Eight Measurements of Multiboson Production at CMS: number five is polarizing!

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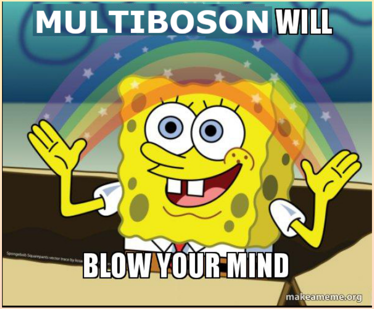
on behalf of the CMS Collaboration

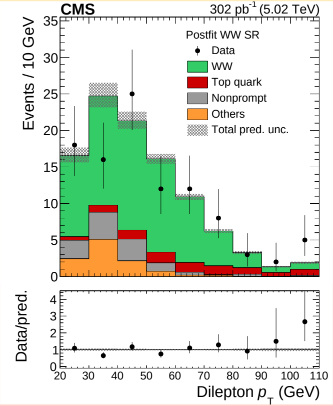


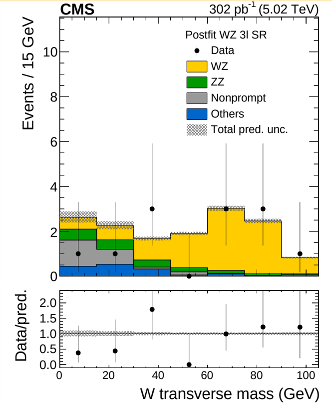
[1] F.N.R.S. and CP3 — IRMP, Université catholique de Louvain

- Precision measurements of SM multiboson production
  - Probe triple and quartic gauge boson couplings
- Recent CMS results
  - Diboson production at 5 TeV: PRL 127 (2021) 191801
  - WZ production at 13 TeV: JHEP 07 (2022) 032 (published today!!!)
  - Observation of WW production via double parton scattering at 13 TeV: 2206.02681 (submitted to PRL)
- Probed in both EWK and VBS production
  - See presentations by Yacine Haddad and Philippe Gras for VBS results

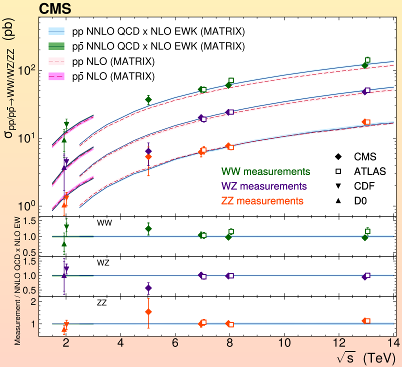
Diboson at 5 TeV (PRL 127 (2021) 191801): experimental setup

- Important probe of the dependence of the cross section on the beam energy
- Single lepton triggers, $p_T > 17/12$ GeV for electrons/muons
- Dedicated signal regions for each diboson combination
  - WW: two opposite-charge different-flavour leptons, $\Delta\phi > 2.8$, trasnverse mass $>$20 GeV, zero jets
  - WZ: three-lepton region, two-muons-same-sign region, tag leptons from Z
  - ZZ: four-lepton region, two-lepton opposite-charge same-flavour, axial p_T^{miss} >50GeV region
- Backgrounds from simulation (nonprompt lepton contributions from data)



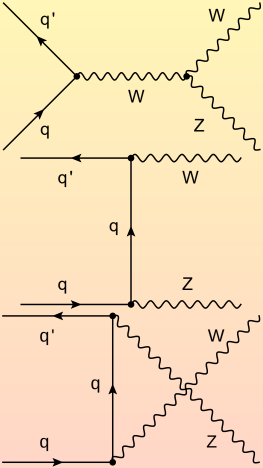


- Results well in agreement with NNLO predictions computed with MATRIX
  - In WZ, the agreement is within two standard deviations



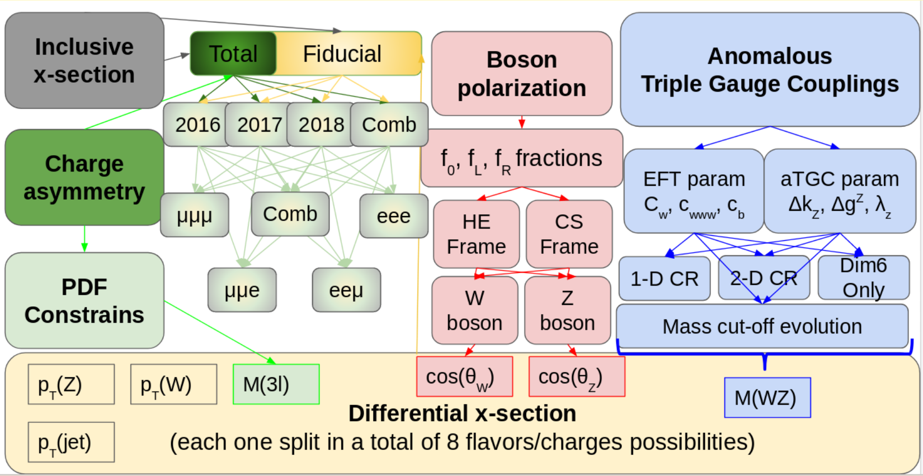
SR	Background	Signal	Data
WZ 3ℓ	$4.0 \pm 0.6 \pm 0.4$	$14.8 \pm 0.1 \pm 0.6$	12
WZ $2\mu ss$	$0.6 \pm 0.1 \pm 0.1$	$3.2 \pm 0.8 \pm 0.2$	4
ZZ 4ℓ	$0.5 \pm 0.2 \pm 0.1$	$2.7 \pm 0.0 \pm 0.2$	3
ZZ $2\ell 2\nu$	$4.8 \pm 0.3 \pm 0.7$	$4.0 \pm 0.0 \pm 0.2$	12

