Search For $W' \rightarrow tb$ All-Hadronic

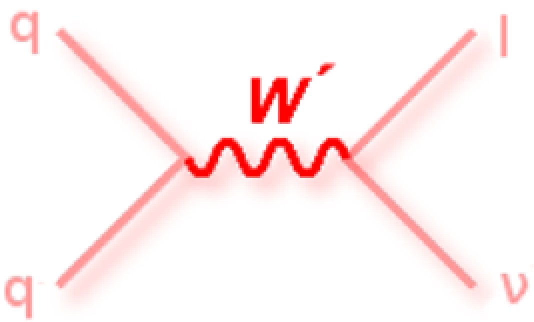
Kevin Nash

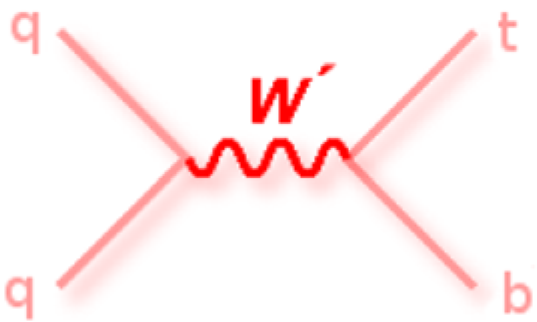
Introduction

- Searching for BSM physics
- Top quarks play an important role
  - New massive gauge bosons (W', Z')
  - Heavy quark partners (t',b')
  - Kaluza-Klein excitations
  - SUSY
  - etc…
- Until recently
  - Leptonic channel searches dominated
  - All-hadronic channel was swamped in QCD background
- $Z' \to t\bar{t}$
  - First analysis to use jet substructure to reduce QCD background
  - Hadronic channel comparable to semileptonic!
- $W' \to t\bar{b}$
  - Apply substructure tools
  - Hadronic channel *might* be competitive

W Prime

- Search for heavy tb resonance
  - W prime
- Predicted by many models
  - KK models, Little Higgs, Composite Higgs etc

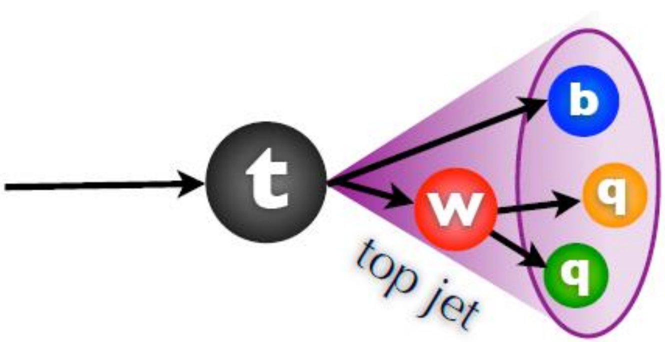




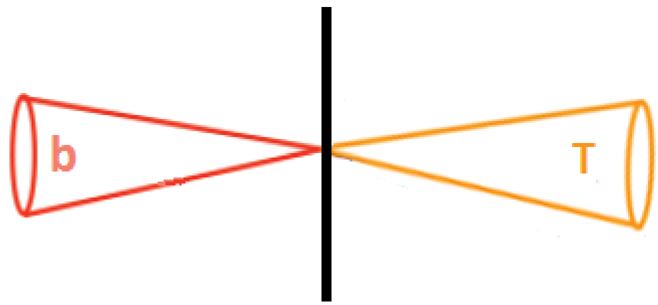
- All-hadronic W′ decay
  - $W' \rightarrow tb$
  - $t \rightarrow W + b \rightarrow (jj) + b$

Boosted Final State

- Primary focus high mass W′
- Top daughter jets highly boosted
  - Merged into a single jet
- b candidate jet in opposite hemisphere
- Interested in high p_T range
  - p_T > 450 GeV for top candidate
  - p_T > 370 GeV for b candidate



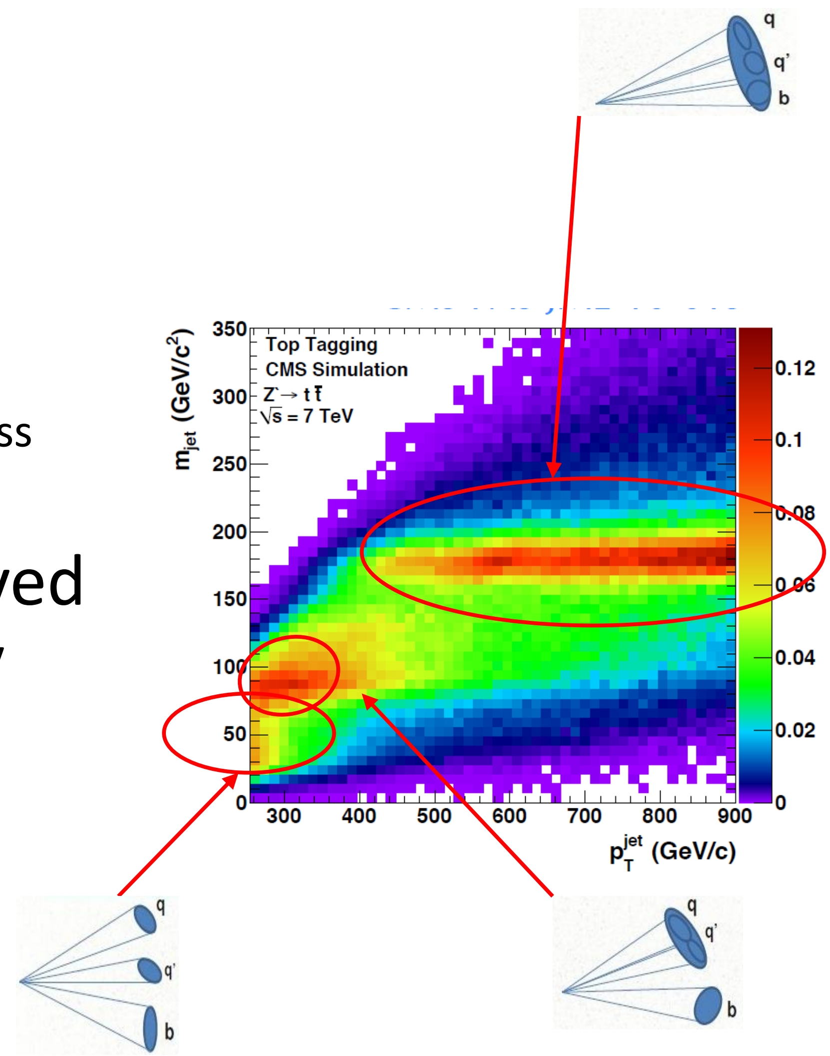
Merged Top Jet



Event Topology

Boosted Final State

- Top quark daughters merge at high boost
  - Boosted top quark identification
    - Sensitivity in very high resonant mass regions.
  - Hadronic top decay resolved as single jet $p_T \geq 400$ GeV

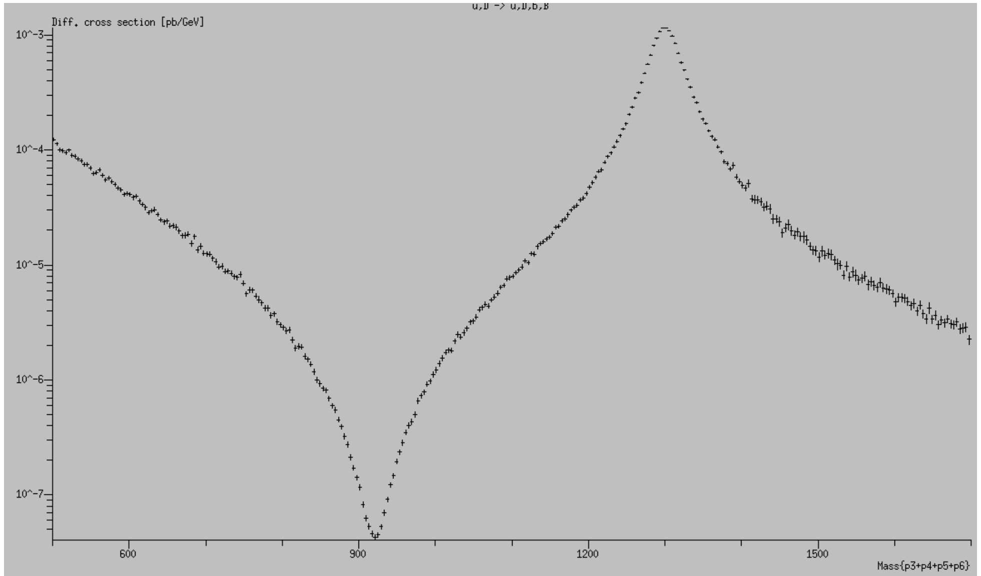


Analysis Strategy

- Boosted top jet identification
- b-tagging
- QCD background estimate from data
- $t\bar{t}$ background shape from Monte Carlo
  - Normalization taken from data
- Place limits on right-handed W'
- Place limits on left- and right-handed W' couplings

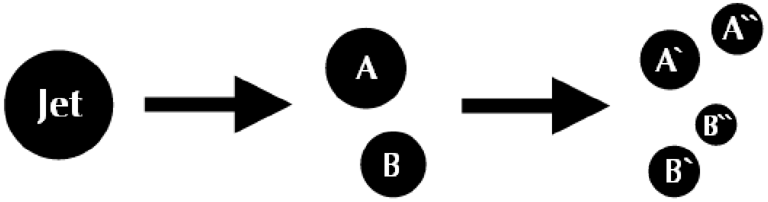
Signal Generation

- Using the CompHEP package
- Generate right, left, and mixed coupling W′ samples
  - Standard model interference on left-handed and mixed
    - 200 GeV generator level p_T cut is applied to the b



CMS Top-Tagging Algorithm

- Try to decompose merged jet into two, and then three or four primordial "subjets"



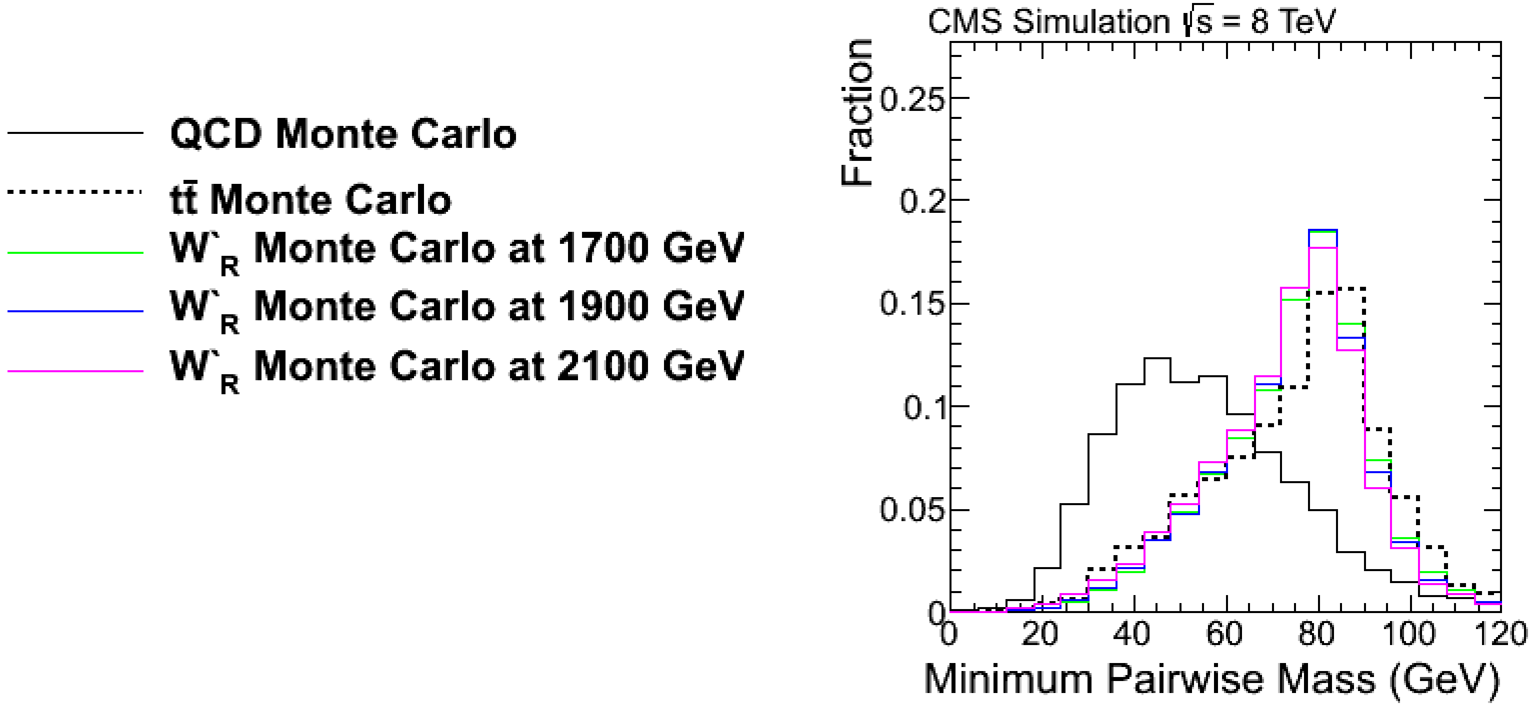
- The top jet should contain three subjets
  - Two from the W decay
  - One from the b quark hadronization
- Use Nsubjets ≥ 3

CMS Top-Tagging Algorithm

- Calculate the pairwise mass of subjets (i, j)
  - $m_{ij} = \sqrt{(E_i + E_j)^2 - (\vec{p}_i + \vec{p}_j)^2}$
- Put a subjet pair within the range of a W boson mass.
  - Cut on minimum $m_{ij} > 50\ \mathrm{GeV}$
- Put jet within top mass range
  - Use $140\ \mathrm{GeV} < M < 250\ \mathrm{GeV}$

CMS Top-Tagging Algorithm

Minimum Pairwise Mass in Signal, $t\bar{t}$, and QCD Monte Carlo



b Candidate Jet

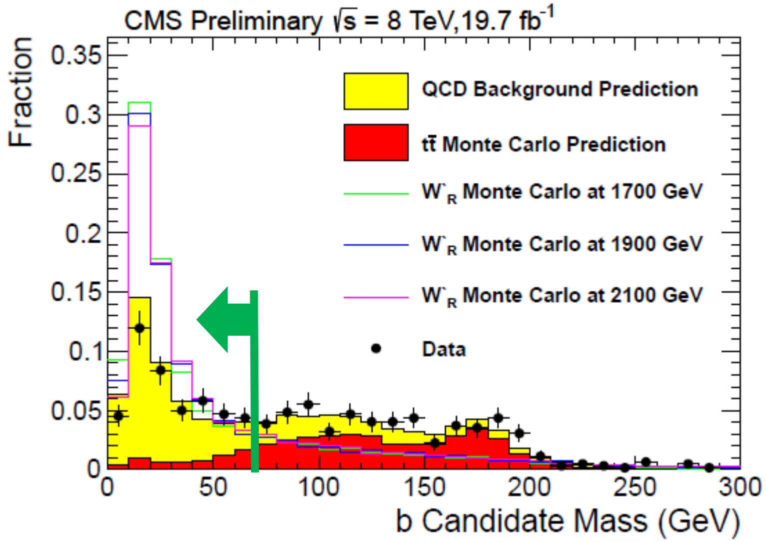
- W′ decay produces a high p_T b-jet
- Use CSV algorithm at the medium operating point
  - CSVM > 0.679
- Use EPS13 Monte Carlo to data Scale Factor

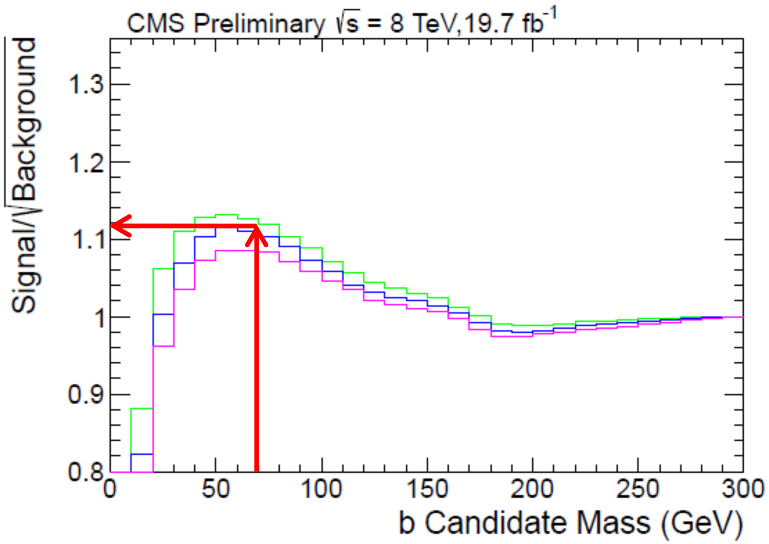
b Candidate Jet

- After top-tagging, the qcd fraction is greatly reduced
- $t\bar{t}$ contribution reduced by approximately the same amount as signal
- High fraction of $t\bar{t}$ in full background estimate
- Suppression of $t\bar{t}$ becomes important

b Candidate Jet

- In $t\bar{t}$, the b candidate jet is commonly a W or merged top
- $t\bar{t}$ reduction can be performed with a simple cut on b mass
- We use b candidate mass < 70 GeV
  - $t\bar{t}$ reduction of ~80%





Δy Cut

- Looking for dijet resonance
- QCD dijets are more likely to have a higher Δy than those from a heavy resonance
  - Similar Δy cut seen in other EXO searches
- Cut at $|\Delta y| < 1.6$
- Discrimination at high mass

Background Estimation

- Extract $t\bar{t}$ shape from Monte Carlo
  - Normalization from data
- Extract QCD background estimate from data (both shape and normalization).
  - Measure the average b-tagging rate for QCD jets in control region.
  - Apply this average b-tagging rate to the pre b-tagged sample in the signal region.

Control Region

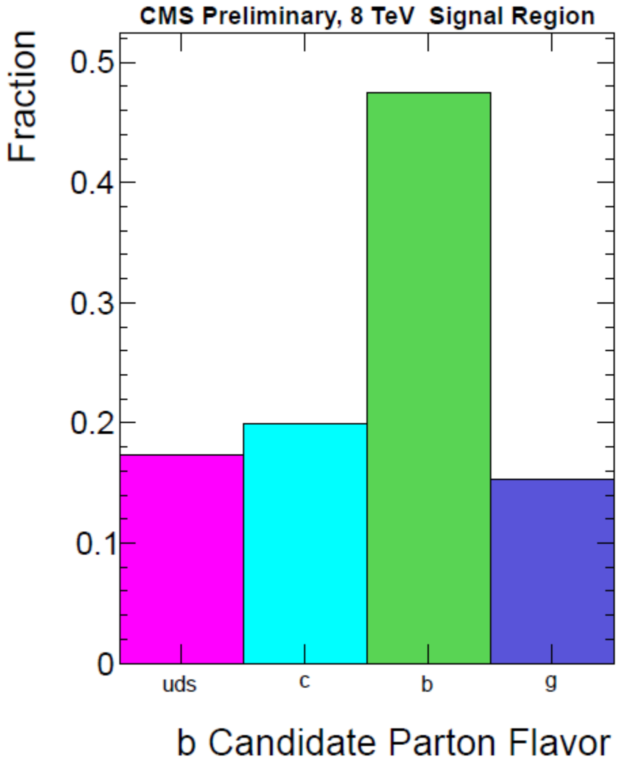
$$\bar{P}_{btag} = \frac{N_{post}}{N_{pre}}$$

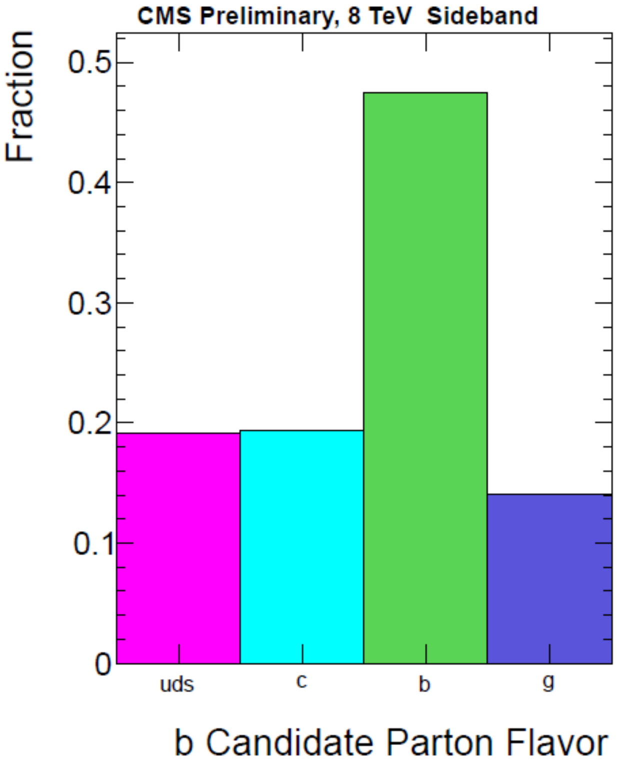
Signal Region

$$N_{post} \cong N_{pre} \times \bar{P}_{btag}$$

Background Estimation

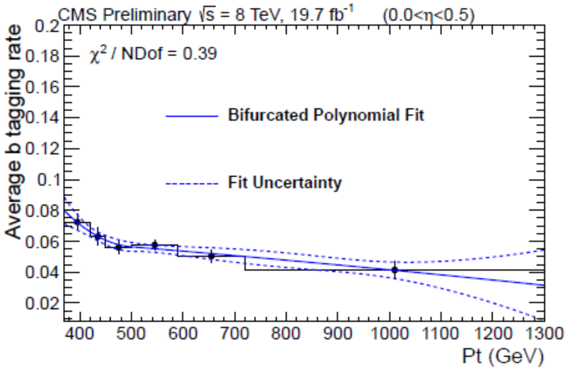
- We use the sideband Nsubjets < 3

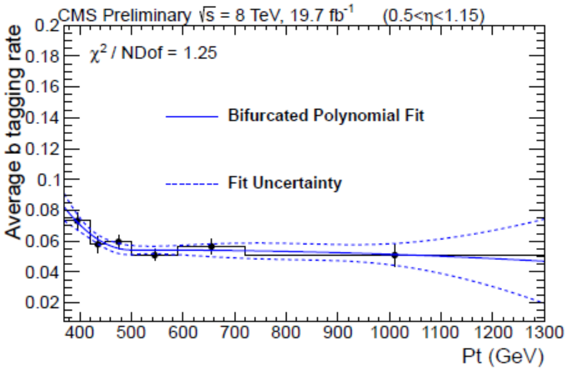


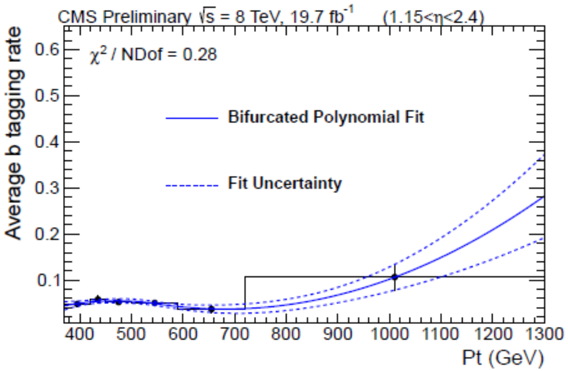


Background Estimation

- Fit average b-tagging rate
- Three η regions
  - $0.0 < |\eta| \le 0.5$
  - $0.5 < |\eta| \le 1.15$
  - $1.15 < |\eta| \le 2.4$

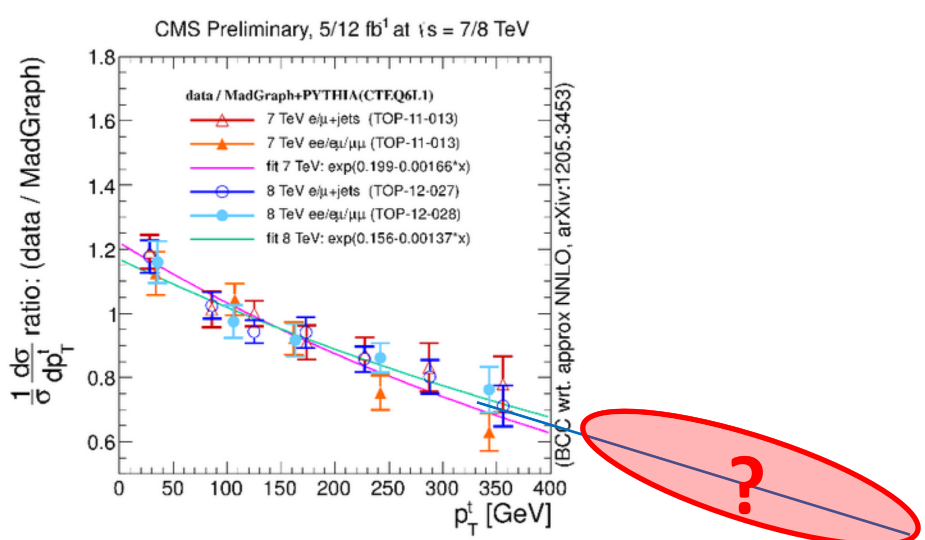






$t\bar{t}$ Normalization

- Use Monte Carlo for $t\bar{t}$ prediction
- Use $t\bar{t}$ p_T reweighting
  - Using TOP PAG prescription
- Not designed for high kinematic range
- Measure $t\bar{t}$ normalization and uncertainty in data

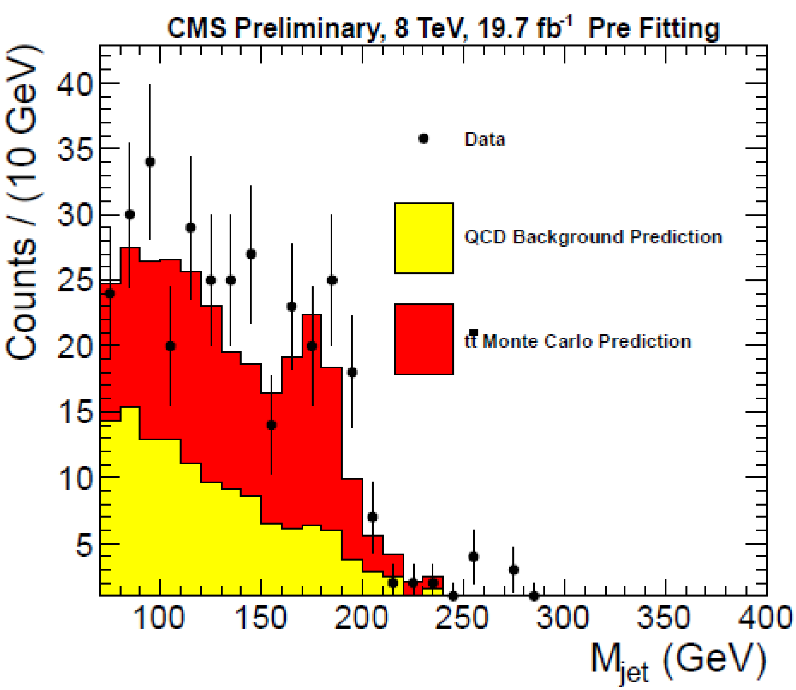


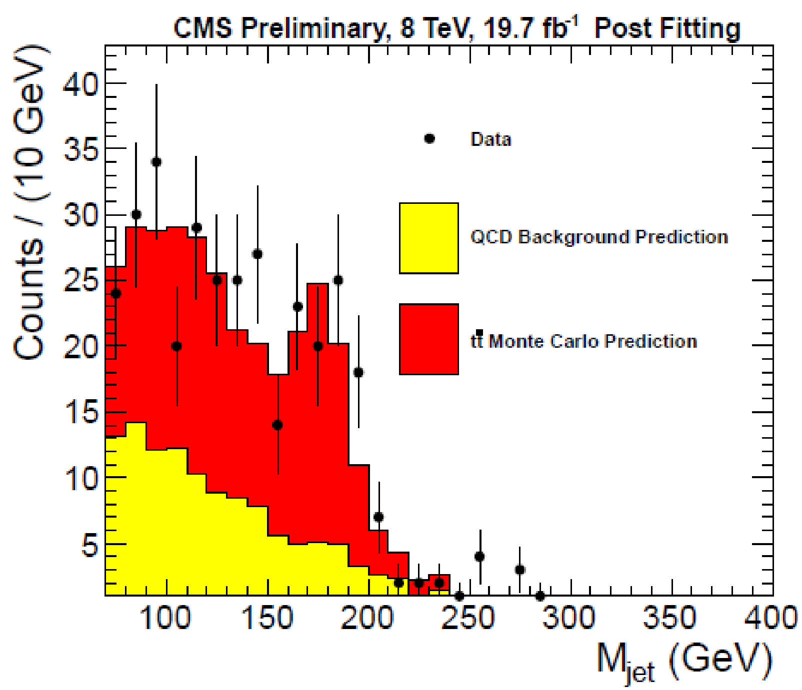
$t\bar{t}$ Normalization

- Define new control region enriched in $t\bar{t}$
  - M_b>70 GeV
- Extract normalization using template fit to the b candidate mass
  - $t\bar{t}$ as one template and QCD as the other
  - QCD moves within it’s errors
  - $t\bar{t}$ is unconstrained

$t\bar{t}$ Normalization

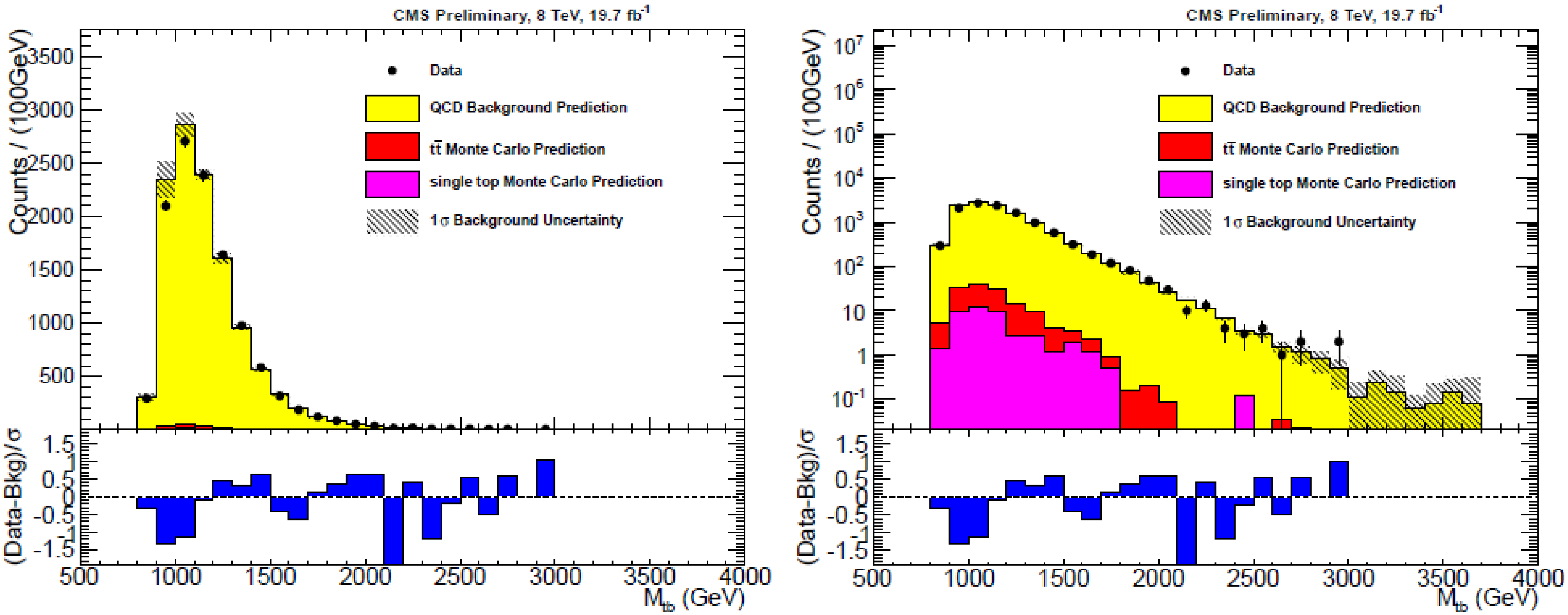
- $t\bar{t}$ needs to be further scaled by 1.23±0.24
- Total rate uncertainty on $t\bar{t}$





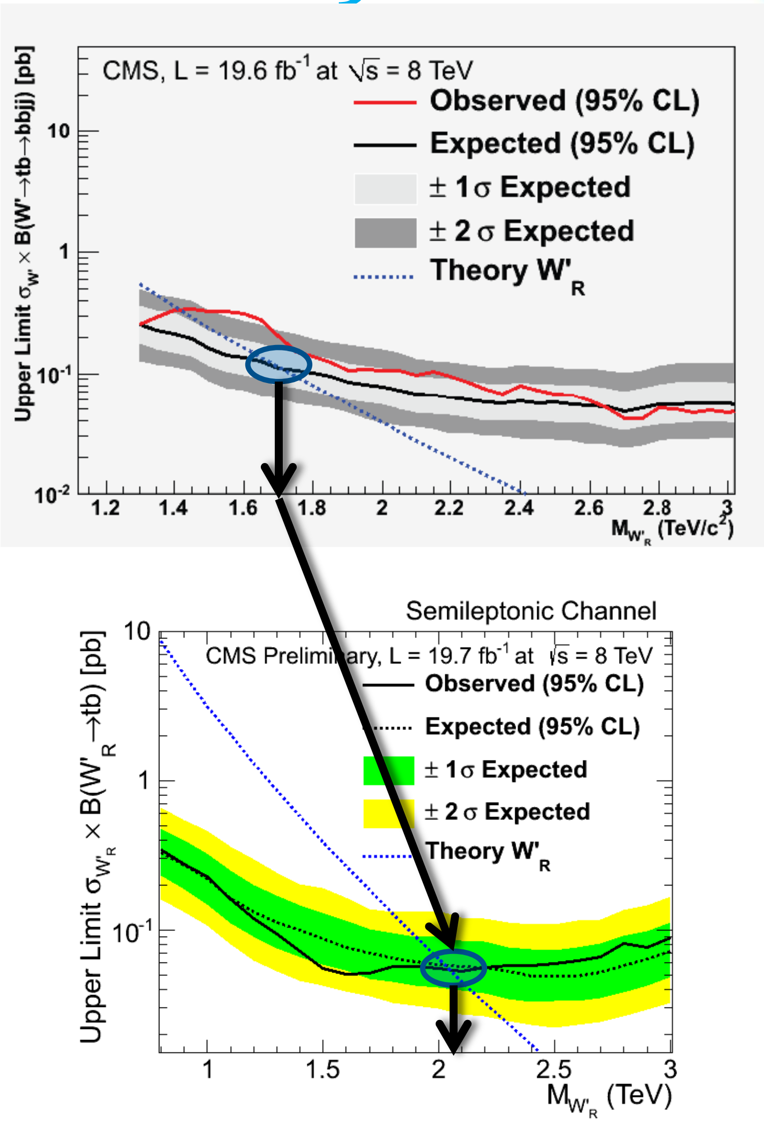
Full Selection (First Iteration)

