



CMS Standard Model 13 TeV Results

**XXII Cracow EIPHANY Conference on the Physics in LHC Run2
07-09 January 2016**

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On behalf of CMS Collaboration**

LHC : Thank you!



An amazing year for LHC team

The CMS Collaboration

1700 physicist, 700 student, 950 engineers/technician, 180 institutions from 43 countries



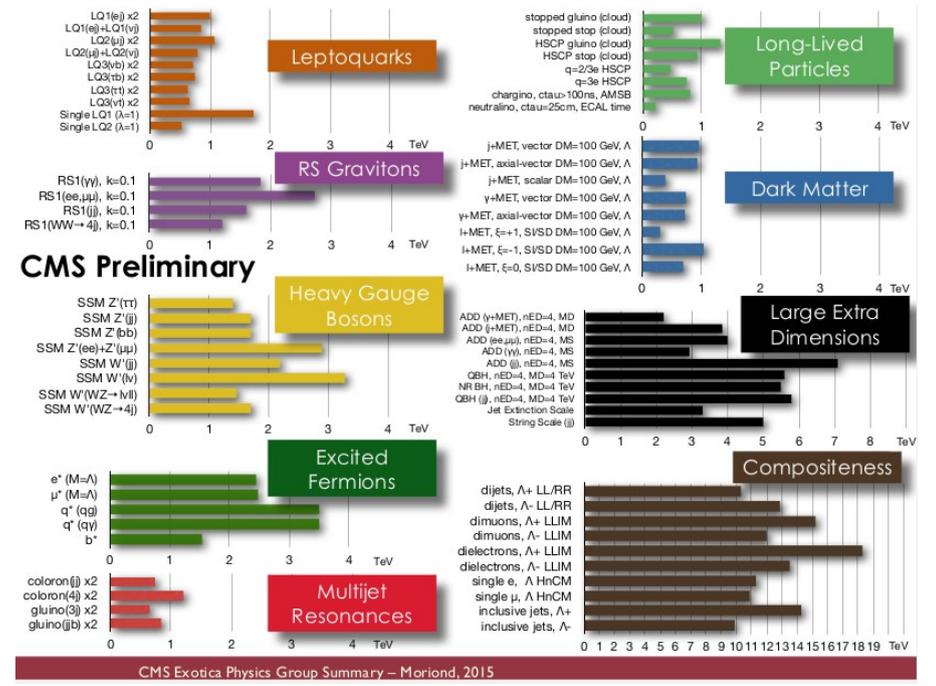
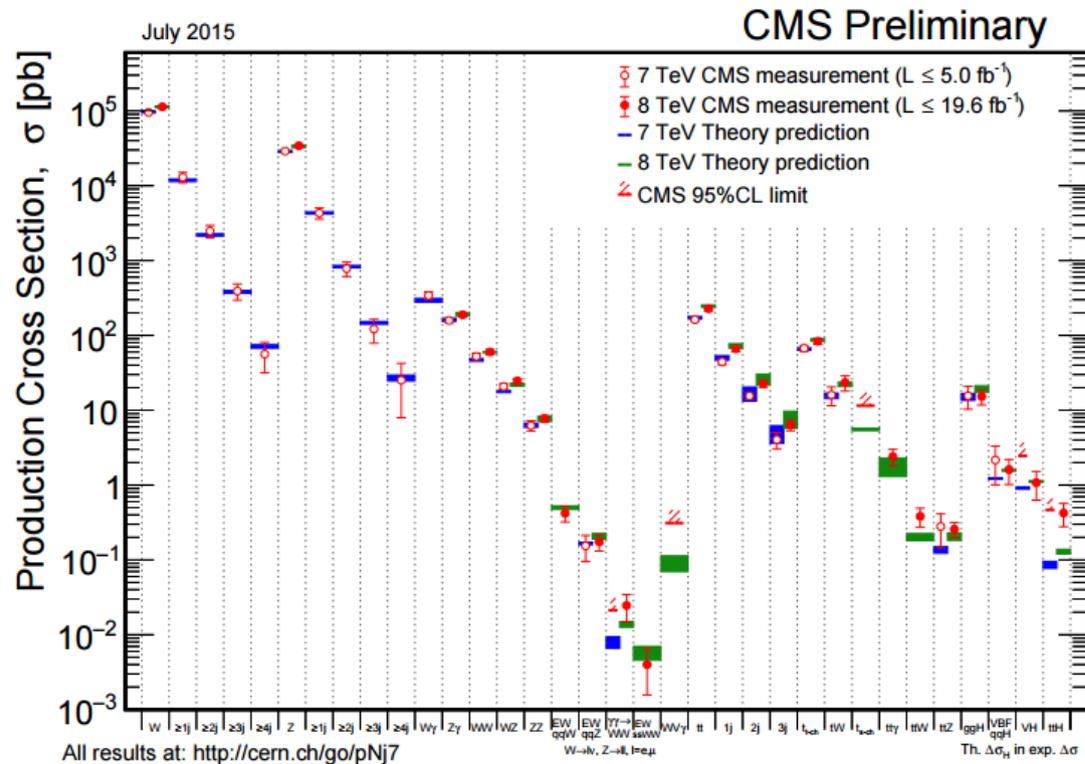
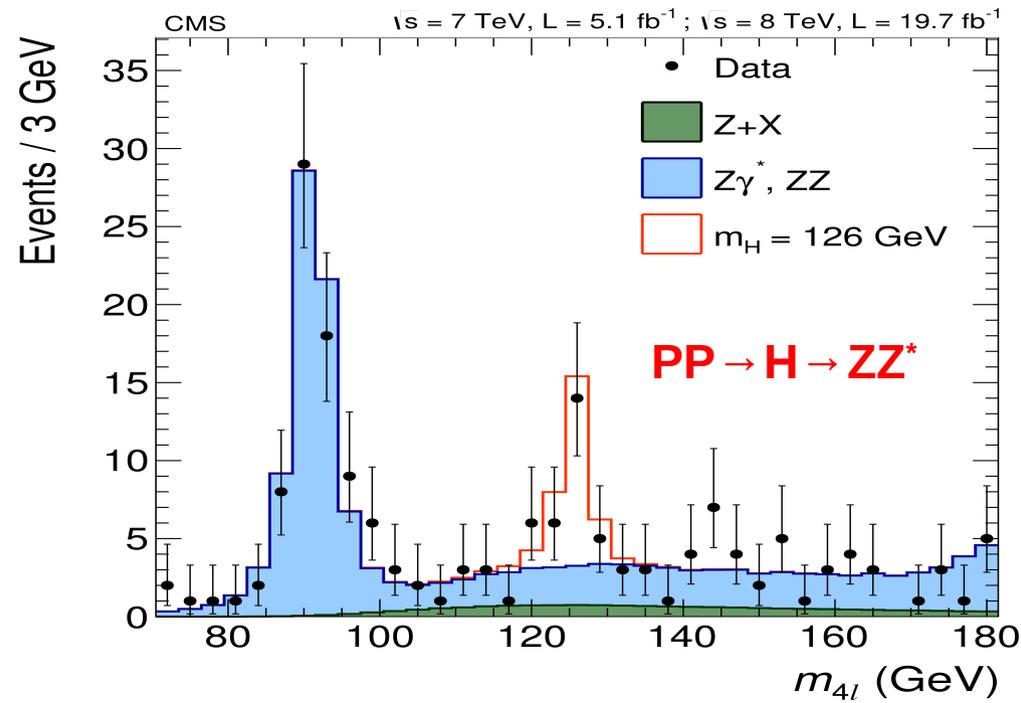
Thanks to all

CMS operation in 2015

- At the end of the Long Shutdown 1 we realized that the performance of the cryogenic system feeding Liquid He to our Magnet was severely impaired by a contamination of the Cold box
- This has affected our operation in 2015: a large effort from the CERN cryogenic and technical departments associated to our Technical Coordination have limited the impact, allowing to collect $\approx 3/4$ of the delivered luminosity with full magnetic field.
- The detector and new acquisition system was ready from the start of LHC running at 13 TeV: we have logged data with efficiency well above 90% with trigger thresholds similar or lower than the ones at Run I
- A detailed plan of repair and cleaning of the cryo system, to be executed Technical Stop started by the End of last Year, is ready and foresees the system to be ready for Physics production by the first week of April, i.e. well ahead of the start of physics production of LHC in 2016

Run I Legacy

- 448 publications published/submitted
- Higgs Boson Discovery
- Plenty of SM measurements
- Many BSM searches, a few bumps



CMS Publication status

→ Run I Publications

448 and counting

→ Run 2 Publications

4 submitted/published

• dN/dh – first 13 TeV

Paper (published)

• Two-particle correlations

(“the ridge”)

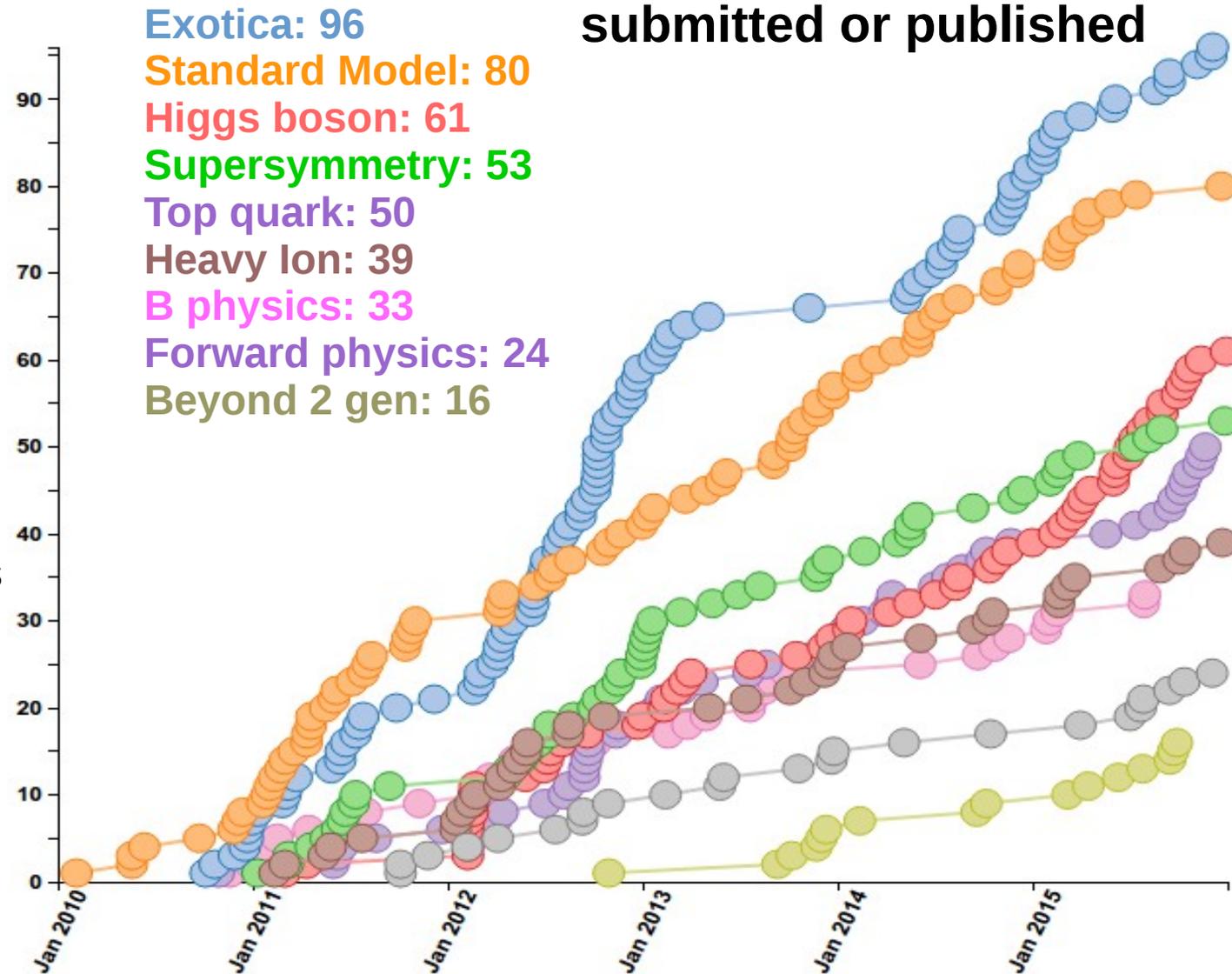
• Search for dijet resonances

(first 13 TeV search,
submitted to PRL)

