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Gamma-ray Test of Minimal Dark Matter

Paolo Panci

based on:
M. Cirelli, T. Hambye, P. Panci, F. Sala, M. Taoso
Published in JCAP 1510 (2015) 10, **026**
[arXiv: 1507.05519]

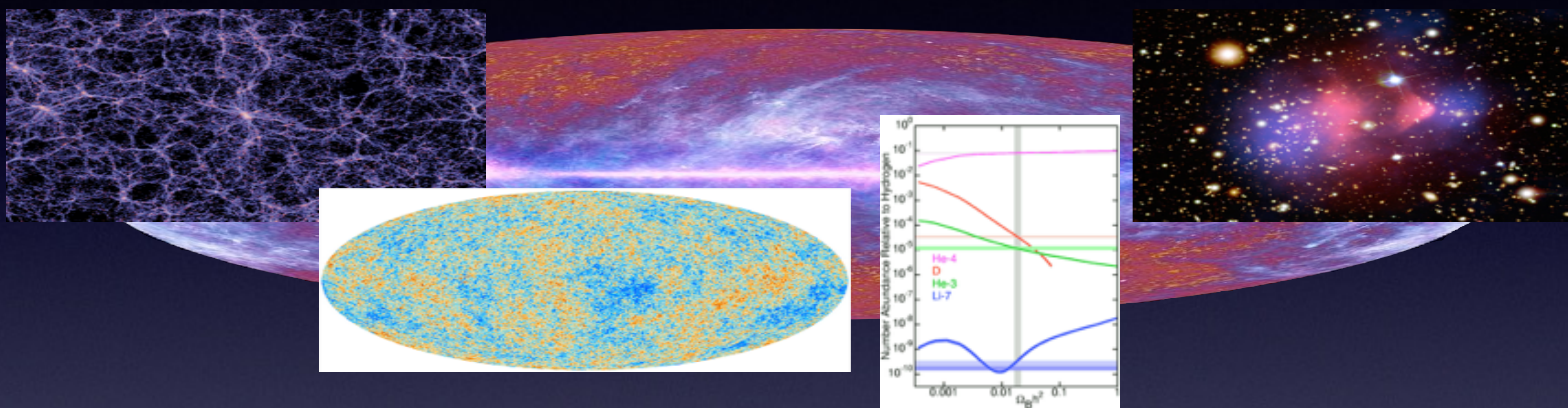
ERC
DARK MATTERS @ IAP/UPMC

IAP

UPMC
PARIS UNIVERSITAS

DM Open Questions

There are compelling and strong evidences of *non-baryonic matter* in the Universe; from galactic to cosmological scale



BUT !!

The microphysics of this new kind of matter is unknown yet

- ☑ ***DM candidate***: axions, wino, MDM 5-plet, wimpzillas, etc...
- ☑ ***Underlying theory***: supersymmetry, technicolor, mirror models, etc...
- ☑ ***DM density profile***: cuspy profile (NFW, Einasto), cored profile (isothermal)

Stability of DM

Stability may be explained in terms of symmetries

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i) ***Impose a symmetry by "hand" to force stability of DM***

- ☑ **Most of DM models use this mechanism:** (e.g. supersymmetric models)
- ☑ **Hope:** Can this symmetry be justified in a UV completions of the model ?

Stability of DM

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ii) ***Stability via accidental symmetries (Elegant & Robust)***

- ☑ **Accidental symmetries:** gift of the specific matter content of the model
- ☑ **This mechanism already exist in nature**: B & L conservation in the SM

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This is the main idea of the **MDM model** "Minimal Dark Matter", Nucl.Phys.**B753** (2006), 178-194

Minimal Dark Matter framework

Standard Model (SM) + **new generic multiplet** χ

$$\mathcal{L}_{\rm SM}$$

$$\frac{1}{2}\bar{\chi}\left(i\gamma_\mu D^\mu - M_\chi\right)\chi$$

Charged under the SM group

Minimal: no additional symmetries are included

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- ☑ **Requirement 1:** χ contains a suitable DM candidate (stable & allowed by present observations)
- ☑ **Requirement 2:** The theory does not develop a Landau pole before the assumed cut-off (Planck scale)

These requirements are used to select the quantum numbers of χ

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Results:

- ☑ The only viable MDM multiplet is a fermionic quintuplet both color- and hypercharged- neutral **(1,5,0)** ← quantum numbers under the SM group

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quantum numbers under the SM group

- ☑ The scalar septuplet **(1,7,0)** is no longer a viable DM candidate!! It decays very quickly due to previously overlooked dim. 5 operator

NO !! $\mathcal{O}_{5d} \equiv \chi\chi\chi H^\dagger H$ ⟹ $\tau_{7p} \sim 1\,\mathrm{s}$ see e.g. arXiv:1504.00359

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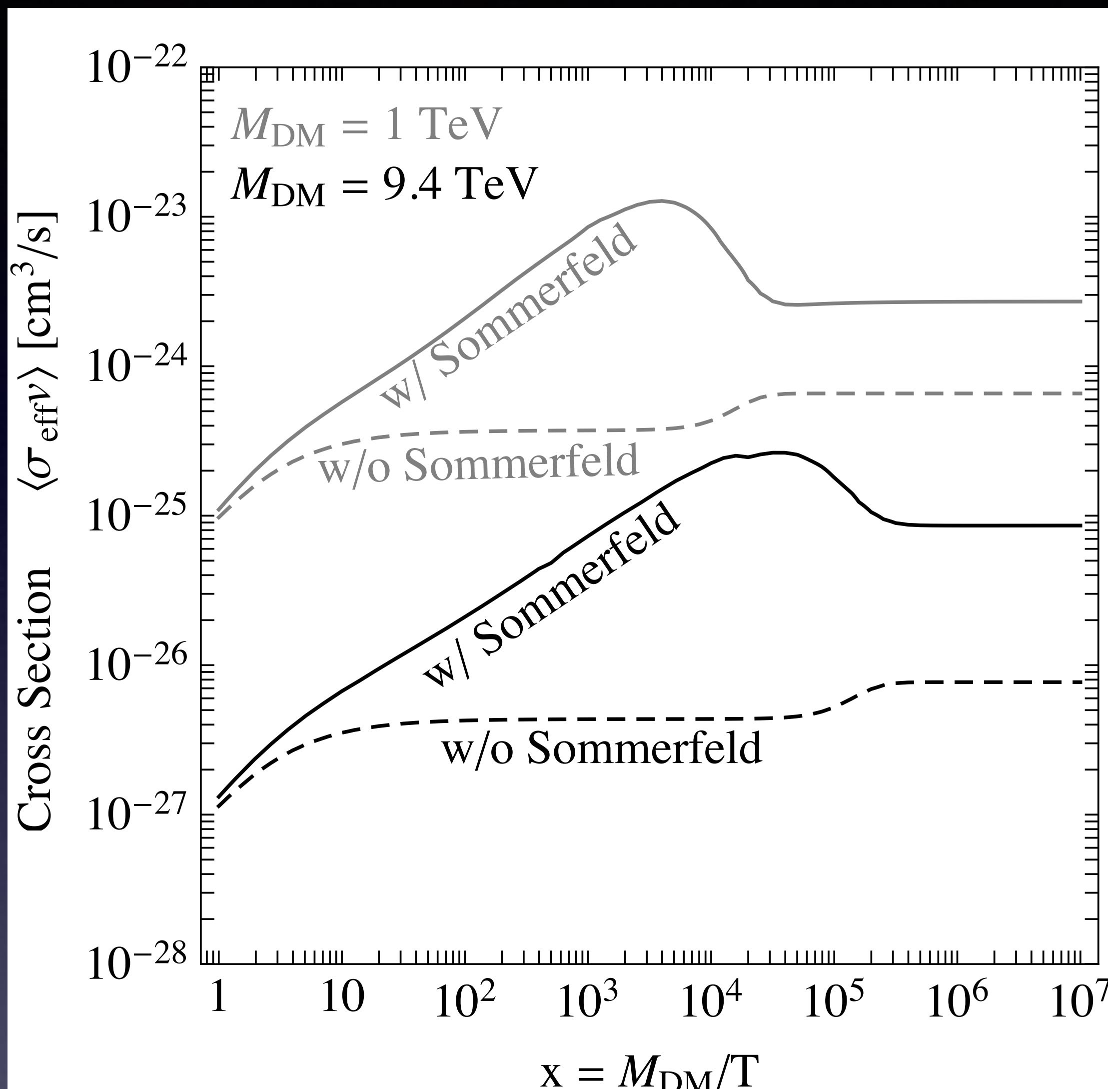
Int. Lagrangian of the 5plet $\chi_\alpha = (\chi_0, \chi^\pm, \chi^{\pm\pm})$:

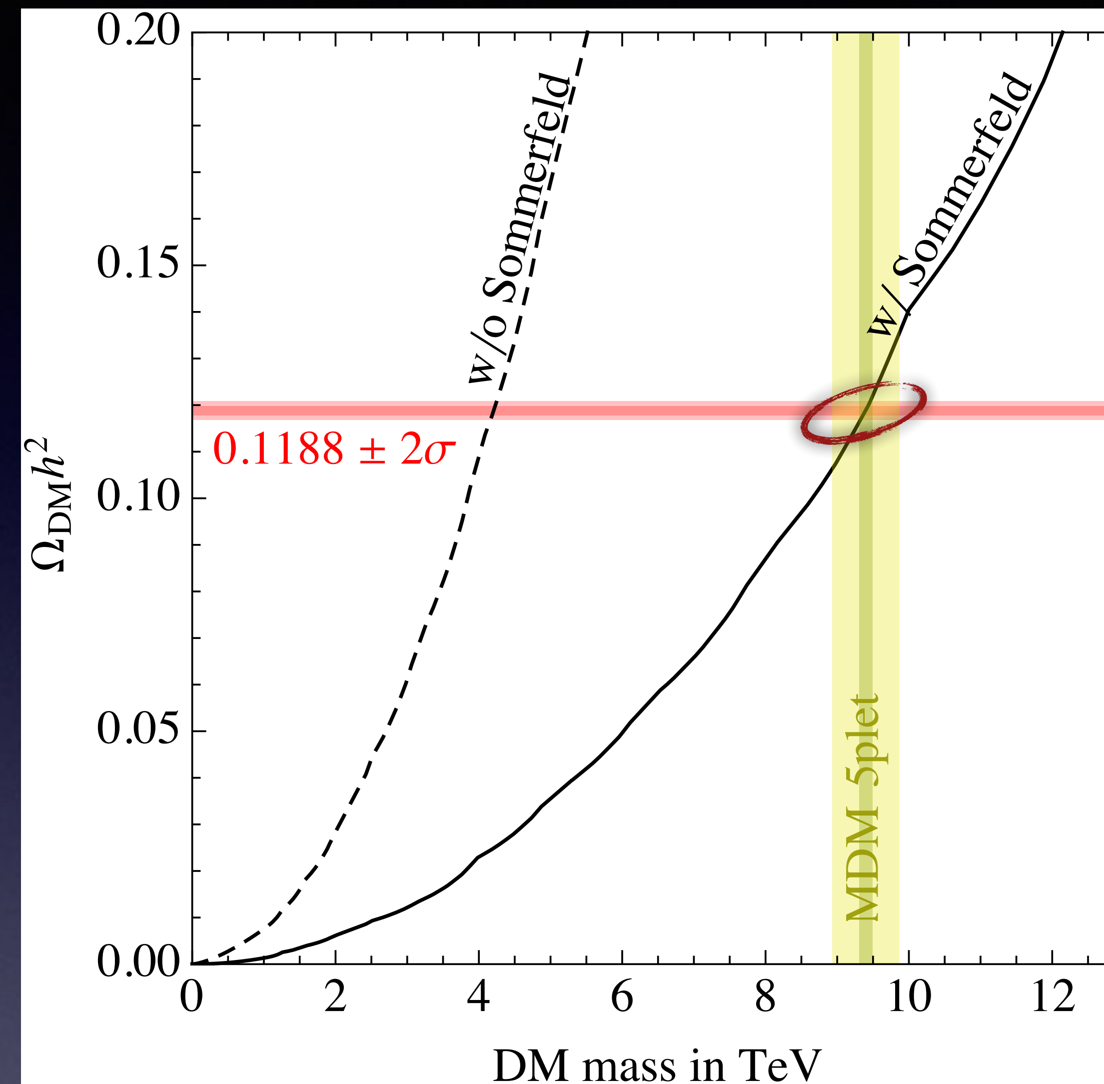
$$\begin{aligned}\mathcal{L}_\chi &= \frac{1}{2}\,\overline{\chi}(i\not{D} - M_\chi)\chi \\ &= \frac{1}{2}\,\overline{\chi_0}(i\not{\partial} - M_{\chi_0})\chi_0 + \overline{\chi^+}(i\not{\partial} - M_{\chi^\pm})\chi^+ + \overline{\chi^{++}}(i\not{\partial} - M_{\chi^{\pm\pm}})\chi^{++} \\ &\quad + g(\overline{\chi^+}\gamma_\mu\chi^+ + 2\,\overline{\chi^{++}}\gamma_\mu\chi^{++})(s_w A_\mu + c_w Z_\mu) \\ &\quad + g(\sqrt{3}\,\overline{\chi^+}\gamma_\mu\chi_0 + \sqrt{2}\,\overline{\chi^{++}}\gamma_\mu\chi_+)W^-_\mu + \text{h.c.}\end{aligned}$$

