Towards a whitepaper on *t*-channel dark matter

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CERN

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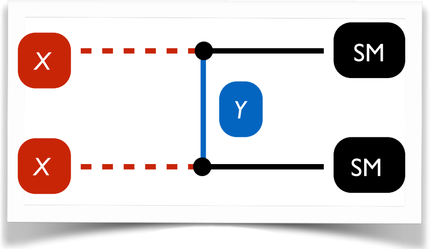
t-channel dark matter - a reappraisal



Interest in a whitepaper on *t*-channel dark matter model for a few years

- Then COVID came…
- A new call for contributions made in Jan 2023
  - ➙ Goal: definition of benchmarks for run 3 analyses (and beyond)
  - ➙ Editorial board: BF [TH], B. Maier [CMS], L. Panizzi [TH], R. Pedro [ATLAS], D.Yu [CMS]
- Lots of studies initiated, on varied *t*-channel models
  - ➙ Coordinators:
    - ➢ C.Arina [cosmo]
    - ➢ M. Baker + A.Thamm [leptophilic]
    - ➢ A. Cornell [non-minimality]
    - ➢ J. Heisig [LLPs],
    - ➢ L. Panizzi + BF [colliders]
    - ➢ R. Pedro [flavoured models]
    - ➢ D. Roy [SV jets]

All topics covered in the talks

Results initially expected by Summer'23

- No delay no fun…
- Realistic timeline: contributions merged within Fall'23

Still time to jump in!

Models for *t*-channel dark matter

Disclaimer

- Not all existing models covered
- Choice driven by the WG participants (and their interests)

Presentation in this talk

- From the most simplified models to less minimal models

Important model missing ?

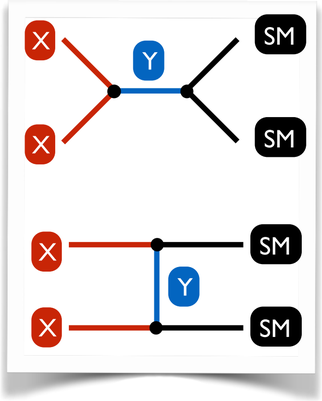
- There is still time to contact us and contribute!

Simplified models for dark matter at colliders

Simplest models of *t*-channel DM

Basic properties of simplified DM models

- DM (X) stable
  - ➙ Odd under some $\mathbb{Z}_2$ discrete symmetry
  - ➙ SM states even
- Mediator (Y) interacting with dark matter and quarks
  - ➙ $\mathbb{Z}_2$-odd: *t*-channel models
  - ➙ Y colour triplet and electrically charged



From generality to restrictions

Free parameters

- 2 spins: J_X, J_Y
- O(10) masses
  - ➙ 1 DM mass: m_X
  - ➙ Generally many mediators
    [SM quark field(s) involved]
- Varied coupling (vectors) in the flavour space
- Restrictions in order: RH quarks
  - ➙ 2 masses and 1 coupling

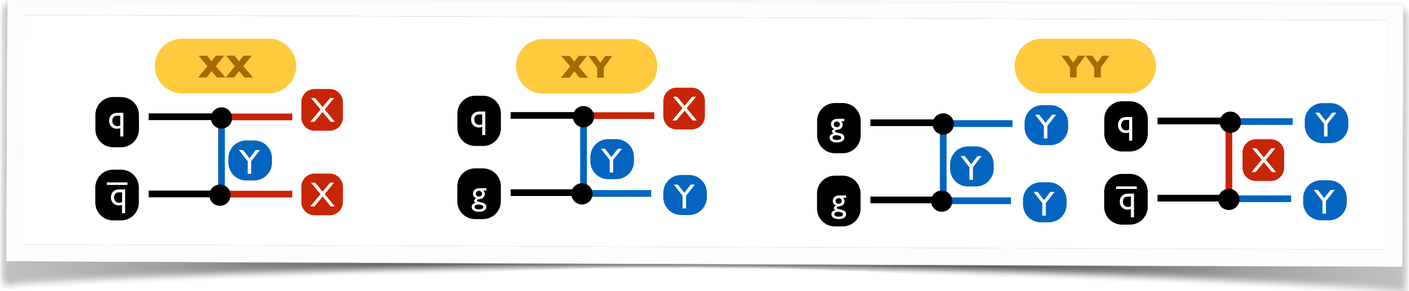
X (DM)	Spin	Self-conj.	Y (med.)	Spin
$\tilde{S}$	0	yes	ψ_Q, ψ_u, ψ_d	1/2
S	0	no		
$\tilde{\chi}$	1/2	yes	$\varphi_Q, \varphi_u, \varphi_d$	0
χ	1/2	no		
$\tilde{V}_\mu$	1	yes	ψ_Q, ψ_u, ψ_d	1/2
V_μ	1	no		

