Multiboson production in CMS

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A gold mine of physics!

$$pp \to VV(V)$$

Vector Boson Scattering

Probing EWSB

See Andrea's talk

EFT interpretation

Sensitive to high dimensions

See Ankita's talk and Zongsheng's talk

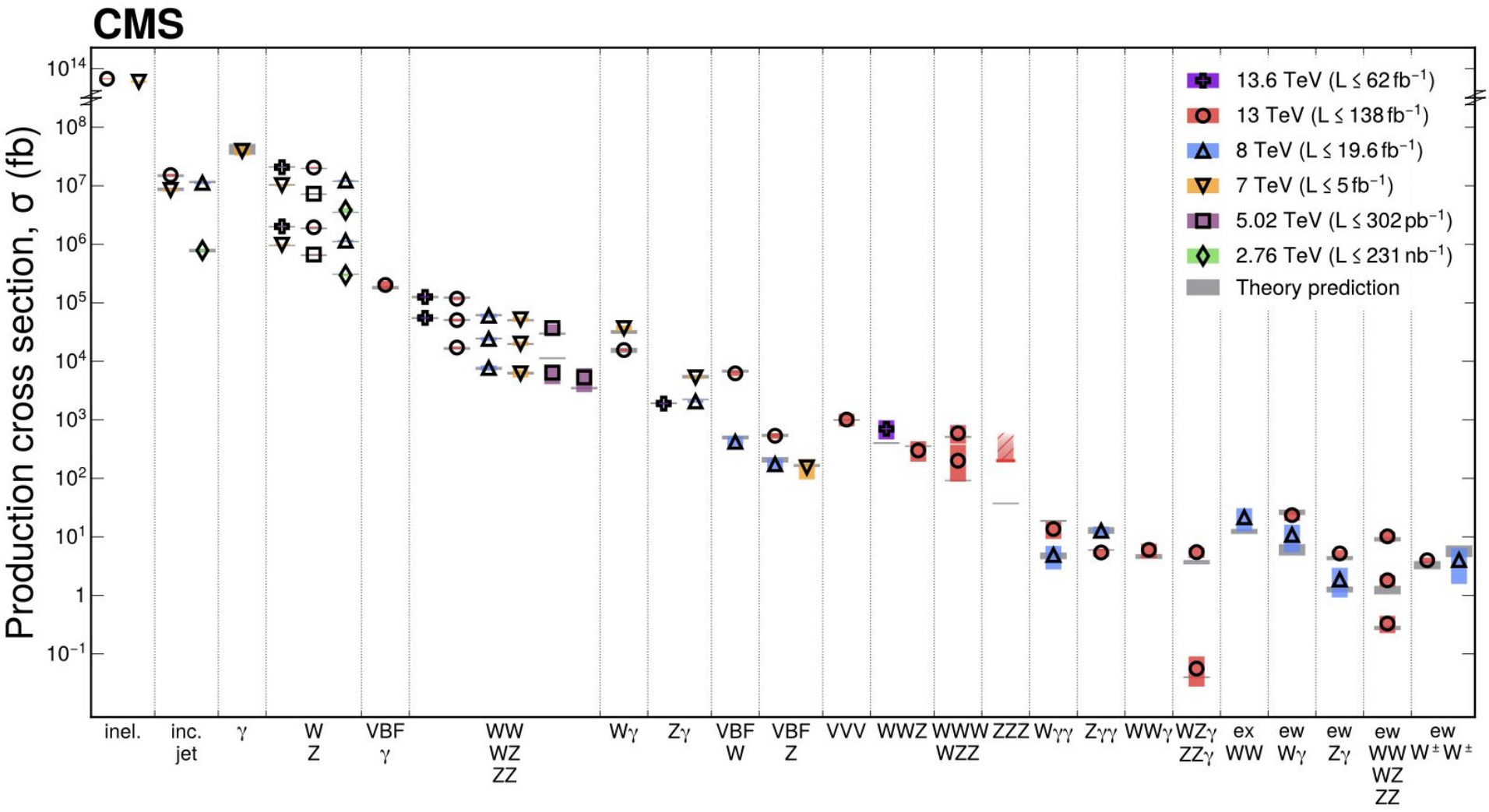
Triboson production

Strong probe to quartic couplings

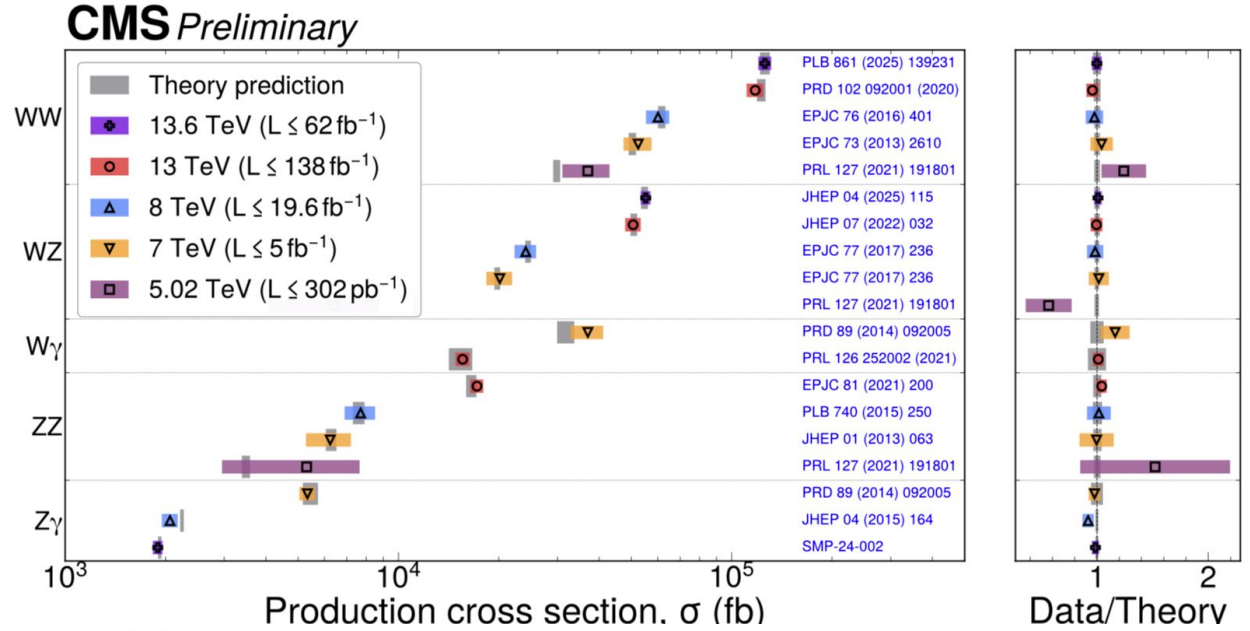
See Antonio's talk

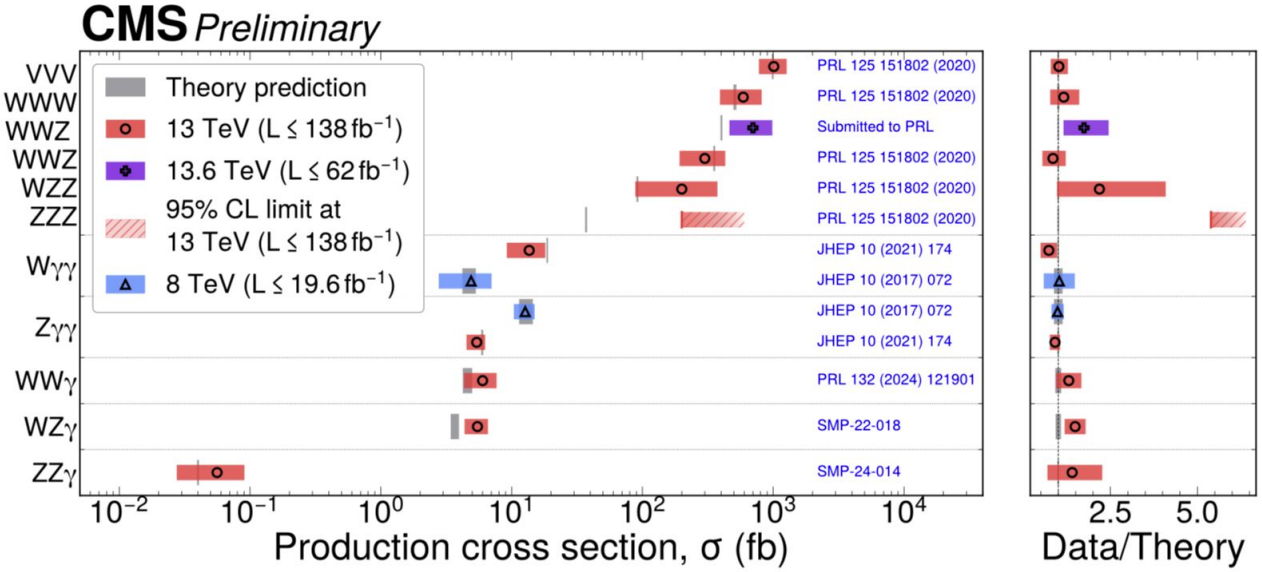
All these interpretations rely on a vast program of searches/measurements of multiboson production

