New WW cross section measurement at 13.6 TeV with the CMS detector

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On behalf of the CMS Collaboration

Work funded by PID2020-113304RB-I00

UC CSIC Consejo Superior de Investigaciones Científicas

IFCA Instituto de Física de Cantabria

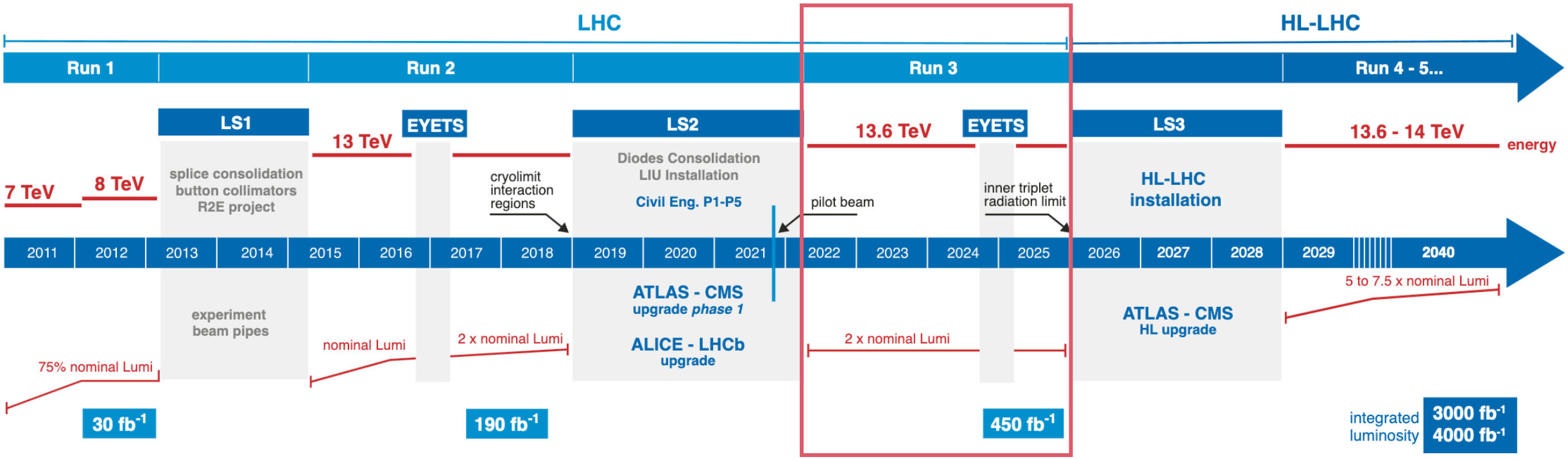
8th Red LHC 2024 May 28, 2024

MINISTERIO DE CIENCIA E INNOVACIÓN

AGENCIA ESTATAL DE INVESTIGACIÓN

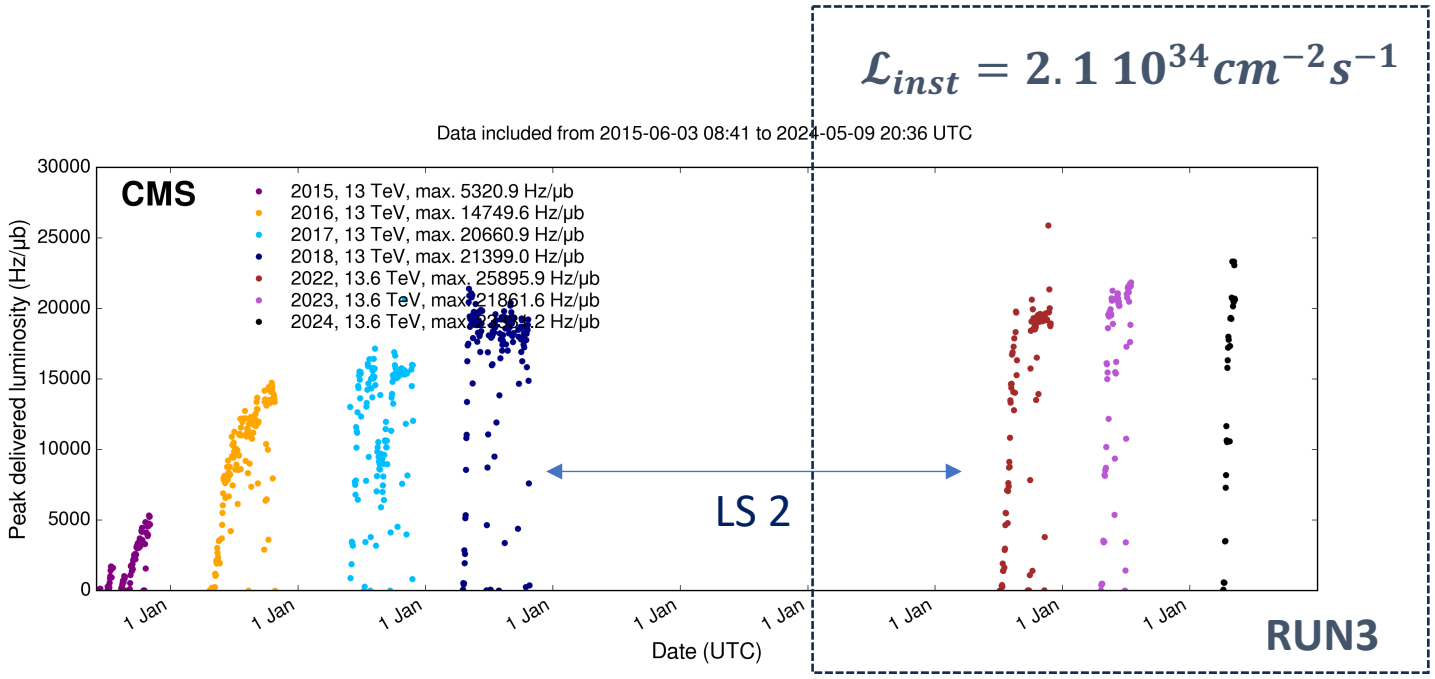
LHC Run 3

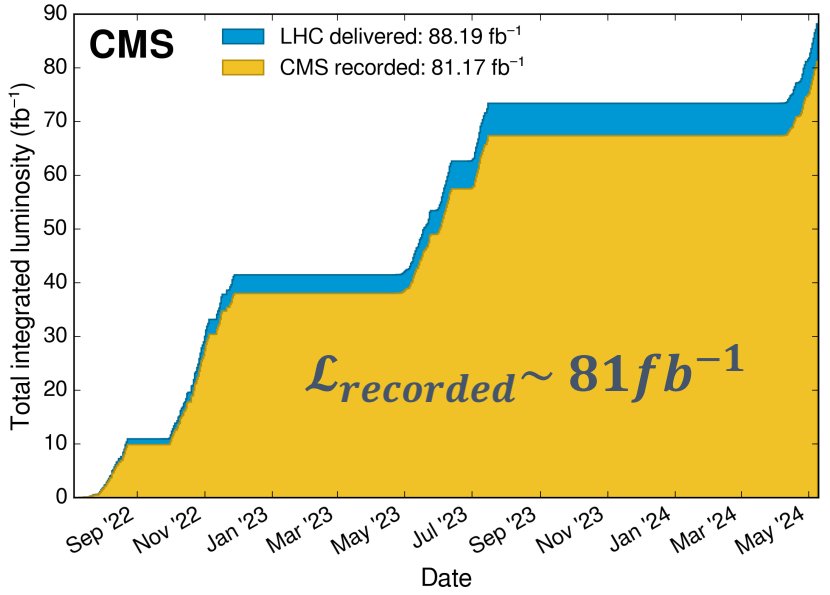
An opportunity to expand the LHC physics program: Run 3 interesting on its own right because of the small increase in energy and large data simples.

