Searches for Heavy Resonances with CMS

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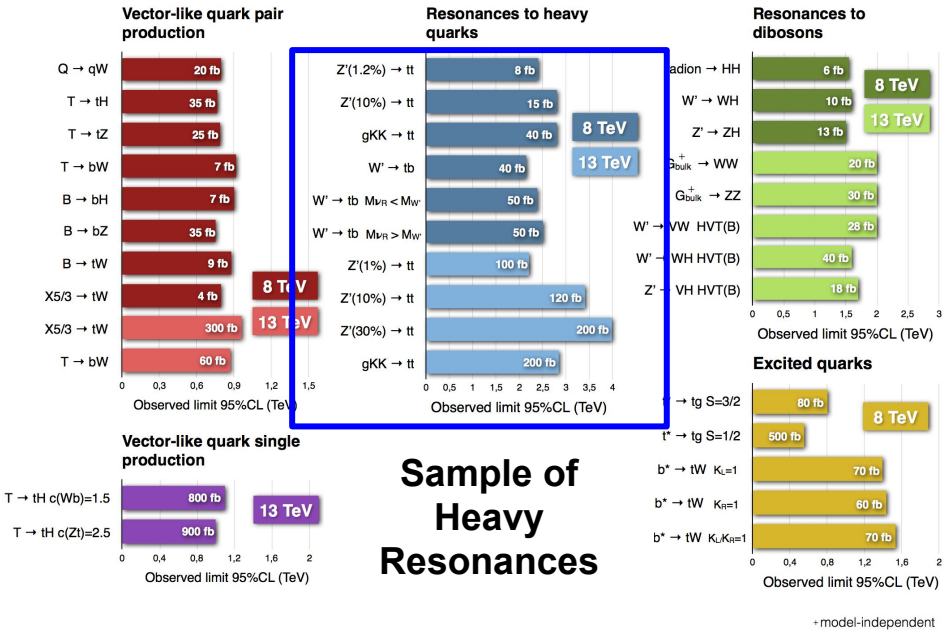
Heavy Resonances at CMS

- Heavy resonances theorized in BSM physics
  - Little Higgs, extra dimensions, etc.
- Focus:
  - W' → lepton + MET
  - Z' → $\tau\tau$
  - top pair resonances
- Up to 2.6 fb^{-1} of 13 TeV data
- Lastest identification techniques for higher energy decay products
  - E.g. jet substructure

D. Marley (CMS & ATLAS)

J. Damgov (CMS)
K. Gregersen (ATLAS)



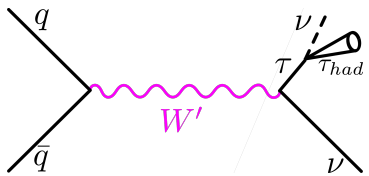
Sample of Heavy Resonances

See Also:

- SUSY: J. Schulte
- Exotics: A. Schmidt, A. Hinzmann, G. Fasanella, M. Chelstowska, R. Nandakumar, Y. Okumura
- Higgs: H. Ohman, M. Pickering, A. Tuna, A. De Wit

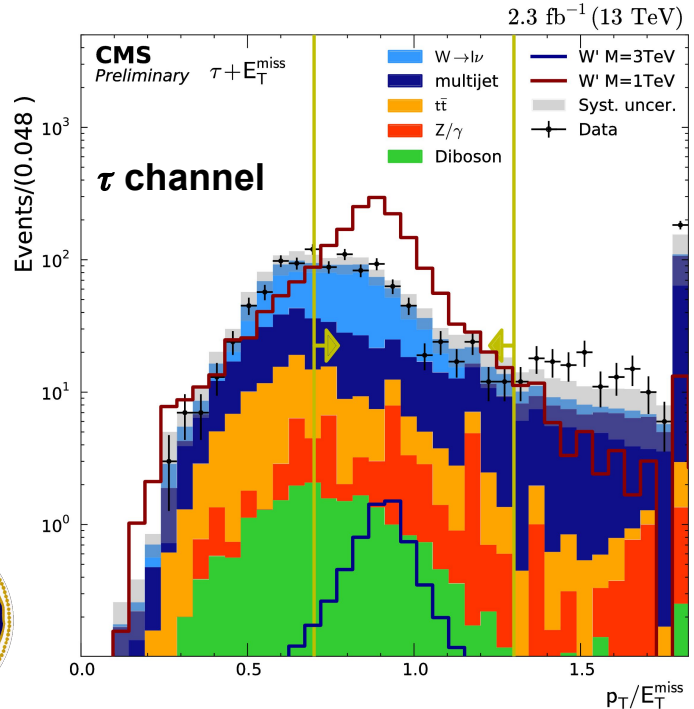
W'→ lepton + MET

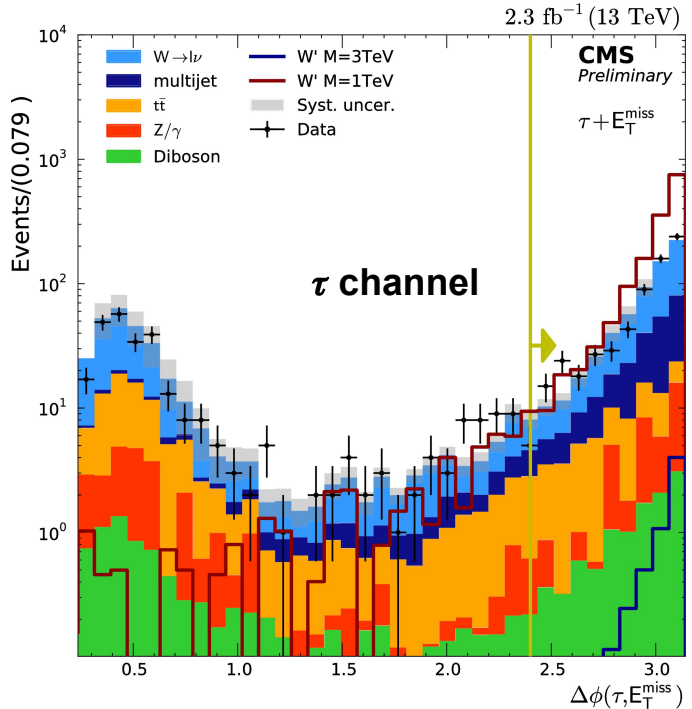
- μ, e, and τ_h channels
  - Look for a high p_T lepton and missing energy



τ channel

- Background rejection
  - $\Delta\phi(p_T^{lep}, p_T^{miss})$ and p_T^{lep}/E_T^{miss} cuts
  - Veto other high p_T leptons
  - QCD estimated from data

