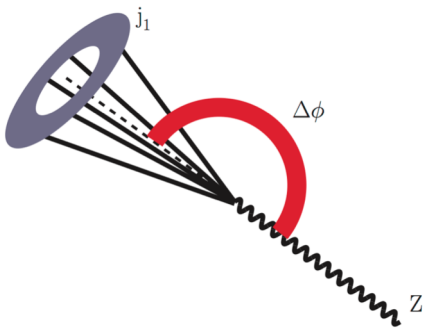
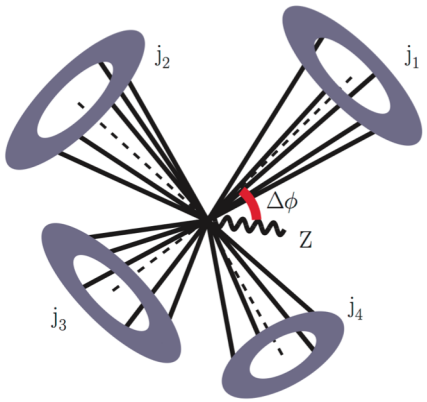
Comparison of PB TMDs to Z + jet results

B, Bilin*, L. Favart*, P. Gras**, H. Jung**

*IIHE-ULB, FNRS
Bruxelles, Belgium
**CEA/Saclay, France
**DESY, Hamburg, Germany

REF 2020
Online World

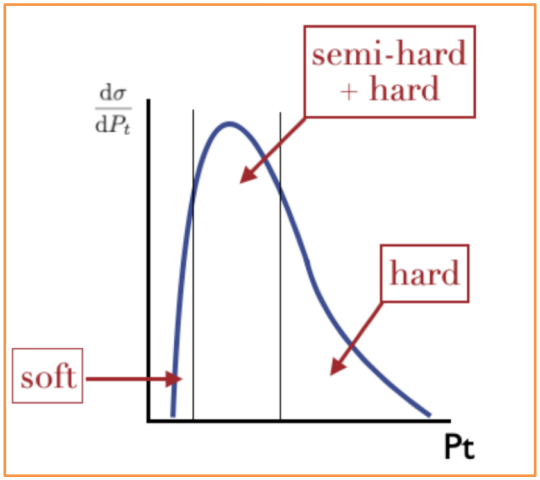


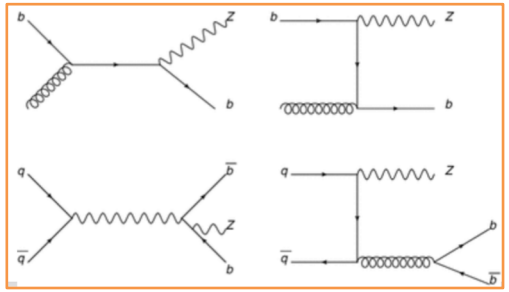


7 December 2020

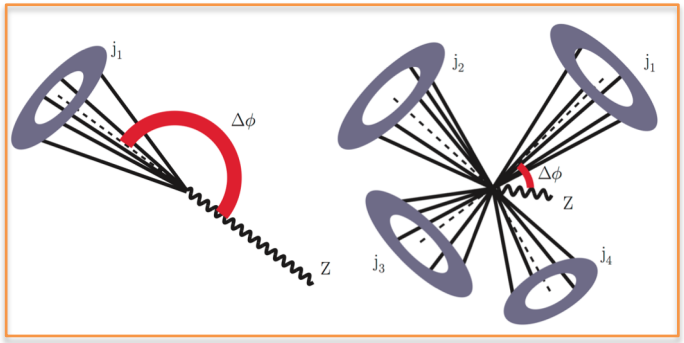
Introduction

- → Processes involving Z boson production are one of the best understood processes at hadron colliders
  - → Z->ll, (l=e,μ) are among the cleanest final states experimentally
  - → Allows probing various QCD effects by studying kinematics precisely
- → Important to study Z+ HF production at the LHC
  - → Can provide understanding of HF production
  - → Can provide understanding of soft QCD effects
    - → Comparison of sensitive variables with TMDs
- → Study of angular variables play an important role in understanding those dynamics. (Δϕ(Z,j)…)





- → In this talk, we present comparison with PB TMD method (Z+1j @NLO + PB TMD)
  - → Madgraph5_amc@NLO generating Z+1j @ NLO
  - → Using Cascade v3, TMDLib v2.2.0
  - → https://cascade.hepforge.org/



Measurements used in comparison

- Measurements of differential production cross sections for a Z boson in association with jets in pp collisions at √s = 8 TeV (JHEP 04 (2017) 022)
- Measurement of Z + b jet at 8 TeV (Eur. Phys. J. C (2017) 77: 751)
- Measurement of associated production of a Z boson with charm or bottom quark jets @ 13 TeV (Phys. Rev. D 102, 032007 (2020))
- Measurement of differential cross sections for Z boson production in association with jets in proton-proton collisions at √s = 13 TeV (Eur. Phys. J. C 78 (2018) 965)

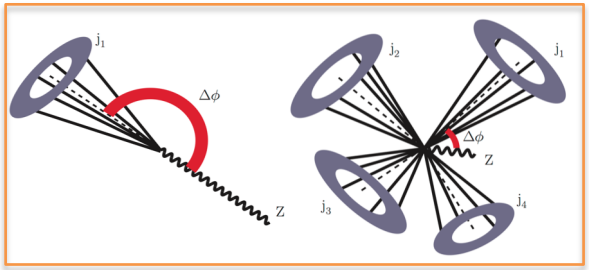
Z +j @8 TeV

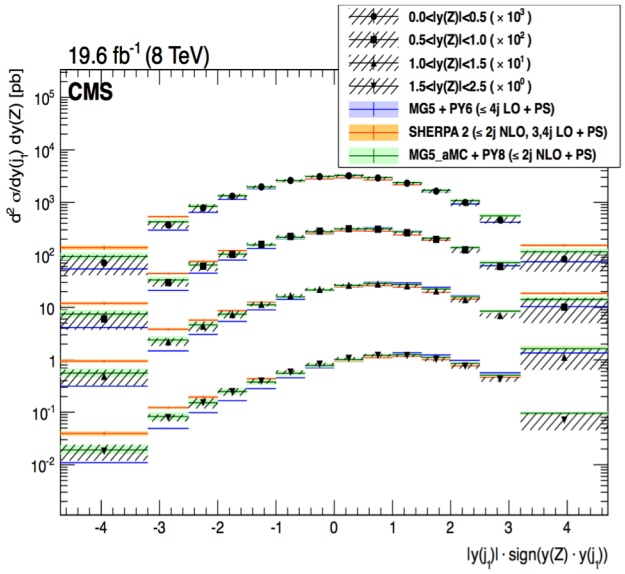
(JHEP 04 (2017) 022)

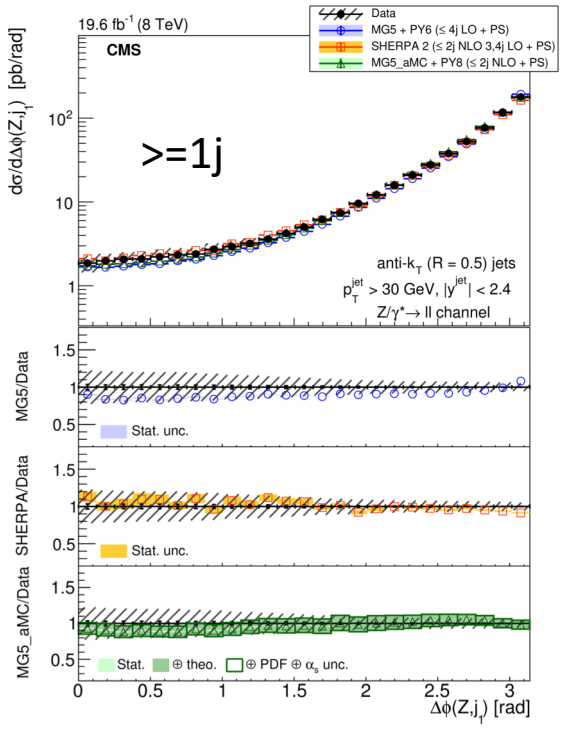
p-p √s=8 TeV
19.8 fb^{-1}

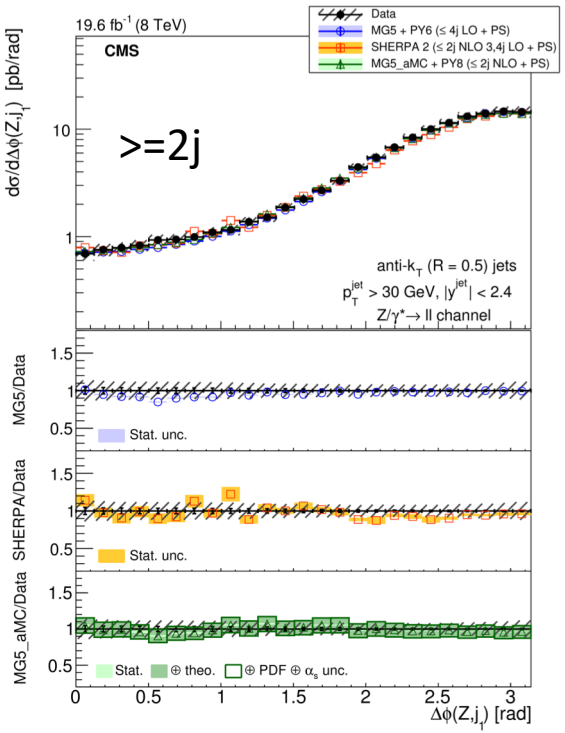
p_T^l >20 GeV, $|\eta^l|$<2.4 71 <M_{ll}<111 GeV

