Search for electroweak WZ vector boson scattering and new physics at CMS

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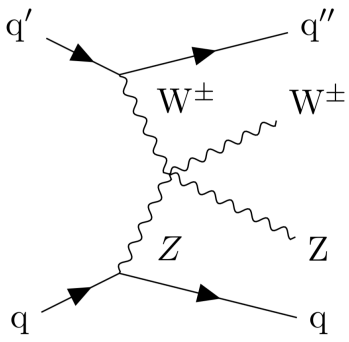
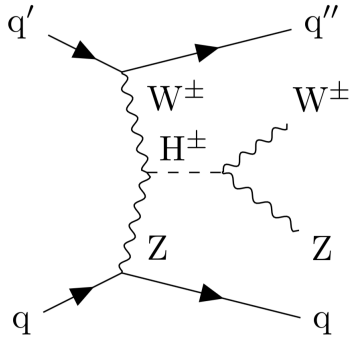
Introduction and Motivation

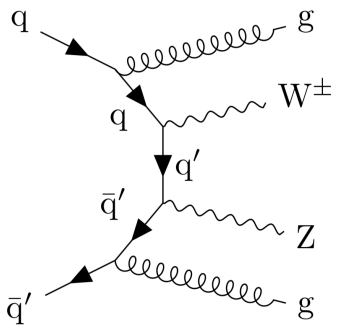
- WZ production via vector boson scattering
  - Important component of WZjj production proceeding entirely via EW interactions at tree level
  - Given SM Higgs, interactions with vector bosons, and V self-interactions precisely predicted
    - Deviations from predictions signal new physics in EW sector



