QCD and EW measurements in the forward region

Phenomenology Symposium 2013, Pittsburgh, USA

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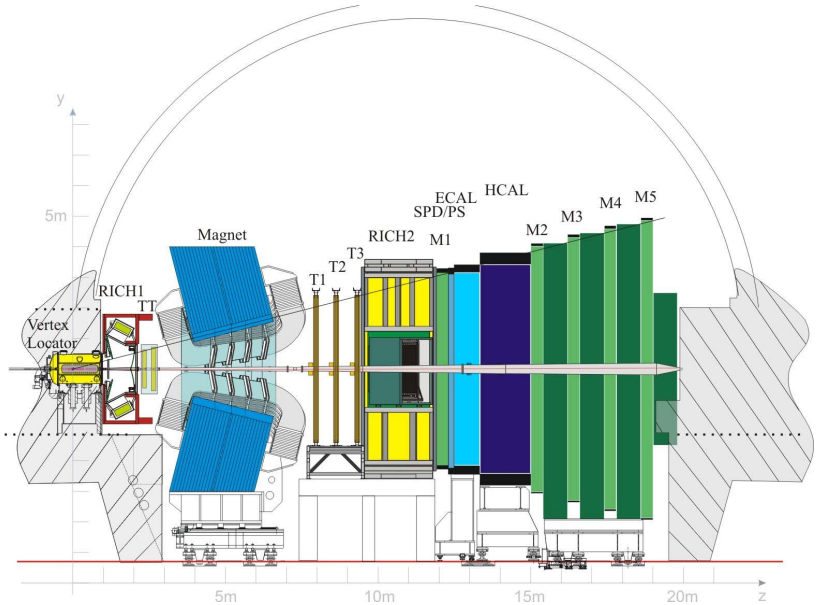
Contents

Introduction

- Single arm spectrometer, fully instrumented in forward region ($1.9 < \eta < 4.9$). Designed for flavour physics.
- Overlap with GPDs in $1.9 < \eta < 2.5$, LHCb unique precision coverage in $2.5 < \eta < 4.9$.
  - allows complementary studies in QCD and EW physics to ATLAS and CMS. The region of overlap also allows comparison of results.



- Excellent vertex resolution (VELO),
- Tracking detectors, ECAL, HCAL, Muon chambers,
- Ring Imaging Cherenkov (RICH) detectors for particle ID,
- Trigger on low p_T objects - e.g. single lepton ($p_T > 10$ GeV).

Prompt Hadron Production Ratios

Eur. Phys. J. C72 (2012) 2168

- LHCb has measured:
  - $\frac{\bar{p}}{p}$, $\frac{\pi^-}{\pi^+}$, $\frac{K^-}{K^+}$, $\frac{p+\bar{p}}{\pi^+ + \pi^-}$, $\frac{K^+ + K^-}{\pi^+ + \pi^-}$, $\frac{p+\bar{p}}{K^+ + K^-}$.
- Probes hadronisation in the forward region:
  - essential for tuning MC generators.
- Focus here on $\frac{\bar{p}}{p}$ - this measurement also constrains models of baryon number transport.

- 0.3 nb^{-1} at $\sqrt{s} = 0.9$ TeV and 1.8 nb^{-1} at $\sqrt{s} = 7$ TeV.
- RICH detectors used to determine particle type. Main systematic comes from uncertainty on particle ID.

Prompt Hadron Production Ratios

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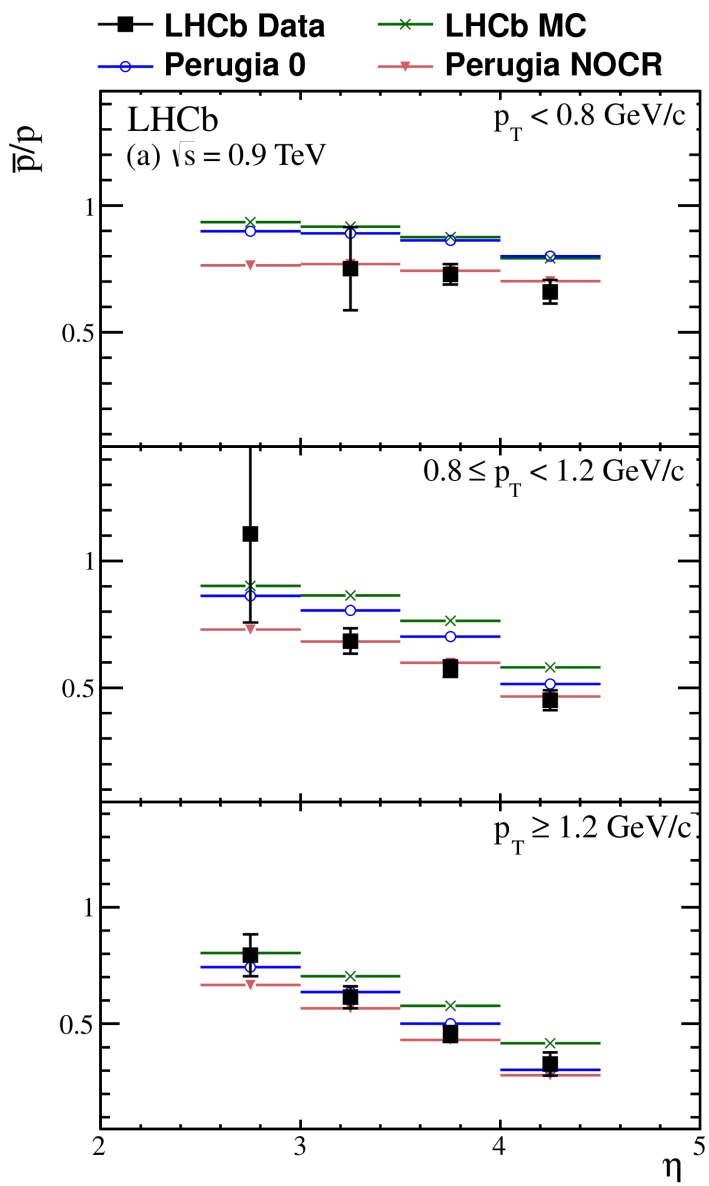
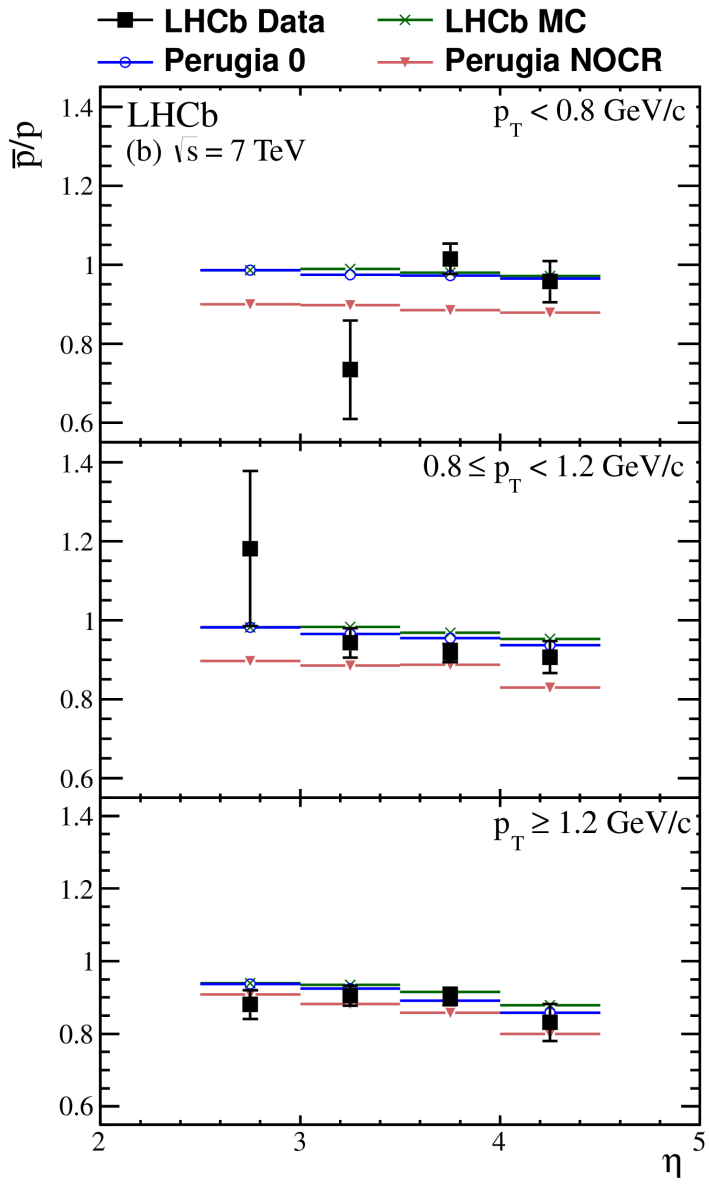
- Best agreement with simulation is seen with PYTHIA 6 Perugia NOCR tune.
- No one tune describes all the data.





Prompt Hadron Production Ratios

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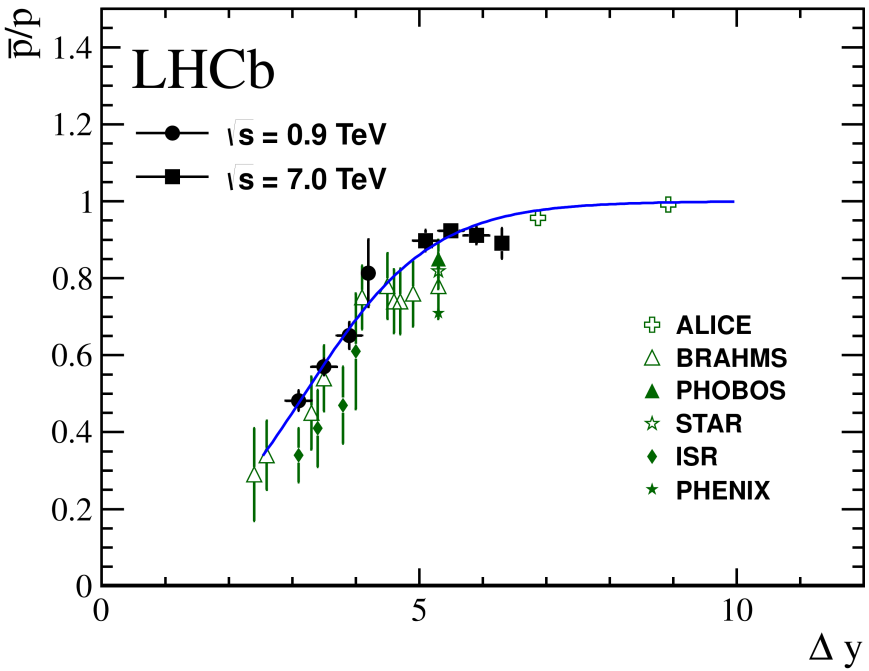
- Measure distributions as a function of rapidity loss,
  $\Delta y = y_{\text{beam}} - y_{\text{particle}}$ $[y_{\text{beam}} = 8.9(6.9)$ at $7(0.9)$ TeV$]$



- LHCb results are high precision and complementary to ALICE measurements.
- Curve fitted to LHCb and ALICE data is Regge model of baryon transport.

Energy Flow in the forward region

arXiv: 1212.4755

- Measure energy flow in low pile-up minimum bias data.
  - $\int \mathcal{L} \cdot dt = 0.1$ nb^{-1}, $\sqrt{s} = 7$ TeV.
- Sensitive to overall event activity:
  - At LHC collision energies inelastic collisions of low x partons are sufficiently energetic to give significant final state production.
  - At low x parton densities are large, so we probe Multiple Parton Interactions (MPI) with energy flow measurements.
- Measure the energy flow differentially in bins of η:

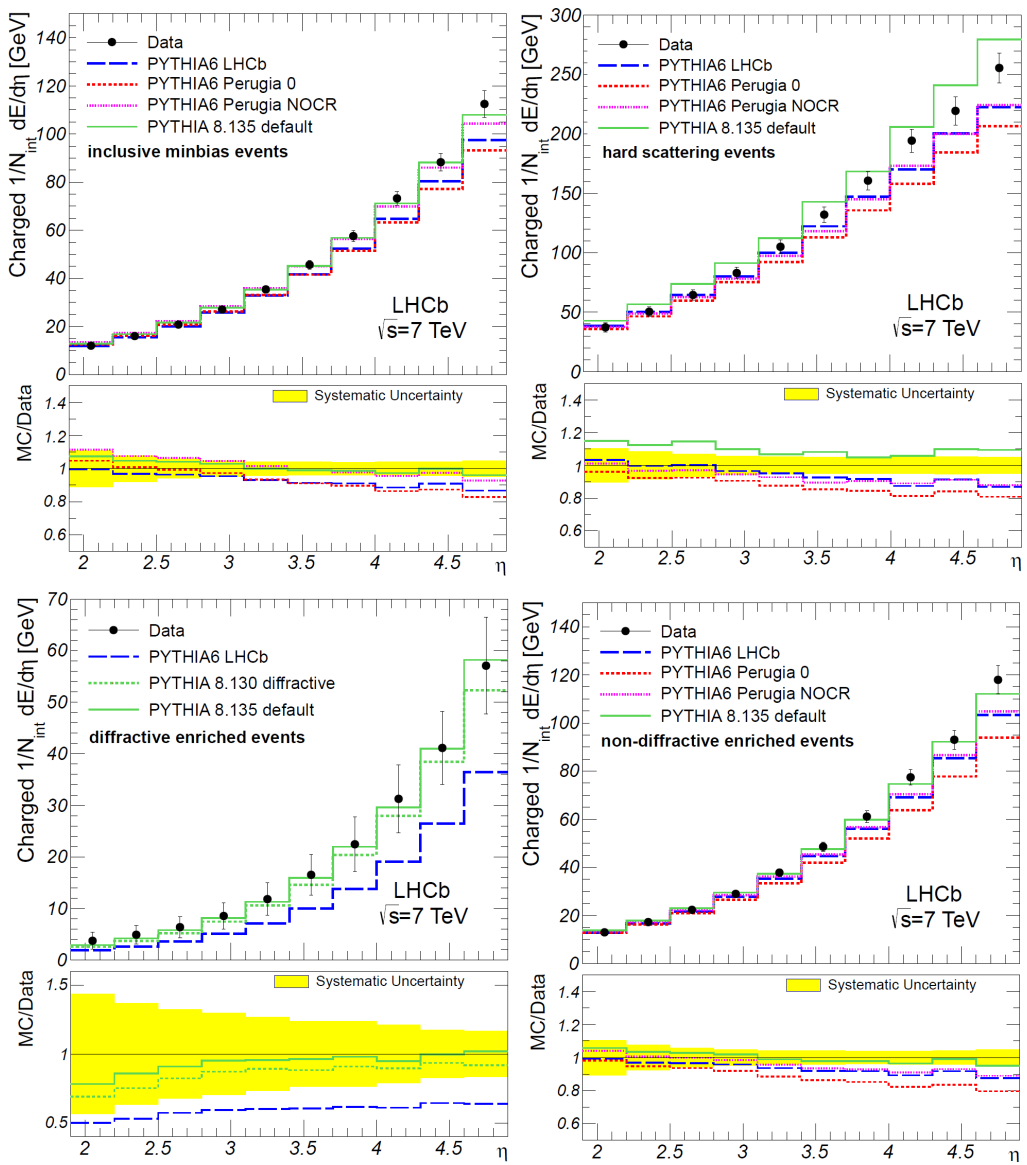
$$\frac{1}{N_{\text{int}}}\frac{dE}{d\eta} = \frac{1}{N_{\text{int}}}\frac{1}{\Delta\eta}\left(\sum_{i=1}^{N\text{parts},\ \eta} E_{i,\eta}\right)$$

- Measure charged content of energy flow, correcting for neutral content from simulation.
- Dominant systematic: Model dependency of corrections from detector level to generator level.