p_T^j >30 GeV, $|\eta^j|$<2.4









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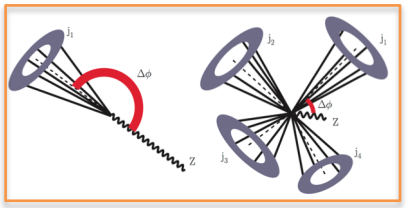
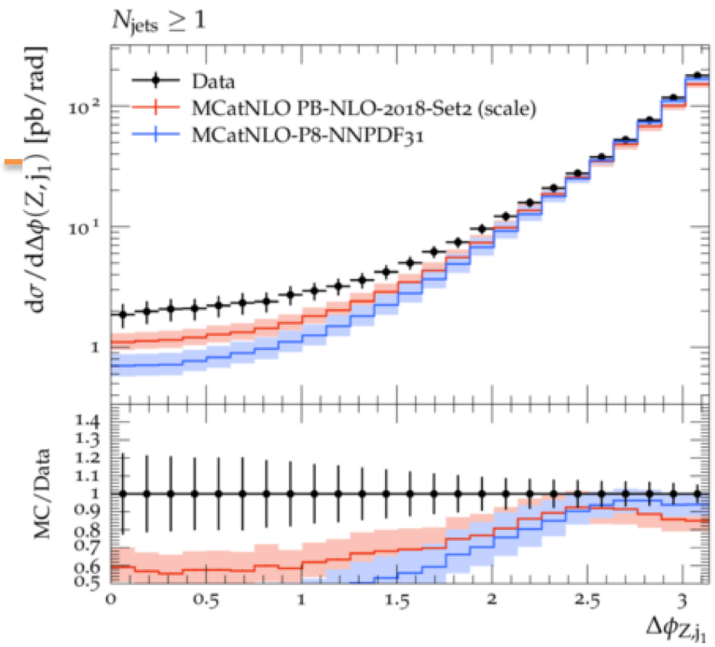
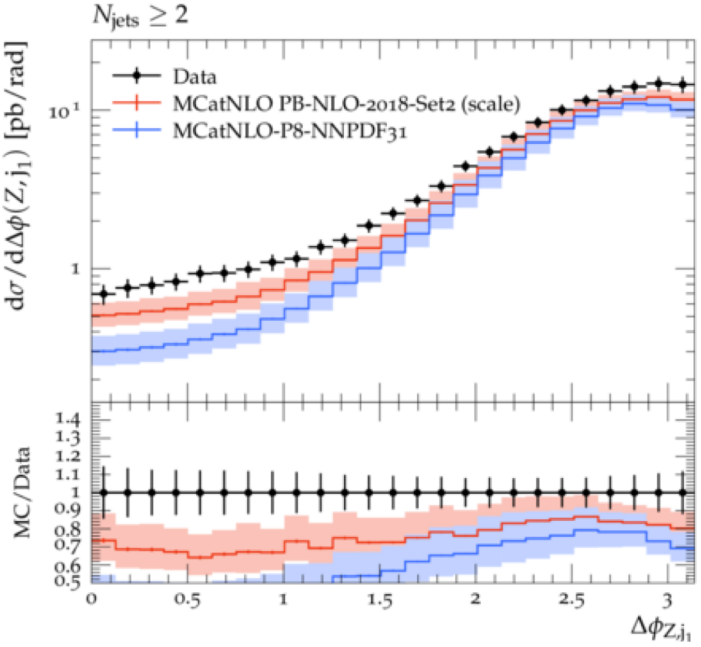
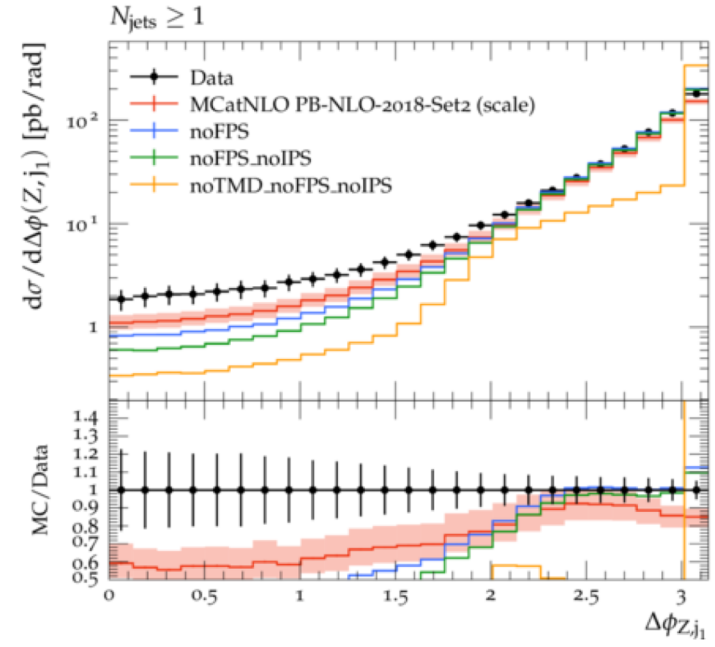
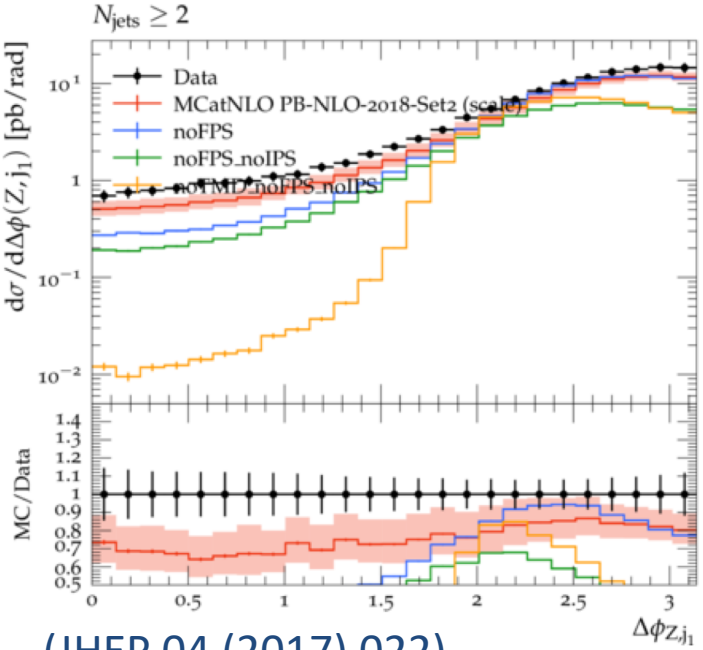










→ Fair agreement with the data by PB-TMD + Z+1j @NLO

→ Low Δϕ not filled by PS, when the closest jet to Z is not the hardest in pT

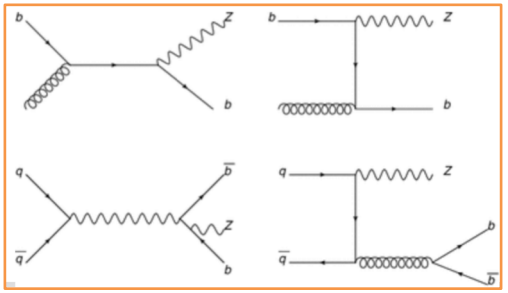
Z+1j @NLO + PB TMD

(JHEP 04 (2017) 022)

Z +b @8 TeV

Eur. Phys. J. C (2017) 77: 751

p-p √s=8 TeV
19.8 fb^{-1}



p_T^l >20 GeV, $|\eta^l|$<2.4 71 <M_{ll}<111 GeV

p_T^j >30 GeV, $|\eta^j|$<2.4

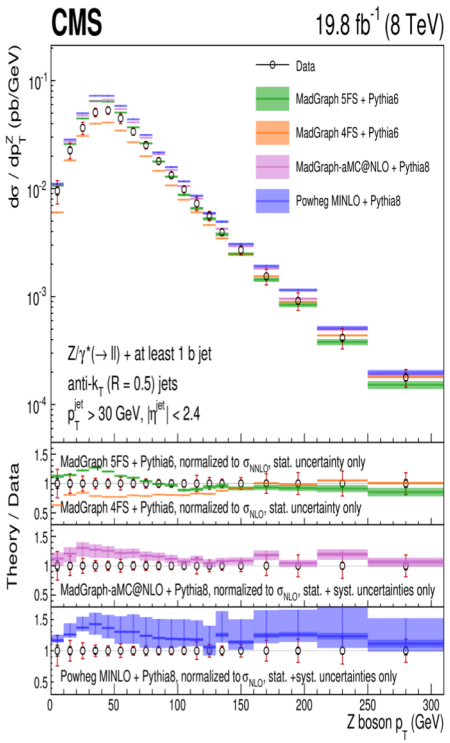
Studies of various variables are carried out

