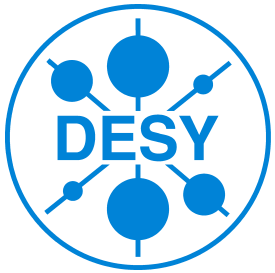
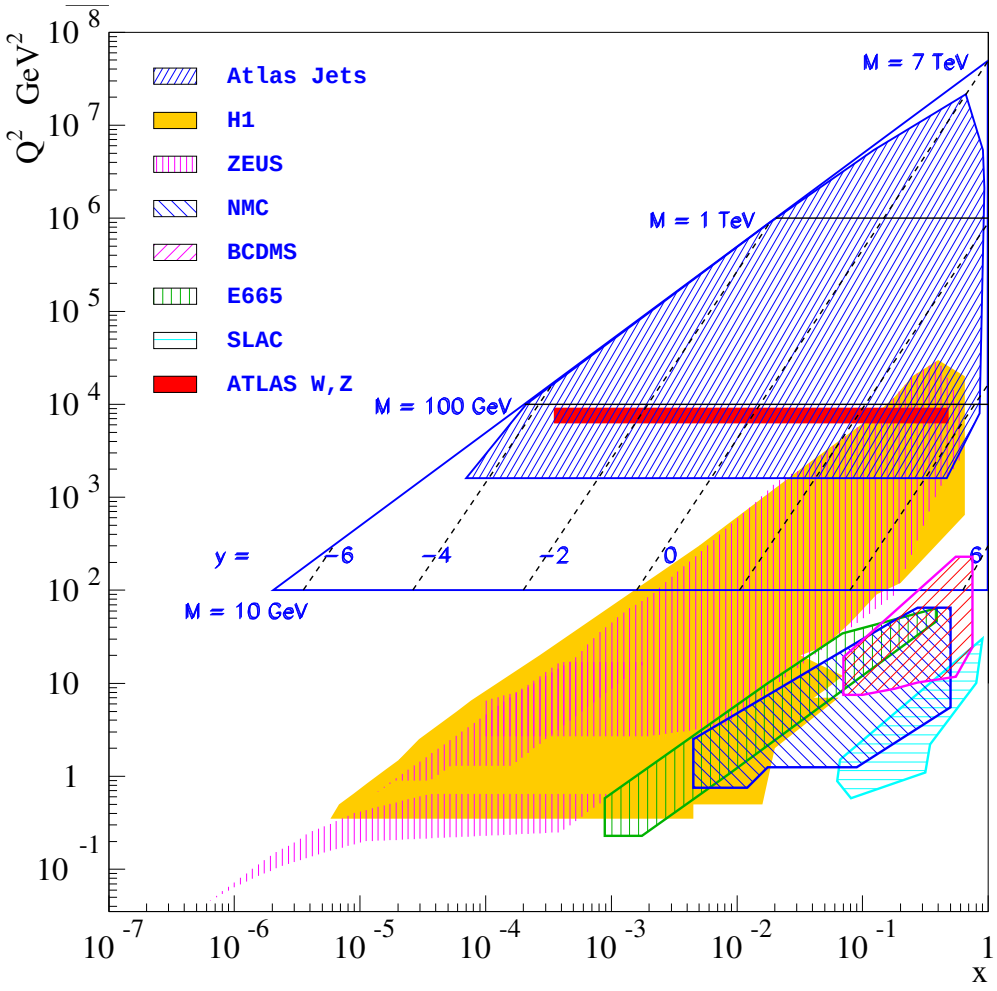


Tests of QCD at Colliders

S. Glazov (DESY)

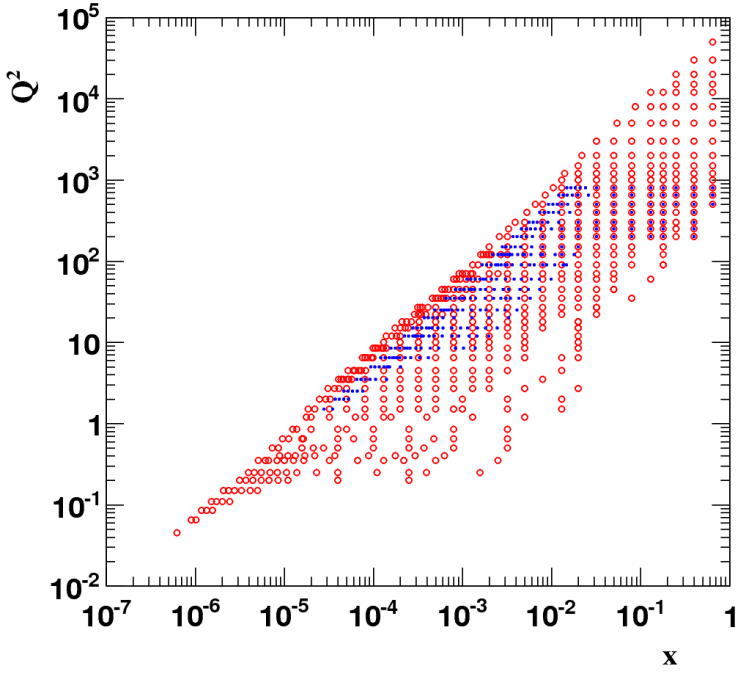
Blois 2014

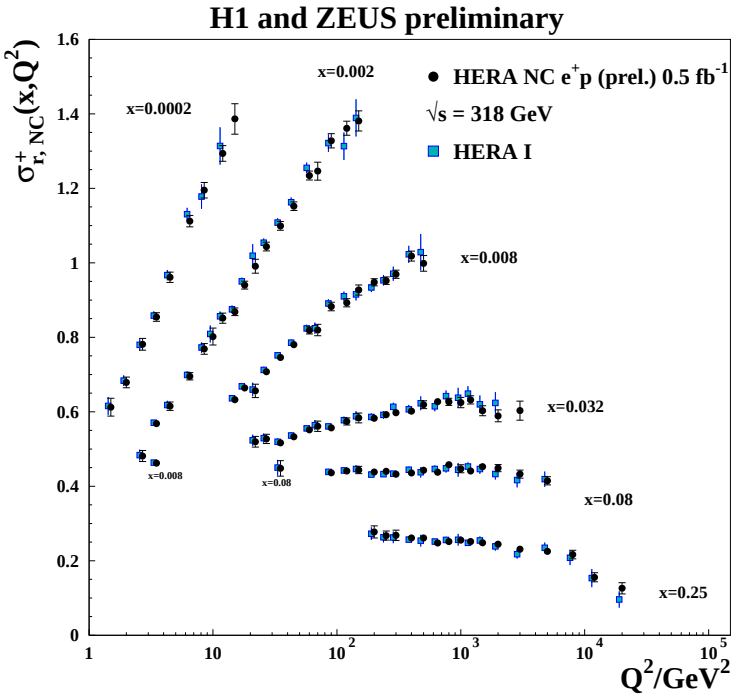
Kinematic coverage of ep and pp colliders



Wide coverage of kinematic range. Tests of parton evolution. Tests of QCD predictive power. Many new results from HERA, Tevatron and LHC.

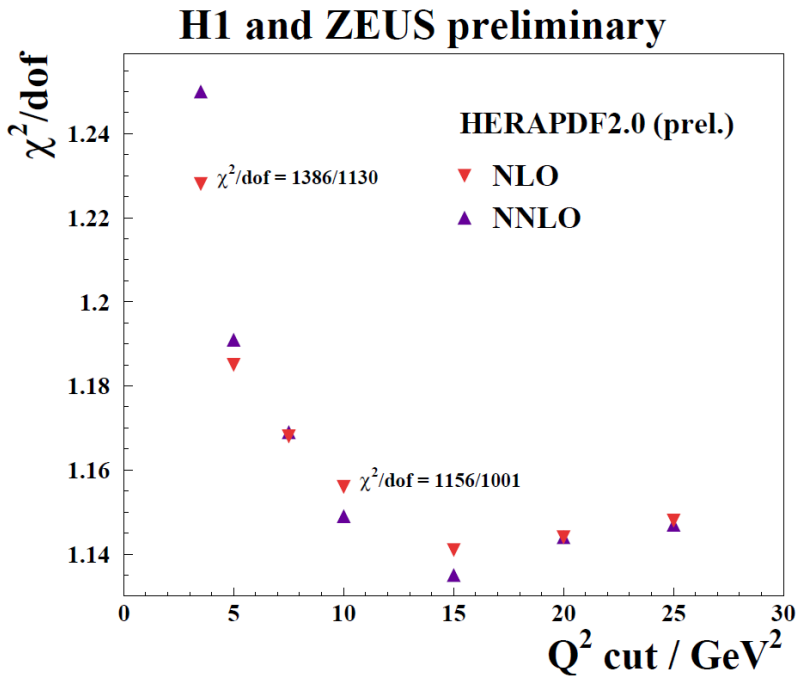
The HERA 2.0 combination

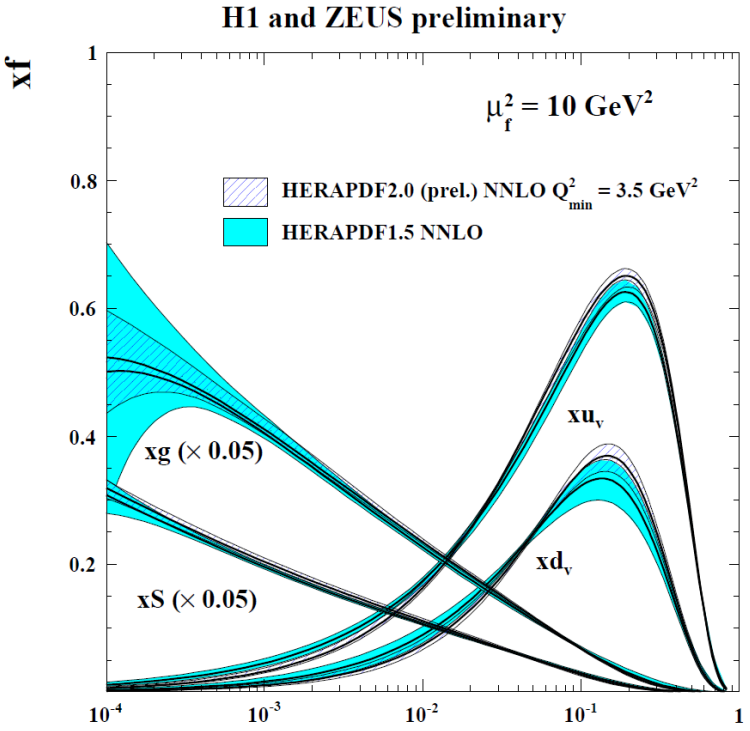




- Combination of the complete HERA sample corresponding to about 1 fb^{-1} of luminosity. New samples vs HERA1.0 include high Q^2 measurements of H1 and ZEUS as well as samples taken with $E_p = 460$ GeV and $E_p = 575$ GeV.
- Good consistency between the two experiments with overall $\chi^2/dof = 1685/1620$; significant reduction of the data uncertainties after the combination.

