A generic UFO implementation for *t*-channel dark matter models

Benjamin Fuks

(LPTHE / Sorbonne Université)

[with Chiara Arina & Luca Mantani]

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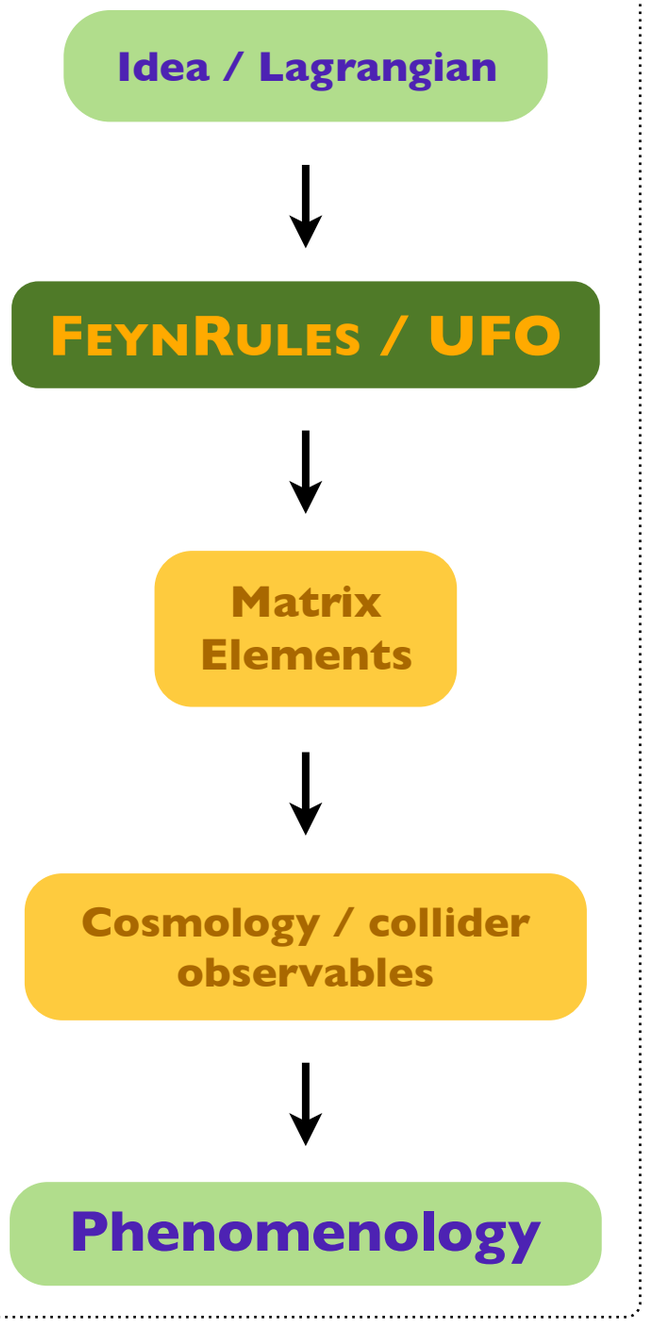
Outline

1. The Über UFO: reminders
2. Illustrative features and validation
3. Outlook

A comprehensive approach to new physics calculations

[Christensen, de Aquino, Degrande, Duhr, BF, Herquet, Maltoni & Schumann (EPJC`11)]



✦ Model building: from Lagrangian to tools

- ✤ FeynRules + NLOCT → UFO @ NLO
- ✤ On-shell renormalisation scheme

[Alloul, Christensen, Degrande, Duhr & BF (CPC'14) ; Degrande (CPC'15)]
[Degrande, Duhr, BF, Mattelaer & Reither (CPC'12)]

✦ Hard scattering

- ✤ Feynman diagram, matrix elements
- ✤ CalcHep / MG5aMC → cosmology at LO
- ✤ MG5aMC → colliders at LO/NLO

[Belyaev, Christensen & Pukhov (CPC'13)]
[Alwall *et al.* (JHEP'14)]

