Search for Supersymmetry with a compressed mass spectrum in VBF topology with 1-lepton final states in pp collisions at $\sqrt{s}$ = 13 TeV with CMS

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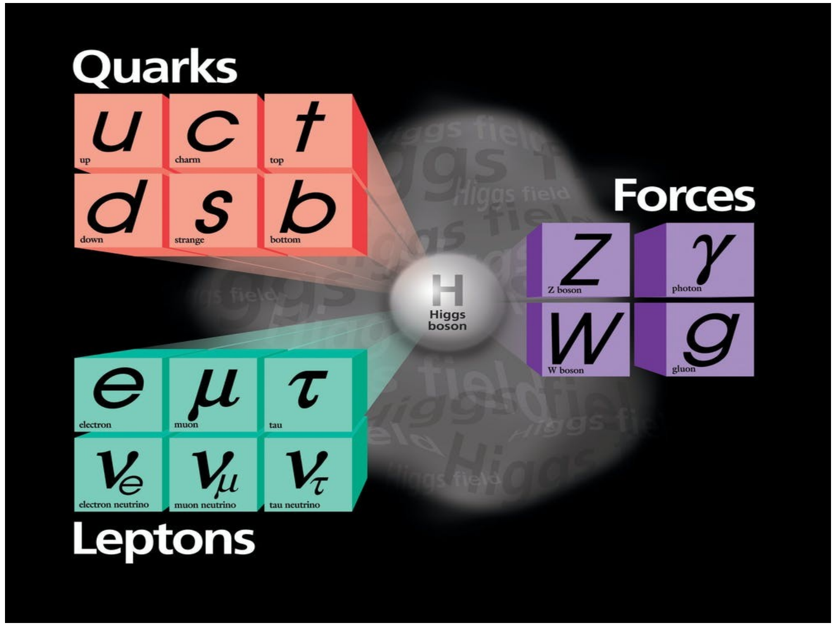
Outline

- Introduction
- Experimental setup
- Event selections
- Background estimation
- Signal Region predictions
- Summary

Introduction

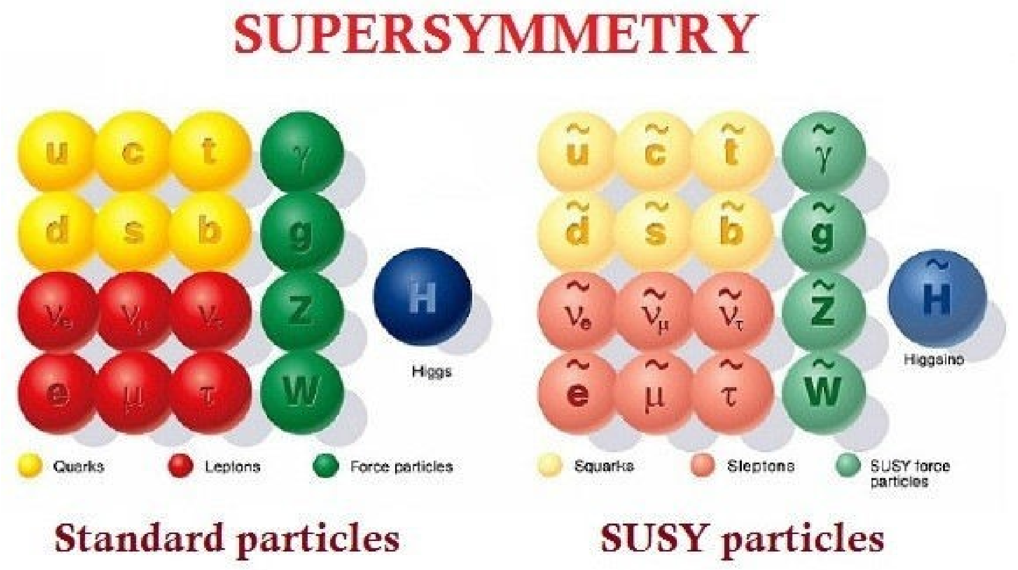
- Standard Model (SM) is a theory of fundamental particles and their interactions.
- The fundamental particles are divided into fermions (6 leptons and 6 quarks) and bosons.
- Although it explains many experimental observations well still it has some limitations such as existence of dark matter, matter-antimatter asymmetry, hierarchy problem, neutrino masses, etc.
- To answer such questions many extensions beyond standard model have evolved.
- One of such possible extension of SM: **Supersymmetry**

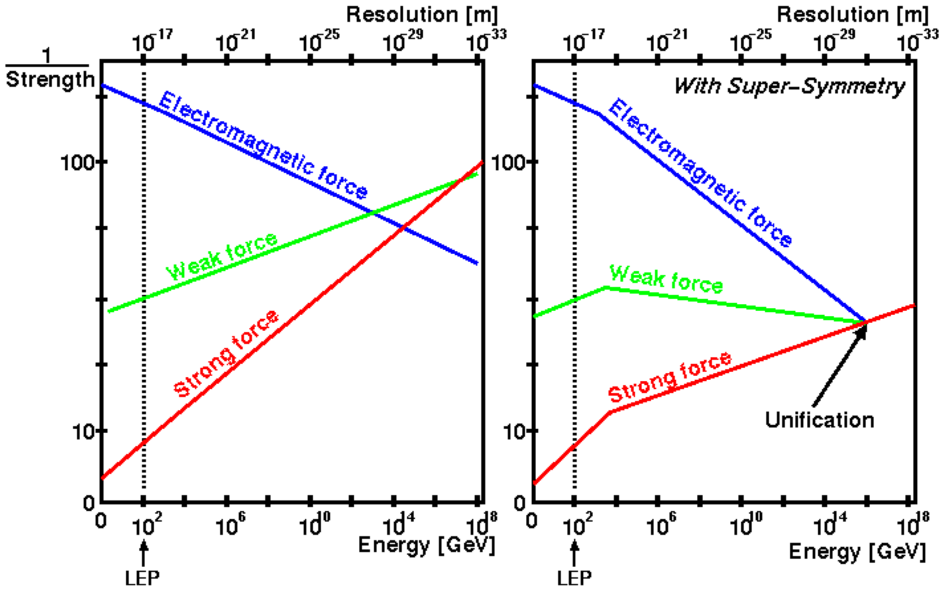


Supersymmetry: Motivation

- Supersymmetry relates every SM particle to its super partner: called **SUSY particle**
- It has a great potential for solving problems of the SM
  - provides the solution to hierarchy problem
  - unification of three forces
  - In R-parity conserving SUSY models, the lightest neutralino $\tilde{\chi}_1^0$ is a dark matter (DM) candidate

