Measurement of the Drell-Yan transverse momentum dependence over a wide mass range and inclusive and differential vector boson (W, Z) measurements from CMS

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Bruxelles, Belgium
on behalf of CMS Collaboration

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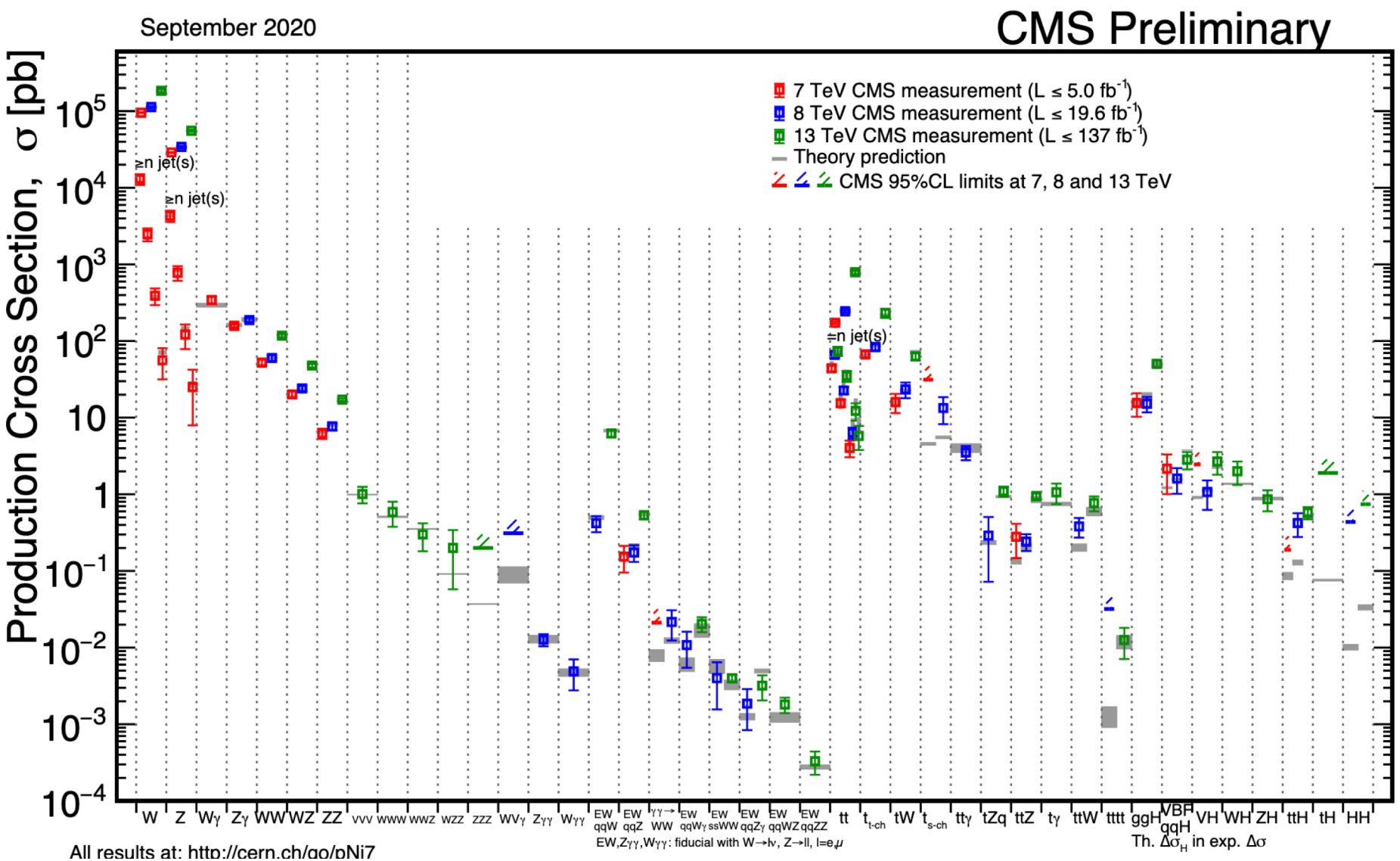
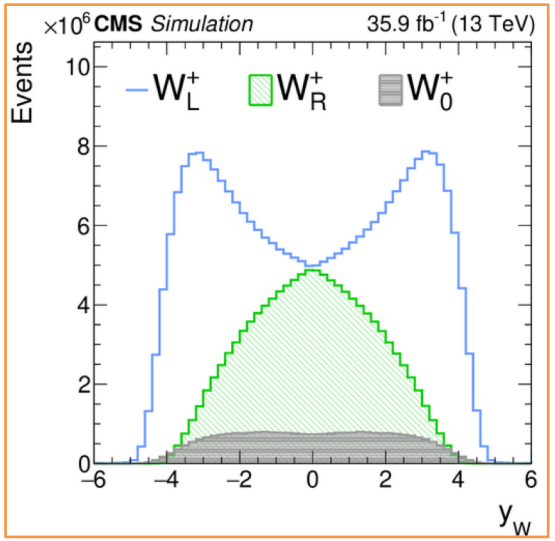
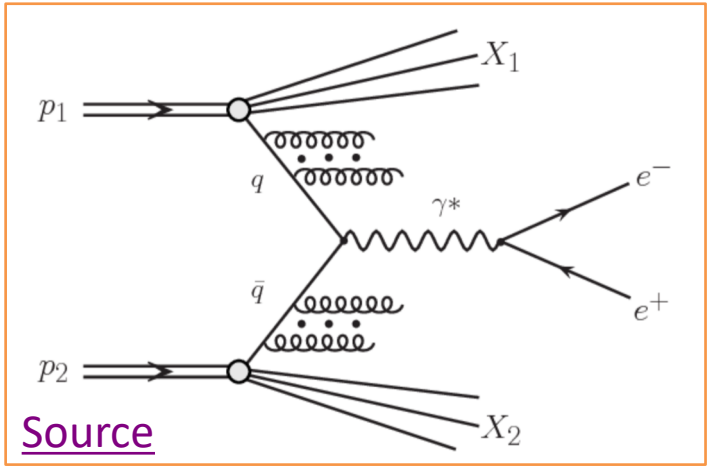


Introduction

- Processes involving W and Z boson productions are one of the best understood processes at hadron colliders
  - W-> lν, Z->ll, (l=e,μ) are among the cleanest final states experimentally
    - Allows probing various QCD effects by studying kinematics precisely
      - Different regions probing pQCD as well as npQCD effects
    - Measure EWK parameters, couplings, A_C, A_{FB}…
  - Can search for rare decay channels.





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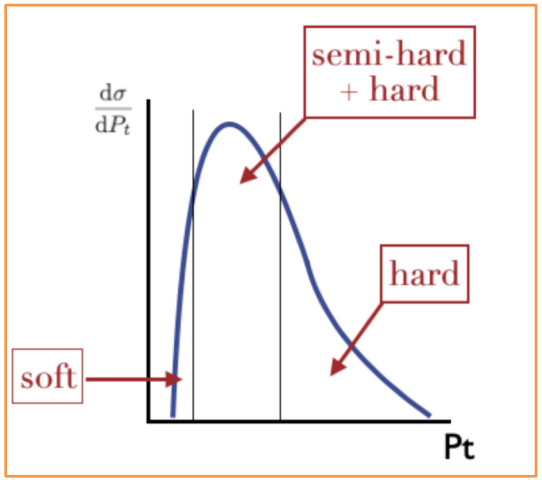
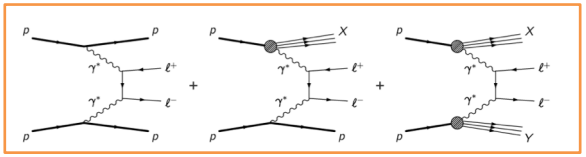




They provide stringent tests of our calculations based on SM

Content

- → Measurement of the differential Drell-Yan cross section in proton-proton collisions at √s = 13 TeV, arXiv:1812.10529 (JHEP 12 (2019) 059)
- → Measurements of differential Z boson production cross sections in proton-proton collisions at √s=13 TeV, arXiv:1909.04133 (JHEP 12 (2019) 061)
- → "Measurement of mass dependence of the transverse momentum of Drell Yan lepton pairs in proton-proton collisions at √s=13 TeV" CMS-PAS-SMP-20-003
- → Measurements of the W boson rapidity, helicity, double-differential cross sections, and charge asymmetry in pp collisions at 13 TeV, arXiv:2008.04174 (Phys. Rev. D 102 (2020) 092012)
- → Search for W boson decays to three charged pions, arXiv:1901.11201 (Phys. Rev. Lett. 122 (2019) 151802)
- → Search for the rare exclusive hadronic decay of a W boson into a pion and a photon in proton-proton collisions at 13 TeV, arXiv:2011.06028, Submitted to PLB

5 publications
1 prelim. result

All CMS public results:https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMP

