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Recent Measurements involving Z Bosons from LHCb

PDF4LHC Workshop December 2013

Albert Bursche on behalf of the LHCb Collaboration

Universität Zürich

Friday 13th December 2013

University of Zurich[UZH]

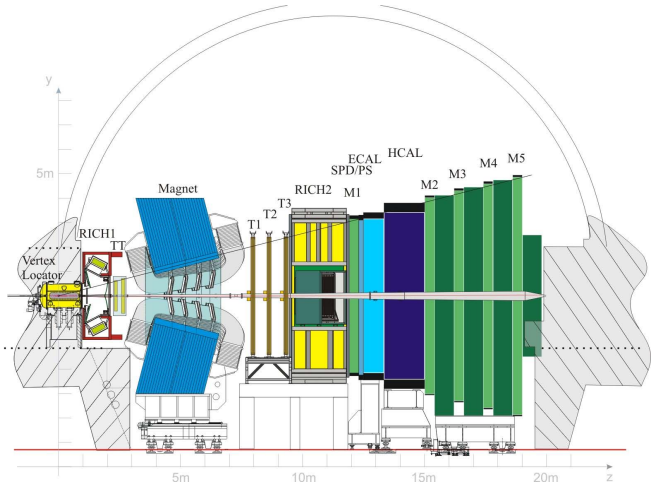
Introduction

Inclusive Z Production

Associated Production of Z Bosons with jets

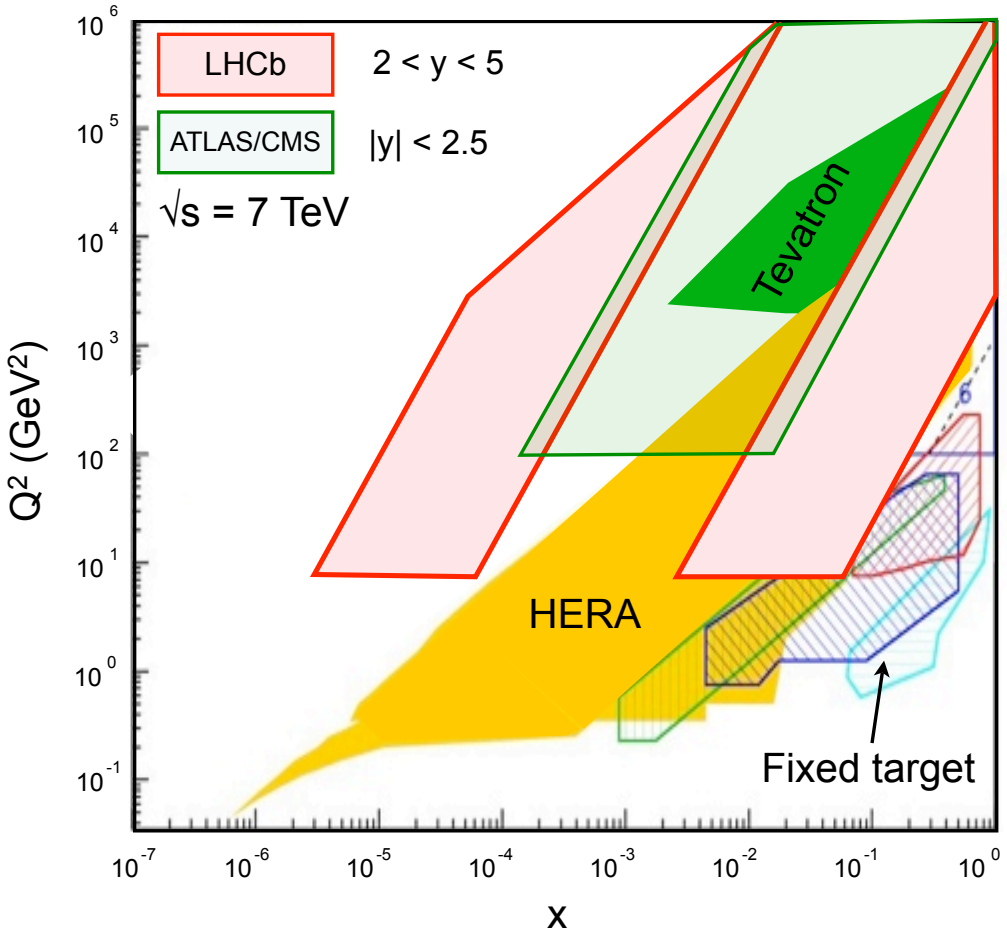
Z plus Charm

LHCb Experiment



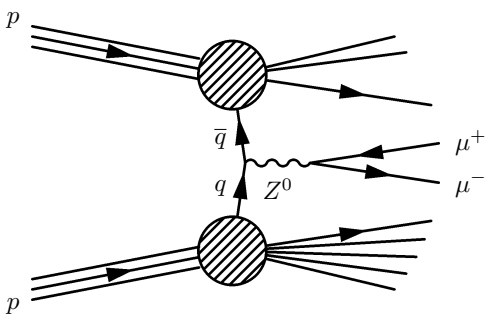
- Stable conditions with constant number of interactions (≈ 1.7) and high trigger rate up to 5 kHz
- Data at $\sqrt{s} = 7$ TeV with 36 pb^{-1}(2010), 1 fb^{-1}(2011)
- Data at $\sqrt{s} = 8$ TeV with 2 fb^{-1}(2012)
- 2013 Special runs: pp at 2.76 TeV and proton lead collisions

Introduction



- $Q^2 = M^2, x_{1,2} = \frac{Me^{\pm y}}{\sqrt{s}}$
- Z Production
  $Q^2 \approx 10000\,\mathrm{GeV}^2$
  $x_2 \in (1.7, 17) \cdot 10^{-4}$
  $x_1 \in (0.1, 1)$

Inclusive Z Production at $\sqrt{s} = 7$ TeV



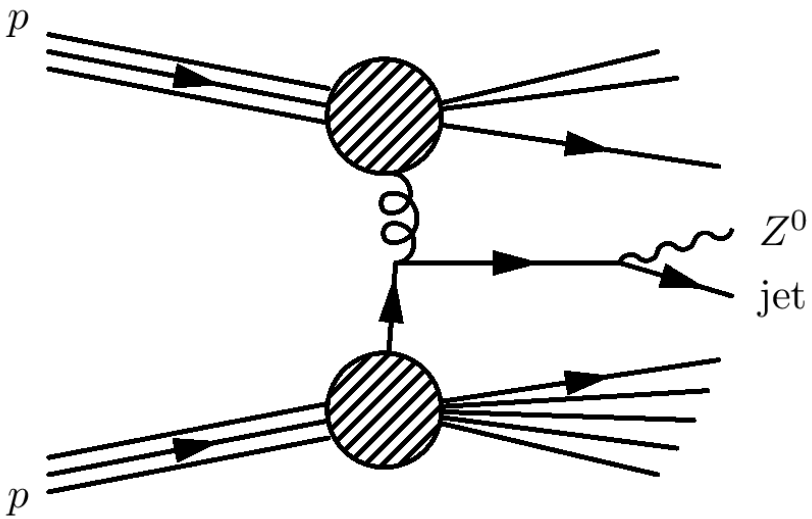
$\approx$ 53000 events

- $q\bar{q}$ initial state
- $2 < \eta_\mu < 4.5$
- $p_{T,\mu} > 20\,\mathrm{GeV}$
- $60 < m_{\mu^+\mu^-} < 120\,\mathrm{GeV}$
- Large statistics available
- The same selection is used to search for Z plus jet events

$\sqrt{s} = 7$ TeV

LHCb-CONF-2013-007

Z plus Jets at $\sqrt{s} = 7$ TeV



$\sigma = 16.0 \pm 0.2 \pm 1.2 \pm 0.6$ pb$(p_T > 10\,\mathrm{GeV})$

$\sigma = 6.3 \pm 0.1 \pm 0.5 \pm 0.2$ pb$(p_T > 20\,\mathrm{GeV})$

- qg initial state
- Probing different PDF
- More direct probe of pQCD than Z p_T
- Using tracks and neutral clusters
- Anti–k_T jets with R=0.5
- $2 < \eta_{\mathrm{Jet}} < 4.5$
- Corrected to hadron level

$\sqrt{s} = 7$ TeV

LHCb-PAPER-2013-058 1310.8197 submitted to JHEP

Jet Energy Reconstruction and Correction

The jets are reconstructed using a particle flow algorithm.

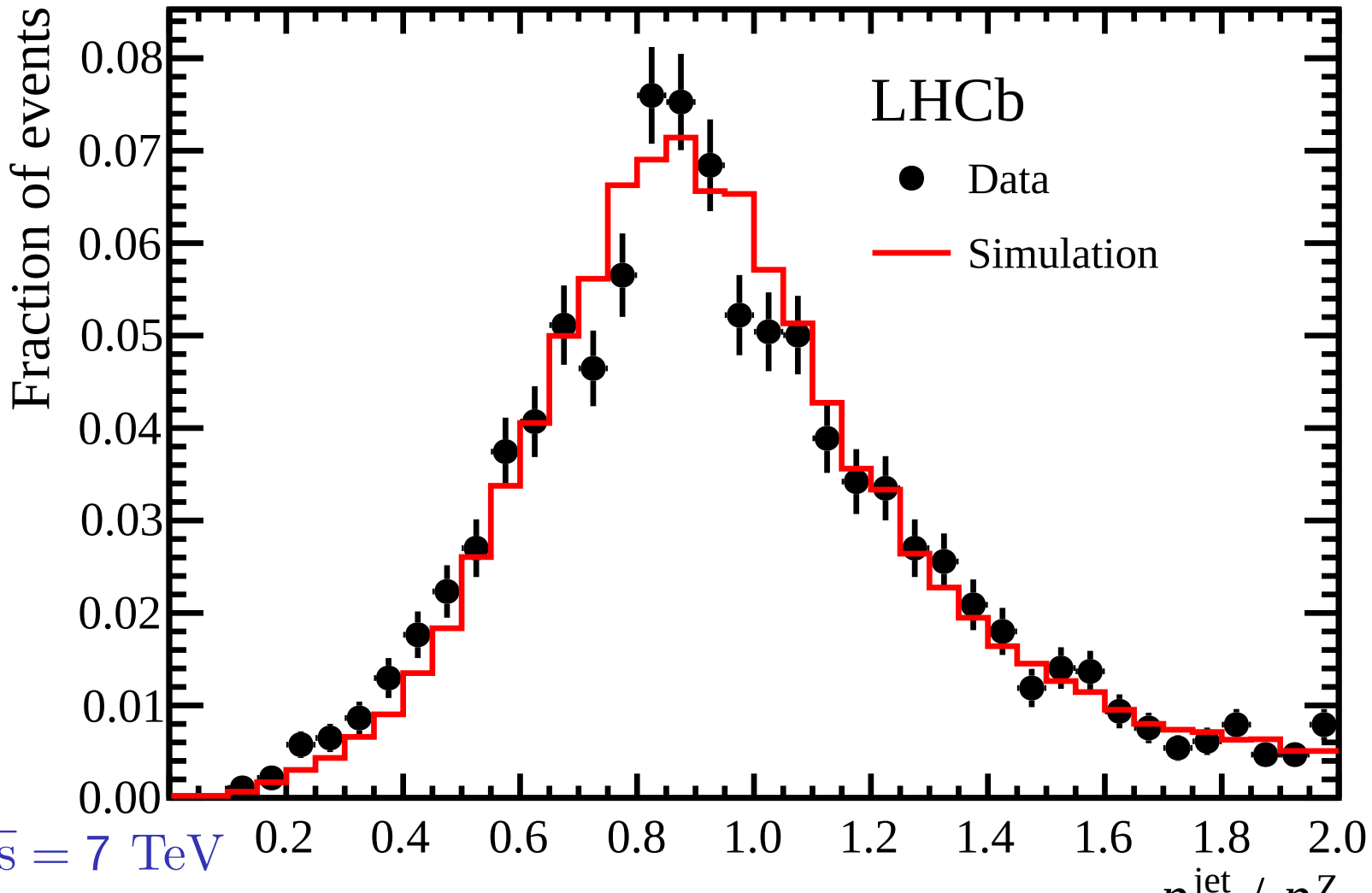
- Select tracks
- Select calo clusters
- Match tracks to clusters
- Subtract track energy from matched clusters
- If there is still significant energy also use the cluster in jet reconstruction.
- Jet energy dominated by tracks

- Run the jet reco on MC
- Run jet algorithm on stable particles (including ν)
- Compare the true and the reconstructed jets
- Use scale factors as function of $p_{T,raw}$, η and n_{PV}
- Typical correction around 10%

