On The Consistent Use Of Mono-Higgs Models

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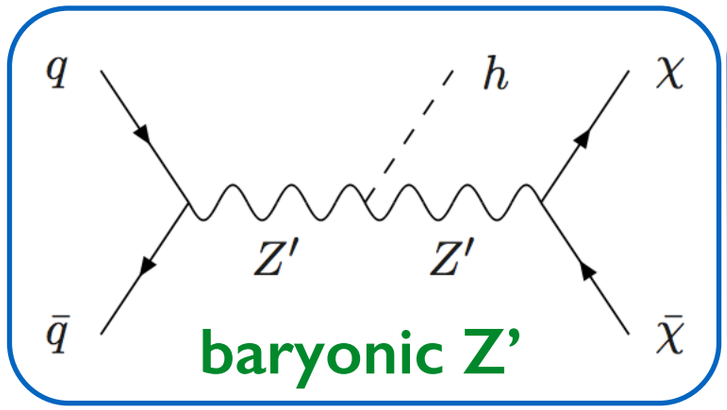
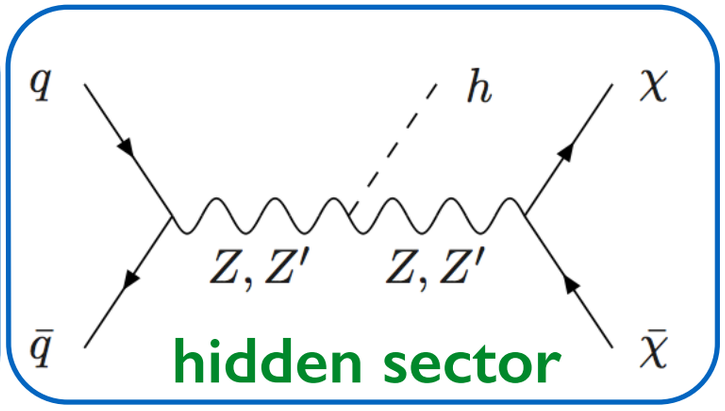
Mono-Higgs Models On The Market

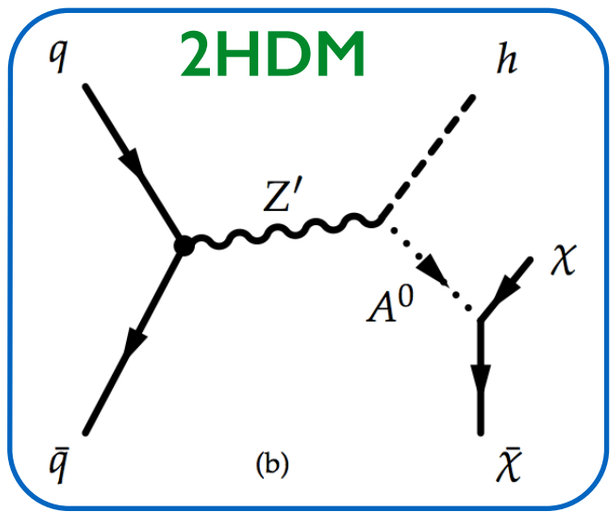
arXiv:1312.2592
axXiv:1402.7074

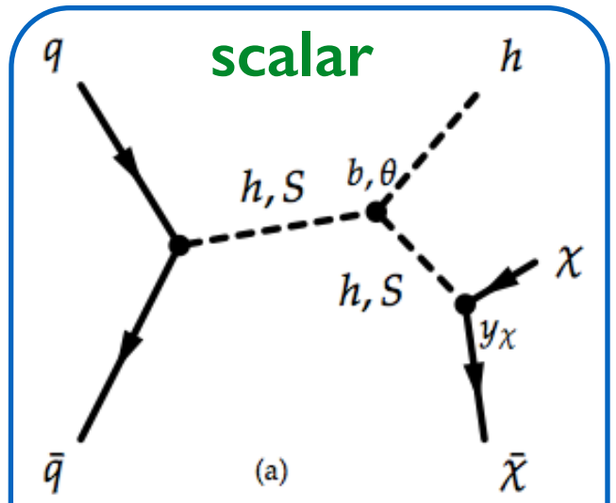
- Effective Field Theory: DM couples directly to Higgs via n-dimensional operator, valid at energies below cutoff scale Λ. →6 EFTs

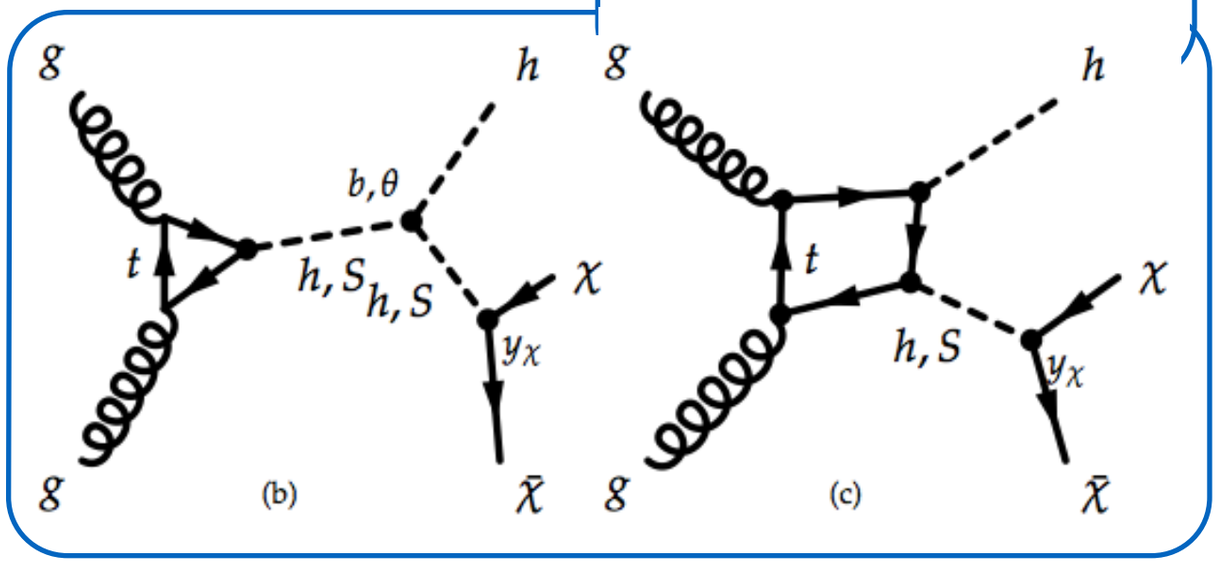
- Simplified Models: New massive particle mediates Higgs-DM interaction, including baryonic Z', Z' from hidden sector, pseudo scalar A^0 from 2HDM, and scalar











