Dark Matter Mono-Lepton Channels
Simplified model in Madgraph

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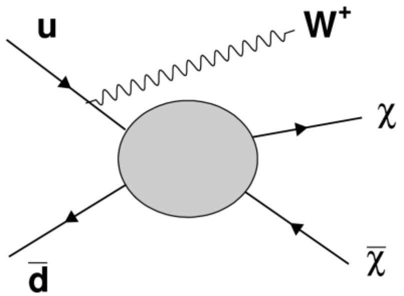
Mono-lepton Channels

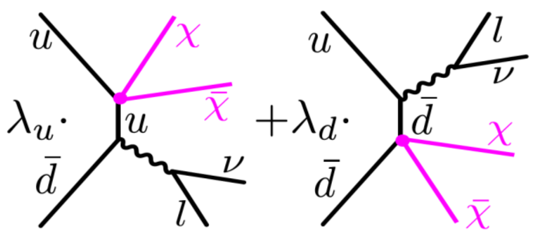


Channels used:

W→eν + MET

W→μν + MET

Signature: high p_T lepton + MET (dominated by $\chi\chi$)



$$\xi = \lambda_u \cdot \lambda_d \quad with \quad |\lambda_i| = 0 \, or \, 1$$

√8 TeV: used EFT. Madgraph.

Vector (V) and axial-vector (AV) couplings

Emphasis on **interference**, limits for $\xi = \pm 1, 0$

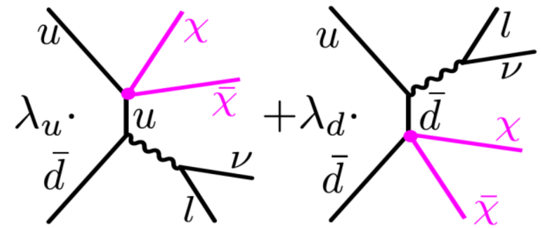
arXiv:1208.4361v2

√13 and √14 TeV: simplified model (DMV) implemented in **Madgraph**

Ref: "Missing Energy Signatures of Dark Matter at the LHC" Patrick J. Fox, Roni Harnik, Joachim Kopp, Yuhsin Tsai (2011). arXiv:1109.4398

Mono-Lepton (EFT)

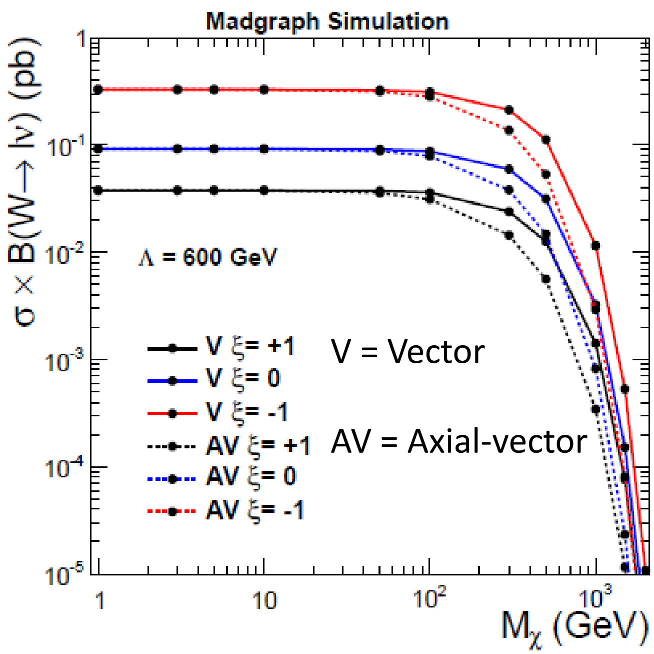
CMS: EXO-12-060, EXO-13-004
and arXiv:1408.2745
Interference from arXiv:1208.4361

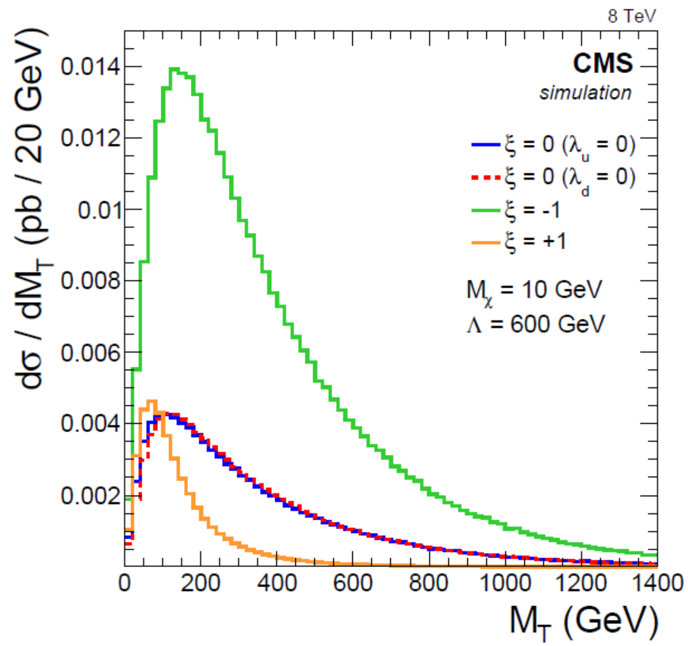


Mono-lepton channel sensitive to possibly different coupling to u- and d-type quarks

Parametrized by $\xi = -1, 0, +1$
(interference)

