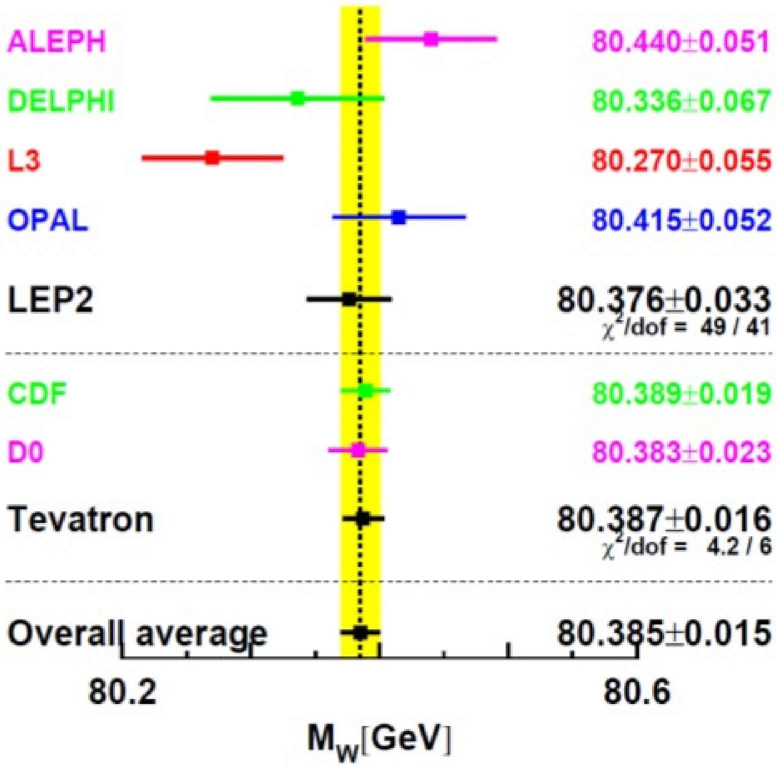
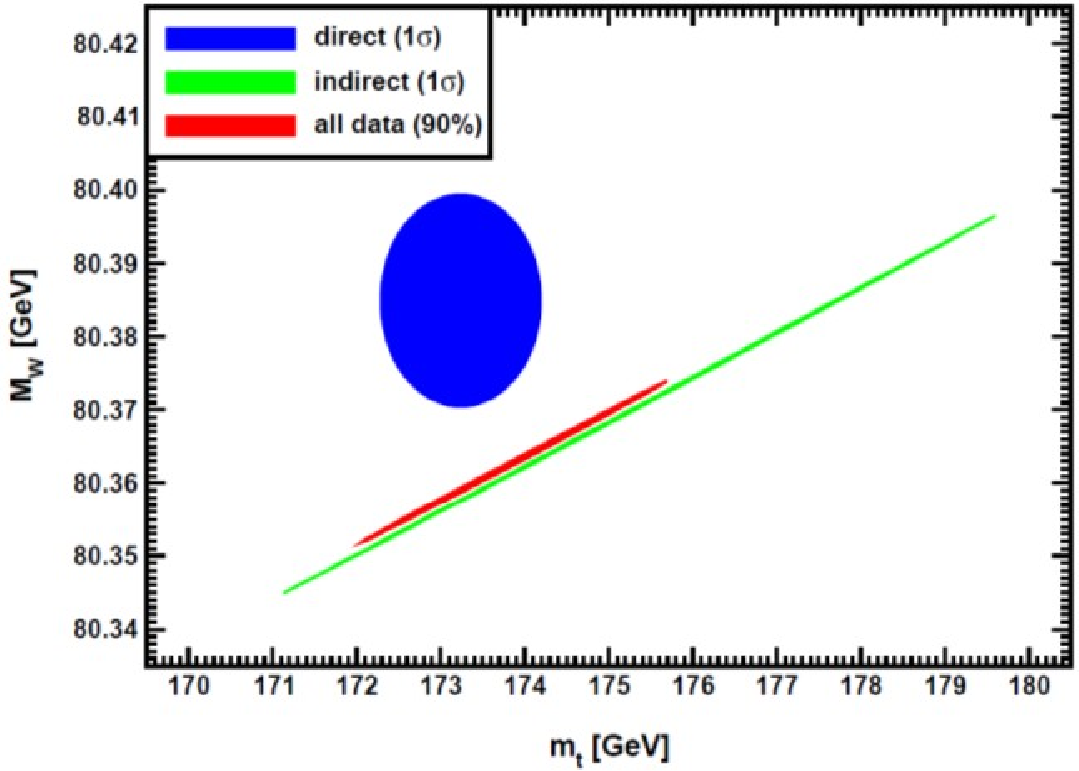
Modeling issues in the M_W measurement

- QCD - PDFs, resummation and their interplay
- EW corrections

Motivation

- M_W is the leading uncertainty in SM consistency tests.
- The indirect determination, and existing and future Tevatron measurements set a natural goal of $\delta M_W < 10$ MeV at the LHC

