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DIBOSON CROSS SECTION MEASUREMENTS AT 5 TEV IN CMS

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(On behalf of the CMS Collaboration)

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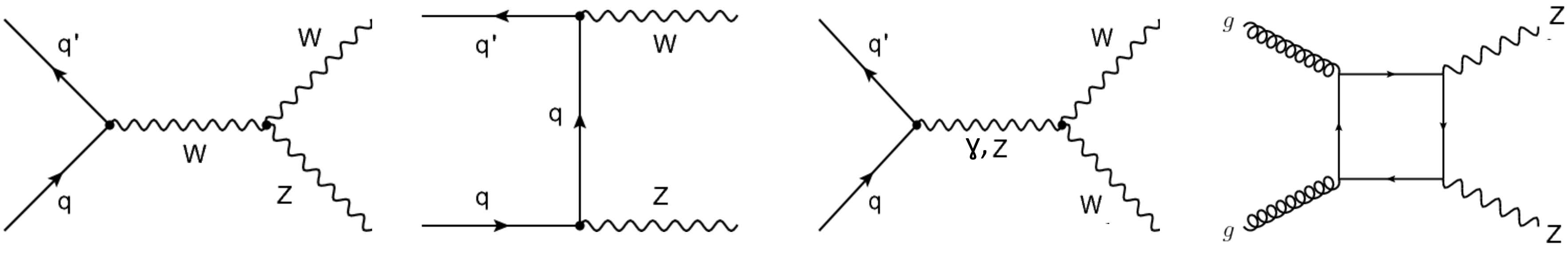
CMS-PAS-SMP-20-012

MOTIVATION

CMS-PAS-SMP-20-012

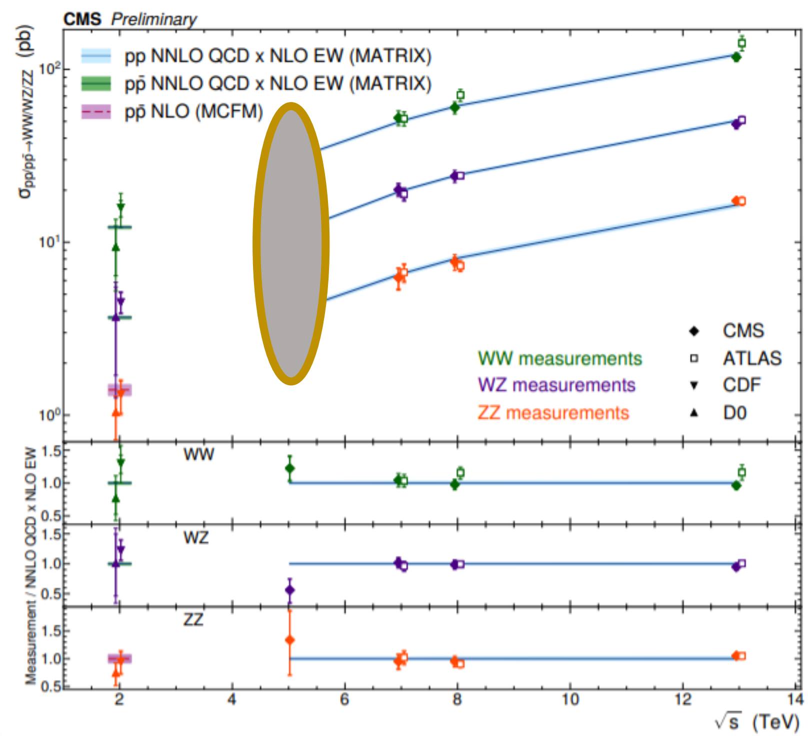
Measurements of the diboson, **W^+W^-, $W^{\pm}Z$ and ZZ**, production cross sections at the **5 TeV** energy regime using 304 pb^{-1} recorded in 2017.



Diboson production is important for several reasons:

- It is a **test of the Standard Model (SM)** of particle physics.
- It is an **irreducible background** in other SM measurements and BSM searches.

First results at 5 TeV!



