(Towards a quantitative study of) Flavour effects on the determination of M_W

giuseppe bozzi

in collaboration with
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European Research Council
UNIVERSITÀ DI PAVIA

The *W* mass

ATLAS, EPJC 78, 110 (2018)

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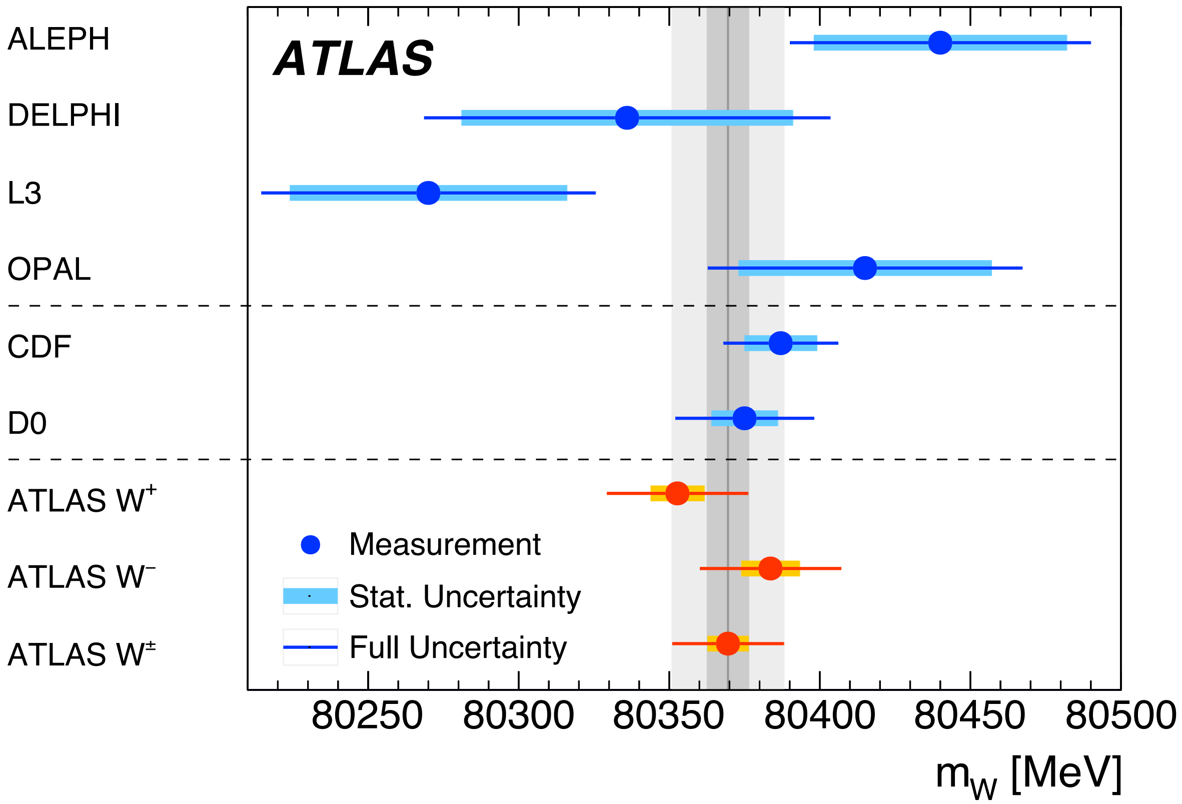

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$$m_W = 80370 \pm 19 \text{ MeV}$$

(7 stat, 11 exp, 14 th)

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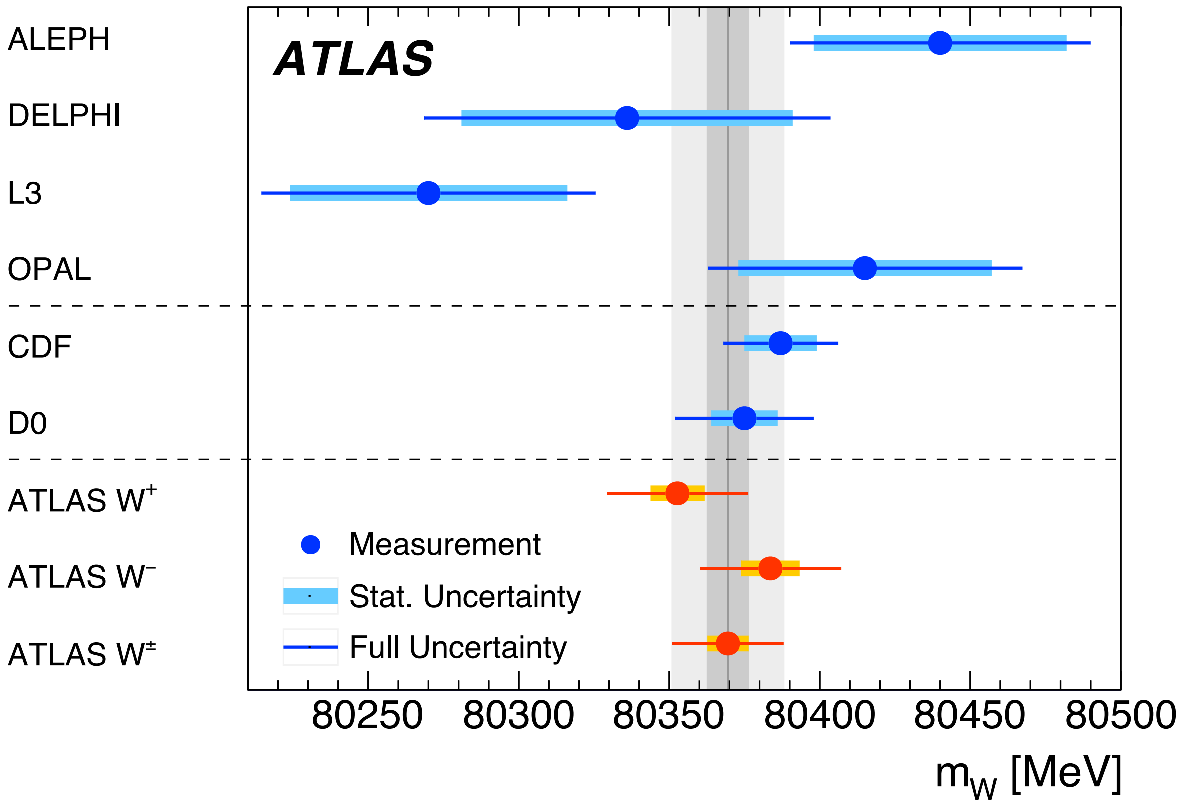

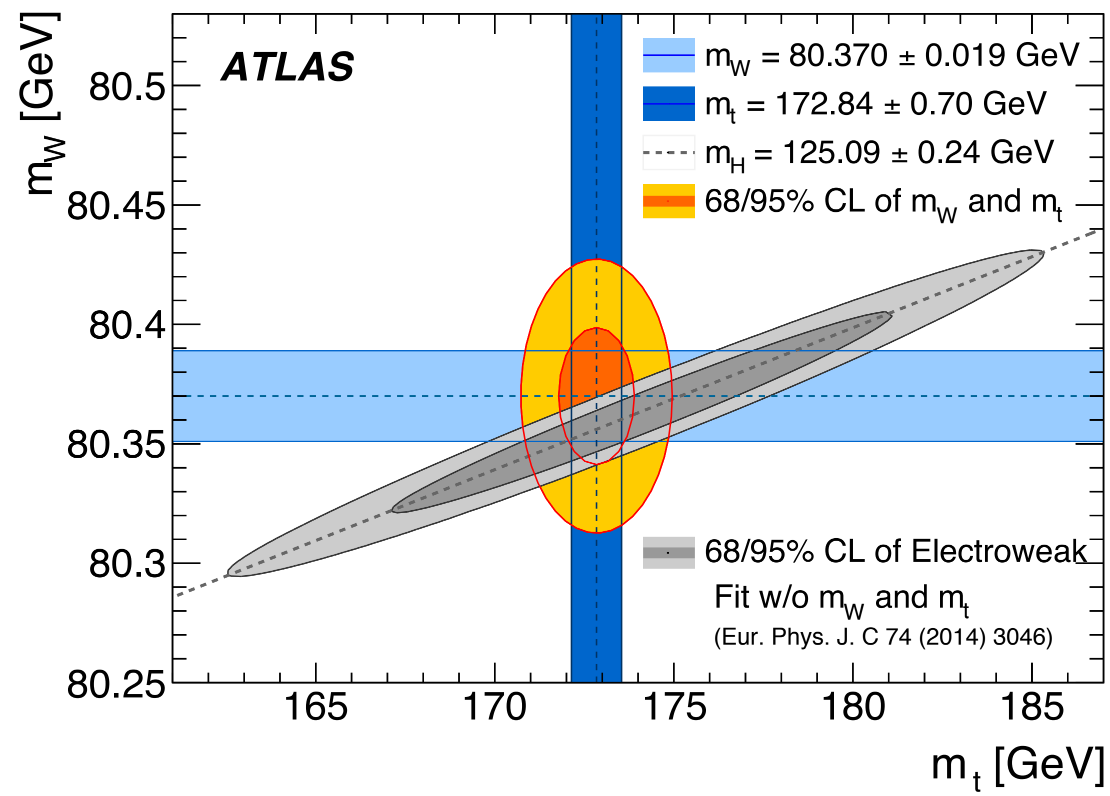

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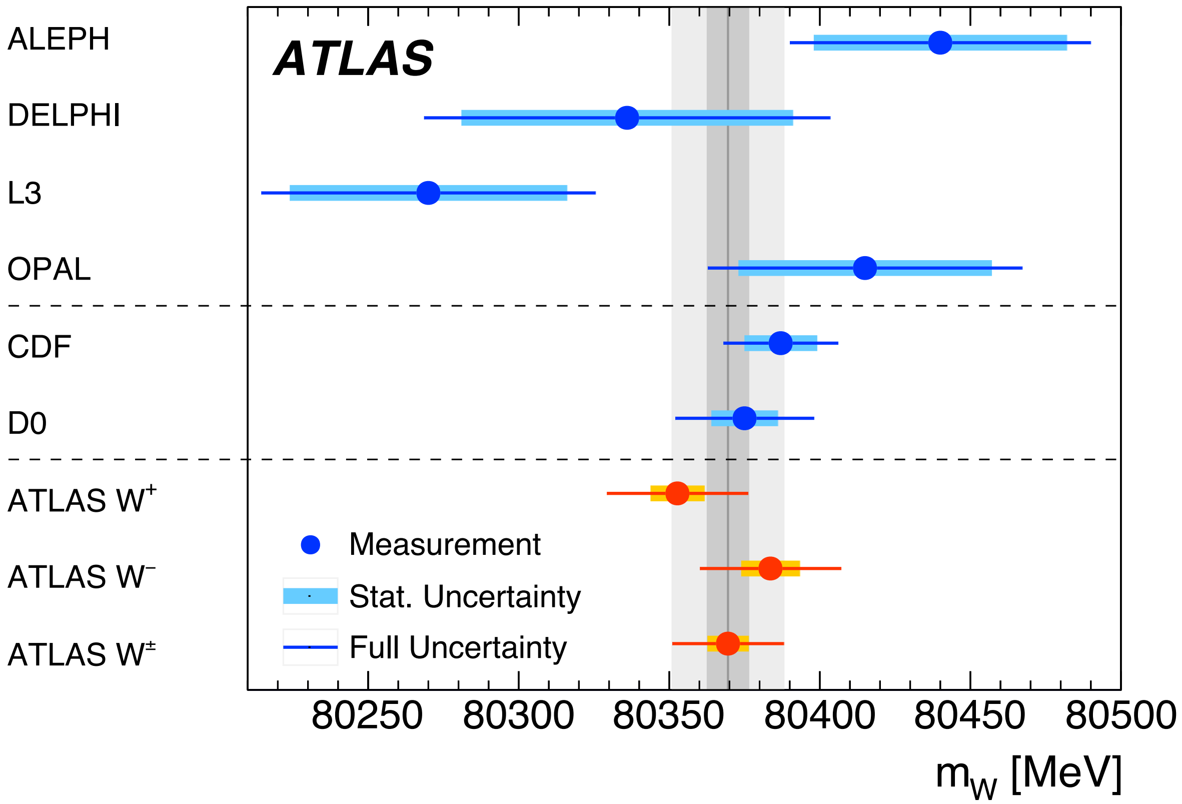

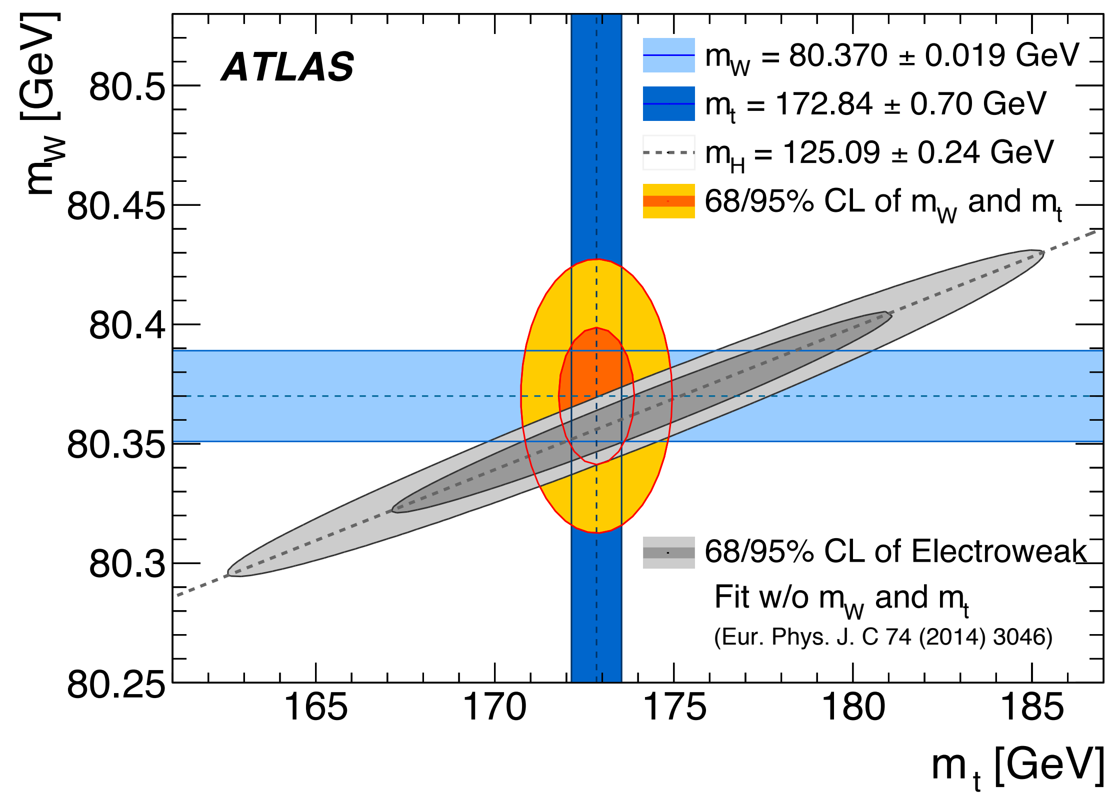

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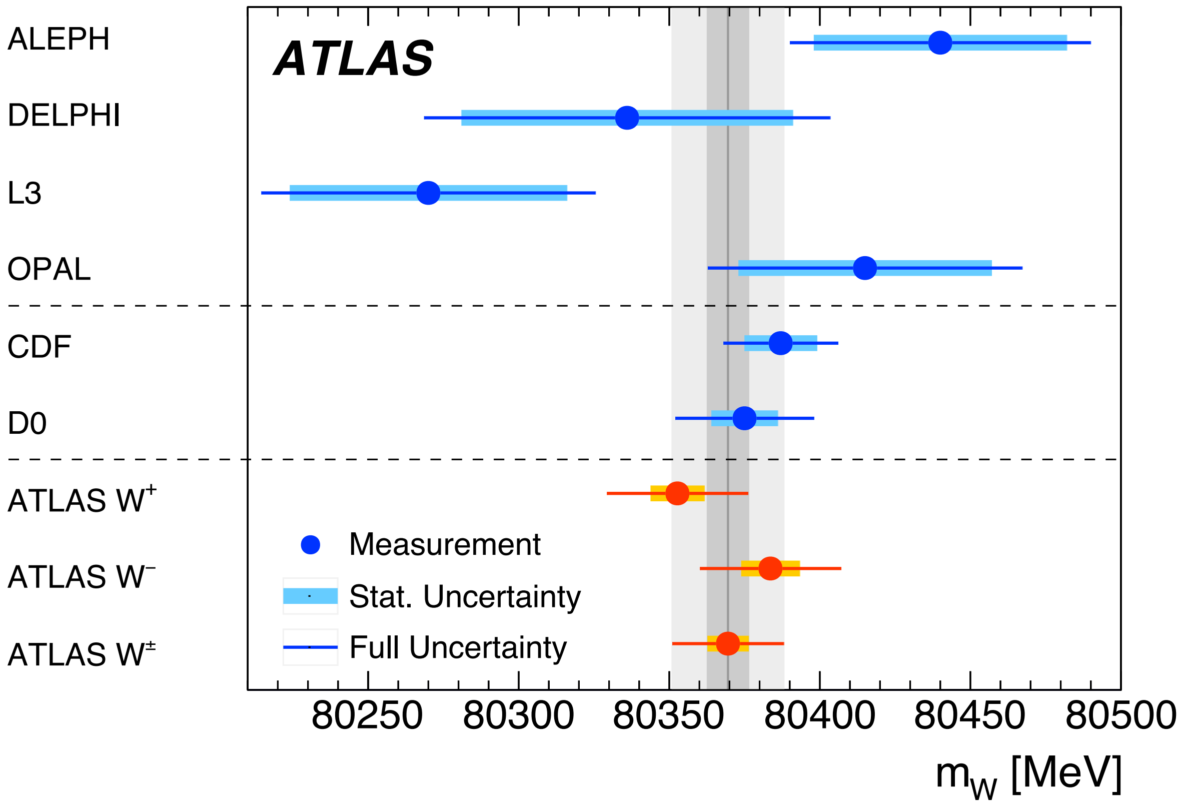