$\sqrt{s} = 7$ TeV

LHCb-PAPER-2013-058 1310.8197 submitted to JHEP

Z +jets:p_T Balance



$\sqrt{s} = 7$ TeV

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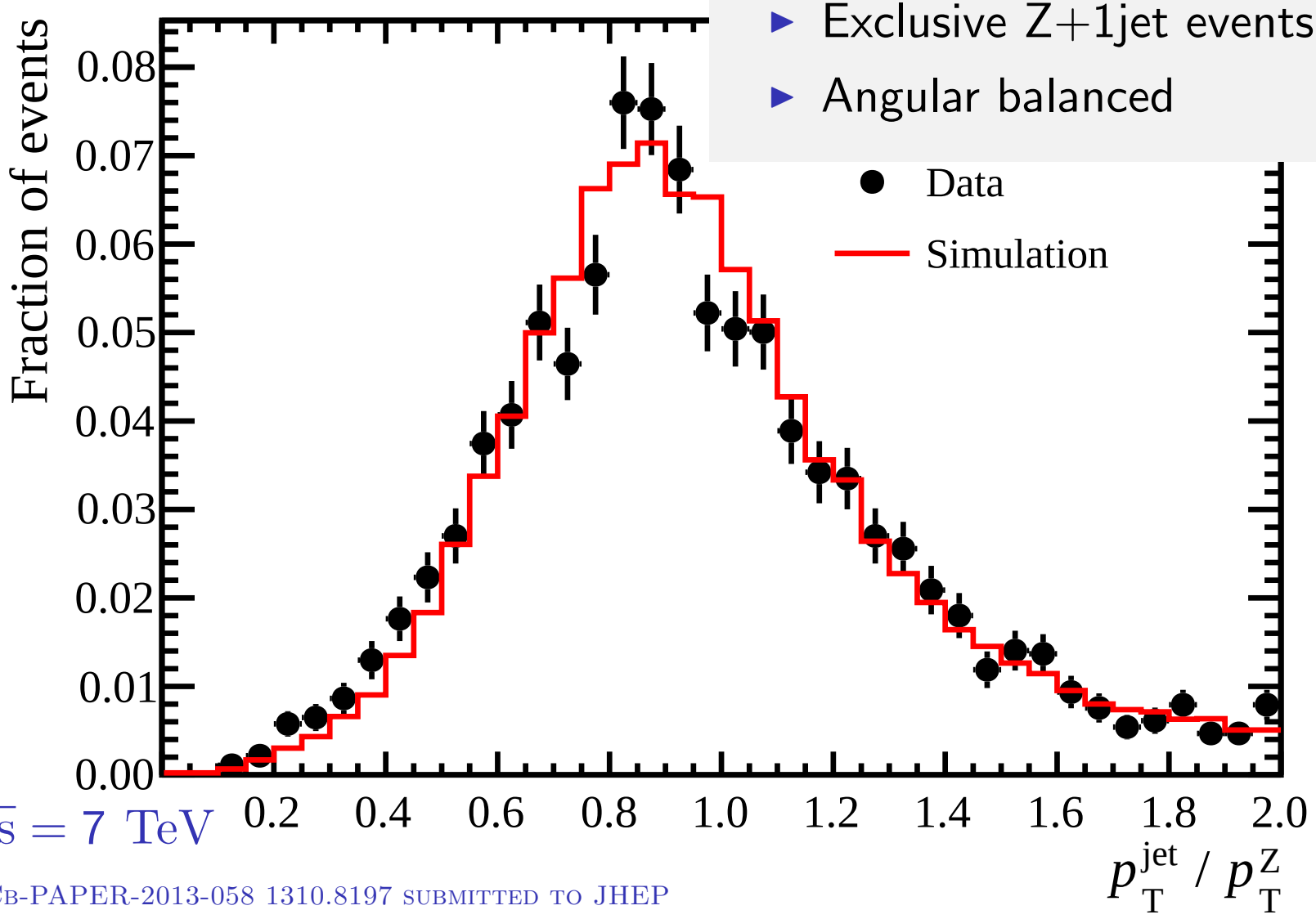
Z +jets:p_T Balance

- Exclusive Z+1jet events (raw)
- Angular balanced



$\sqrt{s} = 7$ TeV

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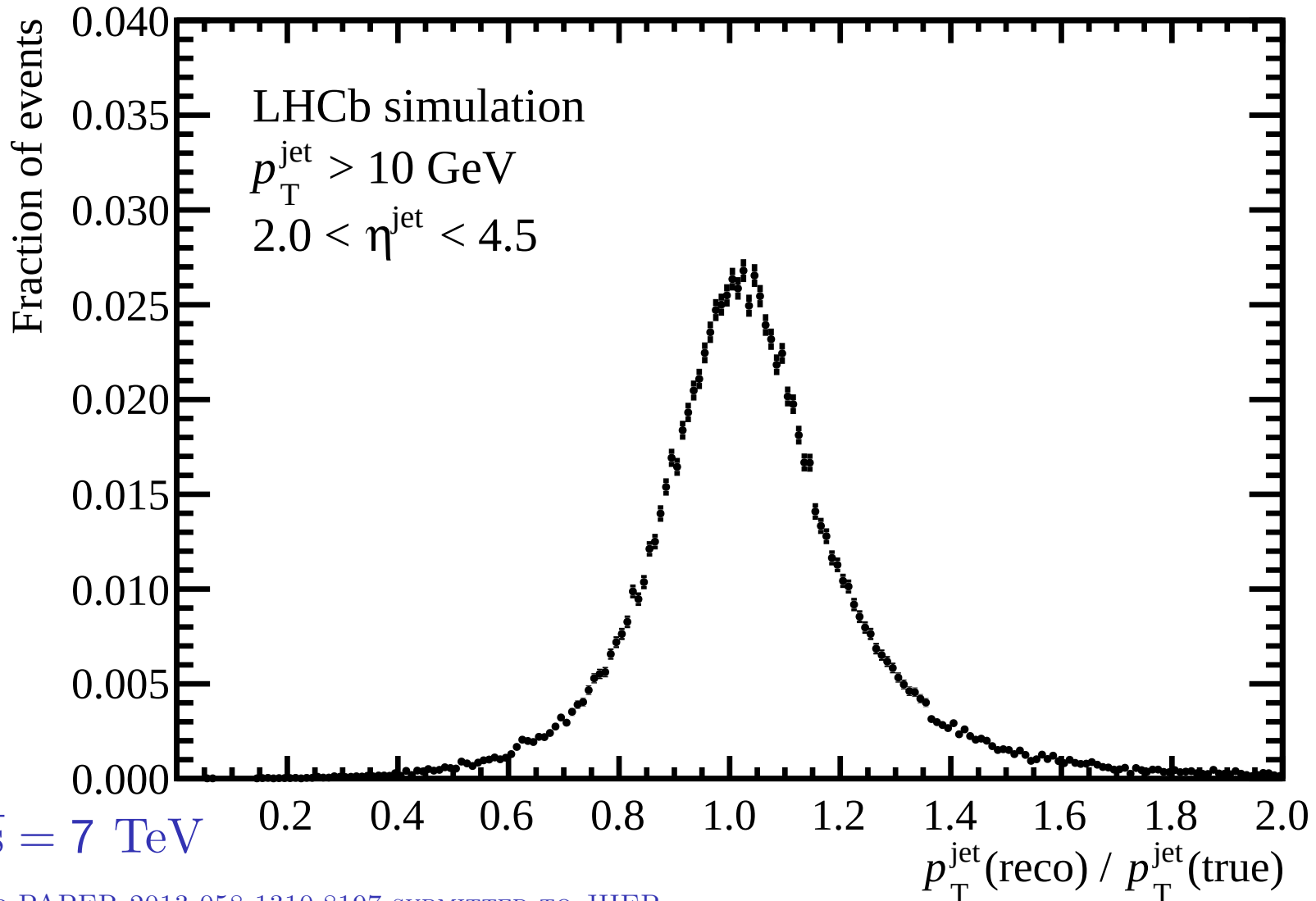
Z +jets: p_T Resolution



$\sqrt{s} = 7$ TeV

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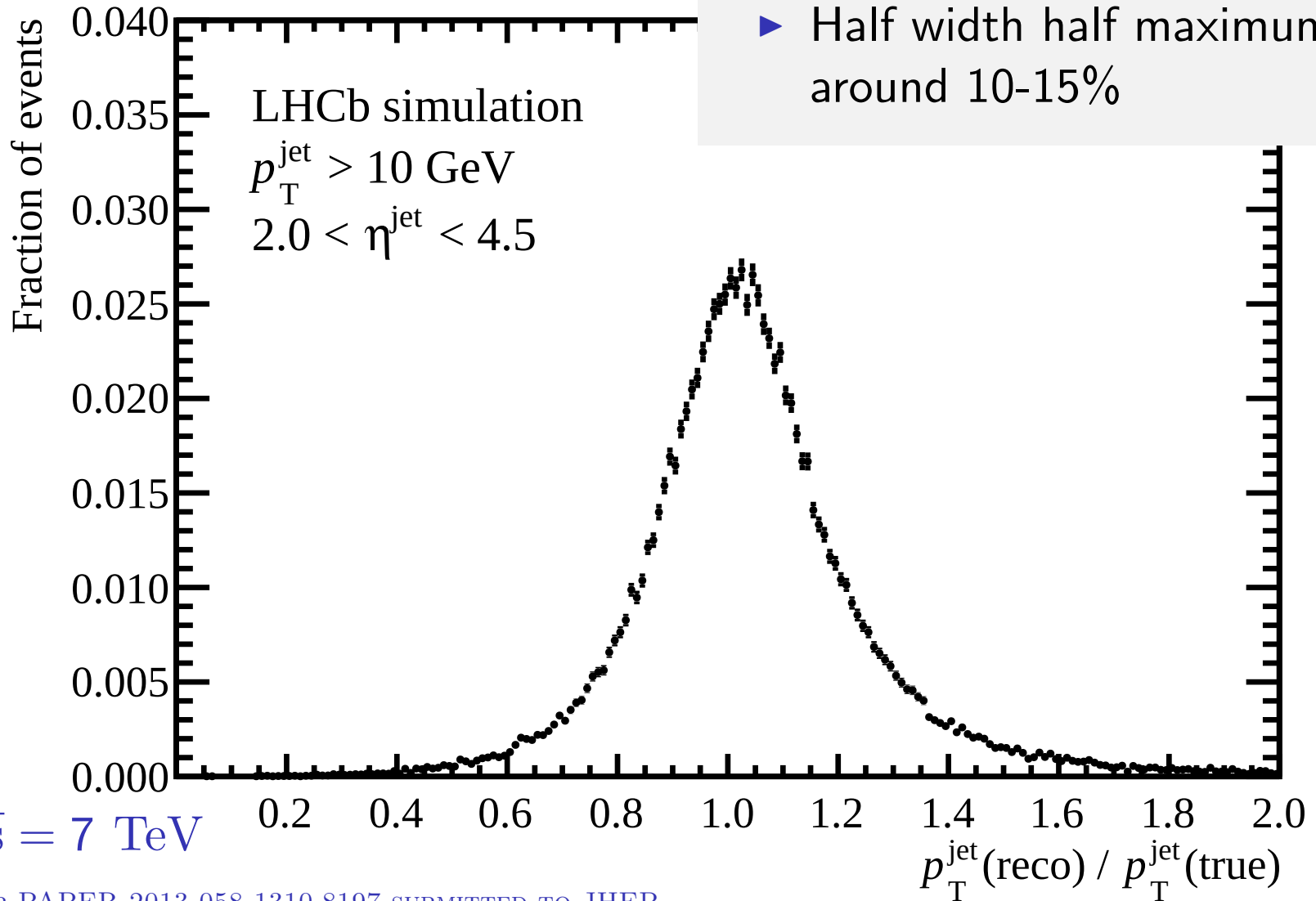
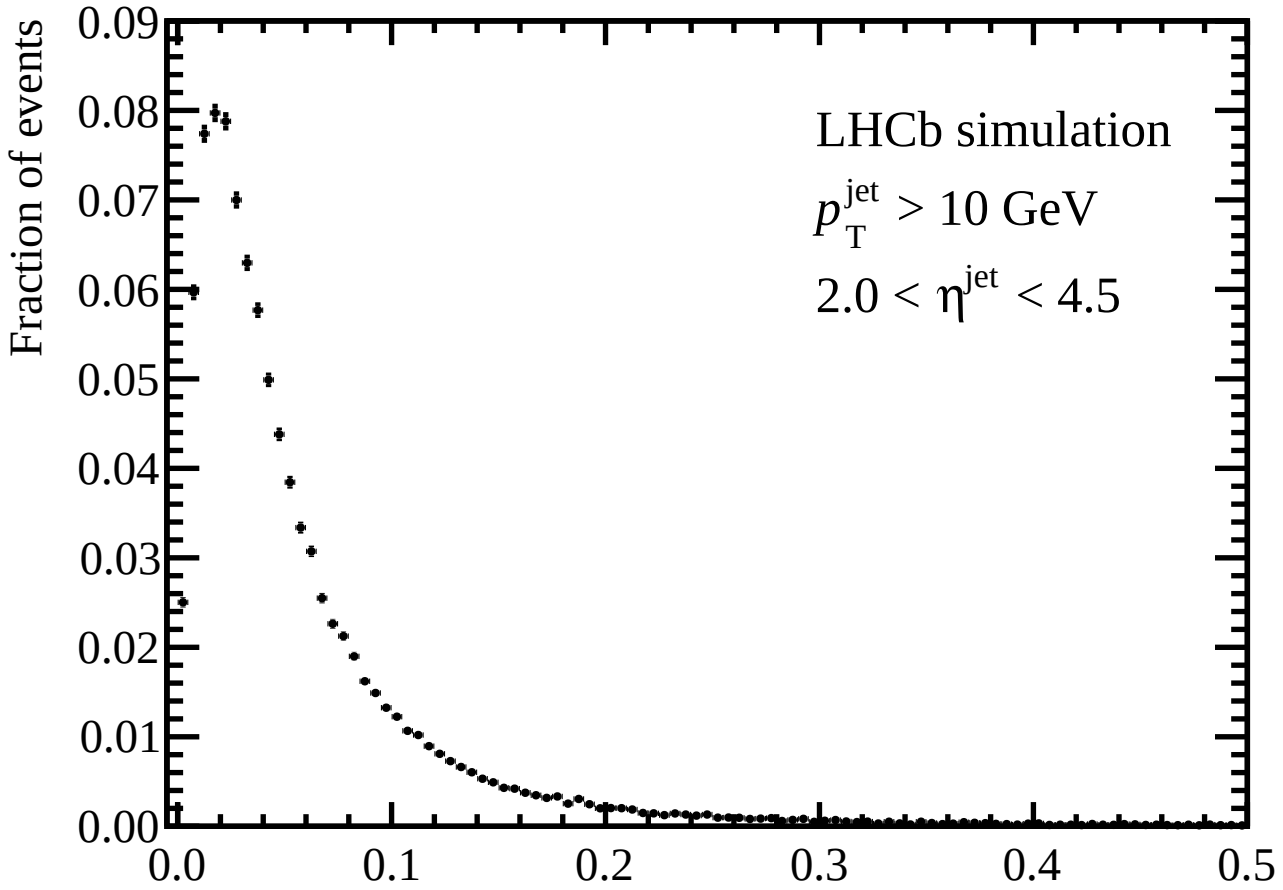
Z +jets:p_T Resolution



