Probing Minimal Dark Matter Scenarios with Cherenkov Telescopes

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Outline

- Motivation: Minimal Dark Matter Scenarios

- Gamma-Ray Spectrum

- H.E.S.S. Limits

- C.T.A. Prospects

- Conclusions

WIMP Paradigm

Direct detection experiments continue to tighten limits on O(100 GeV) mass WIMPs.

8 TeV Large Hadron Collider (LHC): no evidence for WIMPs.

It is crucially important to look into the TeV-scale

Minimal Dark Matter Scenarios

Quantum numbers
$SU(2)_L$ $U(1)_Y$ Spin

Simple assumption: extend the SM with an electroweak multiplet

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3	0	1/2
3	1	0
3	1	1/2
4	1/2	0
4	1/2	1/2
4	3/2	0
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5	0	0
5	0	1/2
7	0	0

Cirelli, Fornengo, Strumia 2005

Minimal Dark Matter Scenarios

Simple assumption: extend the SM with an electroweak multiplet

Inert Doublet Model →

Wino DM model →

Fermionic 5-plet →

Scalar 7-plet →

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Minimal Dark Matter Scenarios

Simple assumption: extend the SM with an electroweak multiplet

Multi-TeV DM models

Inert Doublet Model
0.5-10 TeV

Wino DM model
3.1 TeV

Fermionic 5-plet
9.4 TeV

Scalar 7-plet
25 TeV

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Minimal Dark Matter Scenarios

$$\chi = \begin{pmatrix} \text{DM}^{2+} \\ \text{DM}^+ \\ \text{DM} \\ -\text{DM}^- \\ \text{DM}^{2-} \end{pmatrix} \quad \text{for the 5-plet,} \qquad \chi = \begin{pmatrix} \text{DM}^{3+} \\ \text{DM}^{2+} \\ \text{DM}^+ \\ \text{DM} \\ -\text{DM}^- \\ \text{DM}^{2-} \\ -\text{DM}^{3-} \end{pmatrix} \quad \text{for the 7-plet.}$$

$$\mathcal{L} = \mathcal{L}_{\text{SM}} + \frac{1}{2}\bar{\chi}(i\slashed{D} - M)\chi \qquad \text{(fermion)}$$

$$\mathcal{L} = \mathcal{L}_{\text{SM}} + \frac{1}{2}\left(|D_\mu\chi|^2 - M^2|\chi|^2\right) \qquad \text{(scalar)} .$$

Only the mass is a free parameter.   Very predictive scenarios!

Sommerfeld Effect is responsible for huge cross-sections
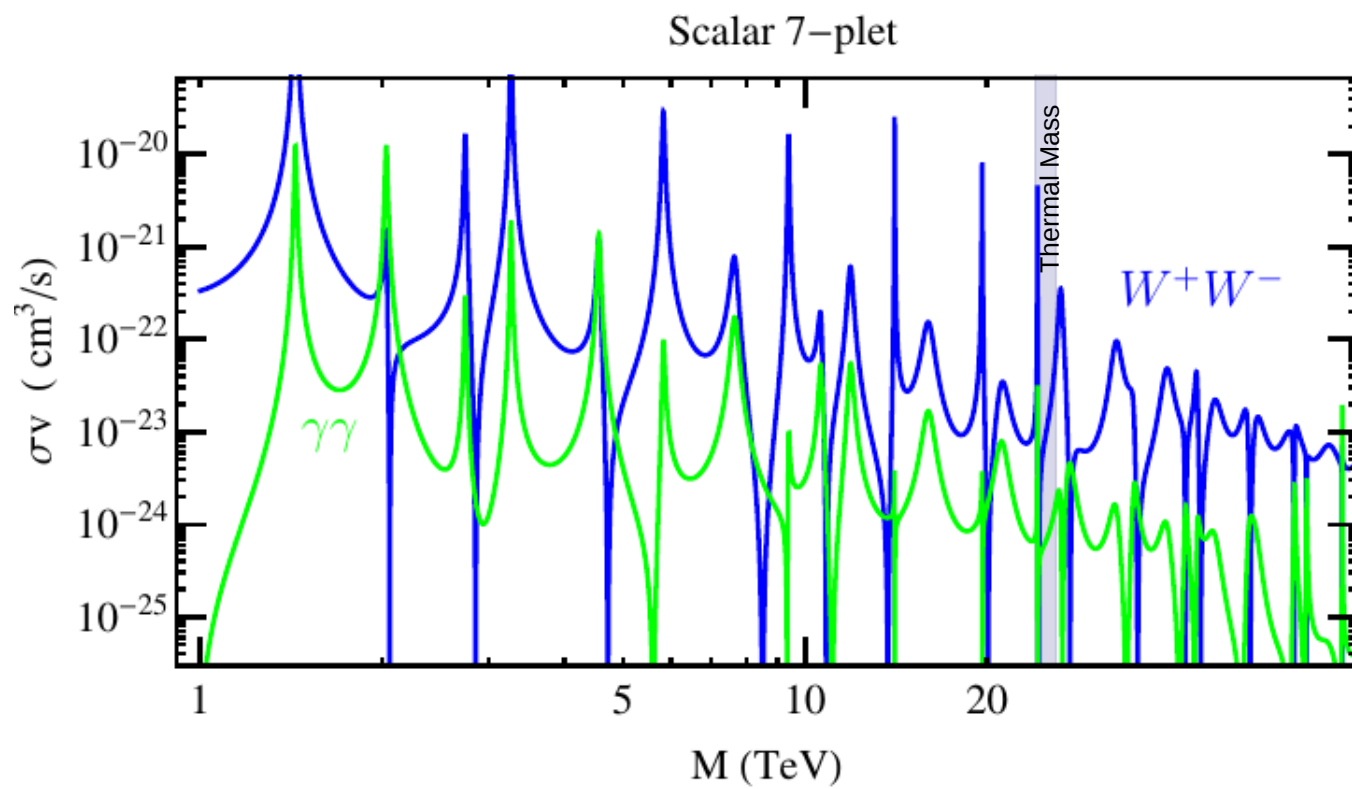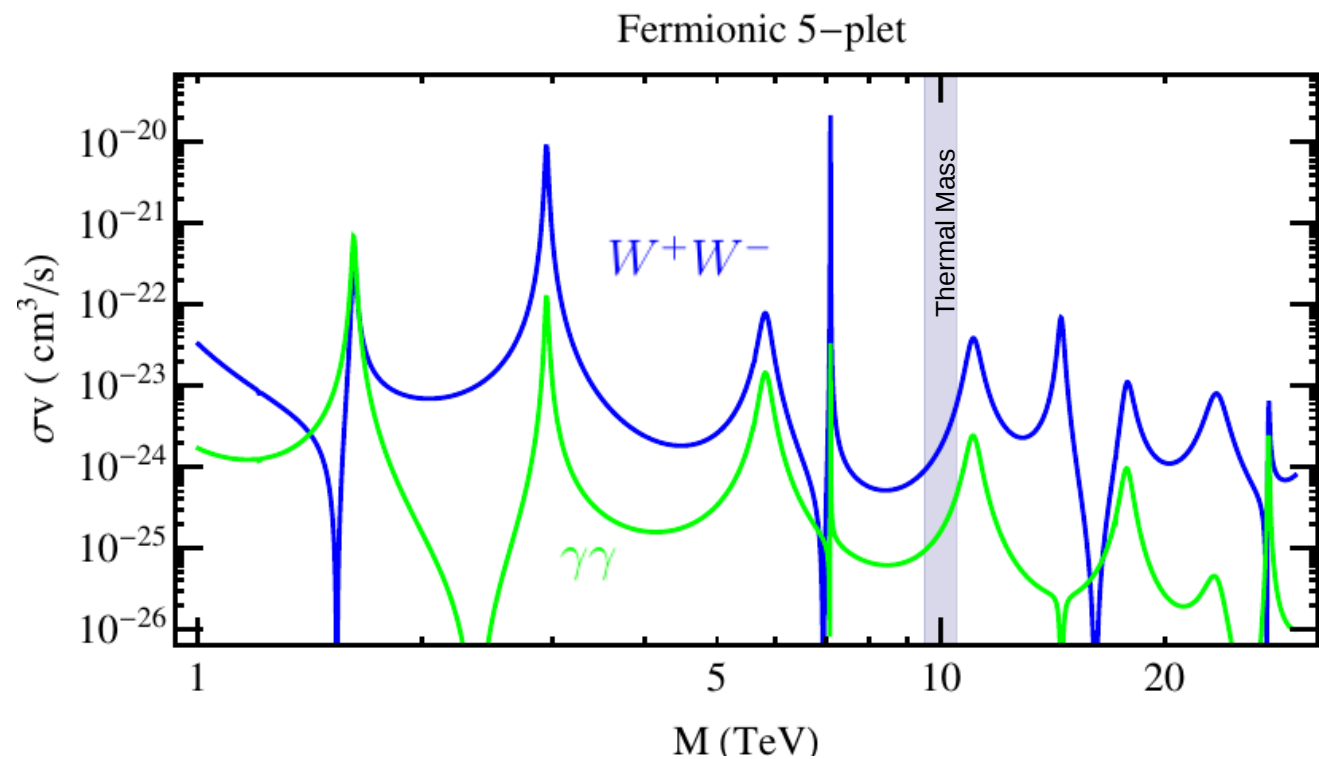
Fermionic 5−plet

σv (cm^3/s)

W^+W^-

$\gamma\gamma$

Thermal Mass

M (TeV)

Scalar 7−plet

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Yukawa Potential

χ^0 χ^- W, Z, γ

w, z, γ ...

χ^0 χ^- W, Z, γ

W^+W^-

$\gamma\gamma$

Thermal Mass

σv (cm^3/s)

