Resummation of large radiative effects in indirect dark matter detection

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Based on
Beneke, Broggio, Hasner, Urban, MV
arXiv:1903.08702
Beneke, Broggio, Hasner, MV
arXiv:1805.07367

Outline

- Motivation
- Gamma rays from DM annihilation
- Sommerfeld and Sudakov resummation
- Factorization formulas for the wino model
- Conclusions

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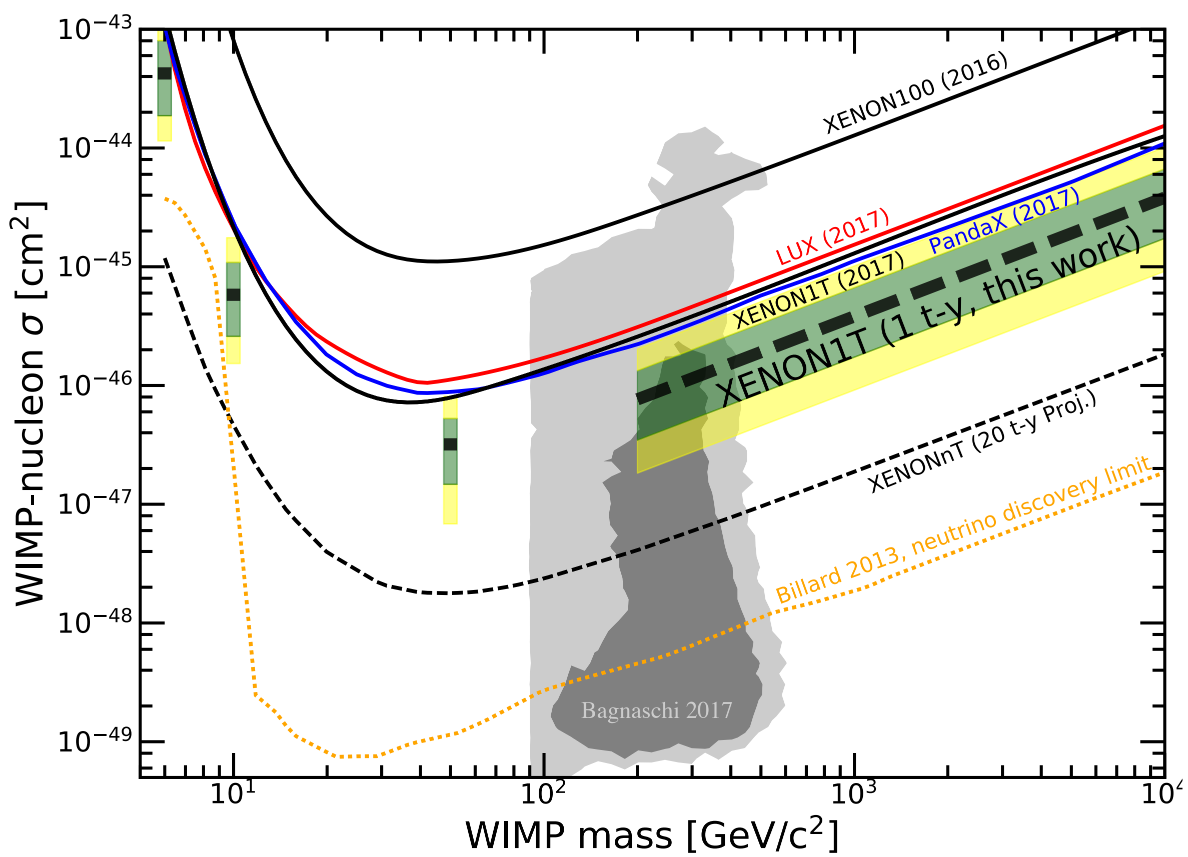
Motivation

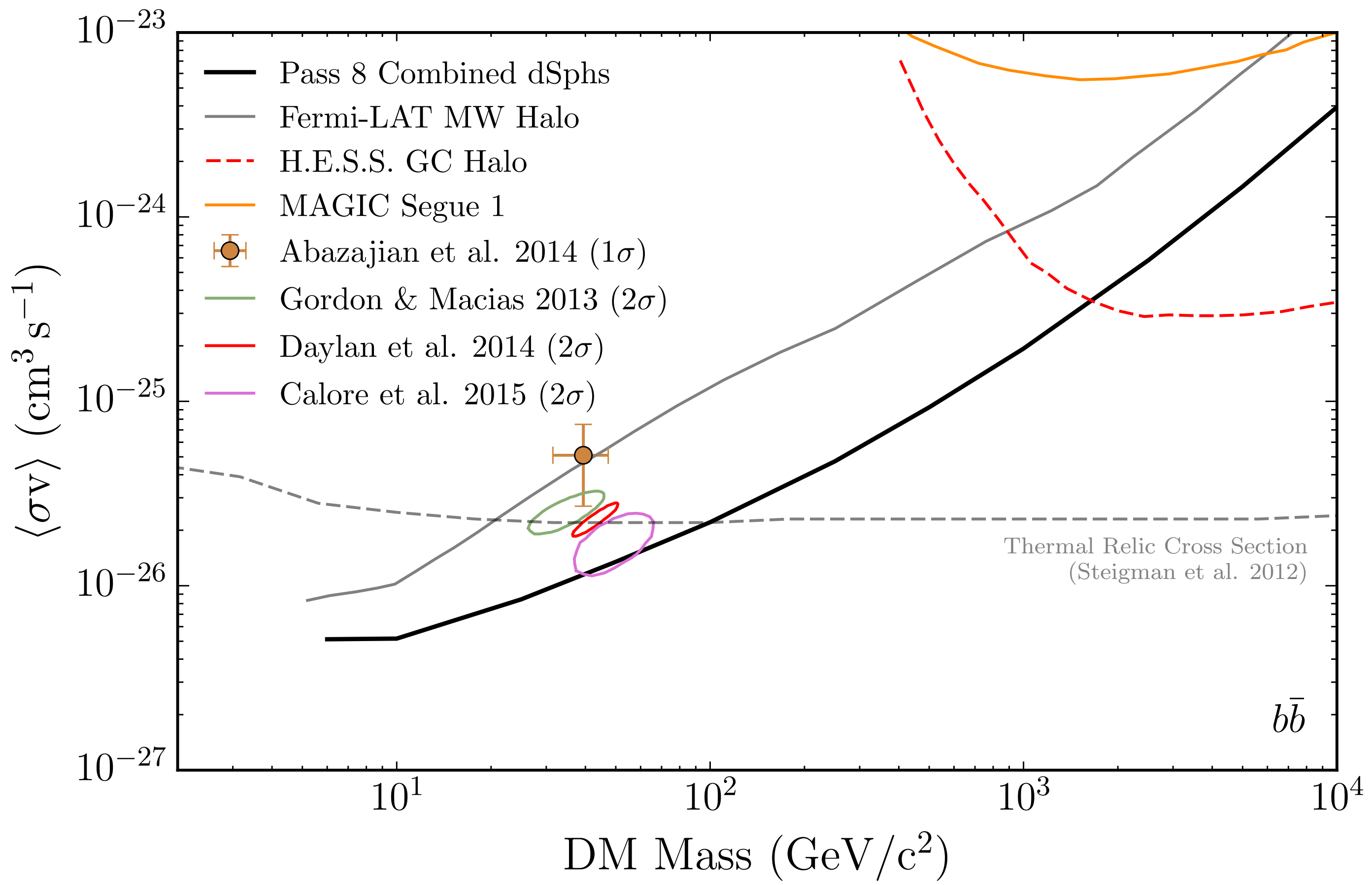
- WIMP DM paradigm is very well motivated and scrutinized
- No discovery so far $\Rrightarrow$ $\mathcal{O}$(1-100GeV) wimp models are subject to stringent constraints

WIMPs not detected so far

XENON collaboration [1805.12562]



Fermi-LAT collaboration [1503.02641]



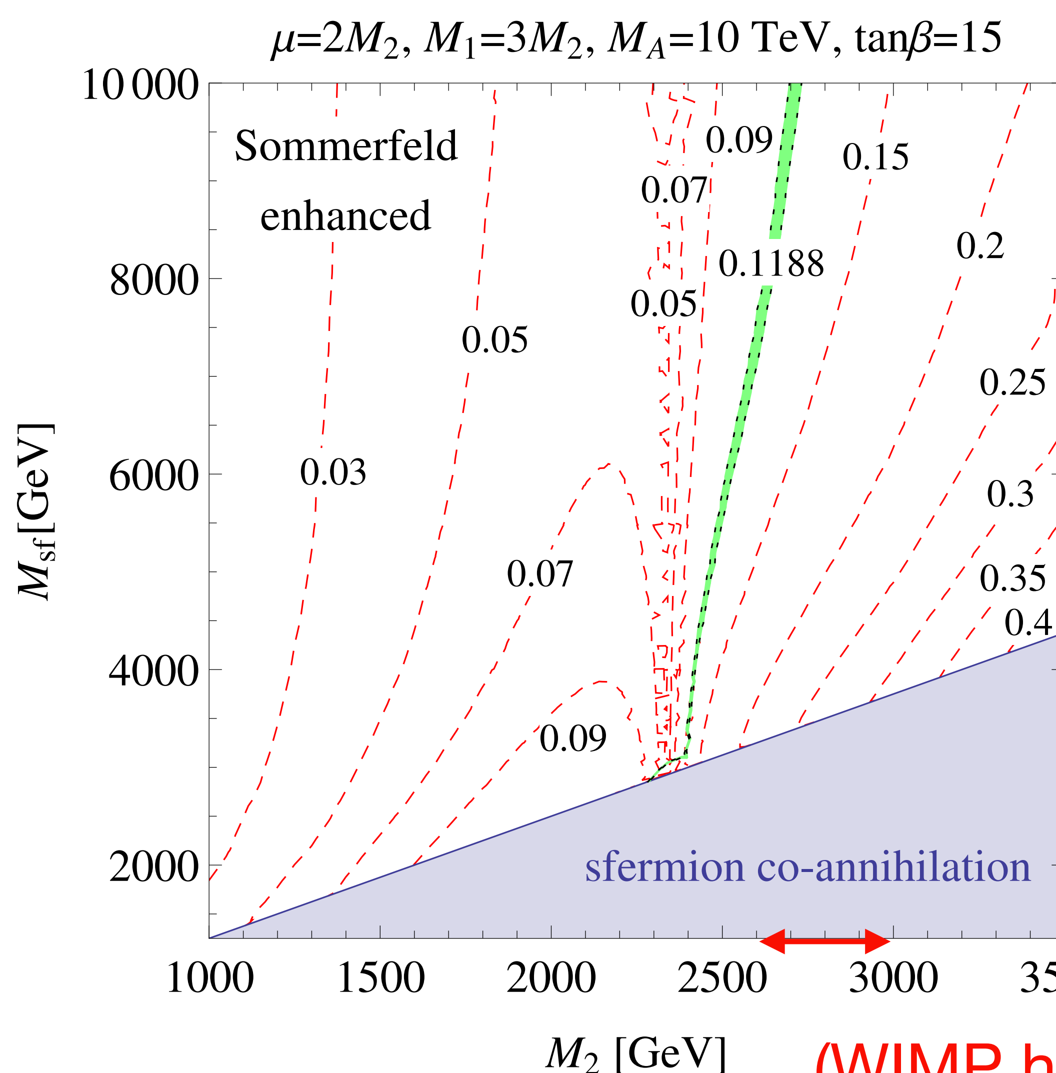
Maybe the DM is **heavier** than what we would have liked!

Motivation

- WIMP DM paradigm is very well motivated and scrutinized
- No discovery so far $\Rrightarrow$ $\mathcal{O}$(1-100GeV) wimp models are subject to stringent constraints
    - Turn attention into **above-TeV** wimps

The wino model (minimal DM)

$$\delta\mathcal{L}_{\text{Wino}} = \frac{1}{2}\bar{\chi}(i\gamma^{\mu}\mathrm{D}_{\mu} - m_{\chi})\chi$$

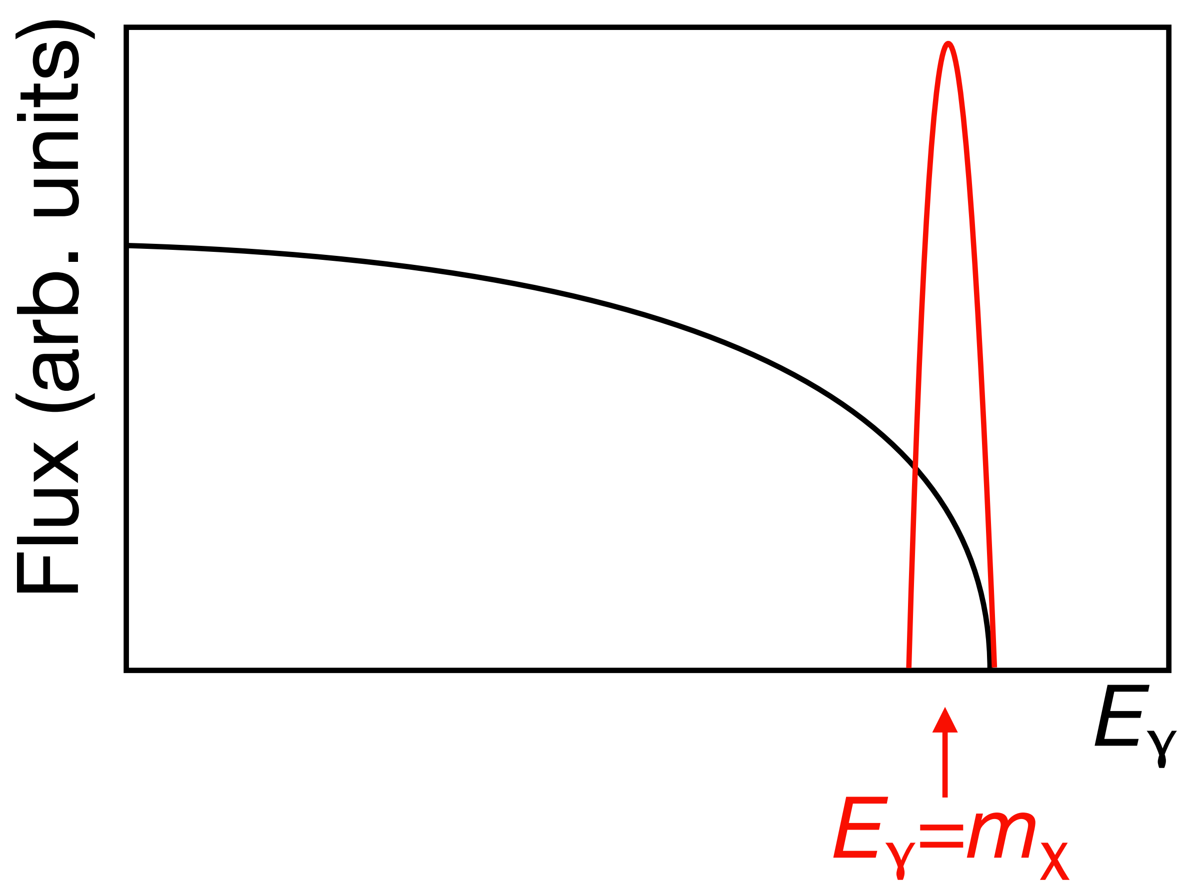


Beneke et al
arXiv:1601.04718

(WIMP hypothesis → **heavy**)

Motivation

- Heavy ($\mathcal{O}$(1-100TeV)) DM → Indirect detection
- Spectral-line feature in gamma ray spectrum is a smoking-gun signature of WIMP DM annihilation

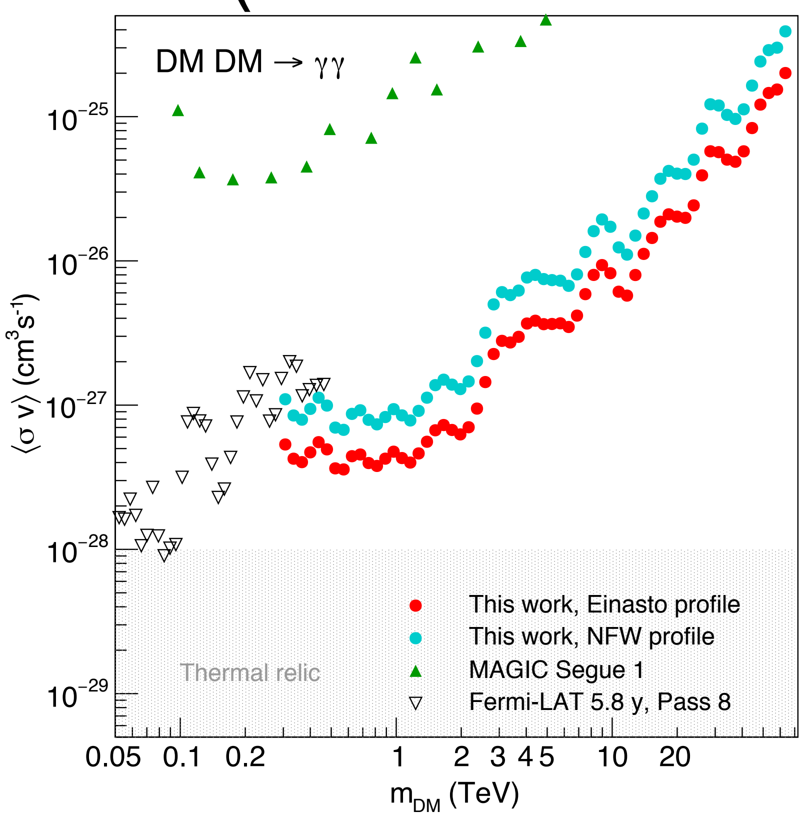


Motivation

- Current- and next-generation gamma-ray telescopes will search for such spectral lines
- Particularly promising is the Cherenkov Telescope Array (**CTA**) with ~1 order of magnitude improved sensitivity w.r.t. current technology

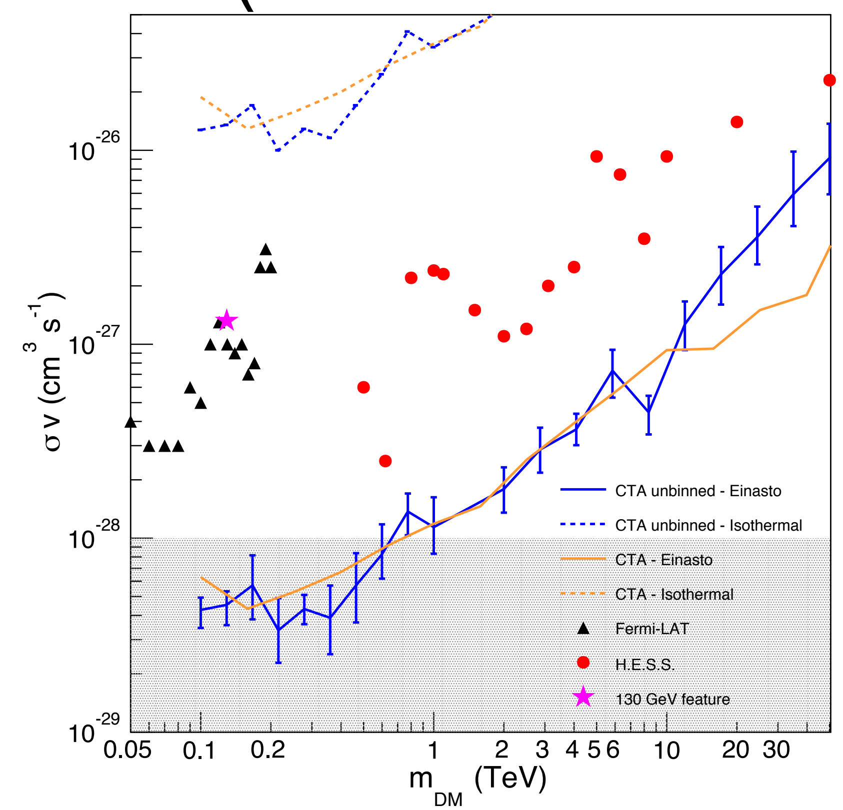
State of the art

HESS (arXiv:1805.05741)



Projected (500hrs)

CTA (arXiv:1709.07997)



Motivation

- Annihilation cross section computations for heavy wimps can be intricate (because the hierarchy $M_{DM} >> M_{SM}$)
- Non-perturbative effects such as the *Sommerfeld* effect play a major role in their determination
- On top of this, large electroweak *Sudakov* double logarithms invalidate the perturbative expansion and need to be resummed
- In this work we focus on the latter (but also systematically treat the former)

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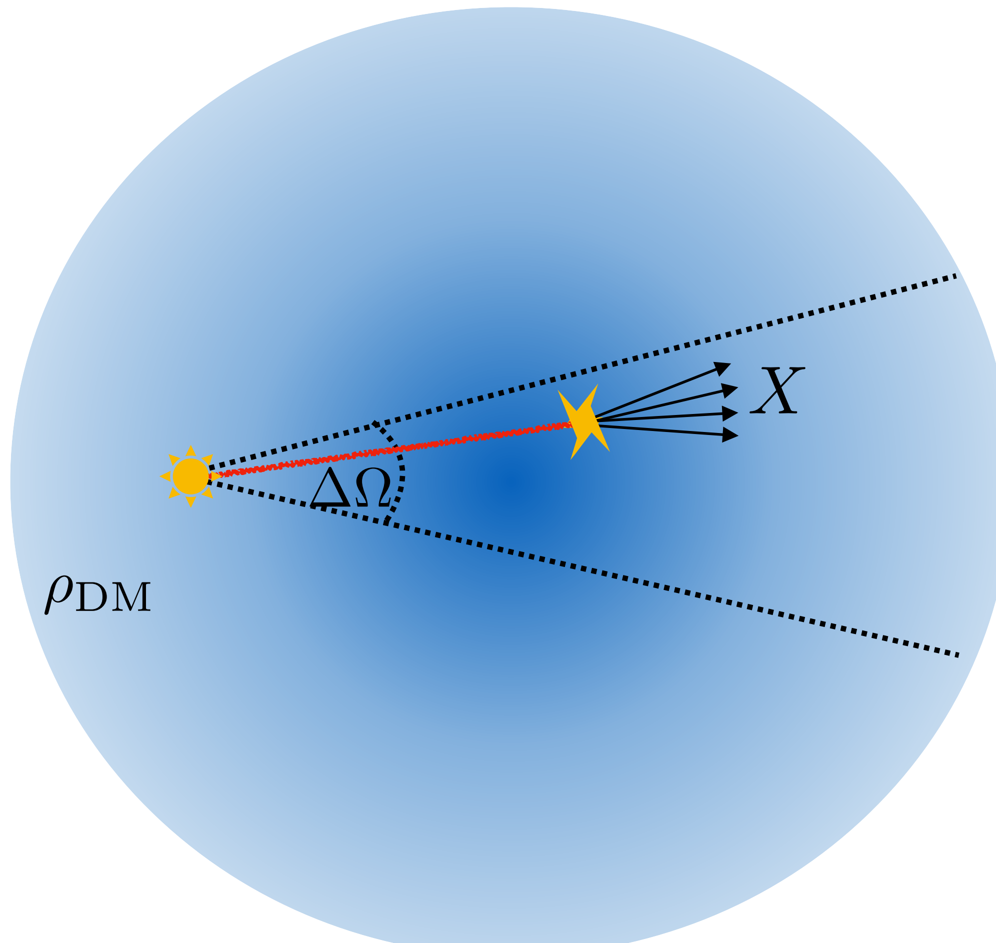
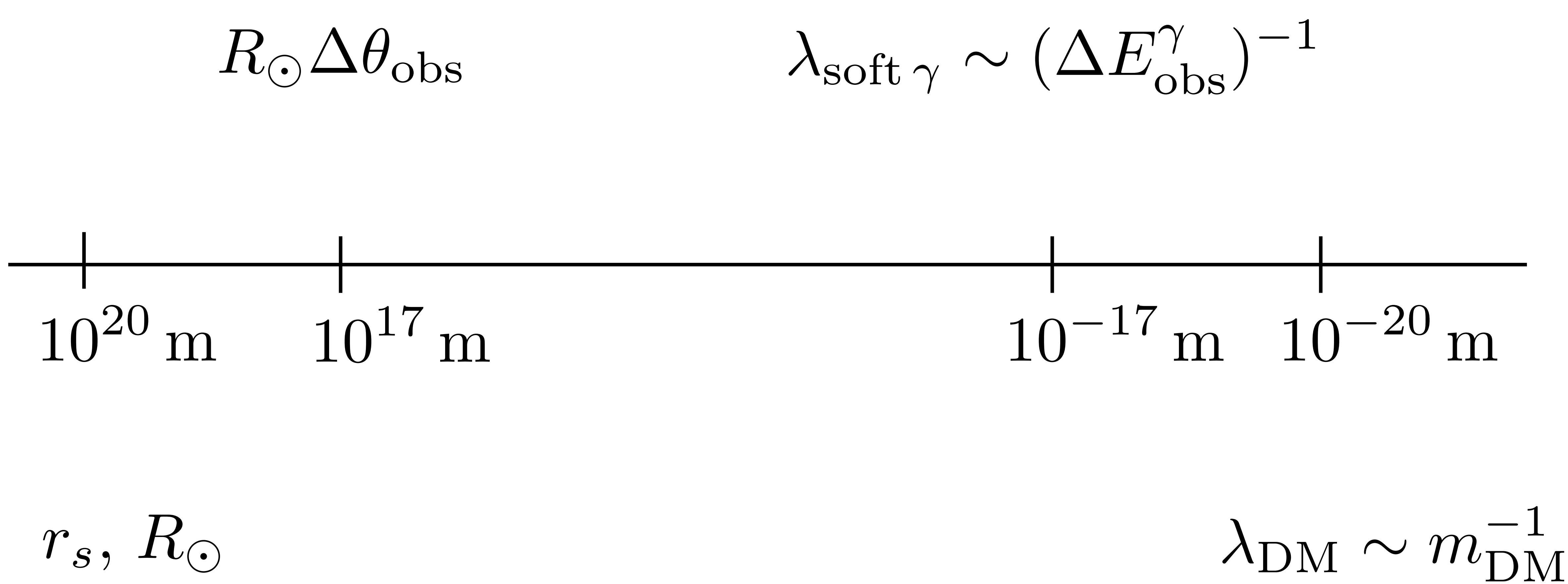
Gamma rays from dark matter annihilation