Madgraph simulation





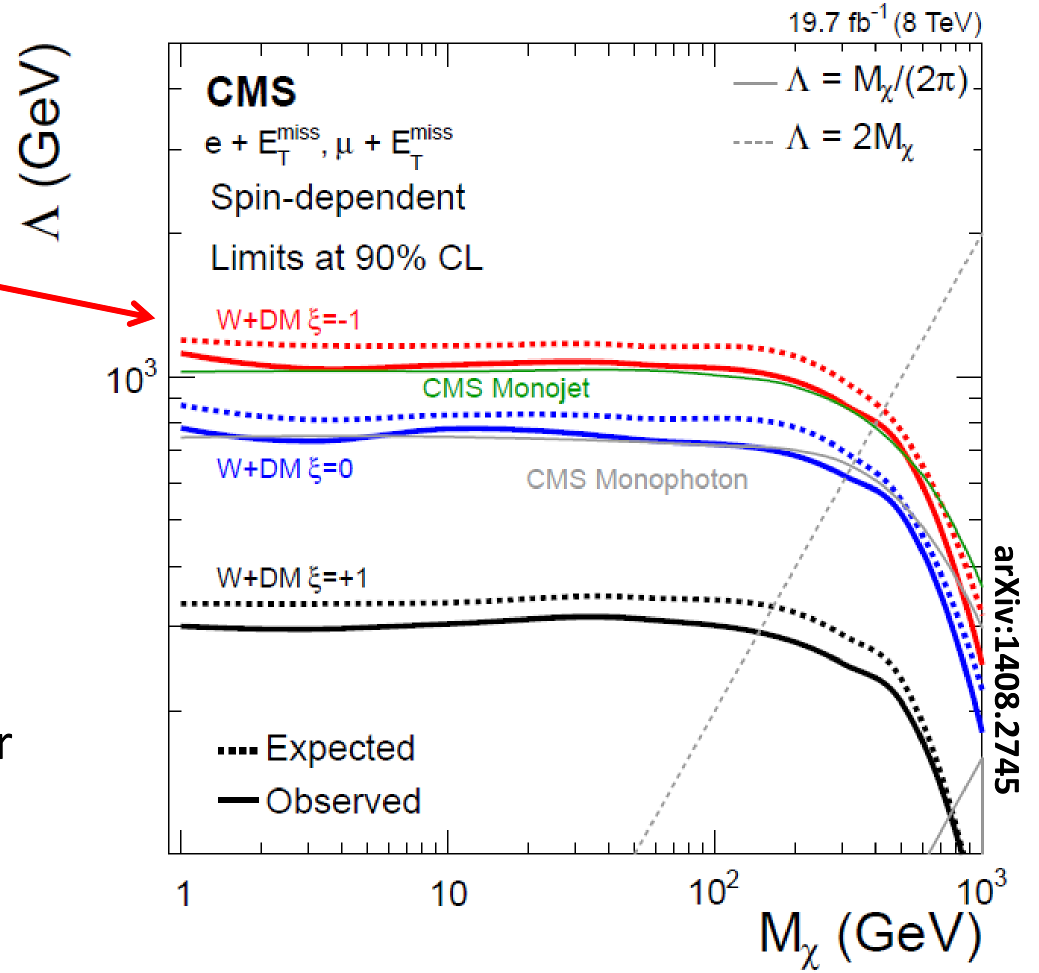
Largest cross section for ξ = -1
For $M\chi$ <~70 GeV same cross section for V and AV coupling of fixed ξ

Interference type influences M_T shape
→ impact on sensitivity

Because of ξ always three results for each coupling

For ξ= -1 maximum cross section. Sensitivity comparable to monojet.
To reduce no. of parameters, concentrate on ξ= -1 in the following, although ξ= +1 has very different signal shape & sensitivity.

pp cross-section and lambda limits nearly independent on coupling (vector vs axial-vector) due to similar cross section.



Turning to Simplified Models

Switch to MG simplified model because it does include interference

(DMV) arXiv:1109.4398

Madgraph-version 2.1.2.

Model version 1.0 from P. Fox, J. Kopp et al.

Mediator = Z´

Four parameters in Madgraph:

- DM mass M_χ
- Mediator mass M_{Med}
- Mediator width Γ_{med}
- Couplings = $\sqrt{g_{SM}\, g_{DM}}$

DMV implemented in MG as **V-A**.