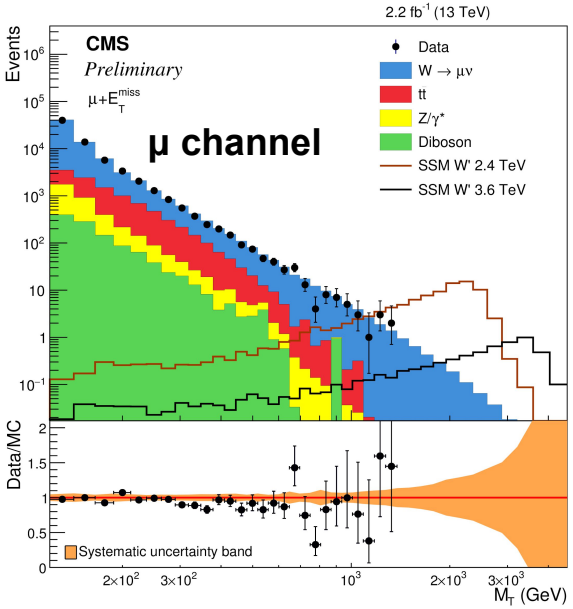


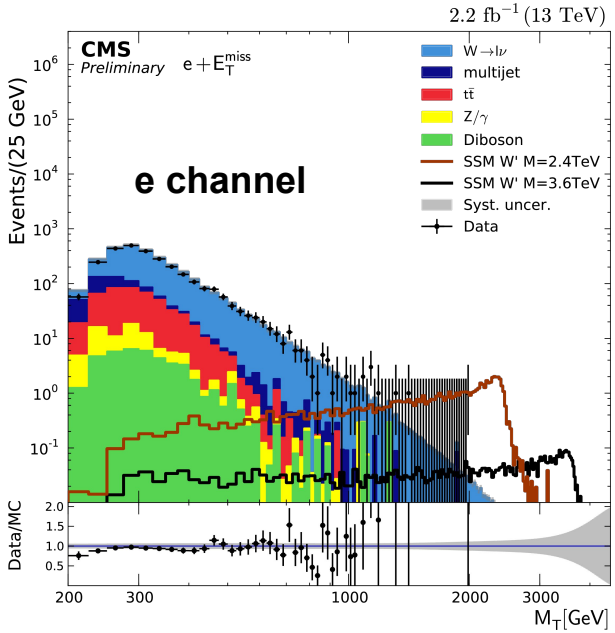


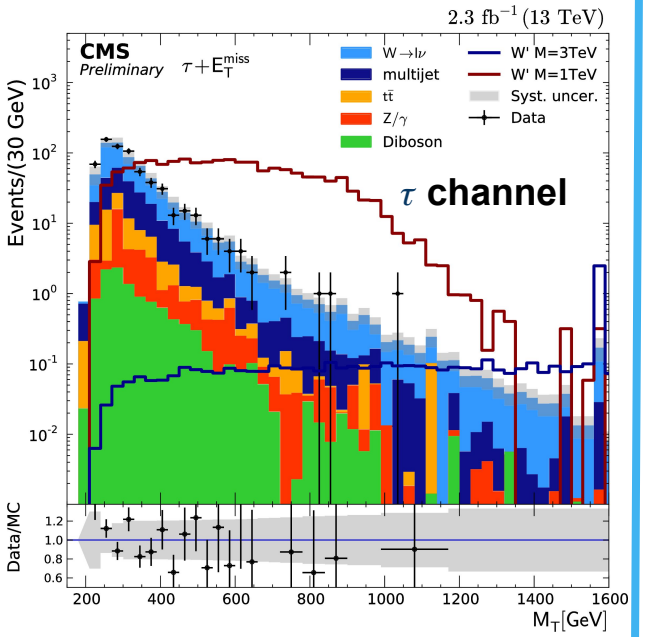
W'→ lepton + MET

- Good discrimination with sensitive variable:

$$M_T = \sqrt{2 p_T^l E_T^{miss} (1 - \cos[\Delta\phi(\vec{p}_T^{\,l}, \vec{p}_T^{\,miss})])}$$

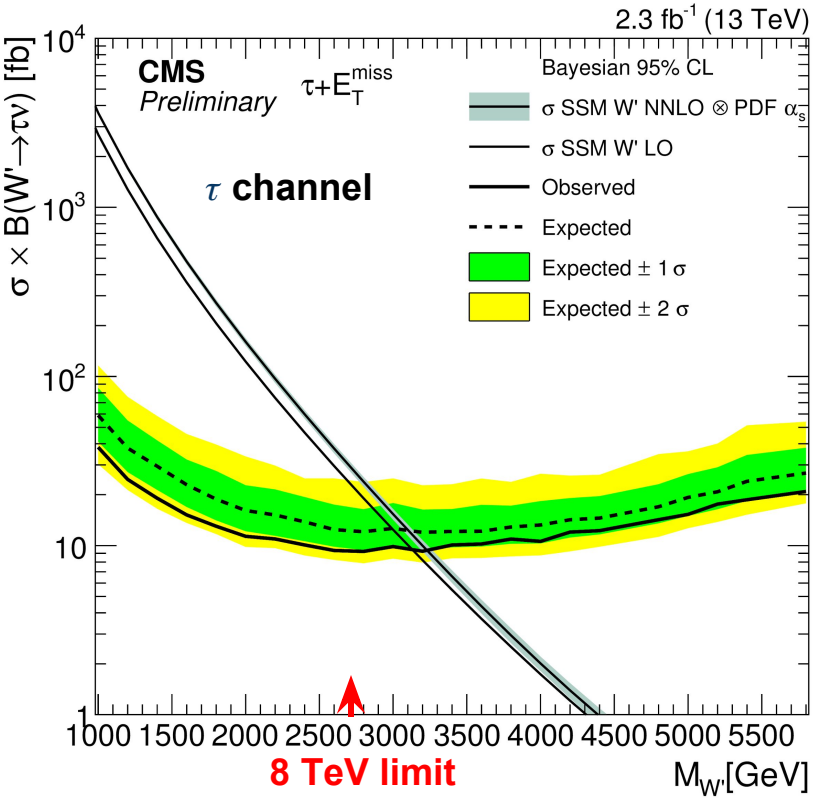


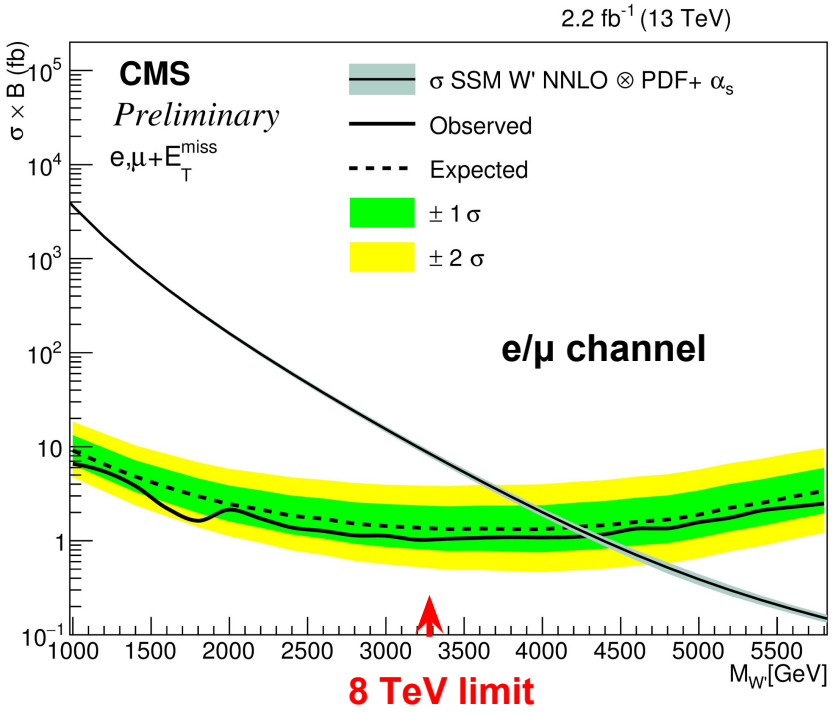




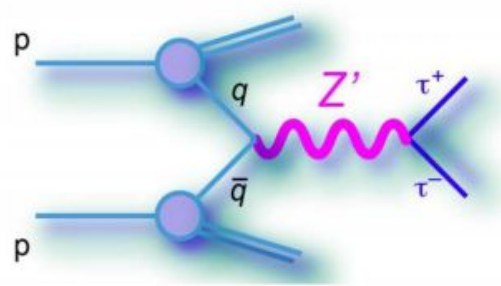
W'→ lepton + MET

- Improved limits since Run I
  - e/μ: 4.4 TeV with 2.2 fb^{-1} of data; previously 3.28 TeV
  - τ: 3.3 TeV with 2.3 fb^{-1} of data; previously 2.7 TeV



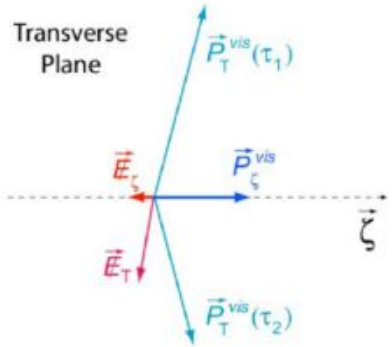


Z' → ττ



- Z' coupling preferentially to 3rd gen.
- $\tau_h\tau_h$, $\tau_e\tau_h$, $\tau_\mu\tau_h$, $\tau_e\tau_\mu$ channels

- Selection:
  - High p_T lepton
  - E_T^{miss} > 30 GeV
  - Back-to-back τ events:
    - τ_e/τ_μ: isolated lepton
    - $\cos\Delta\phi(\tau_1,\tau_2)$ < - 0.95
    - p_ζ - 3.1*p_ζ^{vis} > - 50 GeV