- CMS top-tagger and b-tagging



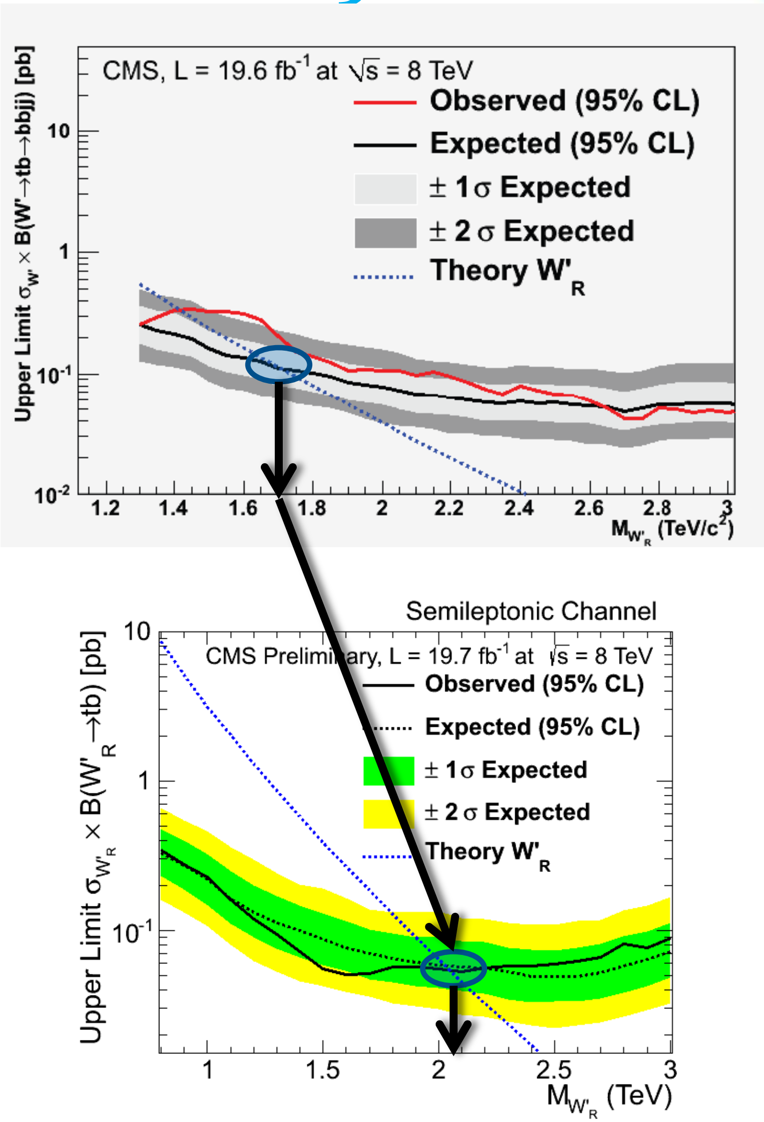
Full Selection (First Iteration)

- Low sensitivity compared to semileptonic
- Need to reduce huge QCD dominated background



Full Selection (First Iteration)

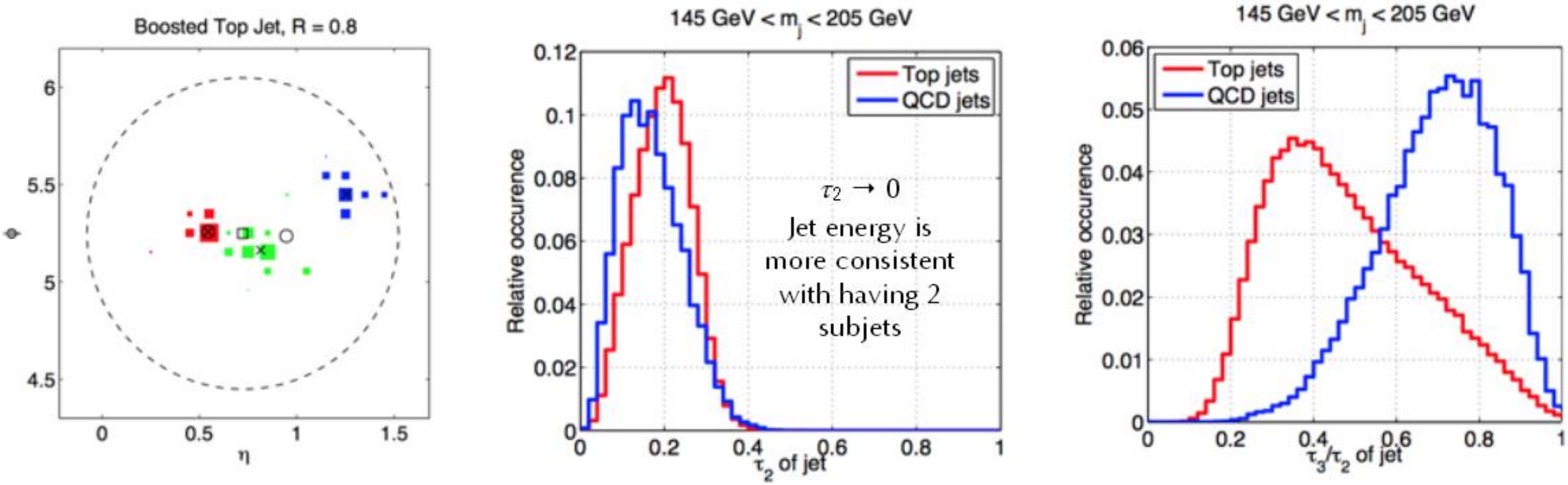
- Look towards cutting edge top-tagging techniques
- N-subjettiness
  - Never before used for top-tagging
- Subjet b-tagging
  - Completely new



N-subjettiness

- Variables τ_N describe how consistent the jet energy is with having N subjets
  - Cut on τ_3/τ_2

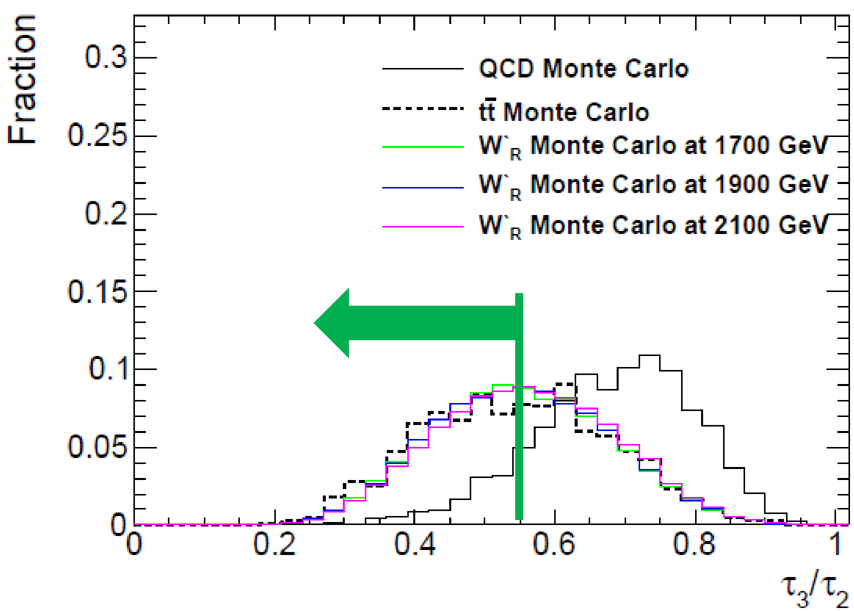
$$\tau_N = \frac{1}{d_0} \sum_k p_{T,k} \min \{ \Delta R_{1,k}, \Delta R_{2,k}, \cdots, \Delta R_{N,k} \}$$



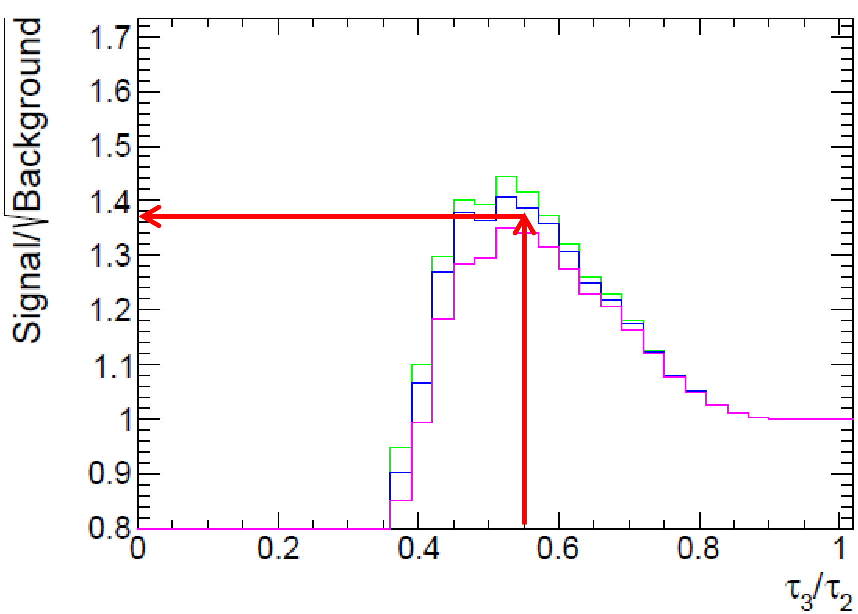
Plots From James Dolen: JetMET Algorithms and Reconstruction Meeting - June 6, 2013

N-subjettiness

τ_3 / τ_2 in Signal, $t\bar{t}$, and QCD Monte Carlo

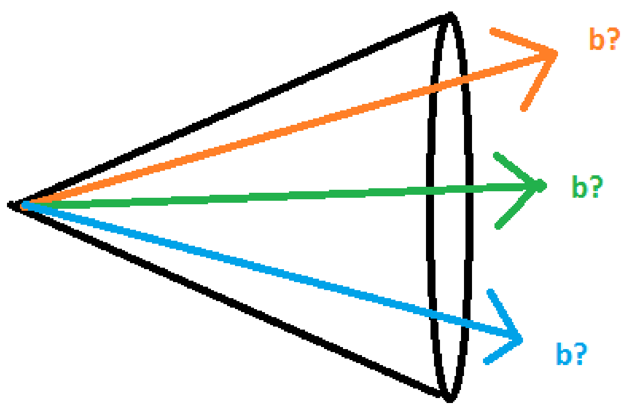


Plot Signal/$\sqrt{\text{Background}}$ for a cut on this variable.
Cut at $\tau_3 / \tau_2 < 0.55$



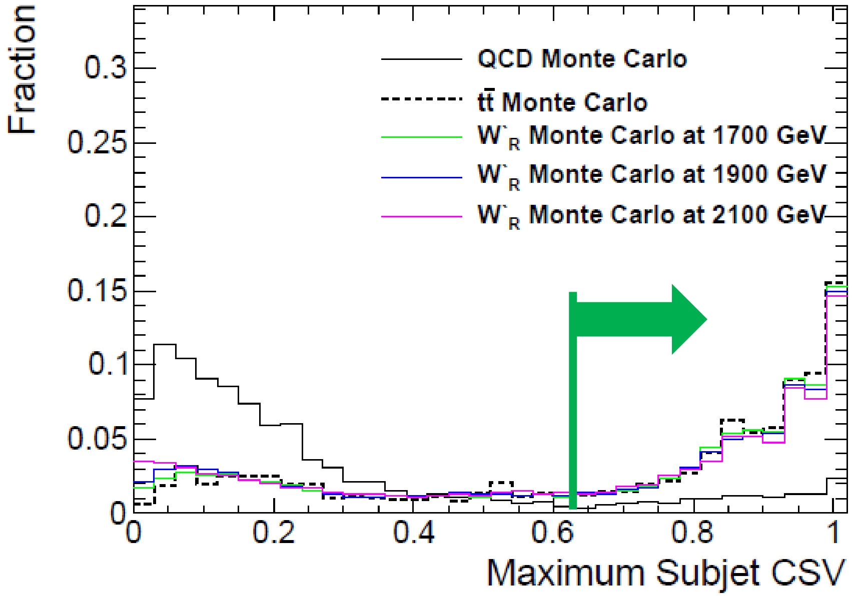
b-tagging Subjets

- $t \rightarrow W + b \rightarrow (jj) + b$
- One of the subjets within the top should be a b-jet
- Allow for any of the three subjets to be b-tagged
- Use CSVM operating point



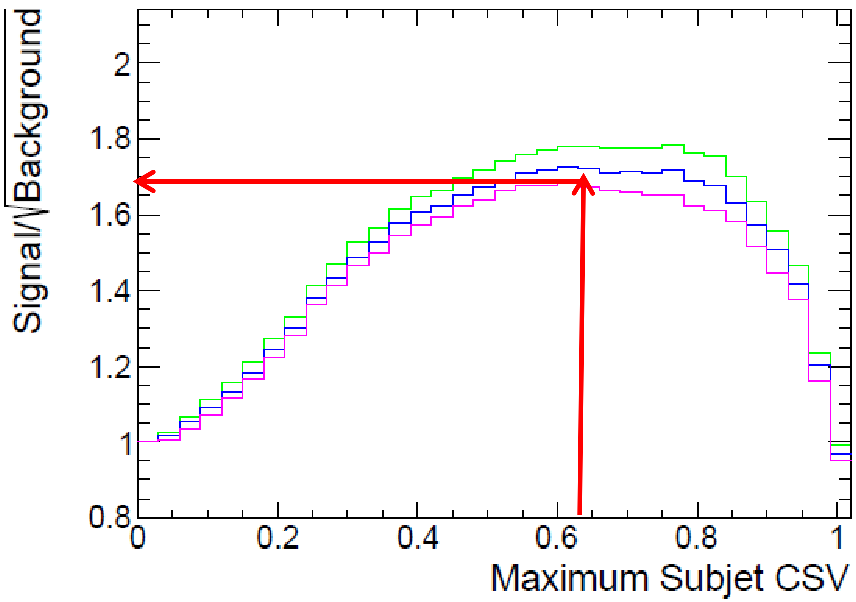
b-tagging Subjets

maximum b discriminant in Signal, $t\bar{t}$, and QCD Monte Carlo

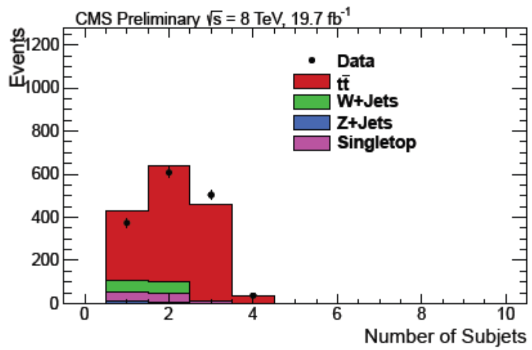


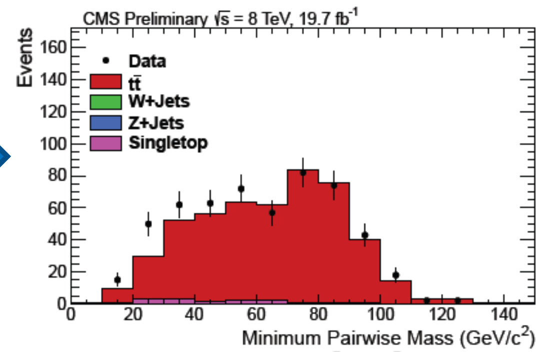
Plot Signal/$\sqrt{\text{Background}}$ for a cut on this variable. Use standard operating point

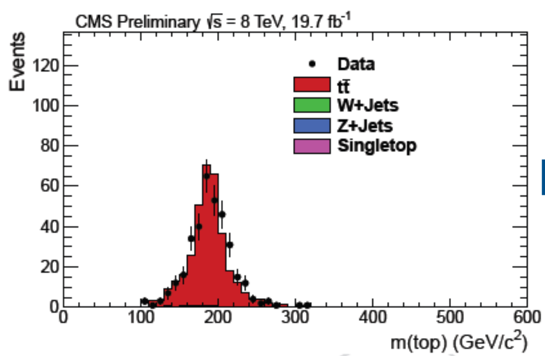
Cut at CSV > 0.679

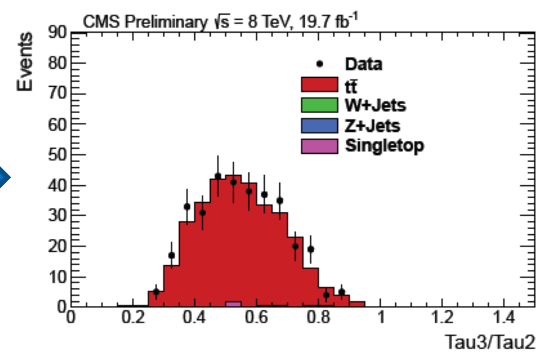


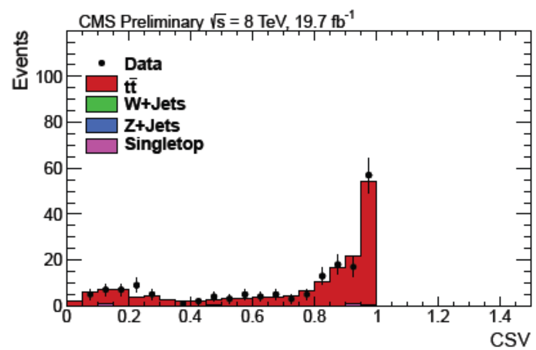
Top-Tagging Scale Factor











SF = 1.04 ± 0.13

Event Selection - Recap

- Top candidate jet
  - $p_T > 450$ GeV
  - CMS top-tagging algorithm
  - N-subjettiness
  - Subjet b-tagging
- b candidate jet
  - $p_T > 370$ GeV
  - CSVM b tag
  - Mass < 70 GeV
- $|\Delta y|_{tb} < 1.6$

Event Selection - Recap

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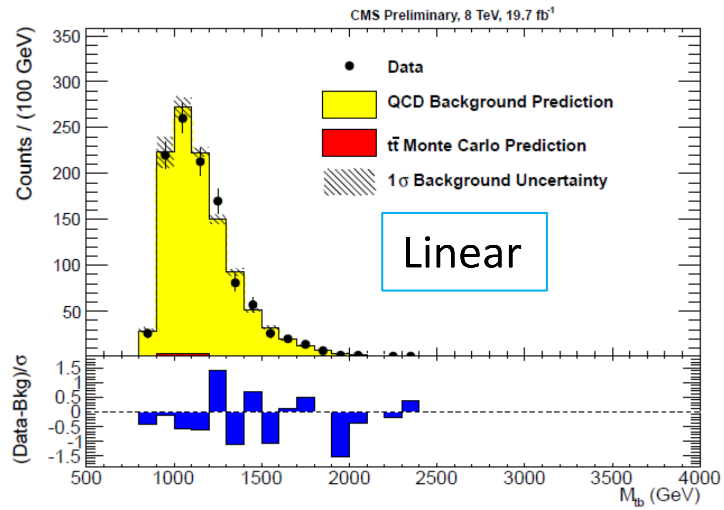
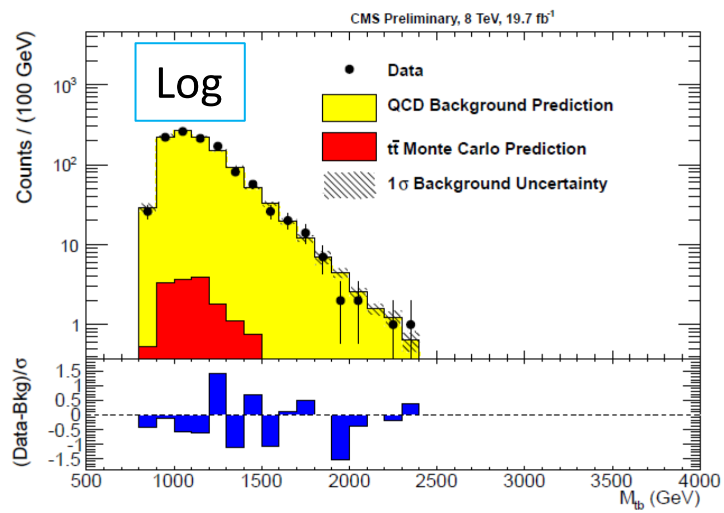
Can be inverted to define control regions with similar kinematics

Closure Test in Data

- Investigate QCD estimate in Control region

Invert Subjet b-tagging

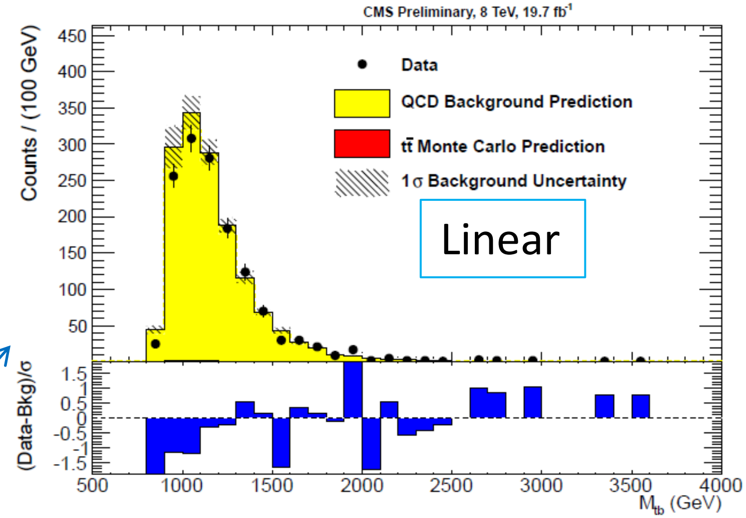


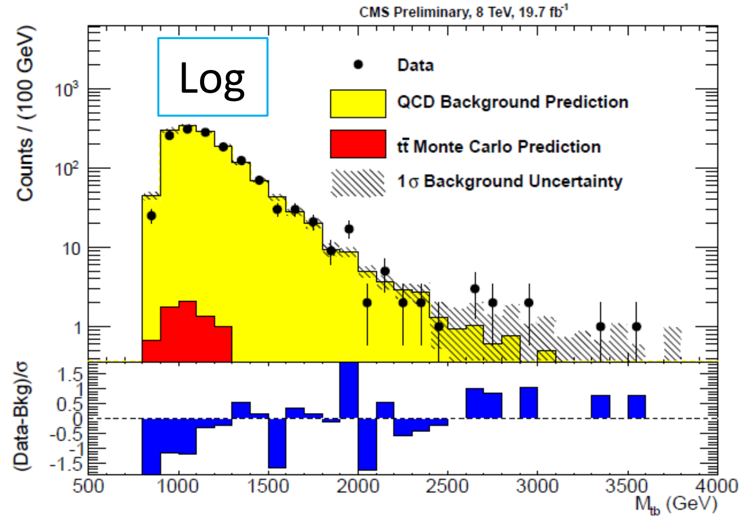


Closure Test in Data II

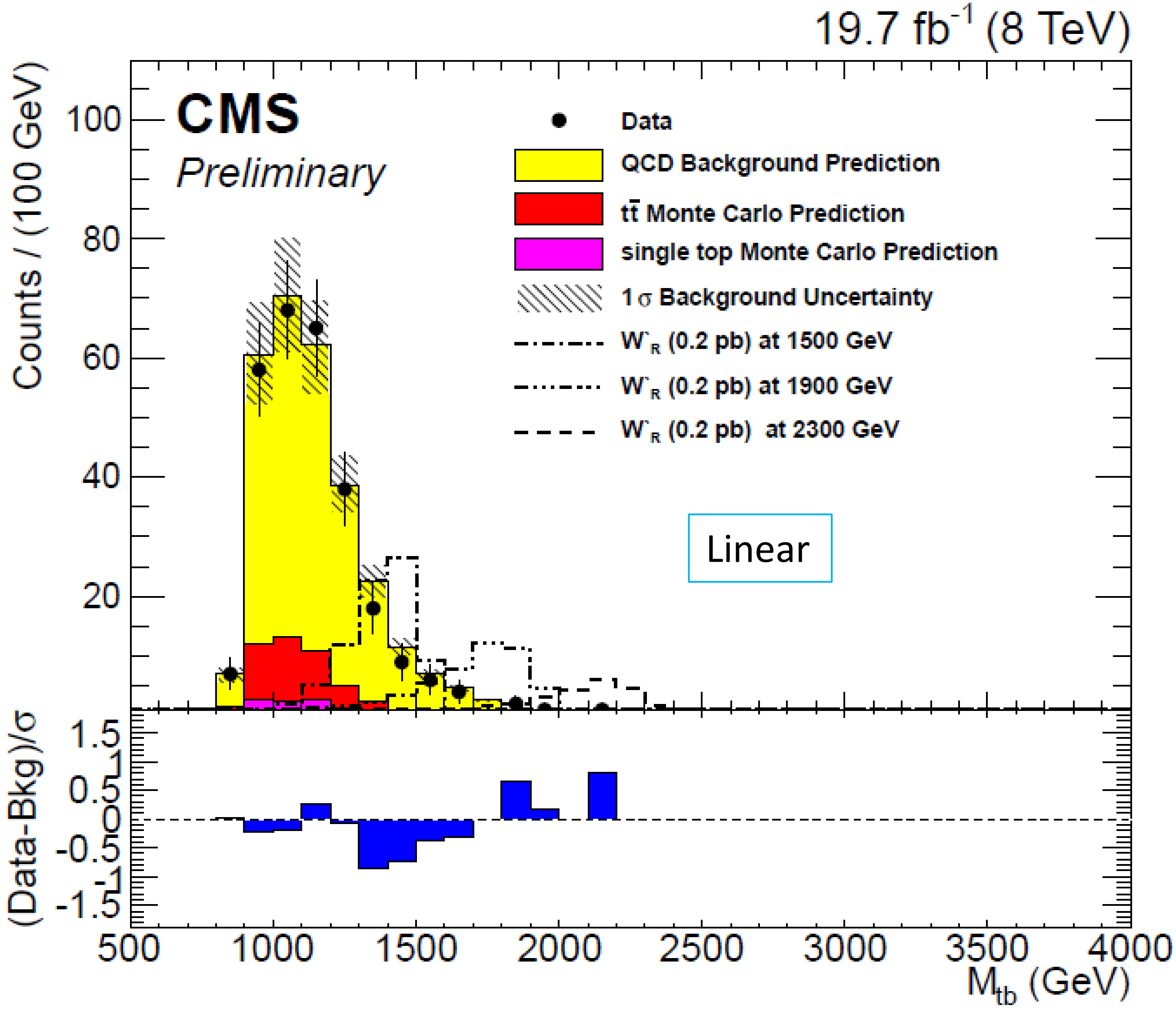
- Investigate QCD estimate in Control region

Invert Minimum Pairwise Mass and τ_3/τ_2

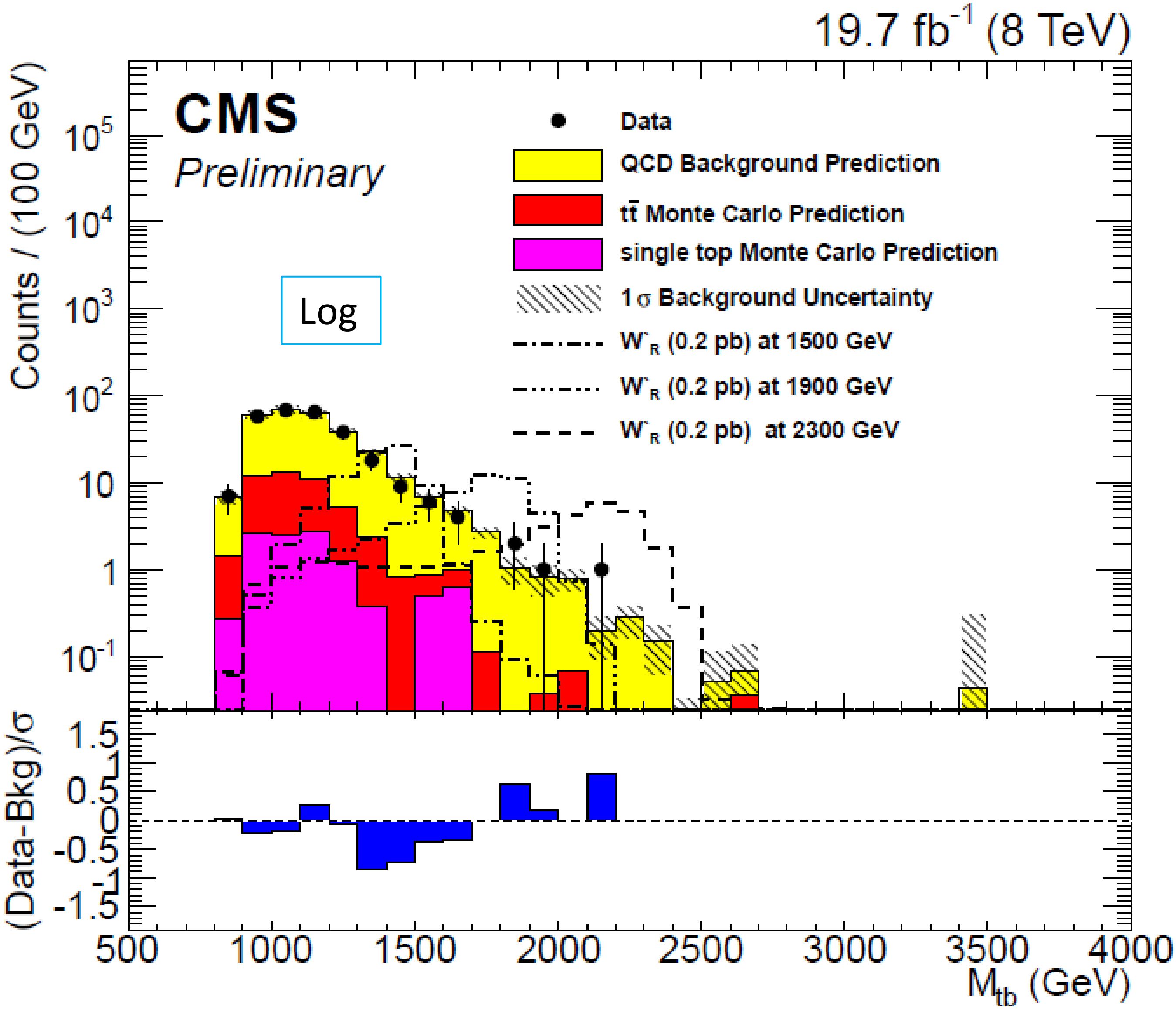




Full Selection

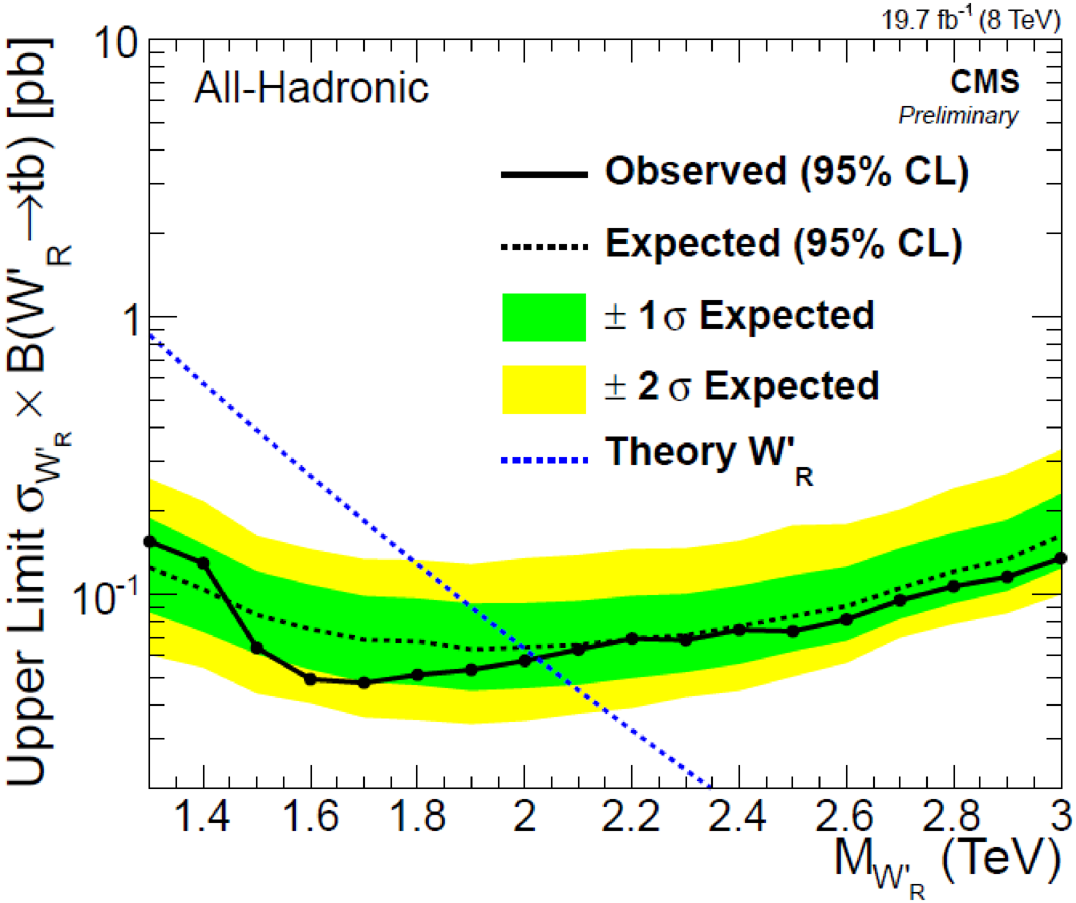


Full Selection



Limits

- Theta package used for limit setting
- Observed
  - 2.0 TeV
- Expected
  - 1.99 TeV
- W'_R