- Half width half maximum around 10-15%

$\sqrt{s} = 7$ TeV

Z +jets: Angular Resolution

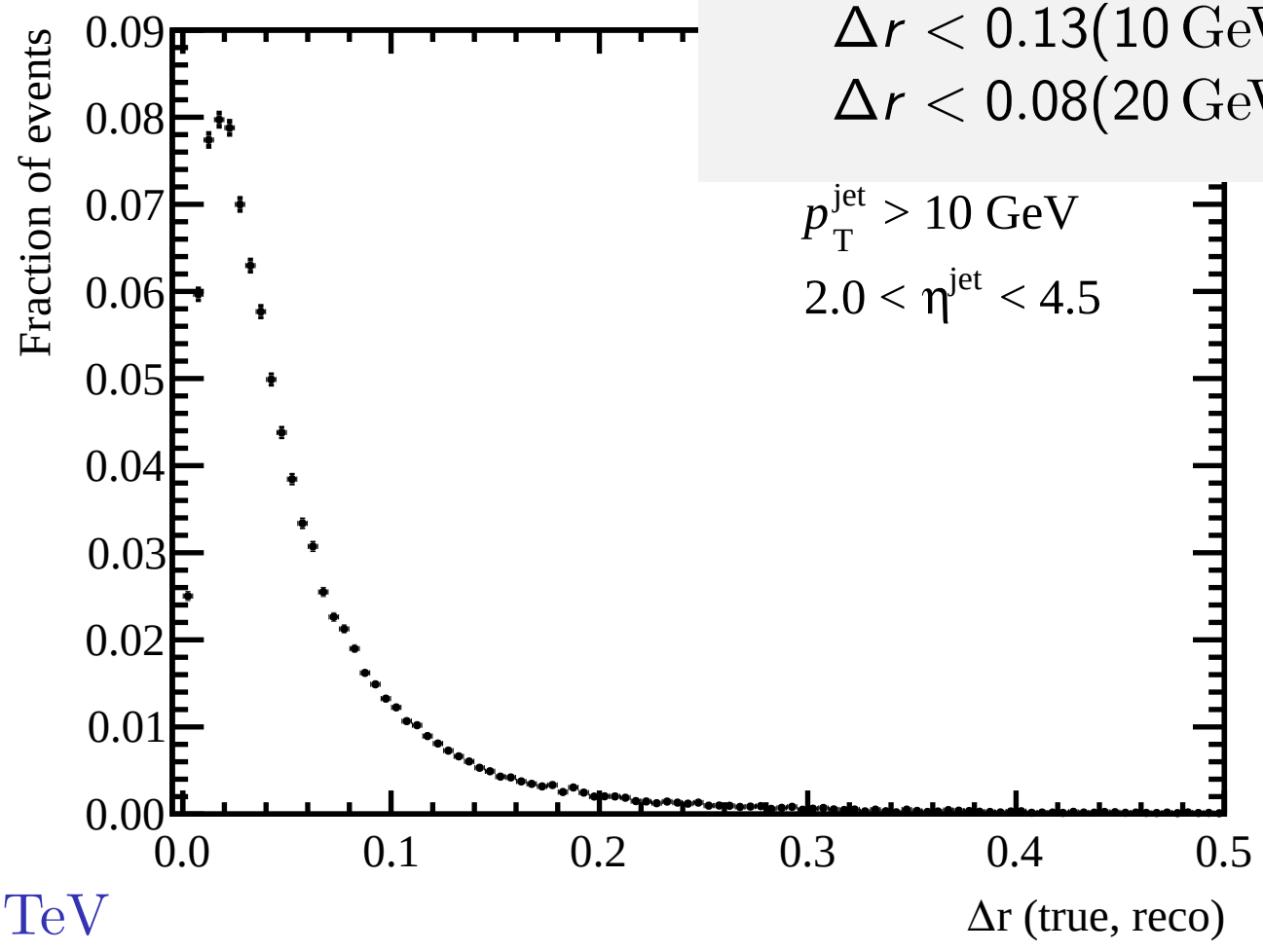


$\sqrt{s} = 7$ TeV

LHCb-PAPER-2013-058 1310.8197 submitted to JHEP

Z +jets: Angular Resolution

- For 90% of the jets $\Delta r < 0.13 (10\,\mathrm{GeV})$ and $\Delta r < 0.08 (20\,\mathrm{GeV})$



$\sqrt{s} = 7$ TeV

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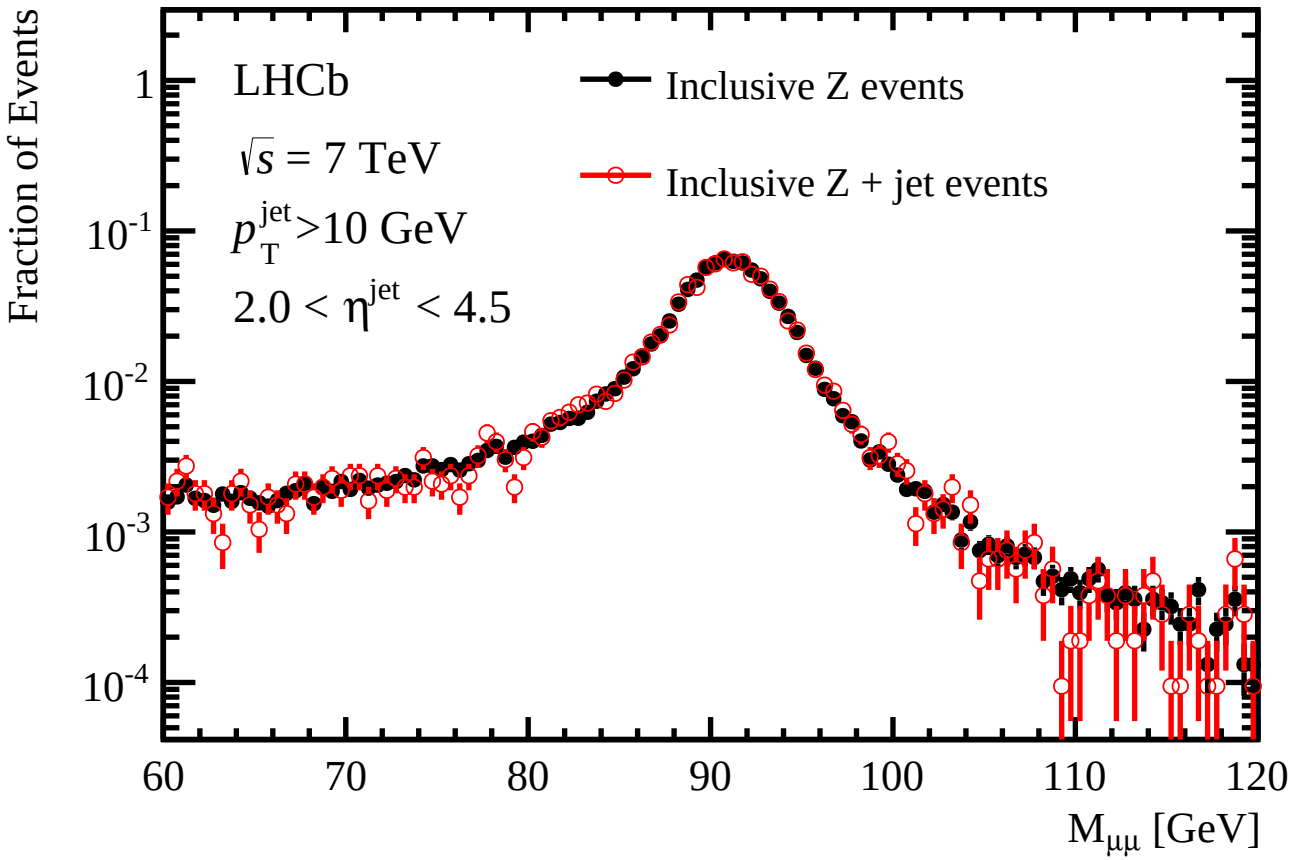
Z +jets: Background

