Tetratop production at the LHC
An effective field theory vision

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Outline.

The top-down approach.

- **Motivations**.
  * **Theoretical ideas**.
    ▶ *e.g.*, **symmetry principles** as for Grand Unified Theories.
  * **Addresses one or several issues** of the Standard Model.
    ▶ *e.g.*, **hierarchy problem** as in Universal Extra Dimensional models.
  * **Predictions** can be made through perturbation theory.
    ▶ *e.g.*, **test at colliders**.
- **Benchmark scenarios**.
  * Many **new parameters** enter in new theories:
    ▶ *e.g.*, **hundreds of parameters** in supersymmetric models.
  * Experimental data **constrains some of them**.
    ▶ *e.g.*, **electroweak precision observables**.
  * **Viable benchmark scenarios**.
- **Signatures at colliders**.
  * **Driven by the benchmark scenarios**.
    ▶ *e.g.*, **same sign leptons $\Leftrightarrow$ new Majorana state**.

The top-down approach: limitations.

- **Signatures at colliders**.
  * Not typical from a **given benchmark of a specific model**.
    ►**Various benchmarks for gravity-mediated supersymmetry breaking**.
  * Not typical from a **specific model**.
    ►**Extra Dimensions and supersymmetry imply both cascade decays**.
- **Theory and data**.
  * **How to relate** observations to a given model/benchmark?
  * **How to disentangle** models and benchmarks?
- **Bias in the expectations**.
  * Are we **missing** some signatures in those investigated?
    ►**Phenomenologically and experimentally**.

The bottom-up approach: we start from a signature.

Outline.

Multiple top quark production at hadron colliders.

- **Production of four top quarks in the Standard Model**.
  - * **Phase-space suppressed**.
  - * Inclusive cross sections: @ 7 TeV: 0.3 fb; @ 8 TeV: 0.7 fb [@leading-order].
  - $\Rightarrow$ **Multitop events (at a large rate) $\Rightarrow$ new physics**.
- **How to model four top production in a model independent way**?
  - * Let us be **pragmatic**....
  - * We start from a model **predicting enhanced four top production**.
  - * **Interface between the top-down and bottom-up** approaches.

Multiple top quark production at hadron colliders.

- **Theoretical framework inspired by R-symmetric supersymmetry**.

  We will consider tops induced by sgluon decays.

- **Sgluon fields also appear in:**
  * $N=1/N=2$ hybrid supersymmetric theories.
  * Vector-like confining theories (colorons).
  * Extra-dimensional theories (with $D \geq 6$).
  * ...

- **Other models predict tetratop signatures (non-sgluon induced).**
  * Vector-like fermions.
  * Compositness models.
  * ...

- **The sgluon analyses presented here can be applied to any of these**.
- **The question of disentangling them is not addressed here**.
  $\Rightarrow$ **Might be interesting?**

Multiple top quark production at hadron colliders.

- **Theoretical framework inspired by *R*-symmetric supersymmetry**.
  - * Predict a scalar color-octet field, the **sgluon**.
  - * **QCD couplings** to gluons.

$$\mathcal{L} = \frac{1}{2} D_\mu \sigma^a D^\mu \sigma_a - \frac{1}{2} m_\sigma^2 \sigma^a \sigma_a \quad \text{with} \quad D_\mu \sigma^a = \partial_\mu \sigma^a + g_s \; f_{bc}{}^a \; G_\mu^b \; \sigma^c$$

  - * **Effective couplings** to quarks and gluons through supersymmetric loops.

$$\mathcal{L} = \sigma^a \bar{d} T_a \left[a_d^L P_L + a_d^R P_R \right] d + \sigma^a \bar{u} T_a \left[a_u^L P_L + a_u^R P_R \right] u + a_g \, d_a{}^{bc} \sigma^a G_{\mu\nu b} G^{\mu\nu}{}_c + \text{h.c.} \; .$$

    - ◇ **Quark - antiquark - sgluon** $\Rightarrow \mathcal{O}\left(\frac{m_q}{M_{\text{SUSY}}}\right)$.
    - ◇ **Gauge boson pair - sgluon** $\Rightarrow \mathcal{O}\left(\frac{1}{M_{\text{SUSY}}}\right)$.

