Simplified models for mono-jet: Proposal for the parameter scan

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DM Forum
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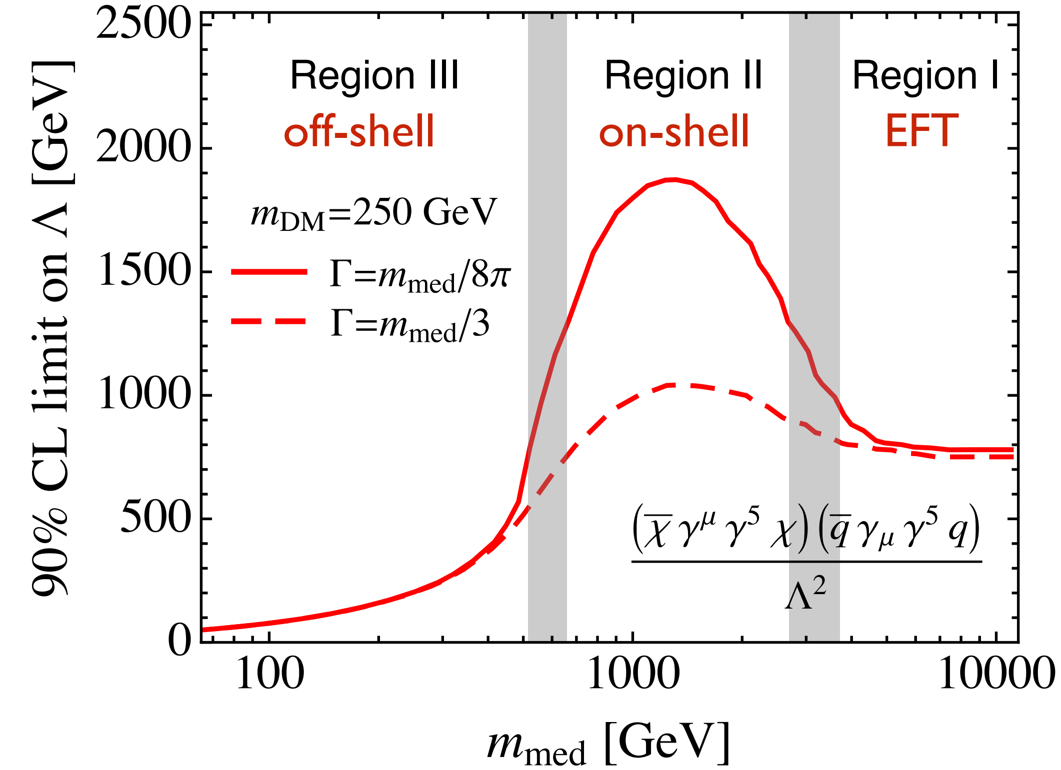
cross-section scaling

plot taken from 1308.6799



- $\Gamma \propto g^2 + g^2$
- propagator $1 / [\sqrt{s}-M + iM\Gamma]$

- for off-shell production ($\sqrt{s} >> M$) and EFT ($\sqrt{s} << M$) the width does not matter in the propagator

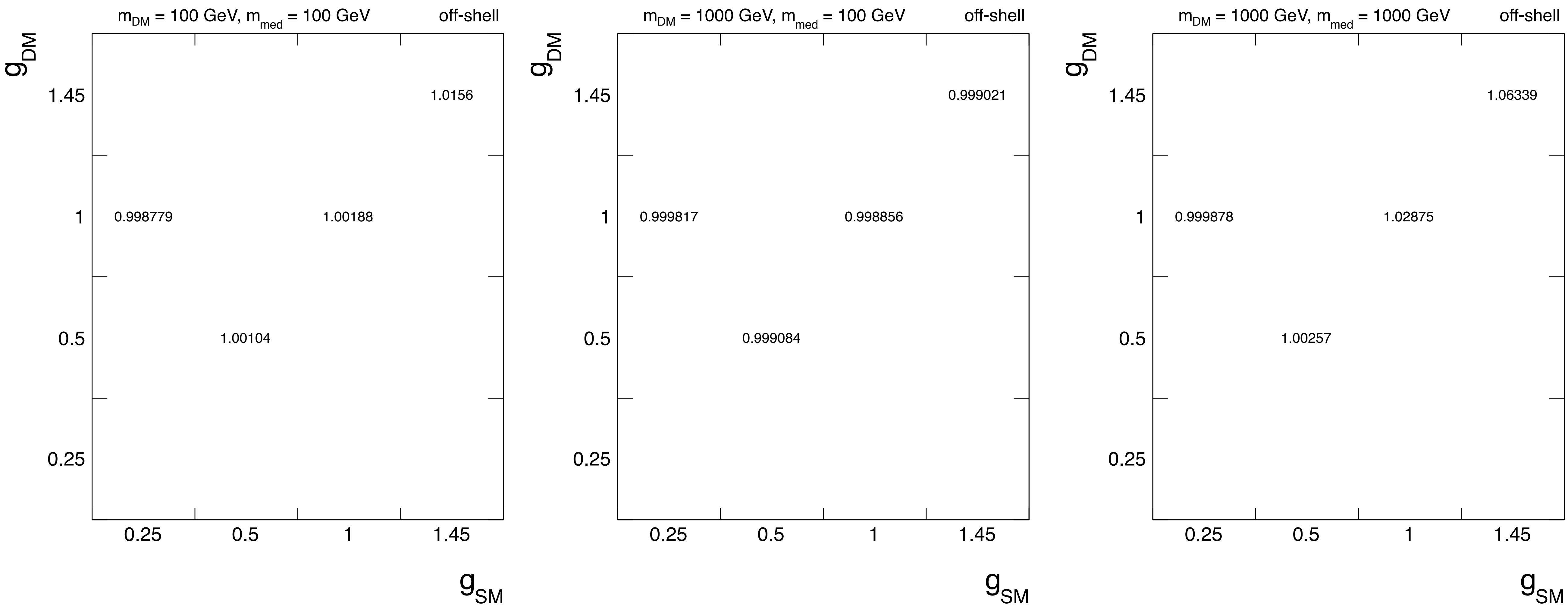
  ➡ $\sigma \propto g^2 g^2$

- for on-shell production ($\sqrt{s} \sim M$) the width gives dominant contribution

  ➡ narrow width approximation: $\int 1 / [(s-M^2)^2 + M\Gamma^2]\, ds = \pi / M\Gamma \rightarrow \sigma \propto g^2 g^2 / \Gamma$

  - extreme case where gDM << gSM: $\sigma \propto gSM^2 gDM^2 / (gSM^2 + gDM^2) \rightarrow gDM^2$
  - extreme case where gDM >> gSM: $\sigma \propto gSM^2 gDM^2 / (gSM^2 + gDM^2) \rightarrow gSM^2$

