

t -channel dark matter - a reappraisal

Benjamin Fuks

Based on works with:

- C. Arina and L. Mantani ([EPJC 2020](#))
- C. Arina, L. Mantani, H. Mies, L. Panizzi and J. Salko ([PLB 2021](#))
- C. Arina, J. Heisig, M. Kramer, L. Mantani, L. Panizzi and J. Salko (230M.NNNNN, 230M.NNNNN)

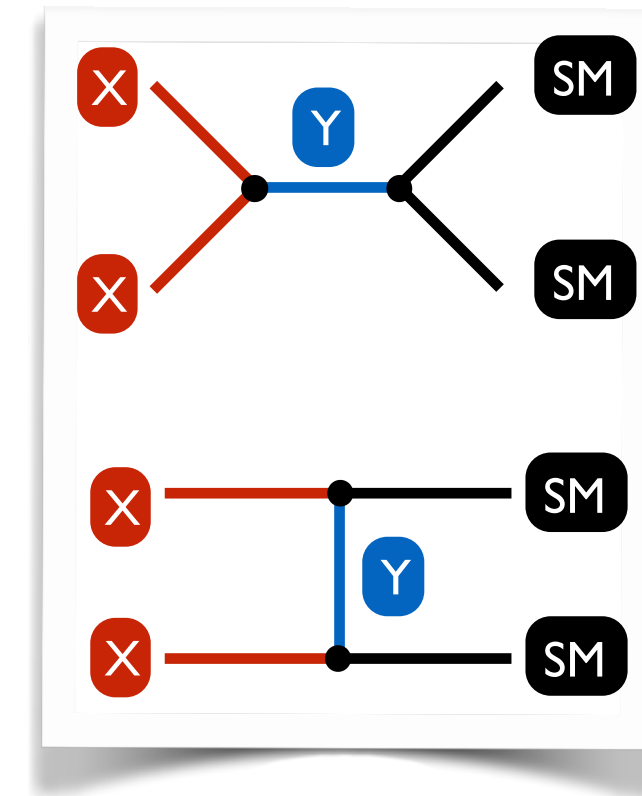
2023 LHC DM WG Winter Meeting

12 January 2023

Simplified models for dark matter at colliders

Basic properties of simplified DM models

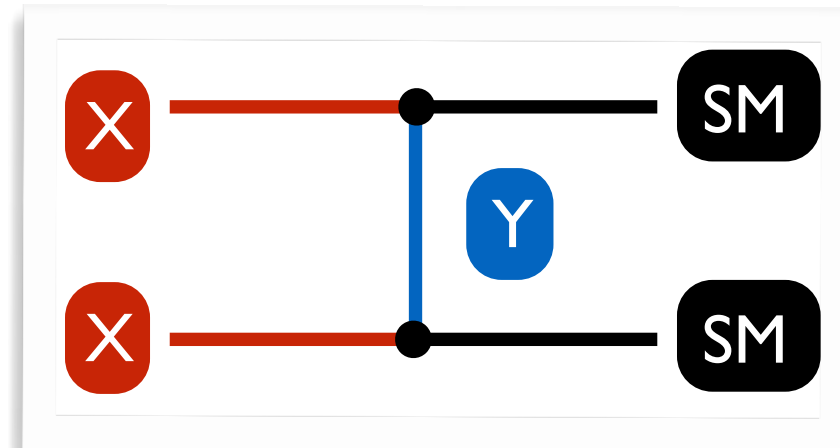
- DM (X) stable
 - ★ Odd under some \mathbb{Z}_2 discrete symmetry
 - ★ SM states even
- Mediator interacting with dark matter and quarks
 - ★ \mathbb{Z}_2 -even: s-channel models \rightarrow colour singlet and electrically neutral
 - ★ \mathbb{Z}_2 -odd: t-channel models \rightarrow colour triplet and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



Free parameters

- 2 spins: J_X, J_Y
- $O(10)$ masses
 - ★ 1 DM mass: m_X
 - ★ Many mediators (cf. SM generation and representation)
- Varied couplings in the flavour space

A generic t-channel DM model



- 2 spins: J_X, J_Y
- 13 masses:
 - ★ 1 DM mass: m_X
 - ★ 12 mediator masses ($SM = u_L, d_L, u_R, d_R$)
- 9 couplings (cf. $SU(2)_L \times U(1)_Y$ invariance)
 - ★ 3 vectors in flavour space
 - ★ $SM = Q_L, u_R, d_R$