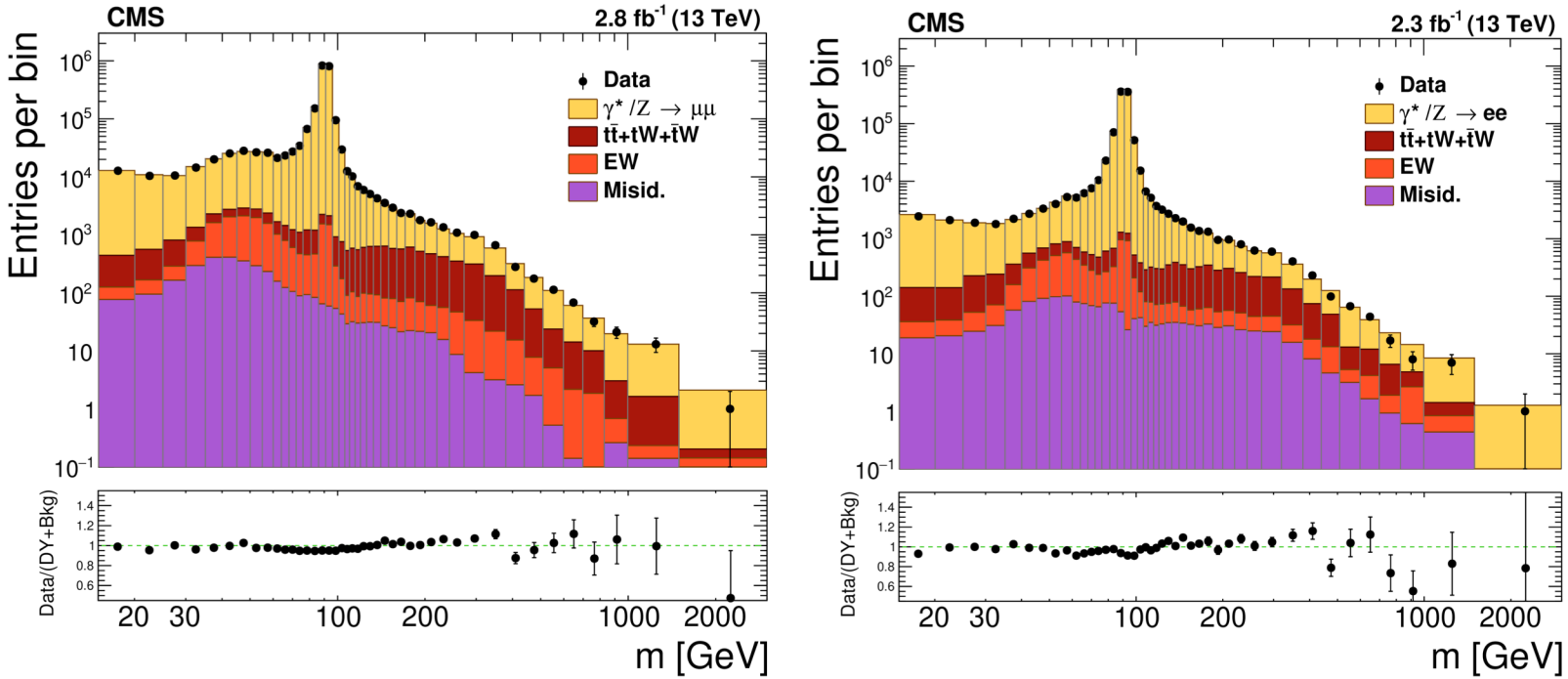
Drell-Yan Mass

JHEP 12 (2019) 059

2.8 (2.3) fb^{-1}

$\mu^+\mu^-$ (e^+e^-); p_T (l) > 25 GeV, $|\eta|$<2.4
15 <M_{ll} < 3000 GeV

Measured differential cross section dσ/dM



The results are in good agreement with the theoretical predictions of the SM

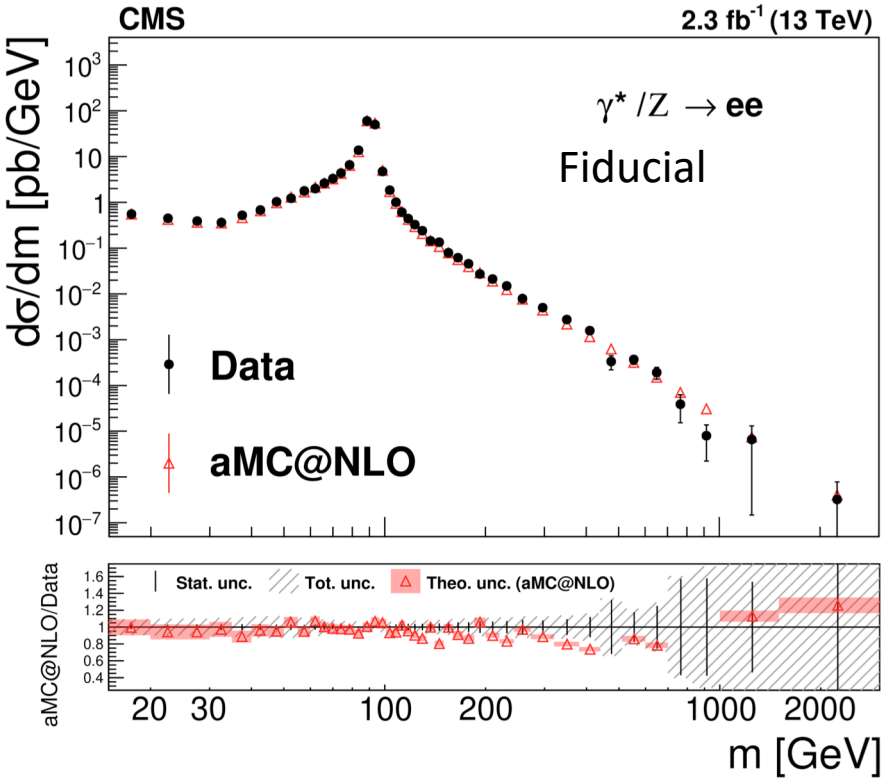
Drell-Yan Mass

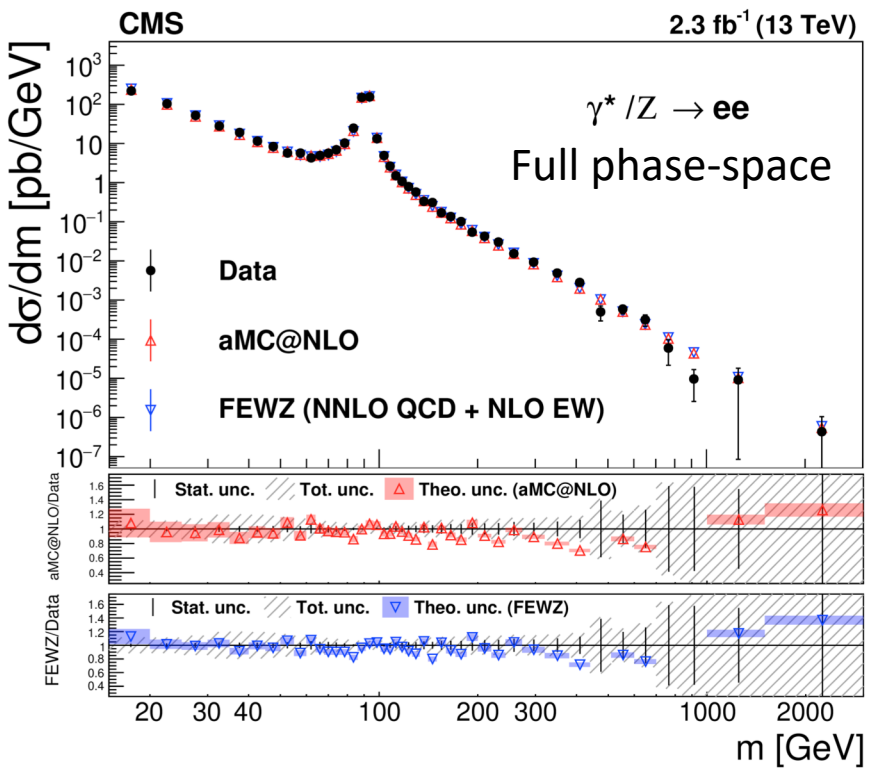
JHEP 12 (2019) 059

2.8 (2.3) fb^{-1}

Unfolded to fiducial space & corrected for acceptance

$\mu^+\mu^-$ (e^+e^-); p_T (l) > 25 GeV, $|\eta|$<2.4
15 <M_{ll} < 3000 GeV
Measured differential cross section dσ/dM





Results are in good agreement with the theoretical predictions of the SM

Drell-Yan Measurements

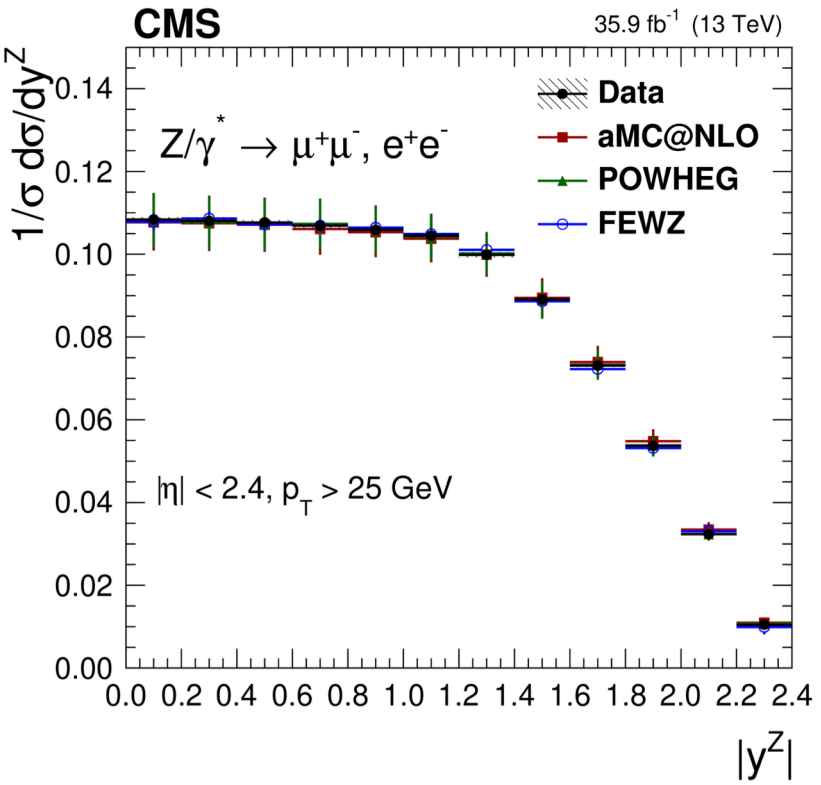
JHEP 12 (2019) 061

35.9 fb^{-1}

Unfolded to fiducial space

$Z \rightarrow \mu^+\mu^-$ (e^+e^-); p_T (l) > 25 GeV, $|\eta|$<2.4
76 <M_{ll} < 106 GeV

