Distinguishing the spin of DM using dilepton events

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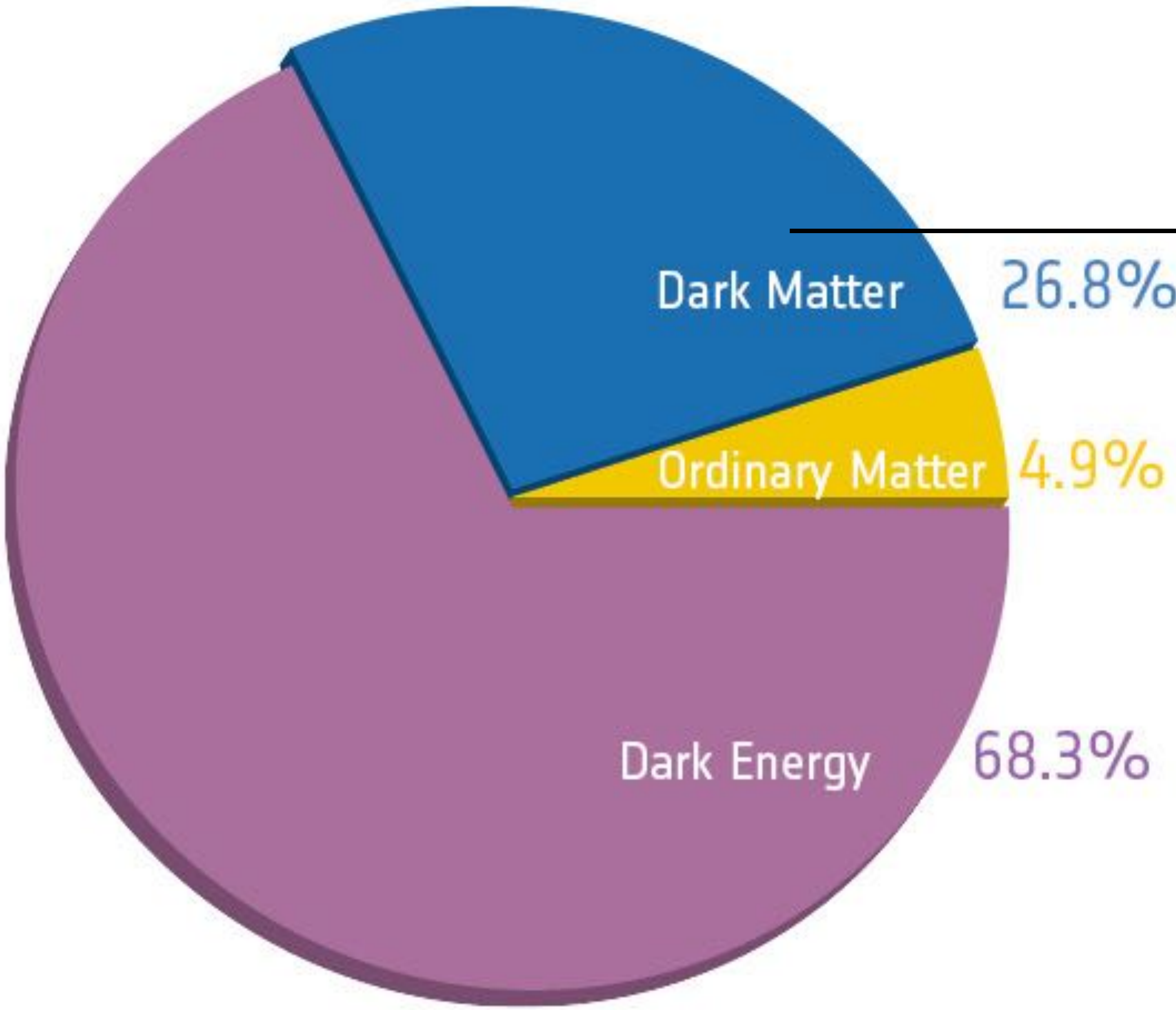
- Introduction
- DM in the compressed region: challenges
- Kinematical variables
- Conclusions

Work done in collaboration with Rodolfo Capdevilla, Nirmal Raj and Adam Martin
arXiv:1709.00439



What is this?

- Is DM its own antiparticle?
- Does it carry spin?
- What is its mass?
- How does it couple to the SM if at all?
- I am going to present a way of ‘partially’ answering this questions using LHC data with fully reconstructed final states.

- Lots of models of DM require extra degrees of freedom apart from the neutral state itself.
- That is needed in order to have renormalizable couplings with SM (with the exception of the Higgs portal)
- I am going to assume a simplified model including our DM and two messengers

$$\mathcal{L} \supset -\sqrt{2}(\lambda_{\tilde{Q}} \tilde{Q} \chi_B^\dagger q^\dagger + \lambda_{\tilde{L}} \tilde{L} \chi_B^\dagger \ell^\dagger) + \mathrm{H.c.}$$

- I am going to assume that DM is either spin 1/2 or 0 and the messenger therefore will have the other spin to be able to write the previous coupling

- The mass terms can be written as (δm is needed to avoid problems with large DD cross-sections)

$$\mathcal{L}_{\rm mass} = \begin{pmatrix}\chi_A & \chi_B\end{pmatrix} \begin{pmatrix}\delta m & m_\chi \\ m_\chi & \delta m'\end{pmatrix} \begin{pmatrix}\chi_A \\ \chi_B\end{pmatrix} + \mathrm{H.c.}$$

Spin 1/2

$$\mathcal{L}_{\rm mass} = \frac{1}{2} \begin{pmatrix}\phi_\chi & \phi_\chi^\dagger\end{pmatrix} \begin{pmatrix}\delta m^2 & m_\chi^2 \\ m_\chi^2 & \delta m'^2\end{pmatrix} \begin{pmatrix}\phi_\chi \\ \phi_\chi^\dagger\end{pmatrix}$$

Spin 0

- Varying the spin and quantum numbers of the messengers one can classify the different scenarios that are going to be analyzed:

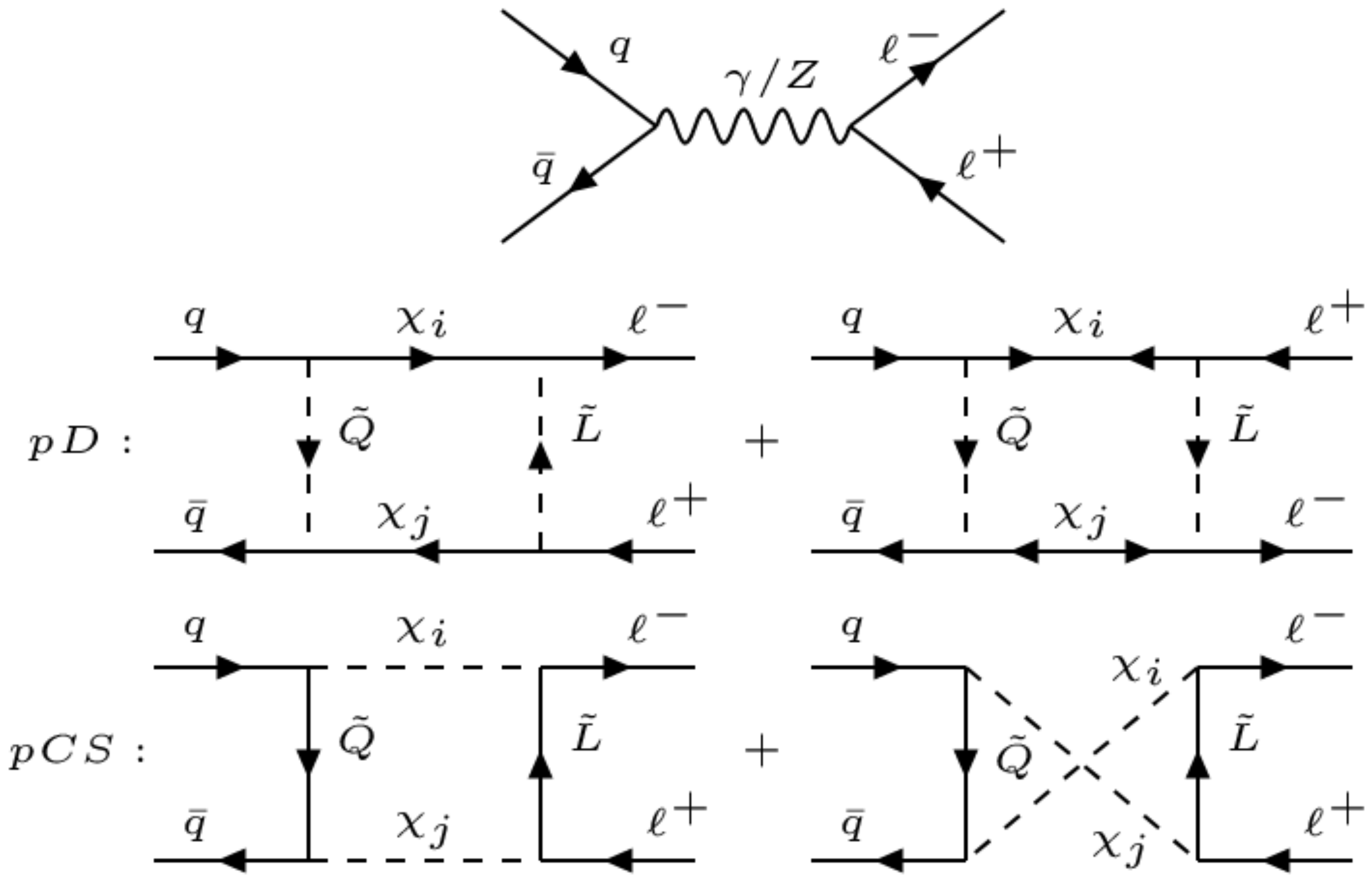
Model	χ spin	$\tilde{Q}, \tilde{L}$ spin	$\tilde{Q}$ under $G_{\rm SM}$	$\tilde{L}$ under $G_{\rm SM}$
$\mathtt{pD}^{\mathtt{u}}_{\rm RR}$	$1/2$	0	$(\mathbf{3}, \mathbf{1}, \mathbf{2/3})$	$(\mathbf{1}, \mathbf{1}, \mathbf{-1})$
$\mathtt{pD}^{\mathtt{u}}_{\rm RL}$	$1/2$	0	$(\mathbf{3}, \mathbf{1}, \mathbf{2/3})$	$(\mathbf{1}, \mathbf{2}, \mathbf{-1/2})$
$\mathtt{pCS}^{\mathtt{u}}_{\rm RR}$	0	$1/2$	$(\mathbf{3}, \mathbf{1}, \mathbf{2/3})$	$(\mathbf{1}, \mathbf{1}, \mathbf{-1})$
$\mathtt{pCS}^{\mathtt{u}}_{\rm RL}$	0	$1/2$	$(\mathbf{3}, \mathbf{1}, \mathbf{2/3})$	$(\mathbf{1}, \mathbf{2}, \mathbf{-1/2})$
$\mathtt{pD}^{\mathtt{d}}_{\rm RR}$	$1/2$	0	$(\mathbf{3}, \mathbf{1}, \mathbf{-1/3})$	$(\mathbf{1}, \mathbf{1}, \mathbf{-1})$
$\mathtt{pD}^{\mathtt{d}}_{\rm RL}$	$1/2$	0	$(\mathbf{3}, \mathbf{1}, \mathbf{-1/3})$	$(\mathbf{1}, \mathbf{2}, \mathbf{-1/2})$
$\mathtt{pCS}^{\mathtt{d}}_{\rm RR}$	0	$1/2$	$(\mathbf{3}, \mathbf{1}, \mathbf{-1/3})$	$(\mathbf{1}, \mathbf{1}, \mathbf{-1})$
$\mathtt{pCS}^{\mathtt{d}}_{\rm RL}$	0	$1/2$	$(\mathbf{3}, \mathbf{1}, \mathbf{-1/3})$	$(\mathbf{1}, \mathbf{2}, \mathbf{-1/2})$

- The usual strategy to discover a model like the one proposed would be to produce the color companion and use the standard search of jets+MET

- But in the compressed case, needed in some scenarios to reproduce the correct relic abundance, the amount of MET may be small so the search may not be completely effective.

- Even if one can discover the messenger using this channel, it is difficult to extract information on the nature of DM since the final state is not fully reconstructed.

- I propose to use the following alternative fully reconstructed signal:



- We first calculate analytically the LO cross-section for both SM and new physics:

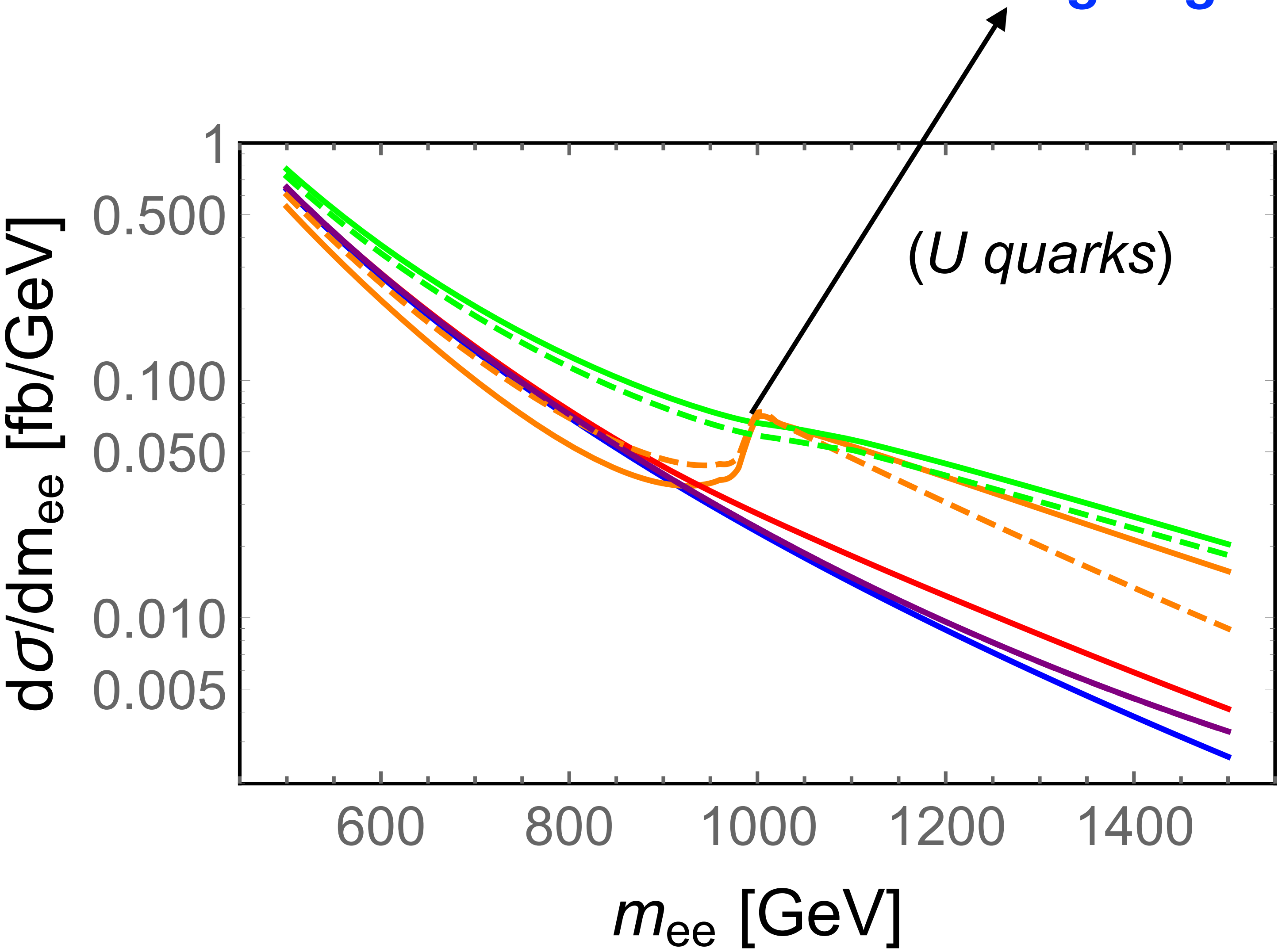
$$
\begin{aligned}
d\sigma_{\rm tot} &\equiv \frac{d^2\sigma_{\rm tot}}{d\cos\theta\ dm_{\ell\ell}} \\
&= d\sigma_{\rm SM} + d\sigma_{\rm int} + d\sigma_\chi
\end{aligned}
$$

$$
\begin{aligned}
d\sigma_{\rm SM} &= \frac{1}{32\pi m_{\ell\ell}^2 N_c}\sum_{\rm spins}|\mathcal{M}_{\rm SM}|^2\ , \\
d\sigma_{\rm int} &= \frac{1}{32\pi m_{\ell\ell}^2 N_c}\sum_{\rm spins} 2{\rm Re}(\mathcal{M}_{\rm SM}\mathcal{M}_\chi^*)\ , \\
d\sigma_\chi &= \frac{1}{32\pi m_{\ell\ell}^2 N_c}\sum_{\rm spins}|\mathcal{M}_\chi|^2\ ,
\end{aligned}
$$

To the σ_{SM} we add the NLO contribution from QCD

MCMF 8.0

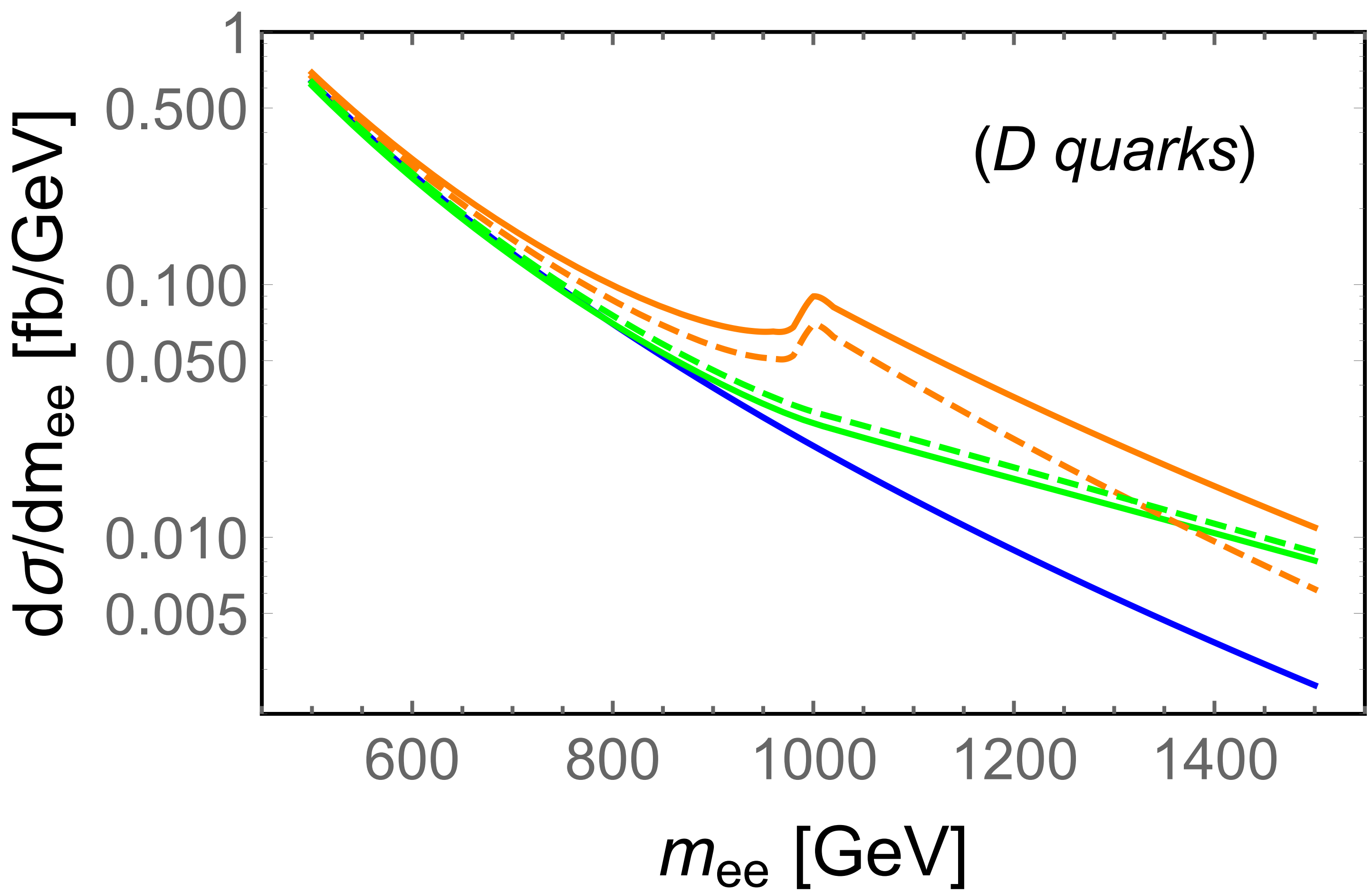
Internal line going on shell



Blue is the SM background
Orange pseudo Dirac
Green pseudo Complex
Red is Majorana
Purple real scalar
Solid is RR
Dashed is RL

λ= 2 m_χ=500 GeV m_ϕ=550 GeV

Majorana fermion DM and Real scalar (self-congugate)
do not give enough signal!!!!