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}_μ	1	yes	ψ_Q, ψ_u, ψ_d	1/2
V_μ	1	no		

Toy model: DM coupling to right-handed up quarks only

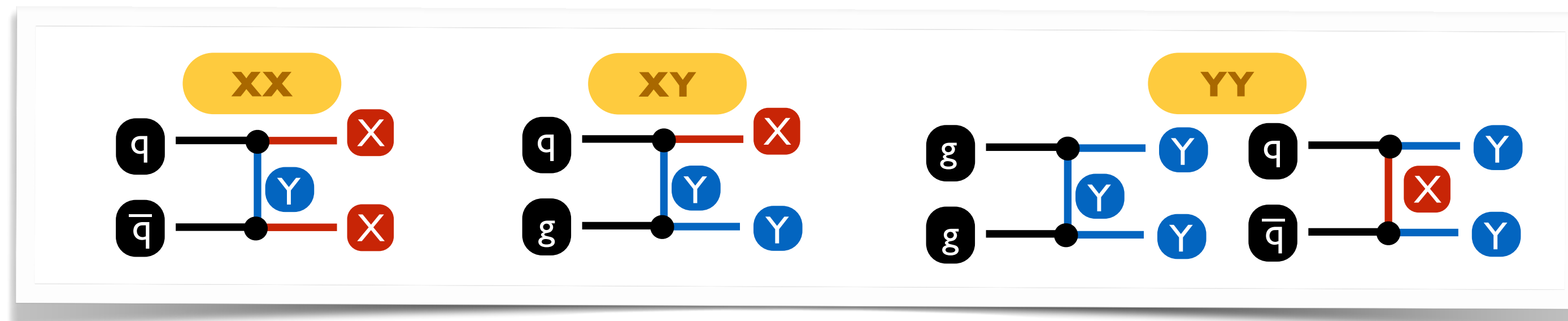
- Simple scenarios investigated by ATLAS and CMS
- Benchmarks for numerous searches
- **Collider-cosmology complementarity** → unexpected LHC phenomenology

$$\mathcal{L}_{X-uR}(X) = \left[\lambda_\varphi \bar{X} u_1 \varphi_{u_1}^\dagger + \text{h.c.} \right]$$

DM @ colliders: the signal...

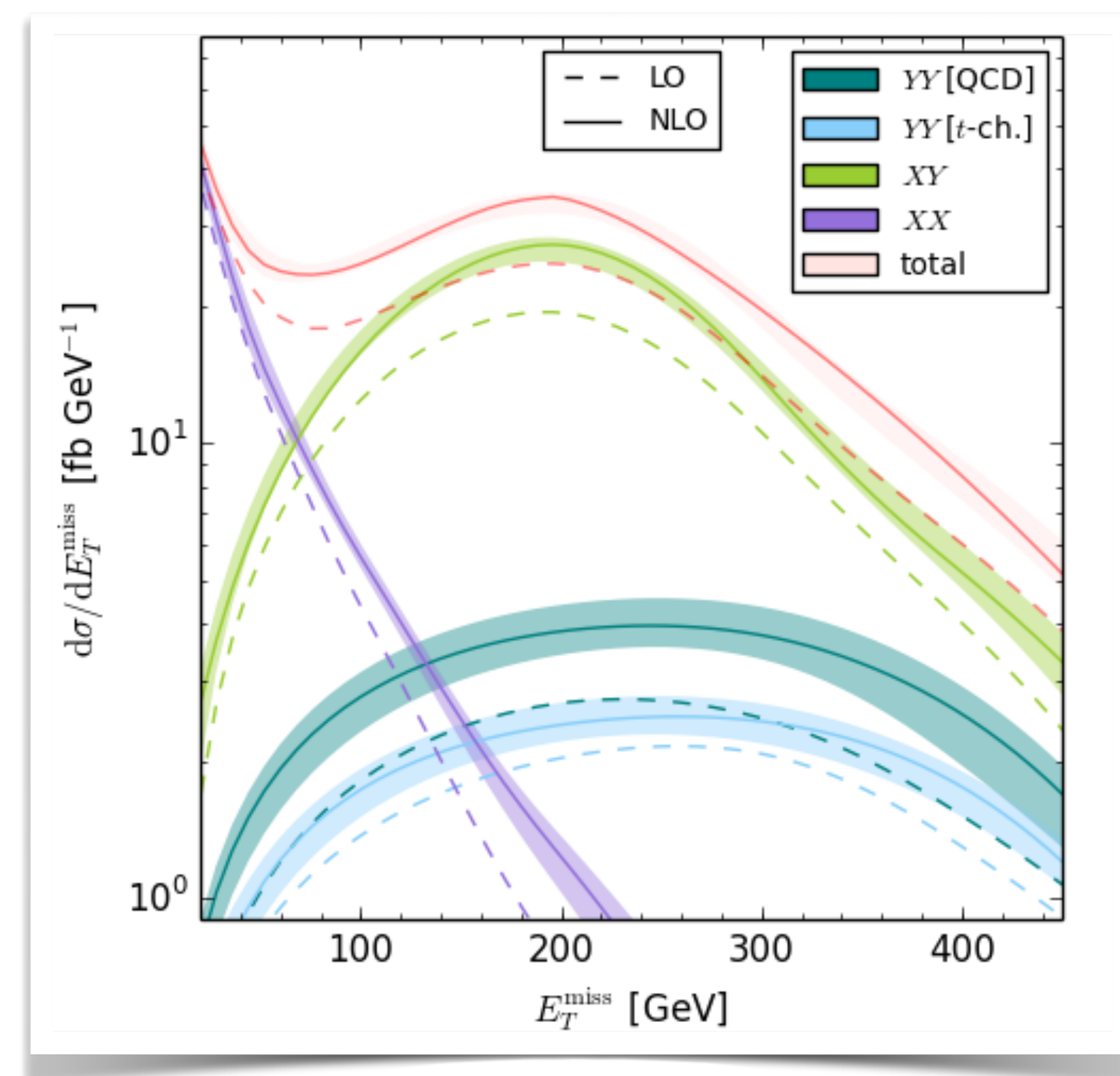
[Arina, BF & Mantani (EPJC'20)]