- SM gauge couplings and mediators
- the **mass** is the only free parameter

M_χ can be determined by demanding that χ_0 is thermally produced

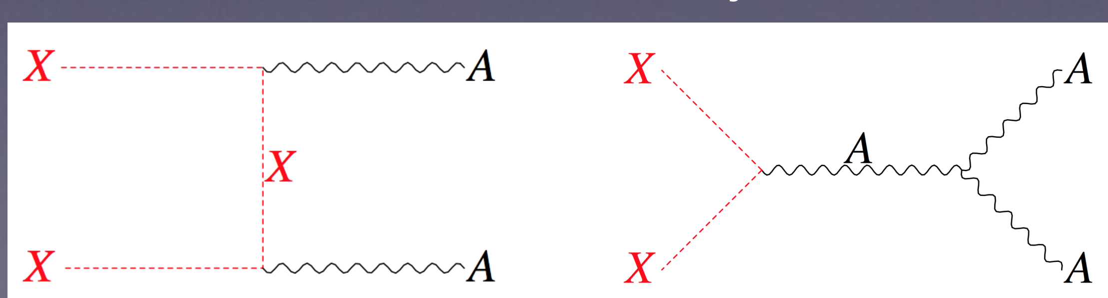
Relic Density





"γ-Ray Test of Minimal Dark Matter", JCAP 1510 (2015) 10, 026

The XS can be fully computed in EW Theory



Important to include:

- ✔ all the possible $\chi_\alpha \chi_\beta$ co-annihilations
- ✔ Sommerfeld corrections (solid lines)

The neutral component of the 5plet has a **mass of 9.4 TeV**

MDM 5plet at Colliders

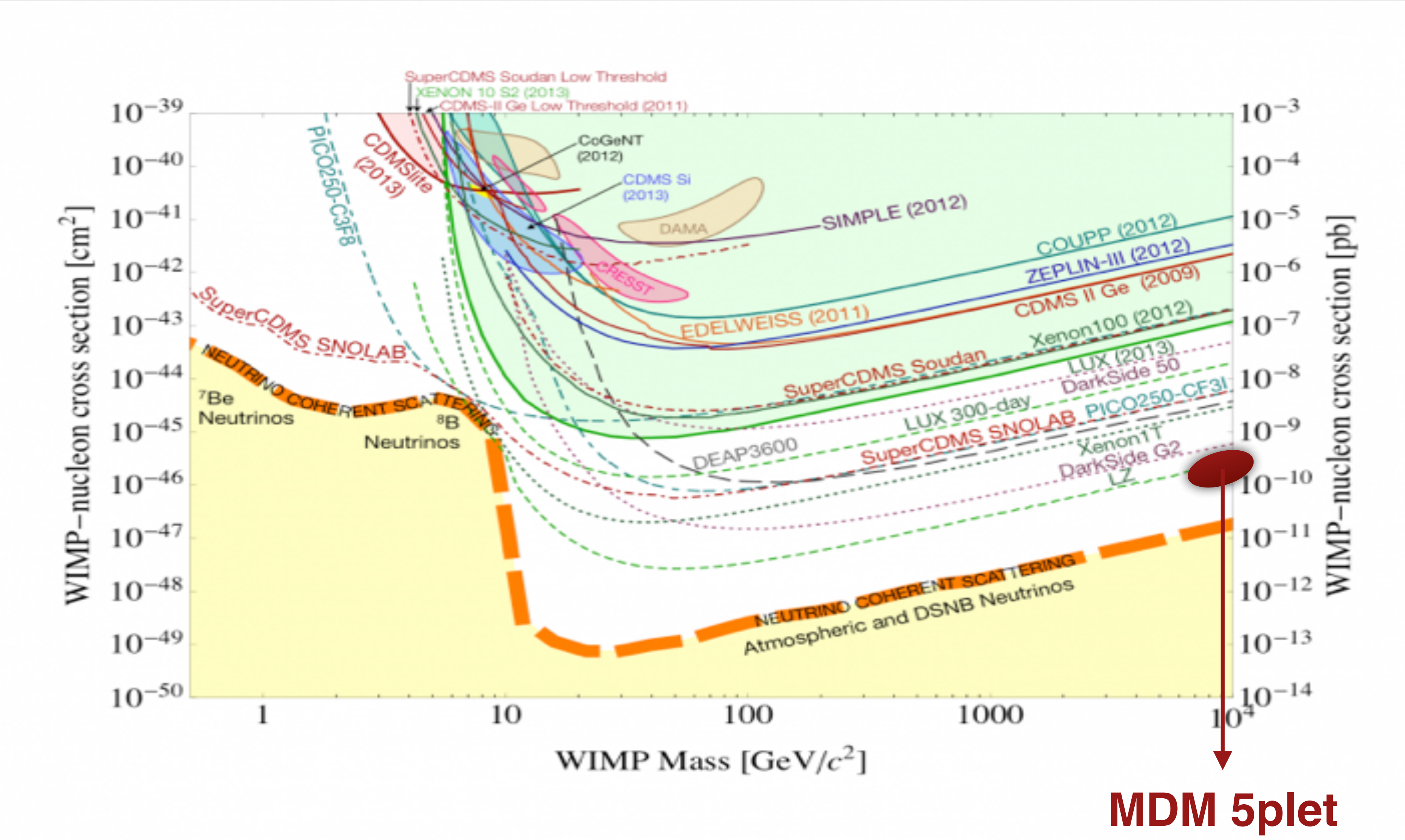
production at colliders

See the talk of **FILIPPO SALA**
- EW multiplets at colliders & ID

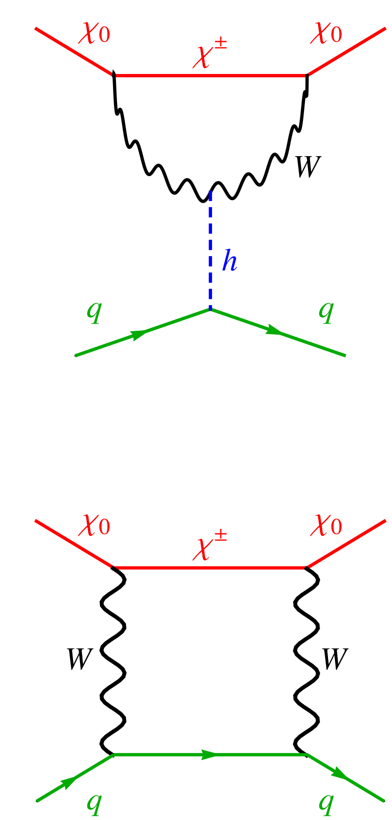
Monday 26.10.2015

- ☑ **NO HOPE** to reach the thermal mass of 9.4 TeV
  (even with a 100 TeV collider)

Direct Detection



Scattering XS



The MDM 5plet **has Y=0** → No tree-level couplings with the Z

Hisano et al. 1504.00915 : $\sigma_{\rm SI}^{\rm 5plet} = 1.9 \times 10^{-46} {\rm cm}^2$ NLO in α_s, $\mathcal{O}(50\%)$ uncertainty

✔ **NO HOPE** to reach the predicted value of the SI scattering cross section (perhaps with LZ !!)

Indirect Detection

Indirect detection is the most promising strategy

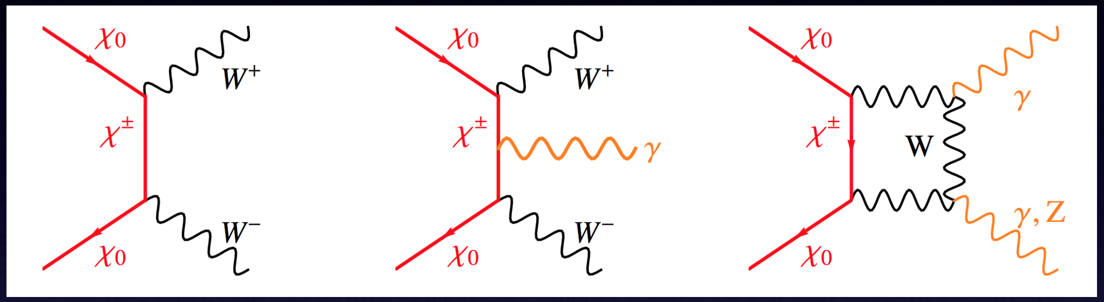
- γ-Ray Test of Minimal Dark Matter
  - γ-Ray Continuum:
    - Constraints from the measurements of the Gal. diffuse emission by Fermi
    - Constraints from the observations of dSphs by Fermi, H.E.S.S. & MAGIC
  - γ-Ray Lines:
    - Constraints from the observations of the Gal. center by H.E.S.S.
    - Only available constraint from the observation of Segue 1 by MAGIC

based on: M. Cirelli, T. Hambye, P. Panci, F. Sala, M. Taoso, JCAP 1510 (2015) 10, **026**
similar work: C. Garcia-Cely, A. Ibarra, A.S. Lamperstorfer, M.H.G. Tytgat, [arXiv:1507.05536]

XS Predictions

Important ingredient:

✔ $M_\chi \gg M_{\rm SM,\,B}$ → the NR Sommerfeld effect can boost annihilation XSs



