Searches for new resonances coupling to 3rd generation of quarks at 13 TeV at CMS

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on behalf of CMS collaboration

BATS@LHC

Introduction

- With Higgs boson, last piece of the SM has been discovered and many extensions of the SM could manifest at higher energies
  → **new resonances at the TeV scale** ?

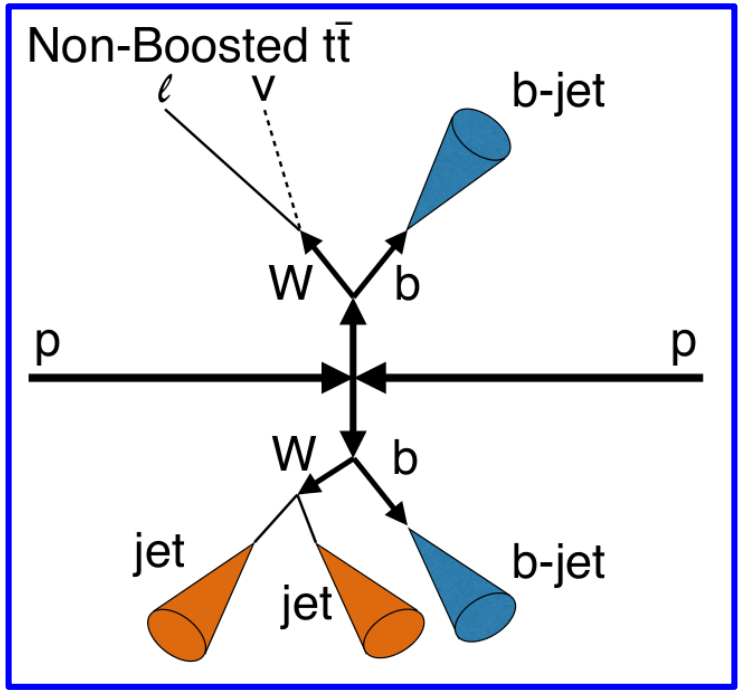
- Searching **di-objects invariant mass provides model-independent method** for BSM searches

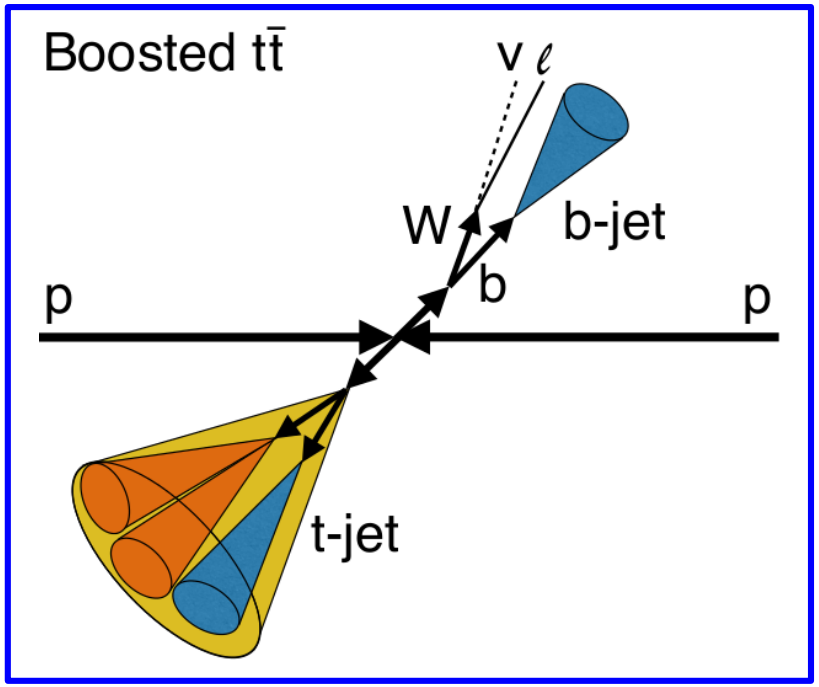
- Several BSM models predict **new resonances** by adding new gauge field, extending the Higgs sector or considering extra-dimensions
  → Randall-Sundrum (RS) gravitation,
  → Kaluza-Klein (KK) excitation of gluons,
  → Composite Higgs models,
  → …

Heavy resonances

- Resonances decaying into Higgs/W/Z discussed **yesterday** **(talk of S. Rappoccio)**
  → focus today on **new resonances coupling to top/bottom quarks**

- Possibly **boosted objects** : require new triggers (non-isolated lepton) and reconstruction strategies (jet p_T cleaning, jet substructure, ...)

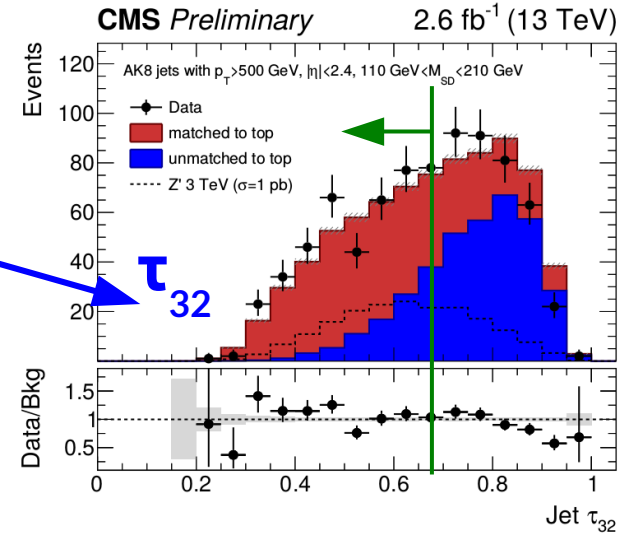




Boosted objects

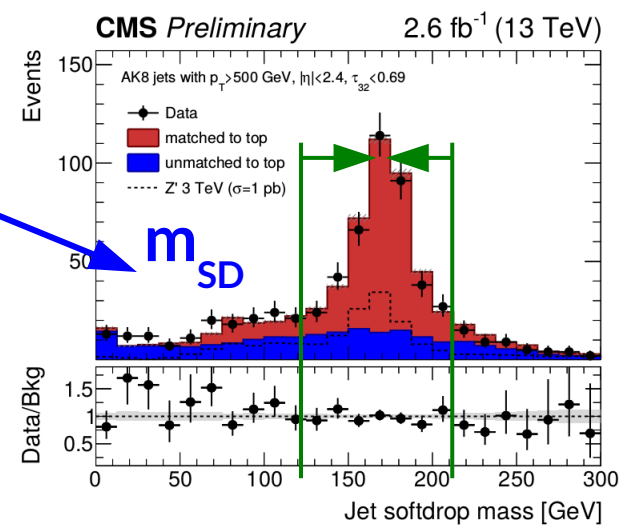
- **top-tagging :** reconstruct fat jets (AK8) and look at substructure (subjets)

  → **n-subjettiness τ_{32}**
  - **is the jet more 3- or 2-subjet-like ?**
  - $\tau_{32} \rightarrow 0$ for 3-prong subjets structure (top)
  - $\tau_{32} \rightarrow 1$ for non-top jets (light quarks or gluons)
  - **typical value : $\tau_{32} < 0.69$**



CMS-PAS-B2G-15-002

  → **soft-drop mass m_{SD}**
  - **mass of the « cleaned » jet**
  - removes soft and wideangle radiations
  - **typical value : $110 < m_{SD} < 210$ GeV**

