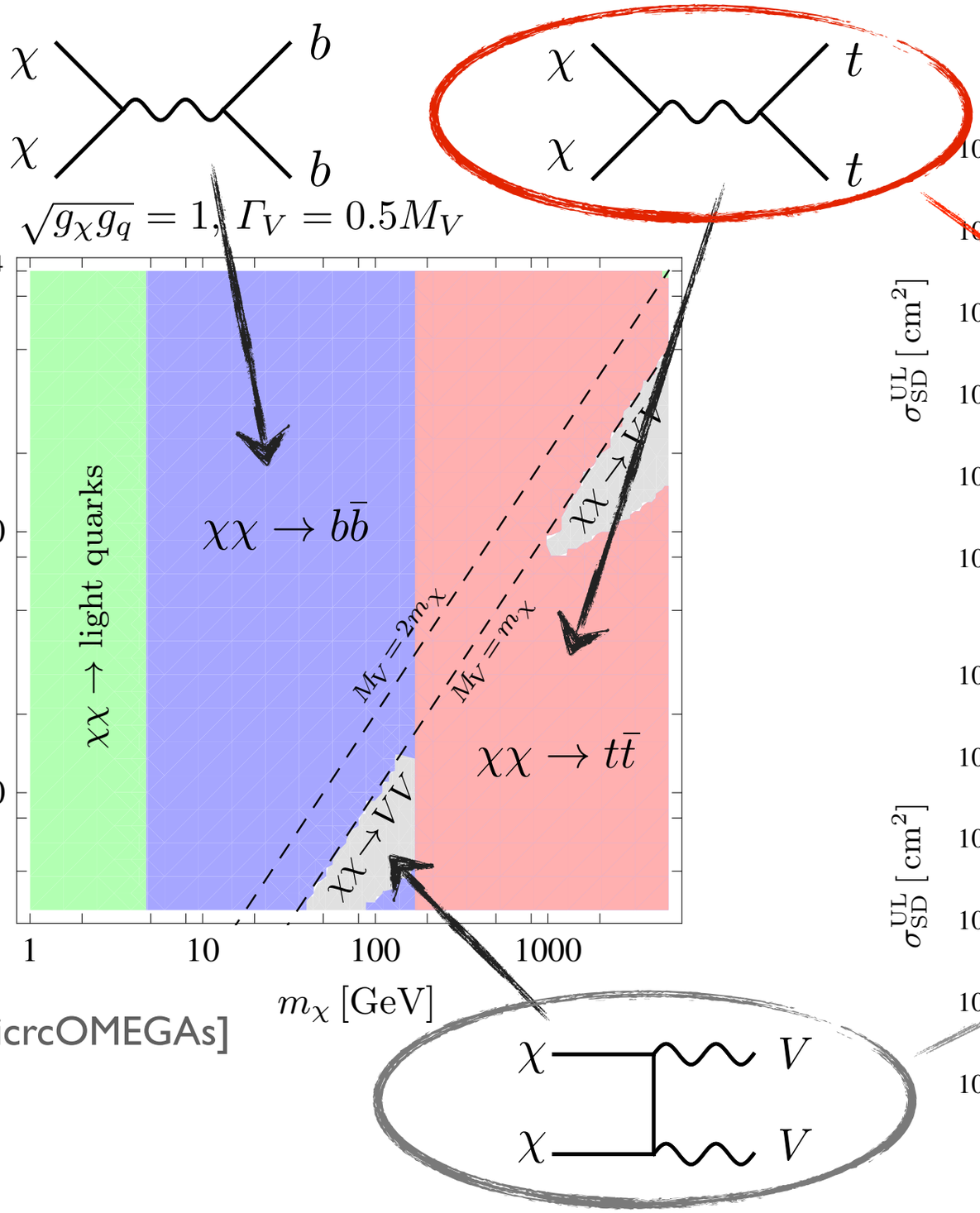

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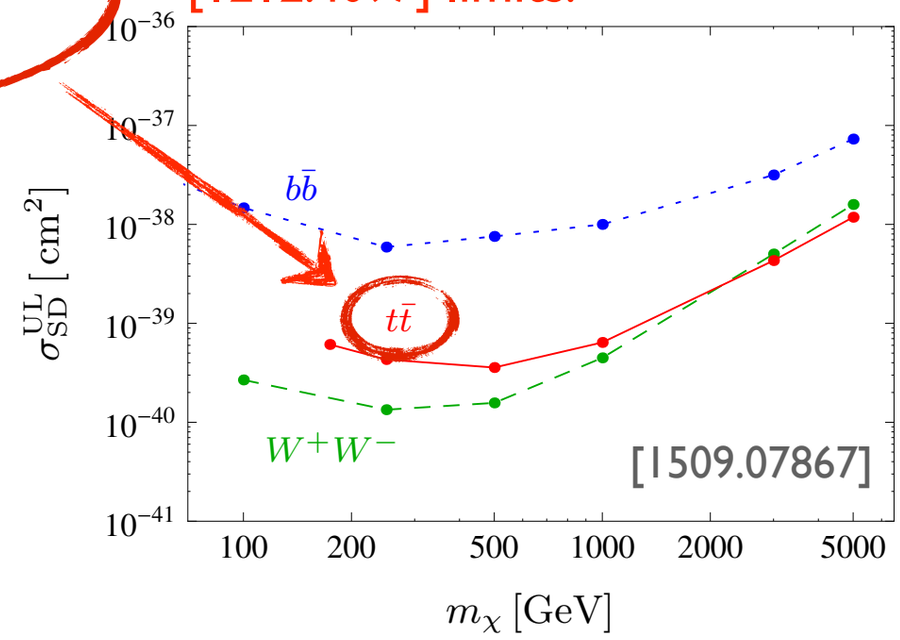
