



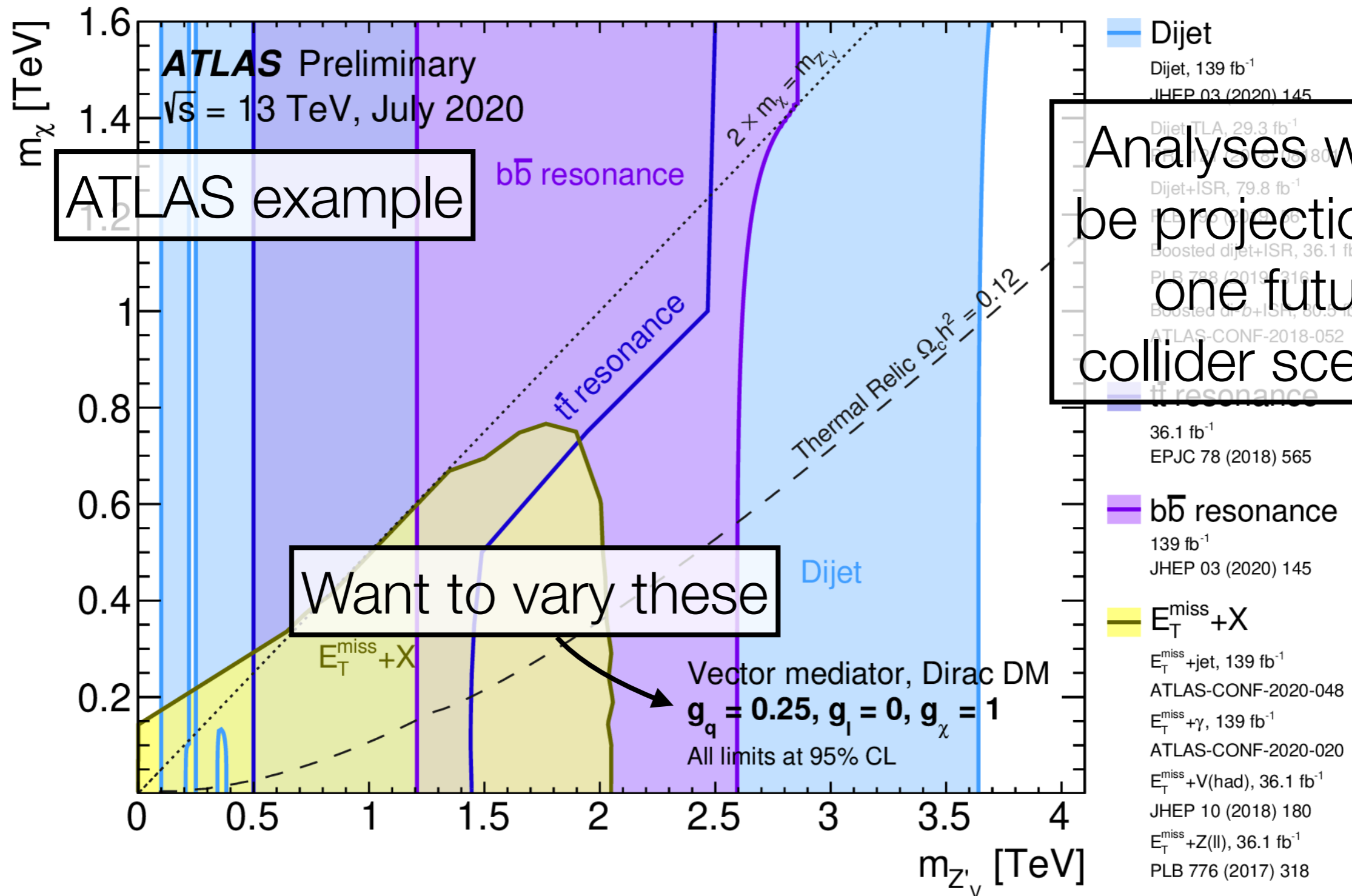
How to make the plots we want

DMWG coupling scan group

What are we talking about

- So questions:
 - What plots are we trying to make?
 - What inputs are necessary to make those plots?
 - Sub-topic: what is possible to extrapolate from other results and what isn't?
- Want to understand “what the future colliders need to give us for the coupling scan”
- Lots of notes in [this google doc](#)