A race to low statistics



A huge program of measurements





WZ production at 13.6 TeV

Published on JHEP04 (2025) 115

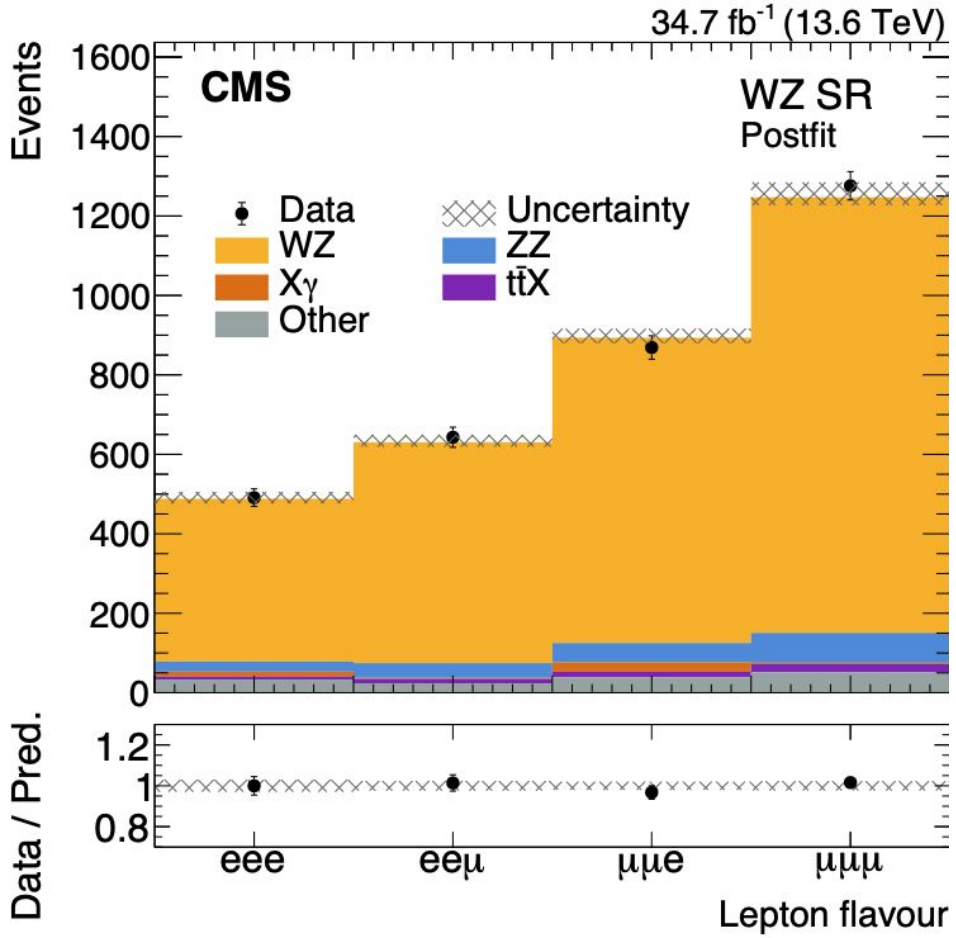
WZ production at 13.6 TeV

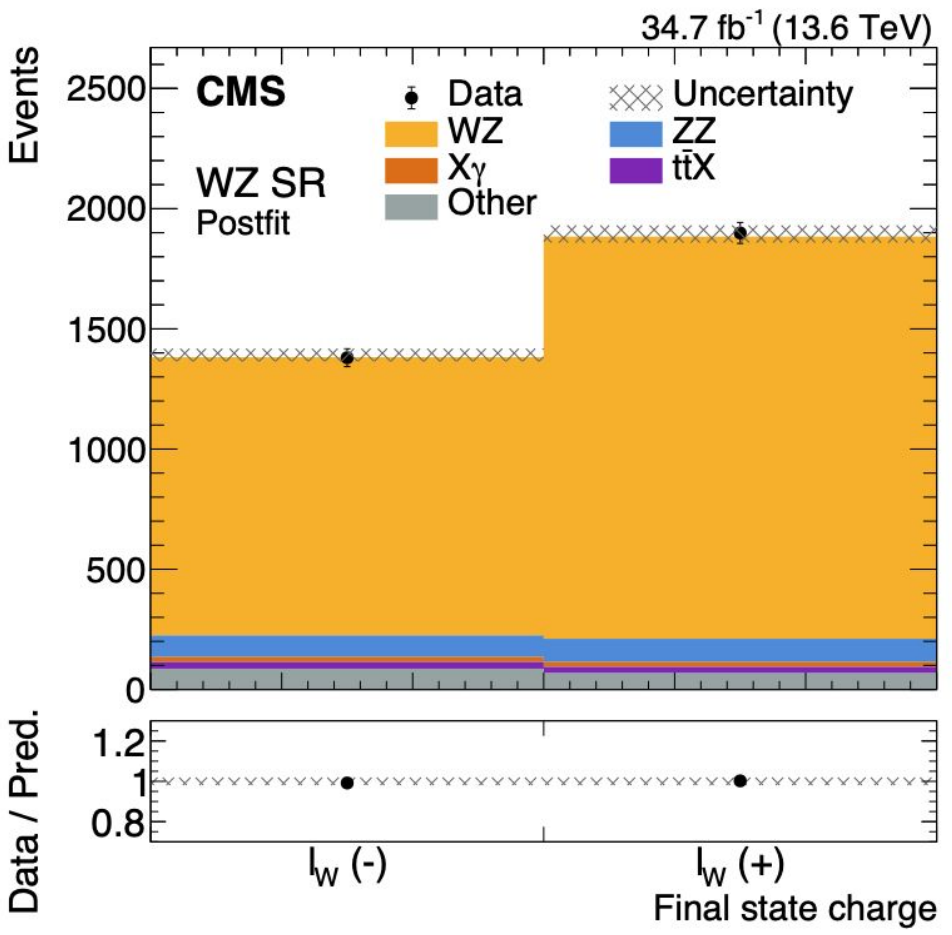
- Measurement in the fully leptonic final state
  - Classify events on number of leptons of a given flavor
- Using the 2022 CMS dataset
- Control regions based on number of leptons, b-tag and missing energy

Region	N_ℓ	$p_T\{\ell^1_Z, \ell^2_Z, \ell_W(\ell_3), (\ell_4)\}$ (GeV)	N_{OSSF}	$\lvert m(\ell^1_Z, \ell^2_Z) - m_Z \rvert$ (GeV)	p_T^{miss} (GeV)	$N_{b\,tag}$	$\min(m(\ell, \ell'))$ (GeV)	$m(\ell^1_Z, \ell^2_Z, \ell_W(\ell_3))$ (GeV)
SR	=3	>{25, 15, 25}	≥1	<15	>35	=0	>4	>100
