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Searching for new particles in $t\bar{t}$ samples

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Preliminary explorations

in collaboration with Andrea Giammanco,

Matthias Schlaffer and Jonathan Shlomi

Overview

- Could new particles be hiding in the bulk of $t\bar{t}$ samples?

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  To some extent.

New physics example(s)

Color-triplet scalar X with charge $-4/3$ produced via QCD

$$pp \to XX^*$$

and decaying as

$$X \to \bar{t}\bar{u} \quad \text{and/or} \quad X \to \bar{t}\bar{c}$$

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Can also imagine scenarios with

- **more jets in the decays**

and/or

- **much lower (e.g., electroweak) cross section**

Existing searches

Two potentially relevant CMS searches; no searches from ATLAS or the Tevatron.

arXiv:1602.08819 [JHEP 1605 (2016) 092]
YK and Matt Strassler

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[1] Search for pair production of excited top quarks in the lepton+jets final state

CMS Collaboration, JHEP 06 (2014) 125 [arXiv:1311.5357]

Benchmark model – "excited top":

$$pp \to t^* \bar{t}^*, \quad t^* \to tg$$

Similar to our scenario (although different cross section; and g instead of u or c).

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[2] Searches for *R*-parity-violating supersymmetry in pp collisions at $\sqrt{s} = 8\ \mathbf{TeV}$ in final states with 0–4 leptons

CMS Collaboration, arXiv:1606.08076

Additional benchmark model – sbottom with RPV decays:

$$pp \to \tilde{b}\tilde{b}^*, \quad \tilde{b} \to \bar{t}\bar{d}, \ \bar{t}\bar{s}$$

Similar to our scenario (although always a light jet, not a charm).

Existing searches

[1] Search for pair production of excited top quarks in the lepton+jets final state

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19.5 fb^{-1} of 8 TeV data

1 lepton, ≥ 6 jets, incl. ≥ 1 b

event reconstruction via a kinematic fit

search for a bump in m_{tg}

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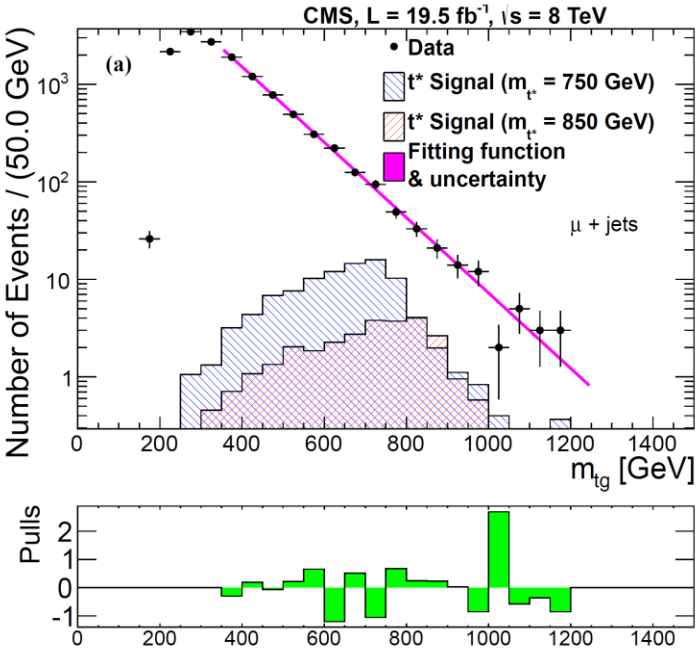