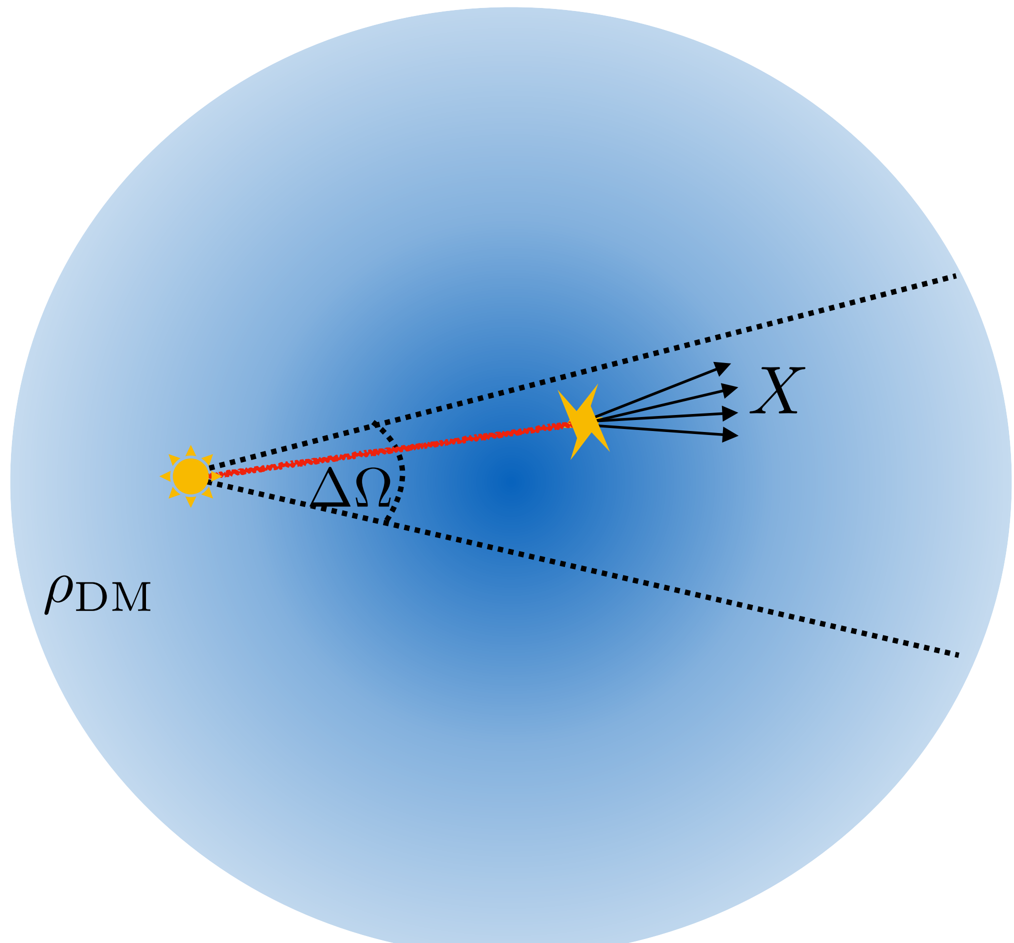


$$\Phi(E_\gamma) = \frac{1}{8\pi m_{\rm DM}^2} \int_{\Delta\Omega} {\rm d}\Omega \int_{\rm l.o.s.} {\rm d}s\, \rho_{\rm DM}^2(\boldsymbol{r}(s)) \frac{{\rm d}}{{\rm d}E_\gamma} [\sigma v]_{\gamma+X}$$

γ rays from dark matter annihilation. Multi-scale problem



γ rays from dark matter annihilation. 1st factorization



$$\Phi(E_\gamma) = \frac{1}{8\pi m_{\rm DM}^2} \underbrace{\int_{\Delta\Omega} \mathrm{d}\Omega \int_{\rm l.o.s.} \mathrm{d}s\, \rho_{\rm DM}^2(\boldsymbol{r}(s))}_{J(\Delta\Omega)} \frac{\mathrm{d}}{\mathrm{d}E_\gamma}[\sigma v]_{\gamma+X}$$

Astrophysical "*J*" factor
independent of gamma-ray energy

γ rays from dark matter annihilation. 1st factorization

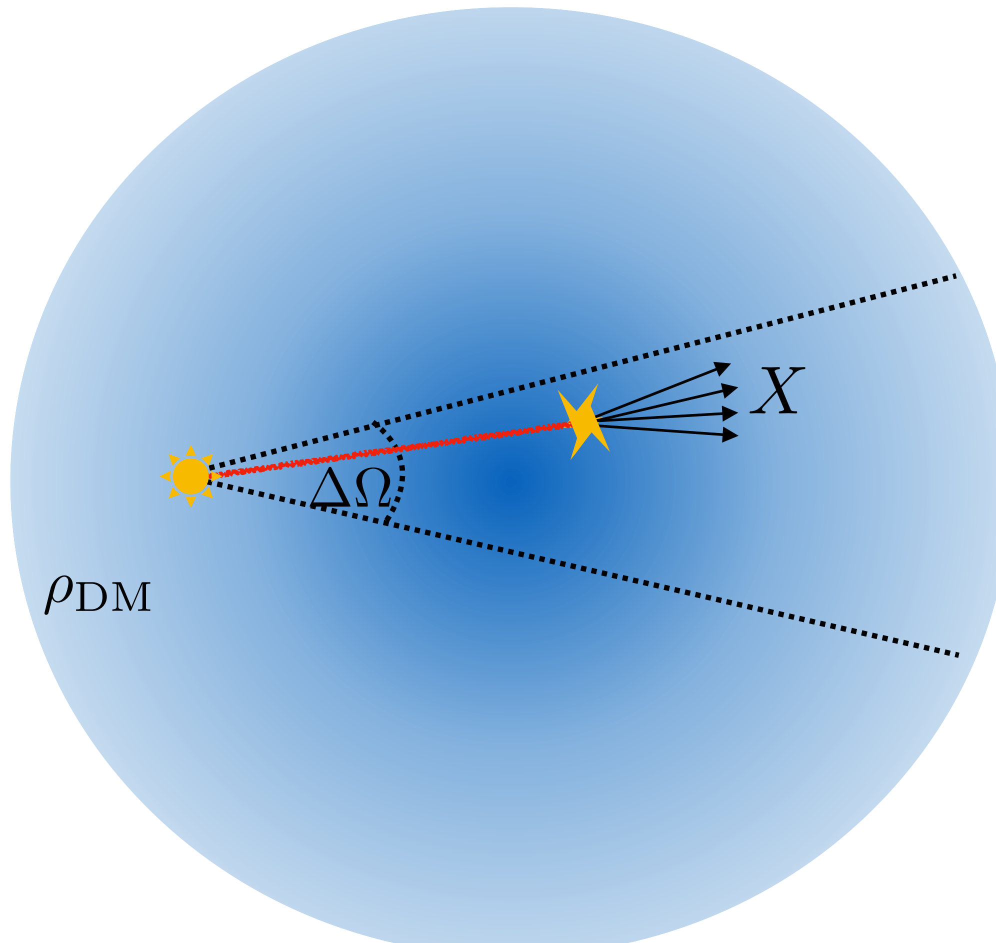
Propagation
does not depend on any scale

New-physics model
m_W, m_χ; $\alpha_{EW} m_\chi$, $m_\chi v$, etc.

Instrument/observation
R_{GC}, r_s, $\Delta\Omega$, ΔE_γ

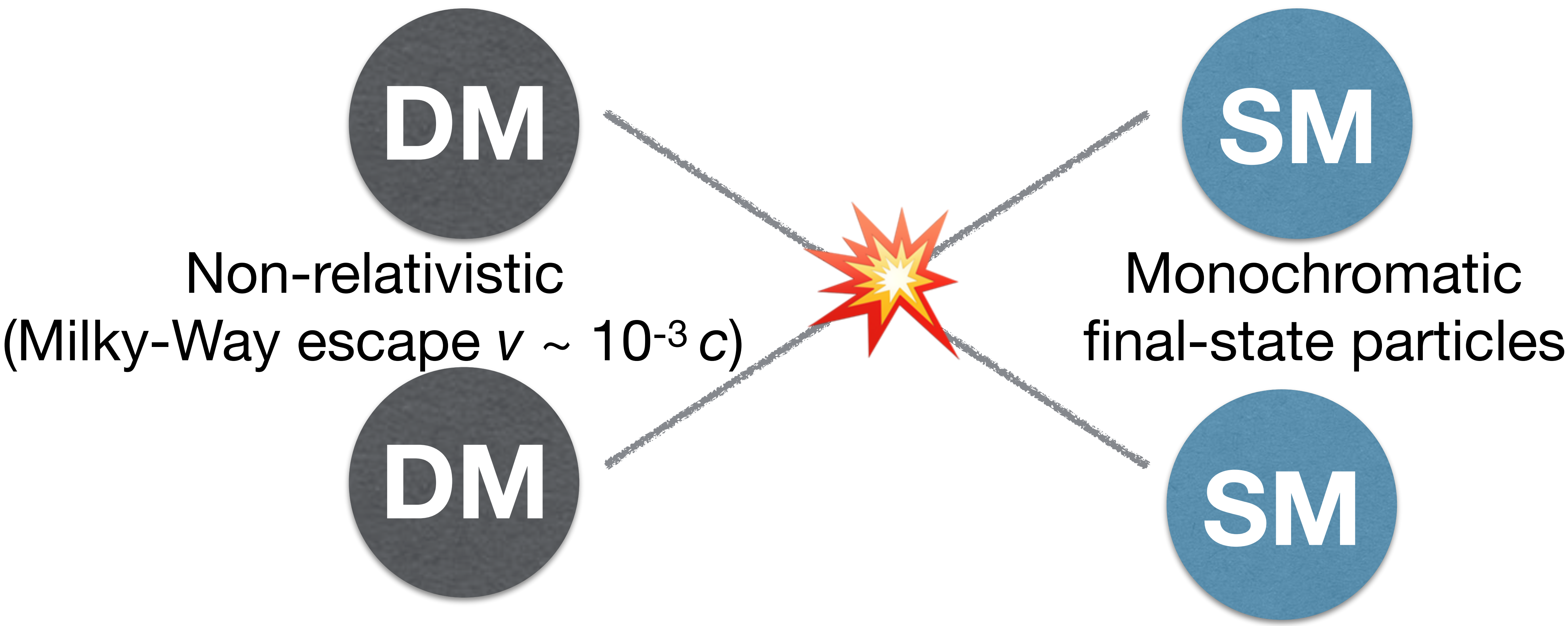
$$\Phi(E_\gamma) = \frac{1}{8\pi m_{\rm DM}^2} \underbrace{\int_{\Delta\Omega} \mathrm{d}\Omega \int_{\rm l.o.s.} \mathrm{d}s\, \rho_{\rm DM}^2(\boldsymbol{r}(s))}_{J(\Delta\Omega)} \frac{\mathrm{d}}{\mathrm{d}E_\gamma}[\sigma v]_{\gamma+X}$$

γ rays from dark matter annihilation. PP term



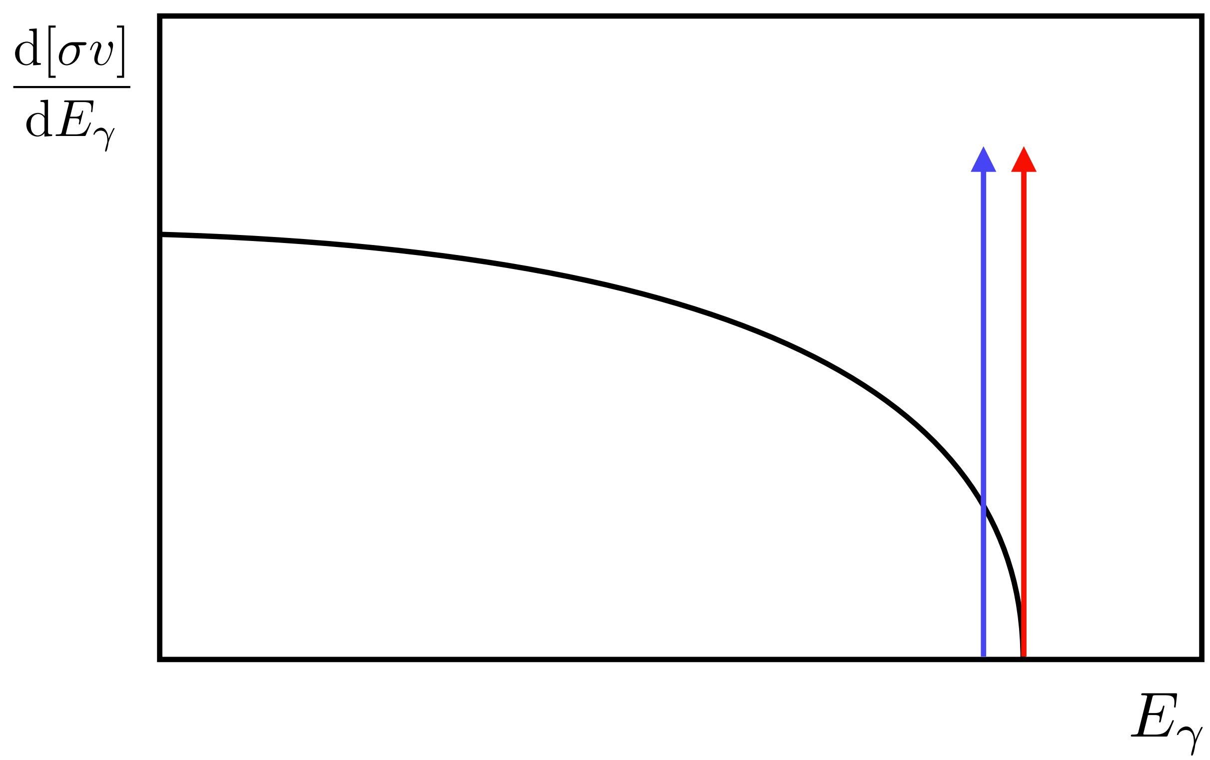
$$\Phi(E_\gamma) = \frac{1}{8\pi m_{\rm DM}^2} \underbrace{\int_{\Delta\Omega} \mathrm{d}\Omega \int_{\rm l.o.s.} \mathrm{d}s\, \rho_{\rm DM}^2(\boldsymbol{r}(s))}_{J(\Delta\Omega)} \frac{\mathrm{d}}{\mathrm{d}E_\gamma}[\sigma v]_{\gamma+X}$$

γ rays from dark matter annihilation. Endpoint spectrum



γ rays from dark matter annihilation. Endpoint spectrum

$$\frac{\mathrm{d}}{\mathrm{d}E_\gamma}[\sigma v]_{\gamma+X} = 2[\sigma v]_{\gamma\gamma}\delta(E_\gamma - m_{\mathrm{DM}}) + [\sigma v]_{\gamma Z}\delta(E_\gamma - E_0^{\gamma Z}) + + \frac{\mathrm{d}}{\mathrm{d}E_\gamma}[\sigma v]_{\gamma+N\geq 2-\mathrm{bodies}}$$

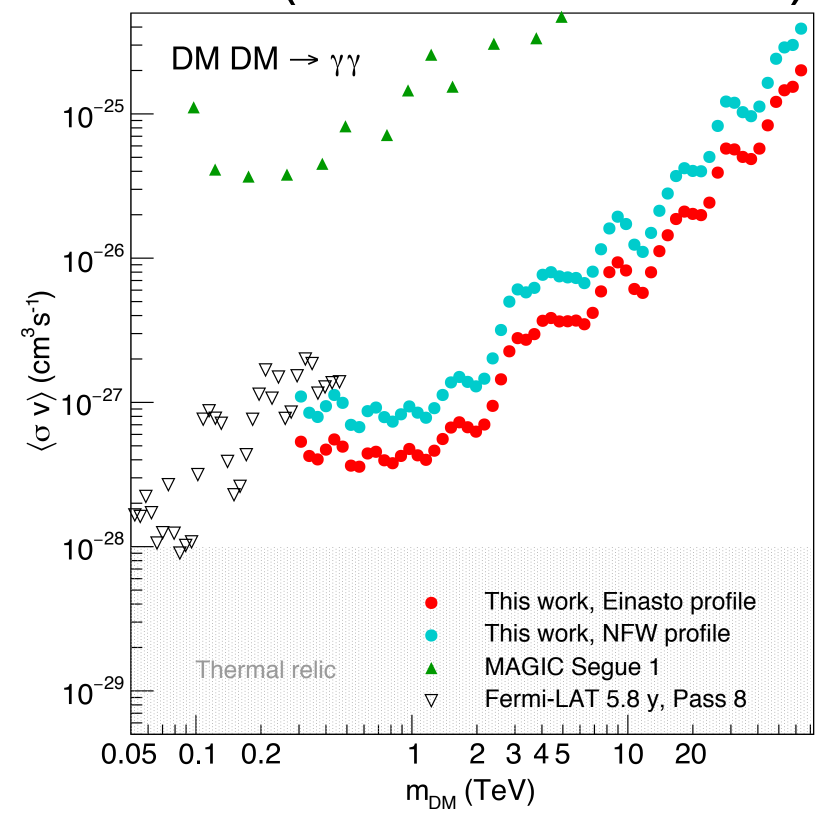


γ rays from dark matter annihilation. Endpoint spectrum

$$\frac{\mathrm{d}}{\mathrm{d}E_\gamma}[\sigma v]_{\gamma+X} = 2[\sigma v]_{\gamma\gamma}\delta(E_\gamma - m_{\mathrm{DM}})$$

State of the art

HESS (arXiv:1805.05741)



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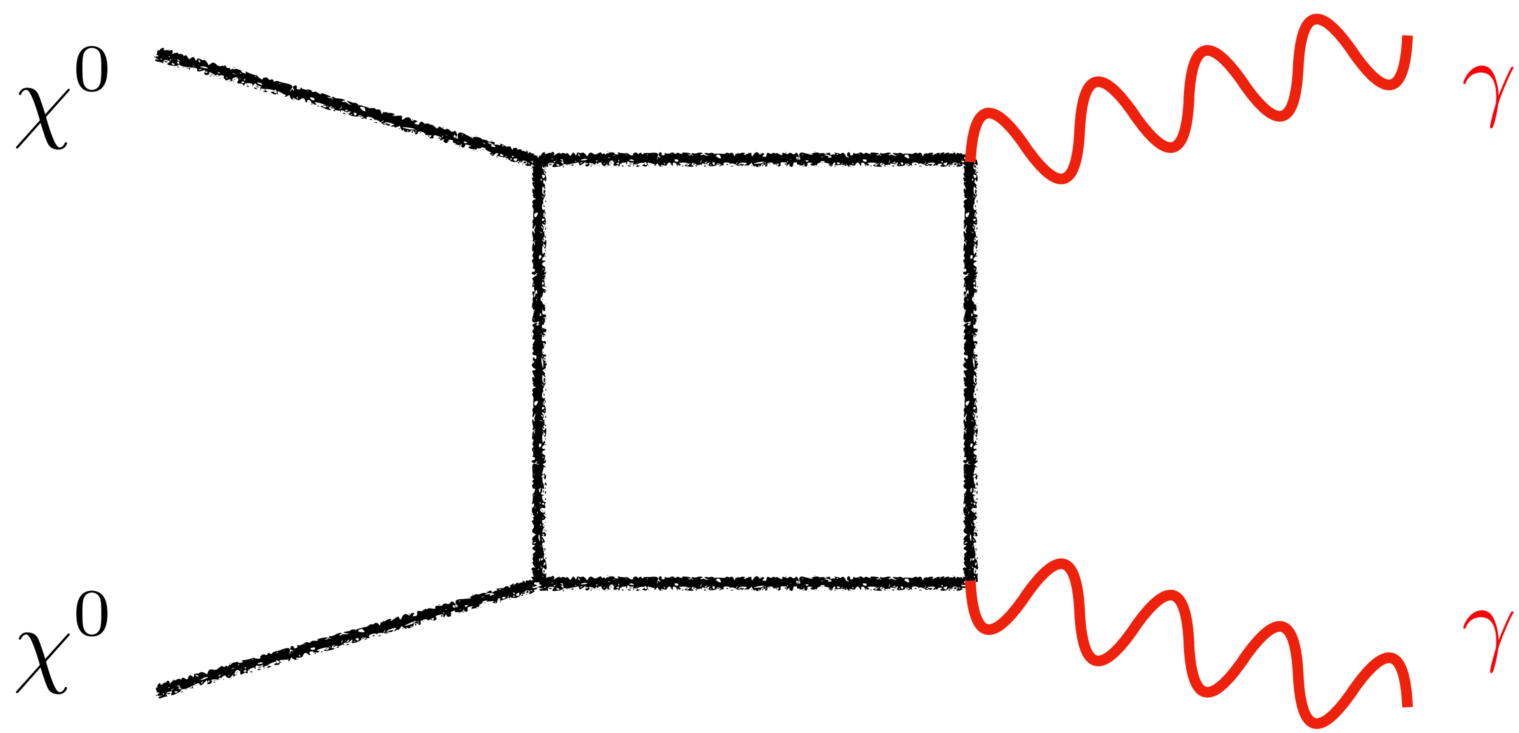
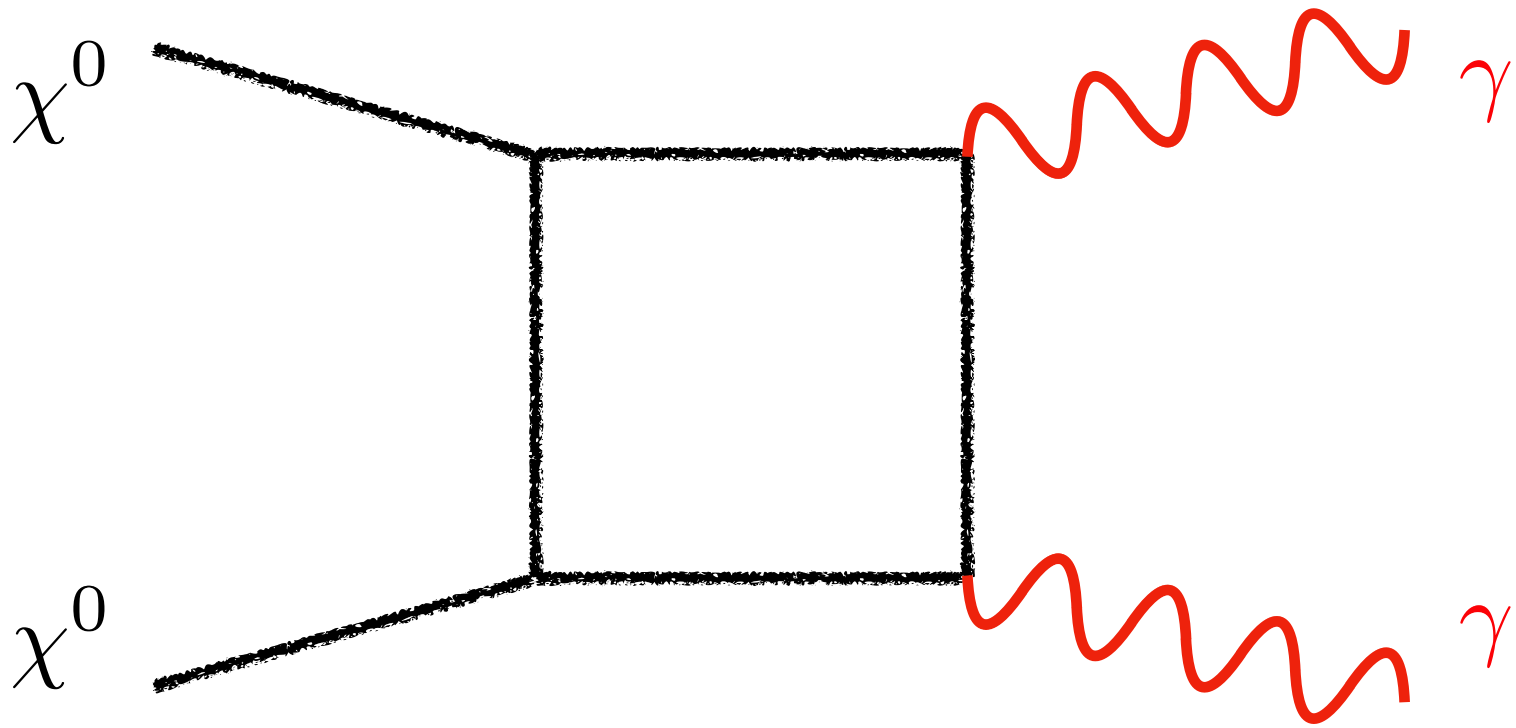
Naive computation of $\sigma v_{\gamma\gamma}$



