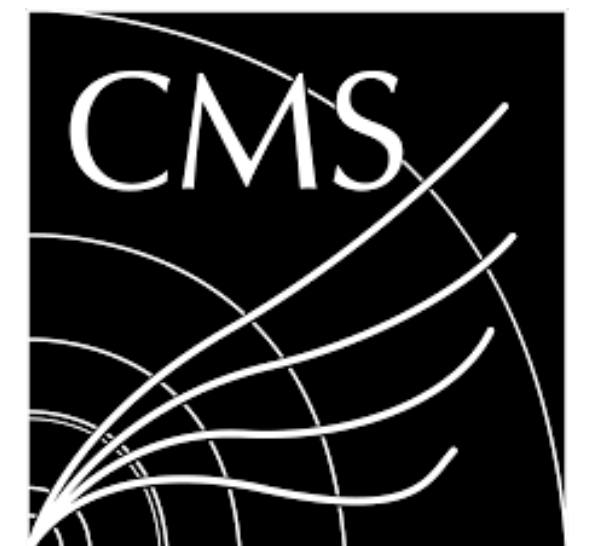# V+HF and intrinsic charm

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On behalf of the ATLAS, CMS and LHCb Collaborations

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- Introduction
    - Z+b can be produced at the LHC via q-g, q-q and g-g interaction
    - great test of perturbative QCD by comparing measured and theoretical cross sections
    - probe b quark PDFs
    - background to many processes [ZH(→bb), single top, tt, WW, etc]

- Measurement of integrated, differential and normalised differential cross sections for Z + ≥ 1b and Z + ≥ 2b jets as a function of different kinematic variables
    - sensitive to PDF, initial-state radiation, final-state radiation, gluon splitting and multiparton interactions

- Data collected during Run-2 with a single lepton trigger
- deepCSV tagger for b-jet identification

- Integrated fiducial cross sections
  - Z + ≥ 1b 6.52 ± 0.04 (stat) ± 0.40 (syst) ± 0.14 (theo) pb
  - Z + ≥ 2b 0.65 ± 0.03 (stat) ± 0.07 (syst) ± 0.02 (theo) pb
  - consistent with MG5_aMC LO expectations
  - ≈10%, 18% and 24% overestimation of MG5_aMC NLO (NNPDF 3.1, NNPDF 3.0) & SHERPA for Z + ≥ 1b
  - ≈29%,38% and 21% overestimation of MG5_aMC NLO (NNPDF 3.1, NNPDF 3.0) & SHERPA for Z + ≥ 2b
- Cross section ratio of the Z + ≥ 2 b and Z + ≥ 1 b
  - 0.100 ± 0.005 (stat) ± 0.007 (syst) ± 0.003 (theo)
  - in agreement with MG5_aMC LO and SHEPRA
  - overestimated by MG5_aMC NLO

- Differential and normalised differential cross section distributions as function of a selection of variables
- None of the simulations describe all the examined spectra
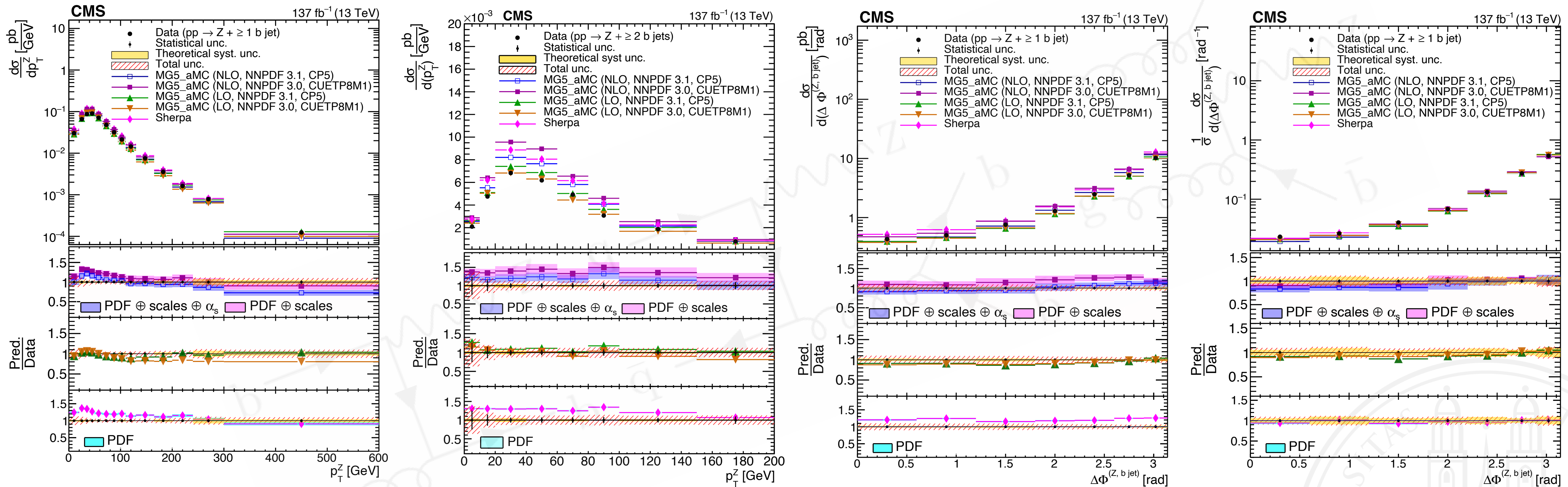
- Introduction
  - comparison and study of MC models and collider measurements of boosted bb production can help us understand and improve
    - validity of parton-shower MC simulations
    - high-p_T associated Higgs processes

- Here, boosted large-R jets are studied produced in association with a vector boson (leptonic decay)
- Differential cross section measurement in kinematic variables of the large-R jet
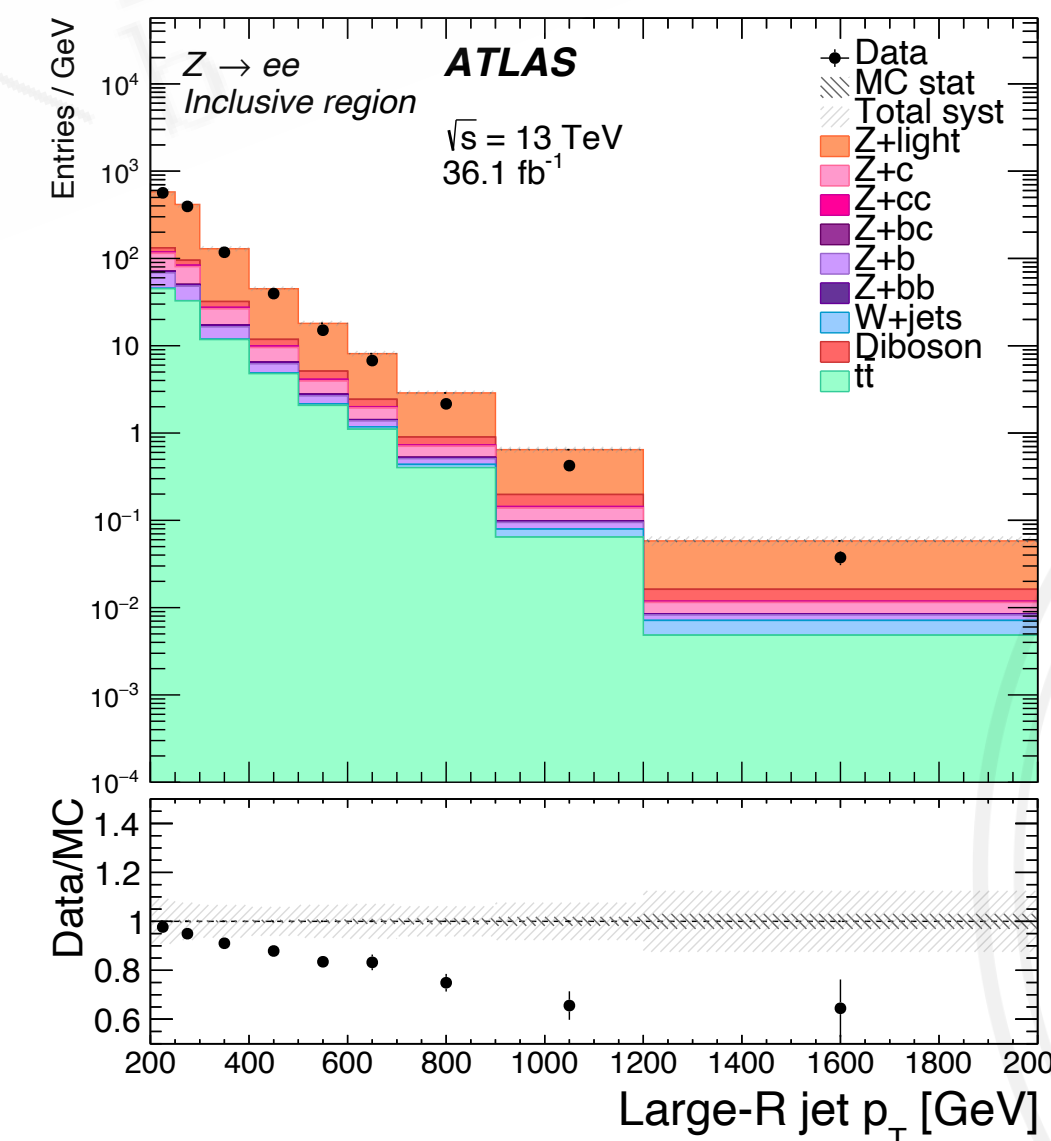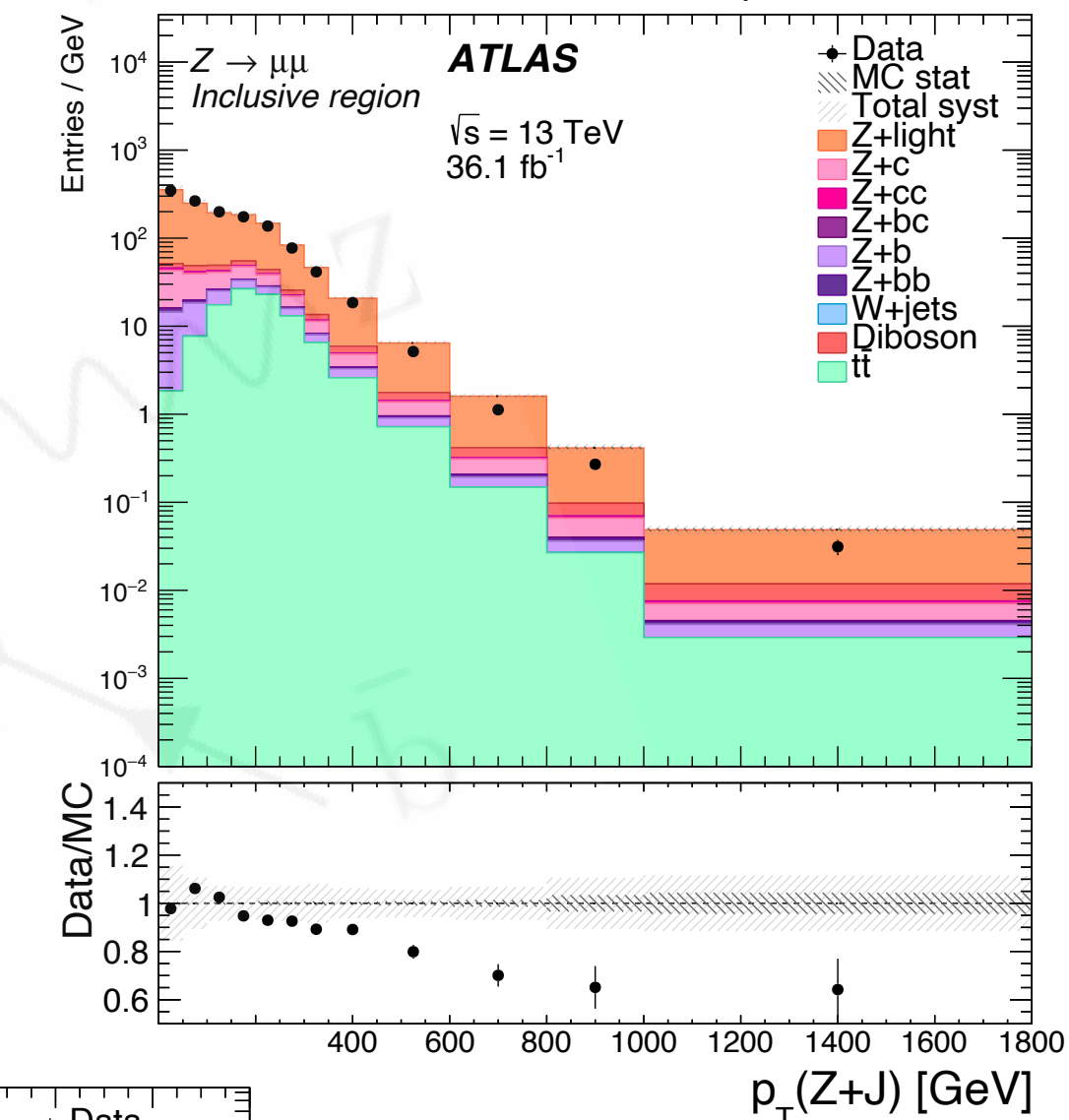 - study of the large-R jet constituents

- 2015-2016 dataset selected with single electron and muon triggers
- Z boson identified by its high-p_T electron and muon pairs
  - τ-lepton decays included
- Large-R jets reconstructed with the anti-k_t algorithm, R=1
- Subjects and b-tagging with anti-k_t algorithm and R=0.2

