Istituto Nazionale di Fisica Nucleare
Sezione di Roma

STANDARD MODEL AT THE LHC
Rome, May 7-10, 2024

SAPIENZA
UNIVERSITÀ DI ROMA

Electroweak measurements using Run 3 data with the CMS detector

Carlos Vico Villalba on behalf of the CMS collaboration

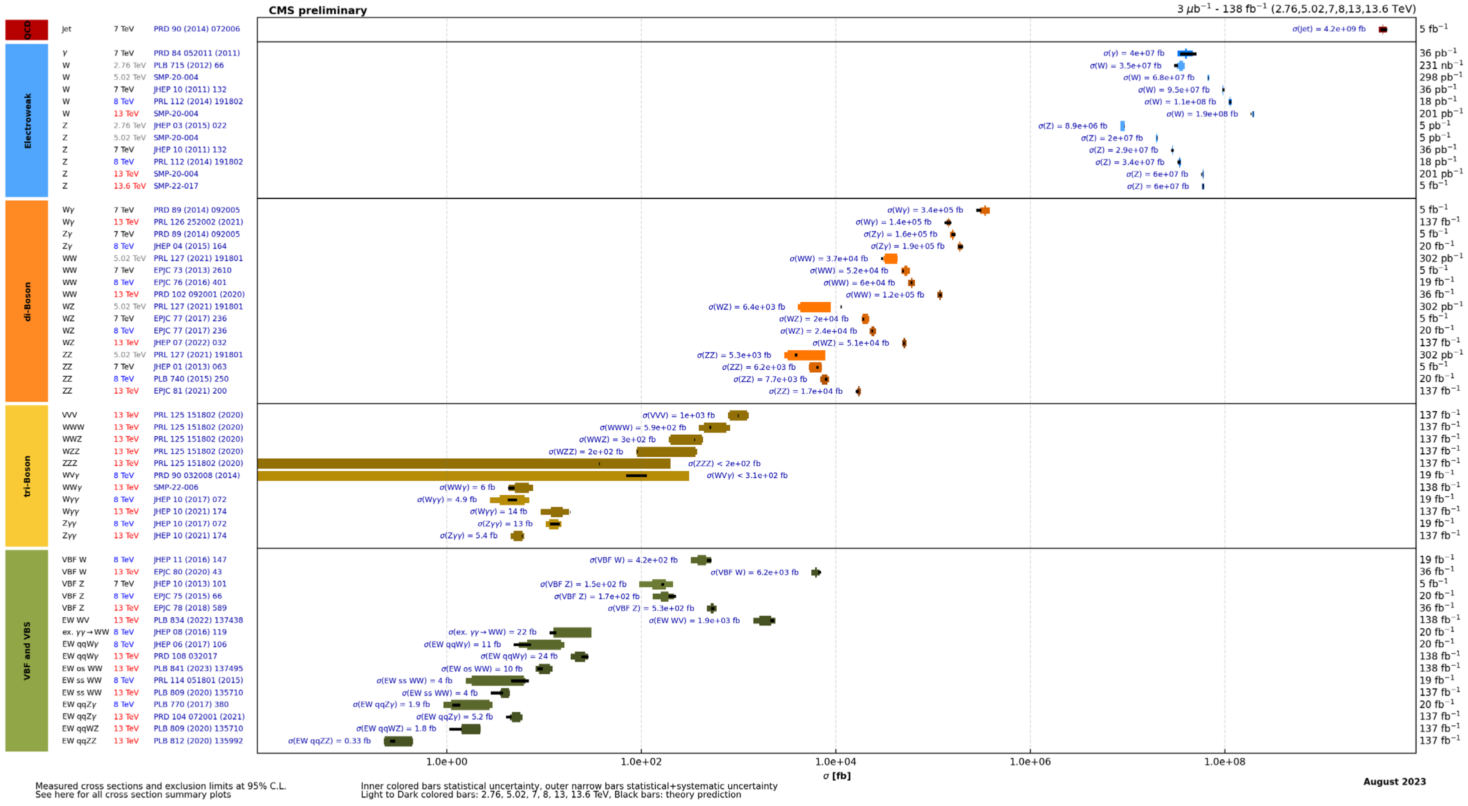
EUROPEAN UNION
European Regional Development Fund
Grant PID2020-113341RB-I00 funded by:
GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA E INNOVACIÓN
AGENCIA ESTATAL DE INVESTIGACIÓN
PCTI ASTURIAS
GOBIERNO DEL PRINCIPADO DE ASTURIAS

ICTEA
Universidad de Oviedo
Universidá d'Uviéu
University of Oviedo

Introduction. Evolution of measurements at the LHC.

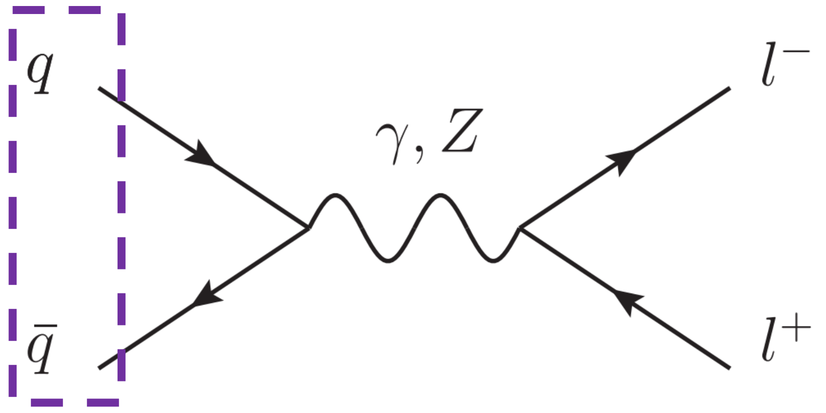
- We learned **a lot of electroweak physics** in Run 2.
  - ~140 fb^{-1} of data recorded.
- **July 2022:** the new Run 3 of the LHC started.
  - At a new center of mass energy of 13.6 TeV!
- With new data, we can extend further our knowledge of the standard model.
  - Expected. Stat unc reduced by factor $\sim\sqrt{2}$
  - New strategies have been developed → expected improvement in the systematics as well.
  - Possible combinations Run 2 + Run 3