Energy Flow in the forward region

arXiv: 1212.4755

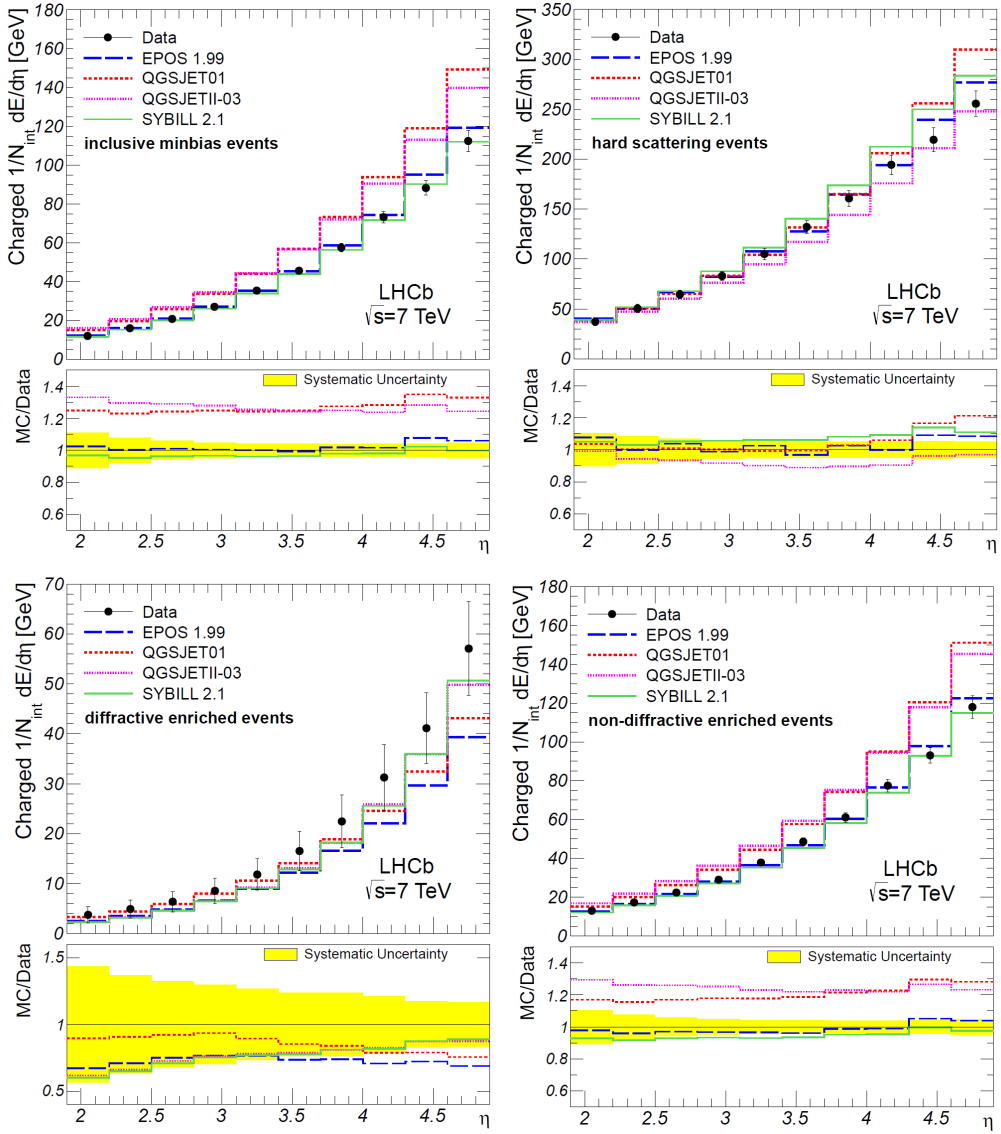
- Consider Energy flow in 4 different event classes:
  - Inclusive Minimum Bias
    ≥ 1 track with $p > 2$ GeV and $1.9 < \eta < 4.9$.
  - Hard Scattering
    ≥ 1 track with $p_T > 3$ GeV and $1.9 < \eta < 4.9$.
  - Diffractive enriched
    no track within $-1.5 < \eta < -3.5$.
  - Non-diffractive
    ≥ 1 track within $-1.5 < \eta < -3.5$.
- PYTHIA8 describes the data best.



Energy Flow in the forward region

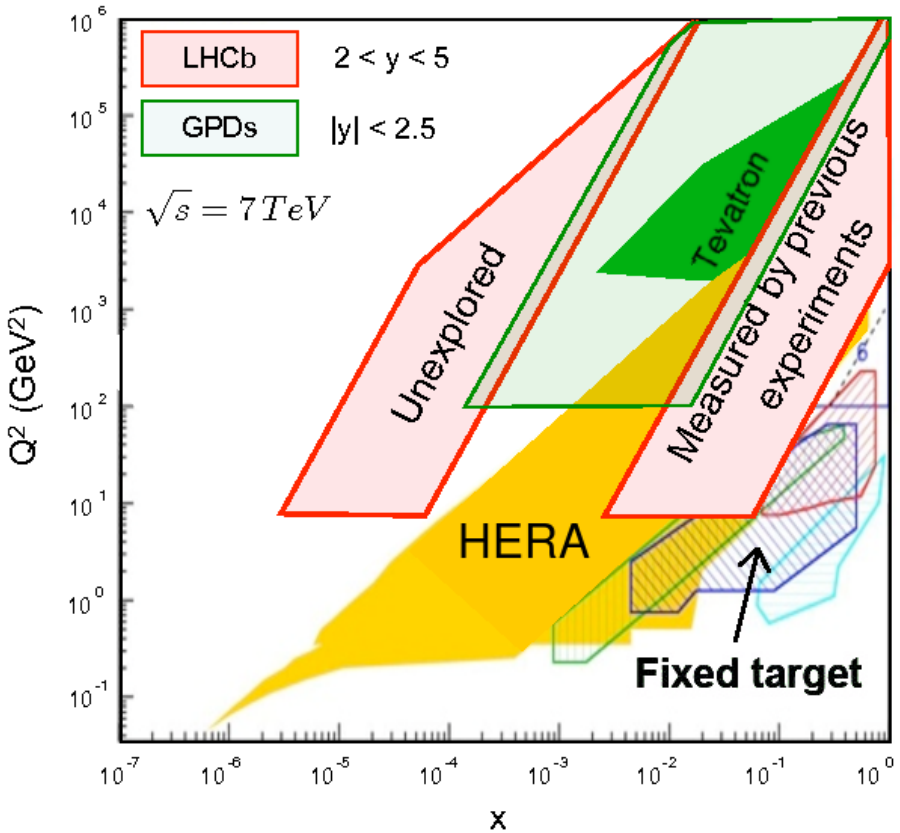
arXiv: 1212.4755

- We consider the same events, and same categories, but now compare to different predictions.
- Can use energy flow measurements to test cosmic ray MC - which can be related to collider predictions by changing frame:
  - $\sqrt{s_{\text{LHC}}} = 2E_{\text{beam}}$
  - $\sqrt{s_{\text{Cosmic}}} \sim \sqrt{2 \cdot m \cdot E_{\text{ray}}}$
- EPOS and SIBYLL perform best.



W & Z production in the forward region

- Main theory uncertainty on benchmark Standard Model Processes comes from uncertainties in parton distribution functions (PDFs).

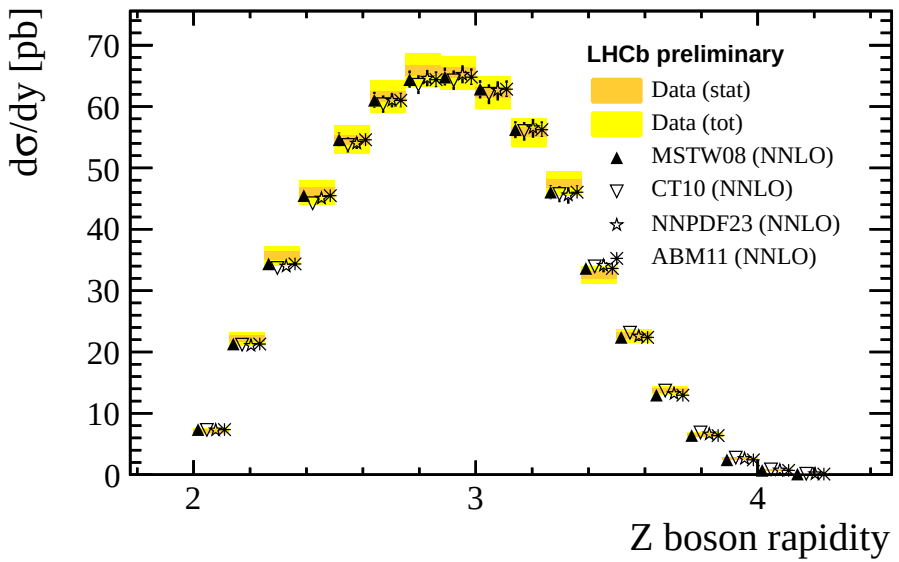


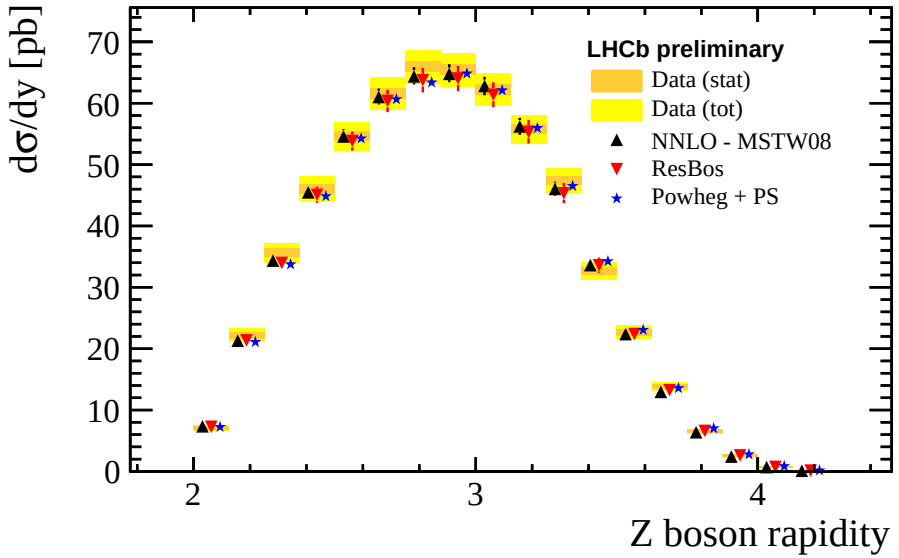
- LHCb is sensitive to previously unexplored region of low x-high Q^2 phase space.
- Can use measurements at LHCb to constrain PDFs.
- PDF uncertainties largely cancel in some cross-section ratios - can also probe the standard model.

Z production in the forward region

LHCb-CONF-2013-007

- 1 fb^{-1} data at $\sqrt{s} = 7$ TeV.
- Consider dilepton final states (right hand plots for dimuon).
- Fiducial Acceptance:
  - $p_T(\ell) > 20$GeV,
  - $2.0 < \eta(\ell) < 4.5$,
  - $60 < M(\ell\ell) < 120$ GeV.
- 99.7% purity in $\mu\mu$ final state.
- Efficiencies taken from data using tag and probe methods.
- Dominant systematic from luminosity (3.5%).





Z production in the forward region

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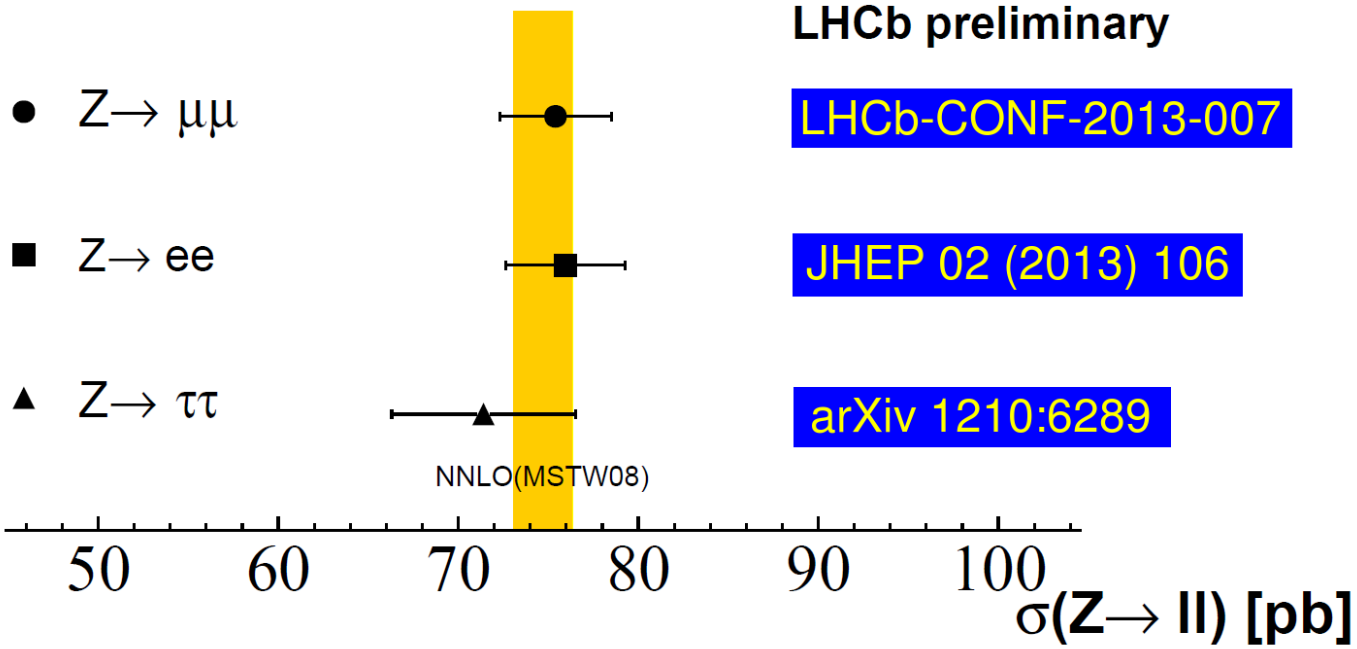
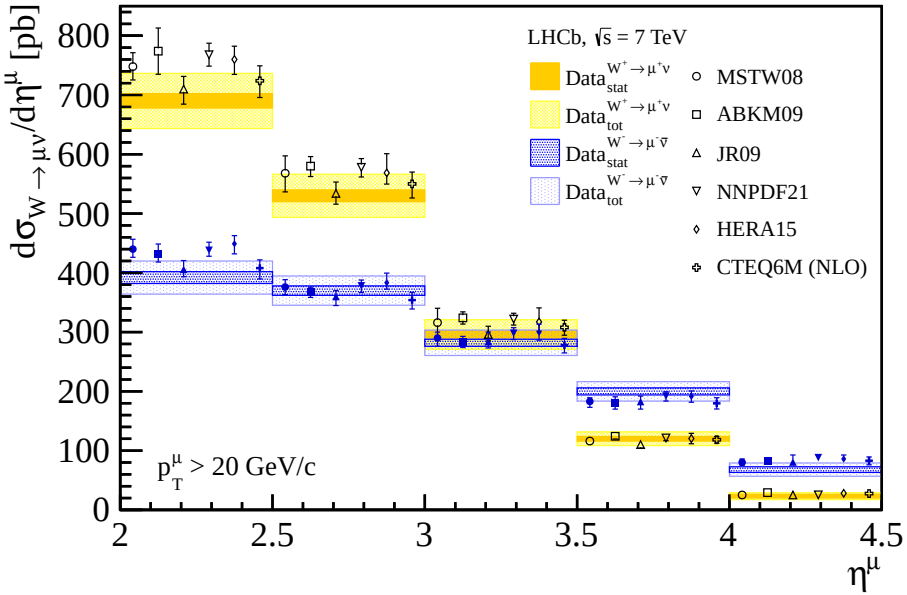


- Recent $Z \to \mu\mu$ result agrees well with other dilepton results.
- Very good agreement with NNLO predictions.

