Constraints on aTwo Mediator Dark Matter Model from Simplified Models

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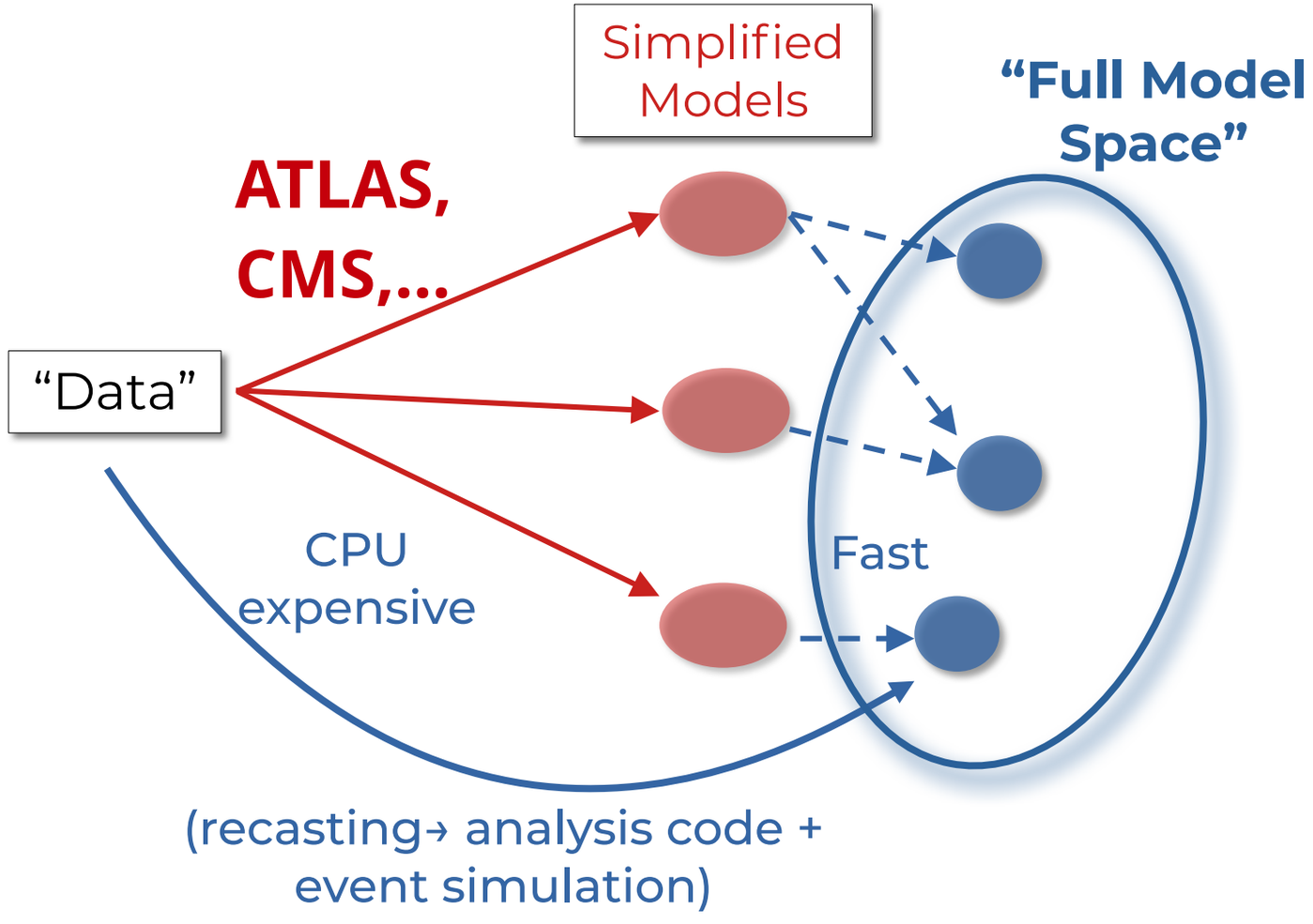
Why Simplified Models?

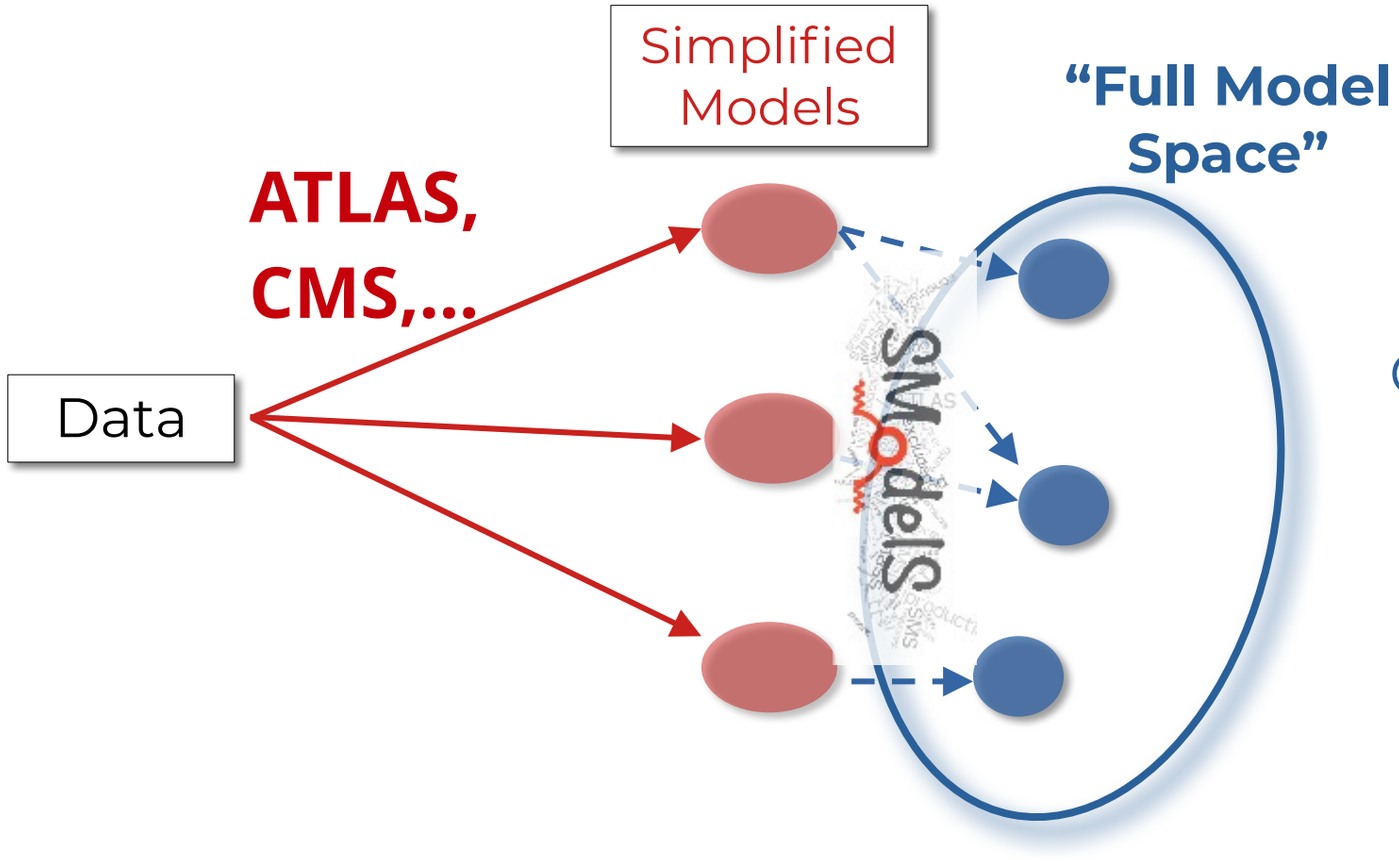
- Most BSM searches are now interpreted using simplified models (SMS)
- They provide a nice framework for less model independent results
- Can be used to compare constraints from distinct searches
- *But they can also be used for re-interpretation!*



- Pros:
  - Many SMS results have been produced by the experimental collaborations
  - No need for recasting or event simulation
  - Sometimes the only alternative for complex searches
  - Very fast!

SModelS v3

- SModelS → a tool for the “last mile”
- It has been applied to study many BSM models
- Until recently contained mostly R-Parity preserving SUSY-inspired SMS
- Version 3 can now handle arbitrary simplified models (→ talk on Thursday)
  - → including “non-SUSY” results from the DM/Exotica groups



Can we use these results to test UV complete DM models?

