Indirect searches of dark matter via polynomial spectral features

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TeV Particle Astrophysics

CERN
Sep 12th, 2016

Based on **JCAP 1608(2016) no.08, 023**. In Collaboration with Julian Heeck.

Outline

- Part I : Motivation

  Box-shaped gamma-ray spectra

- Part II: Another example

  Neutrino features from DM annihilating into SM gauge bosons

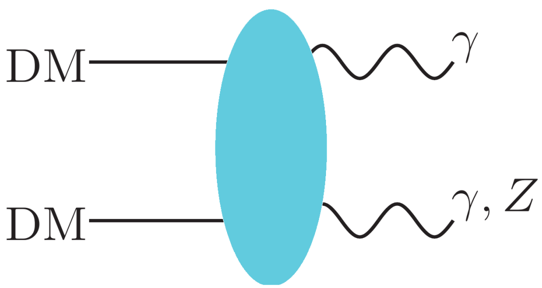
- Part III: General case

  Polynomial spectral features

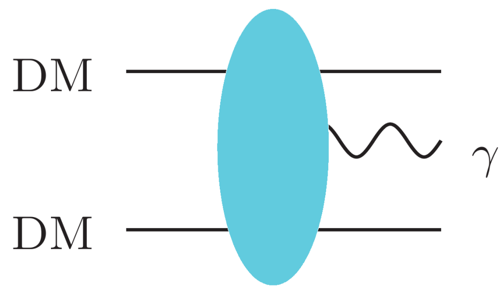
- Conclusions

Gamma-ray spectral features

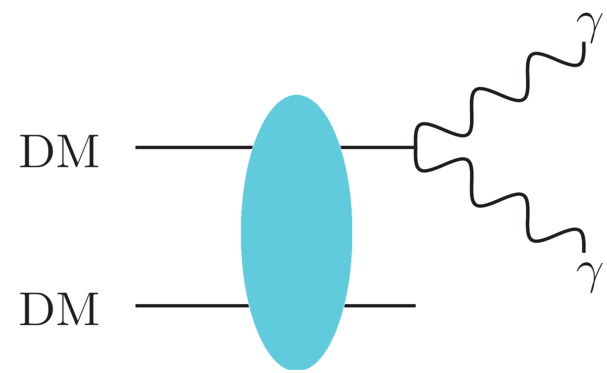
Smoking gun signature for dark matter : no astrophysical process is known to produce a sharp feature in the gamma-ray spectrum



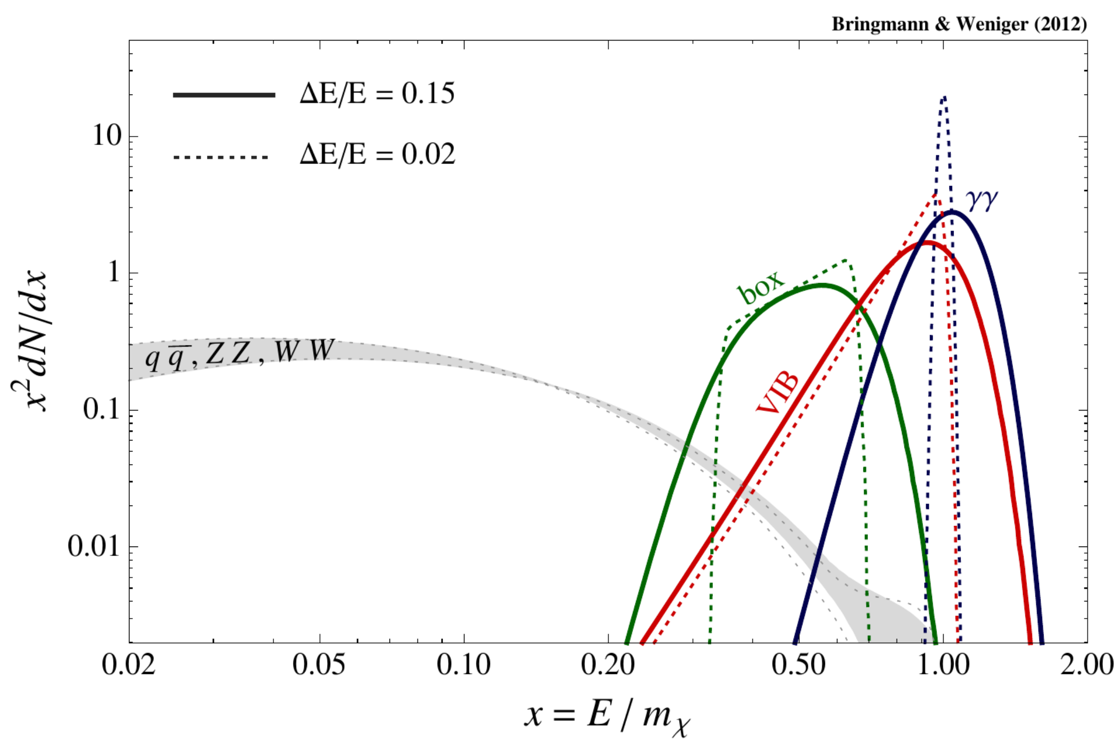
Annihilation into Photons



Virtual Internal Bremsstrahlung (VIB)



Box-shaped spectra



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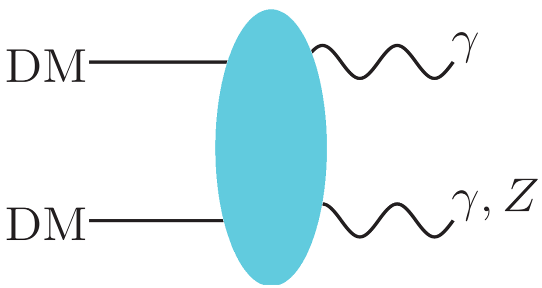

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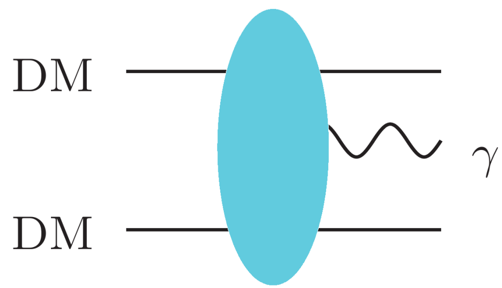

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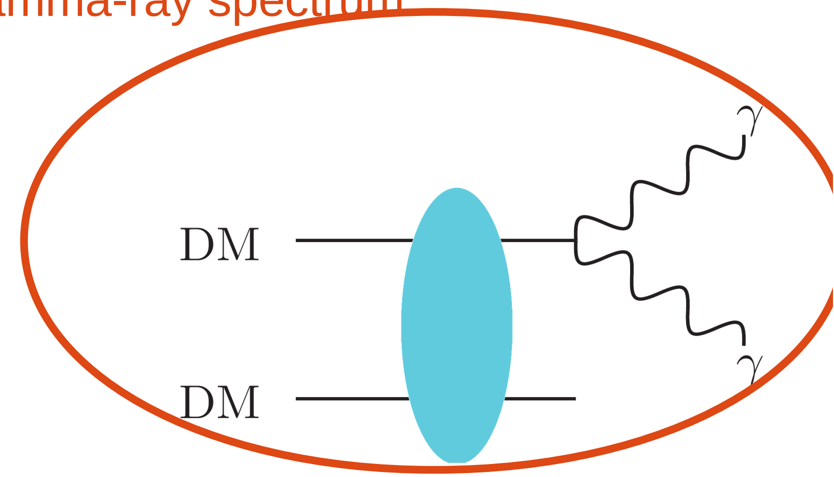

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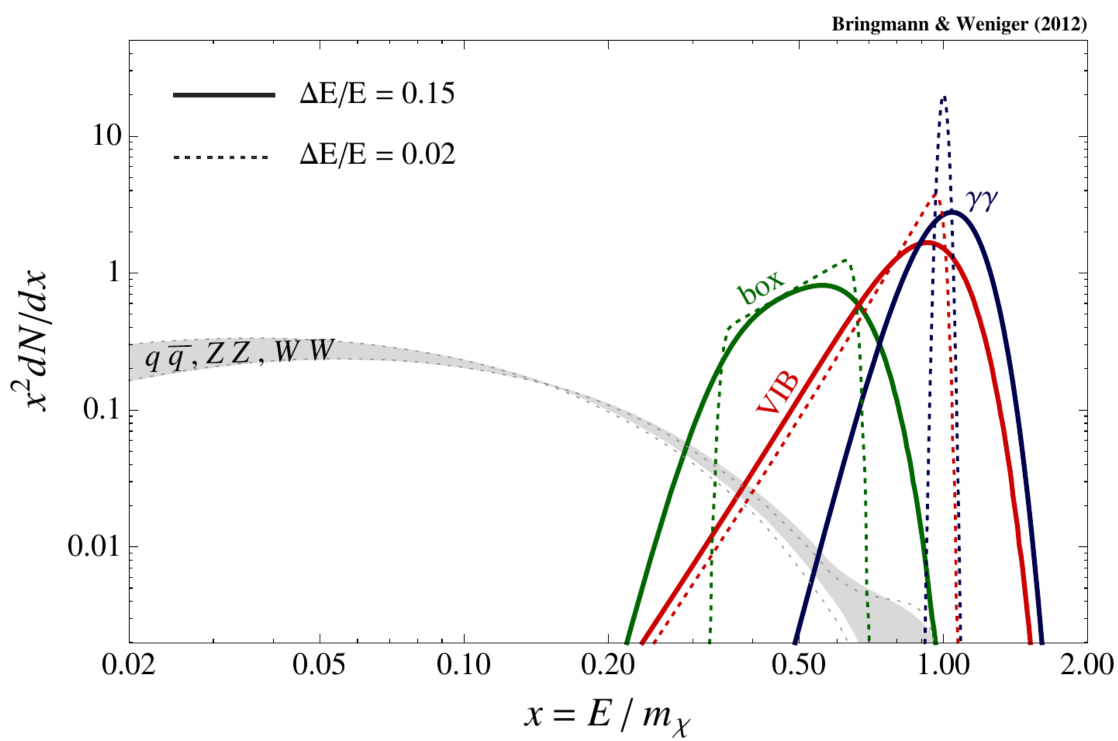

Originally studied for scalar mediators

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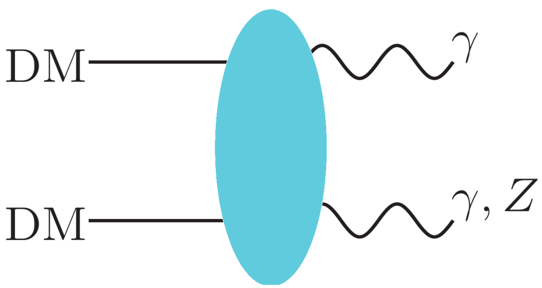

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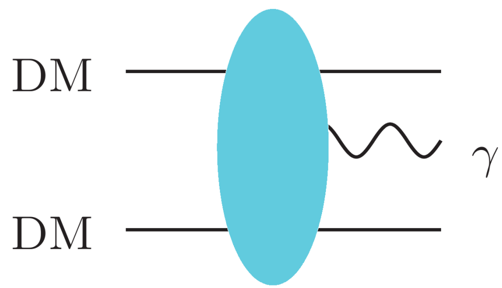

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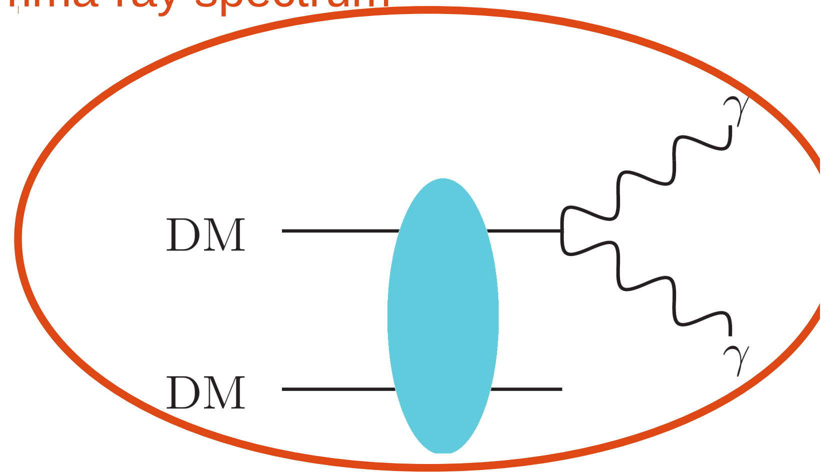