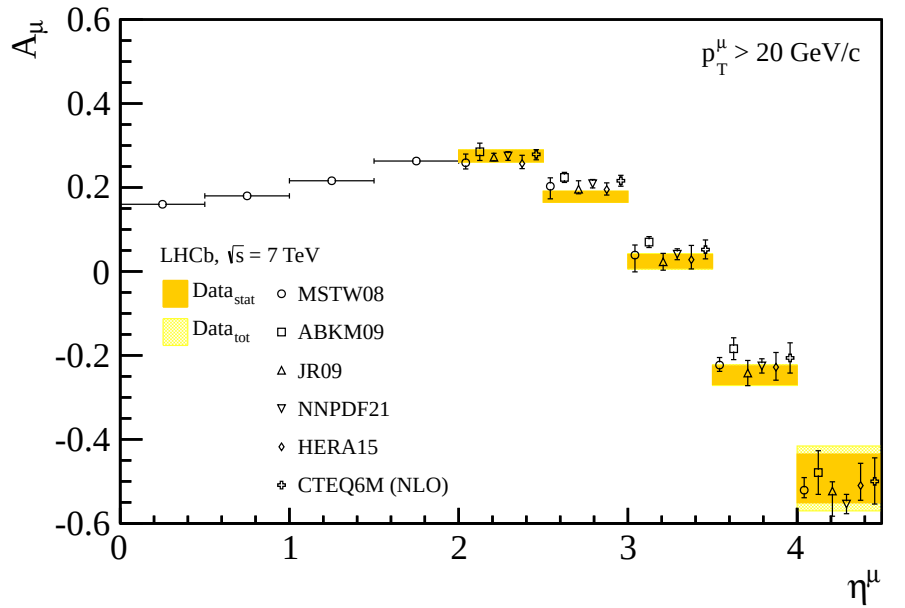
W production in the forward region

JHEP 06 (2012) 058

- 37 pb^{-1} data at $\sqrt{s} = 7$ TeV.
- Fiducial Acceptance:
  - $p_T(\mu) > 20$GeV,
  - $2.0 < \eta(\mu) < 4.5$,



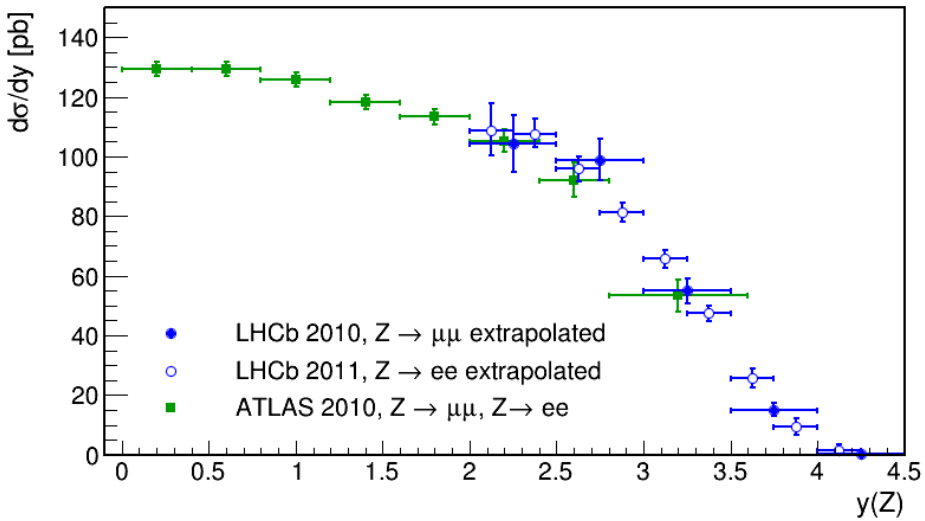
- Lepton charge asymmetry,
  $A_\mu = \frac{\sigma(W^+) - \sigma(W^-)}{\sigma(W^+) + \sigma(W^-)}$
- Many experimental uncertainties cancel in A_μ so we can perform a high precision measurement.

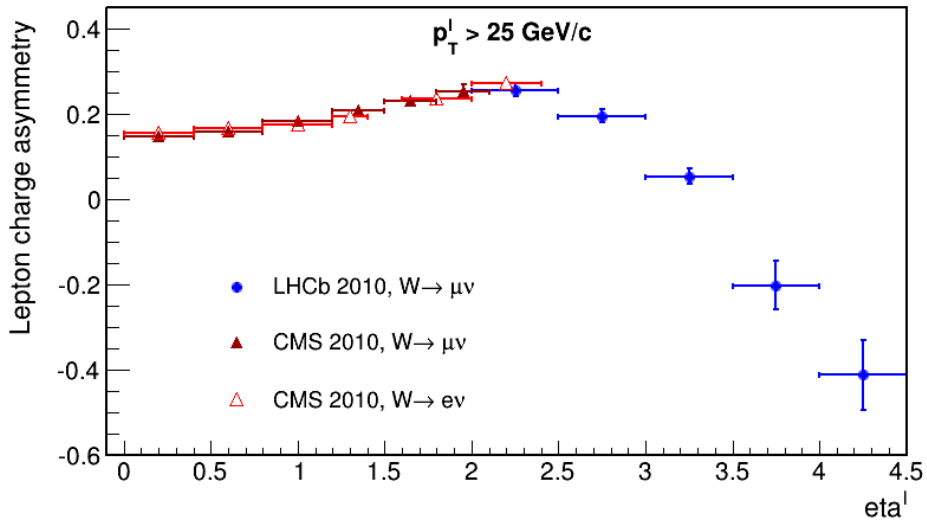


Comparison with ATLAS and CMS

LHCb-CONF-2013-005

- Where necessary, extrapolate LHCb results as a function of (pseudo)rapidity, to account for different ATLAS and CMS fiducial acceptances.
- Dominant uncertainty in extrapolation tends to be from scale variation at low η, and PDF uncertainties at high η.



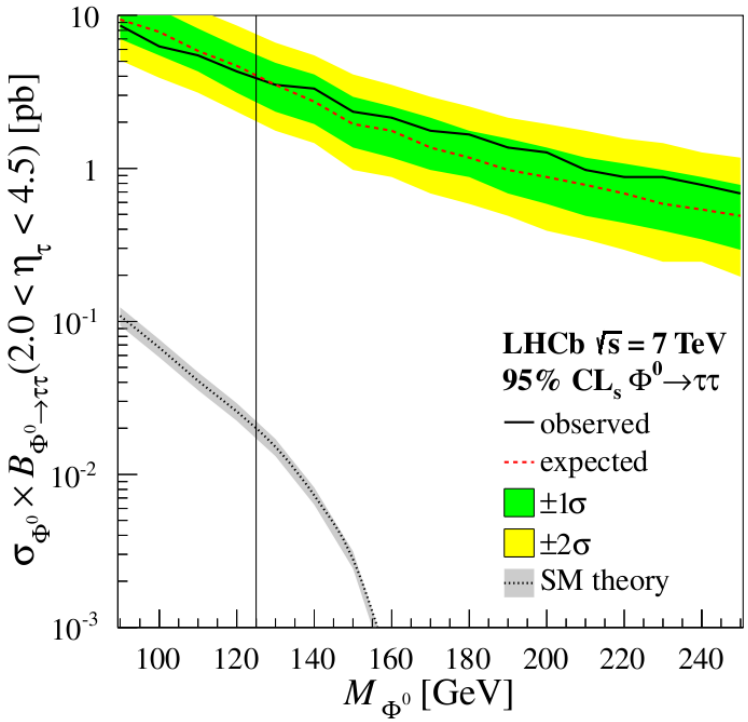


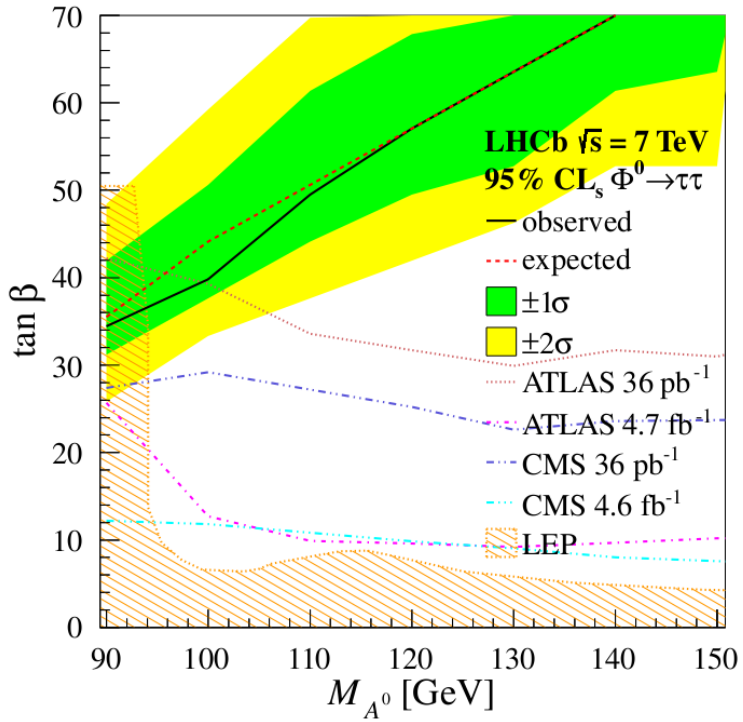
- See very good agreement in region of overlap between ATLAS, CMS and LHCb results.
- LHCb extends the GPD results into a previously unexplored region of phase space which can be used to constrain PDFs.

Limits on Neutral Higgs Production

arXiv: 1304.2591

- Extension to $Z \rightarrow \tau\tau$ analysis (arXiv 1210:6289).
- Treat $Z \rightarrow \tau\tau$ as background to some general neutral Higgs process: $\Phi^0 \rightarrow \tau\tau$.
- No Φ^0 excess seen - set a model-independent limit on cross-section.
- We can express this limit as constraints on MSSM parameters.
- Measurement also adds strong constraints on models where forward production is favoured.





Other results

- Measurement of the cross-section for Z$\rightarrow$ *ee* production in pp collisions at $\sqrt{s} = 7$ TeV

  JHEP 02 (2013) 106
- Exclusive J/ψ and ψ(2S) production in pp collisions at $\sqrt{s} = 7$ TeV

  arXiv: 1301.7084
- Measurement of charged particle multiplicities in pp collisions at $\sqrt{s} = 7$ TeV in the forward region

  Eur. Phys. J. C72 (2012) 1947
- First analysis of the pPb pilot run data with LHCb

  LHCb-CONF-2012-034
- Measurement of jet production in $Z^0/\gamma^* \rightarrow \mu\mu$ events at LHCb in $\sqrt{s} = 7$ TeV pp collisions

  LHCb-CONF-2012-016
- Search for Higgs-like bosons decaying into long-lived exotic particles

  LHCb-CONF-2012-014
- Inclusive low mass Drell-Yan production in the forward region at $\sqrt{s} = 7$ TeV

  LHCb-CONF-2012-013

Summary

- LHCb occupies a unique region of phase space at the LHC, allowing complementary measurements to ATLAS, CMS and ALICE.
- QCD measurements at LHCb provide insight into a range of processes, like baryon number transport and energy flow. These measurements can be used to tune MC generators.
- EW measurements at LHCb can be used to:
  - constrain PDFs in previously unexplored regions.
  - set limits in SUSY parameter space.
  - test the standard model using ratios of benchmark processes which are very well predicted.
- LHCb results show good agreement with Standard Model predictions and measurements by the GPDs.

BACKUP SLIDES

Summary of EW results in the Muon Channels

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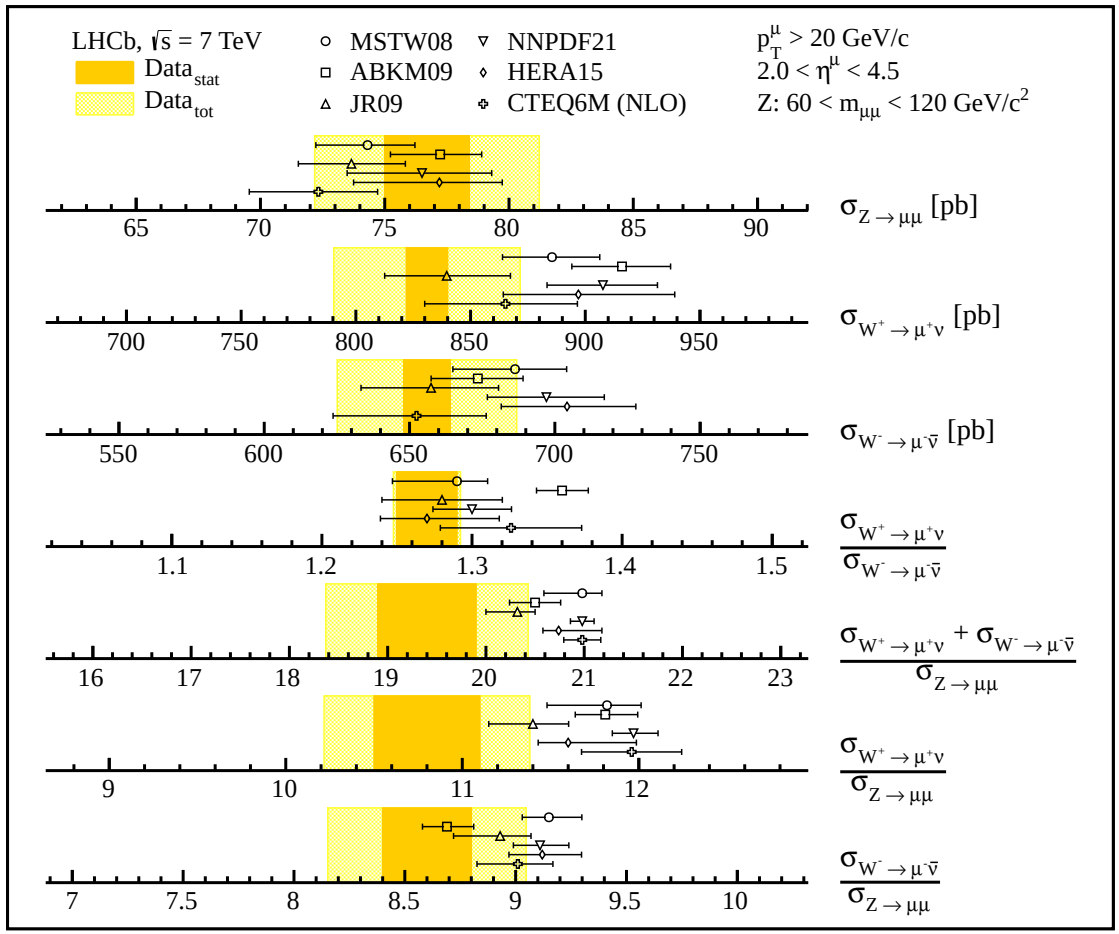

$W \to \mu\nu$

JHEP 06 (2012) 058

Contributions to the systematic uncertainty for the total W cross-sections.