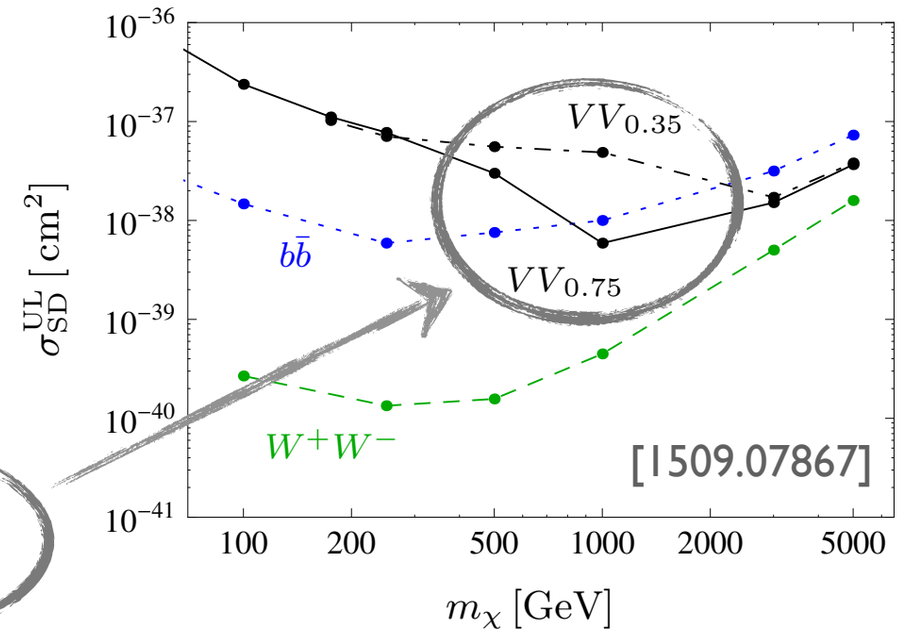
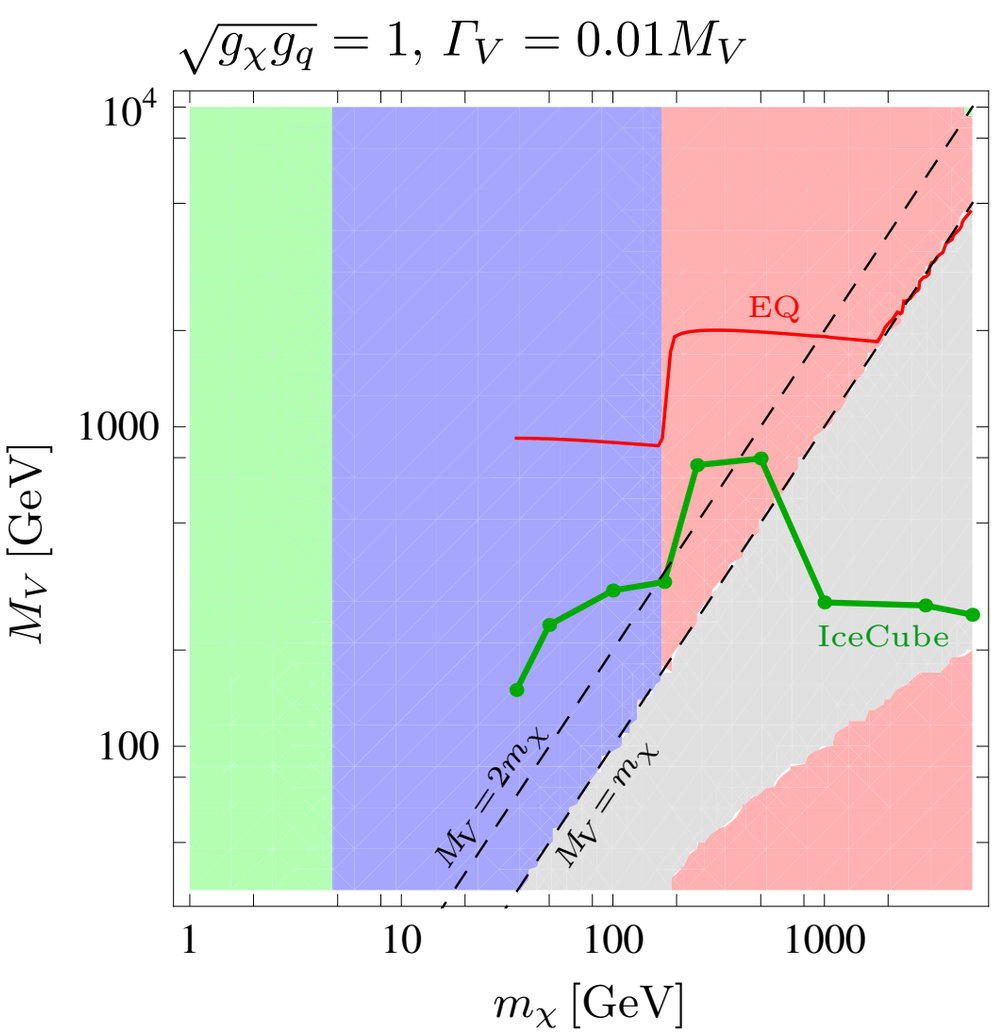
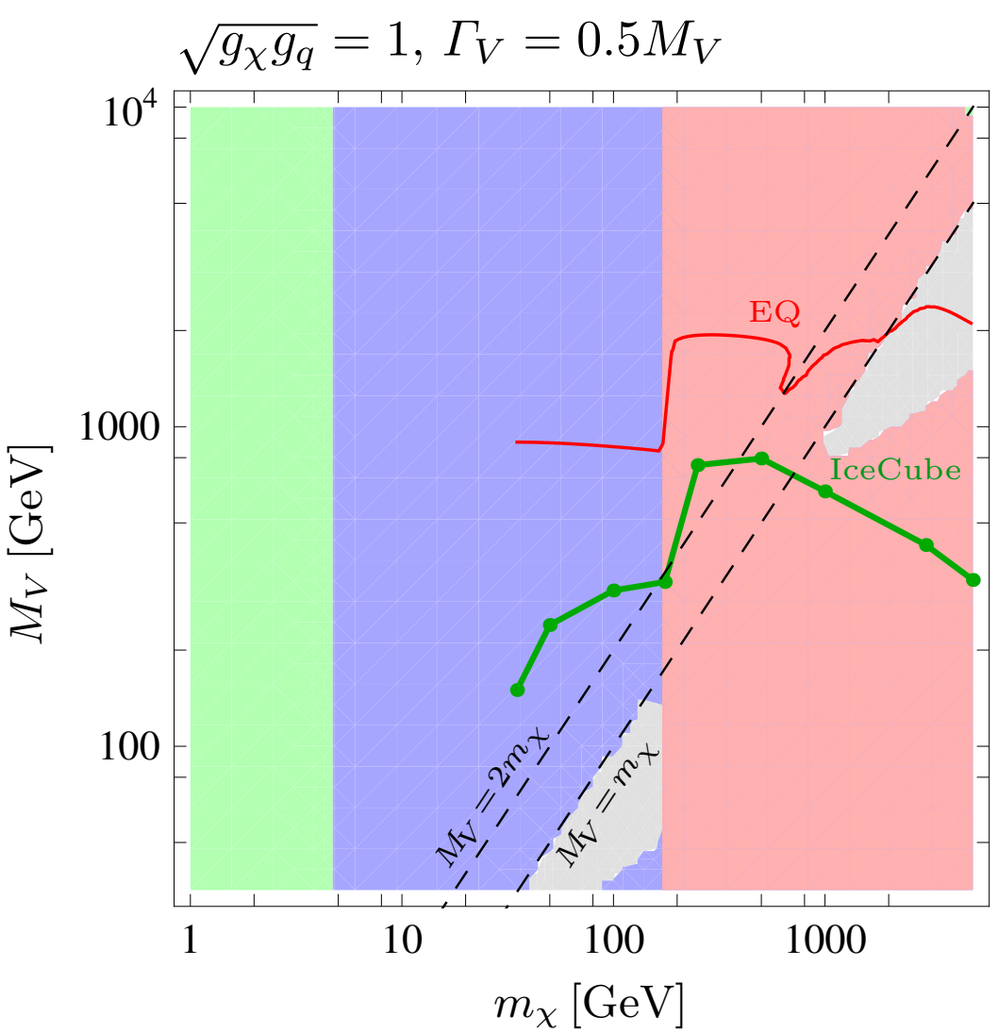




Resulting limits from IceCube

[1509.07867]





