10 March 2016

La Thuile 2016, “Les rencontres de physique de la Vallée d’Aoste”

Indirect Detection of Minimal Dark Matter

Paolo Panci

based on:
E. Del Nobile, M. Nardecchia, P. Panci,
Submitted to JCAP
[arXiv: 1512.05353]

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

Plan of the Talk

- ☑ Critical review of the MDM framework

  MDM: Well motivated model with EW interactions: stability of DM ensured by accidental symmetry

M. Cirelli, N. Fornengo, A. Strumia,
Minimal Dark Matter,
Published in NPB **753** (2006) 178-194, [hep-ph/0512090]

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- ☑ New MDM candidates with small millicharge

  Driven by the same spirit of minimality: stability is protected at all order in EFT expansion

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- ☑ **Phenomenology of the MDM 5plet with Y=0**

  EW multiplets predict large annihilation XS into gamma-ray lines due to NP Sommerfeld corrections

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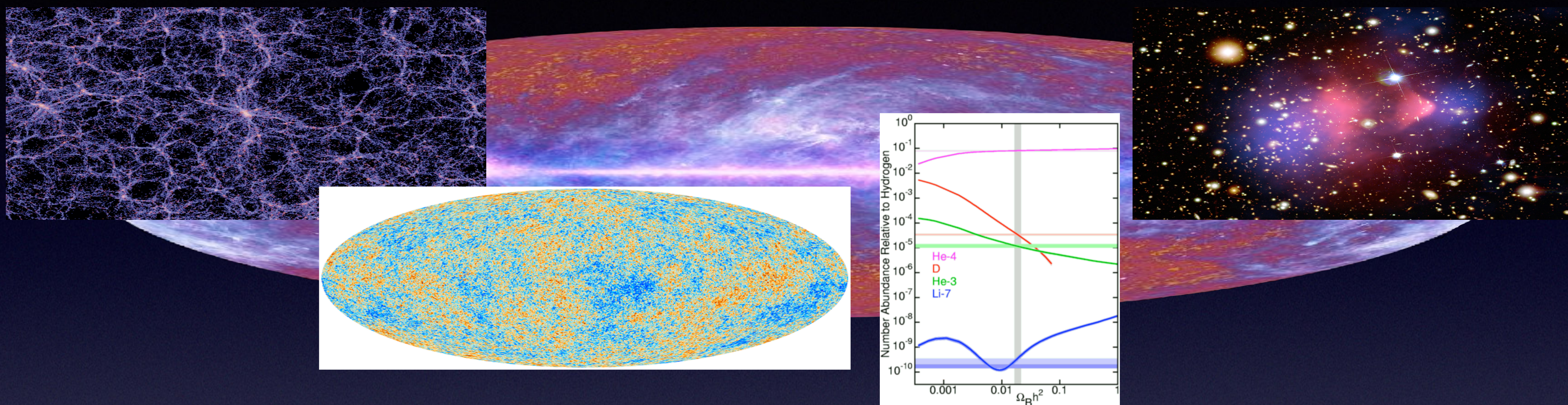
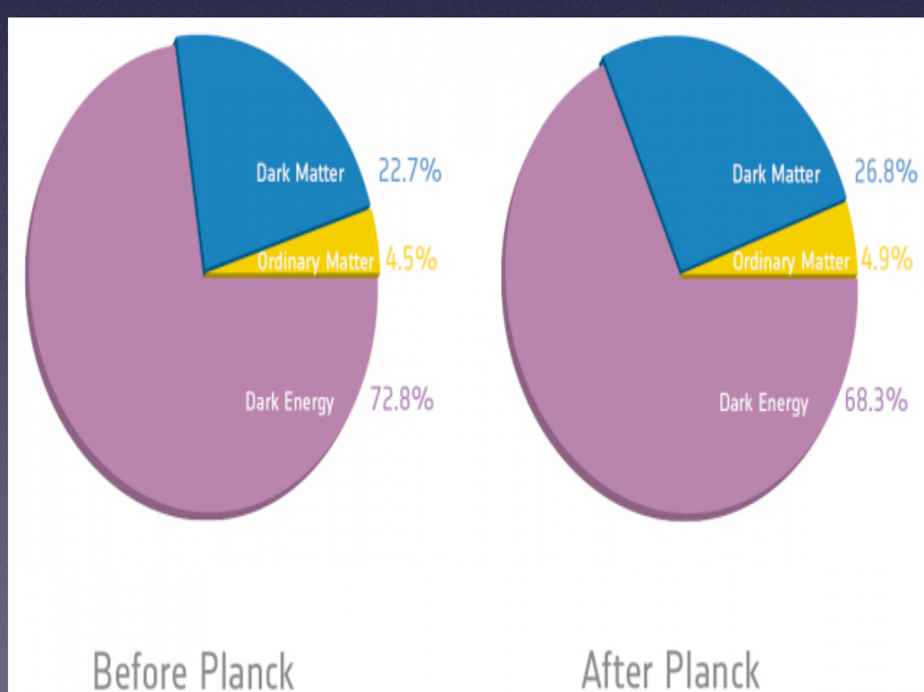
Dark Side: Overview

Precise measurements on CMB, BBN, LSS, etc...





Planck reveals an almost perfect Universe

$$\Omega_{\rm tot} = \Omega_\Lambda + \Omega_{\rm M} + \Omega_{\rm Rad} \simeq 1 \qquad \Omega_{\rm M} = \Omega_{\rm b} + \Omega_{\rm DM}$$

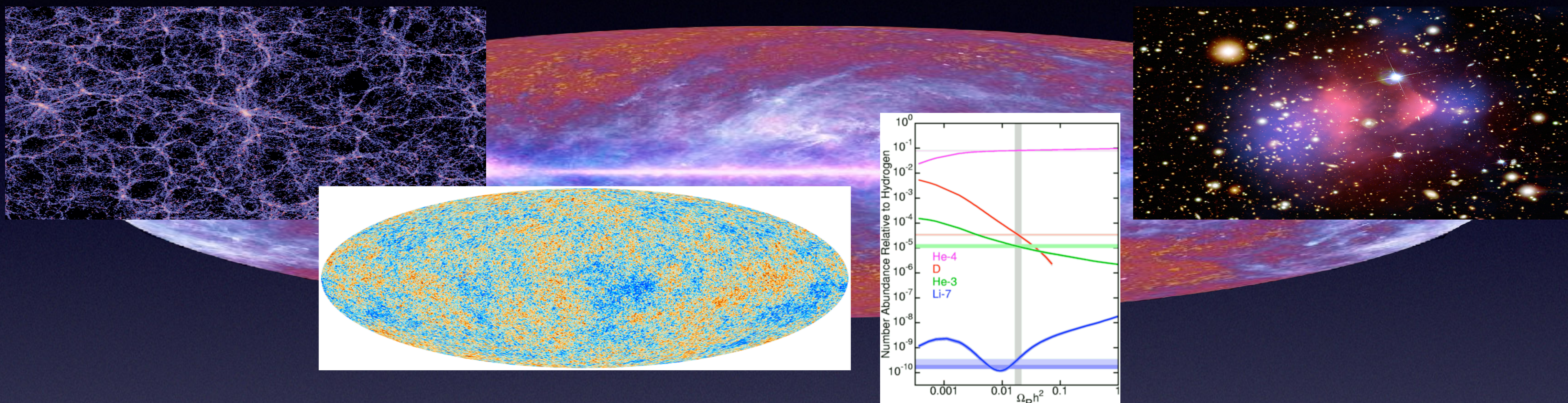
$\Omega_{\rm Rad} \sim 10^{-5}$ $\qquad$ $\Omega_\Lambda \simeq 0.68$

$\Omega_{\rm b} \simeq 0.05$ $\qquad$ $\Omega_{\rm DM} \simeq 0.27$

Dark Sector: $\Omega_{\rm DM} + \Omega_\Lambda = 0.95$

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, wimpzillas, primordial BH, 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

Stability of DM

Stability may be explained in terms of symmetries

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

Stability may be explained in terms of symmetries

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

MDM Candidates

DM Stability via accidental symmetries: "Minimal Dark Matter", Nucl.Phys.**B753** (2006), 178-194

Minimal Dark Matter Candidates with Y=0

Results:

- The only viable MDM multiplet is a fermionic quintuplet both color- and hypercharged- neutral **(1,5,0)**

quantum numbers
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OK !!

quantum numbers under the SM group

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

NO !!

$$\mathcal{O}_{5d} \equiv \chi^3 H^\dagger H \xrightarrow{\text{for } \Lambda = m_P} \tau_{7\mathrm{plet}} \sim 1\,\mathrm{s}$$

see e.g. arXiv:1504.00359
arXiv:1512.05353

Millicharged MDM

MDM candidates with Y=ε: "Millicharge or decay: A critical take on Minimal Dark Matter", arXiv: 1512.05353

New class of MDM candidates with Y=ε

Results:

<u>The Requirement Y=0 is not mandatory</u>

multiplets must be odd under SU(2)
To avoid tree-level coupling with Z

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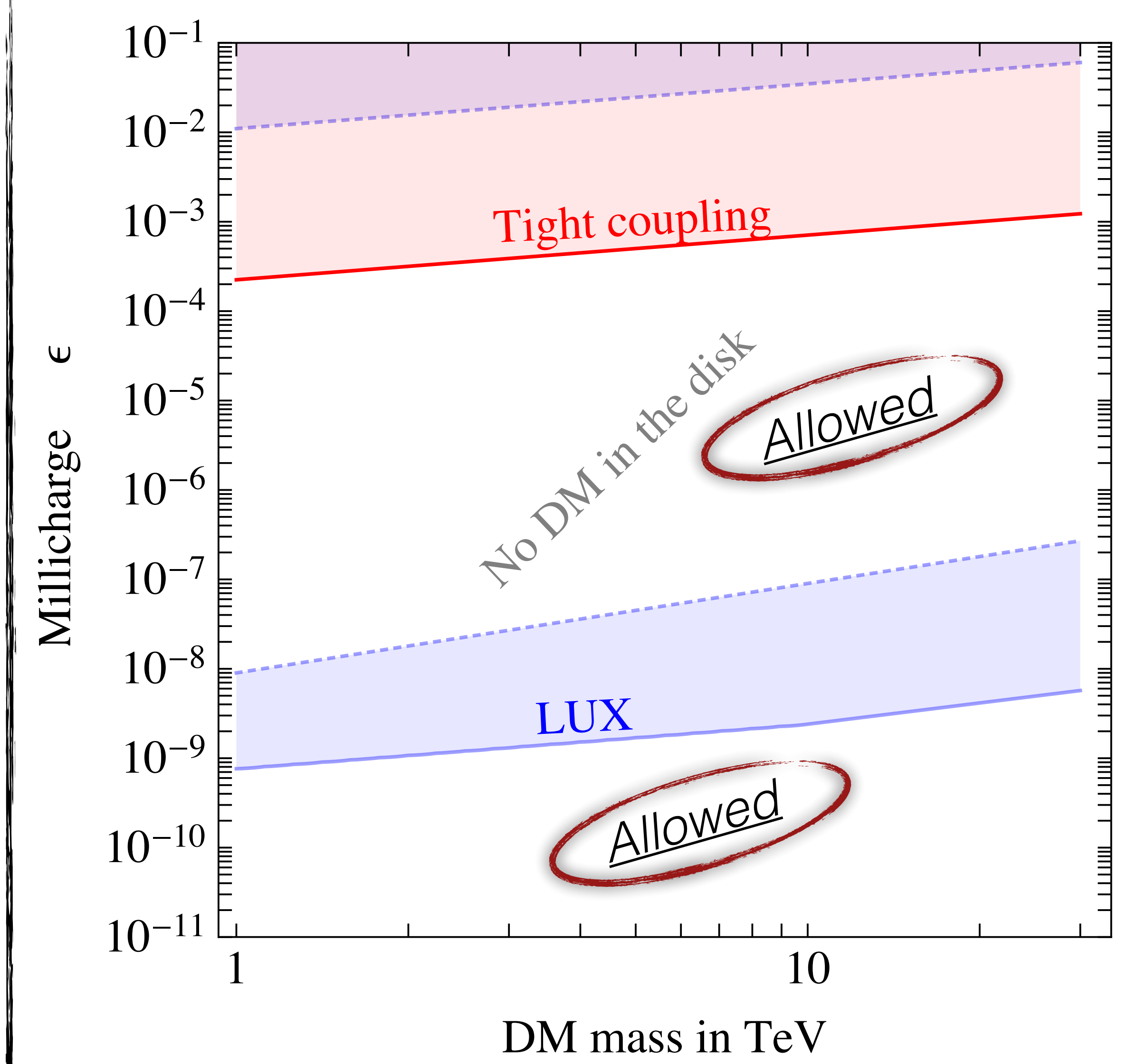
But!!

