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PDF issues in MW measurements

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GGI workshop on the "Uncertainties on the MW measurement"

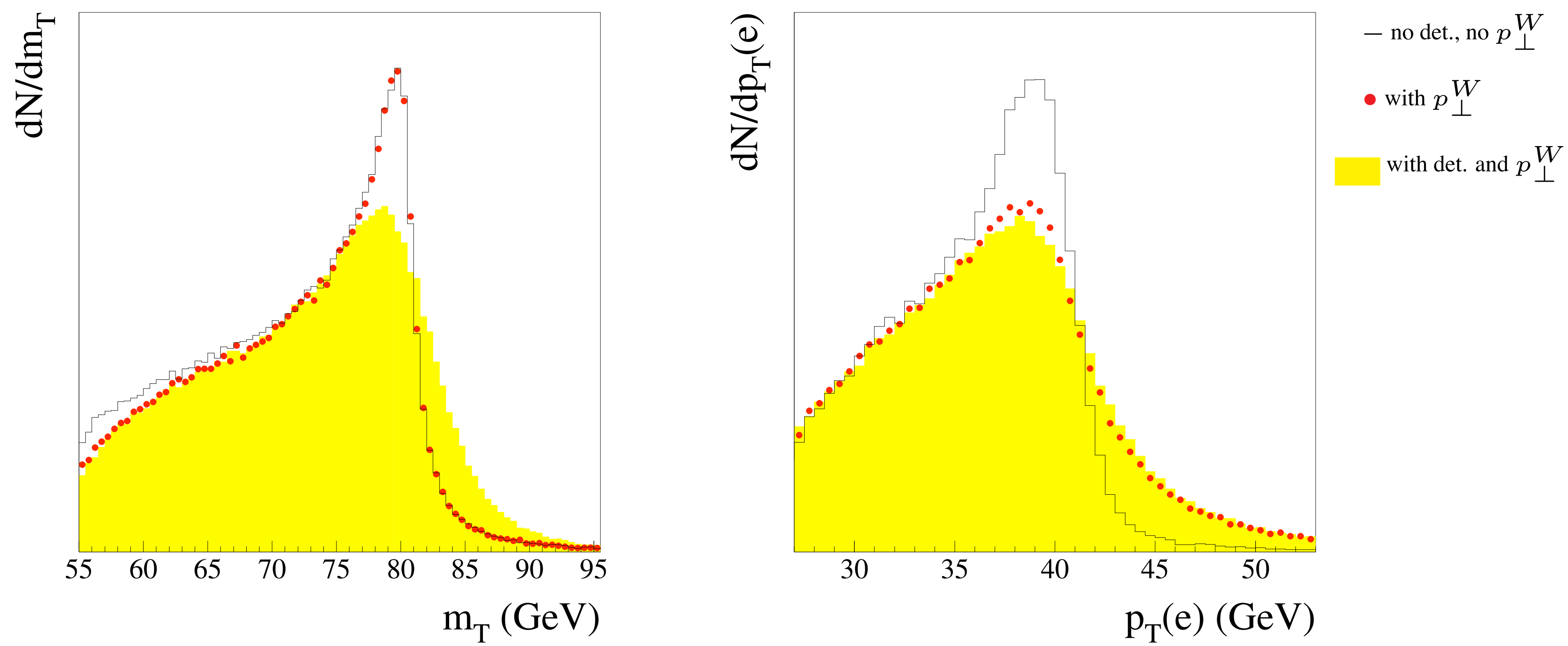
work with G.Bozzi, L.Citelli

very useful conversations in the past two years
with M.Boonekamp, S.Camarda, P. Gambino, A.Kotwal, I.Stark, L.Perrozzi,

MW measurement from Drell-Yan observables

- lepton-pair transverse mass $M_\perp^W = \sqrt{2 p_\perp^l p_\perp^\nu \, (1 - \cos\phi_{l\nu})}$
- charged lepton transverse momentum
- missing transverse momentum

- sensitivity to MW via the jacobian factor peaked at the physical mass value



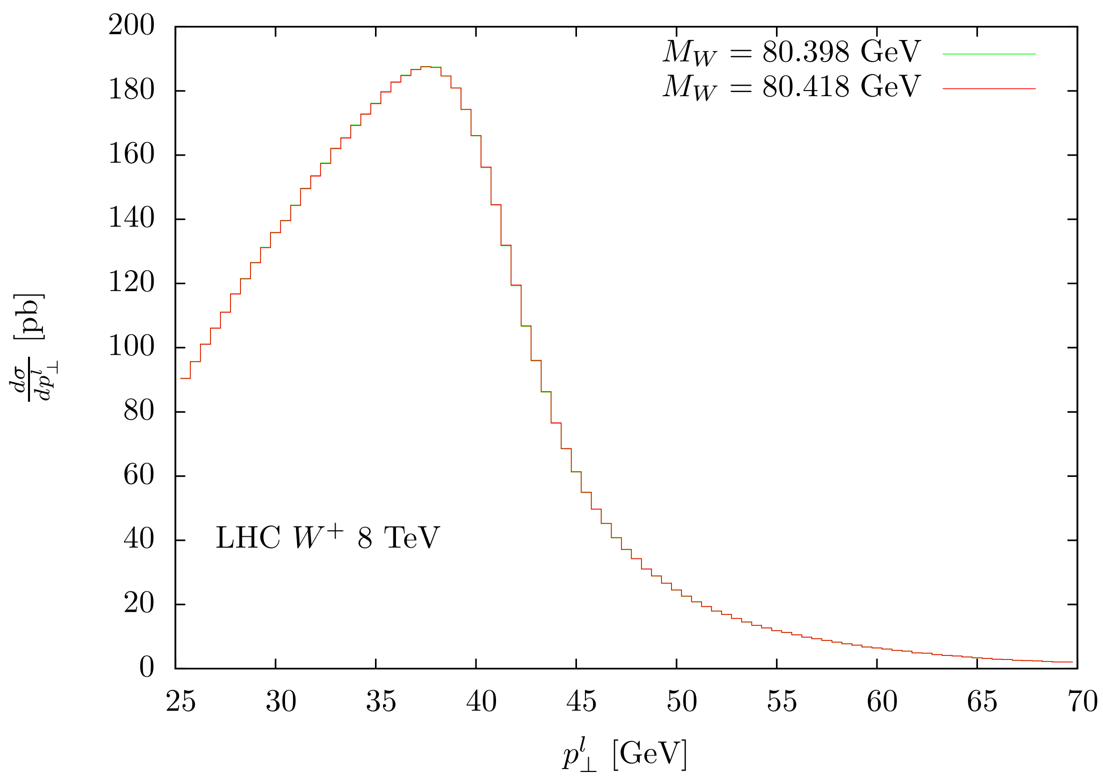
lepton-pair transverse mass

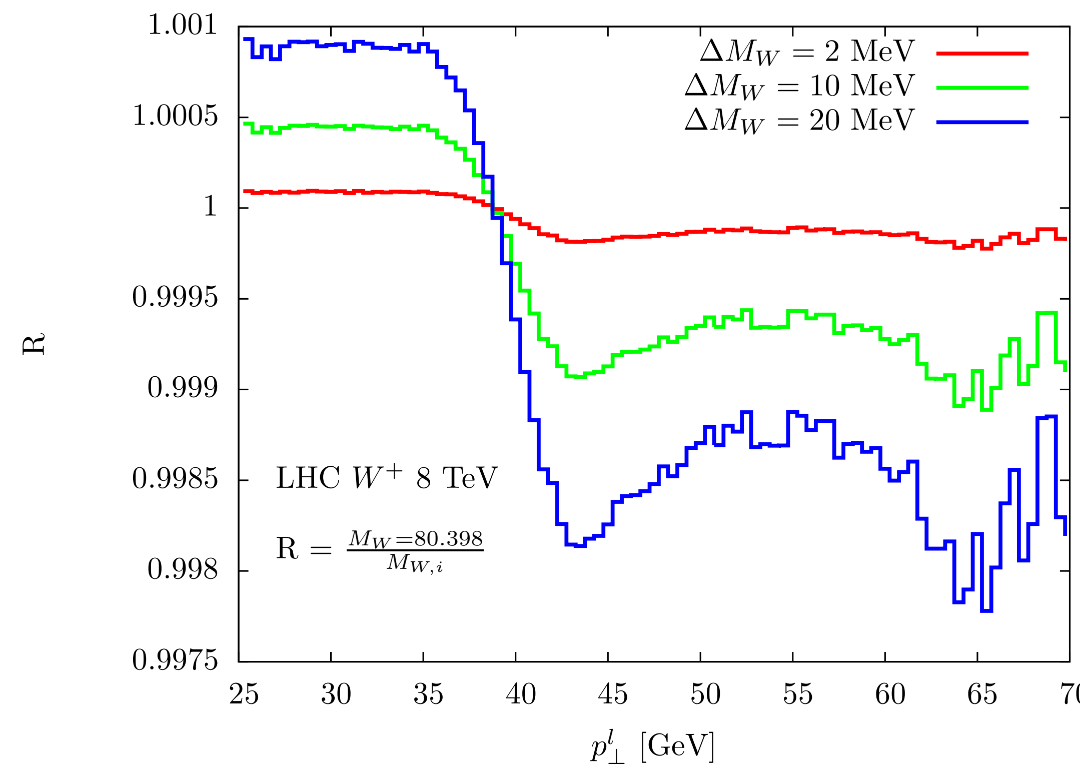
- stable w.r.t. inclusion of radiative corrections
- problematic determination of the neutrino pt in presence of high pile-up (difficult modeling of hadronic recoil)

charged lepton transverse momentum

- highly sensitive to the details of QCD radiation
- "simple" experimental determination (accurate lepton energy/momentum calibration)

