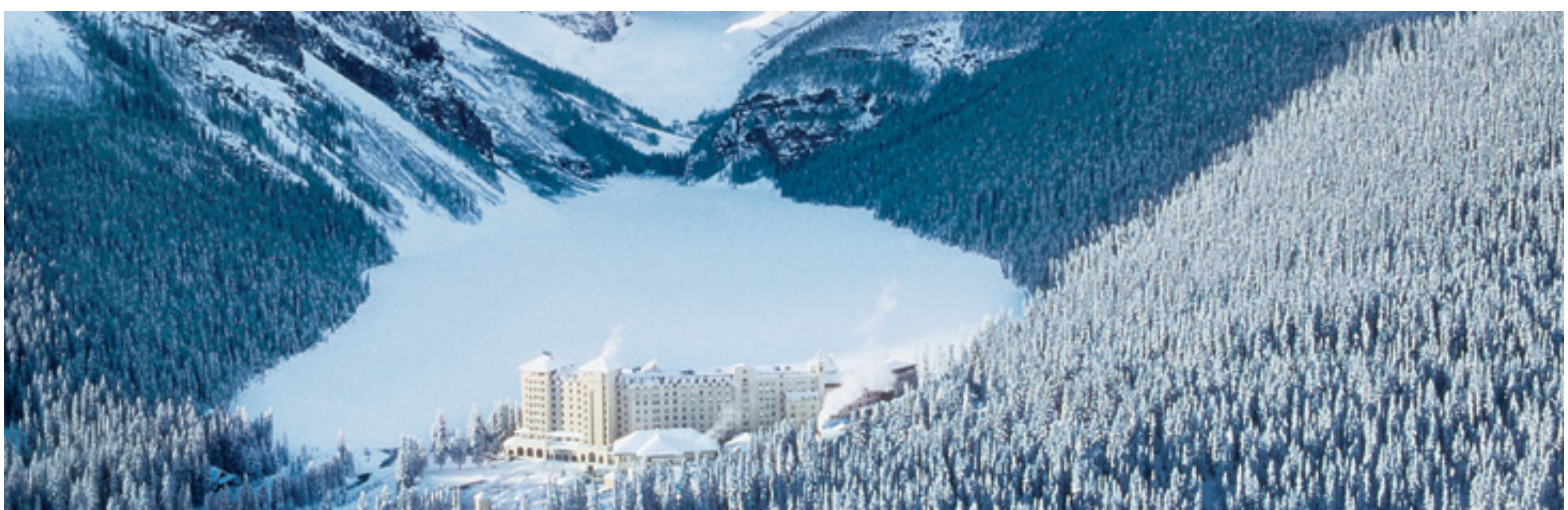
Search for resonant $t\bar{t}$ production with the CMS experiment

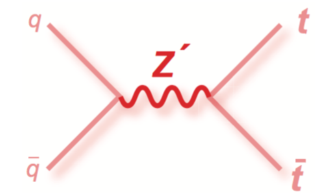
Lake Louise Winter Institute
[7-13 Feb 2015]

Daniel Sandoval
On behalf of the CMS Collaboration

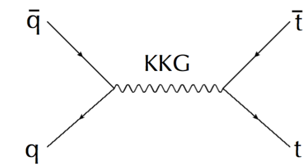


Introduction

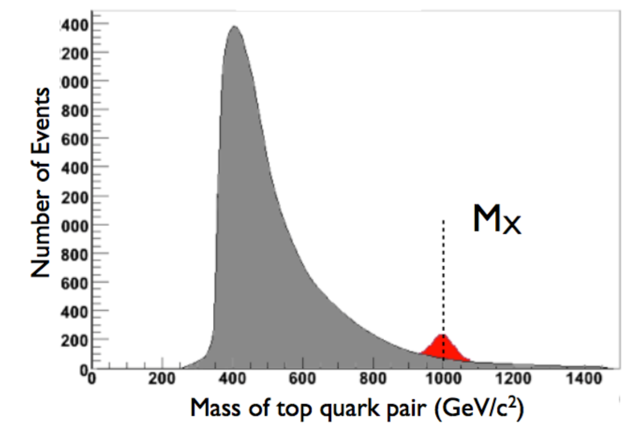
- Many BSM theories predict the existence of heavy resonances that decay preferentially to top-antitop quark pairs.
- Such resonances would manifest as an additional resonant component to the SM top-antitop production.
- For high mass resonances the decay products have a significant Lorentz boost.
- Hadronic, dileptonic and semileptonic analyzes are presented here and correspond to 19.7 fb^{-1} of data taken with the CMS detector at $\sqrt{s}$=8 TeV.

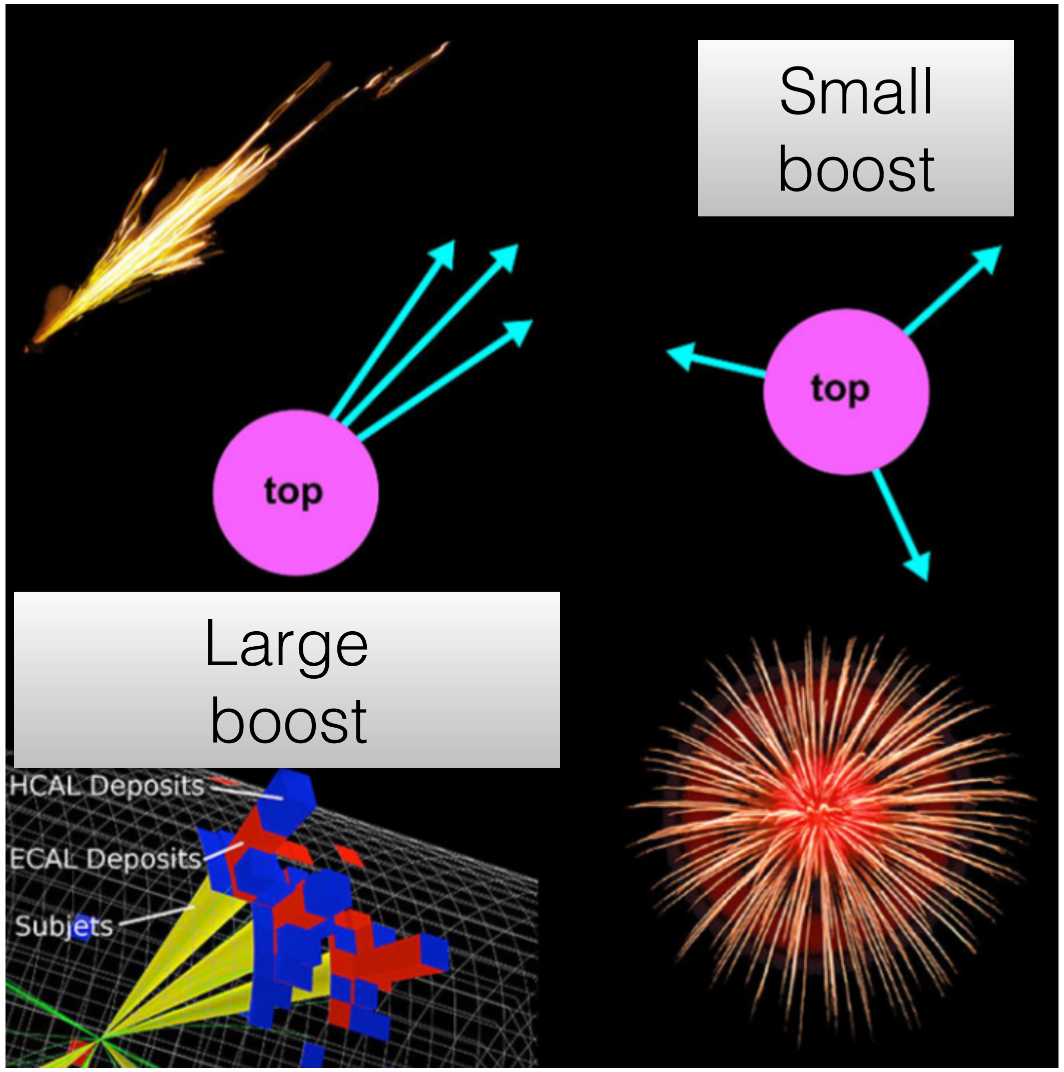


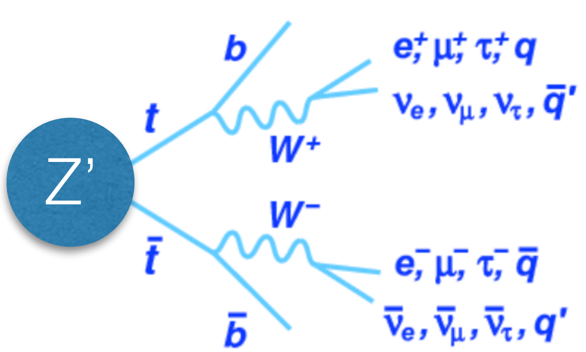
leptophobic top color Z'

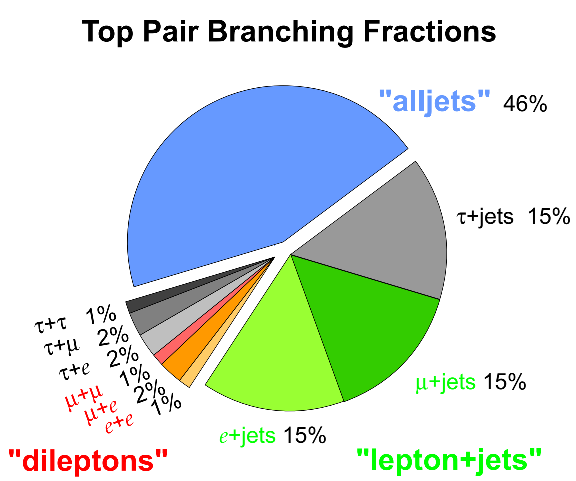


Kaluza Klein gluons







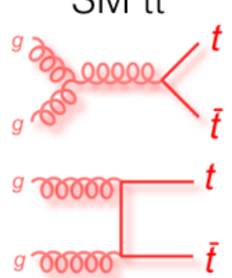


Talk based on: PhysRevD.93.012001

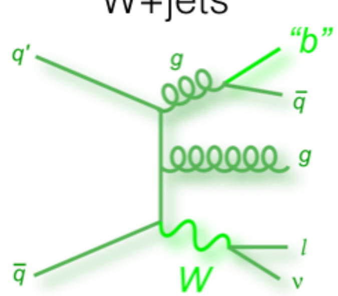
Topology of the event

- Due to the boosted topology of the event, we developed techniques to identify the boosted top quark decay products.
- Non-isolated leptons and merged jets are considered through out the semileptonic and dilepton analyzes.
- Techniques to identify the substructure of jets were used to tag boosted top jets.
- SM processes:

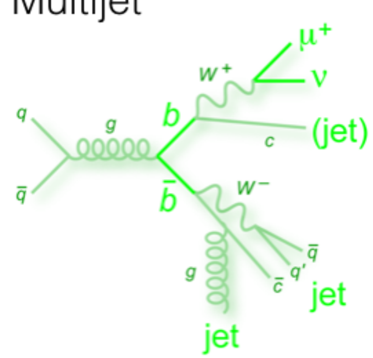
SM tt

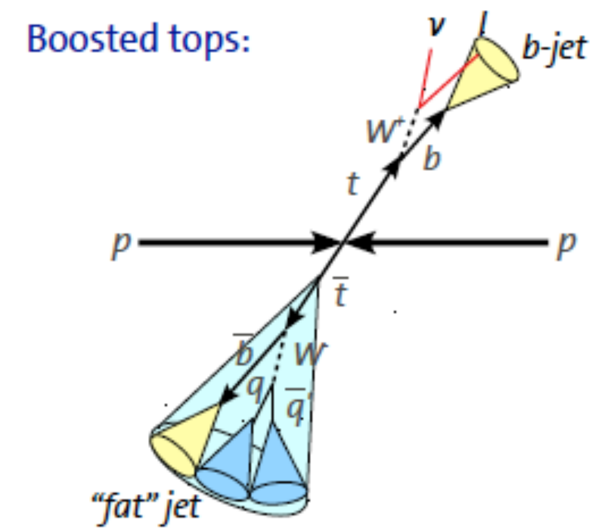


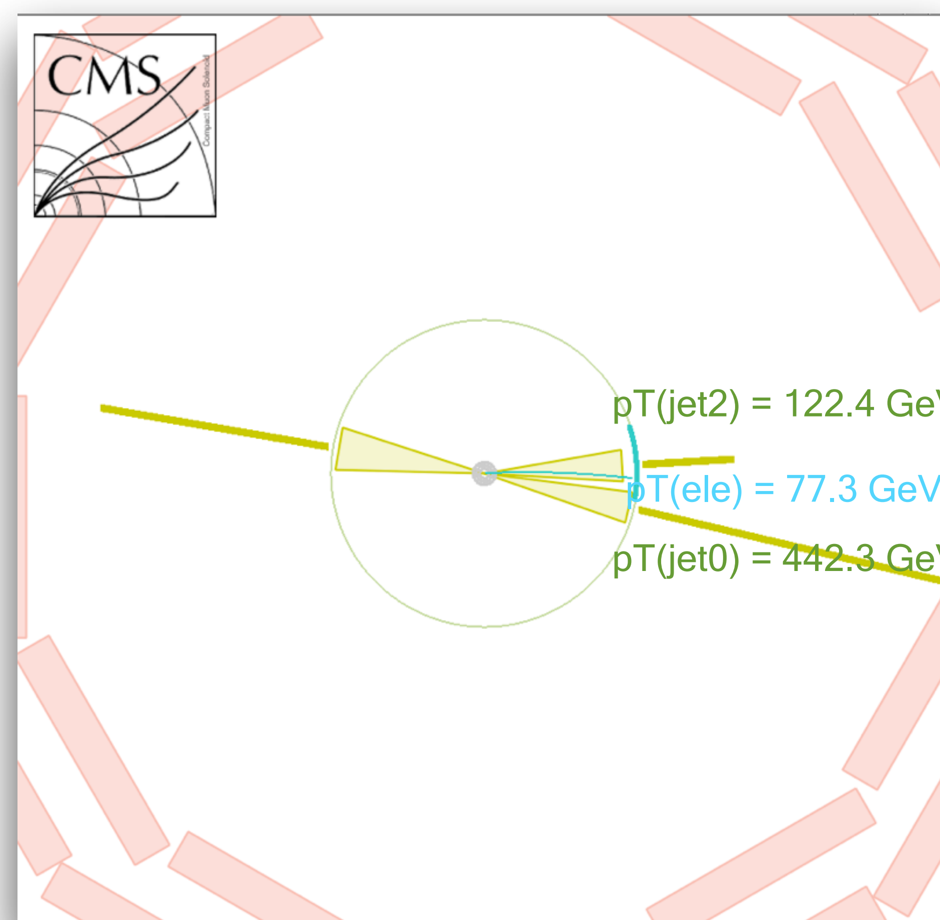
W+jets



Multijet







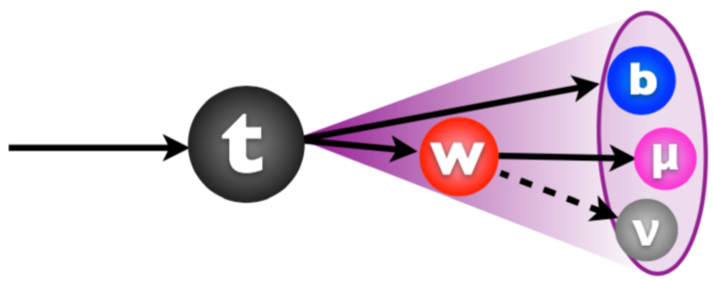
Object identification

- Non isolated leptons : 2D-topological cut

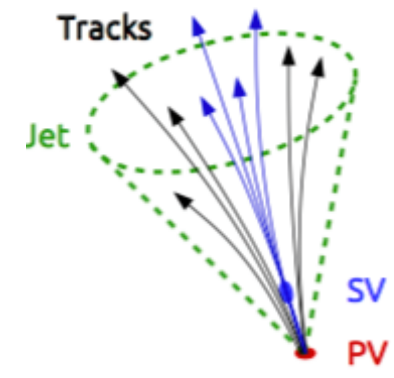
$$\Delta R_{\text{min}}(\ell, j) > 0.5 \text{ OR } p_{T,\text{rel}}(\ell, j) > 25 \text{ GeV}$$

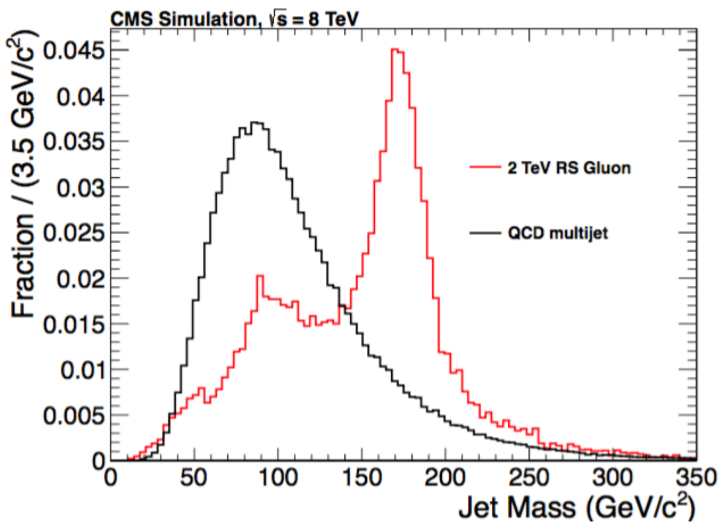
- b-tagging: HEPTT
  - CSV (applied in jets and subjets)
- top-tagging: **CMS PAS JME-13-007**
  - HEPTT , CMSTT , Substructure variables

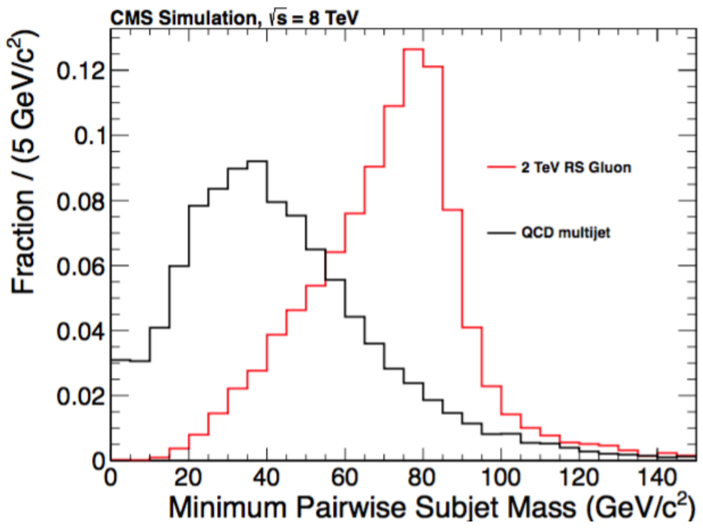
Leptonic top with non-isolated lepton



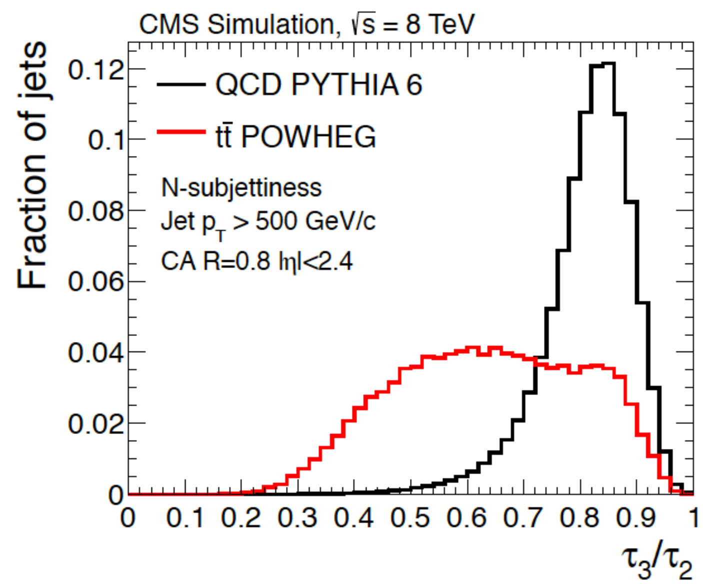
CSV





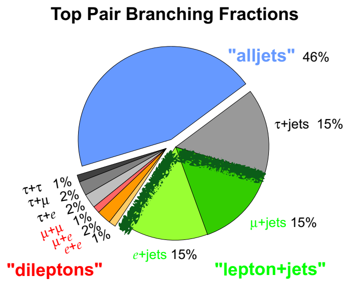


N subjettiness



$$m_{ij} = \sqrt{(E_i + E_j)^2 - (\vec{p}_i + \vec{p}_j)^2}$$
$$m_{\text{min}} = \min[m_{12}, m_{13}, m_{23}]$$

$$\tau_N = \frac{\sum_{i=1}^{n_{\text{constituents}}} p_{T,i} \min\{\Delta R_{1,i}, \Delta R_{2,i}, ..., \Delta R_{N,i}\}}{\sum_{i=1}^{n_{\text{constituents}}} p_{T,i} R}$$



Semileptonic channel

Event Selection

- 1 non-isolated lepton and at least 2 high pT jets [150,50]GeV and MET
- Lepton 2D-cut to reduce QCD background

$$\Delta R_{\text{min}}(\ell, j) > 0.5 \text{ OR } p_{T,\text{rel}}(\ell, j) > 25 \text{ GeV}$$

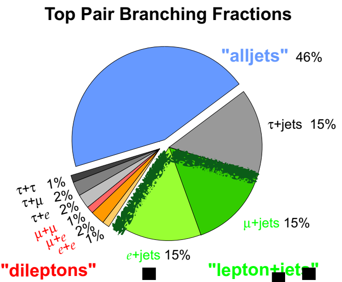
- Triangular cut (e-channel)

$$\frac{-1.5}{75GeV} E_T^{miss} + 1.5 < \Delta\phi(e, E_T^{miss}) < \frac{1.5}{75GeV} E_T^{miss} + 1.5$$

- Veto on events with more than one CA8 top-tagged jet (CMSTT)