<u>they can have a small millicharge (Y=ε)</u>

Bounds on the millicharge



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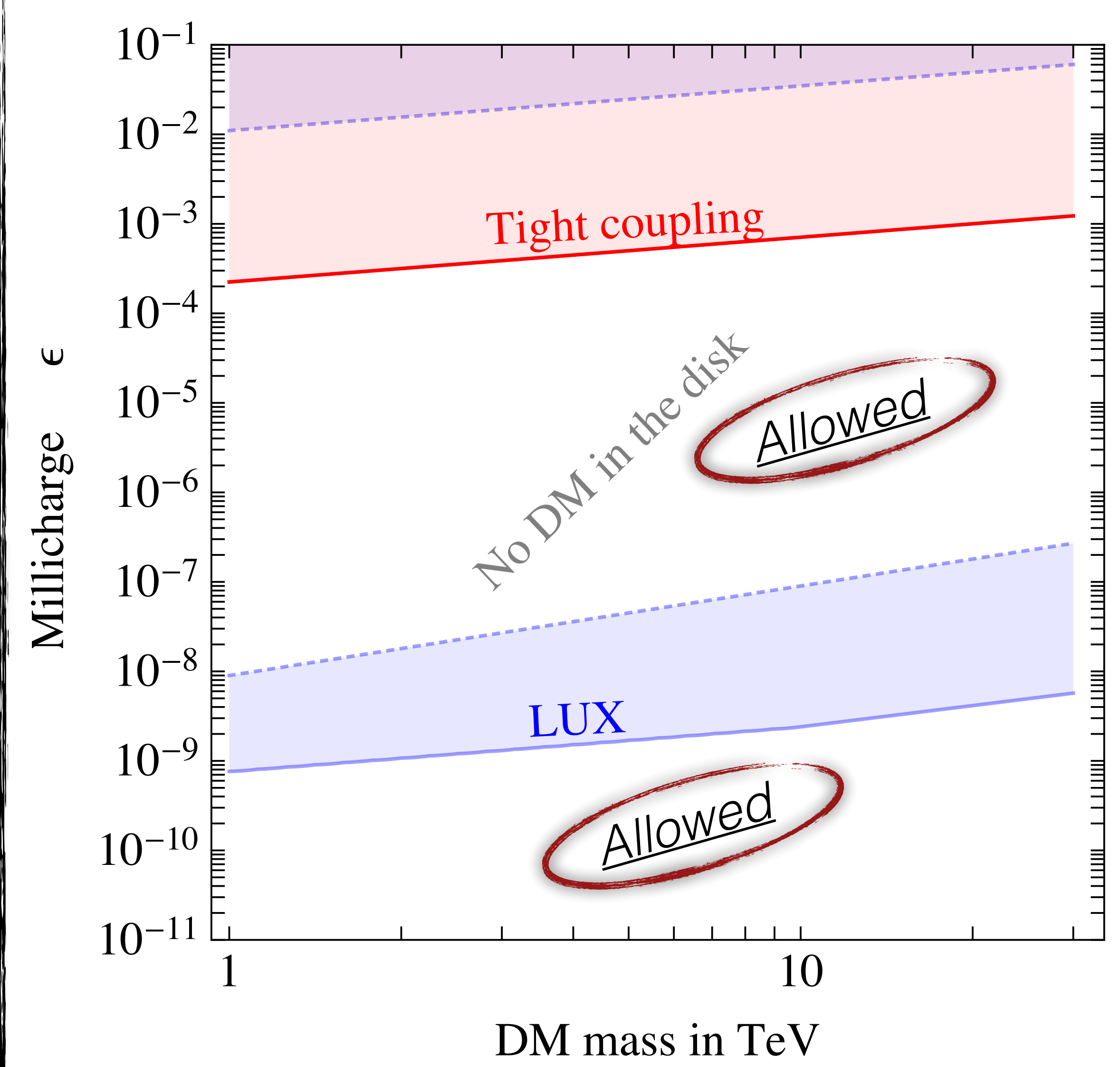
MDM candidates with Y=ε

☑ ***Millicharge MDM must be complex***

Doubling the χ's d.o.f. respect to scalar

$\chi' \to e^{i\theta}\chi$ under U(1) for Y=ε

Bounds on the millicharge



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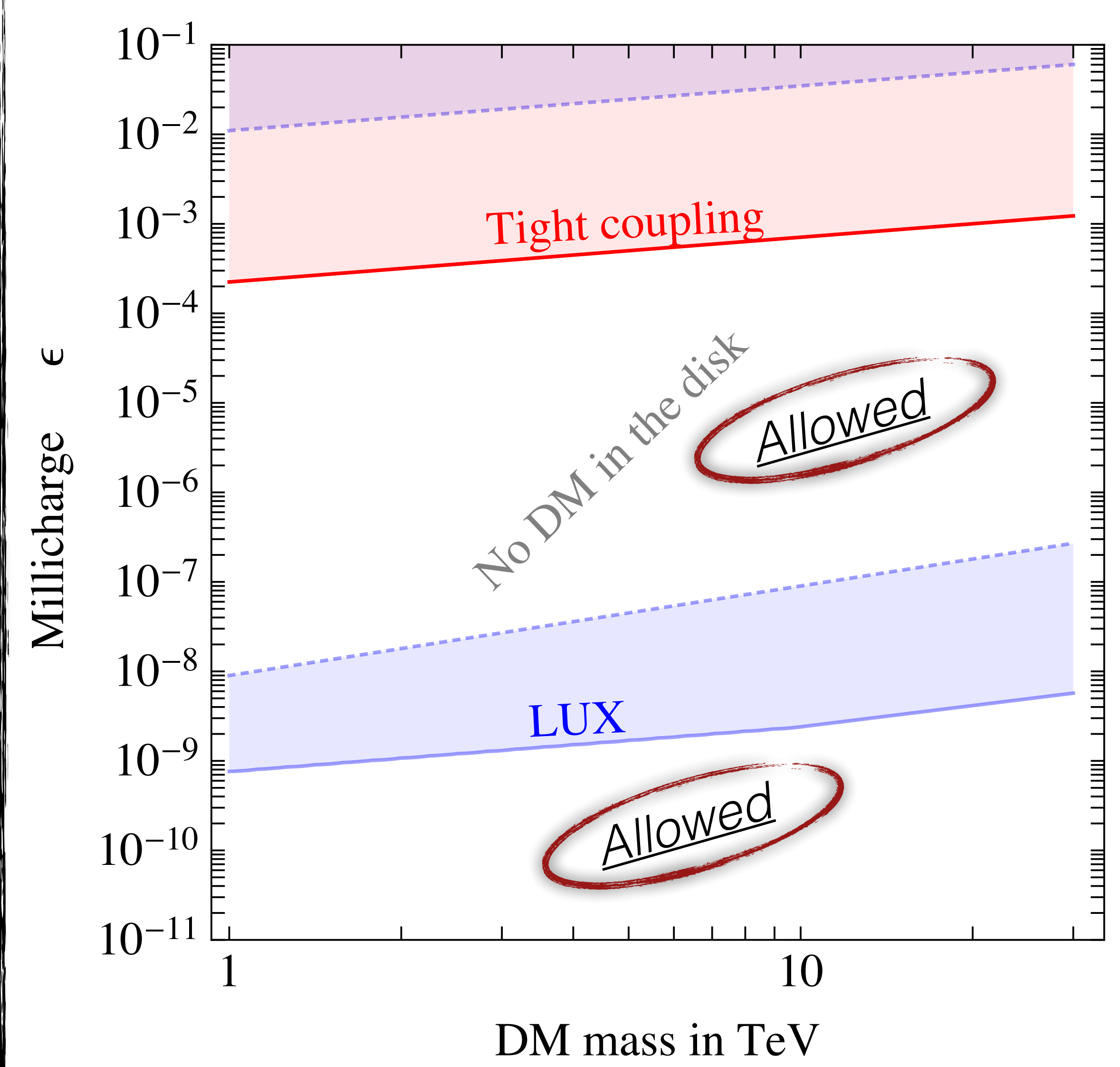
MDM candidates with Y=ε

☑ ***MDM with Y=ε is absolutely stable***

DM is stable at all order in EFT expansion

- no worry about cutoff
- viable DM if $\Lambda_{\text{Landau}} \gtrsim M_{\text{DM}}$

Bounds on the millicharge



MDM Candidates

Minimal Dark Matter Candidates: Summary

Results:

☑ The only viable MDM multiplet with Y=0 is a fermionic quintuplet: **(1,5,0)**

"Minimal Dark Matter", Nucl.Phys.**B753** (2006), 178-194

☑ New MDM odd multiplets under SU(2) with Y=ε: **(1,n,ε)**

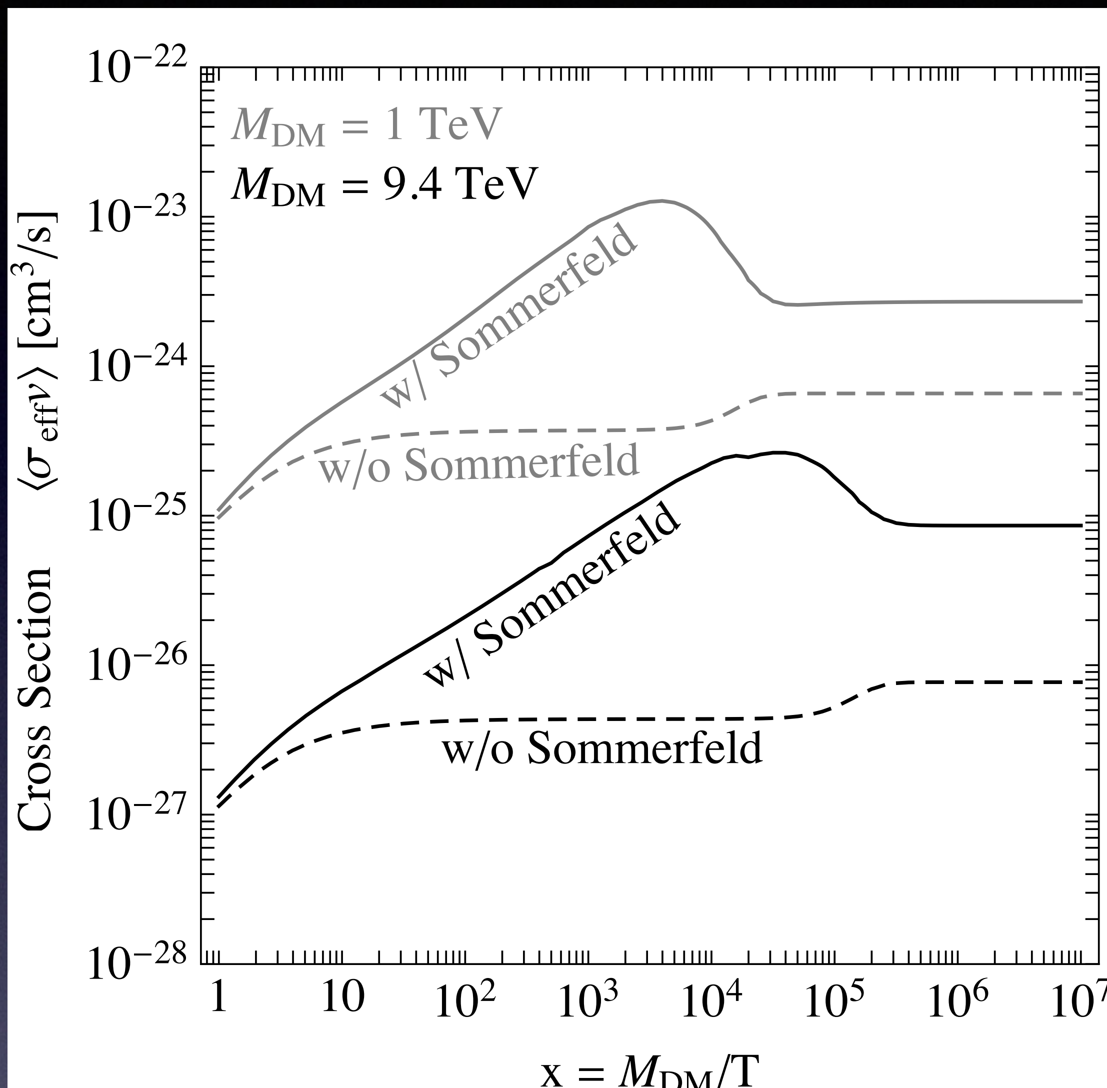
"Millicharge or decay: A critical take on Minimal Dark Matter", arXiv: 1512.05353