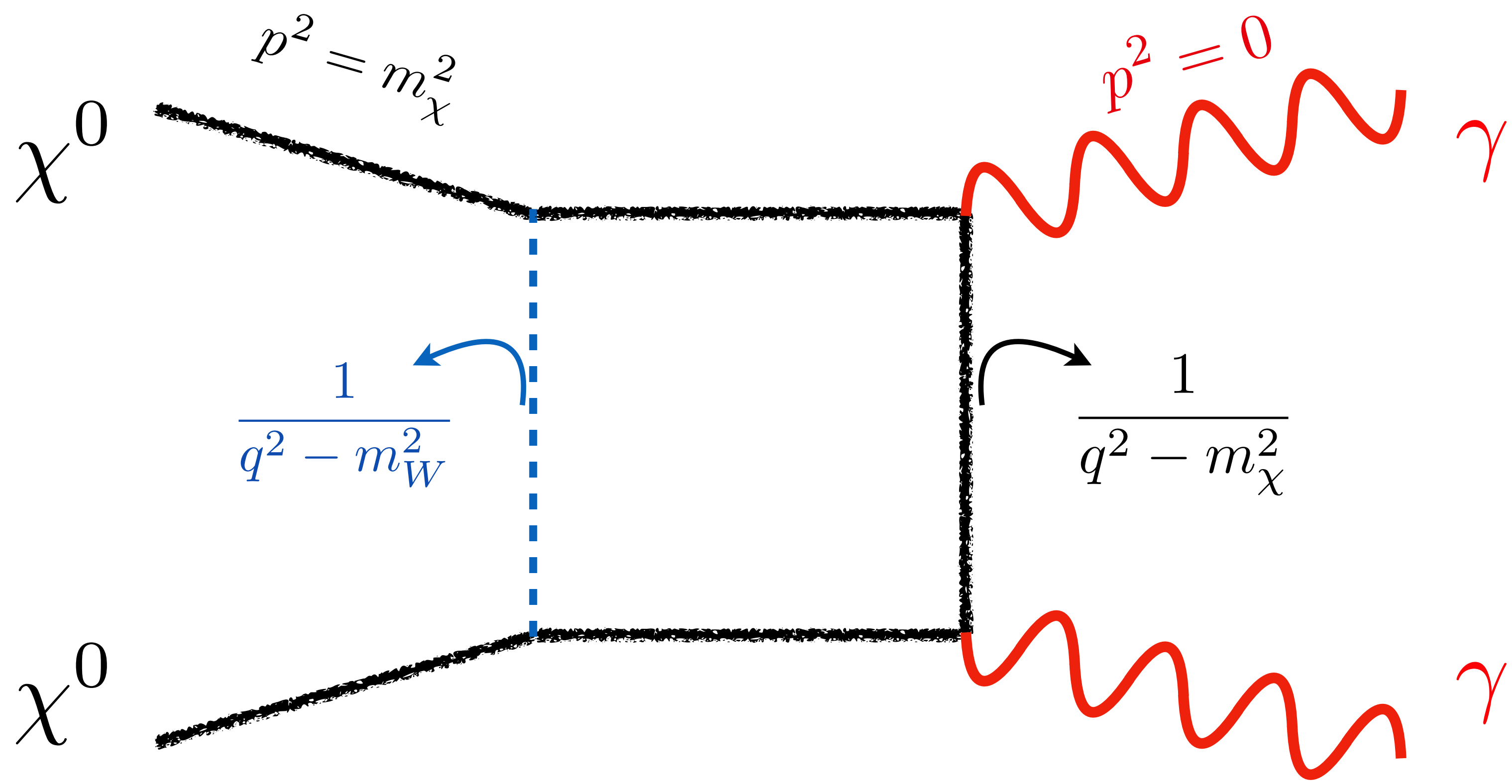
Naive computation of $\sigma v_{\gamma\gamma}$



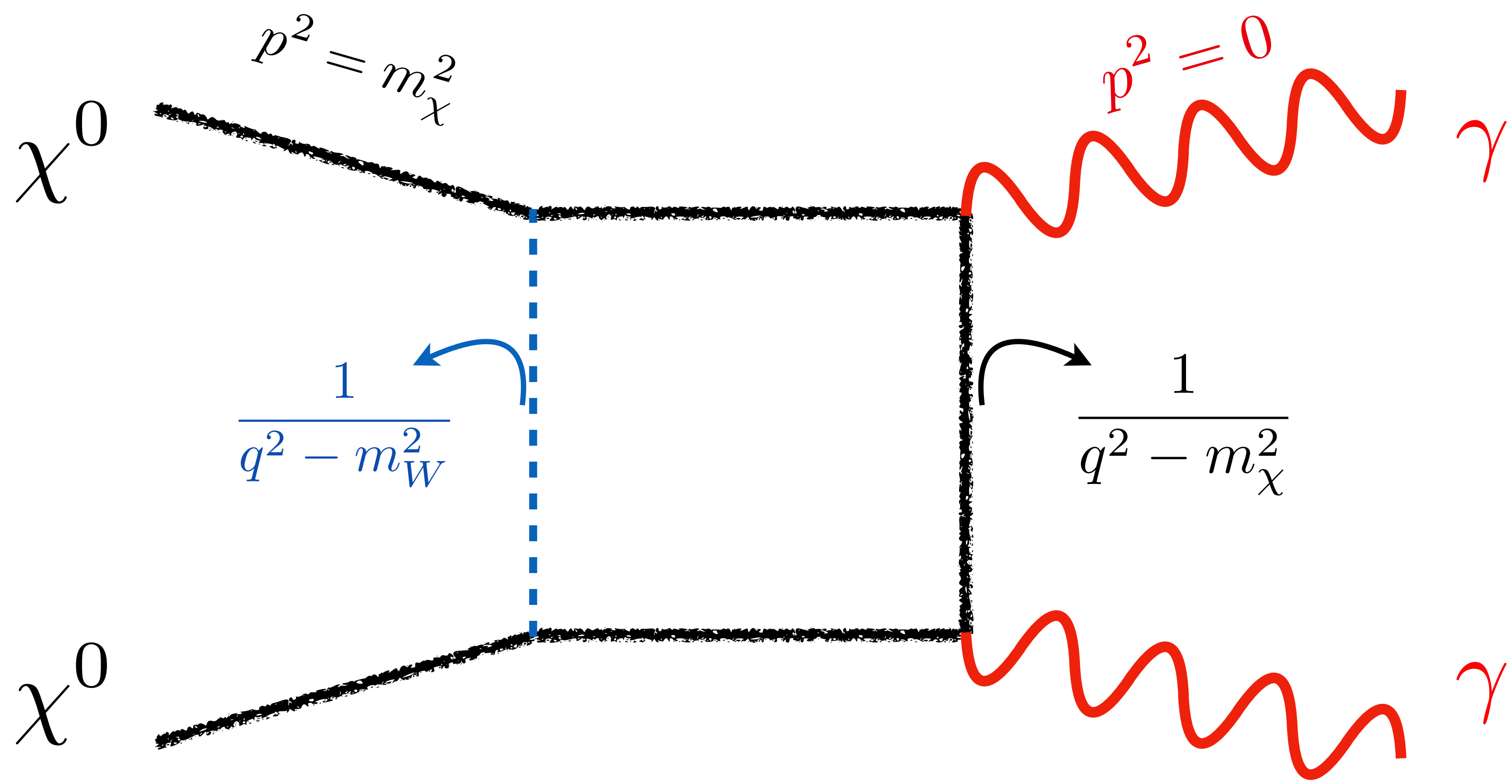
(naively) loop and mass suppressed → $\Phi(E_\gamma) \sim \left(\frac{\alpha_{\rm EW}}{m_{\rm DM}}\right)^4$

(do not give up yet!!)

Naive computation of $\sigma v_{\gamma\gamma}$



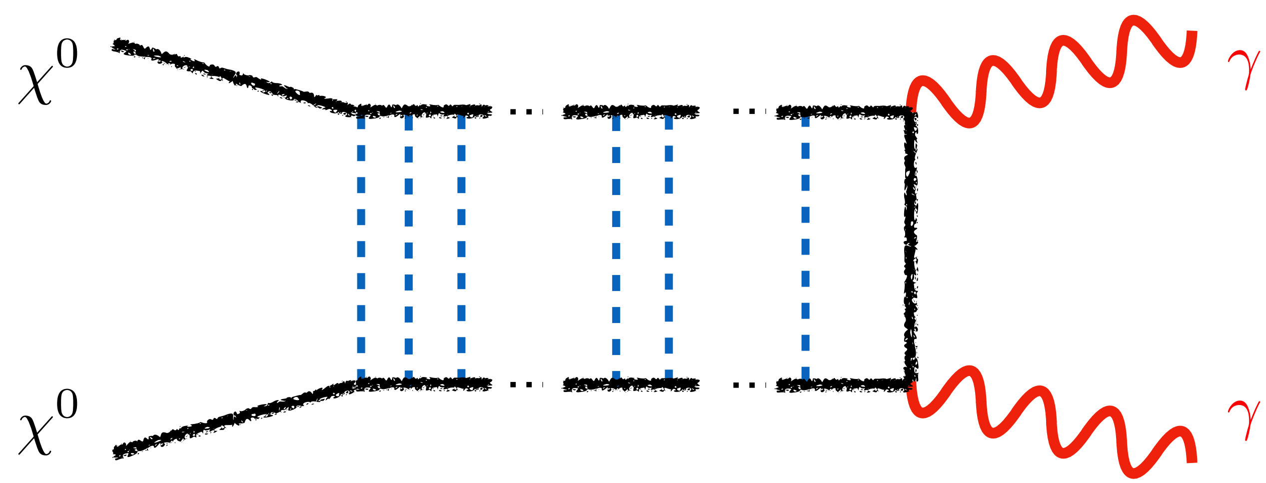
Naive computation of $\sigma v_{\gamma\gamma}$



$$\mathcal{M}_{\mathrm{So}} \sim \frac{g^4 m_\chi^2}{m_W^2} \gg g^2$$

Naive computation of $\sigma v_{\gamma\gamma}$

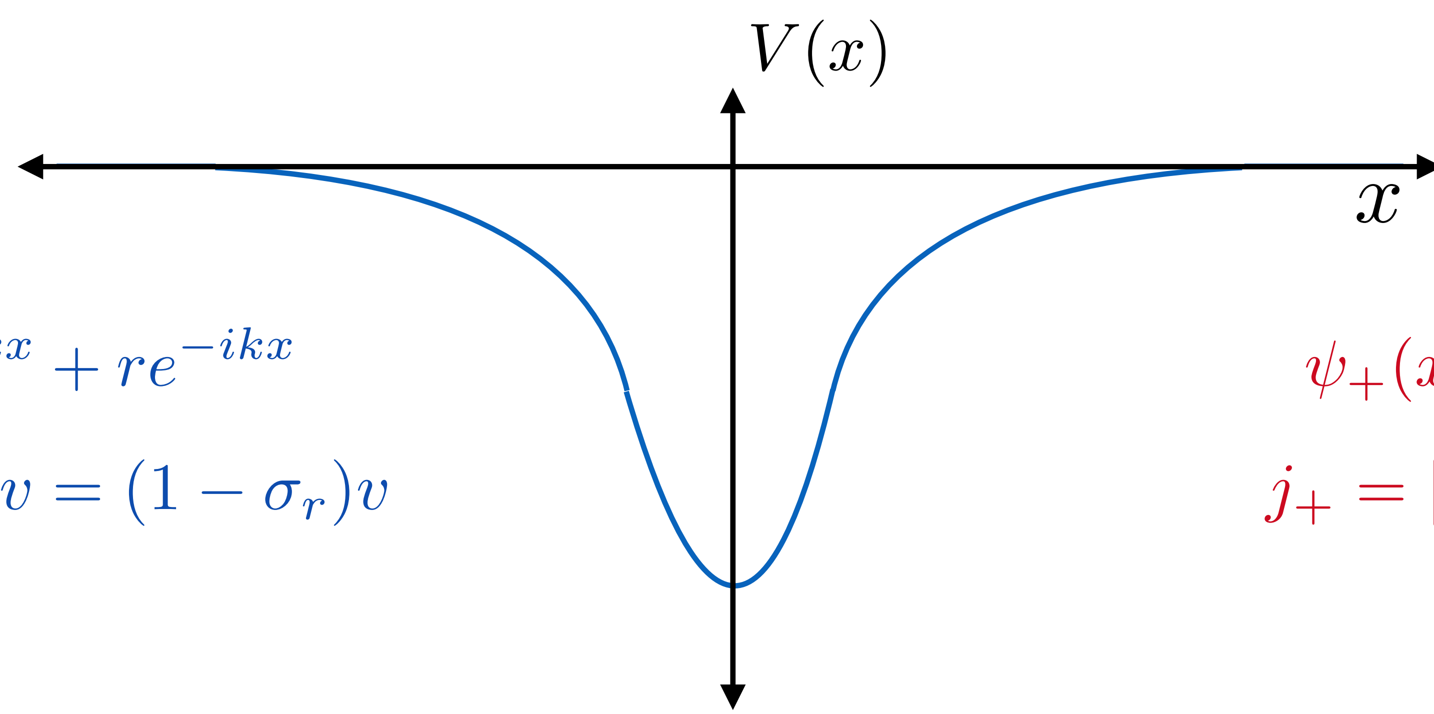
Solution: resum all ladder-like diagrams by matching onto a non-relativistic effective theory



Sommerfeld effect (Scattering states in 1D QM)

$$\left(-\frac{1}{m_\chi}\frac{\mathrm{d}^2}{\mathrm{d}x^2}+V(x)\right)\psi(x)=E\psi(x)$$

$$j(x)=\frac{i}{m_\chi}\left[\psi(x)\psi'^*(x)-\psi^*(x)\psi'(x)\right]$$ = const.



$$\psi_-(x)=e^{ikx}+re^{-ikx}$$

$$j_-=(1-|r|^2)v=(1-\sigma_r)v$$

$$\psi_+(x)=te^{ikx}$$

$$j_+=|t|^2v=\sigma_t v$$

Unitarity: $j_-=j_+ \quad \to \quad \sigma_r+\sigma_t=1$ (No absorption)

Sommerfeld effect (Scattering states in 1D QM)

$$\left(-\frac{1}{m_\chi}\frac{\mathrm{d}^2}{\mathrm{d}x^2} + V(x) + \frac{i}{2}\sigma_a^{(0)} v\delta(x)\right)\psi(x) = E\psi(x)$$

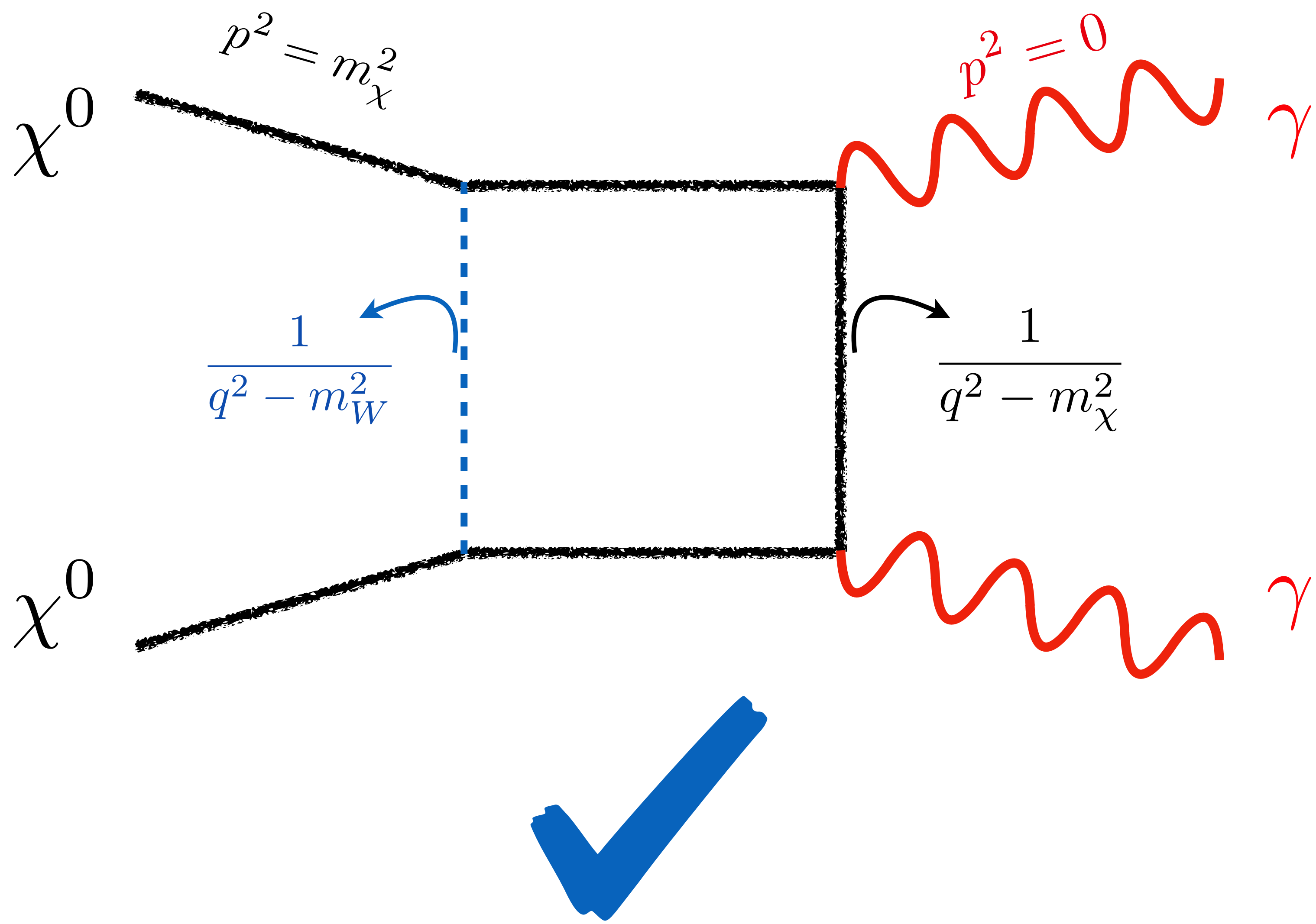
Unitarity-violating term $\rightarrow \quad j_+ = j_- + |\psi(0)|^2\sigma_a v$

$$\sigma_r + \sigma_t + \boldsymbol{\sigma_a} = 1$$

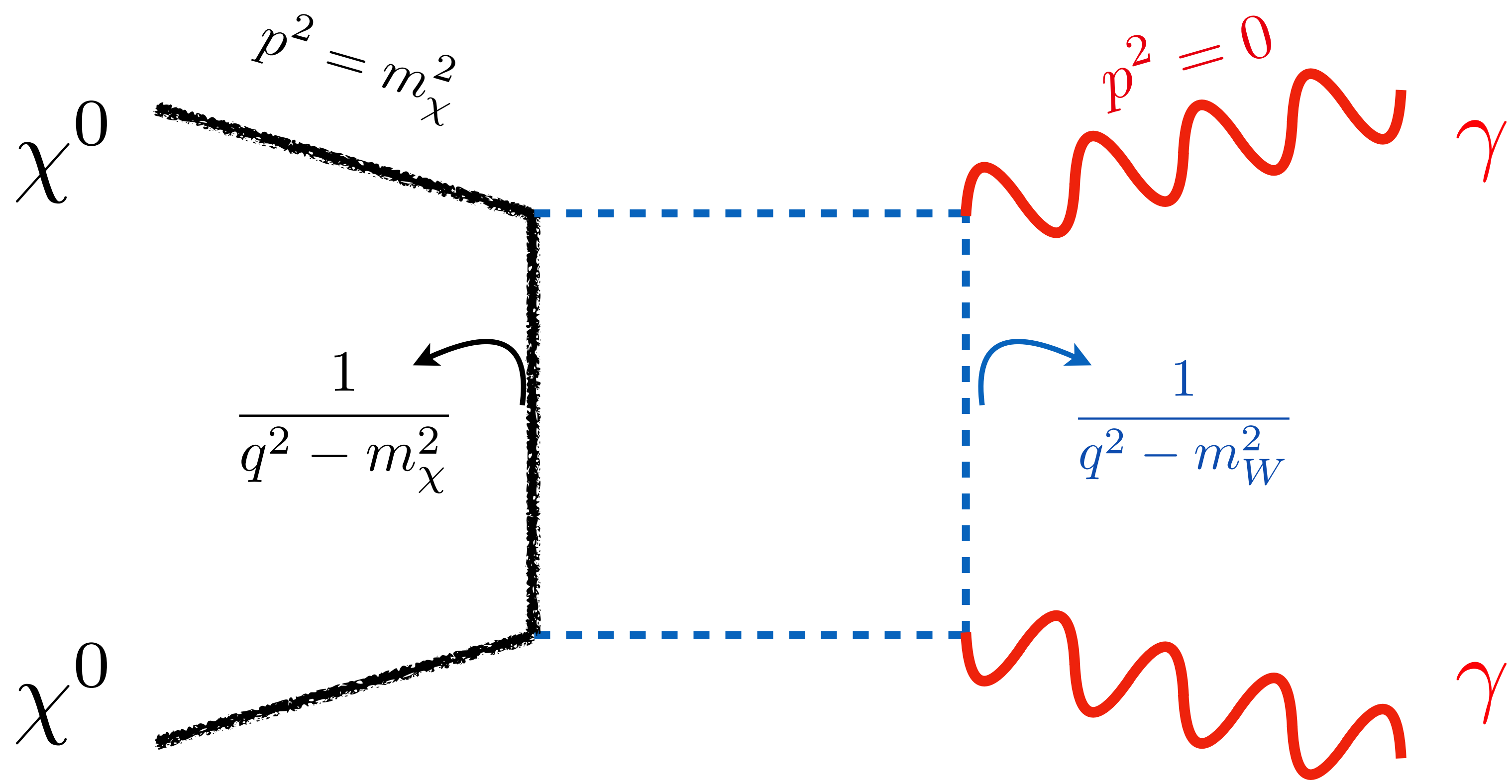
$$\sigma_a = |\boldsymbol{\psi(0)}|^{\mathbf{2}}\sigma_a^{(0)}$$

