

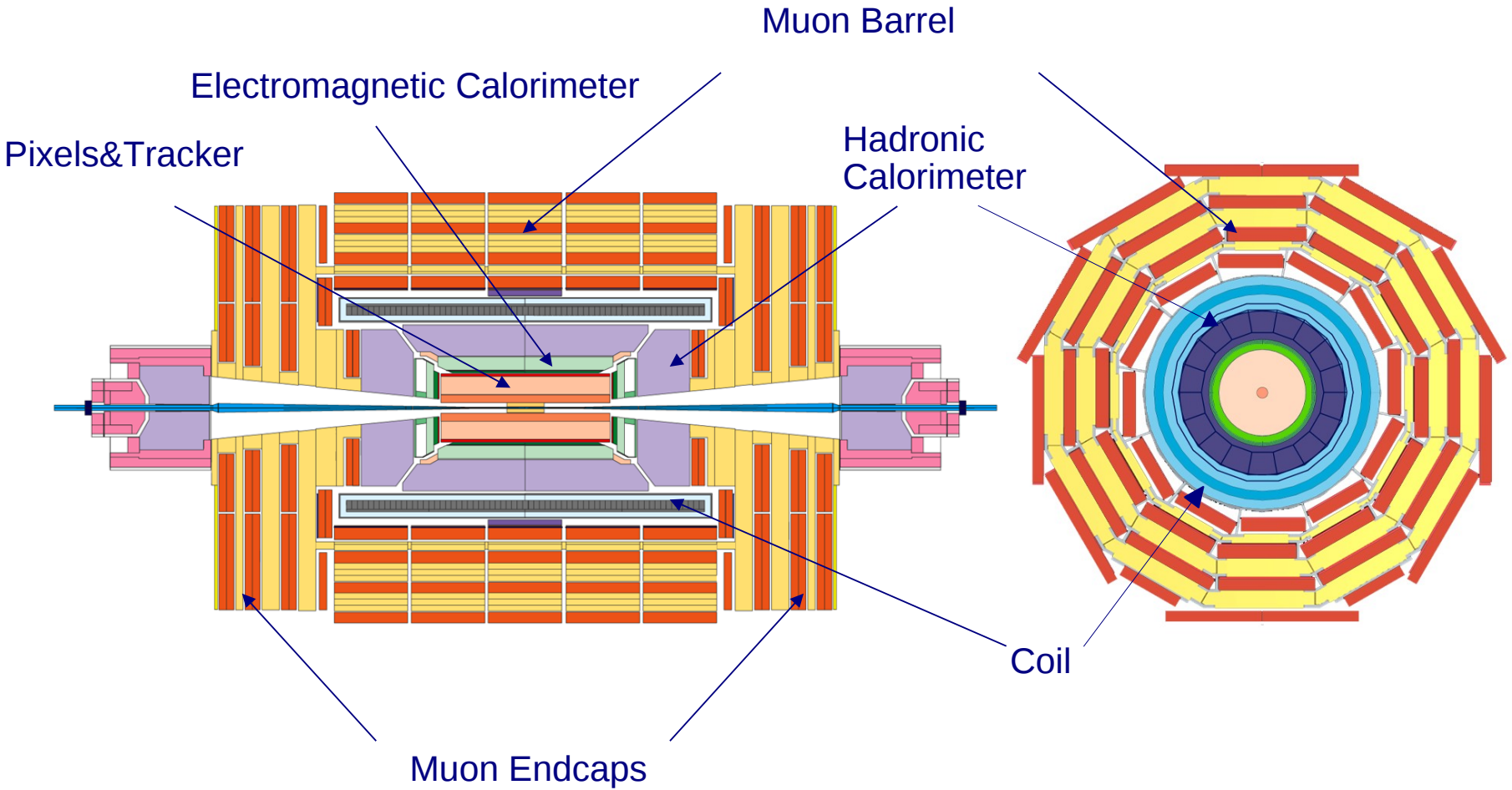
Search for exotic resonances with top quarks at CMS

**Phenomenology 2013
Symposium**

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on behalf of the CMS collaboration



The CMS detector





Outline

Searches for resonances in 19.6 fb^{-1} of data, collected by CMS in 2012:

- ▣ Search for resonant $t\bar{t}$ production
 - ▣ B2G-12-006, lepton + jets signature: 1 e or μ with 2 merged or ≥ 4 regular jets
 - ▣ B2G-12-005, fully hadronic signature: 2 high p_T merged jets with internal substructure
- ▣ Search for narrow t+b resonances
 - ▣ B2G-12-010, lepton + jets signature: 1 e or μ with ≥ 2 jets (≥ 1 b-tagged)
- ▣ Search for pair production of new physics resonances decaying to a top quark and jet
 - ▣ B2G-12-014, lepton + jets signature: 1 e or μ with ≥ 6 jets



Theory motivation

The $Z' \rightarrow tt$ and $W' \rightarrow tb$ searches are well-motivated by many models of new physics, predicting new particles with enhanced couplings to the 3rd generation quarks:

- SUSY and little Higgs theories, addressing fine tuning of Higgs boson mass
- colorons and axigluons models in which a pseudoscalar Higgs boson couples to top quark
- models with extra dimensions such as Kaluza-Klein excitations of SM gluons and gravitons

The $t^* \rightarrow tg$ search is motivated by the compositeness theories



$t\bar{t}$ resonances (1)

[B2G-12-006](#), a model independent search for $t\bar{t}$ resonances in lepton + jets channel:

- light resonances ($M_X \sim 0.5 - 1$ TeV): 1 isolated e/μ + ≥ 4 jets + E_T (>20 GeV)
- heavy resonances ($M_X > 1$ TeV): 1 e/μ + ≥ 2 (merged) jets + E_T (>50 GeV) + few topological cuts

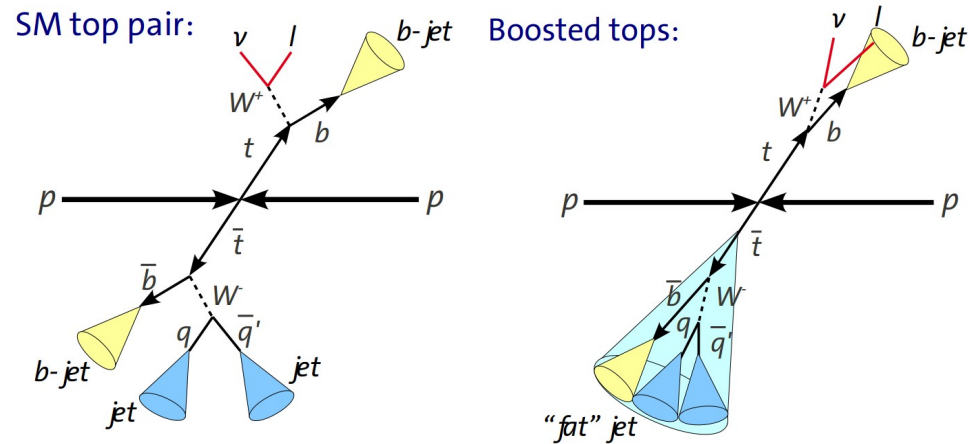
Kinematic $t\bar{t}$ reconstruction:

$$\chi^2 = \left(\frac{M_{lep} - \bar{M}_{lep}}{\sigma_{lep}} \right)^2 + \left(\frac{M_{had} - \bar{M}_{had}}{\sigma_{had}} \right)^2$$

$$\chi^2_{lowmass} = \chi^2 + \left(\frac{M_W - \bar{M}_W}{\sigma_W} \right)^2 + \left(\frac{p_T(t\bar{t}) - \bar{p}_T(t\bar{t})}{\sigma_{pT}} \right)^2$$

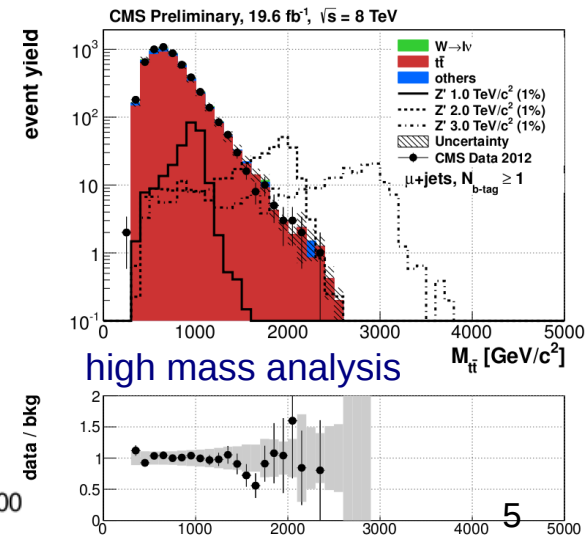
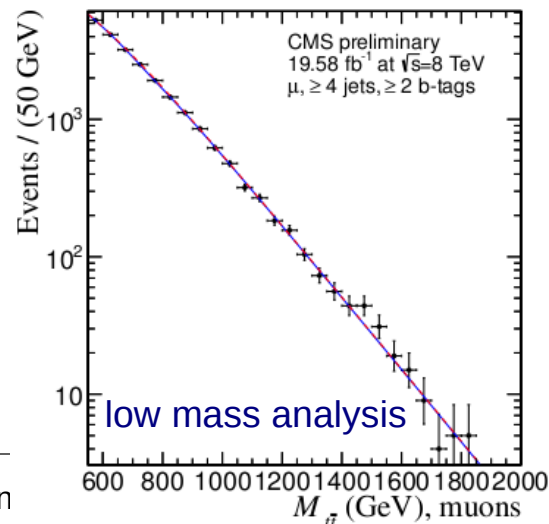
(for the low mass case two additional terms added)

Require $\chi^2 < 10$ to reject most of W+jets events



Look for a bump above background:

- low mass: $\frac{(1 - m/\sqrt{s})^{c_1}}{(m/\sqrt{s})^{c_2 + c_3 \ln(m/\sqrt{s})}}$
smooth data fit:
- high mass: deviation of data from MC background template