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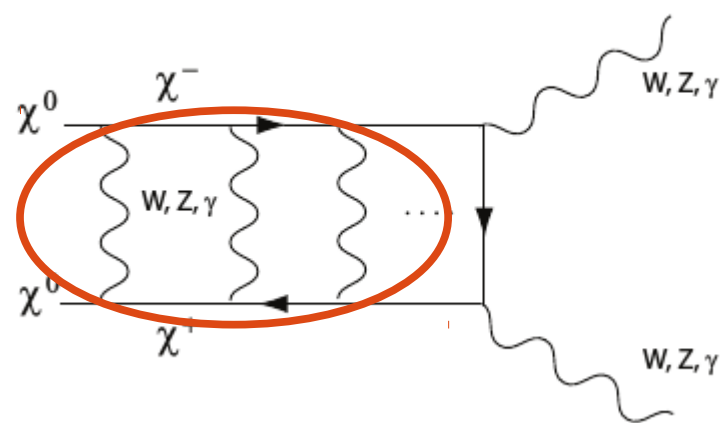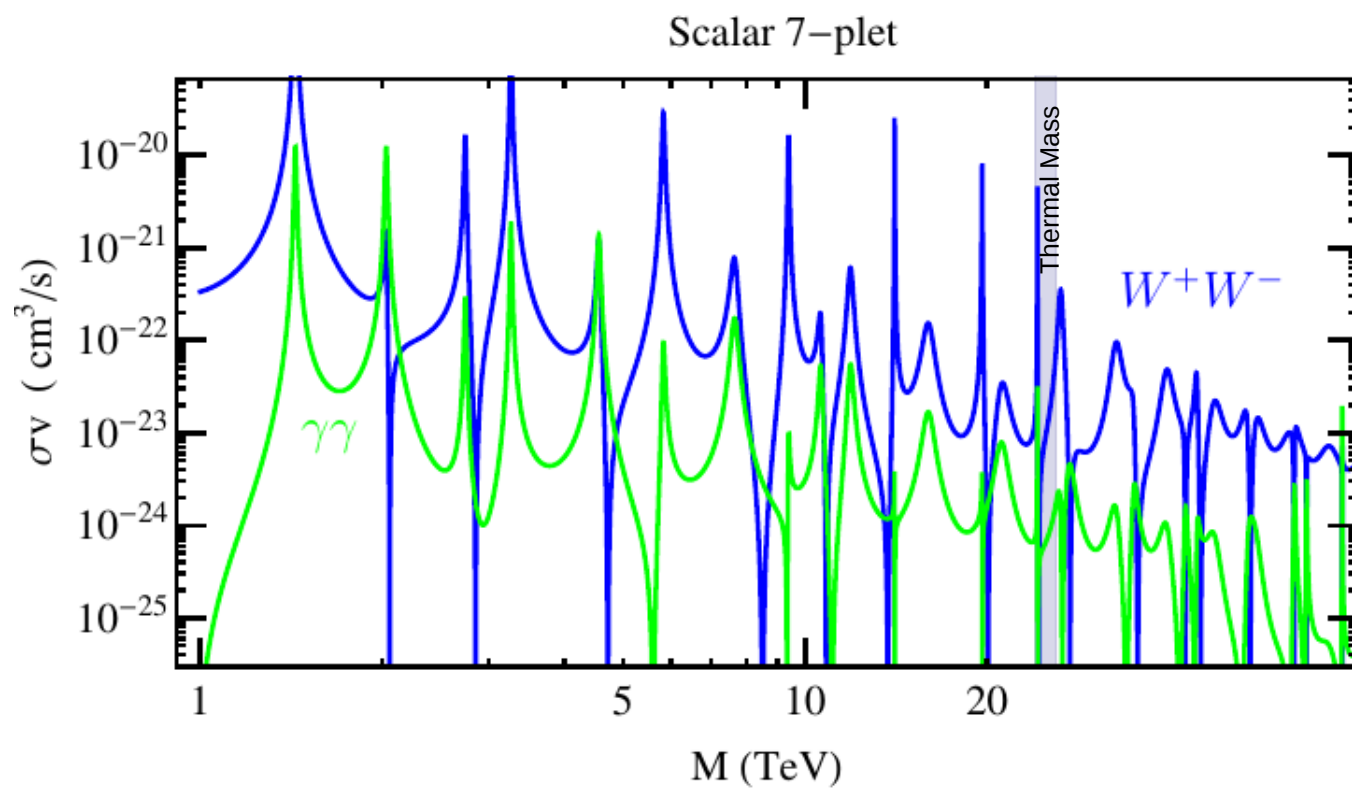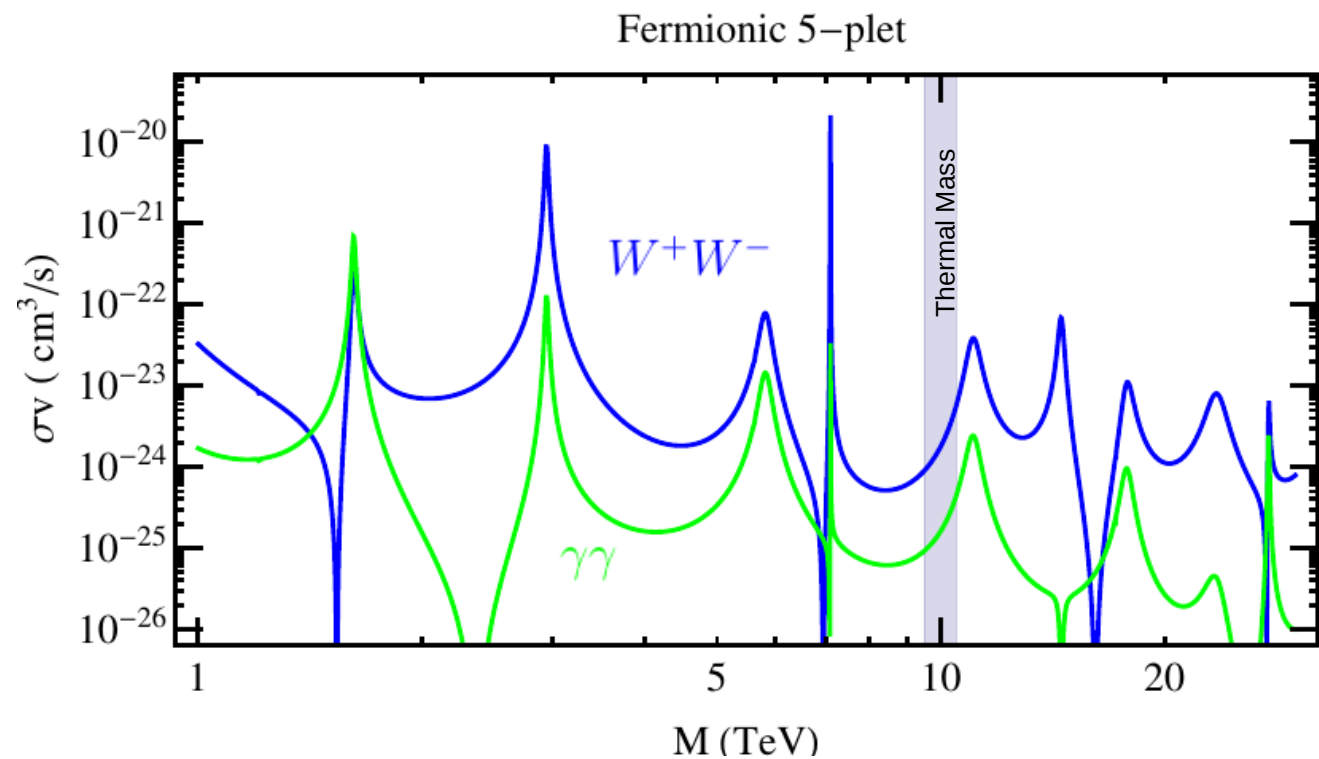
Sommerfeld Effect is responsible for huge cross sections

Cirelli, Strumia, Tambirini 2007
Cirelli, Strumia 2009
Cirelli, Hambye, Taoso, Panci, Sala 2015

Yukawa Potential

Fermionic 5−plet

Sommerfeld Effect is responsible for huge
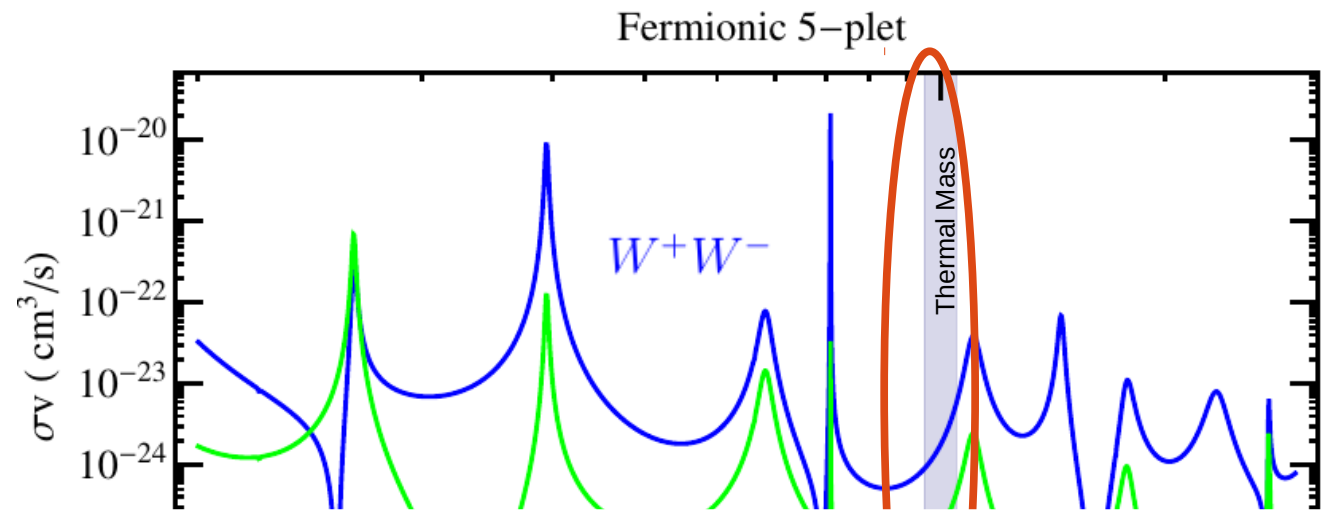
We give up the Freeze-out mechanism to explain DM abundance

We consider other masses below and above the thermal values!
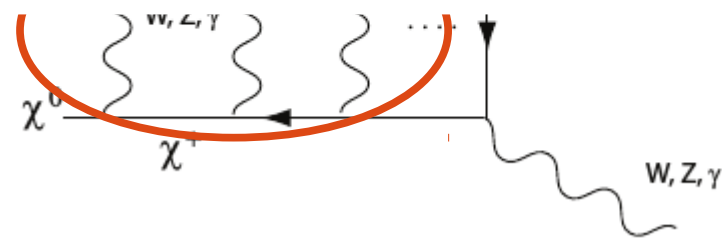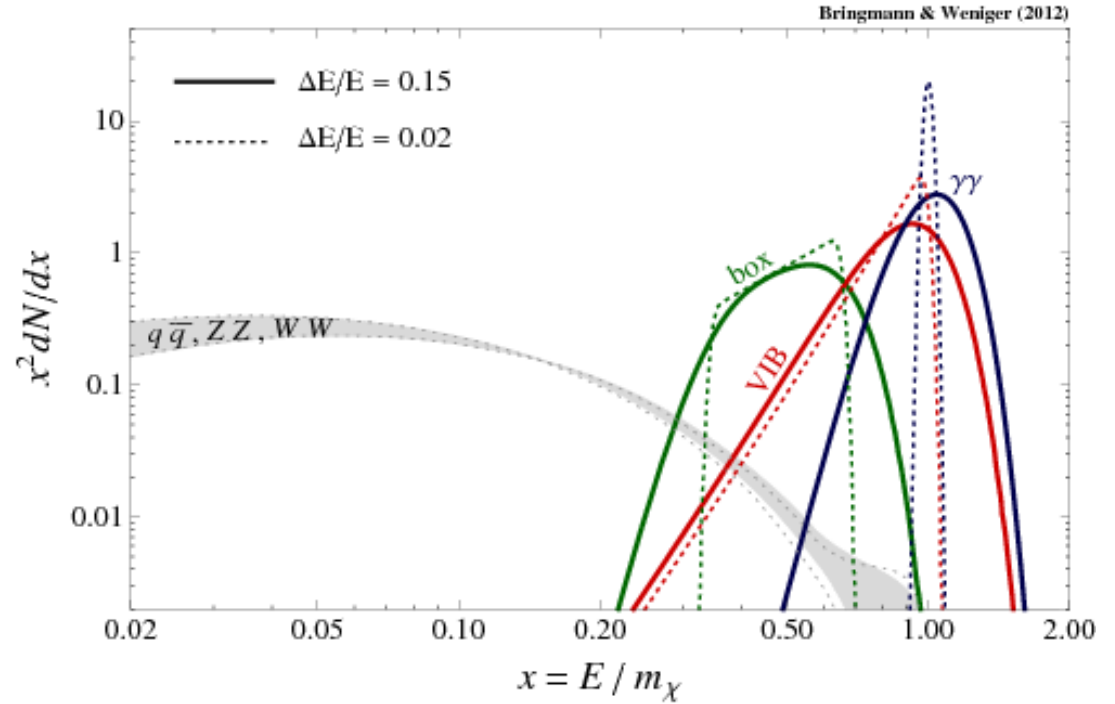