Measured inclusive cross section as well as (double)differentially (absolute and normalized)
$d\sigma/dp_T$,$d\sigma/d\varphi^*$ also in bins of y(Z)



Final state	Data	$Z \rightarrow \ell\ell$	Resonant background	Nonresonant background
$\mu\mu$	20.4×10^6	20.7×10^6	30×10^3	41×10^3
ee	12.1×10^6	12.0×10^6	19×10^3	26×10^3

Cross section	$\sigma\,\mathcal{B}$ [pb]					
$\sigma_{Z\rightarrow\mu\mu}$	694	$\pm$	6	(syst)	$\pm$ 17	(lumi)
$\sigma_{Z\rightarrow ee}$	712	$\pm$	10	(syst)	$\pm$ 18	(lumi)
$\sigma_{Z\rightarrow\ell\ell}$	699	$\pm$	5	(syst)	$\pm$ 17	(lumi)

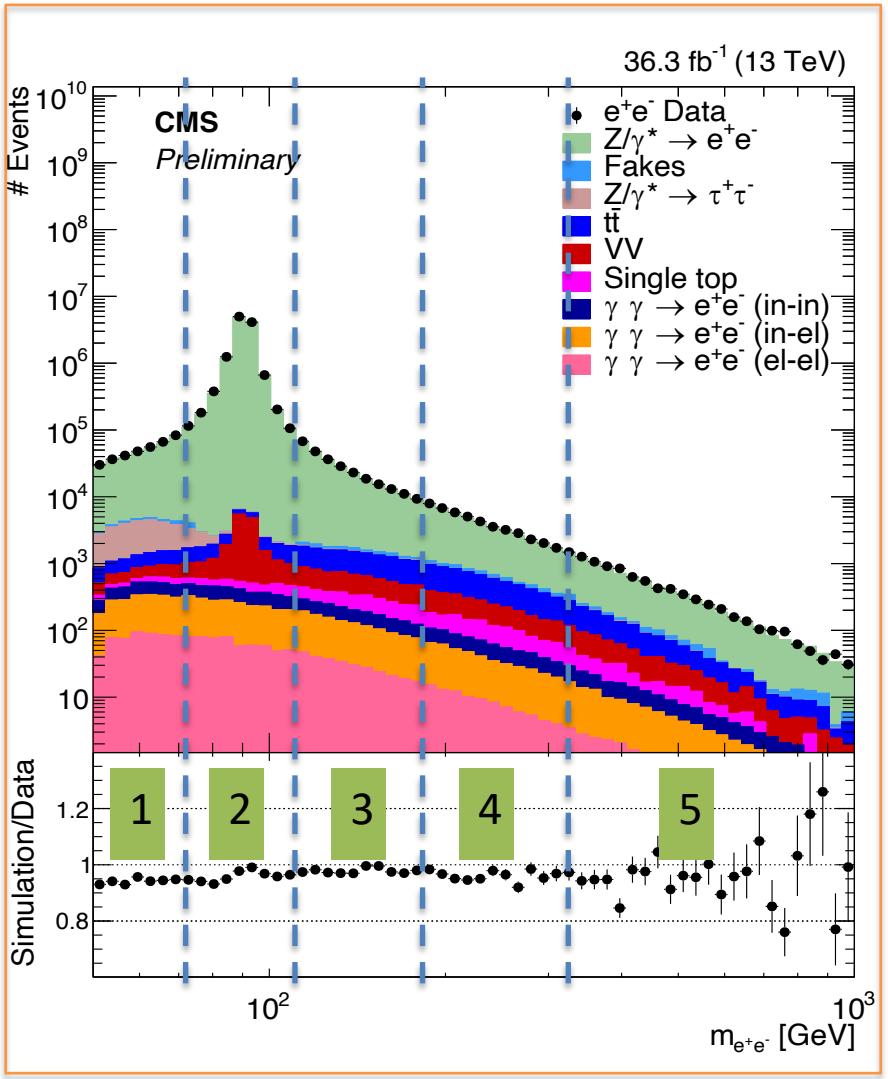
Drell-Yan pT dependence over a wide mass range

PAS-SMP-20-003

NEW

36.3 fb^{-1}

$\mu^+\mu^-$ (e^+e^-); p_T (l) > 25 (20) GeV, $|\eta|$<2.4
50 <M_{ll} < 1000 GeV

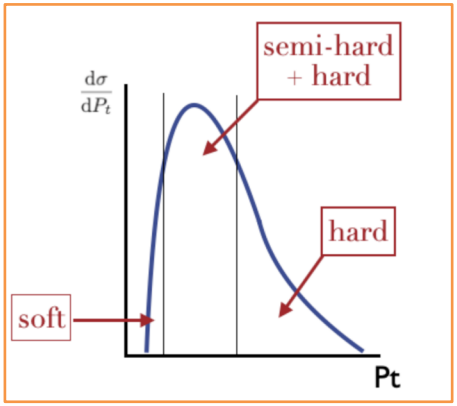


→ Measure the p_T in masses out of the Z peak

→ Observe dependence on the scale μ~m

→ Test models based on the Pythia parton shower as well as models with improved multiple parton emissions (TMD, NNLL + ME)

Measured pT and φ^* in five invariant mass ranges

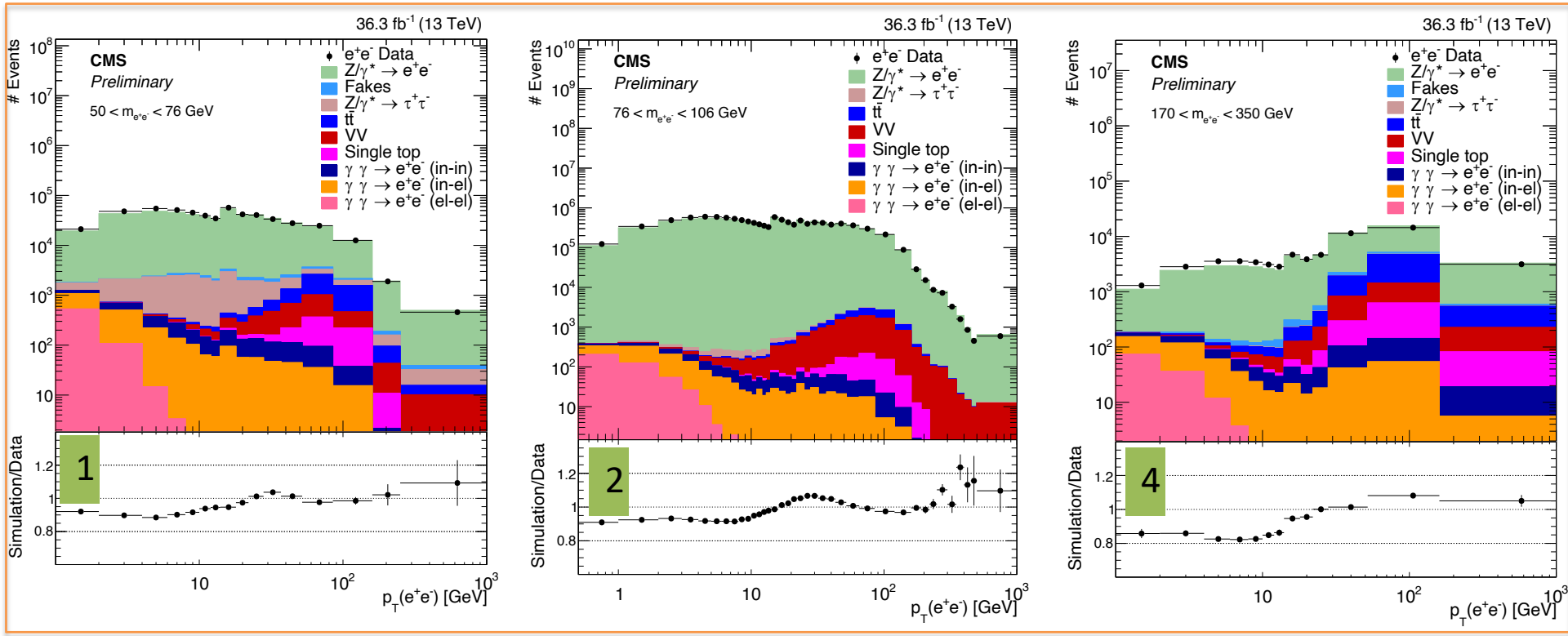


Drell-Yan pT dependence over a wide mass range

PAS-SMP-20-003

NEW

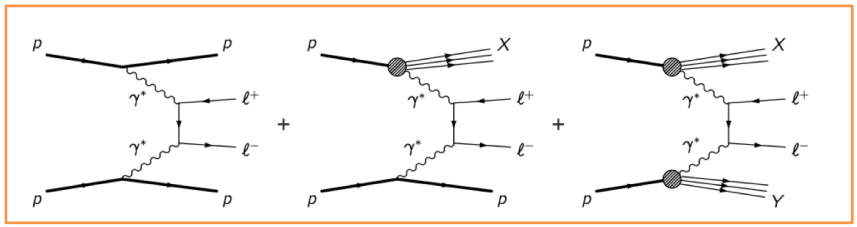
36.3 fb^{-1}



→ tt in high mass, surpressed by vetoing events with b jets (important for high p_T)

→ γγ -> l^+l^-, for elastic and inelastic cases separately (important for low p_T)