Sensitivity of the charged-lepton pt to MW





- a sensitivity to ΔMW=10 MeV
  requires the control of the shape of the distribution at the (sub-) per mill level

- challenging from different points of view
  - experimental
  - MC simulation (statistical fluctuations)
  - theoretical (highly sensitive to the details of QCD radiation description)

Impact of PDF uncertainties of EW precision measurements

- the extraction of masses and couplings, at hadron colliders, relies on a template fit procedure

- the uncertainties/ambiguities that affect the evaluation of the templates are theoretical systematics on the final value of the pseudo-observables that we want to extract

- the use of different PDF replicas yields in general a distortion of the template shapes and in turn a different value of the pseudo-observable

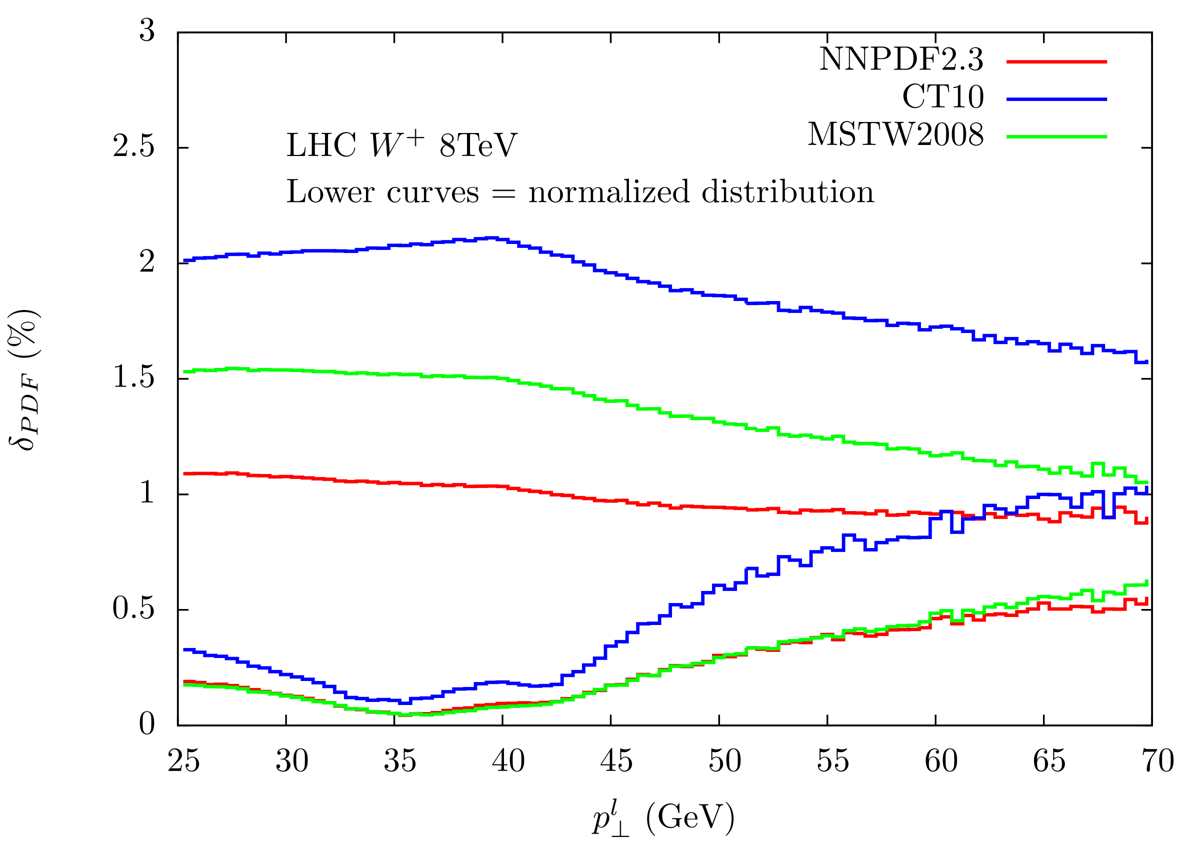
- are PDFs a limiting factor?

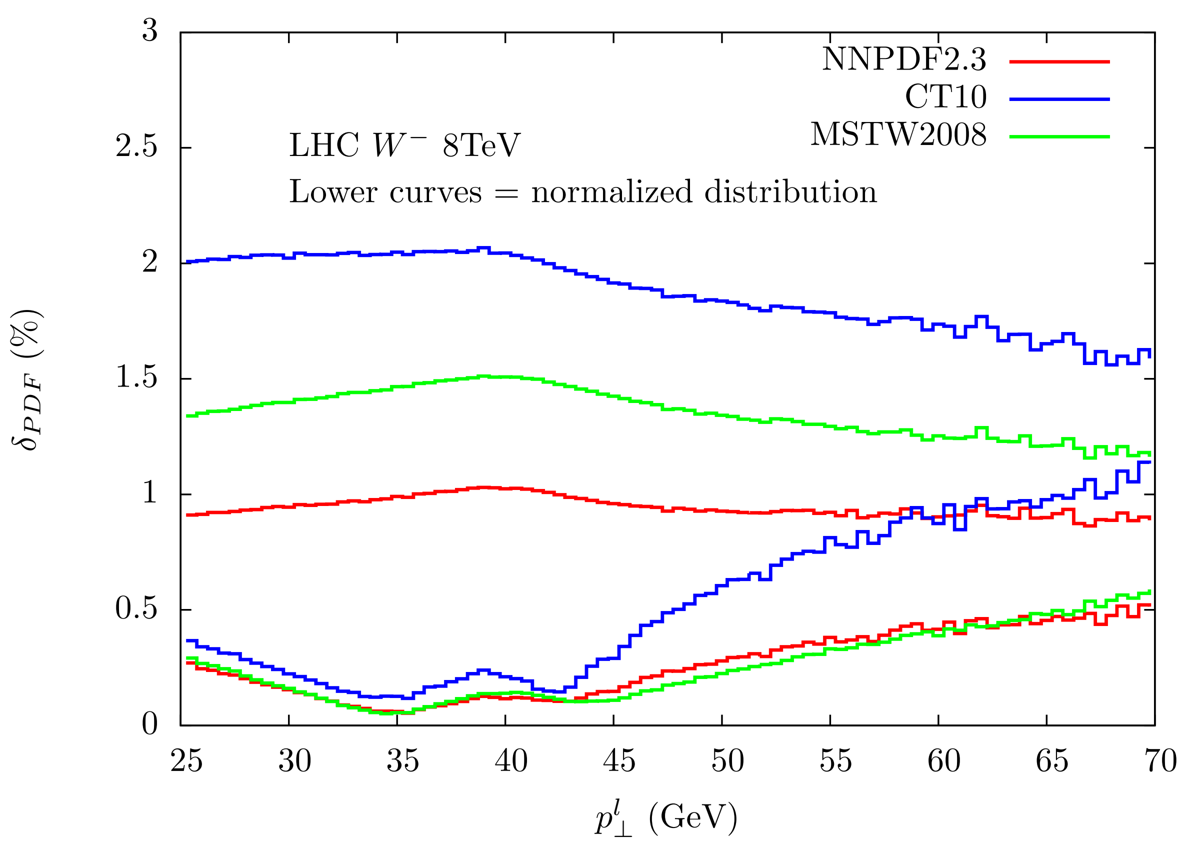
- can we use LHC data to improve the PDFs and to reduce their impact on precision measurements?
  → reweighting technique for a quick estimate of the role of new available data

- search for correlations (w.r.t. PDFs) between all the available EW observables
  → can we build ratios of observables with reduced PDF uncertainty
  still sensitive to the EW parameters?

