NLO predictions for Dark Matter production at the LHC

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In collaboration with:
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"New Physics at the LHC" meeting
Bonn, Germany

28th October 2015

Outlook

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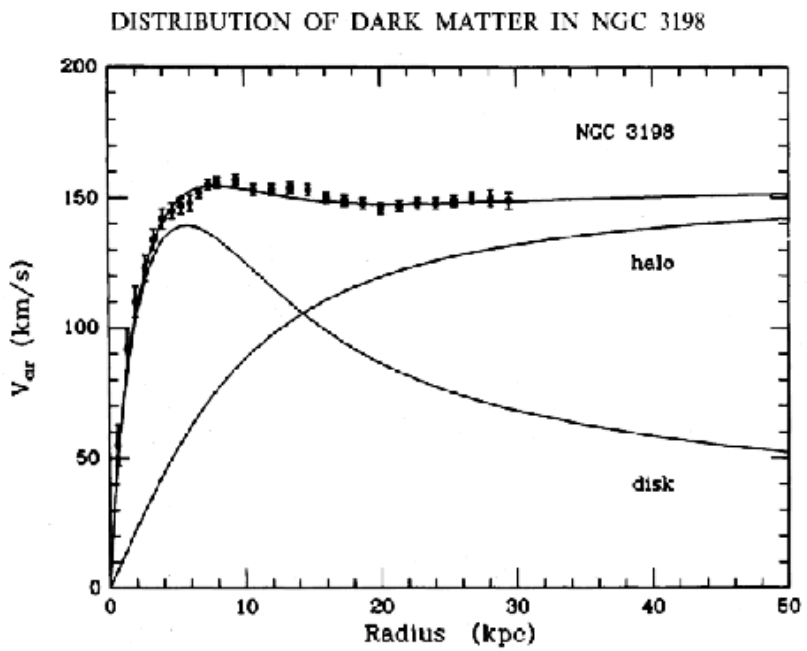
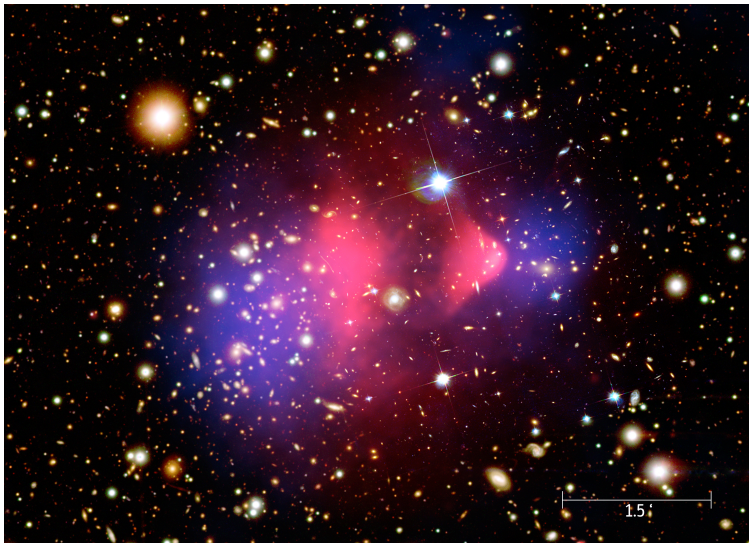
Standard
Model

Evidences for Dark Matter



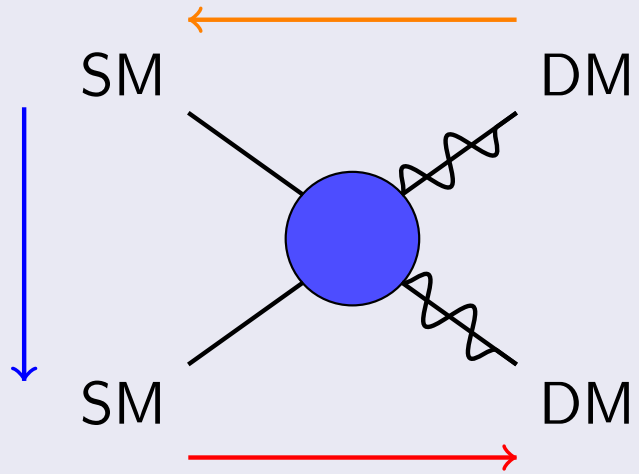
[Rubin, Ford, Kent, 1970]



[Clowe, Gonzalez, Markevitch, astro-ph/0312273]

And more: CMB, weak lensing, large scale structure ...
$\rightarrow$ Weakly Interacting Massive Particles (WIMPs)

Ways to find Dark Matter



- Indirect detection (AMS-02, PAMELA, ...)
- Direct detection (LUX, Xenon, ...)
- Collider search (LHC)

What theory for Dark Matter?