→ The measurement is ~background free in the whole range



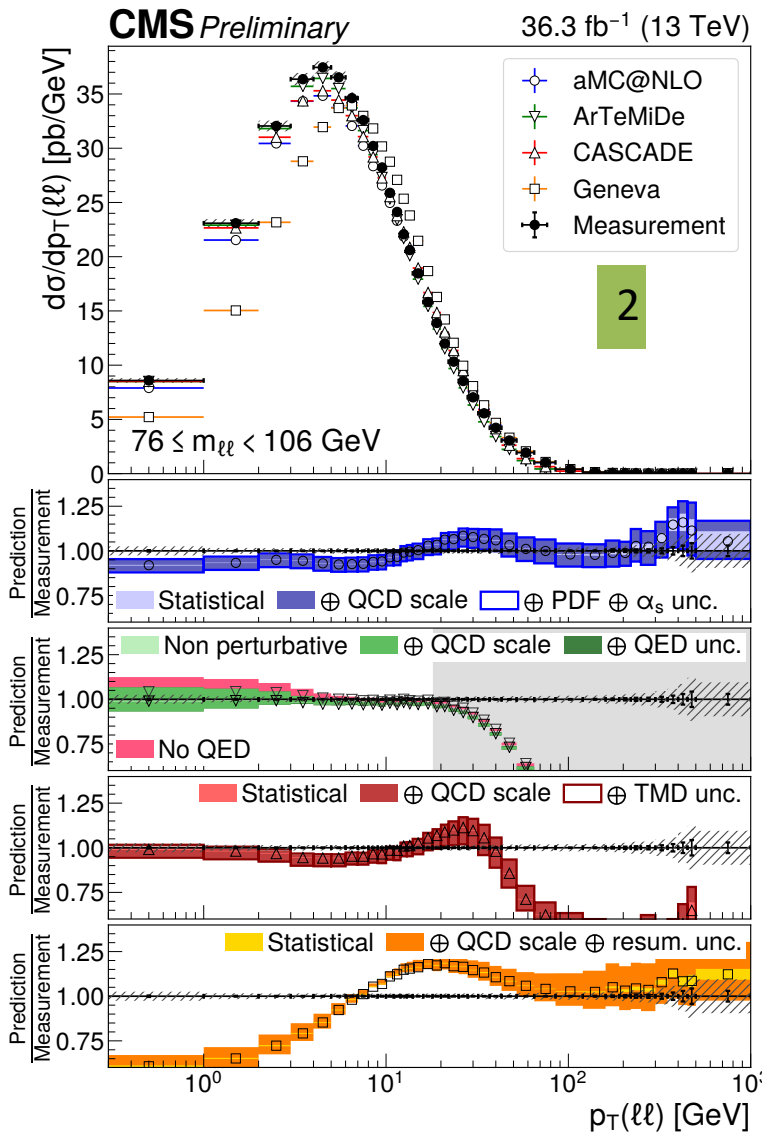
Drell-Yan pT dependence over a wide mass range

PAS-SMP-20-003

36.3 fb^{-1}

Unfolded to fiducial space

NEW



→ Measurement results are compared with:
- → ME + PS approach:
  - → MG5_amc@NLO + Pythia 8 @NLO up to 2 partons + PS
- → TMD approach
  - → CASCADE (amc@NLO+ PBTMD) + Pythia6 for FS and hadronization
  - → Analytic calculation from ArTeMiDe TMD based
- → Resummation
  - → GENEVA, NNLO Z+0j ME and resummation at NNLL'$_\tau$

	aMC@NLO	ArTeMiDe	CASCADE	Geneva
Inclusive ME	NLO	–	NLO	NNLO
≥ 1 jet ME	NLO	N/A	NLO	NLO
Resummation	PS (Pythia8)	N^{3}LL TMD	PB TMD	NNLL'$_\tau$
Parton shower	Pythia8		Pythia6	Pythia8
QED FSR	Pythia8	Our correction	Pythia6	Pythia8 (Possible problem)
Limitations	Low p_T: tune	$p_T < 0.15\, m_{\ell\ell}$	High p_T: higher orders	α_s choice

Consistent with the previous measurement (JHEP 12 (2019) 061) and supersedes it for this distribution

Drell-Yan pT dependence over a wide mass range

PAS-SMP-20-003

36.3 fb^{-1}

Unfolded to fiducial space

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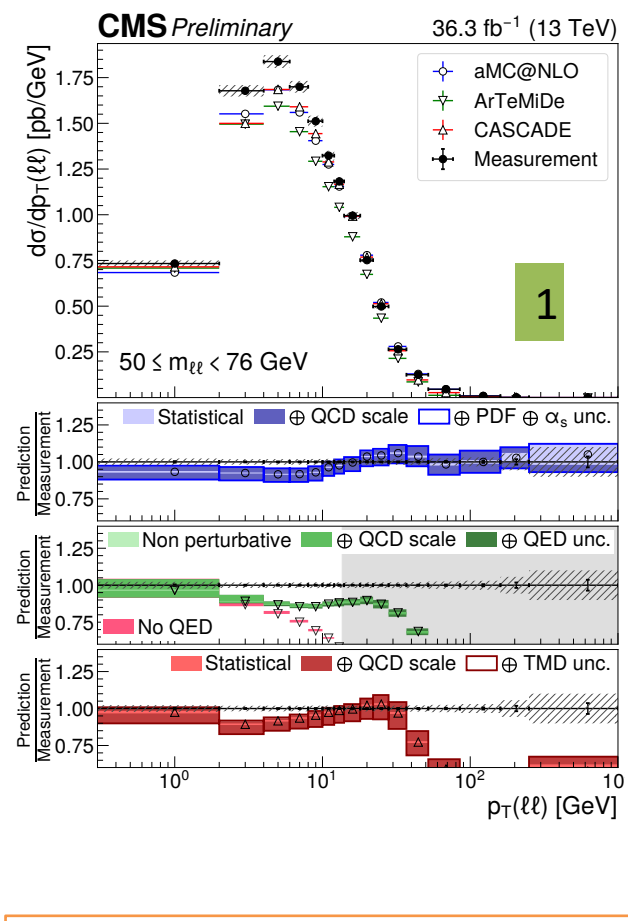
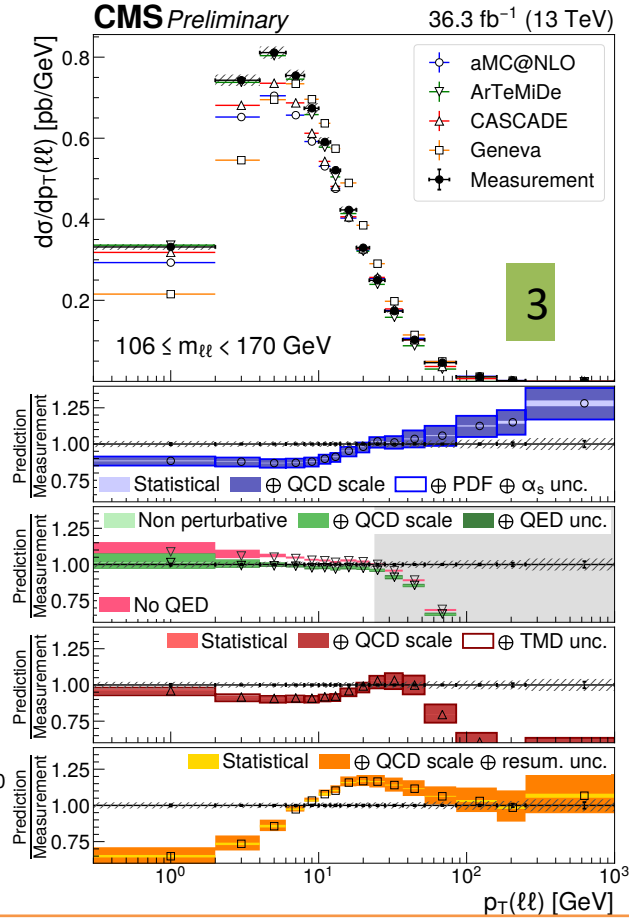
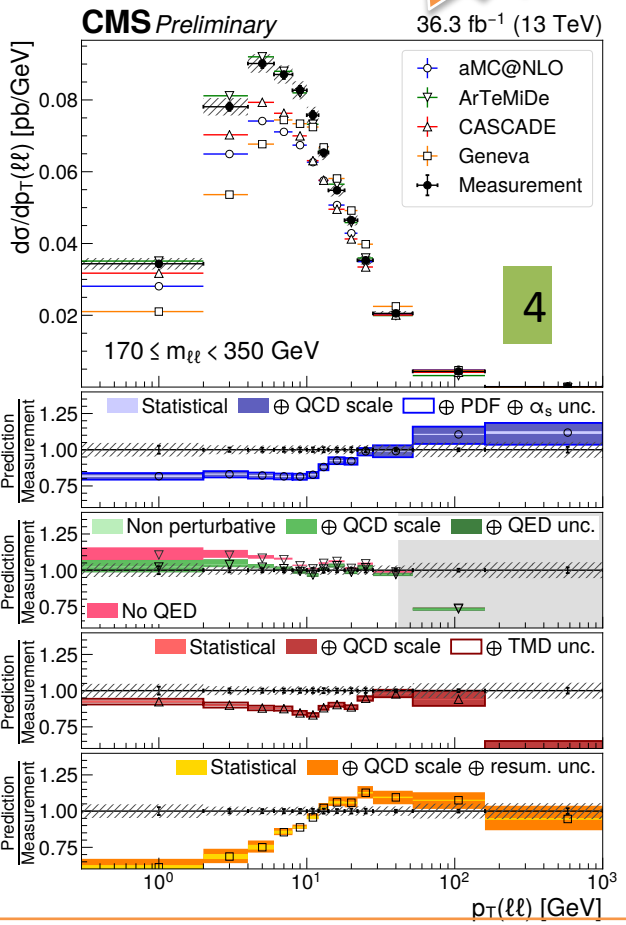






→ amc@NLO+ Pyhthia8 gives overall good description

→ Failing to describe the low p_T, failure increasing for higher m(ll)

→ Cascade (amc@NLO 0j + PBTMD) describes the low p_T better fails at high p_T due to missing orders in ME