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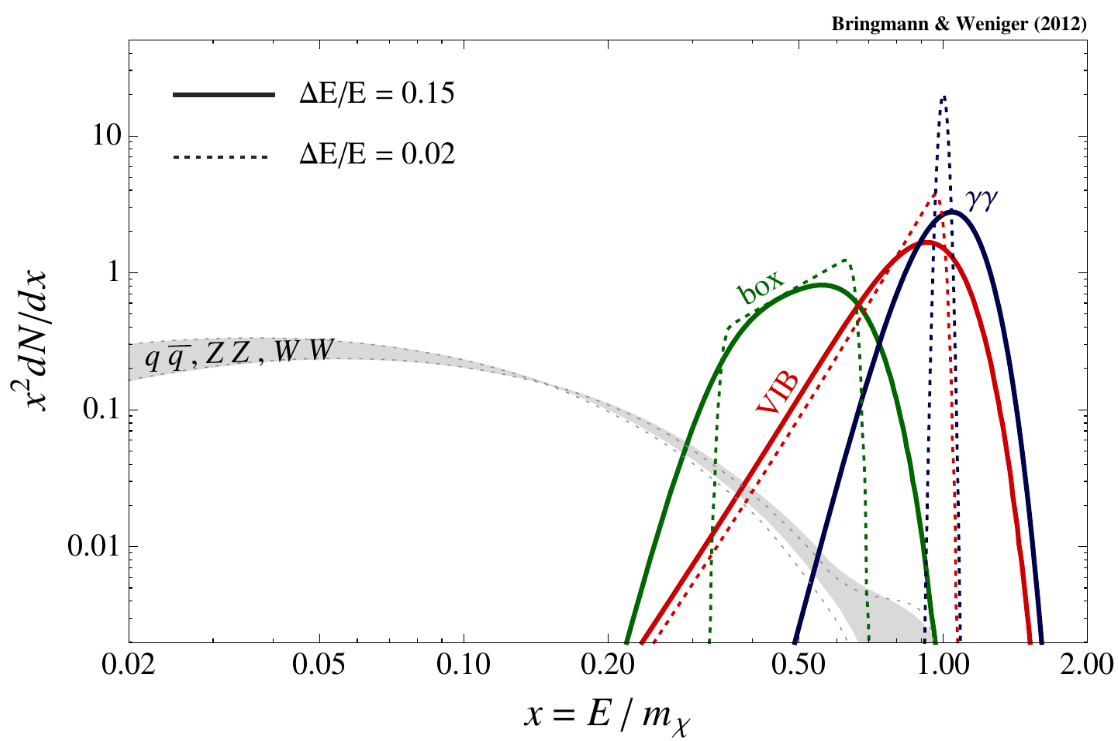
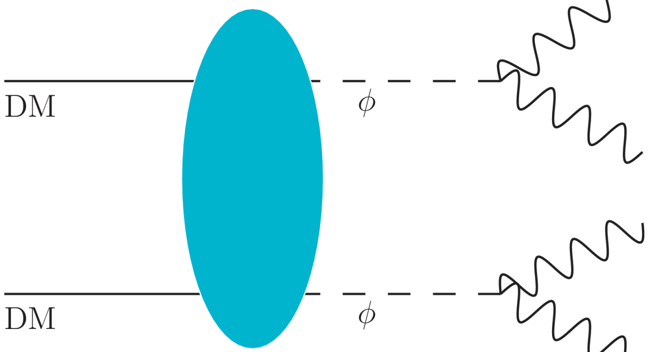
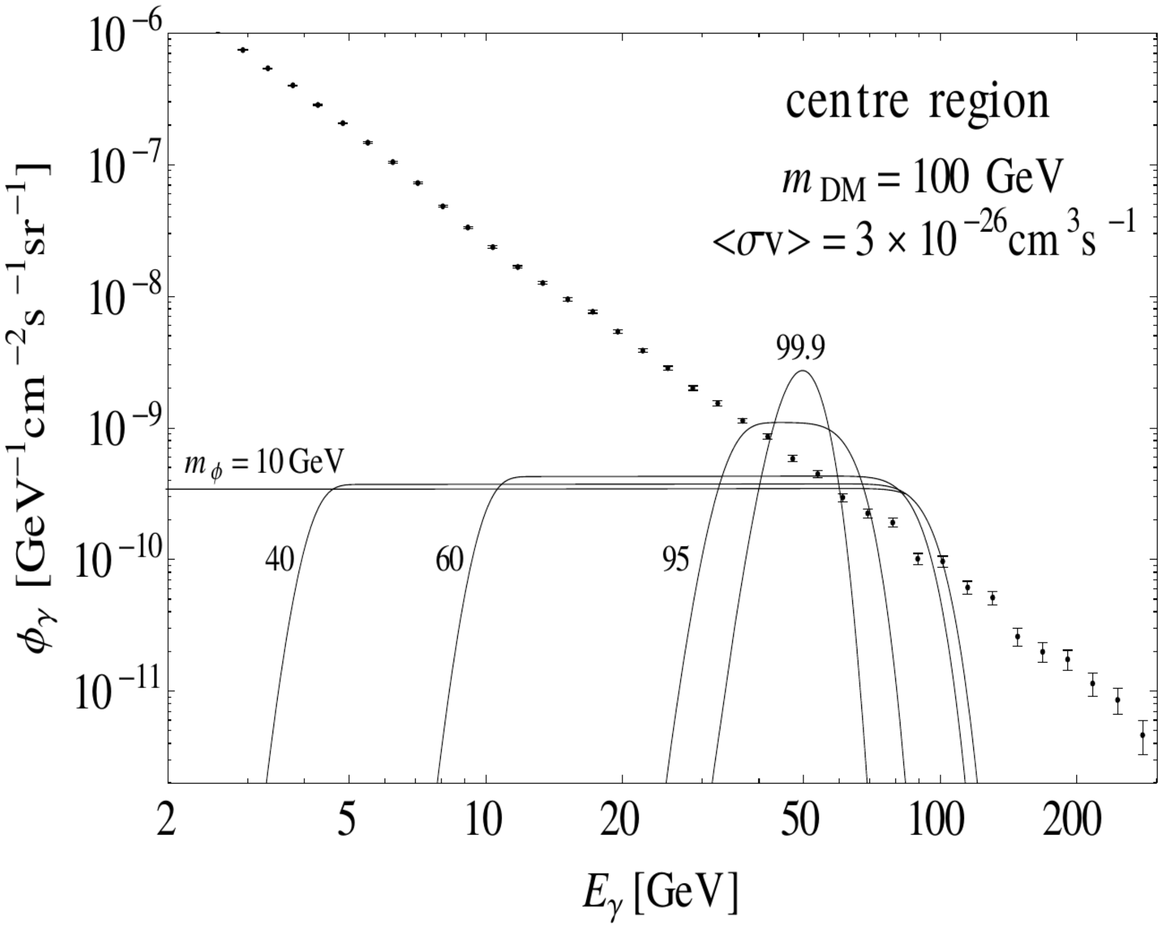


Originally studied for scalar mediators

This talk: Generalize this to an arbitrary intermediate state

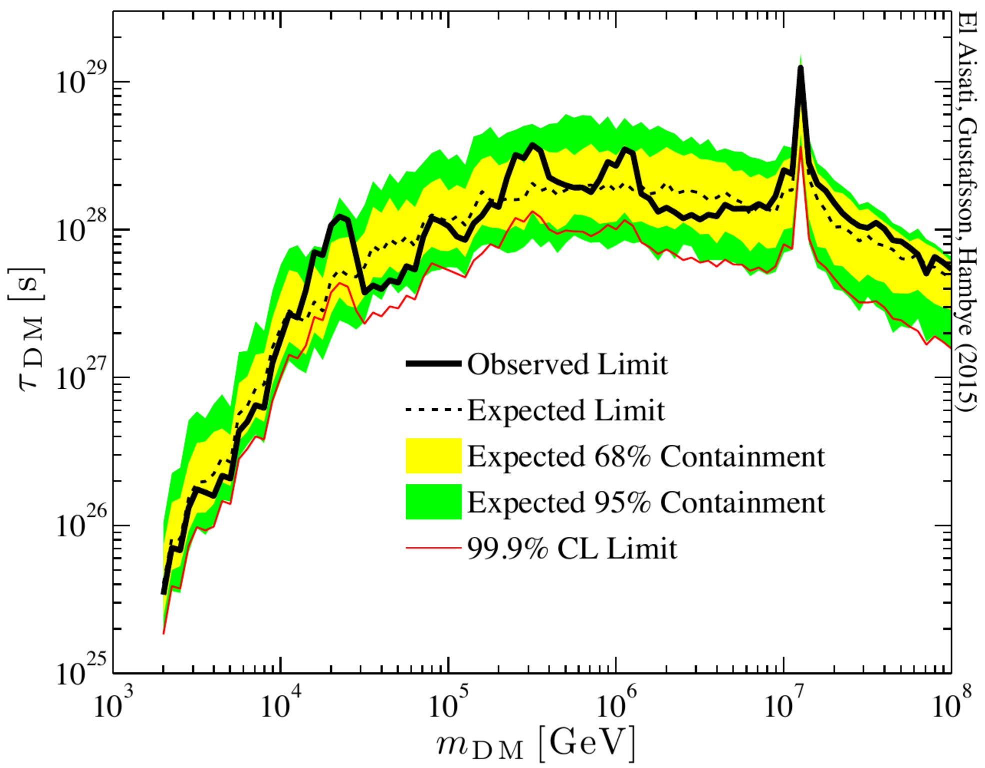
Box-shaped spectra from intermediary scalars





Ibarra et.al 2012

The same applies to neutrinos



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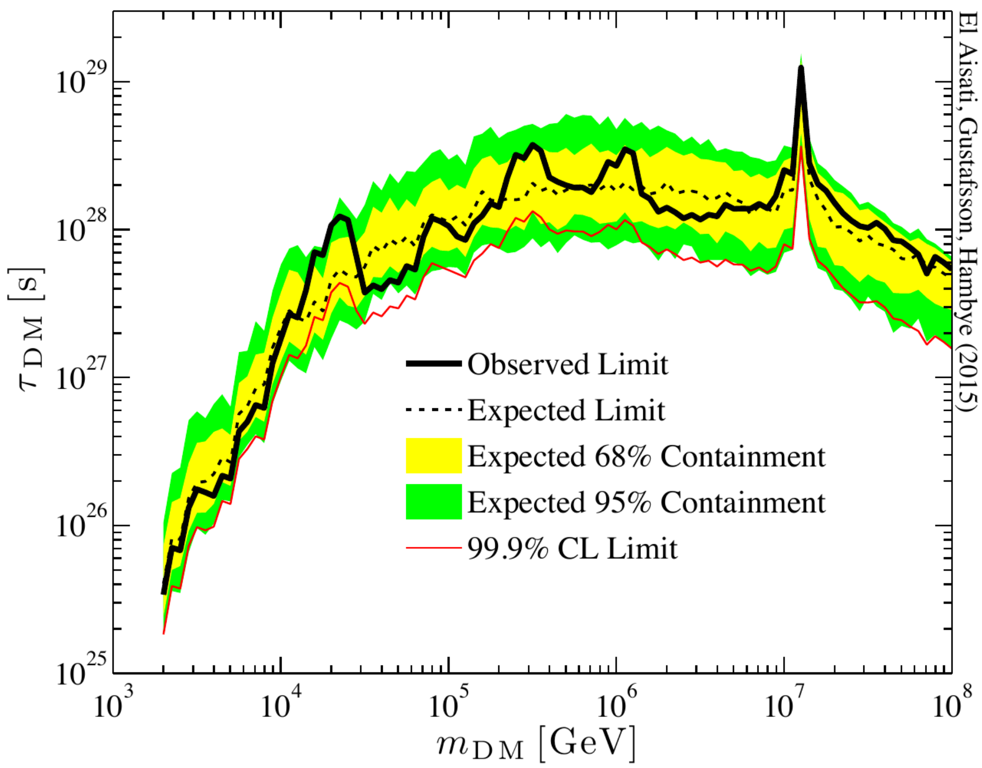