Z+b: p_T^b , η^b, p_T^Z, H_T, $\Delta\phi(Z,b)$

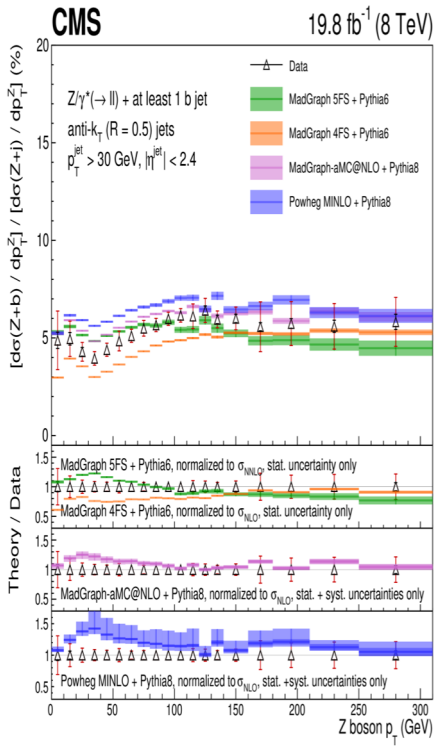
Z+bb: p_T^{b1} ,p_T^{b2}, p_T^Z,M^{bb} ,M^{Zbb} ,p_T^{bb}, $\Delta\phi(bb)$, $\Delta\phi(bb,Z)$, $\Delta R(bb)$…

→ Sensitive to b-quark PDF and initial-state gluon splitting

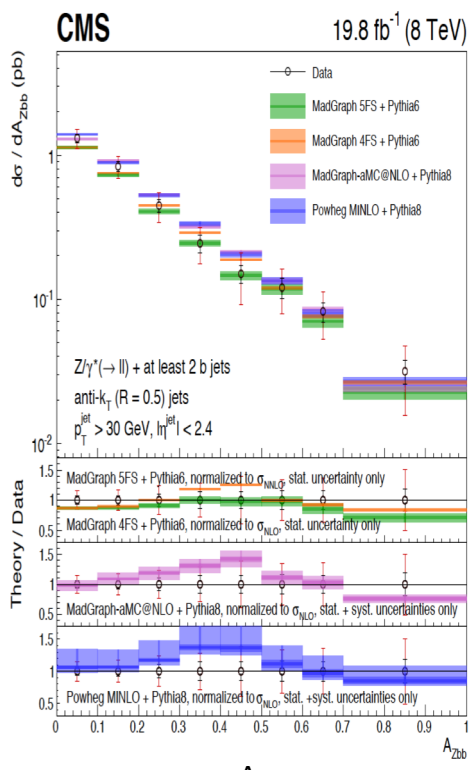
$$A_{Zbb} = \frac{\Delta R_{Zb}^{max} - \Delta R_{Zb}^{min}}{\Delta R_{Zb}^{max} + \Delta R_{Zb}^{min}}.$$



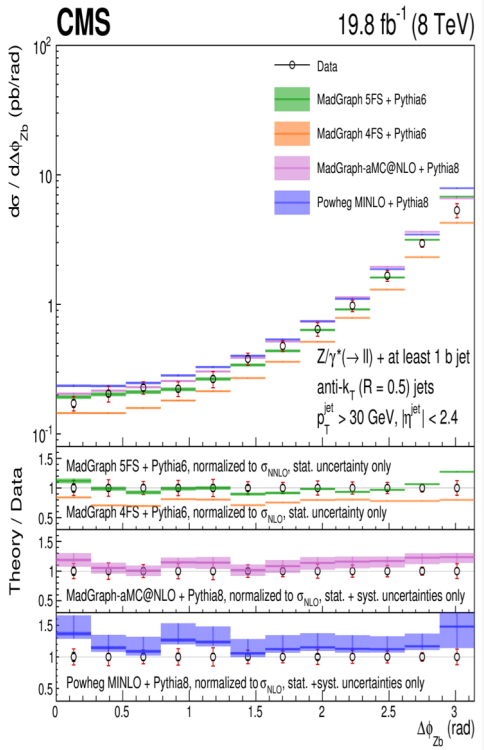
Z pT, Z + >1bj



Z pT, Z + >1bj/>1j



A_{ZBB}



$\Delta\phi_{ZB}$

Z +b @8 TeV

p-p √s=8 TeV
19.8 fb^{-1}

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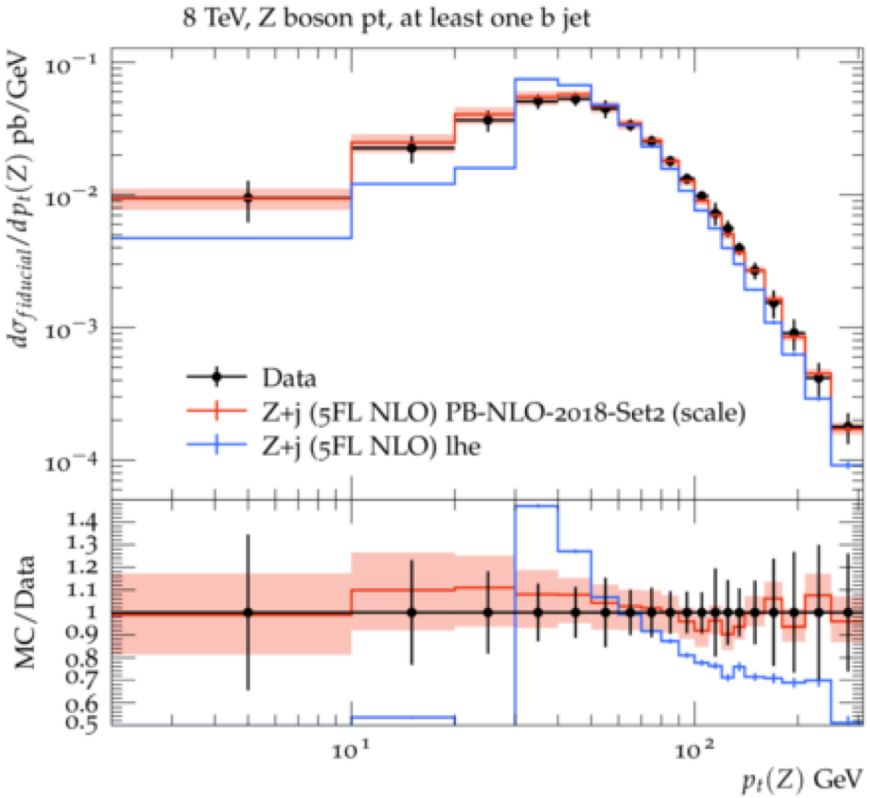
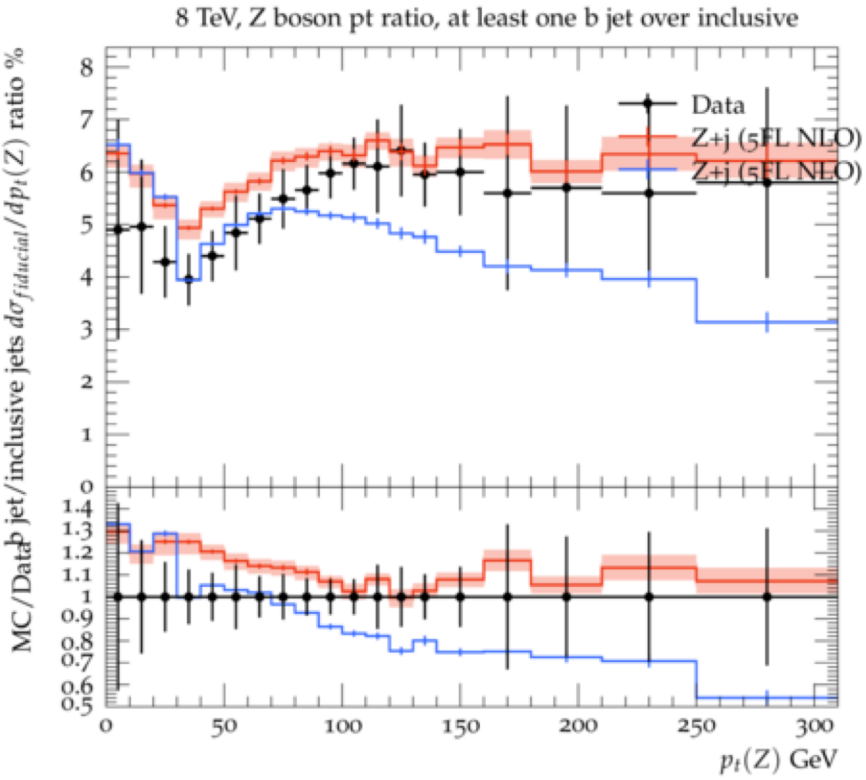




→ Low p_T(Z) well described for the Z + >=1b-jet

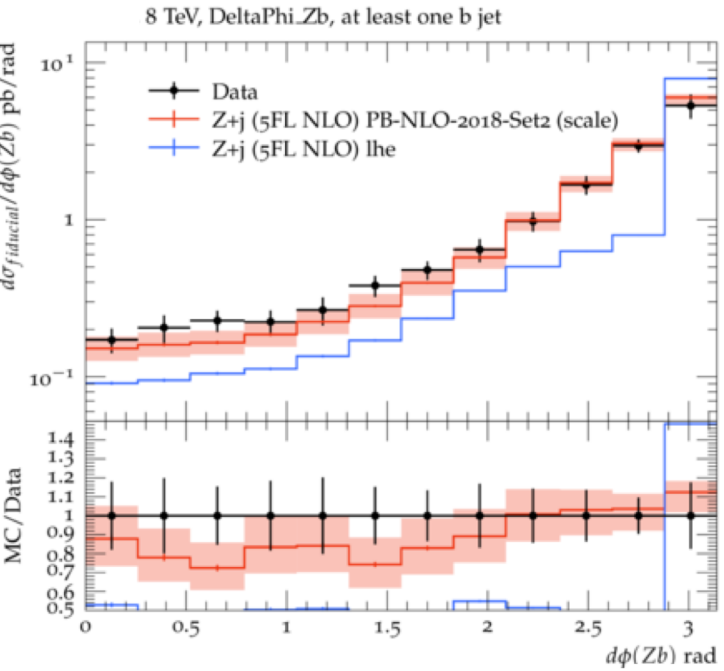
→ Some tension in ratio to describe this region → Failing to describe low p_T(Z) part for Z+ j case

