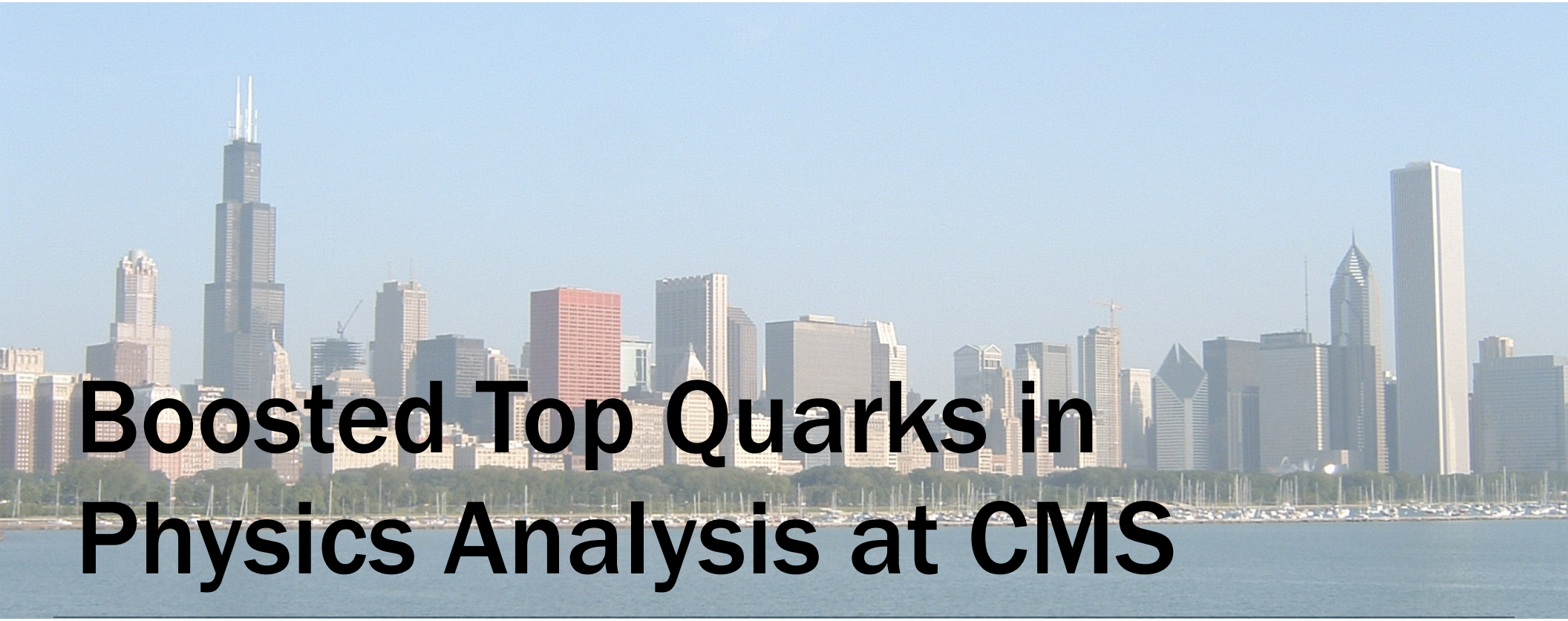


Boosted Top Quarks in Physics Analysis at CMS

Justin Pilot, *University of California — Davis*
on behalf of the CMS Collaboration

BOOST 2015 Conference
Chicago, Illinois

10 August 2015

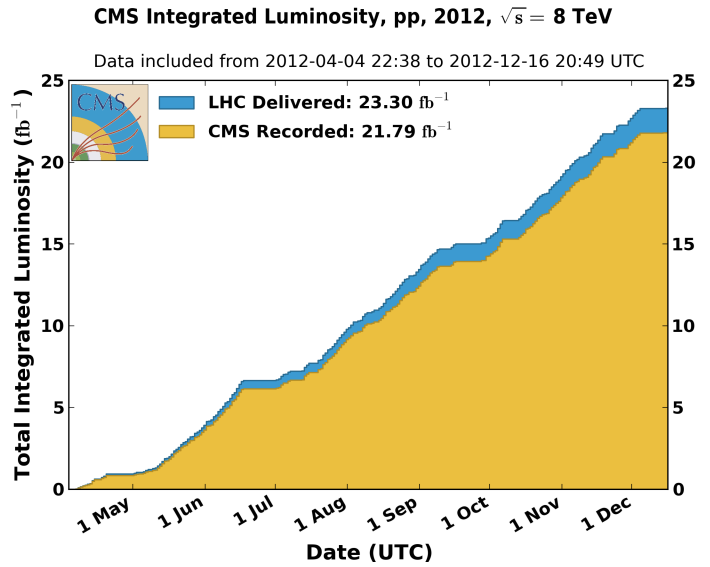
Introduction

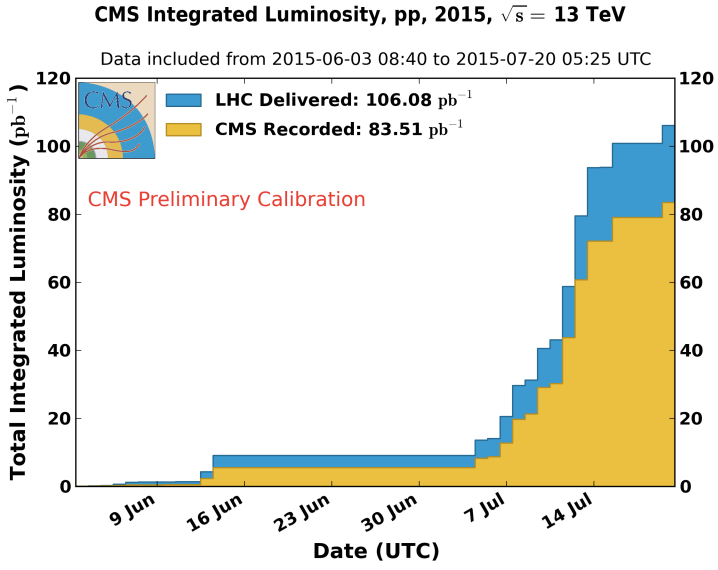
- Boosted top reconstruction becoming more prevalent in CMS analyses
  - Several different algorithms in use
  - Sensitive to wide range of physics processes
  - Large dataset for commissioning object reconstruction and analysis methods

- Today I will give a summary of some recent CMS results relying on boosted top tagging
  - tt resonances (Z')
  - tb resonances (W')
  - SUSY partners (stop)

- For analyses utilizing boosted W/Z/H signatures, see talk by J. Dolen
- Also important in dark matter searches
  - See talk by K. Hahn

- Critical to improve, optimize, and re-commission algorithms for LHC Run 2
  - See talk by G. Kasieczka on 13 TeV performance



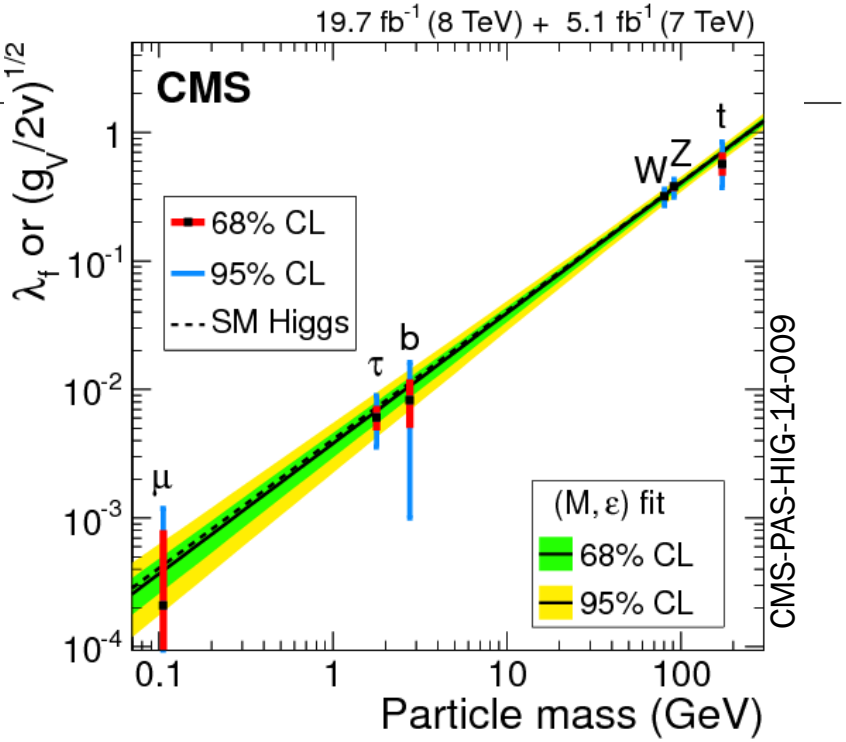


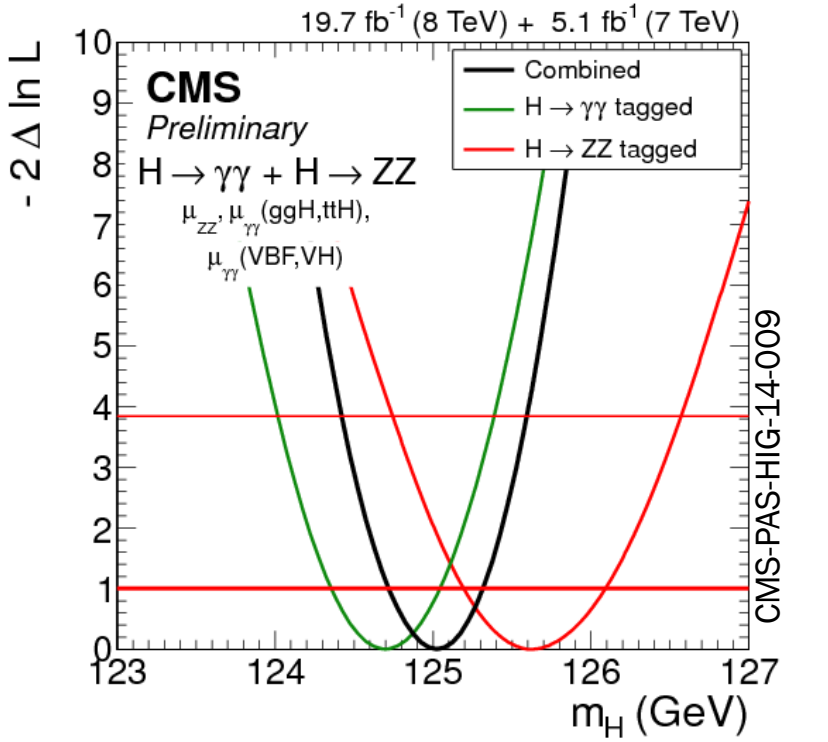
Motivation

- Higgs discovery gives missing piece of the Standard Model

- Precision measurements trying to answer further questions
  - What is the solution to the hierarchy problem?
  - Top quark gives large contribution to Higgs mass quantum correction

- Natural to probe connection to new physics through the top quark
  - Many physics models predict particles in the 1-3 TeV range
  - Perfect for utilizing boosted top reconstruction



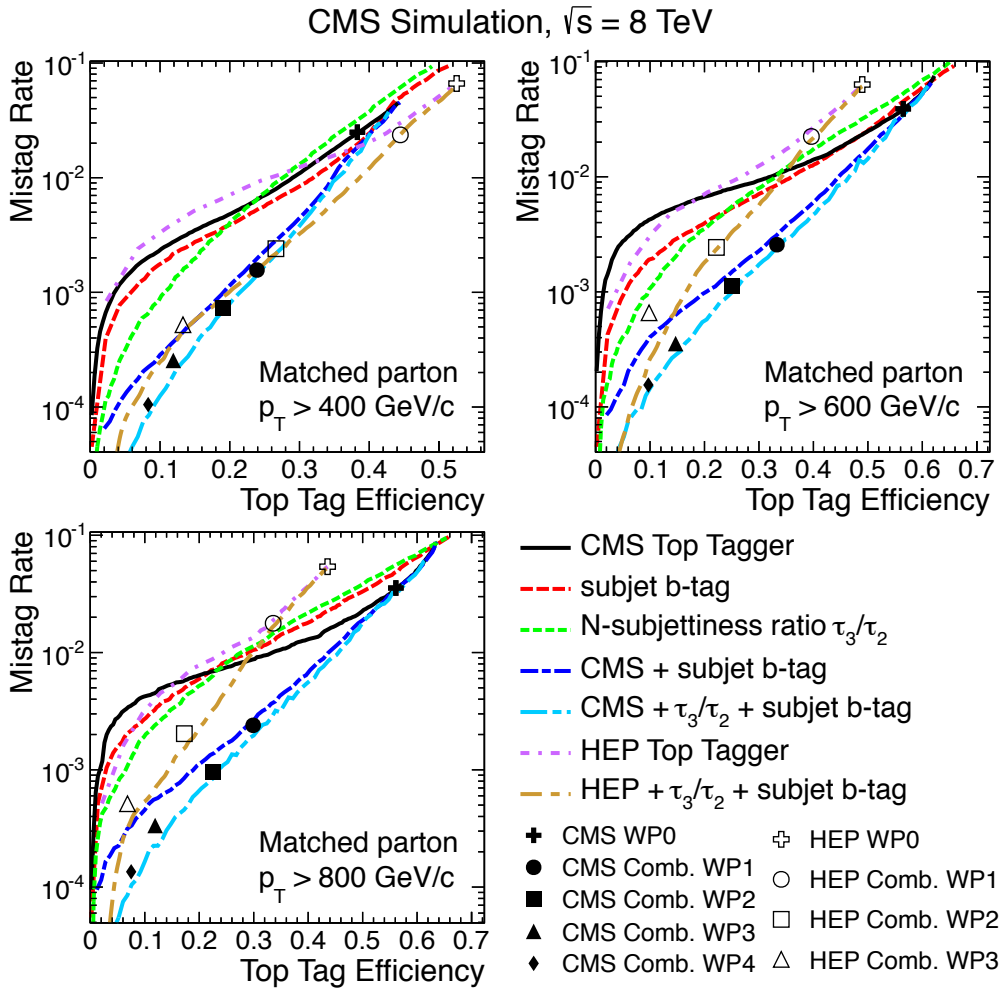


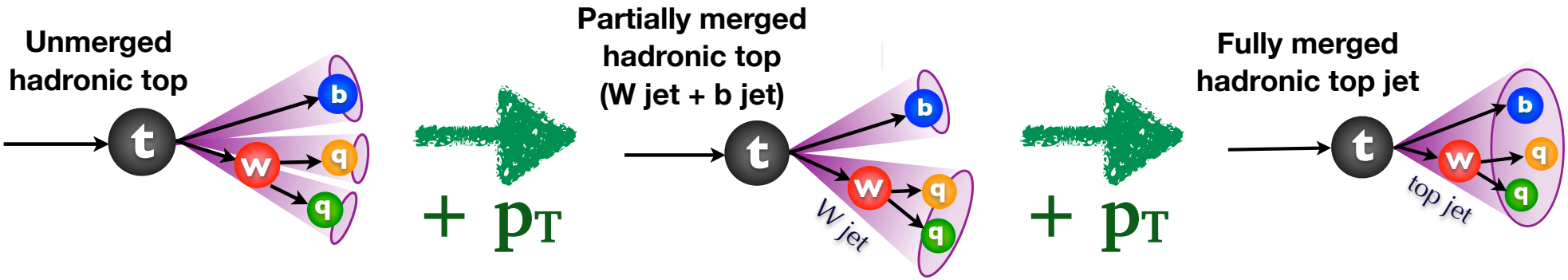
Object Reconstruction

Boosted Top Tagging

CMS-PAS-JME-13-007

- Two algorithms in use at CMS
- For lower boosts, use R = 1.5 jets with the HEPTopTagger algorithm
  - Good for p_T above ~200 GeV
- For high boosts, use R = 0.8 jets with the CMSTopTagger algorithm
  - Better efficiency for p_T above ~400 GeV
- Currently re-optimizing algorithm choices for Run 2 analysis





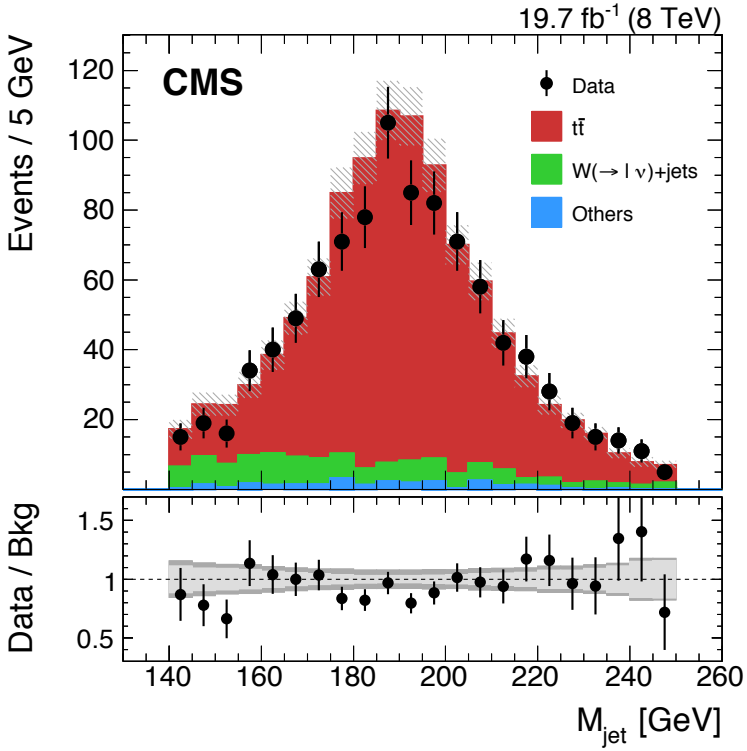
CMS Top Tagger

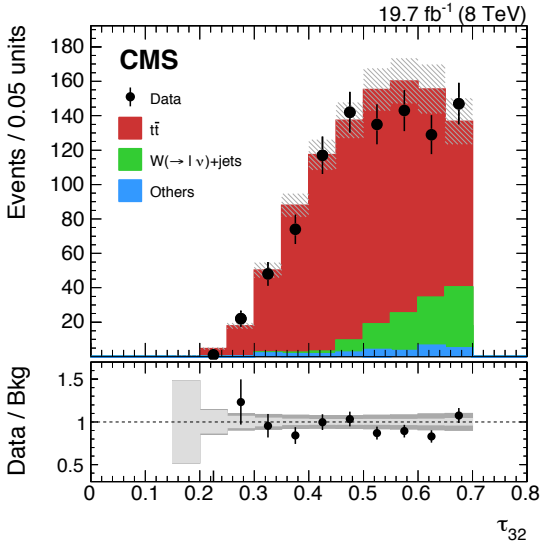
arXiv:1506.3062 /
CMS-B2G-13-008

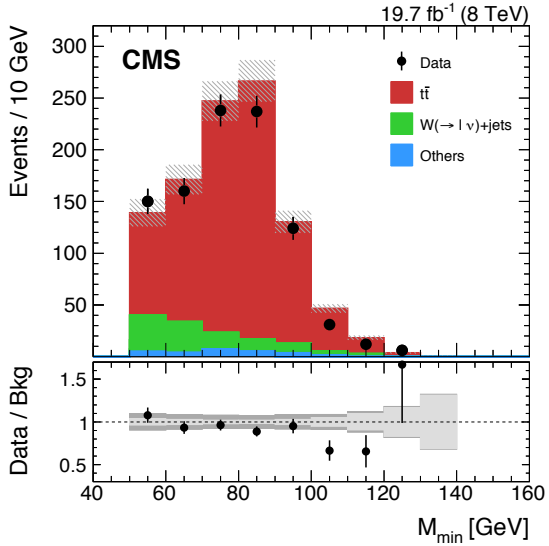
- Decomposition of jet into up to 4 subjets based on adjacency, p_T criteria

- Top tagging requirements:
  - Jet mass in [140, 250] GeV window
  - 3 or more subjets
  - Minimum di-subjet mass above 50 GeV
  - N-subjettiness $\tau_{32} < 0.7$

- Efficiencies measured in lepton+jets sample
  - Agreement with simulation within 5% for central jets, 30% in forward region

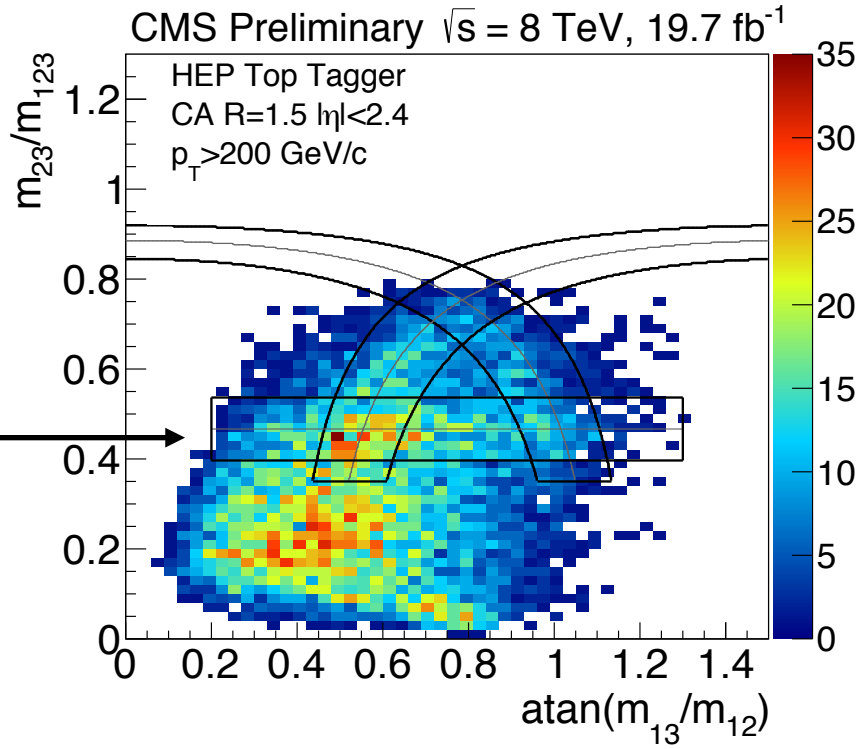






HEP Top Tagger

- Larger R = 1.5 jets used for reconstruction
  - Use jets with p_T > 200 GeV
  - Decompose jet into 3 subjets
  - Subjet combinations used to identify W boson decay products
  - Jet mass in [140, 250] GeV window

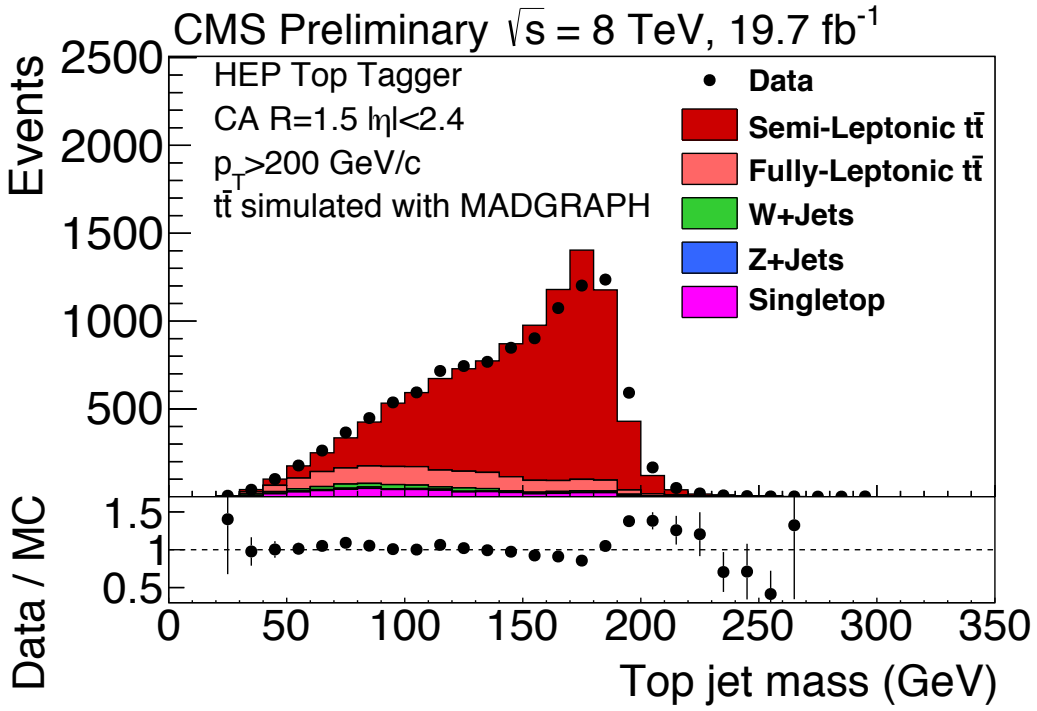


- Mismodeling of substructure leads to efficiency scale factors of ~10-20% depending on p_T, η