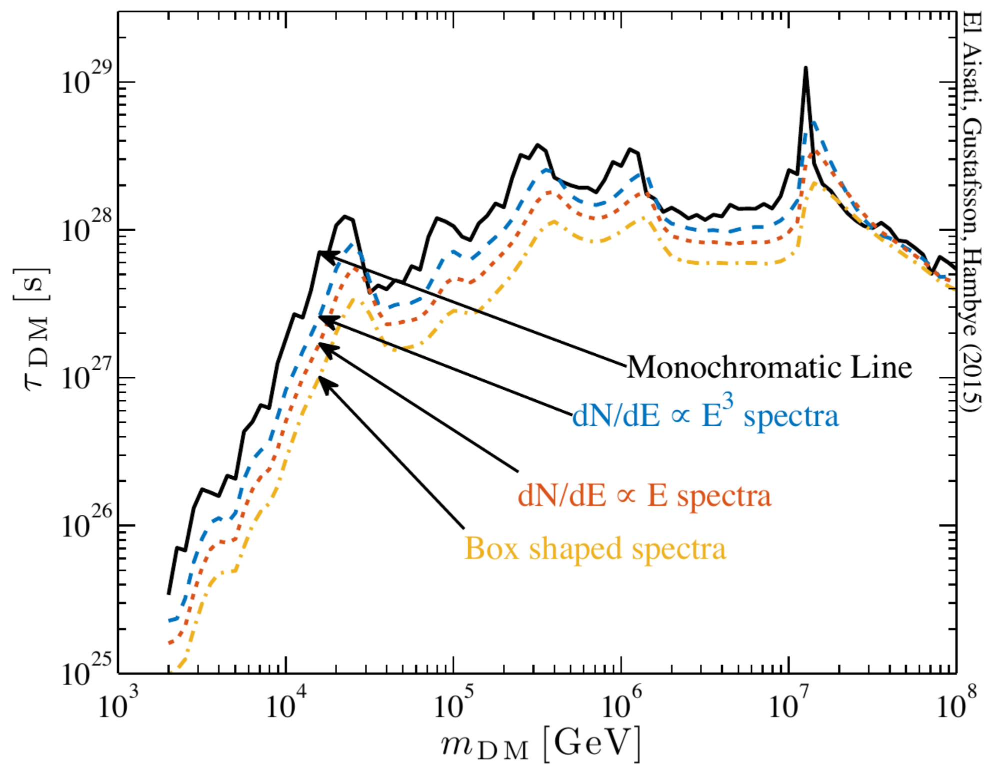

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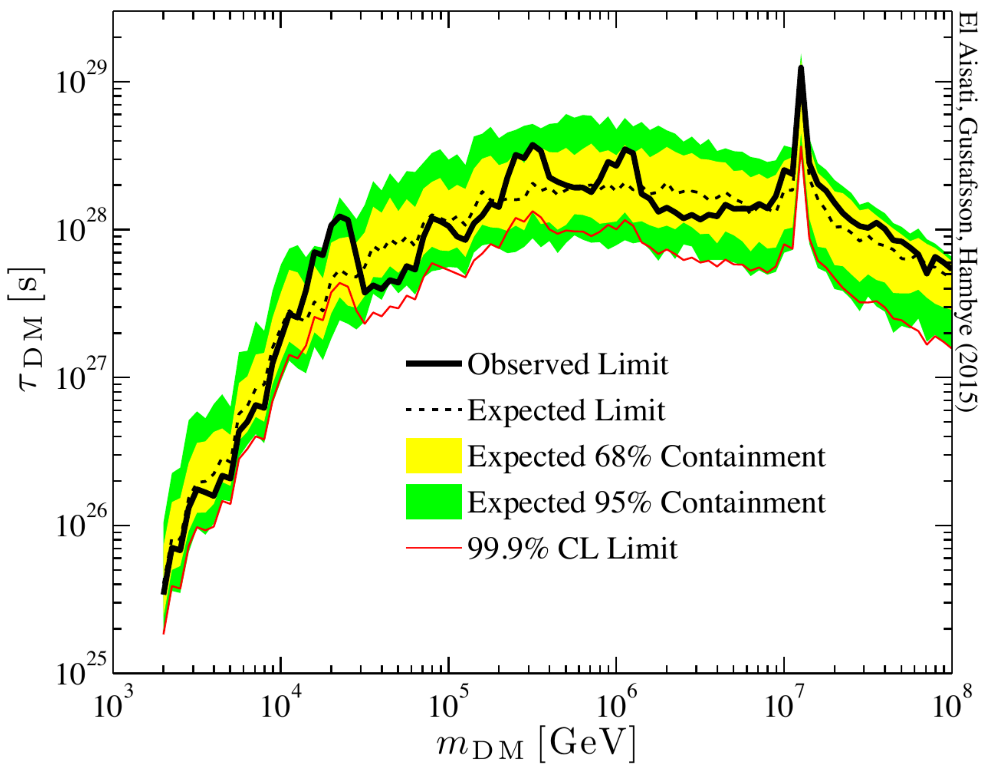
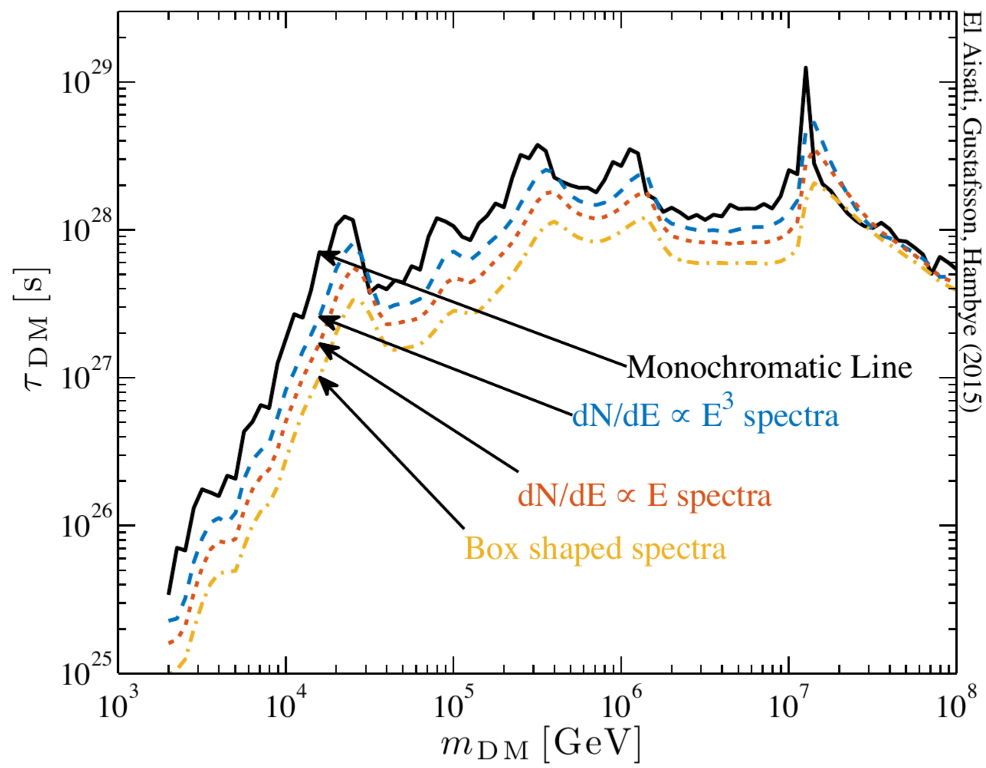
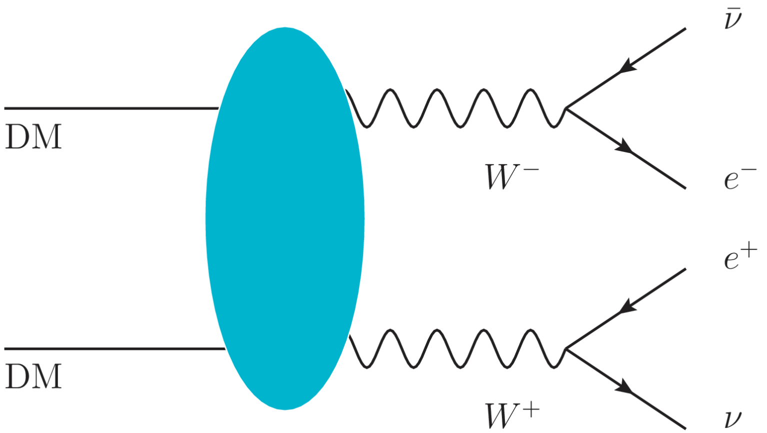
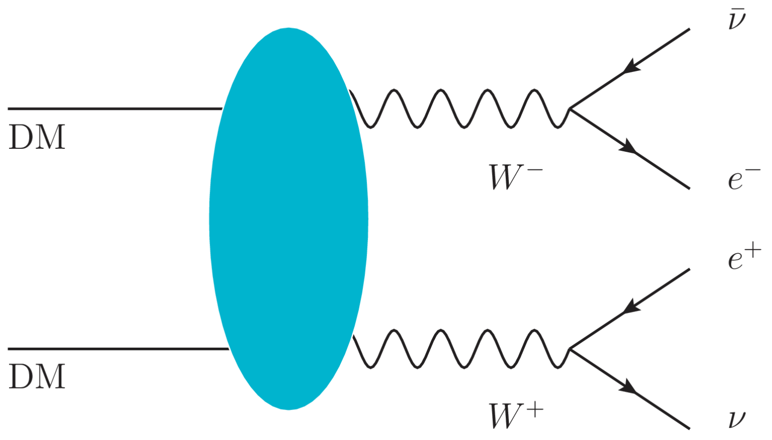




What about?



The case of gauge bosons



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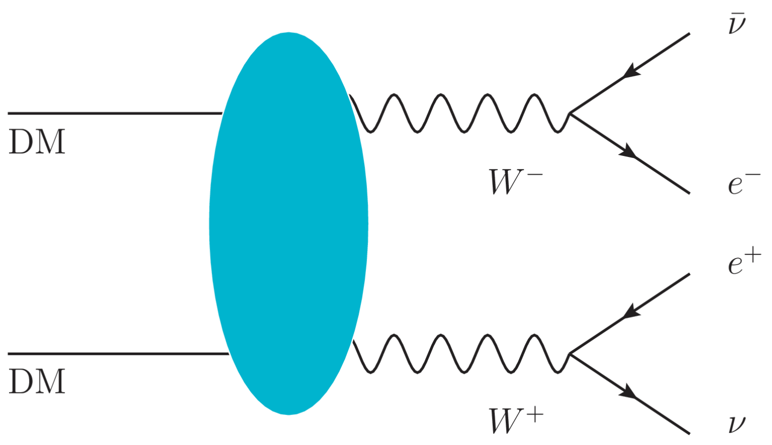

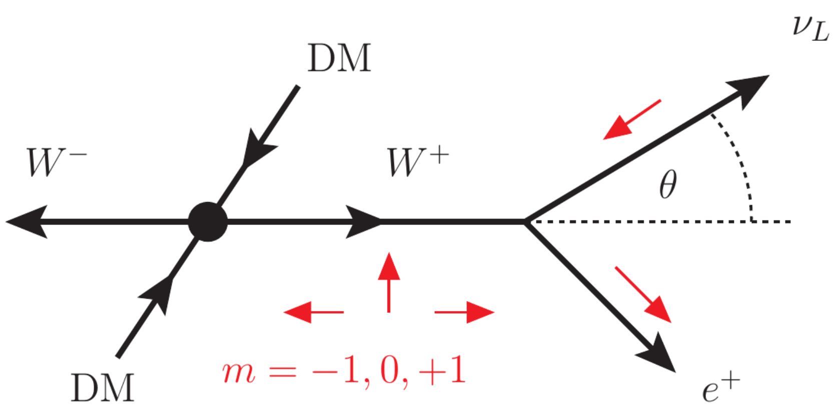

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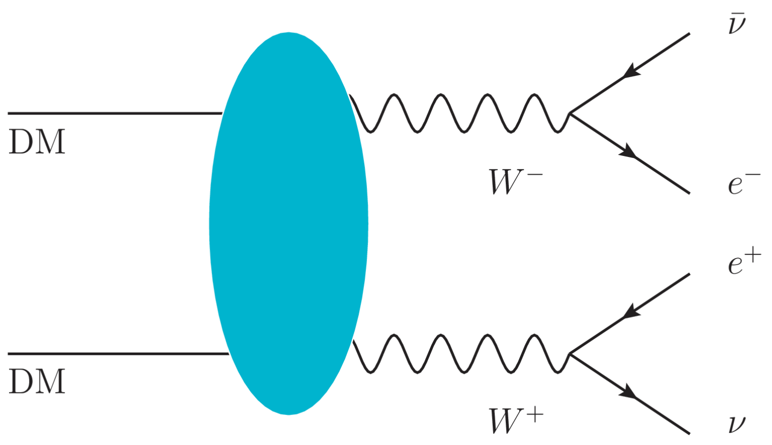