Plot 1 (today's concern): mass-mass exclusions



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- Versions we want (from the gdoc)
- Plot 1, DM mass vs mediator mass with varying couplings
 - Version 1: **vector** model, **without** lepton couplings
 - Version 2: **vector** model, **with** lepton couplings
 - Version 3 [not sure this will be in our final report?]: vector model, with couplings fixed to **dark photon couplings**
 - Version 4: **scalar model** [Caterina remembers this is easier if one assumes no off-shell sensitivity]
 - Version 5: **scalar with Higgs mixing** model, y axis: $\sin\Theta$ of mixing

Tools at our disposal for coupling scans

Note: currently no method for $t\bar{t}$ resonance

Note: dilepton must provide width parameterisation too ⁵

- For vector/A-V models, we can rescale limits from one coupling to a different coupling, but we need to start with one of these inputs:

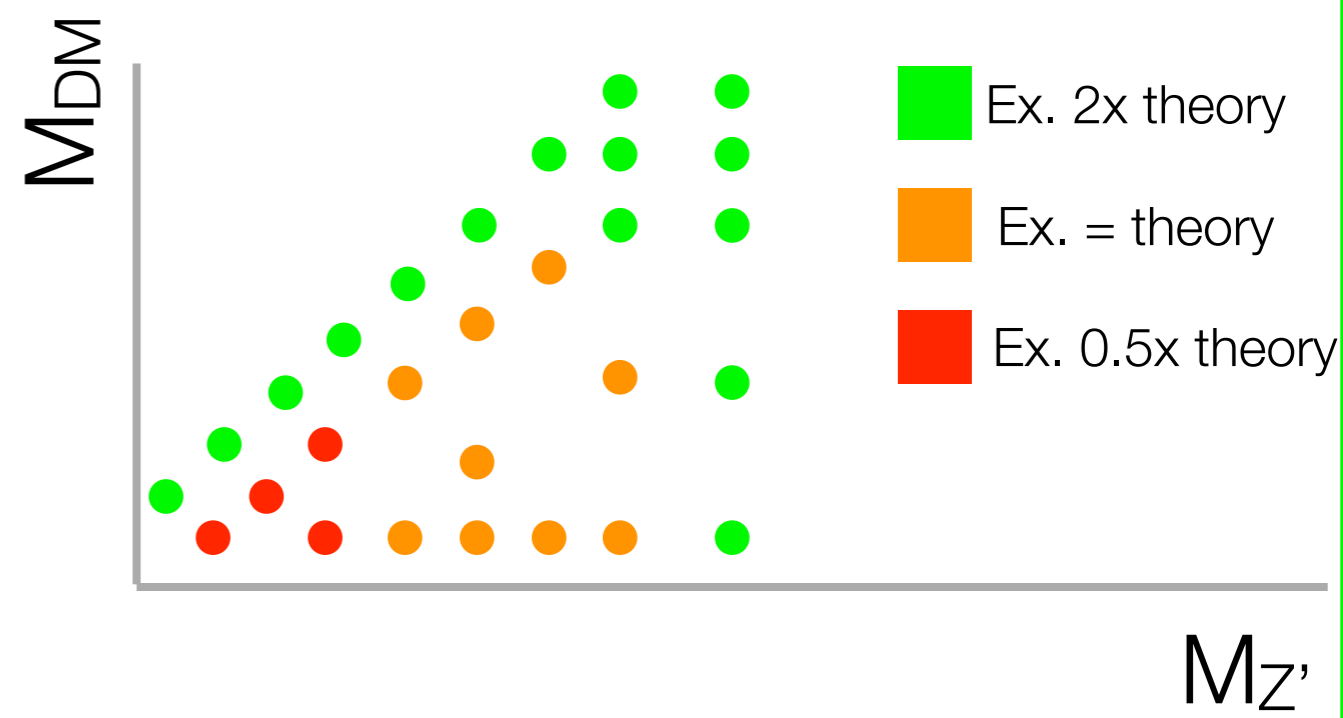
Dijet/dilepton, vector/axial

- Start from coupling limit versus mass for a fixed DM mass and rescale from there*