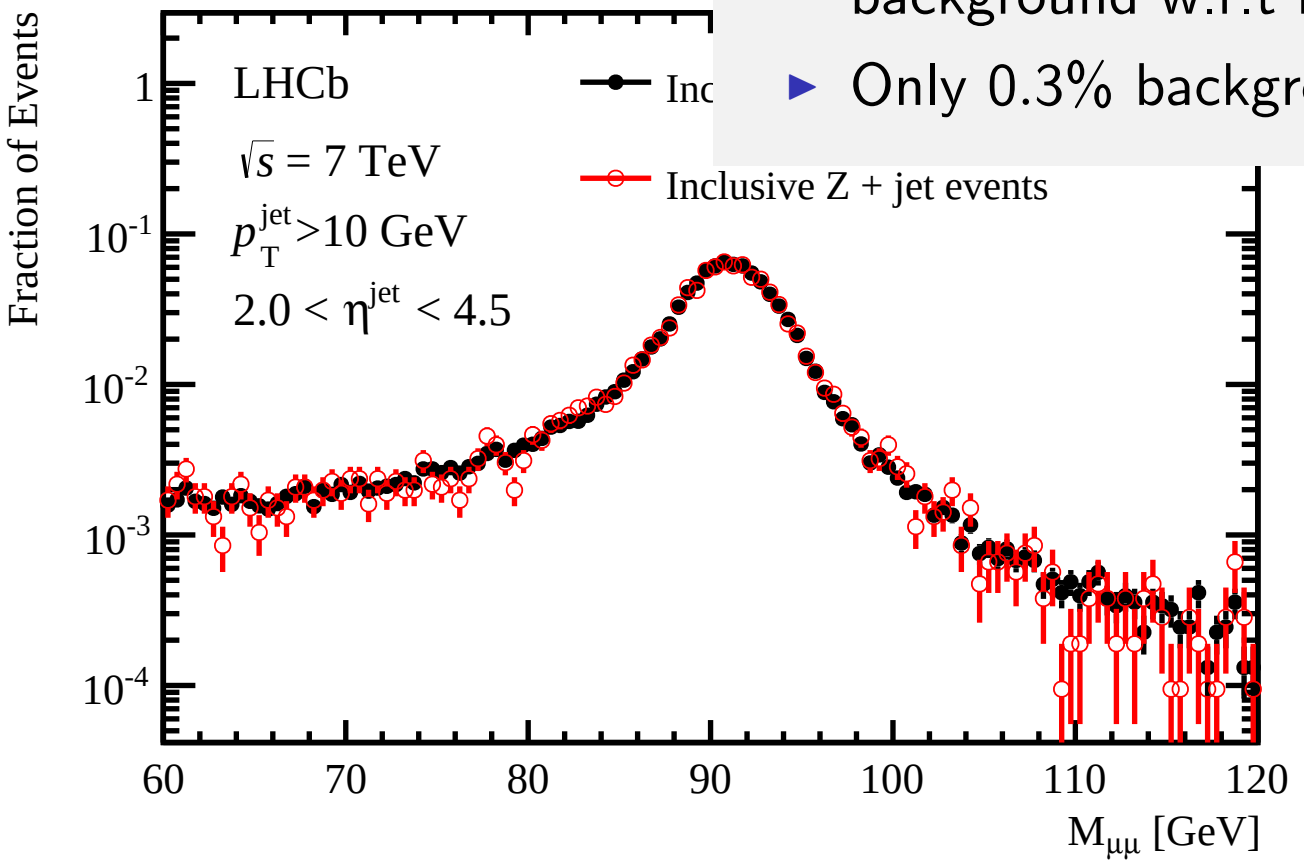


$\sqrt{s} = 7$ TeV

LHCb-PAPER-2013-058 1310.8197 submitted to JHEP

Z +jets: Background

- No evidence for enhanced background w.r.t inclusive Z
- Only 0.3% background



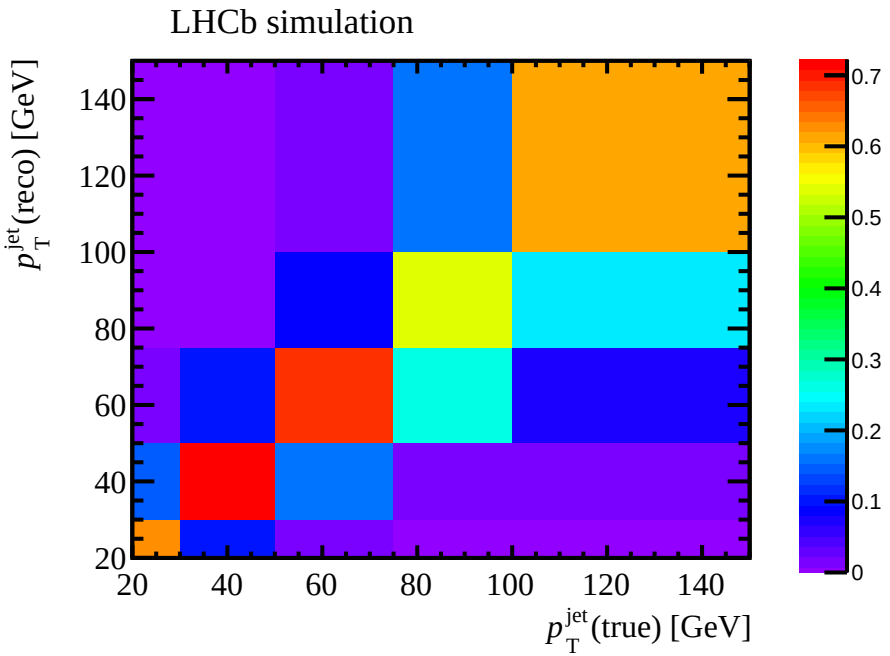
$\sqrt{s} = 7$ TeV

Unfolding

- G. D'Agostini Method with two steps.

  (Nucl. Instrum. Meth. A362 (1995) 487)

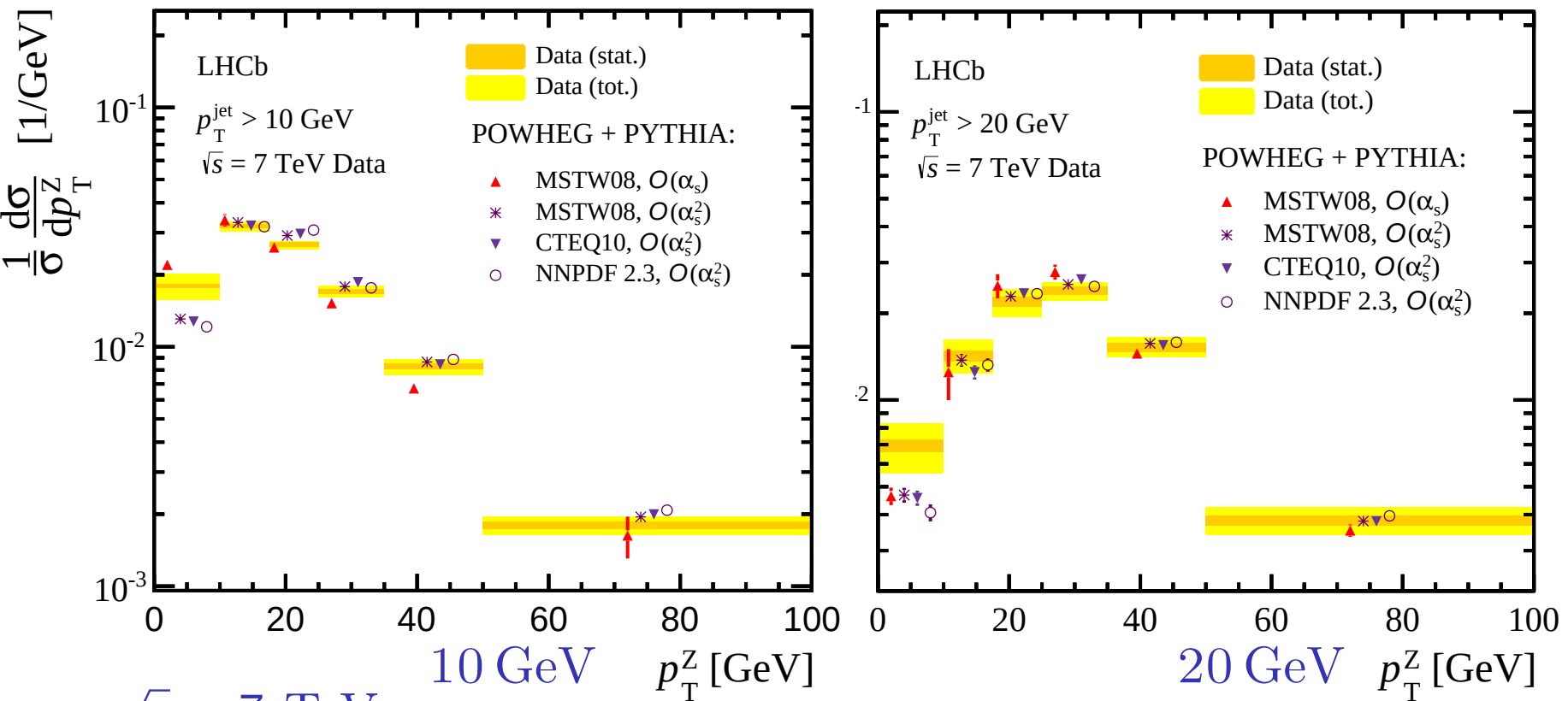
- Used SVD method as cross check and to determine systematics.



Systematic Uncertainties

Source	(%)
Unfolding	1.5
Z Reconstruction	3.5
Jet Reconstruction, Energy Scale, Energy Resolution	7.8
Final State Radiation	0.2
Total without Luminosity	8.6
Luminosity	3.5

Z +jets: Probe pQCD with Z p_T



$\sqrt{s} = 7$ TeV

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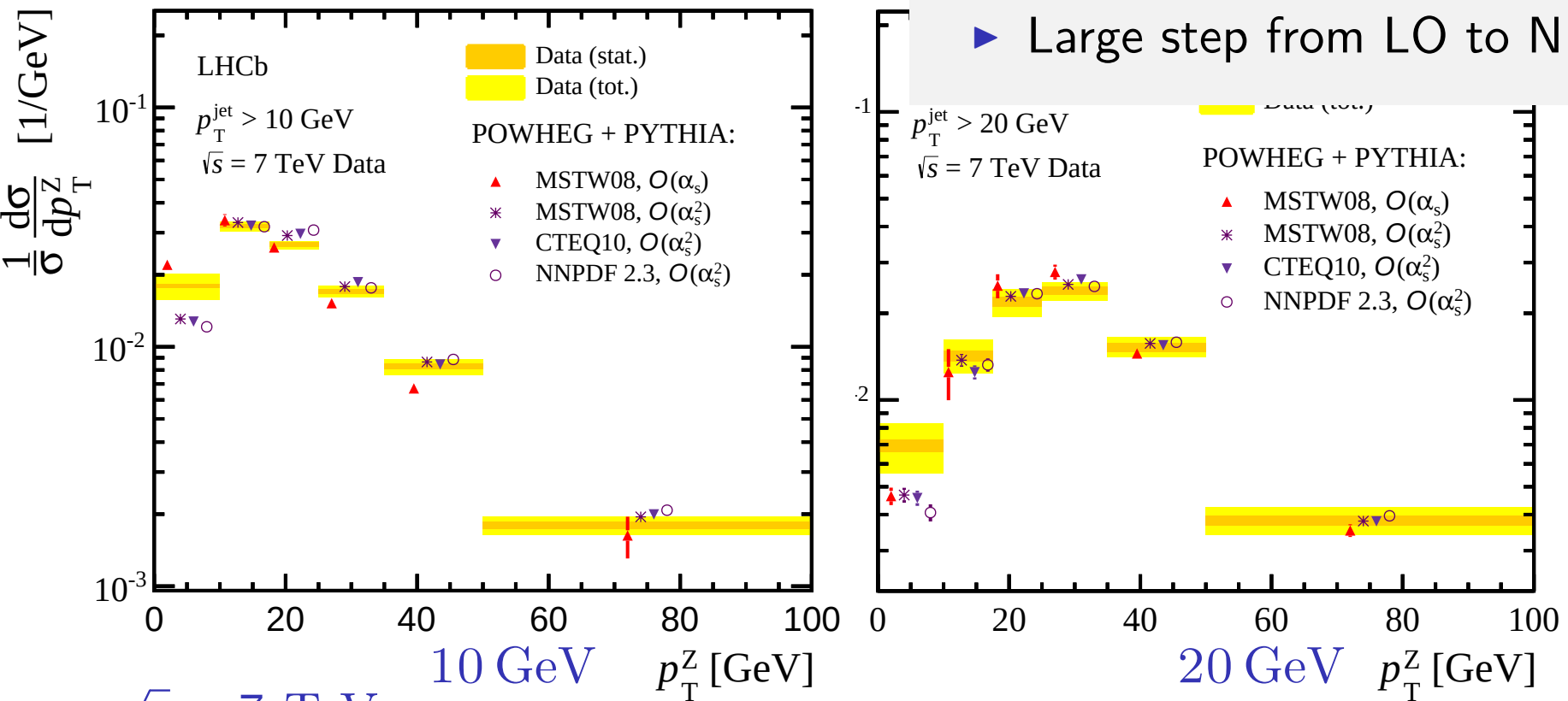
Z +jets: Probe pQCD with Z p_T

- Deviations in lowest bin
- Parton shower describes data
- Large step from LO to NLO



$\sqrt{s} = 7$ TeV

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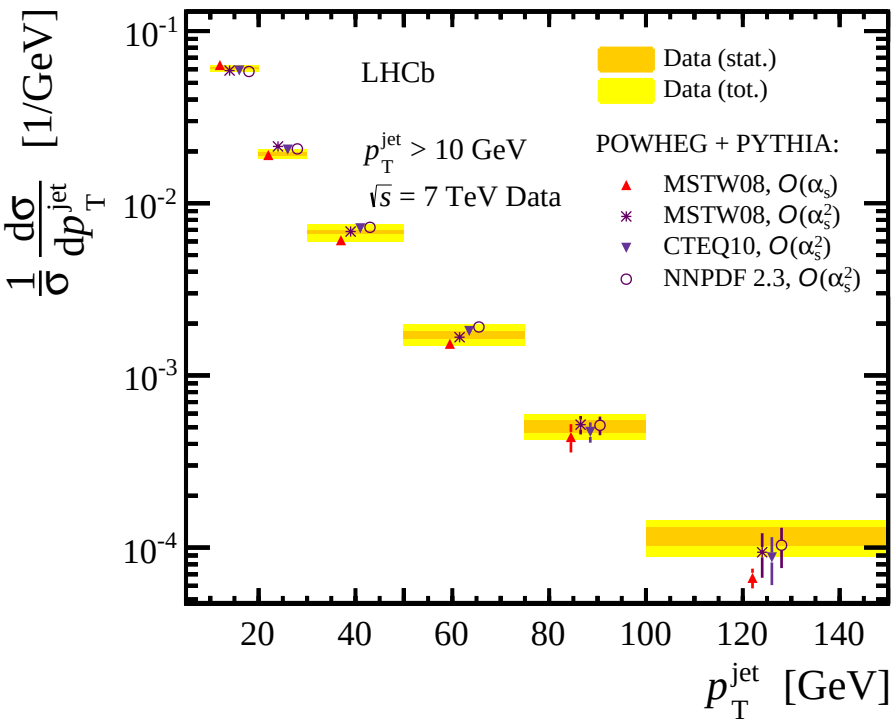
Z +jets: Probe pQCD with jet p_T