Impact of PDF uncertainties on the lepton pt distribution

- PDF sets: CT10nlo, MSTW2008 (for comparison with previous studies), NNPDF2.3_nlo_0119
- simulation code: POWHEG + PYTHIA 6.4.21 (pure QCD, resummation effects via Parton Shower)
- Tevatron 1.96 TeV, LHC 8, 13, 33, 100 TeV
- acceptance cuts: ptl > 25 GeV, Et_miss > 25 GeV
  |eta_l| < 1.0 (Tevatron), |eta_l| < 2.5 (LHC)
- study of absolute and of normalized distributions





Impact of PDF uncertainties on MW from the lepton pt

- goals of the study: 1) estimate of the PDF uncertainty on MW of each set

  2) relative difference between the central predictions of the 3 PDF sets

- template distributions: generated with NNPDF2.3 (replica 0)
  with MW in the range [80.312, 80.470] GeV in 2 MeV steps

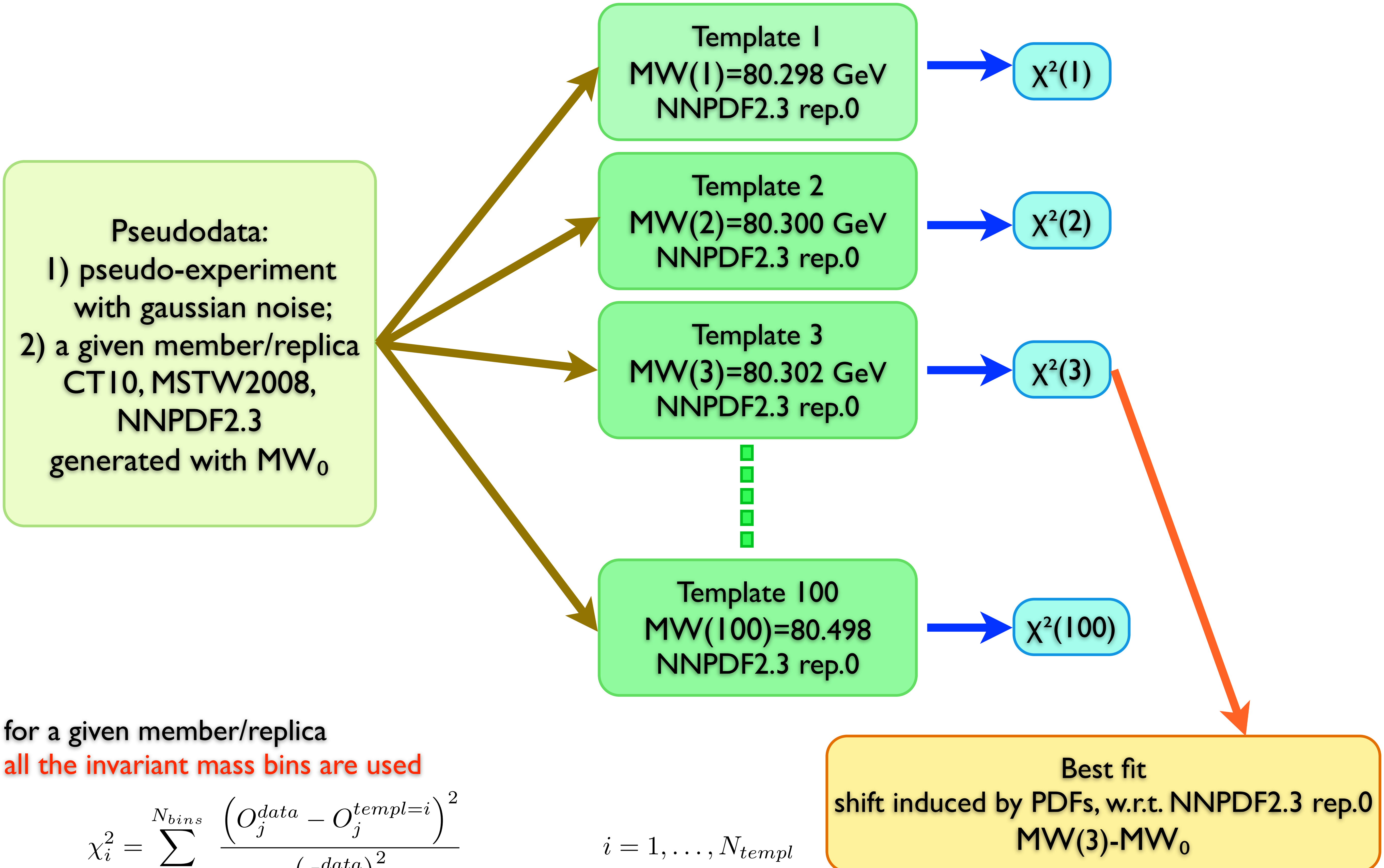
- pseudodata distributions: generated with the different sets/replicas with MW_0=80.398 GeV

- fit interval ptl $\in$ [29,49] GeV

- the template fitting procedure measures the relative distance
  between NNPDF2.3 replica 0 and all the other sets/replicas
  i.e. it is an estimate of the difference that we would find
  if we would fit the real data with different PDFs

The template-fitting procedure

see also Bozzi, Rojo, Vicini, Phys.Rev.D83 (2011) 113008

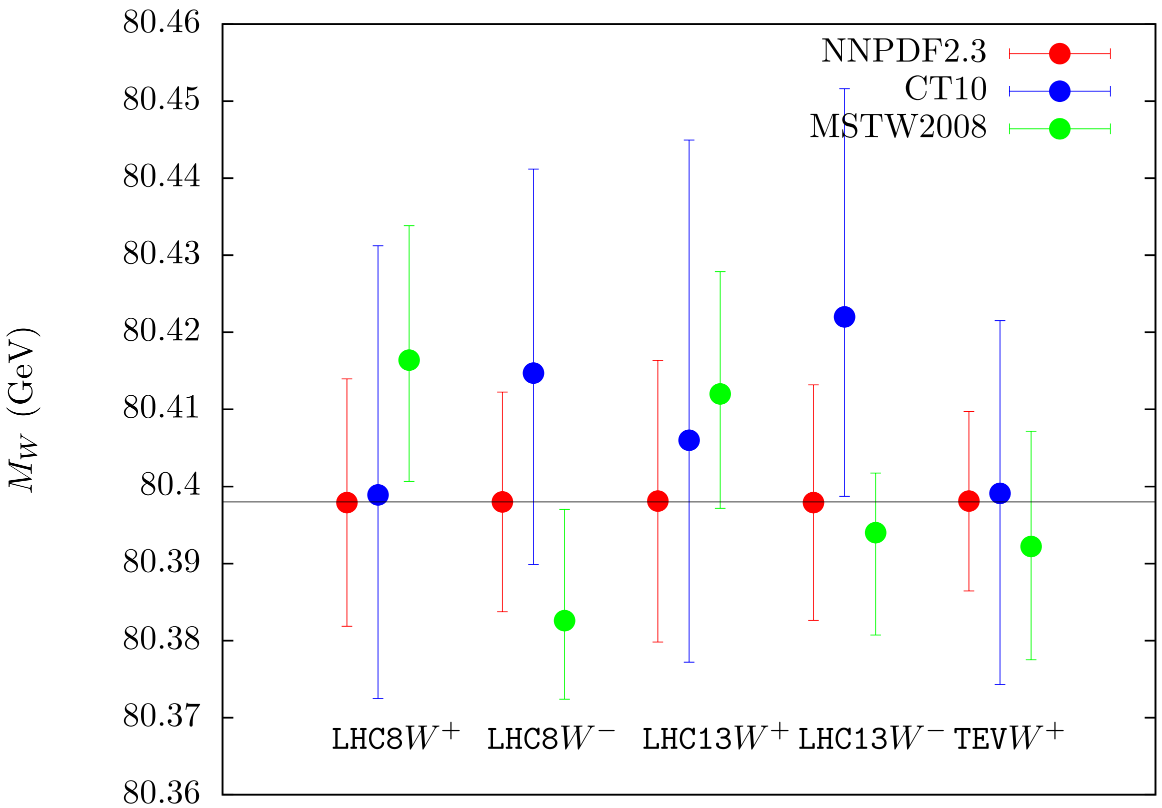


for a given member/replica
all the invariant mass bins are used

$$\chi_i^2 = \sum_{j=1}^{N_{bins}} \frac{\left(O_j^{data} - O_j^{templ=i}\right)^2}{\left(\sigma_j^{data}\right)^2} \qquad i = 1, \ldots, N_{templ}$$