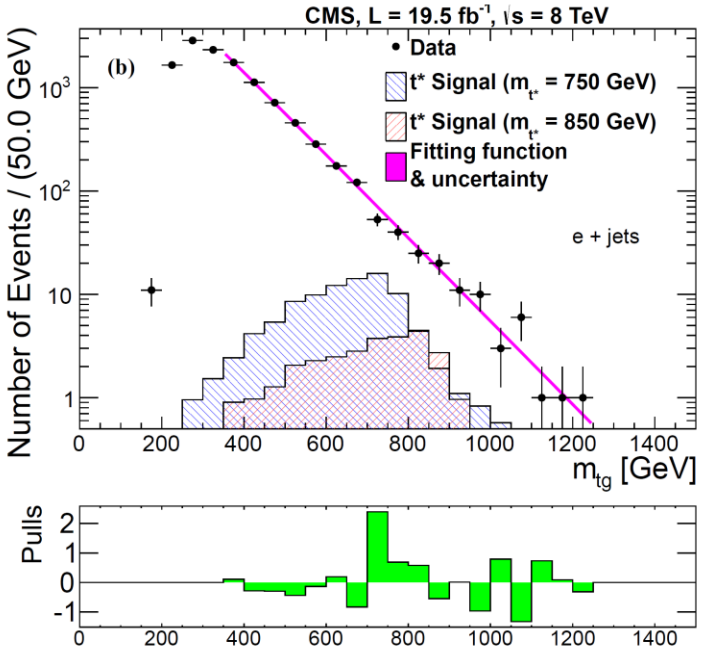

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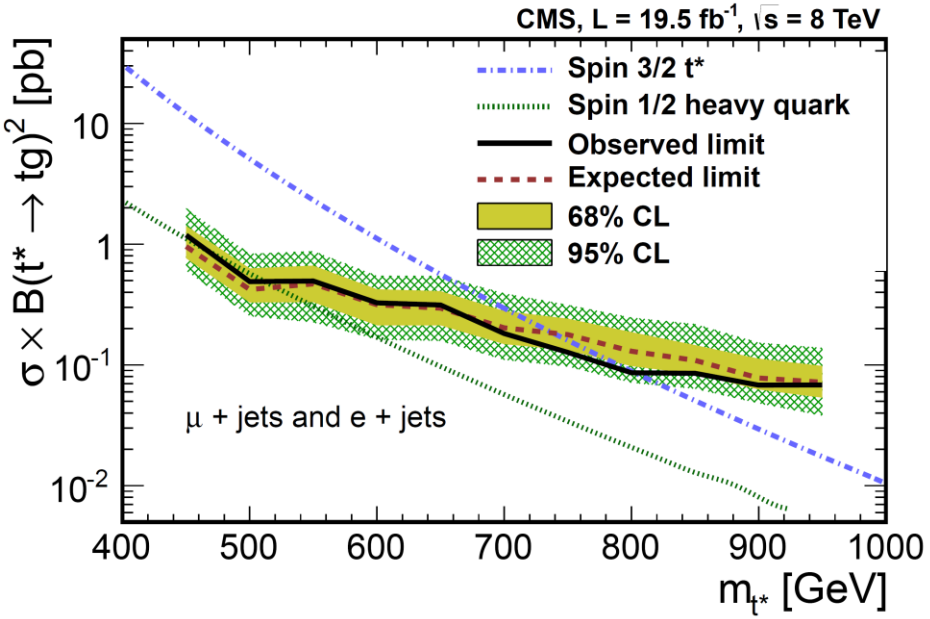

No limit derived below 450 GeV.

Spin-1/2 particles are (barely) excluded near 500 GeV.

For our model (spin 0) cross section is smaller by a factor of ~7.

Existing searches

[2] Searches for *R*-parity-violating supersymmetry in pp collisions at $\sqrt{s} = 8$ TeV in final states with 0–4 leptons CMS Collaboration, arXiv:1606.08076

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2 leptons, ≥ 4 jets, incl. ≥ 2 b (one loose, one medium)

≥ 2 jets must fail loose b tagging

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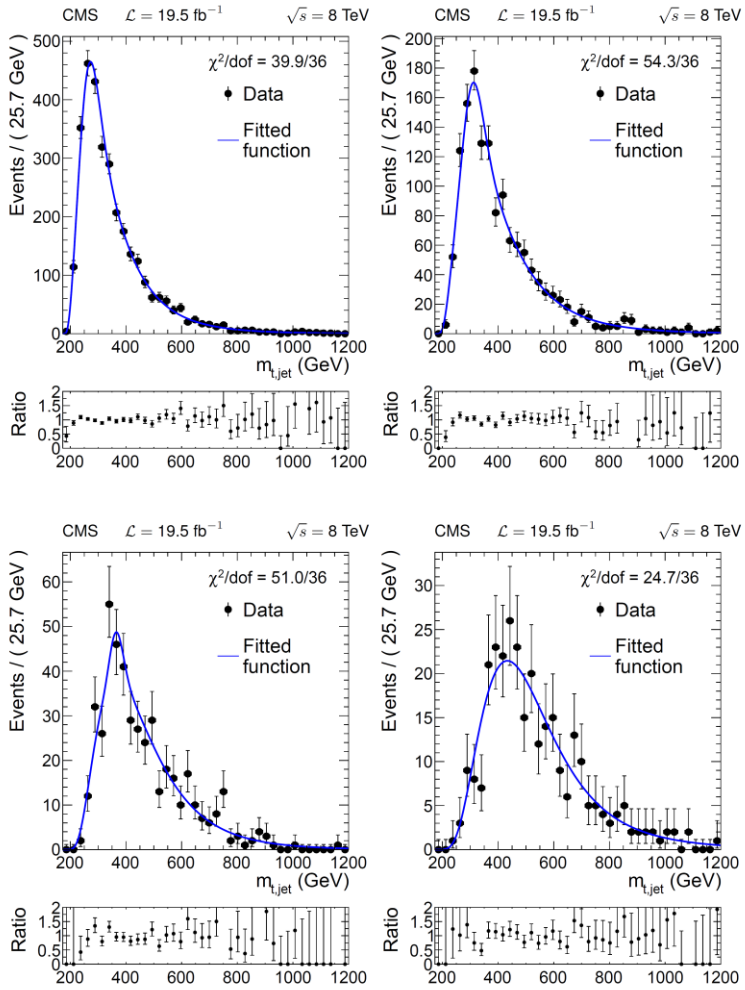