✦ Cosmology

- ✤ Relic density, scattering off nuclei rates, *etc.*
- ✤ MicrOMEGAs / MadDM

[Bélanger, Boudjema, Goudelis, Pukhov & Zaldivar (CPC'18)]
[Ambrogi *et al.* (PDU'19)]

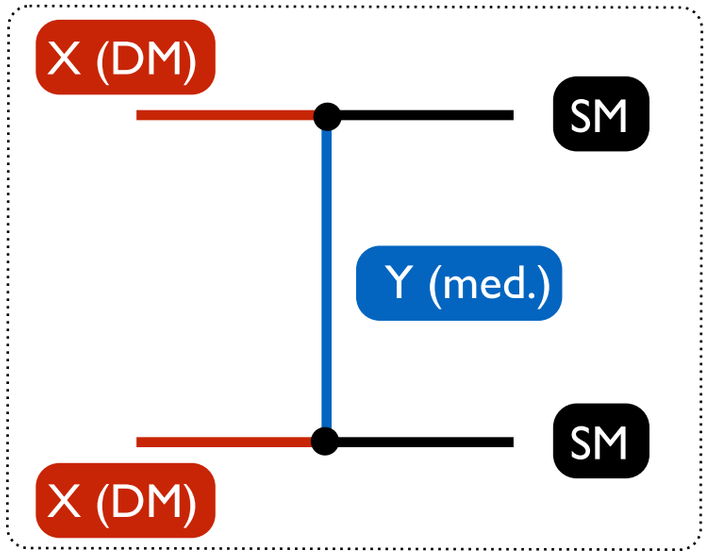
✦ Colliders with MG5_aMC

- ✤ Matching matrix elements with parton showers
- ✤ Heavy particle decays: MadSpin/MadWidth
- ✤ Simplified treatment of the resonances (MadSTR)

[Artoisenet *et al.* (JHEP'13); Alwall *et al.* (CPC`15)]
[Alwall *et al.* (JHEP'14)]
[Frixione, BF, Hirschi, Mawatari, Shao, Sunder & Zaro (1907.04898)]

A generic implementation for *t*-channel DM

A generic *t*-channel DM modelling



- 2 spins: J_X, J_Y
- 13 masses:
  - ★ 1 DM mass: m_X
  - ★ 12 mediator masses (SM = Q_L, u_R, d_R)
- 9 couplings
  - ★ 3 vectors in flavour space
  - ★ SM = Q_L, u_R, d_R

Many free parameters / spin combination

Spin options

X (DM)	Spin	Self-conj.	Y (med.)	Spin
$\tilde{S}$	0	yes	ψ_Q, ψ_u, ψ_d	1/2
S	0	no		
$\tilde{\chi}$	1/2	yes	$\varphi_Q, \varphi_u, \varphi_d$	0
χ	1/2	no		
$\tilde{V}_\mu$	1	yes	ψ_Q, ψ_u, ψ_d	1/2
V_μ	1	no		

- New additions
  - ★ Complex scalar/vector DM
    - →NLO-UFO being generated
- Still missing
  - ★ Vector mediators
    - → coloured vector @ NLO?

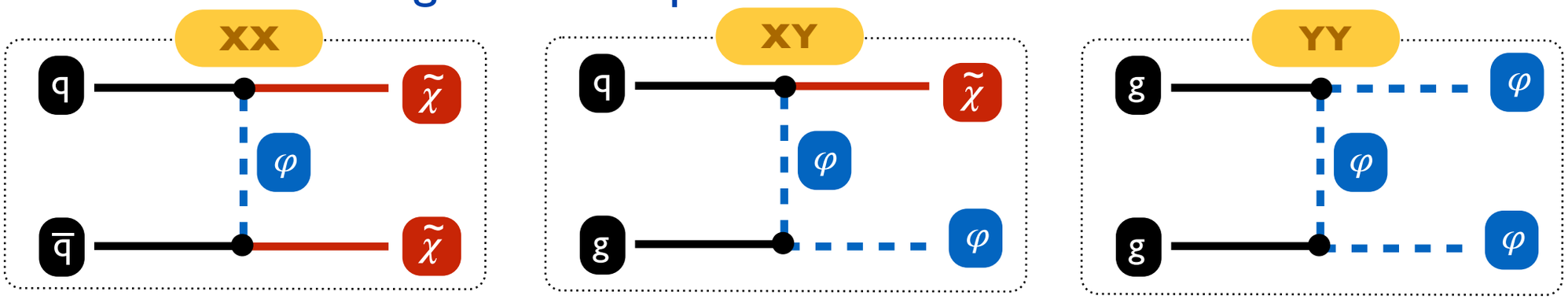
DM production at colliders: the S3D_uni case