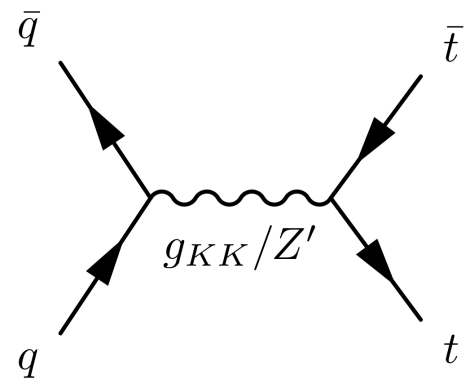
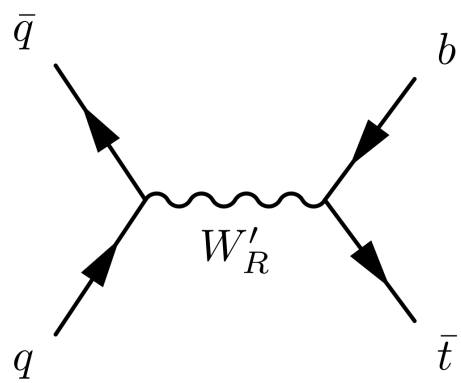


- **b-tagging :** use properties of b-hadrons

  → **track impact parameter**

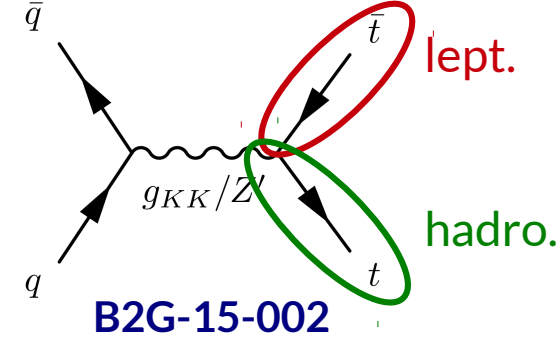
  → **secondary vertex**

- **Numerous final states** to explore → already **several results** at 13 TeV !!

resonance	diagram type	final state	luminosity	CMS-PAS
ttbar		lvbbjj	2.6 fb^{-1}	B2G-15-002
		bbjjjj	2.6 fb^{-1}	B2G-15-003
W'		bbjj	2.6 fb^{-1}	B2G-16-009
		lvbb	2.2 fb^{-1}	B2G-15-004
		lvbb	12.9 fb^{-1} 2016 data	B2G-16-017

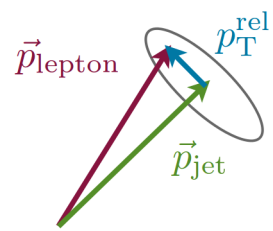
ttbar resonances

semileptonic ttbar



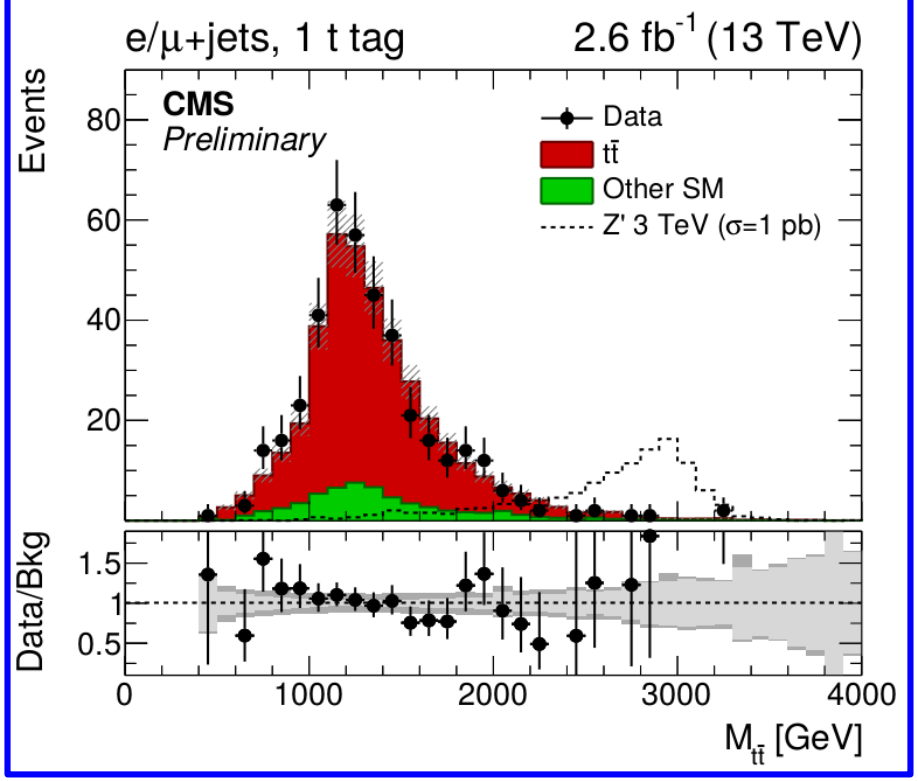
→ Z' resonance with width = 1 %, 10 %, 30%
→ Kaluza-Klein excitation of gluon g_{KK}

- μ/e channel :
  - → exactly 1μ/e : p_T > 50 GeV,
  - → ≥ 2 high-p_T AK4 jets,
  - → MET > 50 (120) GeV,
  - → 2D rejection cut :
    - ΔR (μ/e, j) > 0.4
    - **or**
    - p_T^{rel} (μ/e, j) > 20 GeV,
  - → ttbar system reconstruction : $\chi^2 < 30$.

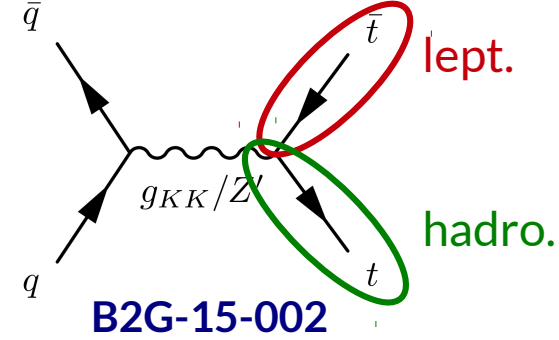


- top-tagging **(AK8 jets)** : (3 % mistag)
- b-tagging **(AK4 jets)** : medium WP (0.1 % mistag)

$M_{t\bar{t}}$ (μ/e channel, 1 t-tag)