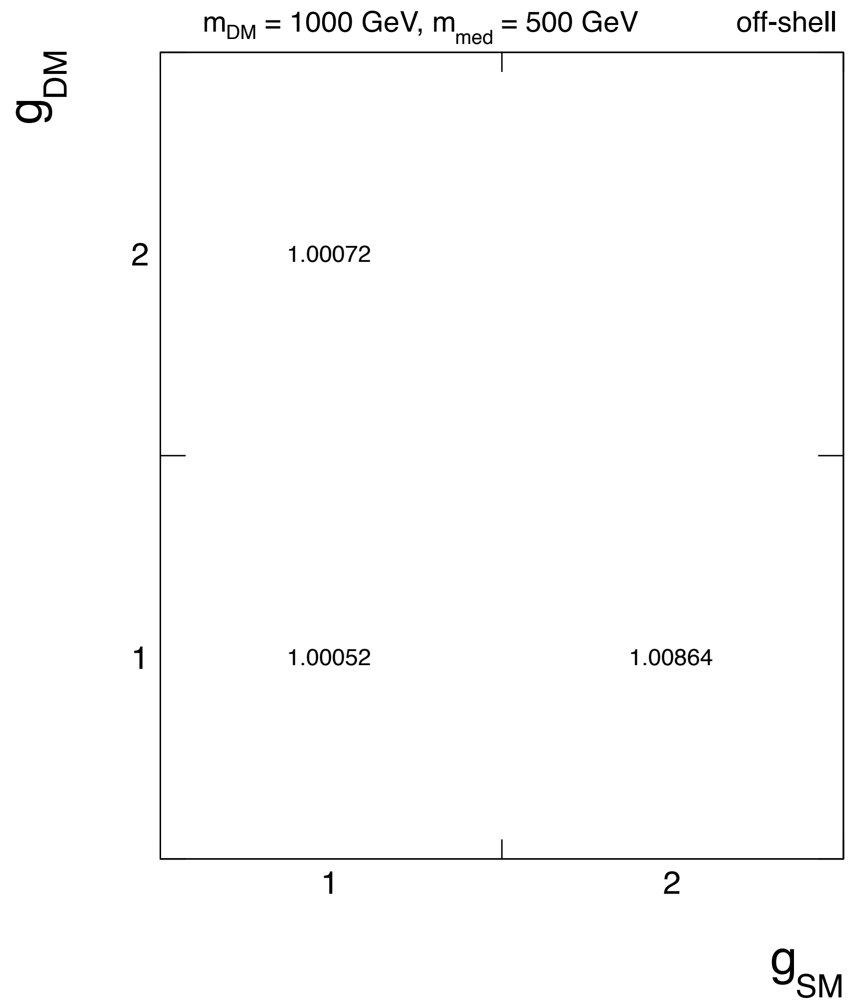
vector mediator, off-shell



1) Generate samples for various choices of couplings
2) Rescale the cross section from the sample with g = g = 0.1 according to $\sigma \propto g^2 g^2$
3) Compare to the rescaled and generated cross sections (see the ratio above)

➡ The scaling works for the off-shell production.

scalar mediator, off-shell



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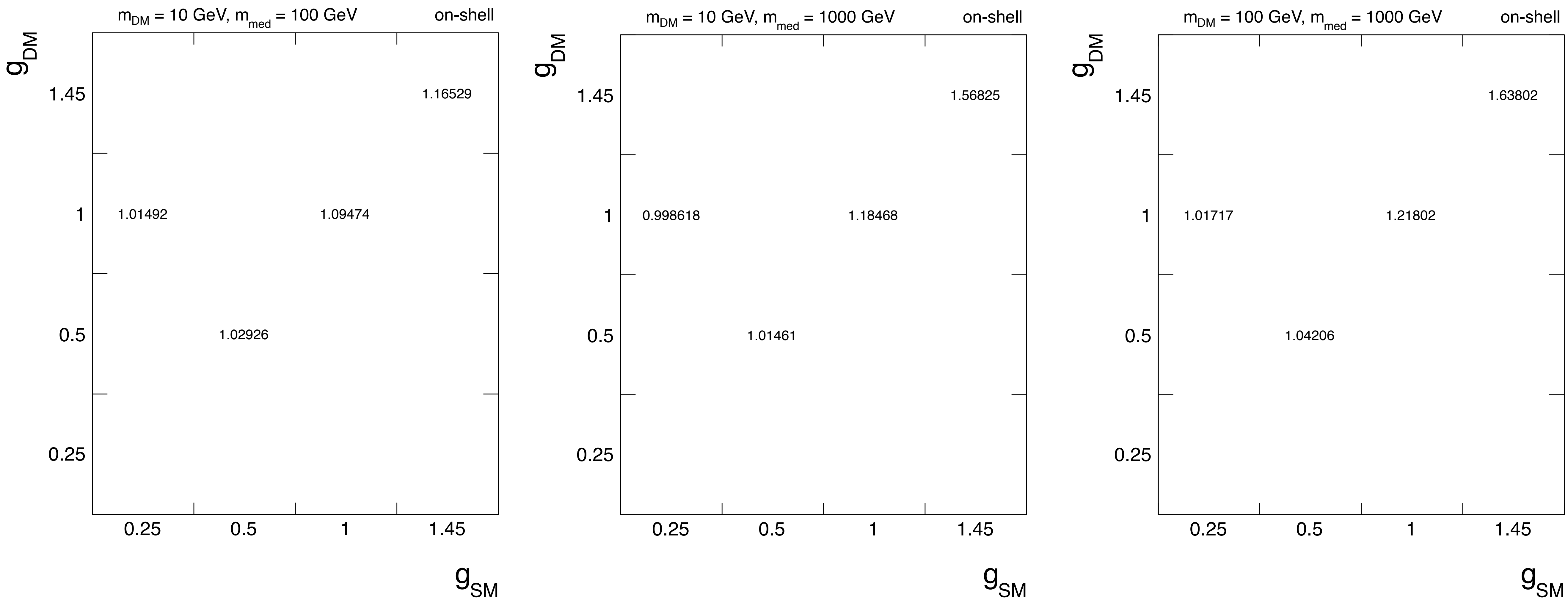

1) Generate samples for various choices of couplings
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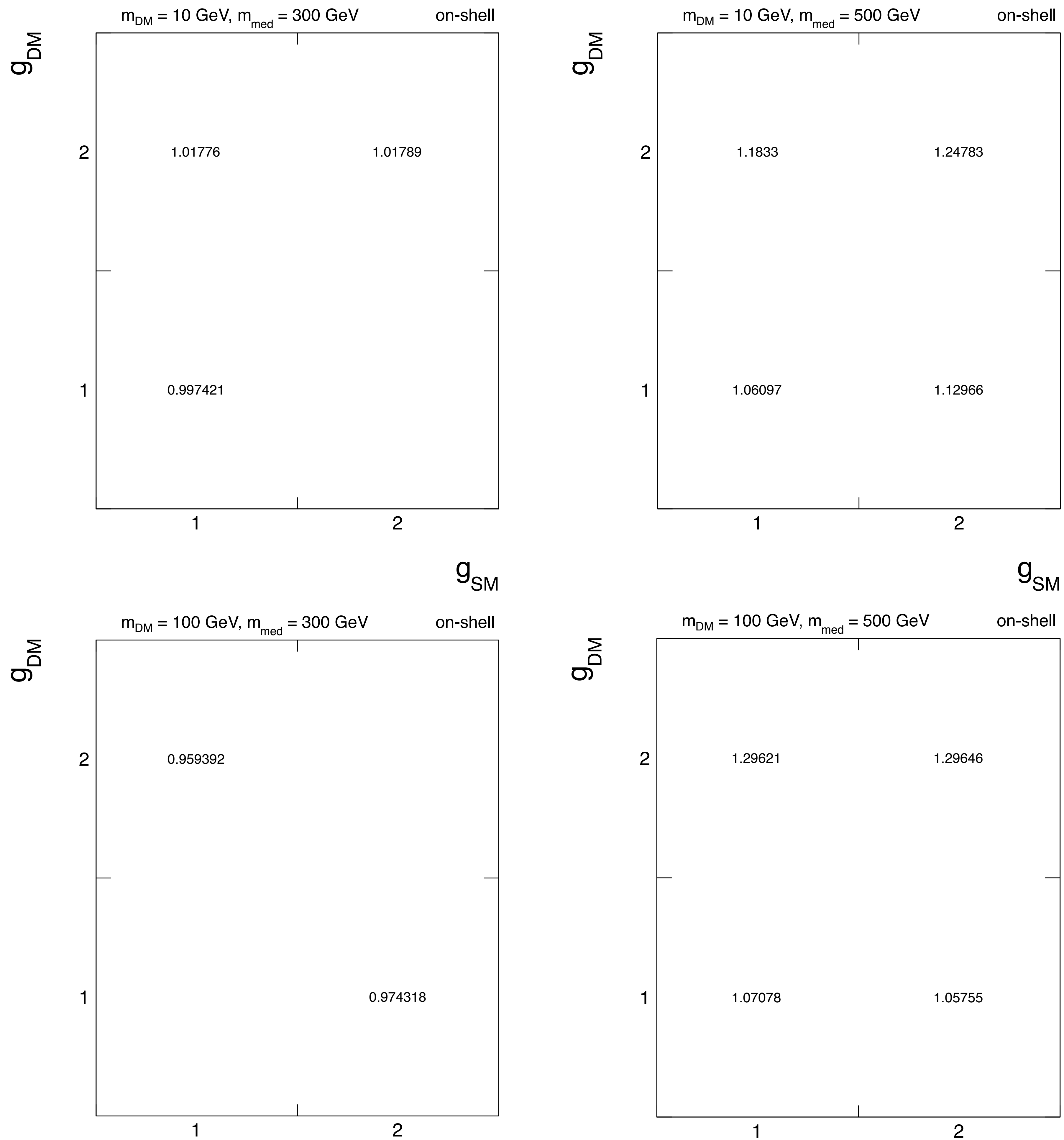
➡ The scaling works only for small mediator width.