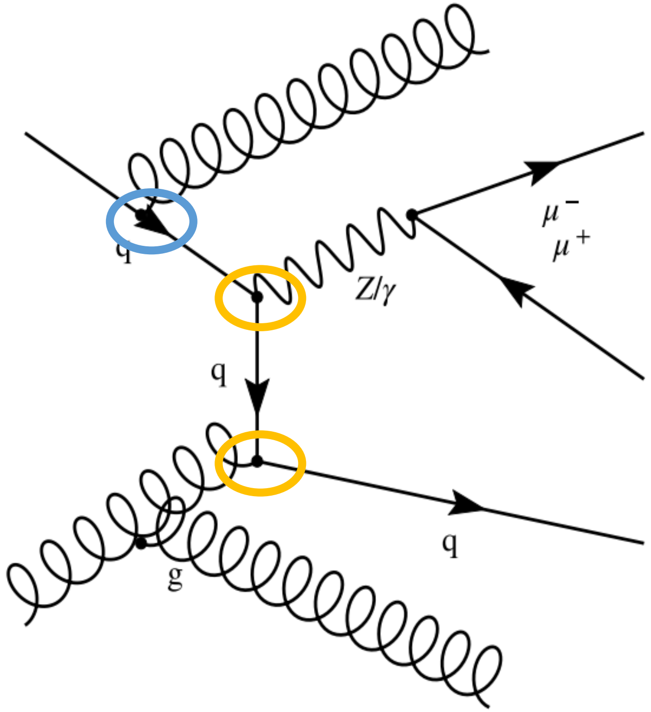
Overview of CMS cross section results



- Of course, most of these improvements will come by the late stages of Run 3, when we will have had collected ~2 times the luminosity of Run 2.
- In the meantime, it's crucial for the LHC physics programme to continue producing scientifically meaningful results, because that way we **test our knowledge on the standard model**, **as well as our detector performance.**
- **Goal for this talk:** to update on the current status of CMS in electroweak measurements using Run 3 data.

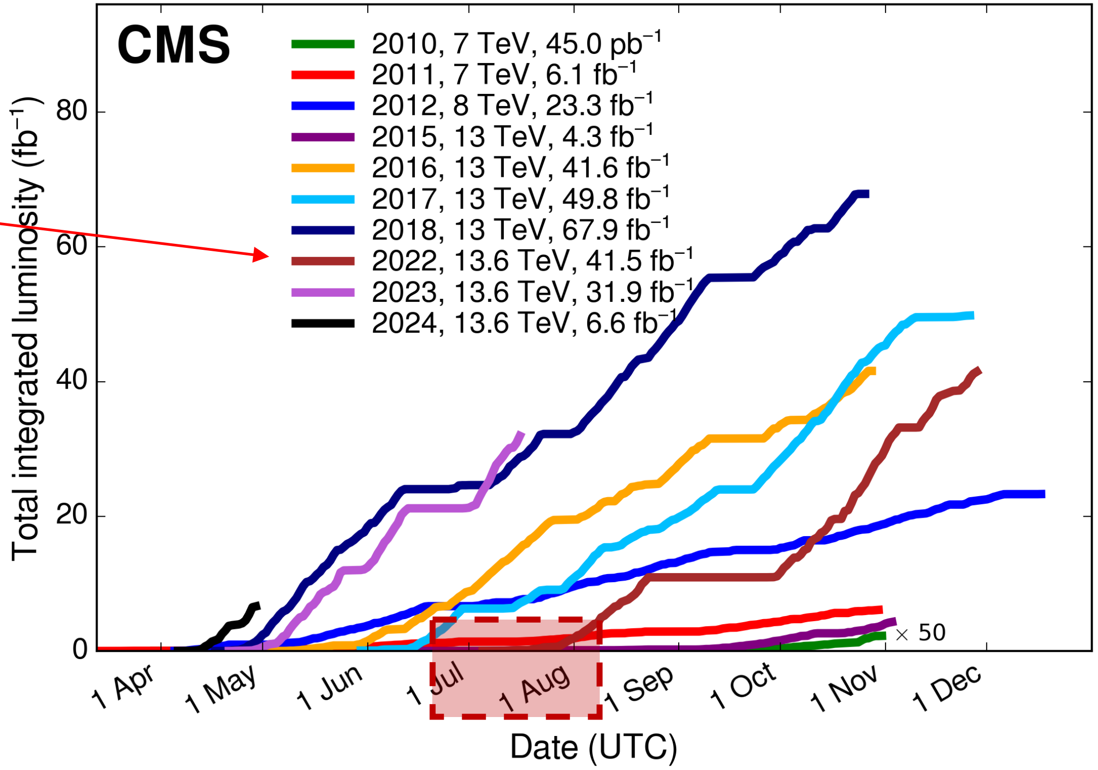
- Physicists have been looking at the Z boson for decades.
- From a theoretical point of view:
    - Constraining of PDFs.
    - Test perturbative and non perturbative effects of higher order contributions in QCD.
    - Parton shower effects.
    - Anomalous triple gauge couplings.
- From a experimental point of view.
    - Z boson factory ($\sigma_Z \sim$ nb).
    - Ideal setup for calibration of many objects.
- So measuring Z (and W) cross sections is important for the LHC programme!
- See Miguel's talk from monday