+24 publications on
first cosmic ray data
recorded by CMS

452 papers

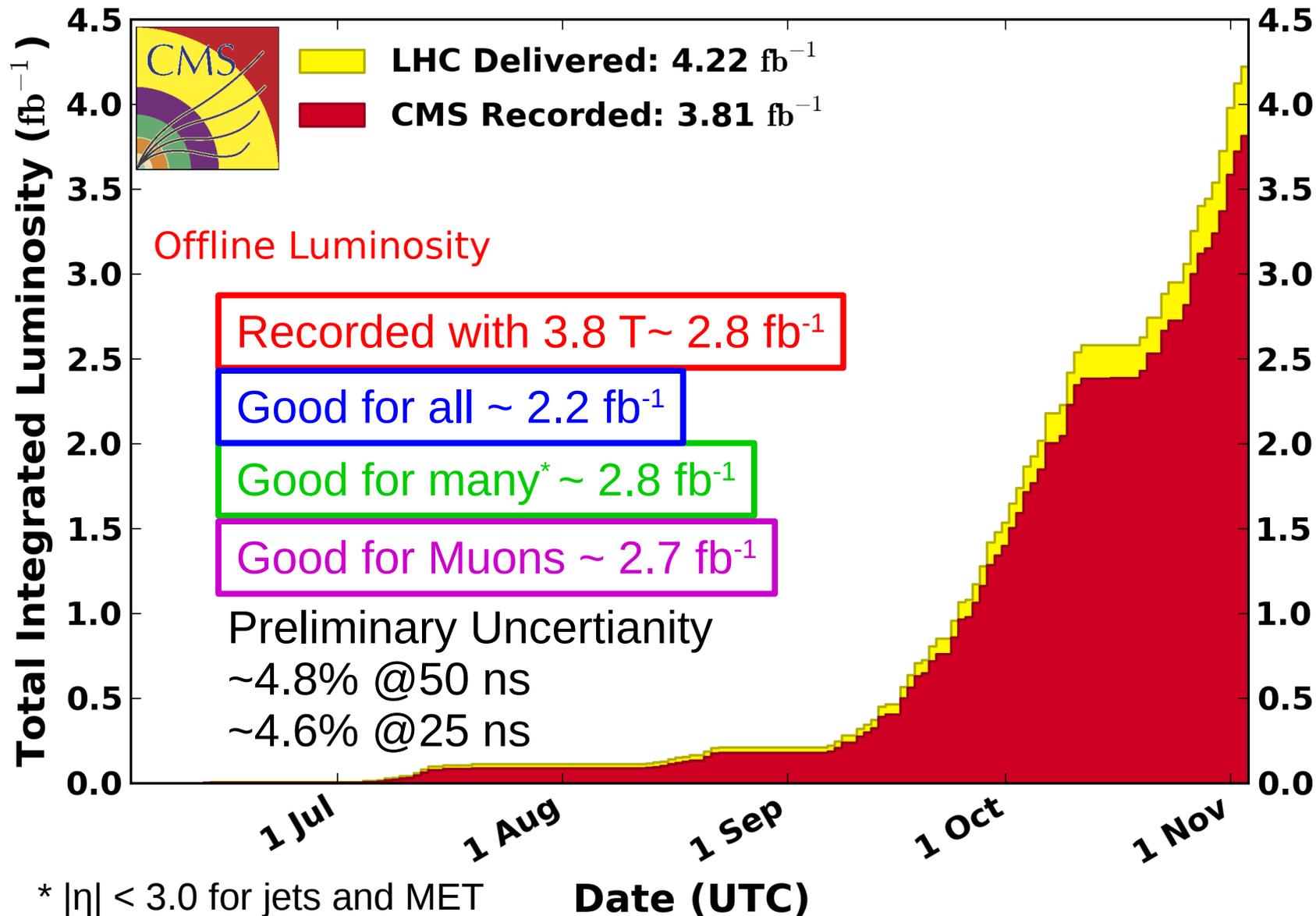
submitted or published



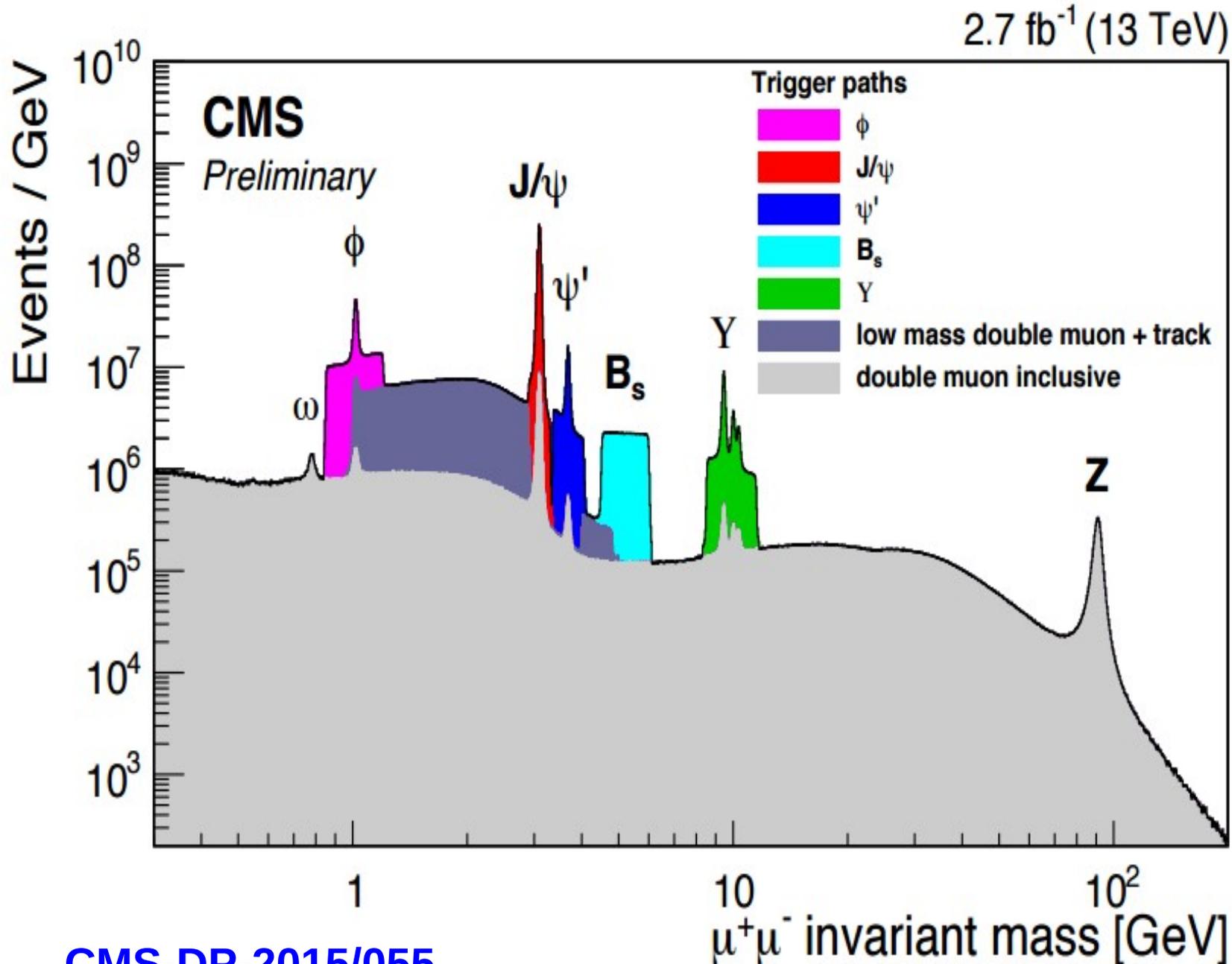
13 TeV dataset

CMS Integrated Luminosity, pp, 2015, $\sqrt{s} = 13$ TeV

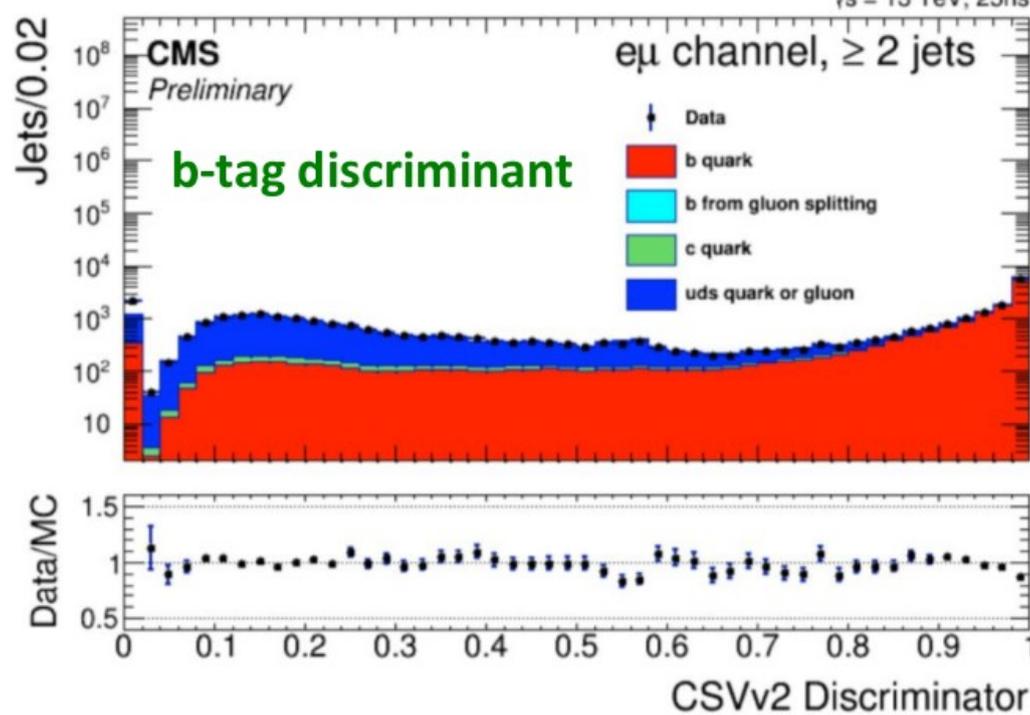
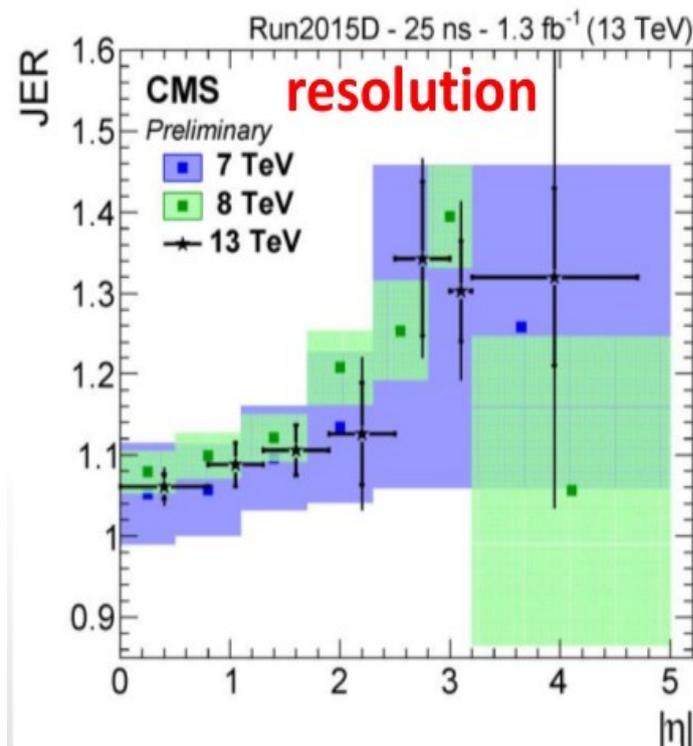
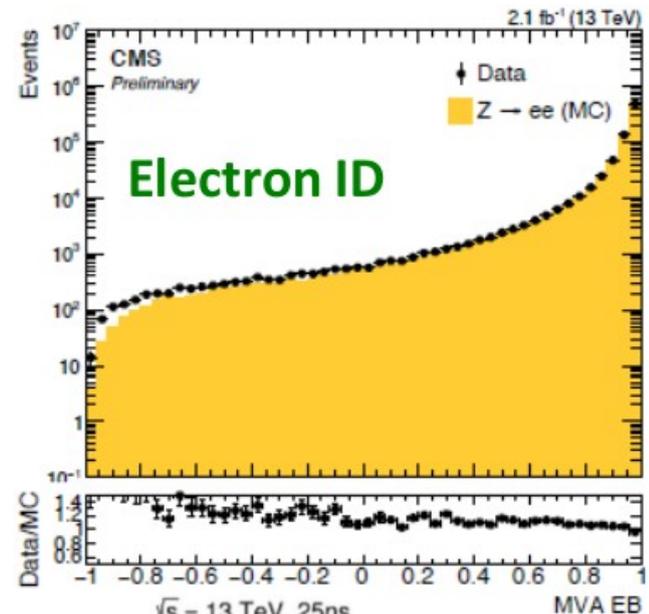
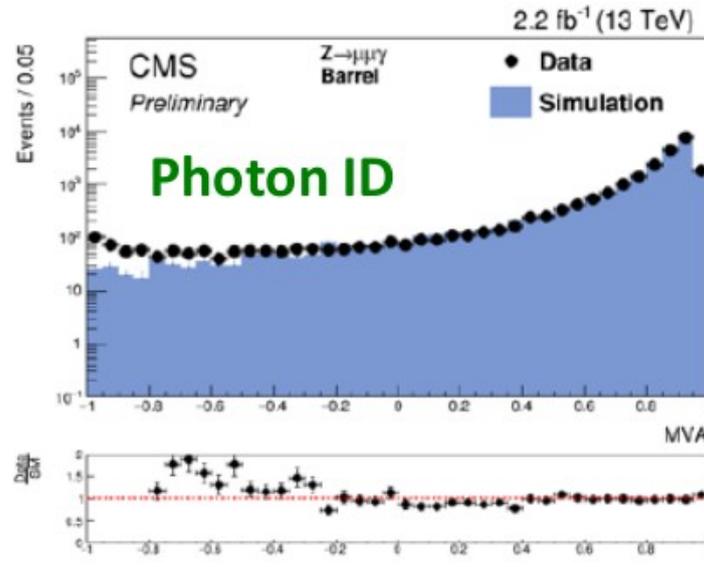
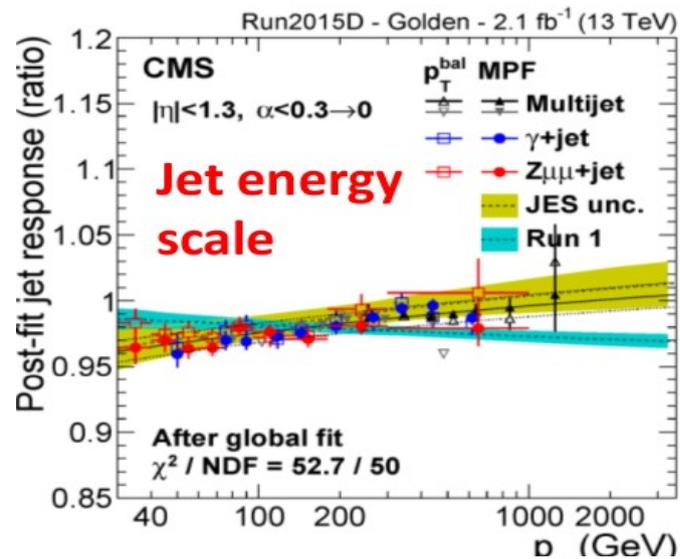
Data included from 2015-06-03 08:41 to 2015-11-03 06:25 UTC