Categorization

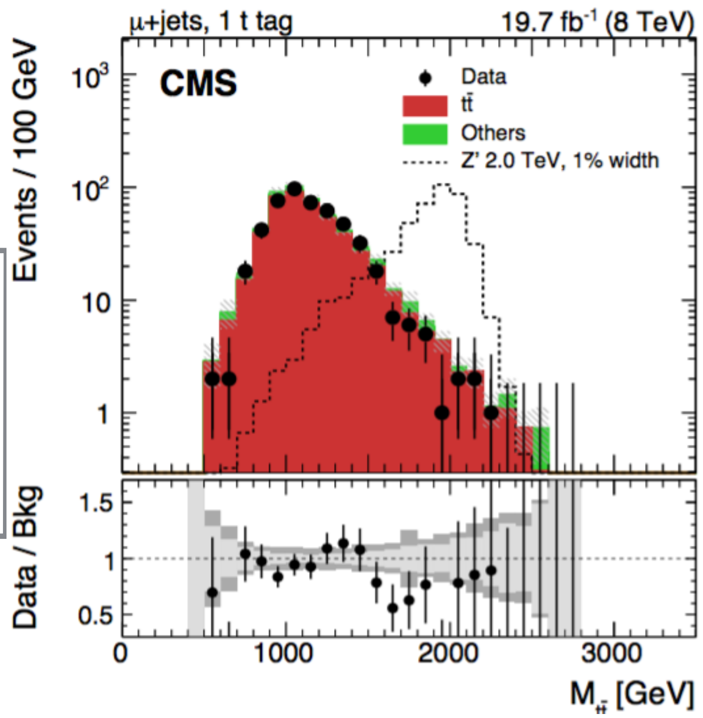
- The selected CA8 CMSTT jet must also pass the $\tau_3/\tau_2 < 0.7$ cut
- Using the combined CSV algorithm we b-tag jets.
- Events are categorized depending on the number of top and b - tagged jets

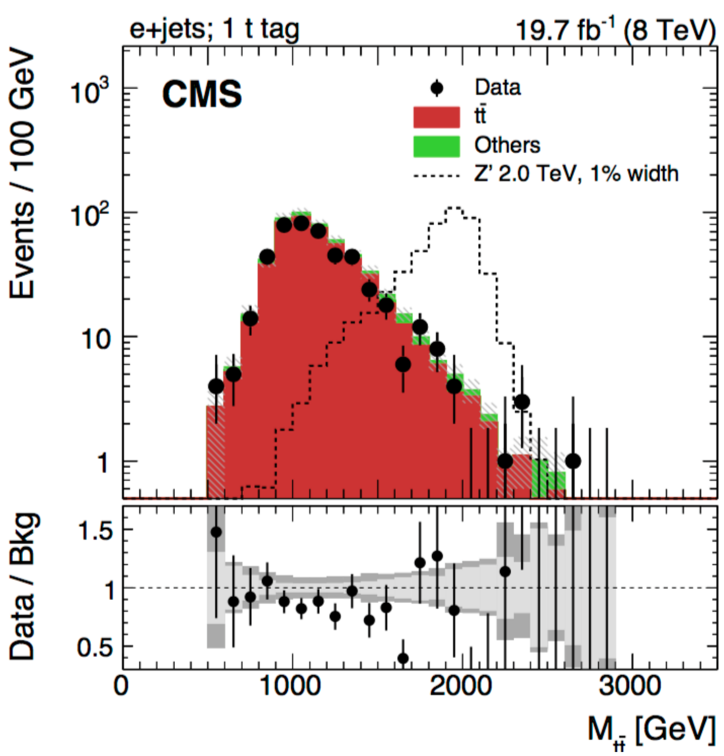


Semileptonic channel

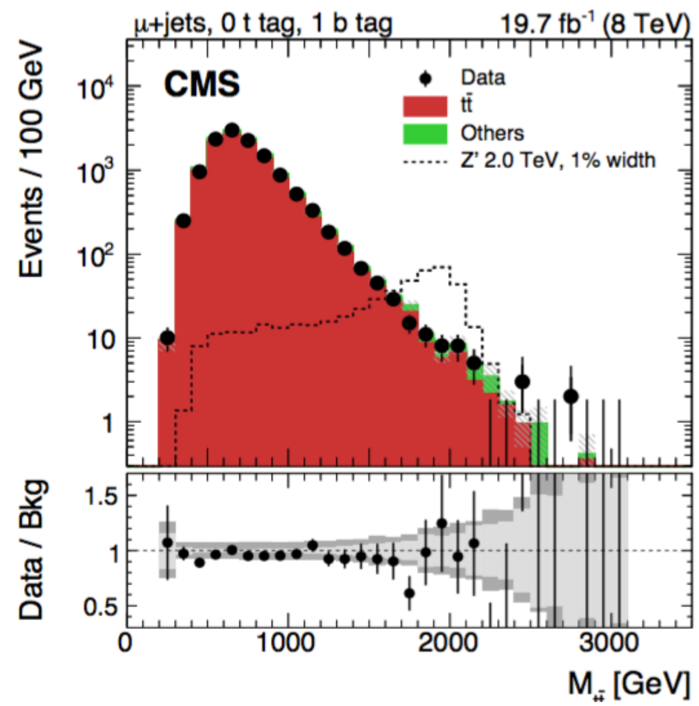
Categorization

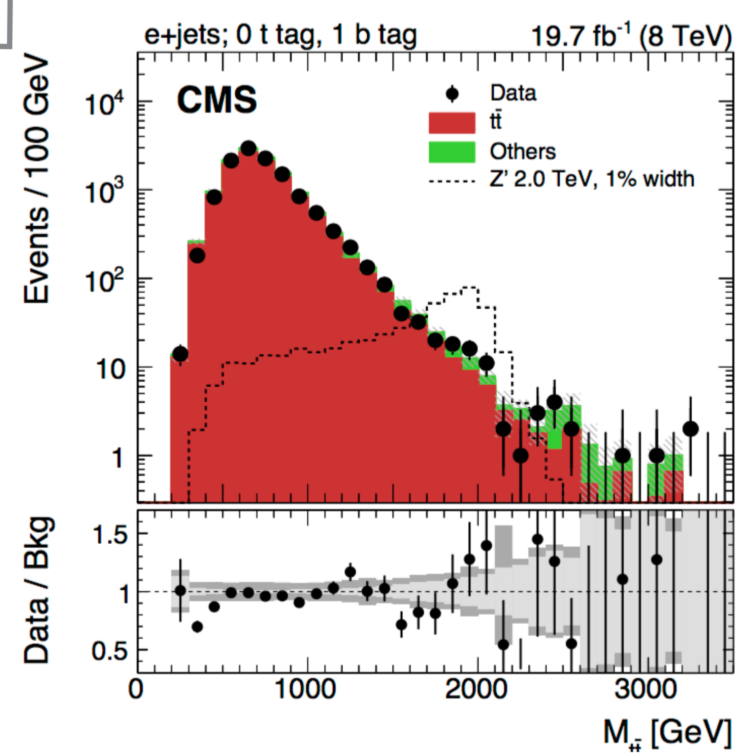
1 top tag



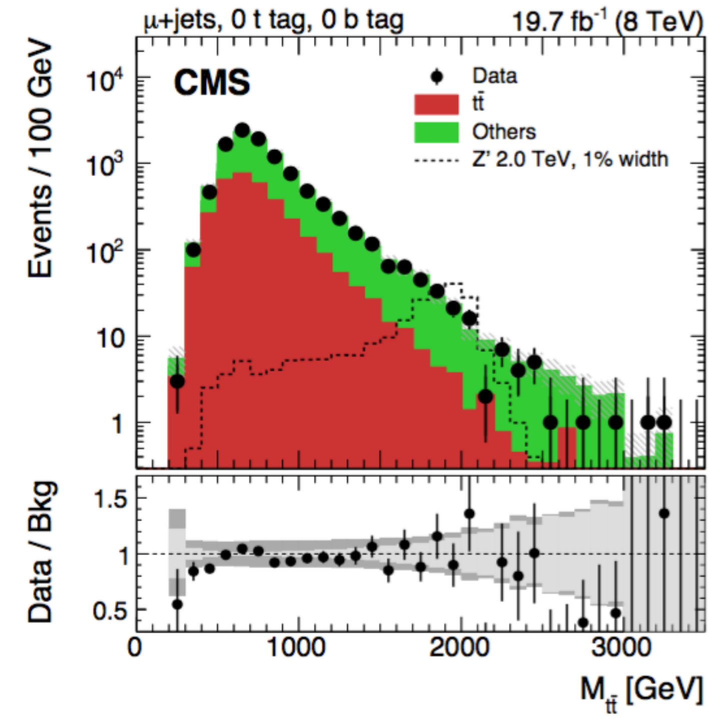


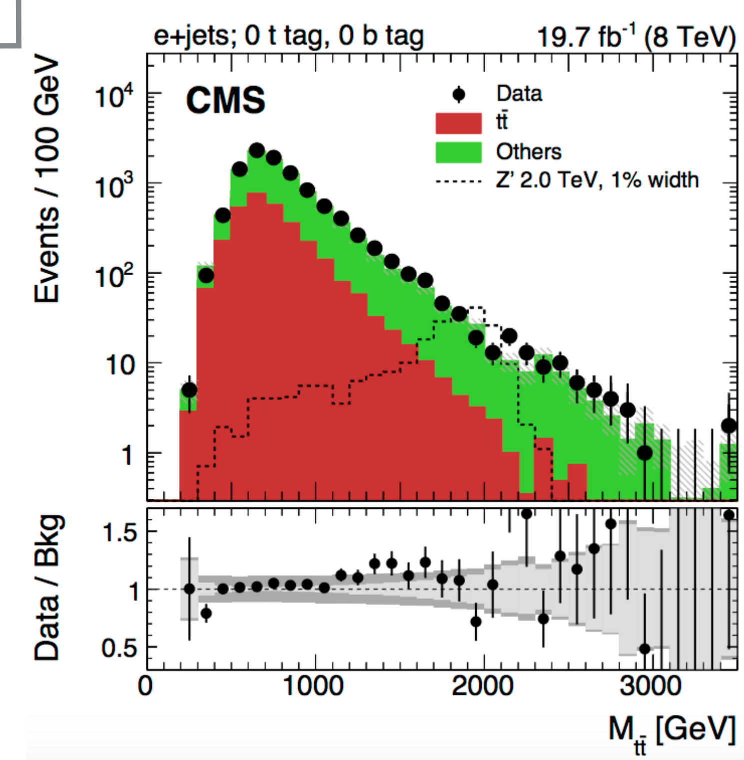
0 top tag & 1b tag





0 top tag & 0b tag





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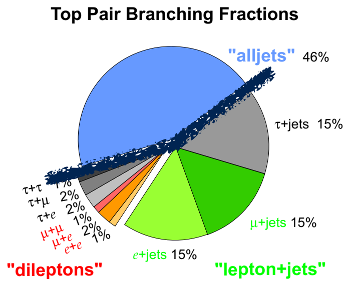


Hadronic channel

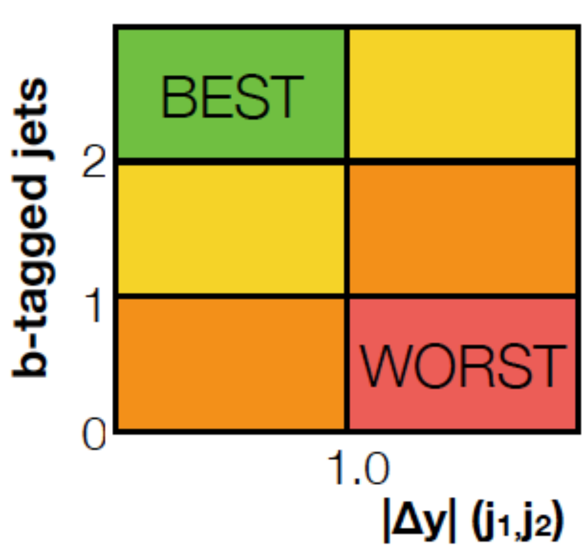
Event Selection

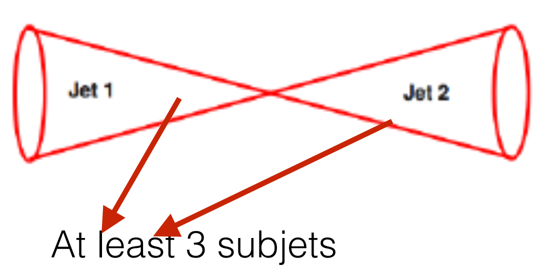
- 2 orthogonal methods for tagging top jets are employed [CMSTT, HEPTT]
- The sensitivity is increased by looking at b-jets within the top tagged jets [subjet b-tagging]