- at low velocity -> NR attractive potential
- the Sommerfeld saturates for $v/c \lesssim 10^{-2}$

Milky Way: $v \sim 10^{-3}c$

dSphs: $v \sim 10^{-5}c$

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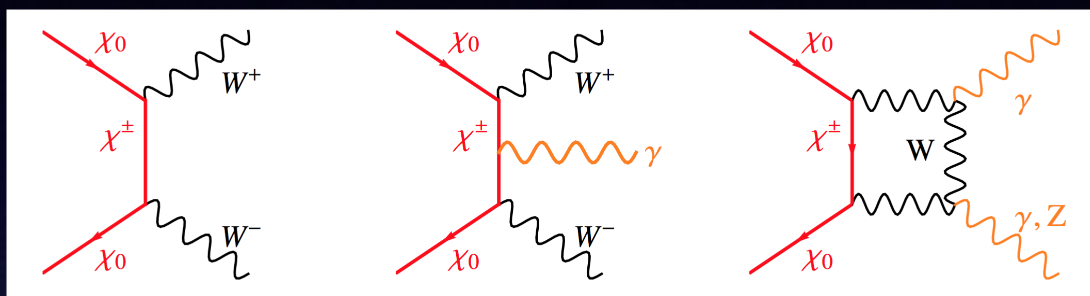

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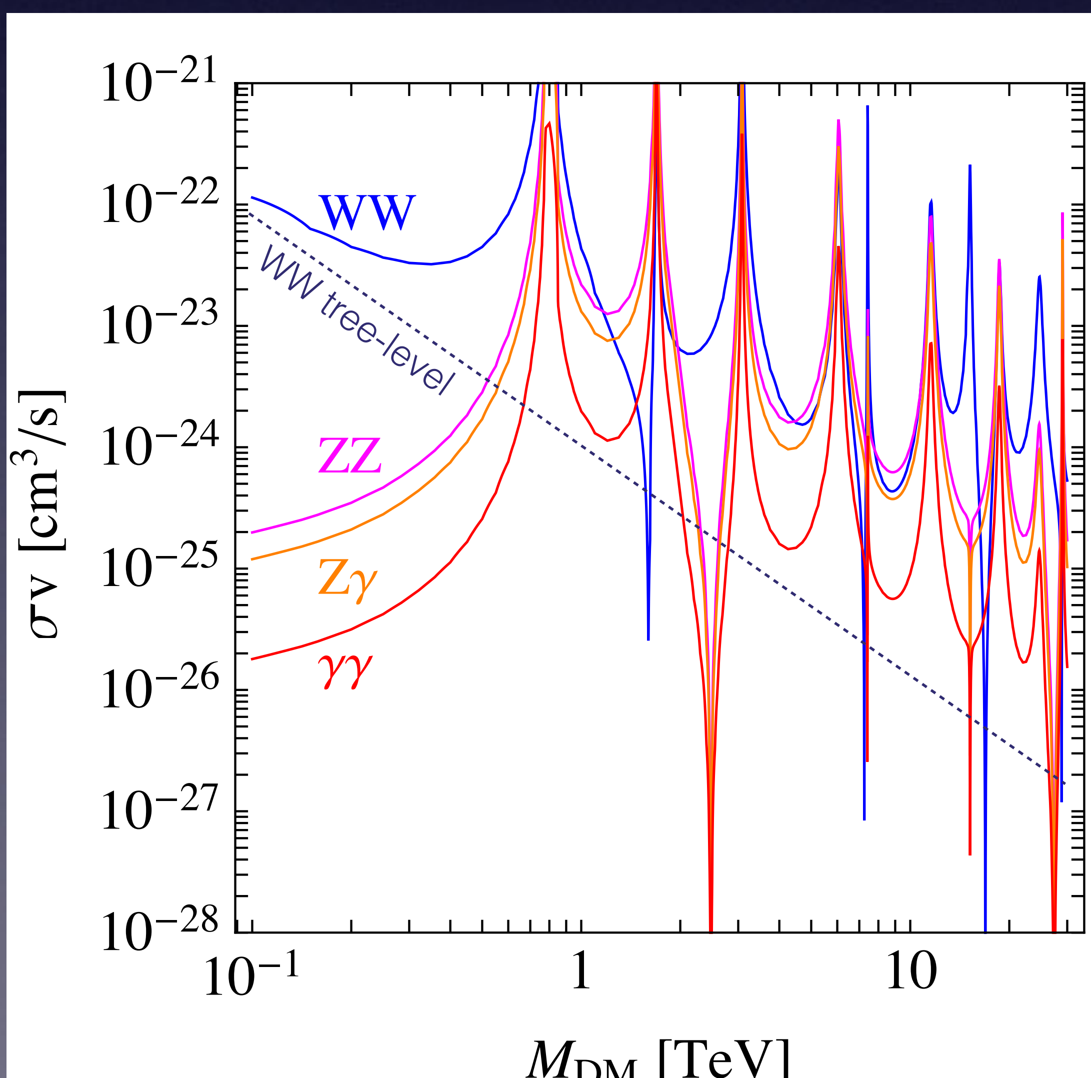

Important Result:

- ✔ The annihilation XSs in γγ and γZ are big !!
  - The Sommerfeld mixes the $\chi_0\chi_0$ initial state with $\chi^+\chi^-$ and $\chi^{++}\chi^{--}$ that couple with γ

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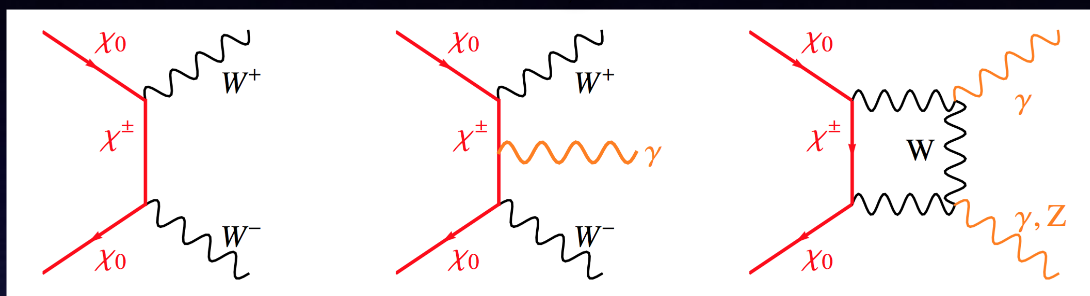

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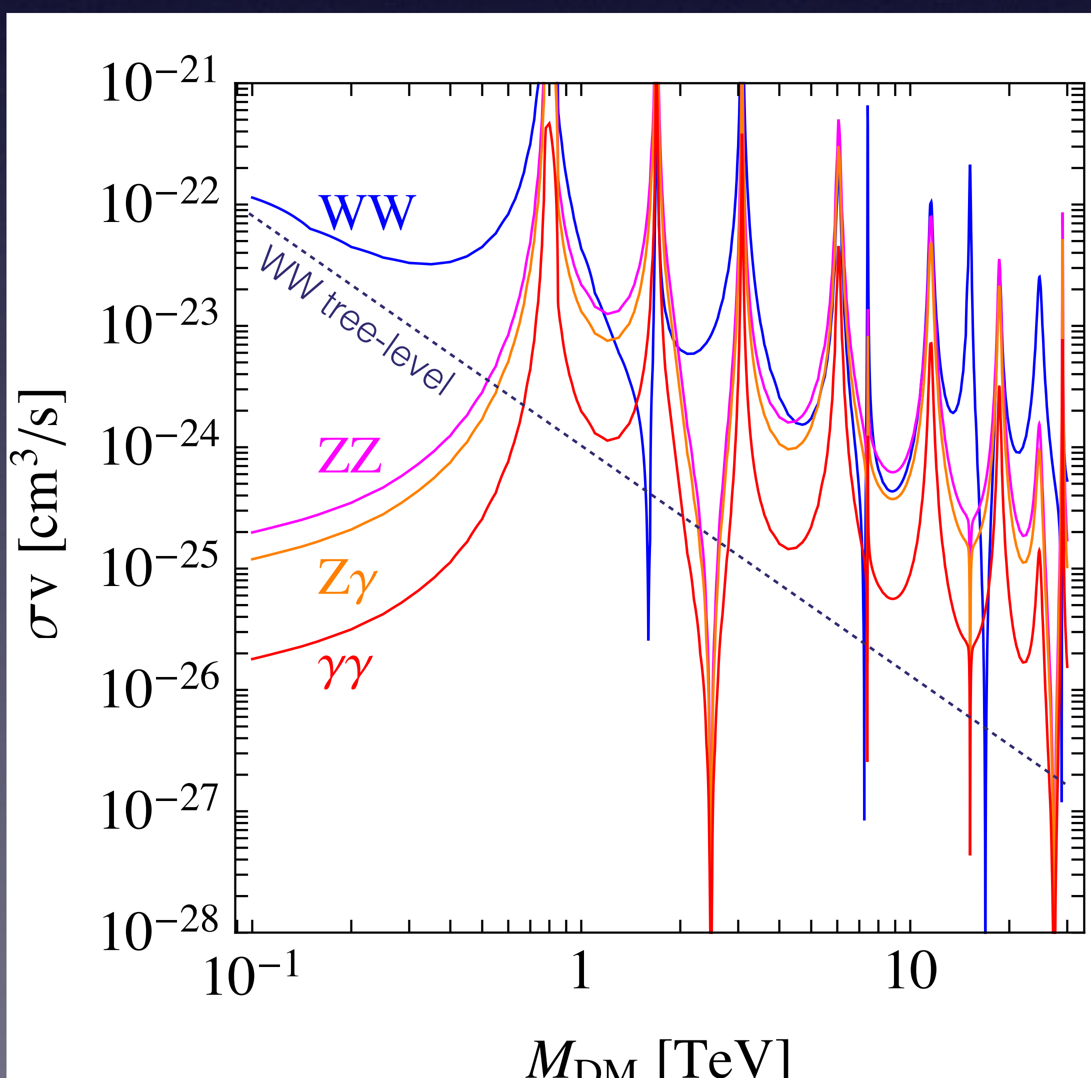

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Comparison with data:

- ✔ Continuum Searches:

$$\langle\sigma v\rangle \equiv \langle\sigma v\rangle_{WW} + \langle\sigma v\rangle_{ZZ} + \langle\sigma v\rangle_{Z\gamma}/2$$

- ✔ γ-ray line Searches:

$$\langle\sigma v\rangle \equiv \langle\sigma v\rangle_{Z\gamma}/2 + \langle\sigma v\rangle_{\gamma\gamma}$$

γ Continuum: Fermi

Constraints from the measurement of the Gal. diffuse emission

- we divide the sky in 35 non-overlapping regions
- in each region, we model the diffuse bkg. considering several components:

  i) a template for the Gal. diffuse emission produced by charged CR
  ii) a template for point-like sources
  iii) a template for the so-called "Fermi bubbles"
  iv) the isotropic γ-ray bkg.