Yukawa Potential
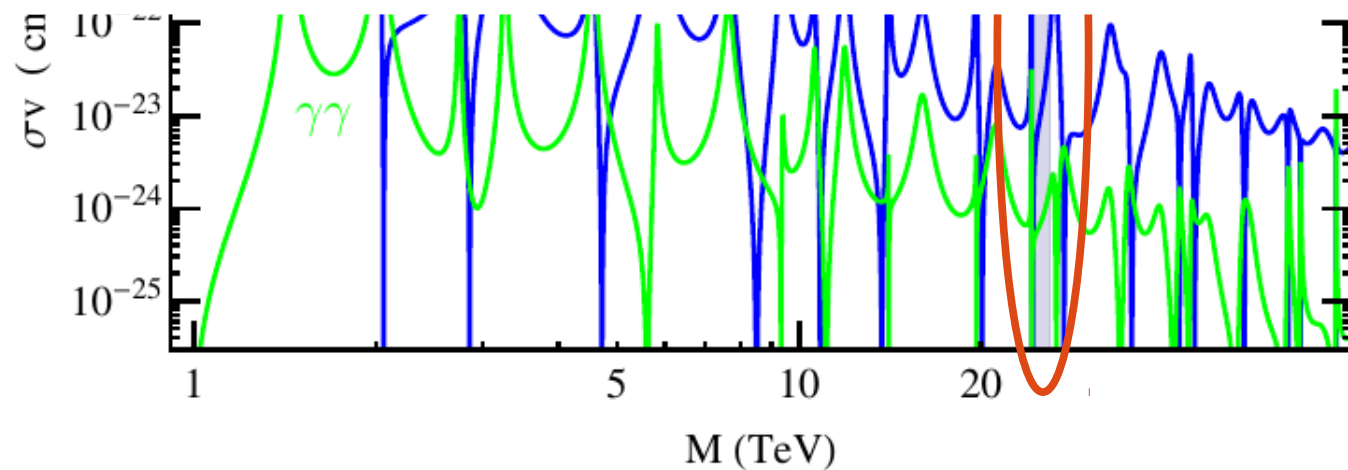
H.E.S.S. Experiment
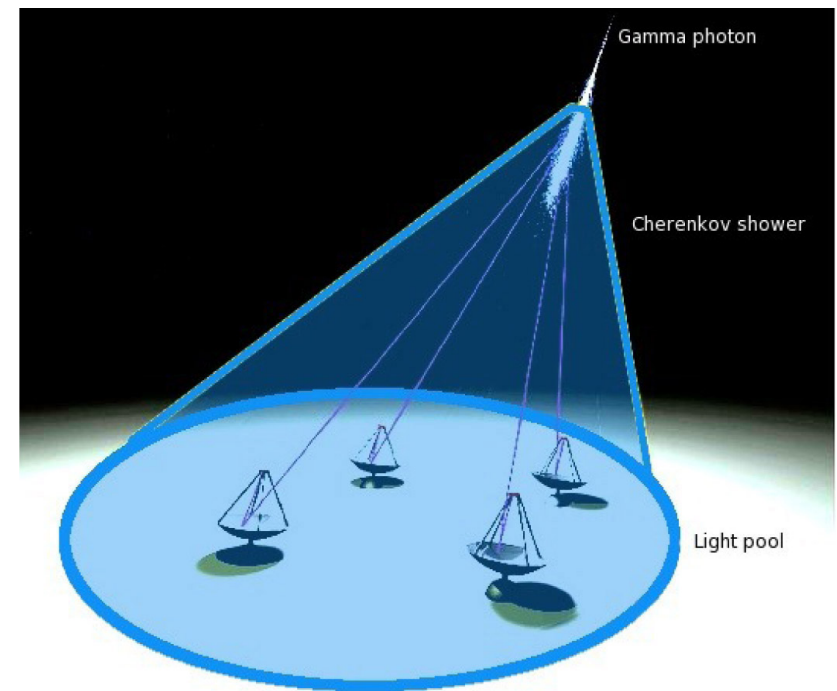
Cherenkov telescopes can probe TeV
dark matter annihiliting into gamma-rays

Gamma-ray spectrum
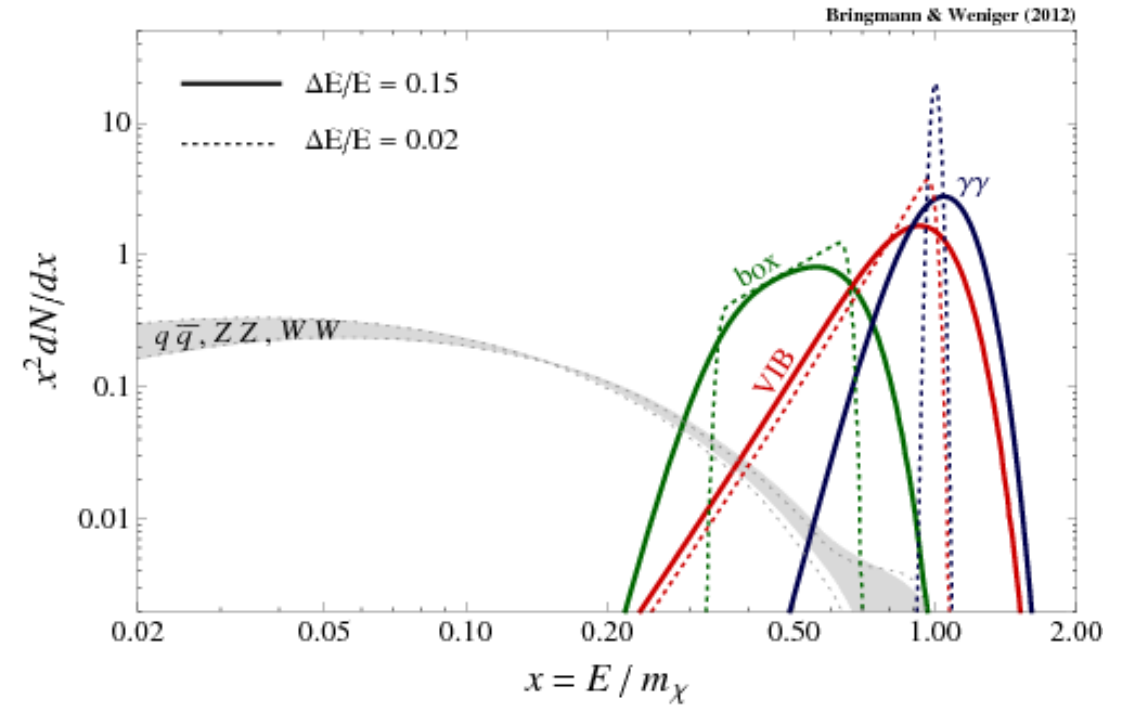
Bringmann & Weniger (2012)

Gamma-ray spectrum

Bringmann & Weniger (2012)
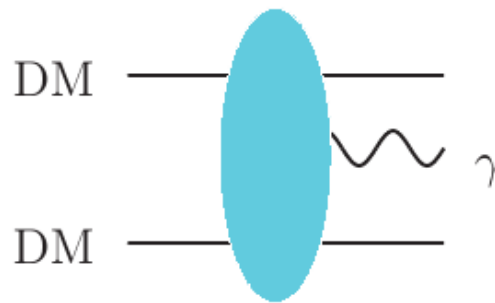
No astrophysical process is known to produce a **sharp feature** in the gamma-ray spectrum
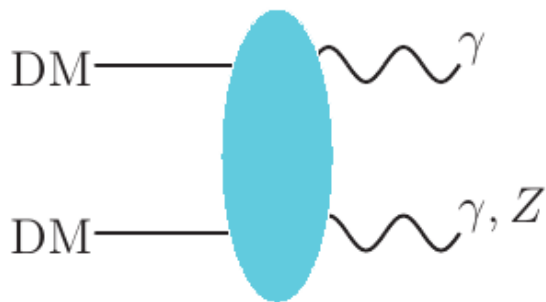
Annihilation into Photons

Gamma-ray spectrum

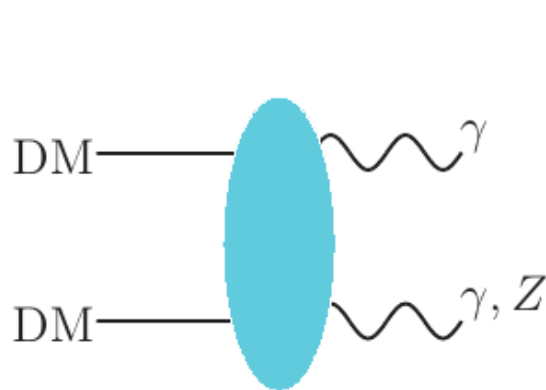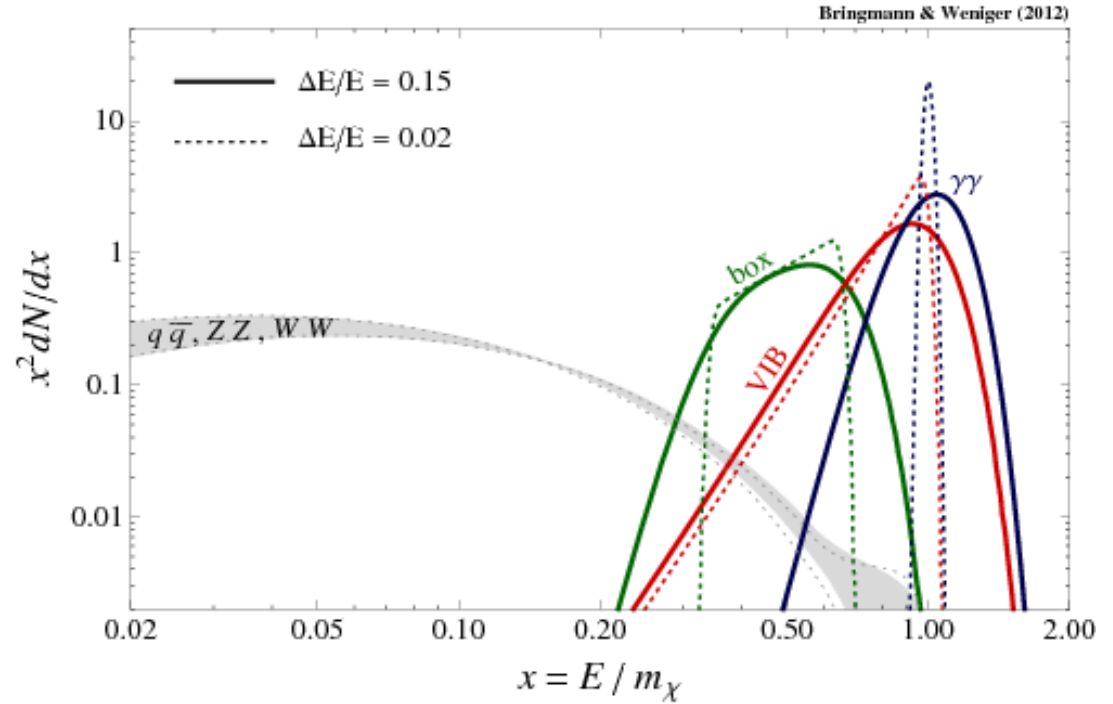No astrophysical process is known to produce a **sharp feature** in the gamma-ray spectrum