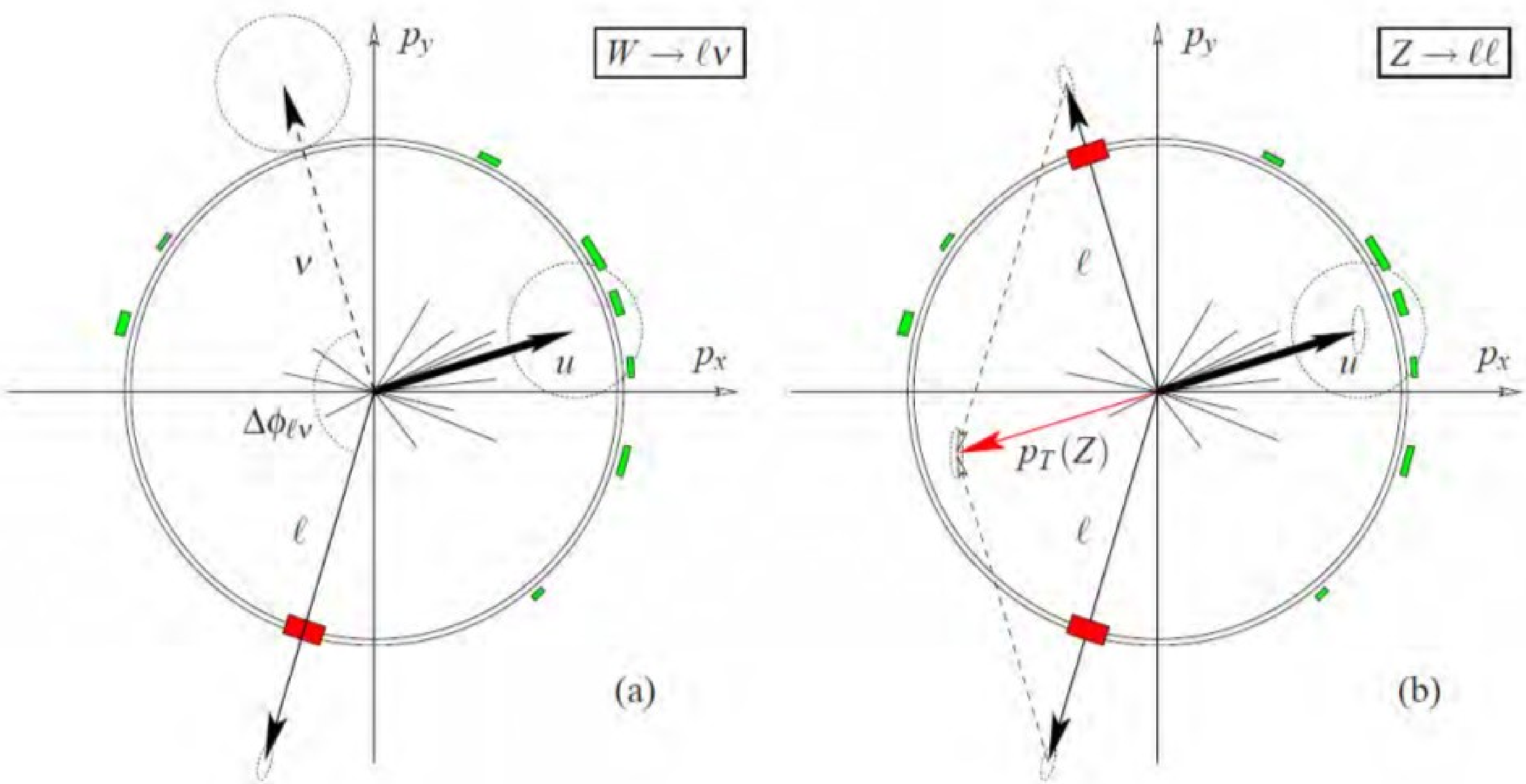




PDG 2014 - Chin.Phys. C38 (2014) 090001

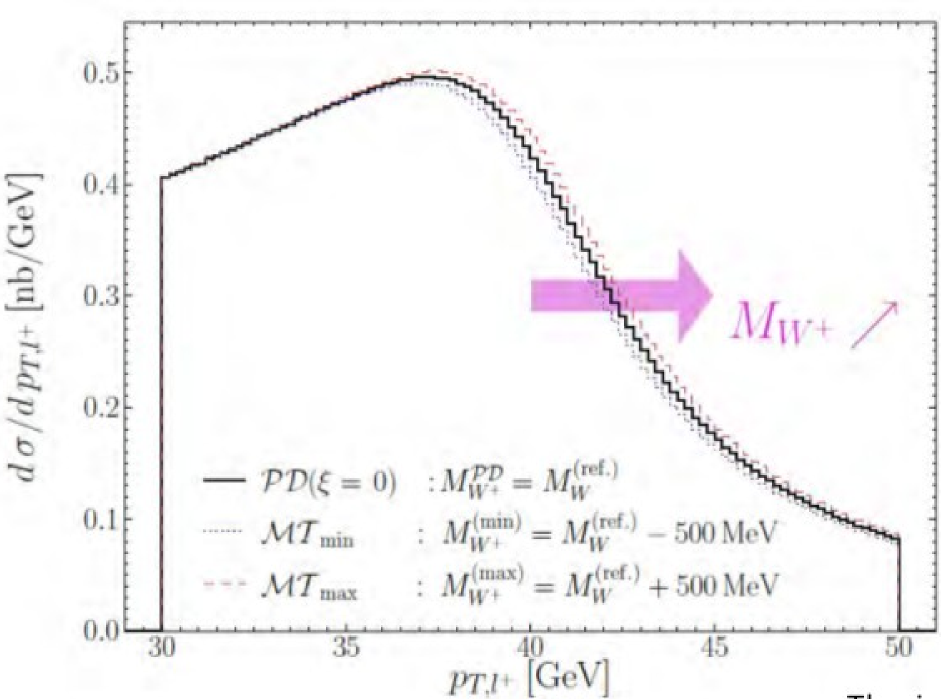
W & Z final states

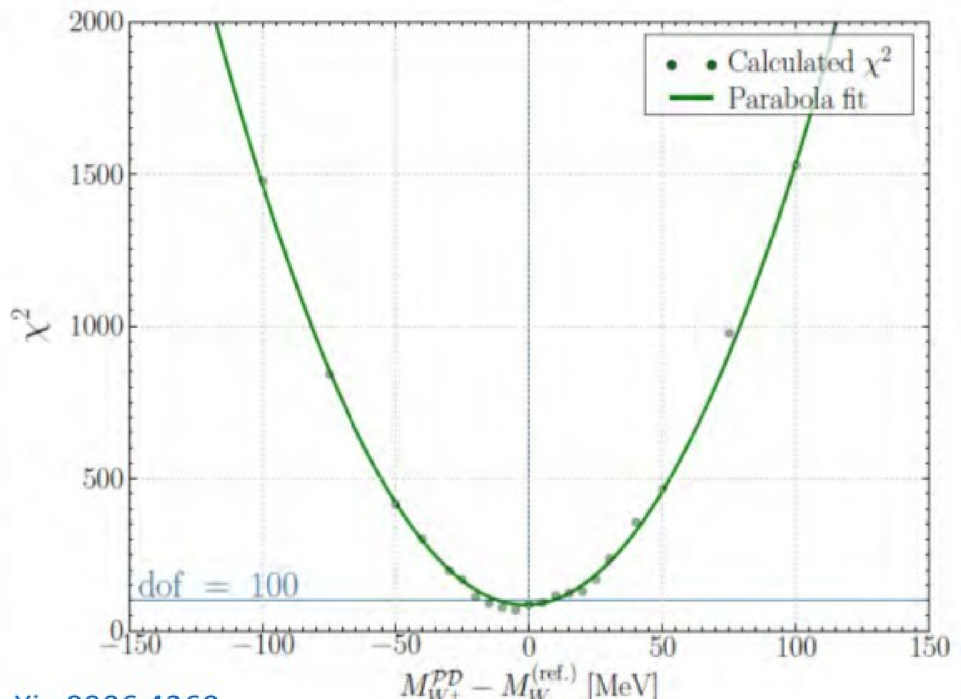
- Basic objects: electron or muon (l); recoil (u)
- Derived quantities in W events:
  - $\overrightarrow{p_T^{\nu}} = -\left(\overrightarrow{p_T^{l}} + \vec{u}\right)$, $E_T^{miss} = \left\|\overrightarrow{p_T^{\nu}}\right\|$, $M_T = \sqrt{p_T^{l} p_T^{\nu}(1 - \cos(\Delta\phi)}$
- Z events can be exploited for calibration: $M_{ll} \approx M_Z$, $\vec{u} \approx -\overrightarrow{p_T^{ll}}$



Measurement principle

- Example cuts at the LHC (compromise btw. statistics & systematics), at 7 TeV:
  - ATLAS: $p_T^{l,\nu} > 30$ GeV, $M_T > 60$ GeV, $u < 30$ GeV
    - 6-9M evts/channel $\delta M_W(stat) \approx 6\ MeV$
  - CMS: $55 > p_T^{l,\nu} > 30$ GeV, $100 > M_T > 60$ GeV, $u < 15$ GeV
    - 3-5M evts $\delta M_W\ (stat) \approx 10\ MeV$
- M_W is extracted from the comparison of data with Monte-Carlo templates of the mass-sensitive distributions: p_T^l, M_T





Thesis - arXiv:0906.4260

Uncertainties – Tevatron experience and LHC expectations

Current best measurements: $\delta(stat) \approx \delta(QCD) \approx \delta(calib)$
Extrpolating to the LHC (and the next Tevatron): $\delta(QCD) > \delta(calib) > \delta(stat)$

Source	Uncertainty
Lepton energy scale and resolution	7
Recoil energy scale and resolution	6
Lepton tower removal	2
Backgrounds	3
PDFs	10
$p_T(W)$ model	5
Photon radiation	4
Statistical	12
Total	19

CDF, Phys. Rev. D 89, 072003 (2014)

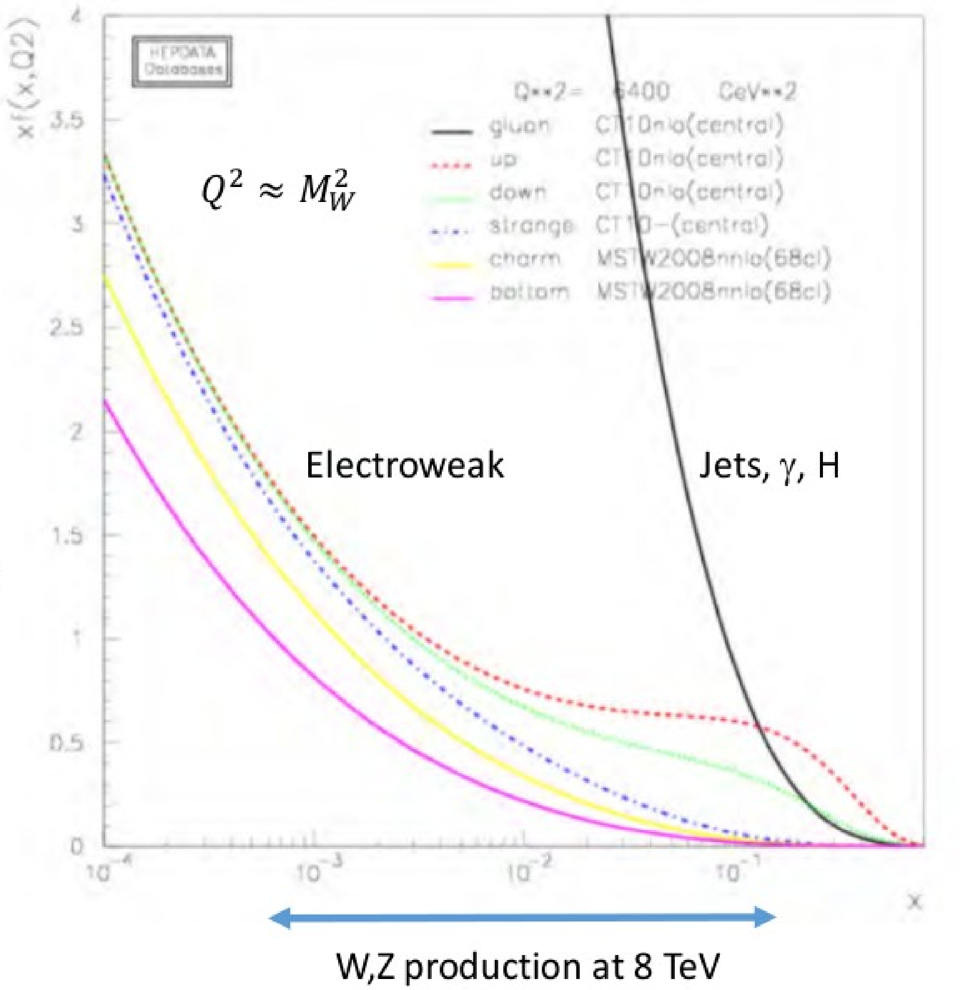
M_W measurements now dominated by modeling. Requires investing in:
- Ancillary measurements (→ constrain physics model)
- Analysis strategy (→ minimize model-dependence)