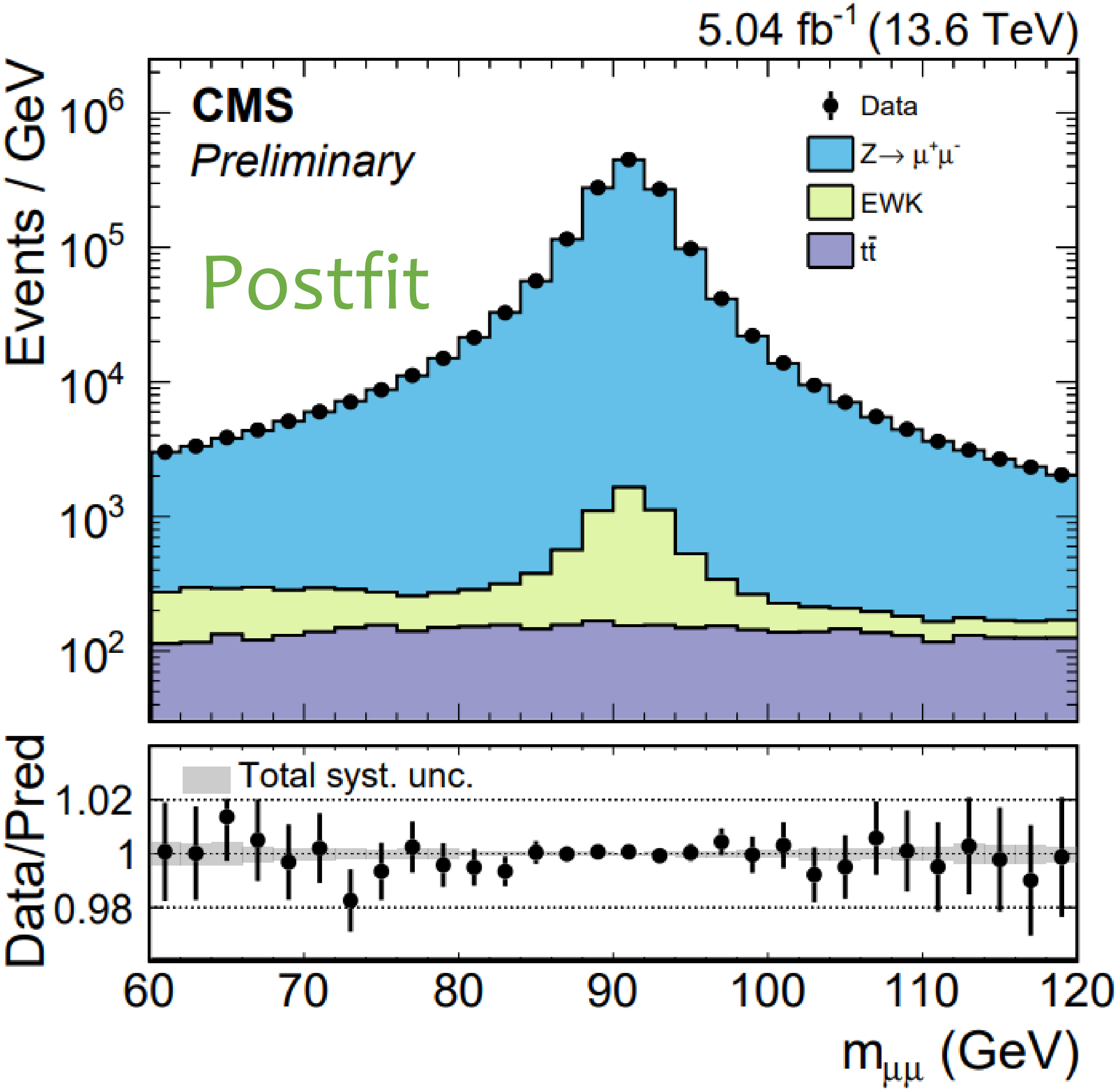
- A measurement of the Z boson production cross section was performed by the CMS experiment at the beginning of Run 3.
- **Goal**: to measure the Z boson production rate at a brand new center of mass energy regime.
- **Dataset used**: first 5.04 fb-1 collected by CMS during 2022 data taking.
- **Target topology:** $Z \to \mu^+\mu^-$
- **Monte Carlo simulation**
  - $Z \to \ell^+\ell^-$ + 2j (MADGRAPH5_AMC@NLO) → signal
  - $W \to \ell^\pm\nu$ +2j (MADGRAPH5_AMC@NLO)
  - WZ, ZZ, WW (PYTHIA8)
  - $t\bar{t}$ and single top (POWHEG V2) → $t\bar{t}$

EWK (the W and diboson samples)



Z cross section measurement at 13.6 TeV

- **Object selection:** optimized for $Z \rightarrow \mu^+\mu^-$
  - Exactly two reconstructed muons passing "tight" quality criteria [JINST 13 (2018) P06015].
  - Opposite sign
  - $p_T > 25$ GeV, $|\eta| < 2.4$
  - $m_{\mu\mu} \in [60, 120]$ GeV
  - Inclusive in jets and b tags.
- **Corrections:** particularly delicate in early analyses.
  - Muon efficiency
  - Scale and energy.
  - Trigger prefiring.
  - Pileup
- **Strategy:**
  - Maximum likelihood fit to the $m_{\mu\mu}$ distribution.