  $\Rightarrow$ **Important for the top quark**.

Benchmark scenarios

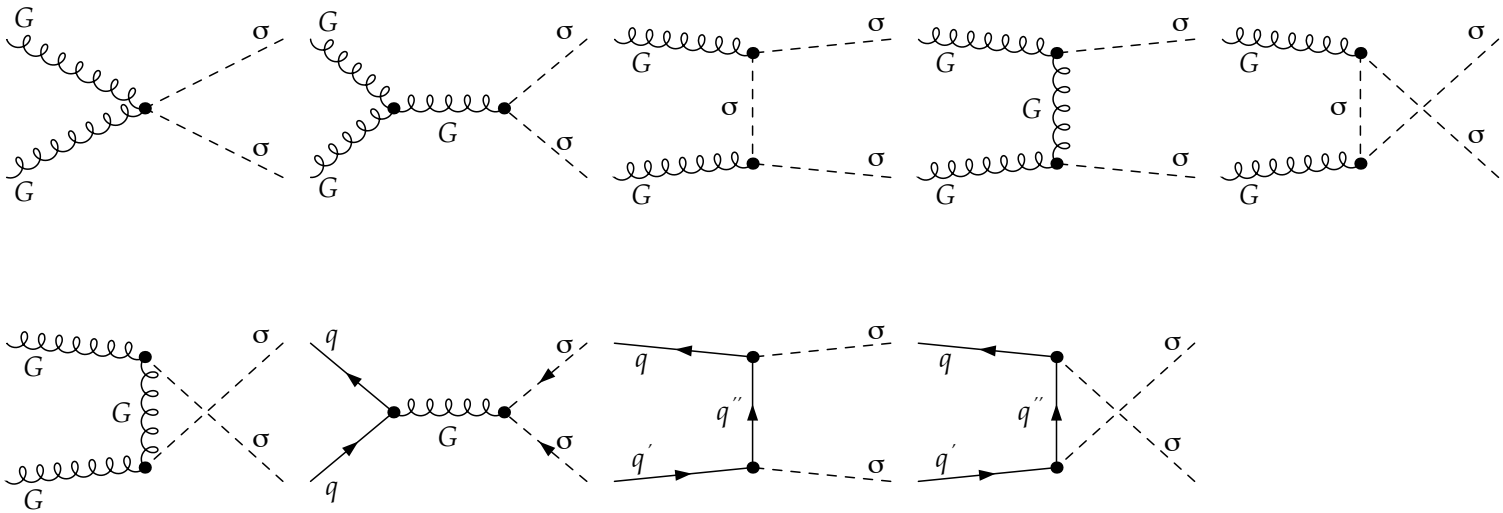
- **Few free parameters**.
  $\Rightarrow$ **very good**.
- **Two classes of scenarios.**
  * **Flavor-universal** sgluon-quark-quark couplings.
  * **Top-only** sgluon-quark-quark couplings.

Parameters	Scenarios of type I	Scenarios of type II
a_g	1.5×10^{-6} GeV^{-1}	1.5×10^{-6} GeV^{-1}
$(a_u)^3{}_3$	$3 \cdot 10^{-3}$	$3 \cdot 10^{-3}$
$(a_u)^3{}_1 = (a_u)^1{}_3$	$3 \cdot 10^{-3}$	0
$(a_u)^3{}_2 = (a_u)^2{}_3$	$3 \cdot 10^{-3}$	0
m_σ	[200-1000] GeV	[400-1000] GeV

- **Sub-TeV sgluons**.
- **Order of magnitude of the couplings**.
  * Inspired from **TeV-scale** supersymmetric scenarios.
  * Orders of magnitude compatible with each other.

Simplified model for sgluon production and decay

- **Signatures.**
  - * Sgluon **pair-production**.



  - * **Decays** to 2, 3 or 4 top quarks.

In numbers...

