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Institute of High Energy Physics
Chinese Academy of Sciences

Search for the production of an excited bottom quark decaying to tW (leptonic top + hadronic W) in proton-proton collisions $\sqrt{s}$=13 TeV

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On behalf of CMS collaboration

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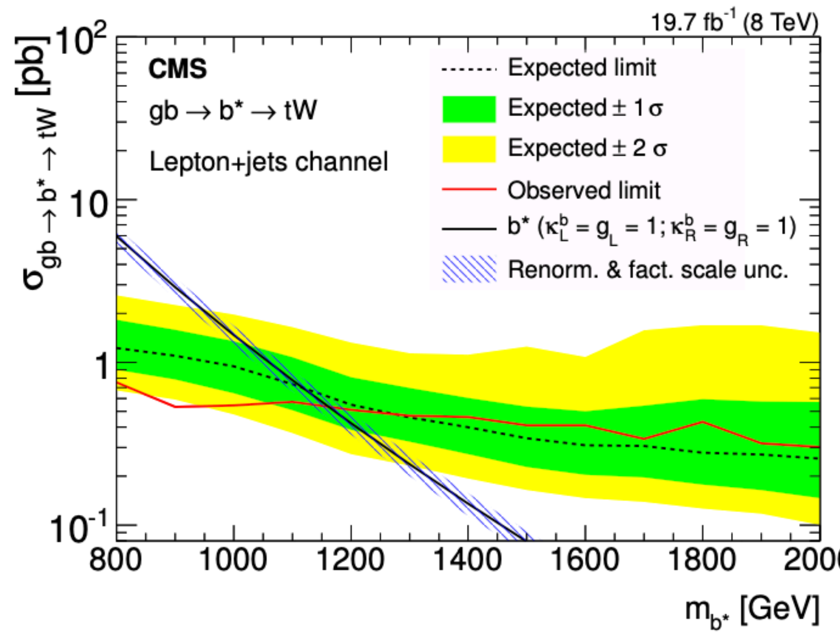
Outline

- Introduction
- Selections
- Background estimation
- Systematic uncertainties
- Results
- Summary

Motivation

- Observations like the existence of dark matter motivates BSM physics.
- Many BSM theories predict the existence of new physics, like excited quarks.
- This analysis searches for excited bottom quark: b*.

- Existing results:
    - Searches for b* at 8 TeV in CMS[1] and ATLAS[2] have been performed.
    - Searches for b* at 13 TeV in CMS in all hadronic channel[3] and leptonic W channel[4].
- No signs of b* find yet.
- We search in different final states complemented the results at 13 TeV.



Result: b* search in Lepton + jet channel at 8TeV in CMS

Introduction

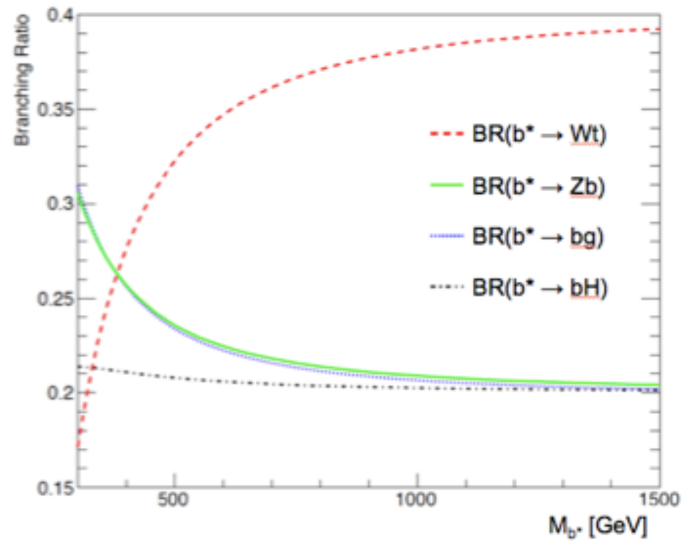
- In LHC, b* can be produced via gluon+b quark by strong interaction:

$$\mathscr{L} = \frac{g_s}{2\Lambda} G_{\mu,\nu} \bar{b} \sigma^{\mu,\nu} (\kappa_L^b P_L + \kappa_R^b P_R) b^* + h.c$$