VBS WZ



H± Production

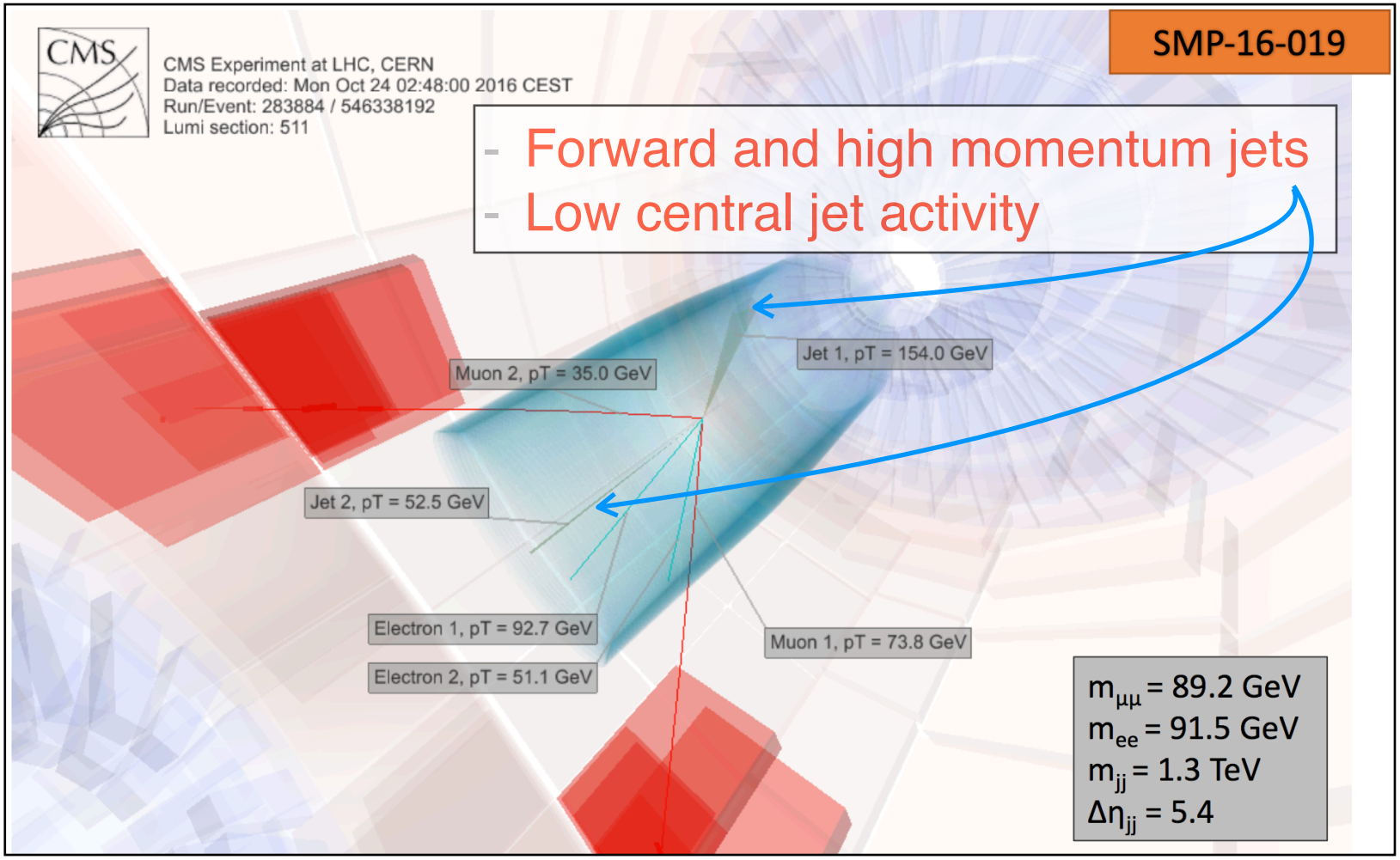


Non-VBF ($\alpha_s^2\alpha^2$) WZjj production

- Low cross sections for VBS just becoming accessible
  - Does it occur with the rate predicted by the SM?
  - Do distributions show any signs of BSM physics?

Picture of a VBS Candidate Event

- Radiation of vector bosons, lack of color flow between jets
  - ➡ Distinct kinematic signature for VVjj EW component



VBS ZZjj Candidate Event from PLB 774 (2017) 682

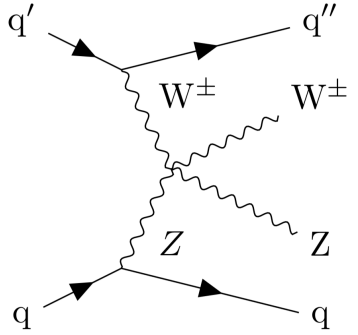
WZ VBS at 13 TeV: Overview

- Why WZjj ⟶3ℓνjj?
  - Sensitive to charged resonances or couplings
  - Less clean signature than ZZ, W±W±, but cross section accessible with large dataset

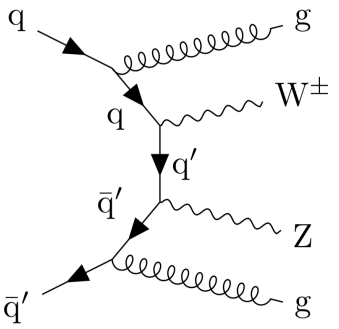
- Event selection
  - Exactly 3 leptons with moderate p_T + p_T^{miss}
  - Tight dijet kinematic cuts reduce QCD WZjj and significant nonprompt contributions
  - Expected contributions in signal region
    - WZ/non-WZ ~ 3/1
    - EW WZ/other ~ 1/3