Bringmann & Weniger (2012)
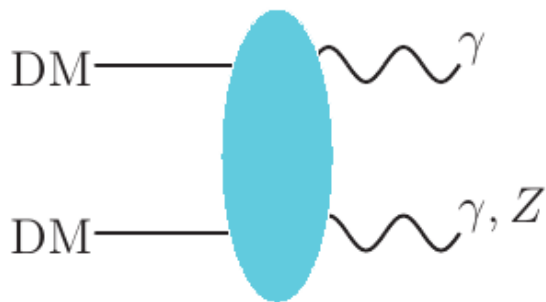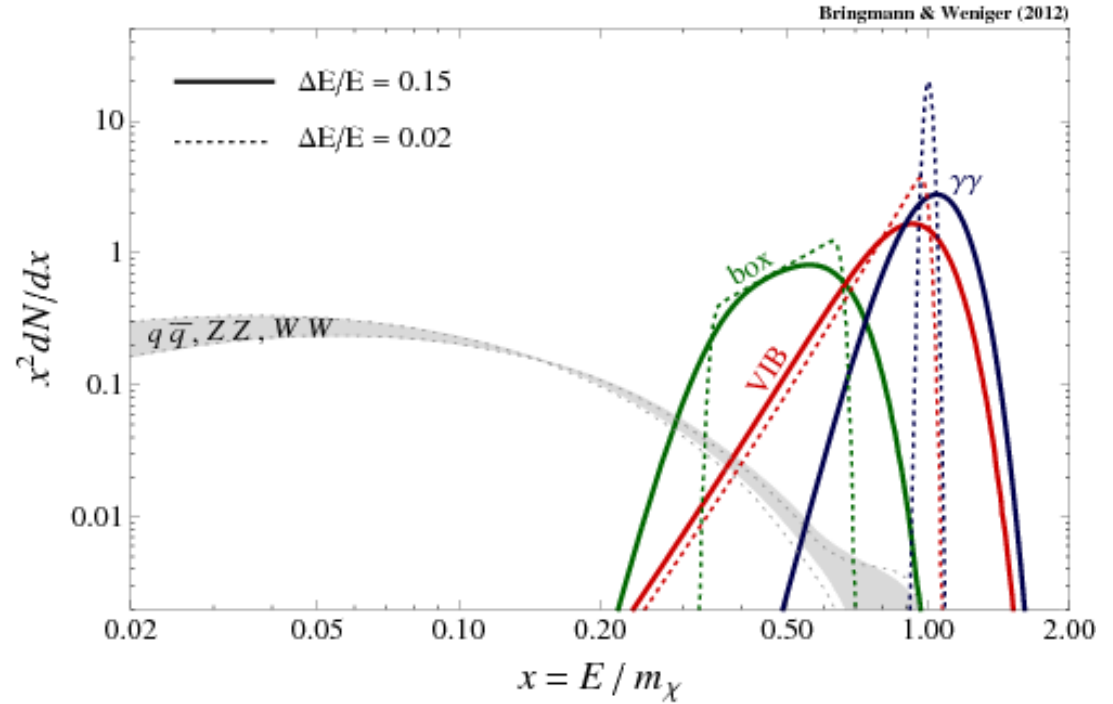
Annihilation into Photons   Virtual Internal Bremsstrahlung
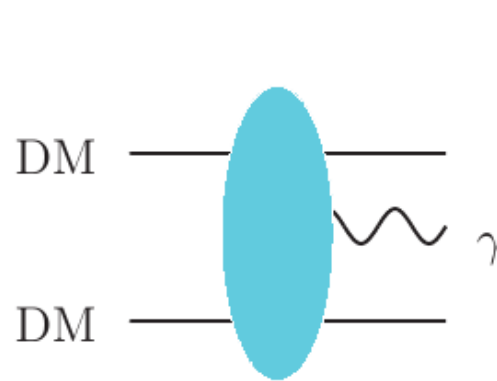
Gamma-ray spectrum

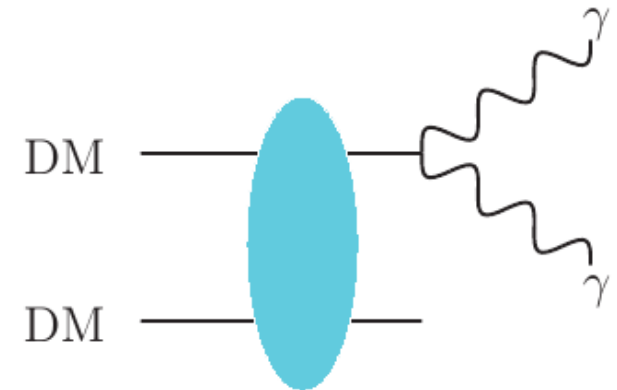No astrophysical process is known to produce a **sharp feature** in the gamma-ray spectrum

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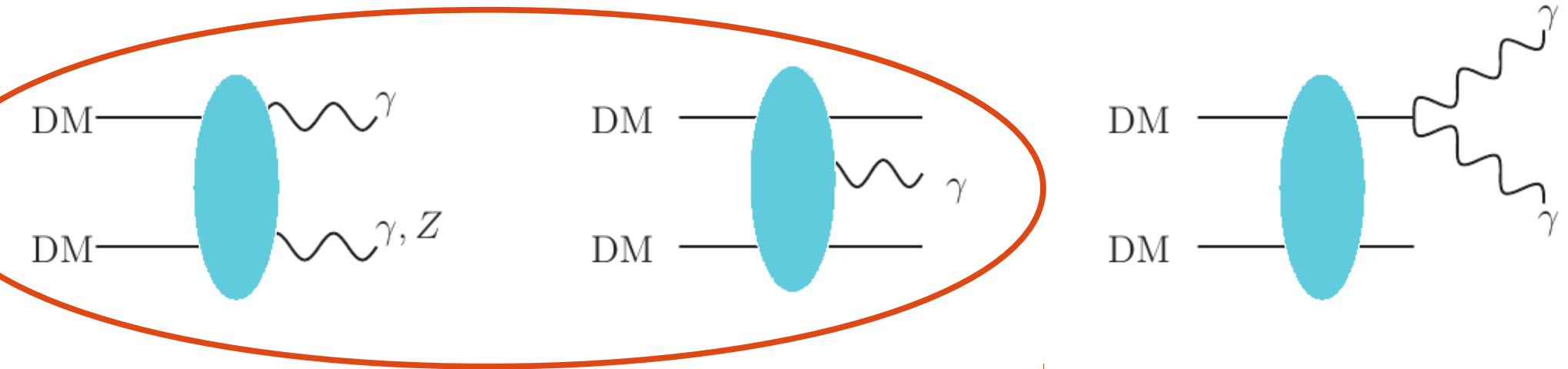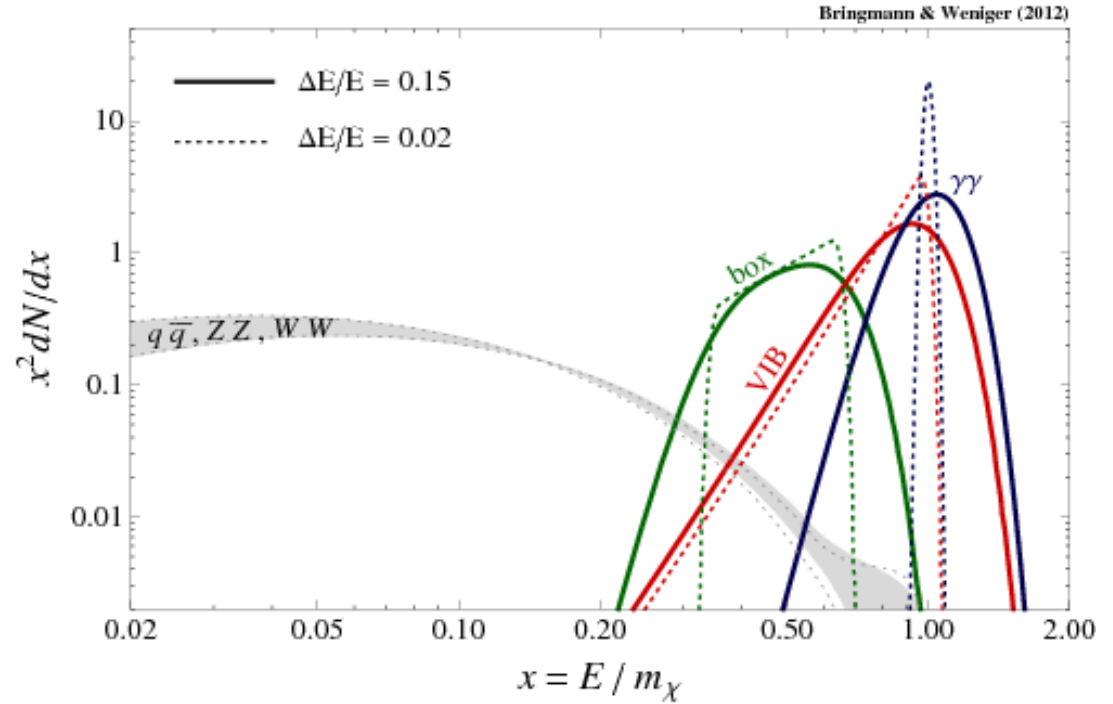
Annihilation into Photons   Virtual Internal Bremsstrahlung   Box-shaped spectra

Gamma-ray spectrum

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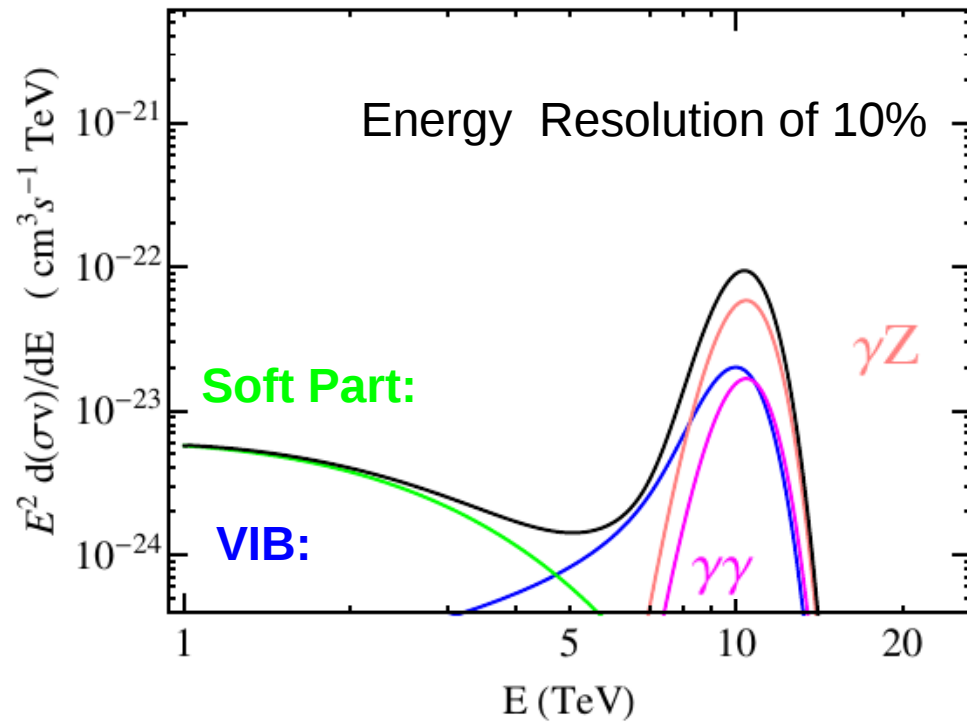