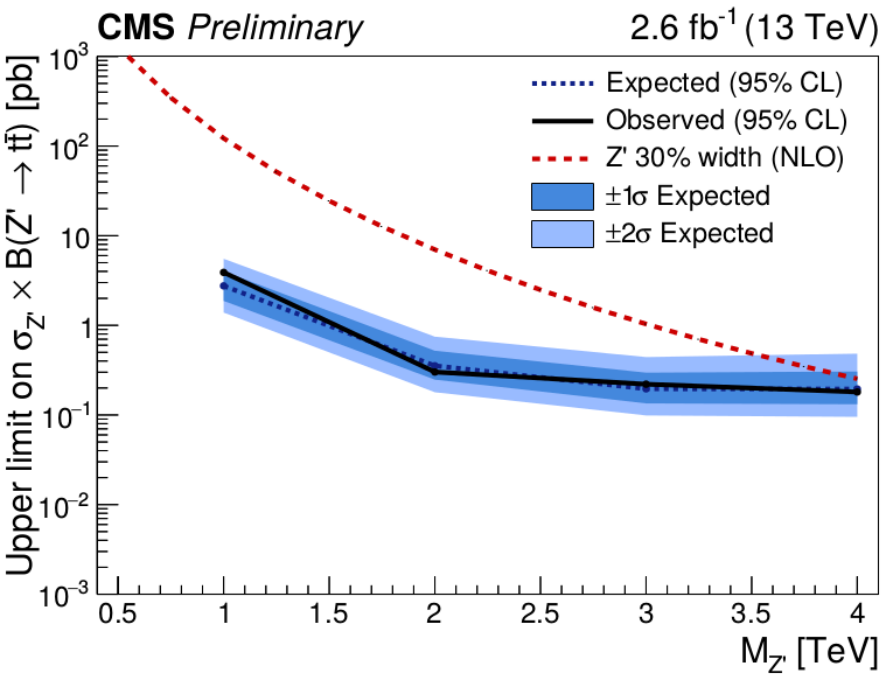


semileptonic ttbar



Signal regions : μ/e channel ⊗	1 t-tag 0 t-tag, 1 b-tag 0 t-tag, 0 b-tag

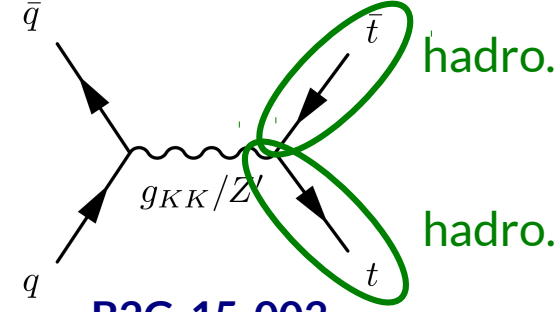
- **Simultaneous fit** of the **ttbar invariant mass** distribution in signal region and in three different control regions (ttbar+jets, W+jets, Z+jets).
- This **minimizes some uncertainties** and **fits the backgrounds cross-sections**.



- Results (with μ/e combination):

Signal	Observed exclusion
Narrow Z' (1%)	[0.6 – 2.3] TeV
Wide Z' (10%)	[0.5 – 3.4] TeV
Extra wide Z' (30%)	[1.0 – 4.0] TeV
KK gluon	[0.5 – 2.9] TeV

hadronic ttbar



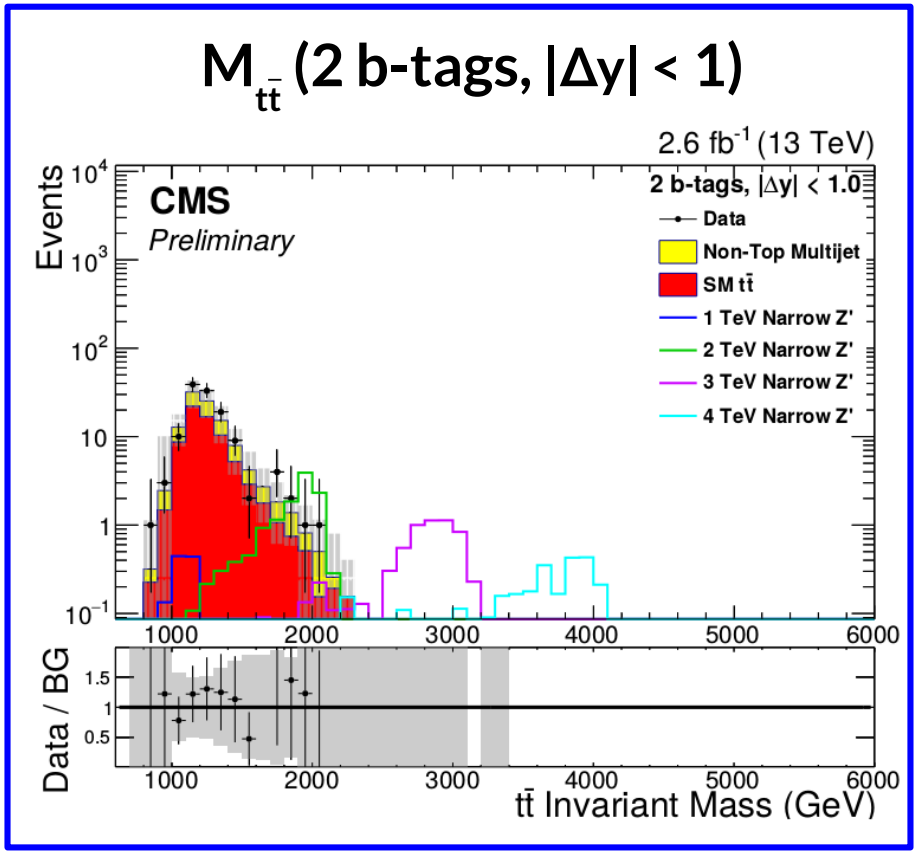
B2G-15-003

→ Z' resonance with width = 1 %, 10 %, 30%
→ Kaluza-Klein excitation of gluon g_{KK}

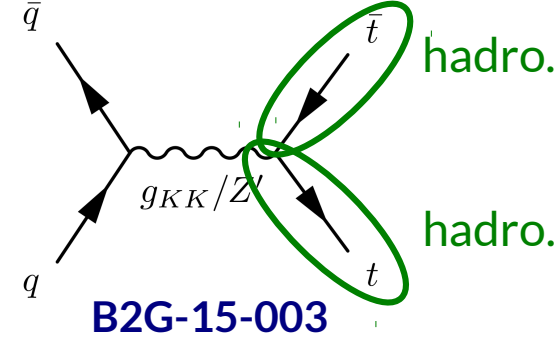
- top-tagging **(AK8 jets)** : (3 % mistag)
- b-tagging **(AK4 jets)** : medium WP (1 % mistag)

- Event selection :
  - → 2 t-tagged AK8 jets : p_T > 400 GeV,
  - → Scalar sum of jets p_T : H_T > 1000 GeV,
  - → $|\Delta\varphi(j_1, j_2)|$ > 2.1 rad.

- QCD multijet estimated from data

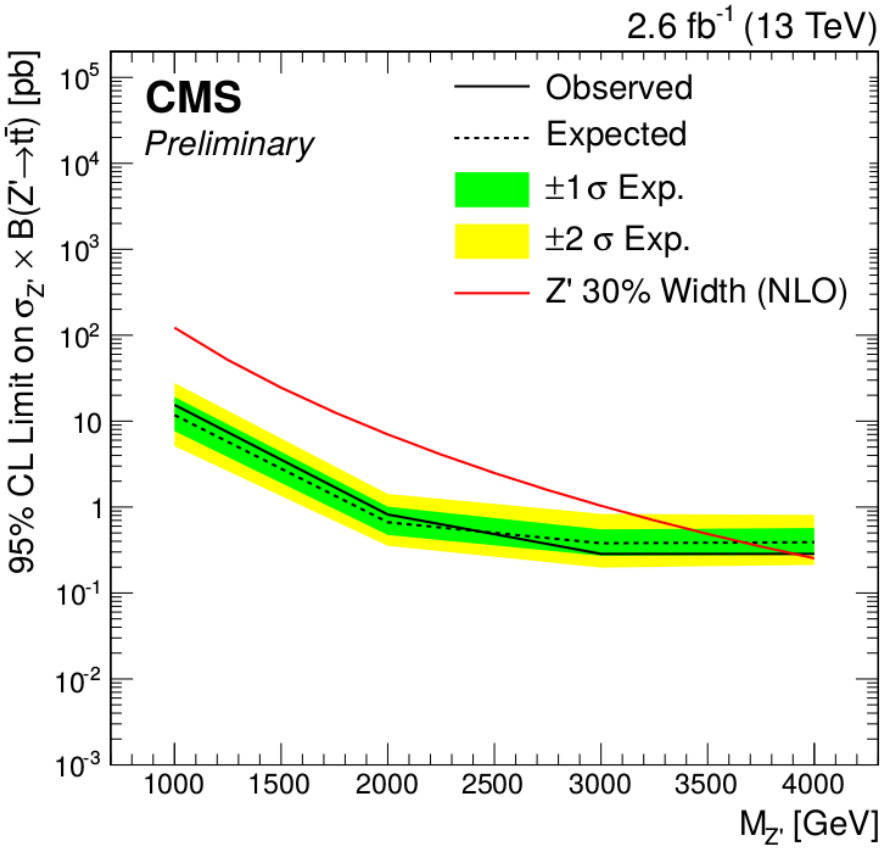


hadronic ttbar



Signal regions :	$\Delta y(j_1,j_2) < 1.0$	⊗	0 b-tag
	$\Delta y(j_1,j_2) > 1.0$		1 b-tag
			2 b-tags