Two Mediator DM (2MDM)

- A minimal (almost UV complete) DM model: $SM + U(1)'$
  - New gauge boson
  - New scalar (breaks U(1)') $\longrightarrow$ $Z'_\mu,\ \phi,\ \chi$
  - New Majorana fermion (DM)

- UV Lagrangian:

$$\mathcal{L} = g_q \sum_q \bar{\psi}_q \gamma_\mu \psi_q Z'^\mu - \frac{1}{4} F'^{\mu\nu} F'_{\mu\nu}\,,$$

$$\mathcal{L}_\phi = \left(\mathcal{D}^\mu \phi\right)^\dagger \left(\mathcal{D}_\mu \phi\right) - \mu_2^2 |\phi|^2 - \lambda_2 |\phi|^4 - \lambda_3 |\phi|^2 |H|^2\,,$$

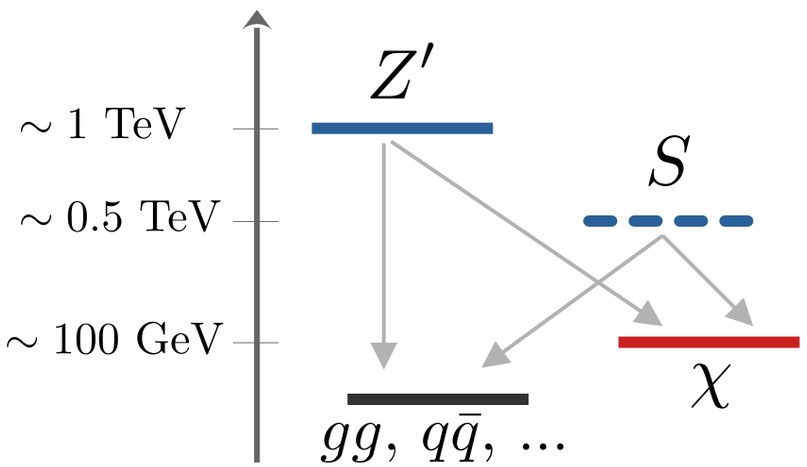
$$\mathcal{L}_\chi = \frac{i}{2}\overline{\chi}\partial\chi - \frac{1}{2} g_\chi Z'^\mu \overline{\chi}\gamma^5\gamma_\mu\chi - \frac{1}{2} y_\chi \overline{\chi}\left(P_L\phi + P_R\phi^*\right)\chi$$

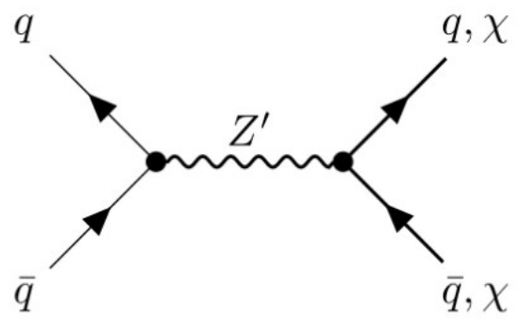
- U(1)' breaking:

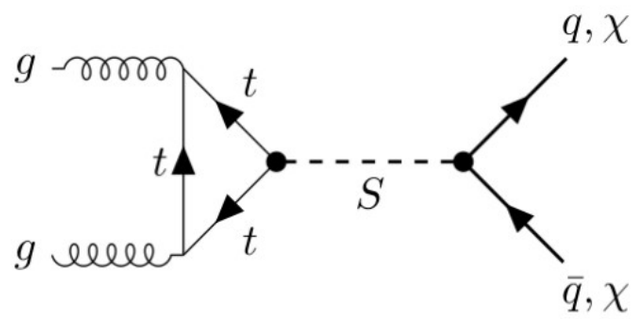
$\langle\phi\rangle$ $\rightarrow$ $m_{Z'},\ m_\chi$

$\phi - H$ mixing $(\sin\alpha)$

- Free parameters: $\left\{m_{Z'},\ m_S,\ m_\chi,\ g_\chi,\ g_q,\ \sin\alpha\right\}$

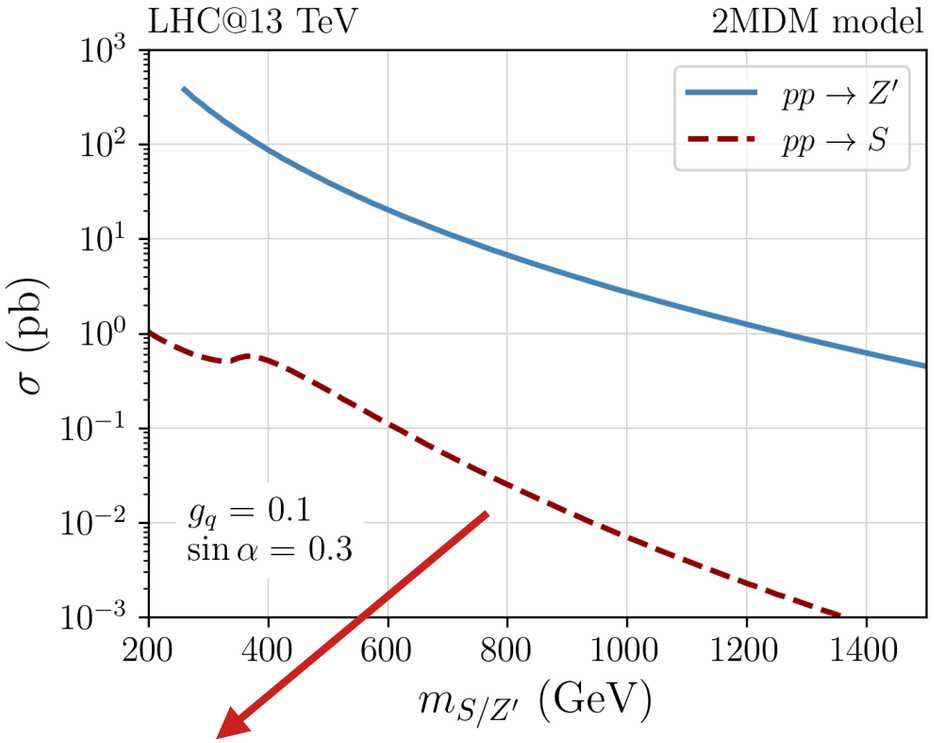






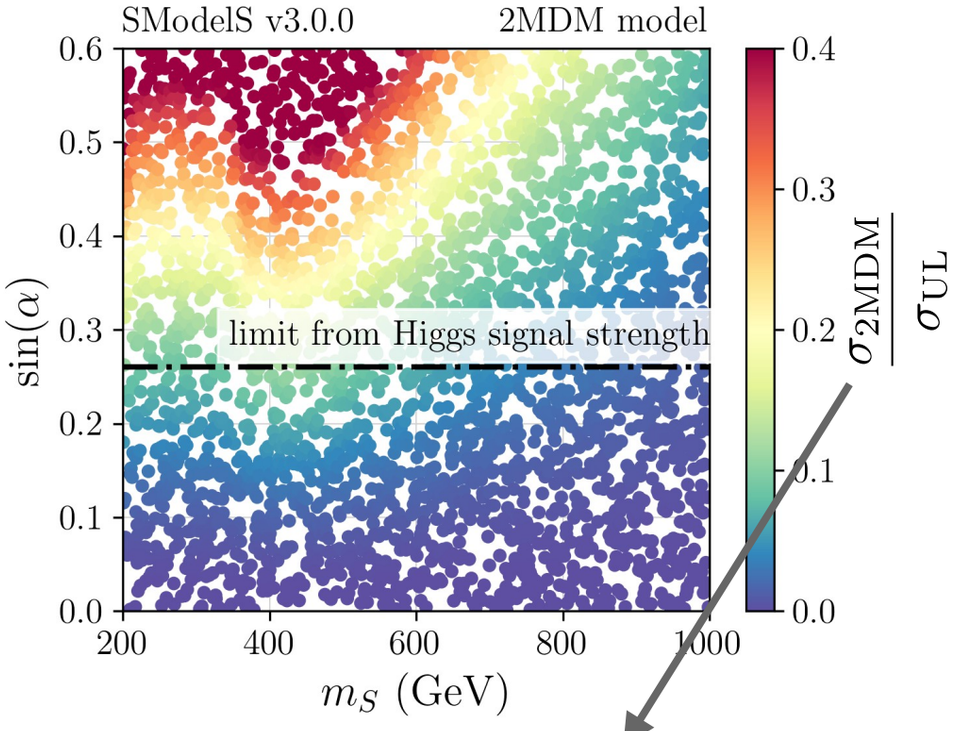
Two Mediator DM (2MDM)

- Production cross-sections:



Loop suppressed

- New Scalar-Higgs mixing:



limit from monojet searches

- The new scalar has a neglible impact on the LHC signal!