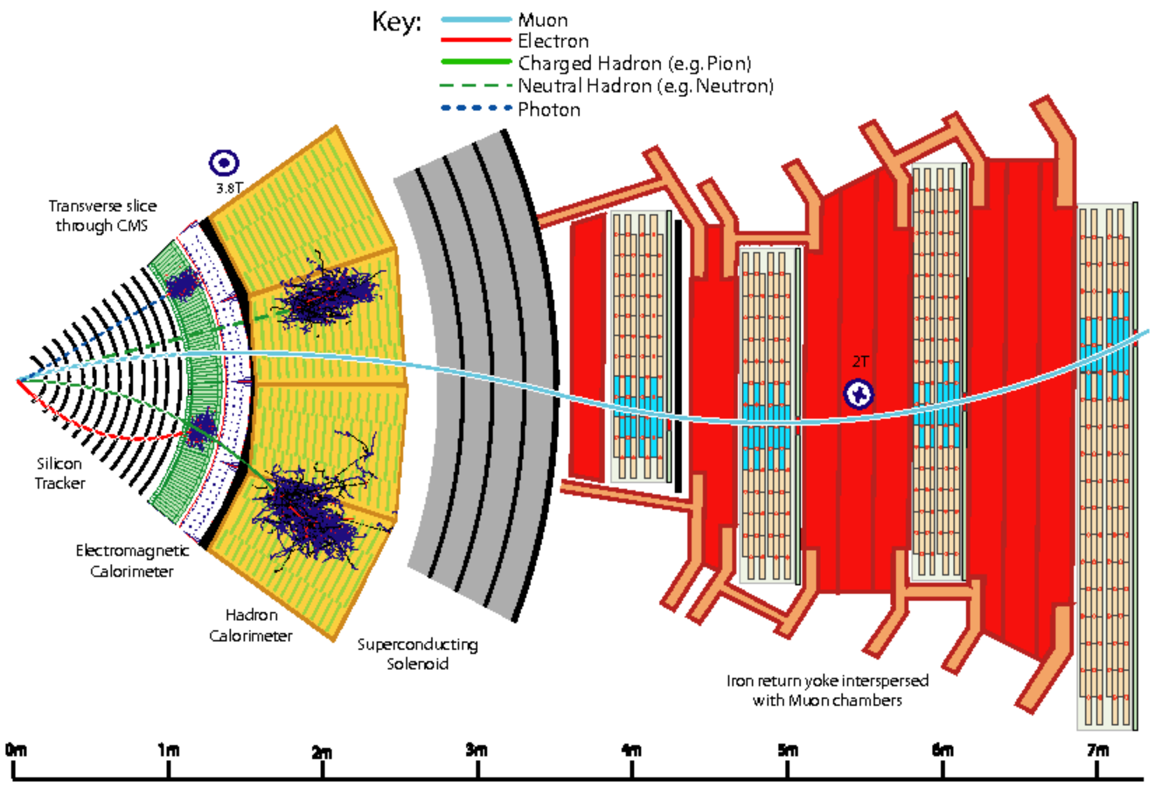
If SUSY is a correct theory, the production and detection of SUSY particles is possible at the Large Hadron Collider (LHC).





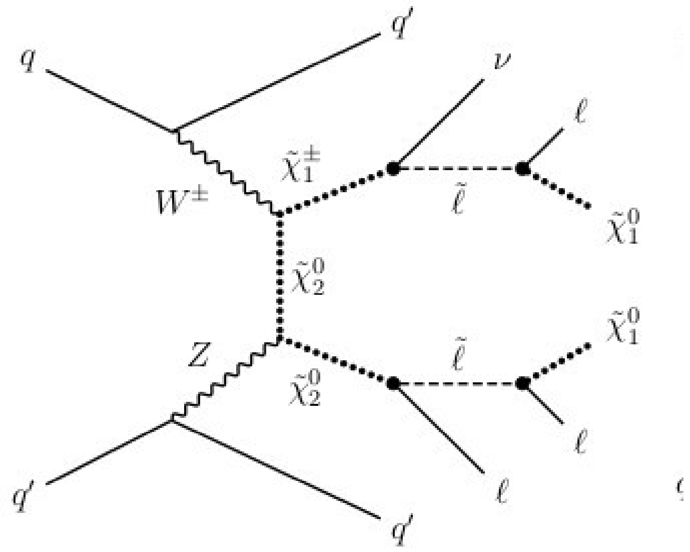
Experimental Setup: CMS Detector

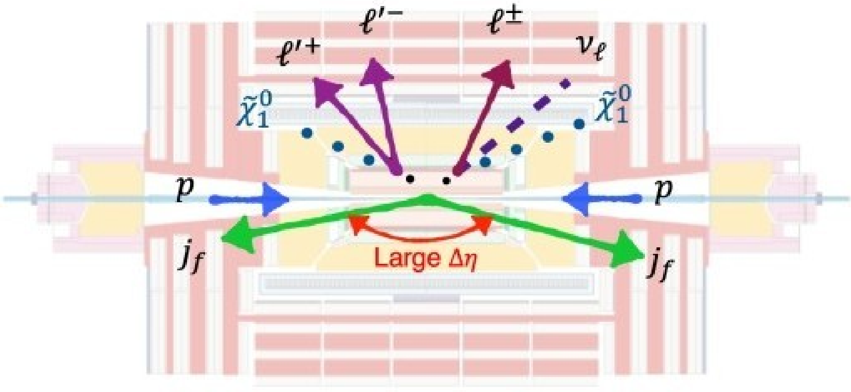
- One of the two general purpose particle physics detectors at the LHC.
- Designed for the precision measurements of the SM processes as well as for the study of the new sectors of physics beyond SM (BSM).
- Sub-detectors inside solenoid magnet: Tracker, Electromagnetic Calorimeter (ECAL), Hadron Calorimeter (HCAL) and Hadron Outer Calorimeter (HO) and Muon system outside the solenoid magnet.



Experimental signatures of signal process

- Compressed mass scenarios are challenging because of the reconstruction of soft decay products
- **Electroweak vector boson fusion (VBF)** provides excellent sensitivity to these scenarios:
  - distinctive signature ⇒ good discrimination power against background,
  - it provides a boost on the particles produced ⇒ higher signal acceptance.