- Compared to Powheg
- Parton Shower with Pythia

$\sqrt{s} = 7$ TeV

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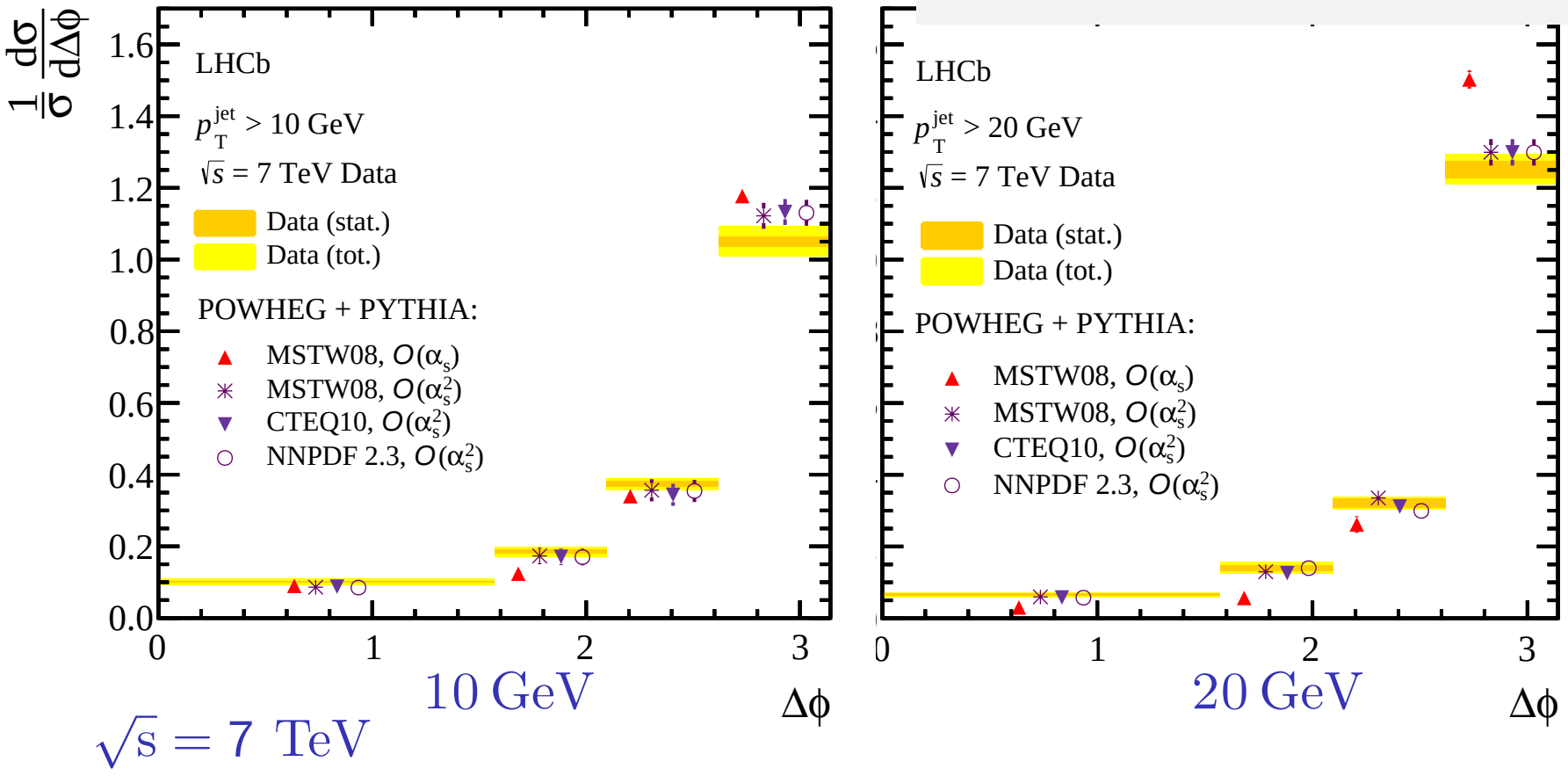
Z +jets: Probe pQCD with $\Delta\Phi$

- Deviations at π
- Parton shower describes data



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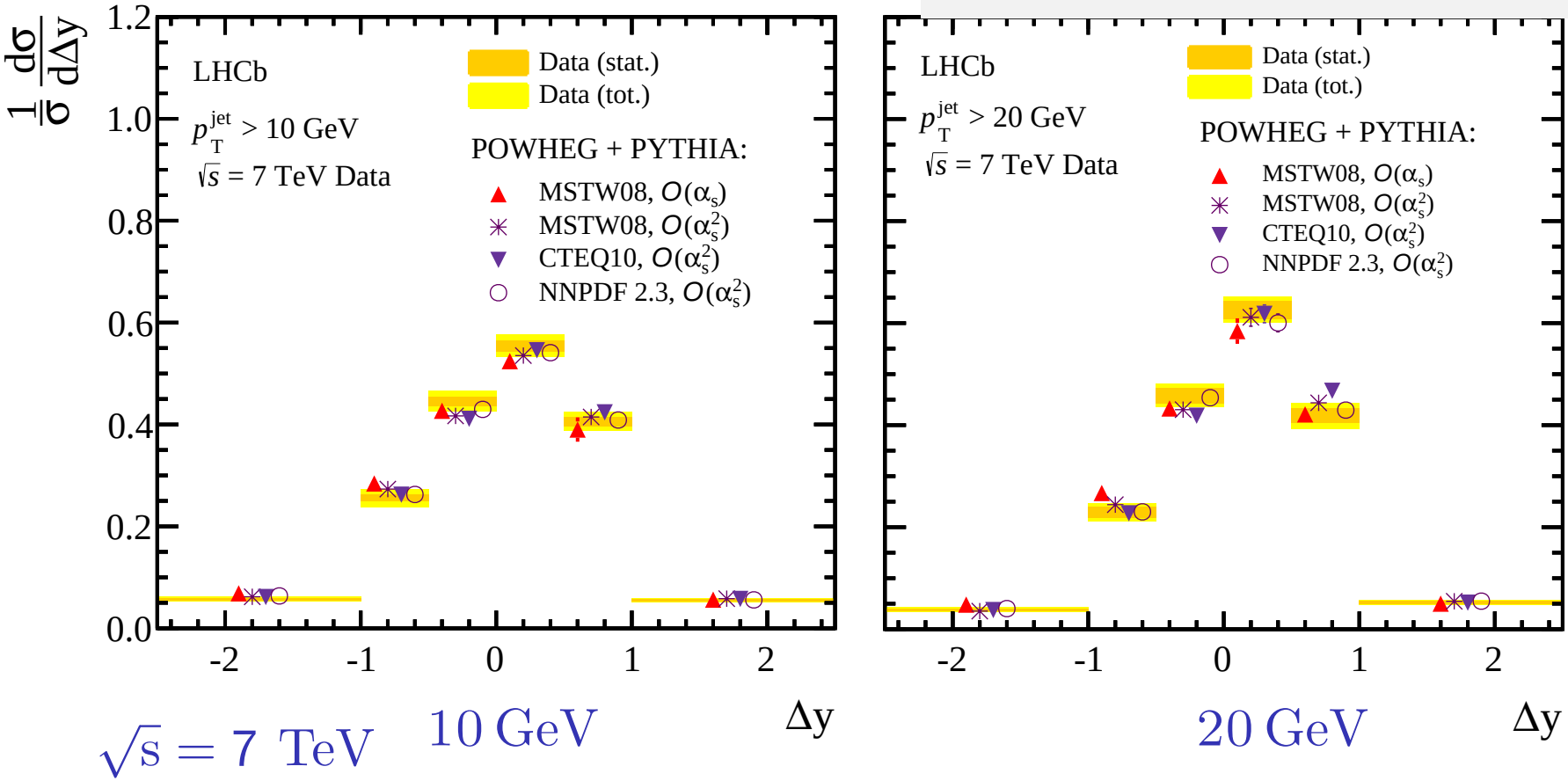
Z +jets: Probe PDFs with Δy

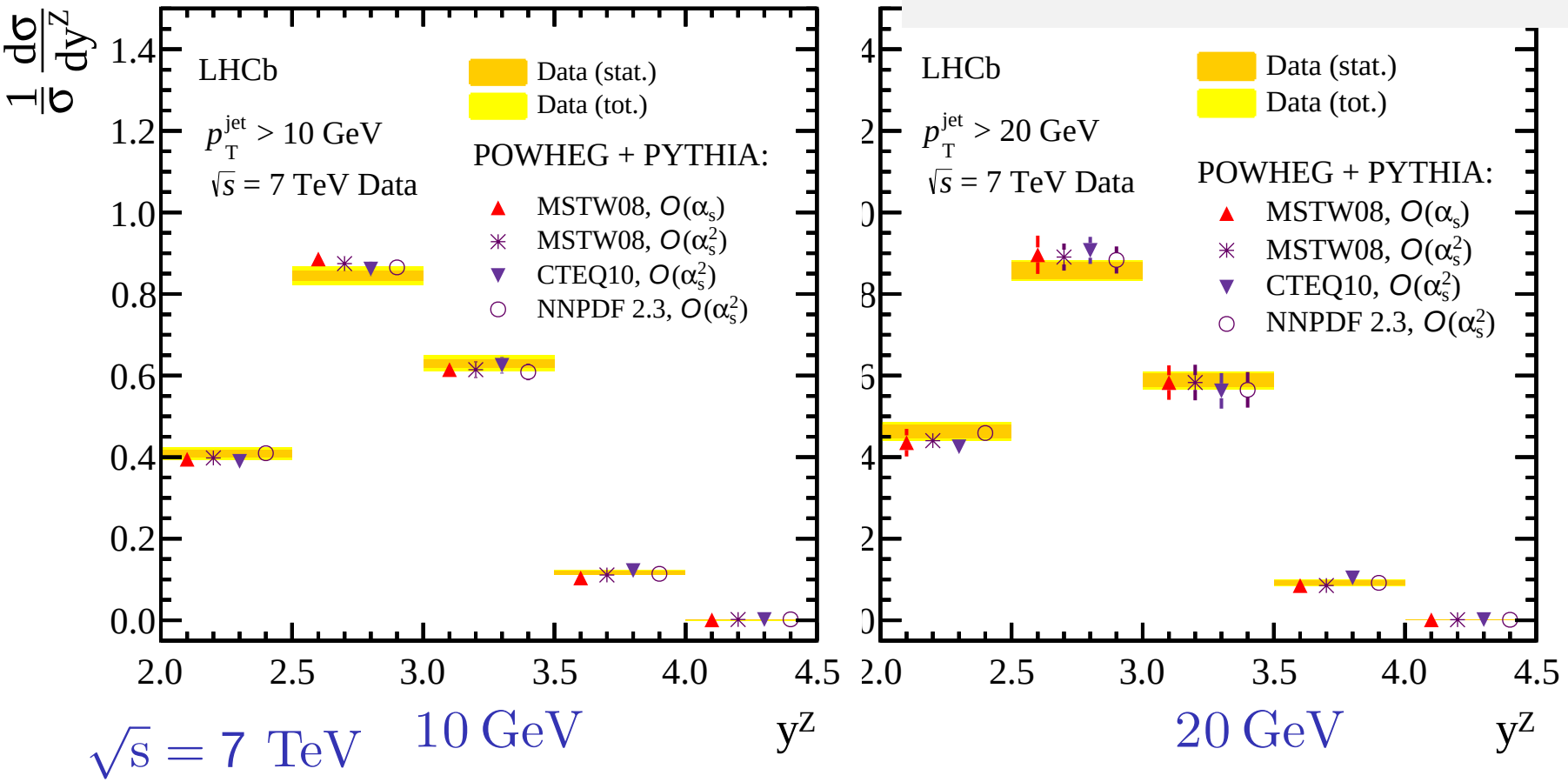
- NNPDF 2.3 used earlier LHCb $W^{\pm}$ data