- Total fiducial cross sections σ^{incl} = 2.37 ± 0.28 pb and $\sigma^{2\text{-tag}}$ = 14.6 ± 4.6 fb
  - compared to Sherpa 2.53 ± 1.25 pb and MG_aMC 2.68 ± 0.67 pb
  - LO MG also overestimates at 2.84 pb
  - older Sherpa version closer to measurement 2.37 pb

- Differential cross sections as a function of event kinematics
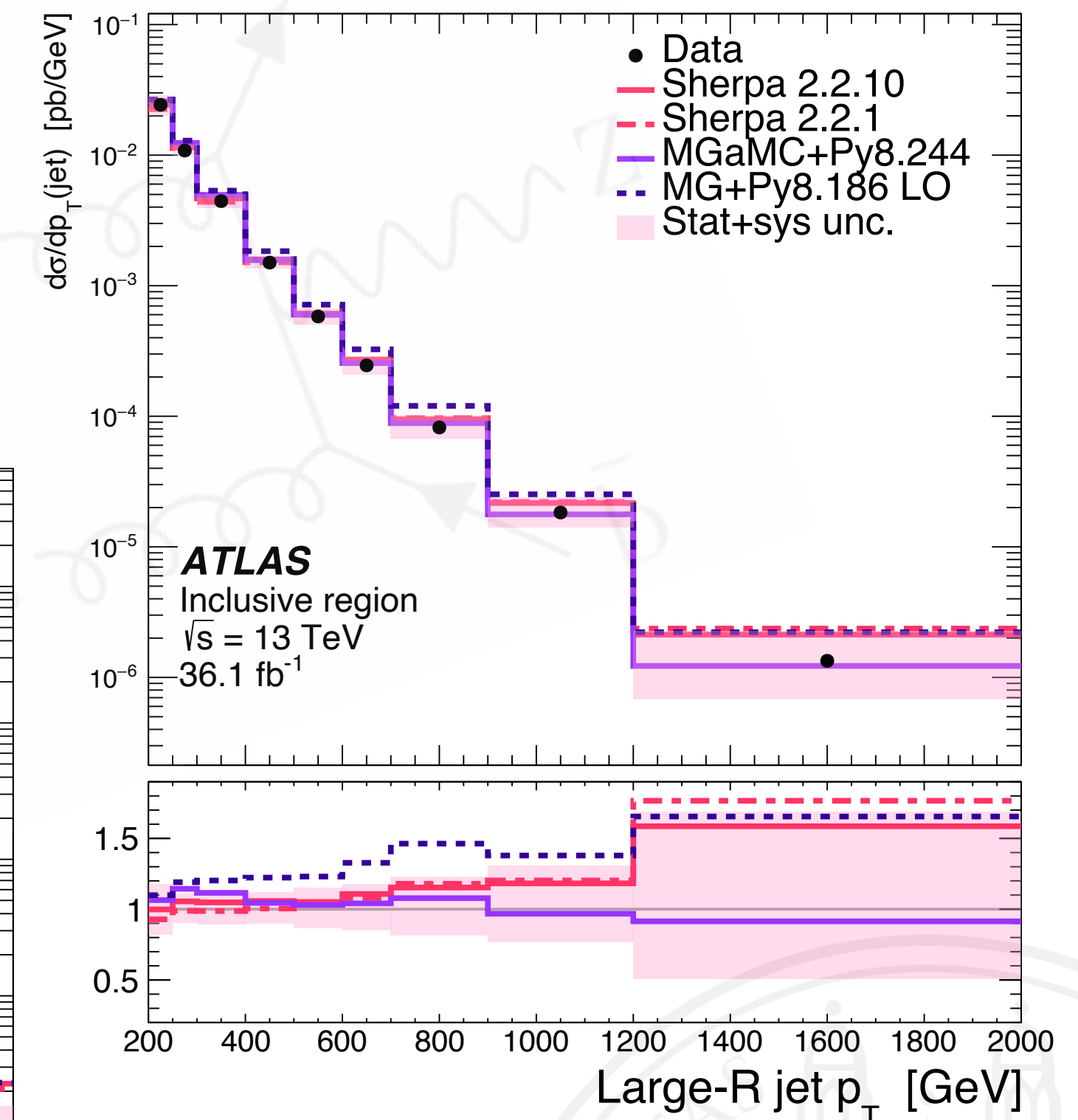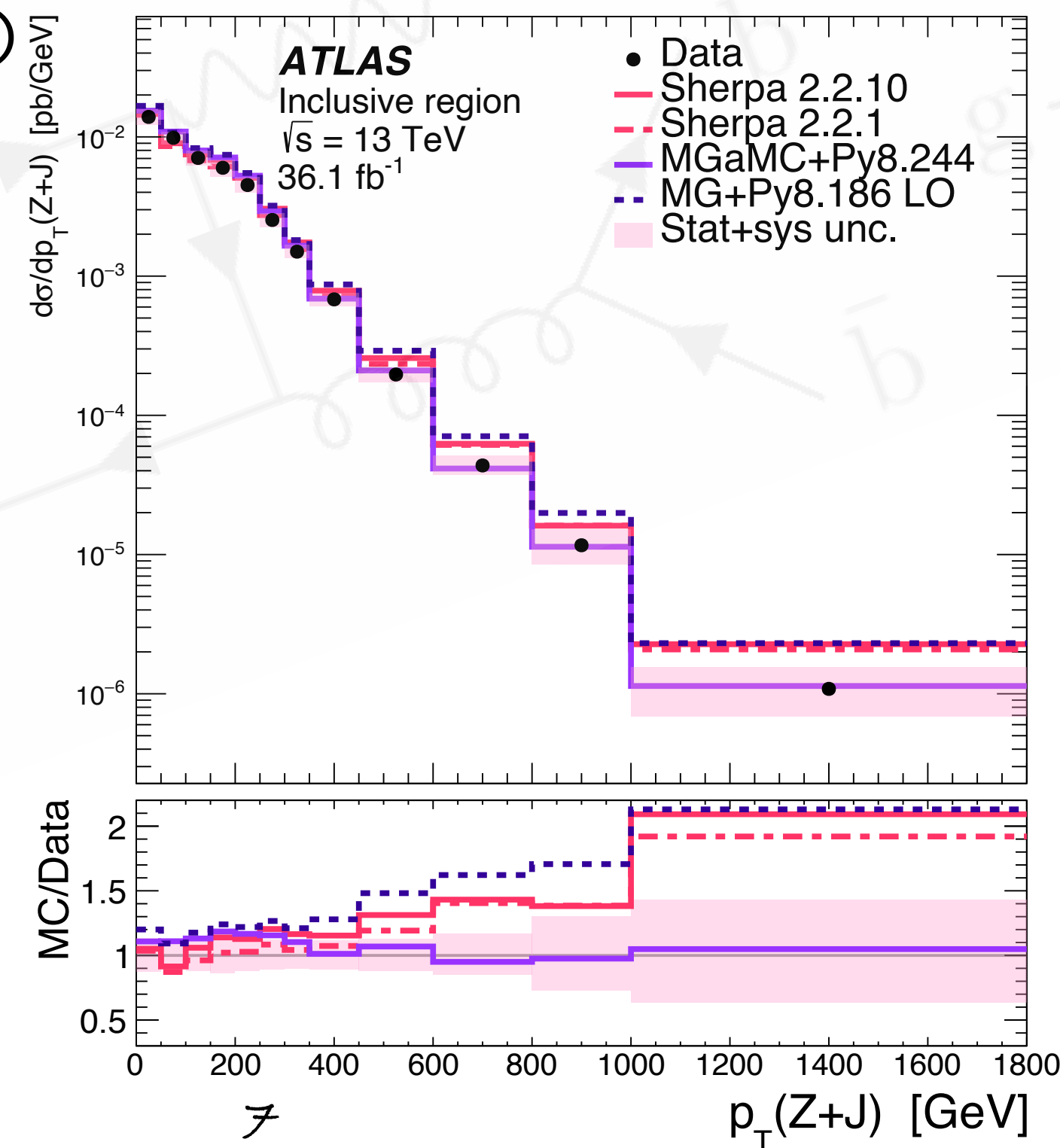 - compared with NLO particle level Sherpa and MG_aMC
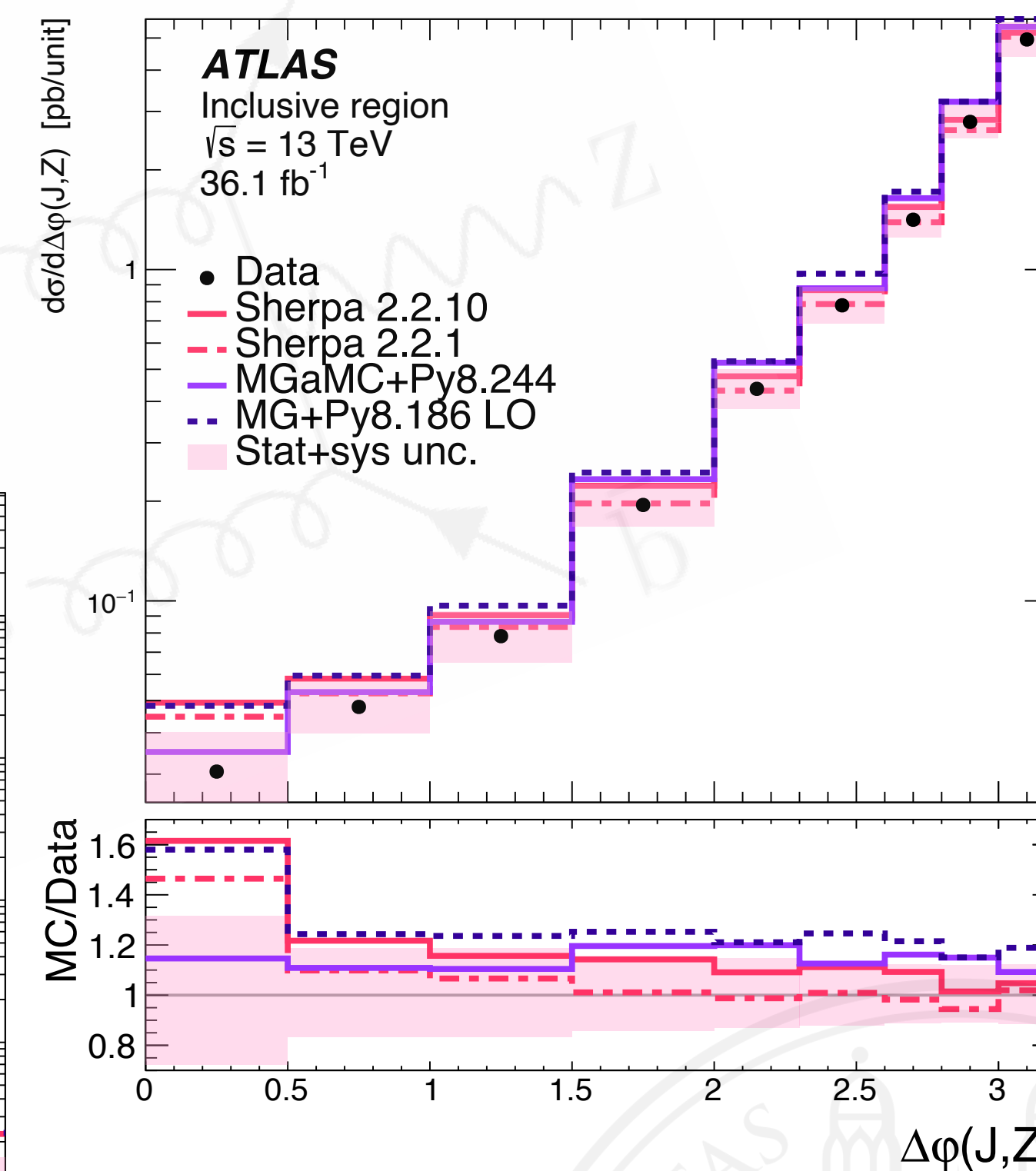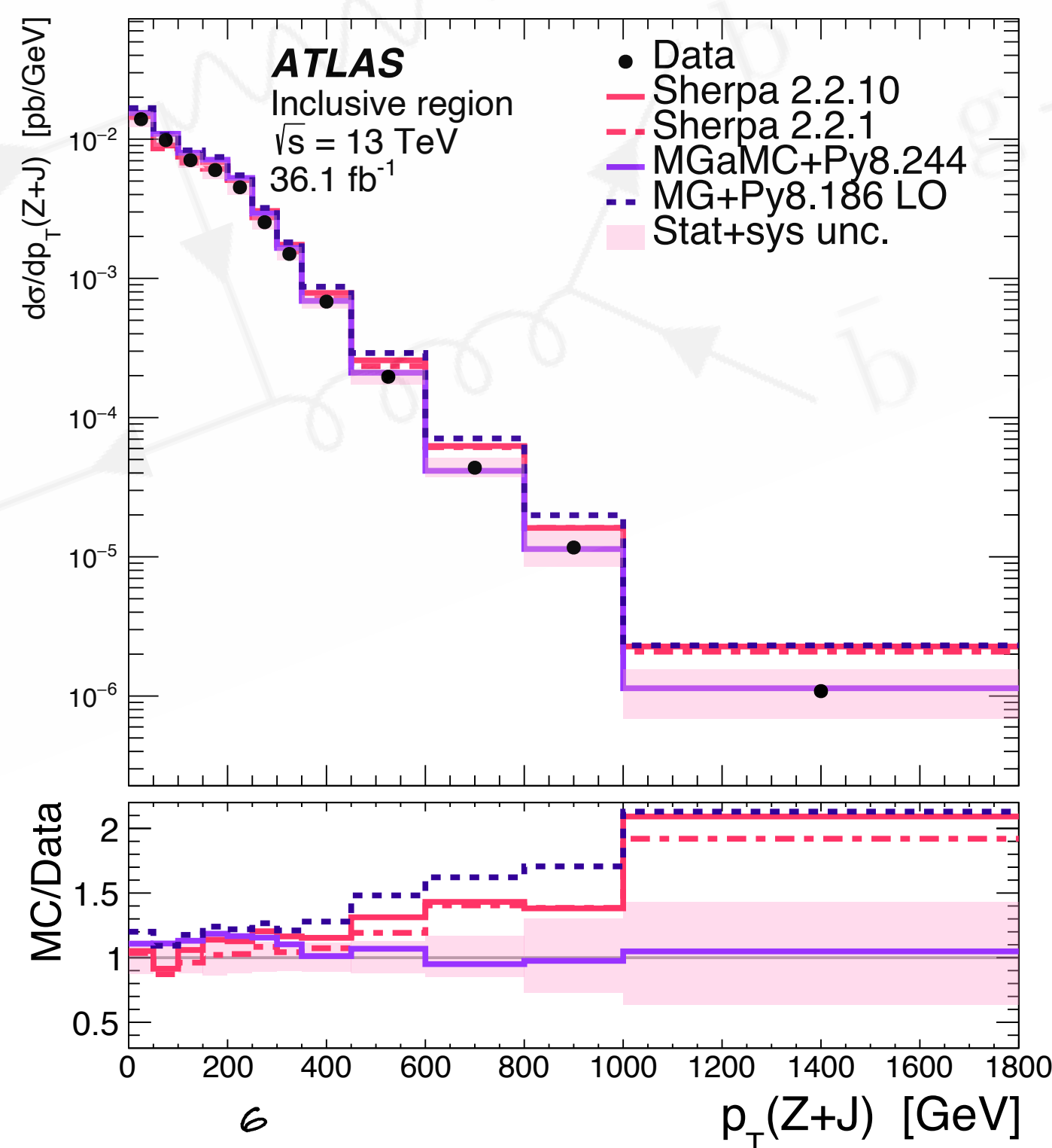
- Best shape agreement from MG_aMC (NLO)