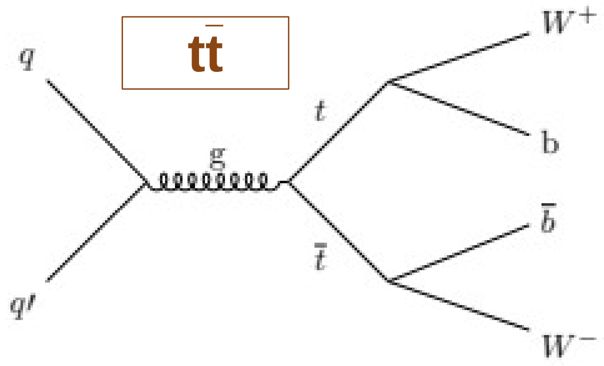




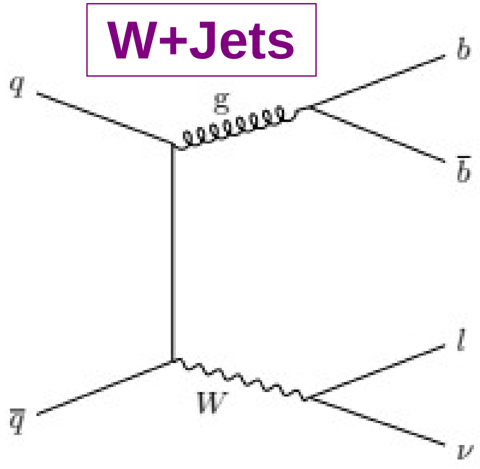
- **Process of interest:** pure electroweak VBF pp → $\tilde{\chi}_1^{\pm}\ \tilde{\chi}_j^{0}$ where only **1-lepton** is reconstructed. (Signals with different lepton multiplicities are explored separately)

SM background processes

Major background processes:



tt̄ : b-jets resulting from the top decay. It produces real jets and E_T^{miss} from neutrinos resulting from leptonic decays of the W



W + jets: W decaying leptonically (W → μ/e/τ + ν) and two jets can fake VBF jets

Other background processes:

Z+Jets, QCD, Diboson .....

Event Selections

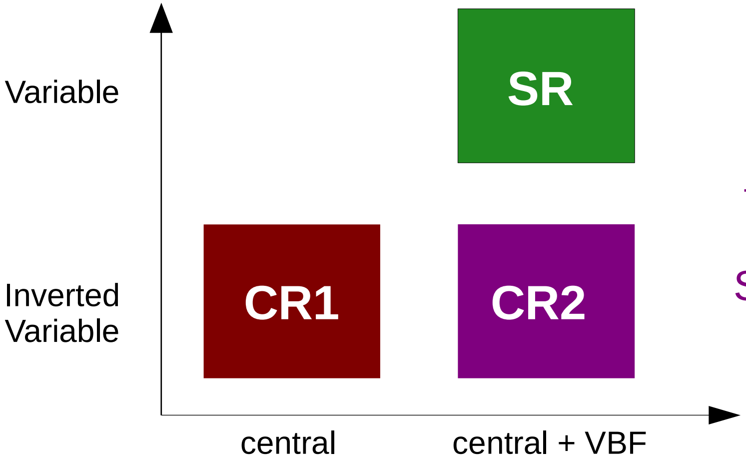
Selection type	Object	Selection cuts			
Central	Trigger	HLT_PFMETNoMu120_PFMHTNoMu120_IDTight			
	Lepton	Flavor	μ	e	τ_h
		ID	Tight	Medium	Tight
		Isolation	0.15	0.15	Tight
		p_T [GeV]	[3, 40]	[5, 40]	[20, 70]
		$m_T(l, p_T^{miss})$	>110 GeV		
		$\|\eta\|$	< 2.1		
	Lepton vetoes	p_T [GeV]	> 3	> 5	> 20
		$\|\eta\|$	< 2.5		
	MET	250 GeV			
	b-jet	N(bjet) = 0, p_T > 30 GeV, $\|\eta\| < 2.4$, DeepCSV			
VBF	Jet	N(j) ≥ 2, $p_T(j)$ > 60 GeV, $\|\eta\| < 5.0$,			
	DiJet comb.	$\eta(j_1) \times \eta(j_2) < 0$, $\Delta\eta(j_1, j_2) > 3.8$, $m(j_1, j_2) > 1000$ GeV			

General background estimation strategy

- The dominant backgrounds are estimated using the data-driven methods.
- The predicted background yield in signal region:

$$N_{predicted} = N_{MC}(\text{SR cuts}) \,.\, SF_{central} \,.\, SF_{VBF}$$

where, N_{MC}(SR cuts) → yield by MC simulation, $SF_{central}$ → scale factor obtained from central selections and SF_{VBF} → scale factor obtained from VBF selections.



Central selections (CR1):

$$SF^{central}_{process} = \frac{N^{central}_{Data} - N^{central}_{non\,process,\,MC}}{N^{central}_{process,\,MC}}$$

Central + VBF selections (CR2):

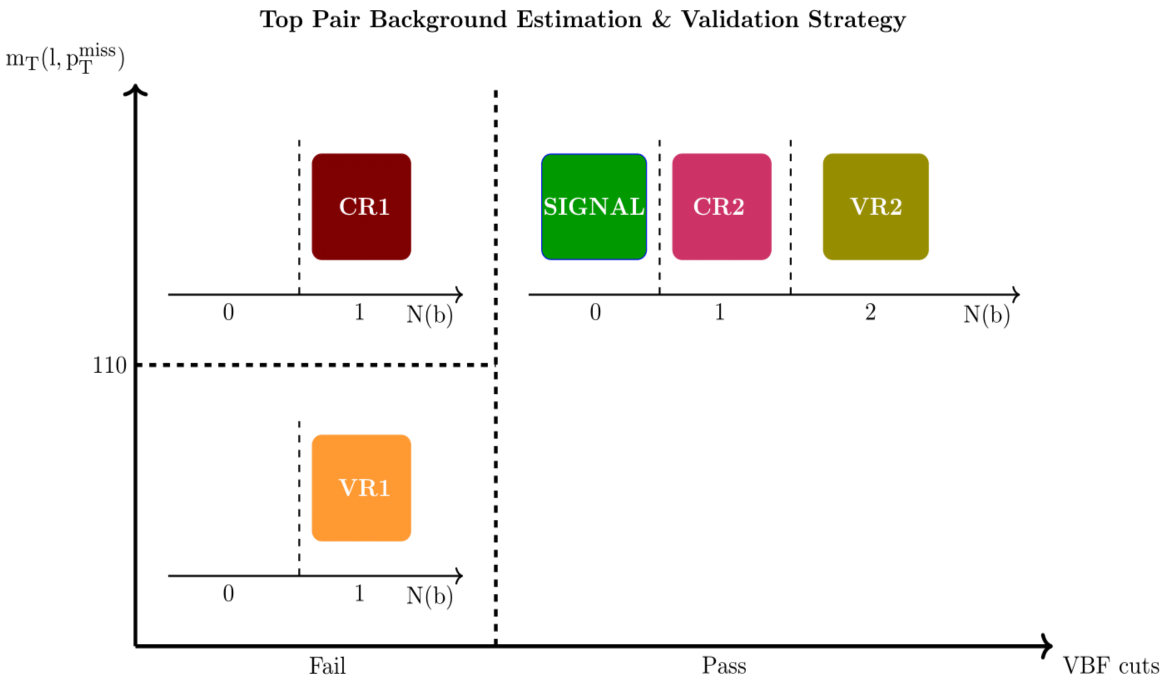
$$SF^{central+VBF}_{process} = \frac{N^{central+VBF}_{Data} - N^{central+VBF}_{nonprocess,\,MC}}{N^{central+VBF}_{process,\,MC}}$$

$$SF^{VBF}_{process} = \frac{SF^{central+VBF}_{process}}{SF^{central}_{process}}$$