The Compact Muon Solenoid



Physics objects @25ns



SM physics results @13 TeV

Standard Model results (15):

BPH-15-004: B^+ production cross section

FSQ-15-001: Pseudorapidity distributions of charged hadrons

FSQ-15-002: Two-particle correlations (the “ridge”)

FSQ-15-007: Underlying event

SMP-15-004: Inclusive W/Z cross section Results highlighted in blue

SMP-15-005: ZZ production cross section shown here for the first time

SMP-15-006: WZ production cross section

SMP-15-007: Inclusive jet production

SMP-15-010: Z+jets differential cross sections

TOP-15-003: Inclusive $t\bar{t}$ cross section in the emu channel

TOP-15-004: t-channel single top production

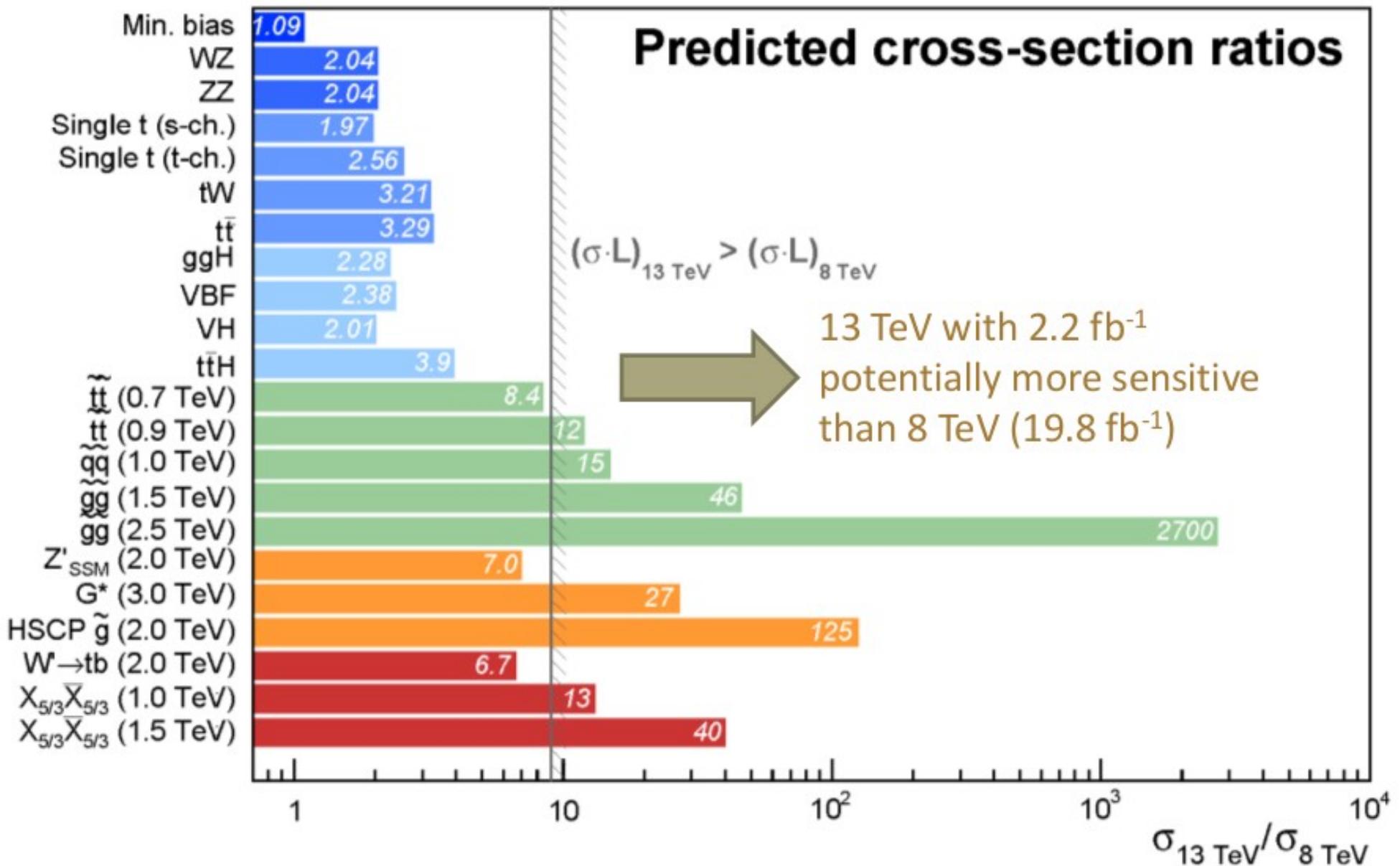
TOP-15-005: Differential $t\bar{t}$ cross section in the lepton + jets channel

TOP-15-010: Differential $t\bar{t}$ cross section in the dilepton channel

TOP-15-013: $t\bar{t}$ differential cross sections as function of HT,..

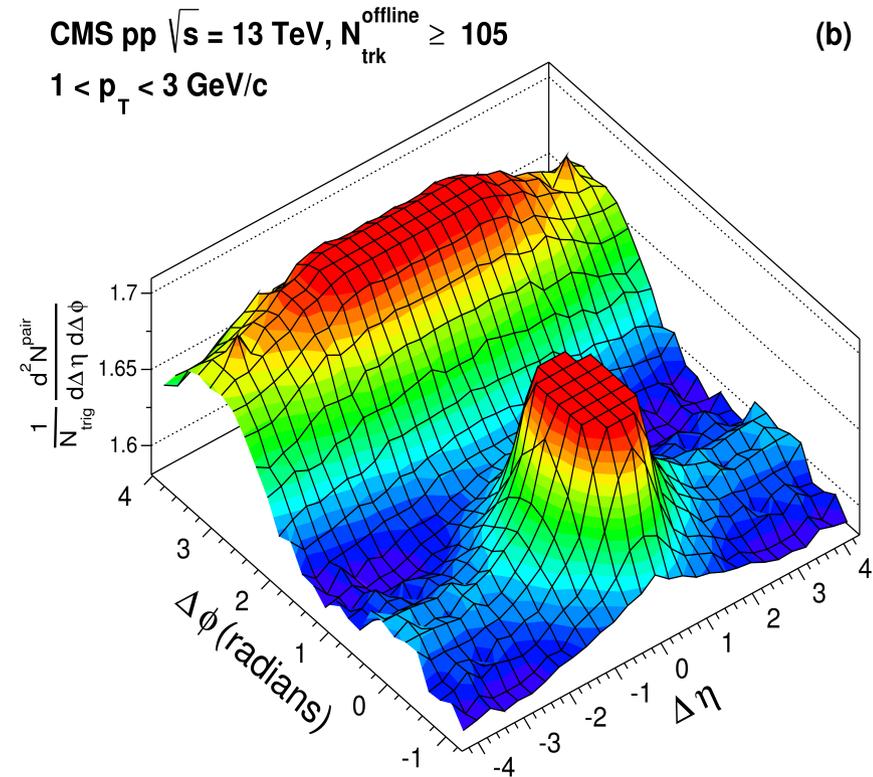
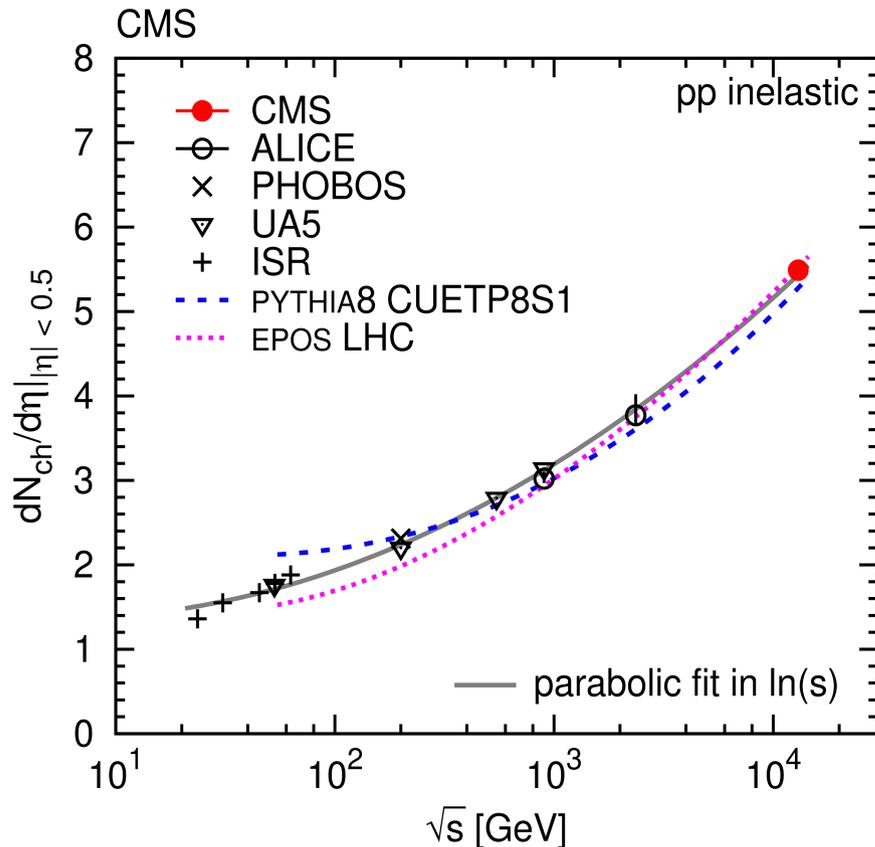
TOP-15-017: Underlying Event studies in $t\bar{t}$ events

Run II vs Run I cross section ratio



Event properties: $dN/d\eta$ and “the ridge”

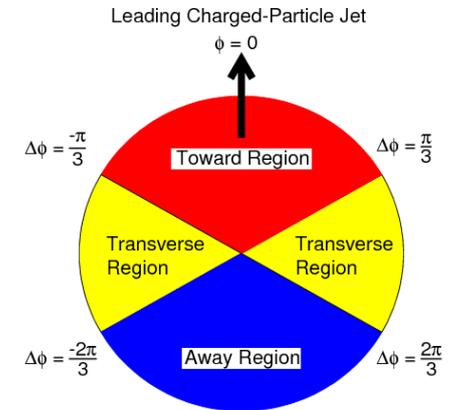
- **FSQ-15-001**: measurement of pseudorapidity distribution of charged hadrons, data consistent with expected dependence on centre-of-mass energy. Published in **PLB 751 (2015) 143**.
- **FSQ-15-002**: two-particle correlations, confirming the presence of a ridge-like structure for same-side ($\Delta\Phi \approx 0$) pairs in high-multiplicity events at 13 TeV. (Submitted to PRL ([arxiv:1507.05915](https://arxiv.org/abs/1507.05915)).)



