中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

Search for single T production in T→tZ(νν) decay mode

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on behalf of the CMS Collaboration

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Introduction

Standard Model

Fermions： quarks, leptons

Mass: Yukawa coupling to the Higgs

Hierarchy problem

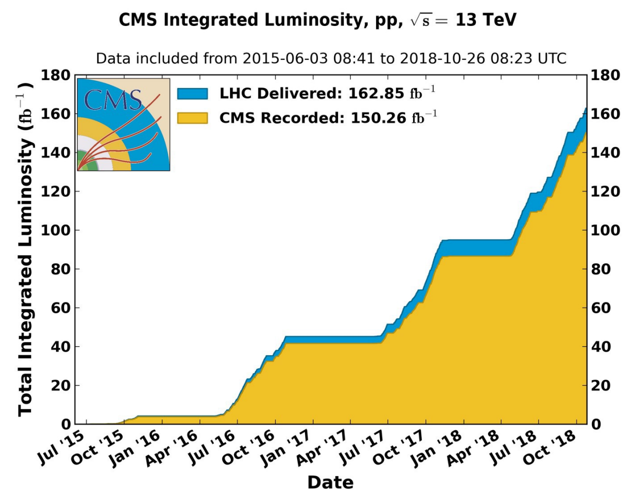
little Higgs, composite Higgs models

Fermions： Vector-like quarks

non-Yukawa coupling terms

Don’t excluded by precision SM measurements

- VLQs: hypothetical new spin -1/2 charge 2/3 particle
- VLQs offer a potential solution to the hierarchy problem of standard model
- Using all the Run2 data to search for VLQs



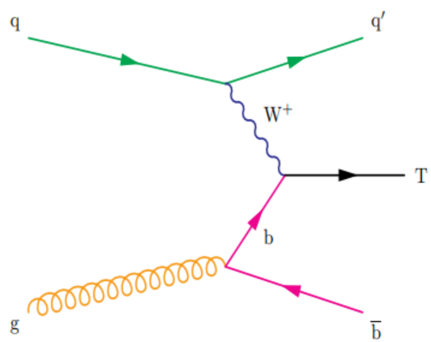
LHC

High Energy(13TeV),

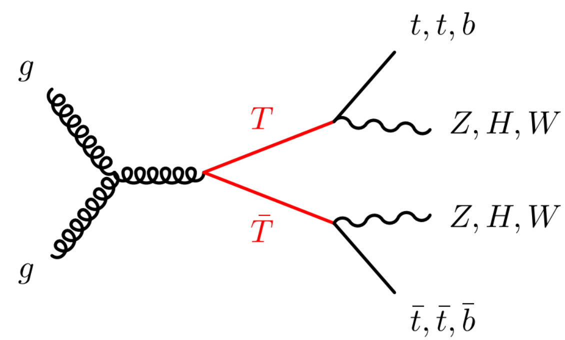
High luminosity(~150fb^{-1})

VLQs production and decay model

Single production

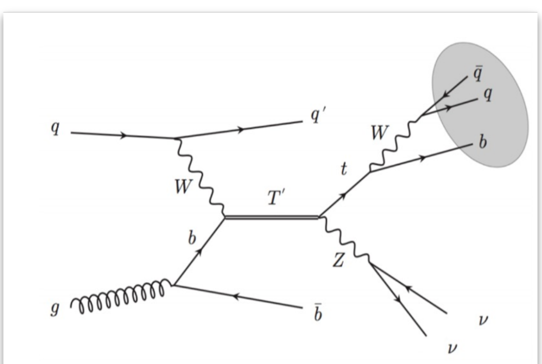


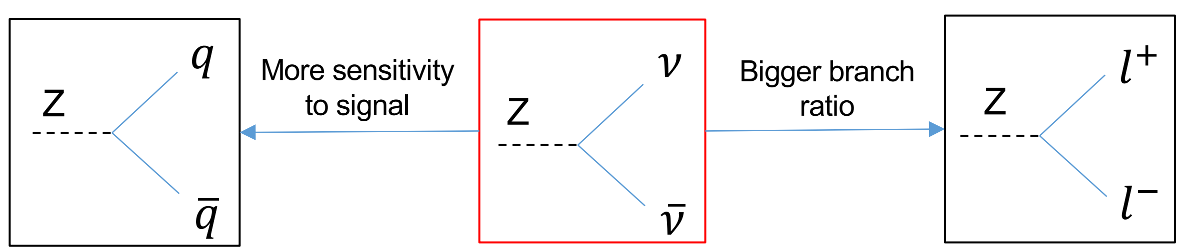
Pair production



Single production of VLQs have larger phase space above 1TeV

- Three different decay channels into SM particles by the assumption of the model: bW, tH, tZ
- We will search for single produced VLQ T' decaying in top quark + Z boson in dineutrino channel



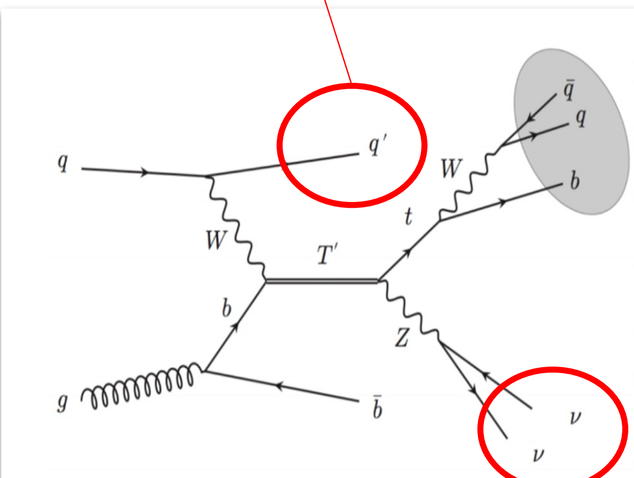


Analysis strategy

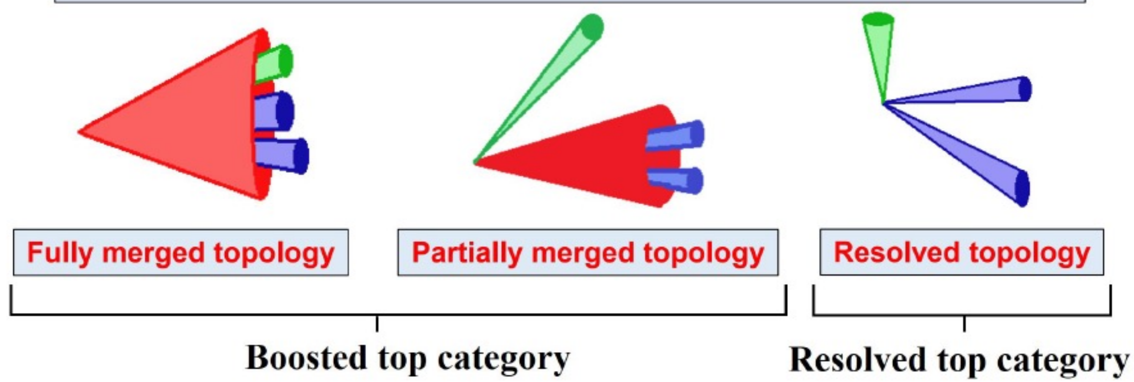
➢ Forward jets: define two categories with enhanced sensitivity
  - ✓ No forward jets
  - ✓ At least 1 forward jet