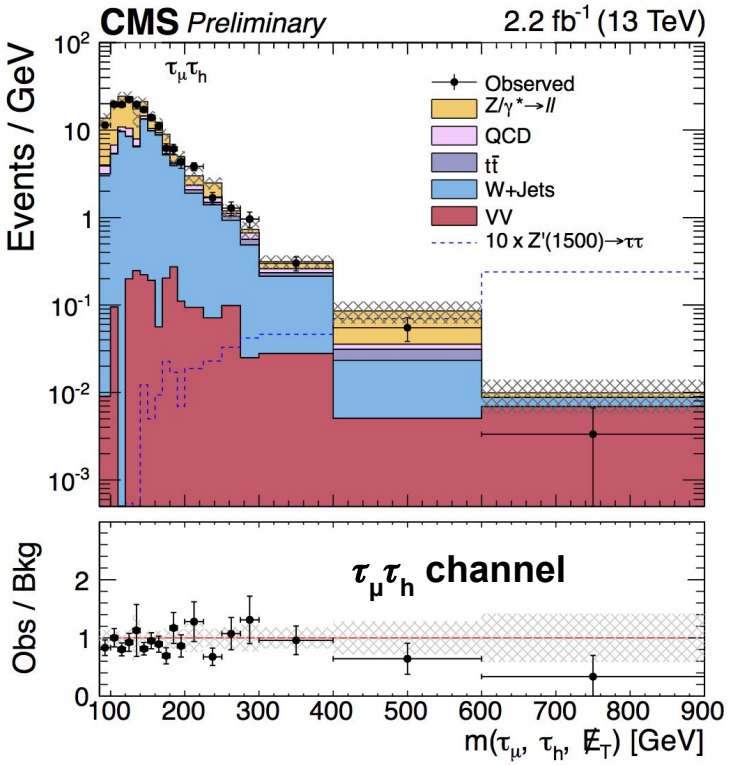


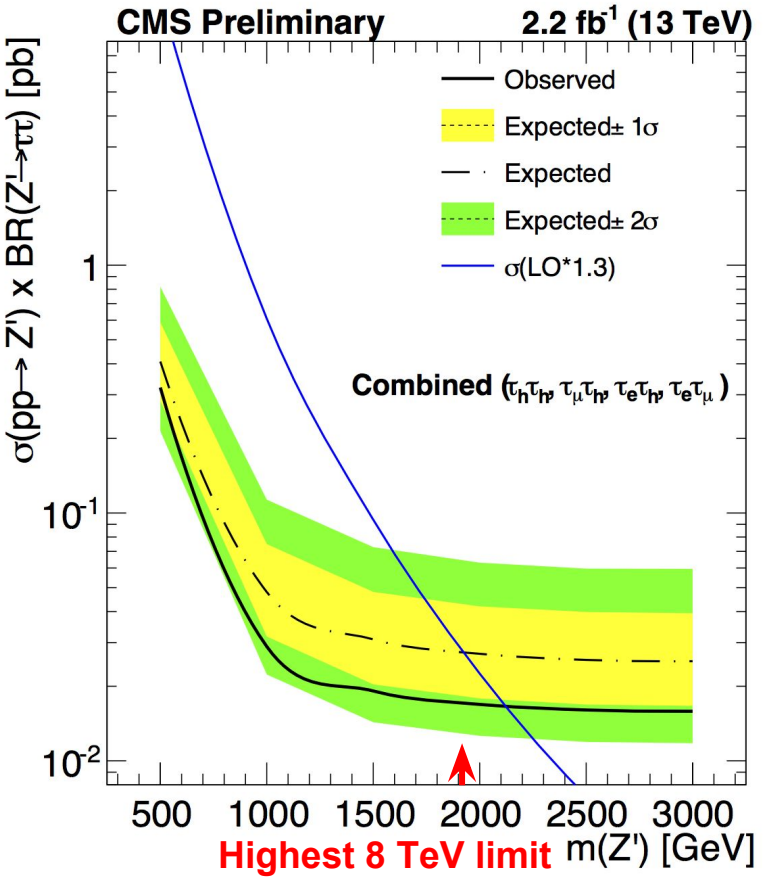
$$p_\zeta^{vis} = (\vec{p}_T^{\tau_1} + \vec{p}_T^{\tau_2}) \cdot \hat{\zeta}$$
$$p_\zeta = (\vec{p}_T^{\tau_1} + \vec{p}_T^{\tau_2} + \vec{\not{E}}_T) \cdot \hat{\zeta}$$

- Backgrounds
  - QCD, W + jets, DY + jets estimated from data
  - ttbar - require 0 b-tagged jets

$Z' \rightarrow \tau\tau$

- Sensitive variable: $m(\tau_1, \tau_2, \not{E}_T) = \sqrt{(E_{\tau_1} + E_{\tau_2} + \not{E}_T)^2 - (\vec{p}_{\tau_1} + \vec{p}_{\tau_2} + \vec{\not{E}}_T)^2}$
  - Look for broad signal peak
- Strictest limits set so far!
  - First 13 TeV exotic $\tau\tau$ results!





CMS-PAS-EXO-16-008

Top Pair Resonances

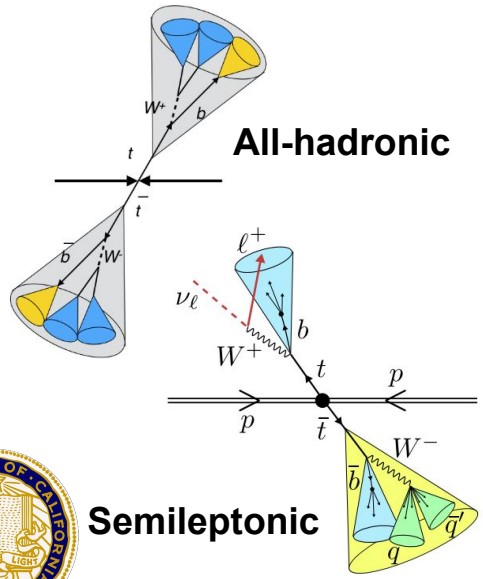
- Event categories
  - All-hadronic:

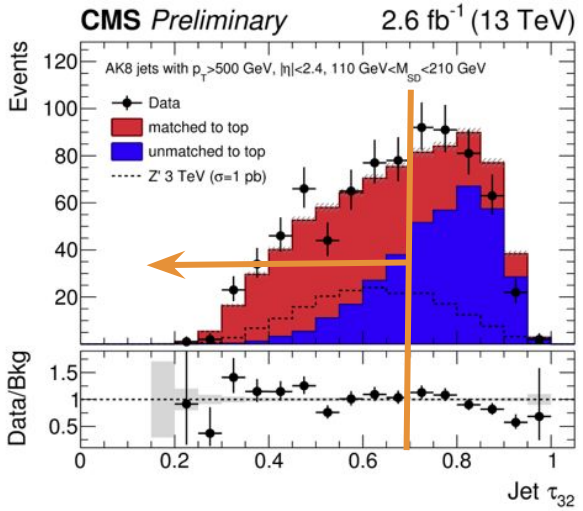
2 top-tags ⊗ Δy < 1.0 / Δy > 1.0 ⊗ 0 b-tags / 1 b-tag / 2 b-tags

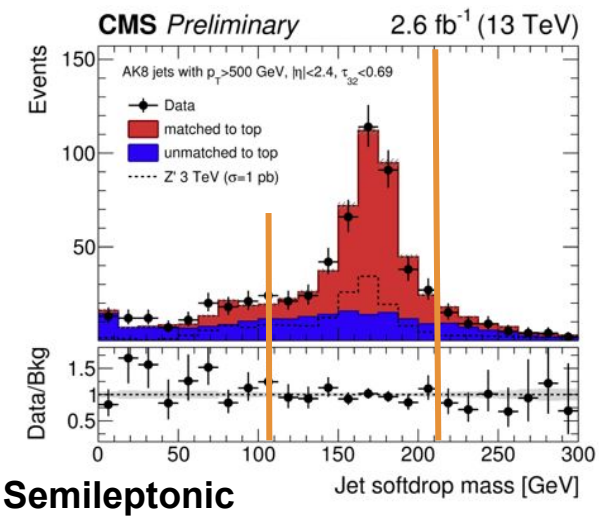
  - Semileptonic:

μ/e + jets ⊗ 1 top-tag / 0 top-tags, 1 b-tag / 0 top-tags, 0 b-tags

- Run II t-tagging - boosted tops!
  - **Soft drop** jet mass = [110, 210] GeV
    - Removes soft and collinear radiation
  - **N-subjettiness** (τ_{32}) < 0.69
    - Distinguishes 3-prong jet substructure (top) from non-top jet



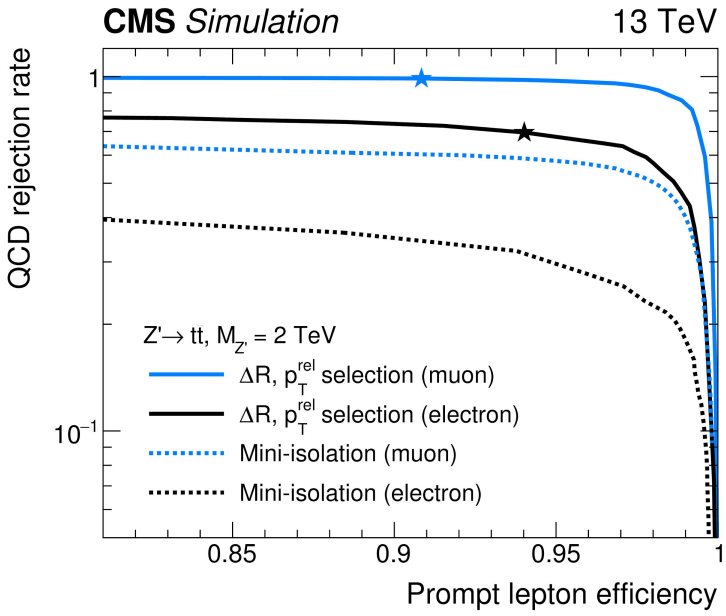


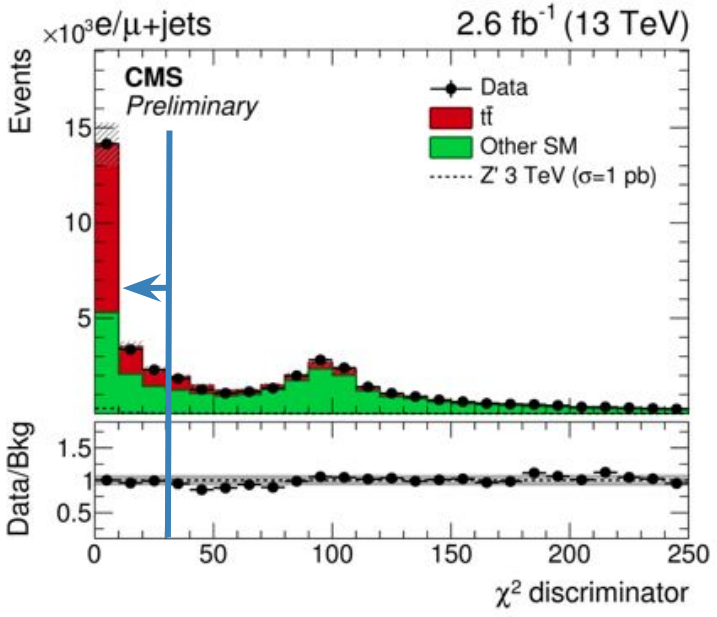


Top Pair Resonances

- All-hadronic: QCD background estimated from data
- Semileptonic background:
  - ttbar, W + jets, single top, Drell-Yan + jets, VV, QCD
  - Rejection methods
    - $\Delta R_{min}(l,j) > 0.4$ || $p_{T,rel}(l,j) > 20$ GeV
    - $X^2 < 30$