Process	Estimation	Total cross section [pb]
WW	MATRIX	$29.8^{+0.7}_{-0.6}$(scale)
	Measured	$37.0^{+5.5}_{-5.2}$ (stat)$^{+2.7}_{-2.6}$ (syst)
WZ	MATRIX	$11.3^{+0.2}_{-0.2}$(scale)
	Measured	$6.4^{+2.5}_{-2.1}$ (stat)$^{+0.5}_{-0.3}$ (syst)
ZZ	MATRIX	$3.9^{+0.1}_{-0.1}$(scale)
	Measured	$5.3^{+2.5}_{-2.1}$ (stat)$^{+0.5}_{-0.4}$ (syst)



- Charged final state, sensitive to quark PDFs (process at tree level completely dominated by $q\overline{q}'$ states)
- Sensitive to anomalous values of the WWZ triple gauge coupling
- Dominant SM process in trilepton final states with low hadronic activity
  - Relevant background in many searches: $t\bar{t}H$, $t\bar{t}V$, SUSY EWKino, etc

WZ at 13 TeV (JHEP 07 (2022) 032): Global overview



WZ at 13 TeV (JHEP 07 (2022) 032): signal and control regions

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en mathématique et physique

Baseline selection

3 tight light leptons (leptonMVA) with an OSSF pair

2 OSSF leptons with closest M_{ll} to M_Z are "Z leptons"

Remaining lepton is "W lepton"

$p_{Z1} > 25$ GeV , $p_{Z2} > 10$ GeV , $p_W > 25$ GeV

$M_{ll} > 4$ GeV

Signal Region (SR)
3 leptons, $E_T^{miss} > 30$ GeV , $N_b = 0$
$M_{lll} > 100$ GeV , $|M_{Z1,Z2} - M_Z| < 15$ GeV

Control Region tX (CRtX)
3 leptons, $E_T^{miss} > 30$ GeV , $N_b > 0$
$M_{lll} > 100$ GeV

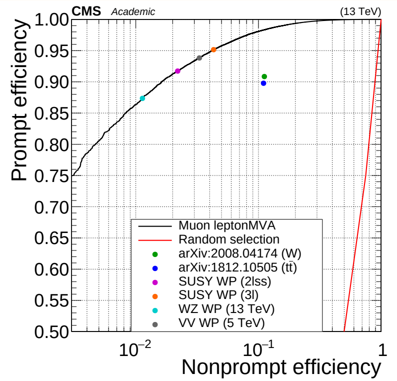
Control Region ZZ (CRZZ)
4 leptons, $E_T^{miss} > 30$ GeV , $N_b = 0$
$M_{lll} > 100$ GeV , $|M_{Z1,Z2} - M_Z| < 15$ GeV

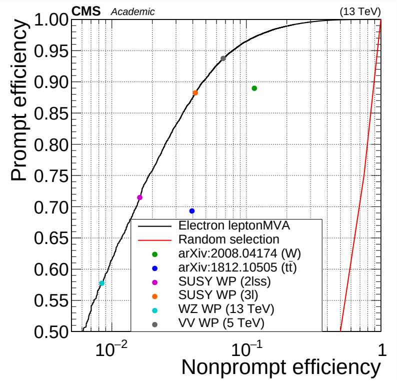
Conversion Control Region (CRconv)
3 leptons, $E_T^{miss} \leq 30$ GeV , $N_b = 0$
$M_{lll} \leq 100$ GeV , $|M_{Z1,Z2} - M_Z| > 15$ GeV

WZ at 13 TeV (JHEP 07 (2022) 032): objects and triggers

- Triggers: $\sim 100\%$ efficiency via soup of $1\ell + 2\ell$ unprescaled lowest-p_T trigger paths
- Lepton reconstruction provides additional background suppression w.r.t. 2016 paper (SMP-18-002, doi:10.1007/JHEP04(2019)122)
  - Leptons are dressed with photon momenta around a radius of 0.10
  - MVA ID tuned against nonprompt leptons now mutuated from optimizations from $\mathrm{t\bar{t}H}$ multilepton observation (HIG-19-008, doi:10.1140/epjc/s10052-021-09014-x)
  - Efficiencies computed in MC events (signal: WZ. background: sum of all nonprompt contributions—mostly $\mathrm{t\bar{t}}$ and DR)

    $$\epsilon(MVA) := \frac{\#\text{events in SR(Loose + MVA cut)}}{\#\text{events in SR(loose)}}$$
  - Also included electron tight-charge criteria: acceptance reduced by $< 1\%$, charge flips from 0.2% to 0.03%!