- Minor backgrounds are obtained directly from MC.

$t\bar{t}$ background estimation

- **CR1:** study data-to-MC correction factor for central selections
- **CR2:** study data-to-MC correction factor for VBF selections
- **VR1:** validate the scale factor obtained for central selections
- **VR2:** validate the scale factor obtained for VBF selections



Expected $t\bar{t}$ event yield in signal region (SR):

$$N_{t\bar{t}}^{expected} = N_{t\bar{t}}^{MC} . SF_{t\bar{t}}^{central} . SF_{t\bar{t}}^{VBF}$$

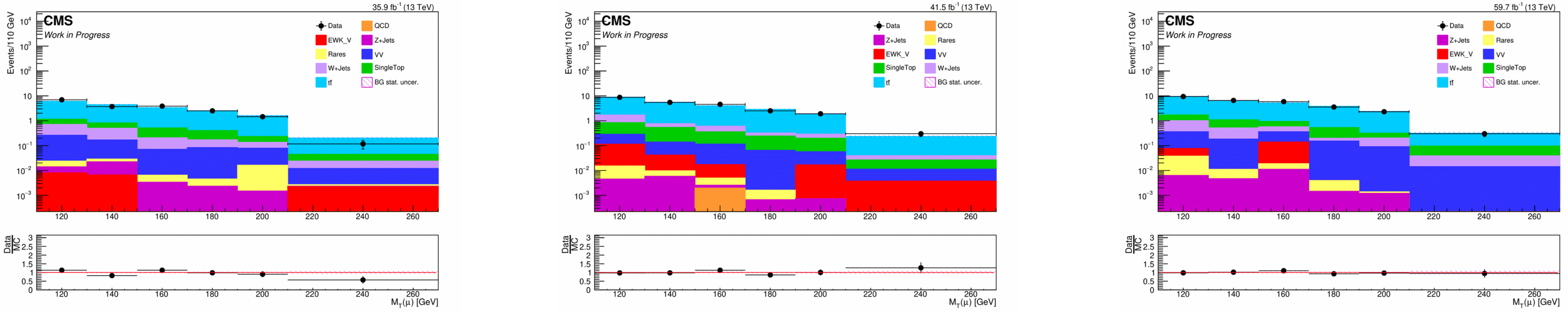
$$SF_{t\bar{t}}^{central} = SF^{CR1} \qquad SF_{t\bar{t}}^{VBF} = \frac{SF^{CR2}}{SF^{CR1}}$$

Notes:

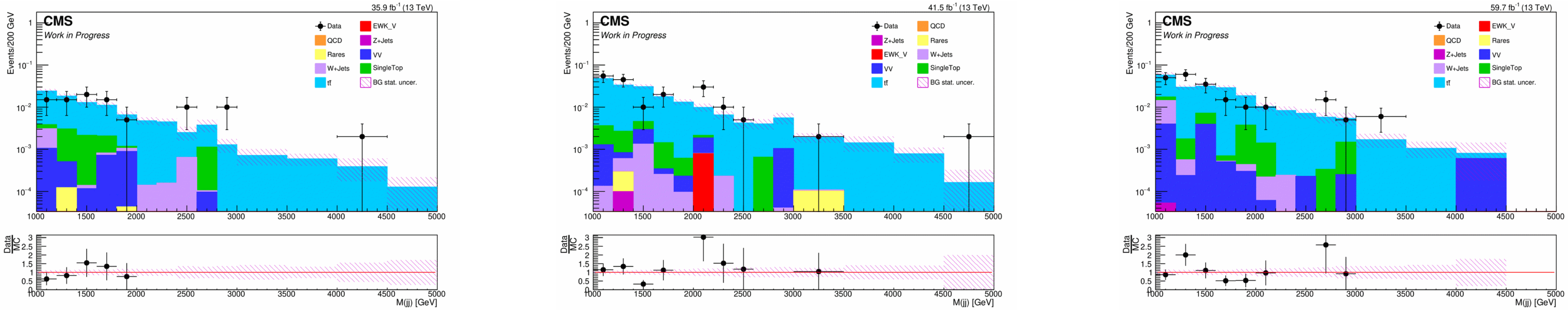
- Scale factors for the central and VBF selections are consistent across various years of LHC data taking.
- Scale factors are validated using VRs

$t\bar{t}$ background: Control region studies

Control Region 1 (CR1): Overall agreement between corrected background yields and the observed data

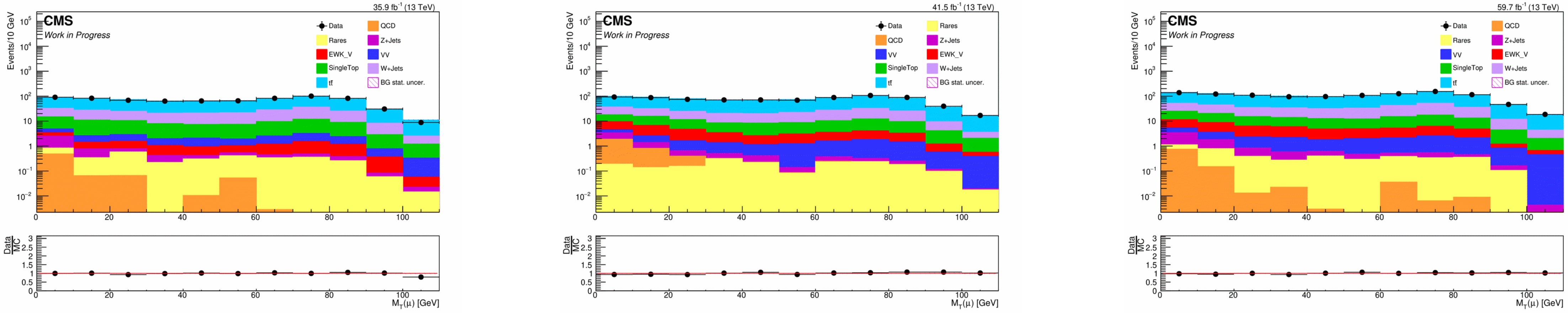


Control Region 2 (CR2): Overall agreement between corrected background yields and the observed data