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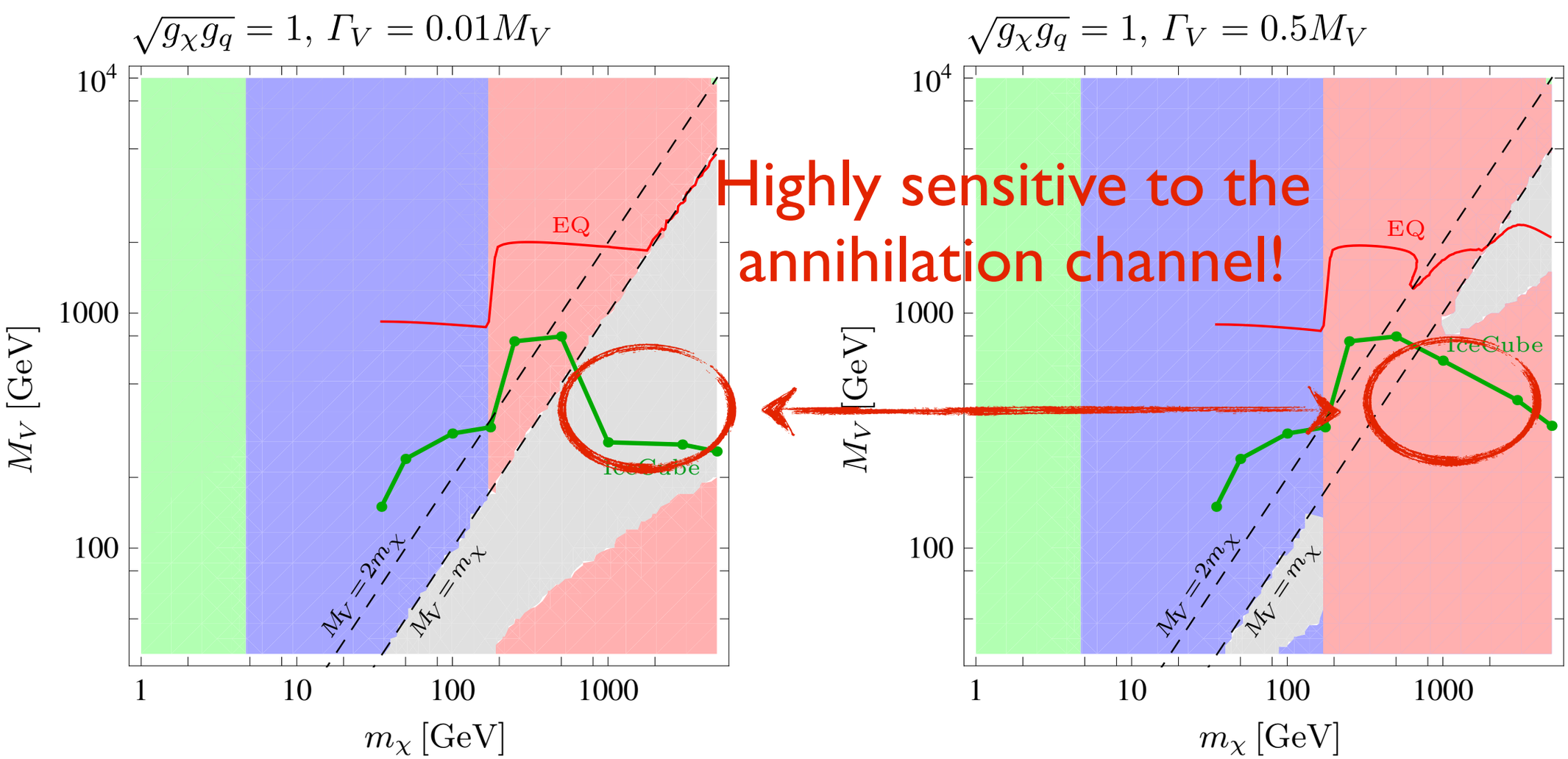
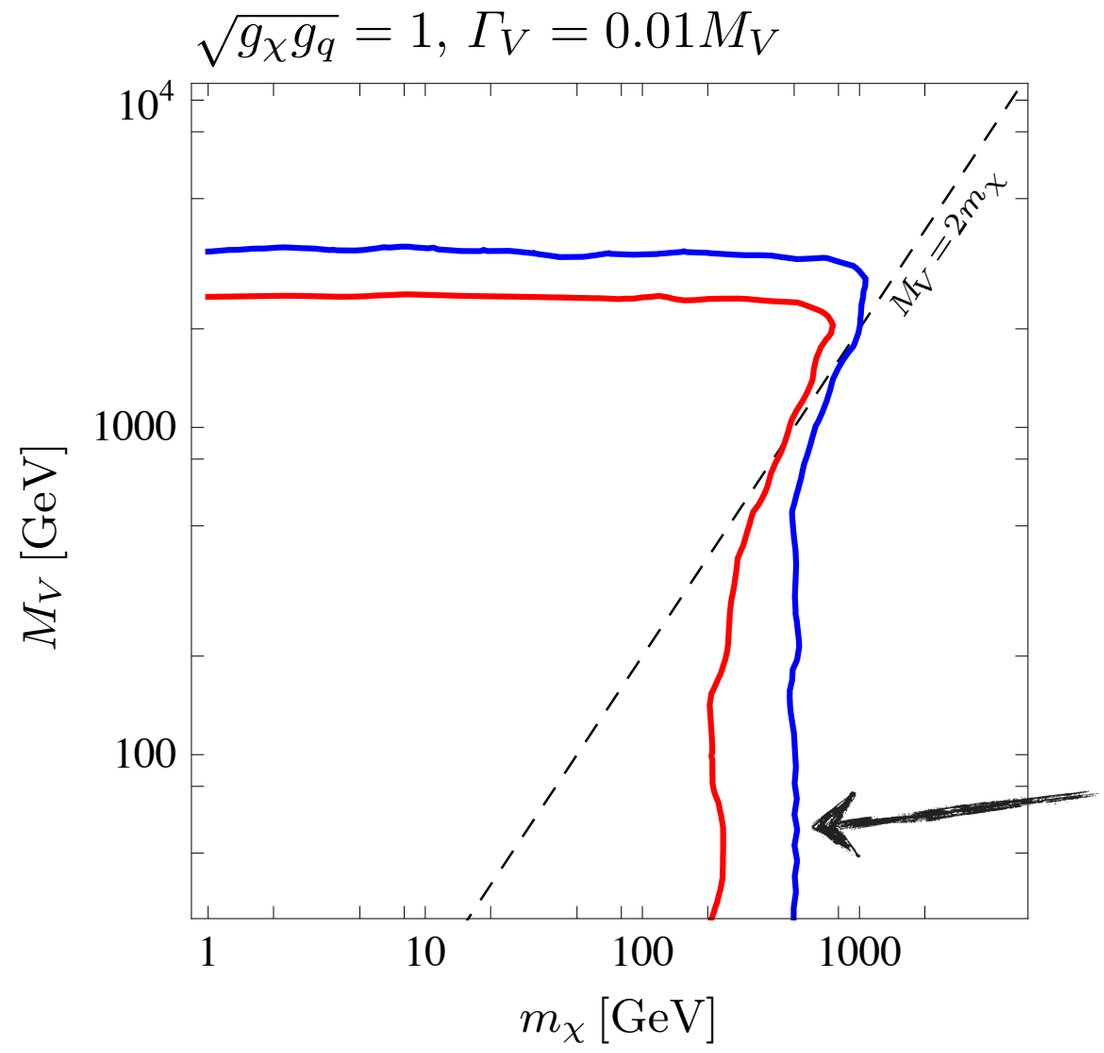


Highly sensitive to the annihilation channel!

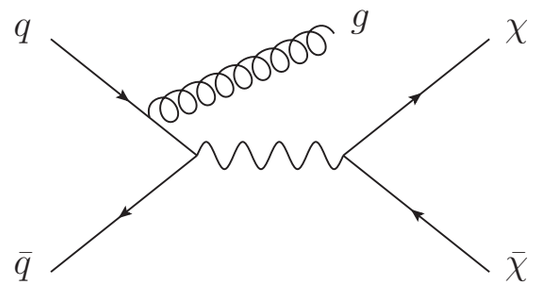
Limits from the LHC

Results from mono-jet searches at 8 TeV LHC

- Re-interpret LHC Run I mono-jet + MET searches [ATLAS:1502.01518, CMS: 1408.3583]
- Simulation: FeyRules/MadGraph/Phythia/Delphes



