Differential W/Z distributions: p_T/phi* , boosted W/Z, generator tuning.

Mykhailo Lisovyi (DESY)

on behalf of the ATLAS & CMS collaborations

SM@LHC 2014, Madrid

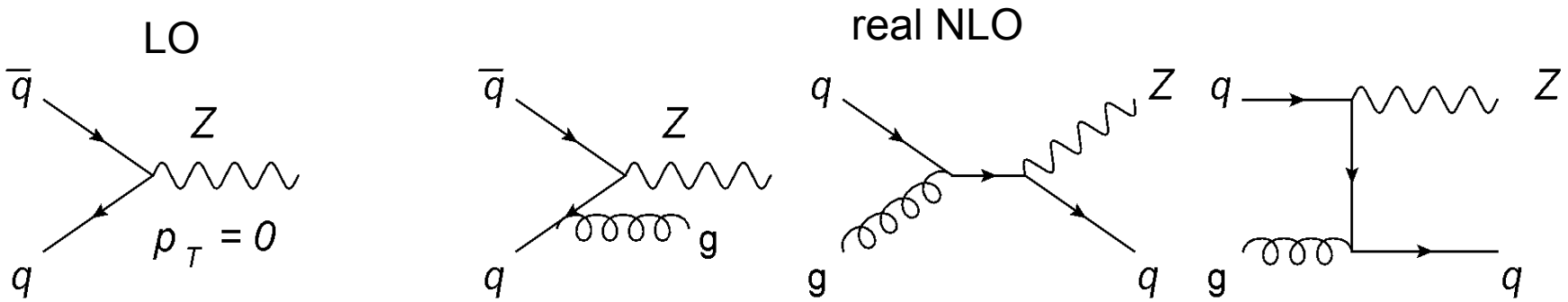
9/04/2014

HELMHOLTZ GEMEINSCHAFT

DESY

Z/W production with $p_T \neq 0$ at LHC.

- $Z \rightarrow l^+l^-$ and $W^+ \rightarrow l^+\nu$ provide clean signatures to study recoil down to low p_T.
- High-p_T Z production in the hadronic decay mode ($Z \rightarrow b\bar{b}$) provides valuable validation of reconstruction and predictions in environment similar to $H \rightarrow b\bar{b}$ and exotics searches.
- Vector-boson production at non-zero p_T due to quark/gluon radiation from the initial-state partons



* V+jets in Gabriele's talk earlier today

DESY

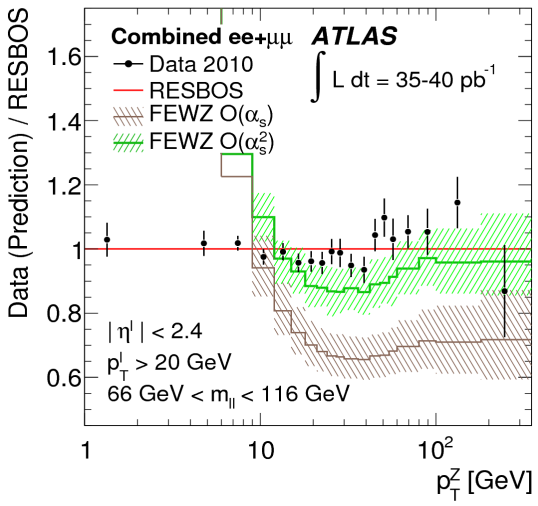
Z/W production with $p_T \neq 0$ at LHC.

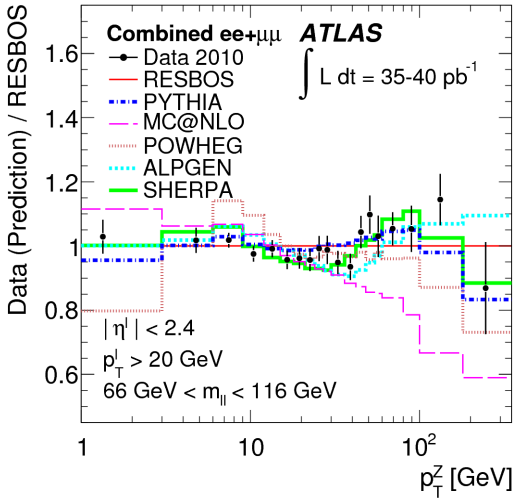
- $p_T(Z)$: essential testing ground for QCD
  - low p_T (multiple soft-gluon radiation): resummation up to NNLL (RESBOS), parton shower (PS) techniques(PYTHIA, HERWIG), ME+PS with ME $O(\alpha_s)$ (MC@NLO, POWHEG);
  - high p_T (hard-gluon emission): fixed-order calculations up to $O(\alpha_s^2)$ (FEWZ, DYNNLO; V+jet @NLO: MCFM, Blackhat+Sherpa), multi-leg tree-level ME+PS(SHERPA, ALPGEN).
- boosted (very high pT) $Z \rightarrow b\bar{b}$: New result
  - NLO ME+PS with ME $O(\alpha_s^2)$ (aMC@NLO, POWHEG);
  - benchmark for searches of hadronic decays of boosted objects: detector performance, tests and optimisation of analysis tools

DESY

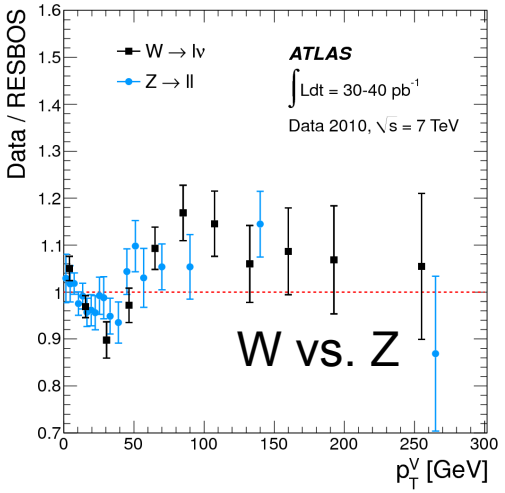
Earlier Z/W p_T results @ 7 TeV.

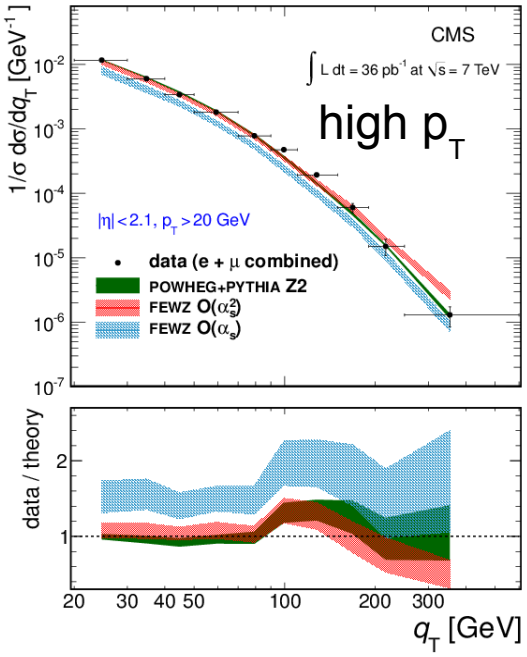
Phys.Lett. B705 (2011) 415

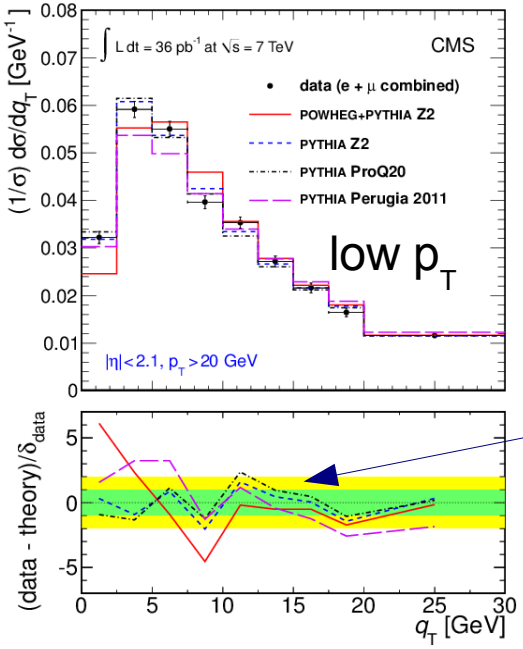




Phys.Rev. D85 (2012) 012005







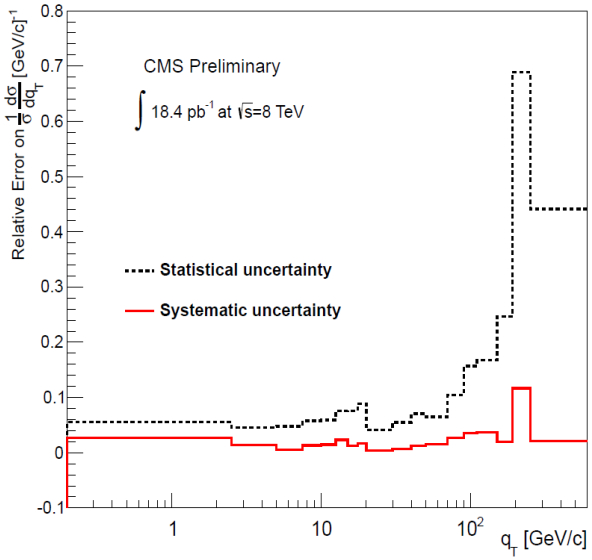
Phys.Rev. D85 (2012) 032002

- High p_T: good agreement with FEWZ, RESBOS
- Low p_T: overall good agreement with RESBOS, PYTHIA, ALPGEN, SHERPA. Sensitivity to PS tune.
- Data/RESBOS ratio for W and Z: similar features