Very Boosted: H_T>800GeV

- At least two jets, p_T> 400 GeV [CA8 Jets]
- Leading jets must be back-to-back
- Jet mass in [140,250] GeV
- N-subjettines τ_3/τ_2 <0.7
- To increase sensitivity we categorize events based on the number of sub b-tagged jets and |Δy|

CMSTT

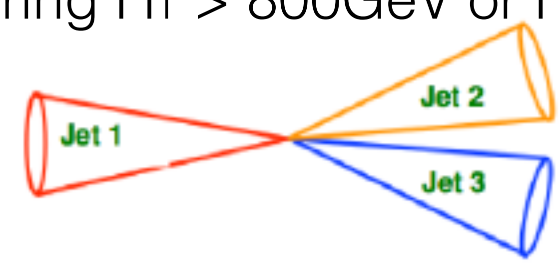


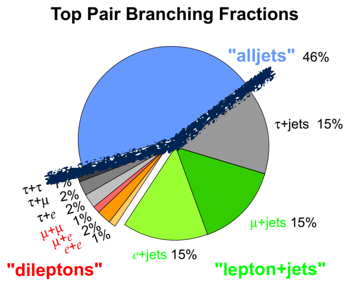


Moderately Boosted

- At least two fat jets, p_T> 200 GeV [CA15Jets]
- Jet mass in [140,250] GeV
- Within the jet, there must be an identified W candidate
- The events are categorized by the number of identified b-subjets and by comparing H_T > 800GeV or H_T<800

HEPTT





Hadronic channel

Categorization

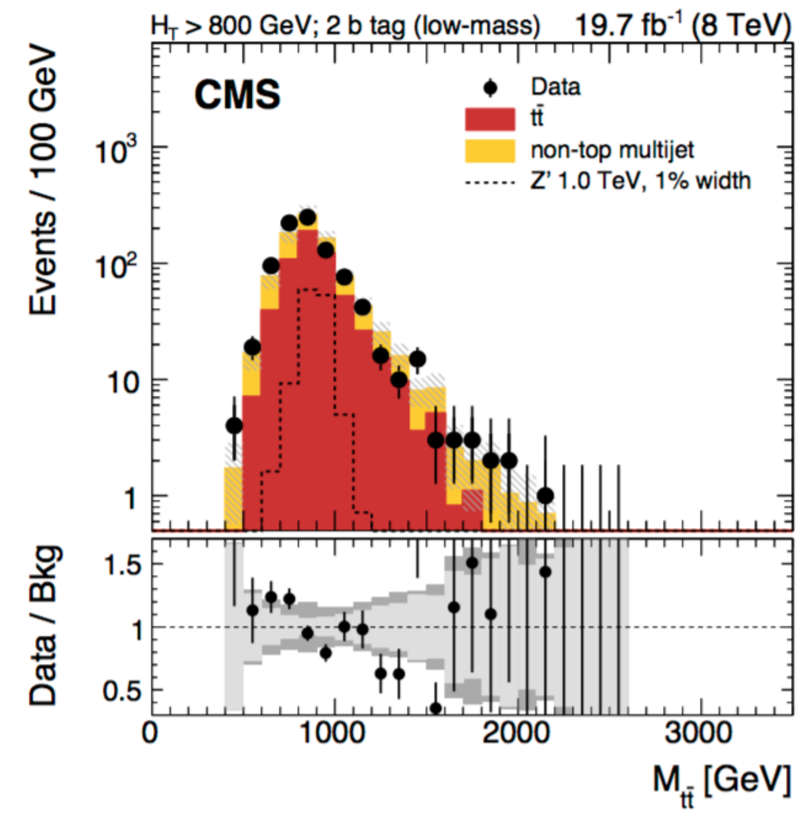
HEPTT

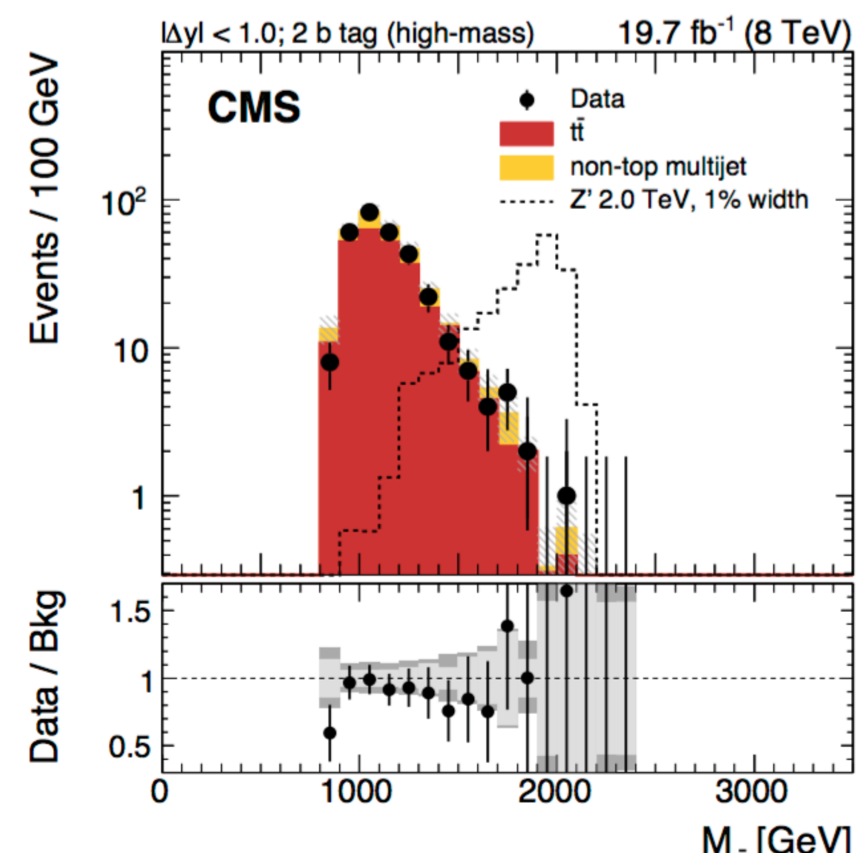
- $H_T>800$
  - 0 sub b-tags
  - 1 sub b-tags
  - 2 sub b-tags
- $H_T<800$
  - 0 sub b-tags
  - 1 sub b-tags
  - 2 sub b-tags

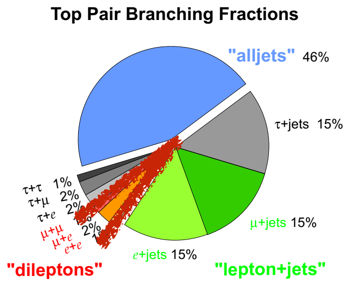
CMSTT

- $|\Delta y| < 1$
  - 0 sub b-tags
  - 1 sub b-tags
  - 2 sub b-tags
- $|\Delta y| > 1$
  - 0 sub b-tags
  - 1 sub b-tags
  - 2 sub b-tags

M_{tt}



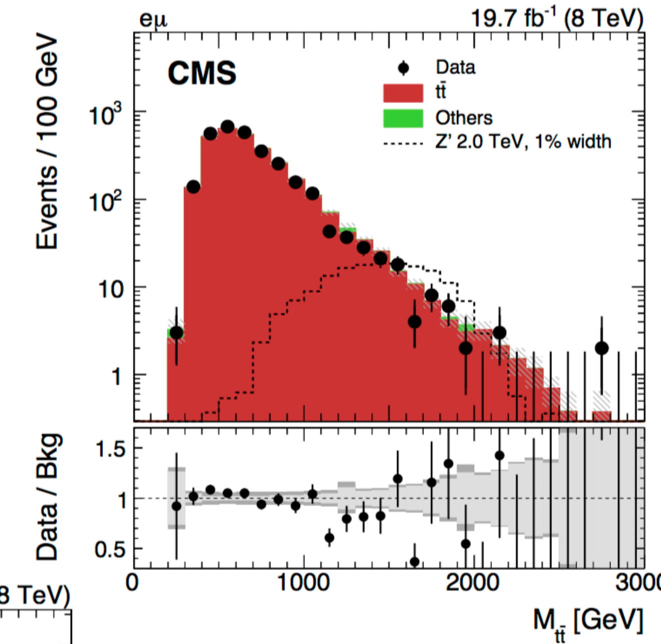


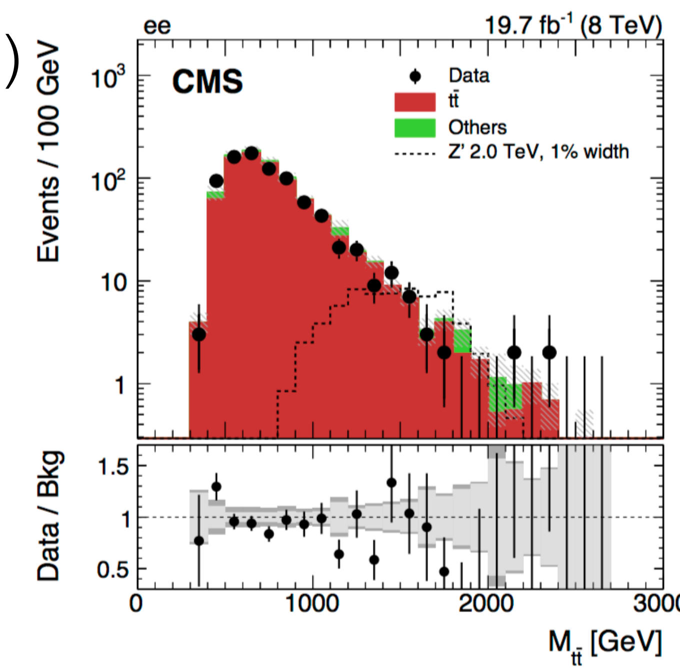


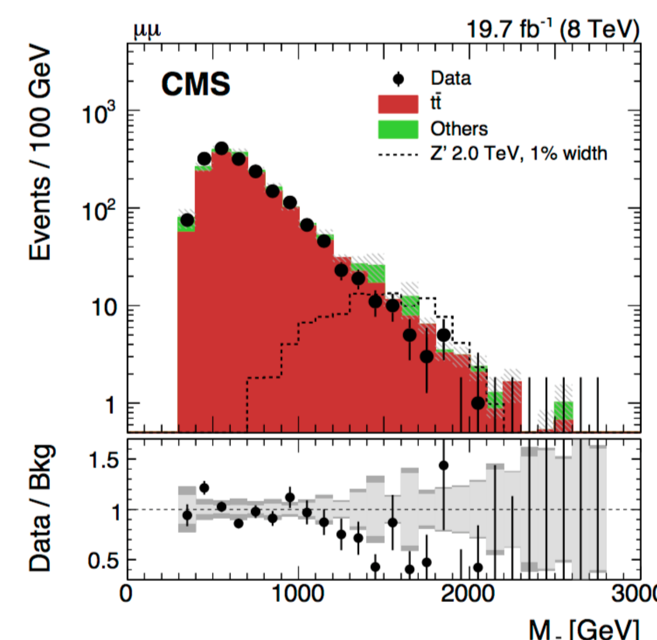
Dilepton channel

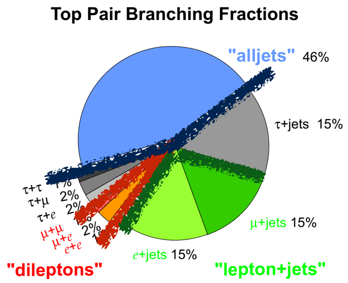
Event Selection

- Two oppositely charged leptons [ee,eμ ,μμ]
- At least two central jets
- M_{ll} > 12 GeV and veto on the [76,106]GeV (Z mass)
- If $\Delta R(l,jet)<0.5$ then $p_{T,REL}(l,jet)>15$GeV
- MET > 30 GeV
- At least 2 loose b-tagged jets or at least one medium b-tagged jet.
- To reduce SM tt background $\Delta R(l_1,jet)<1.2$ and $\Delta R(l_2,jet)<1.5$
- Background processes are estimated from simulation