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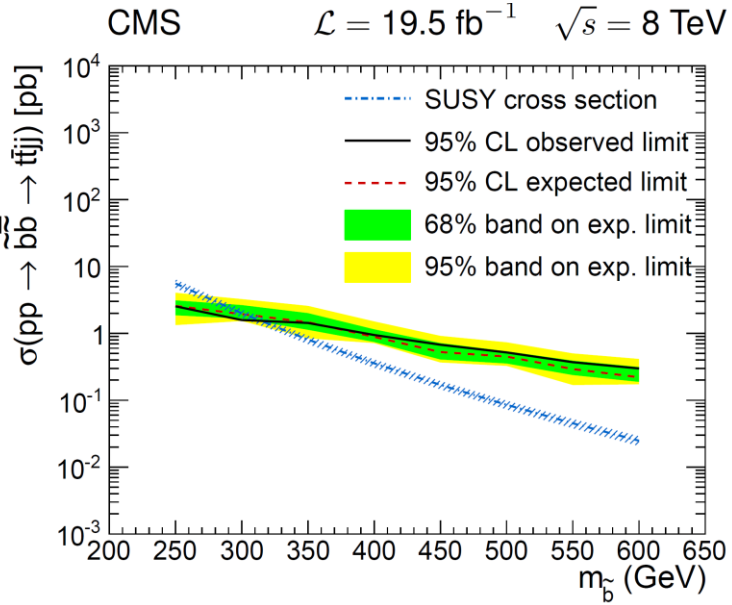
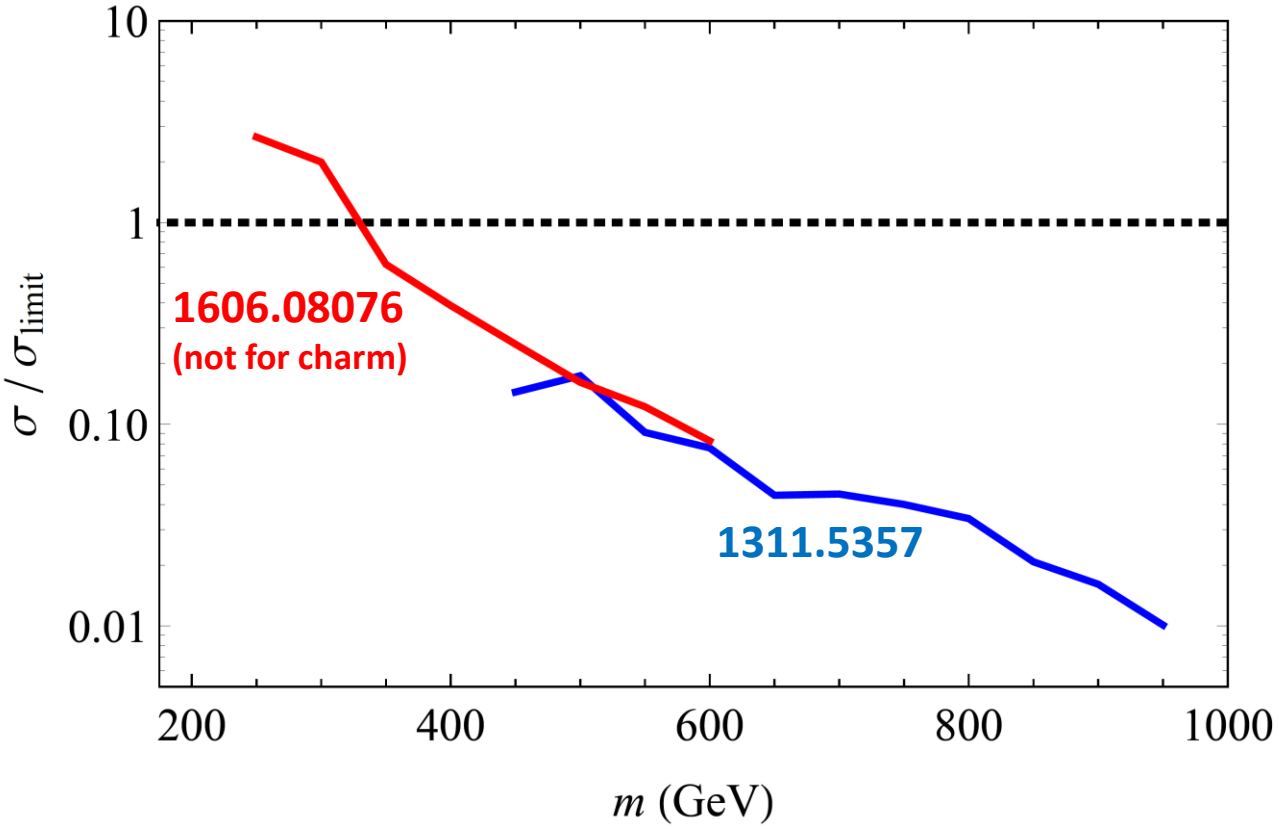


Exclusion only in the range 250 – 307 GeV.

Applicable to our $X \to \bar{t}\bar{u}$ scenario, but not to $X \to \bar{t}\bar{c}$ due to the loose b tag vetoes.

Existing searches

To summarize:



$pp \to XX^*,\ X \to \bar{t}\,\bar{u}$ excluded only between 250 and 307 GeV

$X \to \bar{t}\,\bar{c}$ still allowed for any mass

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  - If just a couple of extra jets ⇨ likely approximately yes.
    But with what uncertainty?
  - With extra c jets (might be b tagged) ⇨ less certain
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  Especially questionable when relying on a kinematic fit.

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  Note also that unfolding entails some loss of sensitivity.

- **Cannot use the full power of distributions without knowing the correlations between bins.**

Approximate limits from $t\bar{t}$ distributions

We proceed anyway and show some preliminary results.

Caveats:

- Not all relevant analyses are included, just several examples.
- Limits are conservative – based on single bins, not full distributions.
- Signal simulated at leading order (MadGraph5 + Pythia8). (Simulating $t\bar{t}$ in a similar way gives decent agreement with distributions from ATLAS/CMS.)