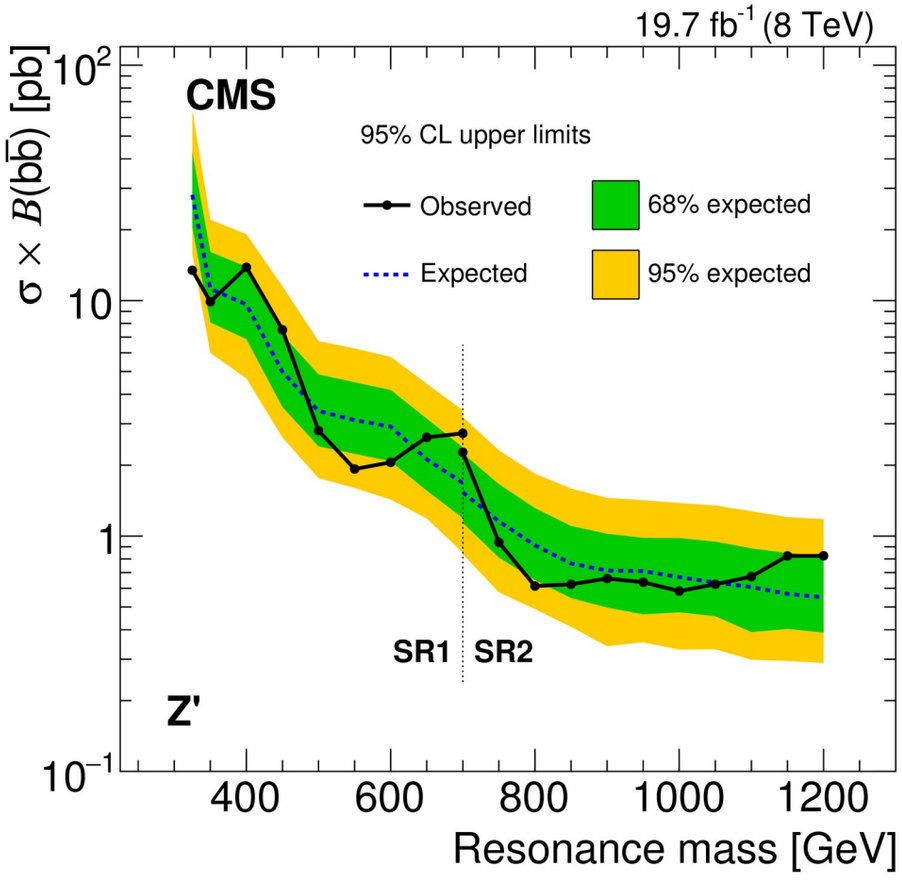
- We consider only the *Z'* signal:

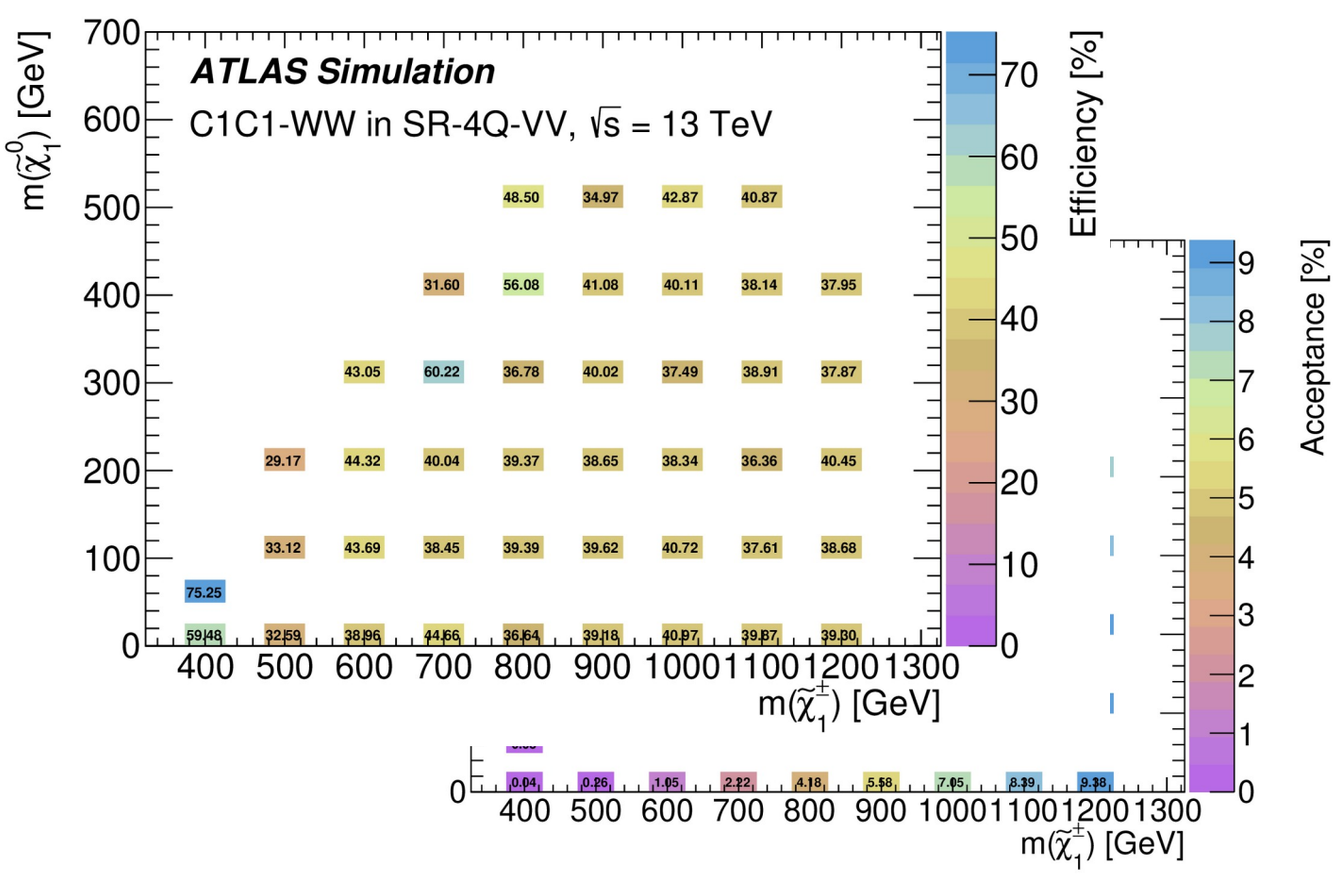
$$pp \to Z' \to q\bar{q} \quad \text{(dijet resonances)}$$

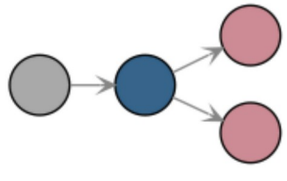
$$pp \to Z' \to \chi\chi \quad \text{(monojet)}$$

Making Use of SMS Results

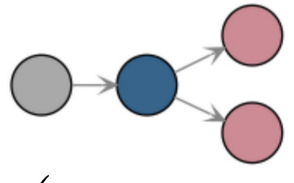
- Signal efficiency mostly depends on: $m_{Z'},\ m_{\chi}\ (\Gamma_{Z'})$
- What can be directly used:







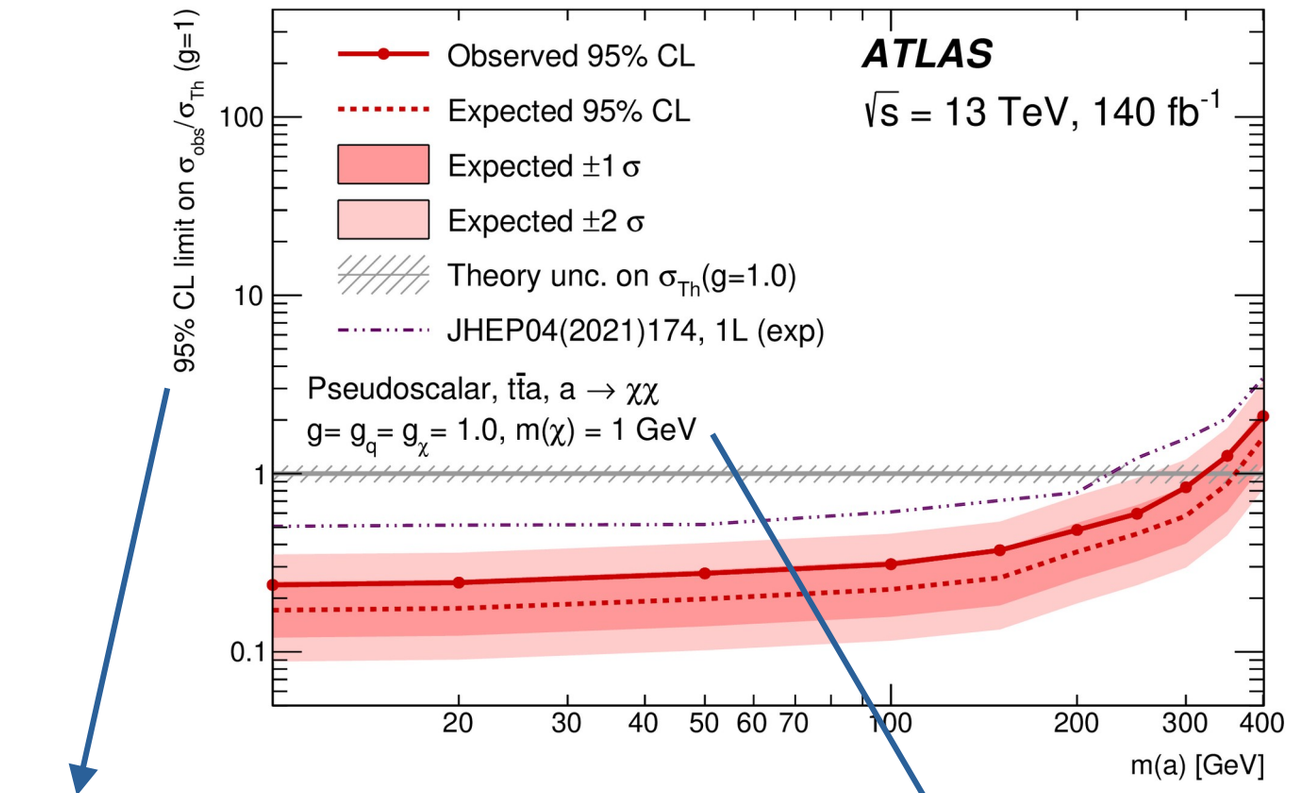
$\sigma_{UL}\,(m_A, m_B, ...)$



$A\epsilon_{\mathrm{SR}}\,(m_A, m_B, ...)$ → Better statistical modeling

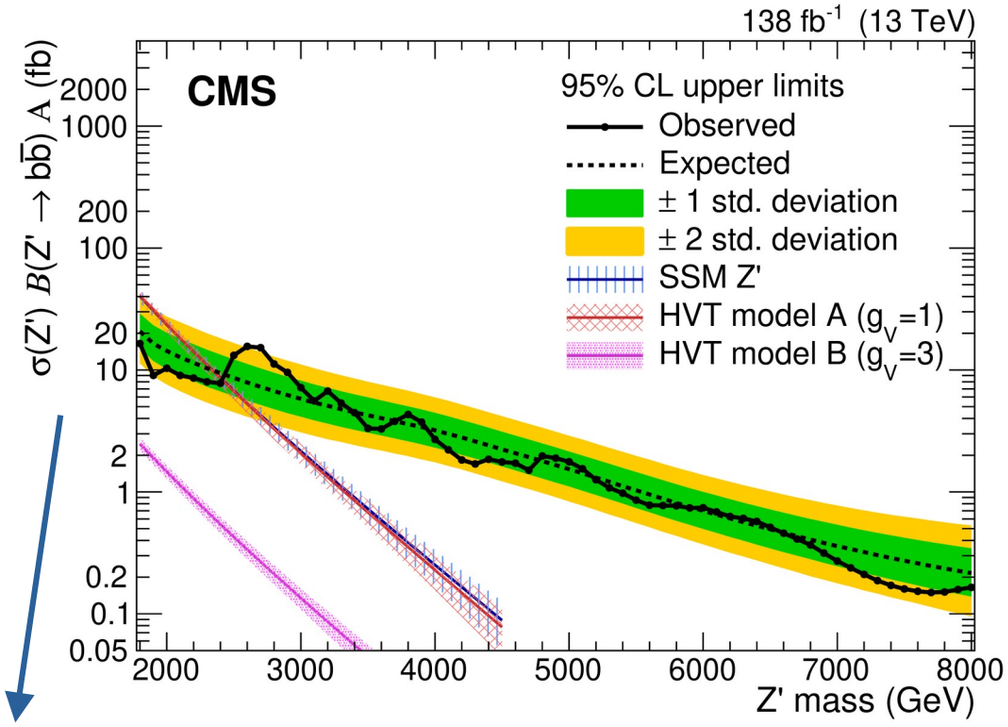
Making Use of SMS Results

- What is often found within the reinterpretation material:



Limits on signal strength ✗

Fixed mass ✗
(1D slice of a 2D space)

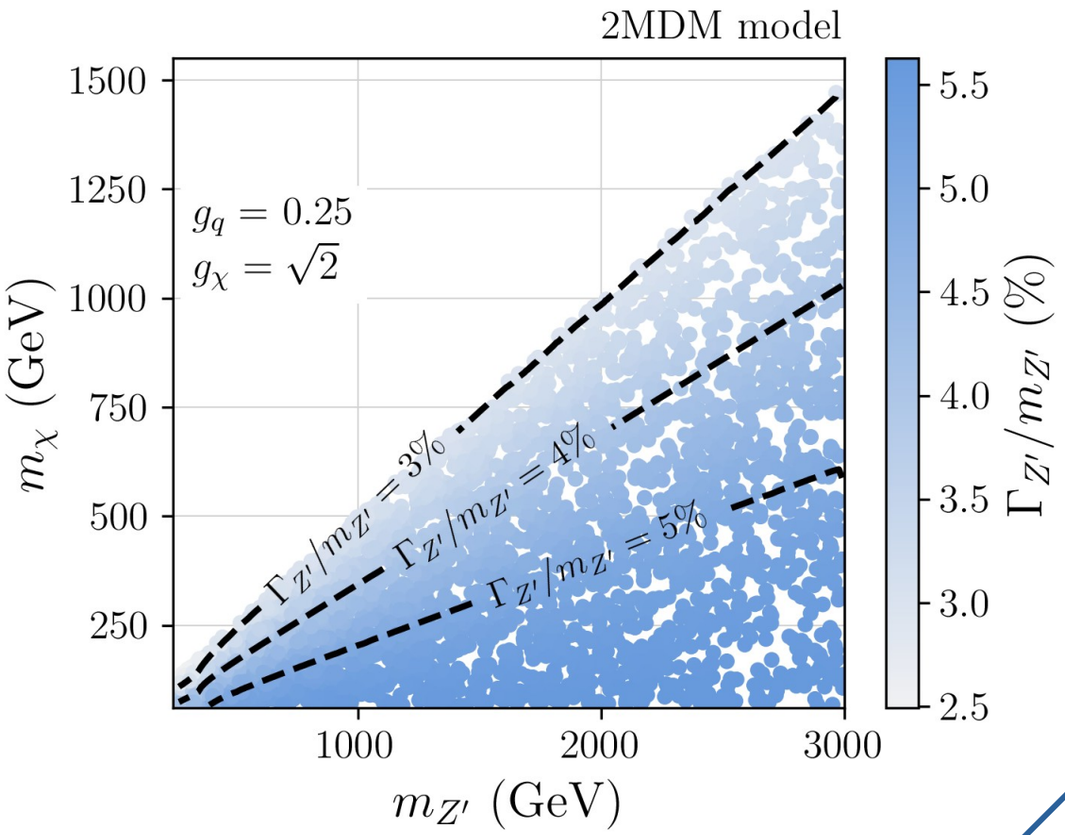


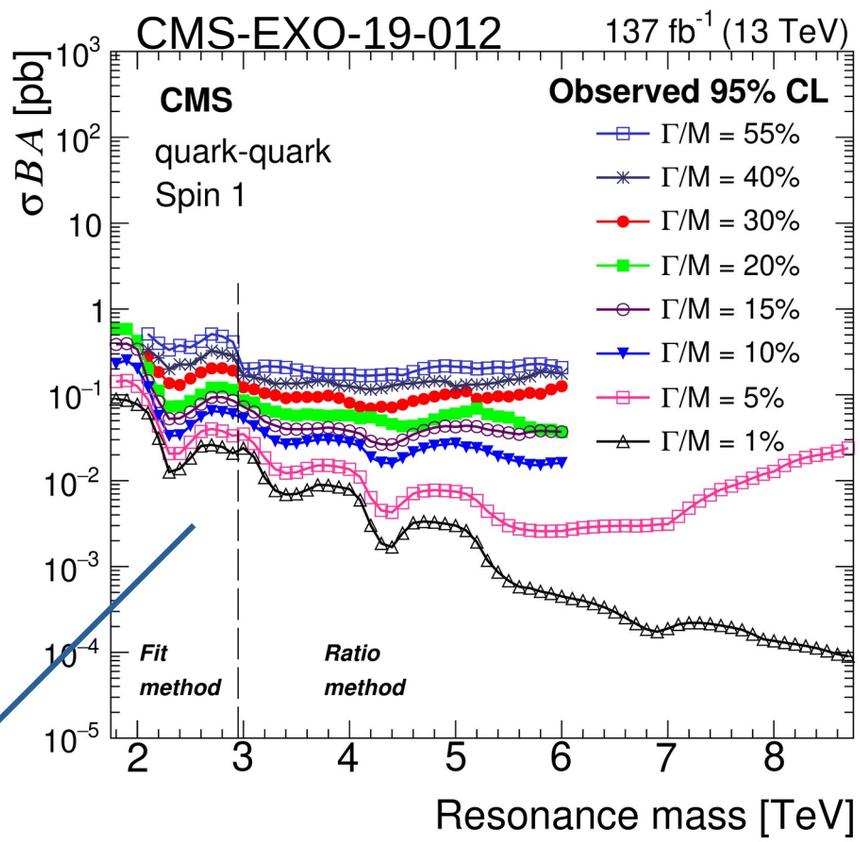
✗ Limits on effective cross-section (depends on signal acceptance)