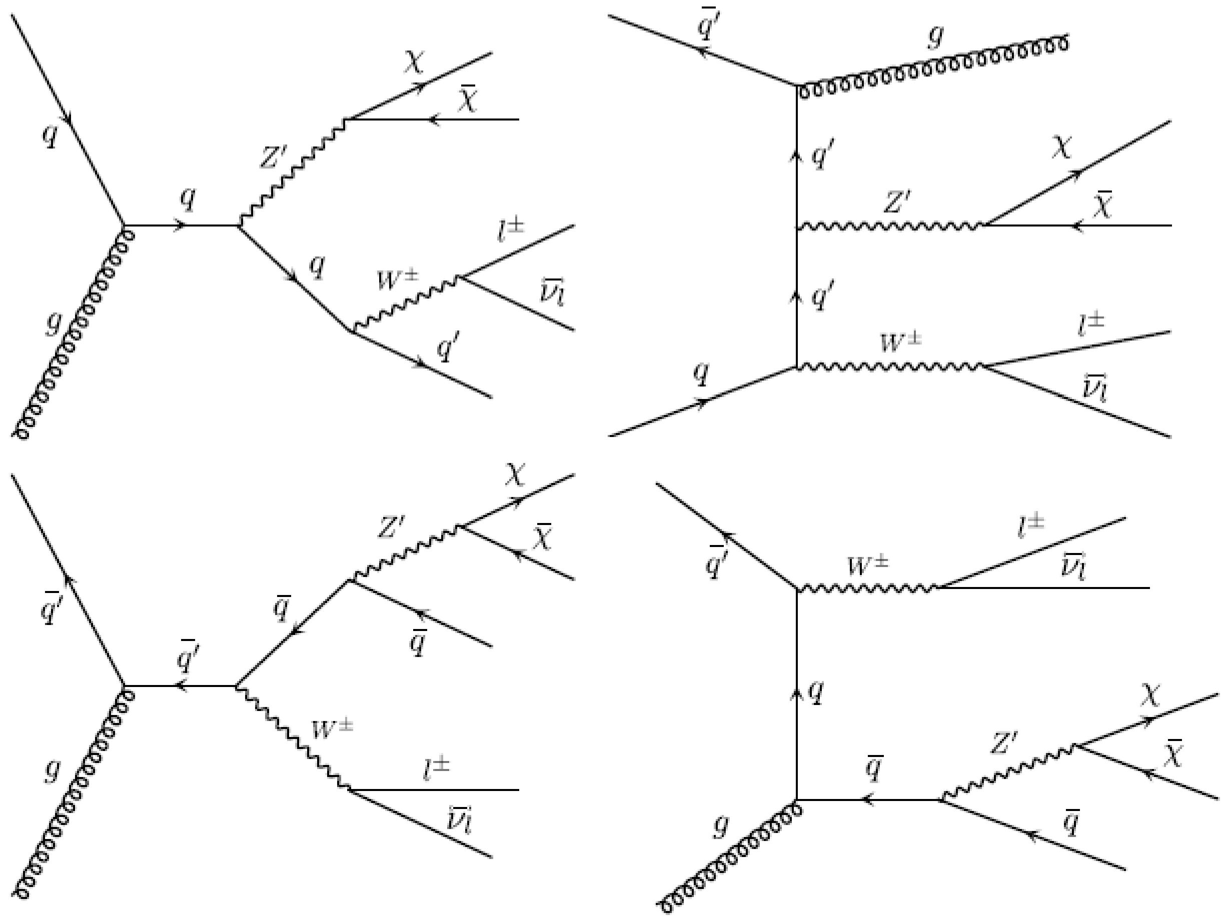
We modified it to either pure V or A.
From EFT interpretation we know V≈A cross sections very similar.
Concentrate on axial-vector coupling where LHC competitive to direct detection for (not for V).

Up to now always used $g_{DM} = g_{SM} = 1$

Discuss width later

Feynman Graphs (Madgraph)

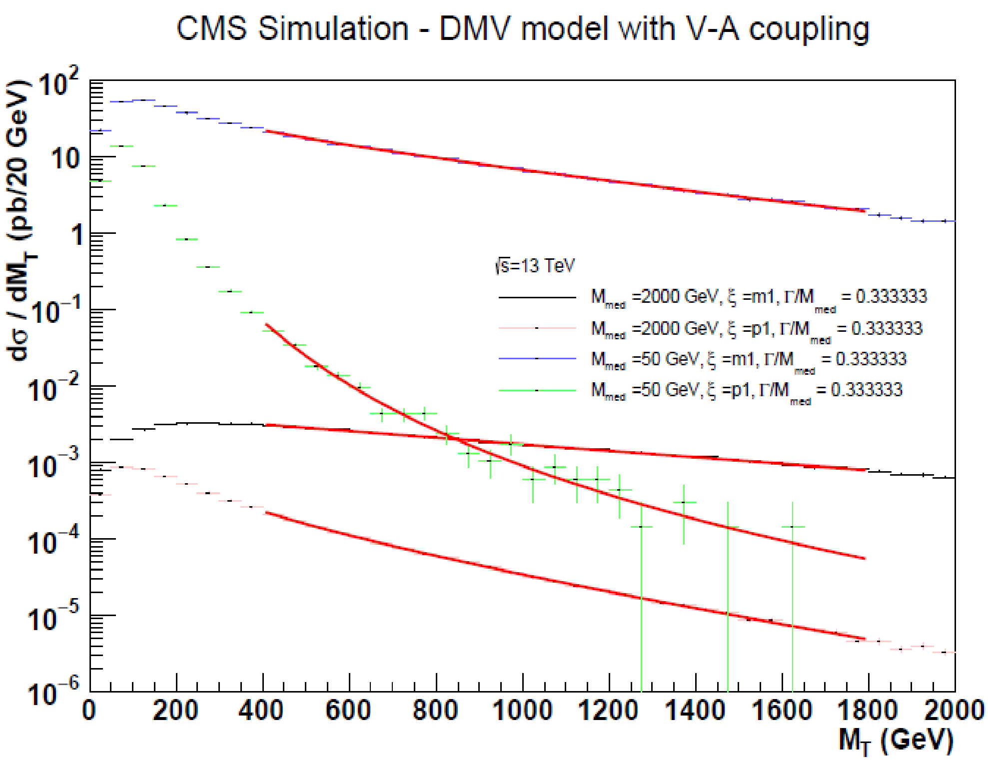
Feynman graph examples for process $pp \rightarrow W\chi\bar{\chi}(j)$, $W \rightarrow l\,\nu_l$:



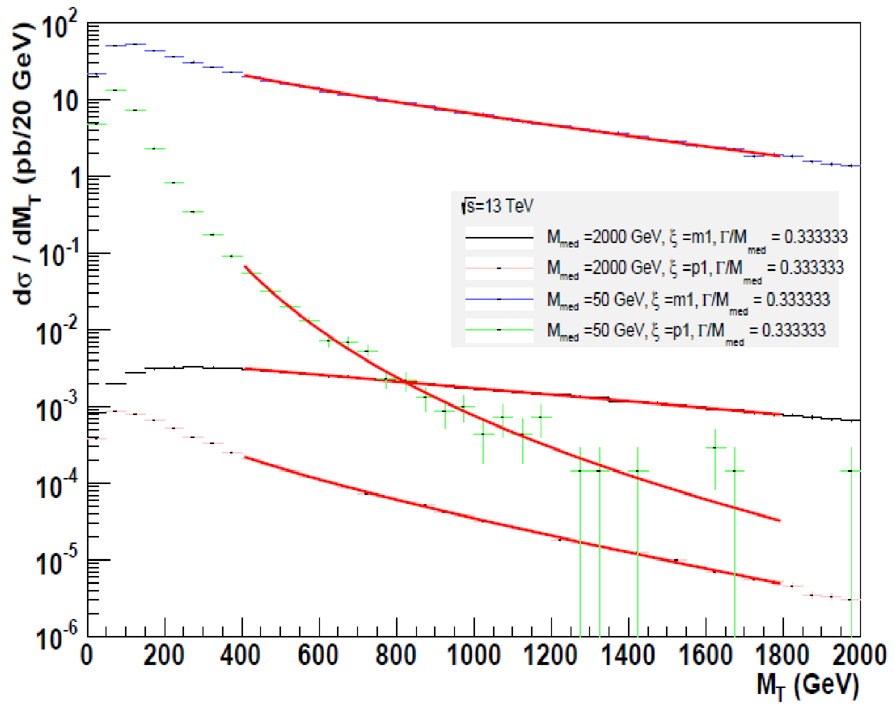
ℓ = e,μ

Same model could be used for hadronic W-channels

Comparison unmodified V-A and modified axial-vector coupling

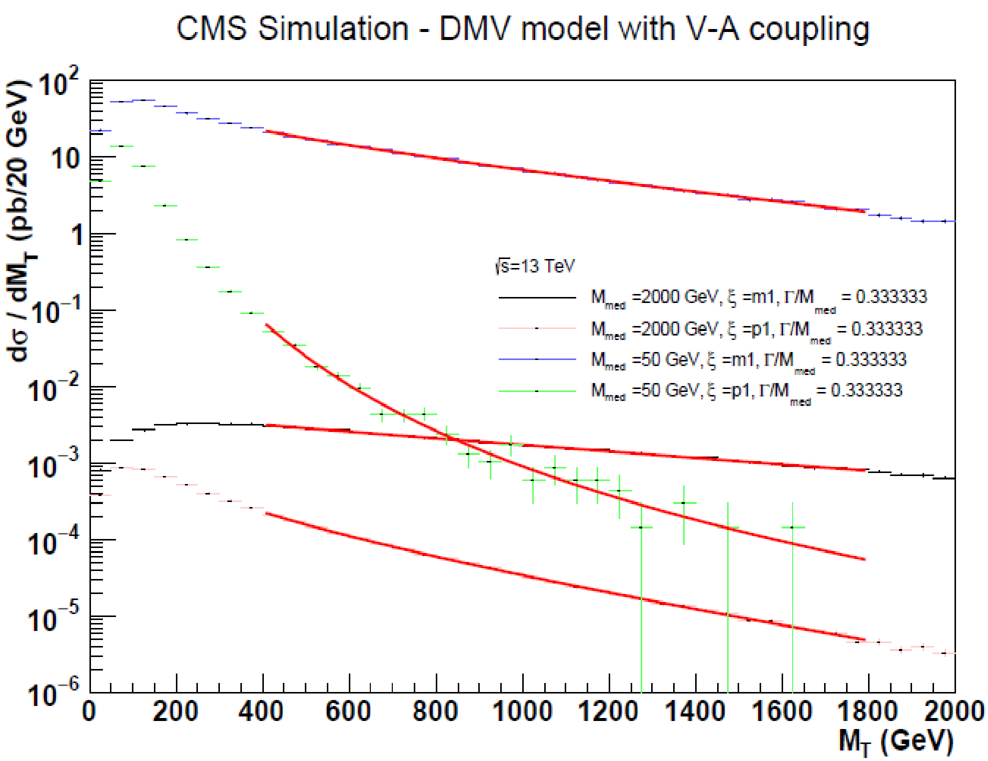


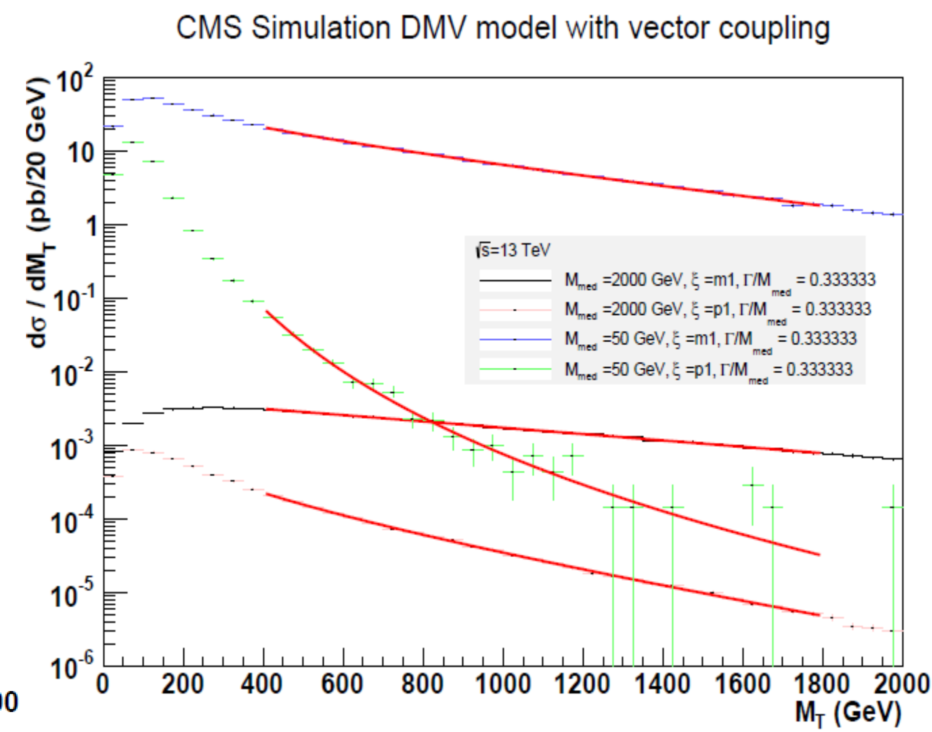
Modified DMV model with axial-vector coupling



→ Nearly no difference

Comparison unmodified V-A and modified vector coupling





Similarities in xsec for V and AV xsec and M_T shape (as seen in EFT) still holds. Allows to reduce number of samples to be generated.

cross section values:

$m_{\mathbf{med}}$ (GeV)	ξ	$\sigma \times$BR (pb), V-A	$\sigma \times$BR (pb), axial vector	$\sigma \times$BR (pb), vector only
50	-1	524.5	503.9 $\pm$ 0.2934	503.9 $\pm$ 0.2934
500	-1	-	5.306 $\pm$ 0.00349	5.306 $\pm$ 0.00349
2000	-1	0.08155	0.08153 $\pm$ 4.974e-05	0.08153 $\pm$ 4.974e-05
50	+1	29.60	28.92 $\pm$ 0.01883	28.92 $\pm$ 0.01883
500	+1	-	0.4943 $\pm$ 0.0003043	0.4943 $\pm$ 0.0003043
2000	+1	0.005660	0.005661 $\pm$ 3.083e-06	0.005661 $\pm$ 3.083e-06

Same xs as well as m_T spectrum for supposedly pure vector and axial vector coupling after changes to the DMV model!

Selected parameters for MG5 sample generation

- $\xi = -1, +1$ — ξ= -1 with max xsec, ξ = +1 with very different MT shape, hence impact on sensitivity. ξ = 0 can be scaled from -1.
- m_{DM} = 1 GeV, 10 GeV, 250 GeV