Plots from the more-than-excellent thesis of Dr. Don Carlos Francisco Erice Cid, https://cds.cern.ch/record/2783330

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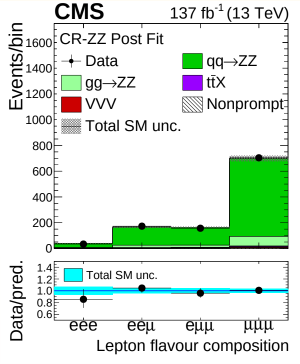
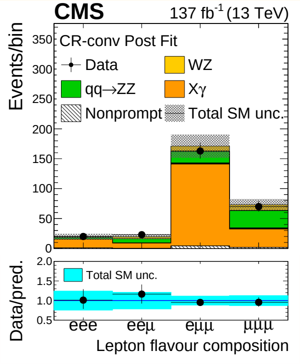
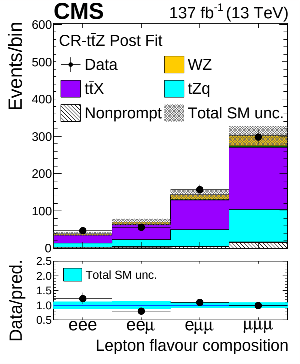
- ZZ CR: Lepton flavour of the 3 leading leptons (i.e. what would affect us in SR if we don't reconstruct the fourth lepton)
- Conversions CR: Stronger electron ID (introduced to reduce nonprompt contributions) reduces this contribution as a side effect
- Top CR: Fakes taken from simulation (mainly $t\bar{t}$ and DY events)

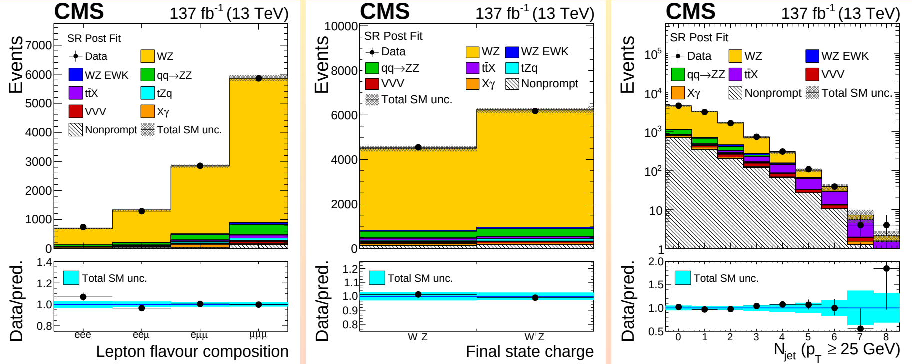






WZ at 13 TeV (JHEP 07 (2022) 032): signal region

- Joint fit to the lepton flavour distributions to extract inclusive cross section (total of 12 bins)



WZ at 13 TeV (JHEP 07 (2022) 032): inclusive cross section

- The observed data favour the MATRIX NNLO predictions
- Fiducial results extrapolated to the total cross section accounting for leptonic branching fractions

$$\sigma_{\mathrm{tot}}(\mathrm{pp} \to \mathrm{WZ}) = \frac{N^{\mathrm{SR}}_{\mathrm{WZ}}}{B(\mathrm{W} \to \ell\nu)B(\mathrm{Z} \to \ell'\ell')\mathcal{A}\epsilon\mathcal{L}} f_\tau$$

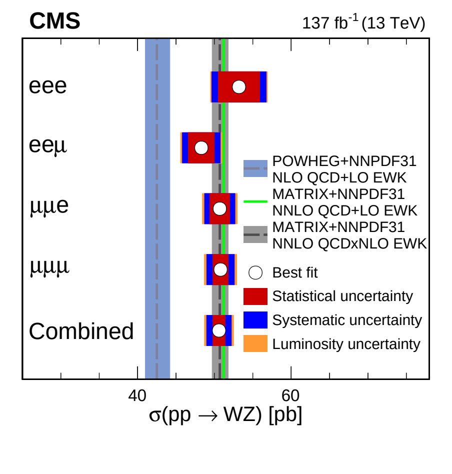
- About 4% total uncertainty!!! (best to date: ATLAS is at about 5% level)
  - Dominant uncertainties (in order): luminosity, b tagging, nonprompt leptons