ZZ CR	=4	>{25, 15, 25, 15}	≥1	<15	—	=0	>4	>100
$t\bar{t}Z$ CR	=3	>{25, 15, 25}	≥1	<15	>35	>0	>4	>100
$X\gamma$ CR	=3	>{25, 15, 25}	≥1	—	≤35	=0	>4	<100

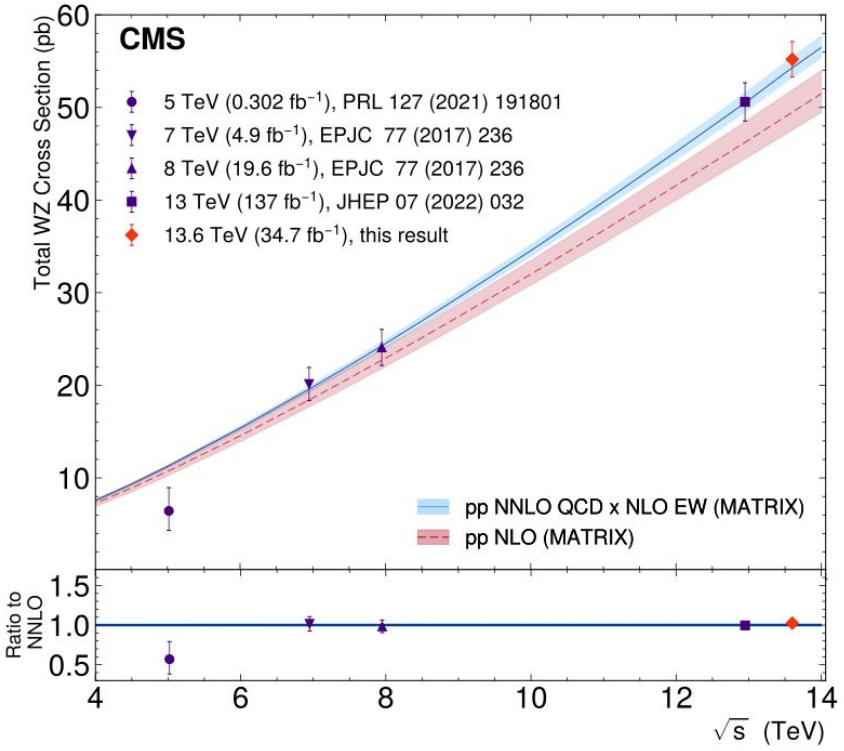
Process	eee	eeμ	$\mu\mu$e	$\mu\mu\mu$	Inclusive
Non-prompt	25 ± 7	13 ± 5	24 ± 7	30 ± 10	93 ± 15
ZZ	25 ± 2	37 ± 1	49 ± 3	75 ± 3	186 ± 5
$X\gamma$	12 ± 2	2.5 ± 0.3	24 ± 2	3.2 ± 0.5	41 ± 3
$t\bar{t}X$	8.0 ± 0.8	11 ± 1	14 ± 1	21 ± 2	54 ± 3
VVV	4 ± 1	5 ± 2	7 ± 3	10 ± 4	27 ± 5
VH	3.0 ± 0.5	3.8 ± 0.7	5 ± 1	9 ± 2	20 ± 2
tZq	4.2 ± 0.5	5.3 ± 0.6	7.5 ± 0.9	11 ± 1	28 ± 2
Background	82 ± 8	78 ± 5	130 ± 9	160 ± 11	450 ± 17
WZ	410 ± 10	556 ± 12	768 ± 14	1096 ± 22	2830 ± 31
Prediction	491 ± 13	634 ± 13	898 ± 16	1256 ± 24	3280 ± 34
Data	491	643	869	1276	3279