- Excess in high p_T and small $\Delta\varphi$
  - there Z+jets behaves like a dijet system
  - collinear Z radiation
  - both generators display similar shape deviations

- $\sigma^{2\text{-tag}} / \sigma^{incl}$ ratio is $(0.62 \pm 0.12)\%$
  - in agreement with Sherpa, MG_aMC (NLO)
  - older Sherpa and LO MG undershoot data

- Limited 2-tag selection due to number of data events
  - good shape agreement between data and MC models
  - strongest feature is the normalisation

- Important input information for future use
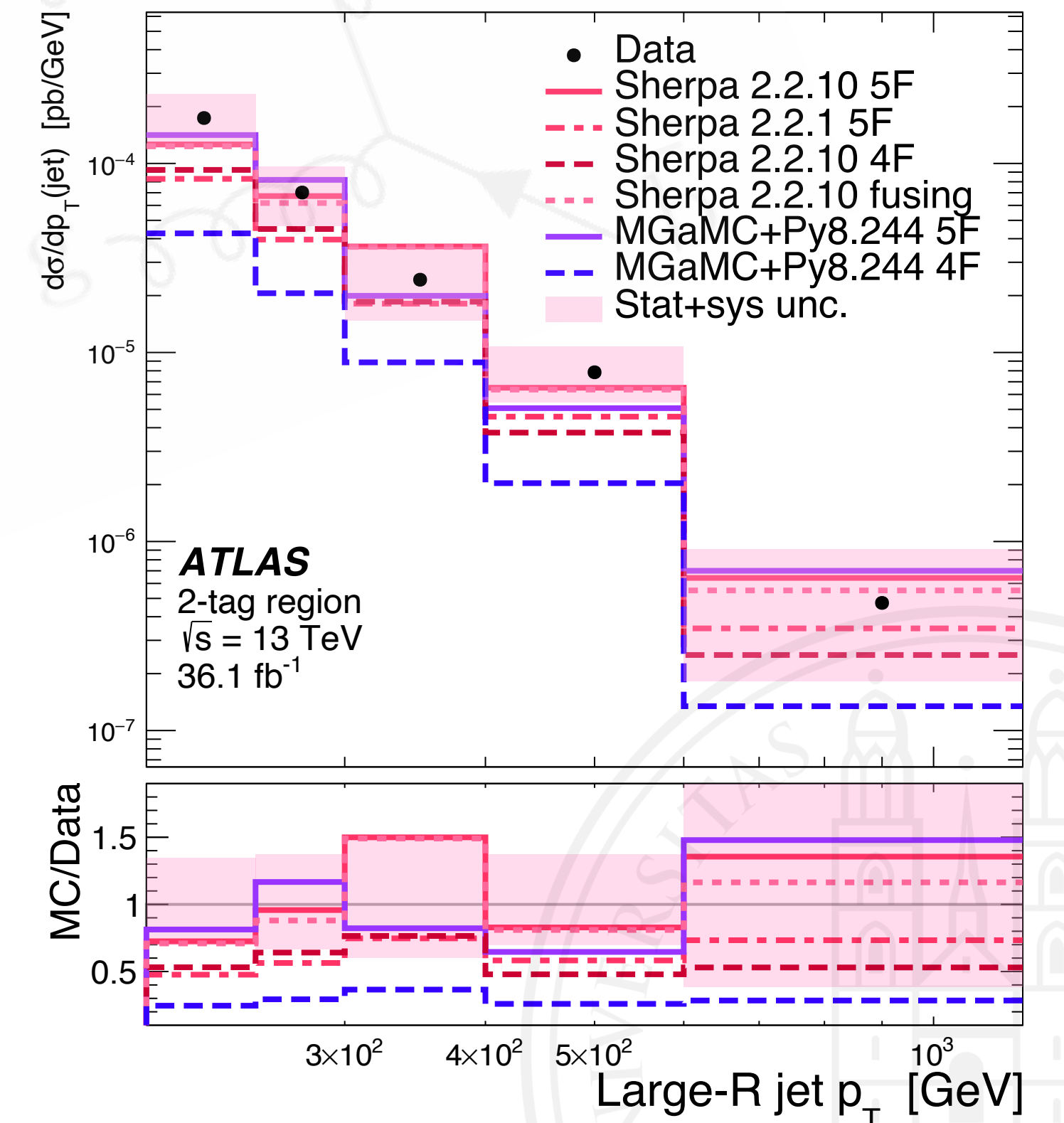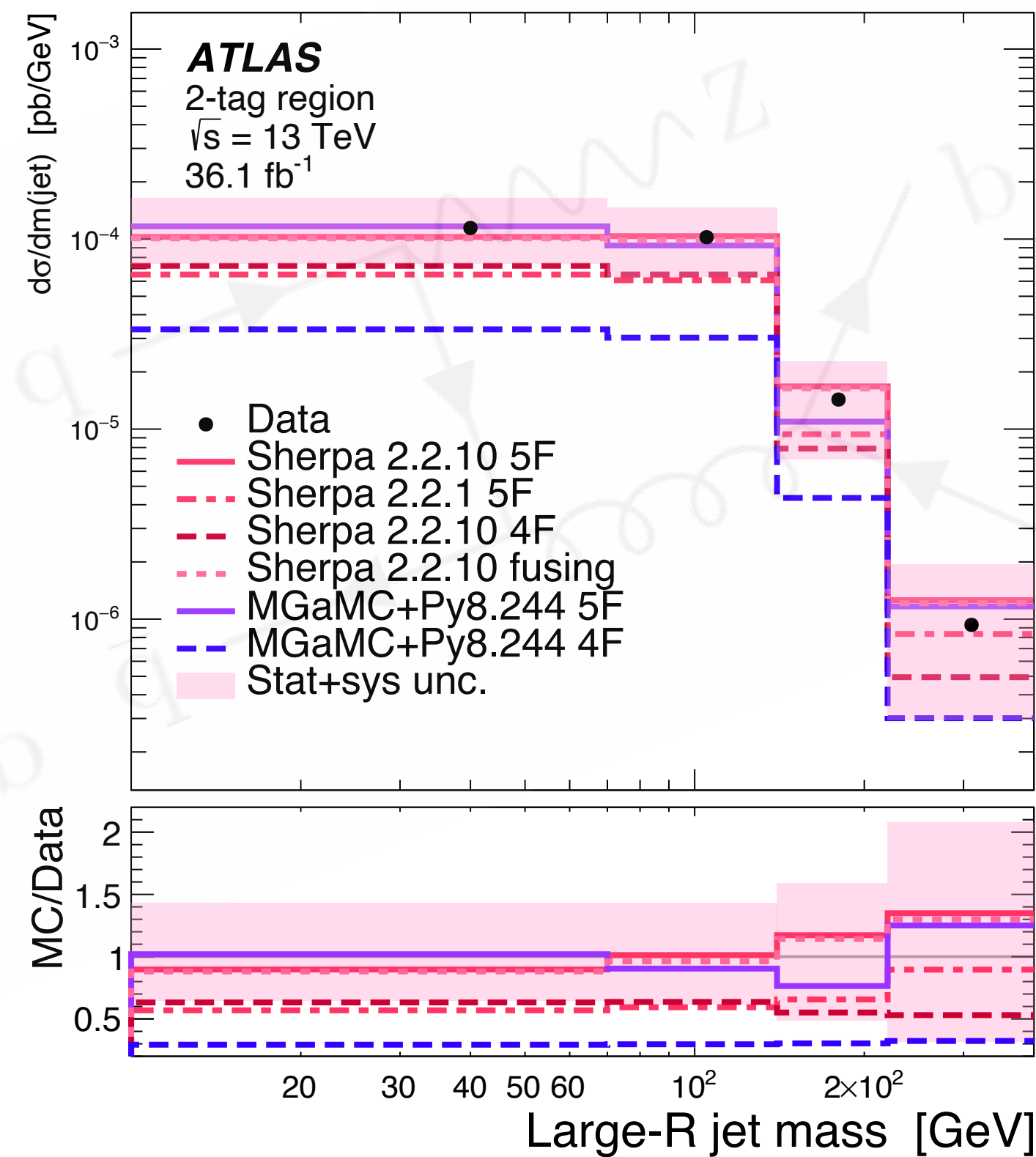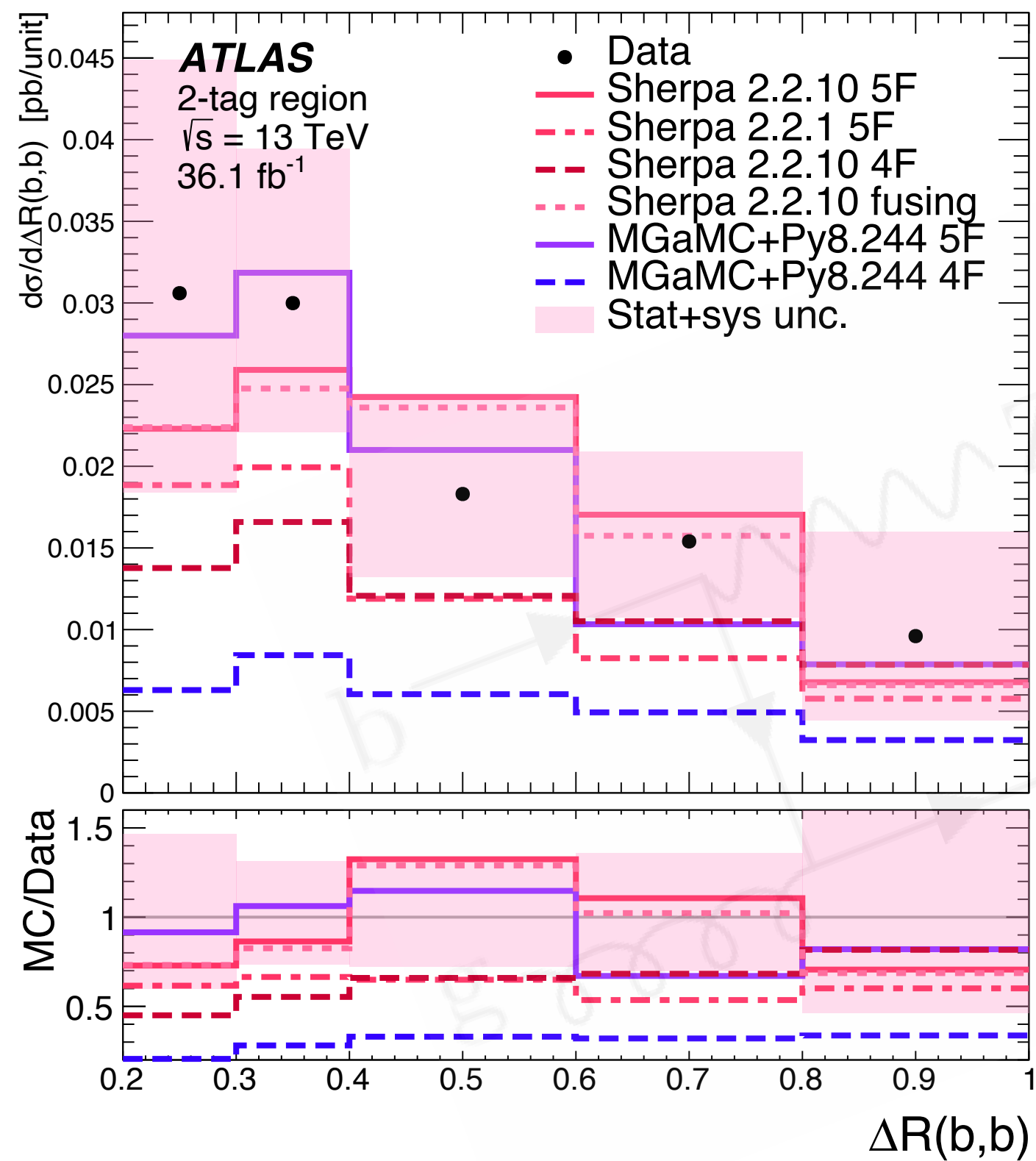
• Introduction