Numerical results: preliminary estimates

normalized distributions			
collider/channel	CT10	MSTW2008	NNPDF2.3
Tevatron, W^+	$80.400 + 0.022 - 0.025$	$80.392 + 0.015 - 0.015$	80.398 ± 0.012
LHC 8 TeV, W^+	$80.398 + 0.032 - 0.026$	$80.416 + 0.017 - 0.016$	80.398 ± 0.016
W^-	$80.416 + 0.026 - 0.025$	$80.383 + 0.014 - 0.010$	80.398 ± 0.014
LHC 13 TeV, W^+	$80.406 + 0.039 - 0.029$	$80.412 + 0.016 - 0.015$	80.398 ± 0.018
W^-	$80.422 + 0.030 - 0.023$	$80.394 + 0.008 - 0.013$	80.398 ± 0.015

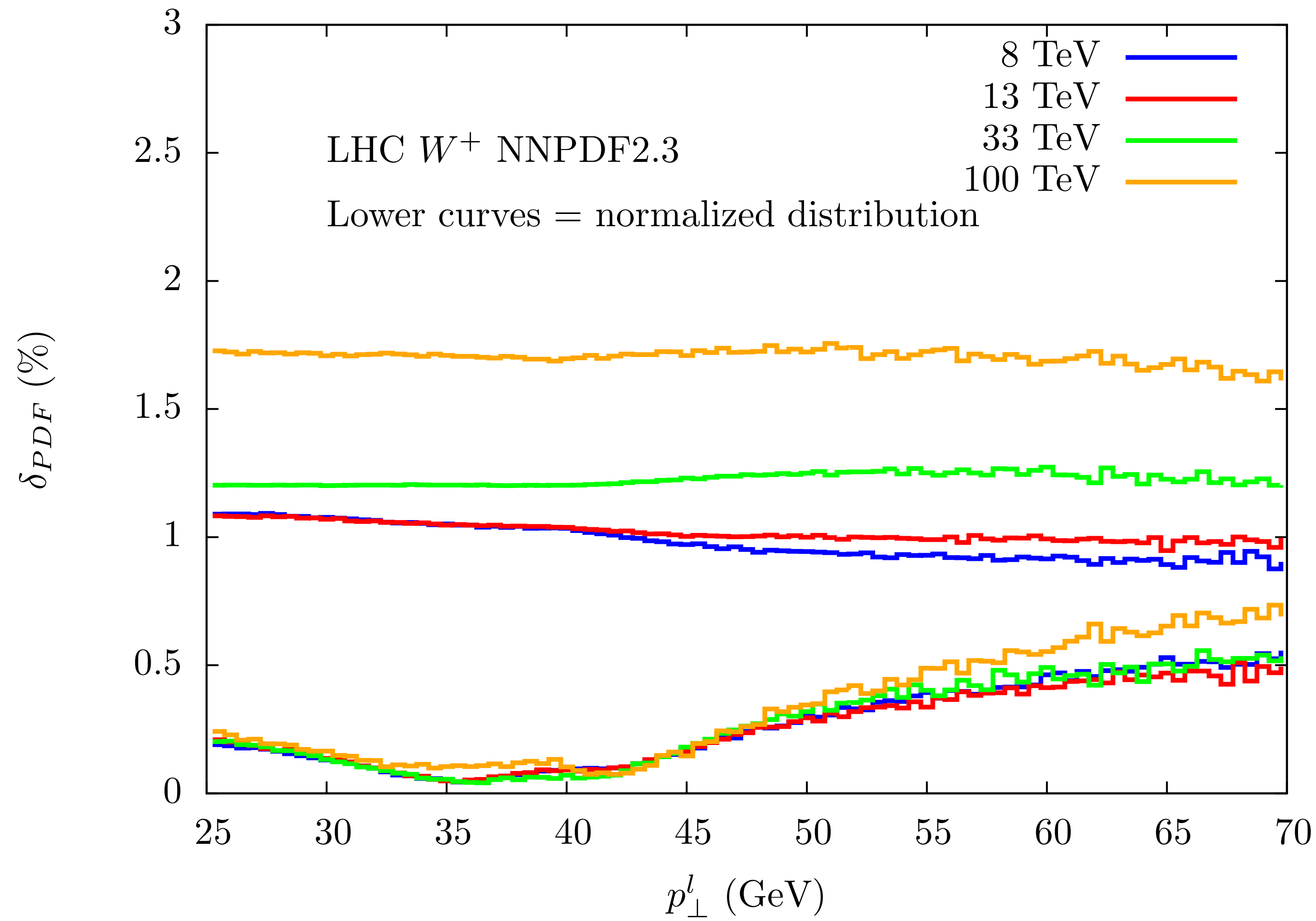


- the uncertainty bands of the 3 sets are roughly similar; CT10nlo has in general larger uncertainties (C90 factor has been included!)
- spread of the central values Δ_{sets} evident in the W- case and growing with the energy
- the old MSTW2008 set suffers of known problems with up and down densities, evident in the central values predictions (runs with MSTW2008deut are in progress)

	δ_{PDF} (MeV)	Δ_{sets} (MeV)
Tevatron 1.96 TeV	23	8
LHC 8 TeV W^+	31	18
W^-	35	33
LHC 13 TeV W^+	34	14
W^-	36	28

- combination of the three sets of results according to the PDF4LHC recipe (envelope) δ_{PDF} is the half-width of the envelope
- Tevatron results larger than in the literature

Numerical results: estrapolation at future collider energies



fit interval [29,49] GeV

normalized distributions				
	8 TeV	13 TeV	33 TeV	100 TeV
W^+	80.398 ± 0.016	80.398 ± 0.018	80.398 ± 0.021	80.398 ± 0.028
W^-	80.398 ± 0.014	80.398 ± 0.015	80.398 ± 0.018	80.398 ± 0.026

- resonant W production occurs at partonic-*x* values decreasing with the energy
- with higher collider energies the PDF error on the normalized distribution almost does not change

Anatomy of the lepton pt distribution (w.r.t. PDF contributions)

$$\mathcal{P}_{ij}(x,\tau) = f_i(x,\mu_F^2) f_j(\frac{\tau}{x},\mu_F^2) + f_j(x,\mu_F^2) f_i(\frac{\tau}{x},\mu_F^2)$$

$$\tau = \frac{M_W^2}{S}, \quad p_\perp^l = 40.5\,\mathrm{GeV}$$

$$\rho(x,\tau) = \frac{\langle \mathcal{P}_{ij}(x,\tau) \frac{d\sigma}{dp_\perp^l} \rangle - \langle \mathcal{P}_{ij}(x,\tau) \rangle \langle \frac{d\sigma}{dp_\perp^l} \rangle}{\sigma_{\mathcal{P}_{ij}}^{PDF} \sigma_{d\sigma/dp_\perp^l}^{PDF}}$$

- correlation w.r.t. PDF (NNPDF2.3) of the parton-parton luminosity with the lepton pt distr.