CMS-SMP-18-001

VBS production



QCD production



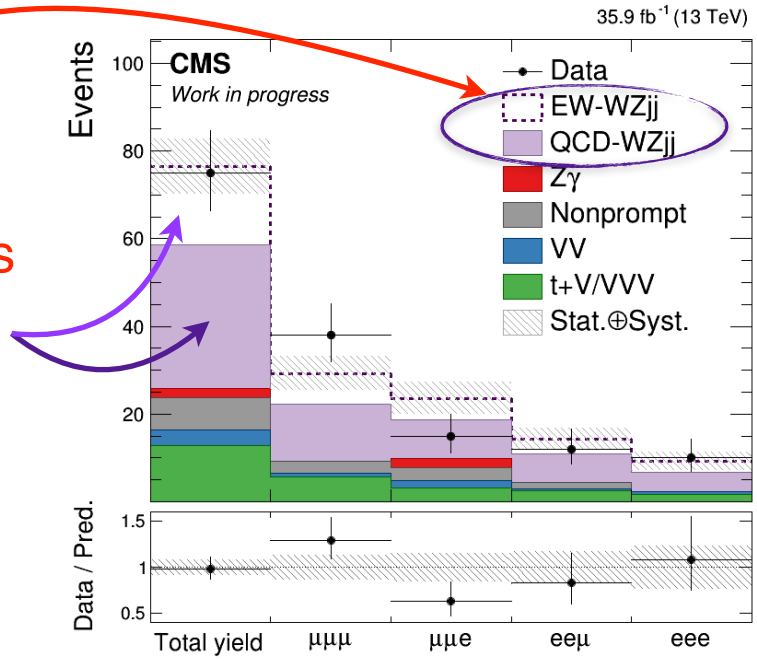
Event selection

	EW signal	Higgs boson
$p_T^{\ell_1}$ [GeV]	> 25	> 25
$p_T^{\ell_2}$ [GeV]	> 15	> 15
p_T^{ℓ} [GeV]	> 20	> 20
$\lvert\eta^{\mu}\rvert$	< 2.4	< 2.4
$\lvert\eta^{e}\rvert$	< 2.5	< 2.5
$\lvert m_{\ell'\ell'} - m_Z\rvert$ [GeV]	< 15	< 15
$m_{3\ell}$ [GeV]	> 100	> 100
$m_{\ell\ell}$ [GeV]	> 4	> 4
p_T^{miss} [GeV]	> 30	> 30
$\lvert\eta^{j}\rvert$	< 4.7	< 4.7
p_T^{j} [GeV]	> 50	> 30
$\lvert\Delta R(j,\ell)\rvert$	> 0.4	> 0.4
n_j	≥ 2	≥ 2
p_T^{b} [GeV]	> 30	> 30
n_b	$= 0$	$= 0$
m_{jj}	> 500	> 500
$\lvert\Delta\eta_{jj}\rvert$	> 2.5	> 2.5
$\lvert\eta^{3\ell} - \frac{1}{2}(\eta^{j_1} + \eta^{j_2})\rvert$	< 2.5	-

WZ VBS at 13 TeV: Results

- Measure WZjj EW+QCD cross section in VBS-enhanced phase space
  - Fit yields in signal region to reduce dependence on theory prediction

EW+QCD treated together as signal!



Fiducial Regions

	Tight fiducial	Loose fiducial
$p_{\mathrm{T}}^{\ell'_1}$ [GeV]	> 25	> 20
$p_{\mathrm{T}}^{\ell'_2}$ [GeV]	> 15	> 20
p_{T}^{ℓ} [GeV]	> 20	> 20
$\lvert\eta^{\mu}\rvert$	< 2.5	< 2.5
$\lvert\eta^{\mathrm{e}}\rvert$	< 2.5	< 2.5
$\lvert m_{\ell'\ell'} - m_{\mathrm{Z}}\rvert$ [GeV]	< 15	< 15
$m_{3\ell}$ [GeV]	> 100	> 100
$m_{\ell\ell}$ [GeV]	> 4	> 4
p_{T}^{miss} [GeV]	-	-
$\lvert\eta^{\mathrm{j}}\rvert$	< 4.7	< 4.7
$p_{\mathrm{T}}^{\mathrm{j}}$ [GeV]	> 50	> 30
$\lvert\Delta R(\mathrm{j},\ell)\rvert$	> 0.4	> 0.4
n_{j}	≥ 2	≥ 2
$p_{\mathrm{T}}^{\mathrm{b}}$ [GeV]	-	-
n_{b}	-	-
m_{jj}	> 500	> 500
$\lvert\Delta\eta_{\mathrm{jj}}\rvert$	> 2.5	> 2.5
$\lvert\eta^{3\ell} - \frac{1}{2}(\eta^{j_1} + \eta^{j_2})\rvert$	< 2.5	-