Model

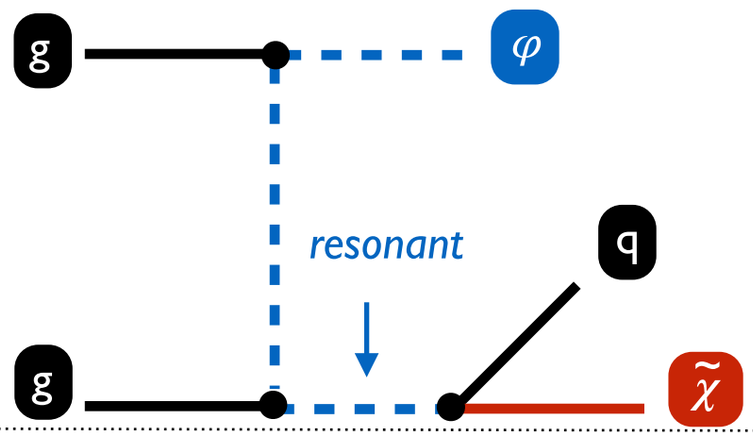
X (DM)	Spin	Self-conj.	Y (med.)	Spin
χ	1/2	no	$\varphi_Q, \varphi_u, \varphi_d$	0

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \mathcal{L}_{\rm kin} + \lambda\left[\bar{\chi} Q_L \varphi_Q^\dagger + \bar{\chi} u_R \varphi_u^\dagger + \bar{\chi} d_R \varphi_d^\dagger + \text{h.c.}\right]$$

Three contributing classes of processes



NLO computations are not trivial



- Overlap at NLO
  - ★ YY @ LO ⊗ Y → Xq decay
  - ★ YX @ NLO (real emission)
- YX @ NLO cannot be evaluated

Benchmarks

Simulation chain

- Fixed order: XX production at NLO
- DR+I: diagram removal while keeping the interferences
- Parton shower matching: PYTHIA 8 (MC@NLO procedure)
- Detector/reco: DELPHES 3 / FASTJET
- Recasting/pheno: MADANALYSIS 5

[Frixone & Webber (JHEP'02); Sjöstrand *et al.* (CPC'15)]
[Frixione, BF, Hirschi, Mawatari, Shao, Sunder & Zaro (1907.04898)]
[Cacciari, Salam & Soyez (EPJC'12); de Favereau *et al.* (JHEP`14)]
[Dumont, BF, Kraml et al. (EPJC '15); Conte & BF (IJMPA'18)]

Considered analyses

- ATLAS SUSY 2016-07: multijet + MET (36 fb^{-1}; 2-6 jets)
- ATLAS EXOT 2016-27: monojet (36 fb^{-1})

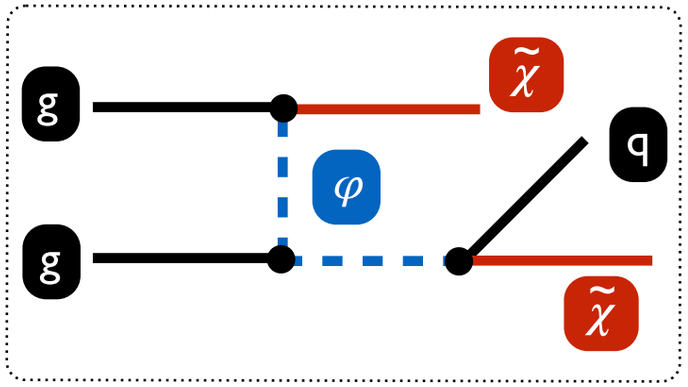
Benchmark BM1: m_X = 150 GeV, m_Y = 500 GeV, λ=1