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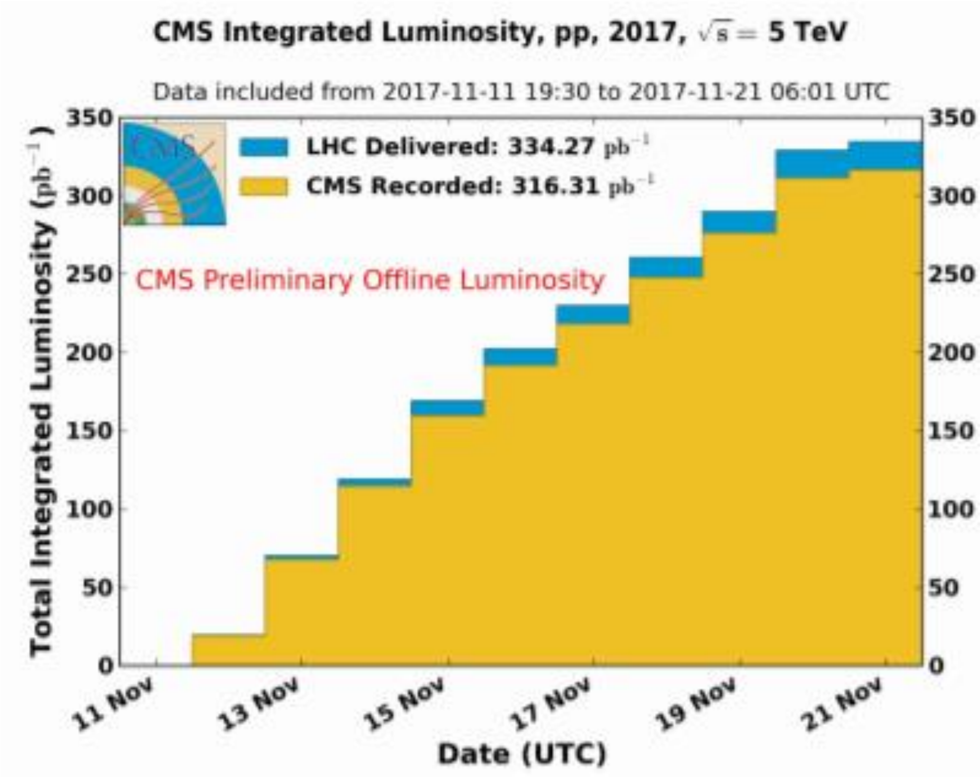
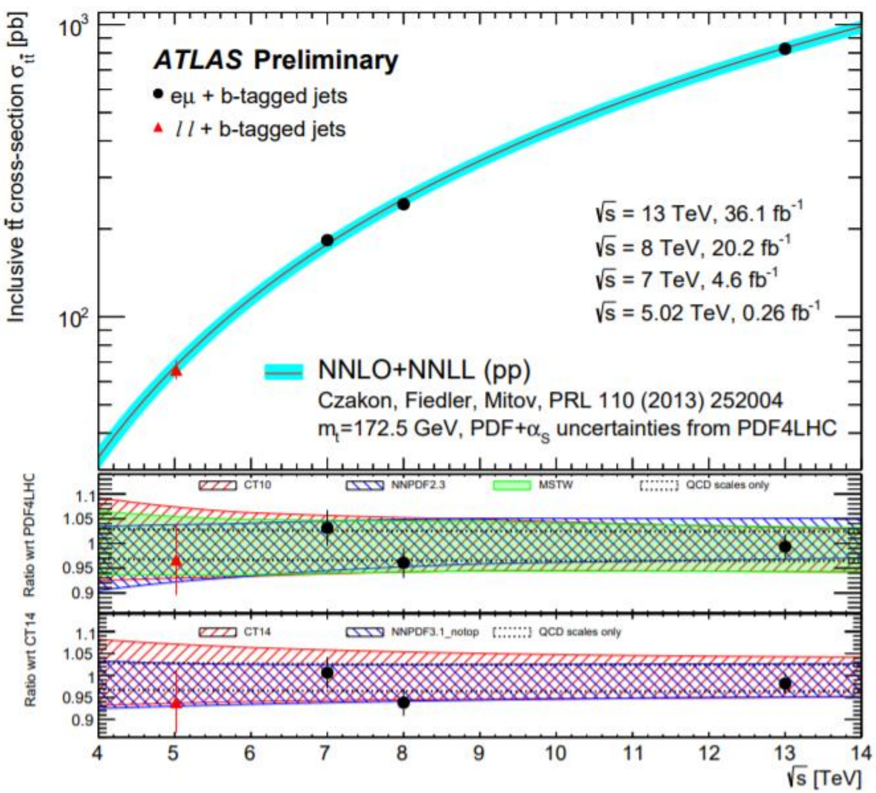
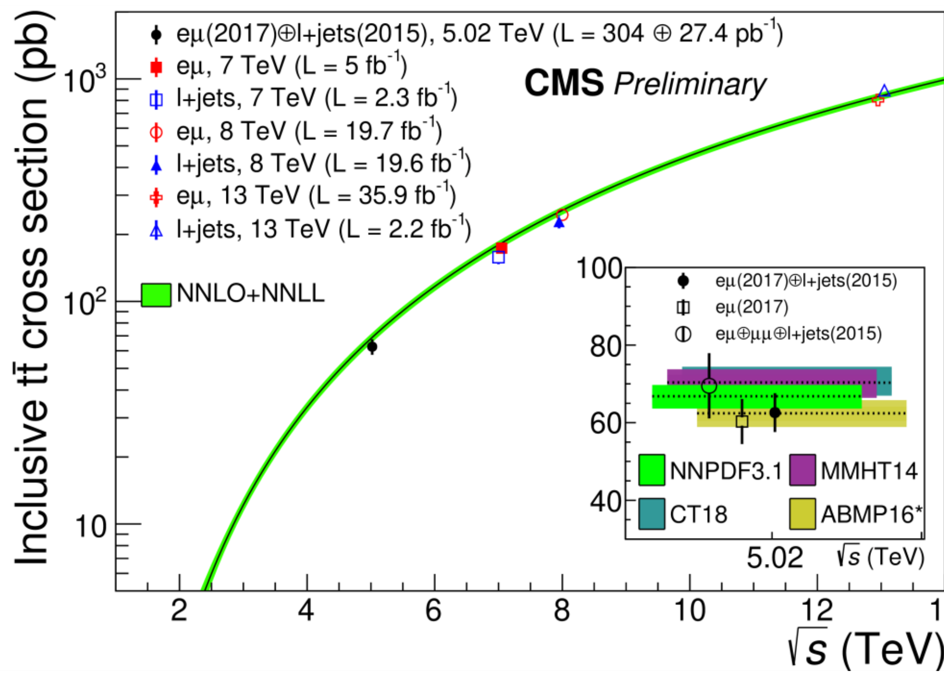