- $g_{DM} = g_{SM} = 1$ — Keep SM and DM couplings at 1 for now.
- upper limit on $\frac{\Gamma}{m_{\text{med}}} = \frac{1}{3}$
- AV coupling implemented in DMV model
- $m_{\text{med}} = 0.05, 0.5, 2$ TeV (selected from shape analysis parameter plots)

[6] $\Gamma = M/8\pi$ corresponds to a mediator that can annihilate into only one quark flavor and helicity and has couplings $g_\chi g_q = 1$. Since in figure 7 we have assumed couplings to all quark helicities and flavors (collider production is dominated by coupling to up-quarks though), and since $g_\chi g_q > 1$ in parts of the plot (see dashed contours), $\Gamma = M/8\pi$ can be regarded as an approximate lower limit on the mediator width.

(rationale for lower limit, arxiv:1109.4398v2)

Vary Mediator Width

Mediator width has impact on sensitivity. But little impact on M_T spectrum, no need to vary kinematic selections.

Width can be set in MG. Starting point: varied width between Γ=$M_{med}/3$ and Γ=$M_{med}/8\pi$

Alternatively, calculate width from axial couplings formulas:

$$\Gamma(Z' \to \bar{\chi}\chi)_{\rm vector} = \frac{g_{\rm DM}^2 M_{\rm med}}{12\pi}\left(1+\frac{2m_{\rm DM}^2}{M_{\rm med}^2}\right)\sqrt{1-\frac{4m_{\rm DM}^2}{M_{\rm med}^2}}$$

$$\Gamma(Z' \to \bar{q}q)_{\rm vector} = \frac{3g_q^2 M_{\rm med}}{12\pi}\left(1+\frac{2m_q^2}{M_{\rm med}^2}\right)\sqrt{1-\frac{4m_q^2}{M_{\rm med}^2}}$$