- The top quark identified in three different scenarios：

So We have six categories in each year



- **Three reconstruction algorithms** to have good sensitivity in all mass range
  - ✓ **Fully merged topology**: top candidate is a top-jet
  - ✓ **Partially merged topology**: top candidate given by one W-jet and one ak4 jet
  - ✓ **Resolved topology**: top candidate given by three ak4 jets



- Neutrinos are not detected in the experimental apparatus.
- T quark four-momentum cannot be reconstruction

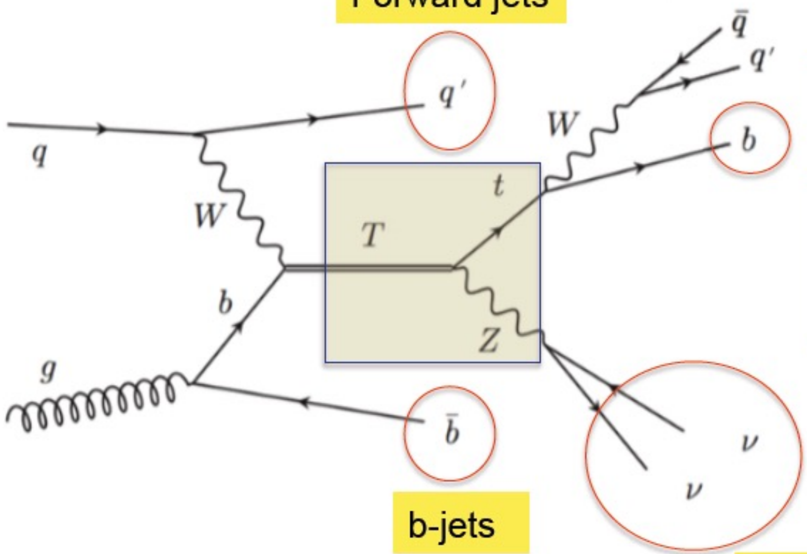
Final discriminating variable: transverse mass M_T between top and MET

$$M_T = \sqrt{2p_T^{top} \cdot p_T^{MET}\,(1 - cos\Delta\phi)}$$

Events reconstruction and Selection

In order to improve the sensitivity of the analysis, the following selection is applied:

Forward jets



b-jets

b-jets

Boosted category
1 merged W jet + 1 b-jet
1 merged top jet
Resolved category
2 AK4 jets + 1 b-jet

Angular separation between MET and jets min[$\Delta\phi$(MET, jets)] → $\Delta\Phi$(Jet,MET)>0.6

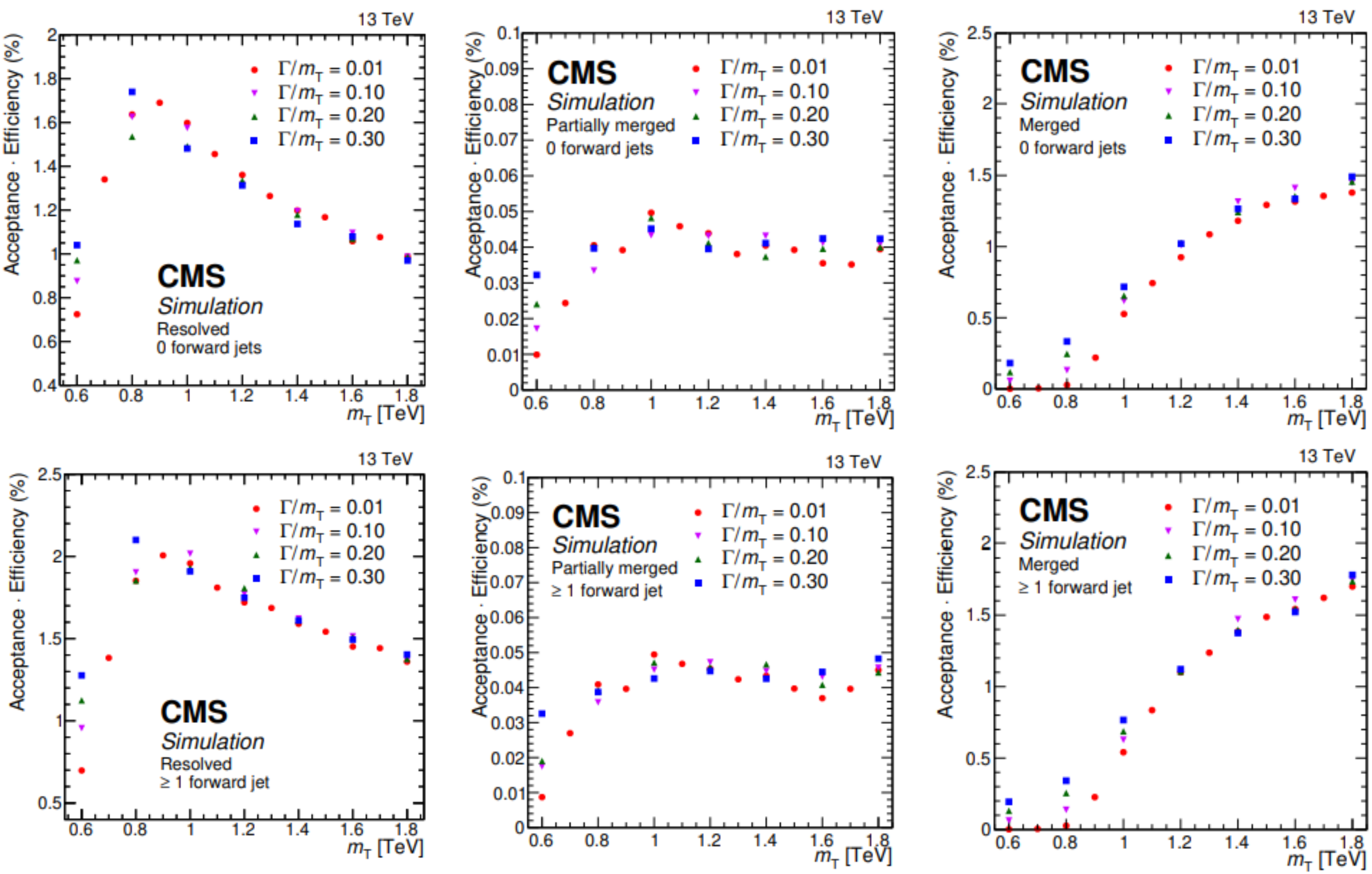
No final state leptons → Veto leptons

Large event MET → MET pt>200GeV

b-tagger	W-tagger	Top-tagger
CHS ak4 Jet	PUPPI AK8 Jet	PUPPI AK8 Jet
pt>30GeV	pt > 200GeV	pt > 200GeV
DeepCSV medium WP	65 < SD mass < 105 GeV	105 < SD mass < 220 GeV
	tau21DDT < 0.43	tau32 < 0.65

signal selection efficiency

- The signal selection efficiency for different categories list here:



Background Estimation

- Main Background: Z+jets, W+jets, ttbar
- Using Data-driven method to get correction factors from control region in data
- Control regions for the main backgrounds are defined as:

➢ Resolved category

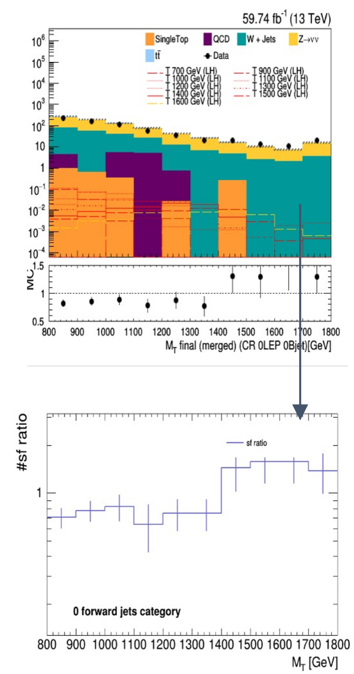
Variable	SR	Z+jets CR	W+jets CR	ttbar CR
lepton	veto	veto	>=1	>=1
Number of midum b jet	>=1	=0	=0	>=1

➢ Partially merged category

Variable	SR	ttbar CR
minΦ(MET,jet)	> 0.6	< 0.6

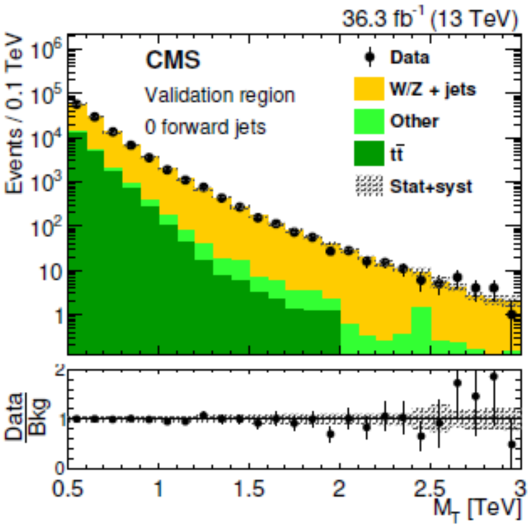
➢ Fully merged category

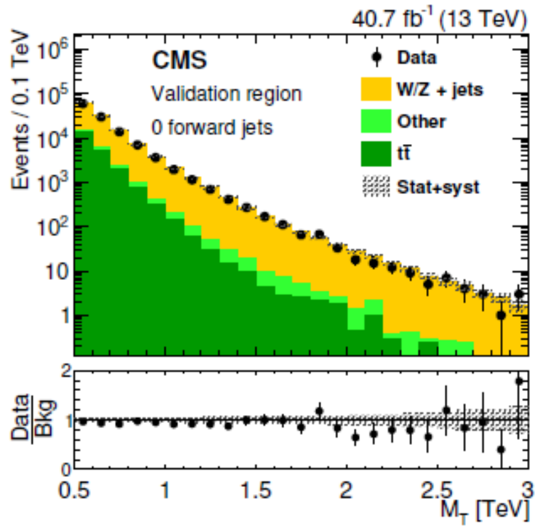
Variable	SR	W/Z+jets CR	ttbar CR
Leotpn	veto	veto	1 loose muon or electron
minΦ(MET,jet)	> 0.6	> 0.6	No cut
Top jet	1 b-subjet	0 b-subjet	1 b-subjet