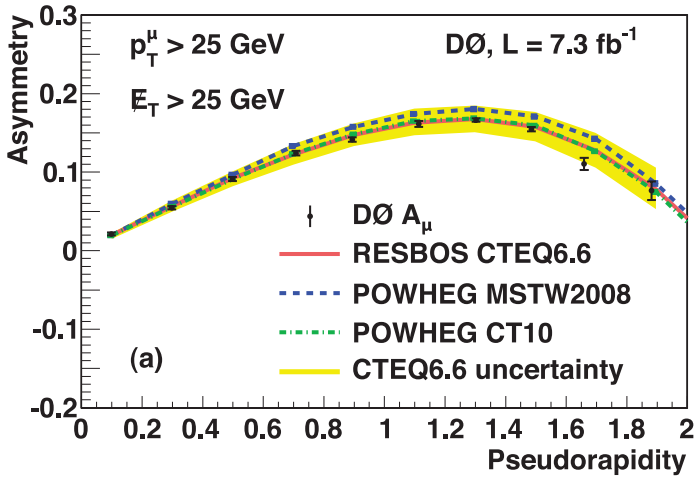
The HERAPDF2.0 set

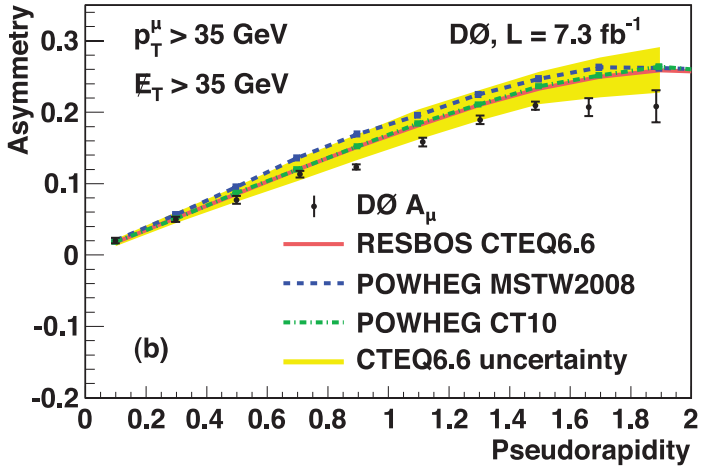


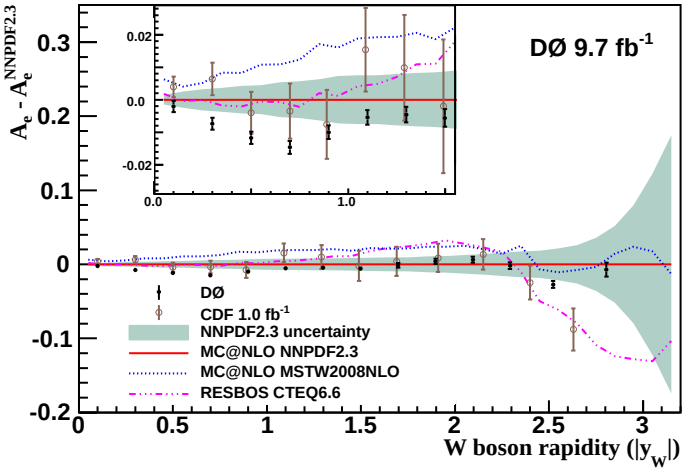


- The combined data are used in NLO and NNLO QCD analysis. A strong dependence of χ^2/dof on Q^2 cut is observed for $Q^2 \leq 10\ \mathrm{GeV}^2$ → default new PDF set uses $Q^2 \geq 10\ \mathrm{GeV}^2$ requirement.
- The new HERAPDF2.0 set is compatible with HERAPDF1.5, while uncertainties are reduced, especially at high x.

Tevatron W asymmetry



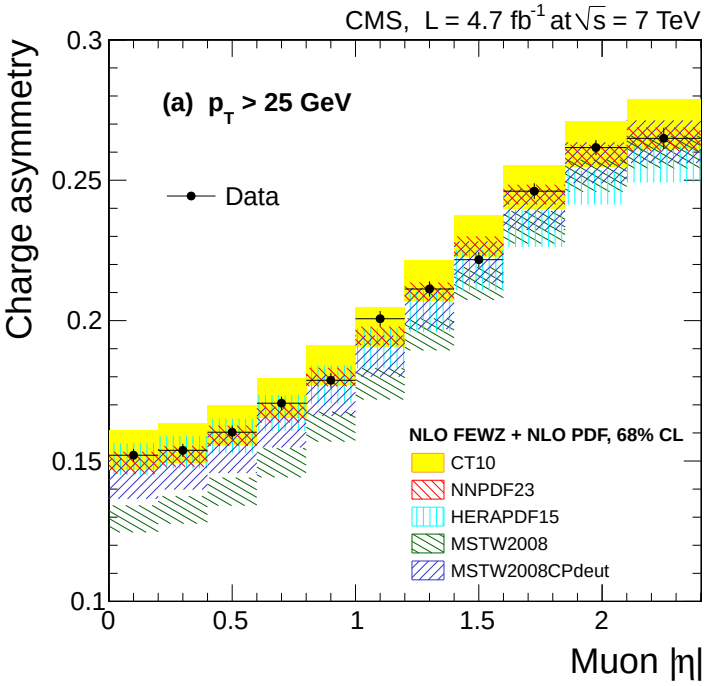


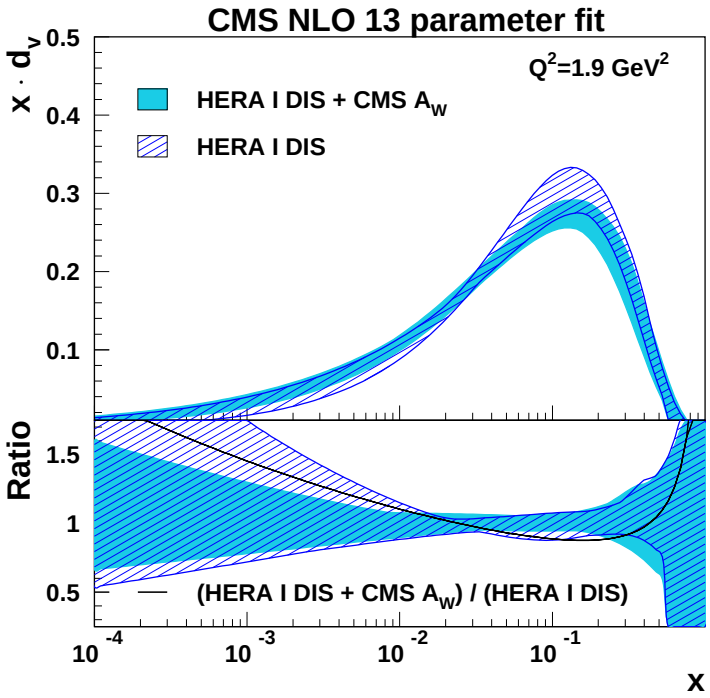


- Measurements of W boson production charge asymmetry is sensitive to u_v/d_v valence distributions.
- D0 finalised measurement of the muon charge asymmetry; higher $p_T > 35$ GeV measurement shows some tension with predictions.
- New measurement of W asymmetry using neutrino weighting method using $W^\pm \to e^\pm \nu$ with $|\eta^e| < 3.2$.

PRD88, 091102 (2013); PRL 112, 151803 (2014)

CMS muon asymmetry measurement

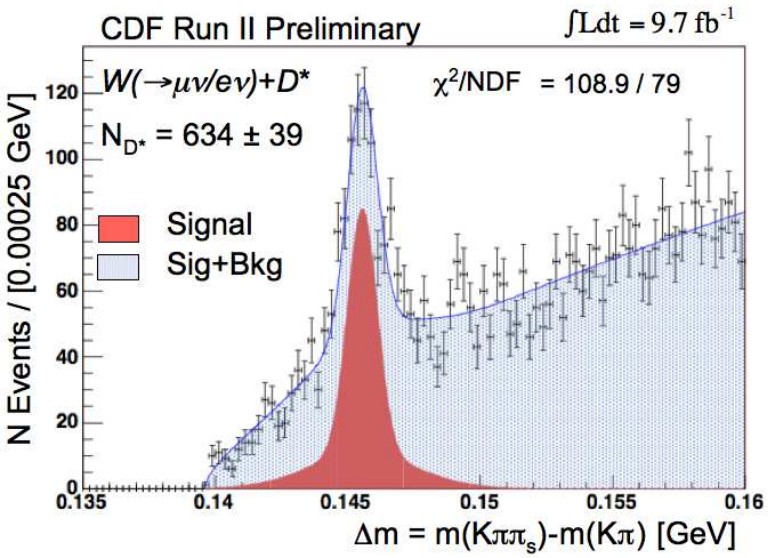


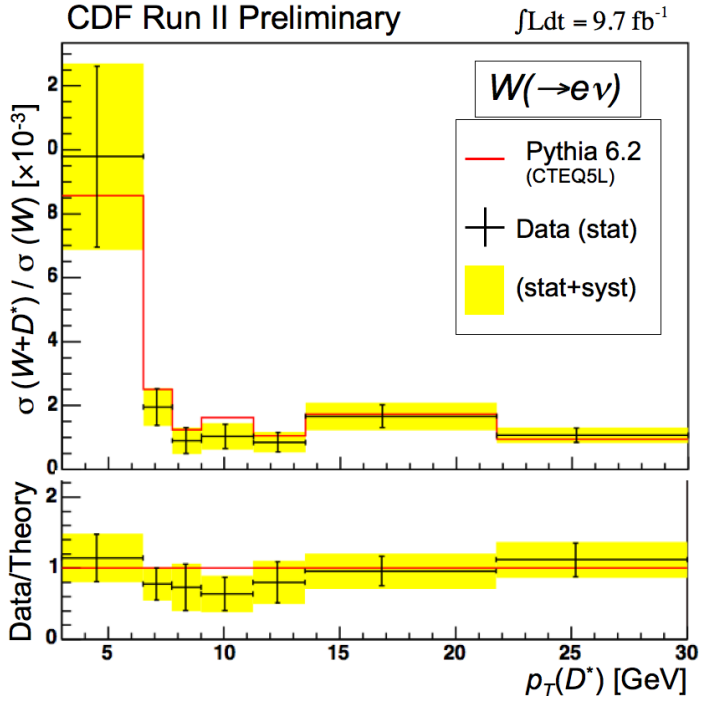


- CMS performs muon charge asymmetry measurement for $W^{\pm} \rightarrow \mu^{\pm}\nu$ decays. MSTW08 PDF is disfavoured, NNPDF2.3 which includes ATLAS W, Z data, describes data well.
- QCD analysis of the HERA+CMS asymmetry data illustrates reduction of the d_v uncertainty in the range where data contributes.