- Note that the width mainly depends on gSM

scalar on-shell

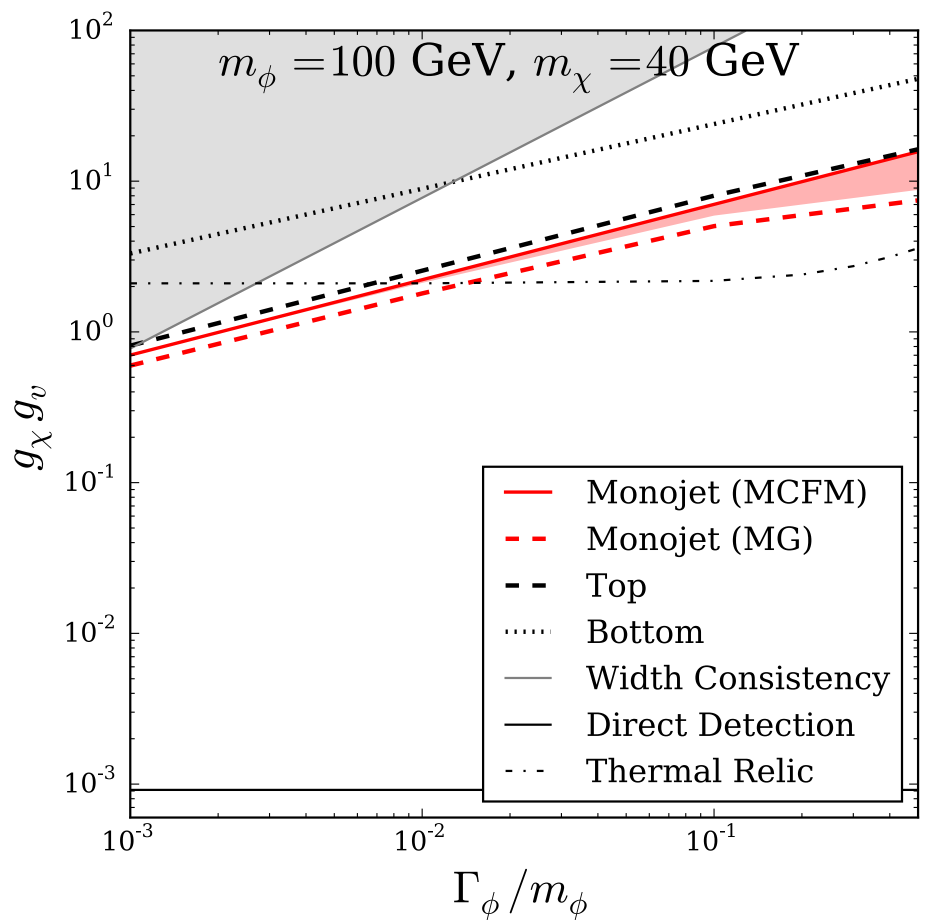
➡ The scaling works only for small mediator width.

- Note that the width mainly depends on gDM
- The factor $1 - 4m^2/M^2$ in the width definition is important to understand the numbers.



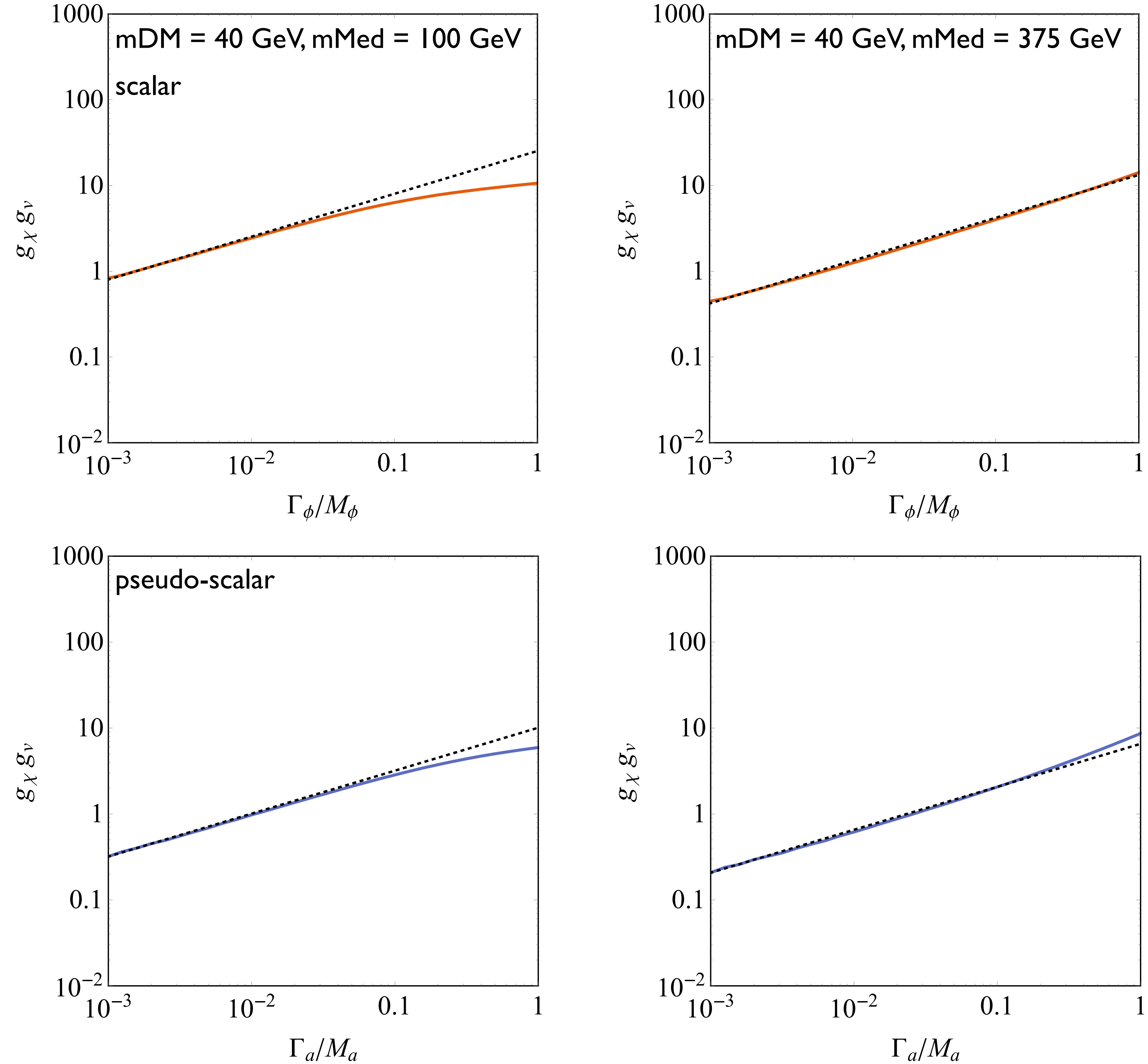
cross-section scaling

- The scaling $\sigma \propto g^2 g^2 / \Gamma$ is indicated in 1410.6497 (MCFM)
- The paper discusses this is true for the finite width calculation whereas there is a secondary effect at $\Gamma/M \gtrsim 0.1$ where the tail of the mediator pT can be increased relative to the narrow width approximation (indicated by the red shaded region).