Proton PDFs and W, Z production

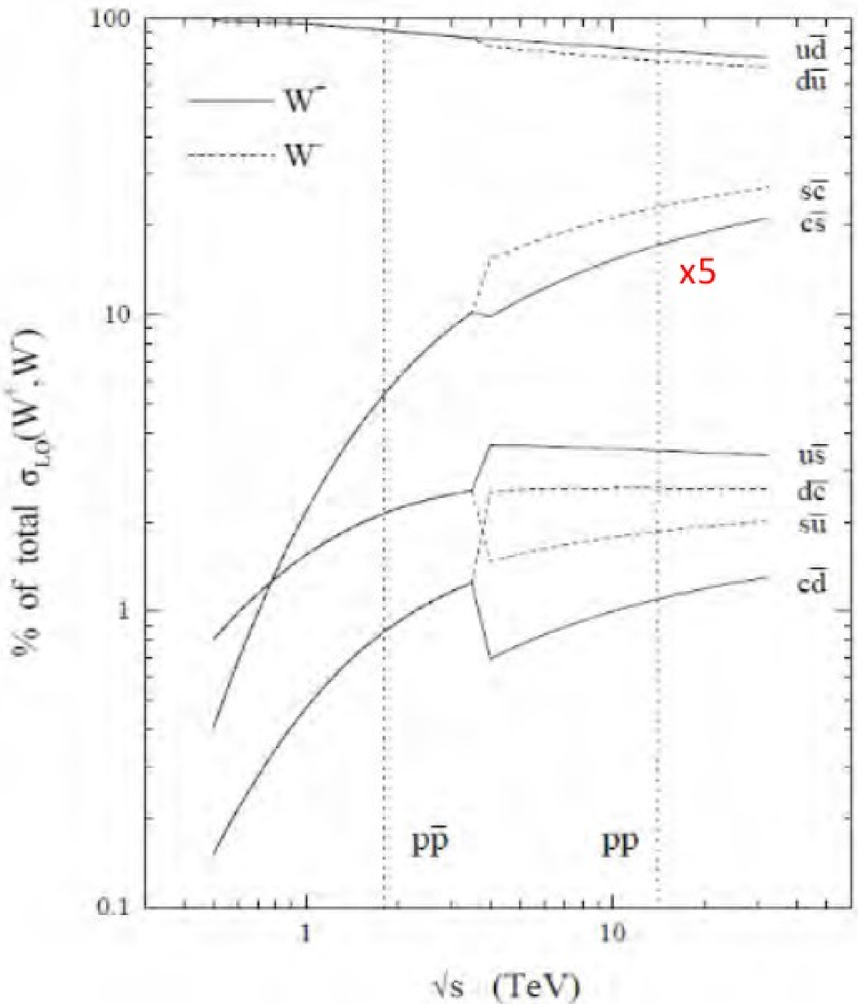
- Pre-LHC: proton model dominated by DIS
  - Measured/fitted: $u_V, d_V, g, sea \quad (\alpha_S)$
  - Theory: $c, b, \mathrm{evol}(Q^2) \quad (\alpha_S)$
  - Assumed: $\bar{u} \approx \bar{d}\ ;\ s \approx \bar{s} \approx \bar{d}/2$

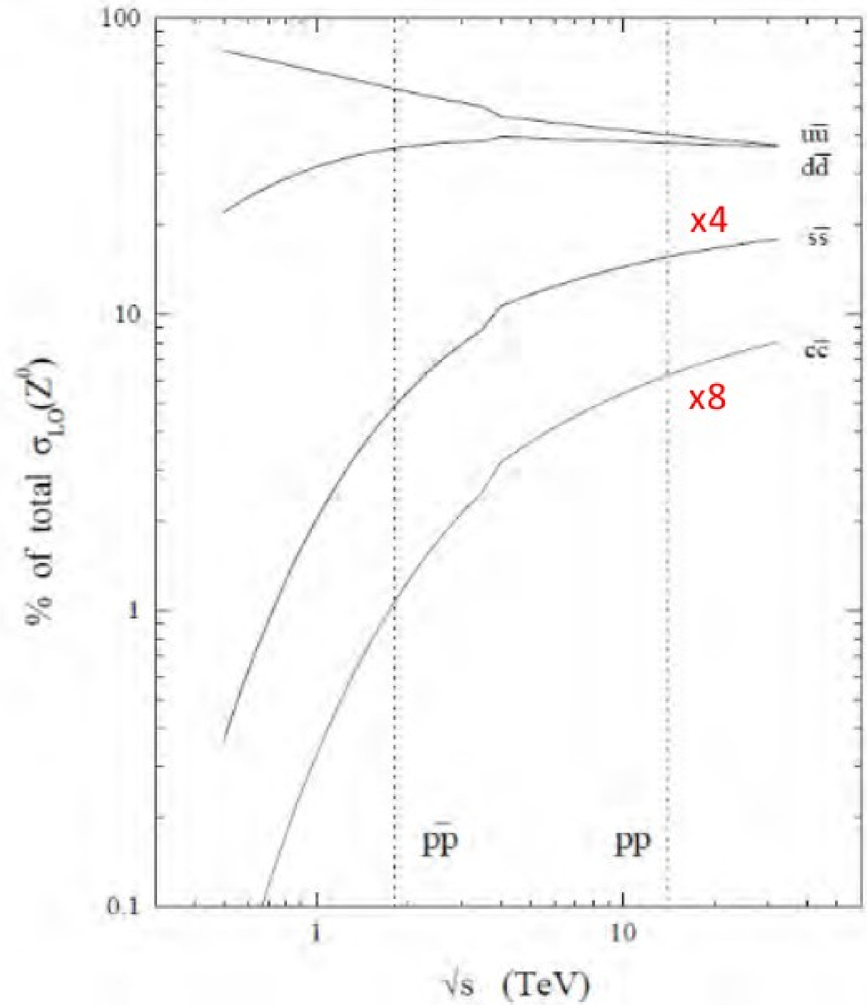
- Very precise data, but little experimental information on the flavour composition of the proton. A (very) simplified view:
  - $\sigma^{NC}, \sigma^{CC} \rightarrow u_V(x), d_V(x), sea(x)$
  - Jet prod. $\rightarrow g(x)$
  - $(F_2^c, \ldots)$

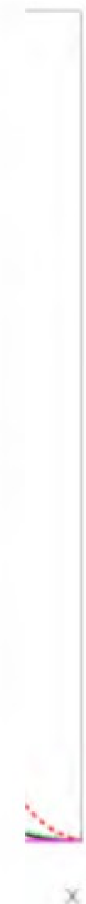
- $Wq\overline{q'}$ and $Zq\bar{q}$ couplings ~flavour democratic
  → Hadron colliders probe different parton combinations than those tightly constrained by DIS