→ ArTeMiDe gives the best description in its validity region

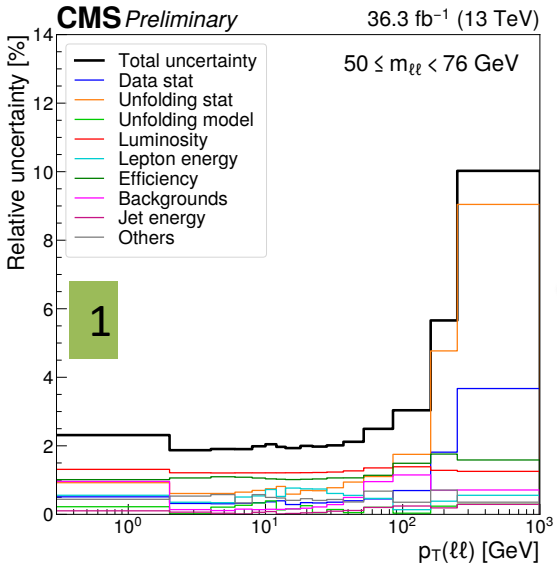
→ GENEVA predicts a harder p_T spectrum (α_s choice)

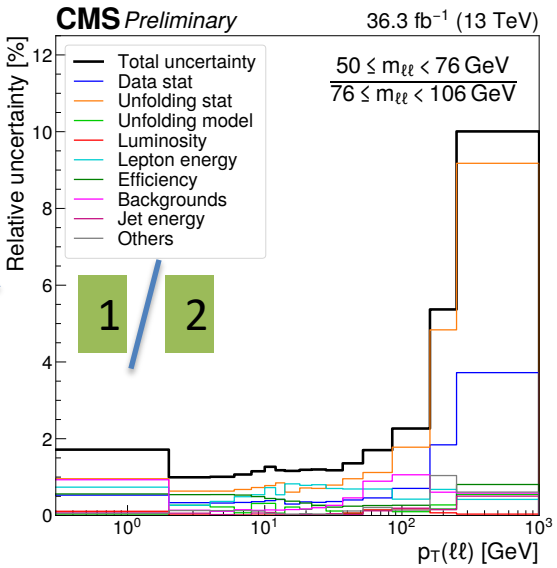
Drell-Yan pT dependence over a wide mass range

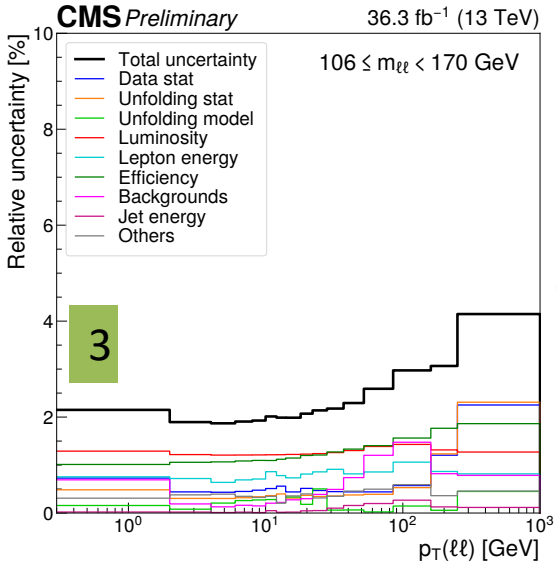
PAS-SMP-20-003

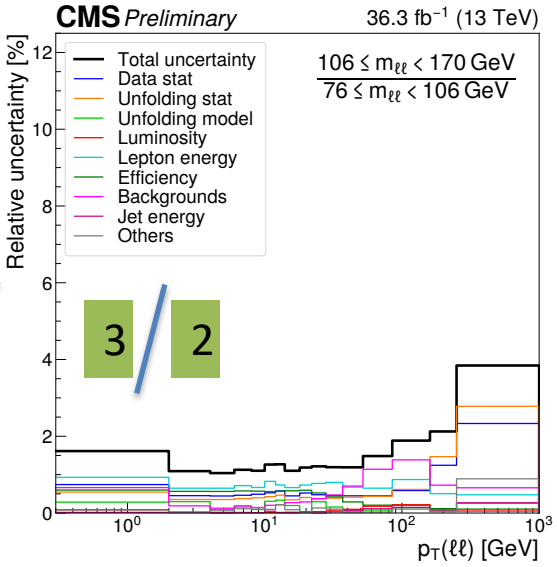
NEW

36.3 fb^{-1}









→ Studying ratio of the cross section to on shell:
- → Benefit from cancellation of several systematic sources
- → Better study the evolution with respect to the mass (→ scale of the hard process)

→ Note that the updated luminosity unc. is ~1.2%*

*: CMS luminosity measurement (2015&2016 data): arXiv:2104.01927

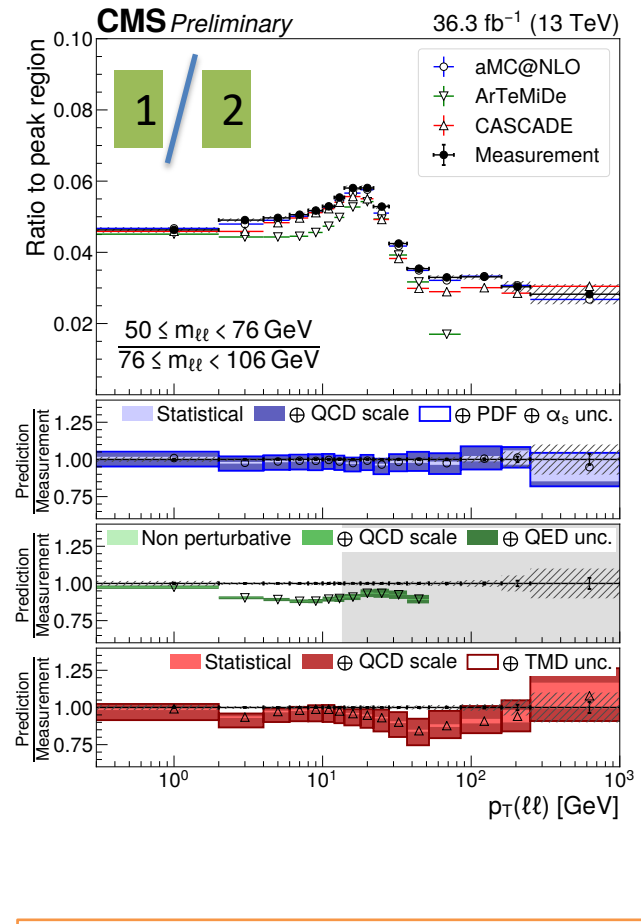
Drell-Yan pT dependence over a wide mass range

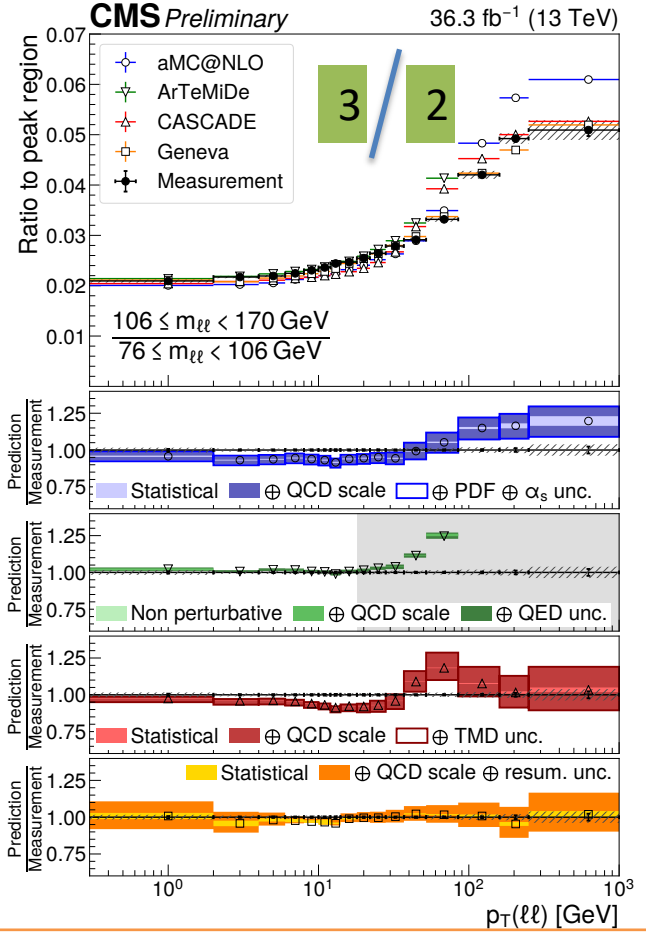
PAS-SMP-20-003

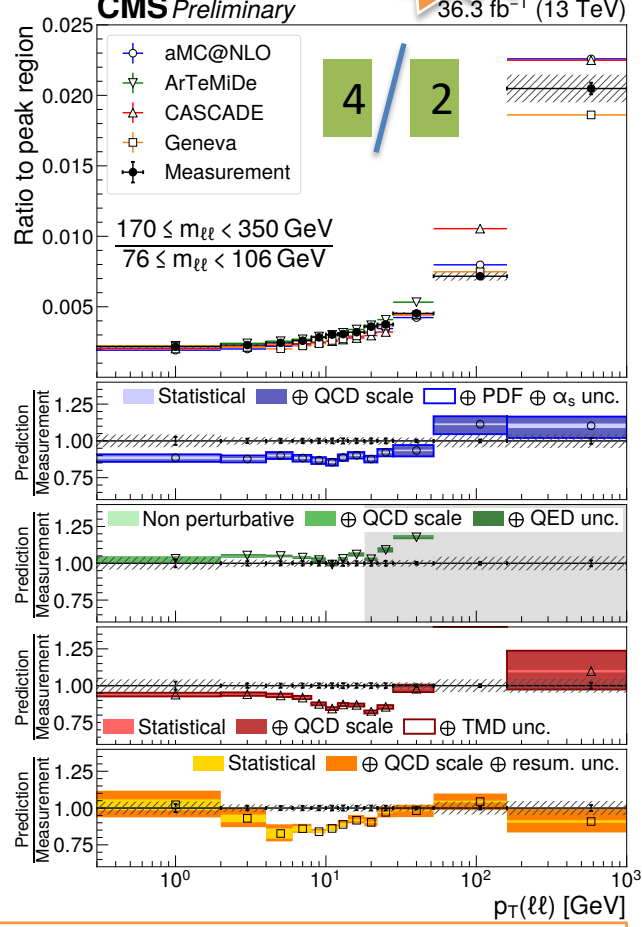
36.3 fb^{-1}

Unfolded to fiducial space

NEW







→ amc@NLO+ Pyhthia8 gives overall good description

→ Failing to describe the low p_T

→ Cascade (amc@NLO 0j + PBTMD) describes the low pT better, and good description in the high pT ratio