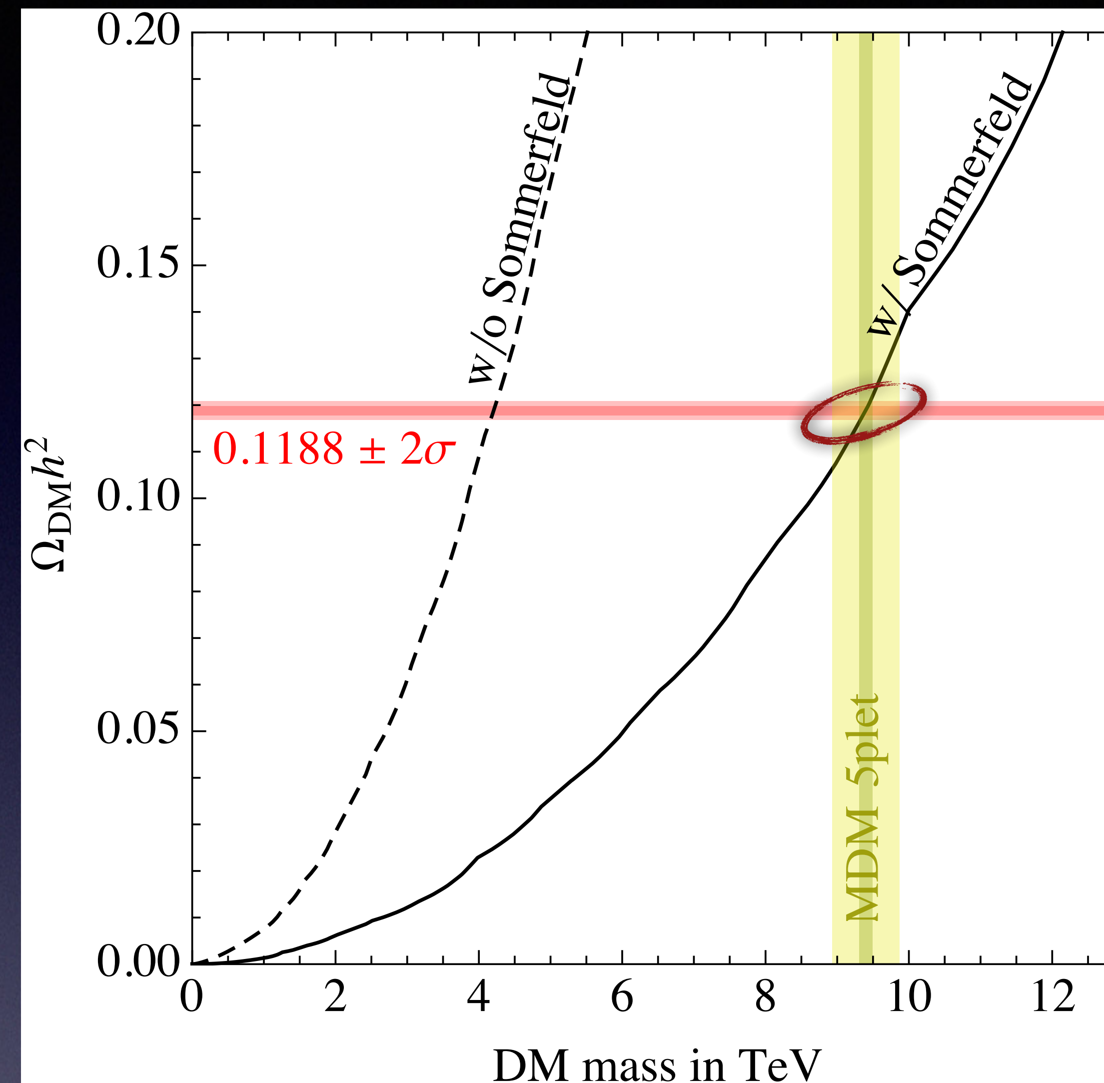
The ann. XS can be fully determined considering NP Sommerfeld corrections

- SM gauge couplings and mediators
- the **MASS** is the only free parameter of the model

M_{DM} can be determined by demanding that $\chi_{(0,\epsilon)}$ is thermally produced

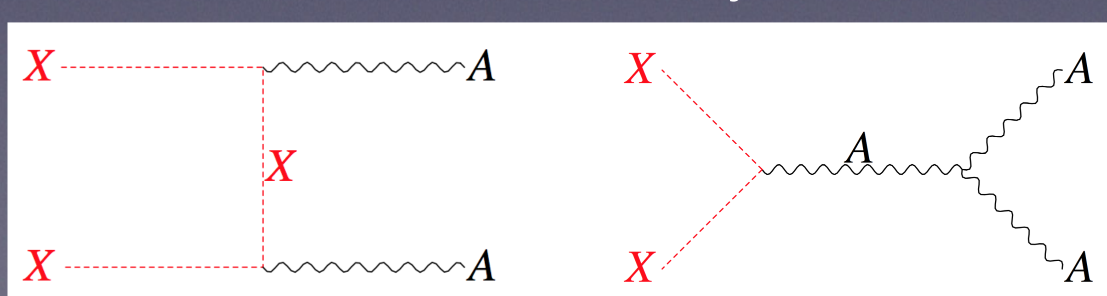
Relic Density (Y=0)





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

The XS can be fully computed in EW Theory

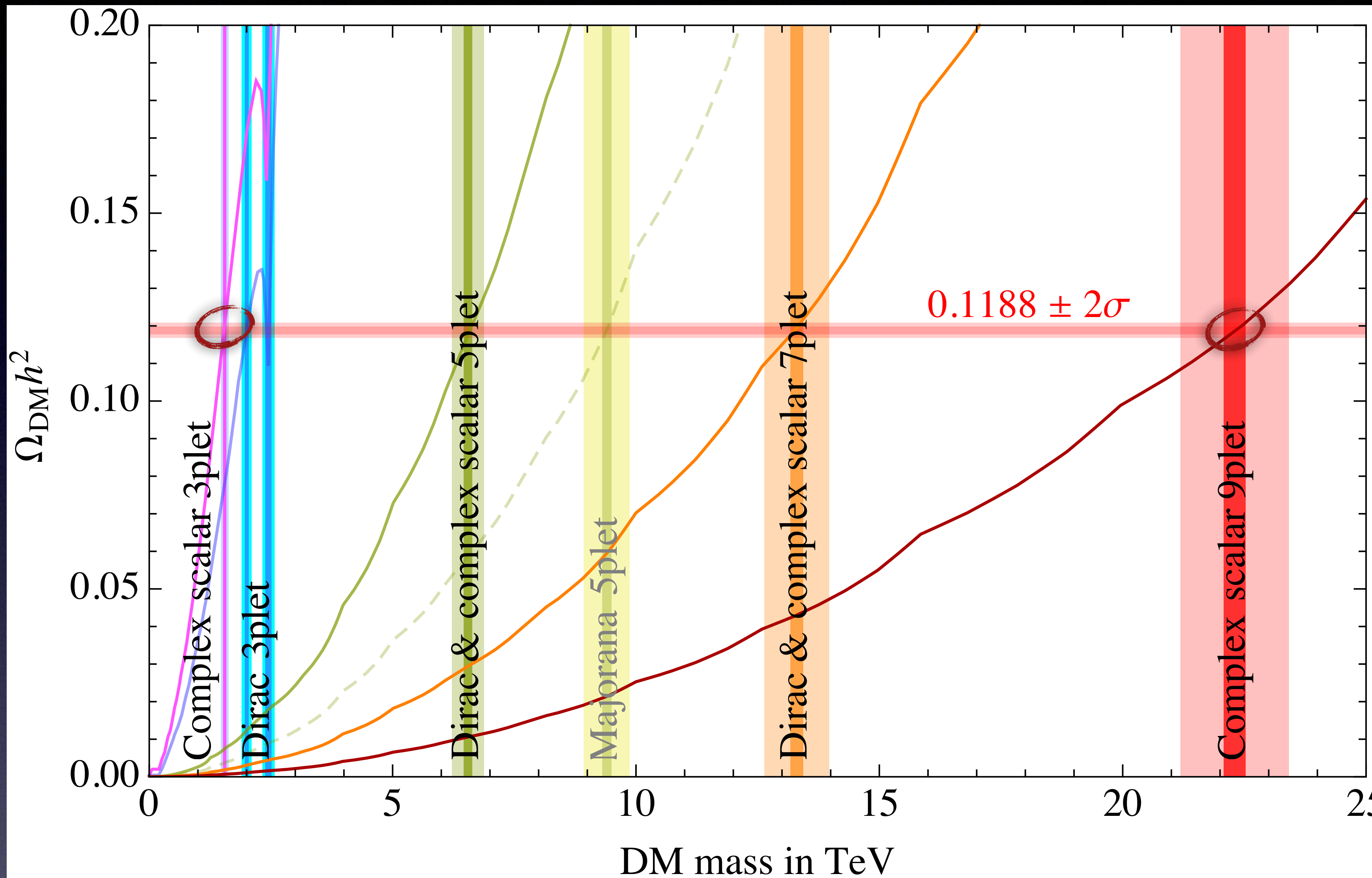


Important to include:

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

The neutral component of the 5plet with Y=0 has a **mass of 9.4 TeV**

Relic Density (Y=ε)



"Millicharge or decay: A critical take on MDM", arXiv: 1512.05353

***Bottom Line*: One can have very heavy thermally produced WIMPs**

Heavy EW Multiplets have:

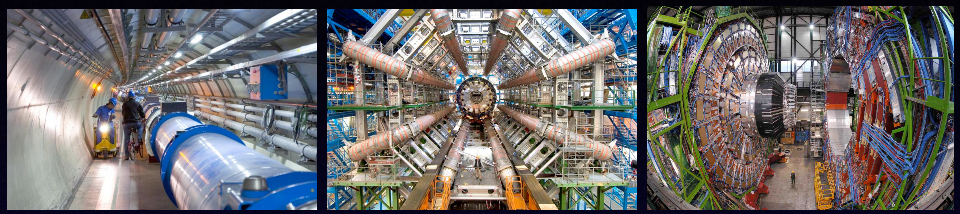
- ✔ Large Sommerfeld corrections
- ✔ many co-annihilations (e.g. for the 9plet)

Which is the largest n we can take?

- ✔ One has to take care of the Landau pole
- ✔ for n>9, the Landau pole ends up at $M_{\rm DM}$