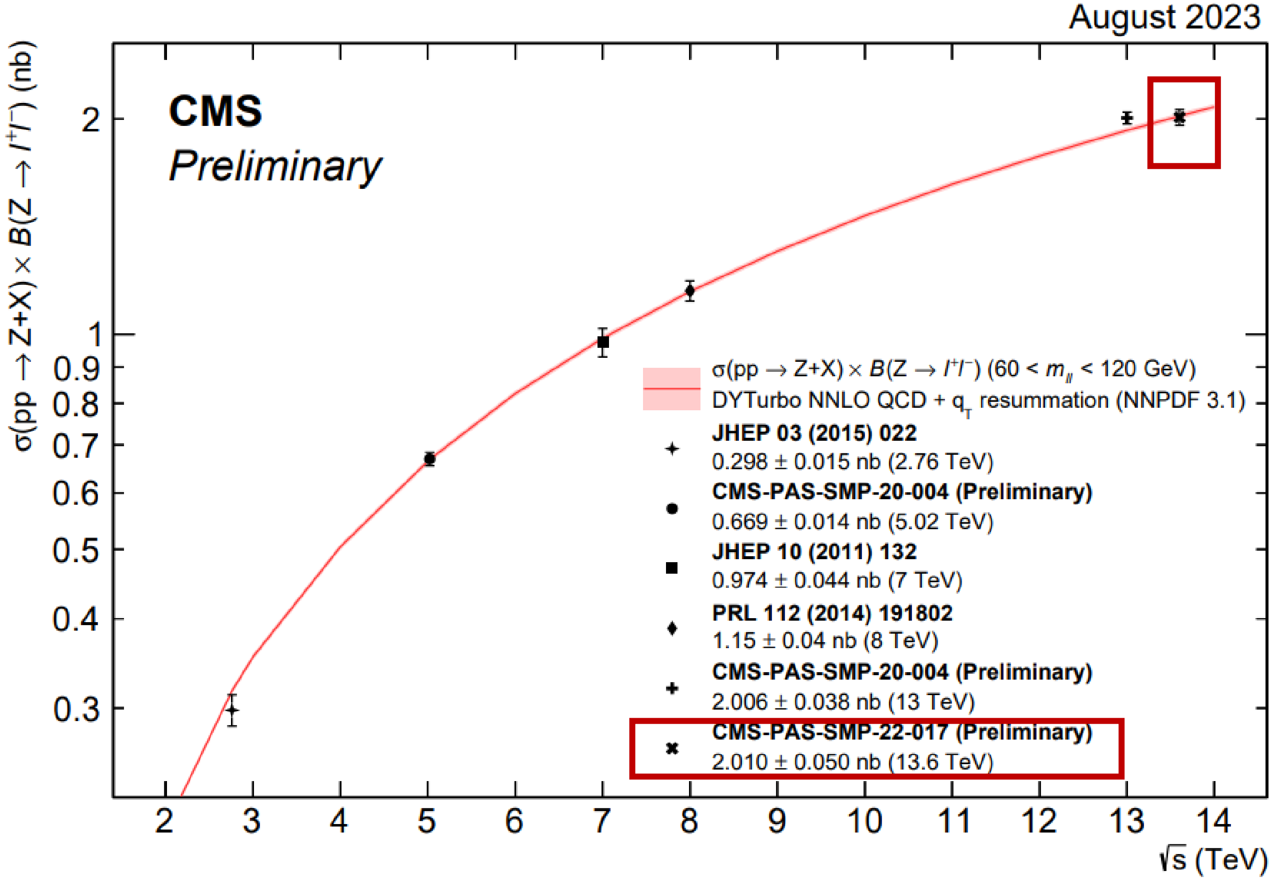
Z cross section measurement at 13.6 TeV

- Measurement of the total cross sections times branching ratio are presented.
- In a fiducial volume ($m_{\mu\mu} \in [60, 120]$ GeV) and in a total volume.
- Measurement dominated by systematics.
- Well in agreement with SM.

$$(\sigma_{\text{fid}}\mathcal{B})_{\text{measured}} = (0.7635 \pm 0.0004(\text{stat}) \pm 0.0069(\text{syst}) \pm 0.0176(\text{lumi}))\ \text{nb},$$
$$(\sigma_{\text{fid}}\mathcal{B})_{\text{predicted}} = (0.7666 \pm 0.0065(\text{PDF})^{+0.0021}_{-0.0045}(\text{scale}))\ \text{nb},$$

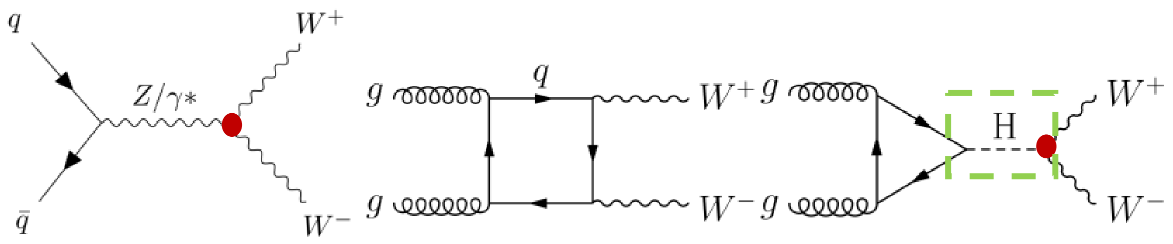
$$(\sigma_{\text{tot}}\mathcal{B})_{\text{measured}} = (2.010 \pm 0.001(\text{stat}) \pm 0.018(\text{syst}) \pm 0.046(\text{lumi}) \pm 0.007(\text{theo}))\ \text{nb},$$
$$(\sigma_{\text{tot}}\mathcal{B})_{\text{predicted}} = (2.018 \pm 0.012(\text{PDF})^{+0.018}_{-0.023}(\text{scale}))\ \text{nb},$$

Source	Uncertainty (%)
Muon efficiencies	0.83
PDF, QCD scale and parton shower	0.53
Finite size of MC samples (bin-by-bin)	0.35
$t\bar{t}$ background	0.16
EWK background	0.12
Pileup	0.08
Muon momentum correction	0.08
Combined syst. uncertainty	0.92
Luminosity	2.3
Stat. uncertainty	0.06