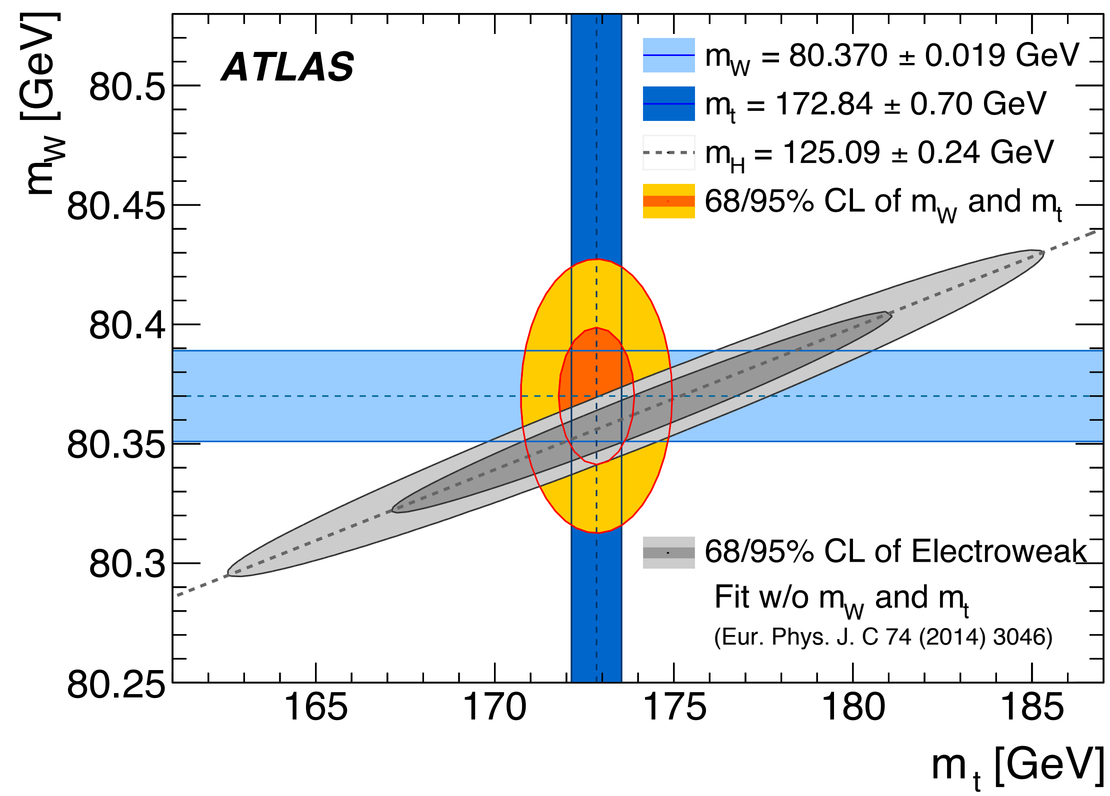

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- accessible via counting experiments: cross sections and asymmetries

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- require a model to be properly defined
  - M_Z at LEP as pole of the Breit-Wigner resonance factor
  - M_W at hadron colliders as fitting parameter of a *template fit* procedure

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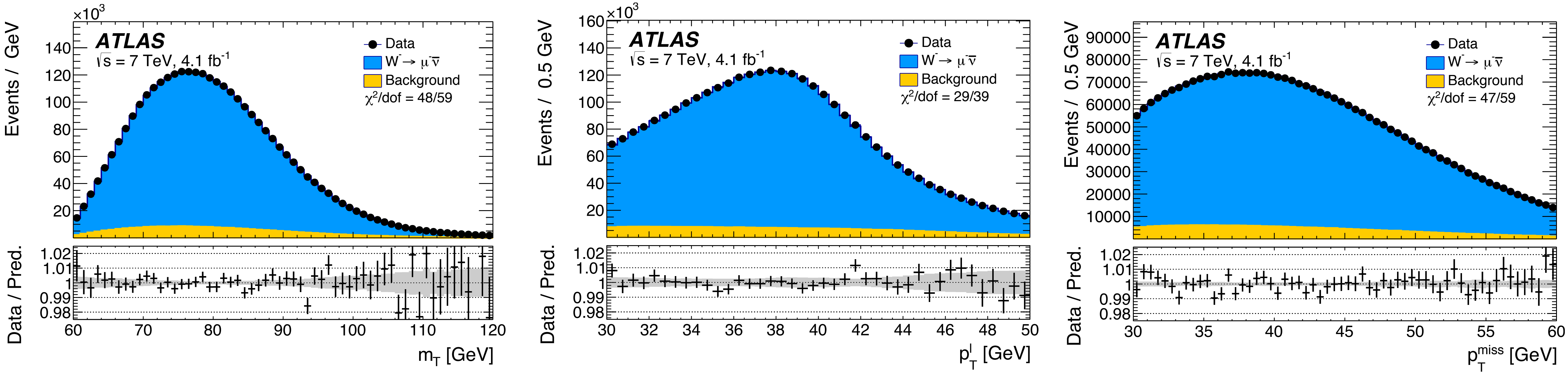
➡ the result of the fit depends on the hypotheses used to compute the templates (PDFs, scales, non-perturbative, different prescriptions, …)

➡ these hypotheses should be treated as theoretical systematic errors

Observables and techniques



M_W extracted from the study of the shape of m_T, p_{Tl}, p_{Tmiss}

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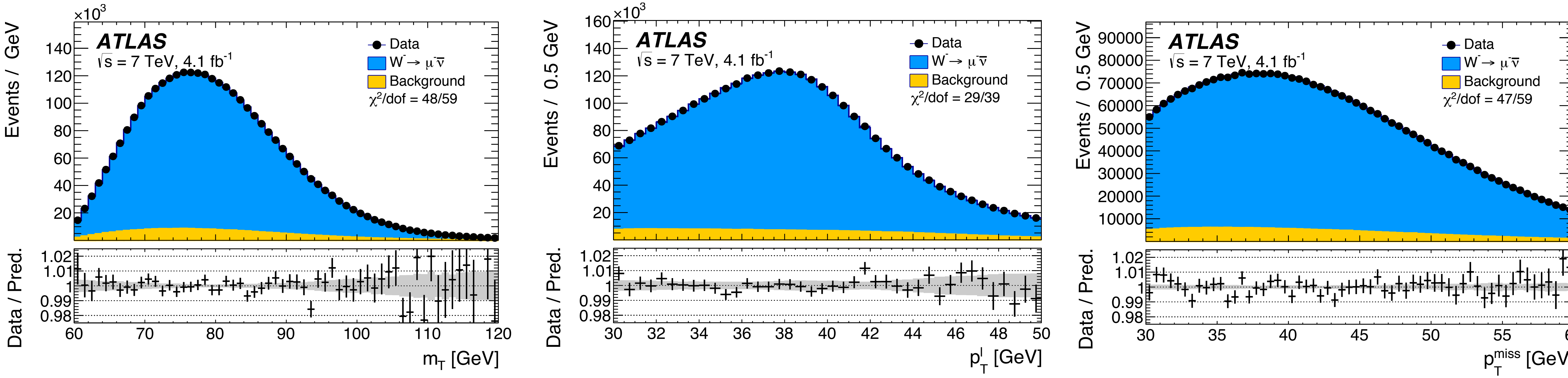

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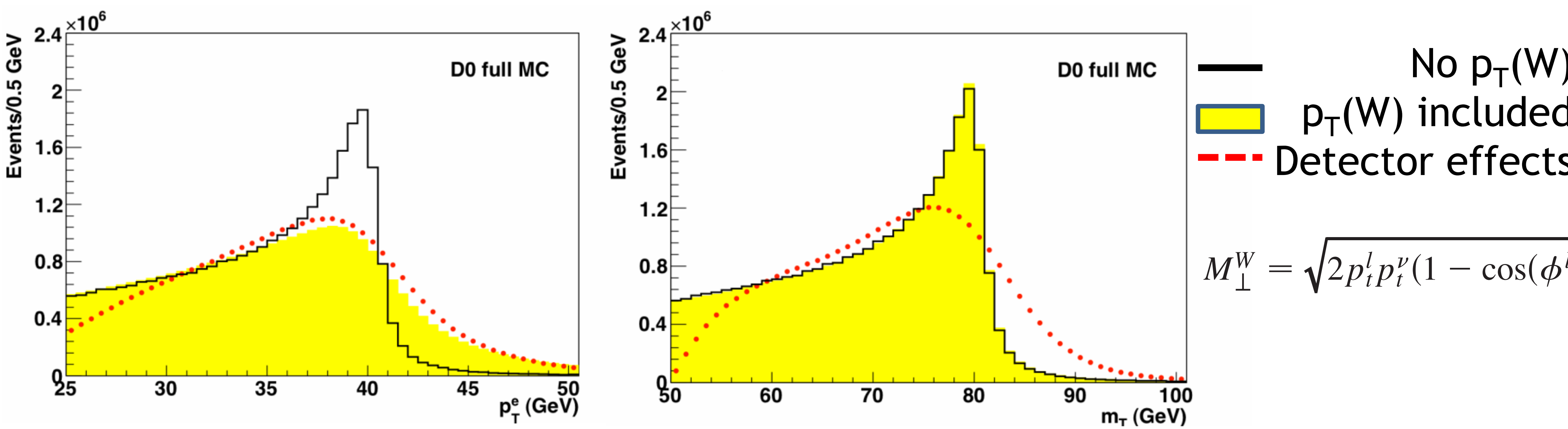

$$M_{\perp}^{W} = \sqrt{2p_t^l p_t^{\nu}(1 - \cos(\phi^l - \phi^{\nu}))},$$

Transverse mass: important detector smearing effects, weakly sensitive to p_{TW} modelling

Lepton p_T: moderate detector smearing effects, extremely sensitive to p_{TW} modelling

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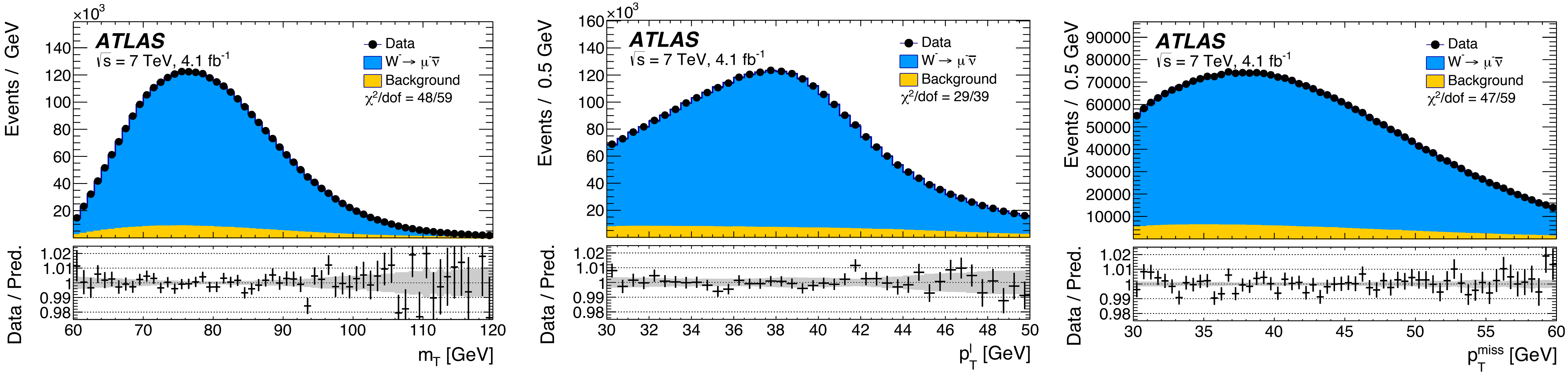

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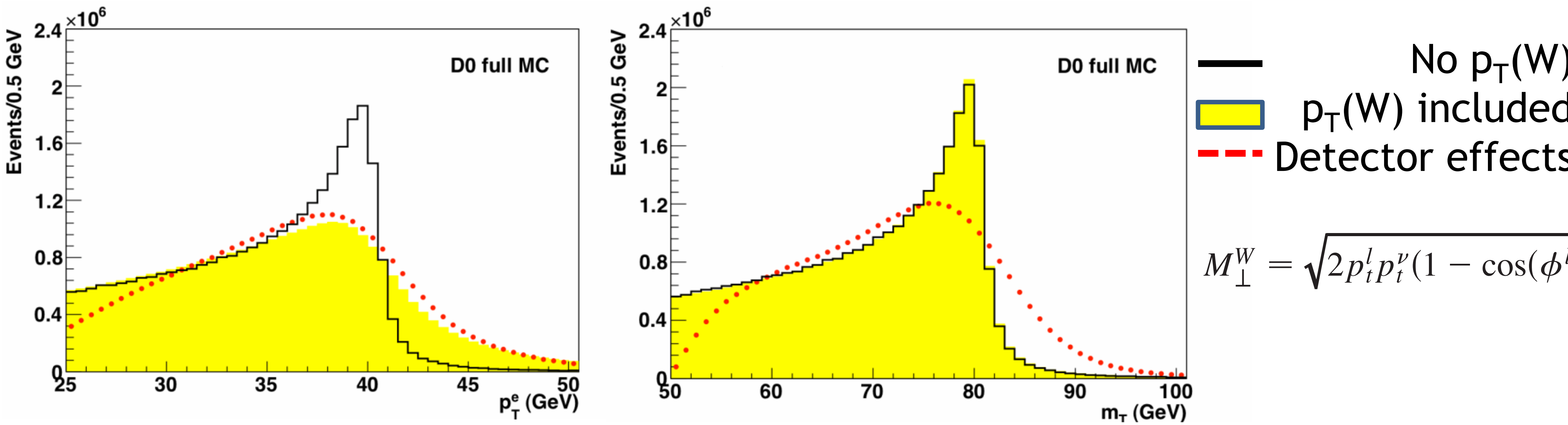