LHCb-PAPER-2013-058 1310.8197 submitted to JHEP

Z +jets: Probe PDFs with y_Z

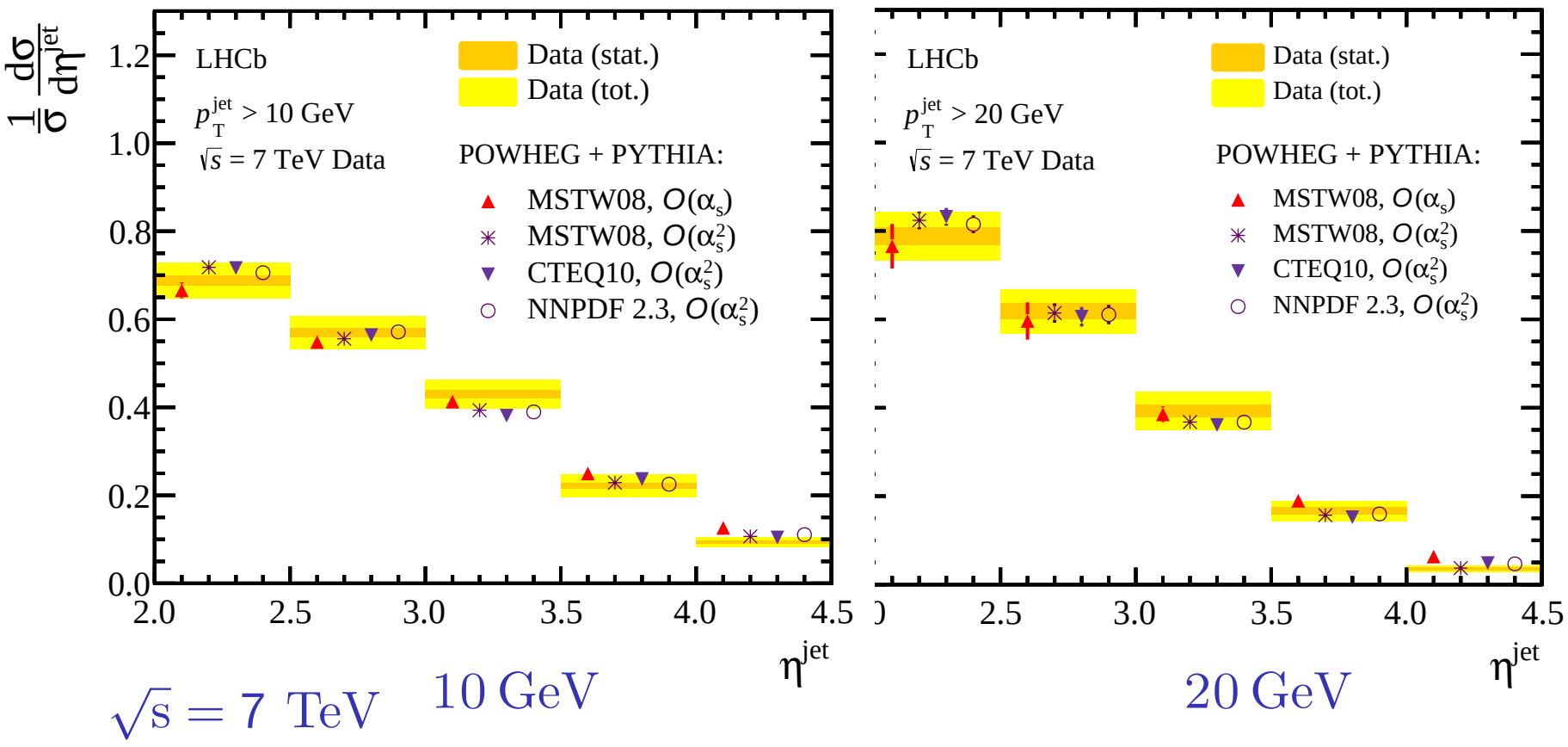
- NNPDF 2.3 used earlier LHCb $W^{\pm}$ data



LHCb-PAPER-2013-058 1310.8197 submitted to JHEP

Z +jets: Probe PDFs with y_{JET}

- NNPDF 2.3 used earlier LHCb $W^{\pm}$ data



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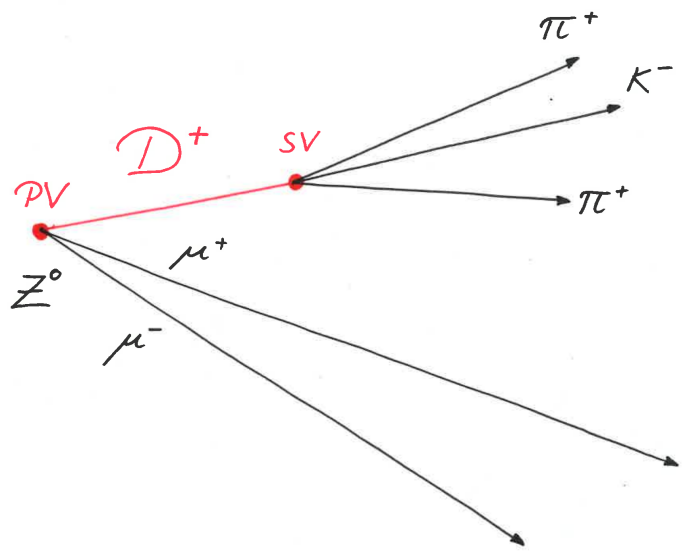
Z plus D
Brand new Result

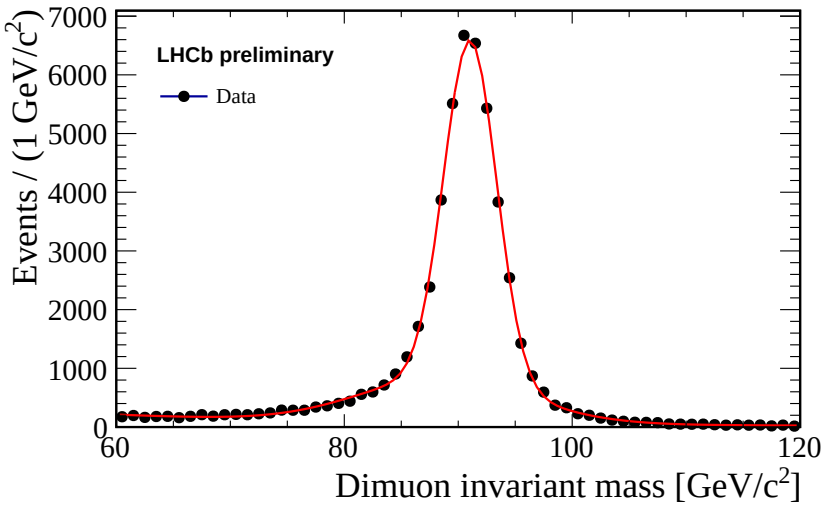


- Z from PV with zero lifetime.
- D from secondary vertex but associated to the same PV as the Z.

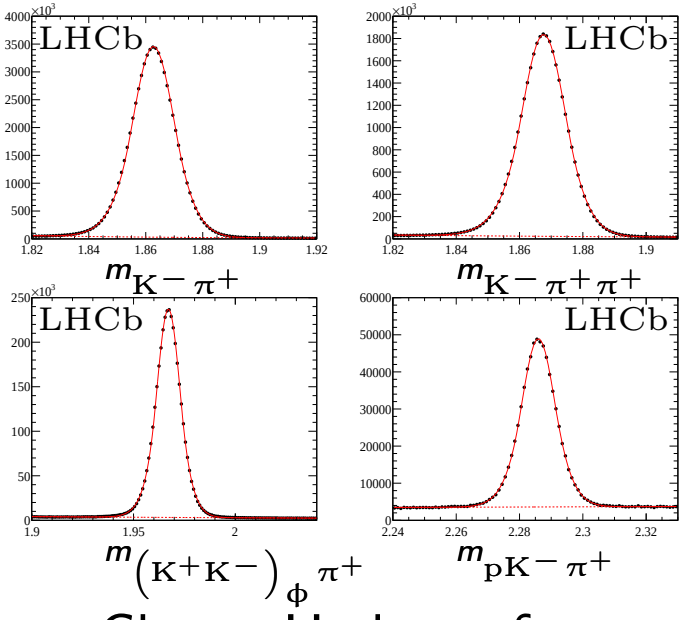
Overview

- $\mathrm{Z} \to \mu^+\mu^-$ as before
- $2 < p_{T,\mathrm{D}} < 12\,\mathrm{GeV}$
- $\mathrm{D}^0 \to \mathrm{K}^-\,\pi^+$
- $\mathrm{D}^+ \to \mathrm{K}^-\,\pi^+\,\pi^+$

Z $+D^0/D^{\pm}$: Ingredients

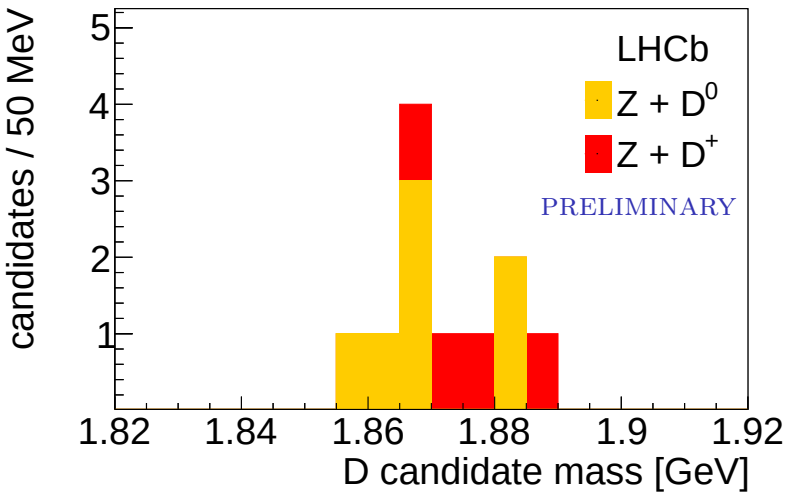


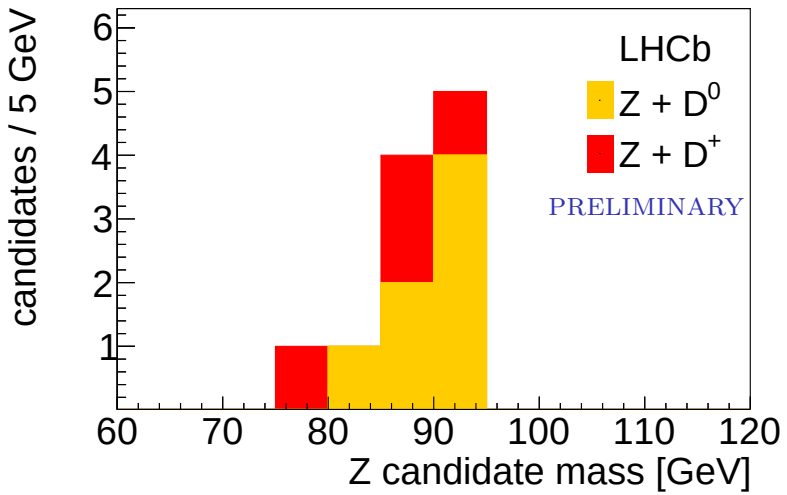
Z bosons from
LHCb-CONF-2013-007



Open Charm Hadrons from
LHCb-PAPER-2012-003

Z $+\mathrm{D}^0/\mathrm{D}^{\pm}$: Candidates



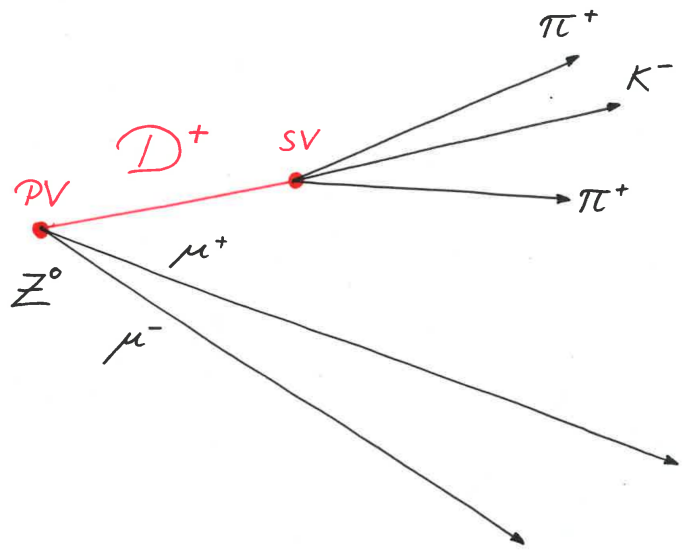


- Stacked plots
- Eleven candidates observed
- Seven D^0 and four D^+

$\sqrt{s} = 7$ TeV

LHCb-PAPER-2013-062(preliminary)

