UNIVERSITÉ
DE GENÈVE

Measurements of the Drell-Yan Process with the ATLAS Detector

Katalin Nikolics on behalf of the ATLAS Collaboration

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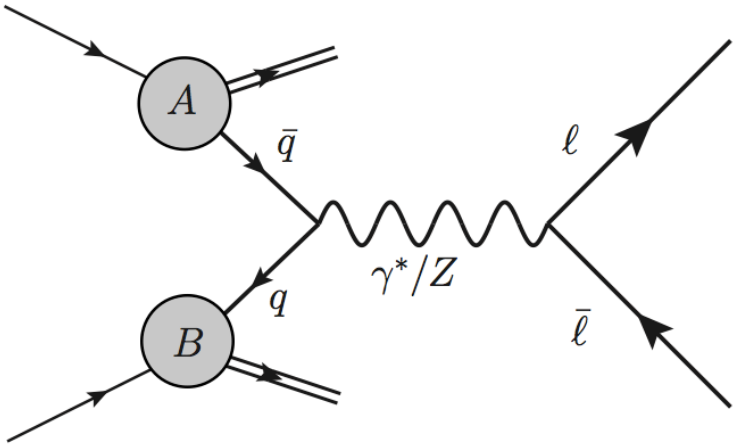
The Drell-Yan (DY) process

S. Drell and T.-M. Yan (1970): quark and anti-quark of two hadrons annihilate to form a EW gauge boson decaying into a lepton - anti-lepton pair

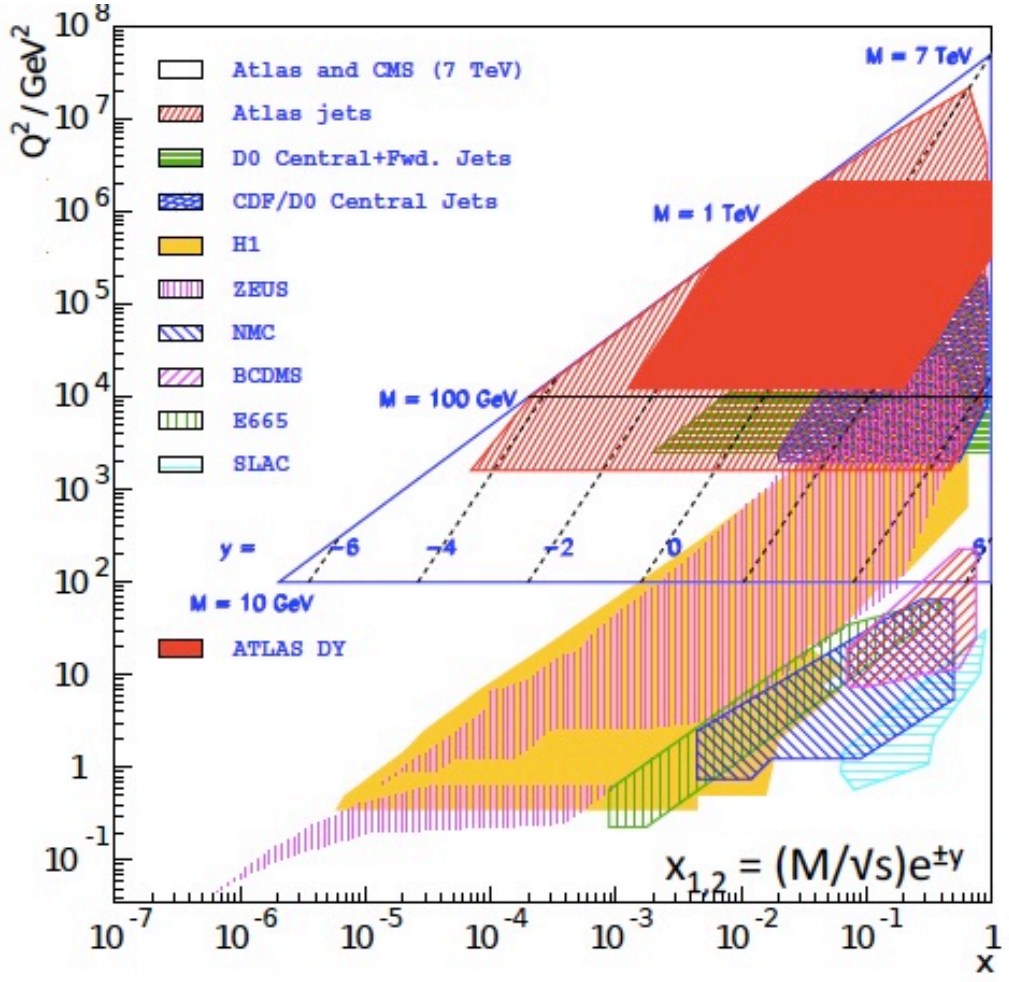


ATLAS EXPERIMENT

1. Inclusive $W^{\pm}$ and Z/γ^* cross section in electron and muon channel, data 2010, PRD 85, 072004 (2012)
2. Strange quark density from $W \rightarrow \ell\nu$ and $Z \rightarrow \ell\ell$ cross sections, data 2010, PRL 109, 012001 (2012)
3. High mass DY ($116 < m_{ee} < 1500$ GeV) cross section only electron-positron final state, data 2011, ATLAS-CONF-2012-159

Why study the DY process?

- Testing perturbative QCD: NNLO pQCD (+ NLO EW), sensitive to proton structure (PDF), especially
  - anti-quark distribution @ high Q^2
  - strange-quark distribution at small x, and
  - constrain high-x PDFs currently suffering from large uncertainties
- High mass: irreducible background to new (exotic) physics searches ➔ improved background modelling



Inclusive $W^{\pm}$ and Z Cross Section

- Data 2010 @ $\sqrt{s}$ = 7 TeV, $L_{int} \approx 35\ pb^{-1}$
- $\sigma \times BR$ for $W^{\pm} \rightarrow \ell^{\pm} \nu$ and $Z \rightarrow \ell\ell$ ($66 < m_{\ell\ell} < 116$ GeV), $\ell = e, \mu$
- Measured differential
  - $W^{\pm}$ - pseudorapidity η
  - Z - rapidity y_z

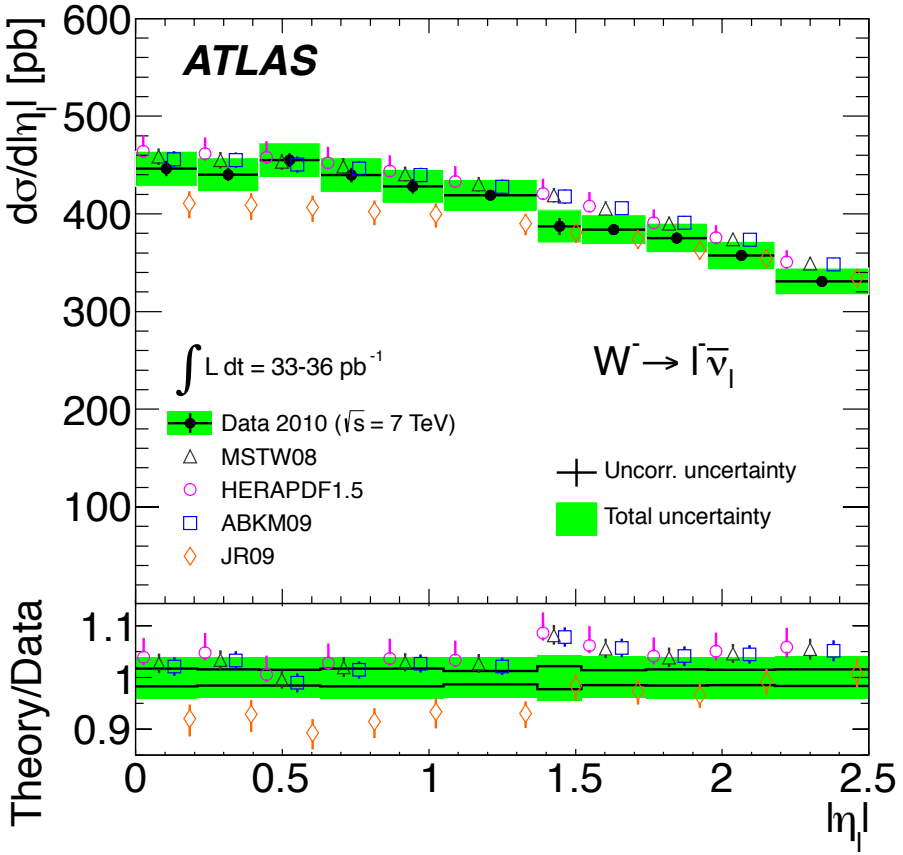
  cross sections in the fiducial volume,

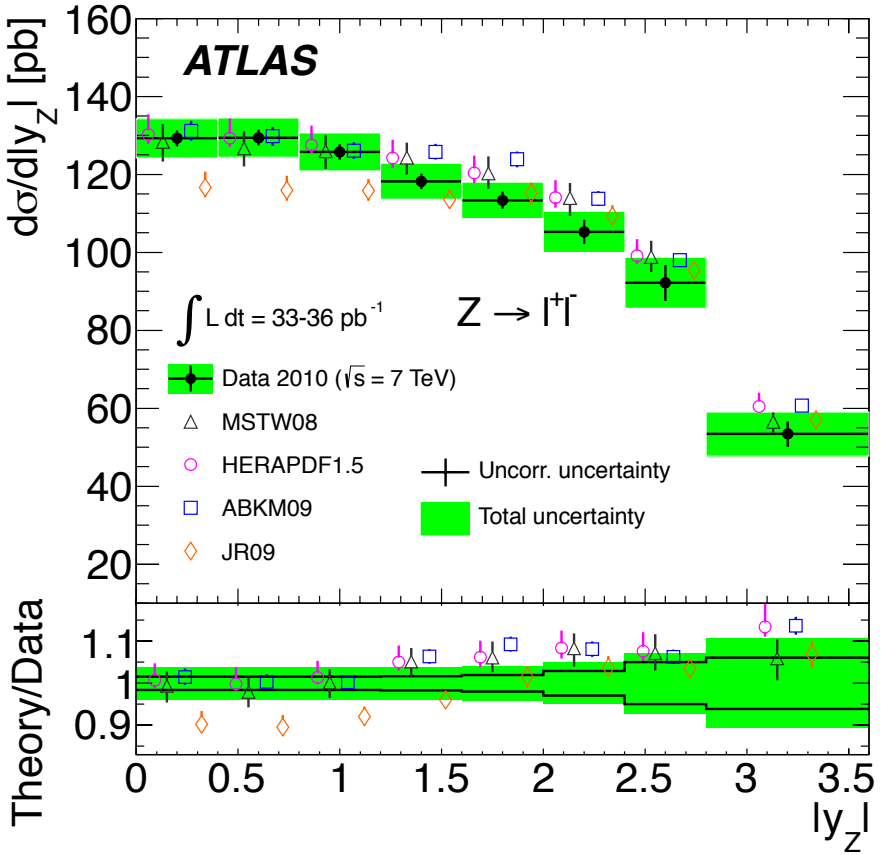
$$\sigma_{\text{fid}} = \frac{N_{\text{Signal}}}{L_{\text{int}} \cdot C_{\text{DY}}}$$