  • probe the |uudcc> component of the proton by studying Z + c jets in the forward region (IC)

  • measurement of the ratio $R_j^c \equiv \sigma(Z+c)/\sigma(Z+j)$ to reduce experimental and theoretical uncertainties

  • leading order Z+c production via g+c → Z+c scattering

  • IC contributions produce enhancements in high Z rapidities

  • incorporating R_j^c measurements into a global analysis should strongly constrain the large-x charm PDF, both in size and in shape

• Differential R_j^c measurement in a fiducial phase-space

  • Z→μμ

• Data collected during Run-2 with a single muon trigger

• Jet reconstruction: particle-flow candidates using the anti-k_t clustering algorithm as implemented in FastJet

• Systematic dominated measurement

  • c-tagging
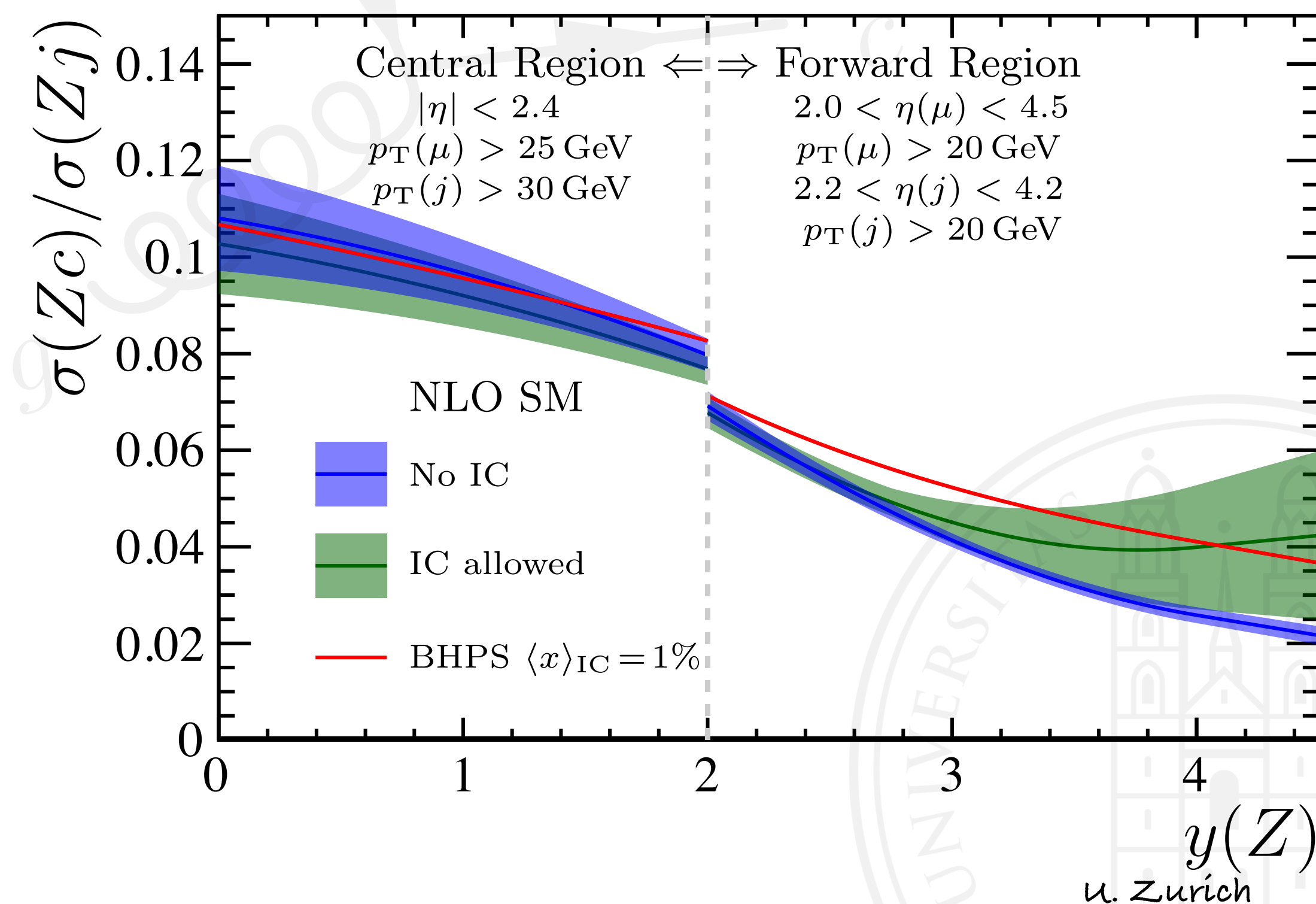
- Discrimination against b and light jets using N_{trk} and the corrected mass
  - minimum mass the long-lived hadron can have, consistent with the flight direction
  - peaks near the c-hadron mass
  - b-hadron decays produce higher number of displaced tracks

- R_j^c measurement in rapidity intervals
- Observed R_j^c values consistent with both no-IC and IC hypotheses in first two bins
- not the case in the forward-most interval
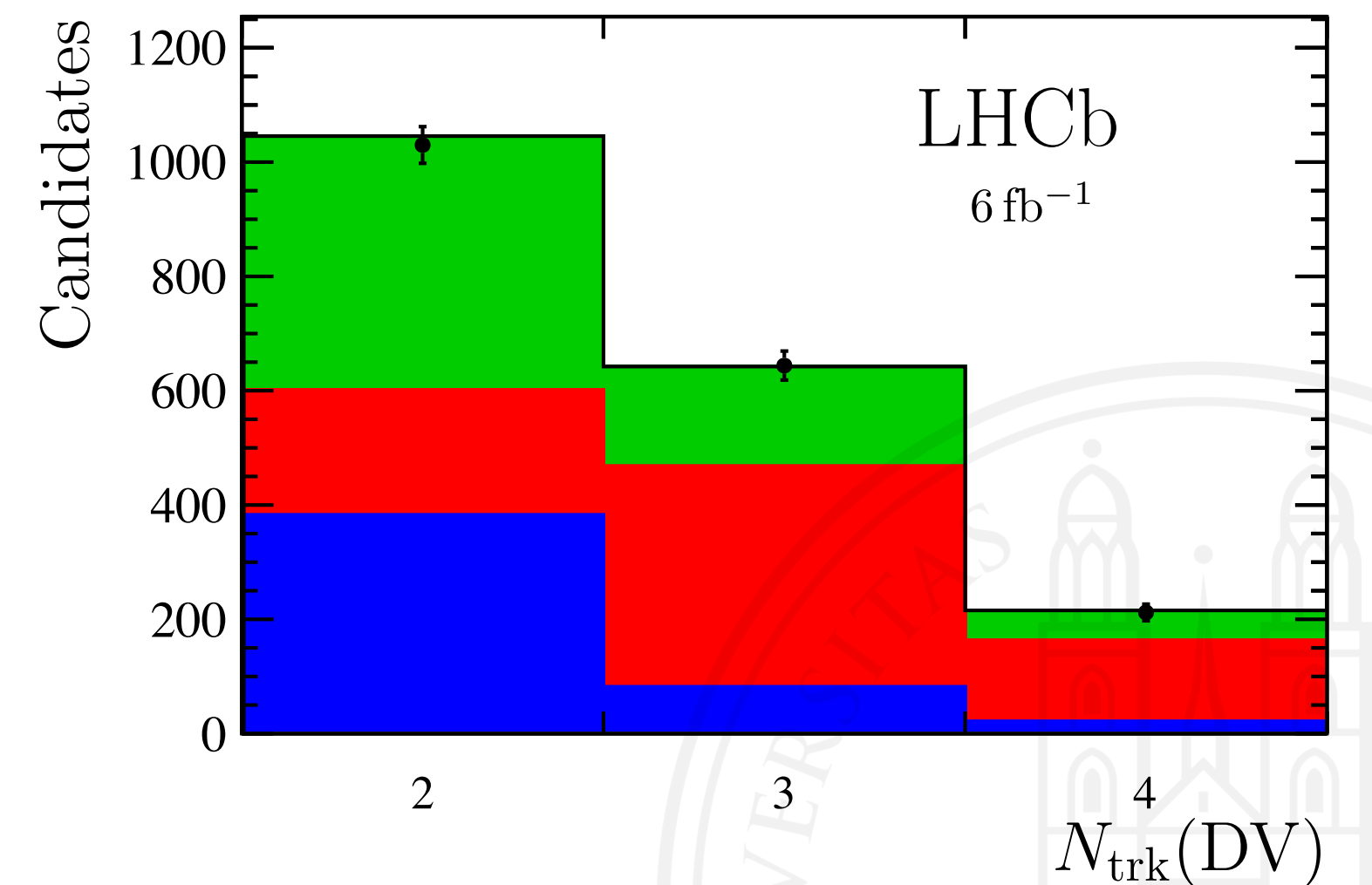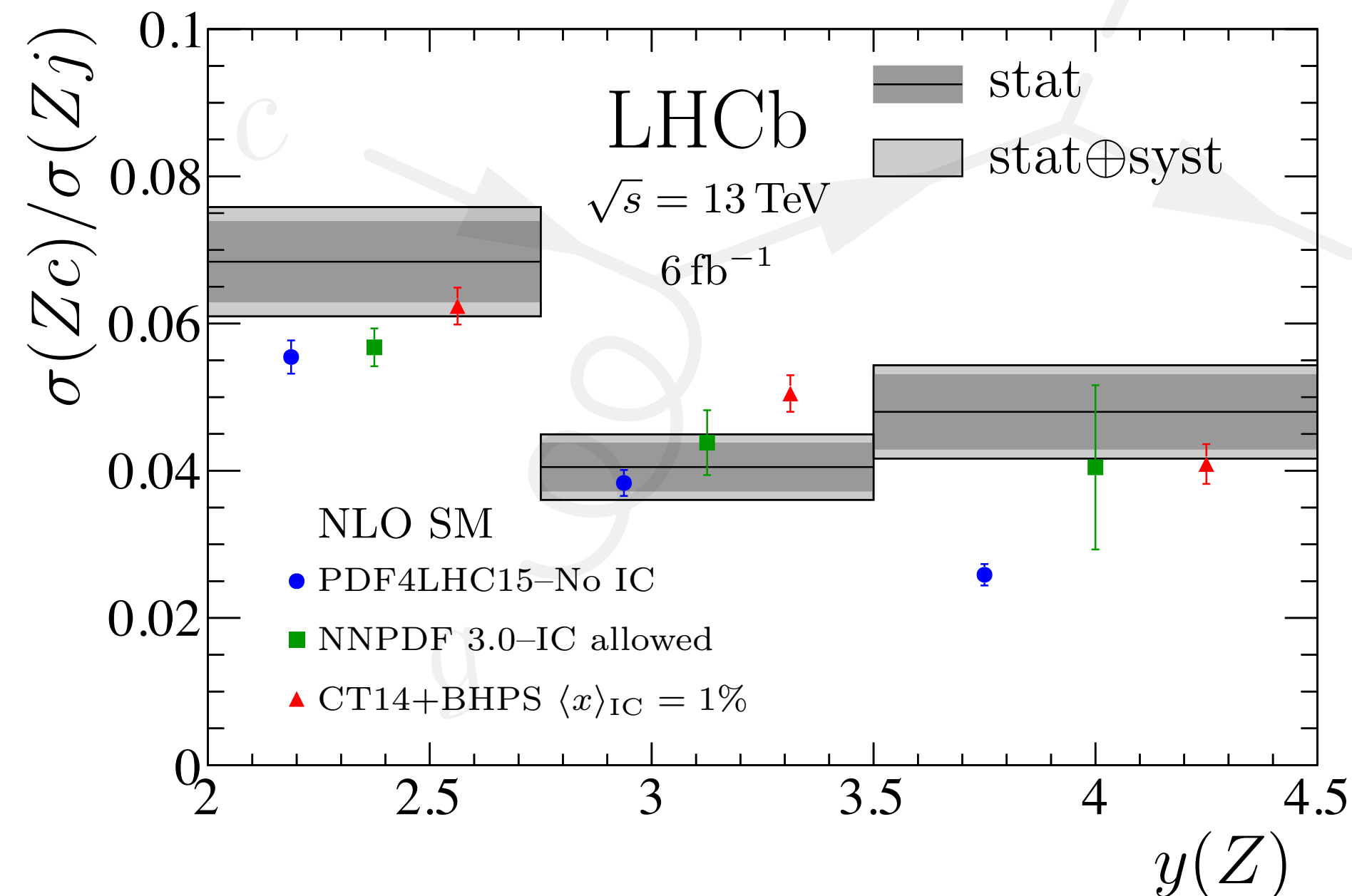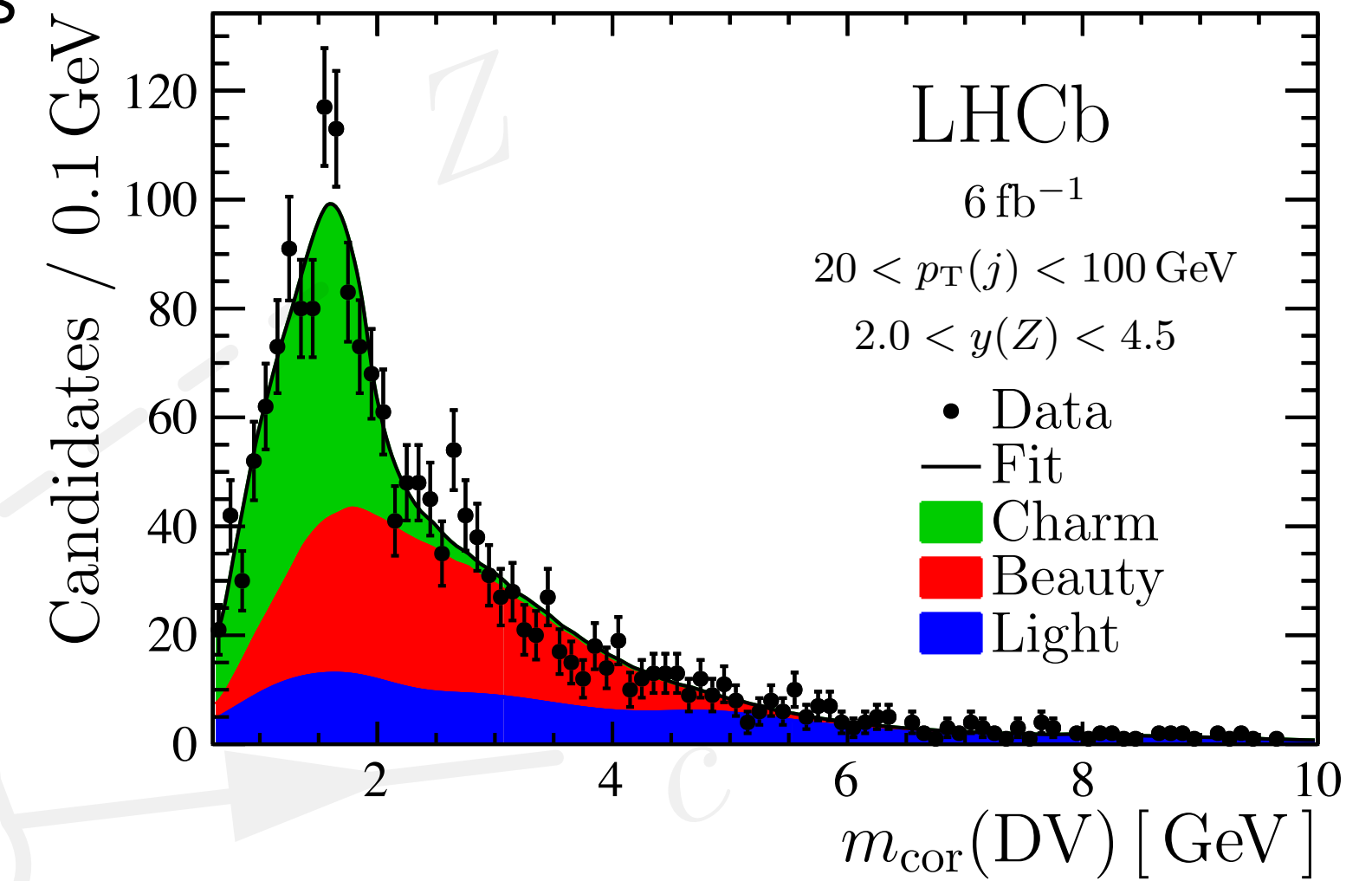
- W+c associated production is sensitive to the strange quark content of the proton