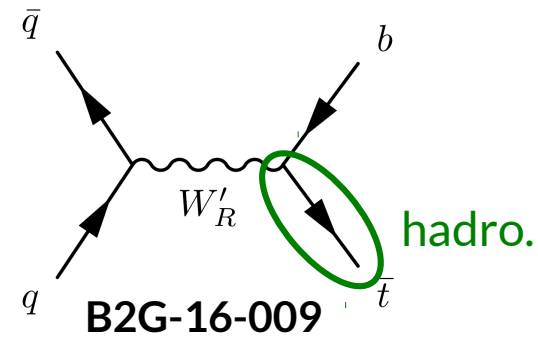
- **Fit** of the **ttbar invariant mass** distribution in signal region.



Signal	Observed exclusion
Narrow Z' (1%)	[1.4 – 1.6] TeV
Wide Z' (10%)	[1.0 – 3.3] TeV
Extra wide Z' (30%)	[1.0 – 3.8] TeV
KK gluon	[1.0 – 2.4] TeV

W' resonances

hadronic W' → tb

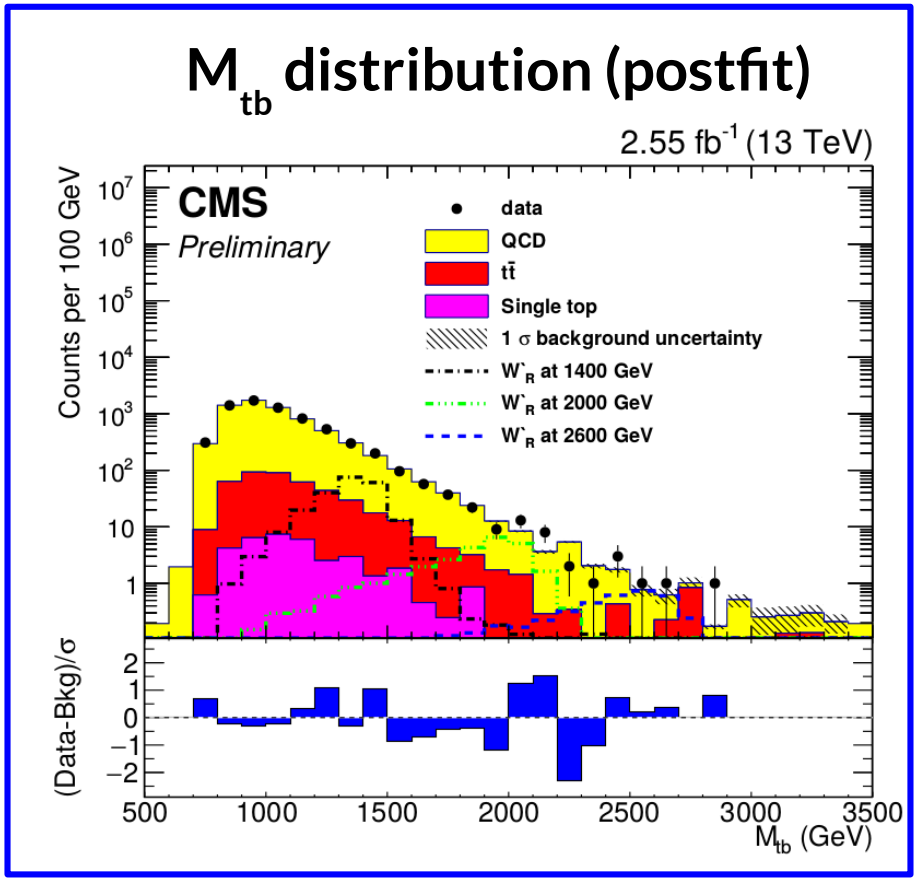


→ Only right-handed interaction searched for
→ W'_R resonance with narrow width (3%)

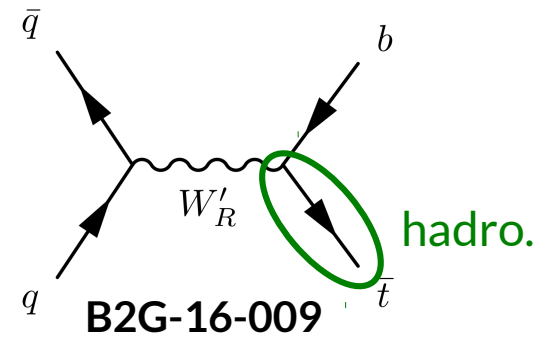
- top-tagging **(AK8 jets)** : (0.3 % mistag)
- b-tagging **(AK4 jets) : loose** WP (10 % mistag)

- Event selection :
  - → ≥ 2 high-p_T jets,
  - → 1 t-tagged AK8 jet,
  - → 1 b-tagged AK4 jet with m_{SD} < 70 GeV,
  - → $|\Delta\varphi(j_1, j_2)| > \pi/2$ rad,
  - → $|\Delta y(j_1, j_2)| < 1.3$.