Approximate limits from $t\bar{t}$ distributions

Measurement of differential $t\bar{t}$ production cross sections in lepton + jets final states at 13 TeV

CMS PAS TOP-16-008 (2.3 fb^{-1})

Unfolding to particle level:

- Use true e, μ, ν's from the hard process
- Cluster and b-tag jets based on true final-state particles
- Selection:

  1 e or μ with $p_T > 30$ GeV, $|\eta| < 2.5$

  ≥ 4 jets (incl. ≥ 2 b) with $p_T > 25$ GeV, $|\eta| < 2.5$

- Choose event interpretation that minimizes

$$K^2 = [M(p_\nu + p_\ell + p_{b_1}) - m_t]^2 + [M(p_{j_1} + p_{j_2}) - m_W]^2 + \\ + [M(p_{j_1} + p_{j_2} + p_{b_2}) - m_t]^2$$

and construct various variables.

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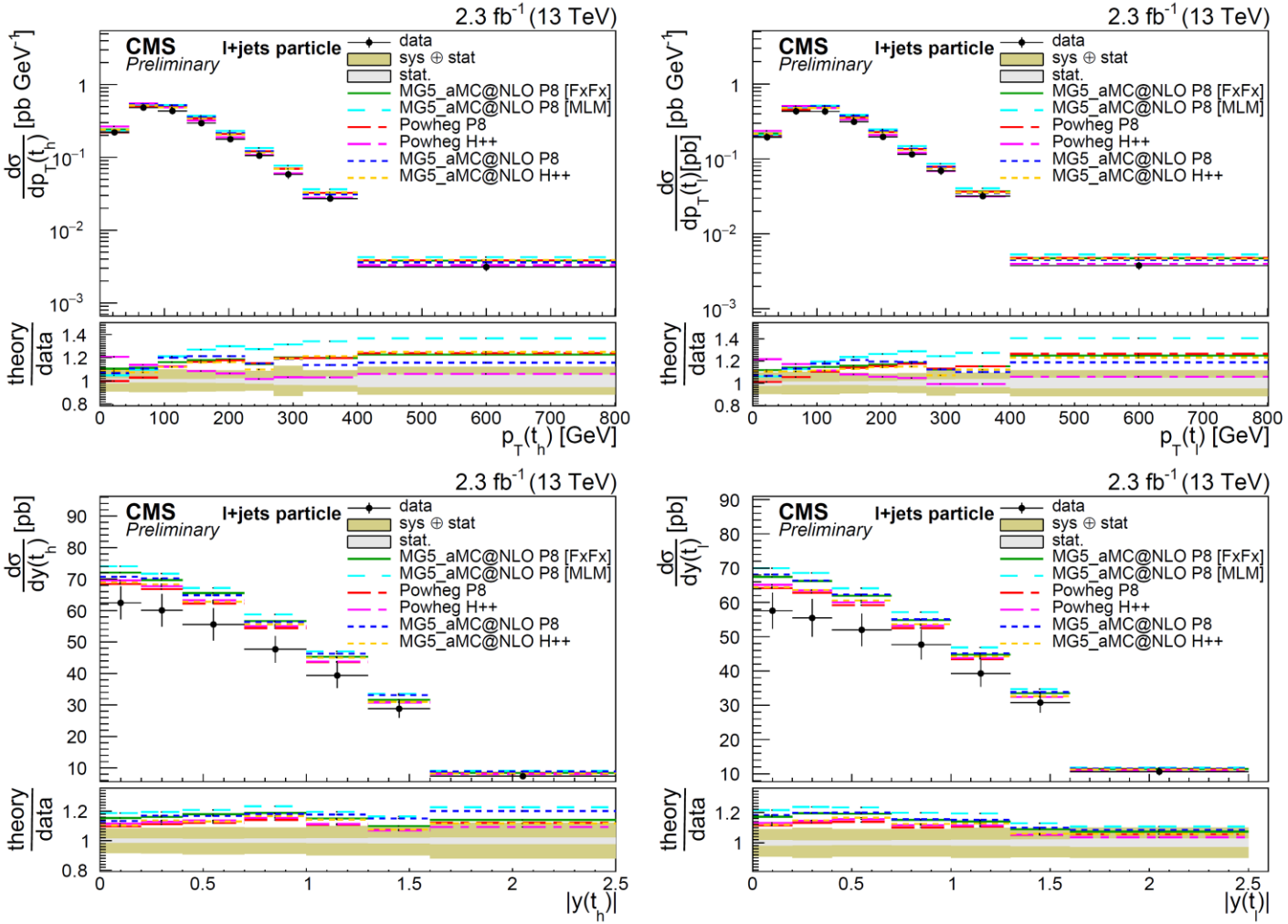

