Signature from Dark Matter in the Vector-like Portal

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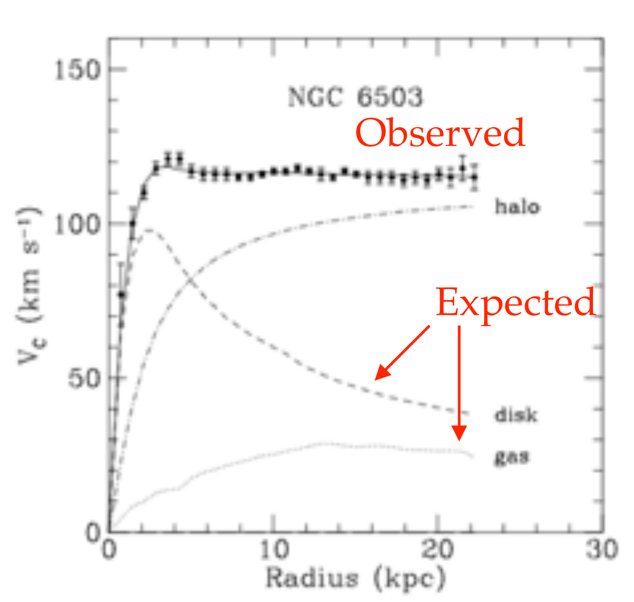
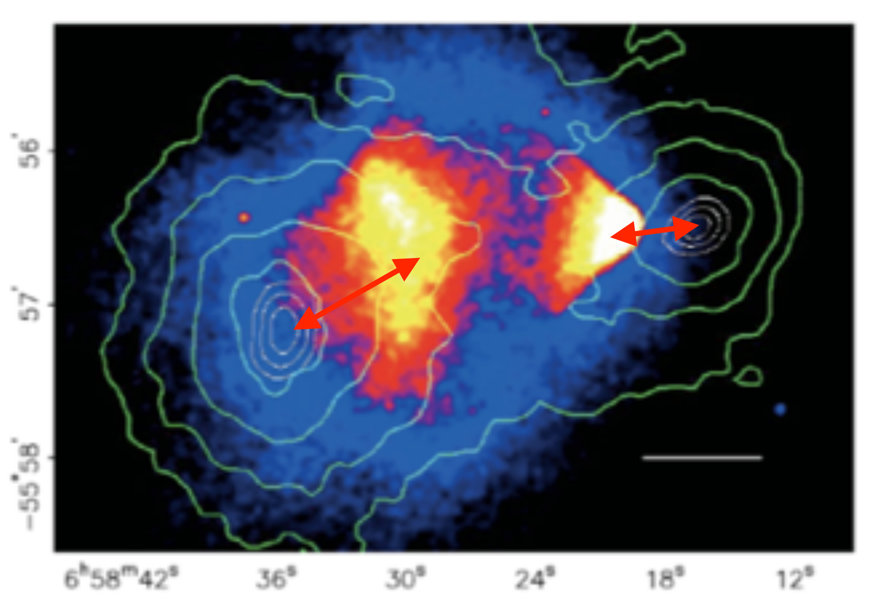
based on: *JCAP10(2013)025 [arXiv 1307.6480]*
JCAP08(2014)046 [arXiv 1405.6921]
to appear soon in arXiv 15XX.XXXX
in collaboration with L. Lopez-Honorez and M. Tytgat,
and A.Ibarra and S.Wild from Technische Universität Munchen (Germany)

Motivation: Why and What?

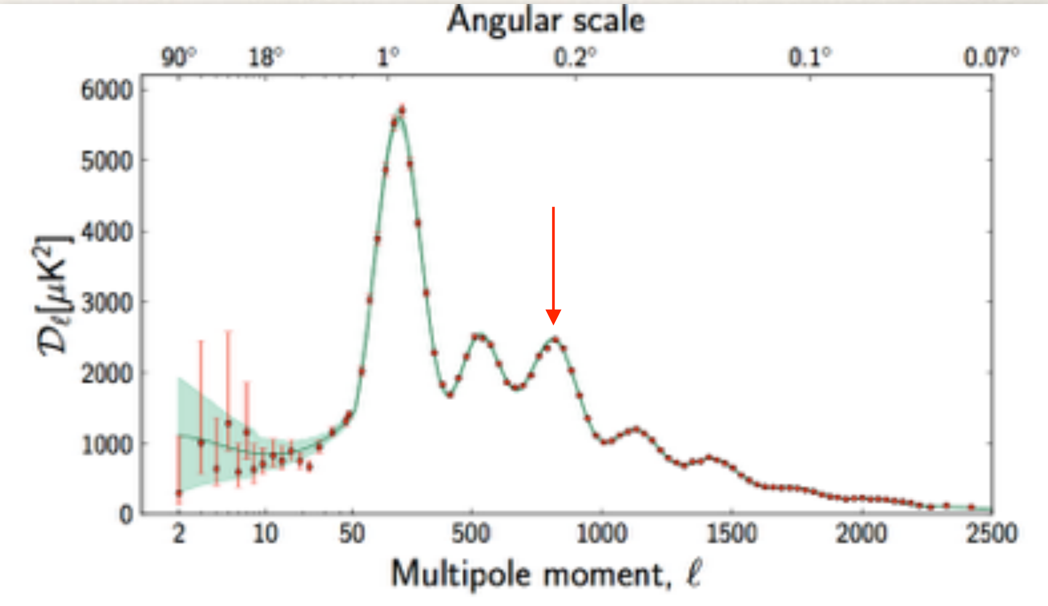
Galactic, ExtraGalactic and Cosmological Evidences



K. G. Begeman et al, Mon.Not.Roy.Astron.Soc. 249



Clowe et al, ApJ 648:L109,2006

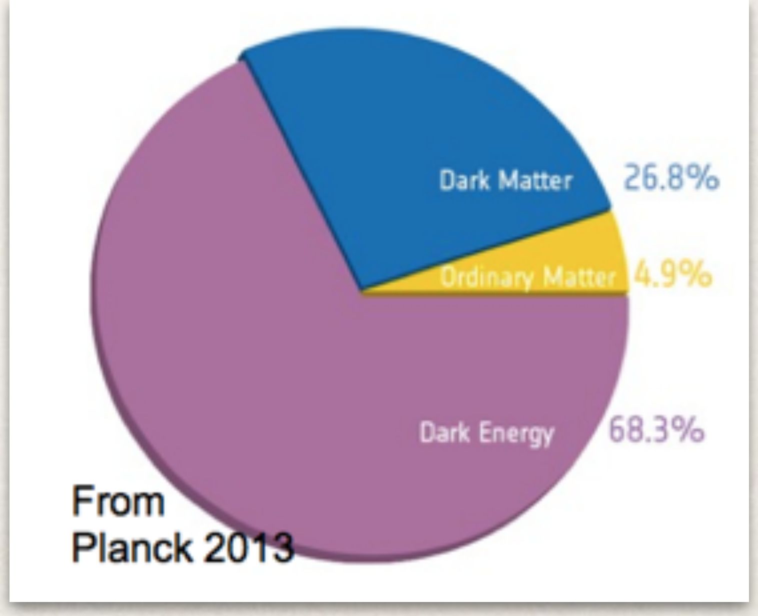


Planck 2013

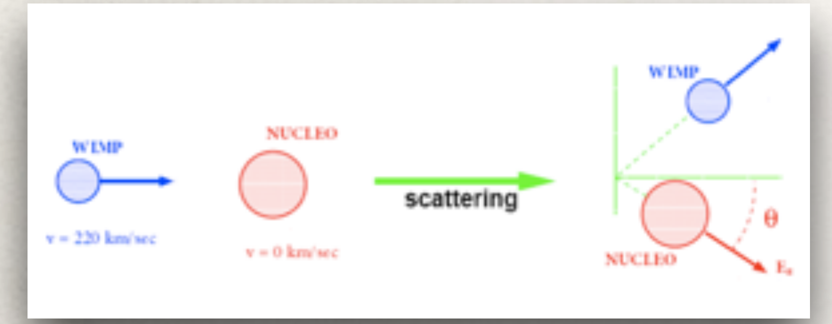
1. Particle in Beyond Standard Model
2. Stable at least of Age of the Universe
3. $\Omega_{DM}h^2 \approx 0.1198 \pm 0.0026$ (Planck + WMAP 68% limits)
4. Freeze-out production mechanism

$$\Omega_{DM}h^2(T_0) \simeq \frac{3\times10^{-27}cm^3s^{-1}}{\langle\sigma v\rangle_{FO}}$$

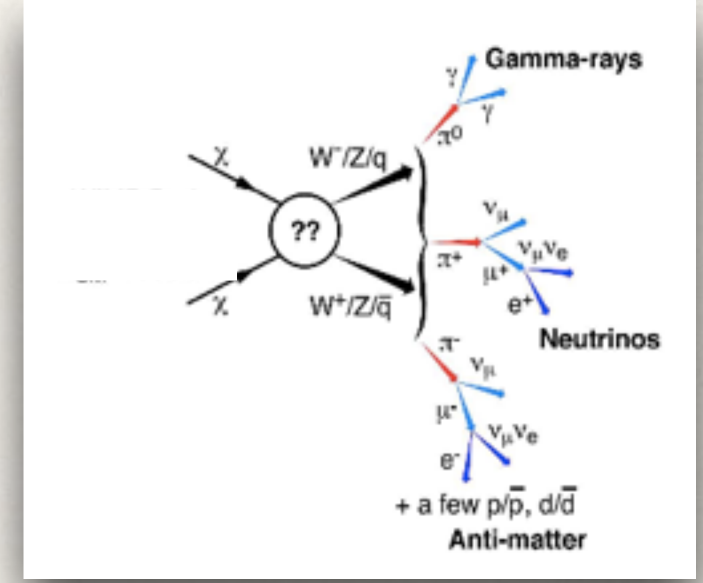
→ Weakly Interactive Massive Particle candidate



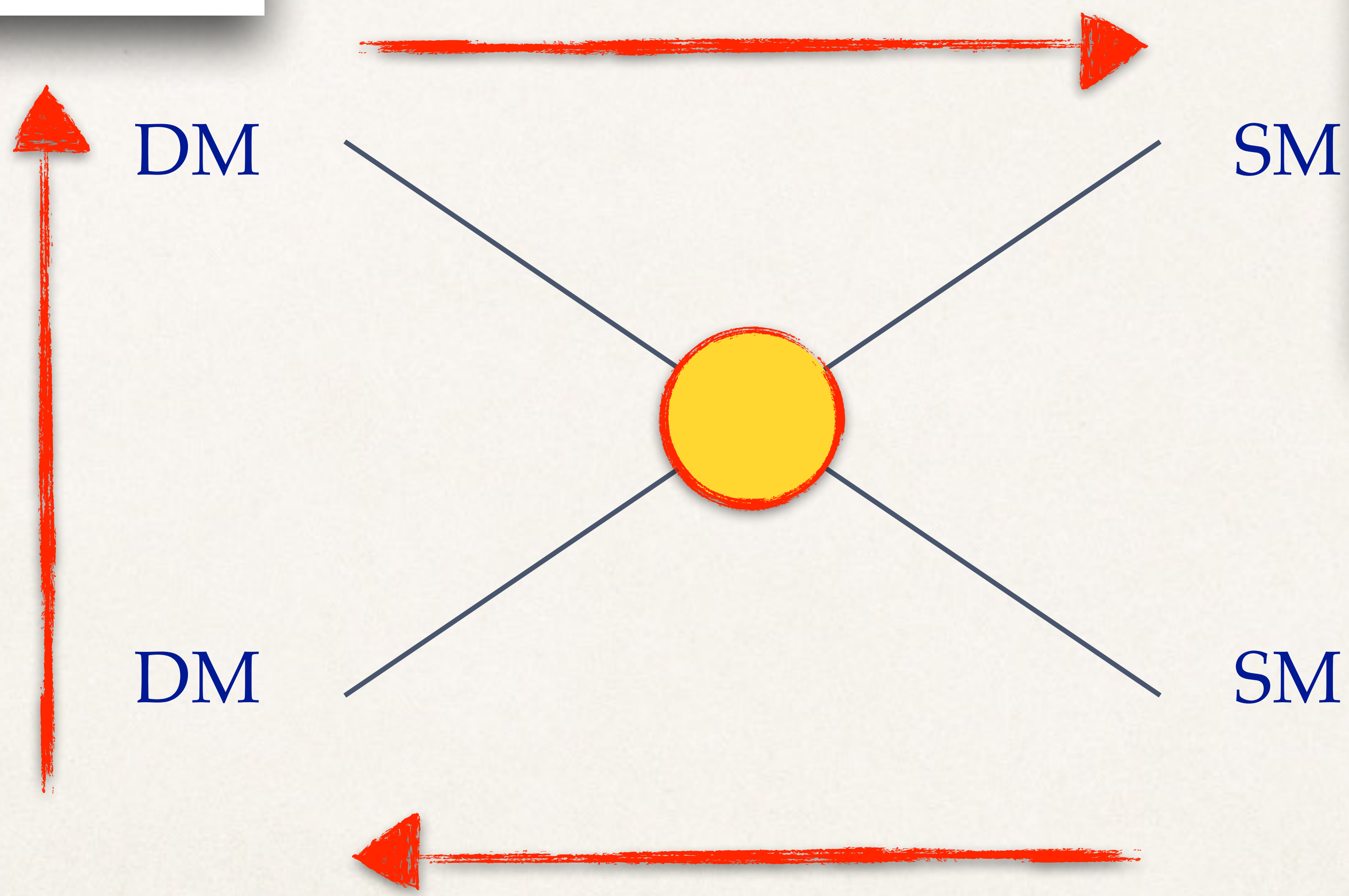
How to Detect a Signal from Dark Matter?