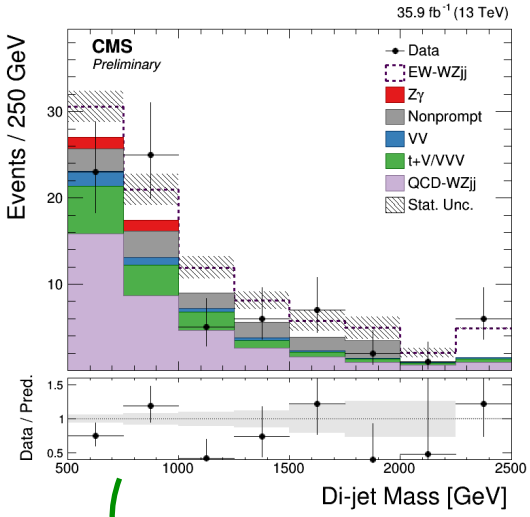
Tight $\sigma^{\mathrm{fid}}_{\mathrm{WZjj}} = 2.91^{+0.53}_{-0.49}\,(\mathrm{stat})\ ^{+0.41}_{-0.34}\,(\mathrm{syst})$

Loose $\sigma^{\mathrm{fid,loose}}_{\mathrm{WZjj}} = 4.01^{+0.72}_{-0.68}\,(\mathrm{stat})\ ^{+0.57}_{-0.47}\,(\mathrm{syst})$

Compare tight fiducial to $\sigma_{\mathrm{fid,MG}} = 3.27\,^{+0.39}_{-0.32}(\mathrm{scale}) \pm 0.15\,(\mathrm{PDF})$

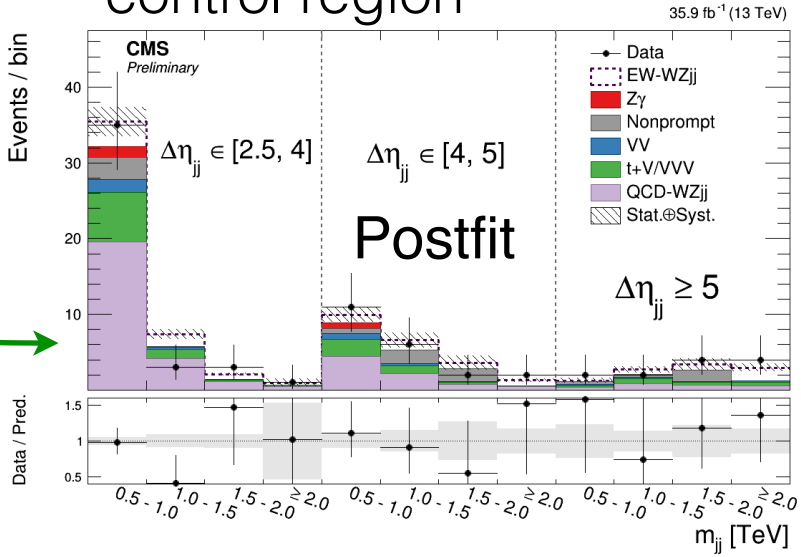
WZ VBS at 13 TeV: EW Extraction

- Simultaneously fit yield from background control region and 2D distribution of m_{jj} and $\Delta\eta(j_1,j_2)$

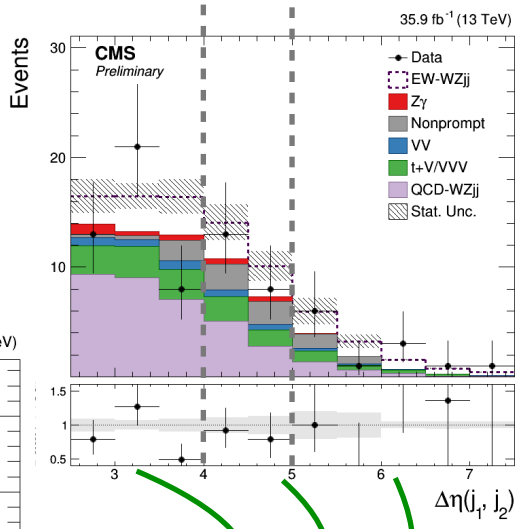


Prefit

- Fit 4 leptonic decay channels independently
- Uncertainties correlated across bins and with control region