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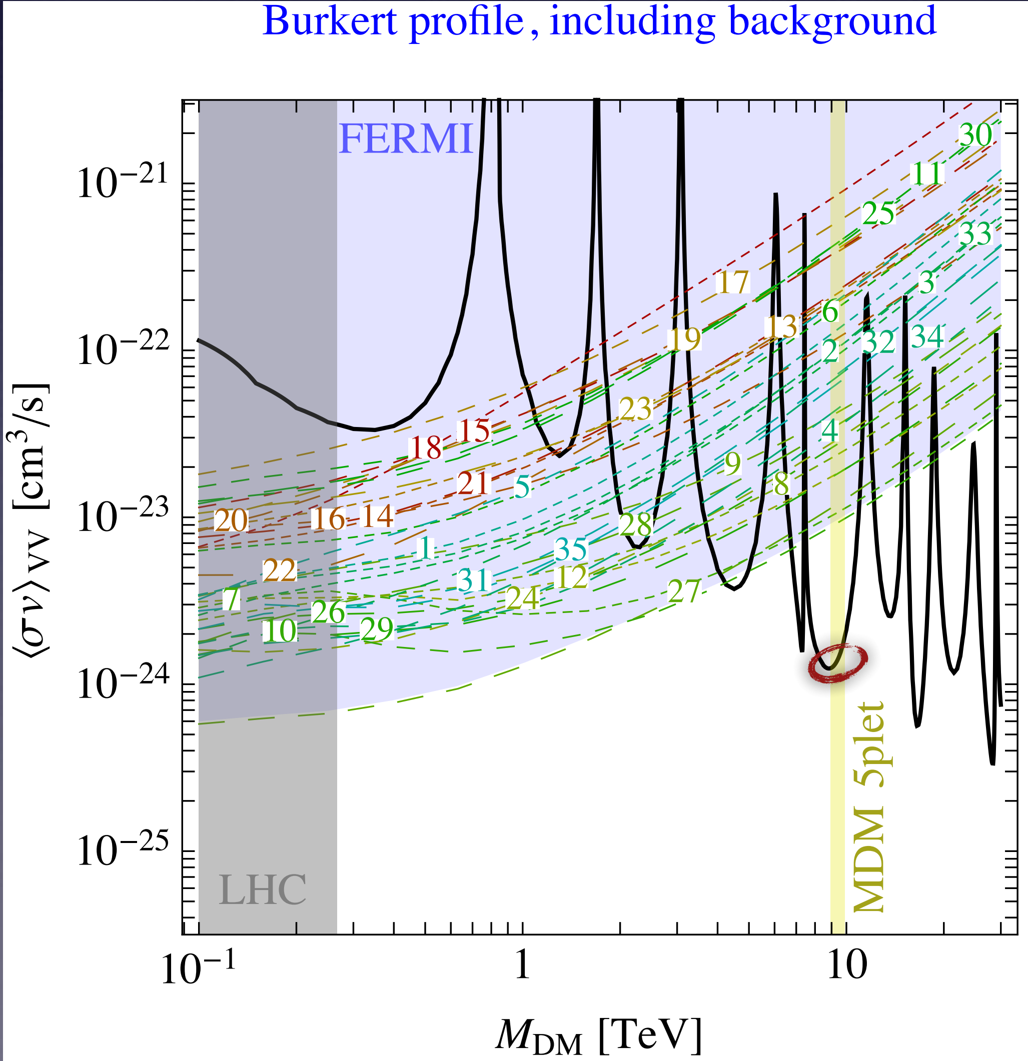

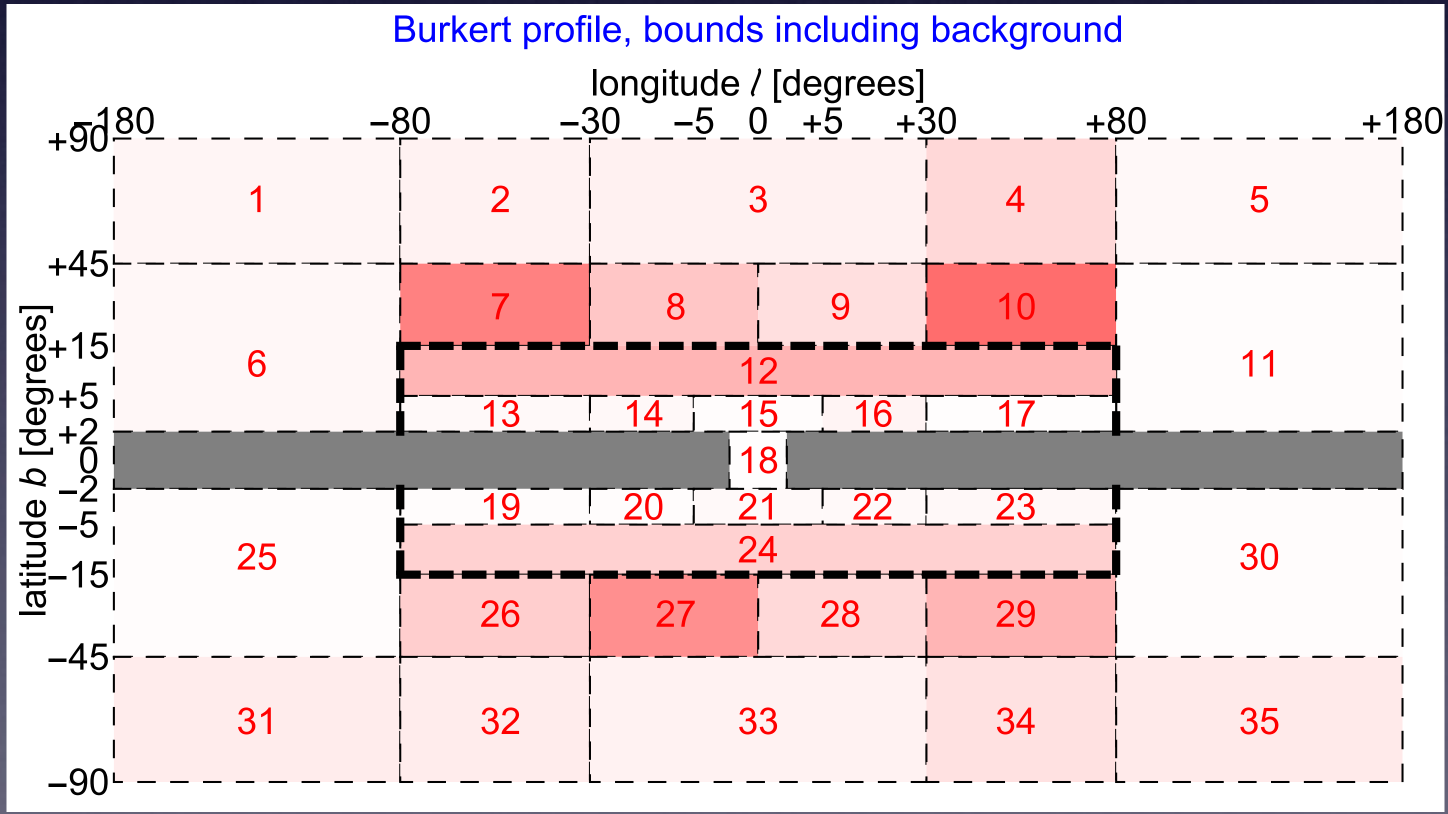

the most stringent bound from RoI 10
factor $\simeq 6$ above the predicted XS

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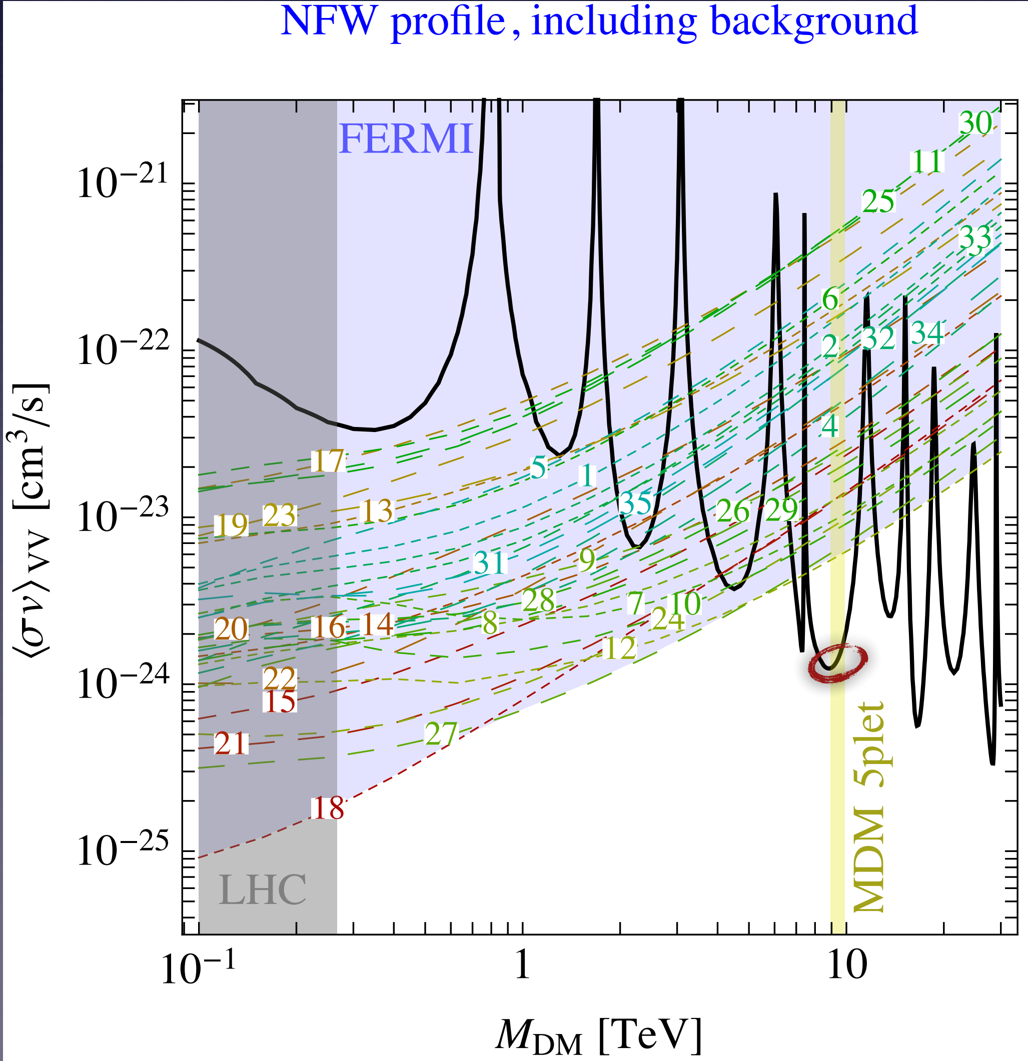