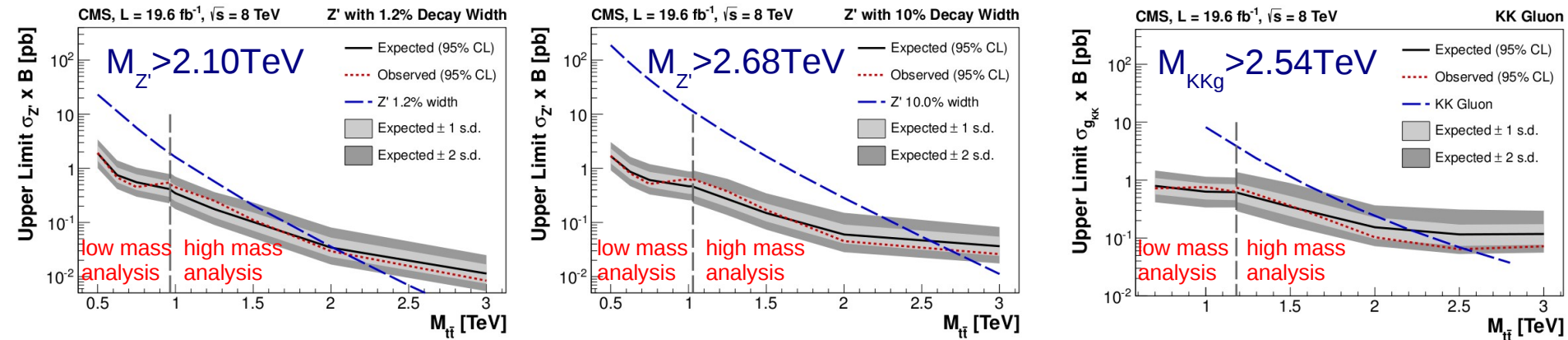
$t\bar{t}$ resonances (2)

Results from [B2G-12-006](#):

□ A benchmark model of $Z' \rightarrow t\bar{t}$:

$\Gamma_{Z'}/M_{Z'}$	0.01	0.10
$M_{Z'}=0.5$ TeV	$\sigma_{\text{obs}} < 1.94\text{pb}$	$\sigma_{\text{obs}} < 1.71\text{pb}$
$M_{Z'}=2.0$ TeV	$\sigma_{\text{obs}} < .029\text{pb}$	$\sigma_{\text{obs}} < .045\text{pb}$

□ Topcolor Z' (left: $\Gamma_{Z'}/M_{Z'}=1.2\%$, center $\Gamma_{Z'}/M_{Z'}=10\%$) and RS KK excitations of gluon (right):

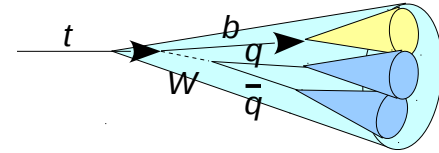




$t\bar{t}$ resonances (3)

[B2G-12-005](#), a model independent search for $t\bar{t}$ resonances in all-hadronic channel

- select events with ≥ 2 top-tagged jets
- estimate main backgrounds: $t\bar{t}$ and QCD multijets
- look for deviations in $m(t\bar{t})$ spectrum



$t\bar{t}$ background (shape from MC, rate is scaled to data):

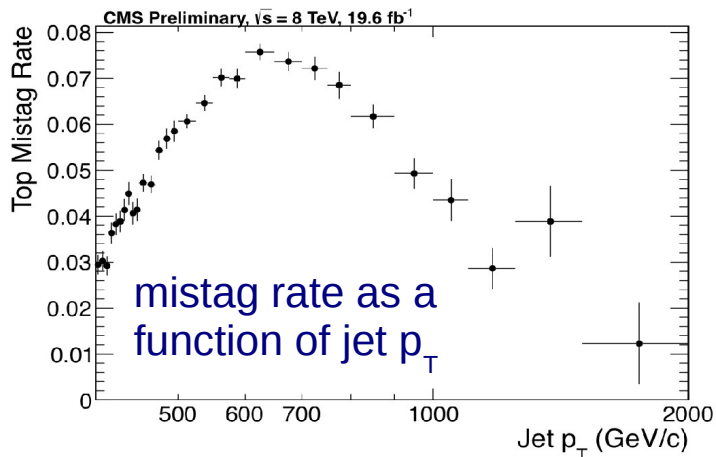
- select control μ +jets data sample (semileptonic $t\bar{t}$ events)
- top-tag a jet and derive MC/data tag-rate scale factor

top-tagged jet ($p_T > 400$ GeV/c):