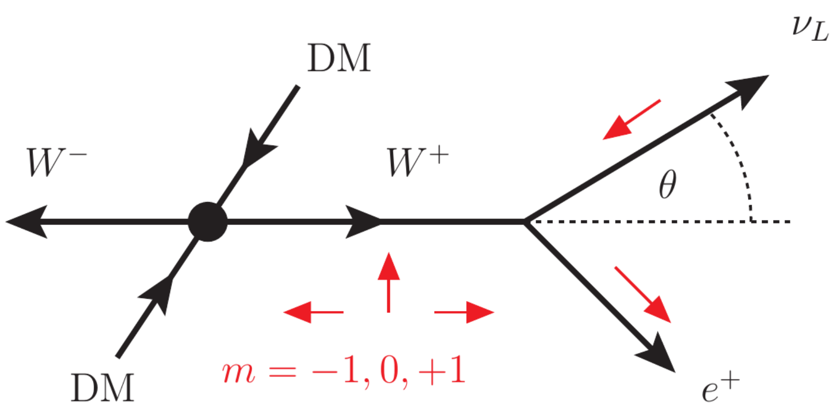

$$\frac{\mathrm{d}\Phi_\nu}{\mathrm{d}E_\nu} = \Phi_\nu \sum_m \mathrm{Br}_m \frac{\mathrm{d}N_{\nu,m}}{\mathrm{d}E_\nu}\,, \quad \Phi_\nu = \frac{(\sigma v)}{8\pi M_{\mathrm{DM}}^2} \bar{J}_{\mathrm{ann}}$$

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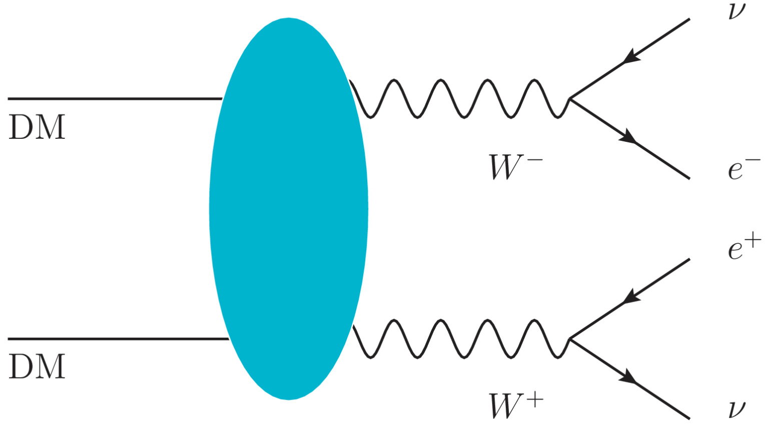

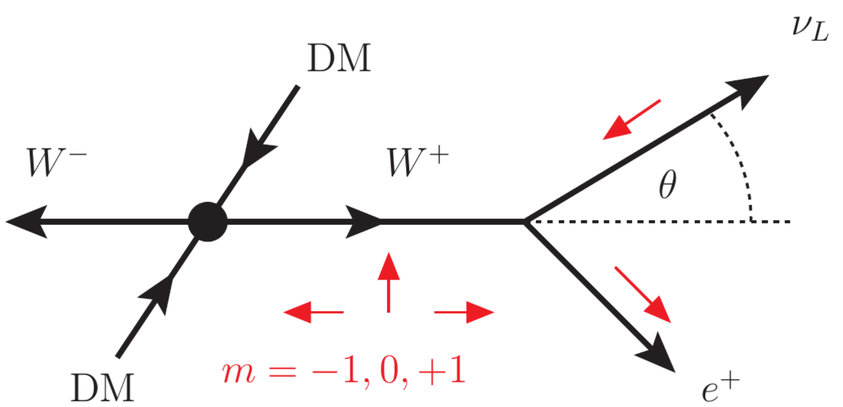

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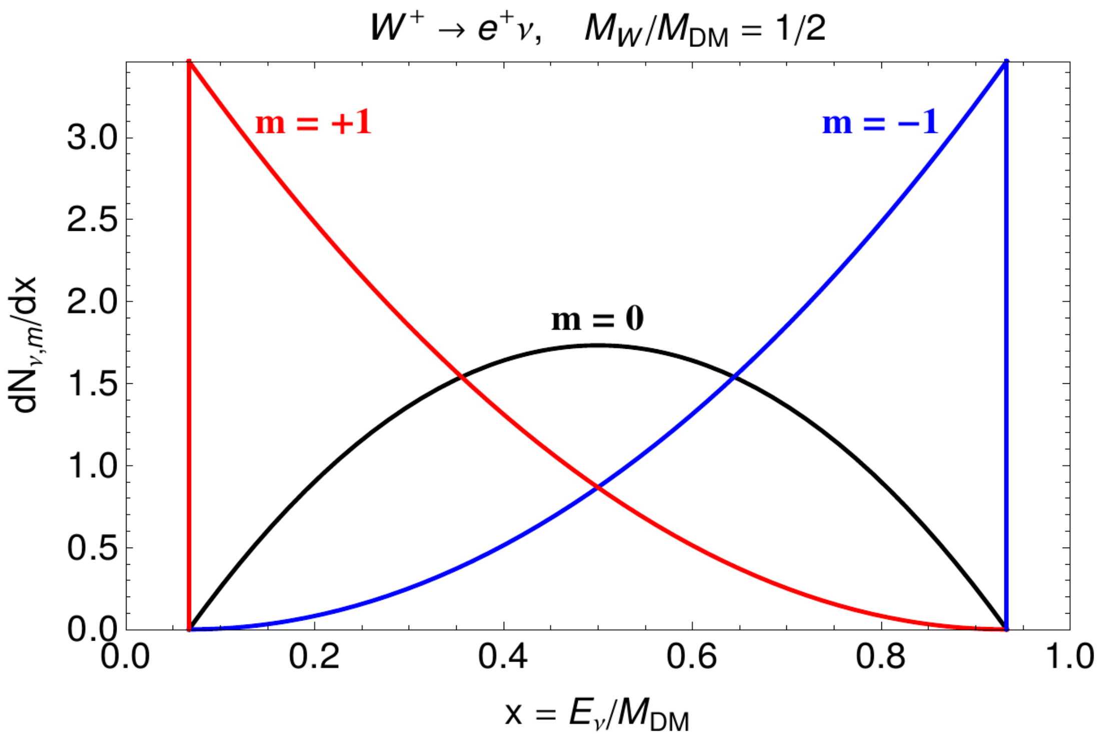

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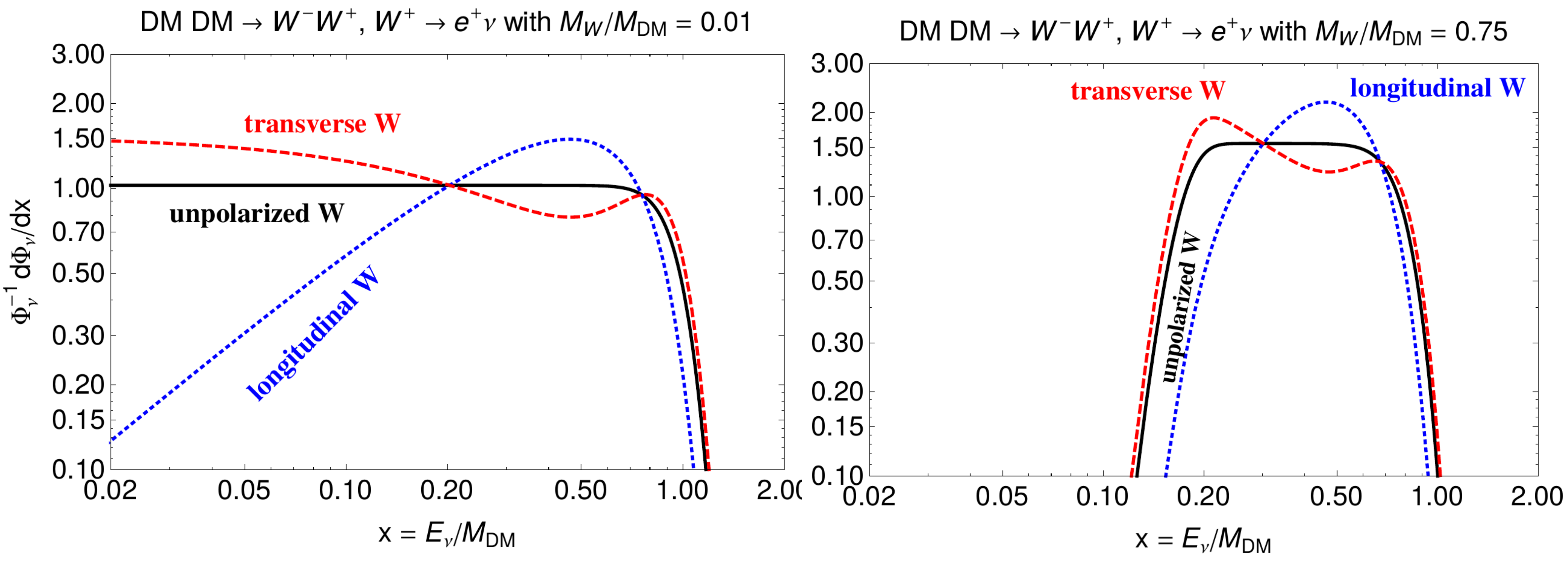

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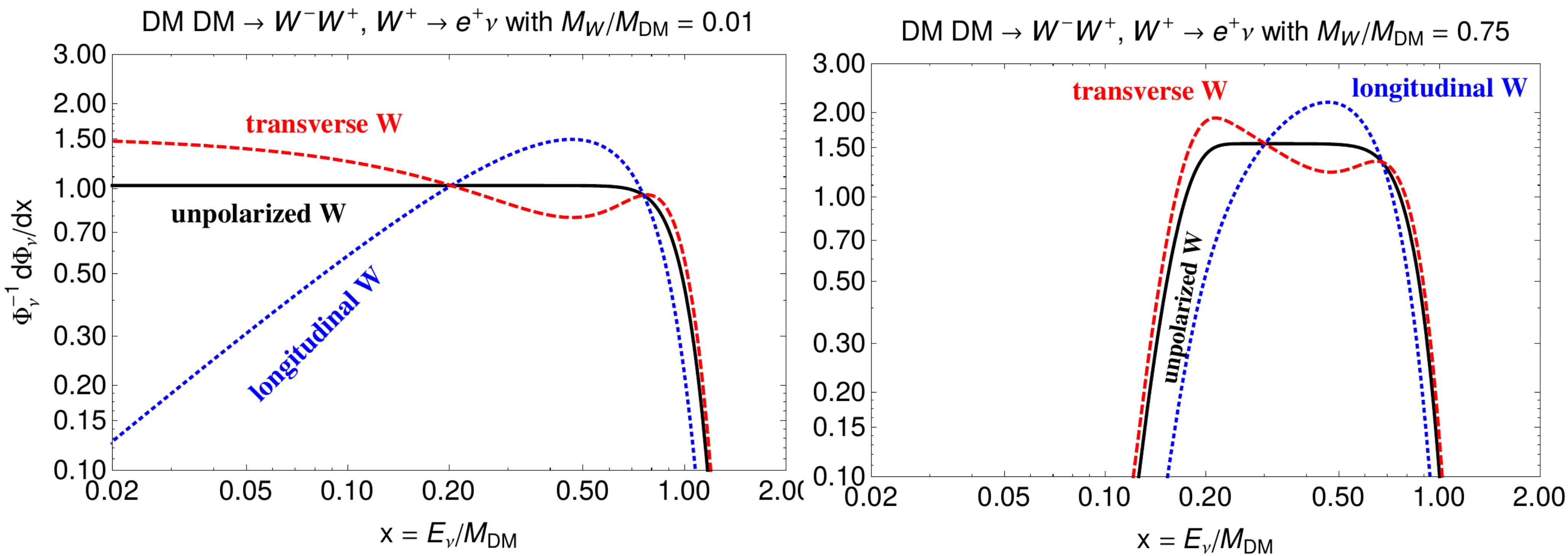
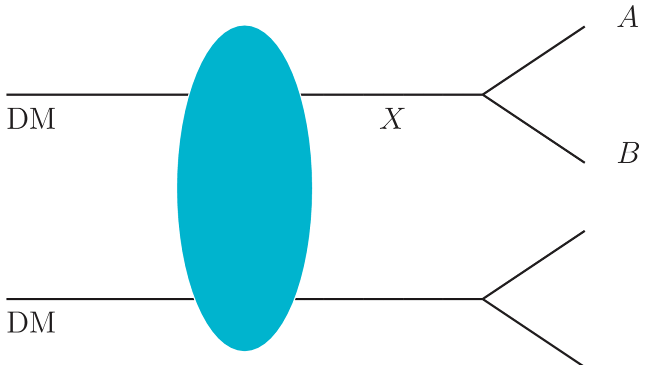