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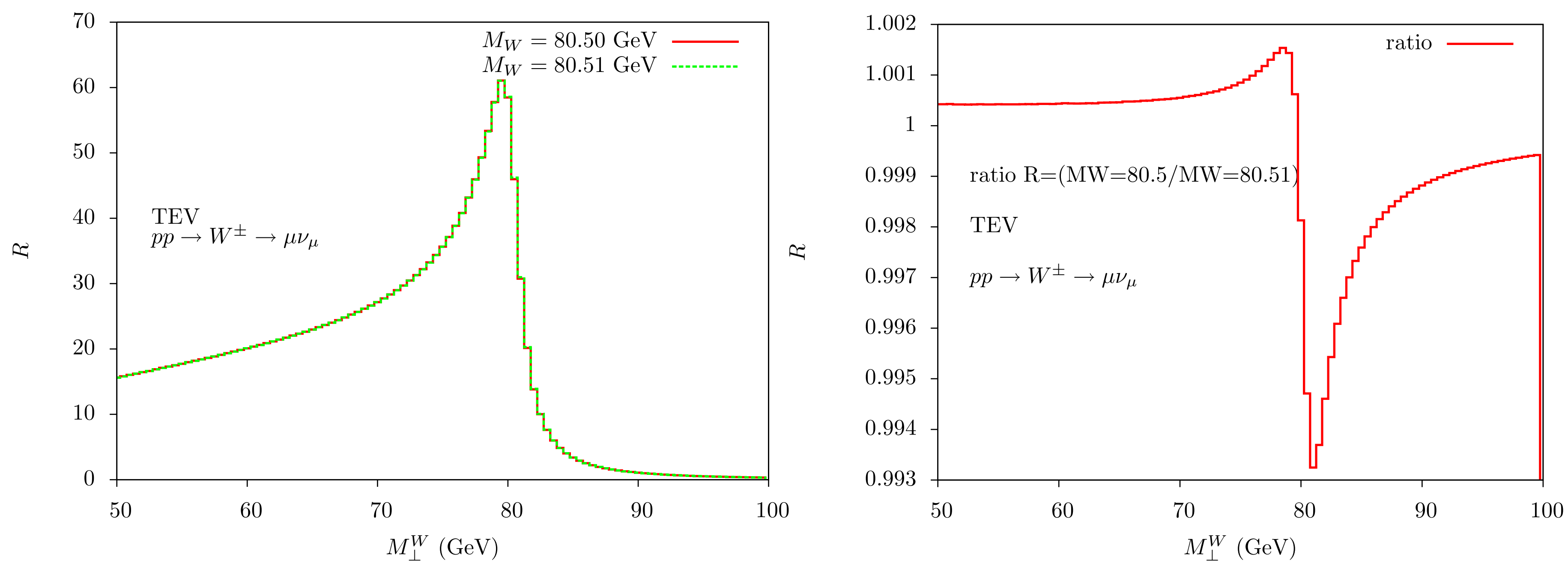
Lepton p_T: moderate detector smearing effects, extremely sensitive to p_{TW} modelling

p_{TW} modelling depends on flavour and all-order treatment of QCD corrections

Observables and techniques

Challenging shape measurement: a distortion at the few per mille level of the distributions yields a shift of O(10 MeV) of the M_W value

m_T



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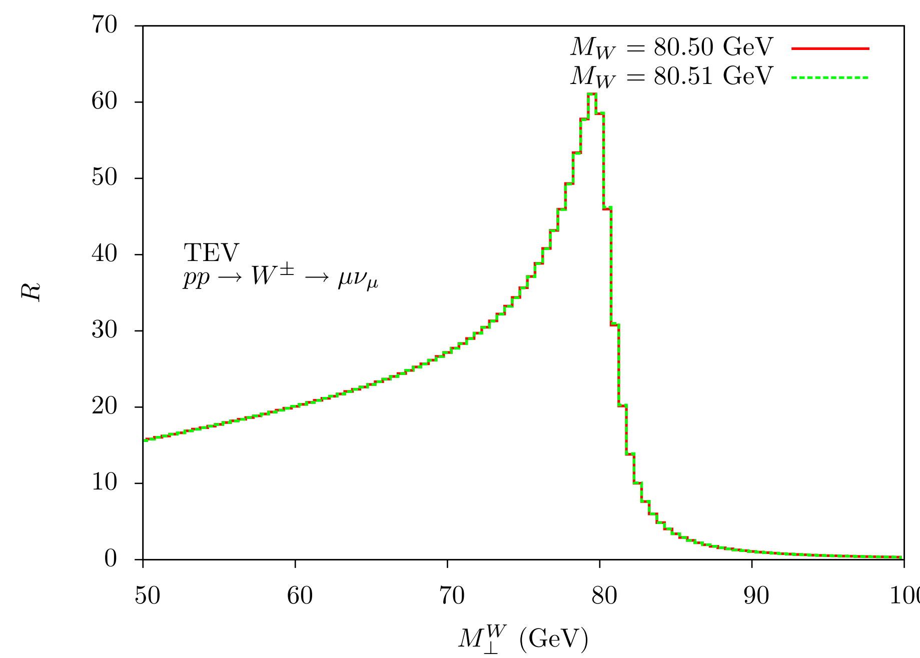
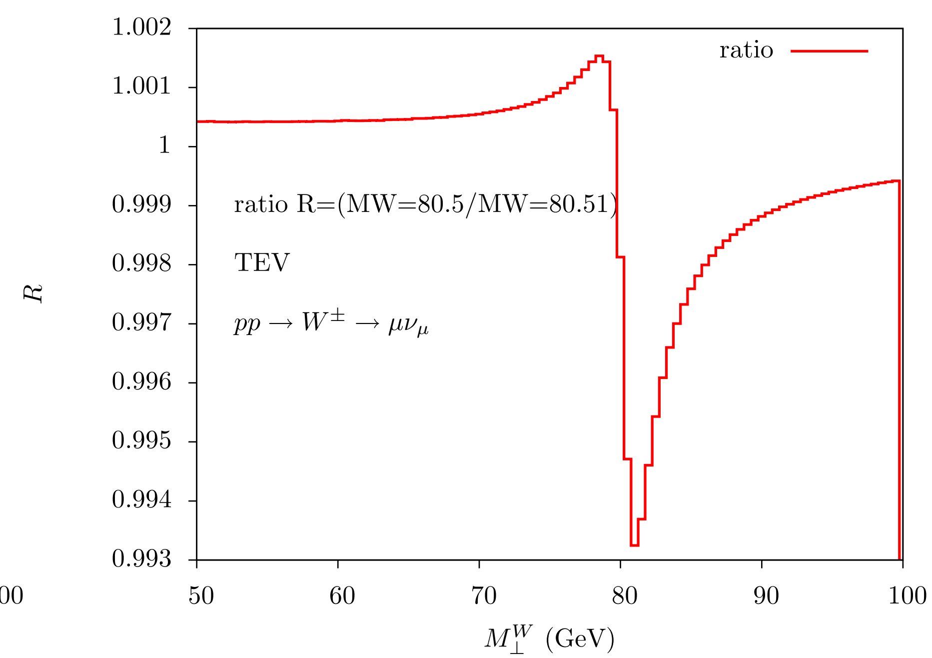
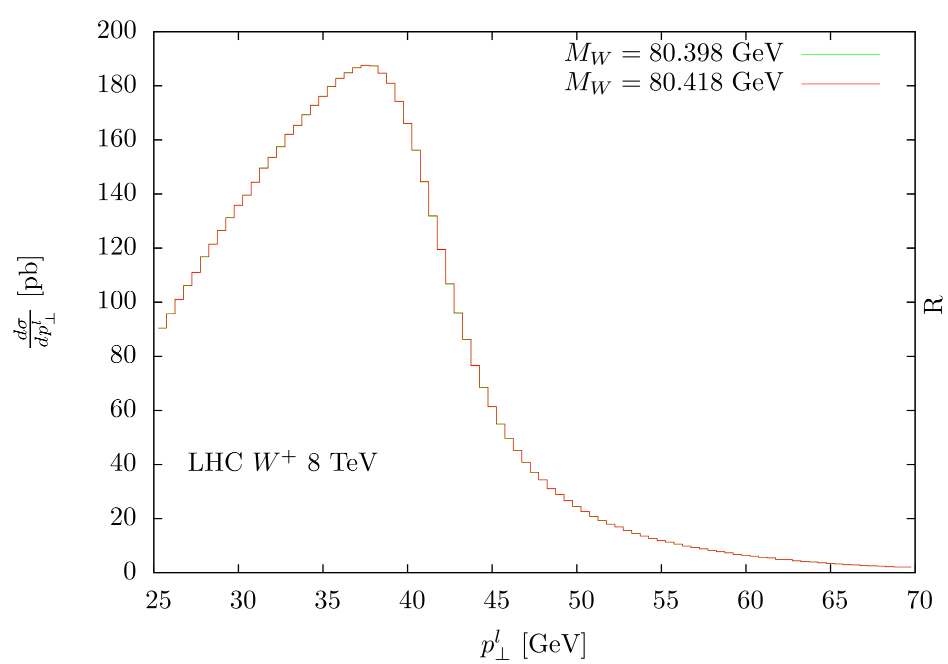
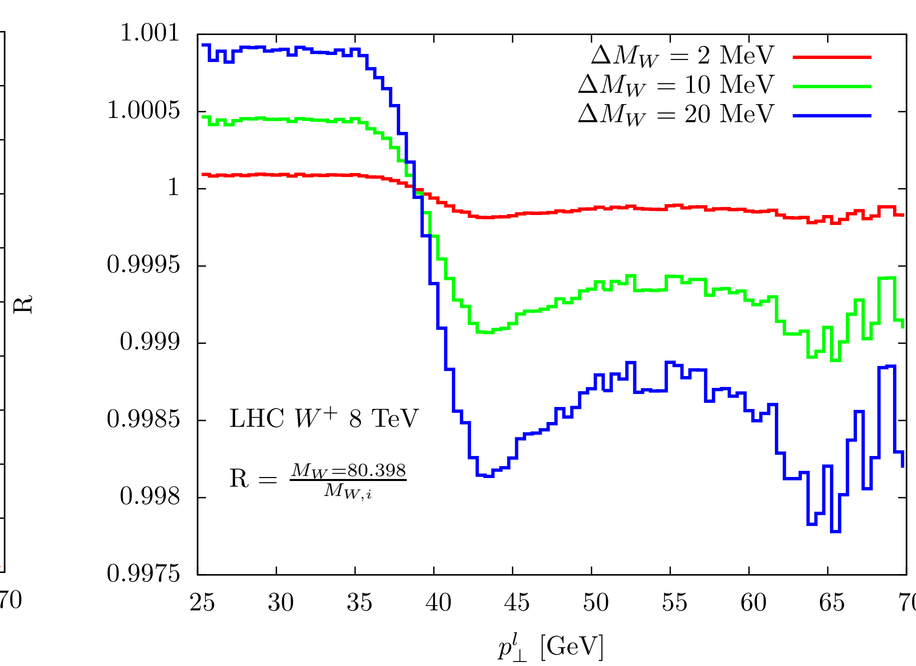




p_{Tl}





Breakdown of uncertainties

CDF

m_T fit uncertainties			
Source	$W \to \mu\nu$	$W \to e\nu$	Common
Lepton energy scale	7	10	5
Lepton energy resolution	1	4	0
Lepton efficiency	0	0	0
Lepton tower removal	2	3	2
Recoil scale	5	5	5
Recoil resolution	7	7	7
Backgrounds	3	4	0
PDFs	10	10	10
W boson p_T	3	3	3
Photon radiation	4	4	4
Statistical	16	19	0
Total	23	26	15

p_T^ℓ fit uncertainties			
Source	$W \to \mu\nu$	$W \to e\nu$	Common
Lepton energy scale	7	10	5
Lepton energy resolution	1	4	0
Lepton efficiency	1	2	0
Lepton tower removal	0	0	0
Recoil scale	6	6	6
Recoil resolution	5	5	5
Backgrounds	5	3	0
PDFs	9	9	9
W boson p_T	9	9	9
Photon radiation	4	4	4
Statistical	18	21	0
Total	25	28	16

D0

Source	Section	m_T	p_T^e	$\not{E}_T$
Experimental				
Electron Energy Scale	VII C 4	16	17	16
Electron Energy Resolution	VII C 5	2	2	3
Electron Shower Model	V C	4	6	7
Electron Energy Loss	V D	4	4	4
Recoil Model	VII D 3	5	6	14
Electron Efficiencies	VII B 10	1	3	5
Backgrounds	VIII	2	2	2
$\sum$(Experimental)		18	20	24
W Production and Decay Model				
PDF	VI C	11	11	14
QED	VI B	7	7	9
Boson p_T	VI A	2	5	2
$\sum$(Model)		13	14	17
Systematic Uncertainty (Experimental and Model)		22	24	29
W Boson Statistics	IX	13	14	15
Total Uncertainty		26	28	33

ATLAS

Combined categories	Value [MeV]	Stat. Unc.	Muon Unc.	Elec. Unc.	Recoil Unc.	Bckg. Unc.	QCD Unc.	EWK Unc.	PDF Unc.	Total Unc.	χ^2/dof of Comb.
m_T, W^+, e-μ	80370.0	12.3	8.3	6.7	14.5	9.7	9.4	3.4	16.9	30.9	2/6
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Shift induced by PDFs: general fitting strategy

Bozzi, Rojo, Vicini PRD 83, 113008 (2011)

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- **pseudodata** with different PDF sets: low-statistics (100M) and fixed M_{W0}
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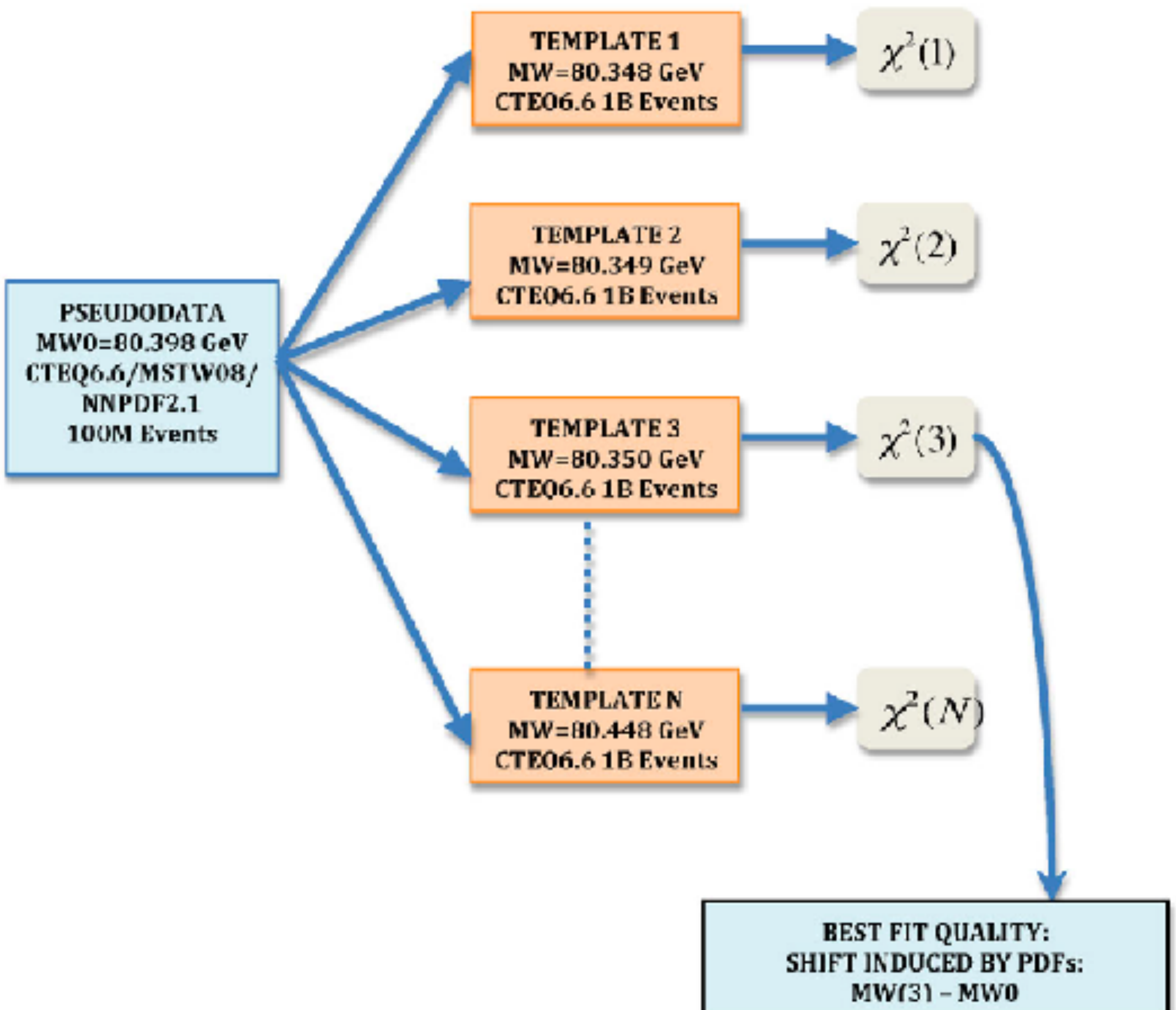
- same code used to generate both pseudodata and templates → only effect probed is the PDF one