arXiv:1312.6283

Measurements of $V+D^*$ from CDF

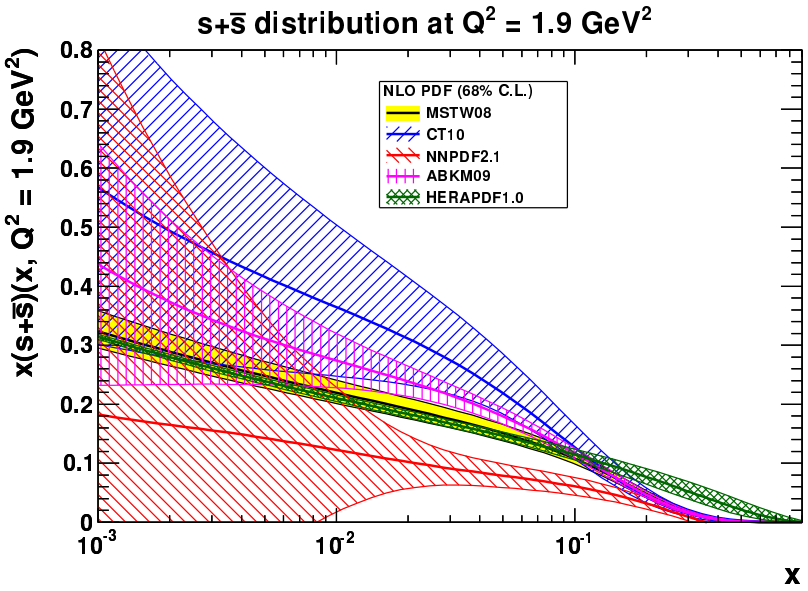


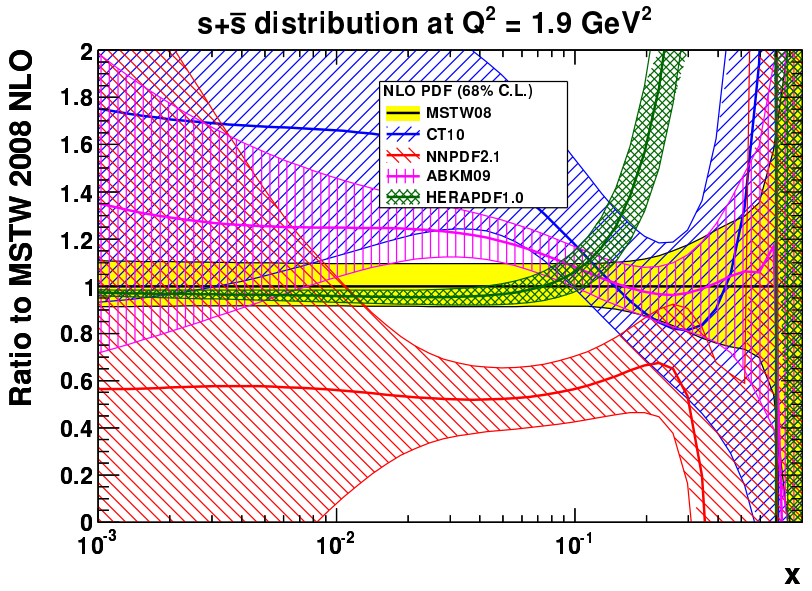


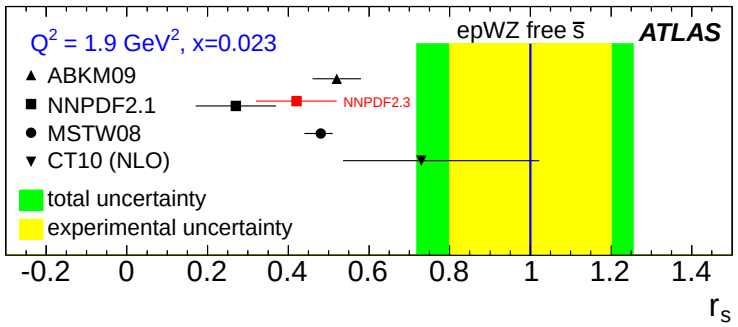
- Measurement of $V + D^*$ production extending to $p_T(D^*) > 3$ GeV using 9.7 fb^{-1} $p\bar{p}$ sample.
- Separate contributions from direct Wc, $14 \pm 6\%$ and "gluon splitting" production Wcc, $73 \pm 8\%$ and Wbb, $13 \pm 5\%$ by comparing same sign and opposite sign production and using difference in $p_T(D^*)$ distribution.

CDF prelim note 11087

Strange-sea PDF

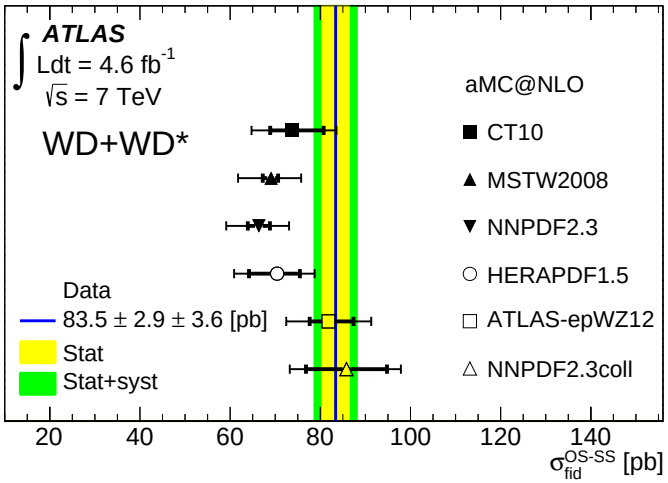


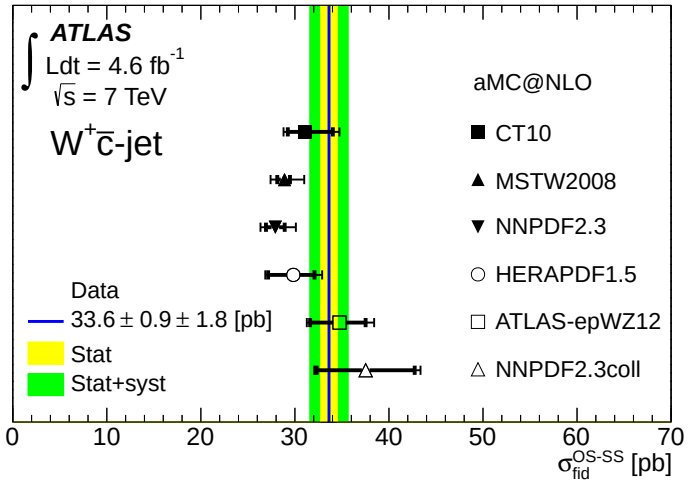


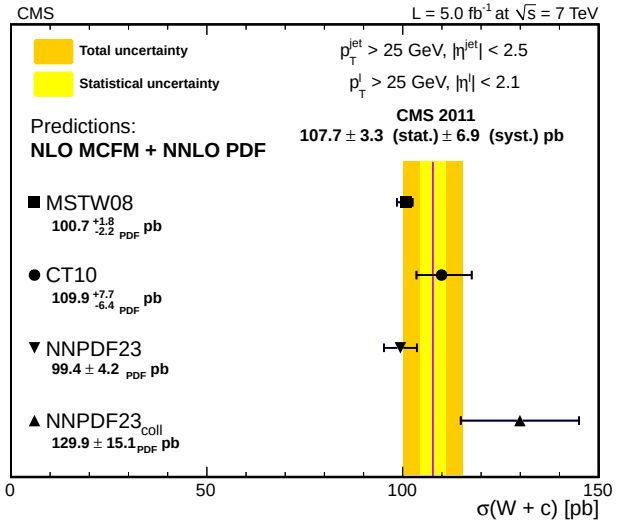


- Large spread of predictions for the strange-sea PDF.
- ATLAS QCD analysis of 2010 W, Z inclusive data suggest unsuppressed $\bar{s}$, $\bar{s}/\bar{d} \sim 1$ (ATLAS-epWZ PDF set).