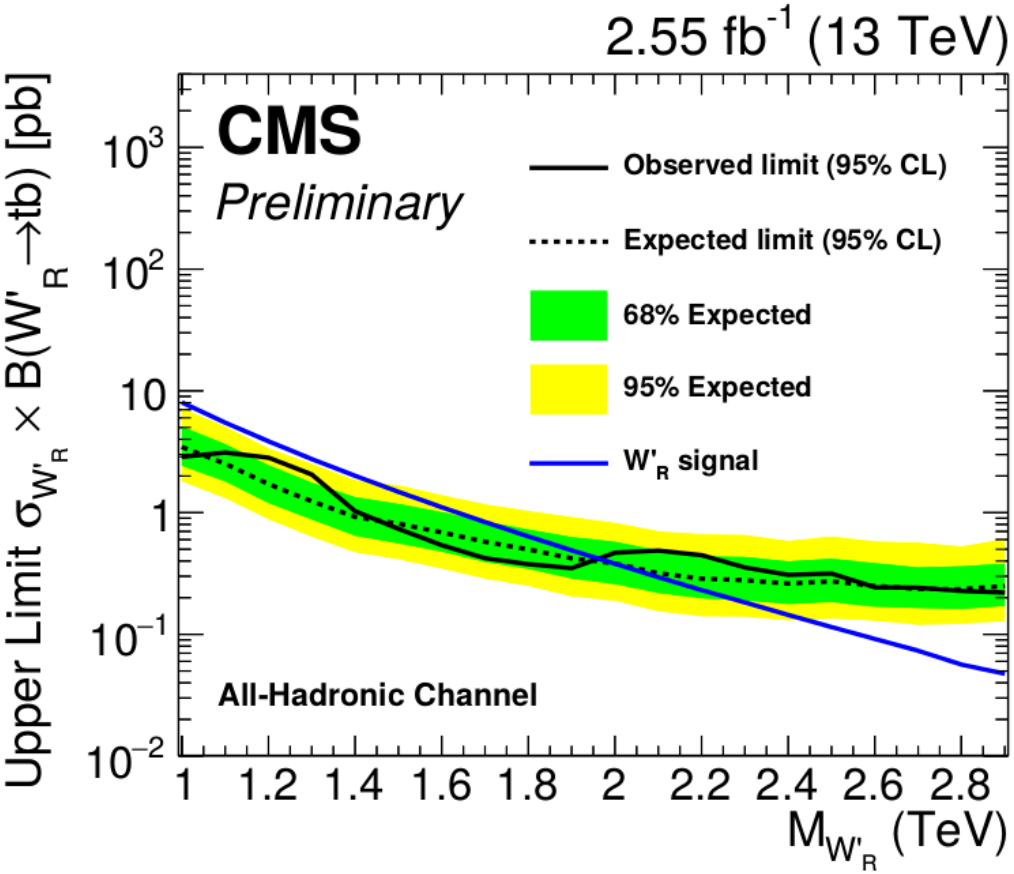
- QCD multijet estimated from data



hadronic W' → tb



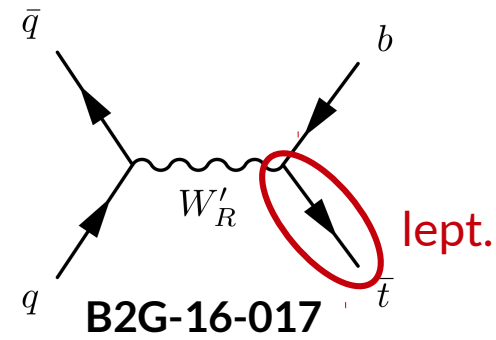
- **Fit** of the **tb invariant mass** distribution in signal region.
- Results :



Signal	Observed exclusion
Narrow W'	[1.0 – 2.0] TeV

leptonic W' → tb

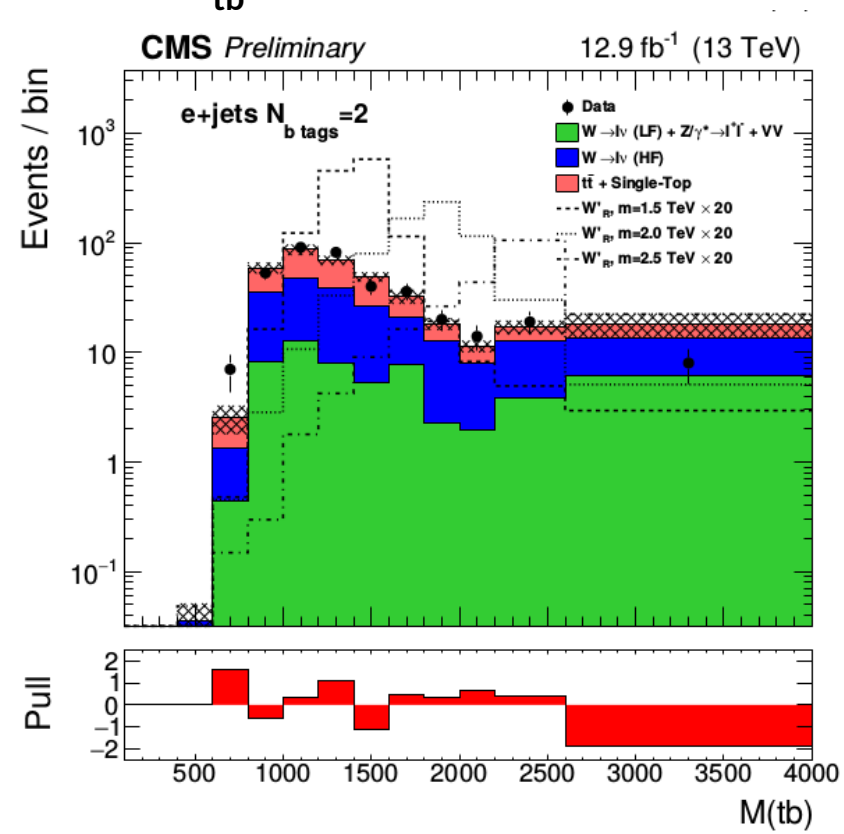
12.9 fb^{-1} of 2016 data



→ Only right-handed interaction searched for
→ W'$_R$ resonance with narrow width
→ Same analysis strategy as B2G-15-004
(one of the first 2015 analysis to come out)

- b-tagging **(AK4 jets) :** medium WP (1 % mistag)
- μ/e channel :
  - → exactly 1 high-p_T μ/e,
  - → ≥ 2 high-p_T AK4 jets,
  - → ≥ 1 b-tagged jet,
  - → MET > 50 (120) GeV,
  - → 2D rejection cut :
    - ΔR (μ/e, j) > 0.4
    - **or**
    - p_T^{rel} (μ/e, j) > 50 (60) GeV,
  - → $p_T(j_1+j_2)$ > 350 GeV, p_T(reco. top) > 250 GeV.

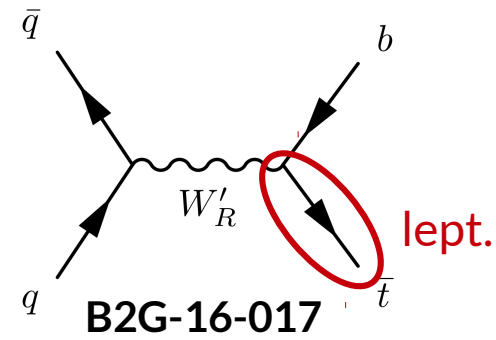
M_{tb} (e channel, 2 b-tags)



Note : pull = (data-background)/σ

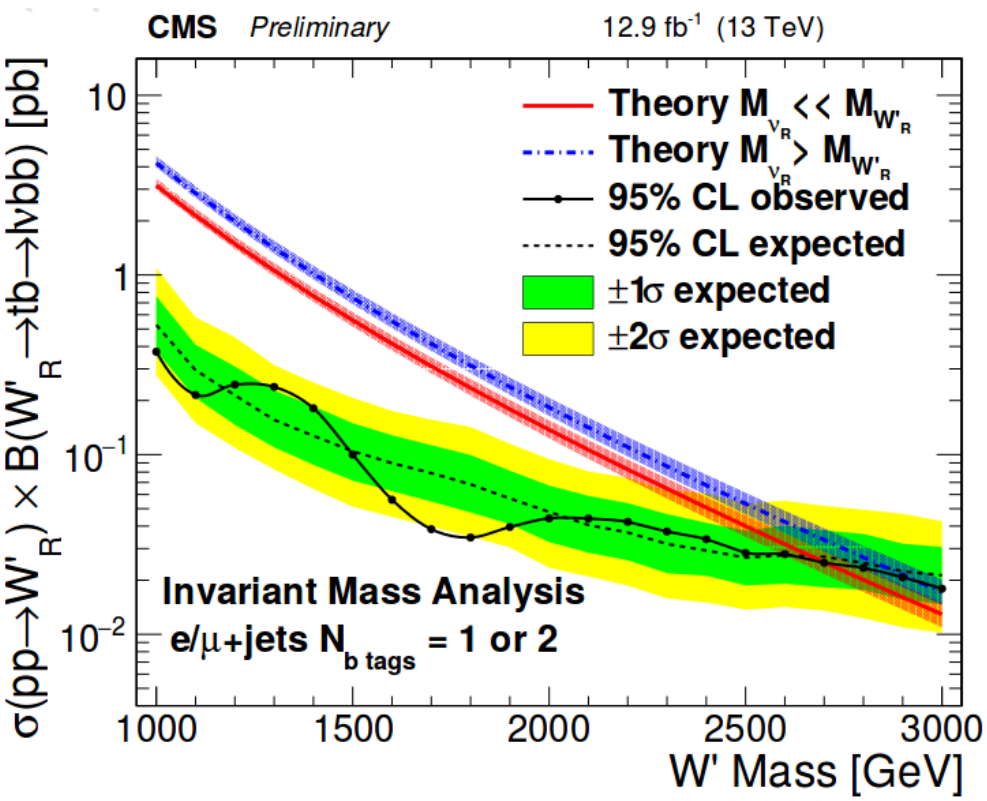
leptonic W' → tb

12.9 fb^{-1} of 2016 data



Signal regions : μ/e channel ⊗ 1 b-tag / 2 b-tags

- **Fit** of the **tb invariant mass** distribution in signal region.