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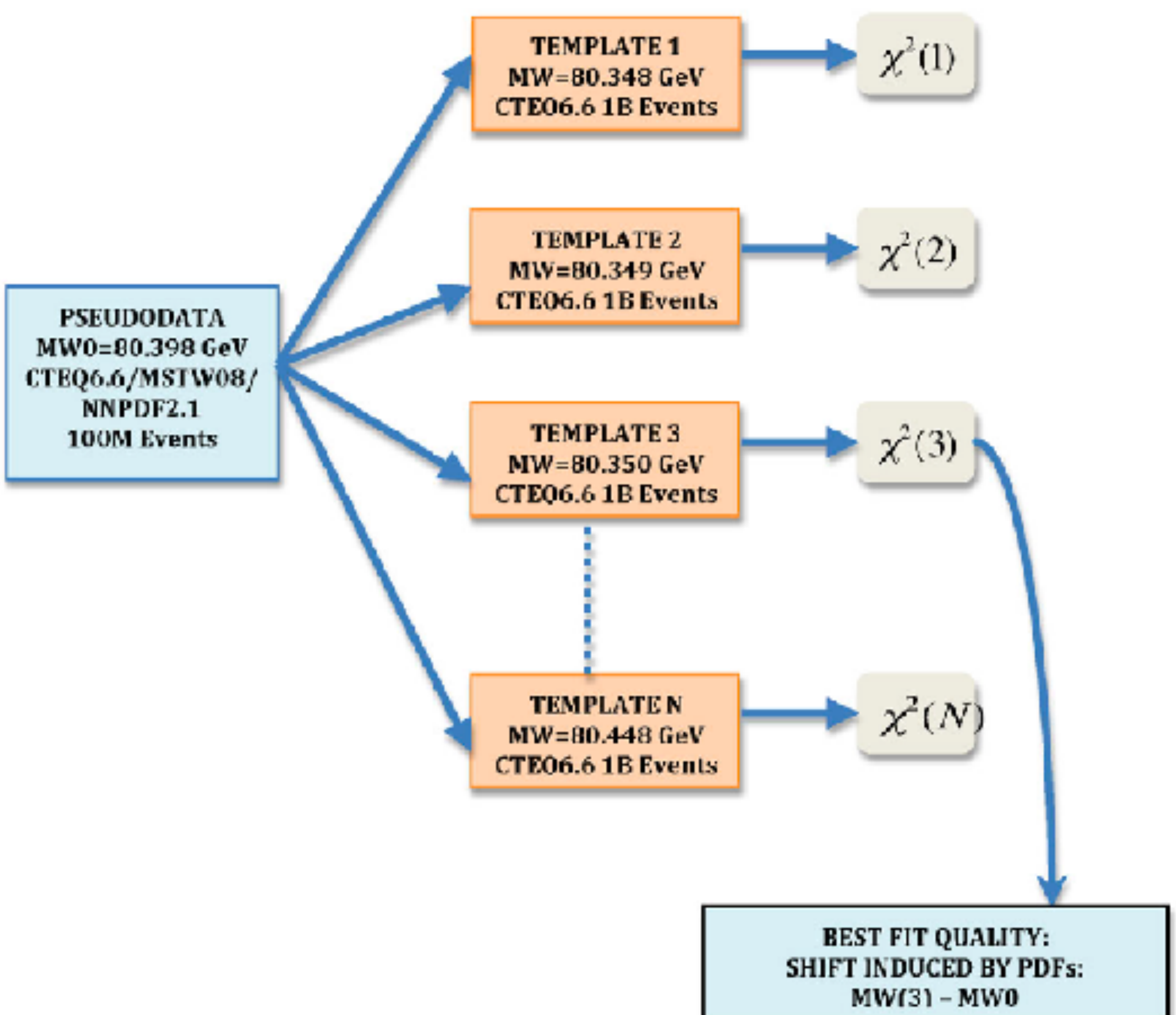

- PDF error = combination of different M_W results from each replica, according to the formulae recommended by the PDF collaborations

Hessian: CTEQ, MSTW

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Montecarlo: NNPDF

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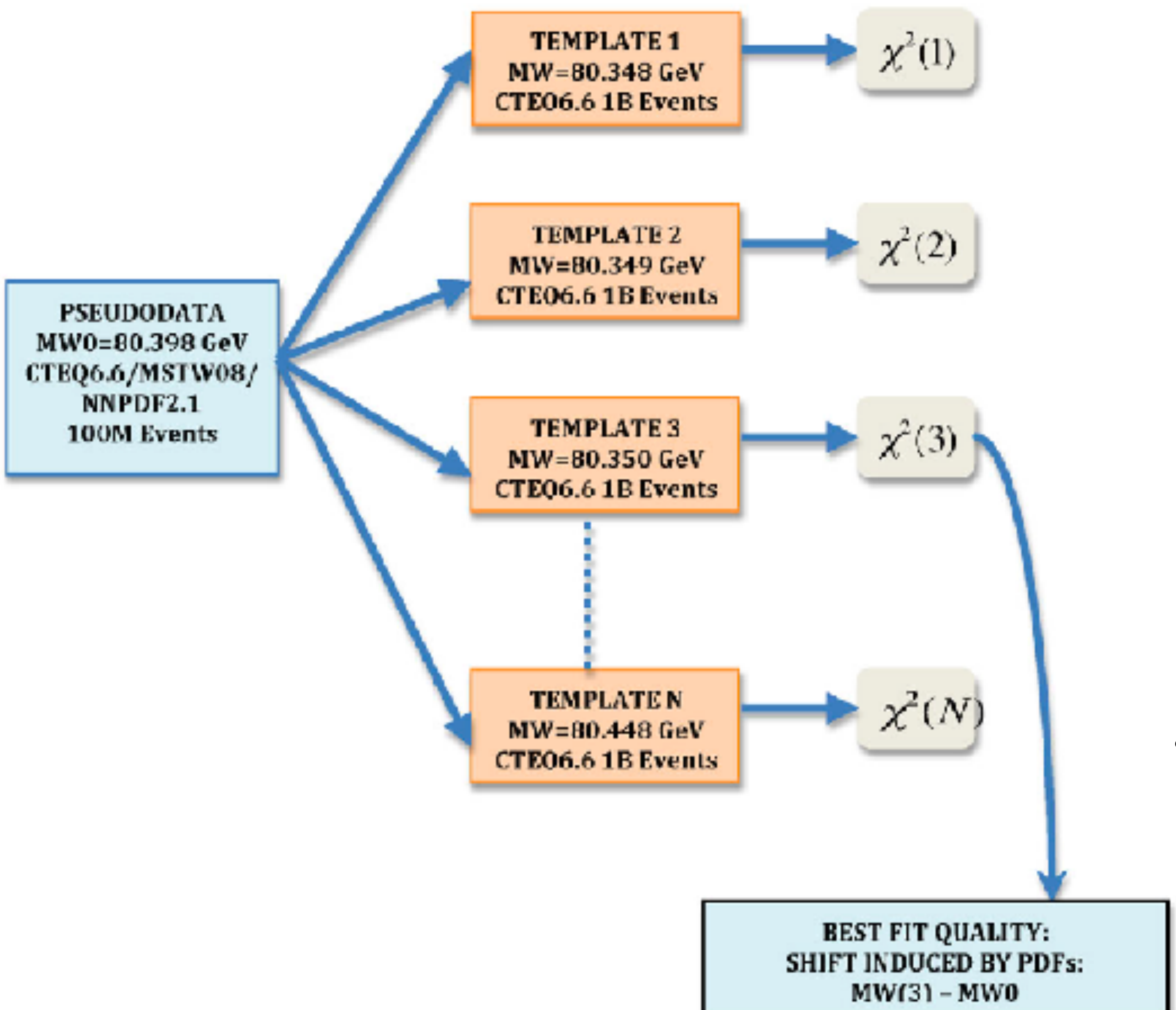

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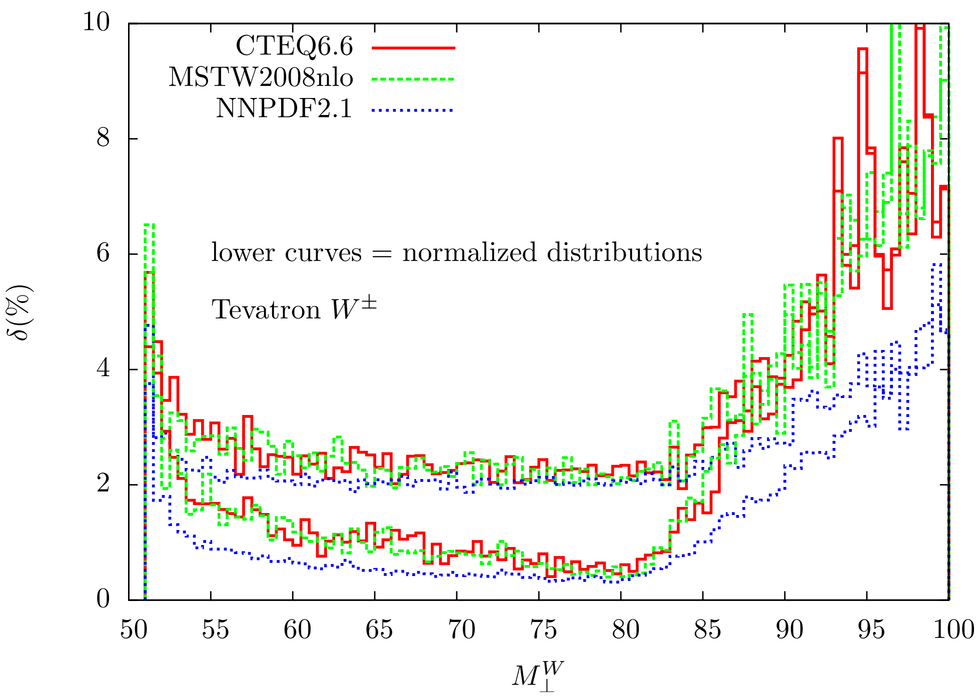
Montecarlo: NNPDF

$$\sigma_X^2 = \frac{1}{N_{\rm rep}-1}\sum_{i}^{N_{\rm rep}}[X^i - X]^2$$

- M_W shift = distance between the PDF set under study and the reference set

Effects on transverse mass



Bozzi, Rojo, Vicini PRD 83, 113008 (2011)

- Normalised distributions: reduced sensitivity to PDFs
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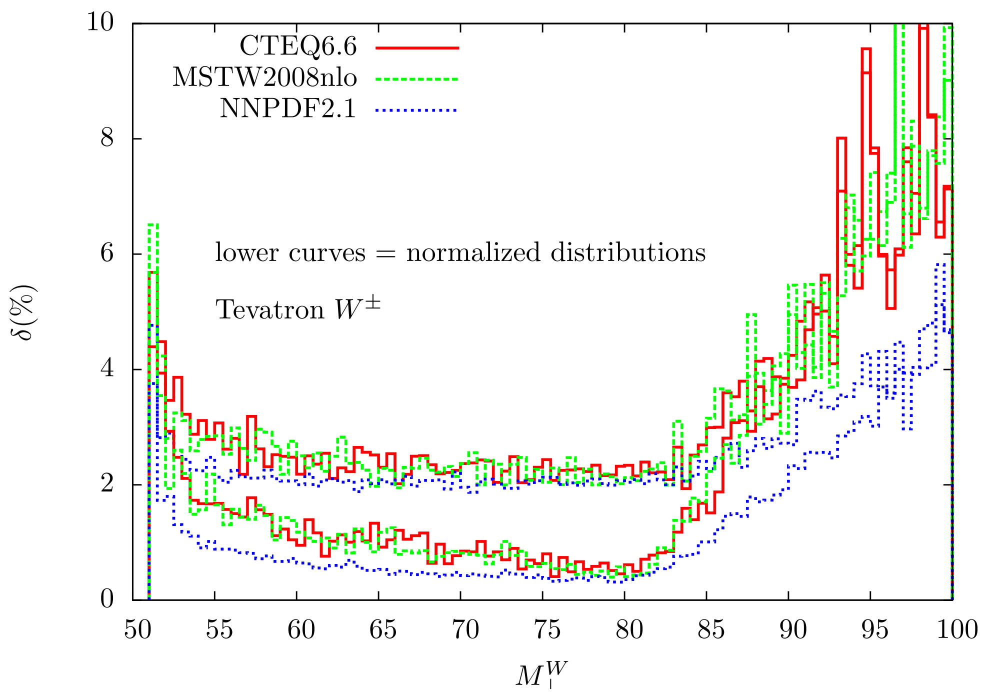

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	CTEQ6.6		MSTW2008		NNPDF2.1		
	$m_W \pm \delta_{pdf}$	$\langle\chi^2\rangle$	$m_W \pm \delta_{pdf}$	$\langle\chi^2\rangle$	$m_W \pm \delta_{pdf}$	$\langle\chi^2\rangle$	δ_{pdf}^{tot}
Tevatron, $W^{\pm}$	80.398 ± 0.004	1.42	80.398 ± 0.003	1.42	80.398 ± 0.003	1.30	4
LHC 7 TeV W^{+}	80.398 ± 0.004	1.22	80.404 ± 0.005	1.55	80.402 ± 0.003	1.35	8
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LHC 14 TeV W^{+}	80.398 ± 0.003	1.34	80.402 ± 0.004	1.48	80.400 ± 0.003	1.41	6
LHC 14 TeV W^{-}	80.398 ± 0.004	1.44	80.404 ± 0.006	1.38	80.402 ± 0.004	1.57	8