Postfit



Prefit

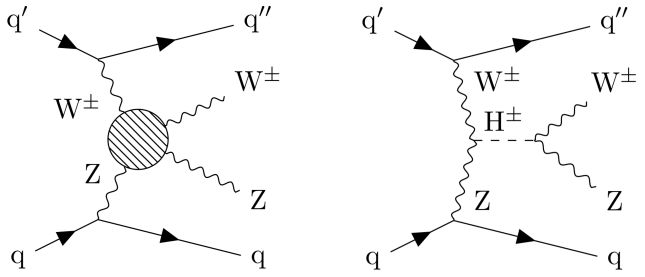
EW contribution (purple dashed, stacked) rises with increasing $m_{jj}/\Delta\eta_{jj}$

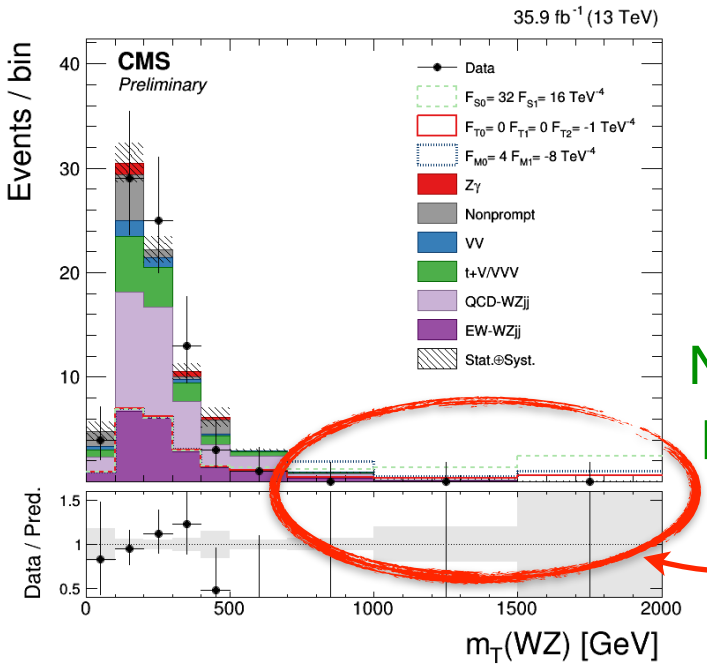
- Observed (expected) significance of EW WZ 1.9σ (2.7σ)

$$\mu_{EW} = \sigma_{EW,obs}/\sigma_{EW,\mathrm{theo}} = 0.64^{+0.45}_{-0.37}$$

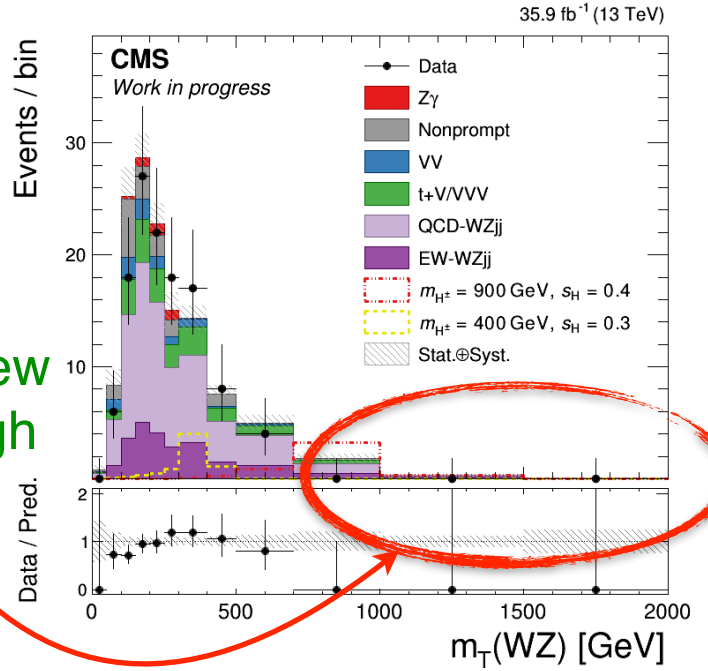
Limits on new physics: Procedure

- New WWZZ interactions likely modify the $m_T(WZ)$ spectrum
  - Sensitive center of mass energy of the scattering system
- Studied in specific and generic models
  - Charged Higgs bosons
    - ➡Resonance-like modification
  - Dimension-8 effective field theory operators
    - ➡Lead to excess of events at high mT