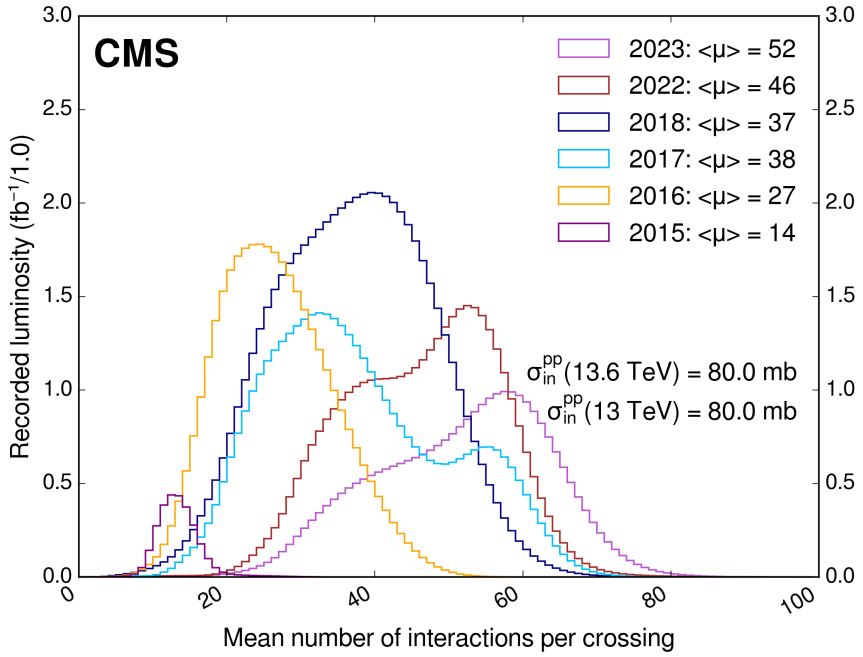


LHC Run 3

- Luminosity increase is one of the main challenges
  - x2 increase in instantaneous luminosity from the original design
  - Strongest requirements for trigger, electronics, radiation hardness and reconstruction algorithms.



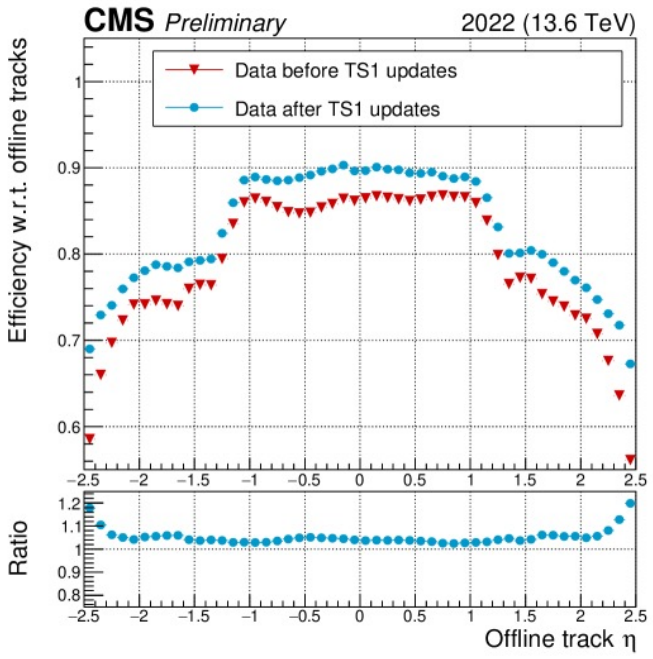




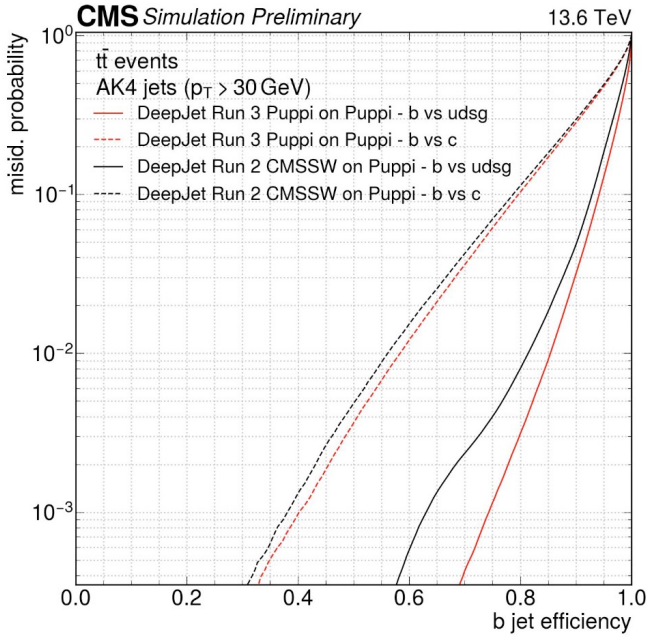
CMS performance

- Require excellent understanding of the detector performance and high-performant object ID to carry out high-precision measurements.
- A lot of effort is put into improving understanding of detector and development of reconstruction/identification algorithms.