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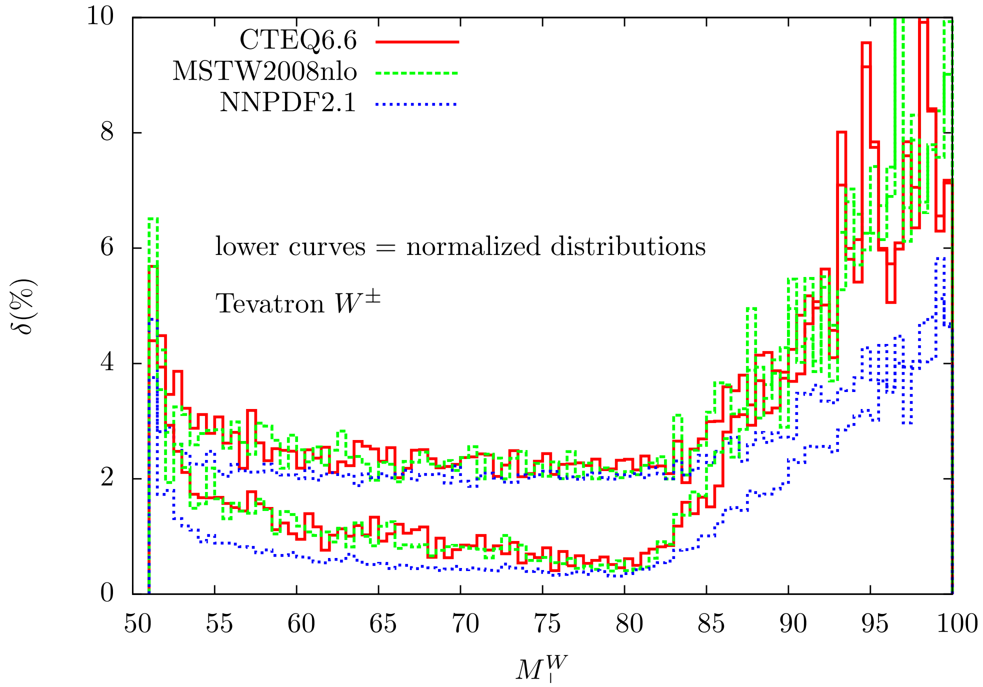

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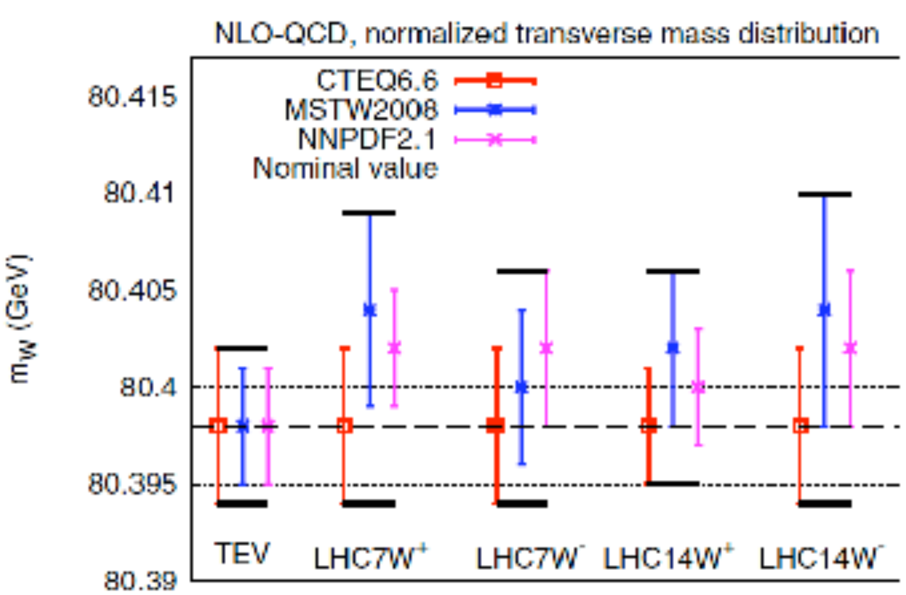

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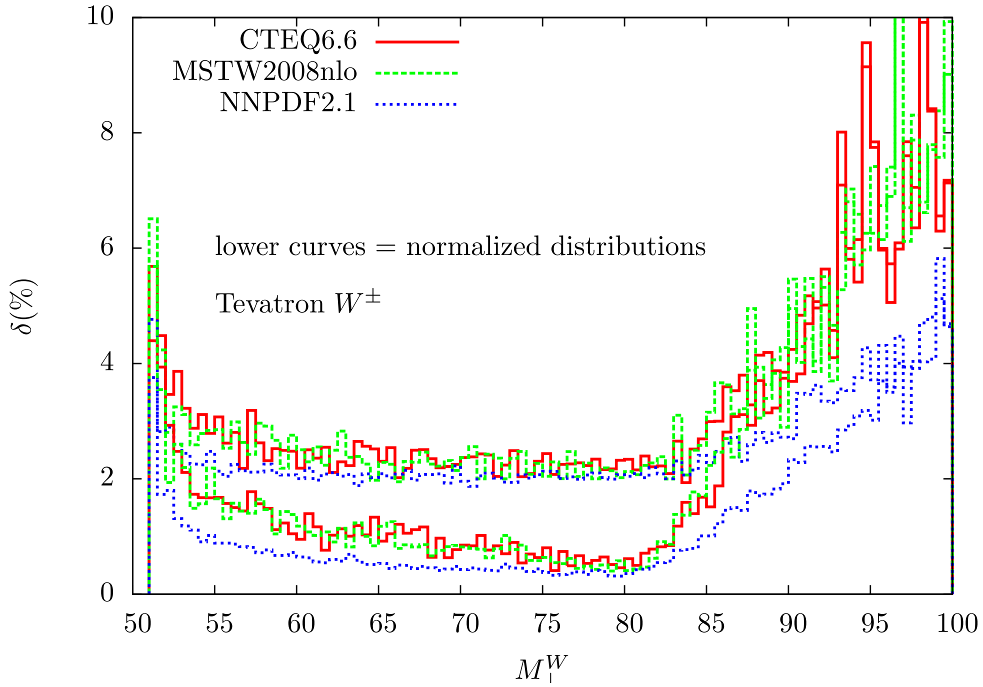

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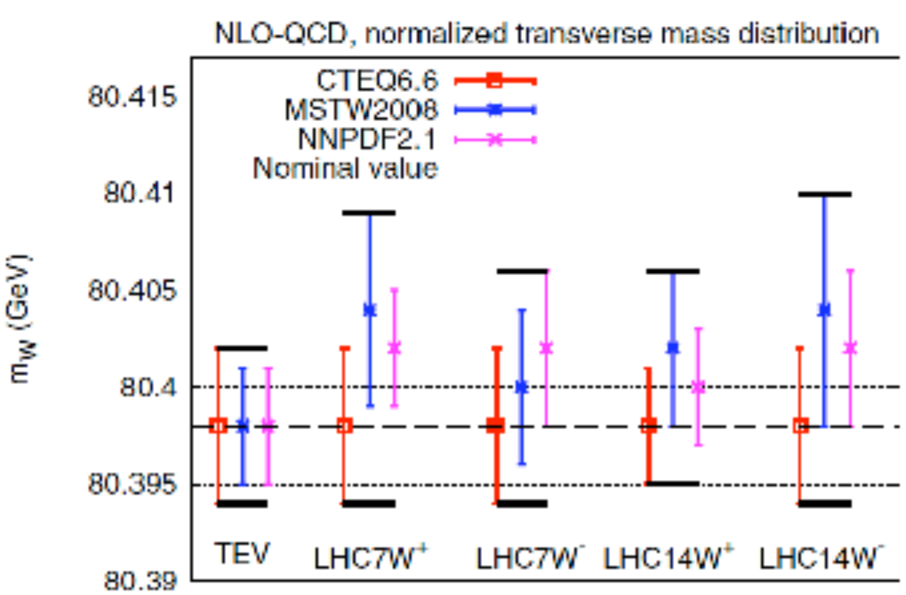
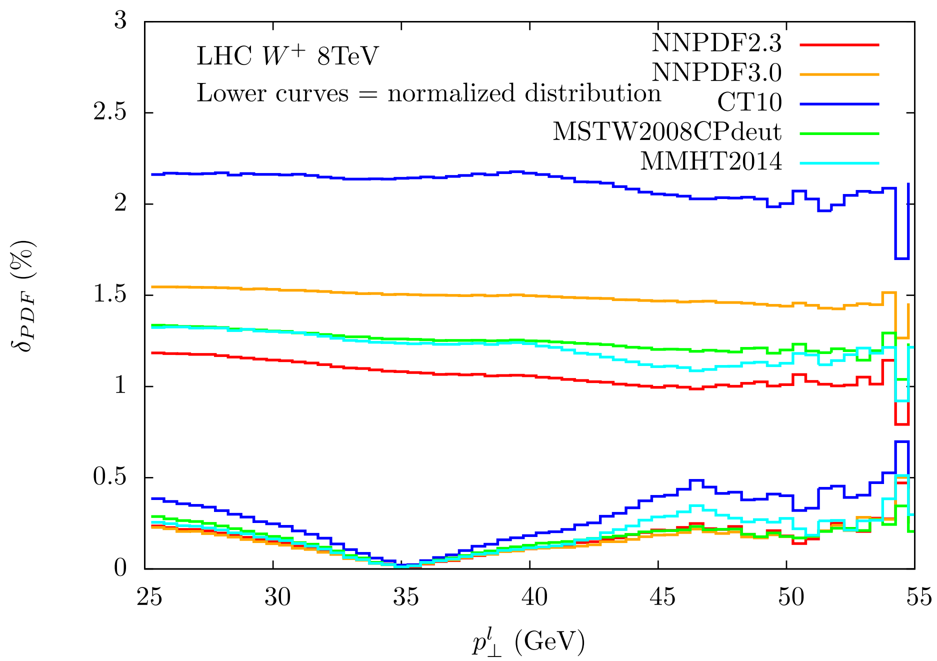


- Accuracy of templates essential: highly demanding computing task!
- For transverse mass distribution, a fixed-order NLO-QCD analysis is sufficient to assess this PDF uncertainty
- PDF error is moderate at the Tevatron but also at the LHC

Effects on lepton p_T

Bozzi, Citelli, Vicini PRD 91, 113005 (2015)



- Conservative estimate of the PDF uncertainty: CC-DY channel alone
- Distributions obtained with **POWHEG+PYTHIA 6.4**
- PDF uncertainty over relevant p_T range almost flat: O(2%)
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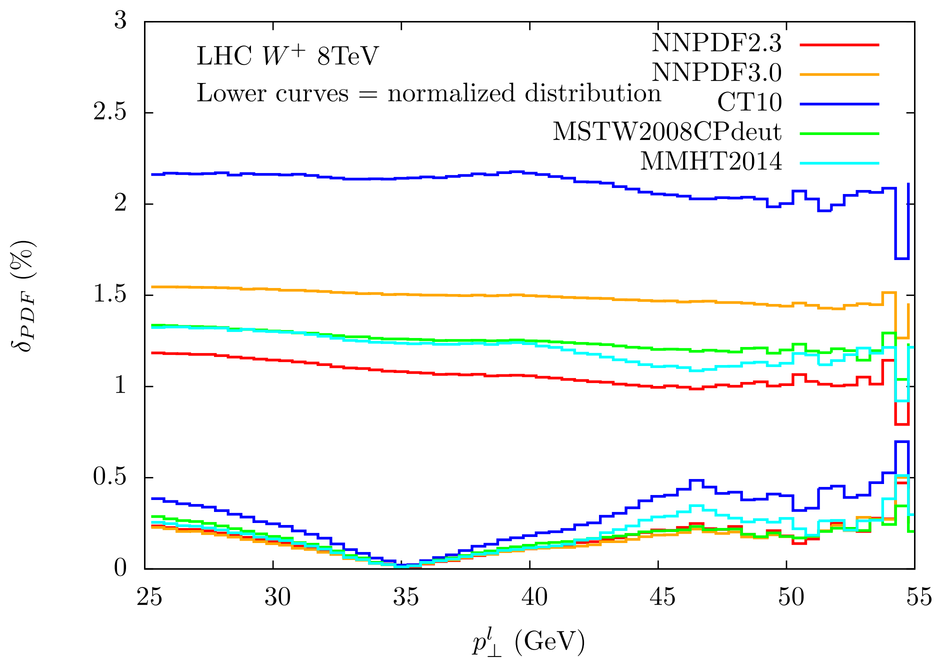

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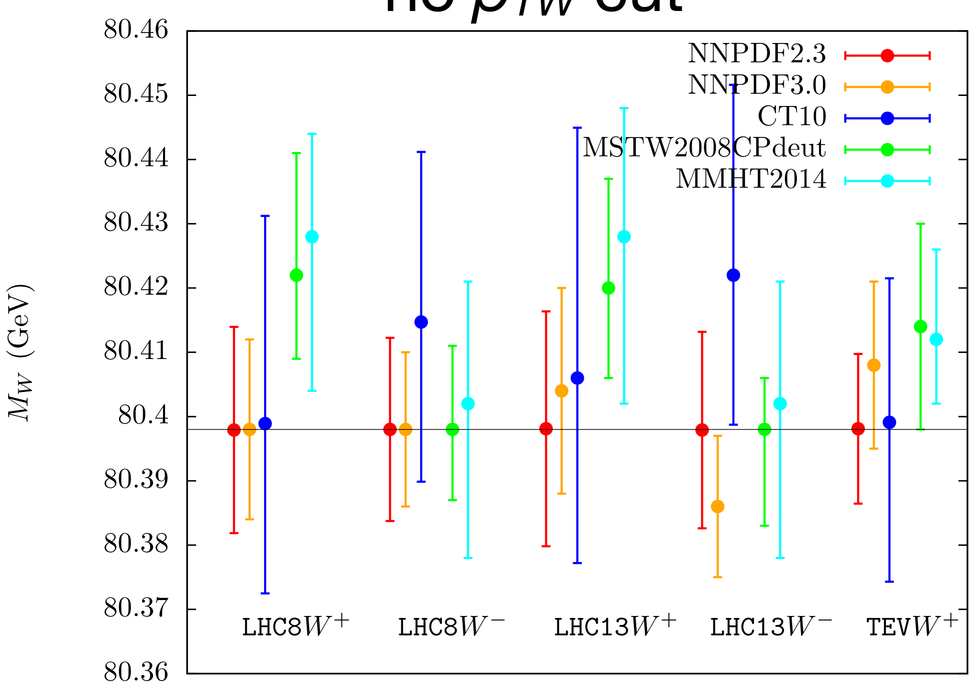
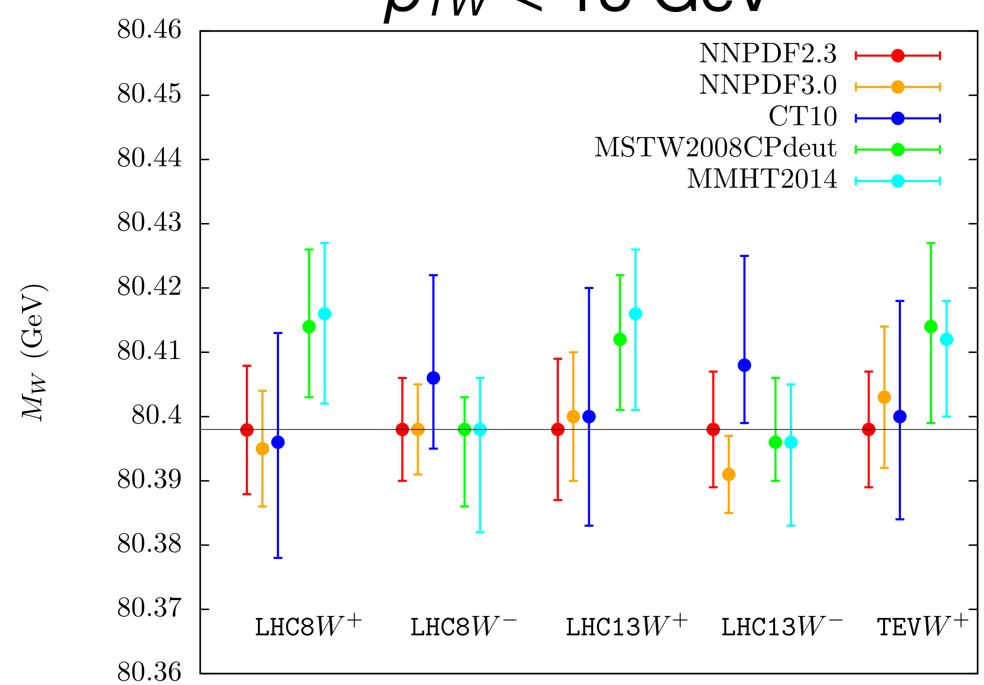
	no $p_\perp^W$ cut		$p_\perp^W < 15$ GeV	
	δ_{PDF} (MeV)	Δ_{sets} (MeV)	δ_{PDF} (MeV)	Δ_{sets} (MeV)
Tevatron 1.96 TeV	27	16	21	15
LHC 8 TeV W^+	33	26	24	18
W^-	29	16	18	8
LHC 13 TeV W^+	34	22	20	14
W^-	34	24	18	12