Cumulative data-simulation scale factor - HEP Top Tagger, HEP Combined Tagger

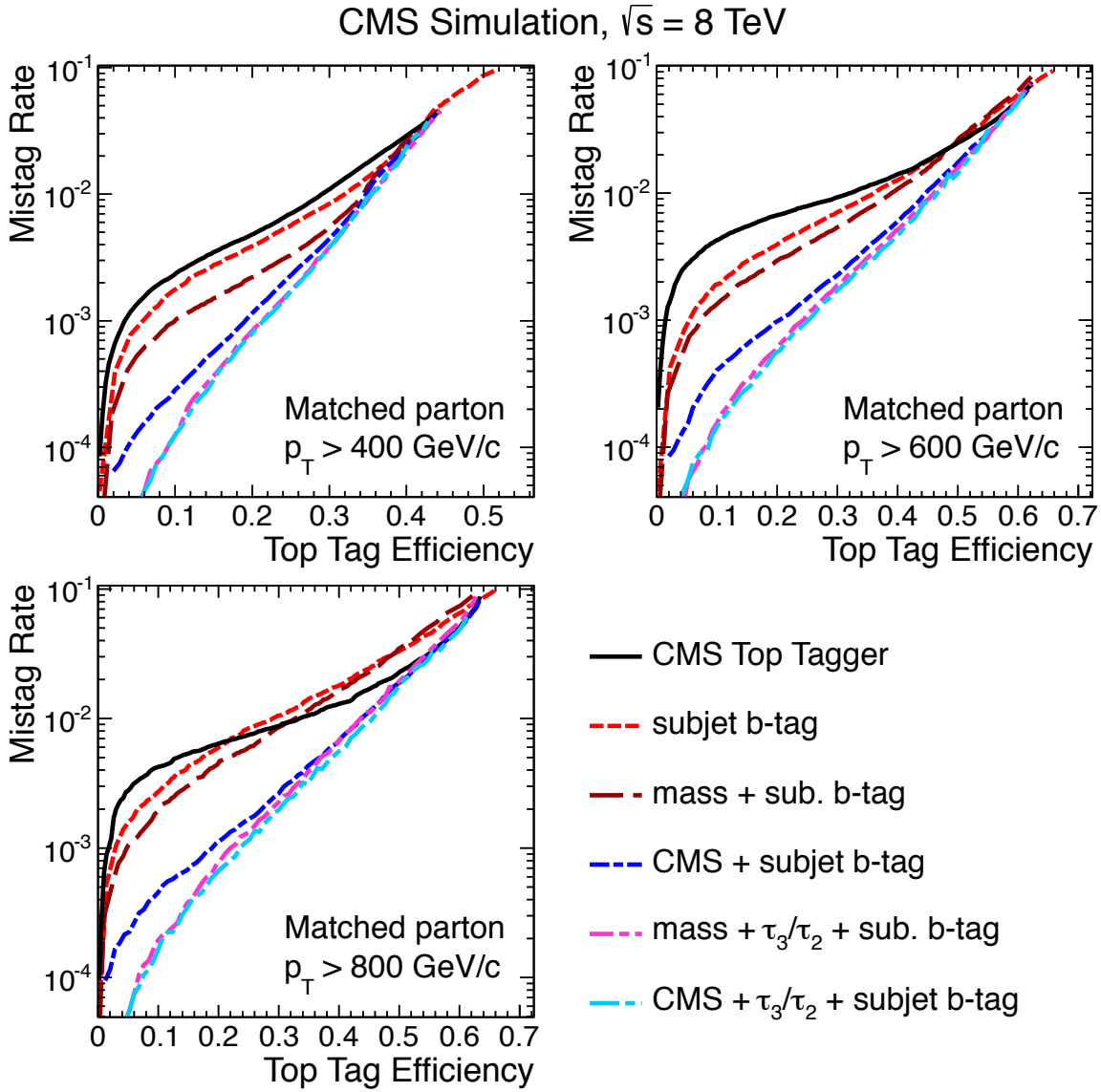
$\|\eta\| < 1.0$				
Tagger	p_T bin (GeV/c)	MADGRAPH	POWHEG	MC@NLO
HEP Combined WP2	$200 < p_T < 250$	0.91 ± 0.04	0.92 ± 0.04	0.88 ± 0.04
	$250 < p_T < 400$	0.93 ± 0.03	0.95 ± 0.03	0.93 ± 0.03
	$p_T > 400$	1.15 ± 0.07	1.36 ± 0.07	1.19 ± 0.07
HEP Combined WP3	$200 < p_T < 250$	0.86 ± 0.05	0.86 ± 0.05	0.86 ± 0.05
	$250 < p_T < 400$	0.91 ± 0.04	0.93 ± 0.04	0.93 ± 0.04
	$p_T > 400$	0.98 ± 0.09	1.10 ± 0.12	1.10 ± 0.12

$1.0 < \|\eta\| < 2.4$				
Tagger	p_T bin (GeV/c)	MADGRAPH	POWHEG	MC@NLO
HEP Combined WP2	$200 < p_T < 250$	0.95 ± 0.05	0.93 ± 0.06	0.93 ± 0.05
	$250 < p_T < 400$	0.91 ± 0.04	0.95 ± 0.05	0.95 ± 0.04
	$p_T > 400$	0.85 ± 0.11	0.95 ± 0.15	0.99 ± 0.13
HEP Combined WP3	$200 < p_T < 250$	1.02 ± 0.07	1.00 ± 0.08	0.96 ± 0.07
	$250 < p_T < 400$	0.90 ± 0.05	0.97 ± 0.06	0.93 ± 0.05
	$p_T > 400$	0.85 ± 0.16	1.00 ± 0.22	0.99 ± 0.19



Subjet b-Tagging

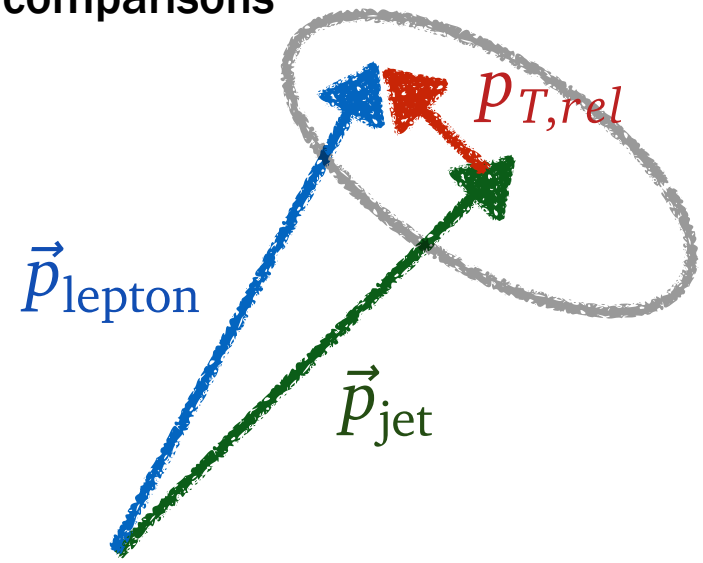
- Subjet b-tagging added to many search analyses using boosted objects
  - Usually divide events into categories of differing purity
- Increases QCD rejection dramatically for same tagging efficiency



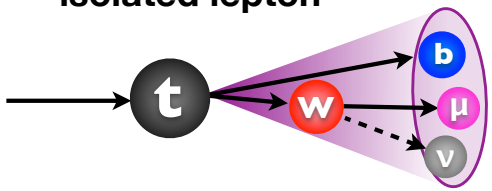
Non-Isolated Leptons

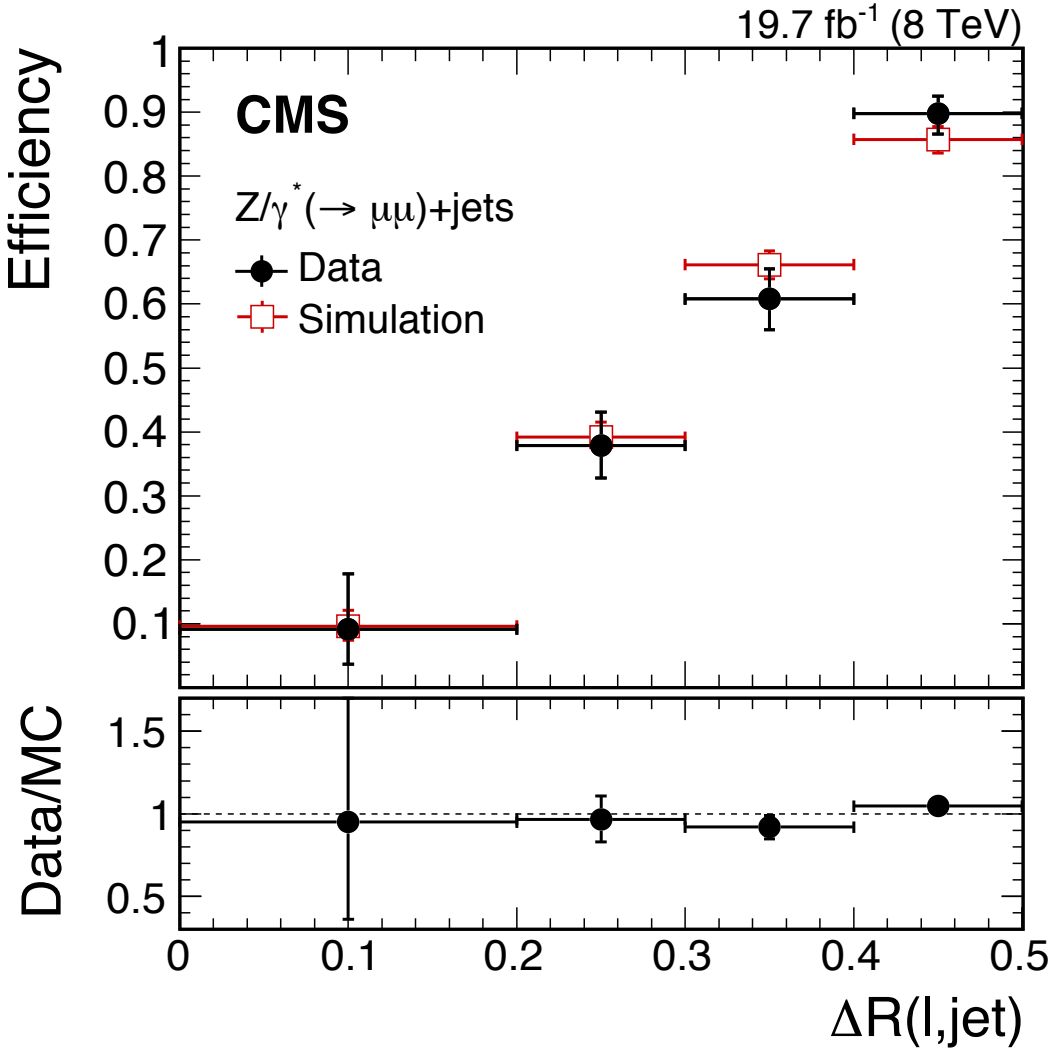
arXiv:1506.3062 /
CMS-B2G-13-008

- For lepton+jets modes, need to efficiently identify non-isolated leptons
  - Standard isolation requirements will remove large fraction of signal acceptance
  - Use component of p_T transverse to jet axis ($p_{T,rel}$)
  - Efficiencies measured and validated in data/simulation comparisons



Leptonic top with non-isolated lepton



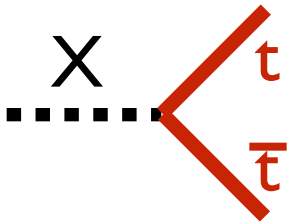


tt Resonances

tt Resonances

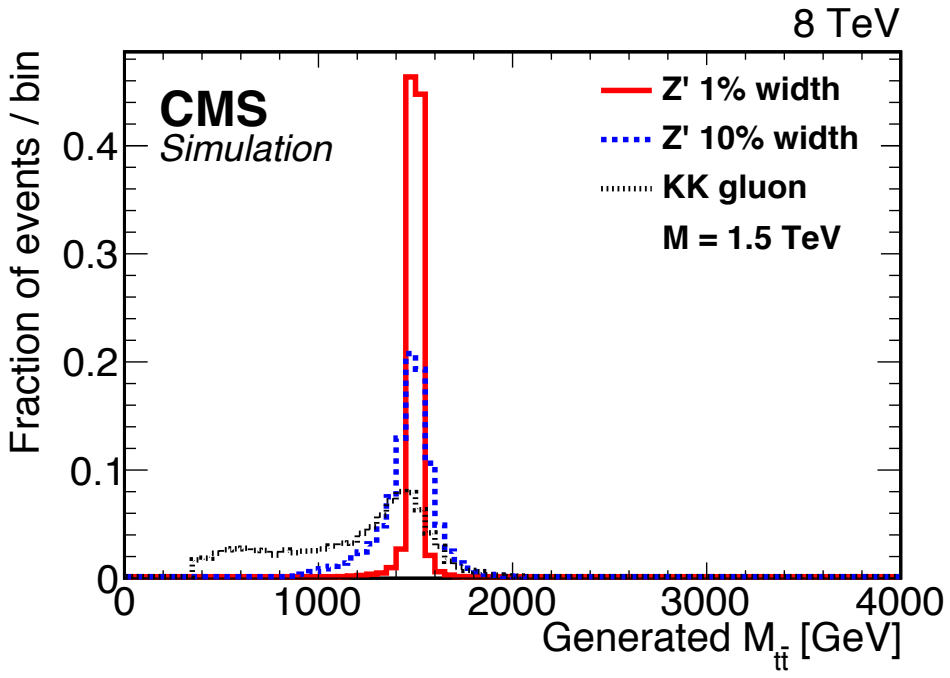
arXiv:1506.3062 / CMS-B2G-13-008

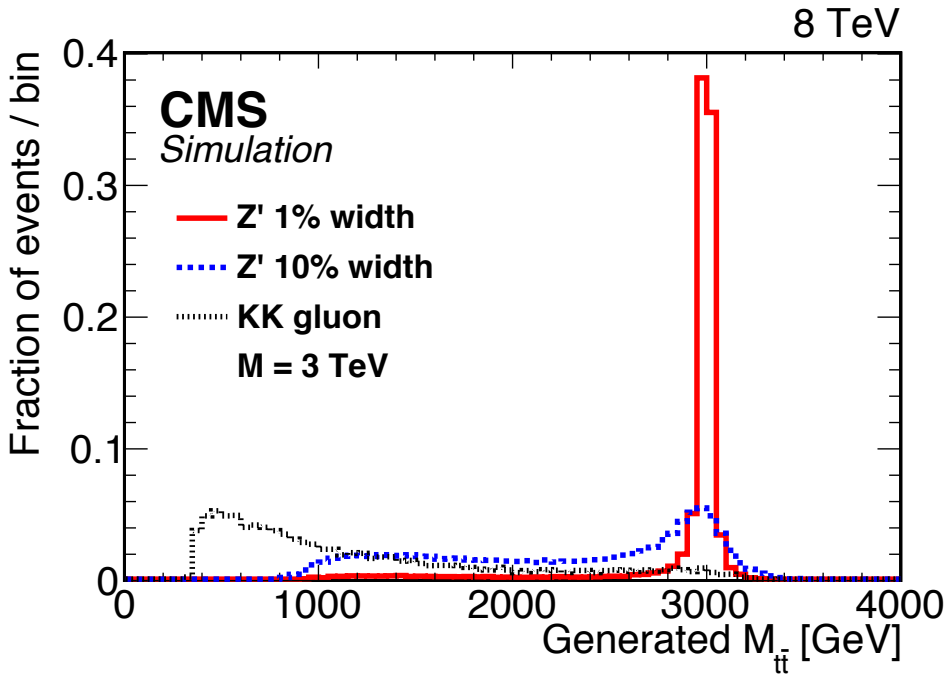
- Search for new heavy resonances decaying to top quark pairs



- Use invariant mass of top quark pair for signal discrimination
  - Narrow (1%) Z'
  - Wide (10%) Z'
  - Randall-Sundrum KK gluon (16% width)

- CMS recently submitted legacy combination of several analyses
  - http://arxiv.org/abs/1506.03062



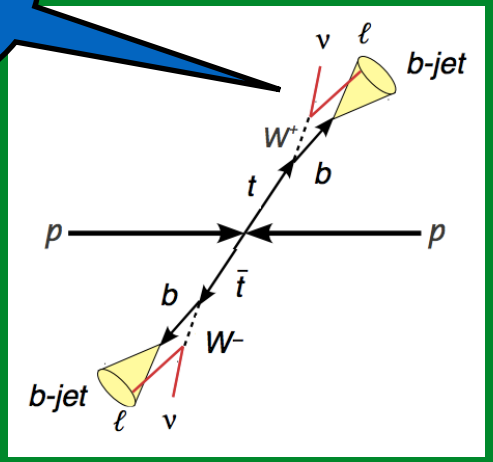


Channels

- Many final state topologies utilized

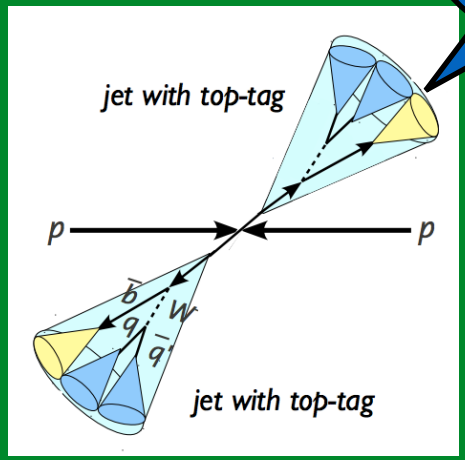
Non-iso. leptons

Dilepton

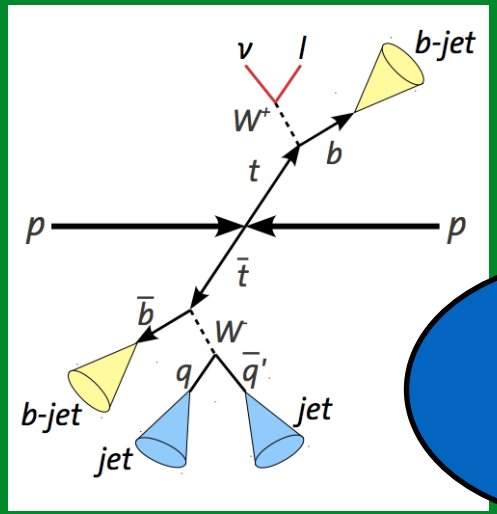


All-Hadronic

Top tagging

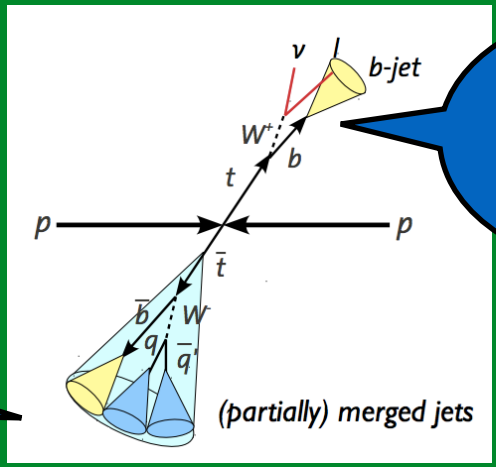


Lepton+jets (Resolved)



W, top tagging

Lepton+jets (Boosted)

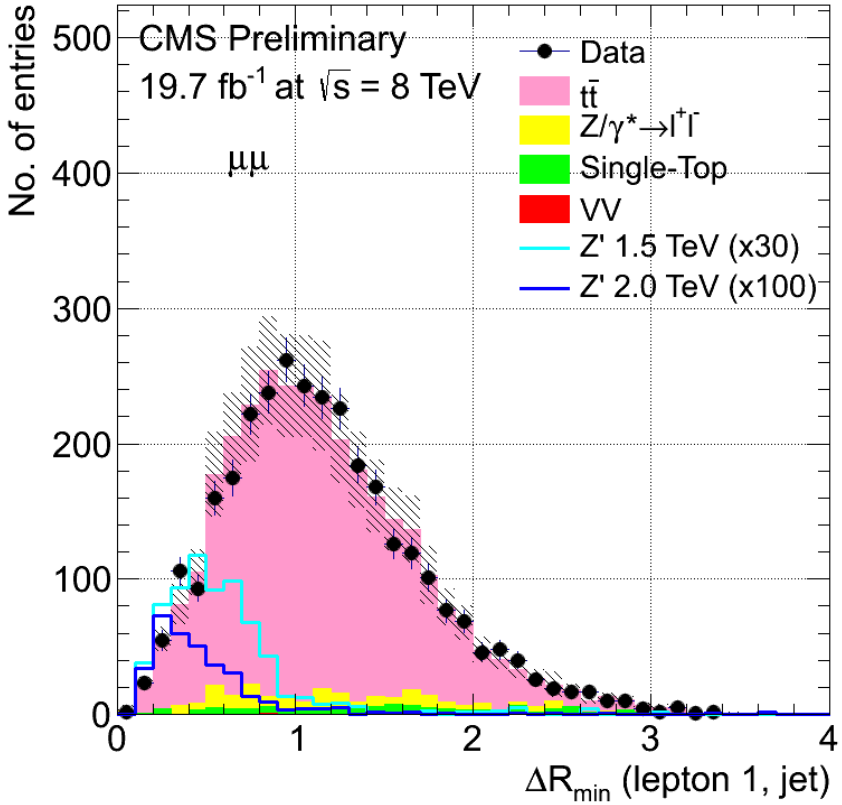


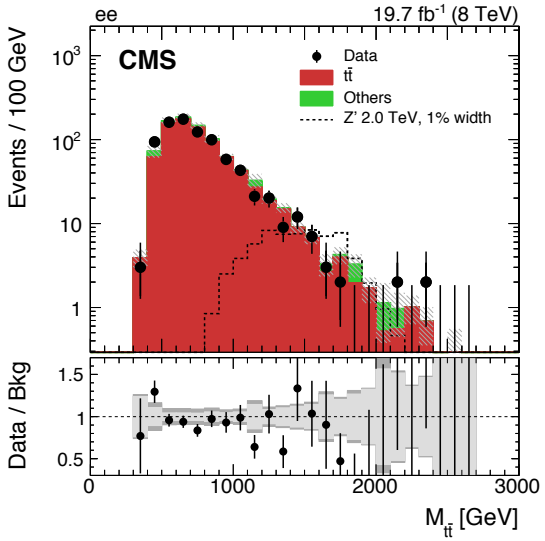
Non-iso. leptons

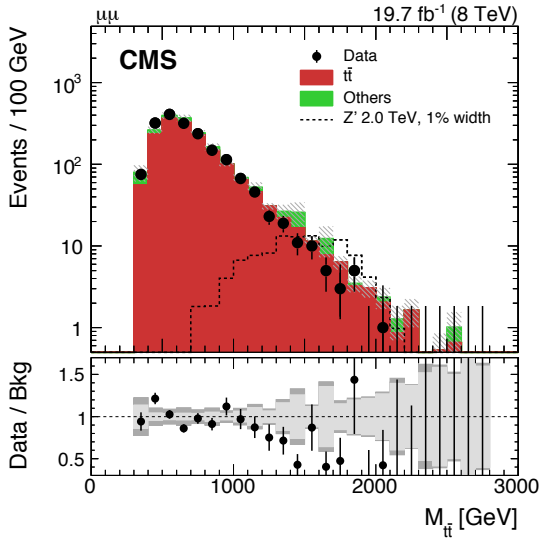
Dilepton Channel

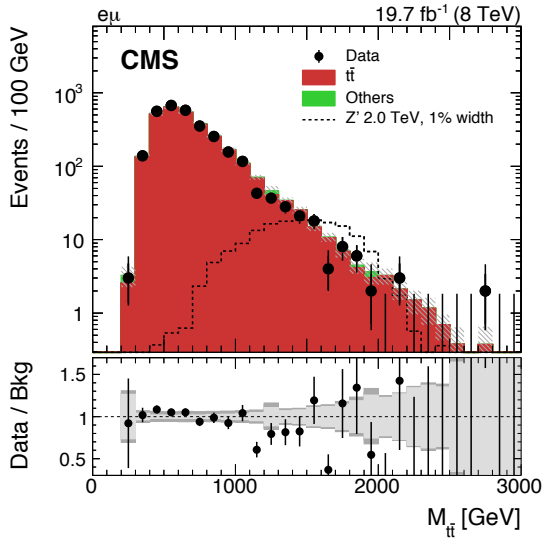
arXiv:1506.3062 /
CMS-B2G-13-008

- Select 2 non-isolated leptons, 2 jets, and missing ET
  - ΔR distribution used to extract ttbar normalization
- Events divided into categories based on b-tagging
  - 1 tight b-tagged jet
  - 2 loose b-tagged jets
- Mass is computed from two leptons, two jets, and missing ET from neutrinos









Lepton+Jets Channel (Boosted)