Simplified Model Limit



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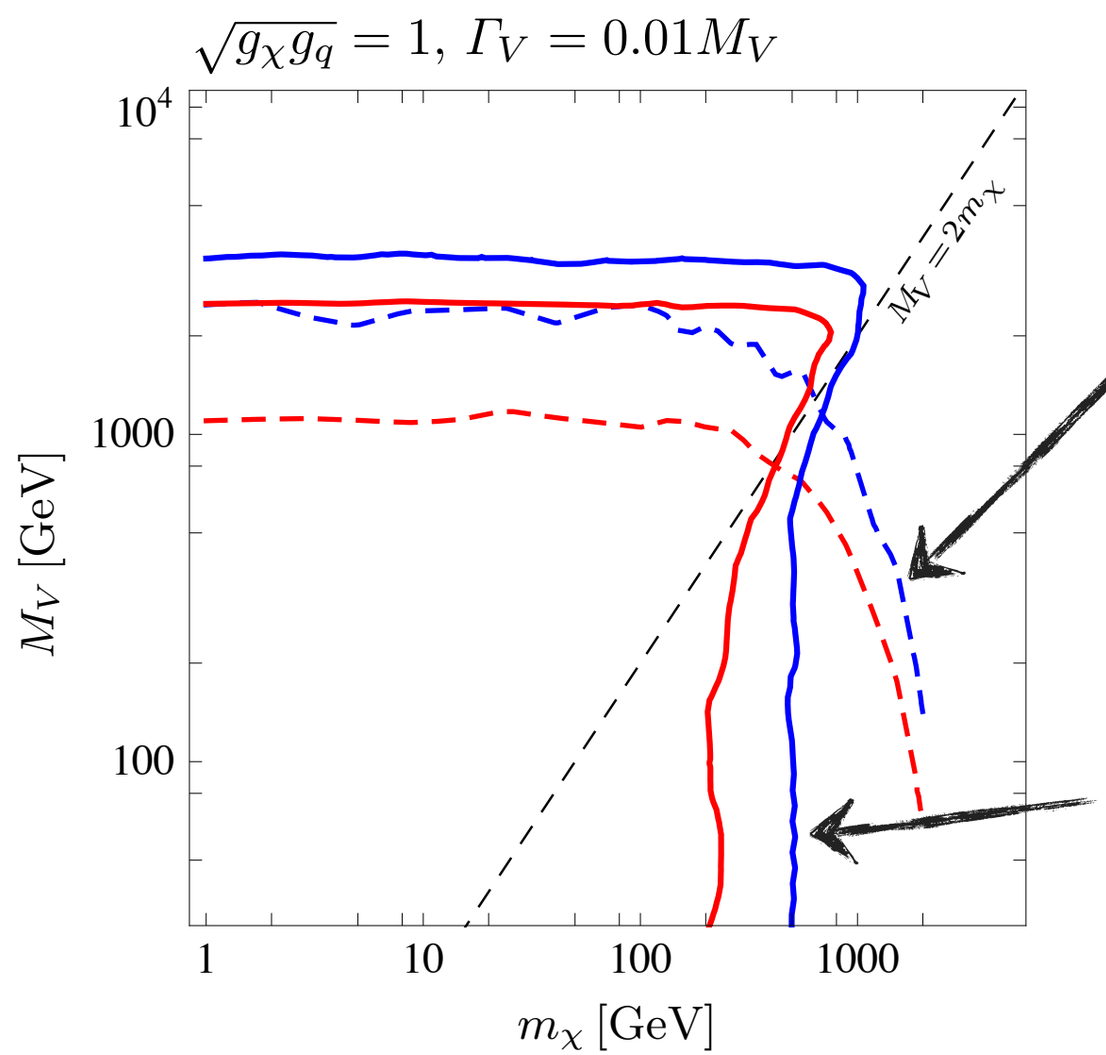

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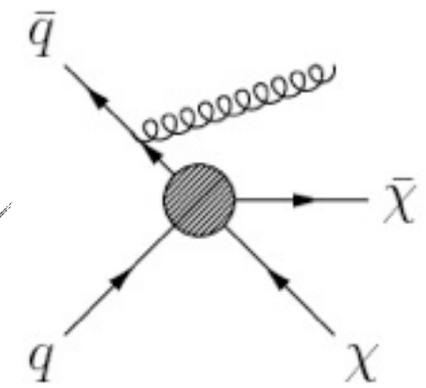

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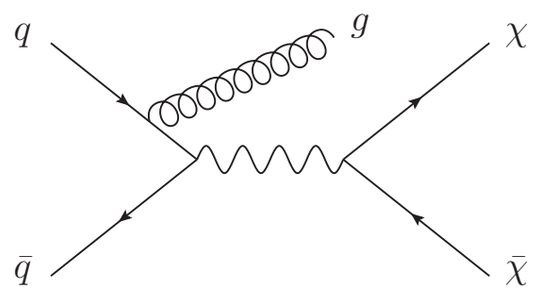

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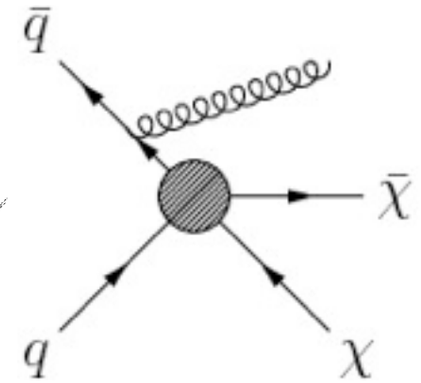
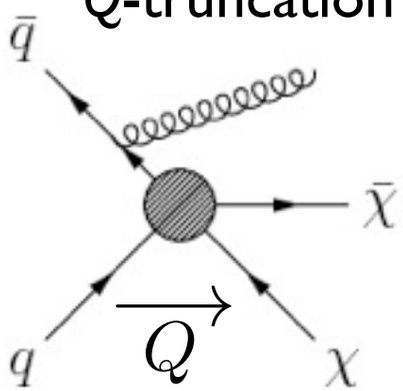
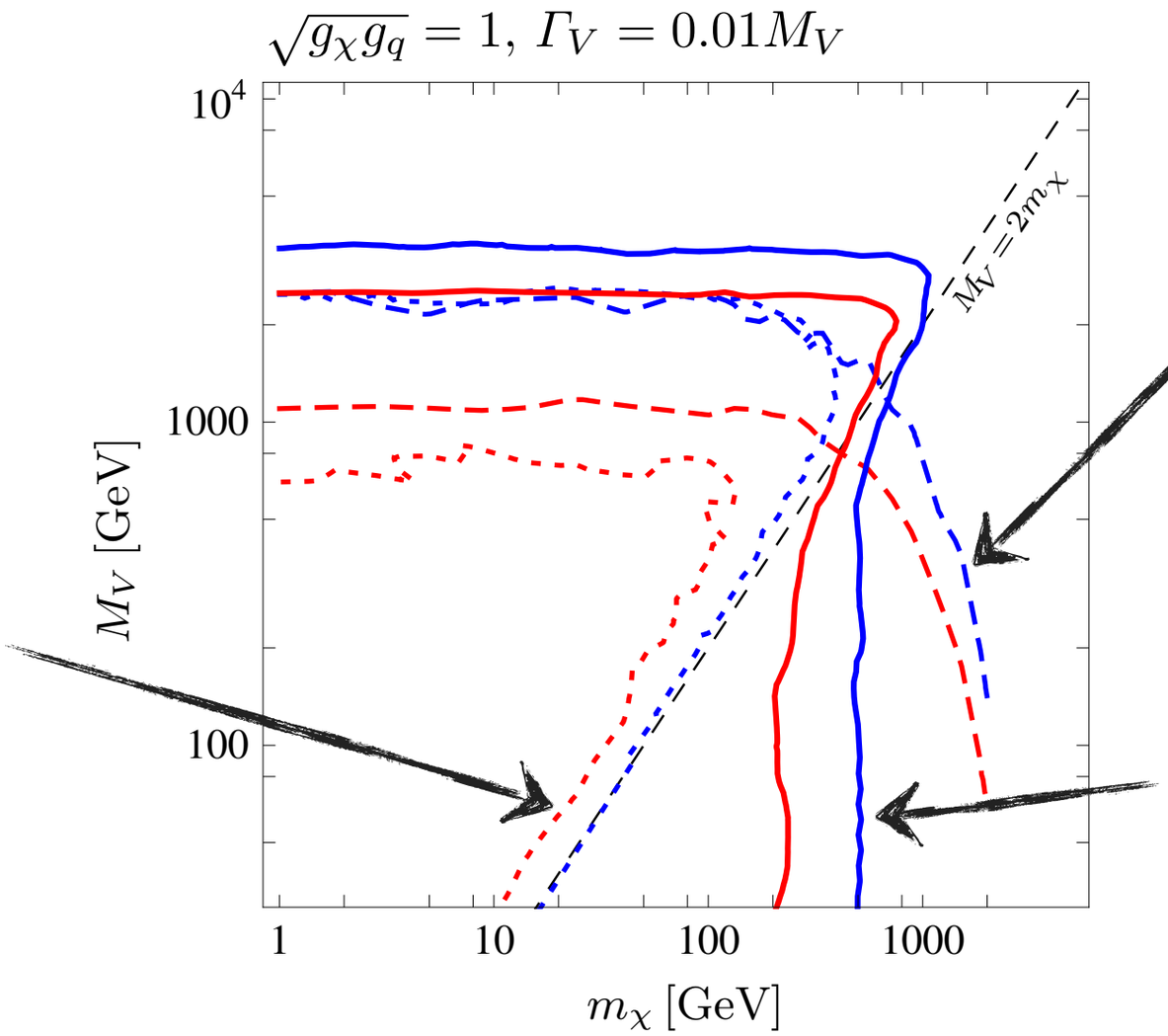