- Plots in digital format are not always available!
- Limits on couplings or other model parameters are more model dependent
- The signal/model assumptions are not always clear → can be avoided with a more model-independent presentation

Making Use of SMS Results

- The Z' can be a broad resonance:





- The limits strongly depend on the width
- *Many resonance searches do not give width-dependent limits!*
  (for these we assume validity only for width/mass < 1%)

Two Mediator DM (2MDM)

- Simplified model results considered:

ID	Signature	Luminosity	SMS Topology	Type
	Run 2 - 13 TeV			
ATLAS-EXOT-2019-03 [12]	Dijet resonance	139 fb^{-1}	$pp \to Z' \to jj, b\bar{b}$	UL
ATLAS-EXOT-2018-48 [13]	$t\bar{t}$ resonance	139 fb^{-1}	$pp \to Z' \to t\bar{t}$	UL
CMS-EXO-19-012 [14]	Dijet resonance	137 fb^{-1}	$pp \to Z' \to jj, b\bar{b}$	UL
CMS-EXO-20-008 [15]	b-jet resonance	138 fb^{-1}	$pp \to Z' \to b\bar{b}$	UL
CMS-EXO-20-004 [16]	Monojet	137 fb^{-1}	$pp \to Z', S \to \chi\chi$	EM
ATLAS-EXOT-2018-06 [17]	Monojet	139 fb^{-1}	$pp \to Z' \to \chi\chi$	UL
ATLAS-SUSY-2018-22 [18]	Multi-jet plus E_T^{miss}	139 fb^{-1}	$pp \to Z' \to \chi\chi$	EM
	Run 1 - 8 TeV			
CMS-EXO-16-057 [20]	b-jet resonance	19.7 fb^{-1}	$pp \to Z' \to b\bar{b}$	UL
CMS-EXO-12-059 [21]	Dijet resonance	19.7 fb^{-1}	$pp \to Z' \to jj$	UL
ATLAS-EXOT-2013-11 [22]	Dijet resonance	20.3 fb^{-1}	$pp \to Z' \to jj$	UL

Efficiency Maps computed using recasting

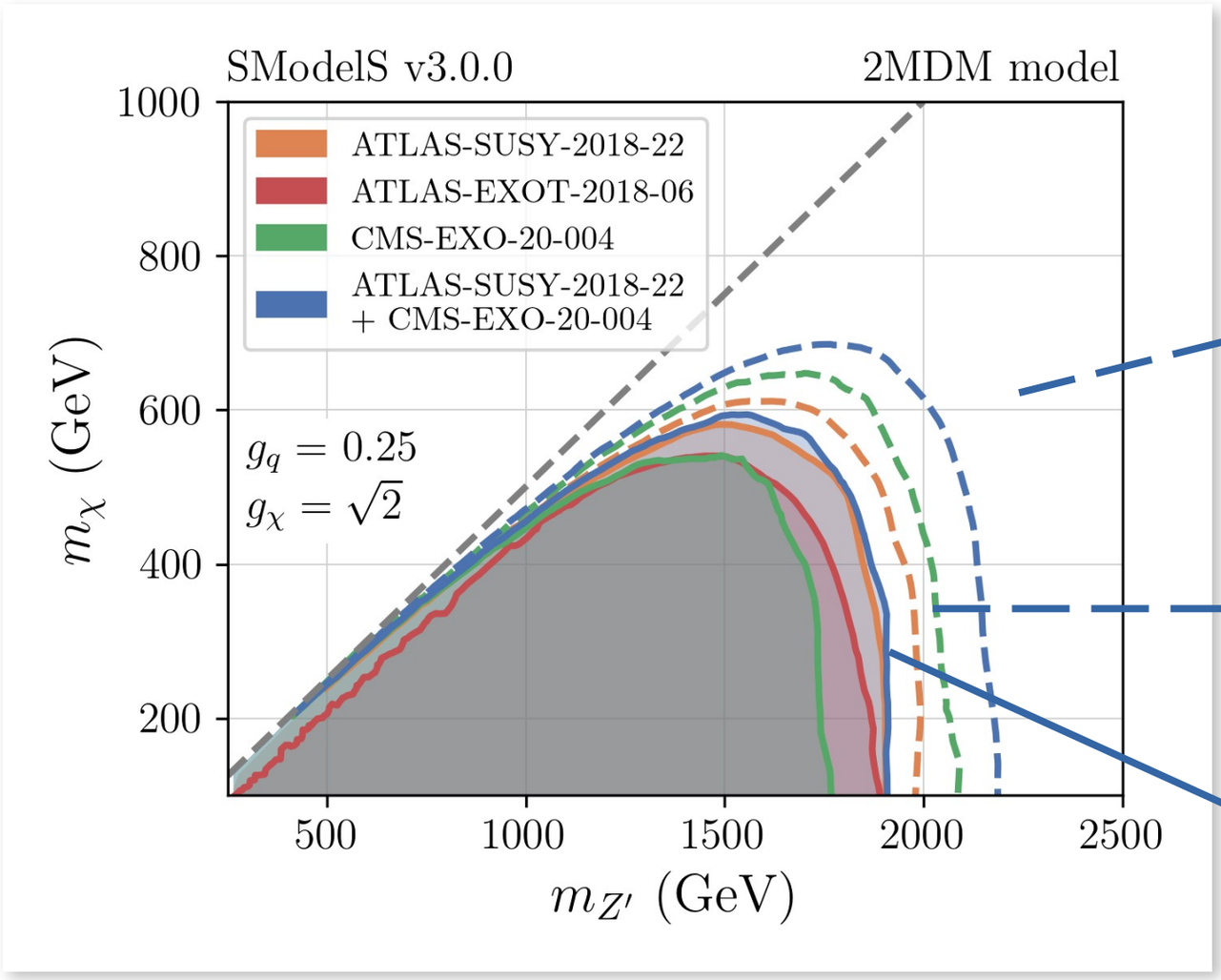
  - We assume CMS monojet and ATLAS multijet to be uncorrelated
    → statistical combination of analyses

- 2MDM scan:

g_q	g_χ	m_χ (GeV)	$m_{Z'}$ (GeV)	N_{points}
$0.1, 0.15$	0.01	65	$(200, 3000)$	6k
$0.15, 0.25$	$1.0, \sqrt{2}$	$(65, m_{Z'}/2)$	$(200, 3000)$	6k
0.1	0.6	$(65, m_{Z'}/2)$	$(200, 3000)$	6k

Two Mediator DM (2MDM)

- Limits from jet(s) plus MET:



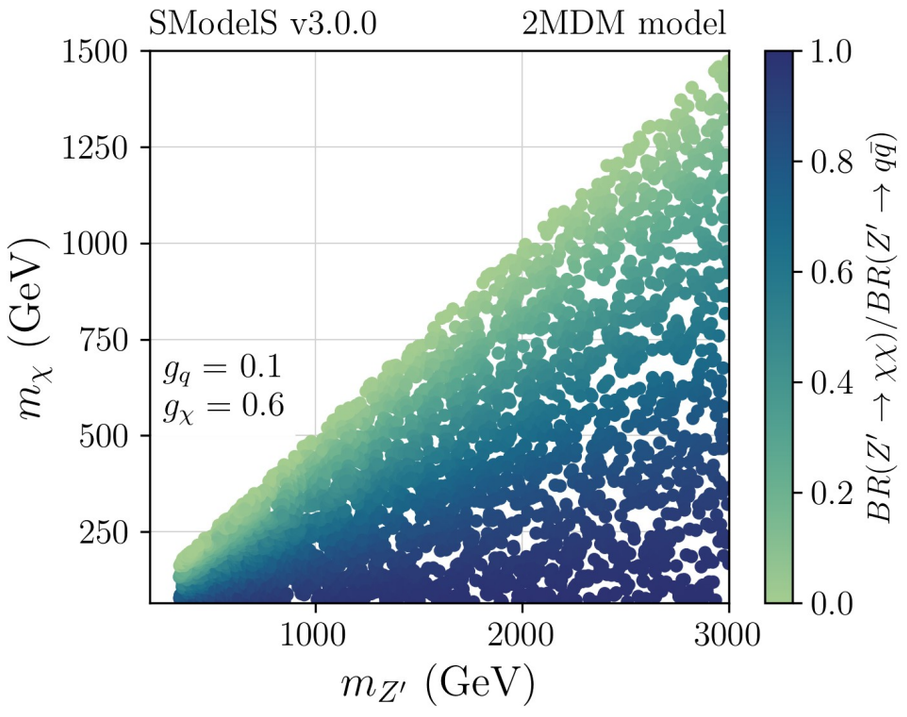
Observed limits are weaker than expected (over-fluctuations)