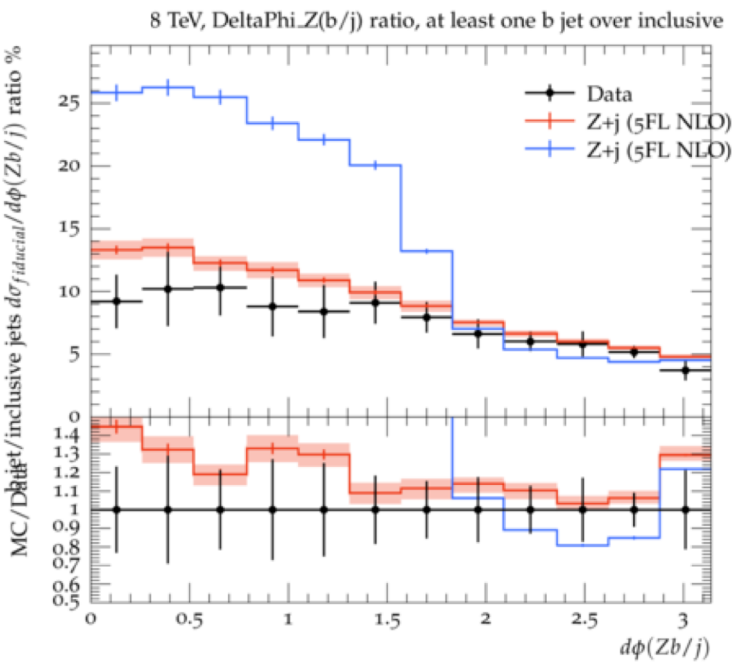
Z+1j @NLO + PB TMD

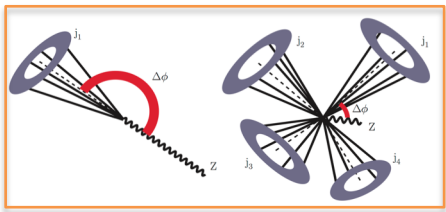
Eur. Phys. J. C (2017) 77: 751

Z +b @8 TeV

p-p √s=8 TeV
19.8 fb^{-1}

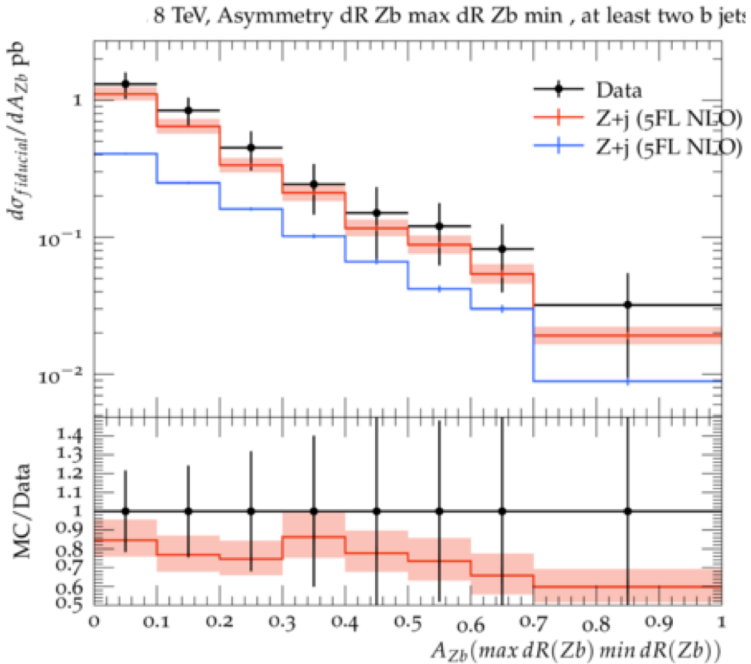






→ Better agreement with the data by PB-TMD + Z+1b case

→ Low Δϕ better filled by PS



$$A_{\mathrm{Zbb}} = \frac{\Delta R_{\mathrm{Zb}}^{\mathrm{max}} - \Delta R_{\mathrm{Zb}}^{\mathrm{min}}}{\Delta R_{\mathrm{Zb}}^{\mathrm{max}} + \Delta R_{\mathrm{Zb}}^{\mathrm{min}}}.$$

Z+1j @NLO + PB TMD

Eur. Phys. J. C (2017) 77: 751

Z+ bjet, Z+cjet ratio

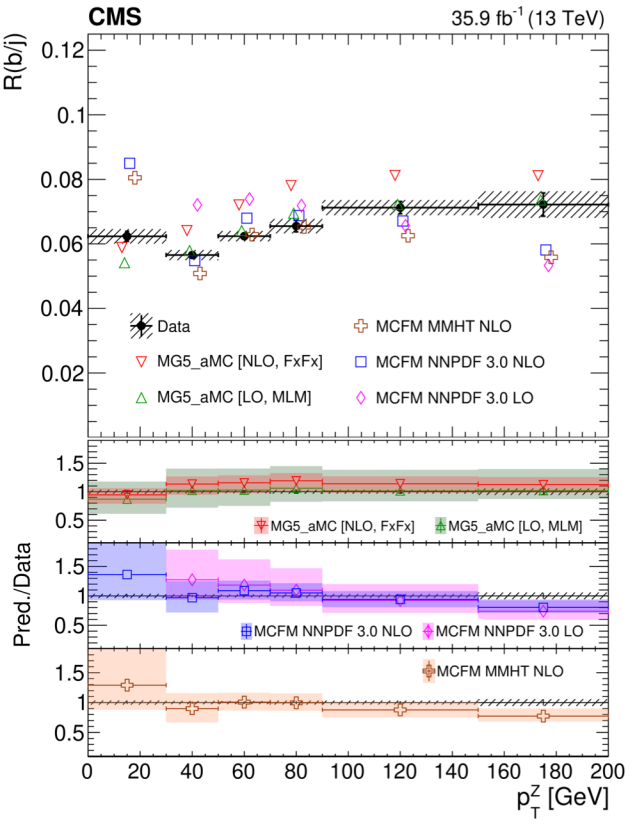
Phys. Rev. D 102, 032007 (2020)

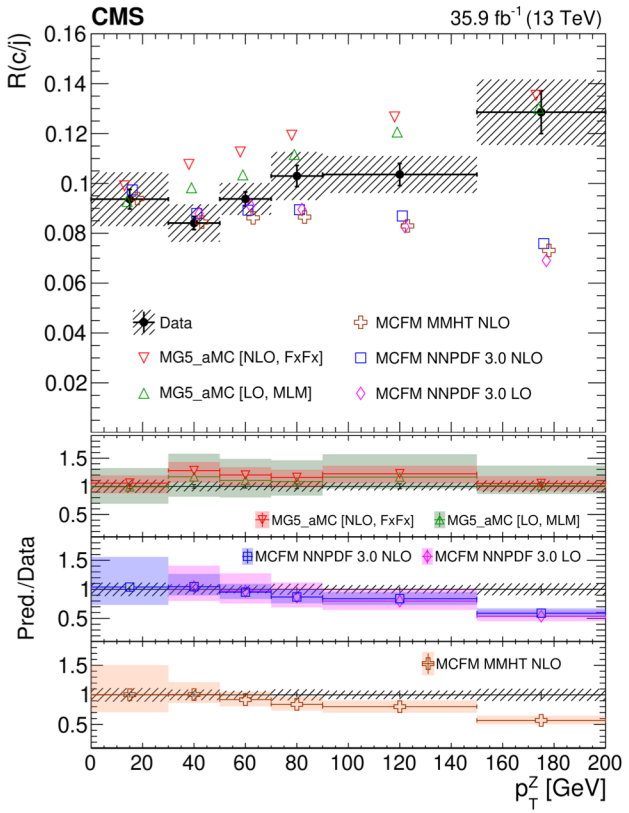
p-p √s=13 TeV
35.9 fb^{-1}

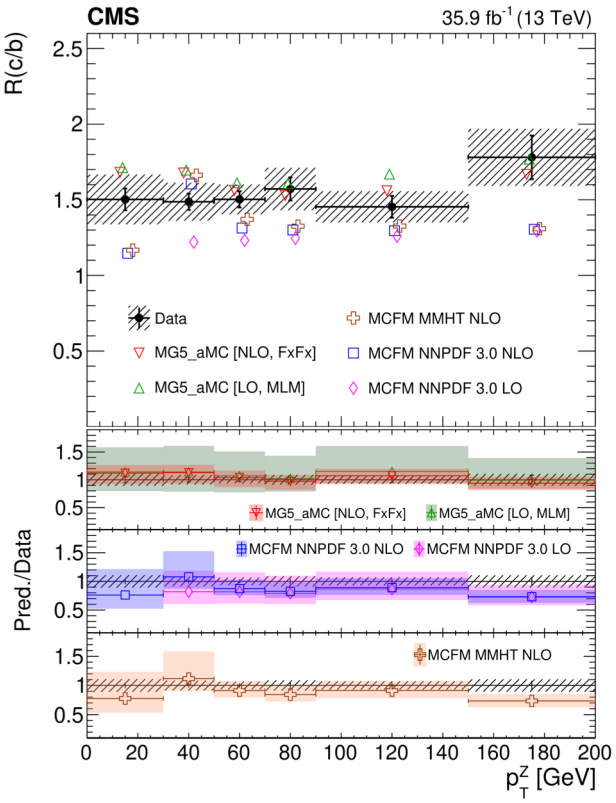
p_T^l >25 GeV, $|\eta^l|$<2.4 71 <M_{ll}<111 GeV

p_T^j >30 GeV, $|\eta^j|$<2.4

Ratios of cross sections,σ(Z+c jets)/σ(Z+jets), σ(Z+b jets)/σ(Z+jets), σ(Z+c jets)/σ(Z+b jets)