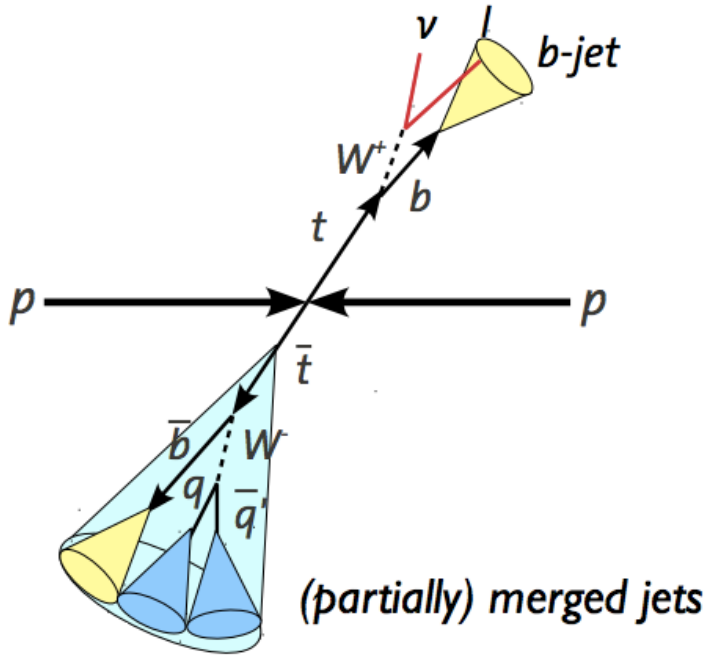
arXiv:1506.3062 / CMS-B2G-13-008

- Maintains sensitivity to resonances above 1 TeV

- 1 electron or muon
- At least two jets, pT > 150, 50 GeV
- Missing E_T

- Objects assigned to leptonic or hadronic hemisphere
  - Chi-squared score used to find best top mass reconstruction
  - Can use both W and top jets

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

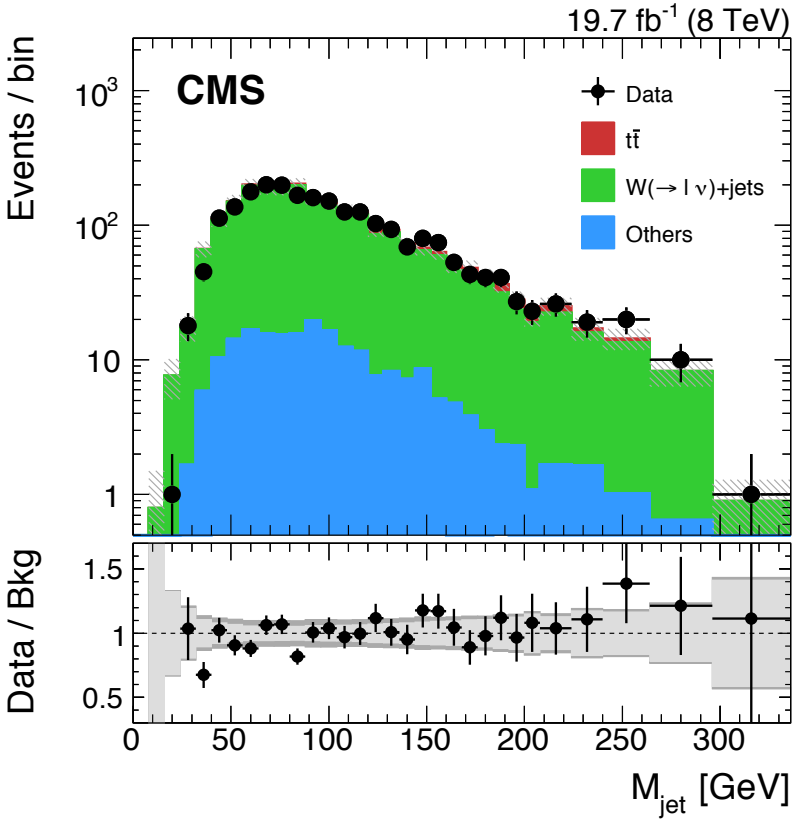


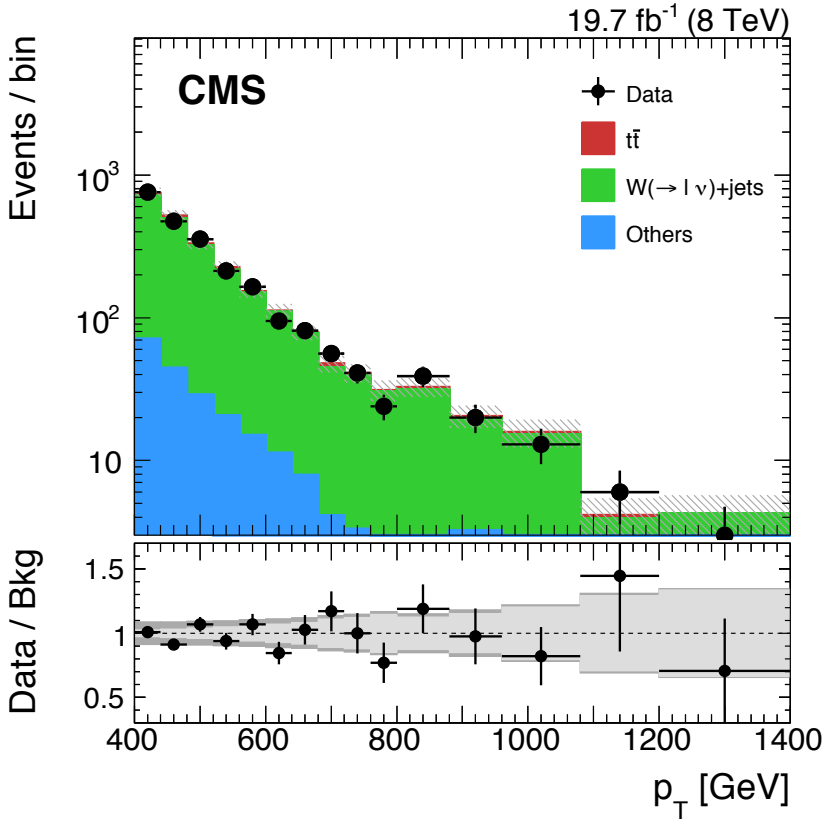
- Cascading selection with all-hadronic channel
  - 1 top-tag + 1 b-tag
  - 1 top-tag
  - 0 top-tag + 0 b-tag

Lepton+Jets Channel (Boosted)

arXiv:1506.3062 / CMS-B2G-13-008

- Mistag rate determined from W+jets control region
  - Used for normalization of non-top background
- Scale factor for top pair background determined in-situ during limit setting
- Measure SF value of 0.83 ± 0.21 in W+jets sample

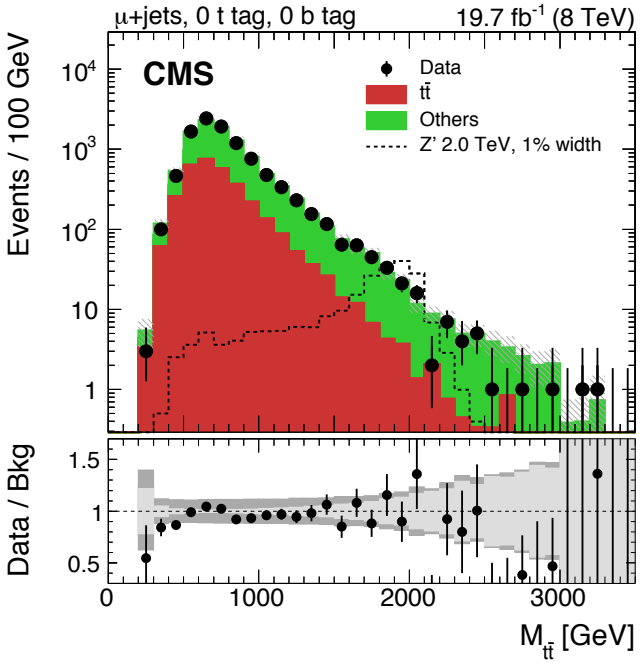


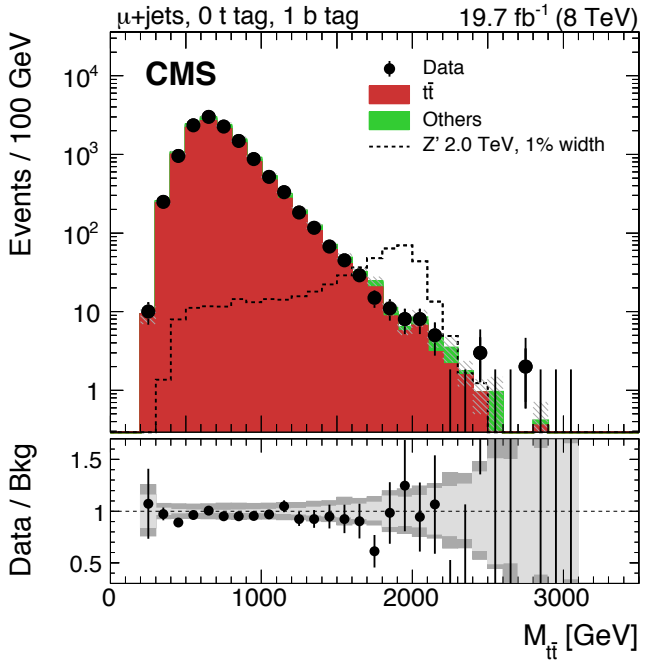


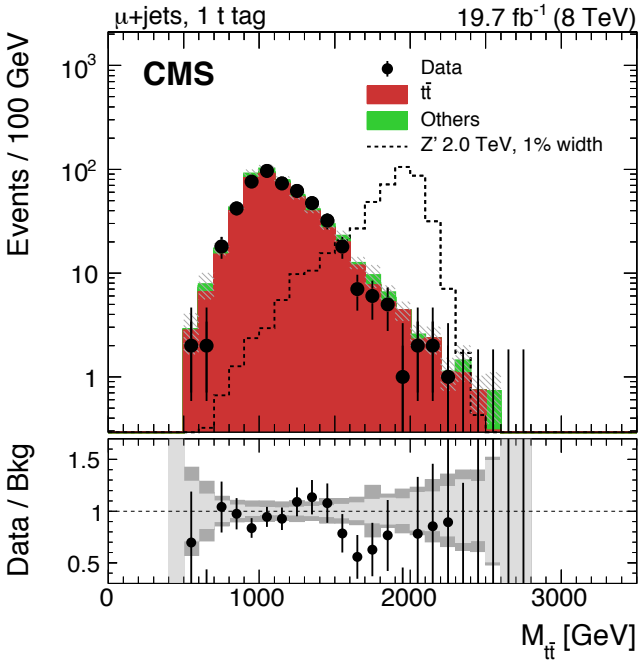
Lepton+Jets Channel (Boosted)

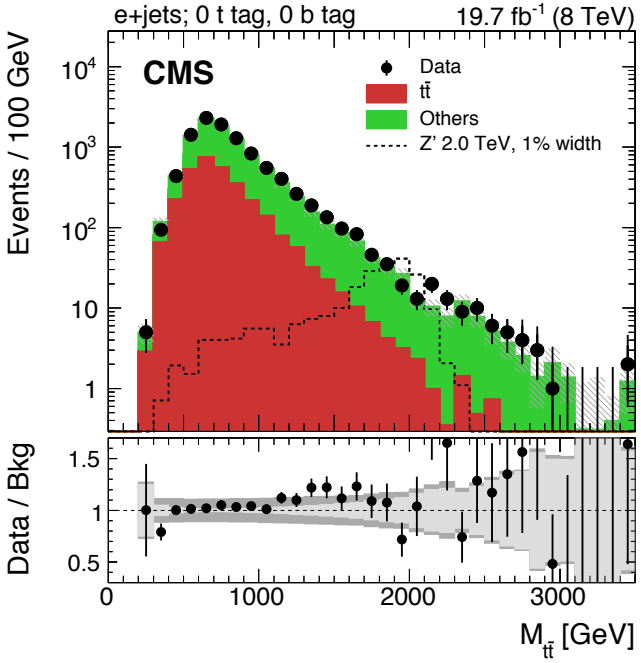
arXiv:1506.3062 /
CMS-B2G-13-008

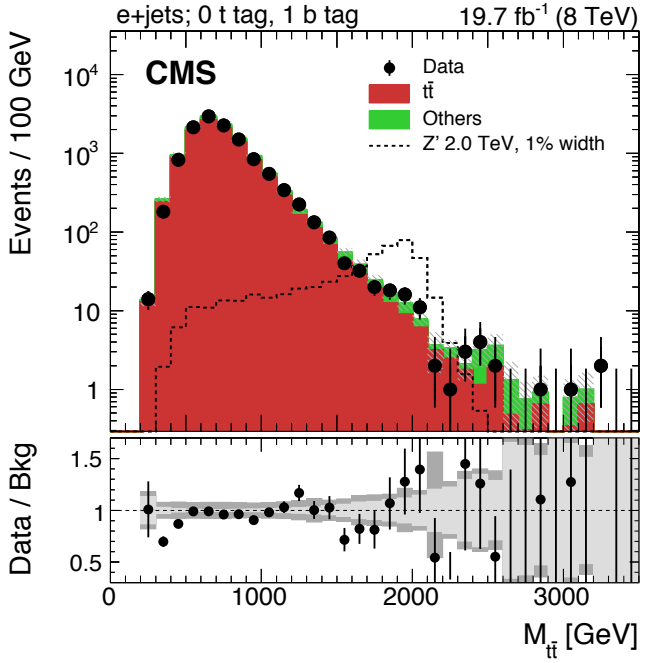
- **Invariant mass distributions for the event categories**

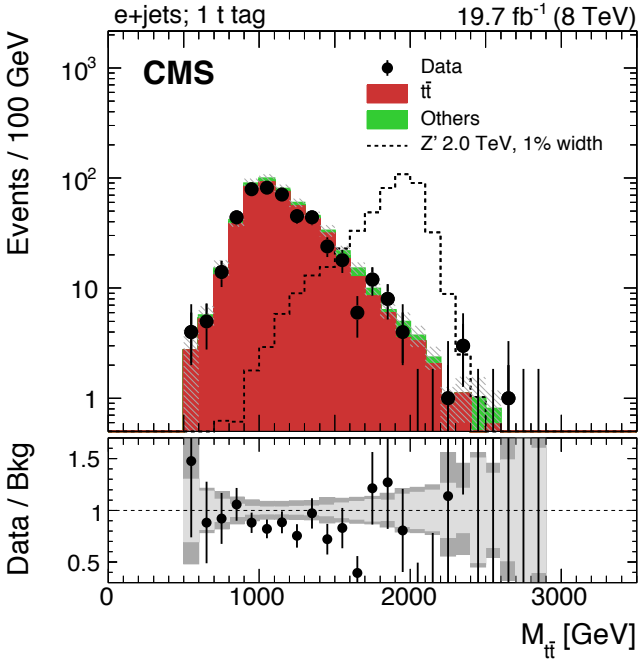








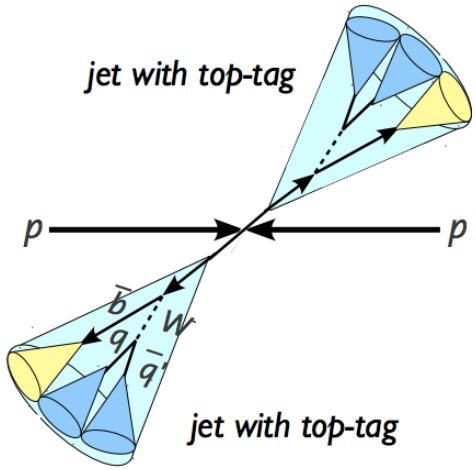




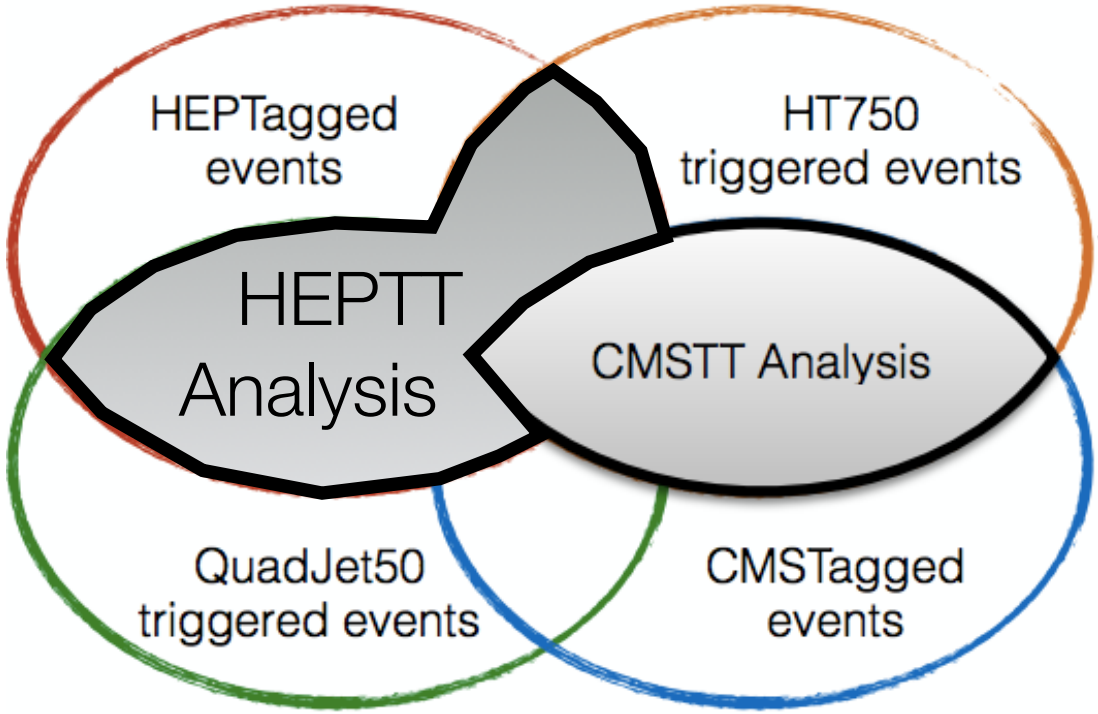
All-Hadronic Channel

arXiv:1506.3062 /
CMS-B2G-13-008

- Two selections for optimization across mass range:
  - Low mass — two R = 1.5 jets, pT > 200 GeV, HEP top-tagged
  - High mass — two R = 0.8 jets, pT > 400 GeV, CMS top-tagged
  - N-subjettiness τ_{32}, subjet b-tagging added for latest analysis
- Divide events based on number of subjet b-tags, rapidity difference between top candidate jets, event H_T

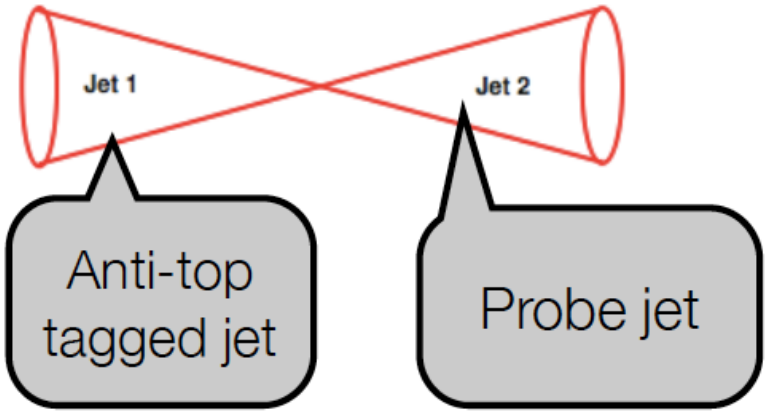


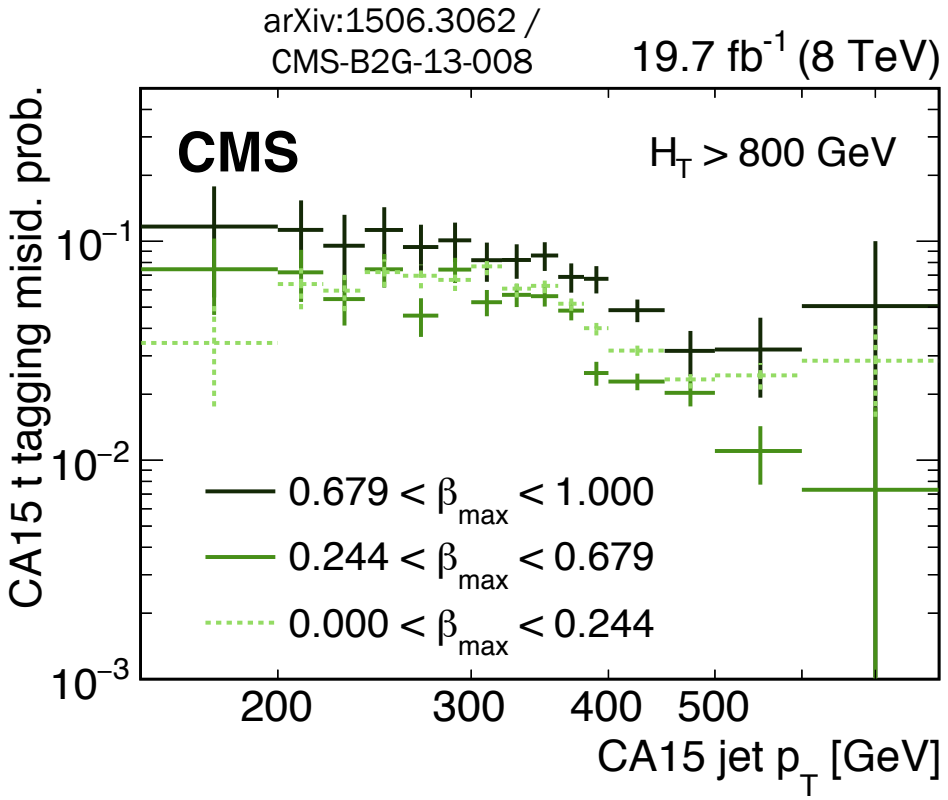
	Subjet b-tags	$\lvert\Delta y\rvert$	H_T
High Mass	0, 1, 2	> 1.0 < 1.0	—
Low Mass	0, 1, 2	—	> 800 < 800 GeV

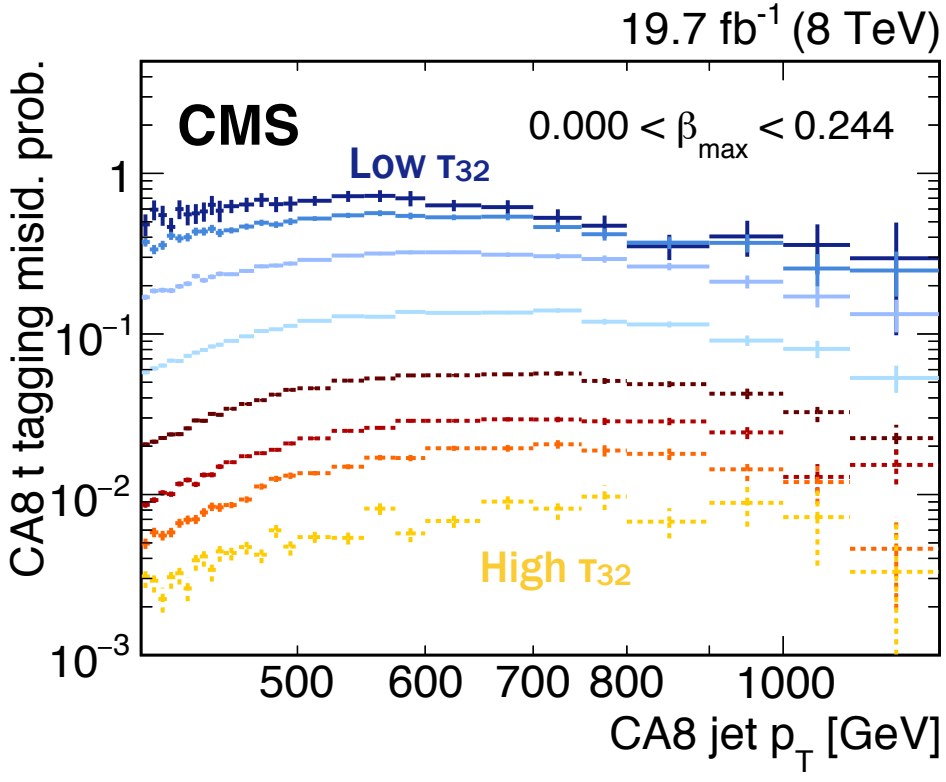


All-Hadronic Channel

- Main background is QCD multijet production
  - Estimated using data-driven method
- Mistag rate extracted from a sample of QCD events selected by anti-top-tagging
  - Parameterized as a function of jet p_T, τ_{32}, subjet b-tag score