Gauge bosons produced in DM annihilations are typically polarized

Above the electroweak scale, Majorana DM with $SU(2)_L$ quantum numbers produce gauge bosons that are mostly transverse.

Scalar DM, also singlet under $SU(2)_L$, produces gauge bosons that are mostly longitudinally polarized.

General case



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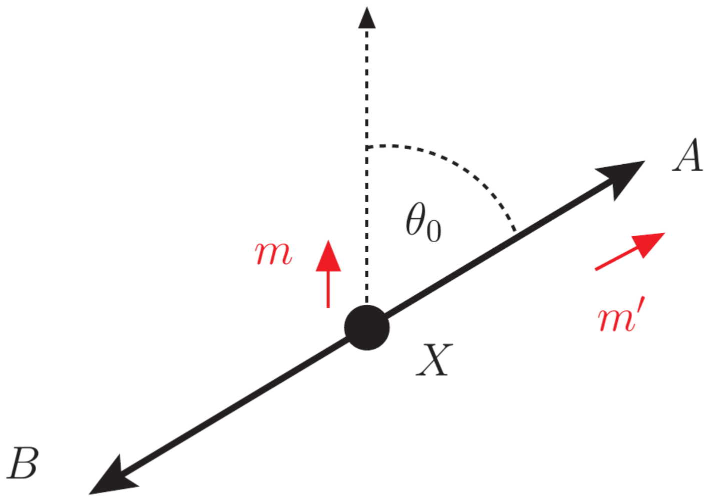

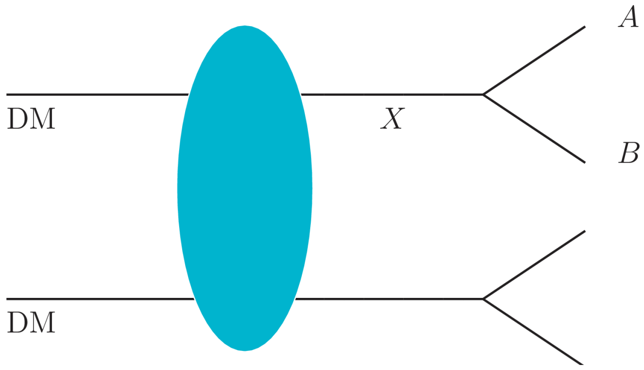

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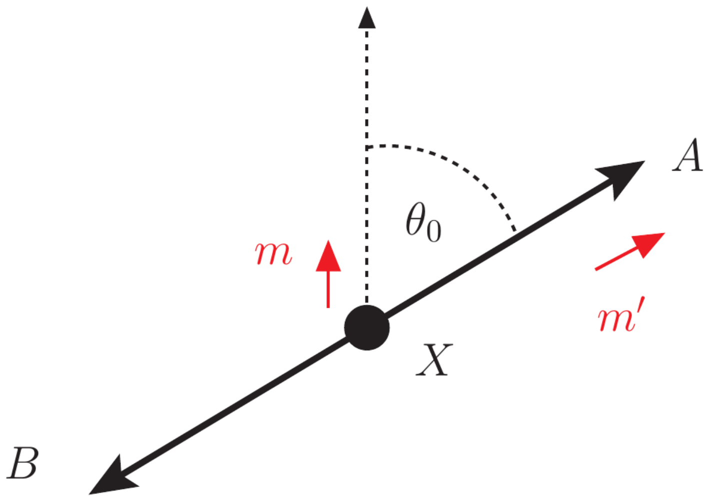

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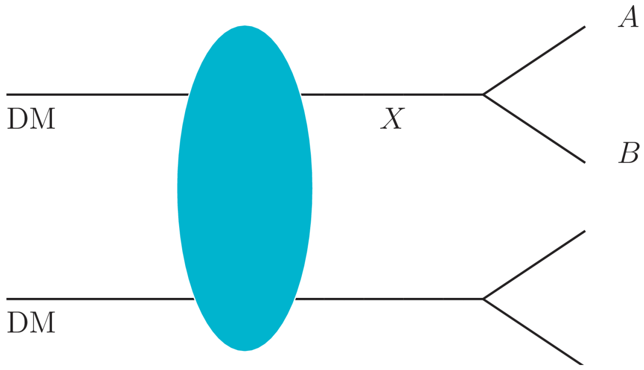

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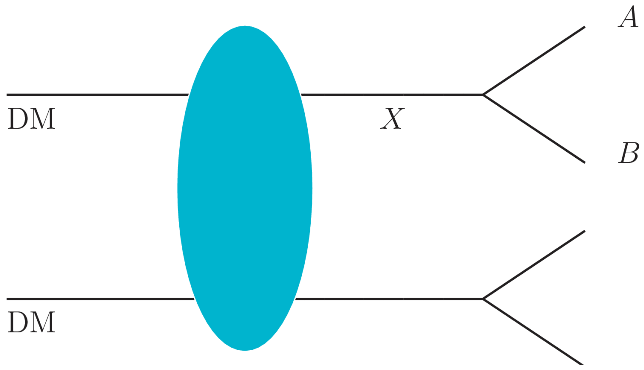

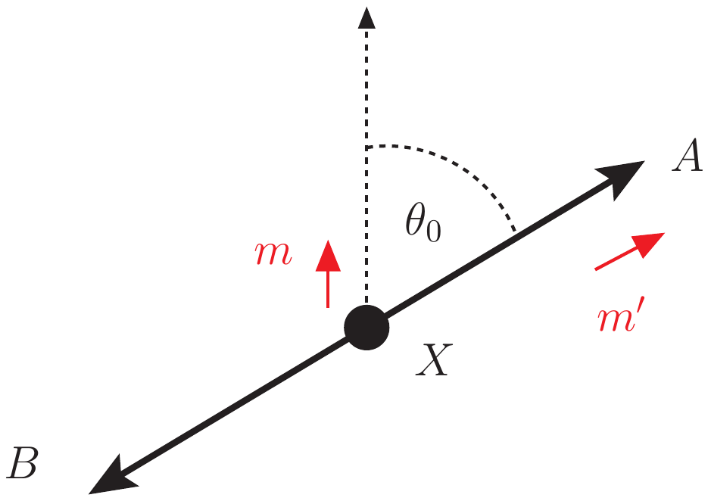

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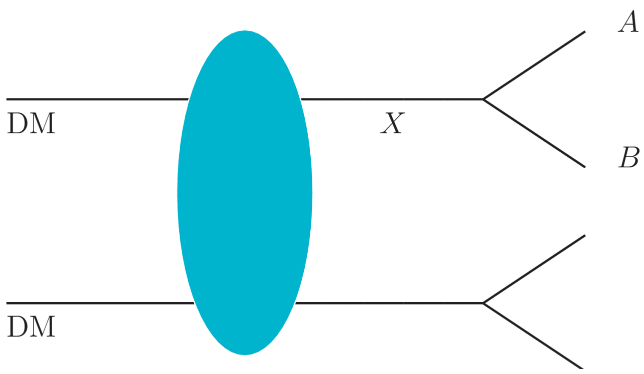

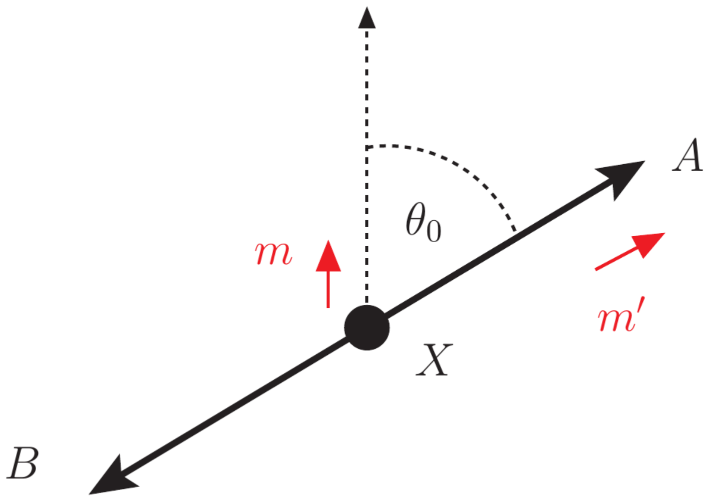

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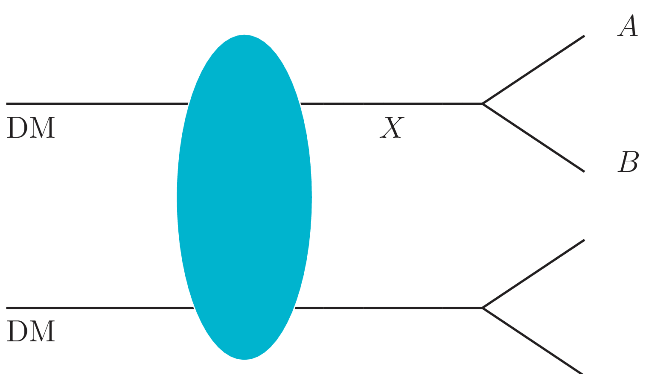

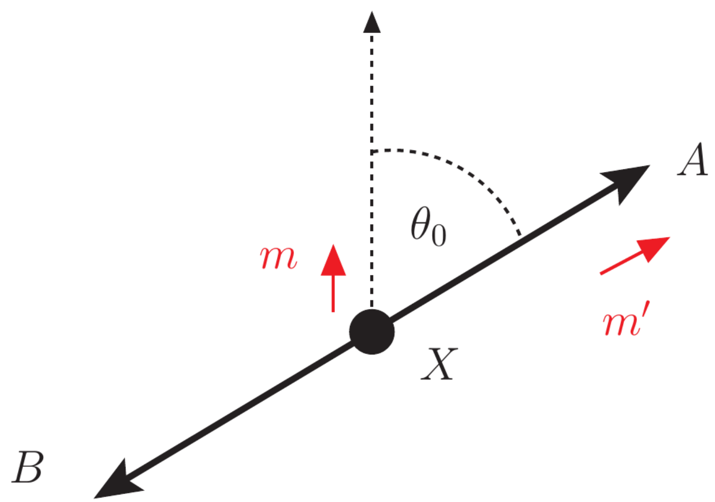

Almost everything fixed by angular momentum.