- Plethora of models $\rightarrow$ Need for model independent tools

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$\rightarrow$ Contact interaction / Effective Field Theory (EFT)

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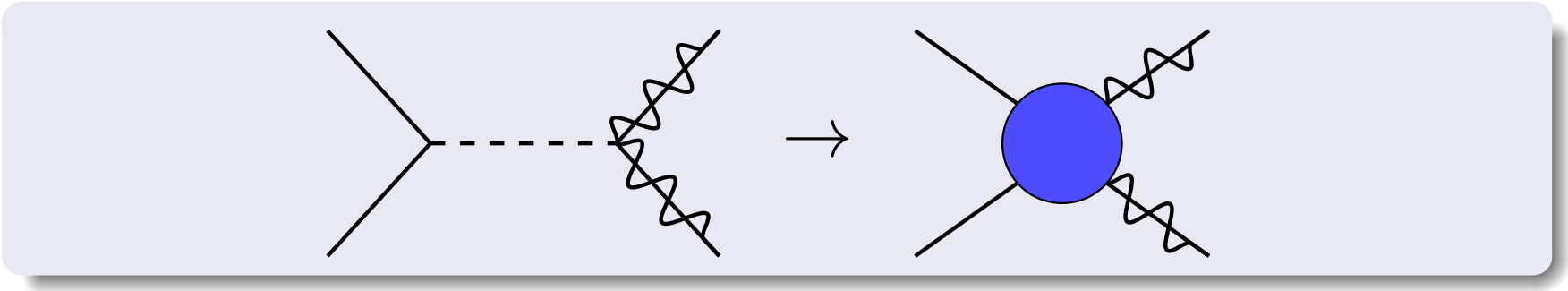
- The mediator is integrated out
  $\frac{1}{Q_{tr}^2 - M^2} = -\frac{1}{M^2}\left(1 + \frac{Q_{tr}^2}{M^2} + O\left(\frac{Q_{tr}^4}{M^4}\right)\right)$
  $\rightarrow \mathcal{O}_S = \frac{1}{\Lambda^2}(\chi\overline{\chi})(q\overline{q})$ with $\frac{1}{\Lambda^2} = \frac{g_\chi g_q}{M^2}$



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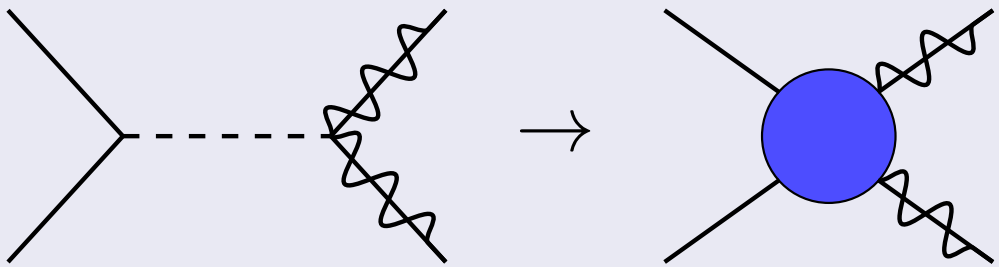
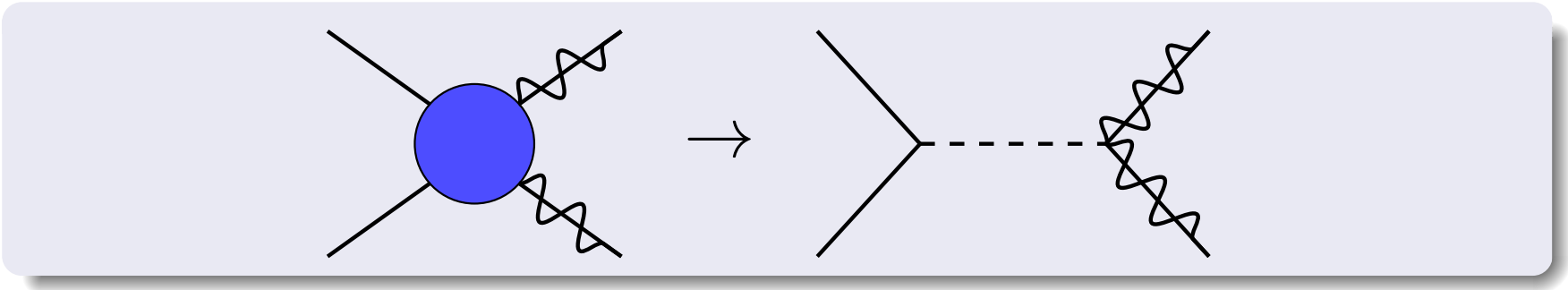


- Problematic at energies probed by the LHC [Busoni et al., 1402.1275]

What theory for Dark Matter?