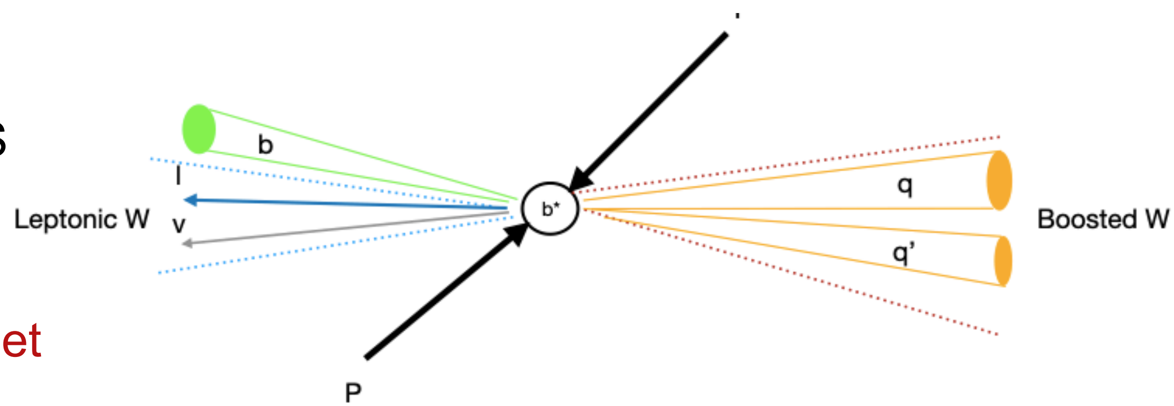
- And decays via tW by the weak interaction:

$$\mathscr{L} = \frac{g_2}{\sqrt{2}} W_\mu^+ \bar{t} \gamma^\mu (g_L P_L + g_R P_R) b^* + h.c$$

- tW is the dominate decay channel after b* mass > ~400 GeV



- This analysis focused on b* decaying to tW at 13TeV in CMS using the full Run II dataset.
- Final state: high pt Top: lepton, neutrino and b jet + Boosted W jet



Preselection

1

- Muon Trigger:
  - HLT– Mu50||HLT– TkMu50(2016)
  - HLT– Mu50||HLT– OldMu100||HLT– TkMu100(2017)
  - HLT– Mu50||HLT– OldMu100||HLT– TkMu100(2018)
- Electron Trigger:
  - HLT–Ele27–WPTight–Gsf||HLT–Photon175||HLT–Ele115–CaloIdVT–GsfTrkIdT(2016)
  - HLT–Ele35–WPTight–Gsf||HLT–Photon200||HLT–Ele115–CaloIdVT–GsfTrkIdT(2017)
  - HLT–Ele32–WPTight–Gsf||HLT–Photon200||HLT–Ele115–CaloIdVT–GsfTrkIdT(2018)

2

- Exactly one lepton:
  - pT > 53 GeV, $|\eta| < 2.4$, $\Delta R(closedbjet, lepton) < 2$
  - 2D cut: $\Delta R(ak4jet, lepton) > 0.4$ or $p_T^{rel} > 15GeV$
  - Muon ID: Tight ID
  - Electron ID: Tight ID remove isolation requirement

3

- At least one b-tagged AK4 jet:
  - pT > 30 GeV, $|\eta| < 2.4$,
  - Medium WP of the DeepJet b tagging

4

- Exactly one W-tagged AK8 jet:
  - pT > 200 GeV, $|\eta| < 2.4$
  - W tagging: 65 GeV< Softdrop mass<105 GeV, $\tau_{21} < 0.4$ (2016),0.45(2017,2018)
  - $\Delta R(AK4jet, AK8jet) < 0.8$