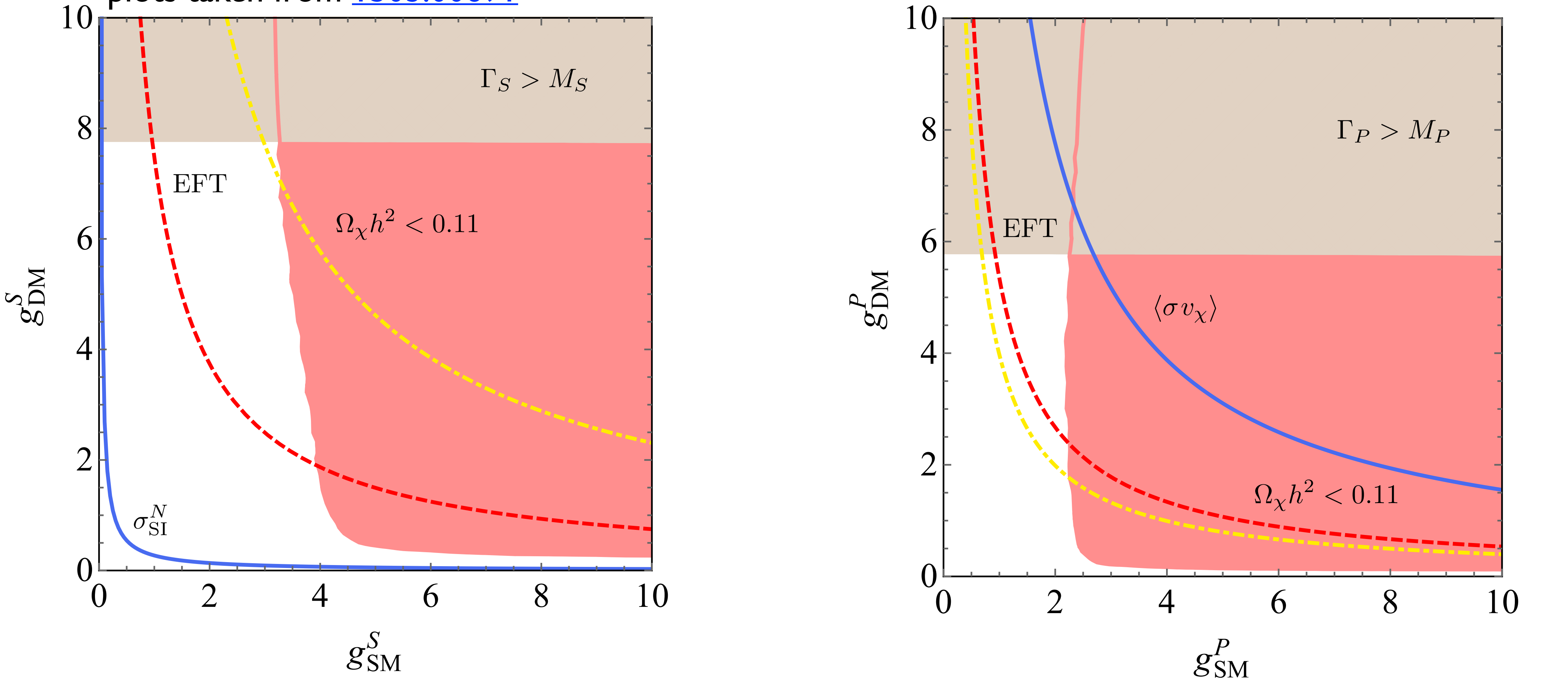
cross-section scaling

- An independent check reveals there are always deviations for sufficiently large Γ/M
- The effect depends in a non-trivial way on the mediator mass and the type of the interaction.



gDM-gSM plane

plots taken from [1503.00691]



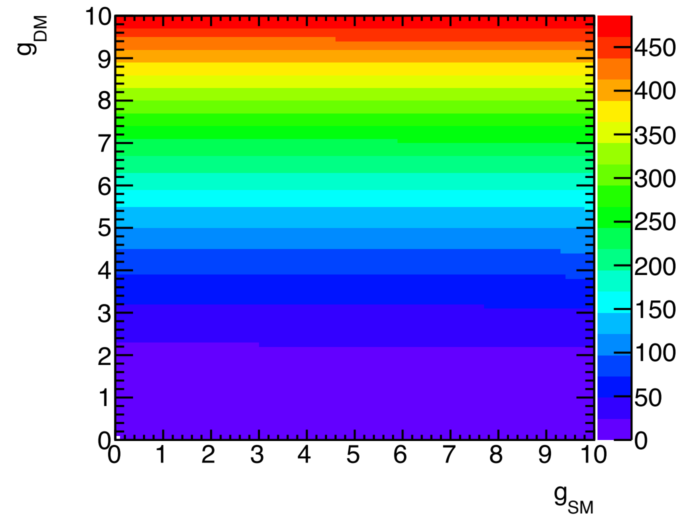
- Show the gDM−gSM plane for one choice of the masses.
- **For fixed mediator width and fixed masses, the cross section scales with $\sigma \propto g^2 g^2$**

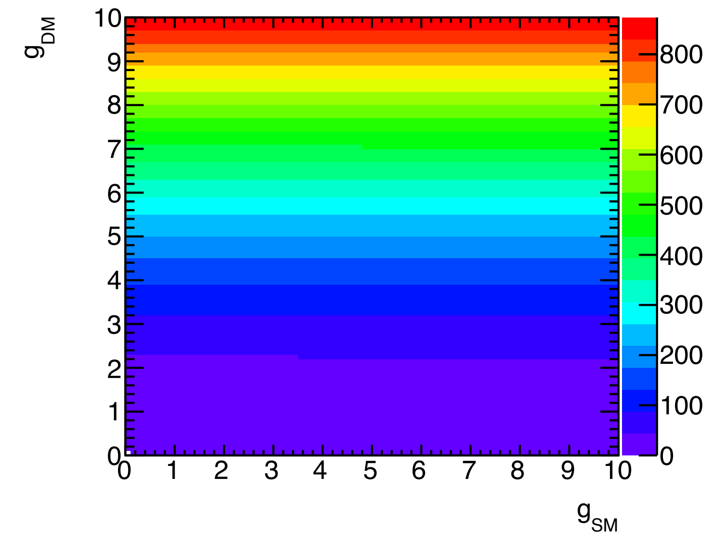
➡ There is no need to generate the full grid in the gDM-gSM plane.

- One can find the lines of constant width and rescale along these lines.

lines of constant width

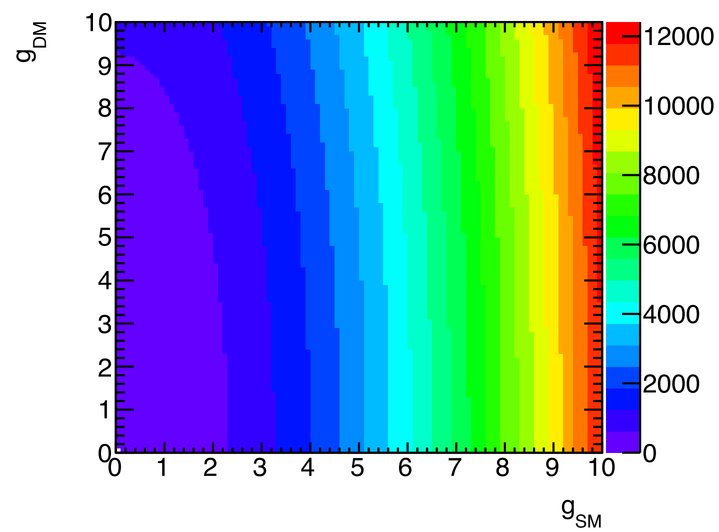
- Mediator width for S and P model with mDM = 100 GeV and mMed = 300 GeV