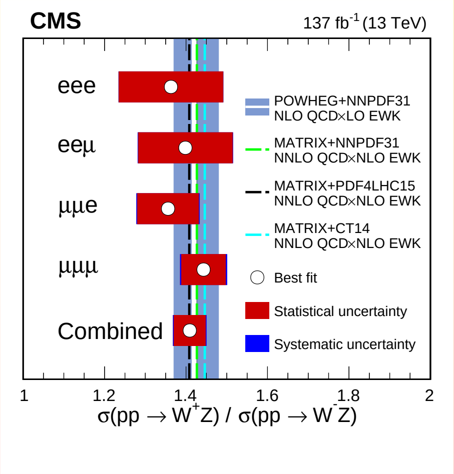
Category or source	Total cross section
POWHEG	$42.5\,^{+1.6}_{-1.4}$(scale) $\pm\, 0.6$(PDF) pb
MATRIX, NNLO QCD	$51.2\,^{+1.2}_{-1.0}$(scale) pb
MATRIX, NNLO QCD $\times$ NLO EWK	$50.7\,^{+1.1}_{-1.0}$(scale) pb
eee (Measured)	53.2 ± 2.7((stat)) $\pm\, 2.3$((syst)) $\pm\, 1.1$((lumi)) $\pm\, 0.5$((theo)) pb
eeμ (Measured)	48.1 ± 1.7((stat)) $\pm\, 1.8$((syst)) $\pm\, 1.1$((lumi)) $\pm\, 0.4$((theo)) pb
$\mu\mu$e (Measured)	50.6 ± 1.3((stat)) $\pm\, 1.5$((syst)) $\pm\, 1.1$((lumi)) $\pm\, 0.5$((theo)) pb
$\mu\mu\mu$ (Measured)	50.8 ± 1.0((stat)) $\pm\, 1.5$((syst)) $\pm\, 1.1$((lumi)) $\pm\, 0.5$((theo)) pb
Combined (Measured)	50.6 ± 0.8((stat)) $\pm\, 1.5$((syst)) $\pm\, 1.1$((lumi)) $\pm\, 0.5$((theo)) pb

Category (Source)	Fiducial cross section
eee (POWHEG)	$62.5\,^{+2.4}_{-2.0}$(scale) $\pm\, 0.9$(PDF) fb
eee (MATRIX, NNLO QCD)	$76.8\,^{+1.8}_{-1.6}$(scale) fb
eee (MATRIX, NNLO QCD $\times$ NLO EWK)	$75.3\,^{+1.7}_{-1.5}$(scale) fb
eee (Measured)	78.6 ± 4.1((stat)) $\pm\, 3.3$((syst)) $\pm\, 1.4$((lumi)) $\pm\, 0.7$((theo)) fb
eeμ (POWHEG)	$62.5\,^{+2.4}_{-2.0}$(scale) $\pm\, 0.9$(PDF) fb
eeμ (MATRIX, NNLO QCD)	$75.3\,^{+1.8}_{-1.6}$(scale) fb
eeμ (MATRIX, NNLO QCD $\times$ NLO EWK)	$73.8\,^{+1.7}_{-1.5}$(scale) fb
eeμ (Measured)	71.3 ± 2.9((stat)) $\pm\, 2.6$((syst)) $\pm\, 1.3$((lumi)) $\pm\, 0.7$((theo)) fb
$\mu\mu$e (POWHEG)	$62.5\,^{+2.4}_{-2.0}$(scale) $\pm\, 0.9$(PDF) fb
$\mu\mu$e (MATRIX, NNLO QCD)	$75.3\,^{+1.8}_{-1.6}$(scale) fb
$\mu\mu$e (MATRIX, NNLO QCD $\times$ NLO EWK)	$73.8\,^{+1.7}_{-1.5}$(scale) fb
$\mu\mu$e (Measured)	74.8 ± 1.9((stat)) $\pm\, 2.1$((syst)) $\pm\, 1.4$((lumi)) $\pm\, 0.7$((theo)) fb
$\mu\mu\mu$ (POWHEG)	$62.5\,^{+2.4}_{-2.0}$(scale) $\pm\, 0.9$(PDF) fb
$\mu\mu\mu$ (MATRIX, NNLO QCD)	$76.8\,^{+1.8}_{-1.6}$(scale) fb
$\mu\mu\mu$ (MATRIX, NNLO QCD $\times$ NLO EWK)	$75.3\,^{+1.7}_{-1.3}$(scale) fb
$\mu\mu\mu$ (Measured)	74.9 ± 1.4((stat)) $\pm\, 1.9$((syst)) $\pm\, 1.4$((lumi)) $\pm\, 0.7$((theo)) fb
Inclusive (POWHEG)	$250.0\,^{+9.7}_{-8.0}$(scale) $\pm\, 3.5$(PDF) fb
Inclusive (MATRIX, NNLO QCD)	$304.2\,^{+7.3}_{-6.5}$(scale) fb
Inclusive (MATRIX, NNLO QCD $\times$ NLO EWK)	$298.1\,^{+6.9}_{-6.3}$(scale) fb
Inclusive (Measured)	298.9 ± 4.8((stat)) $\pm\, 7.7$((syst)) $\pm\, 5.4$((lumi)) $\pm\, 2.7$((theo)) fb

WZ at 13 TeV (JHEP 07 (2022) 032): charge-dependent cross section

- 90% of total uncertainty due to statistical uncertainty
- Reduction in the combination: about 50%, to the 3% level (ATLAS/CMS have 5%)
- Final measurement uncertainty below POWHEG theoretical uncertainties!!!



