The 3D structure of the proton and its impact on high-energy precision measurements

giuseppe bozzi

INFN
Istituto Nazionale
di Fisica Nucleare

3DSPIN
MAPPING
THE PROTON IN 3D

erc
European Research Council

UNIVERSITÀ
DI PAVIA

A neither complete nor exhaustive review of something

giuseppe bozzi
(with the invaluable help of
Valerio Bertone and Miguel Echevarria)

Disclaimer

Just a few slides to stimulate discussion and try to anticipate possible future steps for our benchmark

Kind of bird-eye view of different formalisms, without many technical details and with some "dictionary" included

Please forgive and point out any omission/mistake/inaccuracy: slides are meant to be continuously (even real-time!) updated

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- each function has its own RG evolution: $\dfrac{d \ln X}{d \ln \mu} = \Gamma_X \quad with \quad X = B, H, S$ leading to resummed predictions and customary formula (next slide)

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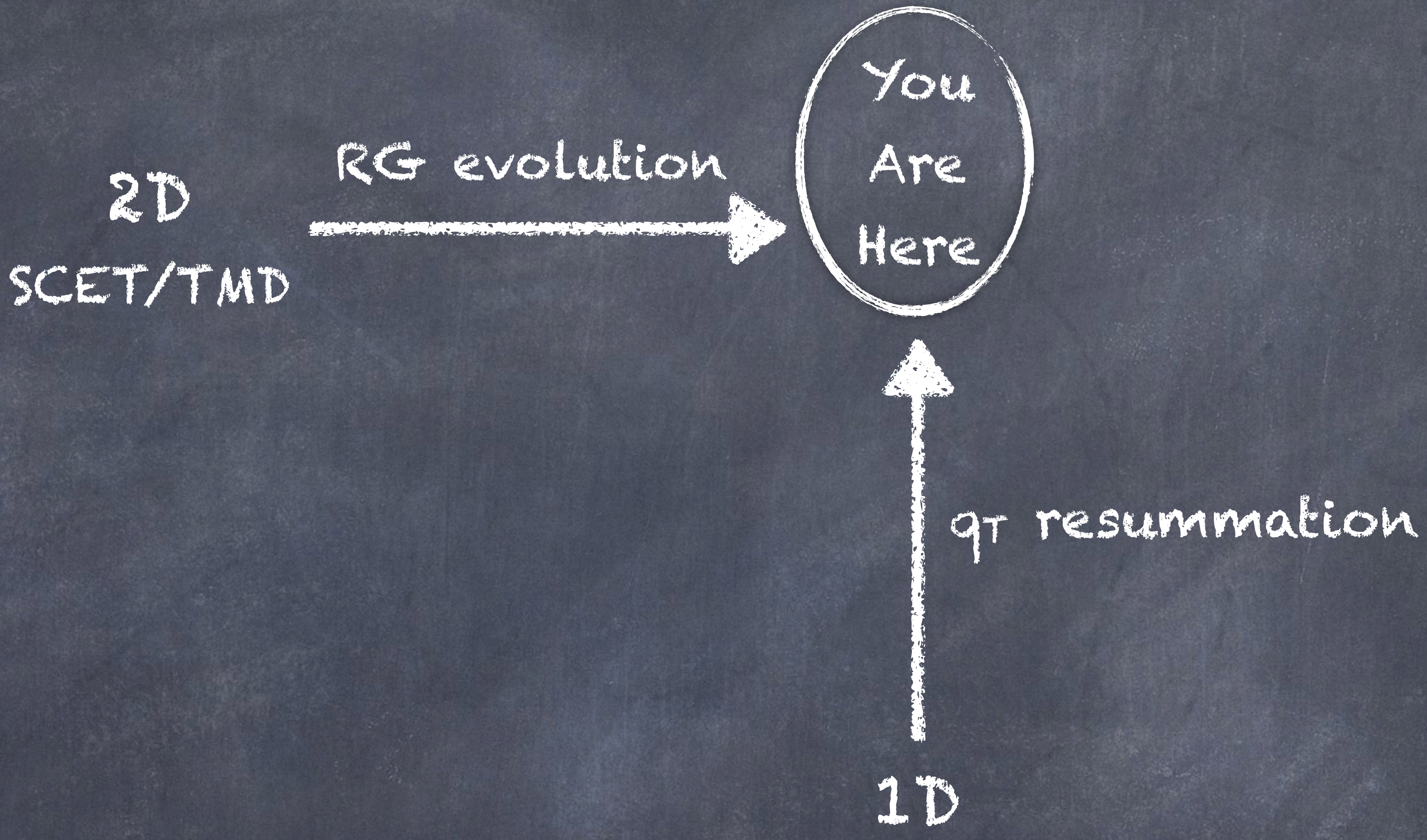

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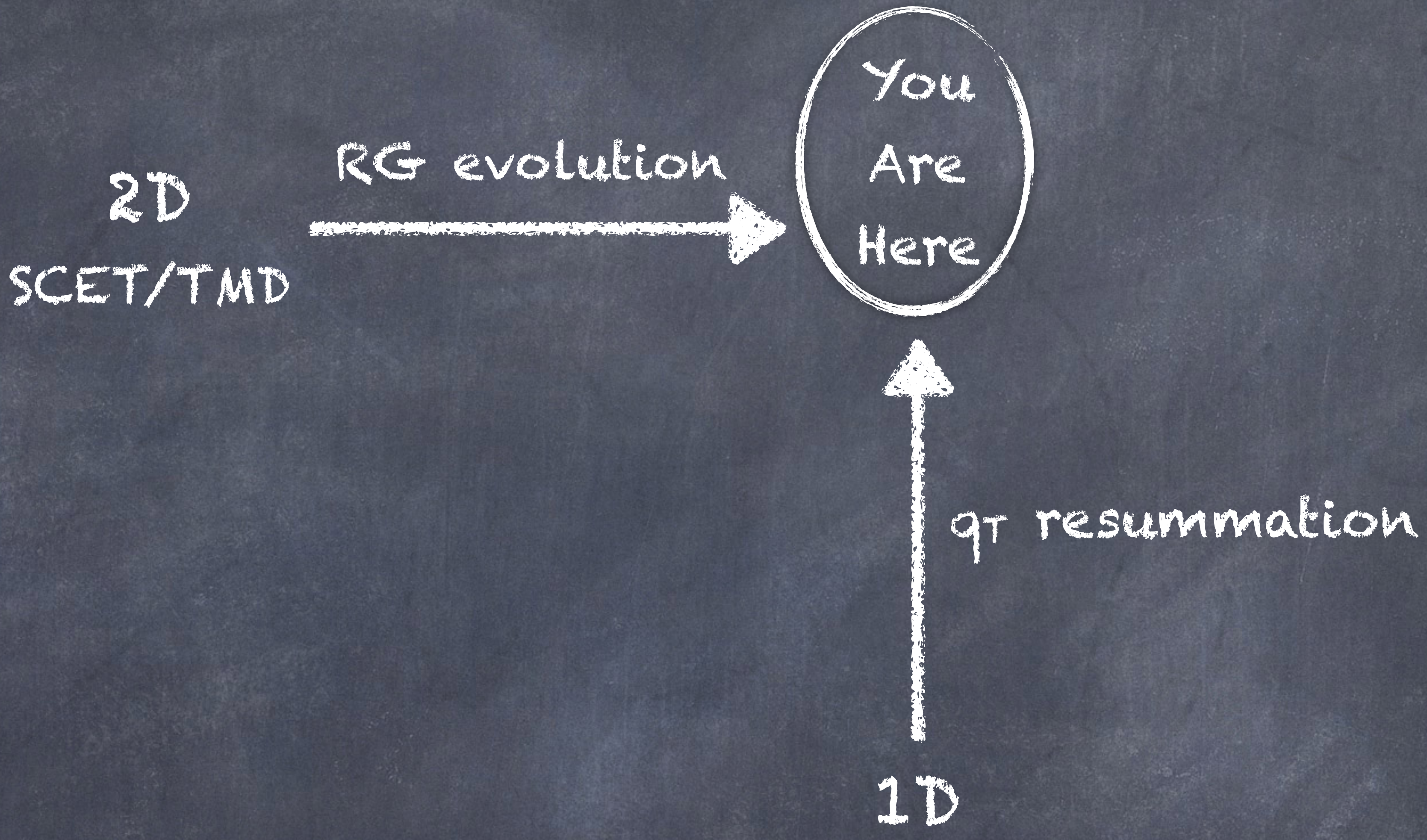

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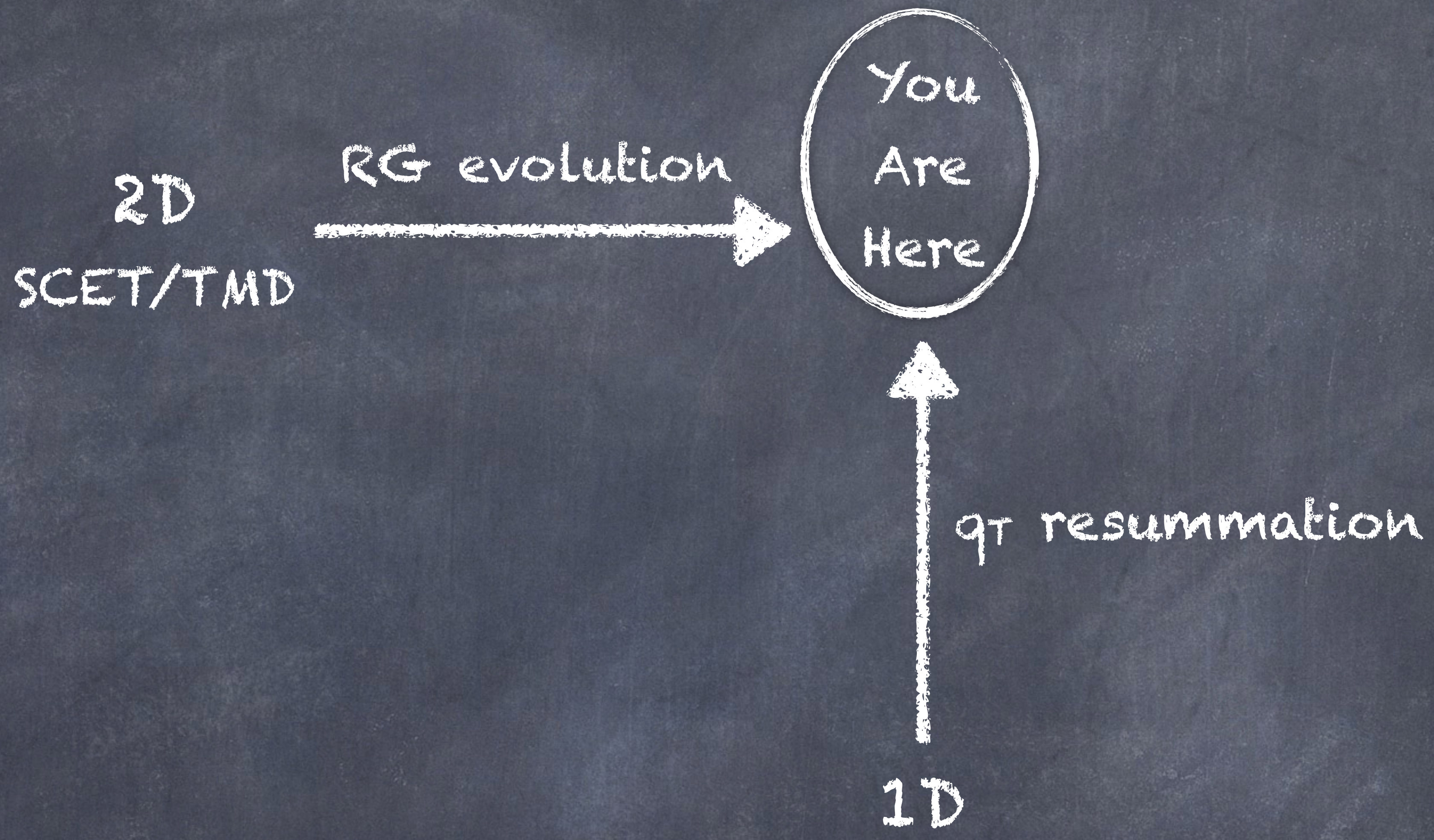

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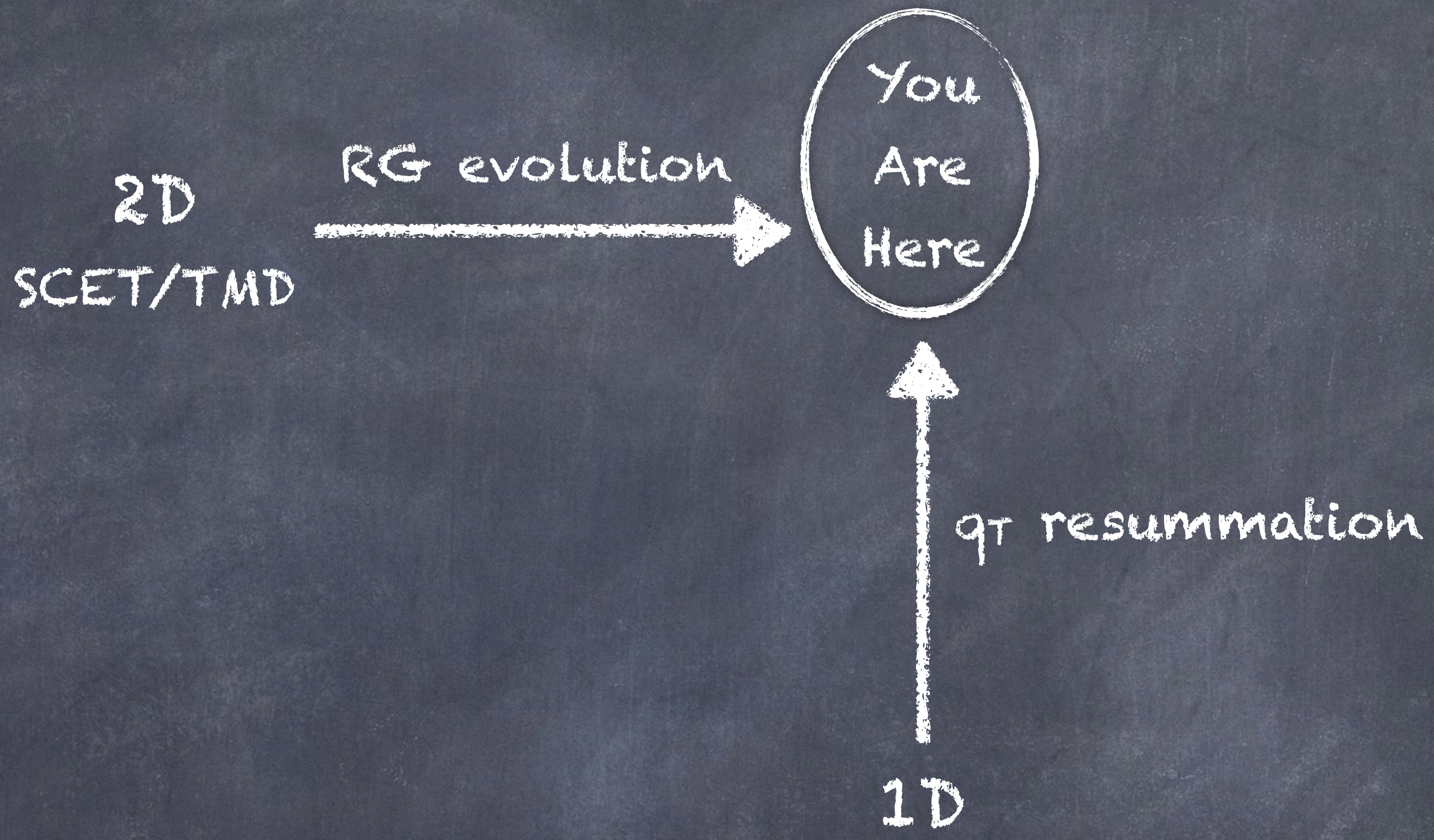

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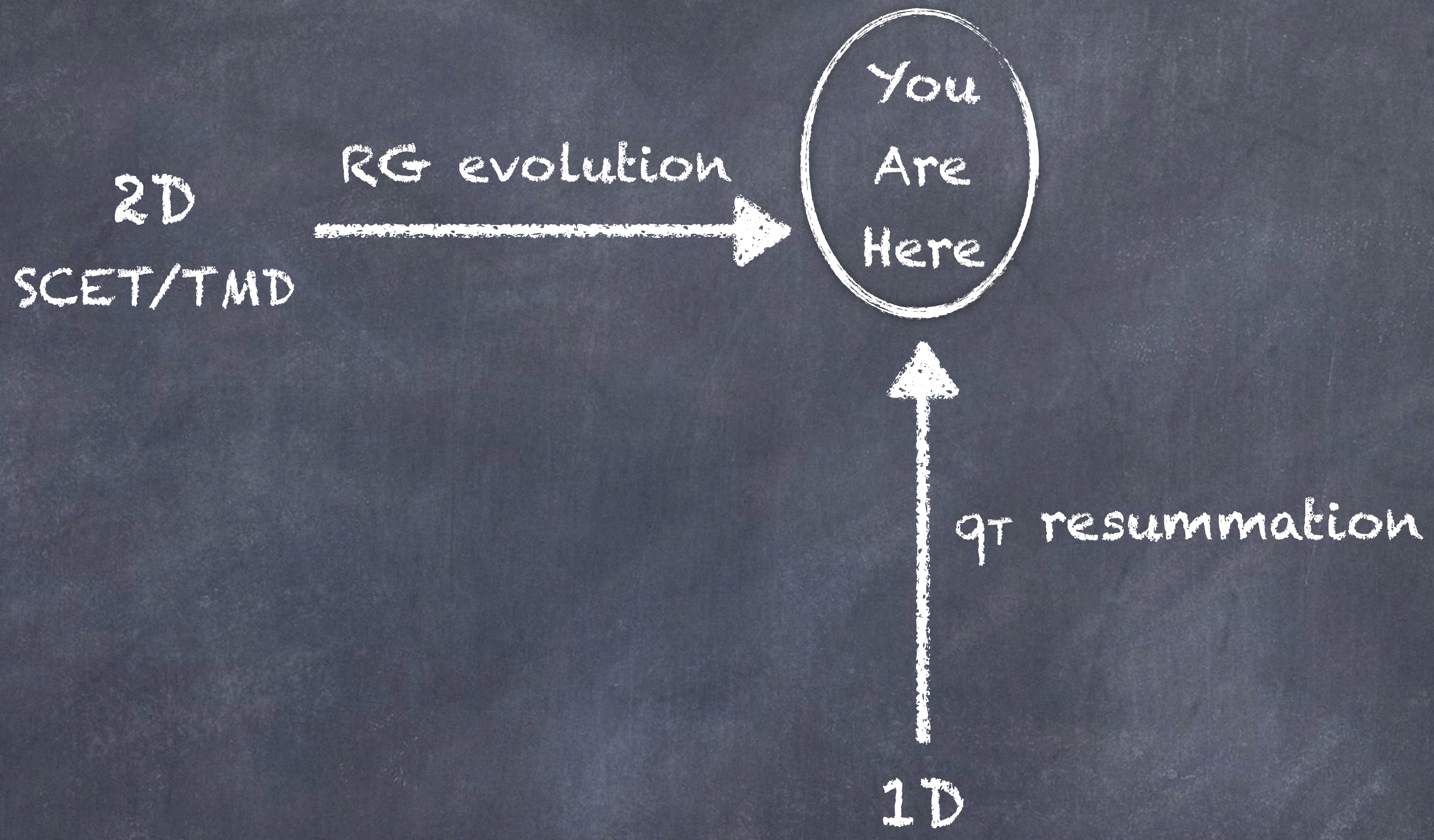

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necessary input:
RG evol. eq. needs initial condition
(to be determined from data)

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- possible to prove formal equivalence with b-space formalism at various accuracies

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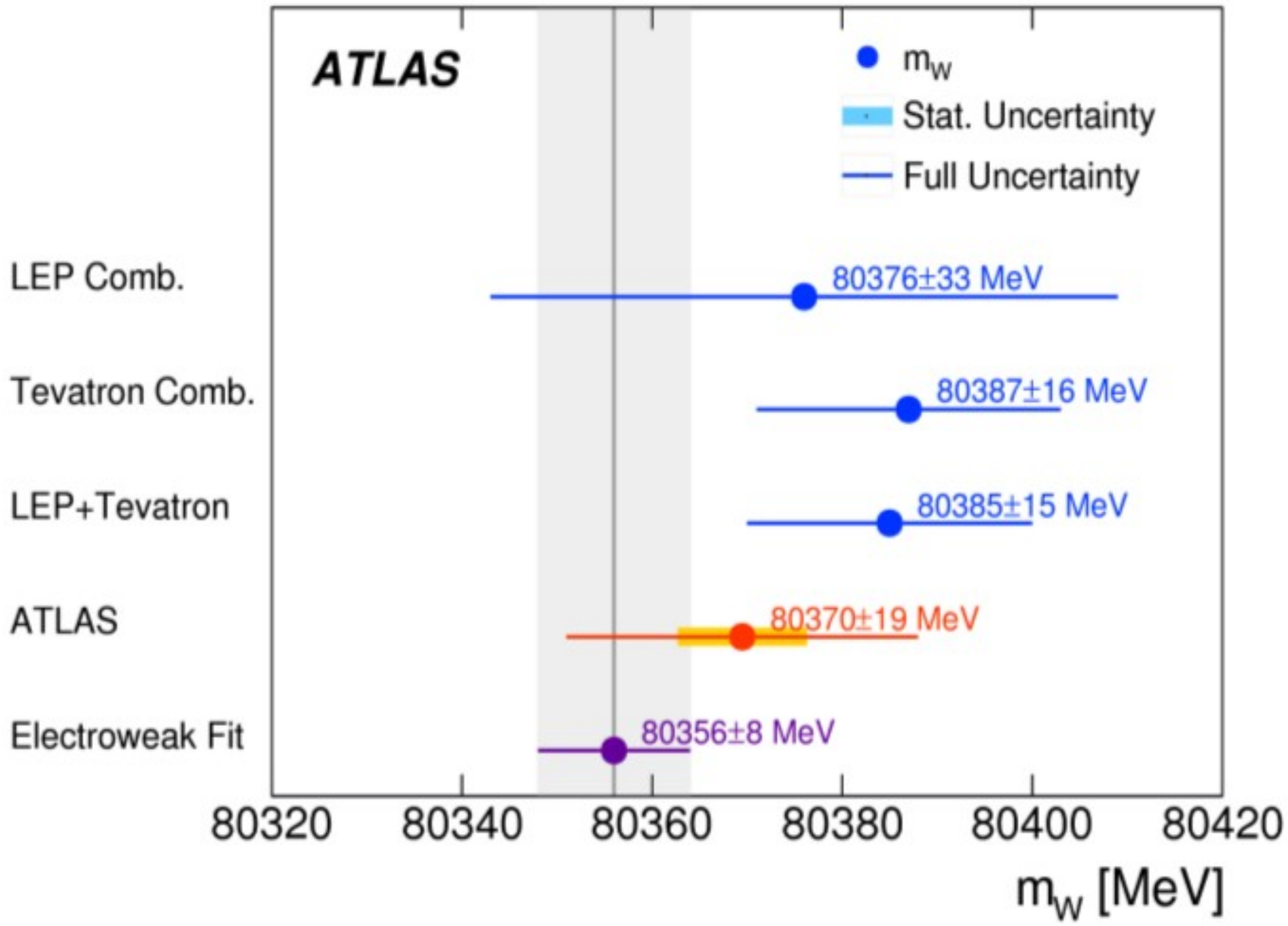
- lepton cuts