MDM 5plet at Colliders

production at colliders

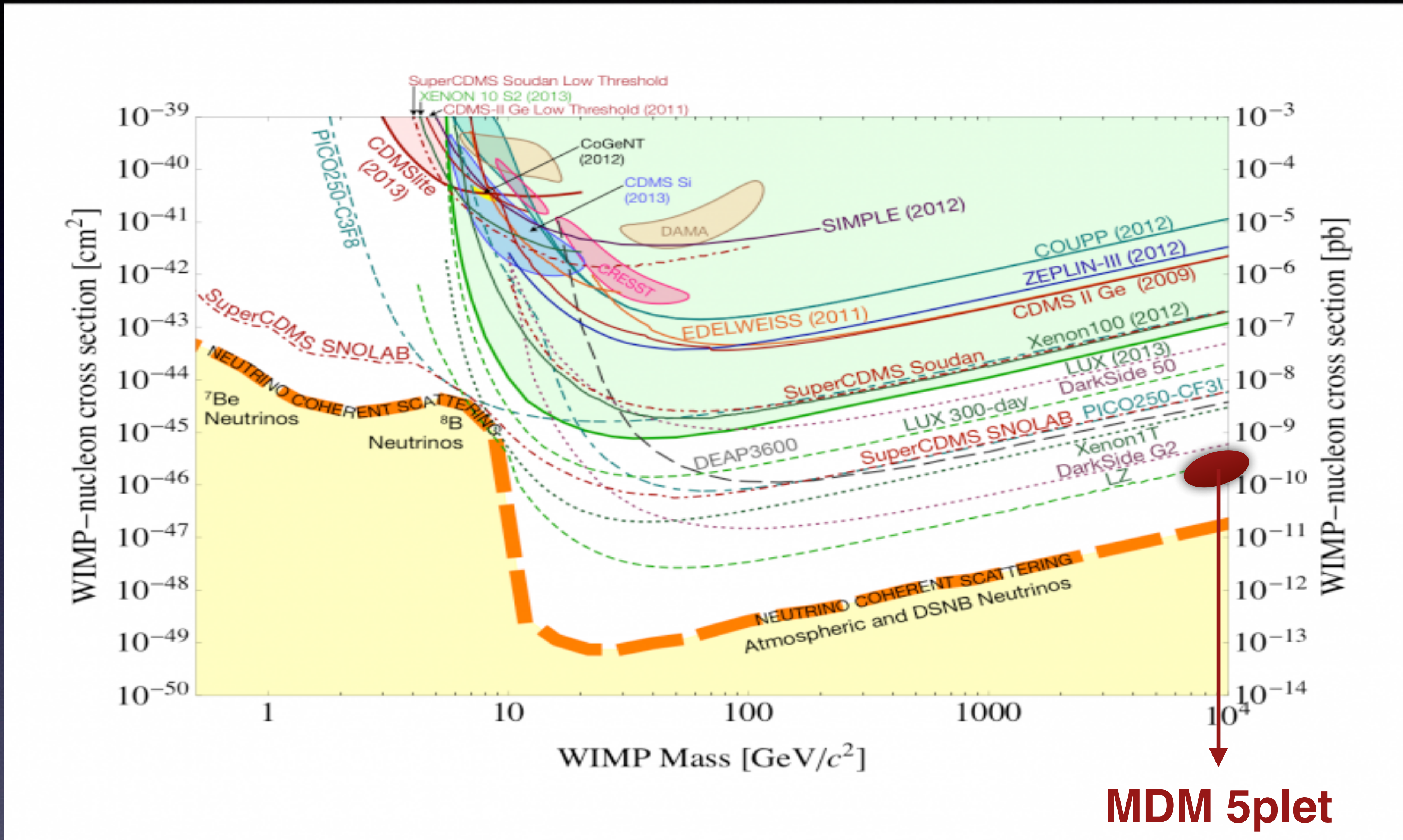


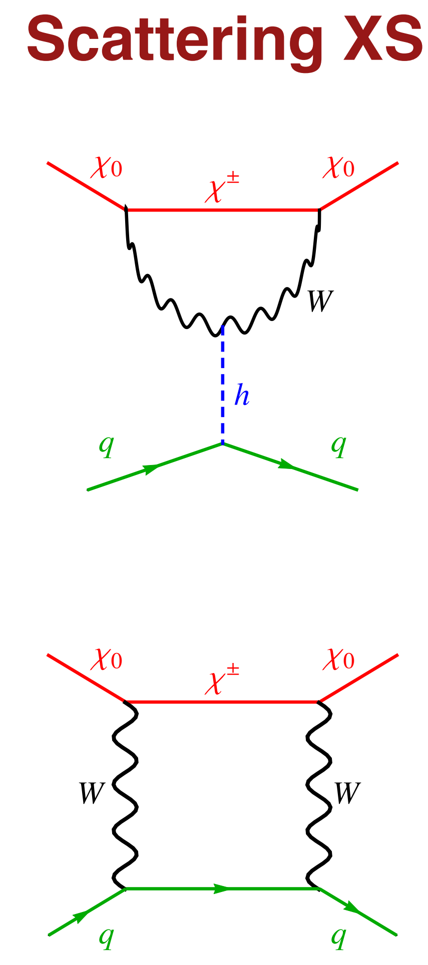
See e.g.: arXiv: 1407.7058
- EW multiplets at colliders

- **NO HOPE** to reach the thermal mass of 9.4 TeV

(even with a 100 TeV collider)

Direct Detection





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

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

☑ <u>**NO HOPE**</u> to reach the predicted value of the SI scattering cross section (perhaps with LZ !!)

Indirect Detection

Indirect detection is the most promising strategy

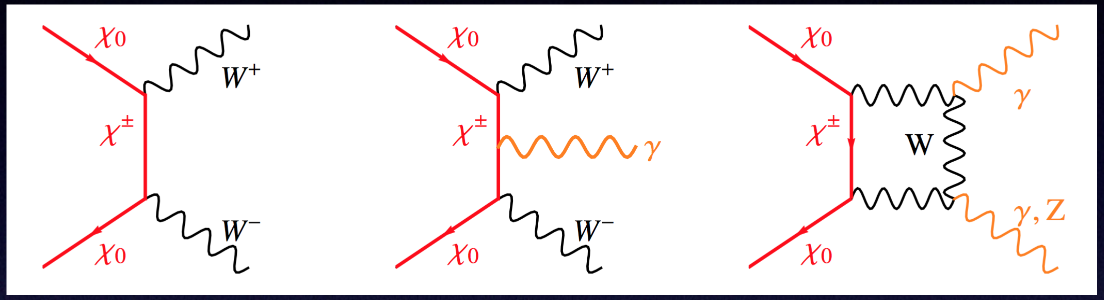
- ☑ γ-Ray Test of Minimal Dark Matter
  - γ-Ray Continuum:
    - Constraints from the measurements of the Gal. diffuse emission by Fermi
    - Constraints from the observations of dSphs by Fermi, H.E.S.S. & MAGIC
  - γ-Ray Lines:
    - Constraints from the observations of the Gal. center by H.E.S.S.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

✓ $M_\chi \gg M_{\mathrm{SM,\,B}}$ → 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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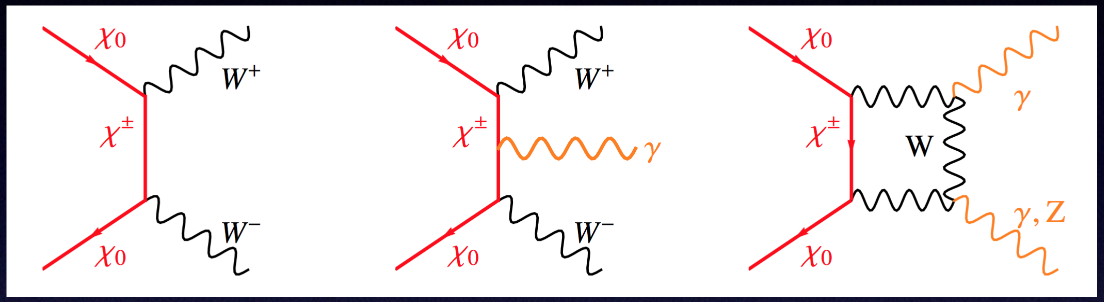

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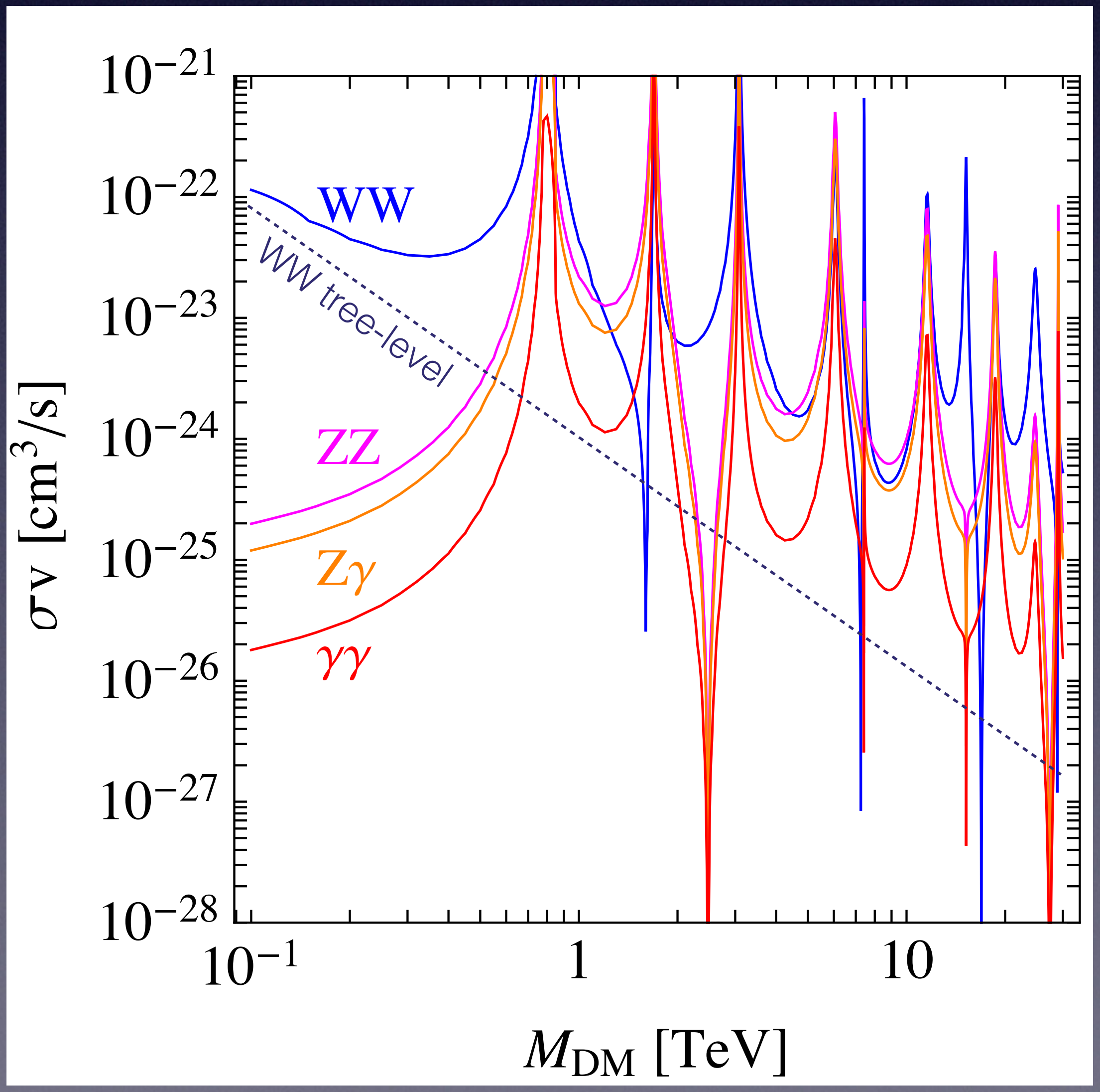

Important Result:

- ✔ 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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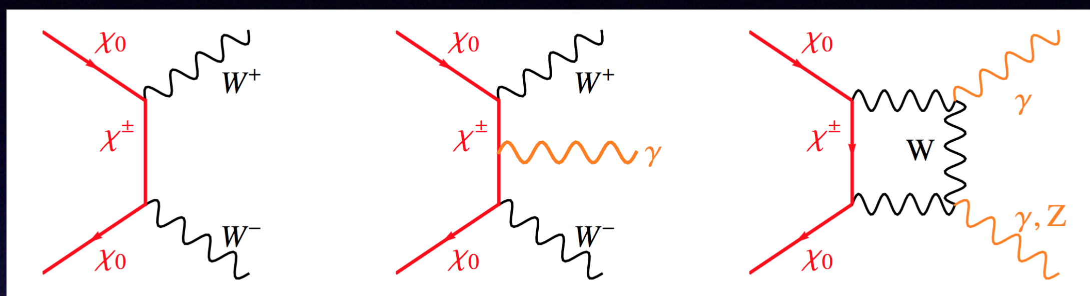

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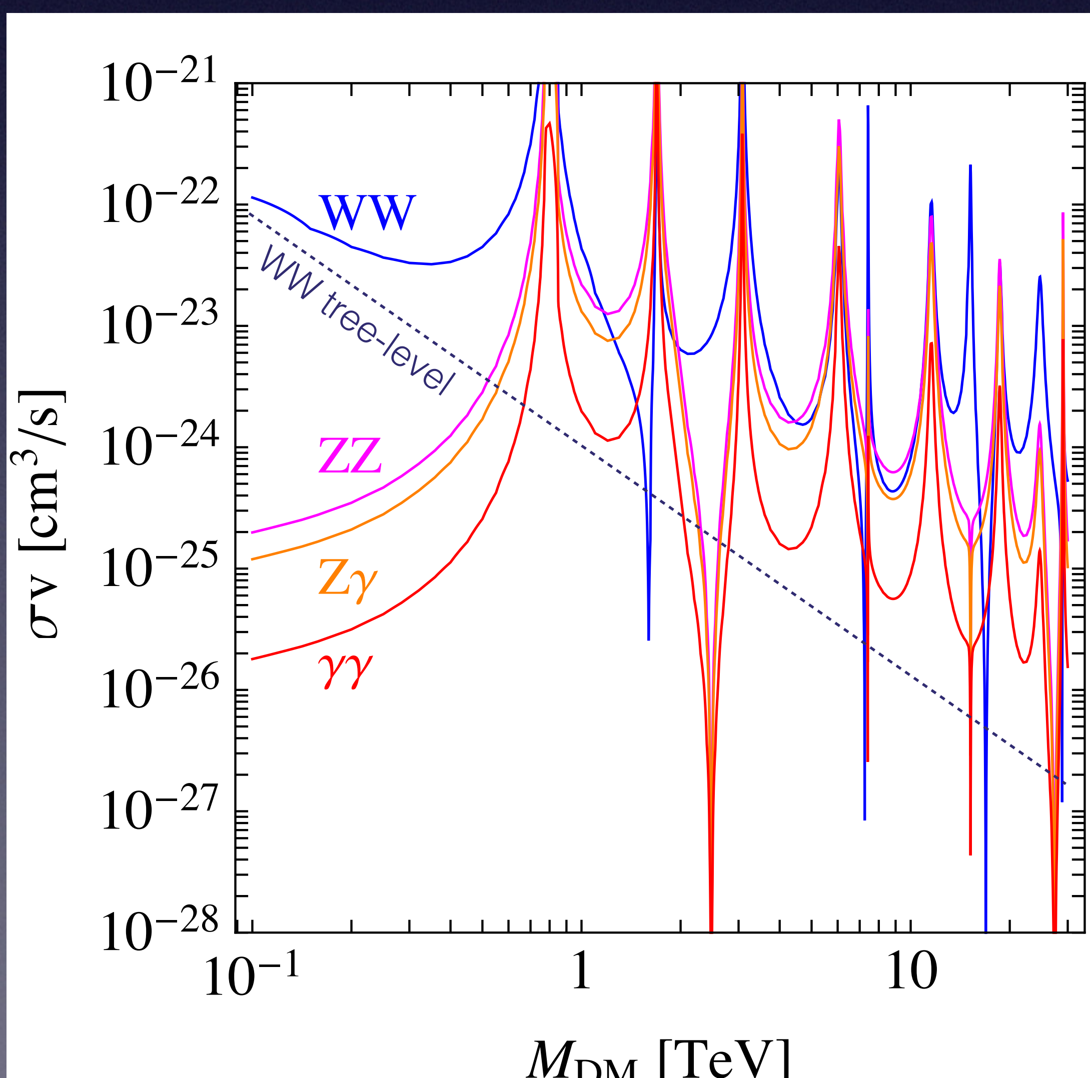