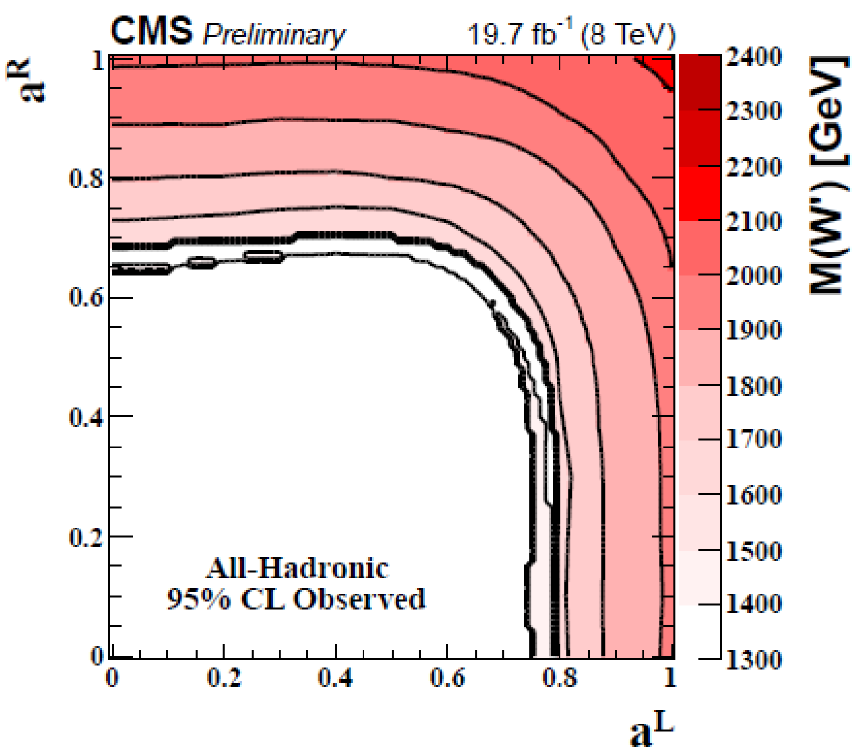
Generalized Coupling Limits

- Cross section limits set on right-handed W′
- W′ could also couple to left-handed fermions
  - Set limits in a^R, a^L space
  - Weight left, right, mixed samples by

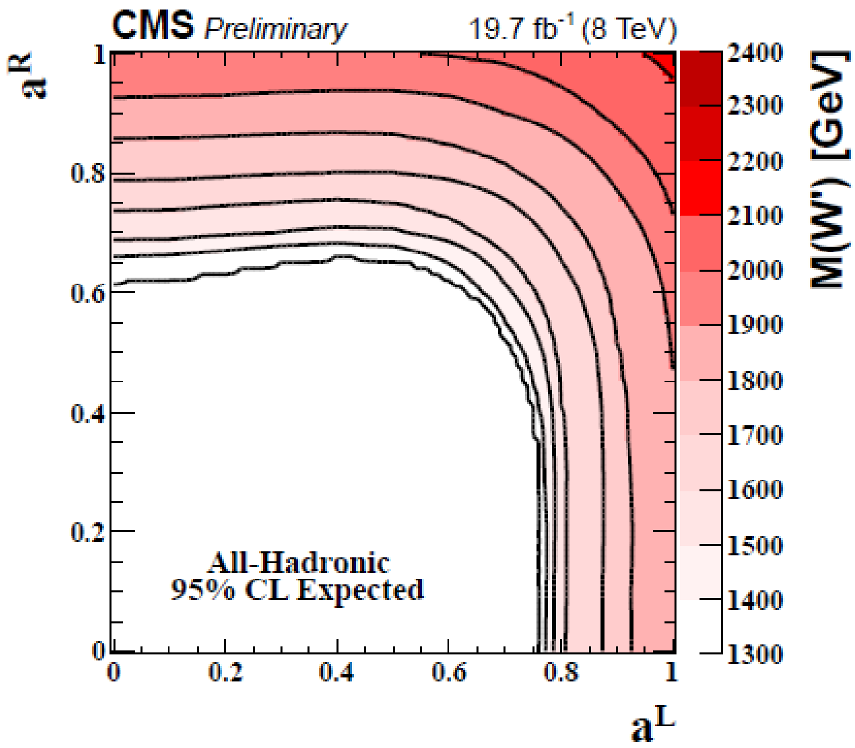
$$
\begin{aligned}
\sigma &= \sigma_{SM} + a^L_{ud} a^L_{tb} \left(\sigma_L - \sigma_R - \sigma_{SM}\right) \\
&+ \left(\left(a^L_{ud} a^L_{tb}\right)^2 + \left(a^R_{ud} a^R_{tb}\right)^2 \right) \left(\sigma_R\right) \\
&+ \frac{1}{2} \left(\left(a^L_{ud} a^R_{tb}\right)^2 + \left(a^R_{ud} a^L_{tb}\right)^2 \right) \left(\sigma_{LR} - \sigma_L - \sigma_R\right)
\end{aligned}
$$

Generalized Coupling Limits

Observed

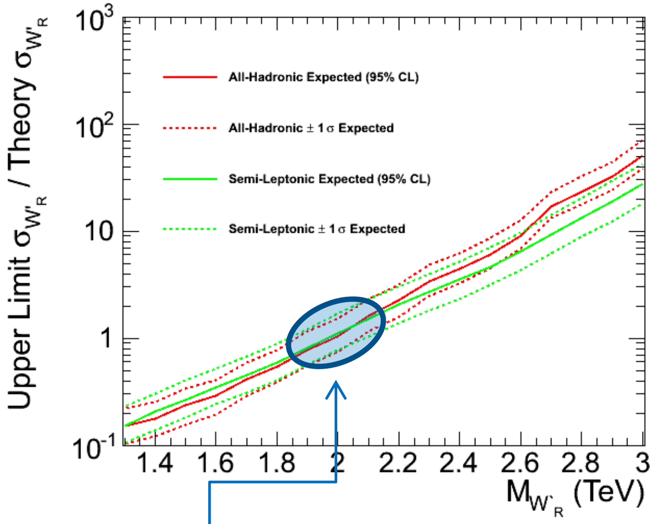


Expected



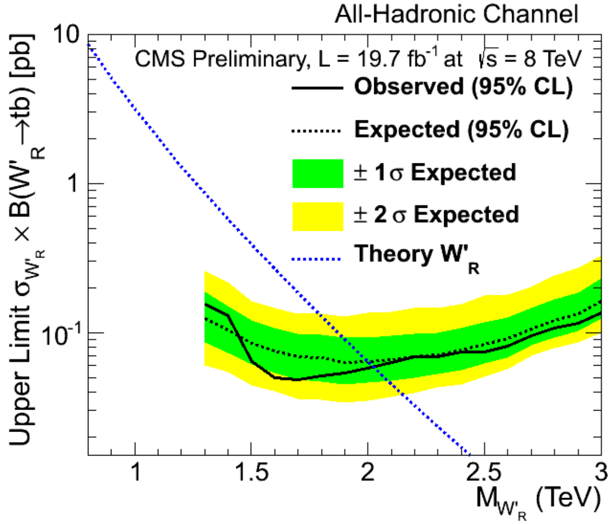
Combination

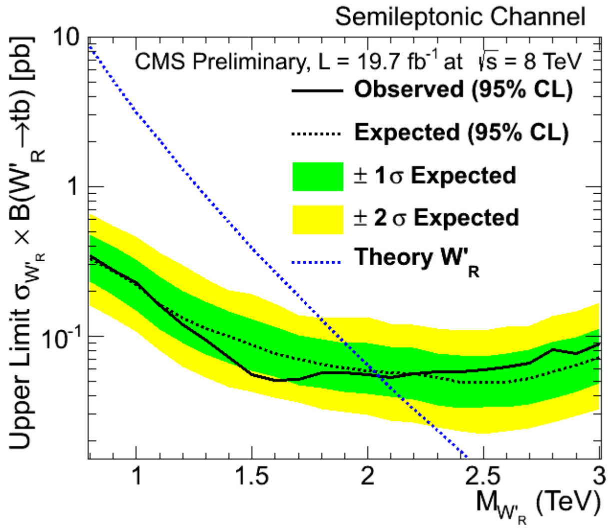
- Semileptonic channel
  - $W' \rightarrow tb$
  - $t \rightarrow W + b \rightarrow (l\nu) + b$
  - Exclude $M_{W'} < 2.03$ TeV

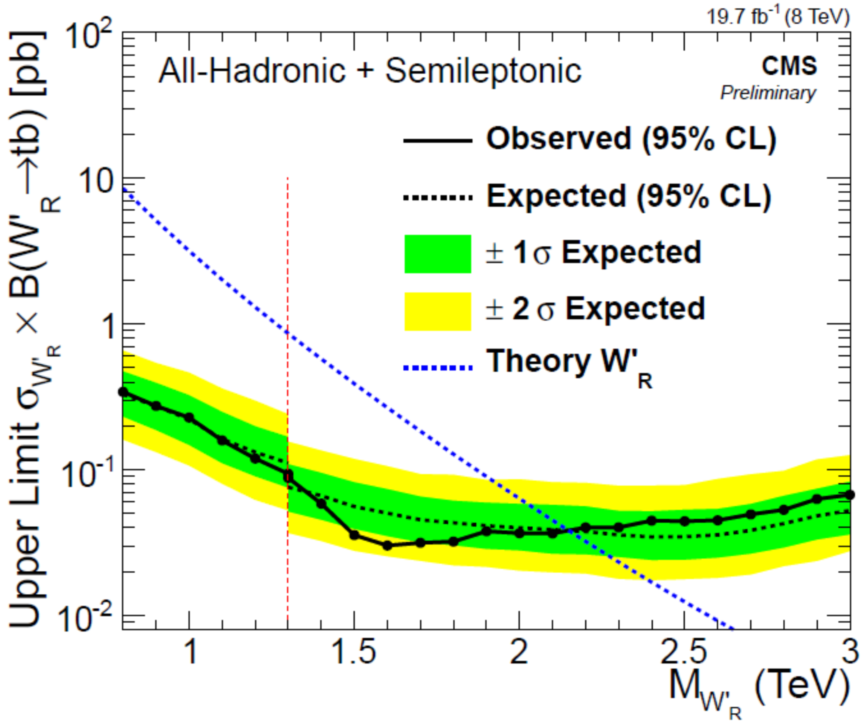


- Nearly identical sensitivity!
- Non-overlapping signal points
  - Combined limits for 1300GeV < $M_{W'}$
  - Semileptonic limits for $M_{W'}$ < 1300GeV

Combination
Right-Handed W'

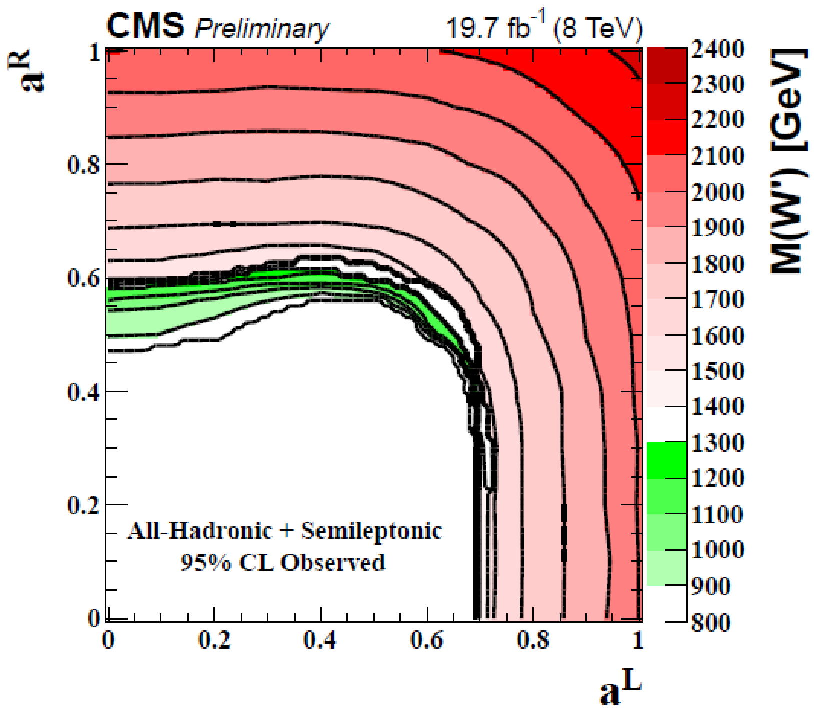




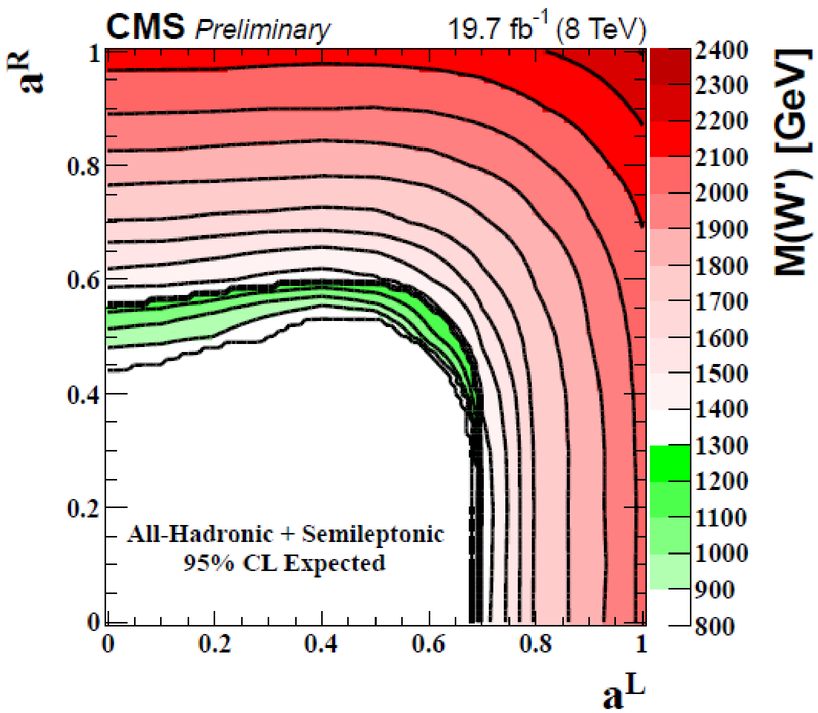


Combination
Generalized Coupling

Observed



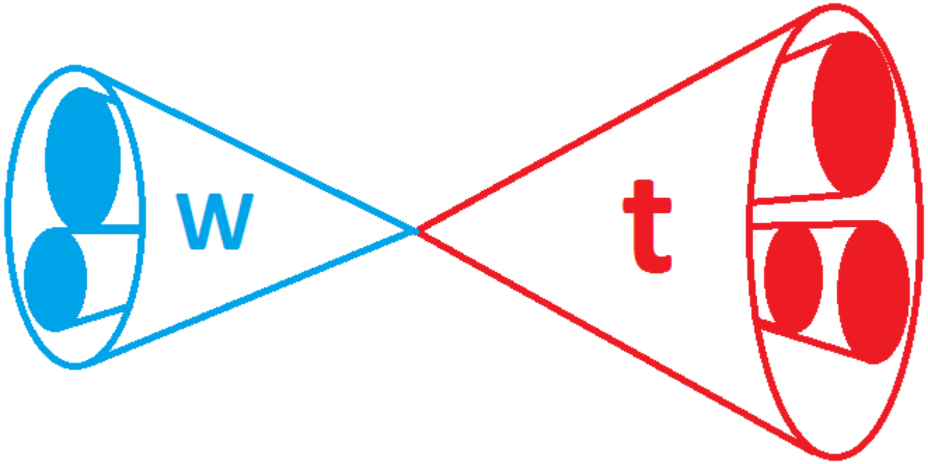
Expected



Search For $b^* \rightarrow tW$ All-Hadronic

Search For $b^* \to tW$ All-Hadronic

- Recycle methods from W′ search
  - QCD background estimate must be tweaked
  - Need to find new control regions
- Use CMS Top Tagger with N-subjettiness and subjet b-tagging
- Use Boosted W jet tagging



Boosted W-Tagging

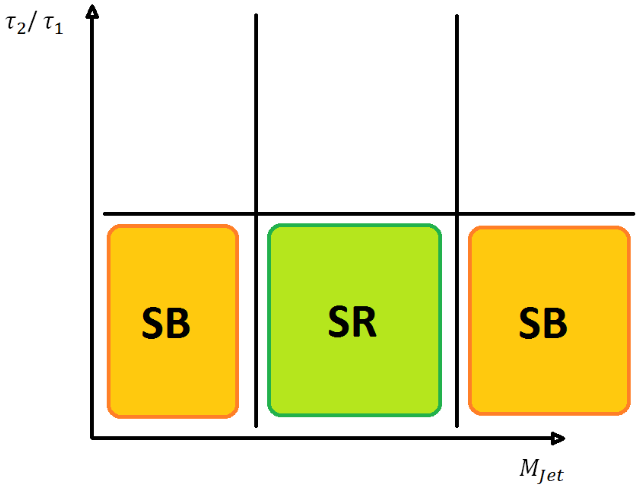
- Use standard boosted W tagging techniques
- Cut on $\tau_2/\tau_1 < 0.5$
- $70 < M_{Jet} < 100$
- Scale factor of 0.86 ± 0.065

Background Estimation

- Extract $t\bar{t}$ shape from Monte Carlo
  - Normalization from data
- Extract QCD background estimate from data.
  - Measure the top-mistagging rate for QCD jets in control region.
  - Apply this top-mistagging rate to the pre top tagged sample in the Signal region.

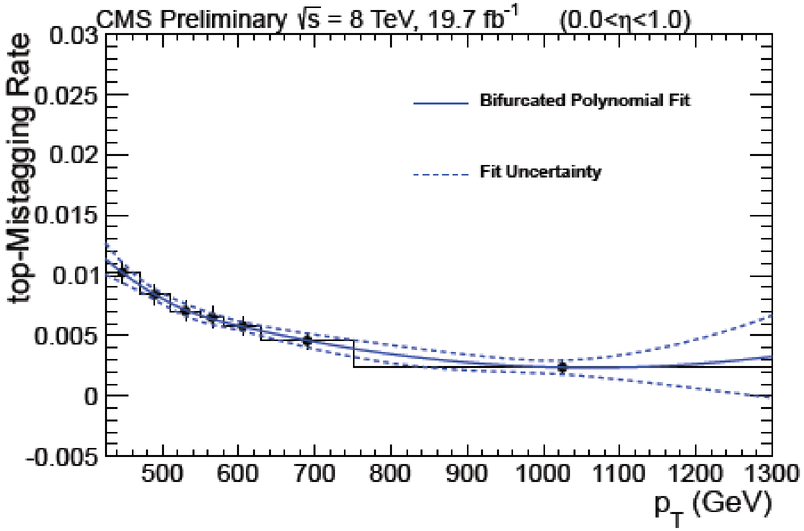
Background Estimation

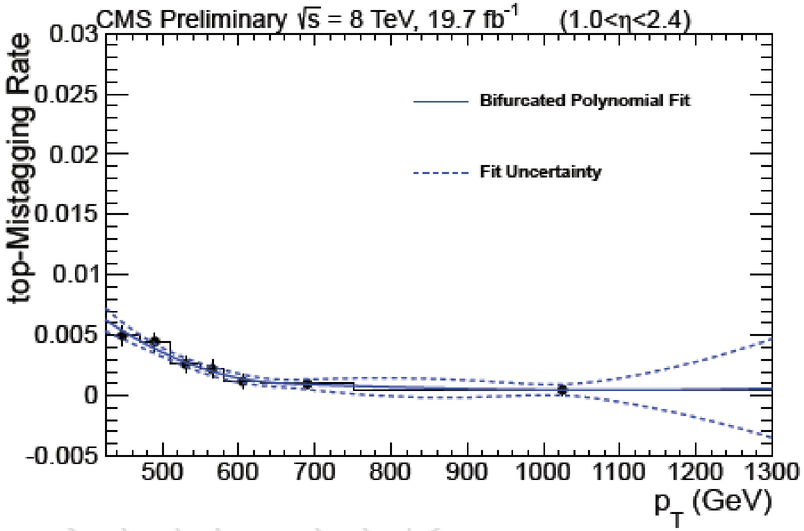
- Need to find control region to extract top-mistagging rate
- Invert W candidate mass requirement
  - $\begin{cases} 30 < \mathrm{M_{Jet}} < 70 \\ 100 < \mathrm{M_{Jet}} \end{cases}$
- Keep top candidate mass requirement
  - Find top-mistagging probability given this jet mass



Background Estimation

- Two η regions
  - $0.0 < |\eta| \leq 1.0$
  - $1.0 < |\eta| \leq 2.4$
- Bin in p_T

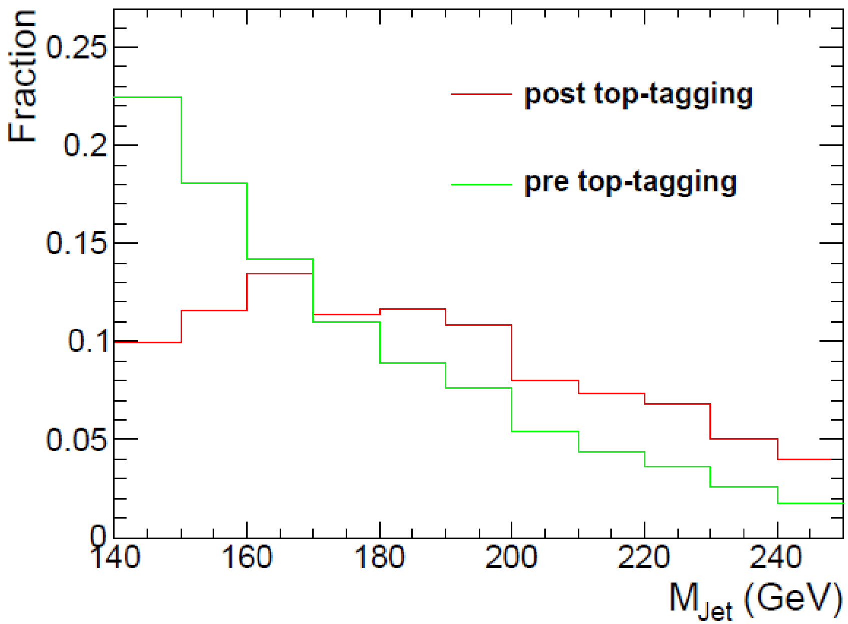


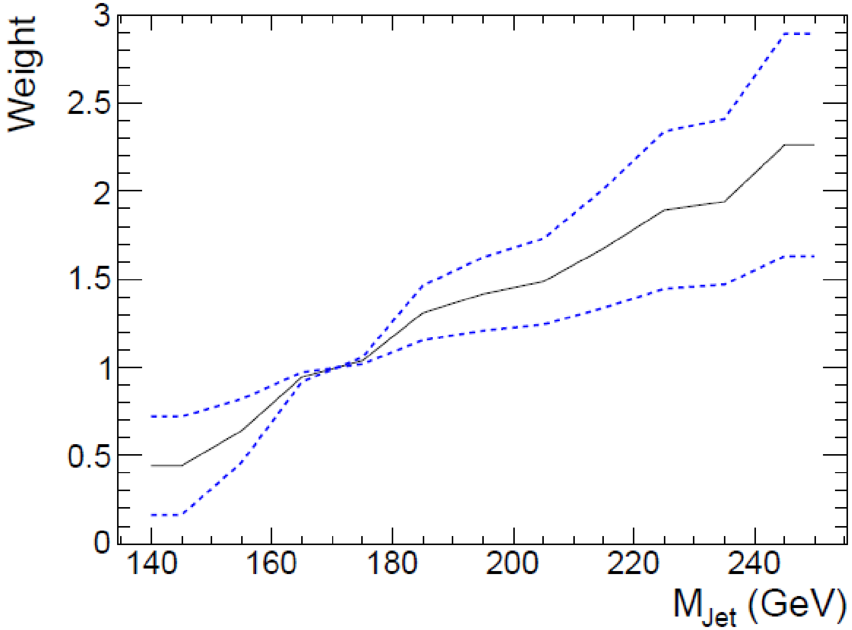


Background Estimation

- Top mass not correctly modeled
  - Keeping the top mass window helps, but there is still a shape discrepancy
- Study effect in QCD Monte Carlo
  - Extract mass distributions before and after the number of subjets and MinMass requirements
  - Extract weights used to correct for this discrepancy

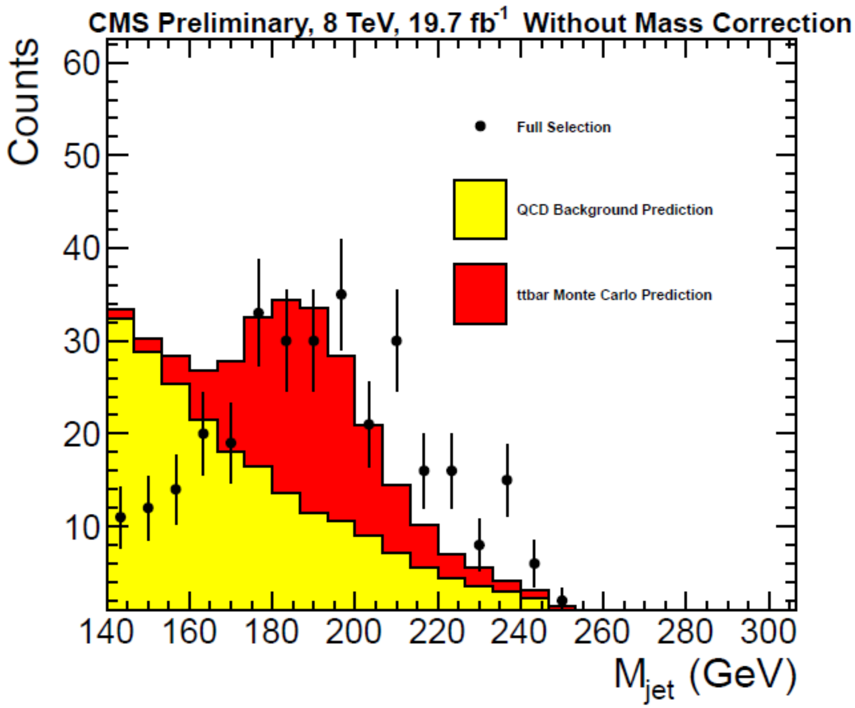
Background Estimation

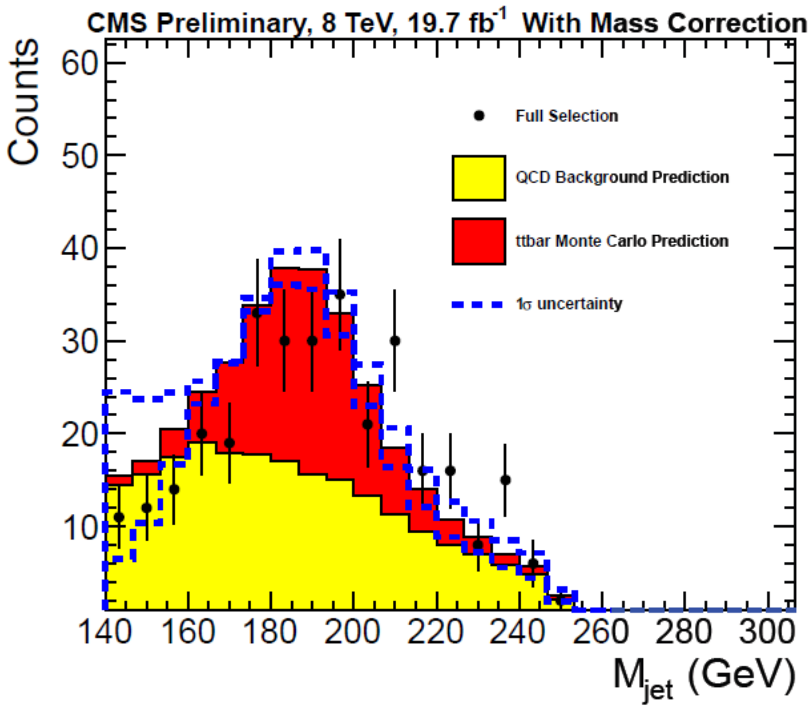




Background Estimation

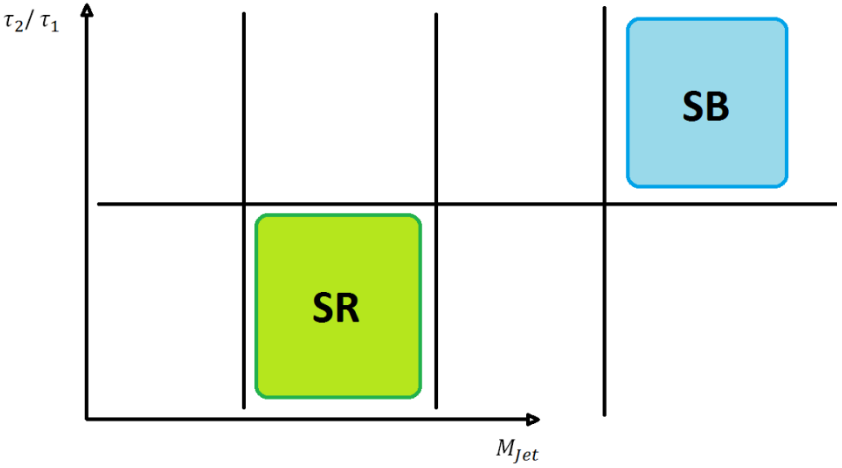
Signal Region





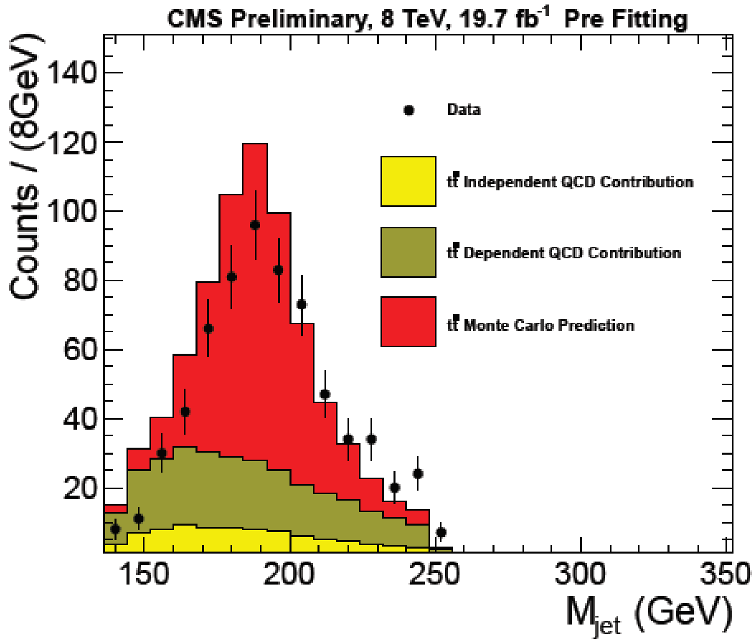
$t\bar{t}$ Normalization

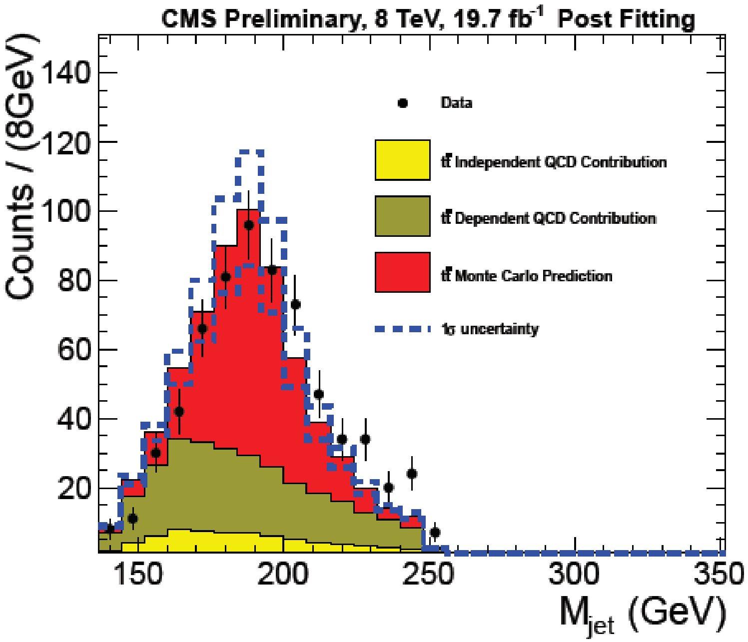
- Extract $t\bar{t}$ normalization and uncertainty using a control region
  - $130 < M_{Jet}$
  - $\tau_2/\tau_1 > 0.5$