Correction factor contains efficiencies for reco & selection cuts

integrated and extrapolated to total kinematic phase space, results compared to NNLO theoretical predictions using DYNNLO & FEWZ (G_{μ} scheme, no EW corrections nor FSR)

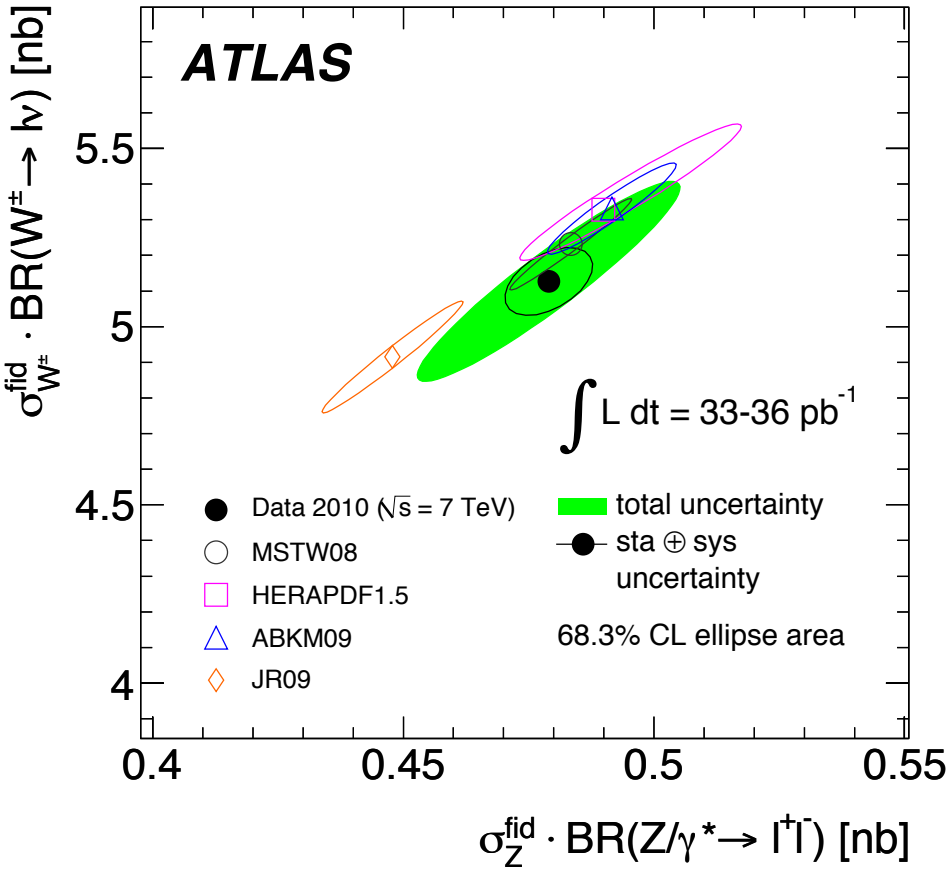
Differential W, Z Cross Section: Comparison to PDF predictions

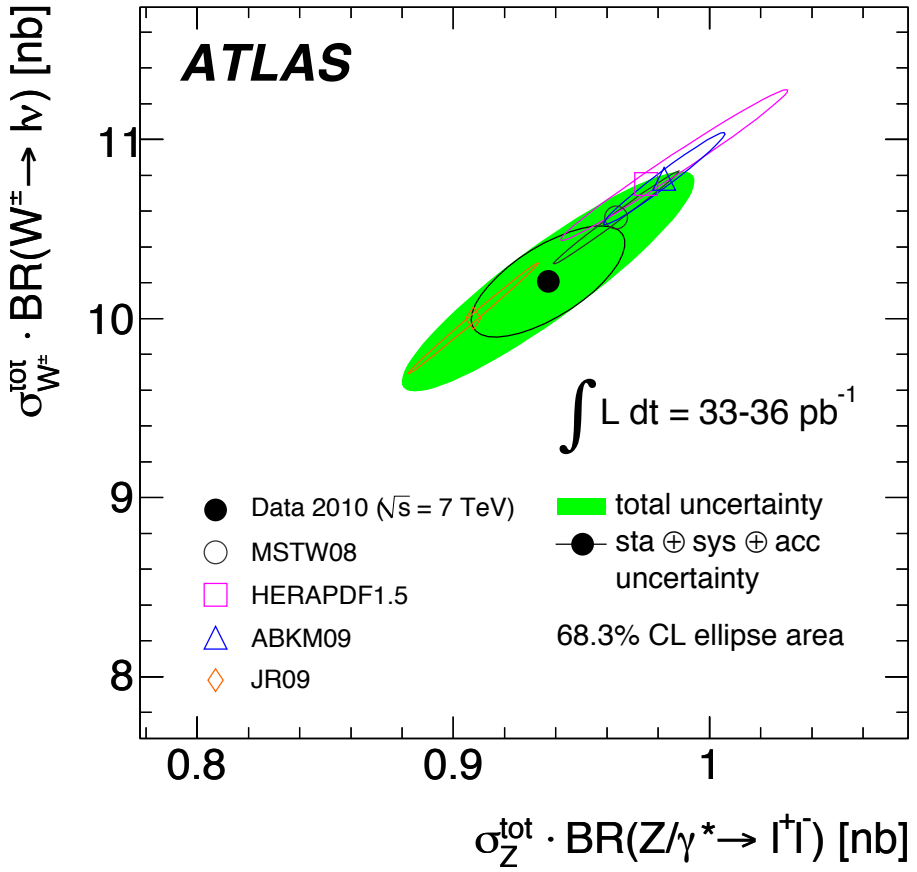




Precision: W ~2%, Z ~2%(central)-10%(forward), dominant sources of uncertainty:
Electron: reconstruction & ID efficiency, E_T^{miss} scale & resolution
Muon: reco efficiency, jet background, C_{DY} theoretical uncertainty

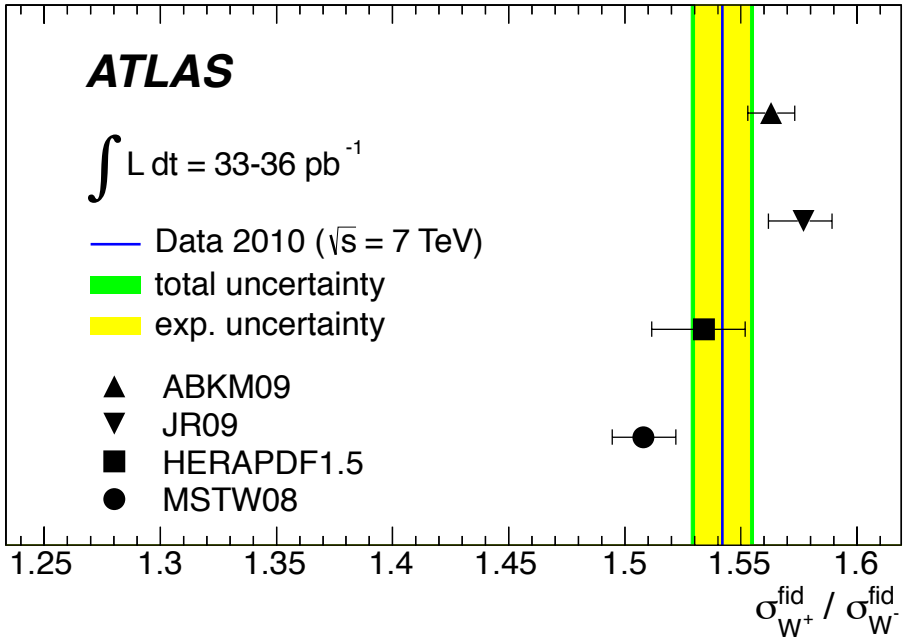
Fiducial & Total W/Z Cross Section

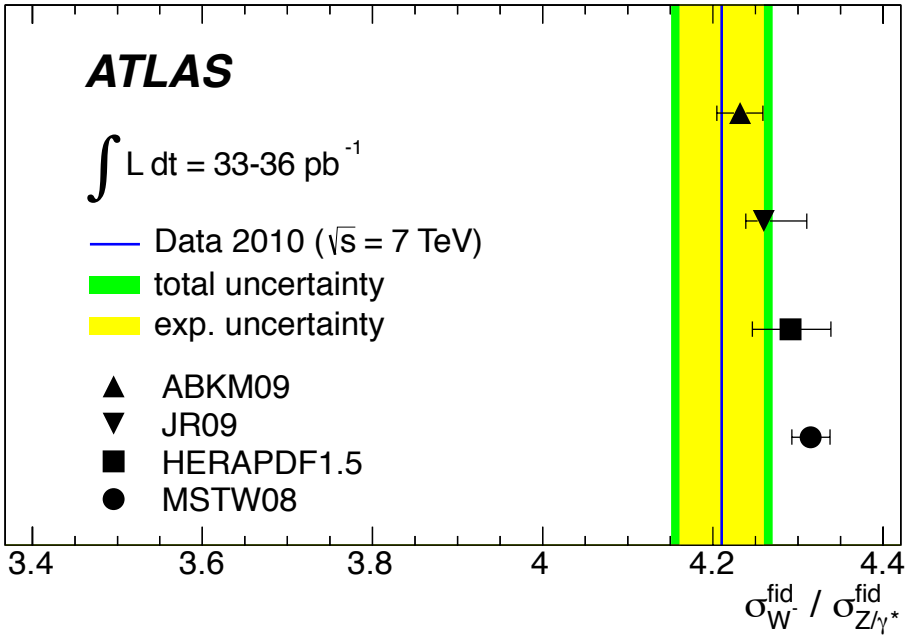




Theoretical uncertainties correspond to PDF uncertainties only
Precision of integrated cross sections ~1.2%