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The differences between U and D quarks come from some interference terms

- We are going to use the following kinematical variables to discriminate the different models:

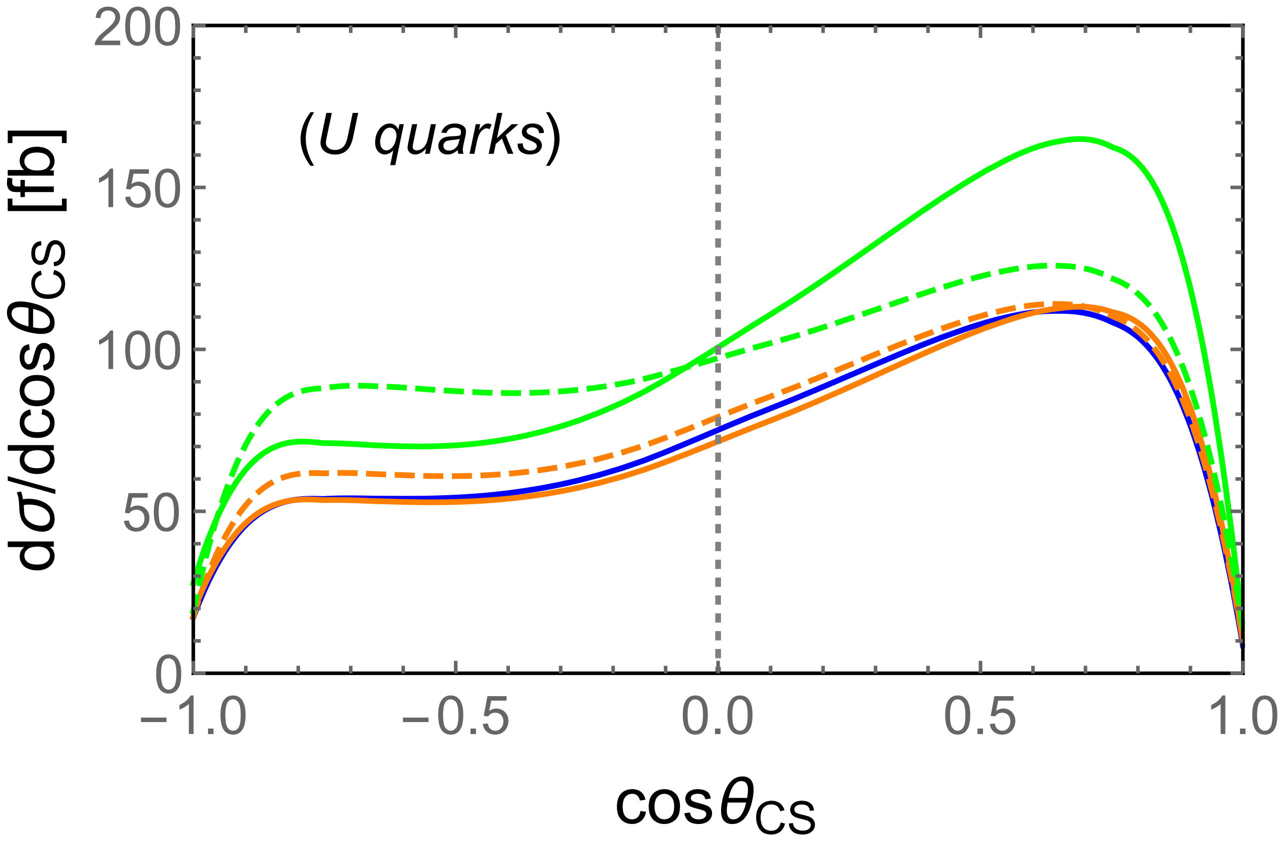
$$\cos\theta_{\mathrm{CS}} = \frac{Q_z}{|Q_z|}\frac{2(p_1^+ p_2^- - p_1^- p_2^+)}{|Q|\sqrt{Q^2+Q_T^2}}$$

Q is the total dilepton momentum
p's are the light-cone momenta

$$A_{\mathrm{CE}} \equiv \frac{N(|\cos\theta| < \cos\theta_0) - N(|\cos\theta| > \cos\theta_0)}{N(|\cos\theta| < \cos\theta_0) + N(|\cos\theta| > \cos\theta_0)}$$

$$A_{\mathrm{FB}} \equiv \frac{N(\cos\theta > 0) - N(\cos\theta < 0)}{N(\cos\theta > 0) + N(\cos\theta < 0)}$$

$$|\eta_{\ell^\pm}| \le 2.4\ , \qquad p_T^{\ell^\pm} \ge 40\ \mathrm{GeV}$$



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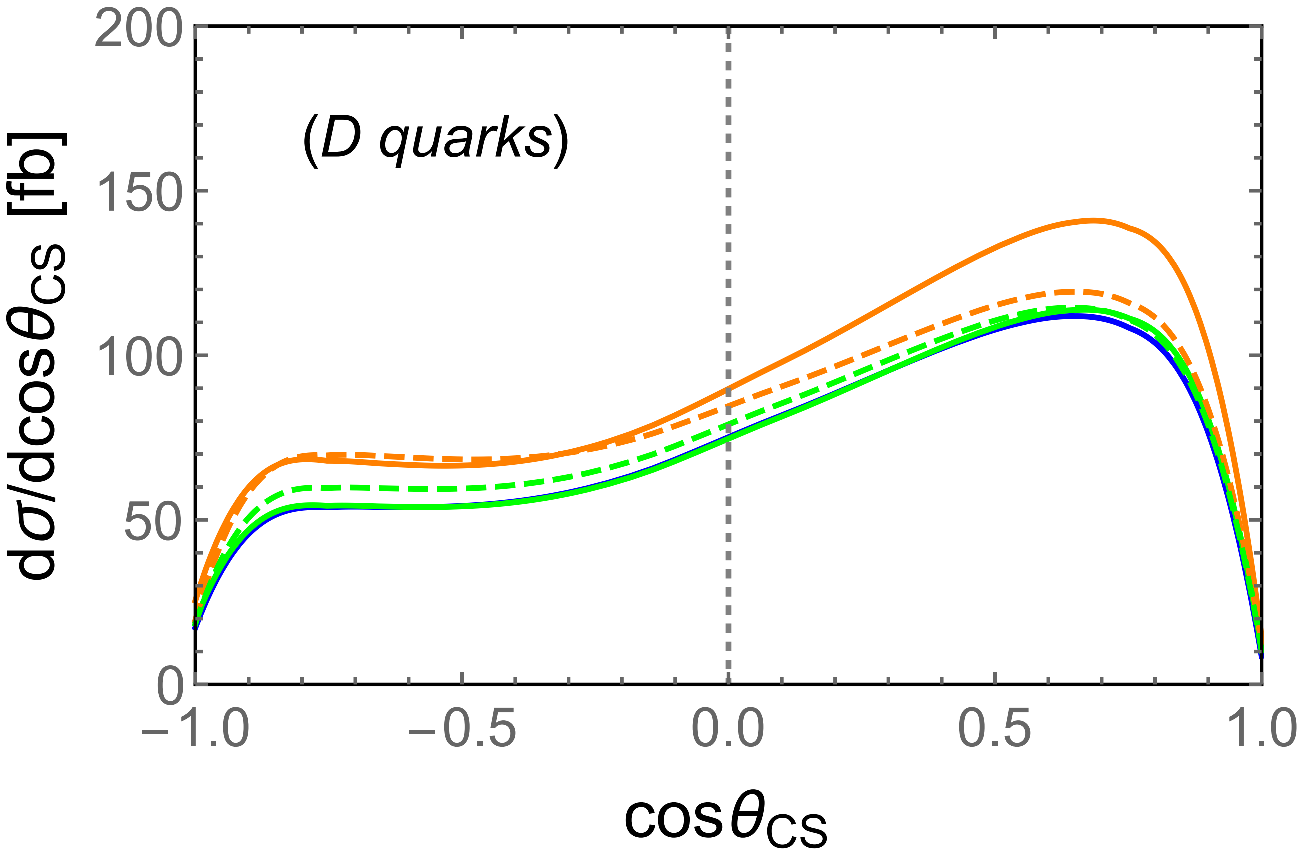