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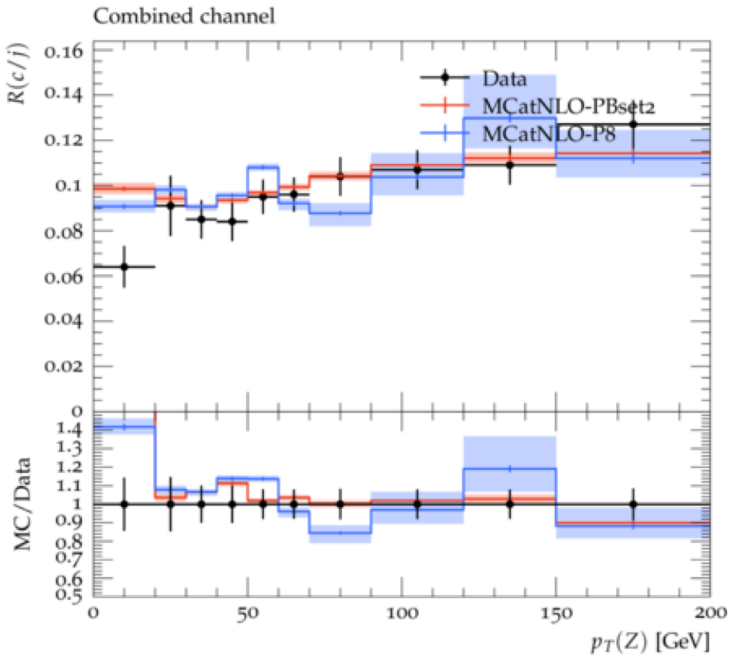

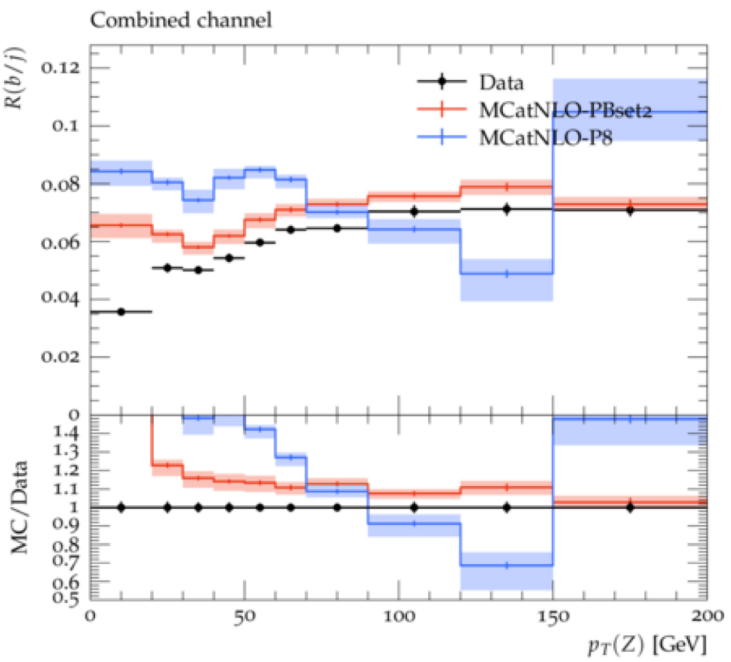

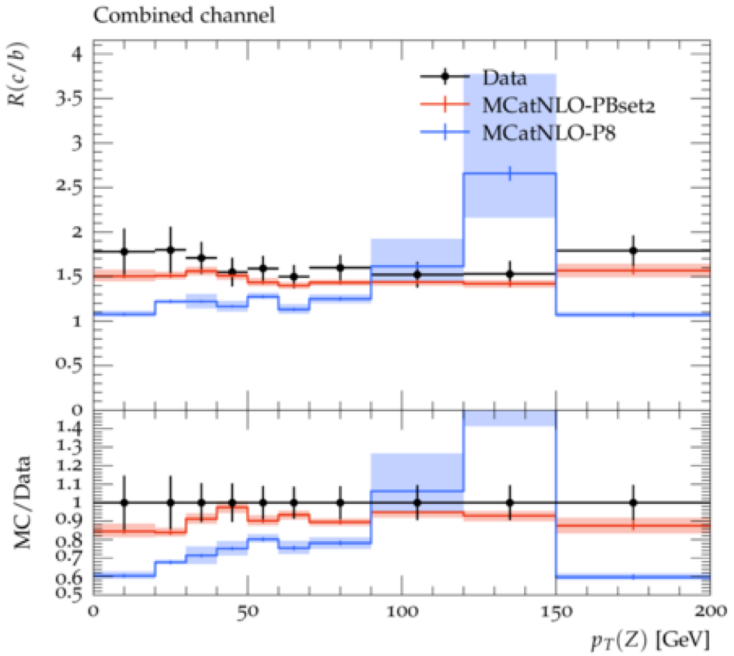

Phys. Rev. D 102, 032007 (2020)

→ PB TMD predicts Z+c/Z+b the best

→ For both Z+b/Z+j and Z+c/Z+j show deficiency at low pT

Z+1j @NLO + PB TMD

Z+ 1jet, Z pT

Eur. Phys. J. C 78 (2018) 965

p-p √s=13 TeV
2.2 fb^{-1}

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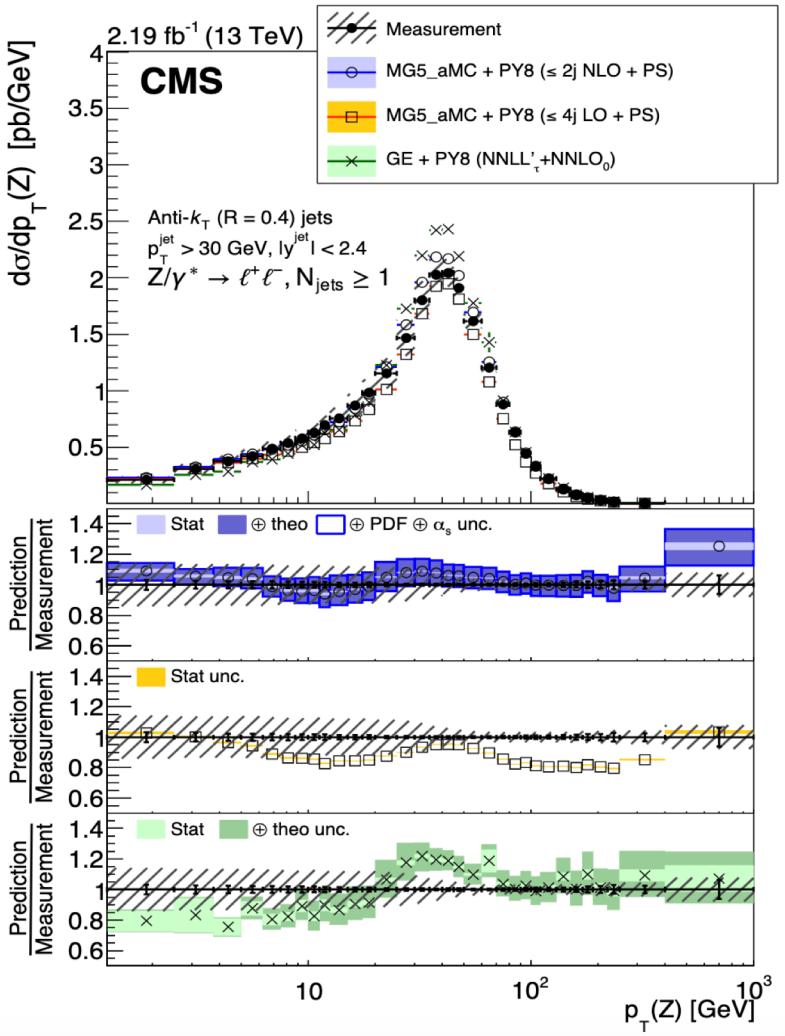