Proton PDFs and W, Z production







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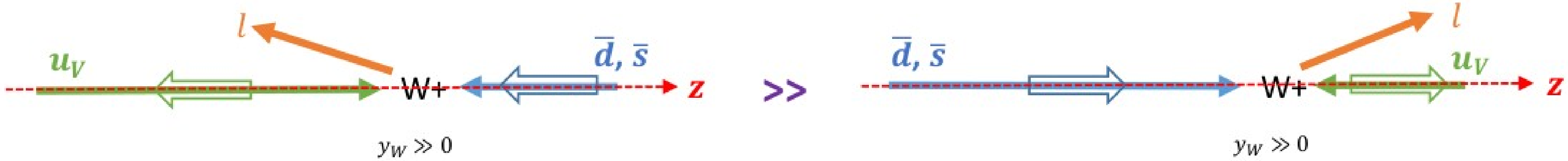
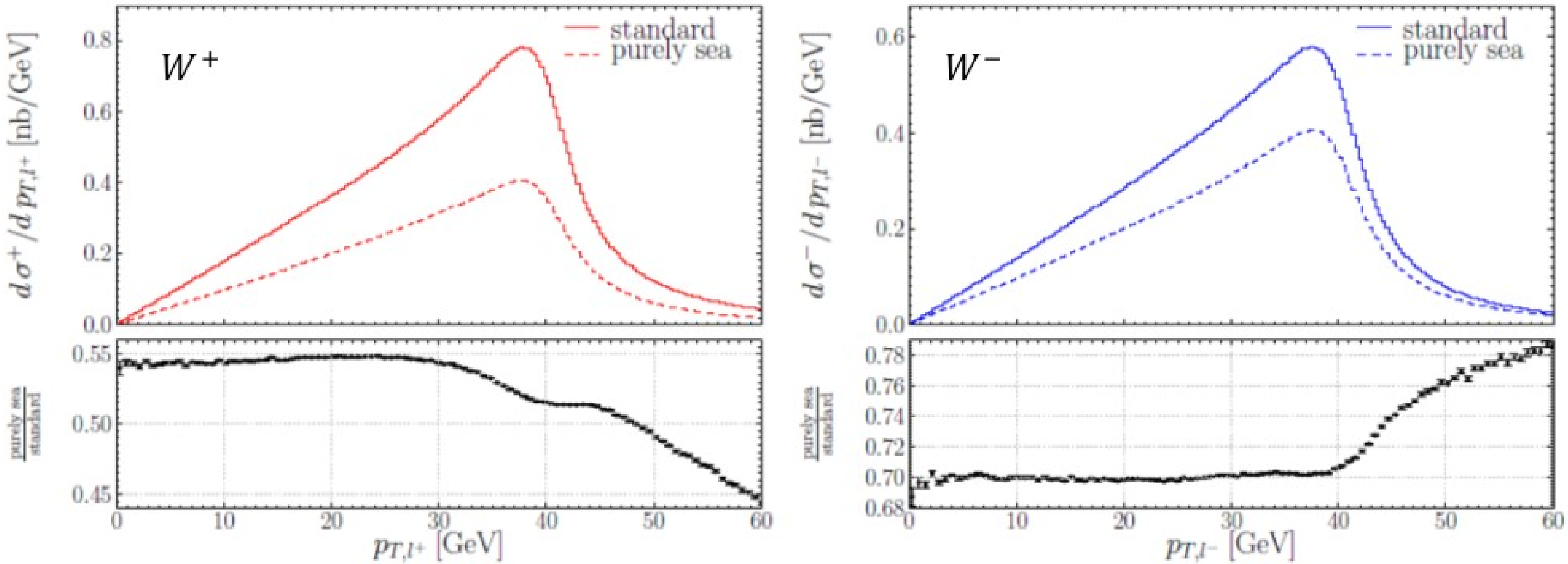
First order: u_V, d_V and the total sea

- Valence/sea PDF uncertainties
  - Determine the rapidity distribution → acceptance effects
  - Valence PDFs polarize the W decay (at any $y_W \neq 0$), with corresponding uncertainties:

Large, LO effect amplified by maximal parity violation in W





Sea: symmetric, unpolarized

Including u_V, d_V leads to an overall polarization along z

Eur.Phys.J.C69:379-397,2010

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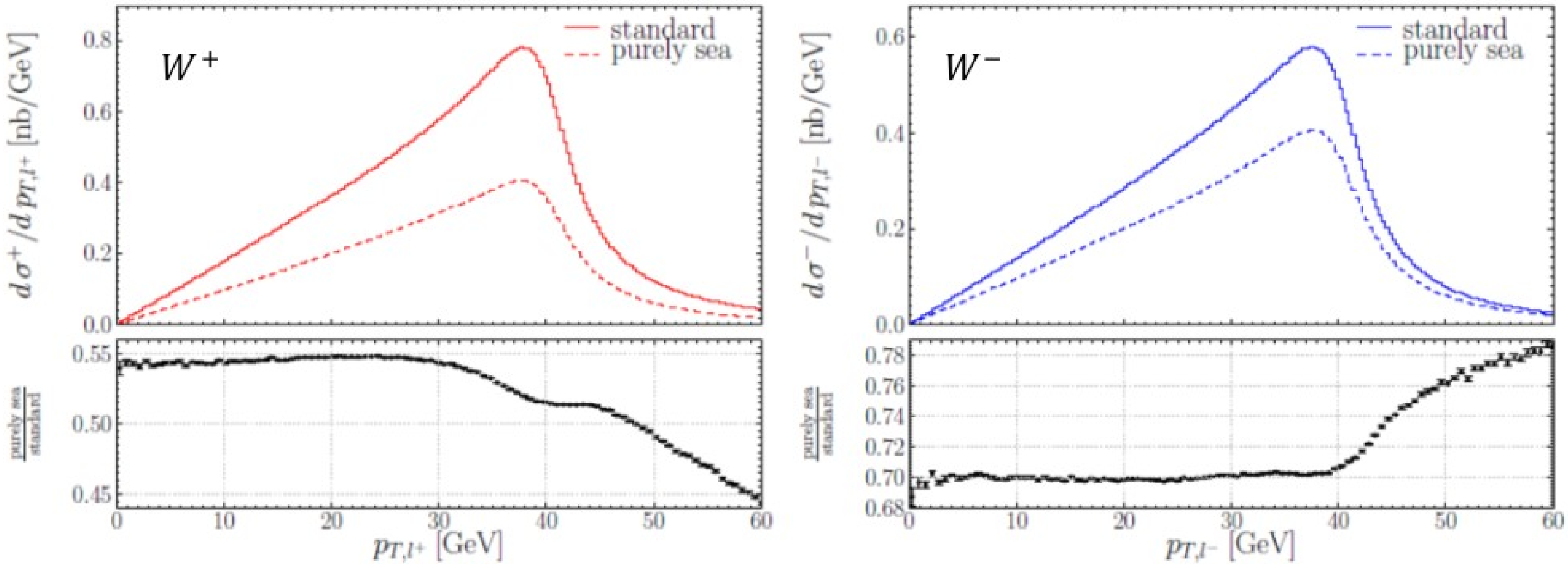

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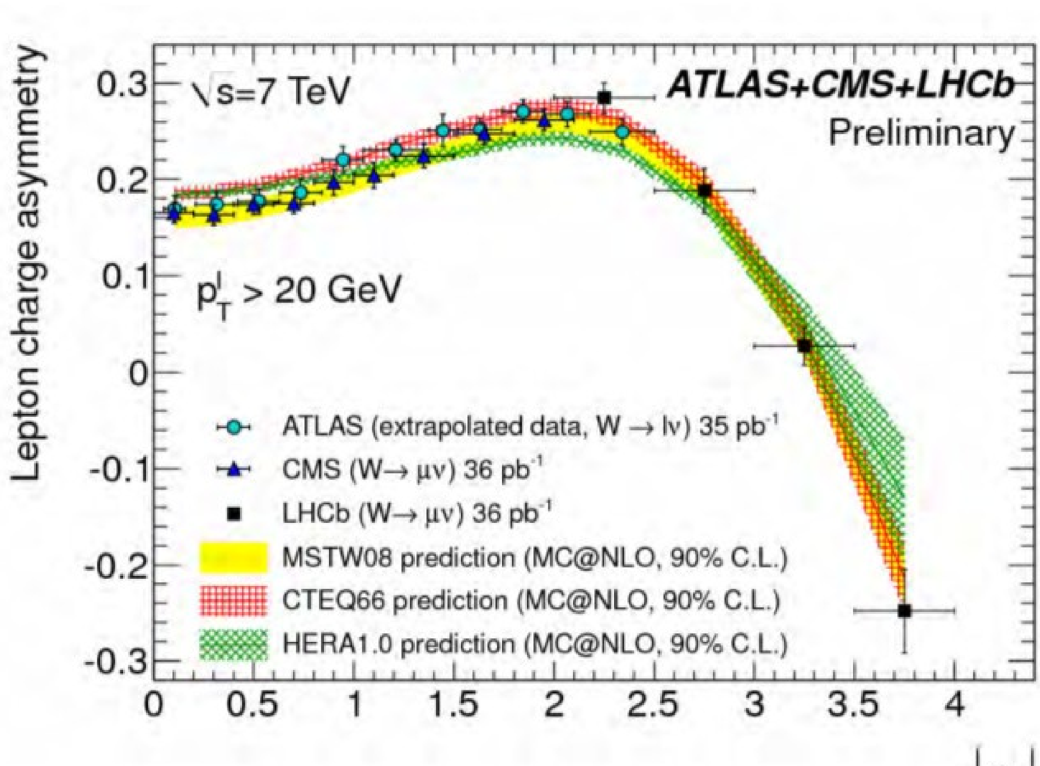
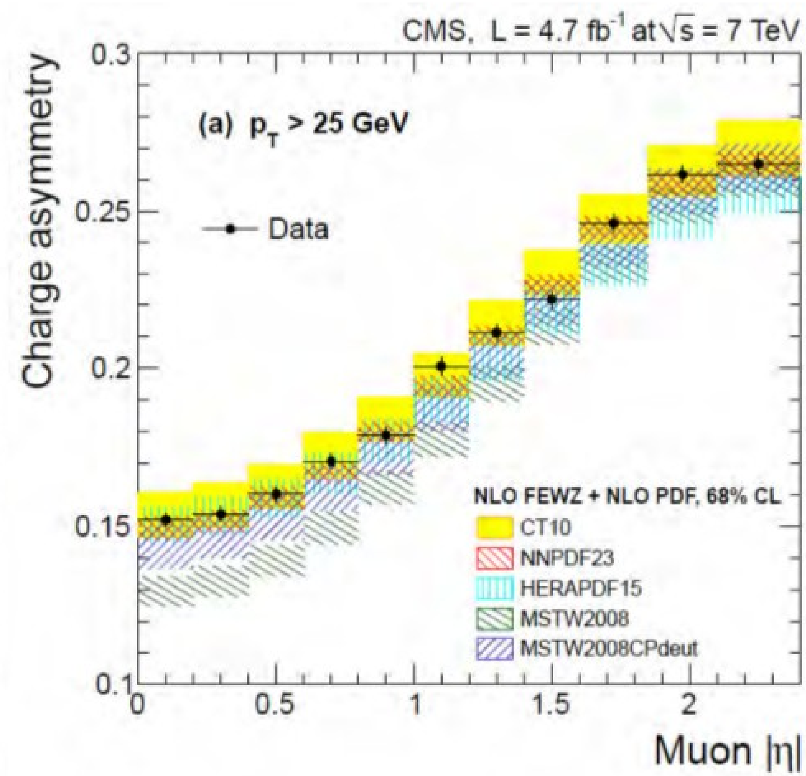
Eur.Phys.J.C69:379-397,2010