Source	$\Delta\sigma_{W^+\to\mu^+\nu}$ (%)	$\Delta\sigma_{W^-\to\mu^-\bar{\nu}}$ (%)
Signal purity	± 1.2	± 0.9
Template shape (fit)	± 0.9	± 1.0
Efficiency (trigger, tracking, muon id)	± 2.2	± 2.0
Additional selection	± 1.8	± 1.7
FSR correction	± 0.01	± 0.02
Total	± 3.2	± 2.9
Luminosity	± 3.5	± 3.5

$W \to \mu\nu$

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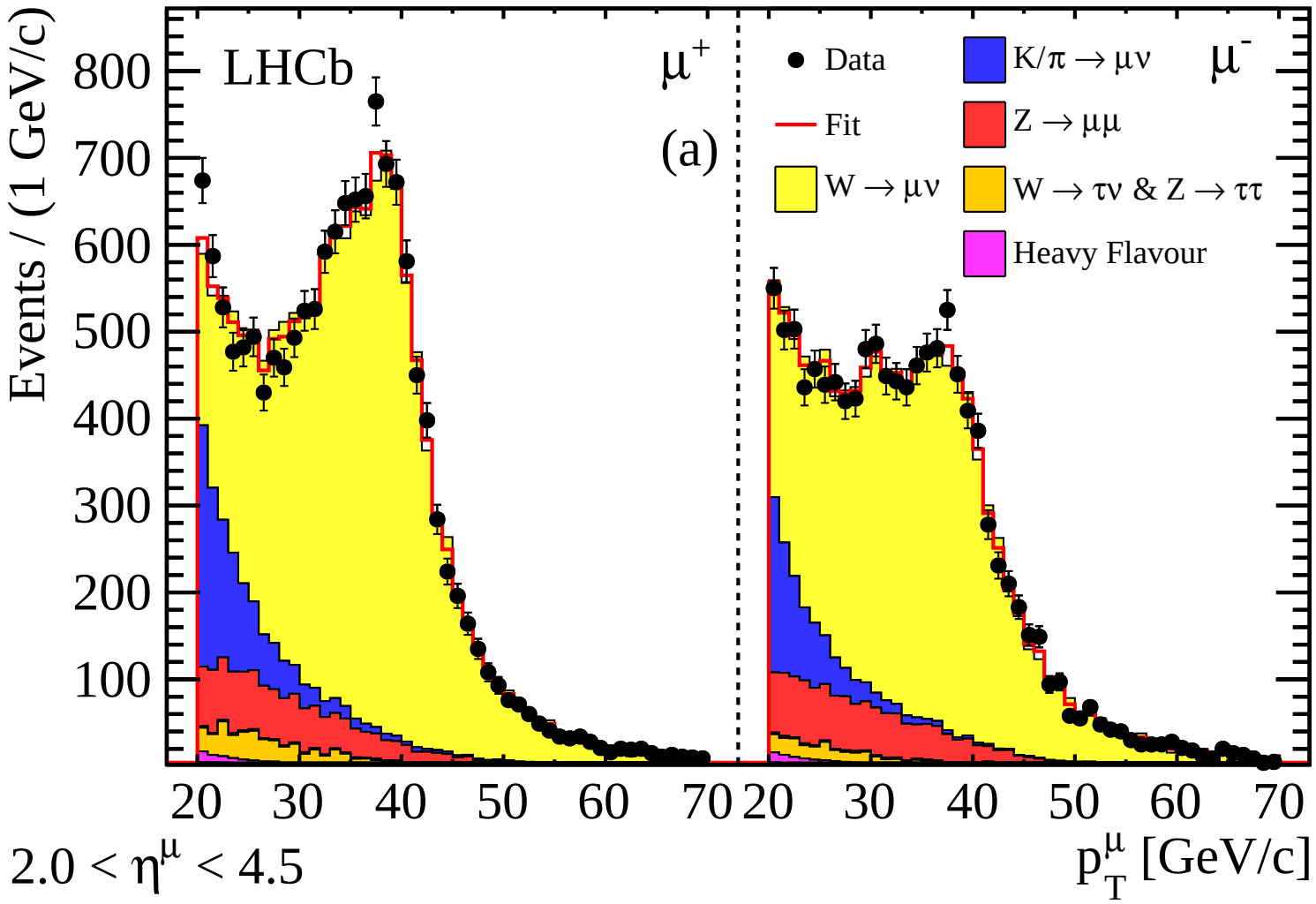

$Z \rightarrow \mu\mu$

LHCb-CONF-2013-007

Contributions to the systematic uncertainty for the total Z cross-sections.

Source	Uncertainty (%)	Between bins
Tracking efficiency	± 1.1	mostly correlated
GEC efficiency	± 1.1	correlated
Muon-id efficiency	± 0.5	mostly correlated
Muon trigger efficiency	± 0.5	mostly correlated
Magnet polarity	± 1.6	uncorrelated
Bin-to-bin migrations	± 0.7	uncorrelated
FSR correction	± 0.2	uncorrelated
Signal purity	± 0.03	correlated
Total	± 2.5	
Luminosity	± 3.5	correlated

$Z \rightarrow \mu\mu$

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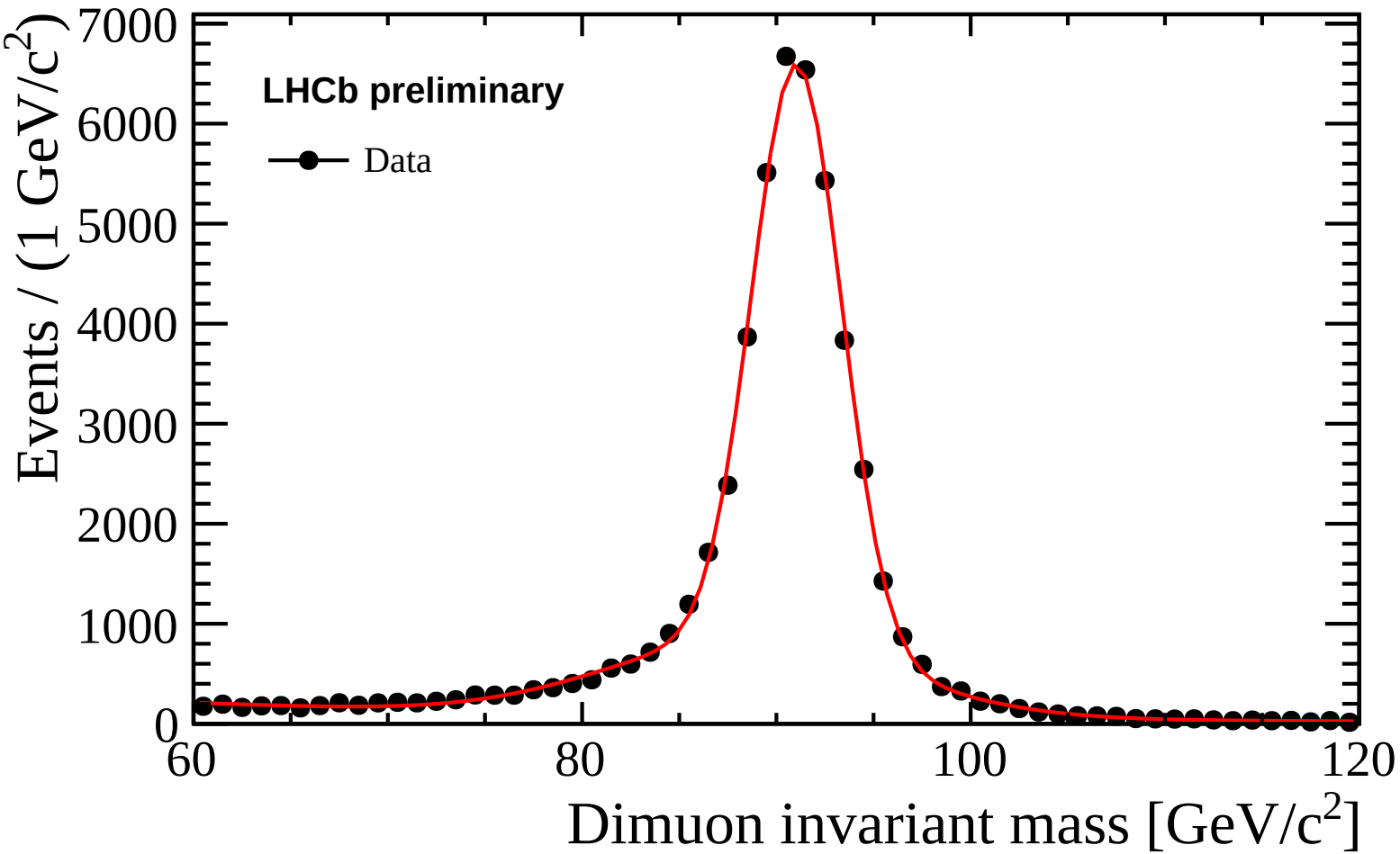

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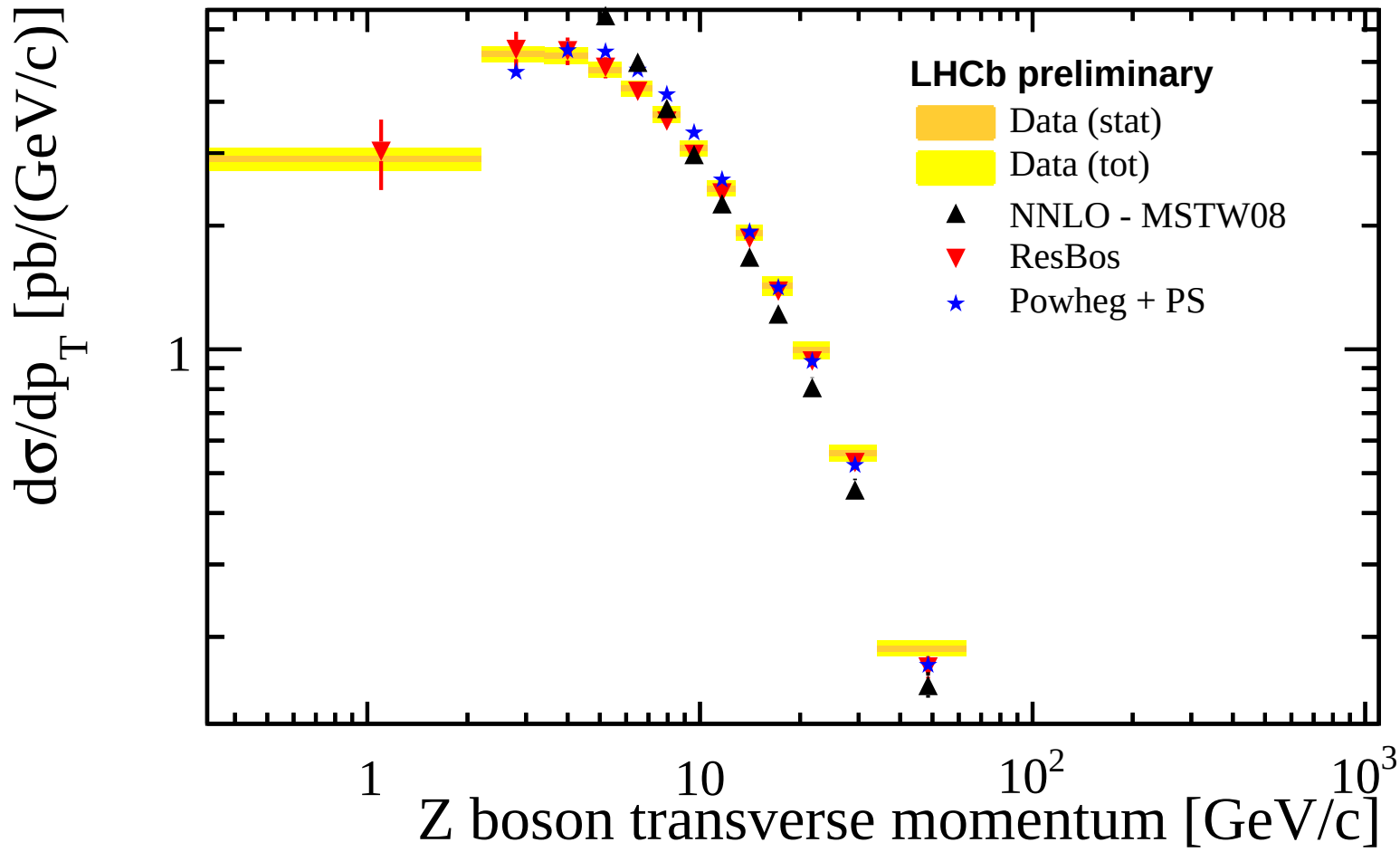

$Z \to \mu\mu$

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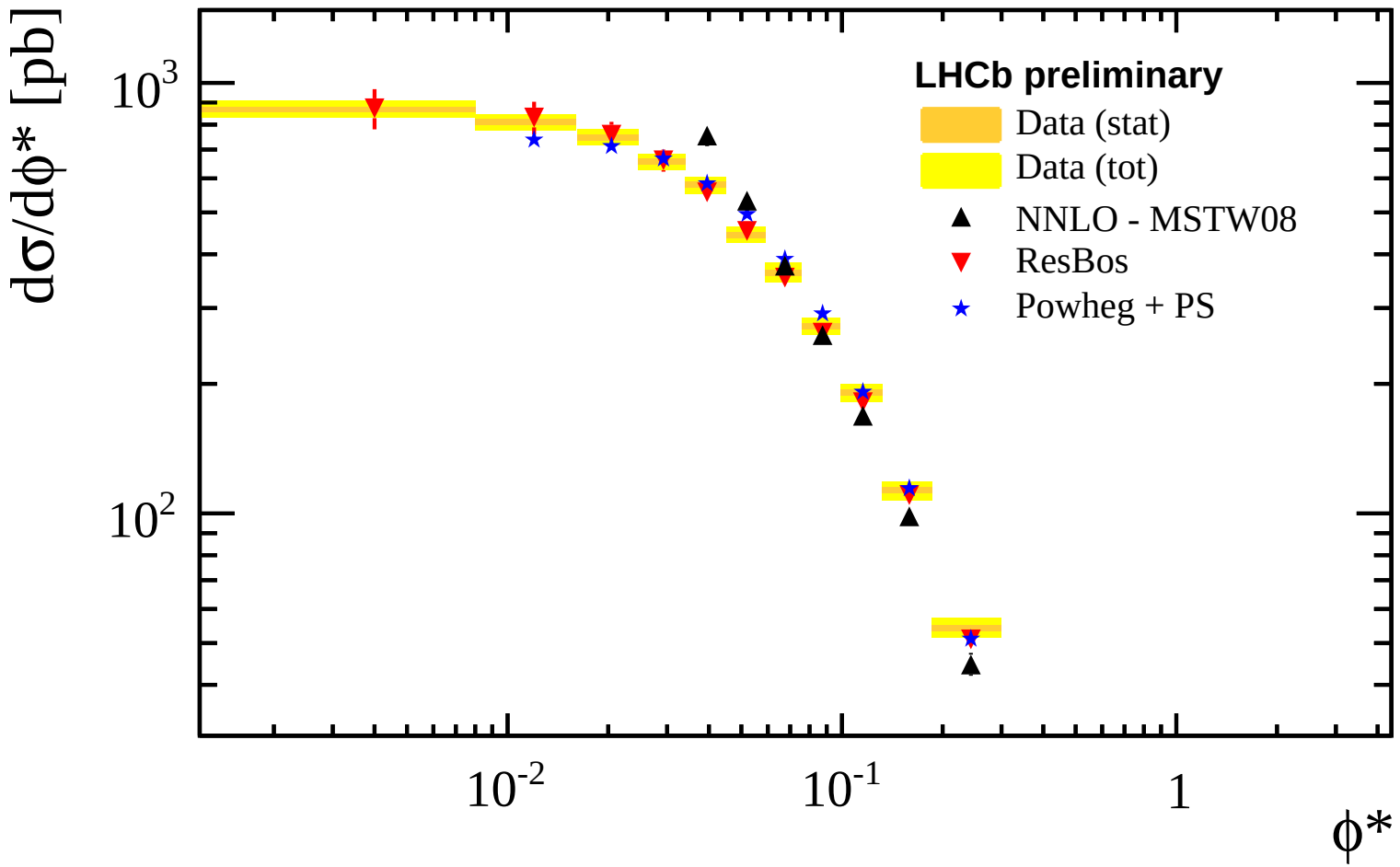