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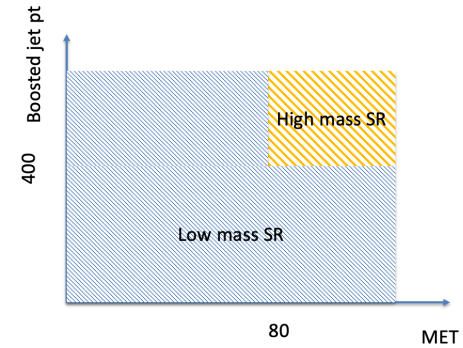
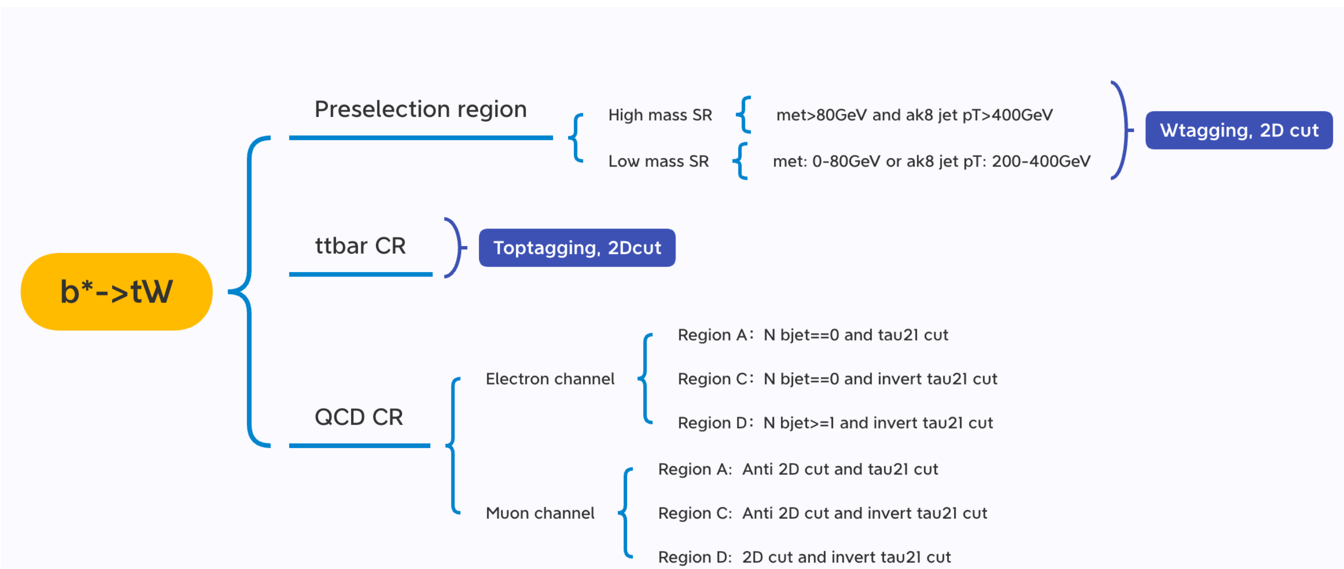
Analysis strategy

- SR definition:
  - Cut optimization performed in preselection region to improve limit sensitivity.
  - Additional MET and AK8 jet pT selections are used to defined two SRs:
    - chosen by compromise between the expected sensitivity and *MtW* distribution statistical precision.
- $t\bar{t}$ background constrained from simultaneous fit to $t\bar{t}$ CR and SRs.
- QCD background predict from data driven: both shape and normalization
- The other backgrounds are predicted from MC directly.