Fiducial Cross Sections

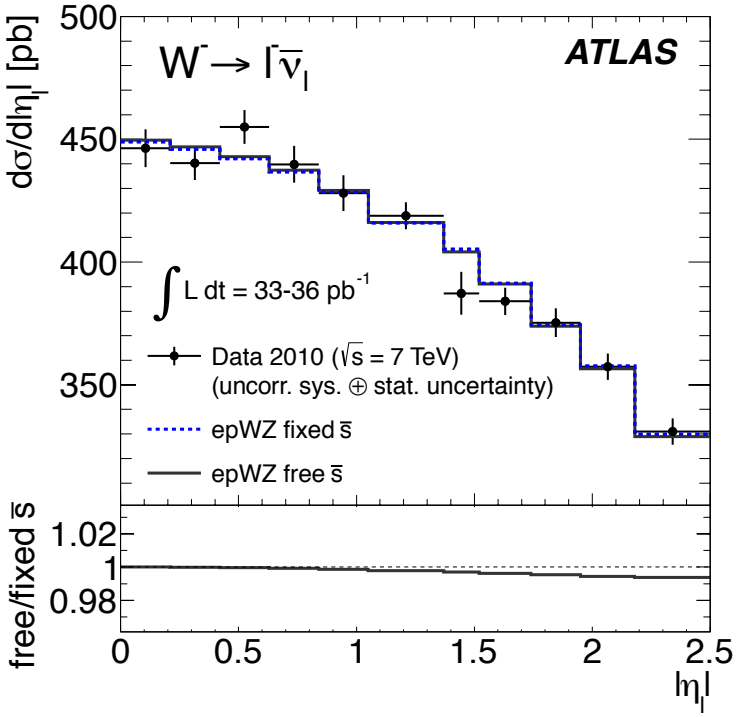


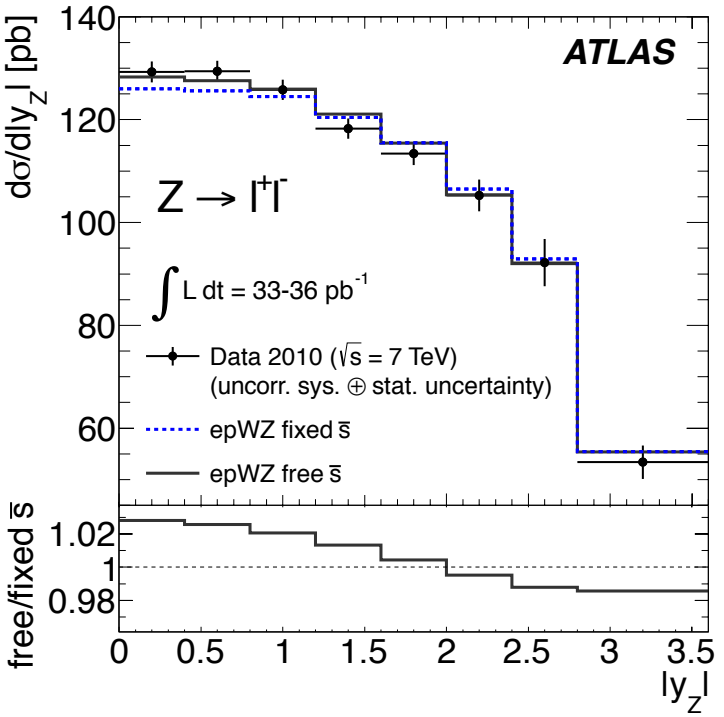


Uncertainties on ABKM, JR and MSTW given by PDF uncertainties corresponding to 68% CL, correlations are derived from eigenvector sets. Results for HERAPDF comprise all sources of uncertainty of that set.

Strange Quark Density

- Flavour *SU*(3) symmetry suggests equal contributions from light sea quarks to PDF, yet strange quarks may be suppressed due to larger mass ➔ composition of the total light sea x Σ ?
- ATLAS (data 2010) + HERA, kinematic range of ATLAS data: $Q^2 \sim M^2_{W,Z}$ and $0.001 < x < 0.1$