→ Simplified models:



- Defined by the mediator and the dark matter
  - S-channel or t-channel
  - Mediator: scalar or vector
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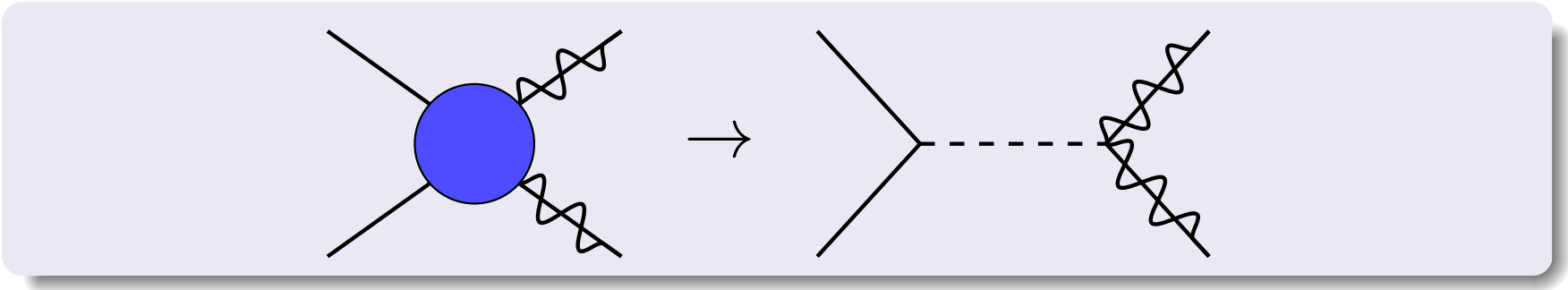

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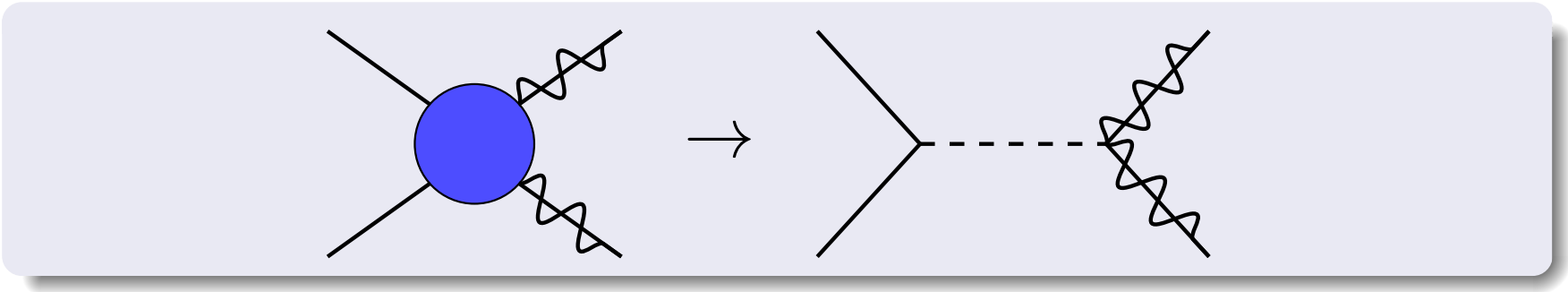

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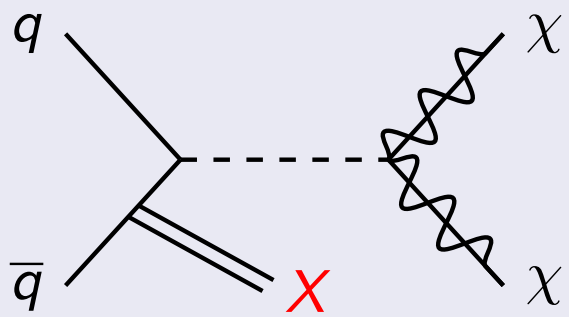
Review - Searches

Detection of dark matter at the LHC:

$\rightarrow$ MET + mono X (= jet, photon, W, Z, h), di-jets or top pair



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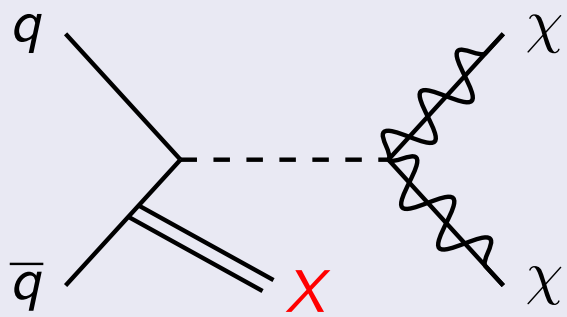