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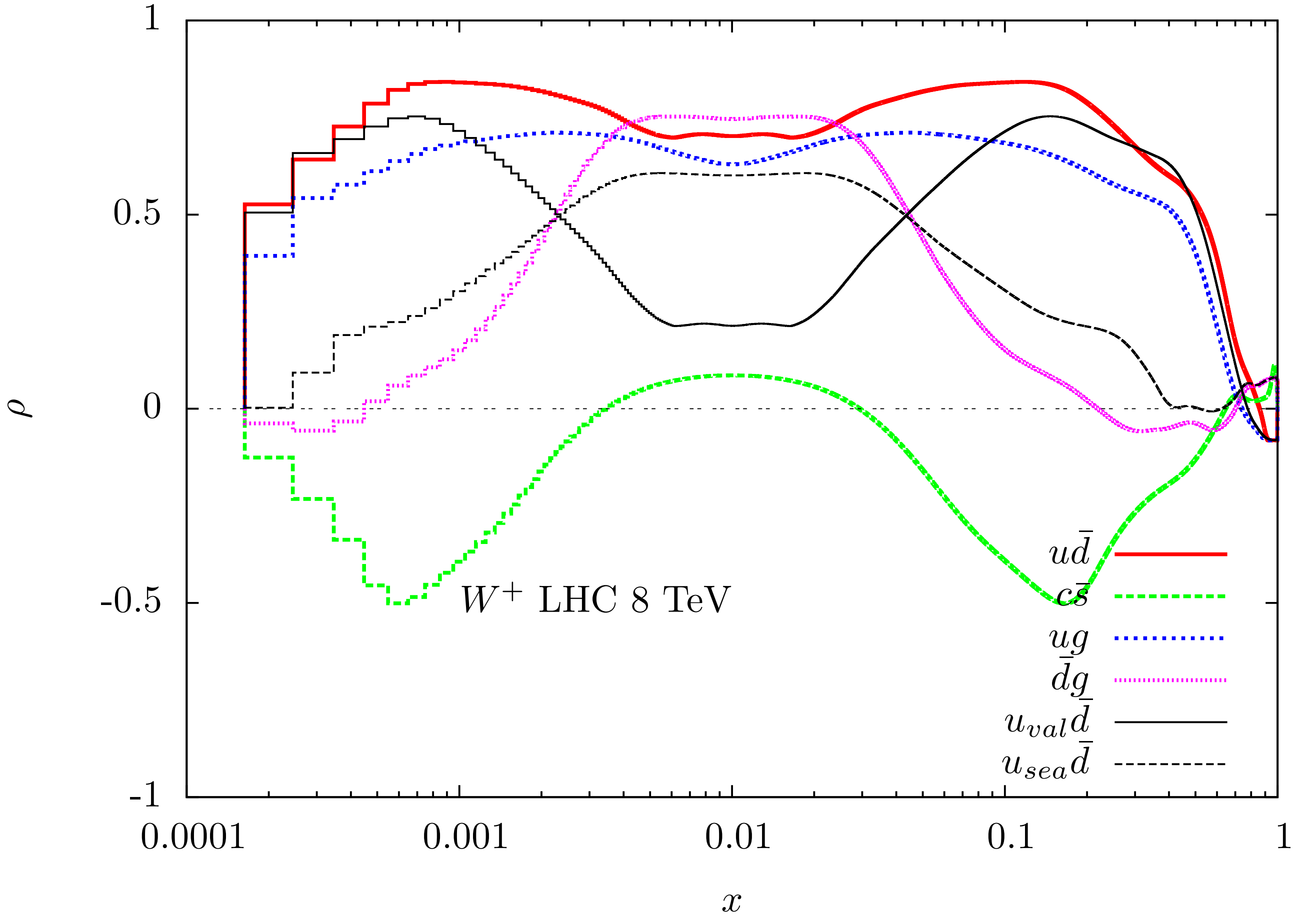

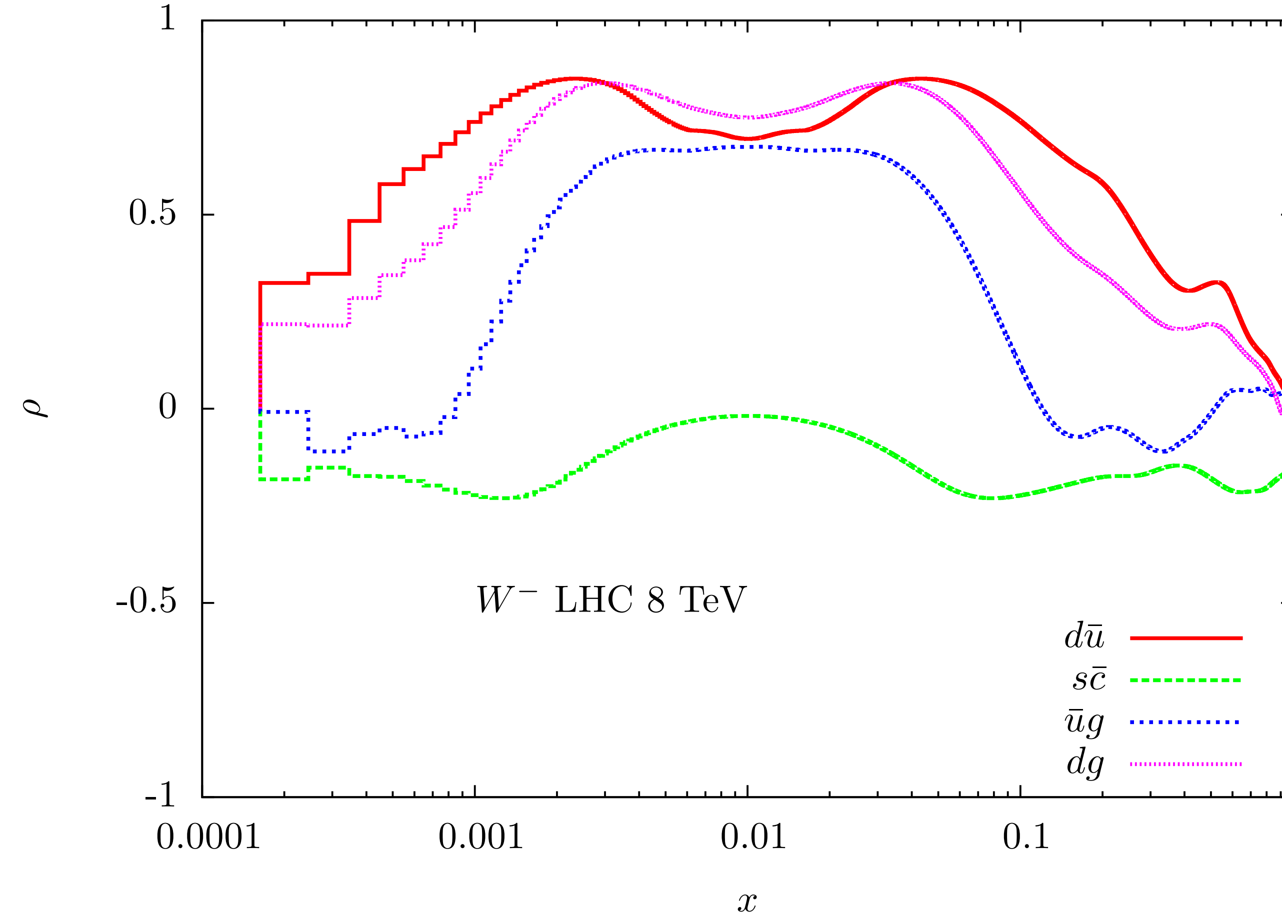

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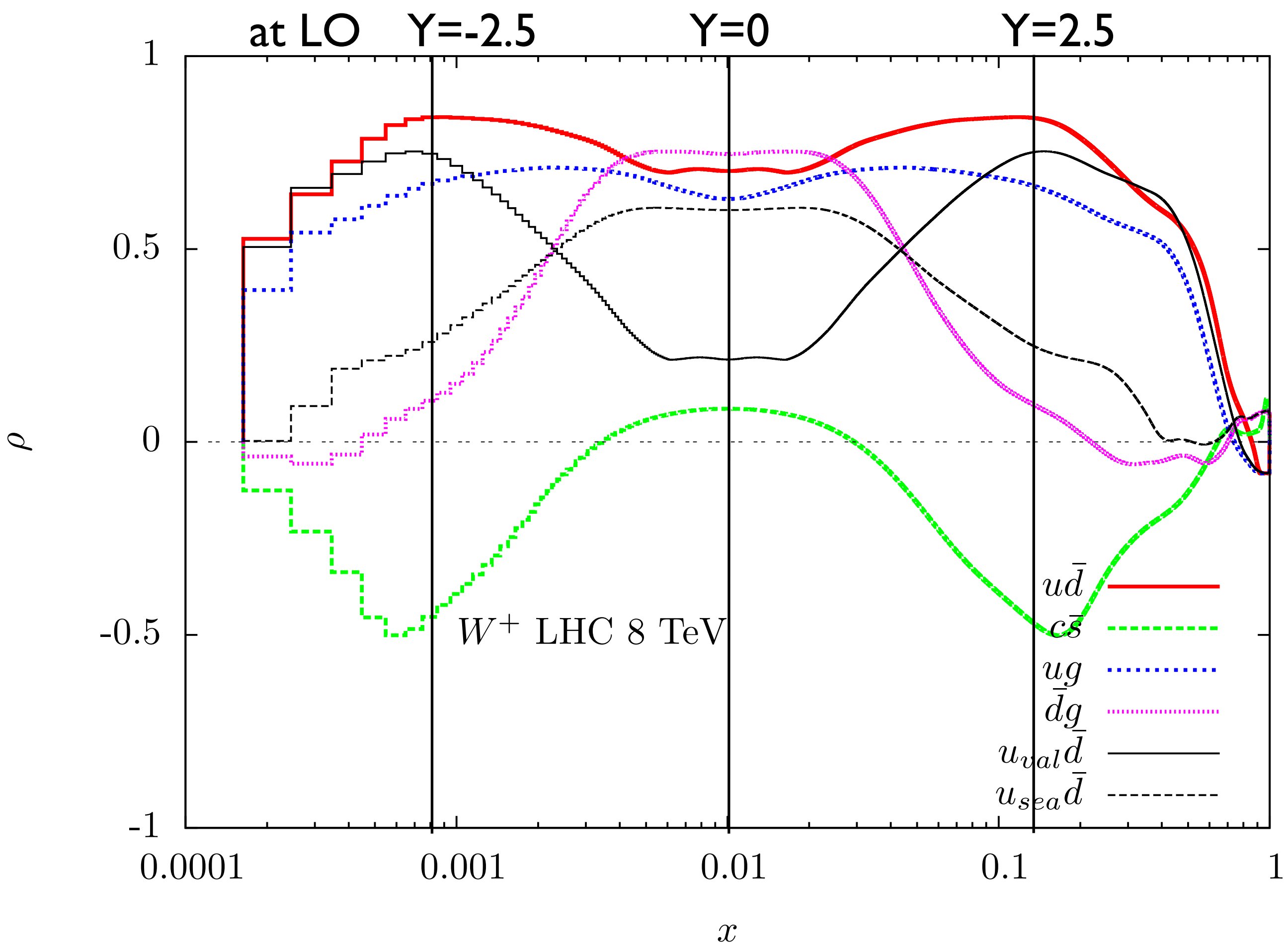