3 classes of processes \rightarrow jets from radiation or Y -decays



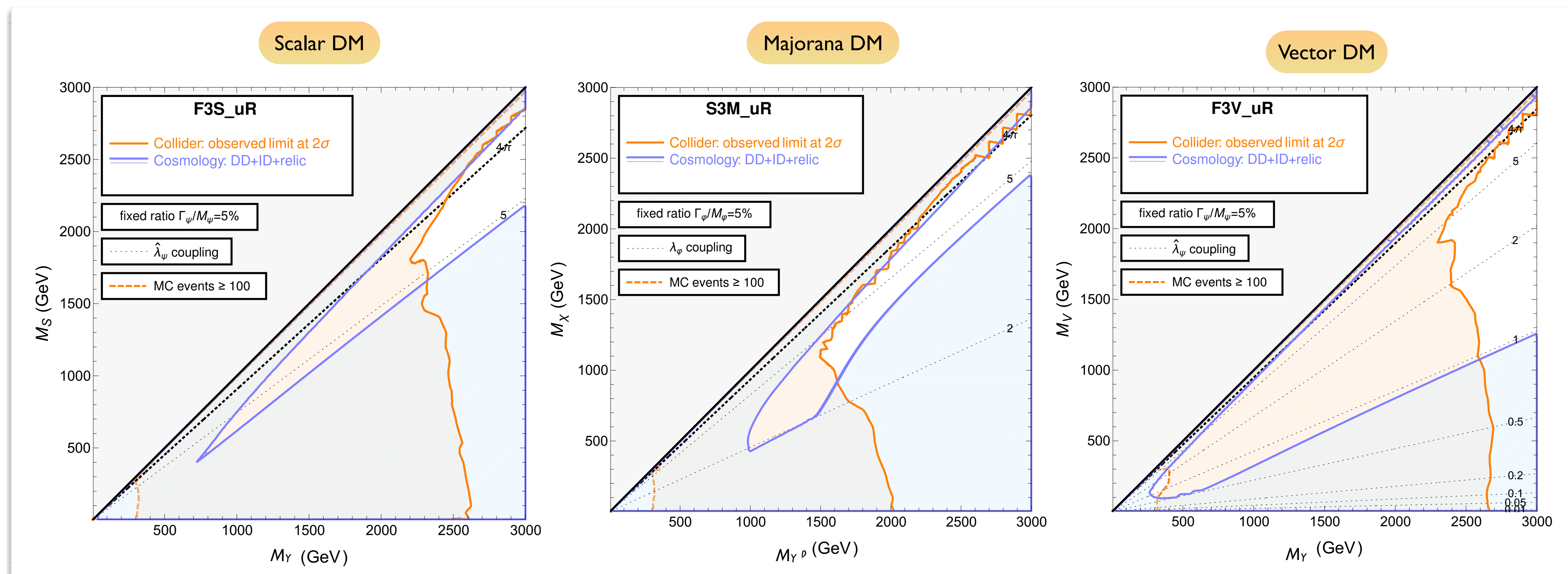
- Typical signal included in LHC simulations
 - ★ DM pair production (+ 1 jet)
 - ★ Mediator QCD pair-production (with mediator decays into DM+jet)
- Some contributions ignored in several papers
 - ★ DM/mediator associated production (with mediator decays into DM+jet)
 - ★ t -channel mediator pair production and interference