[Arina, BF & Mantani (EPJC'20)]

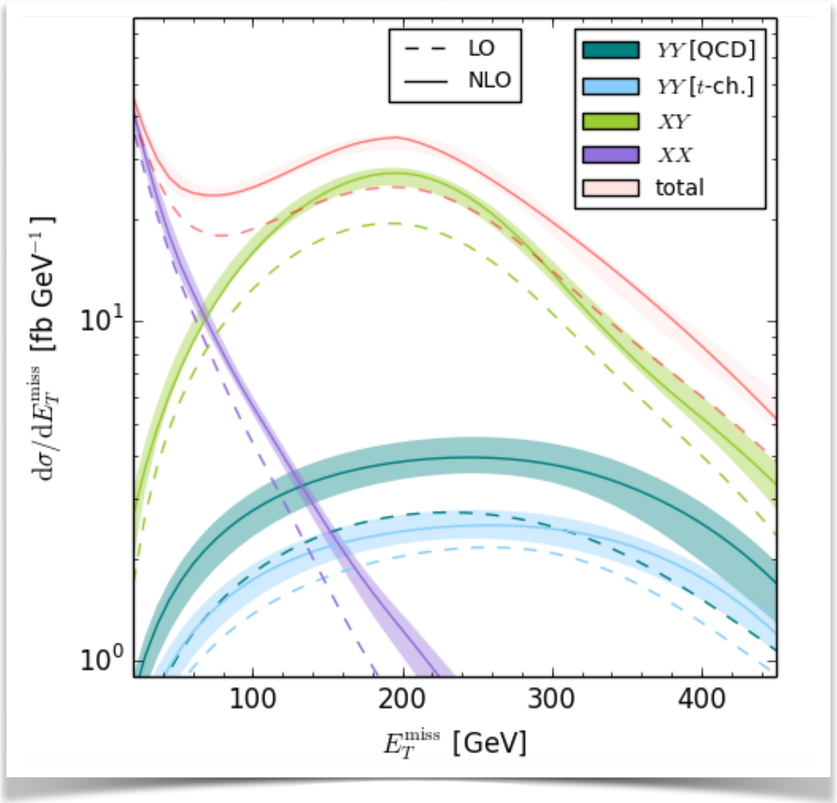
Very simplified models & rich phenomenology

[Arina, BF & Mantani (EPJC'20)]

3 classes of processes ➙ jets from radiation or *Y*-decays



- Typical signal included in LHC simulations
  - ➙ *XX* production (+ 1 jet)
  - ➙ *YY* QCD pair-production (with $Y \to Xq$ decays)
- Extra contributions often ignored
  - ➙ *XY* associated production (with $Y \to Xq$ decays)
  - ➙ *YY* *t*-channel pair production
  - ➙ Interference of the two YY modes



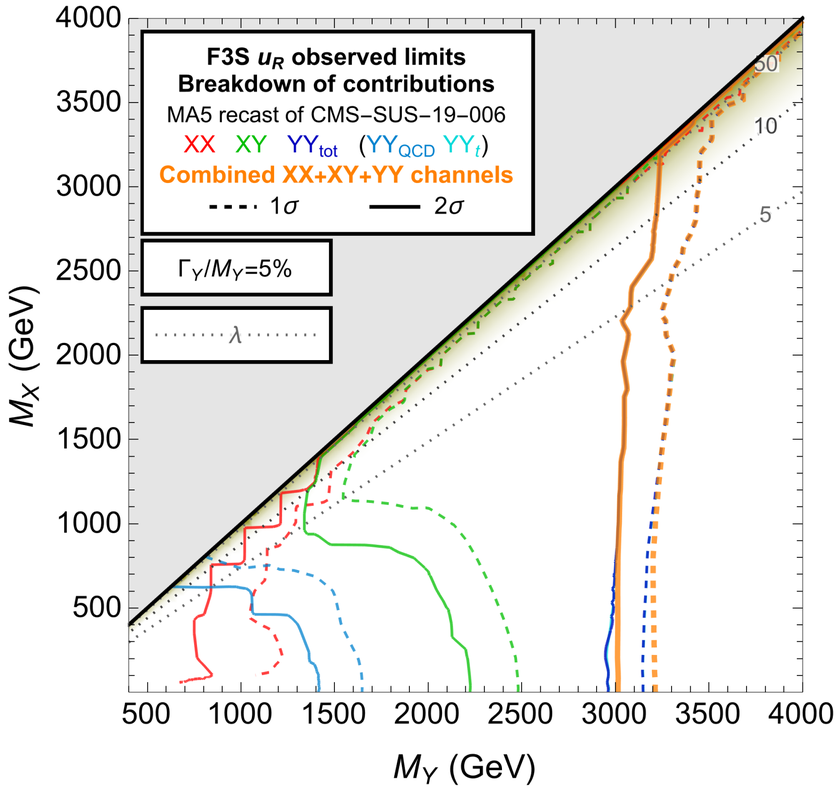
Simplified models explored for the whitepaper