The dependence on the DM Model is encoded in two quantities

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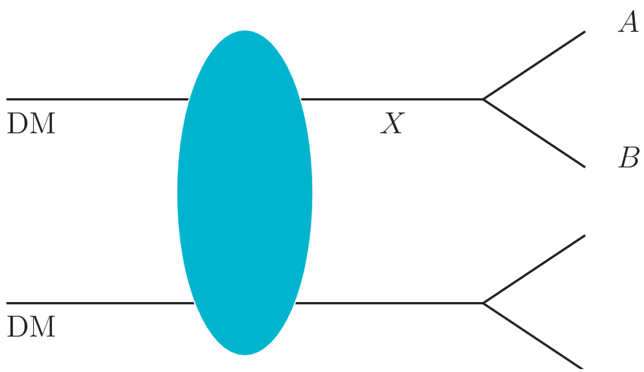

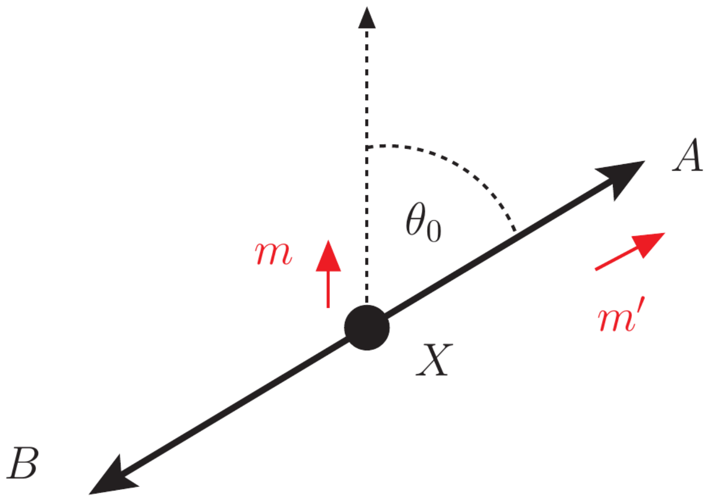

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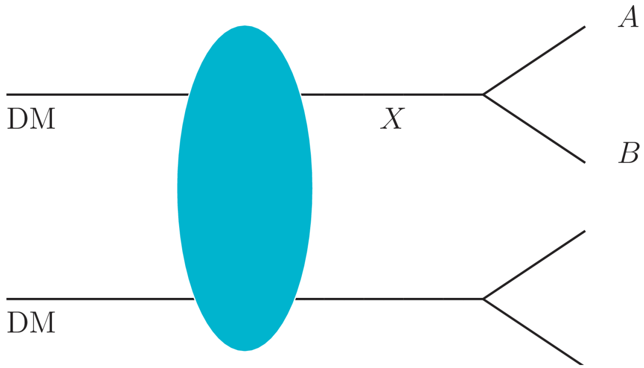

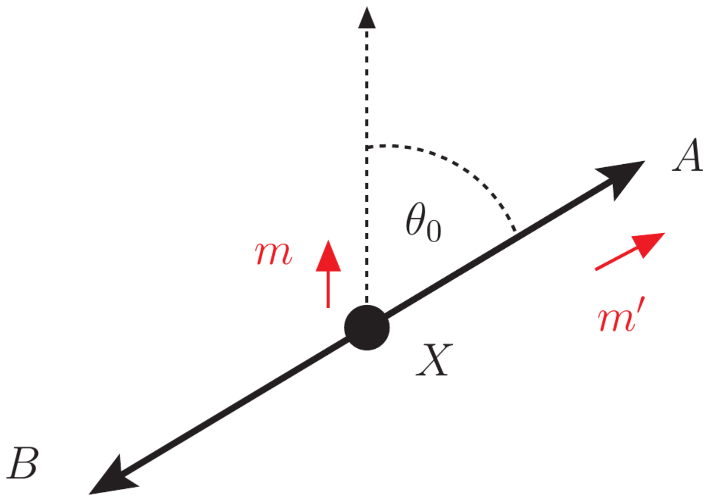

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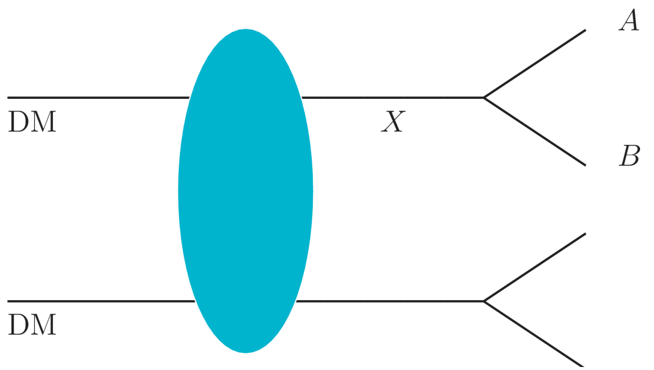
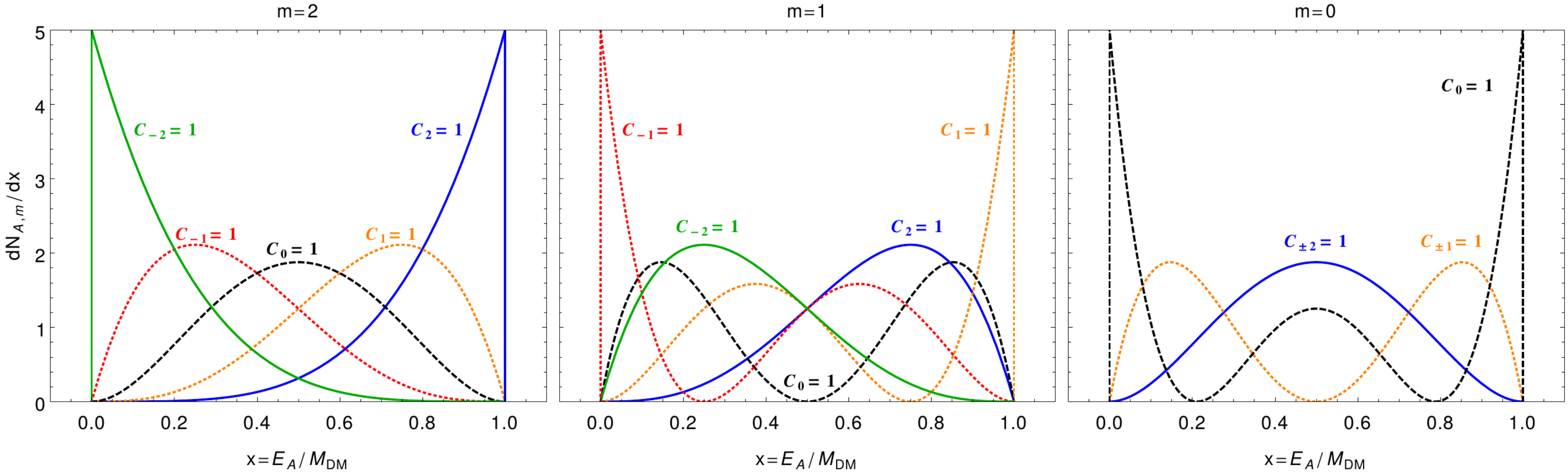
Fixed by the properties of the particle X and the final state

Example with particles of Spin-2





For spin-2 particles coupled to the energy-momentum tensor

final state AB	C_{-2}	C_{-1}	C_0	C_1	C_2
$\gamma\gamma$	$\frac{1}{2}$	0	0	0	$\frac{1}{2}$
ZZ	$\frac{6}{13}$	0	$\frac{1}{13}$	0	$\frac{6}{13}$
W^+W^-	$\frac{6}{13}$	0	$\frac{1}{13}$	0	$\frac{6}{13}$
hh	0	0	1	0	0
$\nu_L\overline{\nu_L}$	0	1	0	0	0
$\nu_R\overline{\nu_R}$	0	0	0	1	0
$\nu\overline{\nu}$ (Dirac or Majorana)	0	$\frac{1}{2}$	0	$\frac{1}{2}$	0

$$f_m^S(x,y) = \frac{(2S+1)}{\sqrt{y^2 - r_X^2}} \Theta\left(x - x^-(y)\right) \Theta\left(x^+(y) - x\right)$$
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Fixed by the properties of the particle X and the final state

Are spin-2 particles arising in DM annihilations polarized ?

Are they coupled to the energy-momentum tensor?

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Boosted regime $M_T^2 \ll p^2$

$$\varepsilon^{\mu\nu}(\pm 2) = \varepsilon^{\mu}(\pm)\varepsilon^{\nu}(\pm)\,,$$
$$\varepsilon^{\mu\nu}(\pm 1) \simeq \frac{1}{\sqrt{2}M_T}\left[p^{\nu}\varepsilon^{\mu}(\pm) + p^{\mu}\varepsilon^{\nu}(\pm)\right]$$
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Are they coupled to the energy-momentum tensor?

↓ **No**

The spin-2 particles are mostly polarized with $m = 0$

$$\mathbf{Br_{0,0} = 1}$$

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States with $m = \pm 1$ **naturally decouple.**
Is there a selection rule forbidding $m = 0$ **?**

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Are they coupled to the energy-momentum tensor?

Yes → **States with** $m = \pm 1$ **naturally decouple. Is there a selection rule forbidding** $m = 0$ **?**

No → **The spin-2 particles are mostly polarized with** $m = 0$

No (from the first question) → **The spin-2 particles are mostly polarized with** $m = 0$

$\mathrm{Br}_{0,0} = 1$

Are spin-2 particles arising in DM annihilations polarized ?

Boosted regime $M_T^2 \ll p^2$

$$\varepsilon^{\mu\nu}(\pm 2) = \varepsilon^{\mu}(\pm)\varepsilon^{\nu}(\pm)\,,$$

$$\varepsilon^{\mu\nu}(\pm 1) \simeq \frac{1}{\sqrt{2}M_T}\left[p^{\nu}\varepsilon^{\mu}(\pm) + p^{\mu}\varepsilon^{\nu}(\pm)\right]$$

$$\varepsilon^{\mu\nu}(0) \simeq \frac{\eta^{\mu\nu}}{\sqrt{6}} + \sqrt{\frac{2}{3}}\,\frac{p^{\mu}p^{\nu}}{M_T^2}\,.$$

Are they coupled to the energy-momentum tensor?

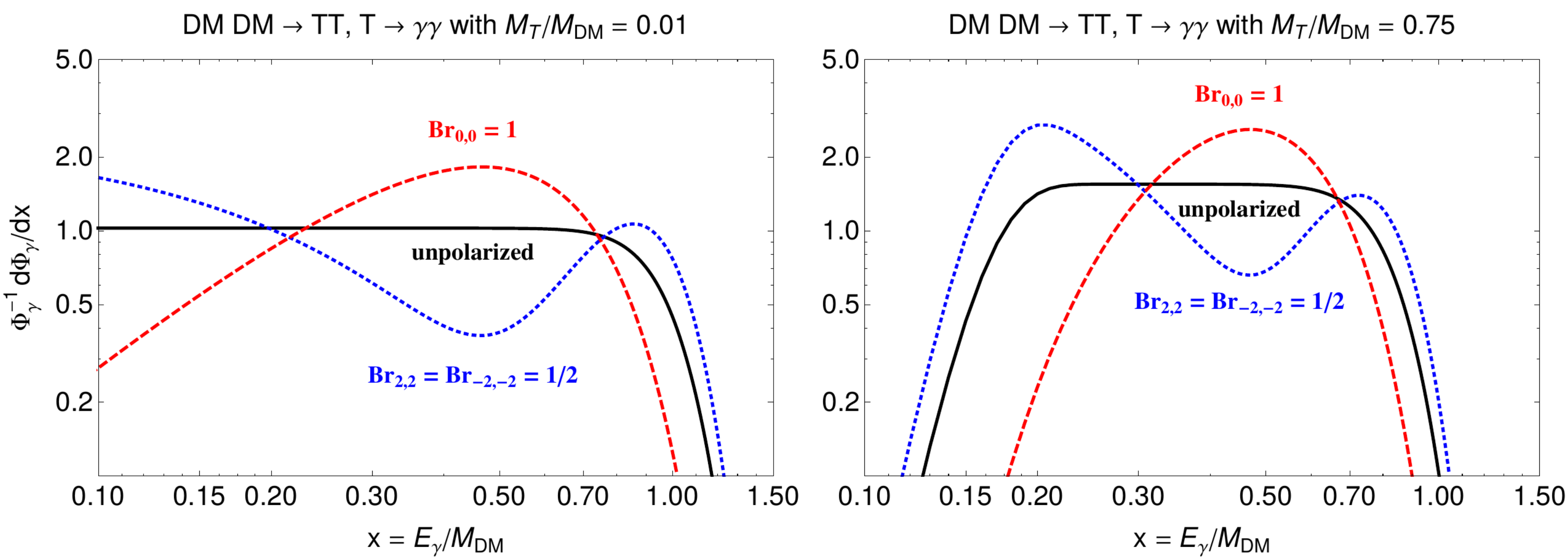
No → **The spin-2 particles are mostly polarized with** $m = 0$