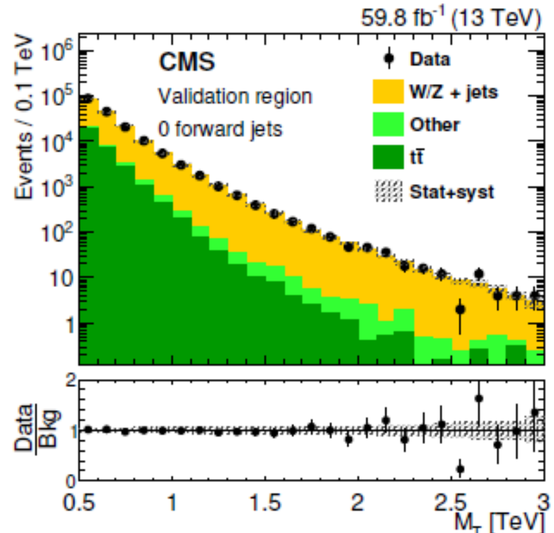


Background estimation test

FWD0

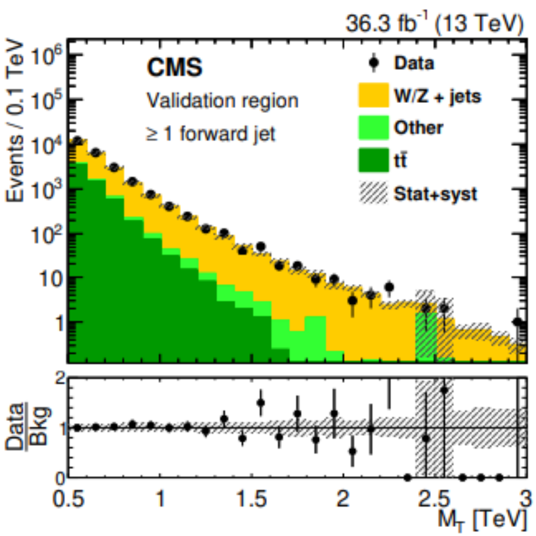


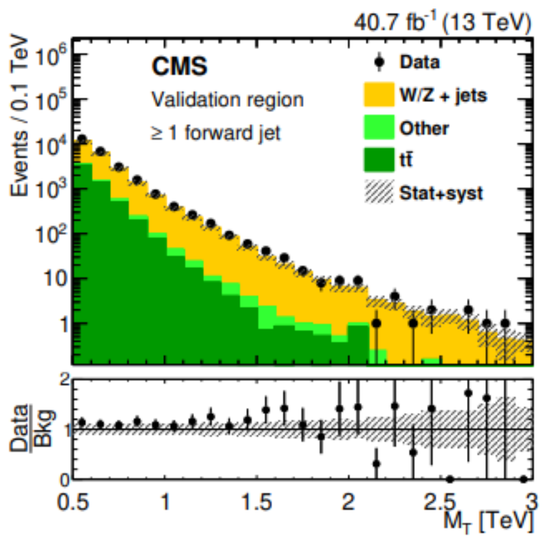


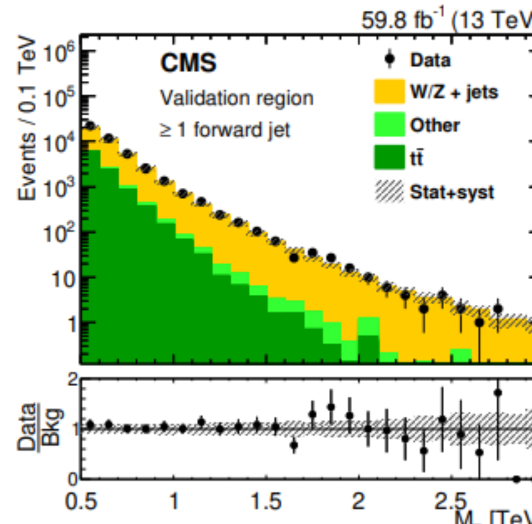


2016 2017 2018

FWD1



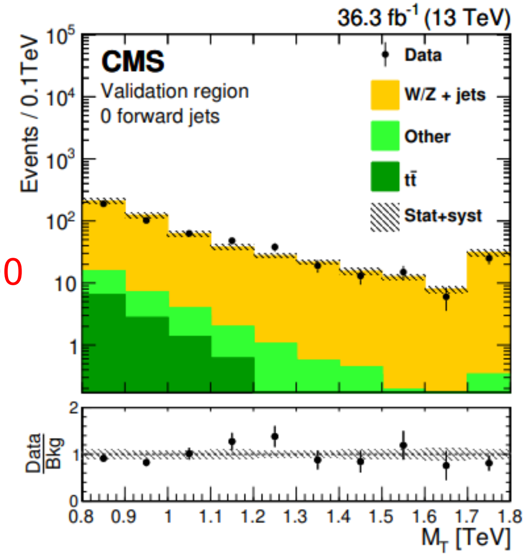


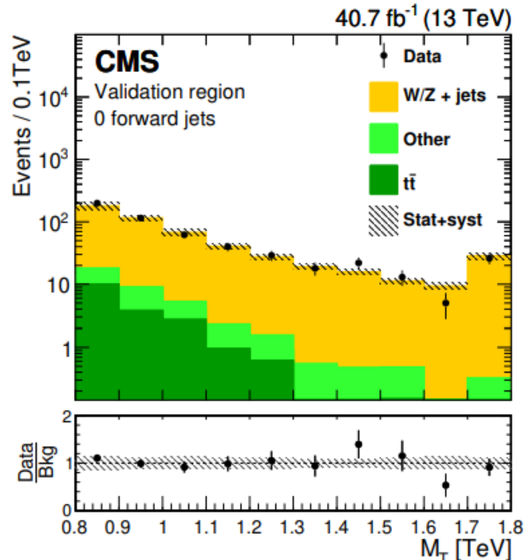


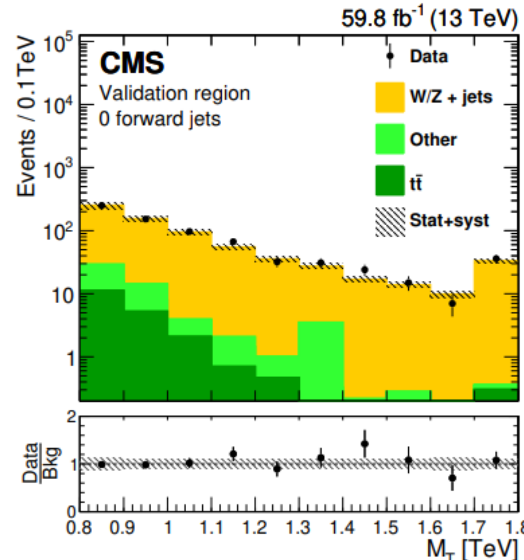
Comparison of data and the predicted background(resolved)