- The mean number of pp interactions per bunch crossing was around 2.
- Maximum inst. luminosity: $\mathcal{L}_{inst}$ **= 1.38 × $10^{33}cm^{-2}\ s^{-1}$.**
- Dataset is characterized by a relatively **low pile-up contribution** as compared to the measurements of weak-boson production performed at higher center-of-mass energies.

Related analyses

This dataset has been used by ATLAS and CMS to measure the $t\bar{t}$ cross section.





The new result is combined with the one of JHEP 03 (2018) 115 which used 27.4 pb^{-1} recorded in 2015.

ATLAS-CONF-2021-003

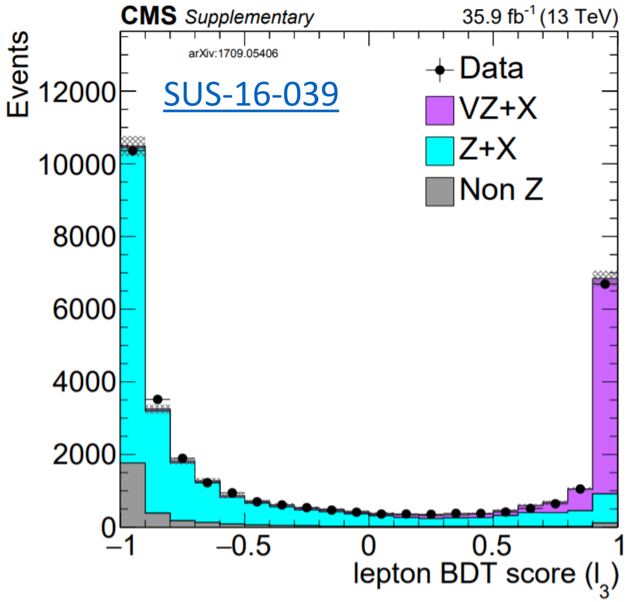
CMS-PAS-TOP-20-004

OBJECT RECONSTRUCTION

The key objects in this analysis are the leptons: electrons and muons.

- A set of identification criteria is specifically designed to separate the leptons produced in W and Z decays from those that arise from nonprompt leptons.

- The ID developed here is based in an existing one at 13 TeV that has been widely used already by CMS: **lepton MVA**. In particular, it was used in a recent measurement of the Higgs boson production rate in association with top quarks. [arXiv:2011.03652]



- Two leptons categories are defined, **loose and tight leptons**:

  - The loose identification criteria are used to preselect all leptons in the events.
    p_T > 8 GeV, $|\eta|$< 2.4, dxy < 0.05 cm, dz < 0.1 cm, isolation < 0.4

  - The tight selection used the lepton MVA method to reduce the nonprompt contribution.
    loose leptons + lepton MVA, tighter isolation cut, cut on the b-tagging DEEPJET discriminator

EVENT SELECTION: SIGNAL REGIONS

WW

- Exactly **2 tight** opposite charge different flavour leptons
- $\mathrm{p_T}(\ell_1)$ > 20 GeV
- $\mathrm{p_T}(\ell_2)$ > 10 GeV
- $\mathrm{p_T}(\ell\ell')$ > 20 GeV
- $\Delta\Phi(\ell\ell')$ < 2.8 rad
- min($m_{\ell\ell'}$) > 12 GeV
- Jet veto ($\mathrm{p_T}$ > 25 GeV)
- min($\mathrm{m_T}(\mathrm{e}, p_T^{miss}), \mathrm{m_T}(\mu, p_T^{miss})$) > 20 GeV