Bringmann & Weniger (2012)

$\Delta E/E = 0.15$
$\Delta E/E = 0.02$

$q\bar{q}, ZZ, WW$

box

VIB

$\gamma\gamma$

$x^2 dN/dx$

$x = E/m_\chi$

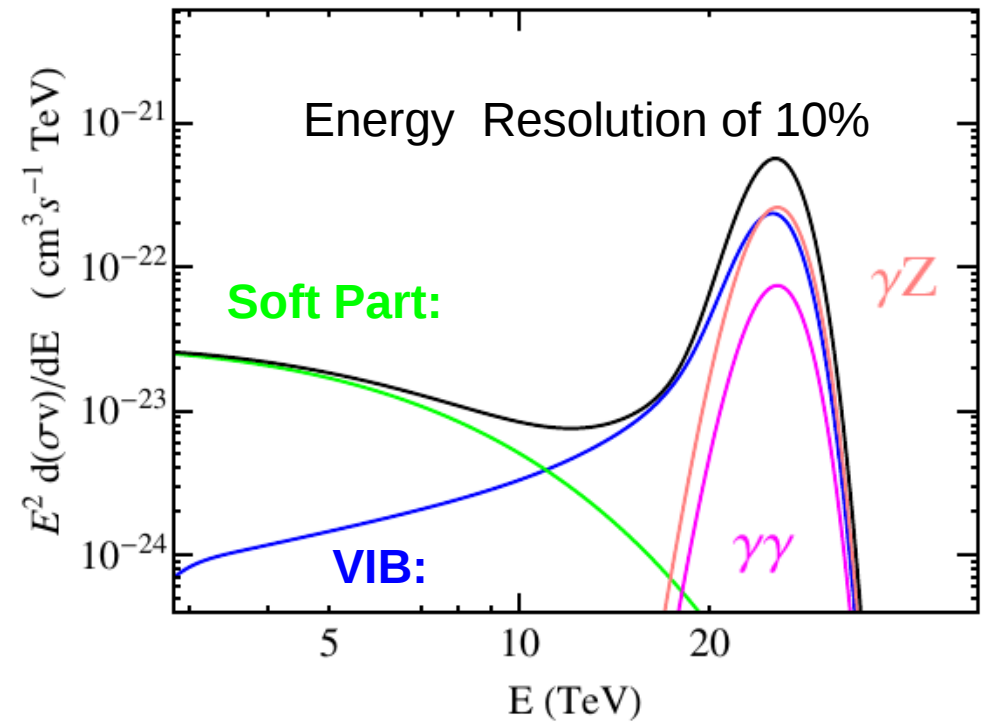Annihilation into Photons   Virtual Internal Bremsstrahlung   Box-shaped spectra

Gamma-ray spectrum

Fermionic 5-plet   M ~ 10 TeV
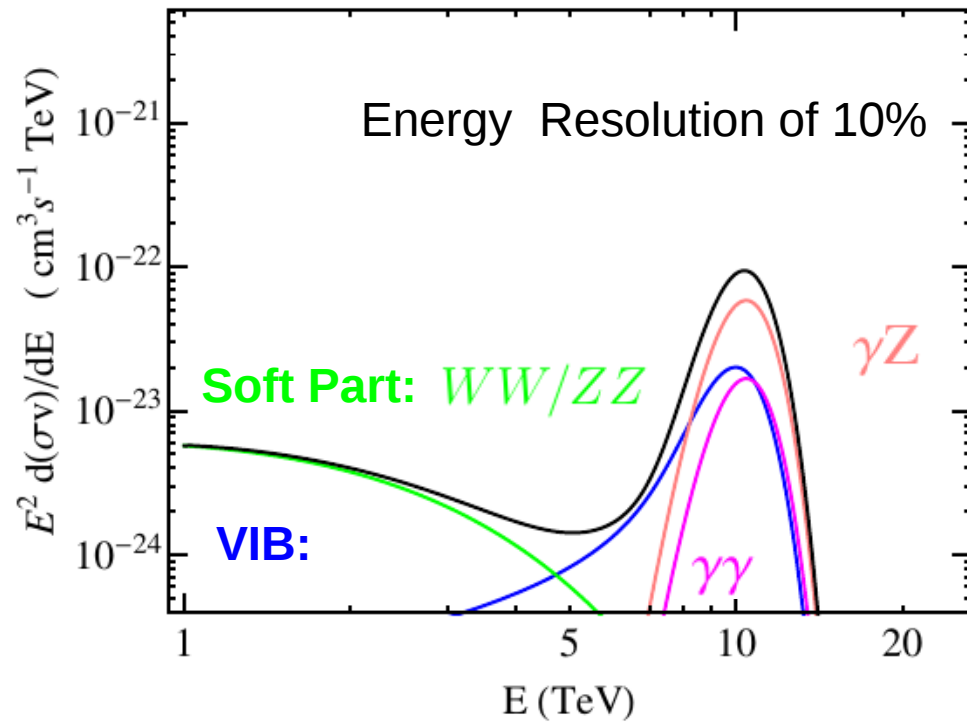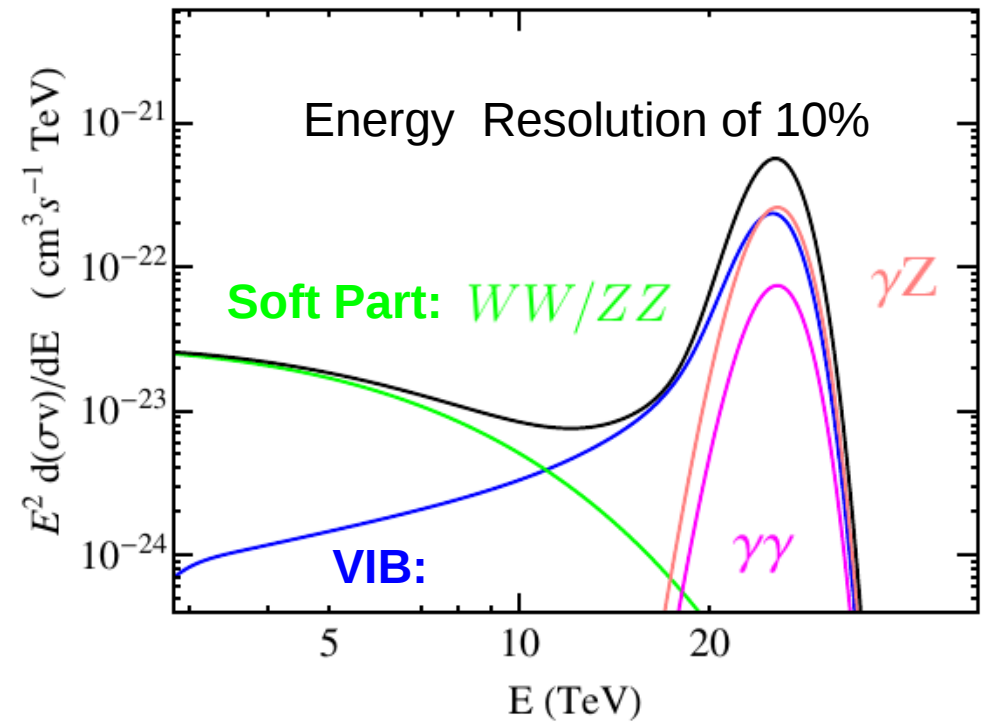
Scalar 7-plet   M ~ 25 TeV
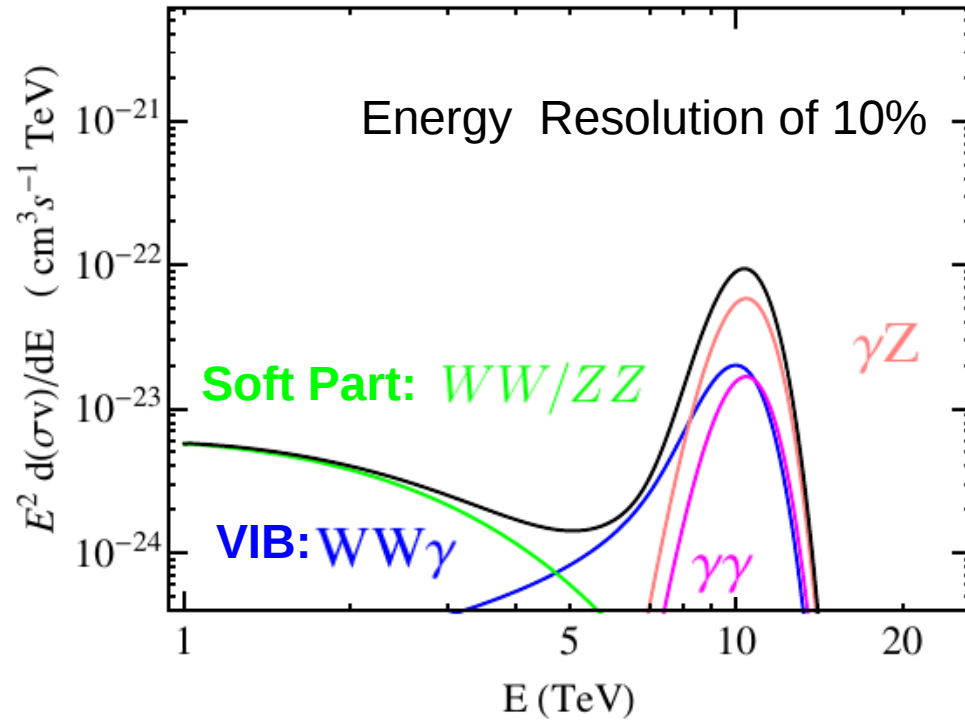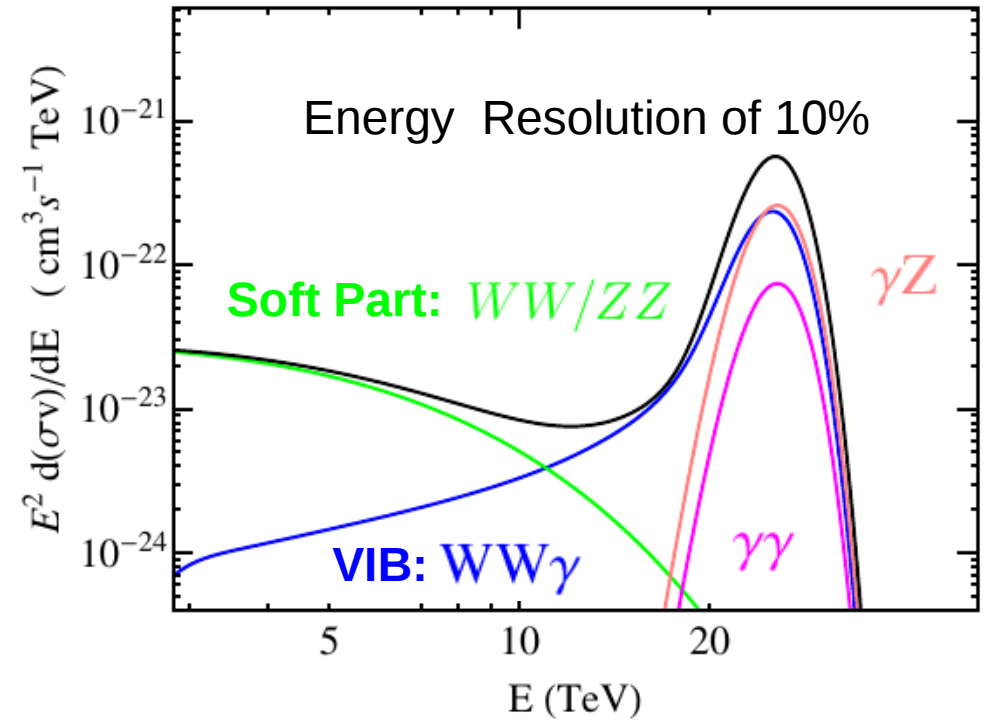
Gamma-ray spectrum