Background estimation test

FWD0

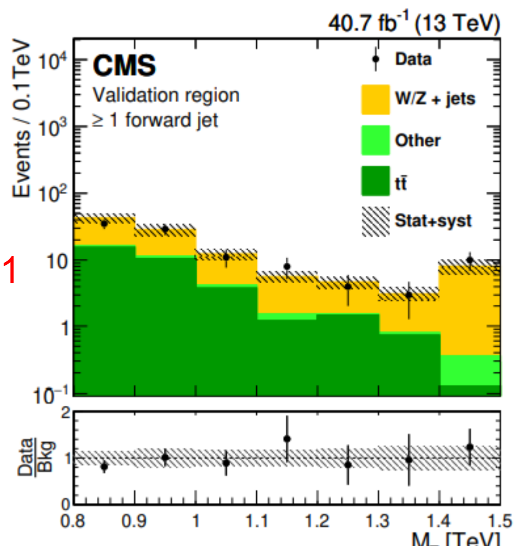


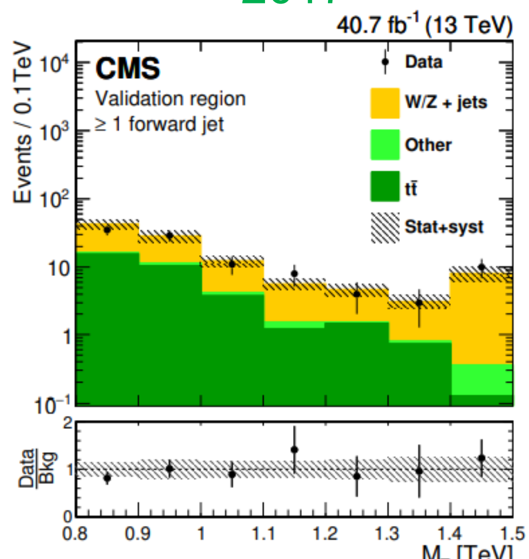


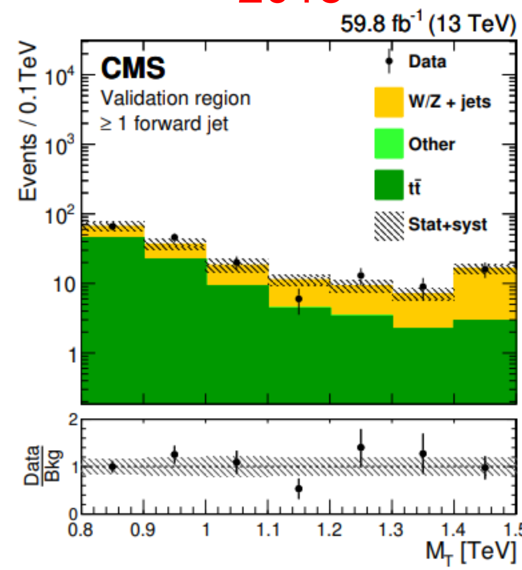


2016 2017 2018

FWD1







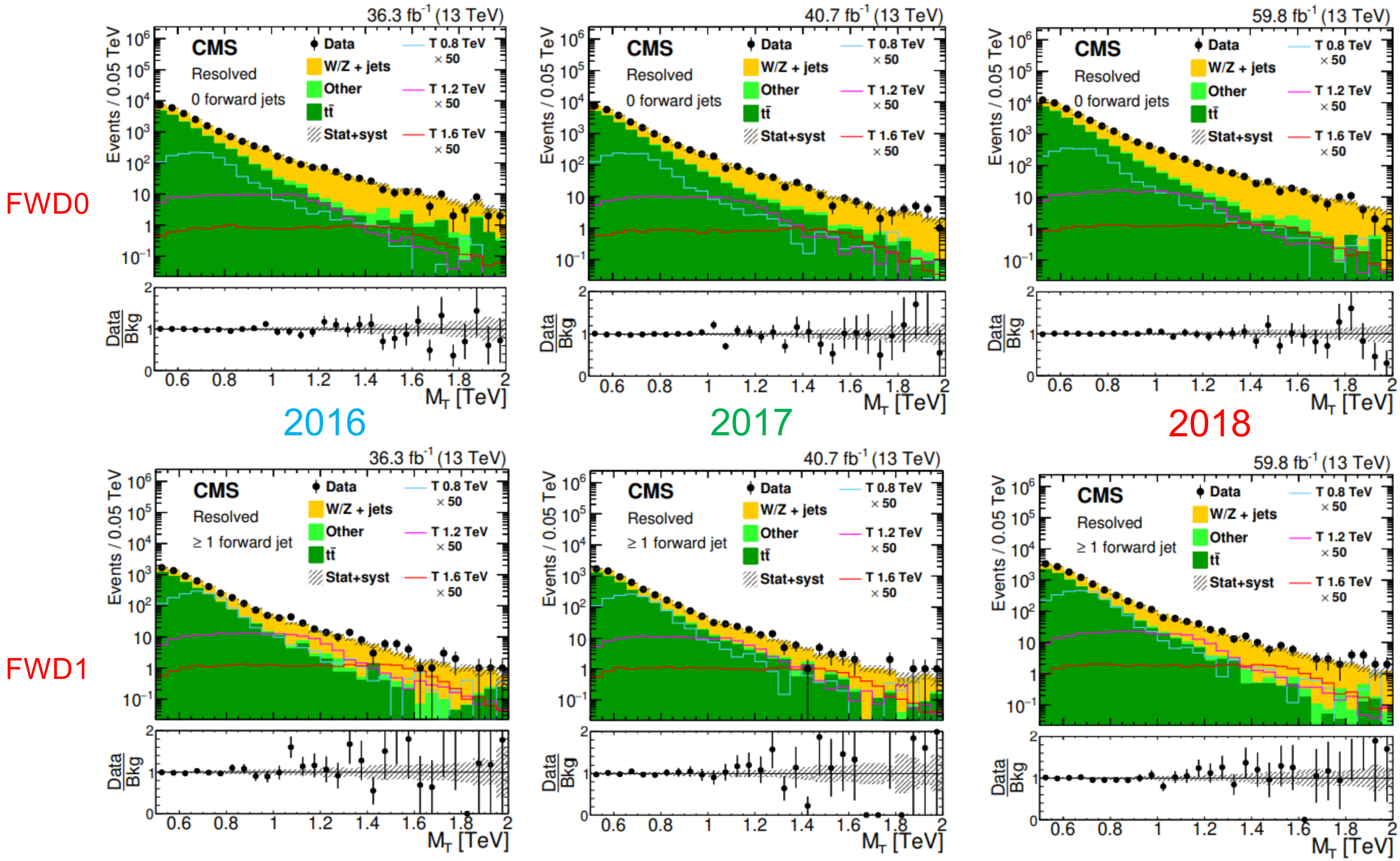
Comparison of data and the predicted background(merged)

Systematics

Source	Effect(%)	Type
Luminosity	1.8	rate
Pileup	0.2-3	rate
b-tagging	0.5-1.2	rate
Top tagging	9-10	rate, shape
W tagging	7-8	rate, shape
Trigger efficiency	1-3	rate, shape
Prefiring	0.2-3	rate, shape
JES	2-18	rate, shape
JER	2-5	rate, shape
PDF	1-5	rate
μ_F和μ_R	8-13	rate, shape
Background scale factors	5-30	rate, shape

The dominant systematics are: top tagging, W tagging, μ_R, μ_F, background SF

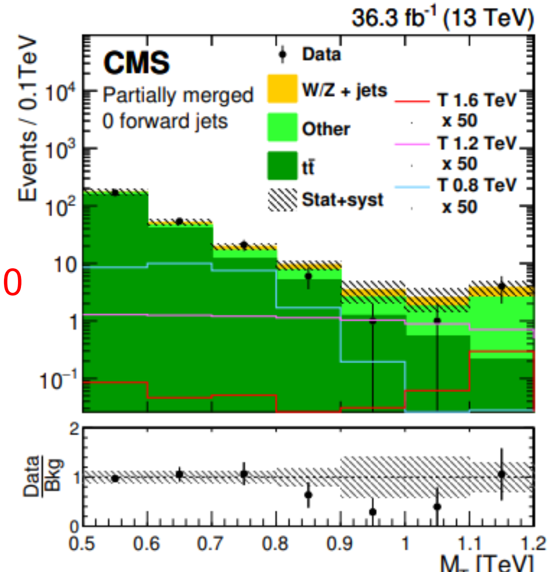
Results-Resolved topology

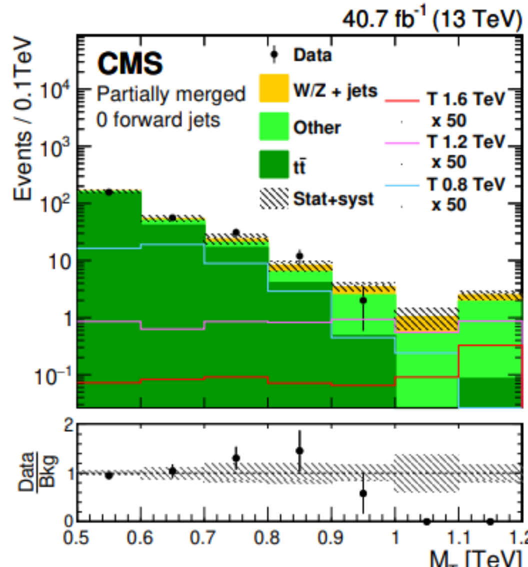


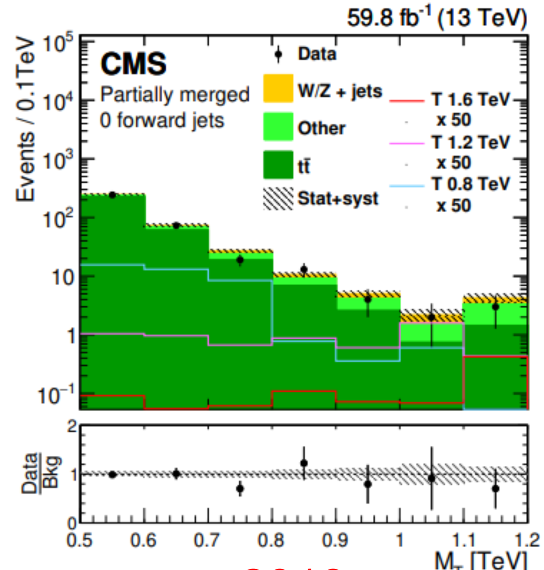
- Distribution of the transverse mass in the signal region
- All background processes are derived from the fit to data