Measurements of $W+c$ from ATLAS and CMS



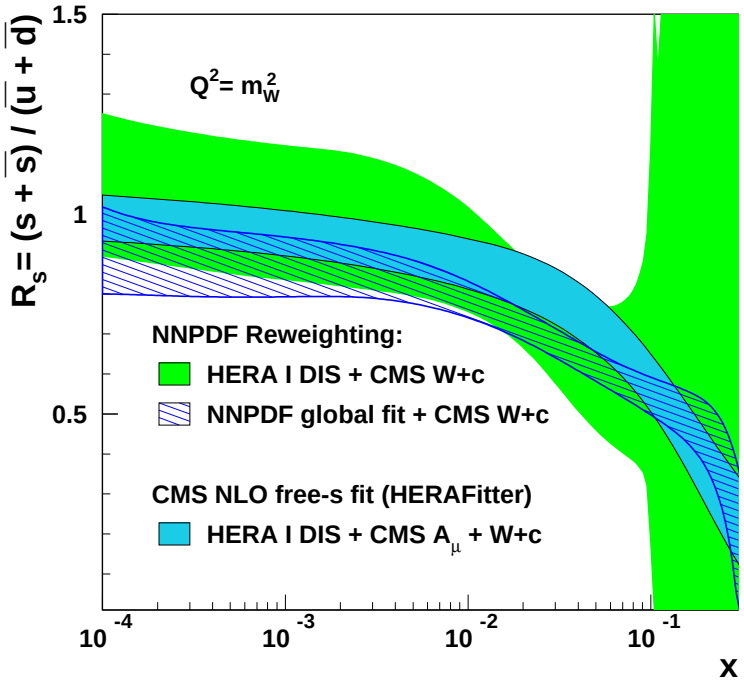


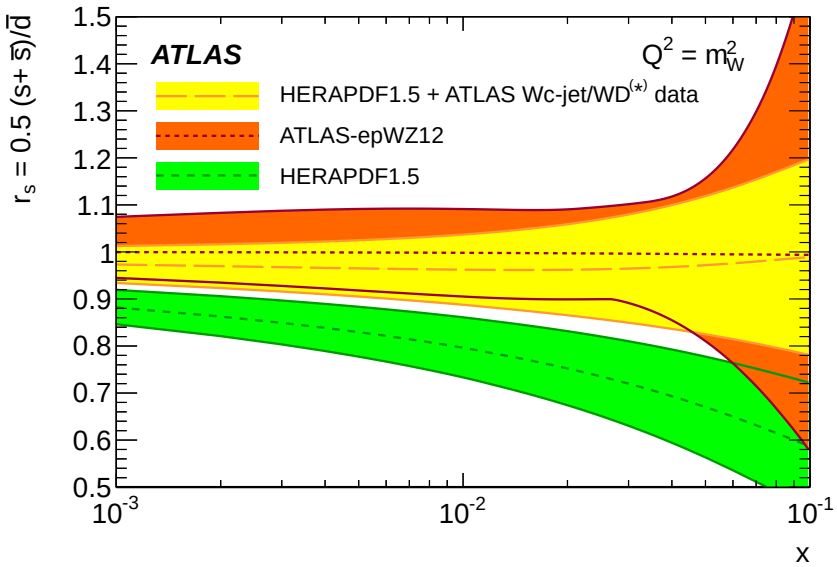


- Measurements of $\sigma(W^{\pm}c^{\mp}) - \sigma(W^{\pm}c^{\pm})$ from ATLAS and CMS, using c-jets tagged by soft muons and $D^{(*)}$ mesons, to probe strange-sea PDF using $gs \rightarrow Wc$ process.
- CMS finds best agreement with PDFs with somewhat suppressed strangeness while ATLAS results agree with ATLAS-epWZ predictions the best.

JHEP 02 (2014) 013, arXiv:1402.6263

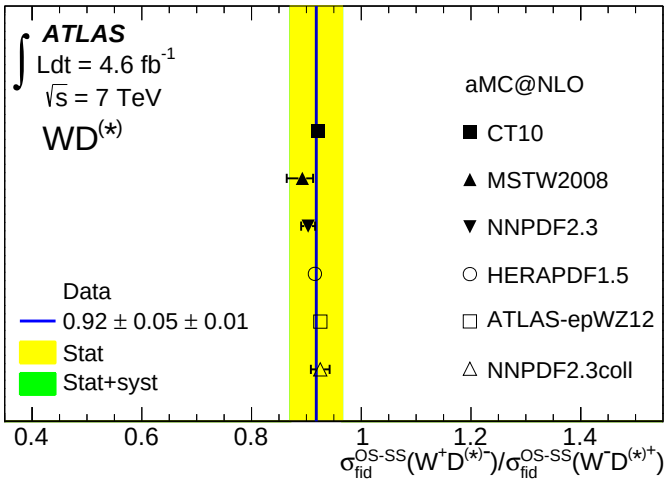
Strange-sea PDF comparison

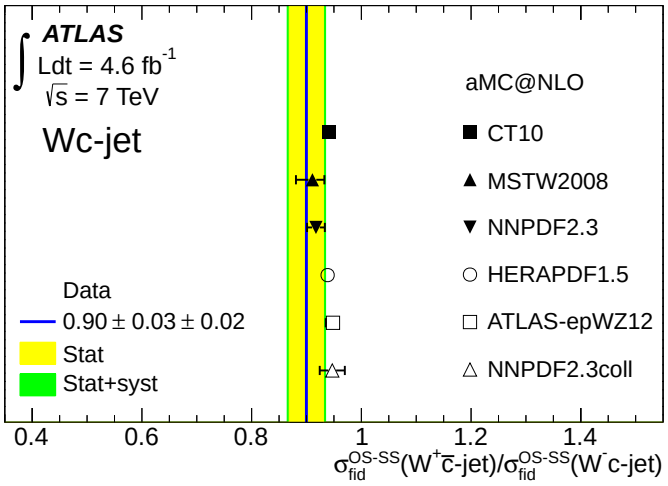


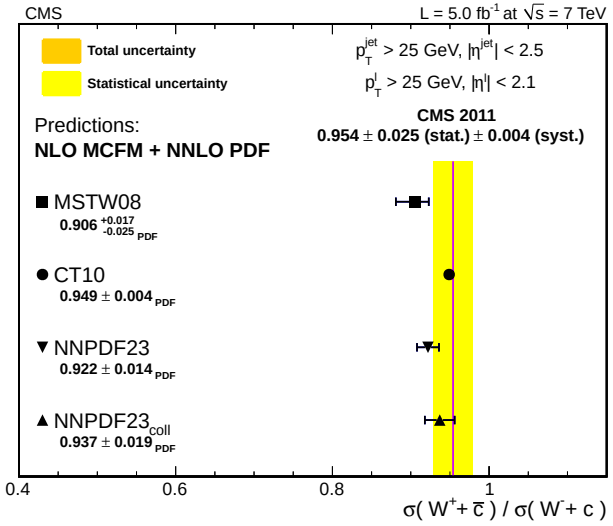


- CMS performs QCD analysis using HERA and CMS W asymmetry and $W + c$ data, reports $\bar{s}/(\bar{u} + \bar{d})$.
- ATLAS profiles HERAPDF1.5 which separates $\bar{s}/\bar{d}$ ratio as an uncertainty sources. The x-independent result $\bar{s}/\bar{d} = 0.96^{+0.26}_{-0.30}$ is consistent with no suppression.

Measurements of $\sigma^{W^+ + c^-} / \sigma^{W^- + c^+}$



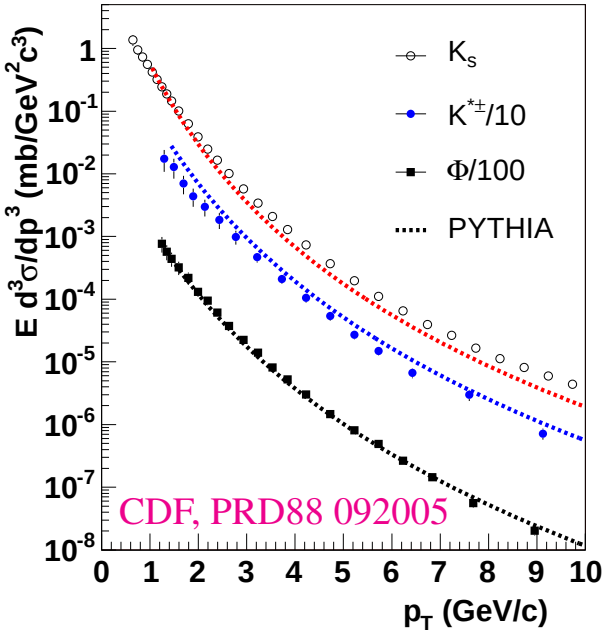


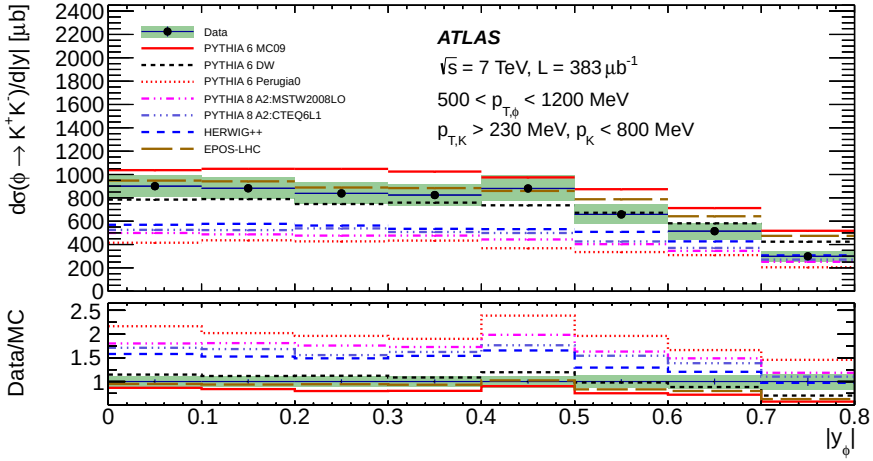


- The ratio $\sigma^{\mathrm{OS-SS}}(W^+c^-)/\sigma^{\mathrm{OS-SS}}(W^-c^+)$ is sensitive to the $s/\bar{s}$ distribution ratio with a small correction due to Cabibbo suppressed $d(\bar{d})g \rightarrow Wc(\bar{c})$ contribution.
- CT10 PDF set assumes $\bar{s}/s = 1$, data are consistent with this assumption.

Measurements are statistics limited, 8 TeV and Run-II data will help.

Strange particle production at LHC and Tevatron

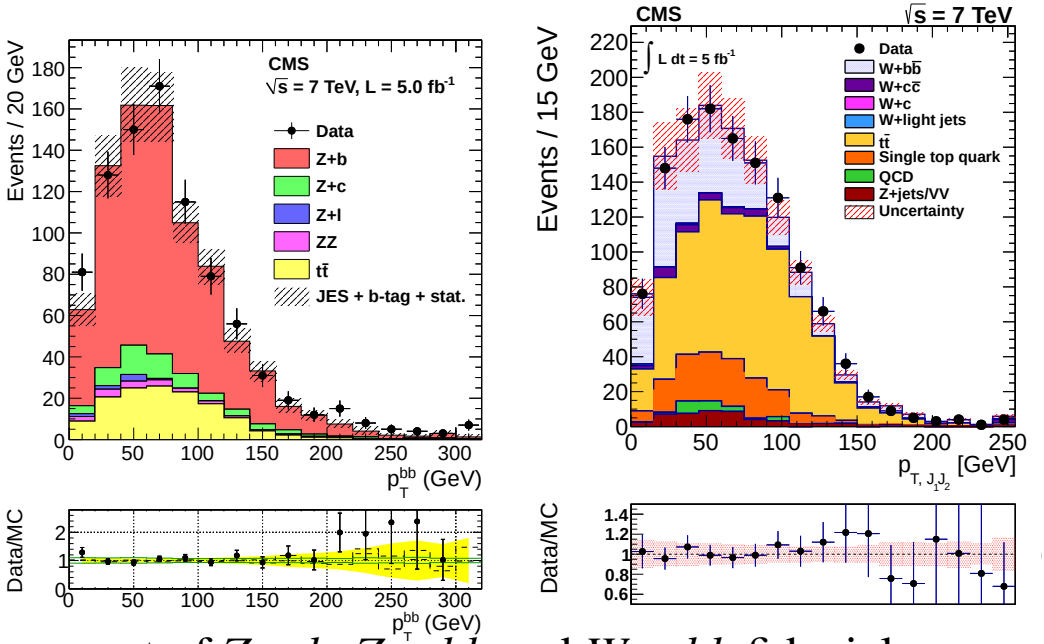




- Recent measurements of CDF and ATLAS of strange production in MB events (and in jets in case of CDF).
- CDF finds that ϕ-meson production rate at Tevatron is well described by default PYTHIA6 while ATLAS finds that more modern tunes struggle to describe the production rate.