DM couplings to u_R

- 3 models:
  - ➙ Fermionic Y and real scalar X ≡ F3S
  - ➙ Fermionic Y and real vector X ≡ F3V
  - ➙ Scalar Y and Majorana X ≡ S3M
- Phenomenology quite explored already
  - ➙ Arina, BF, & Mantani (EPJC 2020)
  - ➙ Arina, BF, Mantani, Mies, Panizzi & Salko (PLB 2021)
  - ➙ Arina, BF, Heisig, Kramer, Mantani, Panizzi (230M.NNNNN)
- Perfect benchmarks to test the simulation chain

New configurations

- Charm-philic dark matter
- Universally coupled dark matter
- Third generation couplings

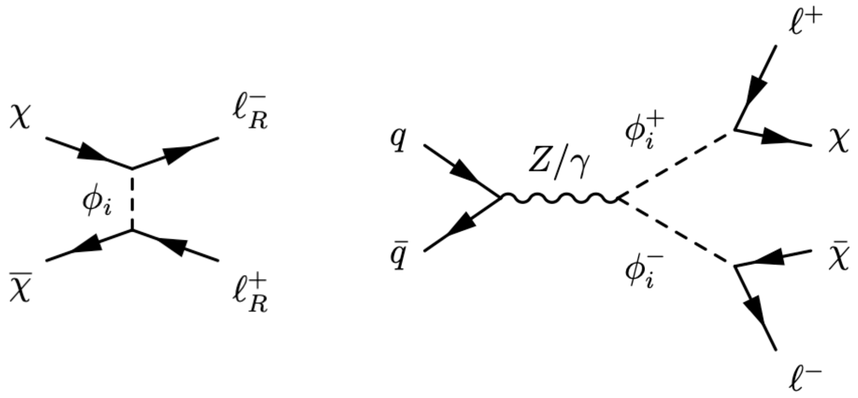


Leptophilic simplified models

DM couplings to leptons (not to quarks)

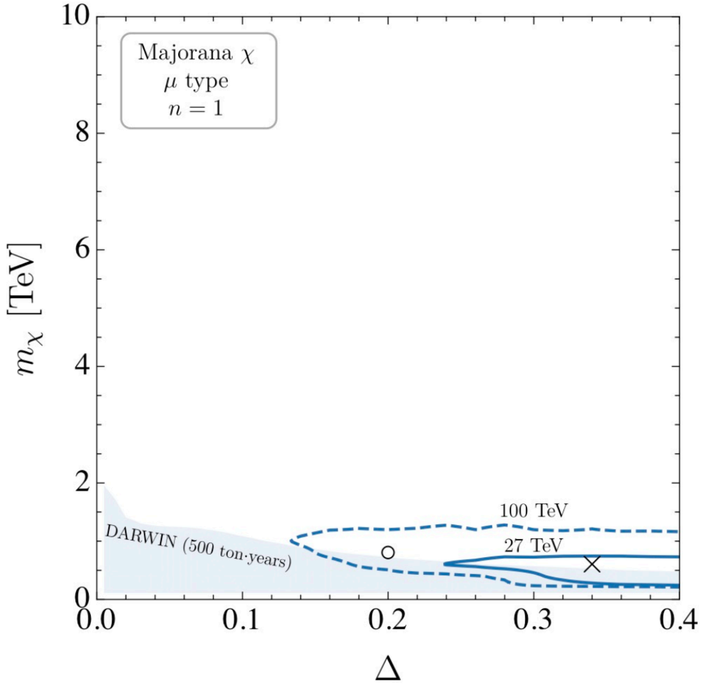
- DM (*X*) stable
- Mediator (*Y*) interacting with dark matter and leptons
  → *Y* colour singlet and electrically charged
- Model proposed by Baker & Thamm (JHEP 2018)