Annihilation: Indirect Detection



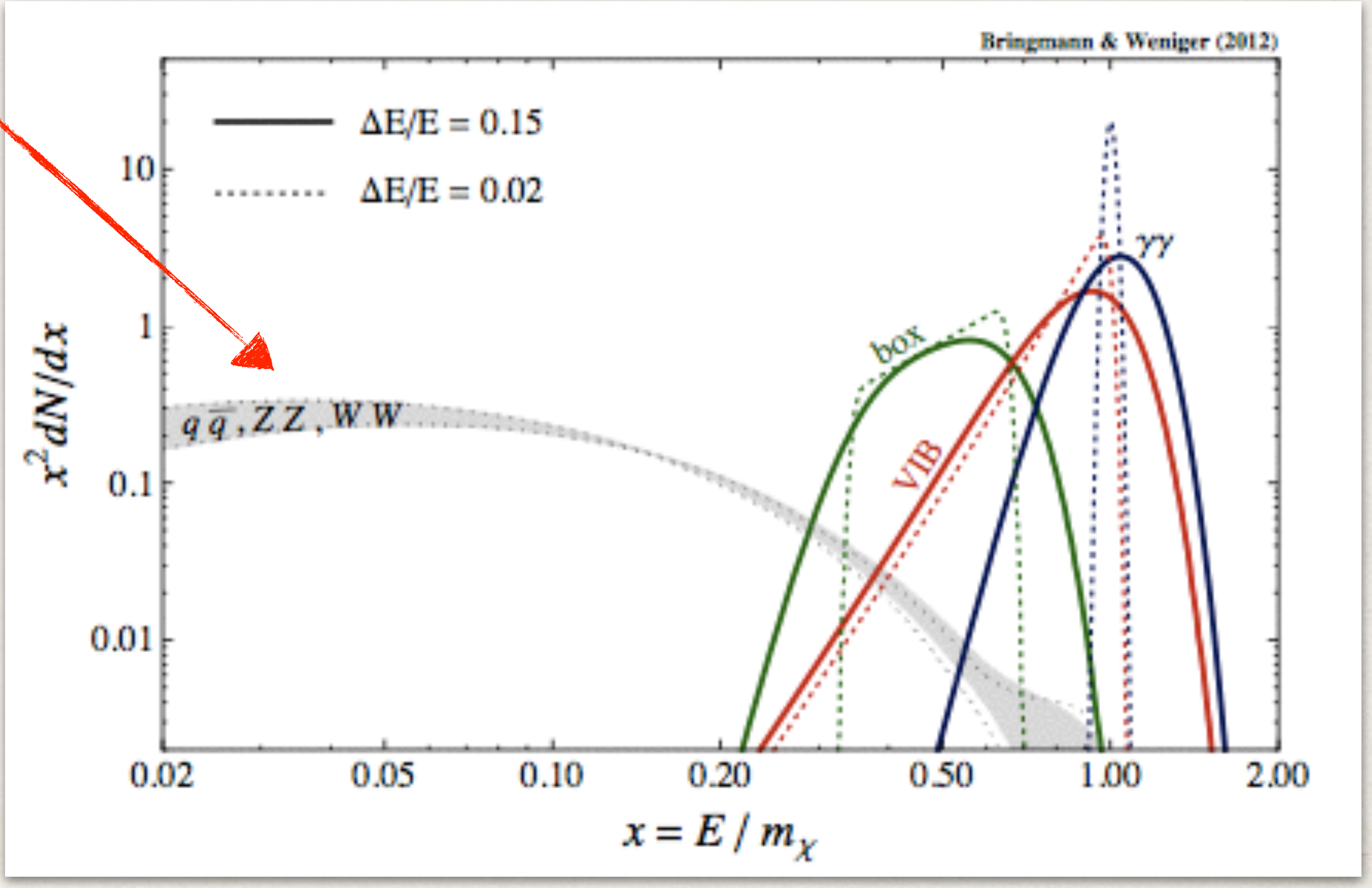
Scattering: Direct Detection



Production: Large Hadron Collider

Indirect detection: Gamma-Ray Research

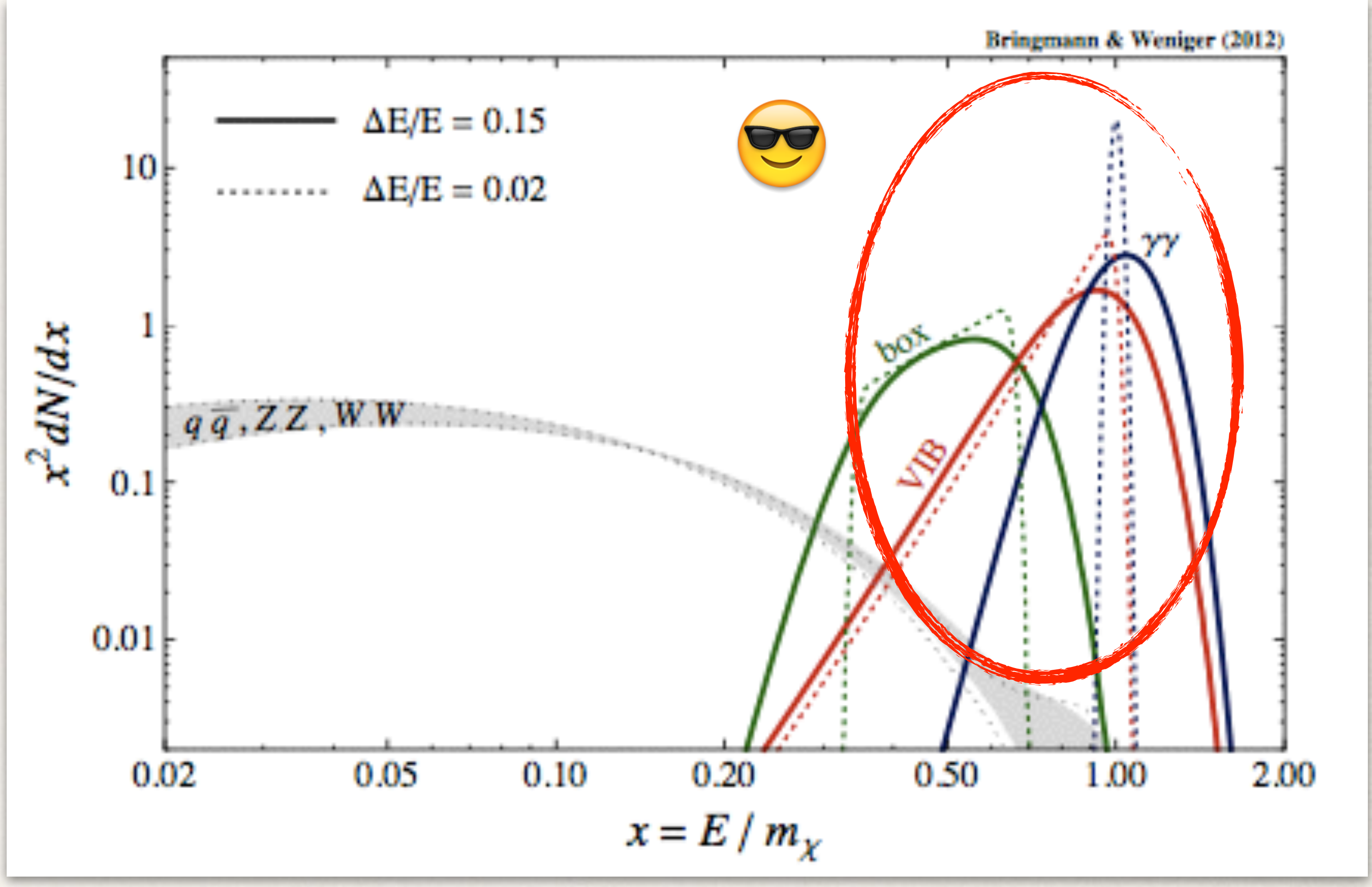
Secondary photon emissions, from decay and fragmentation of SM particles produced in annihilations, involve featureless continuum spectra difficult to discriminate from astrophysical background



Indirect detection: Gamma-Ray Research

"Smoking Gun"
for DM research 🔫

- clear spectral features: $E_\gamma \simeq m_{DM}$
- has no astrophysical counterpart
- point the source
- Actively searched: satellite (Fermi) and ground telescopes (H.E.S.S., CTA)



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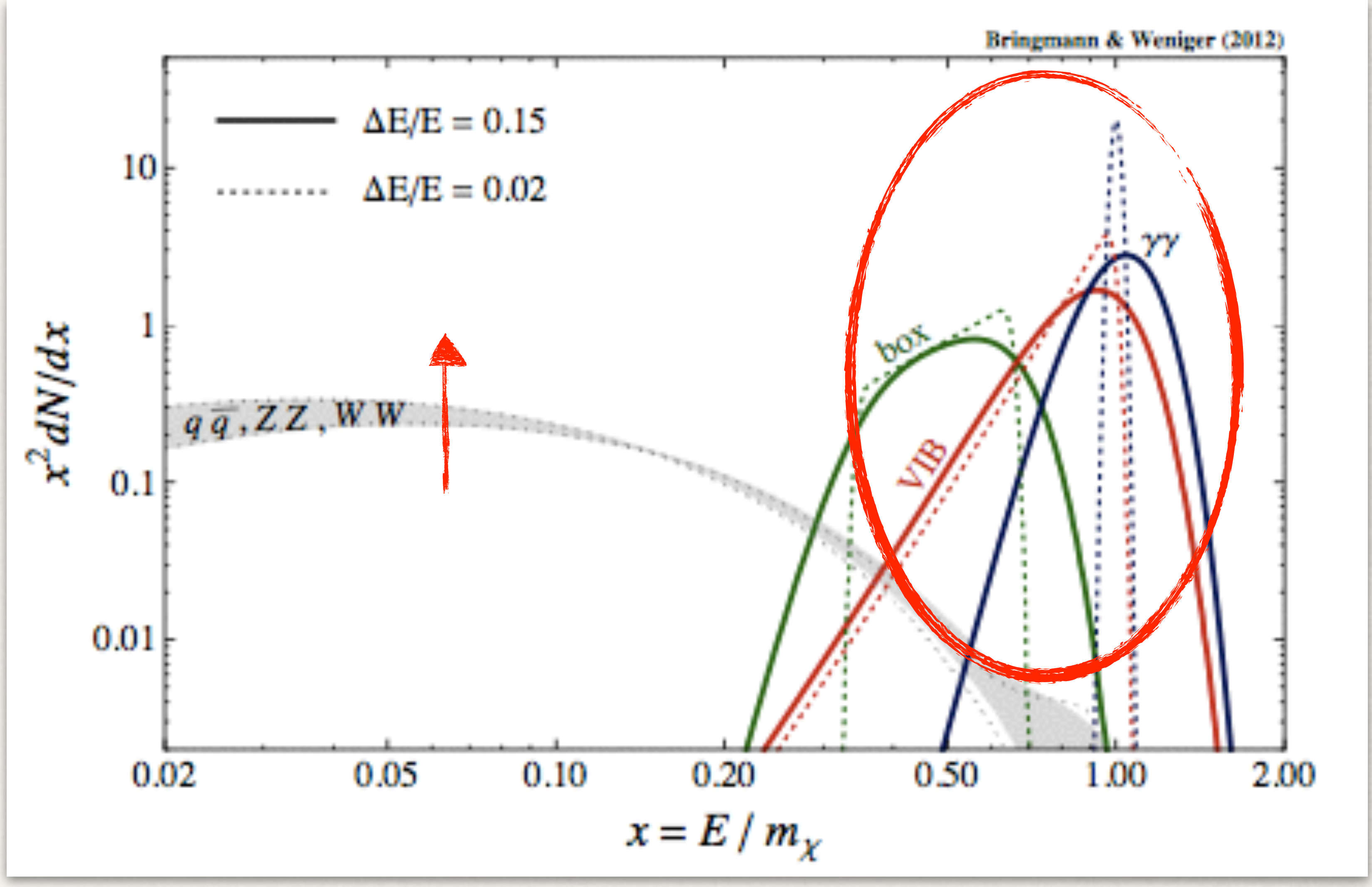
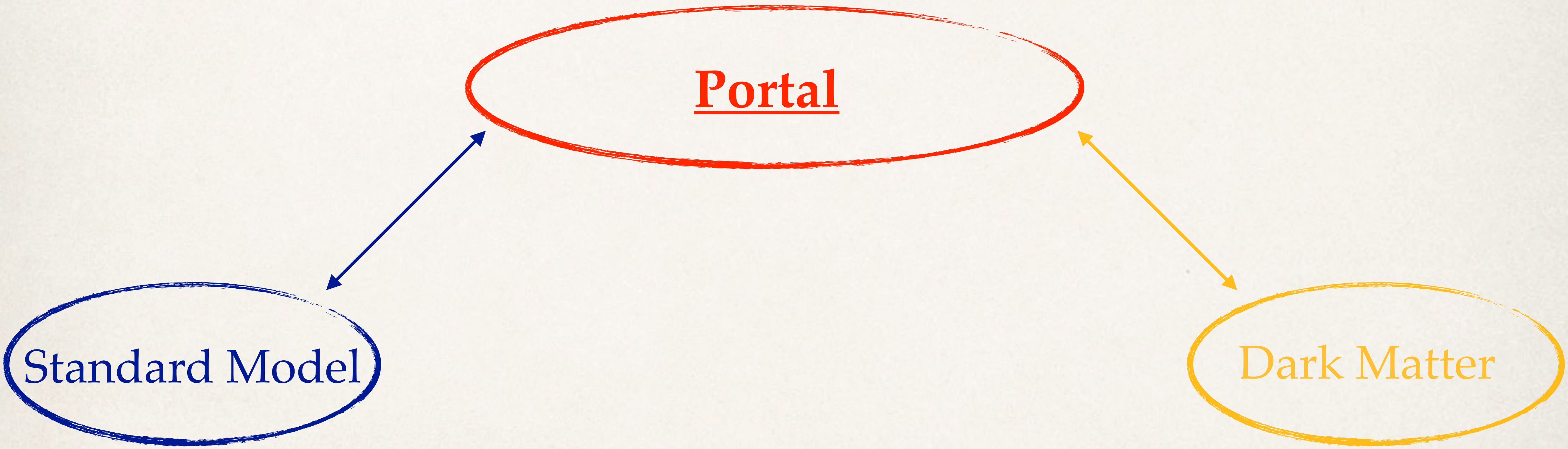