Not justified



Cosmology: strongly coupled t -channel DM

[Arina, BF, Mantani, Mies, Panizzi & Salko (PLB'21)]



Colliders and cosmology complementary

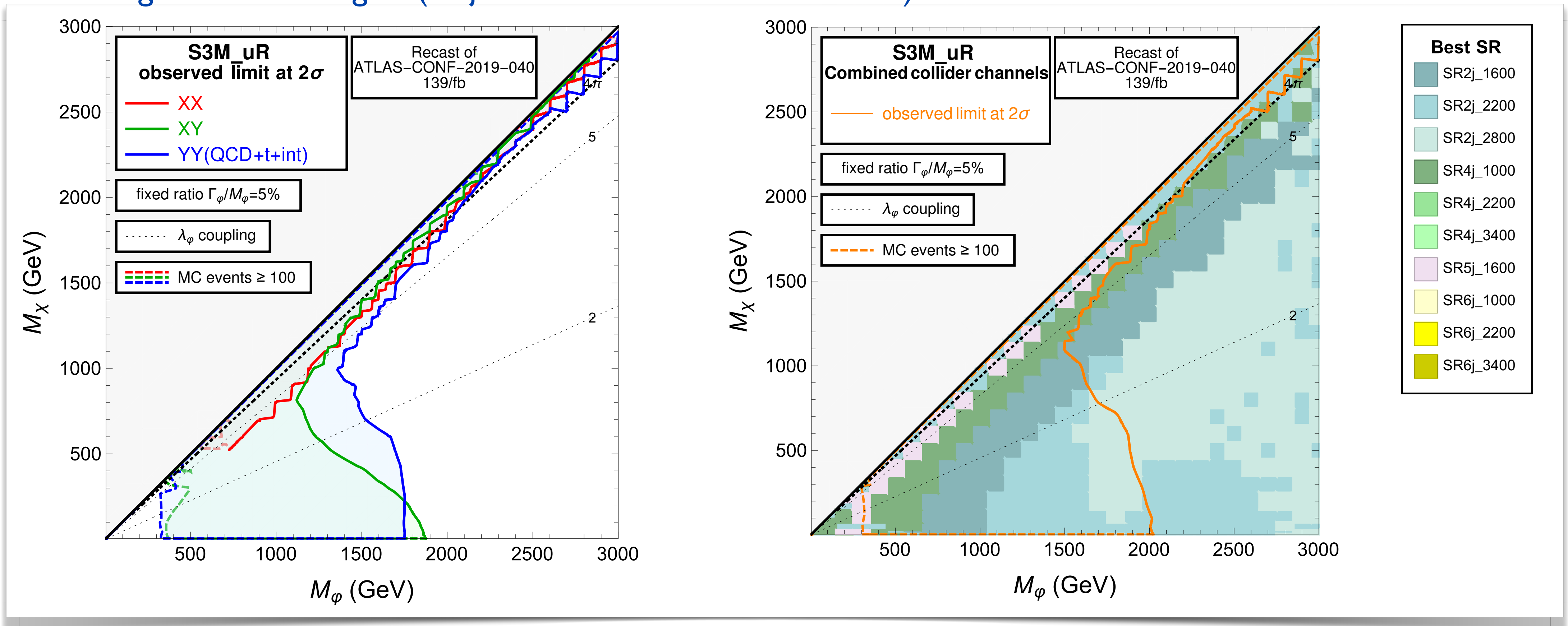
- A narrow mediator \rightarrow **strongly-coupled** DM from **cosmology**
- Lighter options further restricted by multi-jet+MET **collider constraints** (ATLAS-CONF-2019-040)

Estimation of the collider bounds from multi-jet + MET production?