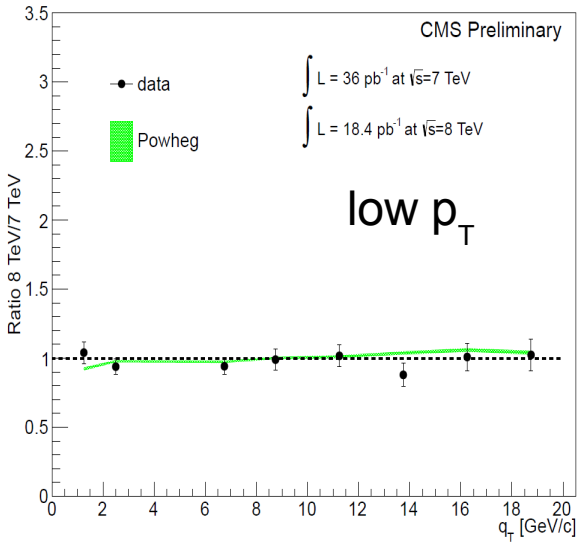
DESY

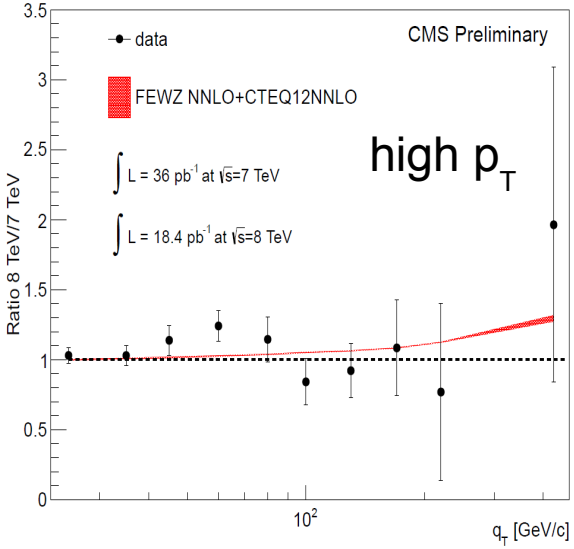
Z p_T results @ 8 TeV.

CMS-PAS-SMP-12-025



- Special run with low pile-up in 2012: 18.4 pb^{-1}
- μμ channel: ~7000 di-muon events
- Systematics is small compared to statistical uncertainty
- Good agreement of 8TeV/7TeV ratio between data and predictions

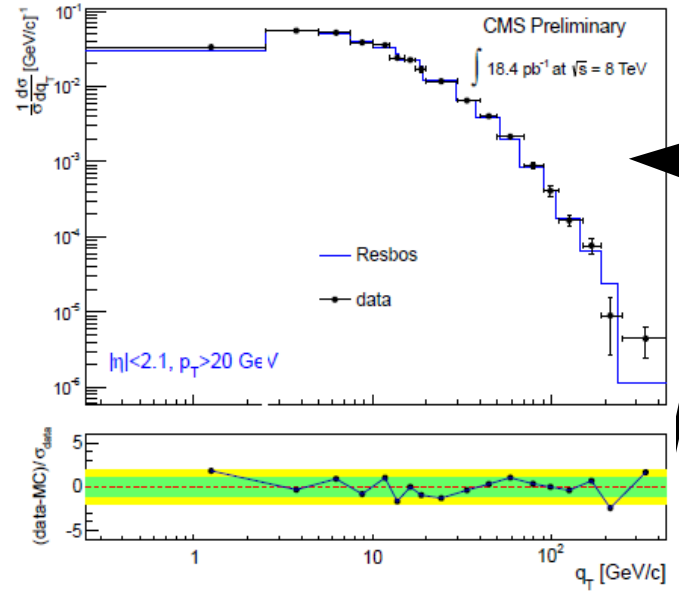


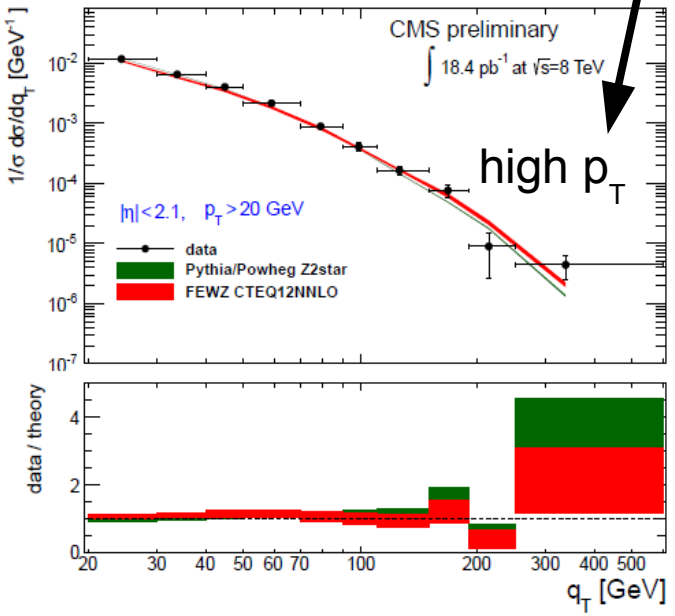


DESY

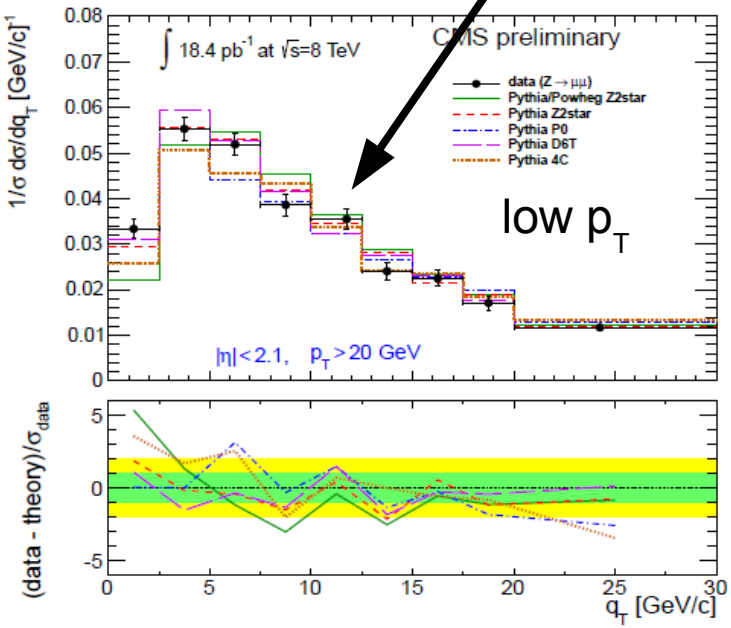
Z p_T results @ 8 TeV.

CMS-PAS-SMP-12-025





- High p_T: good description by RESBOS and MADGRAPH (less good by POWHEG) as well as by FEWZ (but low stat. for p_T> 100 GeV).
- Low p_T: sensitivity to the PS tune. Best description by PYTHIA Z2star; POWHEG+PYTHIA Z2star provide only marginal description of the low-p_T data



Z ϕ^* results @ 7 TeV.

Phys.Lett. B720 (2013) 32

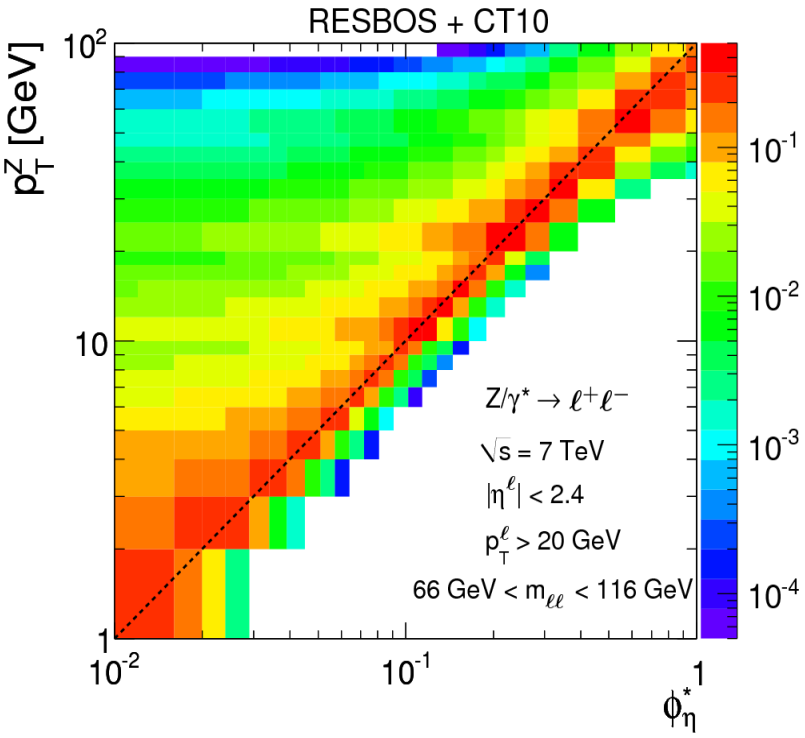
> Measurements at low $p_T(Z)$ are limited by experimental resolution and uncertainties on $p_T(l)$ scale. Use new observable ϕ^*_η:

$$\phi^*_\eta = \tan(\phi_{acop}/2) \times \sin(\theta^*_\eta)$$

$$\phi_{acop} = \pi - \Delta\phi(\ell,\ell)$$

$$\cos(\theta^*_\eta) = \tanh[(\eta^- - \eta^+)/2]$$

Measure of the scattering angle of the leptons wrt the beam axis in the Z rest frame



> ϕ^*_η depends exclusively on angular measurements of the leptons. In ATLAS the angular resolution is ~0.5 mrad on ϕ and ~0.001 on η

> ϕ^*_η is correlated to $p_T(Z)/M$

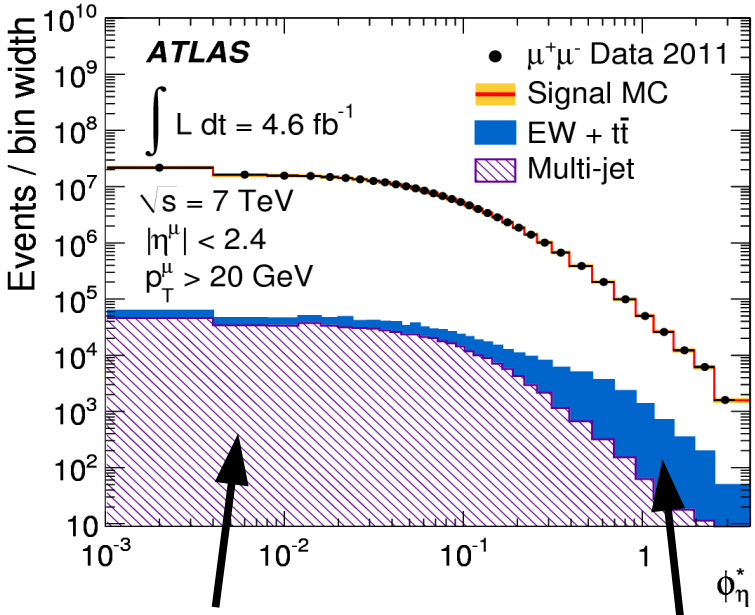
> ϕ^*_η probes the same physics as p_T

DESY

Z ϕ^* results @ 7 TeV.