Studies in simplified model:

- Mono-jet + MET [Buchmueller et al., 1308.6799, 1407.8257], [Heisig et al., 1509.07867]
- Di-jet + MET [Chala et al., 1503.05916]
- Top pair + MET [Haisch and Re, 1503.0069]

→ Dark matter Forum: [Abercrombie et al., 1507.00966]

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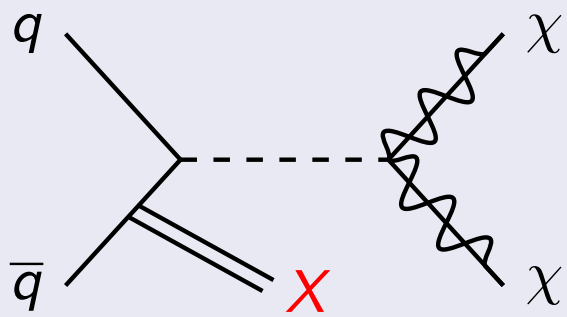

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Review - Computations

Precise predictions:

- NLO QCD correction to dark matter production ...
  - ... in association with gauge boson
    [Wang et al., 1107.2048], [Huang et al., 1210.0195], [Mao et al., 1403.2142],
    [Neubert et al., 1509.05785]
  - ... for mono-jet for EFT [Fox and Williams, 1211.6390],
- Matched to parton shower [Haisch et al., 1310.4491]
- Loop induced [Haisch et al., 1208.4605], [Harris et al., 1411.0535], [Buckley et al., 1410.6497],
  [Mattelaer and Vryonidou, 1508.00564]

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$\rightarrow$ Our work: [Backović, Krämer, Maltoni, Martini, Mawatari, MP; 1508.05327]

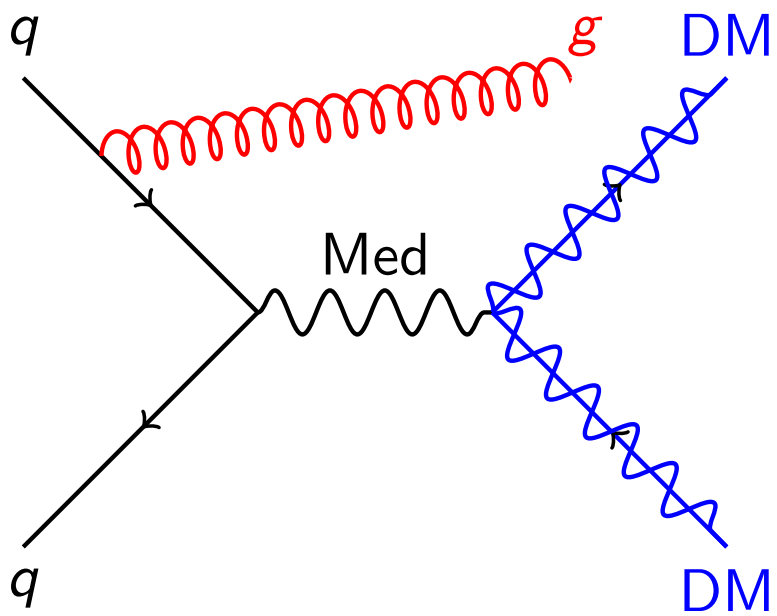
Fully automatised simplified model at NLO accuracy ...
... for arbitrary processes (also loop induced) ...
... matched to parton shower

Outlook

- Vector mediator (Y_1)

$$\mathcal{L}^{Y_1}_{X_D} = \bar{X}_D \gamma_\mu (g^V_{X_D} + g^A_{X_D} \gamma_5) X_D \; Y_1^\mu$$
$$\mathcal{L}^{Y_1}_{\mathrm{SM}} = \sum_{i,j} \left[\bar{q}_i \gamma_\mu (g^V_{q_{ij}} + g^A_{q_{ij}} \gamma_5) q_j \right] Y_1^\mu$$

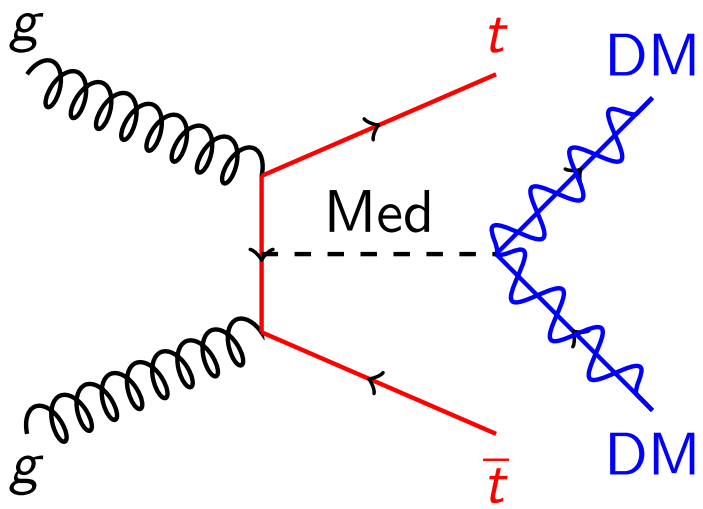
$\rightarrow$ Preferred signature: jet + MET