Resummed cross section = Sommerfeld factor (long range physics) X QFT cross section (short range physics)

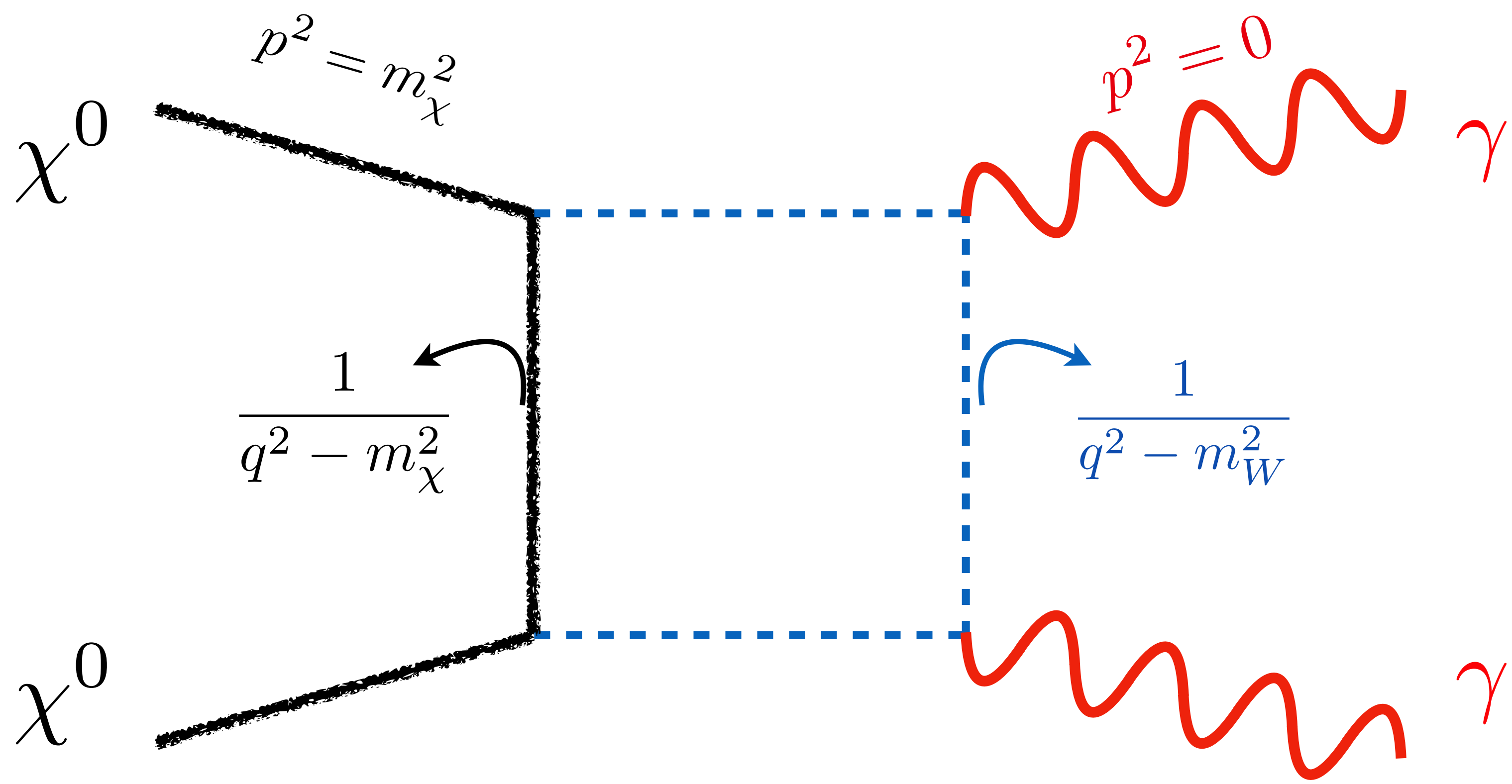
Naive computation of $\sigma v_{\gamma\gamma}$



Naive computation of $\sigma v_{\gamma\gamma}$



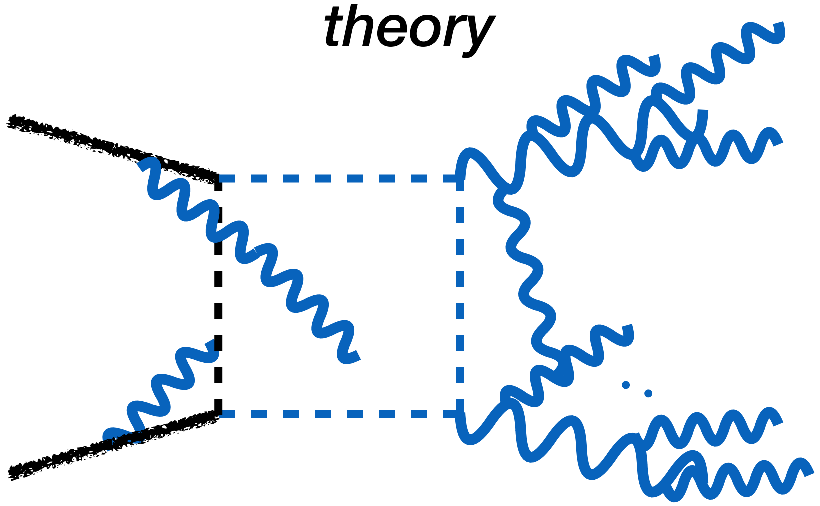
Sudakov double logarithms



$$\mathcal{M} \sim g^4 \log^2 \frac{4m_\chi^2}{m_W^2} \gg g^2$$

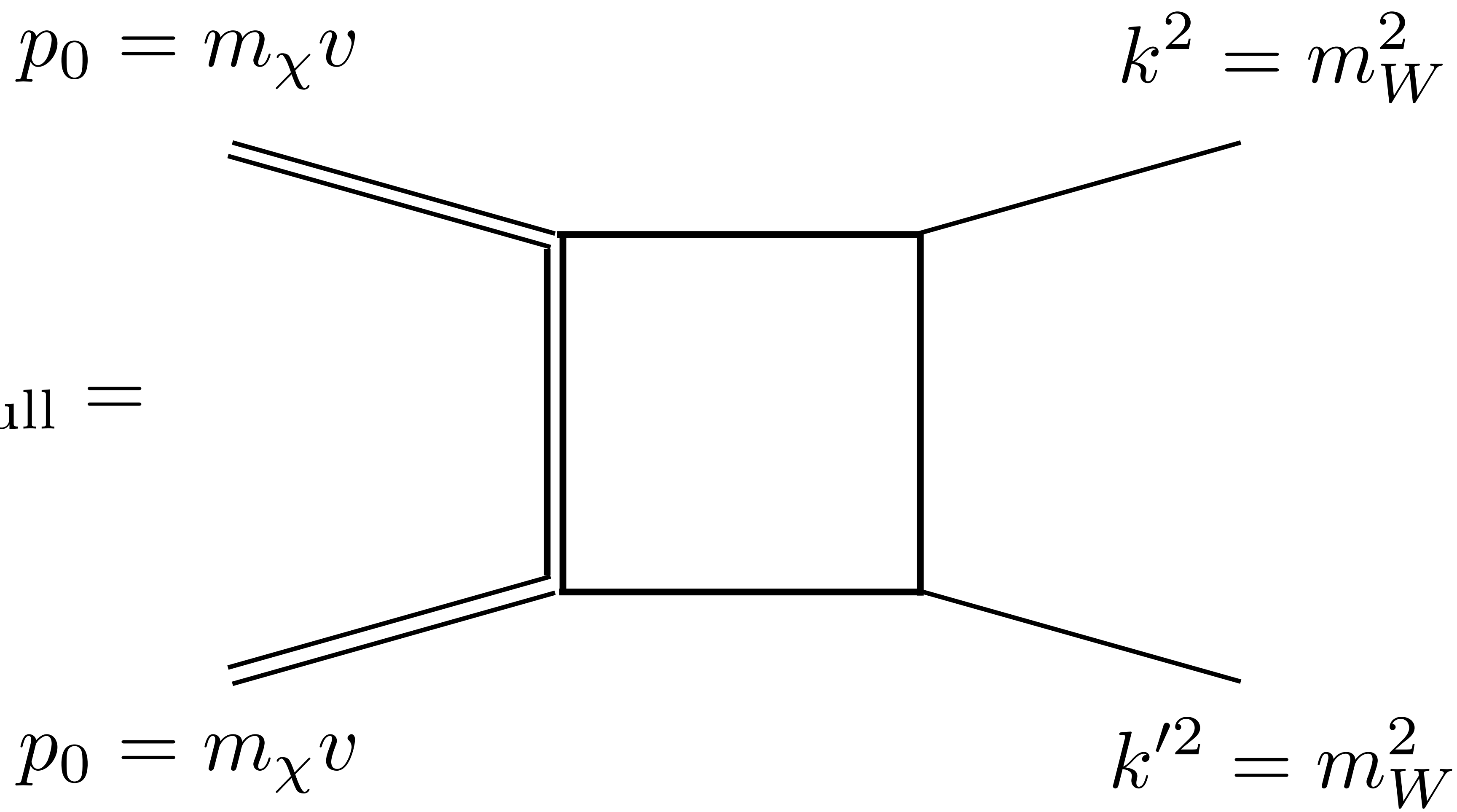
Sudakov-log resummation

Standard solution: resum soft virtual and real emissions by solving renormalization group eqs. in a *(soft-collinear) effective field theory*

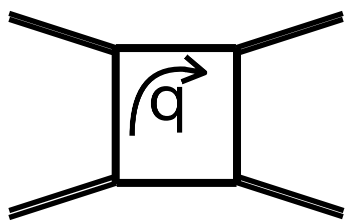


Soft-collinear effective theory (SCET). Method of regions

$$I_{\text{full}} =$$



SCET. Momentum regions

$I_{\text{full}} =$ 

$$= \int \frac{\mathrm{d}^D q}{(2\pi)^D} \frac{1}{(q+k-p_0)^2 - m_\chi^2} \frac{1}{(q+k)^2} \frac{1}{q^2} \frac{1}{(q-k')^2} \Bigg|_{k^2, k'^2 \sim m_W^2 \ll m_\chi^2}$$

Light-cone coordinates $\quad q = q_c n + q_{\bar{c}} \bar{n} + q_\perp \longrightarrow (q_c, q_{\bar{c}}, q_\perp)$

Momentum modes

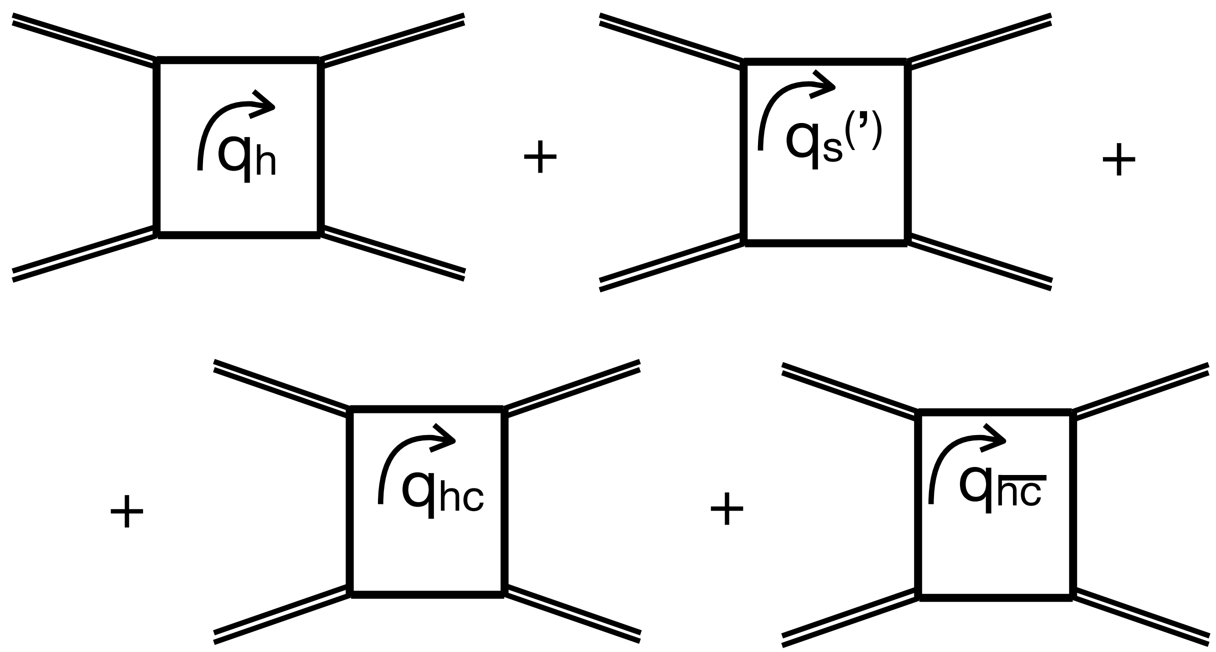
$$q_h \sim m_\chi (1,1,1) \qquad q_s \sim m_W (1,1,1)$$

$$q_{hc} \sim (m_W, m_\chi, \sqrt{m_\chi m_W}) \qquad q_{h\bar{c}} \sim (m_\chi, m_W, \sqrt{m_\chi m_W})$$

$$q_c \sim \left(\frac{m_W^2}{m_\chi}, m_\chi, m_W \right) \qquad q_{\bar{c}} \sim \left(m_\chi, \frac{m_W^2}{m_\chi}, m_W \right)$$

SCET. Momentum regions

$I_{\text{full}} =$

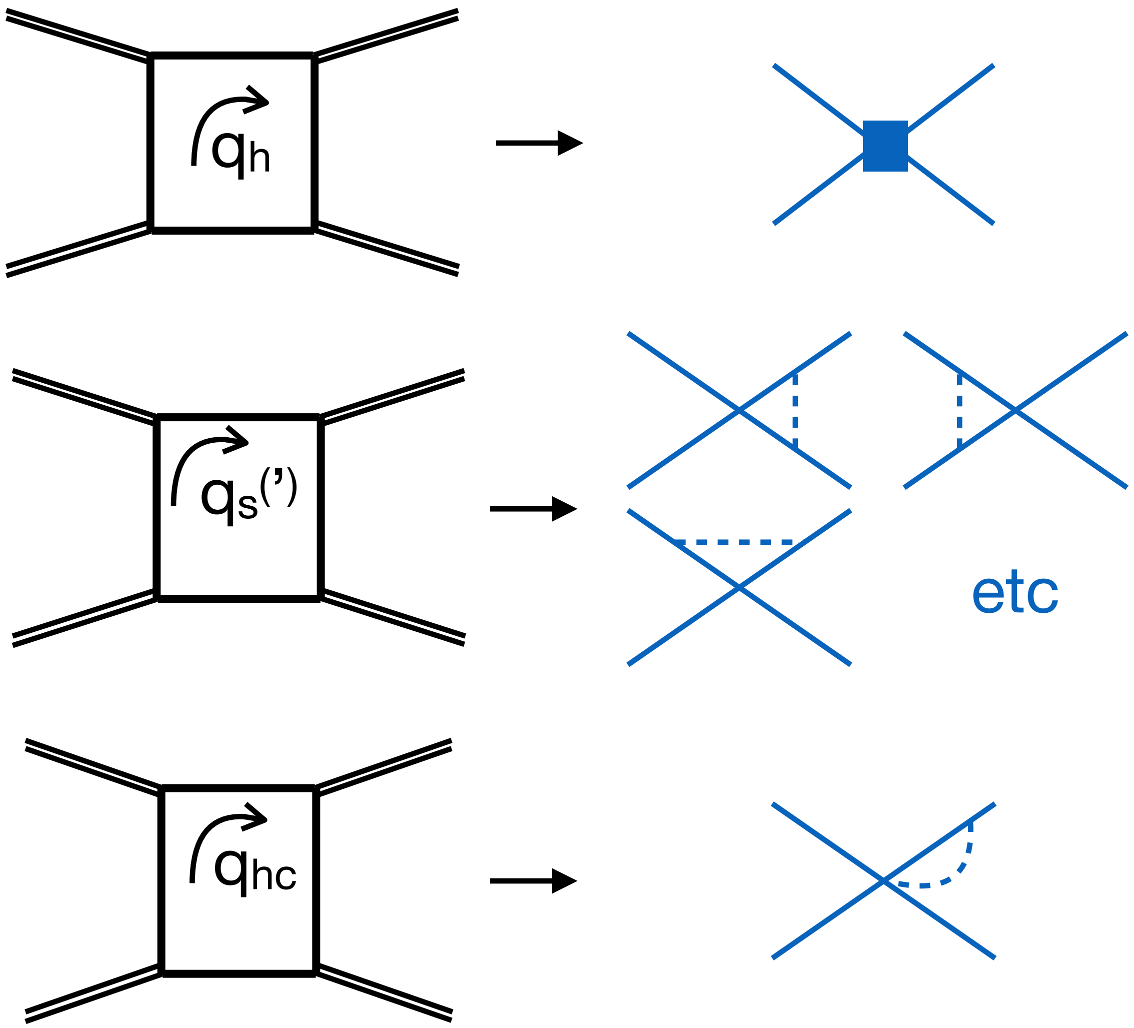


$\Big|_{k^2=0}$

+ power corrections

SCET. Factorization (narrow resolution)

Interpret each expansion as a Feynman diagram of the SCET



Factorization (after including all diagrams)

Wilson coefficients	**only depend on m_χ**
Soft functions	**only depend on m_W**
Jet functions	**only depends on m_W**

SCET-II (narrow resolution)

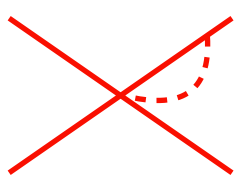
Interpret each expansion as a Feynman diagram of the SCET

Factorization (after including all diagrams)

Breakdown of the factorization

- **can be cured by introducing a regulator**

e. g. rapidity regulator:

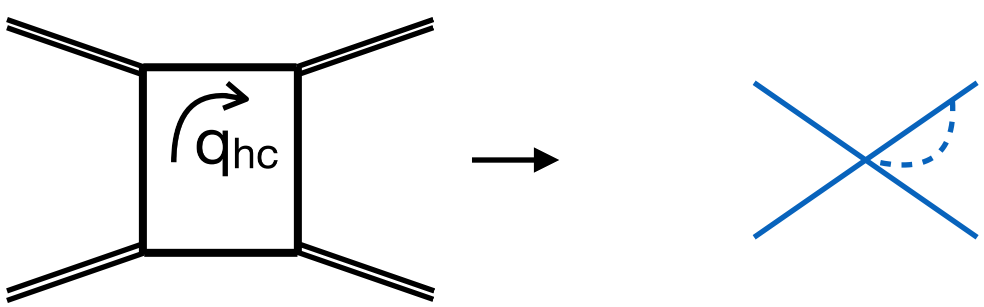


$$\rightarrow \int \frac{\mathrm{d}^D q}{(2\pi)^D} \frac{1}{(q^2 - m_W^2)[(k-q)^2 - m_W^2] n \cdot q} \frac{\nu^\eta}{|n \cdot q|^\eta}$$

s

only depend on m_χ

only depend on m_W



Jet functions

ideally would only depend on m_W

NRDM×SCET for DM annihilation

Integrate out hard modes of the relevant fields but leave hard (anti)collinear and non-relativistic degrees of freedom:

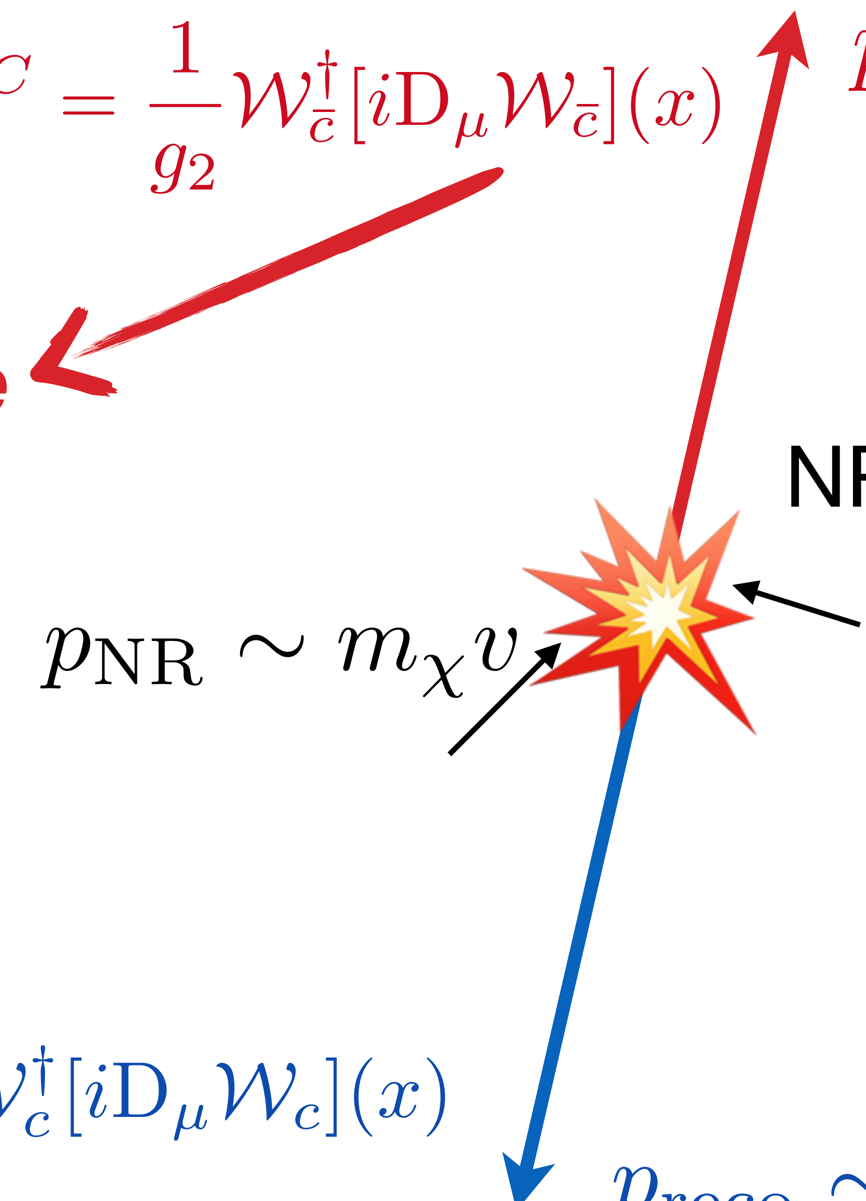
$$\mathcal{L}_{\mathrm{NRDM}\times\mathrm{SCET}} = \mathcal{L}_{\mathrm{NRDM}} + \mathcal{L}_{\mathrm{SCET}} + \frac{1}{2m_\chi}\sum_{i=1}^{2}\int \mathrm{d}s\mathrm{d}t\ \hat{C}_i(t,s,\mu)\mathcal{O}_i$$

Two-dimensional operator basis (for the $\chi\chi \rightarrow \gamma$+X process)

$$\mathcal{O}_1 = \chi_{\mathrm{NR}}^{c\dagger}\chi_{\mathrm{NR}}\varepsilon_\perp^{\mu\nu}\mathcal{A}_\perp^C{}_{c,\ \mu}(sn_+)\mathcal{A}_\perp^C{}_{\bar{c},\ \nu}(tn_-)$$

$$\mathcal{O}_2 = \chi_{\mathrm{NR}}^{c\dagger}\{T^C,T^D\}\chi_{\mathrm{NR}}\varepsilon_\perp^{\mu\nu}\mathcal{A}_\perp^C{}_{c,\ \mu}(sn_+)\mathcal{A}_\perp^D{}_{\bar{c},\ \nu}(tn_-)$$

NRDM×SCET for DM annihilation



NRDM×SCET for DM annihilation

After several steps one can prove that:

$$\frac{\mathrm{d}}{\mathrm{d}E_\gamma}[\sigma v] = |\psi(0)|^2 \times |C|^2(\mu) \times Z_\gamma(\mu,\nu) \times J(\mu,\nu) \otimes W(\mu,\nu)$$