$Z \longrightarrow ee$

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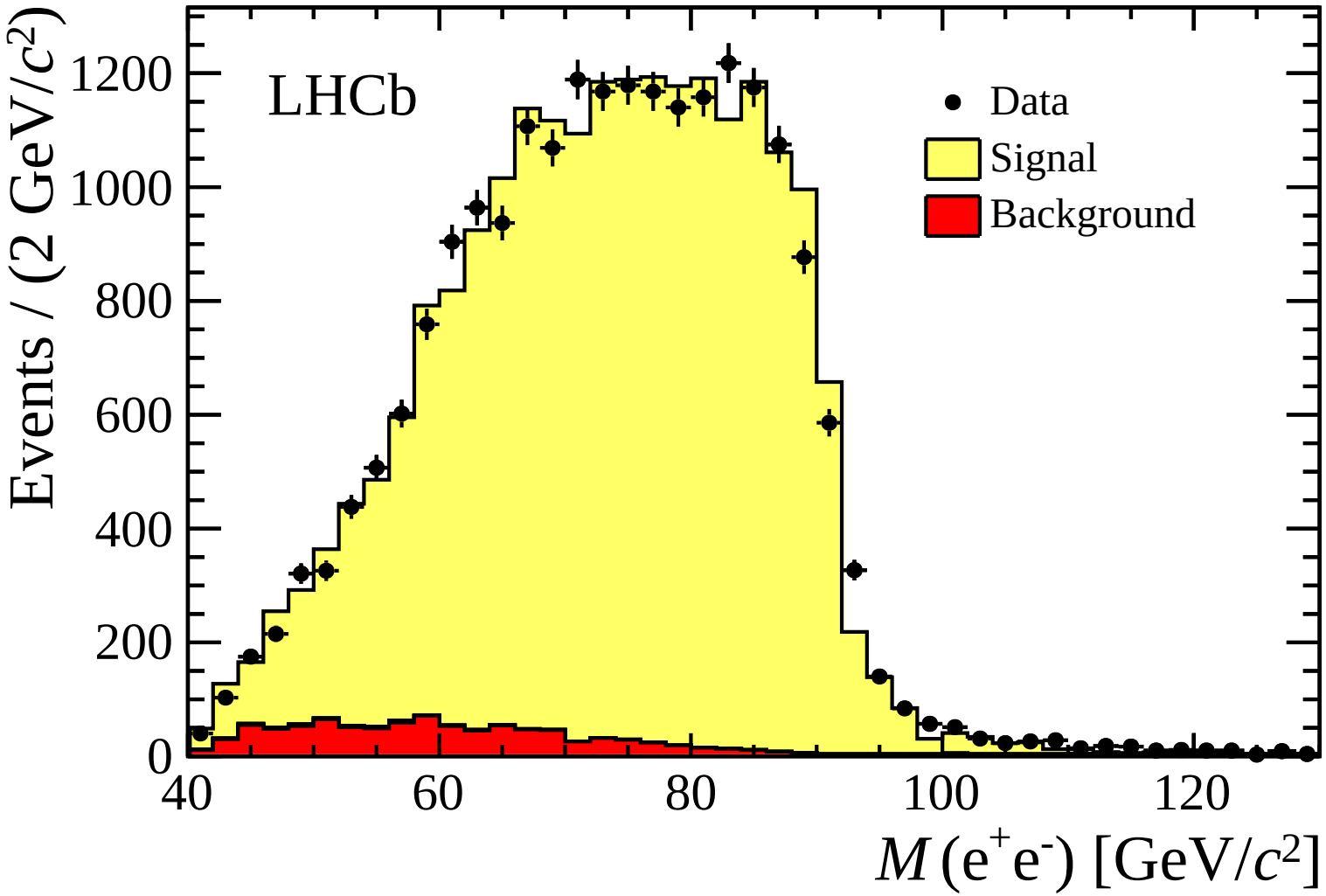

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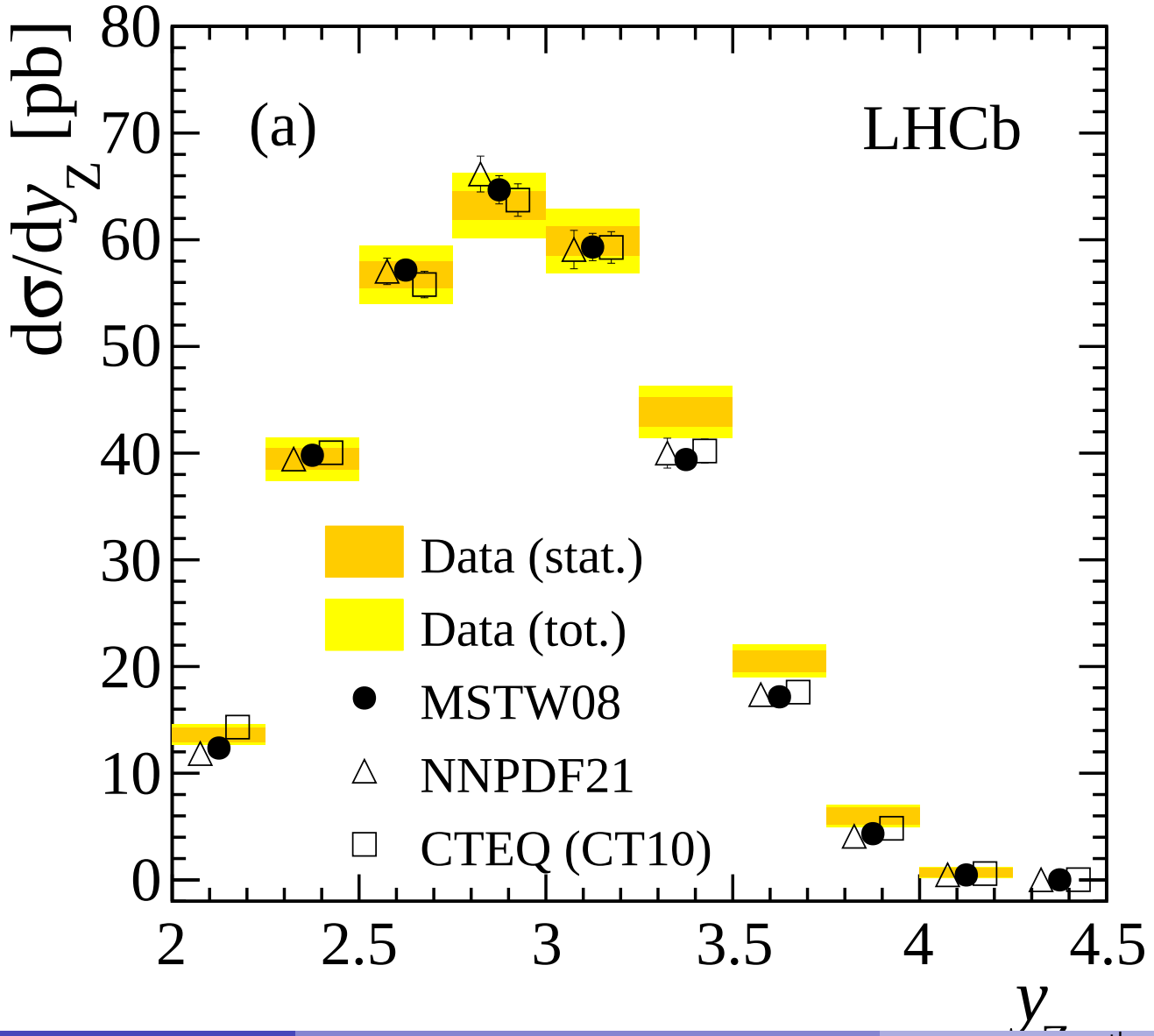

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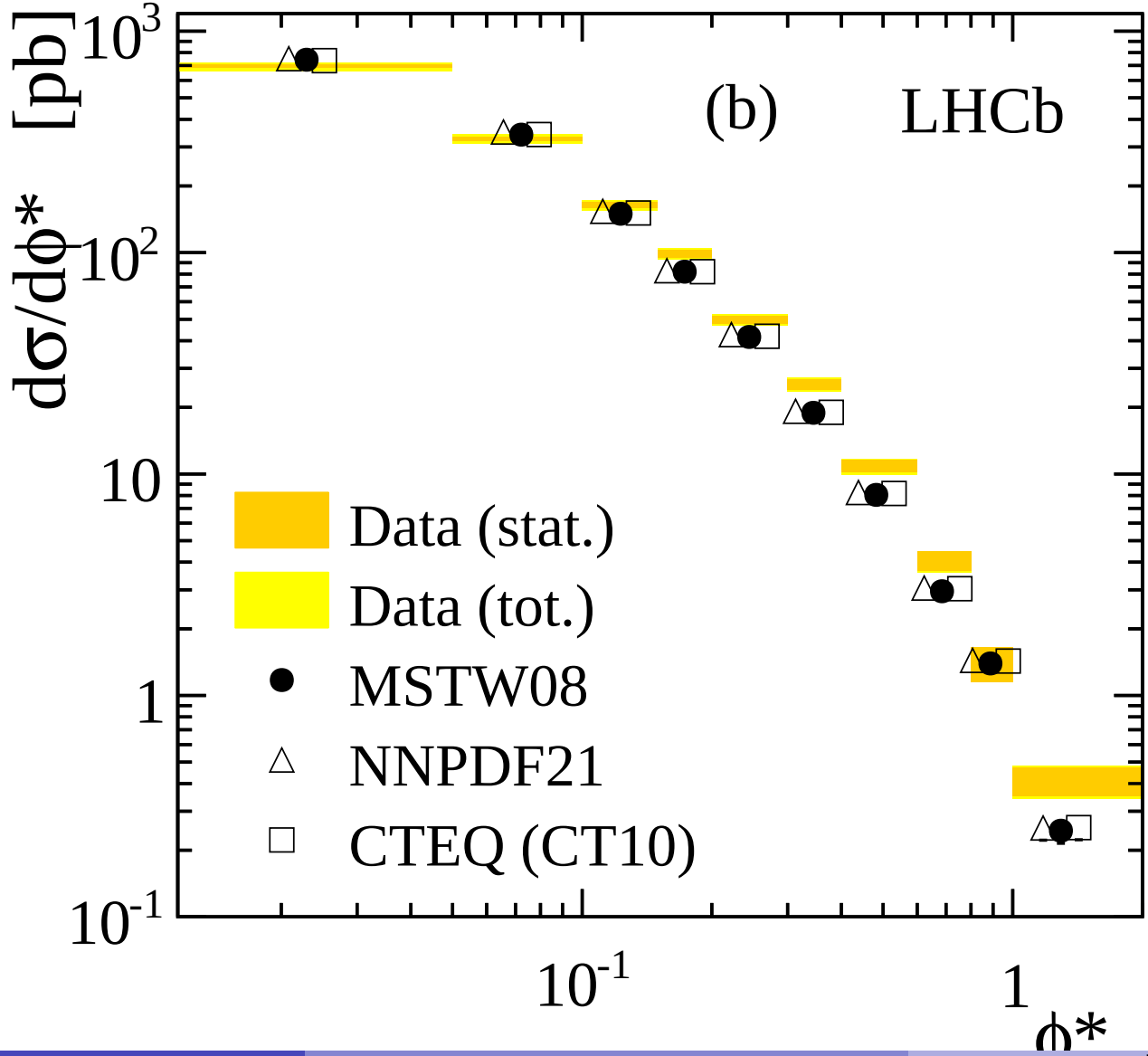
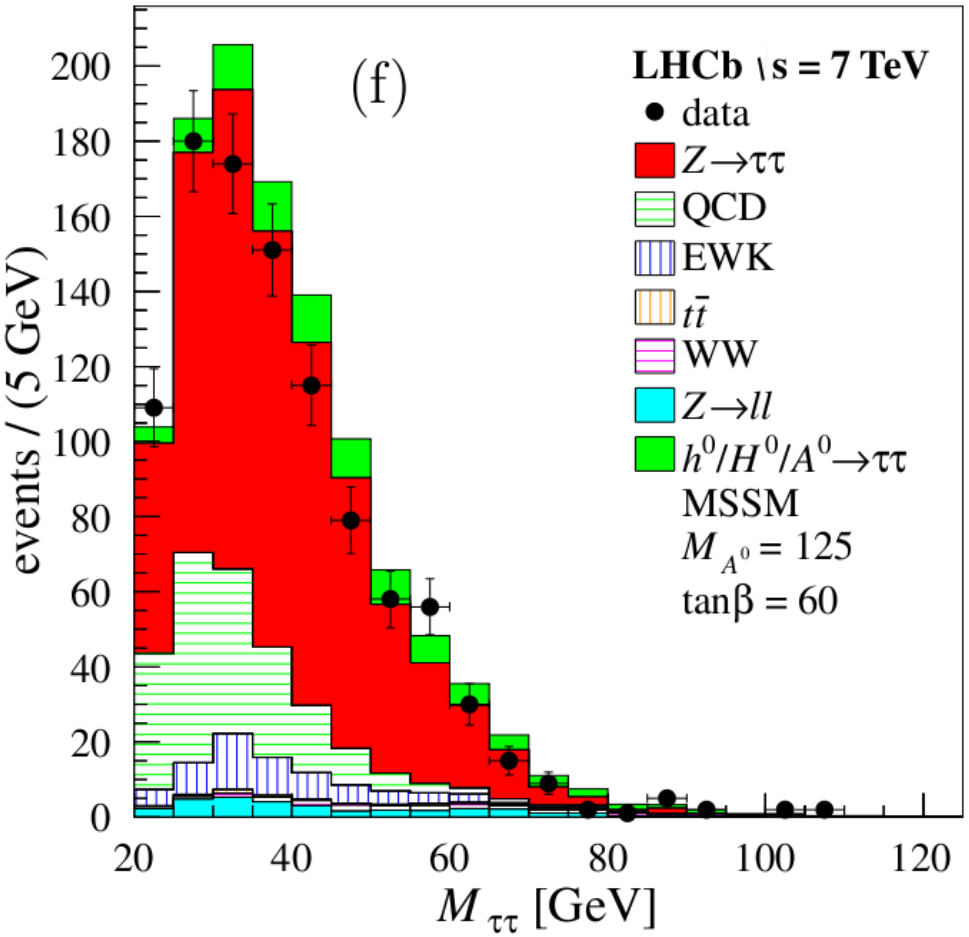


$\Phi^0 \longrightarrow \tau\tau$

arXiv: 1304.2591



Drell-Yan Production

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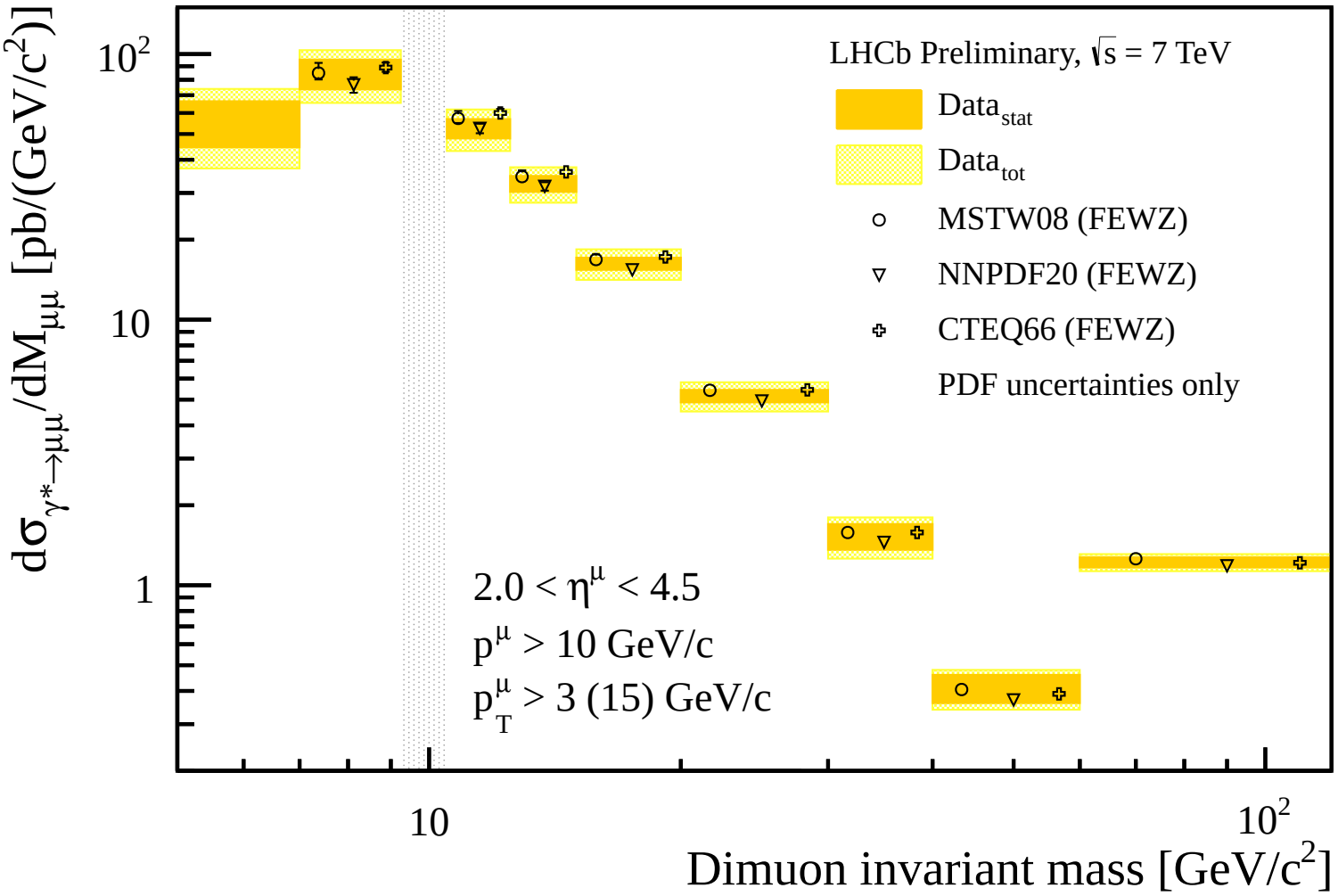