DM @ colliders: the *full* signal for a SUSY-like scenario

[Arina, BF, Mantani, Mies, Panizzi & Salko (PLB'21)]

Dissecting the collider signal (Majorana DM and scalar mediator)

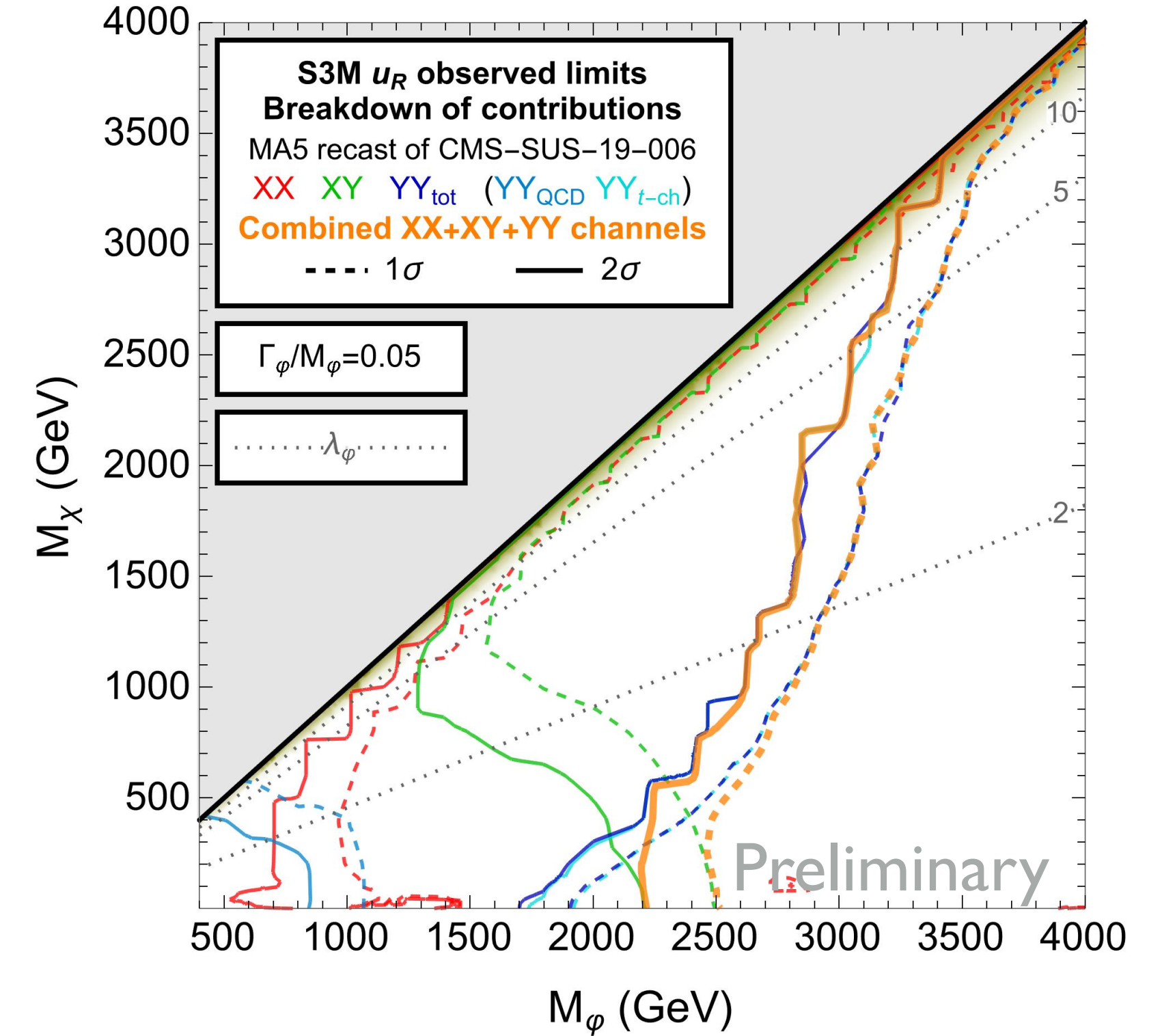