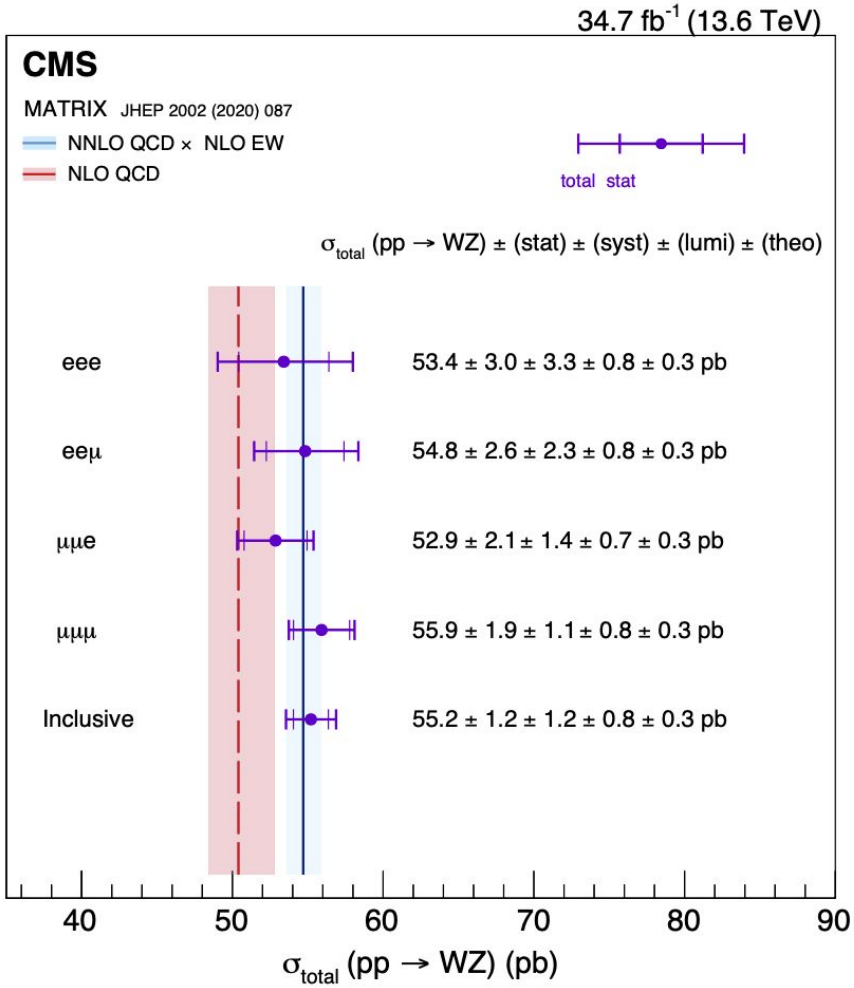
Distributions





Results





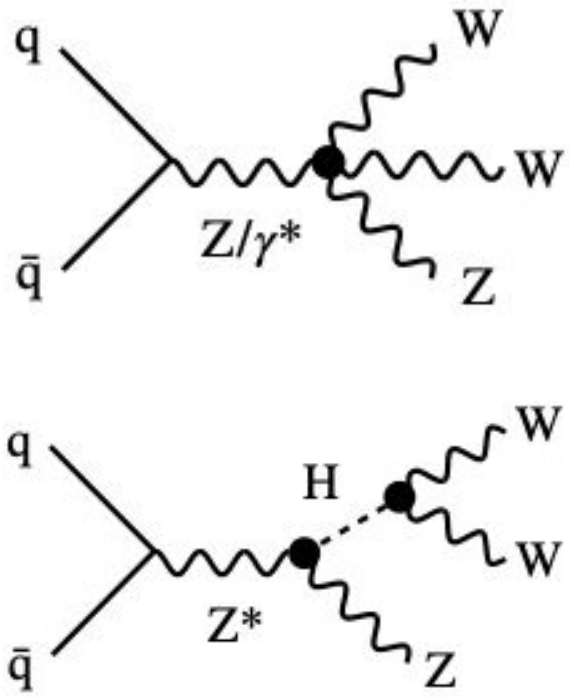
Accuracy	Total cross section (pb)
POWHEG, NLO QCD	$50.5\,^{+2.6}_{-2.1}\,(\text{scale}) \pm 1.1\,(\text{PDF})$
MATRIX, NLO QCD	$50.4\,^{+2.3}_{-2.0}\,(\text{scale})$
MATRIX, NNLO QCD	$55.0\,^{+1.2}_{-1.1}\,(\text{scale})$
MATRIX, NNLO QCD × NLO EW	$54.7\,^{+1.2}_{-1.1}\,(\text{scale})$
Inclusive (Measured)	$55.2 \pm 1.2\,(\text{stat}) \pm 1.2\,(\text{syst}) \pm 0.8\,(\text{lumi}) \pm 0.3\,(\text{theo})$

WWZ & ZH production

CMS-PAS-SMP-24-015, submitted to PRL

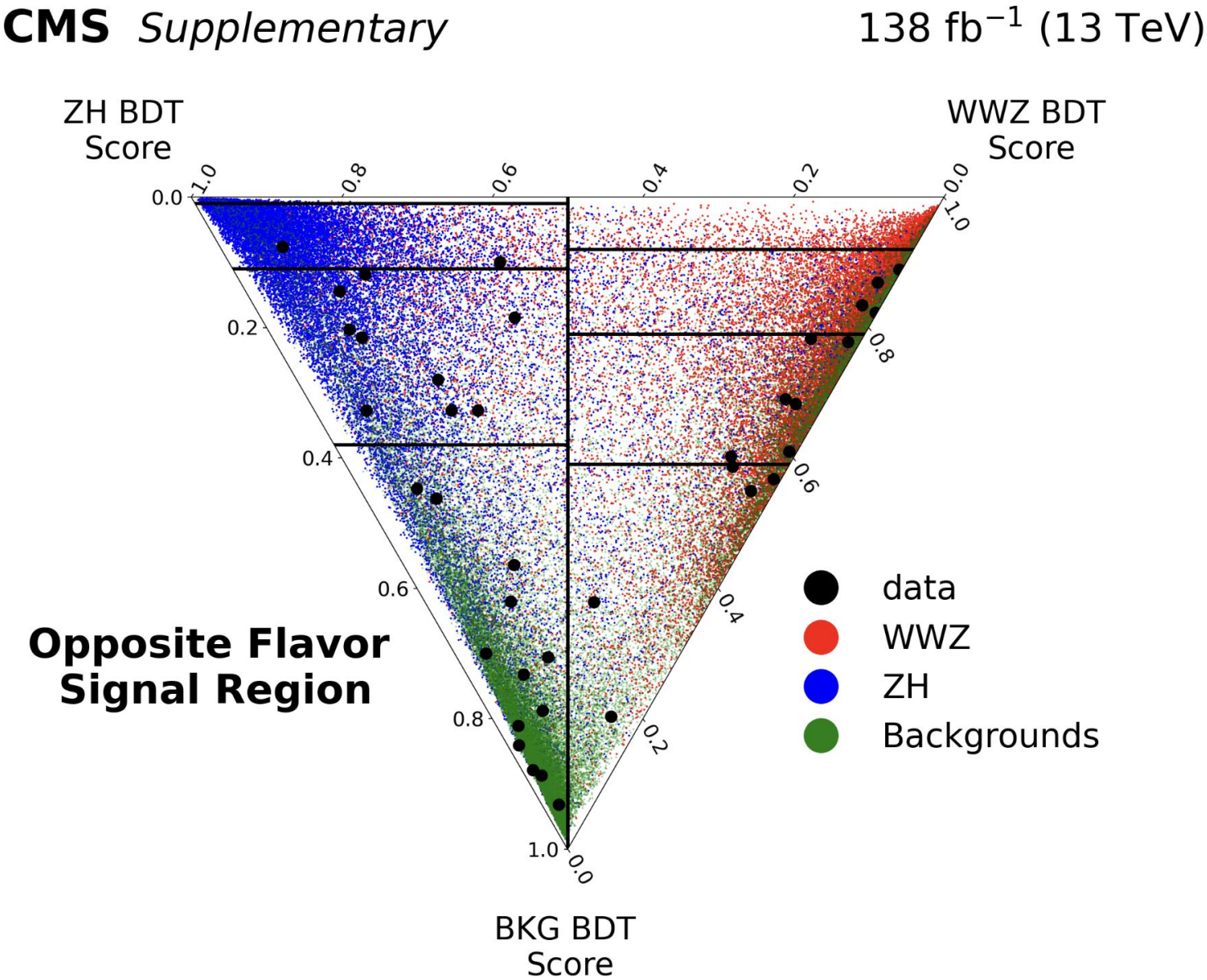
WWZ&ZH

- Search in the fully leptonic final state
- First simultaneous fit of triboson and Higgs associated productions