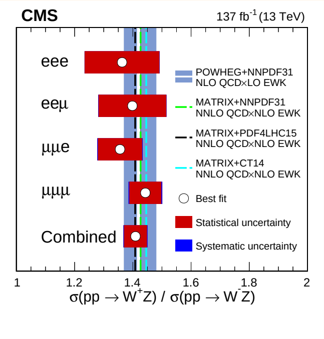


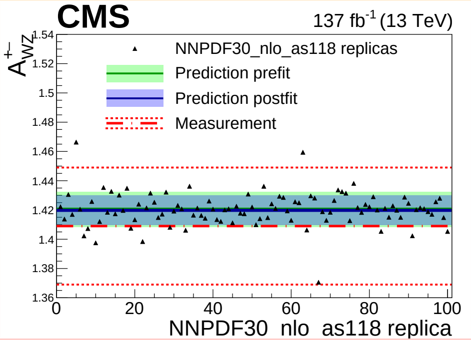
WZ at 13 TeV (JHEP 07 (2022) 032): constraints on parton distribution functions for the LHC

- Sizeable asymmetry between the cross sections of W^+Z and W^-Z

$$A^{+-}(\mathrm{WZ}) = \frac{\sigma_{\mathrm{fid}}(\mathrm{pp} \to \mathrm{W^+Z})}{\sigma_{\mathrm{fid}}(\mathrm{pp} \to \mathrm{W^-Z})}.$$

  - The cause is traced to the behaviour of the up and down quark parton distribution functions (the probabilities to find these quarks in a hadron as a function of the fraction x of the proton's momentum carried by the parton)
  - Several sets of parton distribution functions are computed from theory and used to model a systematic uncertainty
- Bayes theorem: update your belief on the model (prior) using the results of an experiment
  - Bayesian reweighting (Giele, 1998) to estimate the amount of information provided by the measurement



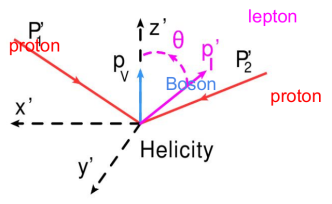


WZ at 13 TeV (JHEP 07 (2022) 032):
W and Z boson helicity measurement

- Helicity of W boson: search for BSM-originated anomalies in the spin correlations between W and its decay products
  - Already explored in $t\bar{t}$, single top, W+jets, etc.
  - So far hard in $WZ \to 3\ell\nu$ (limited statistics): now we have 140 fb^{-1}!
- Assign each leptons to its parent boson: $ee\mu$ and $\mu\mu e$ final states
- Already done by ATLAS: ATLAS CONF 2018-034
- A theory paper
- Estimate spin density matrix for the 3 polarizations of the W.
  At LO and assuming no interference, access diagonal terms measuring

$$\frac{d\sigma}{\sigma d\cos\theta_3} \equiv \frac{3}{8}\left[(1 \mp \cos\theta_3)^2 f_L^{W^\pm} + (1 \pm \cos\theta_3)^2 f_R^{W^\pm} + 2\sin^2\theta_3 f_0^{W^\pm}\right]$$

- θ_3 angle between p(ℓ from W) and p(W)
- Fully reconstructed at gen-level
- Frame-dependent fractions f_L^W, f_R^W, f_0^W
- Helicity frame
  - V boson frame with its z' axis aligned to the boson momentum p_V in the lab frame
  - W mass constraint
  - x-y axis symmetry, broken in case of ϕ-dependent acceptance/efficienciy



WZ at 13 TeV (JHEP 07 (2022) 032): build the W polarization models for WZ

- Reweight WZ events to a given target polarization

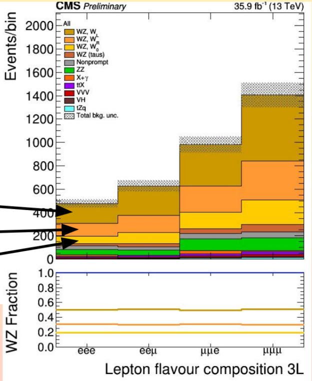
$$w(\theta_{gen}) = \frac{f_L(1 \mp \cos(\theta_{gen}))^2 + f_R(1 \pm \cos(\theta_{gen}))^2 + 2f_0\sin(\theta_{gen})^2}{f_L^{SM}(1 \mp \cos(\theta_{gen}))^2 + f_R^{SM}(1 \pm \cos(\theta_{gen}))^2 + 2f_0^{SM}\sin(\theta_{gen})^2}$$

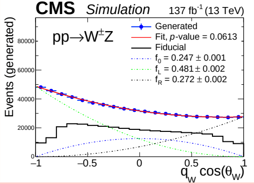
- Signal region (SR) selection
  - 3 leptons (p_{T} >25/25/10)
  - $p_{\mathrm{T}}^{\mathrm{miss}}$ >30 GeV
  - $N_{\mathrm{b}} = 0$
  - $M_{3\ell} > 100$ GeV
  - $|M_{\mathrm{Z1,Z2}} - M_{\mathrm{Z}}| < 15$ GeV
  - Treat events with leptonic τ decays as background

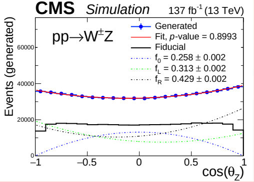
"WZ,W$_L$" := {$f_L = f_L^{SM}$, $f_R = 0$, $f_0 = 0$}