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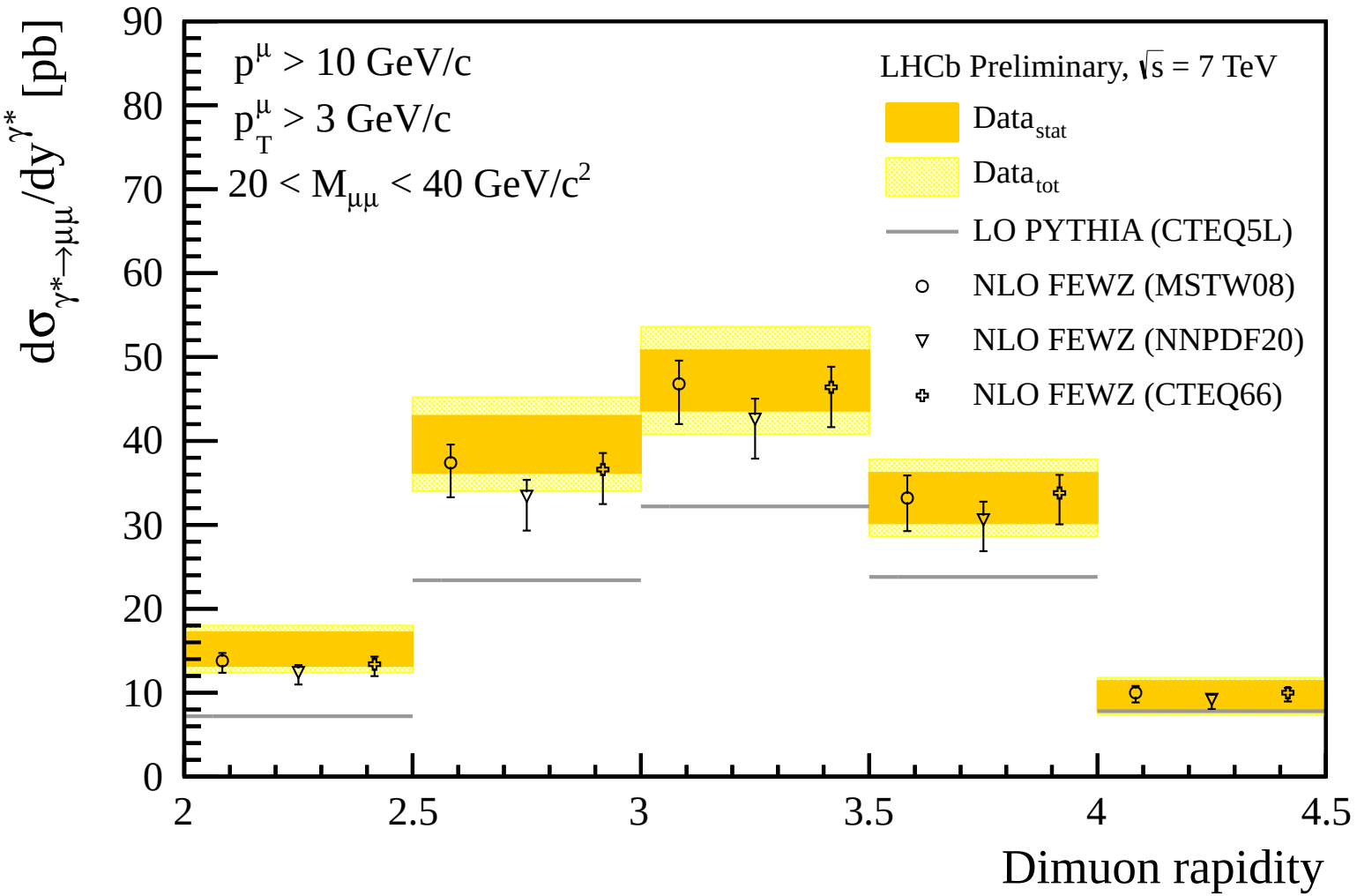
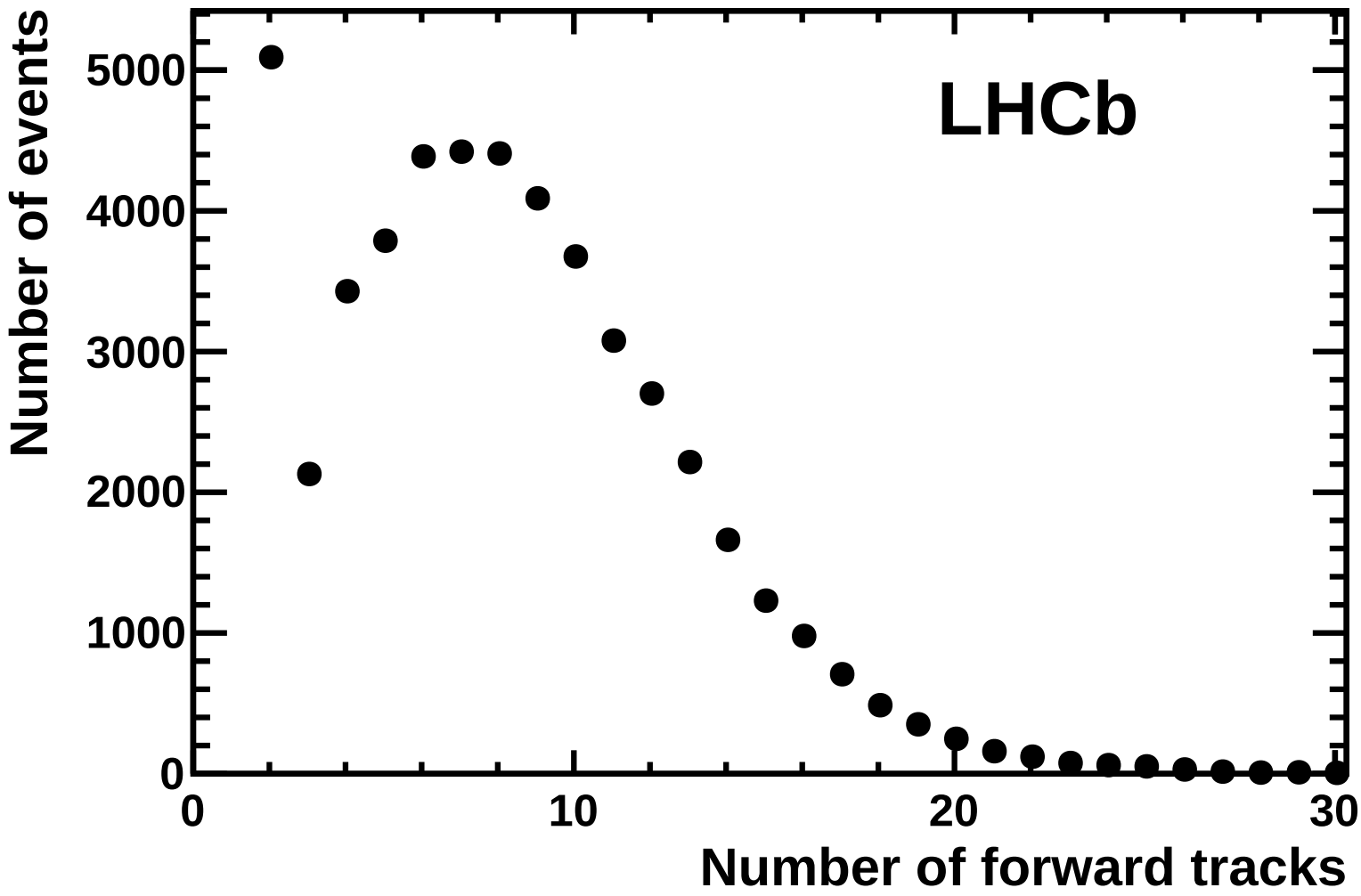


Exclusive Production

arXiv: 1301.7084



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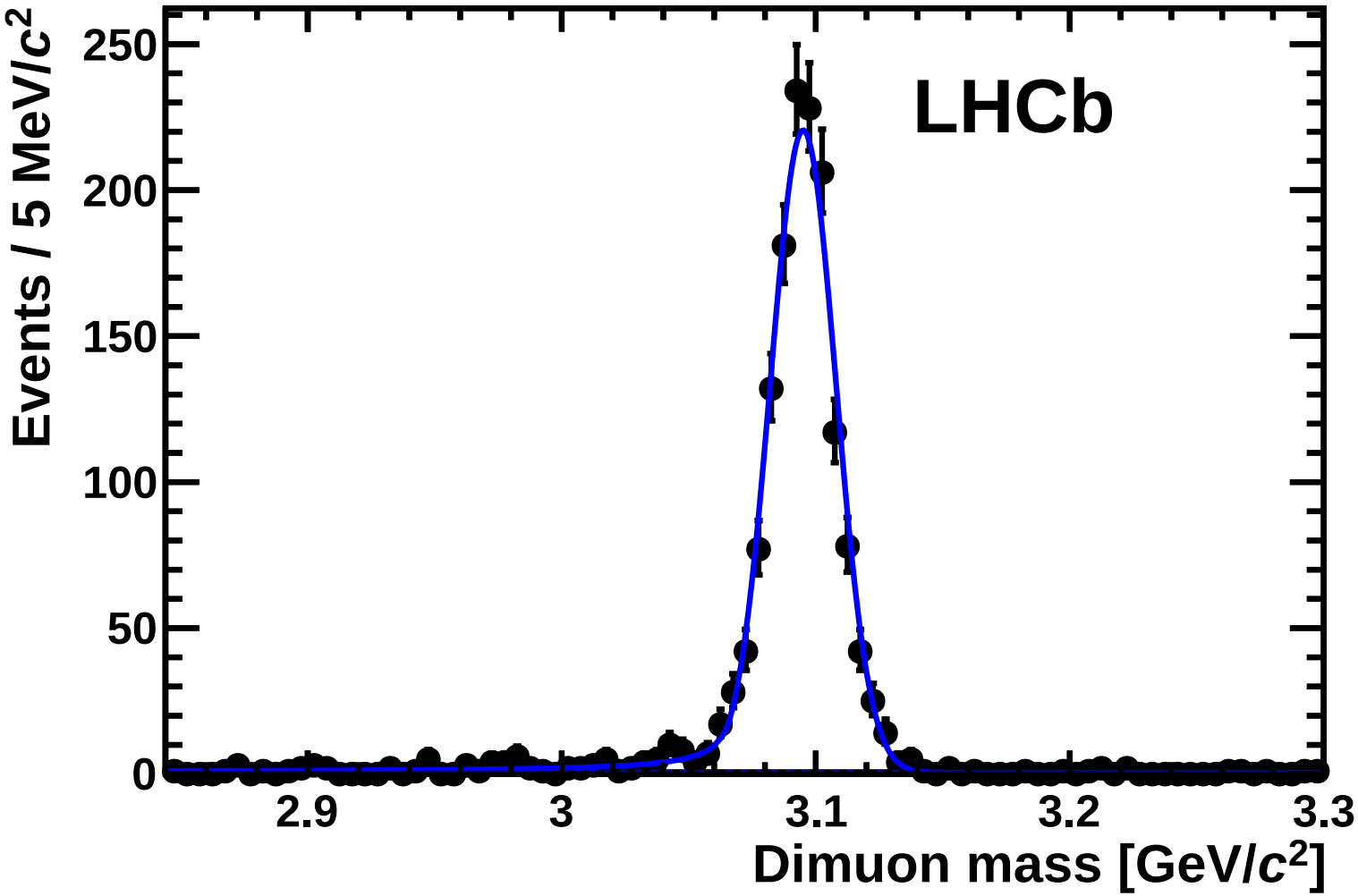

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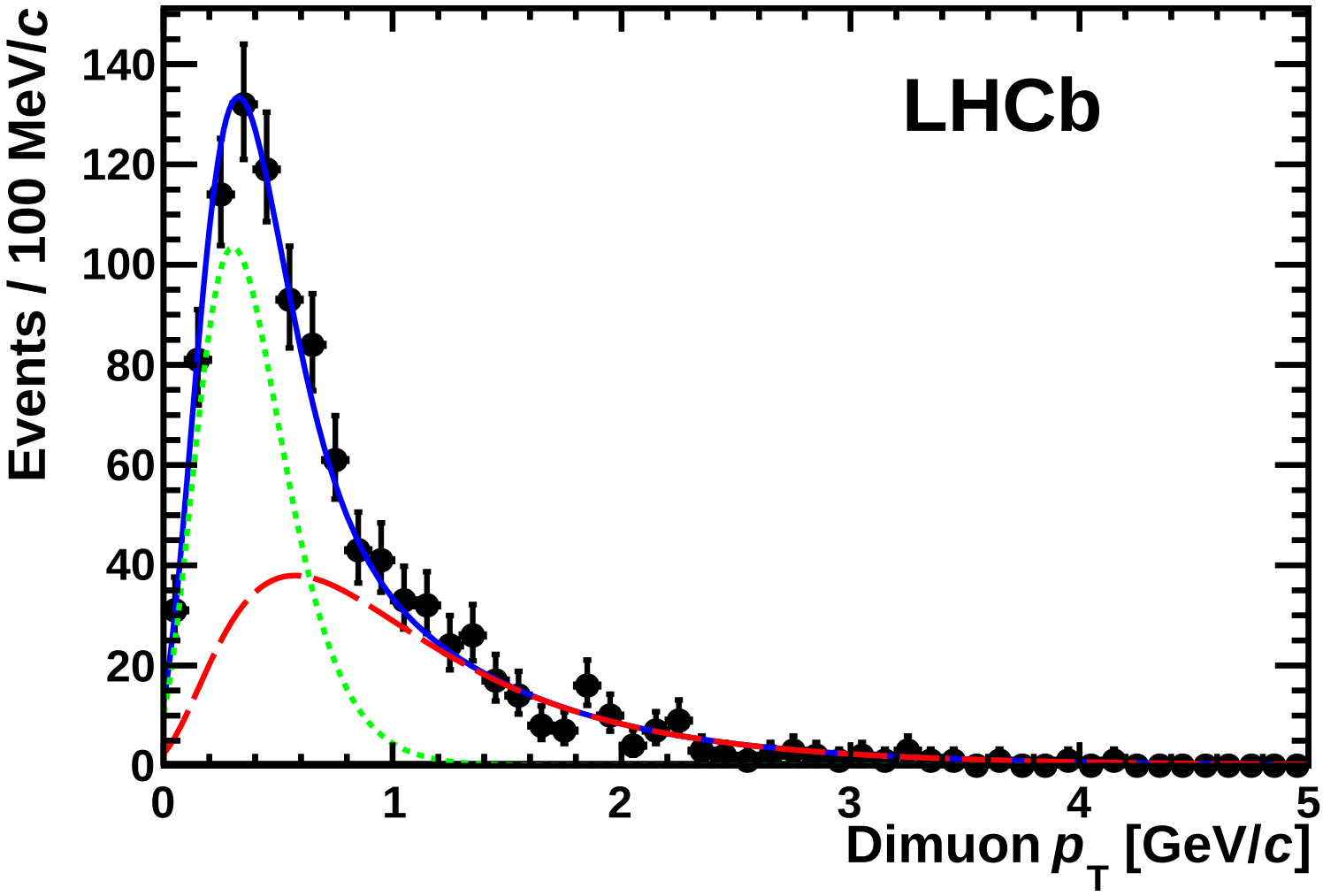

