CMS dilepton interpretation

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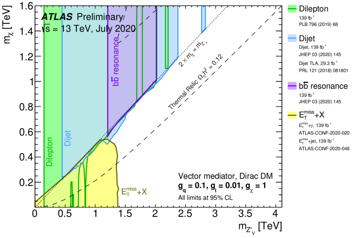
Introduction

- LHC DMWG recommendation for spin-1 mediators with lepton couplings: [1703.05703](1703.05703).

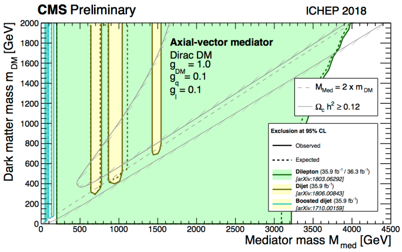
$$\mathcal{L}_{\mathrm{V}} = -g_{\mathrm{DM}} Z'_{\mu}\bar{\chi}\gamma^{\mu}\chi - g_q \sum_{q=\mathrm{u,d,s,c,b,t}} Z'_{\mu}\bar{q}\gamma^{\mu}q - g_{\ell} \sum_{\ell=e,\mu,\tau} Z'_{\mu}\bar{\ell}\gamma^{\mu}\ell \quad (1)$$

$$\mathcal{L}_{\mathrm{AV}} = -g_{\mathrm{DM}} Z'_{\mu}\bar{\chi}\gamma^{\mu}\gamma^{5}\chi - g_q \sum_{q=\mathrm{u,d,s,c,b,t}} Z'_{\mu}\bar{q}\gamma^{\mu}\gamma^{5}q - g_{\ell} \sum_{\ell=e,\mu,\tau} Z'_{\mu}\bar{\ell}\gamma^{\mu}\gamma^{5}\ell \quad (2)$$

Model	Coupling type	g_{DM}	g_q	g_ℓ
A2	Axial vector	1.0	0.1	0.1
V2	Vector	1.0	0.1	0.01



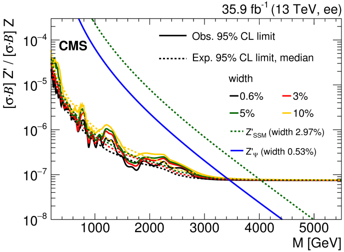
(a)



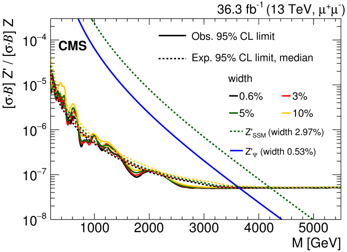
(b)

Width effects

- Unlike dijets, dilepton interpretation can't hide Γ_{med} behind experimental resolution.
  - A2/V2 width goes up to 3.2%.
  - Dijet exp. resolution $\sim 10\% \Rightarrow$ simple scaling valid up to $g_q \sim 0.5$.
  - Dilepton resolution: $1 - 5\%$ for muons, $1 - 2.5\%$ for electrons.
- Analyses have to provide interpretation vs. dilepton peak width.



(a) ee



(b) $\mu\mu$

Procedure

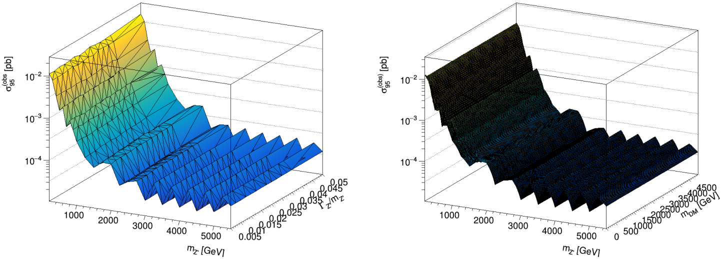
- Accounting for widths in the m_{DM}-m_{med} interpretation is straightforward, but some work.

1. Analysis provides 95% CL limits for different widths, e.g.,
   $[0.50\%,\ 0.75\%,\ 1.0\%,\ 1.25\%,\ 1.50\%,\ 1.75\%,\ 2.0\%,\ 2.25\%,\ 02.50\%,\ 2.75\%,\ 3.0\%,\ 3.25\%,\ 3.50\%,\ 5.0\%,\ 10.0\%]$
   - $(m_{\mathrm{med}},\ \Gamma_{\mathrm{med}},\ \sigma_{95})$.
2. For given point in model space, i.e. $(m_{\mathrm{med}},\ m_{\mathrm{DM}},\ g_\ell,\ g_q,\ g_{\mathrm{DM}})$, compute width and lookup σ_{95} using interpolation.
   - $(m_{\mathrm{med}},\ m_{\mathrm{DM}},\ \sigma_{95})$.
3. Compute cross sections for the model with Madgraph.
   - $(m_{\mathrm{med}},\ m_{\mathrm{DM}},\ \sigma)$.
4. Subtract (use logs for numerical reasons).
   - $(m_{\mathrm{med}},\ m_{\mathrm{DM}},\ \log(\sigma) - \log(\sigma_{95}))$.
5. Compute contours at 0.

Note: CMS Run 2 dilepton isn't out yet, so I made fake limits for these slides.

Analysis inputs and width conversion

- From analysis $\{(m_{\text{med}},\, \Gamma,\, \sigma_{95})\}$, make TGraphs of σ_{95} vs. Γ.
- For given model point, compute Γ and look up excluded cross section with TGraph::Eval() (linear interpolation assumed to be valid).