Suggestions/Concerns From The Mono-Higgs Analyzers

- Propose to have a repository of cross-section grids for each mono-Higgs model. These grids serve as benchmarks and ensure ATLAS/CMS specify all of the model parameters consistently

- Model files at svn of LHCDMF are not necessary up-to-date

  - baryonic Z' model file Higgs_hzpzp_UFO

    ➡ Find one person from each collaboration to make sure that the model files in SVN are up-to-date

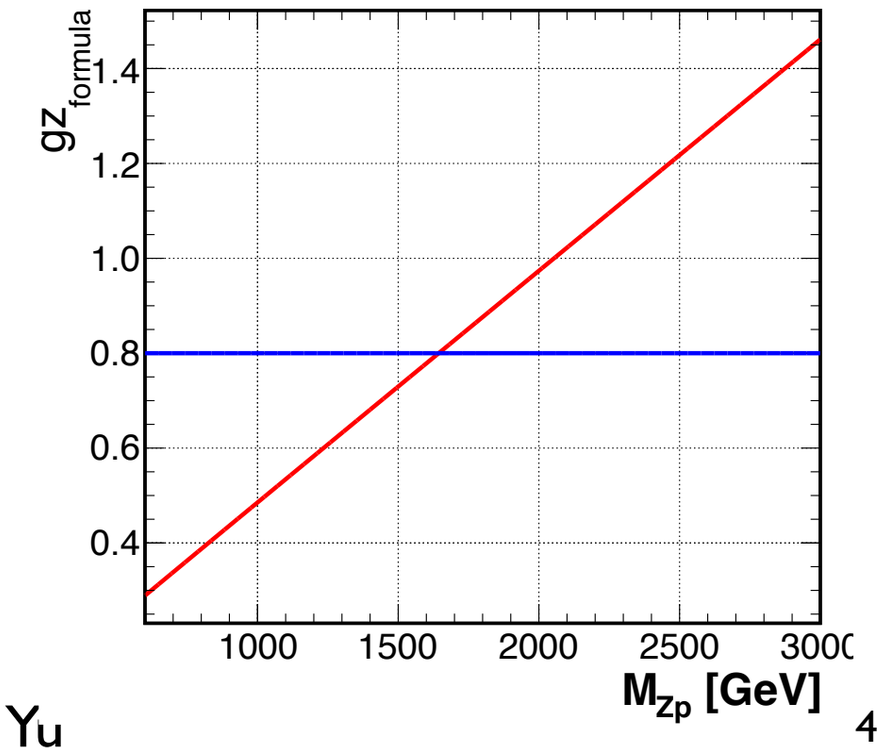
- The recommended values of benchmark parameters in 1507.00966 are not always coherent with other mono-X channels

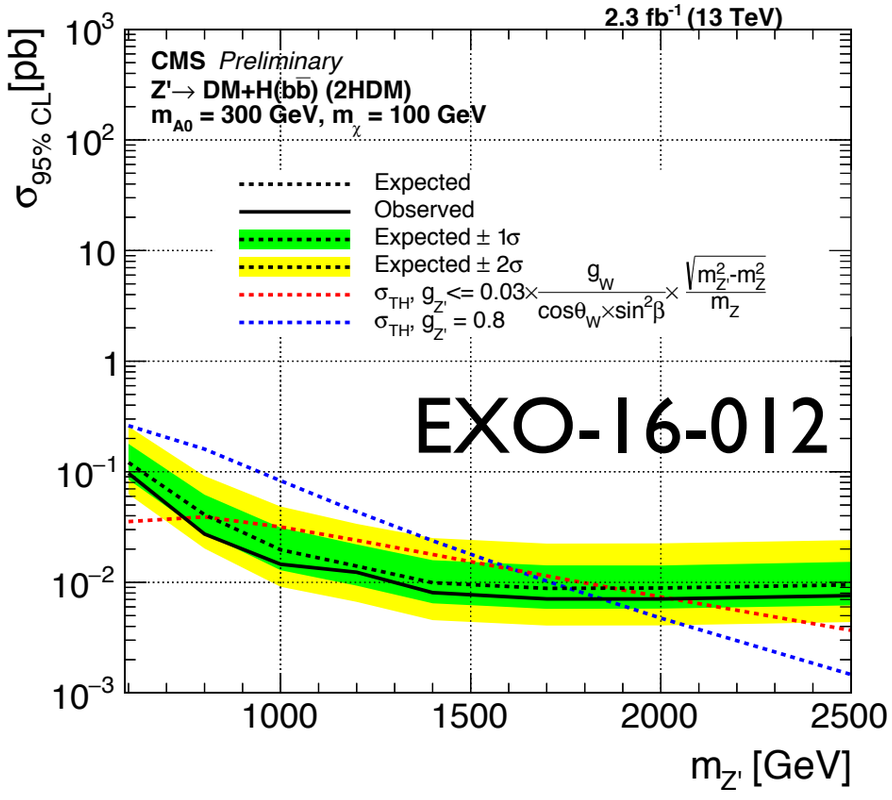
  - recommended value for the Z'-fermion coupling gq=1/3 (instead of 0.25) for the baryonic Z' model

Suggestions From The Mono-Higgs Analyzers

- The recommended values of benchmark parameters in 1507.00966 do not always take into account the constraints from existing searches/EWK measurements
  - The Z' coupling parameter gz' in 2HDM: 0.8 (from 1507.00966) vs the formula from authors (constraints from the EWK measurements taken into account)