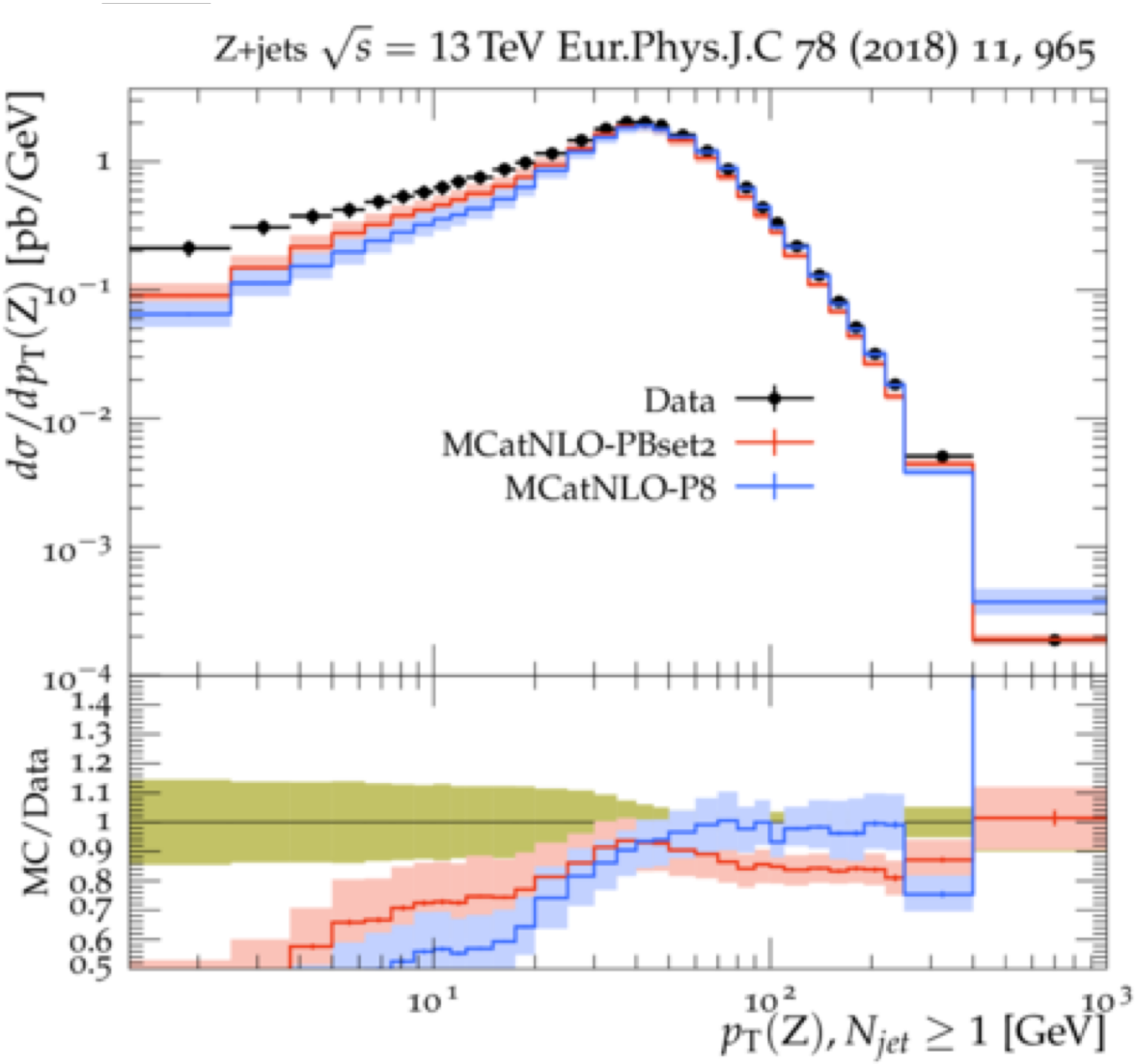
→ possibility of studying multiple gluon emissions away from the non-perturbative region

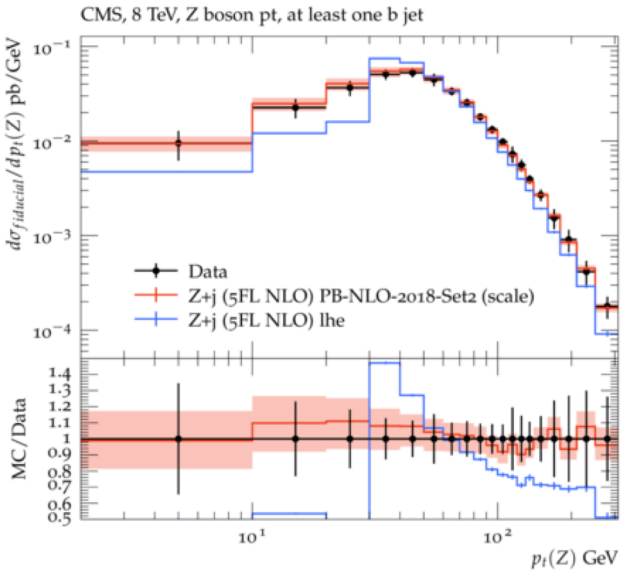
→ Best description by MG5_aMC NLO sample

→ GENEVA describes well the high p_T, fails for the normalization of low p_T.

Z+ 1jet, Z pT

p-p √s=13 TeV
2.2 fb^{-1}





→ Unlike Z + >=1b-jet, low pT spectrum for Z+1jet is not described well

→ not filled by PS, when the closest jet to Z is not the hardest in pT

Z+1j @NLO + PB TMD

Eur. Phys. J. C 78 (2018) 965

Z+ 1jet; p_T^{bal} and JZB

Eur. Phys. J. C 78 (2018) 965

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p_T^l >20 GeV, $|\eta^l|$<2.4 71 <M_{ll}<111 GeV

p_T^j >30 GeV, $|\eta^j|$<2.4

p_T balance between the Z boson and the vector sum of the jets:

$p_T^{bal} = |\vec{p}_T(Z) + \sum_{jets} \vec{p}_T(j_i)|$

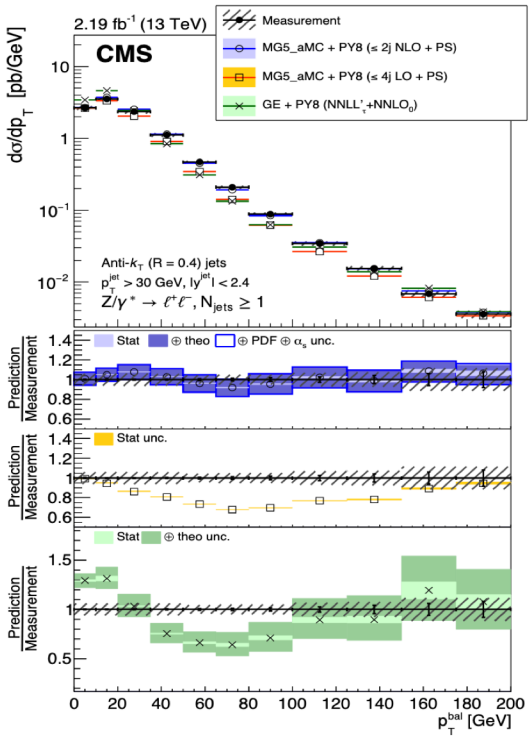
Jets-Z balance (JZB):

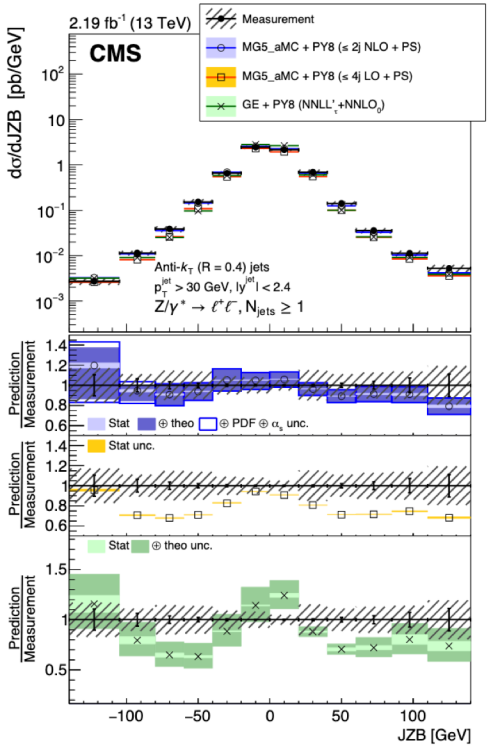
$JZB = |\sum_{jets} \vec{p}_T(j_i)| - |\vec{p}_T(Z)|$

Sensitive to:

→ radiation in the central region, not clustered in a jet

→ hadronic activity outside the jet acceptance





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Z+ 1jet; p_T^{bal} and JZB

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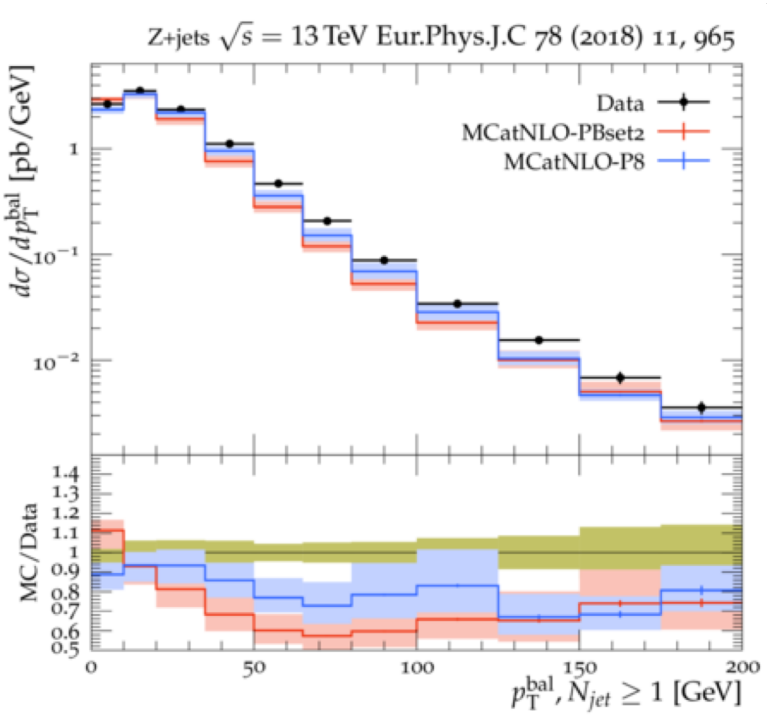
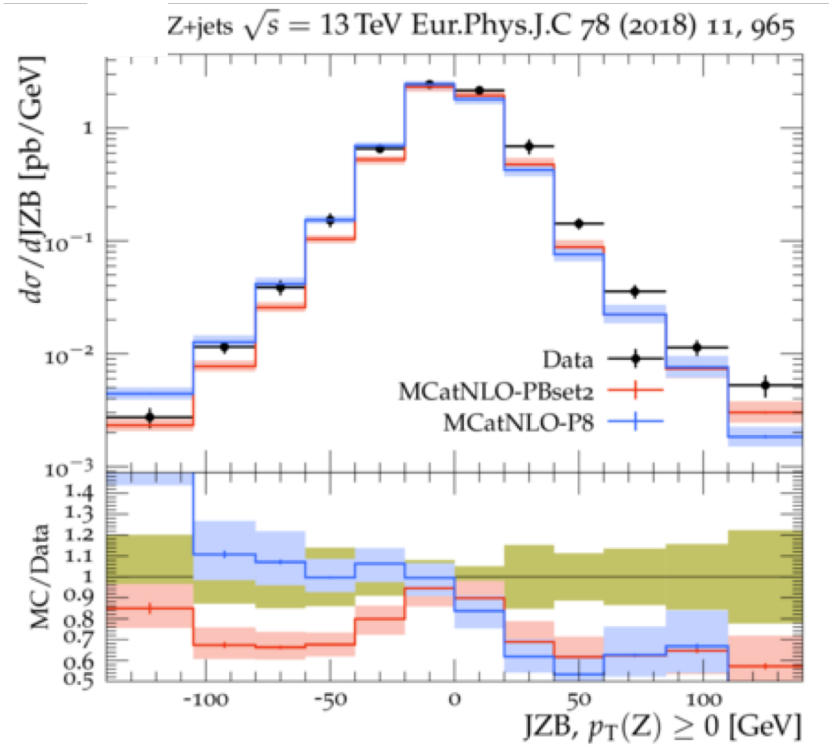