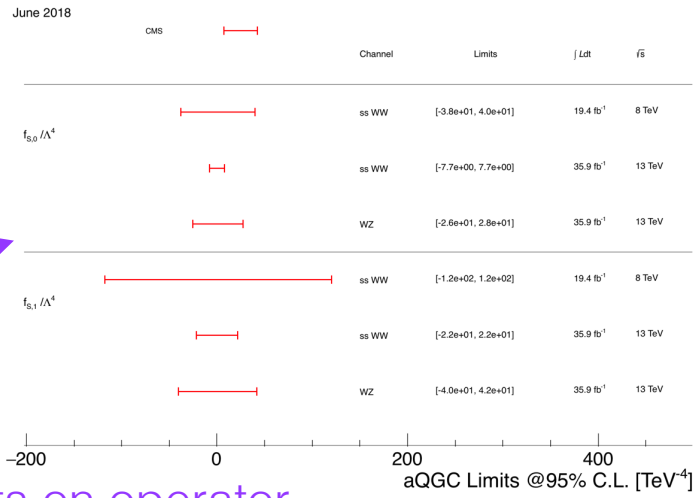


No signs of new physics at high mass!

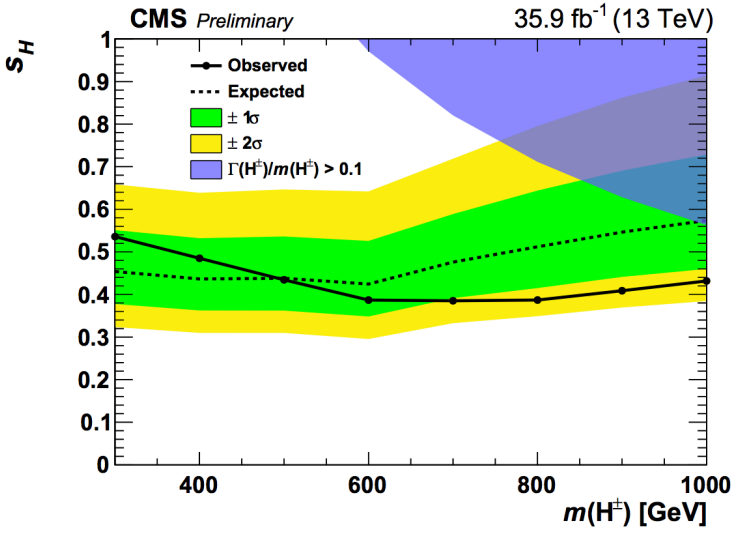


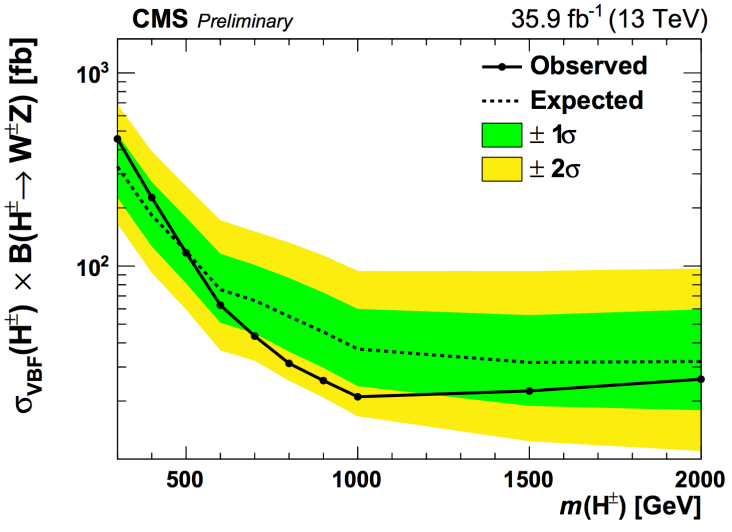
Limits on new physics: Results

- First dimension-8 operator constraints from WZ channel at 13 TeV
  - Limits complementary to SS WW analysis, competitive for several operators
- Charged Higgs limits improve from [previous CMS study](#) at 13 TeV, complement those [from ATLAS](#)