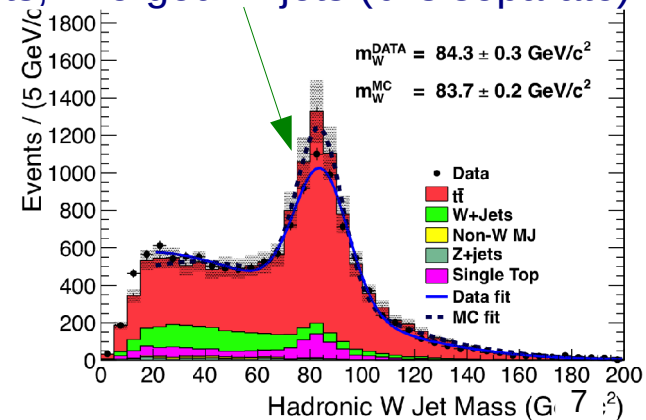
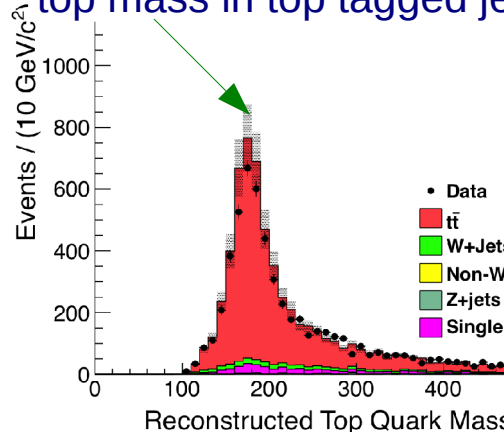
- find ≥ 3 subjets (reverse CA)
- $140 < m_{\text{jet}} (\text{GeV}/c^2) < 250$
- $m_{2 \text{ subjets}}^{\text{min}} > 50 \text{ GeV}/c^2$

QCD multijets background (fully data-driven):

- select QCD control sample by anti-top-tagging of one of the jets ($m_{2 \text{ subjets}}^{\text{min}} < 30 \text{ GeV}/c^2$)
- find top mistag rate using the probe jet
- scale QCD dominated di-jet sample with only 1 top-tag by the mistag rate



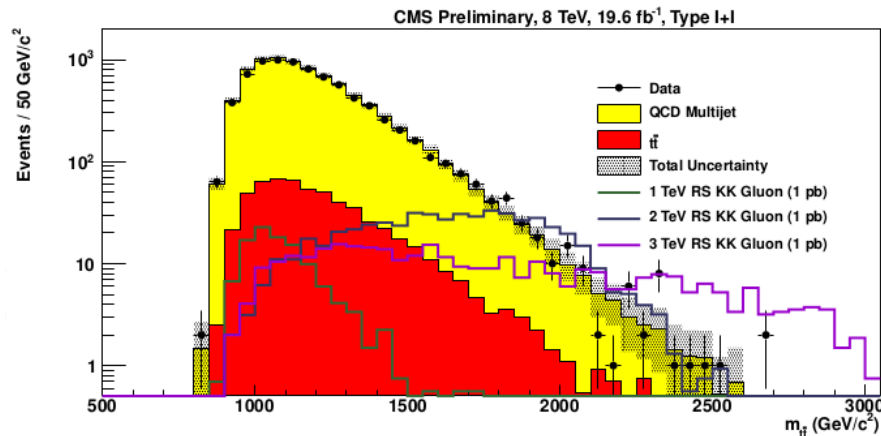
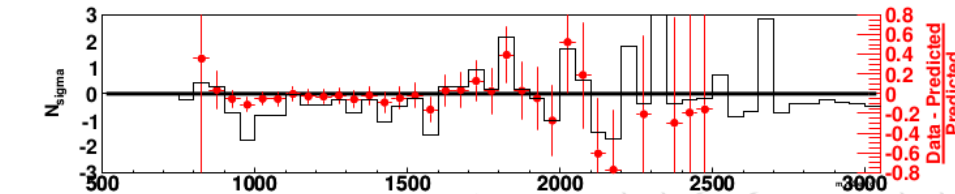
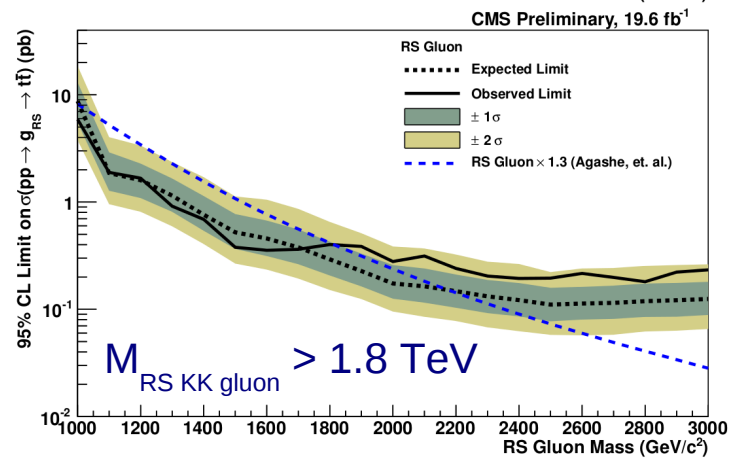
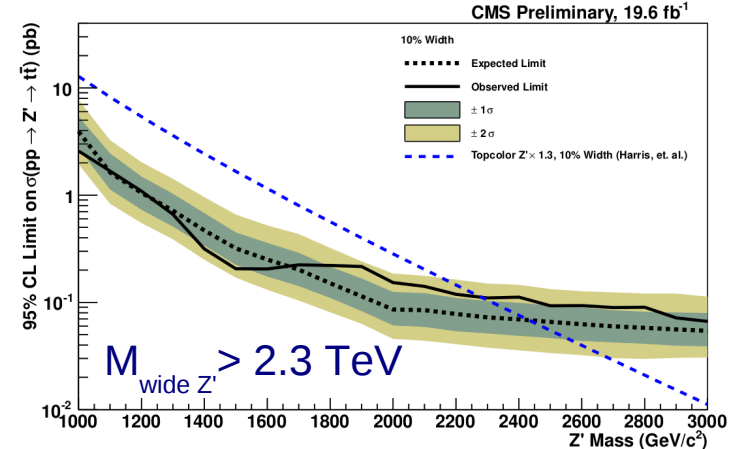
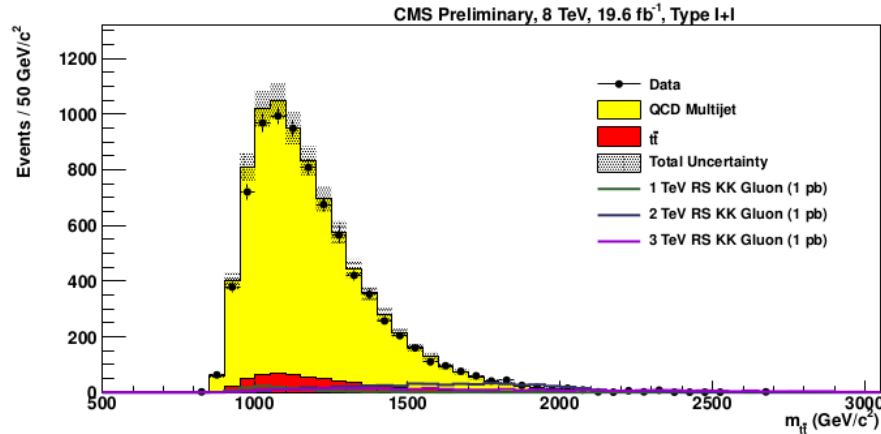
top mass in top tagged jets; merged W jets (b is separate)