Signal	Observed exclusion
Narrow W'	[1.0 – 2.67] TeV

(+ 12 % w.r.t. B2G-15-004)

Conclusion

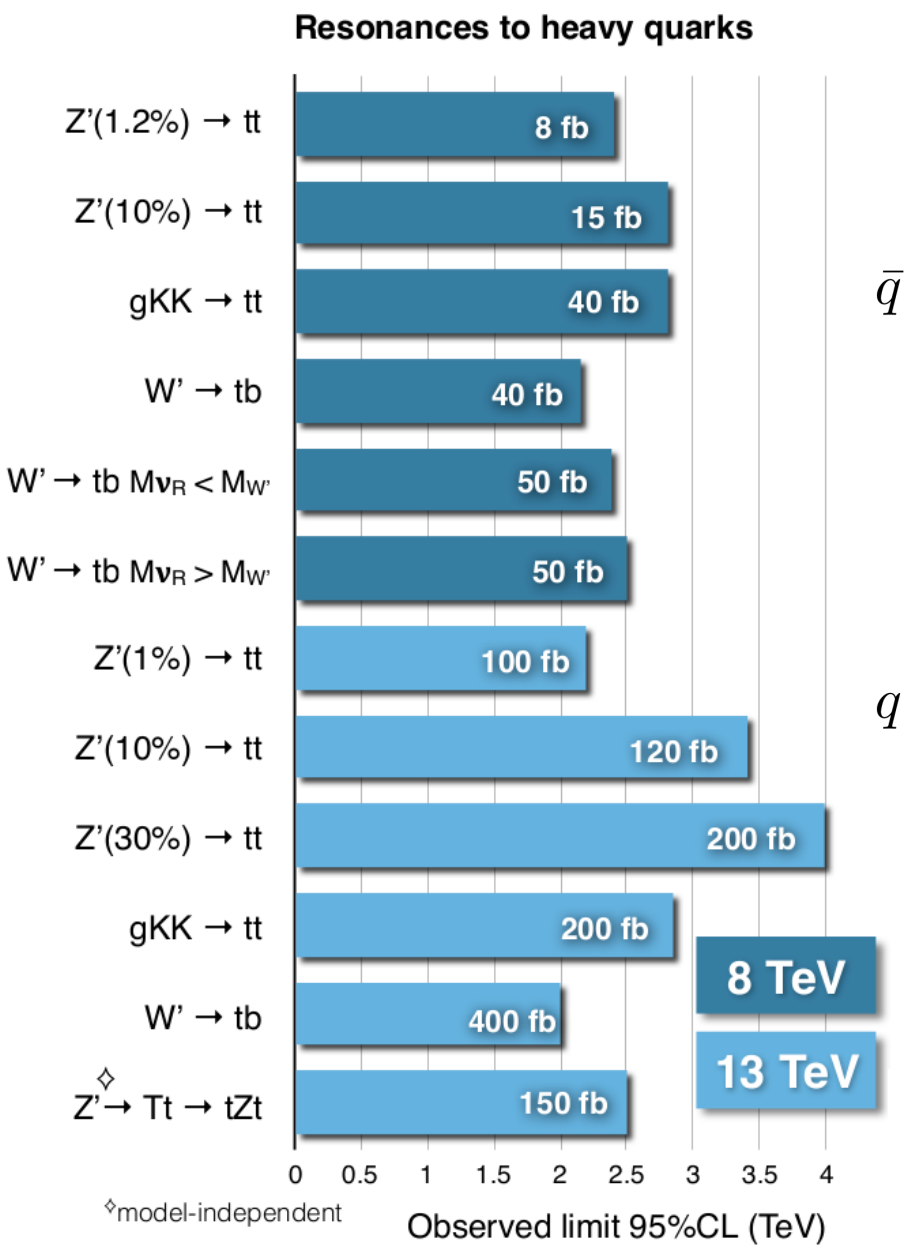
- Many new heavy resonances searched for at CMS !!
    - Z' → ttbar (semileptonic and hadronic channels)
    - W' → tb (leptonic and hadronic channels)
- No sign of new physics
- Run II (2015) data already provide competitive results w.r.t. Run I
- Hadronic/leptonic combination already ongoing !
- Run II (2016) data already under process and more data coming … stay tuned !

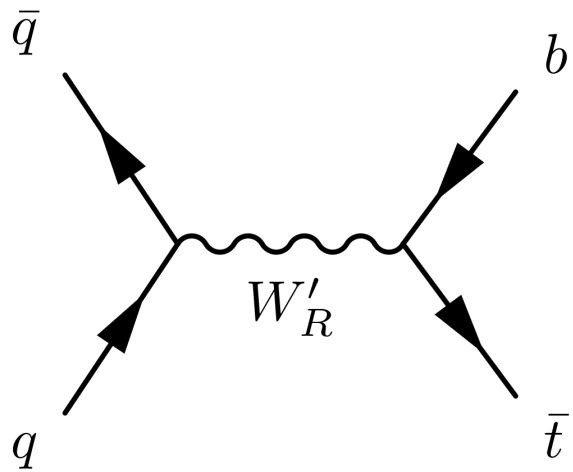
Thank you for your attention !

Any question ?

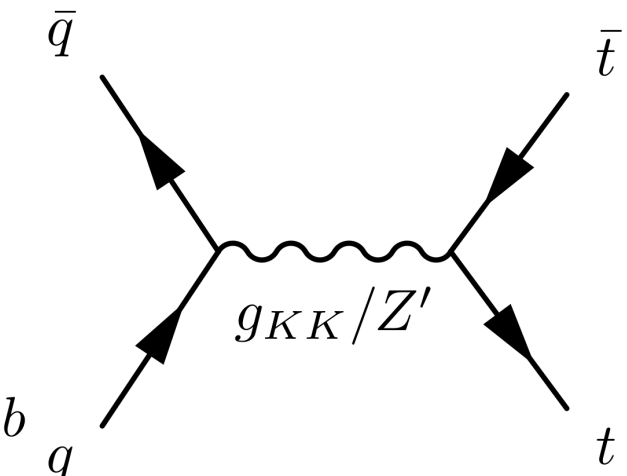
Back up

Introduction

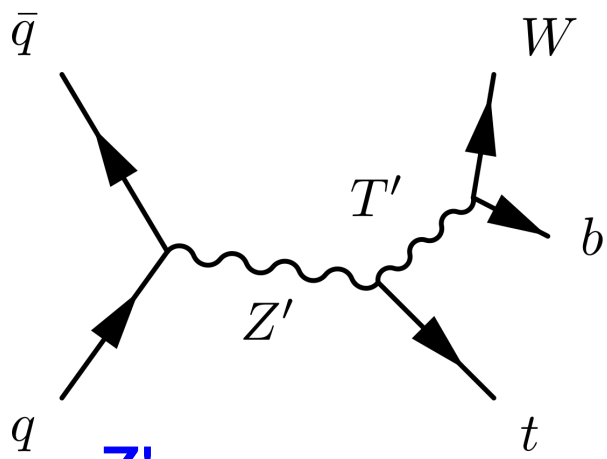




W' resonance



ttbar resonance



Z' resonance

Top-tagging

n-subjettiness

- Jet shape variable that measures the compatibility of a jet with the hypothesis that it is composed of N subjets :