Fermionic 5-plet   M ~ 10 TeV

Energy Resolution of 10%

Soft Part: WW/ZZ

VIB:

γZ

$\gamma\gamma$

$E^2\, d(\sigma v)/dE\ \ (\mathrm{cm^3 s^{-1}\, TeV})$

E (TeV)

Scalar 7-plet   M ~ 25 TeV

Energy Resolution of 10%

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E (TeV)

Gamma-ray spectrum

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Energy Resolution of 10%

Soft Part: WW/ZZ

γZ

VIB: $WW\gamma$

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Scalar 7-plet   M ~ 25 TeV

Energy Resolution of 10%

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$\gamma\gamma$

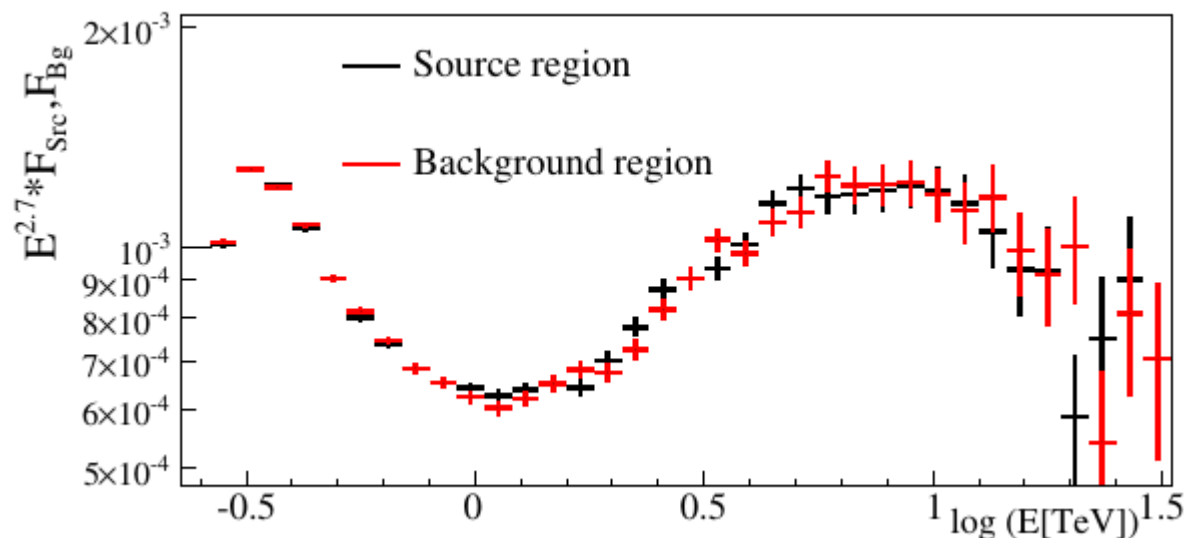# H.E.S.S. Limits from the Galatic Center Soft Part

Target region: a circle of 1° radius centered in the Milky Way Center, excluding the Galactic Plane $|b| \geq 0.3°$

- We calculate constraints on the featureless component from W^+W^- or ZZ annihilations by comparing the gamma-ray fluxes measured with the H.E.S.S. instrument in a "search region" and in a "background region". The inferred residual flux is consistent with zero, thus allowing to derive upper limits on the flux from annihilations.

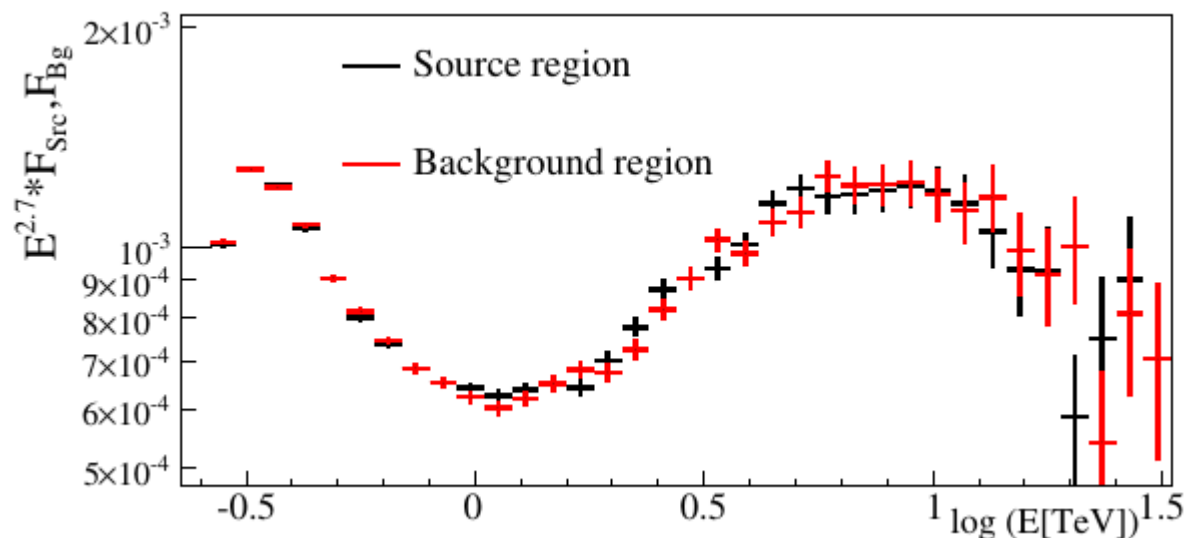(H.E.S.S.Collaboration), Phys.Rev.Lett. **106**, 161301 (2011), 1103.3266.

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This approach is only valid for cuspy DM profiles

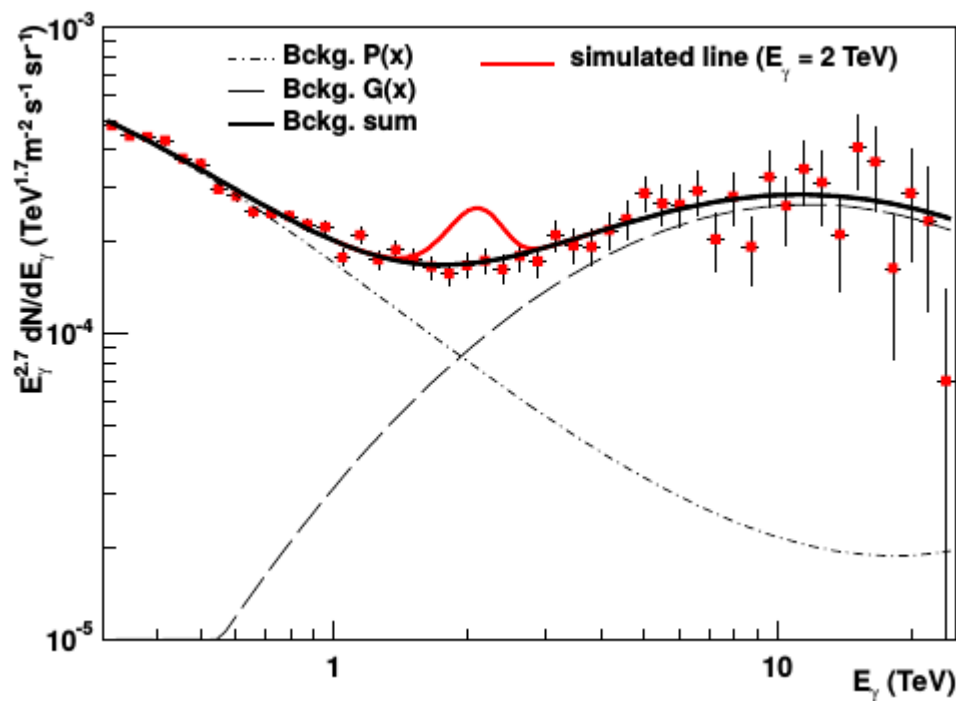# H.E.S.S. Limits from the Galatic Center Sharp Spectral Feature
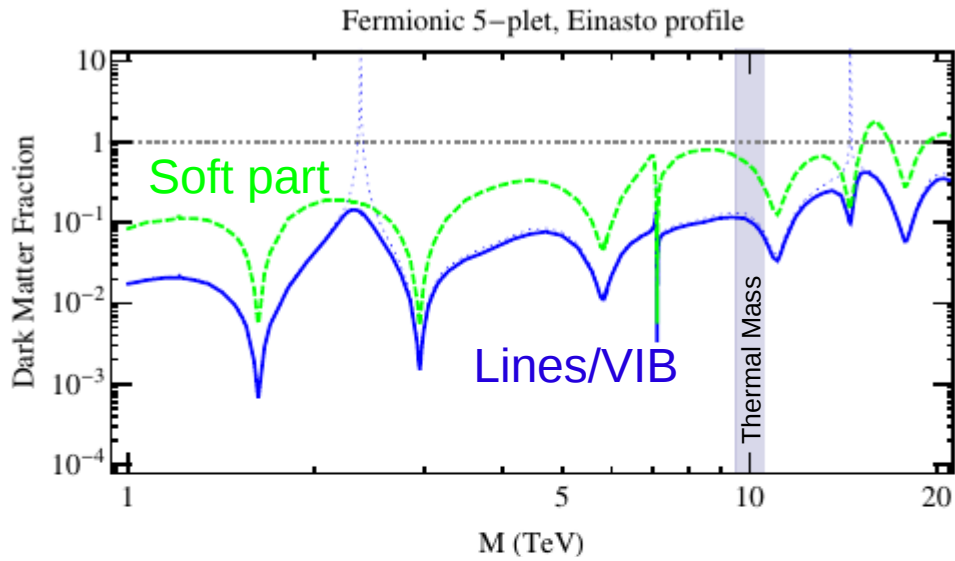
Target region: a circle of 1° radius centered in the Milky Way Center, excluding the Galactic Plane $|b| \geq 0.3°$