$t\bar{t}$ resonances (4)

Results from [B2G-12-005](#):



+ limit on generic enhancement in $M_{t\bar{t}}$ spectrum excludes everything that predicts more than $1.79 \times \text{SM expectation for } M_{t\bar{t}} > 1 \text{ TeV}/c^2$



t+b resonances (1)

[B2G-12-010](#), search for a $W' \rightarrow tb$ in leptonic final state ($t \rightarrow bW \rightarrow b\ell\nu$)

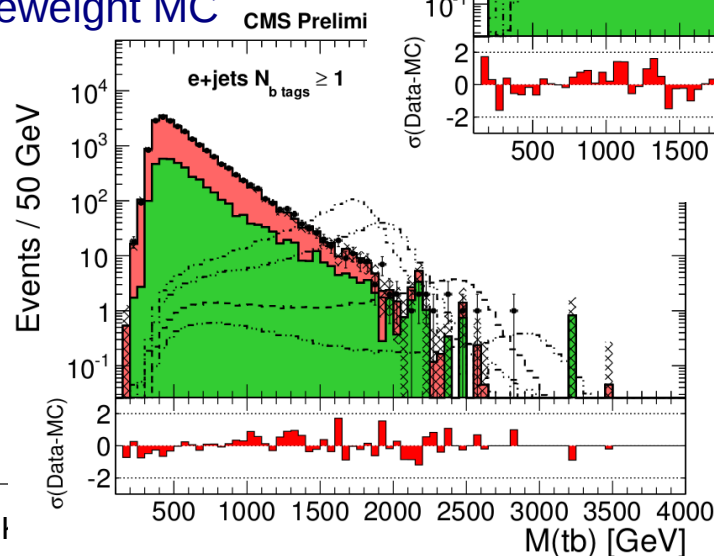
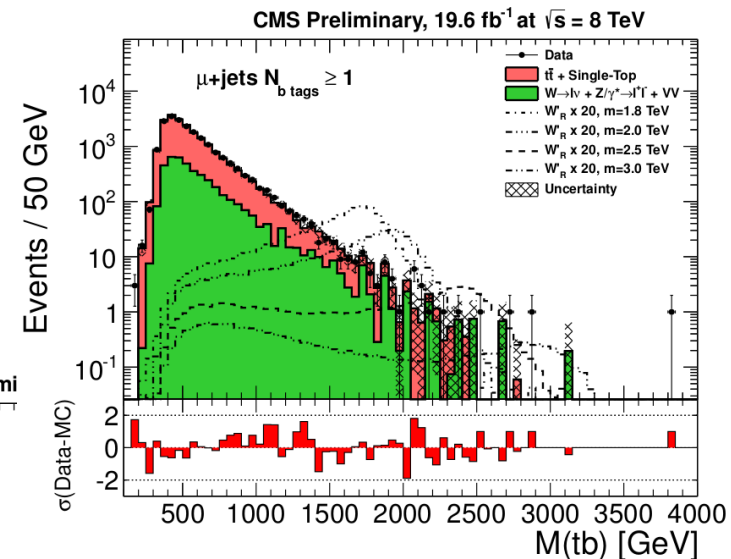
- look for events with: isolated e or μ + ≥ 2 jets + ≥ 1 b-tag + $E_T > 20$ GeV
- reconstruct top quark using $m(\text{jet}+\ell+\nu) = m_{\text{top}}$ (first find p_z^ν from $m(\ell+\nu) = m_W$)
- check spectrum of $m(\text{top} + \text{another jet})$ for deviations from SM predictions