LHC signal from YY (electroweak) production and decays



Configuration investigated: right-handed leptons

- Muon-philic models
- Universally coupled dark matter ≡ three generations of mediators



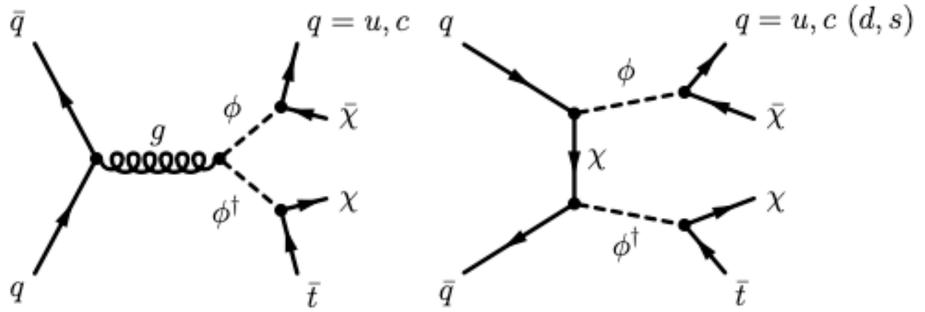
Flavoured models

Dark Minimal Flavour Violation

- Dark *U(3)* flavour symmetry ➞ several flavours of *X*
- Mediator (*Y*) interacting with dark matter and quarks
  ➞ *Y* colour triplet and electrically charged
- Model proposed by Blanke, Pani, Polesello & Rovelli (JHEP 2021)

LHC signal from YY, XY and XX production

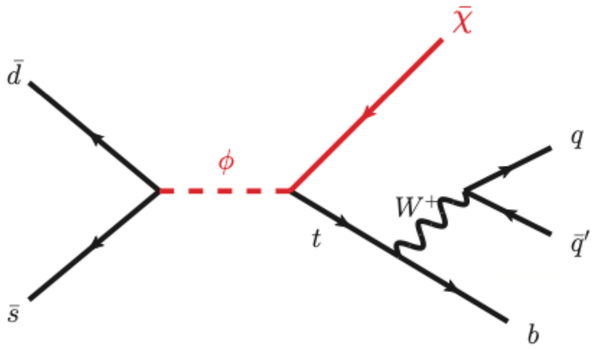
- Final states featuring different quark flavours



Top-philic models: boosted single top probes (monotops)

- Proposed a while ago
  ➞ Andrea, BF & Maltoni (PRD 2011)
  ➞ Boucheneb, Cacciapaglia, Deandrea & BF (JHEP 2015)

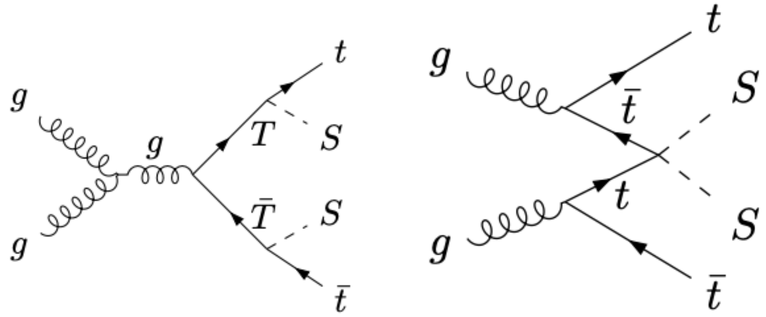
Charm-philic models: use case for charm-tagging (?)