  - s+g → W+c contribution over the suppressed d+g → W+c

  - strange quark parton distribution function is one of the least constrained PDFs

- W+c cross section and $R_c^\pm = \sigma(W^+ + c)/\sigma(W^- + c)$ measurements useful for

  - constraining the ratio between strange and non-strange sea quark PDFs

  - probe s and s-bar PDF asymmetry

- Also background for Higgs to charm decays

- W+c production cross section and $R_c^\pm$ measurement

- Fiducial and differential cross sections (vs η^l and p_T^l)

- Data collected during run-2 with single lepton triggers

- Semileptonic (SL) and Secondary Vertex (SV) channels for charm tagging
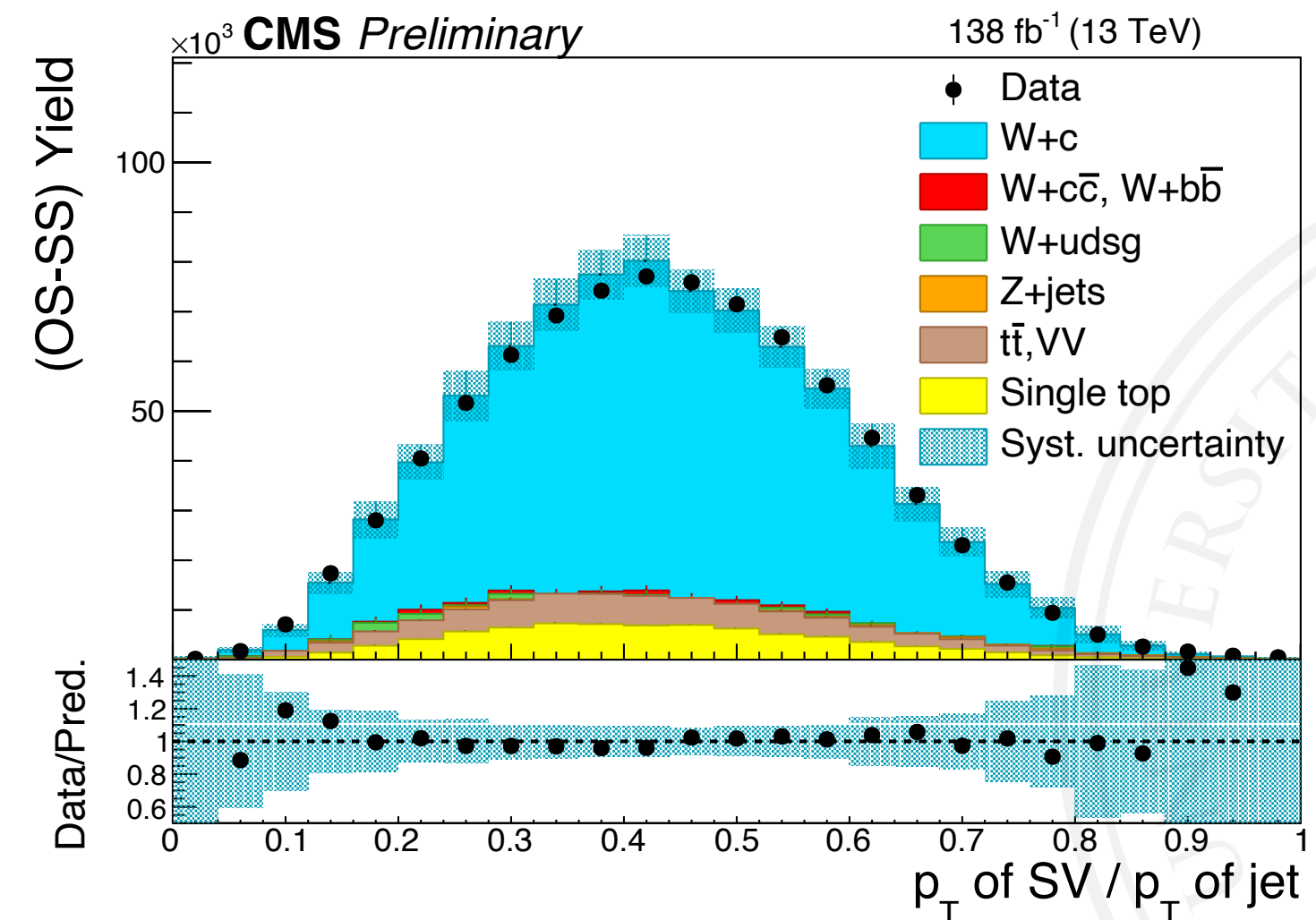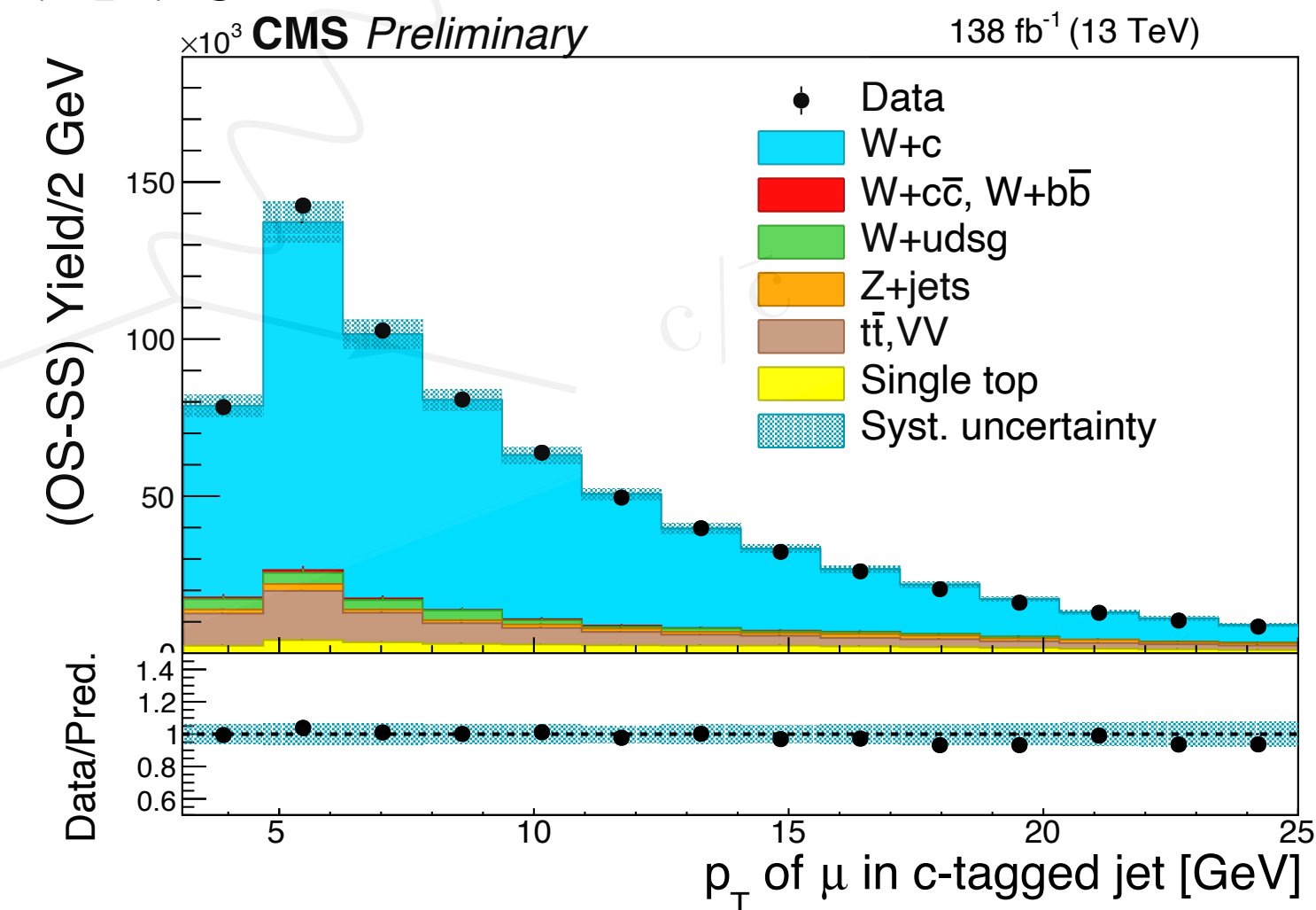
- Fiducial cross sections in $W \rightarrow e\nu/\mu\nu$ and SL/SV channels agree within uncertainties
  - their combination, unfolded to particle level $\sigma(W+c)$ = 148.7 ± 0.4 (stat) ± 5.6 (syst) pb
  - comparison with predictions from aMC@NLO with NNPDF3.0 and NNPDF3.1 PDFs