Discriminable from the continuum? 😕

Model dependent

“Simplified Models”

Few Independent Parameters to add at Standard Model



Vector-like Portal

leptophilic case

FG, L.Lopez-Honorez and M.Tytgat JCAP10(2013)025
FG, L.Lopez-Honorez and M.Tytgat JCAP08(2014)046

S Real Singlet Scalar DM

Ψ Vector-like Charged Heavy Lepton

Stability imposed by unbroken Z_2 symmetry

$$S \to -S$$

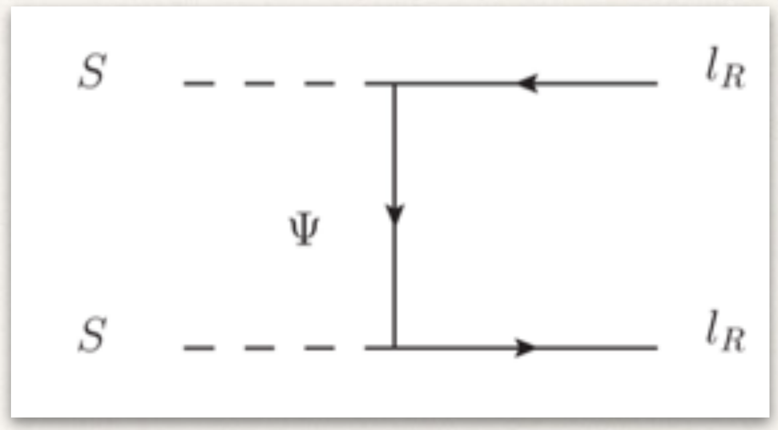
$$\Psi \to -\Psi$$

$$\mathcal{L} \supset y_S S \bar{\Psi} l_R + h.c.$$

Yukawa Interaction between hidden and visible sector

Right-Handed SM lepton (visible sector)

Two-Body Annihilation of DM into SM lepton



$$r = \frac{M_\Psi}{M_S} > 1$$

$$\langle \sigma v \rangle_{(SS \to \bar{l}l)} = \frac{y_S^4}{60\pi} \frac{v^4}{M_S^2 (1+r^4)^2}$$

D-wave
in chiral limit

$$\langle \sigma v \rangle_{(\chi\chi \to \bar{l}l)} = \frac{y_\chi^4}{48\pi} \frac{v^2 (1+r^4)}{M_\chi^2 (1+r^4)^2}$$

P-wave
in chiral limit

suppressed today
(the velocity of the DM is 10^{-3} cm/s in the galaxy)

Relevant in the early universe

at freeze-out to obtain the observed relic abundance → $y_S \gg y_\chi$

Implications in γ-ray researches?

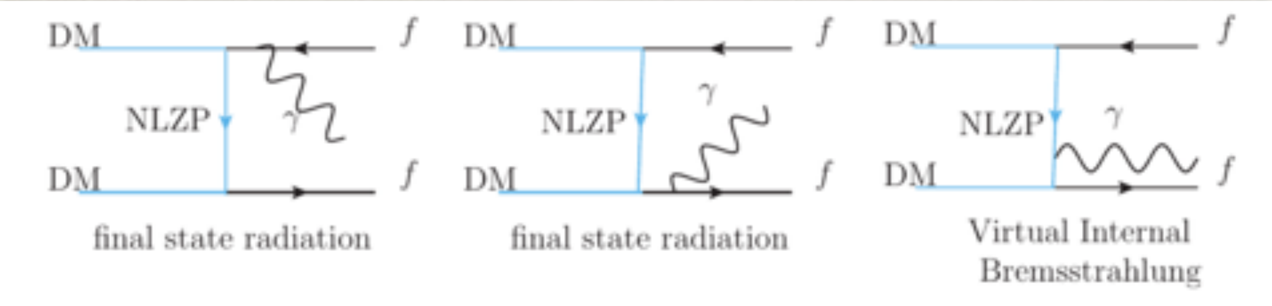
FG, L.Lopez-Honorez and M.Tytgat JCAP10(2013)025

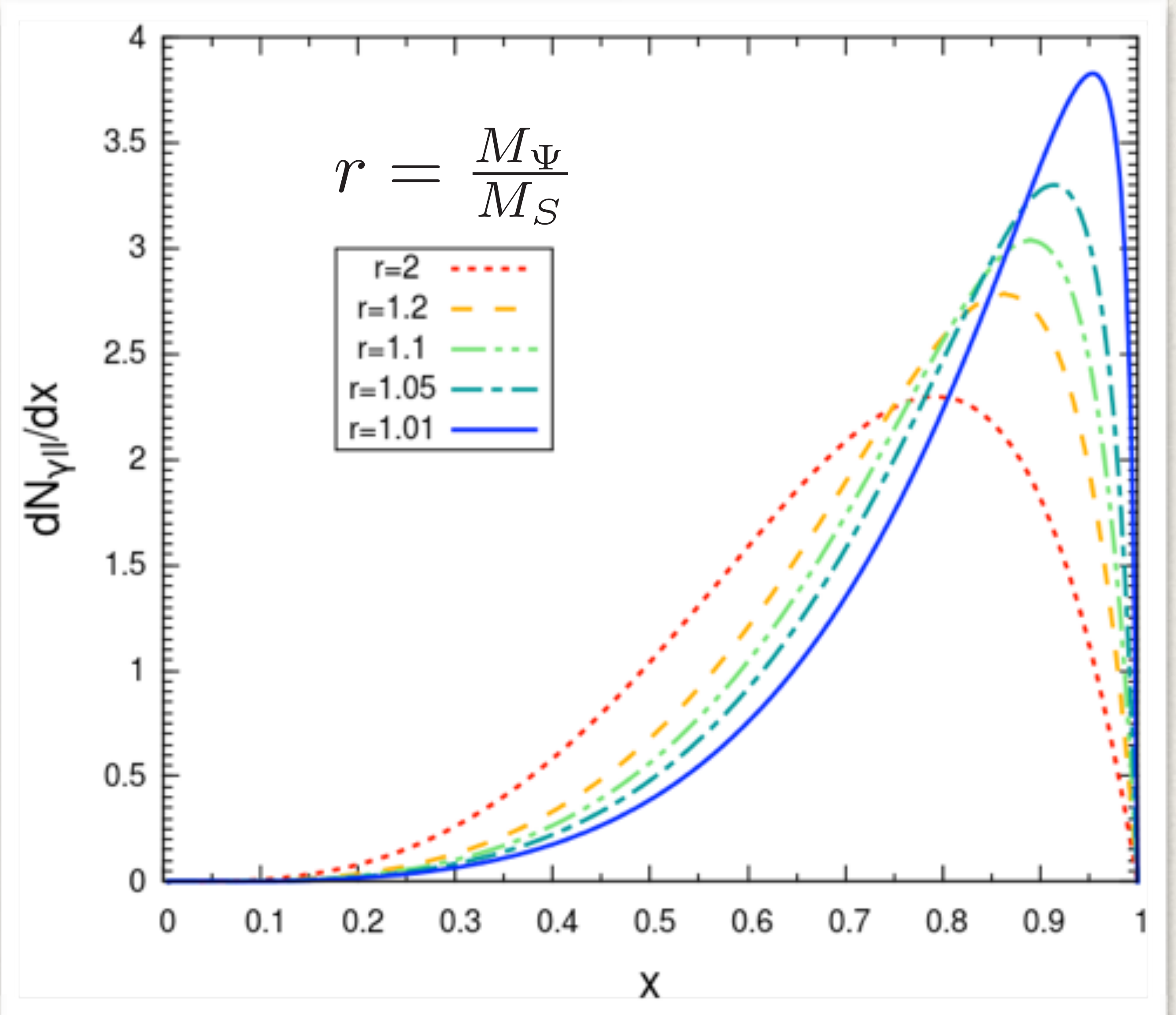
FG, L.Lopez-Honorez and M.Tytgat JCAP08(2014)046

Radiative Emission in Dark Matter annihilation

1. Virtual Internal Bremsstrahlung

$$SS \to l\bar{l}\gamma$$





Peaked at $E_\gamma \sim M_S$ for r →1, but **suppressed**?

$$x = \frac{E_\gamma}{M_S}$$

Radiative Emission in Dark Matter annihilation

1. Virtual Internal Bremsstrahlung

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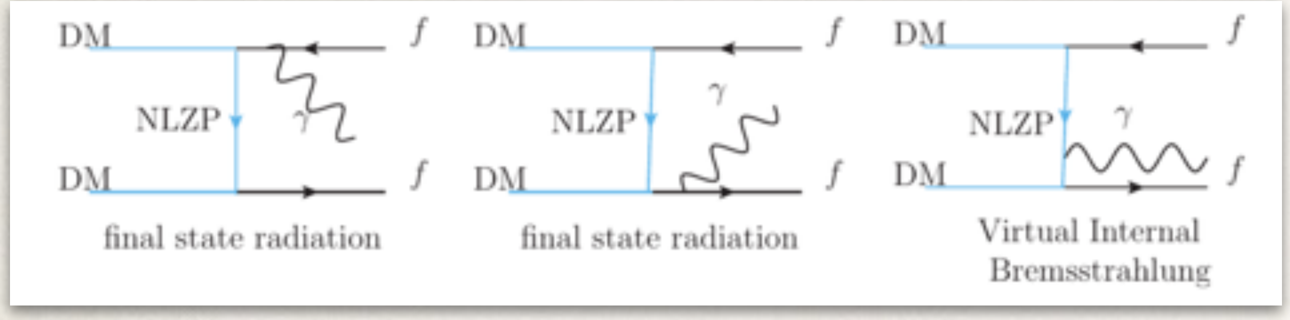
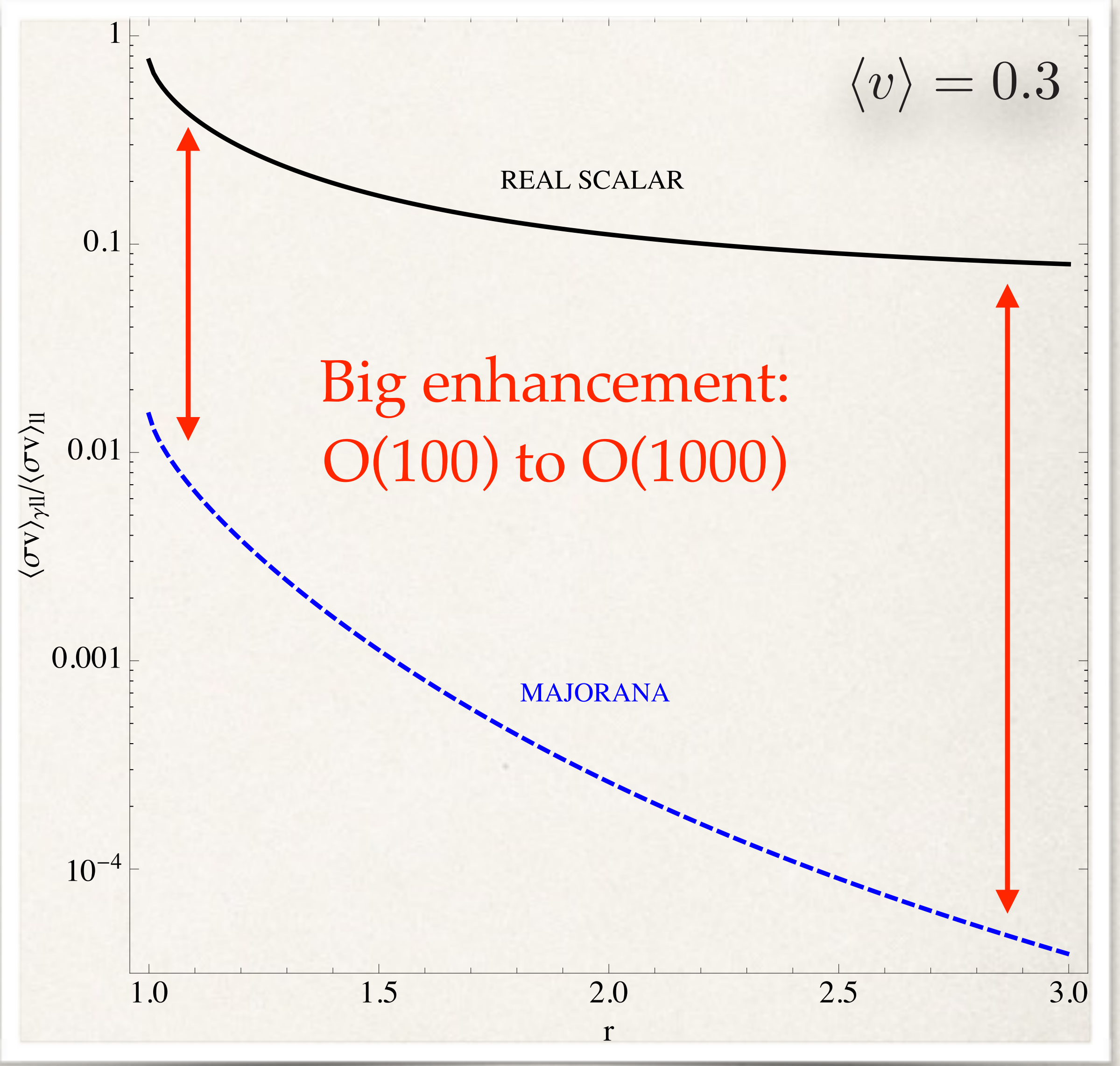