Eur. Phys. J. C 78 (2018) 965

Z+1j @NLO + PB TMD

Summary

→ Presented several measurements of Z+ j final state including Z+HF

→ Compared with PB-TMD predictions from Cascade + Madgraph5_amc@NLO

→ Overall good description, better description of Z+b, Z+c cases

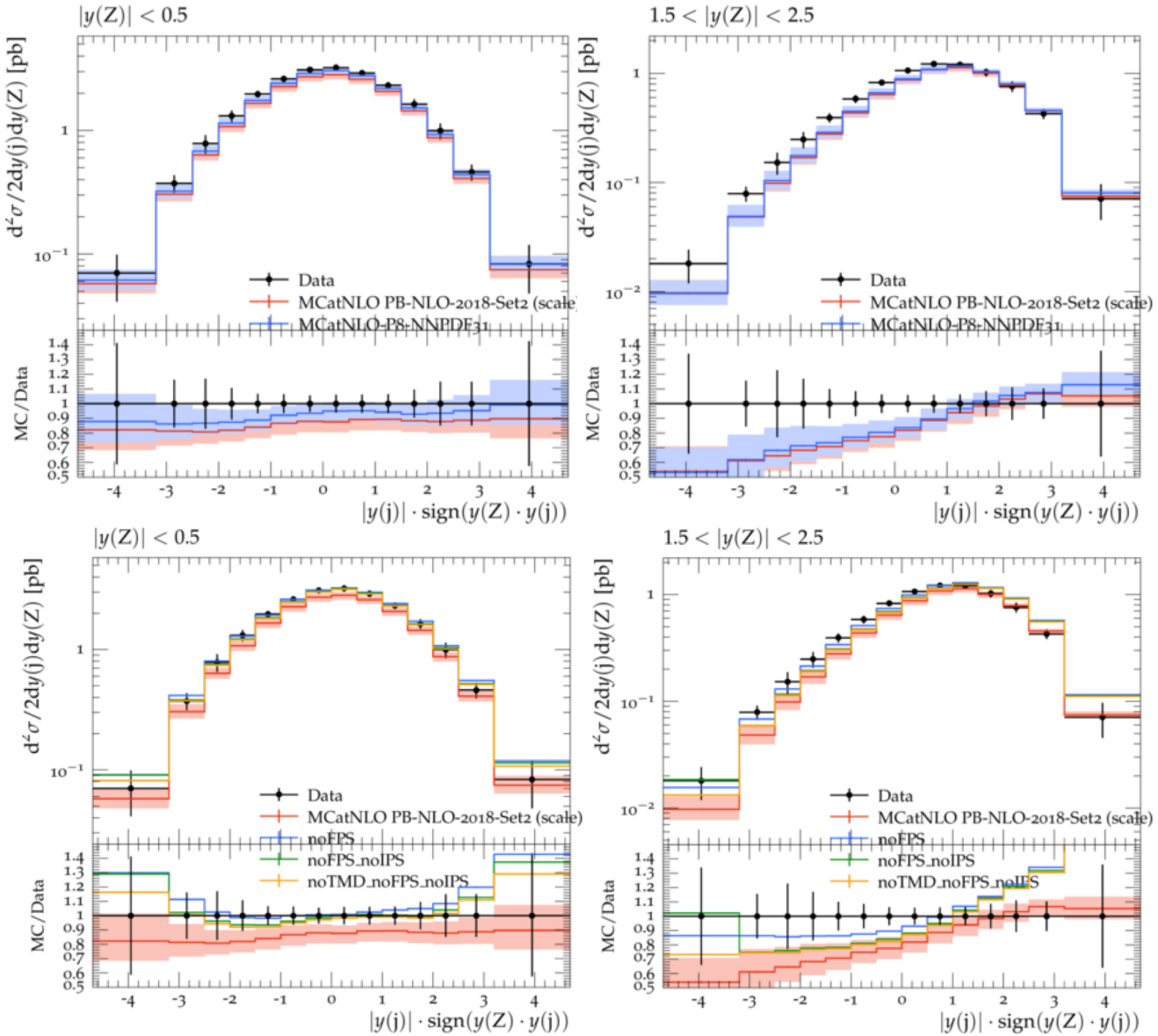
→ Low Δϕ not described well for Z+light jet case

→ Important to include higher orders in ME to fill the missing piece

Thank you

Z +j @8 TeV

p-p √s=8 TeV
19.8 fb^{-1}



(JHEP 04 (2017) 022)

Drell-Yan Measurements

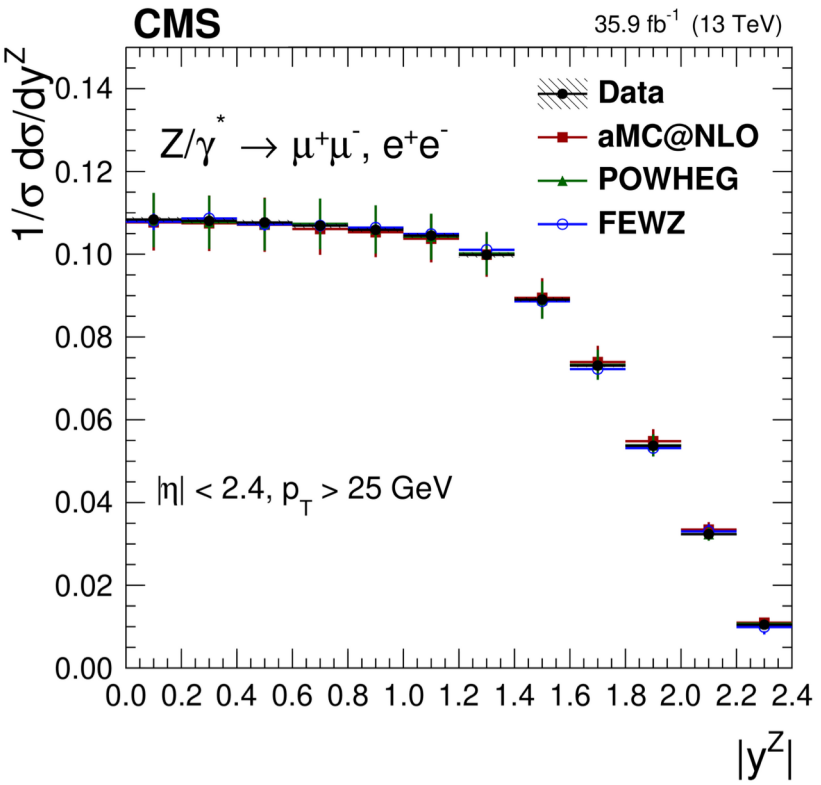
JHEP 12 (2019) 061

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)



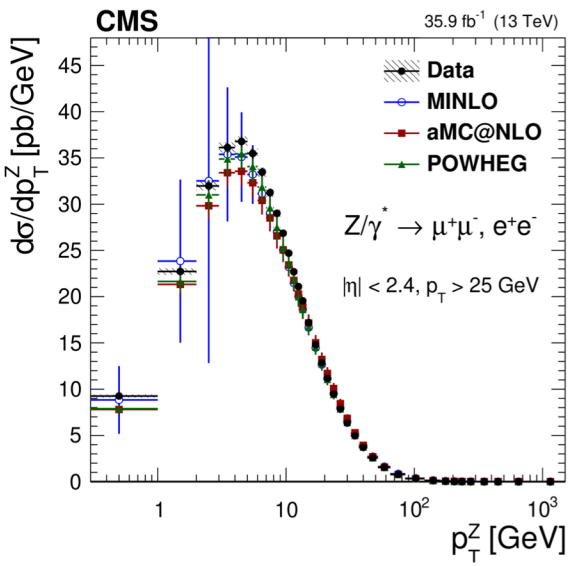
Final state	Data	$Z \rightarrow \ell\ell$	Resonant background	Nonresonant background
$\mu\mu$	20.4×10^6	20.7×10^6	30×10^3	41×10^3
ee	12.1×10^6	12.0×10^6	19×10^3	26×10^3