Region definition

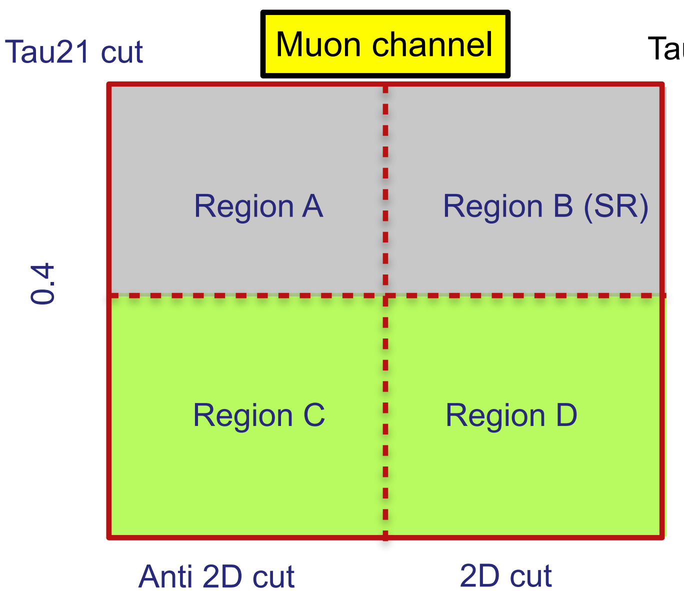


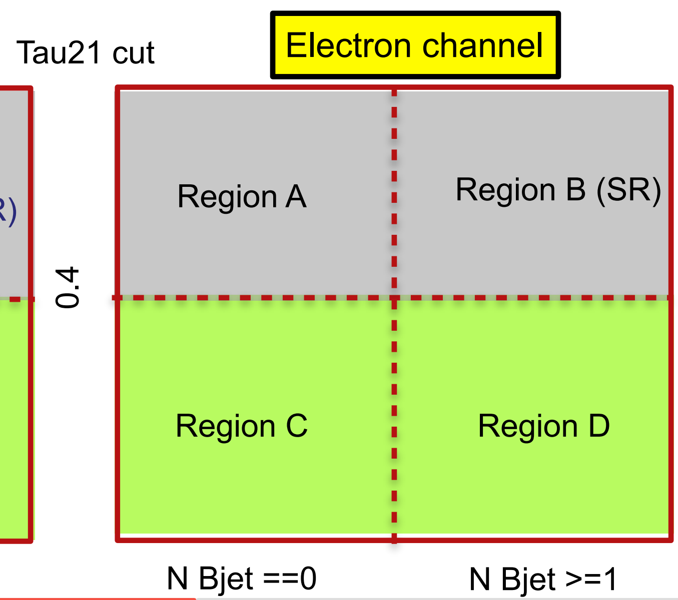
QCD estimation(ABCD method)

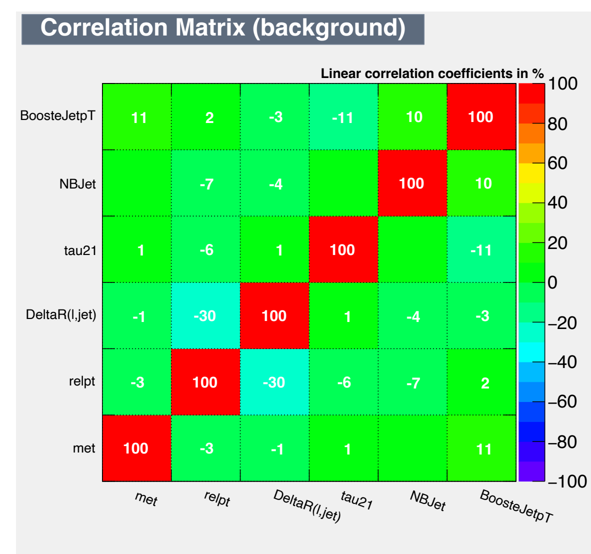
- Splitting phase space by 2 **uncorrelated** observables:
  - Muon: τ_{21} and 2D cut (not optimal for electron channel due to electron have isolation in trigger).
  - Electron: τ_{21} and N_{bjet} ;

*Met cut is removed from region A and C(high mass: improve the QCD statistics; low-mass: ensure statistically independent with high mass)

- SR can be evaluated as: $N_B = (N_A/N_C) * N_D \, . \, N_i = Data - nonQCDMC(i = A, C, D)$.
- **QCD shape: Do ABCD method for each MtW bin.**







ABCD method with fitting method

Fitting model:

$$\mathcal{L} = \prod_{bin}^{N\,Bins, flavor, years} \cdot \prod_{i}^{ABCD} P(n_i, bin \Big| \sum_k Bkg^k_{i,bin} + QCD_{i,bin} \Big| + r \cdot sig_{i,bin}) \times \prod_{j}^{NP} Constraints(\theta_j, \tilde{\theta}_j) \quad (4)$$

Each $QCD_{i,bin}$ is a independent rate parameter with relation $QCD_{B,bin} = \frac{QCD_{A,bin}}{QCD_{C,bin}} \cdot QCD_{D,bin}$ and $\boxed{QCD_{i,bin} >= 0.}$

Implementation following the combine tool ABCD method recommendations : http://cms-analysis.github.io/HiggsAnalysis-CombinedLimit/part2/settinguptheanalysis/#rate-parameters

```
imax 4  number of channels
jmax 0  number of processes -1
kmax *  number of nuisance parameters (sources of systematical uncertainties)
-------
bin                   B      C       D        A
observation           50     100     500      10
-------
bin                   B      C       D        A
process               bkg    bkg     bkg      bkg
process               1      1       1         1
rate                  1      1       1         1
-------

alpha rateParam A bkg (@0*@1/@2) beta,gamma,delta
beta  rateParam B bkg 50
gamma rateParam C bkg 100
delta rateParam D bkg 500
```

- QCD in each region and each bin >=0
- Fit high/low mass SR, QCD CRs and TTCR simultaneously
- QCD prediction from traditional ABCD method and fitting method is consistent with uncertainty
- The traditional ABCD method had been validated in an independent validation region

Systematic uncertainties

Summary of all considered sources of systematic uncertainties that affect the M_{tW} distribution, the third column indicates correlation over the three years, the fourth indicates correlation over different lepton channels.