Impact on precision measurements at the LHC: the W mass case

in collaboration with:
A.Bacchetta (Pavia), M. Radici (Pavia), A. Signori (Argonne)

arXiv:1807.02101 - Phys.Lett. B788 (2019) 542-545

The *W* mass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Stat. Uncertainty
Full Uncertainty
LEP Comb.
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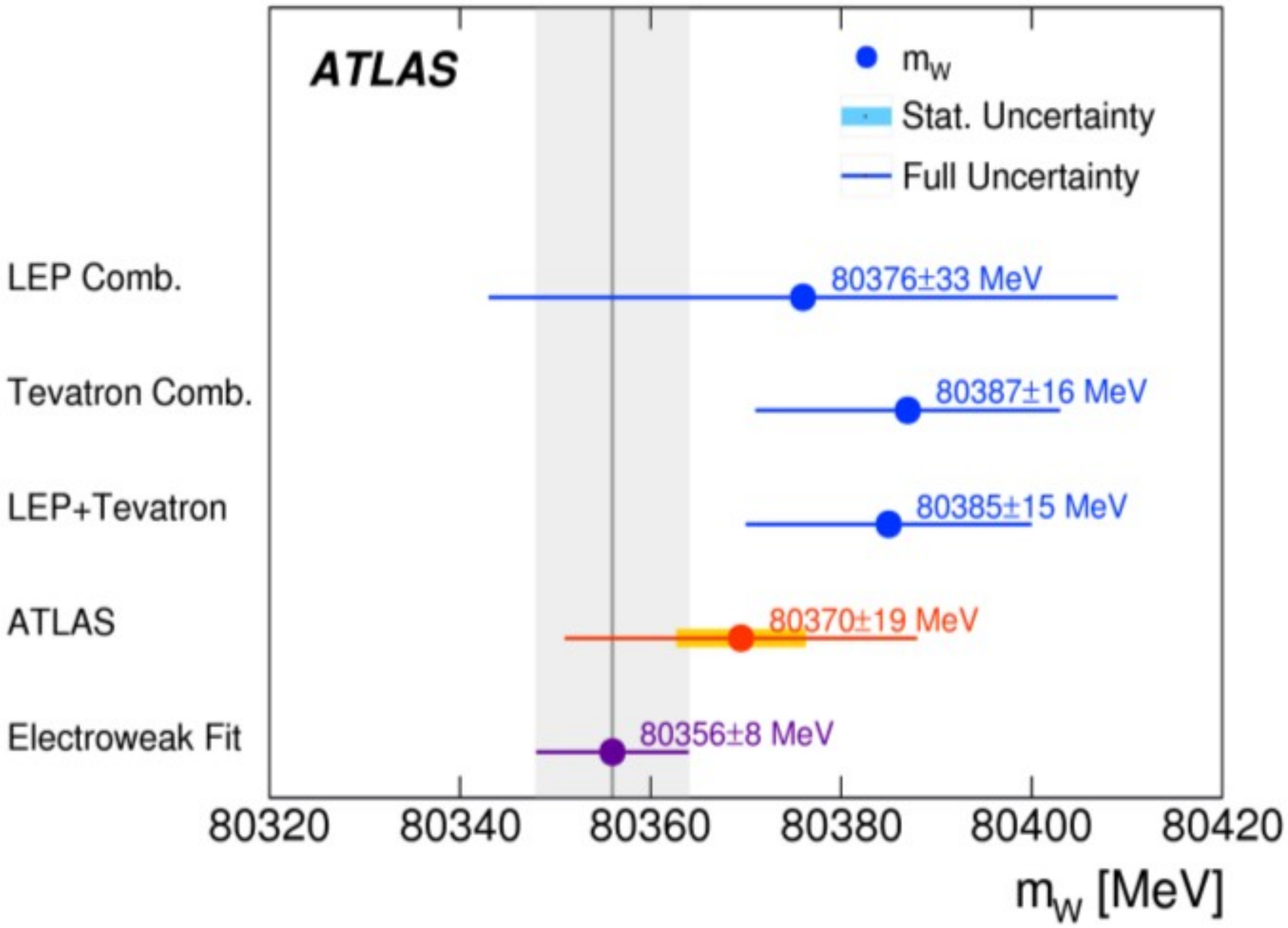

The determination of the *W*-boson mass from the global fit of the electroweak parameters has an uncertainty of 8 MeV, which sets a natural target for the precision of the experimental measurement of the mass of the *W* boson. The modelling uncertainties, which currently dominate the overall uncertainty on the m_W measurement presented in this note, need to be reduced in order to fully exploit the larger data samples available at centre-of-mass energies of 8 and 13 TeV. A better knowledge of the PDFs, as achievable with the inclusion in PDF fits of recent precise measurements of *W*- and *Z*-boson rapidity cross sections with the ATLAS detector [41], and improved QCD and electroweak predictions for Drell-Yan production, are therefore crucial for future measurements of the *W*-boson mass at the LHC.

ATLAS, EPJC 78, 110 (2018)

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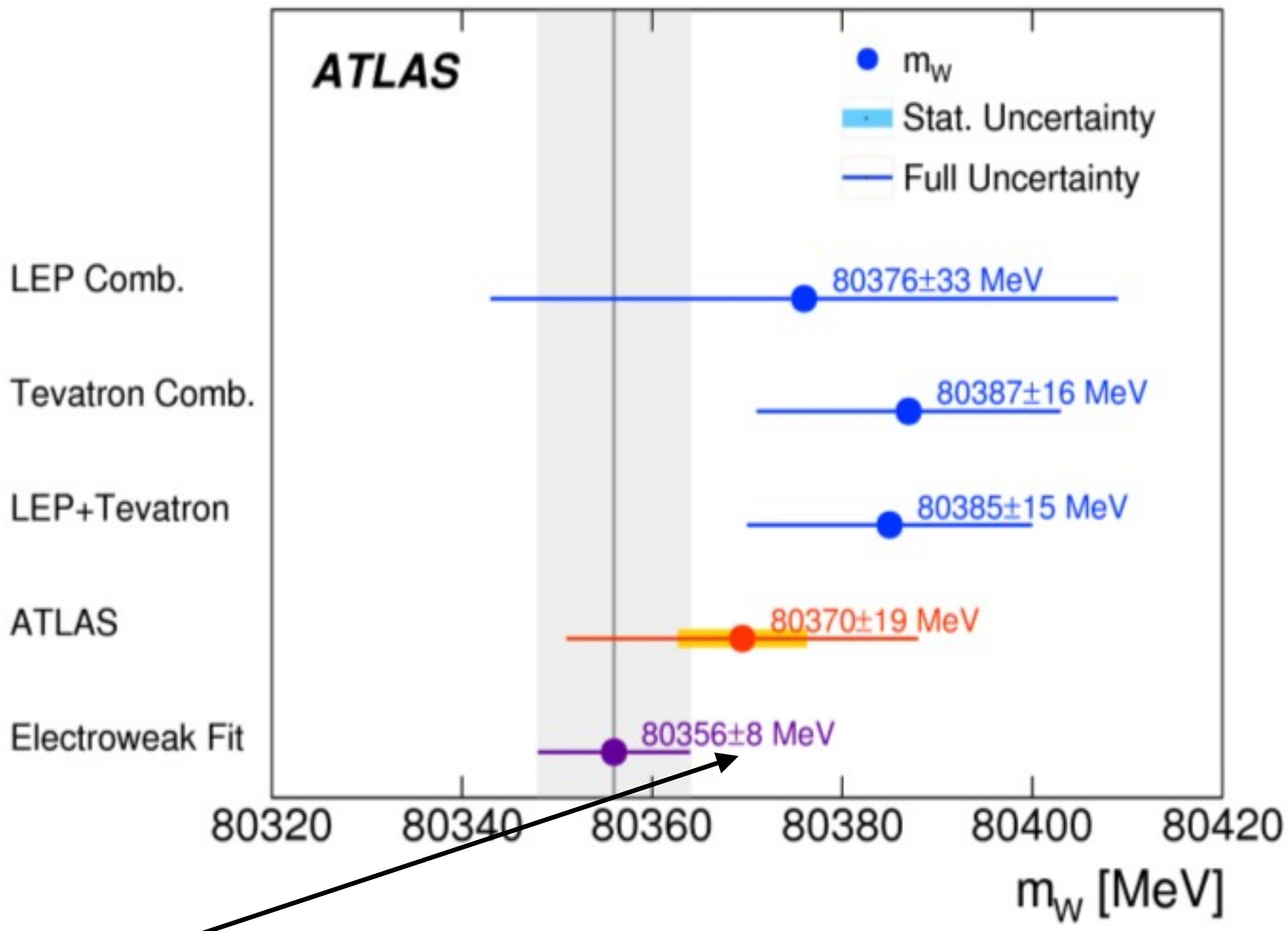

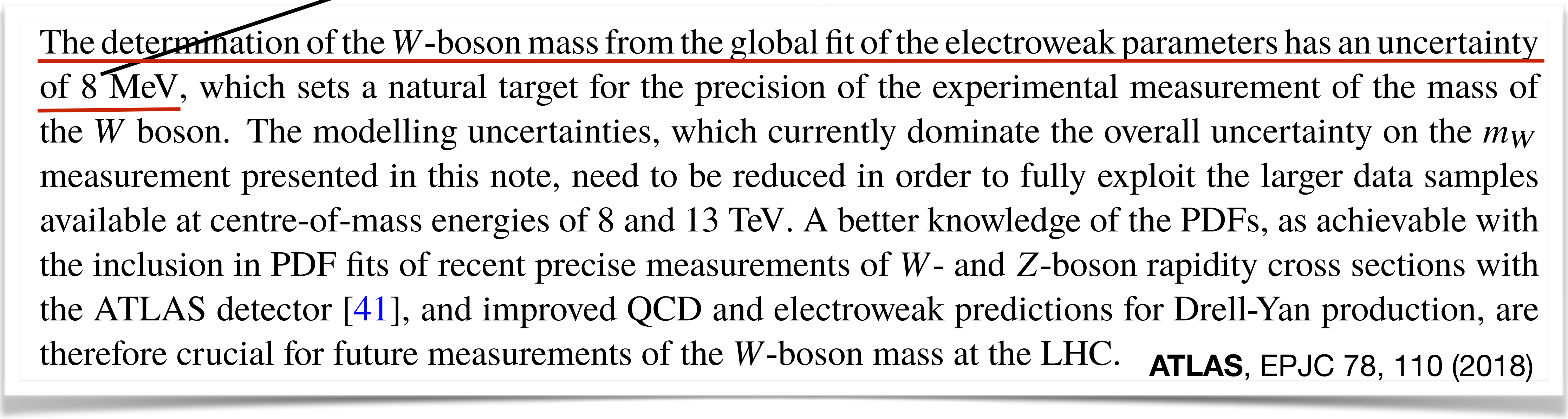
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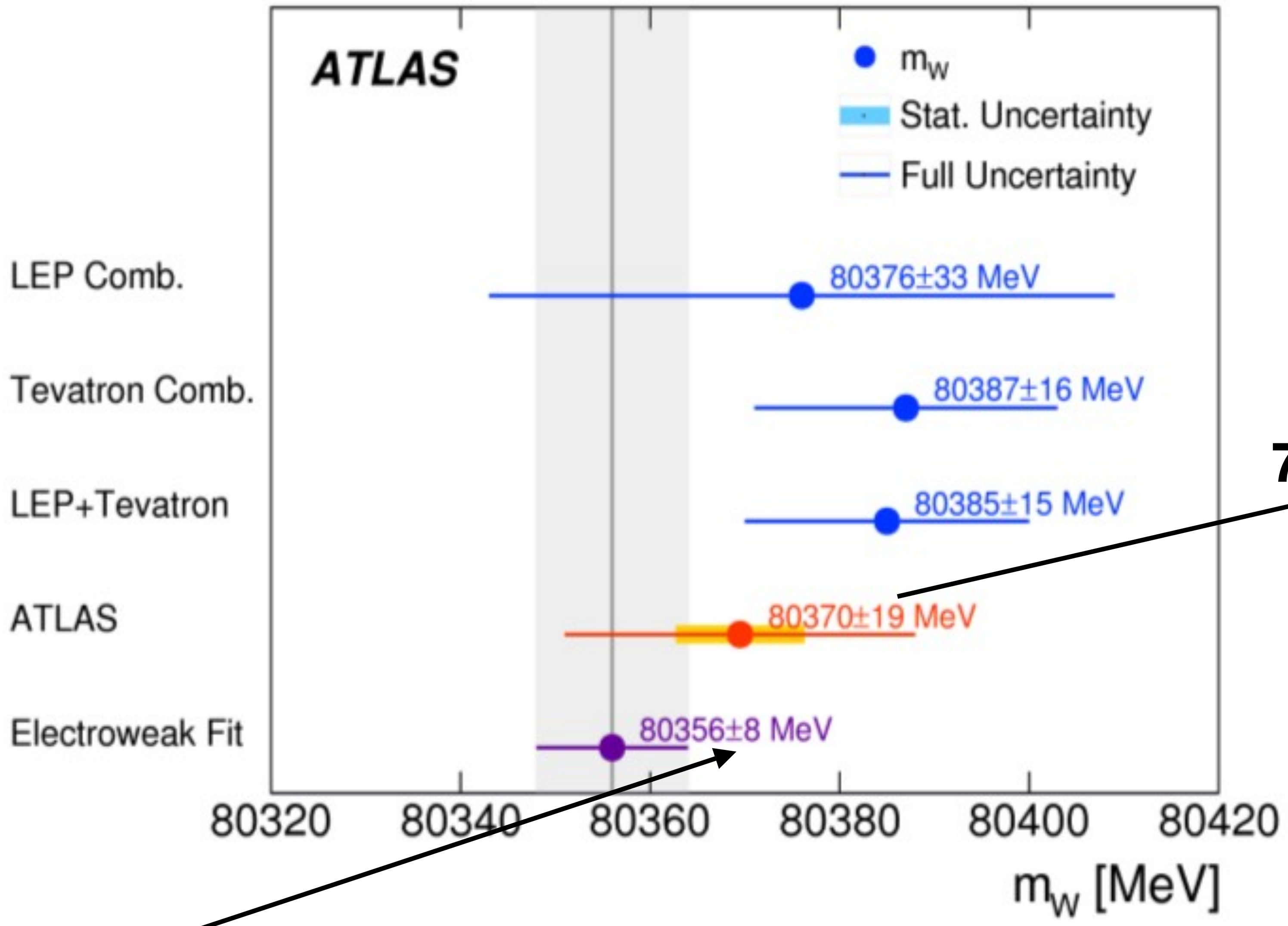
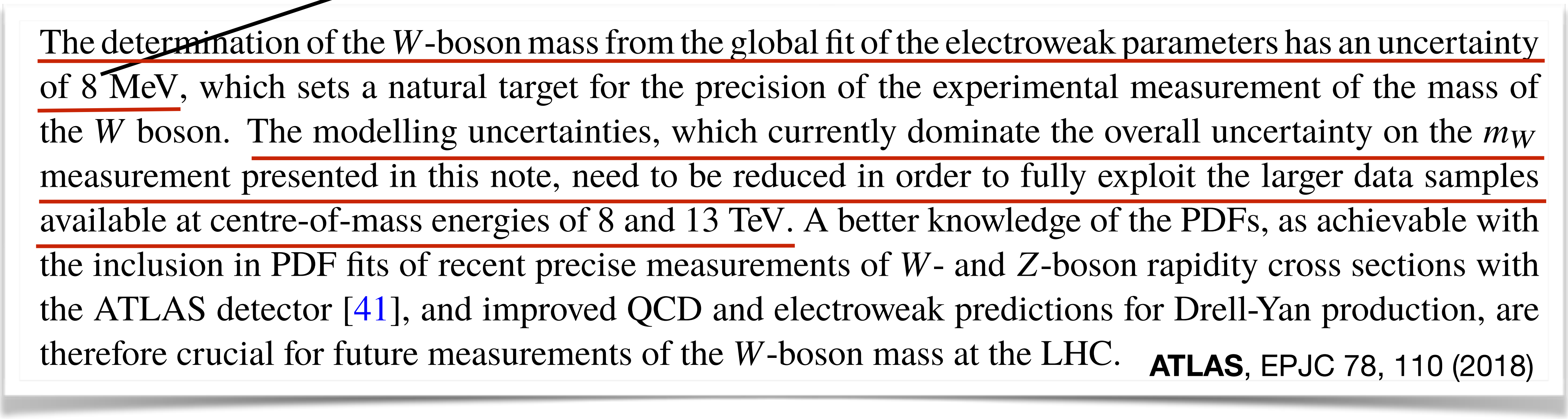


7 stat, 11 exp, 14 th



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  - M_W at hadron colliders as fitting parameter of a *template fit* procedure

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Template fit

1. generate several histograms with highest available theoretical accuracy and best possible detector simulation, and let the fit parameter (e.g. M_W) vary in a range

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Pseudo-Observables

- functions of cross sections and symmetries
- 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

Template fit

1. generate several histograms with highest available theoretical accuracy and best possible detector simulation, and let the fit parameter (e.g. M_W) vary in a range
2. the histogram that best describes data selects the preferred (*i.e. measured*) M_W

The extraction of physical quantities

Observables

- accessible via counting experiments: cross sections and asymmetries

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- functions of cross sections and symmetries
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  - M_Z at LEP as pole of the Breit-Wigner resonance factor
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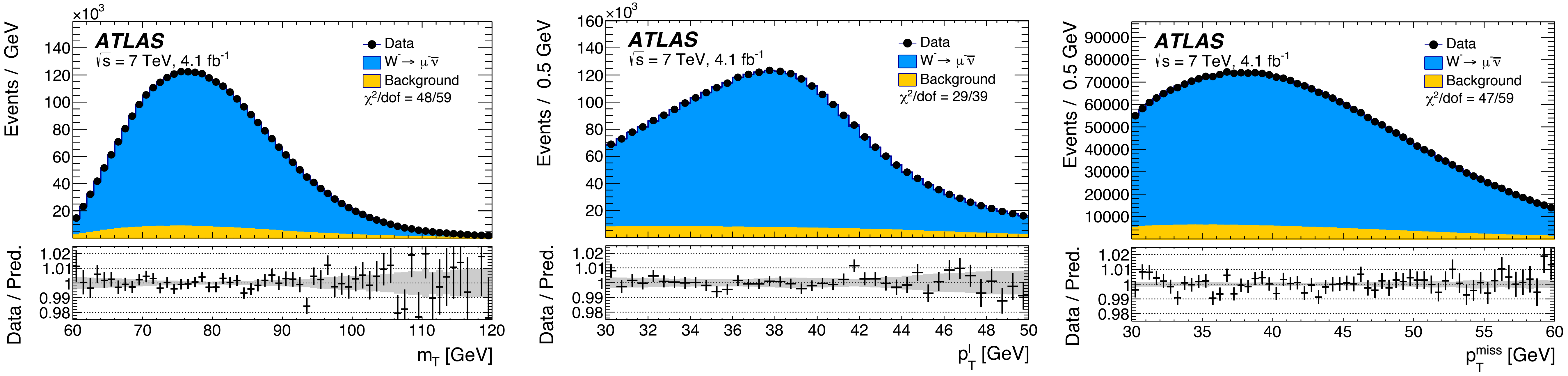
Template fit

1. generate several histograms with highest available theoretical accuracy and best possible detector simulation, and let the fit parameter (e.g. M_W) vary in a range
2. the histogram that best describes data selects the preferred (*i.e. measured*) M_W

➡ 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

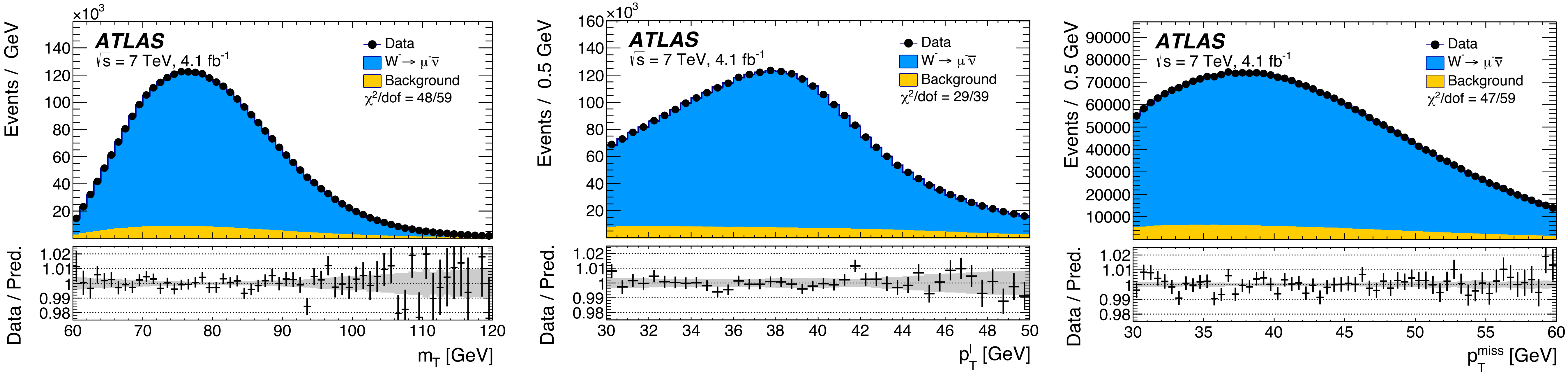
Observables and techniques



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

jacobian peak enhances sensitivity to M_W

Observables and techniques



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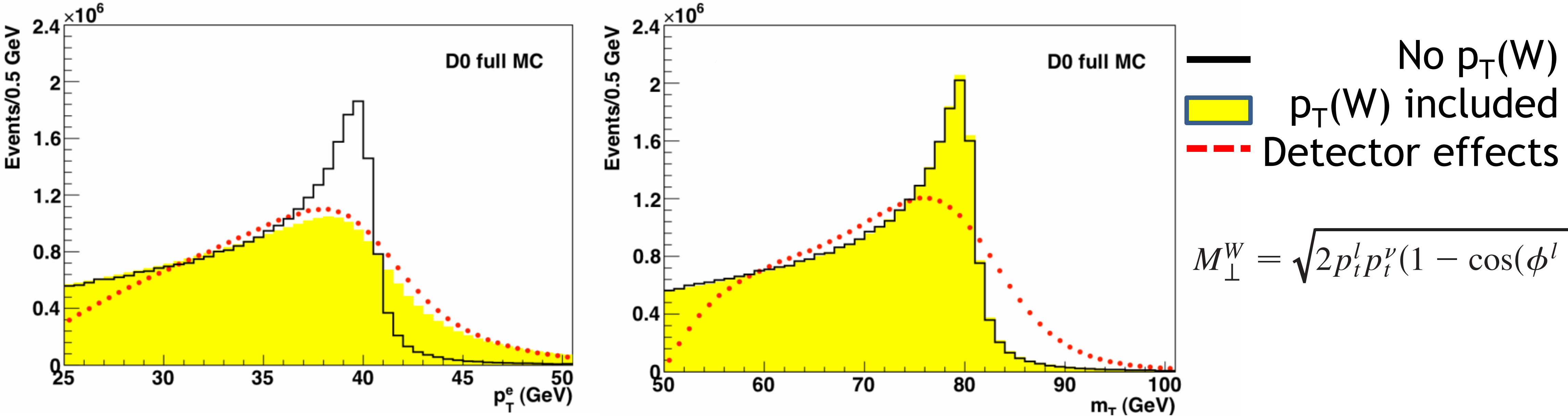
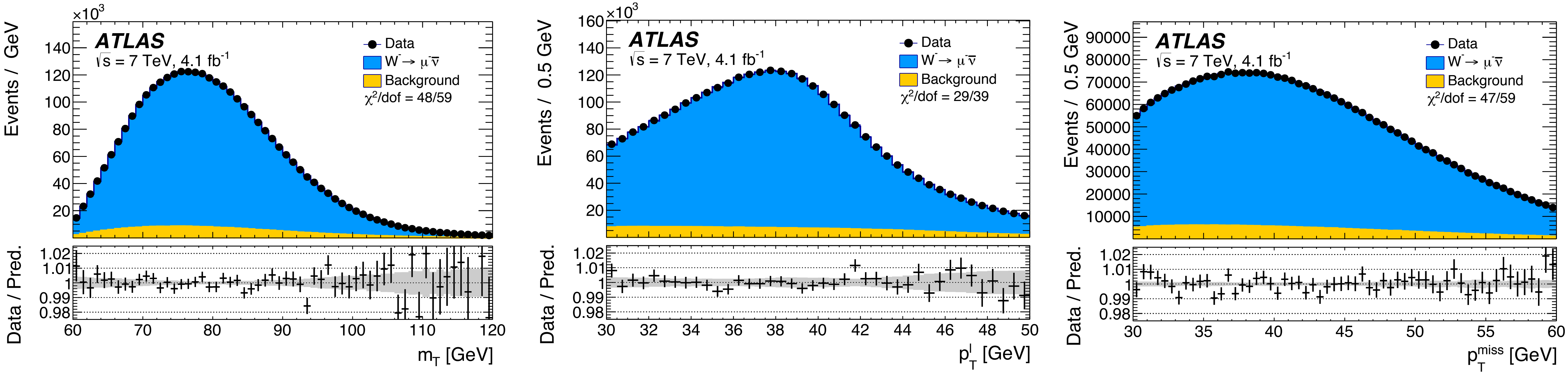