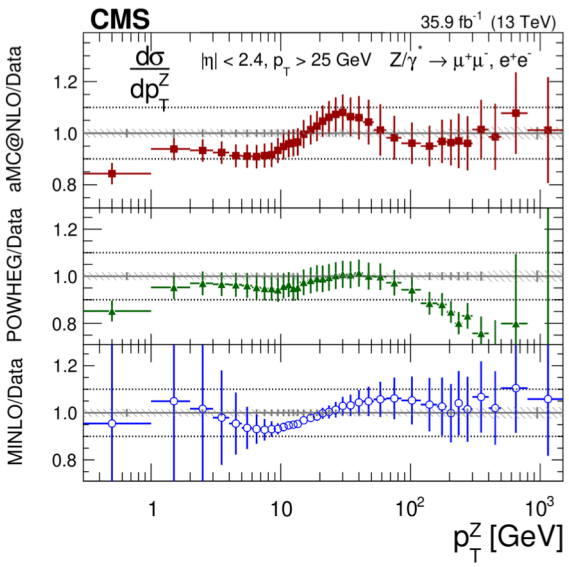
Cross section	$\sigma\mathcal{B}$ [pb]					
$\sigma_{Z\rightarrow\mu\mu}$	694	$\pm$	6	(syst)	$\pm$ 17	(lumi)
$\sigma_{Z\rightarrow ee}$	712	$\pm$	10	(syst)	$\pm$ 18	(lumi)
$\sigma_{Z\rightarrow\ell\ell}$	699	$\pm$	5	(syst)	$\pm$ 17	(lumi)

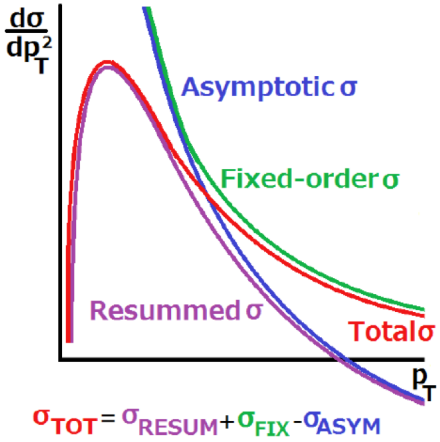
Differential Z p_T

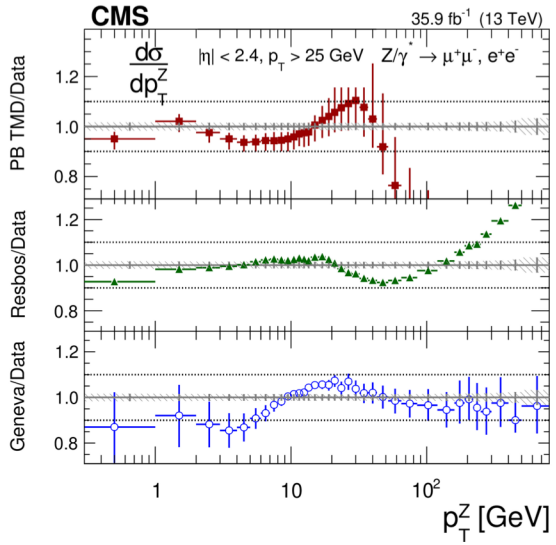
JHEP 12 (2019) 061

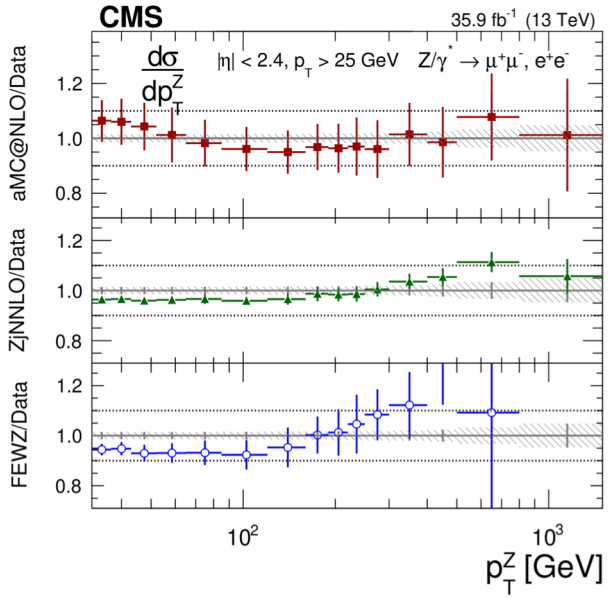
35.9 fb^{-1}











→ Data compared with several models
- → MG5_amc@NLO+PY 8 (Z +0,1,2 j @NLO +PS)
- → ResBos, Geneva
- → Powheg-MINLO
- → PB TMD
- → Z+1 jet at NNLO
- → FEWZ

Differential ϕ^*

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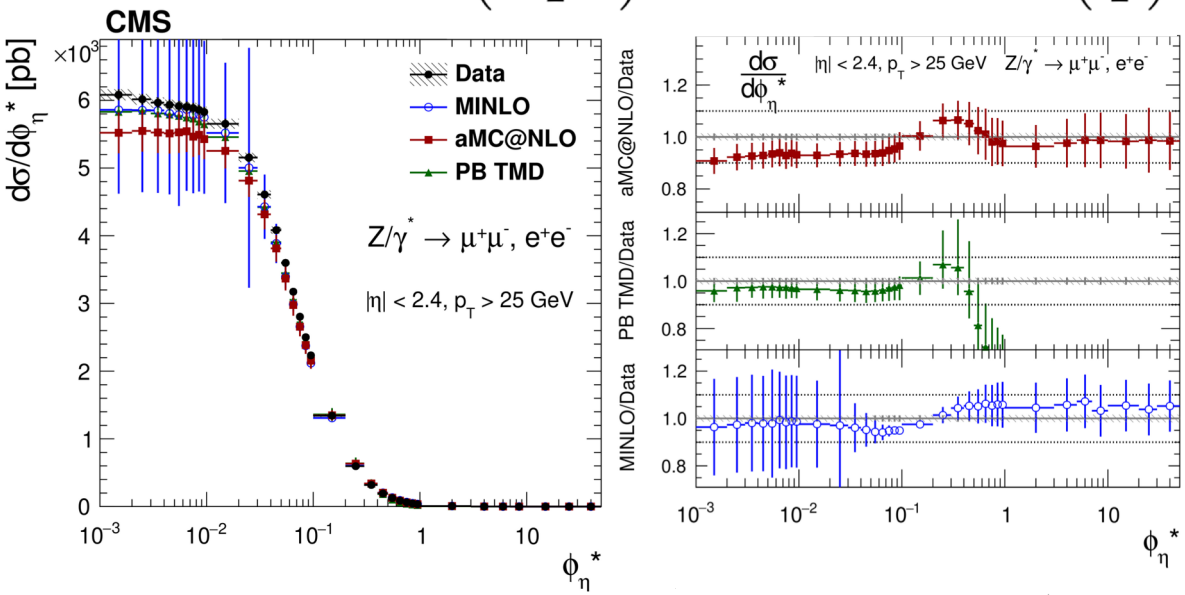
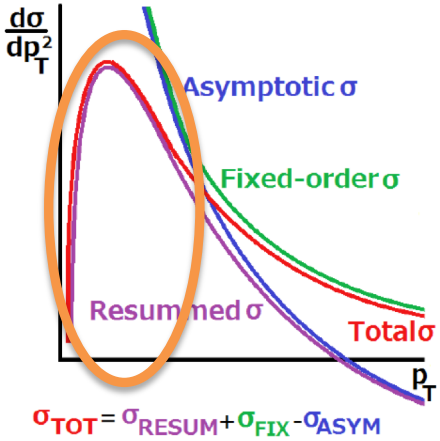
35.9 fb^{-1}

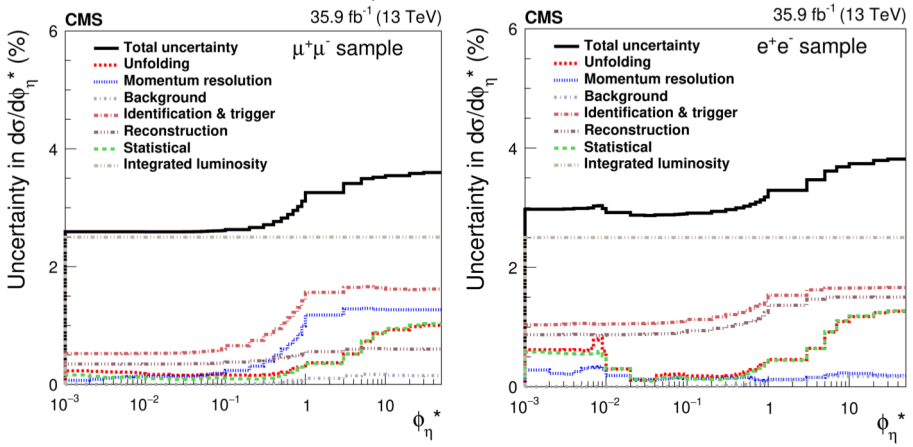
→ Angular variable strongly correlated to p_T
→ Allows studying low pT in more detail

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





→ Data compared with several models
  → MG5_amc@NLO+PY8 (Z +0,1,2 j @NLO +PS)
  → Powheg-MINLO
  → PB TMD



Breakdown of systematics in ee and μμ channels