Measurements involving W, Z bosons (inclusive or in association with jets)

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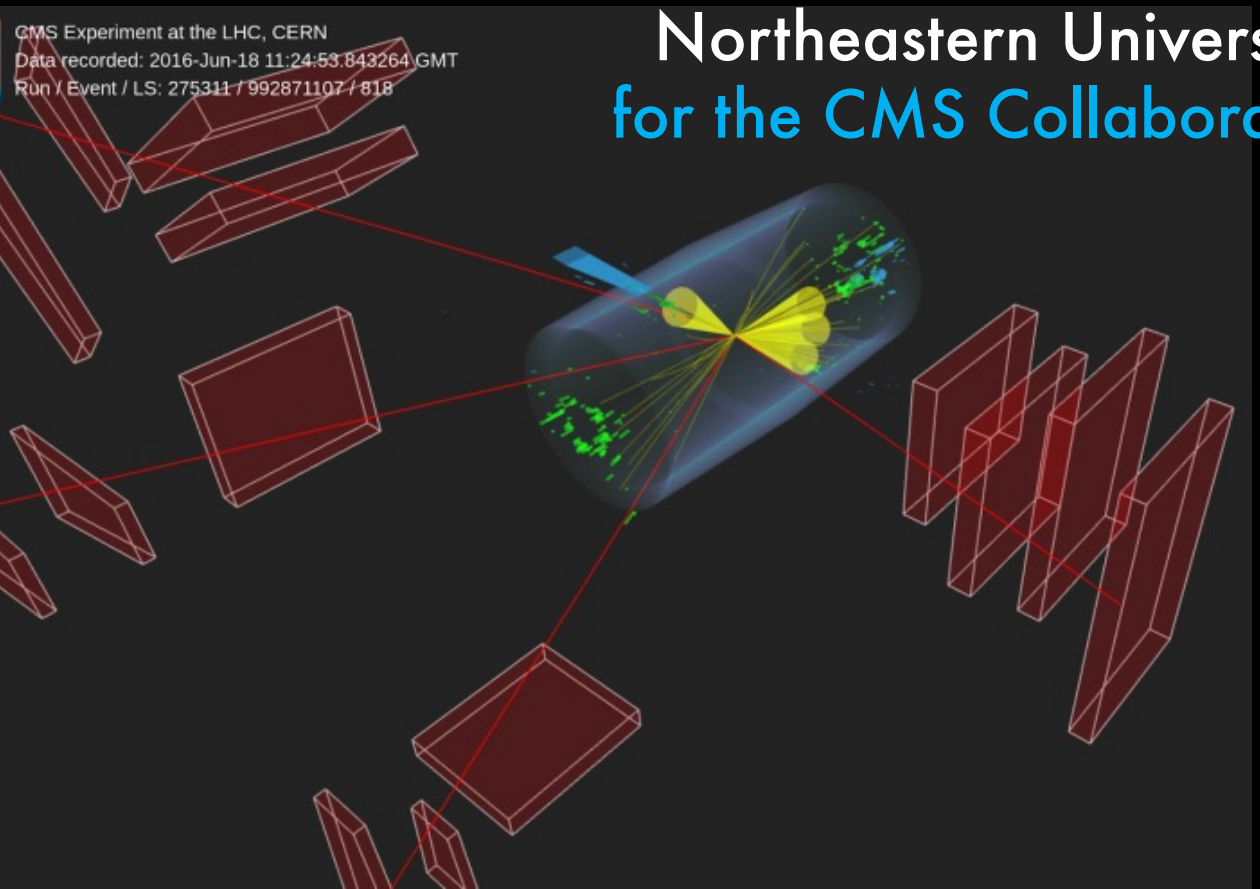


*supported by the NSF

SM physics with W,Z bosons

SM measurements involving W,Z bosons with or w/o jets at the LHC allow us to test a wide range of theory predictions (EW, pQCD, npQCD) with unprecedented precision. They are sensitive to, and constraint new physics contributions. These processes are also backgrounds to all direct searches for new physics.

Outline: recent results from the CMS experiment on

W,Z Production

- Inclusive W and Z production
- Rare decays of Z
- Z polarization
- Invisible Z width

Z+jets

- Z+jets differential cross sections

*(Z,W+HF jets results covered in V. Candelise's talk)