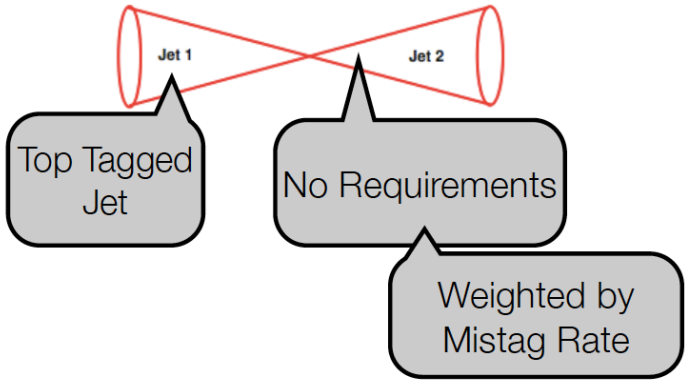


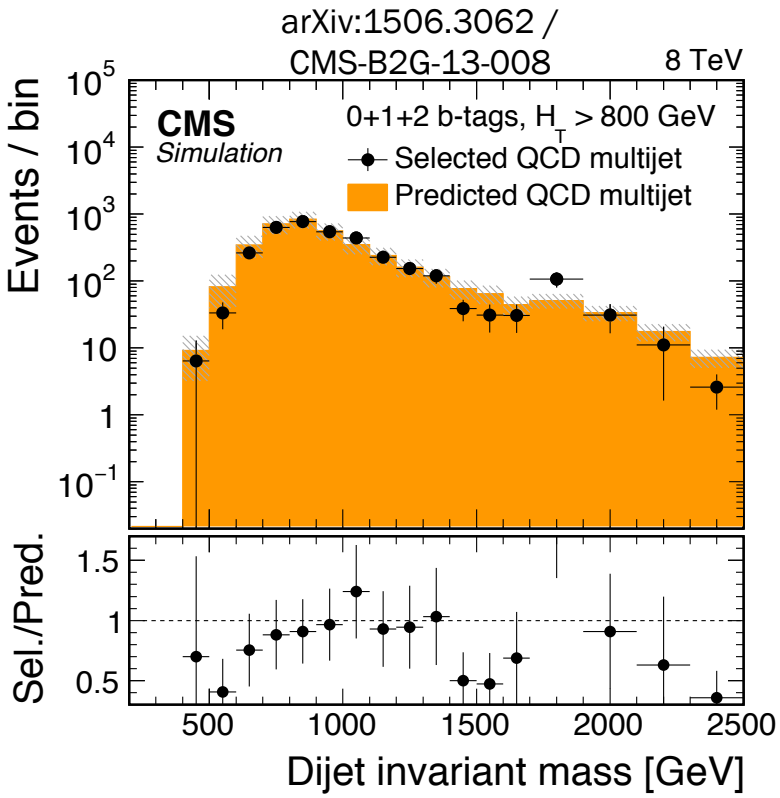


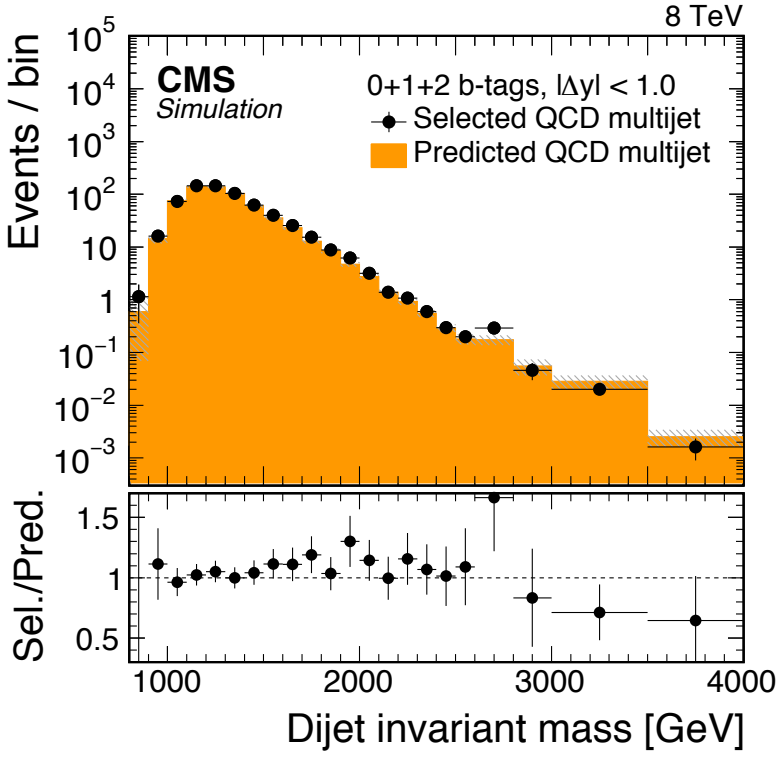


All-Hadronic Channel

- Main background is QCD multijet production
  - Estimated using data-driven method
- Mistag rate extracted from a sample of QCD events selected by anti-top-tagging
  - Parameterized as a function of jet p_T, τ_{32}, subjet b-tag score
- Background in signal region determined by applying rates to jets in a single-top-tagged sample
  - Closure test validates method using simulated events



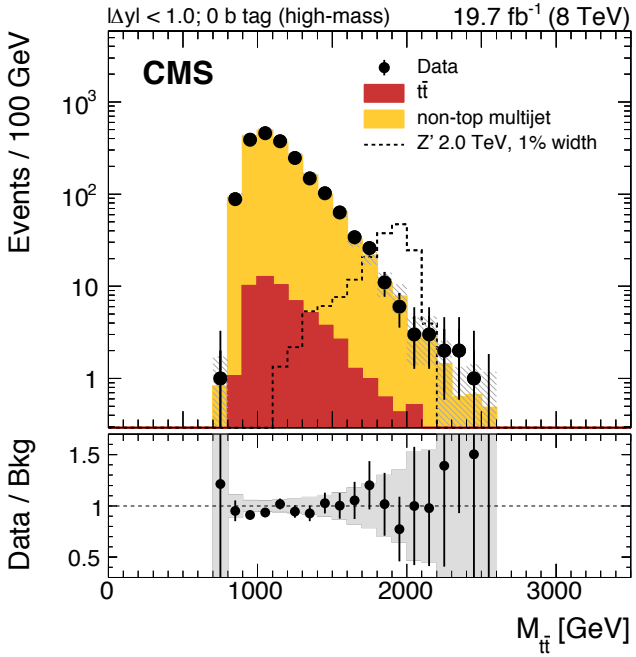


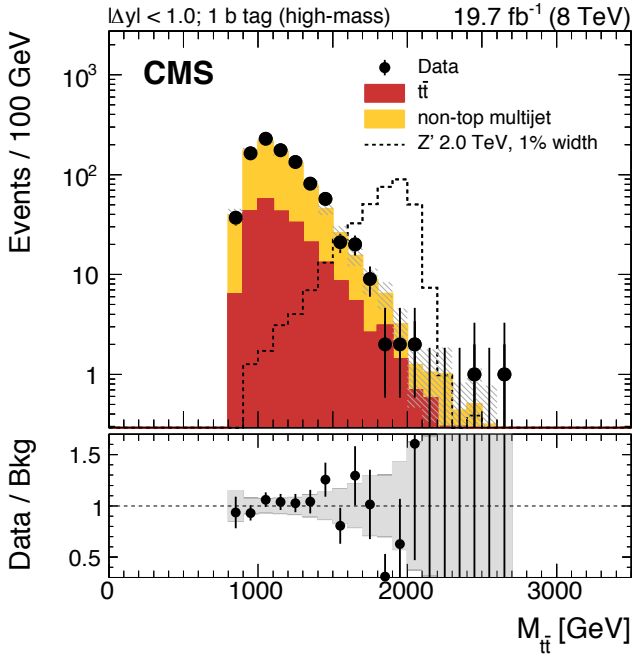


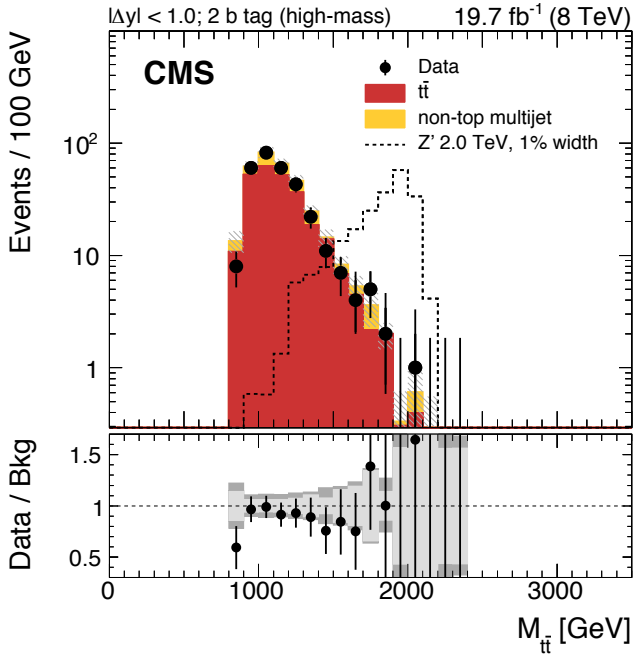
All-Hadronic Channel

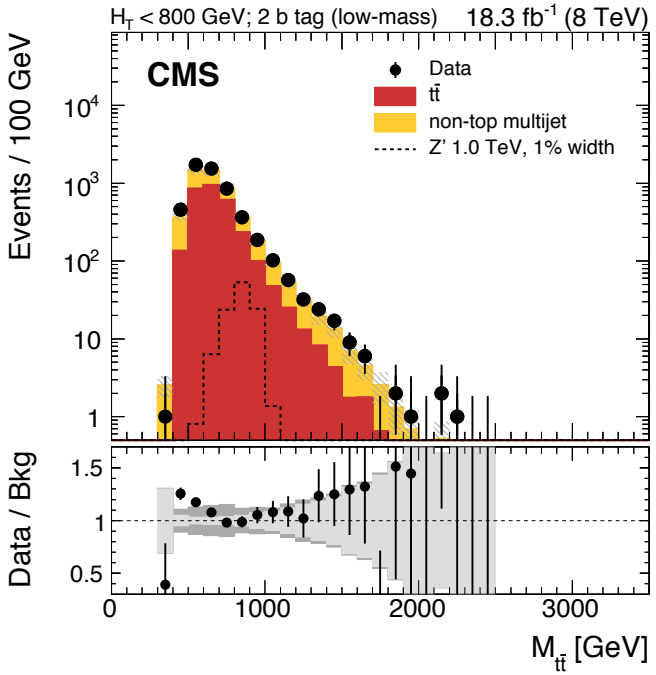
arXiv:1506.3062 / CMS-B2G-13-008

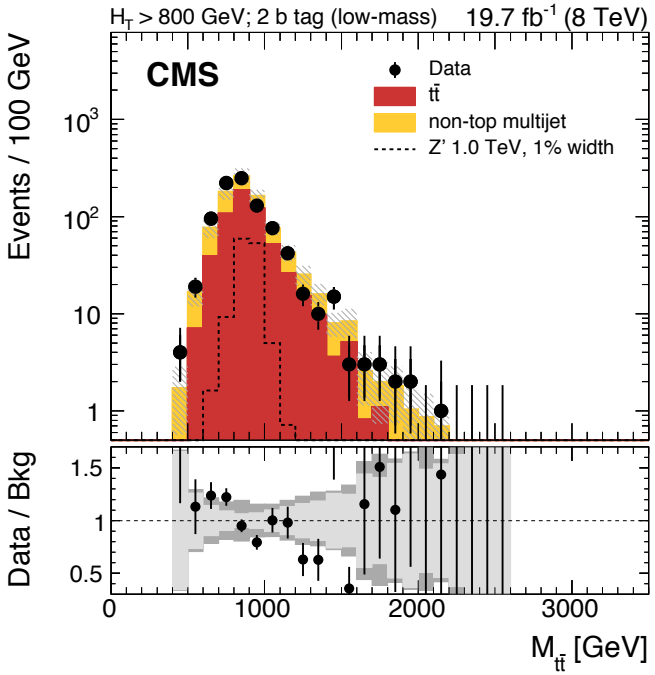
- **Event categories show good agreement with SM expectation**







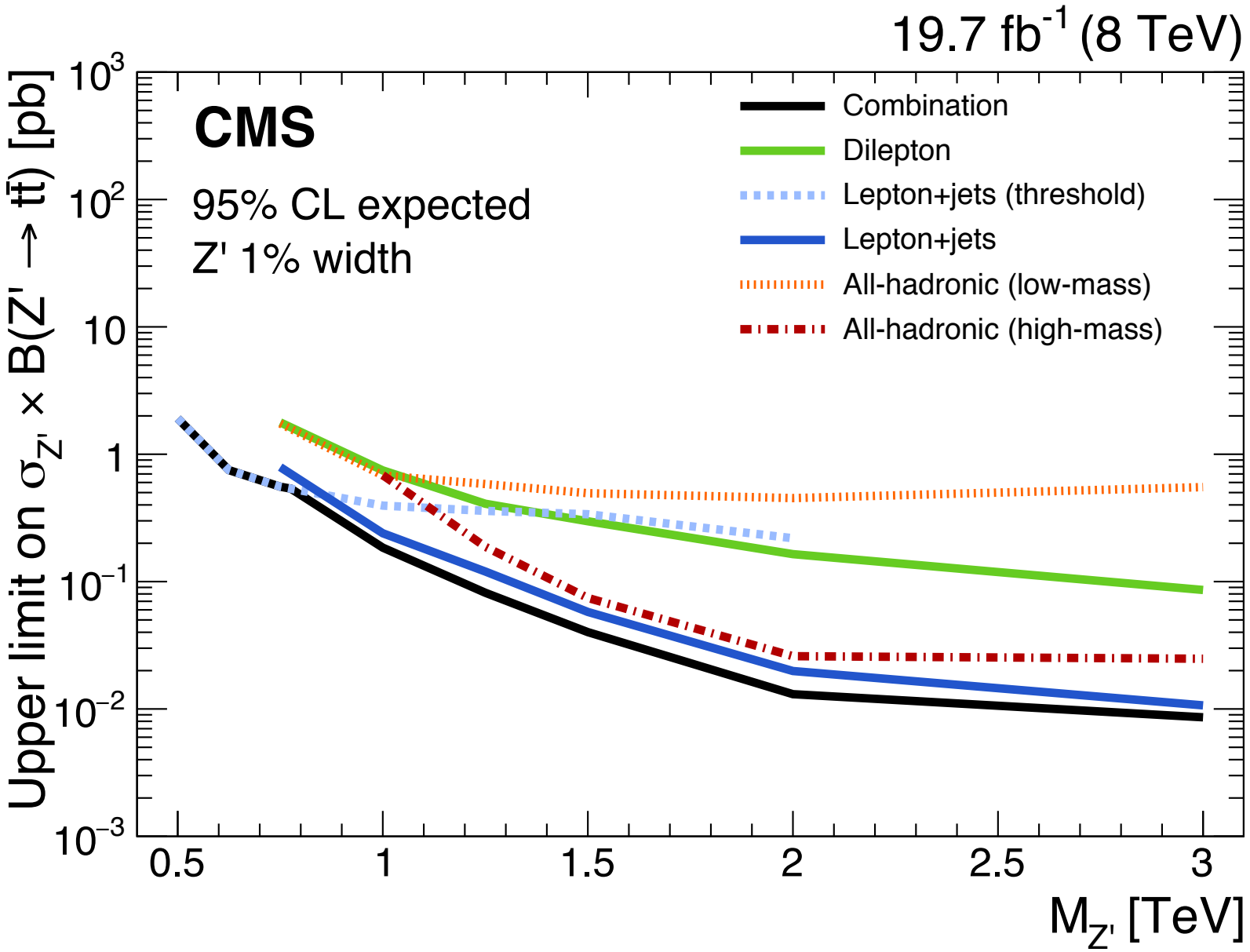




Sensitivity

arXiv:1506.3062 /
CMS-B2G-13-008

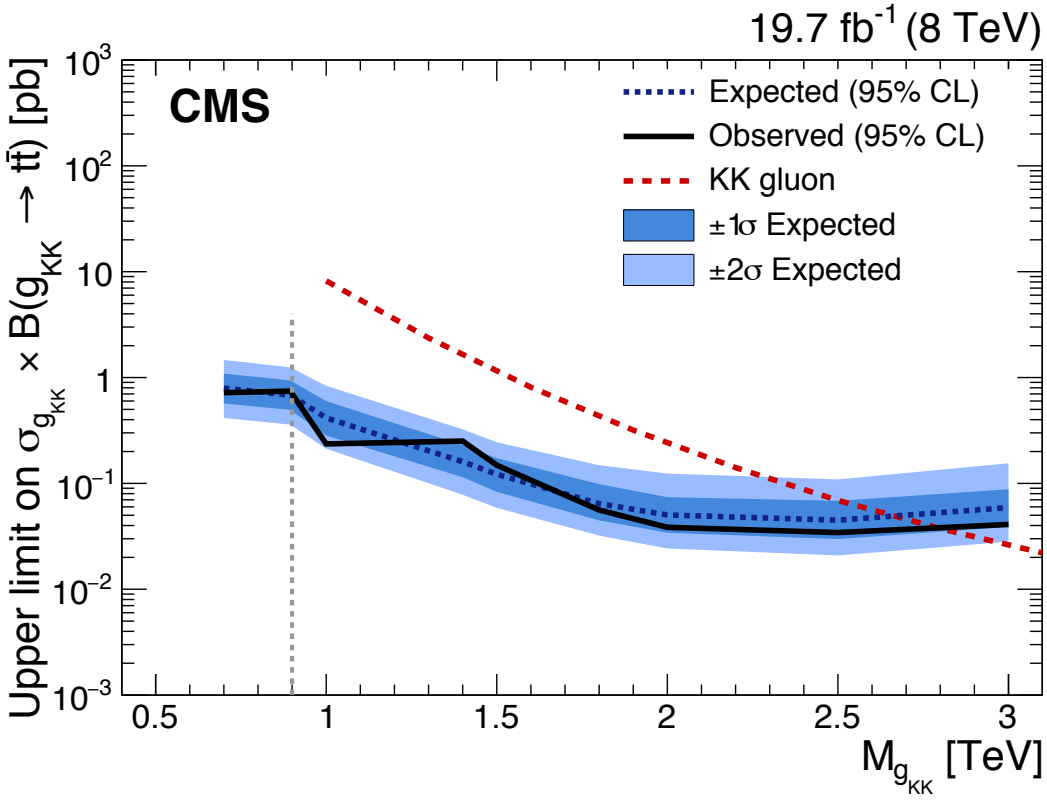
- **Boosted analysis selections critical for high-mass regime!**



Results

arXiv:1506.3062 /
CMS-B2G-13-008

- We observe no significant deviations from the expected SM and set limits on three physics models:
  - Generic Z' resonance (1%, 10% width)
  - Randall-Sundrum KK gluon (~16% width)
- Observed limits exclude masses up to 2.9 TeV!



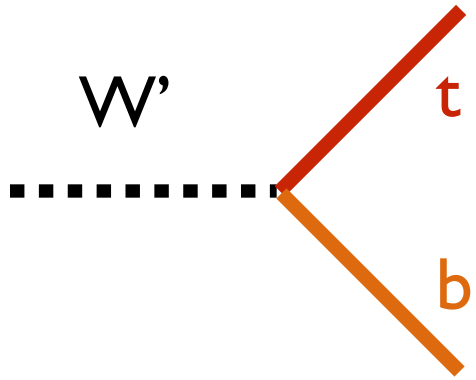
	Mass limit [TeV]							
	Dilepton channel		Lepton+jets channel		All-hadronic channels		Combined	
	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.
$Z', \Gamma_{Z'}/M_{Z'} = 1.2\%$	1.4	1.5	2.2	2.3	2.1	2.1	2.4	2.4
$Z', \Gamma_{Z'}/M_{Z'} = 10\%$	2.1	2.2	2.7	2.8	2.5	2.5	2.8	2.9
RS KK gluon	1.8	2.0	2.5	2.5	2.4	2.3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

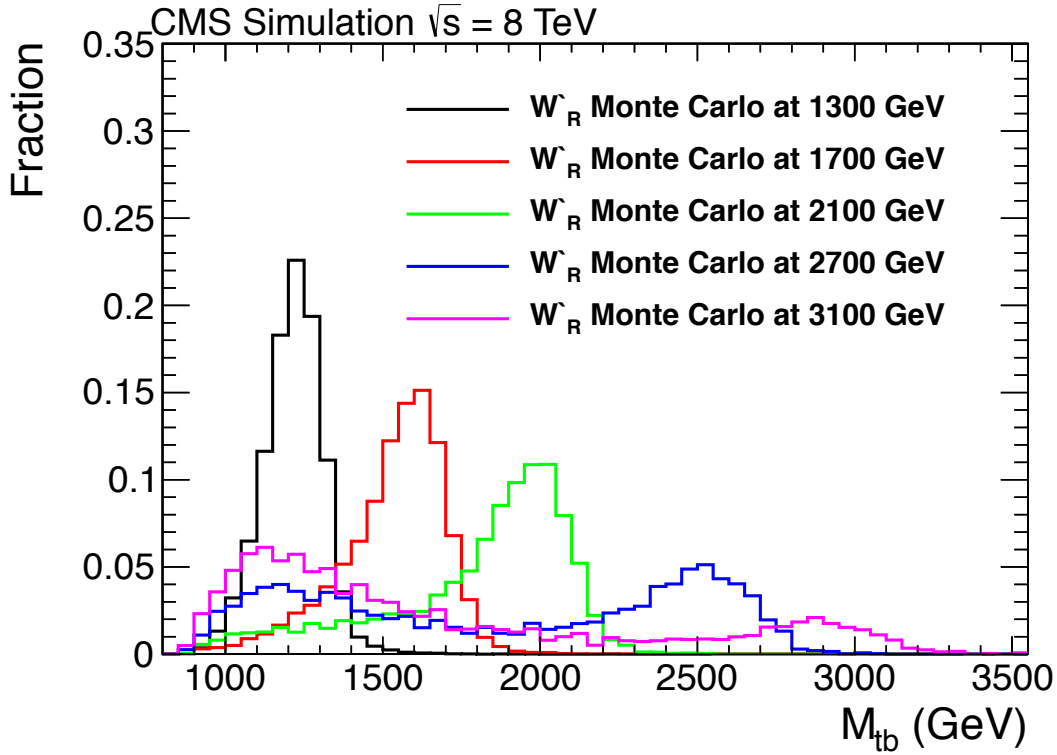
tb Resonances

tb Resonances

CMS-PAS-B2G-12-009

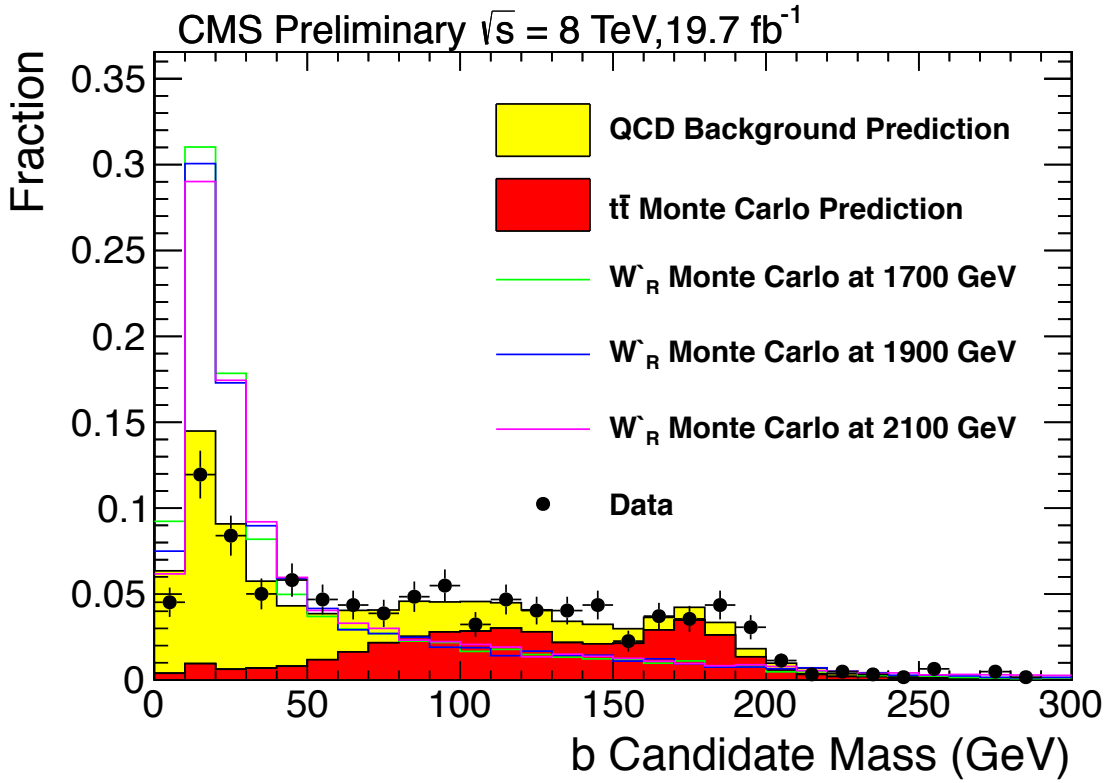
- Search for heavy resonance decaying to top + bottom quarks
  - Lepton + jets channel can use non-isolated leptons
  - Hadronic channel relies on boosted top tagging
- Again search for a signal peak using the t+b invariant mass
  - Left and right-handed W' models explored