Results – Partially merged topology

FWD0

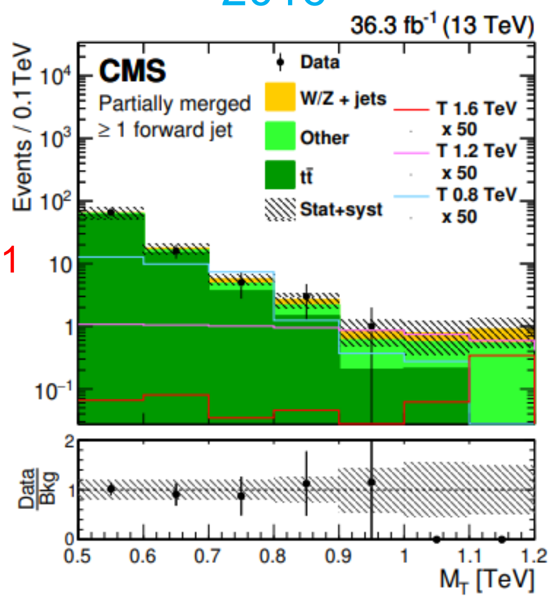


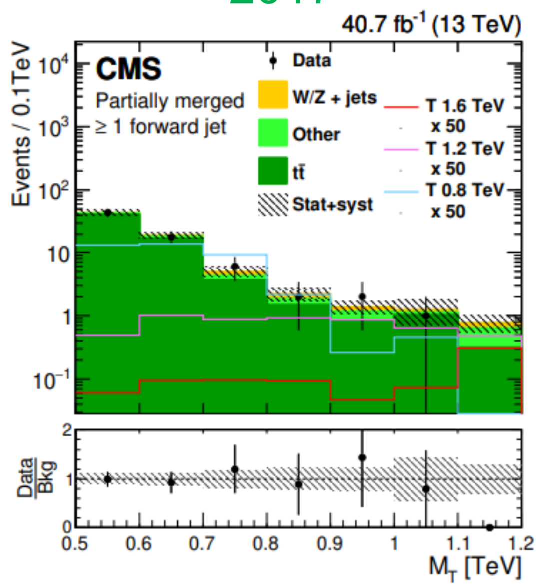


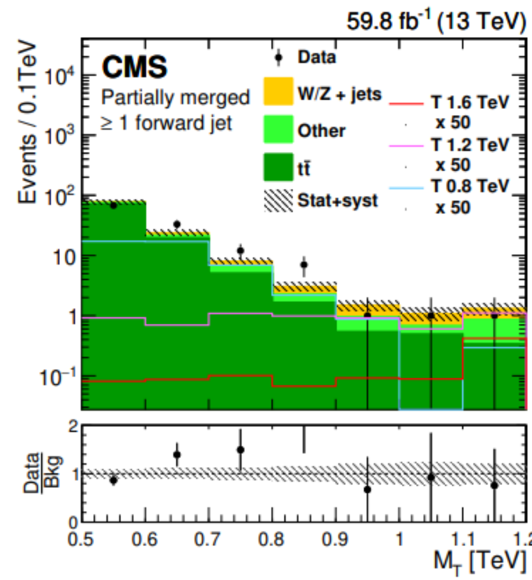


2016 2017 2018

FWD1

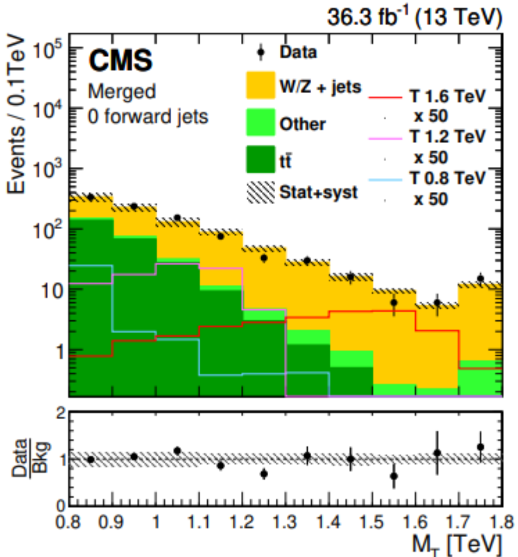


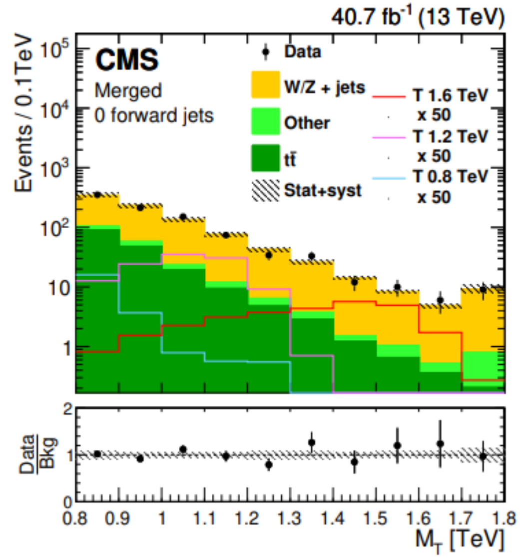


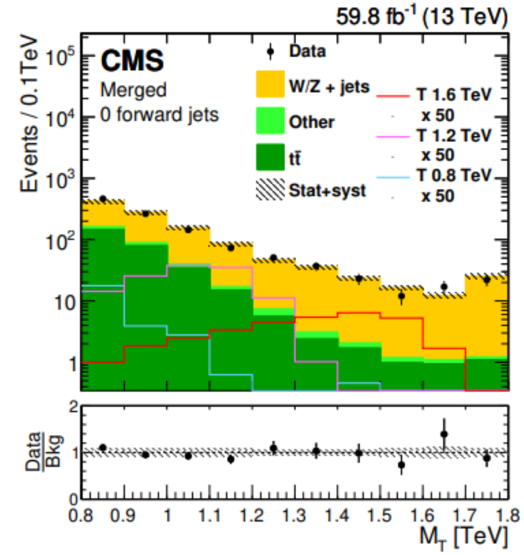


Results – Fully merged topology