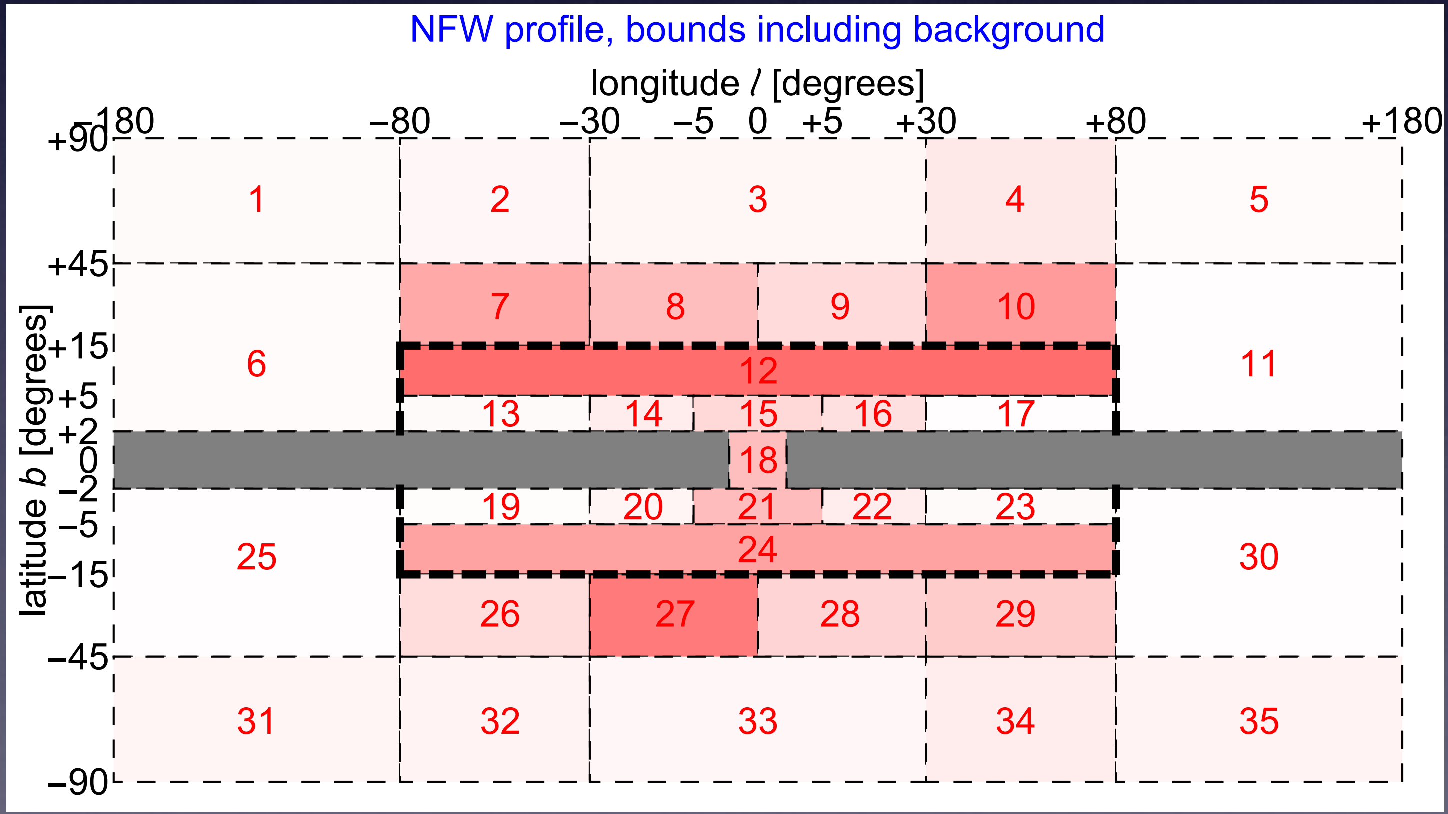

the most stringent bound from RoI 12
factor $\simeq 4$ above the predicted XS

γ Continuum: dSphs

dSph galaxies are probably the cleanest laboratory for looking at DM signals

- high Dark Matter content
- low stellar foreground emission

→ this is why they are good target !!

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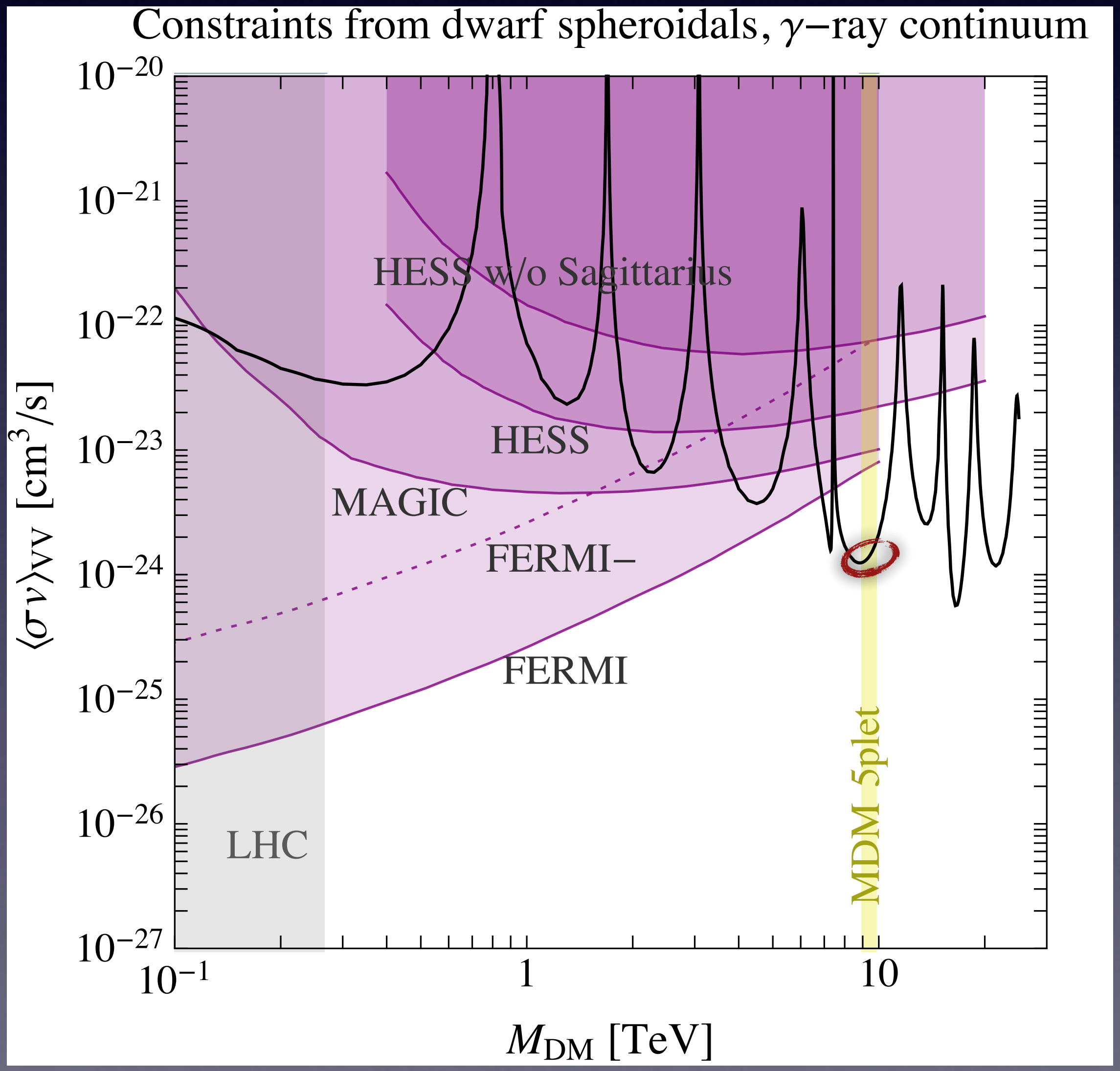

Fermi: staking analysis of 15 dSphs
HESS: a subset of 4 dSphs + Sagittarius
MAGIC: only Segue 1

γ Continuum: dSphs

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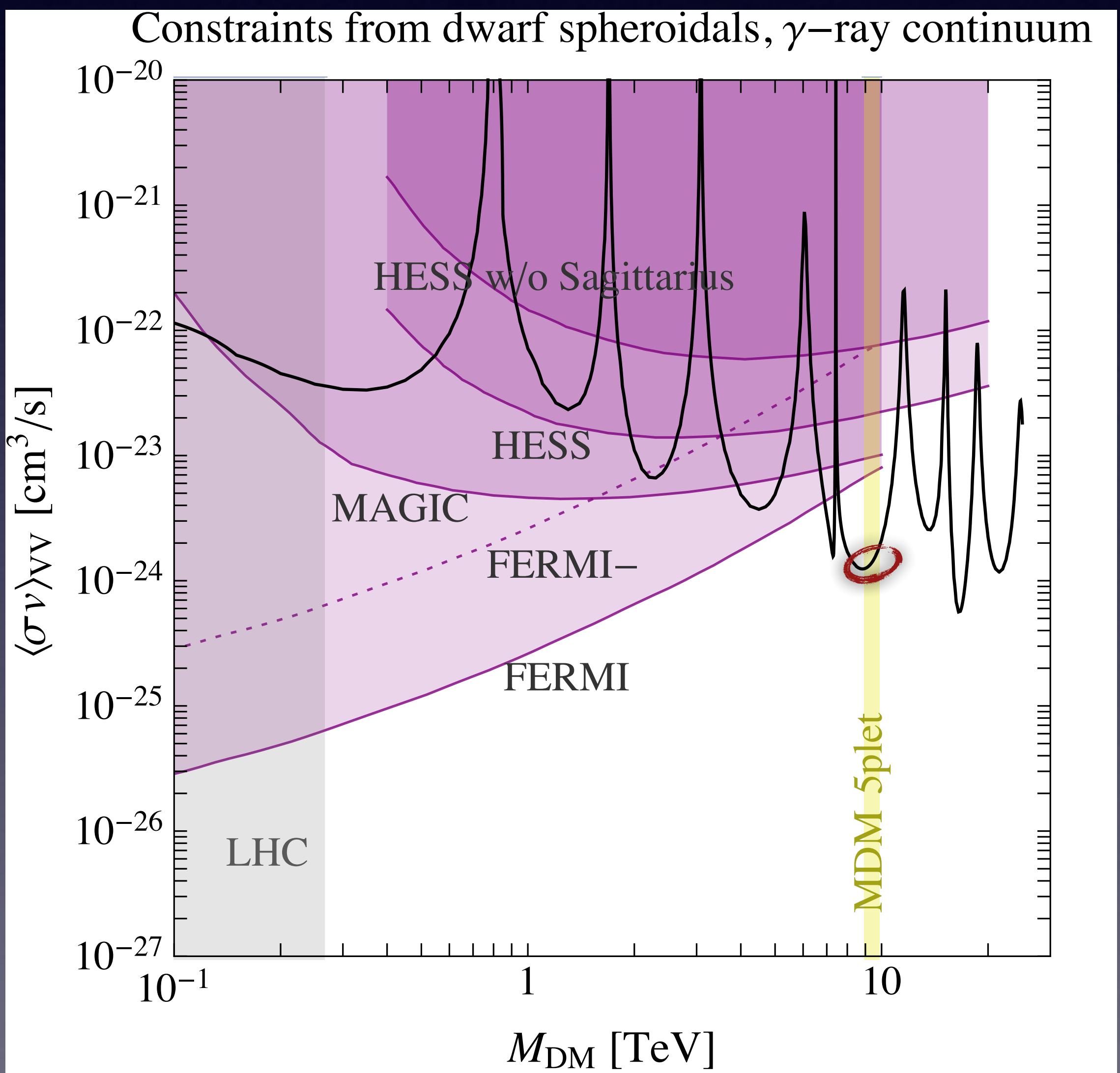