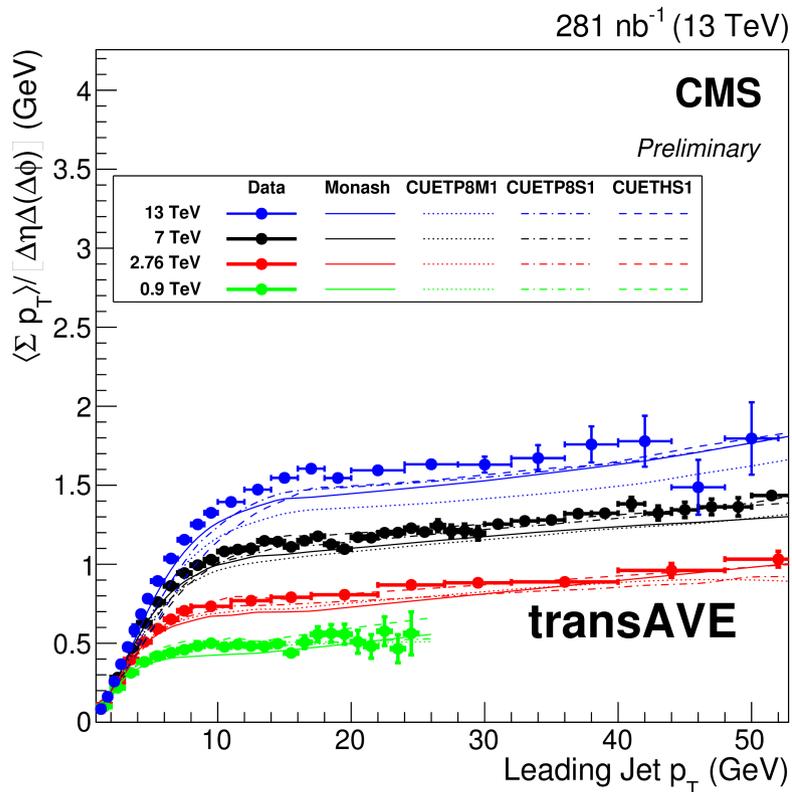
Underlying events

- Measurements of underlying event activity at 13 TeV compared to previous measurements at lower energies
- Data in reasonable (10-20%) agreement with tested tunes; critical input for future improvements

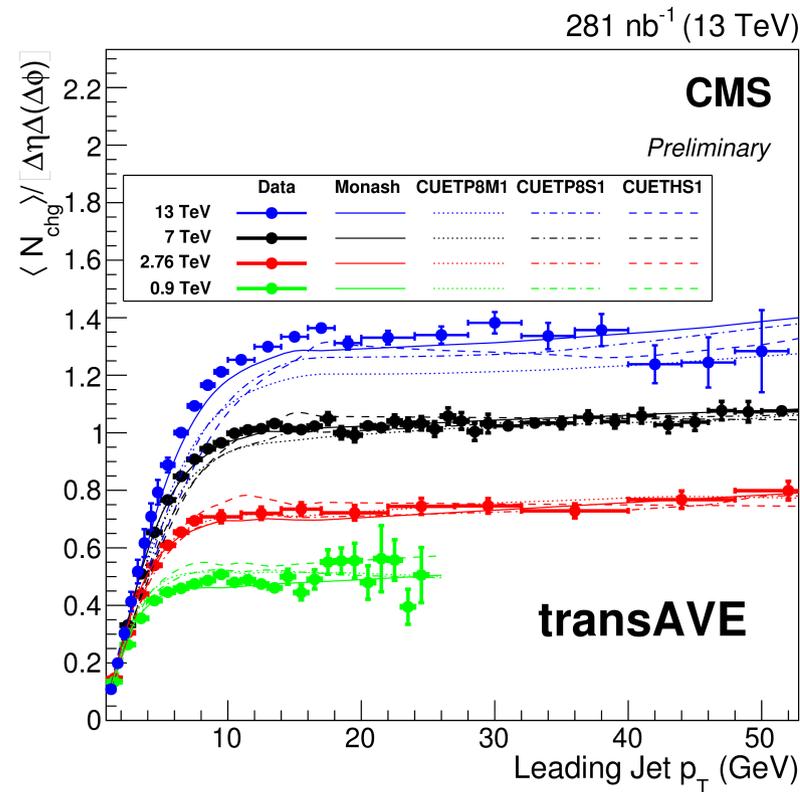
FSQ-15-007



Energy densities

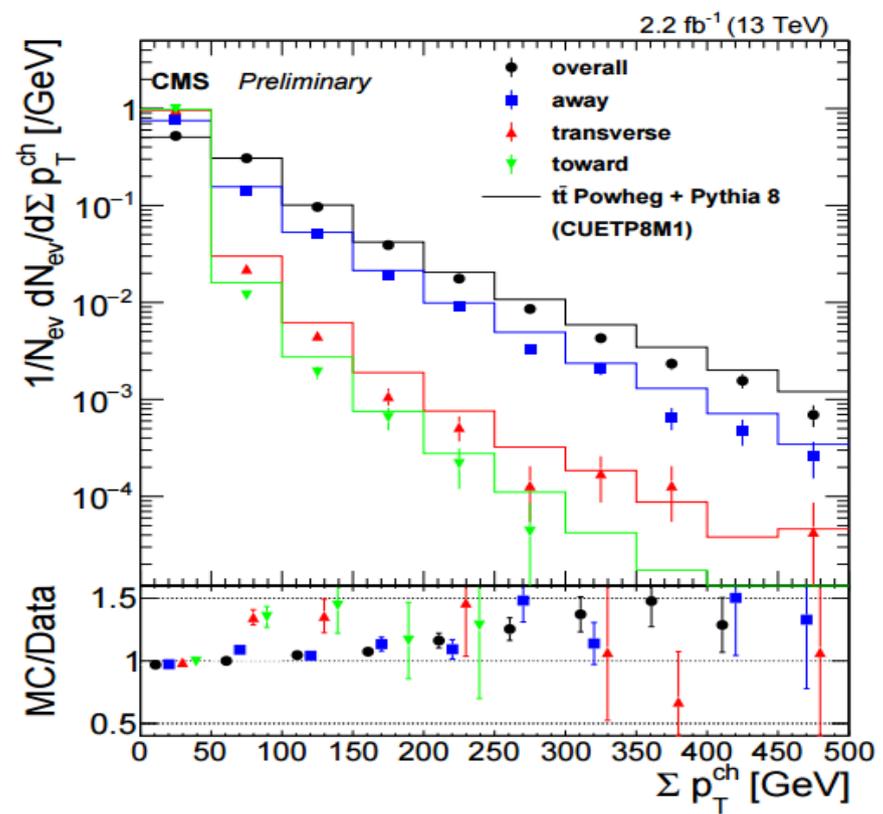
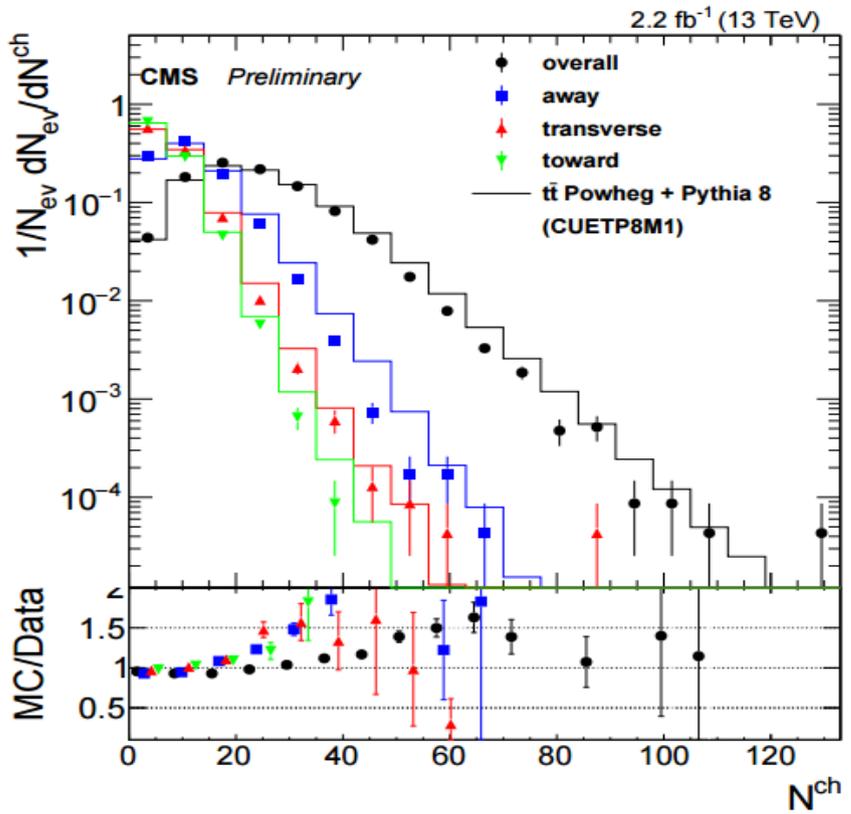
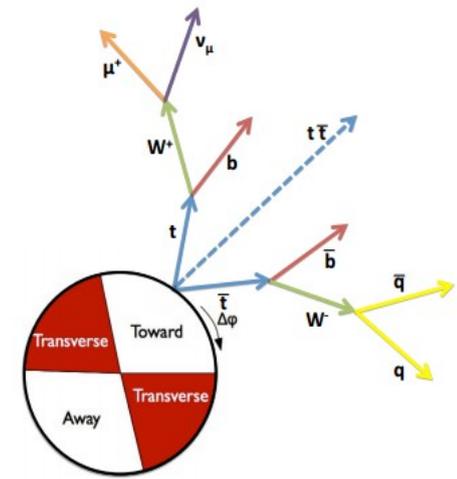


Particle densities



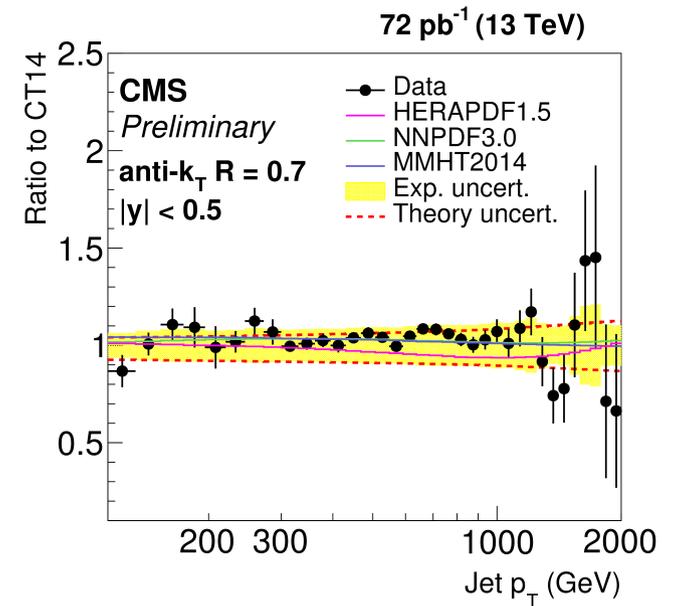
Top underlying events

- Verify/improve all aspects of event modeling in tt production environment
- Measure charged particle activity (N , Σp_T , $\langle p_T \rangle$) separately in regions relative to flight direction of the tt system, as function of $p_T(tt)$ and for different jet multiplicities



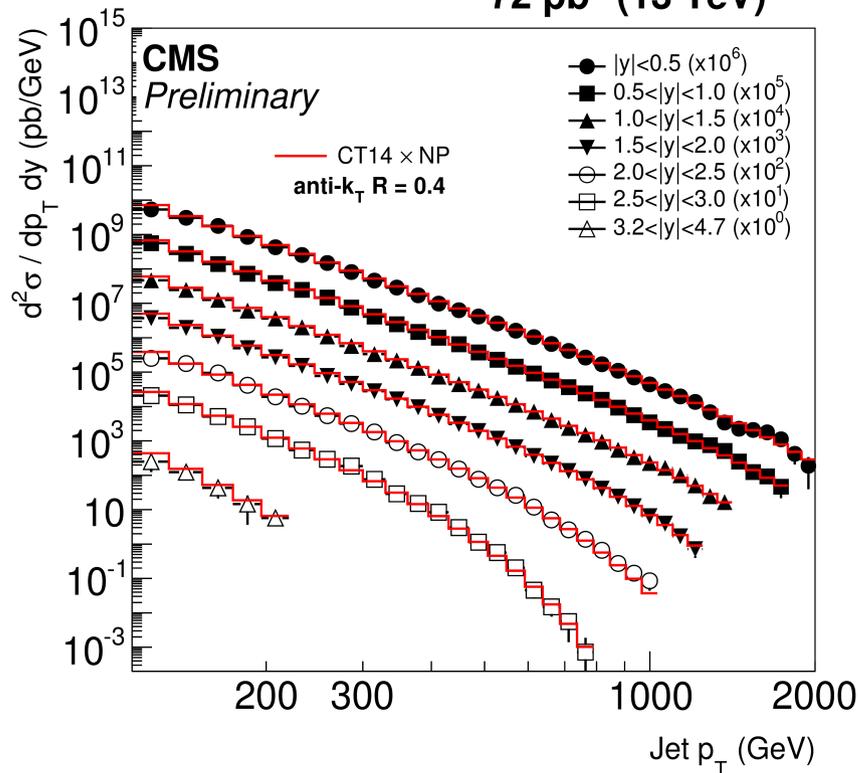
Inclusive jets

- Inclusive jets production in bins of p_T and η
- Good agreement found with prediction with different tuning

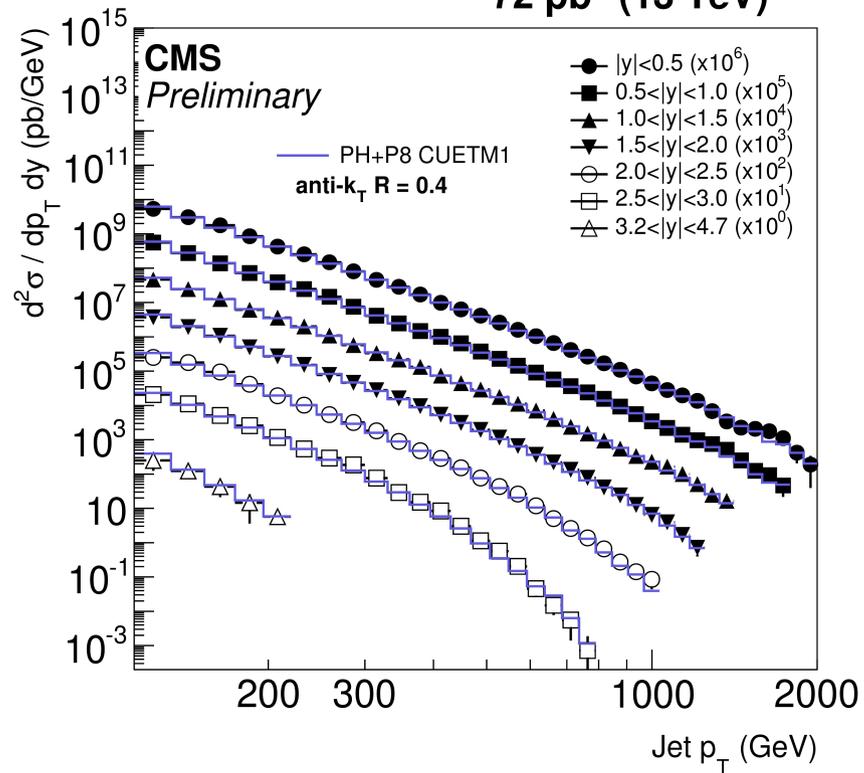


72 pb⁻¹ (13 TeV)