Data driven backgrounds:

- W+jets: $m(tb)$ from control sample with 0 b-tags
- $t\bar{t}$: control sample ≥ 4 jets + ≥ 2 b-tags + $400 < m^{tb} < 750$
 - fit MC/Data ratio for top p_T spectrum
 - extrapolate for high top p_T and reweight MC

(specific cuts reducing W+jets and $t\bar{t}$:

- $130 < m^{\text{top}} \text{ (GeV}/c^2) < 210$
- $p_T^{\text{top}} > 85 \text{ GeV}/c$
- $|\vec{p}_T^{\text{jet1}} + \vec{p}_T^{\text{jet2}}| > 140 \text{ GeV}/c$

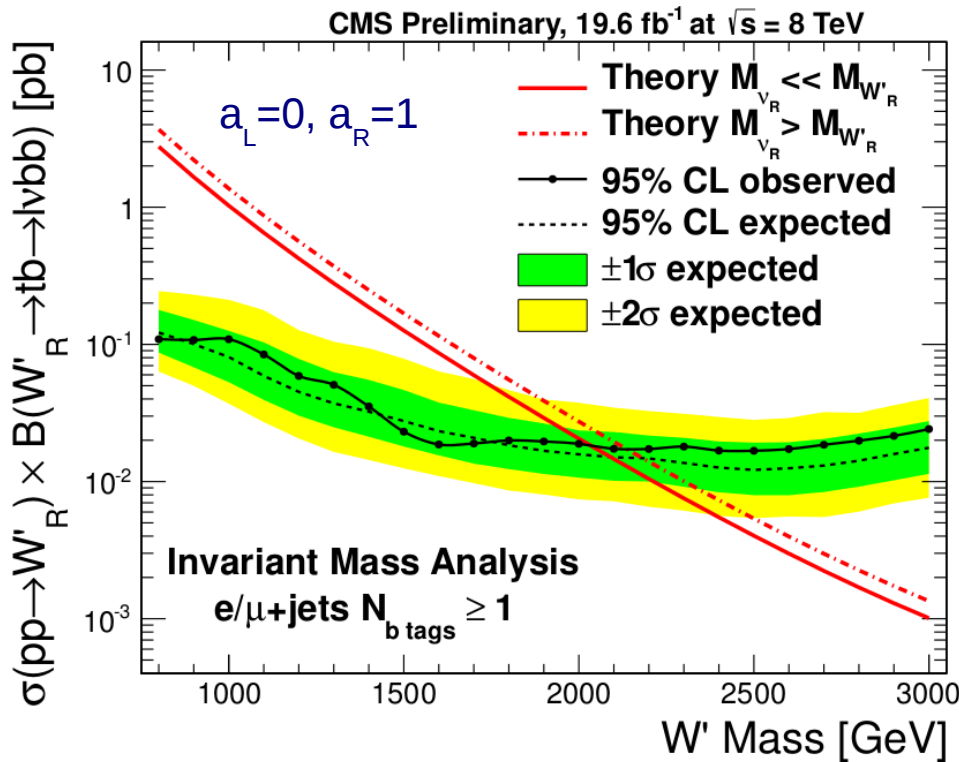




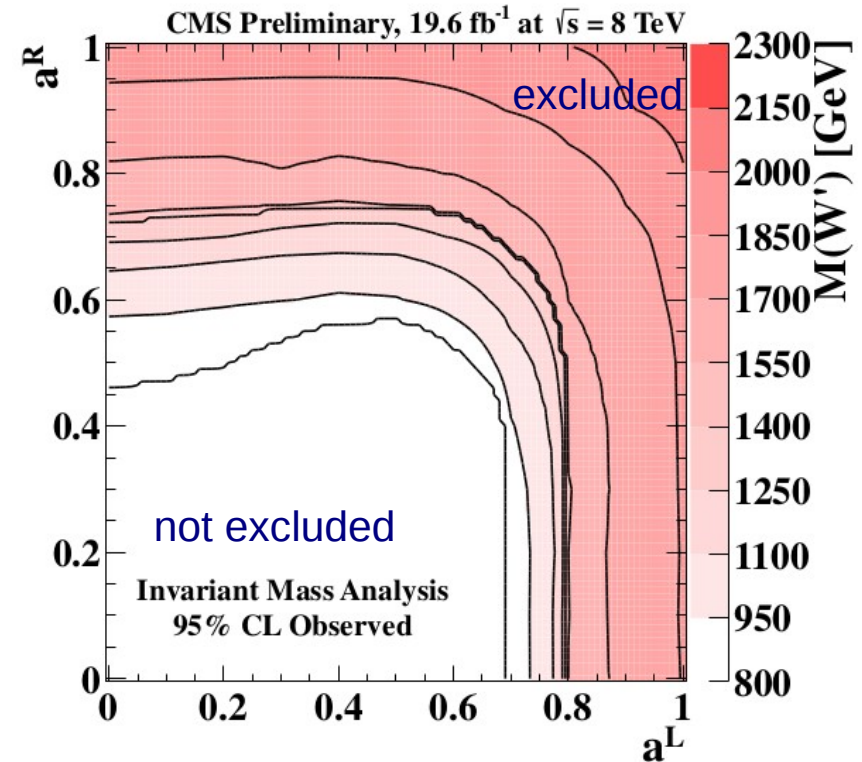
t+b resonances (2)