Scen.	m_σ [GeV]	Γ_σ [MeV]	$BR(t\bar{t})$	$BR(tj/\bar{t}j)$	$BR(gg)$	σ_{tot} [fb]	K
I	200	0.012	-	80%	20%	98600	1.6
I	300	0.105	-	92.3%	7.7%	9802	1.6
I	**400**	0.219	4.4 %	86.9%	8.7%	**1625**	1.7
II		0.029	**33.3%**	-	66.7%		
I	**500**	0.350	9.8 %	79.5%	10.1%	**358.1**	1.8
II		0.072	**47.8%**	-	52.2%		
I	**600**	0.485	12 %	75%	13%	**94.9**	1.8
II		0.124	**48%**	-	52%		
I	700	0.628	13.2 %	70.5%	16.3%	28.4	1.9
II		0.185	44.7%	-	55.3%		
I	800	0.779	13.5 %	66.9%	19.6%	9.26	2.0
II		0.252	41%	-	59%		
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

* **Large** branching to top pairs **possible**.
* **Large** cross sections **expected**.

Simulation setup.

- **Based on two papers**:
  * A comprehensive approach for new physics simulation [Christensen, de Aquino, Degrande, Duhr, BenjF, Herquet, Maltoni, Schumann (EPJC '11)].
  * Beyond the MSSM: from theory to phenomenology [BenjF (IJMPA '12)].
- **The framework**.
  1. Implementation of the simplified models in FeynRules. [Christensen, Duhr (CPC '09); Alloul, Christensen, Degrande, Duhr, BenjF (in prep)]
  2. **UFO** files. [Degrande, Duhr, BenjF, Grellscheid, Mattelaer, Reiter (CPC '11)]
  3. Event generation: MadGraph **5**. [Alwall, Herquet, Mattelaer, Stelzer (JHEP '11)]
  4. Parton showering and hadronization with Pythia. [Sjostrand, Mrenna, Skands (JHEP '06; CPC '08)]
  5. Fast detector simulation with Delphes. [Ovyn, Rouby, Lemaitre ('09)]
  6. Phenomenological analysis.
     * Home-made program using the MCLimit **package**. [http://www-cdf.fnal.gov/∼trj/mclimit/production/mclimit.html]
     * For future analyses ⇒ MadAnalysis 5 [Conte, BenjF, Serret (CPC '13)].

Outline

Standard object selection

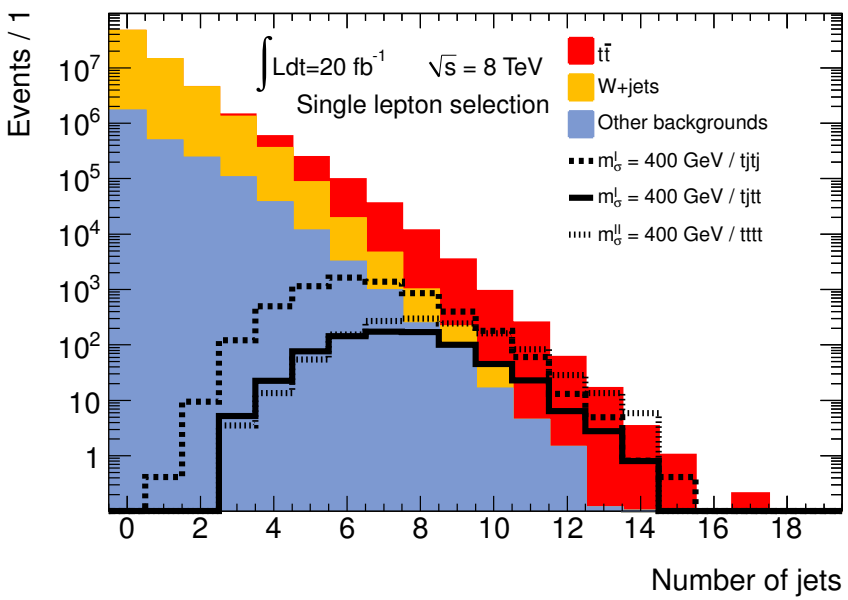
- **Jets**: $E_T^{(\mathrm{cal.})} > 20$ GeV; $\eta < 2.5$.
- **b-tagging**: efficiency: 60%; mistag: 10% (charm) and 1% (light).
- **Jet removal**: if $\Delta R(j, e^{\pm}) \leq 0.1$.
- **Lepton removal**: if $\Delta R(\ell^{\pm}, j) \leq 0.4$.