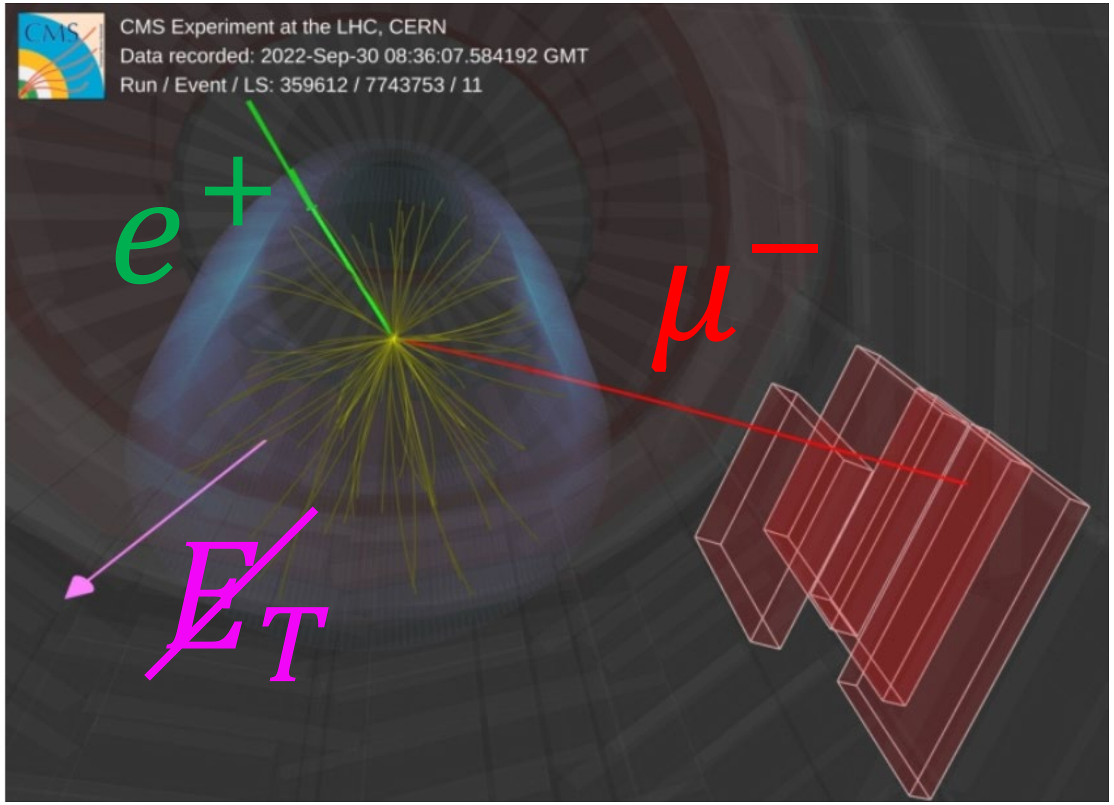


WW measurements at CMS

- Measurement of W-boson pair production cross sections is an important test of the standard model.
- WW production is interesting for various reasons.
- **From a theoretical point of view:**
  - Self couplings between electroweak bosons.
  - Large background to Higgs measurements.



- **From an experimental point of view:**
  - Proof that we can already do complex analyses in Run 3 using a wide variety of physics objects and corrections.
  - And with great precission!



Run 3 provides standard model with new victory at the energy frontier (physics briefing)

WW measurements at CMS

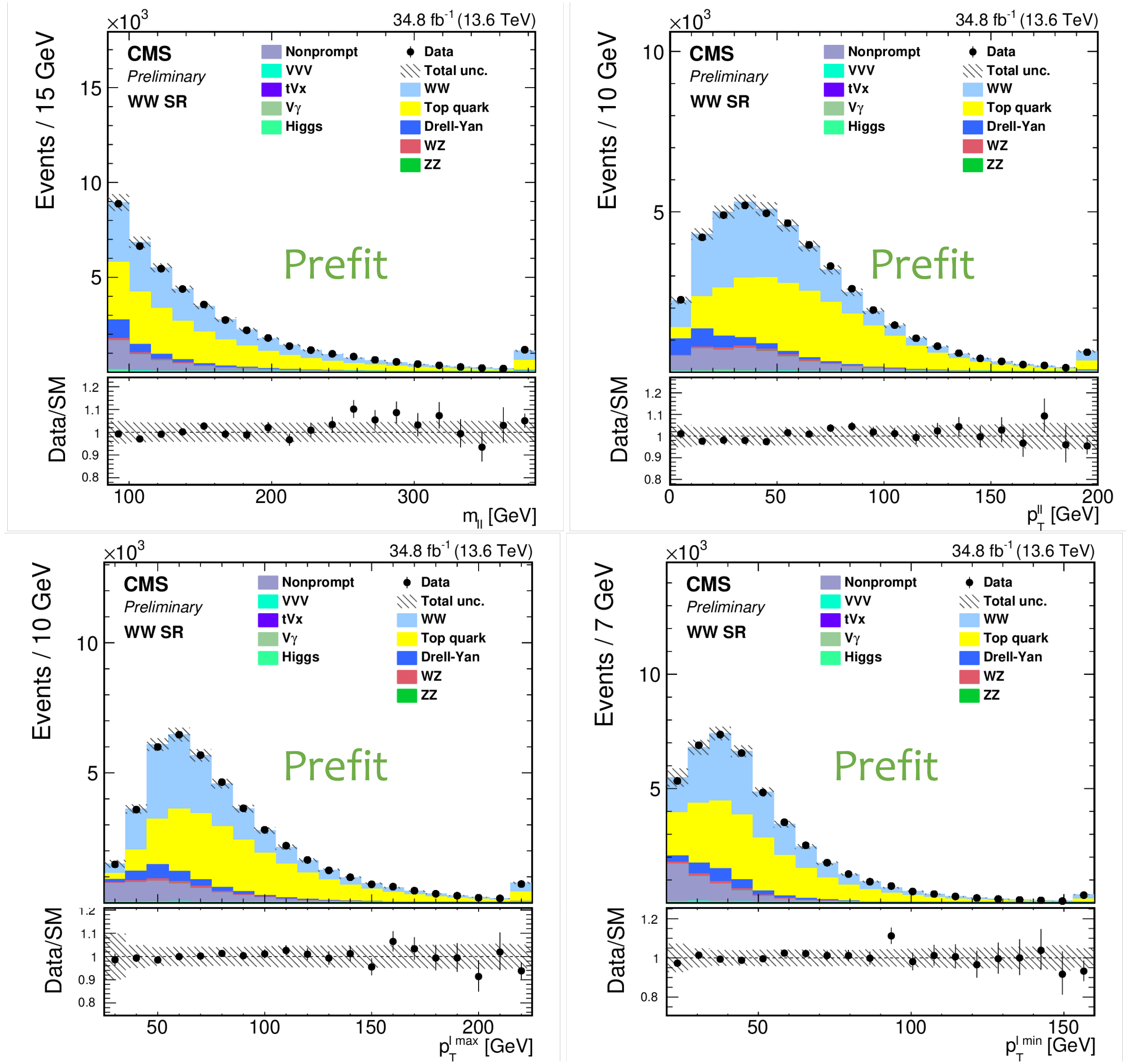
- **Goal**: to provide a competitive result of the inclusive cross section, as well as a report on inclusive and normalized differential cross sections.
- The measurement is performed this time using the whole 2022 dataset recorded by CMS (~35 fb^{-1}).
- Target topology: $W^+W^- \rightarrow e^{\pm}\mu^{\mp}$.
  - One signal region is defined to maximize signal purity.
  - Several control regions are already defined to constraint effect of main backgrounds.
    - TOP, ZZ $\rightarrow \tau\tau$, non prompt, WZ and ZZ $\rightarrow \ell_{light}\ell_{light}\nu\nu$