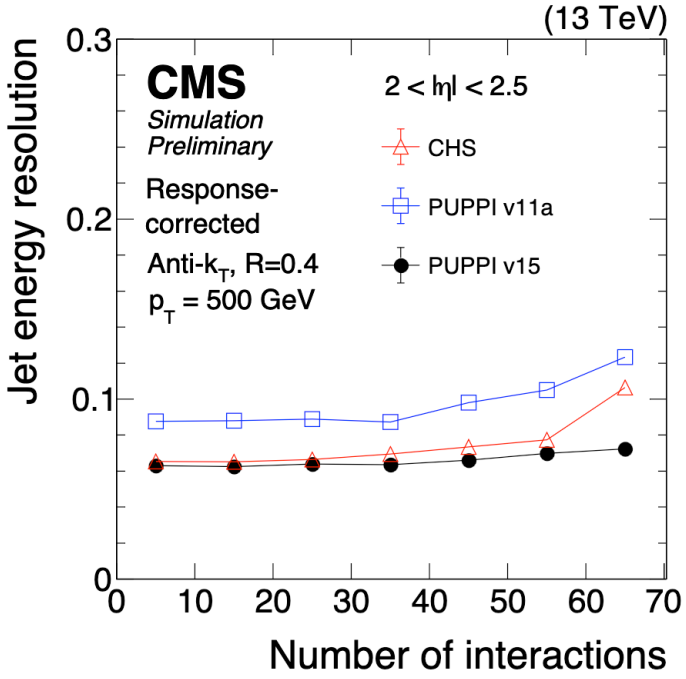
CMS-DP-2023-028
HLT tracking efficiency



CMS-DP-2023-012
DeepJet algorithm

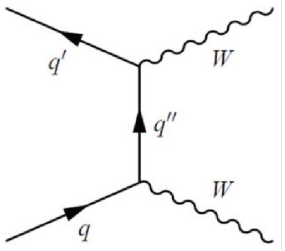


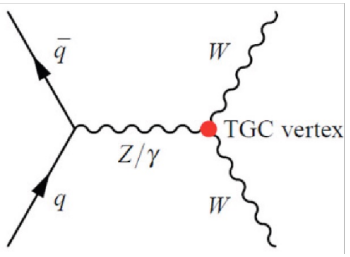
CMS-DP-2023-045
pileup per particle identification (PUPPI)



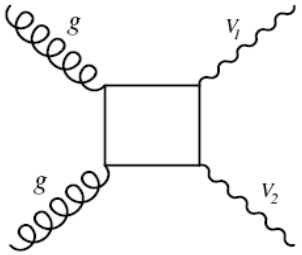
WW production @ LHC

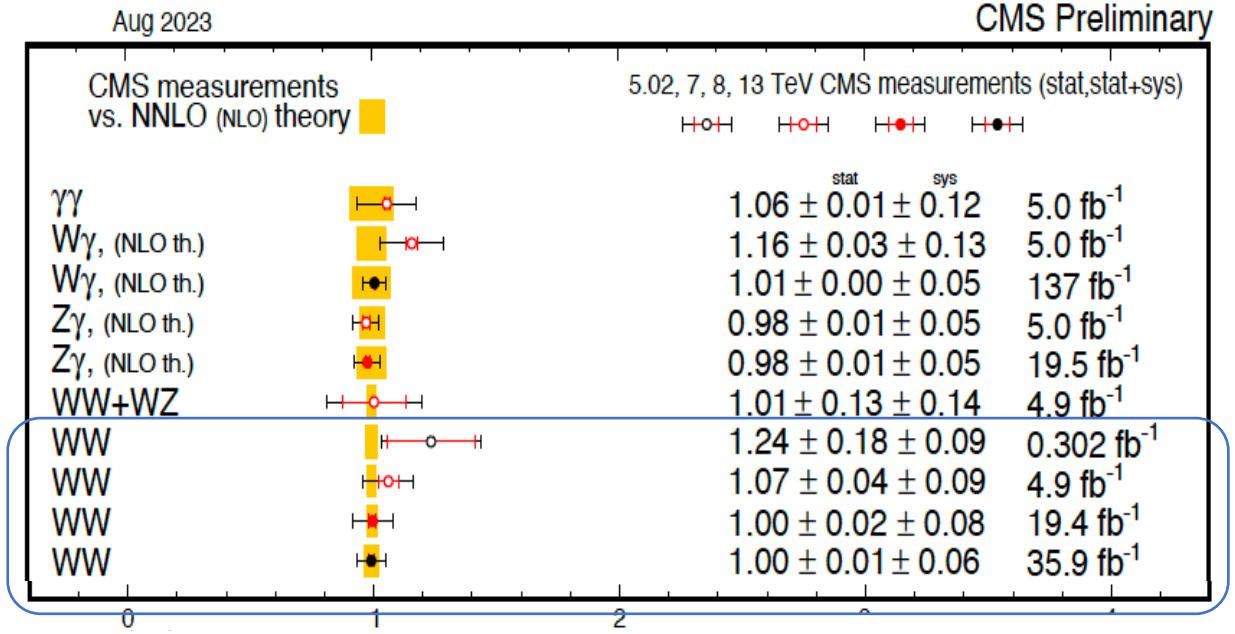
$qq \rightarrow WW$





$gg \rightarrow WW$

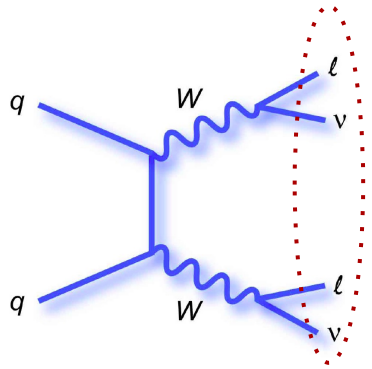




Precision ~ 6-15%

- WW cross section at 13.6 TeV from MATRIX at NNLO in QCD and NLO in EW ($gg \rightarrow WW$ @ LO scaled to NLO)
  - $127.5 \pm 3.7\ pb$ (~ 6% increase on cross section wrt 13 TeV)
- The gg → H → WW is considered as background (~10% smaller than other process)
- Crucial to check the gauge structure of the Standard Model at the new energy.

Event selection



- Run3 2022 data ~35 fb^{-1} at 13.6 TeV
- The **fully-leptonic (μe/eμ)** final state.
  - 2 leptons with P_T > 25/20 GeV, and |η| < 2.4 (2.5) for μ (e)
- Analysis performed inclusive and exclusive in number of jets 0/1/2 / ≥ 3
  - $p_T^{jet} > 30\ GeV$ and $|\eta|^{jet} < 2.5$
- Minimal selection optimized to enhance ratio signal / background.