Z $+D^0/D^{\pm}$: Strategy

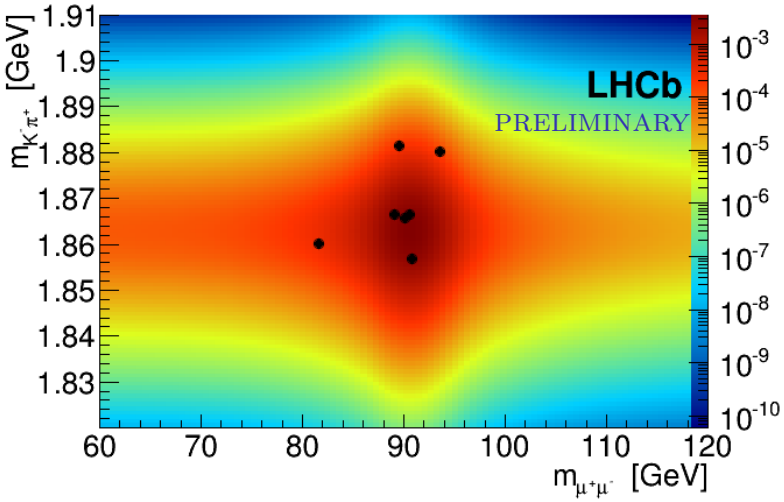


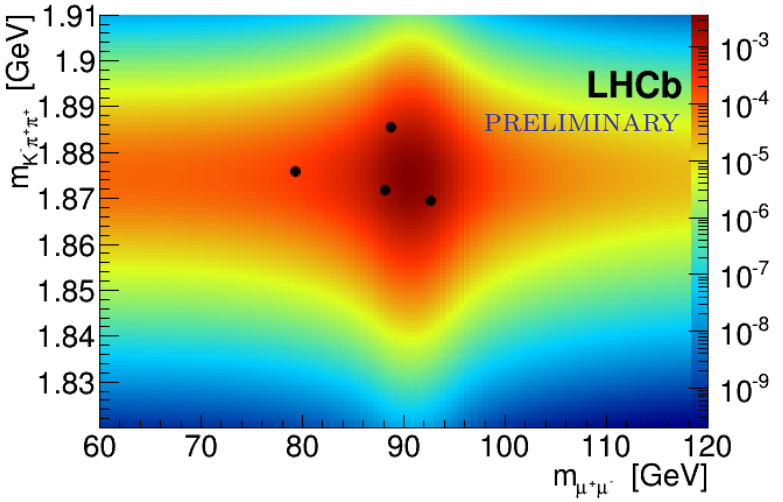
- Z from PV with zero lifetime.
- D from secondary vertex but associated to the same PV as the Z.

Main Backgrounds

- Combinatorial (Random Combinations)
- Pileup (True Z and true D^0 from different *pp* interaction)

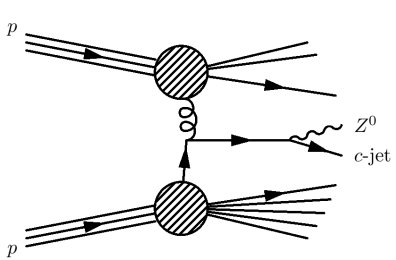
Z $+D^0/D^{\pm}$: Combinatorial Background



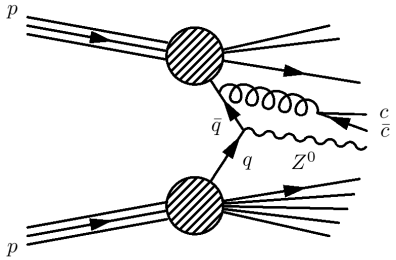


- Shape for Z from FEWZ convolved with CB to describe mass shape of LHCb-CONF-2013-007.
- Shape for D is a modified Novosibirsk Function from LHCb-PAPER-2012-003.
- exponential background
- Background is tiny

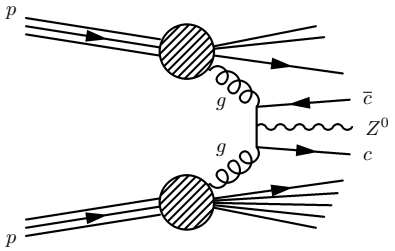
Z +$D^0/D^{\pm}$: Theory Predictions



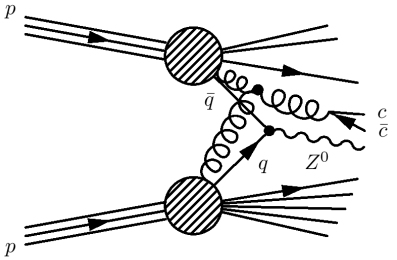
LO



NLO



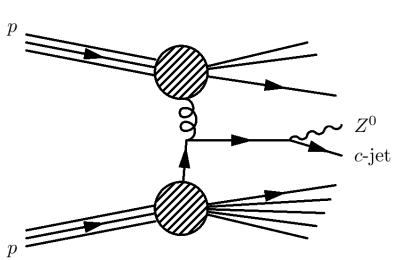
NLO



MPI

- Single Parton Scattering(SPS) is calculated at parton level with MCFM (NLO) and corrected to hadron level
- This doesn't take into account changes in kinematics in c→D. (potentially large A. V. Berezhnoy et. al. arXiv:1204.1058)

Z +$D^0/D^{\pm}$: Theory Predictions



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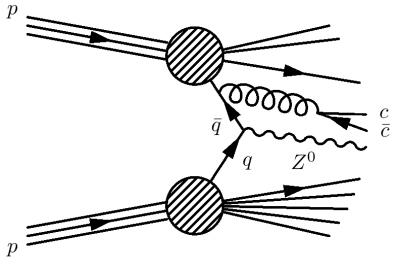
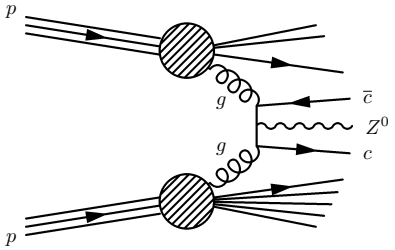
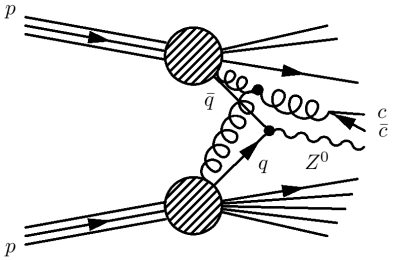


NLO



NLO



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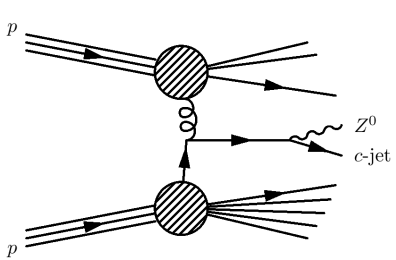
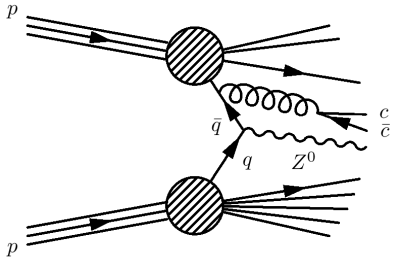
- This doesn't take into account changes in kinematics in c→D. (potentially large A. V. Berezhnoy et. al. arXiv:1204.1058)
- Double Parton Scattering(DPS) is calculated from the measured σ_Z and σ_D as $\sigma_{DPS} = \frac{\sigma_Z \sigma_D}{\sigma_{eff}}$.
- This doesn't take into account the correlations between the partons. (Potentially large V.L. Korotkikh et. al. hep-ph/0404155)

Z +$D^0/D^{\pm}$: Theory Predictions



LO



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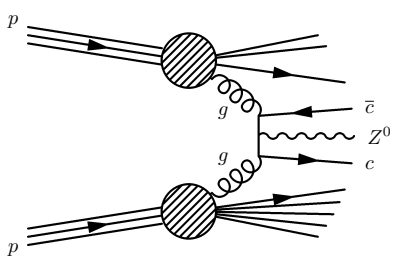
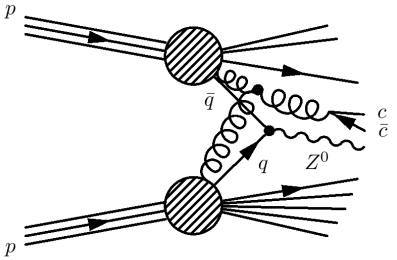


NLO



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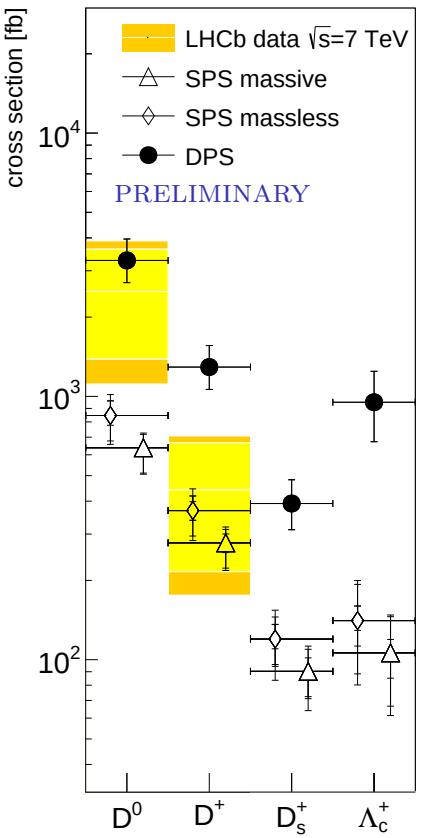
- This doesn't take into account the correlations between the partons. (Potentially large V.L. Korotkikh et. al. hep-ph/0404155)
- Both processes contribute to the cross-section

Results

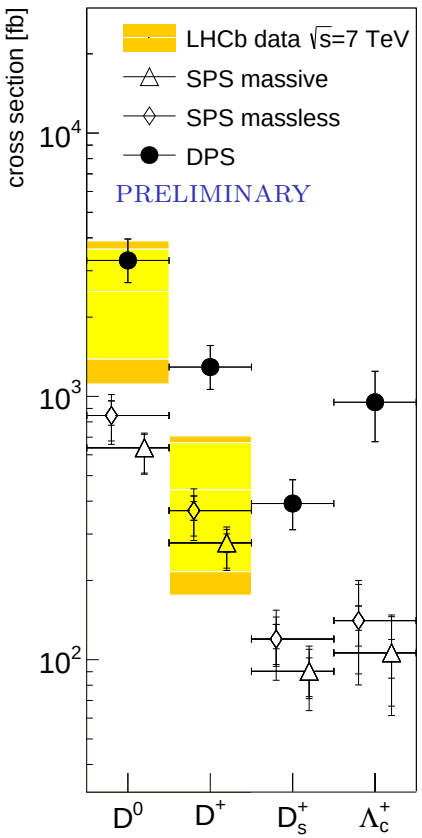


$\sqrt{s} = 7$ TeV

- Preliminary Measurement (in LHCb review)
- $\sigma_{Z\to\mu^+\mu^-,D^0}\mathcal{B}_{Z\to\mu^+\mu^-} = 2.50 \pm 1.12 \pm 0.22\,\mathrm{pb}$
- $\sigma_{Z\to\mu^+\mu^-,D^+}\mathcal{B}_{Z\to\mu^+\mu^-} = 0.44 \pm 0.23 \pm 0.03\,\mathrm{pb}$

LHCb-PAPER-2013-062(preliminary)

Results



$\sqrt{s} = 7$ TeV

- Preliminary Measurement (in LHCb review)
- $\sigma_{Z\to\mu^+\mu^-,D^0}\mathcal{B}_{Z\to\mu^+\mu^-} = 2.50 \pm 1.12 \pm 0.22\,\mathrm{pb}$
- $\sigma_{Z\to\mu^+\mu^-,D^+}\mathcal{B}_{Z\to\mu^+\mu^-} = 0.44 \pm 0.23 \pm 0.03\,\mathrm{pb}$
- Comparison to SPS and DPS predictions.
- The measured cross-section is expected to be composed of both DPS and SPS.

LHCb-PAPER-2013-062(preliminary)

Summary and Outlook

- LHCb measured inclusive Z production, and associated production with jets as well as D mesons at 7 TeV
- Inclusive $\mathrm{Z} \to \mu^+\mu^-$ publication for 2011 data coming soon!
- Inclusive $\mathrm{Z} \to \mu^+\mu^-$ and $\mathrm{Z} \to \mathrm{e}\ \mathrm{e}$ for 2012 are close.
- Plans for cross section measurements for $\mathrm{Z} \to \mu^+\mu^-$ at 2.76 TeV and in proton lead data.