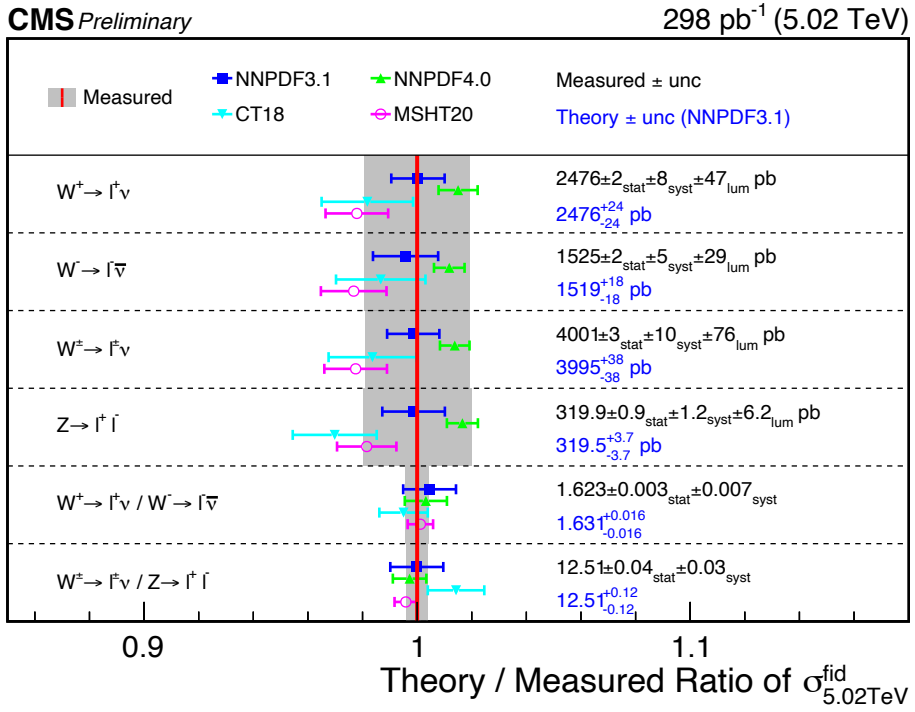
Multi-V(W,Z)+jets

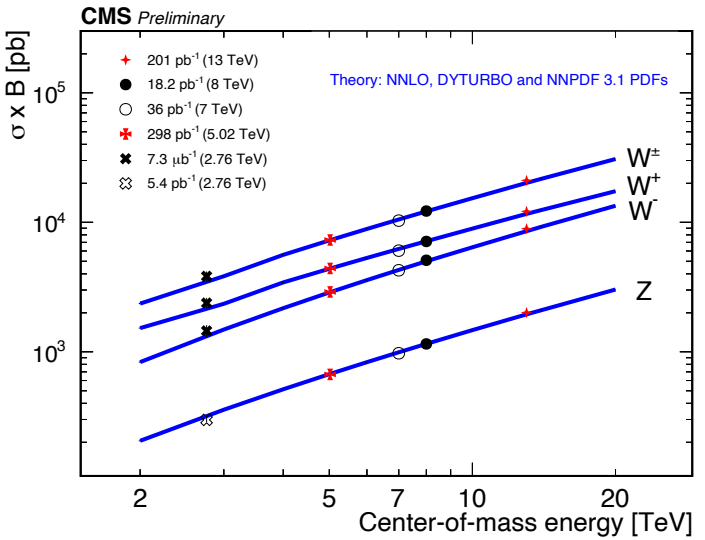
- $W^{\pm}W^{\pm}$ + jets with τ decays
- ZZ + jets differential cross-sections

W and Z production

Cross-sessions (inclusive and differential) are sensitive to EW and QCD sectors of SM: extraction of fundamental parameters of EW theory (M_W, M_Z, $\sin^2\theta_W$), input to proton structure (PDF's), input to modeling of high order corrections in MC for reduction of uncertainty on measurements.

CMS-SMP-20-004





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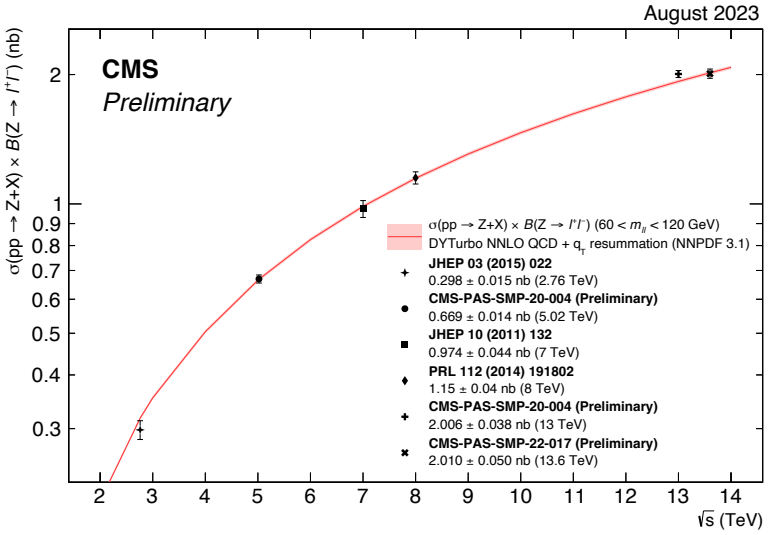


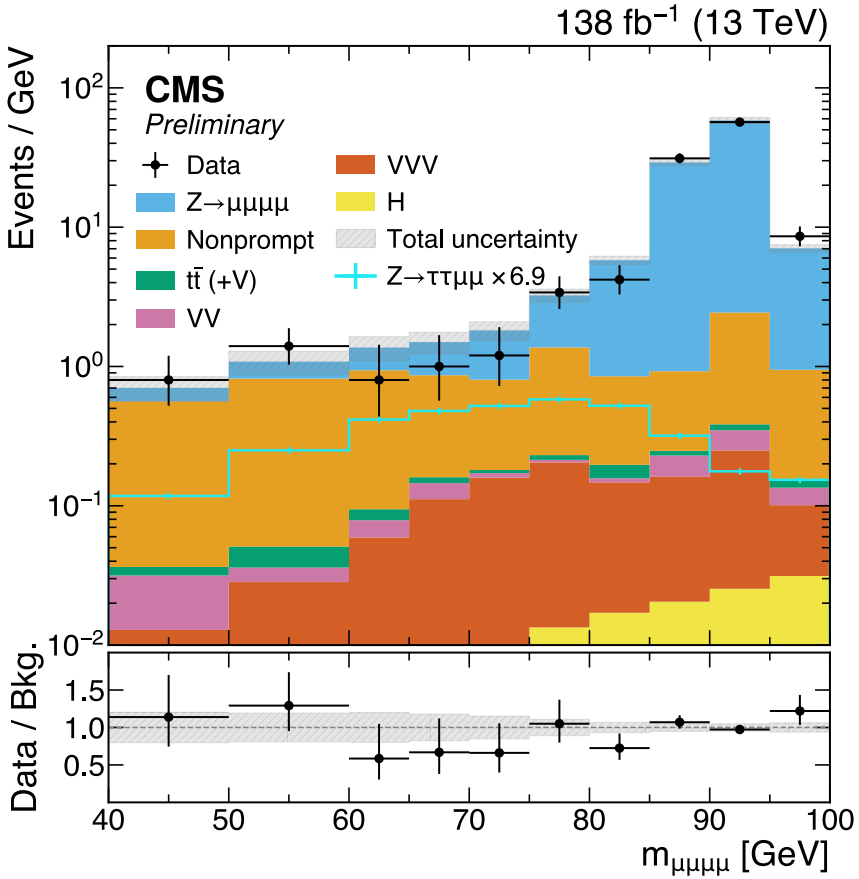
CMS-SMP-22-017

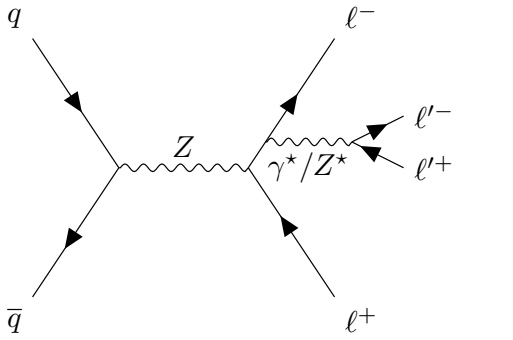
Total and fiducial cross sections, ratios of cross sections of $W^{\pm}$ to Z, W^+ to W^-, and 13 TeV to 5.02 TeV, measurement of Z cross-section at 13.6 TeV. Consistent with pQCD predictions.