Constraints

- u_V tightly constrained by DIS; d_V hugely improved combining with hadron collider data (esp. Tevatron)
- At the LHC, additional information from W charge asymmetry



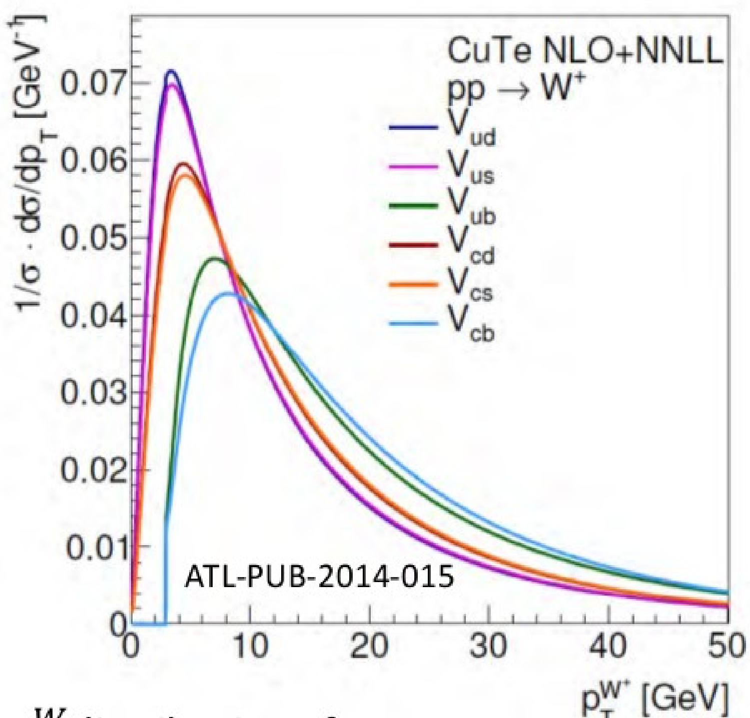
ATLAS-CONF-2011-129



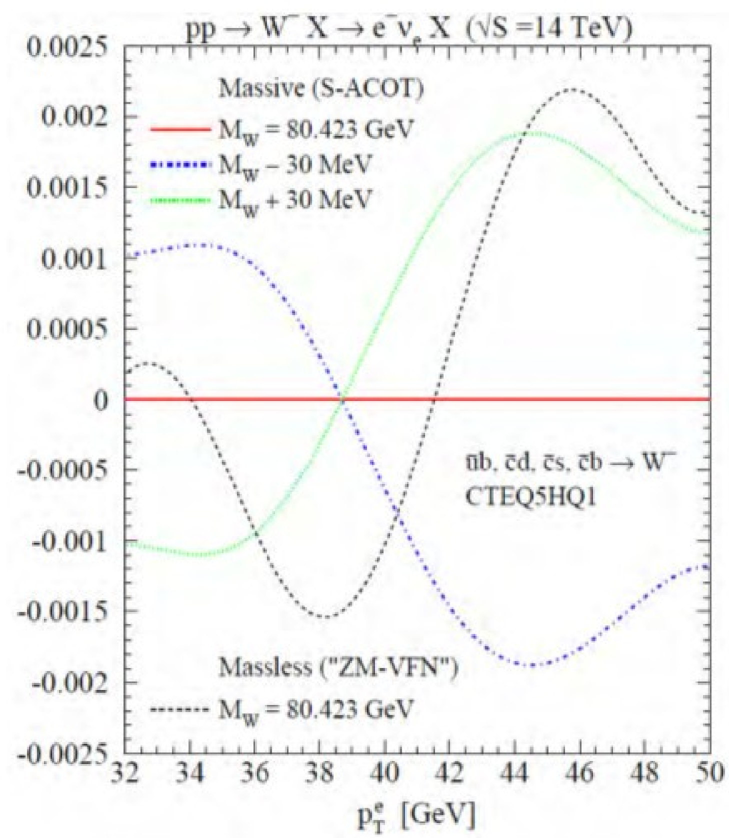
Phys. Rev. Lett. 109 (2012) 111806

Second order: sea flavour composition

- Transverse momentum distribution uncertainties
  - « physics smearing » of the Jacobian peaks from uncertainties in the p_T^W distribution
  - Contributions from non-perturbative parameters (intrinsic k_T, …) and from heavy quark PDFs



p_T^W distributions for different sub-processes

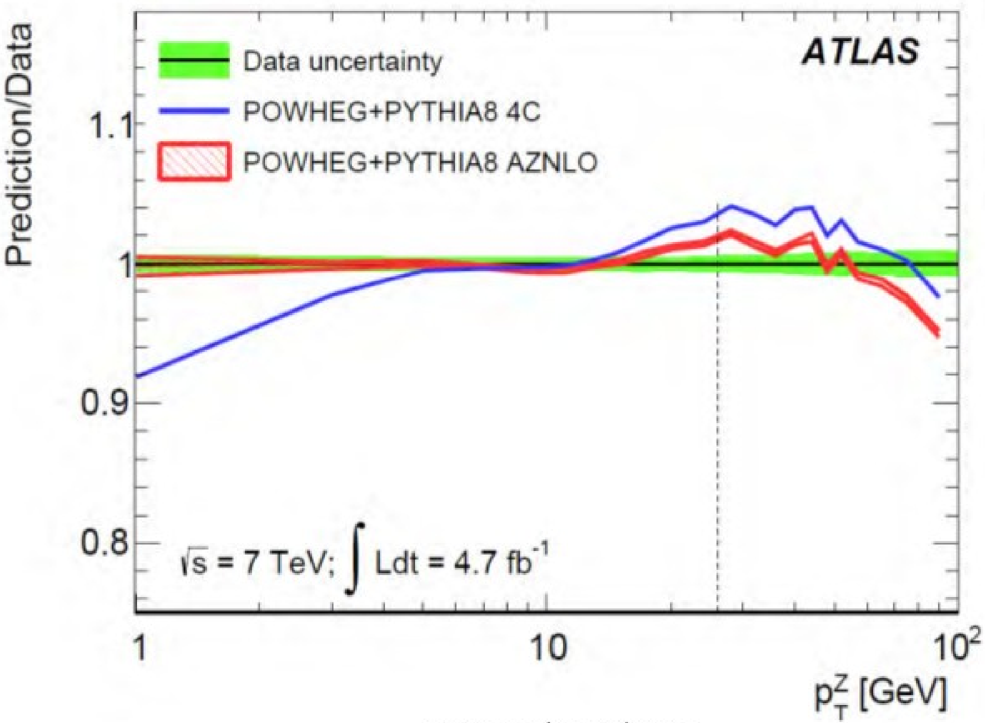


Uncertainty on HQ mass treatment vs. M_W variations

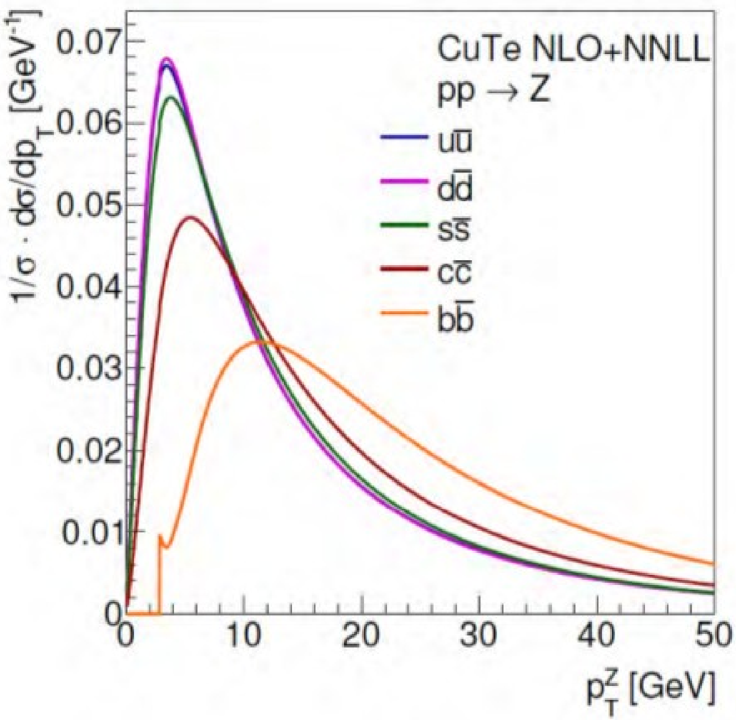
Phys.Rev.D73:013002,2006

Second order: sea flavour composition

- Traditional ansatz: W and Z production are analogous, and non-perturbative effects are universal and factorize from PDFs
  - Measure p_T^Z, tune parton shower (or resummation params.), apply to W
  - Constraints from ATLAS measurement: $\delta M_W < 5$ MeV, assuming no extrapolation uncertainties
- Caution needed at the LHC: Z, $W^+$and W^-all have different contributions from 2nd and 3rd generation PDFs (4-8 times larger than at the Tevatron)