Yes → **States with** $m = \pm 1$ **naturally decouple. Is there a selection rule forbidding** $m = 0$ **?**

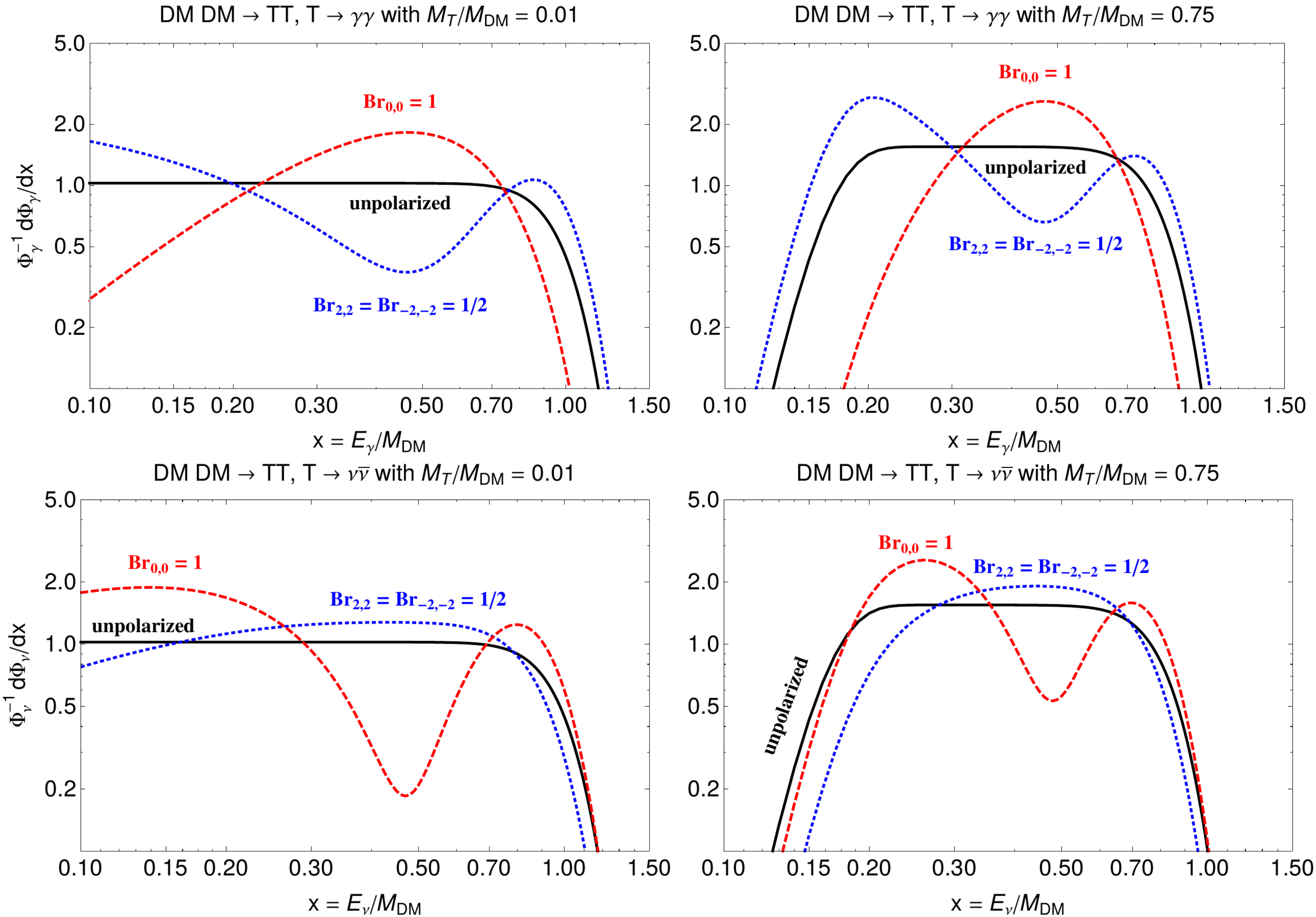
- **No** → **The spin-2 particles are mostly polarized with** $m = 0$
- **Yes** → **The spin-2 particles are mostly polarized with** $m = \pm 2$

$\mathrm{Br}_{0,0} = 1$

$\mathrm{Br}_{2,2} = \mathrm{Br}_{-2,-2} = 1/2$



DM DM → TT, T → γγ with $M_T/M_{\rm DM}$ = 0.01
DM DM → TT, T → γγ with $M_T/M_{\rm DM}$ = 0.75
$\Phi_\gamma^{-1}\, d\Phi_\gamma/dx$
5.0
2.0
1.0
0.5
0.2
0.10
0.15
0.20
0.30
0.50
0.70
1.00
1.50
$x = E_\gamma/M_{\rm DM}$
$\mathrm{Br}_{0,0} = 1$
unpolarized
$\mathrm{Br}_{2,2} = \mathrm{Br}_{-2,-2} = 1/2$


DM DM → TT, T → γγ with M_T/M_{DM} = 0.01
$Br_{0,0} = 1$
unpolarized
$Br_{2,2} = Br_{-2,-2} = 1/2$
$\Phi_\gamma^{-1} d\Phi_\gamma/dx$
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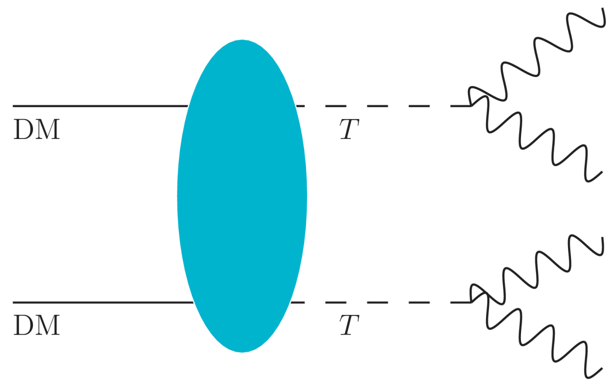
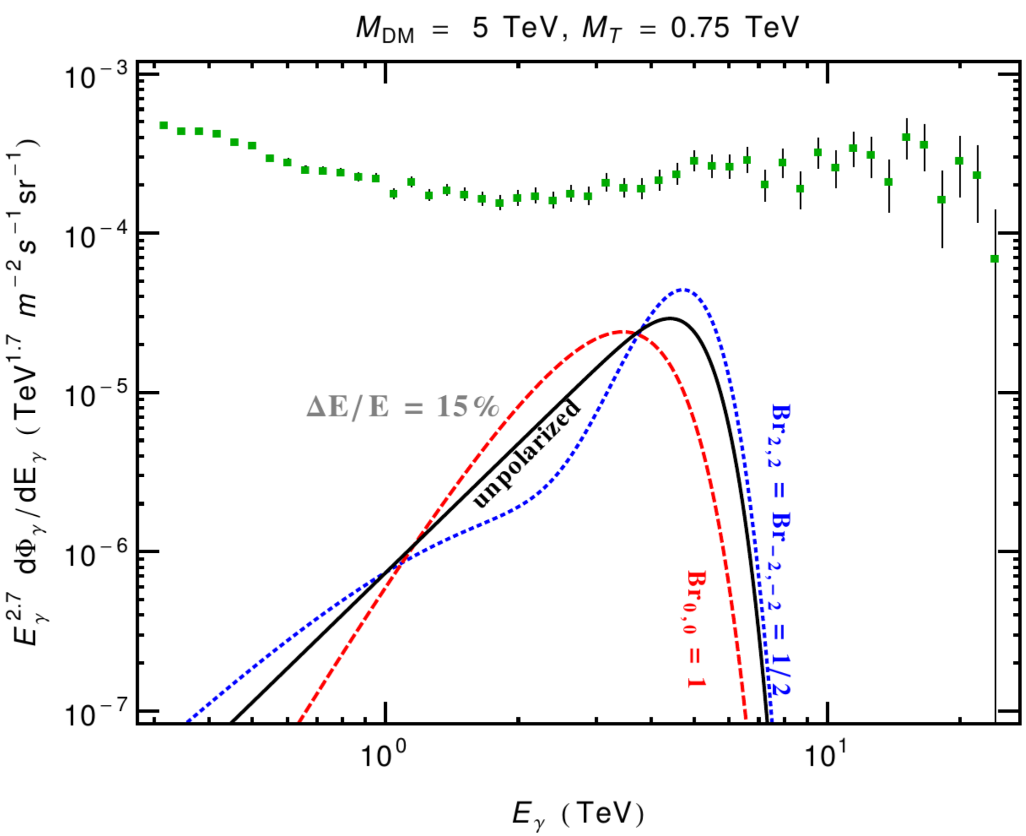
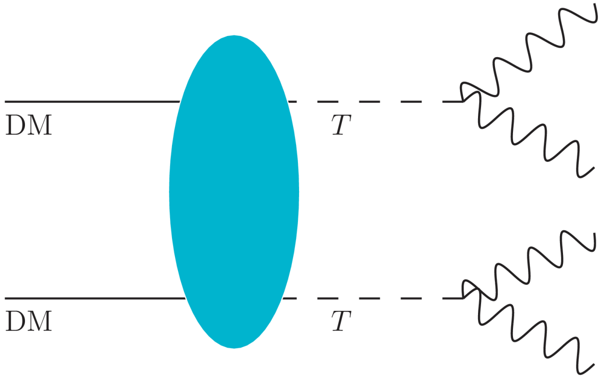
DM DM → TT, T → γγ with M_T/M_{DM} = 0.75
$Br_{0,0} = 1$
unpolarized
$Br_{2,2} = Br_{-2,-2} = 1/2$
$x = E_\gamma/M_{DM}$
DM DM → TT, T → $\nu\bar{\nu}$ with M_T/M_{DM} = 0.01
$Br_{0,0} = 1$
$Br_{2,2} = Br_{-2,-2} = 1/2$
unpolarized
$\Phi_\nu^{-1} d\Phi_\nu/dx$
$x = E_\nu/M_{DM}$
DM DM → TT, T → $\nu\bar{\nu}$ with M_T/M_{DM} = 0.75
$Br_{0,0} = 1$
$Br_{2,2} = Br_{-2,-2} = 1/2$
unpolarized
$x = E_\nu/M_{DM}$

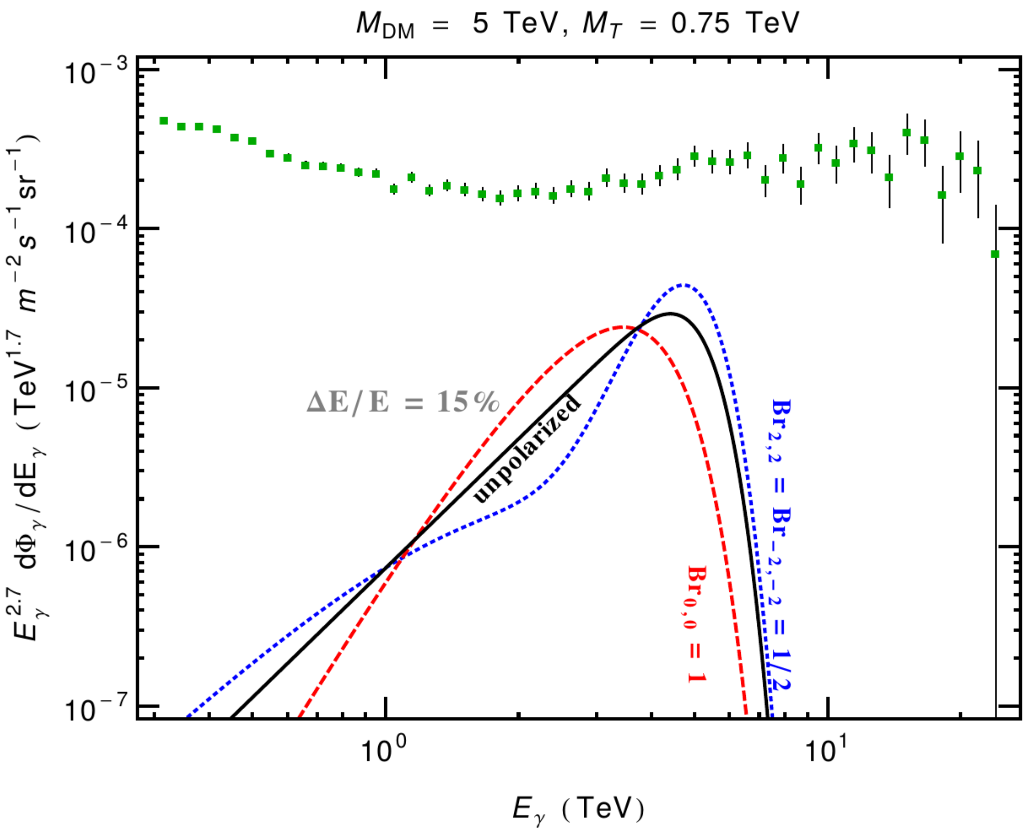
Example with a hypothetical diphoton resonance