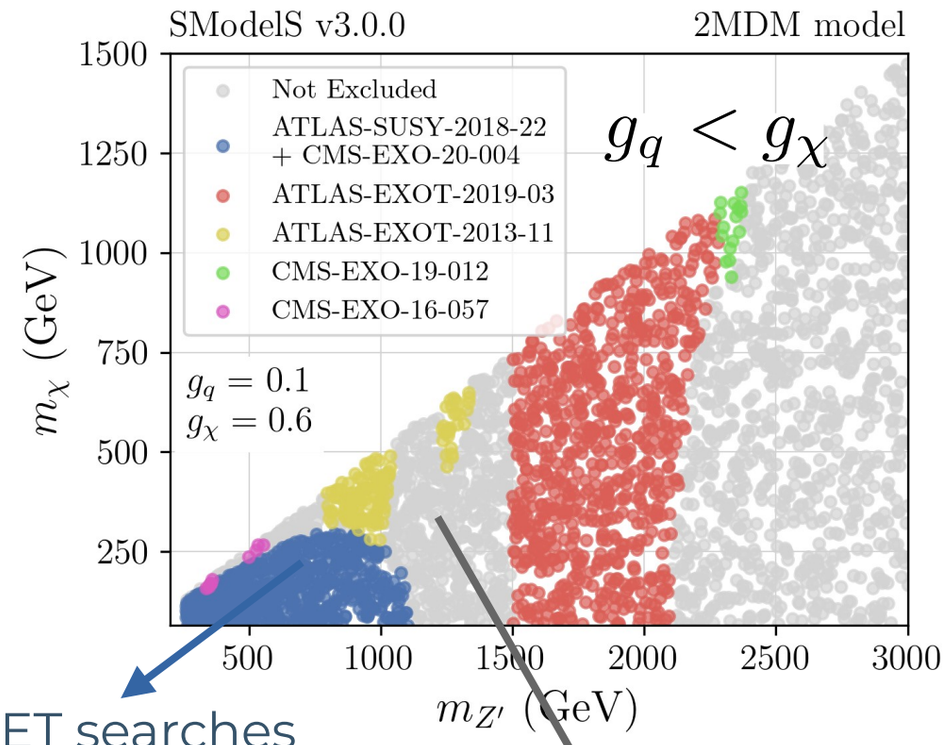
CMS monojet is expected to be stronger than ATLAS multijet, but the opposite is observed

The observed limit is driven by the ATLAS multijet search

Two Mediator DM (2MDM)

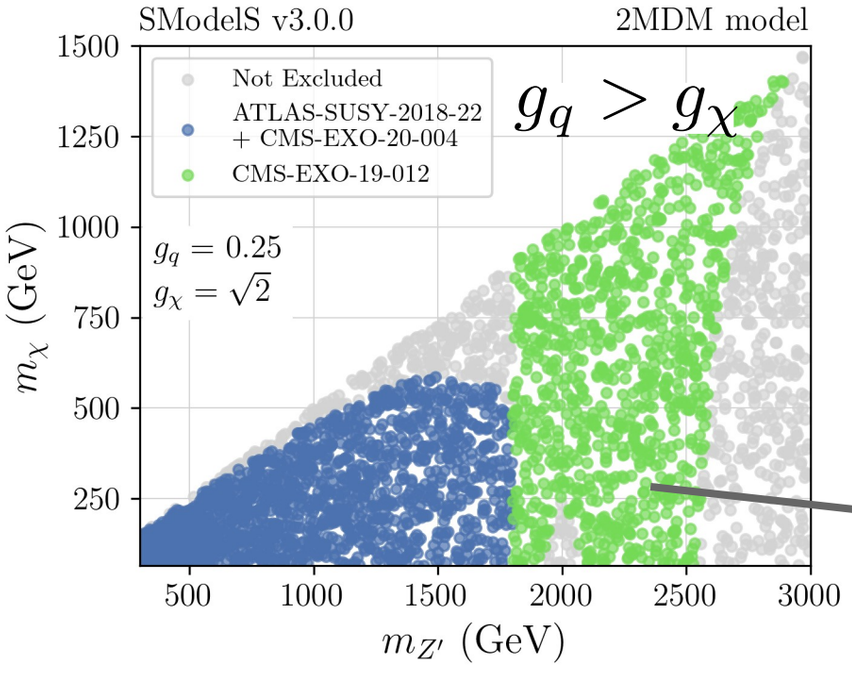
- Monojet versus Resonance searches:





MET searches

Gap from 13 TeV searches



Large width

Only width-dependent limits available

Conclusions

- Simplified model results can be highly useful for reinterpretation
- Producing SMS results in a systematic way can greatly benefit the reinterpretation community:
  - ☐ Limits on σxBR (for UL maps) and not on signal strengths!
  - ☐ Coverage over the relevant simplified model parameters (masses, …) and not over underlying model parameters!
  - ☐ For resonance searches include the width dependence
  - ☐ Whenever possible, provide efficiency maps (Aε)
  - ☐ Statistical information (e.g. pyhf likelihoods)
- Applying the current results to the 2MDM revealed several issues:
  - lack of width-dependent SMS results
  - no (13 TeV) coverage for small masses
  - limits on "secondary" model parameters (couplings, tanβ, …)
  - few efficiency map results,…

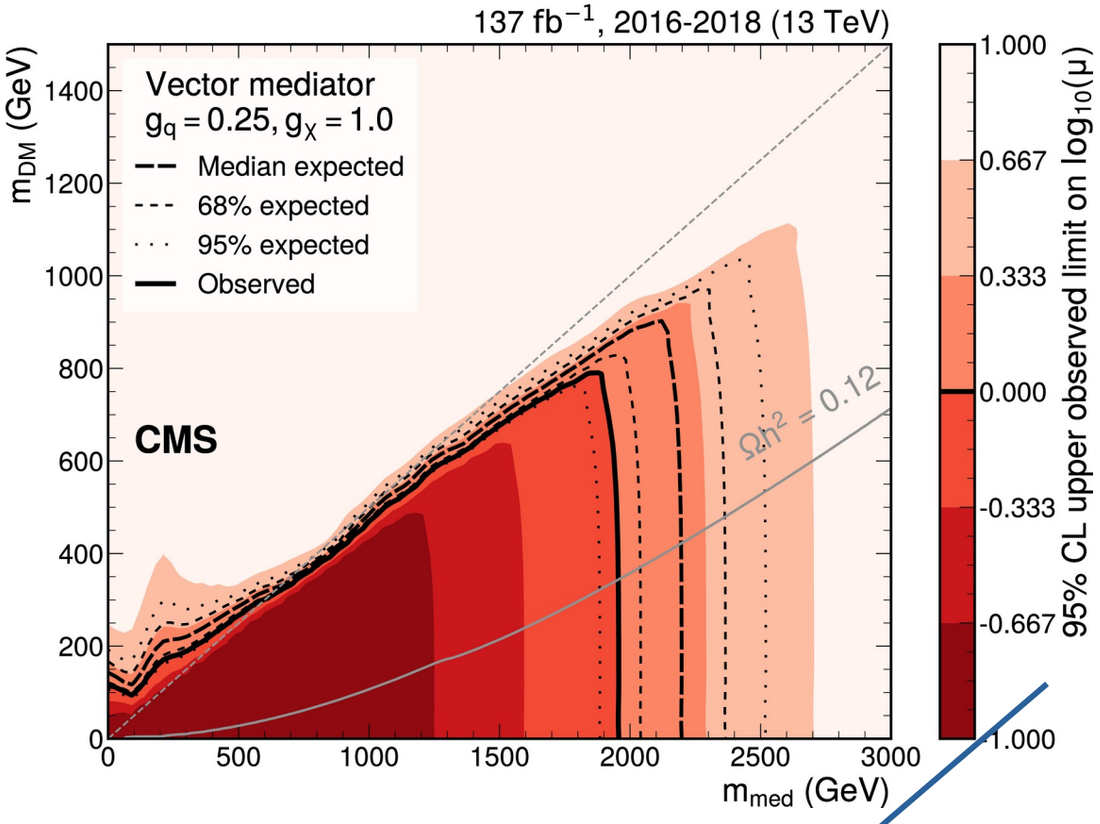
Thanks!