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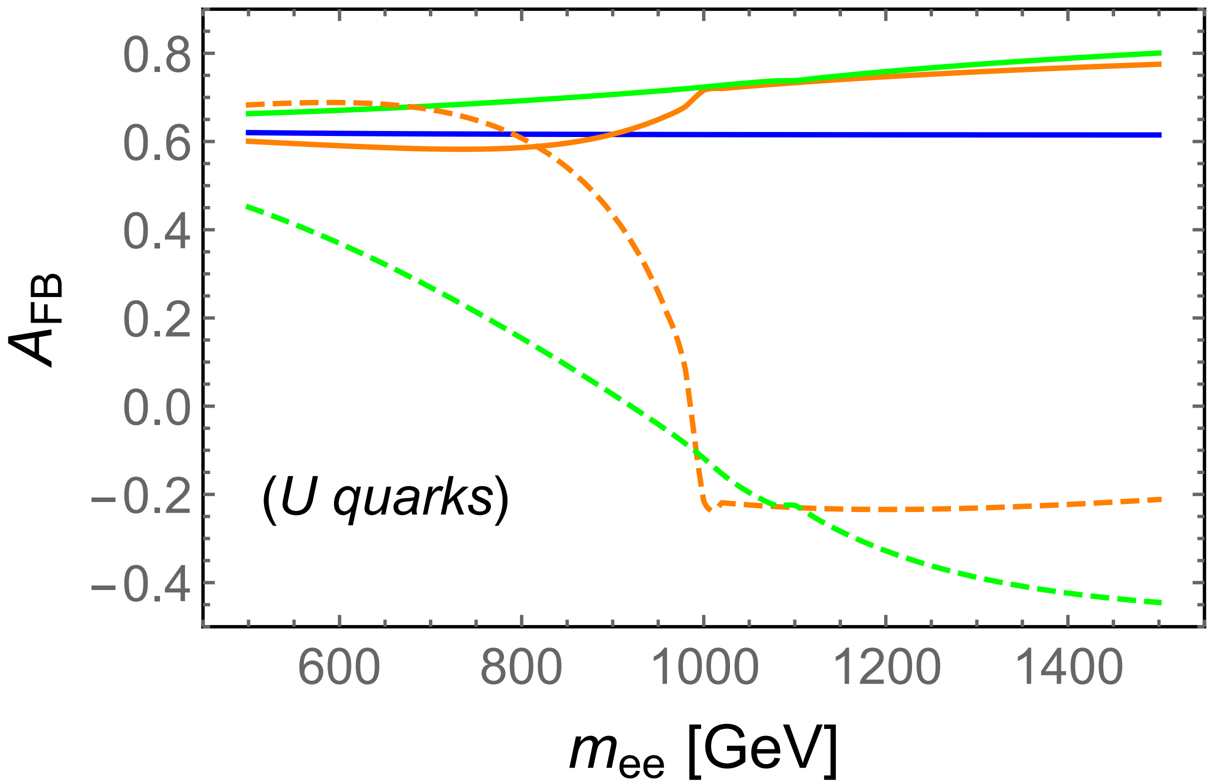