Dominant Bremsstrahlung emission at galactic center

Majorana DM: $\langle \sigma v \rangle_{\gamma l \bar{l}} << \langle \sigma v \rangle_{l\bar{l}}$

Scalar DM: $\langle \sigma v \rangle_{\gamma l \bar{l}} \simeq \langle \sigma v \rangle_{l\bar{l}}$

$$\frac{\langle \sigma v \rangle^{S}_{\gamma l \bar{l}}}{\langle \sigma v \rangle^{\chi}_{\gamma l \bar{l}}} = 8 \frac{y_S^4}{y_\chi^4}$$



$$r = \frac{M_\Psi}{M_S}$$

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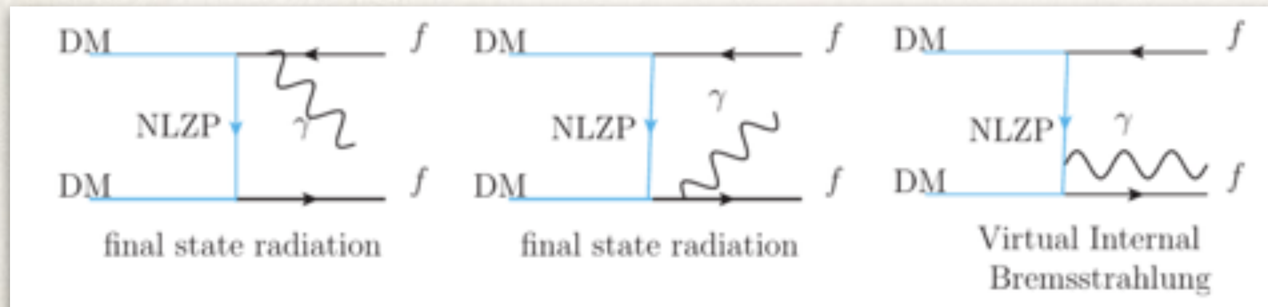

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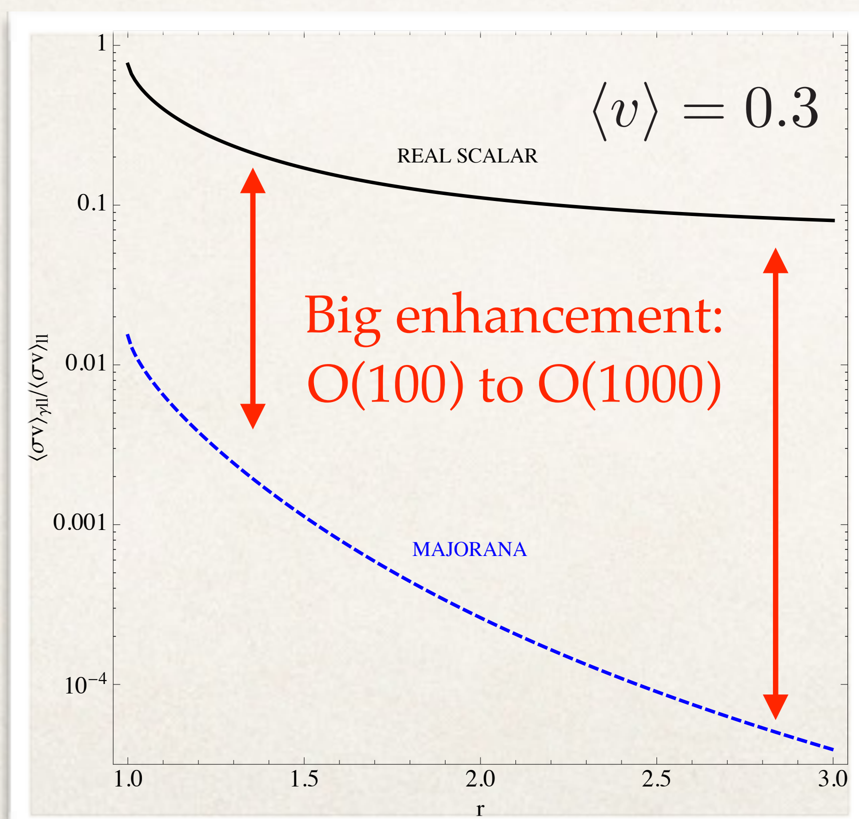
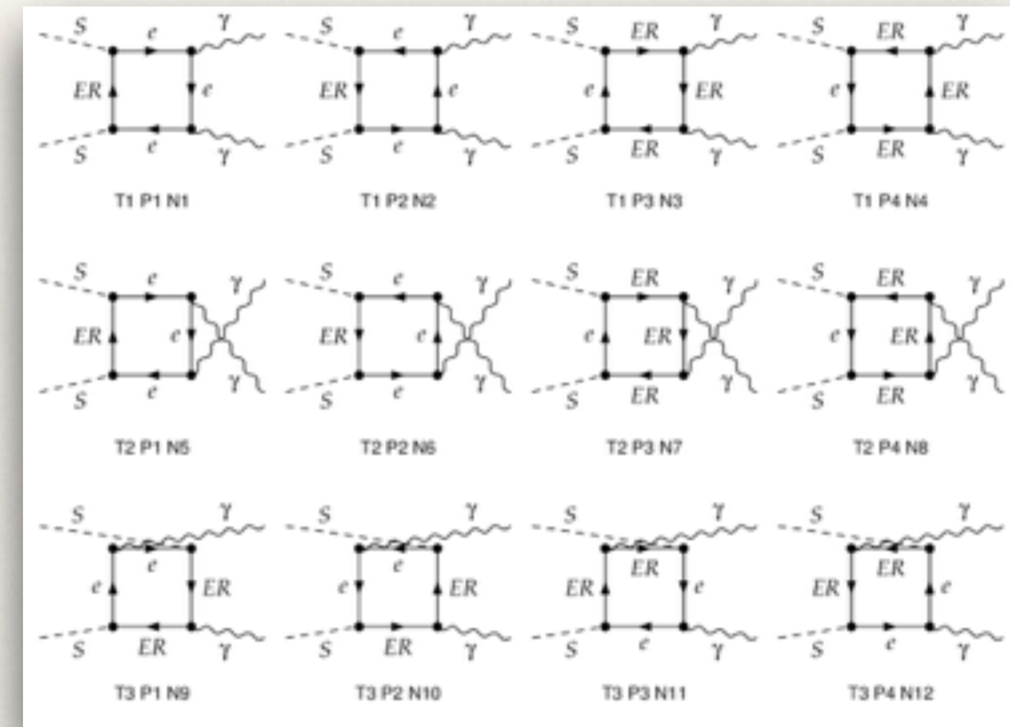


$$r = \frac{M_\Psi}{M_S}$$

2. Monochromatic Gamma ray lines

$$SS \to \gamma\gamma$$



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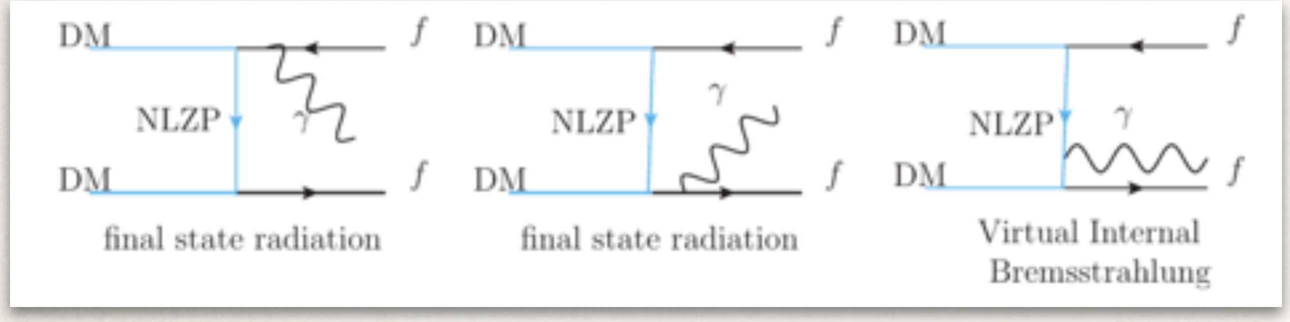

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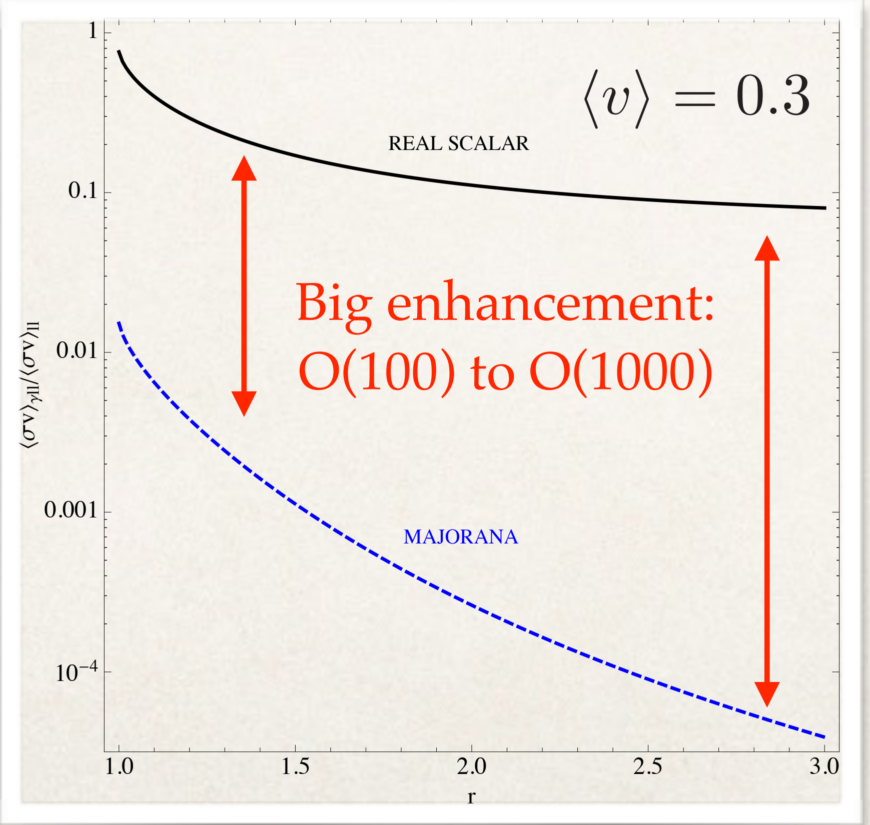