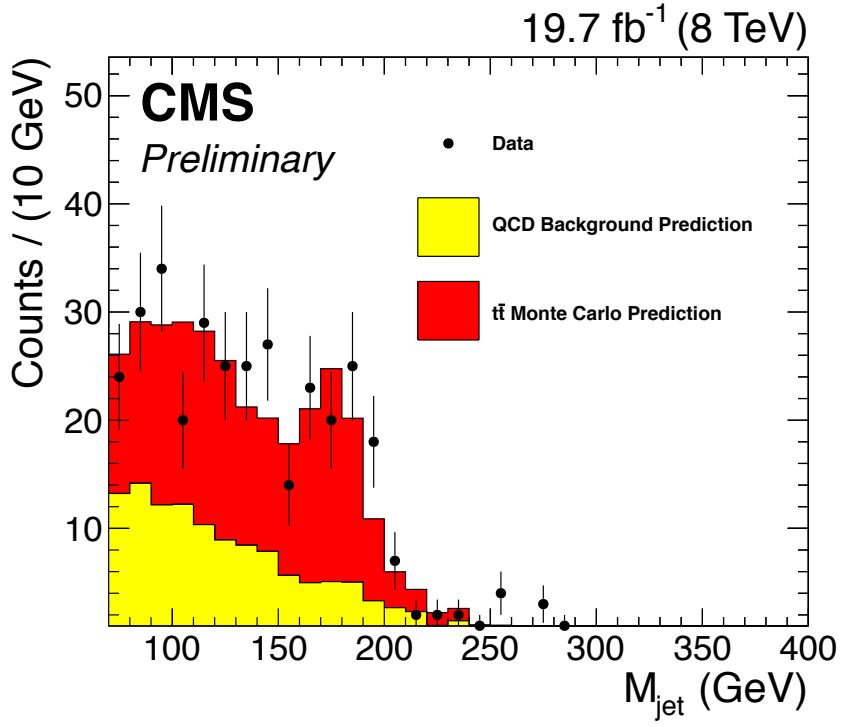




Hadronic Channel

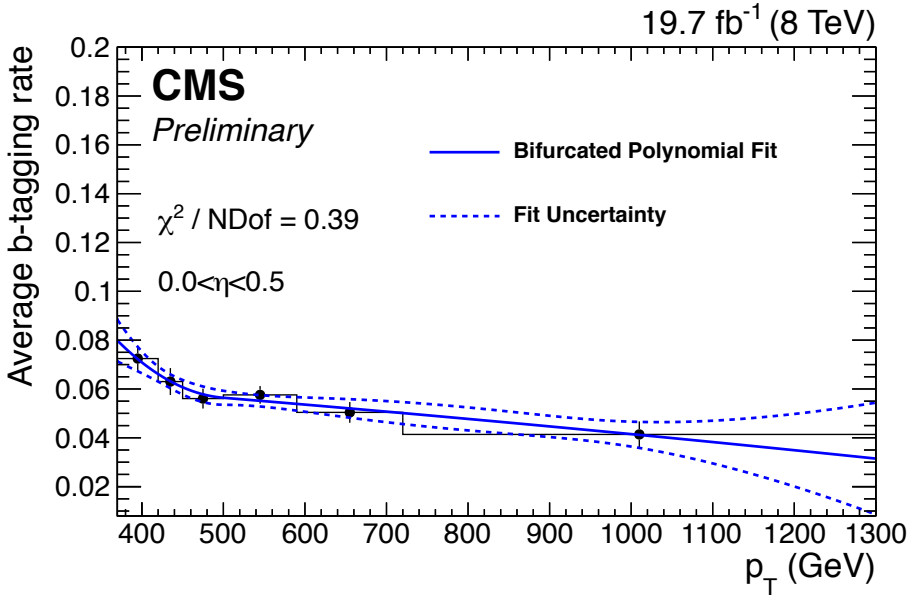
- Top jet selection
  - p_T > 450 GeV
  - CMS top-tagged
  - Subjet b-tagged
- b jet selection
  - p_T > 370 GeV
  - b-tagged
  - Jet mass < 70 GeV
- Jet separation
  - $\Delta\varphi < \pi/2$
  - $\Delta y < 1.6$
- Main background is QCD multijet
  - SM tt normalization determined from sideband region

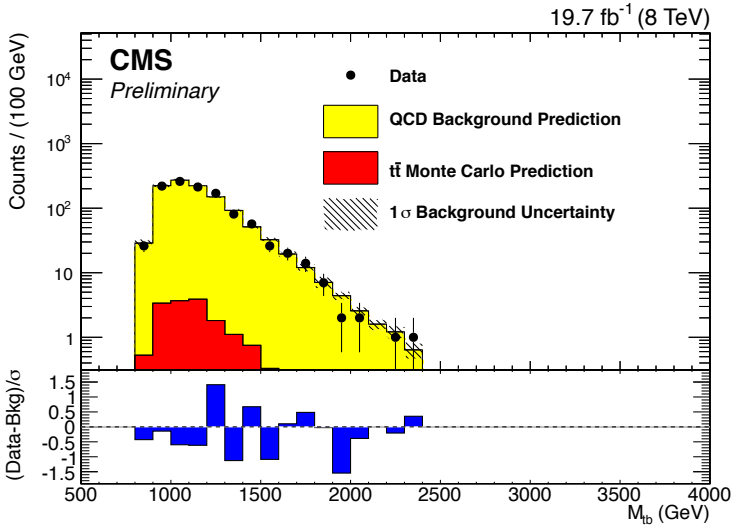


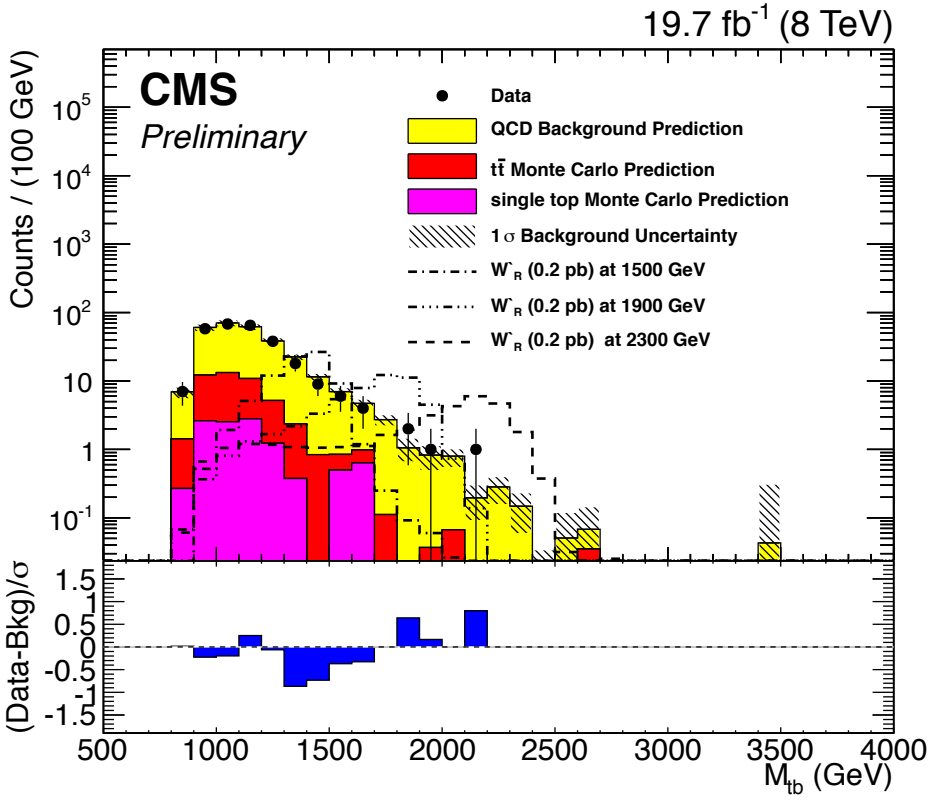


Background Methodology

- b-tagging rate for QCD estimation measured in control region
  - 2 or fewer subjets in top jet candidate
- Mistag rate is measured as a function of p_T
  - Parameterized with bifurcated polynomial in bins of η
- Closure test performed in control regions







Leptonic Channel

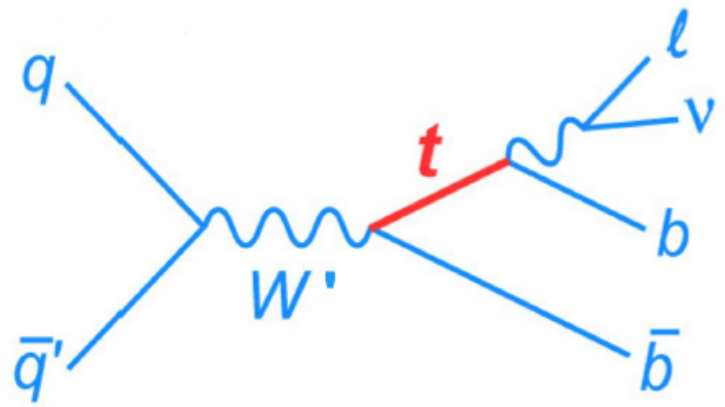
CMS-PAS-B2G-12-010
JHEP 05 (2014) 108

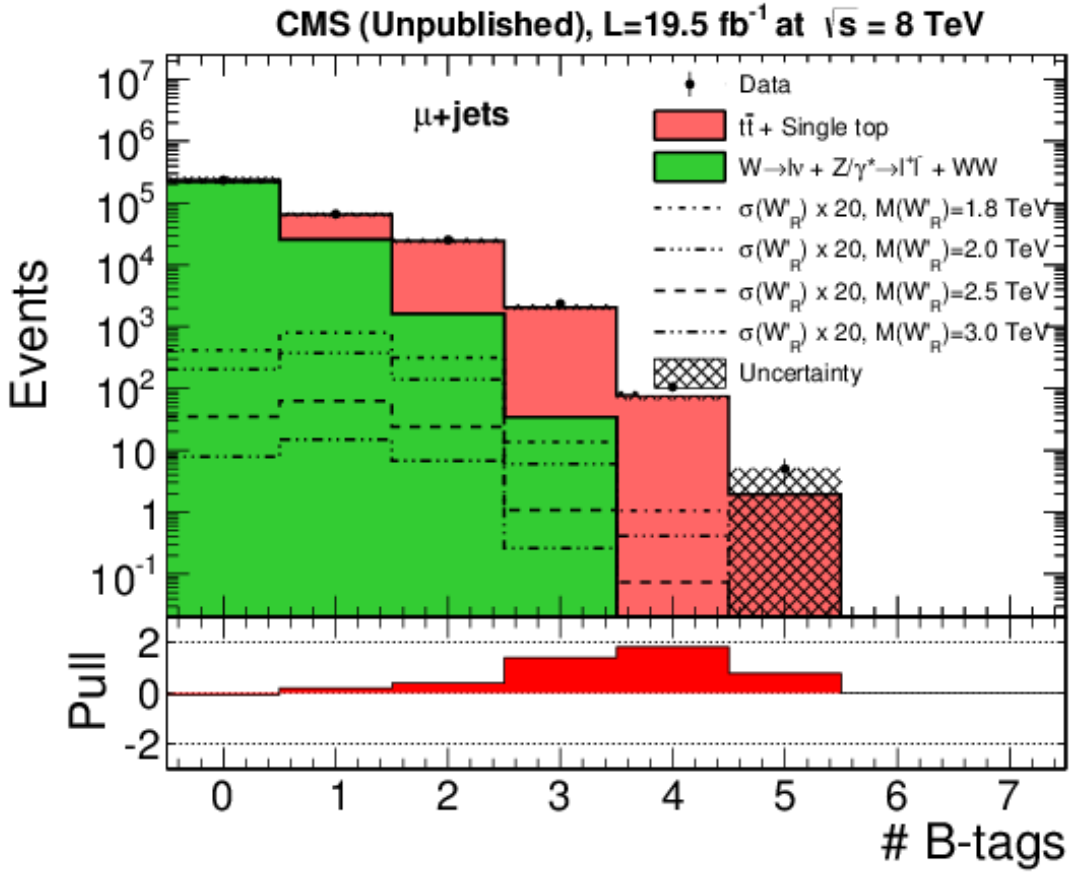
- Run 1 analysis used isolated lepton triggers
- Vector sum of 2 leading jets p_T > 140 GeV
- 1 b-tagged jet

- Top quark reconstructed using mass of lepton, neutrino, "best" associated jet
  - Mass required to be in [130, 210] GeV window
  - Top p_T > 85 GeV

- W' mass reconstructed from top candidate and next-leading jet

- Top pair normalization determined from control region
  - Low M_{tb}, > 1 b-jet

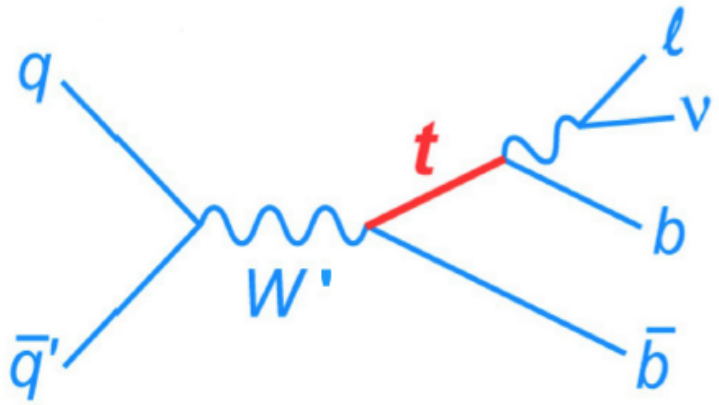


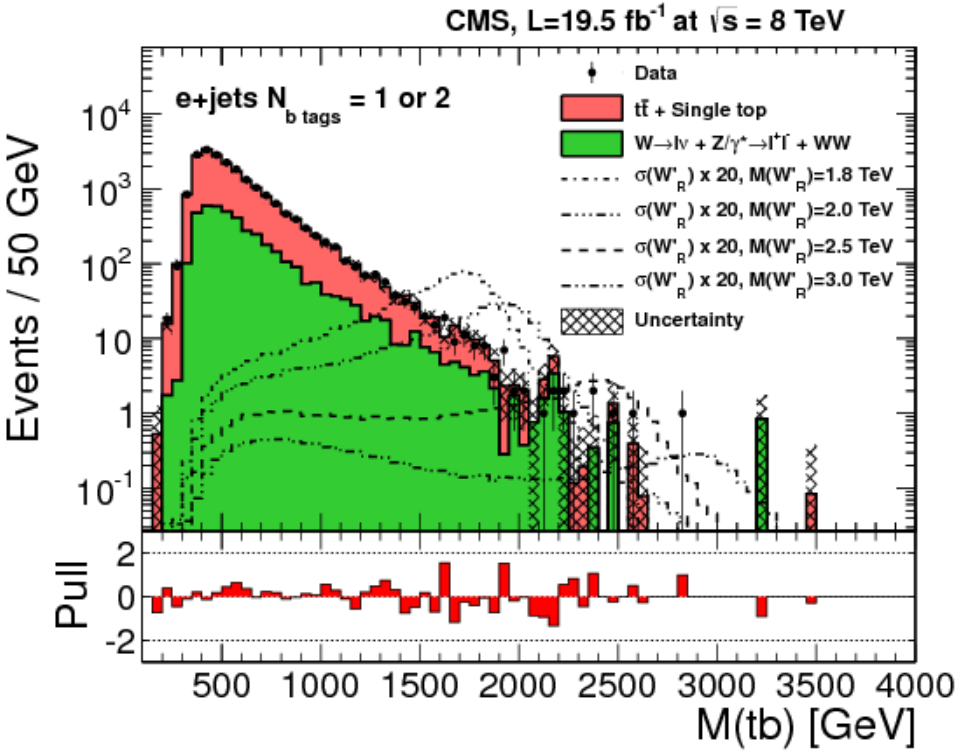


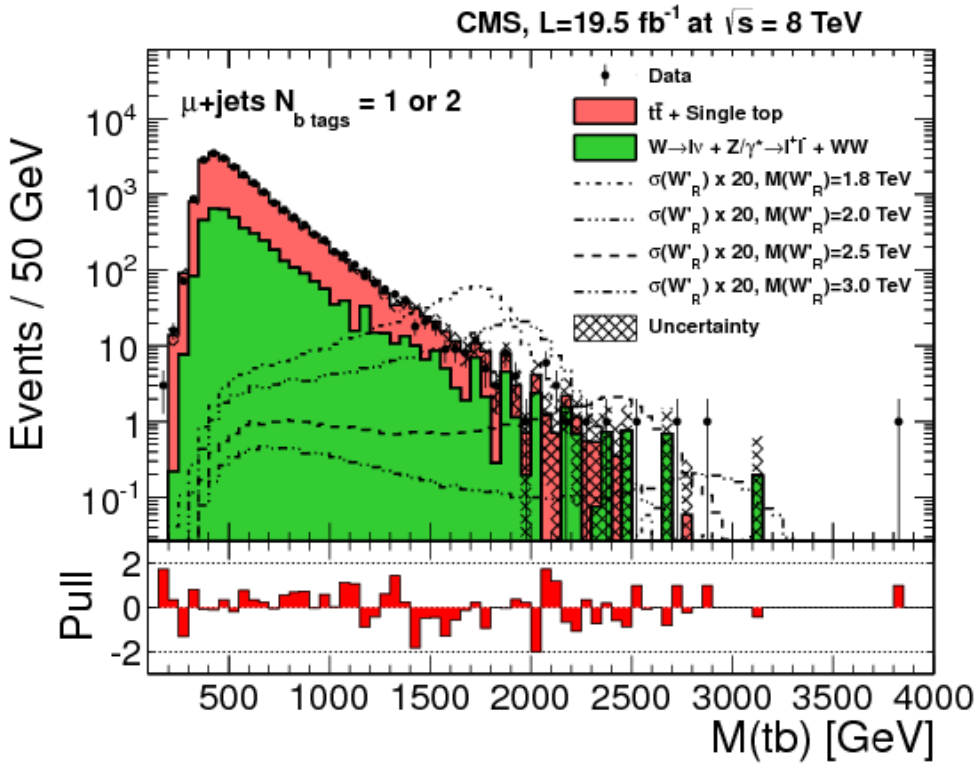
Leptonic Channel

CMS-PAS-B2G-12-010
JHEP 05 (2014) 108

- Reconstructed t+b invariant mass used for signal discrimination



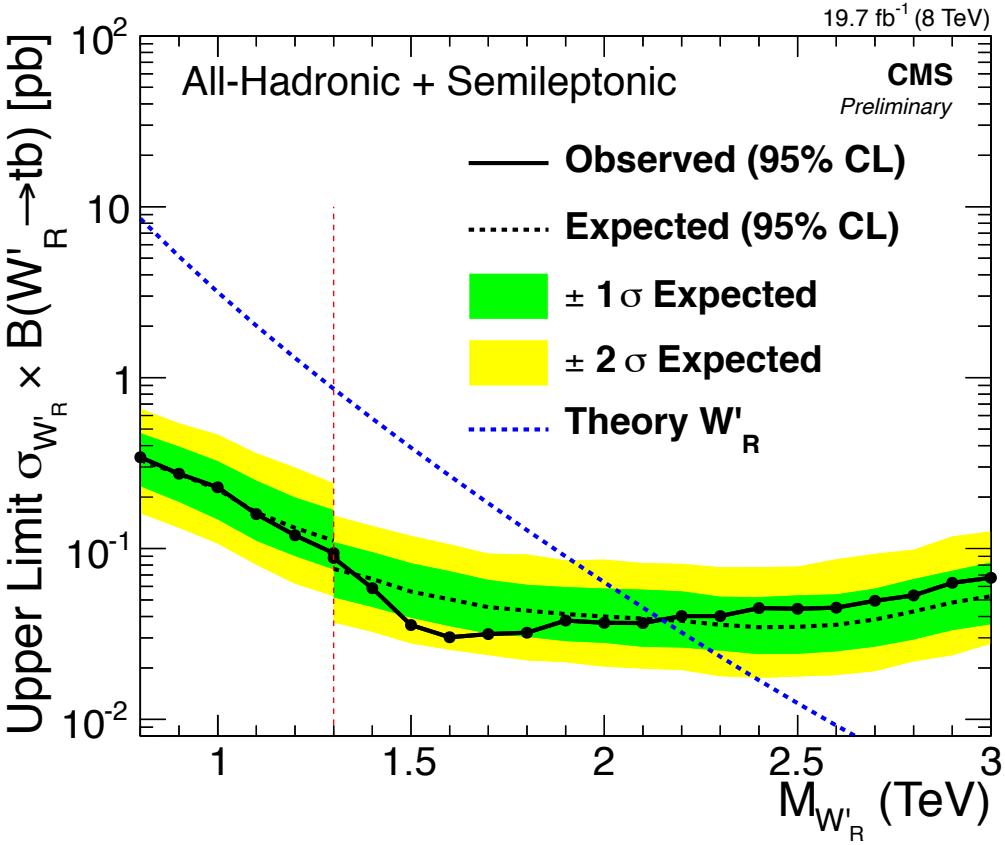


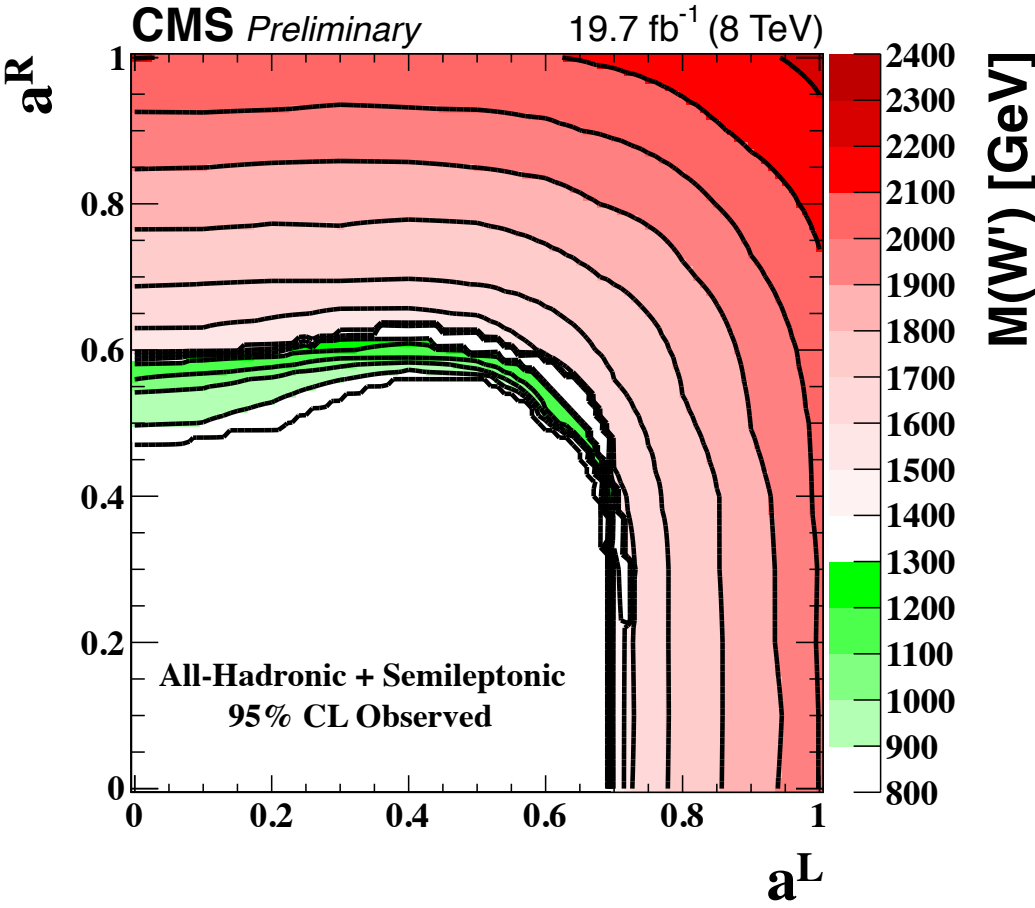


W' Results

CMS-PAS-B2G-12-009

- Combination of semileptonic and all-hadronic decay modes
  - Set limits on left- and right-handed W' models
    - Exclude masses up to 2.15 TeV (right-handed)
- Also scan over coupling phase space
  - Exclusion limits in plane of left, right-handed couplings a_L, a_R