Resummation is achieved by solving

- an appropriate Schrödinger equation
- μ and ν renormalization group equations for every piece of the factorization formula

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The wino-like/MDM triplet model

SM + Majorana SU(2) triplet

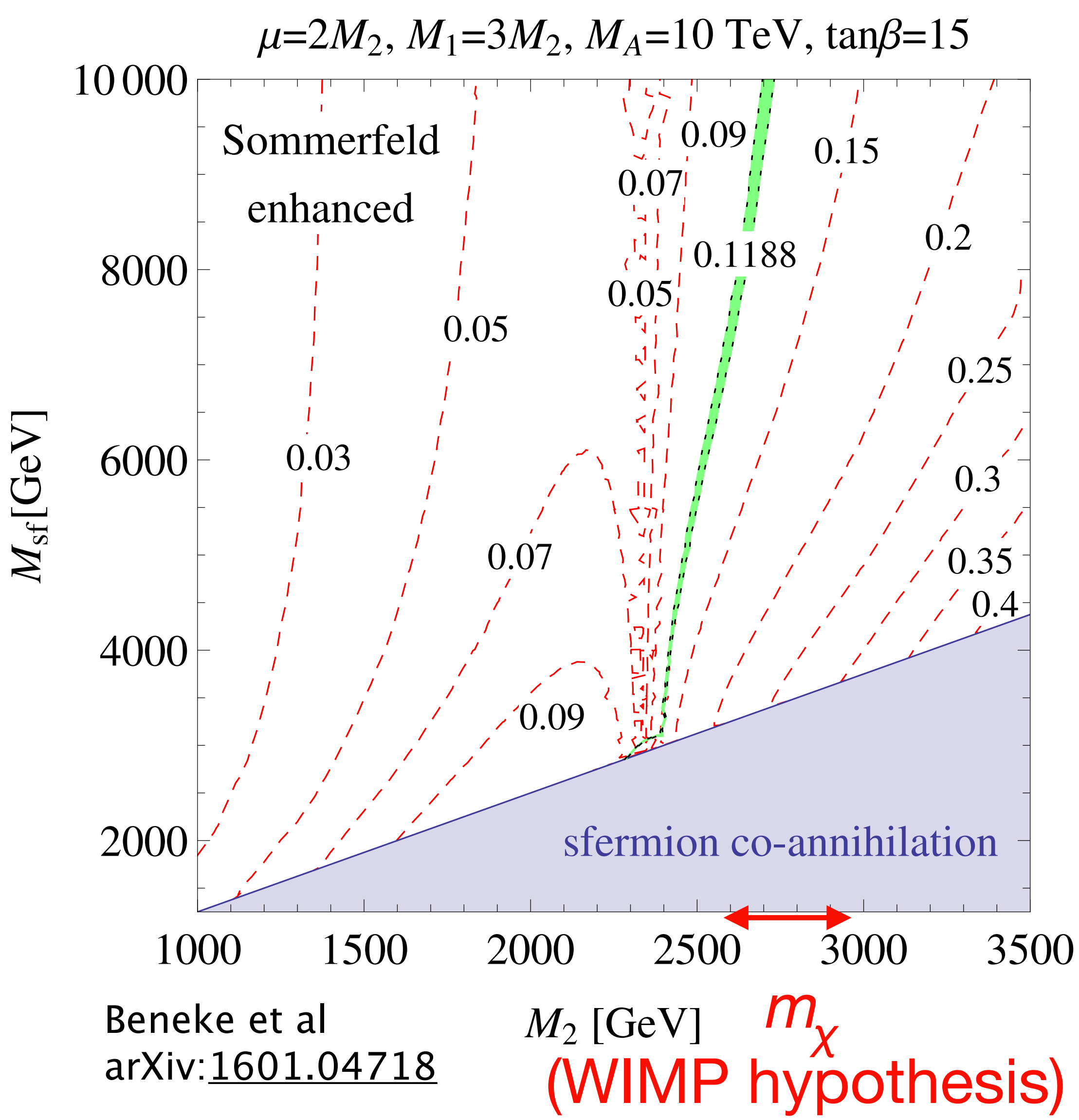
$$\delta\mathcal{L}_{\rm Wino} = \frac{1}{2}\bar{\chi}(i\gamma^\mu \mathrm{D}_\mu - m_\chi)\chi$$

$\not{\text{EW}}$ ⟶

Q=0 *Majorana* DM
Q=1 *Dirac* chargino

- $m_{\chi^\pm}$-$m_{\chi^0} \approx$ 164MeV
- DM stable through a Z_2 symmetry
- Suitable WIMP for $m_{\chi^0} \lesssim$ 3TeV
- Super-partner of the SU(2) gauge bosons in the MSSM

The wino-like/MDM triplet model



Beneke et al
arXiv:1601.04718

- suppressed direct-detection cross sections (below the so-called neutrino floor)
- too heavy for the LHC

Factorization theorem. Sommerfeld effect

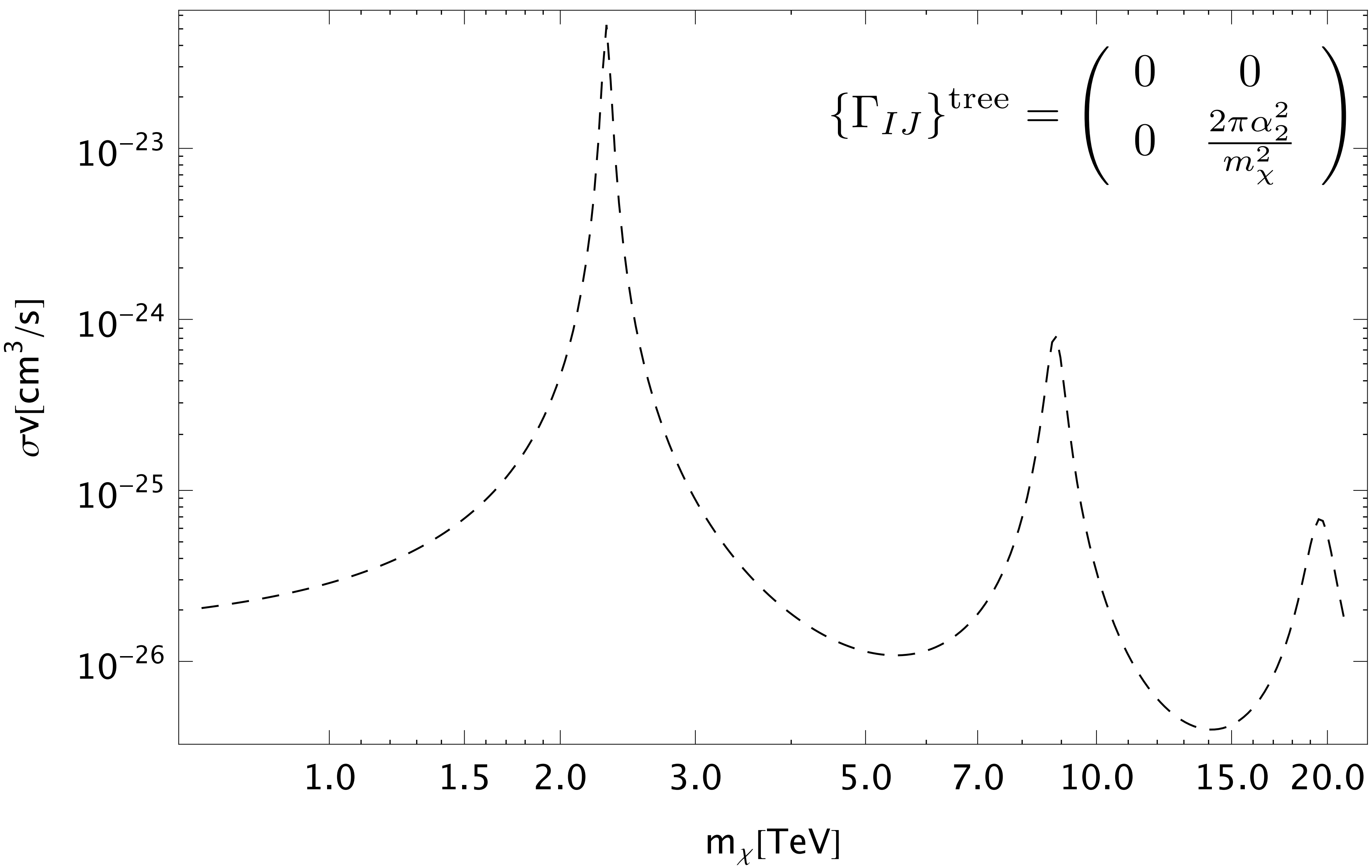
$$\frac{d(\sigma v_{\mathrm{rel}})}{dE_\gamma} = \sum_{I,J} S_{IJ}\,\Gamma_{IJ}(E_\gamma)$$

Sommerfeld matrix
I, *J* = (χ0χ0) or (χ+χ-)

$$V(r) = \begin{pmatrix} 0 & -\sqrt{2}\alpha_2 \frac{\mathrm{e}^{-m_W r}}{r} \\ -\sqrt{2}\alpha_2 \frac{\mathrm{e}^{-m_W r}}{r} & -\frac{\alpha}{r} - \alpha_2 c_W^2 \frac{\mathrm{e}^{-m_Z r}}{r} \end{pmatrix}$$

see e.g. Beneke et al arXiv: 1411.6924
Hisano arXiv: hep-ph/0412403

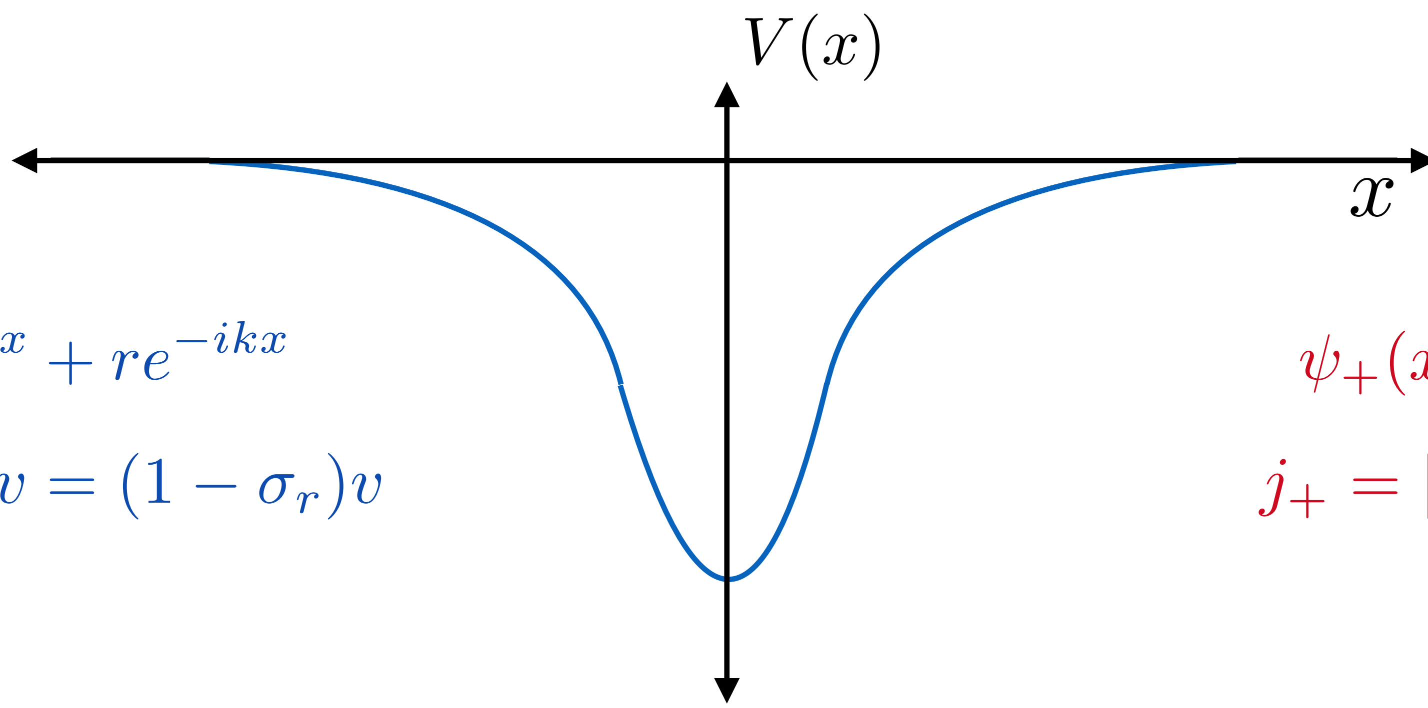
Factorization theorem. Sommerfeld effect



1D QM (revisited)

$$\left(-\frac{1}{m_\chi}\frac{\mathrm{d}^2}{\mathrm{d}x^2} + V(x) \qquad\qquad \right)\psi(x) = E\psi(x)$$

$$j(x) = \frac{i}{m_\chi}\left[\psi(x)\psi'^*(x) - \psi^*(x)\psi'(x)\right]$$ = const.



$$\psi_-(x) = e^{ikx} + re^{-ikx}$$

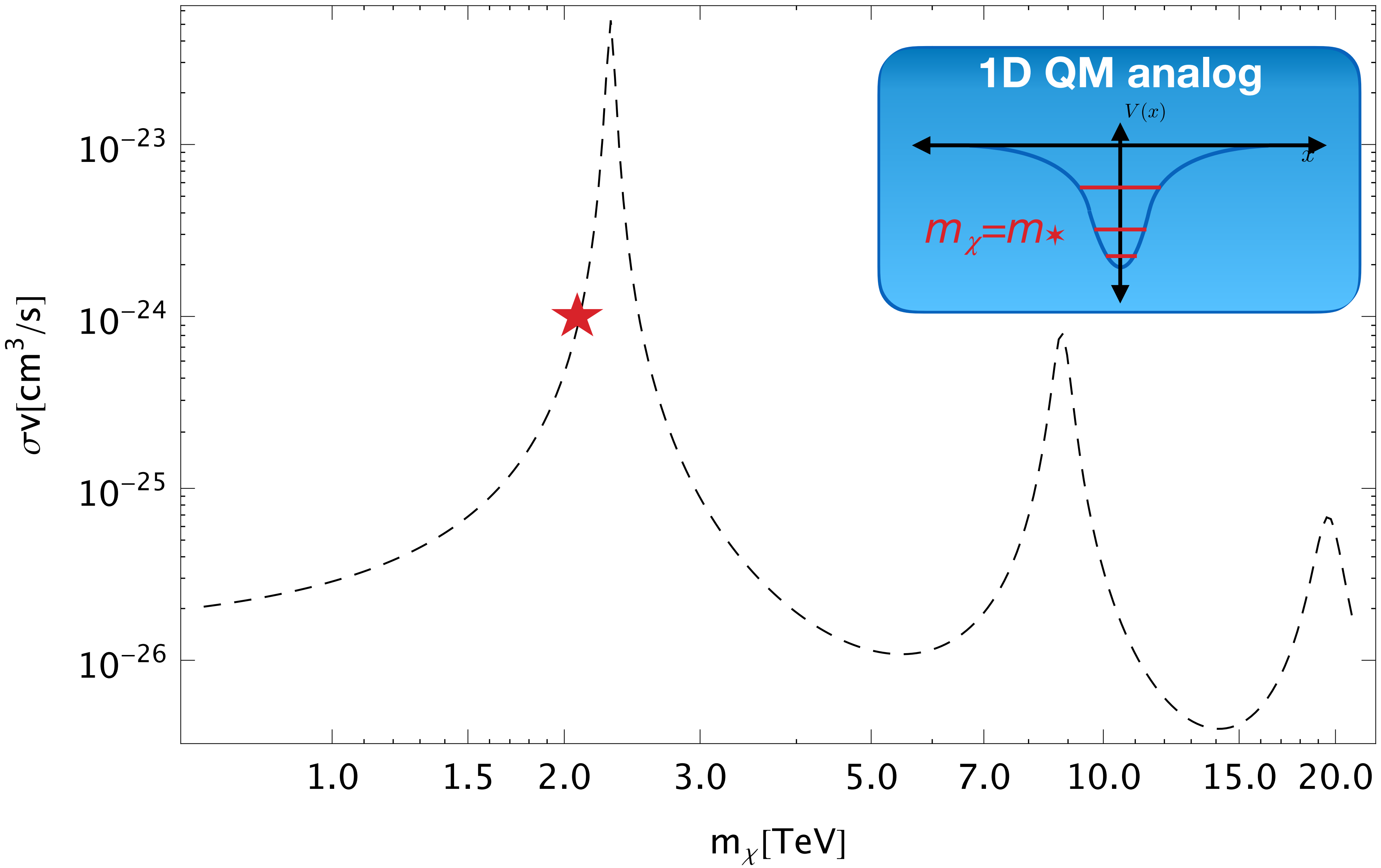
$$j_- = (1-|r|^2)v = (1-\sigma_r)v$$

$$\psi_+(x) = te^{ikx}$$

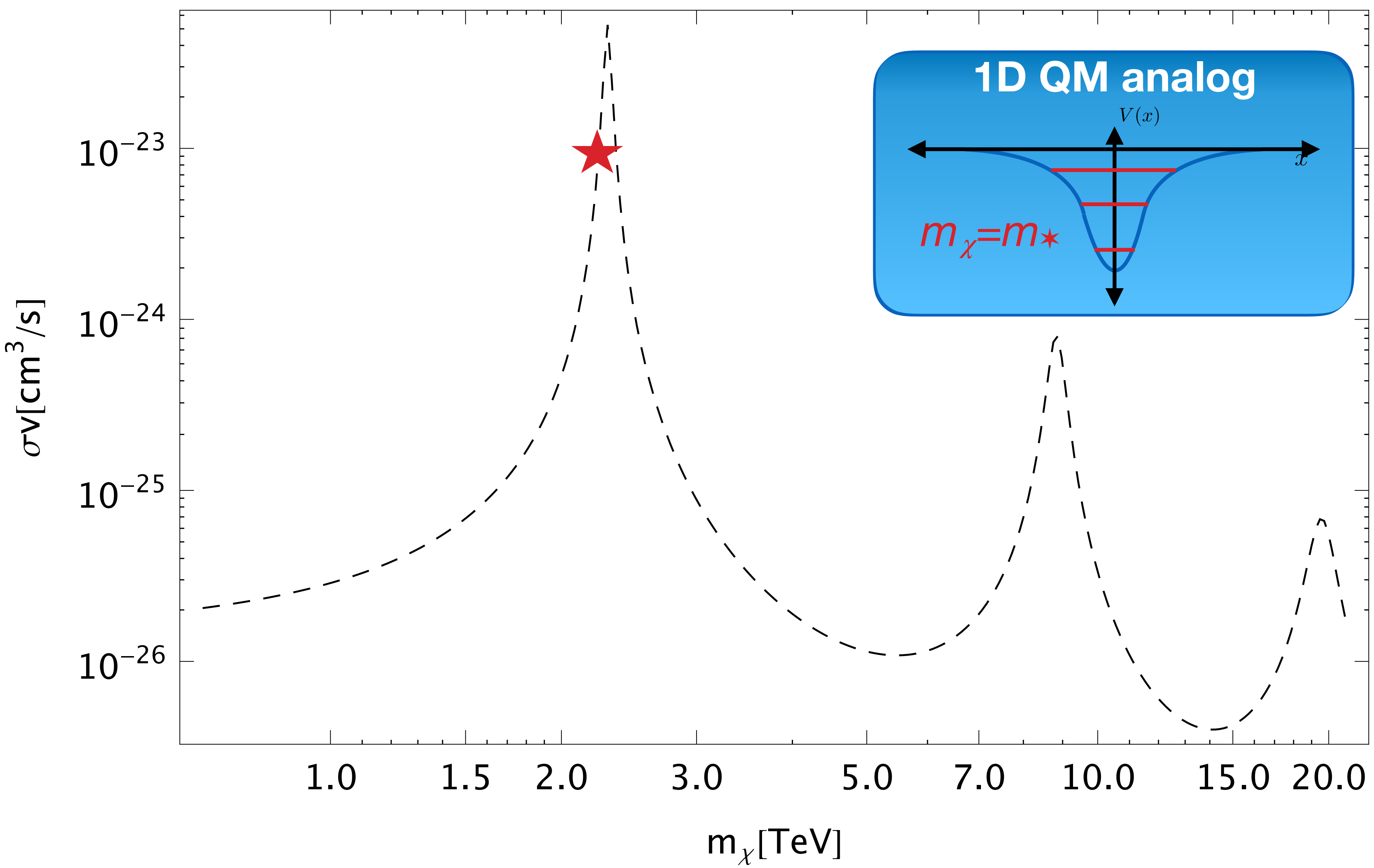
$$j_+ = |t|^2 v = \sigma_t v$$

Unitarity: $j_- = j_+ \quad \to \quad \sigma_r + \sigma_t = 1$ (No absorption)

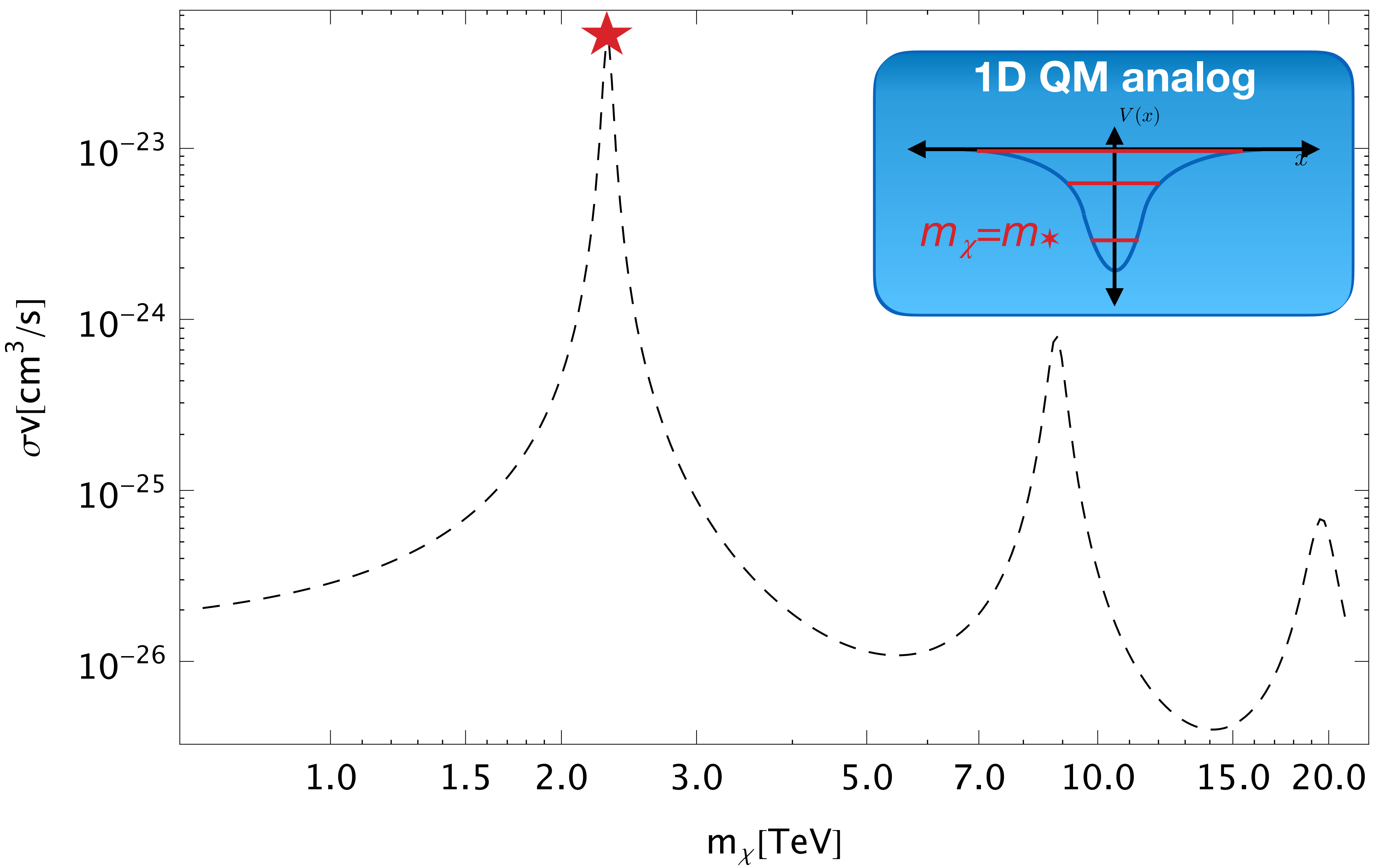
Factorization theorem.
Sommerfeld effect