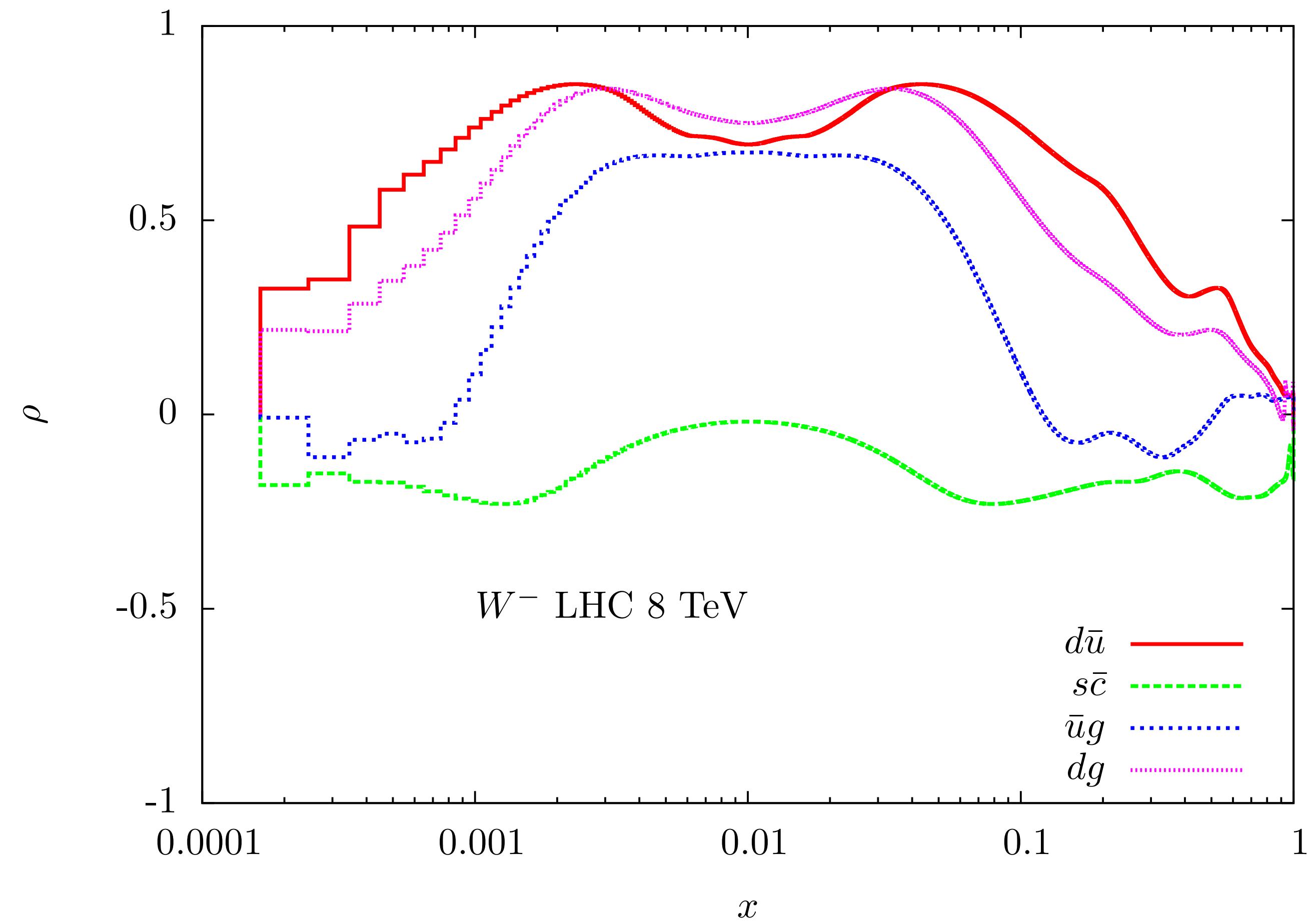

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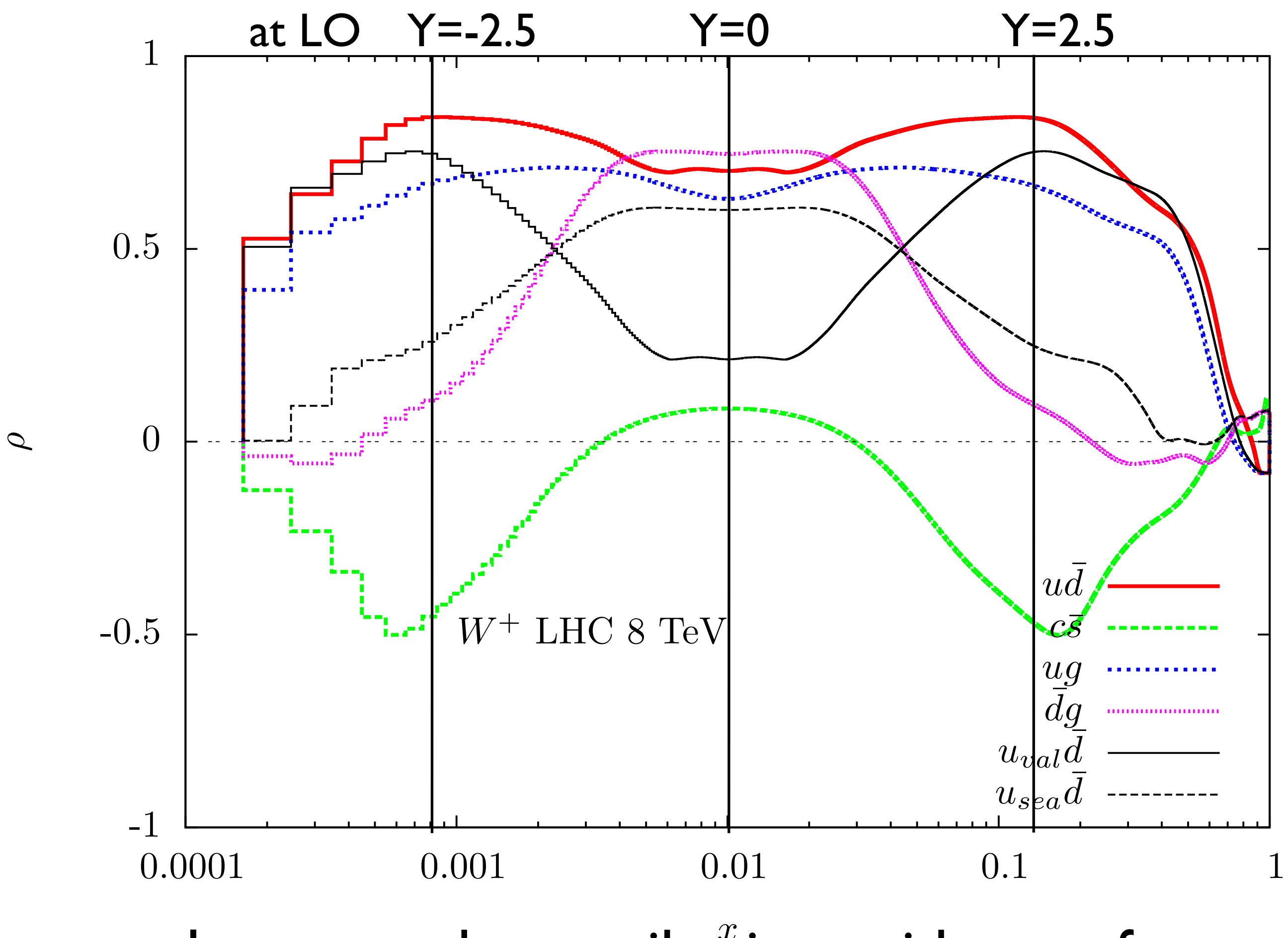
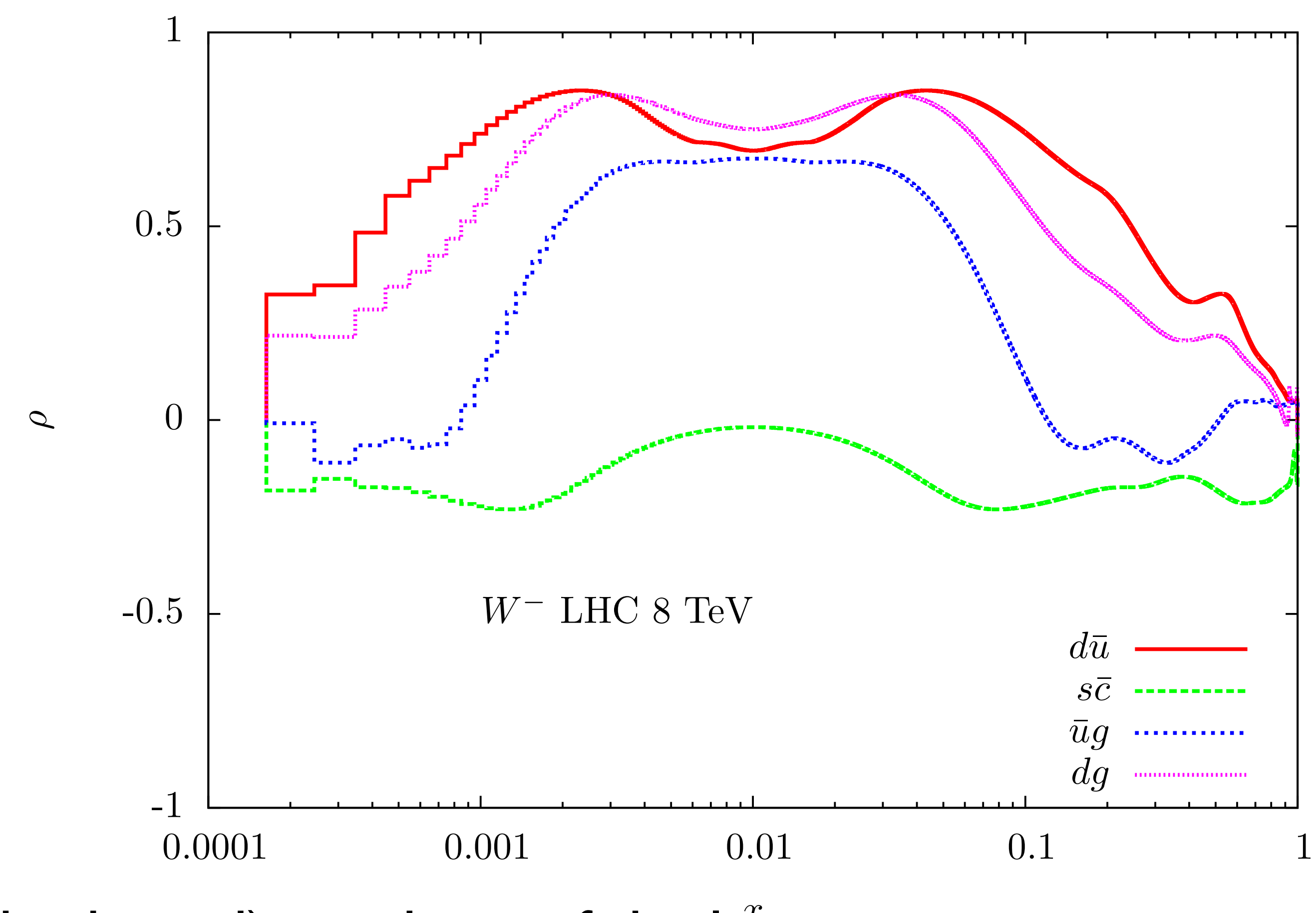




- valence-quark contribution evident at forward (backward) rapidities of the lepton pair

  sea-quark contribution peaked at central rapidities

  anticorrelation between the c-sbar (s-cbar) luminosity and the ptl distribution

  analogous, but not identical, behavior of W+ and W-

Conclusions

- results of a preliminary exercise to estimate the PDF uncertainty on MW from the lepton pt distribution in CC-DY

- stable numerical simulation of the lepton transverse momentum distribution in CC-DY with control of physical effects at the per mill level

- comparison of MSTW2008, CT10nlo, NNPDF2.3 predictions and study of the impact on MW (in progress MSTW2008deut and NNPDF3.0)

- template fit approach to study 1) the PDF error on MW of each set
  2) the spread of the MW central values

- at the LHC 8 TeV the PDF uncertainty of a single set ranges from 16 (12) to 29 (25) MeV for W+(W-)
  central NNPDF2.3 and CT10nlo values differ by 0 (18) MeV for W+(W-)

  the "low" sensitivity to MW enhances the impact of any per mill effect

- more investigation is needed to verify these results