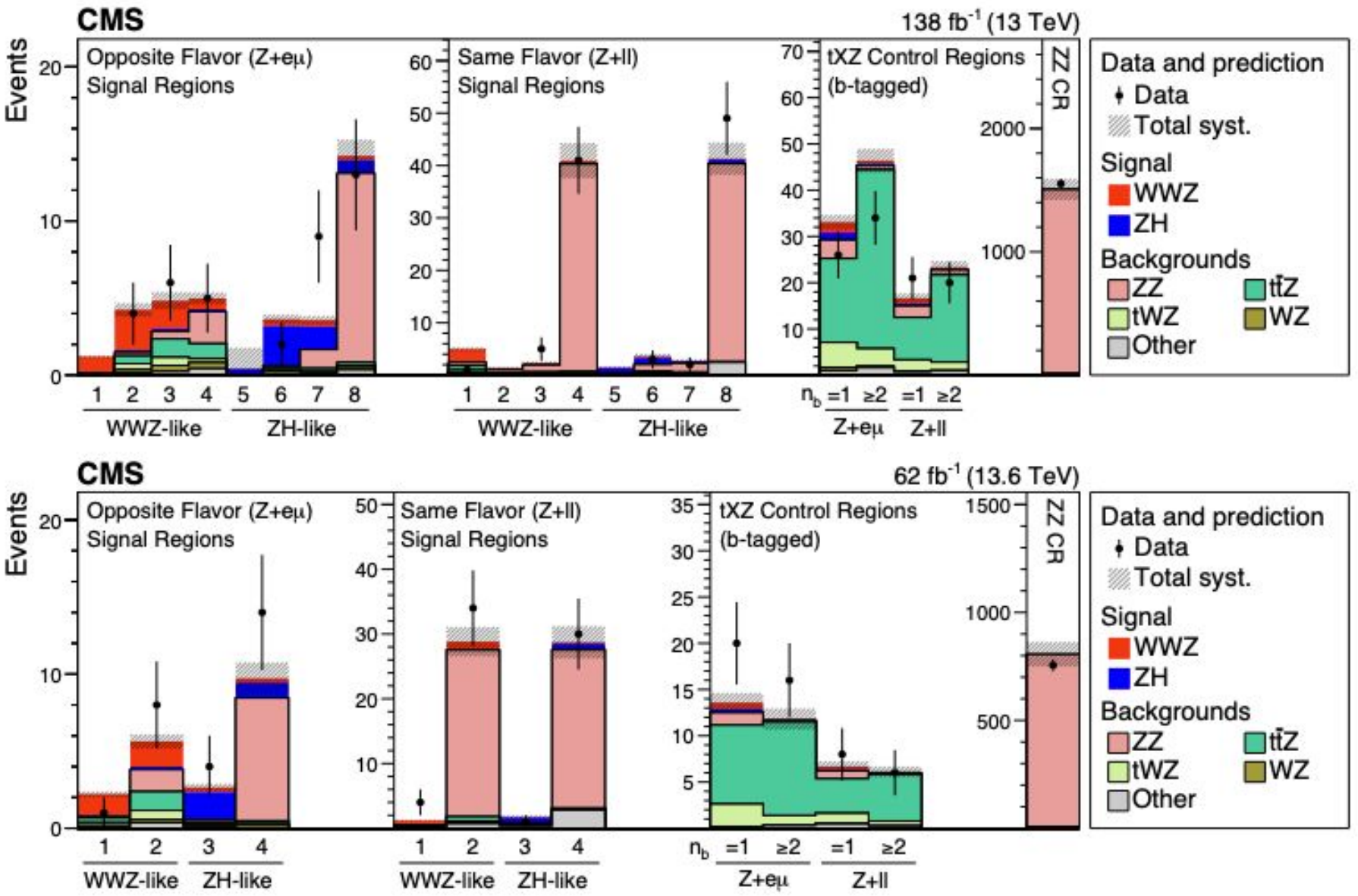


- Using full Run2+2022-23 data
- Categorization on flavors of W decay
- BDT to separate WWZ, ZH and backgrounds