Results from [B2G-12-010](#) interpreted in terms of left-handed and right-handed couplings of W' :

$$\mathcal{L} = \frac{V_{ij}^{CKM}}{2\sqrt{2}} \frac{e}{\sin\theta_W} \bar{f}_i (a^R(1+\gamma^5) + a^L(1-\gamma^5)) W'^{\mu} f_j + H.c.$$



$M(W'_R) > 2.03$ TeV



black contours: $m_{W'} = 800 + n \cdot 150$ (GeV)



t+j resonances (1)

[B2G-12-014](#), search for a pair produced excited top quark (t^*) in leptonic final state

□ signal signature: $pp \rightarrow t^* \bar{t}^* \rightarrow tg \bar{t}g \rightarrow$ isolated e or μ + ≥ 6 jets + ≥ 1 b-tag

□ reconstruct $t^* \bar{t}^* \rightarrow (\ell \nu bg)(q \bar{q} bg)$ event using kinematic reconstruction:

□ $m(\ell + \nu) = m(q + \bar{q}) = M_W$ (from PDG)

□ $m(\ell + \nu + b) = m(q + \bar{q} + b) = M_t$ (from PDG)

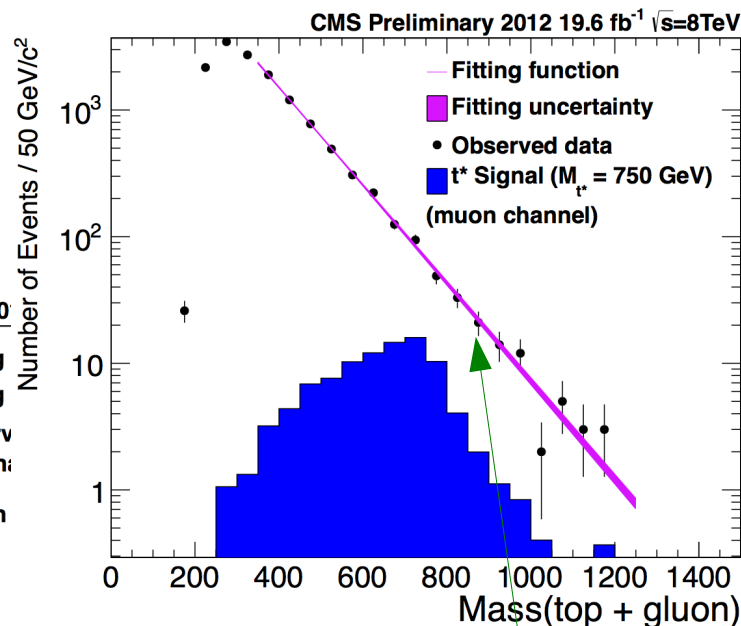
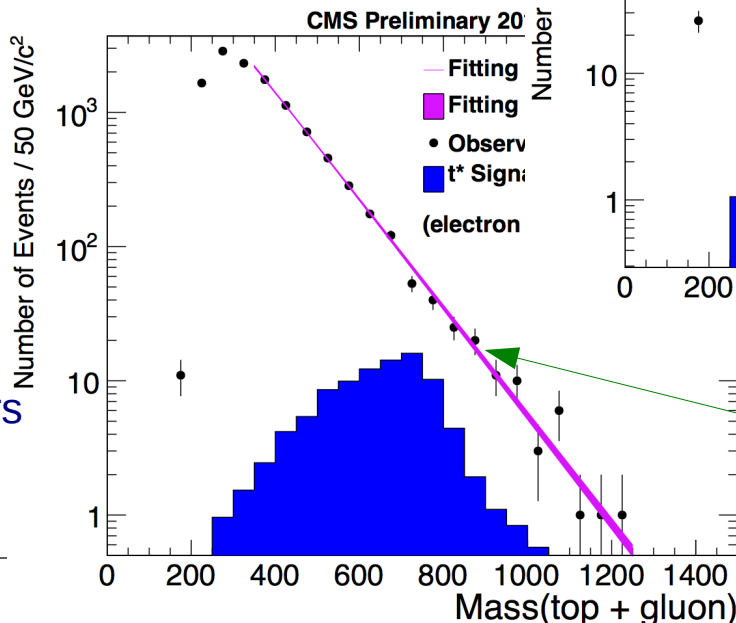
□ $m(\ell + \nu + b + g) = m(q + \bar{q} + b + g) = M_{t+g}$ (free)

□ fit the M_{t+g} spectra in data and look for a bump

Data-driven background:

$$bg(m) = \frac{a}{1 + e^{(m-b)/c}}$$

Signal (MC)+background fit function optimizes σ_{sig} and a,b,c background parameters