- the role of up and down quarks seems crucial (cfr. correlation plots)
  possible interplay with other DY observables sensitive to the same densities

back-up

Reweighting

- MC fluctuations at the per mill level are still present also in simulations with 1 billion of events when bin sizes have to be small

- the estimate of PDF uncertainty on MW requires to appreciate the difference of the value of the distribution in each bin
  → the use of fully correlated distributions reduces the sensitivity to MC fluctuations

- the weights for different templates/replicas have been generated in one single simulation

$$w_0 \quad \to \quad w_j = w_0 \frac{(\hat{s} - m_{W0}^2)^2 + \Gamma_W^2 m_{W0}^2}{(\hat{s} - m_{W,j}^2)^2 + \Gamma_W^2 m_{W,j}^2} \qquad \text{template} \quad j$$

$$w_0 \quad \to \quad w_i = w_0 \frac{f_i(x_1) g_i(x_2)}{f_0^{NNPDF}(x_1) g_0^{NNPDF}(x_2)} \qquad \text{replica} \quad i$$

Checks

- in Bozzi, Rojo, Vicini, Phys.Rev.D83 (2011) 113008
  we studied the PDF impact on MW extracted from the lepton-pair transverse mass distribution
  using DYNNLO with NLO-QCD accuracy

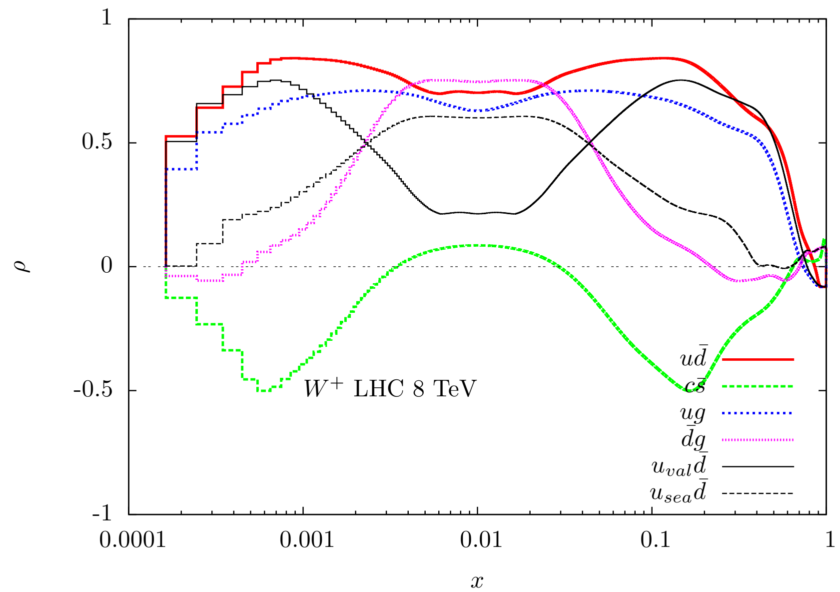
  a fixed-order simulation is sufficient to describe the MT but not the ptl distributions