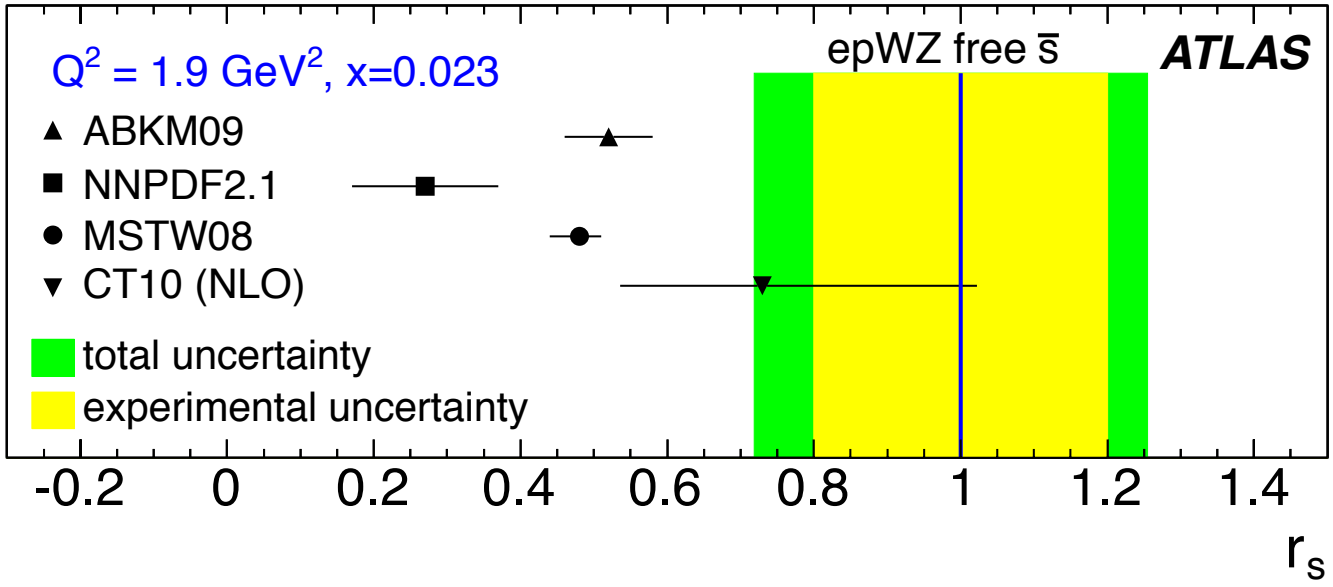




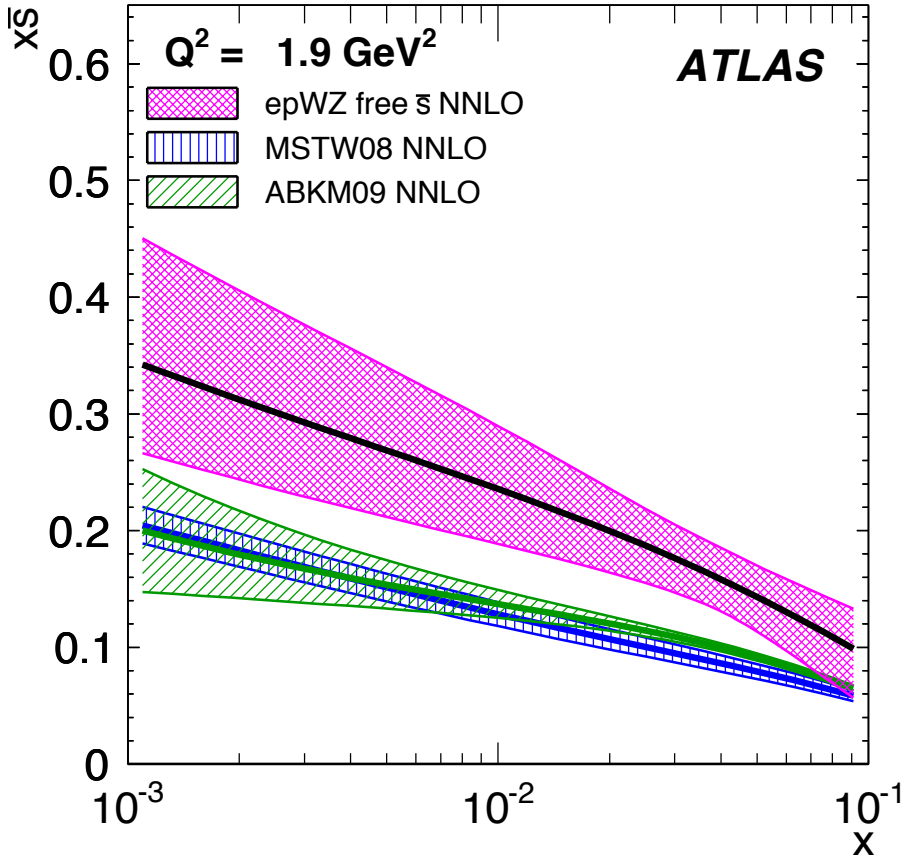
Strange Quark Density: Ratio r_s

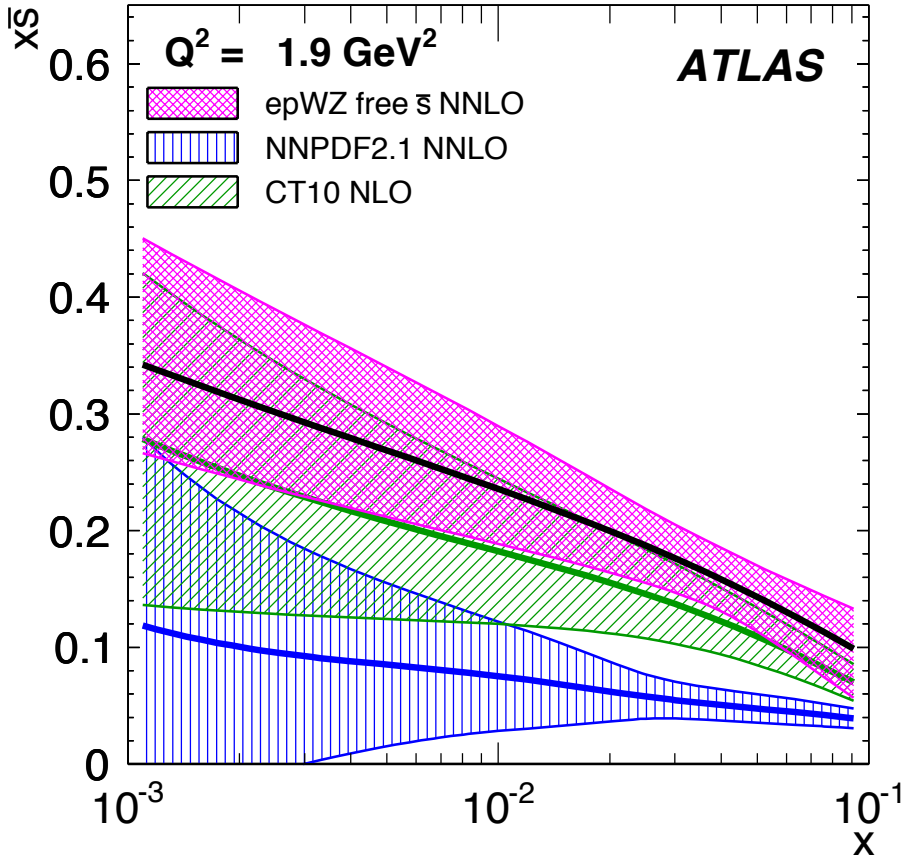
- Two NNLO Fits
  - "epWZ fixed s": s-quark distribution coupled to d-sea-quark, suppressed by fixing ratio of s/d to 0.5
  - "epWZ free s": two free strangeness parameters in quark distribution, $xs = x\bar{s}$
- Predictions for ratio of strange to down-quarks r_s indicate flavour symmetry of light quark sea at small Bjorken x:

$$r_s = 0.5(s+\bar{s})/\bar{d} = 1.00^{+0.25}_{-0.28}$$



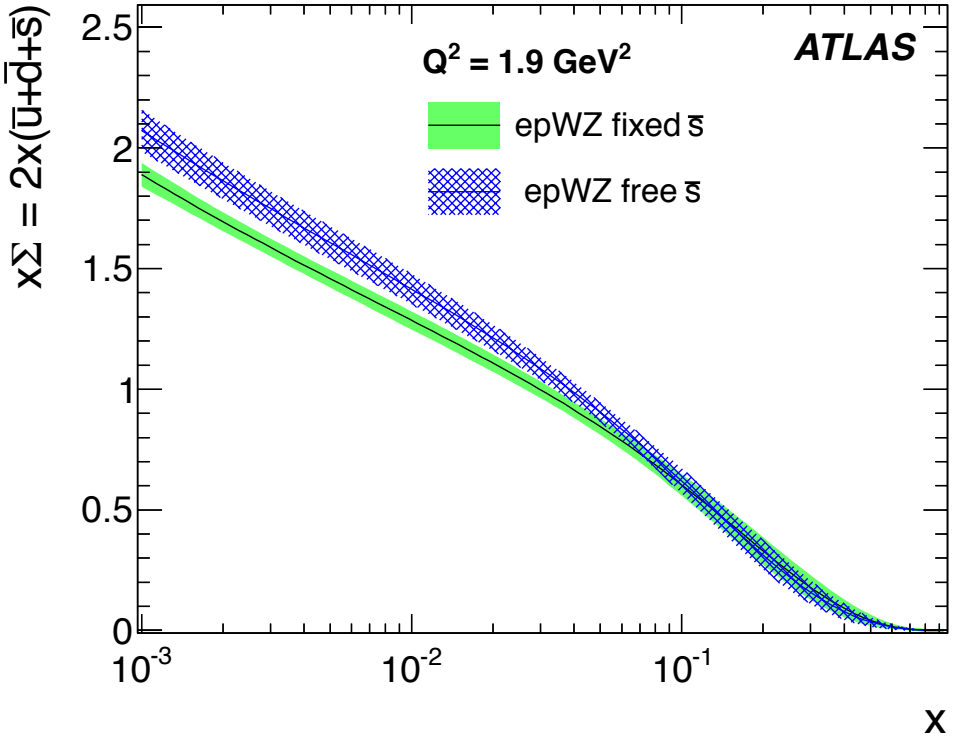
Strange Quark Density: Comparison with PDF Predictions



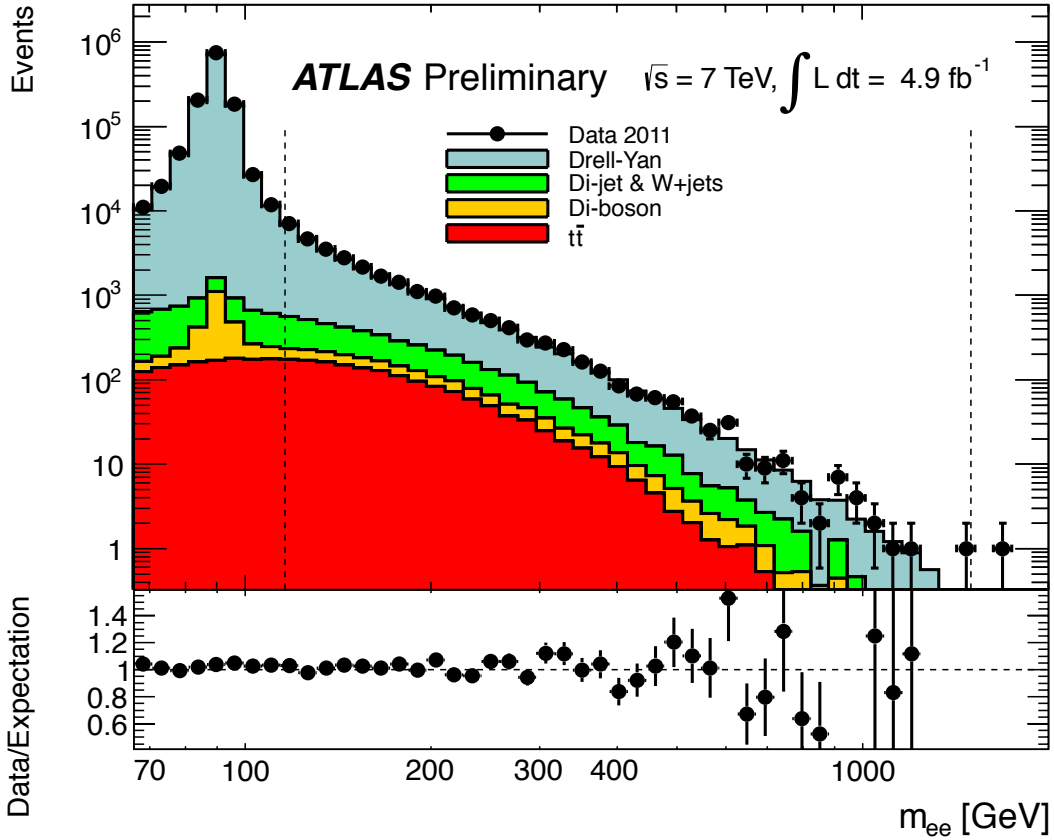


Strange Quark Density: Total Sea

- Enlarged fraction of strange-quark sea ➔ decrease of up- and down sea density at initial scale Q_0^2
- up- and down-sea decreased by ~10%, total sea $x\Sigma = 2x\left(\bar{u} + \bar{d} + \bar{s}\right)$ enhanced by ~8%