$t\bar{t}$ Normalization

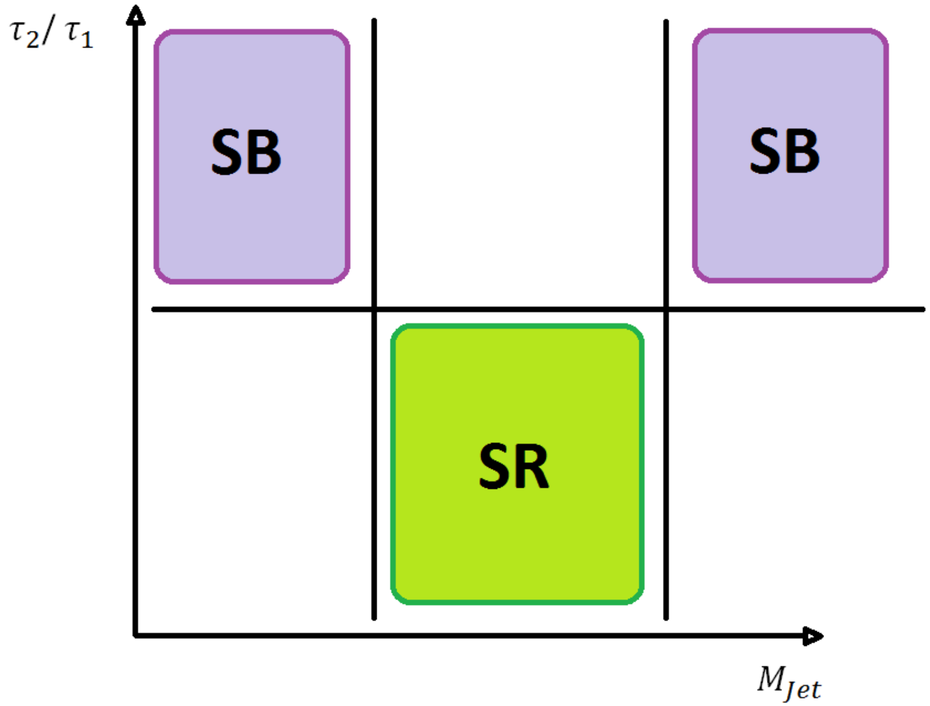
- ML fit within theta
  - Fit top candidate mass distribution
  - QCD constrained to move within its errors
  - $t\bar{t}$ unconstrained
  - $t\bar{t}$ contamination in top-mistagging rate taken into account
- $t\bar{t}$ scaled by 0.78 ± 0.18



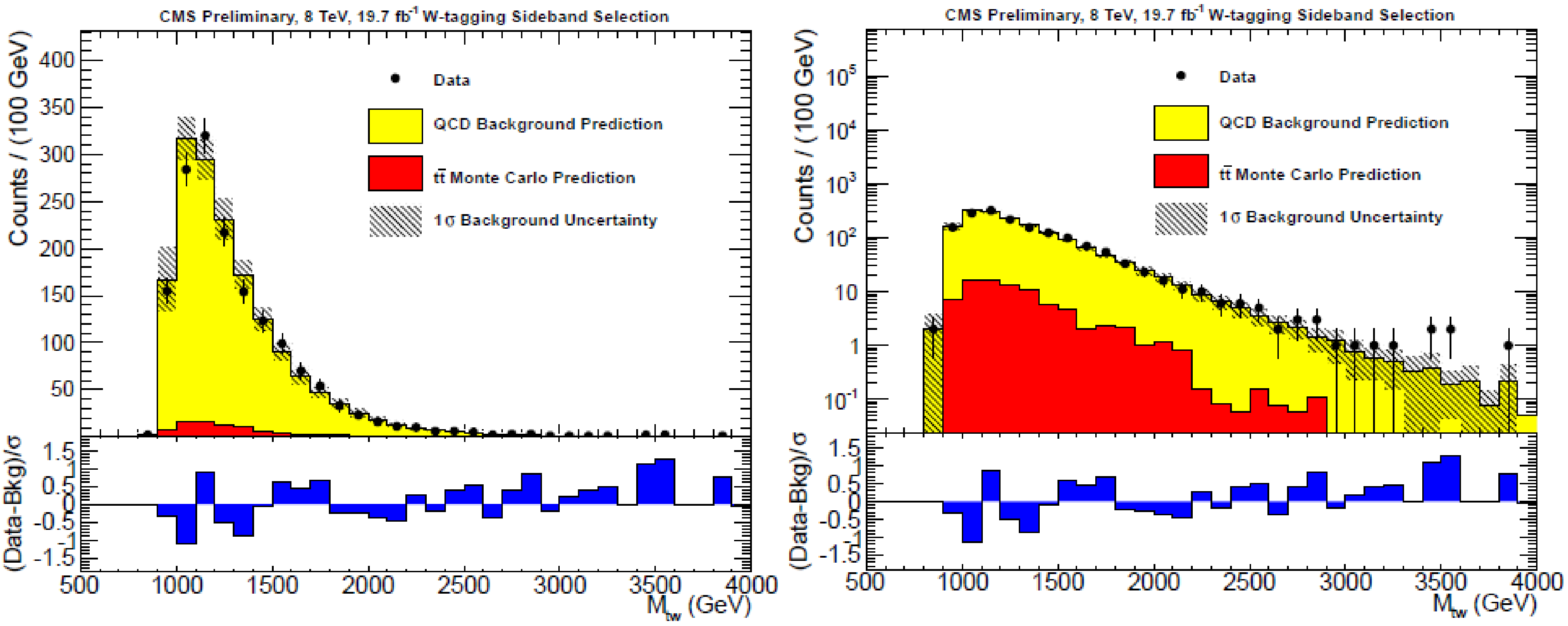


Closure

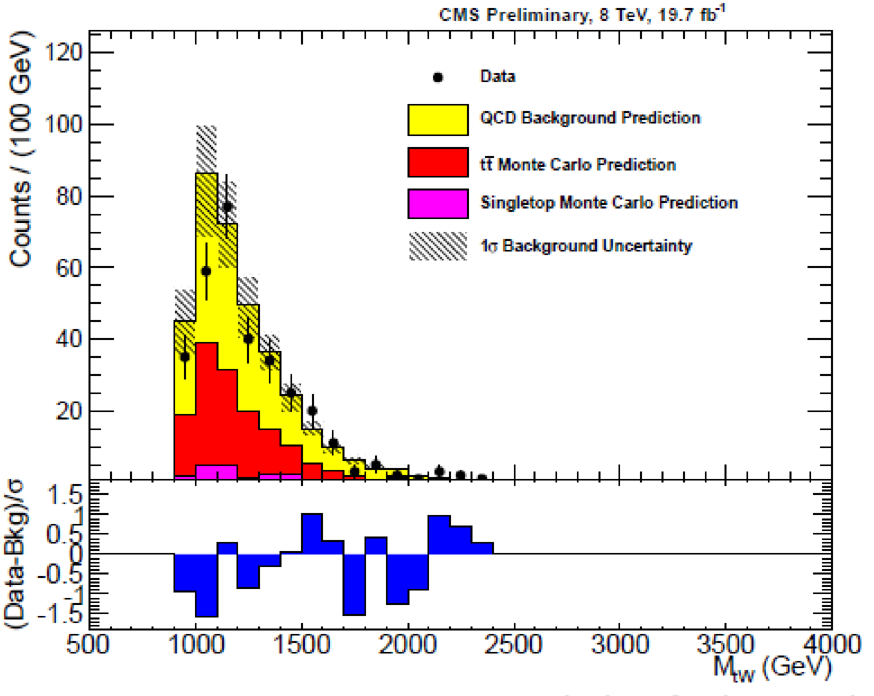
- Find control region to test background estimation procedure
  - $\begin{cases} 30 < M_{Jet} < 70 \\ 100 < M_{Jet} < 130 \end{cases}$
  - $\tau_2/\tau_1 > 0.5$

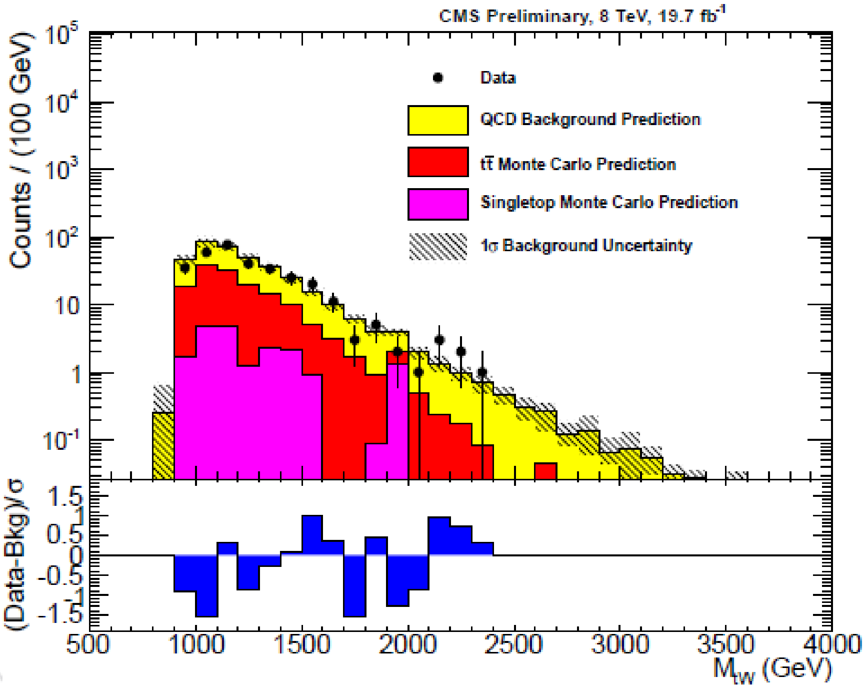


Closure

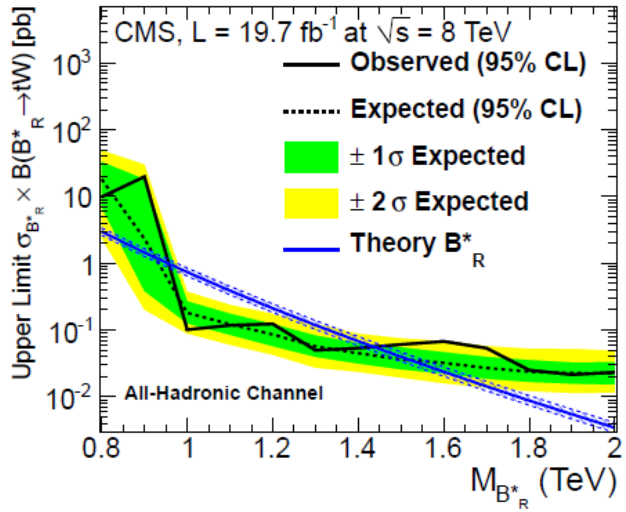

CMS Preliminary, 8 TeV, 19.7 fb^{-1} W-tagging Sideband Selection
Data
QCD Background Prediction
$t\bar{t}$ Monte Carlo Prediction
1σ Background Uncertainty
Counts / (100 GeV)
(Data-Bkg)/σ
M_{tw} (GeV)
CMS Preliminary, 8 TeV, 19.7 fb^{-1} W-tagging Sideband Selection
Data
QCD Background Prediction
$t\bar{t}$ Monte Carlo Prediction
1σ Background Uncertainty
Counts / (100 GeV)
(Data-Bkg)/σ
M_{tw} (GeV)

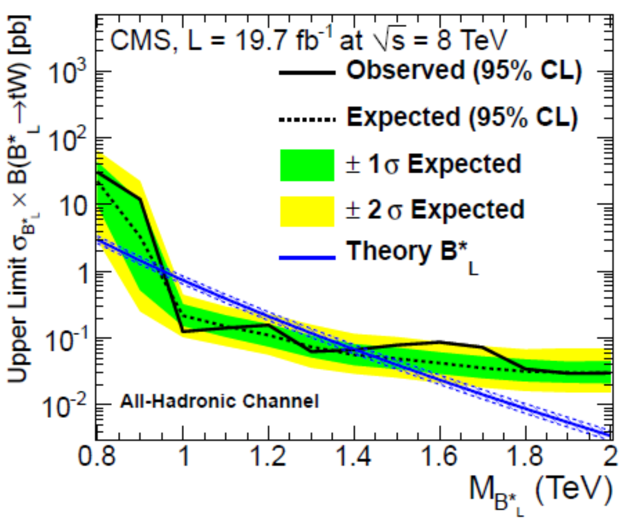
Signal Region

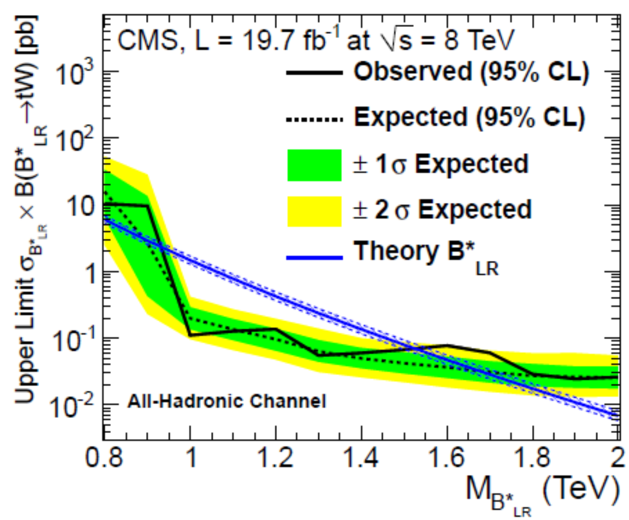




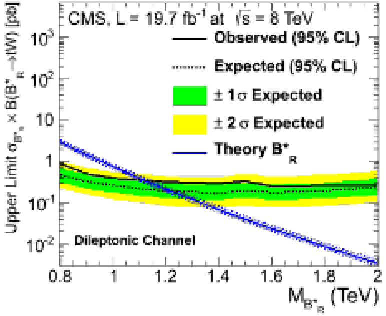
Limits

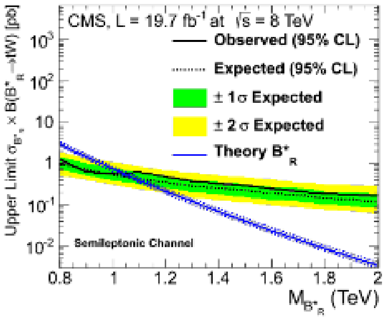

CMS, L = 19.7 fb^{-1} at $\sqrt{s}$ = 8 TeV
Observed (95% CL)
Expected (95% CL)
± 1σ Expected
± 2 σ Expected
Theory B^*_R
All-Hadronic Channel
Upper Limit $\sigma_{B^*_R} \times B(B^*_R \rightarrow tW)$ [pb]
10^3
10^2
10
1
10^{-1}
10^{-2}
0.8
1
1.2
1.4
1.6
1.8
2
$M_{B^*_R}$ (TeV)

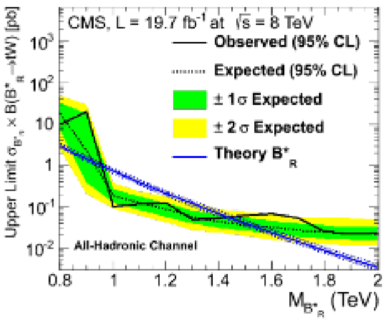

CMS, L = 19.7 fb^{-1} at $\sqrt{s}$ = 8 TeV
Observed (95% CL)
Expected (95% CL)
± 1σ Expected
± 2 σ Expected
Theory B^*_L
All-Hadronic Channel
Upper Limit $\sigma_{B^*_L} \times B(B^*_L \rightarrow tW)$ [pb]
10^3
10^2
10
1
10^{-1}
10^{-2}
0.8
1
1.2
1.4
1.6
1.8
2
$M_{B^*_L}$ (TeV)


CMS, L = 19.7 fb^{-1} at $\sqrt{s}$ = 8 TeV
Observed (95% CL)
Expected (95% CL)
± 1σ Expected
± 2 σ Expected
Theory B^*_{LR}
All-Hadronic Channel
Upper Limit $\sigma_{B^*_{LR}} \times B(B^*_{LR} \rightarrow tW)$ [pb]
10^3
10^2
10
1
10^{-1}
10^{-2}
0.8
1
1.2
1.4
1.6
1.8
2
$M_{B^*_{LR}}$ (TeV)

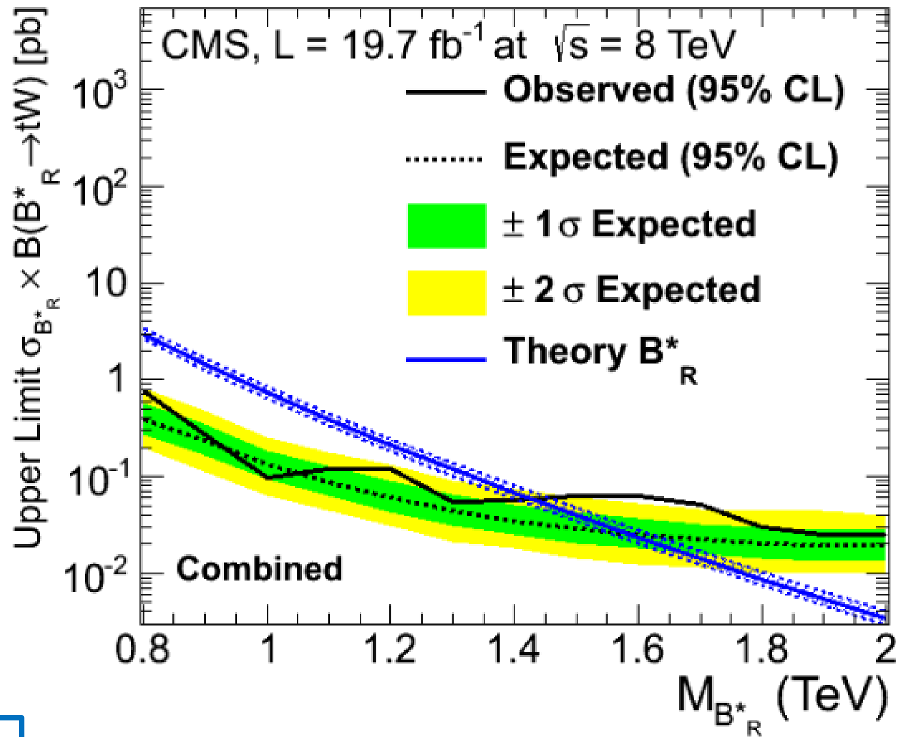
Combination



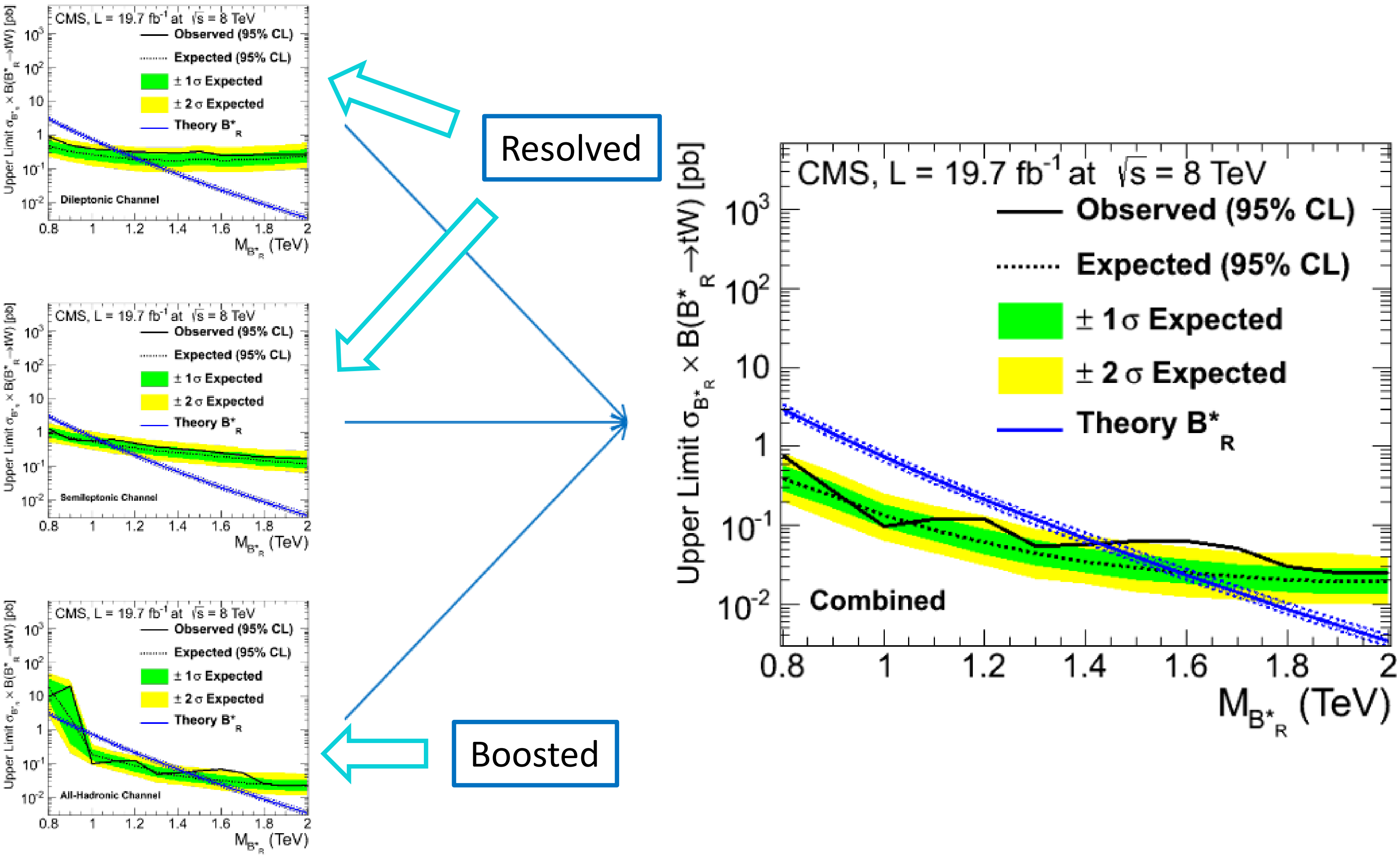




All-Hadronic



Combination



Summary

- Search for new physics performed at 8 TeV
- W' boson below 2.0 TeV excluded
- b^* quark excluded from 1.0 TeV to 1.4 TeV
- Cutting edge boosted top identification
- Analysis methods to prove essential at 13 TeV

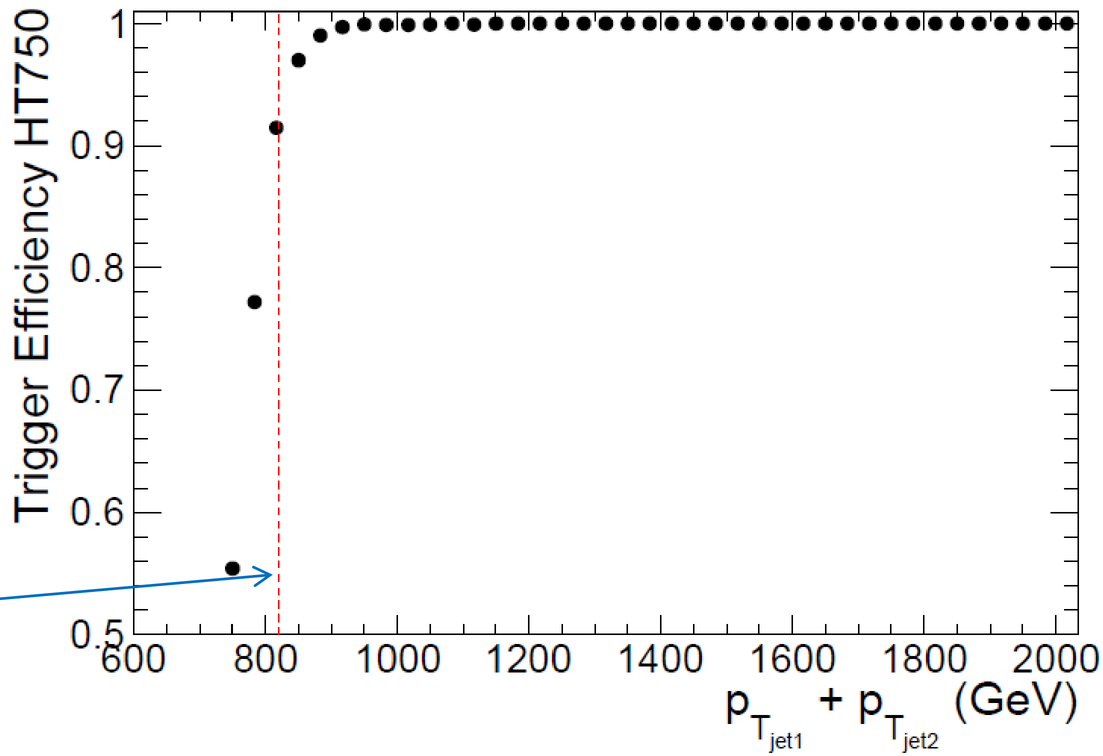
Backup

Trigger

- HT750 Trigger used in data taking

Parameterized in sum of leading and sub-leading jet p_T

Minimum for analysis



Samples

Jet Datasets

Dataset	Luminosity (pb^{-1})
/Jet/Run2012A-22Jan2013-v1/AOD	888
/JetHT/Run2012B-22Jan2013-v1/AOD	4403
/JetHT/Run2012C-22Jan2013-v1/AOD	7052
/JetHT/Run2012D-22Jan2013-v1/AOD	7414
Total Analyzed Luminosity	19757

Monte Carlo Datasets

Dataset	Cross section(pb)
TT_Mtt-700to1000_CT10_TuneZ2star_8TeV-powheg-tauola	245 (NNLO)
TT_Mtt-1000toInf_CT10_TuneZ2star_8TeV-powheg-tauola	245 (NNLO)
T_t-channel_TuneZ2star_8TeV-powheg-tauola	56.4 (NNLO)
Tbar_t-channel_TuneZ2star_8TeV-powheg-tauola	30.7 (NNLO)
Tbar_tW-channel-DR_TuneZ2star_8TeV-powheg-tauola	11.1 (NNLO)
T_tW-channel-DR_TuneZ2star_8TeV-powheg-tauola	11.1 (NNLO)
T_s-channel_TuneZ2star_8TeV-powheg-tauola	3.79 (NNLO)
Tbar_s-channel_TuneZ2star_8TeV-powheg-tauola	1.76 (NNLO)
QCD_Pt-300to470_TuneZ2star_8TeV_pythia6	1759.6
QCD_Pt-470to600_TuneZ2star_8TeV_pythia6	113.9
QCD_Pt-600to800_TuneZ2star_8TeV_pythia6	27.0
QCD_Pt-800to1000_TuneZ2star_8TeV_pythia6	3.57
QCD_Pt-1000to1400_TuneZ2star_8TeV_pythia6	0.738
QCD_Pt-1400to1800_TuneZ2star_8TeV_pythia6	0.0335

Table 1: Primary datasets and Monte Carlo samples used. Including the corresponding integrated luminosity or cross section of each dataset.

JEC

FT_53_V21_AN5
AK7PFchs

START53_V27
AK7PFchs

$t\bar{t}$ cross section:
http://arxiv.org/abs/1303.6254

Samples

Left-Handed Signal Samples

Dataset	$\Gamma_{W'}$ (GeV)	(LO) Cross-Section (pb)	Selection Efficiency
SingletopWprimeTToHad_M-1300_left_TuneZ2star_8TeV-comphep	43.7	0.4405	0.157
SingletopWprimeTToHad_M-1500_left_TuneZ2star_8TeV-comphep	50.0	0.2384	0.104
SingletopWprimeTToHad_M-1700_left_TuneZ2star_8TeV-comphep	57.3	0.1506	0.0679
SingletopWprimeTToHad_M-1900_left_TuneZ2star_8TeV-comphep	64.1	0.1120	0.0507
SingletopWprimeTToHad_M-2100_left_TuneZ2star_8TeV-comphep	70.9	0.0949	0.0429
SingletopWprimeTToHad_M-2300_left_TuneZ2star_8TeV-comphep	77.6	0.0878	0.0397
SingletopWprimeTToHad_M-2700_left_TuneZ2star_8TeV-comphep	91.2	0.0843	0.0379
SingletopWprimeTToHad_M-3100_left_TuneZ2star_8TeV-comphep	104.7	0.0849	0.0379

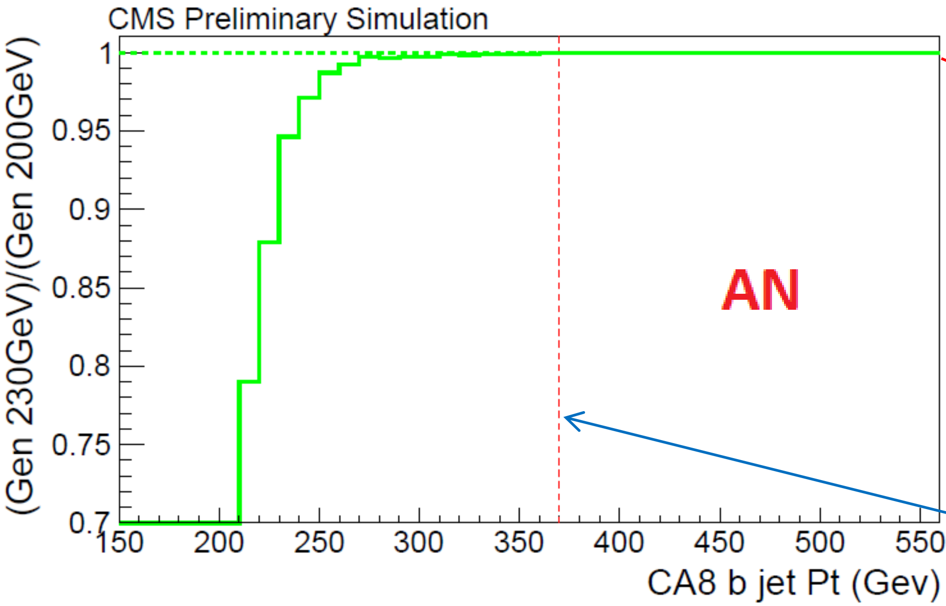
Mixed Signal Samples

Dataset	$\Gamma_{W'}$ (GeV)	(LO) Cross-Section (pb)	Selection Efficiency
SingletopWprimeTToHad_M-1300_mixed_TuneZ2star_8TeV-comphep	87.4	0.8460	0.290
SingletopWprimeTToHad_M-1500_mixed_TuneZ2star_8TeV-comphep	101.0	0.4295	0.172
SingletopWprimeTToHad_M-1700_mixed_TuneZ2star_8TeV-comphep	114.6	0.2455	0.105
SingletopWprimeTToHad_M-1900_mixed_TuneZ2star_8TeV-comphep	128.2	0.1605	0.0711
SingletopWprimeTToHad_M-2100_mixed_TuneZ2star_8TeV-comphep	141.7	0.1209	0.0540
SingletopWprimeTToHad_M-2300_mixed_TuneZ2star_8TeV-comphep	155.3	0.1020	0.0458
SingletopWprimeTToHad_M-2700_mixed_TuneZ2star_8TeV-comphep	182.4	0.0893	0.0400
SingletopWprimeTToHad_M-3100_mixed_TuneZ2star_8TeV-comphep	209.5	0.0869	0.0388

Signal Generation

- Using the CompHEP package
- Generate right, left, and mixed coupling W′ samples
  - For left and mixed, a loose 200 GeV generator level p_T cut is applied to the b