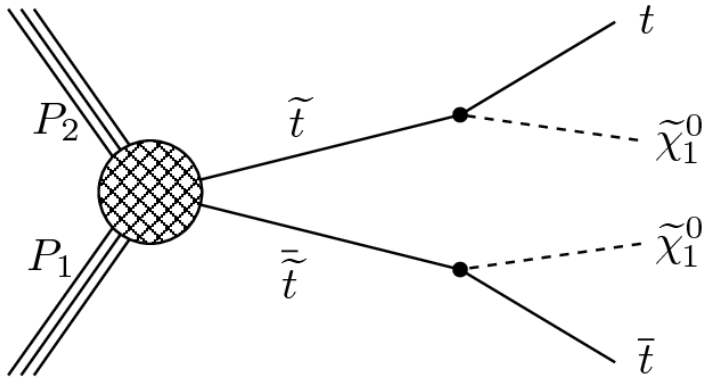
Supersymmetry Searches

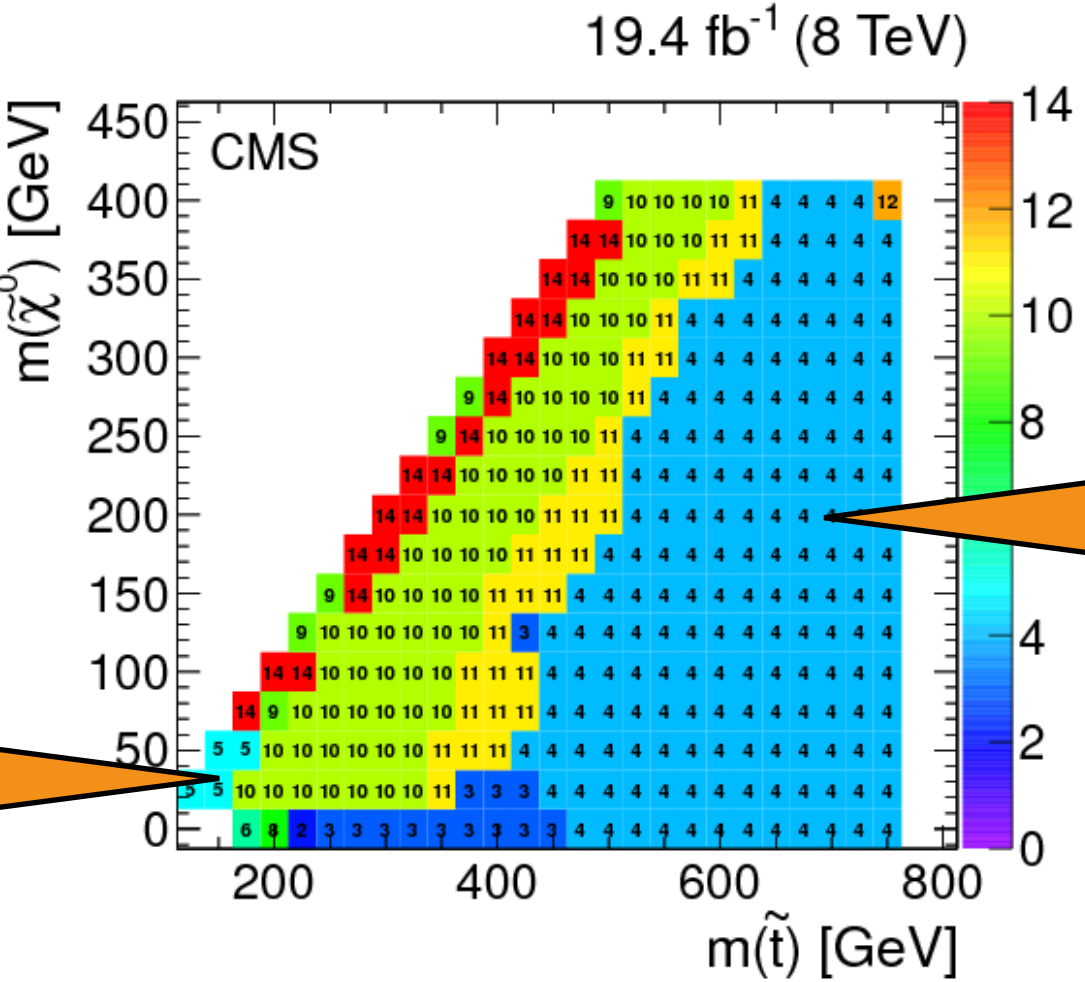
Stop decays

CMS-PAS-SUS-14-001
JHEP 06 (2015) 116

- Decays of stop quarks can produce highly boosted top quarks

- Third-generation stop, sbottom searches covered by several analyses
  - Monojet
  - Dijet b-tagged
  - Multijet top-tagged





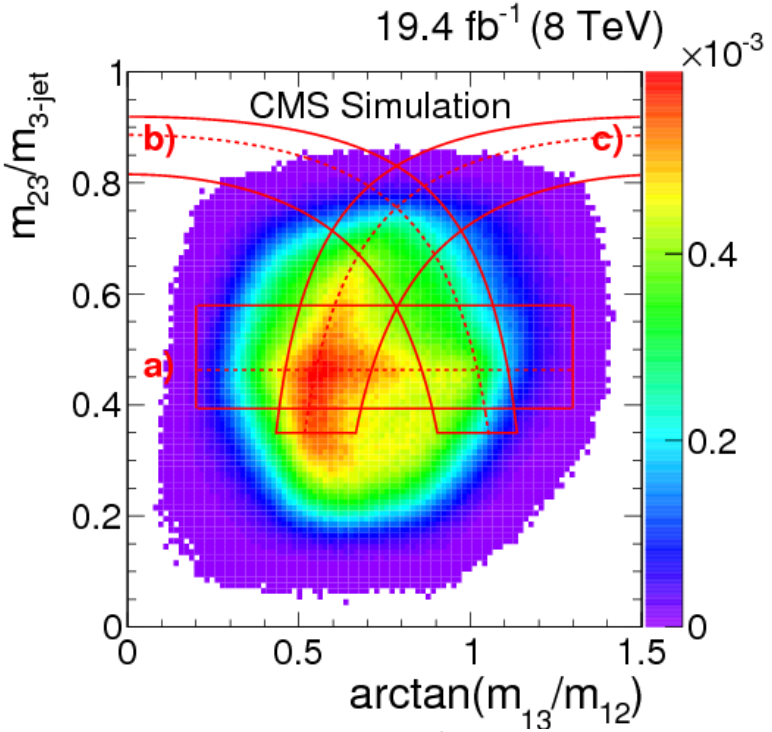
Dijet b-tagged analysis (5-14)

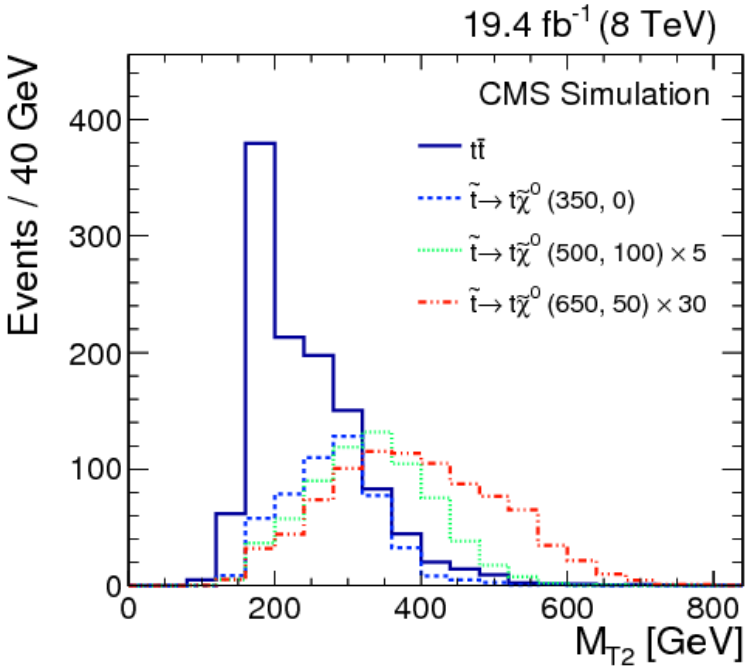
Multijet top-tagged analysis (1-4)

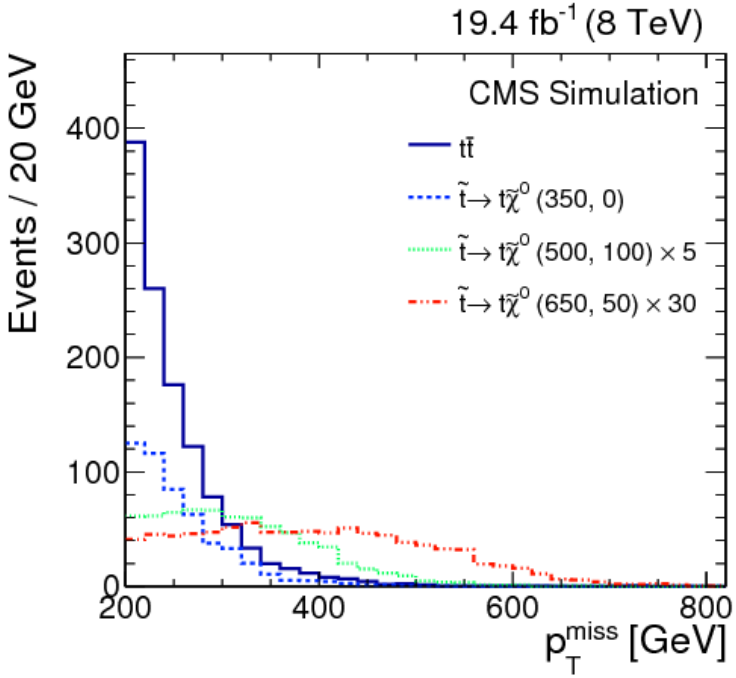
Multijet Top-Tagged Analysis

CMS-PAS-SUS-14-001
JHEP 06 (2015) 116

- Use HEPTopTagger selection to identify top candidates from 3 jets
  - Reduced selections for partial reconstruction of second top candidate
- Missing p_T, M_{T2} used for signal discrimination
  - Missing p_T > 200 GeV
  - M_{T2} > 300 GeV



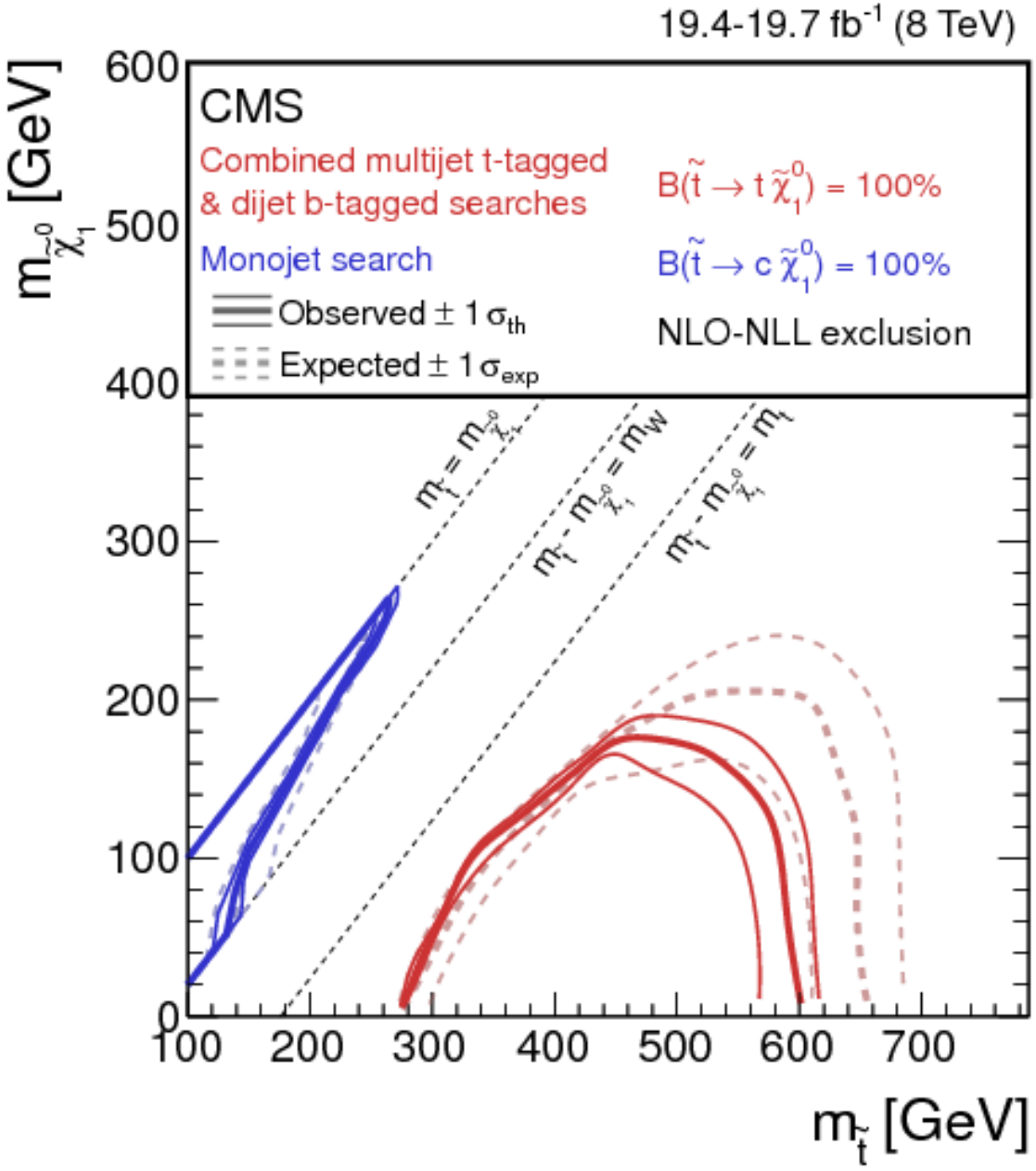




Multijet Top-Tagged Analysis

CMS-PAS-SUS-14-001
JHEP 06 (2015) 116

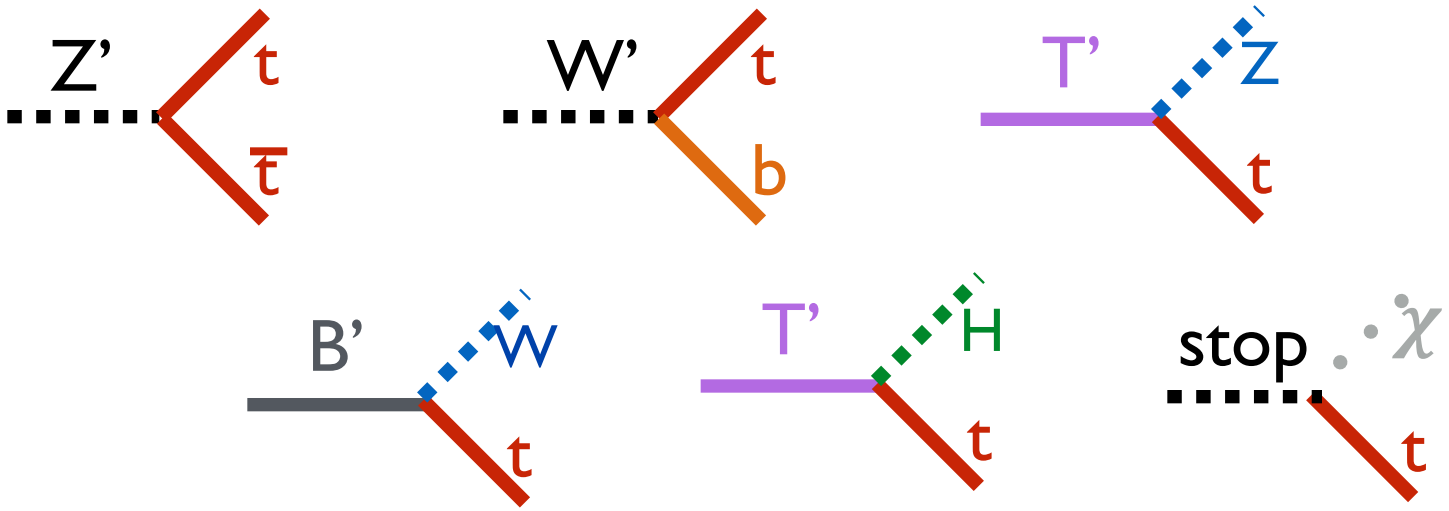
- Use HEPTopTagger selection to identify top candidates from 3 jets
  - Reduced selections for partial reconstruction of second top candidate
- Missing p_T, M_{T2} used for signal discrimination
  - Missing p_T > 200 GeV
  - M_{T2} > 300 GeV
- Bins of missing p_T, number of b-tagged jets used
- Provides sensitivity for high stop masses, low LSP masses



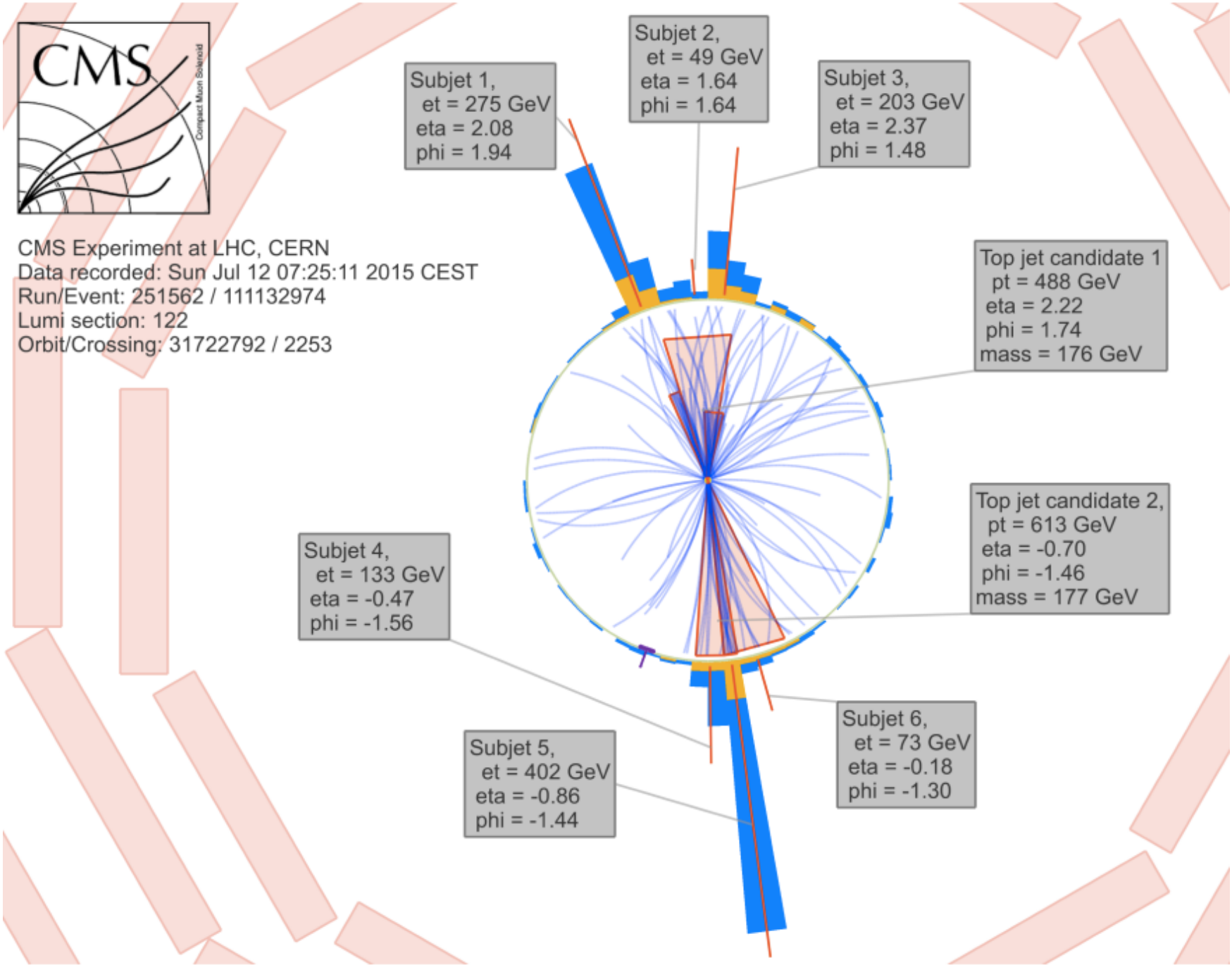
Conclusions

Conclusions

- Many analyses in CMS now use boosted top quark identification
  - Critical tool to maintain sensitivity in Run 2 searches
- Search results exclude new particles with masses up to the 1-3 TeV range
  - With about 3 fb^{-1} of Run 2 data, we can eclipse current sensitivities
  - Hope for discoveries around the corner!
- Work underway to enhance current algorithms with latest jet substructure developments
  - See talks later this week



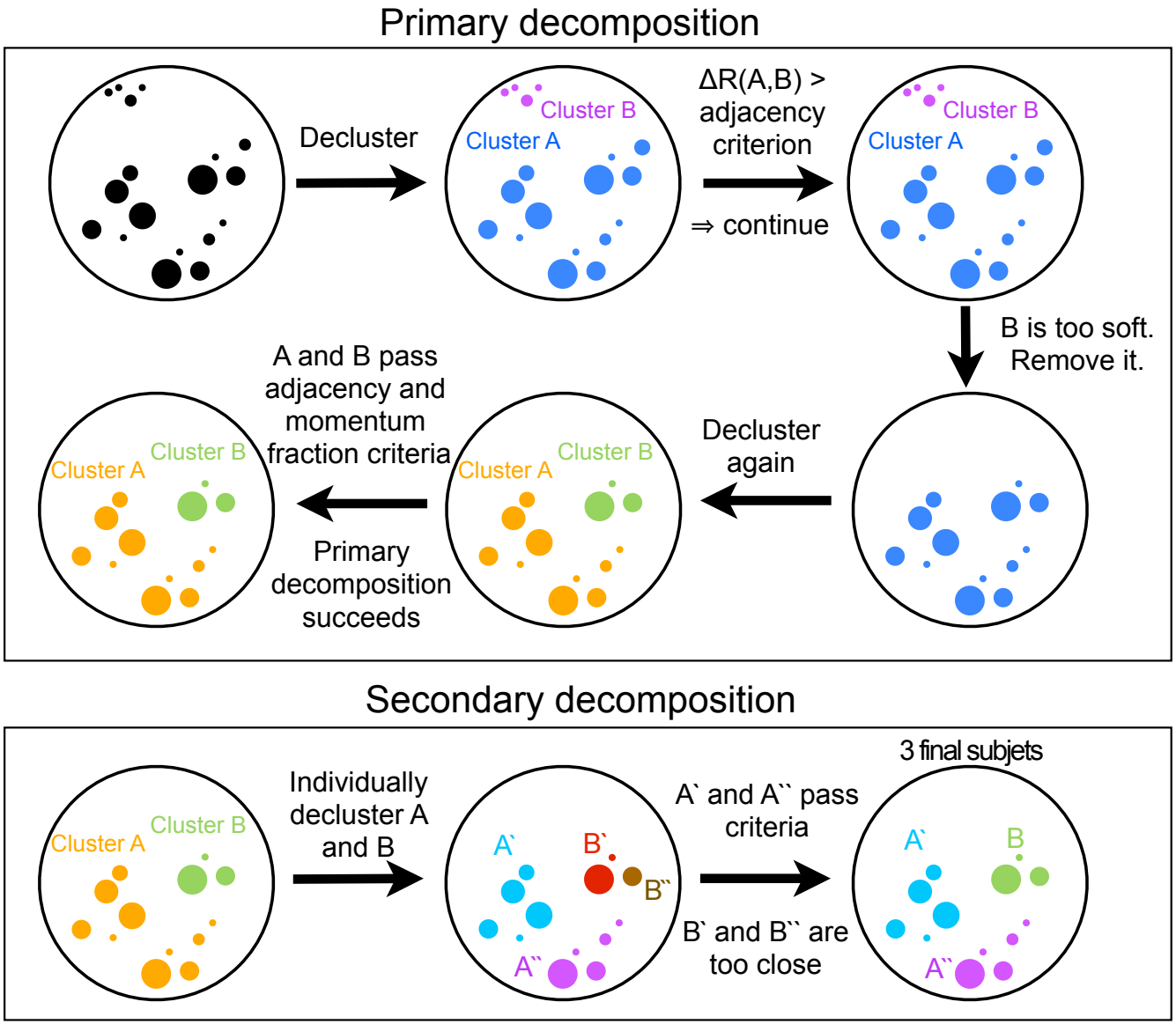
13 TeV Boosted Top Pair Candiate!