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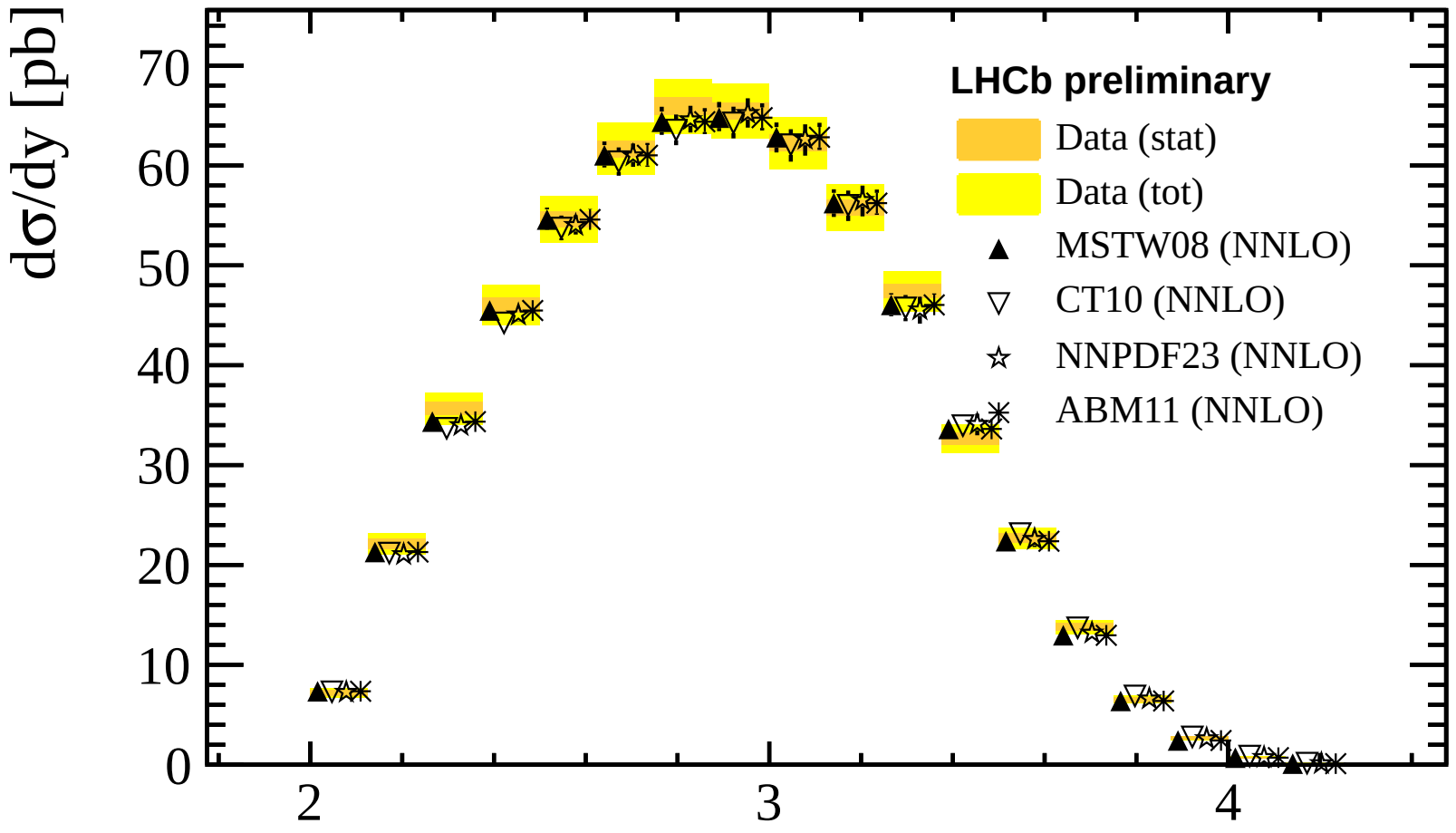
Thank You!

Z: Probe PDFs $x_{1,2} = \frac{me^{\pm y}}{\sqrt{s}}$



$\sqrt{s} = 7$ TeV Predictions: FEWZ at NNLO

LHCb-CONF-2013-007

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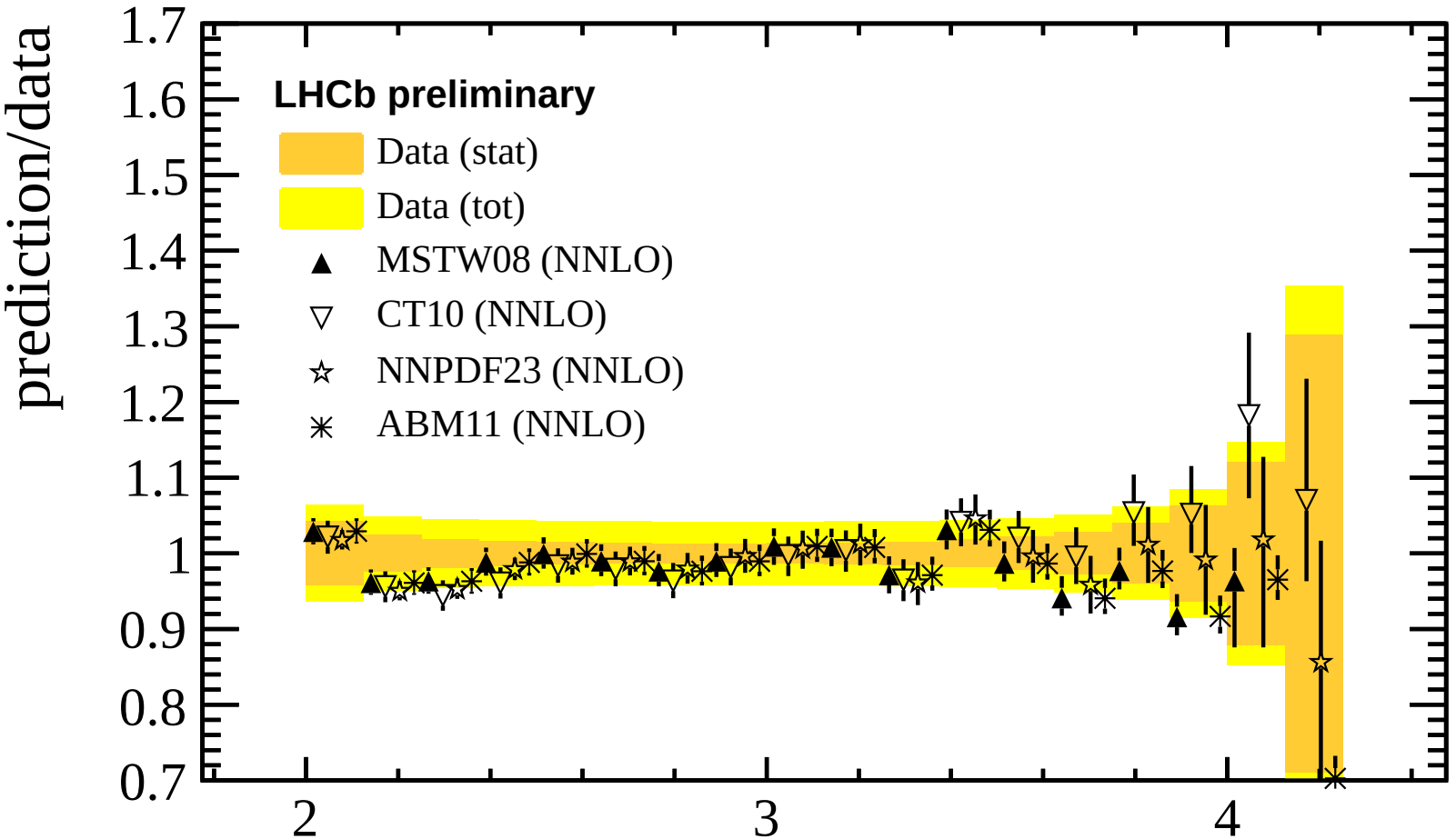
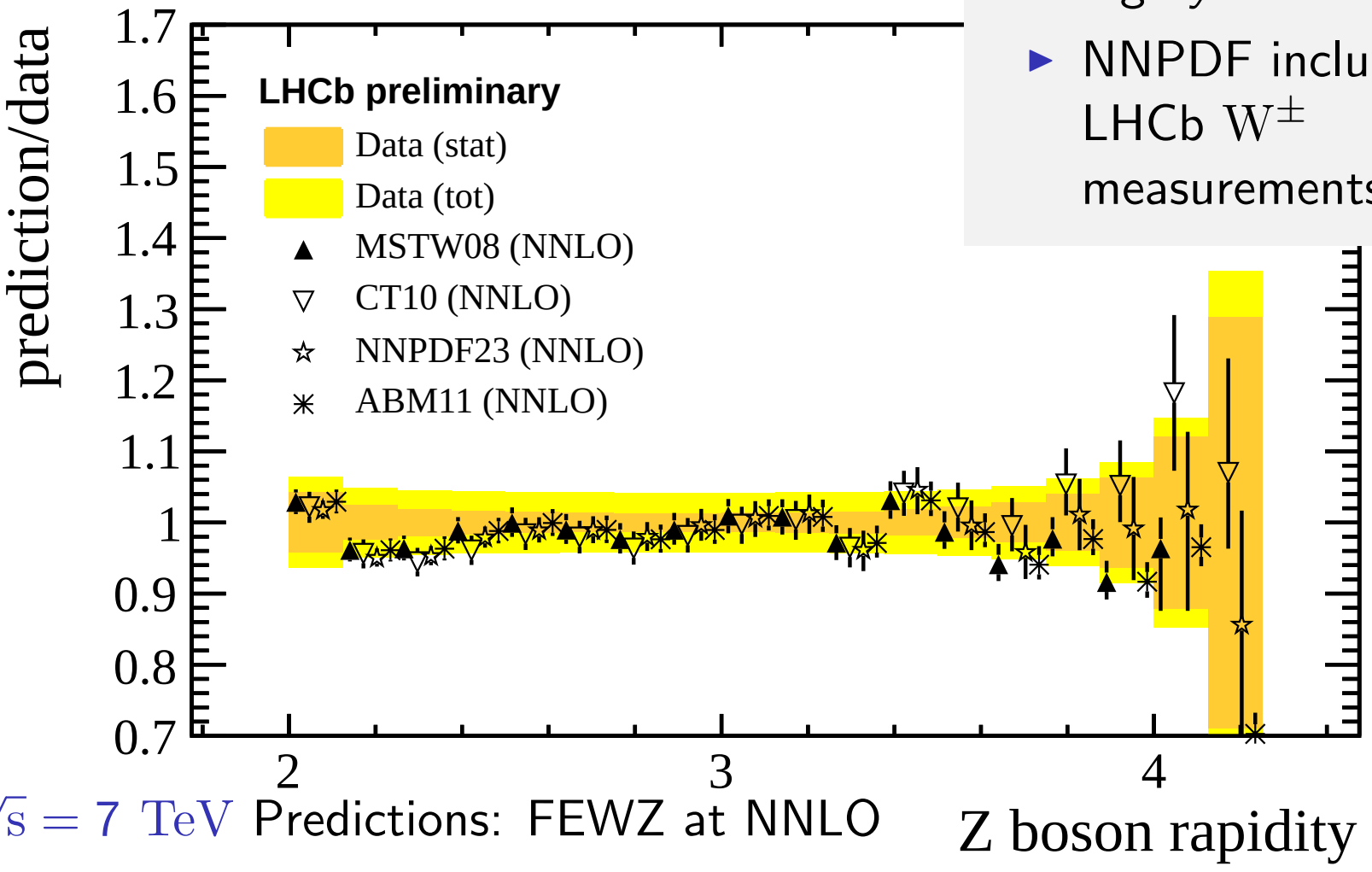


LHCb-CONF-2013-007

Z: Probe PDFs $x_{1,2} = \frac{m e^{\pm y}}{\sqrt{s}}$

- Uncertainty increases towards high y
- NNPDF includes LHCb $W^{\pm}$ measurements



LHCb-CONF-2013-007

D^0 and D^+ selection

		D^0 $K^-\pi^+$	D^+ $K^-\pi^+\pi^+$
y_D		$2 < y_{D^0} < 4$	$2 < y_{D^+} < 4$
$p_{T,D}$	[GeV]	$2 < p_{T,D^0} < 12$	$2 < p_{T,D^+} < 12$
χ^2_{VX}		< 9	< 25
χ^2_{IP}		< 9	< 9
$\frac{\chi^2_{DTF}}{n_{d.o.f}}$		< 5	< 5
$c\tau$	[μm]	$c\tau > 100$	$c\tau > 100$
m	[GeV]	$1.82 < m < 1.92$	$1.82 < m < 1.91$

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- D_s^+ and Λ_c^+ were searched for in the the same channels as in LHCb-PAPER-2013-003 without observing any candiate.
- Z selection almost untouched. Only $\frac{\chi^2_{DTF}}{n_{d.o.f}} < 5$ added w.r.t LHCb-CONF-2013-007