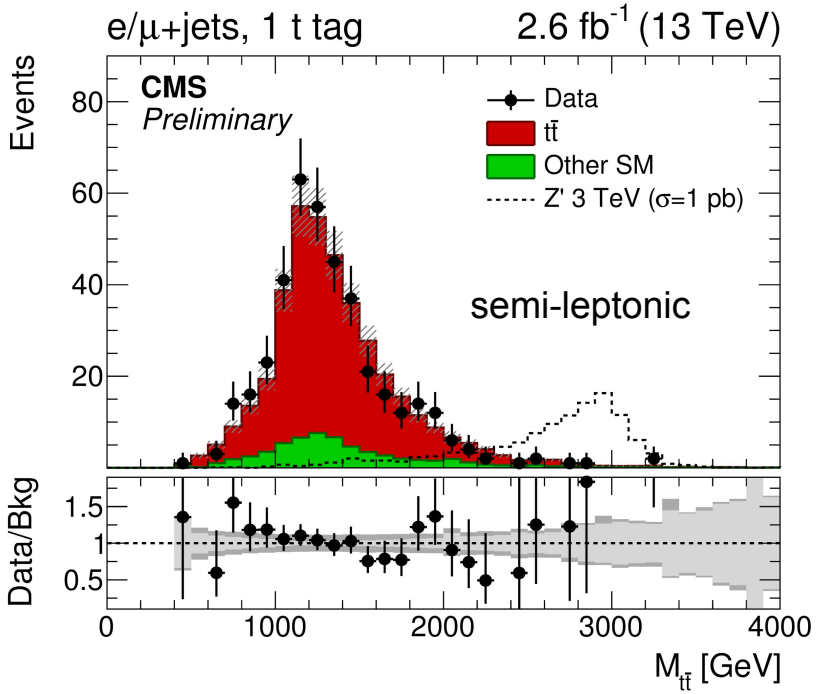
$$\chi^2 = \left[\frac{M_{top}^{lep} - \bar{m}_{top}^{lep}}{\sigma_M^{lep}}\right]^2 + \left[\frac{M_{top}^{had} - \bar{m}_{top}^{had}}{\sigma_M^{had}}\right]^2$$

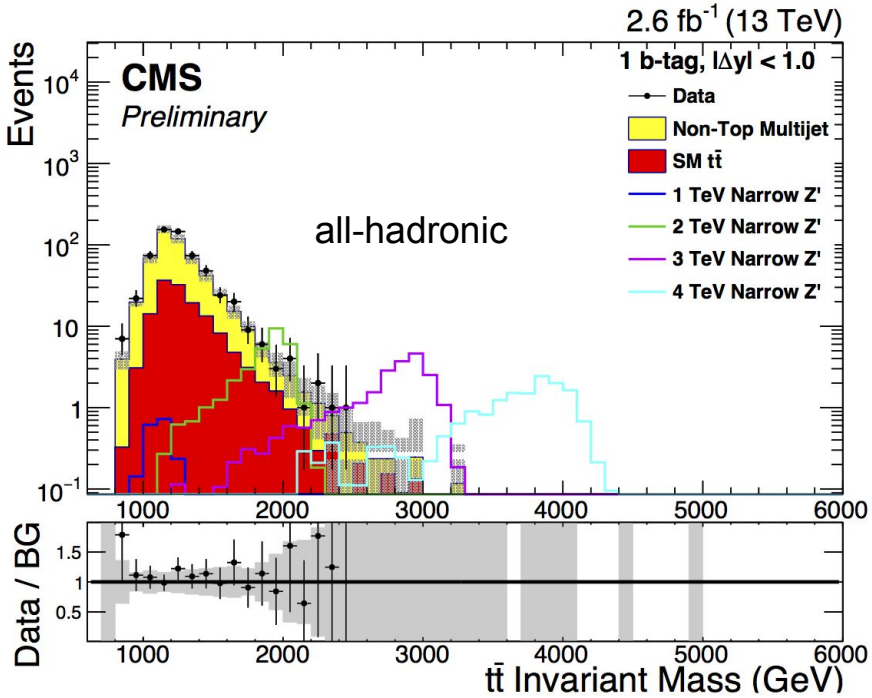




Top Pair Resonances

- Sensitive variable: ttbar invariant mass

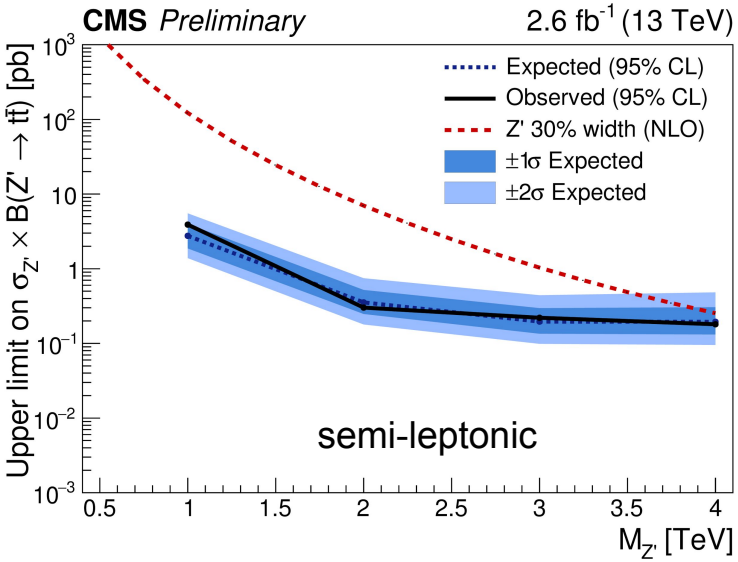


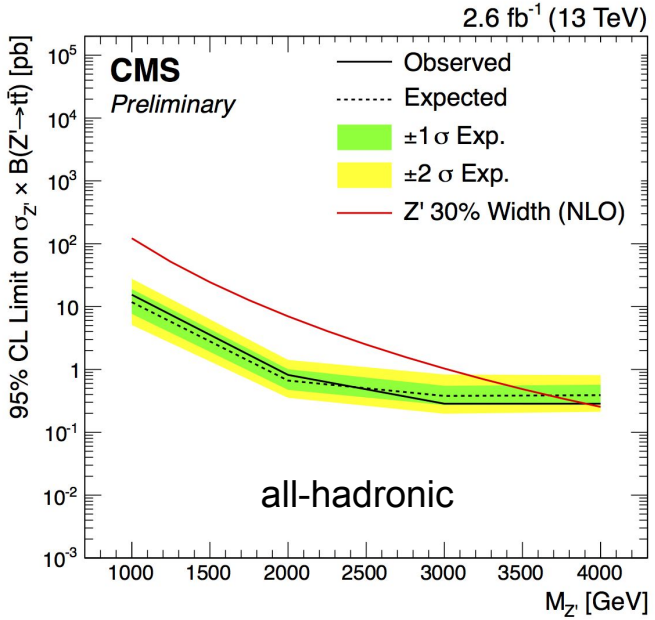


Top Pair Resonances

- g_{KK}; Z' Γ= 1%, 10%, NEW: 30%
- Stricter limits with 2.6 fb^{-1} of data!

	Observed Mass Exclusions (TeV)	
Model	All-Hadronic	Semileptonic
Narrow Z' (1%)	*1.4 - 1.6*	*0.6 - 2.3*
Wide Z' (10%)	*1.0 - 3.3*	*0.5 - 3.4*
Extra Wide Z' (30%)	*1.0 - 3.8*	*0.5 - 4.0*
RS KK Gluon	*1.0 - 2.4*	*0.5 - 2.9*





Combination coming soon!