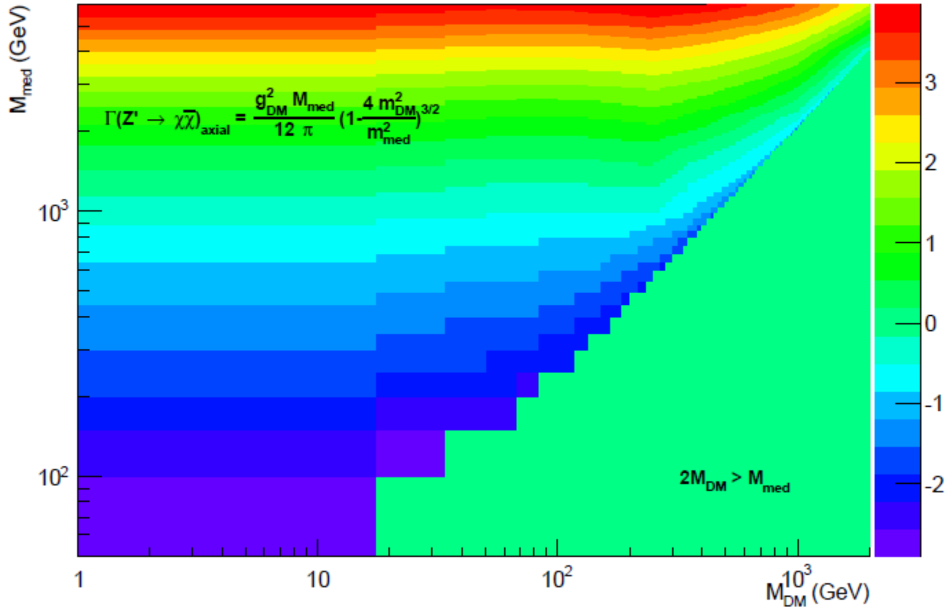
$$\Gamma(Z' \to \bar{\chi}\chi)_{\rm axial} = \frac{g_{\rm DM}^2 M_{\rm med}}{12\pi}\left(1-\frac{4m_{\rm DM}^2}{M_{\rm med}^2}\right)^{3/2}$$

$$\Gamma(Z' \to \bar{q}q)_{\rm axial} = \frac{3g_q^2 M_{\rm med}}{12\pi}\left(1-\frac{4m_q^2}{M_{\rm med}^2}\right)^{3/2}$$

For high M_{med} corresponds rather to $\Gamma \approx M/12\pi$. Resonance becomes very narrow and sensitivity increases.

FT = DMV model

$\log_{10}(\sigma_{EFT}/\sigma_{FT})$, $\sqrt{s}$=13 TeV, ξ=-1, AV



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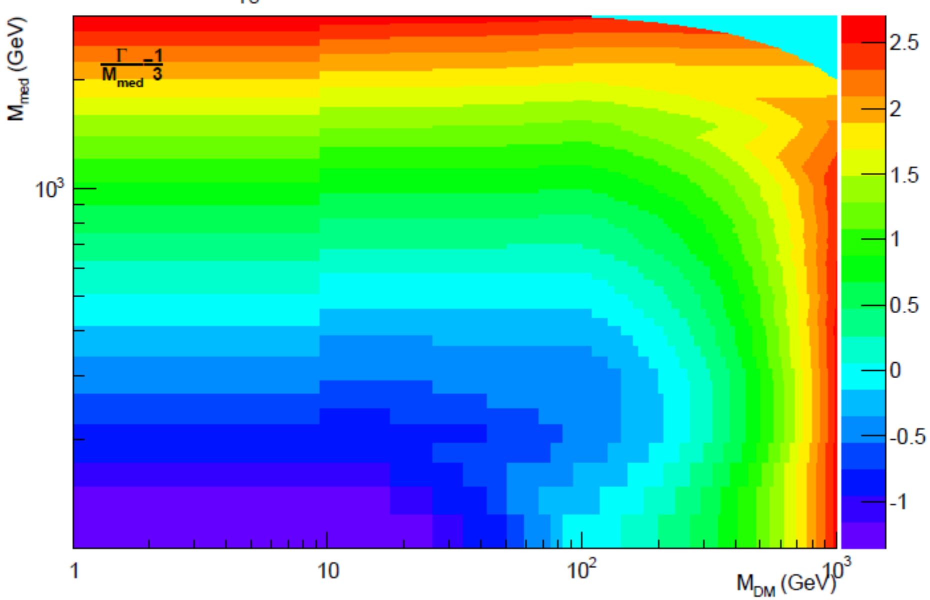