Combination

Summary

Dilepton: 3 categories {ee , eμ , μμ}

Semileptonic: 6 categories

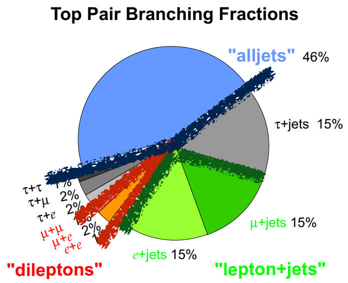
$\{e, \mu\} \otimes \{$1 top-tag, 0top-tag & 1b-tag , 0top-tag & 0b-tag$\}$

Hadronic: 12 categories

$$\begin{Bmatrix} \text{CMSTT} \\ \text{HEPTT} \end{Bmatrix} \otimes \begin{Bmatrix} |\Delta y| > 1 , & |\Delta y| < 1 \\ H_T > 800\text{ GeV} , & H_T < 800\text{GeV} \end{Bmatrix} \otimes \begin{Bmatrix} 0,1,2 \text{ b-subjets} \\ 0,1,2 \text{ b-subjets} \end{Bmatrix}$$

Systematic Uncertainties

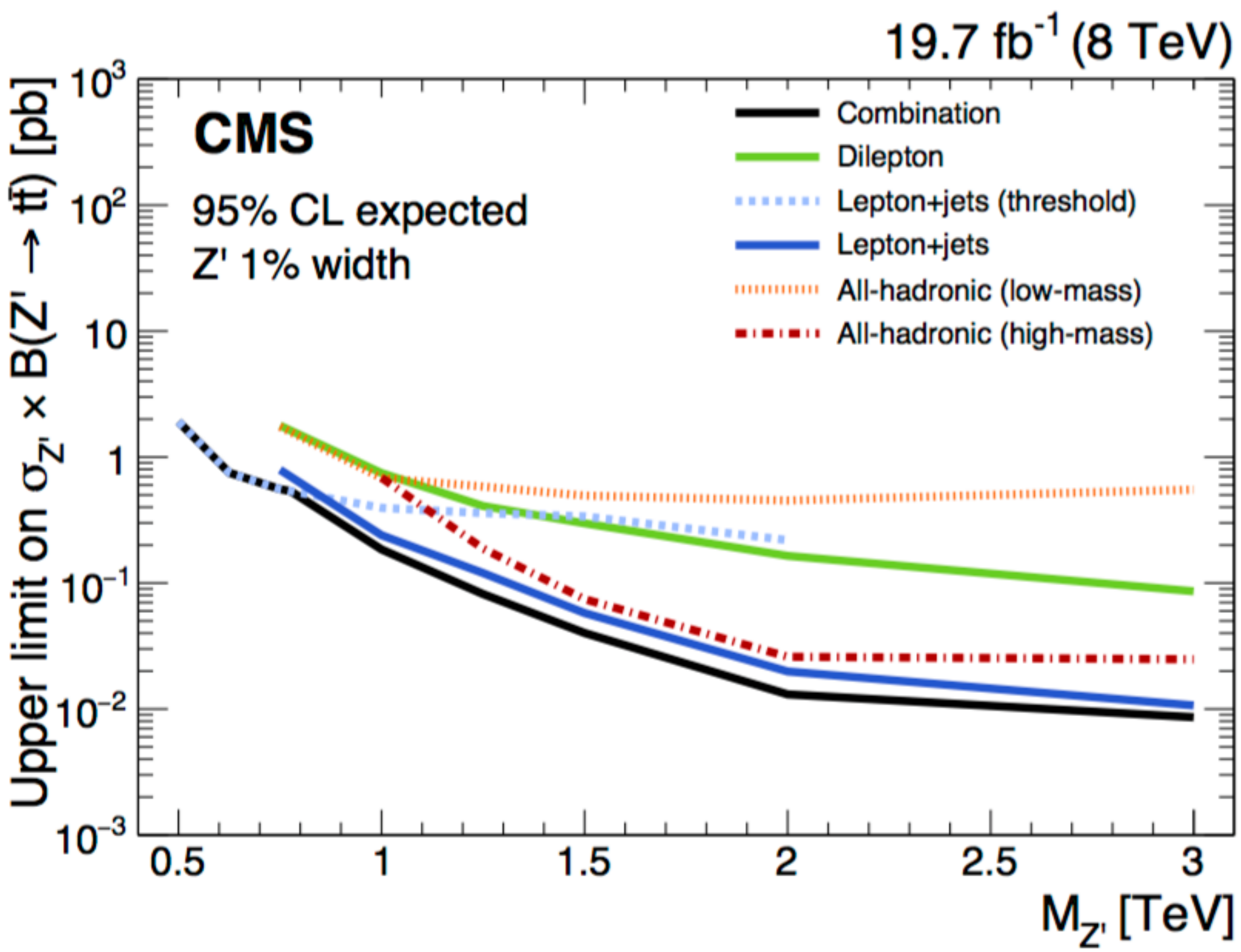
Uncertainties originating from the same source are assumed 100% correlated

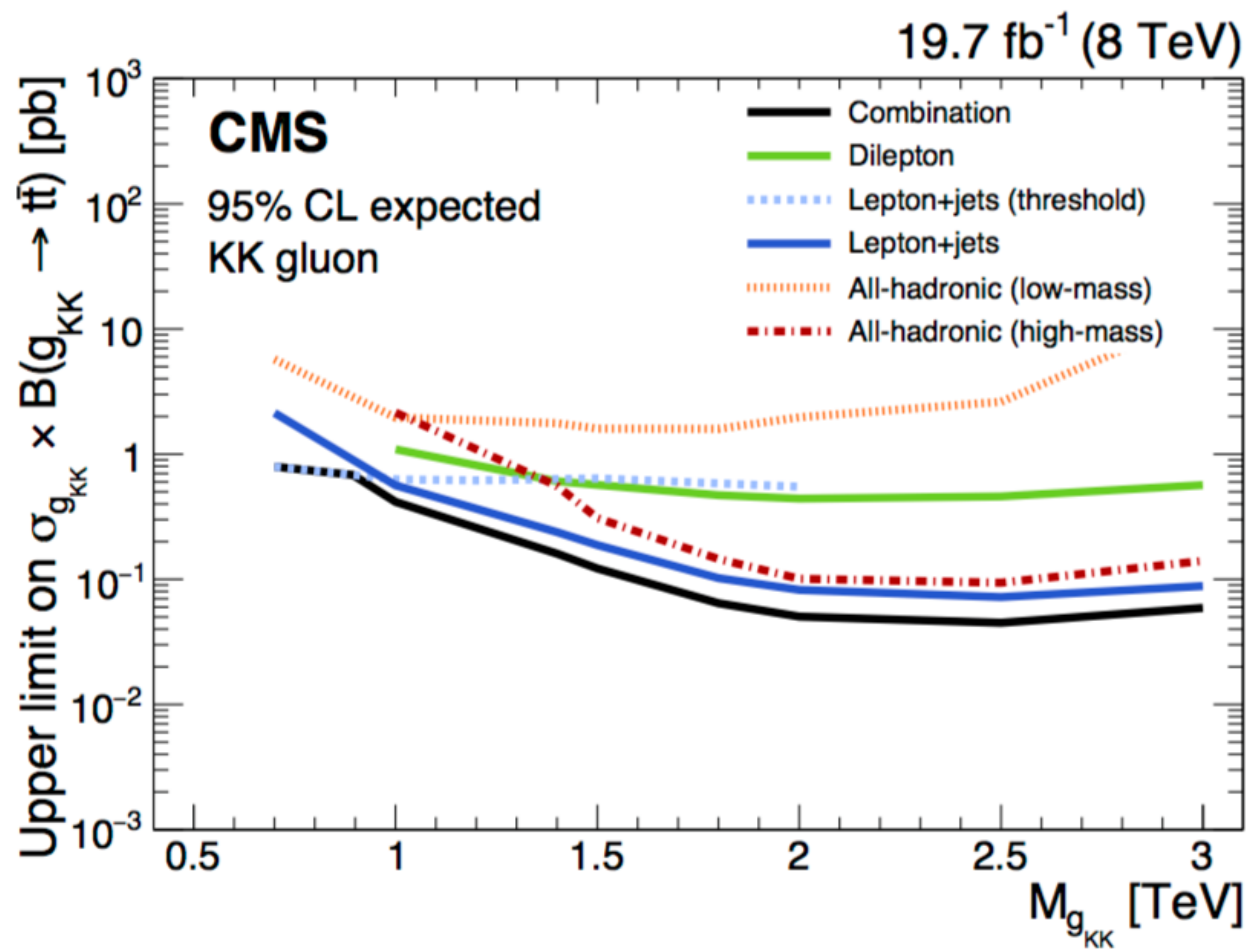


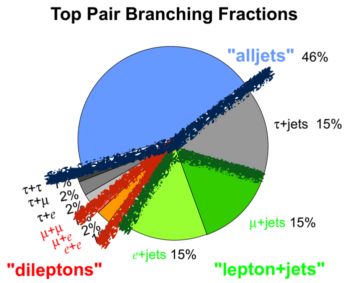
Combination

Limits

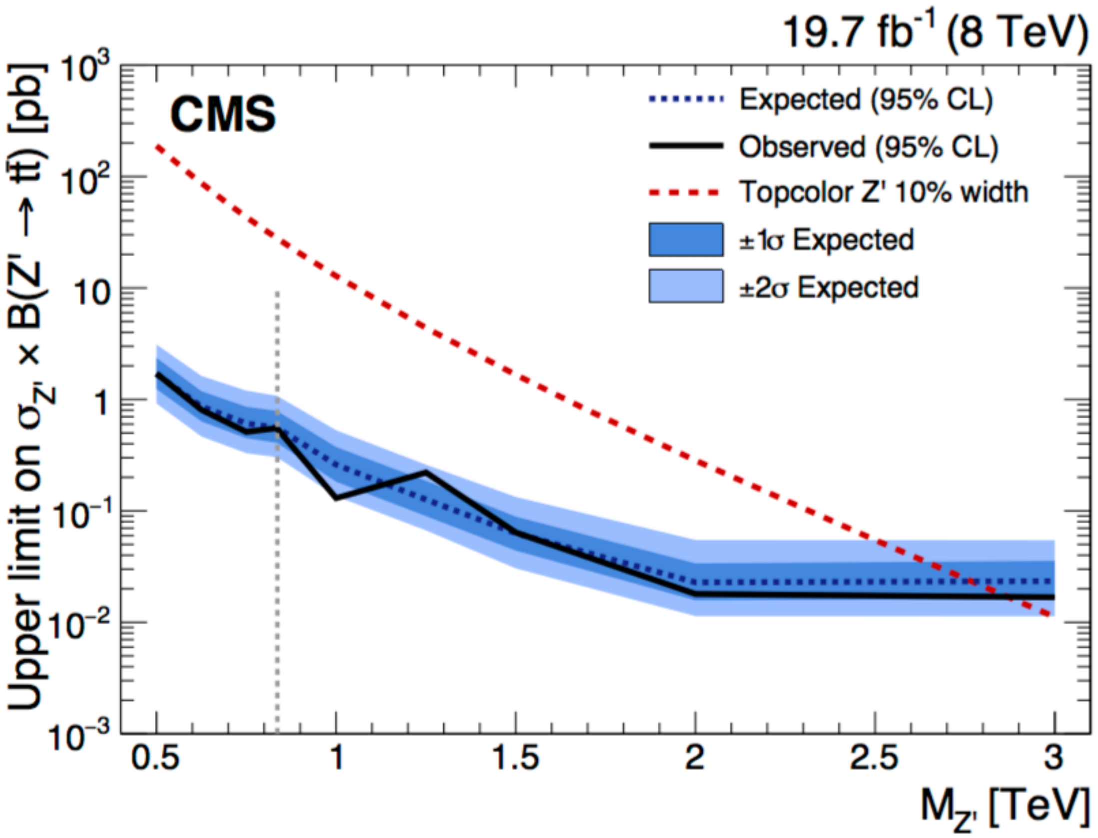
No significant excess of data over expected SM processes is observed. A bayesian statistical method is employed to determine the 95%CL upper limits on the cross section times branching fraction on the bench mark models (Z' and KK-gluons) .