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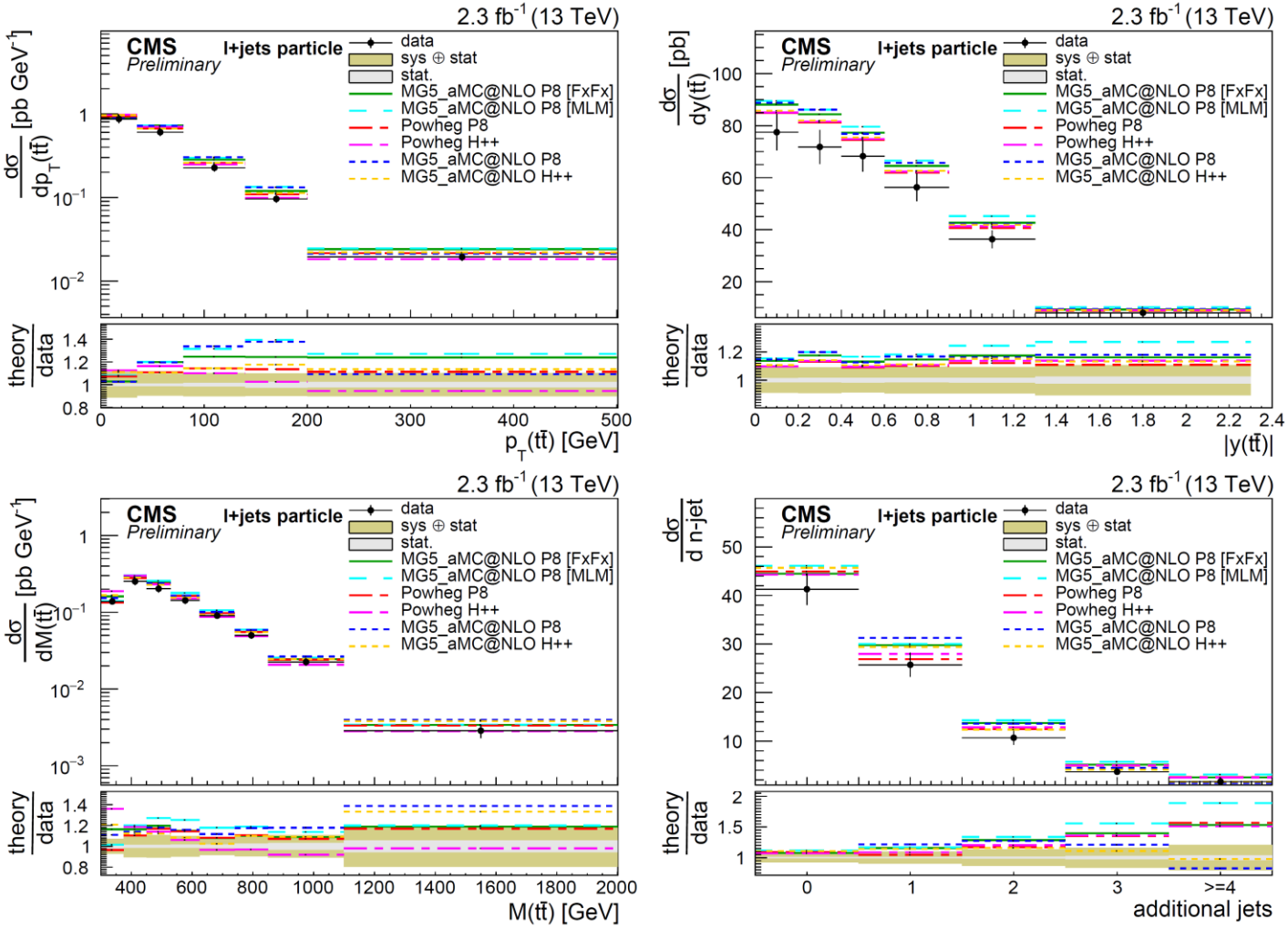

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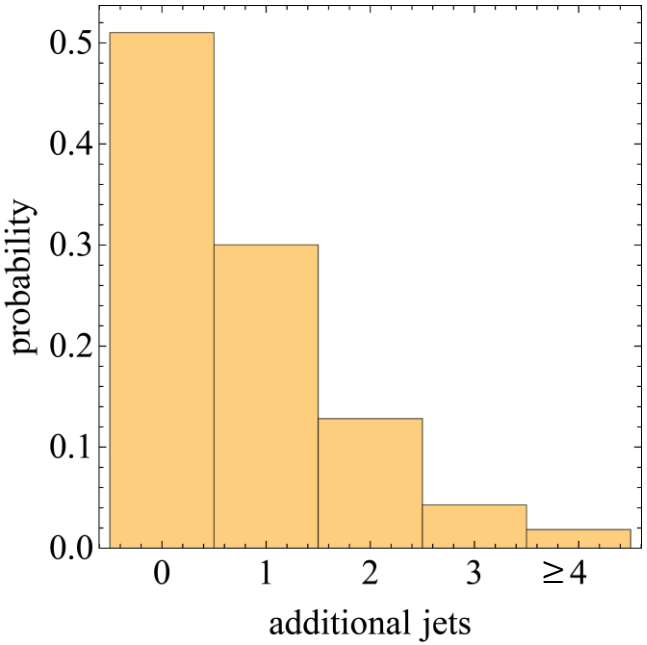
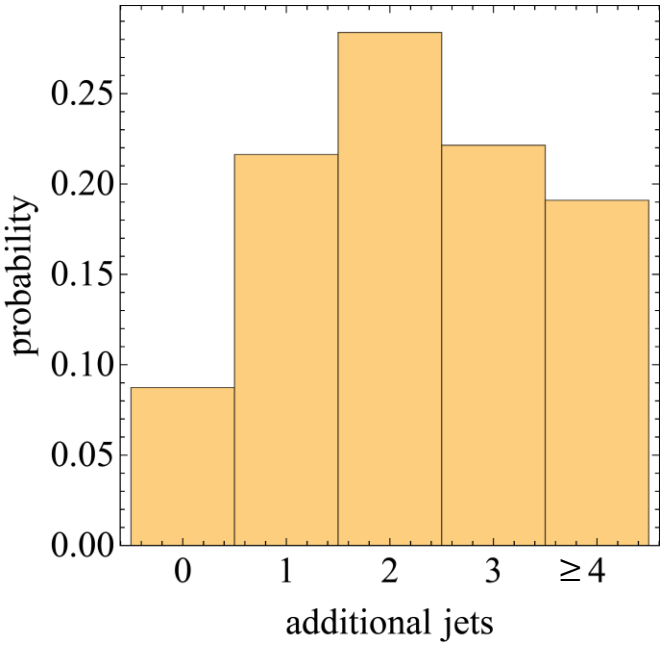
Variable most useful for our scenario:

number of additional jets (with $p_T > 25$ GeV, $|\eta| < 2.5$)

$pp \to t\bar{t}$



$pp \to XX^*,\ X \to \bar{t}\bar{u}$
$m_X = 350$ GeV



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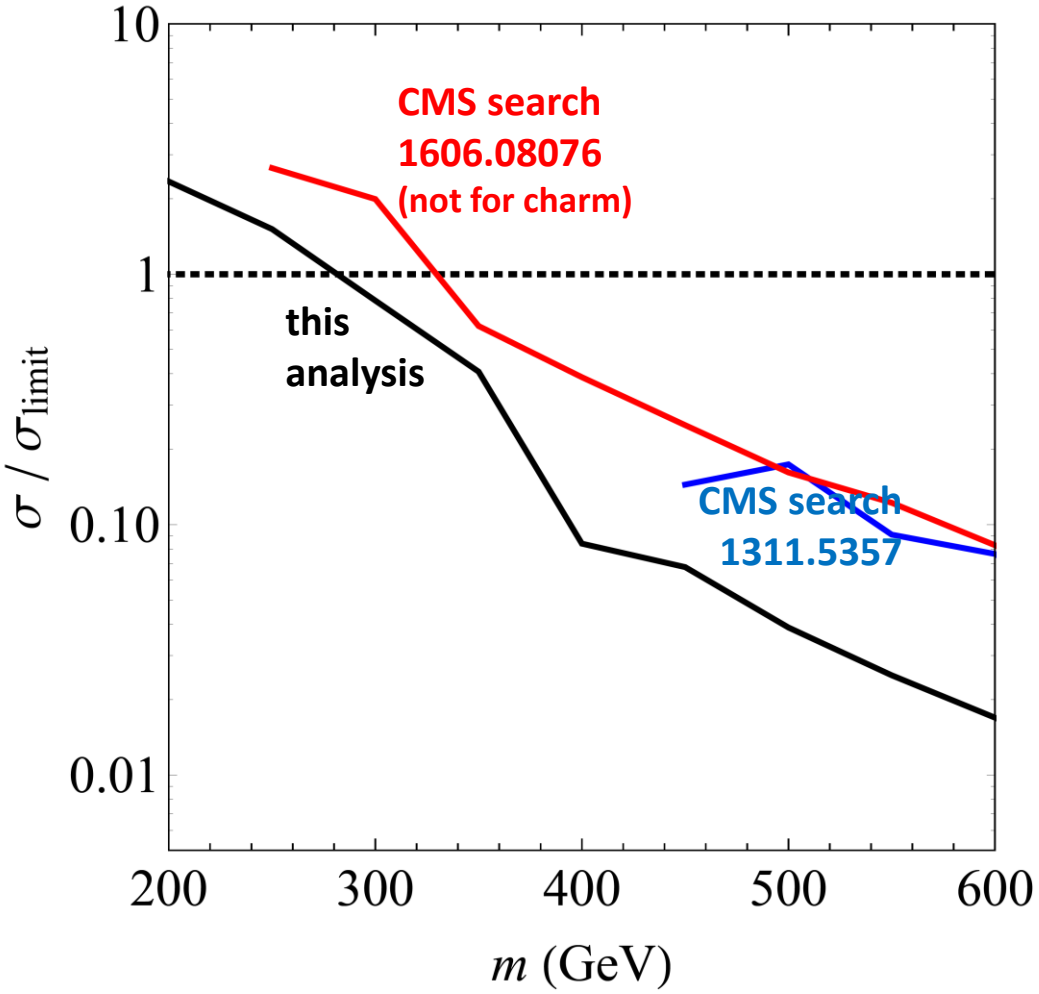

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Measurement of jets produced in top quark events using the di-lepton final state with 2 *b*-tagged jets in *pp* collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

ATLAS-CONF-2015-065 (3.2 fb^{-1})

Unfolding to particle level:

- Use true e, μ, ν's from the hard process
- Cluster and b-tag jets based on true final-state particles
- Selection:

  2 OS leptons (ee, μμ, eμ) with $p_T > 25$ GeV, $|\eta| < 2.5$

  in ee, μμ cases: $|m_{\ell\ell} - m_Z| > 10$ GeV, $m_{\ell\ell} > 40$ GeV

  ≥ 2 b with $p_T > 25$ GeV, $|\eta| < 2.5$

(Normalized) distributions of number of additional jets with

$$p_T > 25, 40, 60, 80 \text{ GeV}, \ |\eta| < 2.5$$

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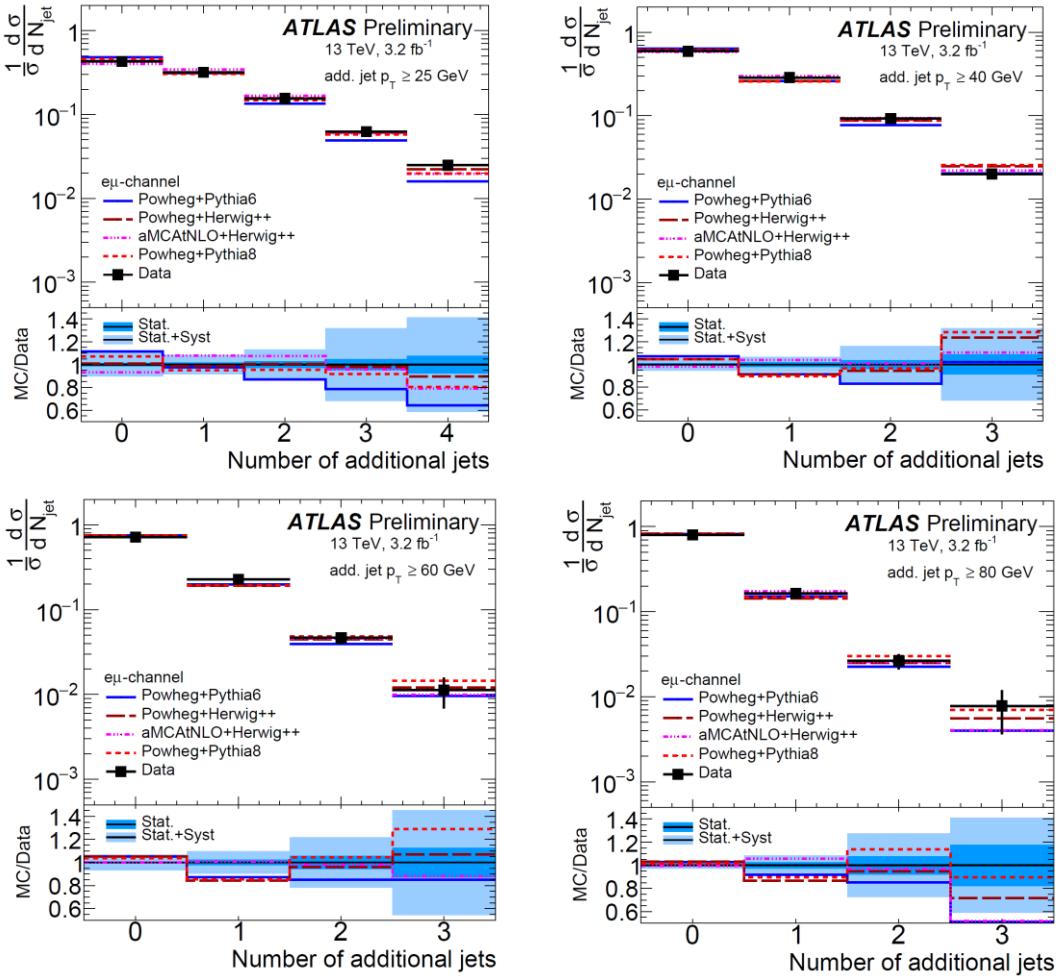

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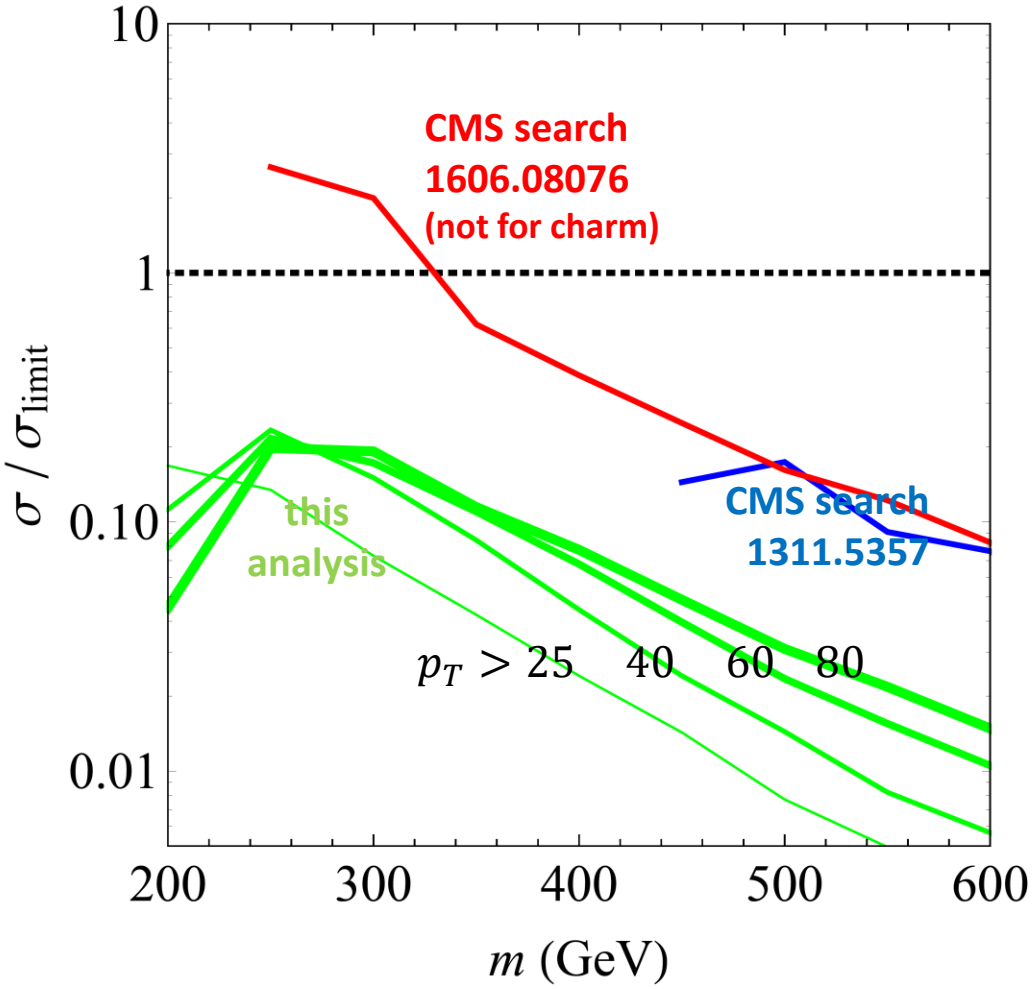