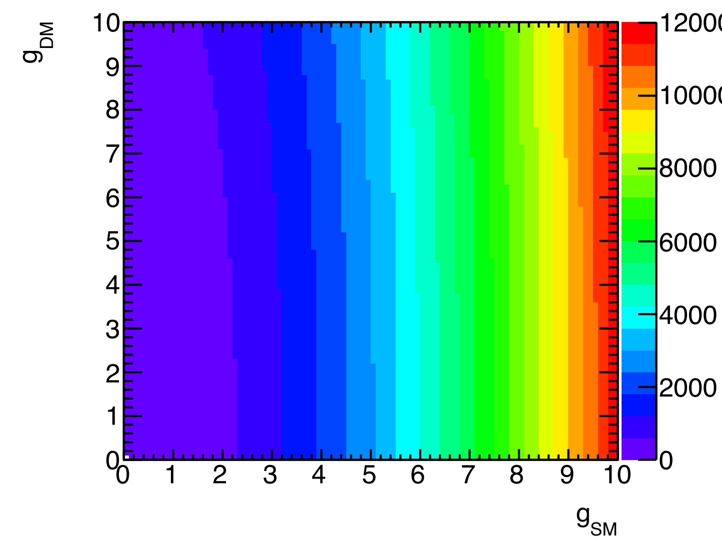




  - The lines of constant width are nearly independent of gSM because of the Yukawa couplings ($\Gamma \propto m_q^2/v^2\, g_{SM}^2 + g_{DM}^2$)

- Mediator width for V and A model with mDM = 100 GeV and mMed = 300 GeV



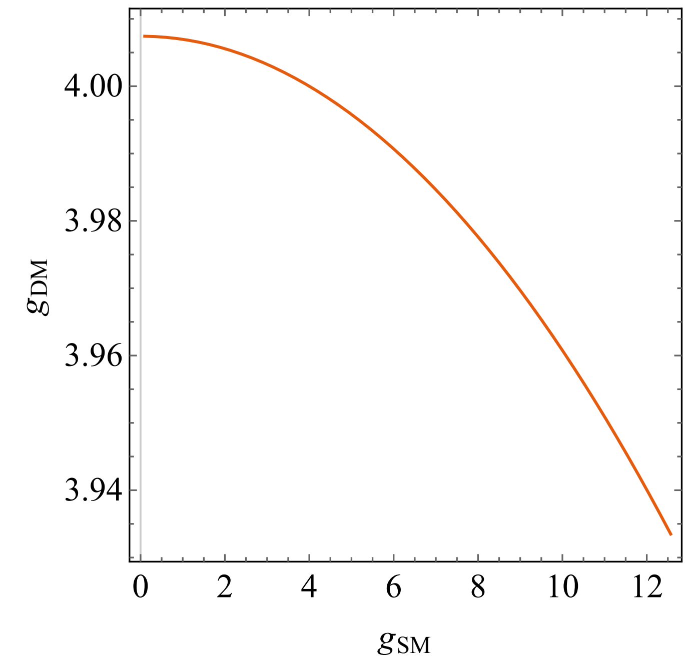


  - There is a stronger dependence on the quark coupling because it larger contribution to the width (color factor and number of flavours)

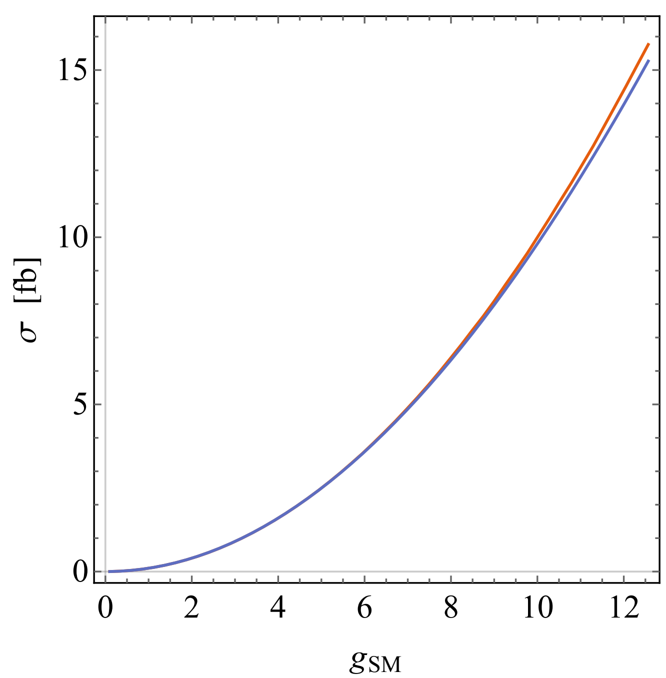
verification of the scaling

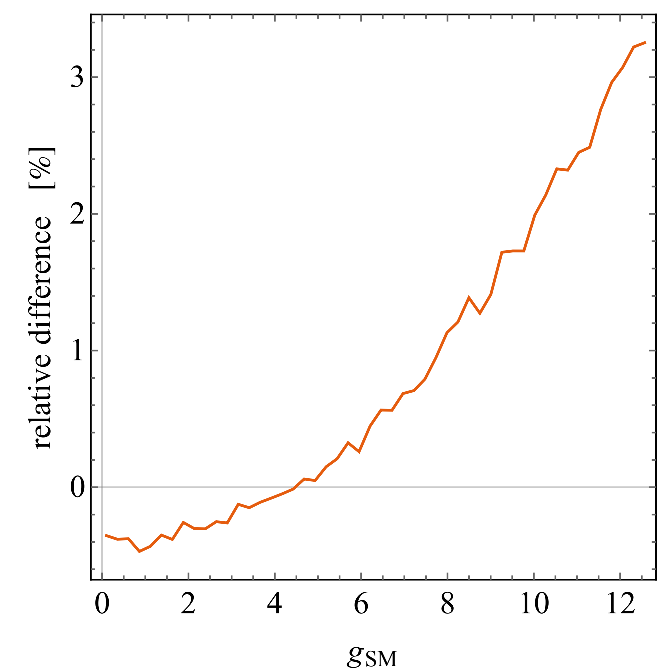
- Scalar model
  mDM = 100 GeV and mMed = 300 GeV

1) Take a line of the constant width:



2) Compare the cross-section from the generator with the rescaled one:

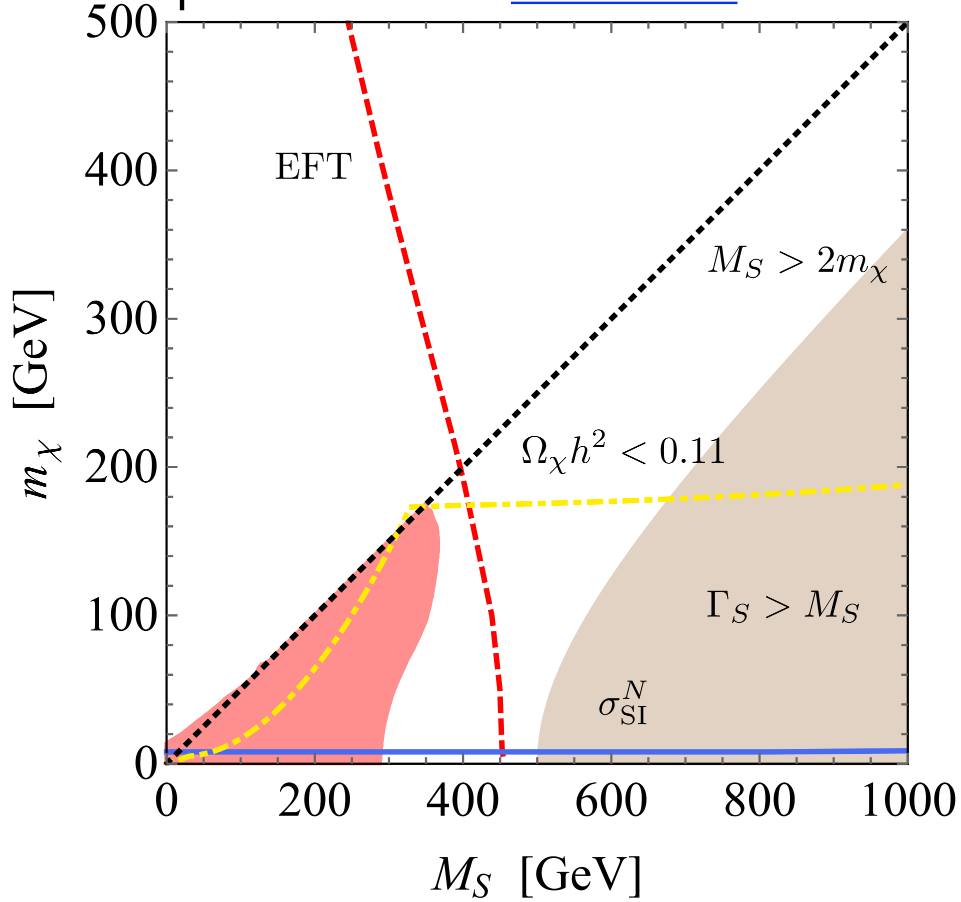


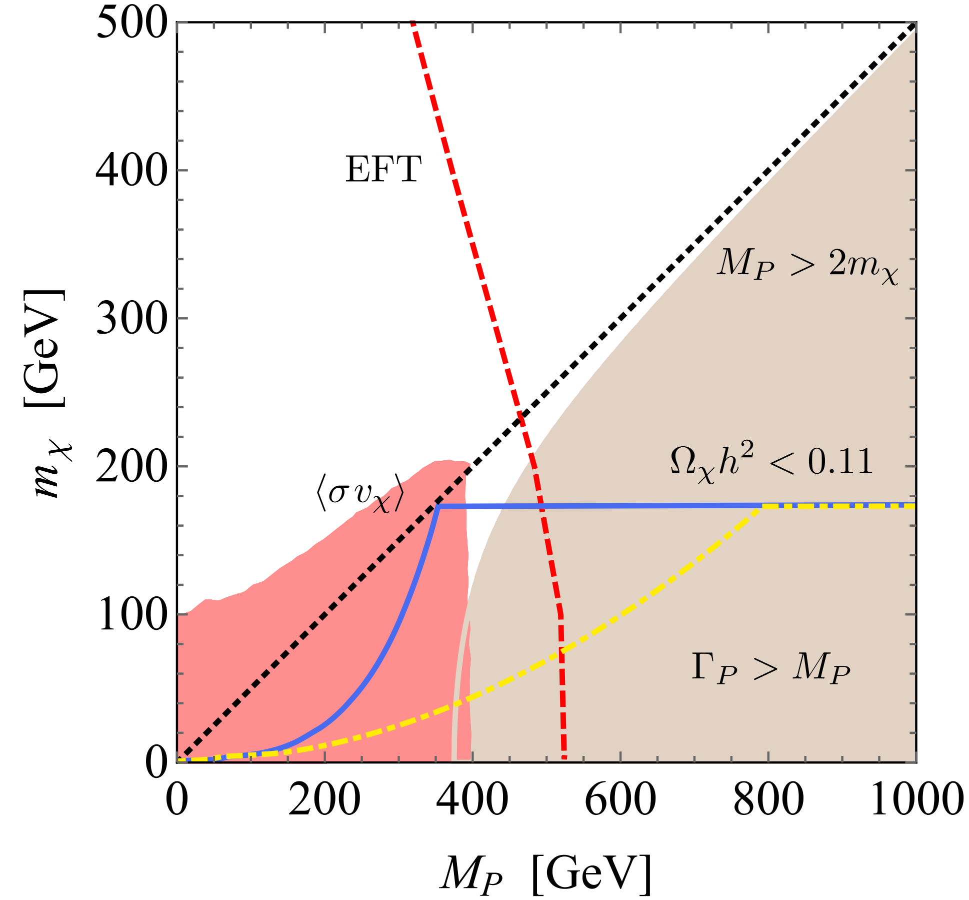


➡ There are only up to 3% differences!

mDM-mMed plane

plots taken from [1503.00691]



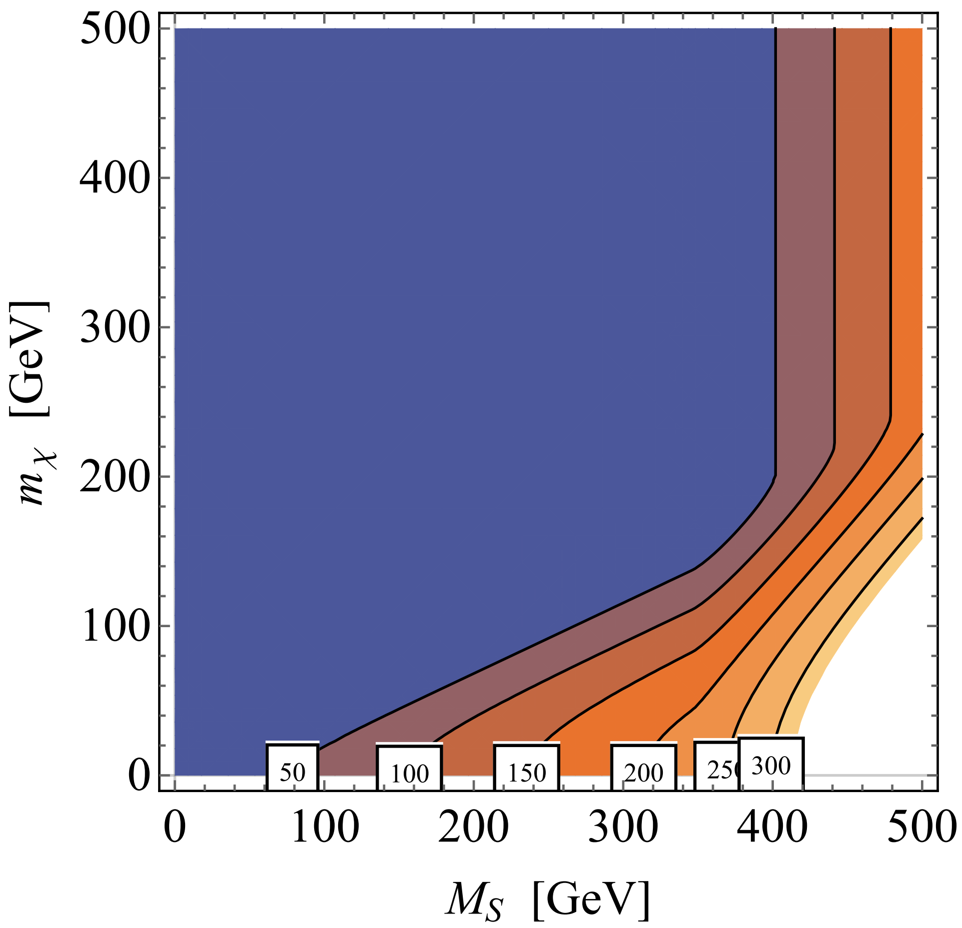


- Can we apply cross-section scaling in the mDM-mMed plane as well?

scaling in the mDM-mMed plane

- The simple scaling $\sigma \propto g^2 g^2$ is not expected to work for different masses:
  - For 2 mDM > mMed, PDF will matter because sufficient $\sqrt{s}$ energy is needed to produce the DM pair.
  - For 2 mDM < mMed, phase-space suppression factor leads to non-trivial scaling with mass.