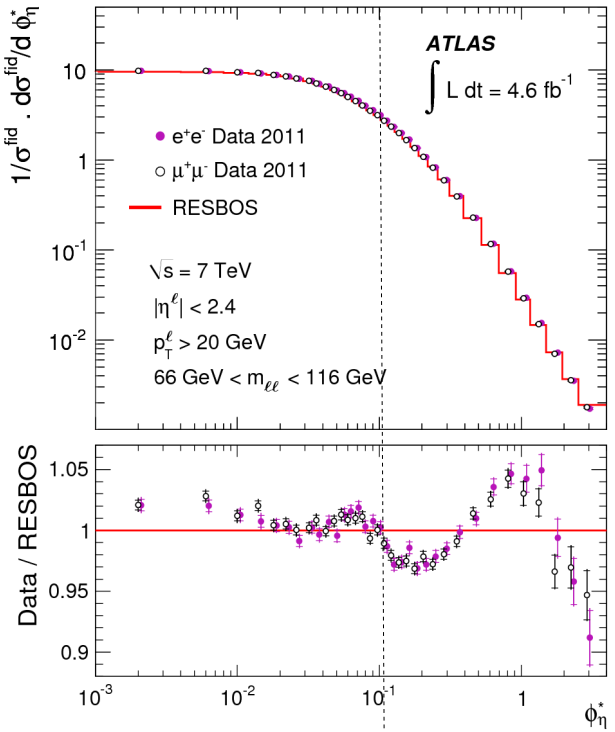
Phys.Lett. B720 (2013) 32

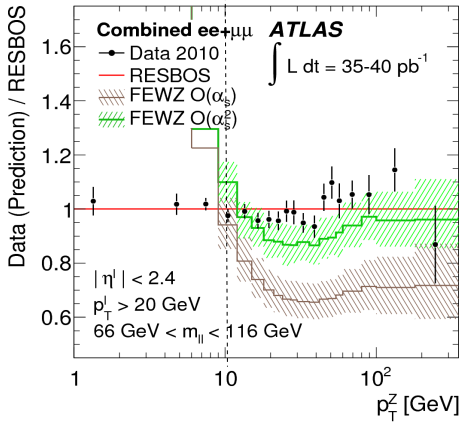
- 2011 data: 4.6 pb^{-1}
- ~1.2*10^6 ee and ~1.7*10^6 μμ events
- ee and μμ channels were combined: χ^2/ndf = 33.2/34
- Improved resolution: more points at low ϕ^*



Low ϕ^*_η : multi-jet background dominates (estimated from data)

High ϕ^*_η : top background dominates



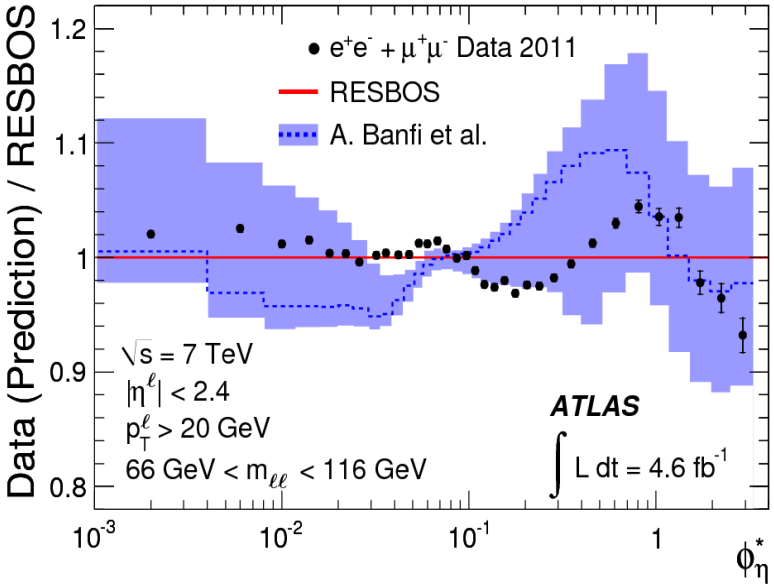


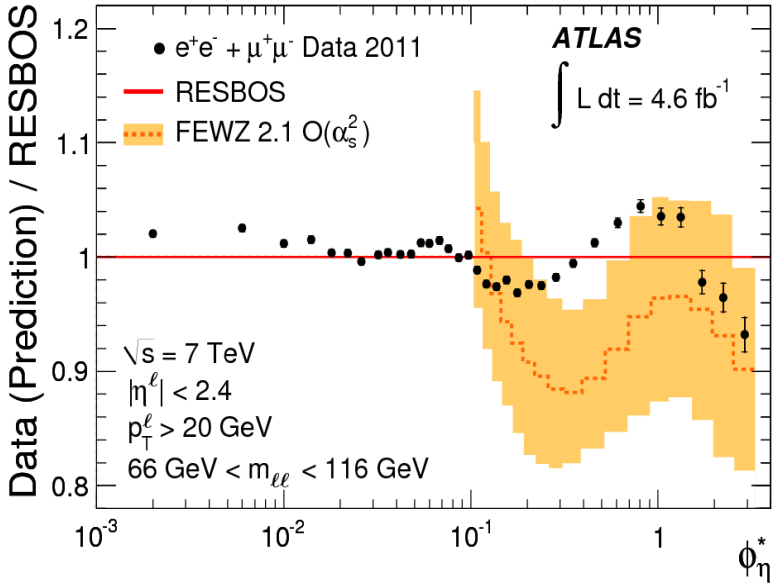
ϕ^*_η<0.1 is ~ p_T<10 GeV

Z ϕ^* results @ 7 TeV.

Phys.Lett. B720 (2013) 32

- RESBOS provides a good description of the data within 5%, which is similar to the PDF uncertainty (4% for ϕ^*_η<0.1 and 6% otherwise)
- NNLL+NLO calculation by Banfi et al. describes the data reasonably well within theoretical uncertainties.
- FEWZ undershoots the data by ~10%



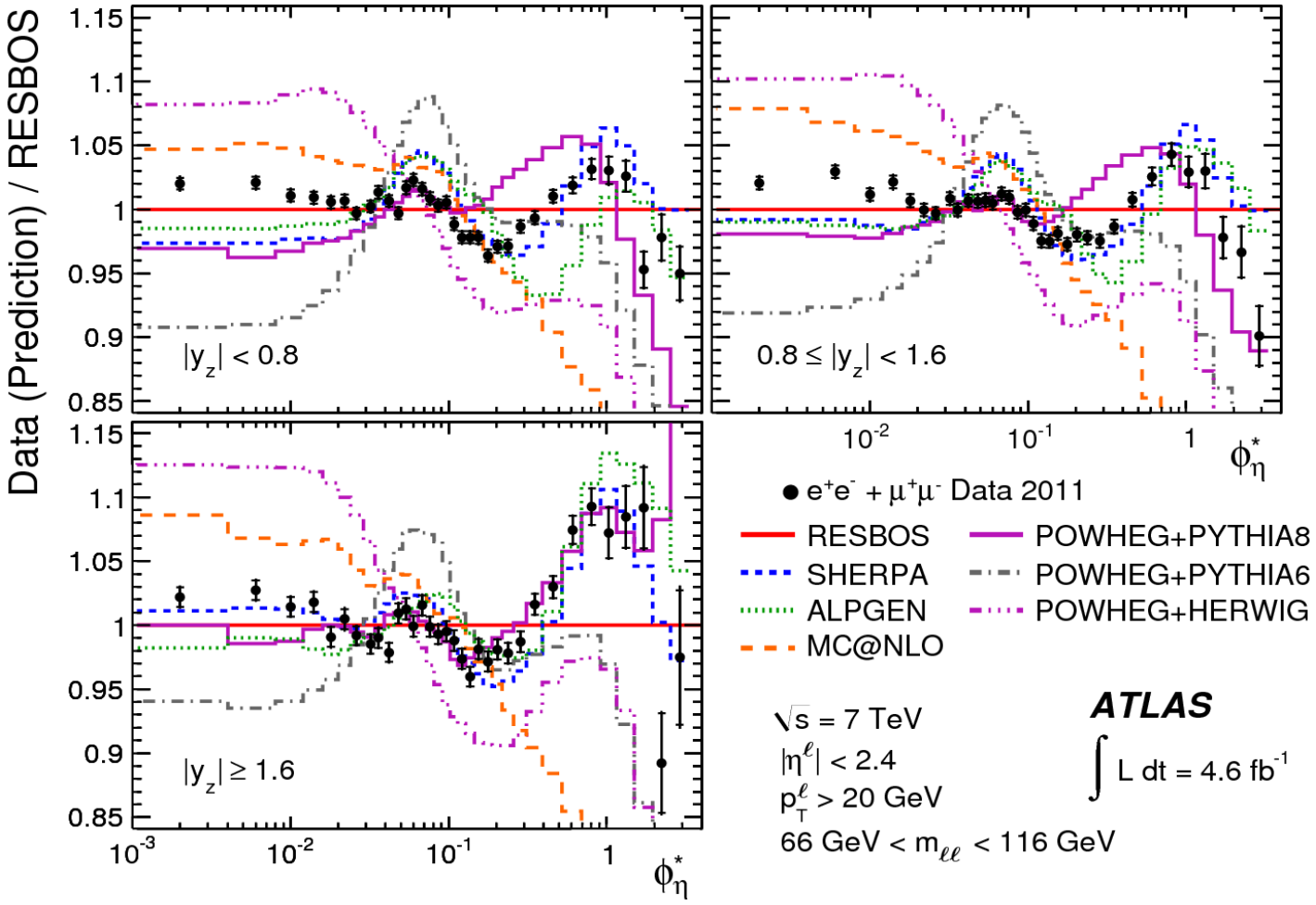


DESY

Z ϕ^* results @ 7 TeV.