$$M_{\perp}^{W} = \sqrt{2p_t^l p_t^{\nu}(1 - \cos(\phi^l - \phi^{\nu}))},$$

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

Observables and techniques



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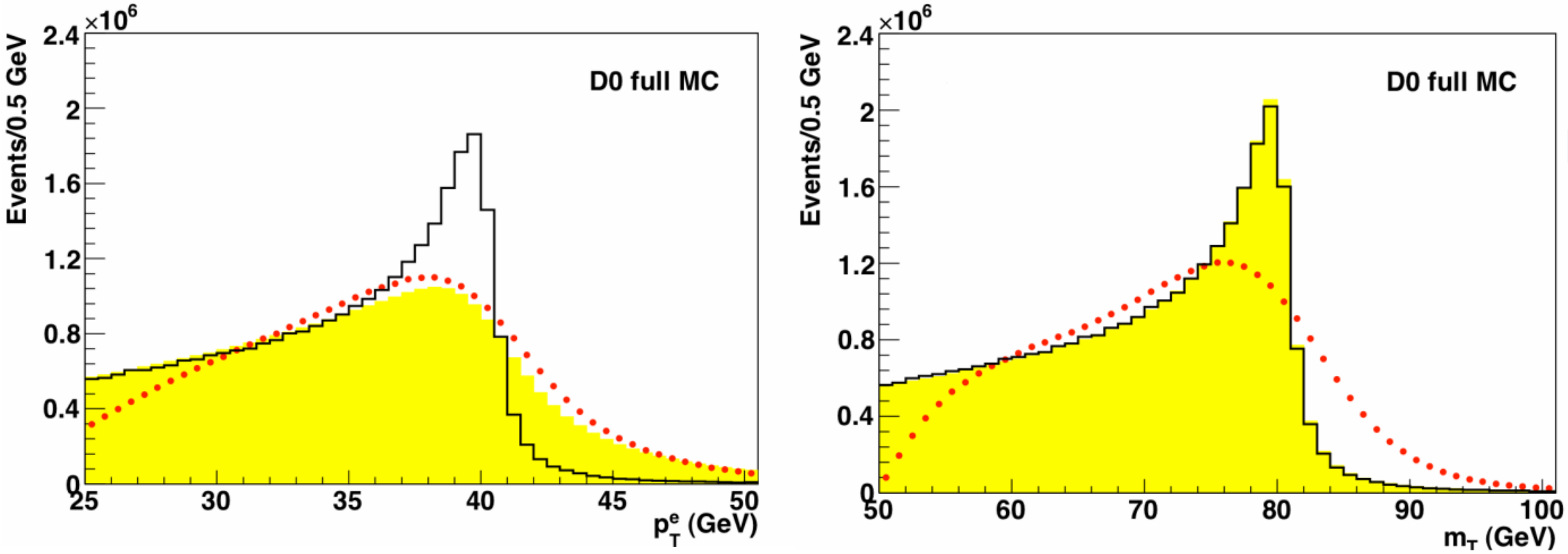


— No $p_T(W)$

🟨 $p_T(W)$ included

- - - Detector effects

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

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

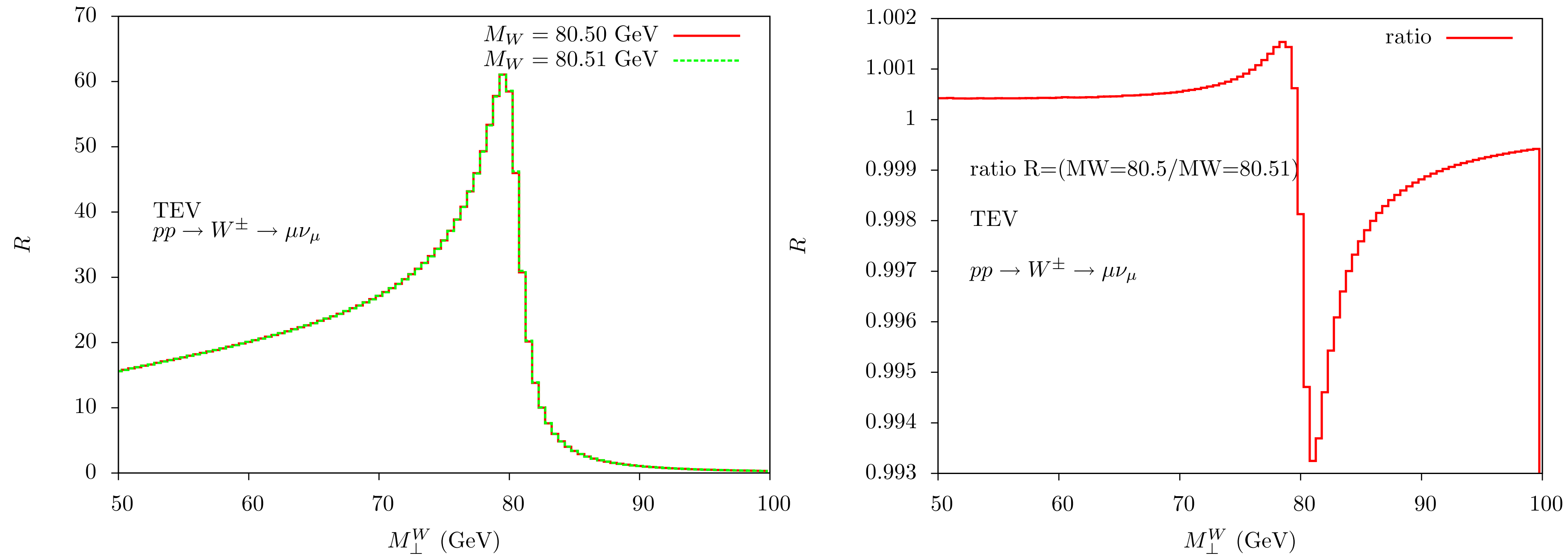
Lepton p_T: moderate detector smearing effects, extremely sensitive to p_{TW} modelling

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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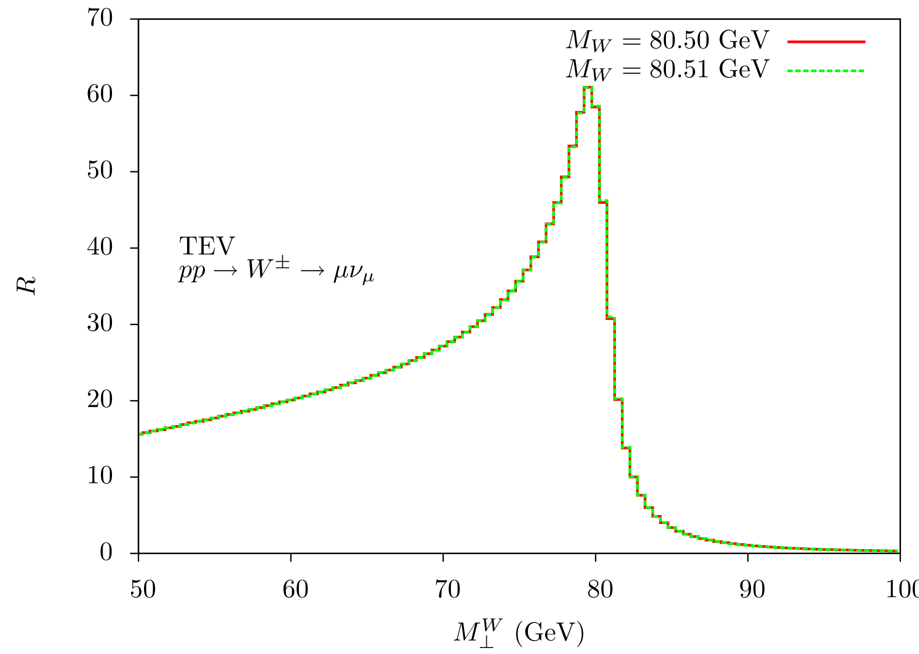
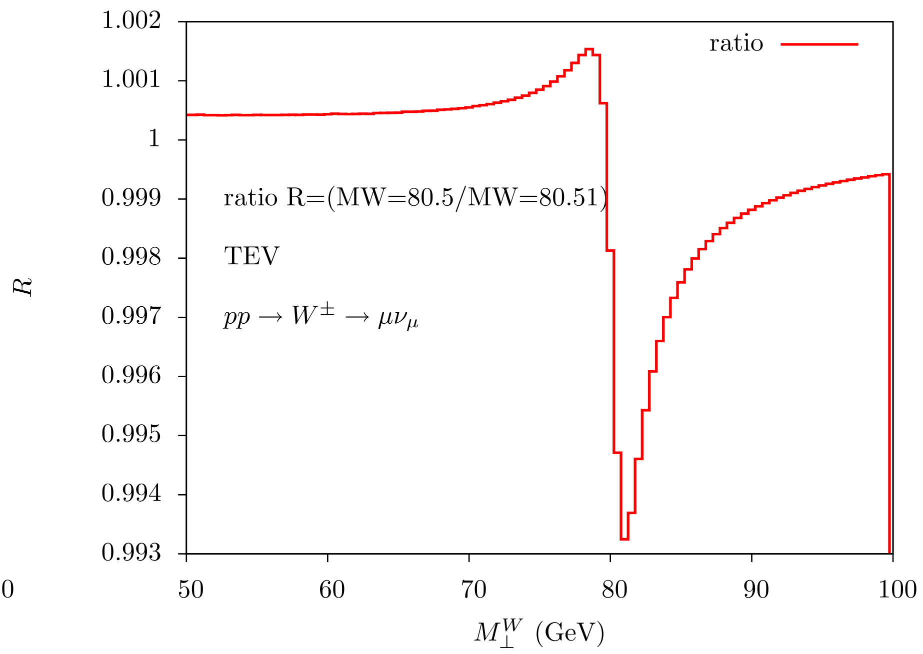
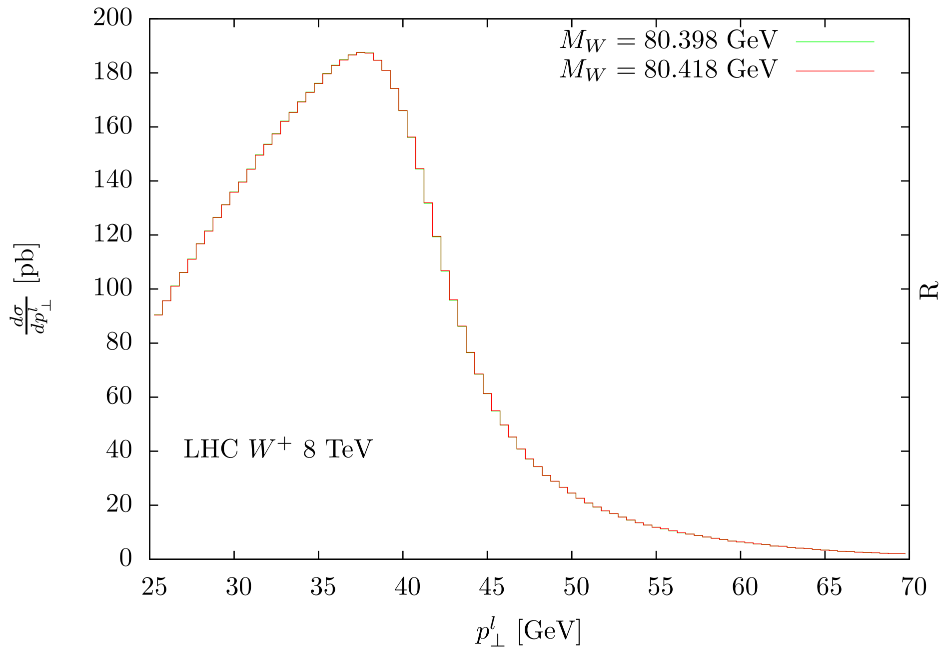
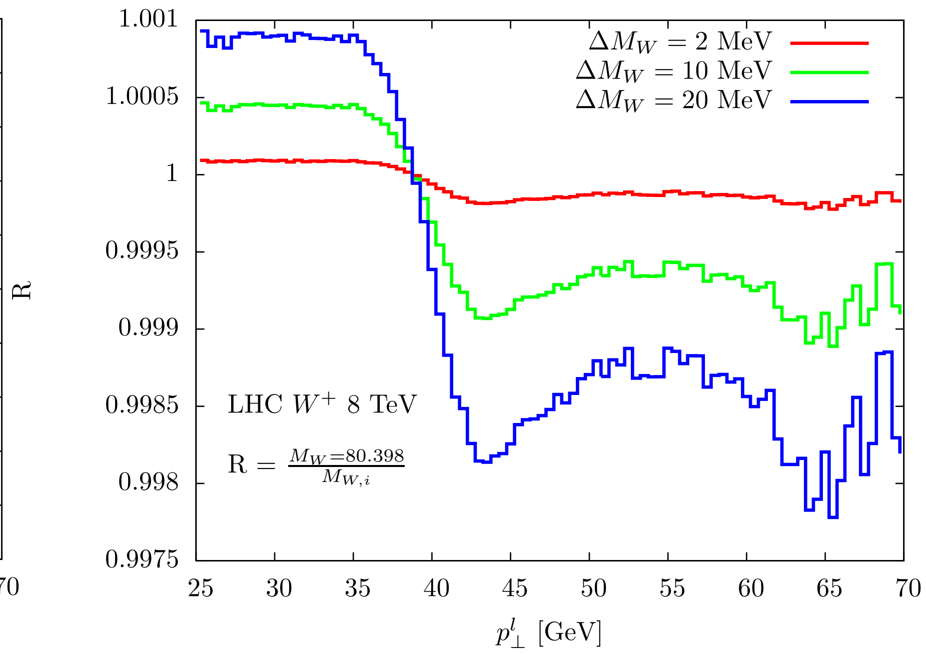




p_{Tl}





Template-fit estimate of theoretical uncertainties (ex:PDF)

Carloni Calame, Montagna, Nicrosini, Treccani PRD 69 (2004)
Bozzi, Rojo, Vicini PRD 83 (2011)
Bozzi, Citelli, Vicini PRD 91 (2015)
Bozzi, Citelli, Vesterinen, Vicini EPJC 75 (2015)

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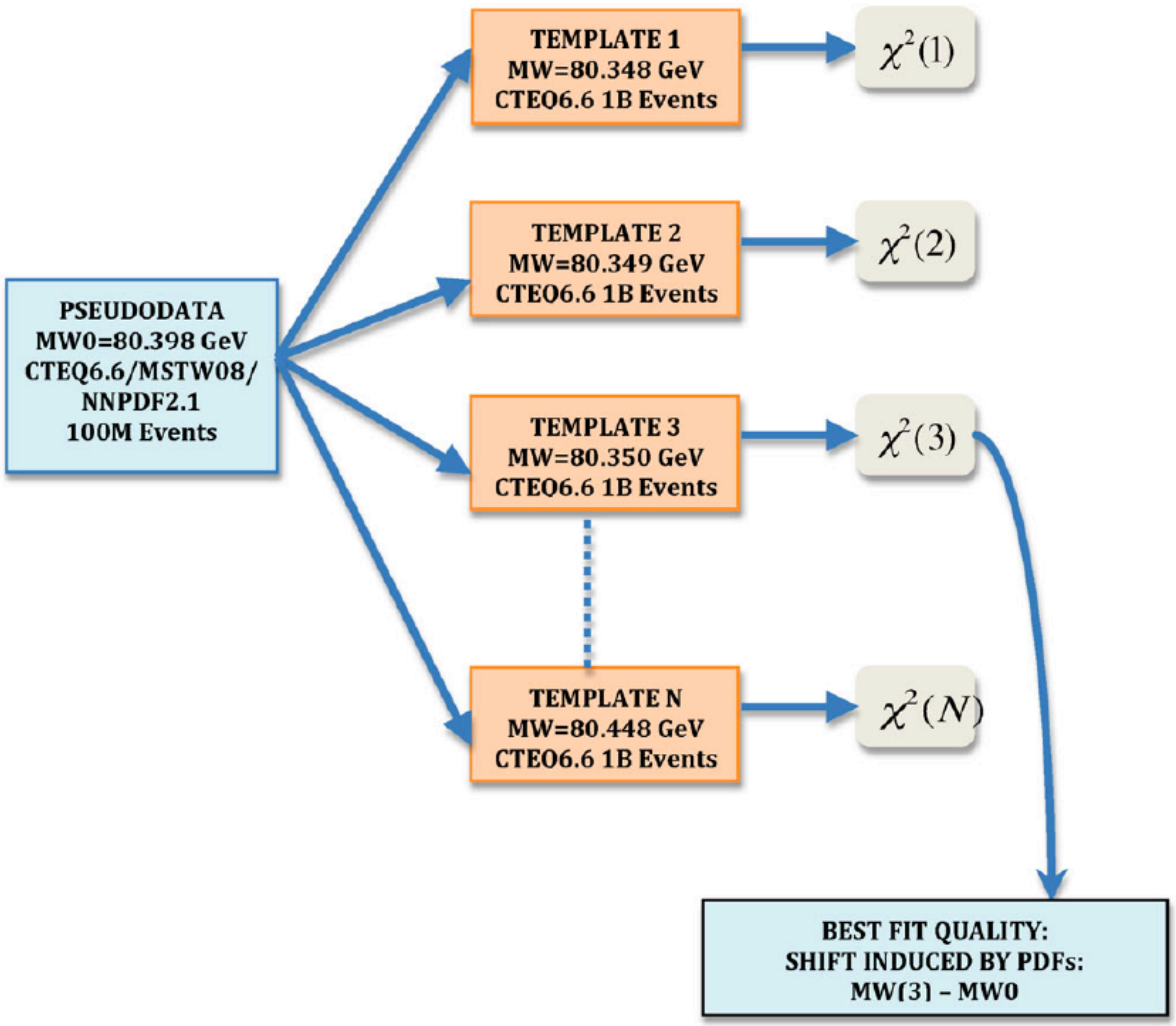
Bozzi, Citelli, Vicini PRD 91 (2015)
Bozzi, Citelli, Vesterinen, Vicini EPJC 75 (2015)

- **pseudodata** with different PDF sets: low-statistics (100M) and fixed M_{W0}
- **templates** with a reference PDF set (CTEQ6.6): high-statistics (1B) and different M_W
- same code used to generate both pseudodata and templates → only effect probed is the PDF one



PSEUDODATA
MW0=80.398 GeV
CTEQ6.6/MSTW08/
NNPDF2.1
100M Events

TEMPLATE 1
MW=80.348 GeV
CTEQ6.6 1B Events

TEMPLATE 2
MW=80.349 GeV
CTEQ6.6 1B Events

TEMPLATE 3
MW=80.350 GeV
CTEQ6.6 1B Events

TEMPLATE N
MW=80.448 GeV
CTEQ6.6 1B Events

$\chi^2(1)$

$\chi^2(2)$

$\chi^2(3)$

$\chi^2(N)$

BEST FIT QUALITY:
SHIFT INDUCED BY PDFs:
MW(3) – MW0

p_{TW} and the modelling of intrinsic k_T

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- $p_{Tl} \Leftarrow p_{TW} \Leftarrow$ QCD initial state radiation + intrinsic k_T

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- Intrinsic k_T effects measured on Z data and used to predict W distributions, *assuming universality*

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but

different flavour structure

different phase space available

p_{TW} and the modelling of intrinsic k_T

- p_{Tl} ⇦ p_{TW} ⇦ QCD initial state radiation + intrinsic k_T
- Intrinsic k_T effects measured on Z data and used to predict W distributions, *assuming universality*

but

different flavour structure

different phase space available

—> *different Gaussian factors for different flavours*

$$f_1^{aNP}(b_T^2) \propto e^{-g_{NP}^a b_T^2}$$

Flavor and ~~kinematic~~ dependent widths

p_{TW} and the modelling of intrinsic k_T

- p_{Tl} ⇦ p_{TW} ⇦ QCD initial state radiation + intrinsic k_T
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—> *different Gaussian factors for different flavours*

$$f_1^{aNP}(b_T^2) \propto e^{-g_{NP}^a b_T^2}$$

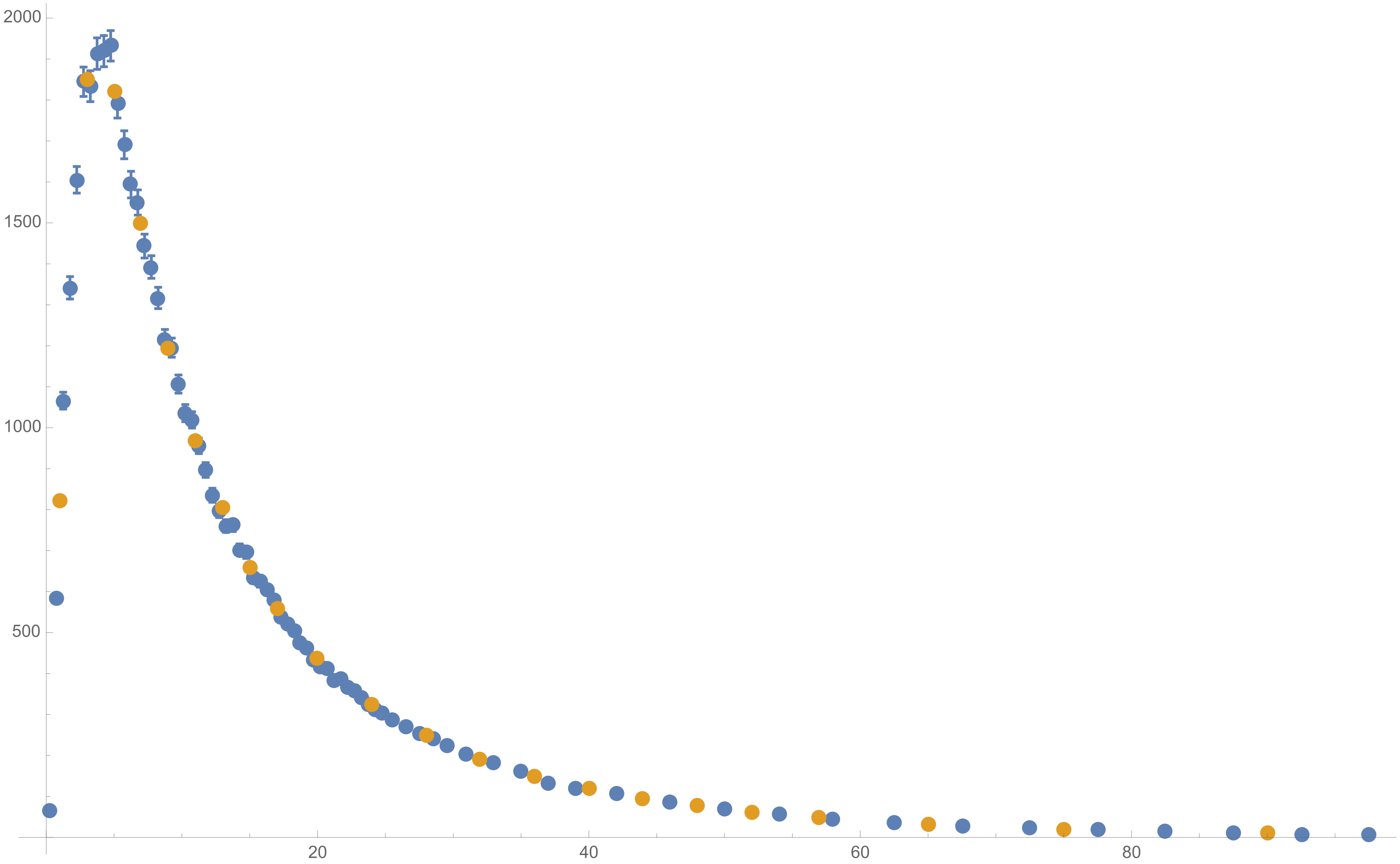
Flavor and ~~kinematic~~ dependent widths