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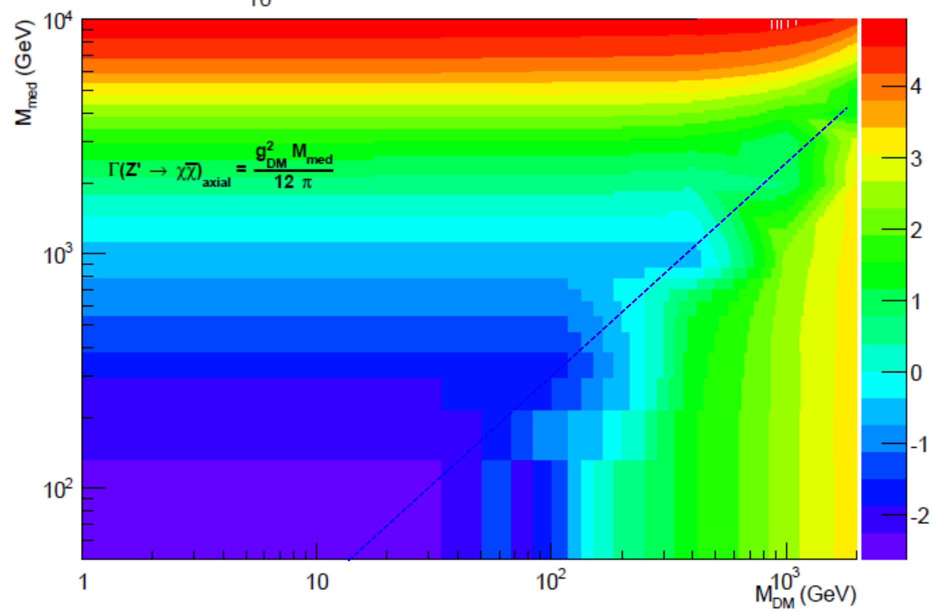
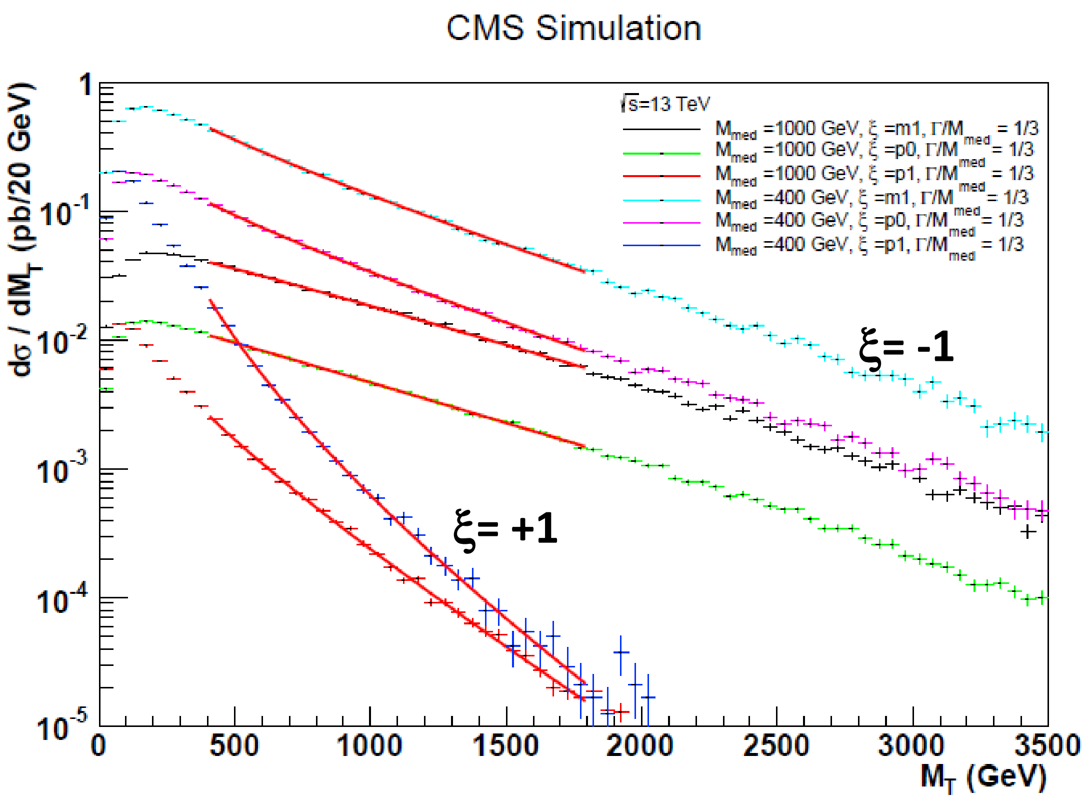


Implications of Simplified Model on M_T Spectrum

Studied impact of model parameters on transverse mass M_T spectrum for 13 TeV. Adress question if kinematic selections (pT/MET, $\Delta\phi$) have to be re-optimized?

For Γ/M = 1/3

See Γ/M=1/8π next page



Conclusions:

- Mediator width has little impact on M_T shape
- Mediator mass slightly changes M_T spectrum
- M_T shape dependence on ξ as seen in EFT

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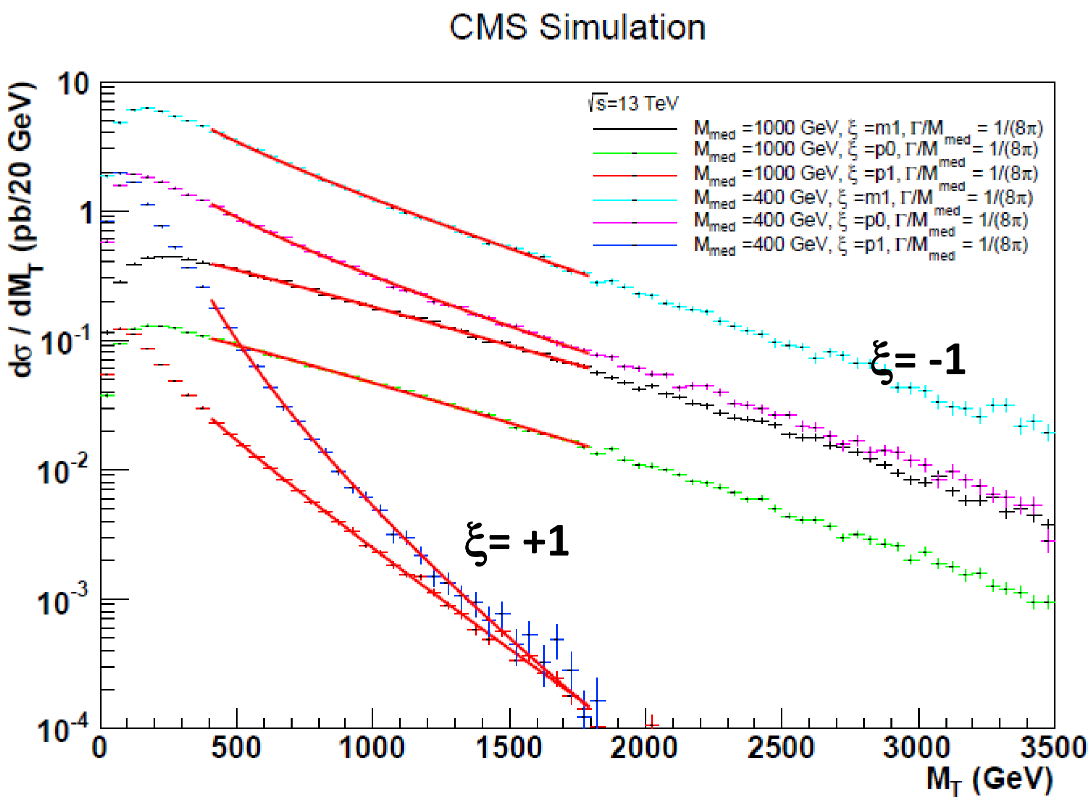