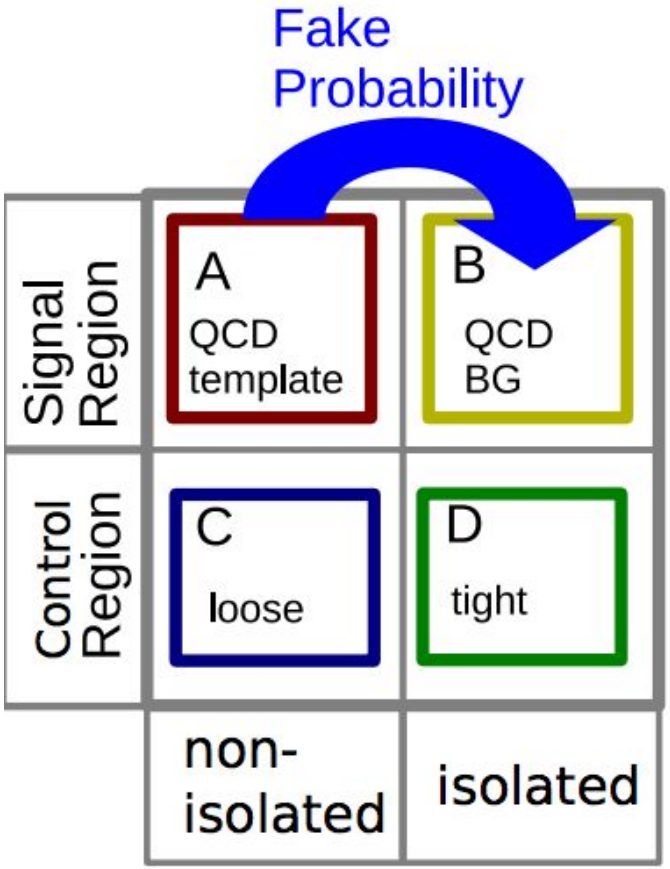
Conclusions

- Many new heavy resonance search results from CMS
  - BSM W' and Z' models
- Run II analyses setting strictest limits so far!
  - With only 10% of the 8 TeV dataset!
- No signs of new physics yet
- Looking forward to more data in 2016!

BACKUP

W'→ lepton + MET: QCD Estimation

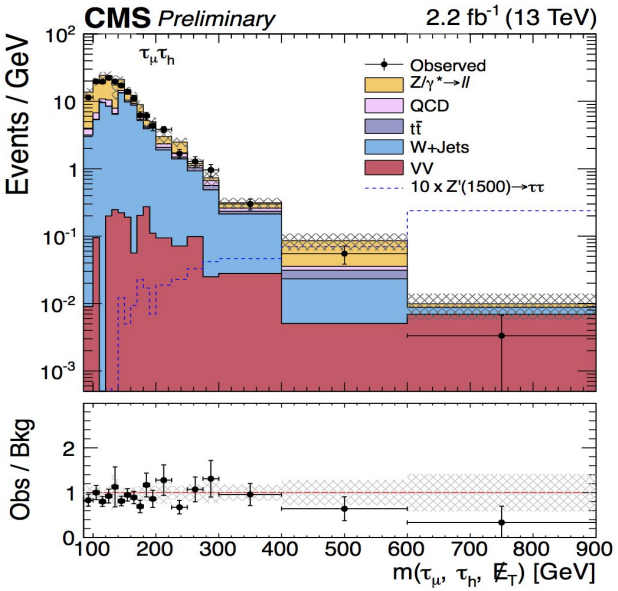
- Method:
  - P(fake) = D/C
  - QCD estimate = P(fake)*A
- Signal Region:
  - τ: one τ
  - μ/e: $0.4 < p^{lep}_T/E^{miss}_T < 1.5$
- Signal Region:
  - τ: one τ + one μ/e
  - μ/e: $0.4 < p^{lep}_T/E^{miss}_T > 1.5$