Phys.Lett. B720 (2013) 32

Double-differential as a function of ϕ^*_η in 3 bins of Z rapidity



SHERPA and ALPGEN provide a good description

POWHEG+PYTHIA8 describe the data better than POWHEG+PYTHIA6 and POWHEG+HERWIG

MC@NLO doesn't describe the ϕ^*_η>0.1 region

MC tuning!

DESY

Tunes to observables sensitive to $p_T(Z)$.

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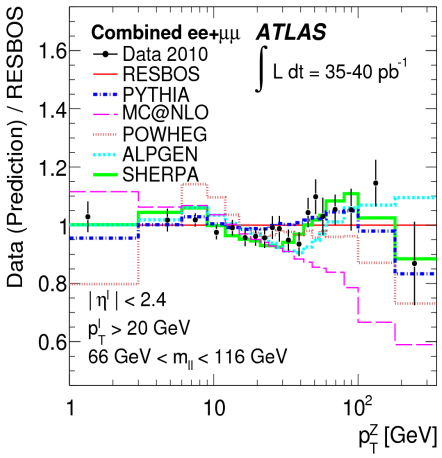

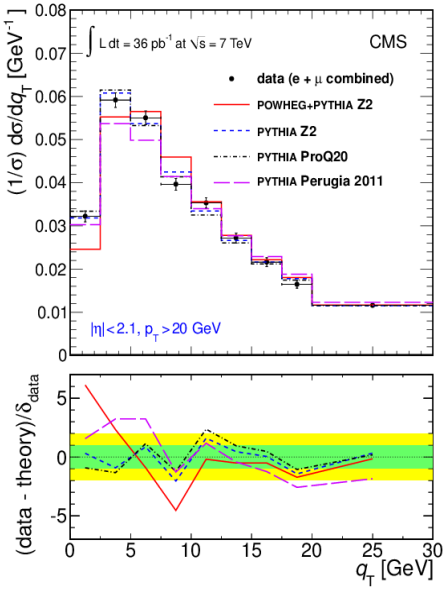

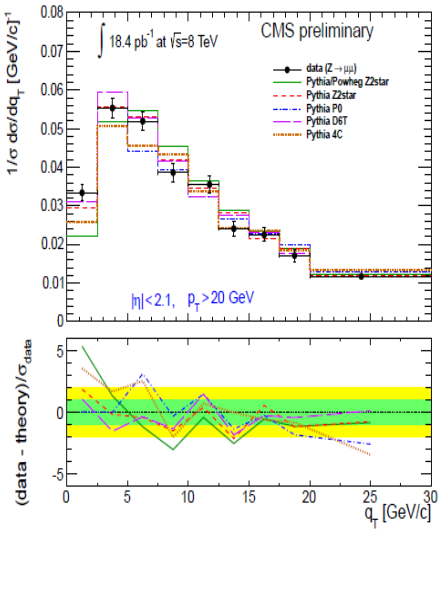

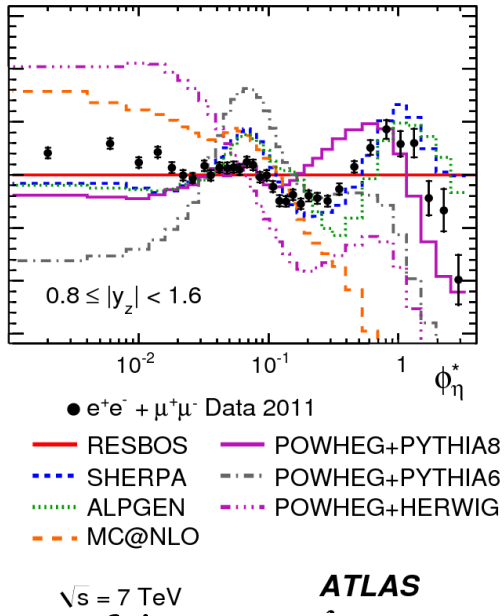

> New tunes to improve the Monte Carlo (MC) description of kinematics of vector boson production:

- improved modeling of low-p_T vector boson => reliable acceptance of p_T(l) cuts in W/Z measurements;
- crucial for W mass measurement (and W/Z, DY for constraining PDFs).

> MC generators studied:

PYTHIA8, POWHEG+PYTHIA8, PYTHIA6, POWHEG+PYTHIA6.

DESY

Tunes to observables sensitive to $p_T(Z)$.

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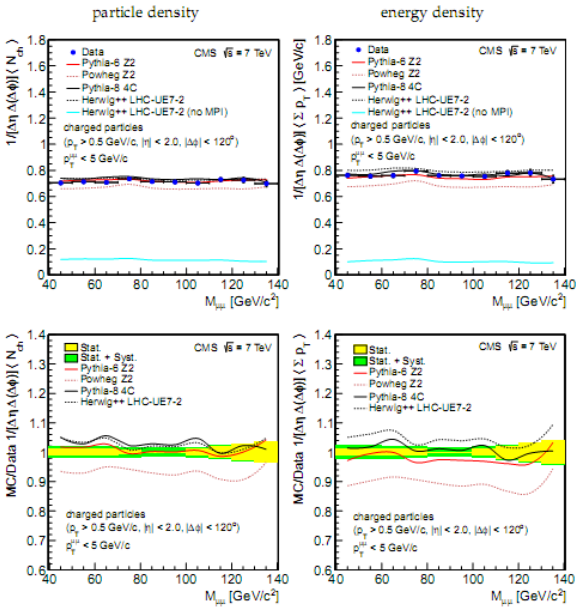
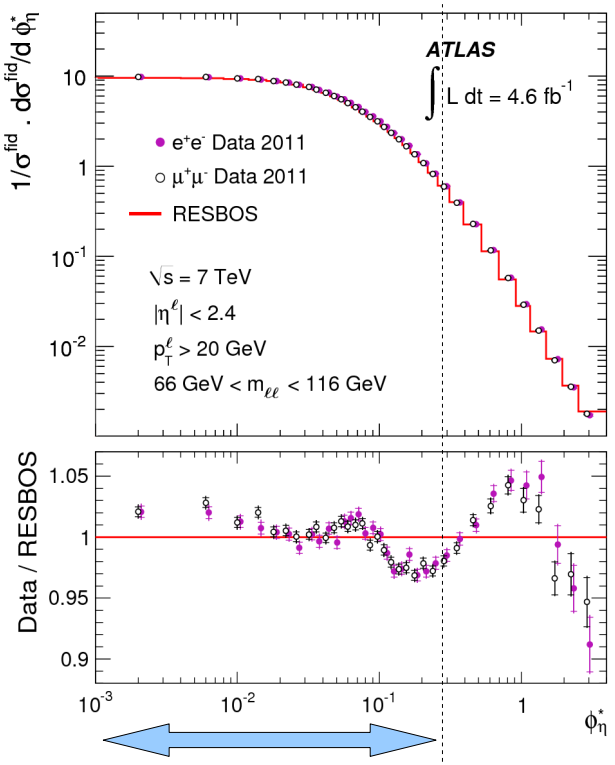
- Tune to Z ϕ^*_η data ($\phi^*_\eta \leq 0.29$) using Professor. Re-tune the MPI cut-off to the Z UE data from CMS (EPJ C72 (2012) 2080) to restore the description of the overall energy and particle flow.
- The tunes were validated against a variety of related observables from Tevatron and LHC.





- $\phi^*_\eta \leq 0.29$

DESY

MC tunes: MC parameters.

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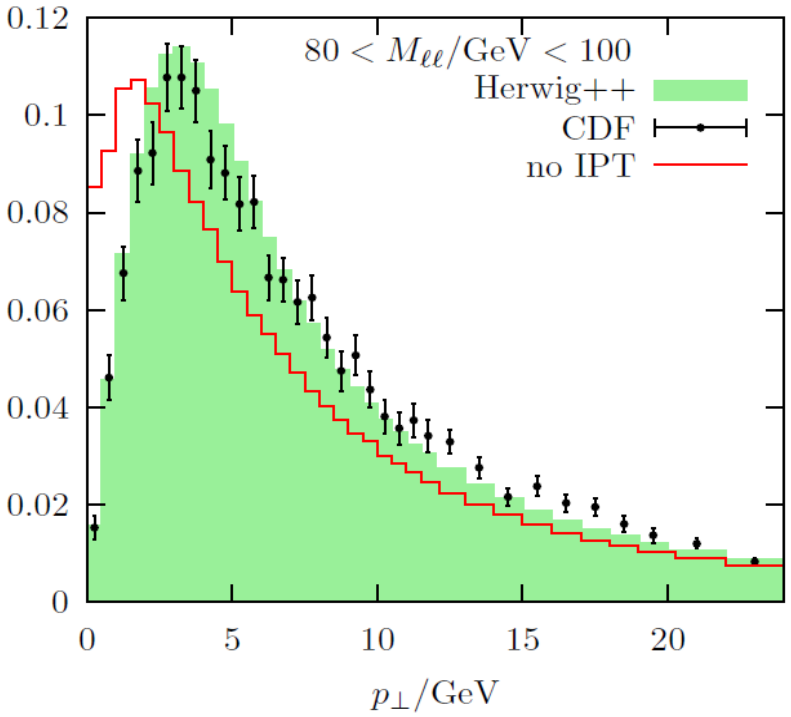
- Initial-state radiation (ISR) shower and ME:
  - ISR cut-off
  - NLO ME real radiation cut-off
  - ISR α_s scale factor on evolution scale
  - ISR $\alpha_s(M_Z)$
- Proton remnants:
  - Intrinsic (primordial) k_T of partons
- Multi-parton interactions (MPI):
  - MPI cut-off

Effect on $p_T(Z)$ of switching off intrinsic k_T in HERWIG++



JHEP 0806 (2012) 001

DESY

MC tunes: PYTHIA8 results.