Investigate tighter generator level p_T cut

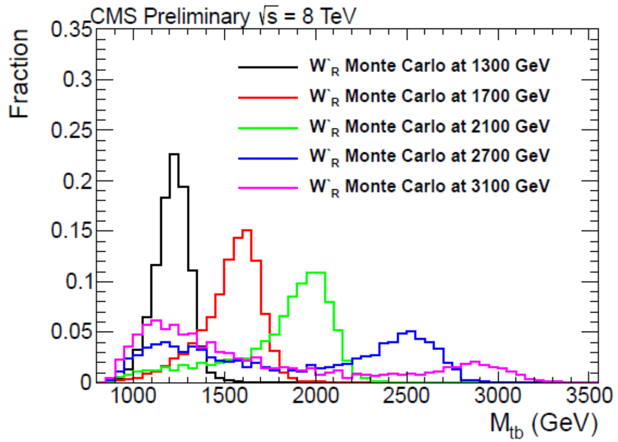


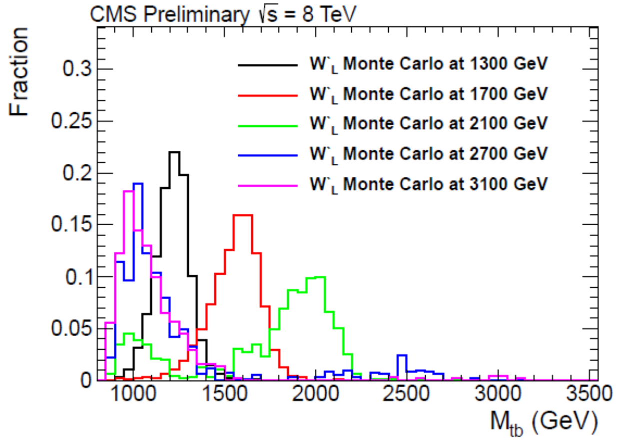
Very small effect

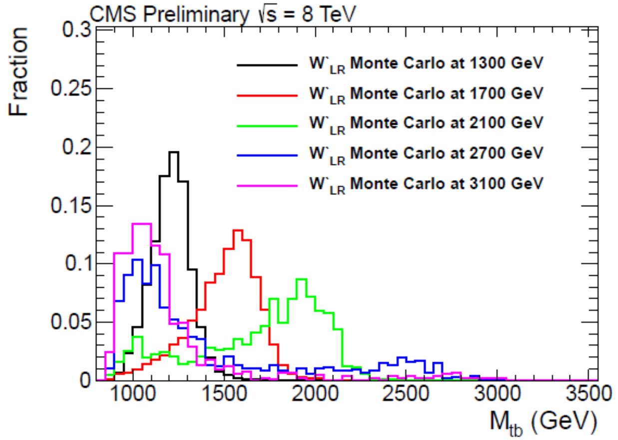
Minimum jet pt

Signal Monte Carlo

- Full Selection in W′ Signal Monte Carlo

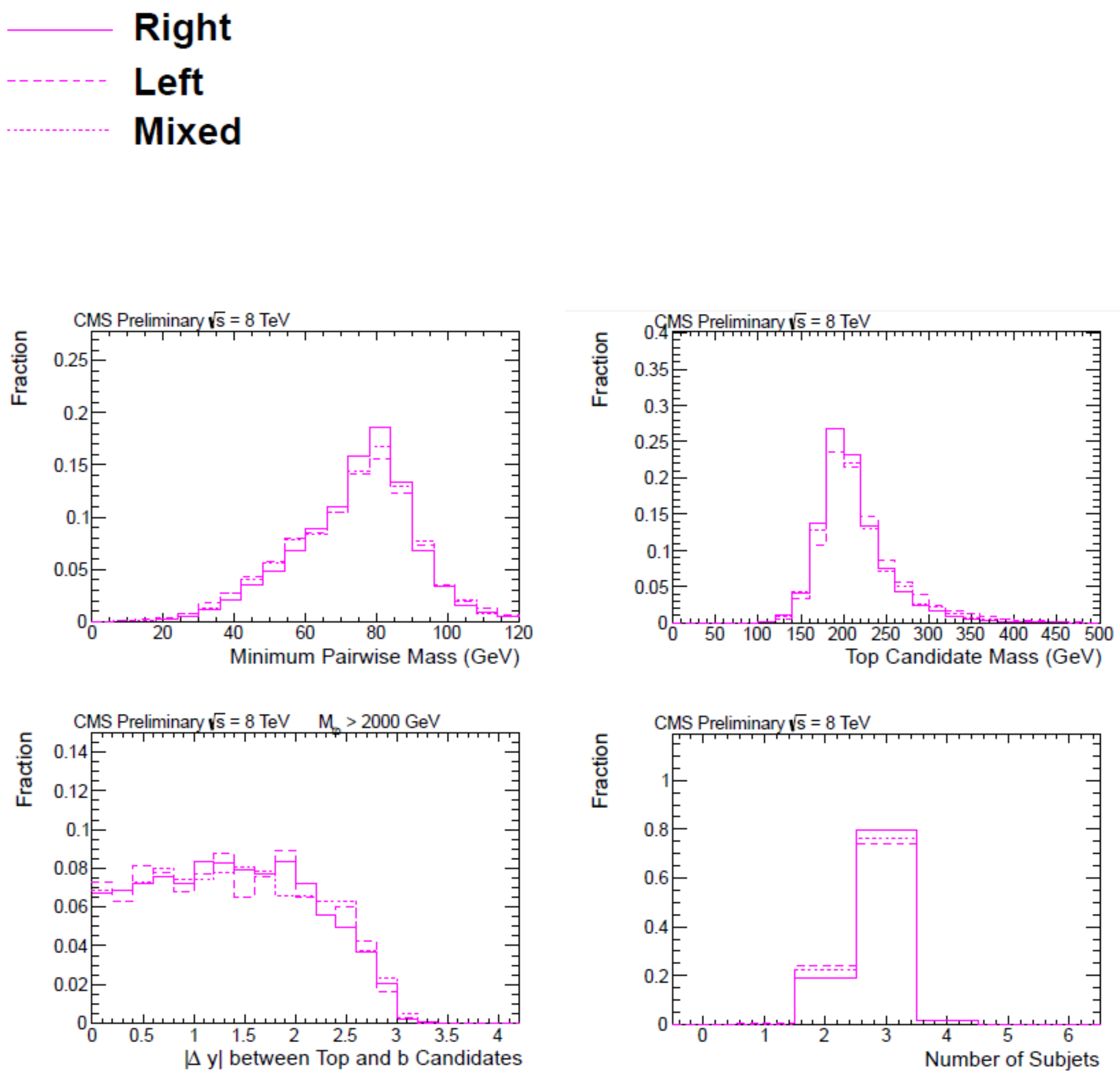






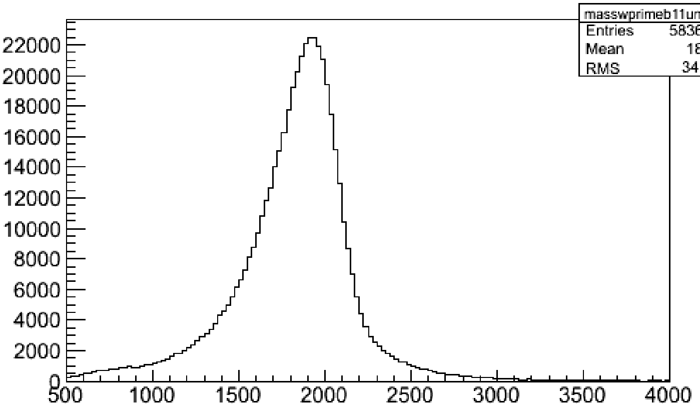
Signal Monte Carlo

Comparison of kinematic variables

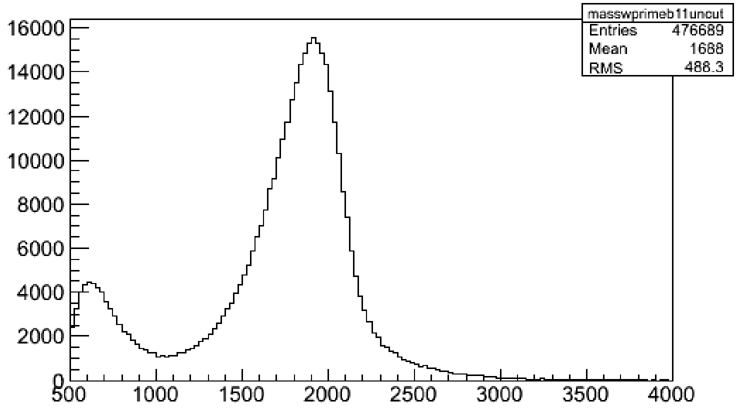


Signal Monte Carlo

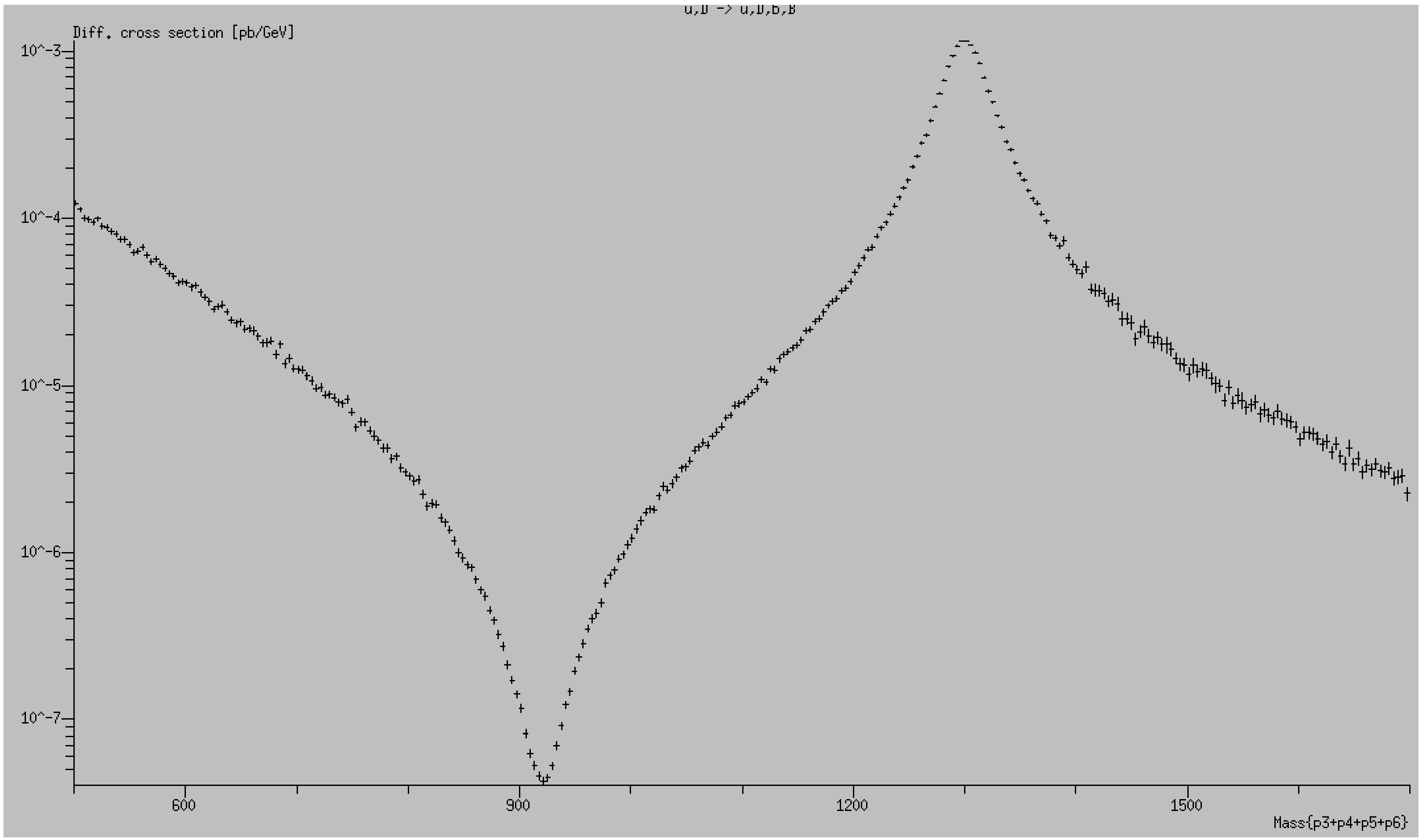
Right



Left



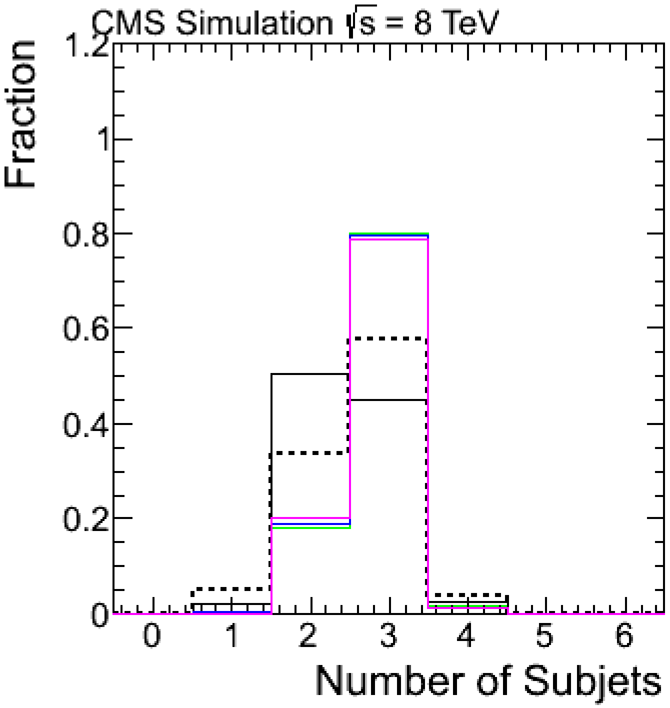
Signal Monte Carlo



CMS Top-Tagging Algorithm

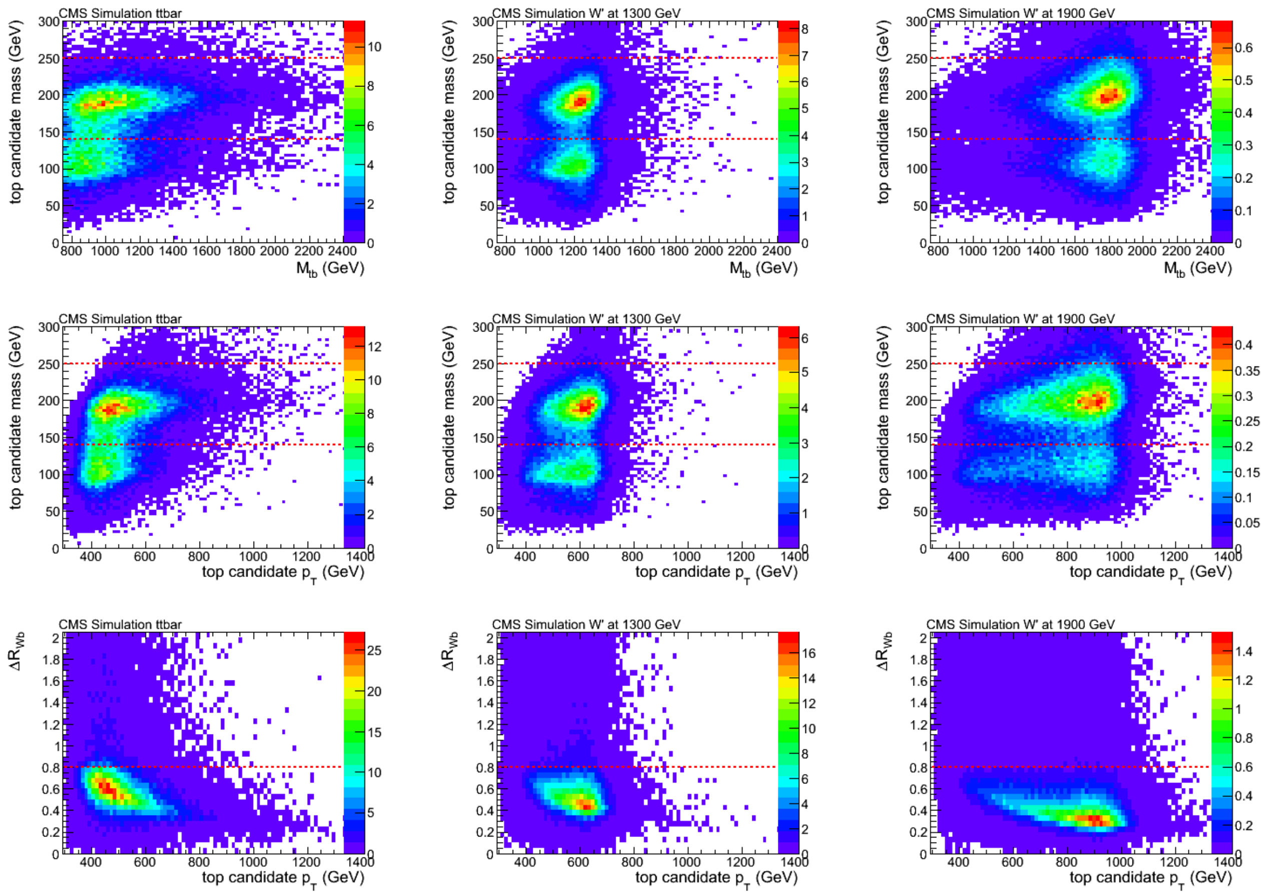
Nsubjets in Signal, $t\bar{t}$, and QCD Monte Carlo

- QCD Monte Carlo (solid black line)
- $t\bar{t}$ Monte Carlo (dotted black line)
- $W`_R$ Monte Carlo at 1700 GeV (green line)
- $W`_R$ Monte Carlo at 1900 GeV (blue line)
- $W`_R$ Monte Carlo at 2100 GeV (magenta line)



CMS Top-Tagger

- Top merging at high pt

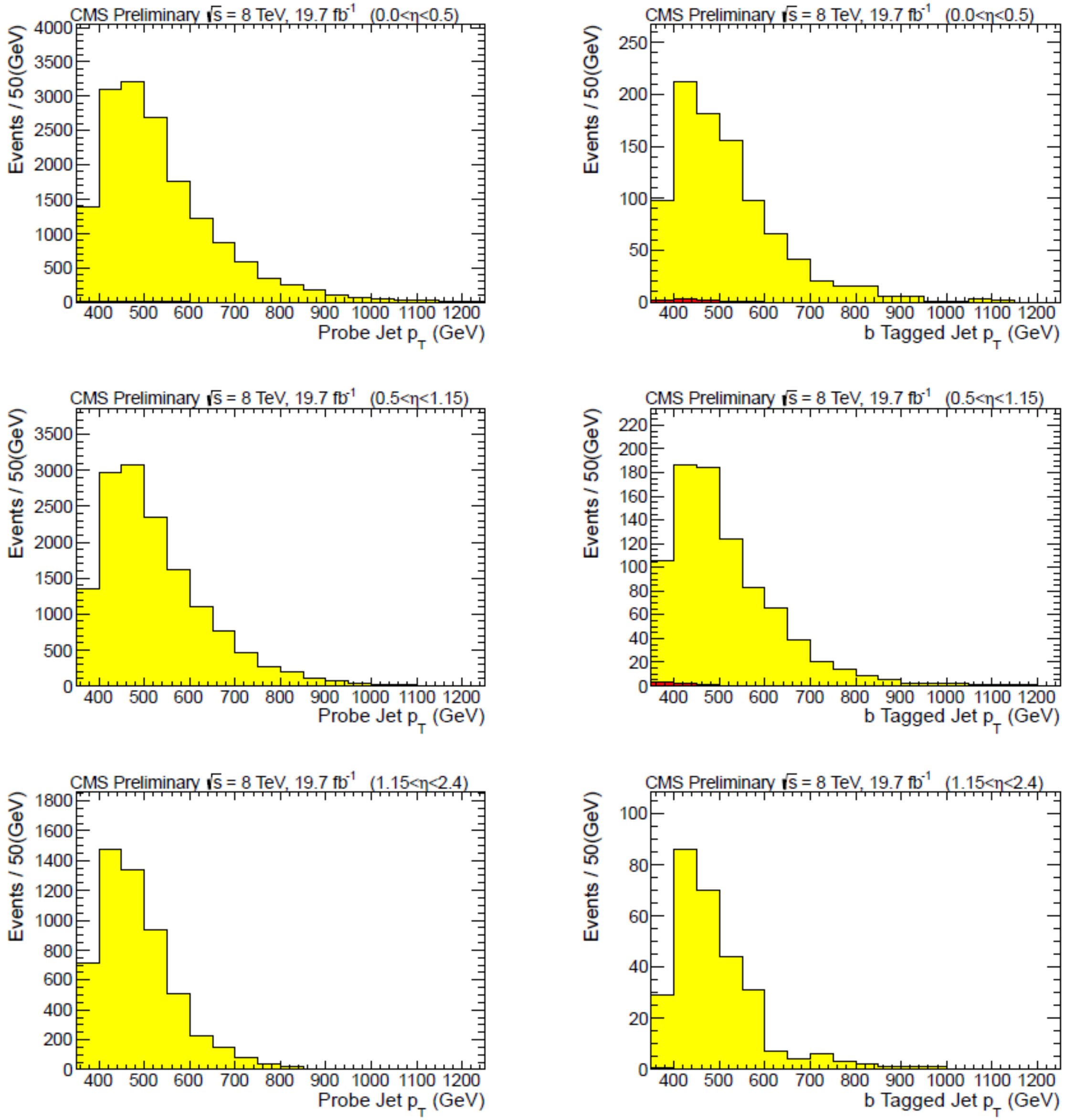


Event Selection Cut-Flow

	Data	QCD	$t\bar{t}$	W' 1300	W' 1700	W' 2100	W' 2700
2 jets	13854873	---	12179	6140	1467	364	48
p_T	4305244	---	4718	4951	1319	338	45
$\lvert\Delta y\rvert$	3376771	---	4219	4704	1047	243	31
M_{top}	992949	---	3216	3021	790	189	24
$N_{Subjets}$	557489	---	2743	2512	636	148	19
Minmass	318520	---	2508	2265	576	129	14
SJ_{CSVMAX}	50642	---	1689	1450	338	69	7
τ_3/τ_2	7200	---	1025	825	180	35	3
M_b	4463	---	179	664	140	26	3
CSV	277	248	37	235	37	5	1

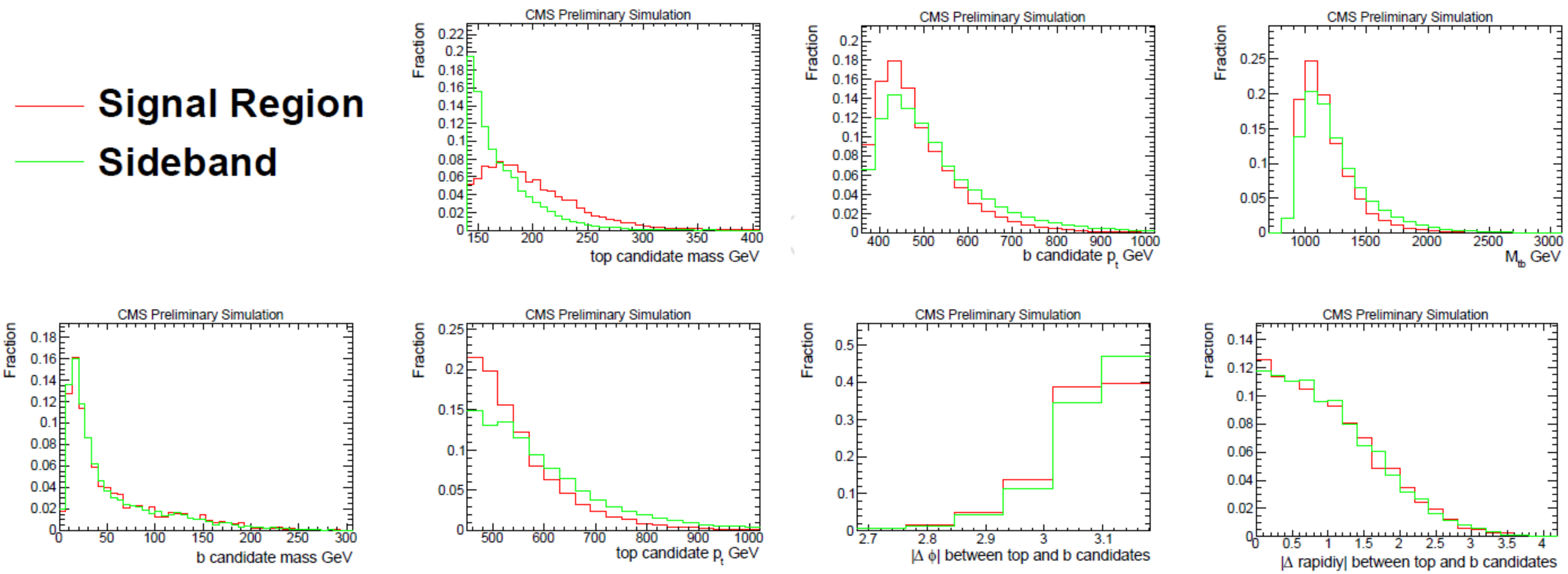
Background Estimation

Numerator and denominator of the average b-tagging rate



Background Estimation

- Sideband kinematics



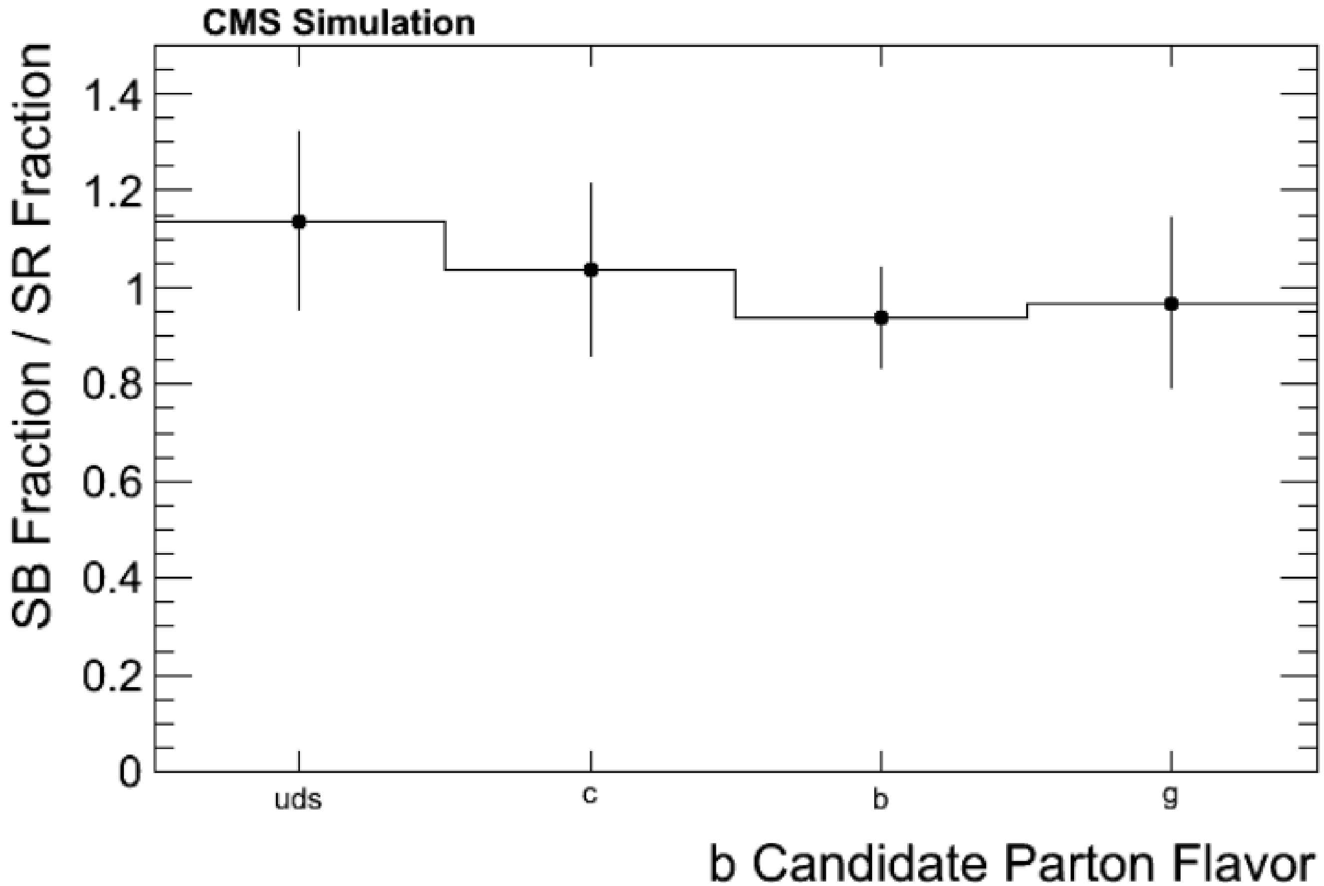
Background Estimation

- $t\bar{t}$ subtraction
  - Subtract $t\bar{t}$ from the numerator and denominator of the average b-tagging rate
  - Subtract $t\bar{t}$ that is expected to fall through the background estimate

	η_1	η_2	η_3
pretag QCD	15922 (99.76%)	14396 (99.78%)	5494 (99.81%)
tagged QCD	924 (99.16%)	847 (99.16%)	285 (99.54%)
pretag $t\bar{t}$	38 (0.24%)	31 (0.22%)	11 (0.19%)
tagged $t\bar{t}$	8 (0.84%)	7 (0.84%)	1 (0.46%)
pretag signal at 1300 GeV	101 (0.63%)	72 (0.50%)	16 (0.29%)
tagged signal at 1300 GeV	34 (3.69%)	23 (2.69%)	4 (1.35%)
pretag signal at 1500 GeV	56 (0.35%)	35 (0.24%)	7 (0.13%)
tagged signal at 1500 GeV	16 (1.70%)	10 (1.16%)	2 (0.61%)
pretag signal at 1700 GeV	28 (0.17%)	17 (0.12%)	3 (0.05%)
tagged signal at 1700 GeV	7 (0.74%)	4 (0.48%)	1 (0.22%)
pretag signal at 1900 GeV	13 (0.08%)	8 (0.05%)	1 (0.02%)
tagged signal at 1900 GeV	3 (0.28%)	2 (0.18%)	0 (0.06%)
pretag signal at 2100 GeV	6 (0.04%)	3 (0.02%)	0 (0.01%)
tagged signal at 2100 GeV	1 (0.12%)	1 (0.08%)	0 (0.03%)

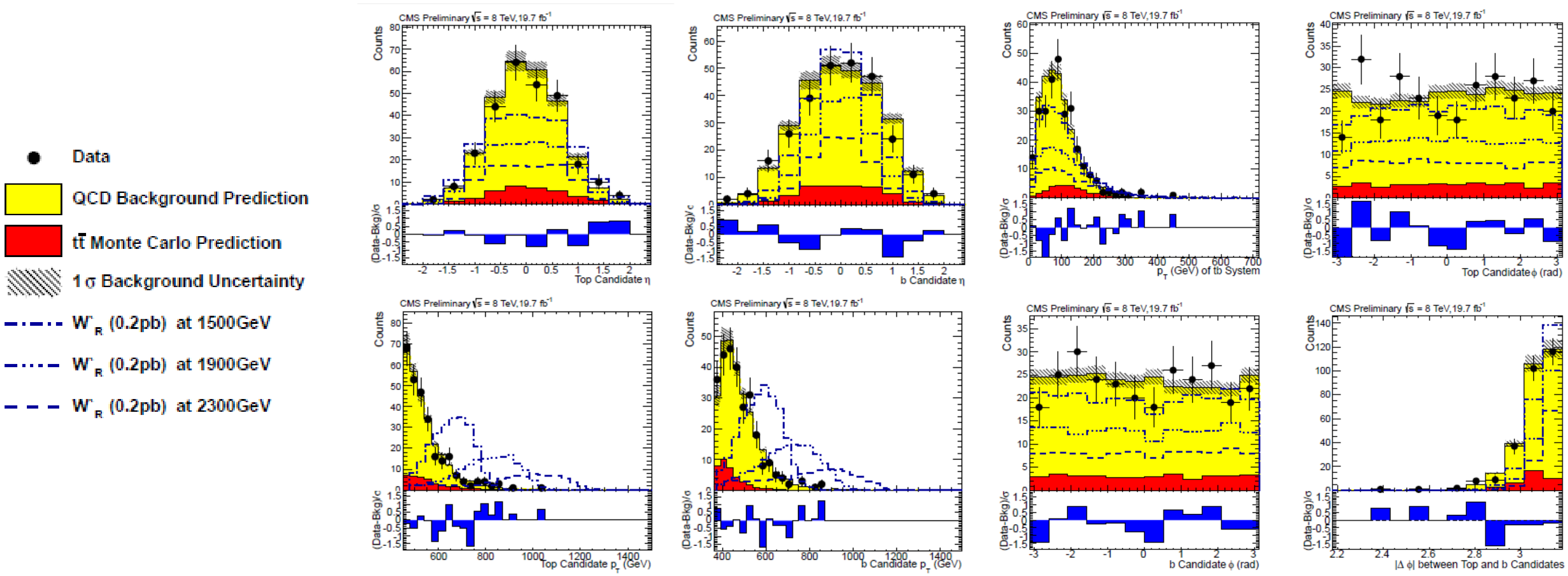
Background Estimation

- Ratio of parton flavor fraction in SB and SR



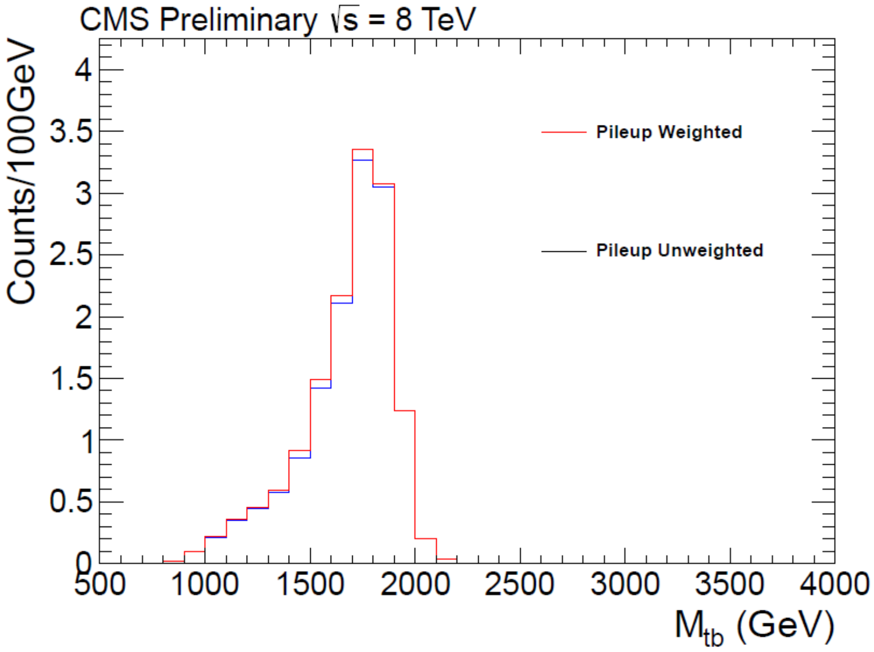
Background Estimation

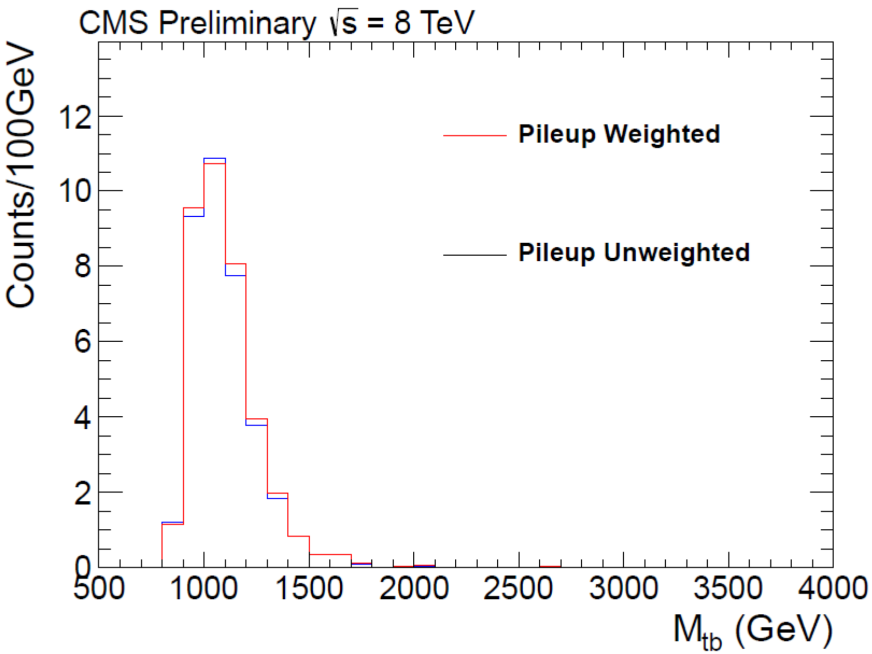
- Investigate QCD estimate of kinematic variables