PRD88 092005 (2013), arXiv:1402.6162

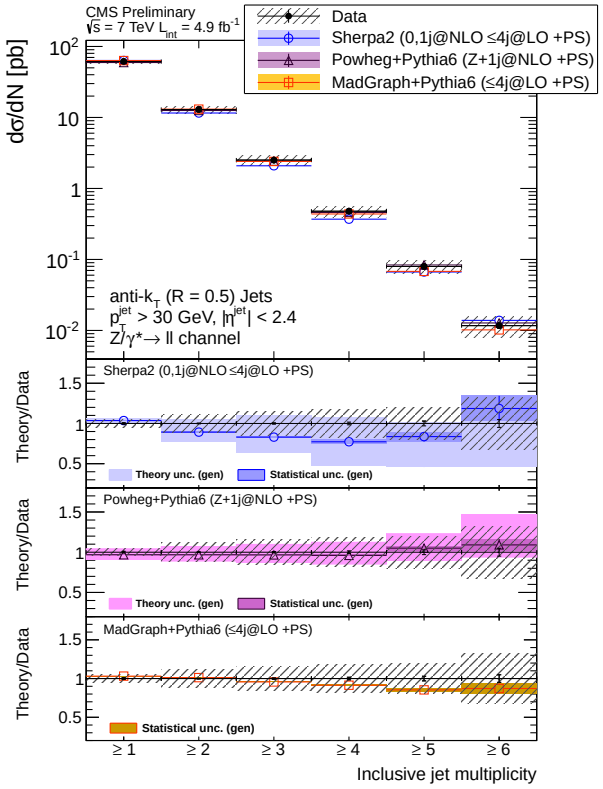
$Z + b(b)$, $W + bb$ studies in CMS

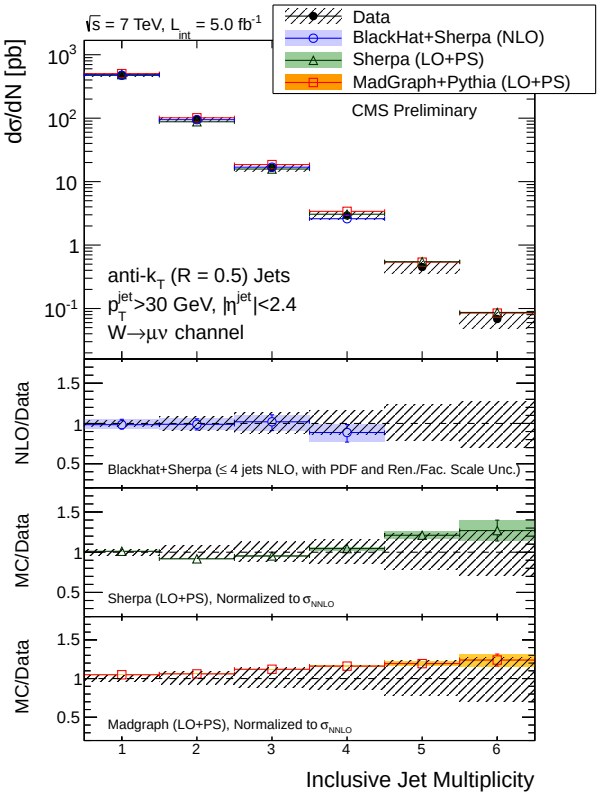


- Measurement of $Z + b$, $Z + bb$ and $W + bb$ fiducial cross sections performed by CMS. Detector-level distributions compared to predictions based on MADGRAPH+PYTHA.
- $Z + b$ cross section agrees better with 5 flavour predictions of MADGRAPH and aMC@NLO while $Z + bb$ cross section is closer to 4 flavour prediction.
- $W + bb$ cross section is an agreement with the expectations, when double-parton interactions contribution is taken into account.

arXiv:1402.1521,arXiv:1312.6608

V+jets measurements

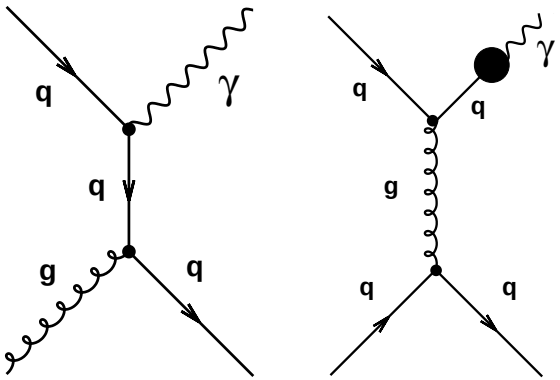


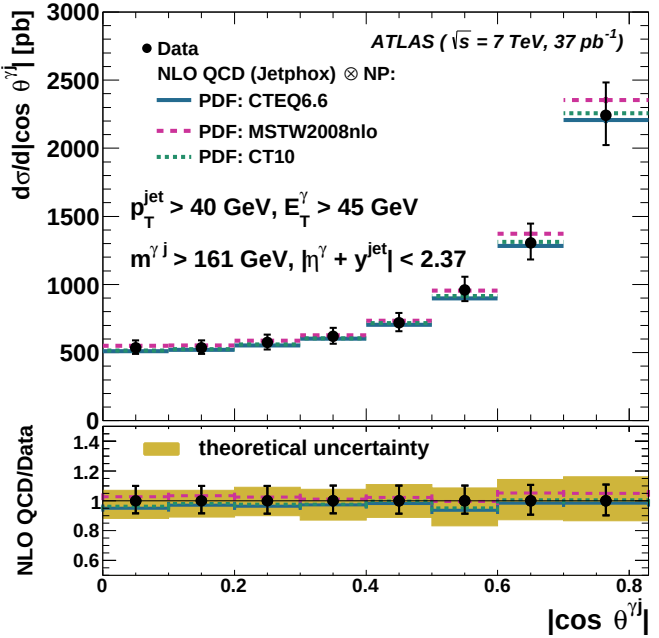


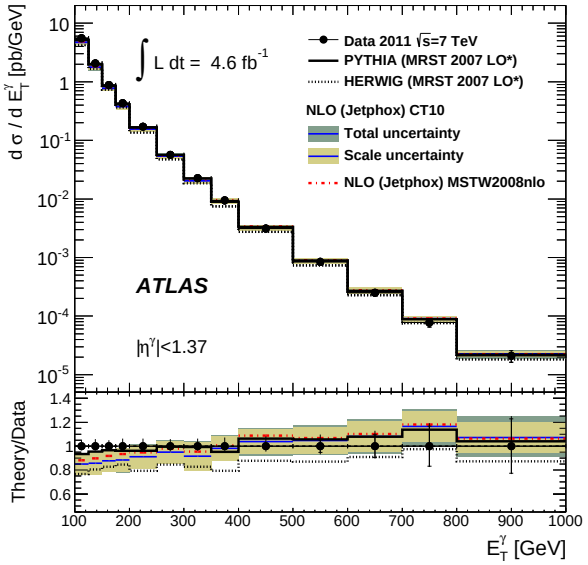
- CMS measurements of *V*+jet production probe high multiplicities; interesting test of modern multi-leg NLO MC techniques.

CMS-PAS-SMP-12-023, CMS-PAS-SMP-12-017, JHEP07(2013)032

Inclusive photon and photon+jets measurements



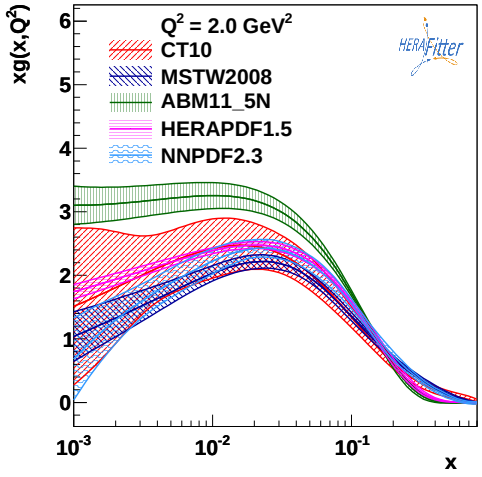


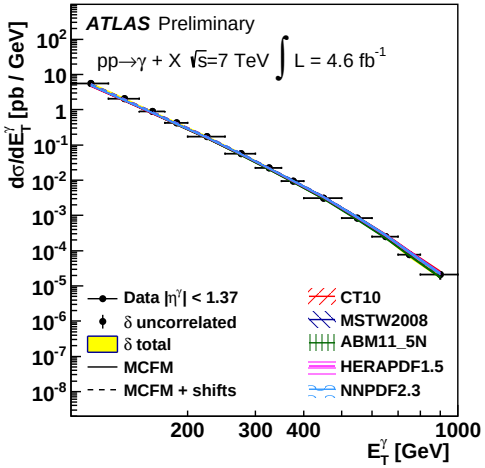


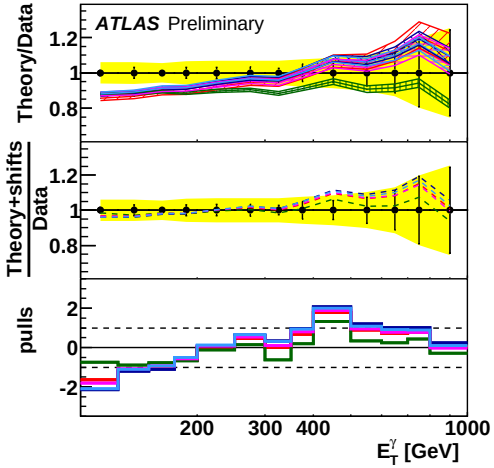
Photon production at the LHC has largest contribution from the Compton scattering: $qg \rightarrow \gamma q$. ATLAS measurements of photon plus jet and inclusive photon production show that the measurements can be described by NLO QCD.