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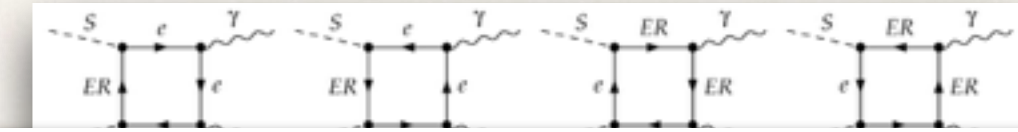
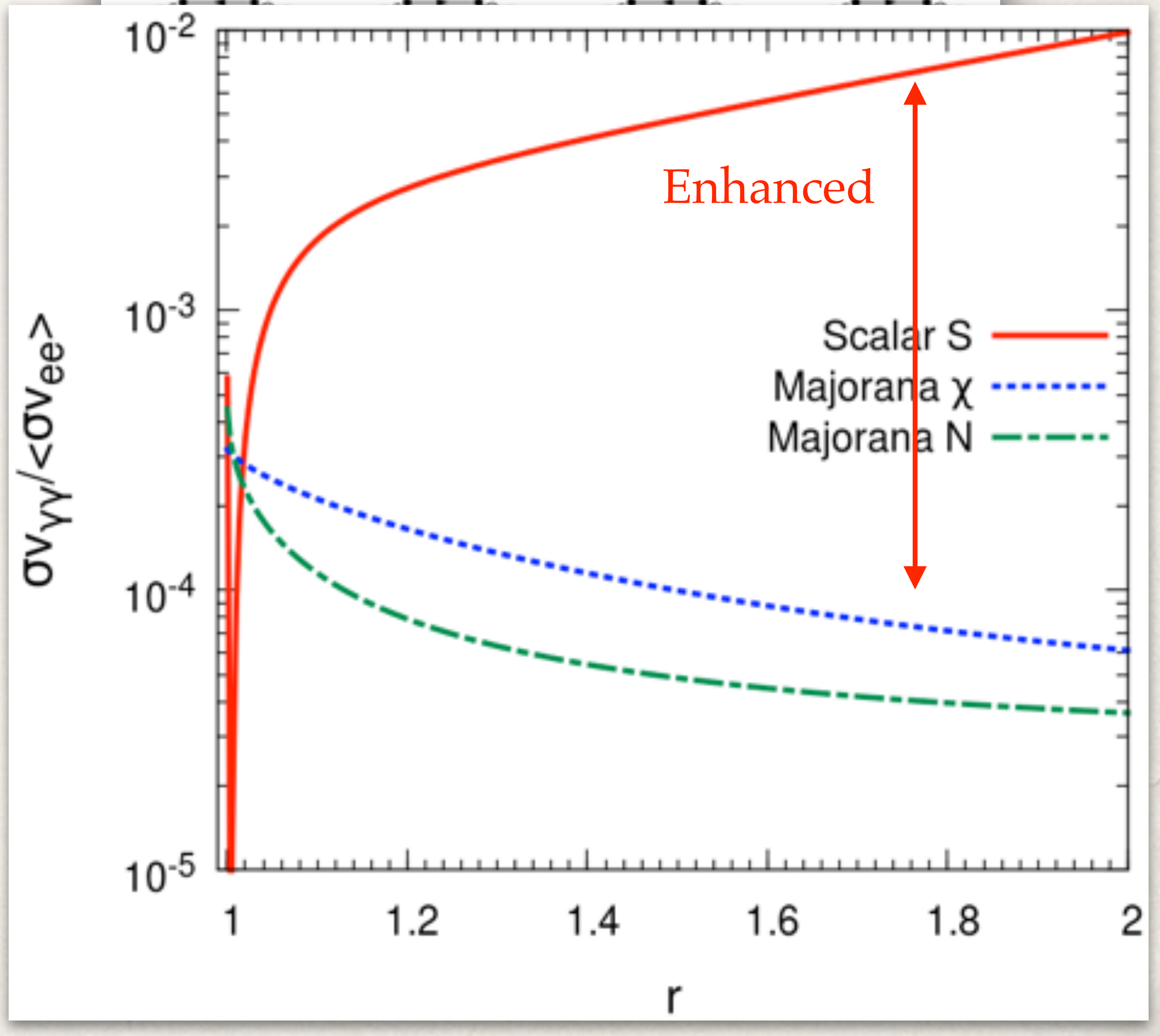


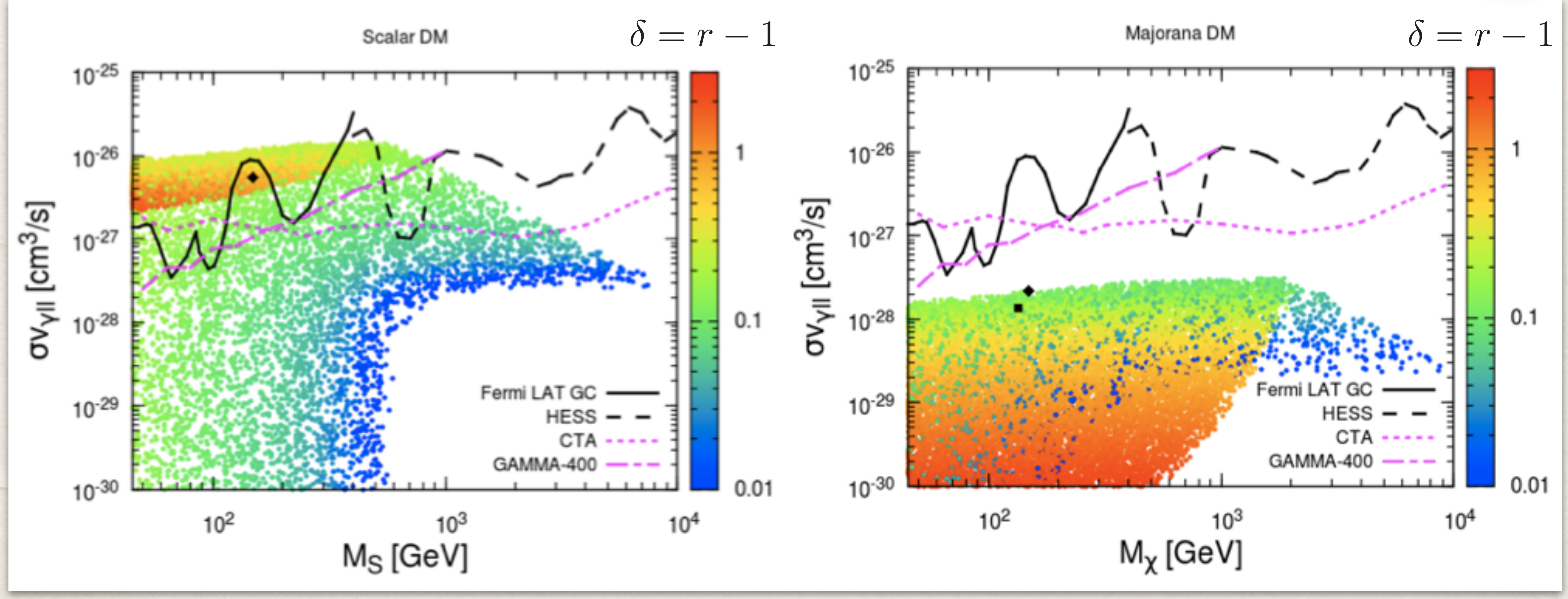


Scan over the allowed Parameter Space (VIB)

all the points match the observed relic abundance of Dark Matter

$$r = \frac{M_\Psi}{M_S}$$

FG, L.Lopez-Honorez and M.Tytgat JCAP10(2013)025



Scalar DM: present (FermiLAT/H.E.S.S.) and future (GAMMA400/CTA) **γ**-ray experiments are sensitive to probe regions of its parameter space

Majorana DM: not expected to produce any observable signal in current or next experiments, parameters always small (unless of a boost factor).

Next Step: extended interaction

$$\mathcal{L} \supset y_S S \bar{\Psi} q_R + h.c.$$

Vector-like Quark

Why is important?

- Re-Computation parameter space for Ω
- Direct Detection Analysis
- Indirect Detection: Antiprotons and **γ** from dwarf galaxies
- Constraints mediator mass from LHC

to appear soon in collaboration with
A.Ibarra, L Lopez-Honorez, M.Tytgat and S.Wild '15

Conclusion and prospects

- VIB + **γγ** (leptophilic case):
  1/ Dominant contributions to the total amount of DM;
  2/ Gamma-ray Spectral Features testable.

- In the model with light-quark interaction, the 3 complementary roads of detection fix the following alive window:

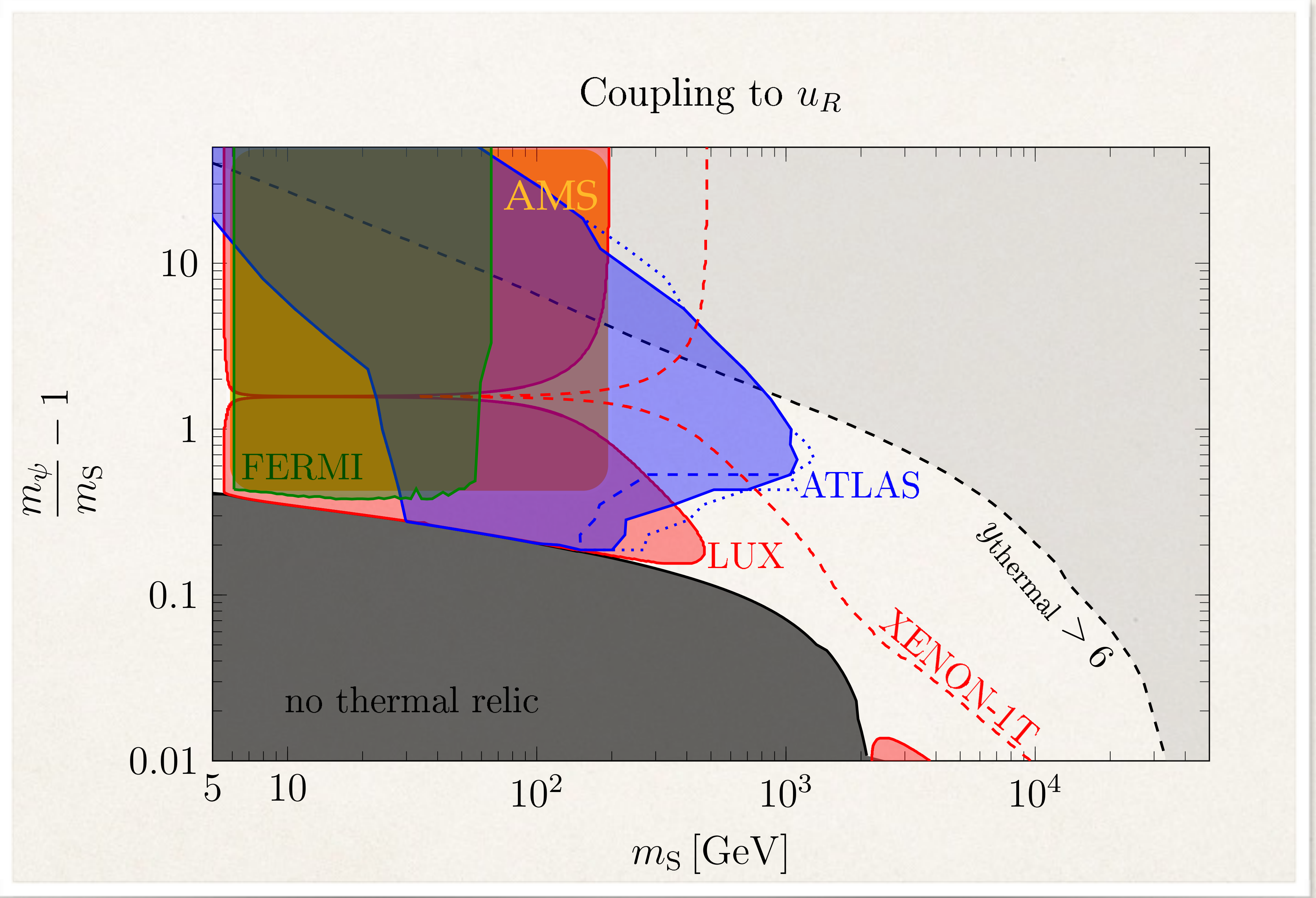
Ms > 1 TeV and r-1 < 1.3

- Future analysis of Vector-like Portal consist on the DM and top-quark interactions.

Thanks for your attention

Backup slides

New Constraints!!