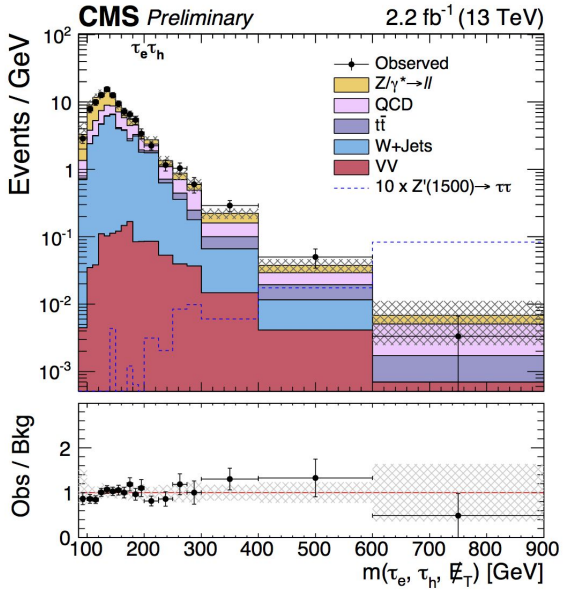
CMS-PAS-EXO-16-008

Z' → ττ: Invariant Mass Plots

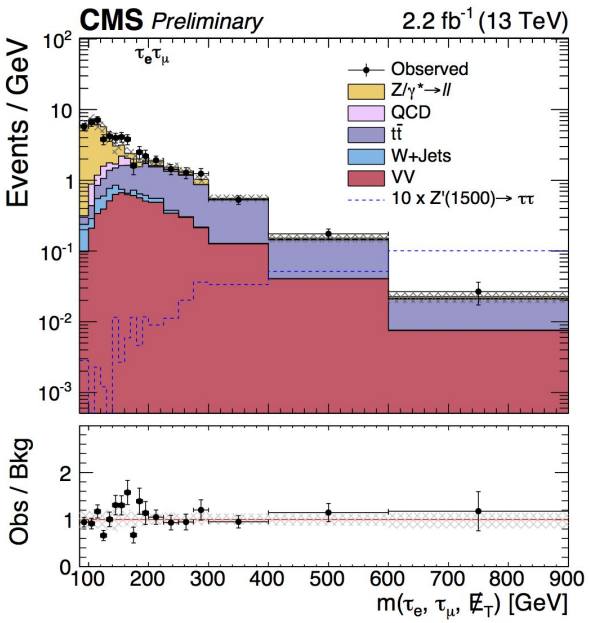
$\tau_{\mu h}$ channel



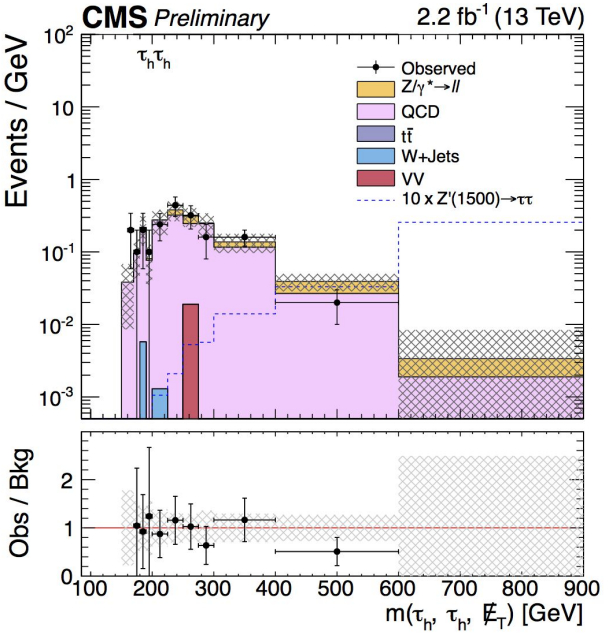
τ_{eh} channel



$\tau_{e\mu}$ channel

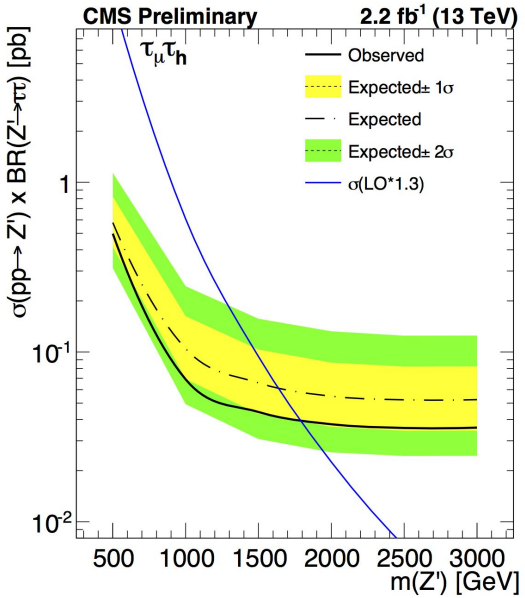


τ_{hh} channel

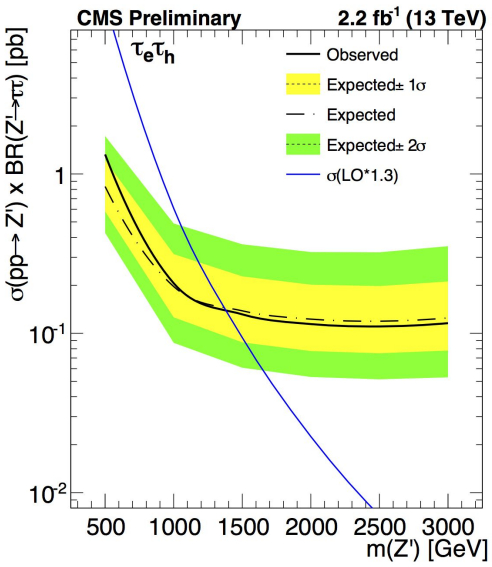


Z' → ττ: Limit Plots by Decay Channel

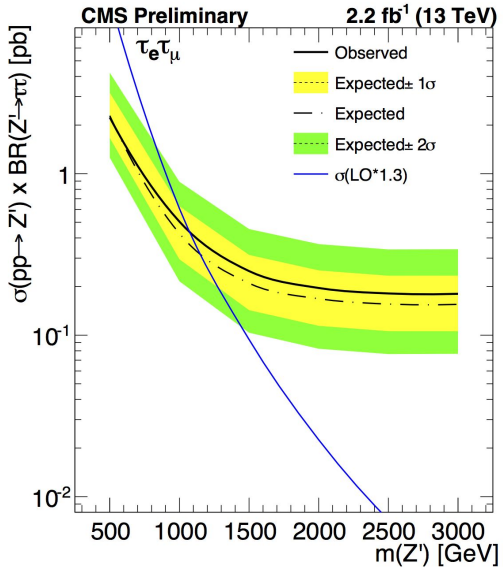
$\tau_{\mu h}$ channel



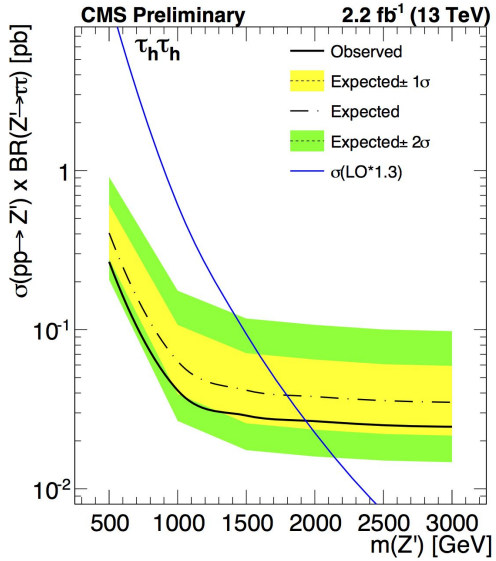
τ_{eh} channel



$\tau_{e\mu}$ channel



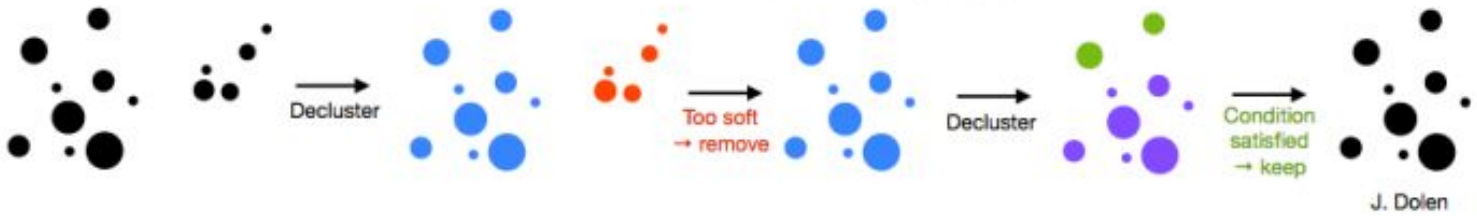
τ_{hh} channel



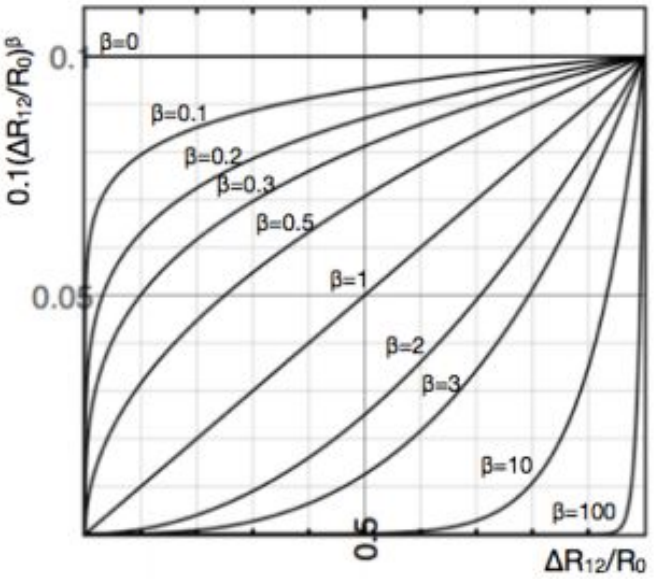
Soft Drop Algorithm

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

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



- Soft wide angle radiation fails the condition
  - As $z_{\text{cut}} \uparrow \Rightarrow$ more aggressive grooming
  - As $\beta \downarrow \Rightarrow$ more aggressive grooming
- Example ($z_{\text{cut}} = 0.1$) :
  - If $\beta = 0$, remove softer subjet if p_T fraction < 0.1 (~equivalent to MMDT)
  - If $\beta > 0$, remove softer subjet if p_T fraction < x, where x increases with ΔR and has maximum value 0.1
  - $\beta \rightarrow \infty$ no grooming
  - $\beta < 0$ soft drop becomes a tagger instead of a groomer (finds jets with hard, large angle subjets)



James Dolen

N-subjettiness

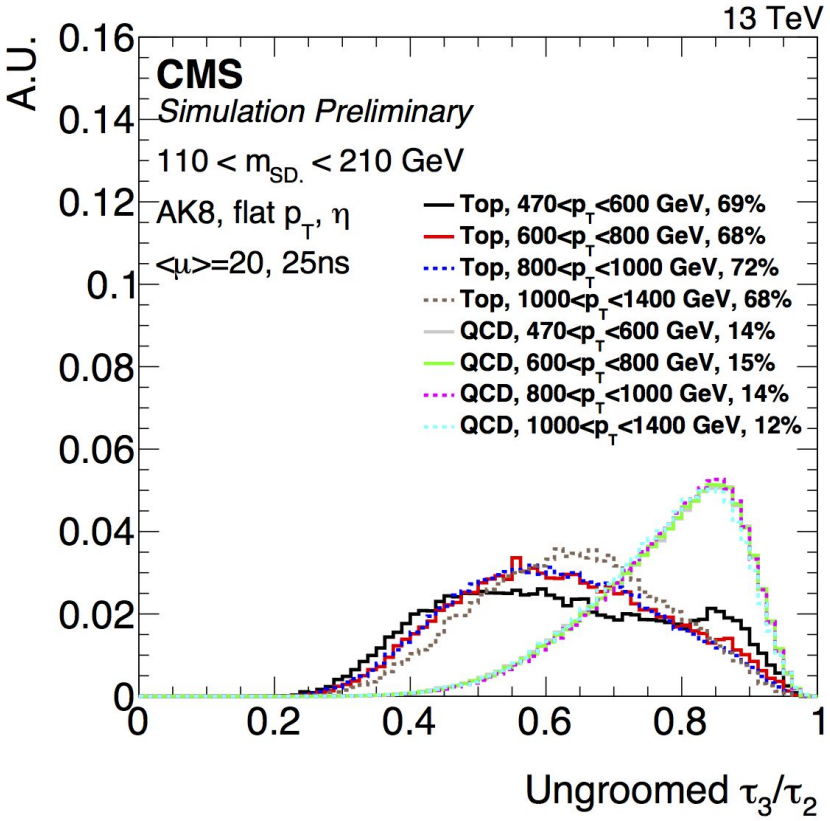
- Jet shape variable to measure consistency of jet to have N subjets

$$\tau_N = \frac{1}{d_0}\sum_k p_{Tk} \times \Delta R_k^{\min} \quad \text{with} \quad d_0 \equiv \sum_k p_{Tk} \times R$$

p_{Tk}: p_T of constituent k

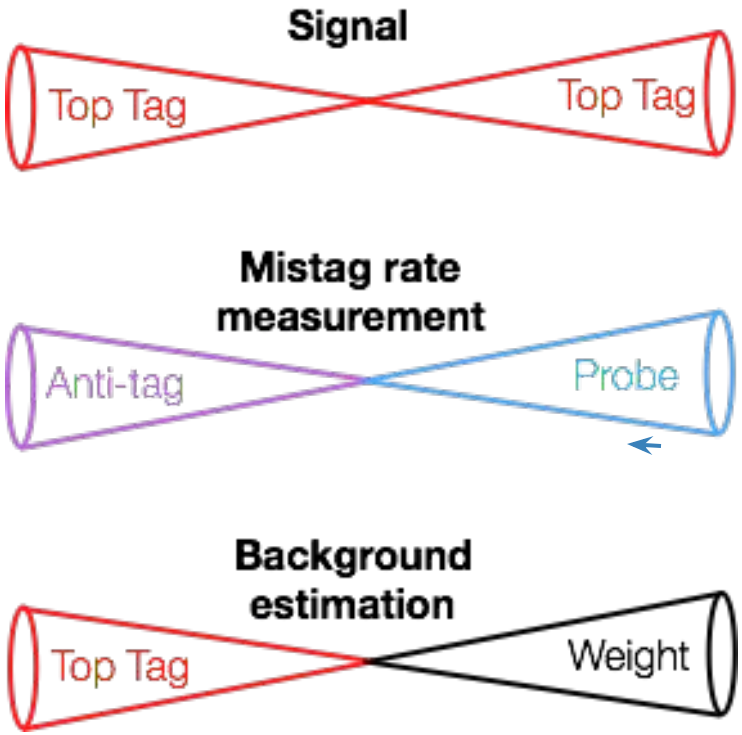
$\Delta R_k^{\min}$: distance between constituent k & axis of closest subjet