"WZ,W$_R$" := {$f_L = 0$, $f_R = f_R^{SM}$, $f_0 = 0$}

"WZ,W$_0$" := {$f_L = 0$, $f_R = 0$, $f_0 = f_0^{SM}$}



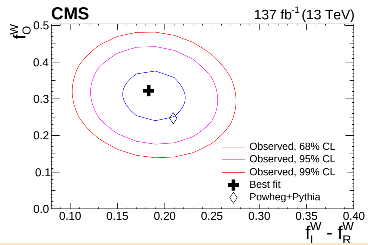


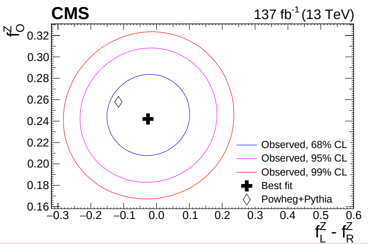


WZ at 13 TeV (JHEP 07 (2022) 032): results for W and Z polarizations

- Build $cos(\theta_3)$ in the SR
  - OSSF lepton pair with mass closest to M_Z as Z, the other is tagged as W
  - Neutrino momentum via p_T^{miss}, using W mass as constraint
- Maximum likelihood fit to the $cos(\theta_3)$ distribution in 10 bins
  - 4 free parameters: r, f_0, f_L, f_R
  - 1 constraint: $f_0 + f_L + f_R = 1$
- Data point at complete decorrelation between the measurements of the longitudinal and transverse polarization components for both boson flavours

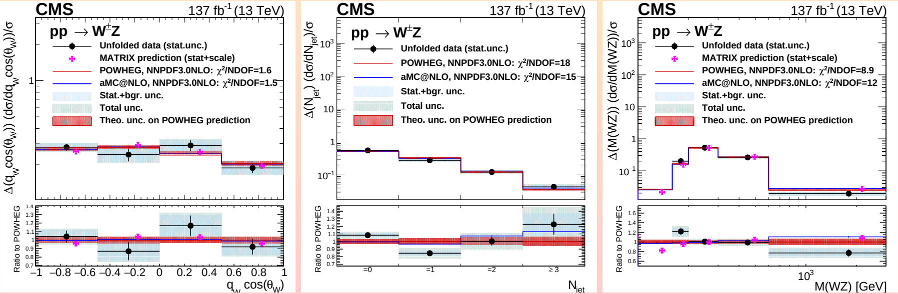
Boson and total leptonic charge	Observable	Observed	POWHEG expected	MATRIX expected
W, inclusive	f_0	$0.322^{+0.080}_{-0.077}$	$0.2470^{+0.0003}_{-0.0003}$	$0.248^{+0.003}_{-0.003}$
	f_{LR}	$0.183^{+0.032}_{-0.032}$	$0.209^{+0.002}_{-0.002}$	$0.210^{+0.006}_{-0.006}$
W, plus	f_0	$0.358^{+0.100}_{-0.096}$	$0.2294^{+0.0003}_{-0.0003}$	$0.237^{+0.004}_{-0.004}$
	f_{LR}	$0.288^{+0.041}_{-0.042}$	$0.305^{+0.003}_{-0.003}$	$0.293^{+0.007}_{-0.007}$
W, minus	f_0	$0.361^{+0.118}_{-0.128}$	$0.2782^{+0.0007}_{-0.0007}$	$0.268^{+0.005}_{-0.005}$
	f_{LR}	$0.010^{+0.055}_{-0.049}$	$0.056^{+0.002}_{-0.002}$	$0.076^{+0.007}_{-0.007}$
Z, inclusive	f_0	$0.245^{+0.024}_{-0.024}$	$0.2583^{+0.0003}_{-0.0003}$	$0.253^{+0.003}_{-0.003}$
	f_{LR}	$-0.038^{+0.078}_{-0.078}$	$-0.116^{+0.002}_{-0.002}$	$-0.120^{+0.006}_{-0.006}$
Z, plus	f_0	$0.236^{+0.030}_{-0.030}$	$0.2710^{+0.0003}_{-0.0003}$	$0.263^{+0.004}_{-0.004}$
	f_{LR}	$0.039^{+0.101}_{-0.101}$	$-0.073^{+0.003}_{-0.003}$	$-0.083^{+0.007}_{-0.007}$
Z, minus	f_0	$0.266^{+0.037}_{-0.037}$	$0.2392^{+0.0005}_{-0.0005}$	$0.238^{+0.004}_{-0.004}$
	f_{LR}	$-0.164^{+0.121}_{-0.121}$	$-0.179^{+0.003}_{-0.003}$	$-0.178^{+0.007}_{-0.007}$





WZ at 13 TeV (JHEP 07 (2022) 032): differential cross section measurements

- Unfold same observables as the 2016 paper doi:10.1007/JHEP04(2019)122
  - p_{T} (lead jet): probes the recoil of the WZ system w.r.t. initial-state radiation
  - $p_T^Z := p_T^{\ell\ell}$, sensitive to anomalies at higher energies.
  - p_{T} (W): sensitive to asymmetries in u/d quark production (also charge split)
  - $M(\mathrm{WZ}) = \sqrt{p(\ell_1) + p(\ell_2) + p(\ell_3) + p(\nu)}$, where $p(\nu) = (0, p_{\mathrm{T}}(p_{\mathrm{T}}^{\text{miss}}), 0, \phi(p_{\mathrm{T}}^{\text{miss}}))$ (also used in aTGC search, see next slide)
- New observables!
  - $cos(\theta_{\mathrm{W}})$: used for W boson polarization
  - $cos(\theta_{\mathrm{Z}})$: used for Z boson polarization
  - N_{jets}: of special interest to observe the validity of jet simulation
- All measurements also split by leptonic charge and flavour (many as additional material)
- MATRIX preductions not included for N_{jets} because they are computed at fixed order and not matched to parton shower