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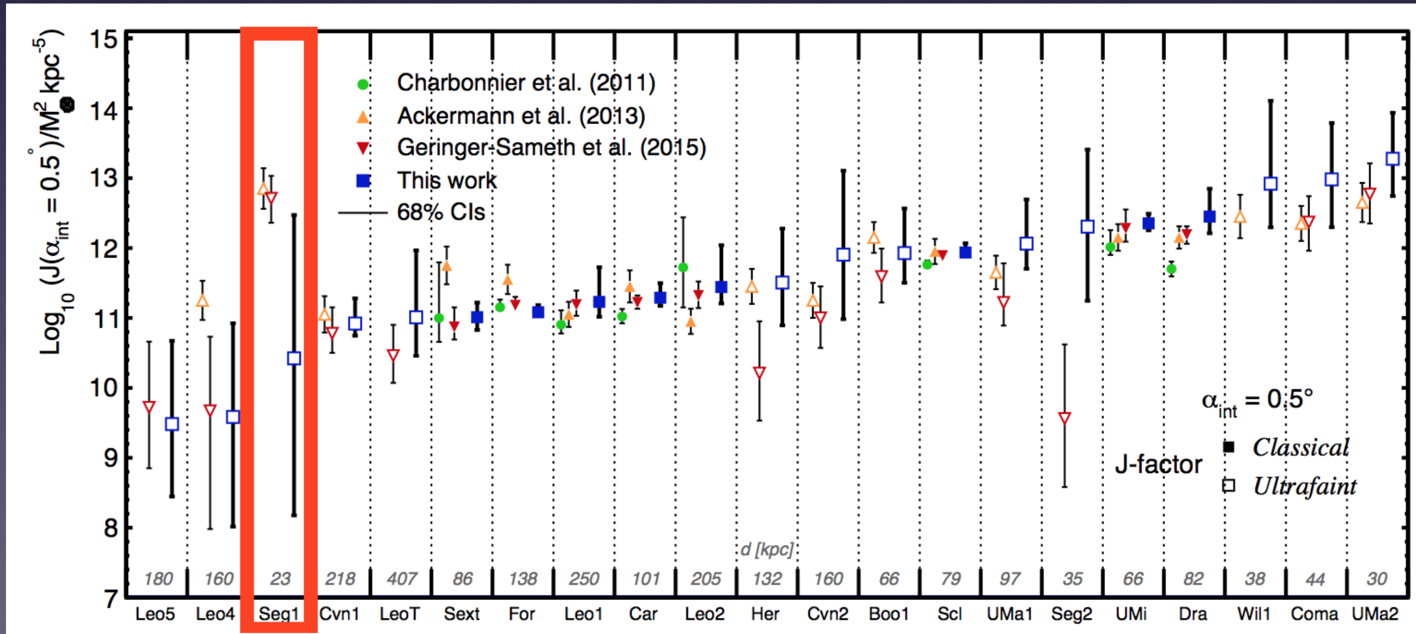

Bonnivard et al 1504.02048

The *J*-factors & statistical errors in Bonnivard et al. are quite different with respect to those used by the exp. collaborations

γ lines: GC & dSphs

The MDM 5plet predicts large cross sections into γγ and γZ

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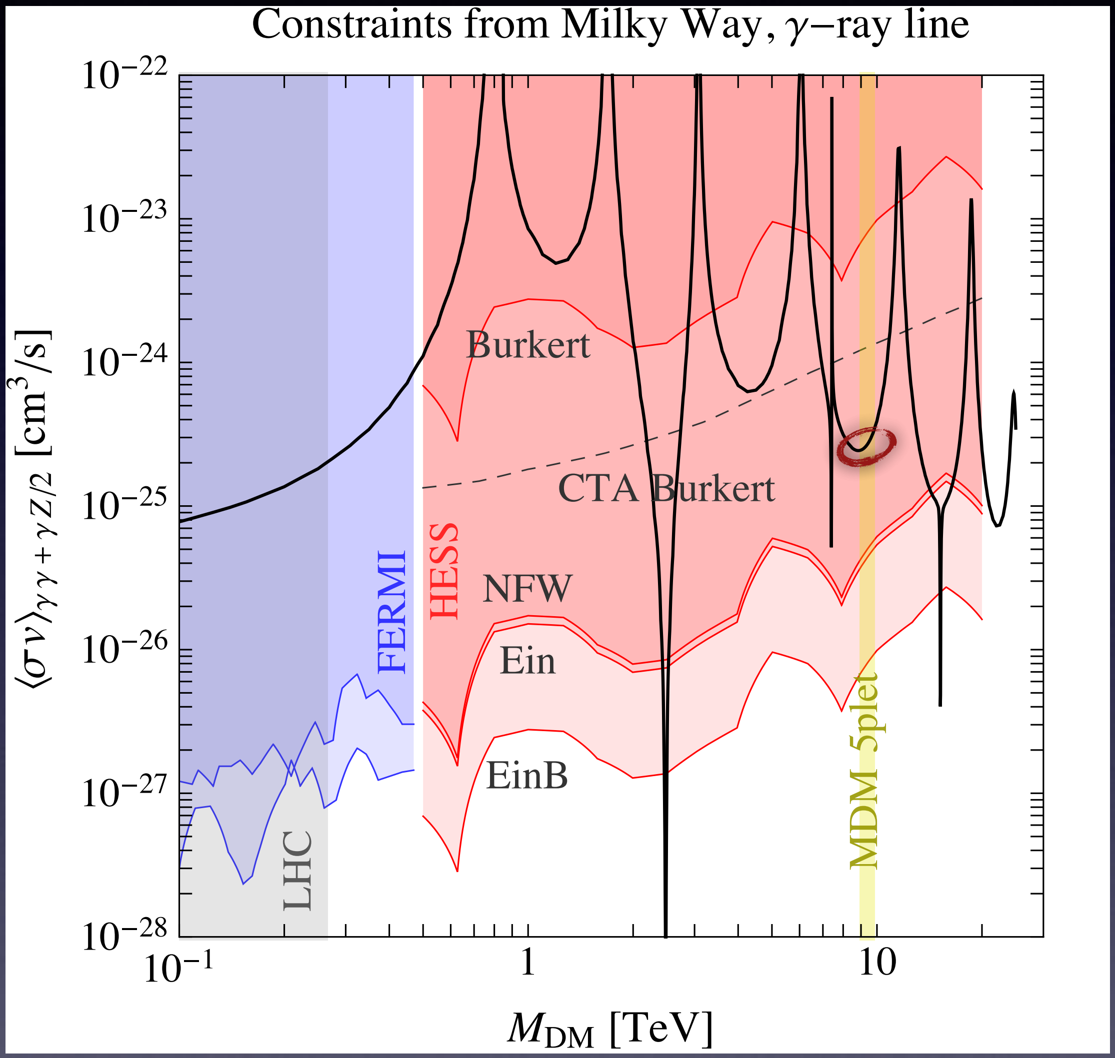