We consider :

- **50 flavour-dependent sets** $\{g_{NP}^{u_v}, g_{NP}^{d_v}, g_{NP}^{u_s}, g_{NP}^{d_s}, g_{NP}^{s}\}$ with $g_{NP}^a \in [0.2, 0.6]\ \mathrm{GeV}^2$
- **1 flavour-independent set** with $g_{NP}^a = 0.4\ \mathrm{GeV}^2$

“Z-equivalent” sets

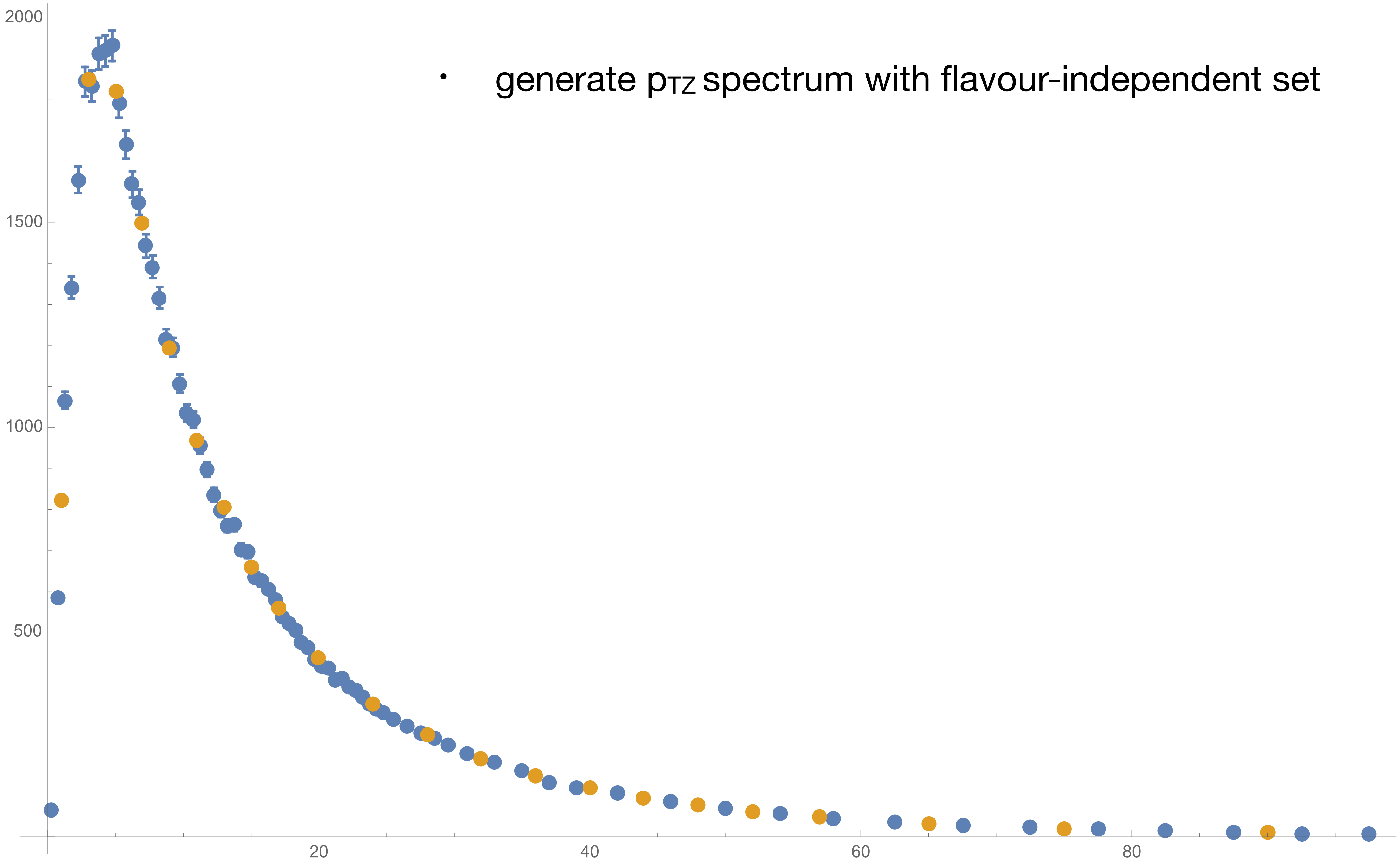
“Z-equivalent” sets



NLL+LO QCD curves obtained through a modified version of the
DYqT code [Bozzi, Catani, deFlorian, Ferrera, Grazzini (2009,2011)]
(Tevatron 1.96 TeV & LHC 7 TeV)

“Z-equivalent” sets

- generate p_{TZ} spectrum with flavour-independent set



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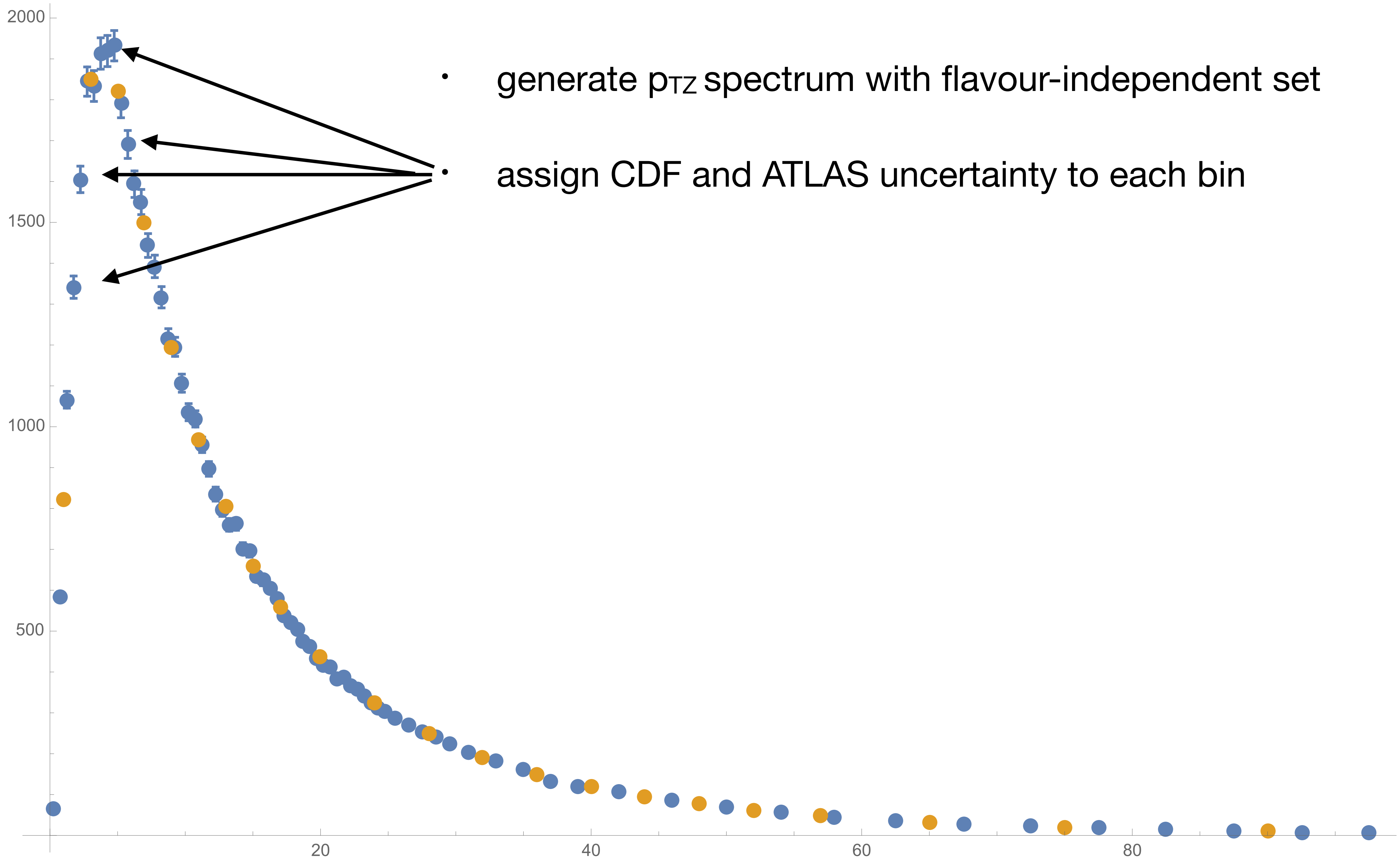

- generate p_{TZ} spectrum with flavour-independent set
- assign CDF and ATLAS uncertainty to each bin

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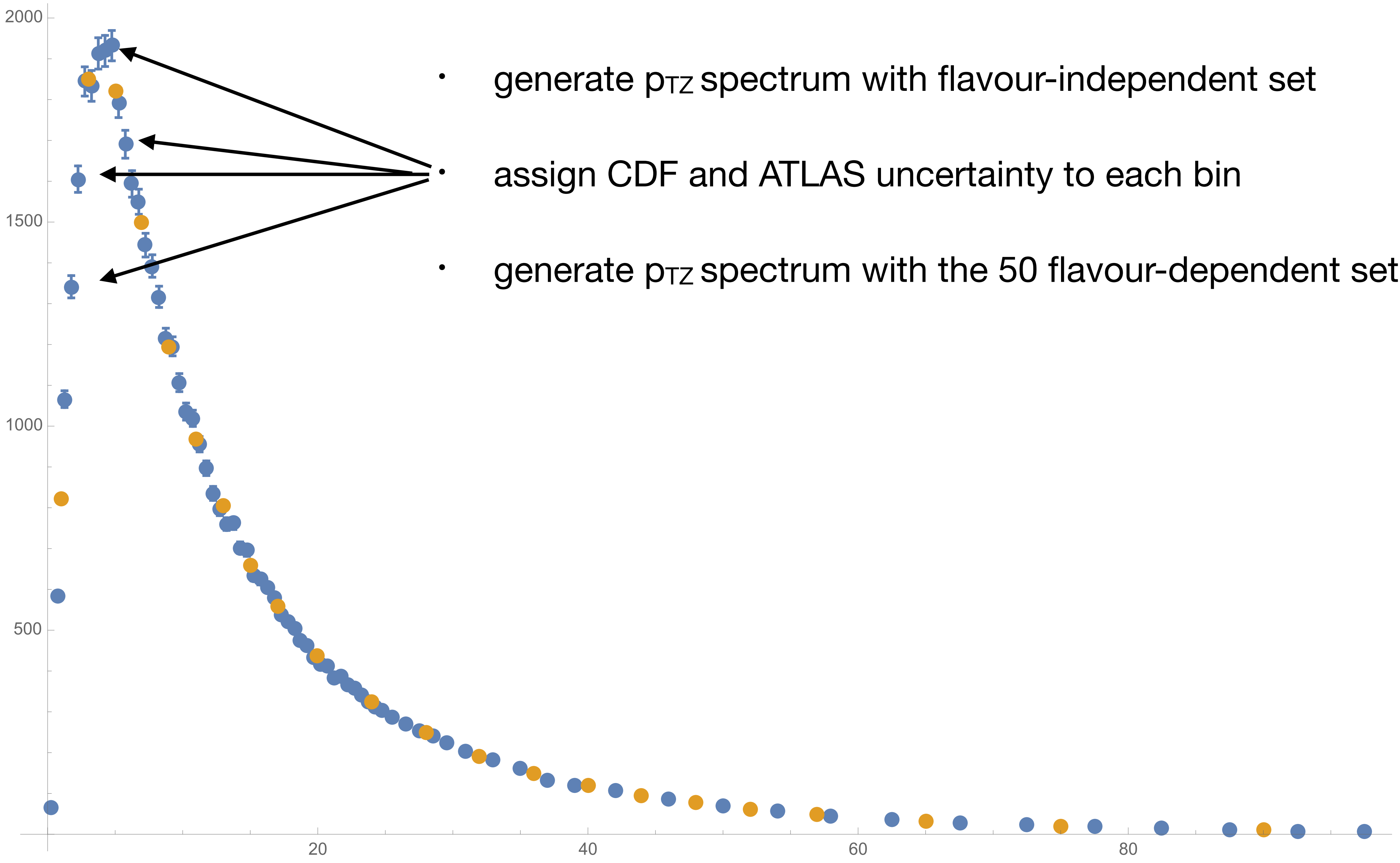

- generate p_{TZ} spectrum with flavour-independent set
- assign CDF and ATLAS uncertainty to each bin
- generate p_{TZ} spectrum with the 50 flavour-dependent sets

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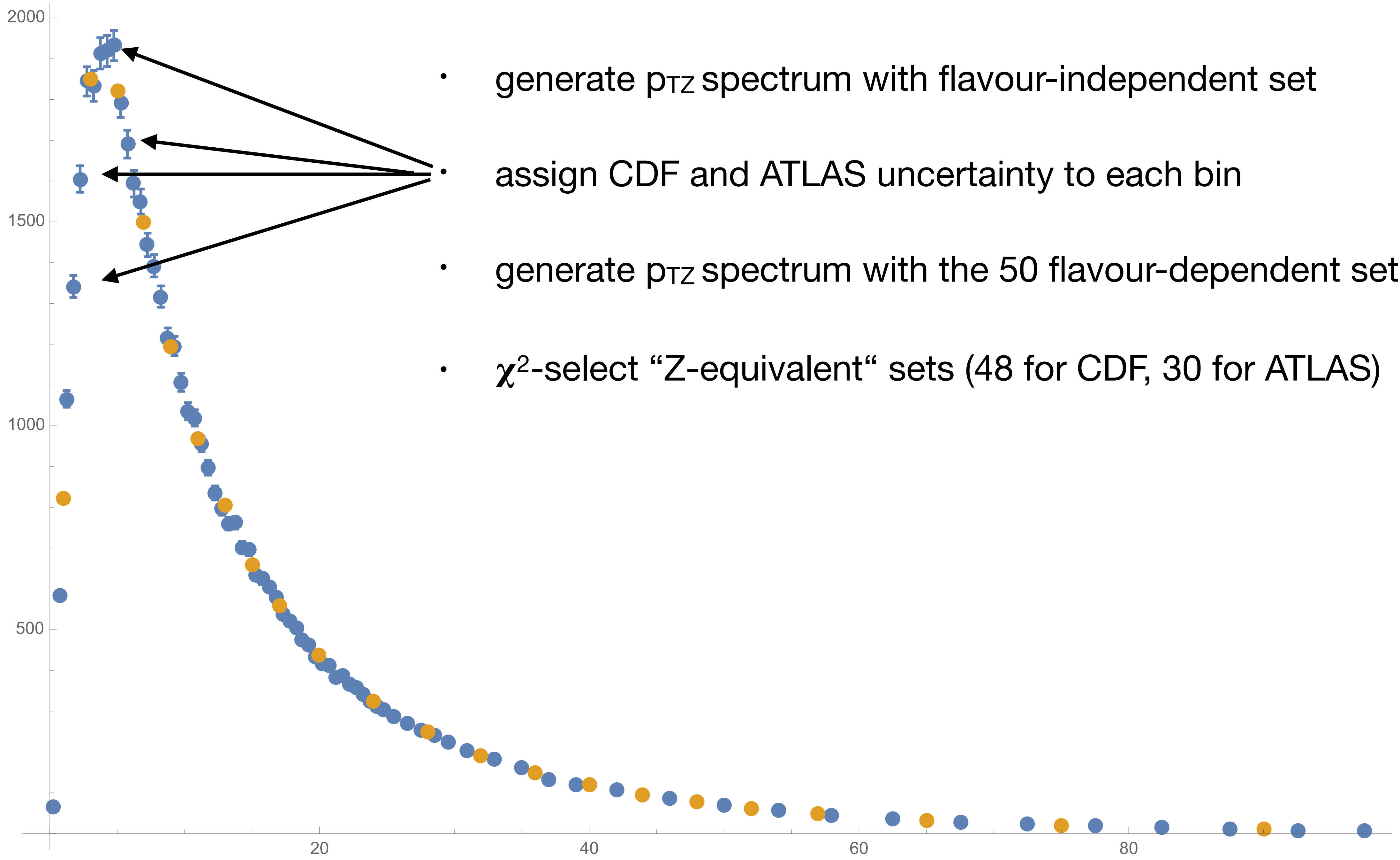

- generate p_{TZ} spectrum with flavour-independent set
- assign CDF and ATLAS uncertainty to each bin
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- χ^2-select “Z-equivalent“ sets (48 for CDF, 30 for ATLAS)

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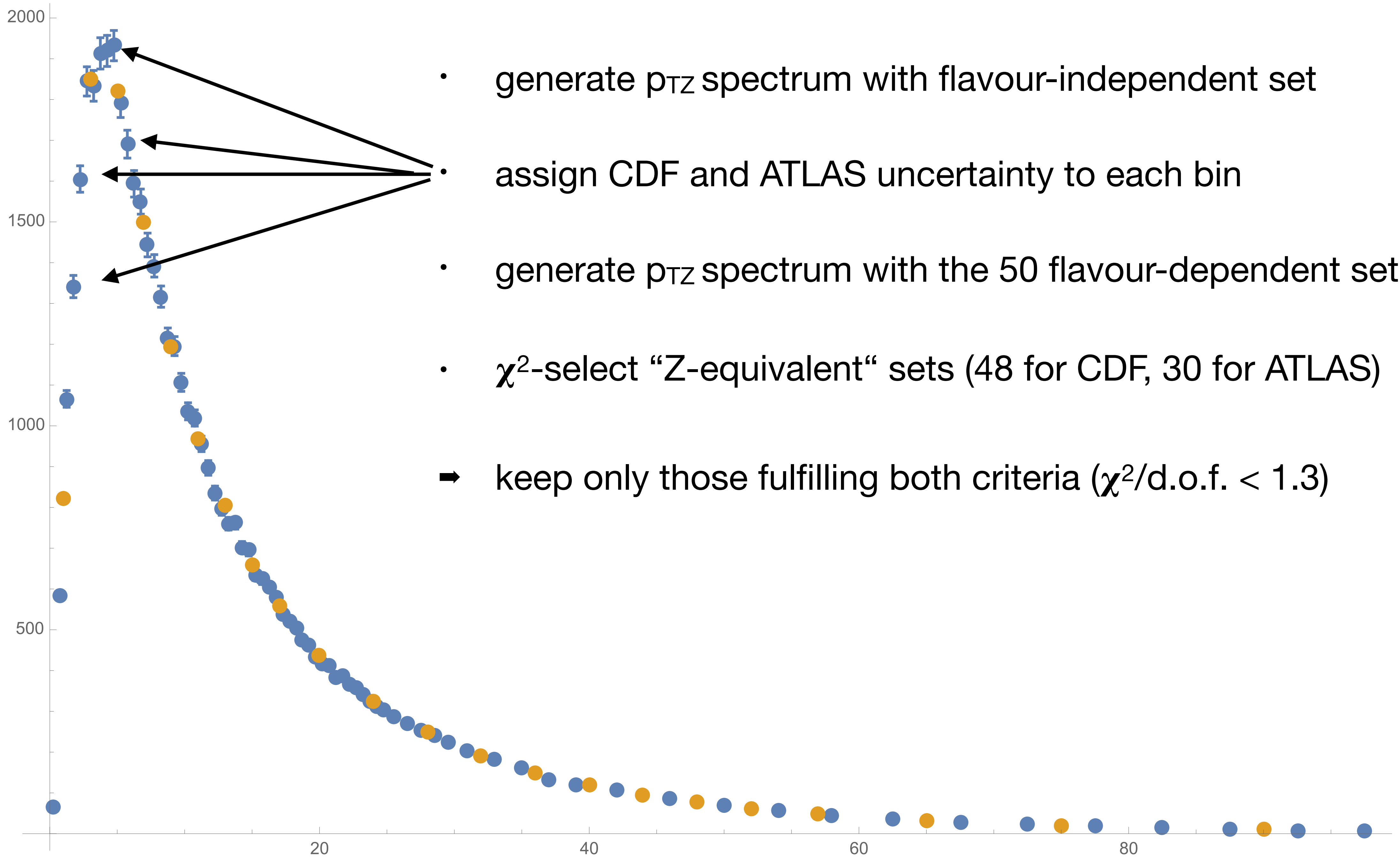

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- assign CDF and ATLAS uncertainty to each bin
- generate p_{TZ} spectrum with the 50 flavour-dependent sets
- χ^2-select “Z-equivalent“ sets (48 for CDF, 30 for ATLAS)

➡ keep only those fulfilling both criteria (χ^2/d.o.f. < 1.3)

NLL+LO QCD curves obtained through a modified version of the
DYqT code [Bozzi, Catani, deFlorian, Ferrera, Grazzini (2009,2011)]
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Impact on the determination of M_W

Impact on the determination of M_W

- Take the “Z-equivalent” *flavour-dependent* parameter sets and compute *low-statistics* (135M) m_T, p_{Tl}, p_{Tn} distributions

Impact on the determination of M_W

- Take the “Z-equivalent” *flavour-dependent* parameter sets and compute *low-statistics* (135M) m_T, p_{Tl}, p_{Tn} distributions

➡ **pseudodata**

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- Take the *flavour-independent* parameter set and compute *high-statistics* (750M) m_T, p_{Tl}, p_{Tn} distributions for 30 different values of M_W

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	ΔM_{W+}			ΔM_{W-}		
Set	m_T	$p_{T\ell}$	$p_{T\nu}$	m_T	$p_{T\ell}$	$p_{T\nu}$
1	0	-1	-2	-2	3	-3
2	0	-6	0	-2	0	-5
3	-1	9	0	-2	4	-10
4	0	0	-2	-2	-4	-10
5	0	4	1	-1	-3	-6
6	1	0	2	-1	4	-4
7	2	-1	2	-1	0	-8
8	0	2	8	1	7	8
9	0	4	-3	-1	0	7

TABLE I: ATLAS 7 TeV

	ΔM_{W+}			ΔM_{W-}		
Set	m_T	$p_{T\ell}$	$p_{T\nu}$	m_T	$p_{T\ell}$	$p_{T\nu}$
1	-1	-5	7	-1	-3	8
2	-1	-15	6	0	5	10
3	-1	1	8	-1	-7	5
4	-1	-15	6	0	-4	5
5	-1	-4	6	-1	-7	5
6	-1	-5	7	0	2	9
7	-1	-15	6	-1	-6	5
8	-1	0	8	0	3	10
9	-1	-7	7	0	4	10