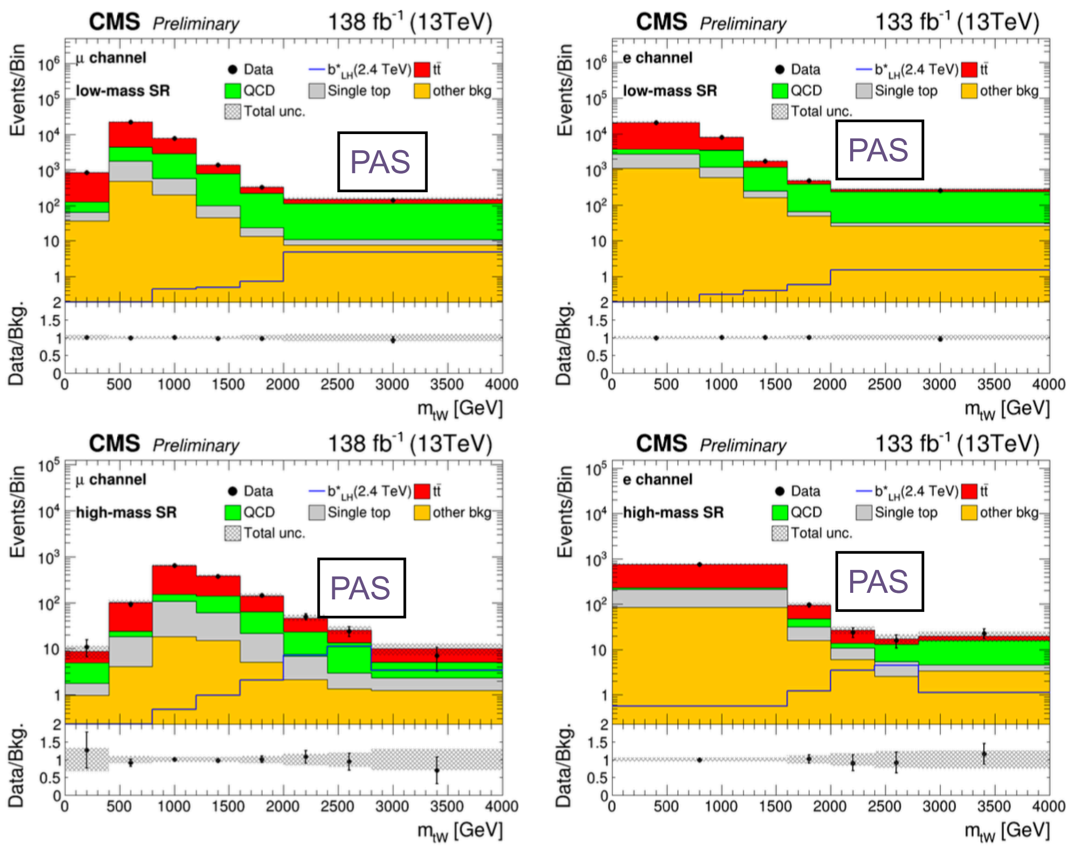
Source	Variation	Correlation between years	Correlation between channels	Samples
Luminosity	1.6%	correlated	correlated	all samples
QCD normalization	50%	correlated	uncorrelated	QCD($t\bar{t}$ CR)
Othbkg normalization	50%	correlated	correlated	other background
single top cross section (tW)	30%	correlated	correlated	single top(tW)
$t\bar{t}$ _xsec	20%	correlated	correlated	tt
2D cut	5%	correlated	correlated	all samples
b tagging(bc)	$\pm1\sigma$	uncorrelated	correlated	all samples
b tagging(udsg)	$\pm1\sigma$	uncorrelated	correlated	all samples
Pileup	$\pm1\sigma$	uncorrelated	correlated	all samples
Lepton(e,muon) triggers	$\pm1\sigma$	uncorrelated	uncorrelated	all samples
Lepton(e,muon) ID	$\pm1\sigma$	uncorrelated	uncorrelated	all samples
Electron reconstruction	$\pm1\sigma$	uncorrelated	uncorrelated	all samples
W tagging	$\pm1\sigma$	uncorrelated	correlated	all samples
JMS	$\pm1\sigma$	uncorrelated	correlated	all samples
JMR	$\pm1\sigma$	uncorrelated	correlated	all samples
JES	$\pm1\sigma$	uncorrelated	correlated	all samples
JER	$\pm1\sigma$	uncorrelated	correlated	all samples
Topp_T reweighting_b	50%	correlated	correlated	tt
PDF	$\pm1\sigma$	correlated	correlated	all samples
Top tagging(merged)	$\pm1\sigma$	uncorrelated	correlated	all samples
Top tagging(semi-merged)	$\pm1\sigma$	uncorrelated	correlated	all samples
Top tagging(non-merged)	$\pm1\sigma$	uncorrelated	correlated	all samples
QCD(ABCD)	$\pm1\sigma$	uncorrelated	uncorrelated	QCD(both SRs)