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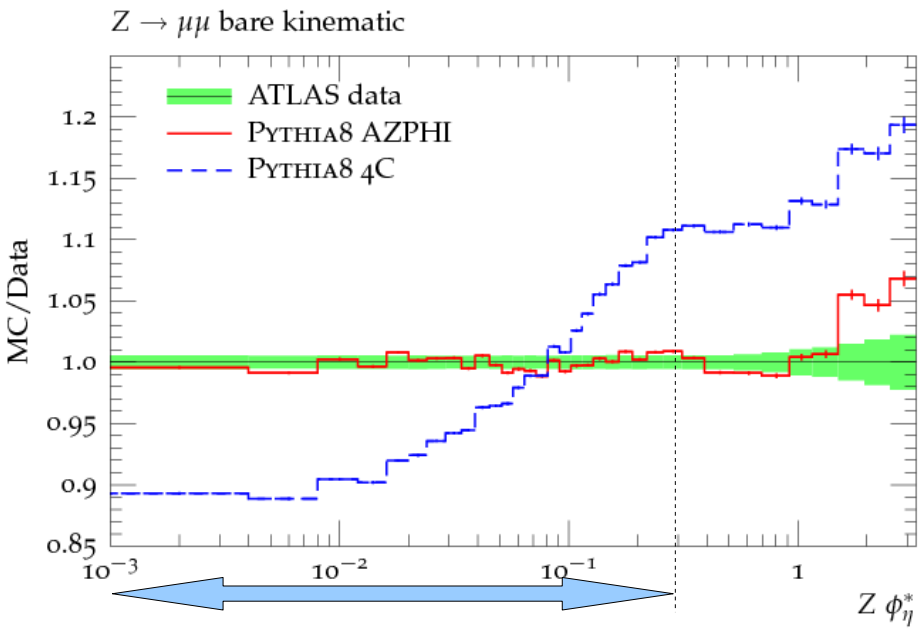

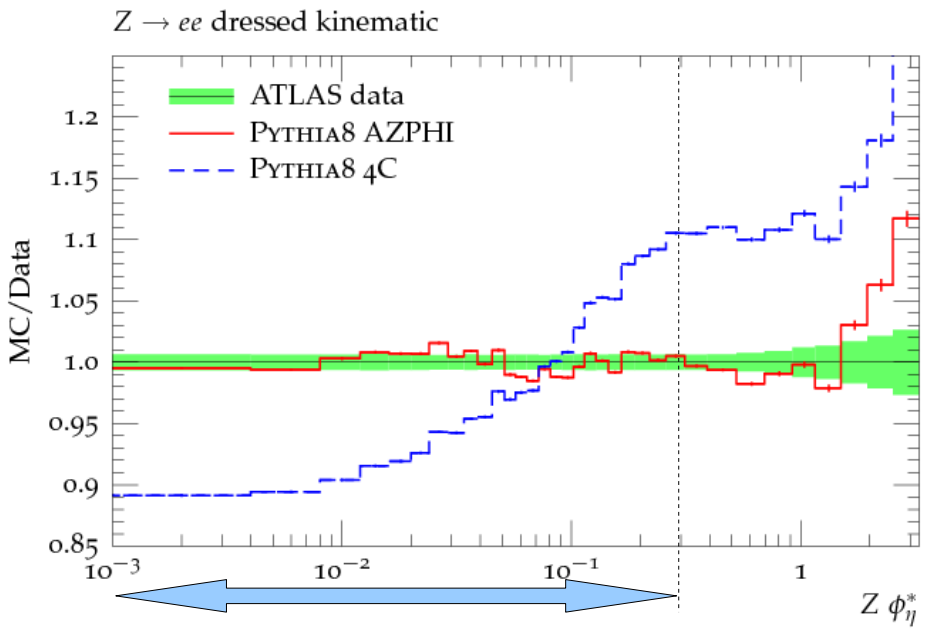

Parameter	Pythia8 setting	Variation range	AZPHI	4C
Primordial kt	BeamRemnants:primordialKThard	1.0 – 2.5	1.73	2.0
ISR $\alpha_s(M_Z)$	SpaceShower:alphaSvalue	0.120 – 0.140	0.124	0.137
ISR cut-off	SpaceShower:pT0Ref	0.5 – 2.5	0.63	2.0
MPI cut-off	MultipartonInteractions:pT0Ref	1.5 – 2.5	2.22	2.085

DESY

MC tunes: PYTHIA8 comparison with other data.

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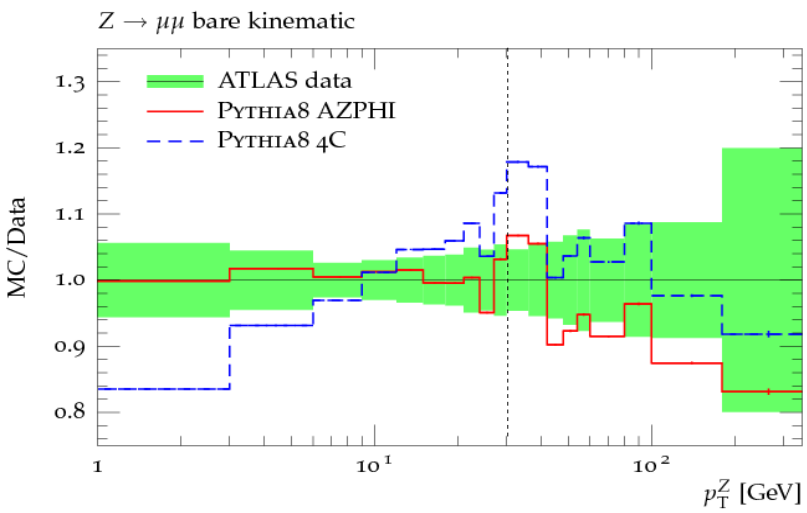
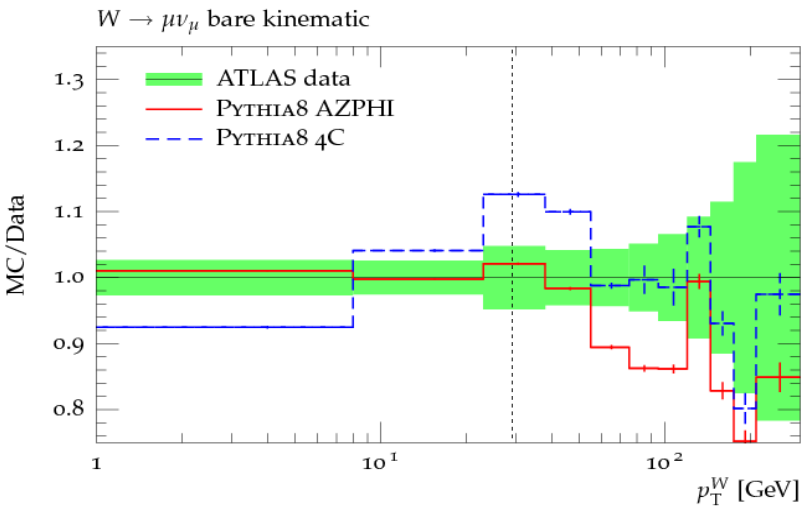
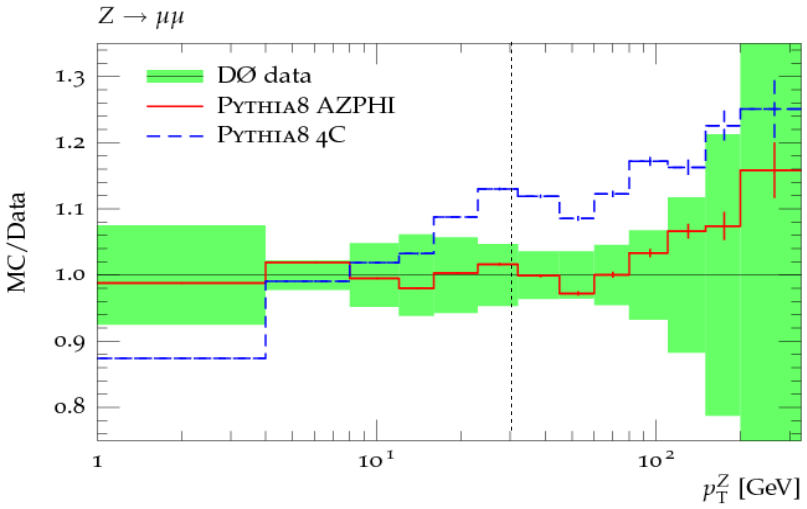
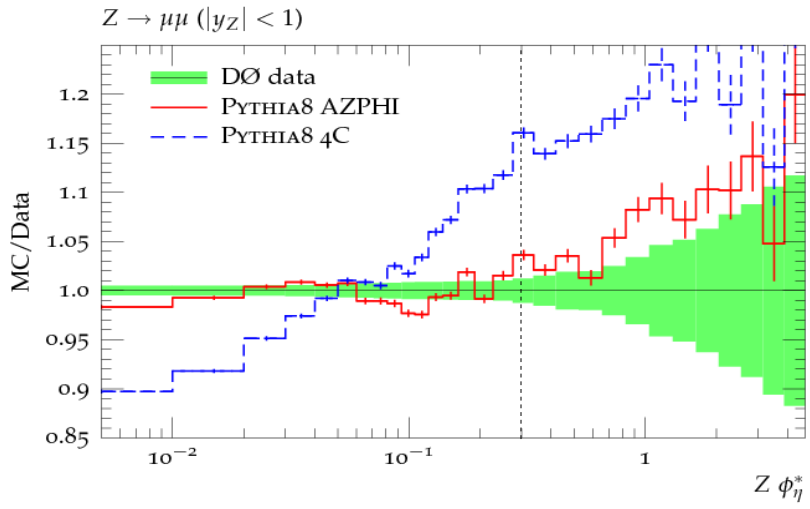