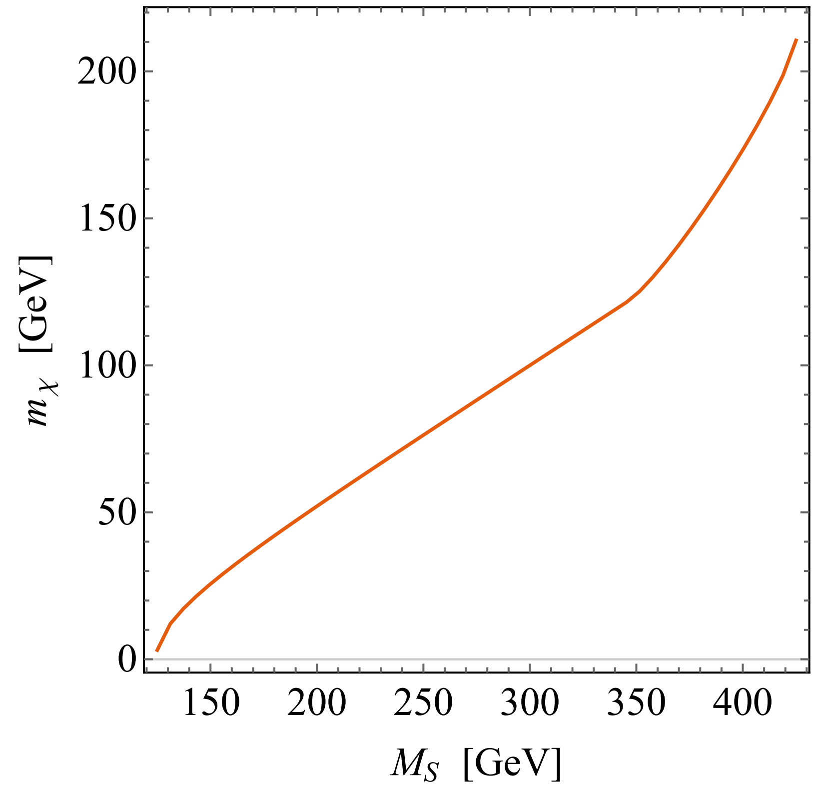
- lines of constant width
  - A kink around the top opening is apparent
  - There is no dependence on mDM for the off-shell production



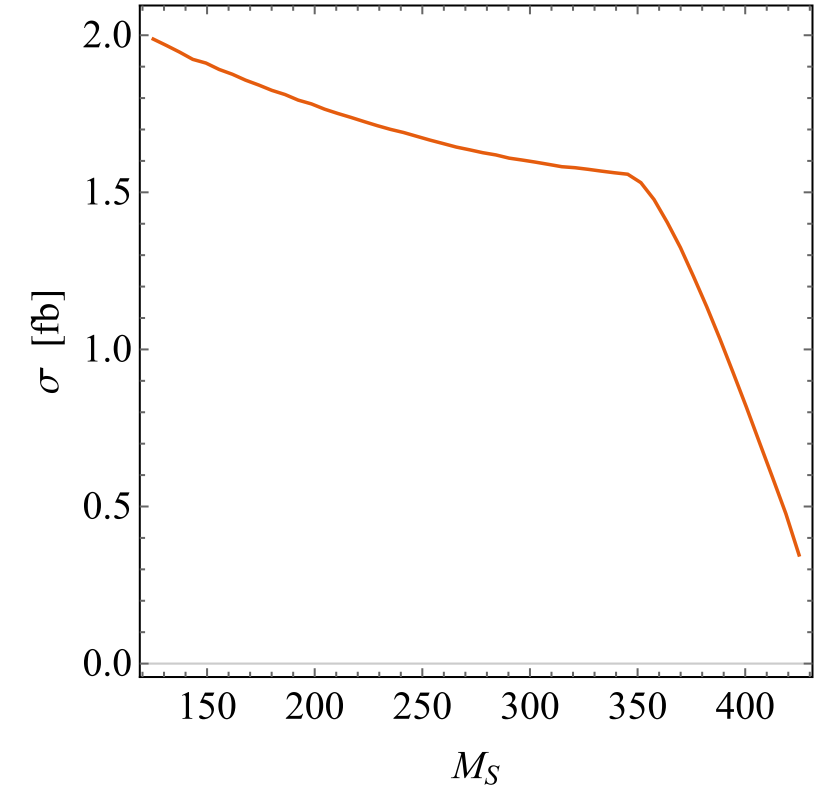
scaling in the mDM-mMed plane

- Scalar model with gSM = gDM = 4

1) Take a line of the constant width:



2) See how the cross section from the generator looks along this line:



➡ The plot does not support scaling with $\sigma \propto g^2 g^2 / \Gamma M$

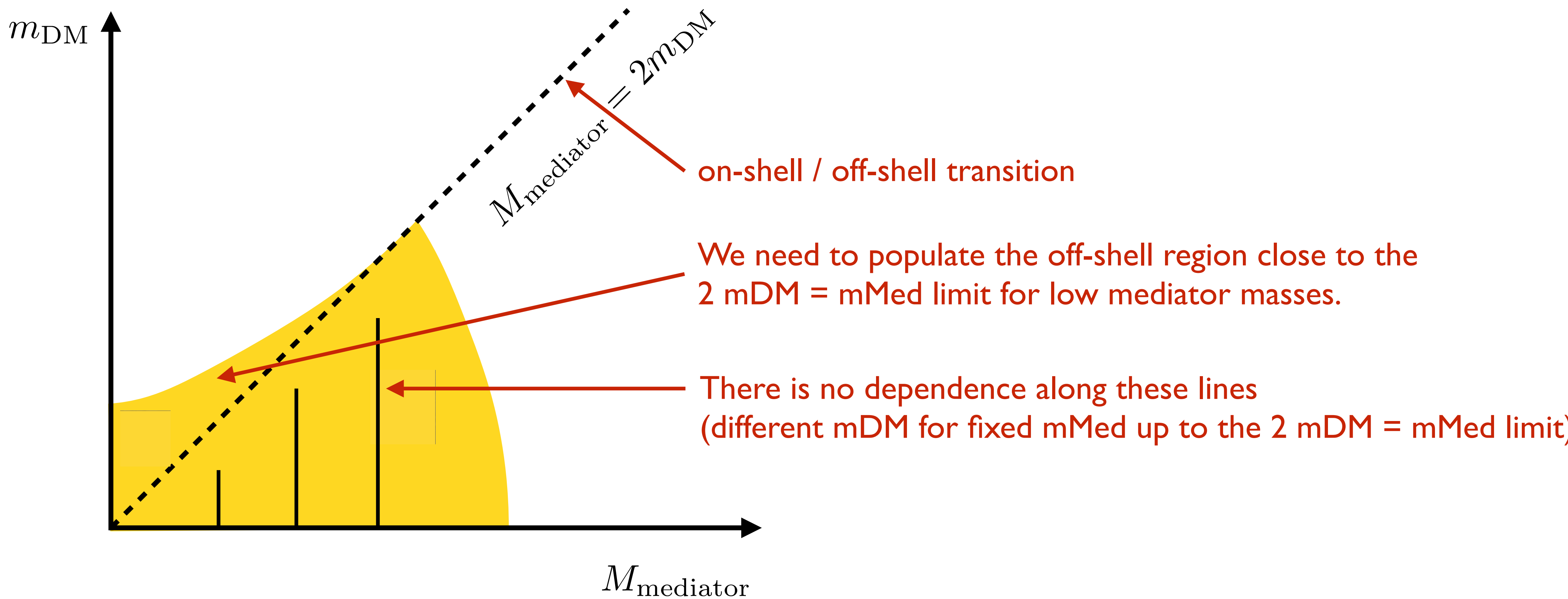
summary of the cross-section scaling

- We can make use of the $\sigma \propto g^2 g^2$ scaling along the lines of constant width in the gSM-gDM plane.
  ➡ For V and A, fix gDM = 1 and choose grid points for gSM.
  ➡ For S and P, fix gSM = 1 and choose grid points for gDM.