Mono-X, vector/axial


- Start from exclusion depth in mass-mass plane for one set of couplings and rescale from there




Plot 1 (today's concern): mass-mass exclusions

- Versions we want (from the gdoc)
- Plot 1, DM mass vs mediator mass with **varying couplings**

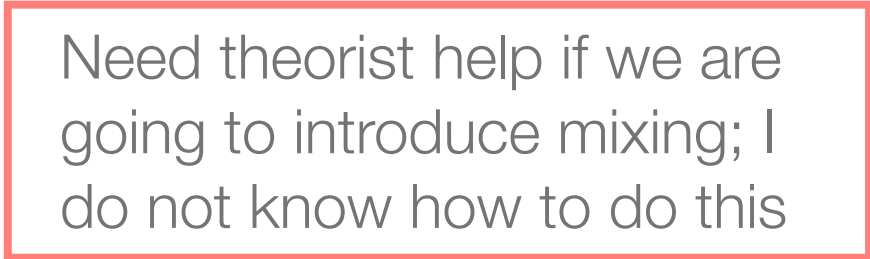
- Version 1: vector model, without lepton couplings
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Easy, just need a single vector model line (dijet) or grid (mono-X) and we can get all three of these



Coupling scan potentially possible but never tested/not worked out. Start with fixed coupling plots



Need theorist help if we are going to introduce mixing; I do not know how to do this

What the existing methods *can't* provide