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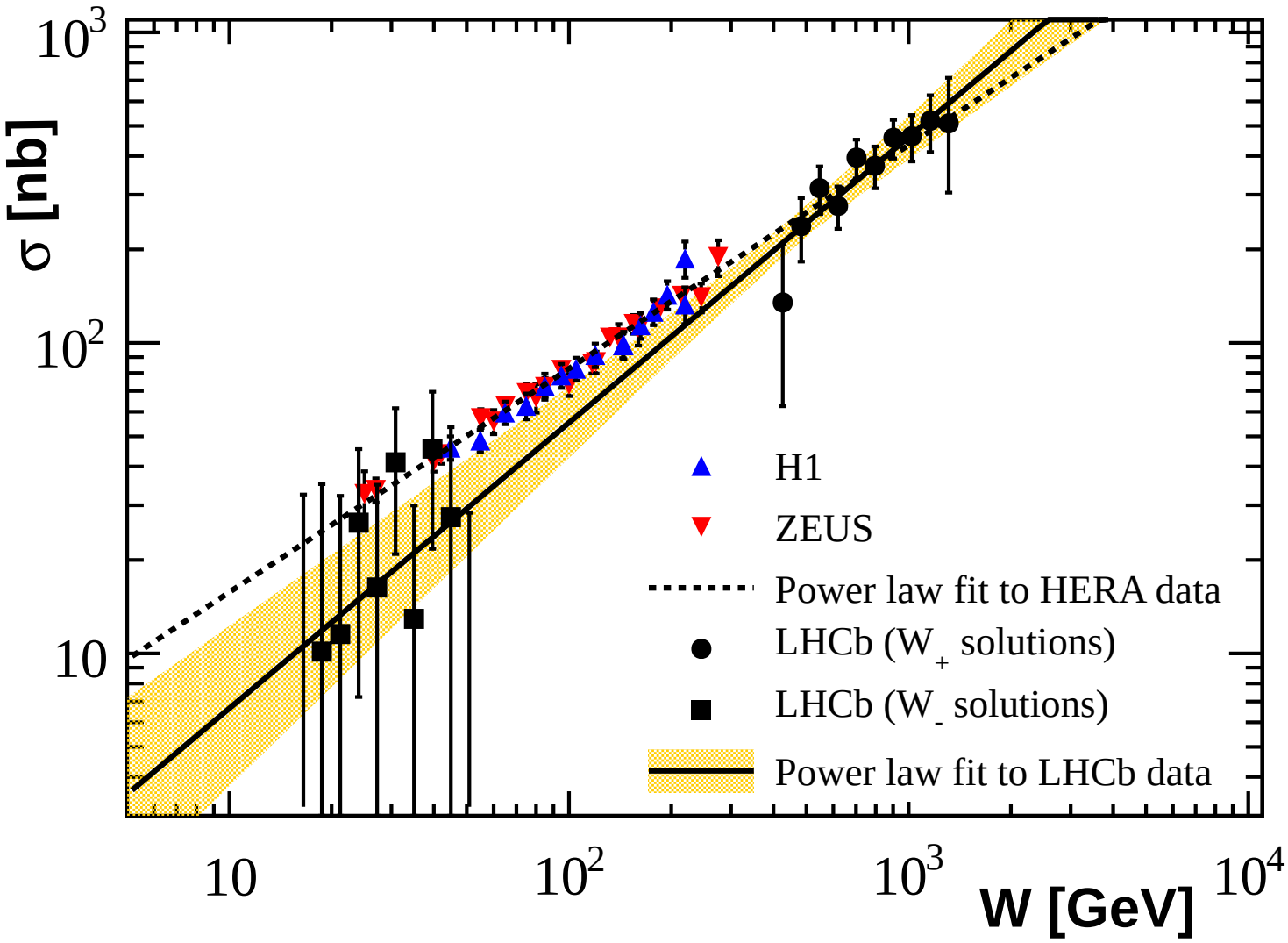

Prompt Hadron Production

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Range of systematic uncertainties, in percent, for same-particle ratios at $\sqrt{s} = 7$ TeV.

	$\bar{p}/p$	K^-/K^+	π^-/π^+
PID	3.4 – 26.4	2.0 – 15.8	0.6 – 2.7
Cross-sections	0.3 – 1.8	0.3 – 0.7	<0.1 – 0.2
Detector material	0.2 – 0.9	0.1 – 0.4	<0.1 – 0.2
Ghosts	<0.1 – 0.4	<0.1 – 0.1	<0.1
Tracking asymmetry	0.5	0.5	0.5
Non-prompt	<0.1 – 0.2	<0.1 – 0.1	<0.1 – 0.1
Total	3.5 – 26.5	2.1 – 15.8	0.8 – 2.8

Prompt Hadron Production

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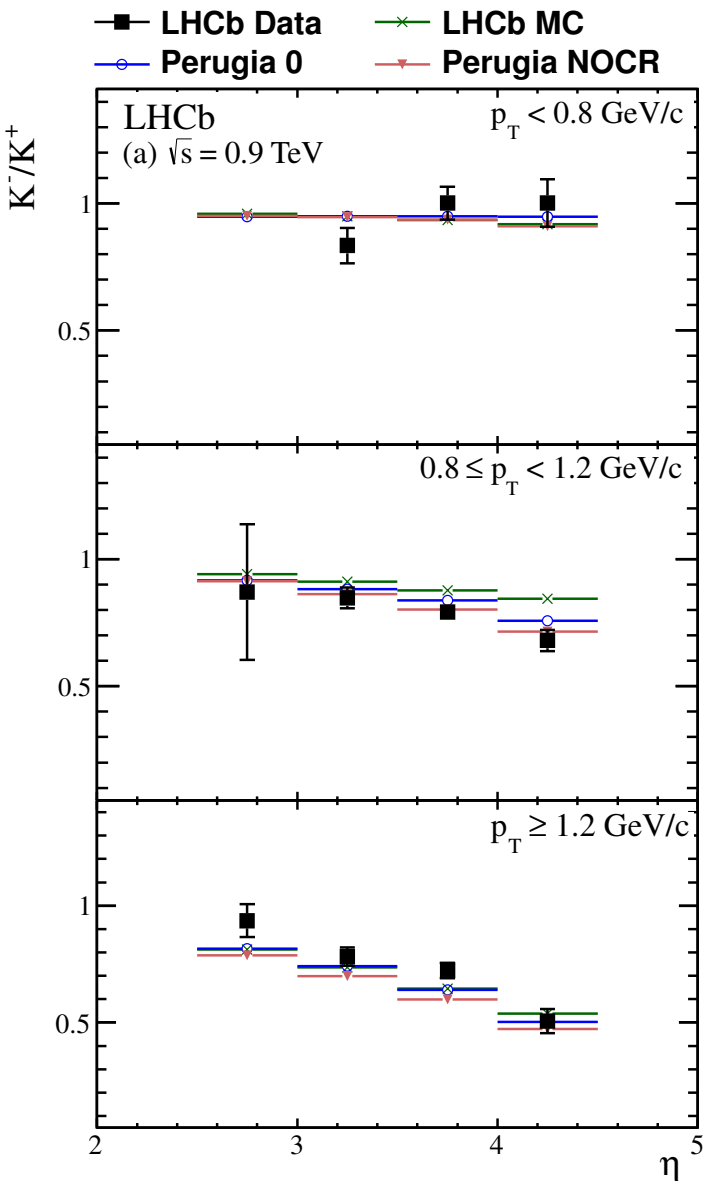

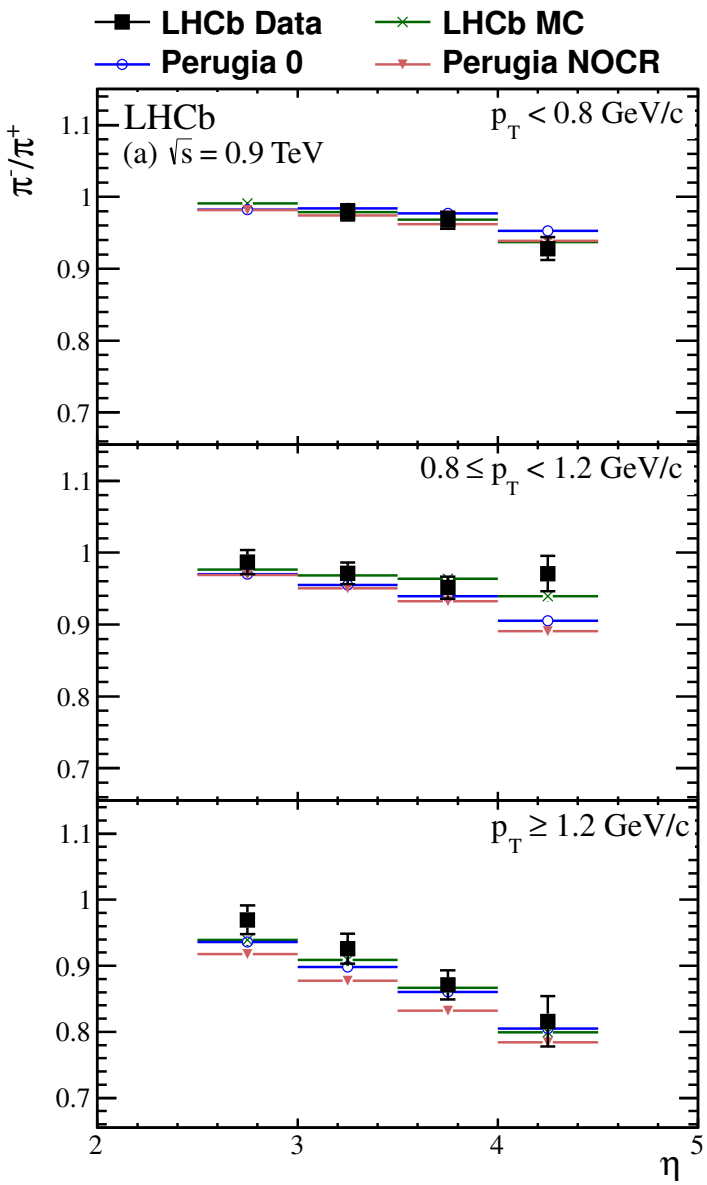

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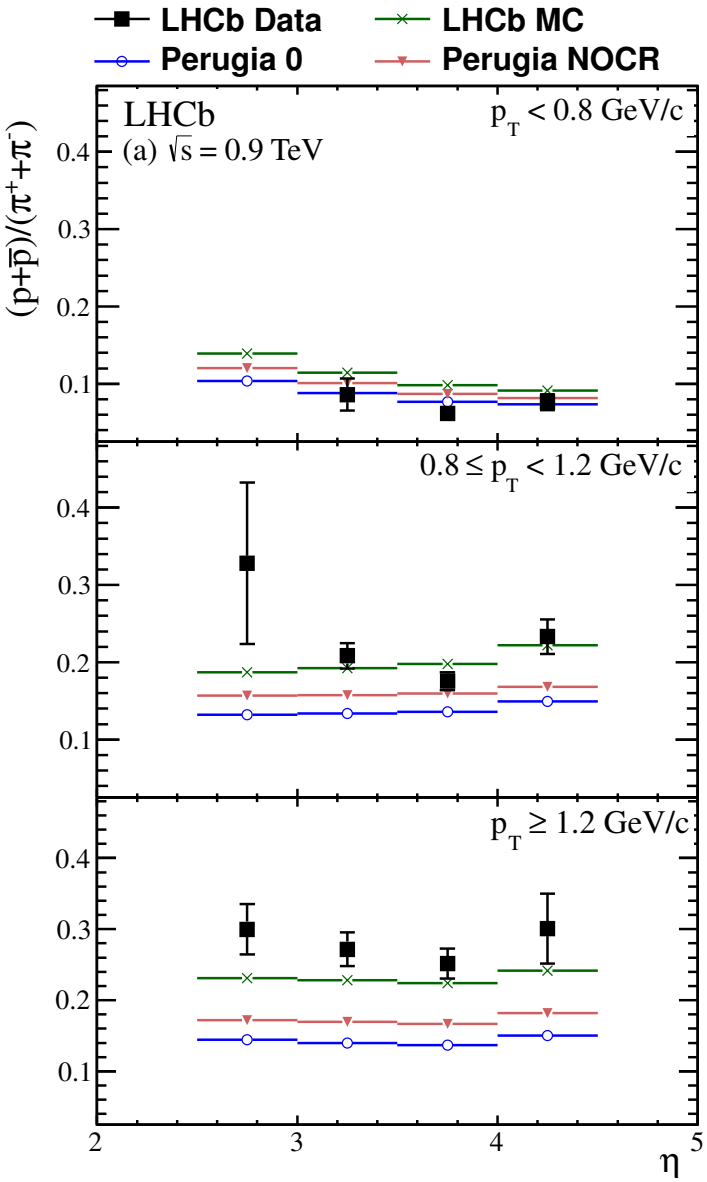

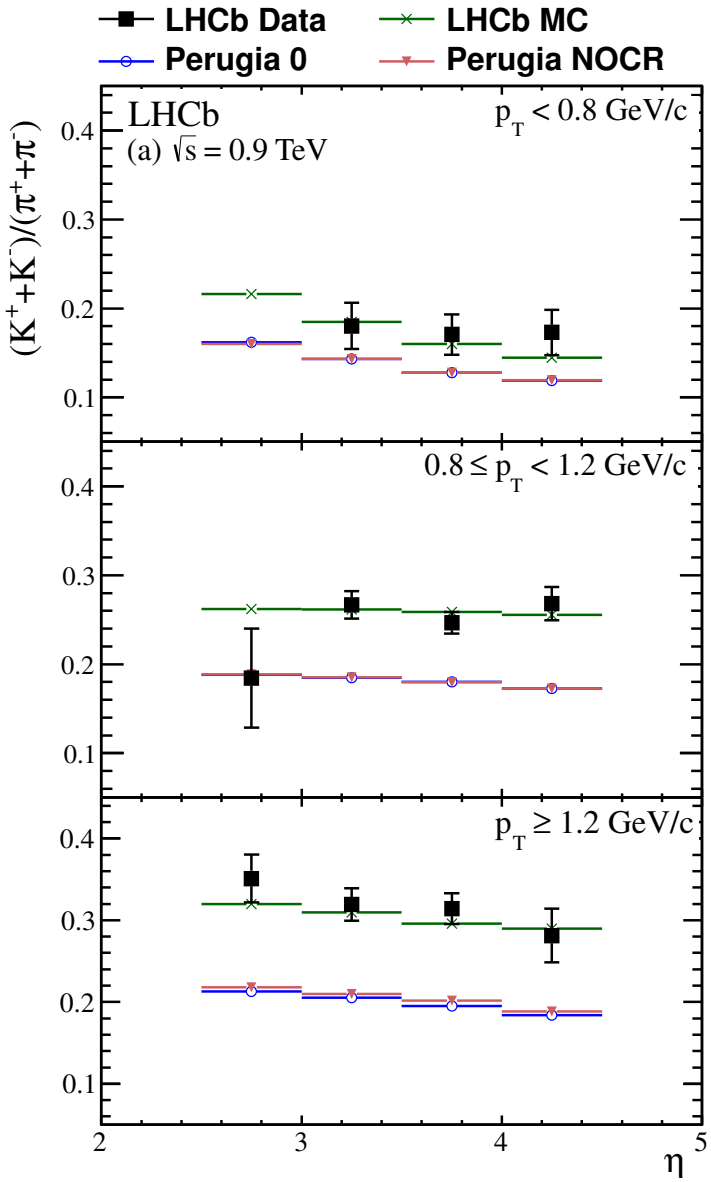

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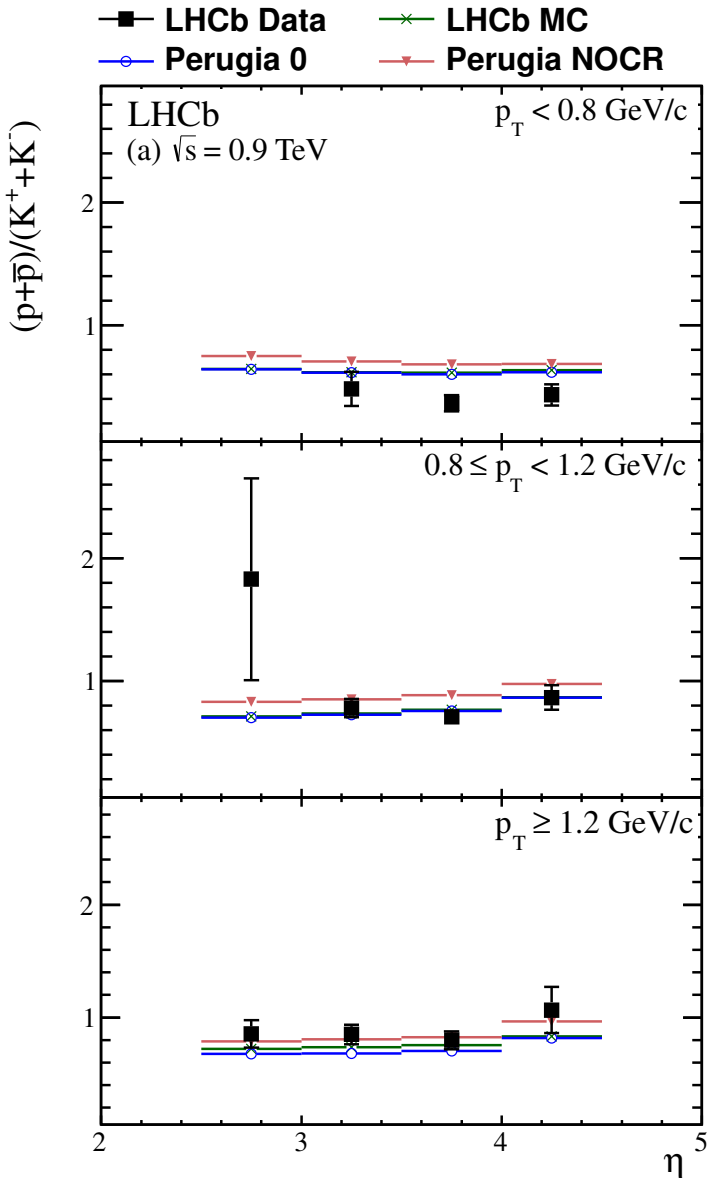

Forward Energy Flow

arXiv: 1212.4755

Relative systematic uncertainties (in percent) affecting the energy flow measurements for all event classes. The ranges indicate the variation of the uncertainty as a function of η.