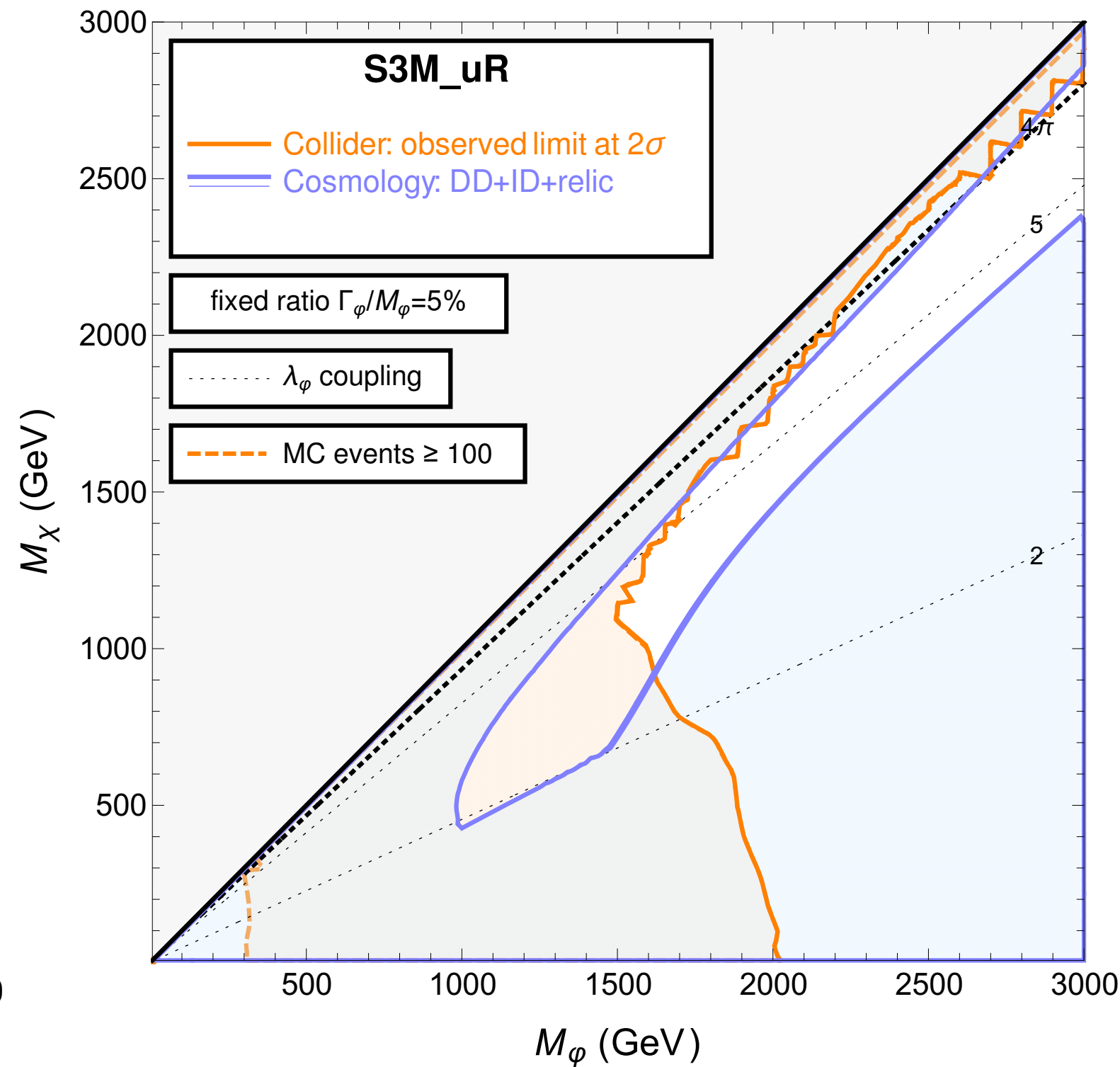
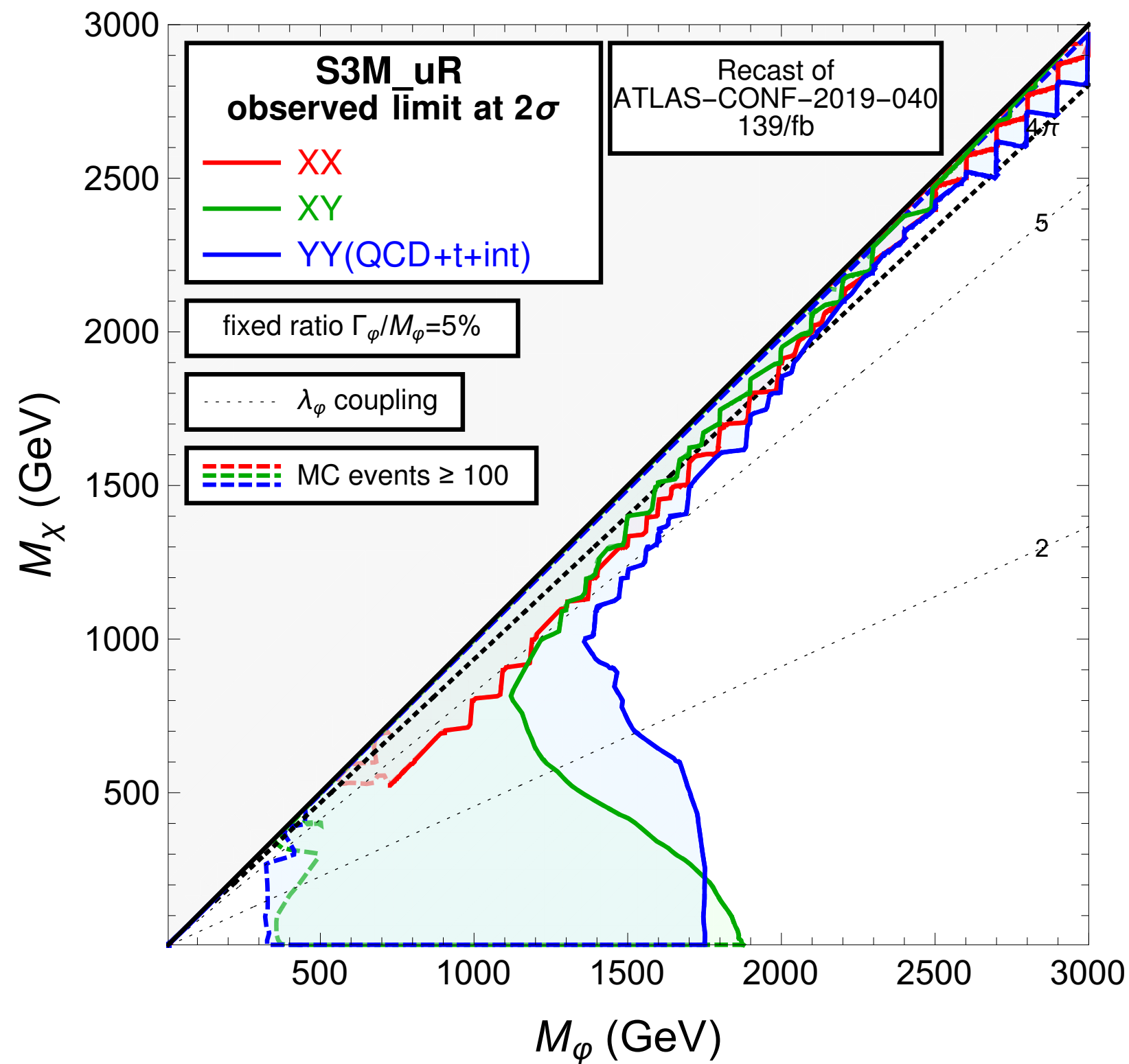