EFT Limit
Q-truncation



$Q^2 < M_V^2$



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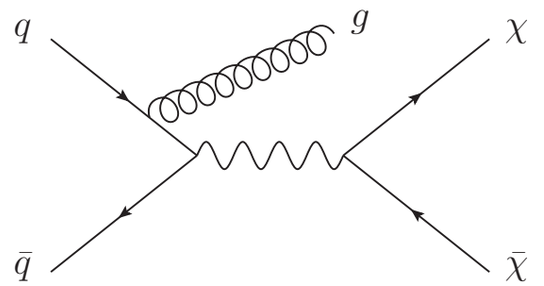

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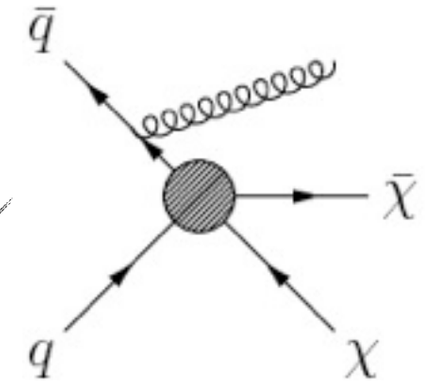

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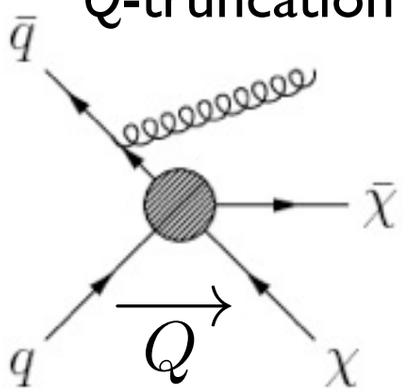

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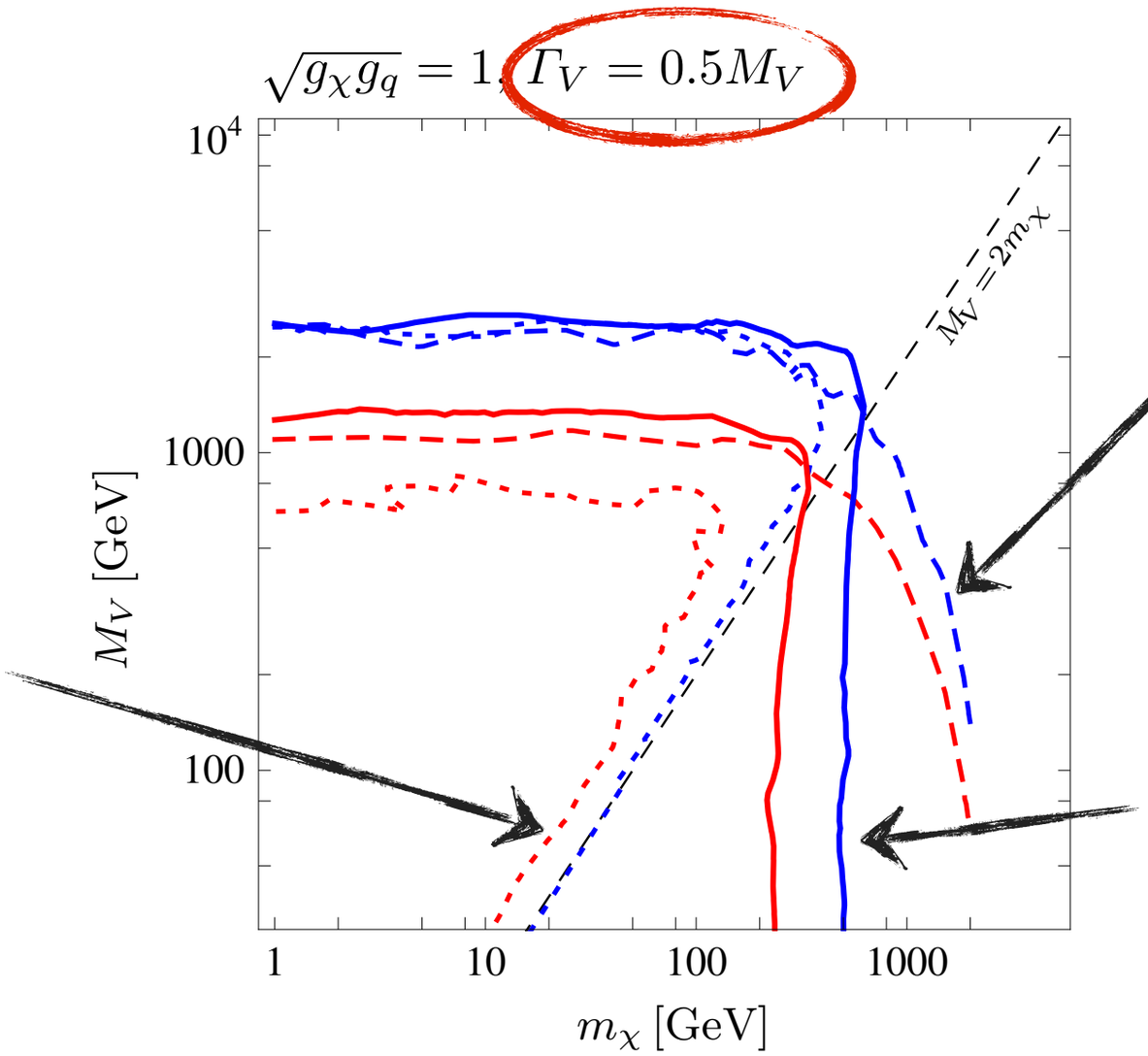