Factorization theorem. Sommerfeld effect



Factorization theorem.
Sommerfeld effect

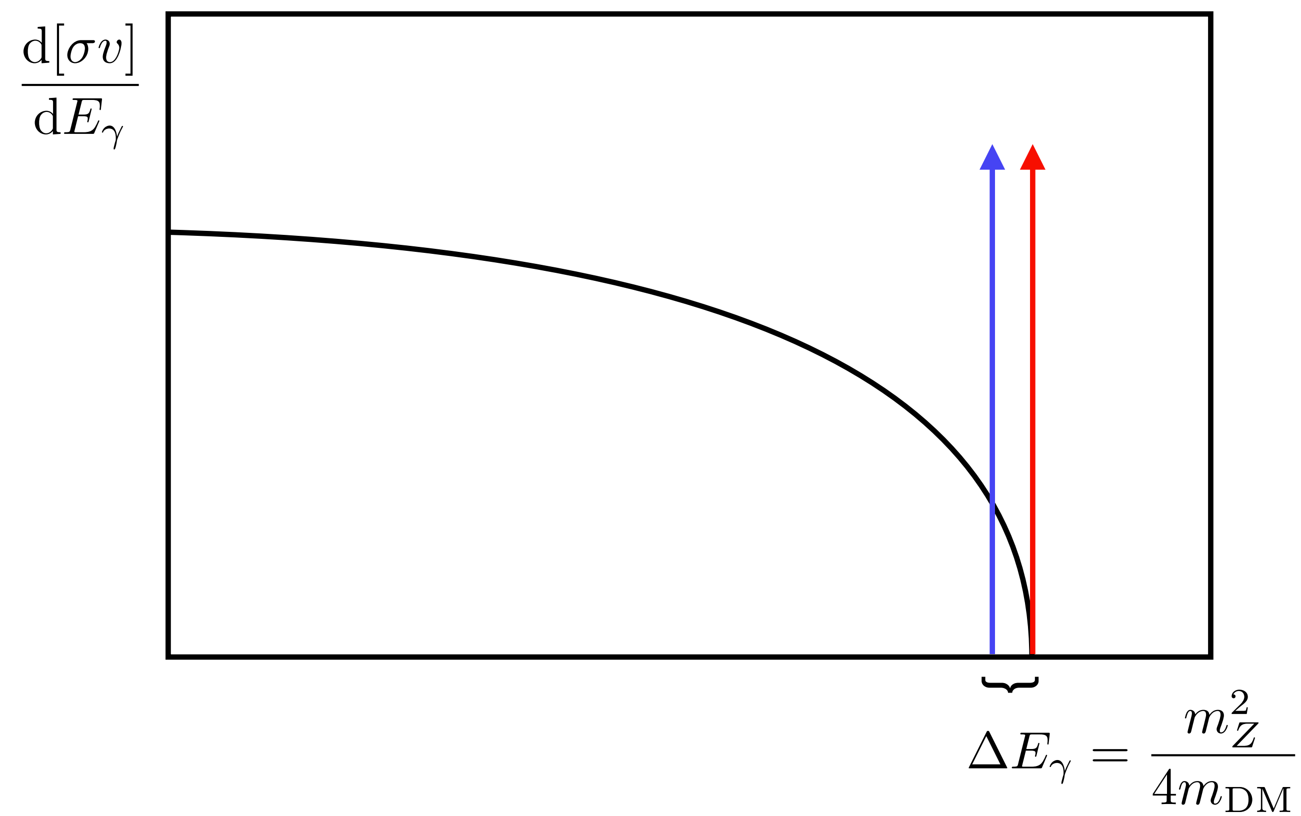


Factorization theorem. Sommerfeld effect

$$\frac{d(\sigma v_{\rm rel})}{dE_\gamma} = \sum_{I,J} S_{IJ}\,\Gamma_{IJ}(E_\gamma)$$

Assumptions on the energy resolutions

The variable $E_{\text{res}} = m_\chi - E_\gamma$ plays a decisive role in the factorization problem



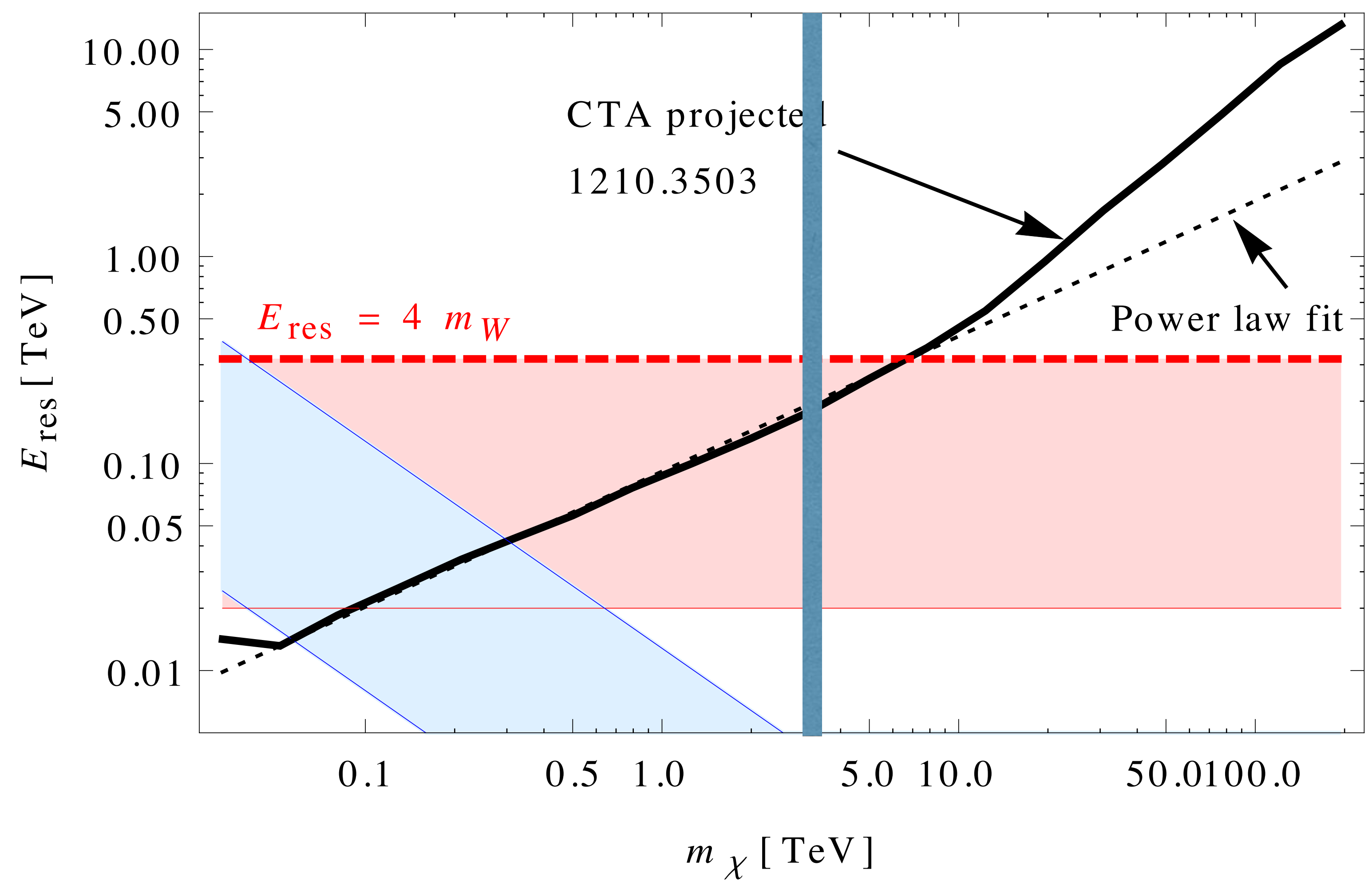
We investigated two situations

$E_{\text{res}} \sim m_W^2/m_\chi$ (1805.07367)

$E_{\text{res}} \sim m_W$ (1903.08702)

See also **Baumgart et al** (1712.07656 and 1808.08956) for the $E_{\text{res}} \gg m_W$ case

Energy resolution



Factorization theorem. Exclusive Wino $\chi\chi\to\gamma$+X annihilation

$$\frac{d(\sigma v_{\rm rel})}{dE_\gamma} = \sum_{I,J} S_{IJ}\,\Gamma_{IJ}(E_\gamma)$$

$$\Gamma_{IJ}(E_\gamma) = \frac{1}{4}\frac{2}{\pi m_\chi}\sum_{i,j=1,2} C_j^*(\mu_W)C_i(\mu_W)Z_\gamma(\mu_W,\nu_W)$$
$$\times\int J\left(4m_\chi(m_\chi - E_\gamma - \omega/2),\mu_W\right)W_{IJ}^{ij}(\omega,\mu_W,\nu_W)$$

Factorization theorem. Exclusive Wino $\chi\chi\to\gamma$+X annihilation

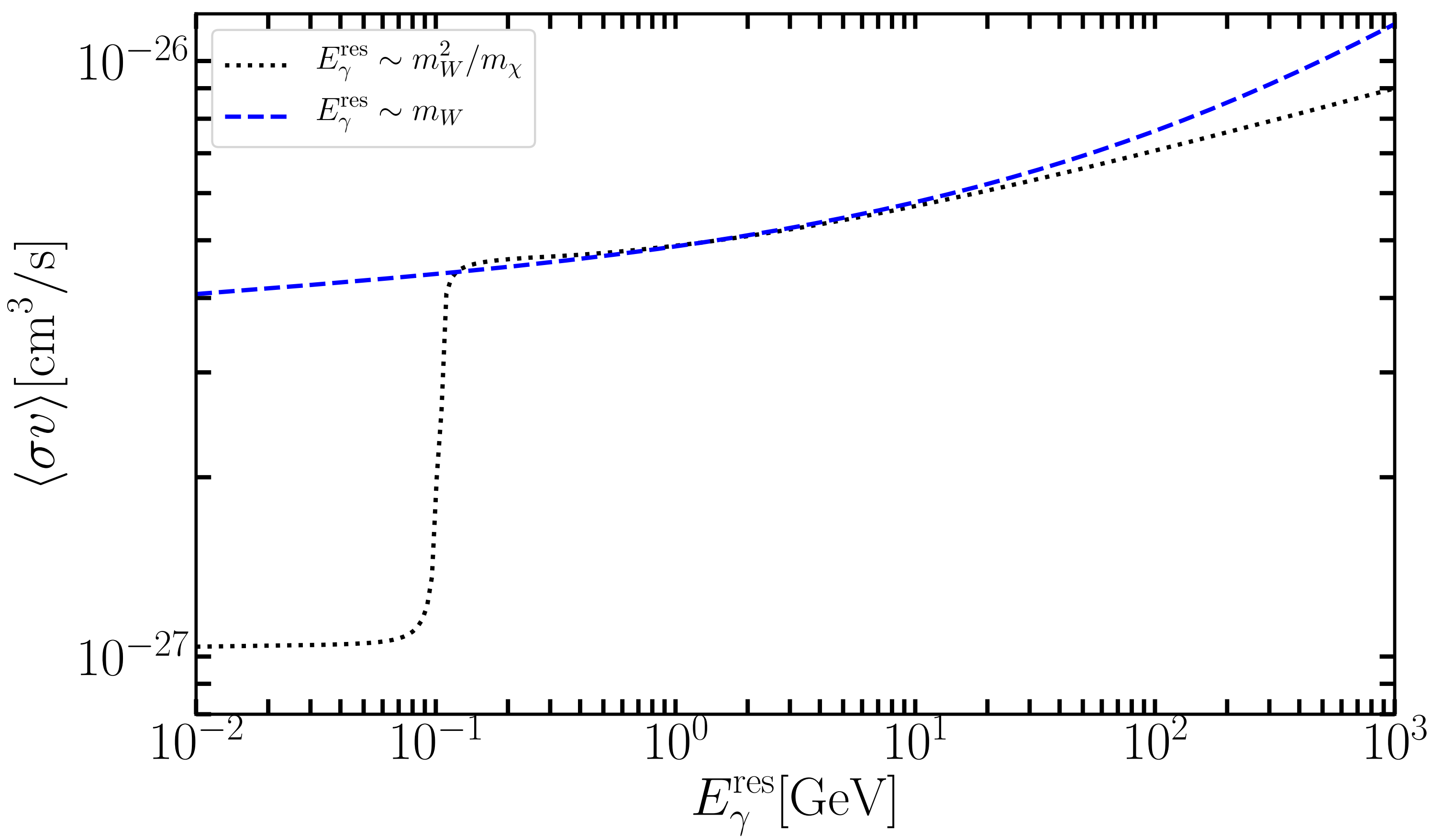
This is highly **non trivial!!**
E.g. all (N>2)-body phase-space integrals reduce to the convoluted J⊗W form (modulo power corrections)
The SCET formalism is such that proving this result amounts to performing a (in the SCET language) trivial multipole expansion

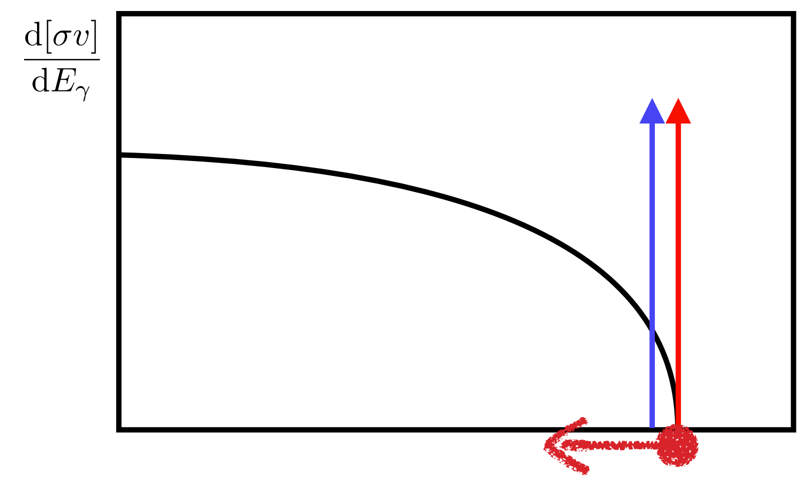
Jet functions are **universal**: they can be used in several contexts

For invariant masses of the order of the EW breaking scale, computed the neutral components of the EW jet function for the first time

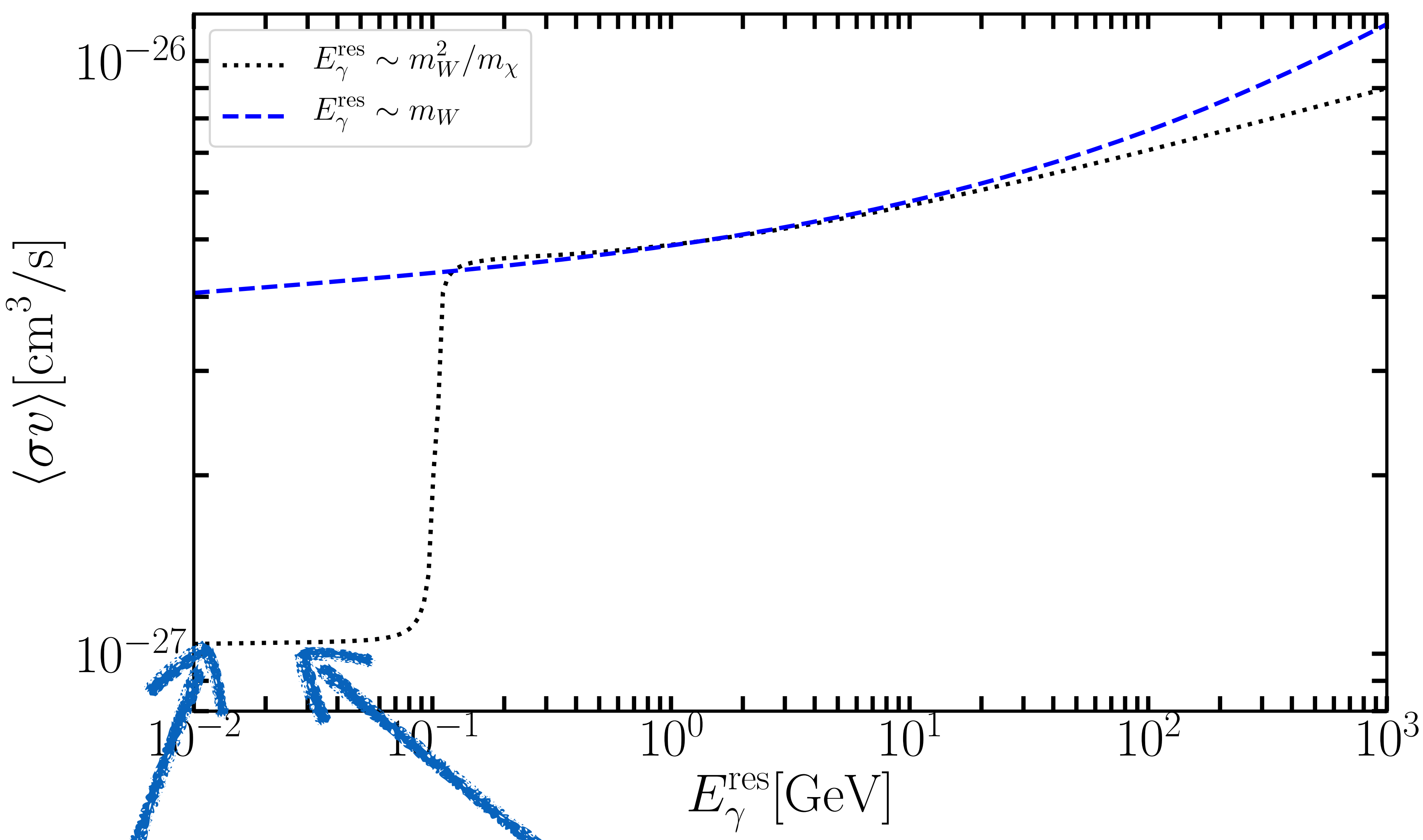
$$\Gamma_{IJ}(E_\gamma) = \frac{1}{4}\frac{2}{\pi m_\chi}\sum_{i,j=1,2} C_j^*(\mu_W)C_i(\mu_W)Z_\gamma(\mu_W,\nu_W)$$
$$\times\int J\left(4m_\chi(m_\chi - E_\gamma - \omega/2),\mu_W\right)W_{IJ}^{ij}(\omega,\mu_W,\nu_W)$$