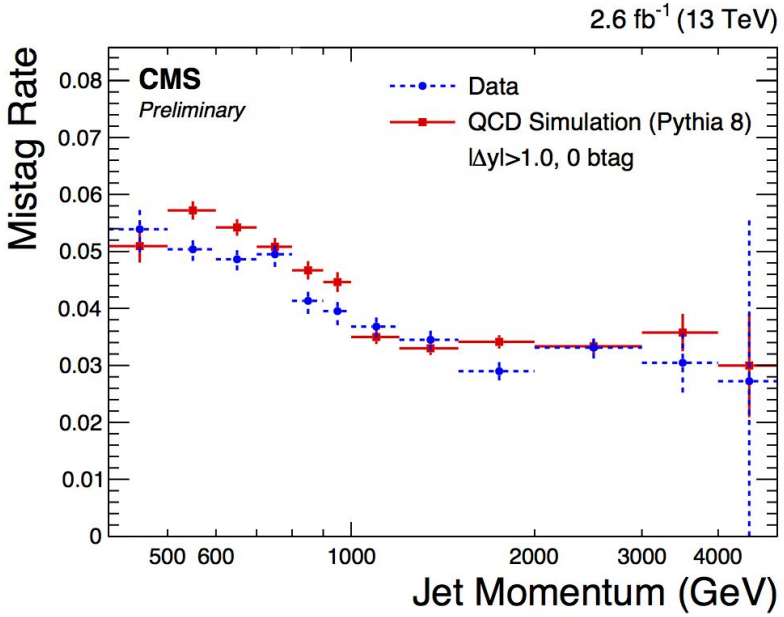
R: large-R jet distance parameter



Top Pair Resonances

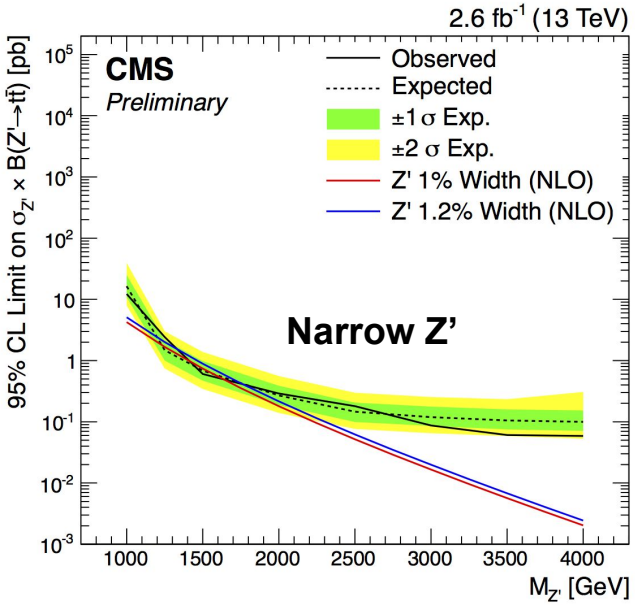
- All-hadronic QCD background estimation
  - Model tt invariant mass spectrum
  - Anti-tag: $\tau_{32} > 0.69$, $m_{SD} = [110, 210]$ GeV

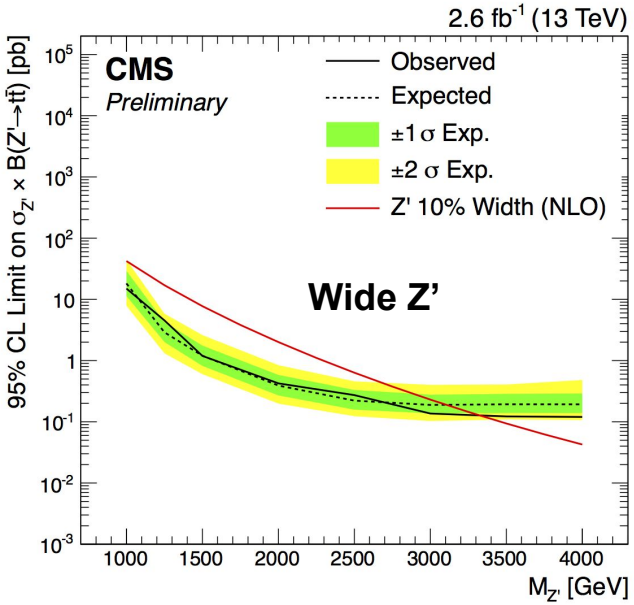


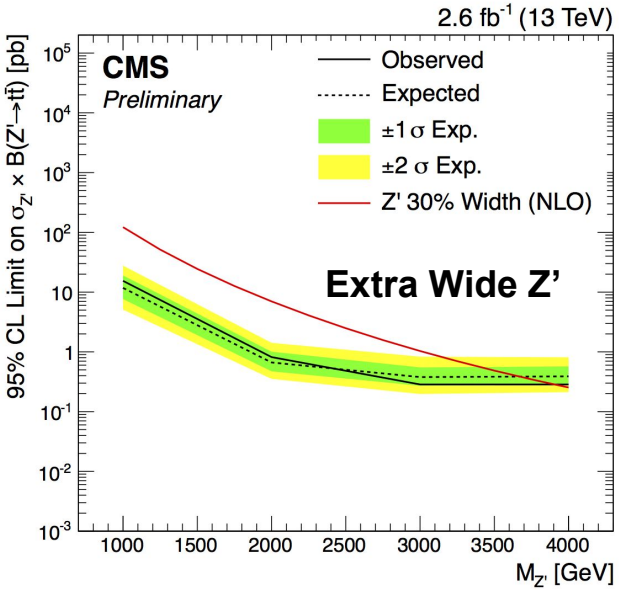


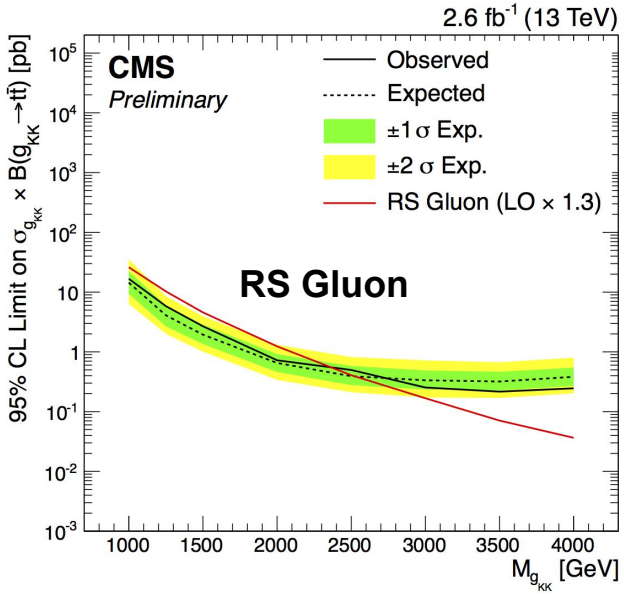
Top Pair Resonances: All-hadronic Limits