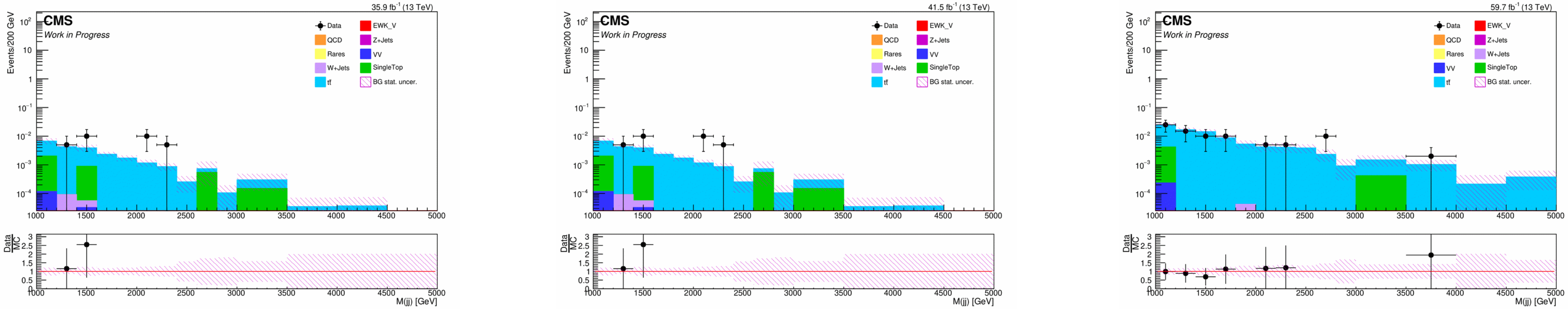


$t\bar{t}$ background: Validation region studies

Validation Region 1 (VR1): Overall agreement between corrected background yields and the observed data

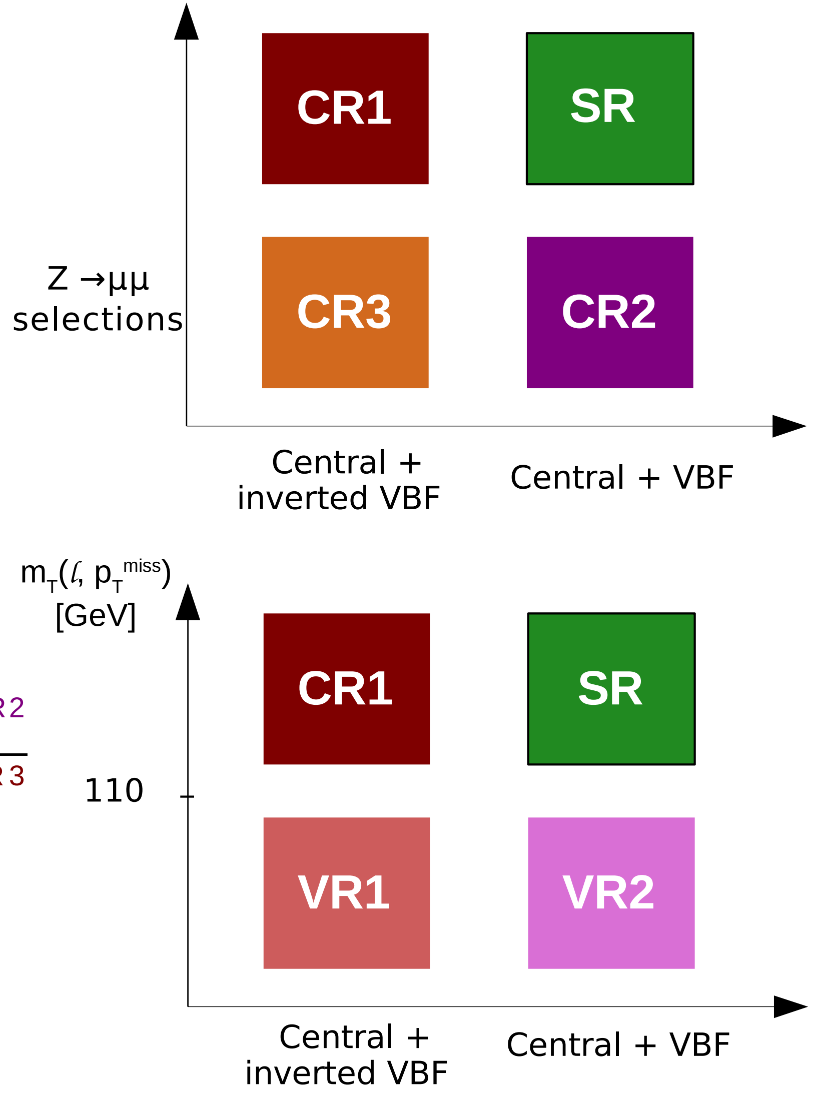


Validation Region 2 (VR2): Overall agreement between corrected background yields and the observed data



W+Jets background estimation

- **CR1:** study data-to-MC correction factor for central selections
- **CR3:** validate the correct calibration of the dimuon identification efficiency
- **CR2:** study data-to-MC correction factor for VBF selections
- **VR1:** validate the scale factor obtained for central selections
- **VR2:** validate the scale factor obtained for VBF selections



Expected W+jets event yield in signal region (SR):

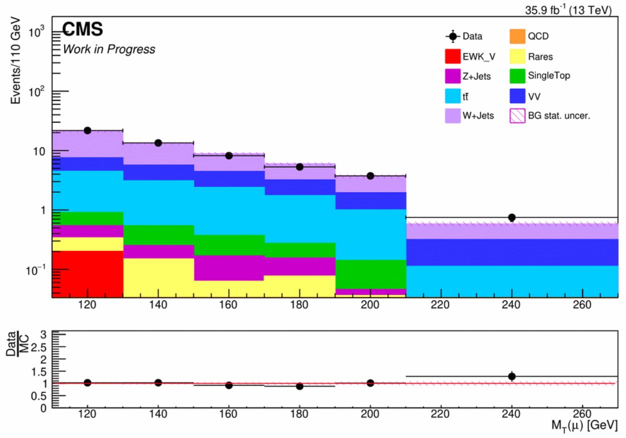
$$N^{expected}_{W+jets} = N^{MC}_{W+jets} \cdot SF^{central}_{W+jets} \cdot SF^{VBF}_{W+jets} \qquad SF^{central}_{W+jets} = SF^{CR1} \qquad SF^{VBF}_{W+jets} = \frac{SF^{CR2}}{SF^{CR3}}$$