Source of uncertainty	Inclusive minbias	Hard scattering	Diffractive enriched	Non-diffractive enriched
Model uncertainty on correction factors	$0.6 - 9.2$	$0.7 - 4.1$	$16 - 43$	$0.7 - 8.6$
Selection cuts	$1.0 - 4.9$	$2.7 - 8.8$	$0.9 - 2.8$	$1.1 - 5.0$
Tracking efficiency	3	3	3	3
Multiple tracks	1	1	1	1
Spurious tracks	$0.3 - 1.2$	$0.4 - 1.7$	$0.2 - 0.7$	$0.3 - 1.2$
Magnet polarity	—	—	$2.6 - 7.7$	—
Residual pile-up	1.7	1.7	1.7	1.7
Total on $F_{\mathrm{char},\eta}$	$3.9 - 11$	$4.9 - 10$	$16 - 43$	$4.0 - 11$
Variation of $R_{\mathrm{gen},\eta}$ and k_η factors	$0.8 - 6.1$	$0.7 - 2.9$	$1.5 - 23$	$0.9 - 5.5$
Photon efficiency	$1.4 - 1.6$	$1.2 - 1.3$	$1.3 - 2.3$	$1.3 - 1.6$
ECAL miscalibration	< 1	< 1	< 1	< 1
Total on $F_{\mathrm{total},\eta}$	$4.4 - 13$	$5.4 - 11$	$17 - 49$	$4.4 - 12$

Double Charm Production

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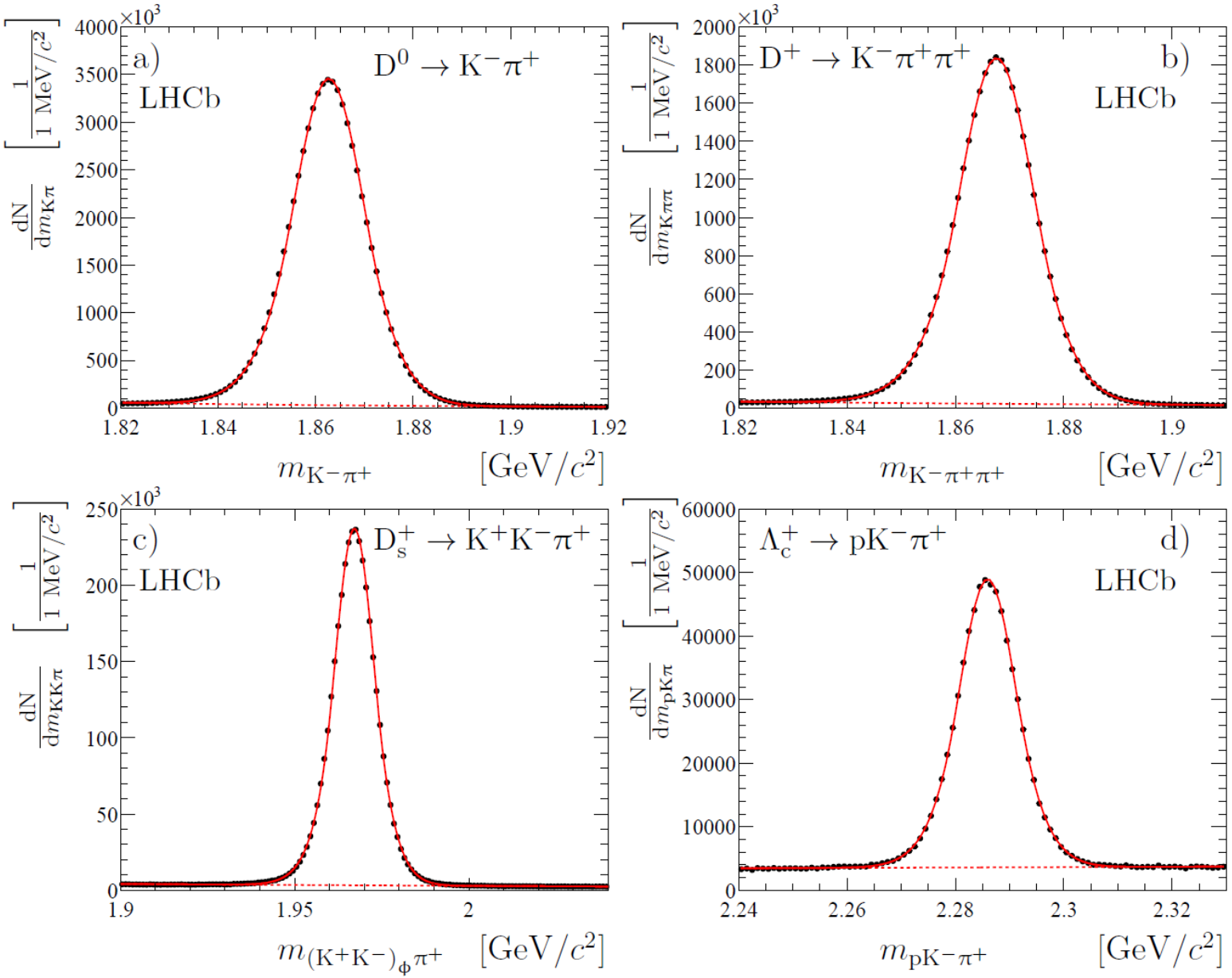

Double Charm Production

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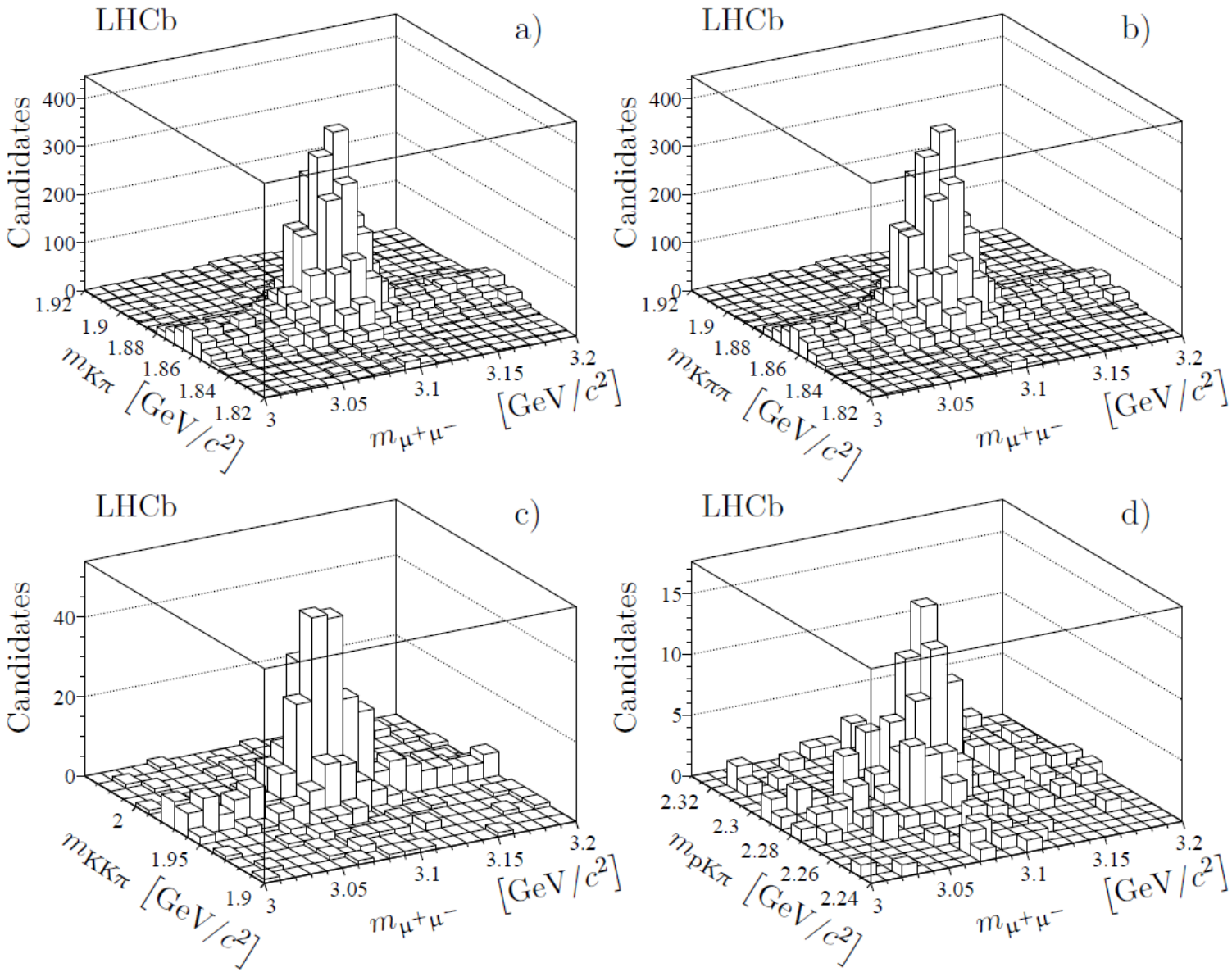

Double Charm Production

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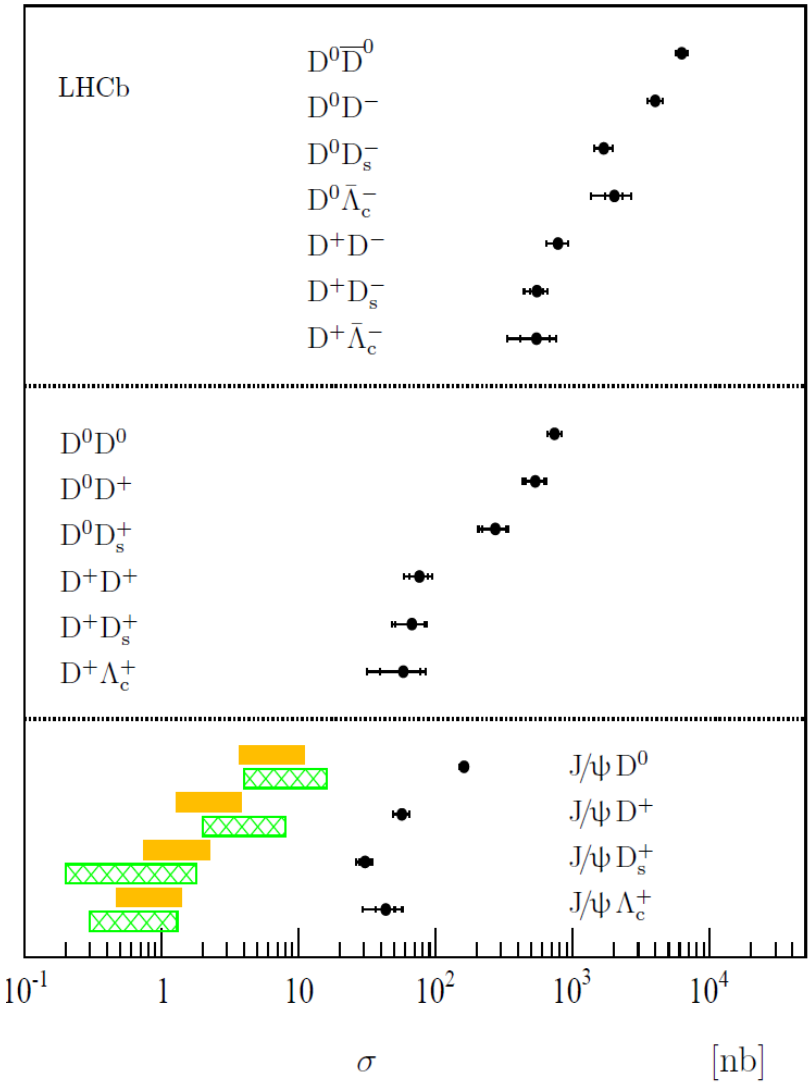

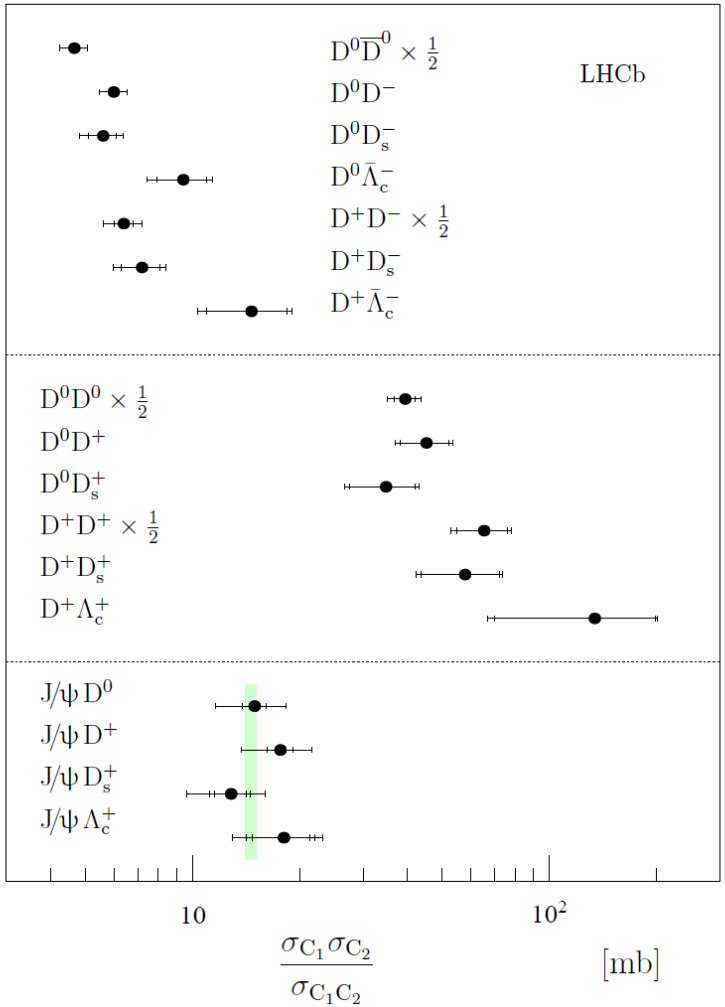

Event display