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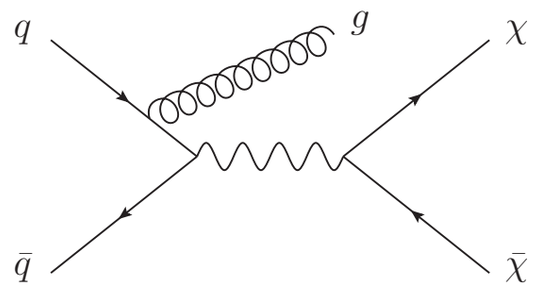
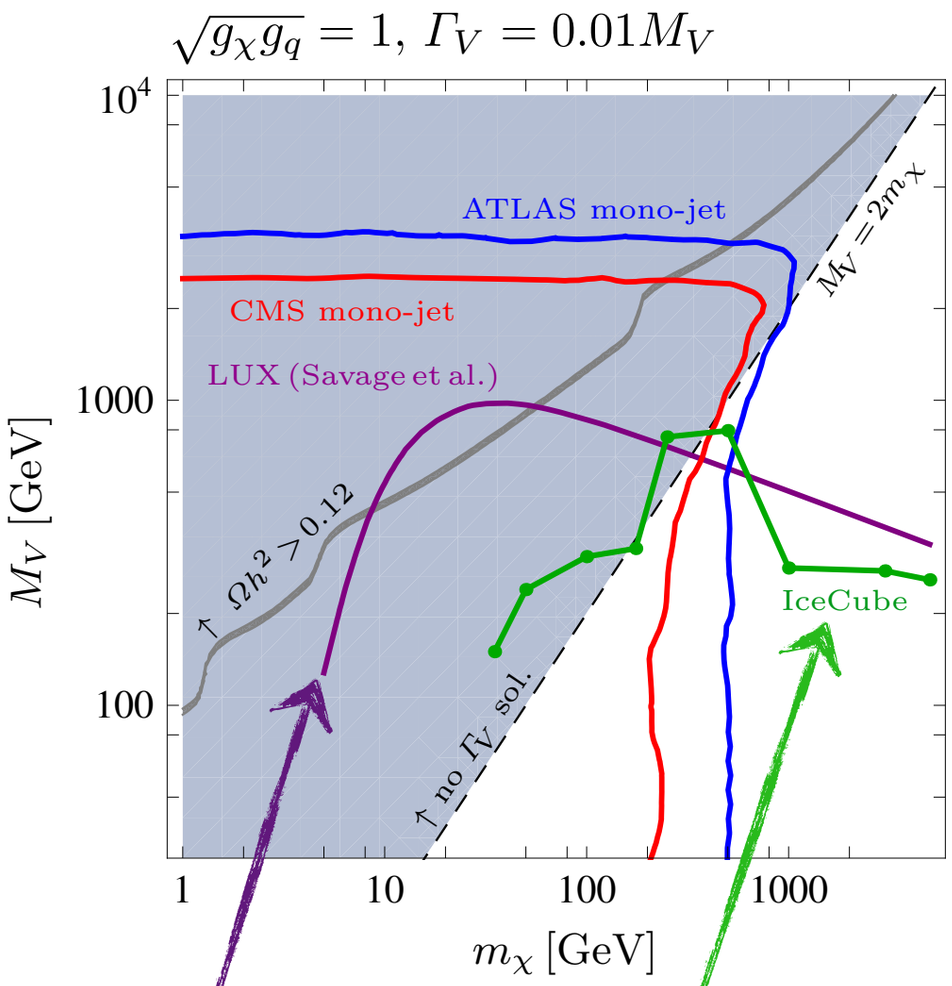
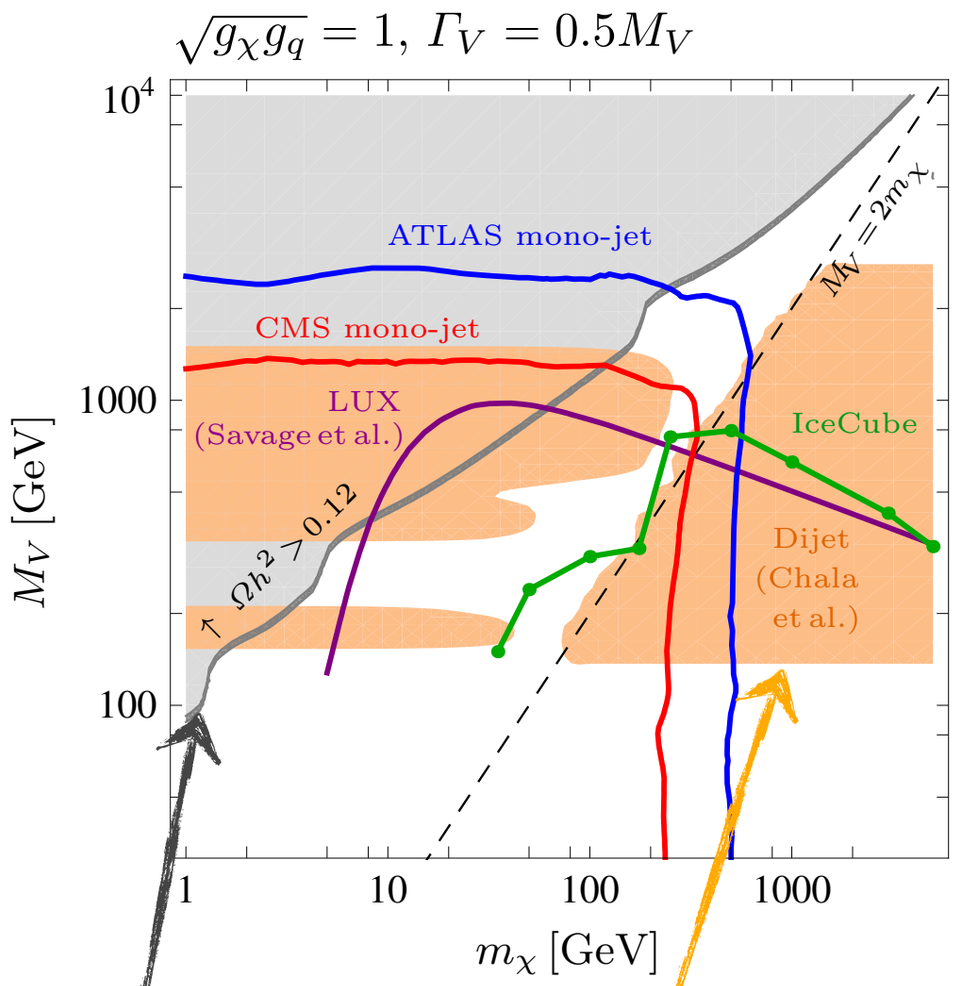


Complementary constraints: Summary Plots

Complementary constraints: Summary

[1509.07867]



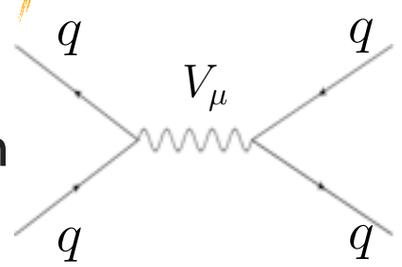


LUX limits from [1502.02667]

IceCube-79 limits

Relic density [micrcOMEGAs] (simpl. model)

LHC Dijet limits from [1503.05916]



Complementary constraints: Summary

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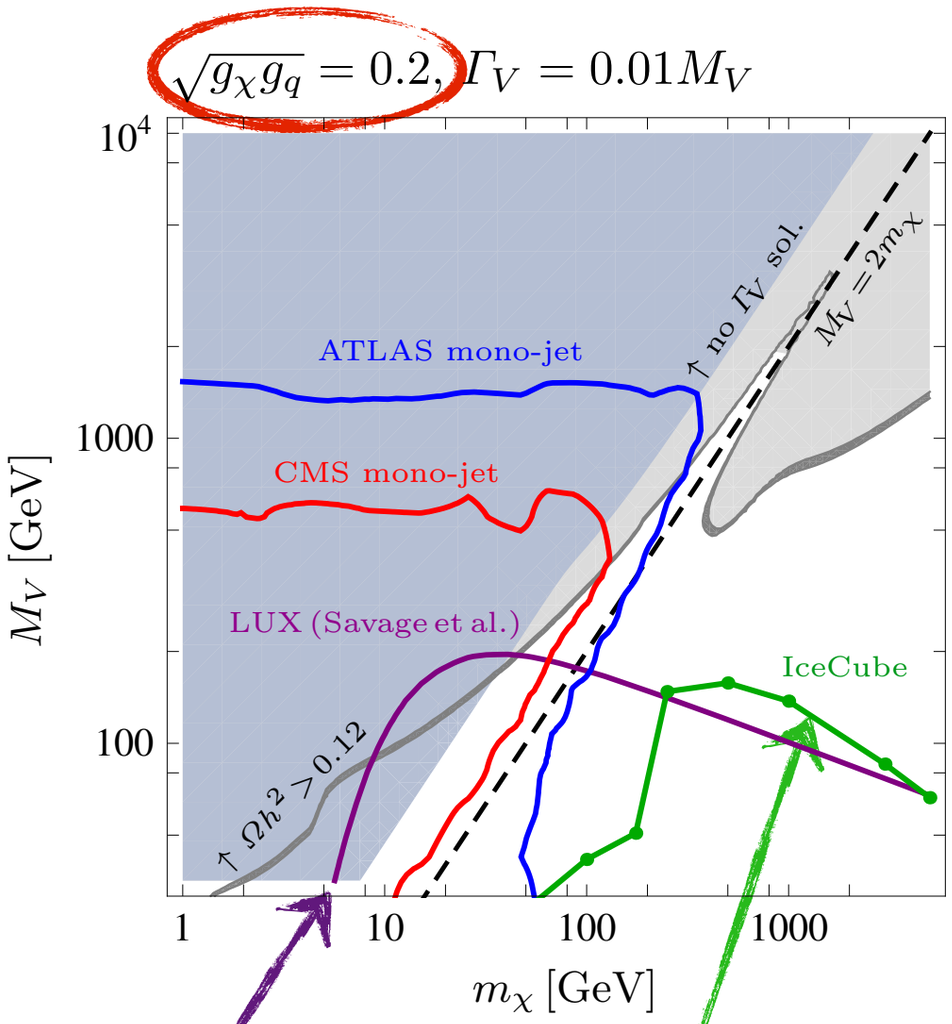