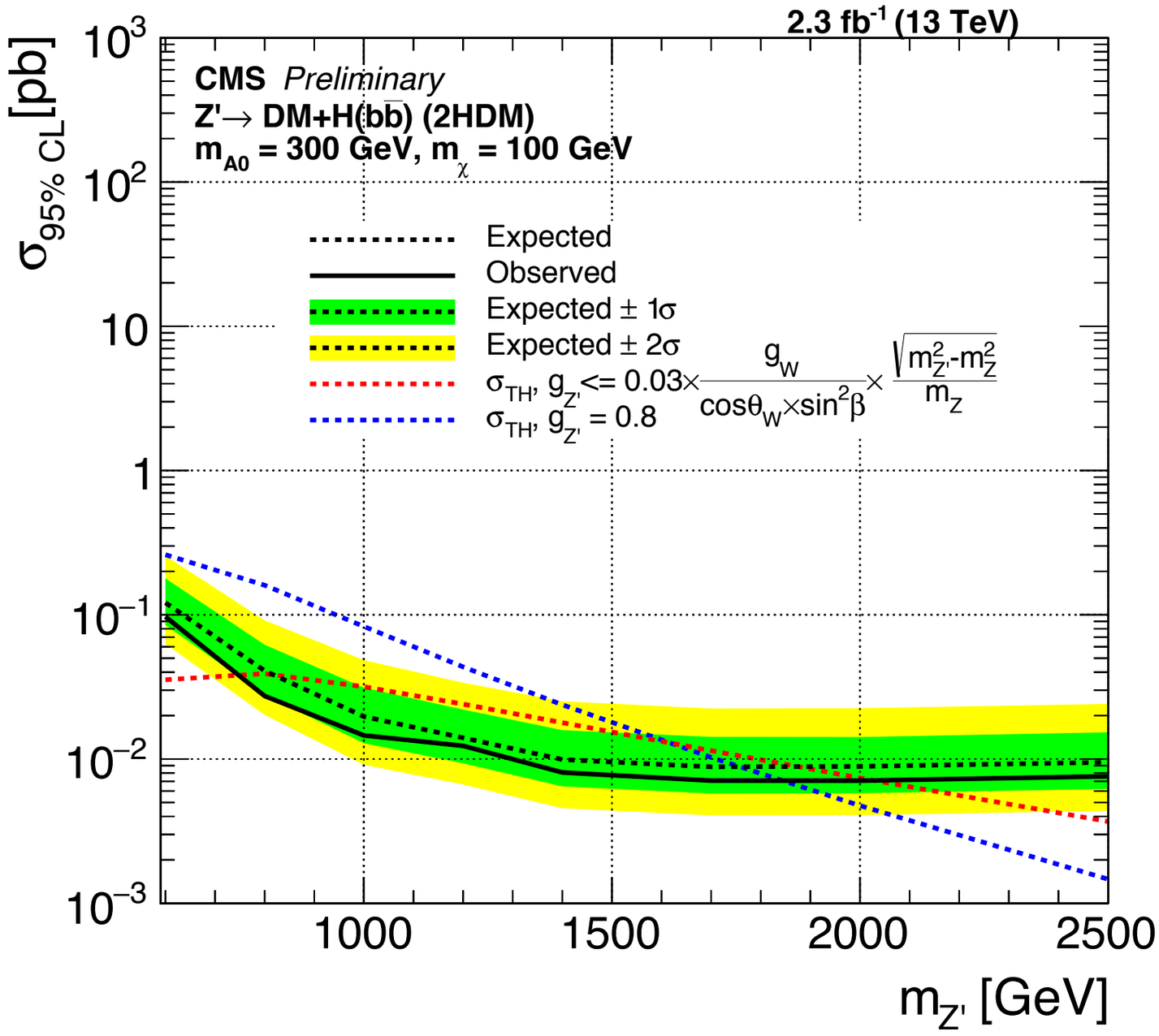
$$g_{Z'} \leq 0.03 \times \frac{g_W}{\cos\theta_W \times \sin^2\beta} \times \frac{\sqrt{m_{Z'}^2 - m_Z^2}}{m_Z}$$

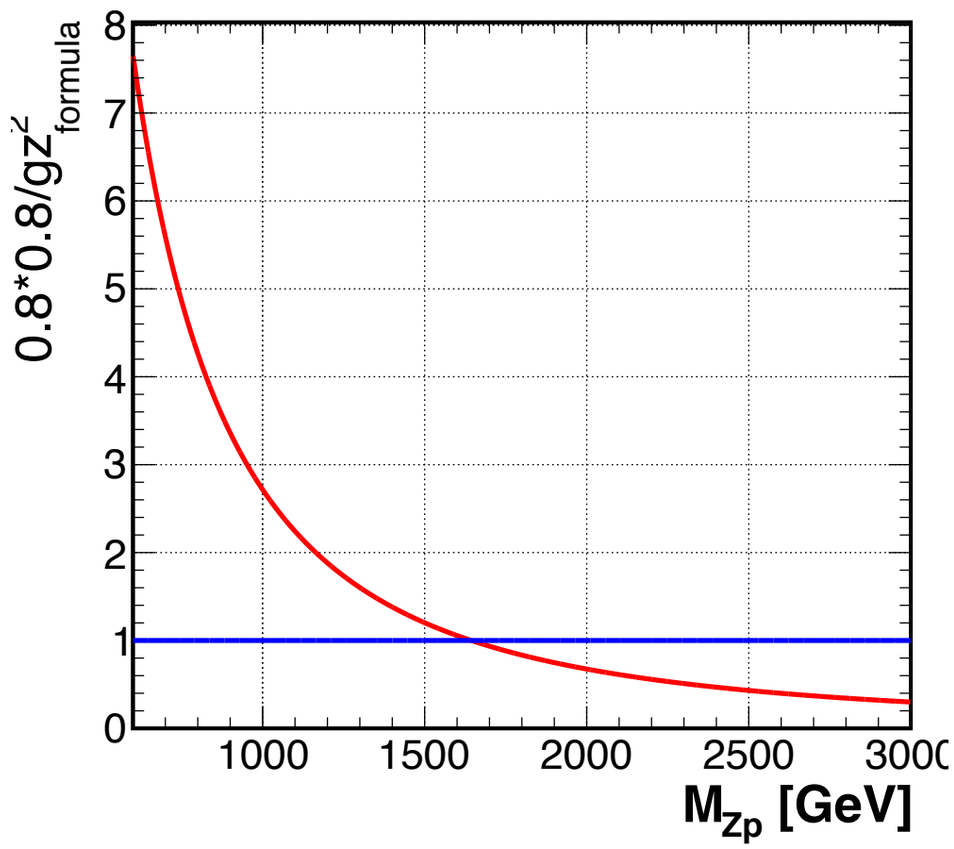




Backup Slides

Limits From CMS Mono-Higgs (bb)