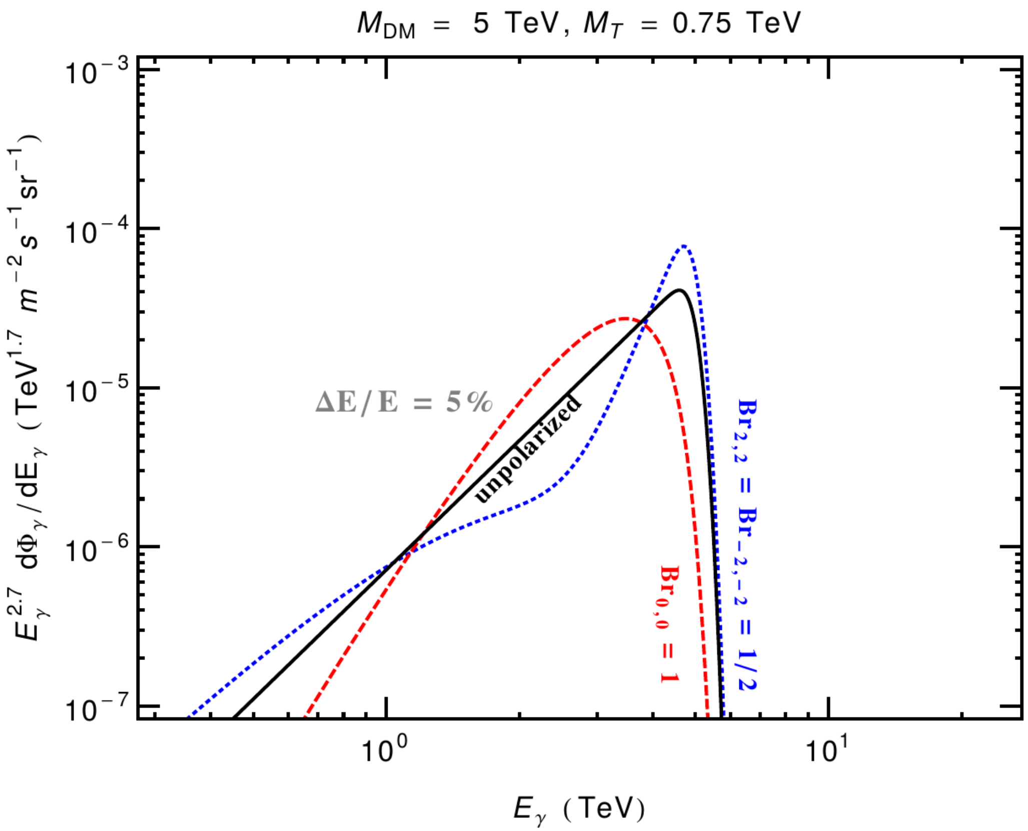




Example with a hypothetical diphoton resonance

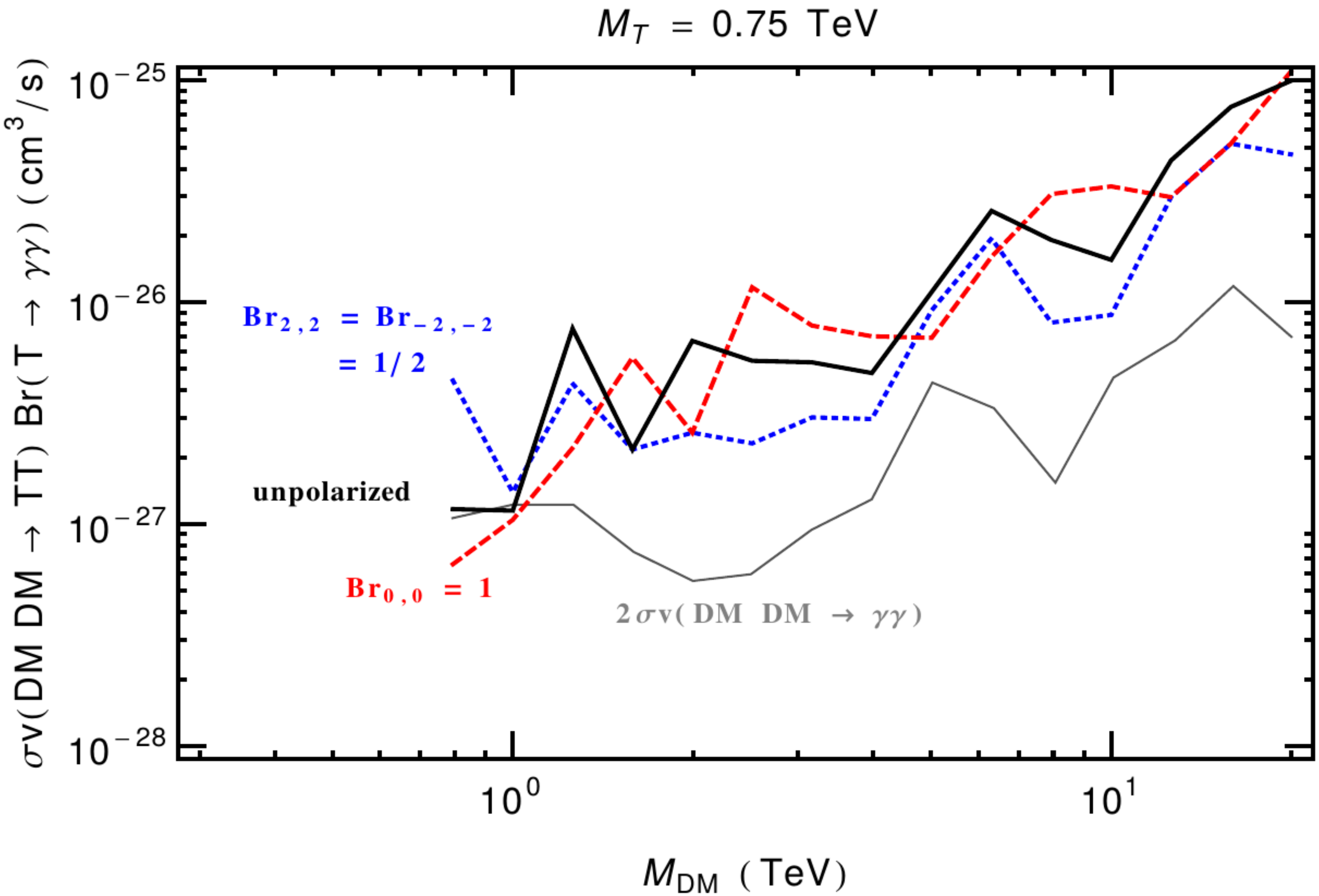






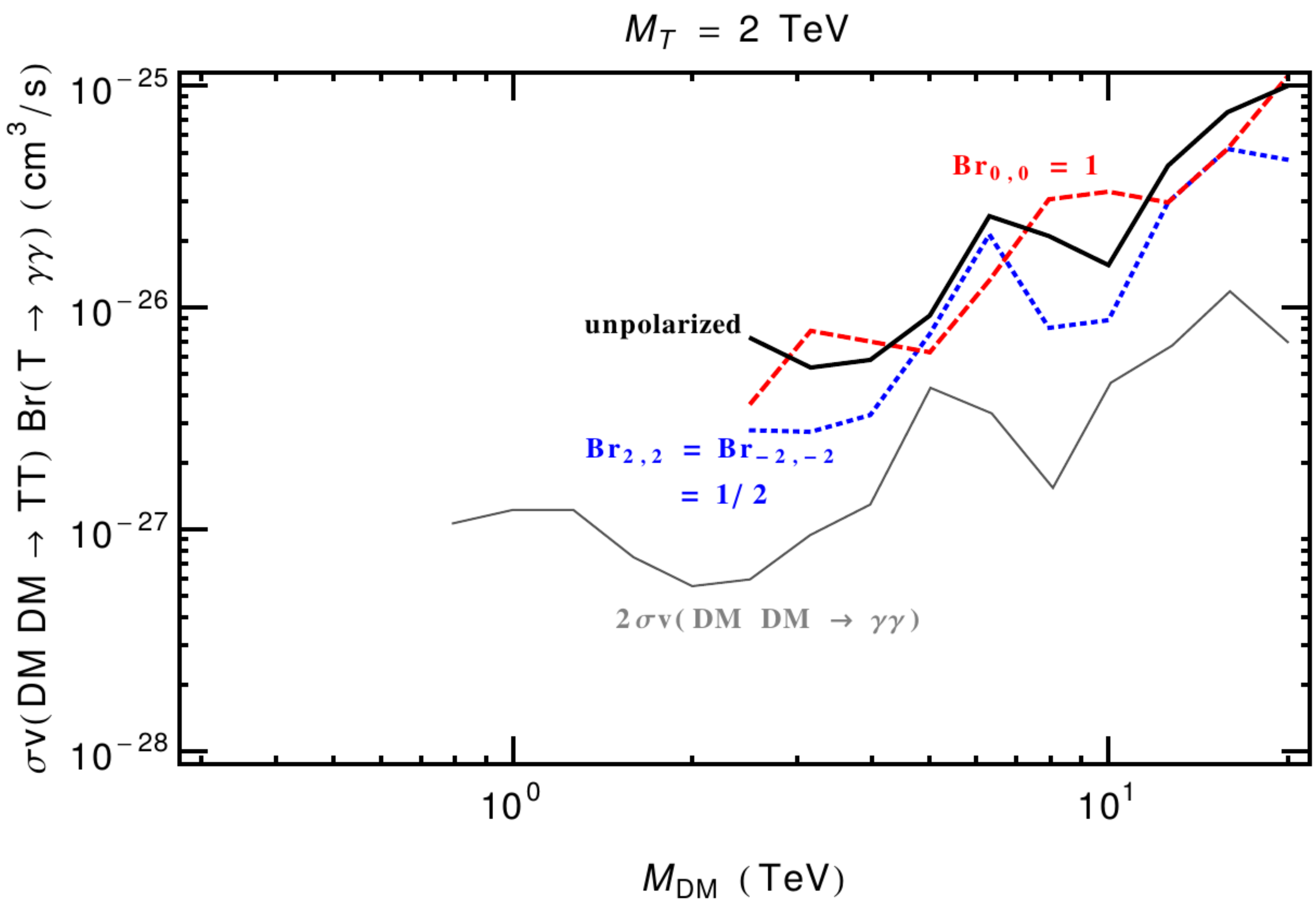
Example with a hypothetical diphoton resonance

H.E.S.S. Limits on spectral features



Example with a hypothetical diphoton resonance

H.E.S.S. Limits on spectral features



Conclusions

- DM annihilations into arbitrary particles that subsequently decay into photons or neutrinos lead to polynomial spectral features.

- Such features are generic and can be studied using a model-independent approach.

- Using this, high resolution of gamma-ray or neutrinos telescopes could tell the spin of the decaying particle.

- We calculate the annihilation spectrum that the asociated to a diphoton resonance if DM annihilates or decays into it.