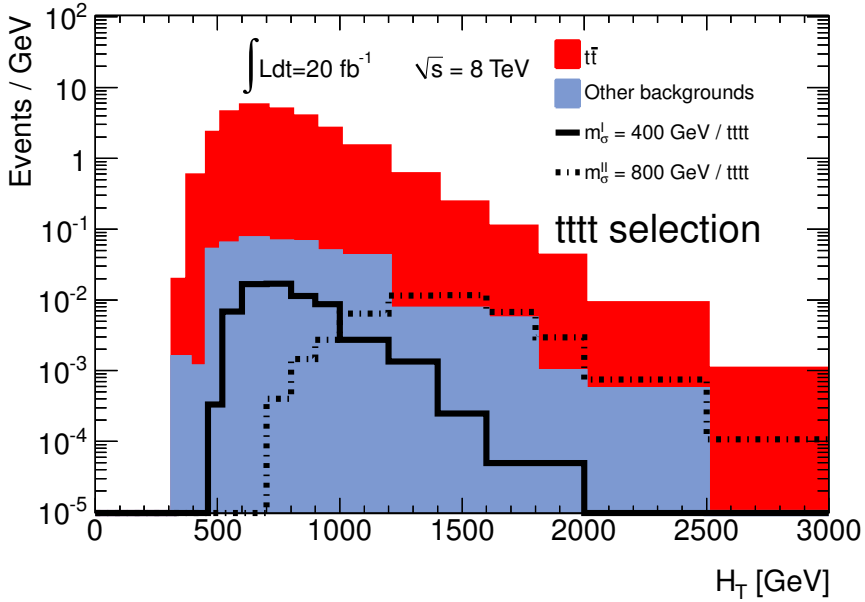
Single lepton analysis (1)

- **Selection cuts.**
  - * **One single lepton**: $p_T \geq 25$ GeV.
  - * **Missing energy**: $\not{E}_T \geq 40$ GeV.
  - * W **transverse mass**: $M_T^W \geq 25$ GeV.
    $\Rightarrow$ **good control of the non-simulated multijet backgrounds**.
  - * **Jet multiplicity cuts**: $N_j \geq 8$; $N_b \geq 2$; $p_T^j \geq 25$ GeV.
- **Main background** $\equiv t\bar{t}$ **+ jets**.
- **Large hadronic activity for the signal**: use H_T as a discriminating variable.

Single lepton analysis (2)

- Left plot: after single lepton + $\not{E}_T$ + M_T^W selection:
- Right plot: after the multijet selection:





Multilepton analysis (1).

