New Physics in Missing ET + b-jet experiments

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Motivation

Deviations in the ratios $R(K^{(*)}), R(D^{(*)})$. Possible explanation through NP.

$$\mathcal{L}_{\mathrm{SMEFT}} \supset \frac{c^{(3)}_{ijkl}}{\Lambda^2}(\bar{Q}_i\gamma_\mu\sigma^a Q_j)(\bar{L}_k\gamma^\mu\sigma_a L_l) + \frac{c^{(1)}_{ijkl}}{\Lambda^2}(\bar{Q}_i\gamma_\mu Q_j)(\bar{L}_k\gamma^\mu L_l) + \frac{c_{u_{ij}e_{kl}}}{\Lambda^2}(\bar{u}_i\gamma_\mu u_j)(\bar{e}_k\gamma^\mu e_l) + \frac{c_{d_{ij}e_{kl}}}{\Lambda^2}(\bar{d}_i\gamma_\mu d_j)(\bar{e}_k\gamma^\mu e_l) + \frac{c_{u_{ij}L_{kl}}}{\Lambda^2}(\bar{u}_i\gamma_\mu u_j)(\bar{L}_k\gamma^\mu L_l) + \frac{c_{d_{ij}L_{kl}}}{\Lambda^2}(\bar{d}_i\gamma_\mu d_j)(\bar{L}_k\gamma^\mu L_l) + \frac{c_{Q_{ij}e_{kl}}}{\Lambda^2}(\bar{Q}_i\gamma_\mu Q_j)(\bar{e}_k\gamma^\mu e_l)$$

Limits on some of these operators set in [1] A. Greljo, D. Marzocca (2017); [2] D.A. Faroughy, A. Greljo, J.F. Kamenik (2017).

Focus on the (LL)(LL) operators:

$$\frac{c^{(3)}_{ijkl}}{\Lambda^2}(\bar{Q}_i\gamma_\mu\sigma^a Q_j)(\bar{L}_k\gamma_\mu\sigma_a L_l) + \frac{c^{(1)}_{ijkl}}{\Lambda^2}(\bar{Q}_i\gamma_\mu Q_j)(\bar{L}_k\gamma_\mu L_l) \quad (1)$$

Consider:

$$c^{(3)}_{ijkl} \sim c^{(3)}\delta_{i3}\delta_{j3}\delta_{k3}\delta_{l3} \quad (2)$$

$$c^{(1)}_{ijkl} \sim c^{(1)}\delta_{i3}\delta_{j3}\delta_{k3}\delta_{l3} \quad (3)$$

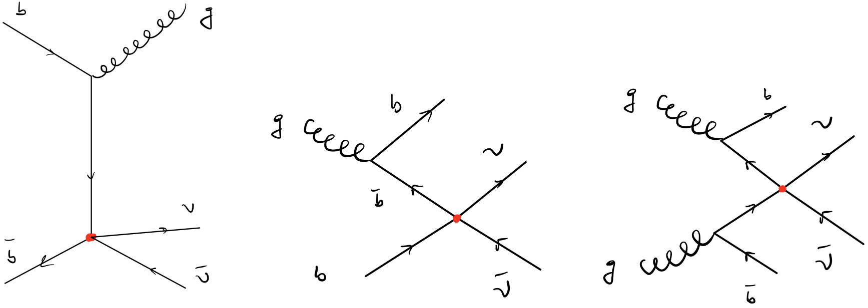
Physical basis, with the down-quarks being aligned in flavour, focus only on neutral-current terms:

$$\frac{c^{(1)}+c^{(3)}}{\Lambda^2}(\bar{b}_L\gamma_\mu b_L)(\bar{\tau}_L\gamma_\mu\tau_L) + \frac{c^{(1)}-c^{(3)}}{\Lambda^2}(\bar{b}_L\gamma_\mu b_L)(\bar{\nu}_\tau\gamma_\mu\nu_\tau) \quad (4)$$

Goal: Set upper limits on the linear combination $\frac{c^{(1)}-c^{(3)}}{\Lambda^2}$.

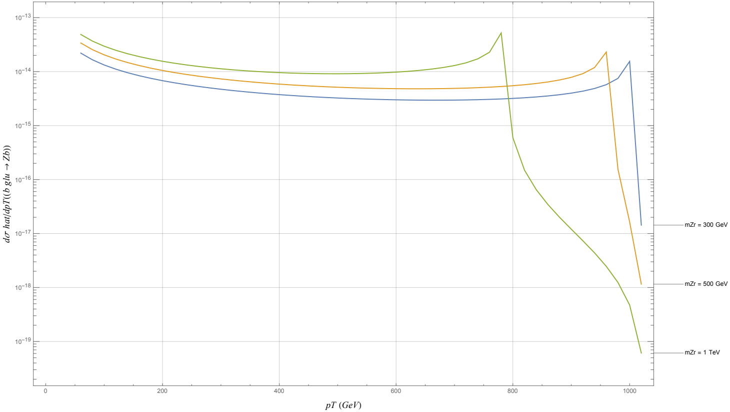
Process of interest

Neutrinos do not interact with any of the detector components. Under the flavour assumptions made, we should look at $pp \to \not{E}_T + b(\bar{b})$ processes. Some of diagrams that contribute to this signal:



High-p_T signature

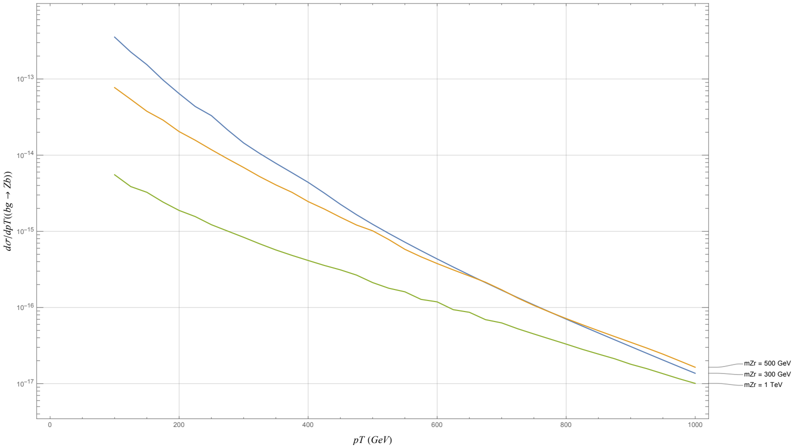
The partonic cross-section characterized by a Jacobian peak:



$$\frac{d\hat{\sigma}}{dp_T} \propto \frac{1}{\sqrt{(\hat{s}-m_{Zp}^2)^2 - 4\hat{s}p_T^2}} \times \frac{1}{(m_{Zp}^2 - m_{Zr}^2)^2 + m_{Zr}^2\Gamma_{Zr}^2} \qquad (5)$$

High-p_T signature

The PDFs wash out this peak, however in high-p_T the contributions to the cross-section are comparable:



ATLAS Search and Recast

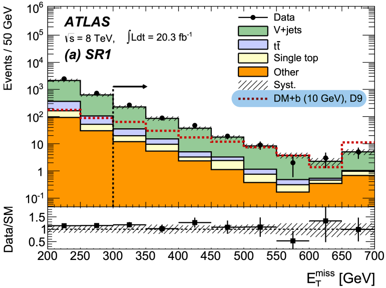
Search for dark matter in events with heavy quarks and MET in pp collisions with the ATLAS detector, arXiv: 1410.4031

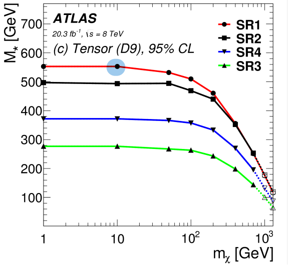
Targeting processes with one outgoing b-quark (Signal Region 1)

Task 1: Recast the signal, introduce the operator

$$D_9 = \frac{1}{M_*^2}(\bar{b}\sigma_{\mu\nu}b)(\bar{\chi}\sigma_{\mu\nu}\chi)\,, \qquad (6)$$

where χ is a Dirac fermion, with mass $m_\chi = 10$ GeV.





- Generate events $pp \to \chi\chi +$ up to 2 additional jets. Set the scale M_* and m_χ.
- Set the cuts given by ATLAS.
- Compare the number of signal events in our event generation with the upper limit of BSM events given by ATLAS. From there, set limits on M_*.

$$\frac{s}{s_{up}} = \frac{\sigma \times \mathcal{L} \times A \times \epsilon}{\sigma_{up} \times \mathcal{L} \times A \times \epsilon} = \frac{M^4_{*\,\mathrm{up}}}{M^4_*} \tag{7}$$

The cuts imposed for SR1, generating 1M signal events $pp \to \nu_\tau \bar{\nu}_\tau +$ jets:

Constraint	No. of events after cut
$\not{E}_T > 300\,\mathrm{GeV}$	1342
$n_\ell = 0$	1342
$n_j = 1, 2;\ n_b > 0$	310
$\Delta\Phi(j_i, \not{E}_T) > 1.0; i = 1, 2$	273
$p_T^{b_1} > 100$ GeV	256

Back to neutrinos: Major difference - interference with SM

$$s_{up} = \sigma(c/\Lambda^2) \times \mathcal{L} \times [A \times \epsilon](c/\Lambda^2) \tag{8}$$

The upper limit at 2σ we get is:

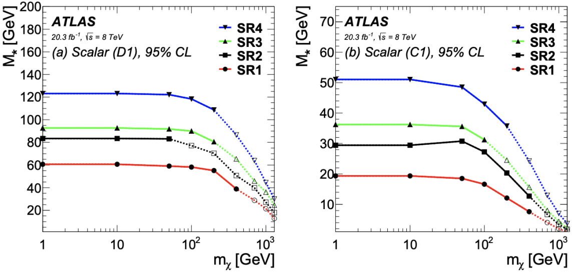
$$-31\mathrm{TeV}^{-2} < \frac{c^{(1)} - c^{(3)}}{\Lambda^2} < 32\,\mathrm{TeV}^{-2} \tag{9}$$

Compared to the limits of $pp \to \tau\tau$ derived in [2] :

$$\frac{|c^{(1)} + c^{(3)}|}{\Lambda^2} < 2.8\,(2.6)\,\mathrm{TeV}^{-2} \tag{10}$$

Conclusions

- The $\not{E}_T + b$ signature gives looser constraints than dilepton searches.
- However...
  - Better understand the cuts, the selection criteria
  - Searches mainly optimized for different DM/FDM models (D9, D1, C1)
- n_j and n_b criteria need a more careful consideration
  - Different approaches in identical ATLAS searches: 1710.11412; ATLAS-CONF-2016-086
- Check also other flavour models - MFV, introduce U(2) breaking



Acknowledgements

Thank you for a very nice first year in Ljubljana!