Backup Material

CMS Top Tagger

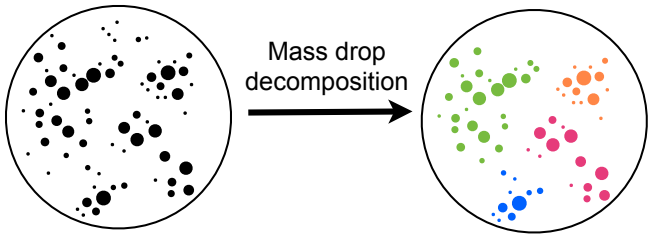
Example: CMS Top Tagger decomposition



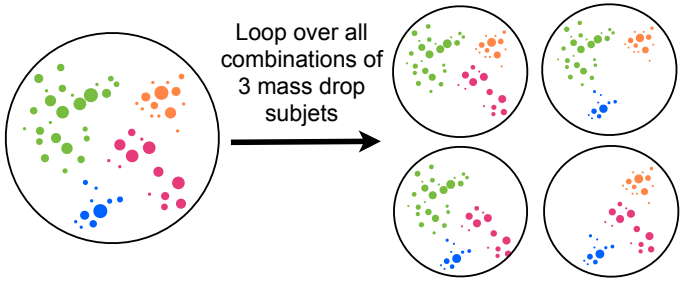
HEP Top Tagger

HEP Top Tagger details

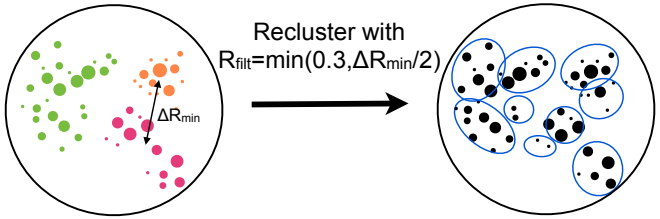
Step 1:



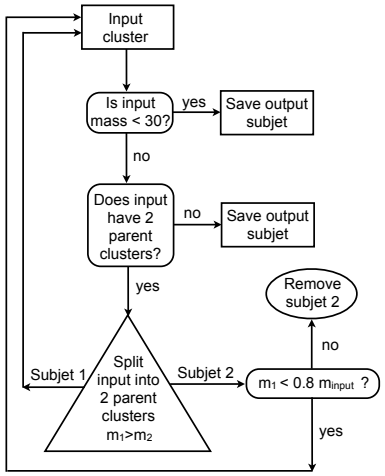
Step 2:



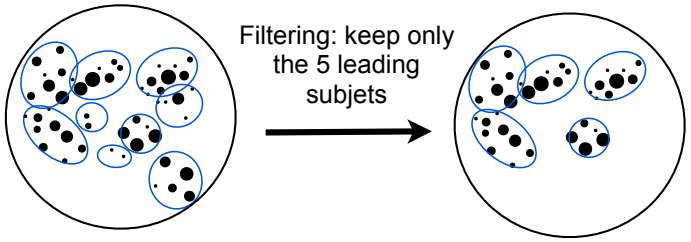
Step 3:



HEP Top Tagger
Mass drop decomposition

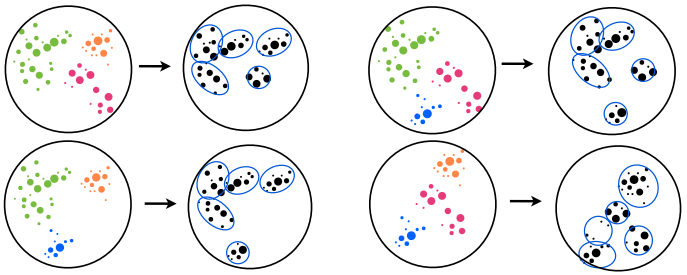


Step 4:

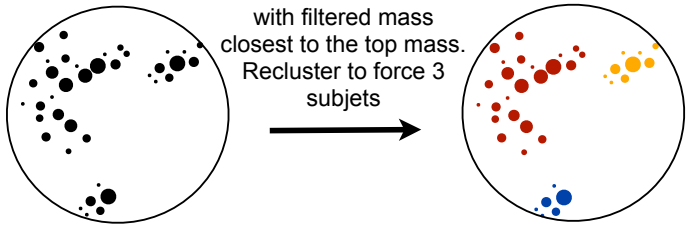


Step 5:

Repeat reclustering and filtering procedure for all combinations of 3 mass drop subjets



Step 6:



HEP Top Tagger

HEP Top Tagger - W mass selection

Bi-dimensional distribution based on the ratio of subjet pairwise masses

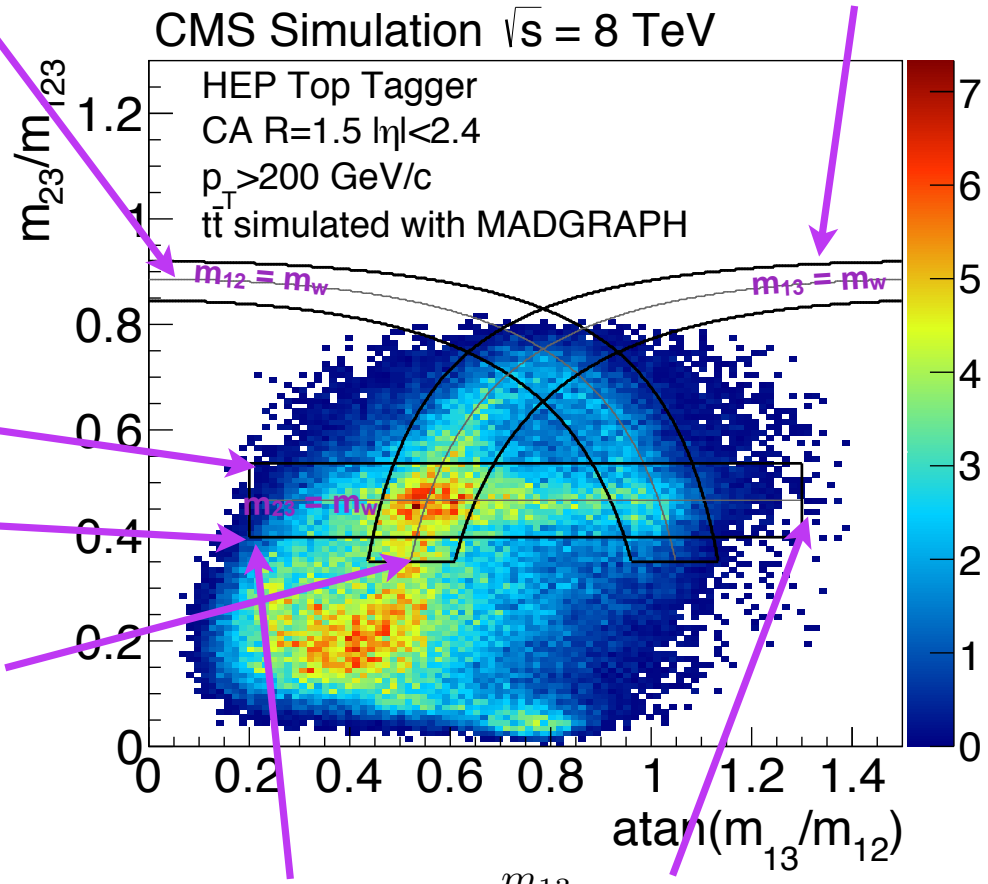
$$R^2_{\min}(1+(\frac{m_{12}}{m_{13}})^2) < 1-(\frac{m_{23}}{m_{123}})^2 < R^2_{\max}(1+(\frac{m_{12}}{m_{13}})^2) \qquad R^2_{\min}(1+(\frac{m_{13}}{m_{12}})^2) < 1-(\frac{m_{23}}{m_{123}})^2 < R^2_{\max}(1+(\frac{m_{13}}{m_{12}})^2)$$

$$R_{\min} < \frac{m_{23}}{m_{123}} < R_{\max}$$

$$R_{\max} = (1+f_W) \times m_W/m_t$$

$$R_{\min} = (1-f_W) \times m_W/m_t$$

$$\frac{m_{23}}{m_{123}} > 0.35$$



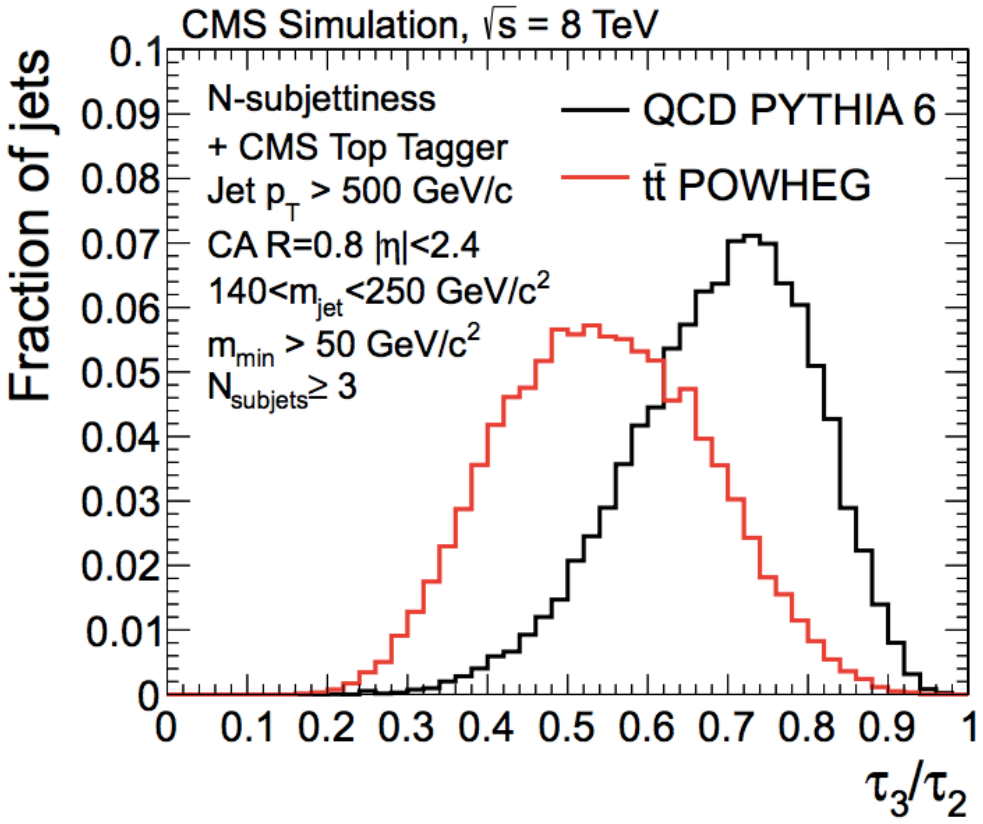
$$0.2 < \arctan\frac{m_{13}}{m_{12}} < 1.3$$

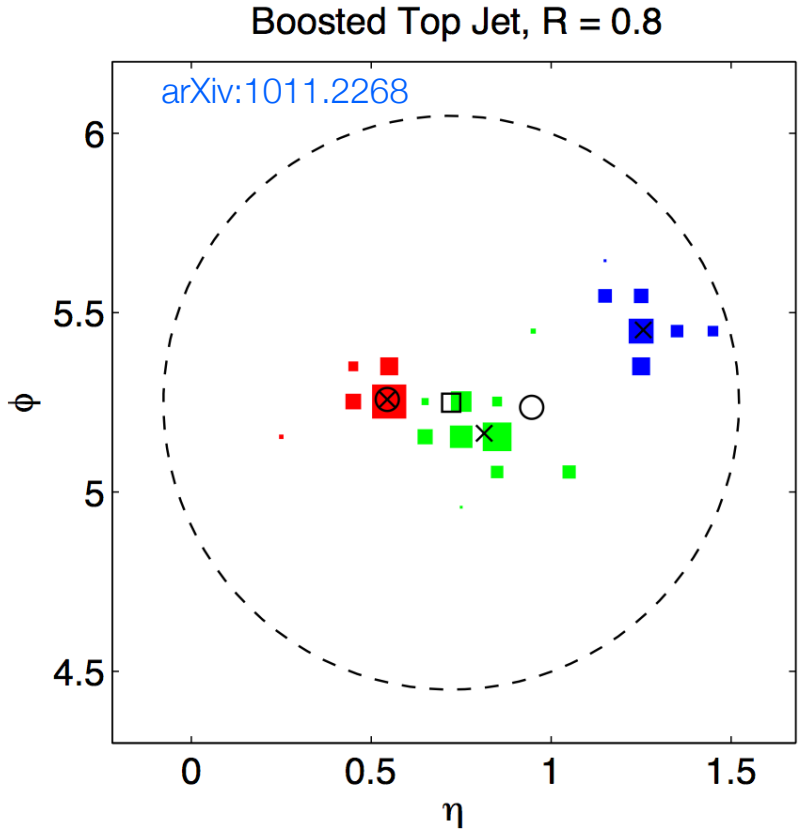
N-Subjettiness

J. Thaler, K Van Tilburg
arXiv:1011.2268

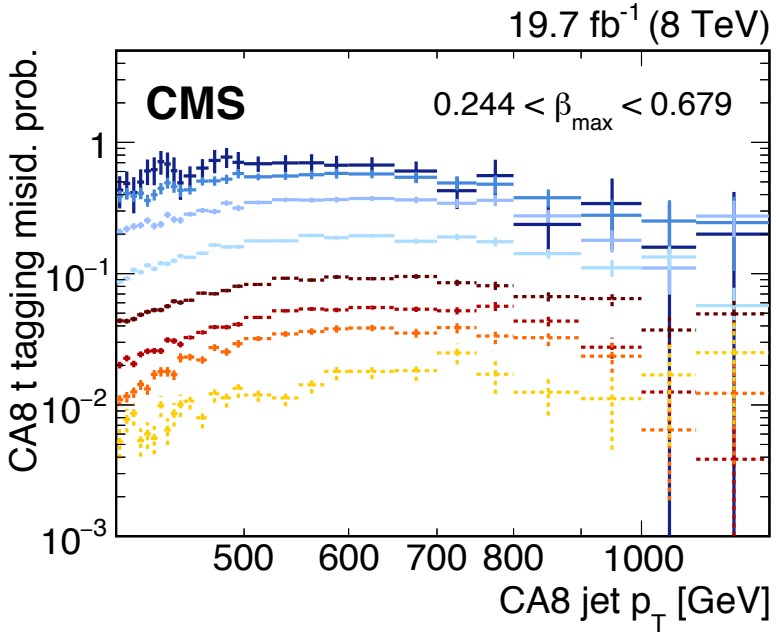
- **A measure of the consistency of jet constituents with N number of subjets**

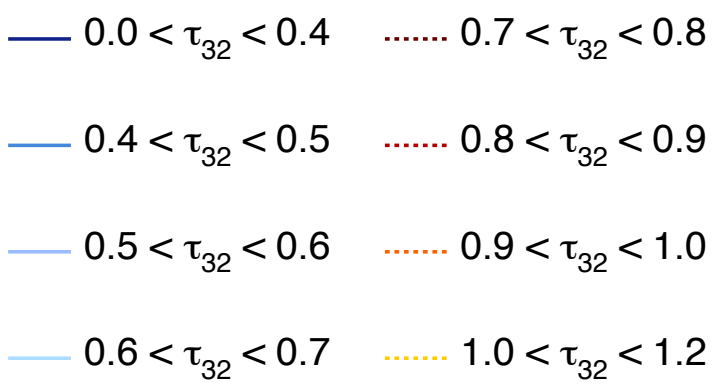
$$\tau_N = \frac{\sum_{i=1}^{n_{\text{constituents}}} p_{\text{T},i} \min\{\Delta R_{1,i}, \Delta R_{2,i}, \ldots, \Delta R_{N,i}\}}{\sum_{i=1}^{n_{\text{constituents}}} p_{\text{T},i} R}$$