Main rejection of:

μ: Medium ID/ tight Isolation e: MVA tight ID $\Delta R(l, jet) > 0.4$	**Non-prompt background (jet→fake lepton)**
$m_{ll} > 80$	**Z→tautau and Higgs**
Apply top-veto based on jet b-tagging (DeepJet algorithm loose WP)	**tW and ttbar production**
Reject events with a third lepton passing looser identification requirements	**WZ / ZZ**

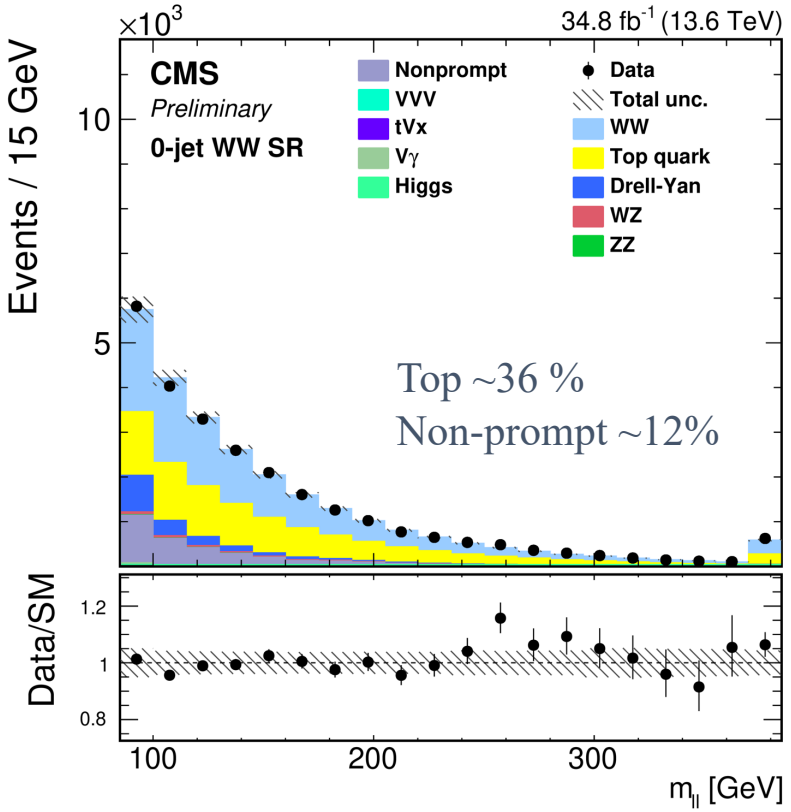
WW signal region

Pre-fit distributions

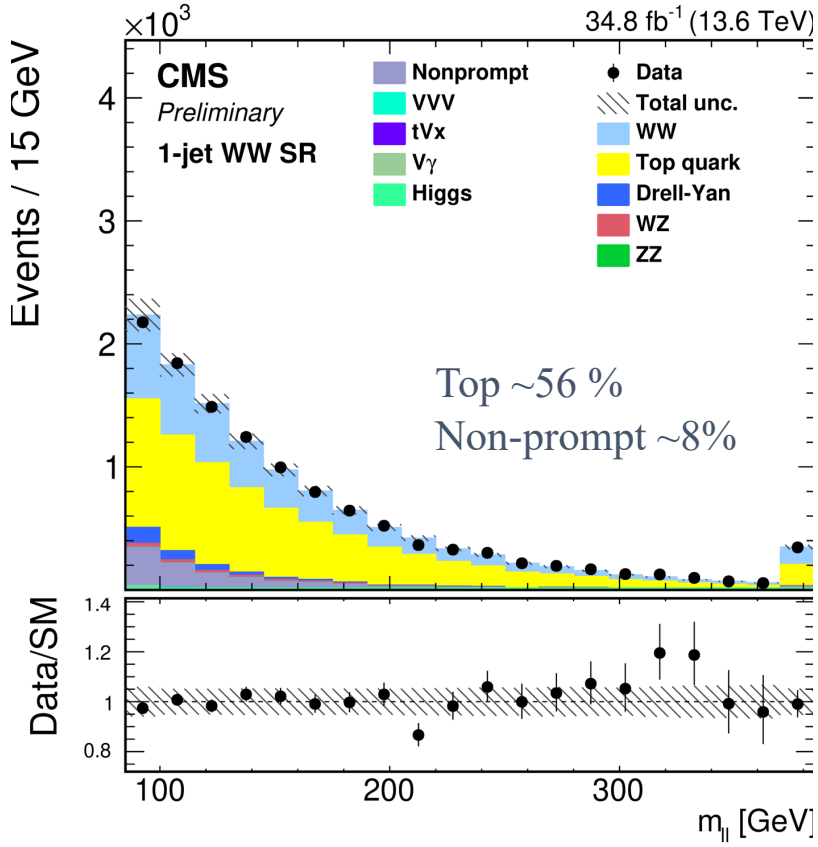
$qq \rightarrow WW$ @ *NLO POWHEG*

$gg \rightarrow WW$ @ LO Madgraph (scaled by $k = \frac{NLO}{LO} = 1.4$)