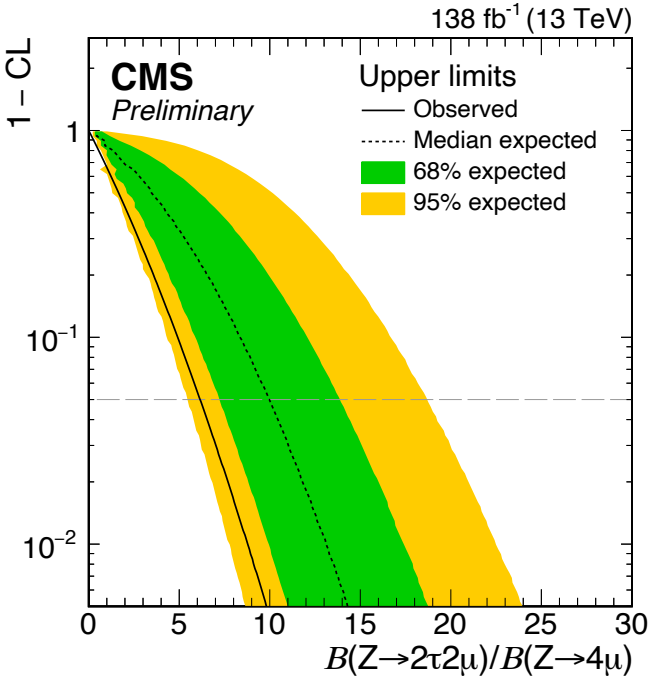
Rare decays of Z

Rare modes can be sensitive to new physics (e.g. Z'). Studies of $Z \to \ell^+\ell^-\ell^+\ell^-$

$Z \to \tau^+\tau^-\tau^+(\to \mu^+)\tau^-(\to \mu^-)$: First search in this rare decay mode (SM Br~10^{-6}). Data compatible with backgrounds. 95% C.L. upper limit of 6.2 on $\mathrm{Br}(Z \to 2\tau 2\mu)/(Z \to 4\mu)$, corresponding to 6.9xSM.





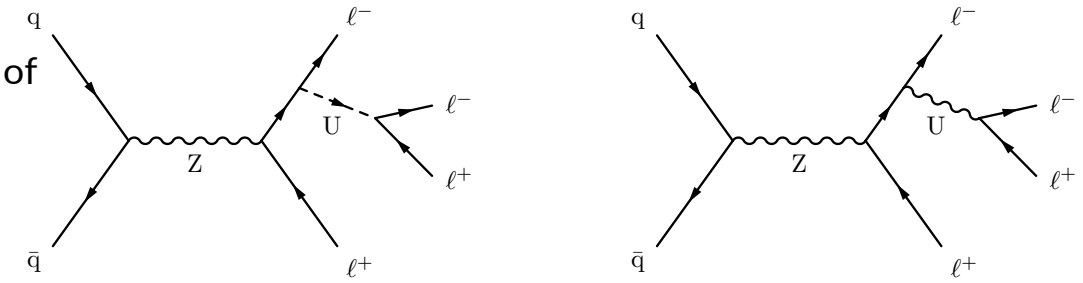


CMS-SMP-22-016

Rare decays of Z

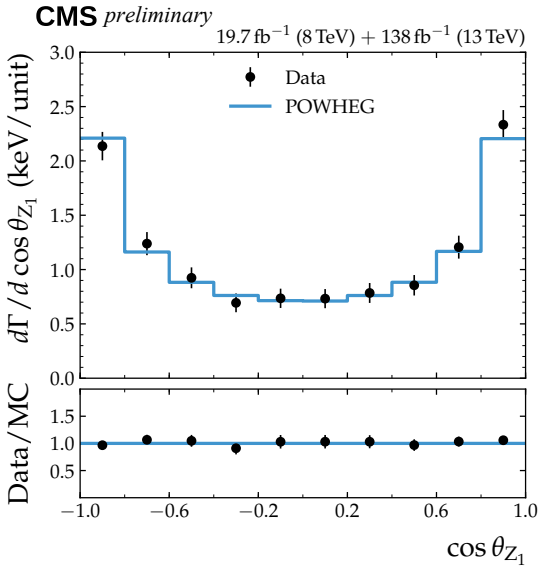
Rare modes can be sensitive to new physics (e.g. Z'). Studies of $Z \to \ell^+\ell^-\ell^+\ell^-$

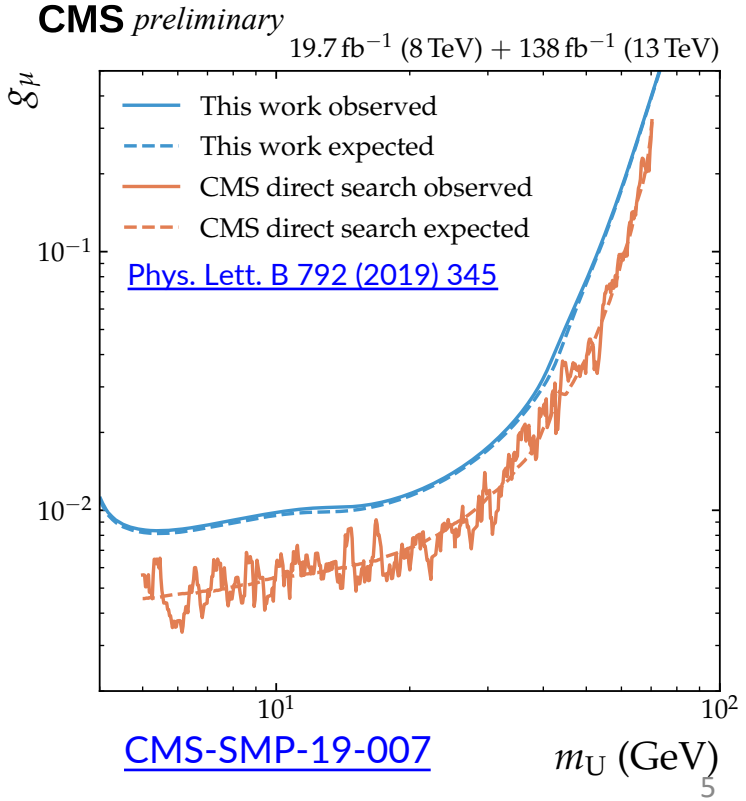
$Z \to 4\ell$: Decays to 4 charged leptons (e or μ). Rare decay mode (SM Br~10^{-6}). Measurement of branching ratios and differential distributions. Good agreement with SM, precision of 3.2%. Limits set on a scalar or vector BSM gauge boson mediator "U".