Limits on operator couplings/ scale of new physics

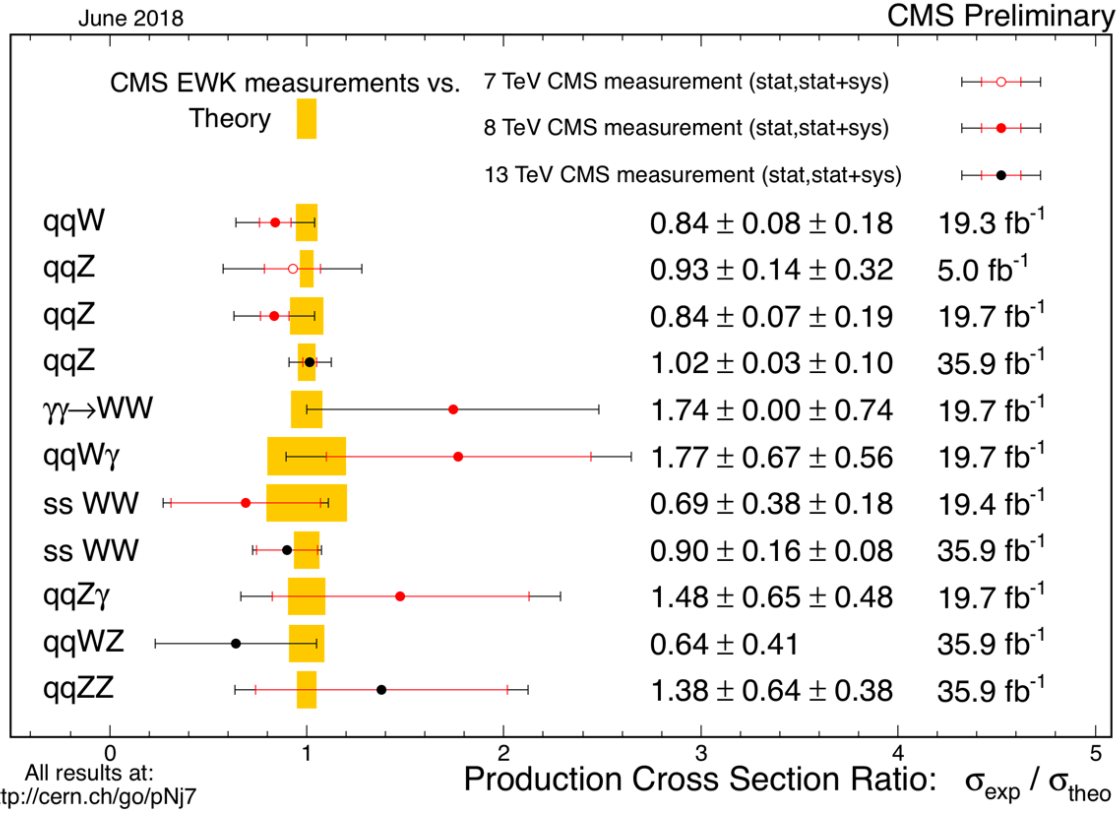




Limits on $\sigma_{H^\pm}$ and in parameters of GM model

Conclusions

- VBS measurements provide an important probe of a previously untested sector of the standard model
- So far the standard model is withstanding these new tests
  - Deviations could be subtle
  - More data and improved techniques help look for cracks with increased precision and at higher energy scales