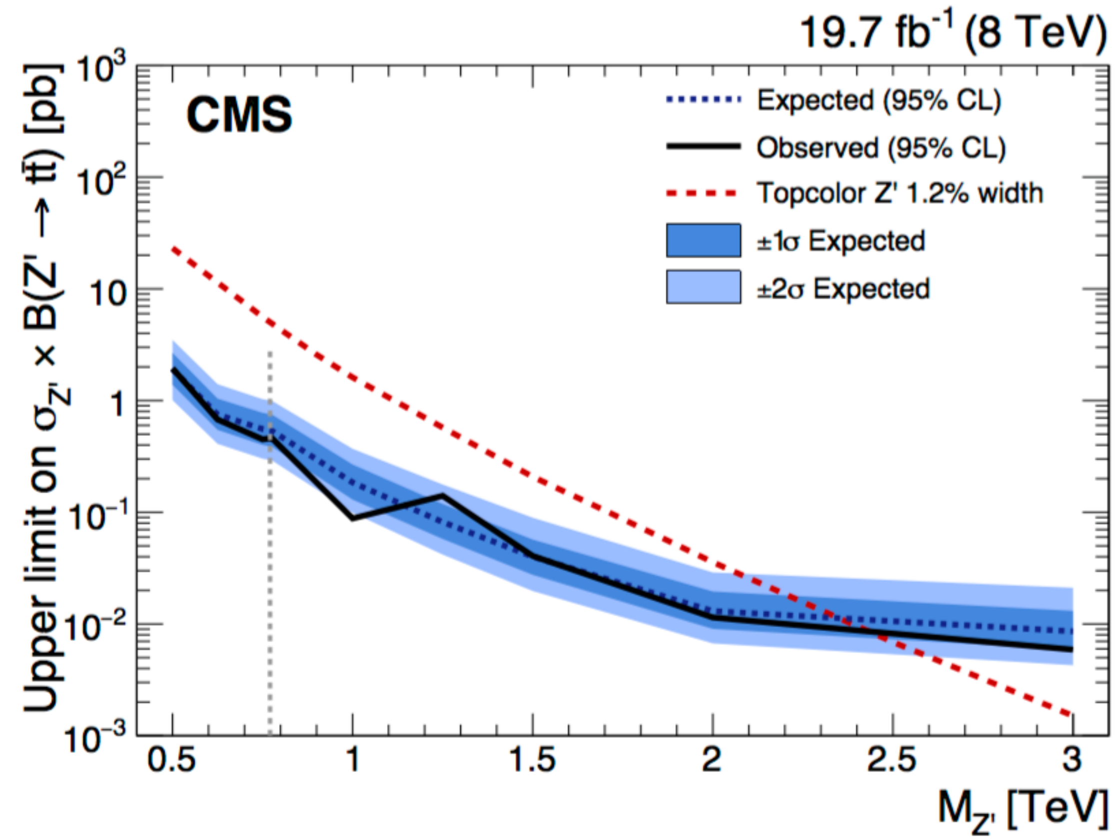


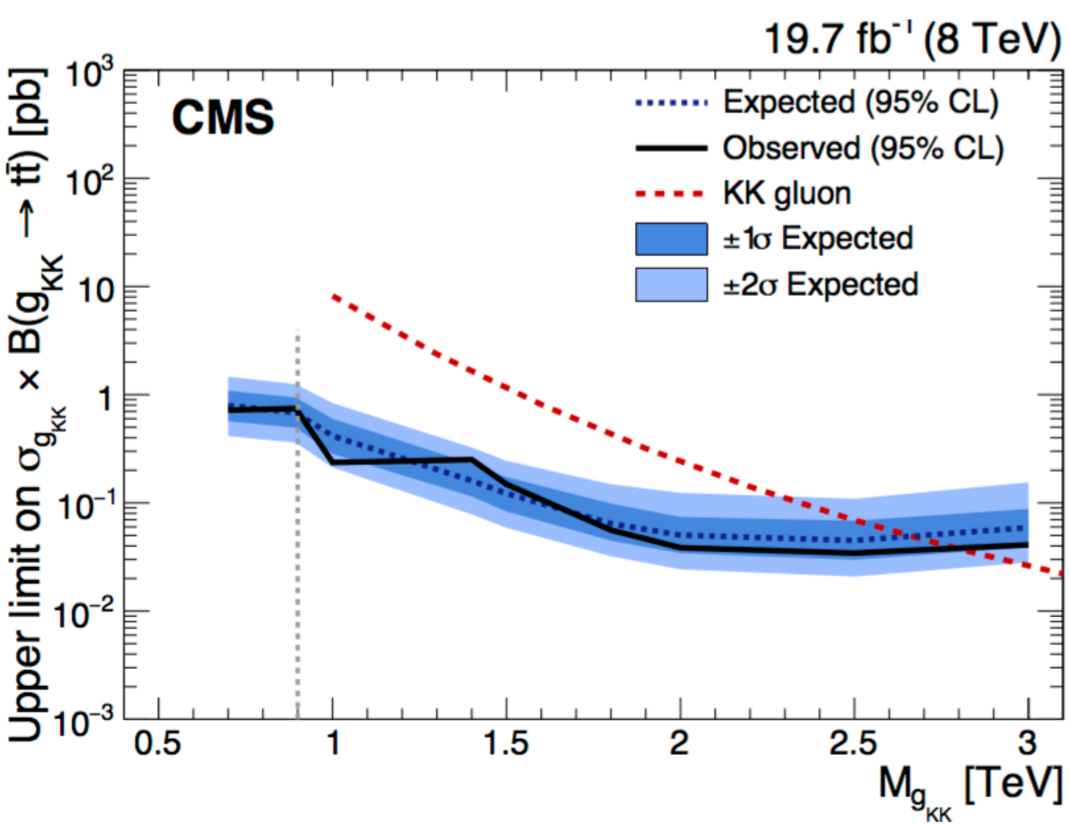




Combination







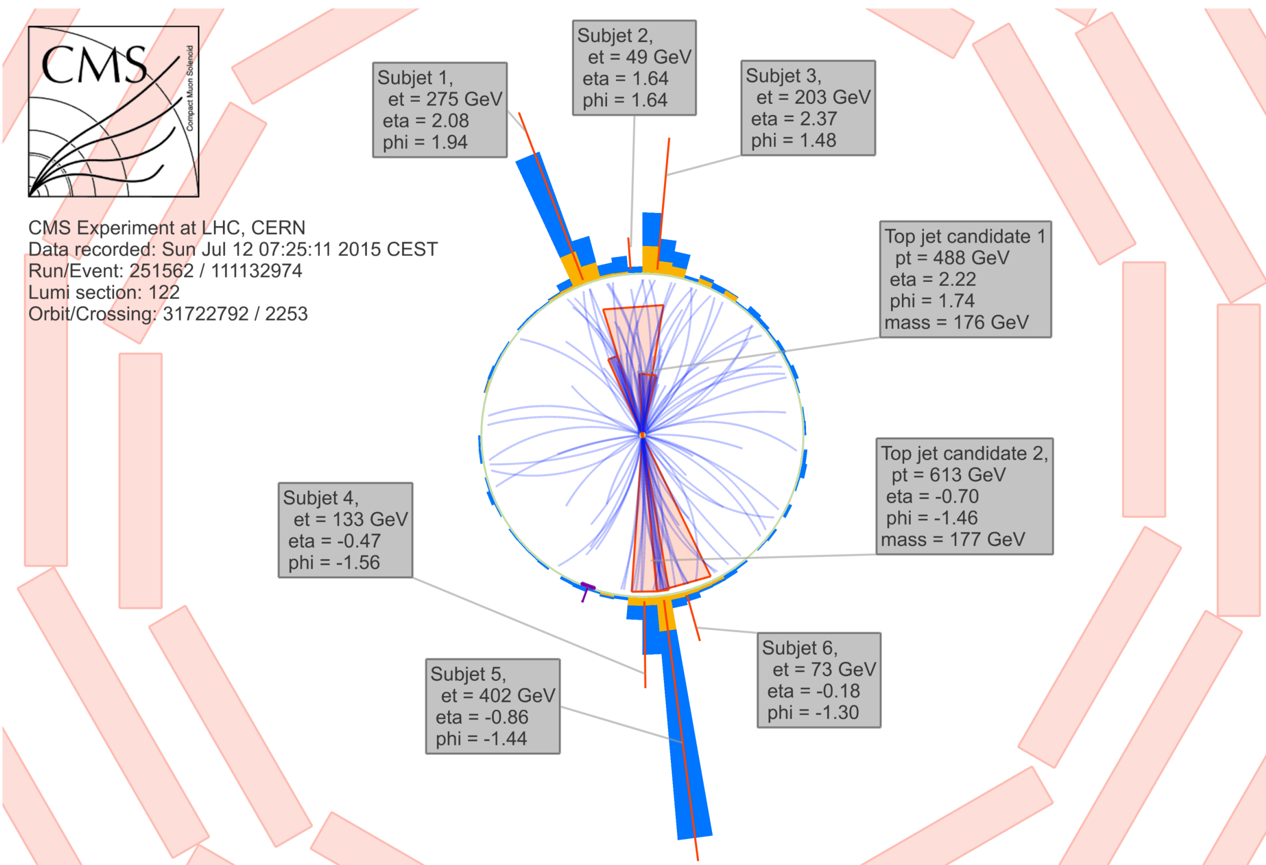
	Mass limit [TeV]							
	Dilepton channel		Lepton+jets channel		All-hadronic channels		Combined	
	Expected	Observed	Expected	Observed	Expected	Observed	Expected	Observed
$Z', \Gamma_{Z'}/M_{Z'} = 1.2\%$	1.4	1.5	2.2	2.3	2.1	2.1	2.4	2.4
$Z', \Gamma_{Z'}/M_{Z'} = 10\%$	2.1	2.2	2.7	2.8	2.5	2.5	2.8	2.9
RS KK gluon	1.8	2.0	2.5	2.5	2.4	2.3	2.7	2.8