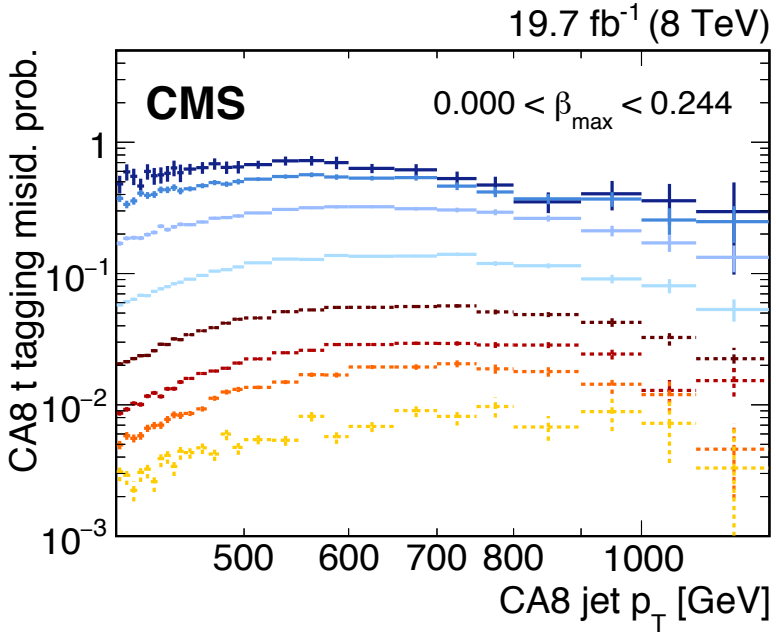


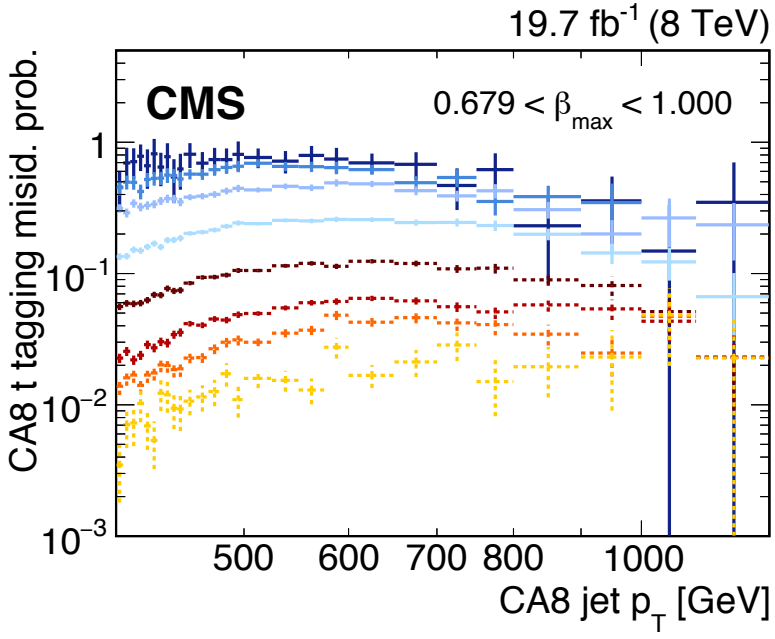


Mistag Rates - CMSTT

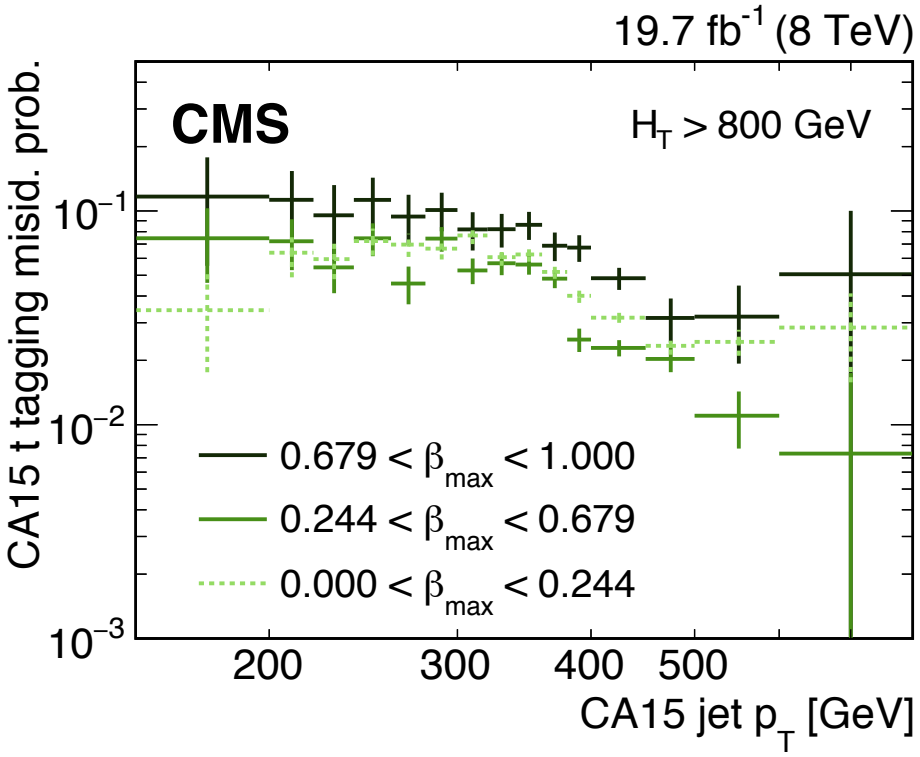


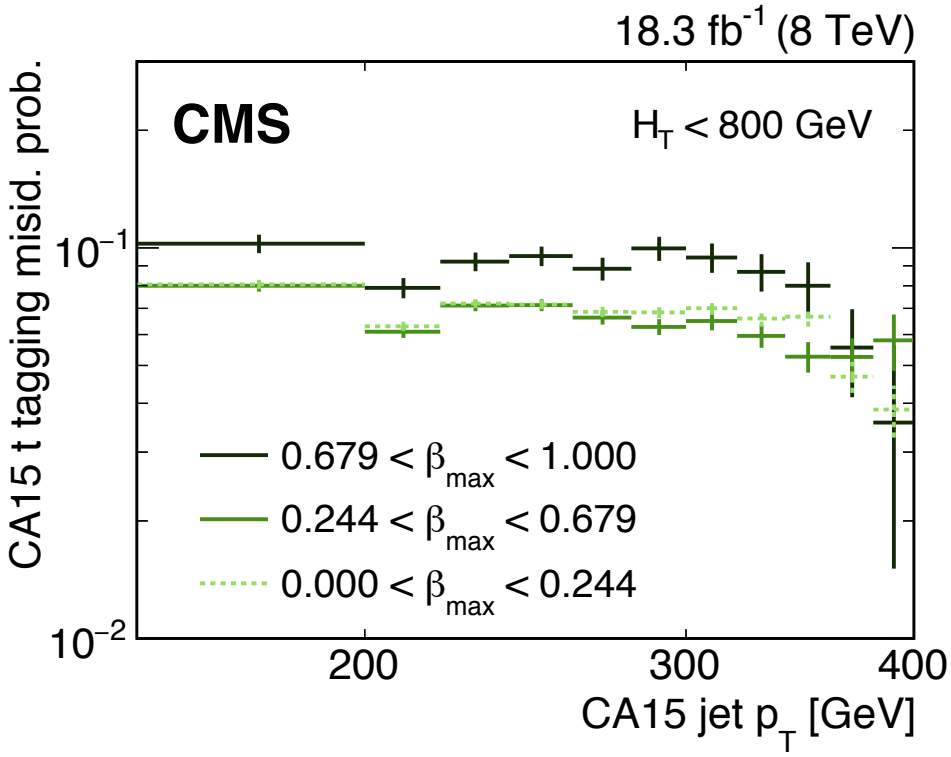




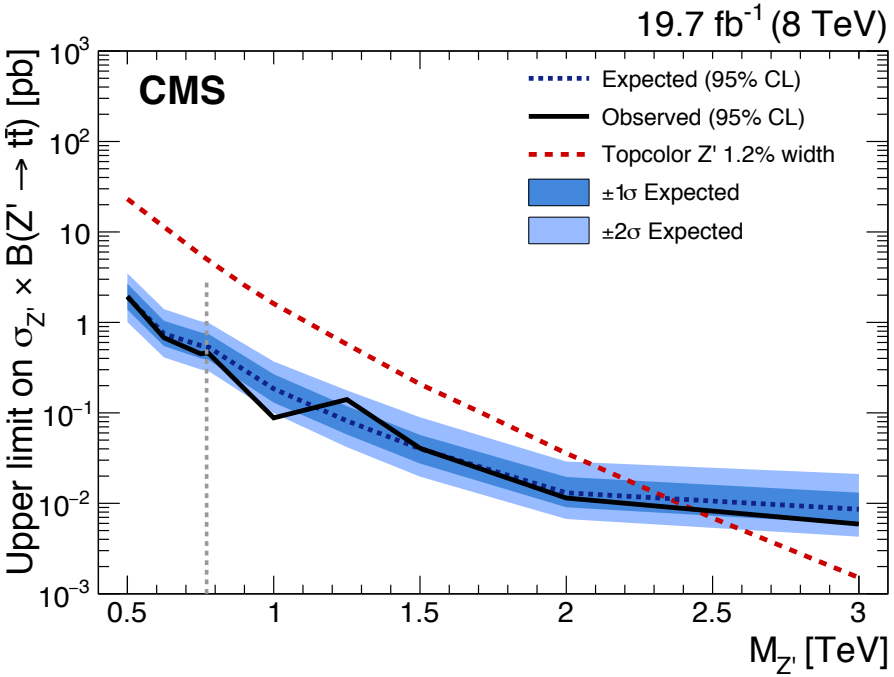


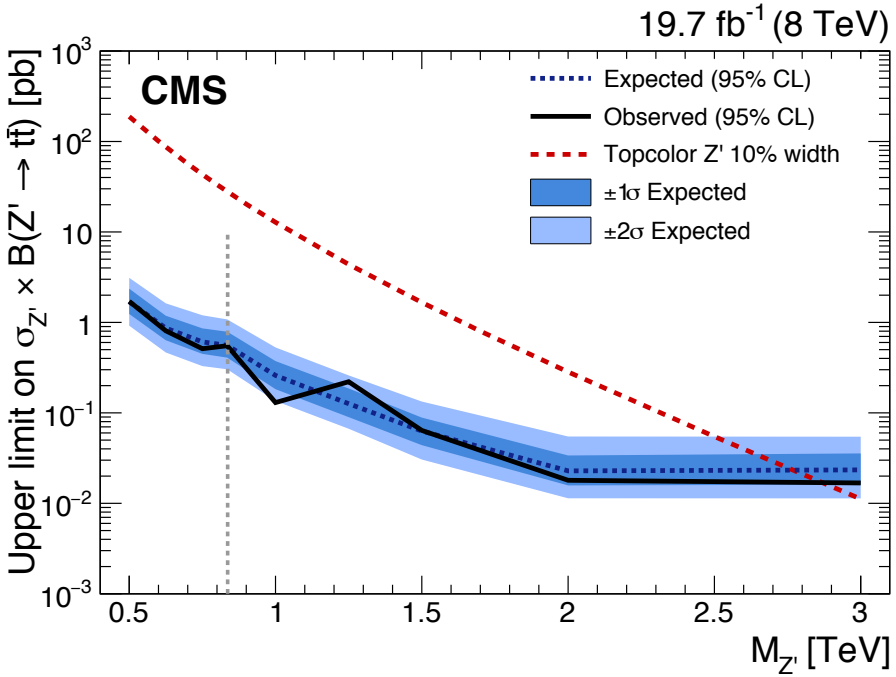
Mistag Rates - HEPTT

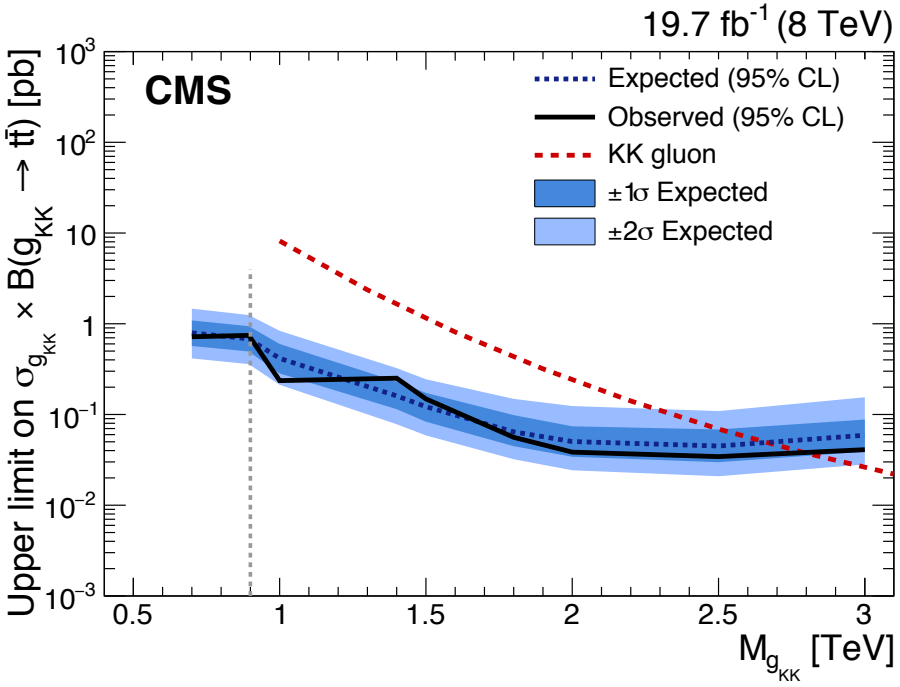




Other Models Results







Systematics

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

(†) AK5 and CA15 subjets

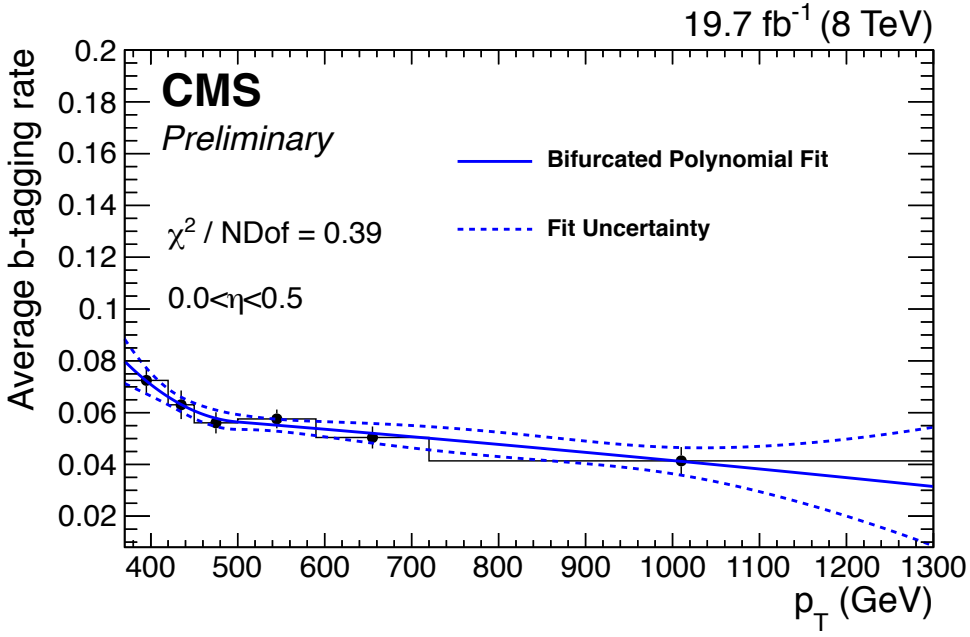
Likelihood Fit Results

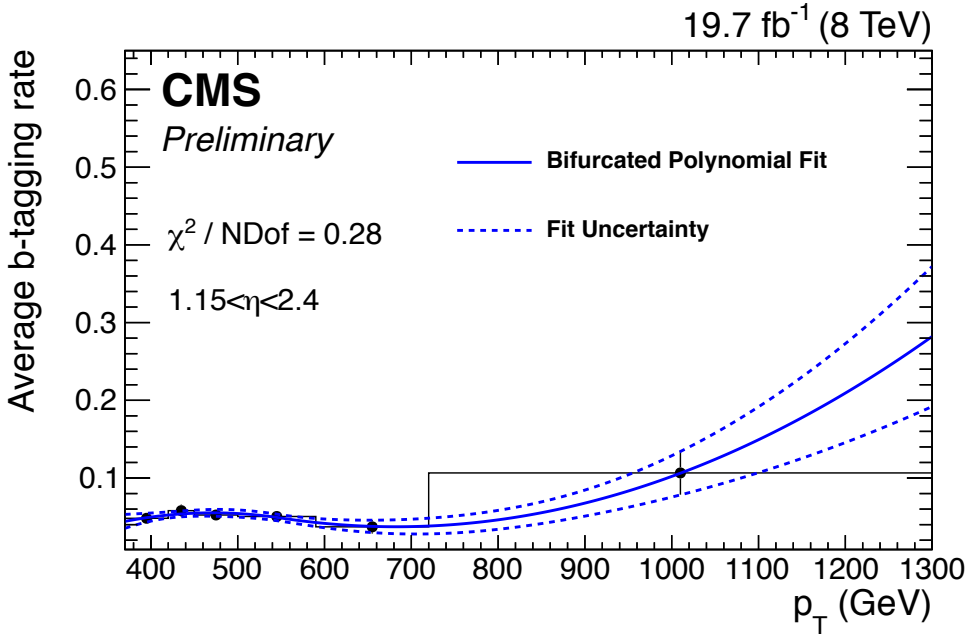
Process	Best fit value	Prior uncertainty	Posterior uncertainty
$t\bar{t}$	0.99	15%	2.1%
W+jets (light flavor)	0.99	9%	5.0%
W+jets (c flavor)	1.06	23%	21%
W+jets (b flavor)	0.95	23%	18%
Single top quark	0.83	23%	22%
Z+jets	1.72	50%	36%
Diboson	1.02	20%	19%
CA8 t-tagged jets scale factor	0.94	unconstrained	3%
CA8 subjet b tagging scale factor	1.3	unconstrained	1.5

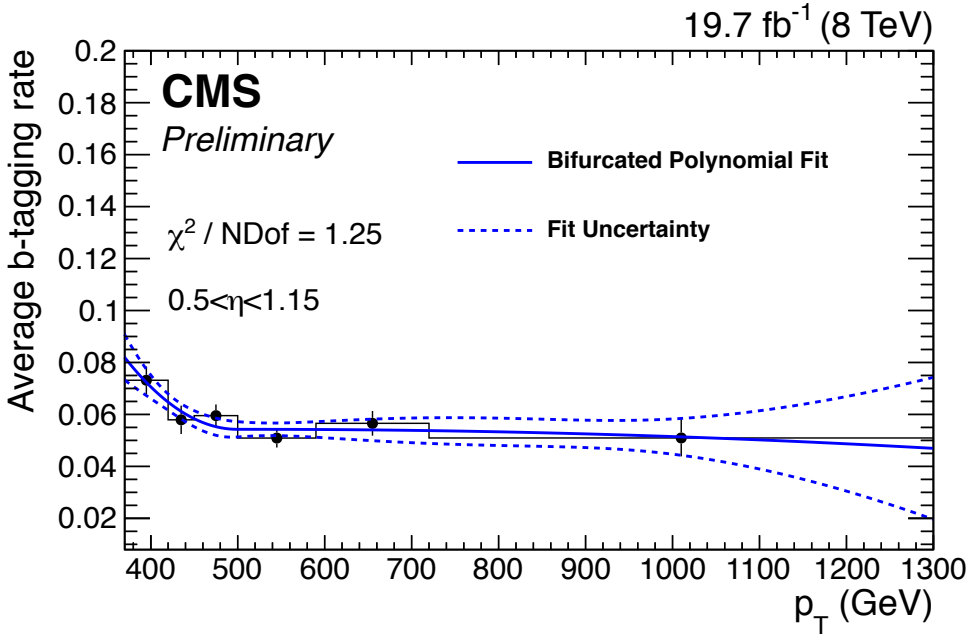
Cross Section Limits

$Z', \Gamma_{Z'}/M_{Z'} = 1\%$				
$M_{Z'}$ (TeV)	Expected (pb)	Expected range ($\pm1\sigma$) (pb)	Expected range ($\pm2\sigma$) (pb)	Observed (pb)
0.75	0.61	0.89 — 0.43	1.3 — 0.32	0.86
1.0	0.18	0.27 — 0.13	0.37 — 0.099	0.088
1.25	0.082	0.12 — 0.058	0.18 — 0.042	0.14
1.5	0.04	0.057 — 0.028	0.089 — 0.02	0.041
2.0	0.013	0.02 — 0.009	0.029 — 0.0067	0.011
3.0	0.0086	0.013 — 0.0059	0.021 — 0.0043	0.0059
$Z', \Gamma_{Z'}/M_{Z'} = 10\%$				
$M_{Z'}$ (TeV)	Expected (pb)	Expected range ($\pm1\sigma$) (pb)	Expected range ($\pm2\sigma$) (pb)	Observed (pb)
0.75	0.83	1.2 — 0.57	1.8 — 0.42	0.89
1.0	0.26	0.37 — 0.18	0.53 — 0.14	0.13
1.25	0.13	0.19 — 0.09	0.26 — 0.067	0.22
1.5	0.063	0.089 — 0.044	0.13 — 0.03	0.064
2.0	0.023	0.034 — 0.016	0.055 — 0.011	0.018
3.0	0.023	0.036 — 0.016	0.055 — 0.011	0.017
RS KK gluon				
$M_{g_{KK}}$ (TeV)	Expected (pb)	Expected range ($\pm1\sigma$) (pb)	Expected range ($\pm2\sigma$) (pb)	Observed (pb)
0.7	1.7	2.5 — 1.2	3.8 — 0.84	3.5
1.0	0.42	0.6 — 0.28	0.84 — 0.21	0.24
1.4	0.16	0.23 — 0.11	0.32 — 0.078	0.25
1.5	0.12	0.17 — 0.083	0.24 — 0.059	0.15
1.8	0.064	0.098 — 0.045	0.15 — 0.032	0.056
2.0	0.05	0.074 — 0.034	0.12 — 0.024	0.038
2.5	0.045	0.068 — 0.03	0.11 — 0.021	0.034
3.0	0.059	0.088 — 0.039	0.15 — 0.028	0.041

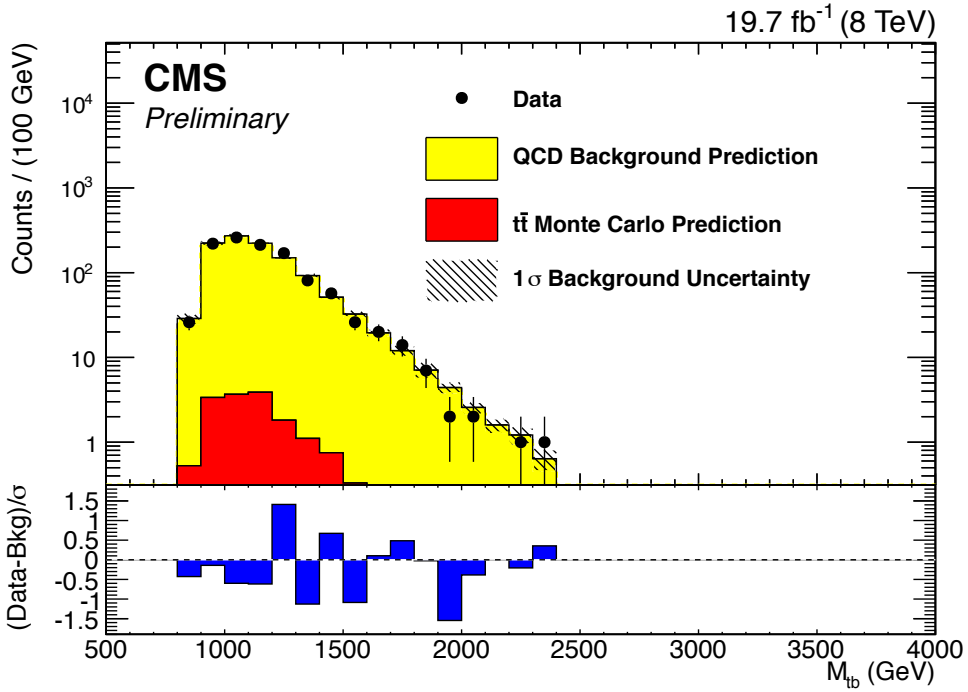
b-tagging Rates

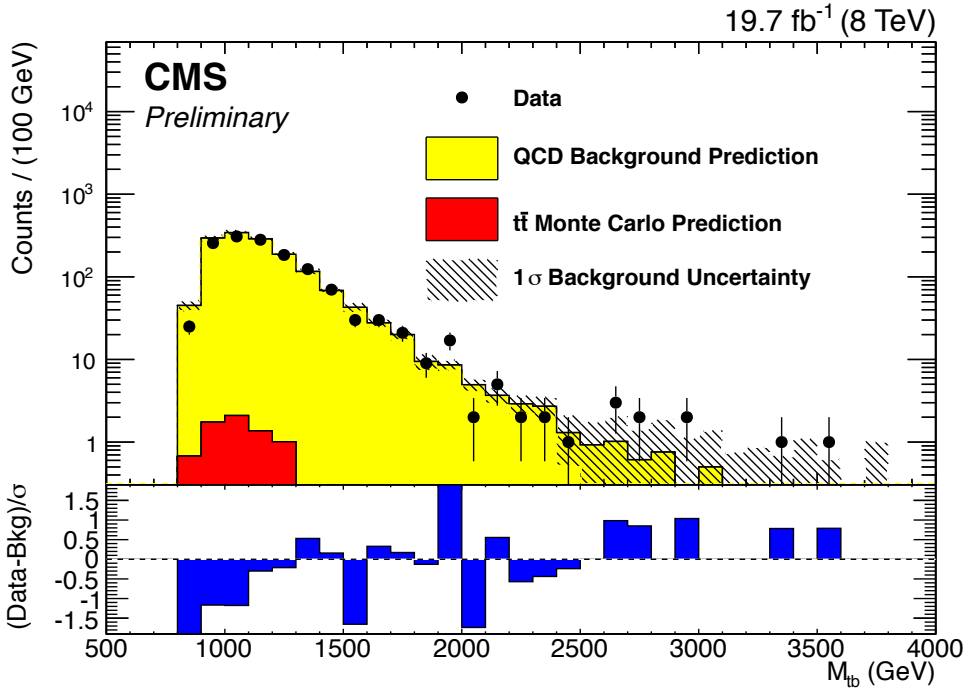




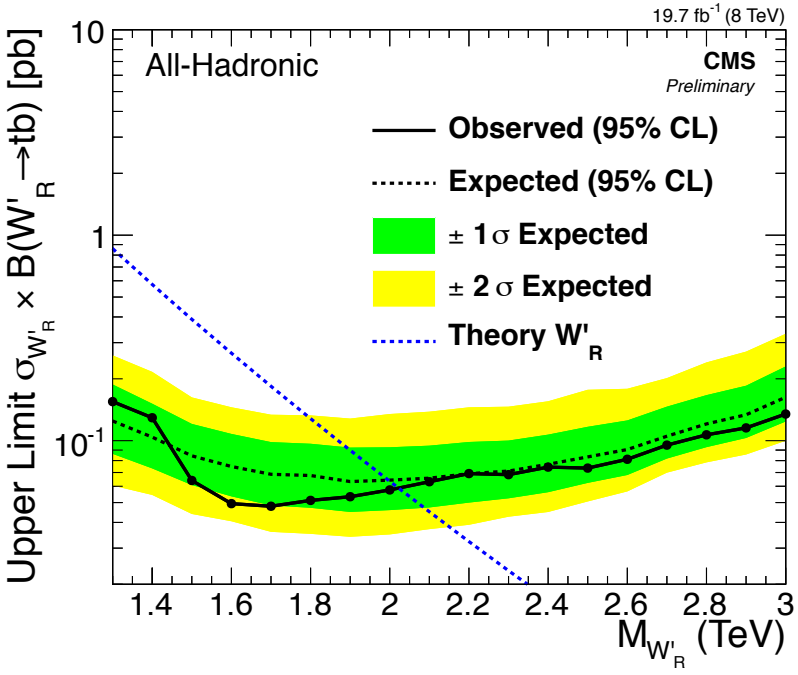


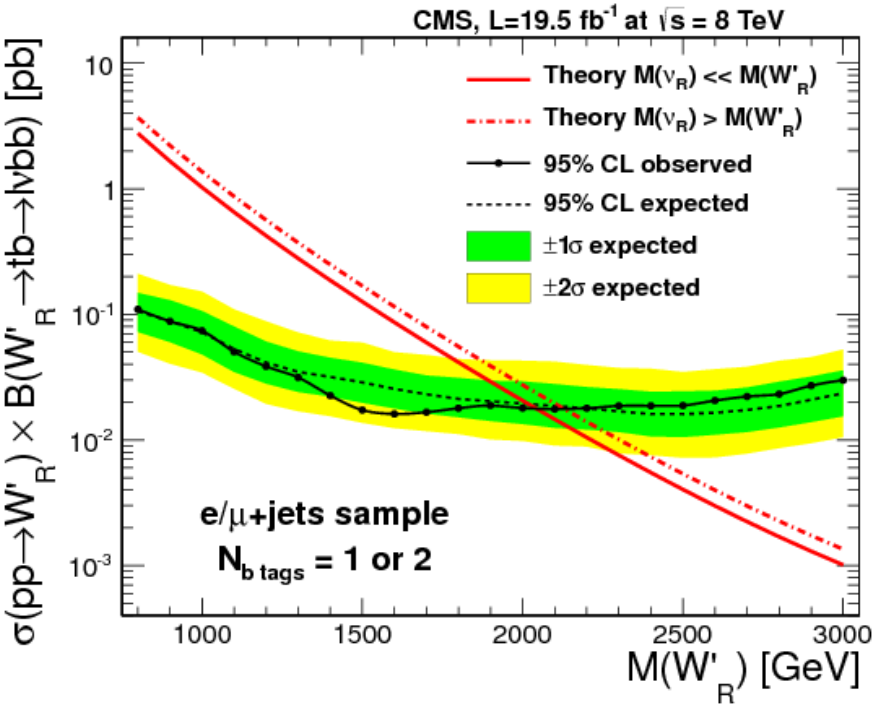
Hadronic W' Closure

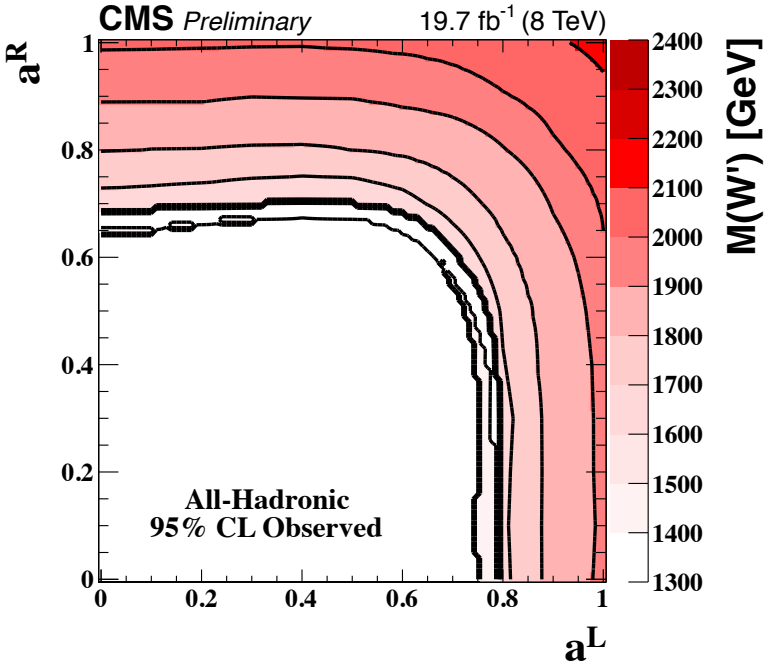


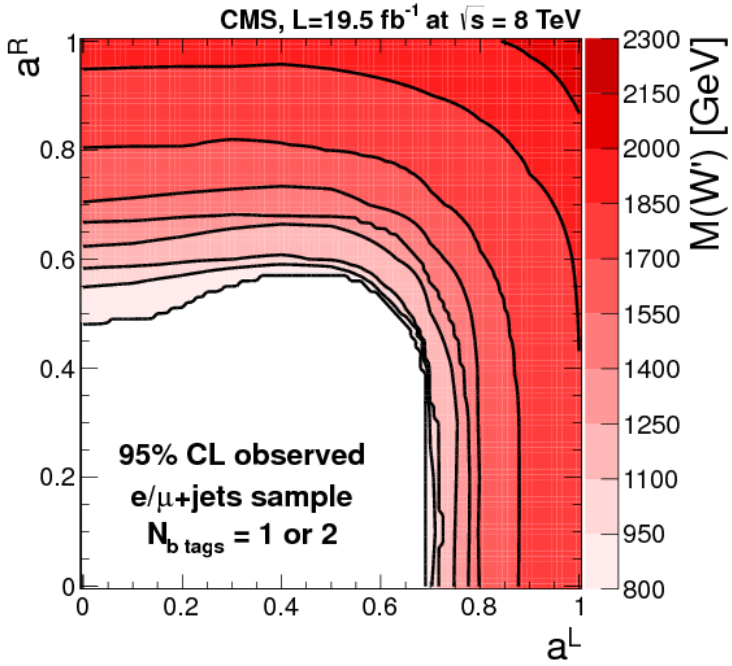


W' Limits


19.7 fb-1 (8 TeV)
All-Hadronic
CMS
Preliminary
Observed (95% CL)
Expected (95% CL)
± 1σ Expected
± 2 σ Expected
Theory W'R
Upper Limit σW'R × B(W'R →tb) [pb]
MW'R (TeV)


CMS, L=19.5 fb-1 at √s = 8 TeV
Theory M(νR) << M(W'R)
Theory M(νR) > M(W'R)
95% CL observed
95% CL expected
±1σ expected
±2σ expected
e/μ+jets sample
Nb tags = 1 or 2
σ(pp→W'R) × B(W'R →tb→lνbb) [pb]
M(W'R) [GeV]


CMS Preliminary
19.7 fb-1 (8 TeV)
aR
aL
M(W') [GeV]
All-Hadronic
95% CL Observed


CMS, L=19.5 fb-1 at √s = 8 TeV
aR
aL
M(W') [GeV]
95% CL observed
e/μ+jets sample
Nb tags = 1 or 2

SUSY Search Regions

CMS-PAS-SUS-14-001
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Search regions	$N_{\text{b jets}}$					
	≥ 0		1		2	
Multijet t-tagged search			SM Pred.	Obs.	SM Pred.	Obs.
$p_{\text{T}}^{\text{miss}} \in [200, 350]$ GeV			148^{+29}_{-24}	141	81^{+13}_{-12}	68
$p_{\text{T}}^{\text{miss}} > 350$ GeV			$33.4^{+7.0}_{-7.8}$	30	$8.6^{+2.6}_{-2.4}$	15
Dijet b-tagged search			SM Pred.	Obs.	SM Pred.	Obs.
$M_{\text{CT}} < 250$ GeV			1540±100	1560	93±10	101
$M_{\text{CT}} \in [250, 350]$ GeV			754±68	807	50.0±6.4	55
$M_{\text{CT}} \in (350, 450]$ GeV			85±10	101	6.5±1.7	8
$M_{\text{CT}} > 450$ GeV			16.0±4.1	23	1.0±0.9	1
ISR			356 ± 41	359	26.0 ± 4.1	28
Monojet search	SM Pred.	Obs.				
$p_{\text{T}}^{j_1} > 250$ GeV	35900±1500	36600				
$p_{\text{T}}^{j_1} > 300$ GeV	17400±800	17600				
$p_{\text{T}}^{j_1} > 350$ GeV	8060±440	8120				
$p_{\text{T}}^{j_1} > 400$ GeV	3910±250	3900				
$p_{\text{T}}^{j_1} > 450$ GeV	2100±160	1900				
$p_{\text{T}}^{j_1} > 500$ GeV	1100±110	1000				
$p_{\text{T}}^{j_1} > 550$ GeV	563±71	565				