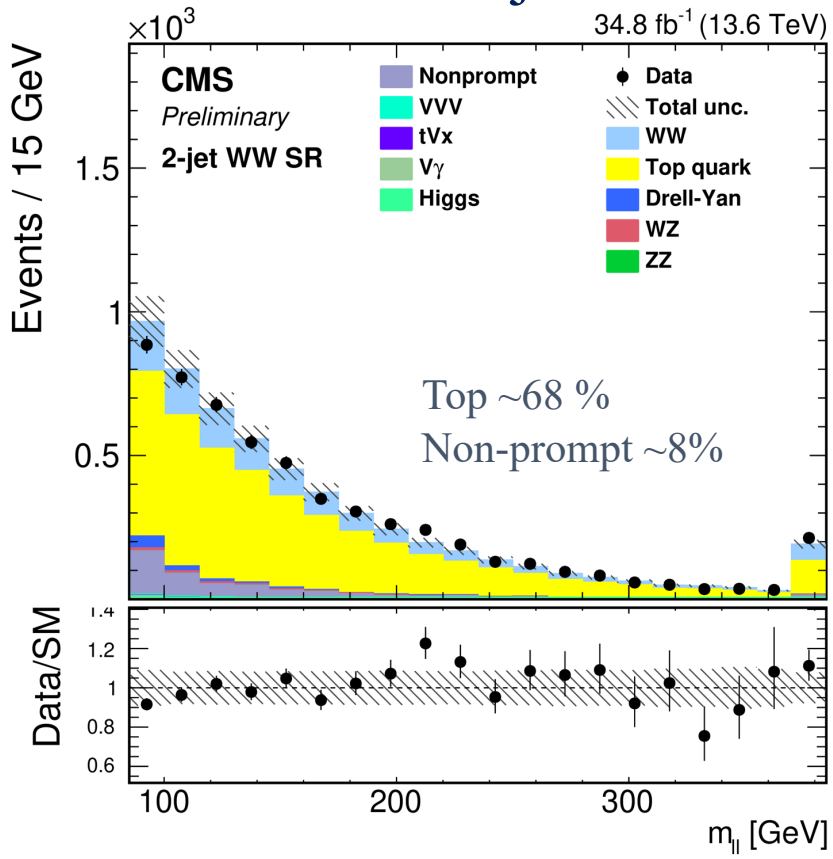
0-jet



1-jet



2-jet

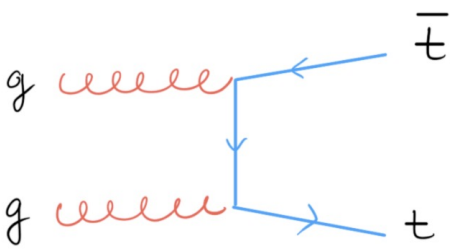


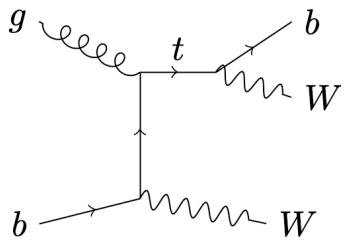
Background overview

- Define orthogonal control regions for the main backgrounds
- Normalization from the simultaneously fit to the SR and CRs.

$t\bar{t}$ and tW

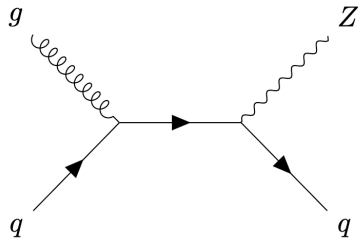
To obtain normalization determined from two data control samples with **one/two btags**.





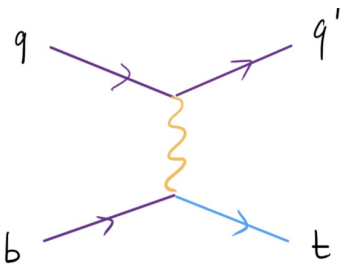
$Z \to \tau\tau$

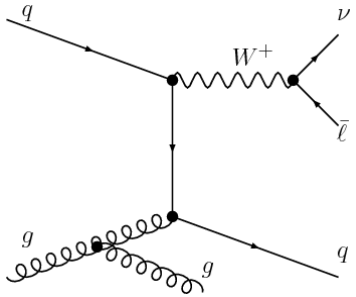
Normalization from an inverted $\boldsymbol{m_{ll} < 85}$ and $\boldsymbol{p_T^{ll} < 30}$ selection.



Non-prompt

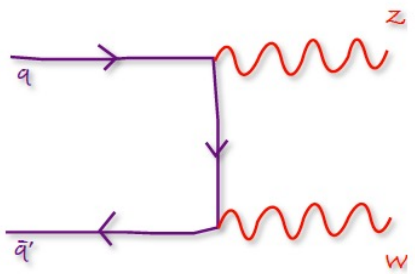
Normalization and shape estimated from **same-sign dilepton** control region enriched in misidentified leptons





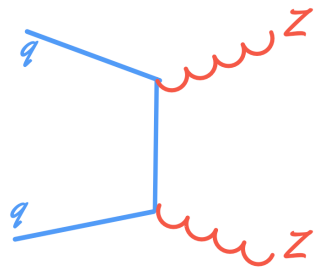
WZ

Normalization from a CR requiring **3 leptons** with $\boldsymbol{m_{3l} > 100}$ and $p_T^{miss} > 30$



ZZ

Normalization from a CR requiring **4 leptons** with $\boldsymbol{m_{4l} > 150}$



Cross section measurement

- **Inclusive** and **fiducial** cross sections.
- Binned maximum likehood fit in N_{jets} to:
  - the **WW signal región**.
  - **two top CR** (1-btag and 2 b-tags), **one non-prompt CR**, **one $Z \rightarrow \tau\tau$ CR**.
    - Including two top CRs in simultaneous fit with signal leads to better control of b-tagging and jet energy scale uncertainty.
  - **$WZ \rightarrow 3l$** and **$ZZ \rightarrow 4l$** regions added to the fit as one single bin each.

Fiducial region at gen level after parton showering and hadronization

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	$\Delta R(j, \ell) > 0.4$

Source of uncertainties

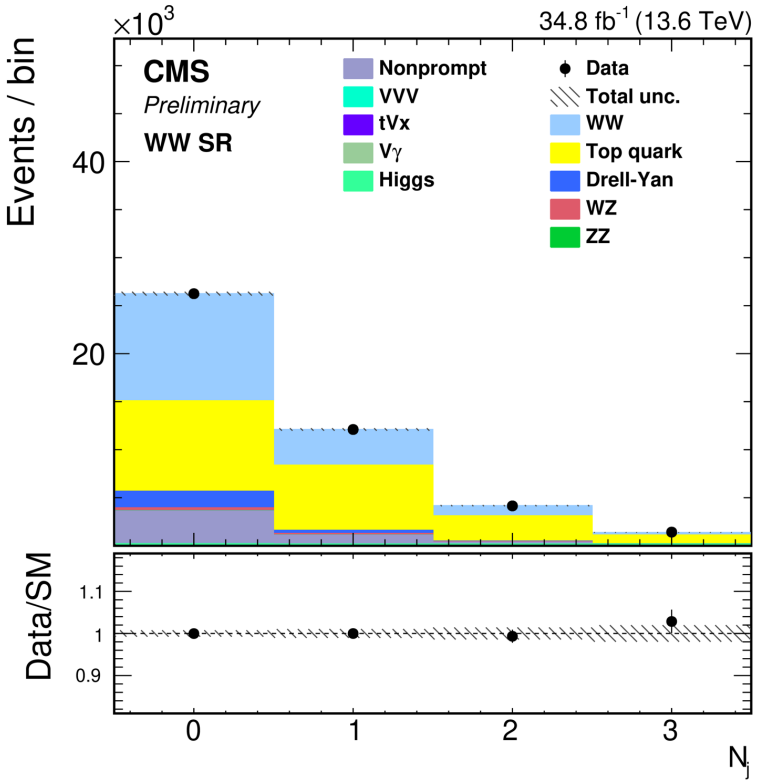
Uncertainty source	$\Delta\mu$
Integrated luminosity	0.014
Lepton experimental	0.019
Jet experimental	0.008
b tagging	0.012
Nonprompt background	0.010
Limited sample size	0.017
Background normalization	0.018
Theory	0.011
Statistical	0.018
Total	0.044