- To calculate limits on the DM annihilation cross section into sharp spectral features, we adopt the phenomenological background model proposed by the H.E.S.S. collaboration, which is described by 7 parameters.
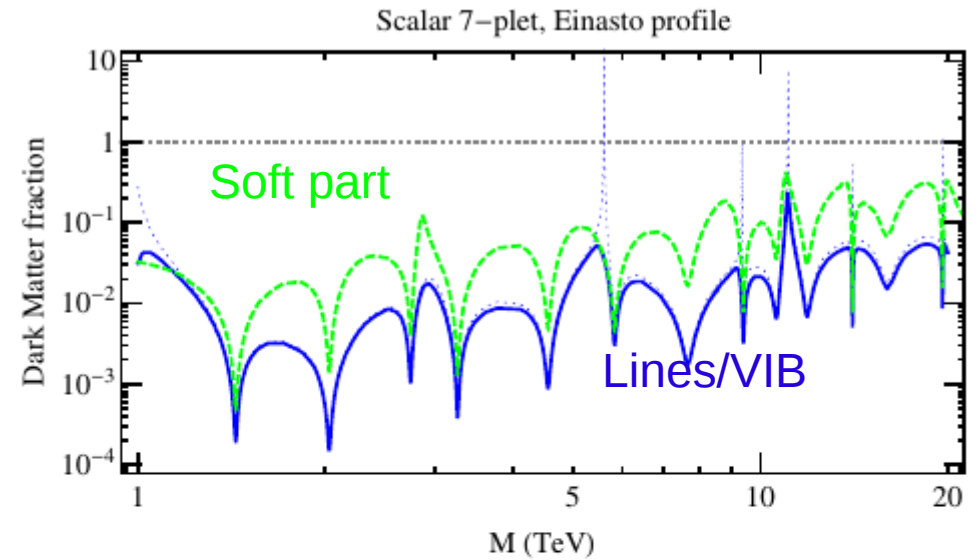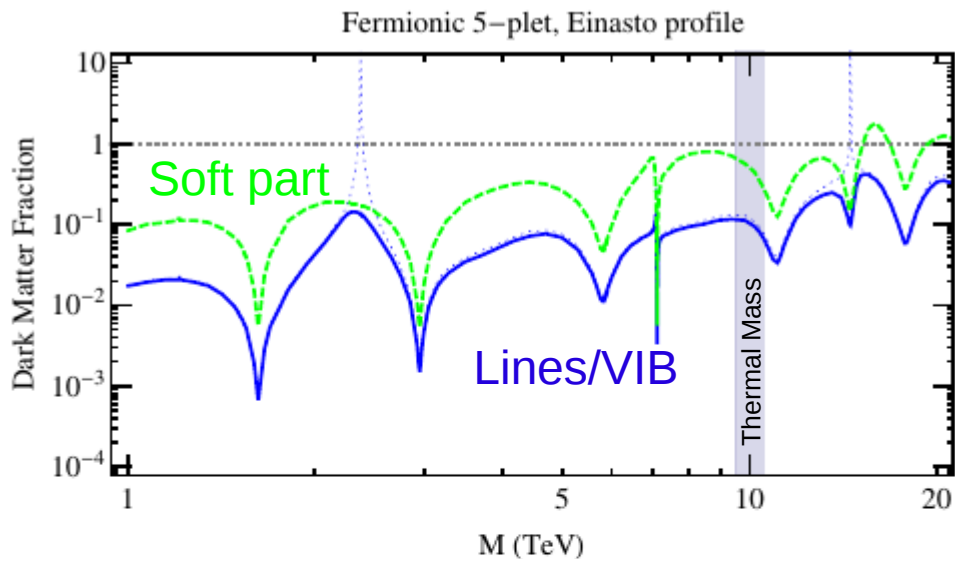
(H.E.S.S. Collaboration), Phys.Rev.Lett. **110**, 041301 (2013), 1301.1173.
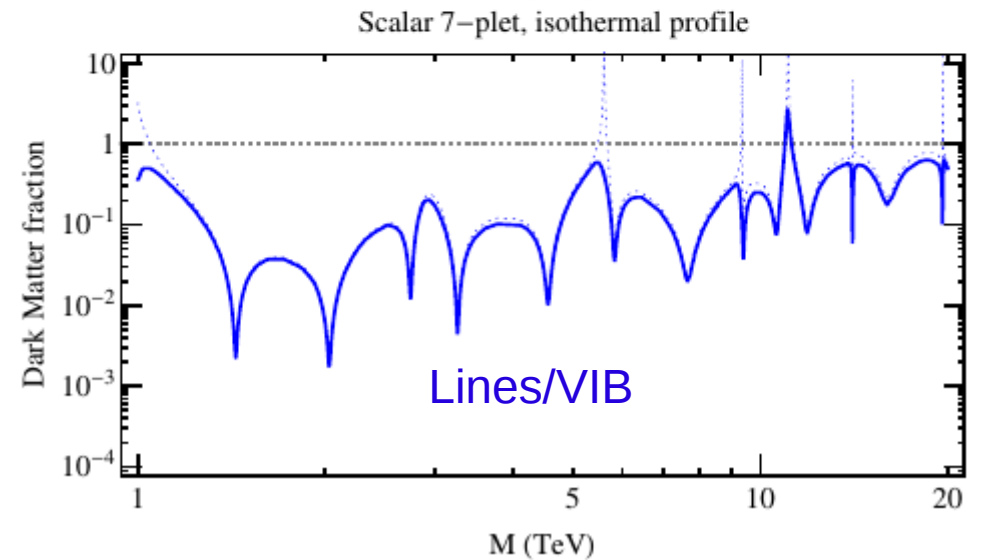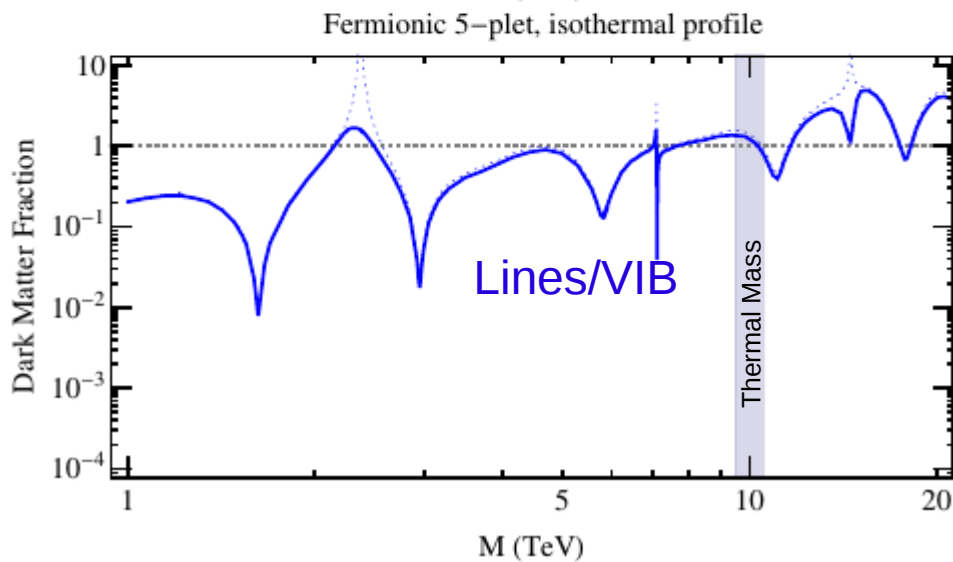
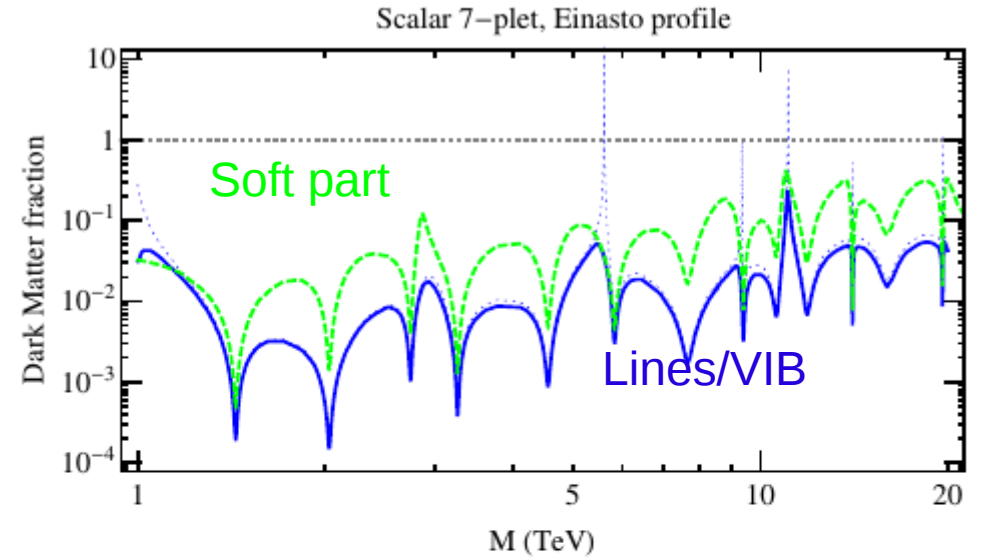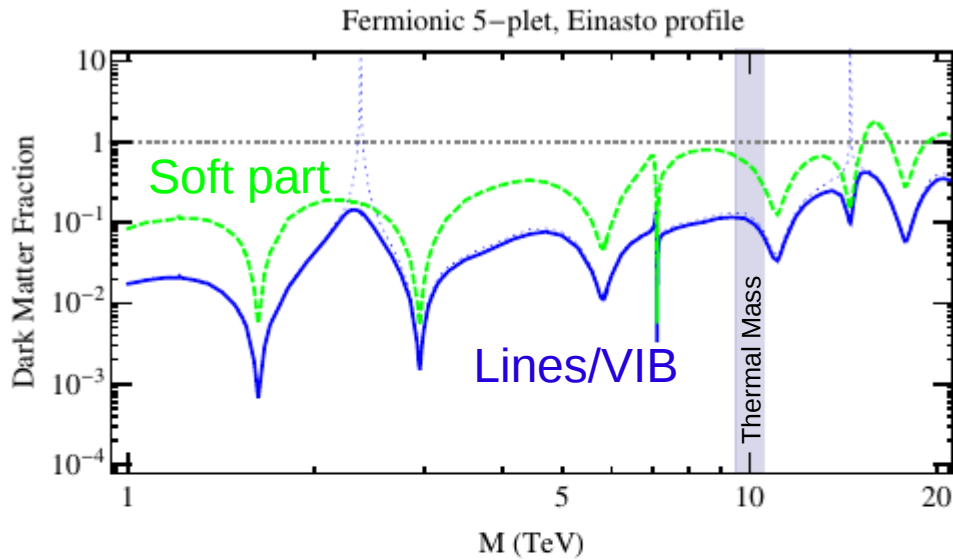# H.E.S.S. Limits from the Galatic Center