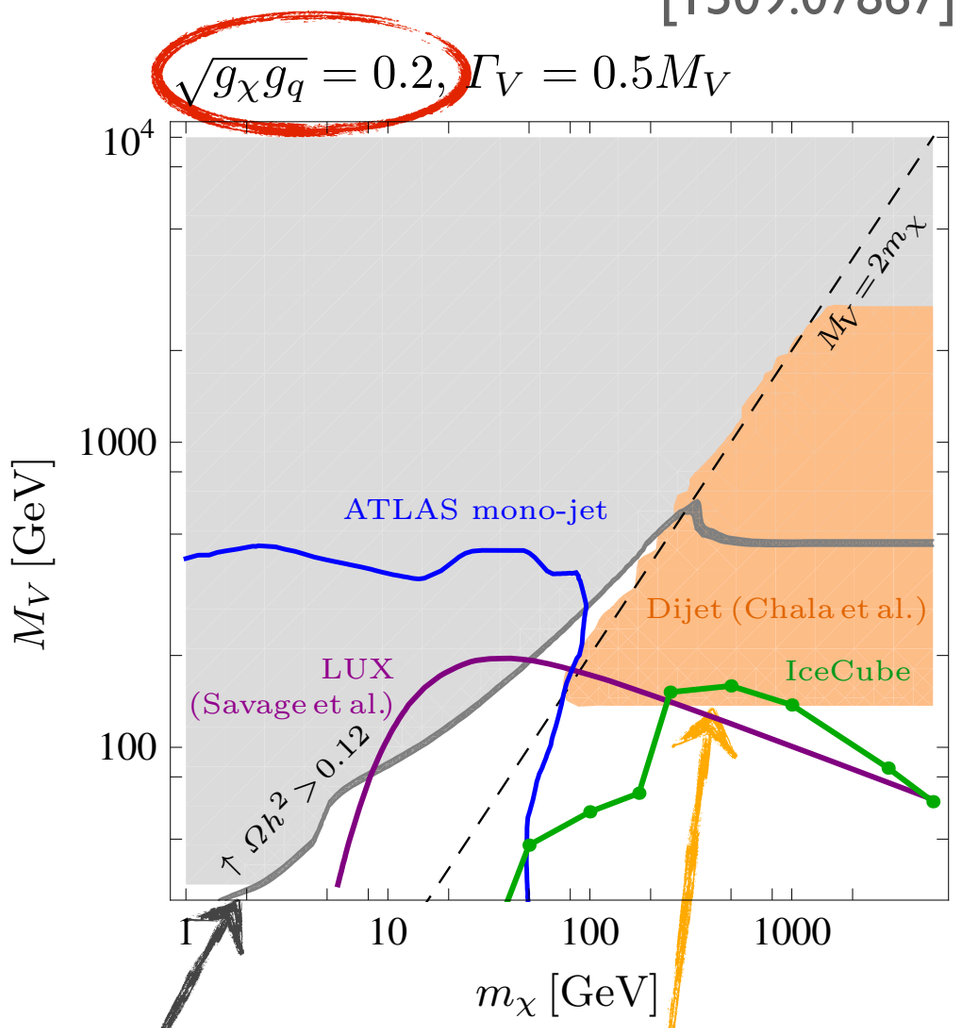

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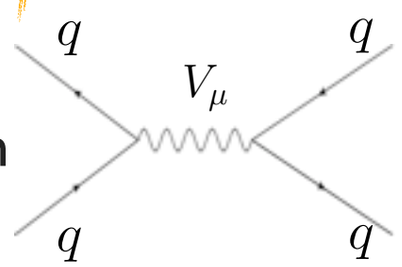