- Individual PDF sets provide non-pessimistic estimates: $\Delta M_W \sim$ O(10 MeV)
- Global envelope still shows large discrepancies of the central values
- p_{TW} cut is relevant

no p_{TW} cut



p_{TW} < 15 GeV



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—> different Gaussian factors for different flavours

$$f_1^a(x,k_T) = f_1^a(x)\,\frac{1}{\pi\langle k_T^2\rangle_a(x)}\,e^{-\frac{k_T^2}{\langle k_T^2\rangle_a(x)}}$$

$$\langle k^2_{\perp,\mathrm{u_v}}\rangle \neq \langle k^2_{\perp,\mathrm{d_v}}\rangle \neq \langle k^2_{\perp,\mathrm{sea}}\rangle$$

Flavor and kinematic dependent widths

Application to W/Z p_T spectrum

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$$\frac{d\sigma^{Z/W^\pm}}{dq_T} \sim \text{FT} \sum_{i,j} \exp\{-g_{ij}\ b_T^2\}$$

$$g_{ij} \sim \langle k_T^2\rangle_i + \langle k_T^2\rangle_j + \text{soft gluons}$$

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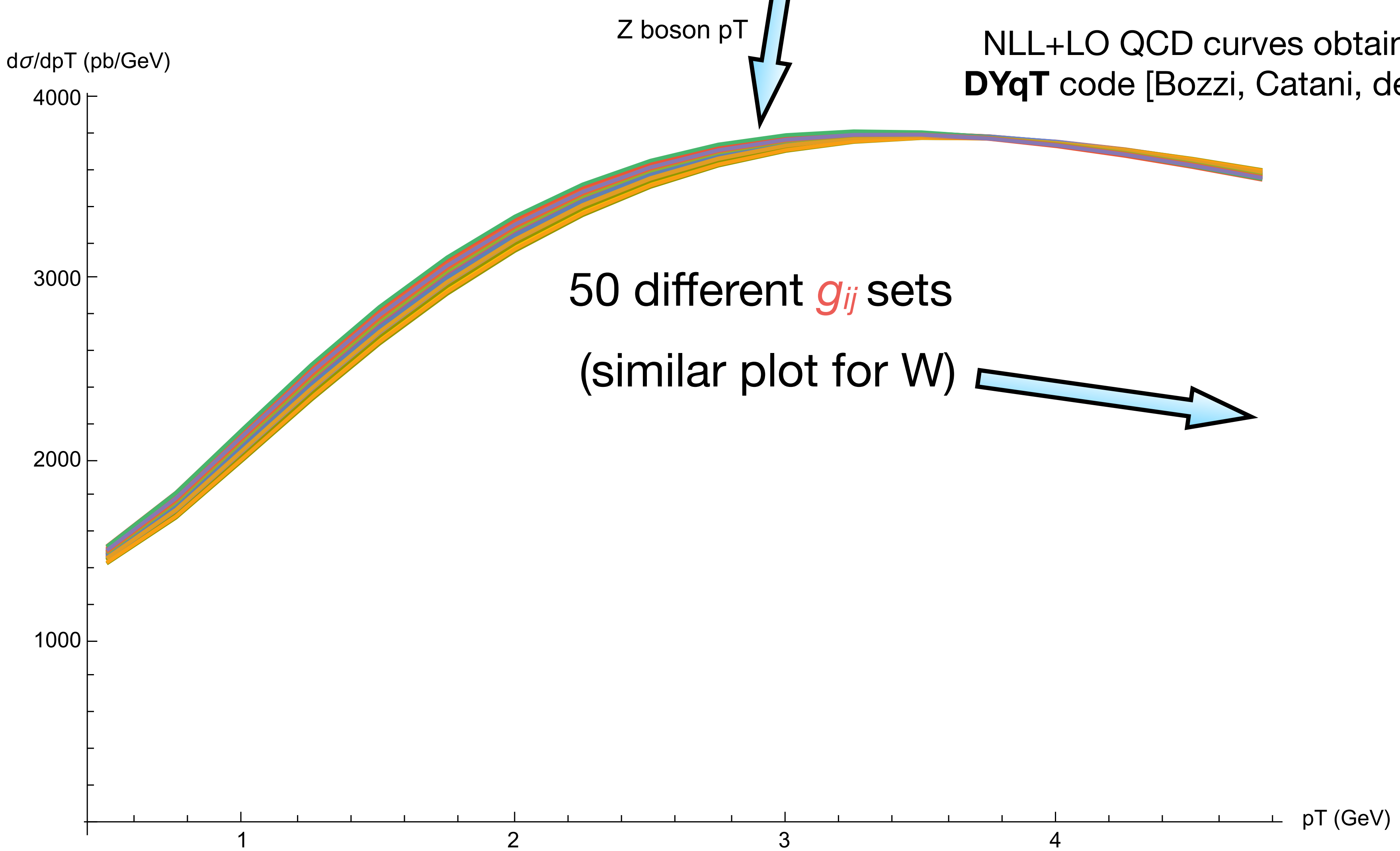

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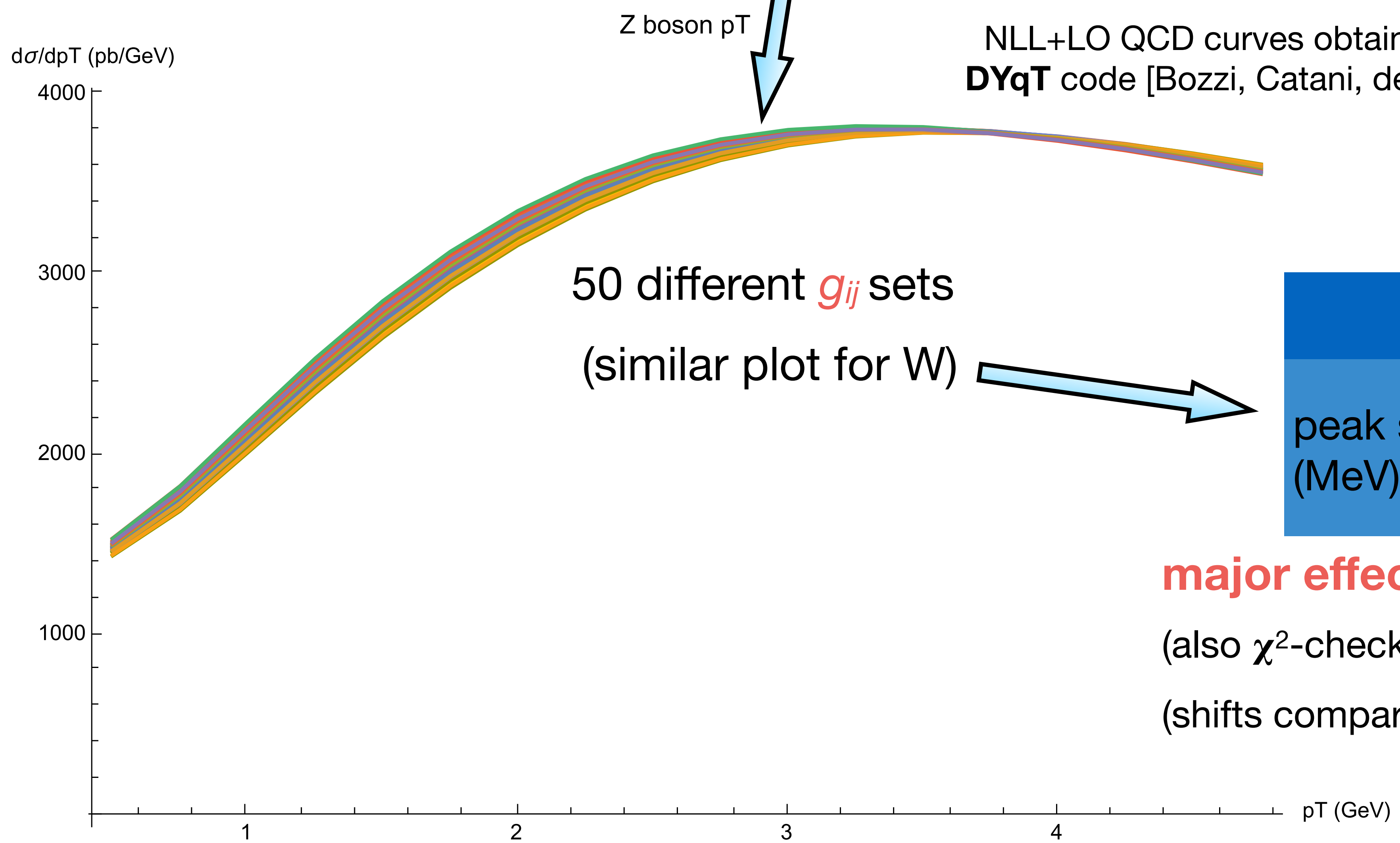

50 different g_{ij} sets

(similar plot for W)

	W^+	W^-	Z^0
peak shift (MeV)	-70 MeV +60 MeV	-60 MeV +90 MeV	< 10 MeV

major effects on W from "Z-equivalent" sets

(also χ^2-checked against flavour-independent run)

(shifts comparable to the ones induced by PDFs)

Impact on the determination of M_W: preliminary results

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W^+

Set	m_T	p_{Tl}	$p_{T\nu}$
1	-1	-15	-7
2	0	-15	4
3	2	1	7
4	2	-7	1
5	-1	9	8
6	0	-15	-15
7	-1	-7	4
8	0	-9	1
9	2	-15	-2
10	1	-4	1
11	0	5	13
12	1	-12	1
13	-1	-3	2
14	0	-15	-13
15	1	3	10

W^-

Set	m_T	p_{Tl}	$p_{T\nu}$
1	-3	2	-6
2	-3	2	-6
3	-1	2	-3
4	-1	-4	-13
5	-3	-11	-15
6	-1	-4	-13
7	-3	-14	-15
8	-2	1	-4
9	-2	-15	-15
10	-1	5	1
11	-3	1	-4
12	-2	-1	-4
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- lepton pt & missing pt: quite important shifts (envelope: up to **25 MeV**)

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- *An especially blended flavour paper soon on your screen by your favourite flavorists!*

Backup slides

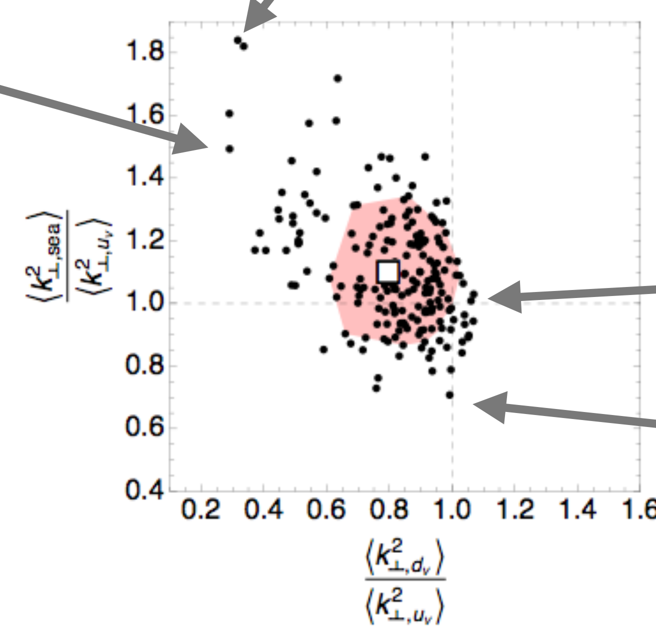
Extraction of parameters from SIDIS

Signori, Bacchetta, Radici, Schnell, JHEP 1311, 194 (2013)

template fit on HERMES data: distribution of parameters

replica 149
χ^2/dof = 1.87

replica 73
χ^2/dof = 1.70



$\frac{\langle k^2_{\perp,sea}\rangle}{\langle k^2_{\perp,u_v}\rangle}$ vs. $\frac{\langle k^2_{\perp,d_v}\rangle}{\langle k^2_{\perp,u_v}\rangle}$

replica 130
χ^2/dof = 1.77

replica 186
χ^2/dof = 1.38

sea width > (mostly) u_v width

point of no flavor dep.

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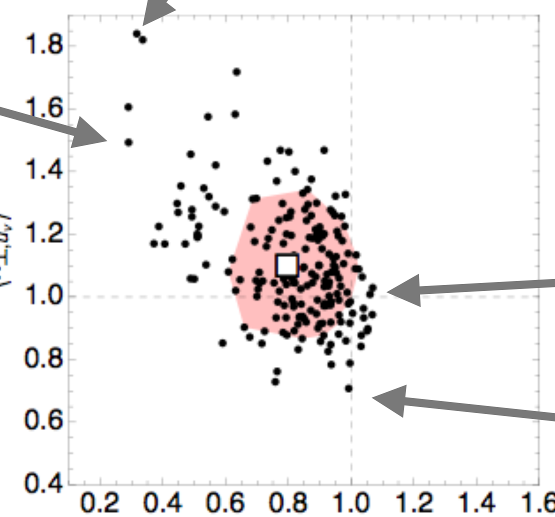

$$\frac{\langle k^2_{\perp,\mathrm{sea}}\rangle}{\langle k^2_{\perp,u_v}\rangle}$$

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d_v width **<** (mostly) u_v width

On average, *sea > u_v > d_v*

Acceptance cuts: interesting insights

Bozzi, Citelli, Vicini PRD 91, 113005 (2015)

normalized distributions			
cut on $p_\perp^W$	cut on $\|\eta_l\|$	CT10	NNPDF3.0
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Acceptance cuts: interesting insights

Bozzi, Citelli, Vicini PRD 91, 113005 (2015)

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strong p_{TW} cut reduces M_W uncertainty

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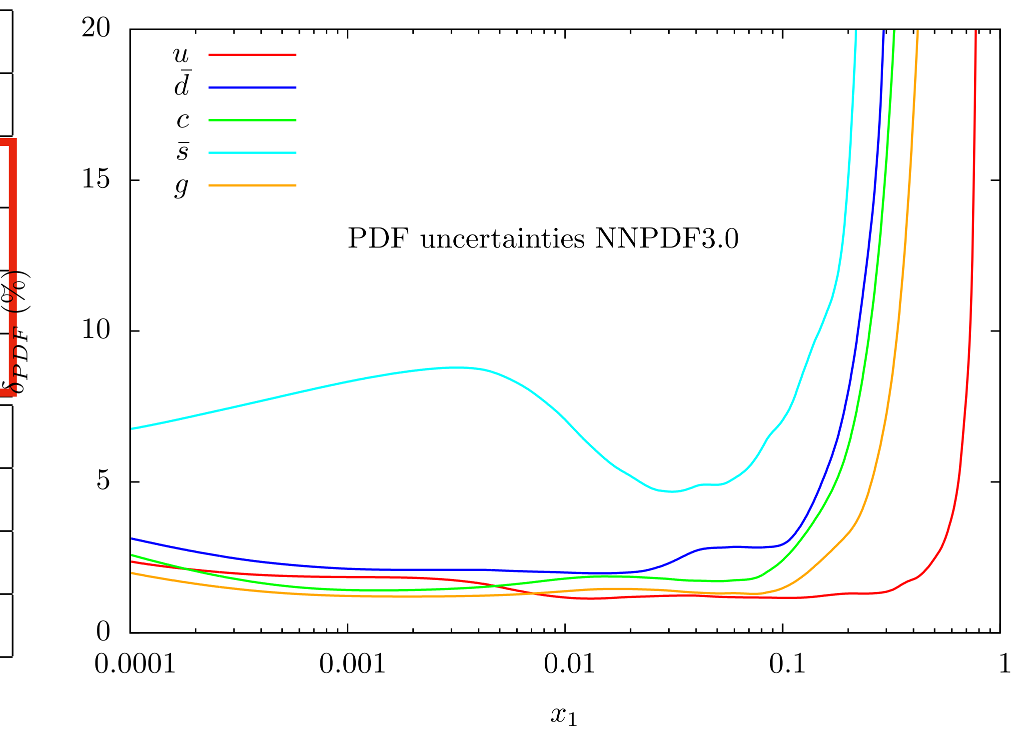