Post-fit distribution in SRs

- Simultaneous fit: (high mass SR +low mass SR+TTCR+QCD CRs) x(2016+2017+2018) x (electron channel+muon channel)
  - For visual purposed all years are shown together in one plot

Low mass SR

High mass SR



- Good post-fit agreement

- Different binning:
  - Motivation: Avoided QCD pred. close to 0 in region C
    - Region B(SR)= A/C*D

- More post-fit plots in backup

Results

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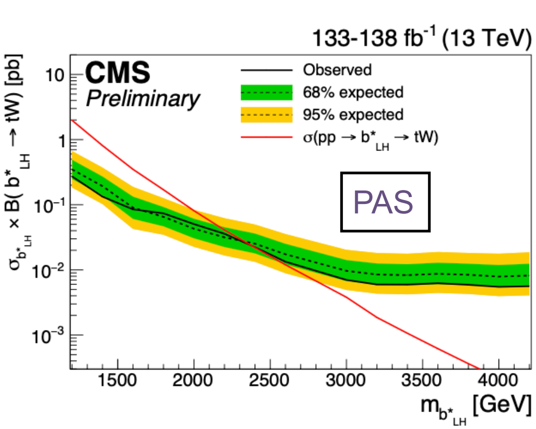
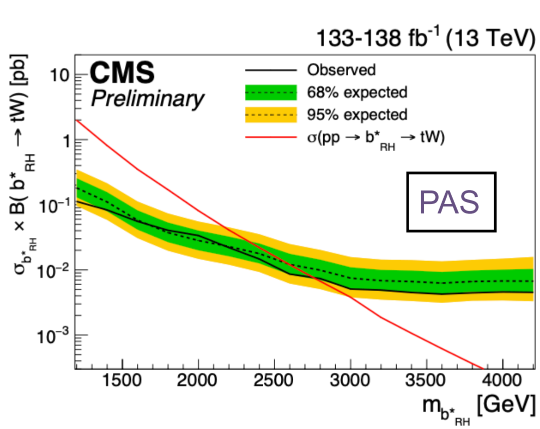
- Search b* on M_{tW} distribution, no excess observed
- Use asymptotic CLs method to set limit (combine tool)

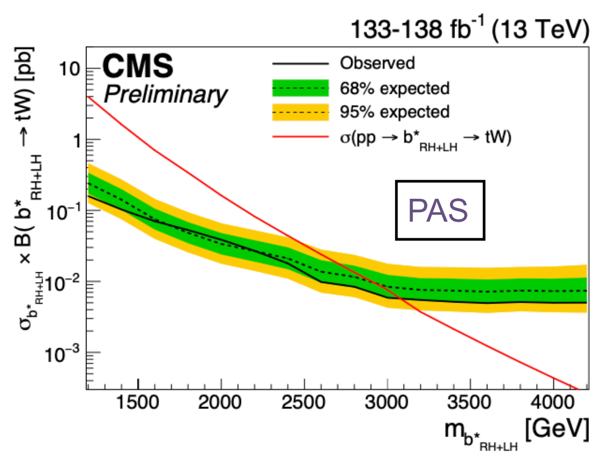
LH



RH



Vector -like



Limit (TeV)	LH	RH	VL
Observed	2.4	2.8	3.1
Expected	2.4	2.6	3.0

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Summary

- Study of b* --> tW --> (lvb) qq analysis with FullRunII data

  - $t\bar{t}$ background dominated, constrained by simultaneous fit with SRs + dedicated $t\bar{t}$ CR.
  - QCD background shape and normalization estimated from data driven method.
  - Observed exclude LH/RH/vector-like b* bellow 2.4/2.8/3.1 TeV

With more data and high center of mass energy,
more parameter space of excited bottom quark will be explored!