gz upper bound in 2HDM

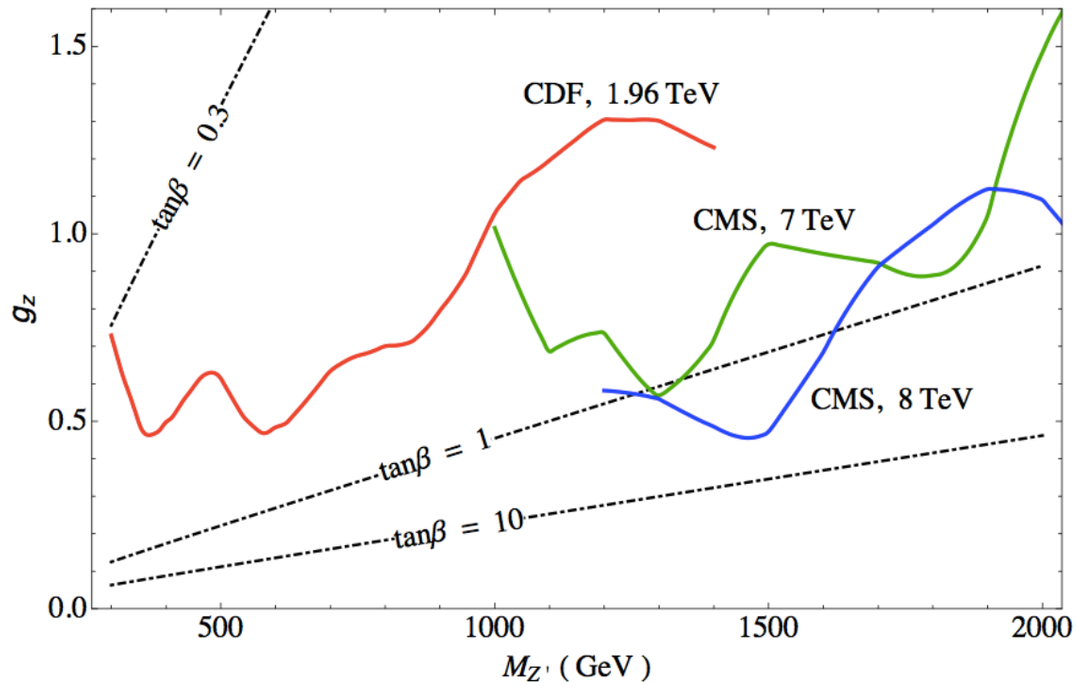
$$M_Z^2 \approx (M_Z^0)^2 - \epsilon^2 \left[(M_{Z'}^0)^2 - (M_Z^0)^2 \right]$$
$$M_{Z'}^2 \approx (M_{Z'}^0)^2 + \epsilon^2 \left[(M_{Z'}^0)^2 - (M_Z^0)^2 \right]$$

where $(M_Z^0)^2 = g^2(v_d^2 + v_u^2)/(4\cos^2\theta_w)$ and $(M_{Z'}^0)^2 = g_z^2(z_d^2 v_d^2 + z_u^2 v_u^2 + z_\phi^2 v_\phi^2)$ are the mass-squared values in the absence of mixing. The result above is accurate to

$$\epsilon \equiv \frac{1}{M_{Z'}^2 - M_Z^2} \frac{g g_z}{2\cos\theta_w} (z_d v_d^2 + z_u v_u^2)$$
$$= \frac{(M_Z^0)^2}{M_{Z'}^2 - M_Z^2} \frac{2 g_z \cos\theta_w}{g} z_u \sin^2\beta.$$

$$\rho_0 = 1 + \epsilon^2 \left(\frac{M_{Z'}^2 - M_Z^2}{M_Z^2} \right)$$

$$\rho_0 \leq 1.0009$$



$$g_{Z'} \leq 0.03 \times \frac{g_W}{\cos\theta_W \times \sin^2\beta} \times \frac{\sqrt{m_{Z'}^2 - m_Z^2}}{m_Z}$$

Baryonic Z' Model

$$\mathcal{L} = g_q \bar{q} \gamma^\mu q Z'_\mu + g_\chi \bar{\chi} \gamma^\mu \chi Z'_\mu$$

When energy << mZ', the effective Lagrangian becomes

$$\mathcal{L}_{\text{eff}} = -\frac{g_q g_\chi}{m^2_{Z'}} \bar{q} \gamma^\mu q \bar{\chi} \gamma_\mu \chi \left(1 + \frac{g_{hZ'Z'}}{m^2_{Z'}} h\right)$$

$$g_{hZ'Z'} = \frac{m_{Z'} 2 \sin\theta}{v_B} \qquad g_{hZ'Z'} < \sqrt{4\pi} m_{Z'} \sin\theta$$

$$g_q = g_B/3 \text{ and } g_\chi = B_\chi g_B$$

EFT For Mono-Higgs

Copied from slides of Dustin Burns

EFT

- Dim 4: $\lambda|H|^2\chi^2$

  Constrained by Br(H > invisible)

- Dim 5: $\frac{1}{\Lambda}|H|^2\bar{\chi}\chi$ $\frac{1}{\Lambda}|H|^2\bar{\chi}i\gamma_5\chi\,,$
- Dim 6: $\frac{1}{\Lambda^2}\chi^\dagger i\overleftrightarrow{\partial^\mu}\chi H^\dagger iD_\mu H$ $\frac{1}{\Lambda^2}\bar{\chi}\gamma^\mu\chi H^\dagger iD_\mu H\,,\quad \frac{1}{\Lambda^2}\bar{\chi}\gamma^\mu\gamma_5\chi H^\dagger iD_\mu H.$

  Constrained by Br(Z > invisible)

-
- Dim 8: $\frac{1}{\Lambda^4}\bar{\chi}\gamma^\mu\chi B_{\mu\nu}H^\dagger D^\nu H,\quad \frac{1}{\Lambda^4}\bar{\chi}\gamma^\mu\chi W^a_{\mu\nu}H^\dagger t^a D^\nu H$

  $\frac{1}{\Lambda^4}\bar{\chi}\sigma^{\mu\nu}\chi B_{\mu\nu}H^\dagger H\,,\quad \frac{1}{\Lambda^4}\bar{\chi}\sigma^{\mu\nu}\chi W^a_{\mu\nu}H^\dagger t^a H$

  Derivative couplings lead to more MET, better acceptance efficiency

- Higgs_hhxx_scalar: renormalizable dim-4 operator, scalar DM
- Higgs_hhxx_combined, Higgs_hhxg5x: non-renormalizable dim-5 operator, fermion DM
- Higgs_xdxhDhs, Higgs_xdxhDhc: non-renormalizable dim-6 operator, real and complex scalar DM
- Higgs_xdxFhDh: non-renormalizable dim-8 operator, fermion DM