- **Total uncertainty ~ 4.4%**
  - Reduction on the luminosity uncertainty ~1.4%
  - Further constraint on jet and b-tag uncertainties.
  - Limited sample size: dominated by non-prompt lepton background estimation.
- Result dominated by the systematic experimental uncertainties ~3.6%
  - Some of them should decrease with a larger data set

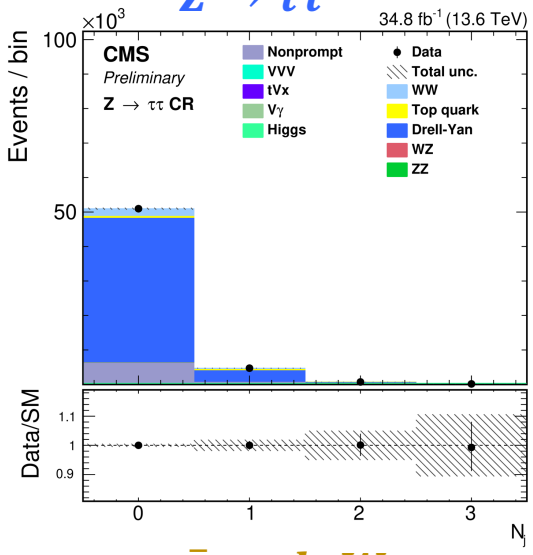
Post-fit distributions

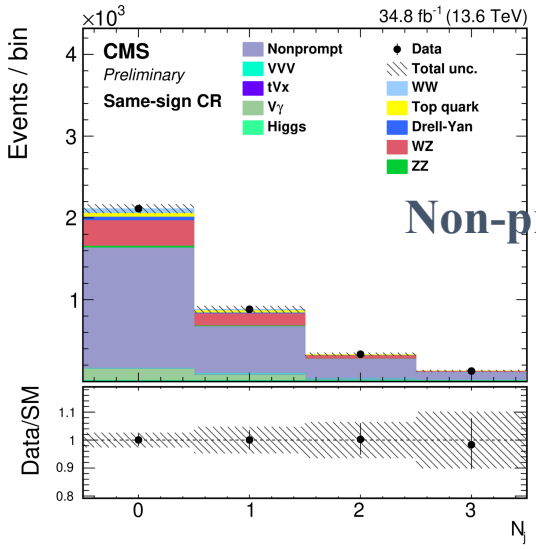
Background normalization syst. ~2.5%

Signal region



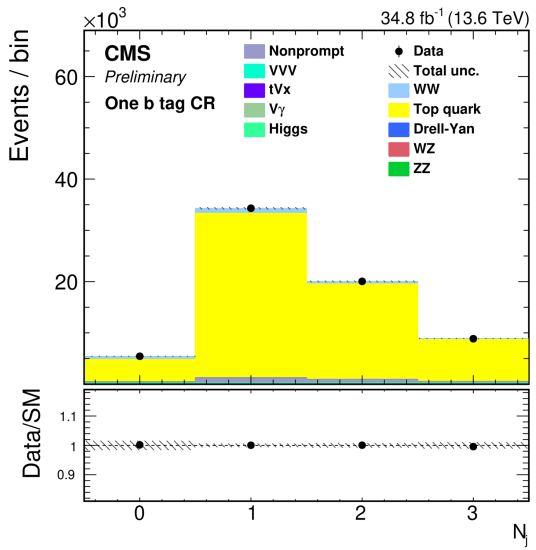
$Z \rightarrow \tau\tau$

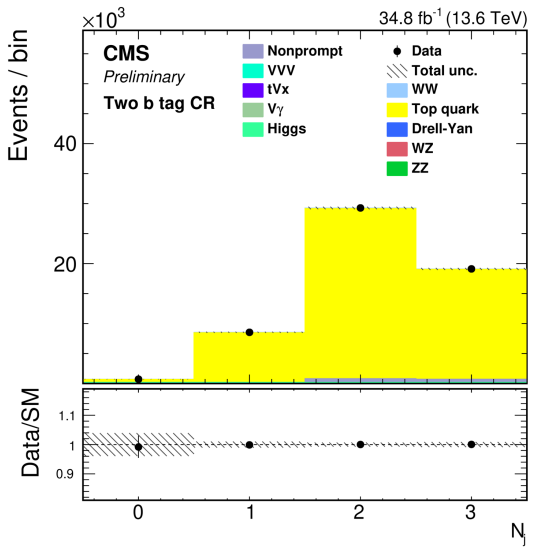




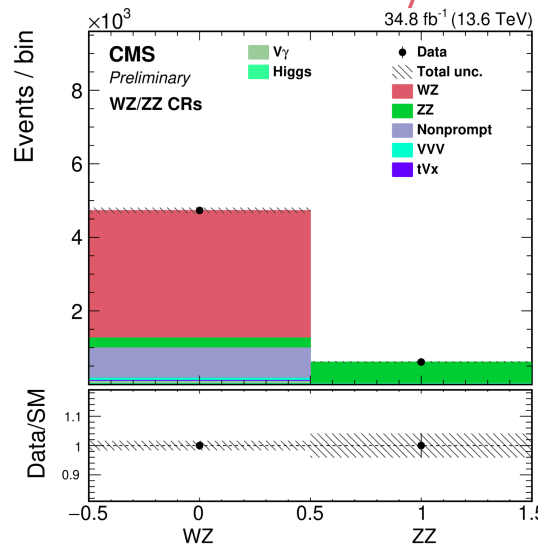
Non-prompt

$t\bar{t}$ and tW





WZ/ZZ



Results

Public results in CMS-PAS-SMP-24-001

- **Inclusive WW production** cross section

$$\sigma_{WW}^{inclusive} = 125.7 \pm 2.3\,(stat.) \pm 5.1\,(syst.) \pm 1.8\,(lum.) = 125.7 \pm 5.9\,pb$$

  - In very good agreement with the MATRIX cross section **127.5 pb** at NNLO in QCD and NLO in EW (gg → WW @ LO scaled to NLO)