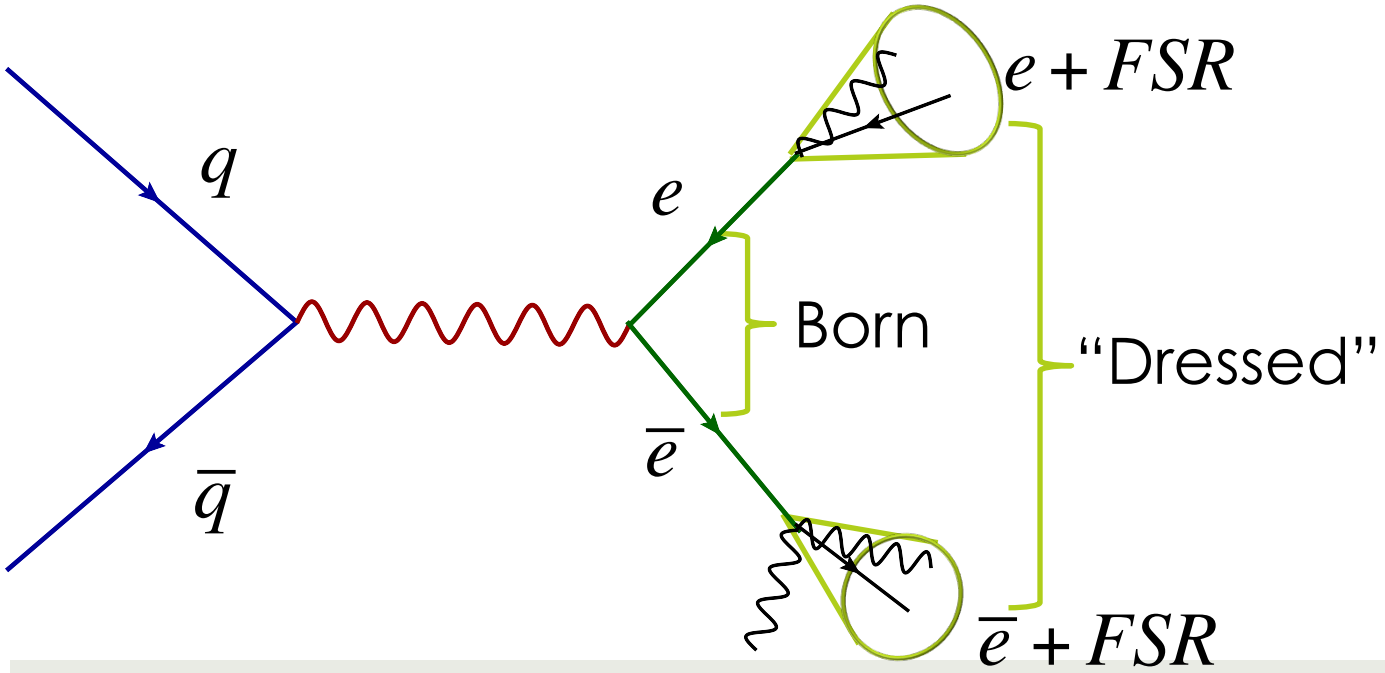
High-mass DY: Z/γ^* Candidate Events in the e^+e^- Channel



2011 data @ √s = 7 TeV: 26844 observed electron-positron candidates after selection cuts

High-mass DY: Fiducial Differential Cross Section

- extended fiducial volume of 2 electrons: $E_T > 25$ GeV, $|\eta| < 2.5$
- invariant mass of the electron-positron pair: $116 < m_{ee} < 1500$ GeV
- Two levels of final state definition, difference ≤ 4%:
  - Born = before finale state radiation (FSR)
  - "Dressed" = after FSR recombined with photons in $\Delta R = 0.1$



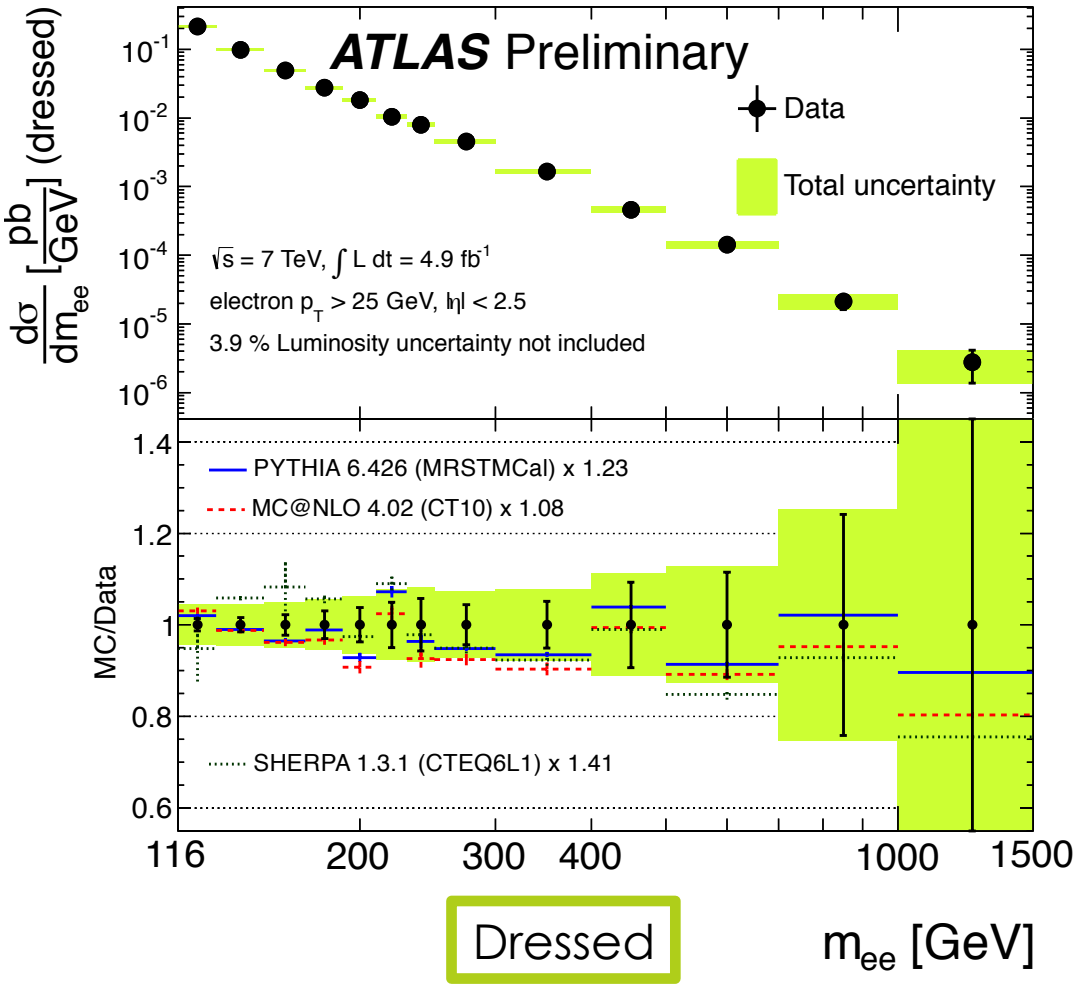
High-mass DY: Correction Factor C_{DY} & Systematic Uncertainties

PYTHIA (+PHOTOS for FSR, reweighted to NNLO pQCD + NLO EW with m_{ee}-dependent *K*-factors)

Systematic Uncertainty on C_{DY} ~0.5%

- PDF choice: < 0.2% (reweighting PYTHIA MRSTMcal to CT10, HERAPDF1.5)
- PDF error set: < 0.5% (~0.4% for lowest m_{ee}), reweighting MC@NLO to 52 CT10 error eigenvectors
- Generator choice: < 0.3%, comparing PYTHIA reweighted to CT10 to MC@NLO, cross-checked with FEWZ2.1 with CT10

High-mass DY: Results I



Dressed

Comparison to 3 Event Generators:

- PYTHIA (MRSTMCal)
- MC@NLO (CT10)
- Sherpa (CTEQ6L1)

no m_{ee}-dependent *K*-factors

global scaling to match number of observed events in data

➔ shape well described

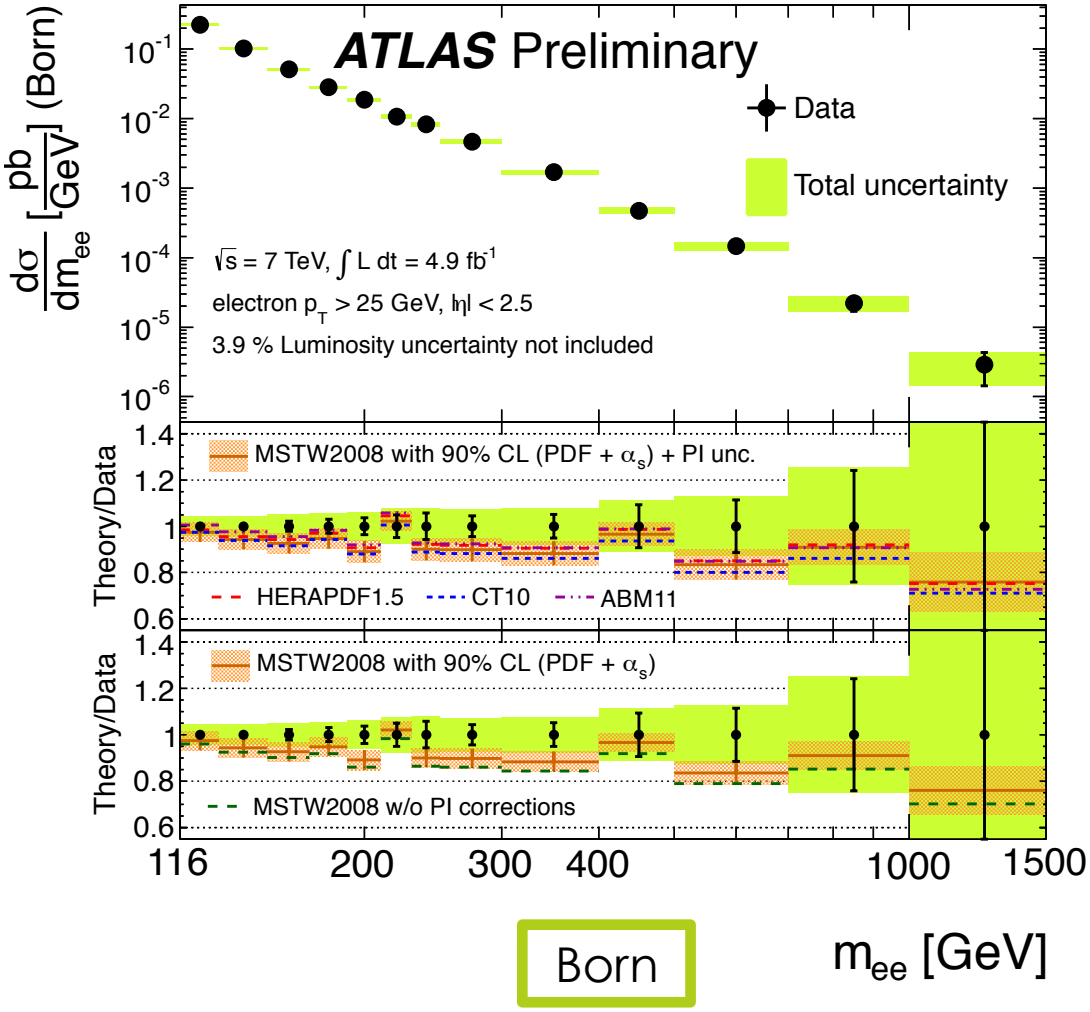
High-mass DY: Results II

FEWZ3.1 framework

NNLO pQCD + NLO EW corrections (G_μ scheme, corrections for non-resonant γ-induced background + W/Z emission using LO MRST2004QED w/ 50% uncertainty)