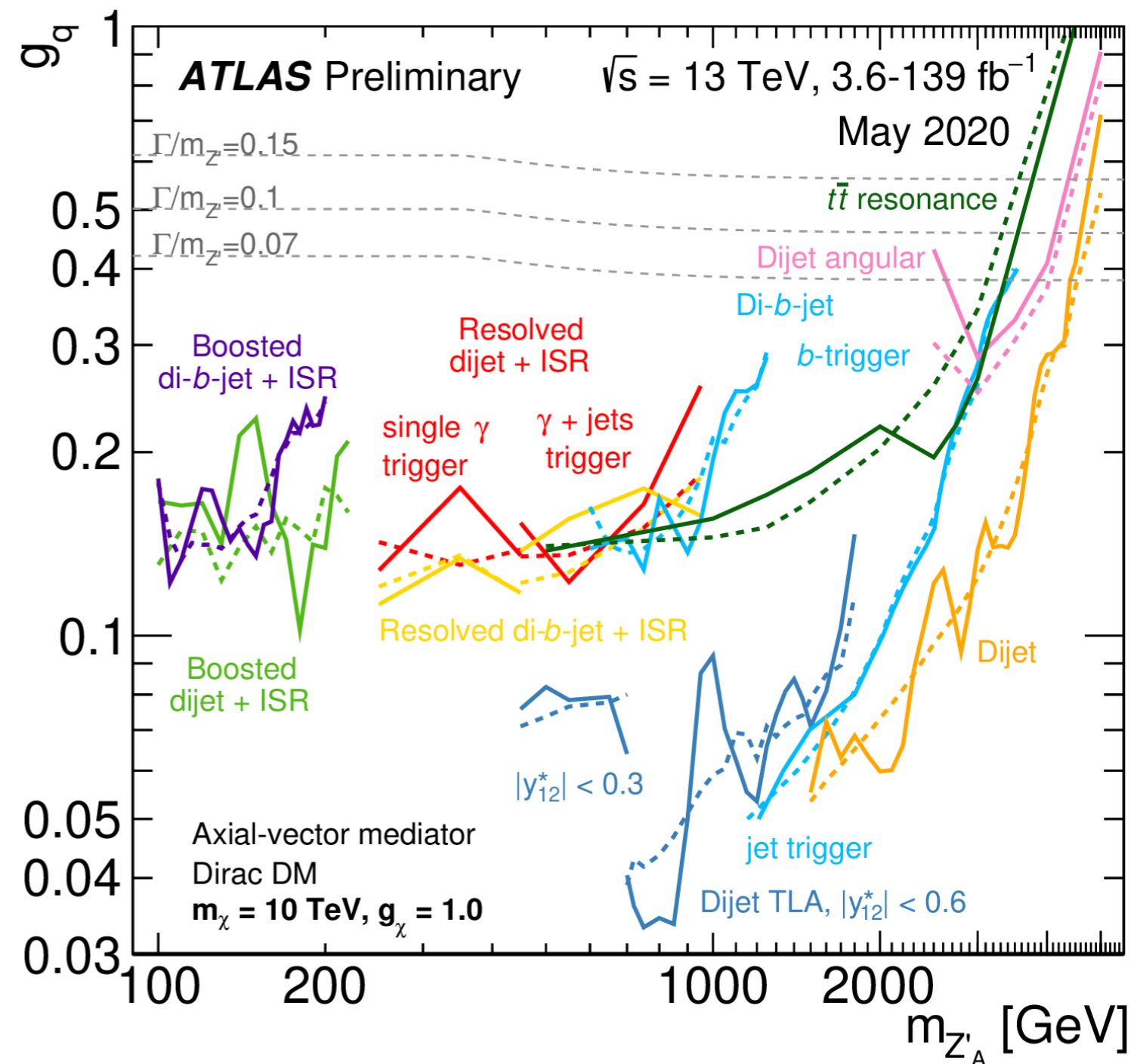
- We are not prepared to rescale **across collider CME**. Therefore to include an analysis limit at 14 TeV or 50 TeV or 100 TeV we need an input which is calculated *in that context*.
 - The cross sections are calculable but the implicit assumptions about analysis acceptance, backgrounds, etc would not be reasonable without more detailed study
- We cannot rescale to **different input particles** (ILC, muon collider, ...), so once again we need dedicated inputs
 - Again, the cross sections are actually quite rescaleable but given that the backgrounds would be completely different it isn't reasonable to use pp collider limits to estimate these
- Takeaway: **produce a dedicated limit** to start from in each context we want to study