→ ArTeMiDe gives the best description in its validity region

→ GENEVA gives a very good description, improves the high pT with the inclusion of NNLO

Drell-Yan pT dependence over a wide mass range

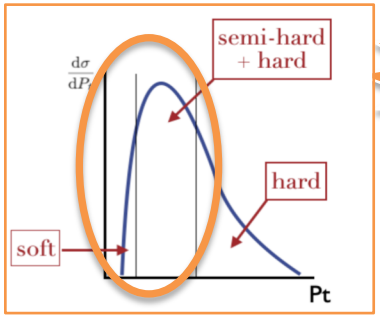
PAS-SMP-20-003

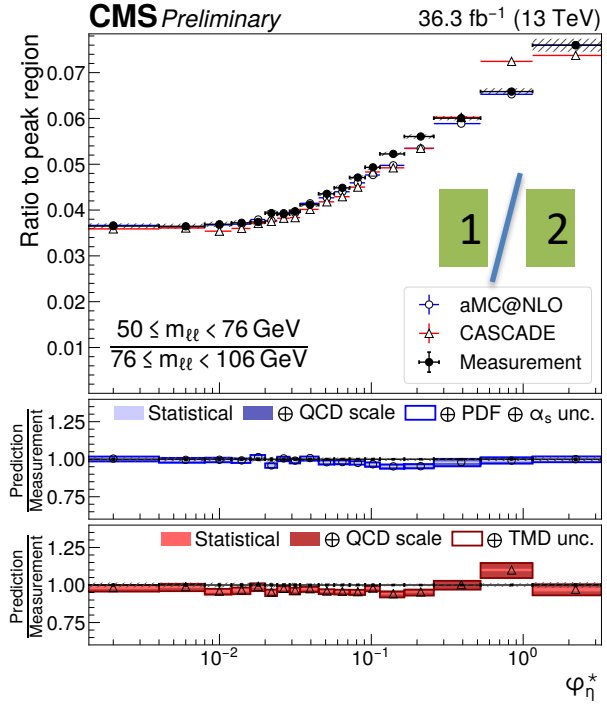
36.3 fb^{-1}

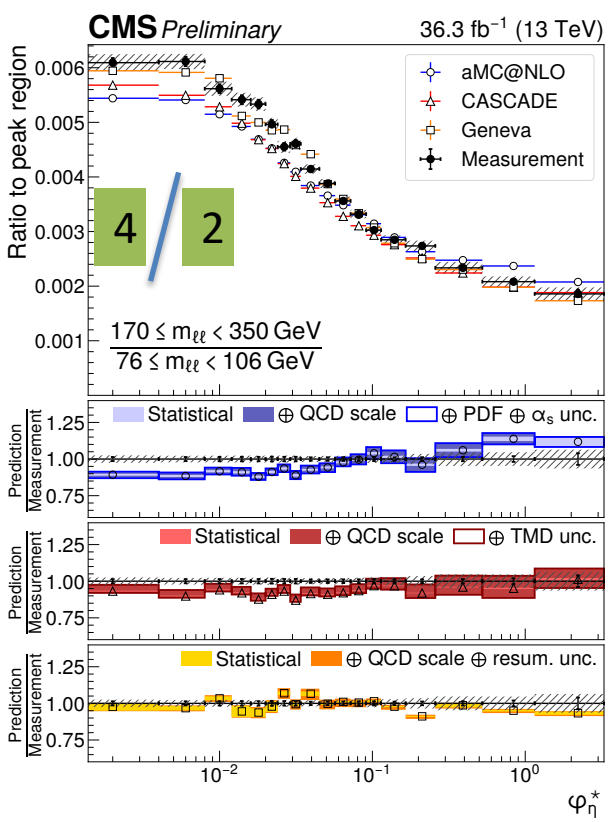
→ Angular variable strongly correlated to p_T
→ Allows studying low pT in more detail

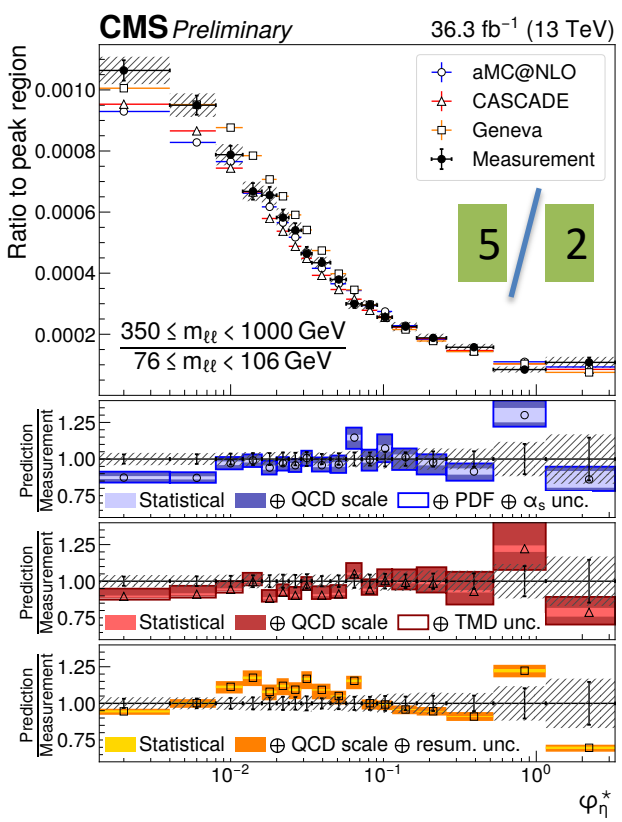
NEW

$$\phi^*_\eta = \tan\left(\frac{\pi - \Delta\phi}{2}\right)\sin(\theta^*_\eta), \quad \cos(\theta^*_\eta) = \tanh\left(\frac{\Delta\eta}{2}\right)$$









→ φ^* ratio measurement provides an ultimate precision
→ But, less discrimination between the models

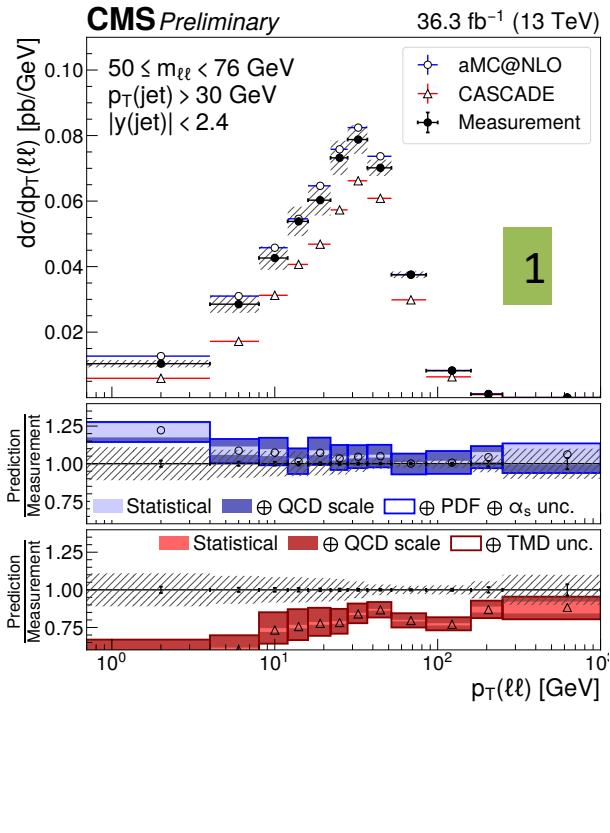
Unfolded to fiducial space

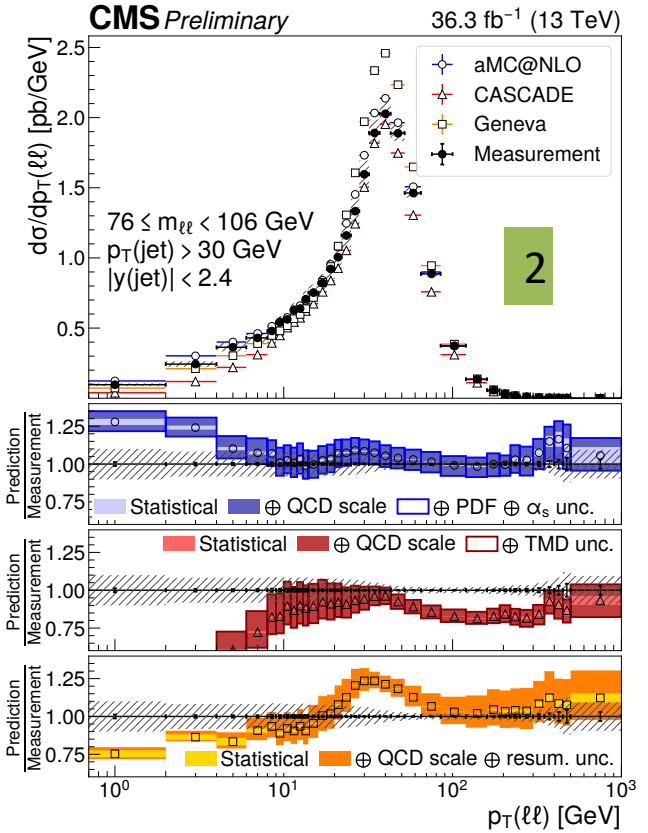
Drell-Yan pT dependence over a wide mass range