Energy-integrated cross section

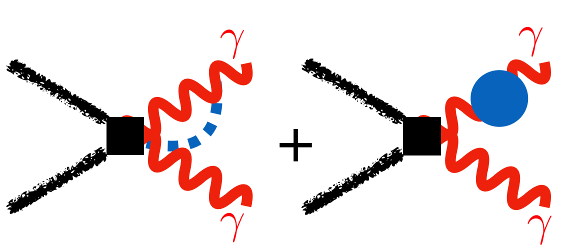




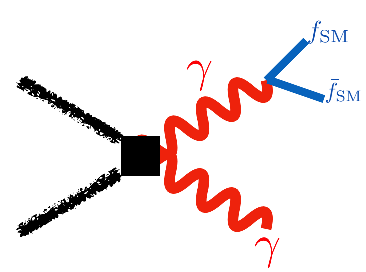
Energy-integrated cross section



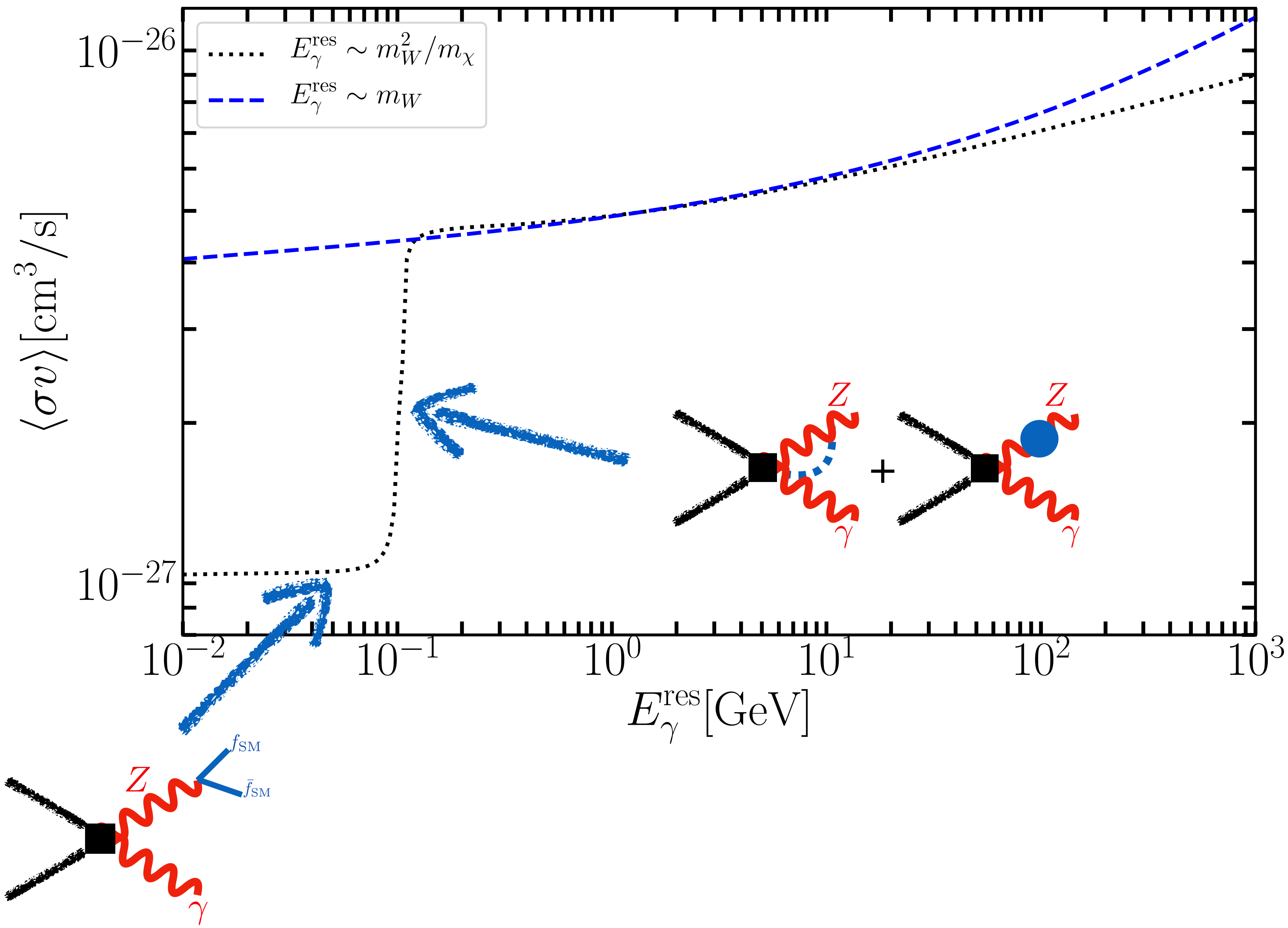
virtual corrections



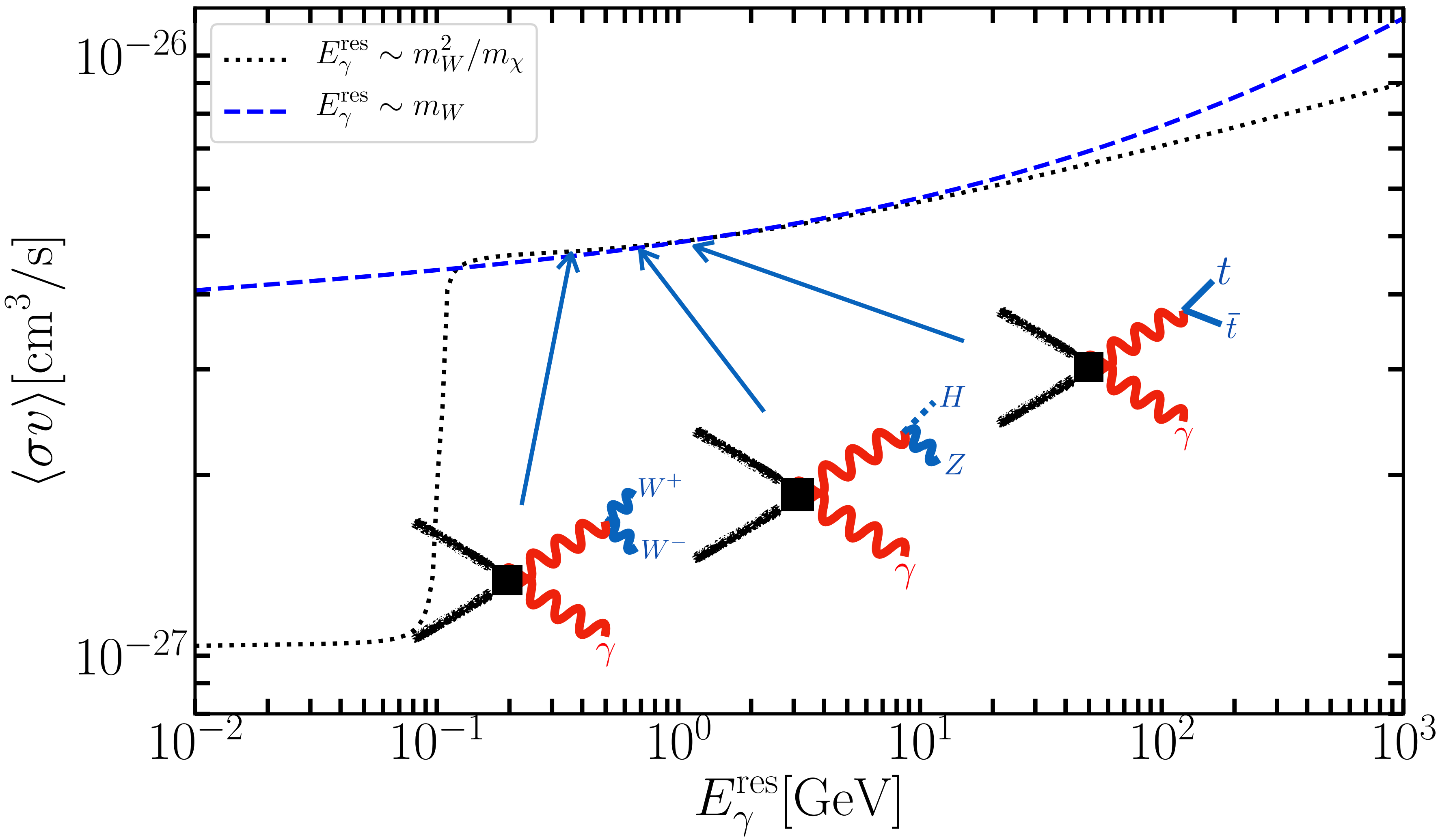
real corrections



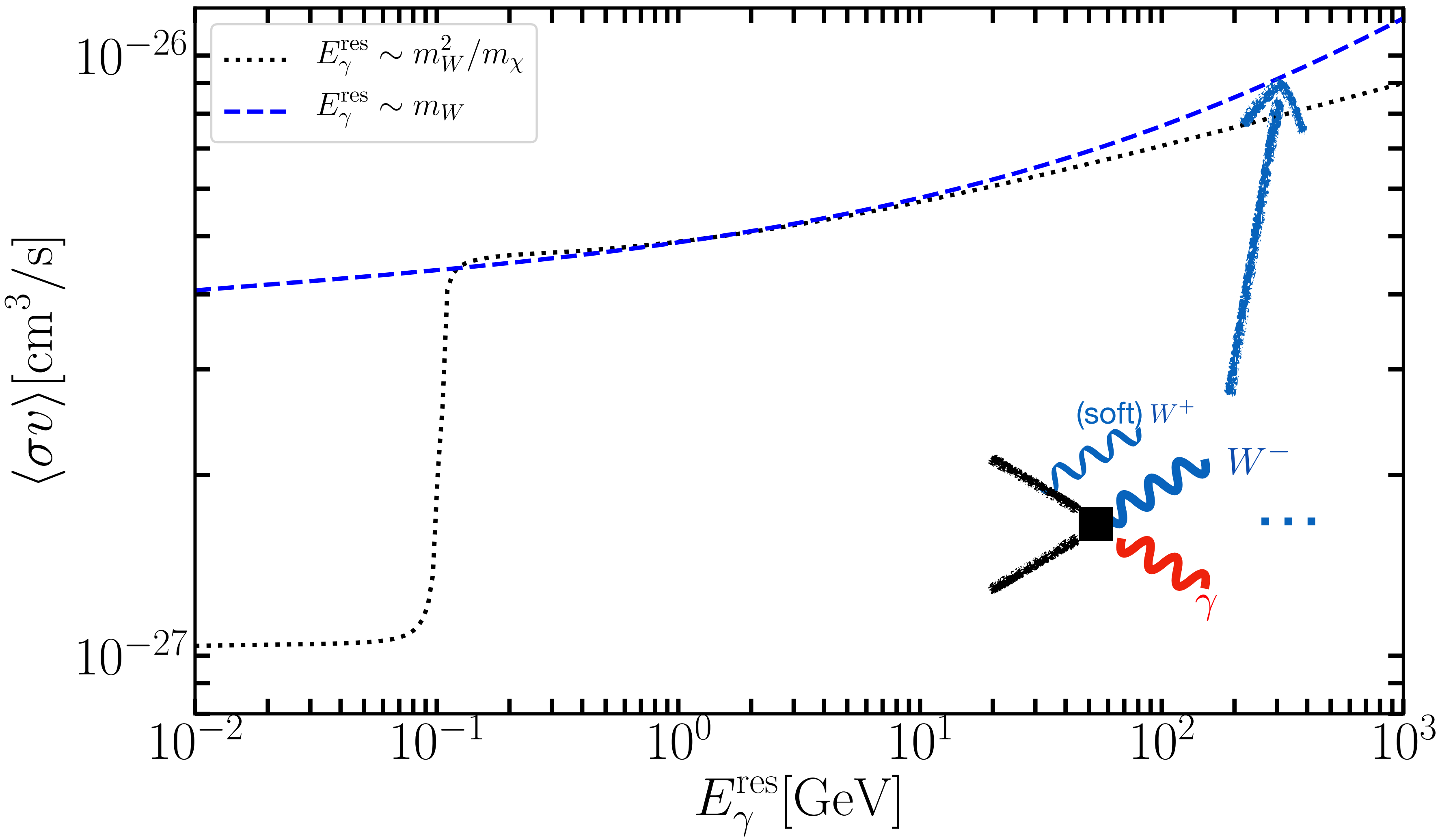
Energy-integrated cross section



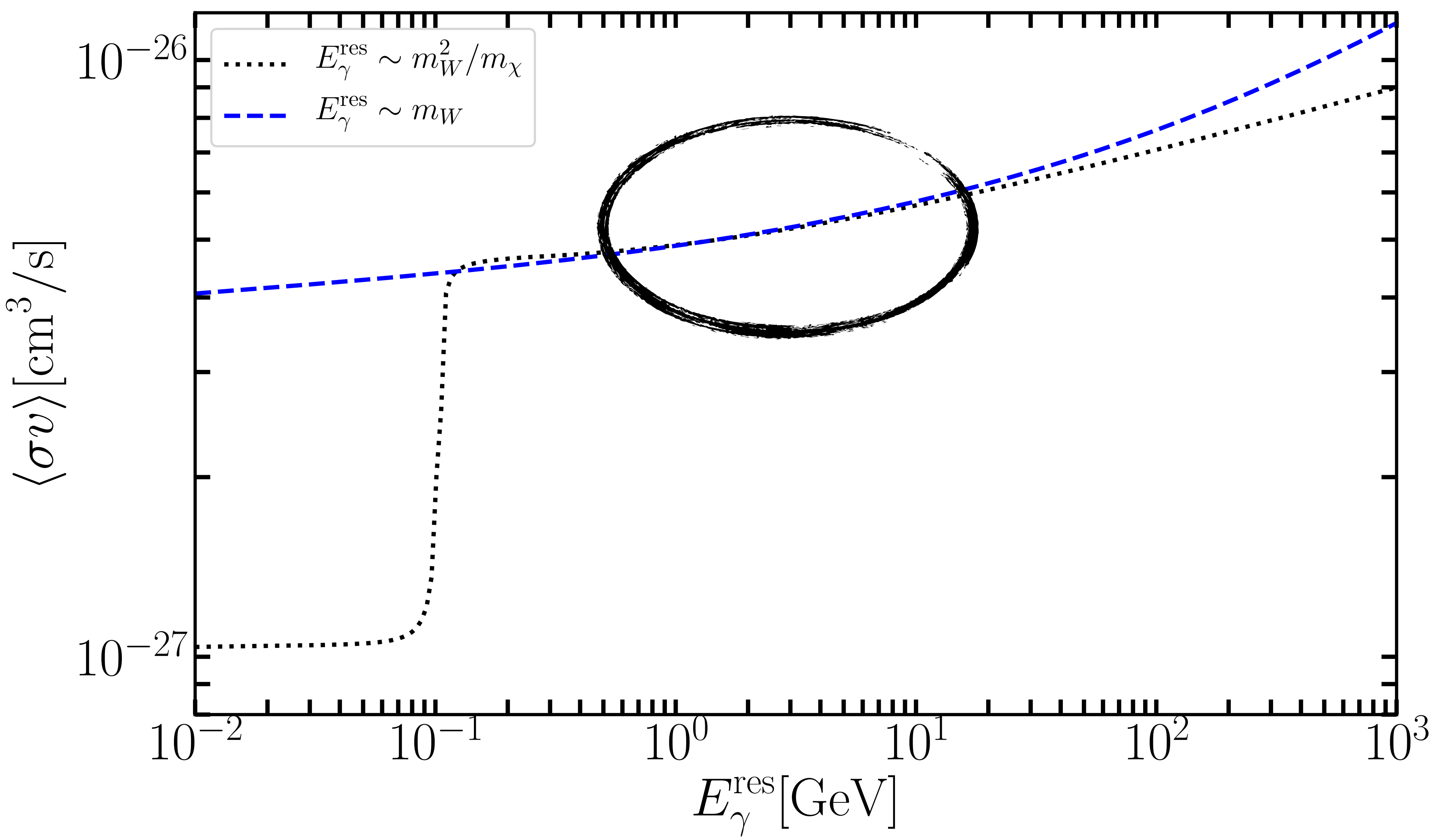
Energy-integrated cross section



Energy-integrated cross section



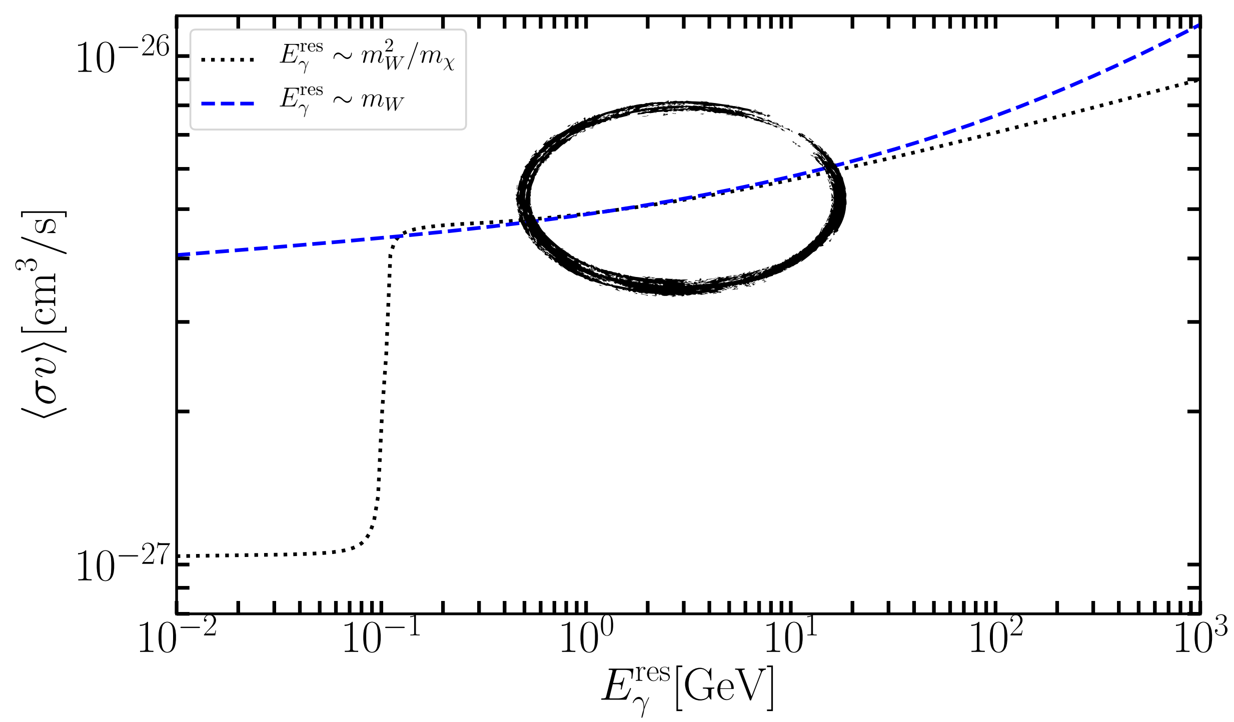
Energy-integrated cross section. Remarkable matching



Energy-integrated cross section. Remarkable matching

Not an obvious result

Can be understood by expanding our factorization formulas at fixed orders



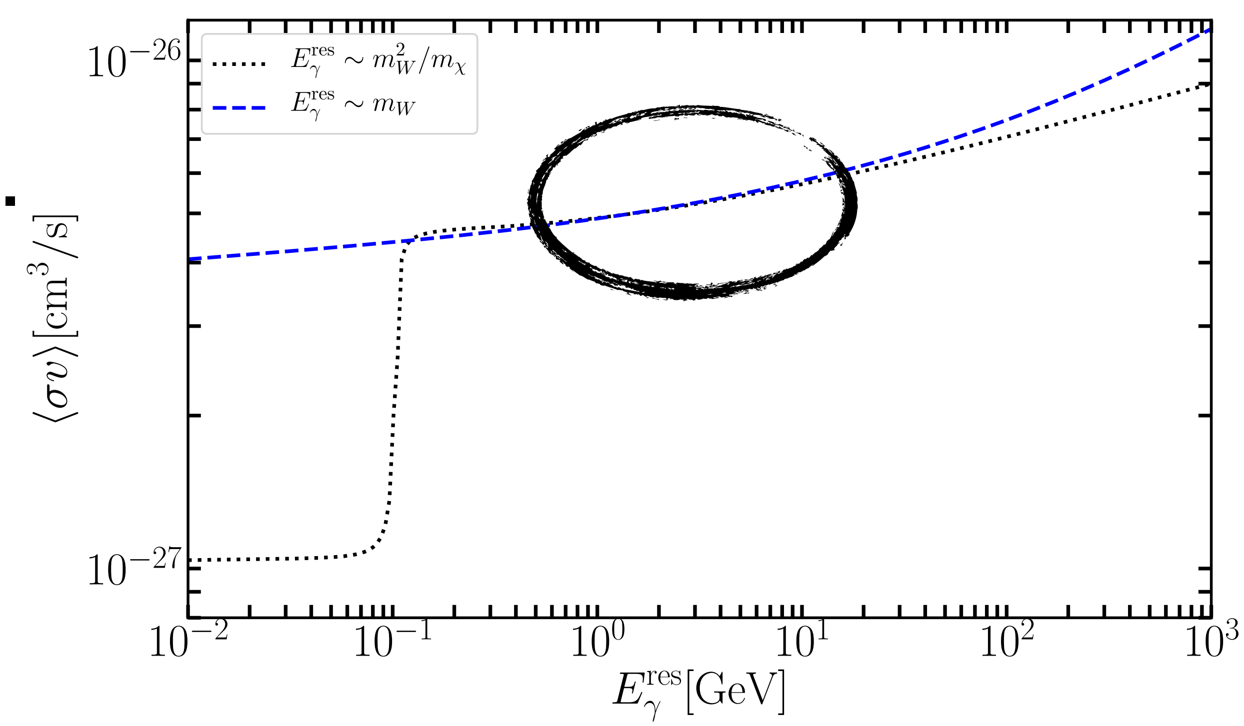
$$[\sigma v]_{IJ}(E_\gamma) = \frac{2\pi \hat{\alpha}_2(\mu) \hat{s}_W(\mu)}{\sqrt{2}^{n_{\rm id}} m_\chi^2} \sum_{n=0}^{\infty} \sum_{m=0}^{2n} c_{IJ}^{(n,m)}(E_\gamma, \mu) \left(\frac{\hat{\alpha}_2(\mu)}{\pi} \right)^n \ln^m \frac{4m_\chi^2}{m_W^2}$$

Energy-integrated cross section. Remarkable matching

$$[\sigma v]_{IJ}(E_\gamma) = \frac{2\pi\hat{\alpha}_2(\mu)\hat{s}_W(\mu)}{\sqrt{2}^{n_{\rm id}} m_\chi^2} \sum_{n=0}^{\infty}\sum_{m=0}^{2n} c_{IJ}^{(n,m)}(E_\gamma,\mu) \left(\frac{\hat{\alpha}_2(\mu)}{\pi}\right)^n \ln^m \frac{4m_\chi^2}{m_W^2}$$

Factorization-theorem dependent

- Coefficients are (by definition) of $\mathcal{O}(1)$ but dependent on E_γ
- When evaluated outside the range of validity of the Fact. Th. they can become large
  - (and contribute to the $(m+1)$ term instead)



Energy-integrated cross section. Remarkable matching

$$[\sigma v]^{\mathrm{nrw(NLO)}}_{(+-)(+-)} = \frac{2\pi\hat{\alpha}_2^2\hat{s}_W^2}{m_\chi^2}\left[1+\frac{\hat{\alpha}_2(\mu)}{\pi}\left(-1\ln^2\frac{4m_\chi^2}{m_W^2}+1\ln\frac{4m_\chi^2}{m_W^2}\right)+c_0(E_\gamma)\right]$$

$$[\sigma v]^{\mathrm{int(NLO)}}_{(+-)(+-)} = \frac{2\pi\hat{\alpha}_2^2\hat{s}_W^2}{m_\chi^2}\left[1+\frac{\hat{\alpha}_2(\mu)}{\pi}\left(-\frac{3}{4}\ln^2\frac{4m_\chi^2}{m_W^2}+\left(\frac{29}{48}+\ln\frac{2E_\gamma^{\mathrm{res}}}{m_W}\right)\ln\frac{4m_\chi^2}{m_W^2}\right)+\tilde{c}_0(E_\gamma)\right]$$

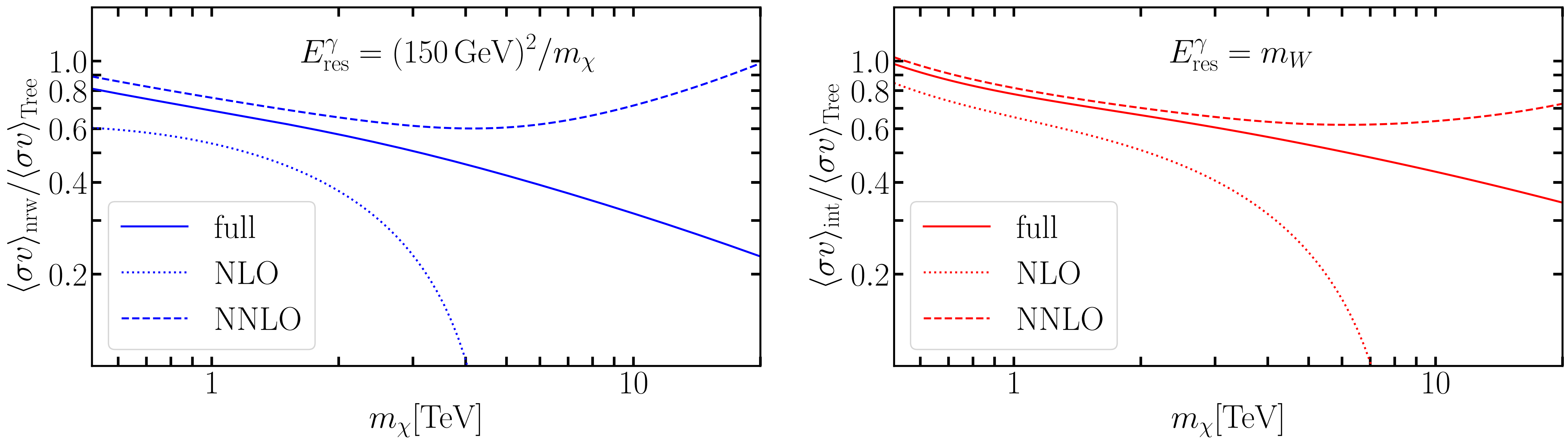
$$c_0(E_\gamma) \sim 4\ln^2\frac{4m_\chi E_\gamma^{\mathrm{res}}}{m_W^2} - \frac{19}{6}\ln\frac{4m_\chi E_\gamma^{\mathrm{res}}}{m_W^2} + \mathrm{const.}$$

$\mathcal{O}(1)$ for $E_\gamma^{\mathrm{res}} \sim m_W^2/m_\chi$ but parametrically large for $E_\gamma^{\mathrm{res}} \sim m_W$

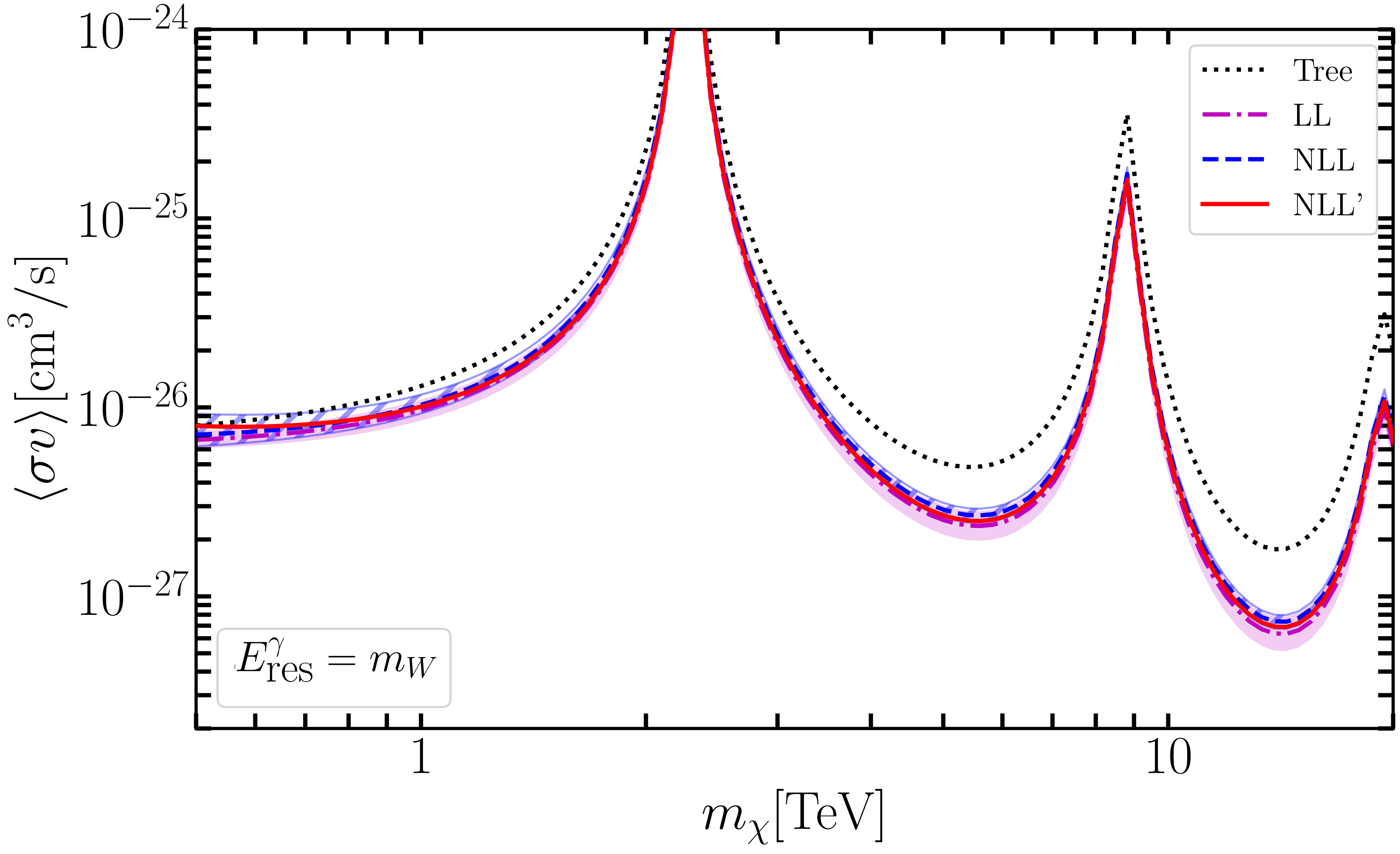
After reshuffling the logs you get

$$[\sigma v]^{\mathrm{nrw(NLO)}}_{(+-)(+-)} = [\sigma v]^{\mathrm{int(NLO)}}_{(+-)(+-)} + \mathcal{O}(\alpha_2^3)$$ **Not even $\alpha_2^3\times$log terms!!**