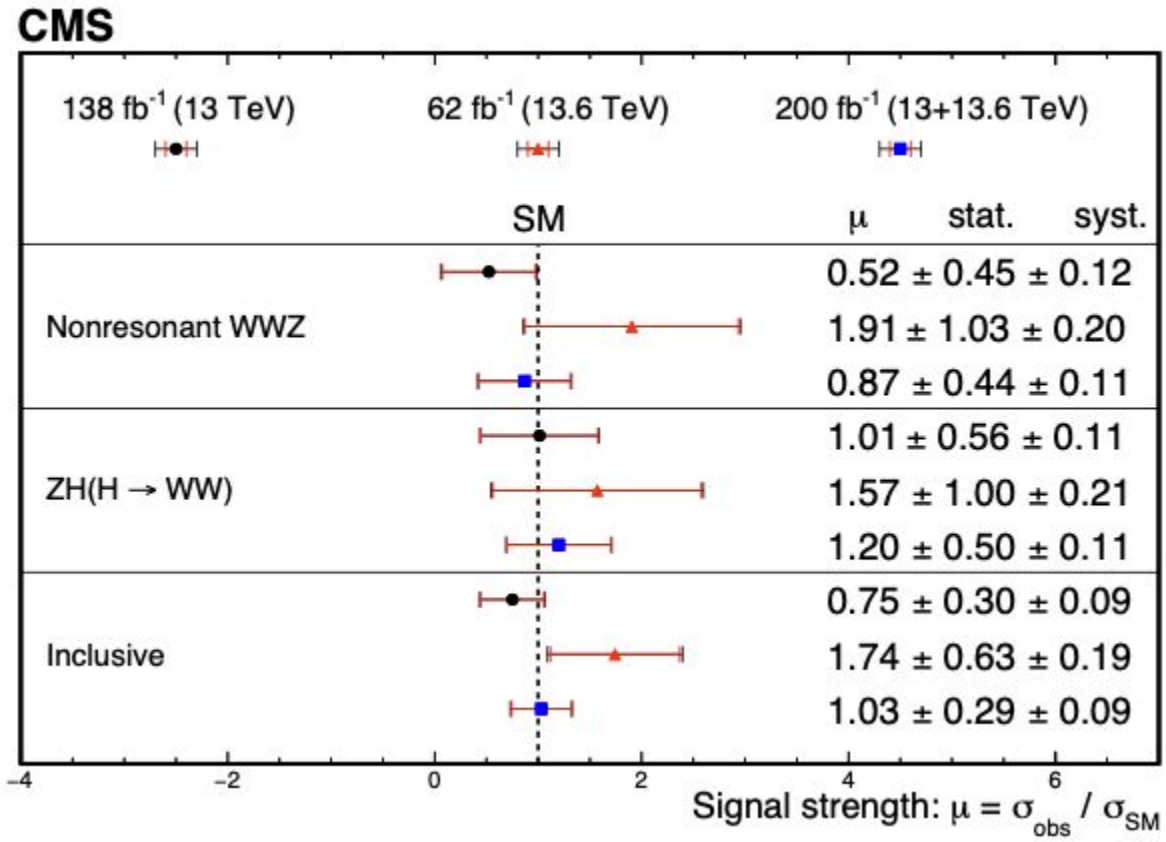
Categorization

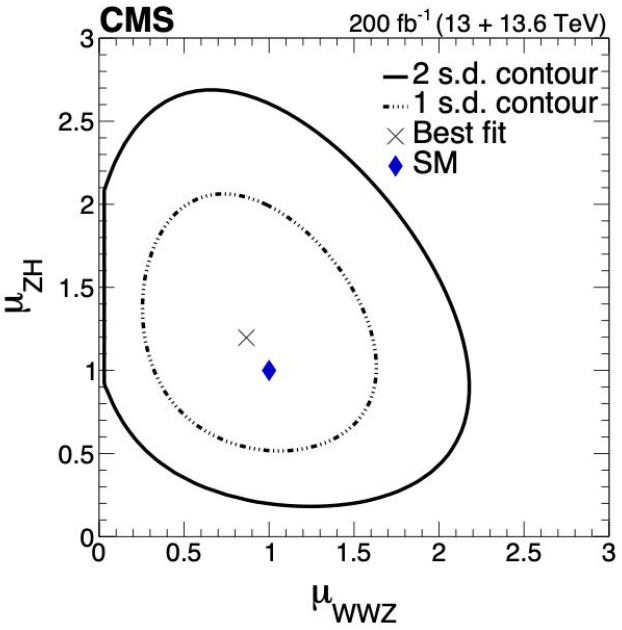


Categorization



Results





Era	Total	WWZ	ZH
Run 2	2.9 (4.4)	1.3 (3.1)	2.0 (2.6)
Run 3	3.8 (2.5)	2.5 (1.3)	2.5 (1.7)
Total	4.5 (5.0)	2.4 (3.3)	3.1 (3.1)

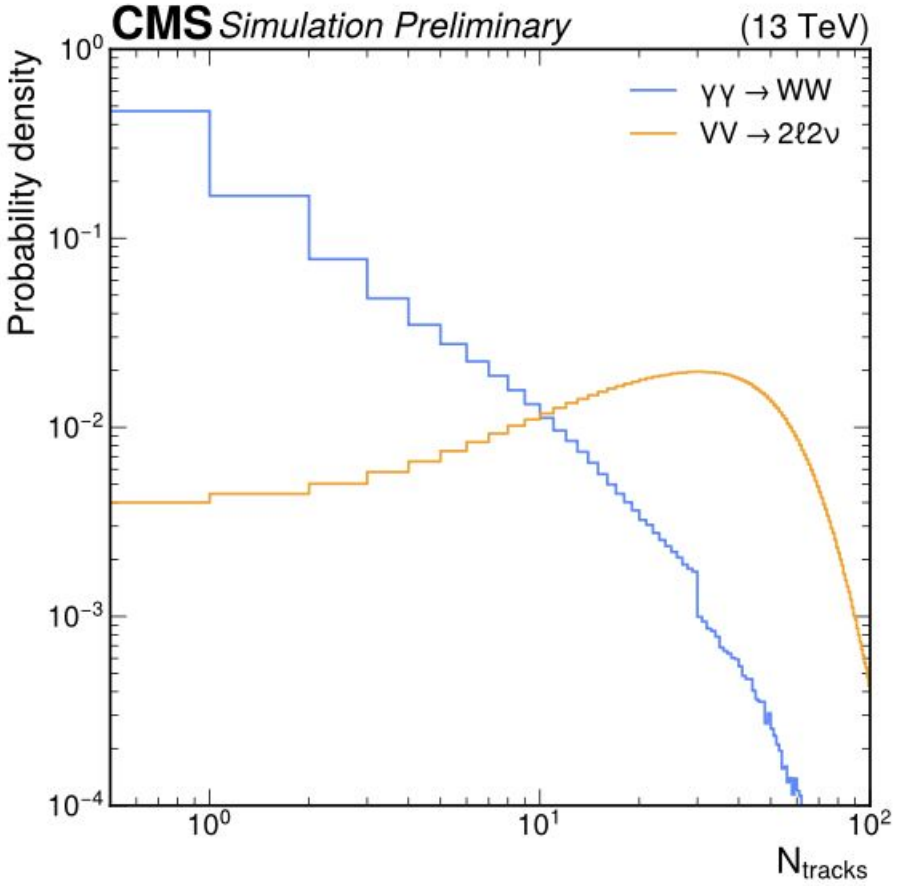
- Most precise inclusive cross section measurement
- First evidence of triboson production at 13.6 TeV!