Conclusions:

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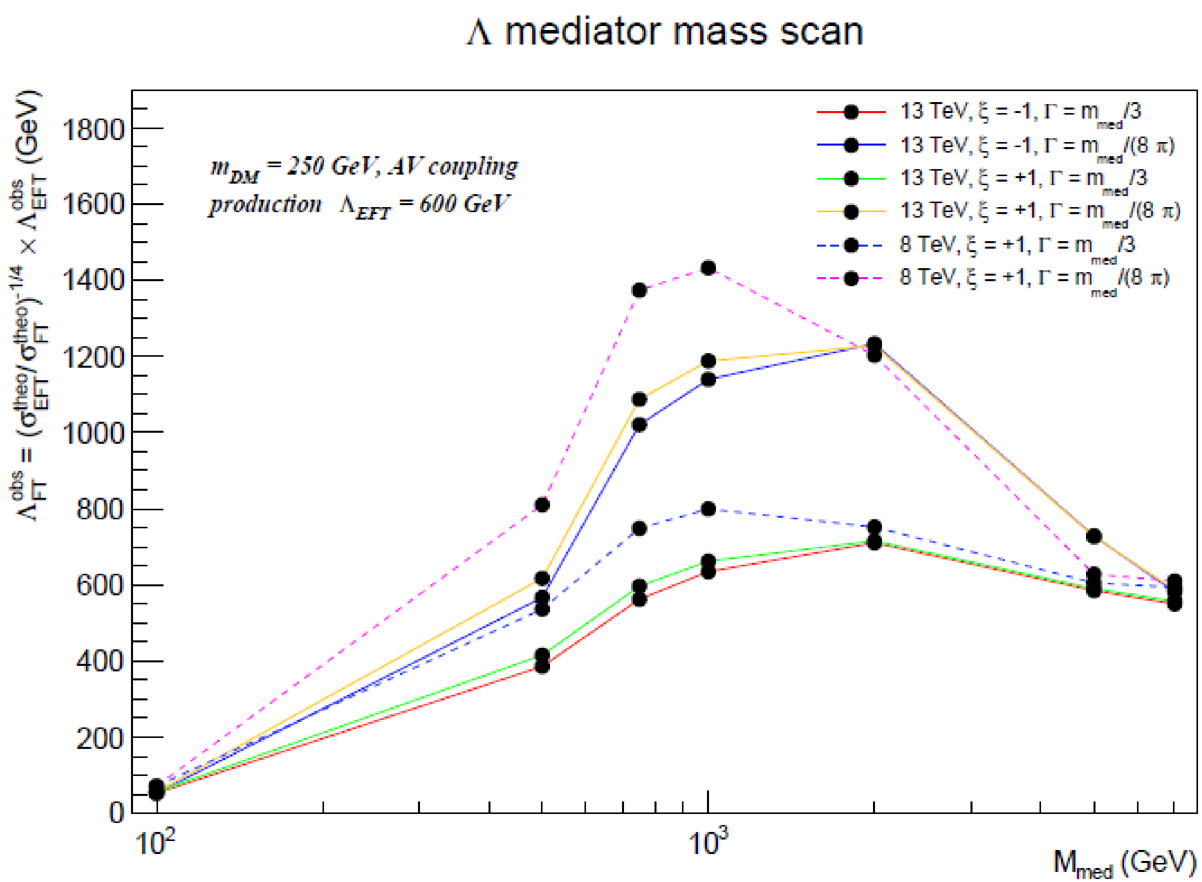
Mediator mass scan for √s = 8, 13 TeV

Varied width between $\Gamma = M_{med}/3$ and $\Gamma = M_{med}/8\pi$



Plans and some Questions

Next round of data analysis in terms of EFT and DMV simplified model (MG implementation). Use MG as baseline to study interference?

Info of this model on twiki?

Vary the width or use only very narrow one?

Take m_{DM} and M_{med} mass points from ATLAS/CMS recommendation.

Need to simulate only ξ = -1 and ξ = +1 where M_T shape is different. ξ = 0 can be scaled.

Also vary coupling strength (so far used $g_{SM} = g_{DM} = 1$).

Proposed values: g_{SM} and g_{DM} = 0.3, 0.5, 1.0 and 1.45

Test other models with mono-lepton final state discussed in this forum