Deviations of PDF sets ~covered by uncertainty on MWST2008 incl. uncertainties on γ-induced contribution, uncertainty on PDF & α_s

➔ Predictions largely consistent with data



Summary

- Precise knowledge of the Drell-Yan cross section important for our understanding of the proton structure as well as new physics searches
- Inclusive W and Z cross sections measured, results agree to state-of-the-art theoretical predictions
- W/Z results sensitive to amount of strangeness, data disfavour strangeness suppression
- For electrons from Z/ γ^*, cross section measurement extended to m_{ee} of 1500 GeV
  - Results consistent with Standard Model predictions

Back-up

W/Z Inclusive Event Selection Phase Space

$W \to e\nu$: $p_{T,e} > 20\,\text{GeV}$, $|\eta_e| < 2.47$,
excluding $1.37 < |\eta_e| < 1.52$,
$p_{T,\nu} > 25\,\text{GeV}$, $m_T > 40\,\text{GeV}$;

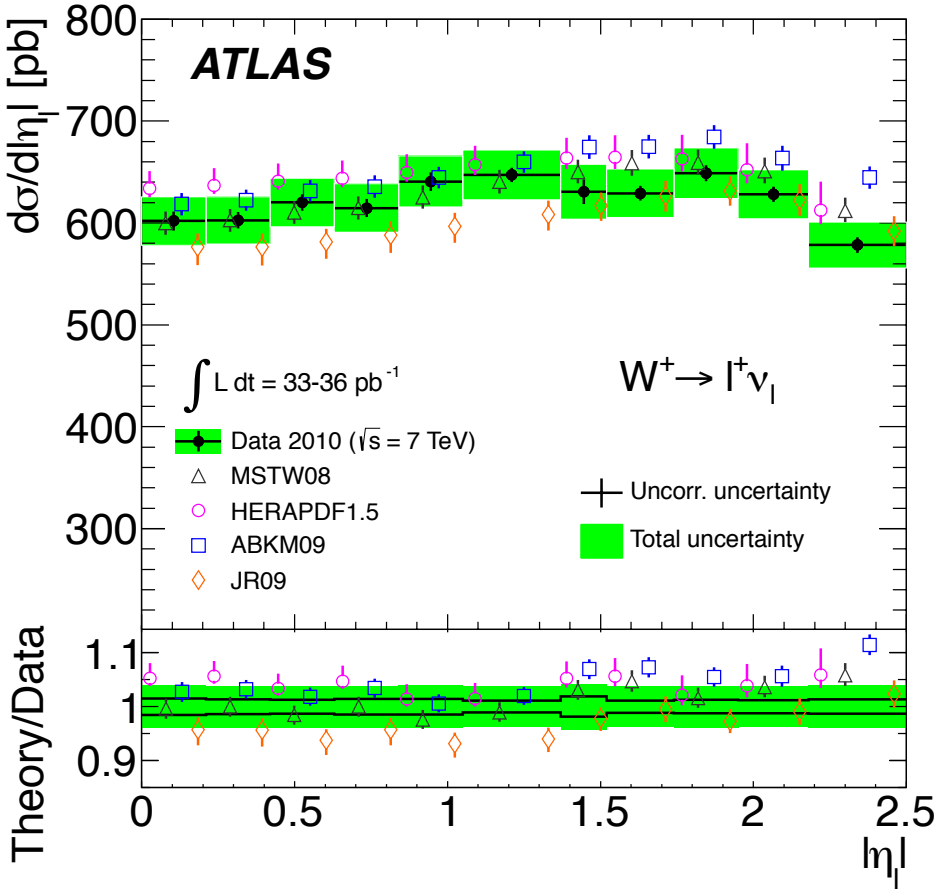
$W \to \mu\nu$: $p_{T,\mu} > 20\,\text{GeV}$, $|\eta_\mu| < 2.4$,
$p_{T,\nu} > 25\,\text{GeV}$, $m_T > 40\,\text{GeV}$;

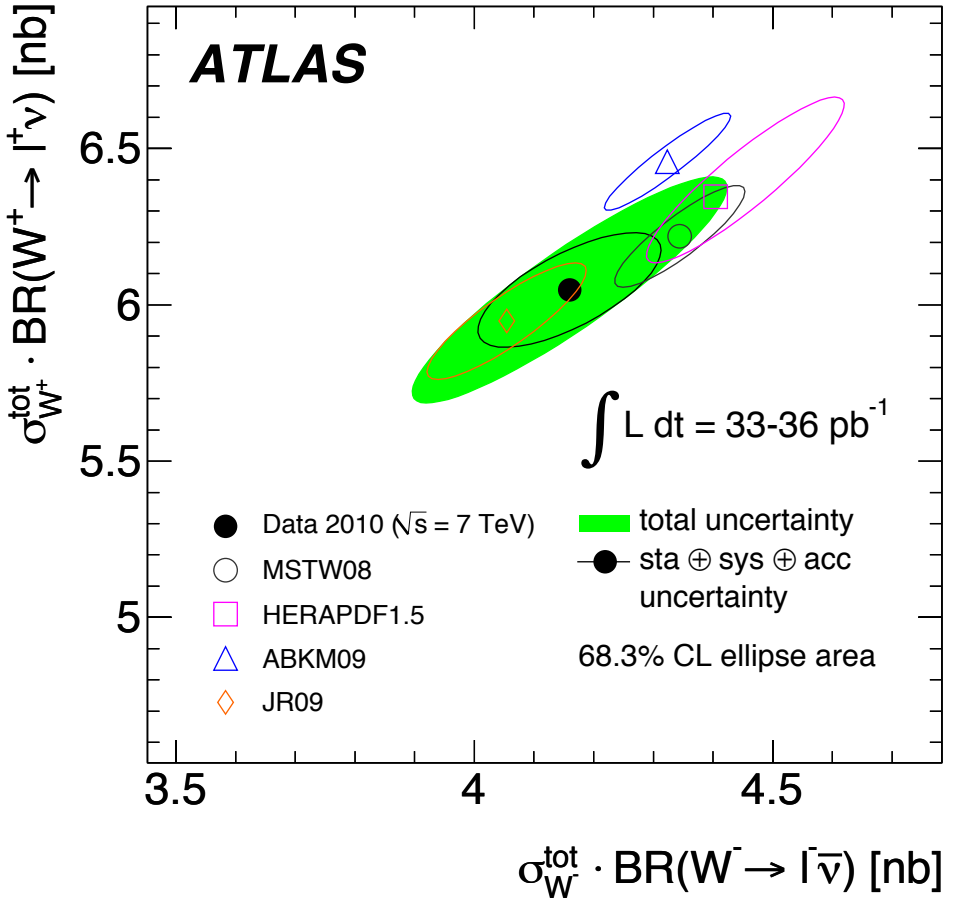
$Z \to ee$: $p_{T,e} > 20\,\text{GeV}$, both $|\eta_e| < 2.47$,
excluding $1.37 < |\eta_e| < 1.52$,
$66 < m_{ee} < 116\,\text{GeV}$;

Forward $Z \to ee$: $p_{T,e} > 20\,\text{GeV}$, one $|\eta_e| > 2.47$,
excluding $1.37 < |\eta_e| < 1.52$,
other $2.5 < |\eta_e| < 4.9$,
$66 < m_{ee} < 116\,\text{GeV}$;

$Z \to \mu\mu$: $p_{T,\mu} > 20\,\text{GeV}$, both $|\eta_\mu| < 2.4$,
$66 < m_{\mu\mu} < 116\,\text{GeV}$.