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Comparison with data:

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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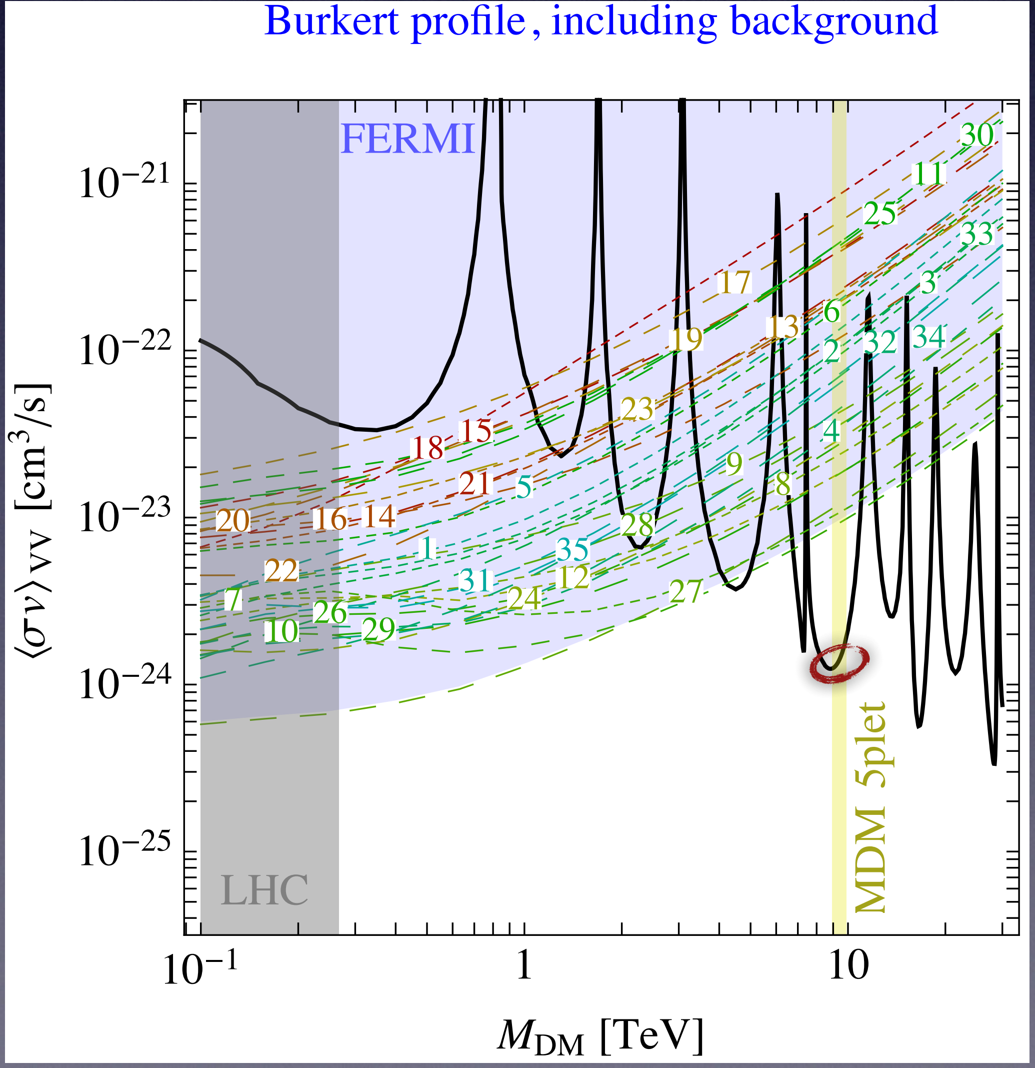

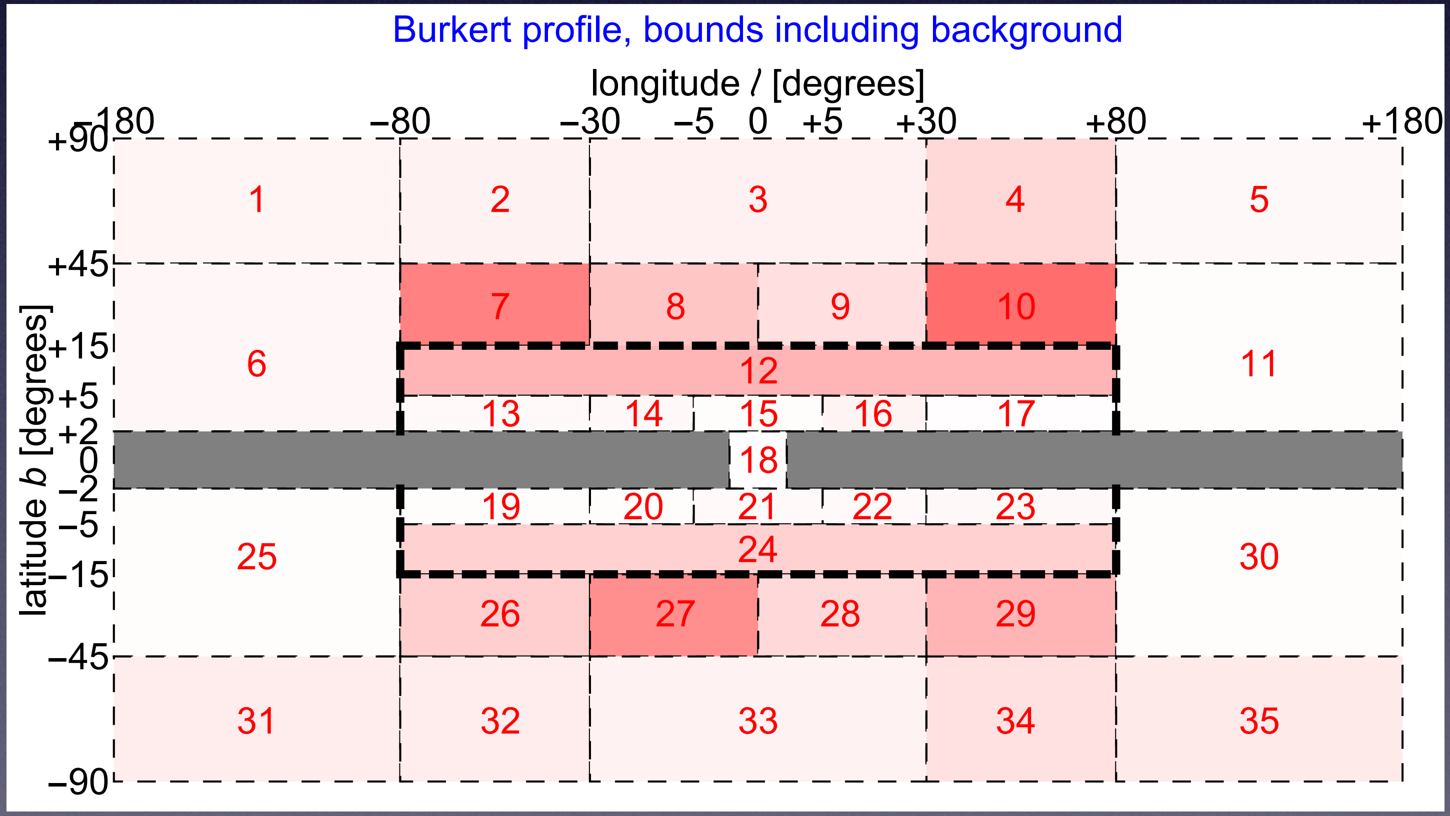

the most stringent bound from RoI 10
factor $\simeq 6$ above the predicted XS

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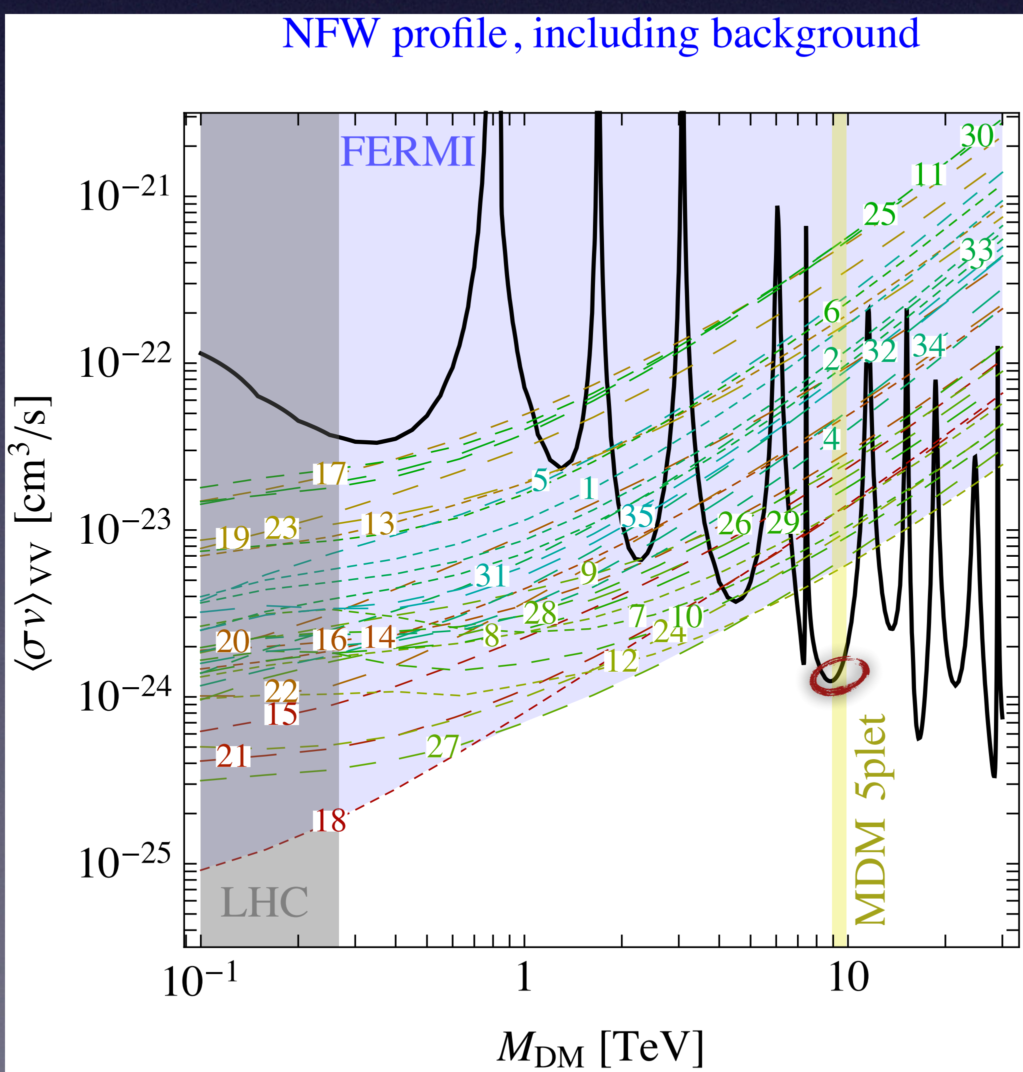