Pileup

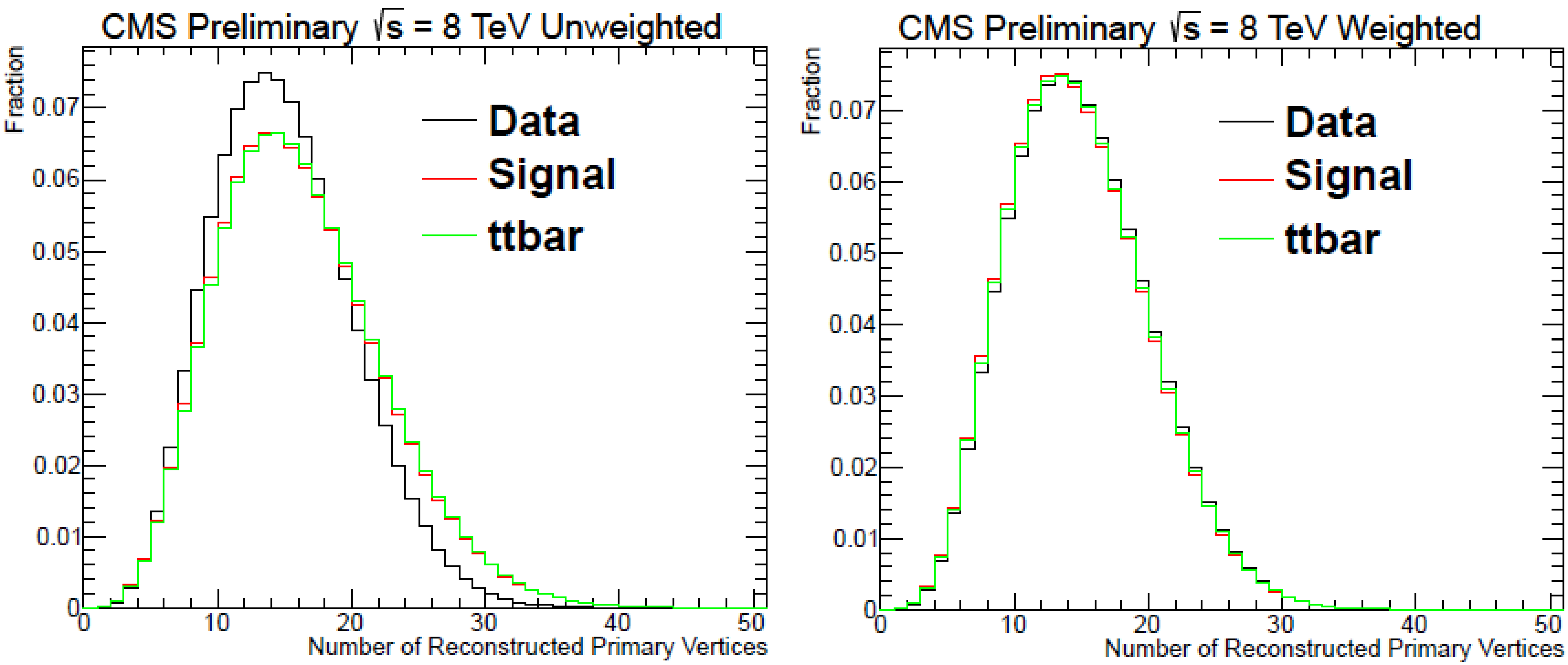
- Compare pileup reweighted and un-weighted distributions



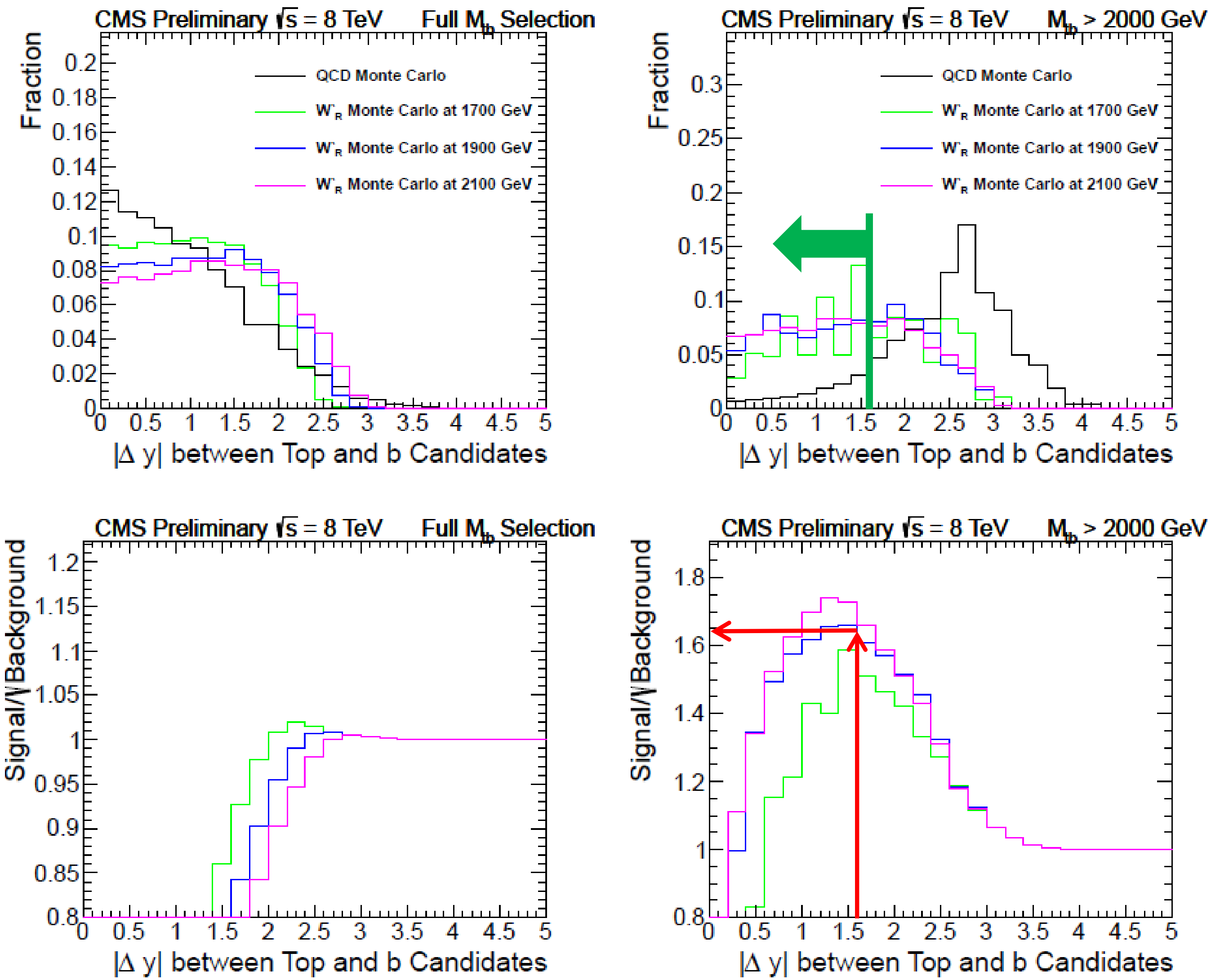


Pileup

- Pileup reweighting
  - Use $\sigma_{\text{minbias}} = 69.4\ \text{mb}$



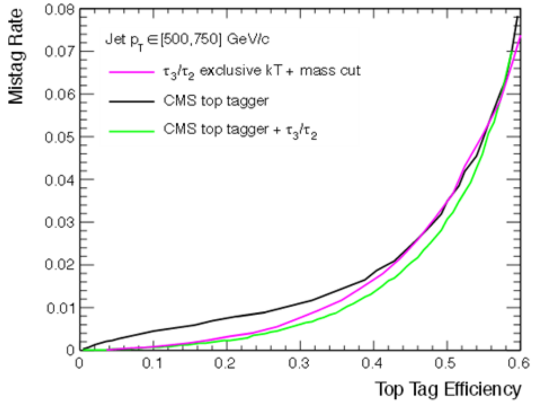
Δy Cut

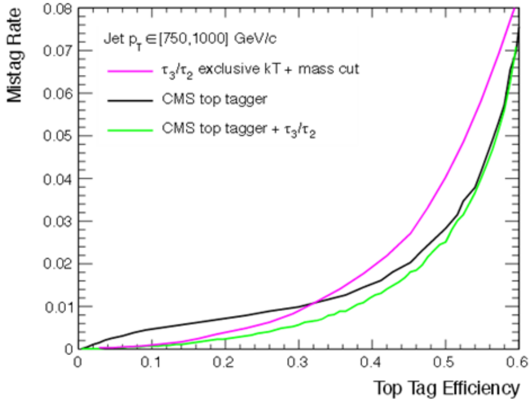


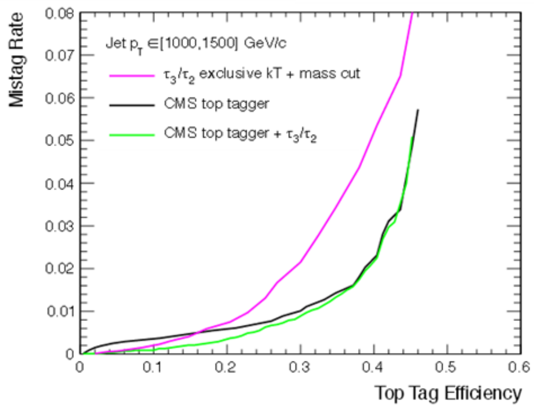
CMS Preliminary √s = 8 TeV Full M_tb Selection
CMS Preliminary √s = 8 TeV M_tb > 2000 GeV
Fraction
Signal/√Background
QCD Monte Carlo
W'_R Monte Carlo at 1700 GeV
W'_R Monte Carlo at 1900 GeV
W'_R Monte Carlo at 2100 GeV
|Δ y| between Top and b Candidates

N-subjettiness

- Additional discrimination possible after application of the "CMS Top Tagger"

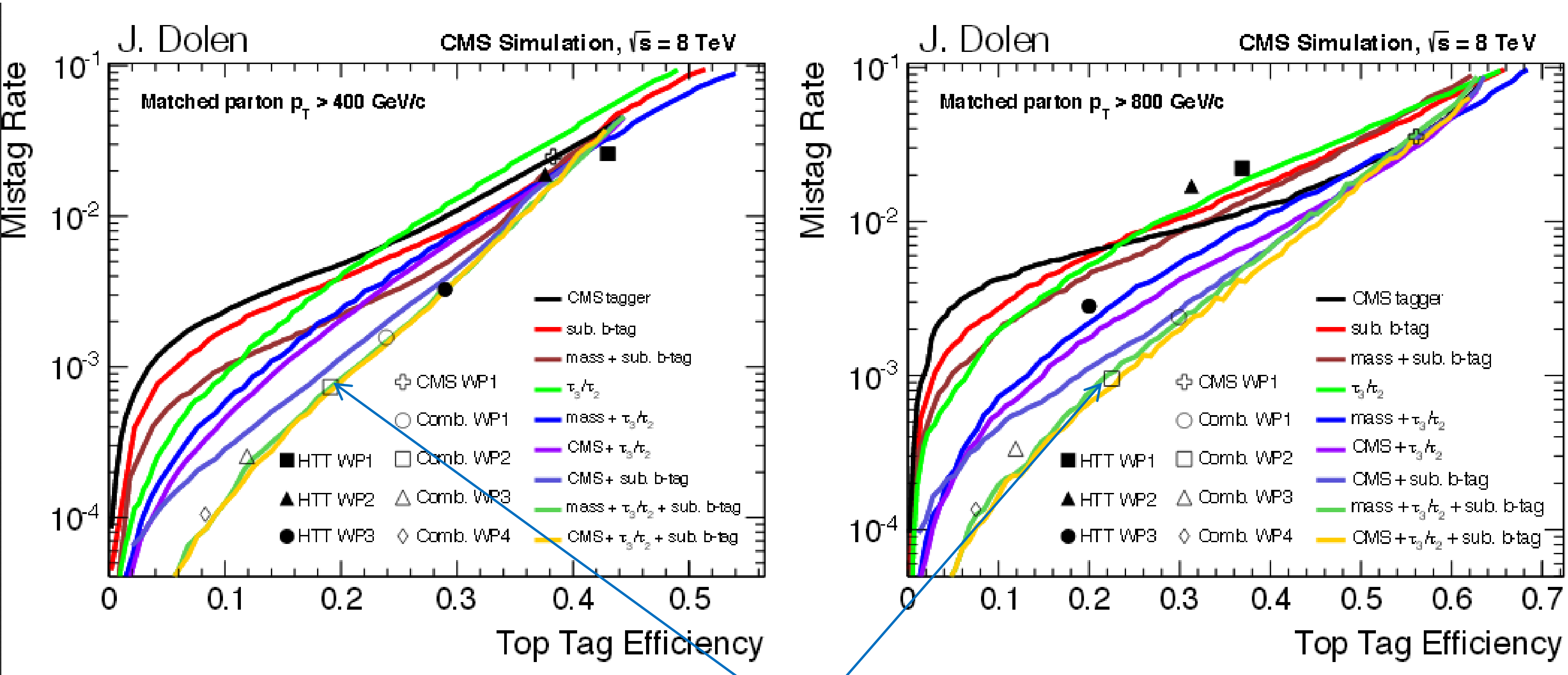






Plots From James Dolen: JetMET Algorithms and Reconstruction Meeting - June 6, 2013

Top Taggers



Our Selection

Scale Factors

- b-tagging scale factor

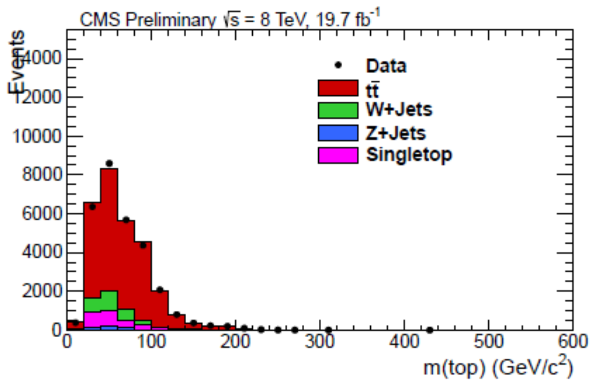
$$SF_b = 0.938887 + 0.00017124 \times p_t - 2.76366 \times 10^{-07} \times p_t^2$$

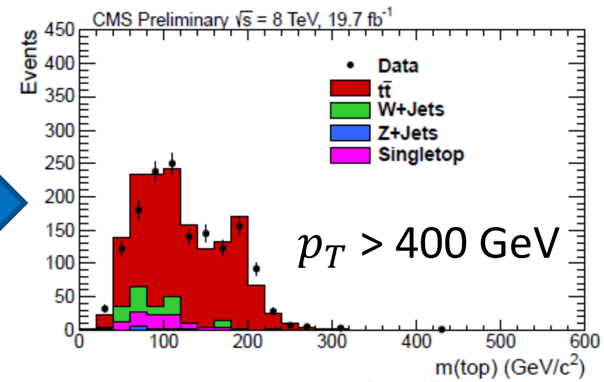
- $t\bar{t}\ p_T$ reweighting

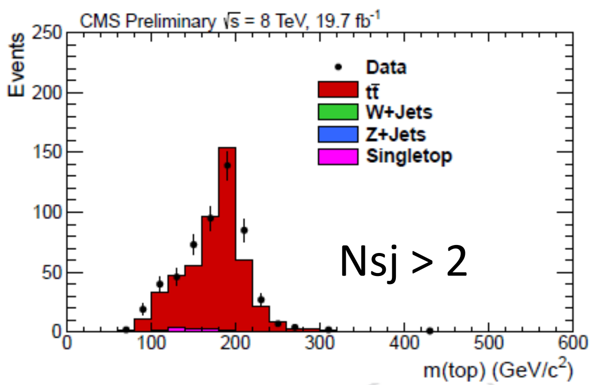
$$SF = \sqrt{e^{0.156-.00137 p_{T_t}} e^{0.156-.00137 p_{T_{\bar{t}}}}}$$

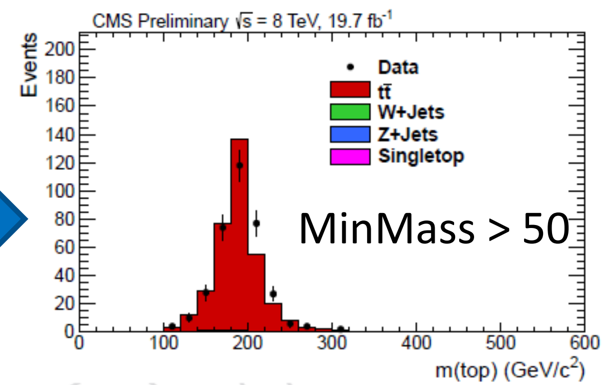
Top-Tagging Scale Factor

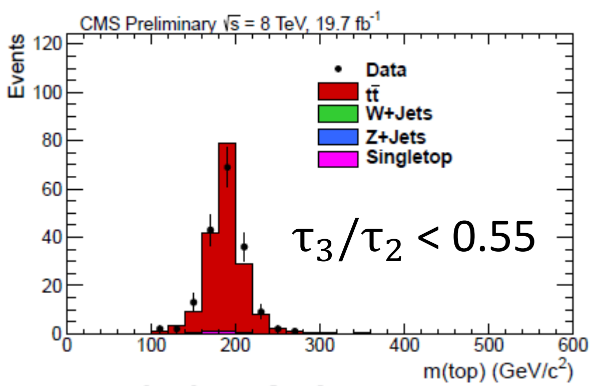
Plots from JME-13-007

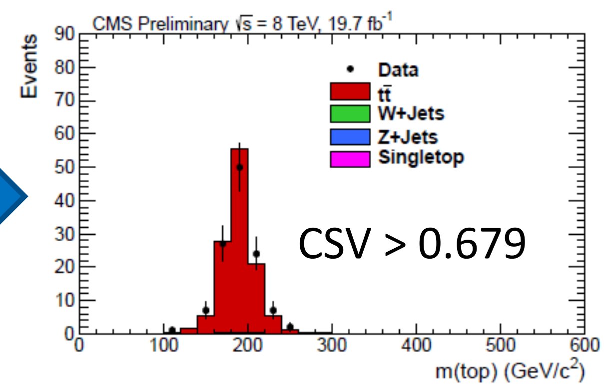










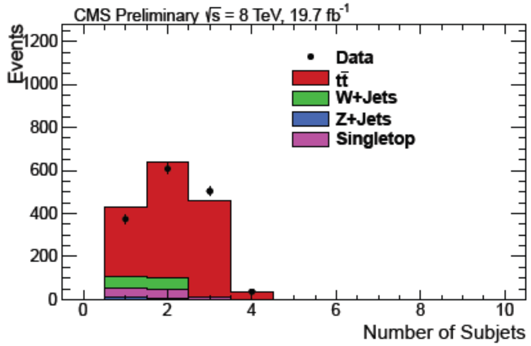


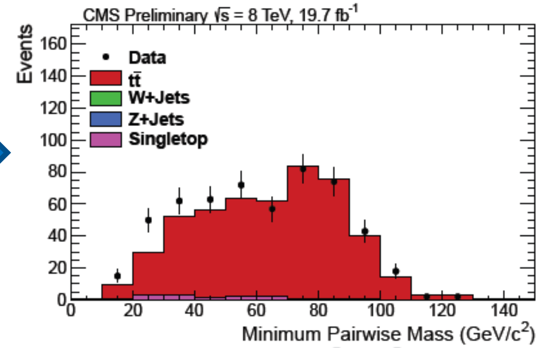
Top-Tagging Scale Factor

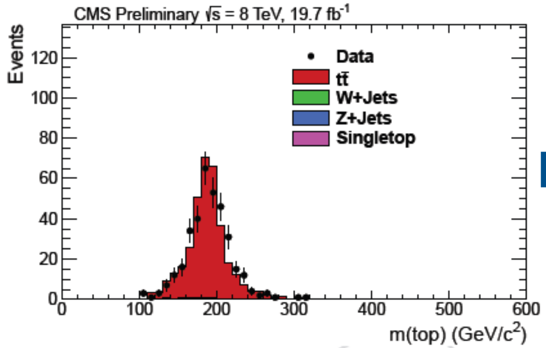
- Use simulation for $t\bar{t}$ and Signal
- Need to extract Monte Carlo to data scale factor for top-tagging.
- We investigate this using a highly pure sample of semileptonic $t\bar{t}$
  - Documented in JME-13-007

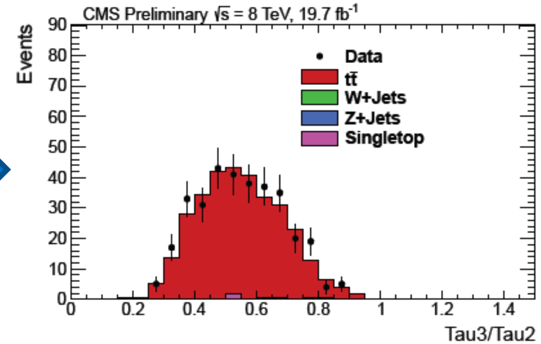
Top-Tagging Scale Factor

Plots from JME-13-007

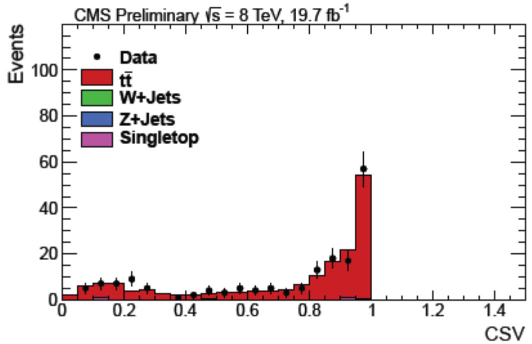








SF = 1.036 ± 0.13



Systematic Uncertainties

- Rate Uncertainties Applied
  - $t\bar{t}$ normalization (23.4%)
  - Top-tagging scale factor (13%)
  - Luminosity (2.6%)
  - CA8 b-tagging (2.0%)
- Sources found to be negligible
  - Pileup reweighting for Monte Carlo
  - pdf uncertainty for Monte Carlo
  - Jet Angular Resolution

- Shape Uncertainties Applied
  - Choice of fit for QCD
  - Uncertainty on the fit for QCD
  - Uncertainty on parameterization choice for QCD
  - b-tagging scale factor
  - $t\bar{t}$ p_T reweighting
  - Q^2 scale for $t\bar{t}$
  - Jet Energy Resolution
  - Jet Energy Scale
  - Trigger efficiency

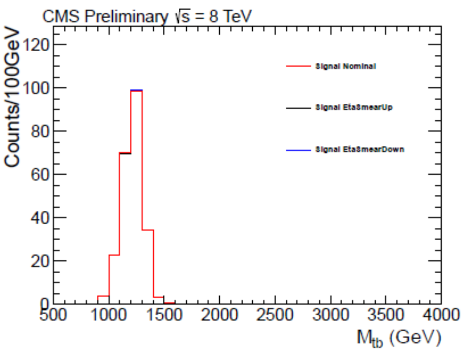
Systematics

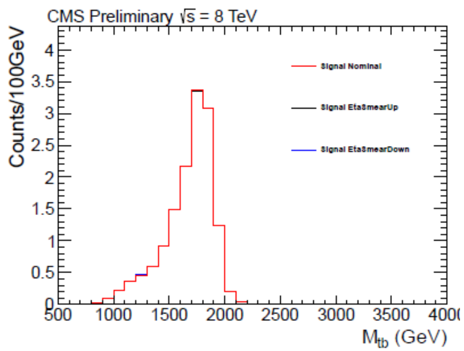
Process	QCD	b-tagging	JES	p_T Reweight	JER	Q^2 Scale	Trigger
qcd	$^{+9.04}_{-8.93}$ (s)	---	---	---	---	---	---
$t\bar{t}$	---	$^{+4.50}_{-4.50}$ (s)	$^{+23.90}_{-24.35}$ (s)	$^{-73.93}_{+77.67}$ (s)	$^{-1.75}_{+15.82}$ (s)	$^{+20.54}_{-15.82}$ (s)	$^{+0.31}_{-0.31}$ (s)
W′ 1300	---	$^{+6.10}_{-6.10}$ (s)	$^{+2.60}_{-7.51}$ (s)	---	$^{-0.55}_{+0.38}$ (s)	---	$^{+0.06}_{-0.06}$ (s)
W′ 1500	---	$^{+6.49}_{-6.49}$ (s)	$^{-0.99}_{-1.11}$ (s)	---	$^{-0.21}_{+0.05}$ (s)	---	$^{+0.02}_{-0.02}$ (s)
W′ 1700	---	$^{+6.95}_{-6.95}$ (s)	$^{-2.56}_{+1.21}$ (s)	---	$^{-0.06}_{+0.10}$ (s)	---	$^{+0.01}_{-0.01}$ (s)
W′ 1900	---	$^{+8.16}_{-8.16}$ (s)	$^{-3.06}_{+2.07}$ (s)	---	$^{-0.14}_{+0.15}$ (s)	---	$^{+0.01}_{-0.01}$ (s)
W′ 2100	---	$^{+9.42}_{-9.42}$ (s)	$^{-3.52}_{+2.44}$ (s)	---	$^{+0.20}_{+0.09}$ (s)	---	$^{+0.01}_{-0.01}$ (s)
W′ 2300	---	$^{+10.05}_{-10.05}$ (s)	$^{-3.47}_{+1.84}$ (s)	---	$^{-0.06}_{+0.19}$ (s)	---	$^{+0.02}_{-0.02}$ (s)
W′ 2700	---	$^{+9.51}_{-9.51}$ (s)	$^{-0.74}_{-0.29}$ (s)	---	$^{-0.27}_{+0.11}$ (s)	---	$^{+0.04}_{-0.04}$ (s)
W′ 3100	---	$^{+8.12}_{-8.12}$ (s)	$^{+2.21}_{-4.46}$ (s)	---	$^{-0.38}_{-0.15}$ (s)	---	$^{+0.06}_{-0.06}$ (s)

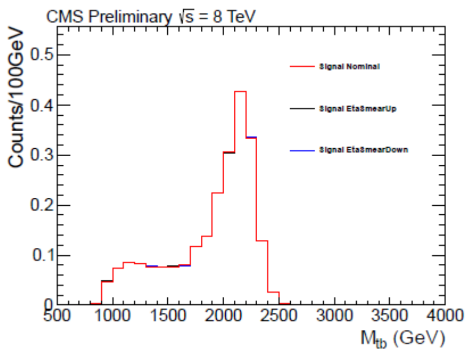
Systematics

- Jet Angular Resolution
  - Smear η,ϕ by ± 10%

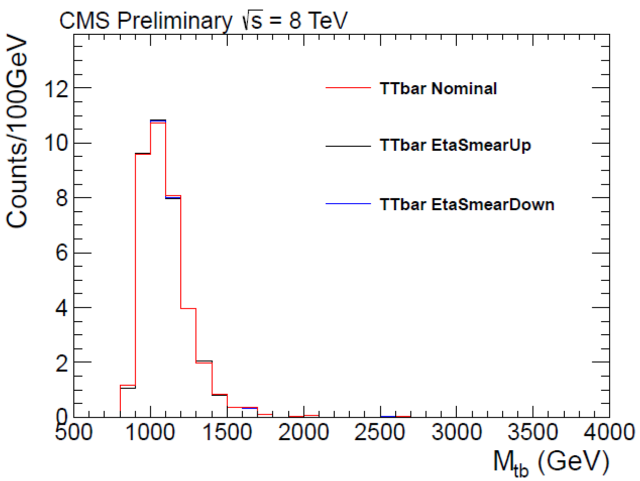
Signal at 1300,1900,2300 GeV







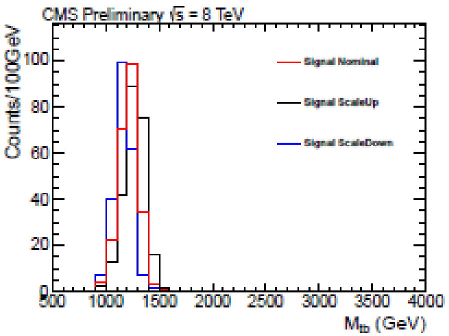
$t\bar{t}$

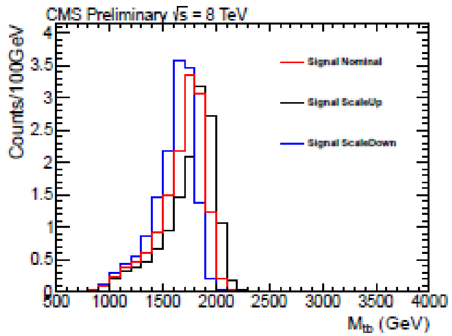


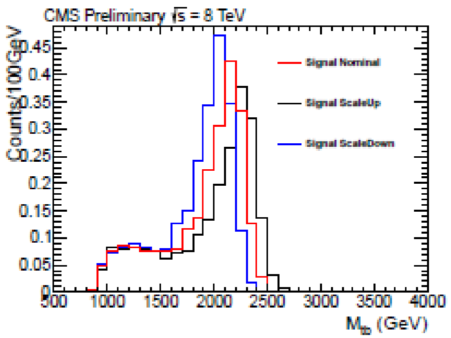
Systematics

- Jet Energy Scale
  - Scale $p_T \pm 5\%$
  - On top of standard JES uncertainty

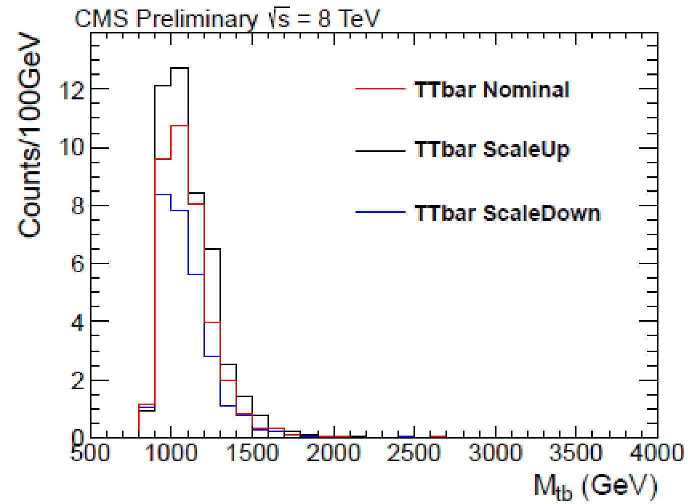
Signal at 1300,1900,2300 GeV







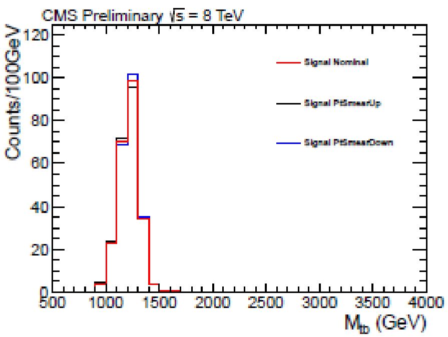
$t\bar{t}$

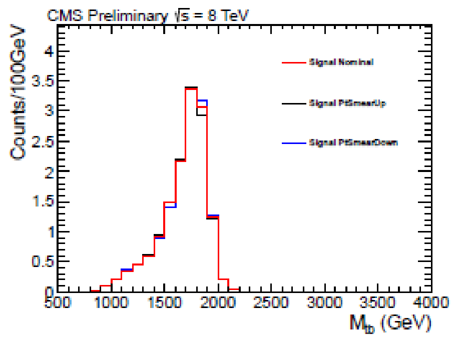


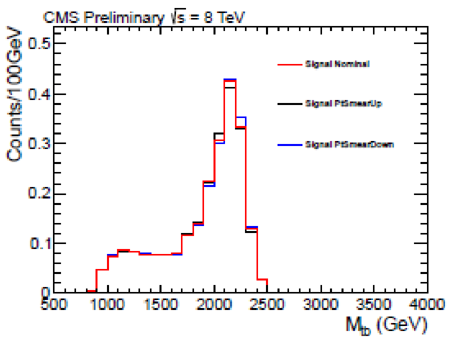
Systematics

- Jet Energy Resolution
  - Use η,ϕ dependent smearing (JER recommended)