Simplified Model For Mono Higgs

Copied from slides of Dustin Burns

Simplified

- Z' from extended gauge group: Gauge Baryon number B. Z' is (leptophobic) gauge boson of corresponding U(1)_B symmetry, spontaneously broken by "Baryonic Higgs" hB, which mixes with SM H.

$$\mathscr{L}_{\text{eff}} = -\frac{g_q g_\chi}{m_{Z'}^2}\bar{q}\gamma^\mu q\bar{\chi}\gamma_\mu\chi\left(1+\frac{g_{hZ'Z'}}{m_{Z'}^2}h\right)$$

Higgs_hzpzp

- Z' from hidden sector mixing with SM: DM charged under new U(1)', SM states neutral. Mass mixing between Z and Z' induces hZ' coupling.

Higgs_Zprime

$$\mathscr{L} \supset \frac{g_2}{2c_W}J^\mu_{\text{NC}}Z_\mu + g_\chi\bar{\chi}\gamma^\mu\chi Z'_\mu\,, \qquad \mathscr{L} \supset \frac{m_Z^2 s_\theta}{v}hZ'_\mu Z^\mu$$

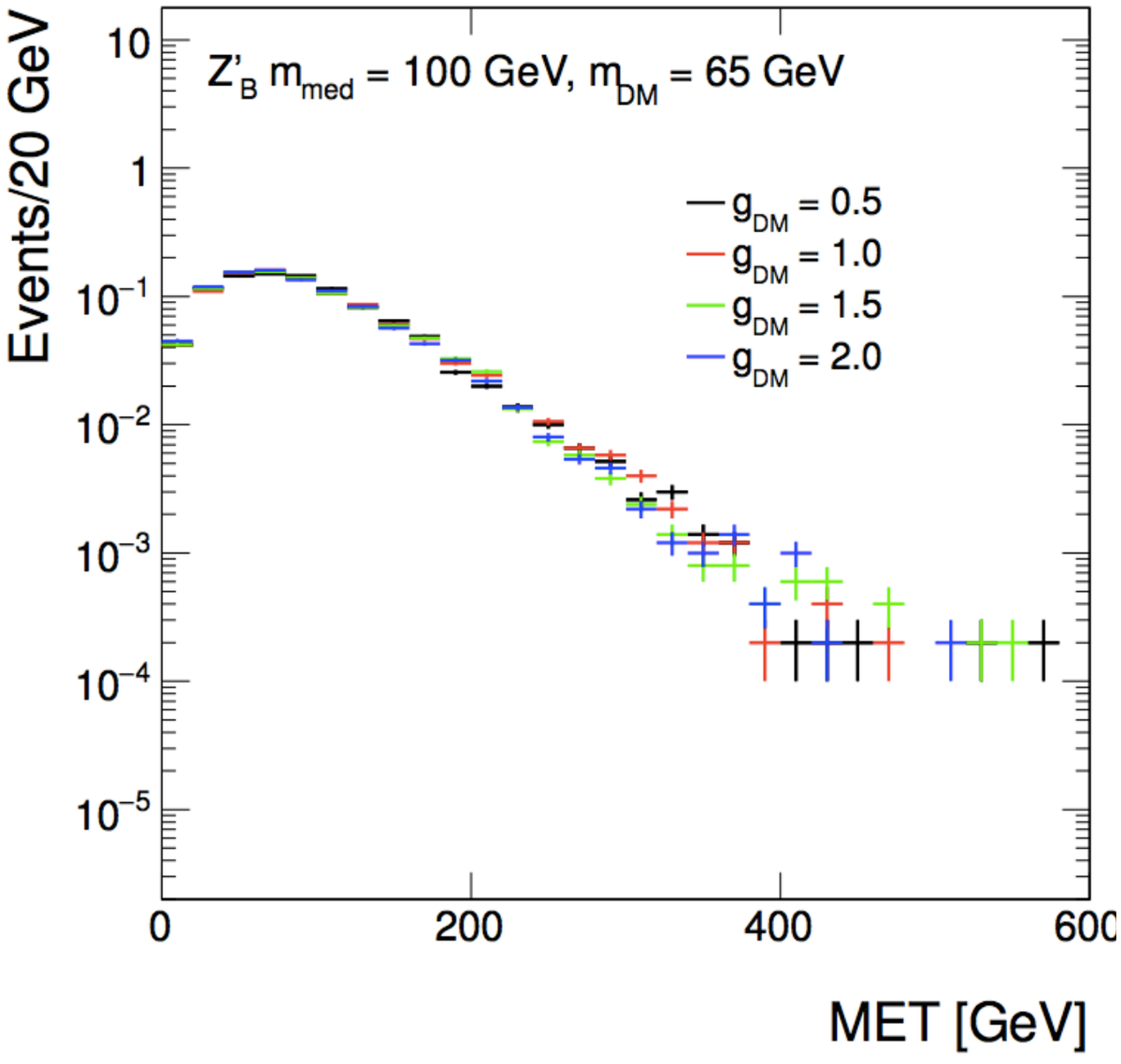
- Scalar S coupling to H: Real scalar singlet S with Yukawa coupling to DM mixes with SM through H only (renormalizability, gauge invariance). hS coupling from scalar potential:

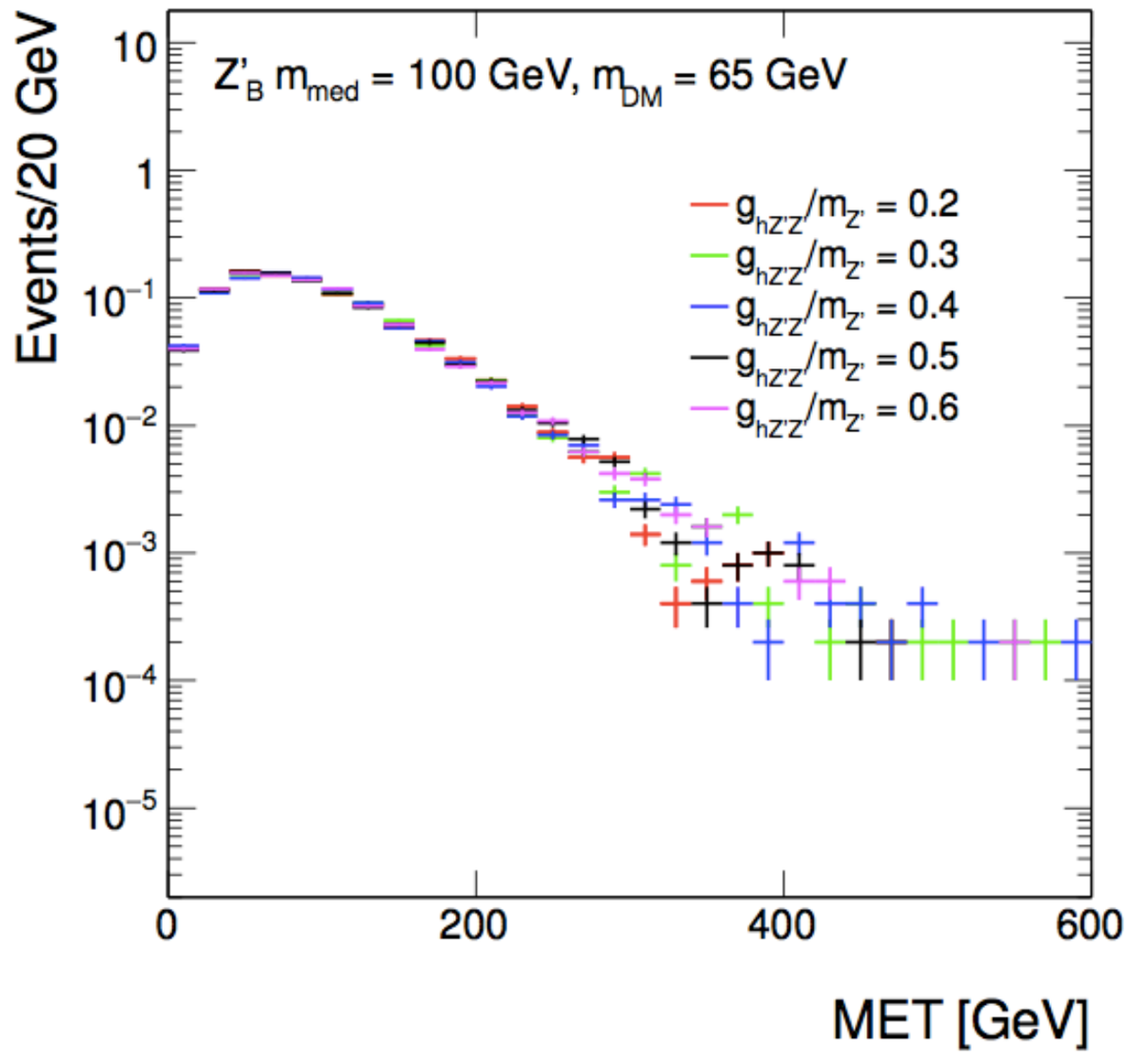
$$V_{\text{cubic}} \approx \frac{\sin\theta}{v}(2m_h^2+m_S^2)h^2S + bvhS^2 + \ldots$$

Higgs_scalar

Factors That Do Not Affect Missing Energy

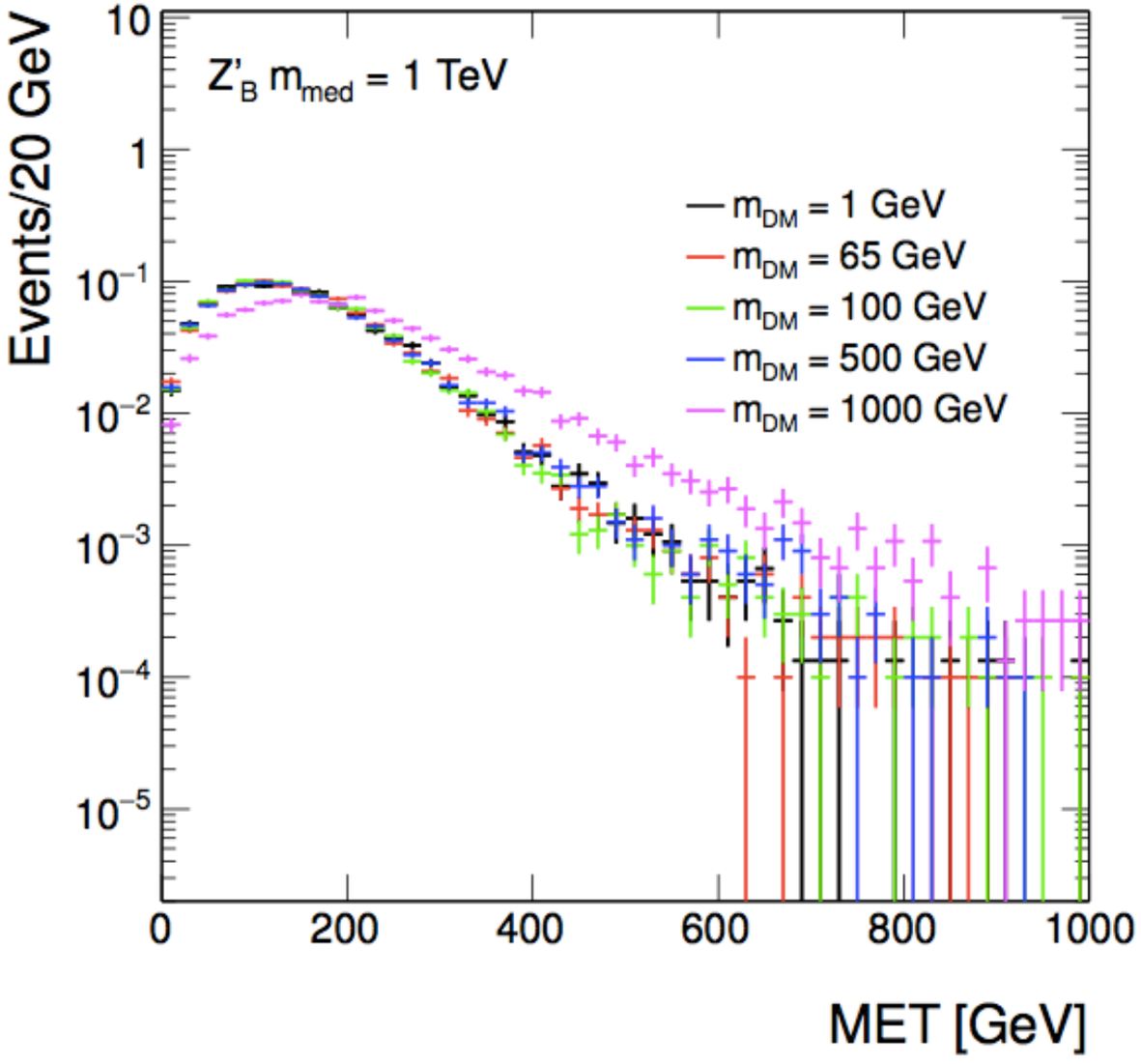
Within the same model, different model parameters give very similar MET distributions