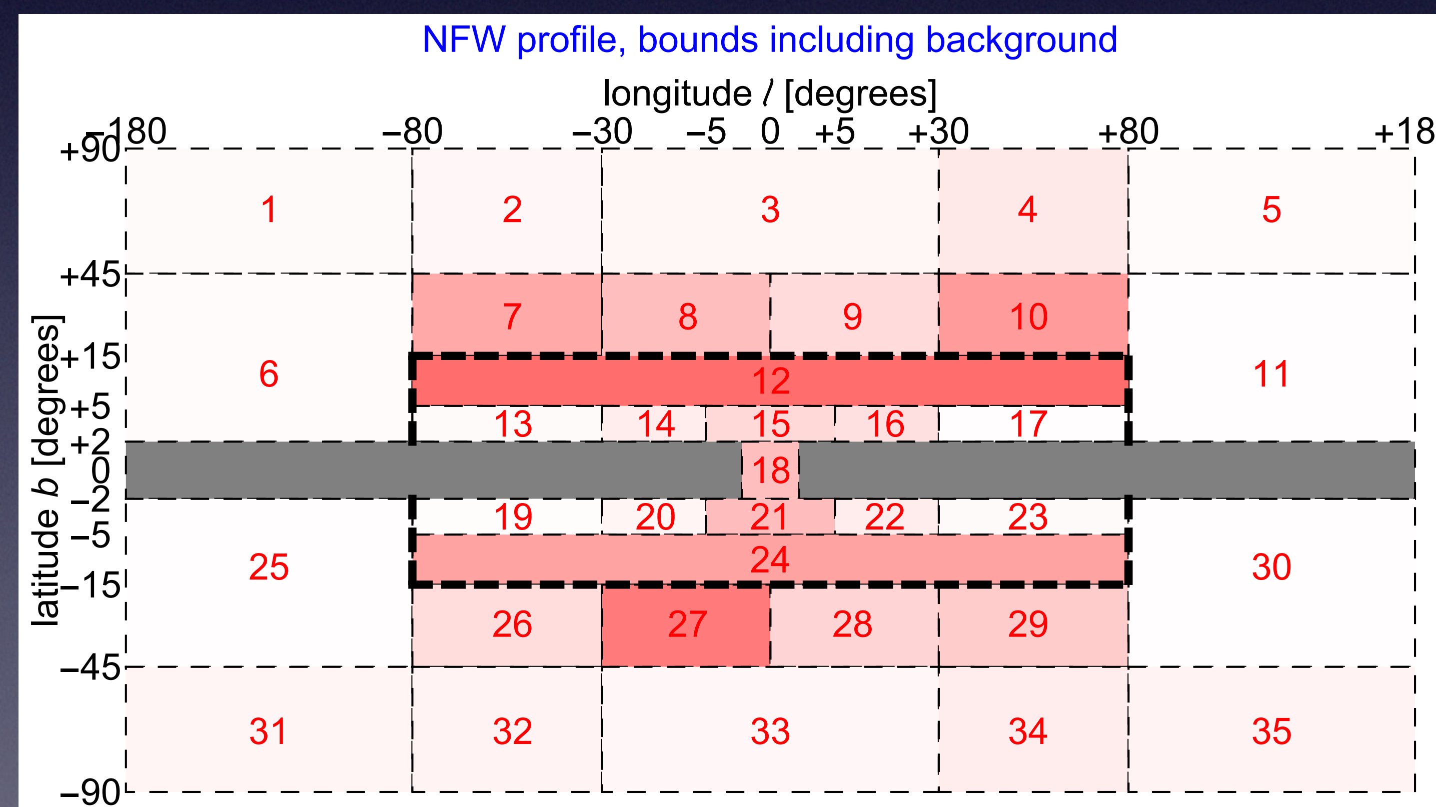

the most stringent bound from RoI 12
factor $\simeq 4$ above the predicted XS

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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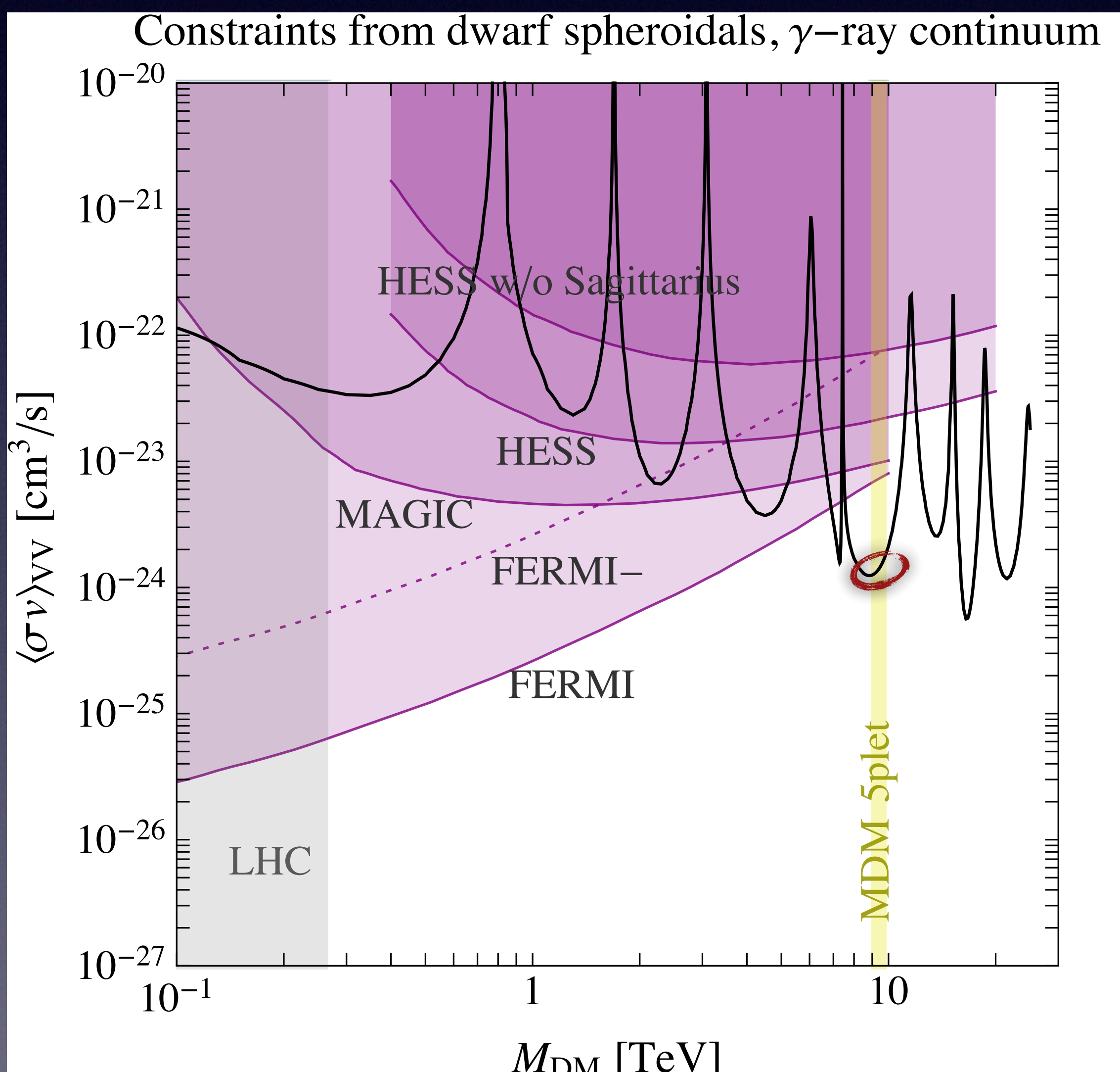

Fermi: staking analysis of 15 dSphs
HESS: a subset of 4 dSphs + Sagittarius
MAGIC: only Segue 1

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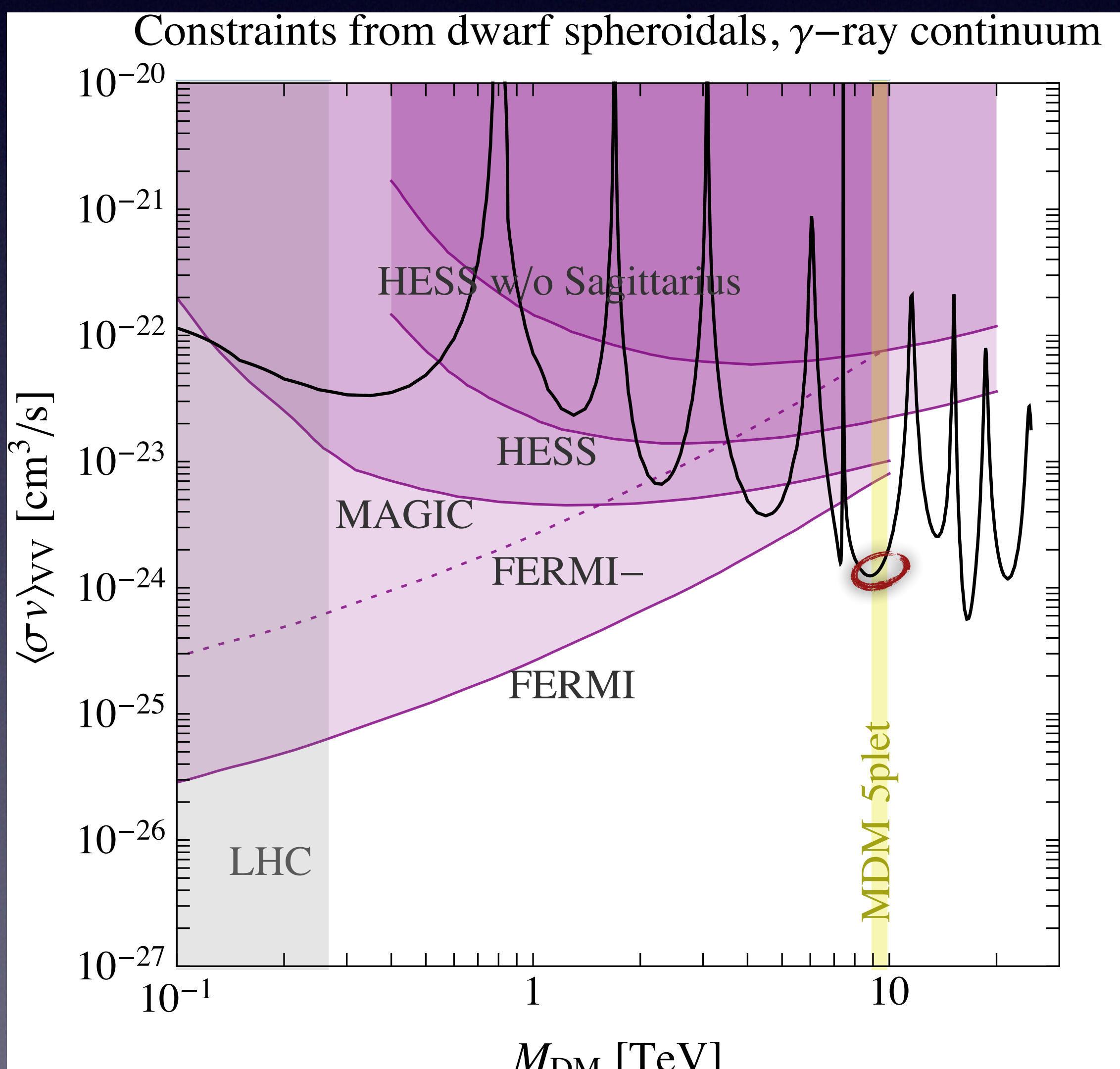