Channel	$\mathcal{B}(Z \to 4\ell)$ [$\times 10^{-6}$] Expected	Observed
4μ	1.20 ± 0.00	1.25 ± 0.04 (stat) ± 0.03 (syst)
$2\mu 2e$	2.31 ± 0.00	2.17 ± 0.08 (stat) ± 0.06 (syst)
$4e$	1.20 ± 0.00	1.16 ± 0.09 (stat) ± 0.06 (syst)
4ℓ	4.70 ± 0.00	4.67 ± 0.11 (stat) ± 0.10 (syst)

Observed symmetry of the angular distributions reflects the CP invariance of the $Z \to 4\ell$ decay process

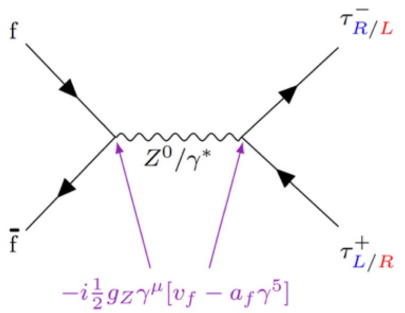




τ polarization in Z→ $\tau\bar{\tau}$ decays

Z→ $\tau\bar{\tau}$ decays used to measure the asymmetry arising from different coupling of Z to left and right handed fermions in the SM. The asymmetry is equal to the negative polarization at the Z pole and it is related to $\sin^2 \vartheta_W^{\text{eff}}$.

Kinematic angular distributions of decay products used to construct templates for several decay categories. Templates used to extract the average polarization by a maximum likelihood fit to data.



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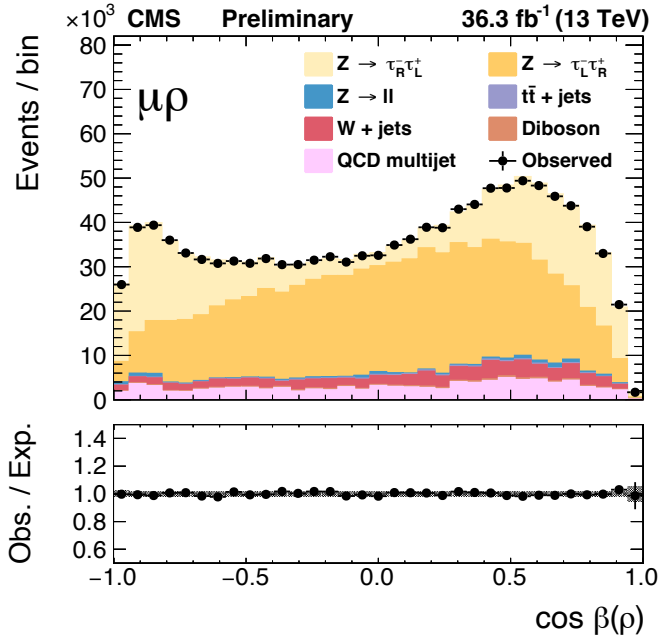
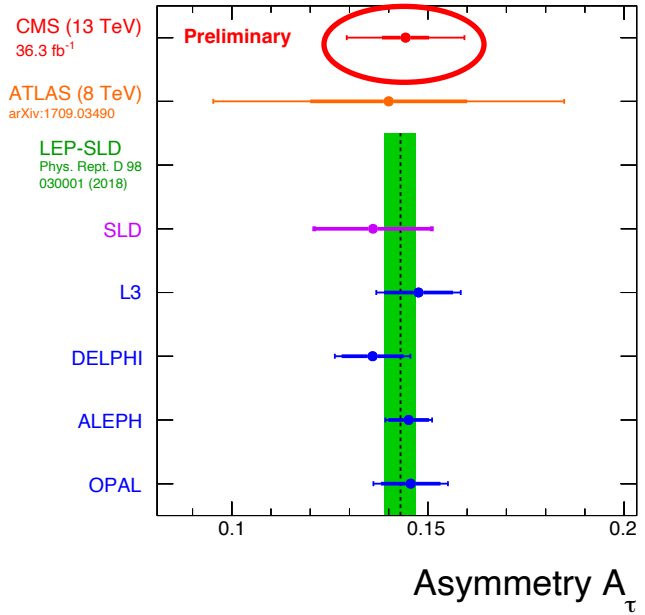




$\sin^2 \vartheta_W^{\text{eff}} = 0.2319 \pm 0.0008\ (\text{stat}) \pm 0.0018\ (\text{syst})$

Measurement dominated by systematic uncertainties but with precision close to single LEP experiments.