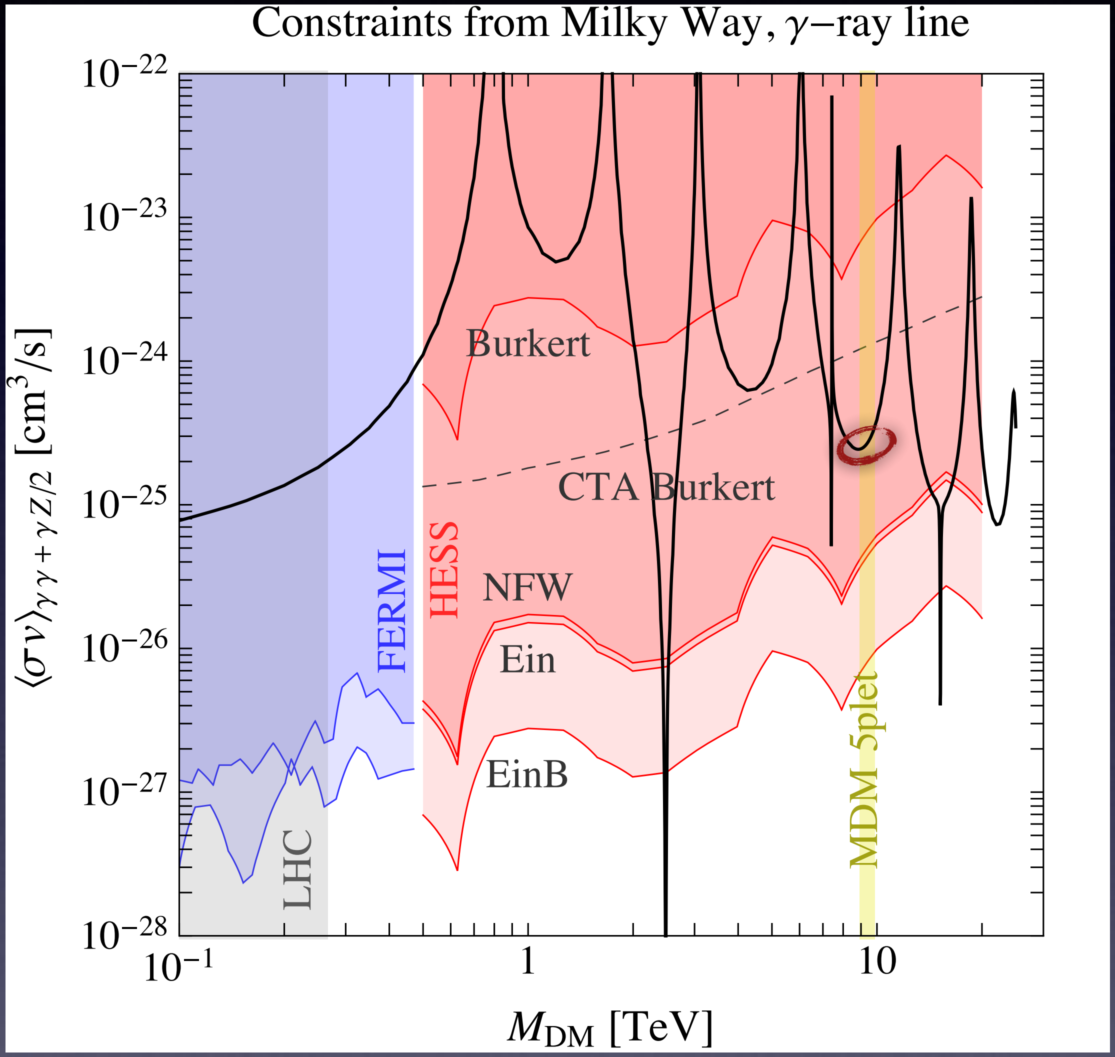
HESS: 112h observations of the GC

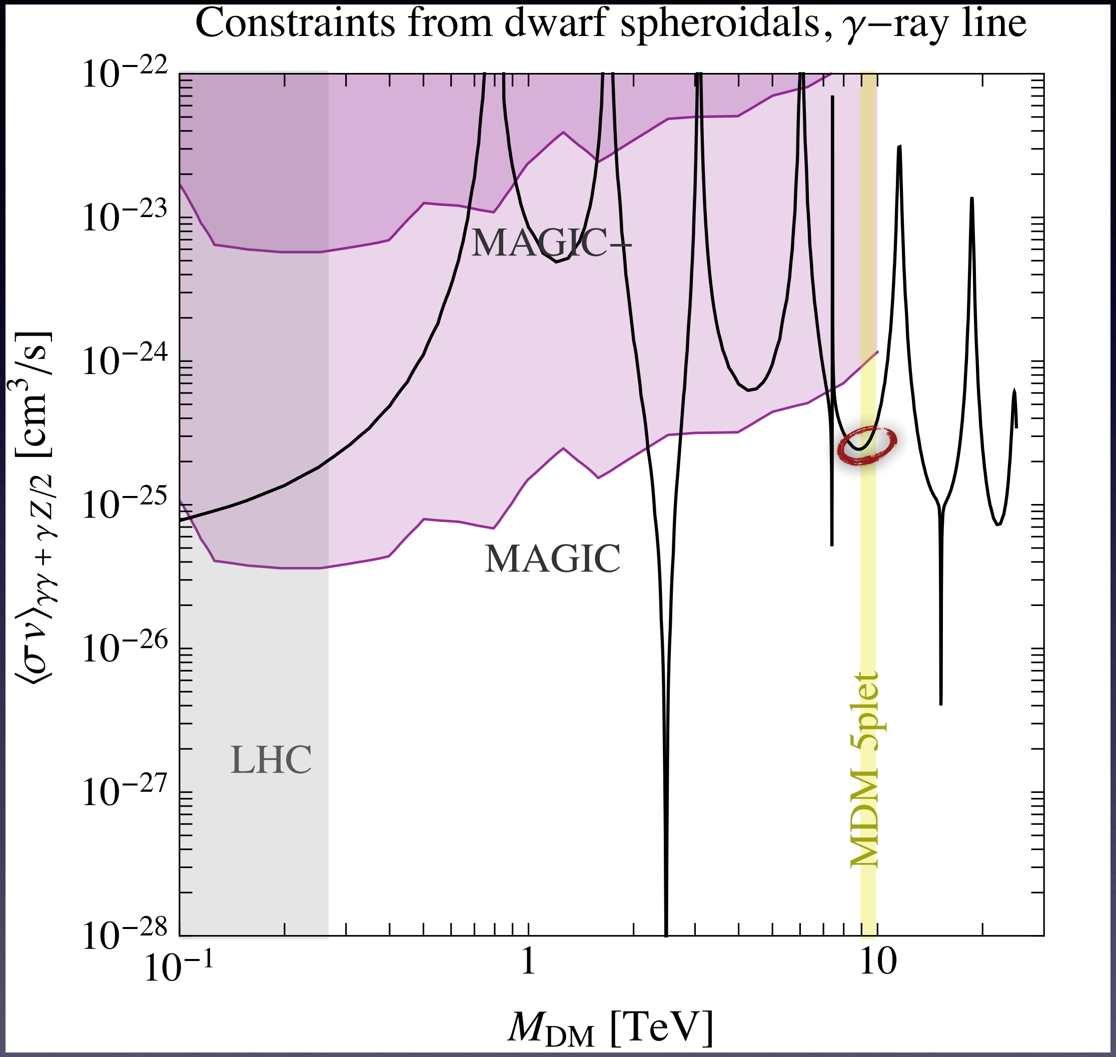
Fermi: threshold below M_χ -> No bound

HESS Bound: from a RoI with an aperture of 0.1° -> **Large uncertainties**

γ lines: GC & dSphs

The MDM 5plet predicts large cross sections into γγ and γZ



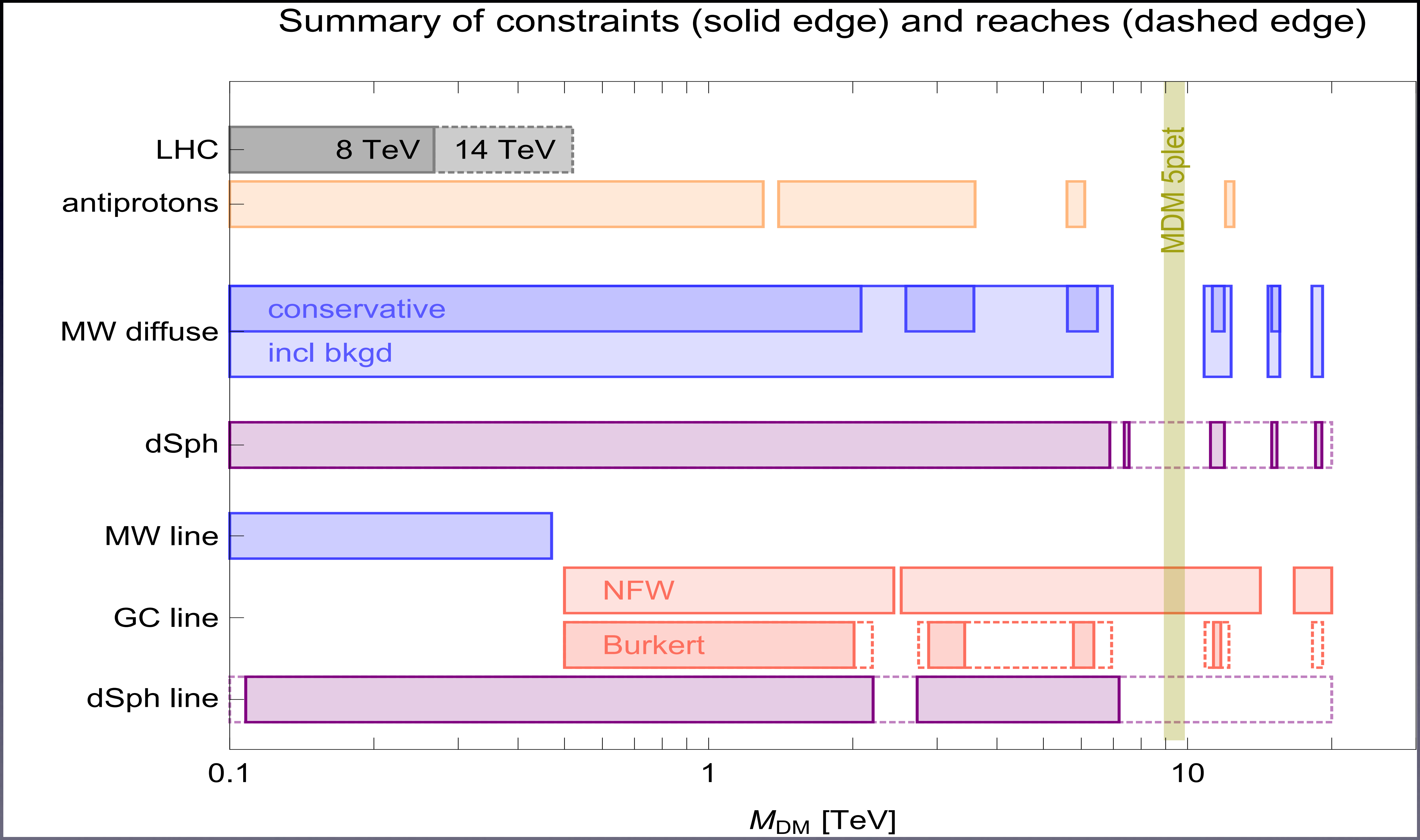


HESS Bound: from a RoI with an aperture of 0.1° -> **Large uncertainties**

MAGIC bound: only available bound from IACTs towards dSph (Segue 1 !!)

Would be interesting to point the Cherenkov arrays towards dSphs
Are the bounds from dSphs affected by **smaller uncertainties** ??

Summary



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Back up slides

γ Continuum: Fermi

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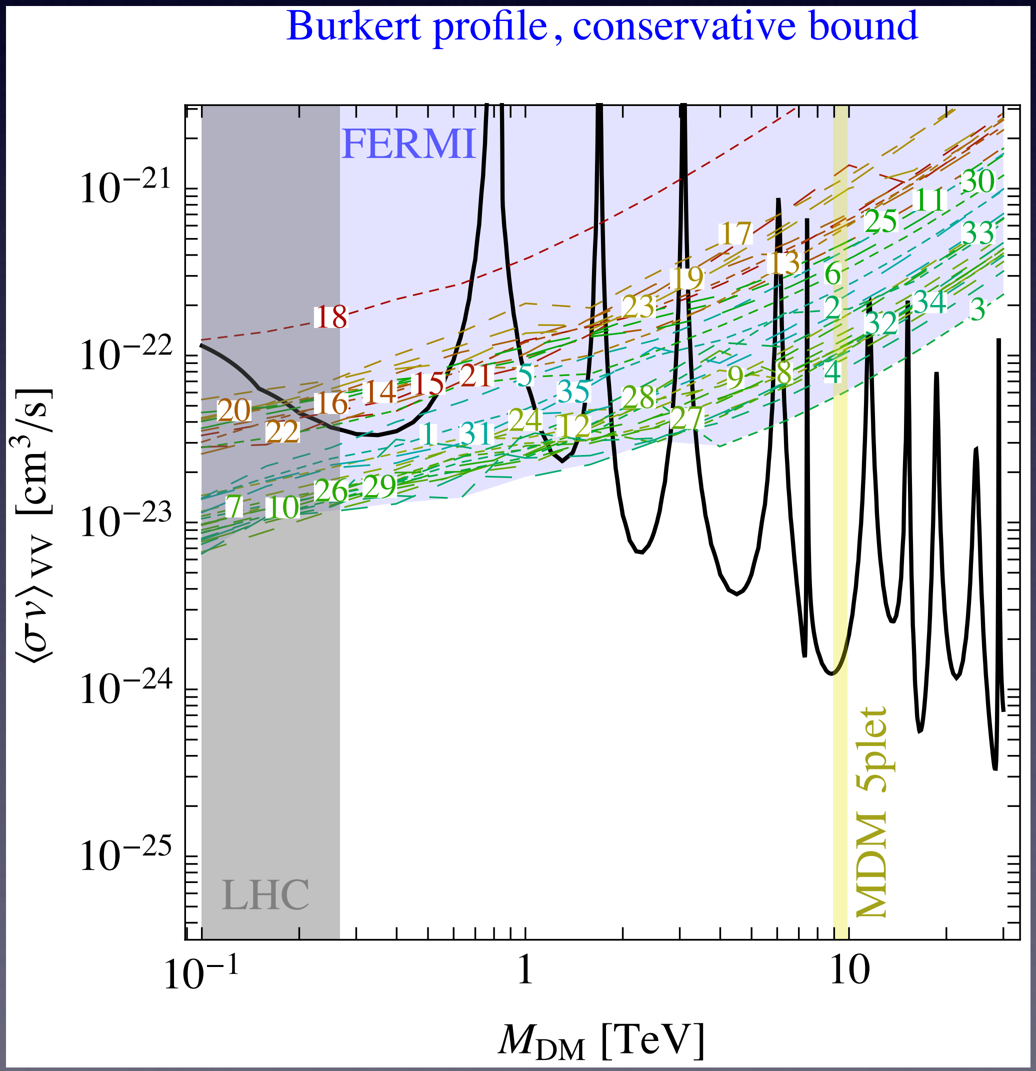
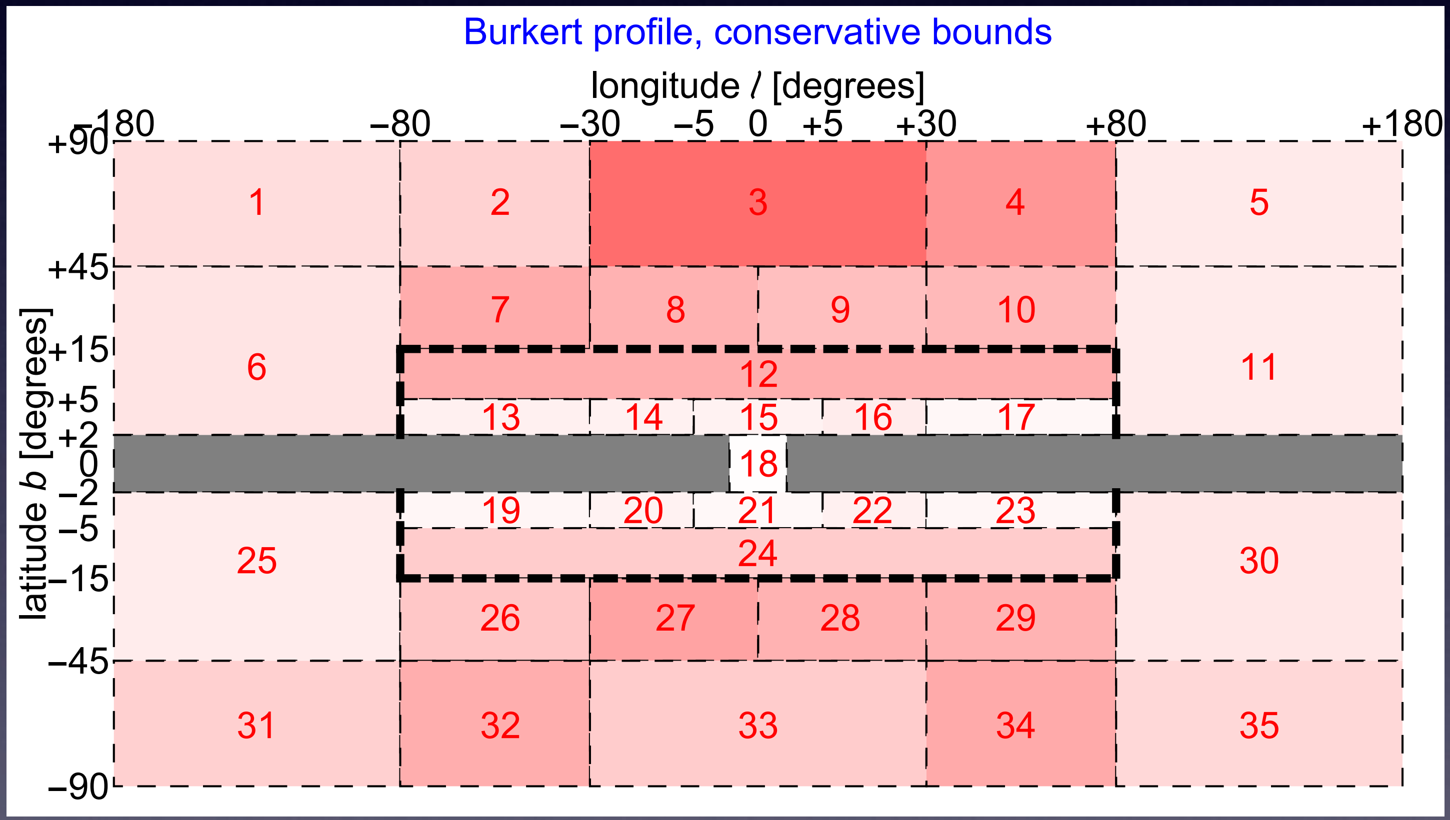
- ✔ Conservative bounds without modelling the diffuse bkg.