TABLE II: LHCb 13 TeV

Set	u_v	d_v	u_s	d_s	s
1	0.34	0.26	0.46	0.59	0.32
2	0.34	0.46	0.56	0.32	0.51
3	0.55	0.34	0.33	0.55	0.30
4	0.53	0.49	0.37	0.22	0.52
5	0.42	0.38	0.29	0.57	0.27
6	0.40	0.52	0.46	0.54	0.21
7	0.22	0.21	0.40	0.46	0.49
8	0.53	0.31	0.59	0.54	0.33
9	0.46	0.46	0.58	0.40	0.28

NLL+LO QCD analysis obtained through a modified version of the **DYRes** code [Catani, deFlorian, Ferrera, Grazzini (2015)]

Statistical uncertainty: 2.5 MeV

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3	-1	9	0	-2	4	-10
4	0	0	-2	-2	-4	-10
5	0	4	1	-1	-3	-6
6	1	0	2	-1	4	-4
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3	-1	1	8	-1	-7	5
4	-1	-15	6	0	-4	5
5	-1	-4	6	-1	-7	5
6	-1	-5	7	0	2	9
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Set	u_v	d_v	u_s	d_s	s
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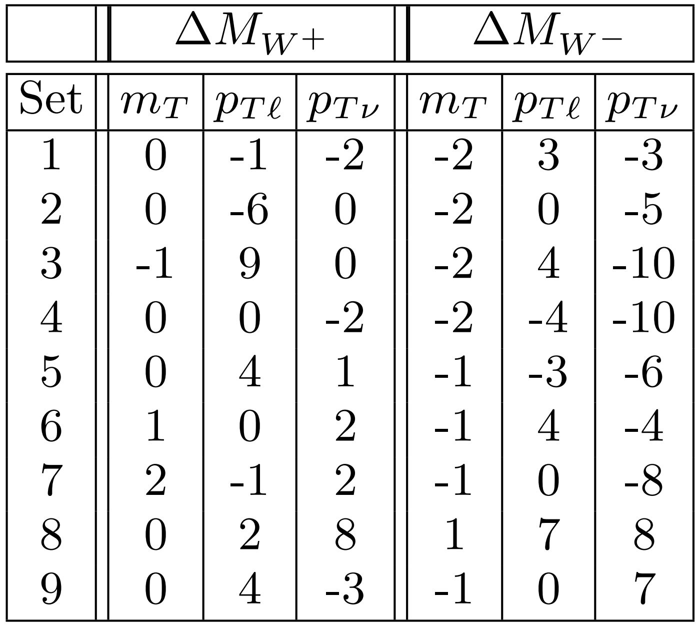
- lepton pt: quite important shifts (envelope **up to 15 MeV**)

- neutrino pt: same order of magnitude (or bigger) as lepton pt



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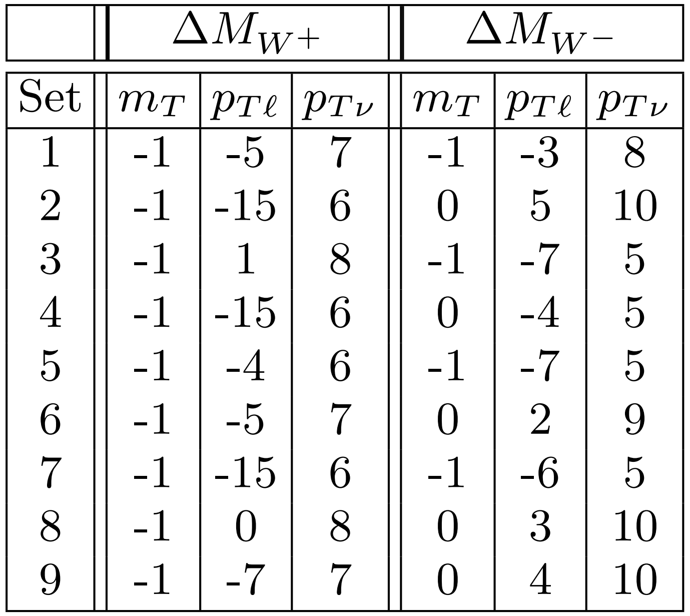
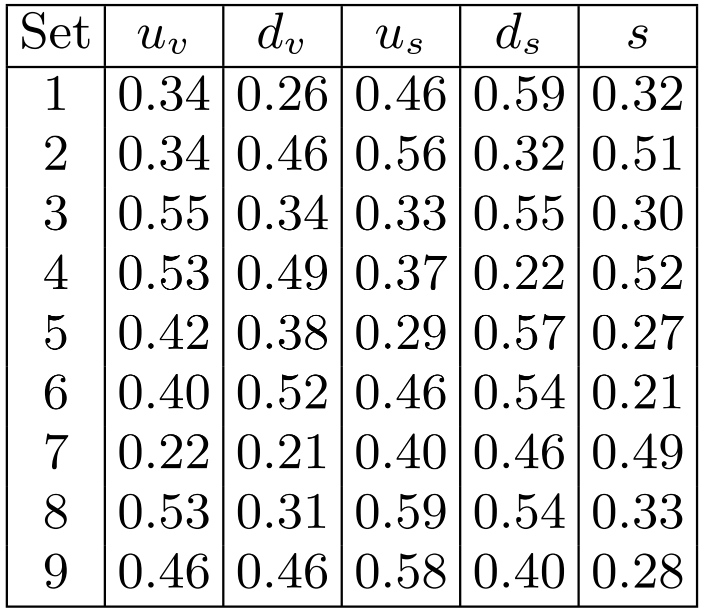


	ΔM_{W+}			ΔM_{W-}		
Set	m_T	$p_{T\ell}$	$p_{T\nu}$	m_T	$p_{T\ell}$	$p_{T\nu}$
1	-1	-5	7	-1	-3	8
2	-1	-15	6	0	5	10
3	-1	1	8	-1	-7	5
4	-1	-15	6	0	-4	5
5	-1	-4	6	-1	-7	5
6	-1	-5	7	0	2	9
7	-1	-15	6	-1	-6	5
8	-1	0	8	0	3	10
9	-1	-7	7	0	4	10

TABLE II: LHCb 13 TeV

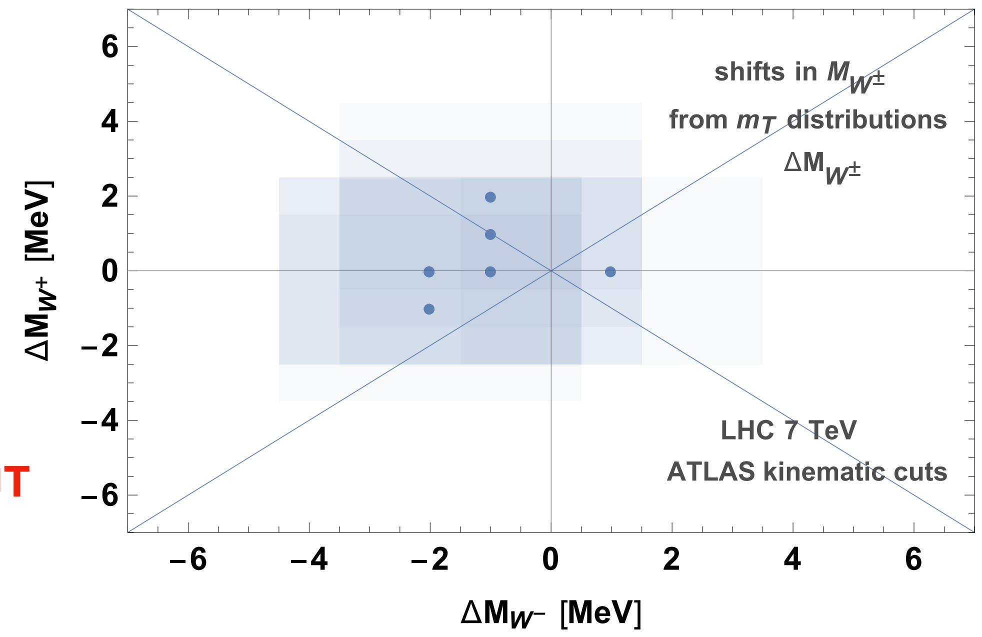


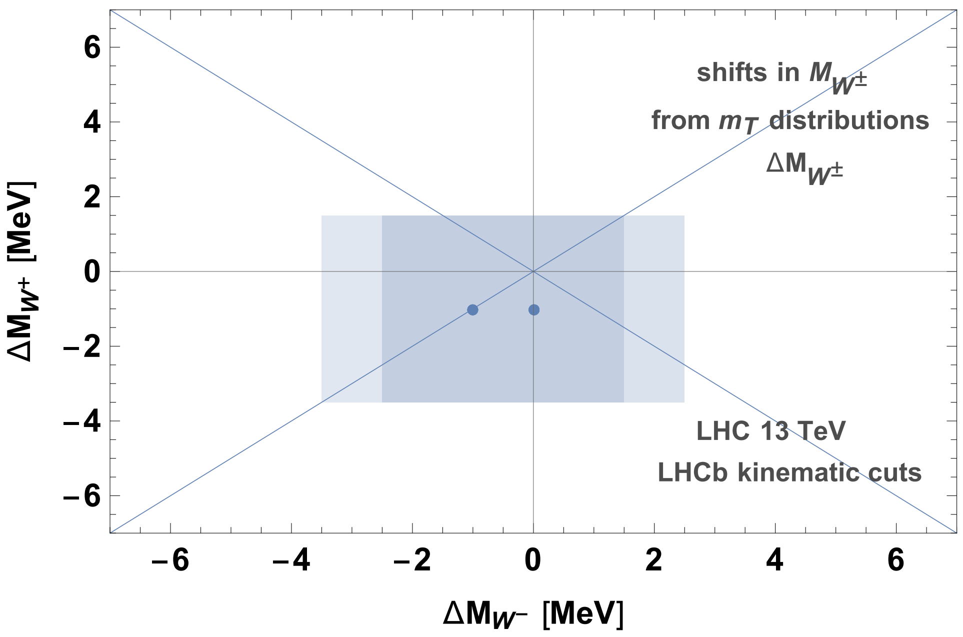
Set	u_v	d_v	u_s	d_s	s
1	0.34	0.26	0.46	0.59	0.32
2	0.34	0.46	0.56	0.32	0.51
3	0.55	0.34	0.33	0.55	0.30
4	0.53	0.49	0.37	0.22	0.52
5	0.42	0.38	0.29	0.57	0.27
6	0.40	0.52	0.46	0.54	0.21
7	0.22	0.21	0.40	0.46	0.49
8	0.53	0.31	0.59	0.54	0.33
9	0.46	0.46	0.58	0.40	0.28

NLL+LO QCD analysis obtained through a modified version of the **DYRes** code [Catani, deFlorian, Ferrera, Grazzini (2015)]

Statistical uncertainty: 2.5 MeV

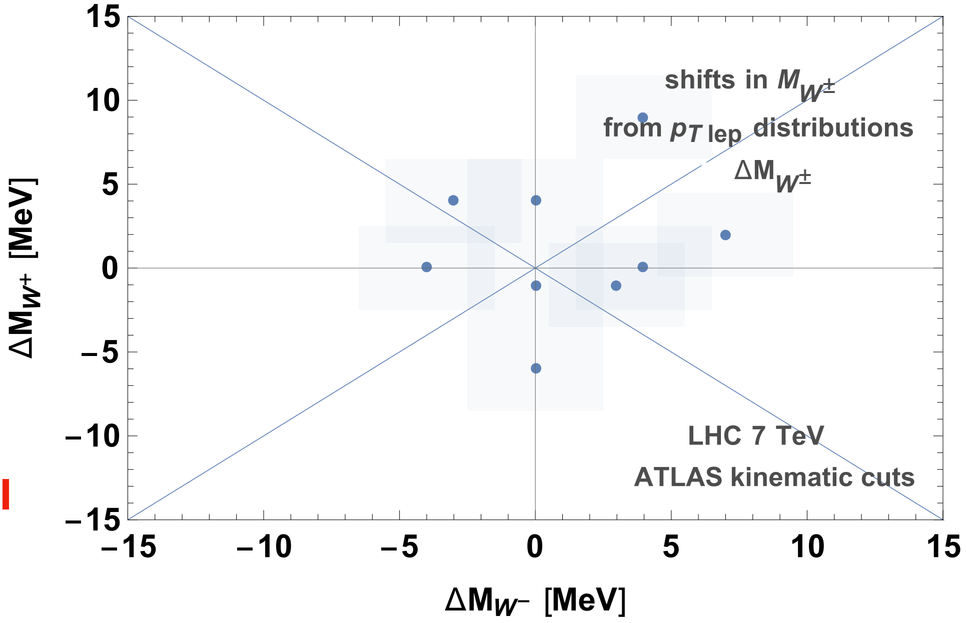
ATLAS m_T

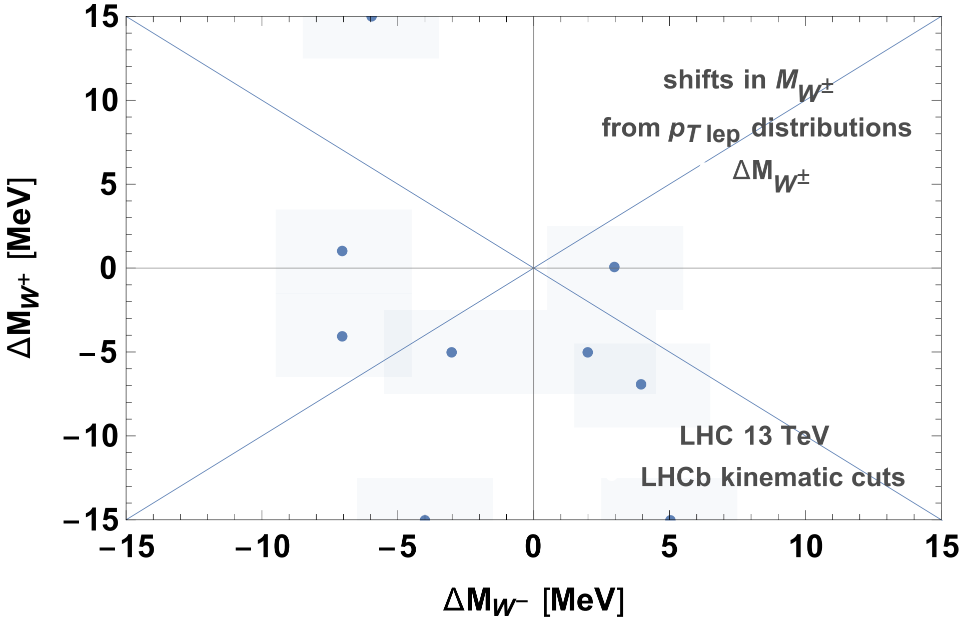




LHCb m_T

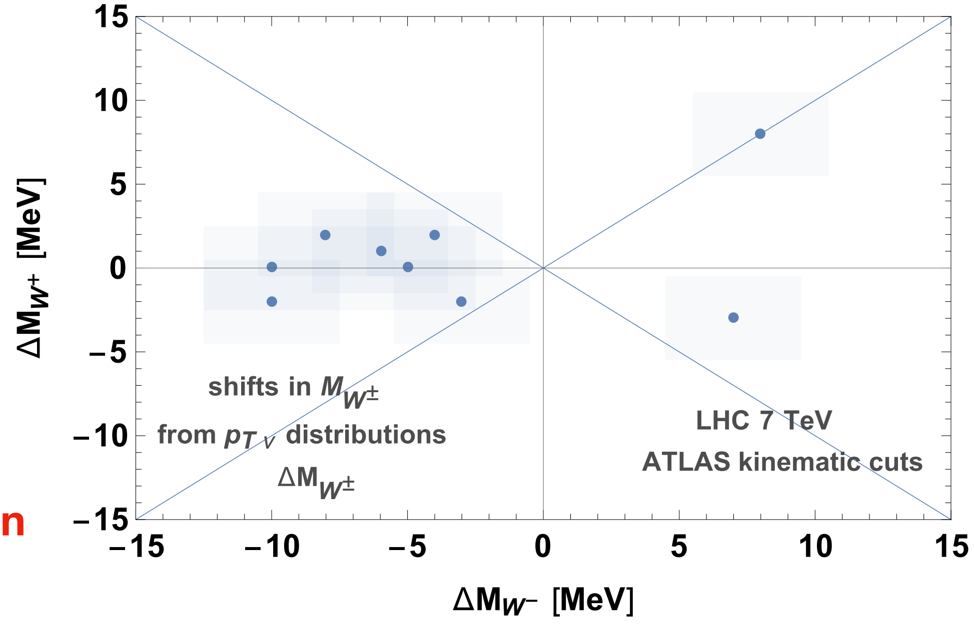
ATLAS p_{Tl}

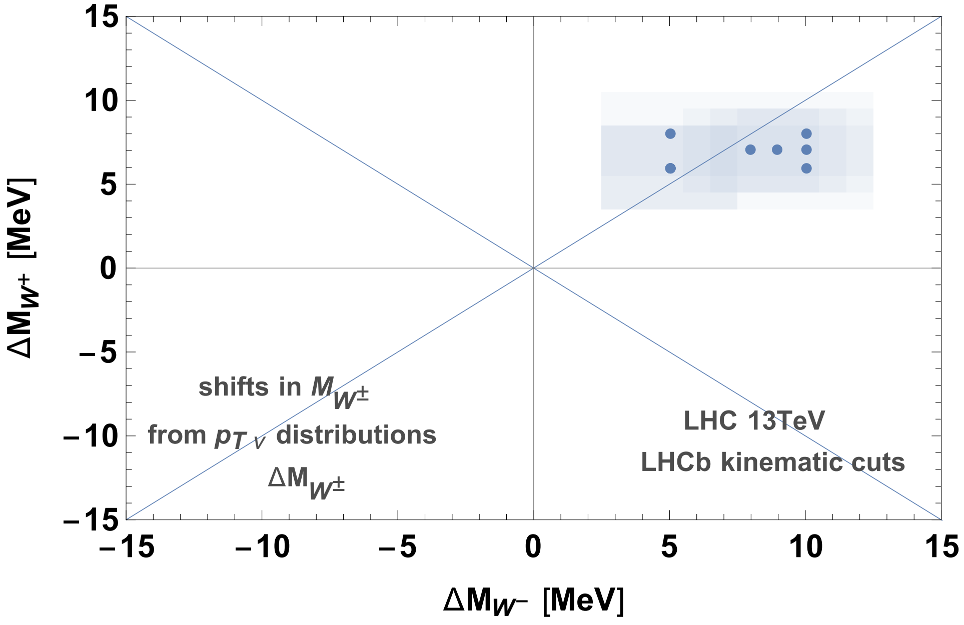




LHCb p_{Tl}

ATLAS p_{Tn}



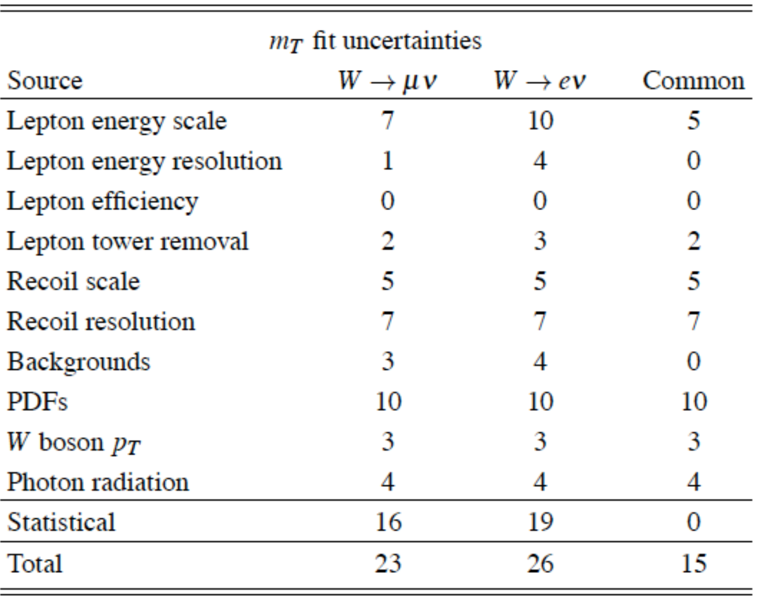


LHCb p_{Tn}

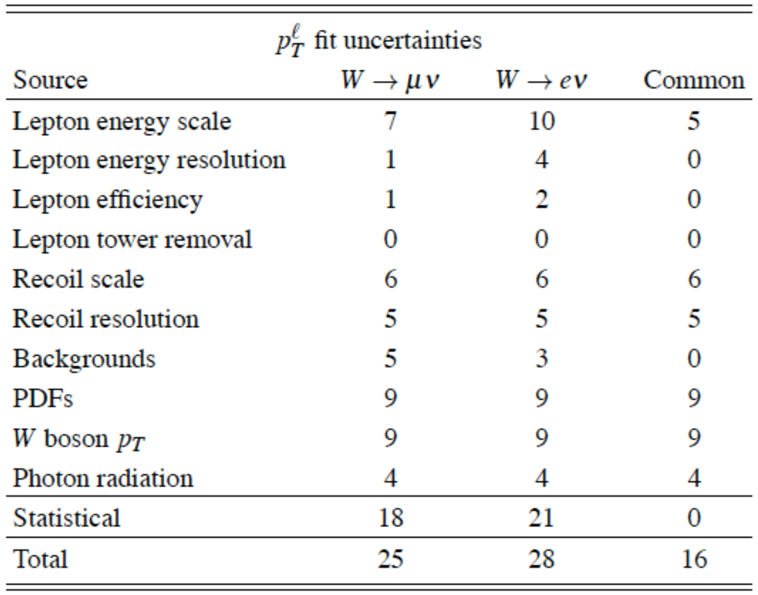
Backup slides

Uncertainties on M_W due to p_{TW}

CDF

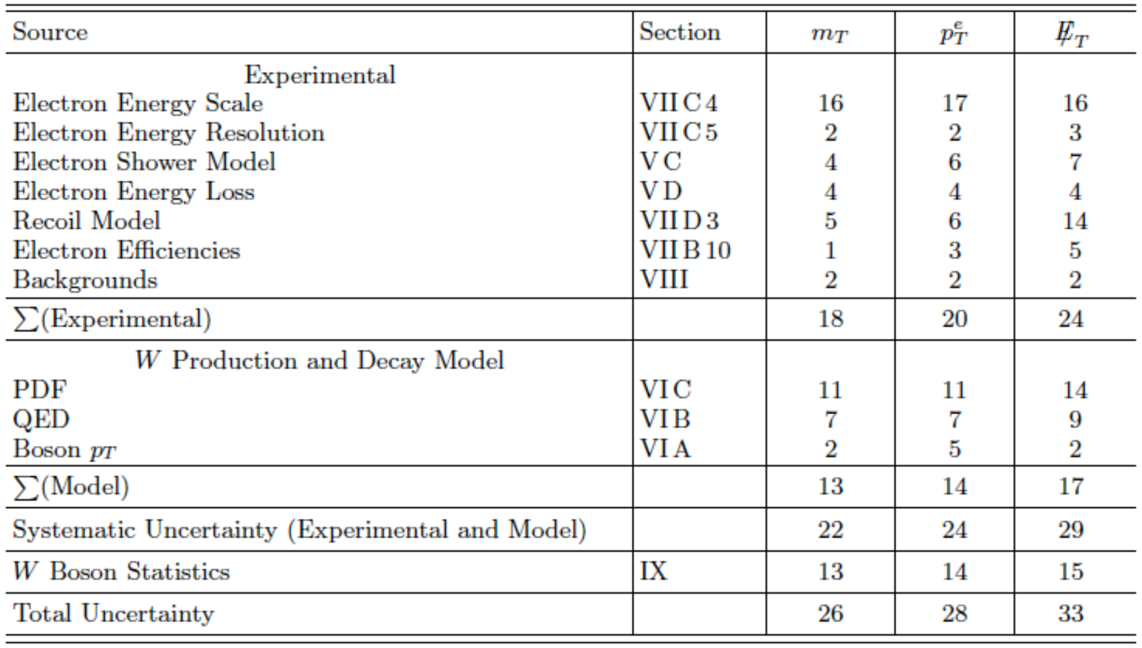


Source	m_T fit uncertainties $W \to \mu\nu$	$W \to e\nu$	Common
Lepton energy scale	7	10	5
Lepton energy resolution	1	4	0
Lepton efficiency	0	0	0
Lepton tower removal	2	3	2
Recoil scale	5	5	5
Recoil resolution	7	7	7
Backgrounds	3	4	0
PDFs	10	10	10
W boson p_T	3	3	3
Photon radiation	4	4	4
Statistical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