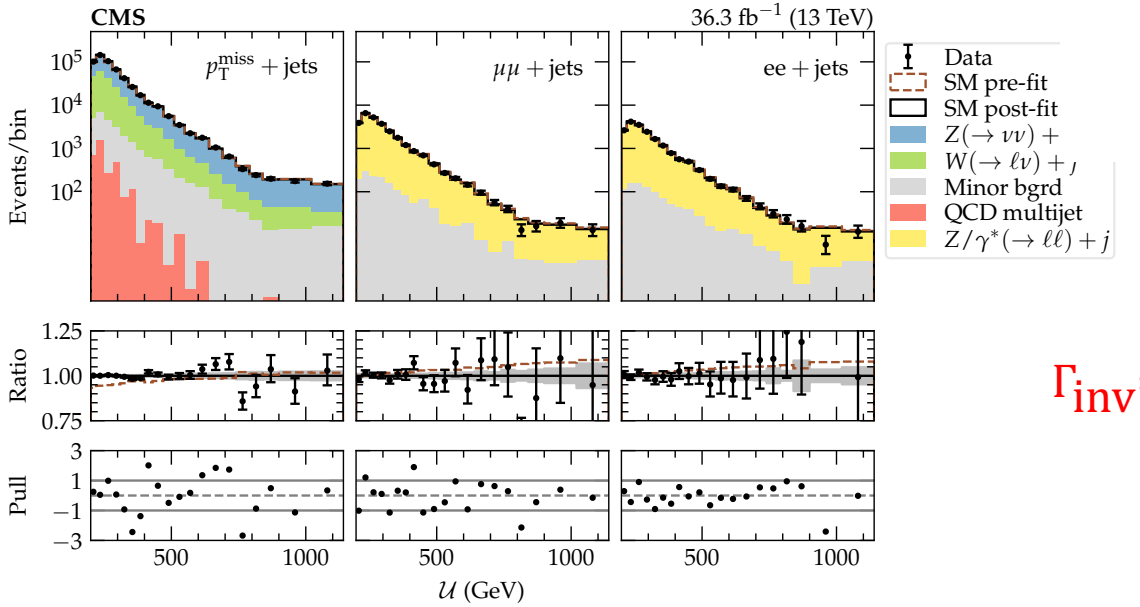
Z invisible width

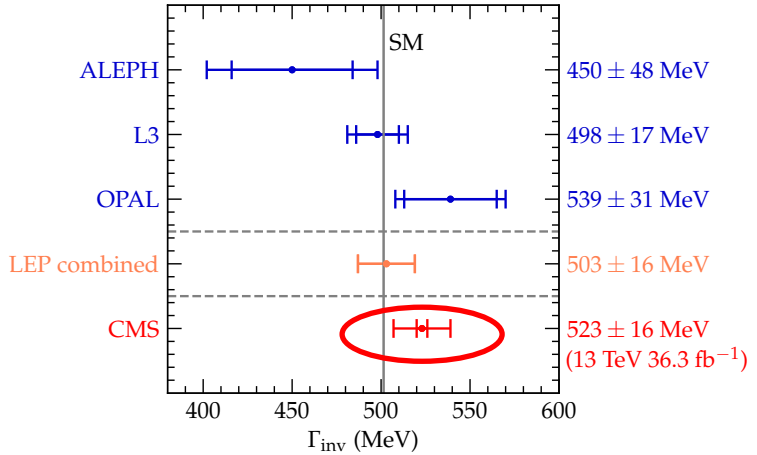
First direct precision measurement of the Z invisible width at a hadron collider.

Exploits the similarity in the kinematic of decay of the Z to neutrinos and to charged leptons (e or μ). It is based on the ratio of branching fractions between these two decay modes, using LEP's measured $Z(\to \ell^+\ell^-)$ partial width.

$$\Gamma(Z \to \nu\bar{\nu}) = \frac{\sigma(Z+\text{jets})\mathcal{B}(Z \to \nu\bar{\nu})}{\sigma(Z+\text{jets})\mathcal{B}(Z \to \ell\ell)}\Gamma(Z \to \ell\ell)$$

Simultaneous fit of the hadronic recoil distribution in $Z \to \ell^+\ell^-$ + jets and $Z \to \nu\nu$ (p_T^{miss}) + jets regions





$\Gamma_{inv} = 523 \pm 3\ (stat) \pm 16\ (syst)$ MeV

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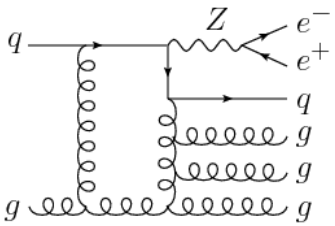
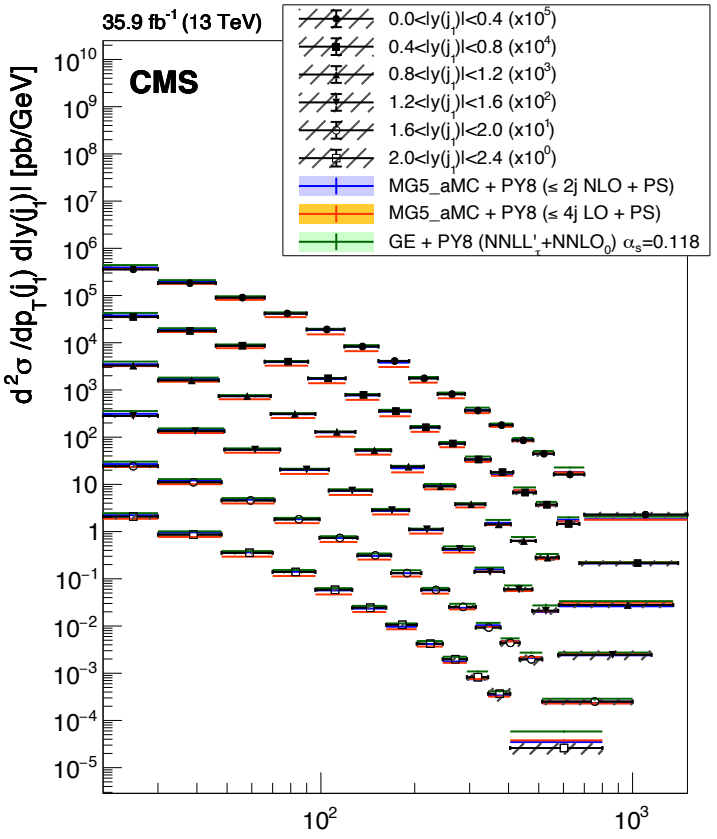
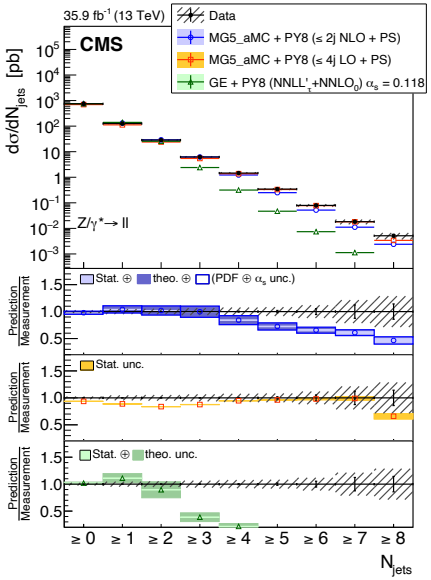
Z+jets

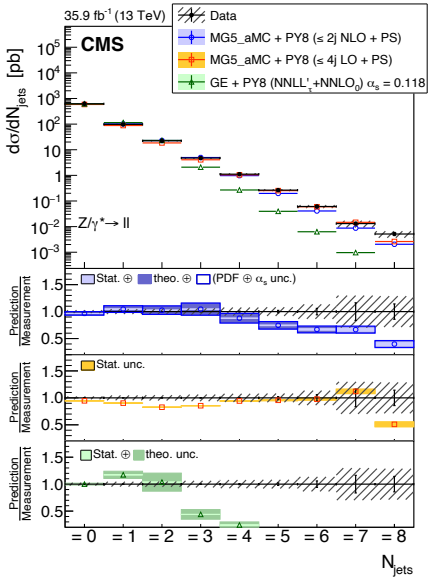
Z + light jets differential cross sections:

- tests of pQCD and non perturbative (NP) effects
- sensitive to higher order (QCD and EW) effects
- backgrounds to BSM searches.
- inputs to u/d/gluon PDFs









Precision differential cross-sections of $Z(\rightarrow e^+e^-)$ and $Z \rightarrow (\mu^+\mu^-)$+jets: inclusive & exclusive jet multiplicity up to eight jets, p_T, H_T, angular variables, dijet invariant mass.