FG, A.Ibarra, L.Lopez-Honorez, M.Tytgat and S.Wild arXiv.15XX.XXXX

Freeze-out Mechanism

Freeze-out: when annihilation rate falls behind expansion rate

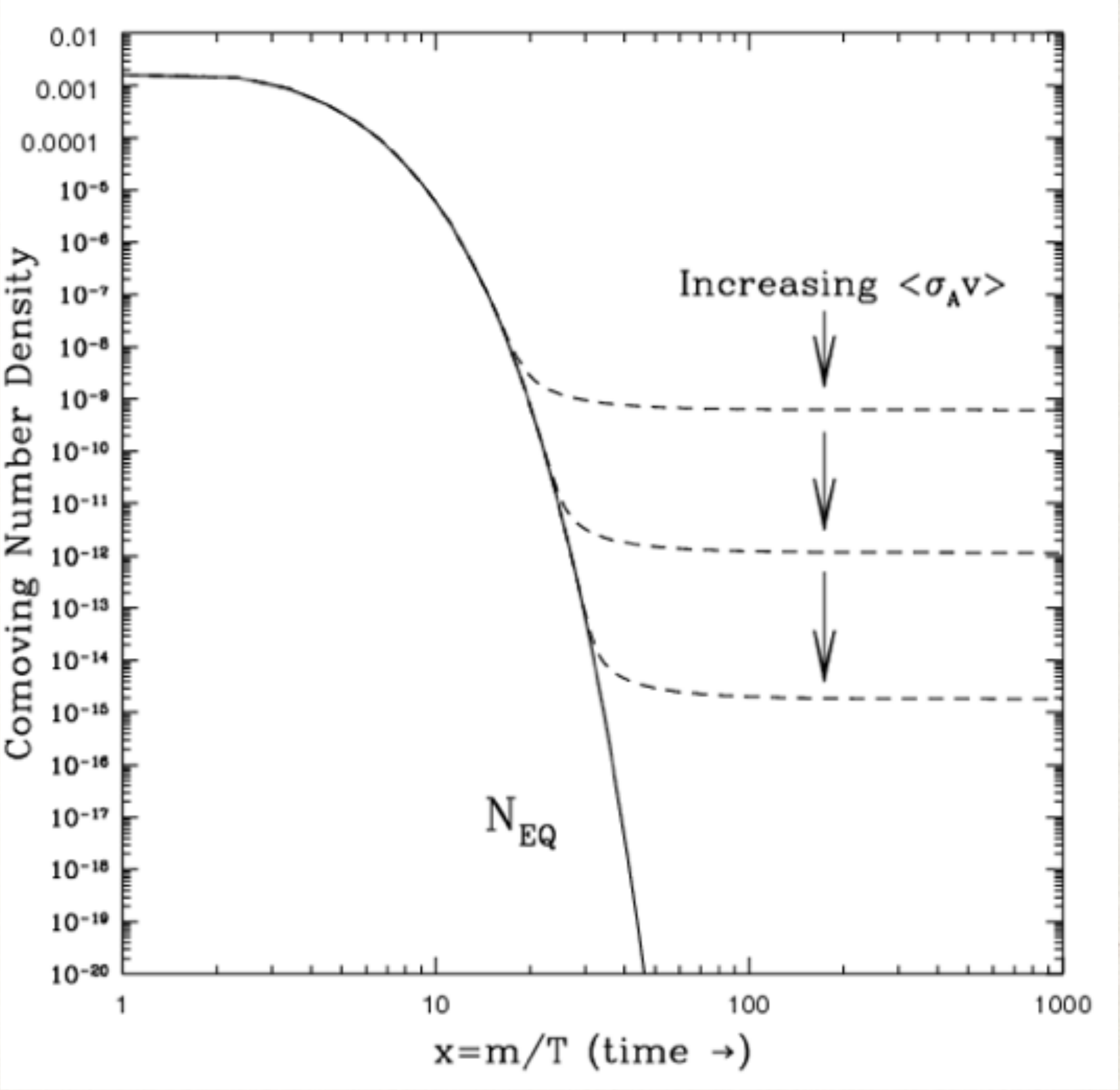
$$Y_{DM}^{FO} \simeq constant$$

depends on annihilation cross section and leads to

$$\Omega_{DM} h^2(T_0) \simeq \frac{3 \times 10^{-27} cm^3 s^{-1}}{\langle \sigma v \rangle_{FO}}$$

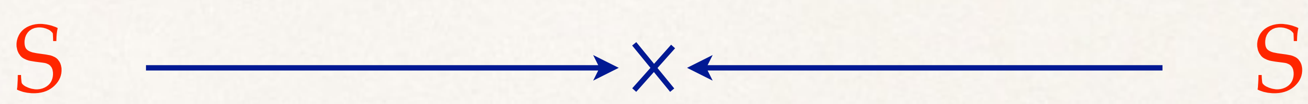
WIMP candidate gives the observed relic abundance value

$$\langle \sigma v \rangle_{FO} \simeq 3 \times 10^{-26} cm^3 s^{-1}$$



Two-Body Result Effective Operators explanation

dark matter annihilation



initial state s-wave

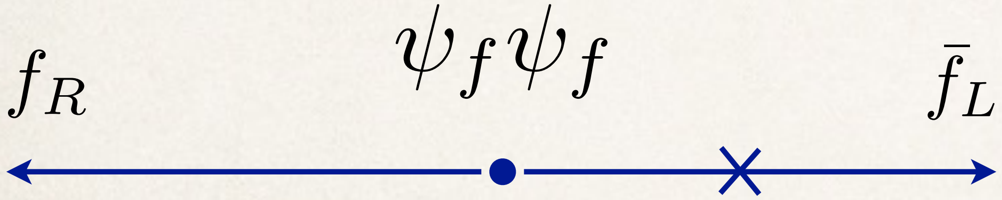
$^1S_0$

initial state d-wave

$^1D_2$

final state s-wave

$\bar{\psi}_f \psi_f$

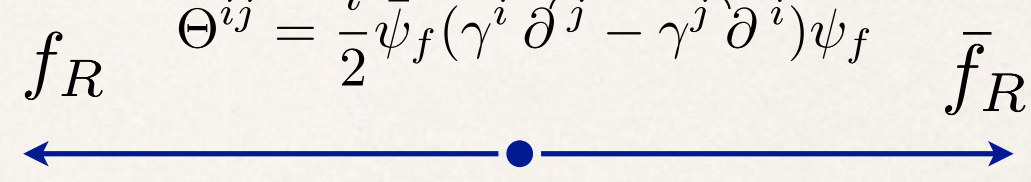


cross section is mass suppressed

$$\mathcal{O}_S = m_f S^2 \bar{\Psi}_f \Psi$$

final state d-wave

$\Theta^{ij} = \frac{i}{2}\bar{\psi}_f(\gamma^i \overrightarrow{\partial}^j - \gamma^j \overleftarrow{\partial}^i)\psi_f$



cross section is v^4 dependent

$$\mathcal{O}_T = \partial_\mu S \partial_\nu S \Theta^{\mu\nu}$$

Virtual Internal Bremsstrahlung

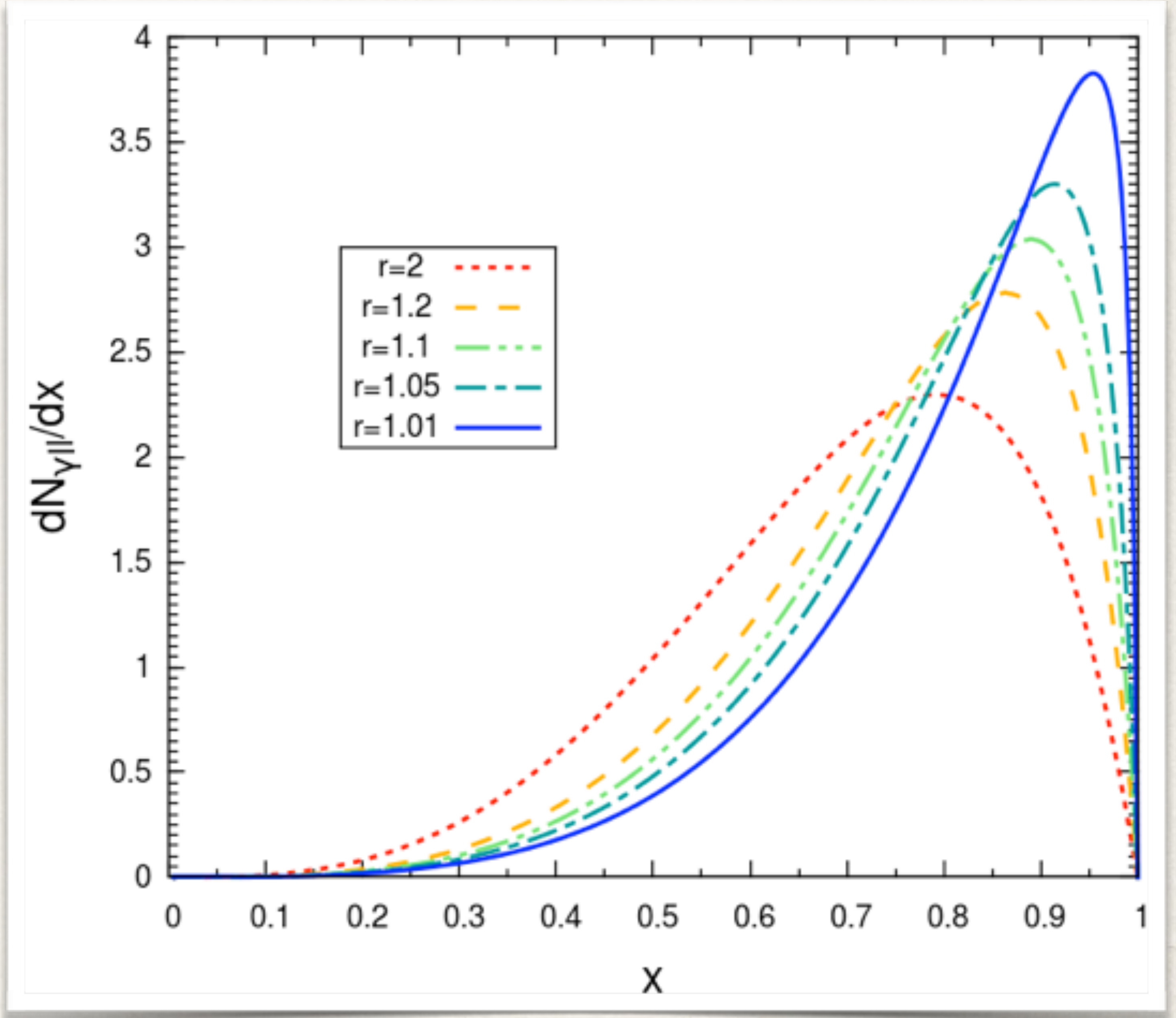
$$\frac{\langle \sigma v \rangle^{S}_{\gamma l \bar{l}}}{\langle \sigma v \rangle^{\chi}_{\gamma l \bar{l}}} = 8 \frac{y_S^4}{y_\chi^4}$$

The γll Spectrum

$$\frac{dN_{\gamma l \bar{l}}}{dx} = \frac{M_S}{\sigma_{\gamma l \bar{l}}} \frac{d\sigma_{\gamma l \bar{l}}}{dE_\gamma}$$

with $x = \frac{E_\gamma}{M_S}$ and $r = \frac{M_\Psi}{M_S}$

peaked at $E_\gamma \sim M_S$ for $r \to 1$



FG, L.Lopez-Honorez and M.Tytgat
JCAP10(2013)025, arXiv 1307.6480

Benchmarks models to explain Gamma ray excess around 130 GeV considering a M_{DM}=150 GeV

Benchmarks	y_i	r	$\sigma v_{\gamma ll}$	$\sigma v_{\gamma\gamma}$
Scalar	$y_l = 1.17$	1.16	$5.4\,10^{-27}$	$1.3\,10^{-28}$
Majorana	$g_l = 0.9$	1.17	$2.2\,10^{-28}$	$8.9 10^{-30}$

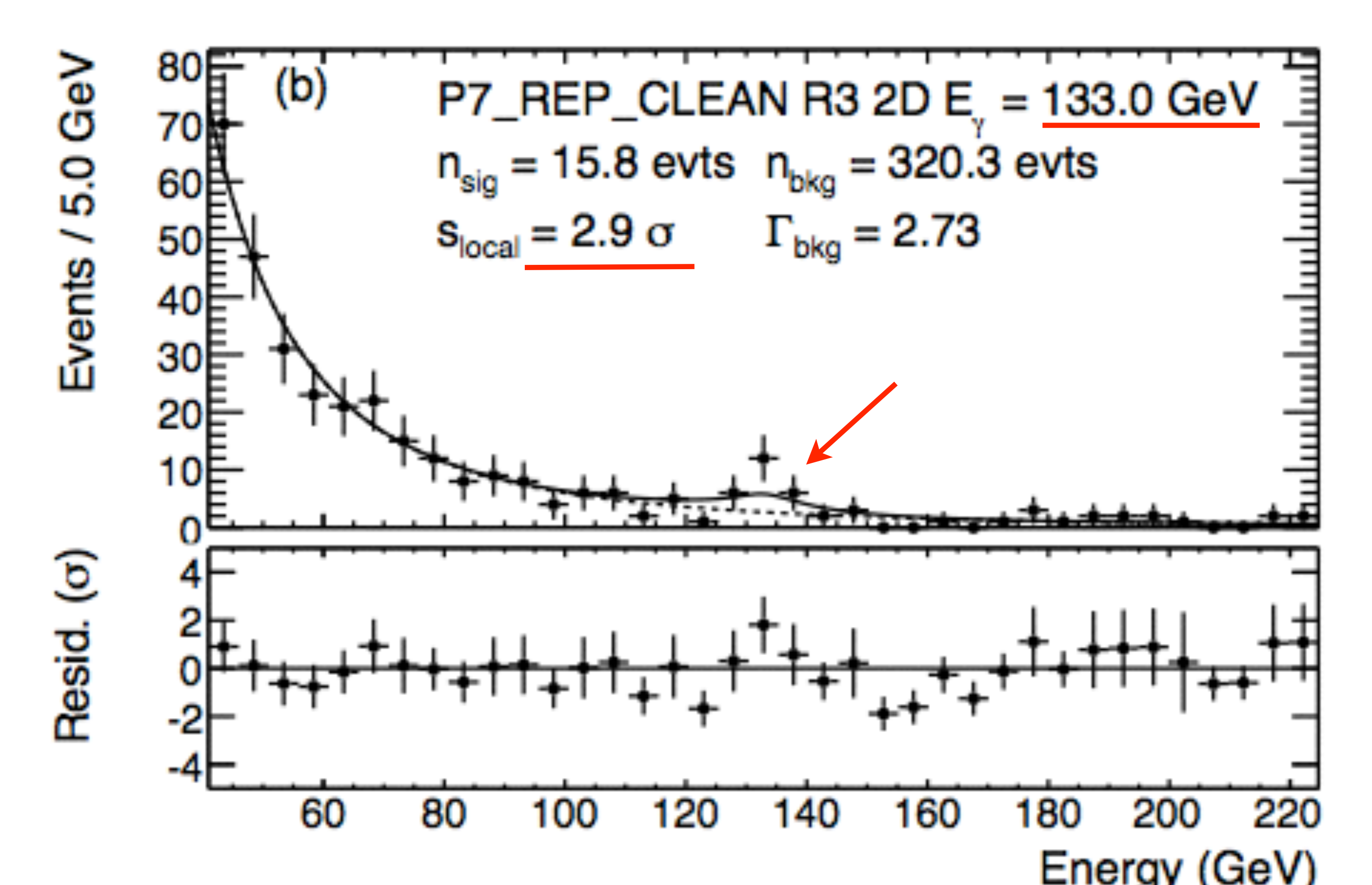
FG, L.Lopez-Honorez and M.Tytgat
JCAP10(2013)025, arXiv 1307.6480