Benchmark BM2: m_X = 150 GeV, m_Y = 1000 GeV, λ=1

XX production

✦ XX @ NLO ≈ XXj @ LO

- ✤ Subtraction of all mediator resonances from the reals
- ✤ BM1: $3.3^{+1.8\%\ +1.6\%}_{-1.2\%\ -1.6\%}$ pb
- ✤ BM2: $0.48^{+1.2\%\ +1.7\%}_{-0.9\%\ -1.7\%}$ pb



✦ LHC sensitivity to BM1 with 36 fb^{-1}

- ✤ ATLAS monojet: 6.6 pb (from the best signal regions)
  - ★ Sensitivity to $\lambda \gtrsim 1.2$
  - ★ Low efficiency: a few permiles / region
- ✤ ATLAS SUSY multijets: 23 pb (from the best signal regions)
  - ★ Sensitivity to $\lambda \gtrsim 1.6$

✦ LHC sensitivity to BM2 with 36 fb^{-1}

- ✤ ATLAS monojet: 4.02 pb ⇝ sensitivity to $\lambda \gtrsim 1.7$
- ✤ ATLAS multijets: 8.47 pb ⇝ sensitivity to $\lambda \gtrsim 2$

XY production

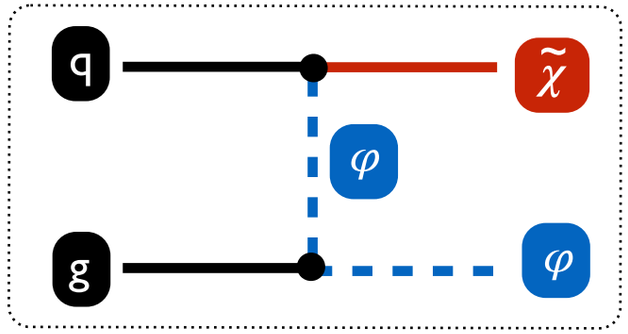
✦ XY @ NLO

✤ Subtraction of all DM/mediator resonances from the reals

✤ BM1:

★ 1st generation: $6.87^{+5.9\%\ +1.2\%}_{-6.4\%\ -1.2\%}$ pb

★ 2nd generation: $1.01^{+5.2\%\ +5.8\%}_{-5.7\%\ -5.8\%}$ pb



✦ LHC sensitivity to BM1 with 36 fb^{-1} (first generation)

✤ ATLAS monojet: 0.37 pb → sensitivity to $\lambda \gtrsim 0.23$

✤ ATLAS multijets: 1.56 pb → sensitivity to $\lambda \gtrsim 0.5$

BM1 excluded

✦ LHC sensitivity to BM1 with 36 fb^{-1} (second generation)

✤ ATLAS monojet: 0.45 pb → sensitivity to $\lambda \gtrsim 0.65$

✤ ATLAS multijets: 4.05 pb → sensitivity to $\lambda \gtrsim 2$

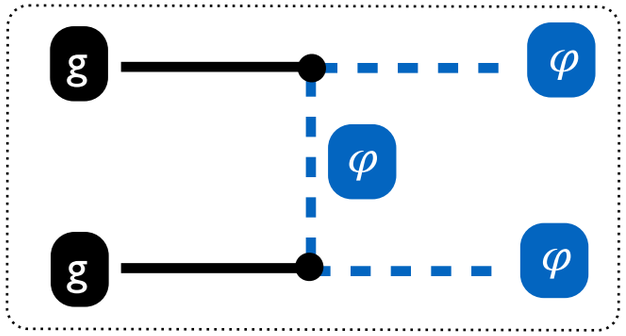
BM1 excluded

YY production

✦YY @ NLO – BM1 [1st]