Quantity	WW SR	One/two b-tags CRs	$Z \rightarrow \tau\tau$ CR	Same-sign CR
Number of tight leptons	Strictly 2			
Additional loose leptons	0			
Lepton charges	Opposite			Same
$p_T^{\ell\,max}$	> 25 GeV			
$p_T^{\ell\,min}$	> 20 GeV			
$m_{\ell\ell}$	> 85 GeV	> 85 GeV	< 85 GeV	> 85 GeV
$p_T^{\ell\ell}$	—	—	< 30 GeV	—
Number of b-tagged jets	0	1/2	0	0
N_J	0/1/2/ ≥ 3			

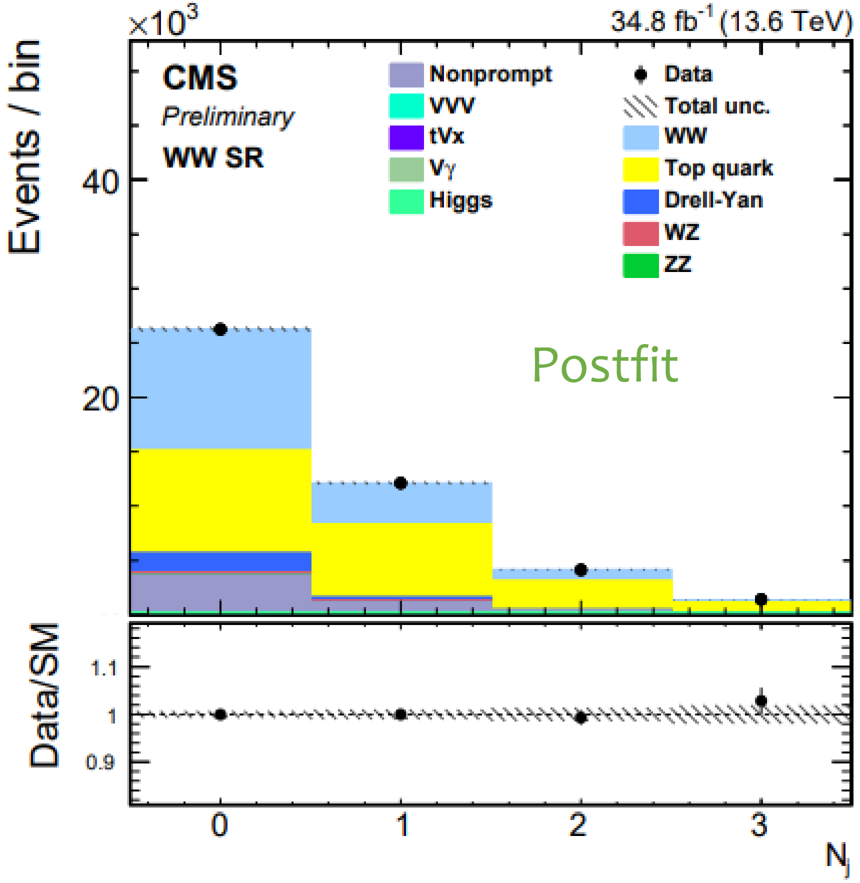
Variable	WZ CR	ZZ CR
Number of tight leptons	Strictly 3	Strictly 4
Additional loose leptons	0	
Lepton p_T	> 25/10/20 GeV	> 25/20/10/10 GeV
$\|m_{\ell\ell} - m_Z\|$	< 15 GeV	< 15 GeV (both pairs)
$m_{3\ell}$	> 100 GeV	-
$m_{4\ell}$	-	> 150 GeV
p_T^{miss}	> 30 GeV	-
Number of b-tagged jets	0	

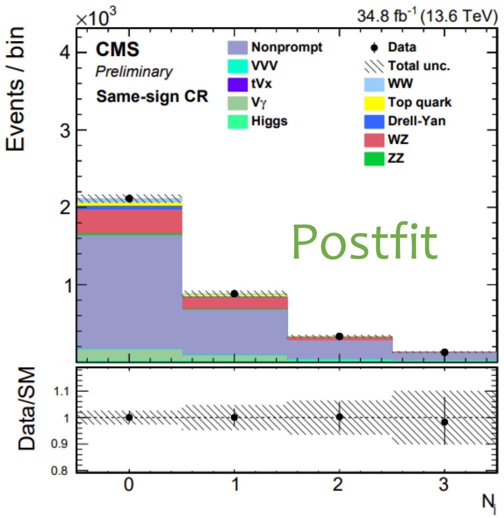
Looking into some distributions…

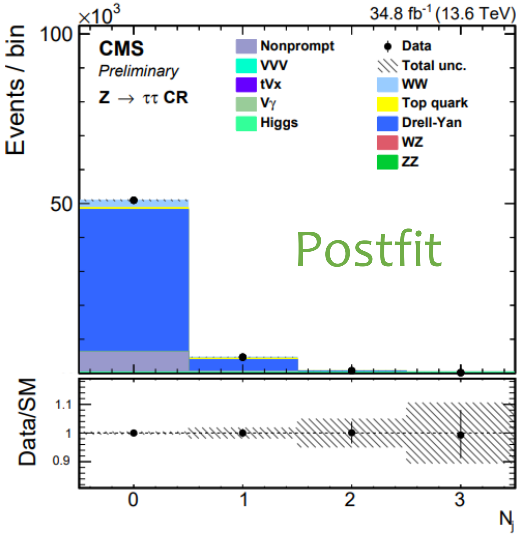
- First **complete** look into an electroweak phase space after Run 2.
- **What is meant by complete here:** Well understood…
    - … dataset and corrections.
    - … montecarlo modelling.
    - … treatment of systematics.
- Agreement is certainly looking good!
- This is the result of a really great effort from many people in CMS.