- Scalar mediator (Y_0)

$$\mathcal{L}_{X_D}^{Y_0} = \bar{X_D}(g_{X_D}^S + ig_{X_D}^P\gamma_5)X_D\, Y_0$$
$$\mathcal{L}_{\mathrm{SM}}^{Y_0} = \sum_{i,j}\left[\bar{q}_i \frac{y_{ij}^q}{\sqrt{2}}(g_{q_{ij}}^S + ig_{q_{ij}}^P\gamma_5)q_j\right] Y_0$$

$\rightarrow$ Preferred signature: top pair + MET



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- Calculation of arbitrary (also loop-induced) processes in MadGraph5_aMC@NLO [Alwall et al., 1405.0301]
- Can be used in MicroMegas [Belanger et al., 0803.2360] and MadDM [Backović et al., 1505.04190]

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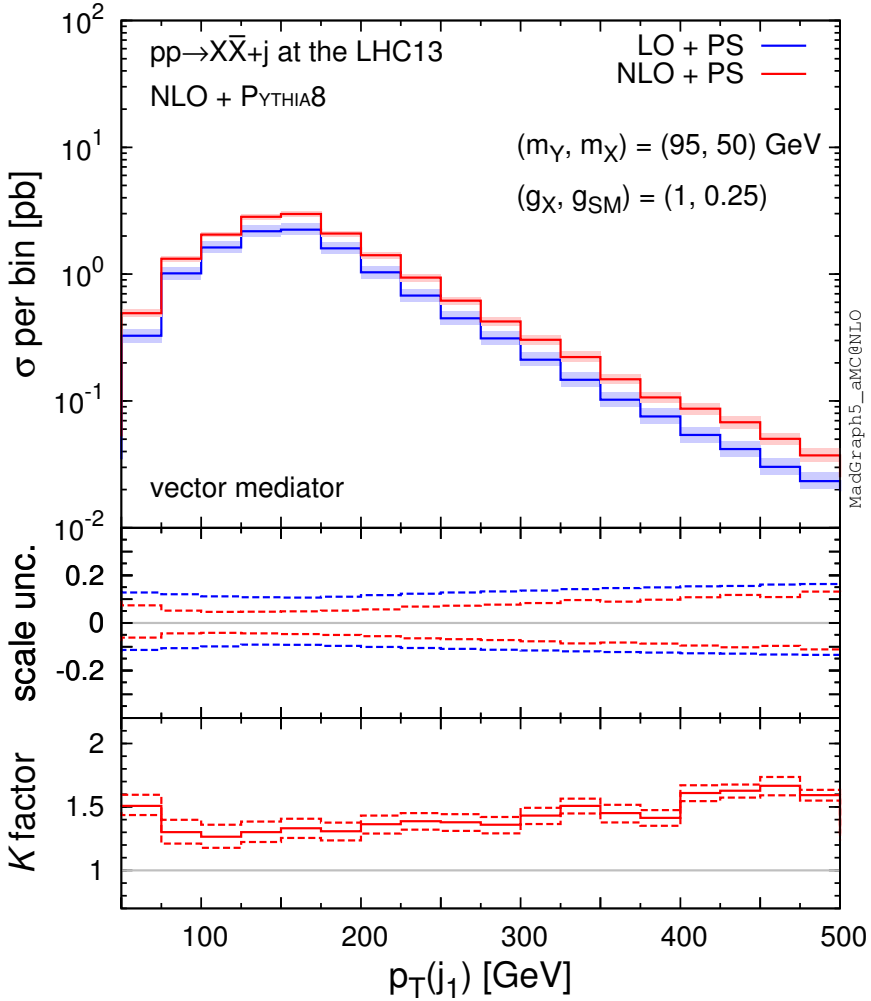
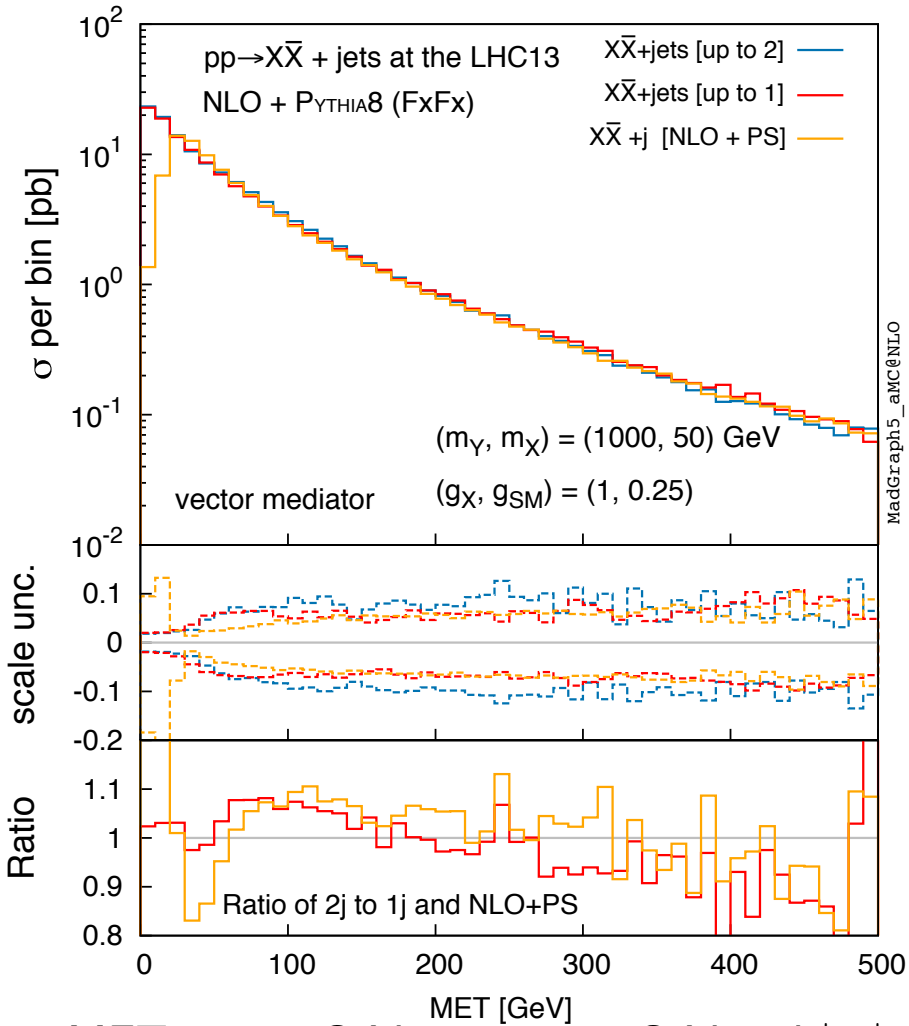