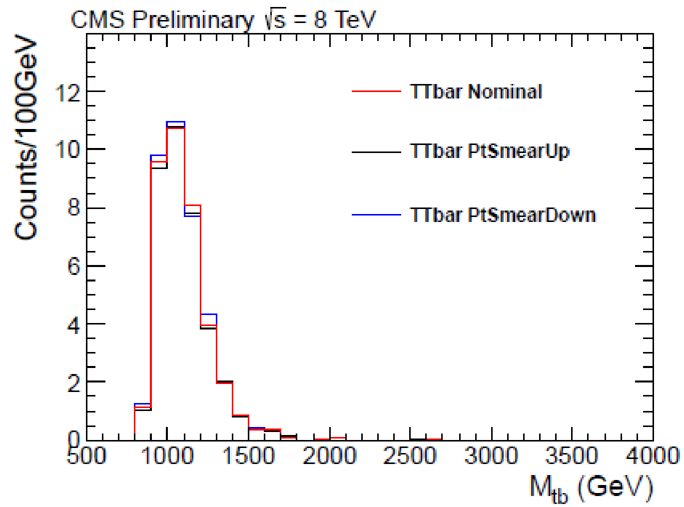
Signal at 1300,1900,2300 GeV







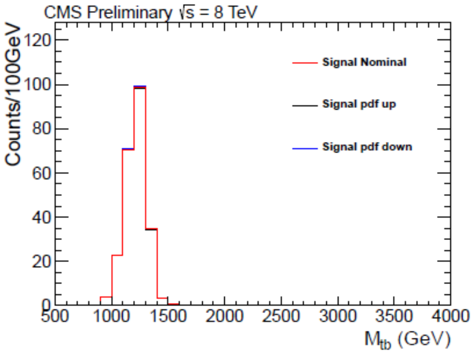
$t\bar{t}$

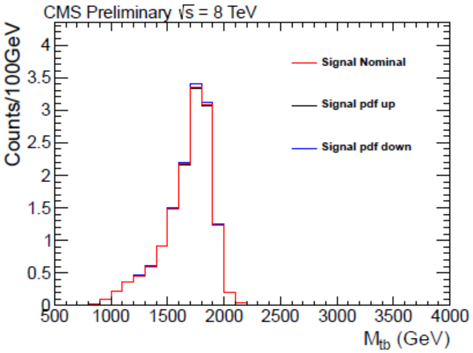


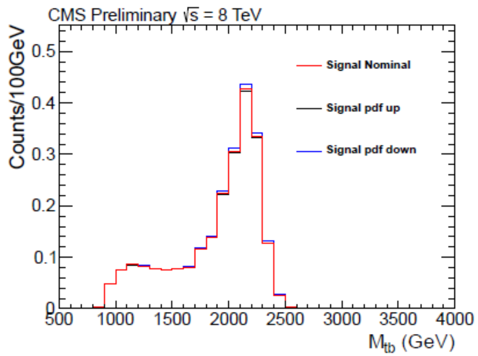
Systematics

- PDF uncertainty
  - Take the average of the 1σ eigenvalues for the pdf input parameters
    - Use Cteq6M (Cteq6.6) for signal ($t\bar{t}$)

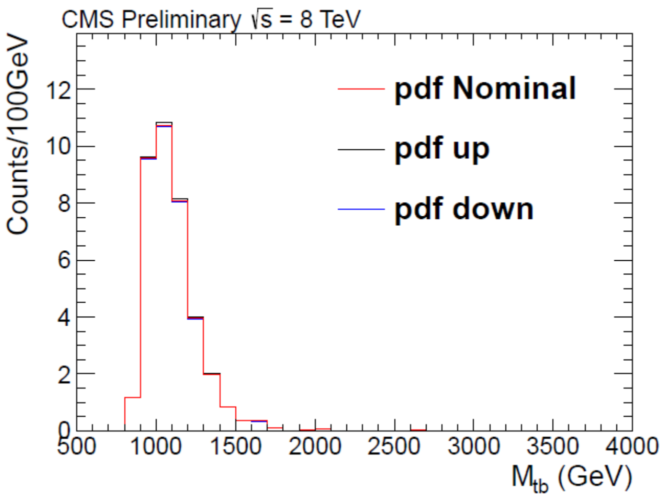
Signal at 1300,1900,2300 GeV







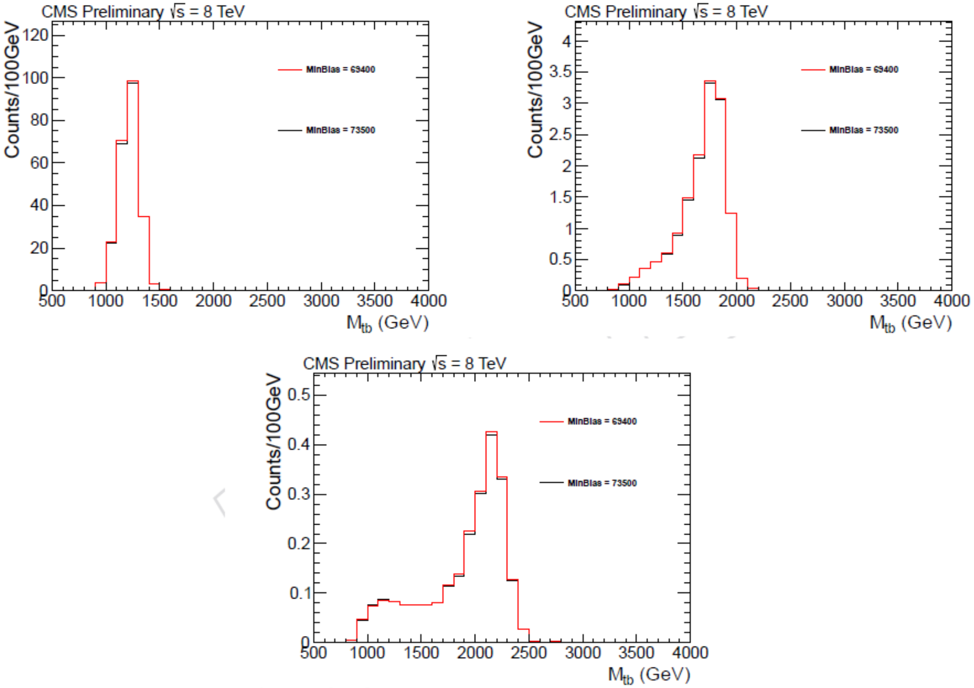
$t\bar{t}$



Systematics

- Pileup
  - Use $\sigma_{mb} = 73500\mu b$ as systematic variation

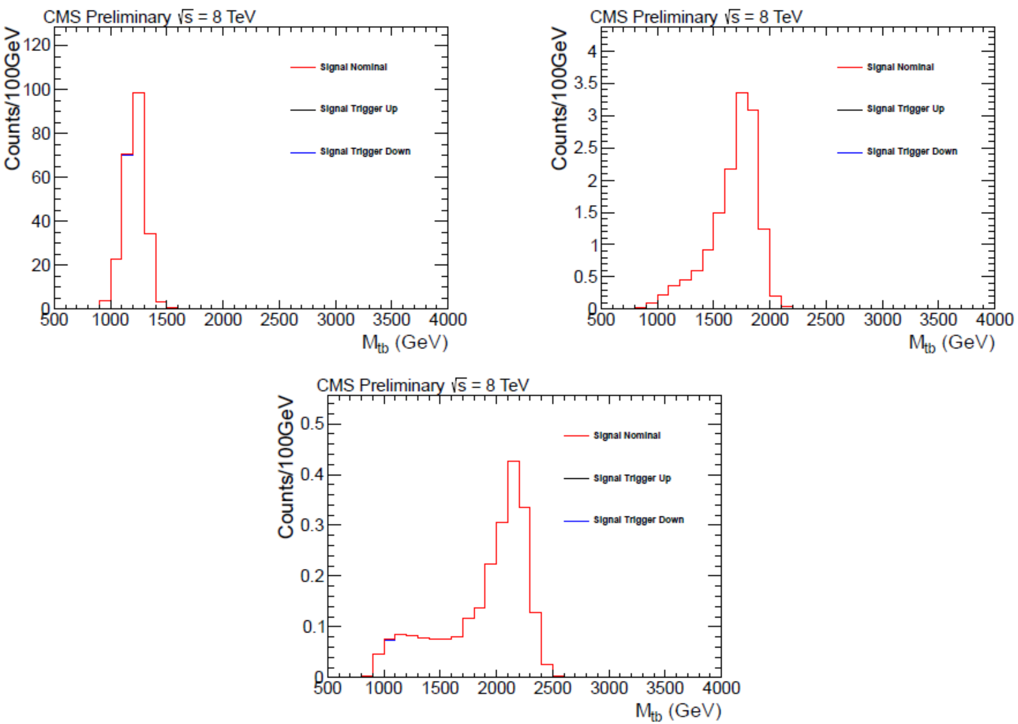
Signal at 1300,1900,2300 GeV



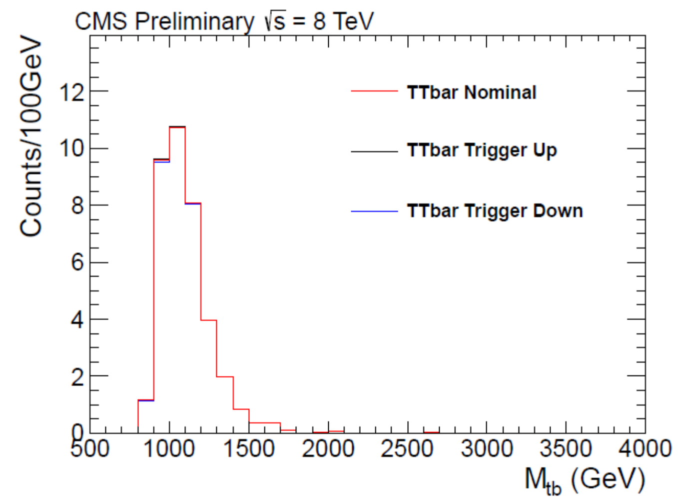
Systematics

- Trigger
  - Use ½ trigger inefficiency

Signal at 1300,1900,2300 GeV



$t\bar{t}$



Systematics

- b-tagging Scale Factor
  - Use EPS13 prescription

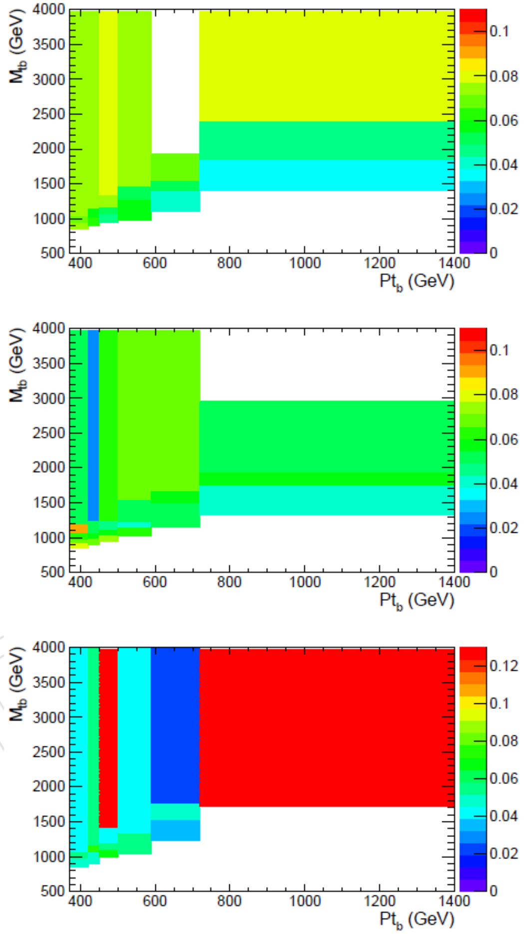
p_t **range**	**Absolute Error on** SF_b
$320\,\text{GeV}/c < p_t < 400\,\text{GeV}/c$	0.0313175
$400\,\text{GeV}/c < p_t < 500\,\text{GeV}/c$	0.0415417
$500\,\text{GeV}/c < p_t < 600\,\text{GeV}/c$	0.0740446
$600\,\text{GeV}/c < p_t < 800\,\text{GeV}/c$	0.0596716

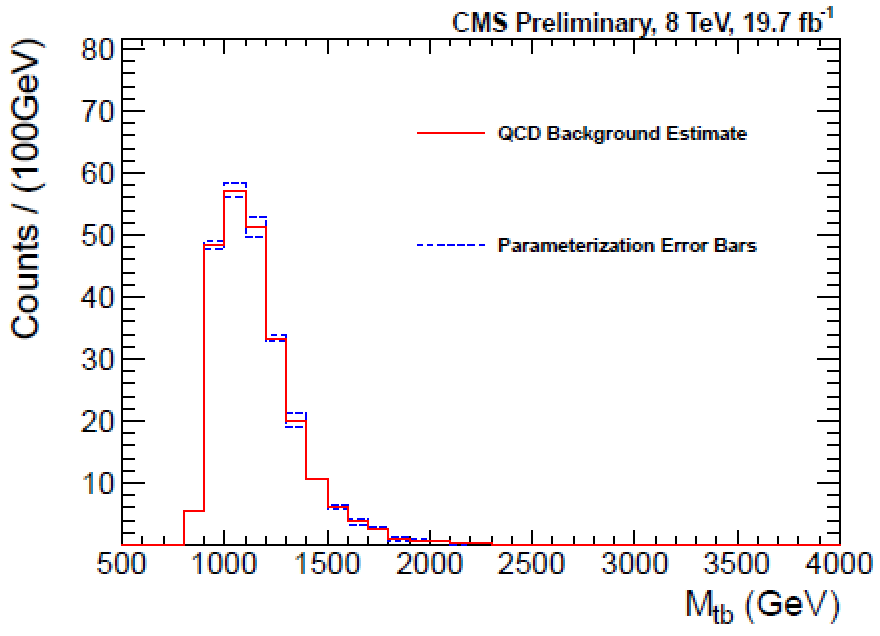
Systematics

- QCD parameterization uncertainty
  - Parameterize average b-tagging rate in p_T and η
  - Use this parameterization to predict M_{tb}
  - Uncertainty in the parameterization choice is evaluated by parameterizing the average b-tagging rate in p_T,η, and M_{tb}
  - Parameterization in the analysis constrains variables with known correlation with b-tagging
    - Therefore the parameterization choice uncertainty is a small and second order effect

Systematics

- QCD parameterization uncertainty

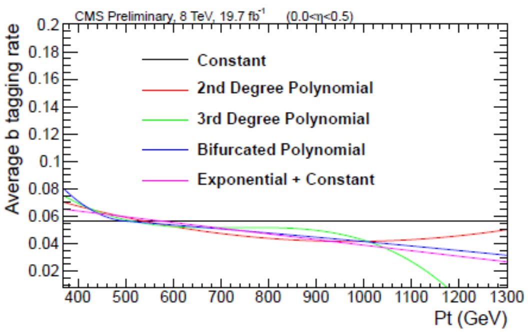


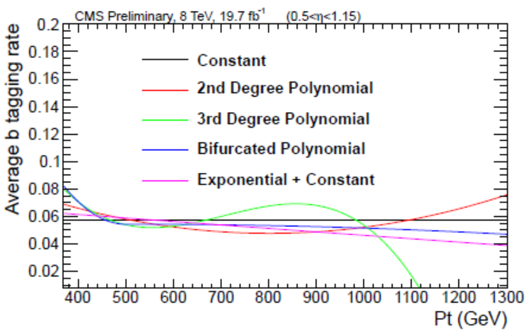


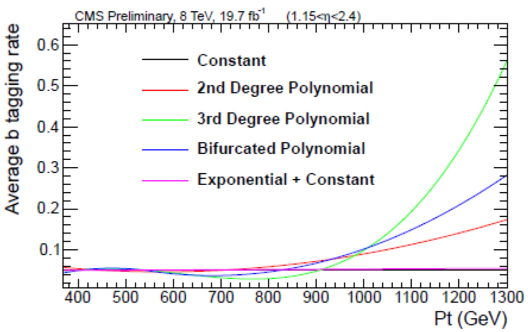
Systematics

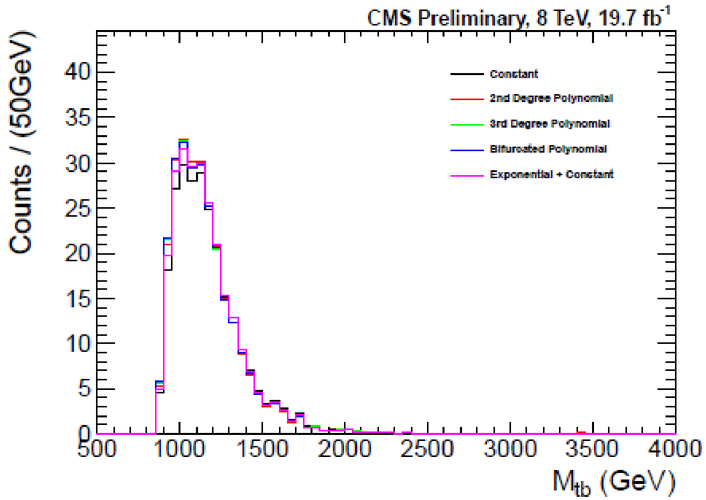
- Choice of fit
  - Extract uncertainty based on the choice of a bifurcated polynomial
  - Plot alternative functional forms and take the mean squared error of the background estimates

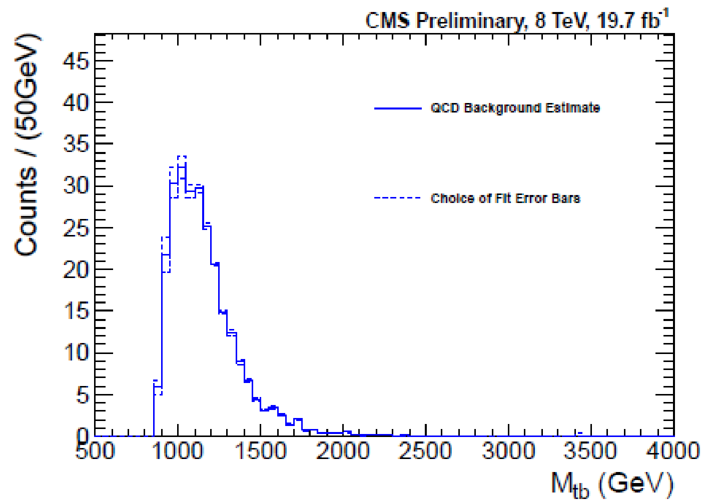
Systematics





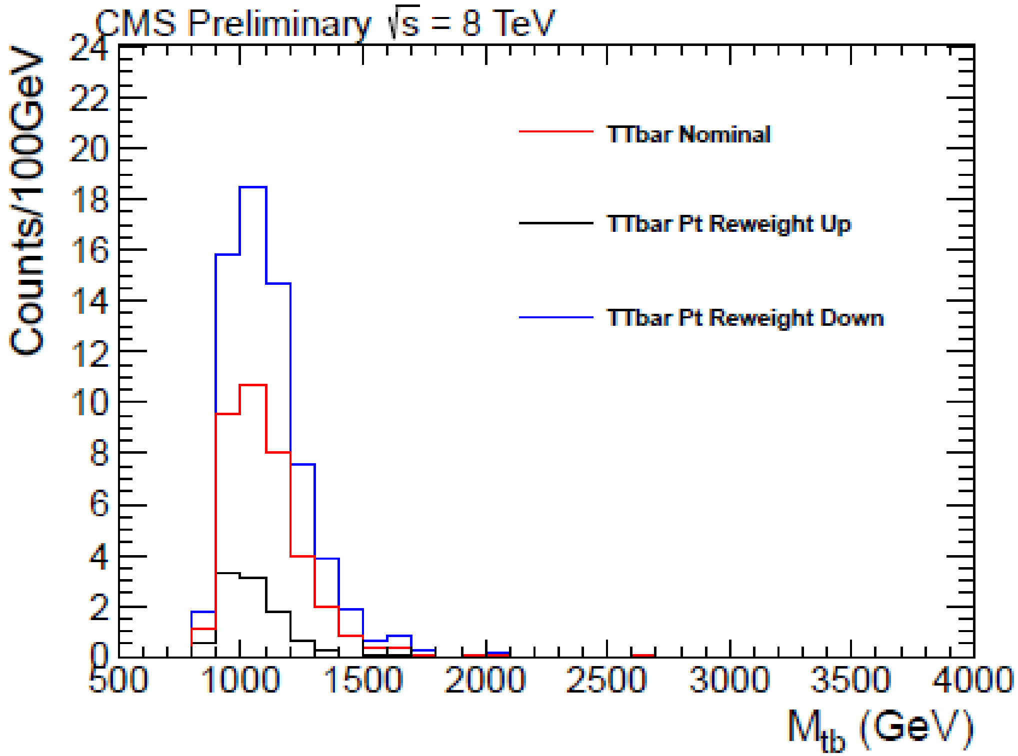






Systematics

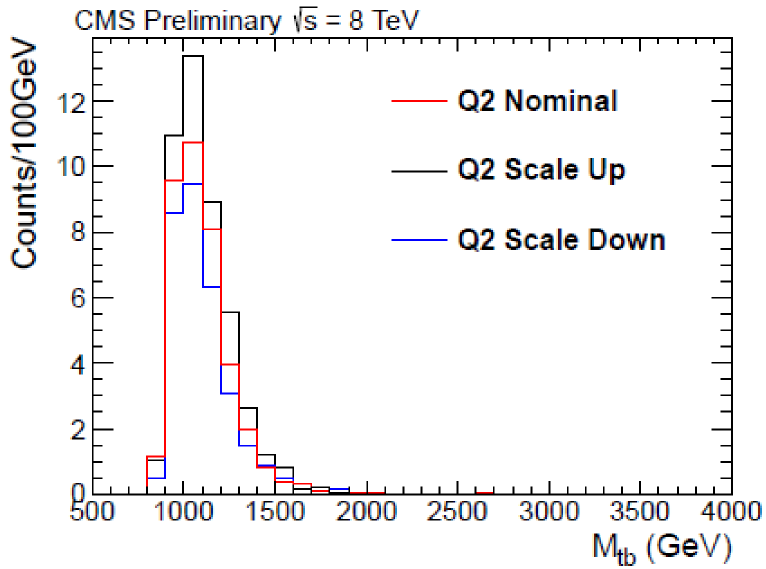
- For $t\bar{t}$ p_T re-weighting, take the un-weighted distribution as the 1σ uncertainty



Systematics

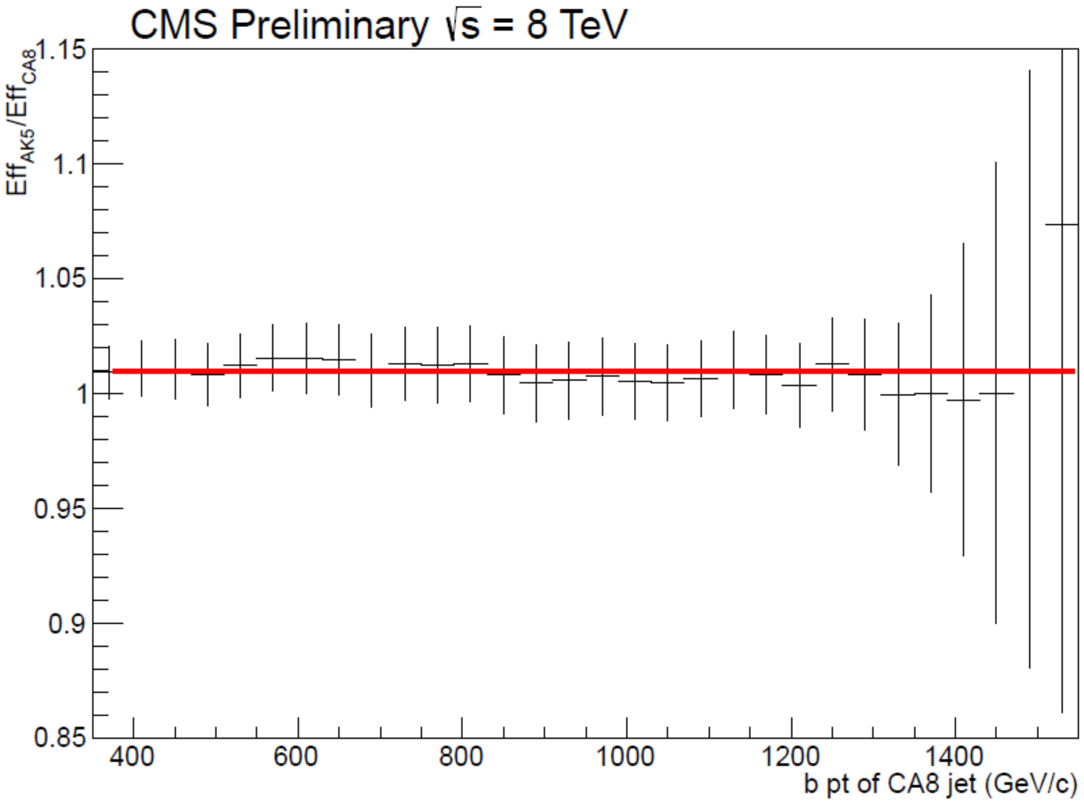
- For $t\bar{t}$ Q^2 scale uncertainty use the samples

$t\bar{t}$ systematic samples
/TT_Mtt-1000toInf_CT10_scaledown_TuneZ2star_8TeV-powheg-tauola/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM
/TT_Mtt-1000toInf_CT10_scaleup_TuneZ2star_8TeV-powheg-tauola/Summer12_DR53X-PU_S10_START53_V7A-v1/AODSIM



Systematics

- AK5 to CA8 b-tagging
  - ~2% effect



Systematics

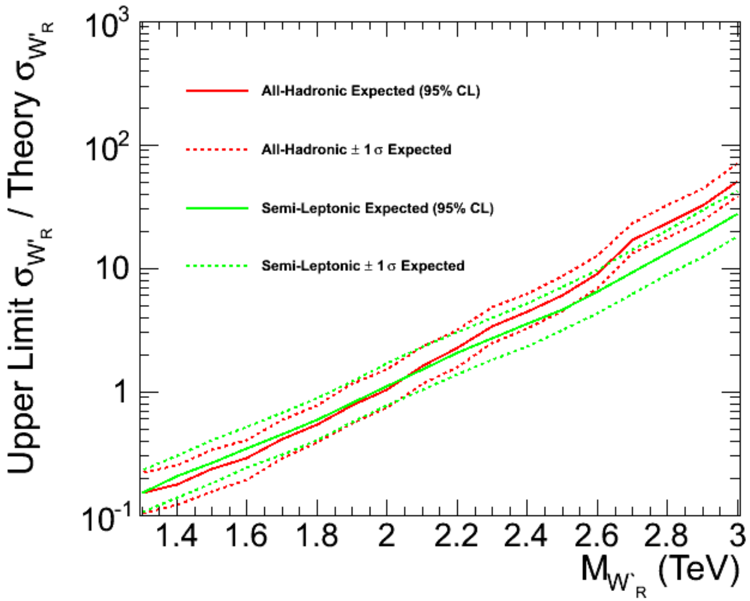
- Nuisance Parameters after the fit

Nuisance Parameters

Sample	JES	Q^2	b-tagging	p_T Re-weight	Trigger	CA btag SF	JER	QCD total	Lumi	Subjet SF	$t\bar{t}$ Norm
wp1300	-0.667 ± 0.669	-0.154 ± 1.309	-0.031 ± 0.993	0.199 ± 0.701	0.002 ± 0.993	-0.000 ± 0.993	-0.027 ± 0.795	-0.489 ± 0.701	-0.000 ± 0.993	0.000 ± 0.994	0.080 ± 0.997
wp1500	-0.544 ± 1.008	0.375 ± 1.112	-0.005 ± 0.992	-0.030 ± 0.656	-0.000 ± 0.993	-0.000 ± 0.993	-0.021 ± 0.929	-0.437 ± 0.703	-0.000 ± 0.993	0.000 ± 0.993	0.101 ± 0.993
wp1700	-0.545 ± 1.007	0.375 ± 1.113	-0.005 ± 0.992	-0.030 ± 0.656	-0.000 ± 0.993	-0.000 ± 0.993	-0.022 ± 0.911	-0.436 ± 0.703	-0.000 ± 0.993	-0.000 ± 0.993	0.100 ± 0.993
wp1900	-0.544 ± 1.008	0.375 ± 1.113	-0.005 ± 0.992	-0.030 ± 0.656	-0.000 ± 0.993	-0.000 ± 0.993	-0.020 ± 0.940	-0.437 ± 0.703	-0.000 ± 0.993	-0.000 ± 0.993	0.101 ± 0.993
wp2100	0.634 ± 0.793	0.149 ± 1.418	-0.018 ± 0.993	0.109 ± 0.649	0.001 ± 0.993	-0.000 ± 0.993	-0.014 ± 1.059	-0.583 ± 0.739	-0.000 ± 0.993	0.000 ± 0.993	0.066 ± 0.980
wp2300	0.659 ± 0.788	0.132 ± 1.446	-0.017 ± 0.992	0.130 ± 0.647	0.000 ± 0.993	0.000 ± 0.993	-0.018 ± 1.055	-0.537 ± 0.721	0.000 ± 0.993	0.000 ± 0.993	0.071 ± 0.981
wp2700	0.659 ± 0.788	0.132 ± 1.446	-0.017 ± 0.992	0.130 ± 0.647	0.000 ± 0.993	-0.000 ± 0.993	-0.018 ± 1.055	-0.537 ± 0.721	-0.000 ± 0.993	-0.000 ± 0.993	0.071 ± 0.982
wp3100	-0.544 ± 1.008	0.375 ± 1.113	-0.005 ± 0.992	-0.030 ± 0.656	-0.000 ± 0.993	-0.000 ± 0.993	-0.021 ± 0.931	-0.437 ± 0.703	-0.000 ± 0.993	-0.000 ± 0.993	0.101 ± 0.993

Combination

- Combination of All-Hadronic and Semileptonic channels in progress
- Similar sensitivity
- Need to check for overlap

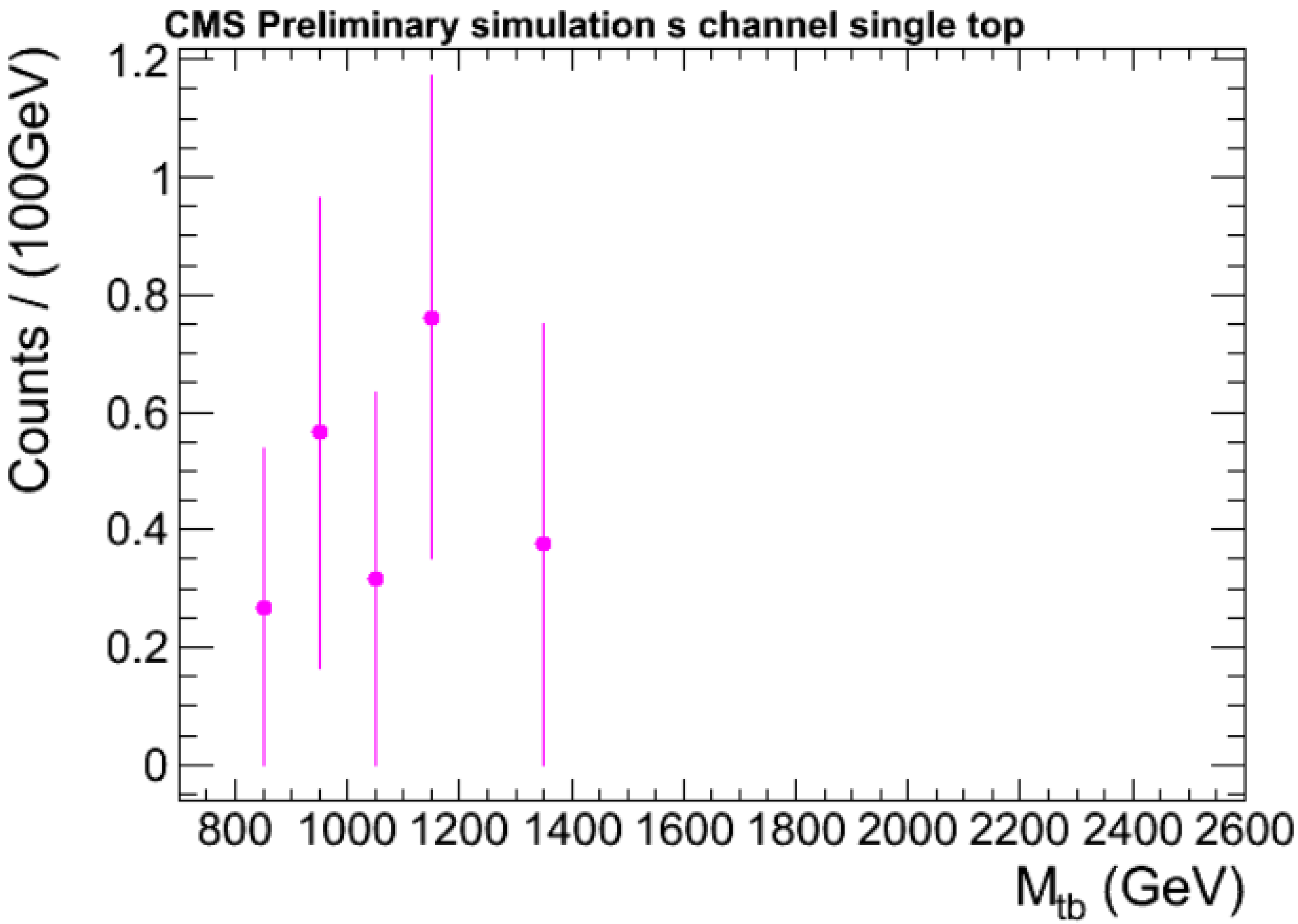


Combination

- Uncertainties Correlated
  - Jet Energy Scale
  - Jet Energy Resolution
  - Luminosity
  - b-tagging
- Uncertainties Uncorrelated
  - Q2 scale
  - ttbar normalization
  - ttbar pt-reweighting