Validation of the PYTHIA8 tune against other p_T-sensitive data

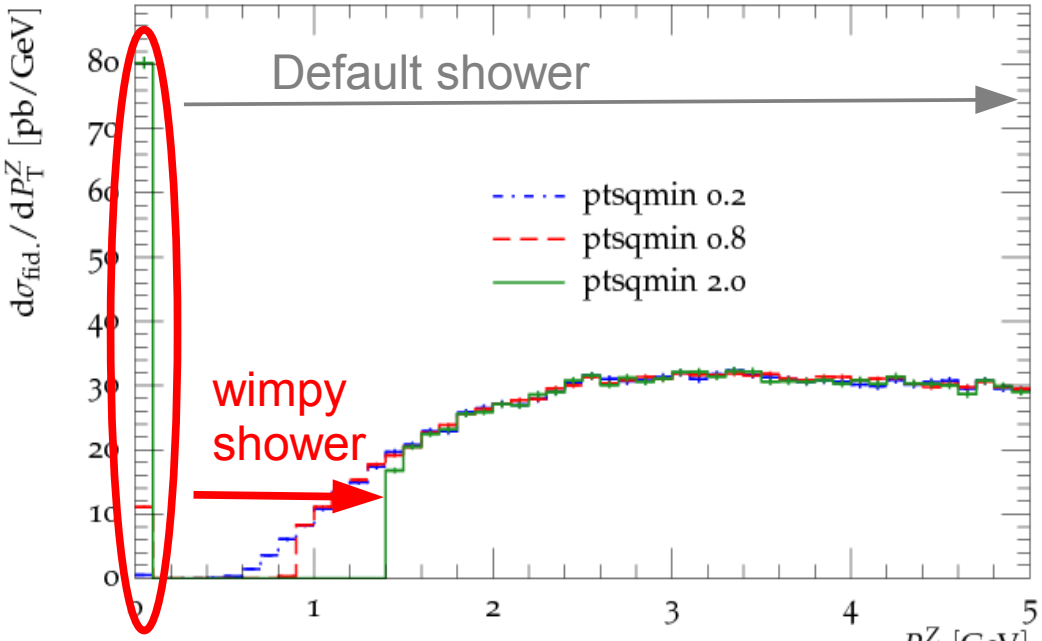
Clear improvement

DESY

ME+PS matching in POWHEG+PYTHIA8

ATLAS-PHYS-PUB-2013-017

- Essential to understand interplay between POWHEG NLO ME and PYTHIA PS:
  - POWHEG generates Z production including the first emission of QCD radiation;
  - the cut-off for the minimum pT of the first emission in POWHEG (ptsqmin) is used as the limit for the shower- "wimpy" shower mode.



Events generated by POWHEG

Z+0 jets (p_T=0 GeV) are showered to populate the phase space only up to the cut-off (passed as a SCALUP=$\sqrt{\text{ptsqmin}}$ variable in Les Houches file)

DESY

MC tunes: POWHEG+PYTHIA8 results.

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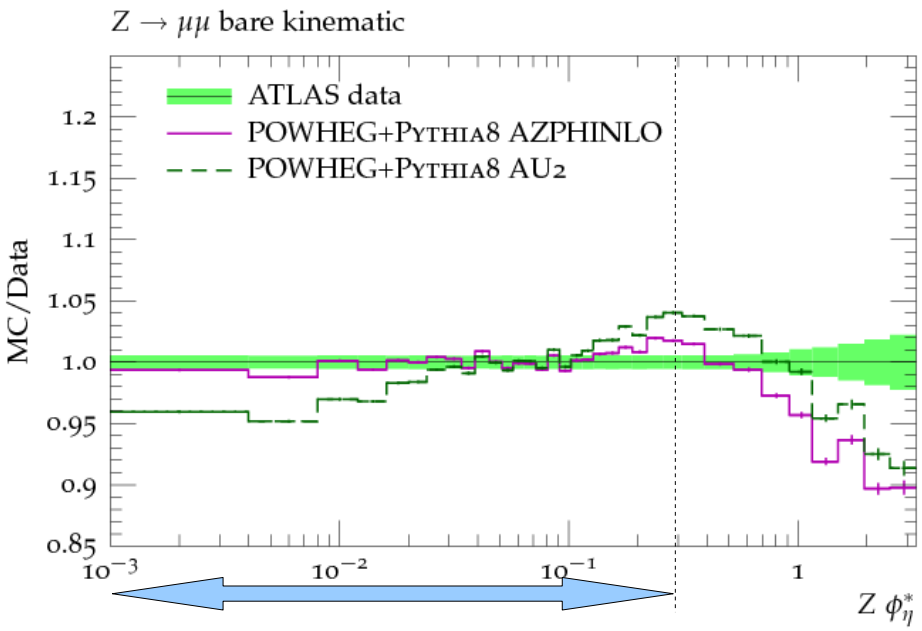
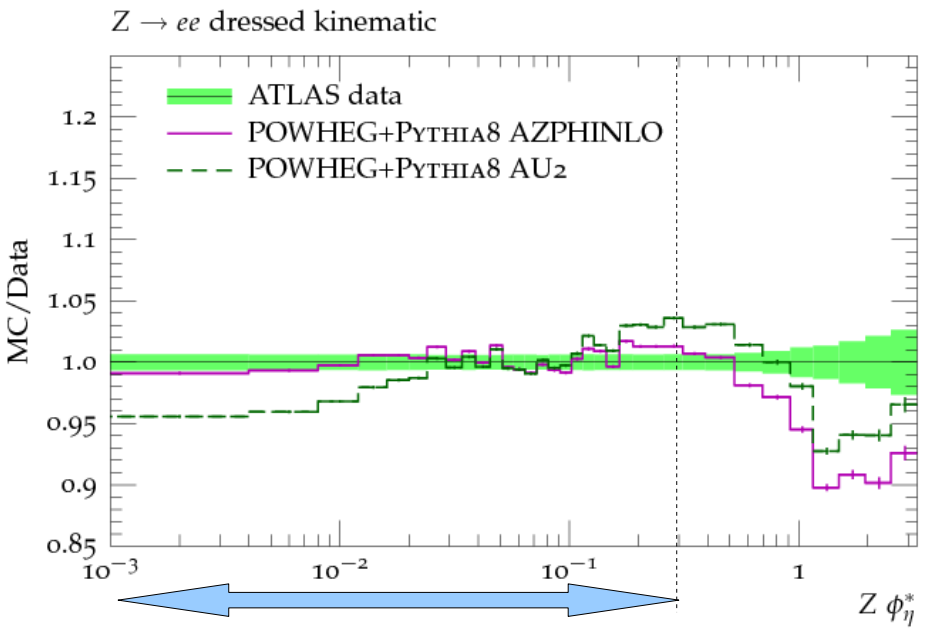
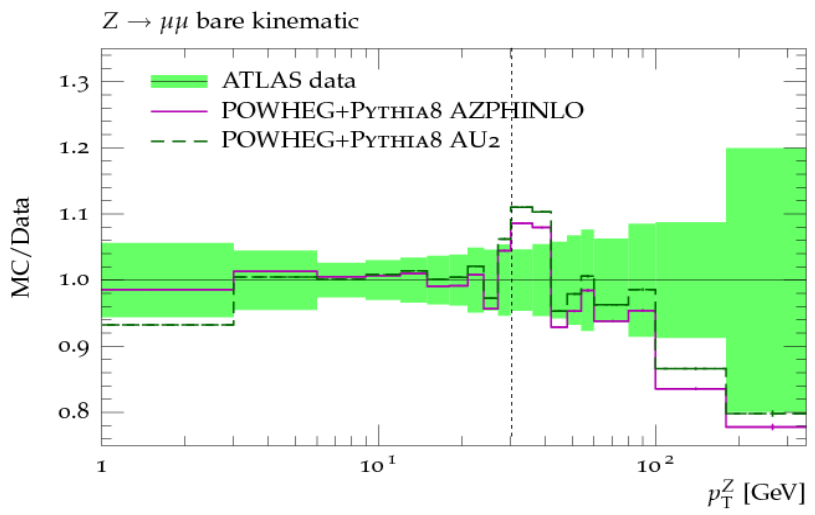