CMS-PAS-B2G-15-002/3

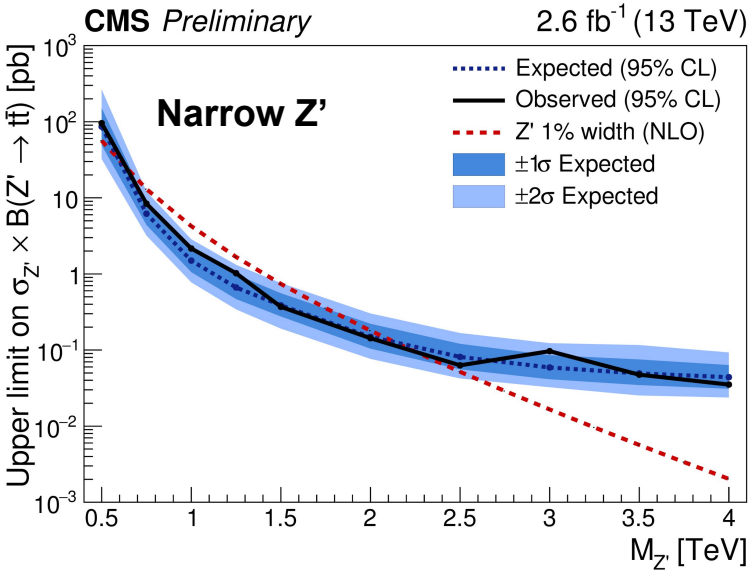


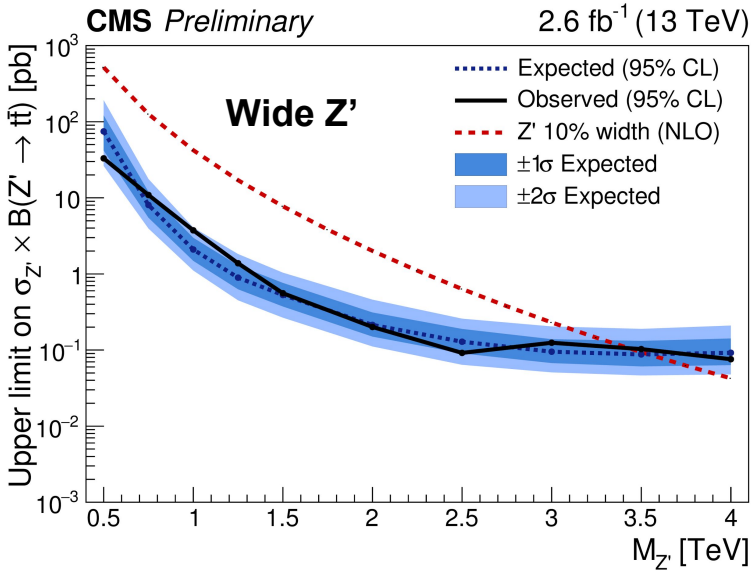


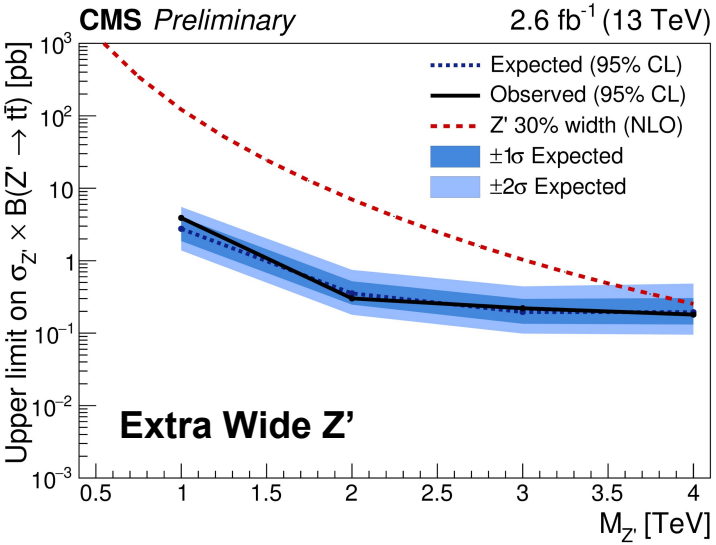


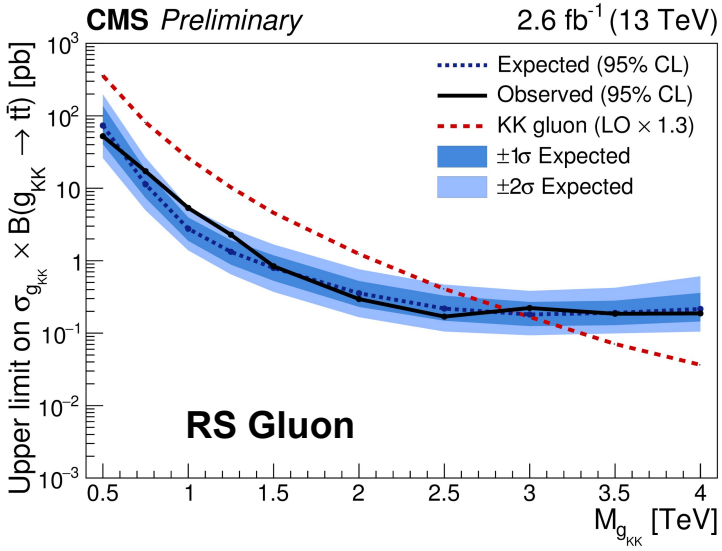


Top Pair Resonances: Semileptonic Limits



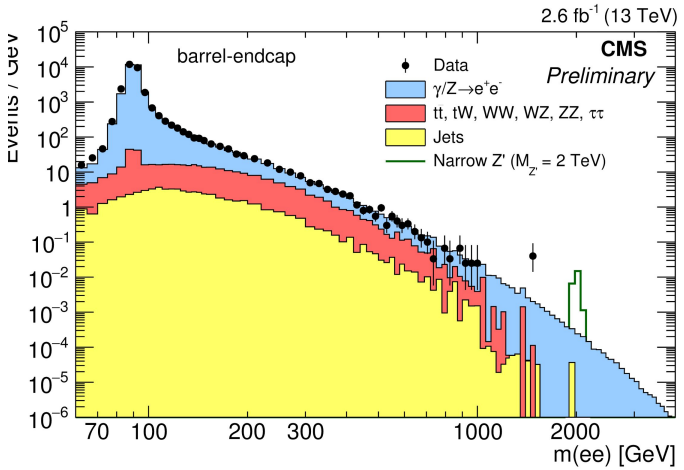


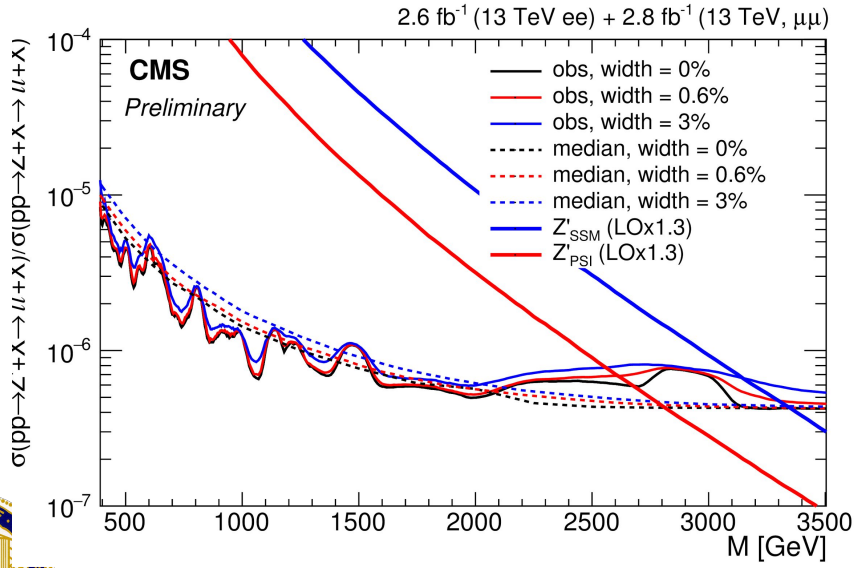


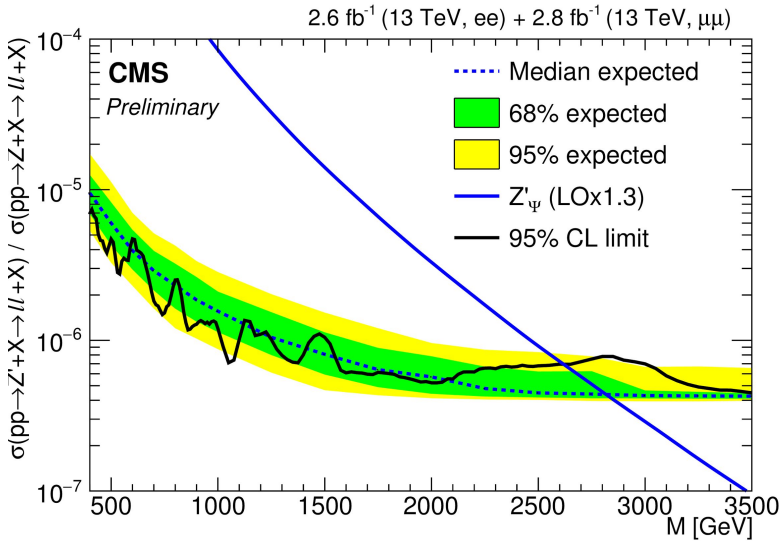


Z' → leptons

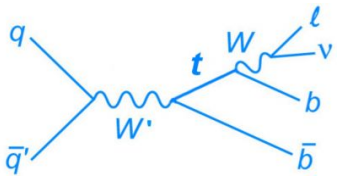
- Search for Z' —> μμ/ee
  - Sensitive variable: dilepton invariant mass
  - electron channel divided into barrel and endcap categories
- Limits surpass Run I results







W'→ tb Search



- Search for W'$_R$ decaying to top, bottom pair
  - Semileptonic channel
- New: no isolated lepton requirement due to boost
- At least one b-tagged jet
- Limits increased: 2.15 TeV → 2.38 TeV; 2.2 fb^{-1} of data