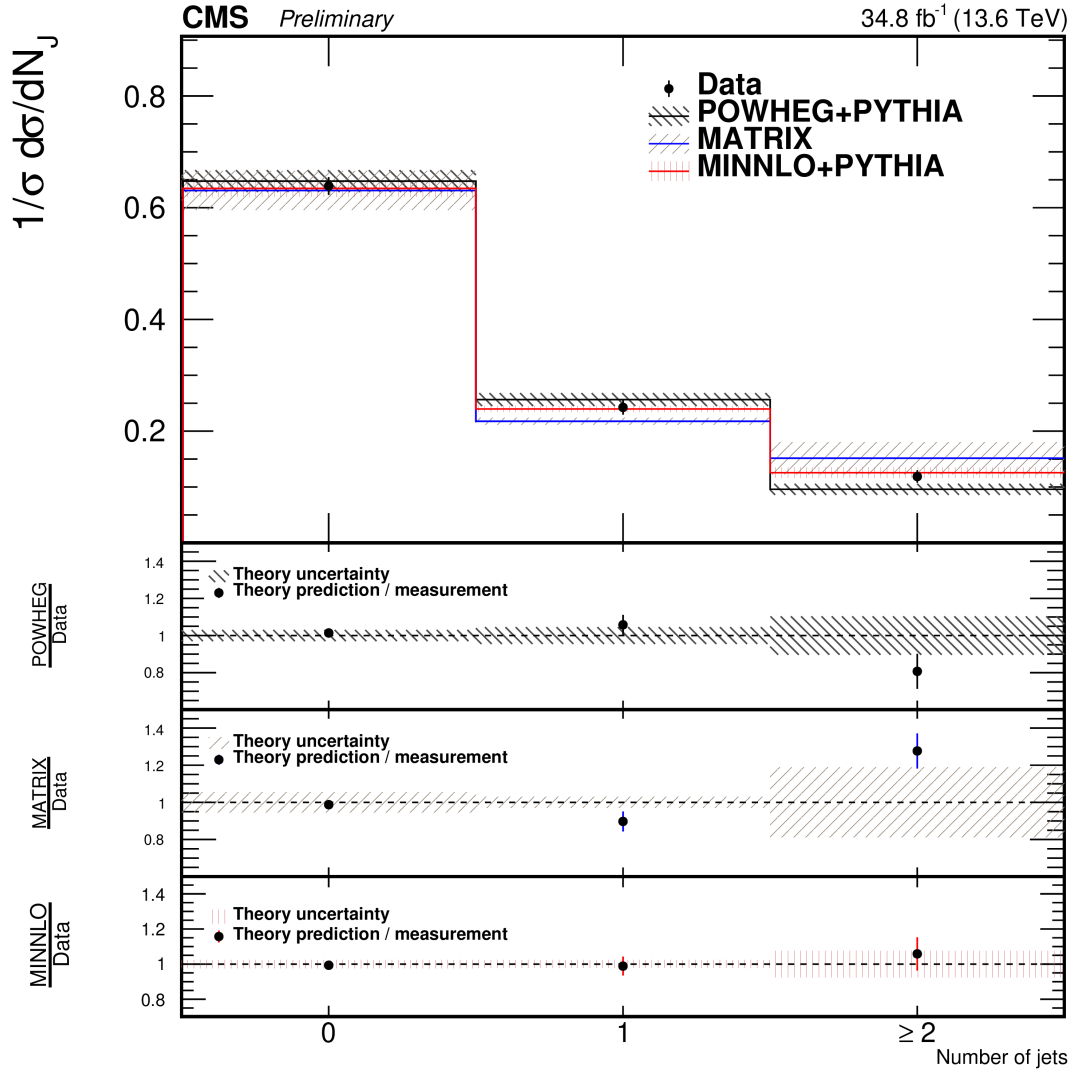
- Simultaneous fit of the **inclusive fiducial and normalized** cross sections.

Observable	Expected	Observed	
Cross section (fb)	$812 \pm 34(31, 15)$	$813 \pm 35(32, 15)$	
0-jet fraction	$0.648 \pm 0.015(0.012, 0.009)$	$0.640 \pm 0.016(0.013, 0.009)$	~ 2.5%
1-jet fraction	$0.256 \pm 0.013(0.008, 0.010)$	$0.243 \pm 0.013(0.009, 0.010)$	~ 5%
$\geq$ 2-jet fraction	$0.096 \pm 0.011(0.008, 0.008)$	$0.119 \pm 0.011(0.008, 0.008)$	~ 9% → Dominated by the statistics

Results

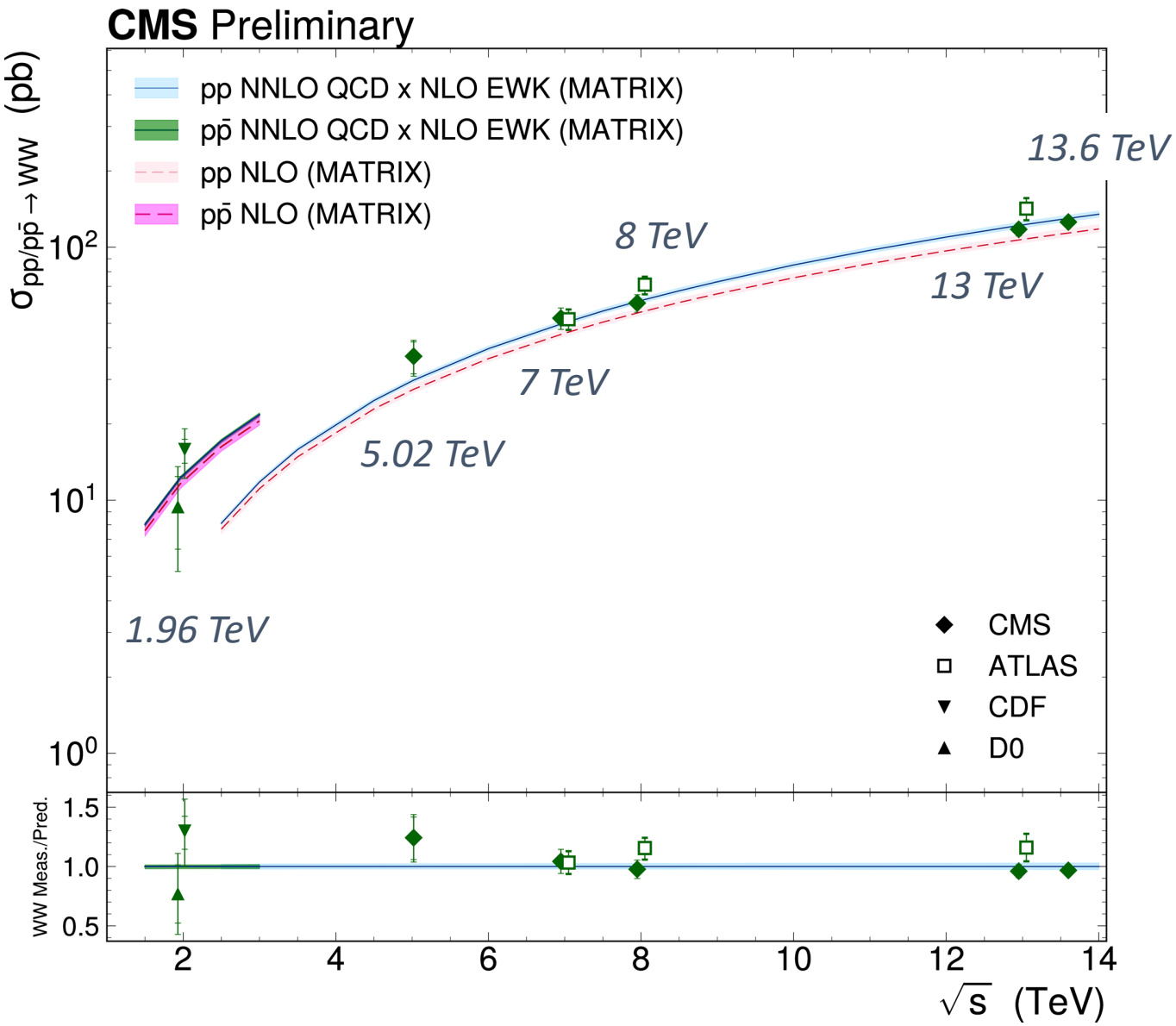
- Comparison of the experimental fiducial normalized WW cross section with different MC predictions:
  - **POWHEG + PYTHIA NLO in QCD** ($gg \rightarrow WW$ LO with Madgraph scaled to NLO)
  - **MATRIX: NNLO in QCD and NLO in EW** ($gg \rightarrow WW$ @ LO scaled to NLO)
  - **MiNNLOPS + PYTHIA NNLO+PS** ($gg \rightarrow WW$ LO with Madgraph scaled to NLO)
- Some larger predicted cross section at high jet multiplicity with MATRIX.
- First ever comparison with MiNNLO+PS generator with excellent agreement between data and prediction.