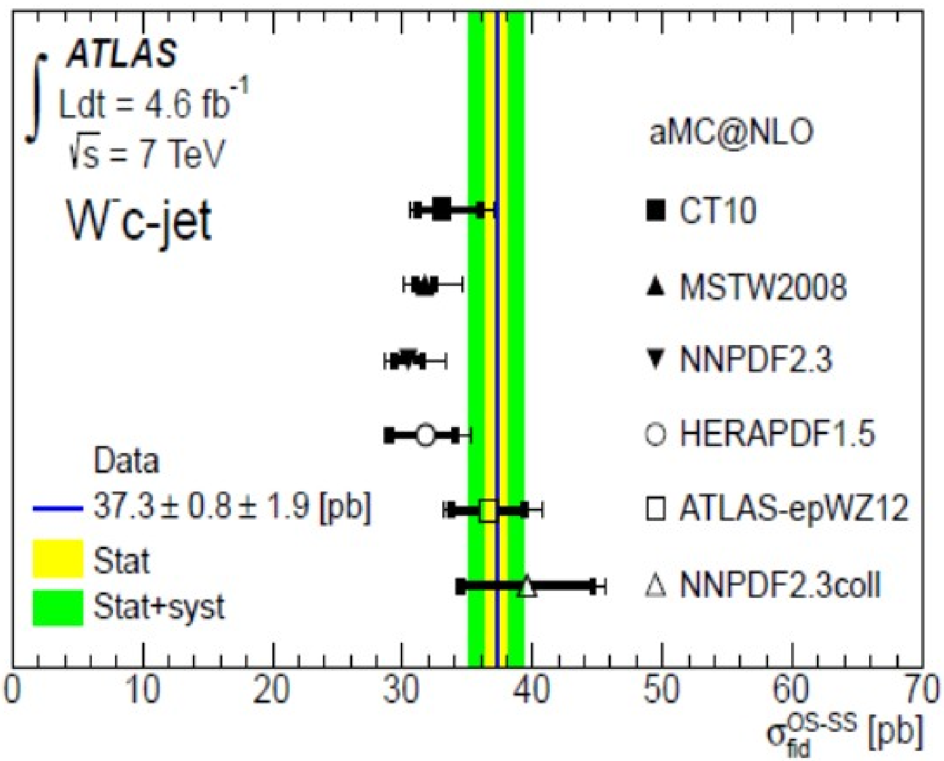


JHEP 09 (2014) 145



Strange density from LHC data

- Marginal agreement: ATLAS sees $r_s \approx 1$ (consistently in W/Z ratios and W+c), CMS prefers $r_s < 1$ for $x >\approx 10^{-2}$ at $Q^2 \approx M_W$
- Impact: ~15% difference in charm-induced W production, affecting y_W, p_T^W



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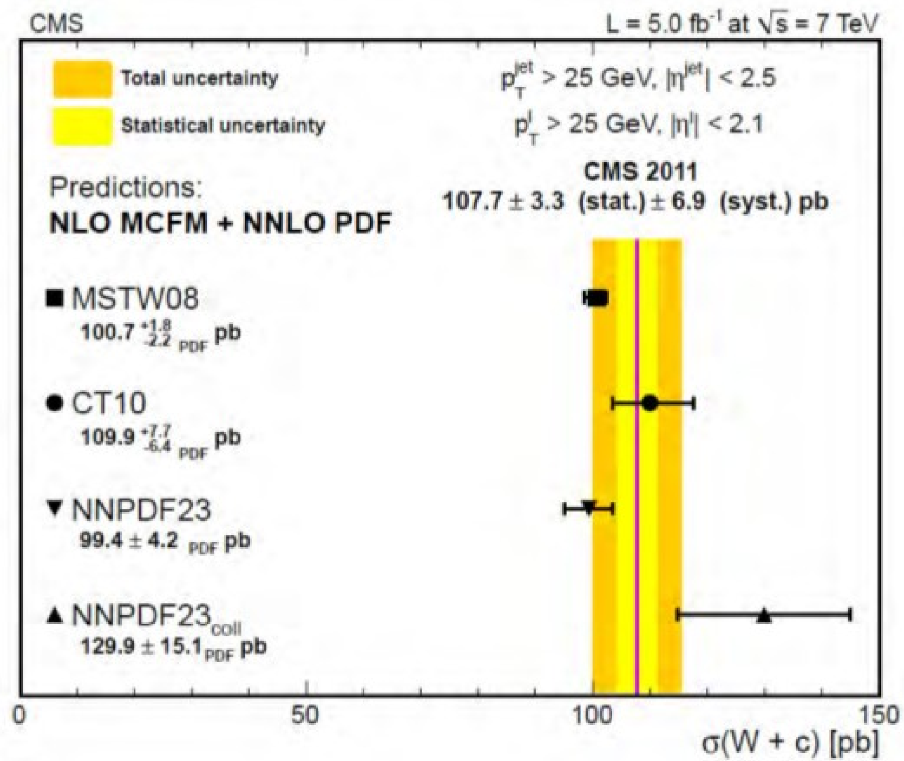
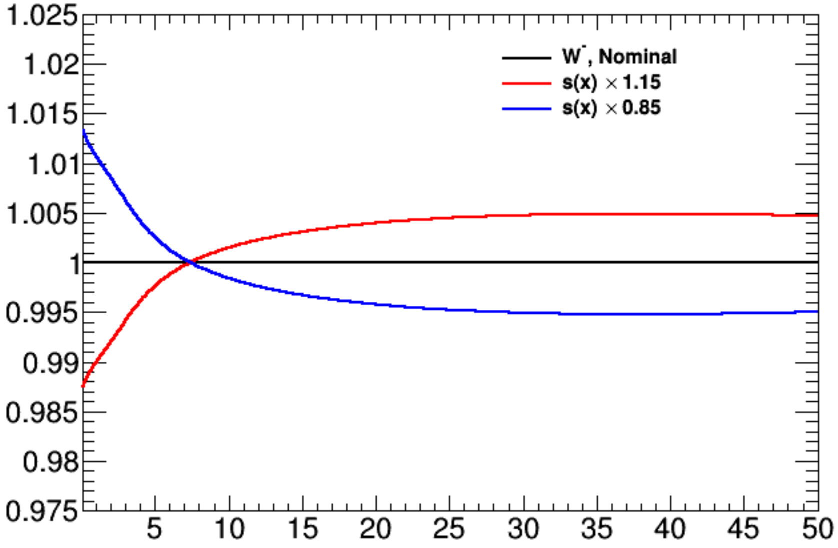
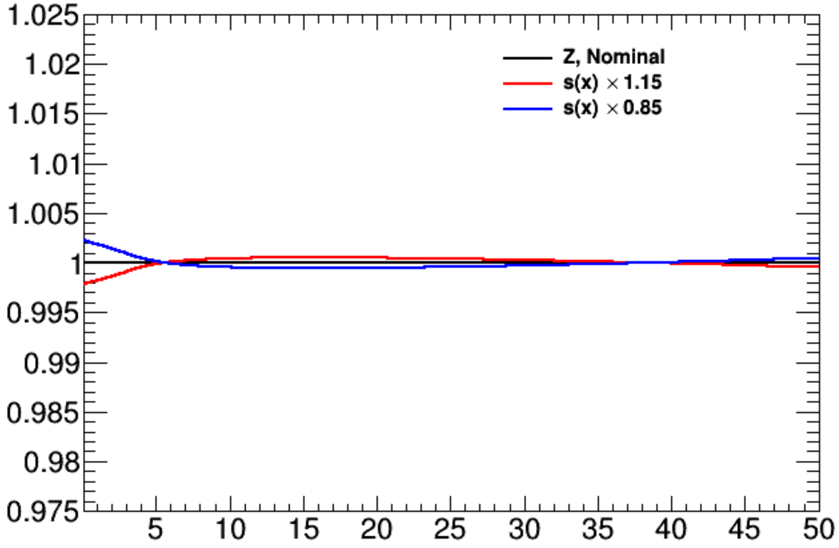