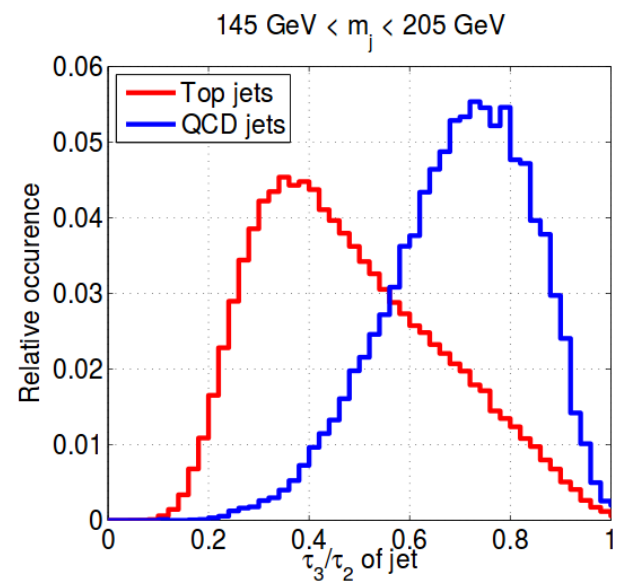
$$\tau_N = \frac{1}{d_0} \sum_k p_T(k) \times \Delta R_k^{\min} \quad \text{with} \quad d_0 \equiv \sum_k p_T(k) \times R$$

p_T of constitutent k

distance between constitutent k and axis of closest subjet

large-R jet distance parameter

- **$\tau_{32} = \tau_3/\tau_2$**: helps to discriminate 3-prong subjets structure (top) from non-top jets.



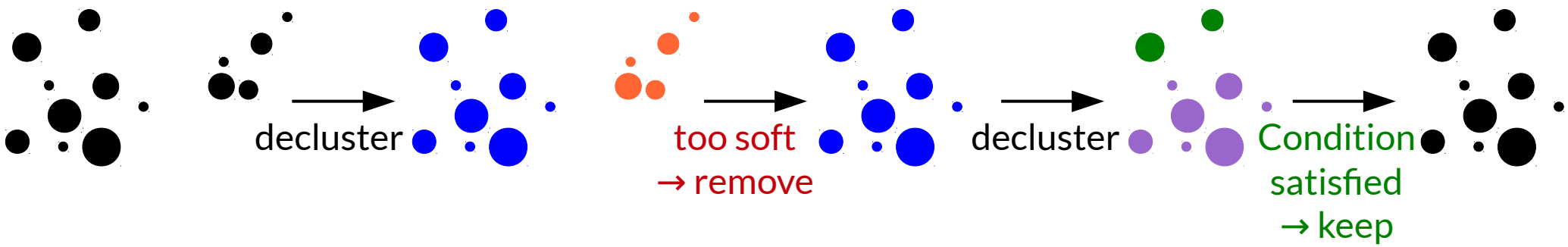
JHEP **1103** (2011) 015

Top-tagging

soft-drop algorithm

- Recursively decluster jet. Remove the softer conponent unless the soft drop is satisfied.

$$\text{Soft Drop Condition}: \frac{\min(p_{T1}, p_{T2})}{p_{T1} + p_{T2}} > z_{\text{cut}} \left(\frac{\Delta R_{12}}{R_0}\right)^{\beta}$$

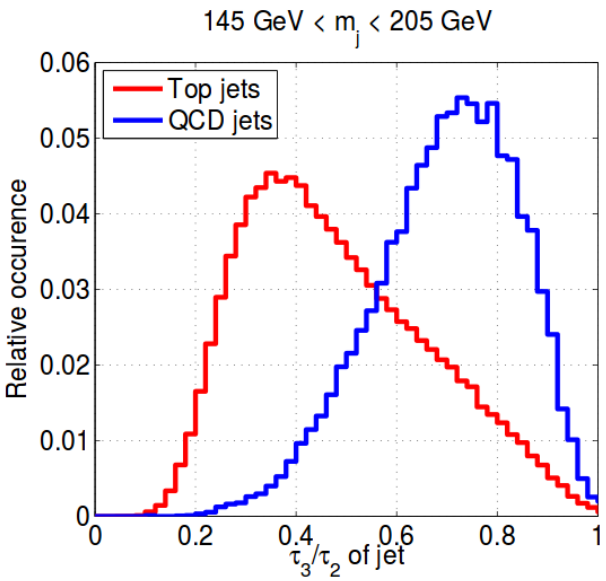


(J. Dolen)

- In the analyses presented in this talk : z_{cut} = 0.1 and β = 0.

Dealing with boosted objects...

- Top-tagging with AK8 jets



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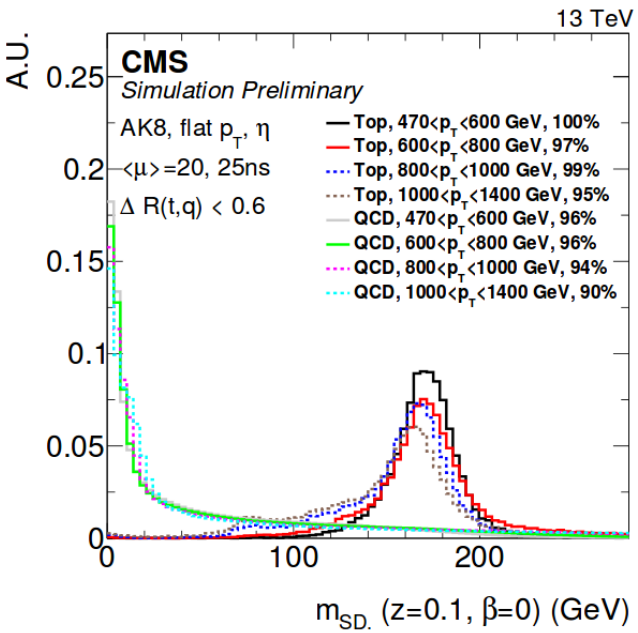

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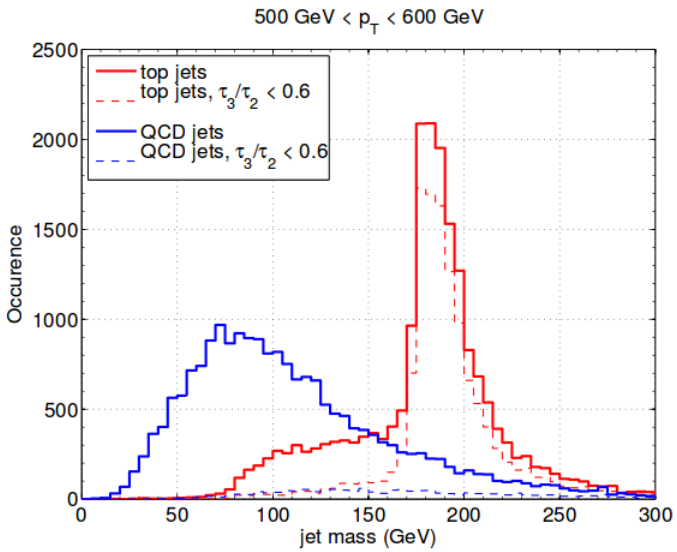
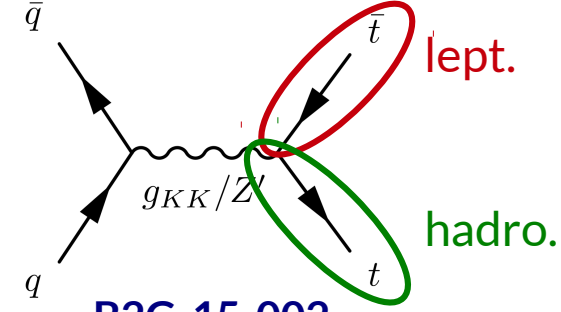