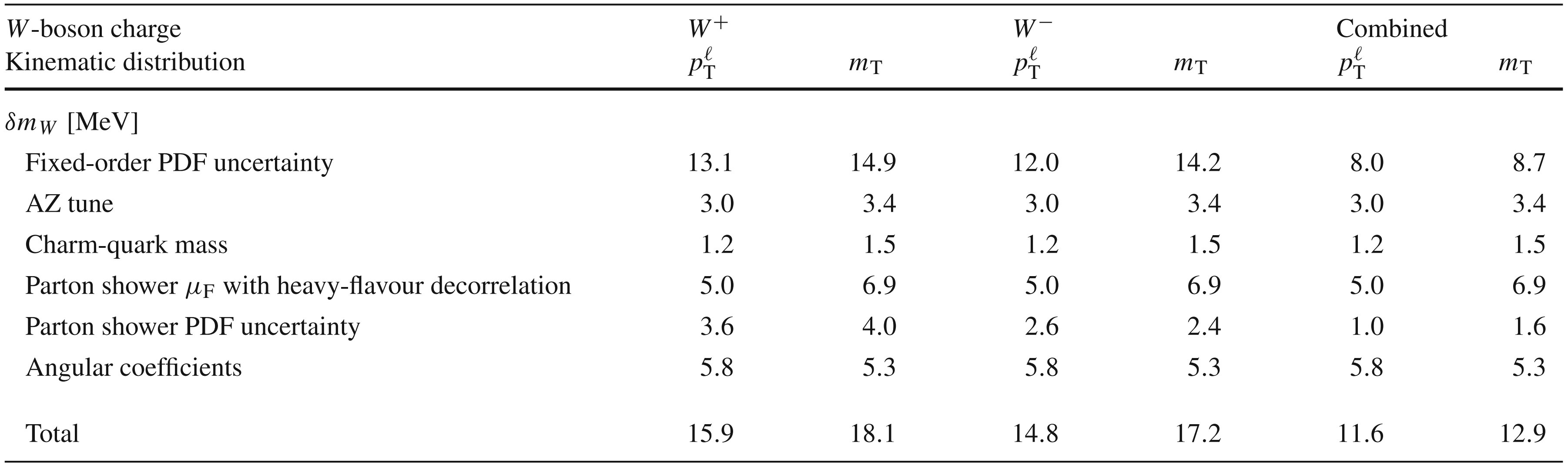
Source	p_T^ℓ fit uncertainties $W \to \mu\nu$	$W \to e\nu$	Common
Lepton energy scale	7	10	5
Lepton energy resolution	1	4	0
Lepton efficiency	1	2	0
Lepton tower removal	0	0	0
Recoil scale	6	6	6
Recoil resolution	5	5	5
Backgrounds	5	3	0
PDFs	9	9	9
W boson p_T	9	9	9
Photon radiation	4	4	4
Statistical	18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

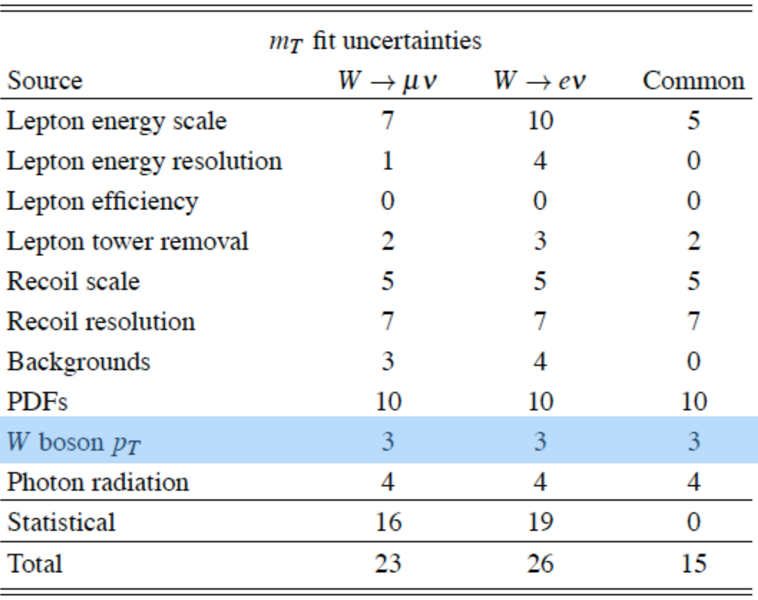
ATLAS



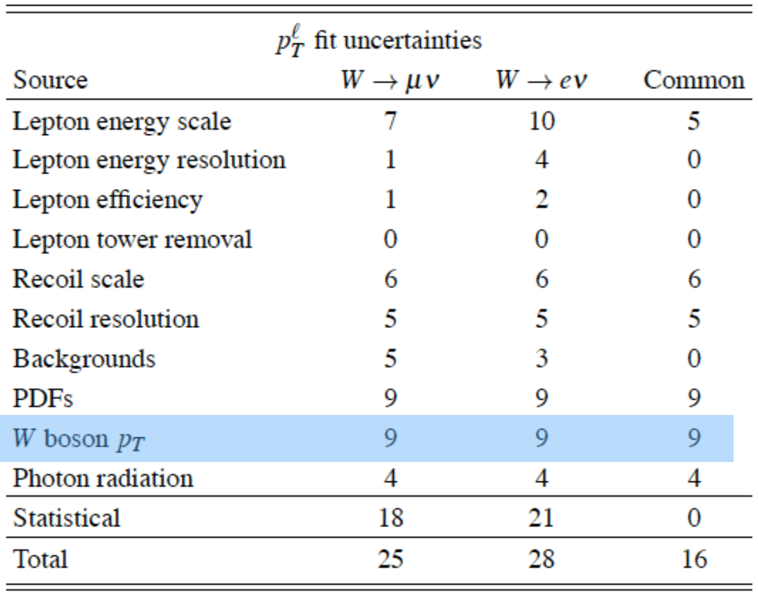
W-boson charge Kinematic distribution	W^+ p_T^ℓ	m_T	W^- p_T^ℓ	m_T	Combined p_T^ℓ	m_T
δm_W [MeV]						
Fixed-order PDF uncertainty	13.1	14.9	12.0	14.2	8.0	8.7
AZ tune	3.0	3.4	3.0	3.4	3.0	3.4
Charm-quark mass	1.2	1.5	1.2	1.5	1.2	1.5
Parton shower μ_F with heavy-flavour decorrelation	5.0	6.9	5.0	6.9	5.0	6.9
Parton shower PDF uncertainty	3.6	4.0	2.6	2.4	1.0	1.6
Angular coefficients	5.8	5.3	5.8	5.3	5.8	5.3
Total	15.9	18.1	14.8	17.2	11.6	12.9

Uncertainties on M_W due to p_{TW}

CDF

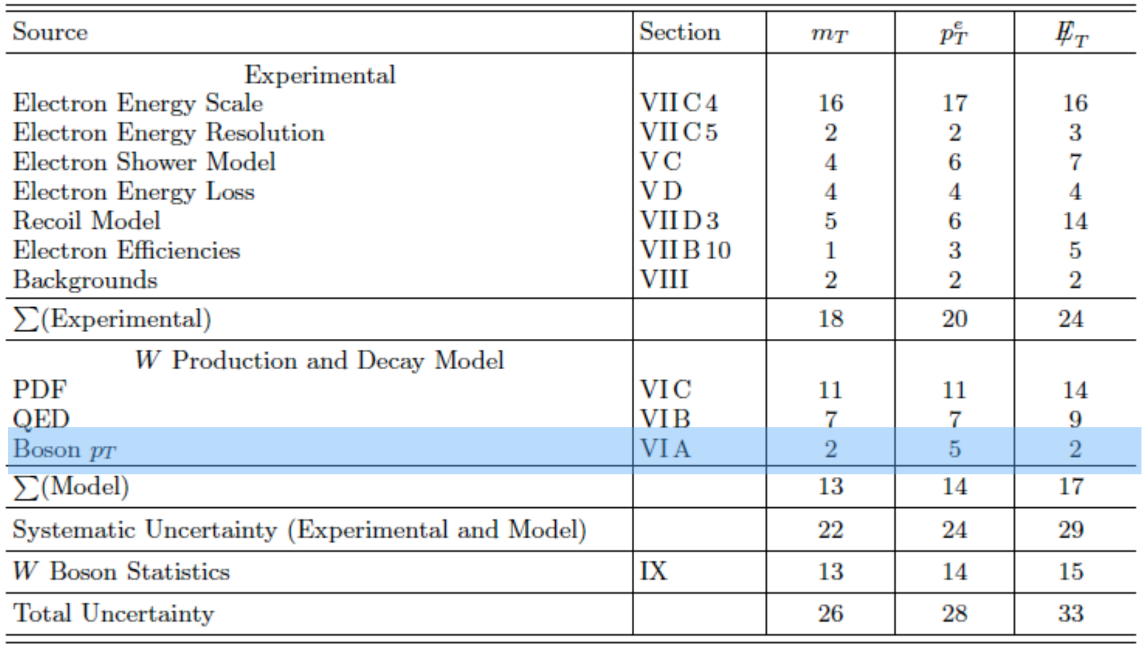


m_T fit uncertainties			
Source	$W \to \mu\nu$	$W \to e\nu$	Common
Lepton energy scale	7	10	5
Lepton energy resolution	1	4	0
Lepton efficiency	0	0	0
Lepton tower removal	2	3	2
Recoil scale	5	5	5
Recoil resolution	7	7	7
Backgrounds	3	4	0
PDFs	10	10	10
W boson p_T	3	3	3
Photon radiation	4	4	4
Statistical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



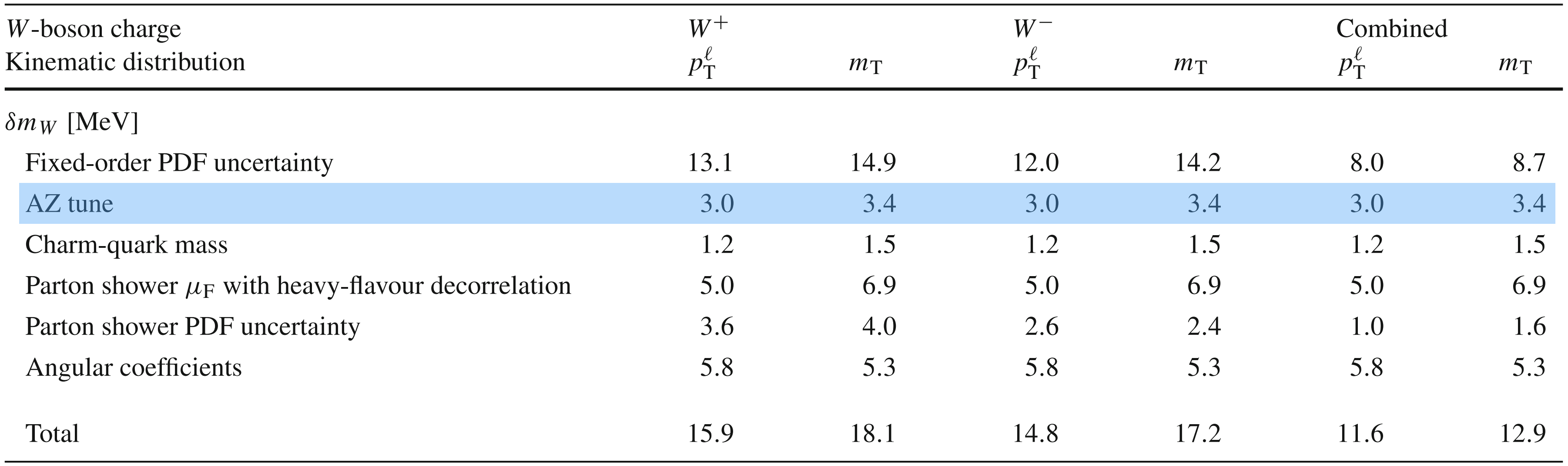
p_T^ℓ fit uncertainties			
Source	$W \to \mu\nu$	$W \to e\nu$	Common
Lepton energy scale	7	10	5
Lepton energy resolution	1	4	0
Lepton efficiency	1	2	0
Lepton tower removal	0	0	0
Recoil scale	6	6	6
Recoil resolution	5	5	5
Backgrounds	5	3	0
PDFs	9	9	9
W boson p_T	9	9	9
Photon radiation	4	4	4
Statistical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

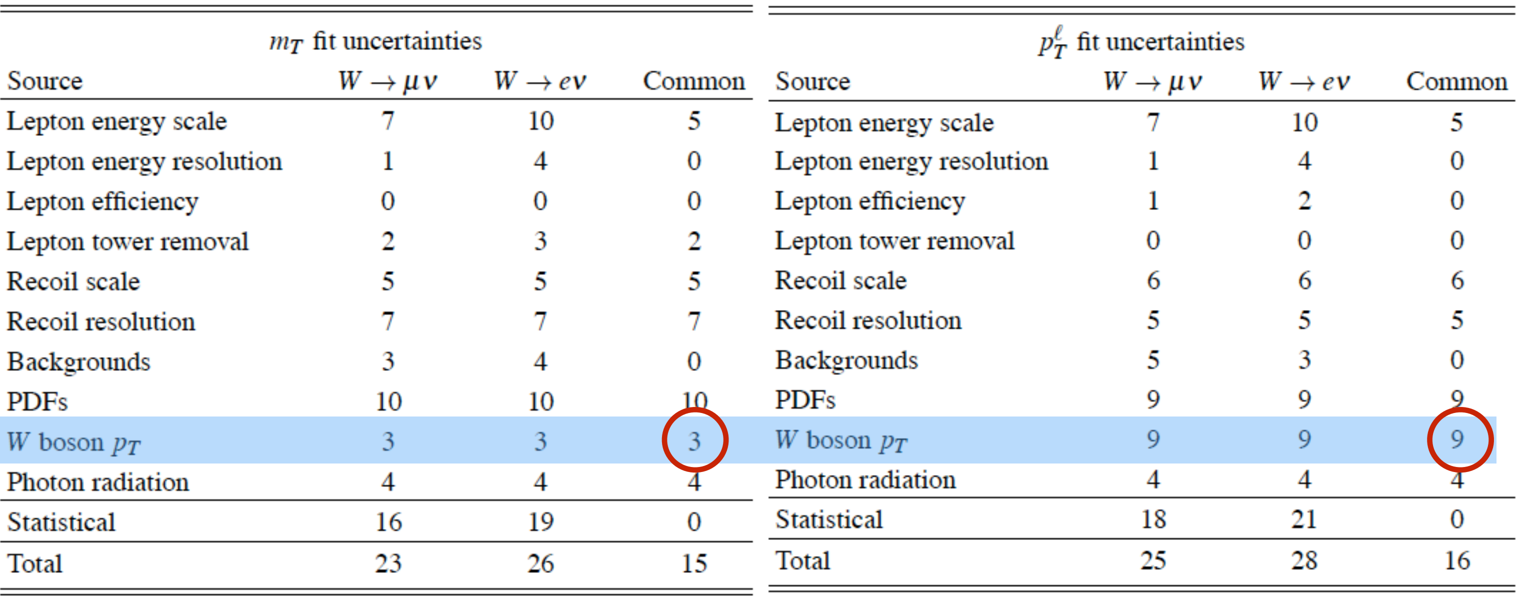
ATLAS



W-boson charge Kinematic distribution	W^+ p_T^ℓ	m_T	W^- p_T^ℓ	m_T	Combined p_T^ℓ	m_T
δm_W [MeV]						
Fixed-order PDF uncertainty	13.1	14.9	12.0	14.2	8.0	8.7
AZ tune	3.0	3.4	3.0	3.4	3.0	3.4
Charm-quark mass	1.2	1.5	1.2	1.5	1.2	1.5
Parton shower μ_F with heavy-flavour decorrelation	5.0	6.9	5.0	6.9	5.0	6.9
Parton shower PDF uncertainty	3.6	4.0	2.6	2.4	1.0	1.6
Angular coefficients	5.8	5.3	5.8	5.3	5.8	5.3
Total	15.9	18.1	14.8	17.2	11.6	12.9

Uncertainties on M_W due to p_{TW}

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
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Lepton efficiency	1	2	0
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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
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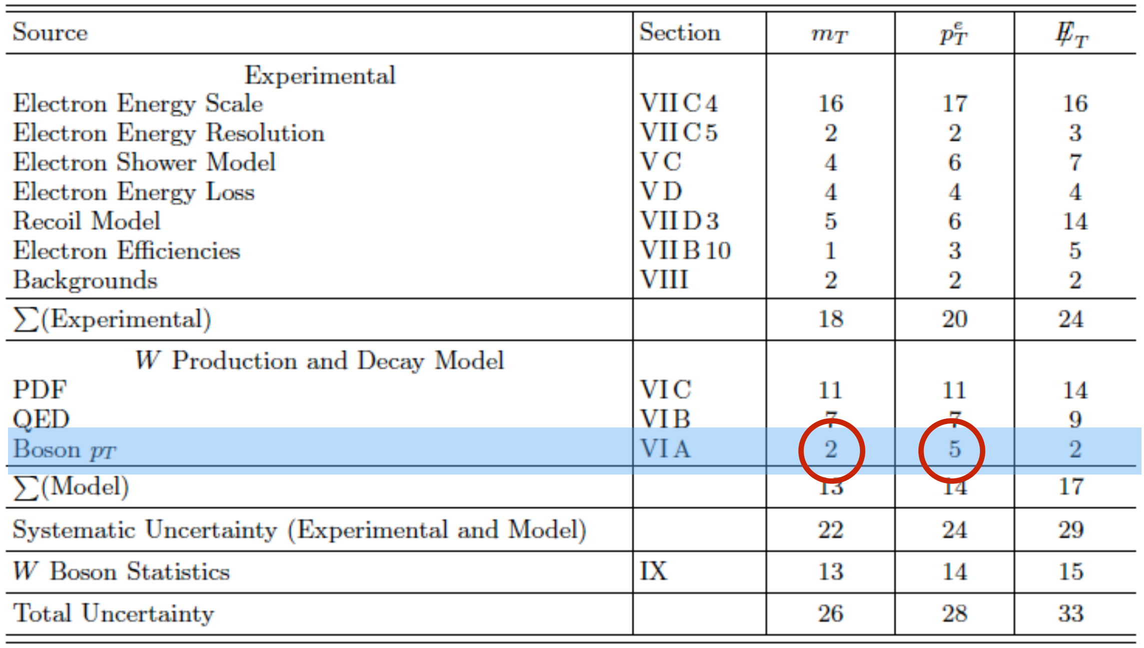
D0



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
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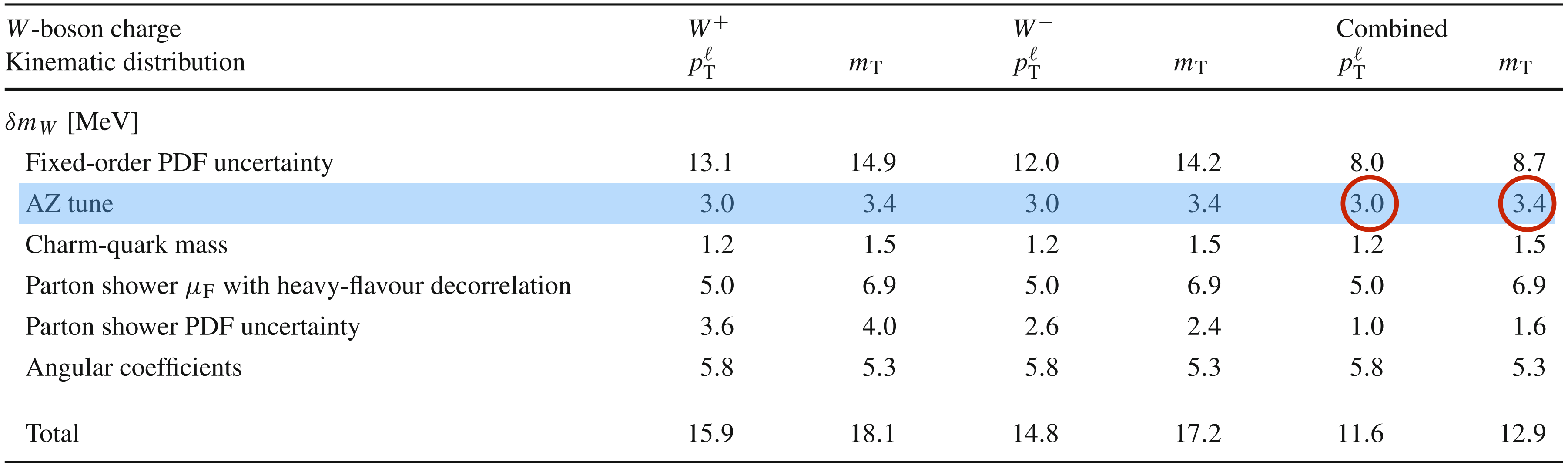

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Charm-quark mass	1.2	1.5	1.2	1.5	1.2	1.5
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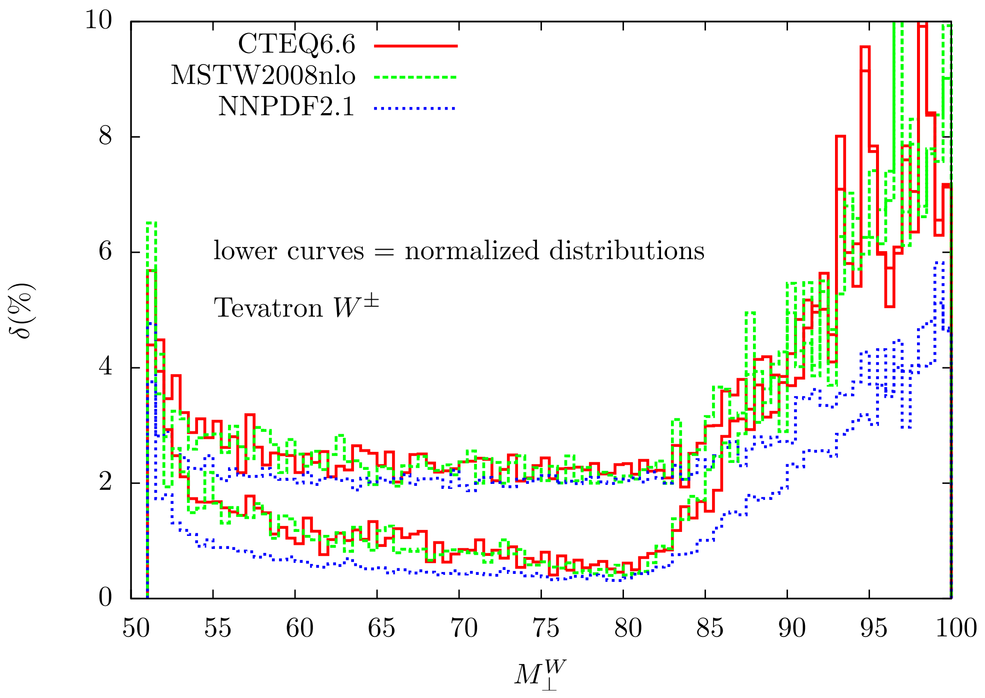
Angular coefficients	5.8	5.3	5.8	5.3	5.8	5.3
Total	15.9	18.1	14.8	17.2	11.6	12.9