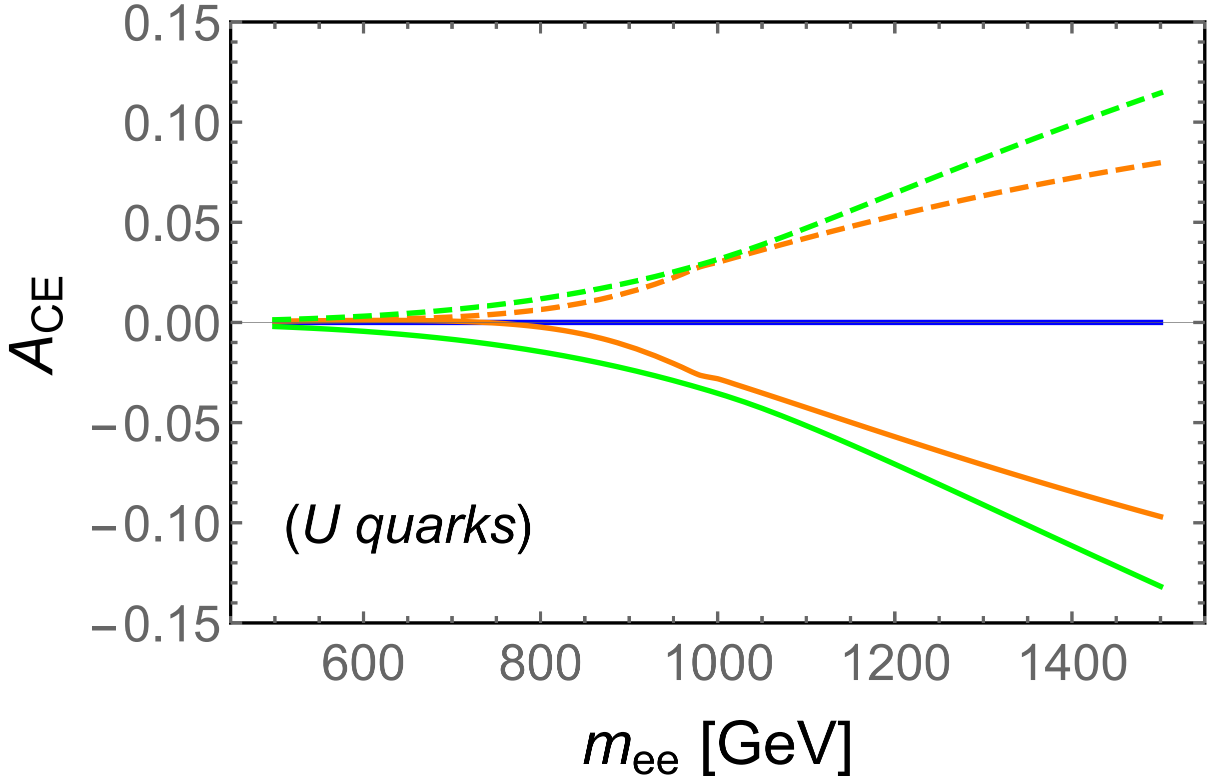

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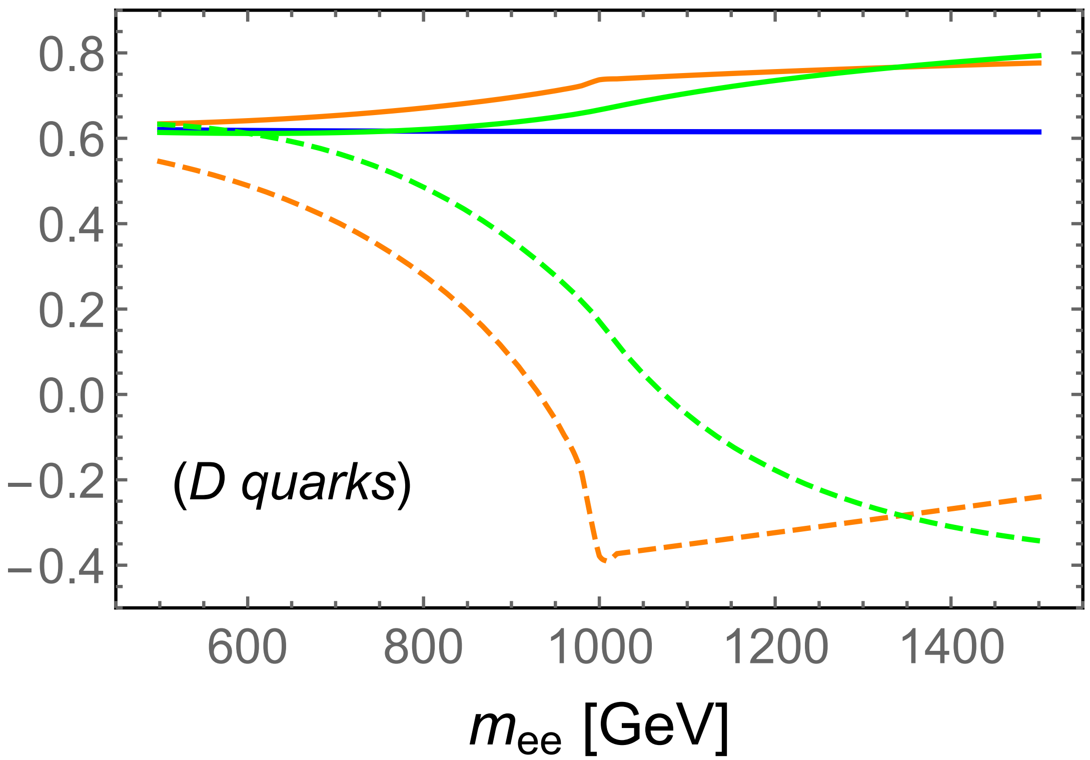