cross sections in units of cm^3/s

$$\langle \sigma v \rangle^{best}_{3Body} \sim 6.2\,10^{-27} cm^3/s$$

$$\langle \sigma v \rangle^{best}_{\gamma\gamma} \sim 1.27\,10^{-27} cm^3/s$$

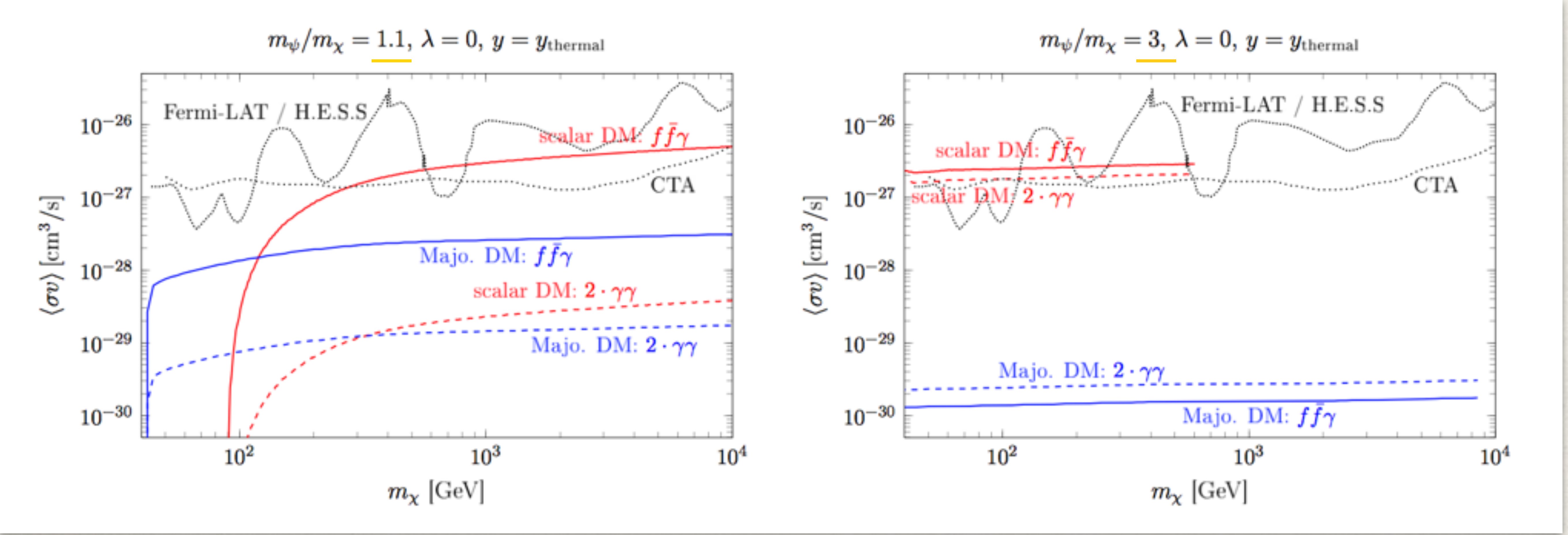
T.Bringmann, X. Huang, A.Ibarra, S.Vogl, C.Weniger
arXiv:1203.1312



FERMI-LAT coll., arXiv 1305.5597

Radiative Emission Cross Sections for the two candidates

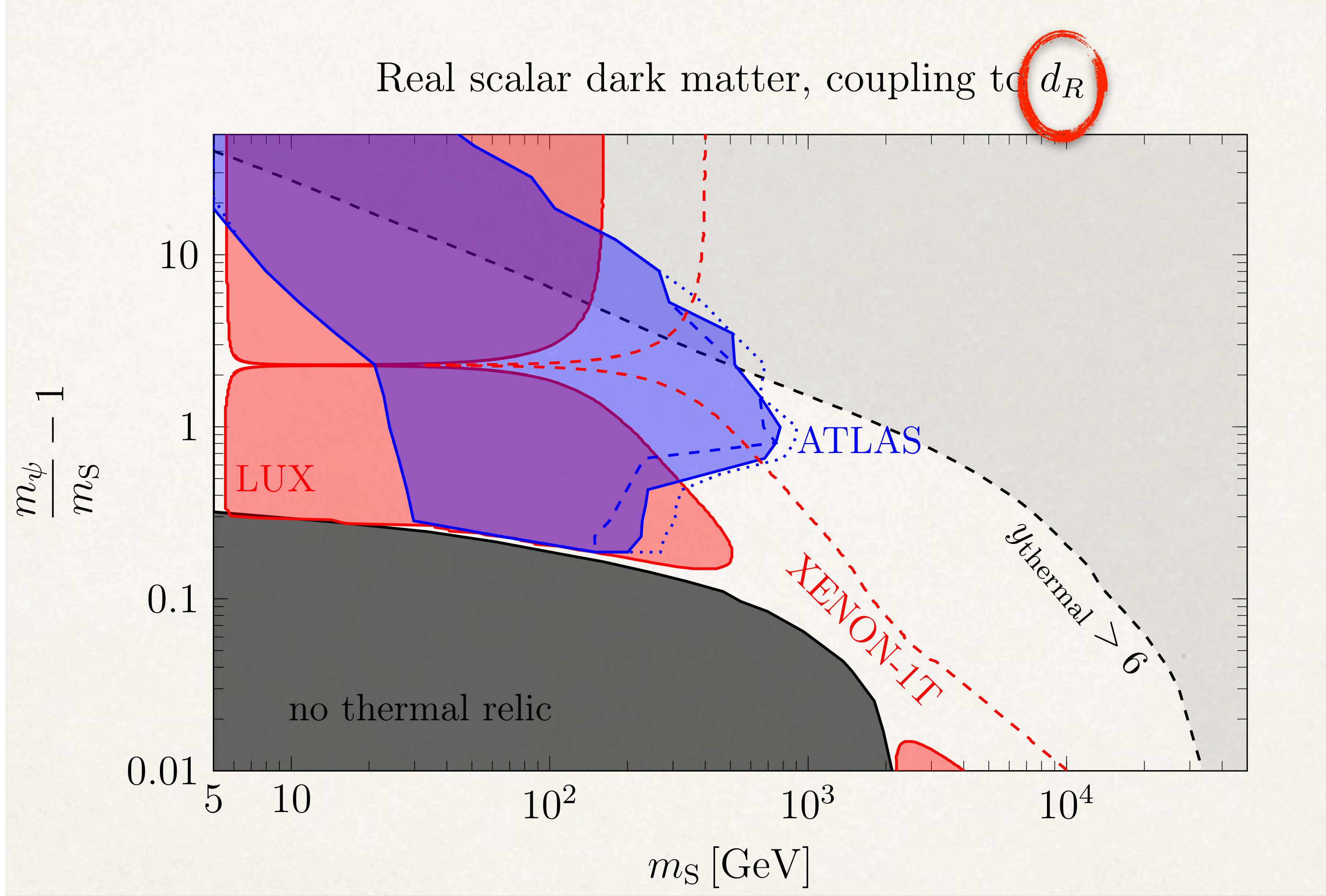
A.Ibarra, T.Toma, M.Totzauer and S.Wild
Phys.Rev. **D90**(2014)4,043526



DM = Scalar: VIB always larger than $\gamma\gamma$, the gap decreases at increasing r $\Longrightarrow$ Testable

DM = Majorana: at small r VIB larger than $\gamma\gamma$,changed relationship at larger r $\Longrightarrow$ never Testable

New Constraints!!



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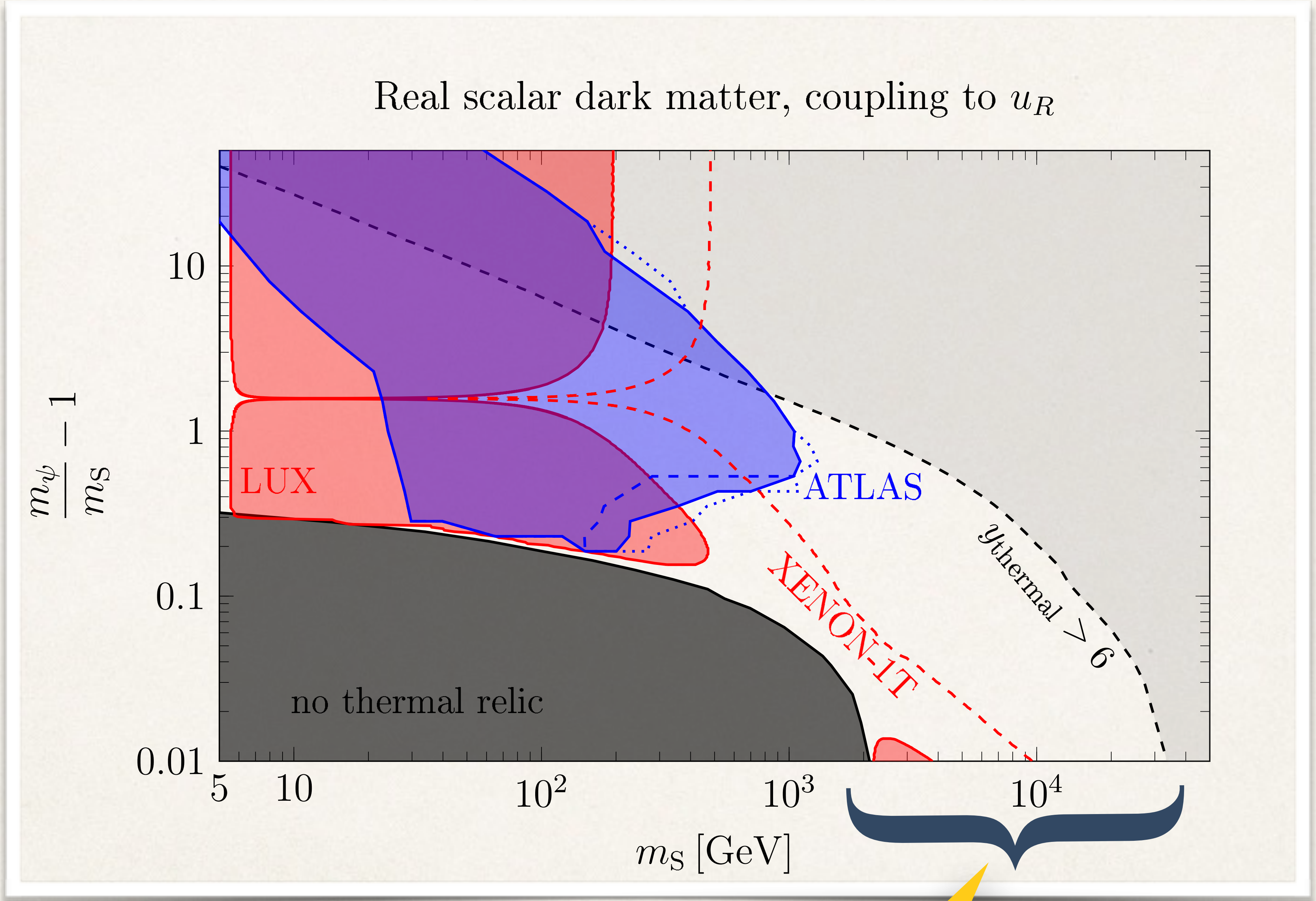
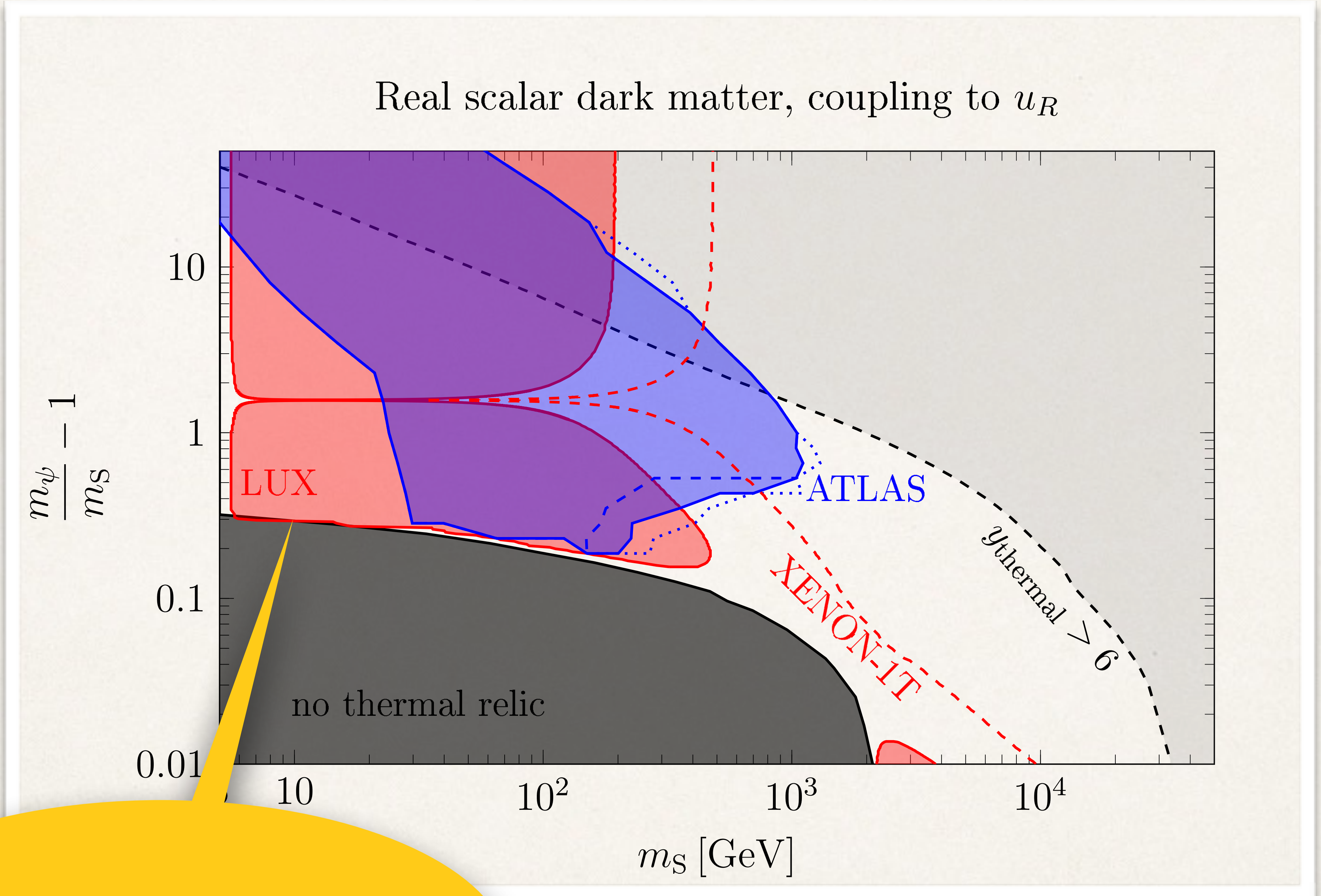