JHEP 02 (2014) 013

Flavour composition and the pT distribution

Assuming a ~15% up/down variation of the strange density, the effect is
- +- 1.5% slope in the W- distribution
- <0.2% for the Z

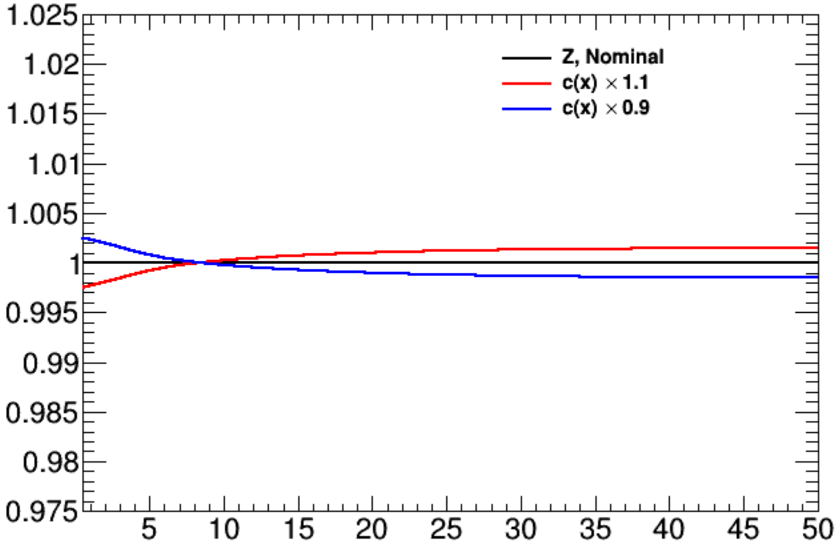


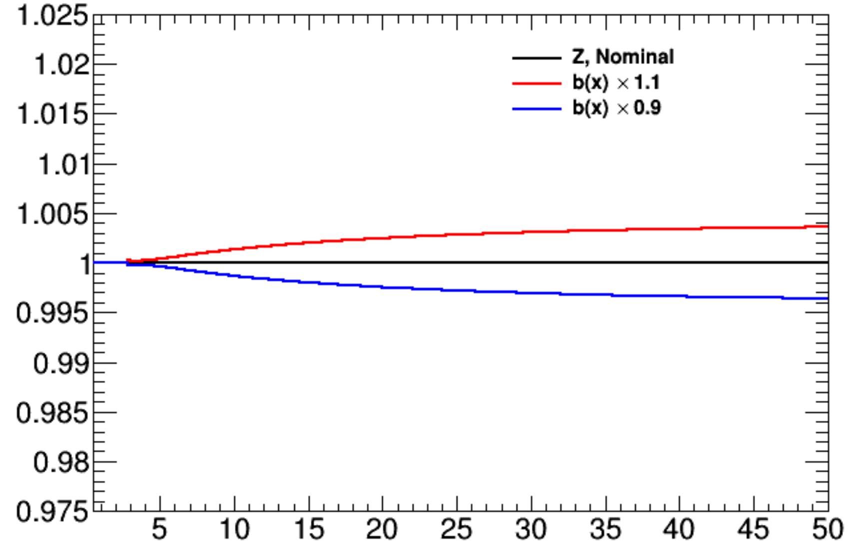


CuTe [arXiv:1109.6027]

Flavour composition and the pT distribution

Charm and especially bottom density variations also affect the pTZ distribution, while not affecting the W (marginal effect)

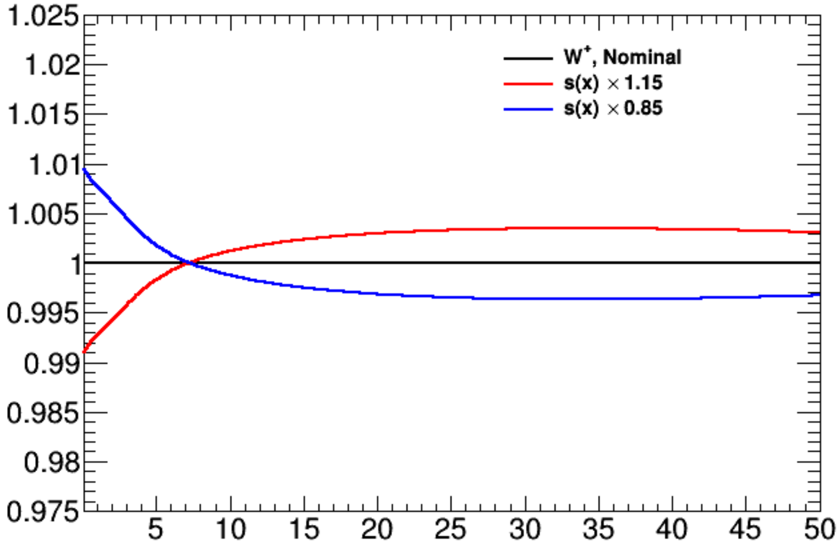


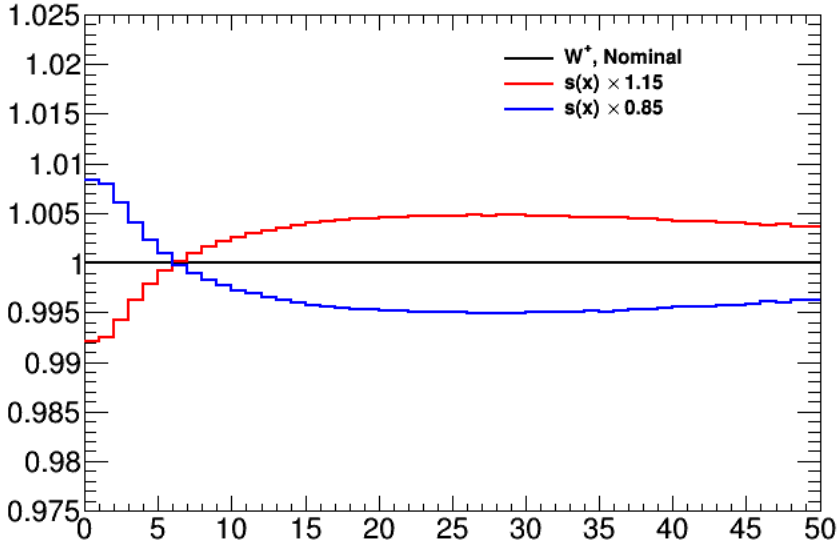


CuTe [arXiv:1109.6027]

Flavour composition and the pT distribution

Model dependence?
Comparing predictions from CuTe and Pythia:
Agreement better than ~15% of the size of the effect

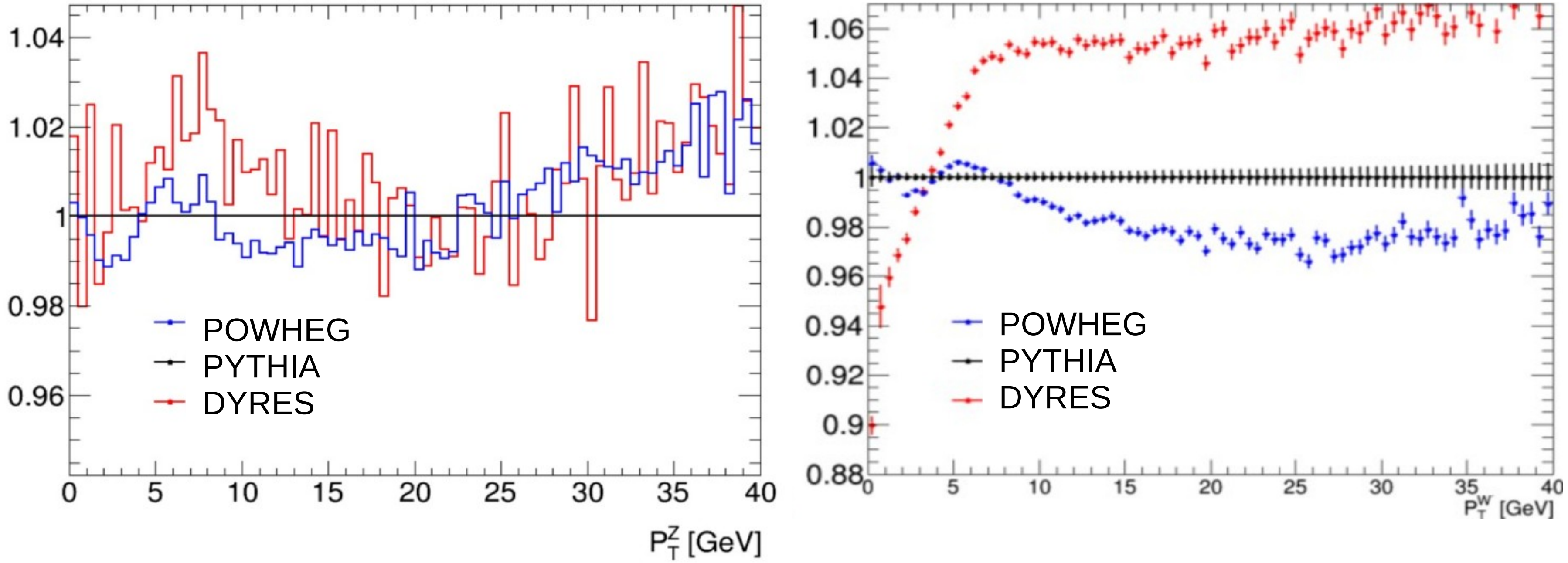




Naive comparison to be cleaned for a few small differences
(initial PDFs, resonance form, etc).