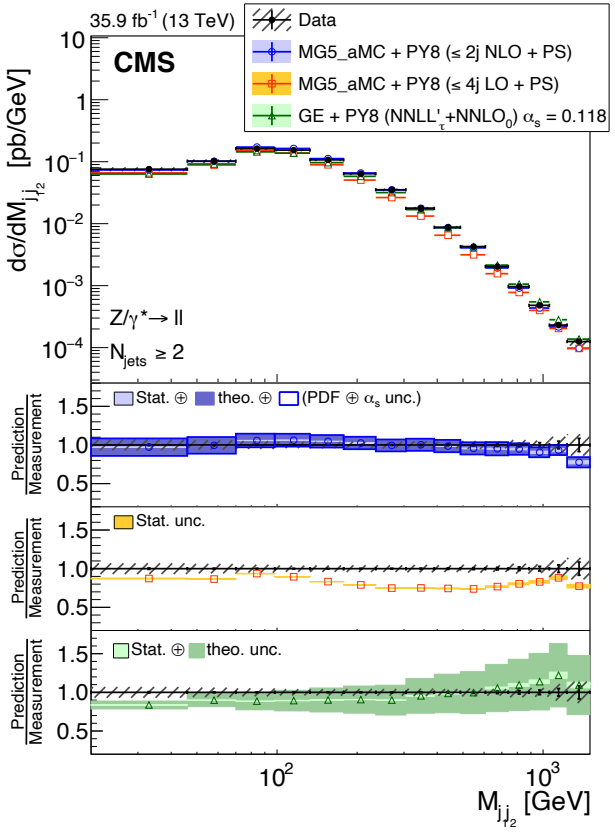
Double differential cross-sections in p_T and |y| of Z and of five leading jets.

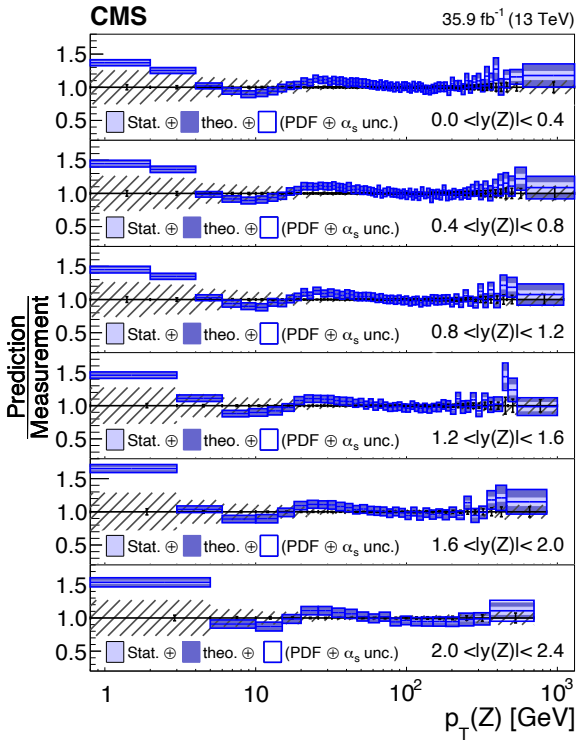
Measured cross-sections are compared to multi-leg LO(+PS) NLO(+PS) MCs, and to the Geneva MC (NNLO Z+0j ME and resummation at NNLL'ᴛ)

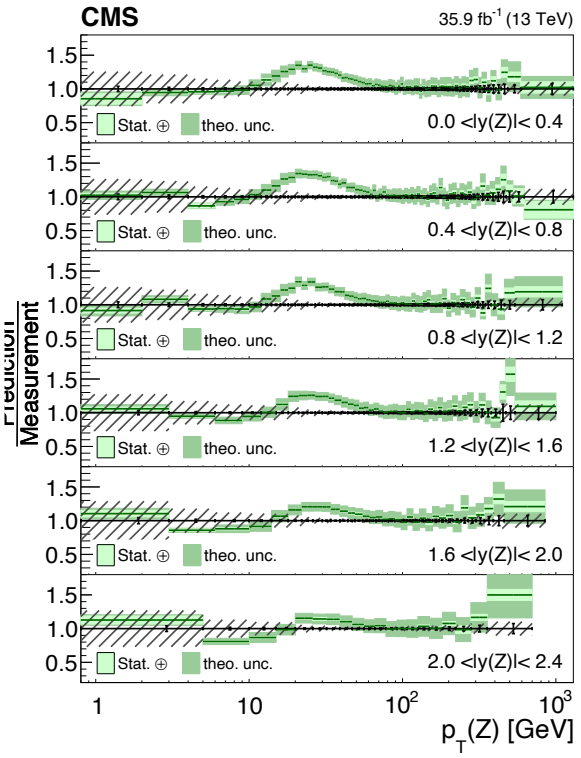
CMS-SMP-19-009 Accepted by PRD

Z+jets

Good agreement over a wide range of kinematic observables with NLO MG5_aMC predictions. Discrepancies arising at high jet multiplicities. Good agreement with Geneva model up to 2 jets, especially in regions (low p_T) where resummation effects are significant.