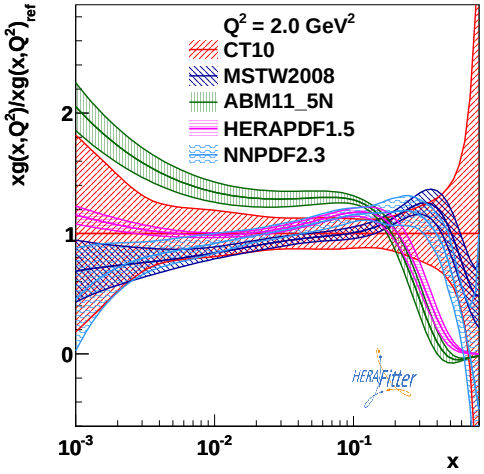
NPB 875 (2013) 483, PRD 89 (2014) 052004

PDF sensitivity of the inclusive photon data







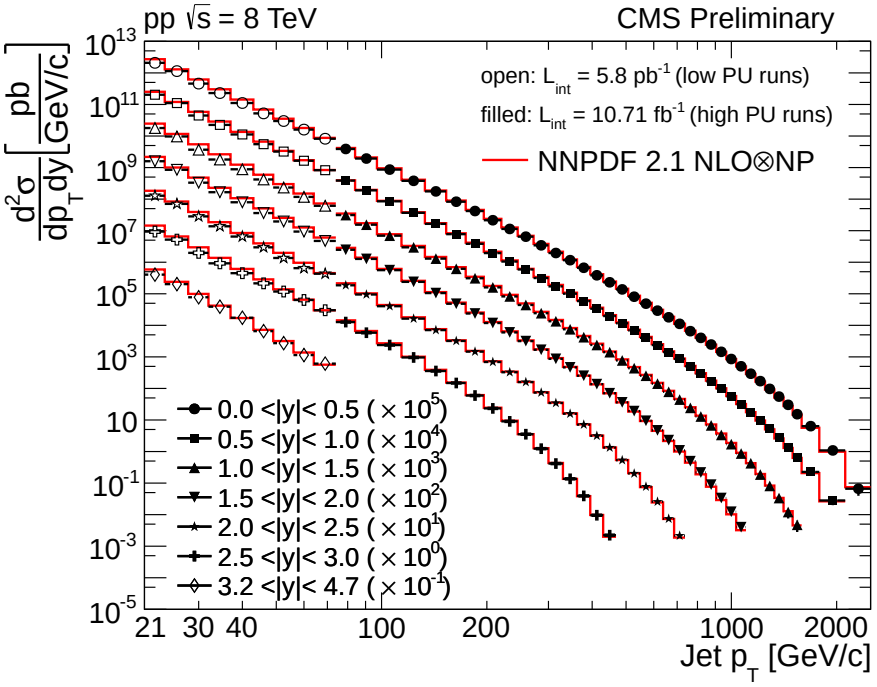


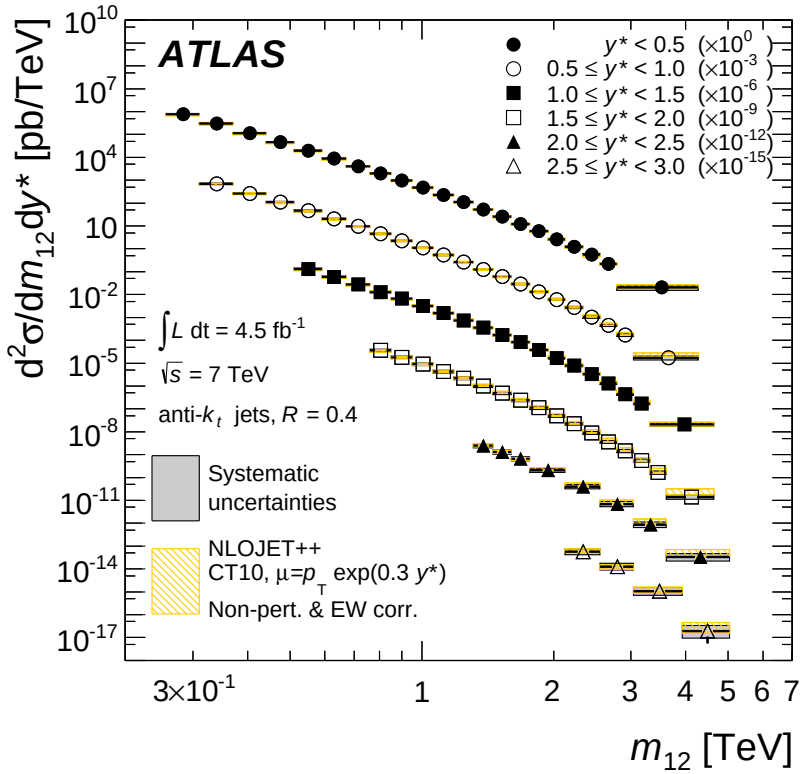
ATLAS data compared to predictions using MCFM, interfaced to APPLGRID for fast computations: → getting ready to include in PDF fits.

Better shape agreement for ABM11 PDF, which has relatively soft gluon density at high x.

ATL-PHYS-PUB-2013-018

Inclusive and dijet measurements

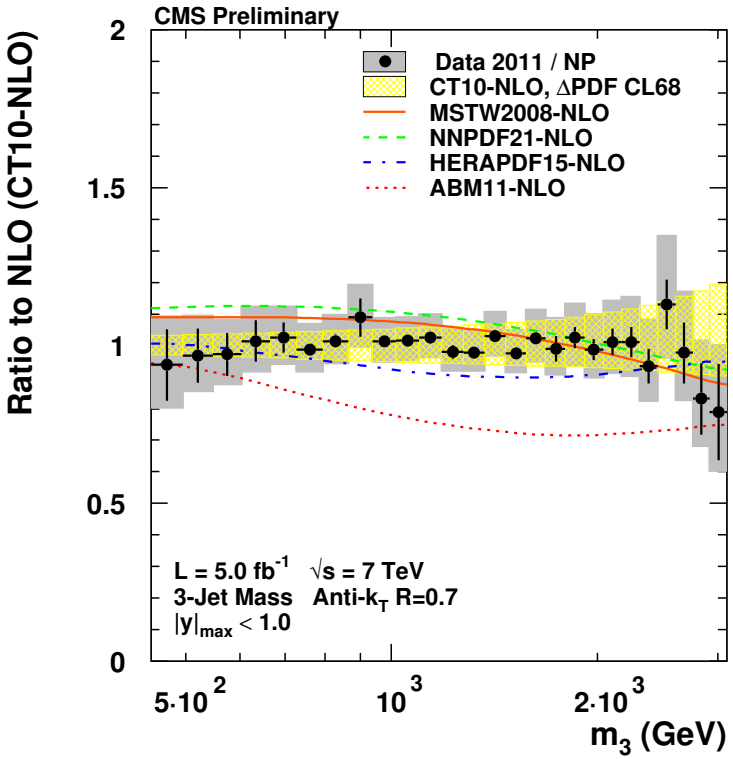


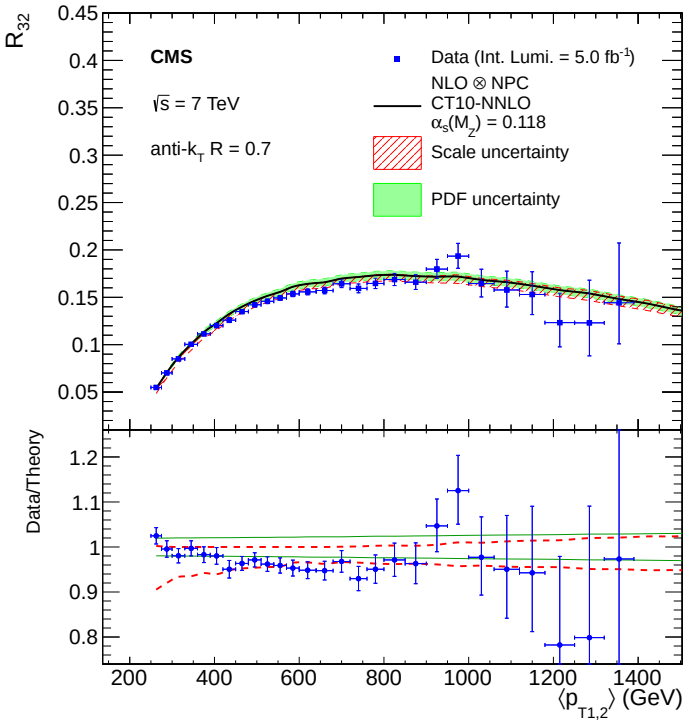


- Jet measurements at the LHC cover very large range kinematic cross sections range.
- Overall good agreement is observed with SM expectations.