More on SModelS: https://smodels.github.io/

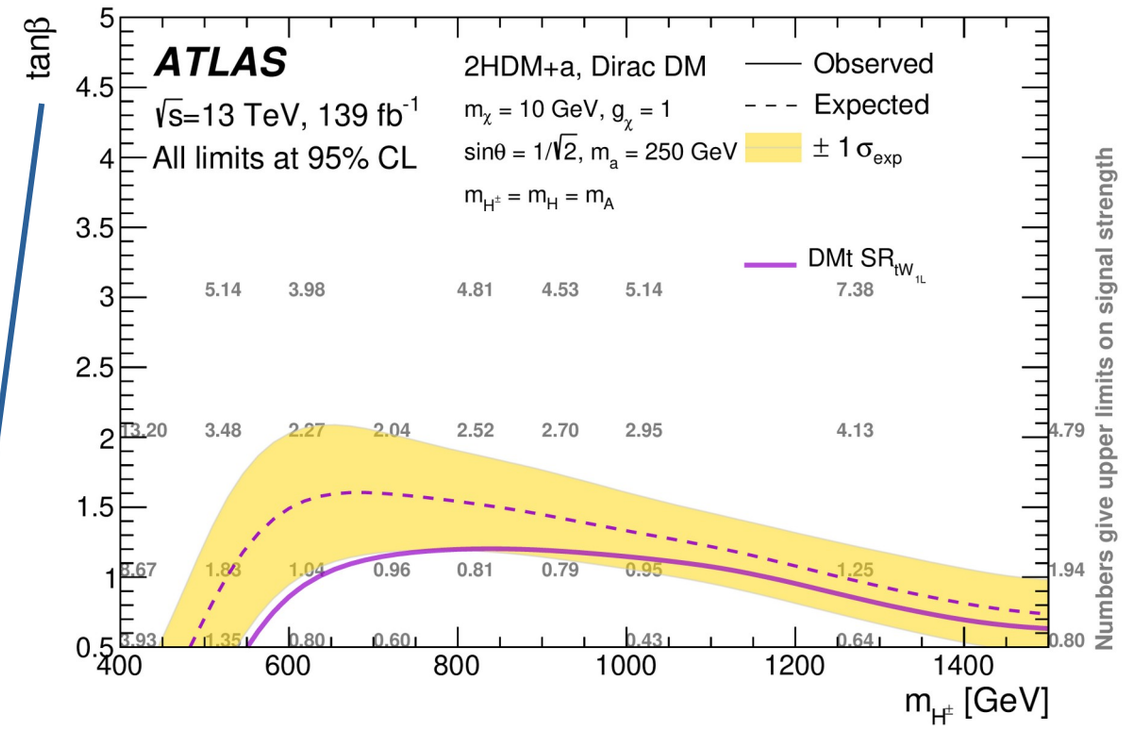
Backup

Making Use of SMS Results

- Other issues with SMS results



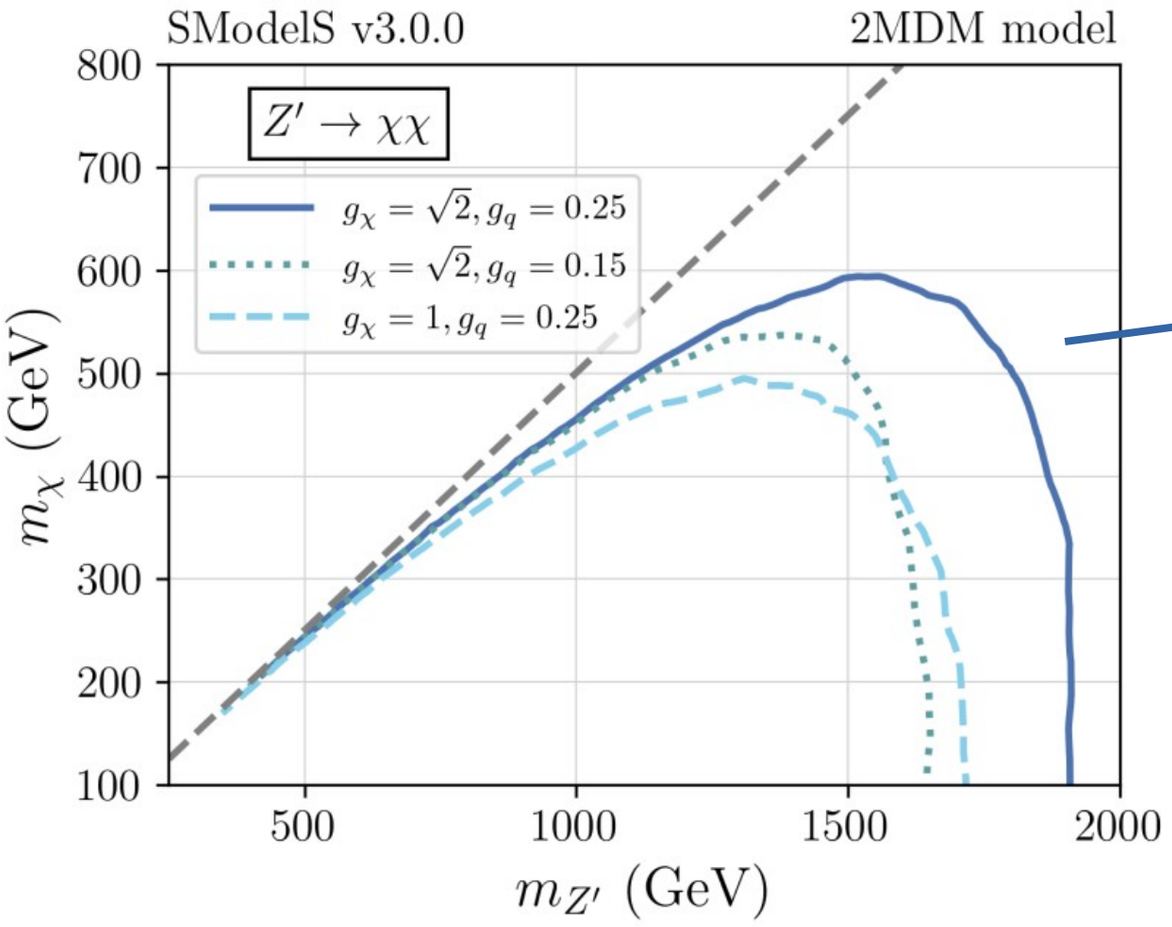
Coarse grain grid on signal strength ✗



Model (non-observable) parameter ✗

Two Mediator DM (2MDM)

- Limits from jet(s) plus MET:

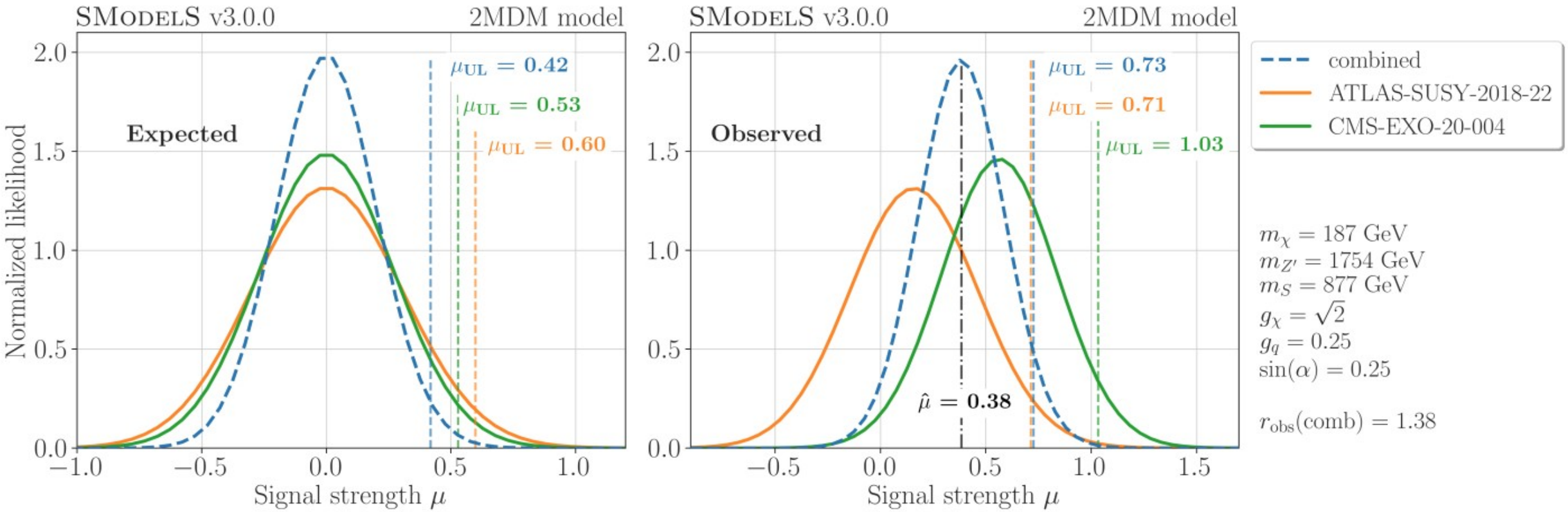


Signal increases with both couplings

$$\sigma(pp \to Z') \times \mathrm{BR}(Z' \to \chi\chi) = \frac{\sigma(pp \to Z')\,\Gamma(Z' \to \chi\chi)}{\Gamma(Z' \to \chi\chi) + \Gamma(Z' \to q\bar{q})} \propto g_q^2 \frac{1}{1 + g_q^2/g_\chi^2}$$