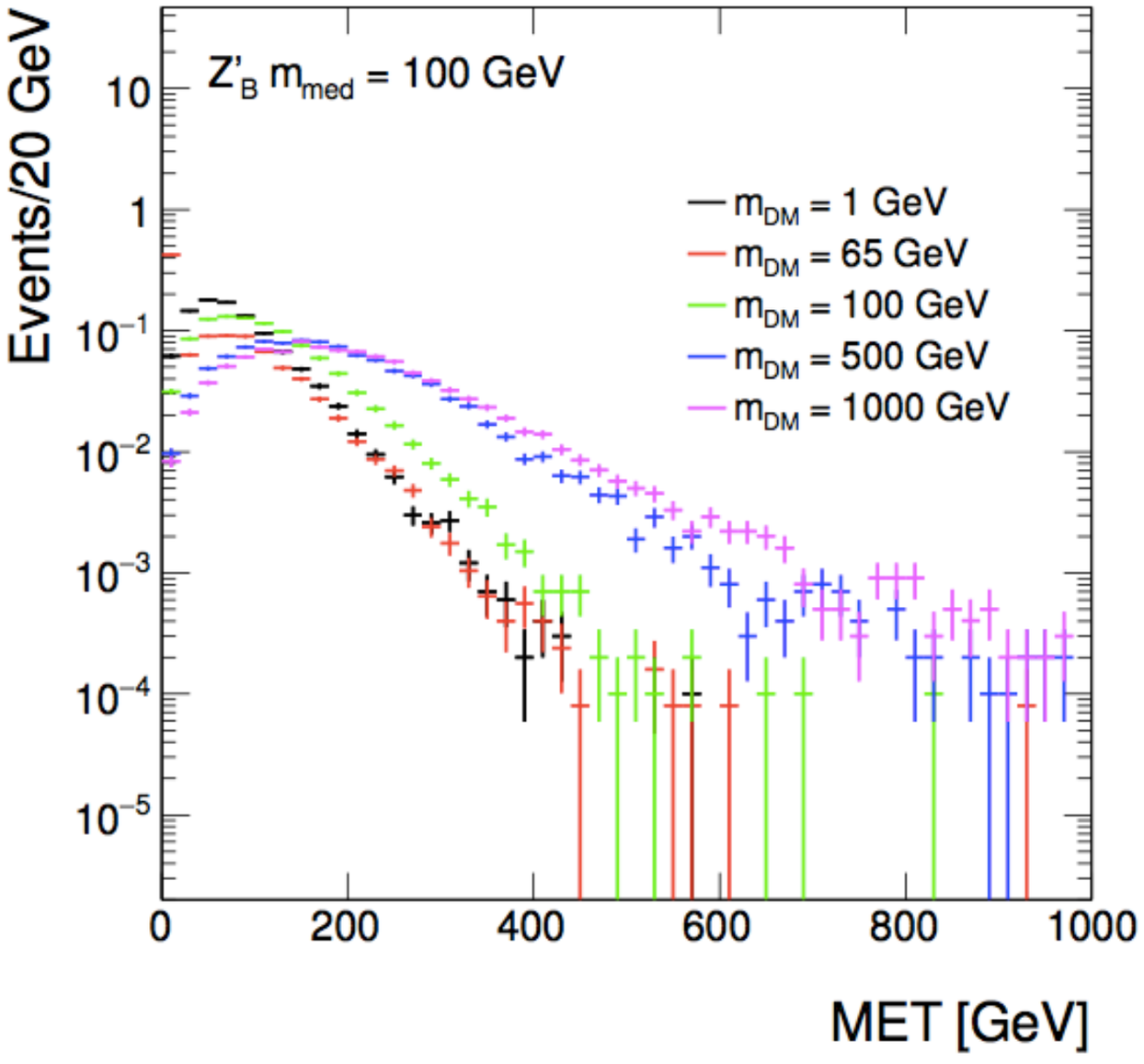


Factors That Affect Missing Energy

on-shell mediator



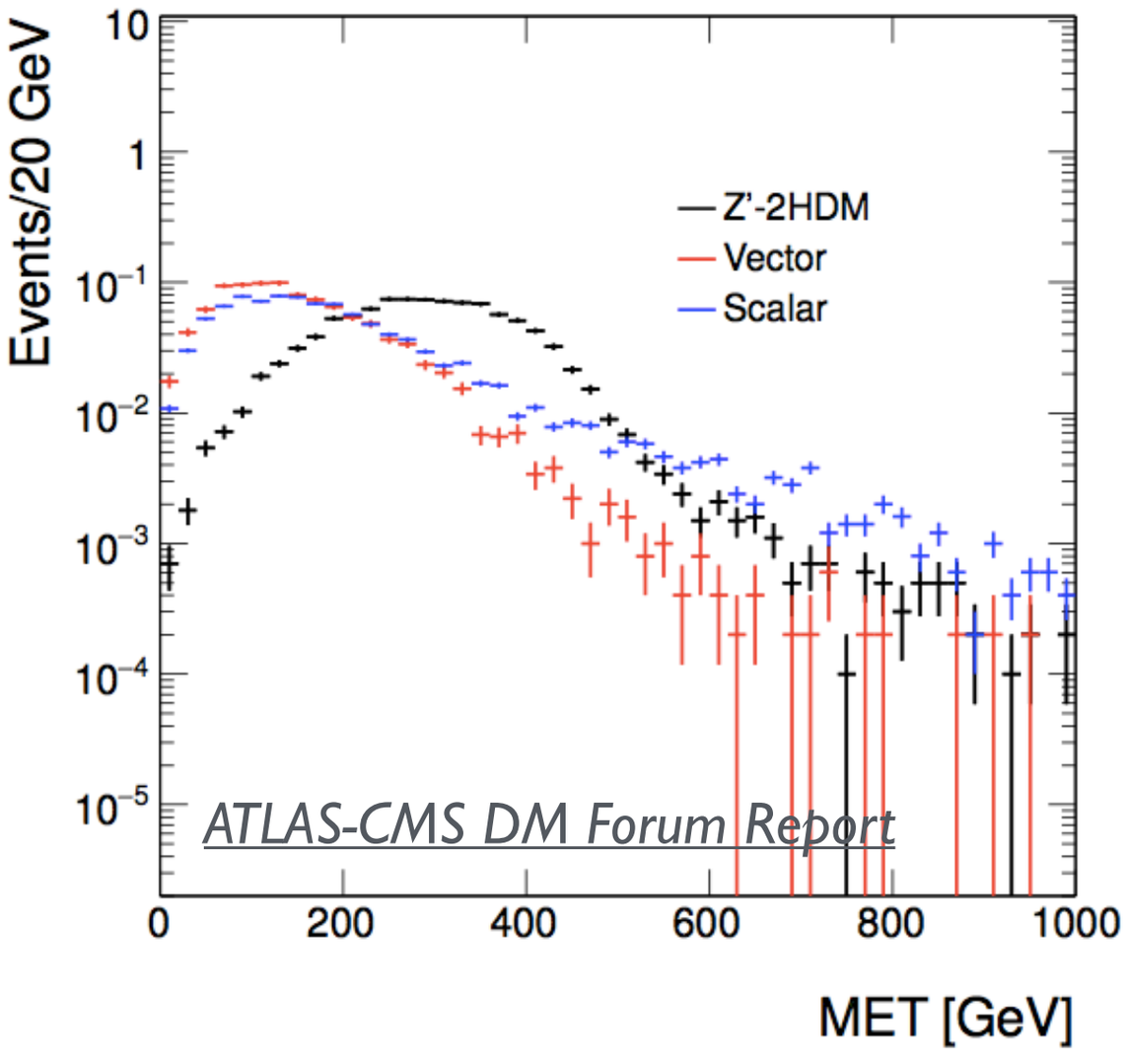
off-shell mediator



Missing Energy Of Simplified Models

$$M_{Z_B'} = M_{Z'} = M_S = M_{A^0} = 1 \text{ TeV}$$