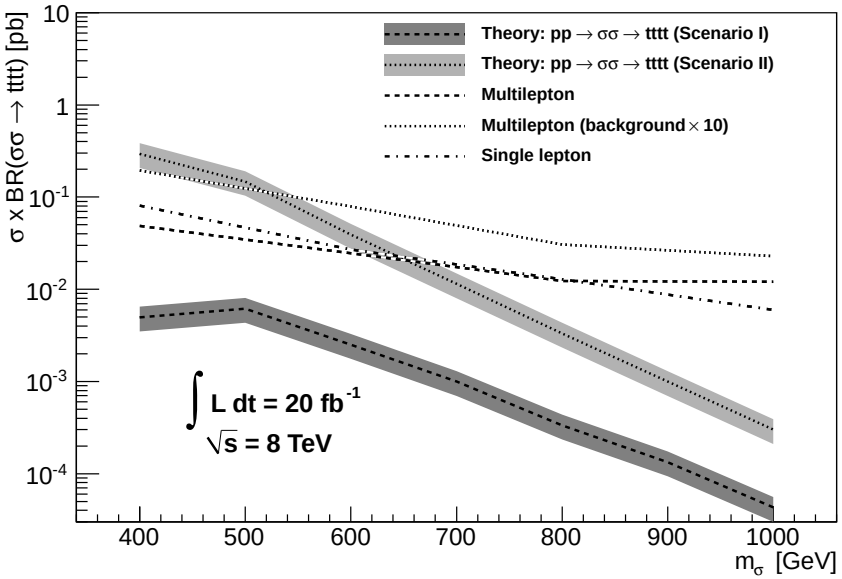
- **Selection cuts.**
  - $N_\ell \geq 2$ **leptons with** $p_T^\ell > 20$ **GeV**.
  - $m_{\ell\ell} \geq 50$ **GeV**$\Rightarrow$ **rejection of hadronic resonances**.
  - **Missing energy**: $\not{E}_T \geq 40$ GeV$\Rightarrow$ **good rejection of the** Z **background**.
  - **Jet multiplicity cuts**: $N_j \geq 5$; $N_b \geq 3$; $p_T^j \geq 25$ GeV.
- **Main bgd** $\equiv t\bar{t} + V(V')$ **+ jets**.
- **Large hadronic activity for the signal**: use H_T as a discriminating variable.
- **Statistically hard** (for two examples of sgluon scenarios):

Selections	$m_\sigma^I = 400$ GeV	$m_\sigma^{II} = 800$ GeV	Backgrounds
$N_\ell \geq 2$, $p_T^\ell \geq 20$ GeV	11.33 ± 0.33	7.90 ± 0.24	$(1.722 \pm 0.002)\cdot 10^7$
$m_{\ell\ell} \geq 50$ GeV	10.42 ± 0.32	7.56 ± 0.22	$(1.717 \pm 0.002)\cdot 10^7$
$\not{E}_T \geq 40$ GeV	8.78 ± 0.29	7.03 ± 0.21	$(1.598 \pm 0.004)\cdot 10^5$
$N_j \geq 5$, $p_T^j \geq 25$ GeV	7.50 ± 0.27	6.60 ± 0.20	$(8.11 \pm 0.06)\cdot 10^3$
$N_b \geq 3$	1.61 ± 0.13	1.93 ± 0.11	$(1.88 \pm 0.06)\cdot 10^2$
Same sign dilepton	0.69 ± 0.08	0.82 ± 0.07	10.3 ± 1.5

Multilepton analysis (2).

- **Multijet background + fakes.**
  - If $N_\ell = 2$: we ask for **same sign leptons**.
  - After cuts, multijet is **10 x larger** than the rest (ATLAS-CONF-2012-130).
  - **Two considered cases** (the truth should be in between).
    - Without multijet + fakes .
    - Without multijet + fakes but after multiplying the bgd by 10.

Extracting the LHC sensitivity.



	Single lepton analysis	Multilepton analysis	Multilepton analysis (background $\times 10$)
S-I	-	-	-
S-II	$640\ ^{+40}_{-30}$ GeV	$650\ ^{+30}_{-40}$ GeV	$520\ ^{+50}_{-110}$ GeV

- **Gray bands: theory curves for all our scenarios** (with scale uncertainties).
- **Expectations** for 20 fb^{-1} @ 8 TeV (using MCLIMIT).

Outline

Summary and perspectives.

- **Exploiting the FeynRules - UFO - MadGraph - Pythia - Delphes chain.**
  - We a **develop** simplified model.
  - Investigate its **phenomenology** at the LHC.
- **Sgluon-induced tetratops.**
  - Sgluon masses up to **525-650 GeV** can be probed.
- **The future (from the phenomenology side):**
  - **Possible use of MadAnalysis 5** $\Rightarrow$ user-friendly and efficient framework.
  - **Other top-down-inspired** model leading to tetratops?
  - Les Houches 2013 is approaching $\Rightarrow$ perfect for TH-EXP works.
  - Nothing in my mind for the moment $\Rightarrow$ **let's discuss!**
- **The future (from the CMS and ATLAS side):**
  - **Please speak up!**