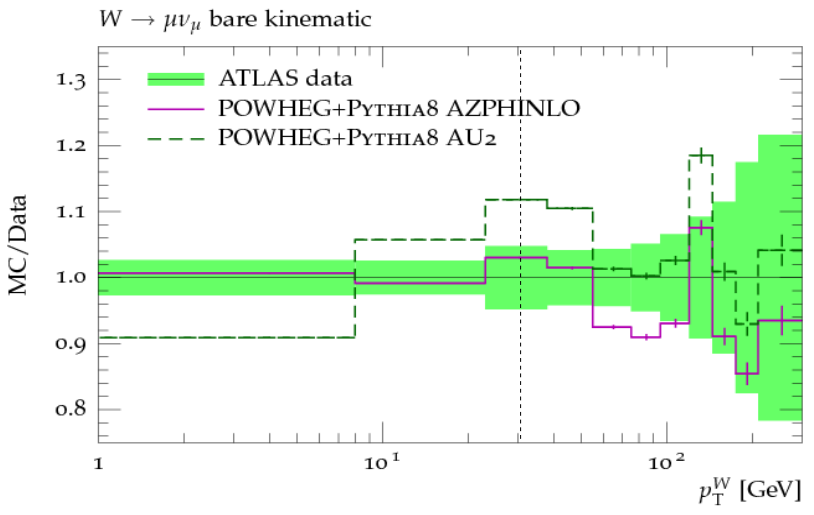


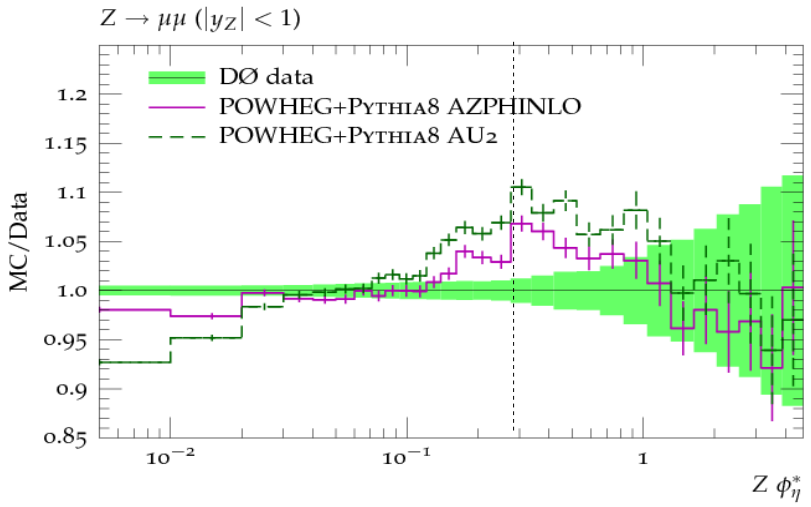
Parameter	PYTHIA8 setting	Variation range	AZPHINLO	AU2-CT10
Primordial kt	BeamRemnants:primordialKThard	1.0 – 2.5	1.74	2.0
ISR cut-off	SpaceShower:pT0Ref	0.5 – 2.5	1.91	2.0
ISR $\alpha_s(M_Z)$	SpaceShower:alphaSvalue	fixed	0.118	0.137
ISR α_s order	SpaceShower:alphaSorder	fixed	2	1
ISR limit	SpaceShower:pTmaxMatch	fixed	1	0
MPI cut-off	MultipartonInteractions:pT0Ref	1.0 – 2.5	1.57	1.70
Parameter	POWHEG setting			
Radiation cut-off	`ptsqmin`	fixed	4	0.8

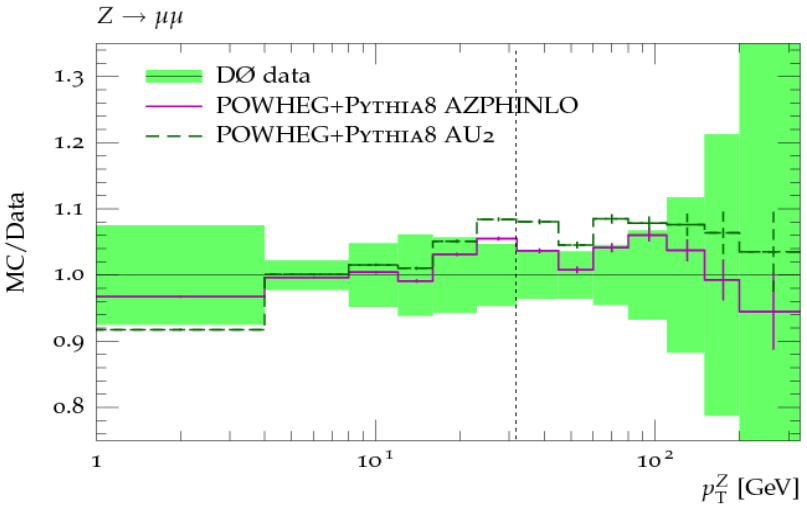
MC tunes: POWHEG+PYTHIA8 comparison with other data.

ATLAS-PHYS-PUB-2013-017









Validation of the POWHEG+PYTHIA8 tune against other p_T-sensitive data.

Clear improvement.

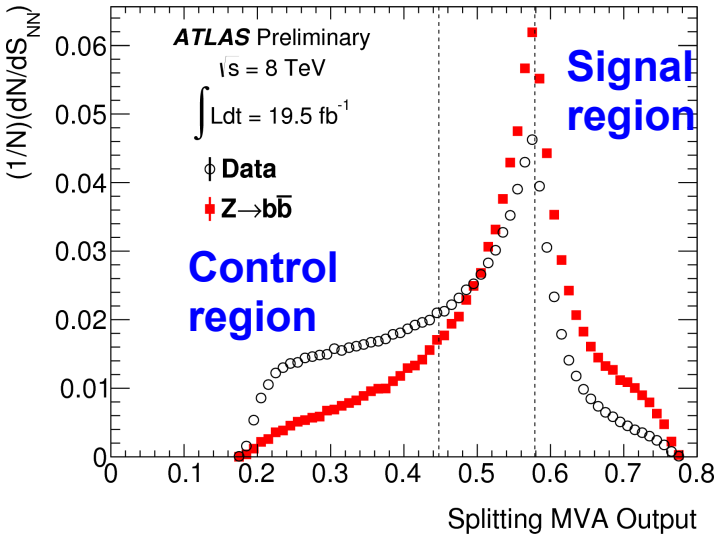
DESY

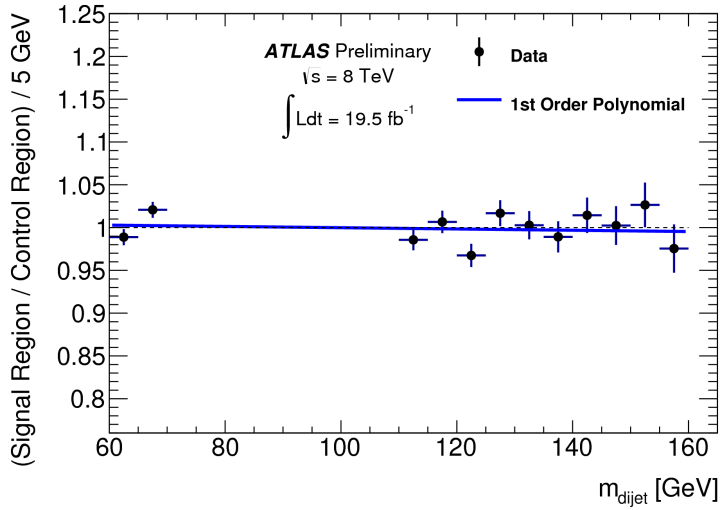
High-p_T $Z \to b\bar{b}$.

Hot press

ATLAS-STDM-2013-04

- An observation of the $Z \to b\bar{b}$ at high p_T in a fully hadronic decay mode
- Phase space: 2 anti-KT b-jets with R=0.4, p_T(jet)>40 GeV, |η(jet)|<2.5, ΔR<1.2, p_T(dijet)>200 GeV, 60 < M(dijet) < 160 GeV.
- Data-driven QCD background model:
  - NN based on Δη(dijet, balancing jet) and |η(dijet)|
  - Separate signal and control regions
  - Inputs are ~ uncorrelated with M(dijet)
  - Use the data in the QCD-background-dominated control region to constrain the background in the signal region





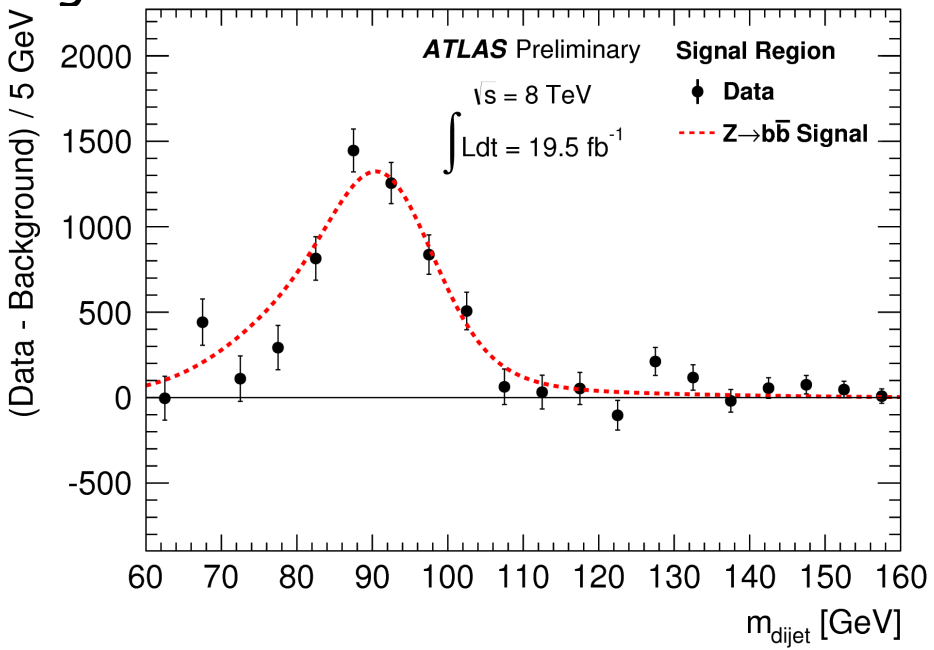
DESY

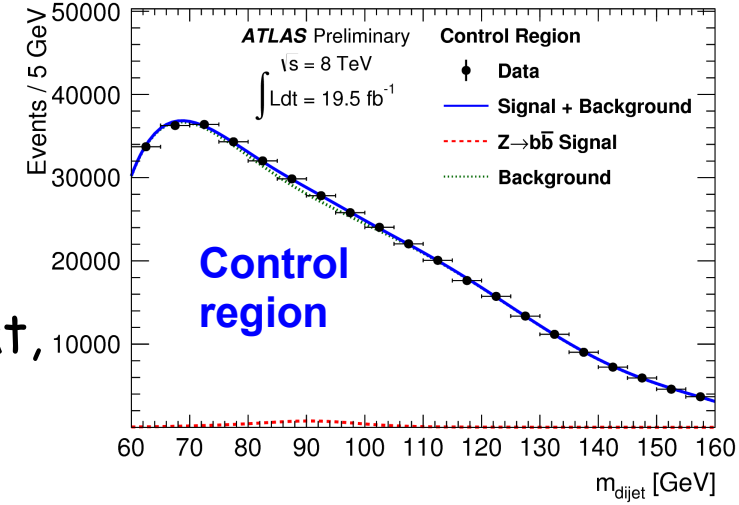
High-p_T $Z \to b\bar{b}$: signal extraction.