Can we do a coupling scan for lepton colliders if we did have one dedicated input?

- I think so, **yes**
- Formulas for coupling scans are just coming from the tree-level Feynman diagrams for new particle production in all cases
- Swap first vertex from qq to ll and recalculate approximations -> should give equivalent and equally simple formulas
- Can work this out if we get interest/inputs, but **will take some time**
- Harder for scalar/pseudoscalar (but we don't have the coupling scan sorted out there for hadron colliders yet either!) - if this is desired we need to involve a theorist cause I don't even know what Feynman diagrams we need to be considering

Plot 2: coupling vs mediator mass

- Used for fully visible final states
- Comes “for free” in dijet family analyses since this is the input format we are requesting for Plot 1
- No rescaling plan for $t\bar{t}$, so if we want a version included we’ll need to request it specially
- Let’s discuss lepton couplings, but in general would be feasible if we have limits for full range of relevant widths and are comfortable hopping in between



Other plots and public code repository

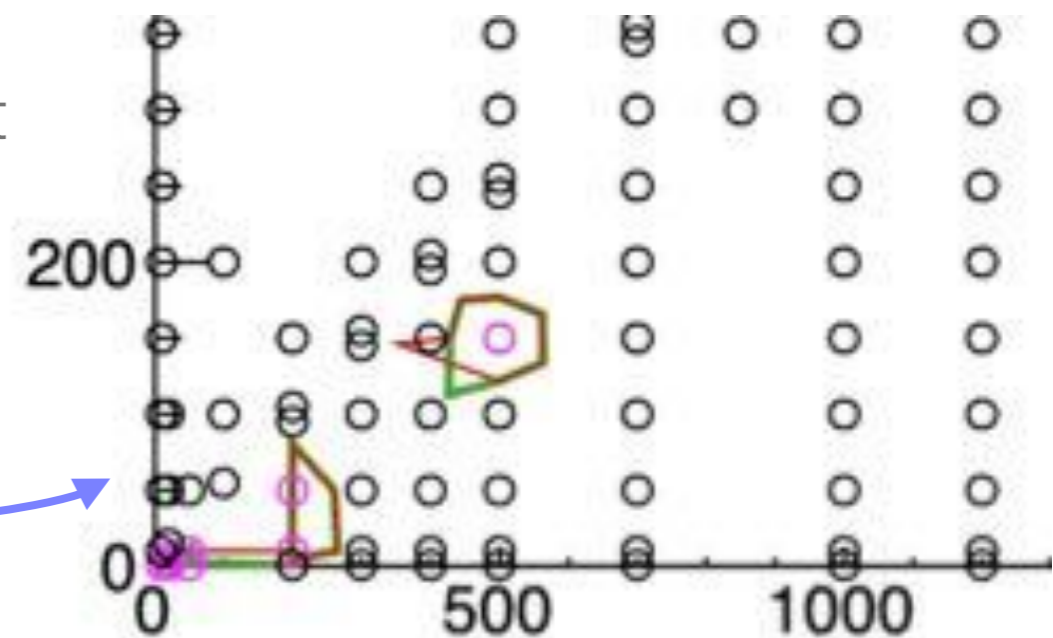
- Direct and indirect detection plots (plots 3 and 4) are doable starting from mass-mass plots
- Coupling scan code in development (slowly) here: <https://github.com/LHC-DMWG/DMWG-couplingScan-code>
- Still needs cleanup and reorganisation, as well as testers on different platforms. If anyone wants to discuss how to make it most useful, please get in touch with Boyu and I, plus Andreas Albert

Summary

- For each analysis and each future collider scenario (machine, energy, luminosity) which could affect kinematics, acceptance, etc :
 - If fully visible final state, just need the 1 line that is coupling vs mass
 - If mono-X analysis, need 2d grid of exclusion depth for one selected set of couplings
 - If scalar or pseudo-scalar simplified model, that 2D grid ought to do as well, but this still needs to be worked out in considerably more detail
- Coupling scan formulas not calculated for lepton colliders - work would be required from our side too here
- Do we have a comprehensive list anywhere of future collider projections being done in different final states?

Caveats to make users aware of

- Granularity of the input limit affects quality of the output
 - Especially important for mono-X style searches in the low mass corner: at small couplings when the limit shrinks down to just this area, it looks terrible if the input wasn't sufficiently granular
 - This is what Boyu brought up in our Slack channel:
- If they have reason to believe that changing couplings would meaningfully change their acceptance, they need to tell us and we won't scale the couplings