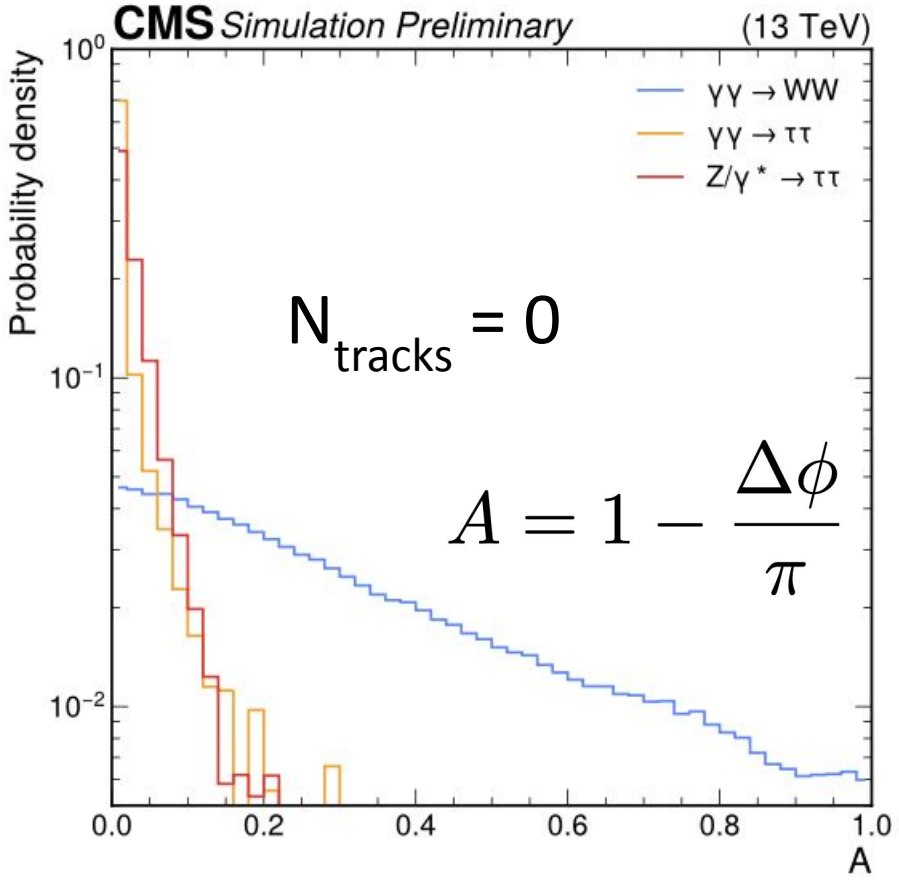
Photon induced WW production

CMS-PAS-SMP-24-019, NEW!

Photon-induced production

- Search in the opposite-flavor leptonic final state
- Limited track activity in the vertex
- Topological selection to limit $\tau\tau$ background





Strategy

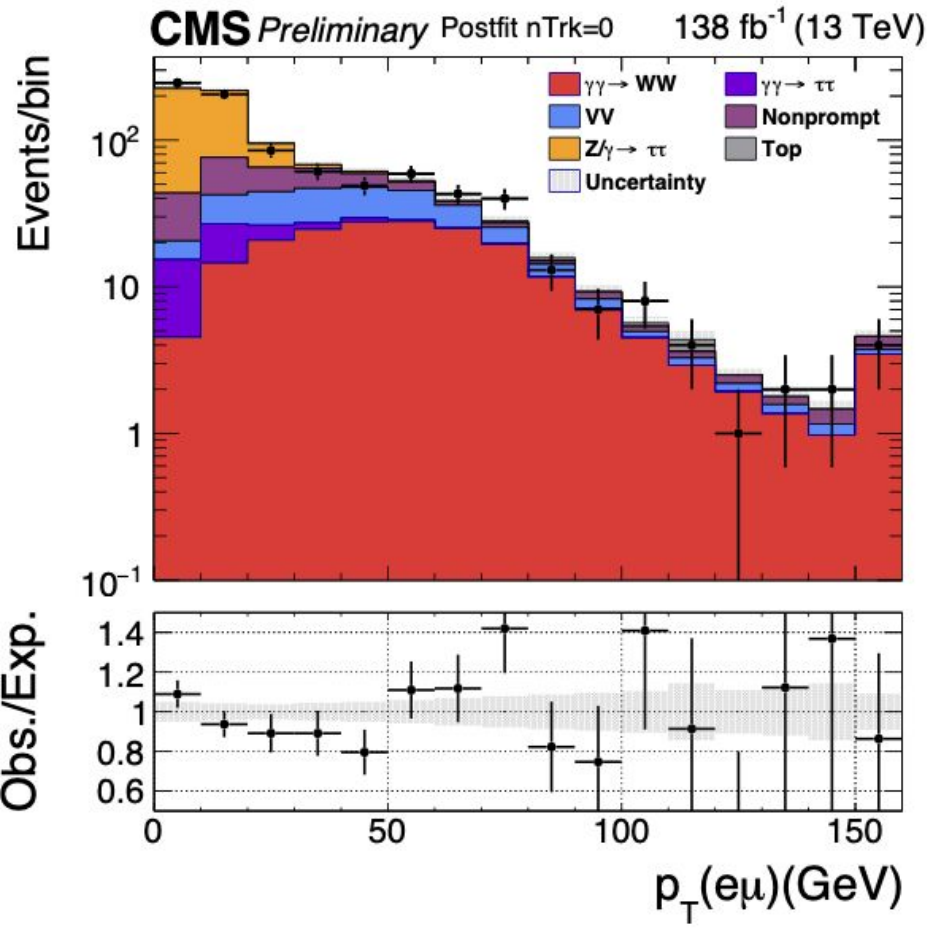
- Fit dilepton p_T in two regions (control on DY background)
- Correction on track multiplicity using $\mu\mu$ events
- Non-prompt leptons estimated with SS sample
- Fit simultaneously:
  - Signal normalization
  - DY and inclusive WW (correlated with CR)
  - N_{tracks} correction

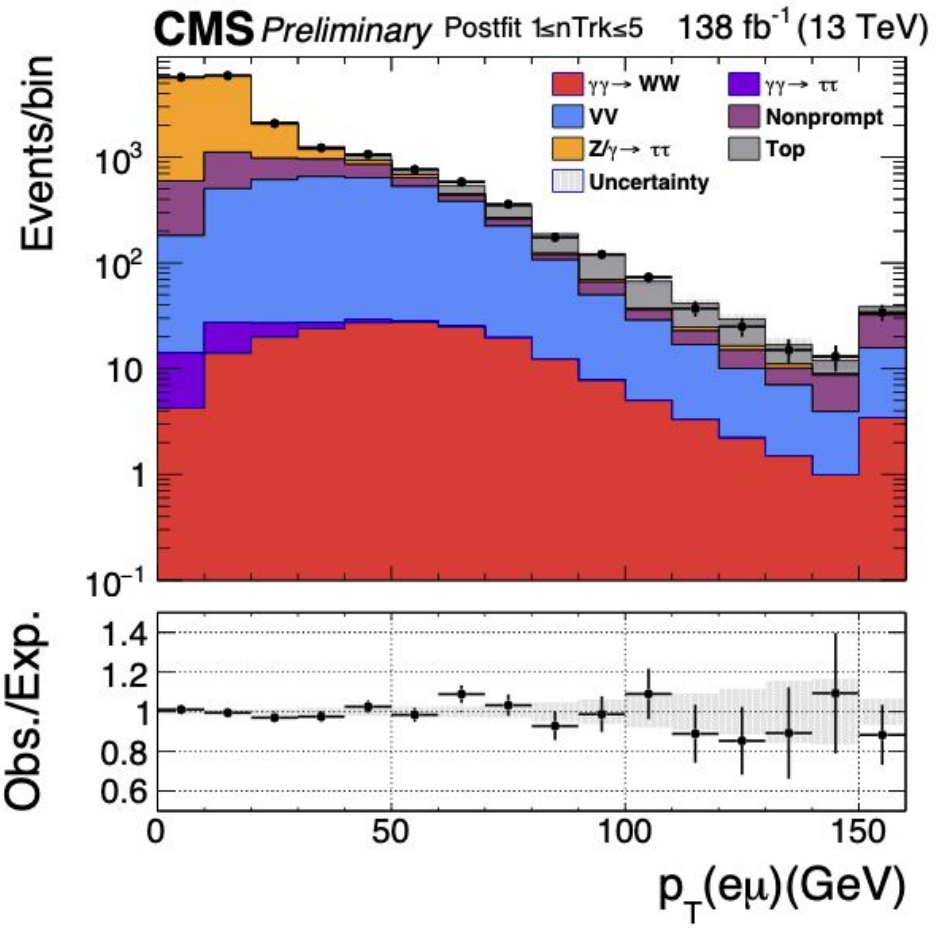
	$e\mu$ SR (CR)	$\mu\mu$
ep_T (GeV)	$> 15/24$	—
$\lvert e\eta \rvert$	< 2.5	—
μp_T (GeV)	$> 24/15$	$> 26 - 29/10$
$\lvert \mu\eta \rvert$	< 2.4	—
$m_{\ell\ell}$ (GeV)	> 20	> 50
OS	yes	yes
$\lvert dz(\ell,\ell) \rvert$ (cm)	< 0.04	< 0.1
ΔR	> 0.5	> 0.5
A	> 0.015	—
N_{tracks}	0 ([1, 5])	—