CMS-SMP-19-009 Accepted by PRD

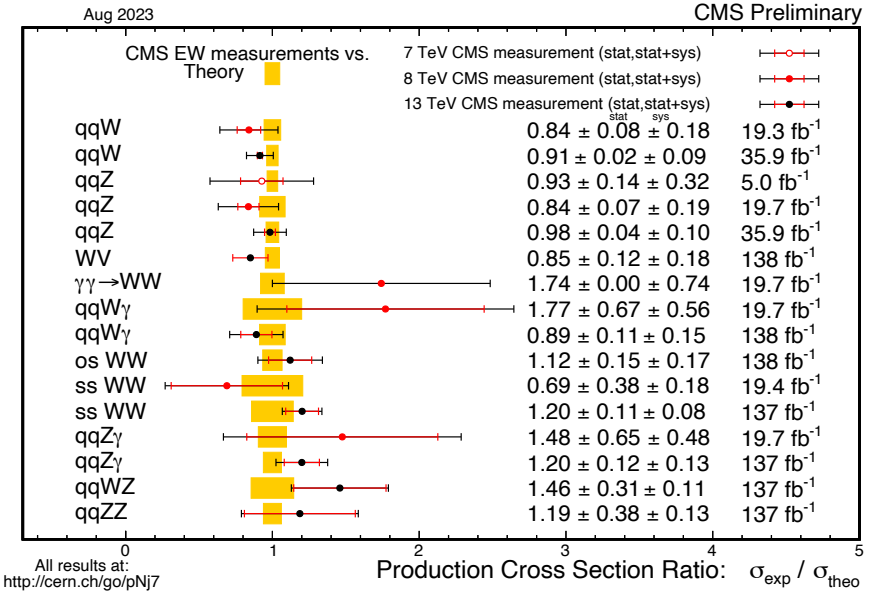
Multi-boson production

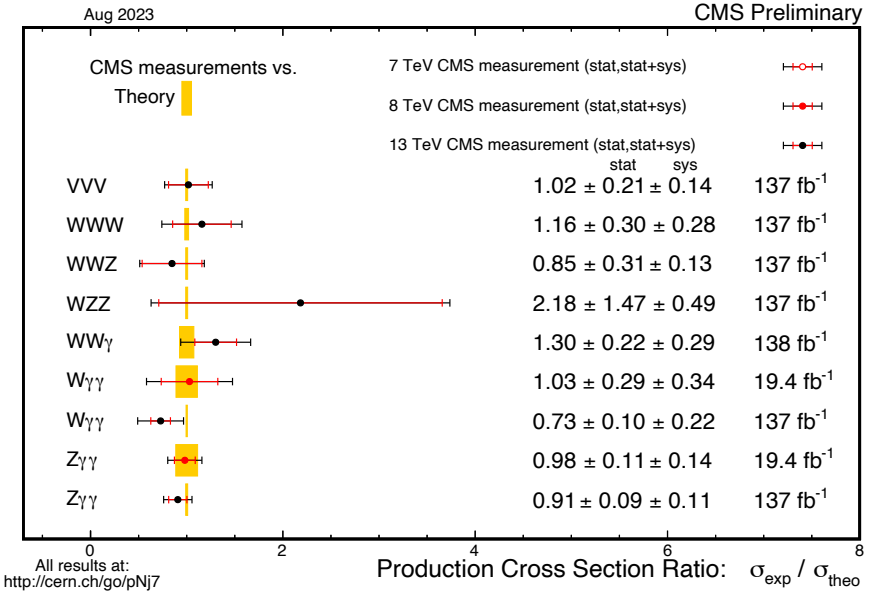
Backgrounds to Higgs and searches, sensitive to higher order corrections. Tests of the SM EW gauge structure.

Anomalous vector boson couplings: new physics at higher scales leading to modified couplings → probe for σ increase.
aTGC constrained w/ inclusive VV and EW Vjj.
aQGC constrained w/ EW VVjj and VVV.

$$L_{\mathrm{EFT}} = L_{\mathrm{SM}} + \sum_i \frac{\bar{C}_i^{(6)}}{\Lambda^2}\mathcal{O}_i^{(6)} + \sum_i \frac{\bar{C}_i^{(8)}}{\Lambda^4}\mathcal{O}_i^{(8)} + \ldots$$

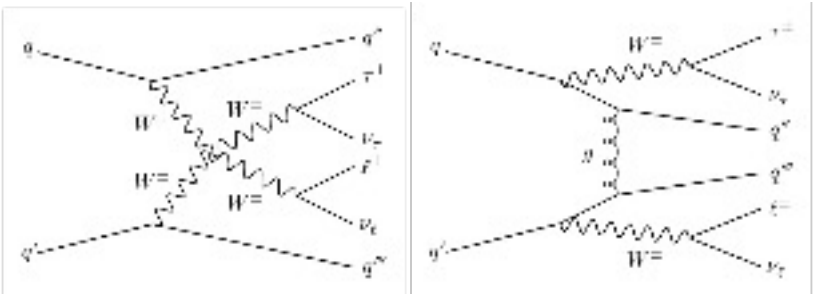
Many recent 13 TeV results in good agreement with SM. We are now increasingly sensitive to rare processes, tri-bosons and vector boson scattering (VBS) and able to measure cross-sections with increased precision.



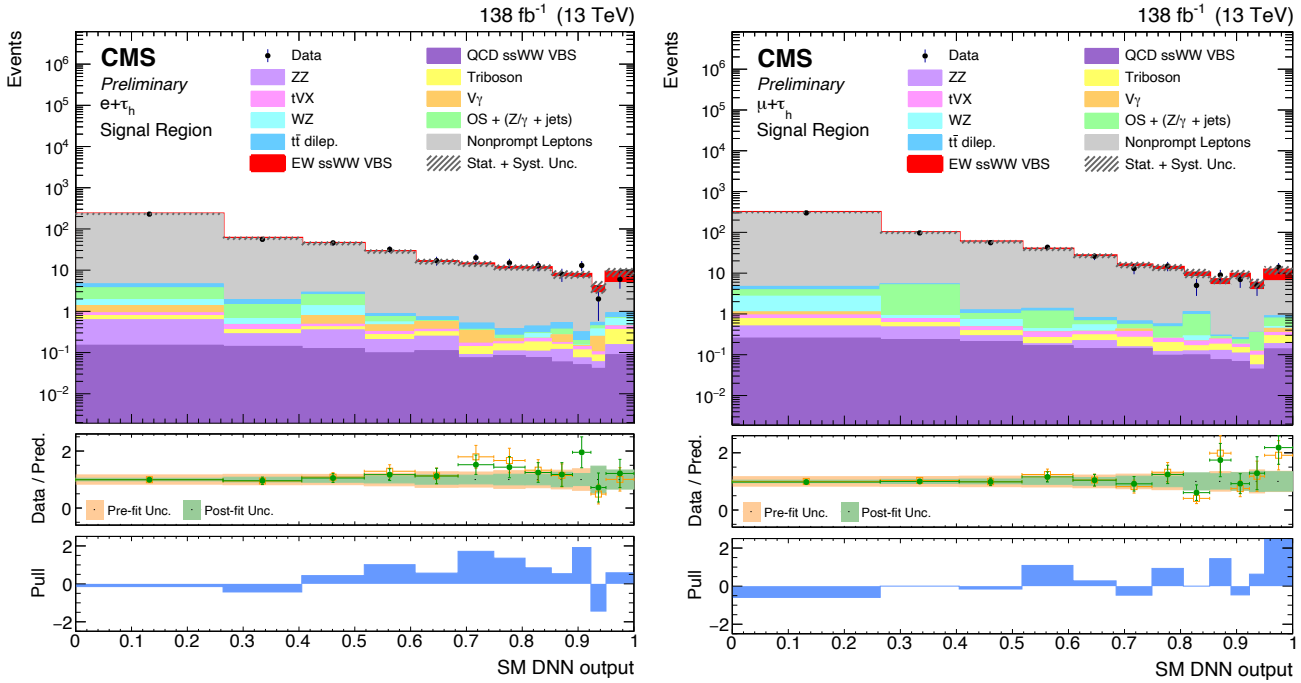


$W^{\pm}W^{\pm}$ with τ decays

Vector Boson Scattering (VBS): Probes EWSB. Sensitive to BSM in a model-independent approach, with Effective Field Theory (EFT) expansion. Forward jets topology with rapidity separation, and low hadronic activity in between.