FWD0

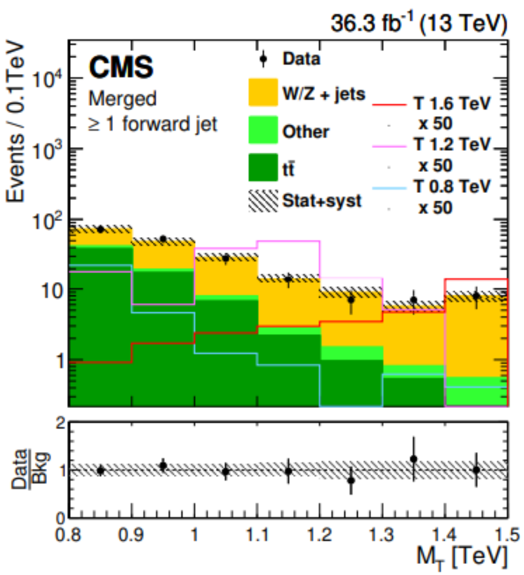


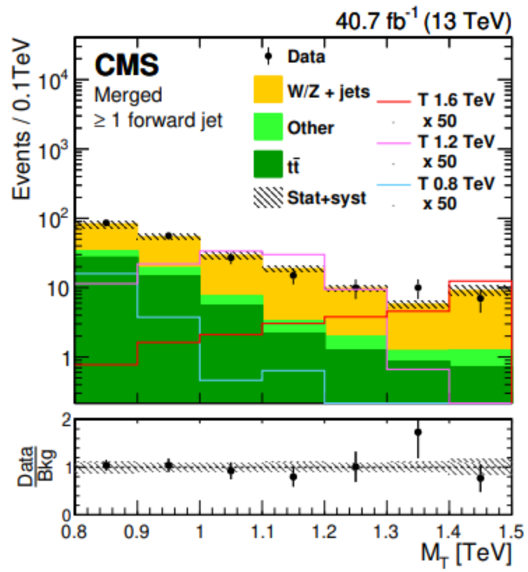


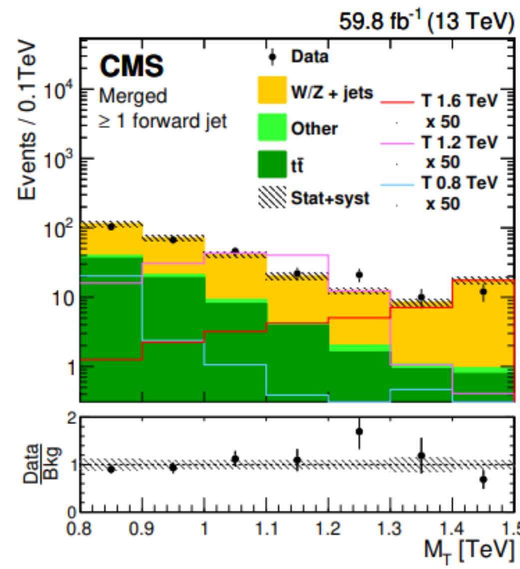


2016 2017 2018

FWD1

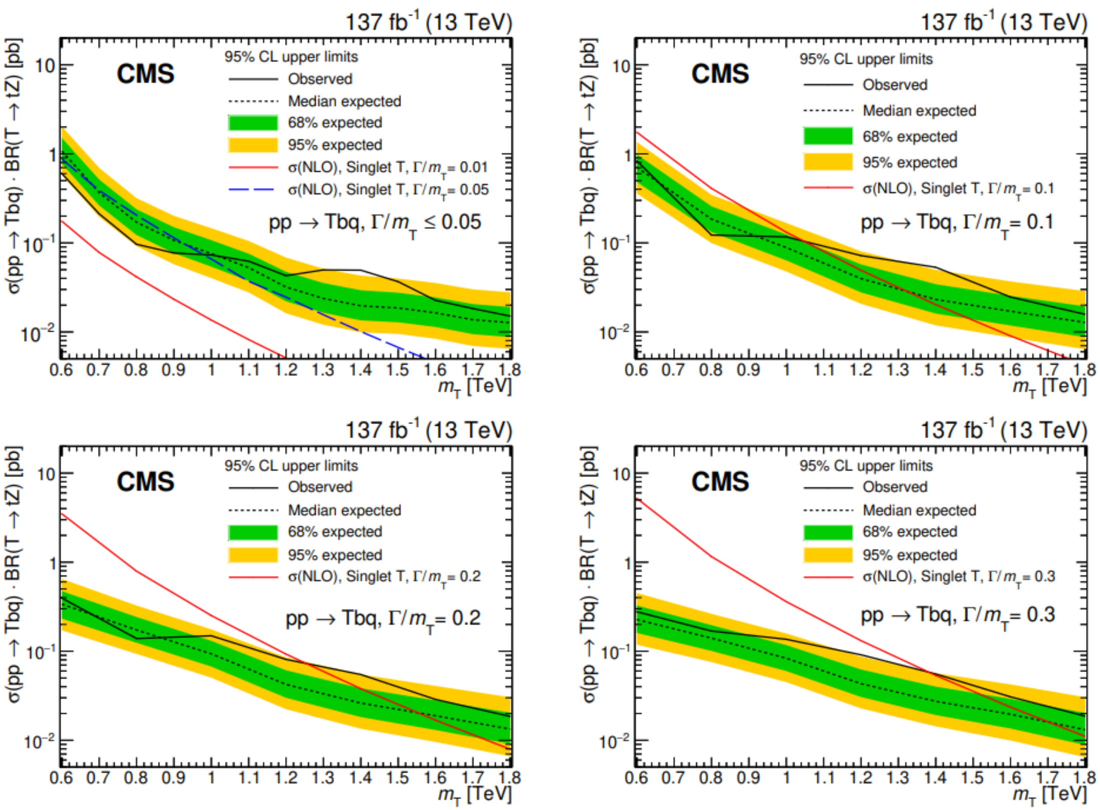


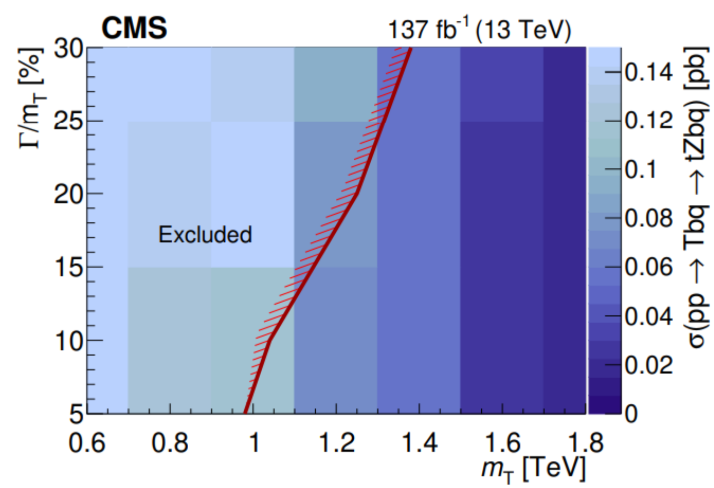




Results-limit

95% confidence level(CL) exclusion limits on the production cross section of T’ times BR