EVENT SELECTION: SIGNAL REGIONS

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- $p_T(\ell_2) > 10$ GeV
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- $\Delta\Phi(\ell\ell') < 2.8$ rad
- $\min(m_{\ell\ell'}) > 12$ GeV
- Jet veto ($p_T > 25$ GeV)
- $\min(m_T(e, p_T^{miss}), m_T(\mu, p_T^{miss})) > 20$ GeV

WZ

➢ **3ℓ**

- Exactly 3 leptons with $p_T > 8$ GeV and the 2LSS passing a tight ID
- $p_T(\ell_W) > 20$ GeV
- $\min(m_{\ell\ell'}) > 12$ GeV
- $m_{\ell_{Z1},\ell_{Z2},\ell_W} > 100$ GeV
- $|m_Z - 91.2| < 30$ GeV

➢ **2μ same-sign**

- 2 muons same-sign passing a tight ID and tight charge with $p_T > 20,10$ GeV.
- $\min(m_{\ell\ell'}) > 12$ GeV
- Jet veto ($p_T > 25$ GeV)
- $p_T^{miss} > 25$ GeV

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- 2 muons same-sign passing a tight ID and tight charge with p_T >20,10 GeV.
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- $p_T^{miss} > 25$ GeV

ZZ

➢ 4ℓ

- Exactly 4 leptons with $p_T > 8$ GeV
- $\min(m_{\ell\ell'}) > 12$ GeV

➢ $2\ell2\nu$

- Exactly 2 tight opposite charge same-flavour leptons with $p_T > 20,10$ GeV
- $\min(m_{\ell\ell'}) > 12$ GeV
- $|m_Z$-91.2$| < 10$ GeV
- Jet veto ($p_T > 25$ GeV)
- $|p_T^{miss} - p_T^Z|/p_T^Z < 0.3$
- $-p_T^{miss} \times \cos(\Delta\Phi(p_T^{miss}, p_T^Z)) > 50$ GeV

BACKGROUND ESTIMATION

- Signal samples are generated using **POWHEG+PYTHIA8**.
- All background contributions are estimated from **MC simulation** except for those involving 2 nonprompt leptons.
- The **nonprompt SM sources** depend on the decay channel:
  - At least 3 leptons: Z+jets and dileptonic $t\bar{t}$ production. -> estimated from MC.
  - 2 leptons: W+jets and semileptonic $t\bar{t}$ production. -> estimated using a leptons misidentification rate method based on the misidentification rate measured in a simulated $t\bar{t}$ sample and applied to control region data.