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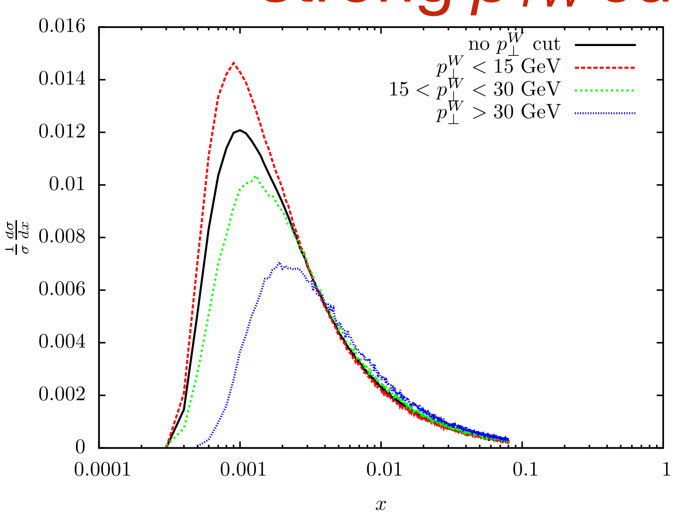

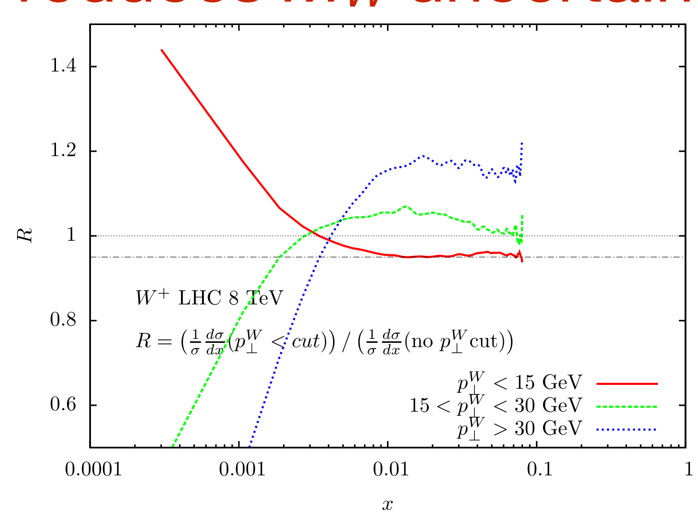

suppression of the large-*x* region

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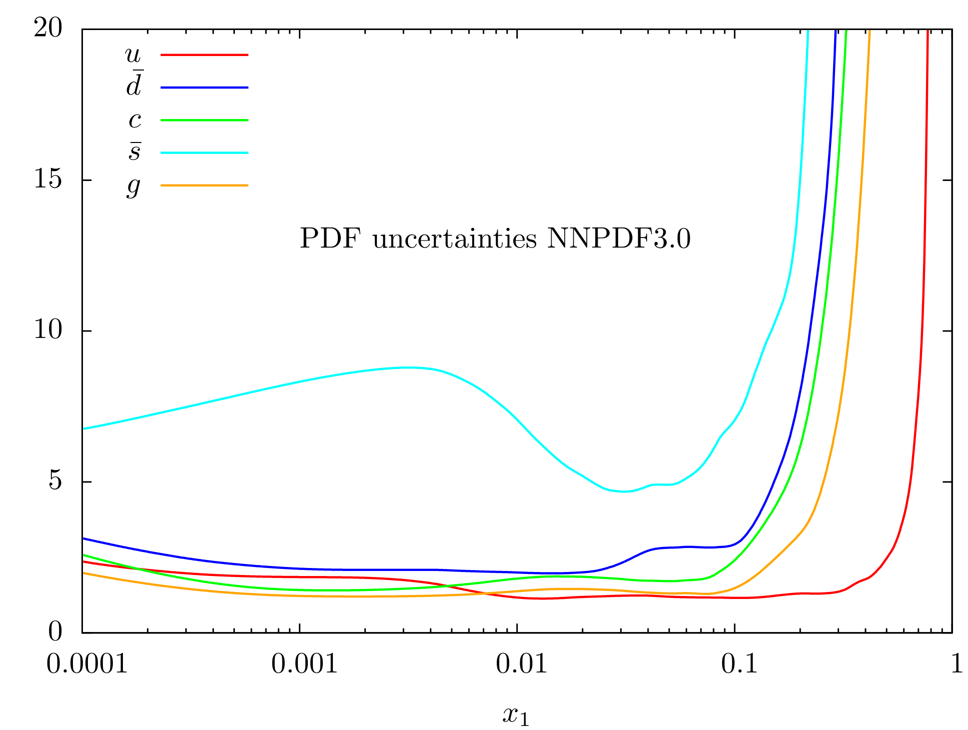

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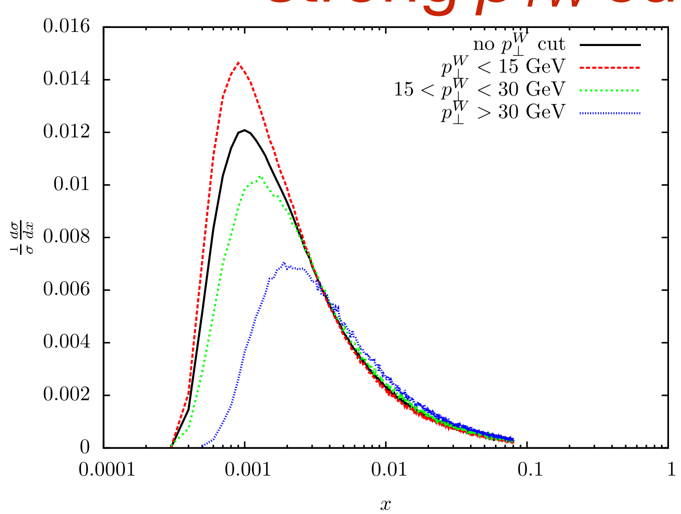
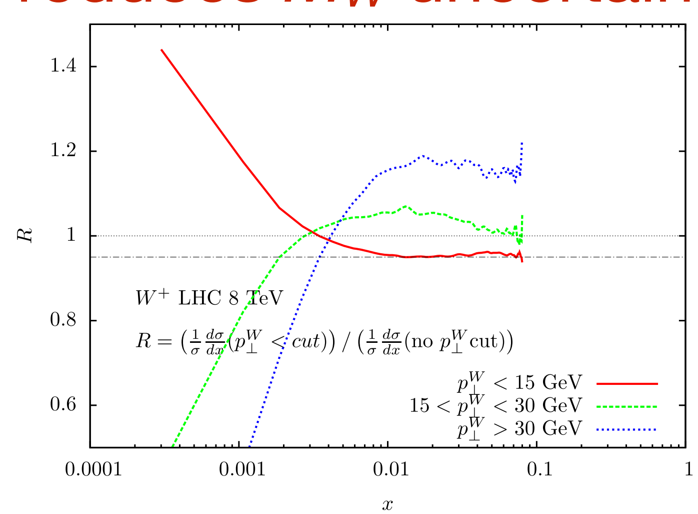
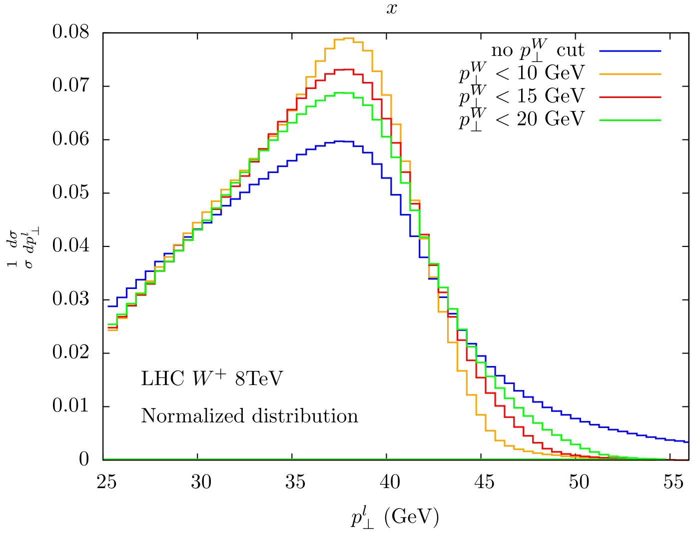
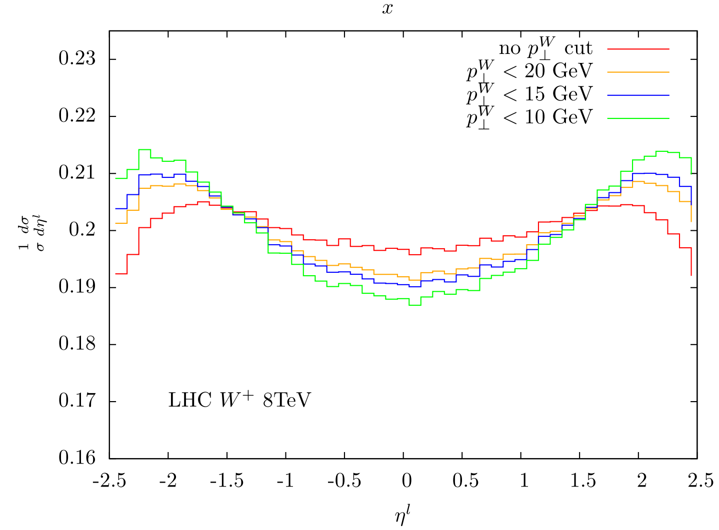




suppression of the large-x region



steeper shape of the p_{Tl} distribution



enhancement of high rapidity regions

Acceptance cuts: interesting insights

Bozzi, Citelli, Vicini PRD 91, 113005 (2015)

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loose lepton pseudorapidity cut reduces M_W uncertainty

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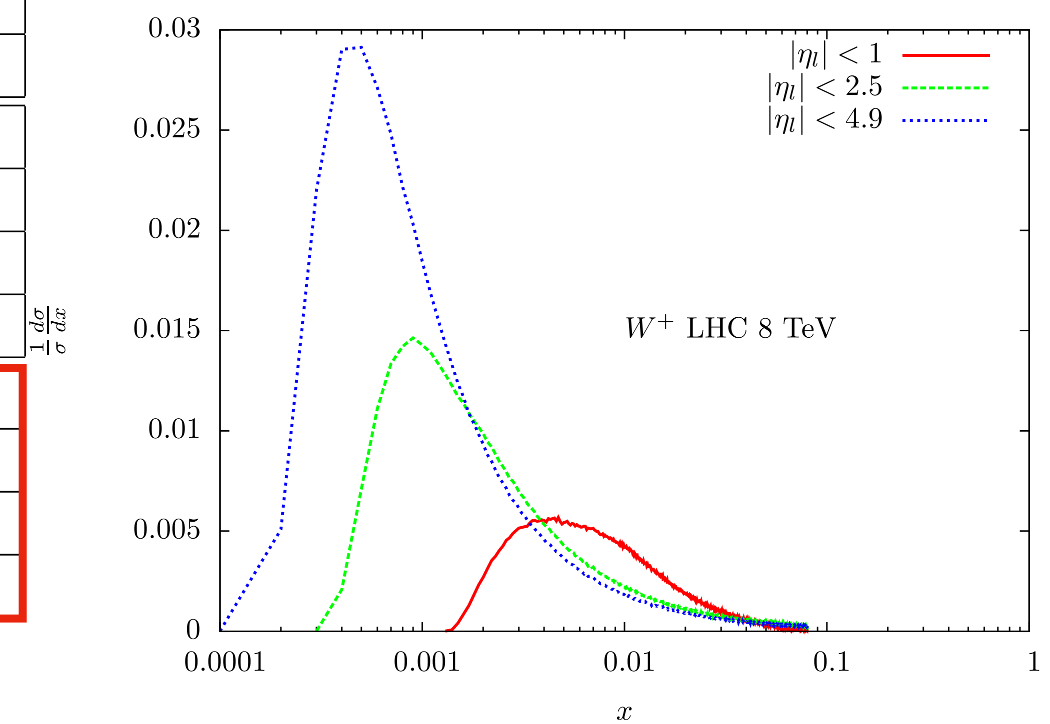

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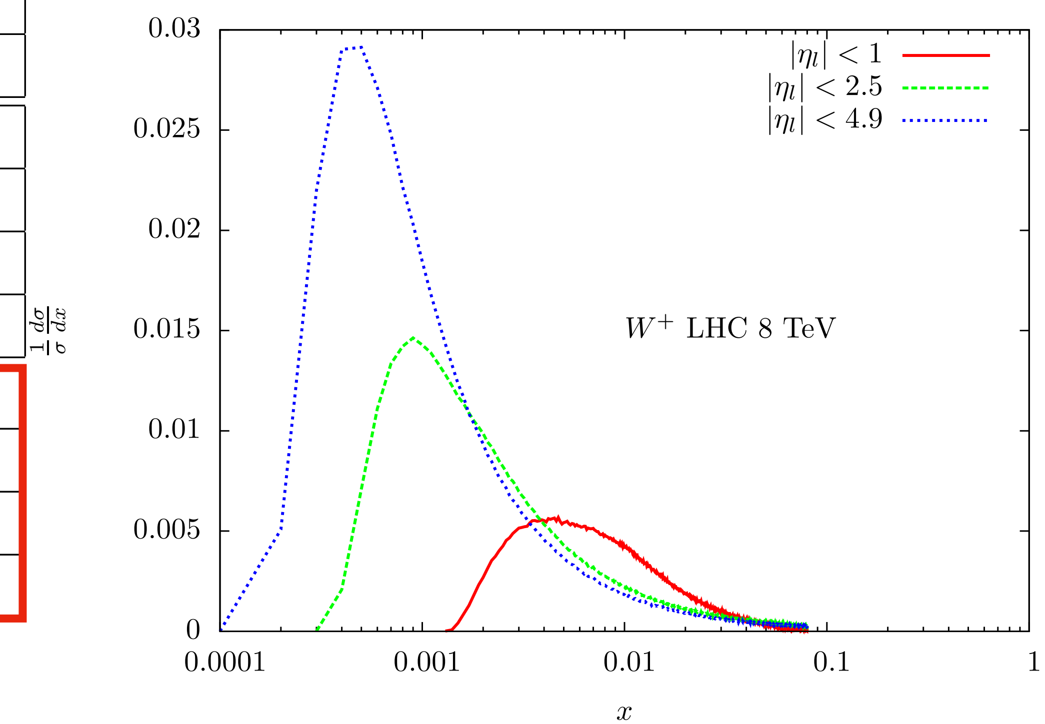