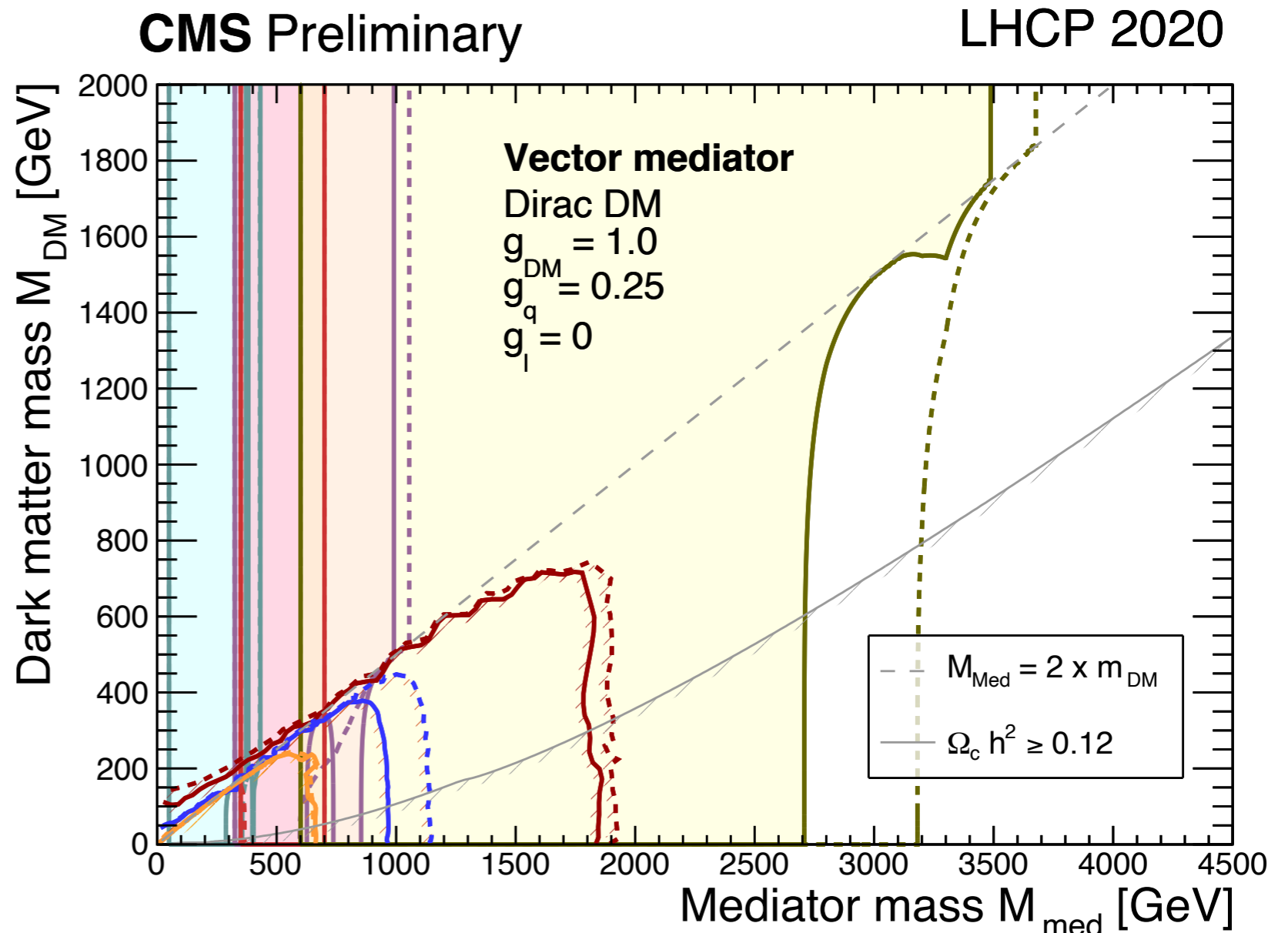


Backup

Goal: produce the same kinds of plots with less labour!

Introduction: the problem

- Making these plots has been very **time consuming** historically
- How they're done: generate a lot of MC with fixed couplings in the mass-mass plane, then scale existing analysis limits to the cross sections of the new samples
- Problems: this is very slow and so **limits the number of couplings** etc which we can display



Given a signal strength limit μ for one set of model parameters, can we easily and accurately find μ for another set of parameters?