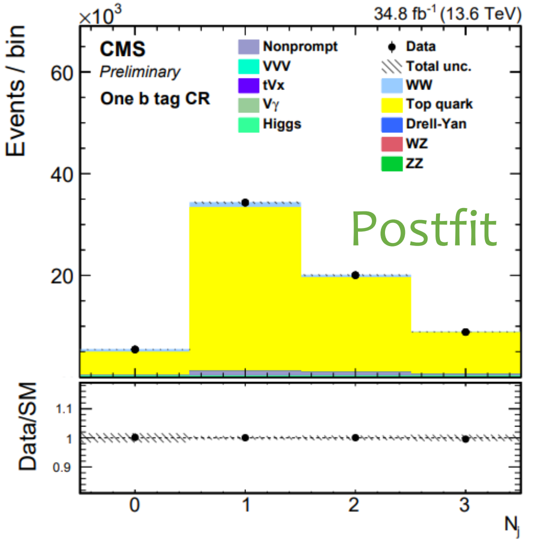


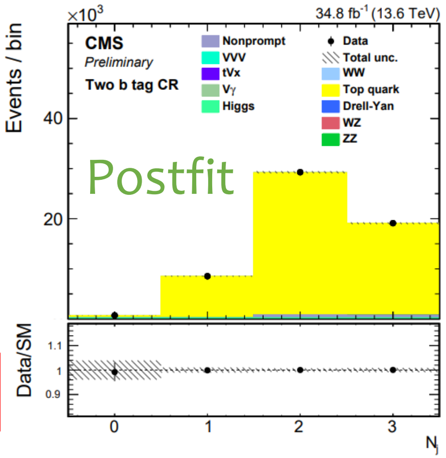
- The inclusive WW cross section is extracted from a maximum likelihood fit to the observed yields as a function of the number of jets.
- The fit is performed simultaneously to the signal region and all control regions.

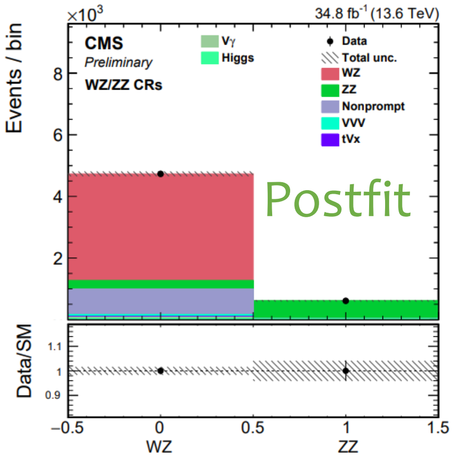












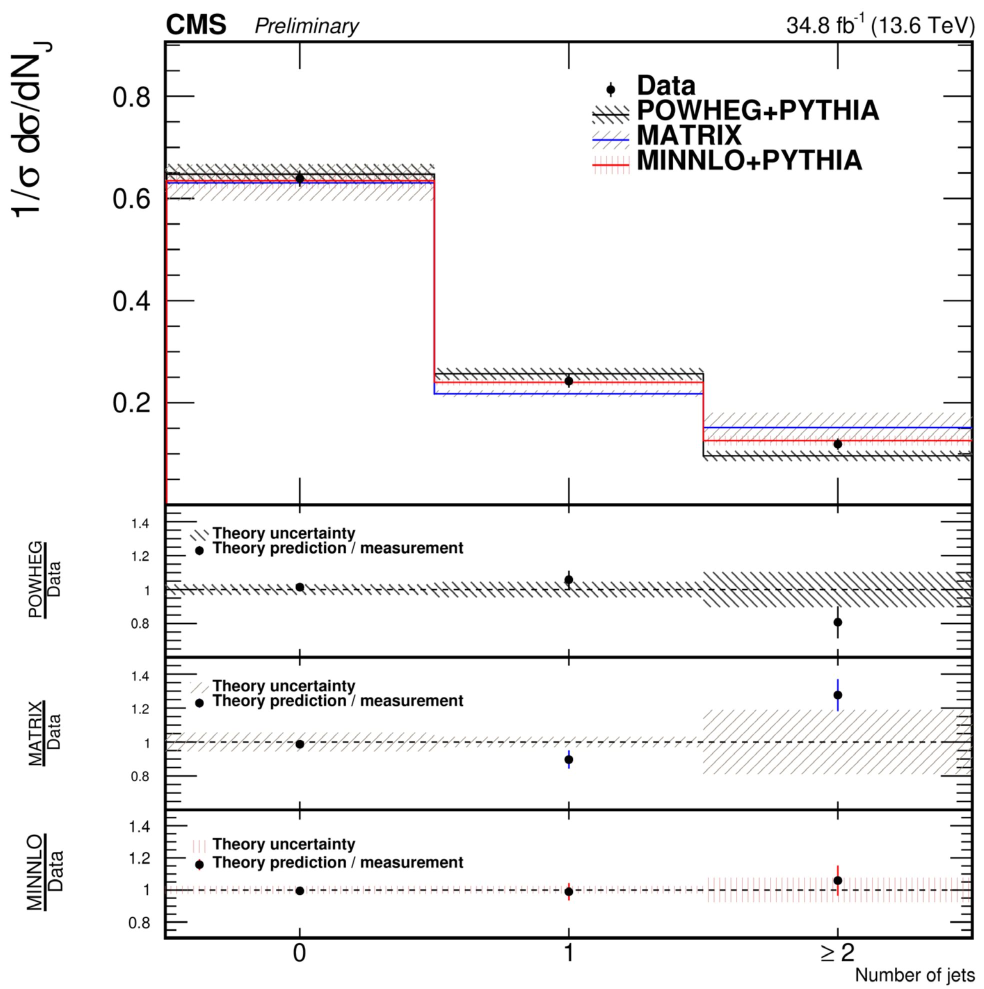
σ = 125.7 ± 2.3 (stat) ± 4.8 (syst) ± 1.8 (lumi) pb

Uncertainty source	$\Delta\mu$
Integrated luminosity	0.014
Lepton experimental	0.019
Jet experimental	0.008
b tagging	0.012
Nonprompt background	0.010
Limited sample size	0.017
Background normalization	0.018
Theory	0.011
Statistical	0.018
Total	0.044

- The unfolding to particle level is performed using likelihood-based unfolding.
- Fiducial **inclusive** and **normalized** cross sections are extracted in a **fiducial region** that mimics the selection used at detector level.
- First ever comparison with MiNNLO+PS generator.
  - Good agreement with SM is reported.