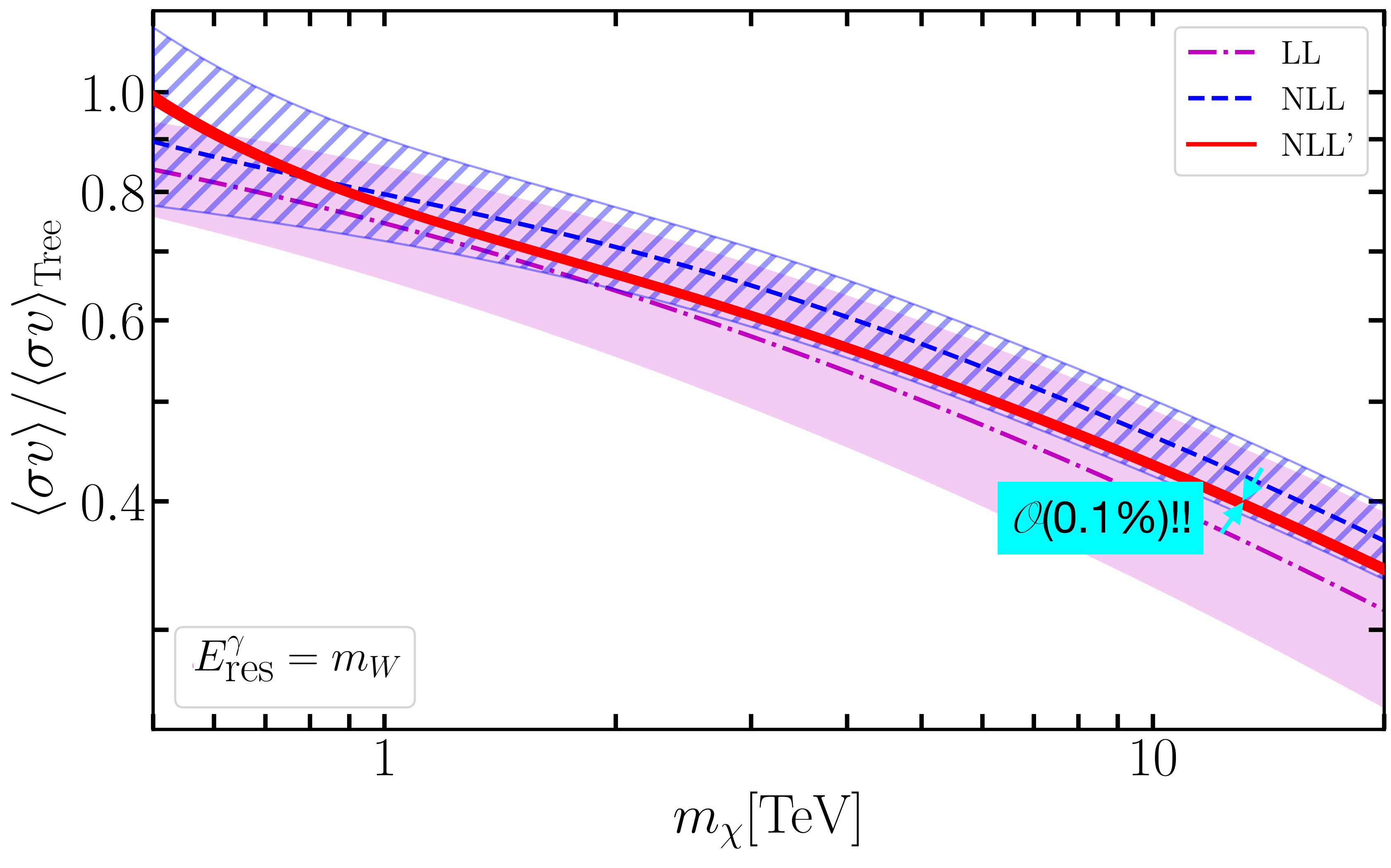
Further applications of our fixed-order expansions



$\chi\chi \to \gamma$+X cross sections (E_{res} ~ m_W)



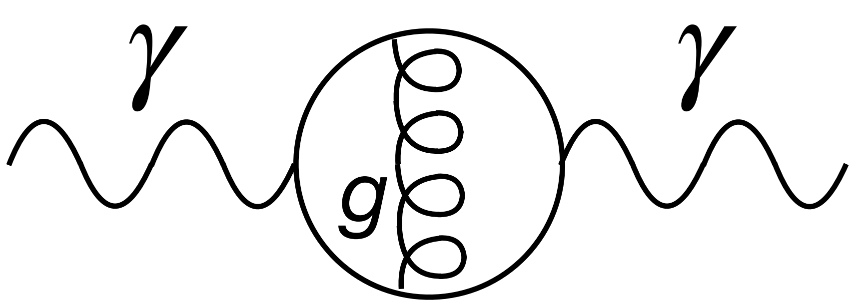
Effect of the Sudakov resummation



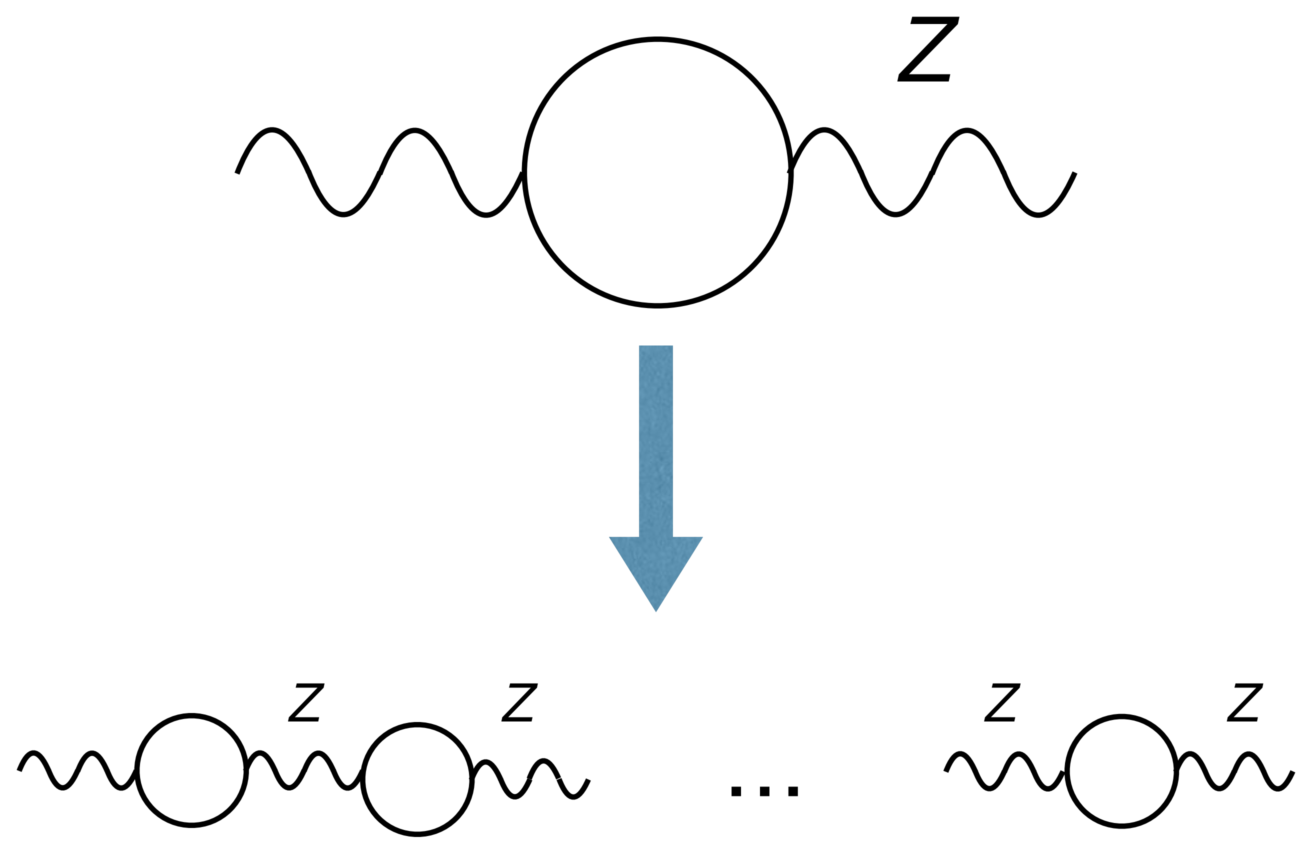
Further technicalities addressed

Photon jet function (by definition) sensitive to the lowest scales in the SM

In particular, large QCD effects on the wave-renormalization of the photon field are tackled by using dispersion-relation methods



Z-pole singularity can be cured by Dyson-resumming the Z propagator



Summary

Sudakov is the new Sommerfeld for indirect DM detection

$$\text{Flux} \approx \frac{1}{8\pi m_\chi^2 c^4} \times J \times S_{(+-)(+-)} \mathrm{e}^{-\frac{\alpha_2}{\pi}\frac{3}{4}\ln^2\frac{4m_\chi^2}{m_W^2}} \frac{2\pi\hbar^2\alpha_2^2 \sin^2\theta_W}{m_\chi^2 c}\delta(E_\gamma - m_\chi)$$

FRESH RESULTS!!
Higgsino DM

Higgsino DM in a nutshell:

- Minimal DM pseudo-Dirac doublet
- Hypercharge ≠ 0
- $$\delta\mathcal{L}_{\text{Higgsino}} = \bar{\chi}(i\gamma^\mu \mathrm{D}_\mu - m_\chi)\chi + \mathcal{L}_{\text{dim}-5}$$
- EWSB → 2 Majorana χ_1^0, χ_2^0 and 1 chargino χ^+
- Thermal production hypothesis:

$$m_\chi \approx 1\,\text{TeV}$$

FRESH RESULTS!!
Higgsino DM

Factorization:

Sommerfeld matrix
$I, J = (\chi_1^0\chi_1^0), (\chi_2^0\chi_2^0)$ or $(\chi^+\chi^-)$

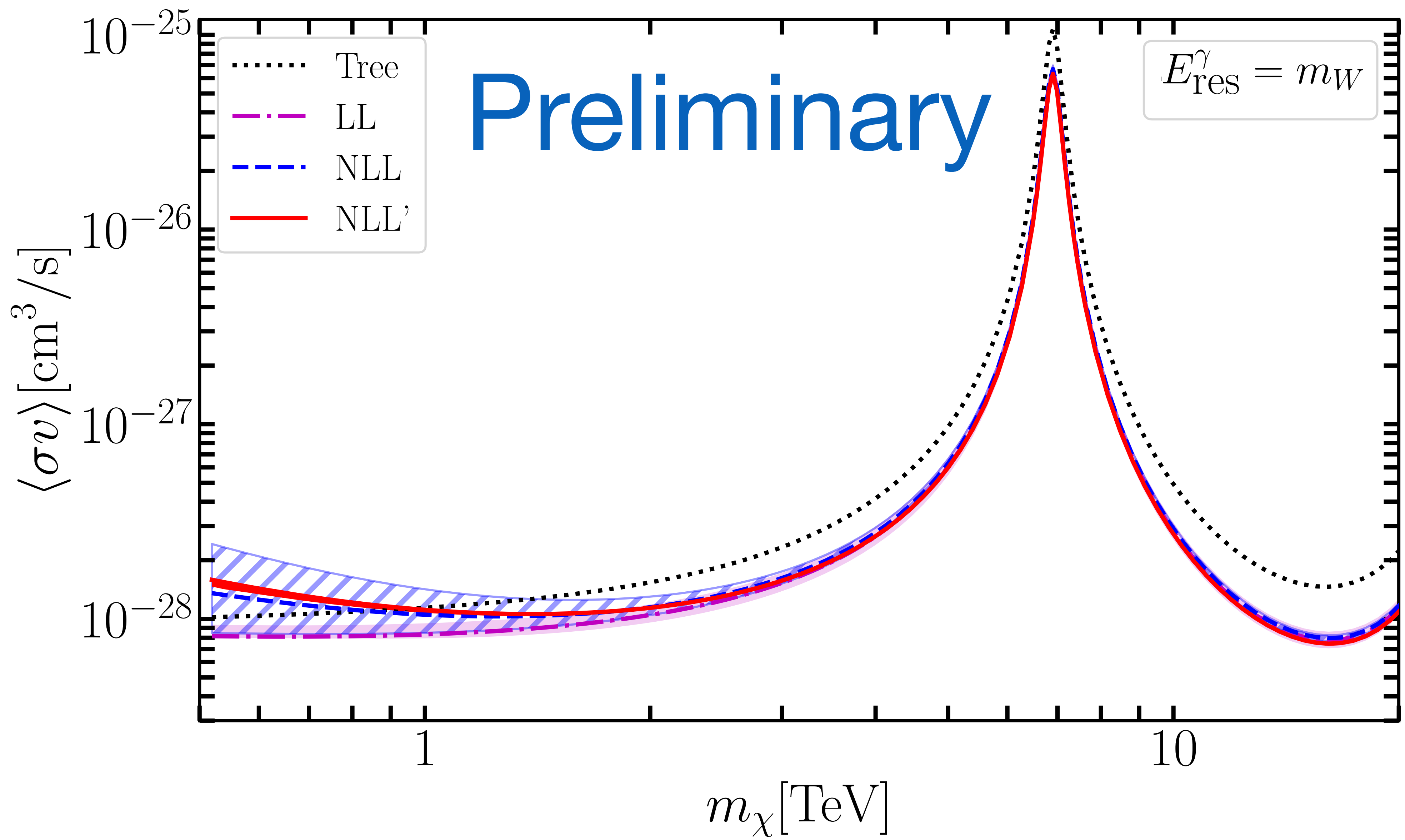
$$\frac{d(\sigma v_{\rm rel})}{dE_\gamma} = \sum_{I,J} S_{IJ}\,\Gamma_{IJ}(E_\gamma)$$

$$\Gamma_{IJ}(E_\gamma) = \frac{1}{4}\frac{2}{\pi m_\chi}\sum_{i,j} C_j^*(\mu)C_i(\mu)Z_\gamma^{WY}(\mu,\nu)$$

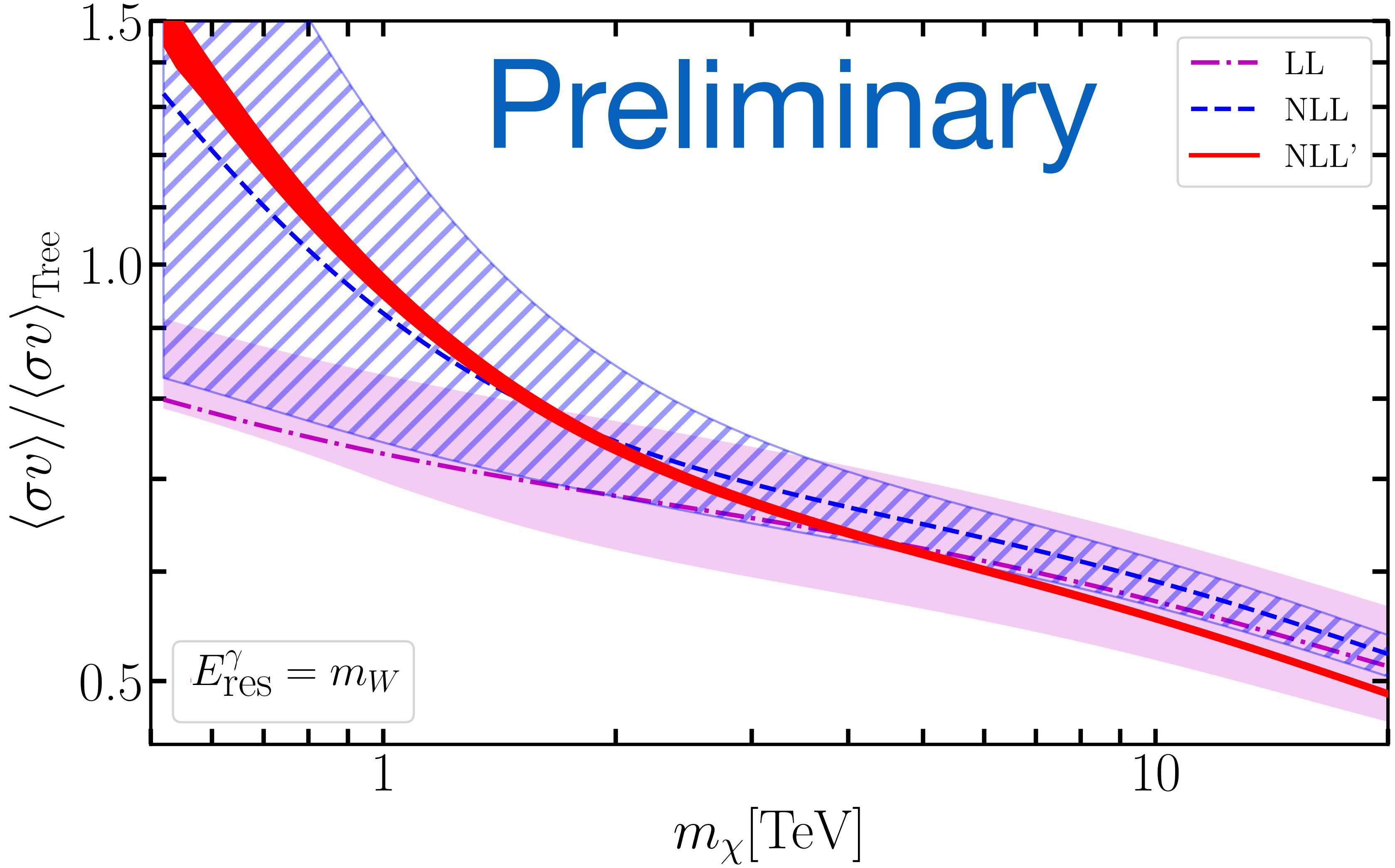
$$\times \int \mathrm{d}\omega \left(J^{\rm SU(2)}(2m_\chi(2E^\gamma_{\rm res}-\omega),\mu)W^{{\rm SU(2)}\,ij}_{IJ,WY}(\omega,\mu,\nu) \right.$$

$$\left. + J^{\rm U(1)}(2m_\chi(2E^\gamma_{\rm res}-\omega),\mu)W^{{\rm U(1)}\,ij}_{IJ,WY}(\omega,\mu,\nu)\right)$$

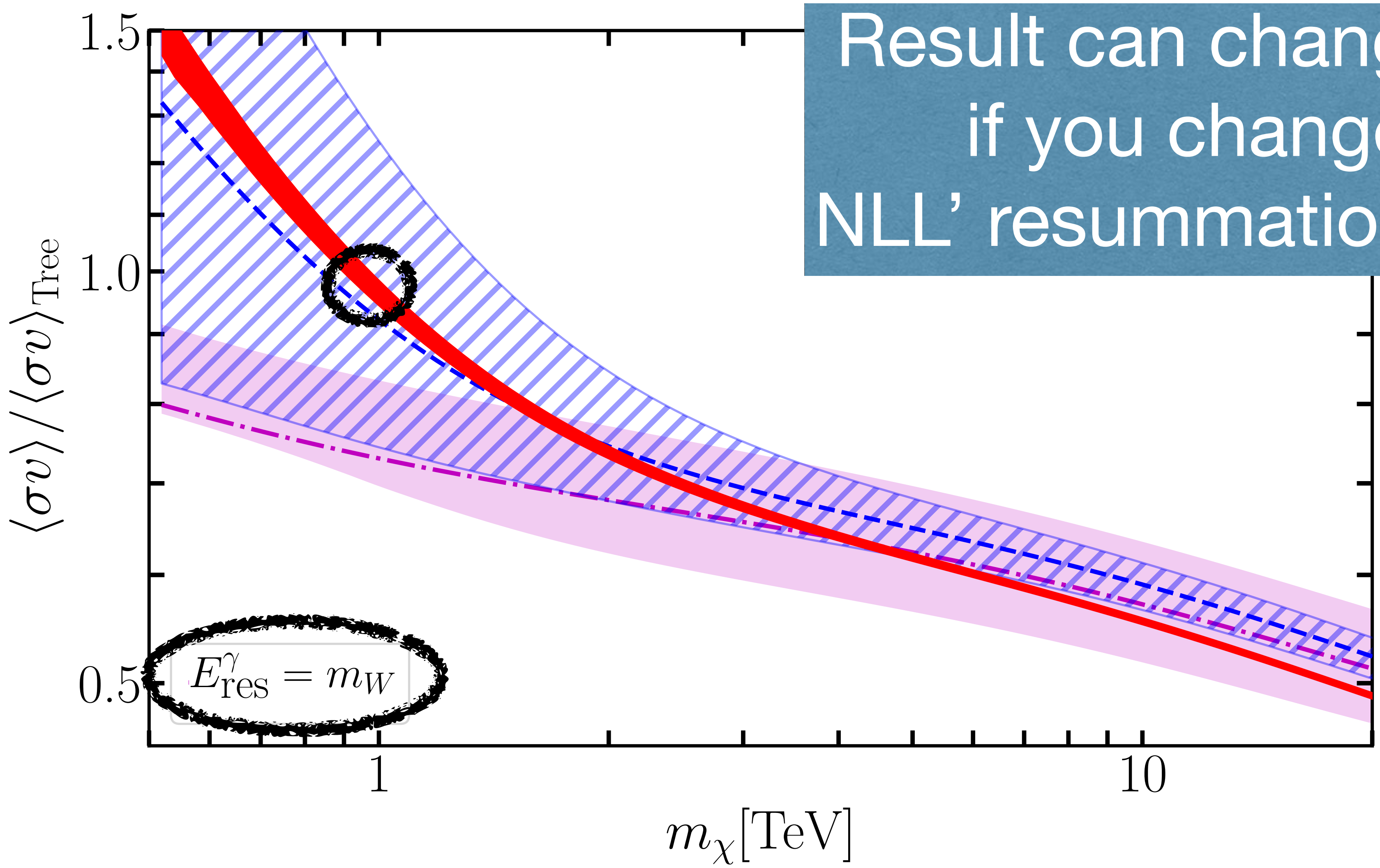
$\chi\chi\to\gamma$+X cross sections ($E_{\rm res}$ ~ m_W) for Higgsino DM



$\chi\chi \to \gamma + X$ ratio plots ($E_{res} = m_W$) for Higgsino DM



$\chi\chi \to \gamma$+X ratio plots ($E_{res} = m_W$) for Higgsino DM



Result can change by 50% if you change E_{res}!!!
NLL' resummation is **crucial**

Conclusions

- Heavy WIMP region will be probed by indirect detection observations in the near future. Theory input is urgent!
- Tackled the technically/conceptually involved problem of correctly predicting cross sections that are relevant for spectral multi-TeV γ-ray line searches in two regimes: *narrow* and *intermediate* energy resolution
- Employed these methods on **wino** and **Higgsino** DM
  - Reduced theoretical uncertainties down to the **permille** level for the (intermediate) *energy resolutions of the CTA* at the interesting mass range of 1-10 TeV
  - Observed a remarkable matching of the two factorization formulas in the “transition” region (narrow <—> intermediate resolutions)