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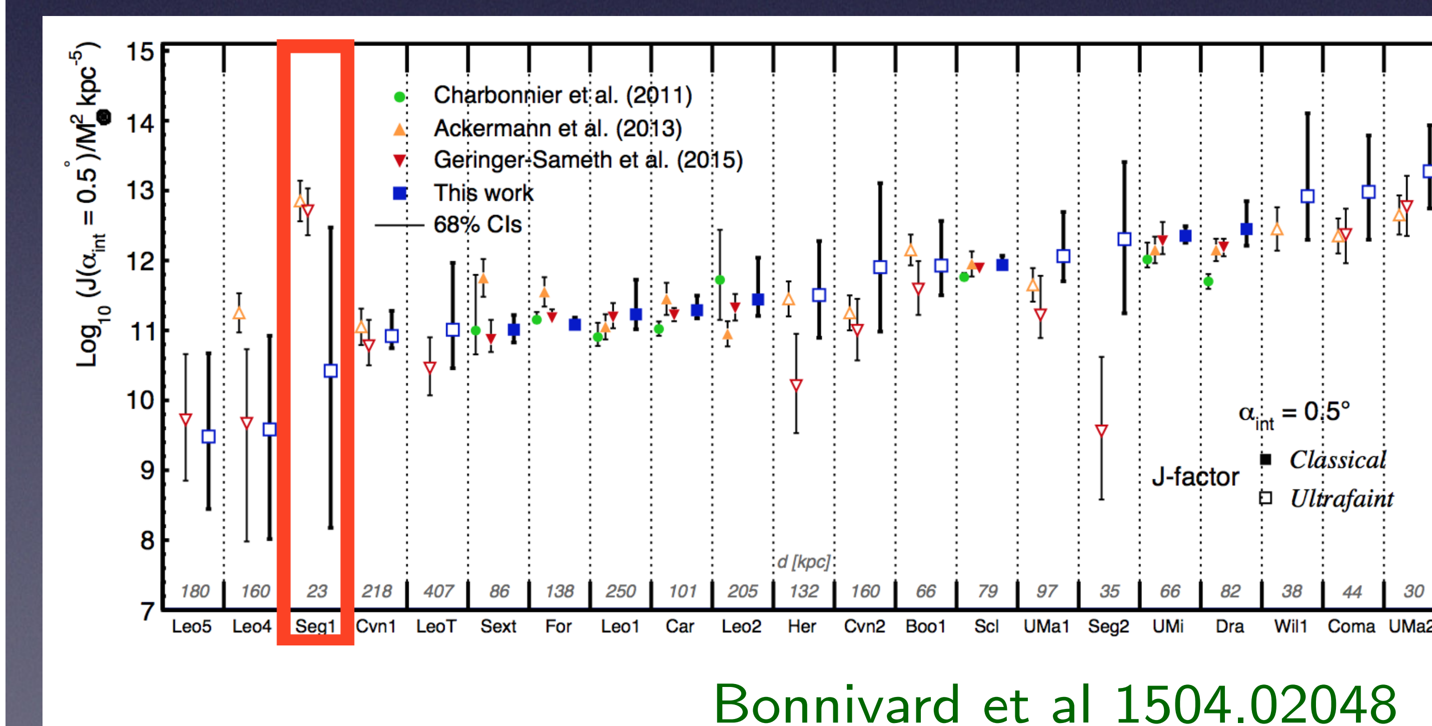

The *J*-factors & statistical errors in Bonnivard et al. are quite different with respect to those used by the exp. collaborations

γ lines: GC & dSphs

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

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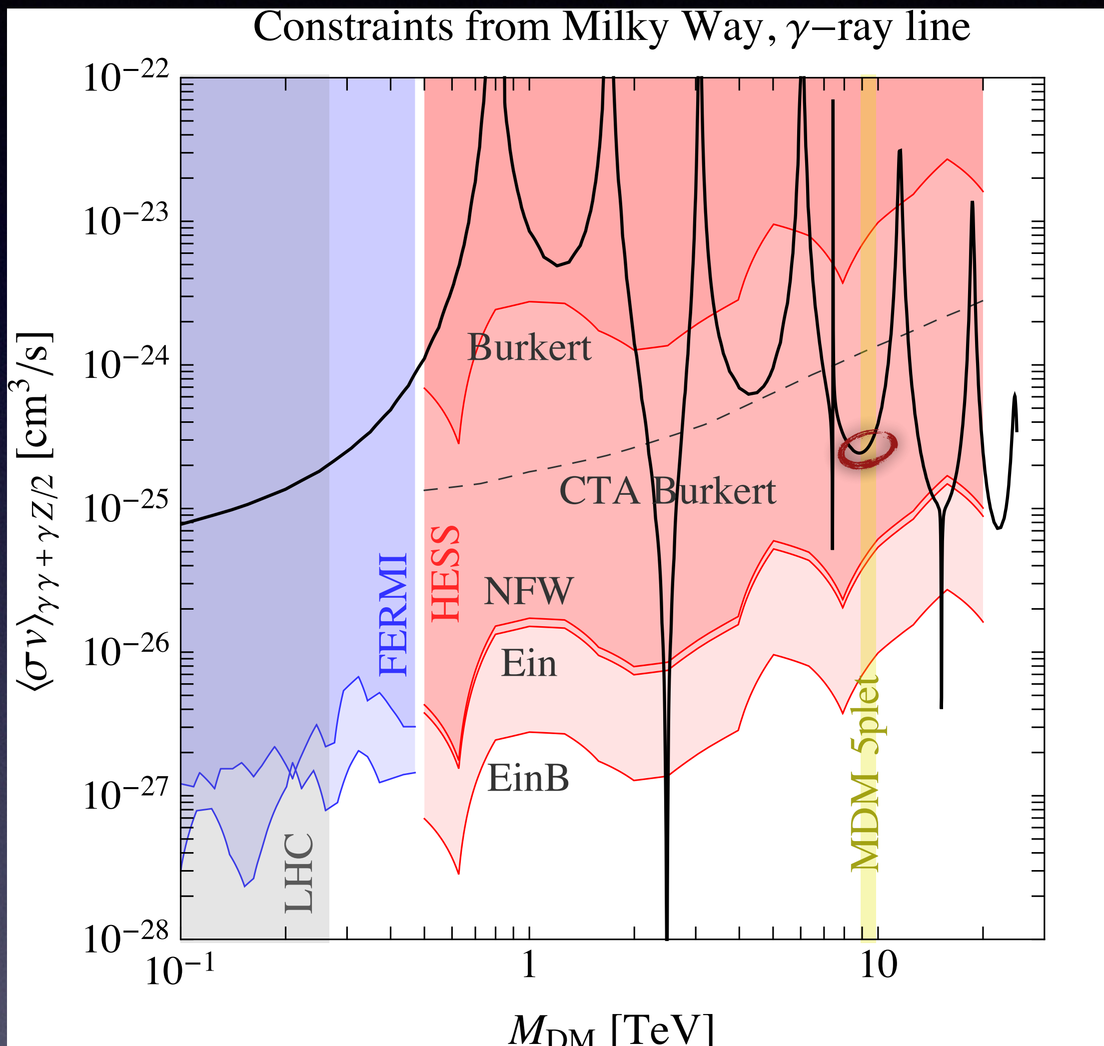

HESS: 112h observations of the GC

Fermi: threshold below M_χ -> No bound

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

γ lines: GC & dSphs

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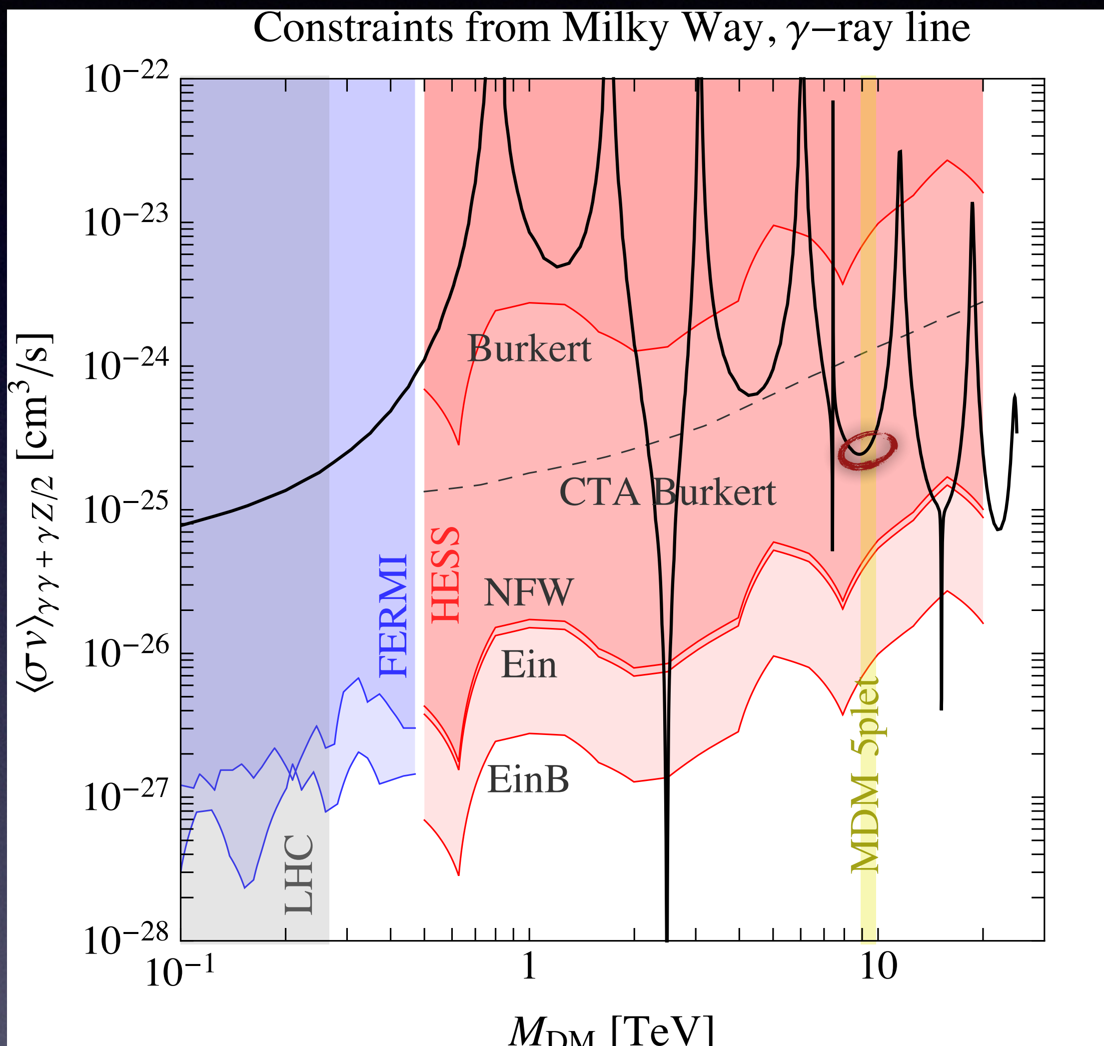
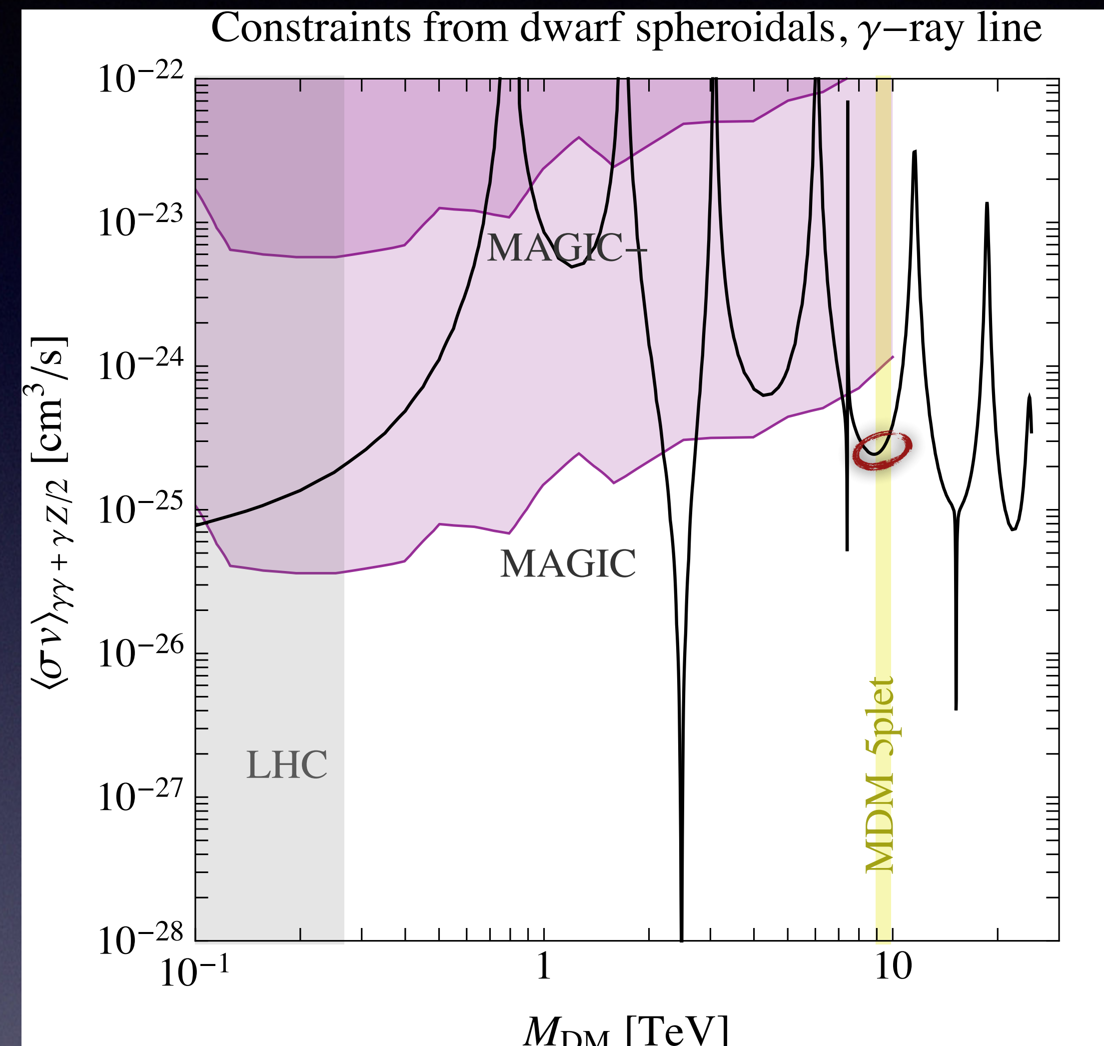