- Narrow width resonance: Cross section : greater than 602–15 fb. Masses: below 0.98TeV
- 10-30% width resonance : Cross section : greater than 836–16 fb Masses: below 1.4TeV
- 2D limit: The hashed red line indicates the boundary of the excluded region

Summary

- Study of single production of VLQ in tZ (top hadronic, Z to neutrinos) has been shown all Run2 data

	Cross section@95%CL	Mass@95%CL
Narrow width resonance	>602-15fb	<0.98TeV(5%)
10-30% width resonance	>836–16 fb	<1.4TeV(30%)

- This is first result of MET + jets final state in CMS
- This is the current best published result on single-VLQ T' in the tZ(vv) decay channel.
- This result has been published in JHEP

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backup

Scale factor

- To make things brief

$a1 = N_{Znunu}^{CS1}$ $b1 = N_{WJet}^{CS1}$ $c1 = N_{ttbar}^{CS1}$ $d1 = N_{otherBKG}^{CS1} - N_{data}^{CS1}$

$a2 = N_{Znunu}^{CS2}$ $b2 = N_{WJet}^{CS2}$ $c2 = N_{ttbar}^{CS2}$ $d2 = N_{otherBKG}^{CS2} - N_{data}^{CS2}$

$a3 = N_{Znunu}^{CS3}$ $b3 = N_{WJet}^{CS3}$ $c3 = N_{ttbar}^{CS3}$ $d3 = N_{otherBKG}^{CS3} - N_{data}^{CS3}$

$$SF1 = -\frac{b3*c2*d1 - b2*c3*d1 - b3*c1*d2 + b1*c3*d2 + b2*c1*d3 - b1*c2*d3}{a3*b2*c1 - a2*b3*c1 - a3*b1*c2 + a1*b3*c2 + a2*b1*c3 - a1*b2*c3}$$

$$SF2 = -\frac{-a3*c2*d1 + a2*c3*d1 + a3*c1*d2 - a1*c3*d2 - a2*c1*d3 + a1*c2*d3}{a3*b2*c1 - a2*b3*c1 - a3*b1*c2 + a1*b3*c2 + a2*b1*c3 - a1*b2*c3}$$

$$SF3 = -\frac{a3*b2*d1 - a2*b3*d1 - a3*b1*d2 + a1*b3*d2 + a2*b1*d3 - a1*b2*d3}{a3*b2*c1 - a2*b3*c1 - a3*b1*c2 + a1*b3*c2 + a2*b1*c3 - a1*b2*c3}$$

- We use this three formula to calculate the SFs bin by bin in 2D bins of HT and MET pt.
- If you use the error propagation formula, you can calculate the error of SFs in each bin(the formula is here)

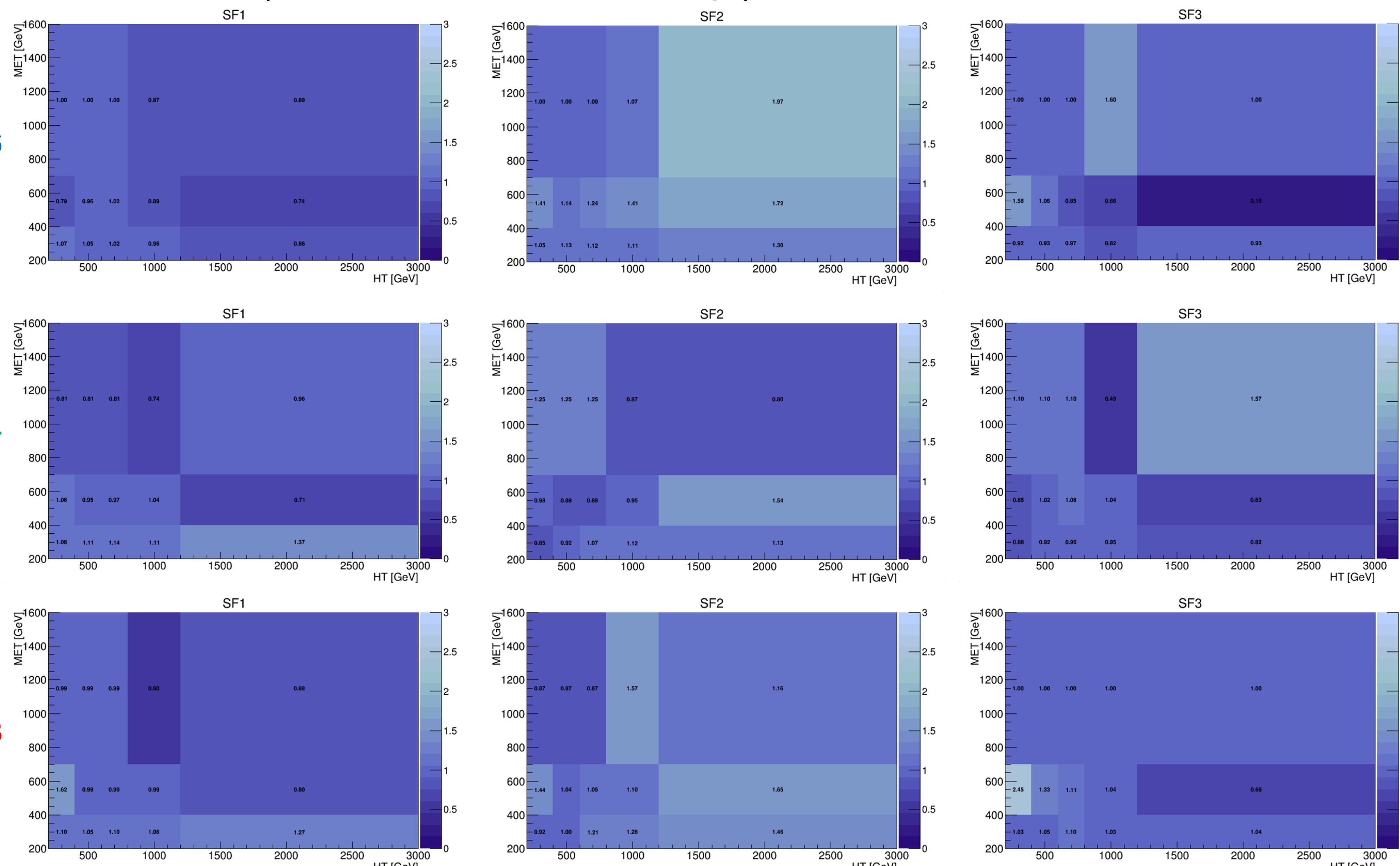
Scale factor

scale factor(in 2D bins of HT and MET pt)

2016

2017

2018



ZToNuNu WToLNu ttbar

QCD rejection: minDPhi

Min-dphi:

- Minimum angle between MET and AK4 jets

→ Useful to discriminate against QCD

→ Can help defining control/signal regions

Cut at min $\Delta\varphi_{MET,jets}$ > 0.6

- Reduces QCD, enriches with ZJets + vv;

[signal you see at low mindphi are semi-leptonic top decays]