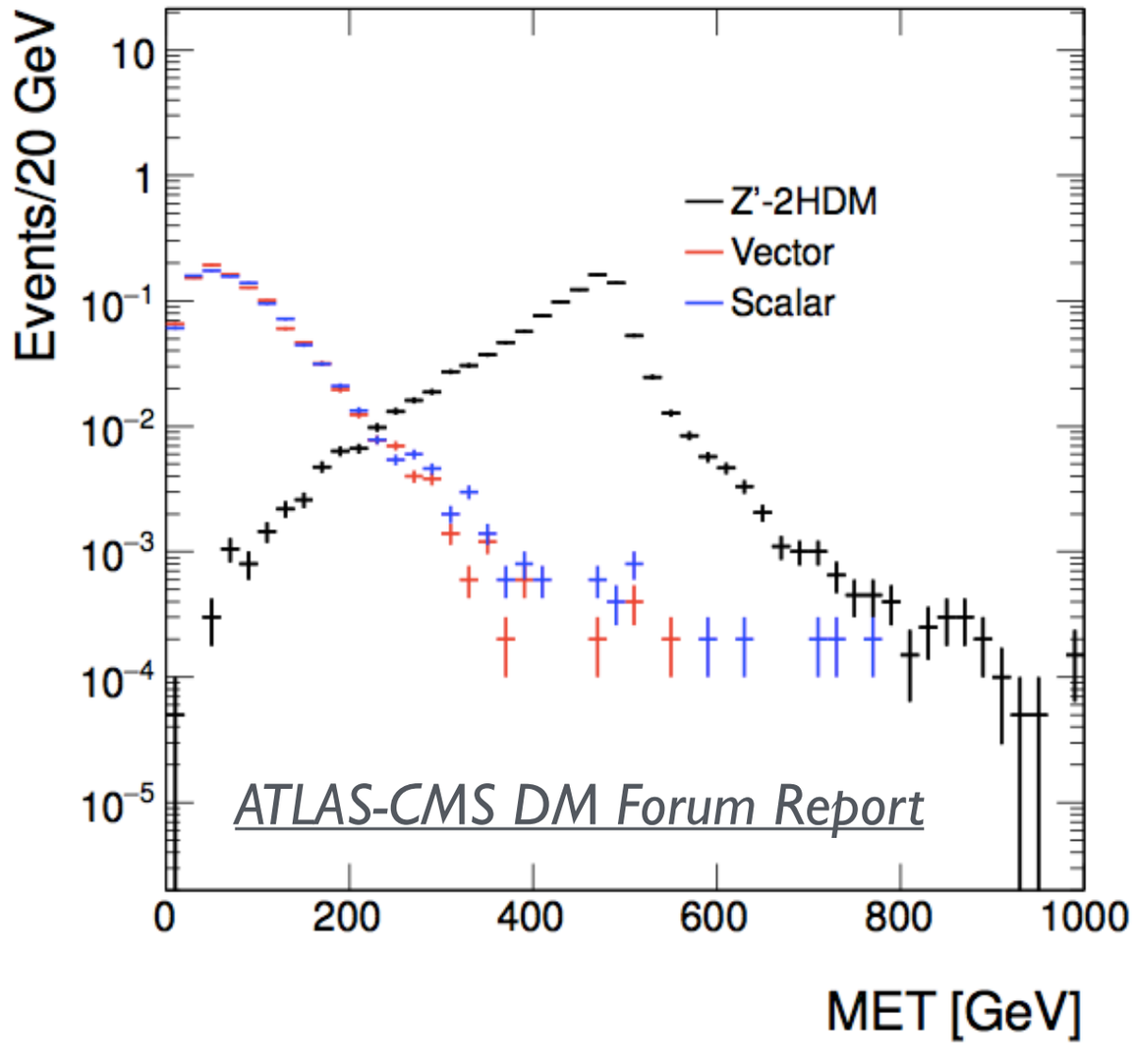
$$M_\chi = 50 \text{ GeV}, 65 \text{ GeV}$$



(a) High mediator mass

$$M_{Z_B'} = M_S = M_{A^0} = 100 \text{ GeV}$$

$$M_{Z'} = 1 \text{ TeV}, \; M_\chi = 1 \text{ GeV}$$



(b) Low mediator mass