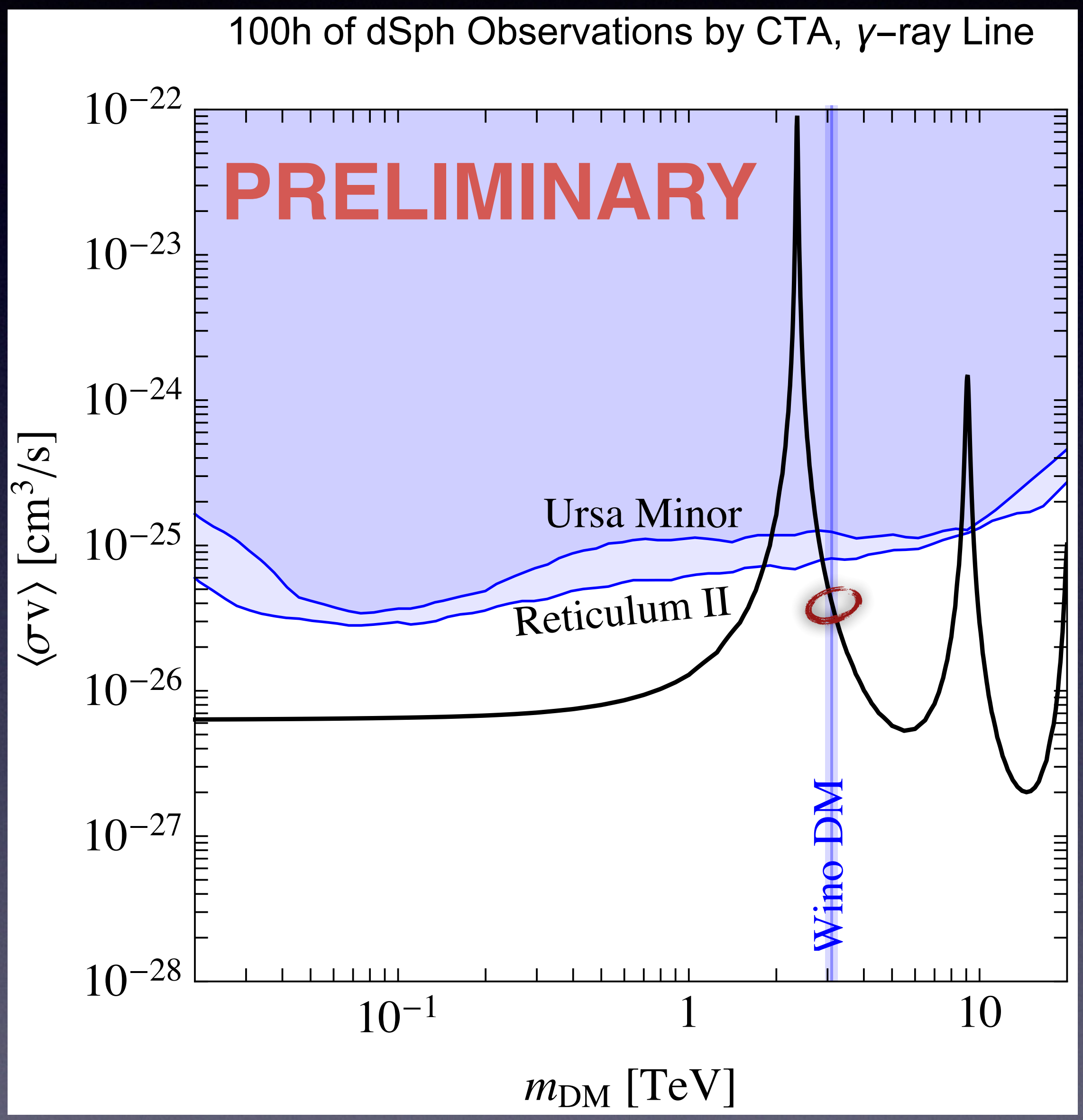
HESS Bound: from a RoI with an aperture of 0.1° -> **Large uncertainties**

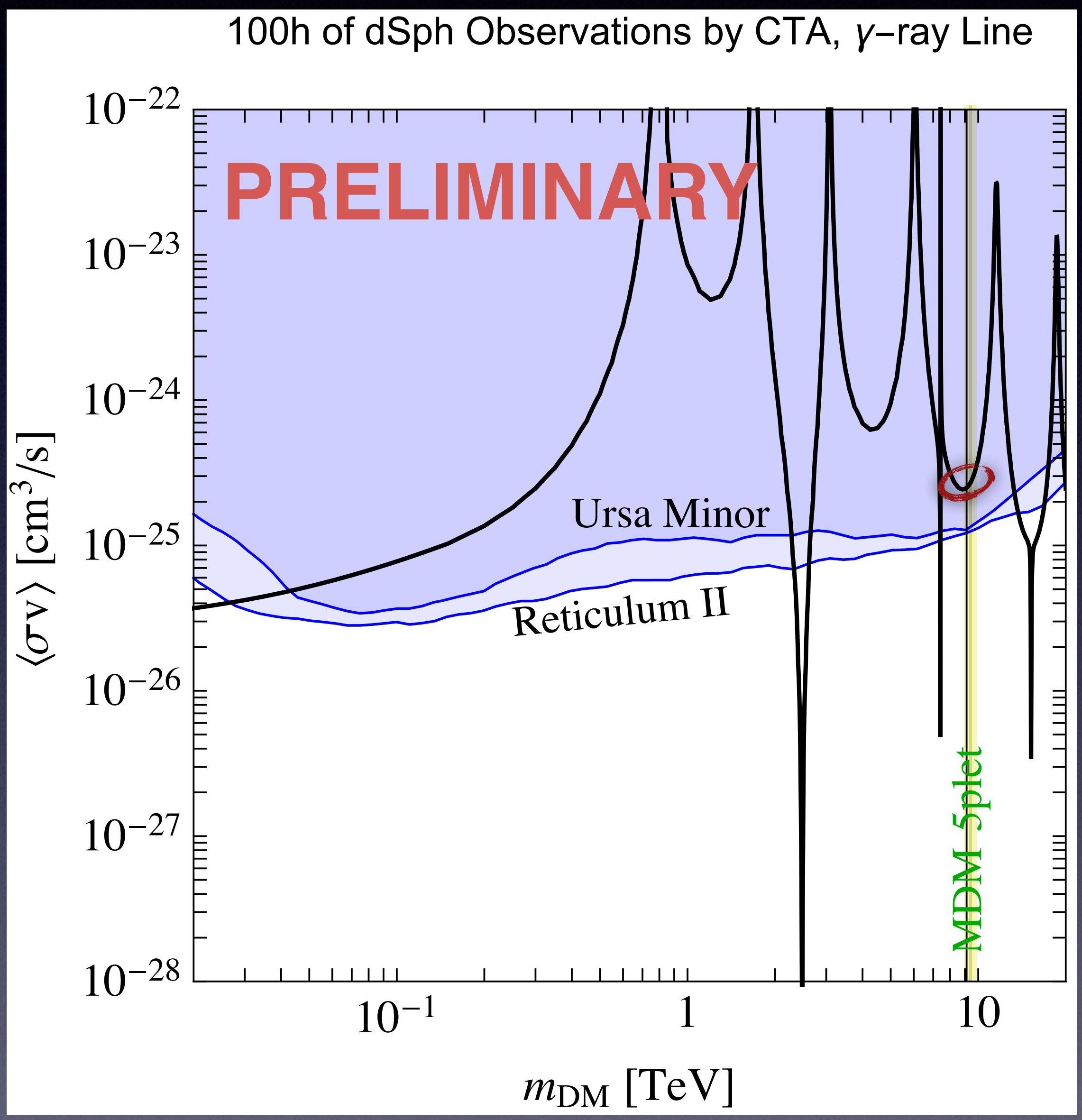
MAGIC bound: only available bound, but from Segue 1 -> wrong *J*-factor

- quantify the statistical & systematical errors in the determination of *J*
- point the currently operating & upcoming IACTs towards the best dSph

100h CTA sensitivity: dSphs

EW Multiplets have large cross sections into γγ and γZ





Bottom Line: with 100h of observations by CTA towards Reticulum II the parameter space of well motivated EW multiplets can be probed

based on: V. Lefranc, E. Moulin, P. Panci, F. Sala, J. Silk, in preparation

Conclusions

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  One can have very heavy WIMP absolutely stable: a C.scalar 9plet can have a mass of 25 TeV

Conclusions

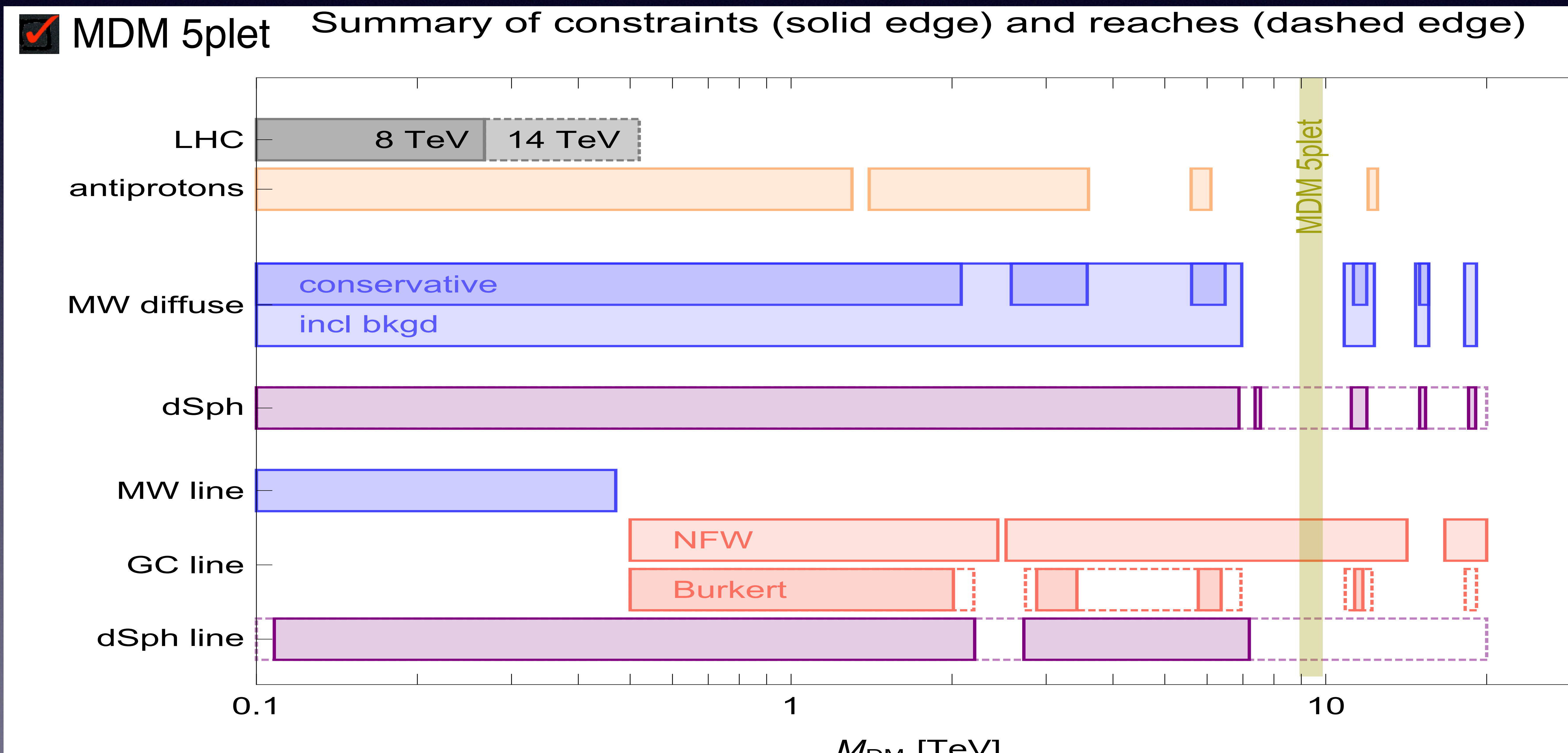
- Critical review of the MDM framework

  The scalar eptaplet is no longer a good MDM candidate: it decays very quickly due to 5 dim. operator

- New MDM candidates with small millicharge

  One can have very heavy WIMP absolutely stable: a C.scalar 9plet can have a mass of 25 TeV

- MDM 5plet



End