Back up

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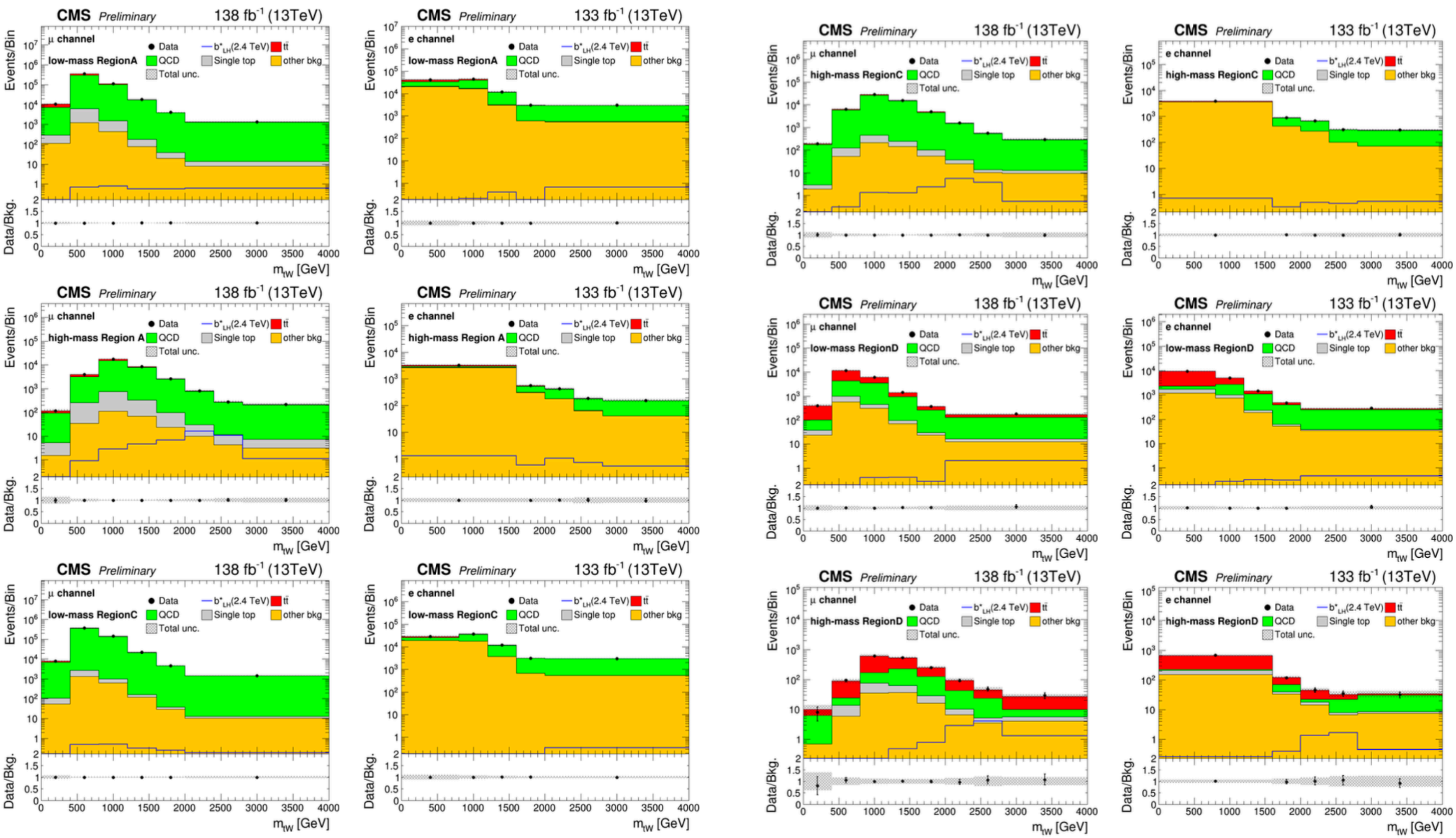
Post-fit distribution -QCD CRs



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Post-fit distribution-TT CR