CMS-PSQ-12-031,CMS-PAS-SMP-12-012,arXiv:1312.3524

3-jet production and measurement of 3/2 jet rate ratio

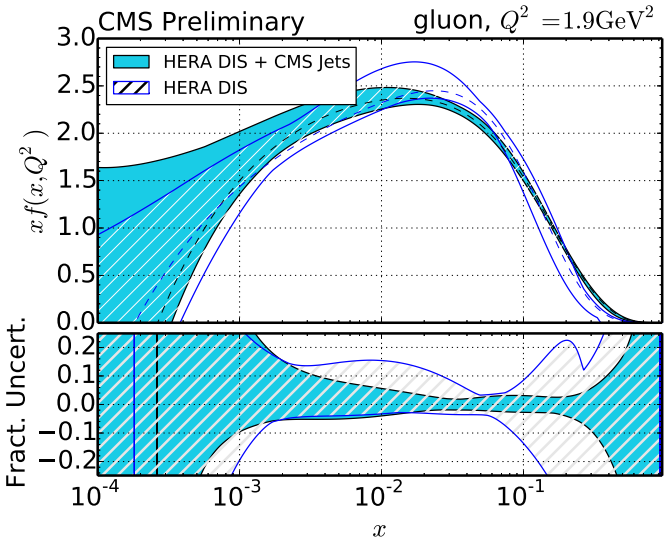


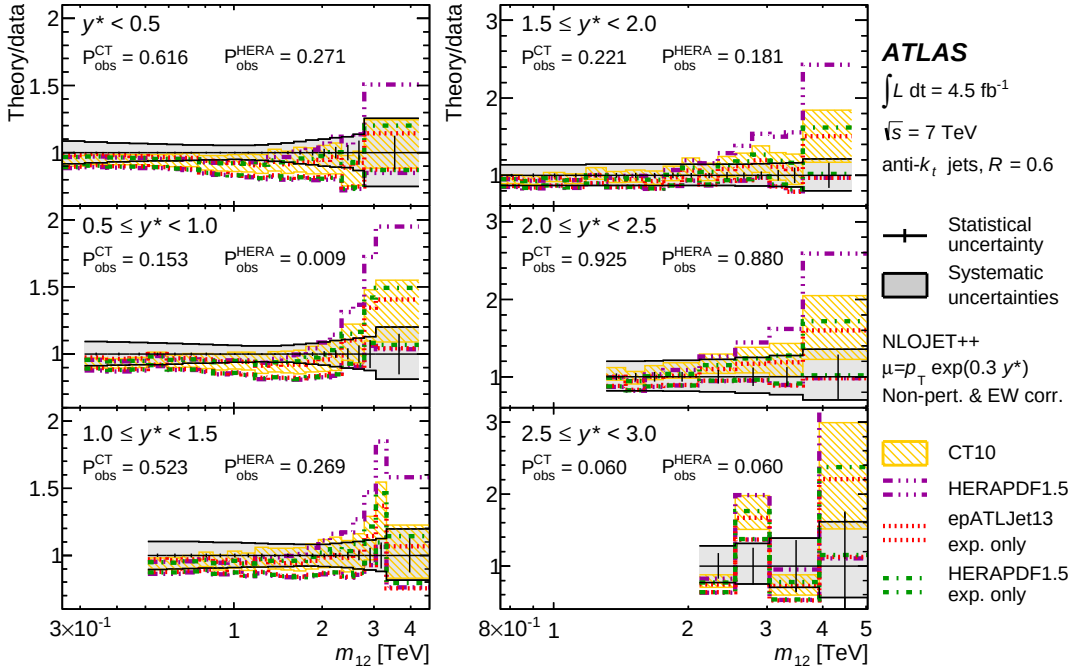


- 3-jet production cross section is sensitive to the gluon PDF and α_S while 3/2 jet rate has reduced PDF sensitivity and can be used to extract α_S.

  CMS-PAS-SMP-12-027, EPJ C73 (2013) 2604

PDF sensitivity of the jet data

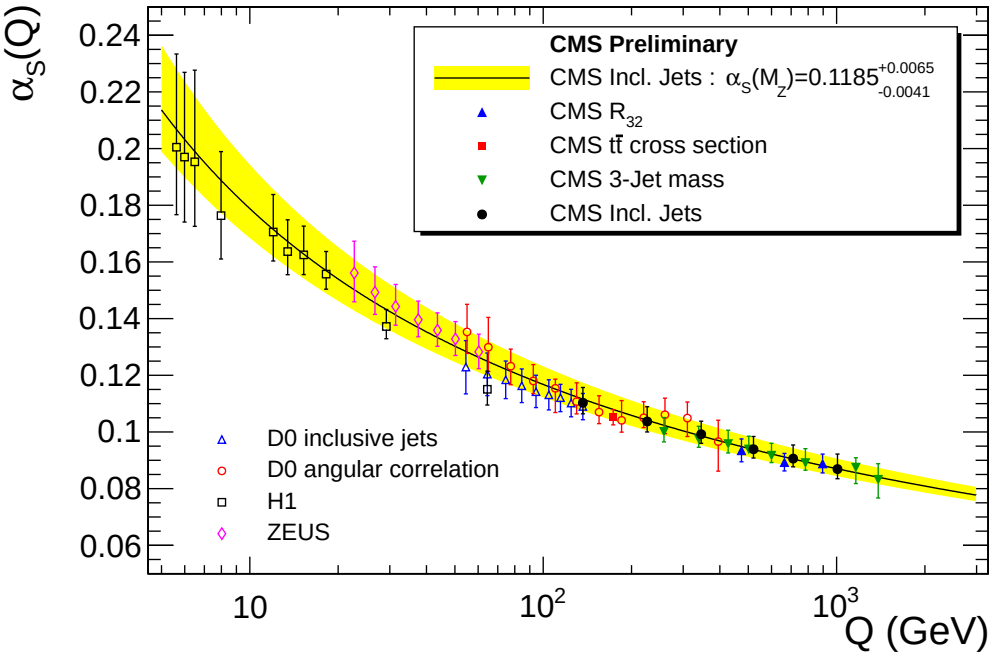


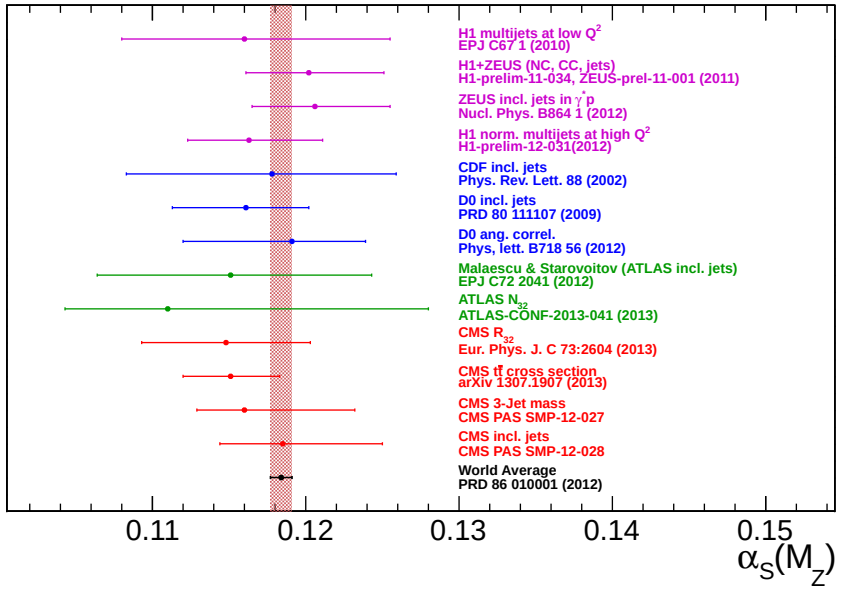


- CMS performed NLO QCD analysis of the inclusive jet plus HERA data, finds that data prefers harder gluon, reduces uncertainty at high x.
- ATLAS compared dijet data to NLO QCD+EWK predictions based on various PDFs, using frequentist approach. Good agreement with CT10, MSTW08 and NNPDF2.3 while ABM11 is disfavored.

CMS-PAS-SMP-12-028, arXiv:1312.3524

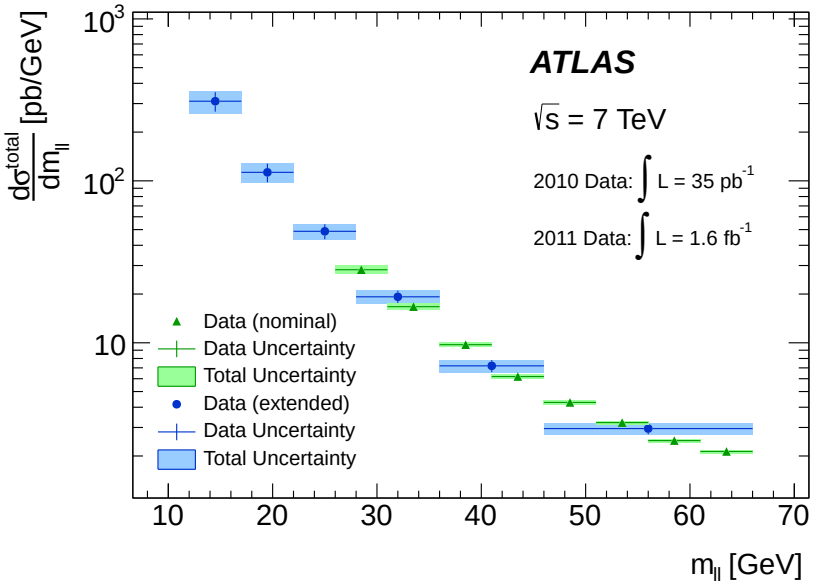
α_S measurements

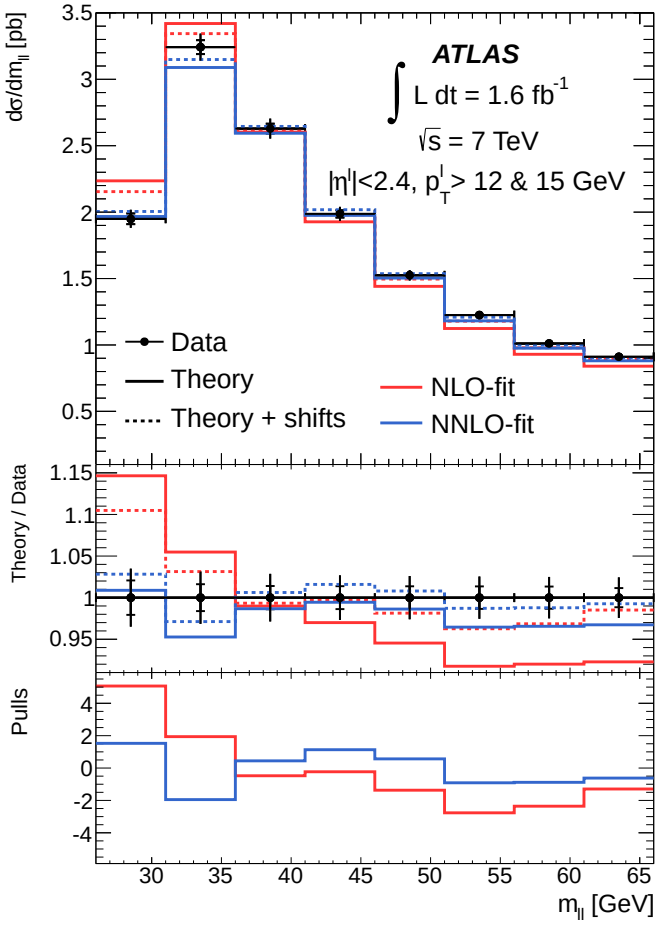




- Several methods employed by CMS to extract α_S.
- α_S running is probed up to TeV scales.
- The measurements are consistent with each other and with the world average.