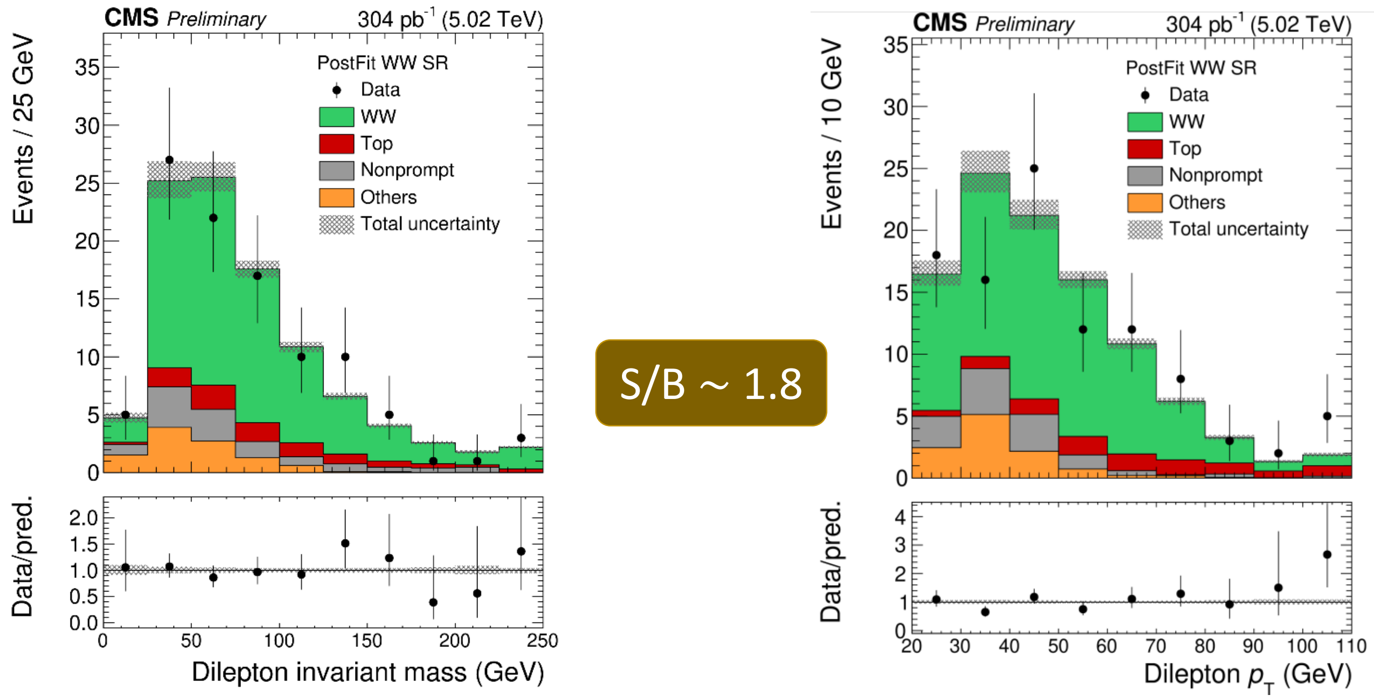
DY VALIDATION REGION

Determined from the WW SR by replacing the two opposite-flavor leptons with two **same-flavor** leptons.

TOP VALIDATION REGION

Defined inverting the **jet-veto** requirement from the WW SR to enhance the top quark processes contribution.

WW SIGNAL REGION

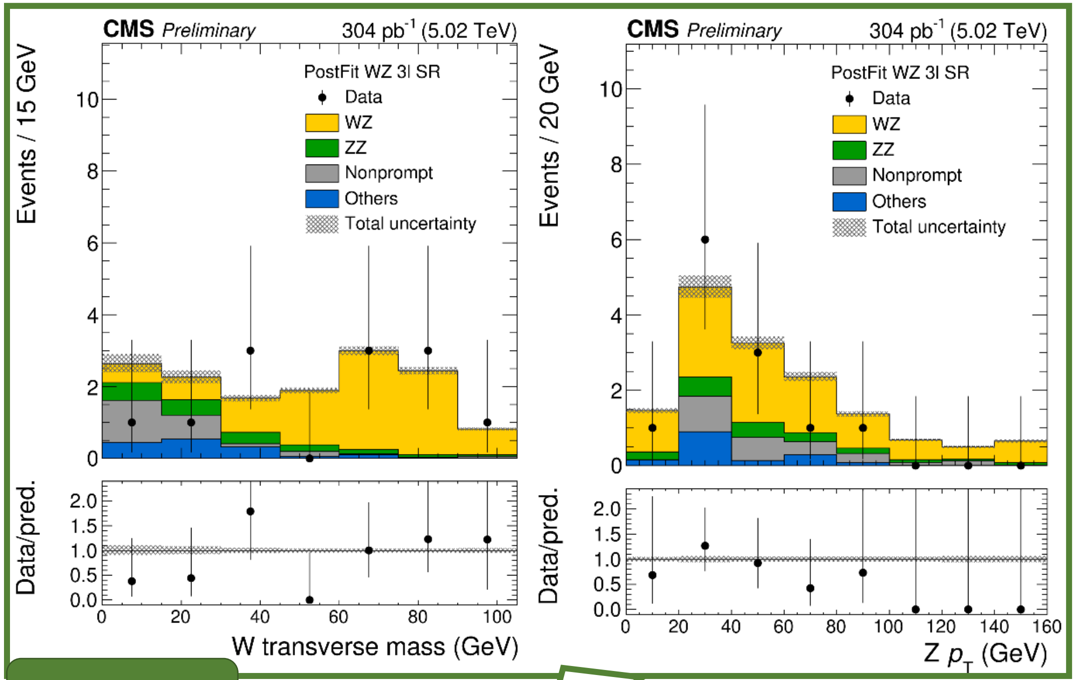


S/B ~ 1.8

Source	Number of events
Top	$9.1 \pm 0.1 \pm 1.1$
VV	$5.7 \pm 1.0 \pm 1.1$
DY	$1.8 \pm 0.5 \pm 0.2$
Conversions	$2.7 \pm 0.7 \pm 0.7$
Nonprompt	$11.1 \pm 1.3 \pm 3.4$
Background	$30.4 \pm 1.9 \pm 3.9$
WW Signal	$55.5 \pm 0.3 \pm 1.7$
Observed data	101

Main background contributions are from nonprompt and top.