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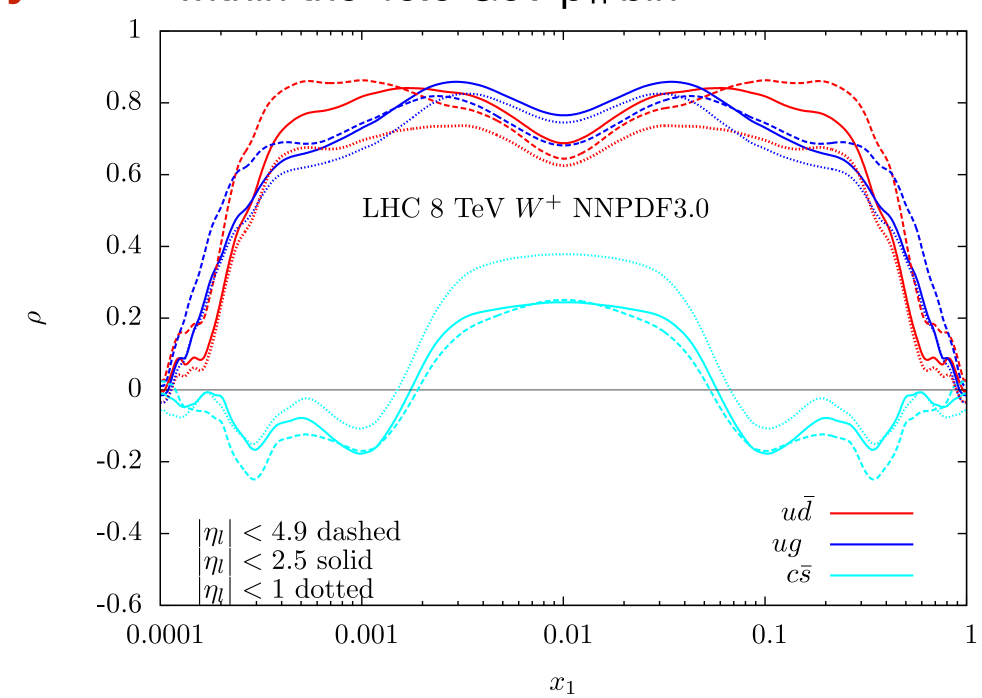
correlation of parton luminosities within the 40.5 GeV p_{Tl} bin



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

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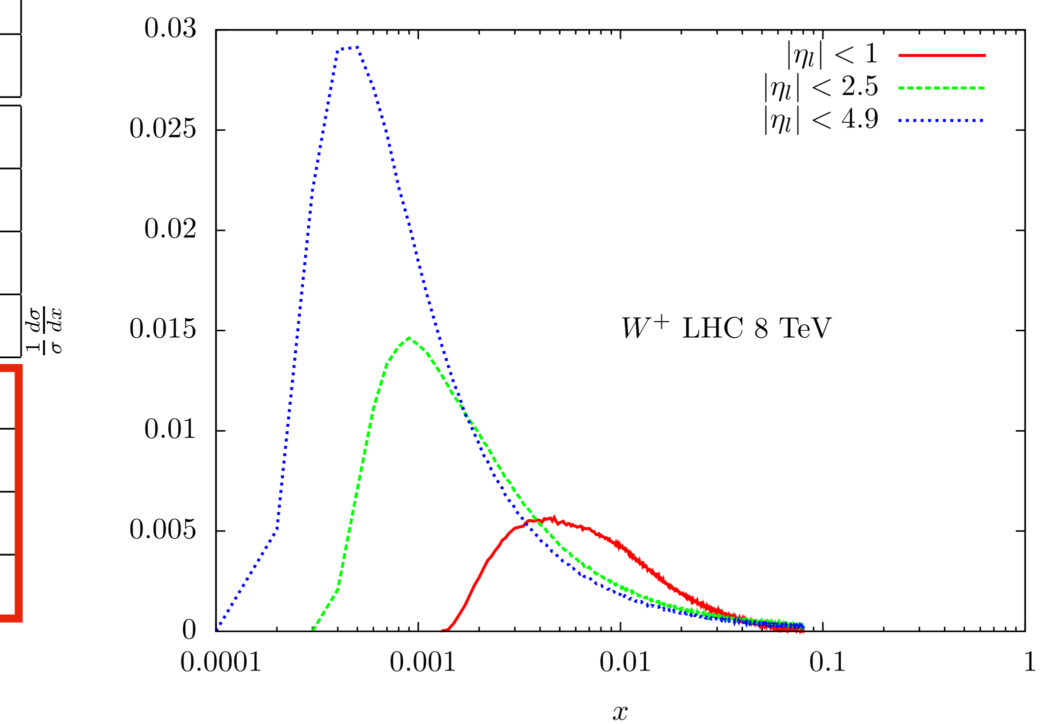
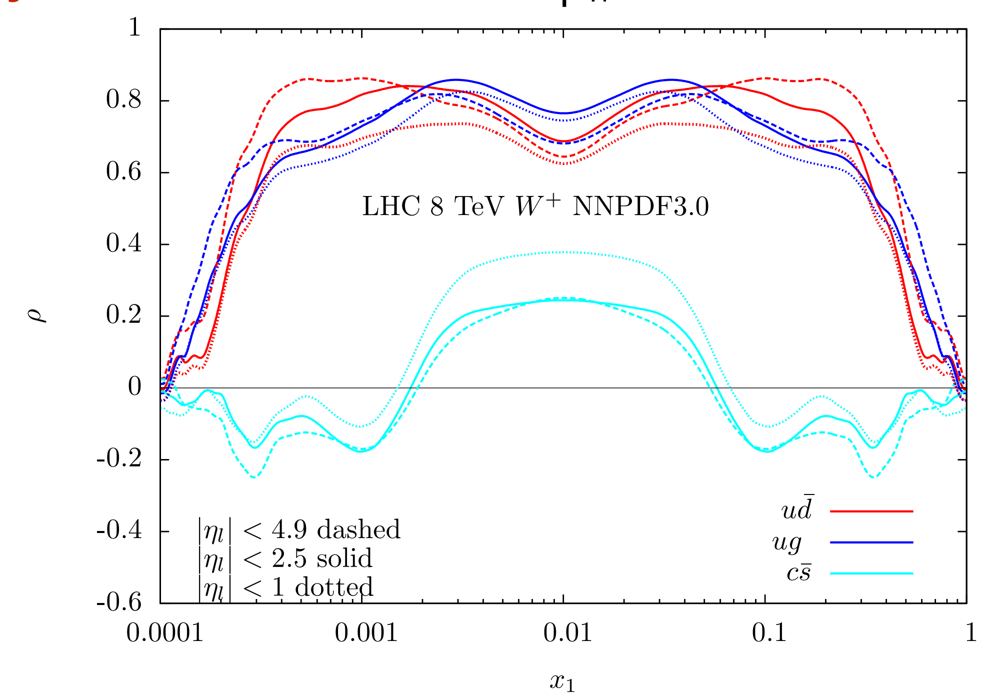


loose lepton pseudorapidity cut reduces M_W uncertainty

- uncertainties for (eta<1) and for (1<eta<2.5) are *separately larger* than for (eta<2.5)
- normalized p_{Tl} distribution, integrated over whole rapidity range, does not depend on x
- PDF sum rules → *non trivial compensations between different rapidity intervals among different flavours*

correlation of parton luminosities within the 40.5 GeV p_{Tl} bin



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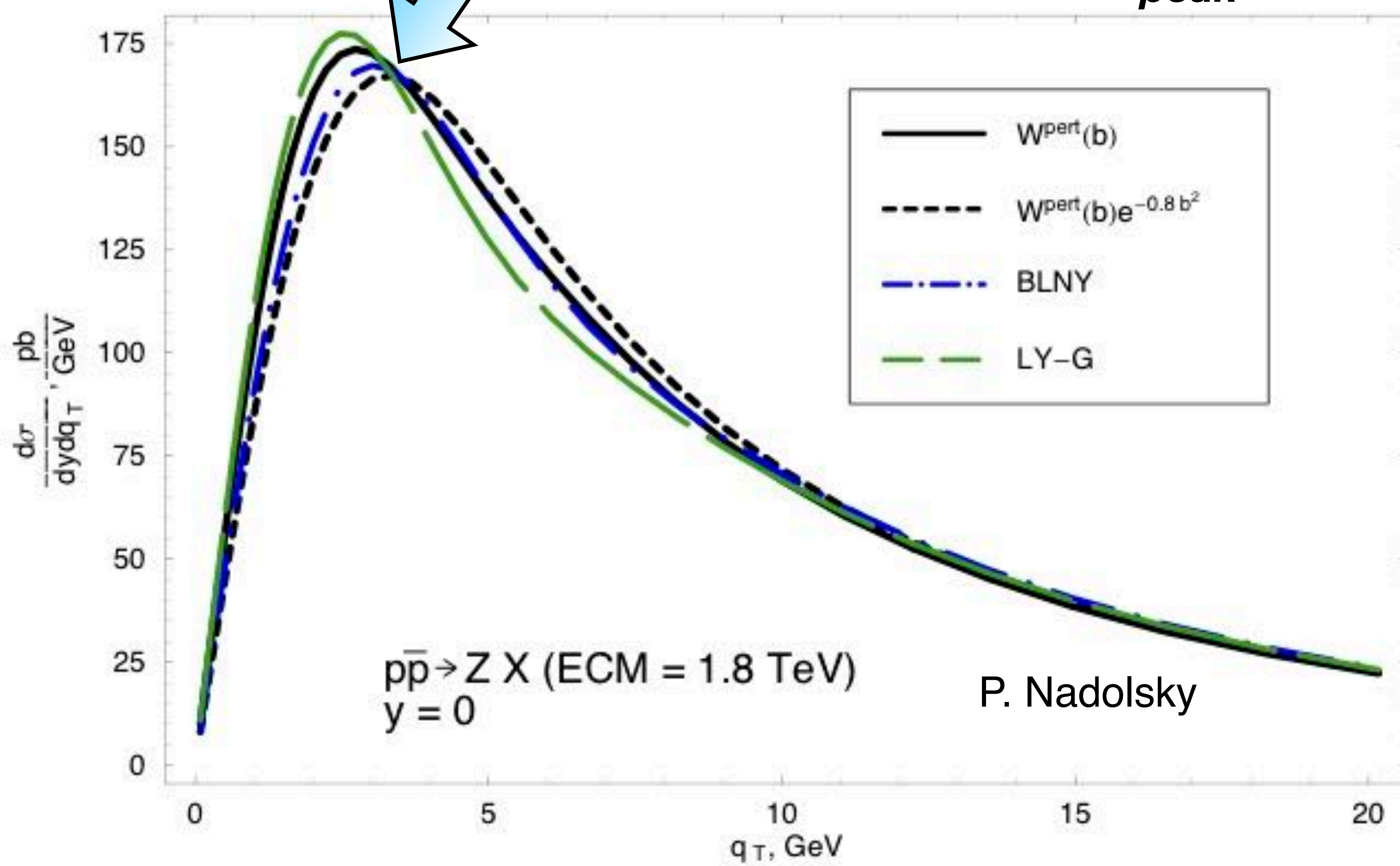
Application to W/Z p_T spectrum

$$\frac{d\sigma^{Z/W^\pm}}{dq_T} \sim \mathrm{FT} \sum_{i,j} \exp\{-g_{ij}\, b_T^2\}$$

$$g_{ij} \sim \langle k_T^2\rangle_i + \langle k_T^2\rangle_j + \text{soft gluons}$$

g comes from 2 TMD PDFs and ***controls the position of the peak***



Application to W/Z p_T spectrum

Use of flavour-dependent configurations that respect the experimental constraint on Z producing different distributions for W

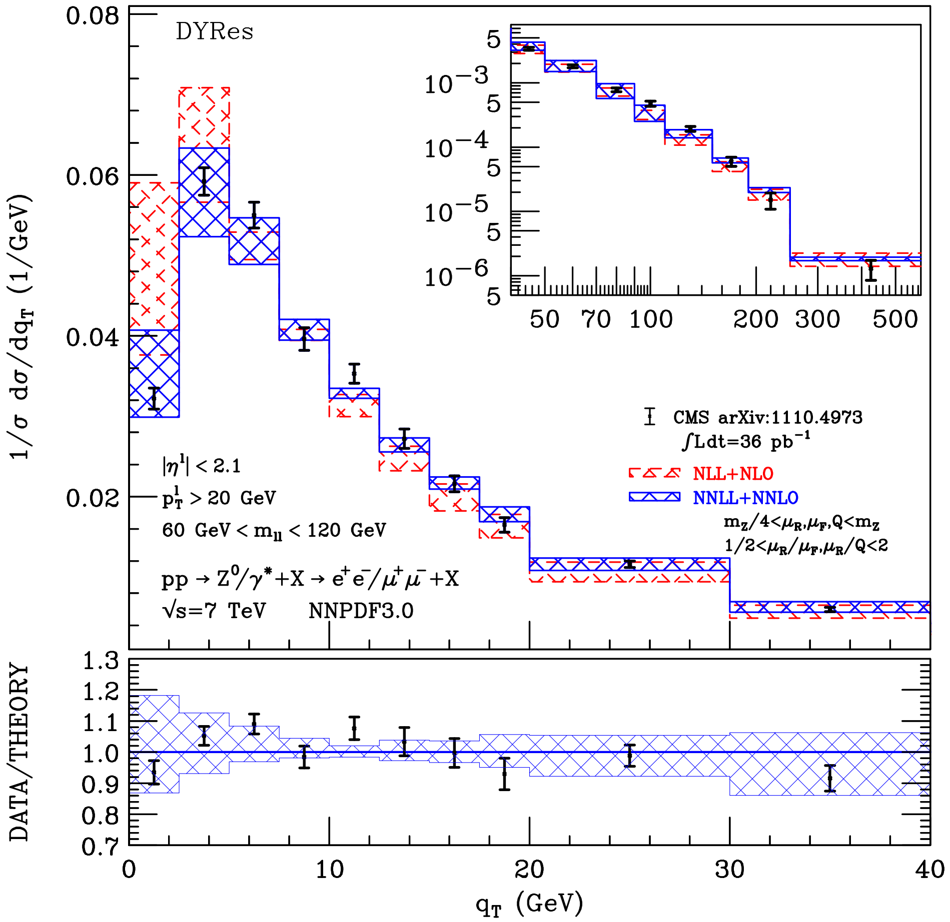
$$g_{ij}(Z) \ : \ [\mathrm{GeV}^2]\ 0.7 = u + \bar{u} = 0.2 + 0.5$$
$$= d + \bar{d} = 0.3 + 0.4$$
$$= \dots = 0.6 + 0.1 = \dots$$
$$g_{ij}(W) \ : \ [\mathrm{GeV}^2]\ 0.6 = u + \bar{d} = 0.2 + 0.4 = \dots$$

	W^+		W^-		Z	
$\mu_R = \mu_c/2, 2\mu_c$	+0.30	−0.09	+0.29	−0.06	+0.23	−0.05
pdf (90% cl)	+0.03	−0.05	+0.06	−0.02	+0.05	−0.02
$\alpha_S = 0.121, 0.115$	+0.14	−0.12	+0.14	−0.14	+0.15	−0.15
f.i. $\langle \mathbf{k}_T^2 \rangle = 1.0, 1.96$	+0.16	−0.16	+0.16	−0.14	+0.16	−0.15
f.d. $\langle \mathbf{k}_T^2 \rangle$ (max W^+ effect)	+0.09			−0.06	±0	
f.d. $\langle \mathbf{k}_T^2 \rangle$ (max W^- effect)		−0.03	+0.05		±0	

Table 7.2. Summary of the shifts in GeV for the peak position for q_T spectra of $W^\pm/Z$ arising from different sources. The colors for the flavor dependent (f.d.) and independent (f.i.) variations match the ones in Sec. 7.4.6.

The uncertainty including intrinsic transverse momentum is comparable in magnitude with the one associated to collinear PDFs

Impact on the determination of M_W: in progress!



- DYRes (NNLO-QCD + NNLL) with leptonic decays

Catani, de Florian, Ferrera, Grazzini, JHEP 1512, 047 (2015)

- NNLO accuracy on the total cross section matched with NNLL accuracy in the description of the low p_{TZ} region
- good description of p_{TZ} data (within uncertainty bands)
- M_T distribution: remarkable stability at jacobian peak
- p_{Tl} distribution: distortion at few % level (NLL—>NNLL)
- flavour dependence coded and consistently-checked: stay tuned for the complete template fit analysis!