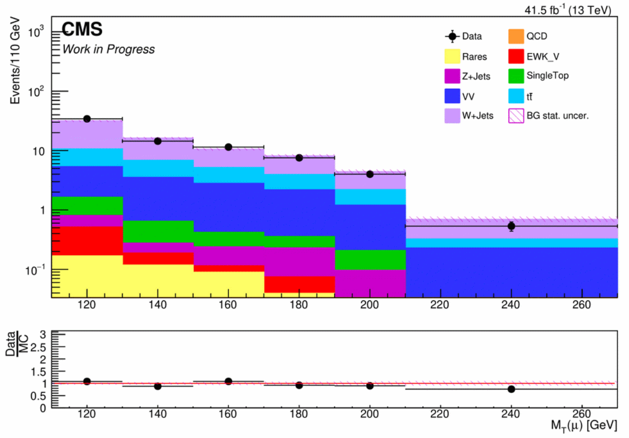
Notes:

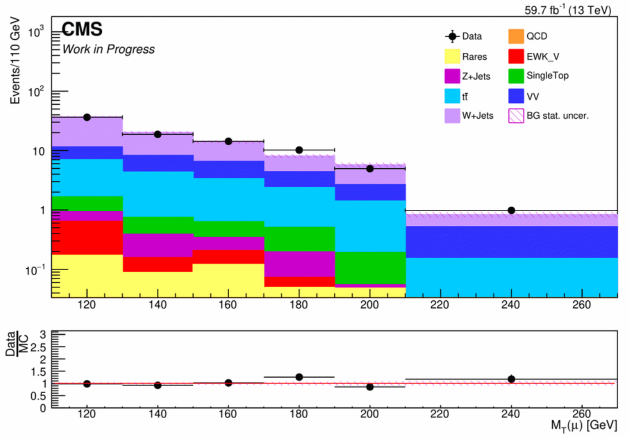
- Scale factors for the central and VBF selections are consistent across various years of LHC data taking.
- Scale factors are validated using VRs

W+Jets background: Control region studies

Control Region 1 (CR1): Overall agreement between corrected background yields and the observed data

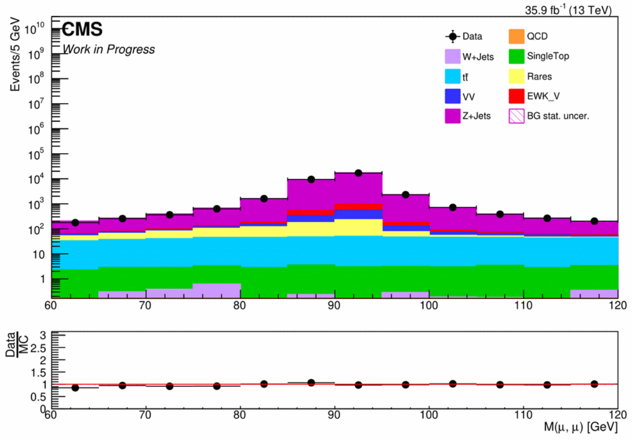


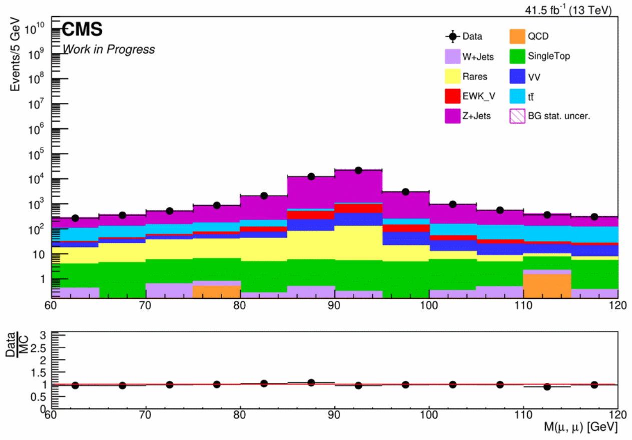


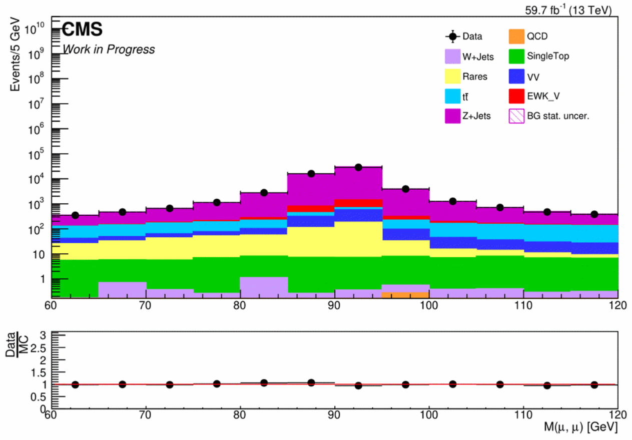


W+Jets background: Control region studies

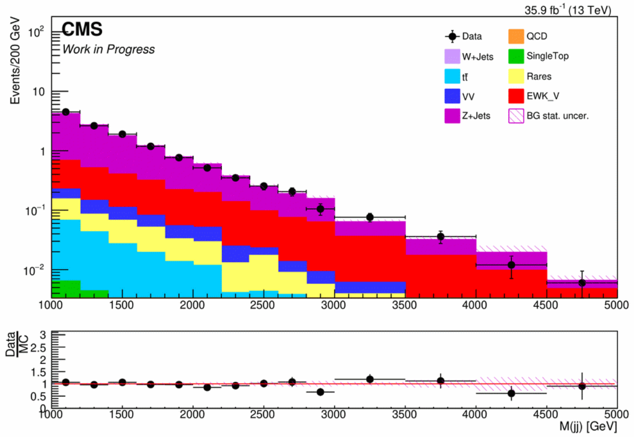
Control Region 3 (CR3): Overall agreement between corrected background yields and the observed data