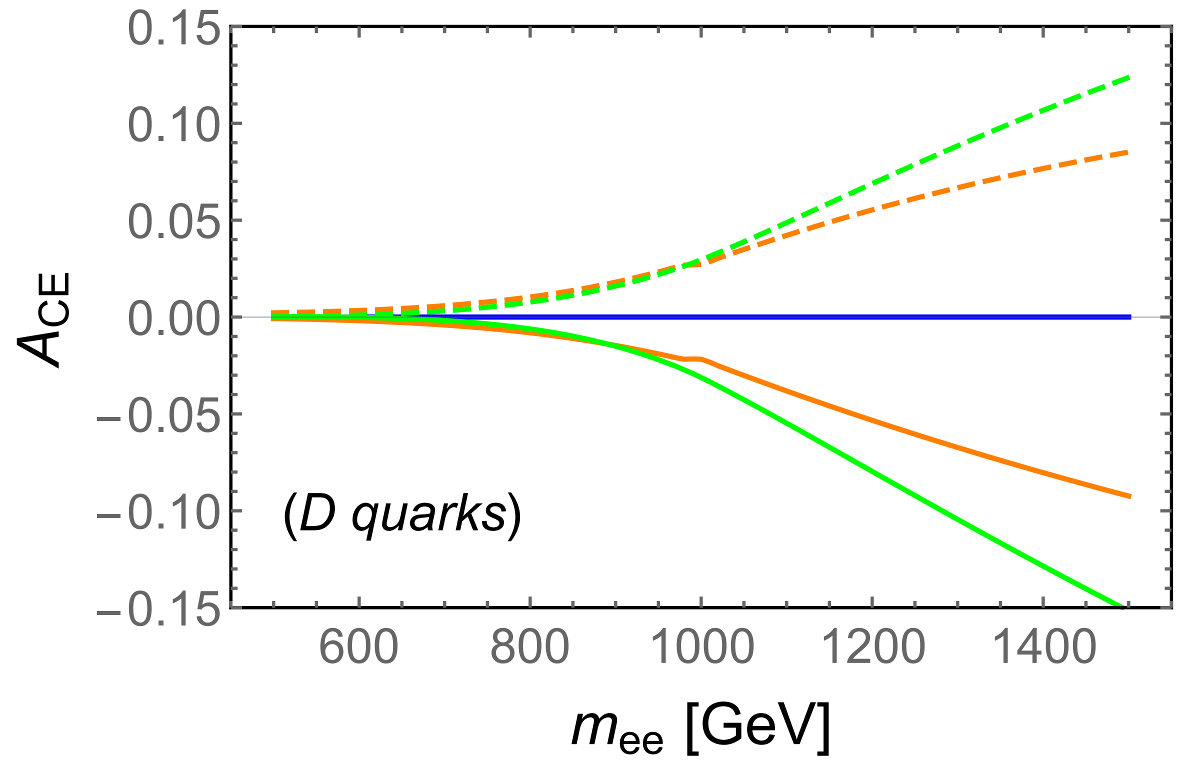

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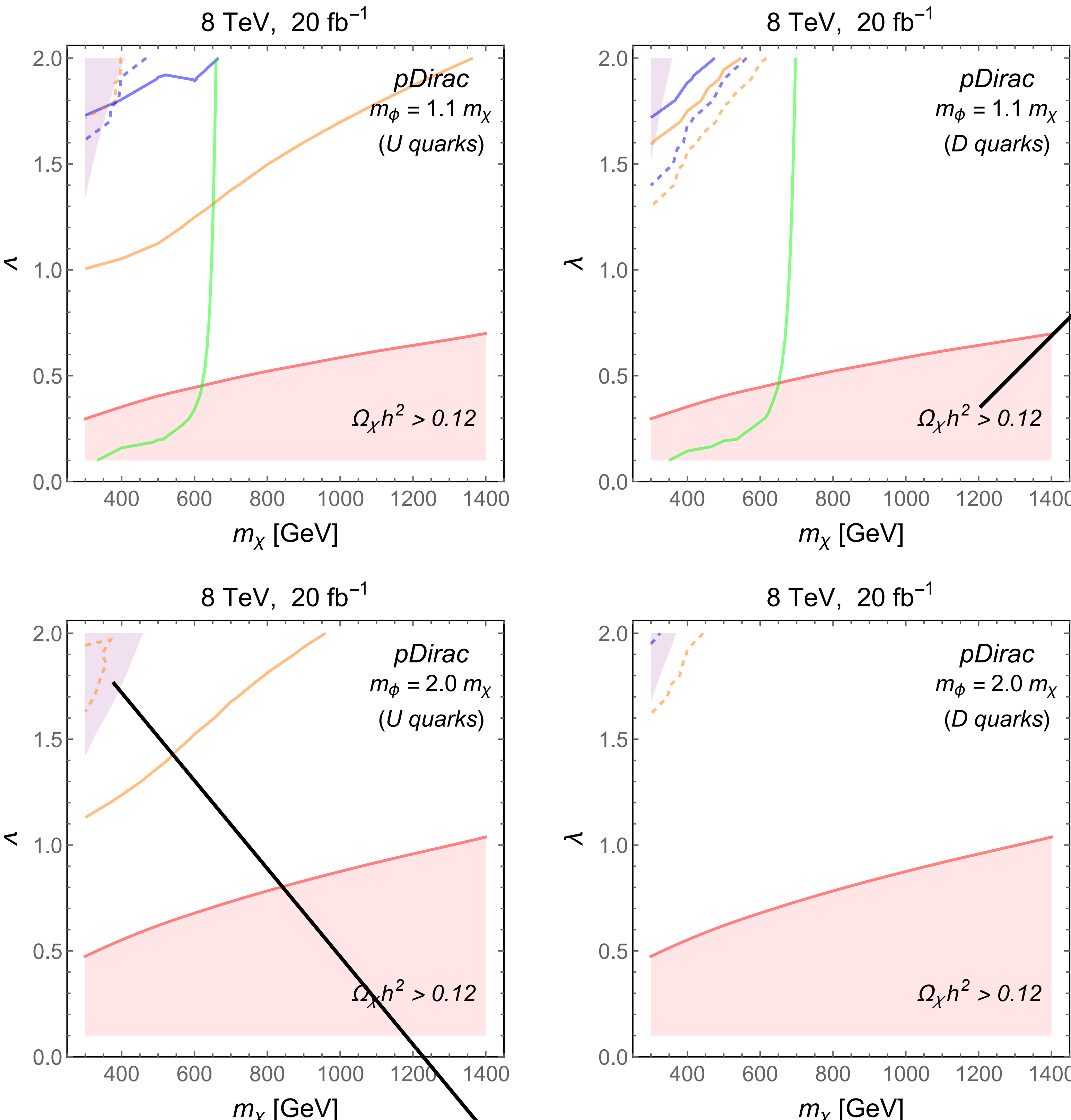
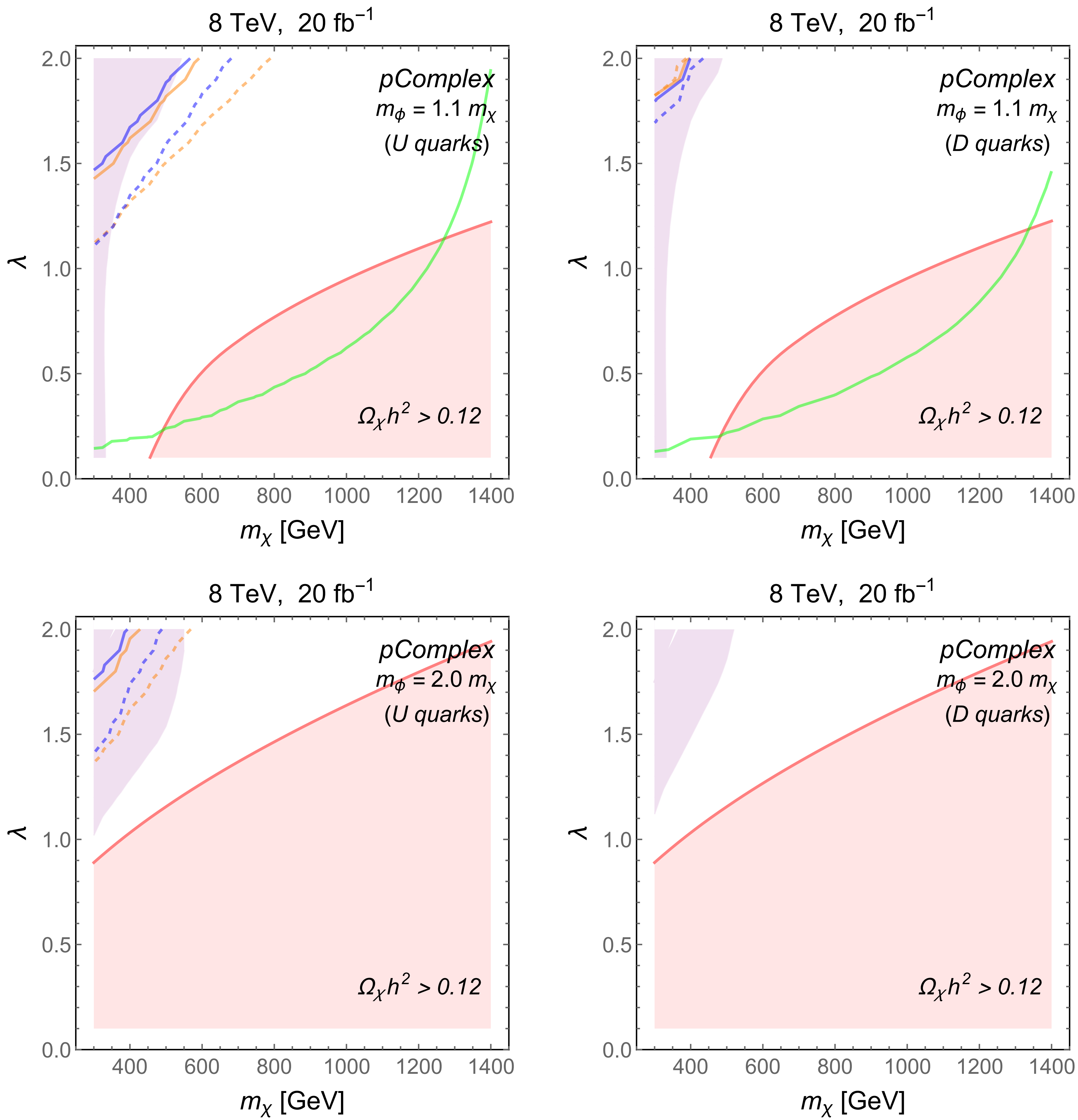
- Bounds from 8 TeV:



MicrOmegas

Purple jets+MET bound
Blue is RL model
Orange is RR model
green is DD bound
solid is m_{ee}
dashed is $\cos\theta_{CS}$