- No scaling is recommended for the mDM-mMed plane.
  ➡ Full grid is needed.
  - Can we make use of the studies of fiducial cross-sections and shapes of kinematic distributions to define regions where cars binning and interpolation is sufficient?
    - see detailed plots here https://indico.cern.ch/event/374678/
    - or the summary https://indico.cern.ch/event/374678/session/0/material/3/0.pdf

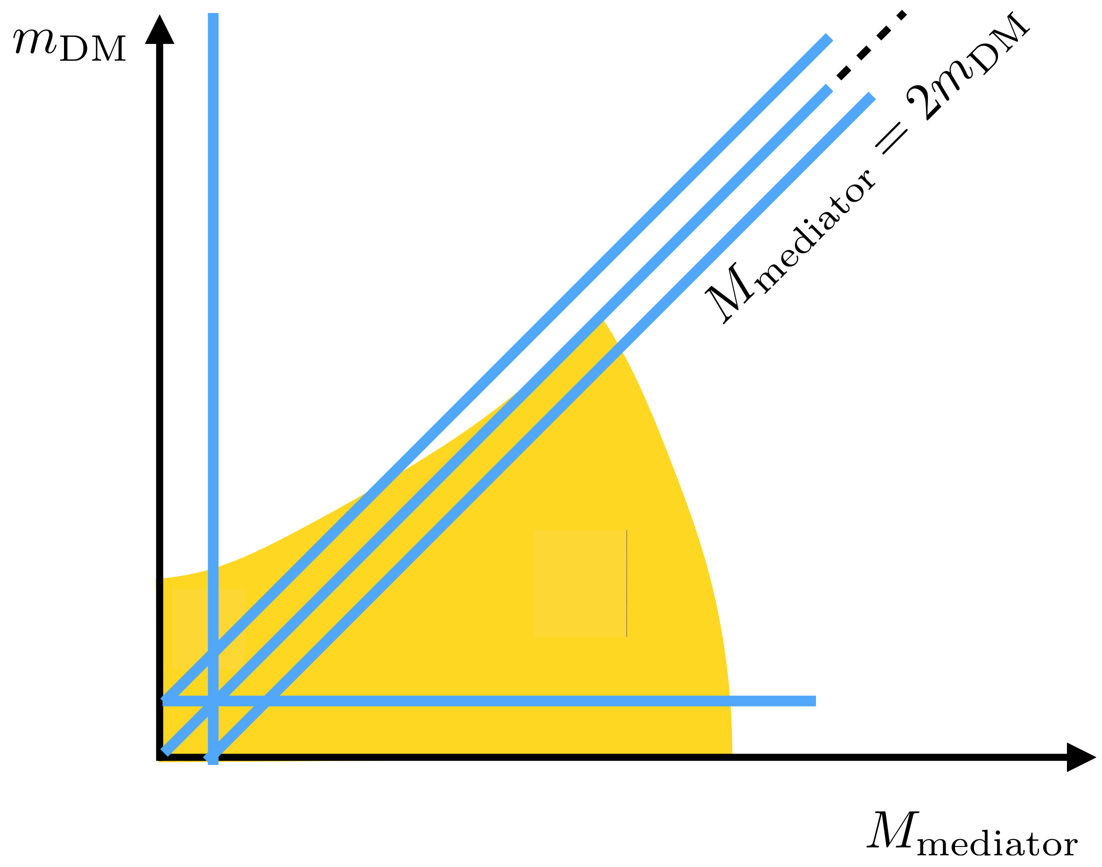
proposal for the parameter scan

- Show the mDM−mMed plane for one choice of couplings.
- General picture:



- Consider mediator masses from 10 GeV to 3 TeV.
    - proposed binning: 10, 30, 100, 300, 1000, 3000 GeV
    - For scalar, add 125.5 GeV as well and remove the highest 3 TeV point.

proposal for the parameter scan



- Five scan directions:
  1) Generate a set of samples for light mDM (1 GeV) and scan over mMed.
  2) Generate a set of samples for 2 mDM = mMed, 2 mDM = mMed ± Δ in order to better populate the transition region.
  3) Generate a set of samples for light mediator and scan over mDM.

➡ With 6 mass points, this is ~30 samples per model.

mediator width

- In case of the S and P models, it may be interesting to consider cases where the width is larger than the minimal width.
- It has been shown that the shapes of kinematic distributions do not change for different couplings★

➡ Modifying the mediator width is equivalent to choosing different couplings!

★ However, one needs to be careful in the case of very narrow mediators
(see https://indico.cern.ch/event/378495/contribution/10/material/slides/0.pdf slides 5 and 11
and https://indico.cern.ch/event/374678/session/0/material/3/0.pdf slide 23)

summary

- The most important task of the experimental collaborations is understanding the data and getting precise background estimates.

- The following two planes are proposed for the presentation of the results in terms of simplified models:
  - gSM-gDM plane
    - Only a 1-dimensional grid is needed as one can scale the cross section along the lines of constant mediator width.
  - mDM-mMed plane
    - Full grid scan is needed.
    - The transition region around 2 mDM = mMed needs to be well populated, with a coarser binning otherwise (five scan directions are proposed).

extra material

mediator width

$$\Gamma_S^{\chi\chi} = \frac{g_\chi^2}{8\pi} M (1 - 4m_\chi^2/M^2)^{3/2} \Theta(M - 2m_\chi)$$

$$\Gamma_S^{qq} = \sum_q 3 \frac{g_q^2}{8\pi} \frac{M m_q^2}{v^2} (1 - 4m_q^2/M^2)^{3/2} \Theta(M - 2m_q)$$

$$\Gamma_P^{\chi\chi} = \frac{g_\chi^2}{8\pi} M \sqrt{1 - 4m_\chi^2/M^2} \Theta(M - 2m_\chi)$$

$$\Gamma_P^{qq} = \sum_q 3 \frac{g_q^2}{8\pi} \frac{M m_q^2}{v^2} \sqrt{1 - 4m_q^2/M^2} \Theta(M - 2m_q)$$

$$\Gamma_S^{gg} = \frac{\alpha_s^2 M^3}{8\pi \Lambda^2}$$

- The mediator does not couple to leptons and gluons.
- Yukawa scaling is assumed for the couplings to SM quarks.
- On the contrary, this is not assumed for the coupling to DM.
- The last equation corresponds to the ggS EFT vertex.
- The maximum coupling value allowed by $\Gamma \leq$ mMed is 3.2,
  assuming gSM = gDM, mMed > 2 mDM and and mMed > 2 m_top,
  neglecting the couplings to other than the top quark
  (note that this is not the most interesting scenario as gSM = gDM is non-trivial in a full theory and and the top channel is not open for light mediators)

summary for the scalar models

- Coupling strength does not have an effect on the shape of the kinematic distributions.

- The early Run-2 data can be sensitive to coupling strengths around 1 for light mediators and larger for heavy mediators.
- The LHC will be sensitive up to mediator masses at the order of 100 GeV.

- Do not generate samples for mMed ≲ mDM (they are suppressed).
- The samples with mDM ≲ mMed < 2 mDM are still accessible and should be generated.
- For the samples with mMed > 2 mDM, we expect to see no dependence of the kinematic distributions on mDM for fixed mMed (the cross sections will change slightly).

- No special care needs to be taken for mediator masses around the top channel opening.

mediator width

$$\Gamma_V^{\chi\chi} = \frac{g_\chi^2}{12\pi} M (1 + 2m_\chi^2/M^2)\sqrt{1 - 4m_\chi^2/M^2}\,\Theta(M - 2m_\chi)$$

$$\Gamma_V^{qq} = \sum_q 3\frac{g_q^2}{12\pi} M (1 + 2m_q^2/M^2)\sqrt{1 - 4m_q^2/M^2}\,\Theta(M - 2m_q)$$

$$\Gamma_A^{\chi\chi} = \frac{g_\chi^2}{12\pi} M (1 - 4m_\chi^2/M^2)^{3/2}\Theta(M - 2m_\chi)$$

$$\Gamma_A^{qq} = \sum_q 3\frac{g_q^2}{12\pi} M (1 - 4m_q^2/M^2)^{3/2}\Theta(M - 2m_q)$$

- The maximum coupling value allowed by Γ ≤ mMed is 1.4,
  assuming gSM = gDM, coupling to all six quark flavours, mMed > 2 m_top and mMed > 2 mDM.

summary for the vector models

- We observe differences in the kinematic distributions for heavy narrow mediators that are possibly due to PDFs.
- Otherwise, the choice of the couplings does not seem to have an effect on the shape of the kinematic distributions.

- The early Run-2 data can be sensitive to coupling strengths around 0.1 for light mediators and above 1 for heavy mediators.
- The LHC will be sensitive up to mediator masses at the order of 1000 GeV.

- Do not generate samples for mMed ≲ mDM (they are suppressed).
- The samples with mDM ≲ mMed < 2 mDM are still accessible and should be generated.
- For the samples with mMed > 2 mDM, we expect to see no dependence of the kinematic distributions on mDM for fixed mMed (the cross sections will change slightly).