WZ SIGNAL REGIONS



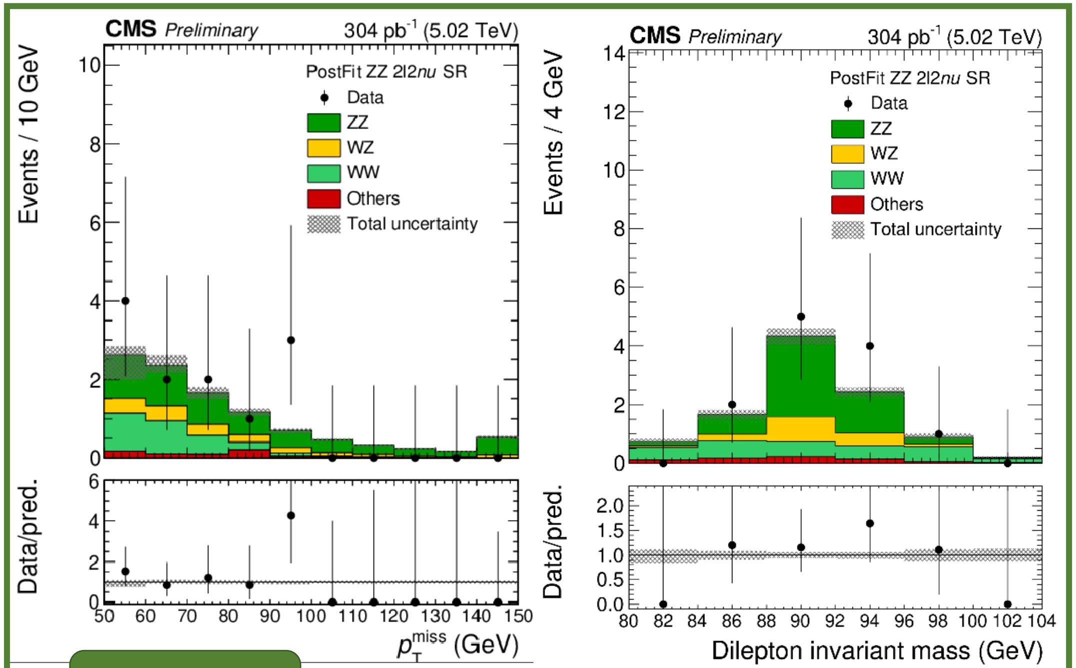
S/B ~ 3.7

S/B ~ 5.3

Source	WZ 3ℓ	WZ $2\mu ss$
ZZ	$1.7 \pm 0.0 \pm 0.1$	$0.1 \pm 0.0 \pm 0.0$
Conversions	$0.8 \pm 0.3 \pm 0.2$	—
Nonprompt	$1.2 \pm 0.5 \pm 0.2$	$0.5 \pm 0.1 \pm 0.1$
WZ	$14.9 \pm 0.1 \pm 0.6$	$3.2 \pm 0.8 \pm 0.2$
Background	$4.0 \pm 0.6 \pm 0.4$	$0.6 \pm 0.1 \pm 0.1$
Observed Data	12	4

Main background contributions from ZZ.

ZZ SIGNAL REGIONS



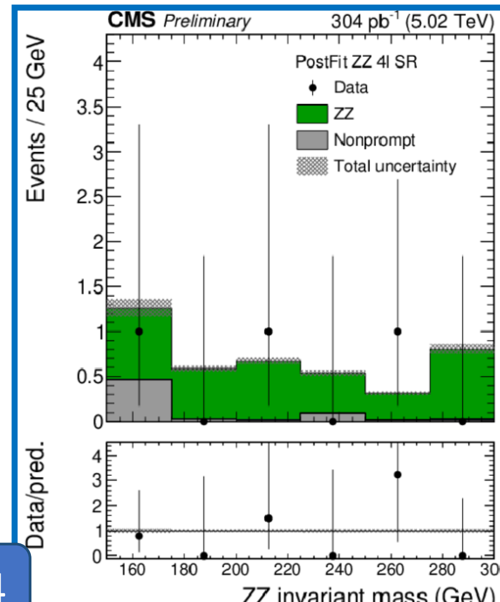
S/B ~ 0.8

$2\ell 2\nu$

Source	Number of events
WZ	$1.7 \pm 0.0 \pm 0.3$
WW	$2.6 \pm 0.1 \pm 0.5$
Top	$0.46 \pm 0.03 \pm 0.06$
Drell–Yan	$0.2 \pm 0.3 \pm 0.1$
ZZ	$4.0 \pm 0.0 \pm 0.2$
Background	$4.9 \pm 0.3 \pm 0.7$
Observed Data	12

4ℓ

Source	Number of events
Conversions	$0.03 \pm 0.01 \pm 0.01$
Nonprompt	$0.5 \pm 0.2 \pm 0.1$
ZZ	$2.7 \pm 0.0 \pm 0.1$
Background	$0.5 \pm 0.2 \pm 0.1$
Observed Data	3