SMP-15-007

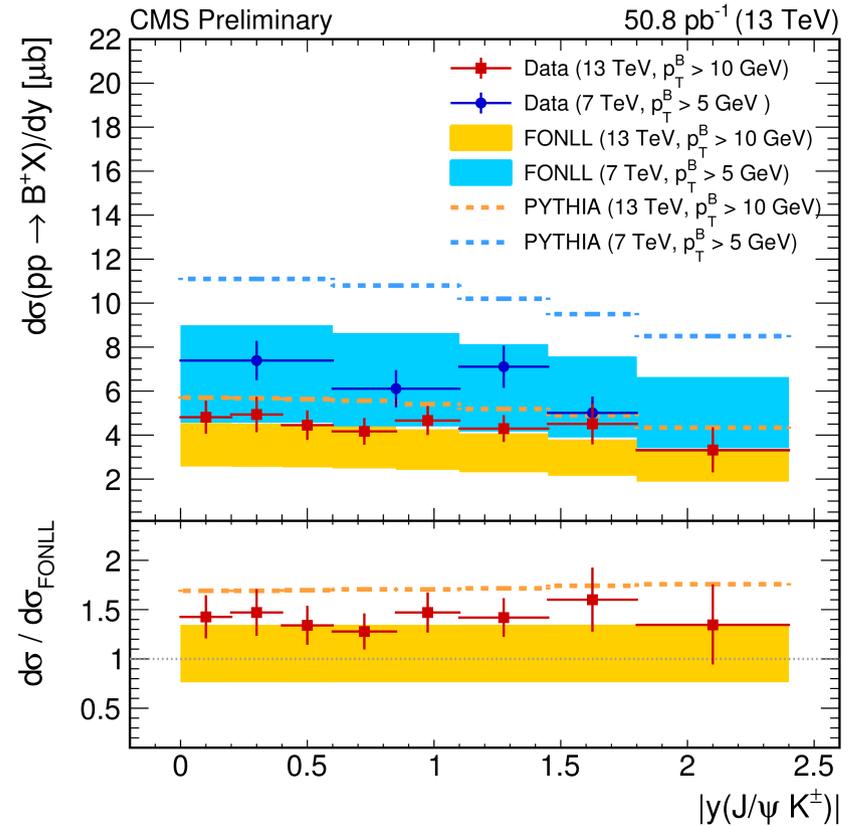
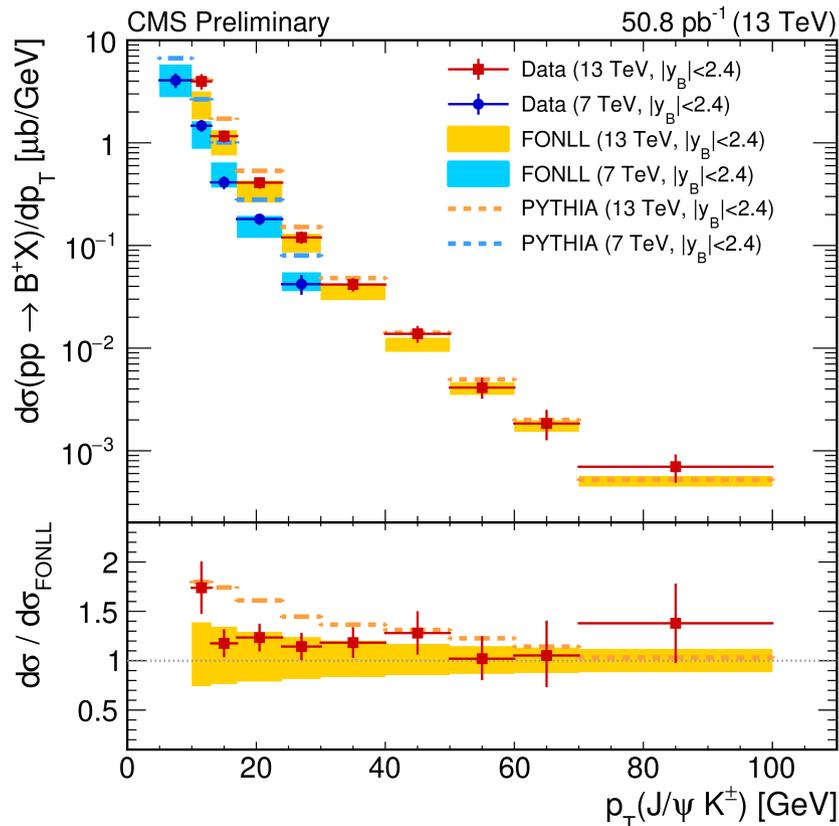
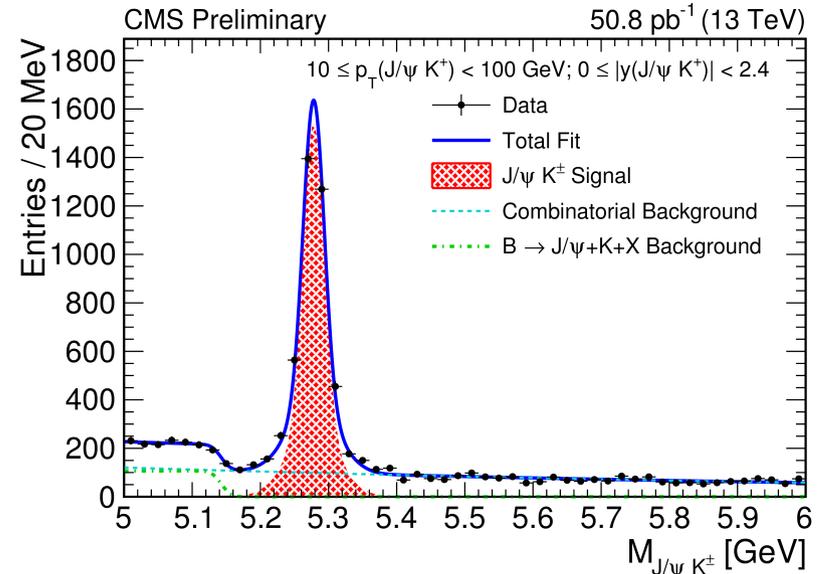


72 pb⁻¹ (13 TeV)



B meson production

- $B^+ \rightarrow J/\psi K^+$ cross section vs. p_T and y compared to FONLL predictions and CMS data at 7 TeV
- Good agreement with theory up to $p_T \approx 100$ GeV

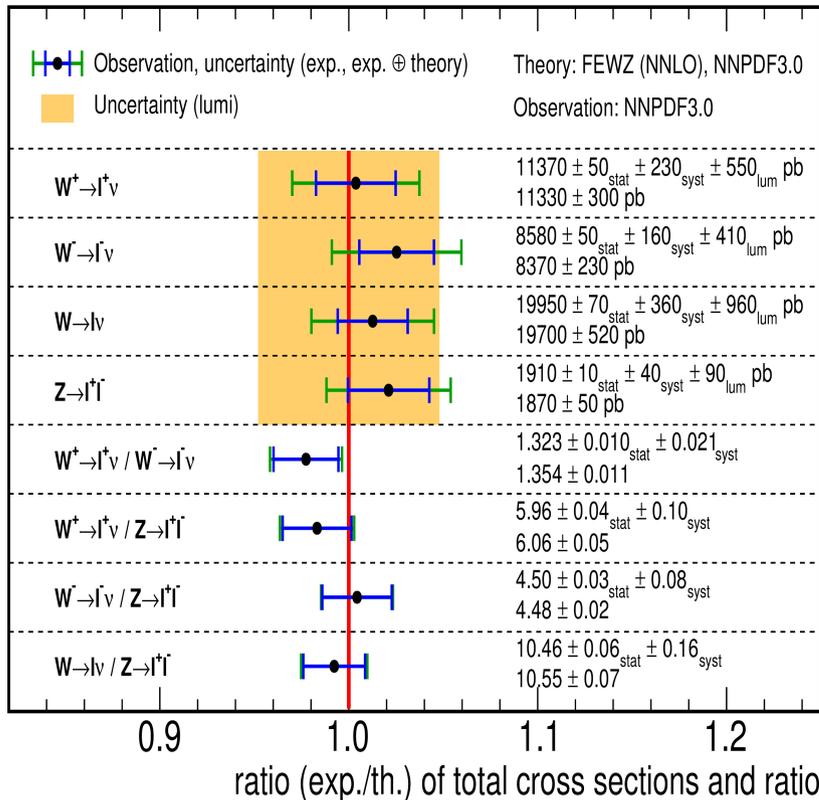


W and Z production

SMP-15-004

→ Total inclusive and fiducial W and Z boson production cross sections in lepton, semi lepton final state

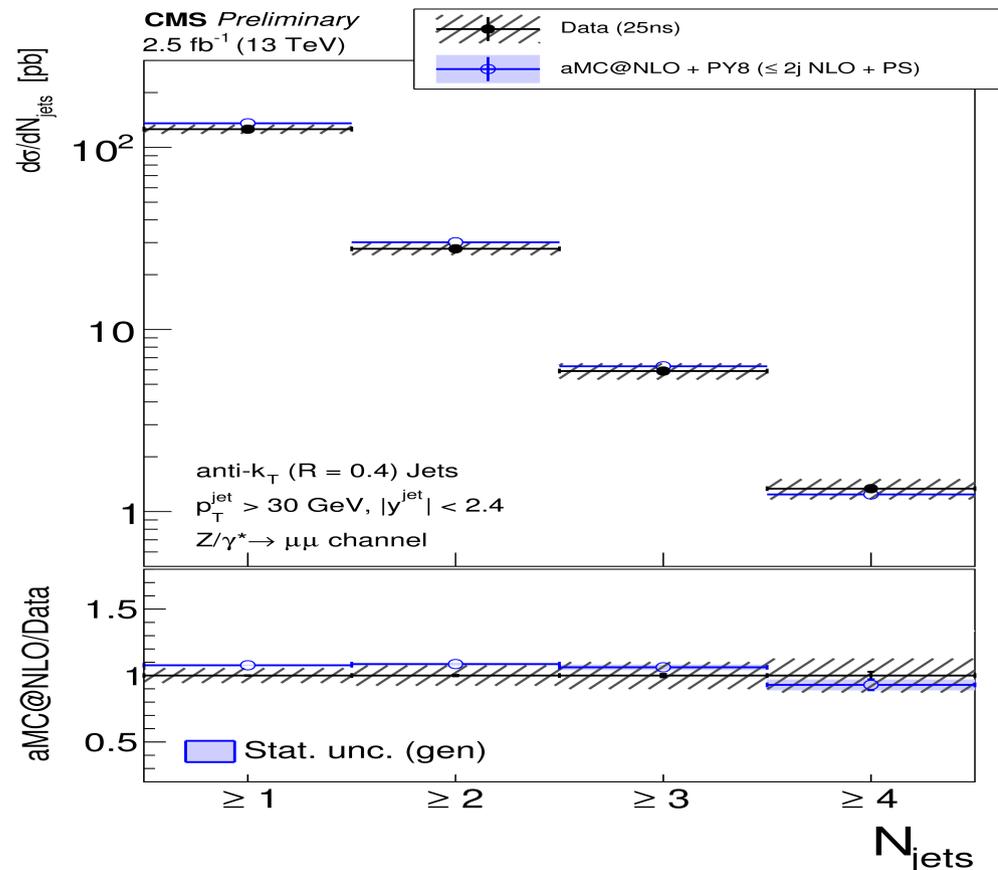
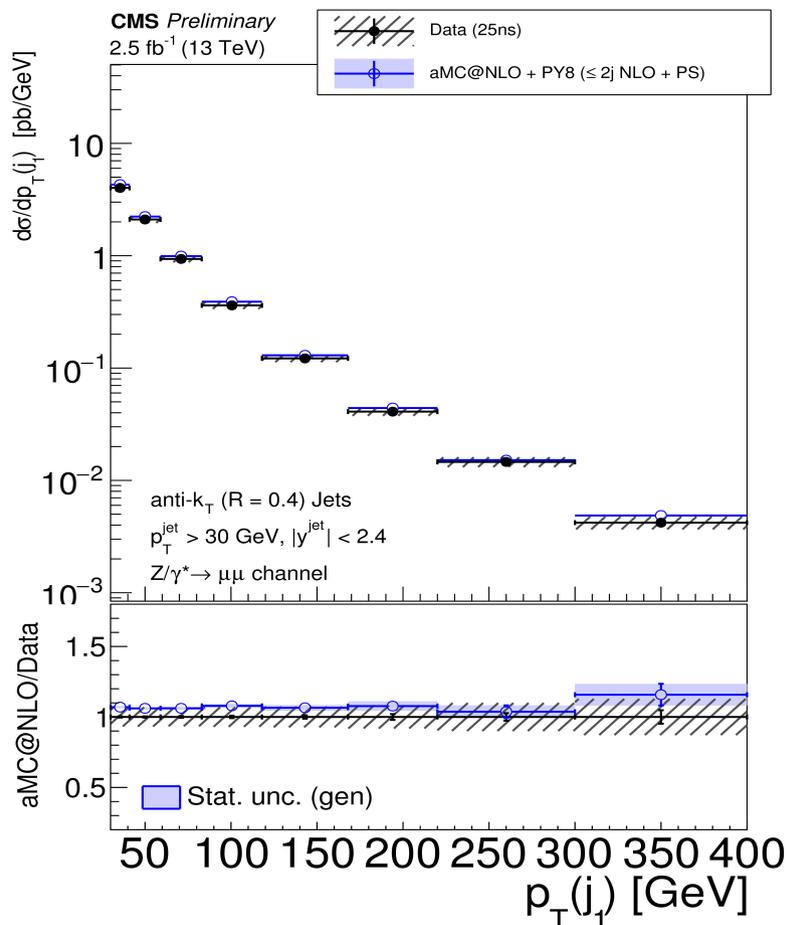
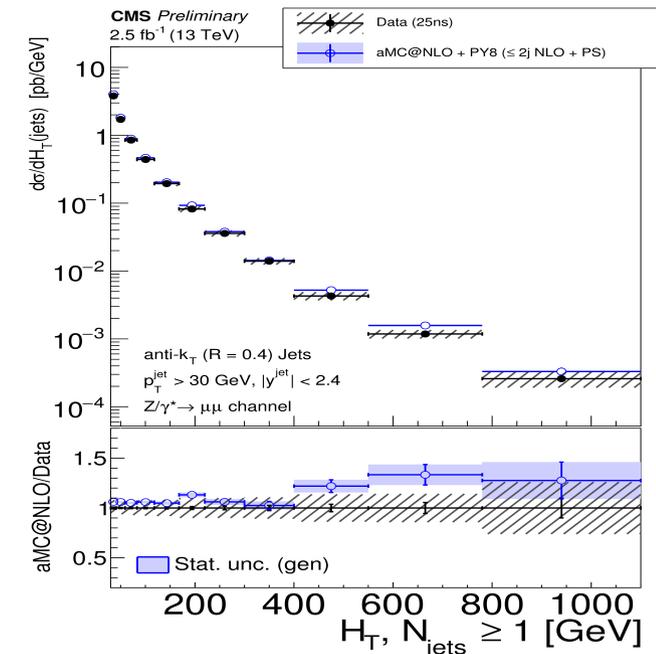
CMS Preliminary 43 pb⁻¹ (13 TeV)