Comparison with pTZ tuning uncertainties

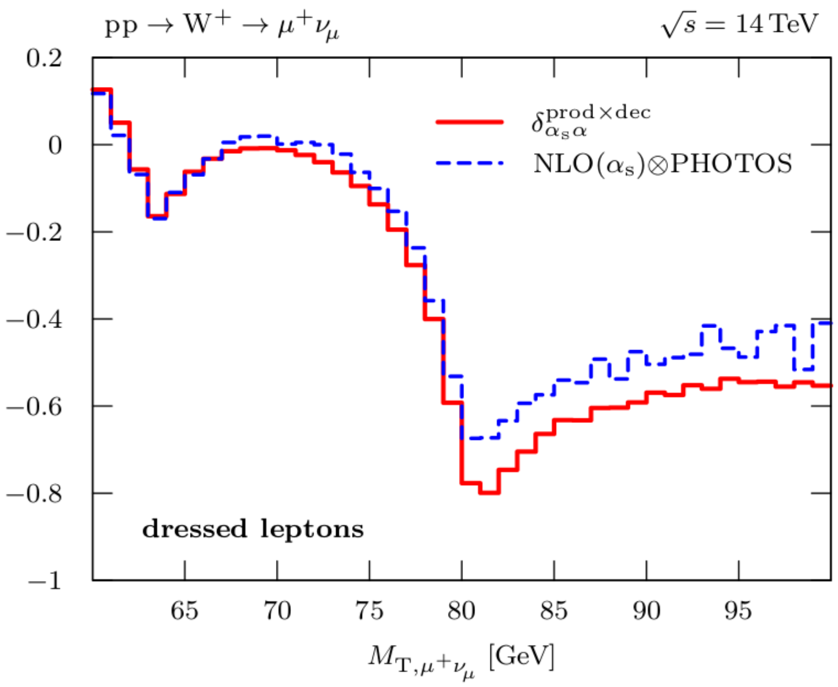
- Further comparisons: Powheg, Pythia and the state-of-the-art DYRES
  - Fully exclusive W and Z production, at NNLO+NNLL
  - All three were tuned to the pTZ data and agree at the 1-2% level, as they should
  - Applying the result to W production shows large differences, esp. for DYRES



Issue being traced to the flavour number scheme used in the resummation
Very sensitive! Can destroy a prediction for which resummation is a strong point

NLO QCDxEW corrections

- Not really xFitter related – but related uncertainties are of similar size as the pure QCD uncertainties, so should be mentioned.
- Recent calculations with Dittmaier, Huss, Schwinn:
  - potentially a 4 (14) MeV effect for MT when using bare (dressed) leptons
  - Based on fixed-order predictions: effect of further photon and gluon emissions?

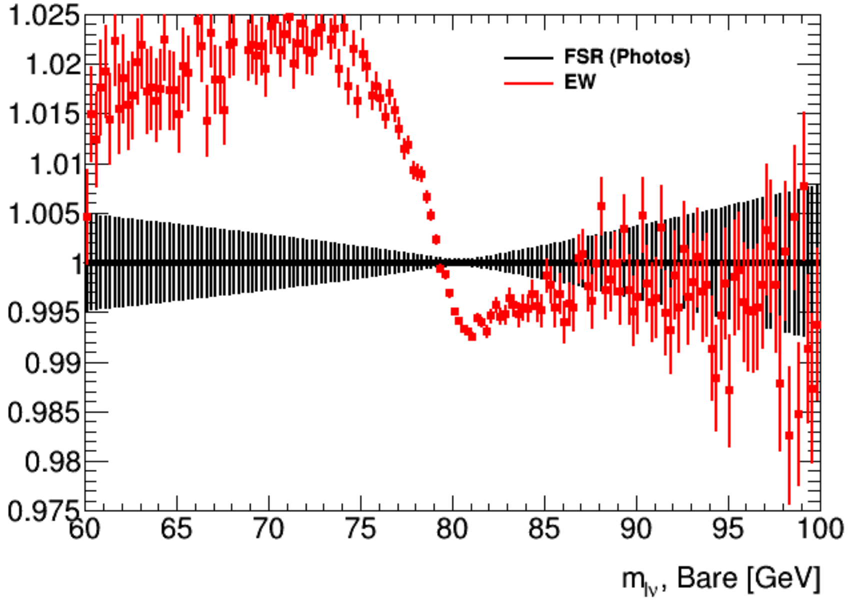


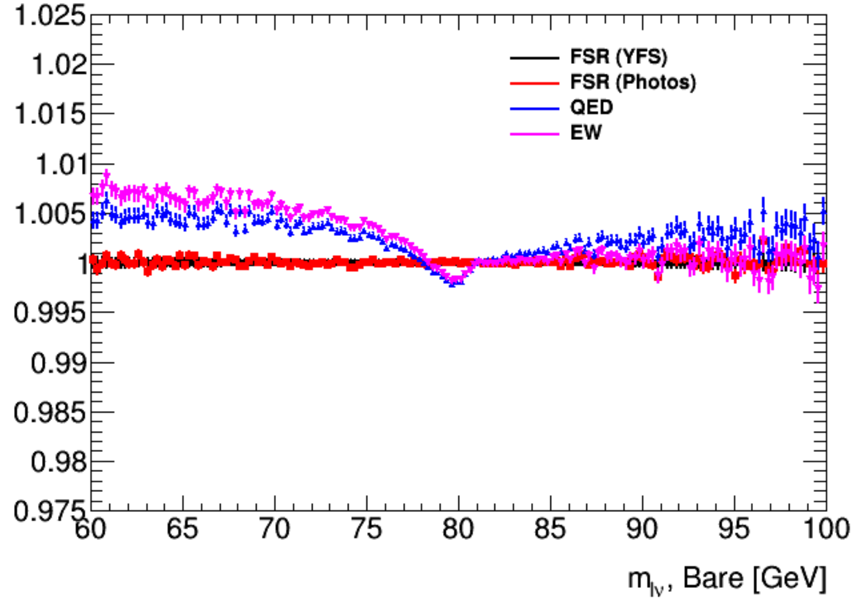
	bare muons		dressed leptons	
	M_W^{fit} [GeV]	ΔM_W	M_W^{fit} [GeV]	ΔM_W
LO	80.385	− 90 MeV	80.385	− 40 MeV
NLO_{ew}	80.295		80.345	
$\text{NLO}_{\text{s}\oplus\text{ew}}$	80.374	− 14 MeV	80.417	− 4 MeV
NNLO	80.360		80.413	

NLO QCDxEW corrections

- Mw is performed at reconstruction level → need fully exclusive predictions
  - QCD corrections: O(α_s), parton shower
  - EW: full O(α) + multiple photon emissions
- Two programs pass requirements: Powheg-EW (strictly), Winhac (almost)

  Prediction however are very different:





Difference should reflect the NLO QCD correction absent in Winhac.
Appears too large, especially for the inv. Mass distribution

Discussion - QCD

- Polarization and acceptance effects on the measurement are largest but “easy” to address, as they are pure PDF effects – all the uncertainty is in the u_V, d_V, and total sea PDFs

  When data become more accurate, theoretical accuracy and parametrization bias should follow

- The pT spectrum is an extremely rich topic and mixes PDFs, fixed order QCD and resummation.

  Here a prediction combining state-of-the-art QCD accuracy (NNLO+NNLL) and a consistent FN scheme in the resummeds part is still lacking

  Related (although probably subleading): how much would resummed W,Z predictions influence PDF fits?

Discussion - QCDxEW

- FSR
  - Real, multiple photon emissions is the largest effect but under control.
  - Fermion-pair production is formally subleading, but has a visible effect on the distributions

- Full O(α)
  - Winhac seems to give reliable predictions relative to FSR only. EW corrections benchmarked against SANC at the 0.1% level or better

- O($\alpha\alpha_s$) : still a confusing situation –
  - in the MC world, tempting is to use Winhac + a small uncertainty from the missing fixed-order QCD part (parton shower is applied)
  - Fixed-order calculations need to be “bridged” to the detector level distributions