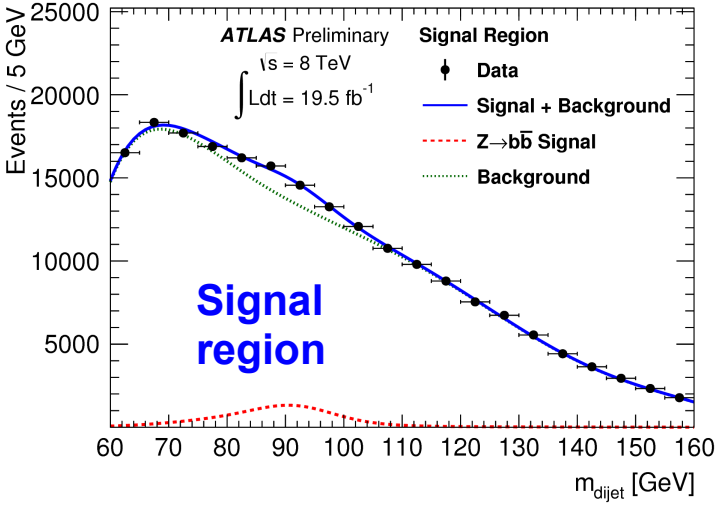
Hot press

ATLAS-STDM-2013-04

- Model QCD background with a function (same shape for the signal and control regions).
- Other small backgrounds from MC.
- Allow signal peak position and yield to float, other parameters- from MC.
- Simultaneous fit in the signal and control regions







DESY

High-p_T $Z \to b\bar{b}$: results.

Hot press

ATLAS-STDM-2013-04

> Fitted N($Z \to b\bar{b}$)=6420 ± 640 (stat.).
Acceptance = 16.2%

> p_T(dijet) > 200 GeV

$$\sigma^{\text{fid}}_{Z\to b\bar{b}} = 2.02 \pm 0.20\,(\text{stat.}) \pm 0.25\,(\text{syst.}) \pm 0.06\,(\text{lumi.})\,\text{pb}$$

> NLO ME+PS predictions:

$$\text{POWHEG}: \quad \sigma^{\text{fid}}_{Z\to b\bar{b}} = 2.02\ ^{+0.25}_{-0.19}(\text{scales})\ ^{+0.03}_{-0.04}(\text{PDF})\,\text{pb}$$

$$\text{aMC@NLO}: \quad \sigma^{\text{fid}}_{Z\to b\bar{b}} = 1.98\ ^{+0.16}_{-0.08}(\text{scales}) \pm 0.03(\text{PDF})\,\text{pb}$$

> The predictions are in very good agreement with the data!

DESY

Summary.

- Many measurements that probe kinematics of W/Z production at LHC.
- $p_T(Z)$ @ 8 TeV: low p_T gives sensitivity to the parton-shower model and to resummation effects; high p_T – test of higher-order calculations
- $Z\ \phi^*_\eta$ @ 7 TeV: probes same physics as p_T, but doesn't depend on momentum scale; test of resummation and parton-shower models
- MC tunes to p_T/ϕ^*_η data: improved modeling of the low-p_T region; crucial for W-mass measurement.
- $Z\rightarrow b\bar{b}$ for p_T(dijet) > 200 GeV: good description by NLO ME+PS generators; important check for searches using boosted system

DESY

Backup

POWHEG+PYTHIA8: configuration.

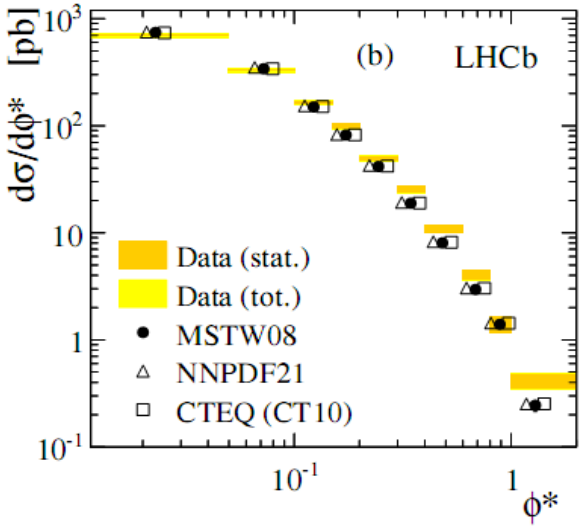
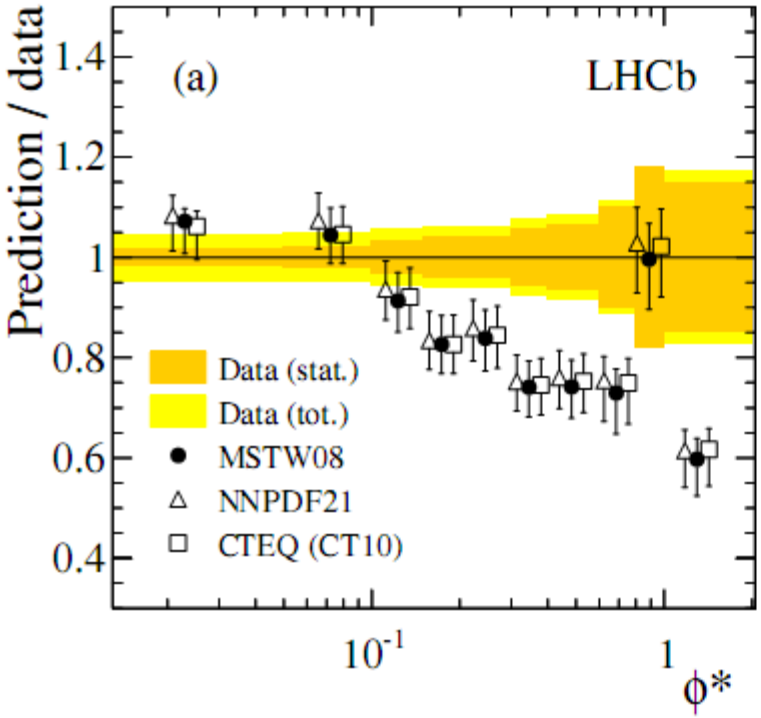
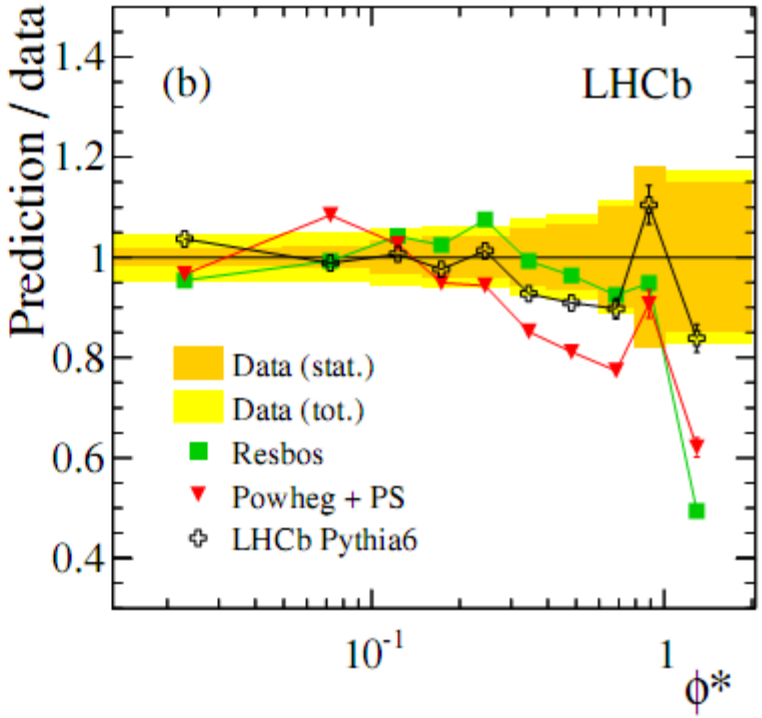
ATLAS-PHYS-PUB-2013-017

- Goal: improve the low-p_T region down to 2 GeV
- Advanced methodology in POWHEG+PYTHIA8 settings:

POWHEG and PYTHIA were tuned simultaneously;
α_s in the shower was matched to the one used in POWHEG.

- Raise the ptsqmin cut-off in POWHEG from default 0.8 to 4.0 GeV^2:
  - increase the number of Z+0 jets events, such that the ISR wimpy shower can fill the low-pT region
- Match α_s value and running between POWHEG ME and PYTHIA8 ISR shower:
  - $\alpha_s(M_Z)$=0.118
  - NLO running
- Tune intrinsic k_T and ISR cut-off

DESY

Z φ*: LHCb

- 2 < η < 4.5
- pT> 20 GeV
- 60 < M < 120 GeV
- PYTHIA and RESBOS provide the best description