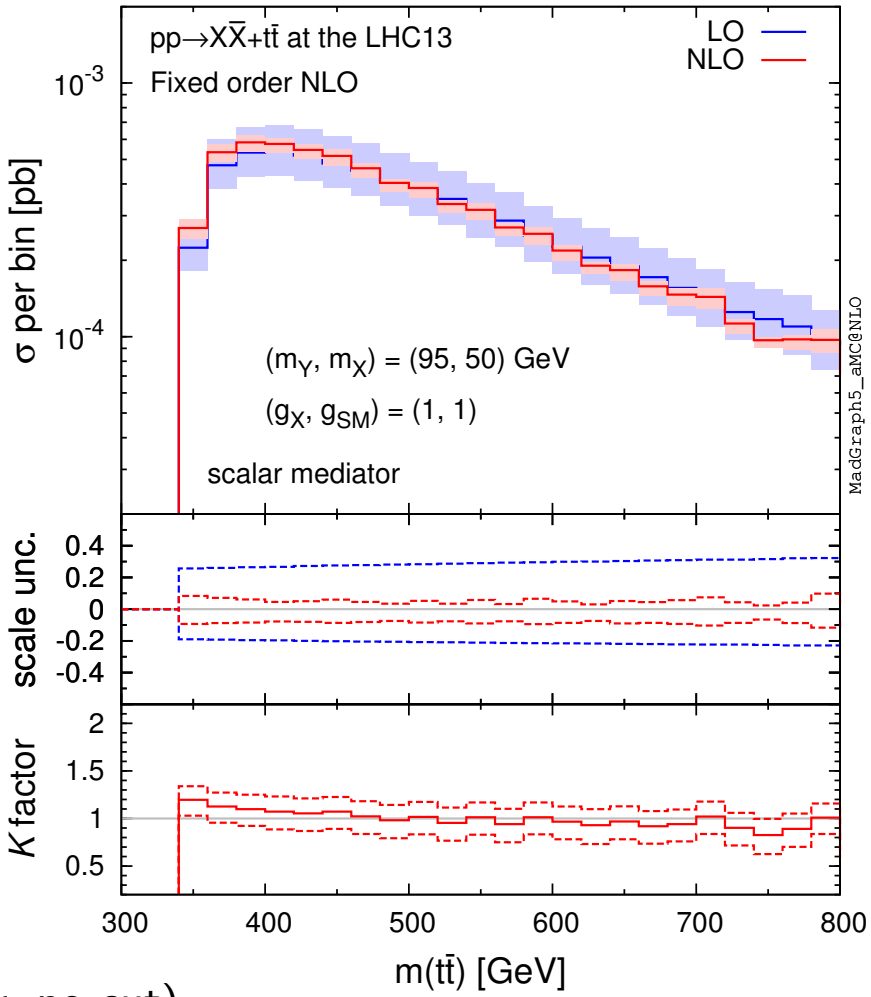
(pure vector mediator, MET $>$ 150 GeV)