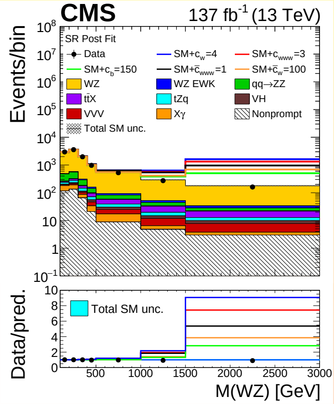


WZ at 13 TeV (JHEP 07 (2022) 032): anomalous trilinear gauge coupling

- Sensitivity to multiple BSM effects as effective low energy theories
- Using generic model w/ three different couplings

$$\frac{\mathcal{L}_{\mathrm{TGC}}}{g_{WWV}} = i g_1^V \left(W^-_{\mu\nu} W^{+\mu} V^\nu - W^-_\mu V_\nu W^{+\mu\nu}\right) + i\kappa_V W^-_\mu W^+_\nu V^{\mu\nu} + \frac{i\lambda_V}{M_W^2} W^-_{\delta\mu} W^{+\mu}_\nu V^{\nu\delta}$$

- SM: $g_1^Z = 1,\ k_Z = 1,\ \lambda_Z = 0$
- Less sensitive to k_Z term
  - No access to the p_T of the W propagator
- Production is enhanced at high p_T
- Use $M_{\ell\ell\ell E_T^{\text{miss}}}$ to constrain aTGC



- Use EFT parameterization to generate samples, transform to AC lagrangian to express the results

$$\kappa_Z = 1 + \left(c_W - c_B \tan^2\theta_W\right)\frac{m_W^2}{2\Lambda^2}$$

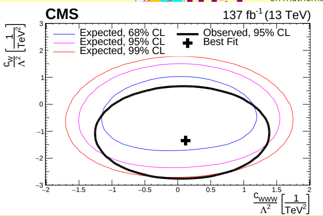
$$\lambda_Z = \lambda_\gamma = c_{WWW}\frac{3g^2 m_W^2}{2\Lambda^2} \qquad g_1^Z = 1 + c_W \frac{m_Z^2}{2\Lambda^2}$$

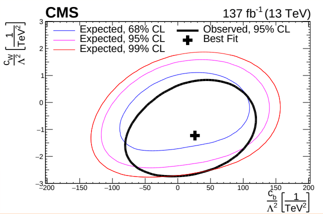
	λ_z (95% CL)	Δg_1^z (95% CL)	Δk_z (95% CL)
ATLAS WZ (8TeV)	[-0.014,0.013]	[-0.015,0.030]	[-0.13,0.24]
CMS WZ (8TeV)	[-0.018,0.016]	[-0.018,0.035]	[-0.21,0.24]

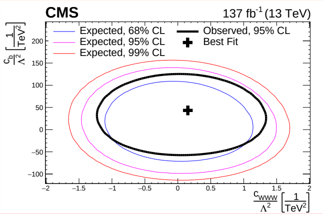
WZ at 13 TeV (JHEP 07 (2022) 032): aTGC results

- aTGC modelled using quadratic functions of the couplings
- New since 2016 paper: probed CP-violating parameters!
- Possible correlations across the CP-conserving EFT terms can be read in the two-dim plots

Parameter	95% CI, exp. (TeV^{-2})	95% CI, obs. (TeV^{-2})	Best fit, obs. (TeV^{-2})
c_{w}/Λ^2	$[-2.0, 1.3]$	$[-2.5, 0.3]$	-1.3
$c_{\mathrm{www}}/\Lambda^2$	$[-1.3, 1.3]$	$[-1.0, 1.2]$	0.1
c_{b}/Λ^2	$[-86, 125]$	$[-43, 113]$	44
$\tilde{c}_{\mathrm{www}}/\Lambda^2$	$[-0.76, 0.65]$	$[-0.62, 0.53]$	-0.03
$\tilde{c}_{\mathrm{w}}/\Lambda^2$	$[-46, 46]$	$[-32, 32]$	0



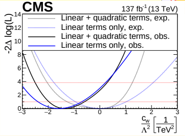


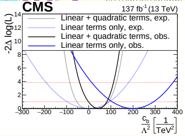


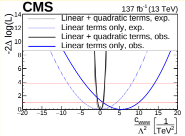
WZ at 13 TeV (JHEP 07 (2022) 032): crosschecking EFT

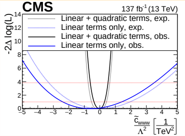
- The quadratic terms used in the statistical model the pure BSM contributions from EFT
- Dim-6 operators: BSM-SM interference described by linear terms, but Λ^{-2}- and Λ^{-4}-suppressed
- Dim-8 operators would introduce additional interference term, and results would be accurate only up to Λ^{-2}-suppressed contributions
- Additional fit using only the linear terms of the quadratic fitting functions, to check effect of dropping Λ^{-4} terms
- Dim-6 operators lead to nonphysical (unitarity breaking, infinite xsecs) results at arbitrarily high energies. Cutoff scale to suppress EFT at high energies introduced