Normalized fiducial Xsec



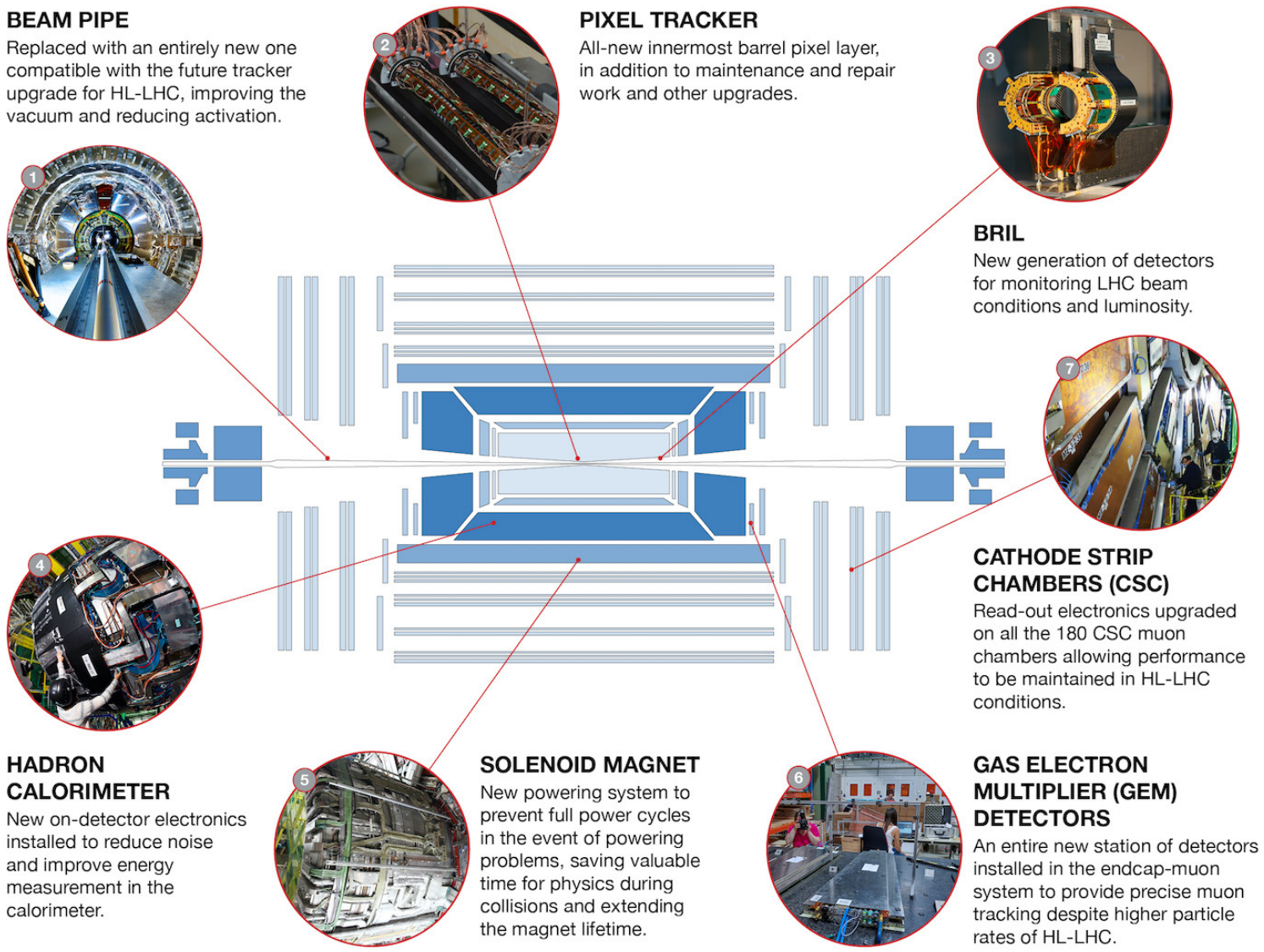
Summary

- CMS is working at excellent performance.
- Probing the SM at a new energy of 13.6 TeV with high precision.
  - Good agreement with predictions in a wide energy range.
- Next steps target the improve in precision
  - Include all Run 3 data for legacy results
- Study further distributions and WW properties, such the final Ws polarization, or possible combination of Run2+Run3.




BACKUP

CMS ready for Run3



During the LS2 (2018-2022)

- New HCAL barrel readout (reduce noise +improve energy resolution)
- New barrel pixel (layer 1)
- First GEM chambers installed and upgrade of CSC electronics for luminosity increase.
- GPU at the HLT and transitioned to a hybrid CPU+GPU in trigger software.

Background overview

Quantity	One/two b-tags CRs	$Z \to \tau\tau$ 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
$p_T^{\ell\ell}$	—	< 30 GeV	—
Number of b-tagged jets	1/2	0	0
N_J	$0/1/2/\geq 3$		

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
$\lvert m_{\ell\ell} - m_Z \rvert$	< 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	