What we can use

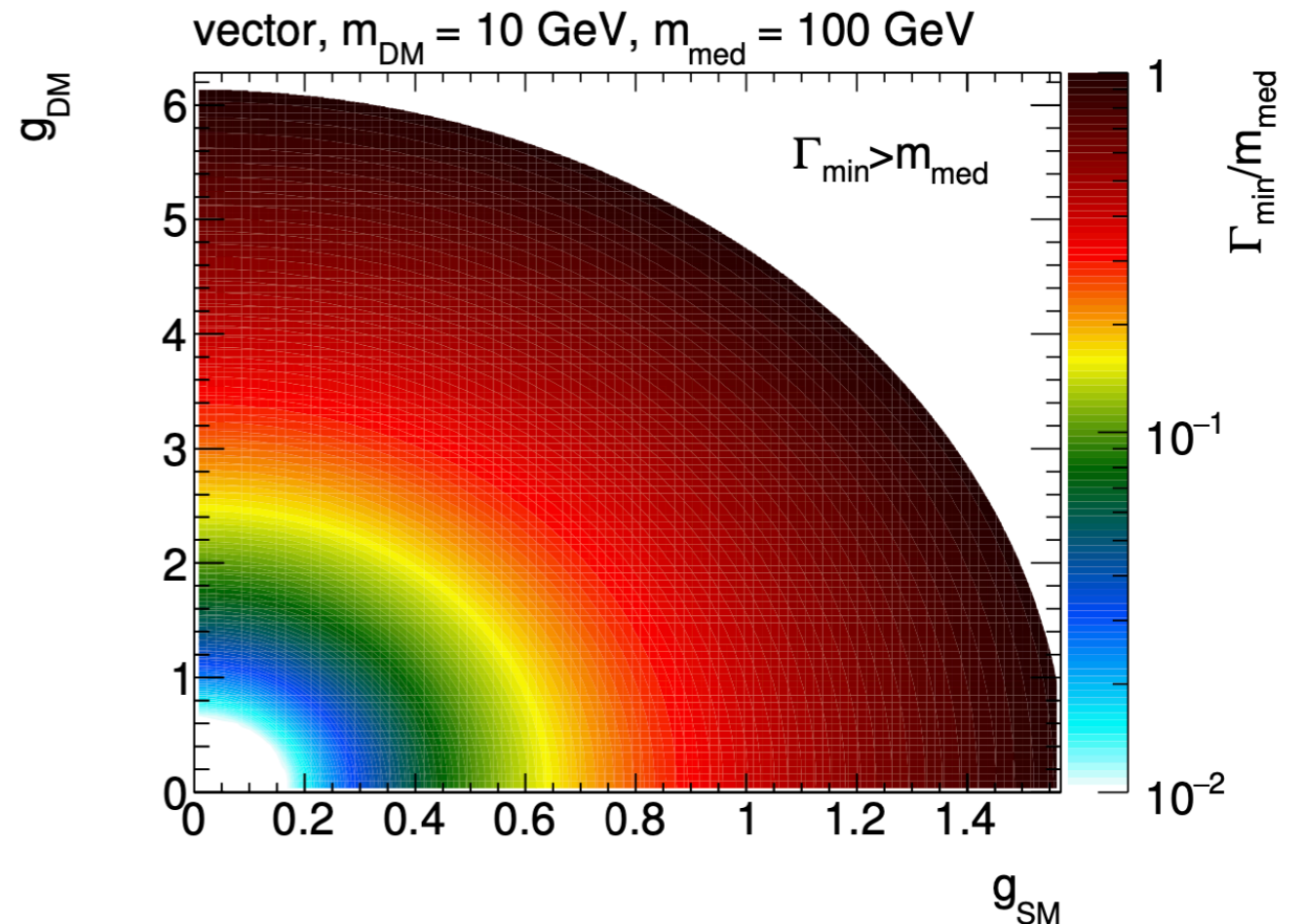
- These plots (and others) are based around s-channel simplified model described [here](#)
- We have known analytical relationships between the mediator branching ratio/width and cross section and the couplings and masses:

$$\Gamma_{\text{vector}}^{\chi\bar{\chi}} = \frac{g_{\text{DM}}^2 M_{\text{med}}}{12\pi} (1 - 4z_{\text{DM}})^{1/2} (1 + 2z_{\text{DM}}) ,$$

$$\Gamma_{\text{vector}}^{q\bar{q}} = \frac{g_q^2 M_{\text{med}}}{4\pi} (1 - 4z_q)^{1/2} (1 + 2z_q) , \quad \text{etc.}$$

- We can use this information to rescale limits from one set of couplings to another*

arXiv:1507.00966



Relationship between mediator width and couplings for an example point in m_{DM} , m_{med} space

* many caveats apply

The challenges

Type 1: cross section

- Effect of masses and couplings on cross sections is analytically computable (with some edge cases)
- Same for ~all analyses

Type 2: kinematics etc.

- Effects of coupling changes on acceptance, kinematics, etc via (for example) changing a resonance width
- Very analysis dependent

- In this project, we focus on **solving the type 1** challenges. Requires providing clear recipes for users, benchmarking performance, understanding edge cases
- On type 2 challenges, we will define regions of validity for rescaling methods so analyses know what they need to check before using them