- we reproduce with POWHEG+PYTHIA the DYNNLO results for MT
  but now we can also study the ptl distribution

normalized distributions, CTEQ6.6, Tevatron 1.96 TeV	
code, observable	prediction
DYNNLO, $M_\perp$	80.398 + 0.004 - 0.004
POWHEG+PYTHIA, $M_\perp$	80.398 + 0.001 - 0.003
POWHEG+PYTHIA, $p_\perp^l$	80.394 + 0.019 - 0.019

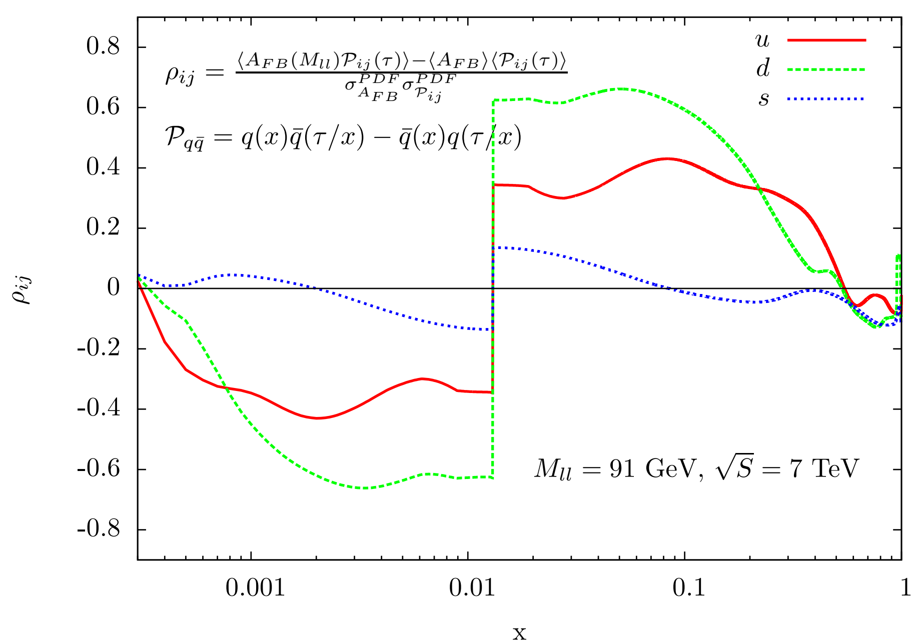
- the generator-level different sensitivity to MW partially explains that
  small PDF differences have a more pronounced effect in the ptl case

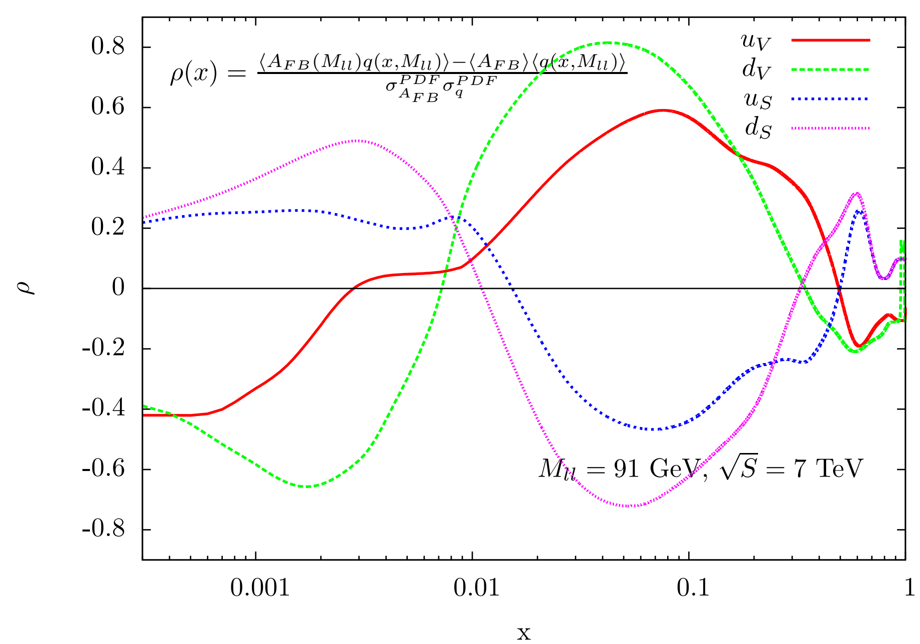
Correlation between different observables



- CC-DY
  (lepton pt, qqbar lumi)

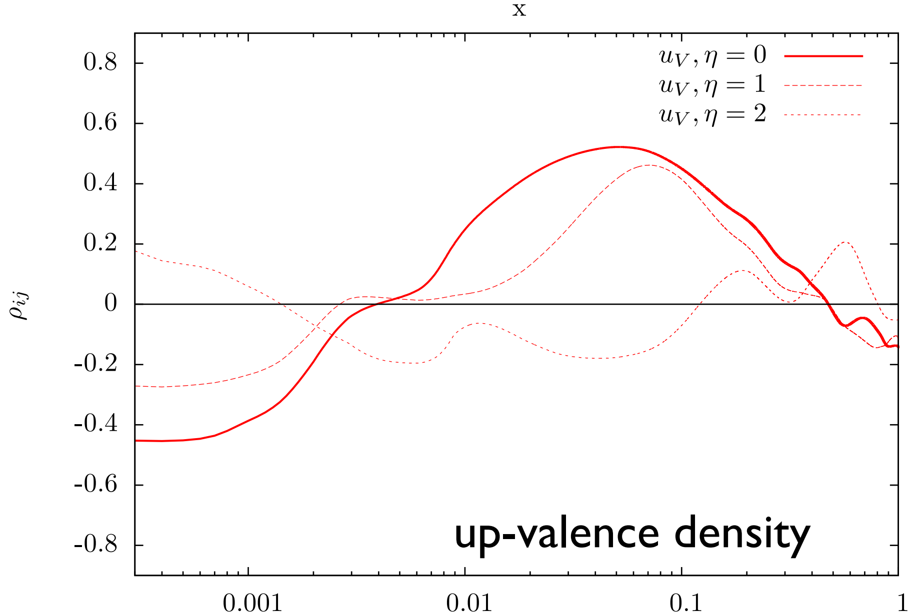
direct comparison with lepton pt distribution not possible because of different collider energy

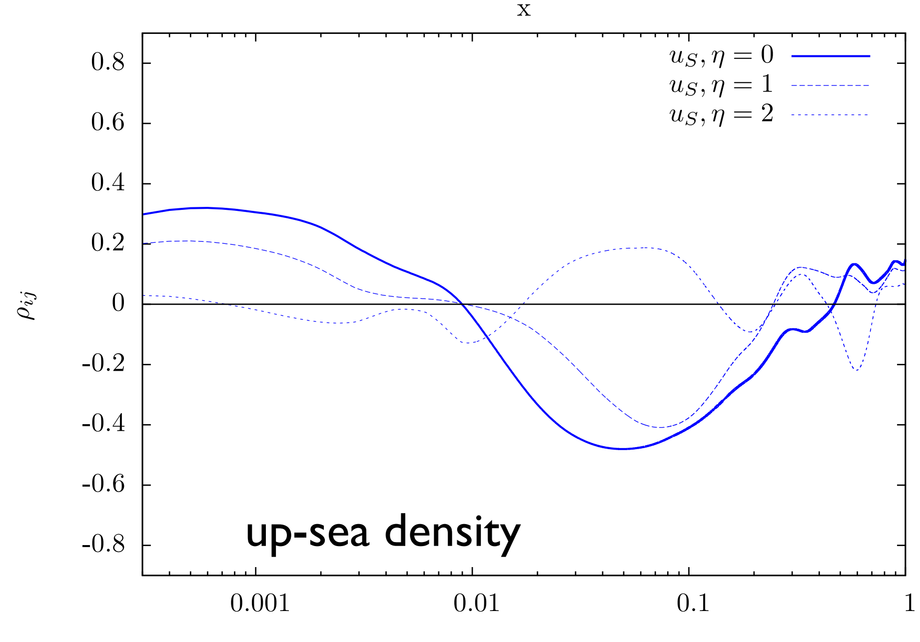




- NC-DY
  (AFB, diff qqbar lumi)

  NC-DY
  (AFB, single parton density)





- CC-DY
  (lepton charge asymmetry, single parton density)