the most stringent bound from RoI 3
factor $\simeq 40$ above the predicted XS

γ Continuum: Fermi

Constraints from the measurement of the Gal. diffuse emission

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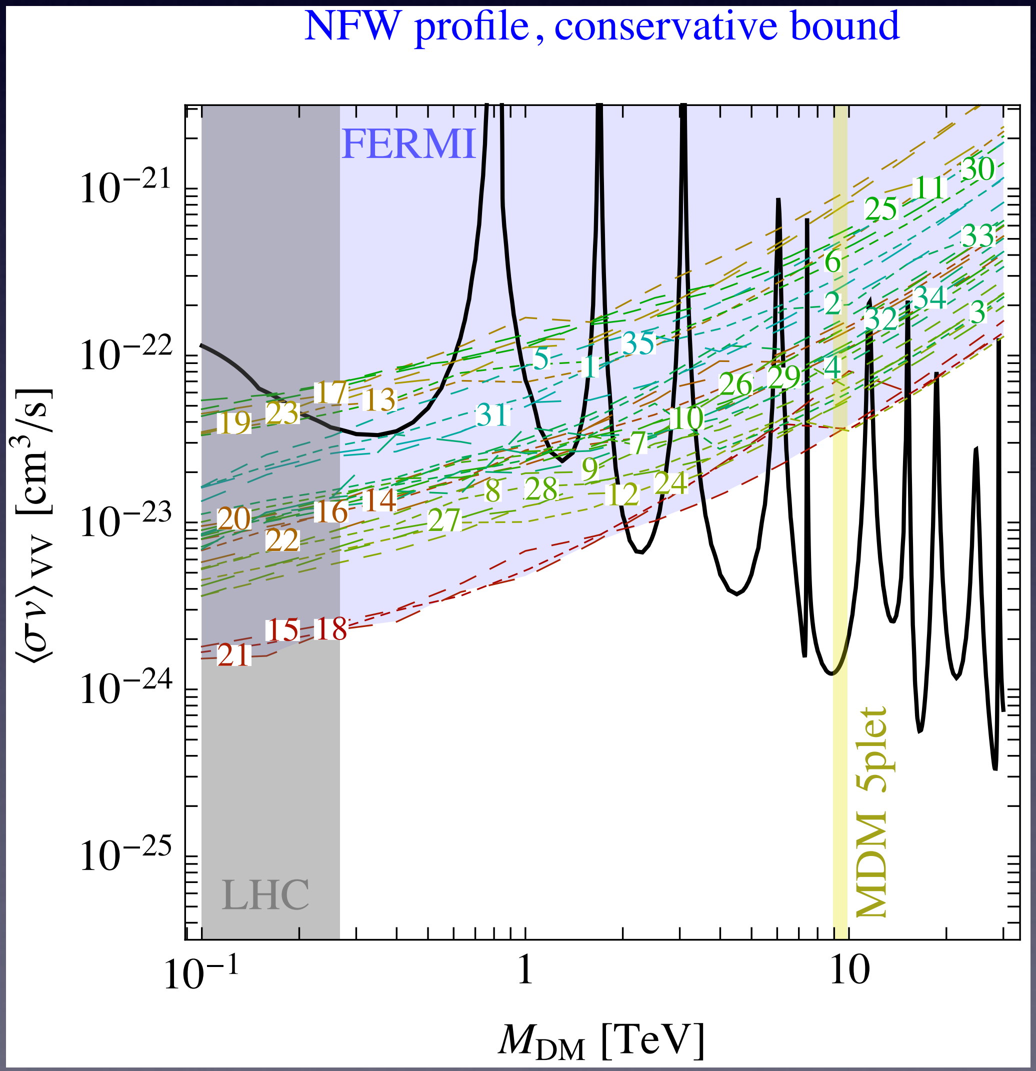

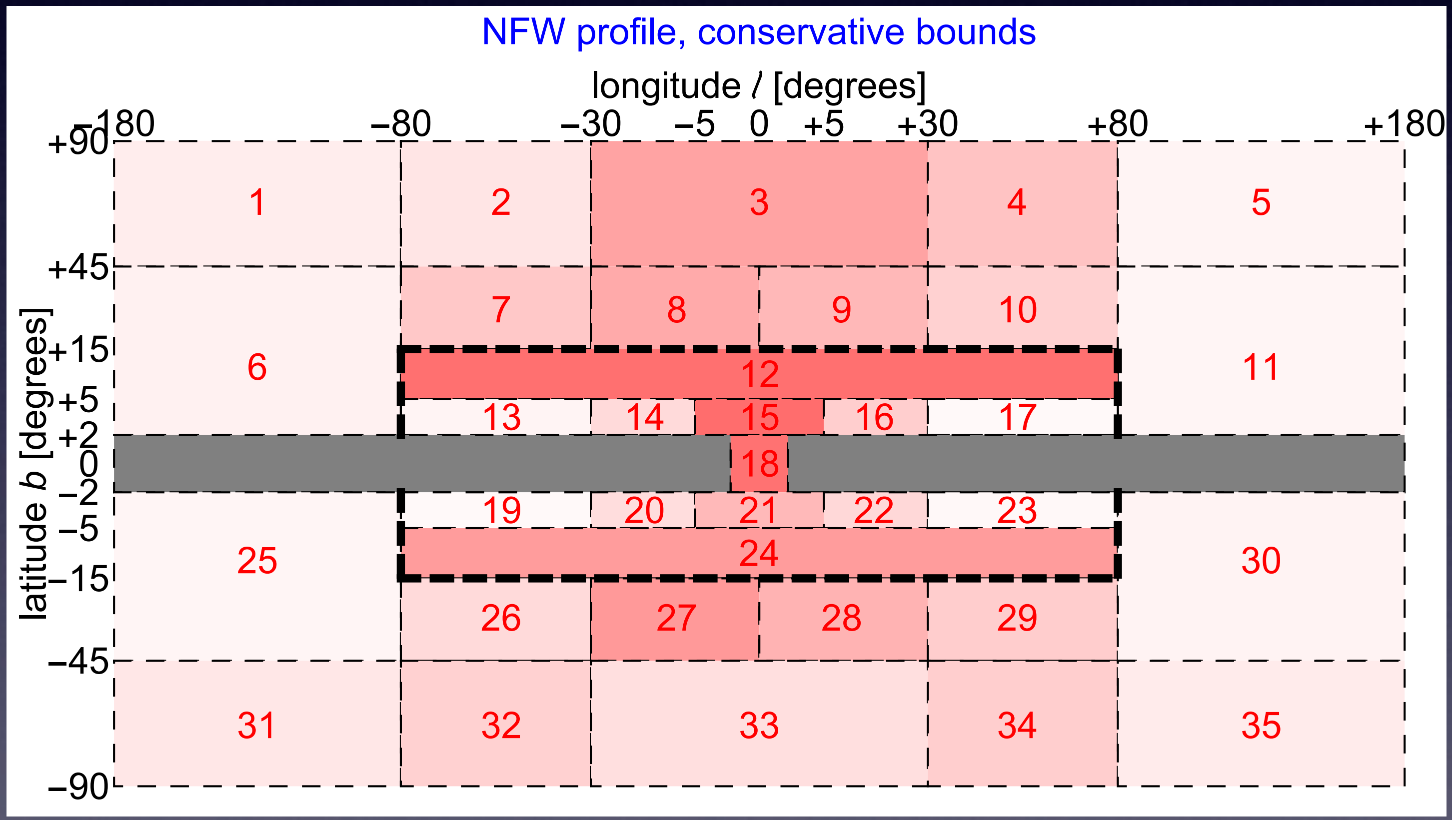

the most stringent bound from RoI 18
factor $\simeq 25$ above the predicted XS

End