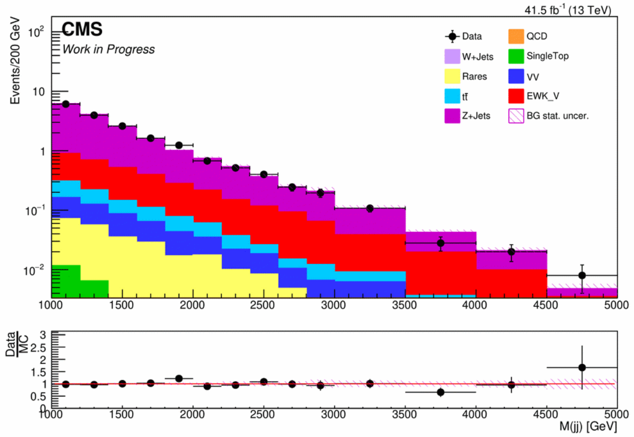


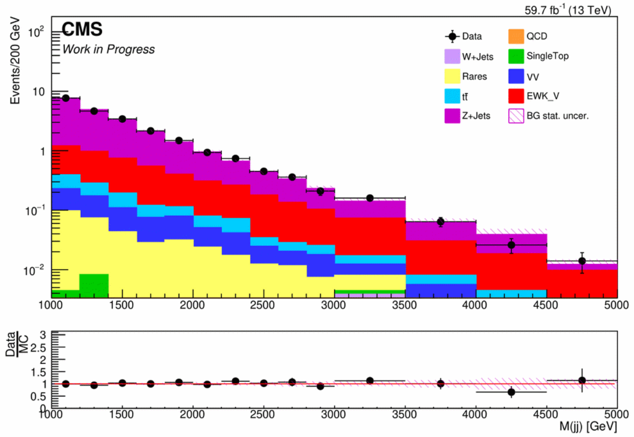




Control Region 2 (CR2): Overall agreement between corrected background yields and the observed data

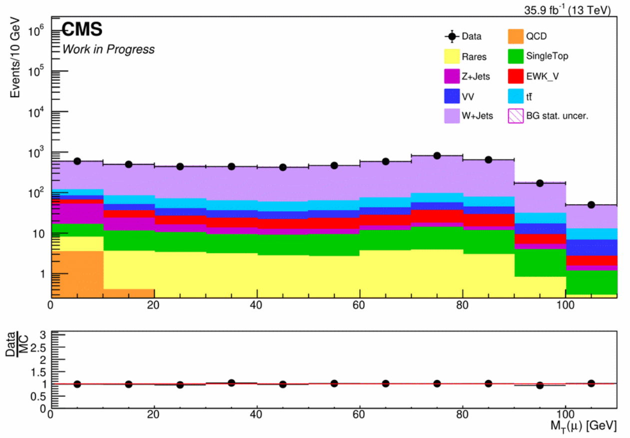


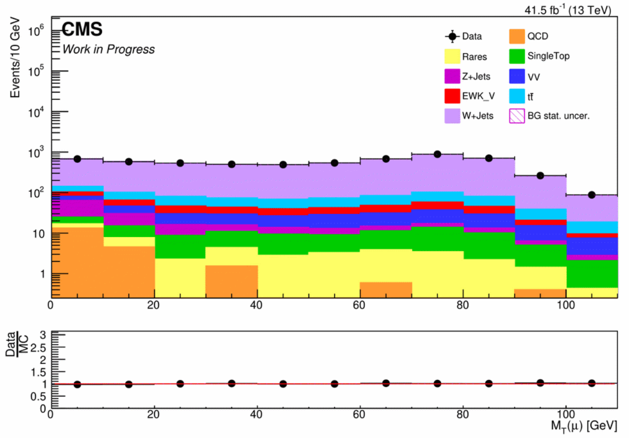


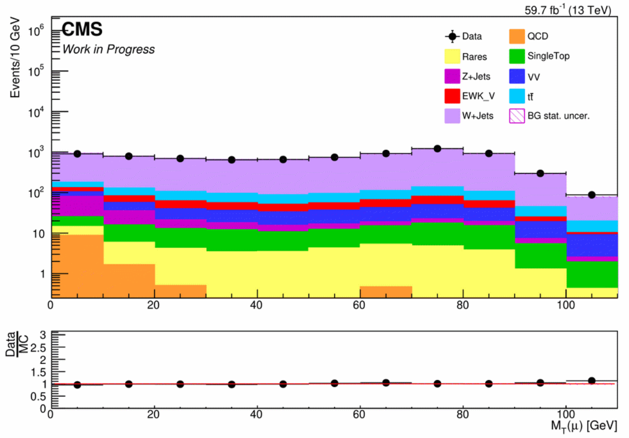


W+Jets background: Validation region studies

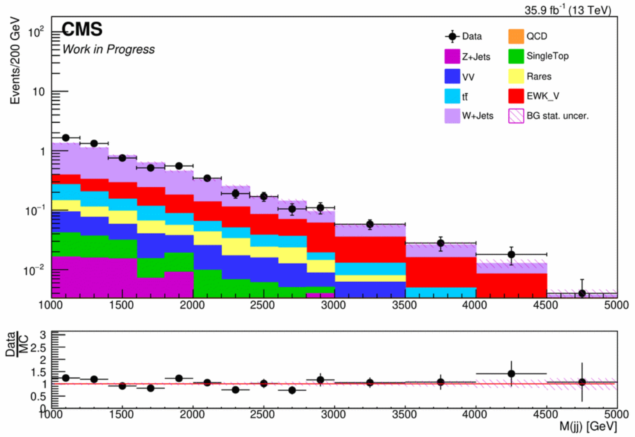
Validation Region 1 (VR1): Overall agreement between corrected background yields and the observed data

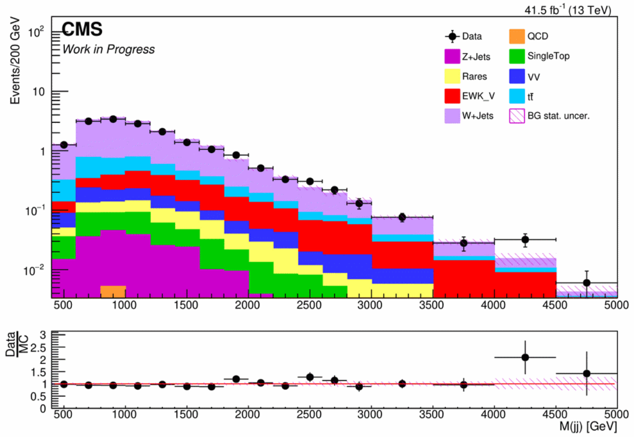


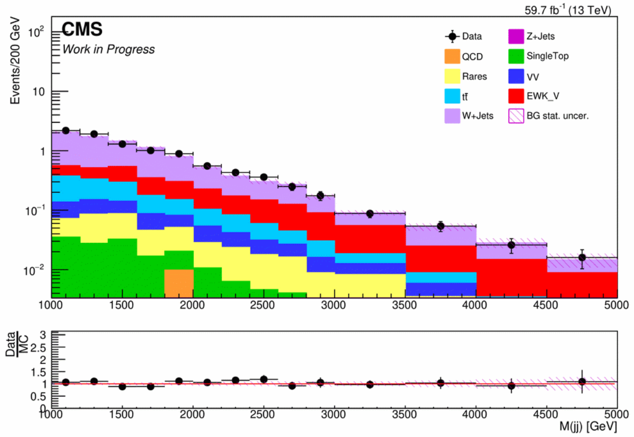




Validation Region 2 (VR2): Overall agreement between corrected background yields and the observed data