Channel	$\sigma \times \mathcal{B}$ [pb] (total)	NNLO [pb]	
W^+	$e^+ \nu$	11390 ± 90 (stat) ± 340 (syst) ± 550 (lumi)	11330^{+320}_{-270}
	$\mu^+ \nu$	11350 ± 60 (stat) ± 320 (syst) ± 550 (lumi)	
	$l^+ \nu$	11370 ± 50 (stat) ± 230 (syst) ± 550 (lumi)	
W^-	$e^- \nu$	8680 ± 80 (stat) ± 250 (syst) ± 420 (lumi)	8370^{+240}_{-210}
	$\mu^- \nu$	8510 ± 60 (stat) ± 210 (syst) ± 410 (lumi)	
	$l^- \nu$	8580 ± 50 (stat) ± 160 (syst) ± 410 (lumi)	
W	$e \nu$	20070 ± 120 (stat) ± 570 (syst) ± 960 (lumi)	19700^{+560}_{-470}
	$\mu \nu$	19870 ± 80 (stat) ± 460 (syst) ± 950 (lumi)	
	$l \nu$	19950 ± 70 (stat) ± 360 (syst) ± 960 (lumi)	
Z	$e^+ e^-$	1920 ± 20 (stat) ± 60 (syst) ± 90 (lumi)	1870^{+50}_{-40}
	$\mu^+ \mu^-$	1900 ± 10 (stat) ± 50 (syst) ± 90 (lumi)	
	$l^+ l^-$	1910 ± 10 (stat) ± 40 (syst) ± 90 (lumi)	
Quantity	Ratio (total)	NNLO	
R_{W^+/W^-}	e	1.313 ± 0.016 (stat) ± 0.028 (syst)	$1.354^{+0.011}_{-0.012}$
	μ	1.334 ± 0.011 (stat) ± 0.031 (syst)	
	l	1.323 ± 0.010 (stat) ± 0.021 (syst)	
$R_{W^+/Z}$	e	5.94 ± 0.07 (stat) ± 0.16 (syst)	$6.06^{+0.04}_{-0.05}$
	μ	5.98 ± 0.05 (stat) ± 0.14 (syst)	
	l	5.96 ± 0.04 (stat) ± 0.10 (syst)	
$R_{W^-/Z}$	e	4.52 ± 0.06 (stat) ± 0.12 (syst)	$4.48^{+0.03}_{-0.02}$
	μ	4.49 ± 0.04 (stat) ± 0.10 (syst)	
	l	4.50 ± 0.03 (stat) ± 0.08 (syst)	
$R_{W/Z}$	e	10.46 ± 0.11 (stat) ± 0.26 (syst)	$10.55^{+0.07}_{-0.06}$
	μ	10.47 ± 0.08 (stat) ± 0.20 (syst)	
	l	10.46 ± 0.06 (stat) ± 0.16 (syst)	

Z +jets production

- The cross sections are measured as a function of jet multiplicity, the jet transverse momenta, and the jet rapidity for different jet multiplicities .
- Predictions are NLO+PS merged calculation
[arXiv:1209.6215](https://arxiv.org/abs/1209.6215) , [arXiv:1209.6215](https://arxiv.org/abs/1209.6215)



Diboson (WZ) production

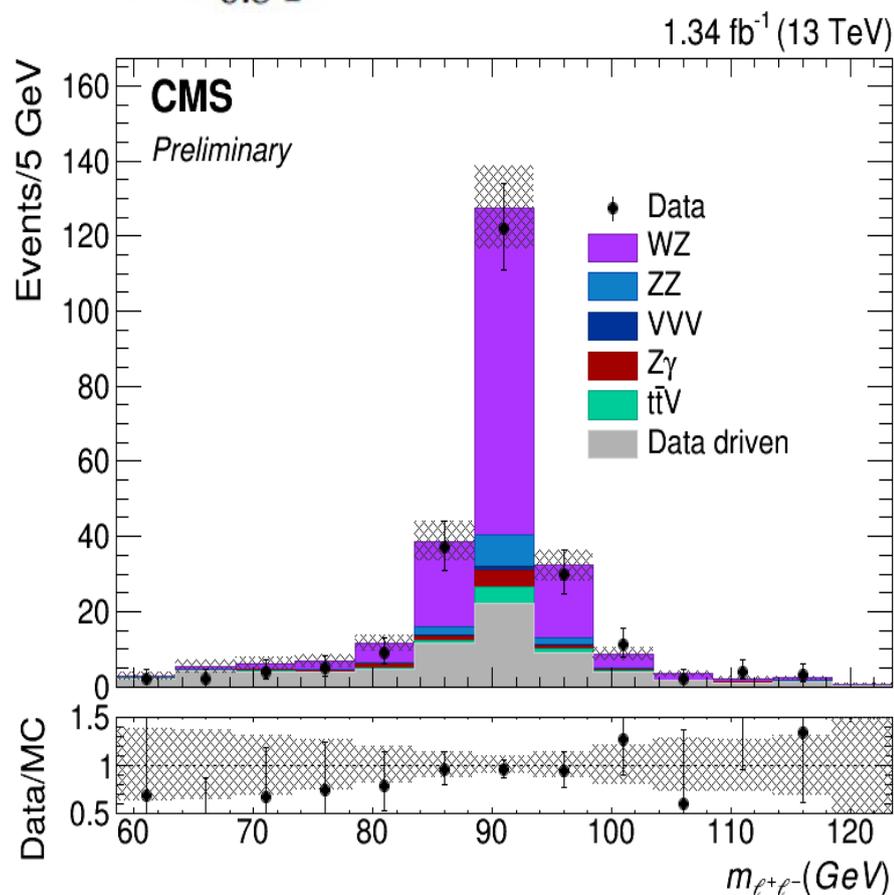
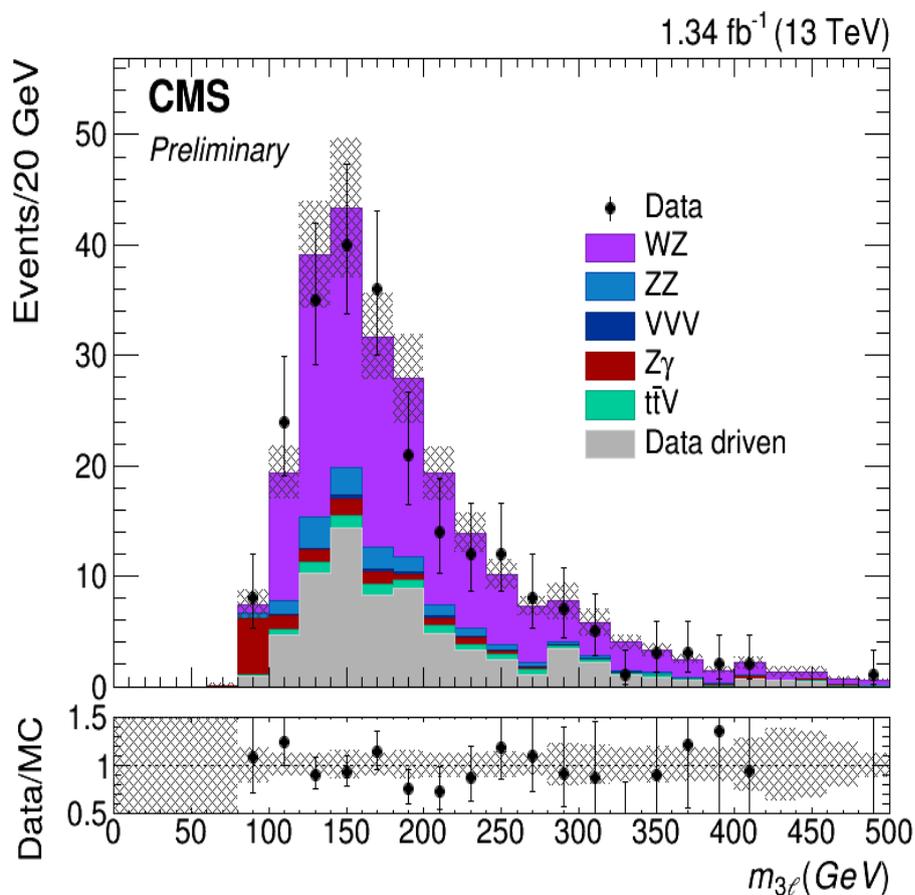
→ The cross sections of WZ production for Z boson produced in the mass region $60 < m_Z < 120$ GeV

→ The measurement is performed in the leptonic decay modes

$WZ \rightarrow \ell\nu\ell\ell'$, $\ell = e, \mu$

$$\sigma(pp \rightarrow WZ) = 36.8 \pm 4.6 (\text{stat})_{-6.2}^{+8.1} (\text{syst}) \pm 0.6 (\text{theo}) \pm 1.7 (\text{lum}) \text{ pb}$$