Fermionic 5−plet, Einasto profile

H.E.S.S. Limits from the Galatic Center

Fermionic 5-plet, Einasto profile

Scalar 7-plet, Einasto profile

H.E.S.S. Limits from the Galatic Center

Fermionic 5−plet, Einasto profile

Scalar 7−plet, Einasto profile

Fermionic 5−plet, isothermal profile

Scalar 7−plet, isothermal profile

C.T.A.
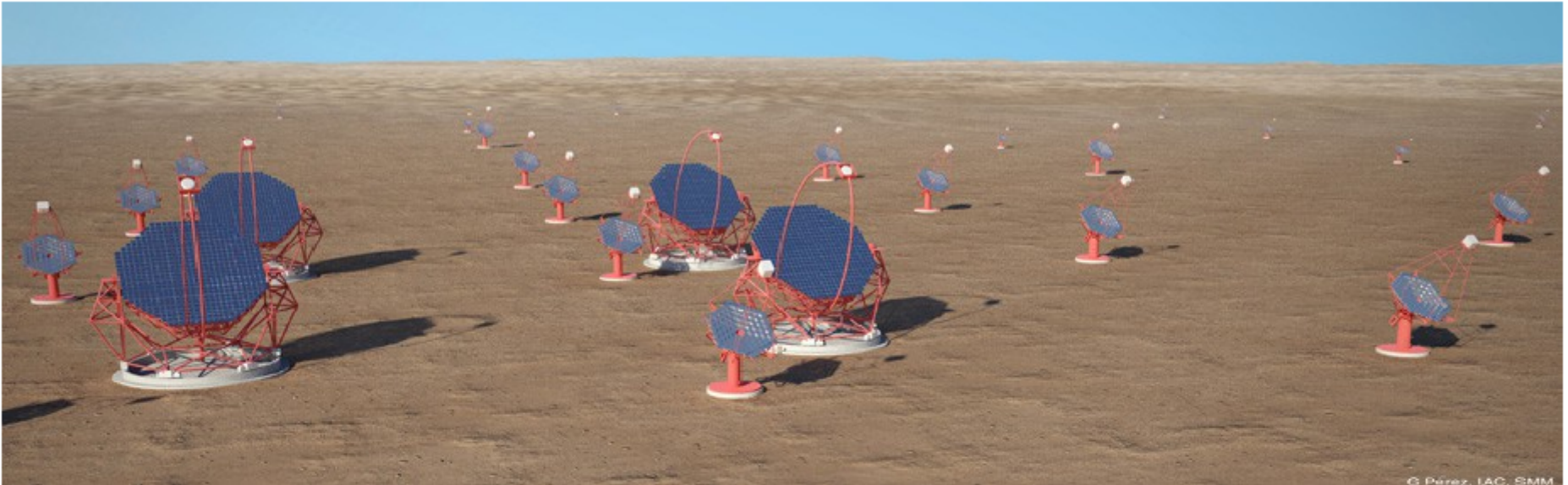
- Use detailed instrument properties for array I (arXiv:1210.3503)
- Balanced southern array: 3 large, 18 medium and 56 small telescopes
- Effective area exceeds $10^6 \, \mathrm{m}^2$ above a few TeV
- Resolution is better than 10% above a few TeV
- Wide energy range from tens of GeV to above 100 TeV

- First, we generate mock data. The expected number of counts in the energy bin i is

$$n^i_{\text{exp}} = \Delta t \int_{\Delta E_i} \mathrm{d}E \int \mathrm{d}E'\, R(E, E')\, A_{\text{eff}}(E')\, \frac{\mathrm{d}\Phi_{\text{tot}}}{\mathrm{d}E_\gamma}(E')$$

observation time

energy bin

instrument properties

flux according to background model

- We consider the same region around the Galactic Center and 112h of observation time.

- Background model : p, $e^{\pm}$, difusse gamma-rays from molecular cloud

- In this analysis we use 200 energy bins per decade. Then, from the mean number of counts in each energy bin, we generate 200 sets of mock data using Poisson distributed random numbers.

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- The limits are calculated using the sliding energy window technique: The background is locally well described by a power law.

C.T.A. Prospects on VIB+Lines

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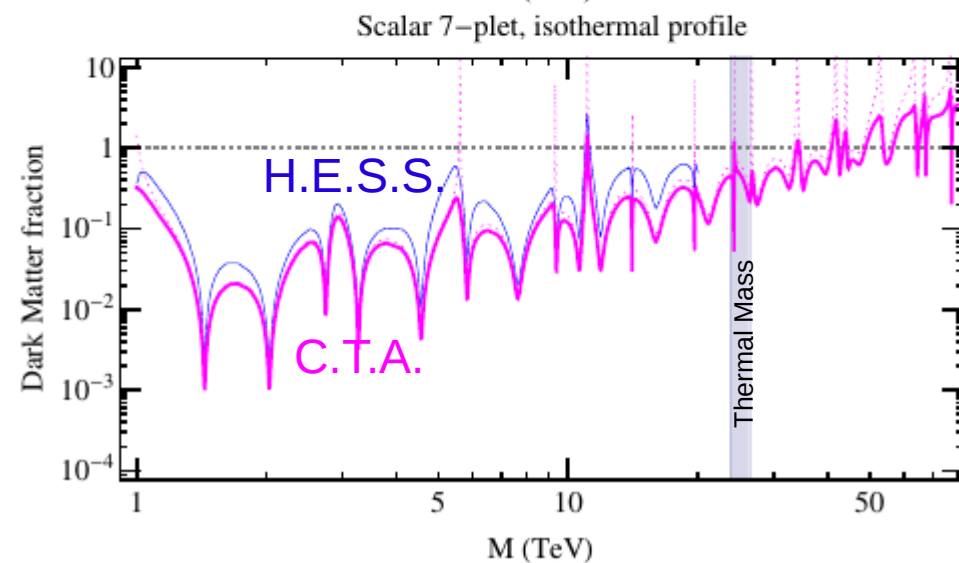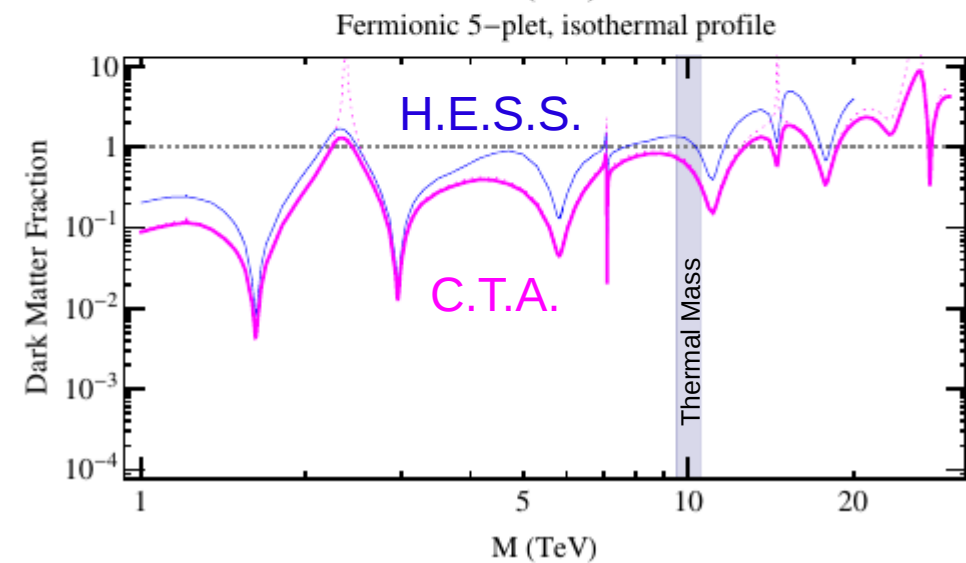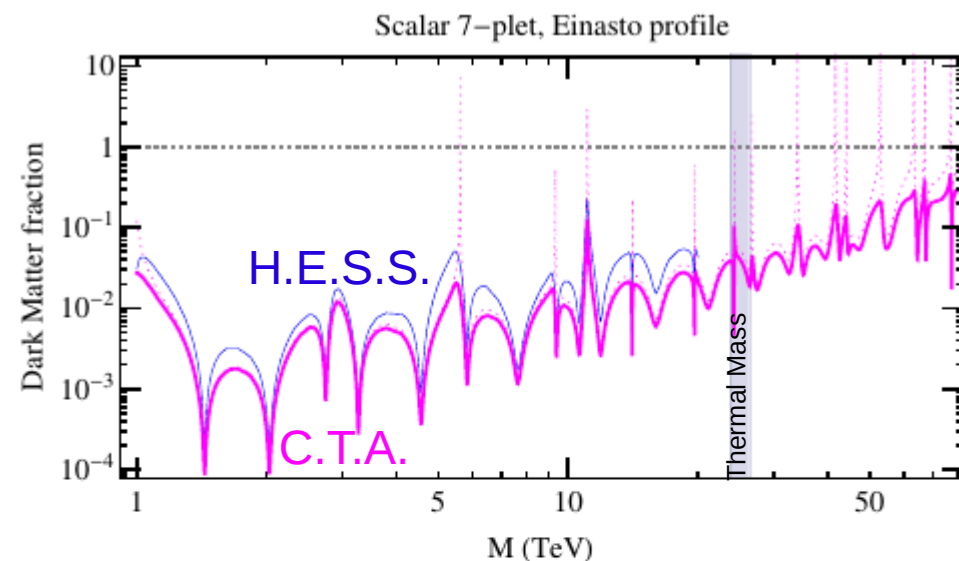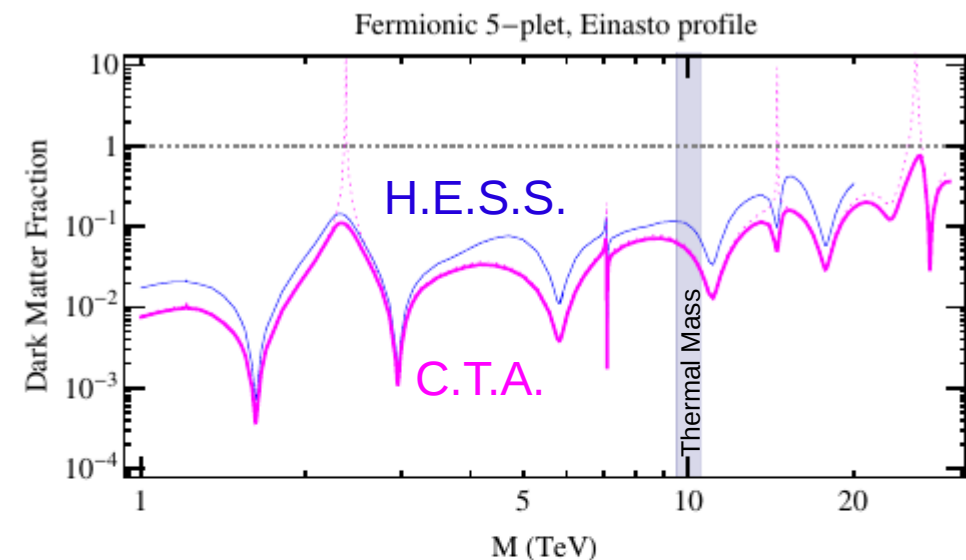
Conclusions

- Minimal Dark Matter models predict a significant annihilation cross-sections into gamma-rays due to the Sommerfeld Enhancement.

- These can be searched for with Cherenkov telescopes and eventually found or excluded in the near future.