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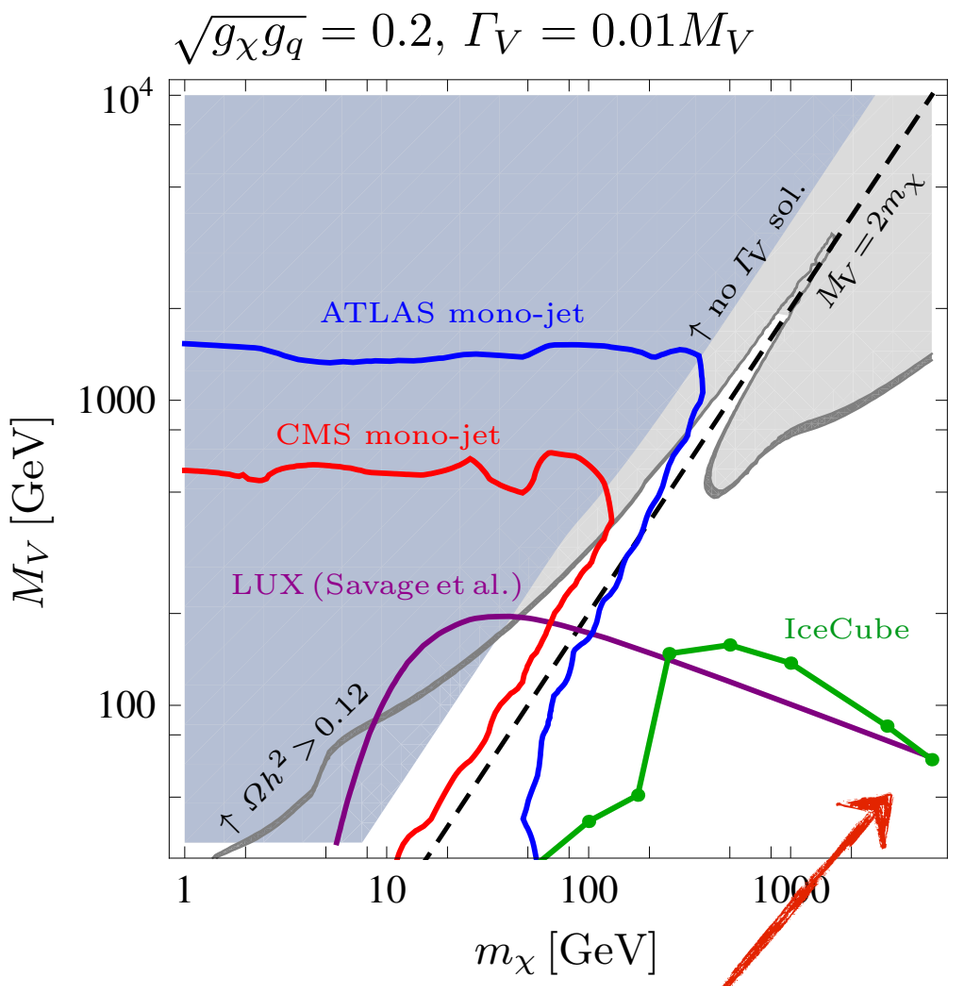
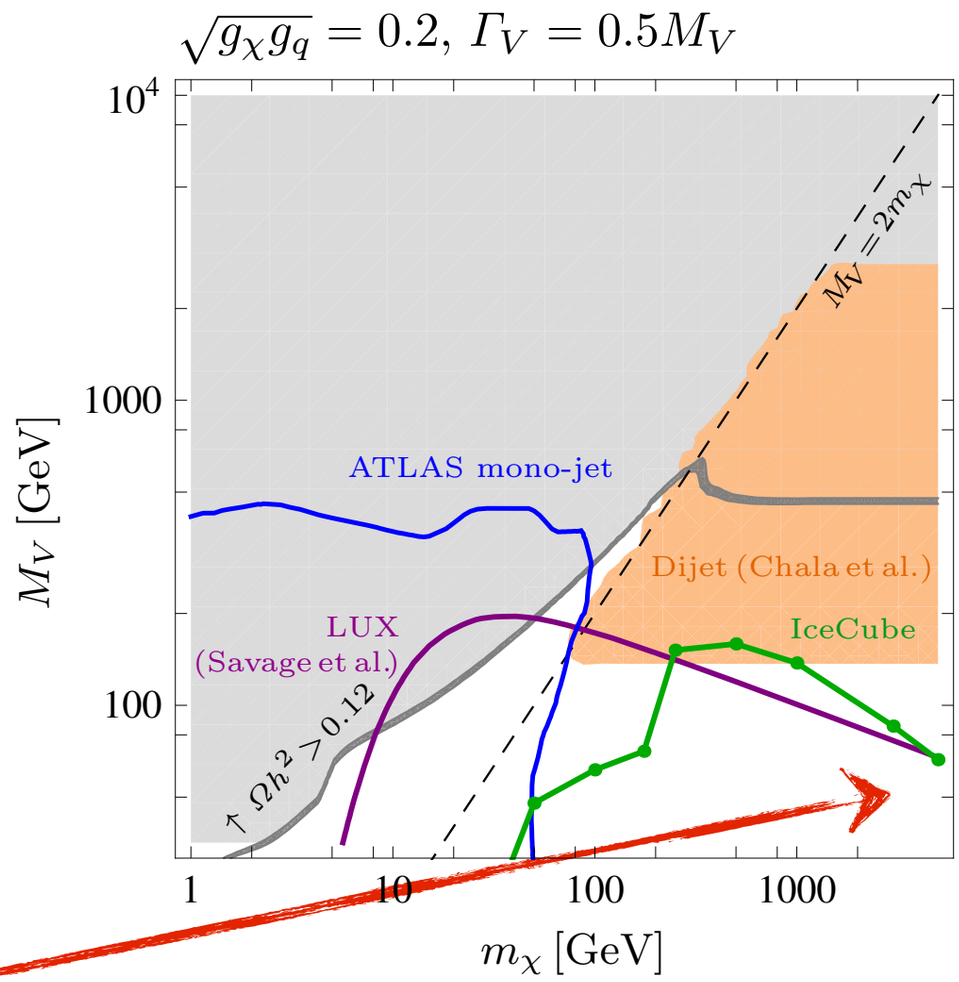




Note that $M_V \ll m_\chi$ strongly constraint from unitarity [see e.g. 1510.02110]

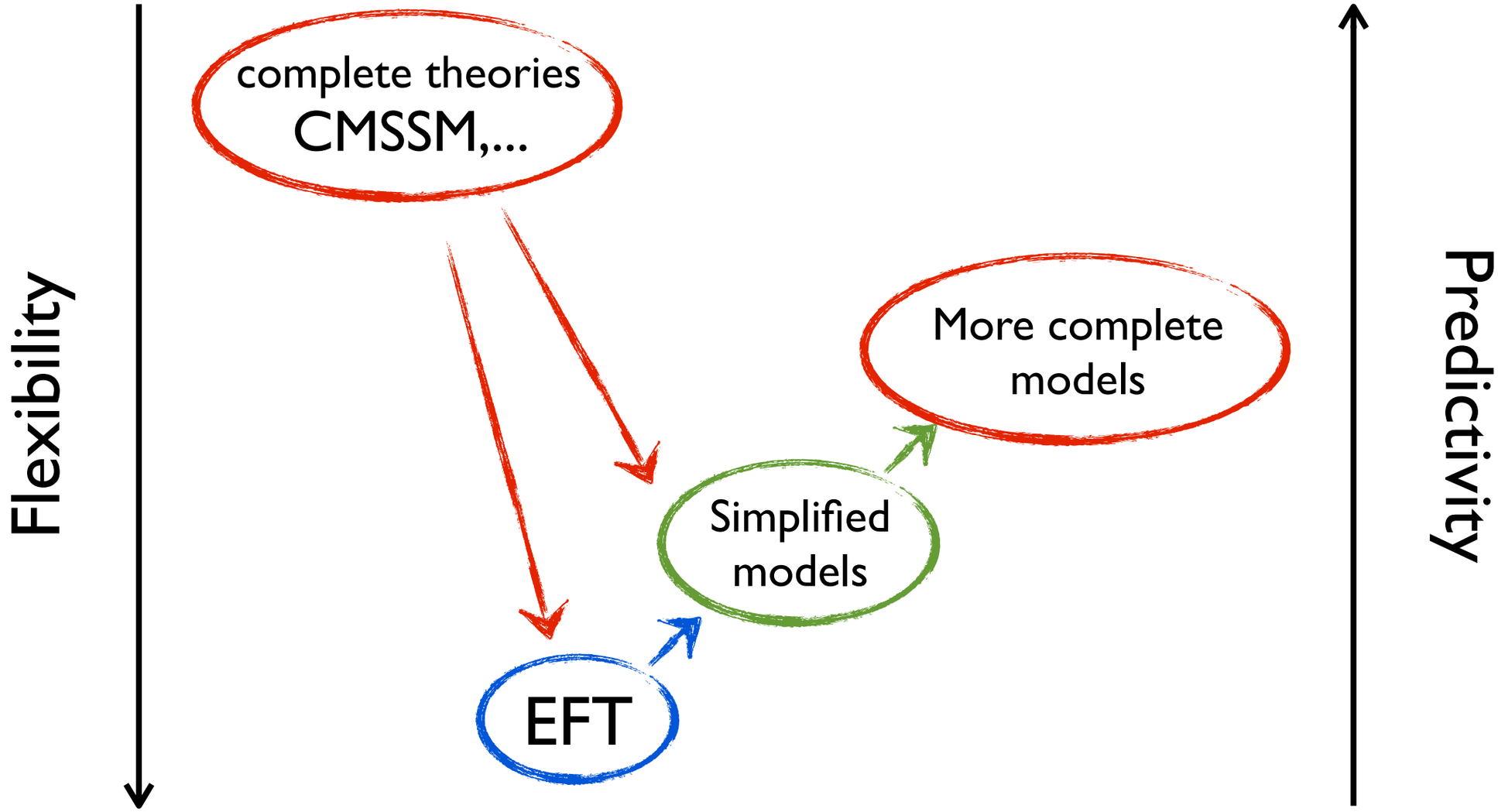
→ A more complete model is needed (add 'dark' Higgs sector)

Summary

- Considered "direct detection-phobic" model: Vector mediator with axial couplings
- Striking complementarity between various constraints
  - LHC: EFT not reliable, *Q*-truncation conservative estimate
  - ATLAS mono-jet strongest constraint on thermal relic strip sensitive up to $M_V \simeq 3\,\mathrm{TeV}$
  - IceCube important for annihilation into *tt*: Strongest limits for $m_\chi \approx 200 - 500\,\mathrm{GeV}$

Summary

Simplified and more complete models



Thank you for your attention!