Backup

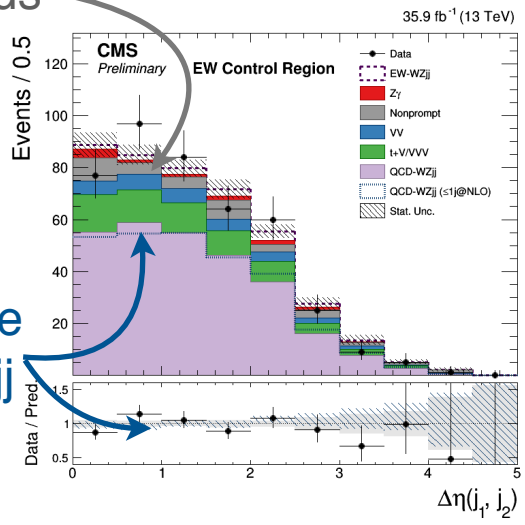
WZ VBS at 13 TeV: Backgrounds

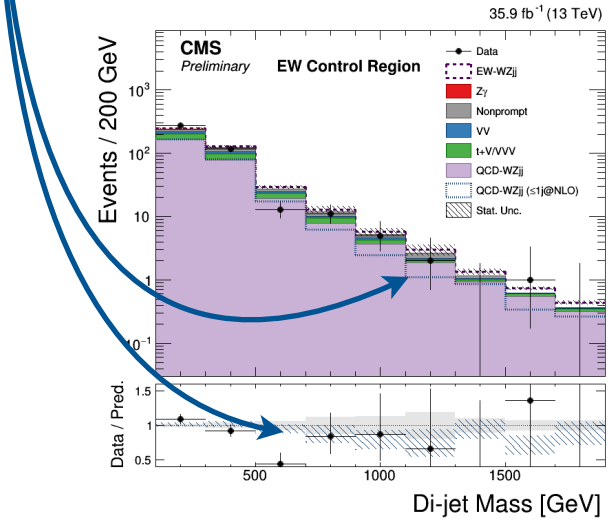
- Nonprompt background
  1. Define "loose" ID with ID+isolation relaxed from "tight"
  2. Measure tight/loose ratio in Z+jet (dijet) events
  3. Apply loose ⟶ tight factors to events passing full analysis selection but failing analysis ID (tight)

- QCD WZjj background
  - Simulated with MG5_aMC+Py8 ≤3j@LO
    - Compare to predictions from MG5_aMC+Py8 ≤1j@NLO, each normalized to data in control region
  - Normalization constrained in control region
    - m_{jj} > 100 GeV, but fail dijet signal cuts
  - Uncertainty: LO scale+PDF+10% normalization from MC comparisons

Nonprompt backgrounds

Alternative QCD-WZjj

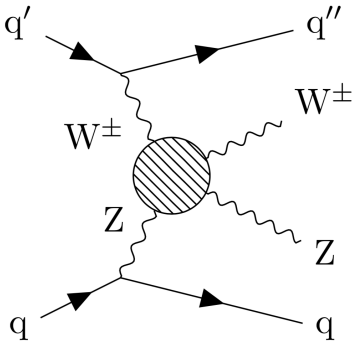


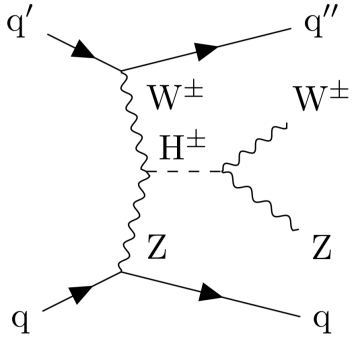


Models of new physics

- Study deviations from SM from two perspectives
  - Explicit BSM models well-motivated by shortcomings in the SM
    - Example: charged Higgs bosons
    - Arise in extensions of the SM with extended Higgs sector, VBS production important when couplings to vector bosons dominant

Generic modification of WWZZ interaction





Charged Higgs production

- Generalized language for new physics in vector boson interactions
  - EFT expansion with Wilson coefficients c_i and New Physics scale Λ

$$\mathcal{L}_{SM} \longrightarrow \mathcal{L}_{eff} = \mathcal{L}_{SM} + \sum_{n=1}^{\infty} \sum_{i} \frac{c_i^{(n)}}{\Lambda^n} \mathcal{O}_i^{(n+4)}$$

  - Observed as deviations at high mass

Approaches are complementary!