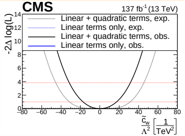
Parameter	95% CI, exp. (TeV^{-2})	95% CI, obs. (TeV^{-2})	Best fit, obs. (TeV^{-2})
c_{w}/Λ^2	$[-1.8, 2.1]$	$[-3.1, 0.3]$	-1.6
$c_{\mathrm{www}}/\Lambda^2$	$[-8.5, 8.5]$	$[-4.2, 14.2]$	5.5
c_{b}/Λ^2	$[-200, 180]$	$[10, 380]$	200
$\tilde{c}_{\mathrm{www}}/\Lambda^2$	$[-3.3, 4.1]$	$[-4.0, 3.6]$	-0.6
$\tilde{c}_{\mathrm{w}}/\Lambda^2$	—	—	—

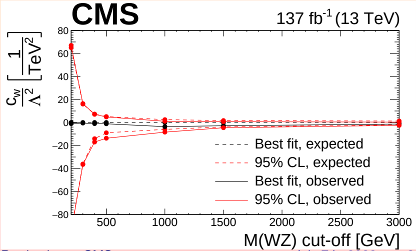


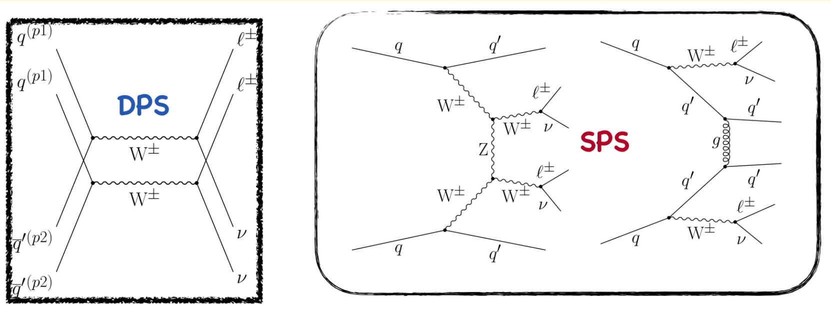






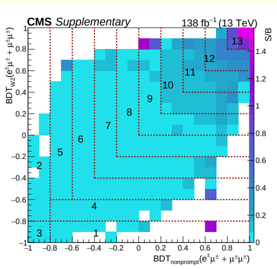


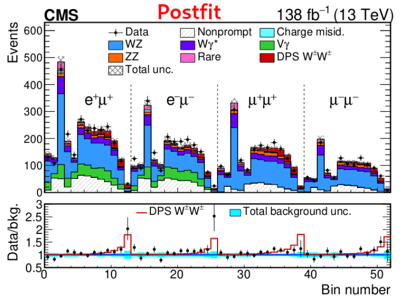


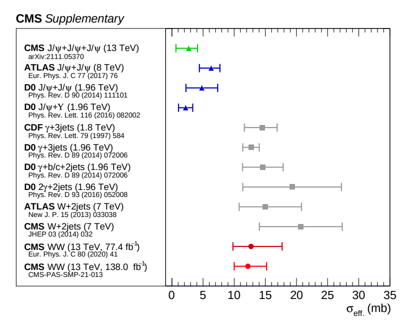


- Double parton scattering processes: info on transverse profile of the proton and its energy evolution
  - Interparton correlation models: study parton correlations in terms of spin, colour, momentum, etc.
- Two-lepton-same-sign channel is golden to study DPS
  - Suppress SPS production by vetoing extra jets
  - Leptonic W decays provide clean final state, background with WW from pileup events is negligible
- $\mathrm{WW} \to \mathrm{e}\mu/\mu\mu +$ MET final states, full Run 2 luminosity (138 fb^{-1})

WW DPS at 13 TeV (2206.02681): results







- Main backgrounds: WZ and nonprompt leptons
- S/B discrimination is based on BDTs
- First observation of WW via DPS!!!
  - Significance ~ 6 s.d.
- Inclusive and fiducial xsec measurements in agreement with predictions from FEWZ
- Effective cross section also measured, characterizing the transverse distribution of partons in the proton
- Sensitivity towards parton correlations is limited by statistics

Summary of multiboson production studies

- Shown two recent precision measurements of SM multiboson production
- Diboson production at 5 TeV: PRL 127 (2021) 191801
  - Important probe of the SM at a new energy
  - Data favour NNLO predictions by MATRIX
- WZ at 13 TeV: JHEP 07 (2022) 032 (published today!!!)
  - Inclusive and differential cross section measurement
  - Charge asymmetry measurement
  - Constraints on LHC PDFs
  - Constraints on anomalous trilinear gauge coupling
  - All SM results favour NNLO predictions by MATRIX
- Observation of WW DPS at 13 TeV: 2206.02681 (submitted to PRL)
  - Observation at the 6 s.d. level
  - Inclusive and fiducial cross sections consistent with NLO predictions from FEWZ
  - Results consistent with measurements from final states with vector bosons
  - Effective cross section also measured, characterizing the transverse distribution of partons in the proton
- Remeasure in Run 3 with improved precision!