$$\text{NLO theoretical prediction} = 42.7_{-0.8}^{+1.6} \text{ pb}$$

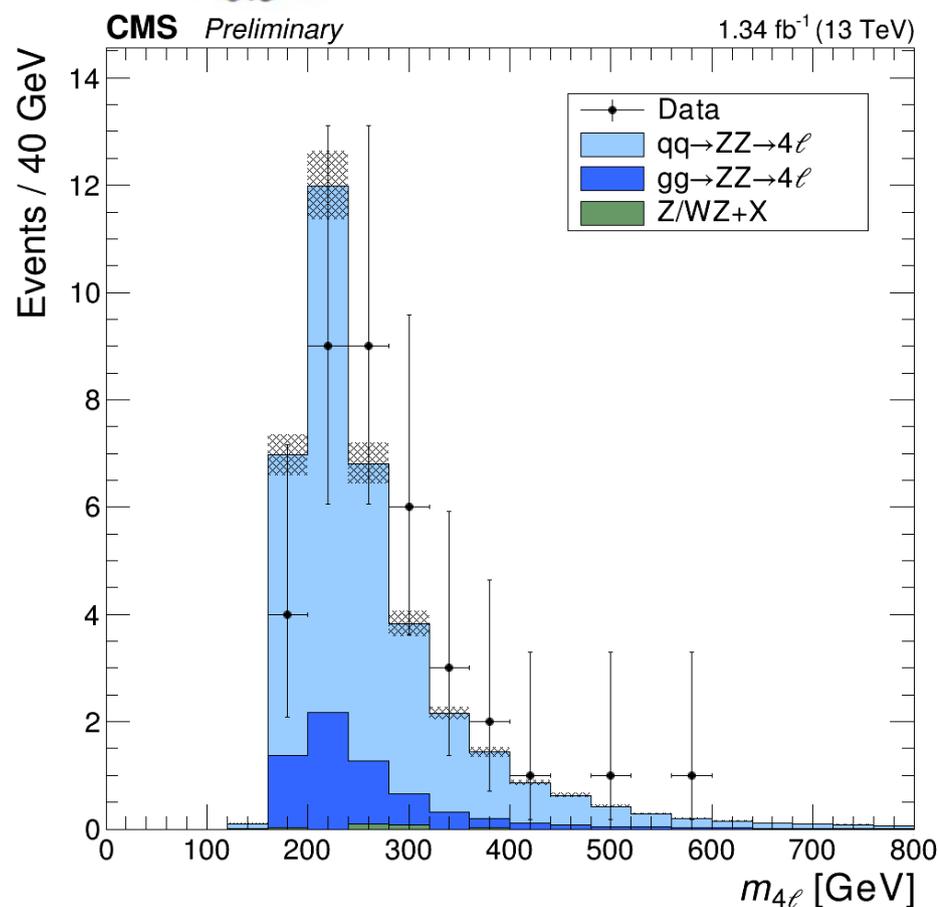
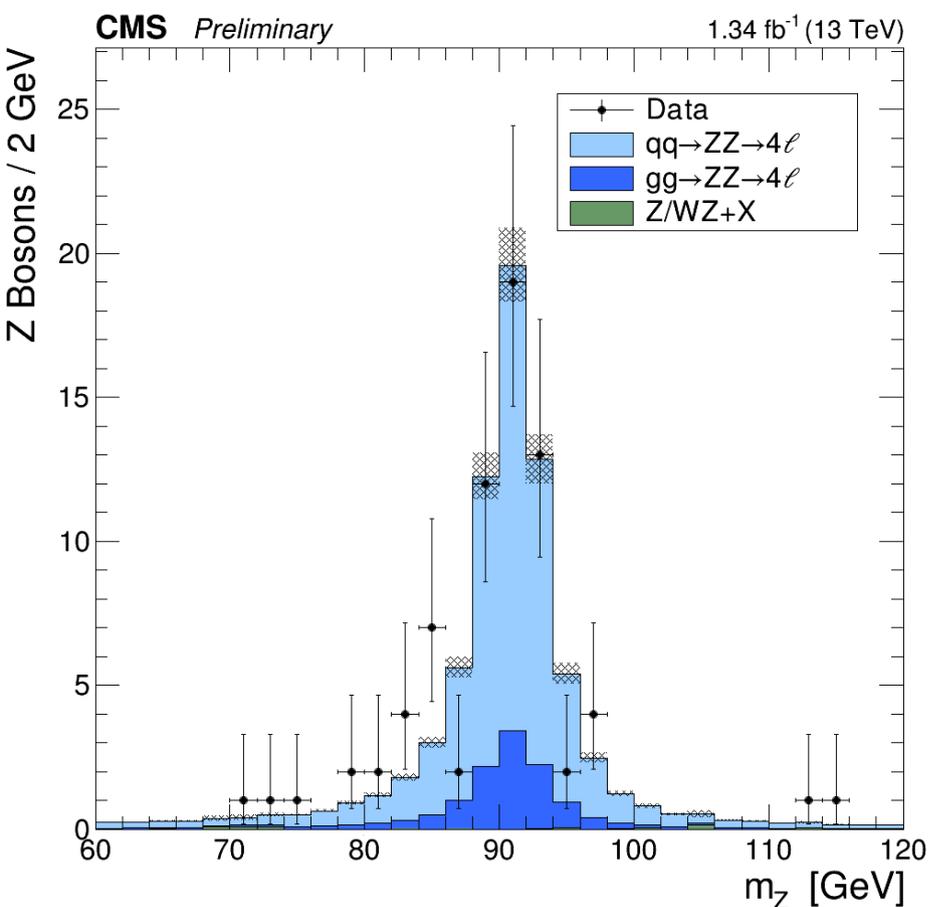


Diboson (ZZ) production

- The cross sections of ZZ production for for Z boson produced in the mass region $60 < m_z < 120$ GeV
- The measurement is performed in the leptonic decay modes
- $ZZ \rightarrow \ell\ell'\ell\ell'$, $\ell = e, \mu$

$$\sigma(pp \rightarrow ZZ) = 16.7^{+2.9}_{-2.6} \text{ (stat)}^{+0.7}_{-0.5} \text{ (syst)} \pm 0.3 \text{ (theo)} \pm 0.8 \text{ (lum)} \text{ pb.}$$

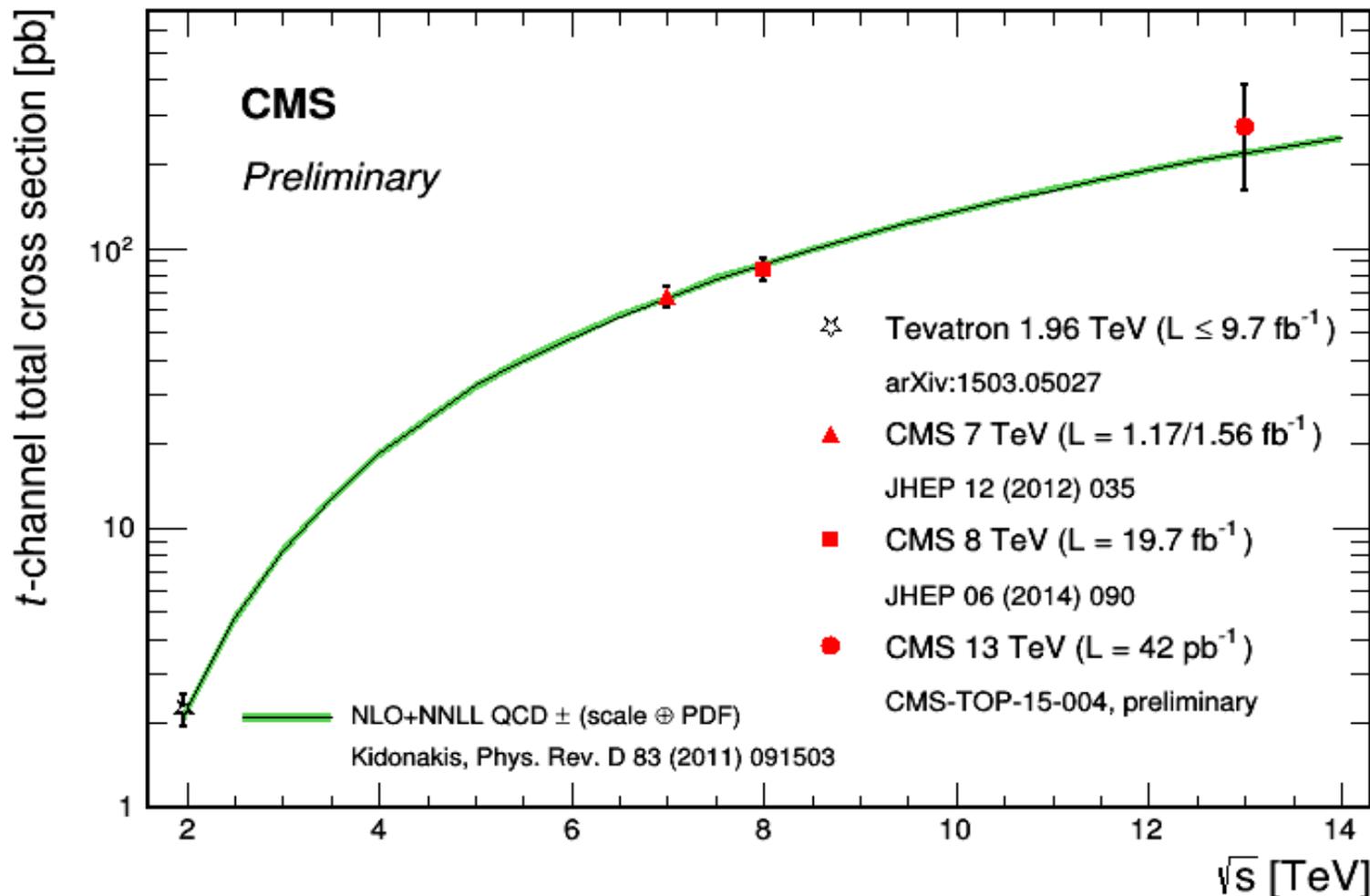
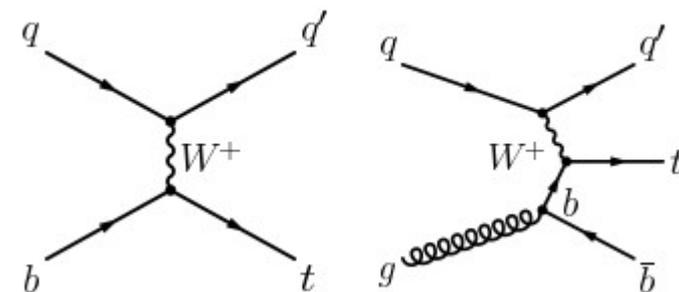
$$\text{NLO theoretical prediction} = 16.5^{+0.7}_{-0.5} \text{ pb}$$



Single Top quark production

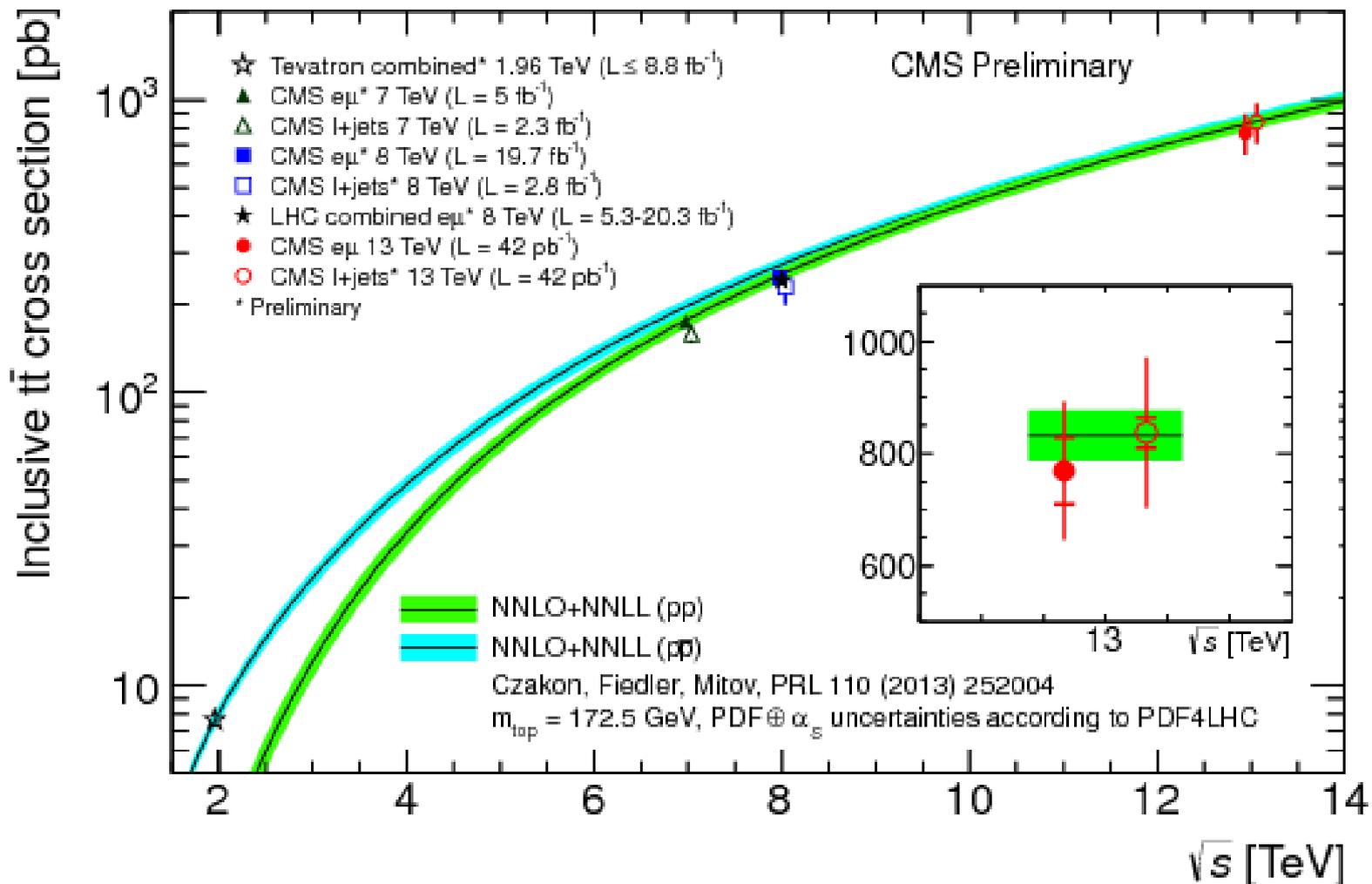
TOP-15-004

- A measurement of the t-channel single top-quark cross section is performed, events are selected with one muon in the final state.
- The results are found to be in agreement with predictions by the standard model.