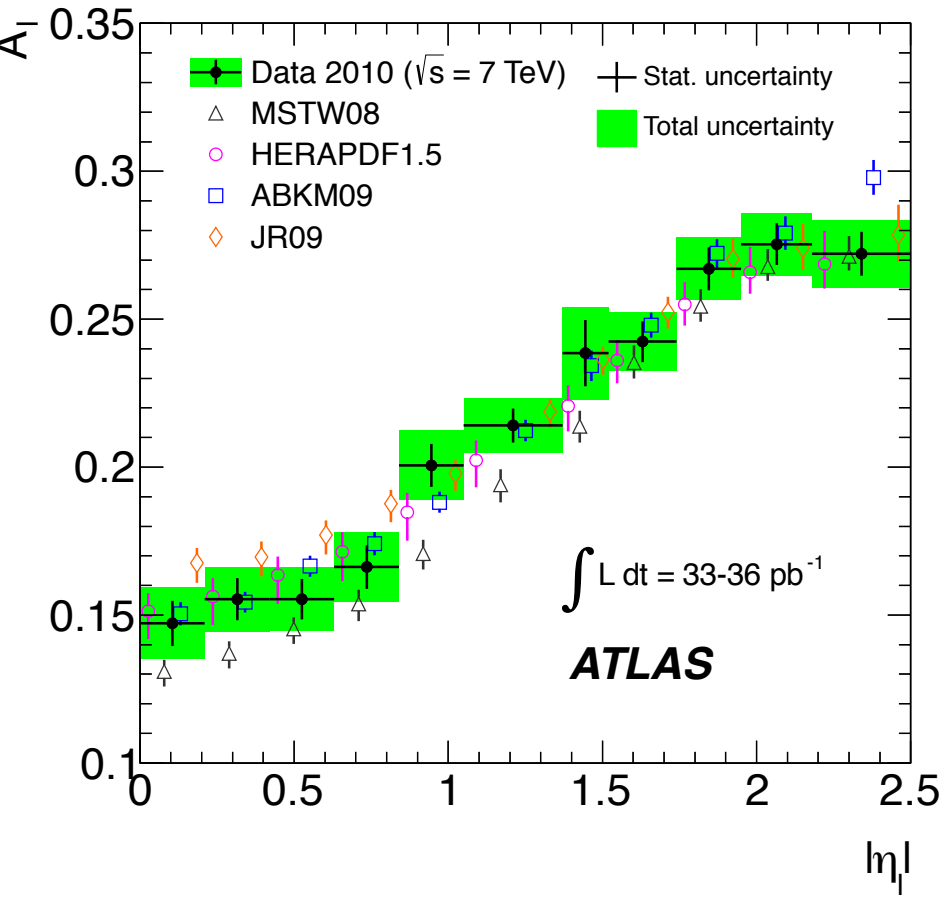
Differential/Total W^+ Cross Section

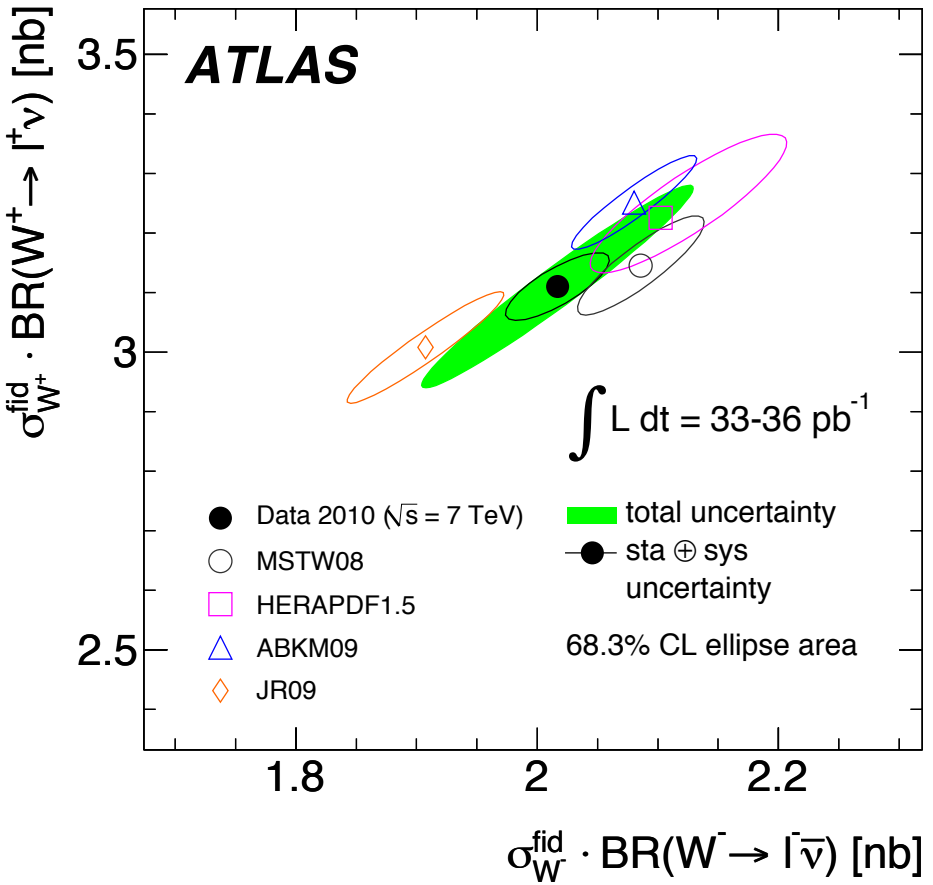




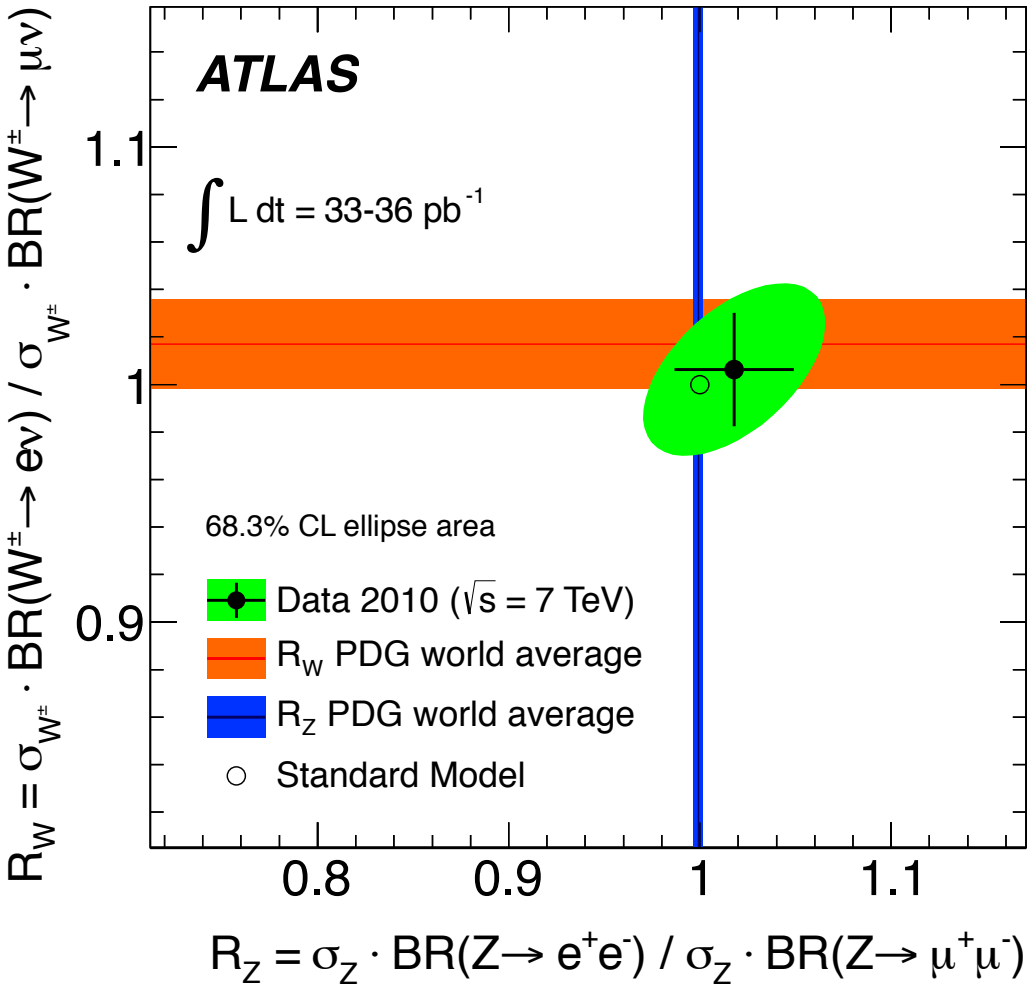
Charge asymmetry

$$A_\ell(\eta_\ell) = \frac{d\sigma_{W^+}/d\eta_\ell - d\sigma_{W^-}/d\eta_\ell}{d\sigma_{W^+}/d\eta_\ell + d\sigma_{W^-}/d\eta_\ell}$$





Inclusive W/Z: Electron/Muon Ratio



High-mass DY: MC Samples & Corrections

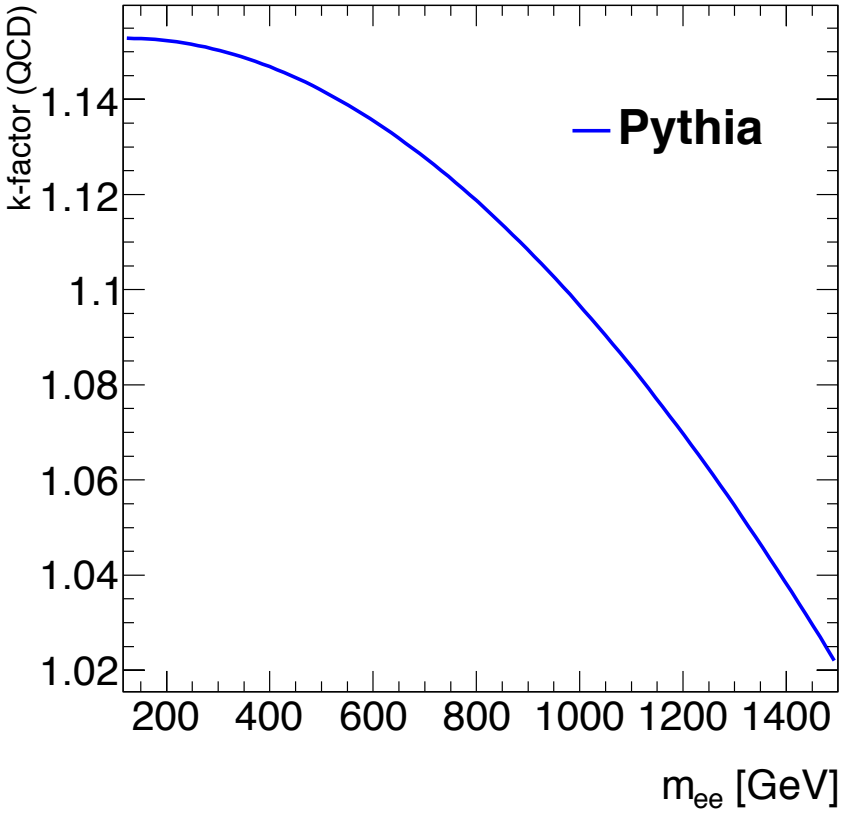
- DY Signal
  - PYTHIA 6.426 (MRSTMCal) + PHOTOS 3.0, normalized to NNLO pQCD + NLO EW (m_{ee}-dependent)
  - MC@NLO 4.03 (CT10) + HERWIG 6.520 + JIMMY + PHOTOS 3.0, normalized to NNLO pQCD (m_{ee}-dependent)
  - Sherpa 1.3.1. (CTEQ6L1) w/ up to 3 additional partons