Generalized Coupling Limits

s-channel single top

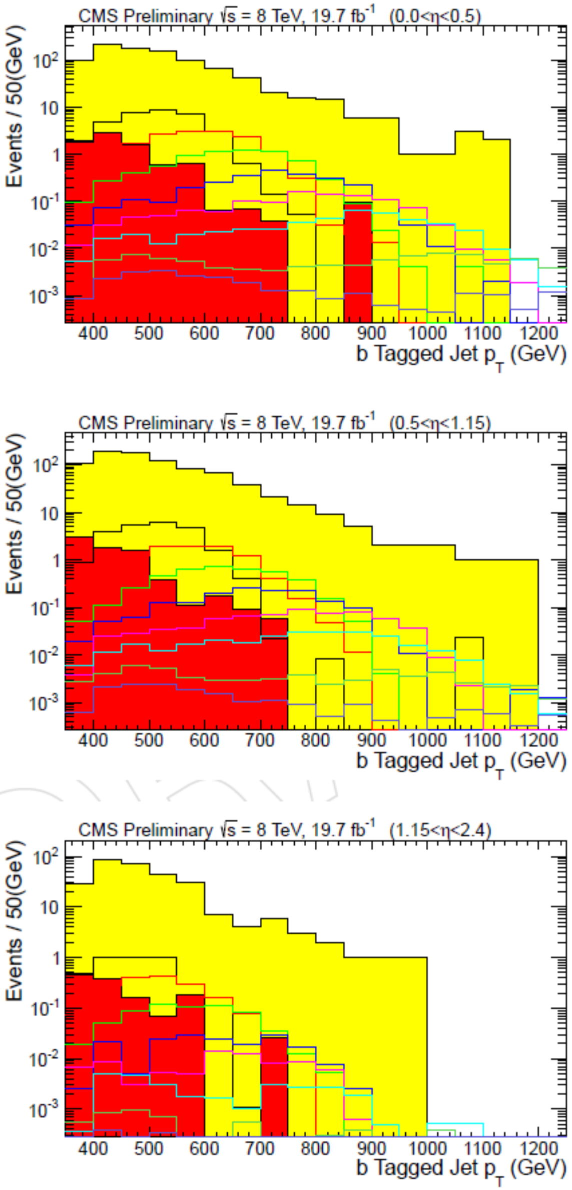


Generalized Coupling Limits

- W'_L excluded below 1.91 TeV
- W'_{LR} excluded below 2.10 TeV

Signal Contamination

In average b-tagging rate



Signal Contamination

In Sideband

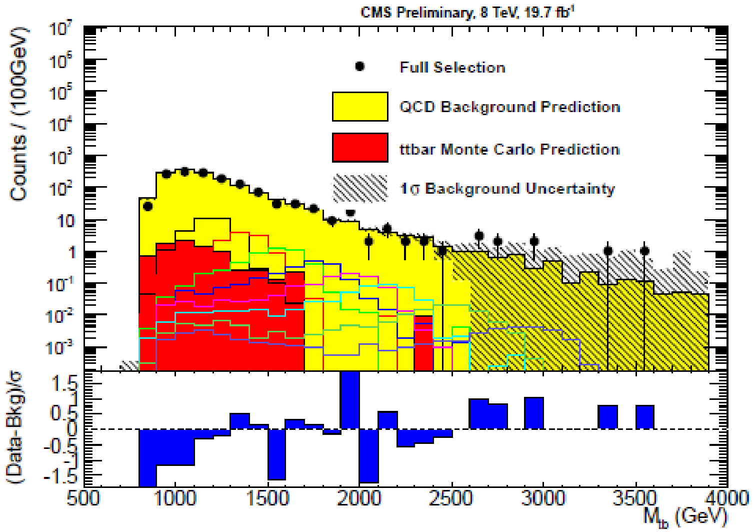
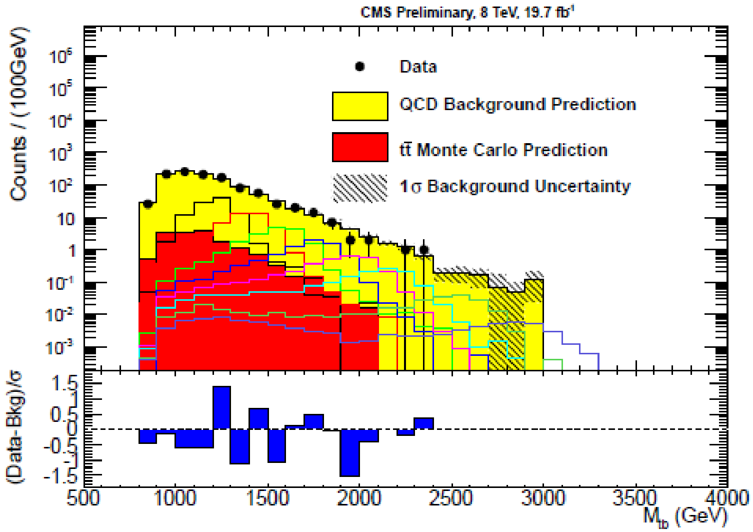
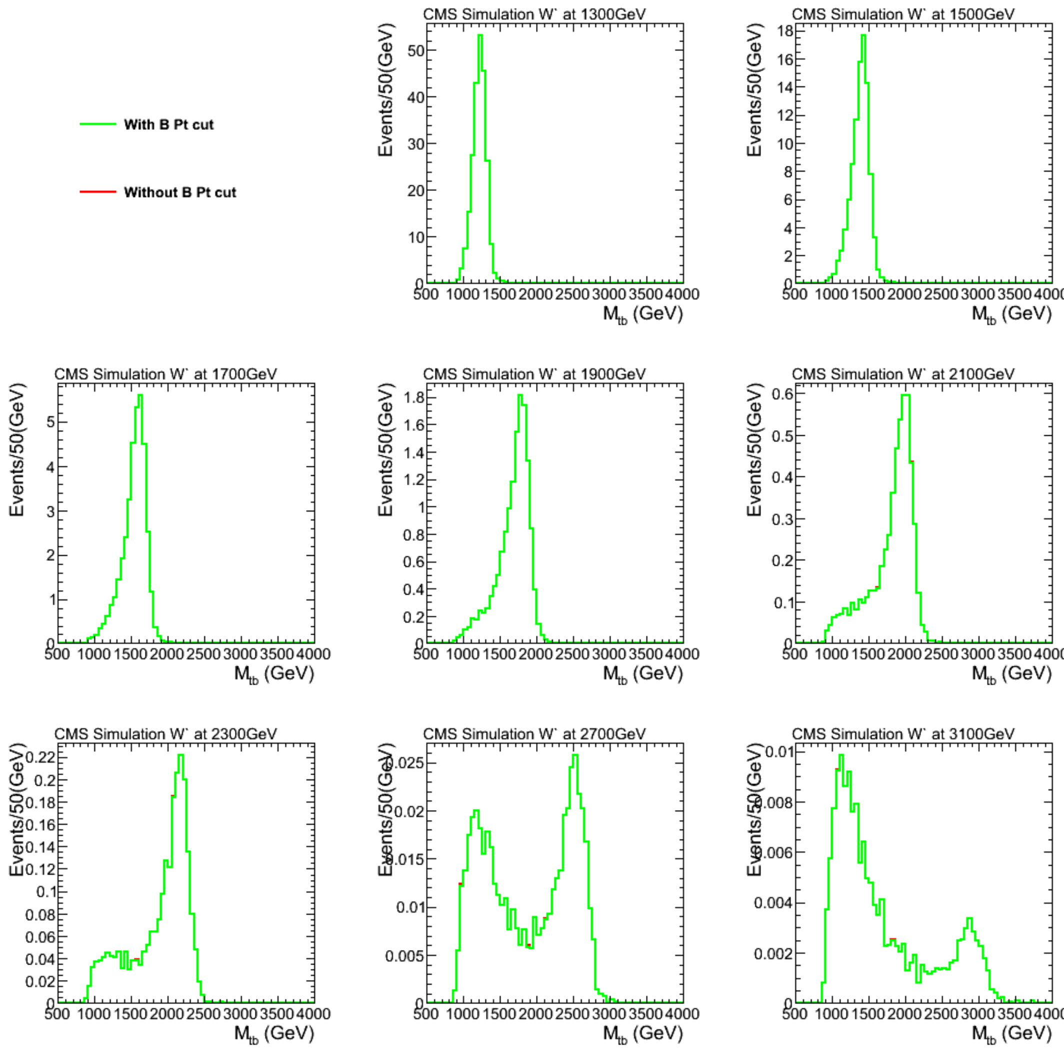


Figure 56: Signal contamination in sideband



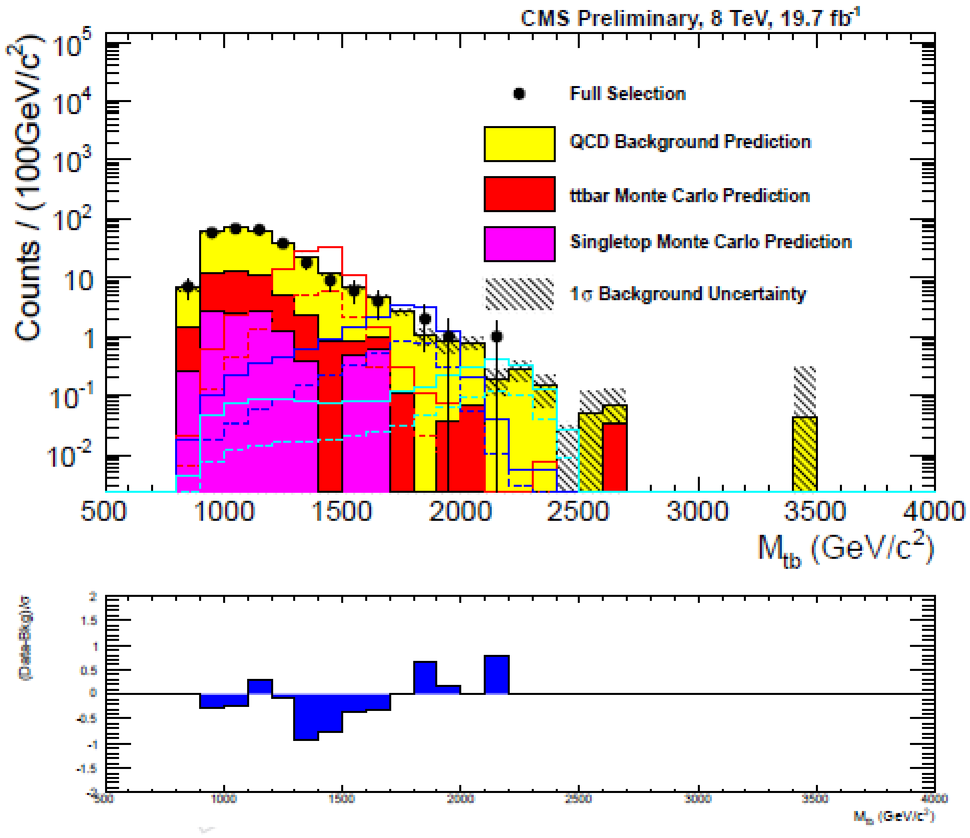
Review twiki

Apply generator pt cut to right handed sample



Signal Contamination

In Full Selection



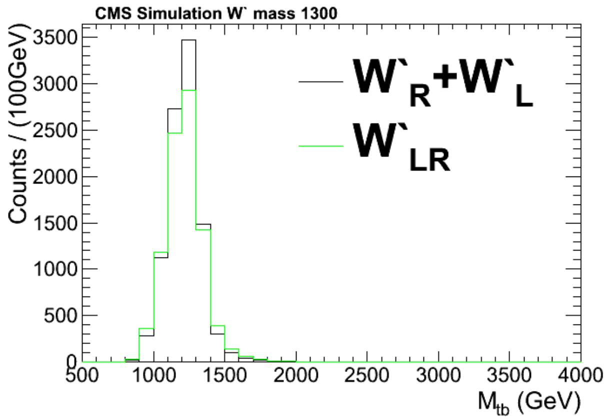
Review twiki

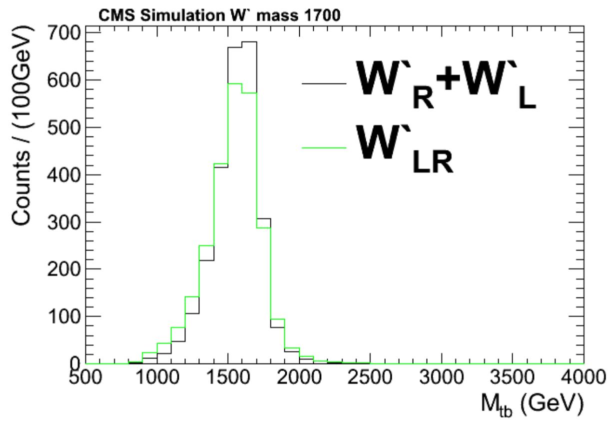
B2G-12-009

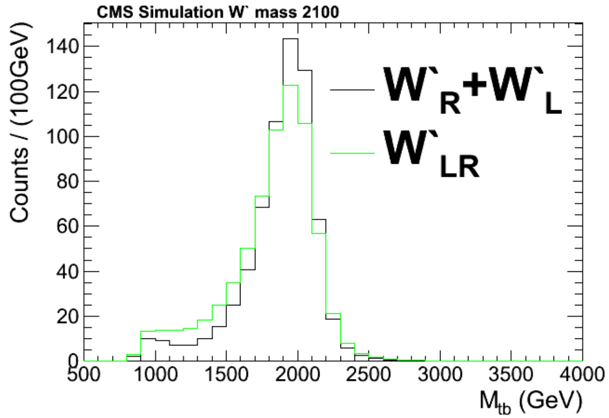
1300 GeV: Left+Right = 9612 events Mixed = 9070 events

1700 GeV: Left+Right = 2607 events Mixed = 2572 events

2100 GeV: Left+Right = 668 events Mixed = 685 events:







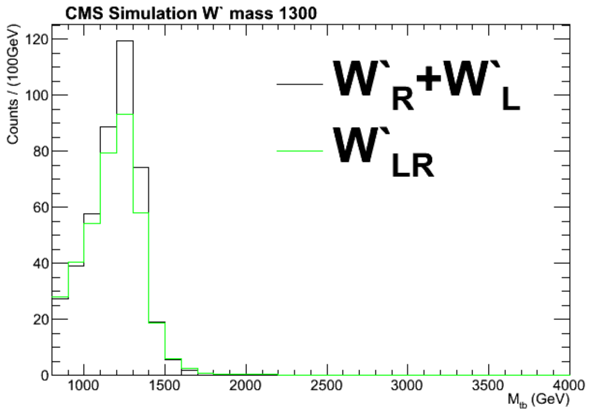
Review twiki

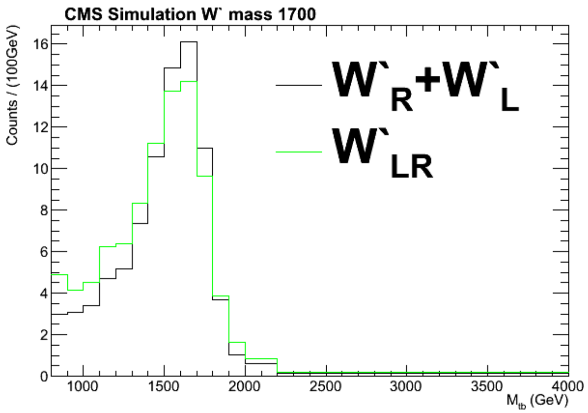
B2G-12-010

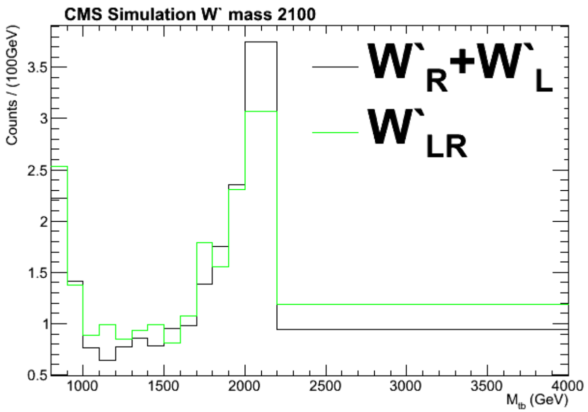
1300 GeV: Left+Right = 434.1 events Mixed = 382.2 events

1700 GeV: Left+Right = 84.7 events Mixed = 89.8 events

2100 GeV: Left+Right = 19.6 events Mixed = 20.36 events:







ARC Review

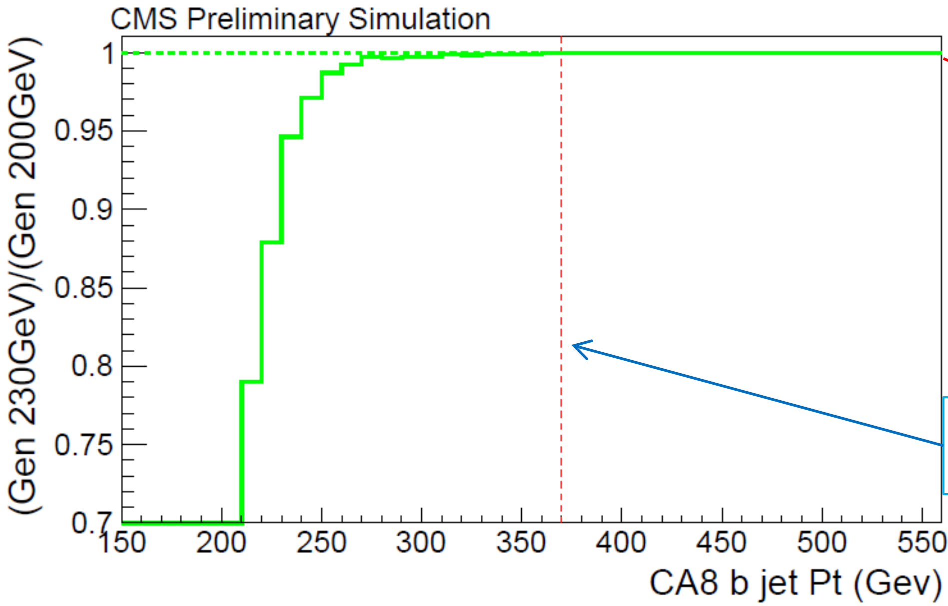
- Many thanks to the ARC review for the improvements to the analysis.
- All cross checks have been performed and requested changes to AN and PAS have been implemented
  - Investigate generalized coupling limit setting procedure
    - Effect of the generator level p_{T} cut
  - Investigate loose selection background estimate
  - Investigate strange φ distribution in signal
  - Expand pdf uncertainty to consider multiple pdf sets
  - Investigate potential uncertainty from signal contamination in the average b-tagging rate
- All textual and minor comments have been implemented

https://twiki.cern.ch/twiki/bin/viewauth/CMS/B2G12009Review

ARC Review

- Effect of the generator level p_T cut on the left-handed and mixed coupling W′ samples

W'_{LR} at 1300 GeV



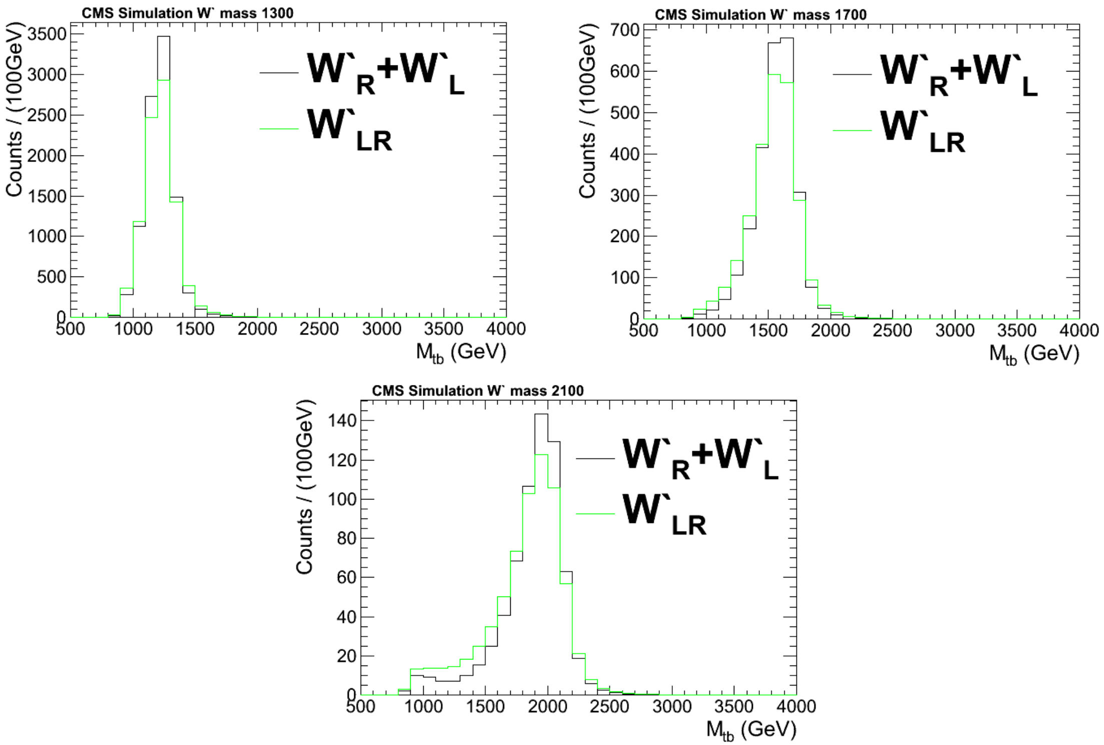
Investigate tighter generator level p_T cut

Very small effect

Minimum jet p_T

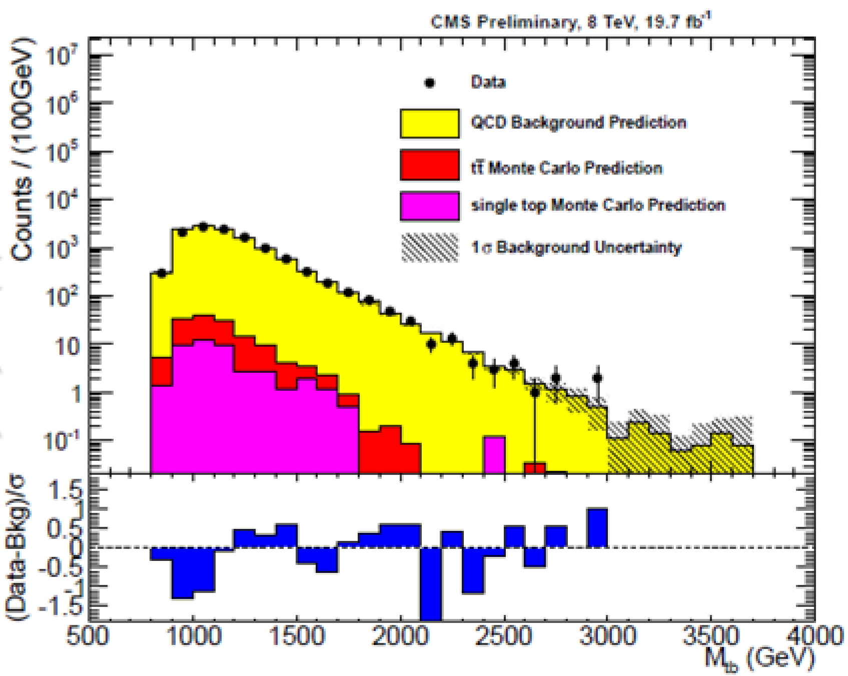
ARC Review

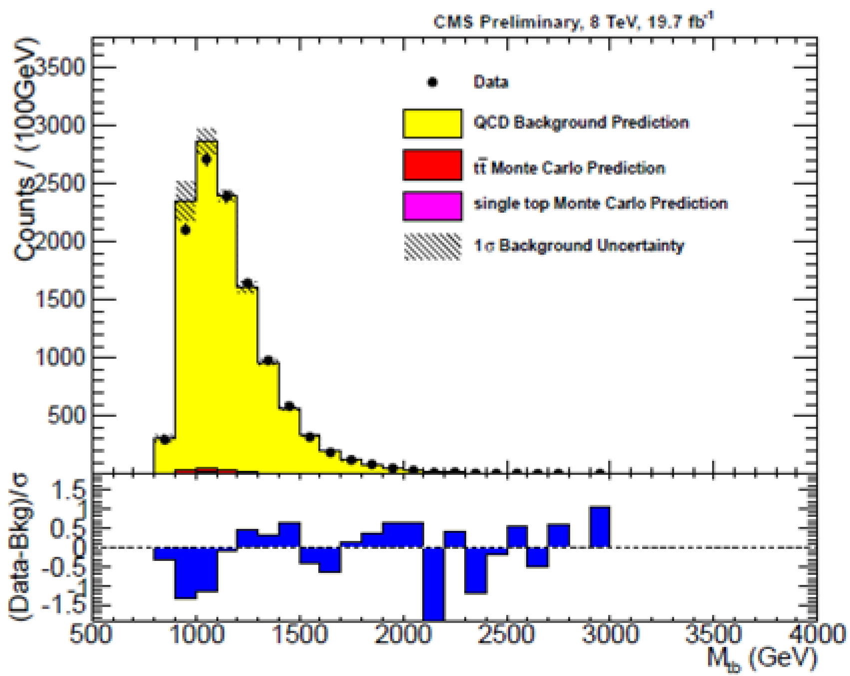
- Disagreement seen in $\mathrm{W'}_{\mathrm{R}} + \mathrm{W'}_{\mathrm{L}}$ vs $\mathrm{W'}_{\mathrm{LR}}$
  - Similar disagreement seen in B2G-12-010
  - Does not seem to be due to generator p_{T} cut



ARC Review

- Investigate background estimate in a loose selection
  - Do not apply N-subjettiness and subjet b-tagging



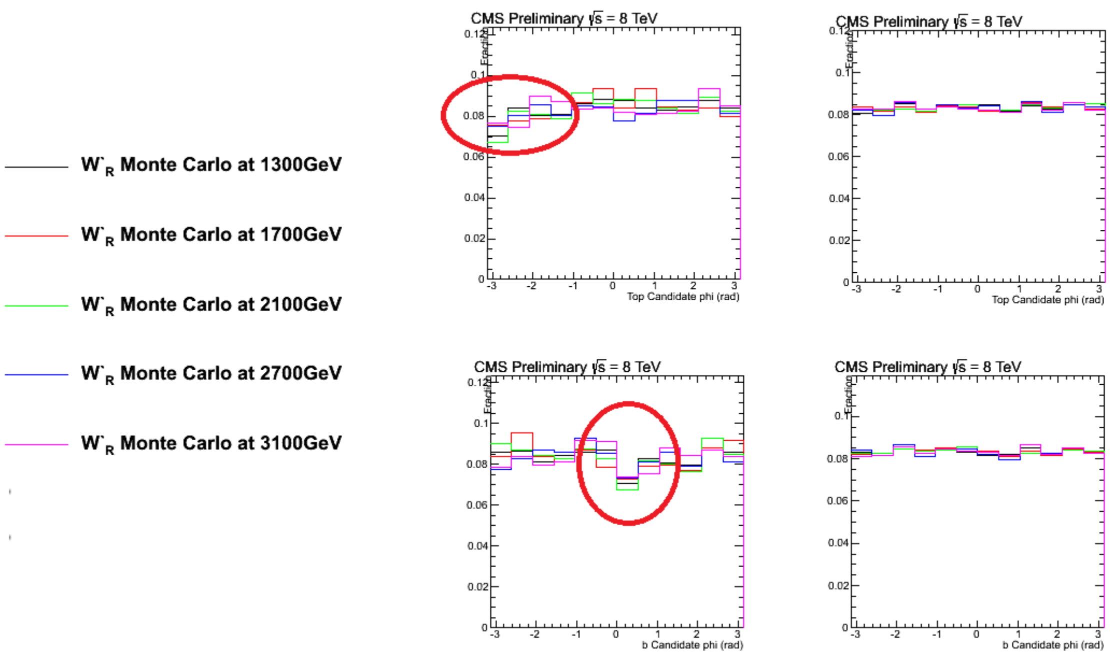


ARC Review

- Investigate φ dip for top candidate jet in signal Monte Carlo

Post b-tagging

Pre b-tagging



https://hypernews.cern.ch/HyperNews/CMS/get/btag/910.html

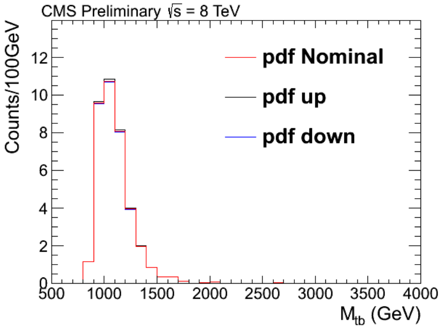
ARC Review

- Extract pdf uncertainty using the maximum of three pdf sets
  - CTEQ6.6
  - CTEQ6M
  - MRST2006nnlo
- Same procedure as EXO-12-024
  - With the addition of CTEQ6M

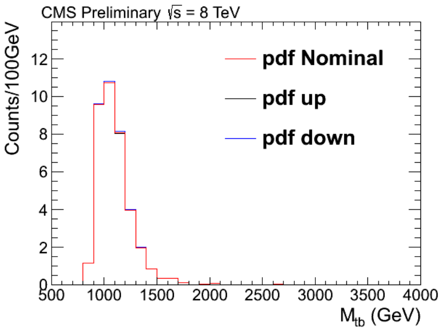
ARC Review

- $t\bar{t}$
  - Maximum uncertainty from CTEQ6.6

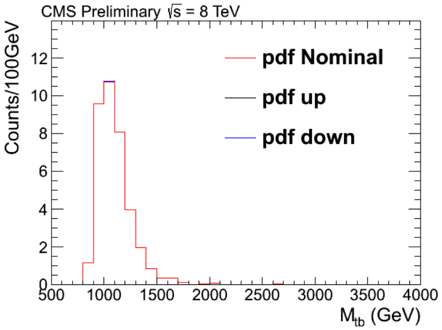
CTEQ6.6



CTEQ6M



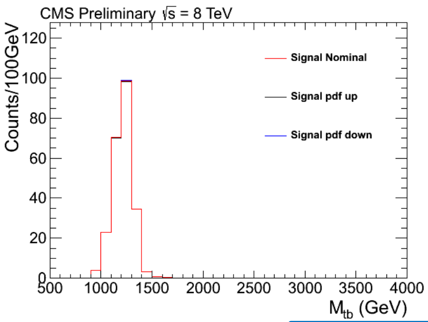
MRST2006nnlo



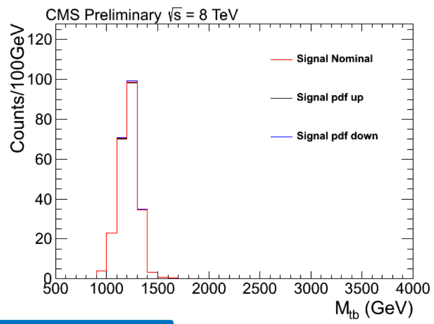
ARC Review

- Signal (1300 GeV)
  - Maximum uncertainty from CTEQ6M

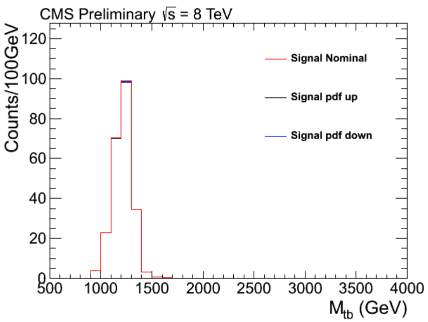
CTEQ6.6



CTEQ6M

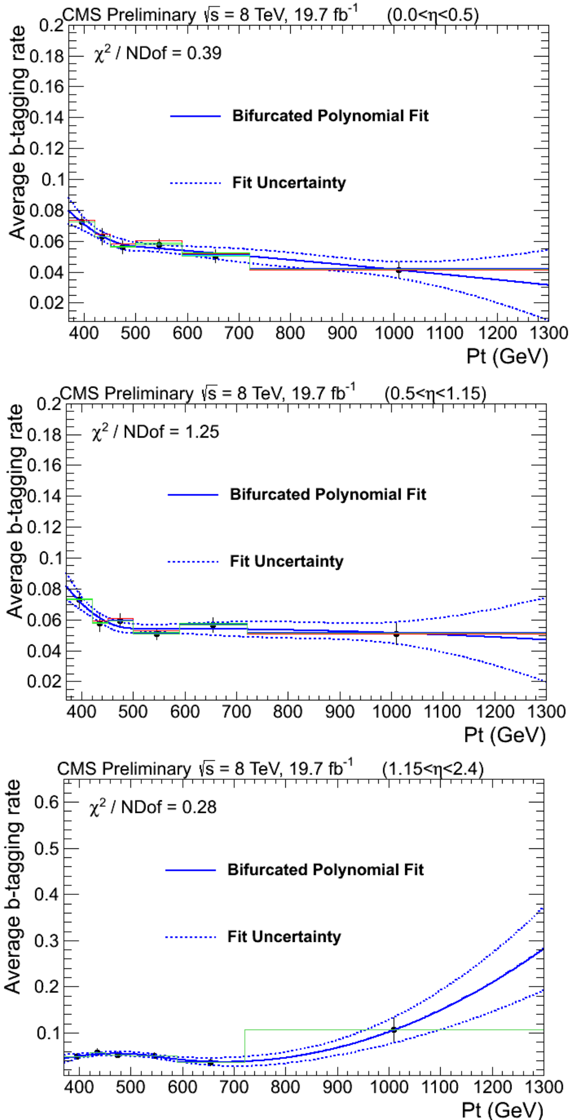


MRST2006nnlo



ARC Review

- Investigate uncertainty due to signal contamination of the average b-tagging rate
  - Small effect



Samples

Jet Datasets

Dataset	Lumiosity (pb^{-1})
Run2012A-22Jan2013-v1	888
Run2012B-22Jan2013-v1	4403
Run2012C-22Jan2013-v1	7052
Run2012D-22Jan2013-v1	7414
Total Analyzed Luminosity	**19757**

$t\bar{t}$ Monte Carlo samples

Dataset	Cross Section (pb)
TT_Mtt-700to1000_CT10_TuneZ2star_8TeV-powheg-tauola	245.8
TT_Mtt-1000toInf_CT10_TuneZ2star_8TeV-powheg-tauola	245.8