First measurement of ssWW with τ in final state: $\ell^{\pm}\,\tau_h^{\pm}$ jets + p_T^{miss} (ℓ = e, μ). Dedicated DNN multi-classifier algorithm for τ-id. Maximum likelihood fit using DNN templates from SR and $t\bar{t}$ and opposite sign background CRs.



Measured cross section for EW ssWW scattering: $1.44^{+0.63}_{-0.56}\times$SM.

Observed (expected) EW ssWW signal significance: 2.7 (1.9) σ.

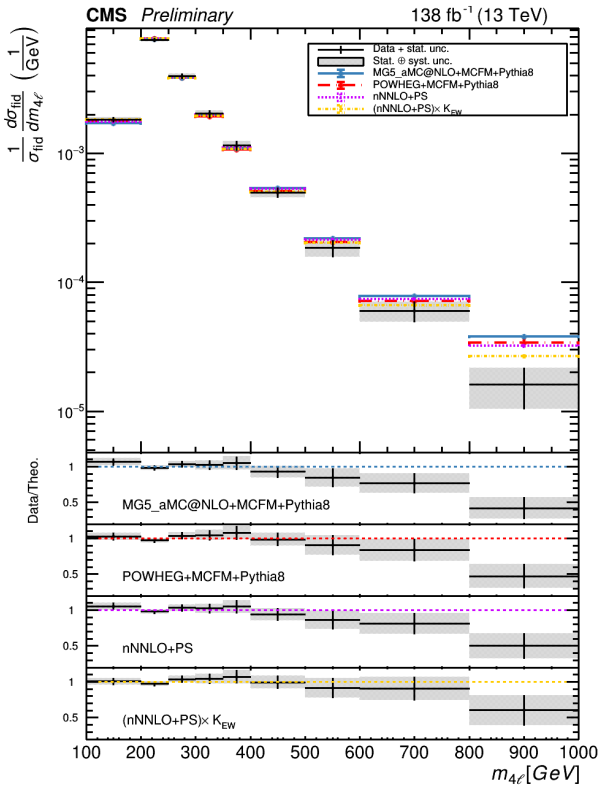
Observed (expected) EW + QCD ssWW signal significance: 2.9 (2.0) σ.

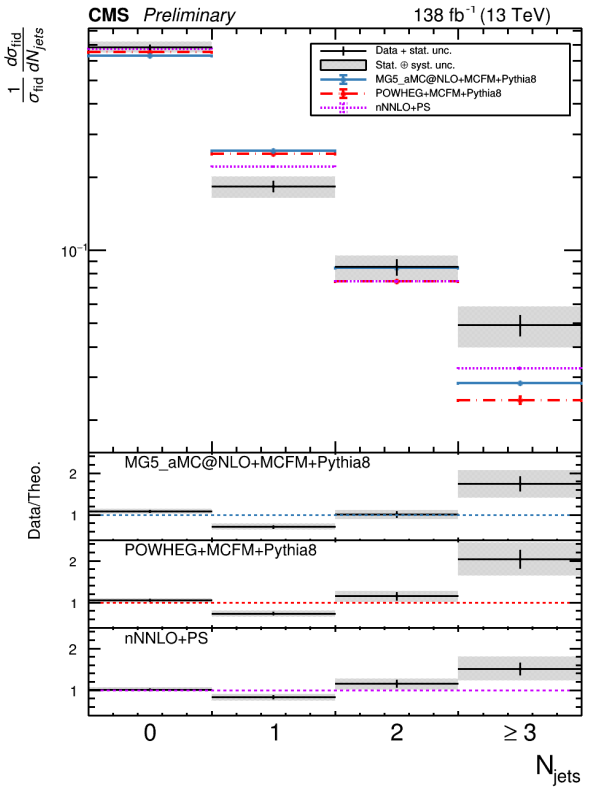
CMS-SMP-22-008

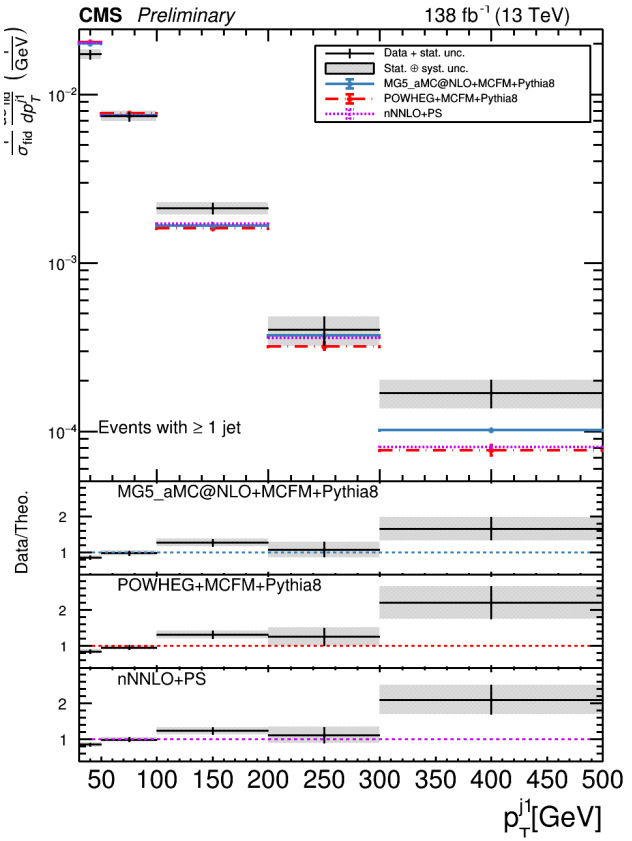
ZZ+jets production

Differential cross-section measurements of VBS ZZ+jets production.

With respect to various kinematic variables: jet multiplicity, p_T and η, invariant dijet invariant mass, and $\Delta\eta$ among two leading jets, $m_{4\ell}$ for different jet multiplicities. Comparison with theoretical predictions: nNNLO+PS describes the distribution of jet multiplicities better than MadGraph5_aMC@NLO and POWHEG, and the inclusion of EW corrections improves the description of the $m_{4\ell}$ distribution.







CMS-SMP-22-001

Conclusions

Broad range of Standard Model Electroweak and QCD physics results with 8 TeV, and 13 TeV data deepen and challenge our understanding of Electroweak interactions and their theoretical modeling.

Era of precision physics: Increasingly more precise and complex SM measurements now dominate on dedicate direct searches in probing for new physics.

The full set of Standard Model CMS results is available at http://cms-results.web.cern.ch/cms-results/public-results/publications/

Thank you!

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