S/B ~ 5.4

UNCERTAINTIES

Categories	Source	WW	WZ	ZZ
Experimental	Trigger efficiencies	5% (p_T <15 GeV), 1%	3% (2ℓ), <0.5% (3ℓ)	1% (2ℓ), <0.5% (4ℓ)
	Lepton efficiencies	1% (2%) for μ (e)	1-3%	~2%
	JES	~1-2%	~1% (only 2μss)	~1% (only 2ℓ)
	JER	~1-2%	~1% (only 2μss)	~1% (only 2ℓ)
	L1 Prefiring	< 2%	1-2%	1%
	Nonprompt closure	30% (e), 15% (μ)	30% (e), 15% (μ) only 2μss	—
	Luminosity	1.5%	1.5%	1.5%
Background normalization	Nonprompt	—	20% (3ℓ)	20% (4ℓ)
	Flips	—	20%	—
	Conversions	30%	30%	30%
	VV	20%	20%	20% ($2\ell 2\nu$)
	Top	10%	—	10% ($2\ell 2\nu$)
	Drell–Yan	10%	—	10% ($2\ell 2\nu$)
Theory	PDF + α_S	< 1%	< 1%	~ 2%
	QCD scale	< 3%	< 3%	~ 3-4%

STRATEGY

Goal: extraction of **total observed cross section.**

- The number of events in the signal region is measured in a counting experiment in a region with high signal purity.
- Compare with **MATRIX NNLO QCDxNLO EWK** predictions.

Total region definitions

- WW: $\mathrm{m}^{0\mathrm{SSF}}$> 4 GeV
- WZ : $\mathrm{m}^{0\mathrm{SSF}}$> 4 GeV and 60 GeV < m_Z < 120 GeV.
- ZZ : $\mathrm{m}^{0\mathrm{SSF}}$> 4 GeV , 60 GeV < m_{Z1} < 120 GeV. and 60 GeV < m_{Z2} < 120 GeV.

$$\sigma = \frac{N_{signal}^{SR}}{BR(V \to XX)BR(V \to XX)\epsilon\mathcal{L}'}$$

TOTAL CROSS SECTIONS

Overall uncertainty dominated by statistical component.

Process	Estimation	Total cross section [pb]
WW	MATRIX	$29.8\ ^{+0.7}_{-0.6}(\text{scale})$
	Measured	$36.5^{+5.5}_{-5.1}(\text{stat})^{+2.6}_{-2.5}(\text{syst})$
WZ	MATRIX	$11.3\ ^{+0.2}_{-0.2}(\text{scale})$
	Measured	$6.4^{+2.4}_{-2.1}(\text{stat})^{+0.5}_{-0.3}(\text{syst})$
ZZ	MATRIX	$3.9\ ^{+0.1}_{-0.1}(\text{scale})$
	Measured	$5.3^{+2.5}_{-2.0}(\text{stat})^{+0.5}_{-0.4}(\text{syst})$

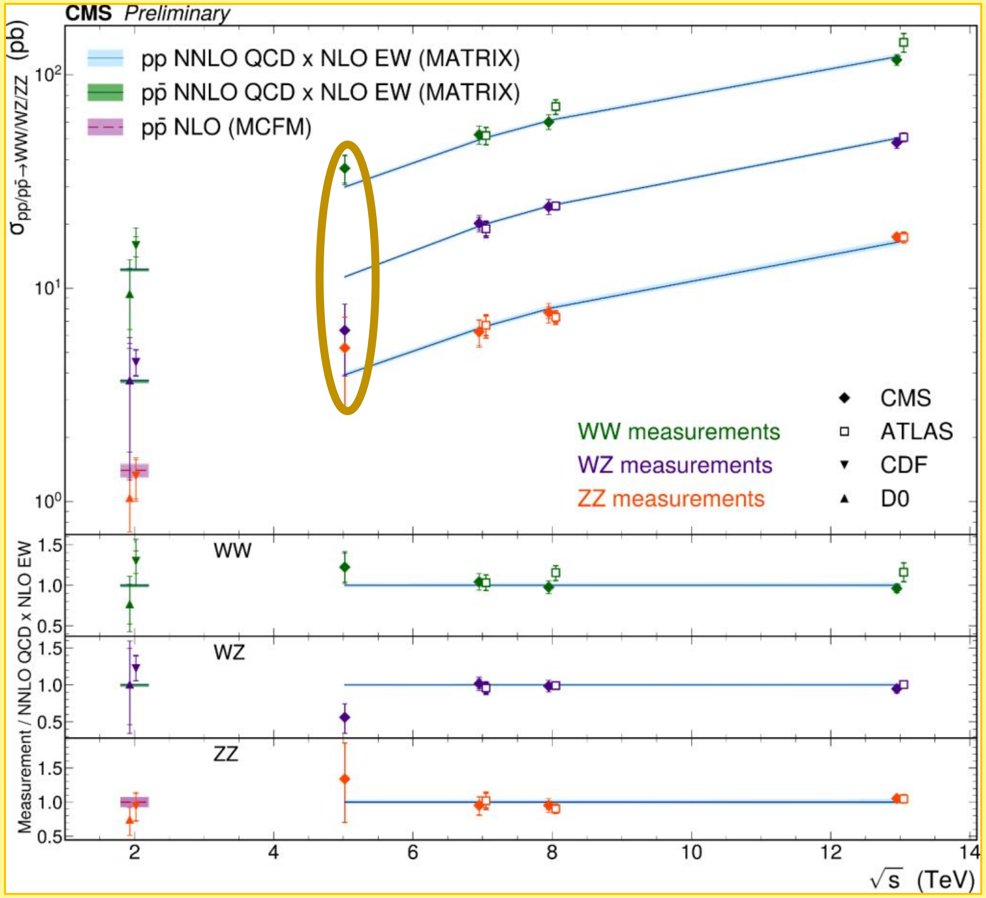
*Predictions from MATRIX at **NNLO QCDxNLO EWK**.