- All channels contribute (larger rates)
 - ★ $XX \sim \lambda^4$
 - ★ $XY \sim \lambda^2$
 - ★ $YY \sim \lambda^4 + \lambda^2 + \lambda^0$

- ATLAS-CONF-2019-040 targets different topologies
 - ★ XX: small number of softer jets
 - ★ XY: medium number of mostly softer jets
 - ★ YY: larger number of hard jets

The story is not over...

[Arina, BF, Heisig, Kramer, Mantani, Panizzi & Salko (to appear)]



A more inclusive search: CMS-SUS-19-006

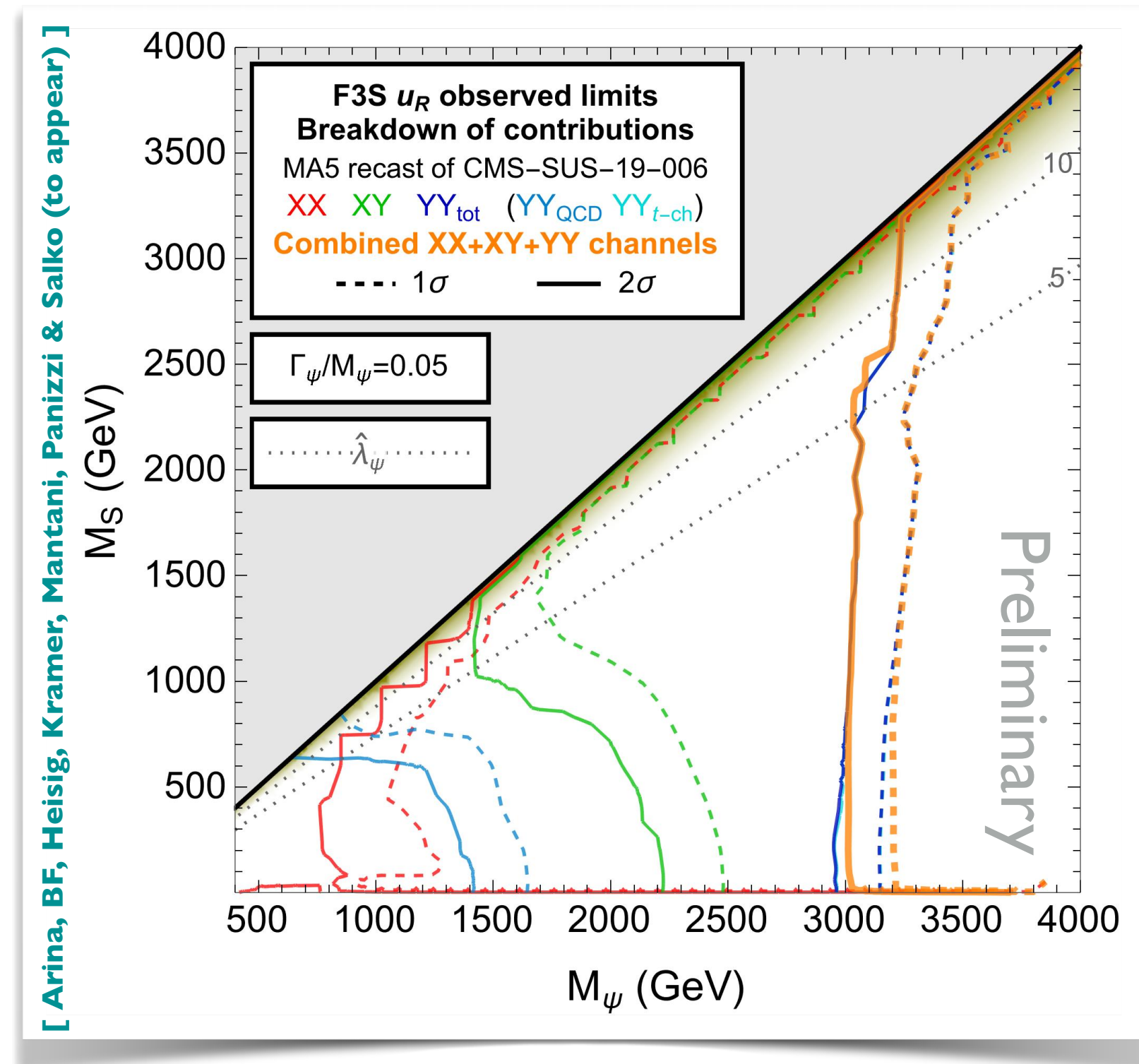
- Better constraints on XY
- Slightly better constraints on XX

Mediator pair production very different

- t -channel DM exchanges dominate
- $p p \rightarrow YY$ very large (more than $p p \rightarrow YY^*$)
 - new channel included (enhanced by valence quarks)
 - significant improvements of the bounds

Collider simulations to be rethought!

Summary



Robust predictions crucial for a discovery

- NLO corrections
- Signal modelling, in particular at colliders

A last (preliminary) plot...

- Couplings on VLQs coupling to u_R and DM
 - 3 TeV VLQs are excluded!
[regardless of the DM mass]
 - Naive VLQ signal: bounds smaller than 1.5 TeV

t-channel DM white paper → let's revive this

- Call for contributions → signal your interest by the end of the month
- Contacts: Benjamin Fuks, Benedikt Maier, David Yu
(fuks@lpthe.jussieu.fr, benedikt.maier@cern.ch, david_yu@brown.edu)