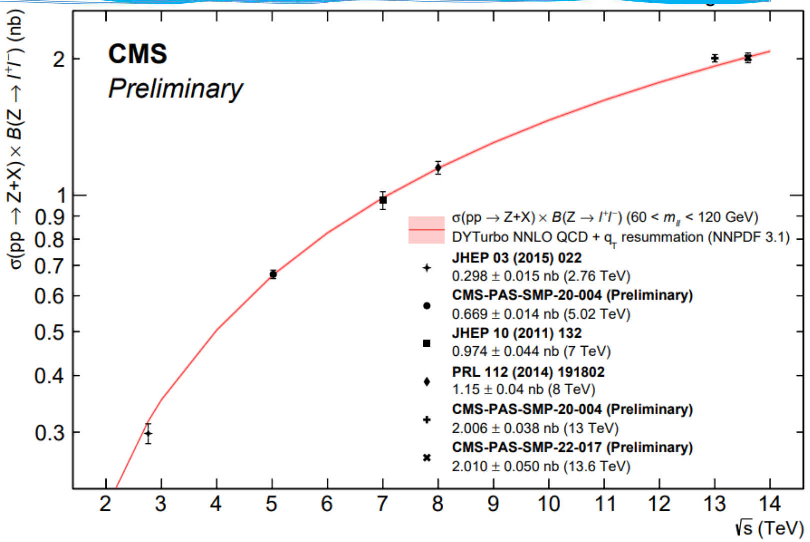
Observable	Requirement
Lepton origin	Direct decay of a W boson
Lepton definition	Dressed-leptons ($e^{\pm}\mu^{\mp}$)
Leading lepton p_T	$p_T^{\ell\,max} > 25$ GeV
Trailing lepton p_T	$p_T^{\ell\,min} > 20$ GeV
$\|\eta\|$ of leptons	$\|\eta\| < 2.5$
Dilepton mass	$m_{\ell\ell} > 85$ GeV
Jet p_T	$p_T^{j} > 30$ GeV
$\|\eta\|$ of jets	$\|\eta^{j}\| < 2.5$
Jet-lepton removal	$\Delta R(j,\ell) > 0.4$

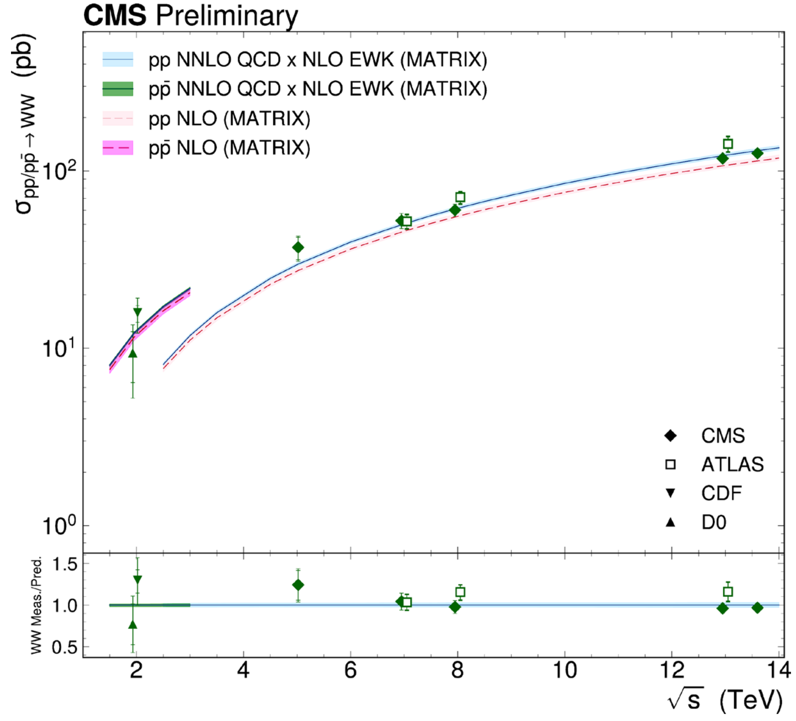
Observable	Expected	Observed
Cross section (fb)	$812 \pm 34(31, 15)$	$813 \pm 35(32, 15)$
0-jet fraction	$0.648 \pm 0.015(0.012, 0.009)$	$0.640 \pm 0.016(0.013, 0.009)$
1-jet fraction	$0.256 \pm 0.013(0.008, 0.010)$	$0.243 \pm 0.013(0.009, 0.010)$
$\geq$ 2-jet fraction	$0.096 \pm 0.011(0.008, 0.008)$	$0.119 \pm 0.011(0.008, 0.008)$



- A summary on the status of electroweak measurements in CMS during Run 3 has been presented.
    - Z boson production using the first few runs of Run 3
    - Measurements of WW inclusive and differential cross sections using the 2022 dataset.
- **General conclusion**: results are in good agreement with the SM prediction.
    - **As expected!**
    - This proves that after the long shutdown, **CMS is still working at excellent performance**.
        - We know our detector.
    - We are able to start measuring at high precission already with 1/10th of the total expected lumi.
- Of course, more results are to come with much data.
- The analyses already allow to expect very promising results for the rest of Run 3.

Stay tuned!





Backup