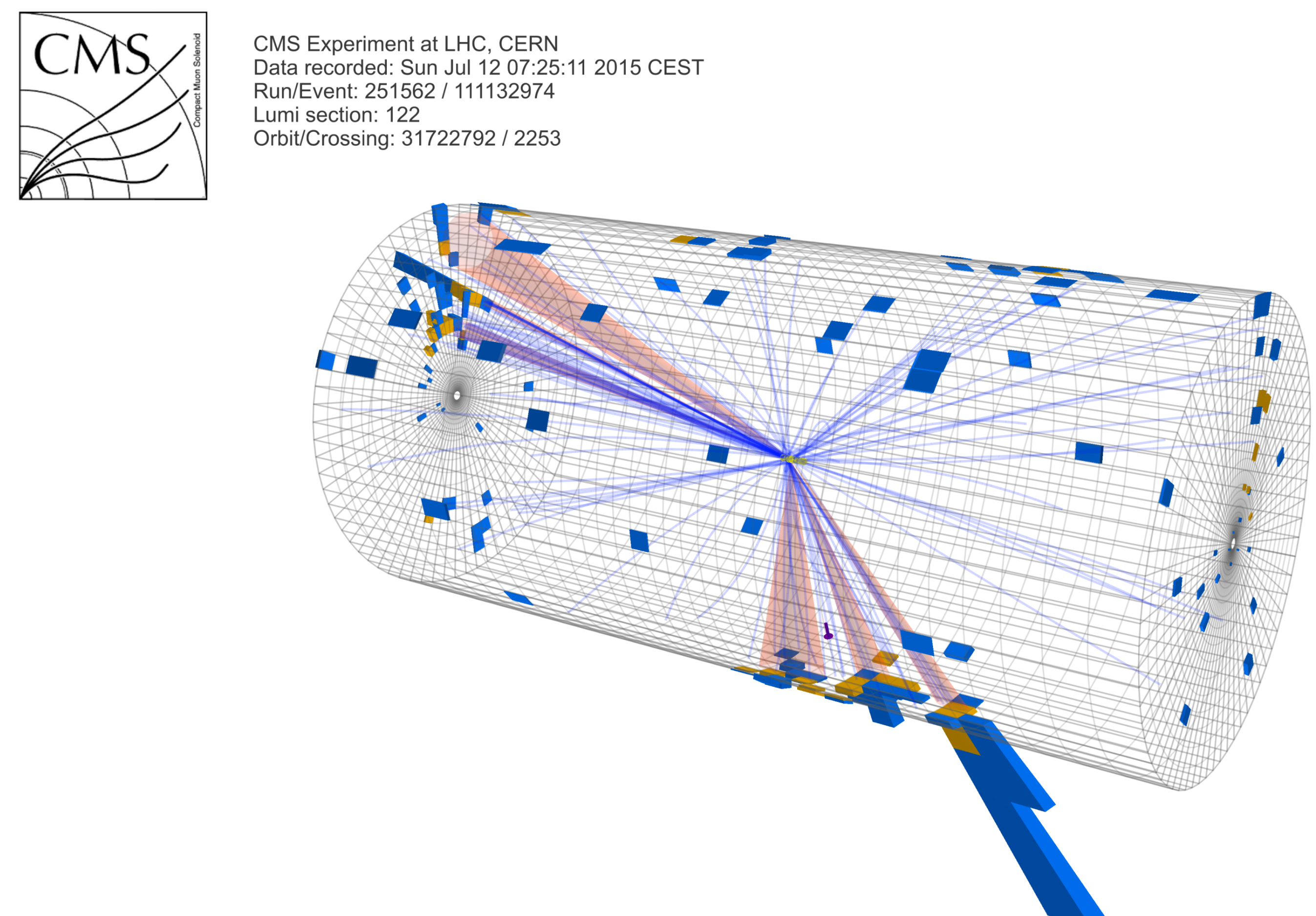
Summary & Outlook

- Using 19.7 fb-1 of data collected with the CMS detector in pp collisions at 8 TeV, no excess above the SM ttbar production was observed.
- We obtained the most stringent limit on the Mz’ and MgKK to date
- The development of substructure techniques for boosted topologies were key factors to achieve better limits in this analyzes
- A lot of refinement on the employed substructure techniques has been done in the past year and it is expected to be crucial for future analyzes
- Huge effort has been directed to improve the HLT algorithms such that they also consider these boosted topologies

Summary & Outlook

- Last year the LHC delivered ~ 4 fb^{-1} at $\sqrt{s}$=13TeV





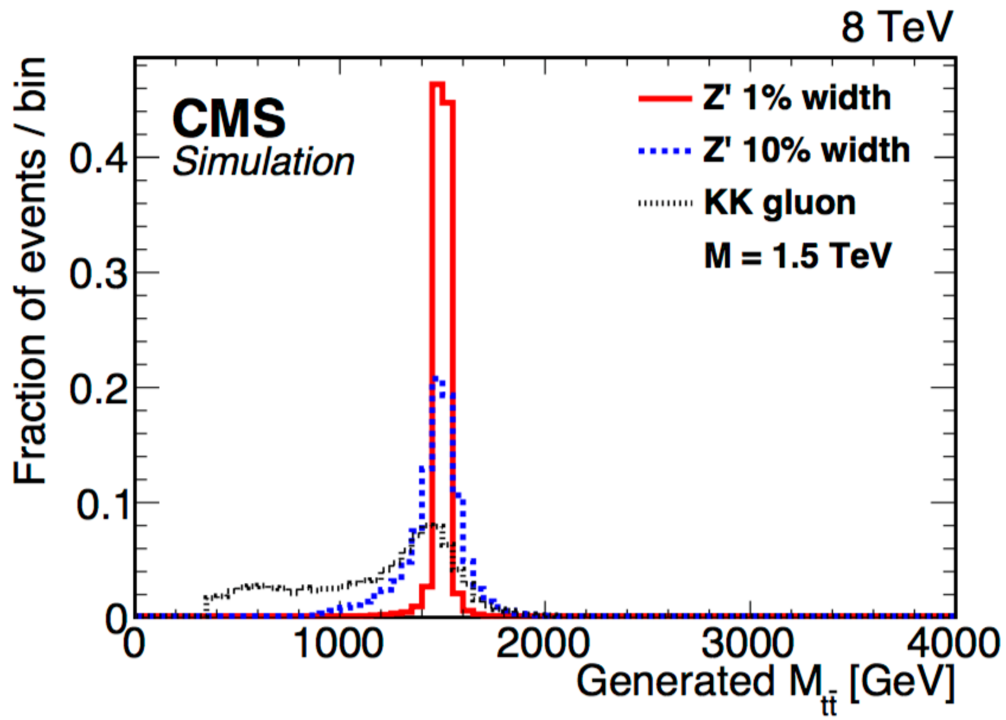
- Analysts have started looking at the new data and new results should be coming out soon …

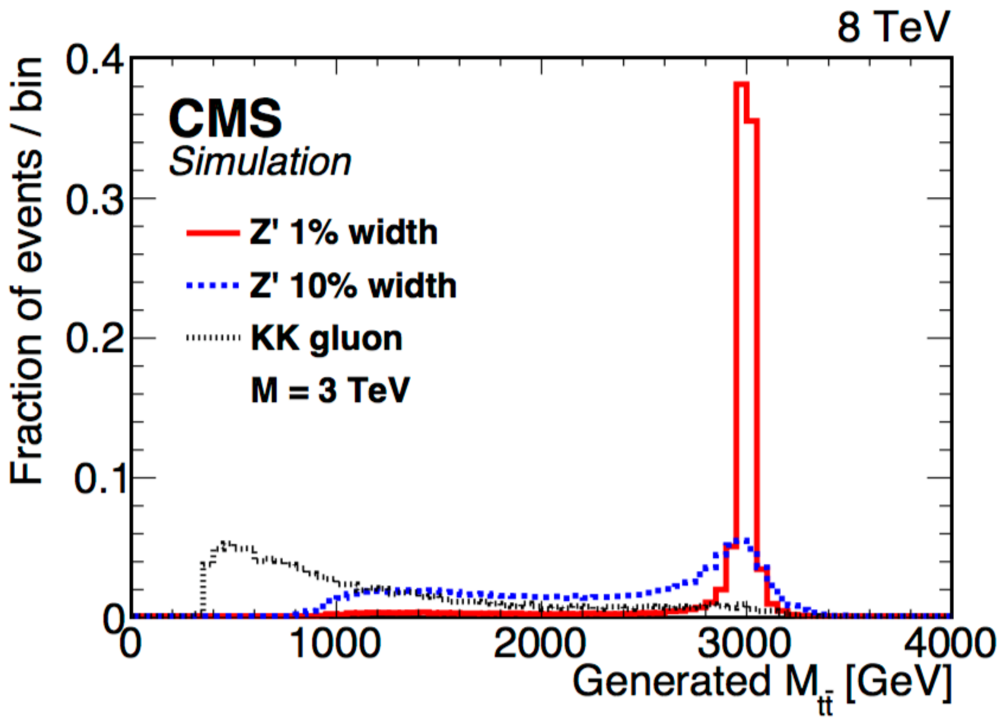
- Expect around the same or better sensitivity with ~3 fb^{-1} (at $\sqrt{s}$=13TeV) than what we had with 19.7 fb^{-1} at $\sqrt{s}$=8 TeV