    - systematics in the predictions include factorization and renormalization scale uncertainties and PDF uncertainties
    - predictions higher than the measured value
- Differential cross sections vs η and p_T of the W-lepton are also compared with aMC@NLO
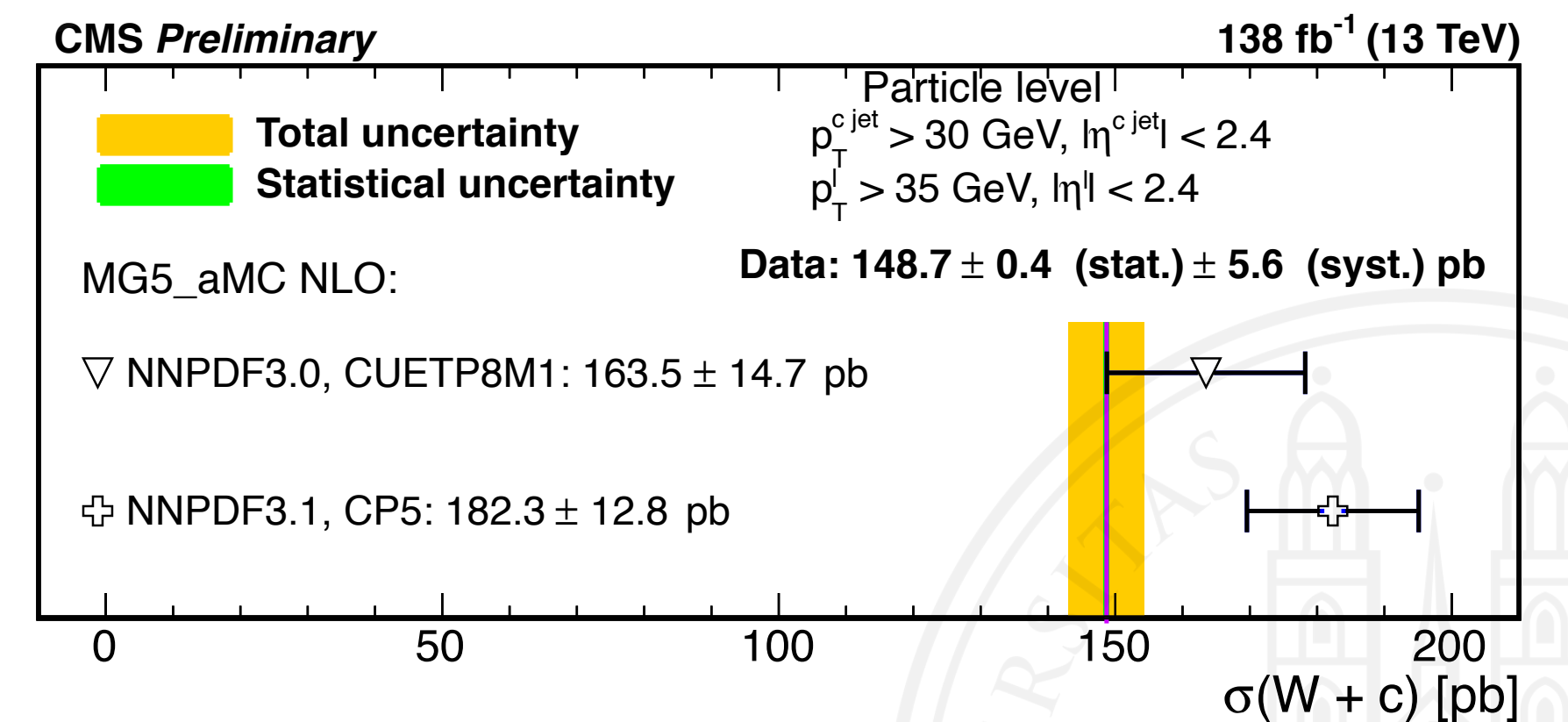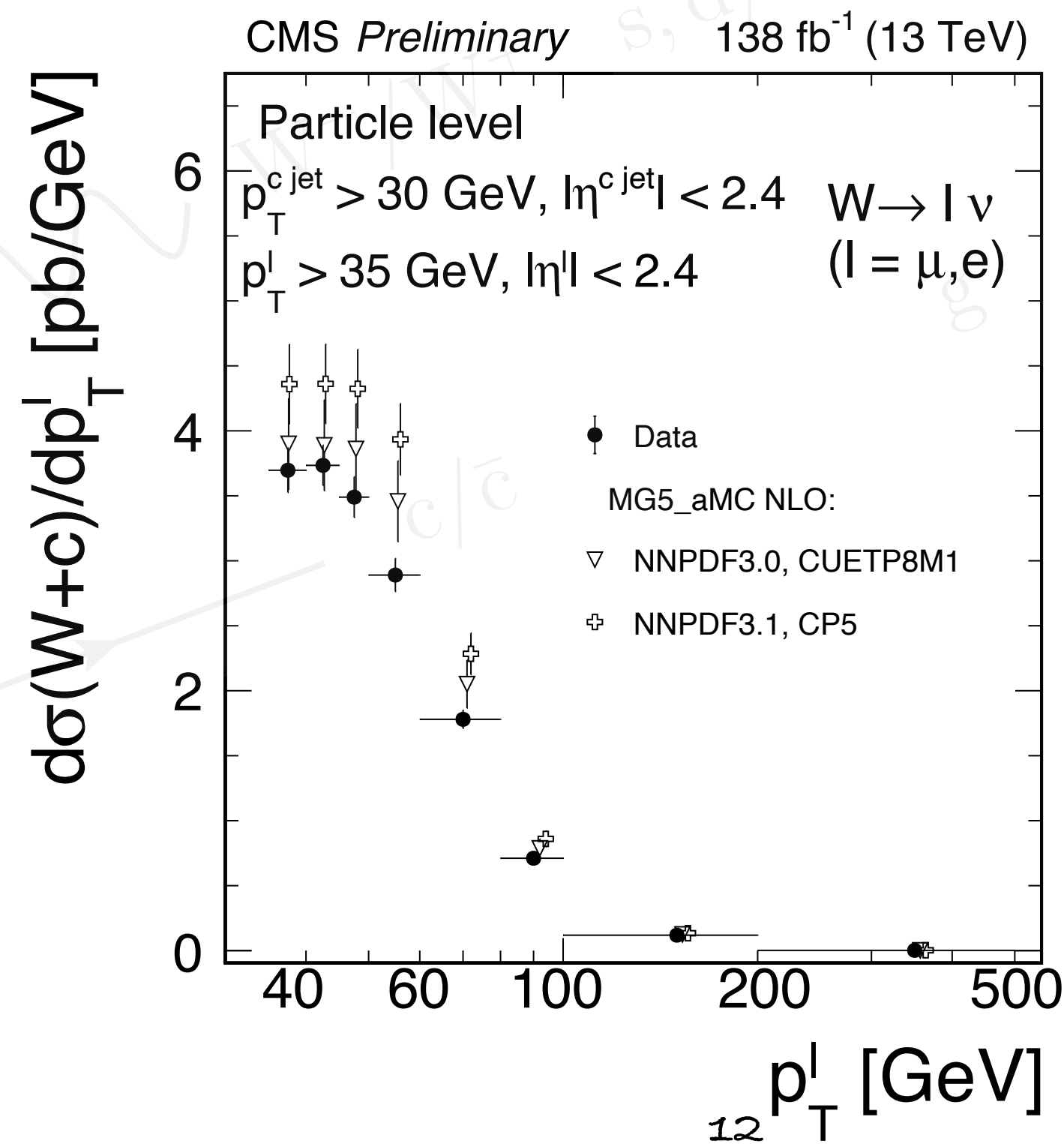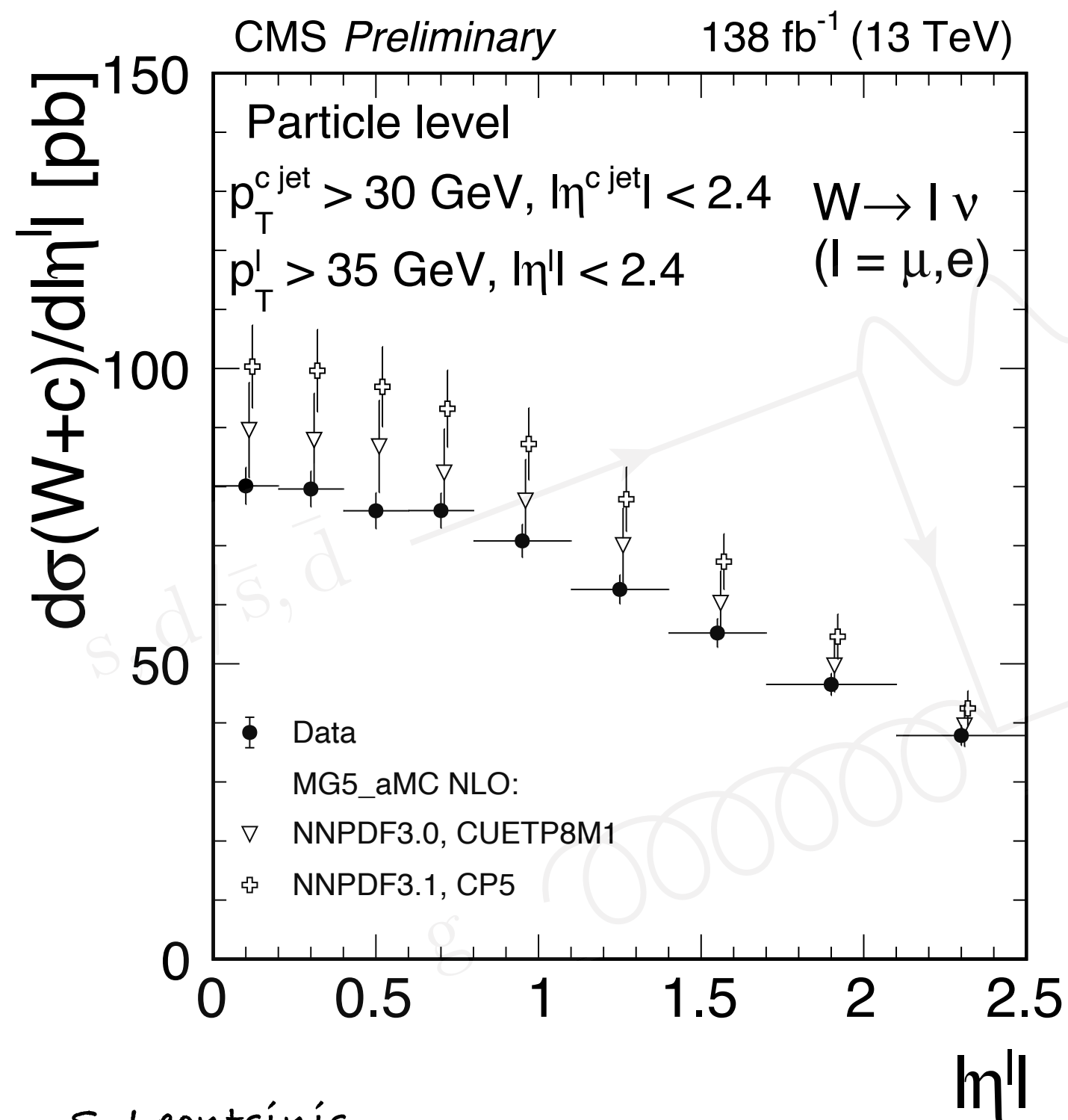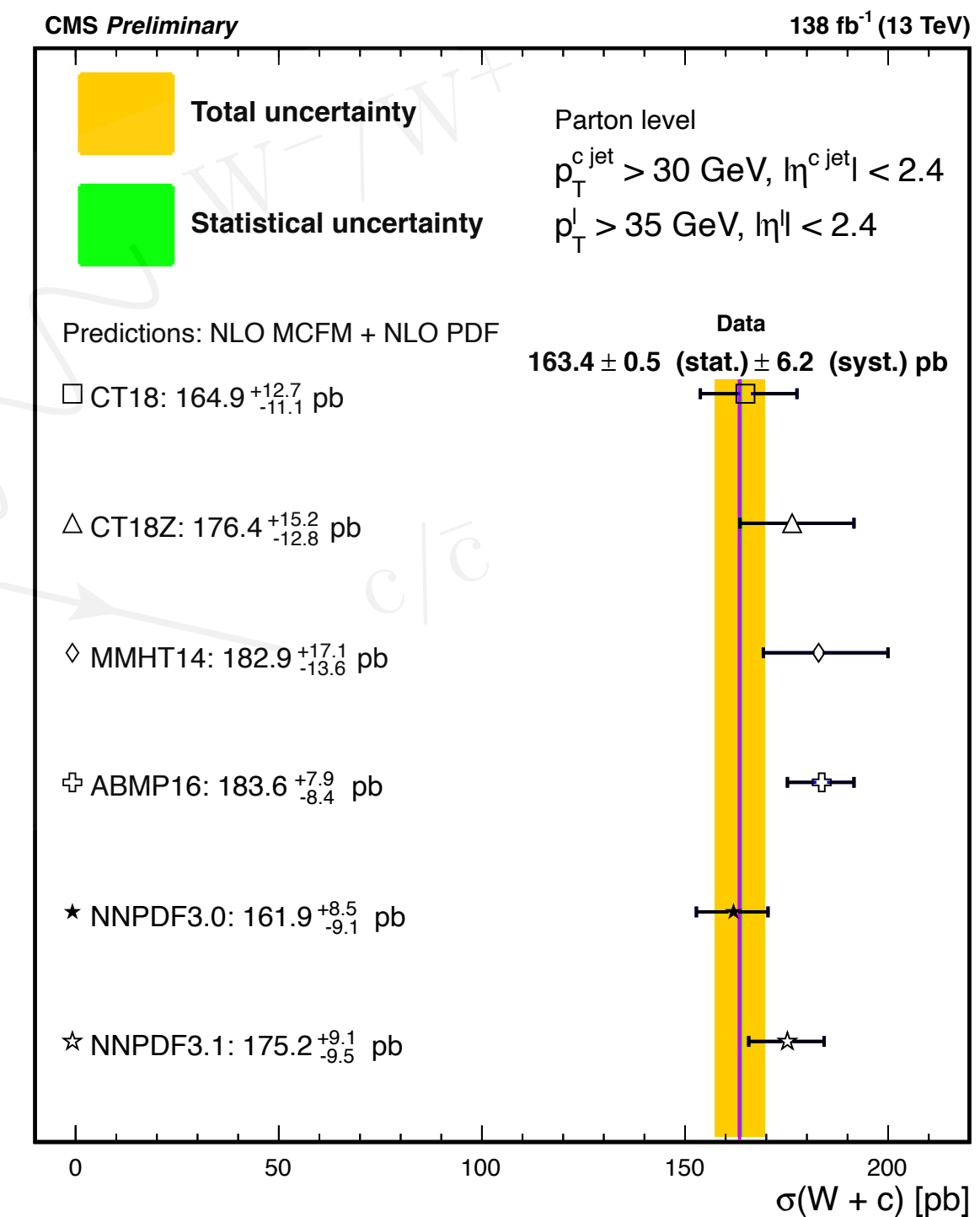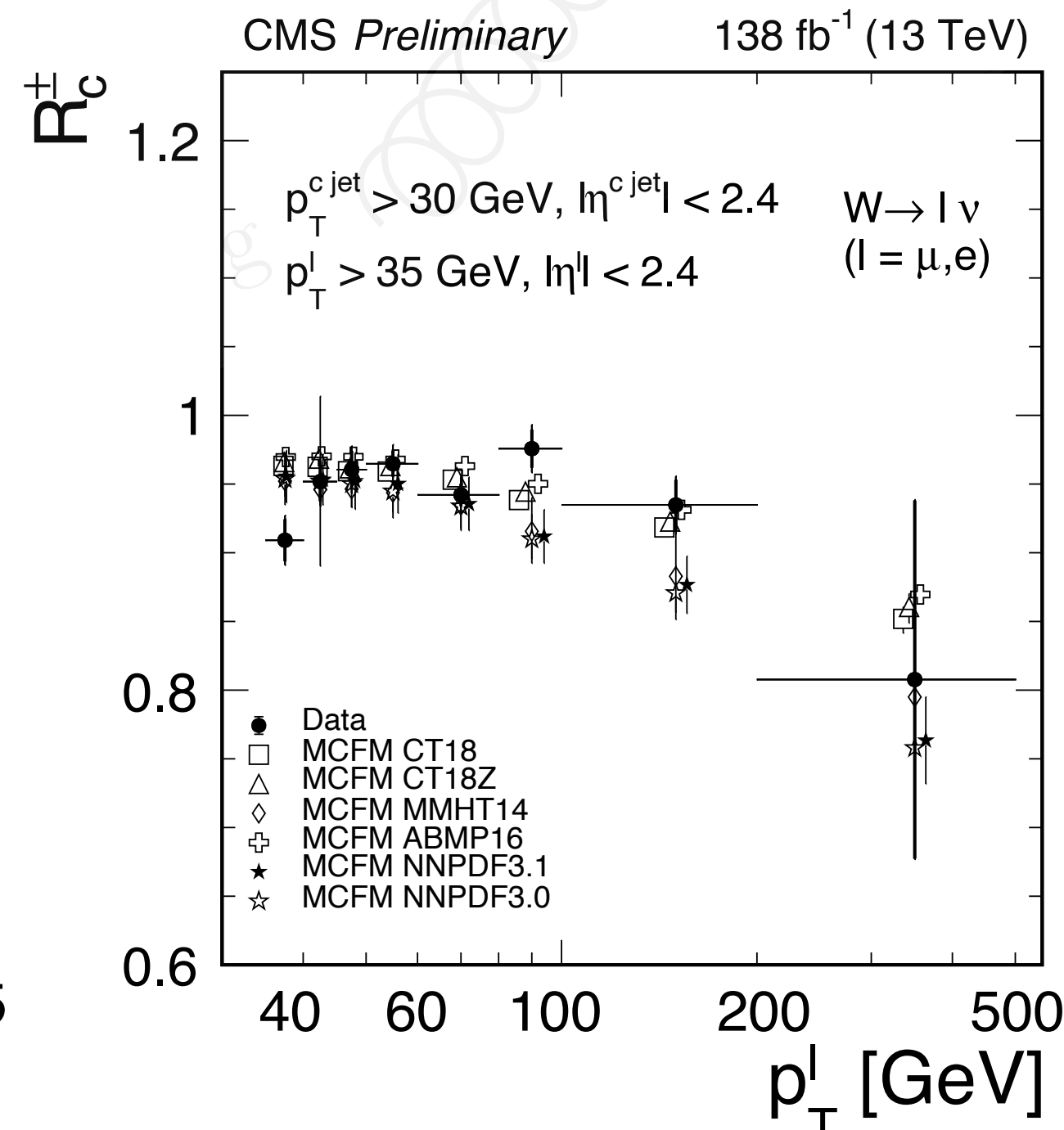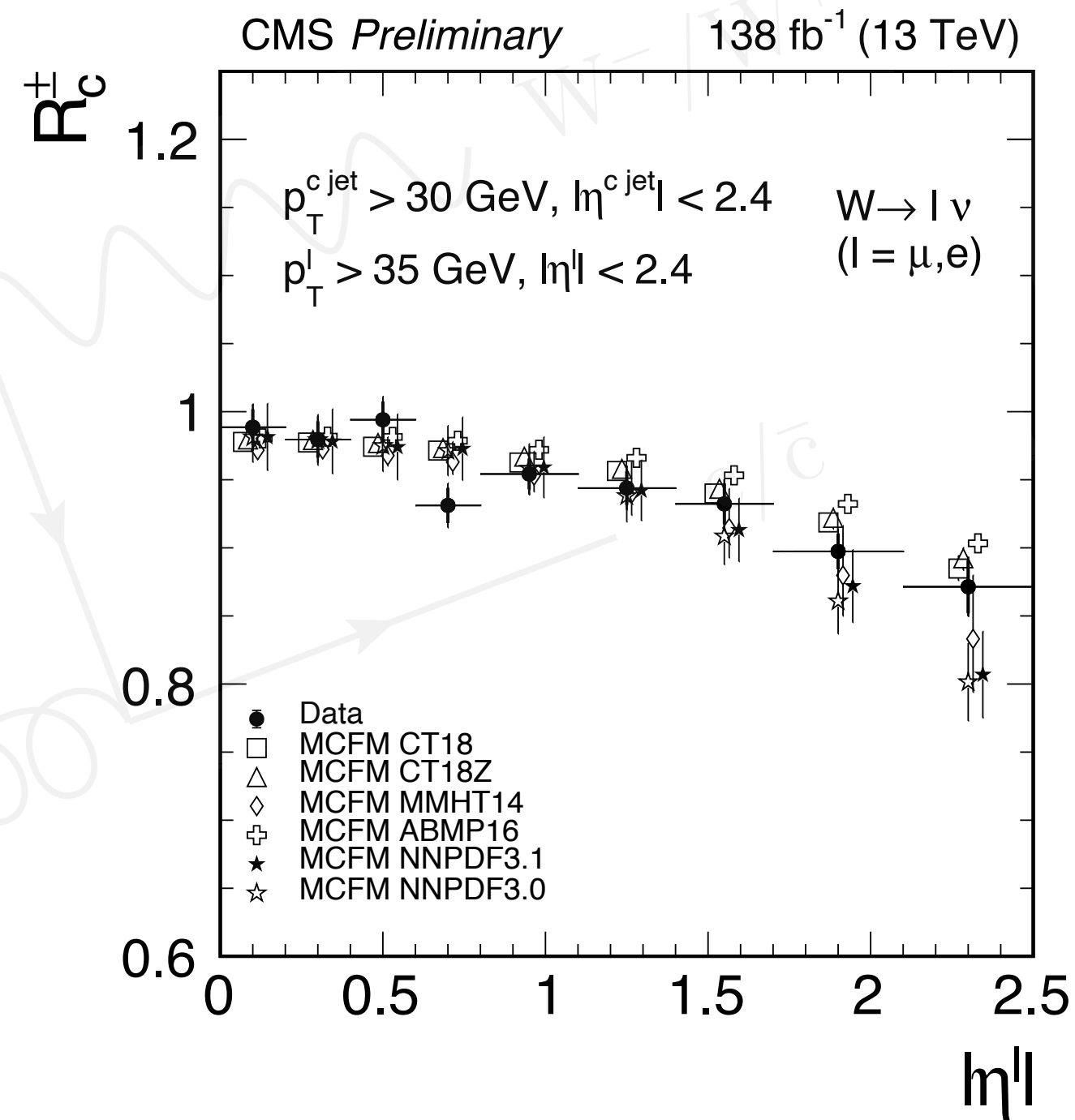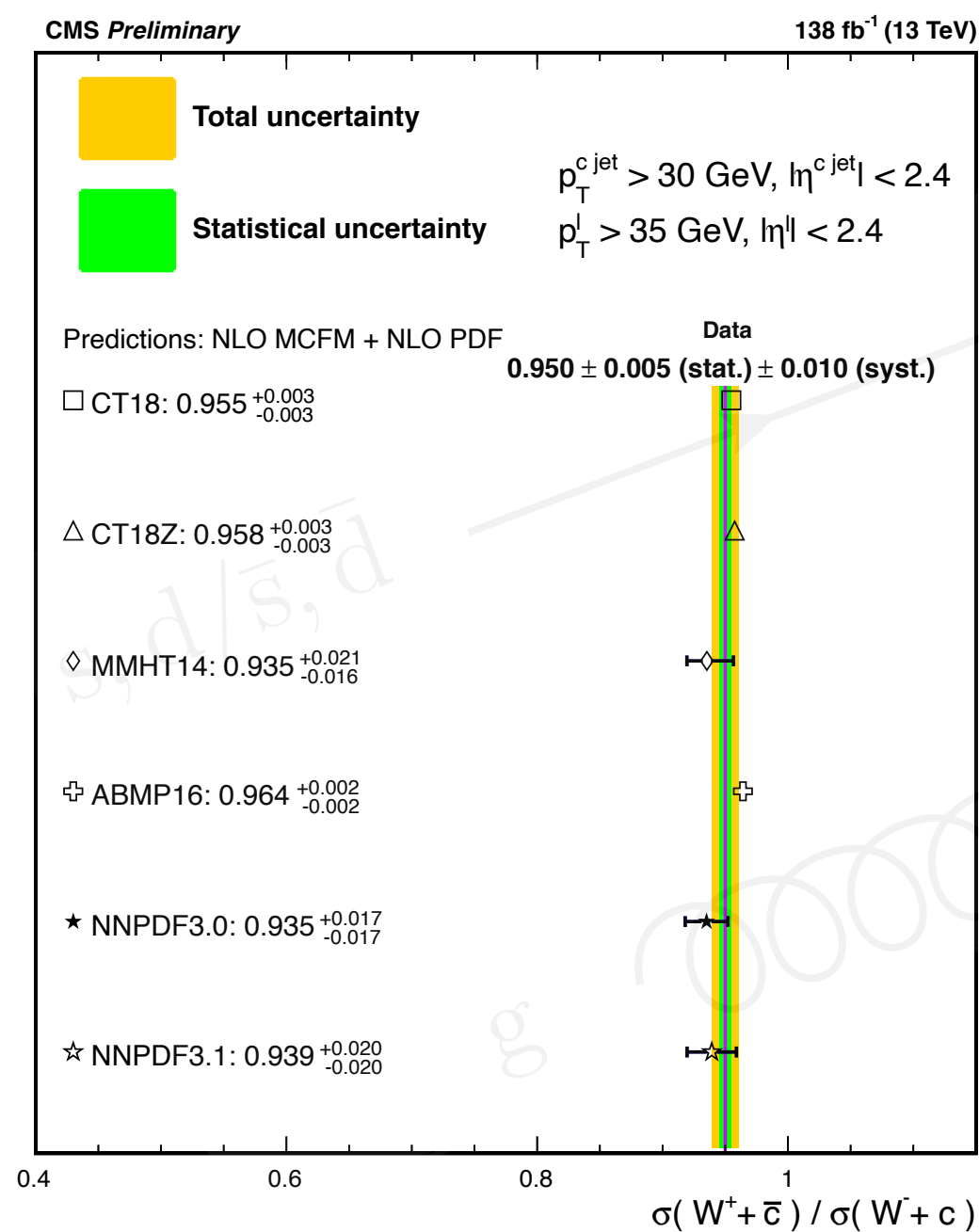
- Measurement also unfolded to parton level