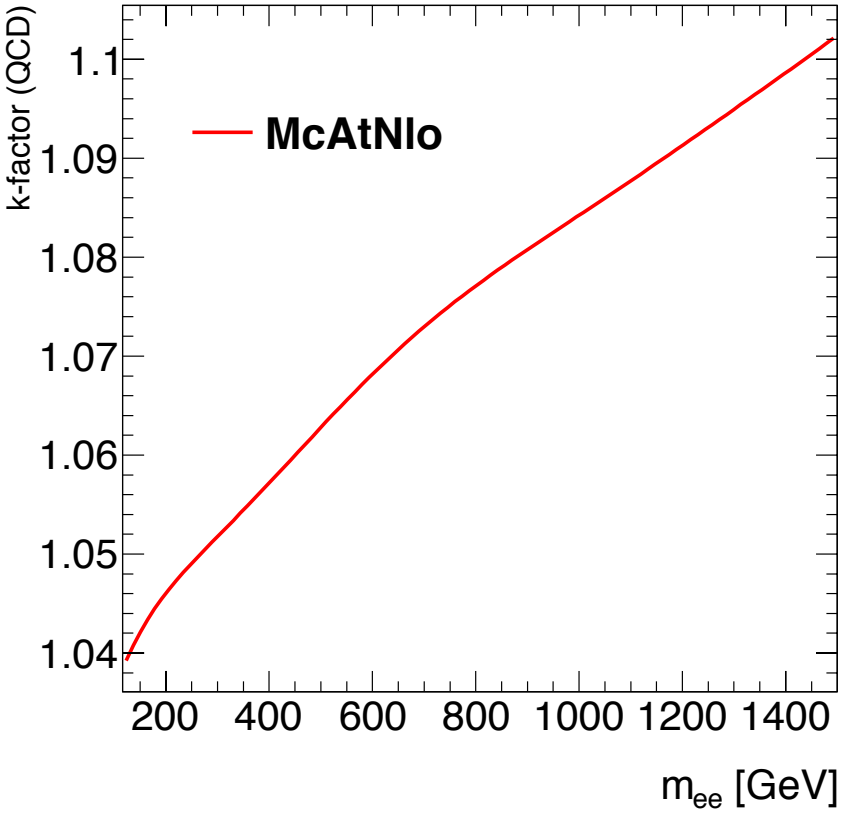
- Background
  - W+jets: ALPGEN 2.13 (CTEQ6L1) w/ up to 5 additional partons
  - tt(ℓX): MC@NLO 4.01 (CT10), normalized to approx. NNLO
  - Di-boson: HERWIG 6.520 (MRSTMCal), normalized to NLO

- MC corrections
  - Pile-up reweighting
  - z vertex position reweighting only included for systematics
  - $p_T(Z)$ reweighting for PYTHIA DY sample only
  - Electron energy resolution smearing
  - Efficiency scale factors (reco, trigger, ID, isolation)

High-mass DY: *K*-factors

Obtained by ratio of cross section at LO(NLO)/NNLO





arXiv:0911.2329v2, U. Klein

EW Schemes

- $\alpha(0)$-*scheme:* The fine-structure constant $\alpha(0)$ and all particle masses define the complete input. In this scheme, the relative corrections to the $q\bar{q} \to \gamma/\mathrm{Z} \to l^- l^+$ cross sections sensitively depend on the light-quark masses via $\alpha \ln m_q$ terms that enter the charge renormalization. ➔ has to be used for photon induced processes

- $\alpha(M_\mathrm{Z})$-*scheme:* The effective electromagnetic coupling $\alpha(M_\mathrm{Z})$ and all particle masses define the basic input. Tree-level couplings are derived from $\alpha(M_\mathrm{Z})$, and the relative corrections receive contributions from the quantity $\Delta\alpha(M_\mathrm{Z})$, which accounts for the running of the electromagnetic coupling from scale $Q = 0$ to $Q = M_\mathrm{Z}$ (induced by light fermions) and cancels the corresponding $\alpha \ln m_q$ terms that appear in the corrections to the $q\bar{q}$ channels in the $\alpha(0)$-scheme. ➔ default schema in FEWZ 2.0, 2.1, e.g. used by CMS for PAS EWK-11-007
  ➔ we use it as a cross check

- G_μ-*scheme:* The Fermi constant G_μ and all particle masses define the basic input. Tree-level couplings are derived from the effective coupling $\alpha_{G_\mu} = \sqrt{2} G_\mu M_\mathrm{W}^2 (1 - M_\mathrm{W}^2/M_\mathrm{Z}^2)/\pi$, and the relative corrections receive contributions from the quantity Δr [40], which describes the radiative corrections to muon decay. Since $\Delta\alpha(M_\mathrm{Z})$ is contained in Δr, there is no large effect on the $q\bar{q}$ channels induced by the running of the electromagnetic coupling in the G_μ-scheme either. ➔ we used it in our W,Z publication
  ➔ our nominal EW parameter schema

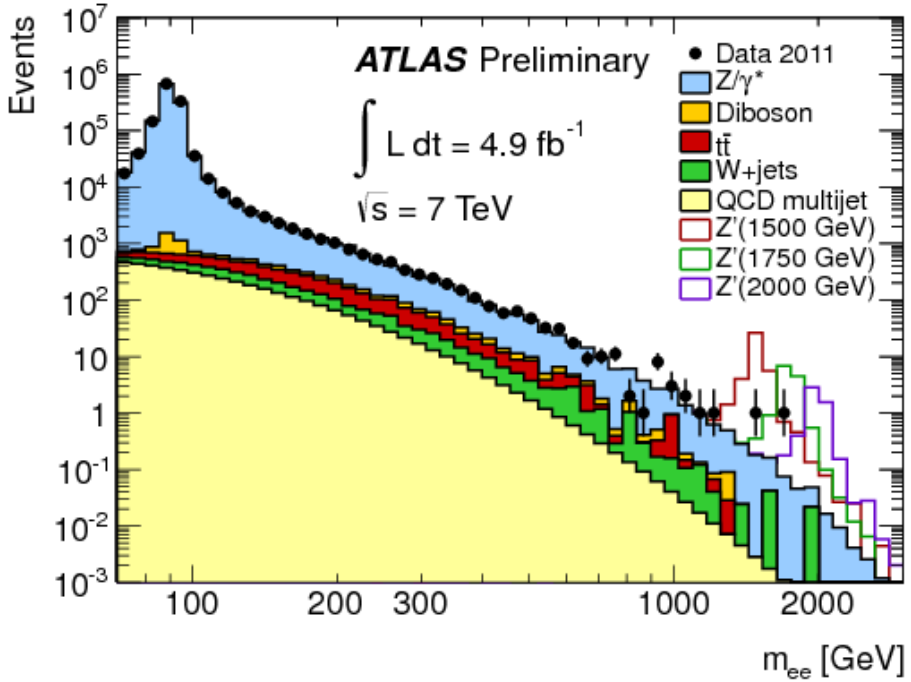
New Physics I

2011 Contact Interaction search in e^+e^- channel, systematics for 1 TeV (2 TeV):

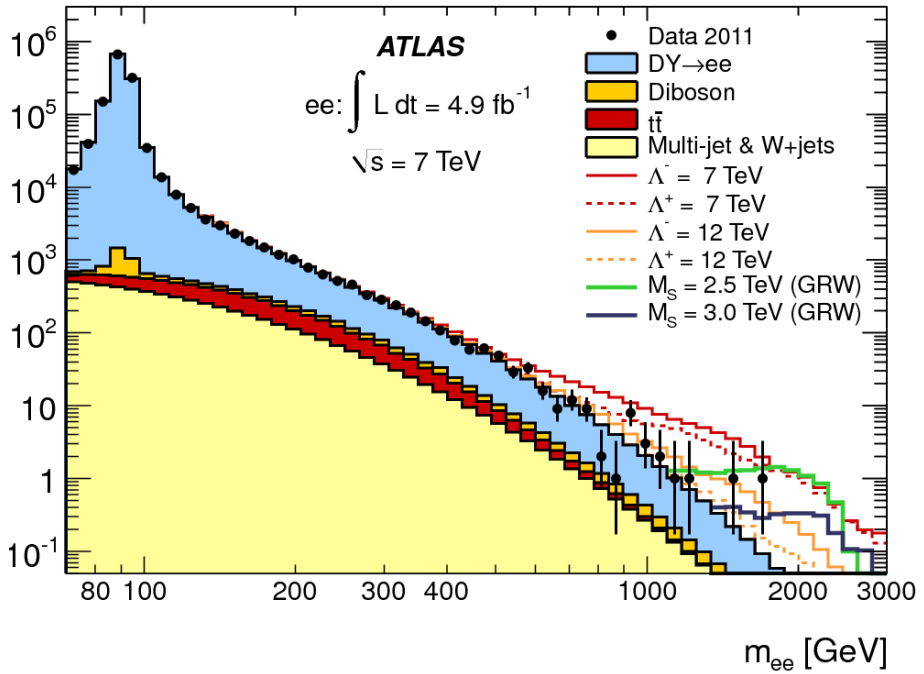
Source	ee		$\mu\mu$	
	Signal	Background	Signal	Background
Normalization	5% (5%)	NA	5% (5%)	NA
PDFs/α_S/scale	NA	7% (20%)	NA	7% (20%)
Electroweak K-factor	NA	2.3% (4.5%)	NA	2.3% (4.5%)
Efficiency	1.0% (2.0%)	1.0% (2.0%)	3.0% (6.0%)	3.0% (6.0%)
Scale/Resolution	1.2% (2.4%)	1.2% (2.4%)	1.2% (12%)	1.2% (12%)
Multi-jet/W+jets background	NA	12% (26%)	NA	$< 0.1\%$
Total	5% (6%)	14% (33%)	6% (14%)	8% (25%)

Careful choice of PDF not to "fit away" new physics!

New Physics II



Z'/G* heavy gauge boson search



Contact Interaction search

New Physics 2012 – Z'