SUMMARY

- The measurements of the weak diboson production cross sections at a **new energy regime** that was never probed before for these processes have been presented.

- A very complete summary plot including diboson production cross sections from **ATLAS, CMS, D0 and CDF** in the full energy regime is shown.

- The gap between Tevatron and LHC measurements has been reduced.



BACK UP

OBJECT RECONSTRUCTION

Loose leptons

Lepton Variables	Electrons	Muons
p_T	>8 GeV	> 8 GeV
$\|\eta\|$	< 2.5	< 2.4
dxy	< 0.05 cm	< 0.05 cm
dz	< 0.1 cm	< 0.1 cm
sip3d	< 8	< 8
convVeto	True	–
nlostHits	0	–
Working Point	mvaFall17V2Iso_WPL	mediumPromptId
miniPFRelIso_all	< 0.4	< 0.4

Tight leptons

Lepton Variables	Electrons	Muons
mvaTTH	> 0.125	> 0.55
miniPFRelIso_all	< 0.085	< 0.325
Jet_btagDeepB	< 0.152	< 0.152

Jets

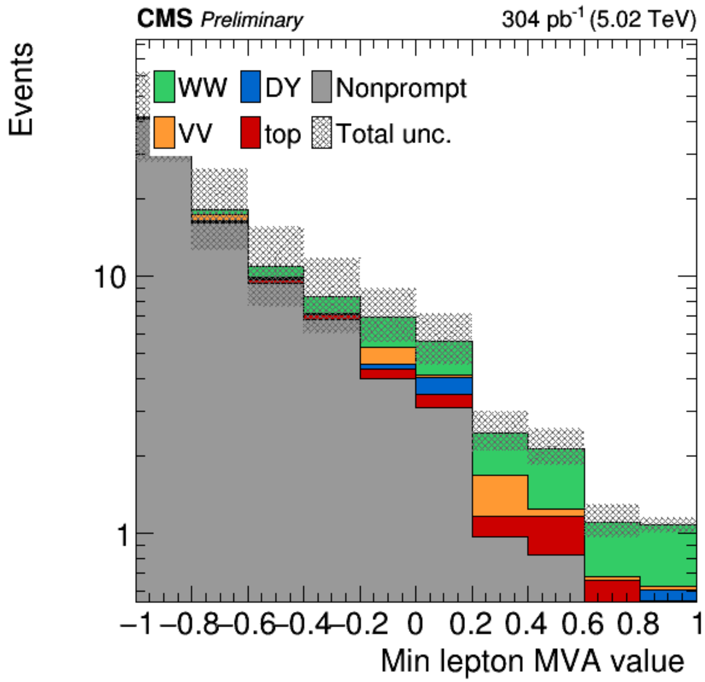
AK4 PFJets (Tight ID)

p_T > 25 GeV and $|\eta|$ < 2.4

ΔR(jet, lepton) > 0.4

MET

Corrected Type-1



UNCERTAINTIES

Experimental uncertainties

- **Lepton efficiencies**: varying p_T and η dependent SFs by their uncertainties.
- **Trigger efficiencies**: is very close to 1 and no correction is applied to the simulation. The relative difference between the trigger efficiency and the unity is used as an uncertainty.
- **Jet energy scale (JES):** varying the jet energy corrections by their uncertainties
- **Jet energy resolution (JER):** varying JER SF by uncertainties.
- **L1 prefiring**: varying the dedicated SFs by their uncertainties.
- **Nonprompt closure**.

Modeling uncertainties

- **PDF + α_S**: reweighing events according to the 30 replica PDF sets + 2 α_S. (PDF4LHC15_nlo_nf4_30_pdfas)
- **QCD scale**: varying the default renormalization and factorization scale choices independently by a factor of 2 or 1/2.

Others

- Luminosity.
- Background normalization.
- Data statistics.