  - σ(W+c) = 163.4 ± 0.5 (stat) ± 6.2 (syst) pb

  - some MCFM analytical calculations slightly overshoot measurement

- $R_c^{\pm}$ = σ(W$^+$ + c)/σ(W$^-$ + c) measured to be 0.950 ± 0.005 (stat) ± 0.010 (syst)

  - differential measurements also vs η^l and p_T^l

  - all predictions compatible with measurement within experimental and theoretical uncertainties

- Measurement of a W boson produced in association with a $D^{(*)}$ meson
  - $W(\to e\nu/\mu\nu) - D^+ \to K\pi\pi - D^{*+} \to D^0\pi^+ \to (K^-\pi^+)\pi^+$
- Classification of events to opposite- and Same- Sign W/D candidates
  - in LO only OS pairs are expected
  - background mostly symmetric in charge → signal = OS - Same Sign candidates

- Measurement includes fiducial and differential $W+D^{(*)}$ cross sections
  - comparison with NLO calculations
- Cross section ratio of $R_c^\pm = \sigma_{fid}(W^+ + D^{(*)}) / \sigma_{fid}(W^- + D^{(*)})$
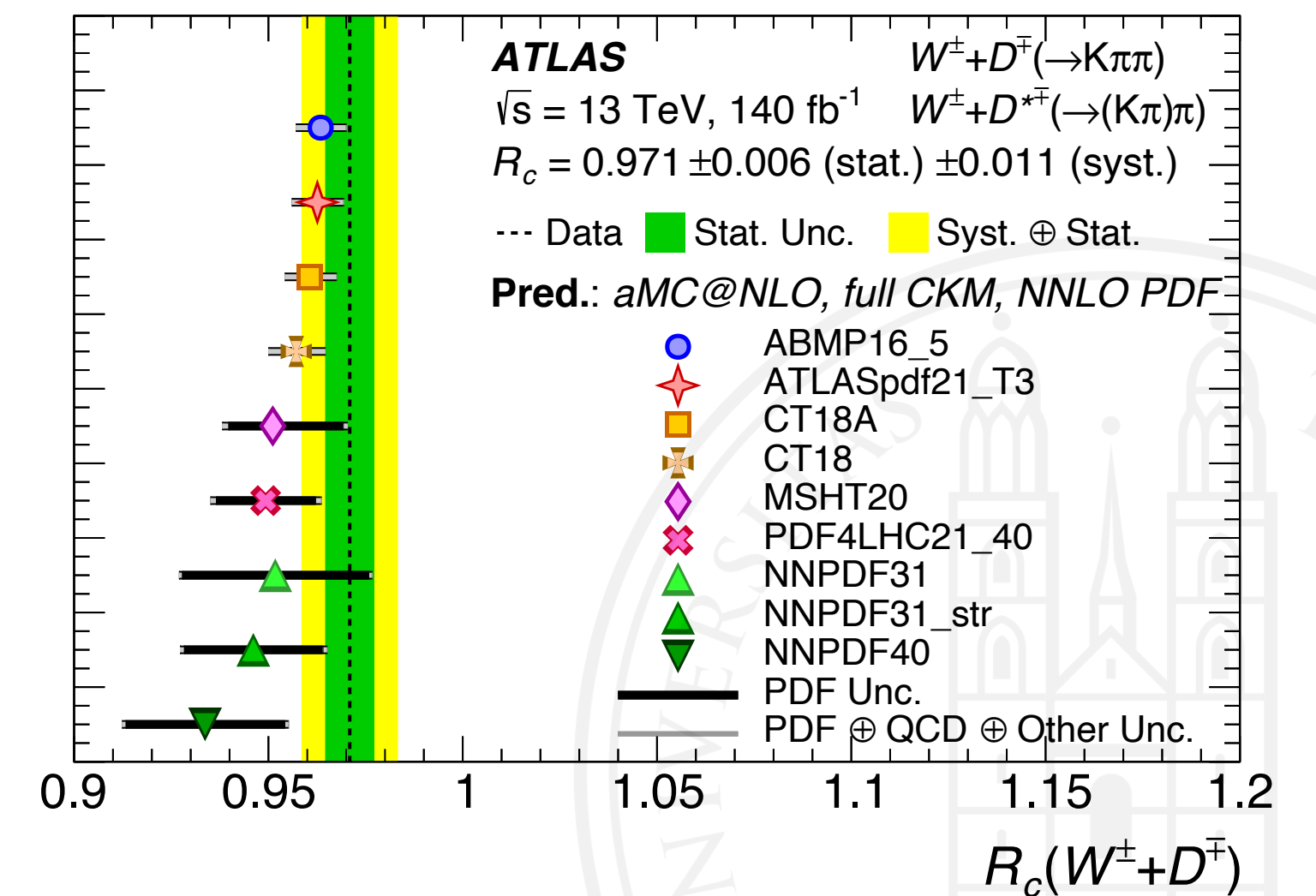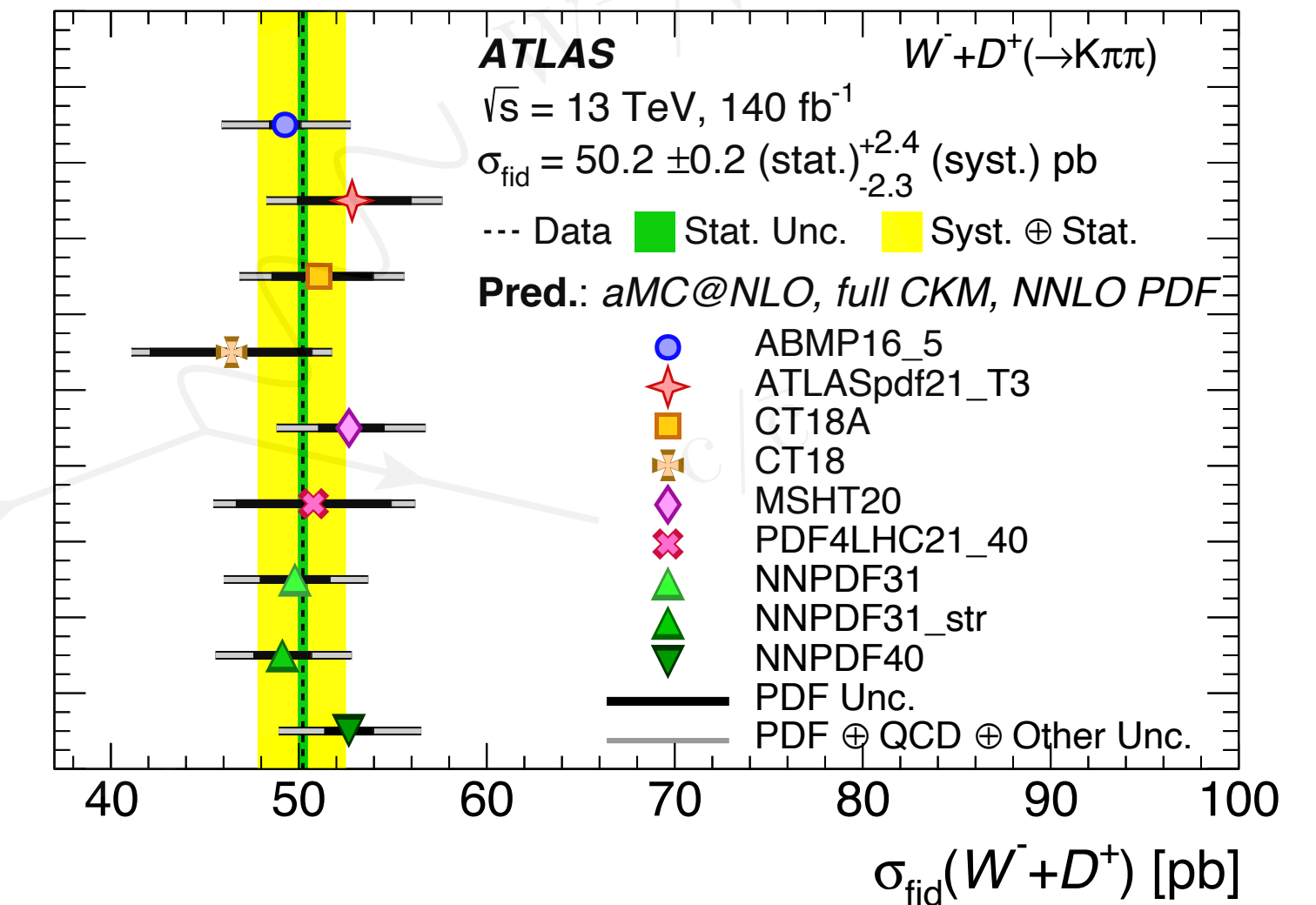
- Data collected during run-2 with single lepton triggers
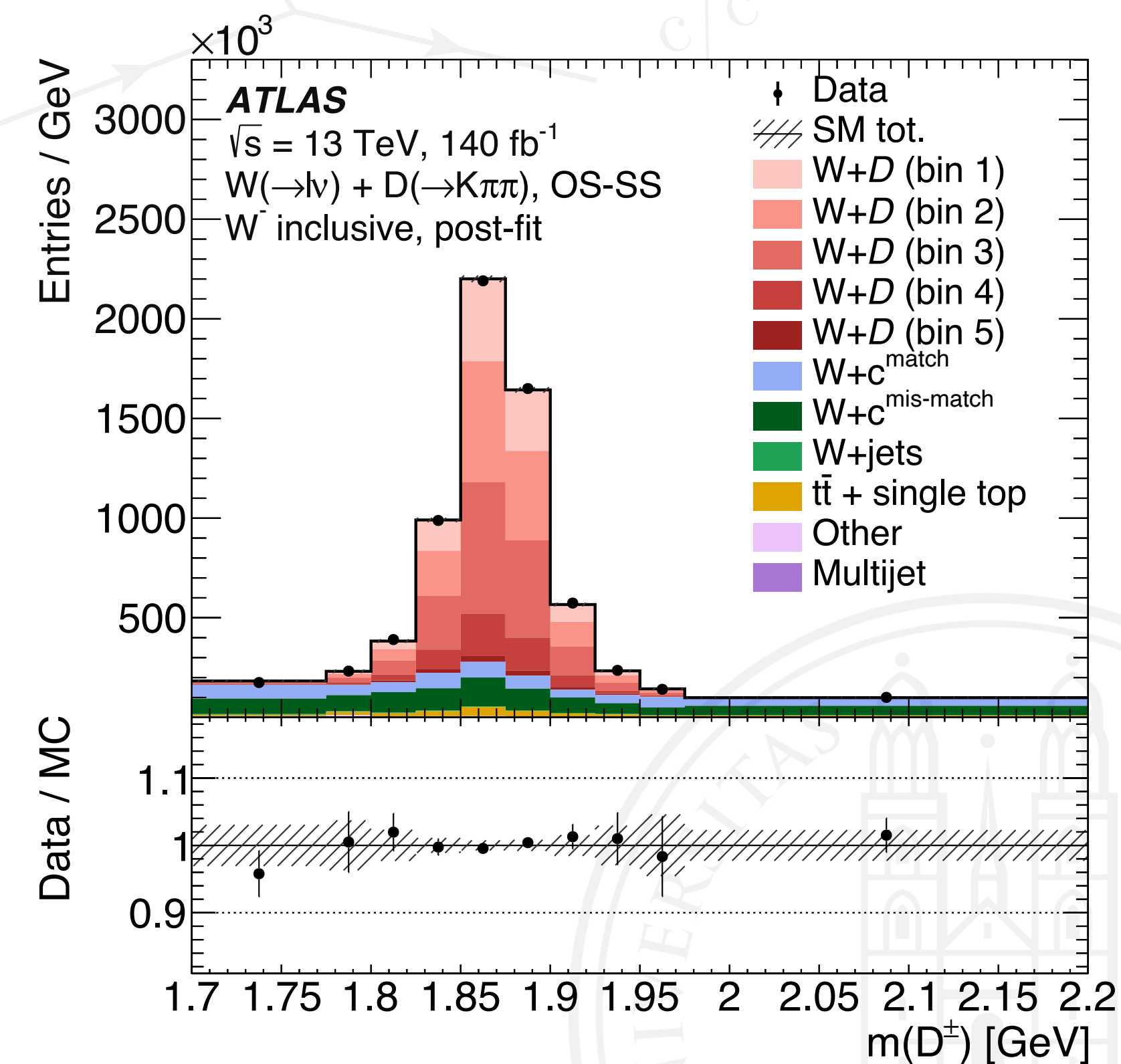
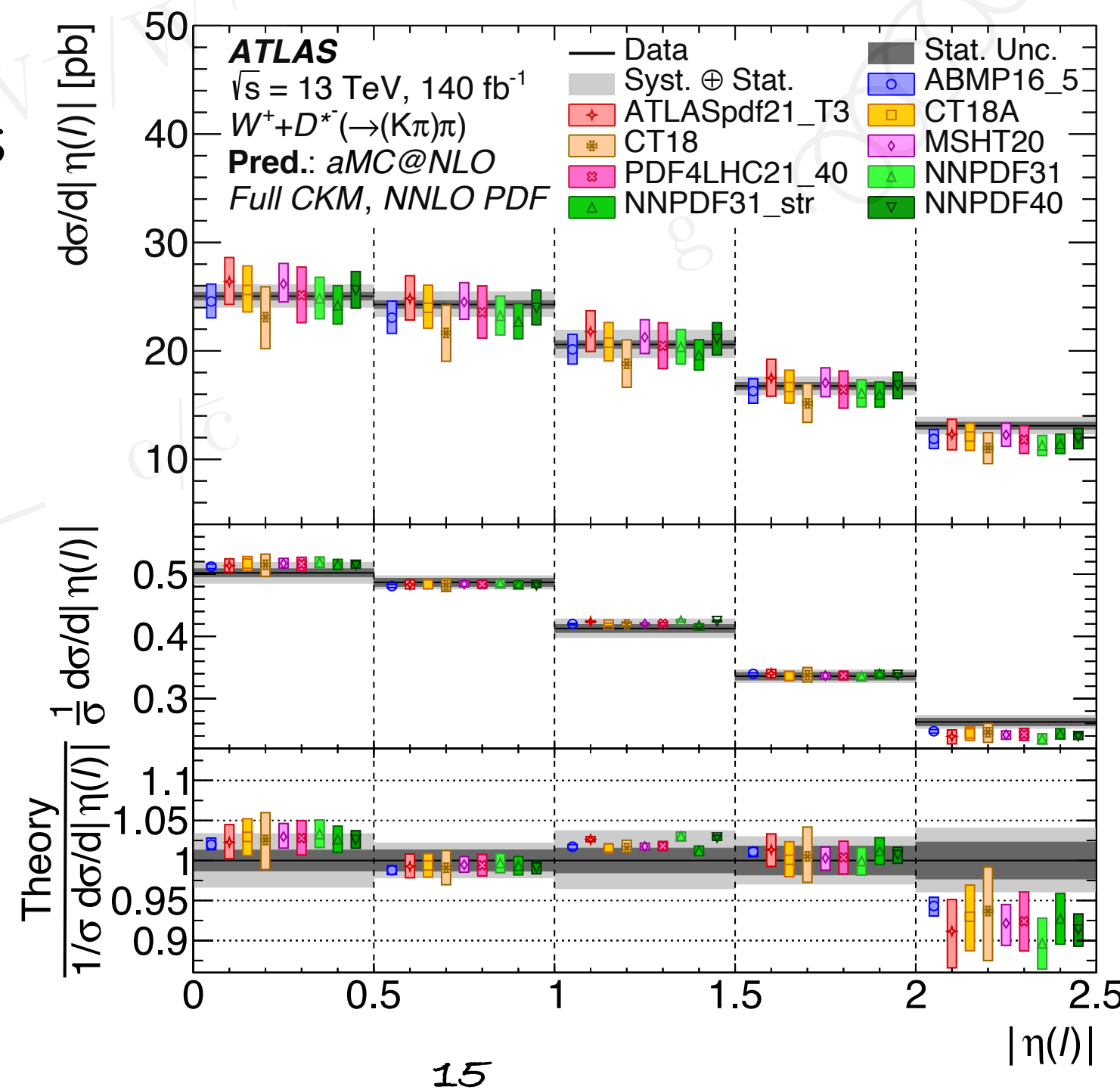- Fiducial cross sections are compared with the theoretical predictions from different NNLO PDF sets
  - all four channels are consistent with expectation
- Cross section ratio $R_c^\pm$ is shown for the combined D^+ and D^{*+}
  - consistent with most PDF sets, apart from NPDF4.0$_{NNLO}$
  - PDF sets in can/cannot impose restrictions the strange sea to be symmetric
  - agreement hints for small s - s-bar asymmetry
- Differential cross sections as a function of the p_T of the D meson and η of the W lepton
  - consistent patterns in the D mesons

end