$\rightarrow$ Significant shape distortion



(pure vector mediator, MET > 150 GeV, $p_{T,j} > 30$ GeV and $|\eta_j| < 4.5$)

$\rightarrow$ Possibility to merge different samples automatically

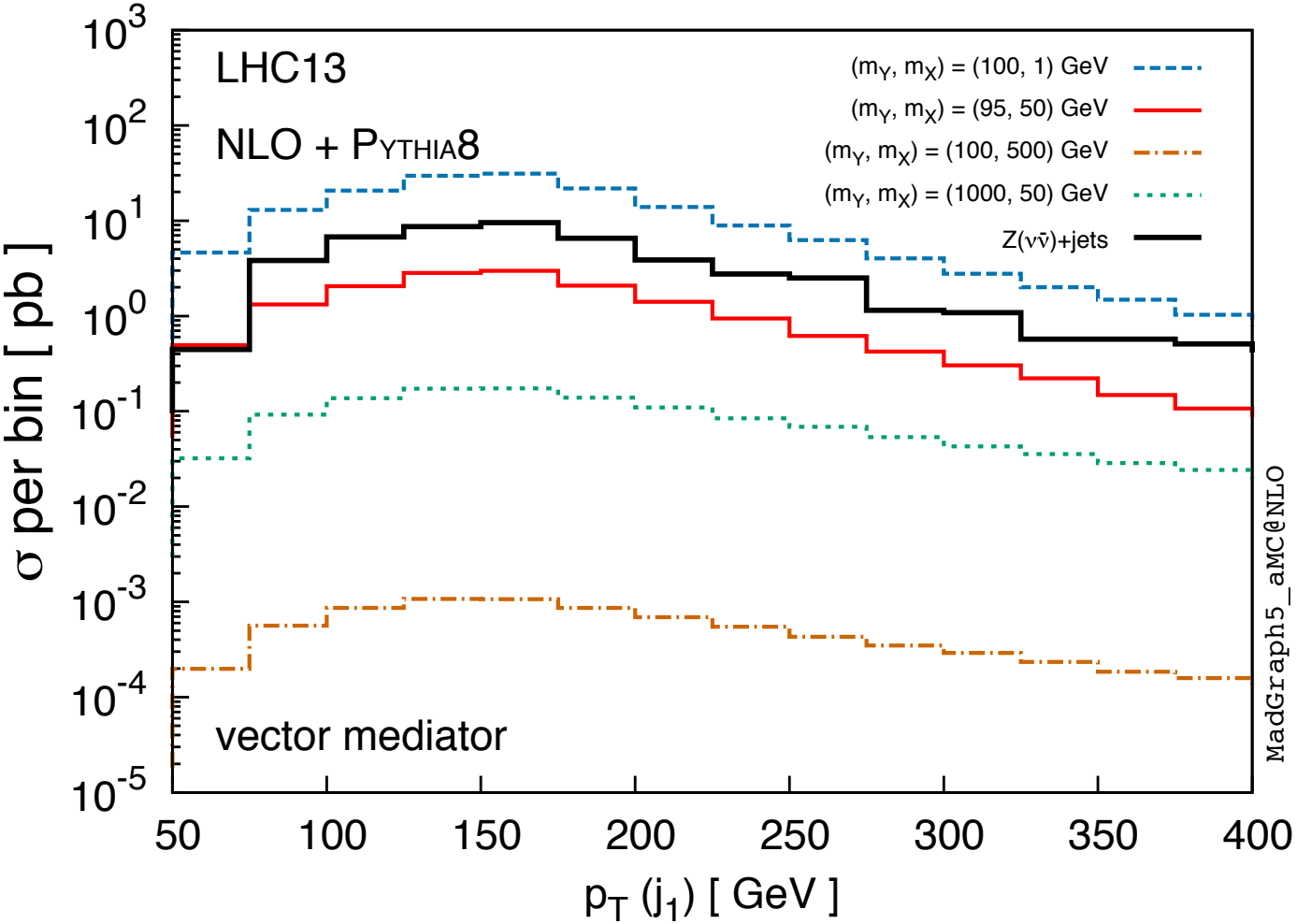


(pure scalar mediator, no cut)

→ No significant shape distortion ...