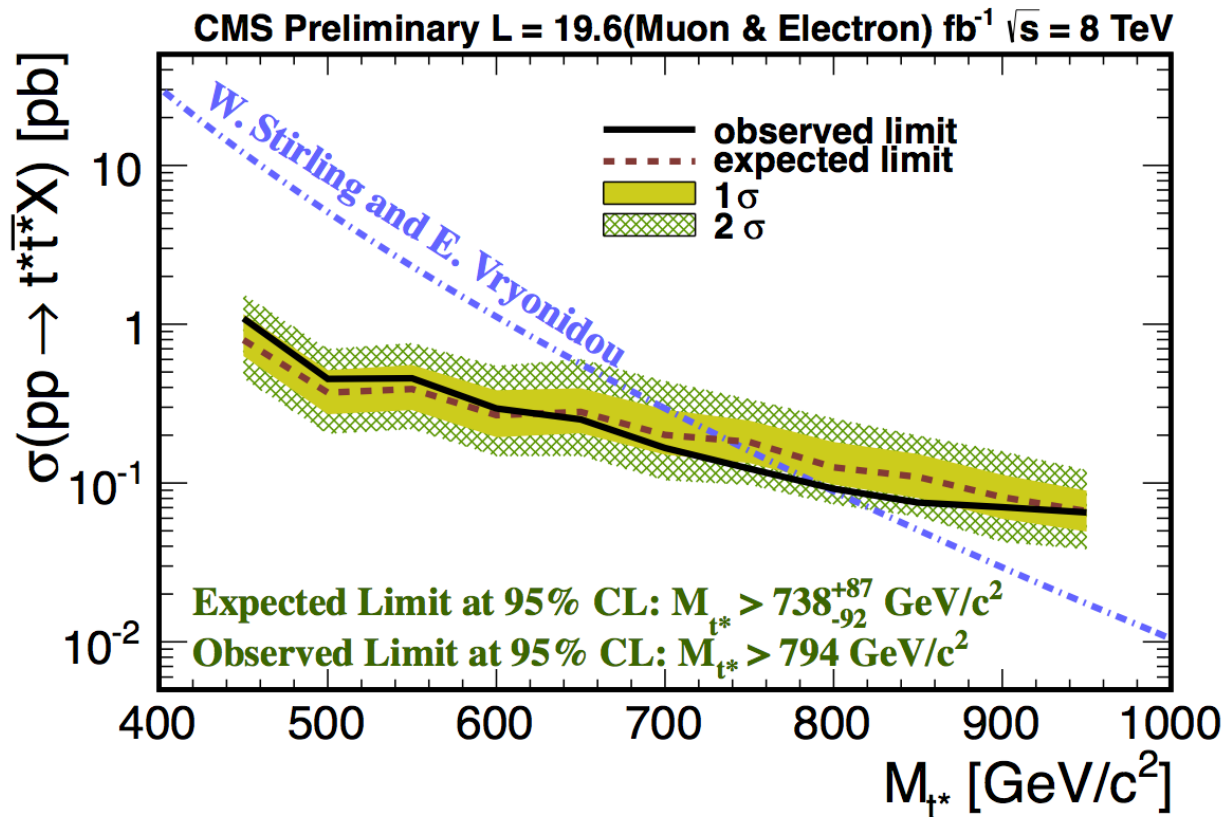


fully data-driven background, no MC needed



t+j resonances (2)

Results from [B2G-12-014](#): interpreted in terms of spin-3/2 Randall-Sandrum t^* :





Summary

- CMS performed several new physics searches for exotic top resonances with top quarks
- No deviations from the Standard Model were found
- New limits were set on the new physics models:
 - up to 2.68 TeV on topcolor Z'
 - up to 2.54 on RS KK excitation of gluon
 - up to 2.03 on right-handed W'
 - up to 0.794 on excited top quark (t^*)



Bibliography

- Search for resonant $t\bar{t}$ production in lepton+jets events in pp collisions at $\sqrt{s}=8$ TeV, [CMS PAS B2G-12-006](#)
- Search for resonant $t\bar{t}$ production in all hadronic events in pp collisions at $\sqrt{s}=8$ TeV, CMS PAS B2G-12-005
- Search for narrow $t+b$ resonances in the leptonic final state at $\sqrt{s} = 8$ TeV, [CMS PAS B2G-12-010](#)
- Search for pair production of new physics resonances decaying to a top quark and jet in the lepton+jets decay channel, [CMS PAS B2G-12-014](#)
- Search for anomalous $t\bar{t}$ production in the highly-boosted all-hadronic final state, 7 TeV, [CMS PAS EXO-11-006](#) (superseded by [CMS B2G-12-005](#))
- Search for Z' resonances decaying to $t\bar{t}$ in dilepton+jets final states in pp collisions at $\sqrt{s} = 7$ TeV, [CMS PAS TOP-11-010](#)
- Search for resonant $t\bar{t}$ production in lepton+jets events in pp collisions at $\sqrt{s}=7$ TeV, [CMS PAS TOP-12-017](#) (superseded by [CMS B2G-12-006](#))