Signal Region Prediction:

2016 VBF1 μ channel				
Sample	$N^{\text{MC/Data}}_{\text{Process}}$(SR/CR)	SF^{CR1} or TF_1	SF^{CR2} or TF_2	$N^{\text{Predicted}}_{\text{Process}}$
EWK V	0.5 ± 0.3	—	—	0.5 ± 0.3
Diboson	7.3 ± 0.9	0.821 0.056	1.42 0.24	8.5 ± 1.9
QCD	0.0 ± 0.0	—	—	0.0 ± 0.0
Single Top	1.5 ± 0.5	—	—	1.5 ± 0.5
W + jets	7.7 ± 1.5	1.27 ± 0.09	1.18 ± 0.04	11.5 ± 2.4
DY + jets	0.1 ± 0.0	—	—	0.1 ± 0.0
$t\bar{t}$	12.7 ± 0.8	1.00 ± 0.07	0.739 ± 0.212	9.4 ± 2.8
Rares	0.7 ± 0.3	—	—	0.7 ± 0.3
SR BG Prediction	30.5 ± 2.0	—	—	32.2 ± 4.2
$m(\tilde{\chi}_1^{\pm}), m(\tilde{\chi}_2^0), m(\tilde{\chi}_1^0) =$ 300, 300, 295 GeV	0.1 ± 0.0	—	—	0.1 ± 0.0
$m(\tilde{\chi}_1^{\pm}), m(\tilde{\chi}_2^0), m(\tilde{\chi}_1^0) =$ 300, 300, 270 GeV	2.2 ± 0.0	—	—	2.2 ± 0.0
$m(\tilde{\chi}_1^{\pm}), m(\tilde{\chi}_2^0), m(\tilde{\chi}_1^0) =$ 300, 300, 250 GeV	2.5 ± 0.0	—	—	2.5 ± 0.0
$m(\tilde{\chi}_1^{\pm}), m(\tilde{\tau}), m(\tilde{\chi}_1^0) =$ 300, 297.5, 295 GeV	0.0 ± 0.0	—	—	0.0 ± 0.0
$m(\tilde{\chi}_1^{\pm}), m(\tilde{\tau}), m(\tilde{\chi}_1^0) =$ 300, 285, 270 GeV	0.8 ± 0.1	—	—	0.8 ± 0.1
$m(\tilde{\chi}_1^{\pm}), m(\tilde{\tau}), m(\tilde{\chi}_1^0) =$ 300, 275, 250 GeV	1.1 ± 0.1	—	—	1.1 ± 0.1
Data	Unblinded	—	—	—

Table 138: Predicted and observed rates in the signal region for 2016 VBF1 μ channel.

$$N_{pred} = N_{MC}(SR) \,.\, SF_{central} \,.\, SF_{VBF}$$

Note:

- We have similar results for all years

Summary

- SUSY is one of most promising scenarios beyond the Standard Model.
- Search for SUSY particles is being performed in single lepton + VBF jets + MET final states using full LHC Run II data at $\sqrt{s}$ = 13 TeV.
- The VBF topology is a powerful and complementary tool to search for new physics such as SUSY at the LHC.
- The analysis is under review by a CMS physics group.

Thank You!

Additional Material

Data and MC samples:

Data Samples used:

- /MET/Run2016*-Nano1June2019-v1/NANOAOD (Luminosity 35.9 fb -1)
- /MET/Run2017*-Nano1June2019-v1/NANOAOD (Luminosity 41.5 fb -1)
- /MET/Run2018*-Nano1June2019-v1/NANOAOD (Luminosity 59.7 fb -1)

Possible backgrounds:

- DY+Jets
- QCD
- W+Jets
- Single top
- $t\bar{t}$
- Diboson (WW, WZ, ZZ)

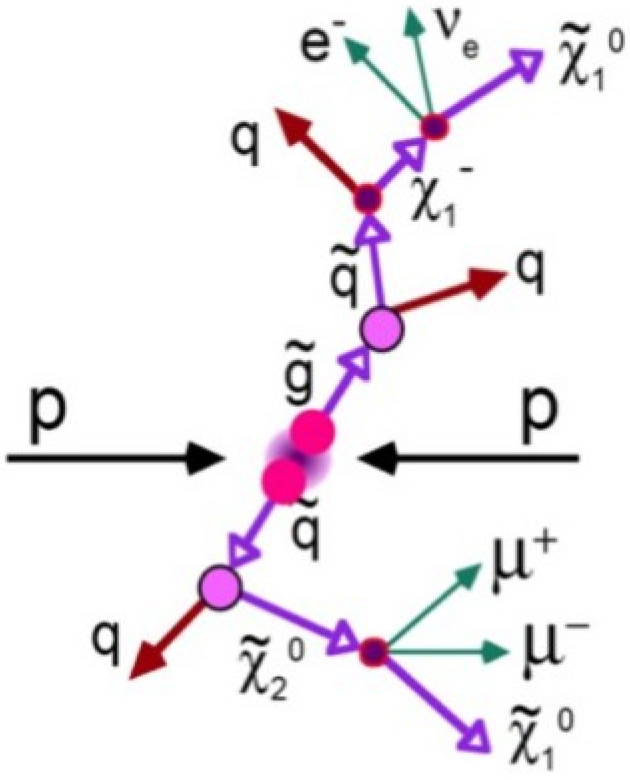
R-parity

- In many SUSY models there is possible violation of lepton and baryon number
- R-parity is introduced to suppress such violation

$$R = (-1)^{3(B-L) + 2S}$$

where S, B and L correspond to the spin, baryon and lepton numbers of the particle

- R-parity conservation leads to consequences:
  - sparticles are produced in pairs
  - lightest sparticle, known as LSP, must be stable → possible dark matter candidate



If SUSY is a correct theory, the production and detection of SUSY particles is possible at the Large Hadron Collider (LHC).