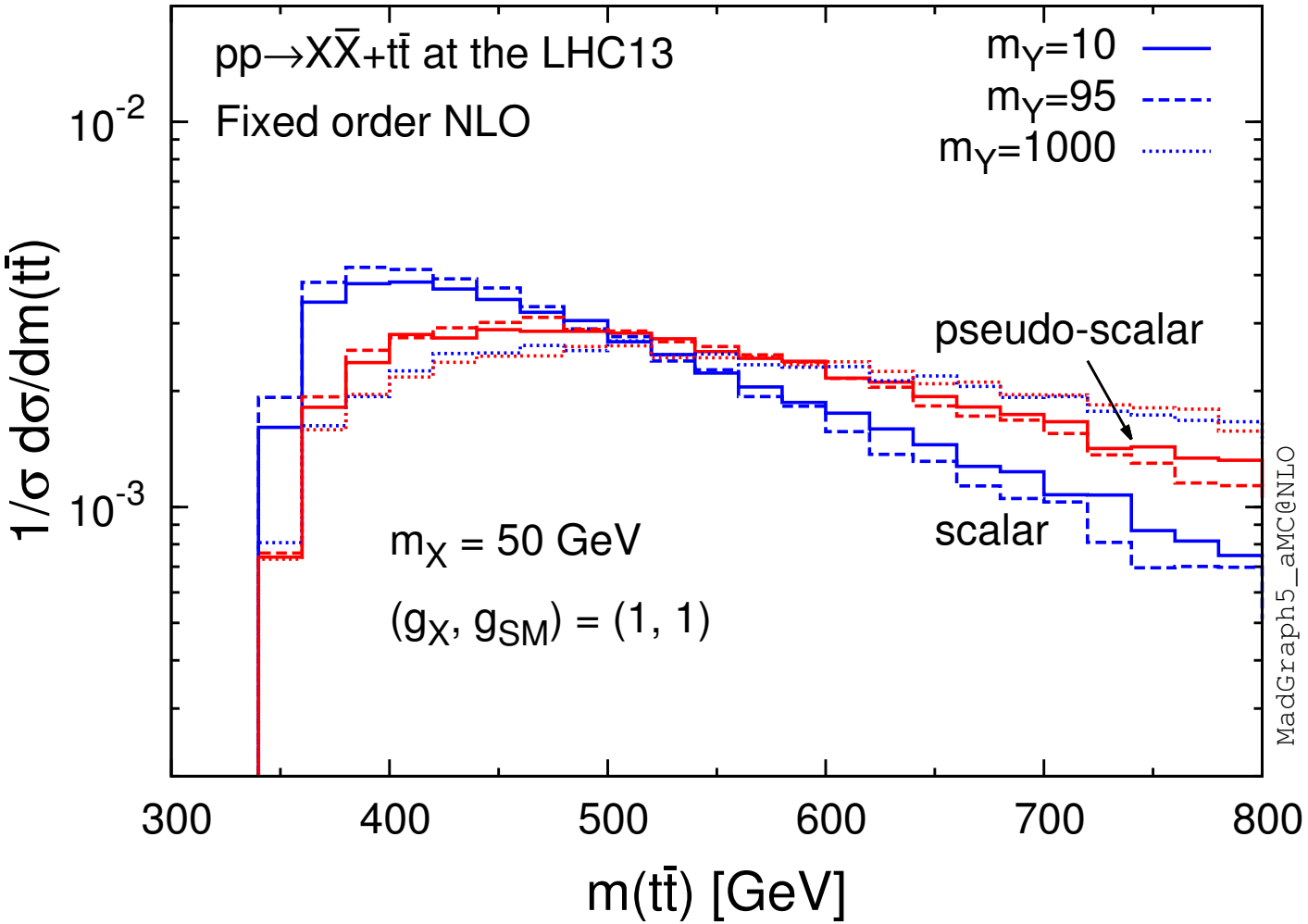
... but huge reduction of the theoretical uncertainty

Outlook



(pure vector mediator, MET > 150 GeV, $p_{T,j} > 30$ GeV and $|\eta_j| < 4.5$)

$\rightarrow$ Possibility to distinguish signal from background



(no cut)

→ Different shape for different coupling structure

Outlook

Summary

- Simplified models are key at the LHC
- NLO QCD effects are important
- Possibility of systematic studies in an uniform framework

Precise predictions for the Standard Model background ...
... and the Dark Matter signal are required

NLO model publicly available at:
`http://feynrules.irmp.ucl.ac.be/wiki/DMsimp`