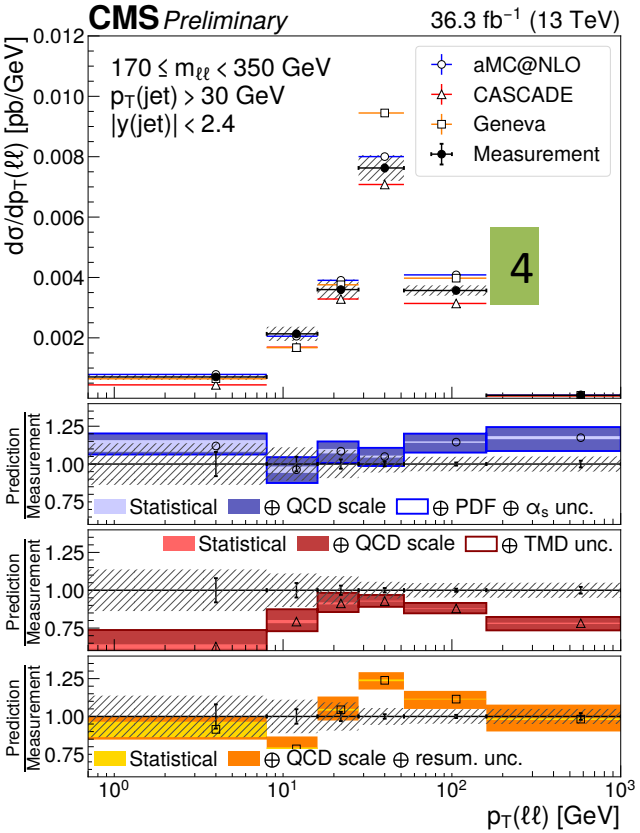
PAS-SMP-20-003

36.3 fb^{-1}

NEW







→ possibility of studying multiple gluon emissions away from the non-perturbative region
- → Best description by MG5_aMC NLO + Py8 sample
- → Cascade (amc@NLO 1j + PBTMD) fails to describe the regions with Z+ >=2j
- → GENEVA describes well the high p_T, fails for the normalization of low p_T.

Unfolded to fiducial space

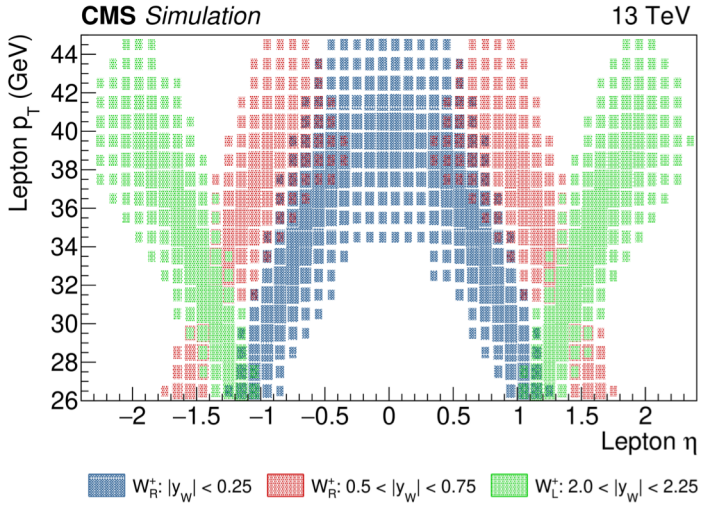
W rapidity, Helicity, Double-differential Cross Sections, and Charge Asymmetry

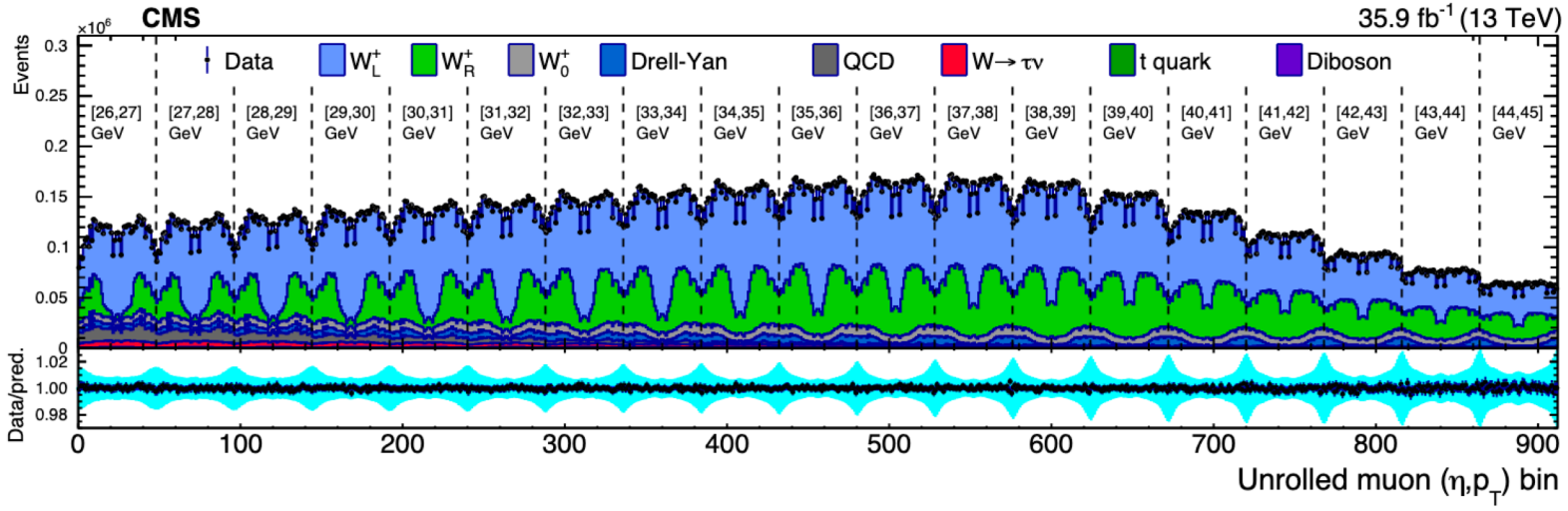
Phys. Rev. D 102 (2020) 092012

35.9 fb^{-1}

$W^{\pm}$ --> $\mu^{\pm}$ ($e^{\pm}$) ν ; p_T (μ (e)) > 26 (30) GeV
veto extra leptons with p_T > 10 GeV
M_T > 40 GeV

Measurement is carried out using template fitting technique

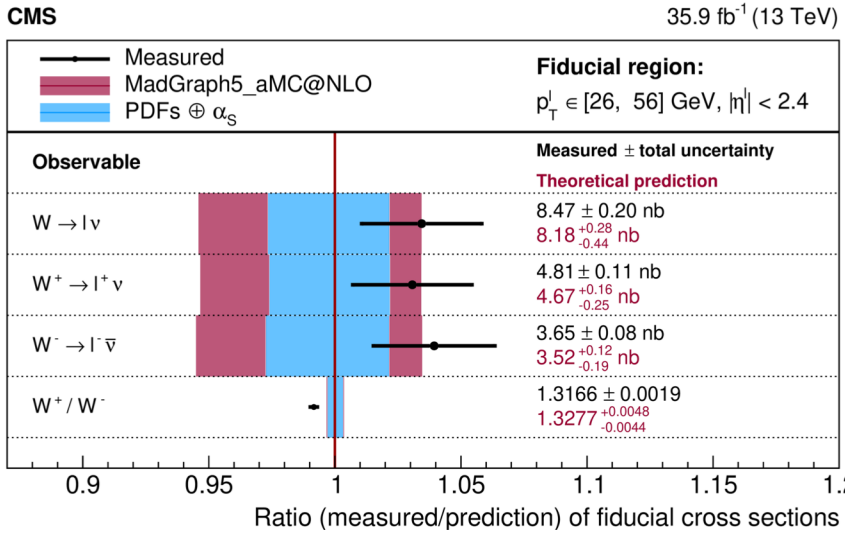




W rapidity, Helicity, Double-differential Cross Sections, and Charge Asymmetry

Phys. Rev. D 102 (2020) 092012

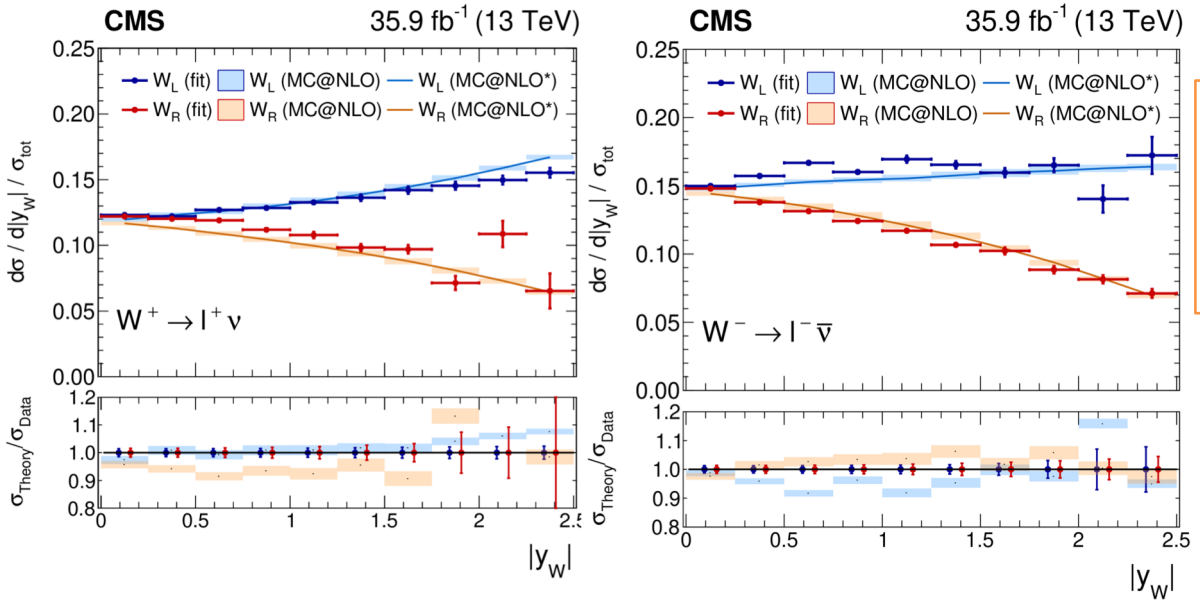
35.9 fb^{-1}



Total fiducial cross section:

→ W+, W- measured separately

→ W+/W- ratio

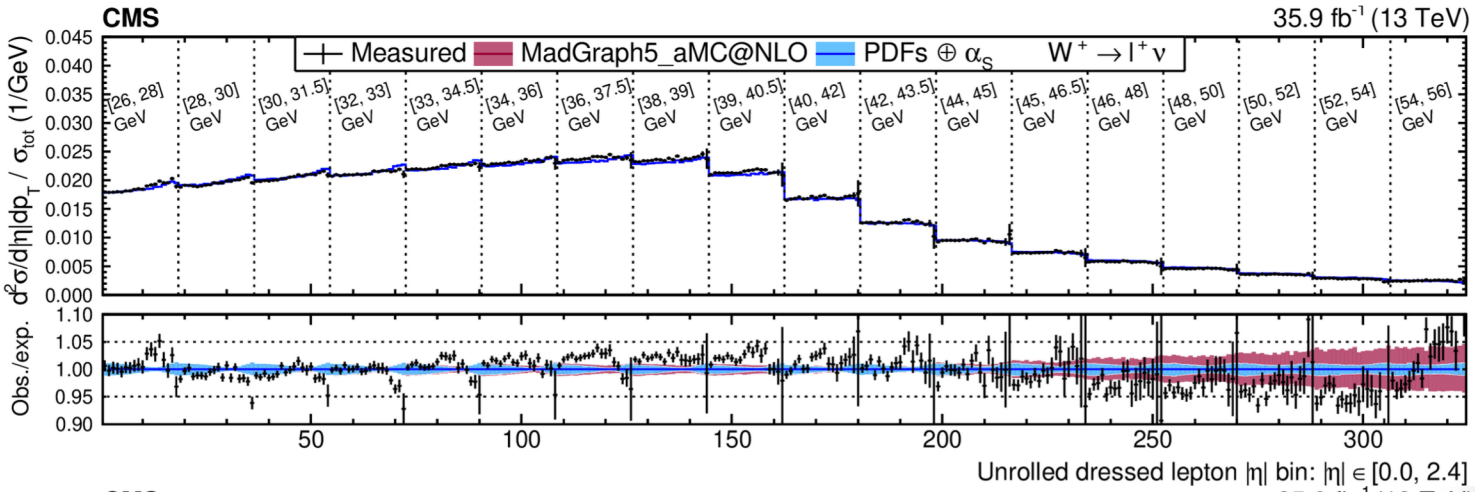


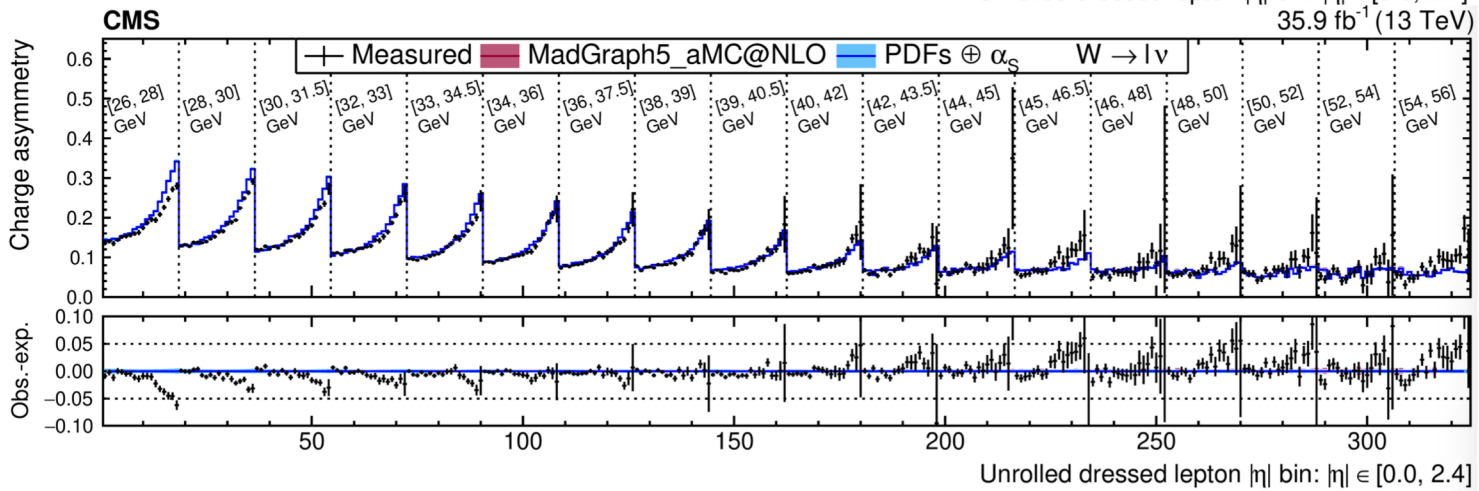
Differential cross section wrt y (W), for different helicity states

W rapidity, Helicity, Double-differential Cross Sections, and Charge Asymmetry

Phys. Rev. D 102 (2020) 092012

$26 < p_T(l) < 56$ GeV $|\eta(l)| < 2.4$





Double-differential x-sec wrt p_T (l) and η(l)

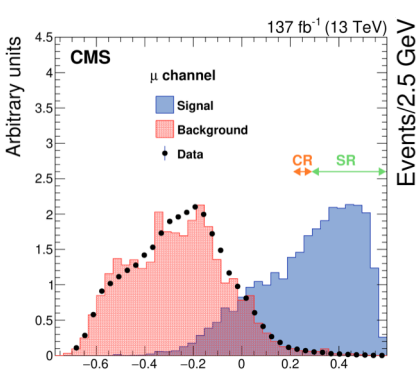
Differential A_C wrt p_T (l) and η(l)

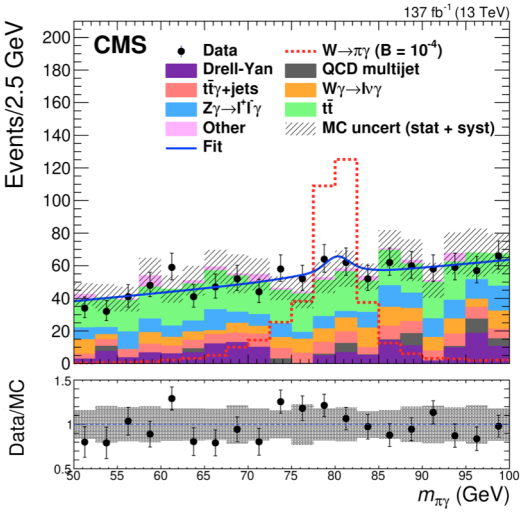
Search for W Exclusive Decays

137 fb^{-1}

$W^{\pm} \to \pi^{\pm}\gamma$

→ Using tt events where one of the W is decaying leptonically ($W^{\pm}$ --> $\mu^{\pm}$ ($e^{\pm}$) ν)
→ Other W is used to search for $\pi^{\pm}\gamma$ decay





Upper limit at a 95% CL:

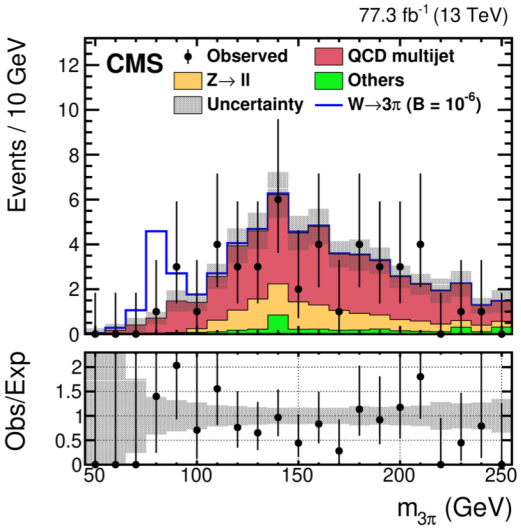
$$\mathcal{B}(W \to \pi\gamma) < 1.51 \times 10^{-5}$$

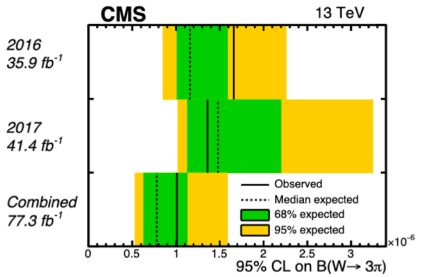
arXiv:2011.06028

77.3 fb^{-1}

$W^{\pm} \to \pi^{\pm}\pi^{\pm}\pi^{\mp}$

→ Using di-τ triggers
→ Reconstructing pion decays using hadronic τ algorithm





Upper limit at a 95% CL:

$$\mathcal{B}(W \to 3\pi) < 1.01 \times 10^{-6}$$

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Summary

→ Summarized several measurements including W and Z bosons with 13 TeV data

→ Providing stringent test of our models based on SM

→ Probing perturbative and non-perturbative QCD effects

→ Testing various MC approaches (ME+PS, TMD, resummation…) and their validity at different corners of phase-space

→ Measuring EWK parameters, couplings, A_C, A_{FB}…

→ Probing rare decay channels, putting limits

→ Valuable input to improve theoretical models

As usual; more to come; stay tuned!

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMP

Thank you