(a) $(m_{Z'},\, \Gamma_{Z'})$

(b) $(m_{Z'},\, m_{\text{DM}})$

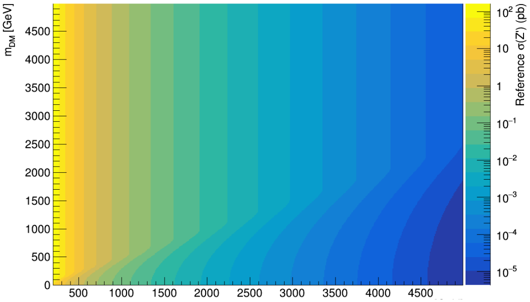
- Note: $(m_{\text{med}},\, m_{\text{DM}})$ spacing has to be fairly fine to avoid bumpy contours (coarse triangulation look really bad!).
- $\Rightarrow$ second interpolation in m_{med} is performed using `scipy.interpolate.interp2d`, giving 10 GeV spacing.

Reference cross sections

- Generate large grid of NLO cross sections:

```
import DMsimp_s_spin1
define l+ = mu+ e+ ta+
define l- = mu- e- ta-
generate  p p  > y1 > l+ l-[QCD]
```

- Mass range specified ($\pm$650 GeV, min. 30 GeV) in `Template/NLO/SubProcesses/cuts.f`.
- Interpolate to same grid as limits.



Contour finding

- Make `TGraph2D`: $(m_{\text{med}}, m_{\text{DM}}, \log_{10}(\sigma_{\text{ref}}) - \log_{10}(\sigma_{95}))$.
  - Positive values are excluded.
  - $\log_{10}$ avoids numerical issues with interpolation, contour finding.
  - Pad with $-\epsilon$ around left and top edges, so the contours close "automatically".
- Contour given by `TGraph2D::GetContourList()`.

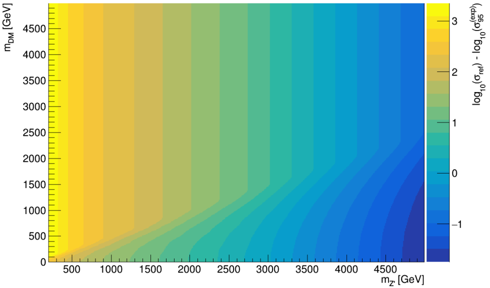
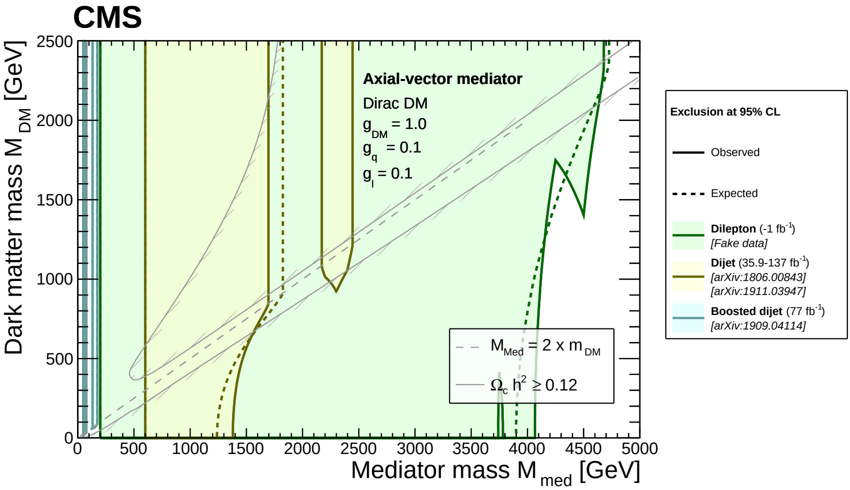
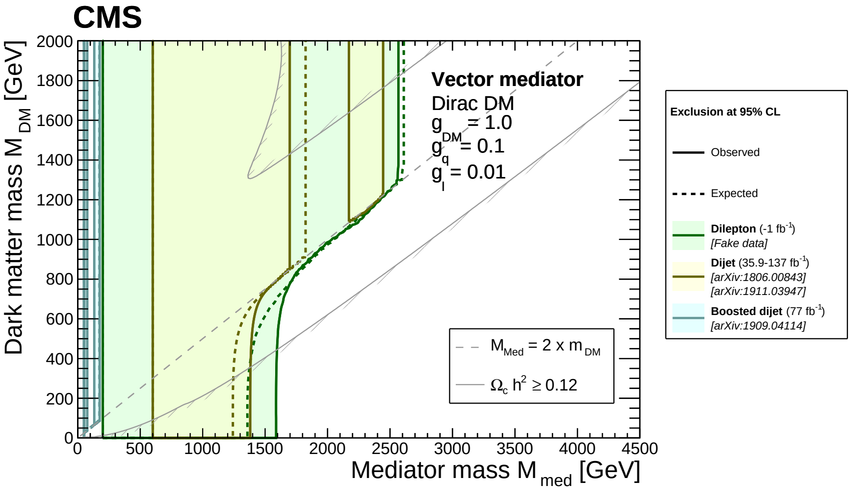


Figure : Difference of the $\log_{10}$s of reference and exp. limit cross sections.

Summary plot: axial vector mediator



Summary plot: vector mediator



Discussion

- Dilepton interpretation is straightforward but kind of tedious.
  - Relies on a few interpolations; assumes these are valid.
  - Code could be packaged and shared, but tbh it's pretty ugly right now...
- What about different couplings?
  - Larger: worry about off-shell tails, interference?
  - Smaller: don't need to worry about all this? Esp. if width is dominated by g_q.
- Anything else to worry about?

Backup