On the way to non-minimality

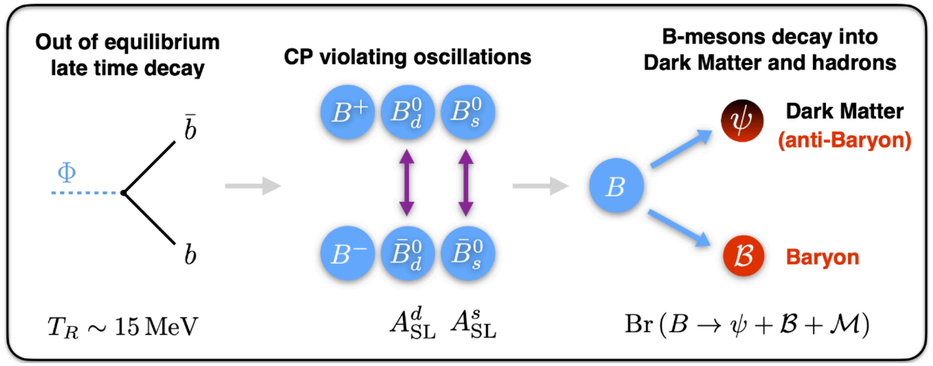
Composite models

- X is a composite scalar resonance, Y a vector-like top quark
- Composite realisation often predicts:
  - ➙ Both *CP*-odd and *CP*-even mediators
  - ➙ Higher-dimensional couplings
- Phenomenology explored initially in:
  - ➙ Cornell, Deandrea, Flacke, BF & Mason (JHEP 2021; PRD 2023)



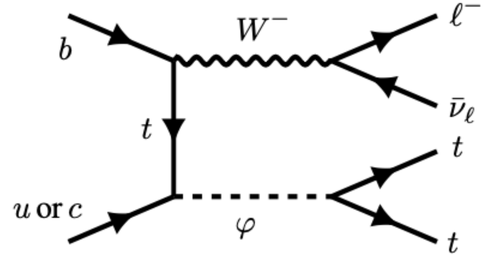
Mesogenesis models

- New B meson decay into DM
- Investigations of rare B decays @ LHC
- Explored initially in:
  - ➙ Alonso-Álvarez, Elor & Escudero (PRD 2021)



Frustrated DM

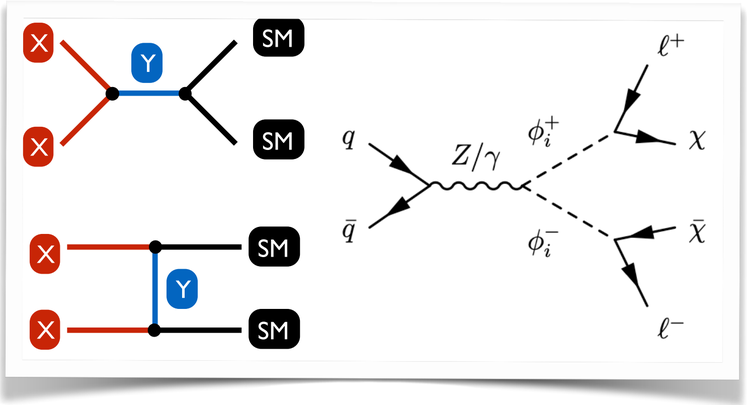
- Pair of colour-sextet mediators (1 scalar φ, 1 fermion ψ) + Yukawa coupling $\varphi\psi X$
- Large variety of MET and non-MET signatures @ LHC
- Explored initially in:
  - ➙ Carpenter, Murphy & Tait (JHEP 2022)



Models for *t*-channel dark matter - a summary

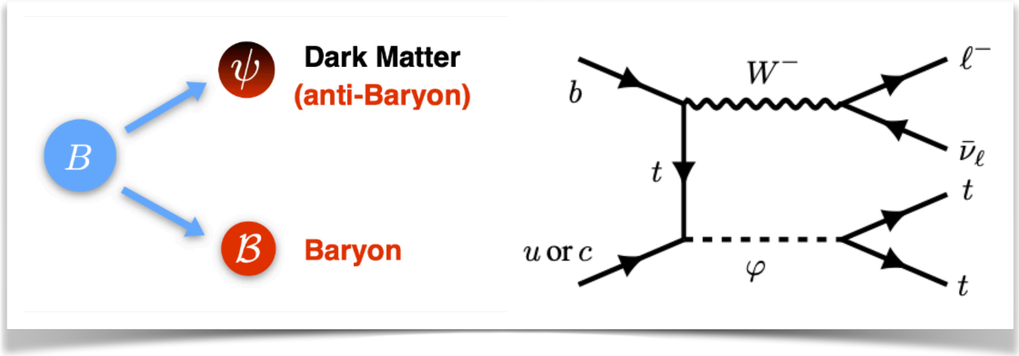
Most WG activities focus on variations of the minimal model

- Couplings to up quarks (usual benchmarks)
- Universal couplings
- Charm-philic
- Top-philic
- Lepto-philic



Several non-minimal directions investigated

- Flavoured DM
- Mesogenesis models
- Frustrated DM
- More realistic composite extensions



Join us and contribute!