Viable parameter space considering for coannihilations processes Sommerfeld effects (up to 15% changing)

New Constraints!!



Effective approach at fundamental level

✤ *Direct Detection*

$$\sigma_{SN} = \frac{f_N^2 \mu_{SN}^2}{\pi m_S^2}$$

μ_{SN} DM-nucleon reduced mass

f_N coupling interaction between DM and nucleon

Spin-Independent SCATTERING CROSS-SECTION of the Dark Matter off nucleon

Direct Detection

$$\sigma_{SN} = \frac{f_N^2 \mu_{SN}^2}{\pi m_S^2}$$

μ_{SN} DM-nucleon reduced mass

f_N coupling interaction between DM and nucleon

EFFECTIVE APPROACH:
Lagrangian as a sum of higher relevant dimensional operators

Direct Detection

$$\sigma_{SN} = \frac{f_N^2 \mu_{SN}^2}{\pi m_S^2}$$

μ_{SN} DM-nucleon reduced mass

f_N coupling interaction between DM and nucleon

$$\frac{f_N}{m_N} = \frac{y^2}{m_S^2}(f_{T_u}^N C_S^u + 3/4 C_T^u(u(2) + \bar{u}(2)) - 8/9 f_{T_g}^N C_S^g)$$

$$C_S^u = \frac{2r^2-1}{4(r^2-1)^2}$$

$$C_T^u = \frac{1}{(r^2-1)^2}$$

SCALAR & TENSORIAL interaction between DM and quarks found at tree level

Direct Detection

$$\sigma_{SN} = \frac{f_N^2 \mu_{SN}^2}{\pi m_S^2}$$

μ_{SN} DM-nucleon reduced mass

f_N coupling interaction between DM and nucleon

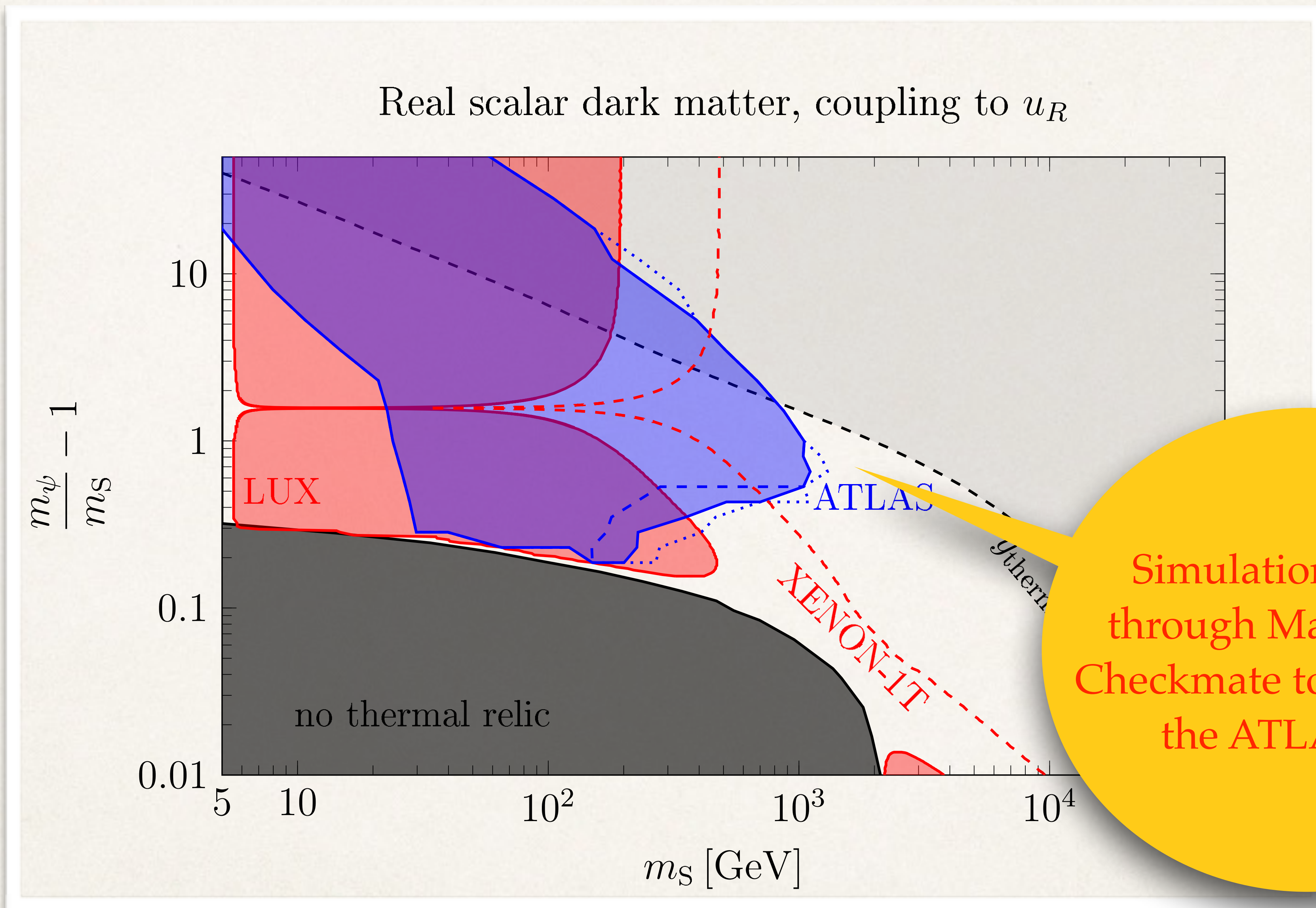
$$\frac{f_N}{m_N} = \frac{y^2}{m_S^2}(f_{T_u}^N C_S^u + 3/4 C_T^u(u(2) + \bar{u}(2)) - 8/9 f_{T_g}^N C_S^g)$$

$$C_S^g = \frac{1}{24(r^2-1)}$$

SCALAR interaction between DM and gluons found at one-loop level: *short-distance regime*

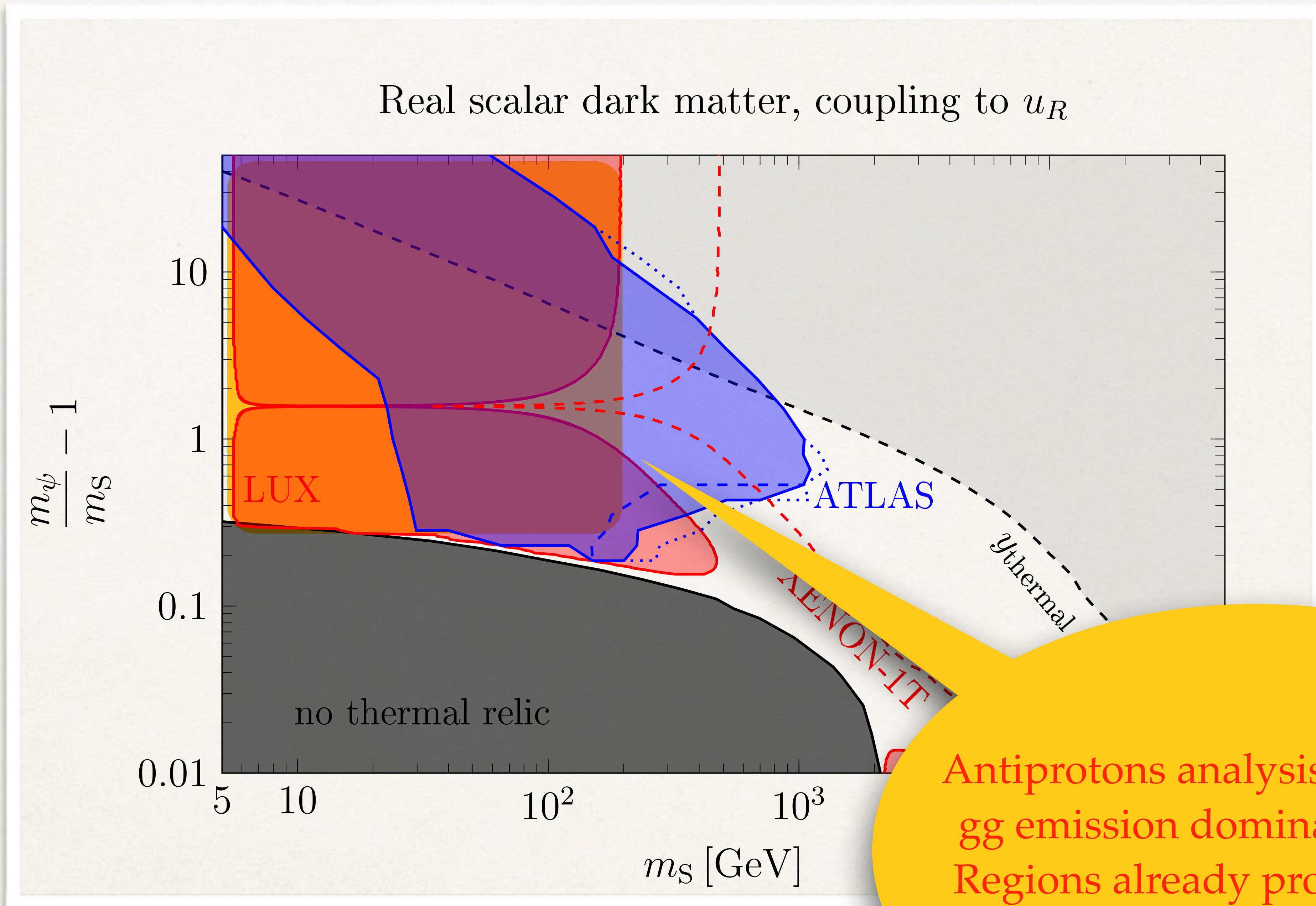
$$M_\Psi - M_S >> m_q$$

New Constraints!!



Simulation of MET through MadGraph + Checkmate to implement the ATLAS data

New Constraints!!



Antiprotons analysis: VIB gluon + gg emission dominant channels. Regions already probed by other approaches

Antiprotons constraints