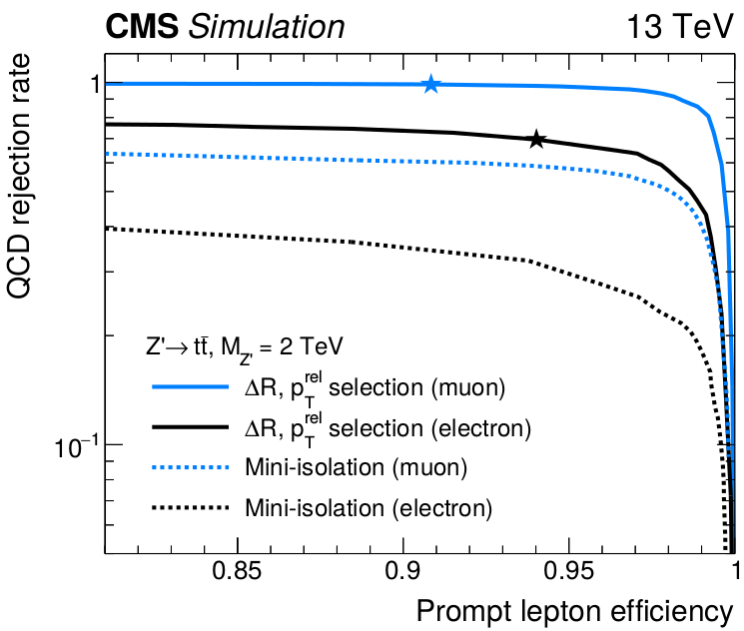
JHEP 02 (2012) 093

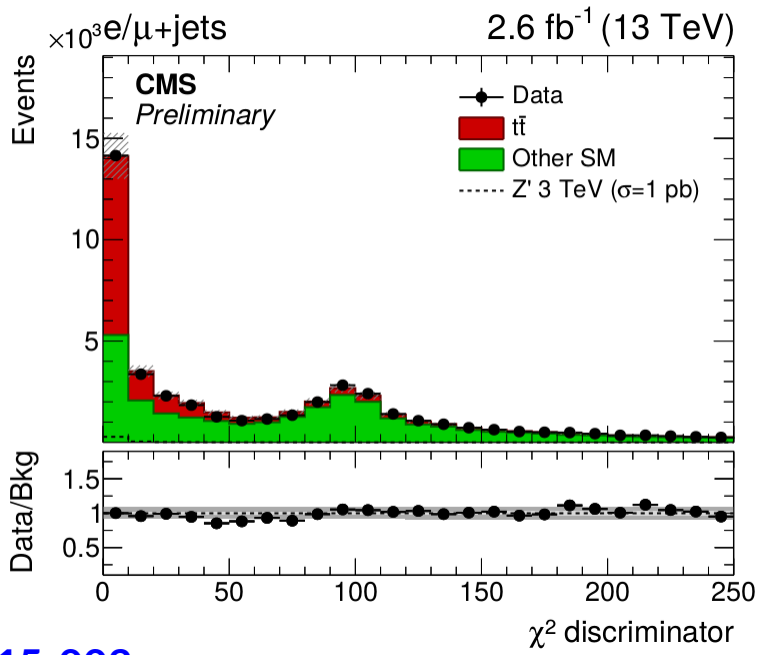
semileptonic ttbar



B2G-15-002

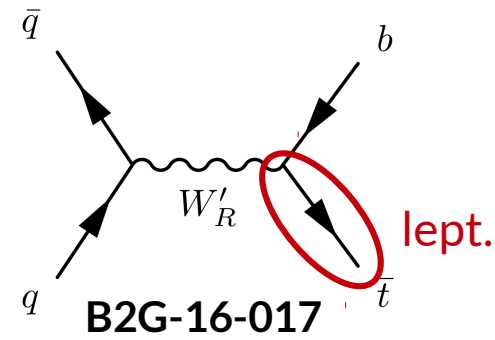
- **μ/e** channel :
  - → exactly 1**μ/e** : p_T > 50 GeV, |η|< 2.1 (2.5),
  - → ≥ 2 AK4 jets : |η|<2.4, $p_T(j_1)$ > 150 (250) GeV, $p_T(j_2)$ > 50 (70) GeV,
  - → MET > 50 (120) GeV, MET + p_T (μ) >150 GeV,
  - → 2D rejection cut : ΔR (μ/e, j) > 0.4 **or** p_T^{rel} (μ/e, j) > 20 GeV,
  - → ttbar system reconstruction : $\chi^2 < 30$ with $\chi^2 = [\frac{M_{top}^{lep} - \bar{m}_{top}^{lep}}{\sigma_M^{lep}}]^2 + [\frac{M_{top}^{had} - \bar{m}_{top}^{had}}{\sigma_M^{had}}]^2$.





CMS-PAS-B2G-15-002

leptonic W' → tb

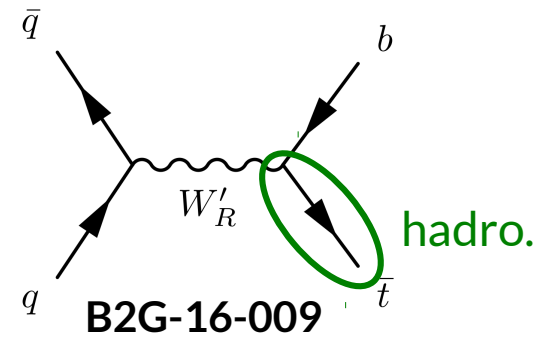


→ Only right-handed interaction searched for
→ W'_R resonance with narrow width

- CMS btagger **(AK4 jets) :** medium WP of CSV algorithm

- **μ**/**e** channel :
  - → exactly 1**μ**/**e** : p_T > 180 GeV, |η|< 2.1 (2.5),
  - → ≥ 2 AK4 jets : |η|<2.4, p_T (j_1) > 350 (450) GeV, p_T (j_2) > 30 GeV,
  - → ≥ 1 b-tagged jet,
  - → MET > 50 (120) GeV, |Δφ(MET,e)| < 2 rad,
  - → 2D rejection cut : ΔR (μ/e, j) > 0.4 **or** p_T^{rel} (μ/e, j) > 50 (60) GeV,
  - → $p_T(j_1+j_2)$ > 350 GeV,
  - → p_T(reconstructed top) > 250 GeV, 100 < m_{top} < 250 GeV.

hadronic W' → tb



→ Only right-handed interaction searched for
→ W'_R resonance with narrow width (3%)

- top-tagging **(AK8 jets)** : **τ_{32} < 0.61** and **110 < m_{SD} < 210 GeV** (0.3 % mistag)
- b-tagging **(AK4 jets) : loose** WP (10 % mistag)

- Event selection :
  - → H_T > 800 GeV (trigger),
  - → ≥ 2 jets : $|\eta|$< 2.4, p_T > 350 GeV,
  - → 1 t-tagged AK8 jet : $|\eta|$< 2.4, p_T > 350 GeV,
  - → 1 b-tagged AK4 jet : $|\eta|$<2.4, p_T > 350 GeV, m_{SD} > 70 GeV,
  - → $|\Delta\varphi(j_1, j_2)|$ > π /2 rad,
  - → $|\Delta y(j_1, j_2)|$ < 1.3.

- QCD multijet estimated from data