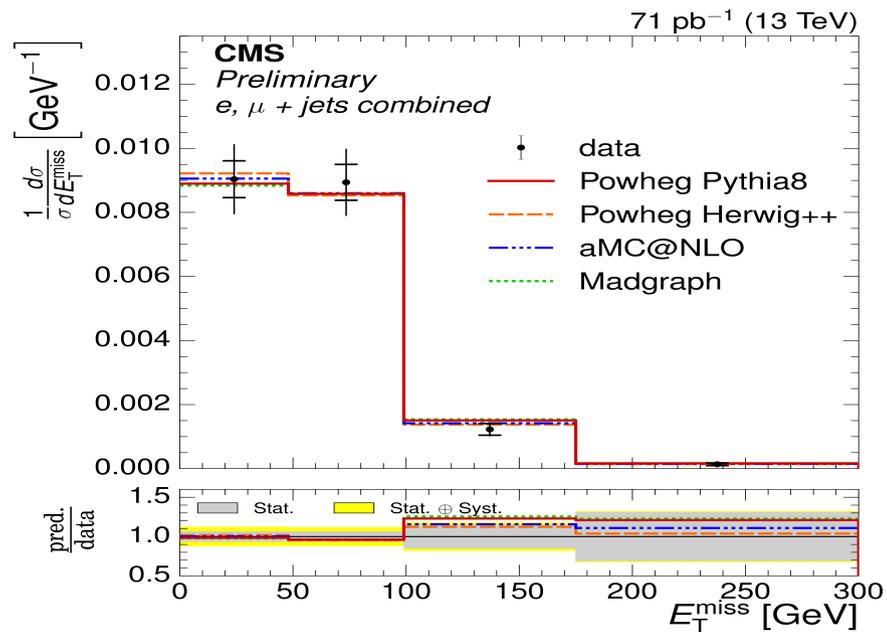
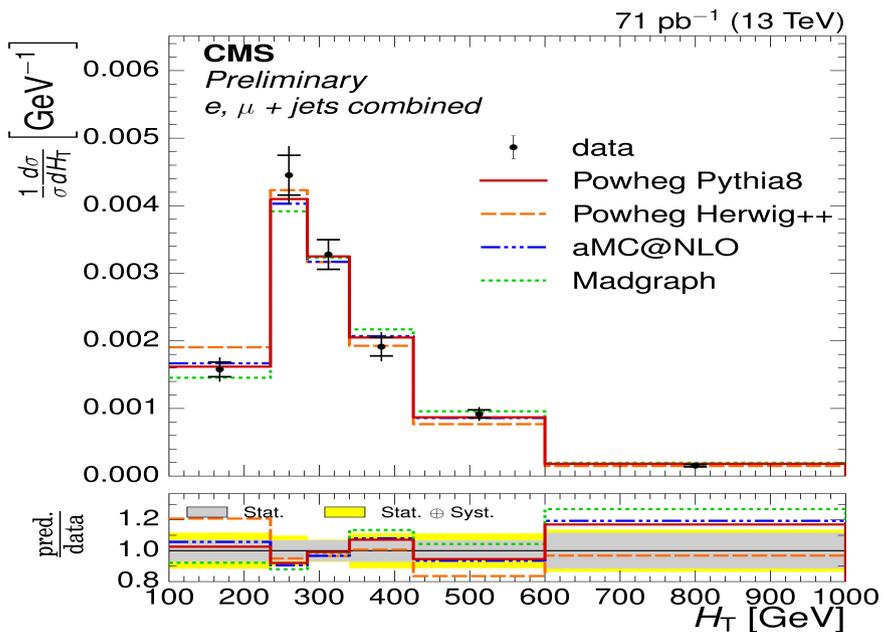
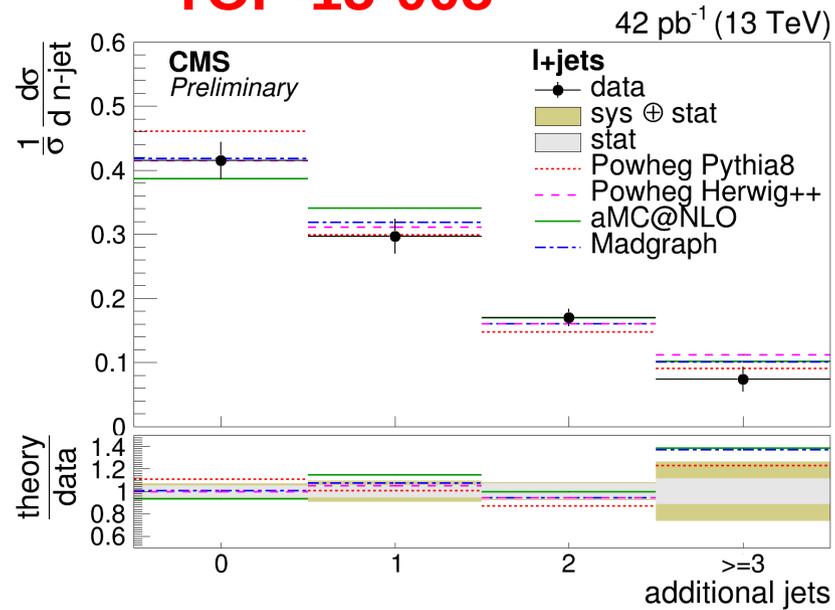
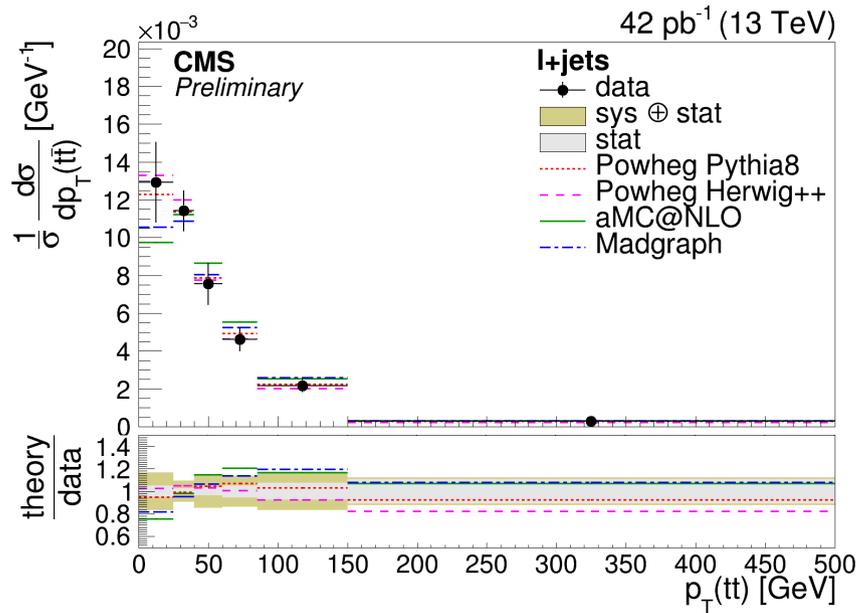


Top pair production

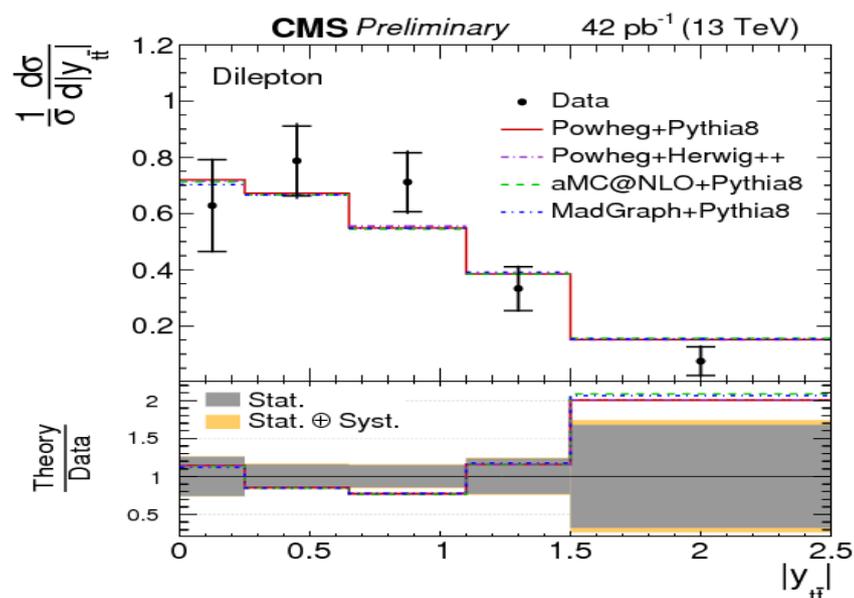
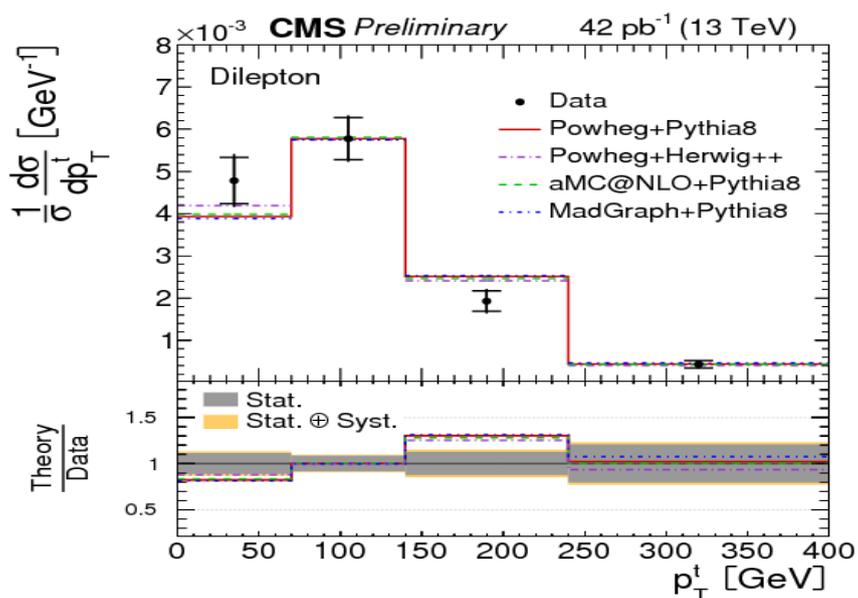
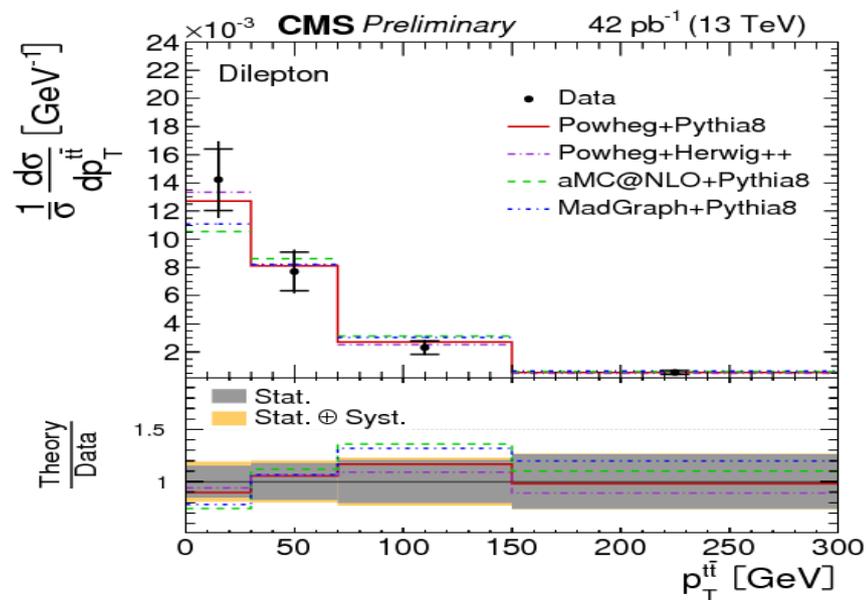
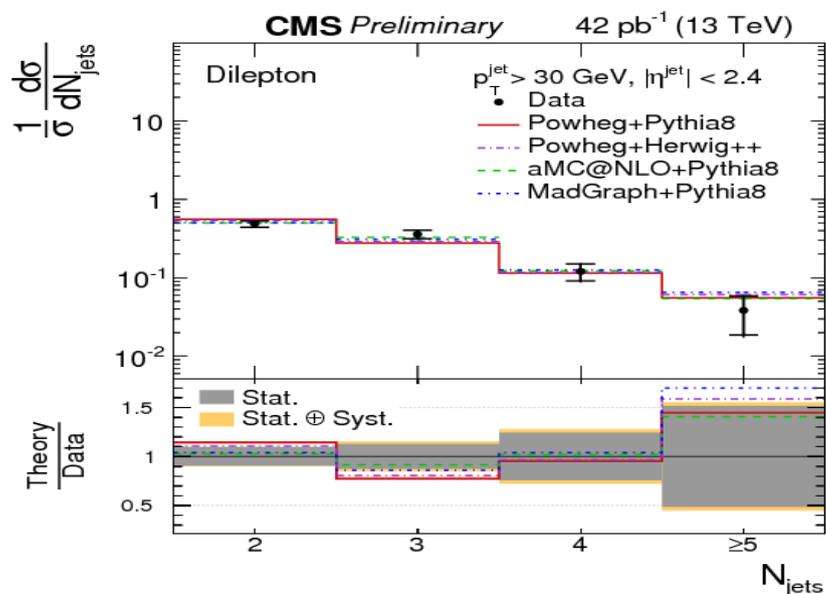
- **TOP-15-005, TOP-15-013** : Top quark pair production cross differential section as a function of various kinematic observables in lep+jets final state
- **TOP-15-010** : Differential cross section in dilepton final state
- **TOP-15-003** : Inclusive top pair production cross section , eμ final state



Top pair production (differential)



Top pair production (differential)



Summary and outlook

- An extraordinary year for CMS
 - LS1 work successfully completed
 - Recorded 90% of collisions delivered by LHC, 75% @ 3.8 T
 - Physics object commissioning well advanced
 - New challenge of 25 ns operation has been met
- 33 results on 13 TeV data so far
 - SM measurements confirming general (and in some cases, precision) agreement at new energy

More results (and updated) coming for Moriond conference!

All CMS Public results can be found at link below

<http://cms-results.web.cern.ch/cms-results/public-results/publications/>