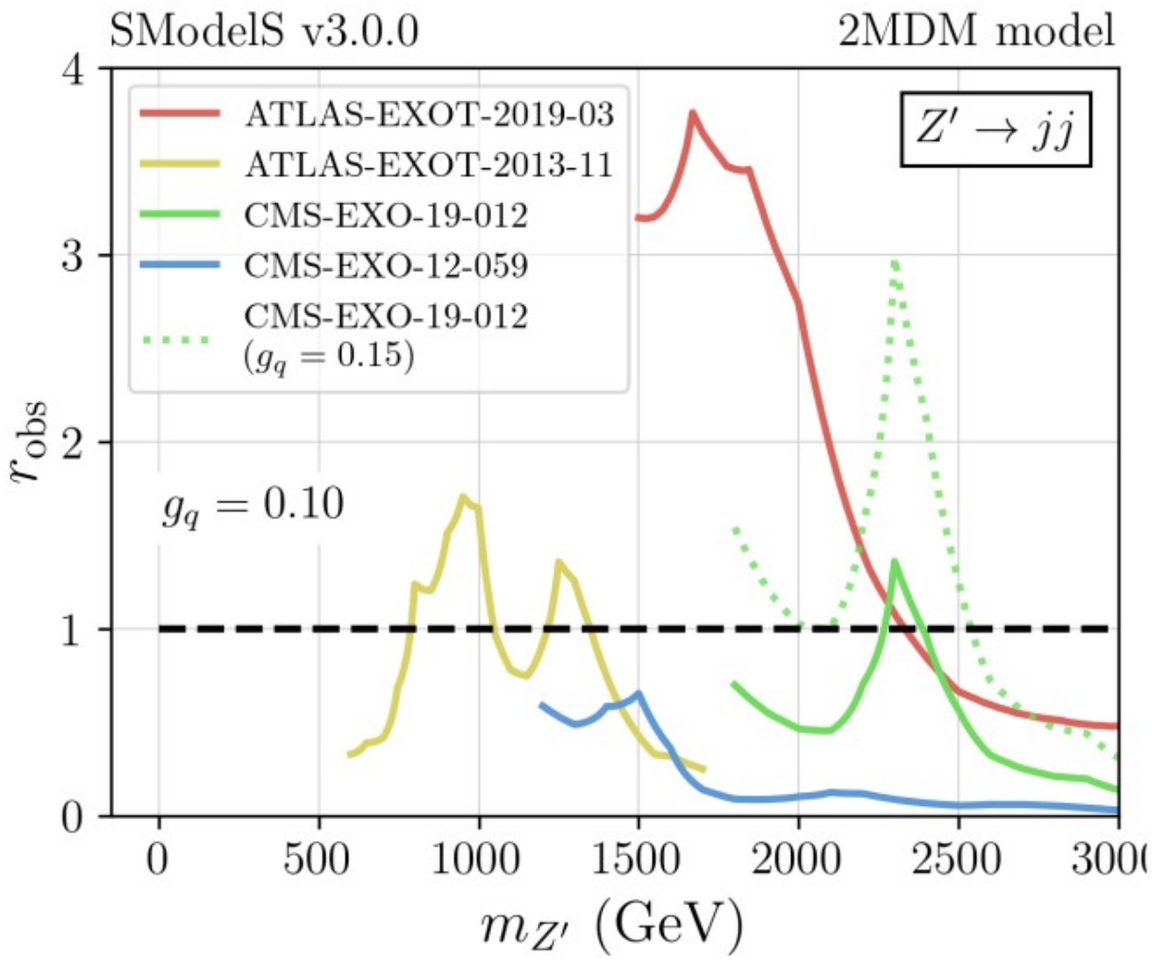
Two Mediator DM (2MDM)

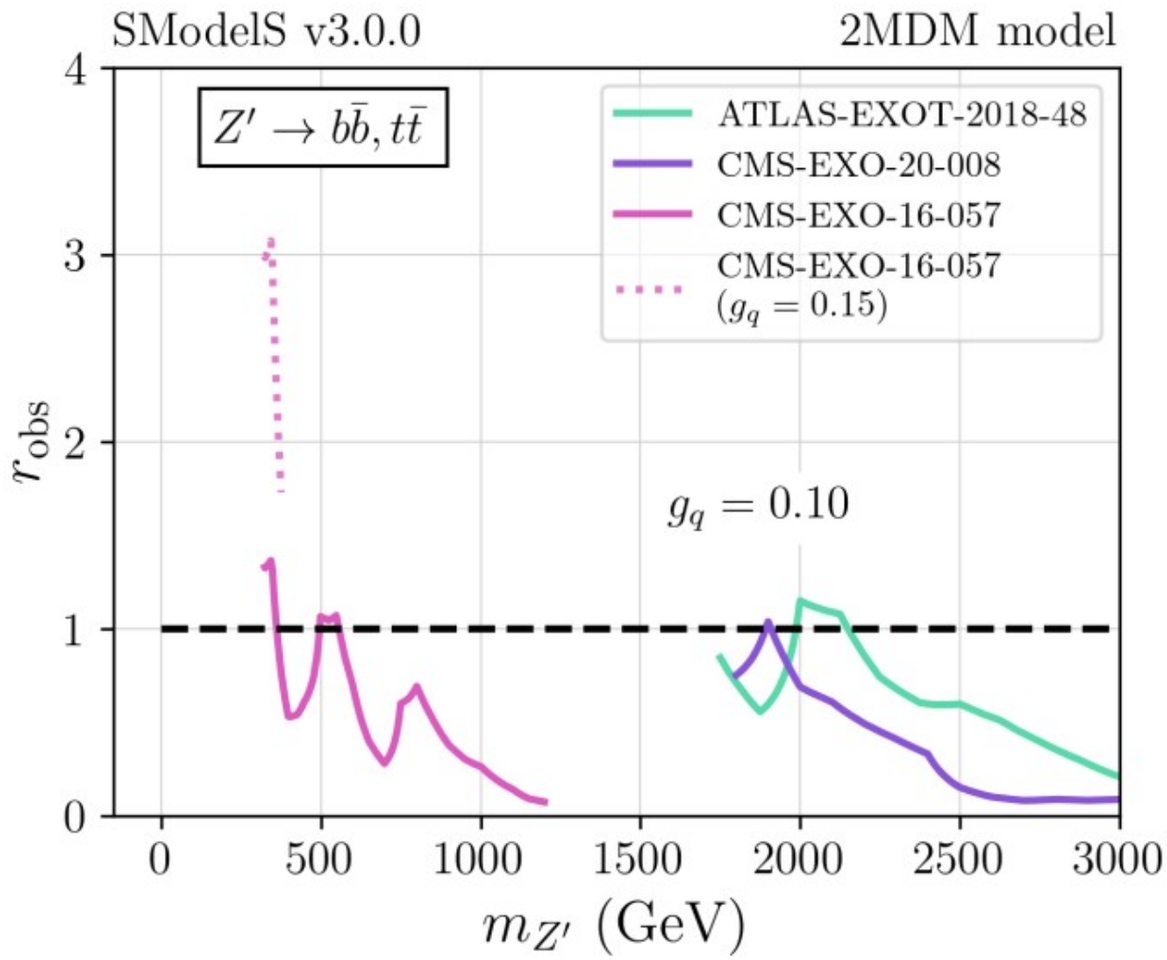
- Analyses combination: $\mathcal{L}_{\rm tot}(\mu) = \prod_i \mathcal{L}_i(\mu)$



Two Mediator DM (2MDM)

- Resonance searches:





$$\sigma BR \propto \frac{g_q^4}{g_\chi^2 + g_q^2} \qquad \Gamma_{Z'} \propto g_\chi^2 + g_q^2$$

→ Large cross-section → large width