Reinterpretation of T2qq



Purple jets+MET bound
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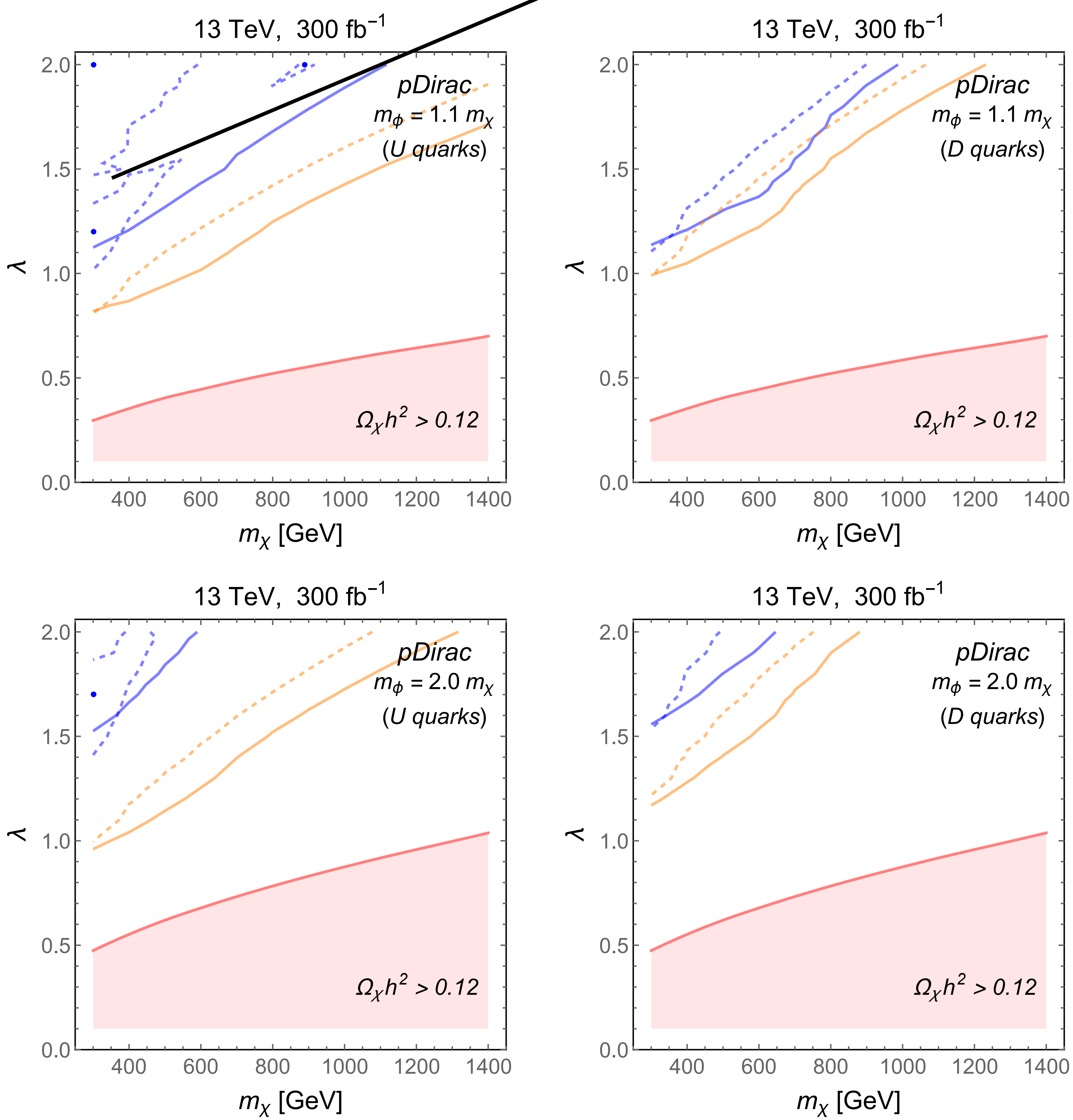
green is DD bound
solid is m_{ee}
dashed is $\cos\theta_{CS}$

- Prospect for 13 TeV:

Negative interference



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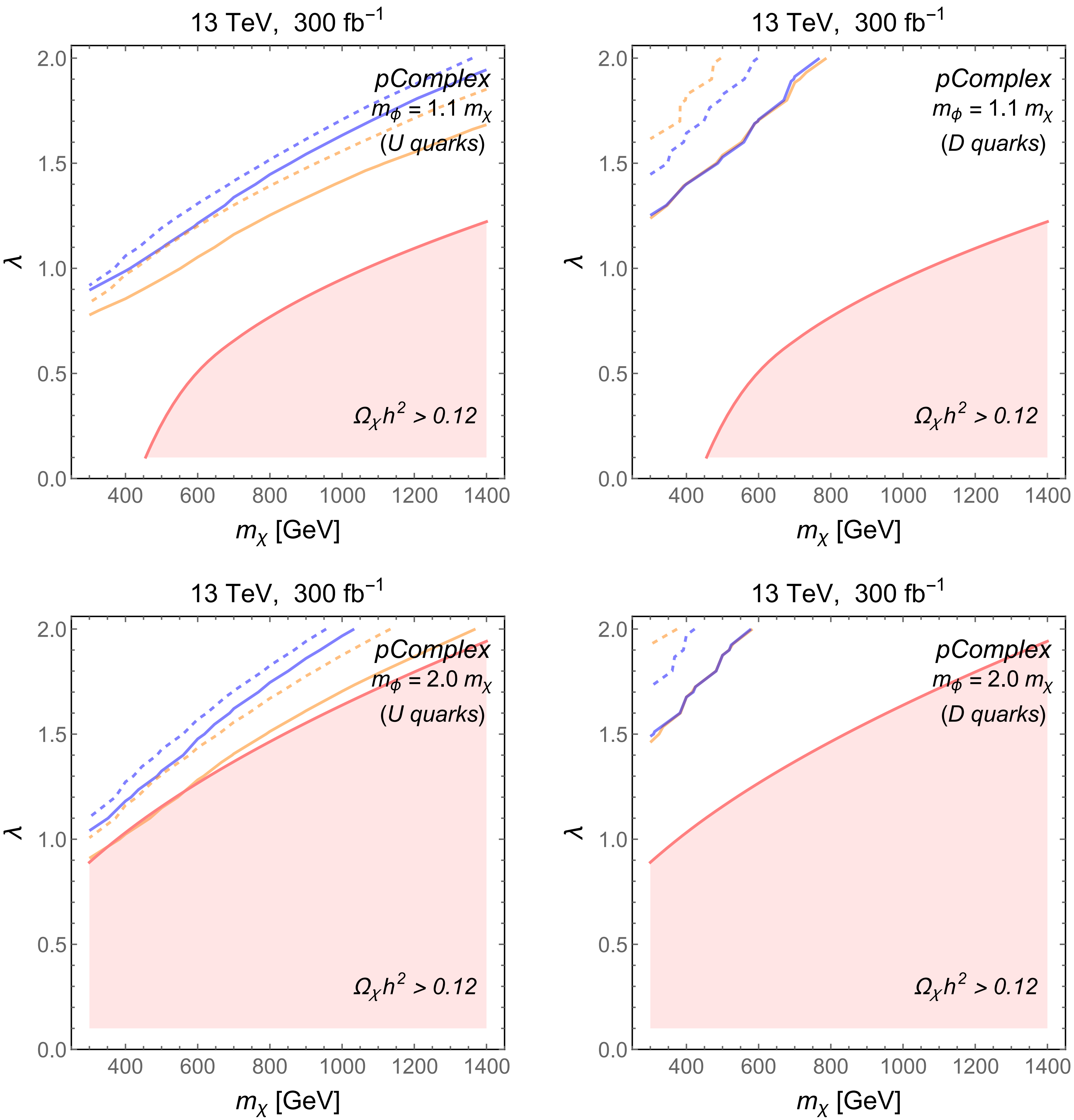

Blue is RL model
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solid is m_{ee}
dashed is cos θ_{CS}

Conclusions

- DM is one of the reasons that we need physics BSM.
- It is one that has some experimental evidence (although only gravitational)
- In models where DM couples to the SM one can use a mono-X channel to discover it….
- or use a cascade decay into DM (susy like…..)

- In this talk I have shown an alternative way of discovering DM using dilepton events

- If there are color and uncolor messengers (à la susy) one can produce dilepton via loops.

- Interference of those loops with the SM DY production can be the handle to discover new physics at the LHC.

- Angular correlations depend heavily on the spin of DM.

- The same approach can be use for LQ or Z’.