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Measurement of the $t\bar{t}$ production cross-section using $e\mu$ events with *b*-tagged jets in *pp* collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

Phys. Lett. B761 (2016) 136 [arXiv:1606.02699] (3.2 fb^{-1})

Measured cross section:

$$\sigma_{t\bar{t}} = 818 \pm 36 \text{ pb}$$

Theory prediction (NNLO+NNLL):

$$\sigma_{t\bar{t}} = 832^{+40}_{-46} \text{ pb}$$

Allowed $t\bar{t}$-like new physics (95% CL):

$$\sigma_{\text{NP}} \lesssim 100 \text{ pb}$$

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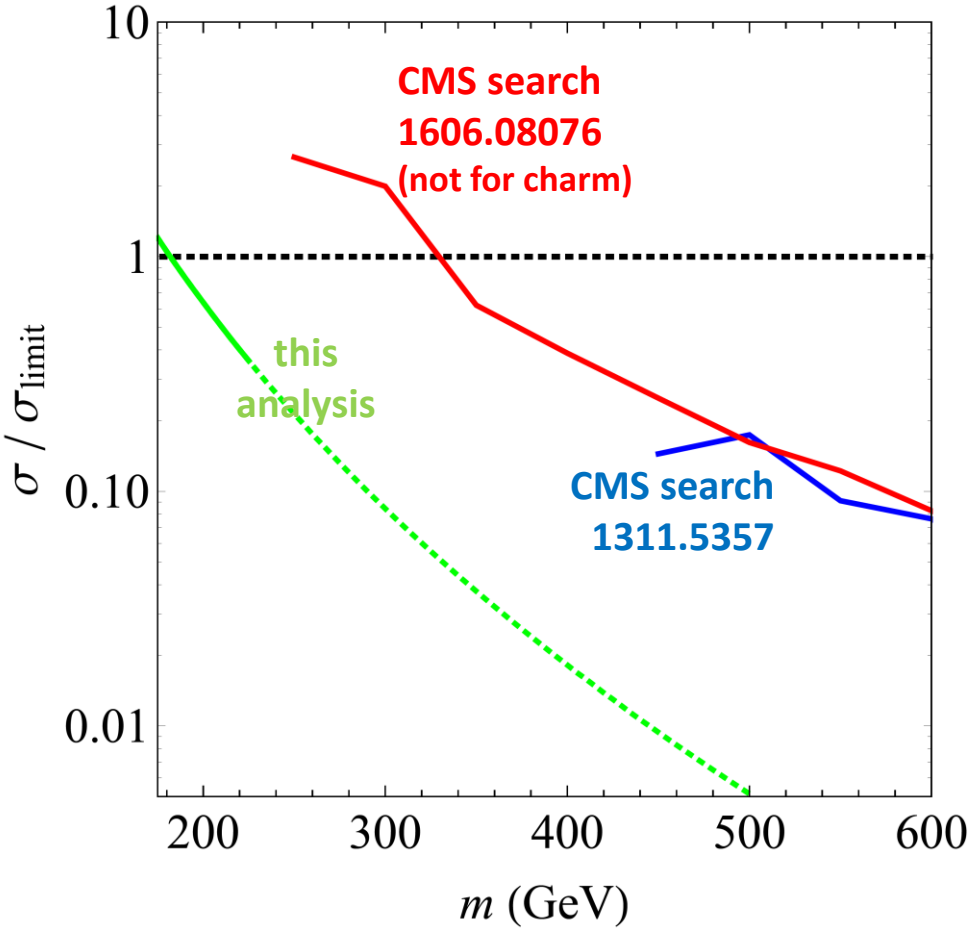

Summarizing questions (to you, if you wish)

- What's the best way to bridge the gap between

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- Any other comments?

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