PDF effect on transverse mass

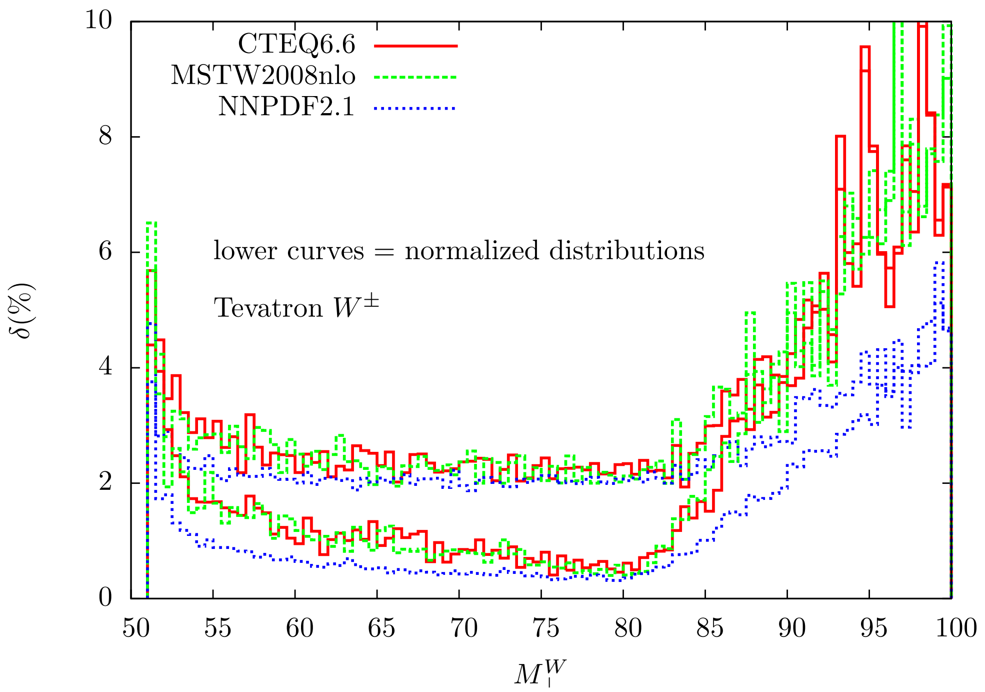


Bozzi, Rojo, Vicini PRD 83, 113008 (2011)

- Normalised distributions: reduced sensitivity to PDFs
- Ratio of (non-)normalised distributions w.r.t. to central PDF set
- Distributions obtained with **DYNNLO**

in first approximation the PDF effects factorise w.r.t. all other theoretical and experimental factors

PDF effect on transverse mass



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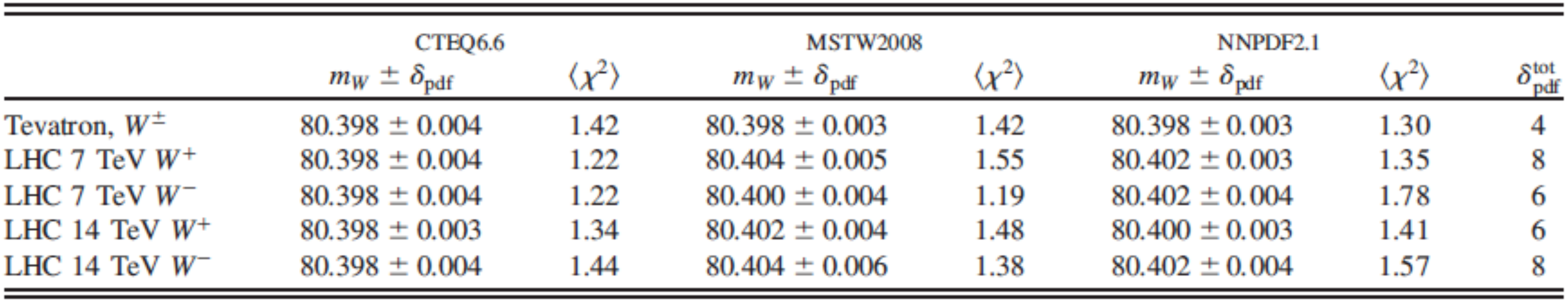
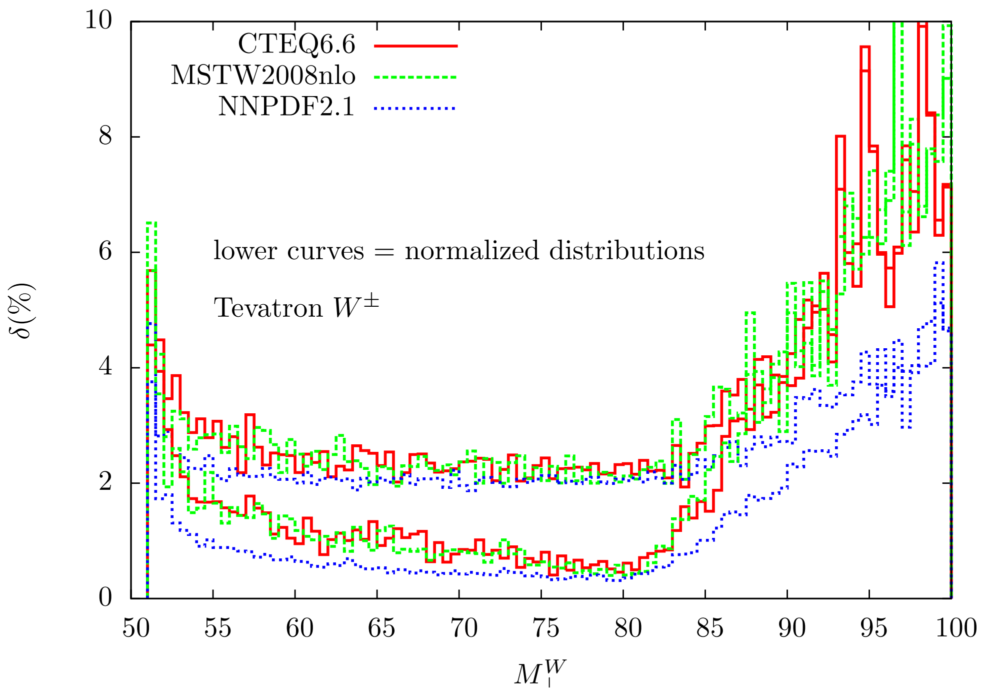


	CTEQ6.6		MSTW2008		NNPDF2.1		
	$m_W \pm \delta_{\rm pdf}$	$\langle\chi^2\rangle$	$m_W \pm \delta_{\rm pdf}$	$\langle\chi^2\rangle$	$m_W \pm \delta_{\rm pdf}$	$\langle\chi^2\rangle$	$\delta_{\rm pdf}^{\rm tot}$
Tevatron, $W^\pm$	80.398 ± 0.004	1.42	80.398 ± 0.003	1.42	80.398 ± 0.003	1.30	4
LHC 7 TeV W^+	80.398 ± 0.004	1.22	80.404 ± 0.005	1.55	80.402 ± 0.003	1.35	8
LHC 7 TeV W^-	80.398 ± 0.004	1.22	80.400 ± 0.004	1.19	80.402 ± 0.004	1.78	6
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

PDF effect on transverse mass



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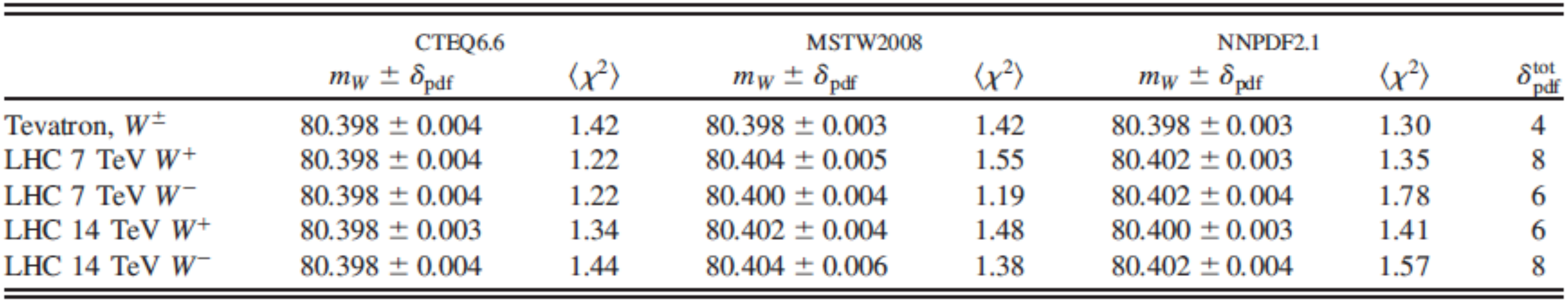

	CTEQ6.6		MSTW2008		NNPDF2.1		
	$m_W \pm \delta_{\rm pdf}$	$\langle\chi^2\rangle$	$m_W \pm \delta_{\rm pdf}$	$\langle\chi^2\rangle$	$m_W \pm \delta_{\rm pdf}$	$\langle\chi^2\rangle$	$\delta_{\rm pdf}^{\rm tot}$
Tevatron, $W^{\pm}$	80.398 ± 0.004	1.42	80.398 ± 0.003	1.42	80.398 ± 0.003	1.30	4
LHC 7 TeV W^{+}	80.398 ± 0.004	1.22	80.404 ± 0.005	1.55	80.402 ± 0.003	1.35	8
LHC 7 TeV W^{-}	80.398 ± 0.004	1.22	80.400 ± 0.004	1.19	80.402 ± 0.004	1.78	6
LHC 14 TeV W^{+}	80.398 ± 0.003	1.34	80.402 ± 0.004	1.48	80.400 ± 0.003	1.41	6
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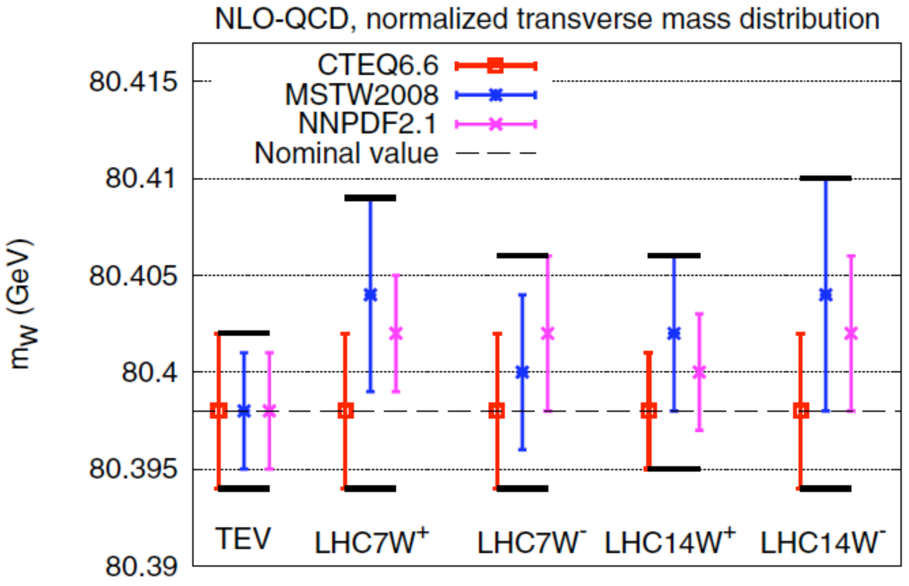
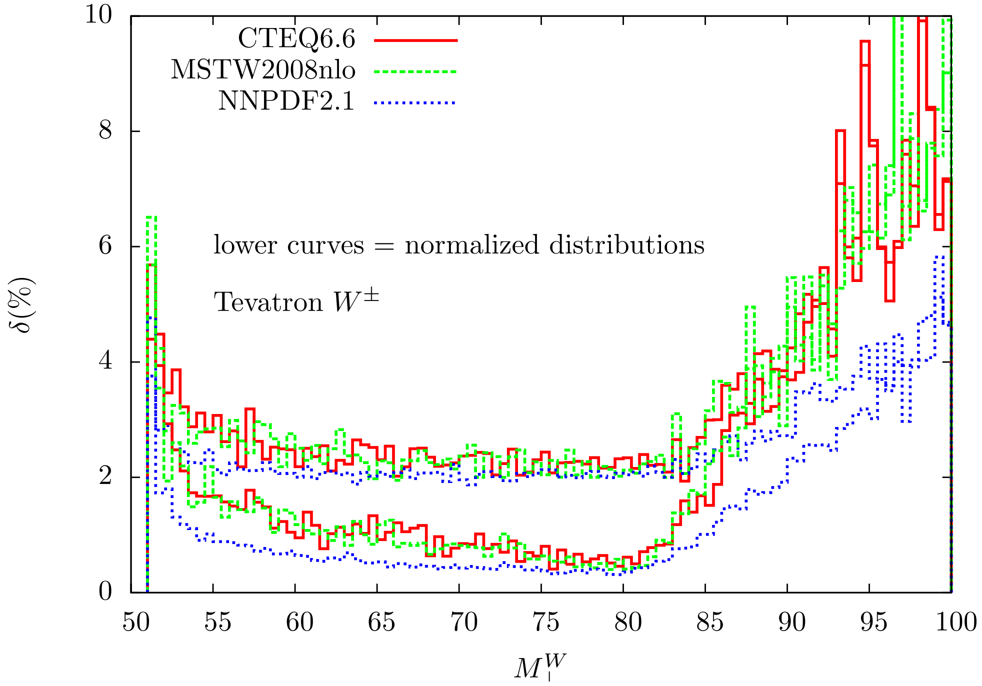


PDF effect on transverse mass

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



- Normalised distributions: reduced sensitivity to PDFs
- Ratio of (non-)normalised distributions w.r.t. to central PDF set
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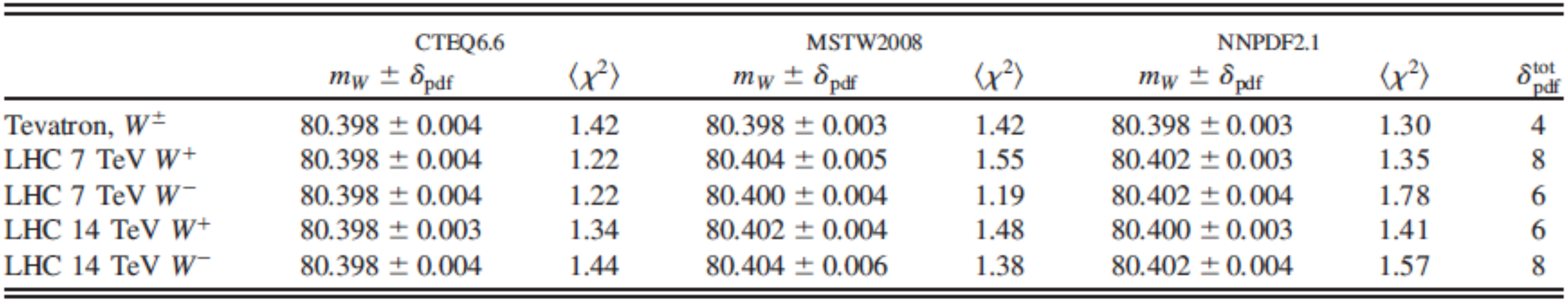
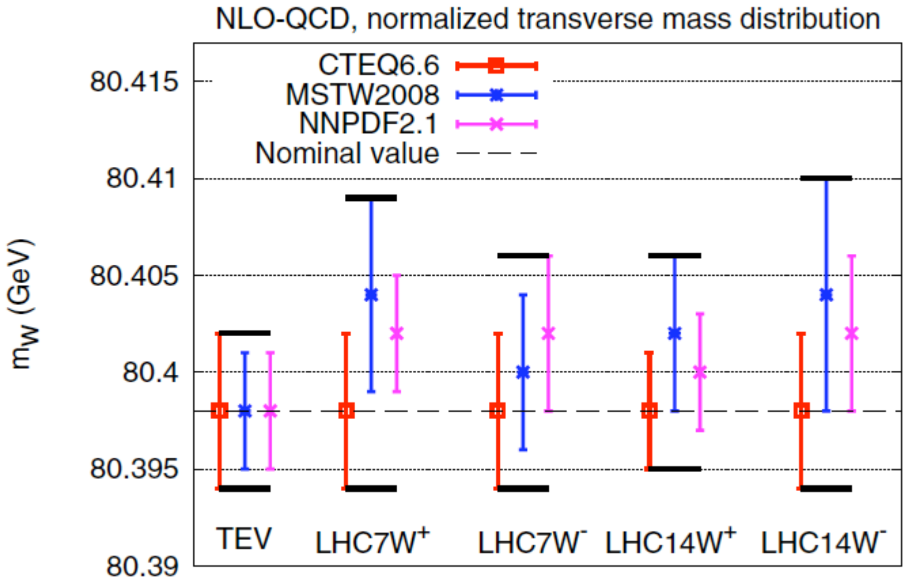
in first approximation the PDF effects factorise w.r.t. all other theoretical and experimental factors



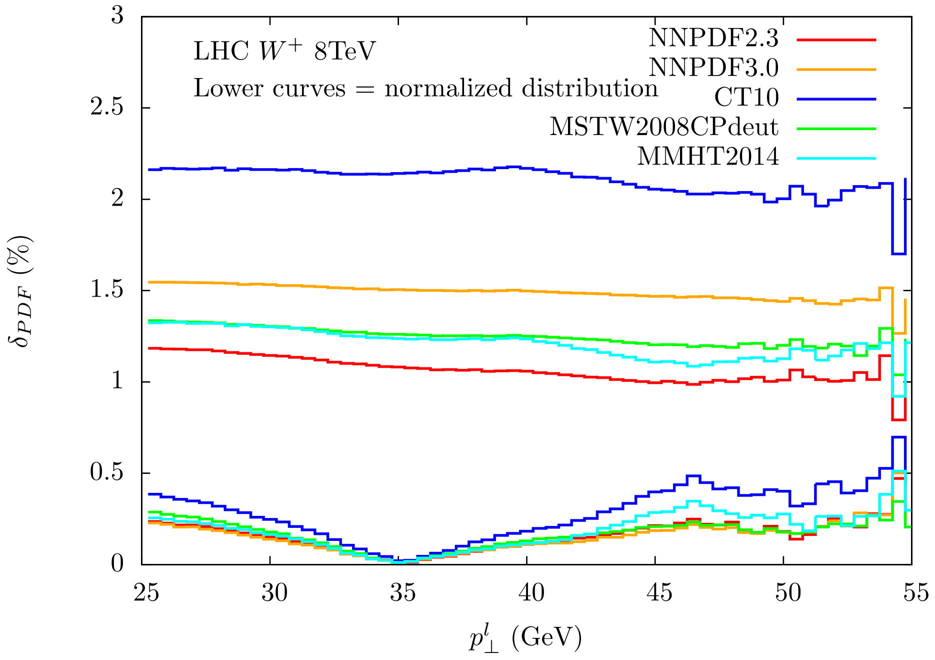
	CTEQ6.6		MSTW2008		NNPDF2.1		
	$m_W \pm \delta_{\rm pdf}$	$\langle\chi^2\rangle$	$m_W \pm \delta_{\rm pdf}$	$\langle\chi^2\rangle$	$m_W \pm \delta_{\rm pdf}$	$\langle\chi^2\rangle$	$\delta^{\rm tot}_{\rm pdf}$
Tevatron, $W^\pm$	80.398 ± 0.004	1.42	80.398 ± 0.003	1.42	80.398 ± 0.003	1.30	4
LHC 7 TeV W^+	80.398 ± 0.004	1.22	80.404 ± 0.005	1.55	80.402 ± 0.003	1.35	8
LHC 7 TeV W^-	80.398 ± 0.004	1.22	80.400 ± 0.004	1.19	80.402 ± 0.004	1.78	6
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



- Accuracy of templates <u>essential</u>: 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

PDF effect on lepton p_T

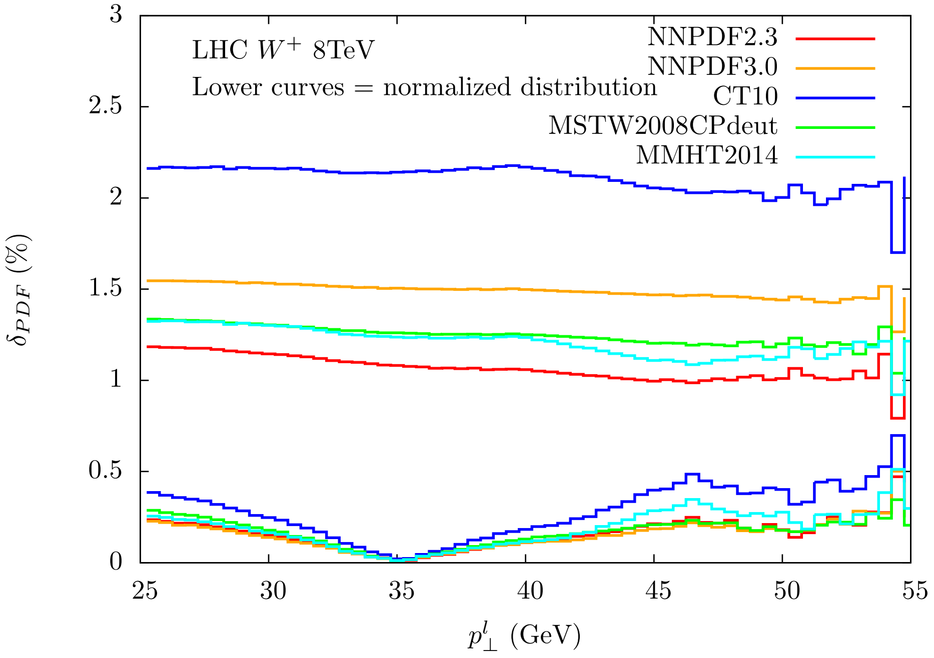
Bozzi, Citelli, Vicini PRD 91, 113005 (2015)



- 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%)
- Uncertainty of normalised distributions: below the O(0.5%) level (but still sufficient to yield large M_W shifts)

PDF effect on lepton p_T

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

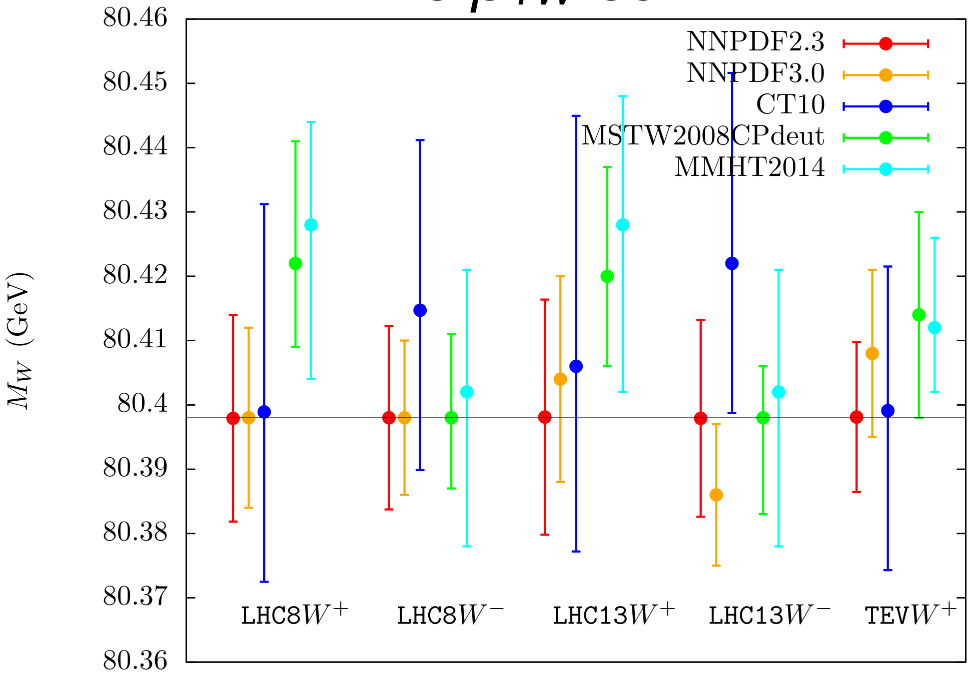


- Conservative estimate of the PDF uncertainty: CC-DY channel alone
- Distributions obtained with **POWHEG+PYTHIA 6.4**
- PDF uncertainty over relevant p_T range almost flat: O(2%)
- Uncertainty of normalised distributions: below the O(0.5%) level (but still sufficient to yield large M_W shifts)