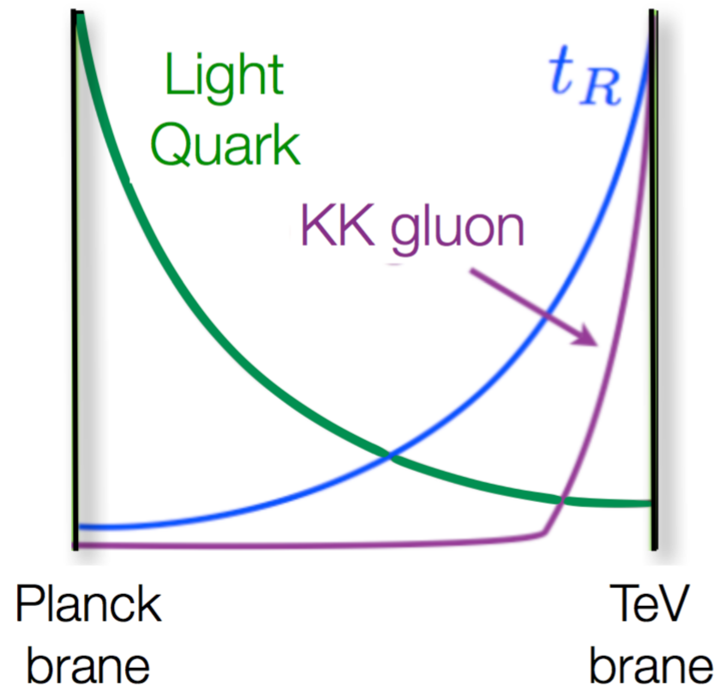
BACKUP

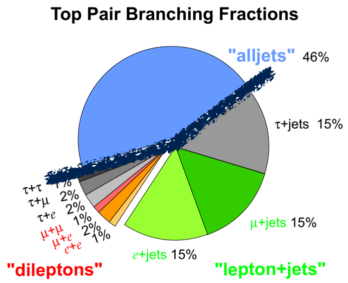
BSM

Bench mark models





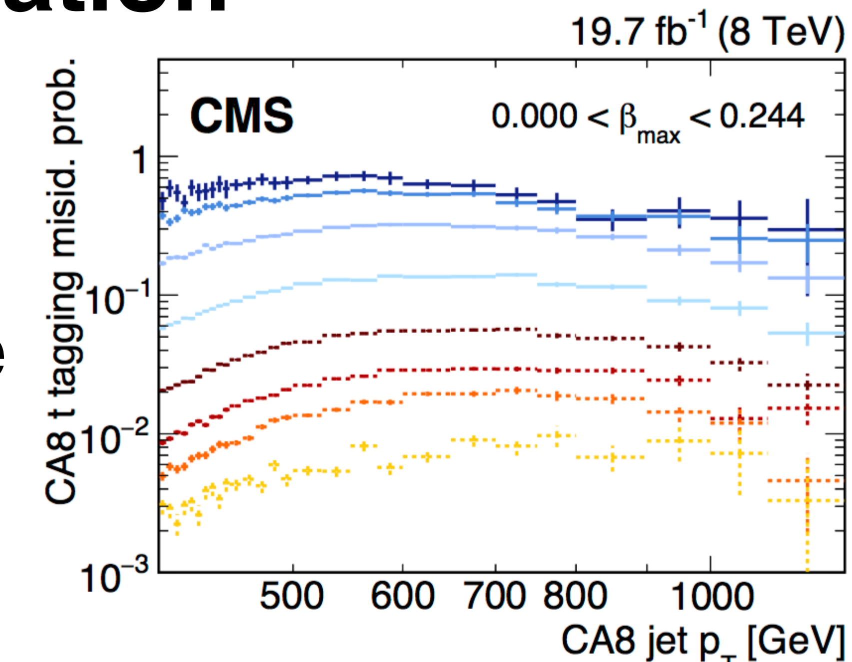


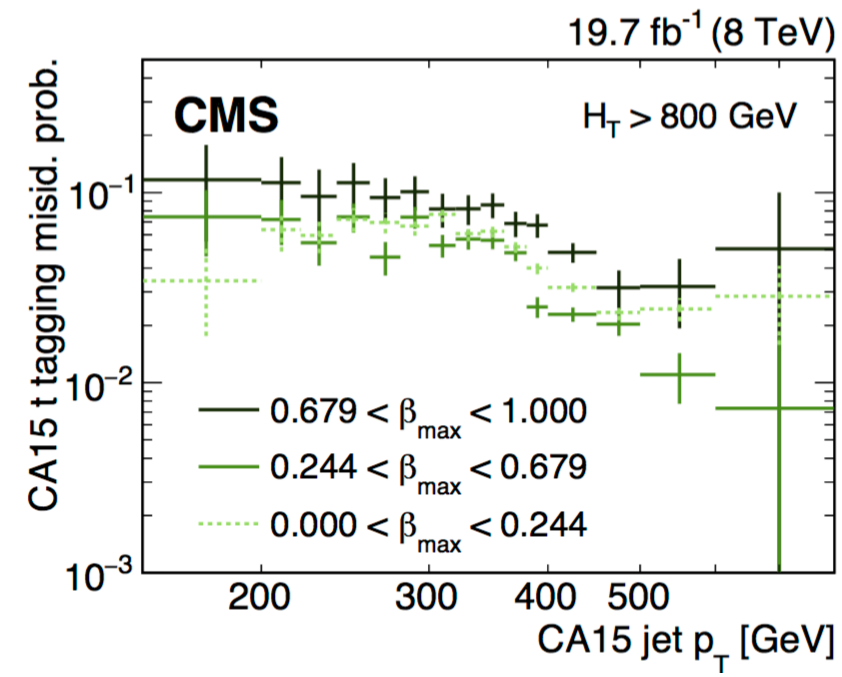


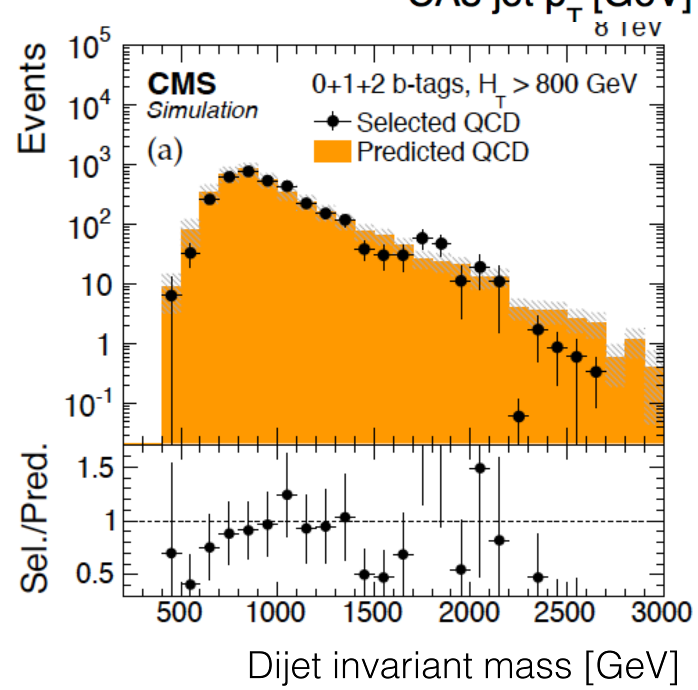
Hadronic channel

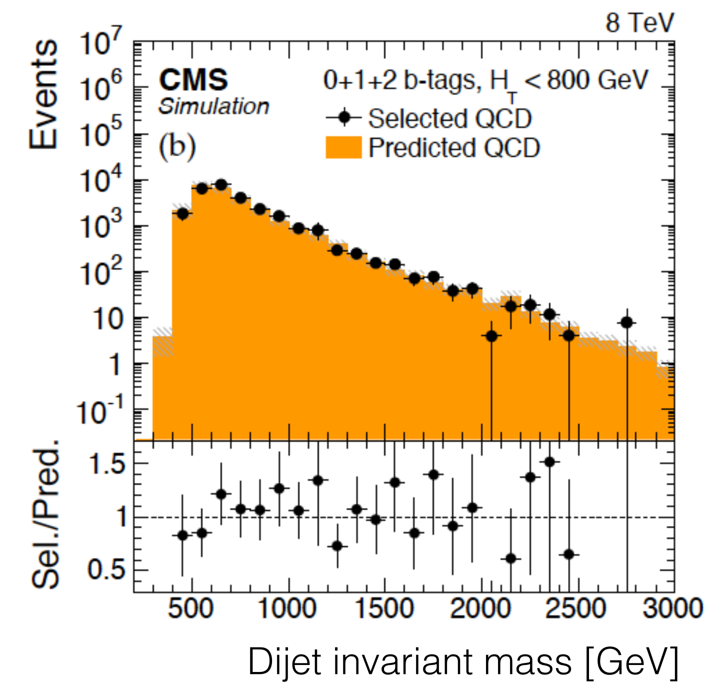
Background Estimation

- Non Top Multijet production (NTMJ) and SM tt production are the main backgrounds
- NTMJ production modeling is poor.
- To estimate NTMJ background, a data-derived method is employed.









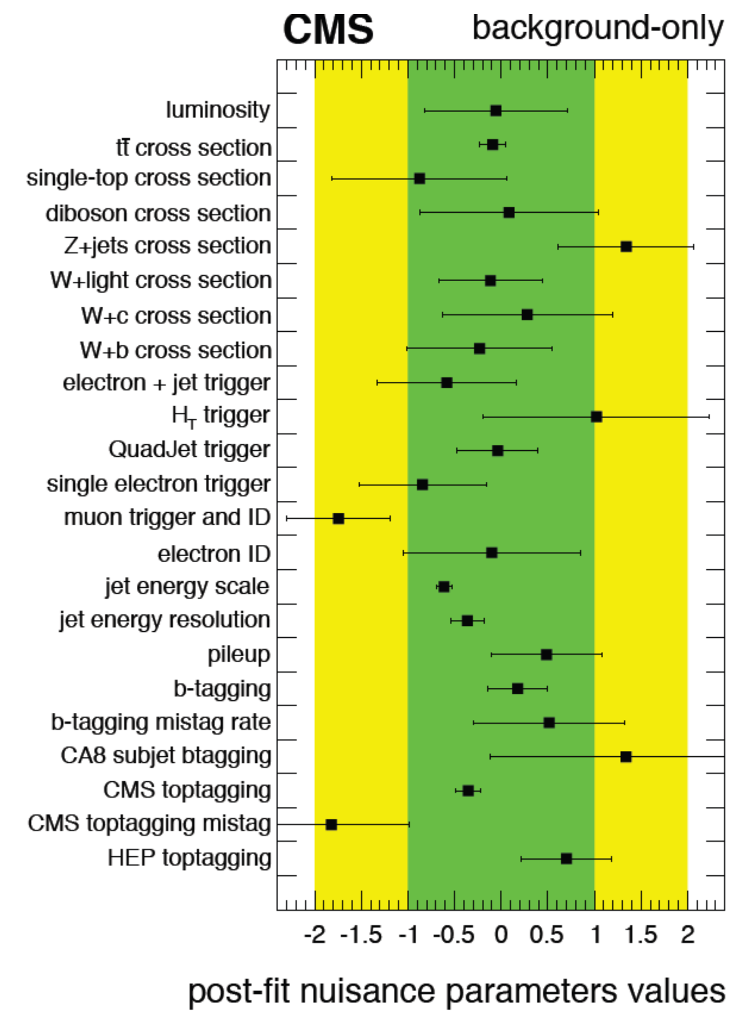
Combination

Systematics

Uncertainties originating from the same source are assumed 100% correlated

Source of uncertainty	Prior uncertainty	2ℓ	ℓ+jets	Had. channel high-mass	Had. channel low-mass
Integrated luminosity	2.6%	⊕	⊕	⊕	⊕
$t\bar{t}$ cross section	15%	⊕	⊕	⊕	⊕
Single top quark cross section	23%	⊕	⊕		
Diboson cross section	20%	⊕	⊕		
Z+jets cross section	50%	⊕	⊕		
W+jets (light flavor) cross section	9%		⊙		
W+jets (heavy flavor) cross section	23%		⊙		
Electron+jet trigger	1%		⊙		
H_T trigger	2%			⊕	⊕
Four-jet trigger	$\pm1\sigma(p_T)$				⊙
Single-electron trigger	$\pm1\sigma(p_T,\eta)$	⊙			
Single-muon trigger and id	$\pm1\sigma(p_T,\eta)$	⊕	⊕		
Electron ID	$\pm1\sigma(p_T,\eta)$	⊕	⊕		
Jet energy scale	$\pm1\sigma(p_T,\eta)$	⊕	⊕	⊕	⊕
Jet energy resolution	$\pm1\sigma(\eta)$	⊕	⊕	⊕	⊕
Pileup uncertainty	$\pm1\sigma$	⊕	⊕	⊕	⊕
b tagging efficiency(†)	$\pm1\sigma(p_T,\eta)$	⊕	⊕		⊕
b tagging mistag rate (†)	$\pm1\sigma(p_T,\eta)$	⊕	⊕		⊕
CA8 subjet b tagging	unconstrained			⊙	
CA8 t tagged jet efficiency	unconstrained		⊕	⊕	
CA8 t-tagged jet mistag	±25%		⊙		
CA15 t-tagged jet efficiency	$\pm1\sigma(p_T,\eta)$				⊙
QCD multijet background	sideband			⊙	⊙
MC statistical uncertainty		⊙	⊙	⊙	⊙
PDF uncertainty	$\pm1\sigma$	⊕	⊕	⊕	⊕
$t\bar{t}$ ren. and fact. scales	$4Q^2$ and $0.25Q^2$	⊕	⊕	⊕	⊕
W+jets ren. and fact. scales	$4Q^2$ and $0.25Q^2$		⊙		
W+jets matching scale μ	2μ and 0.5μ		⊙		

(†) AK5 and CA15 subjets



⊙ Uncorrelated

⊕ Correlated