Process	$N_{tracks} = 0$	$1 \leq N_{tracks} \leq 5$
$Z/\gamma^* \to \tau\tau$	359.9 ± 22.4	11262.3 ± 166.4
Jet mis-ID	120.4 ± 10.2	2176.1 ± 186.1
Inclusive VV	115.2 ± 10.0	3733.7 ± 184.4
$\gamma\gamma \to \tau\tau$	34.2 ± 1.4	37.3 ± 1.5
Top	7.0 ± 1.5	718.6 ± 114.9
Nonfiducial $\gamma\gamma \to$ WW	11.5 ± 0.5	70.5 ± 2.4
Total bkg.	648.1 ± 28.3	17998.5 ± 174.3
Fiducial $\gamma\gamma \to$ WW	183.7 ± 22.2	124.0 ± 15.8
Total	835.4 ± 28.8	18122.5 ± 159.6
Observed	829	18112

Results

More details and aQGC interpretation in Zongsheng's talk





$\sigma_{fid} = 4.1 \pm 0.5\text{fb}$ first observation at CMS

$\sigma_{\text{pred}}^{\text{fid}} = 3.87 \pm 0.08\,\text{fb}$ from SUPERCHIC

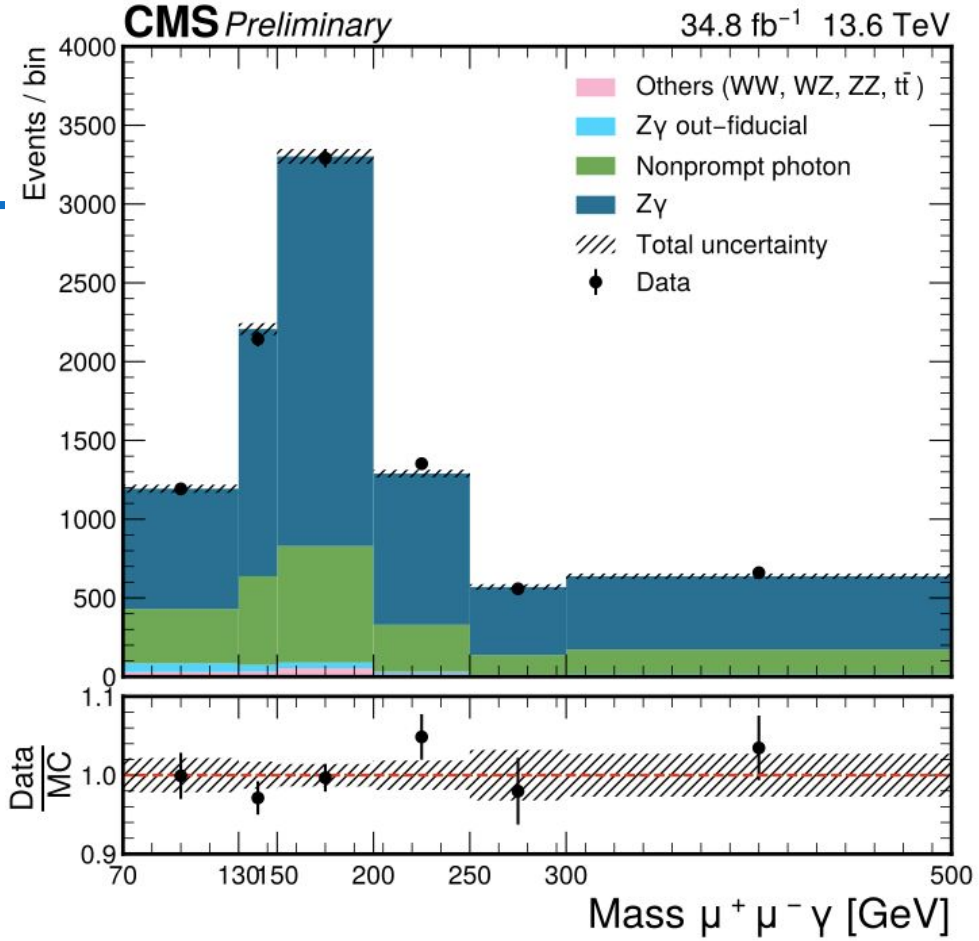
$\sigma_{incl} = 658.8^{+81.7}_{-77.7}\text{fb}$

$Z\gamma$ production

CMS-PAS-SMP-24-002

$Z\gamma$ production

- Leptonic final state
- Using 2022 13.6 TeV data
- Fit $m_{\ell\ell\gamma}$ to extract signal strength



Channel	$\sigma \times BR(Z\gamma \to l^+l^-\gamma) \pm$ th. $\pm$ syst. $\pm$ stat. (pb)
predicted $Z\gamma$ ($\mu\mu$)	$0.961 \pm 0.004 \pm 0.028 \pm 0.019$
predicted $Z\gamma$ (ee)	$0.961 \pm 0.004 \pm 0.037 \pm 0.021$
predicted $Z\gamma$ (combined)	$1.922 \pm 0.006 \pm 0.056 \pm 0.033$
observed $Z\gamma$ ($\mu\mu$)	$0.928 \pm 0.004 \pm 0.027 \pm 0.018$
observed $Z\gamma$ (ee)	$0.975 \pm 0.003 \pm 0.038 \pm 0.021$
observed $Z\gamma$ (combined)	$1.896 \pm 0.006 \pm 0.054 \pm 0.033$

Conclusions

- Multiboson production is an effective playground to test the SM at LHC!
- Vast program of production mechanisms and final states
- Allows for (re)interpretation in different contexts
- Interest in probing at different energies
- Variety of techniques and statistical regimes
- Ramping up activities on Run-3 data
  - But the bulk of statistics is still to be analyzed!
  - And many multiboson analyses are still statistically limited

To be continued....