- ✤Subtraction of all DM resonances from the reals
- ✤QCD: $1.93\ ^{+10.5\%\ +3.4\%}_{-12.3\%\ -3.4\%}$ pb
- ✤*t*-channel: $2.76\ \lambda^4\ ^{+2.6\%\ +2.9\%}_{-2.7\%\ -2.9\%}$ pb
  - ★Interference @ LO: $-0.36\ \lambda^2$ pb

non-QCD graphs relevant



✦YY @ NLO – BM1 [2nd]

- ✤QCD: $1.92\ ^{+10.5\%\ +3.4\%}_{-12.3\%\ -3.4\%}$ pb
- ✤*t*-channel: $0.08\ \lambda^4\ ^{+1.3\%\ +16.9\%}_{-1.6\%\ -16.9\%}$ pb
  - ★Interference @ LO: $-0.009\ \lambda^2$ pb

✦YY @ NLO – BM1 [3rd]

- ✤QCD: $1.93\ ^{+10.5\%\ +3.4\%}_{-12.3\%\ -3.4\%}$ pb
- ✤*t*-channel: negligible

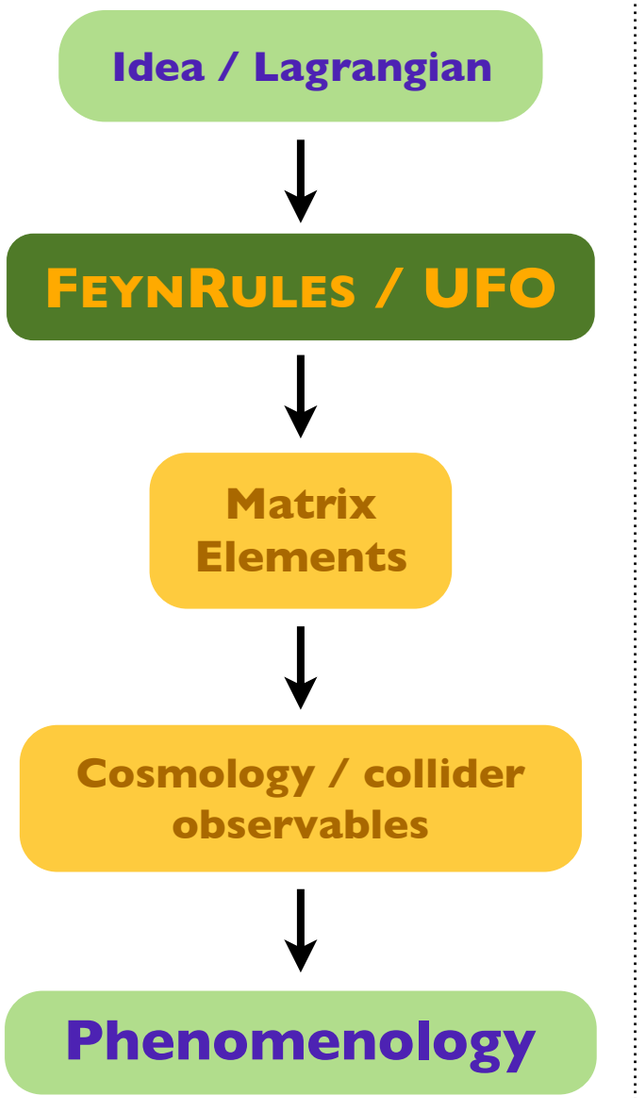
✦LHC sensitivity with 36 fb^{-1} (all generation)

- ✤ATLAS monojet or multijets: 0.35 pb [QCD production only]

BM1 excluded

Comparison with LO? BM2?

Summary- outlook



✦ A first version of the Über UFO is available
- ✤ Some spin configurations still missing
- ✤ LO calculations straightforward (collider + cosmo)
- ✤ NLO @ colliders → not so straightforward

✦ Validation done
- ✤ Comparison with the literature
- ✤ Validation achieved
- ✤ Documentation being written