Drell-Yan production

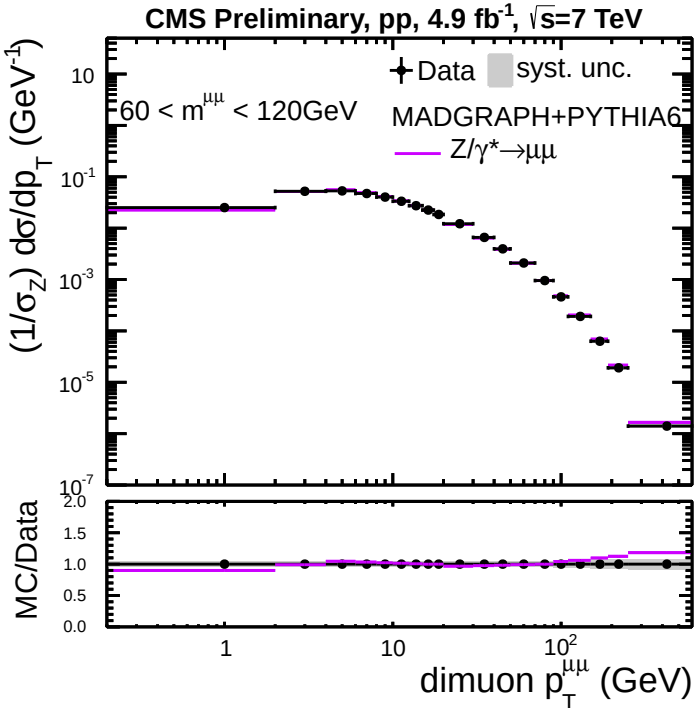


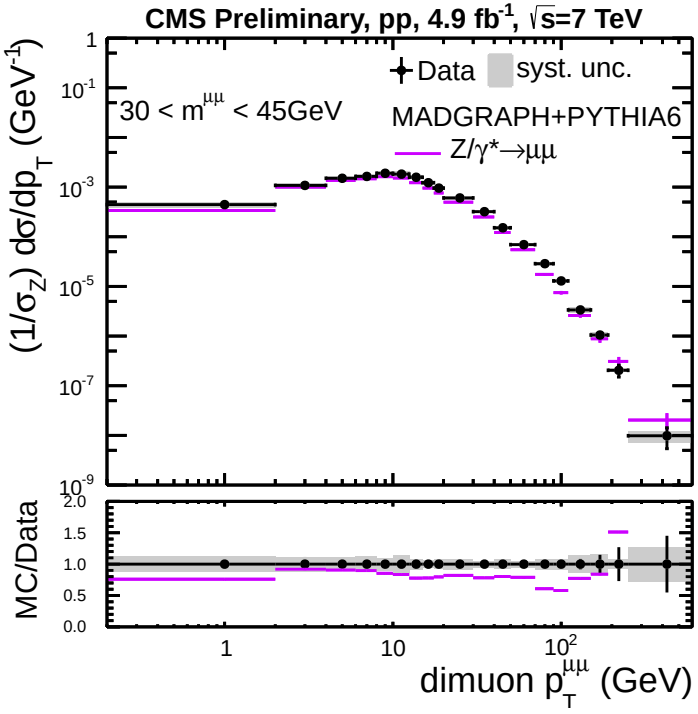


ATLAS measures low mass DY for two distinct kinematic regions: $p_T^\ell > 12\&15$ GeV and $p_T^\ell > 6\&9$ GeV. The ATLAS data are subject of QCD fit together with HERA-I. Good description by NNLO fit while NLO QCD fails to describe the data at low masses.

arXiv:1404.1212

CMS DY transverse momentum vs $m_{\mu\mu}$

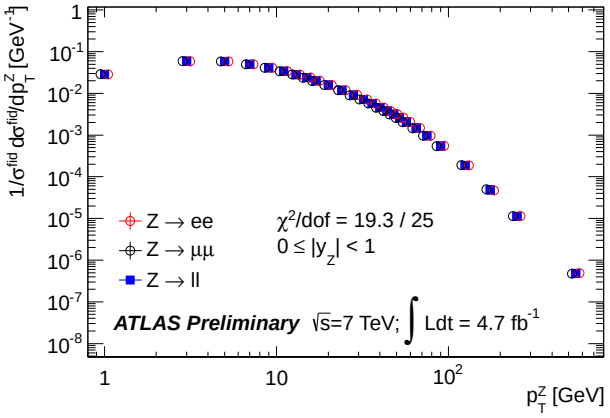


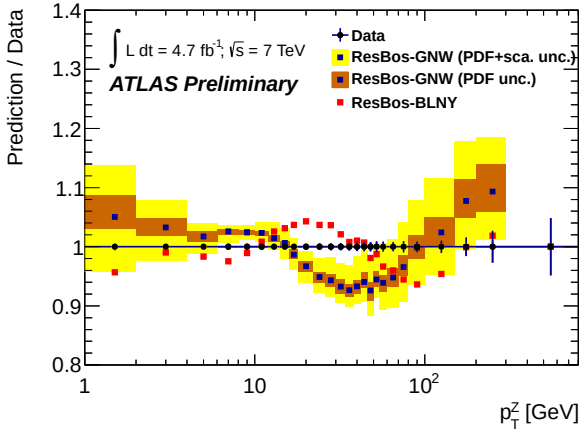


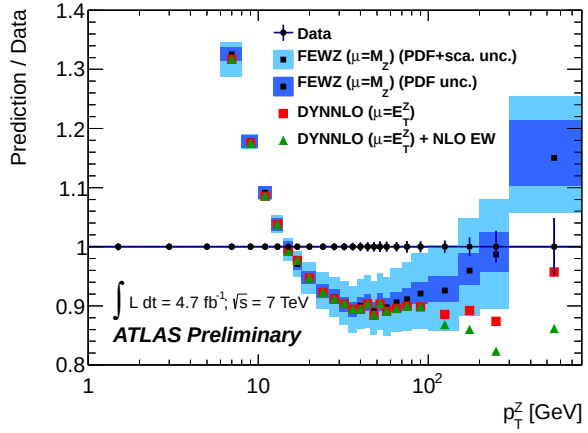
- CMS performed measurement of $Z/\gamma^* \to \mu\mu$ as a function of $m^{\mu\mu}$ and $p_T^{\mu\mu}$ for $30 < m^{\mu\mu} < 1500$ GeV inclusively and for events with 1, 2 jets.
- The inclusive measurement is reasonably well described by MADGRAPH+PYTHIA for the Z peak region, however there are deviations for off-peak regions. The measurement is sensitive to EWK corrections, $\gamma\gamma \to \ell\ell$ scattering.

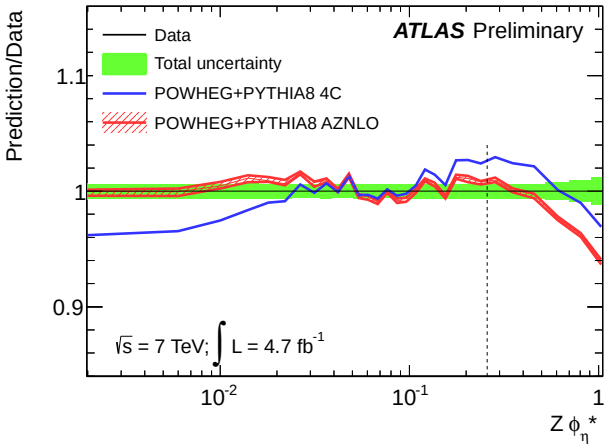
CMS-PAS-FSQ-13-003

Z transverse momentum measurements





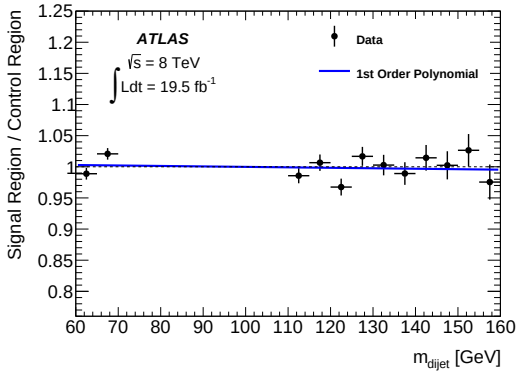


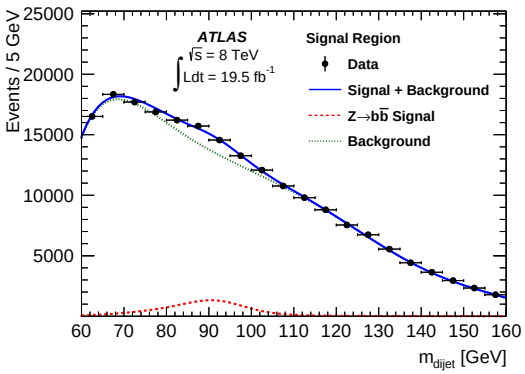


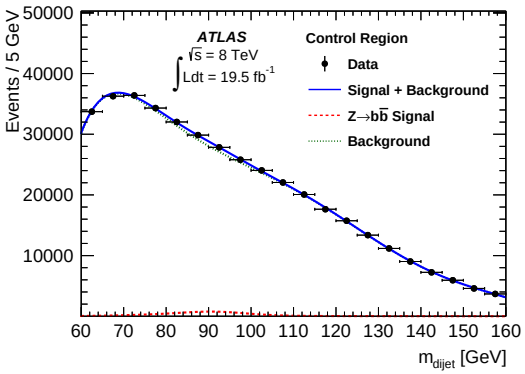
- ATLAS measurement of Z transverse momentum distribution for $Z \to \mu\mu$ and $Z \to ee$ events. Good agreement between channels. Comparisons with NLO+NNLL and NNLO EWK corrected calculations.
- ATLAS $Z \to ee$ ϕ^* and $Z \to \mu\mu$ p_T measurements are used to tune POWHEG+Pythia8 generator for the first time. Improvements of the low ϕ^* and p_T description is achieved.

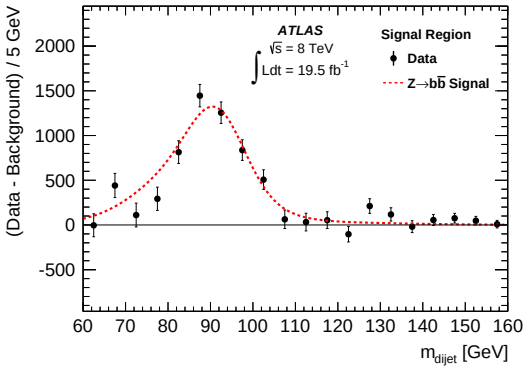
ATLAS-STDM-2012-23

$Z \to bb$ measurement by ATLAS









- Measurement of high p_T $Z \to bb$ production in hadron collider environment using pair of anti-k_T jets with $R = 0.4$.
- Important for $H \to bb$, b-jet energy scale check.
- Signal/control region separated by kinematic cuts, simultaneous fit to both regions.
- Resulting fiducial cross section $\sigma_{\text{fid}} = 2.02 \pm 0.33$ pb is consistent with NLO MC predictions: POWHEG $2.02^{+0.25}_{-0.19}$; aMC@NLO $1.98^{0.16}_{-0.08}$.

arXiv:1404.7042

Summary

- Very many new results from HERA, Tevatron and LHC in the past 6 months.
- Various aspects of QCD are tested with increasing accuracy.
- Observations of ATLAS and CMS are consistent with each other for most of observables.
- Several measurements have significant constraining power: LHC enters precision era.