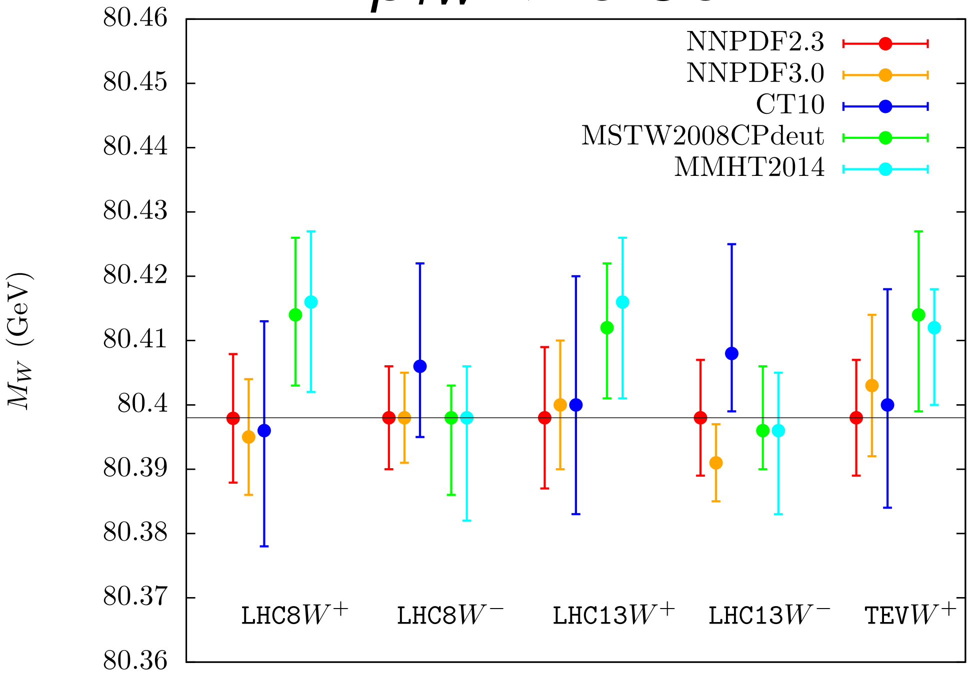
	no $p_\perp^W$ cut		$p_\perp^W < 15$ GeV	
	δ_{PDF} (MeV)	Δ_{sets} (MeV)	δ_{PDF} (MeV)	Δ_{sets} (MeV)
Tevatron 1.96 TeV	27	16	21	15
LHC 8 TeV W^+	33	26	24	18
W^-	29	16	18	8
LHC 13 TeV W^+	34	22	20	14
W^-	34	24	18	12

- Individual PDF sets provide non-pessimistic estimates: ΔM_W ~ 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



Acceptance cuts: interesting insights

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

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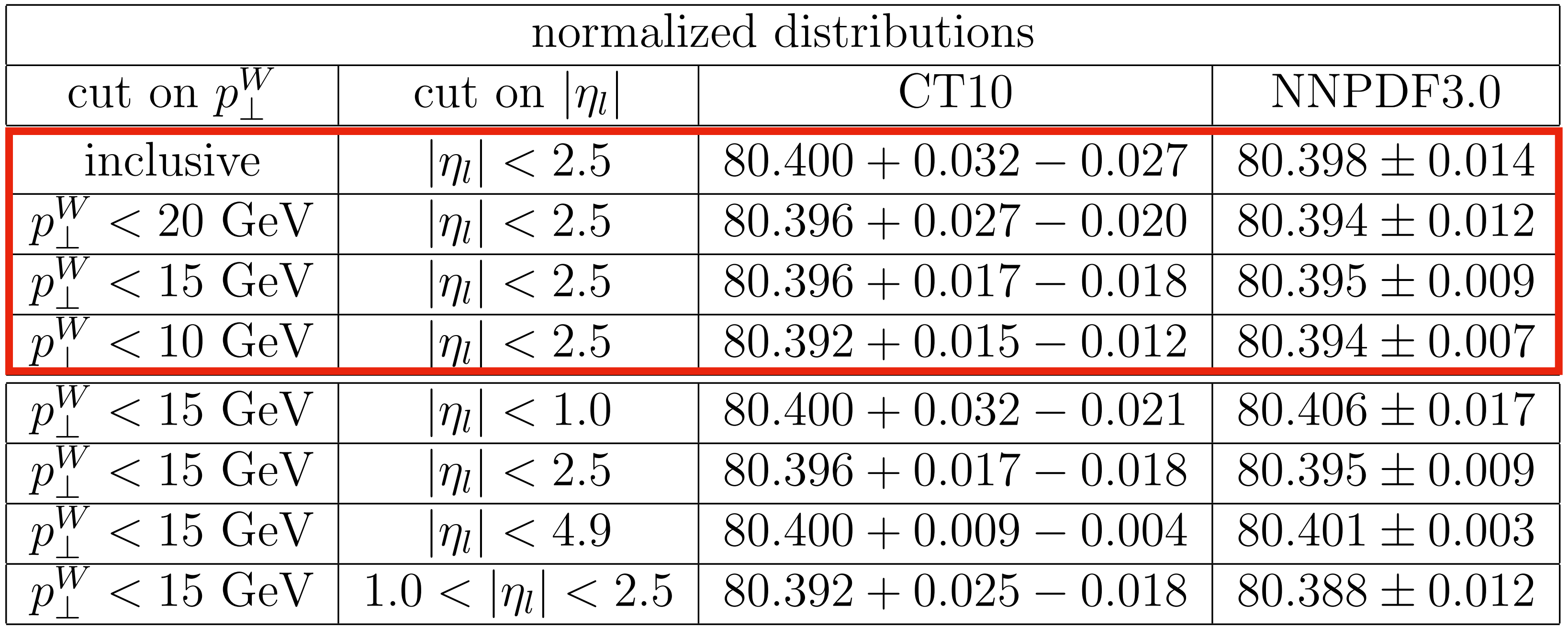

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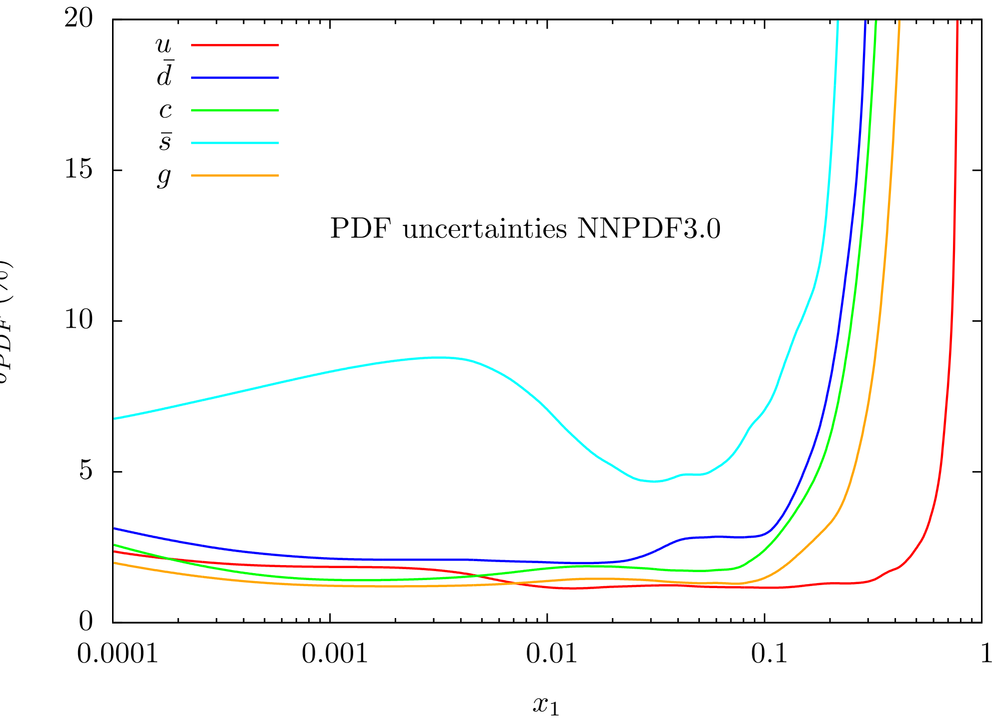

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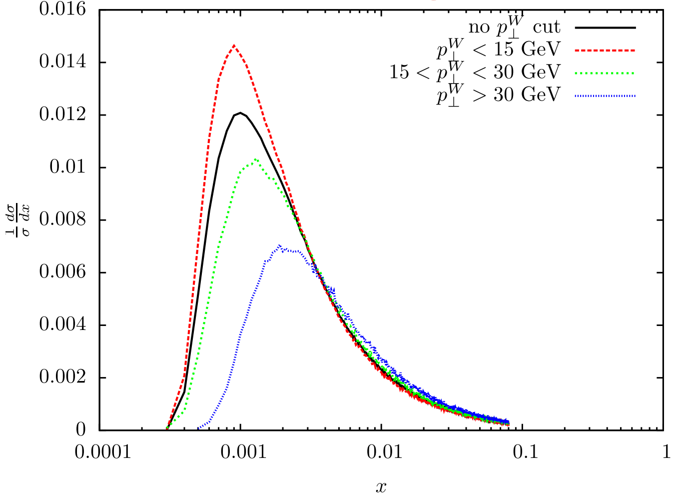

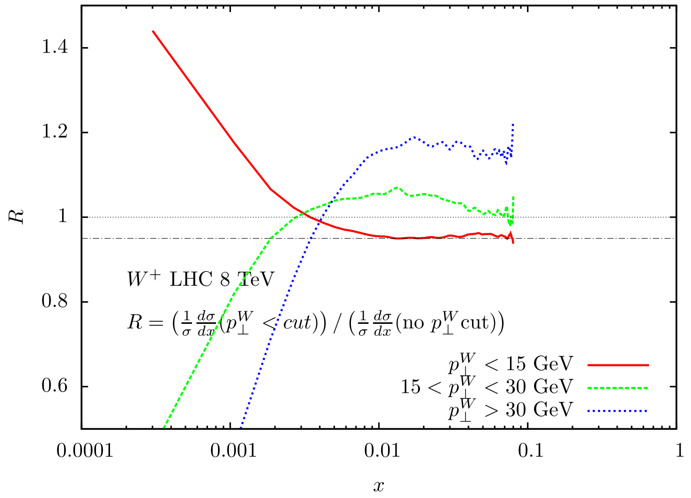

suppression of the large-*x* region

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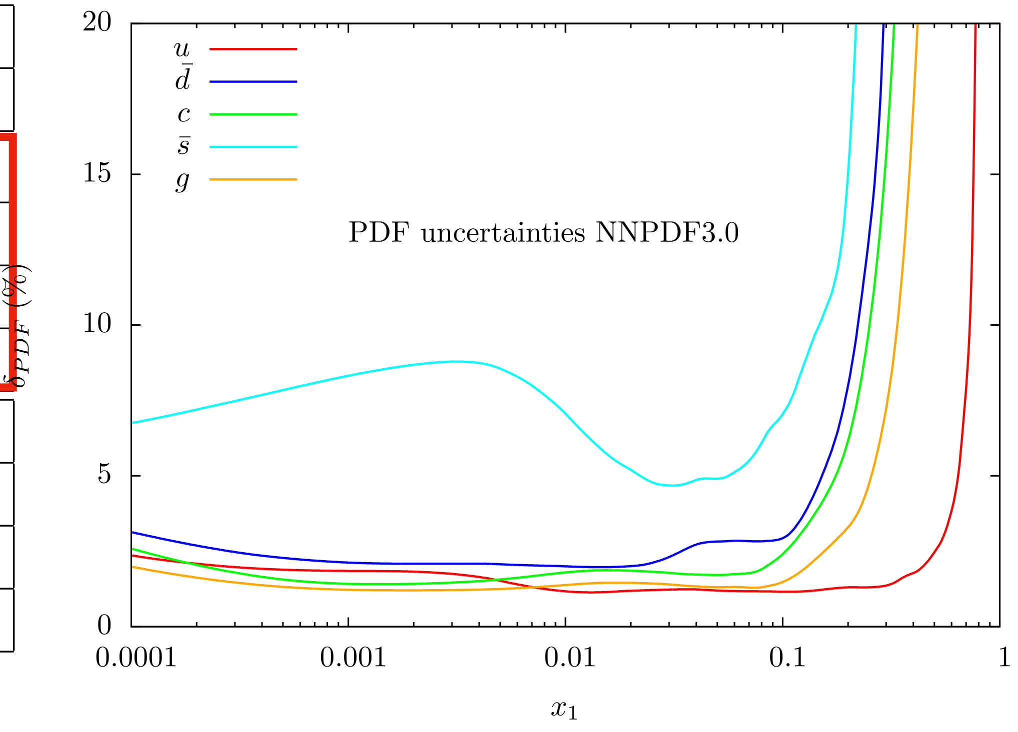

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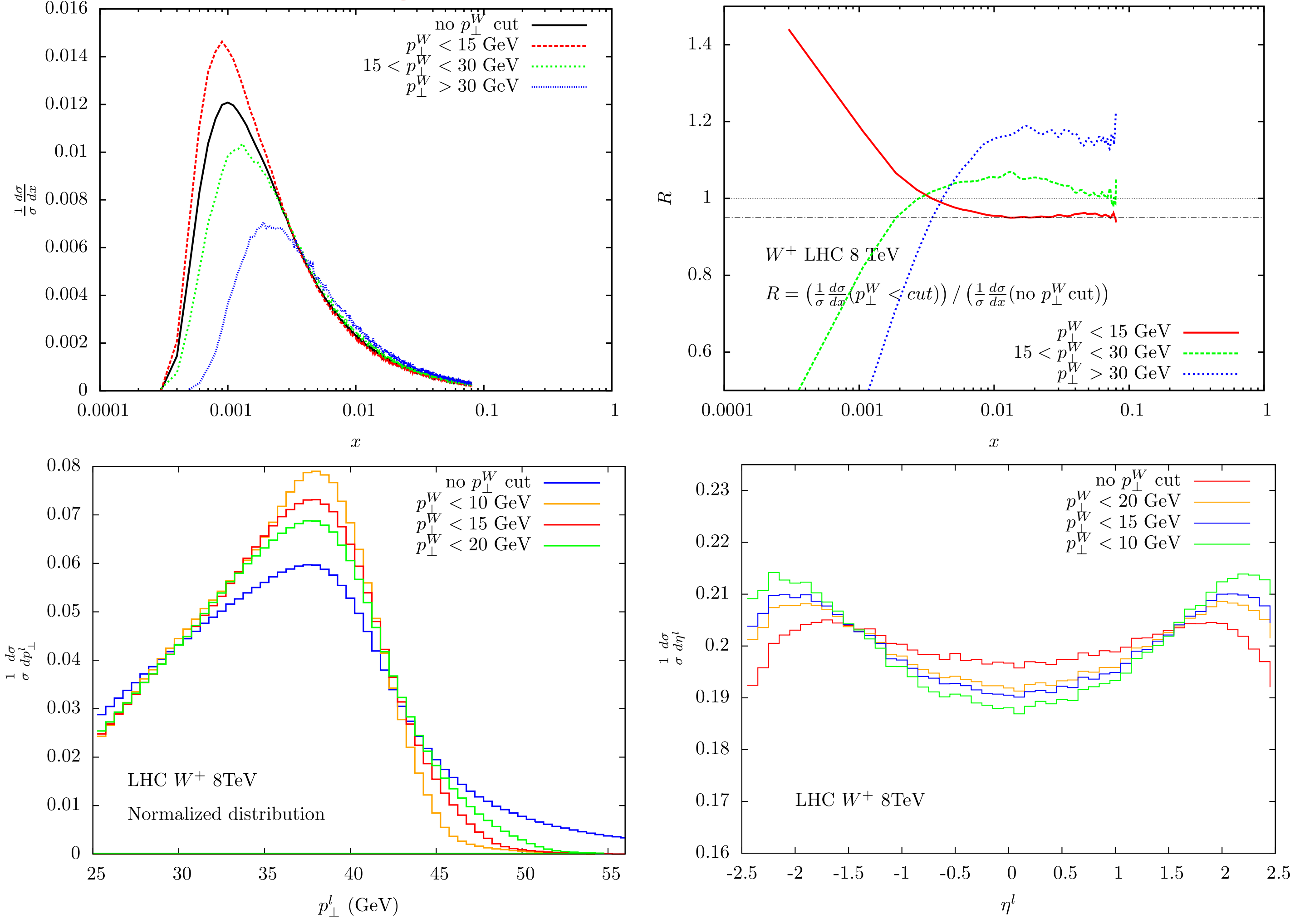


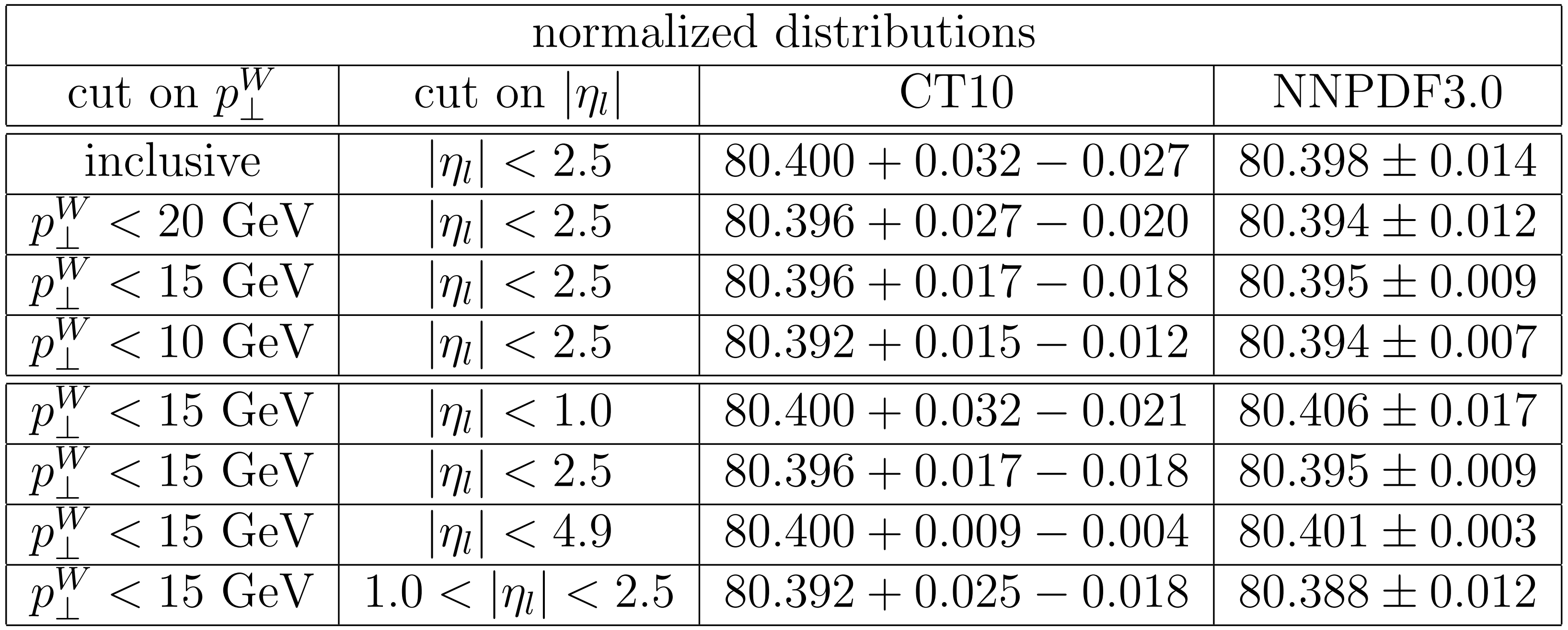
suppression of the large-*x* region

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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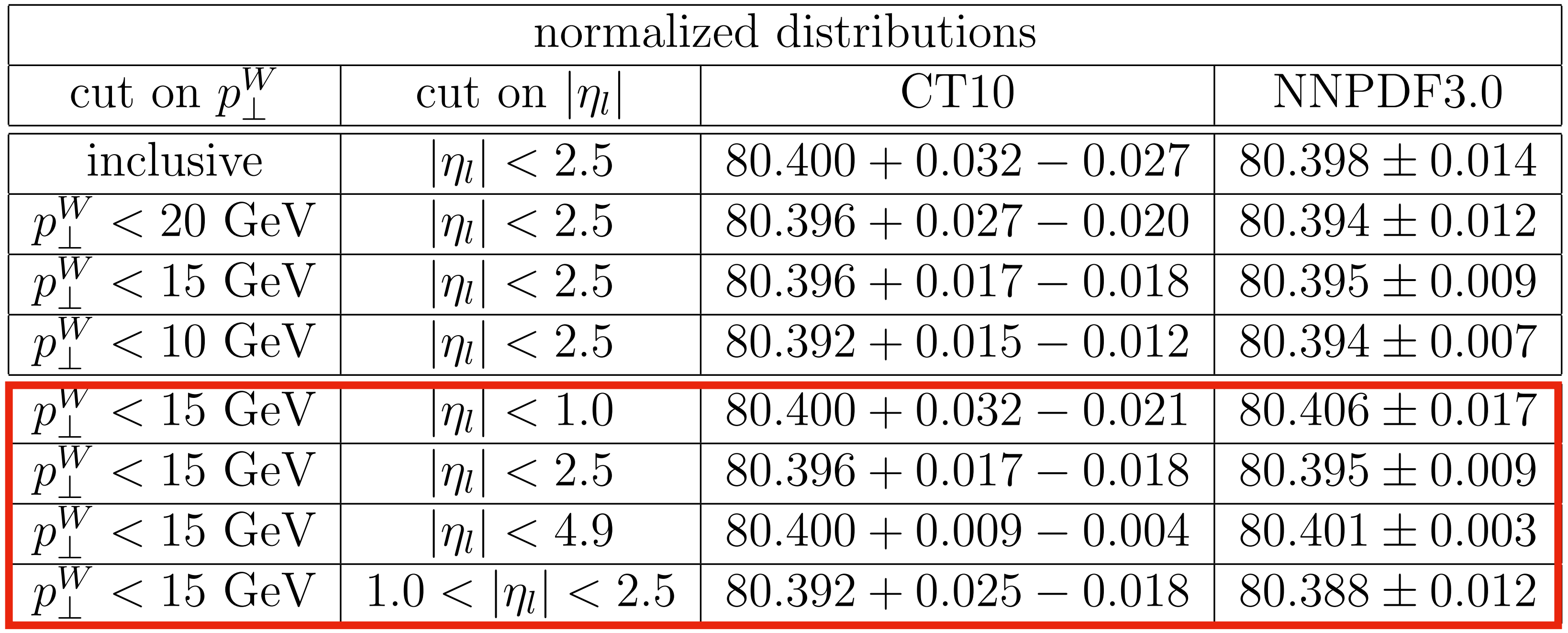

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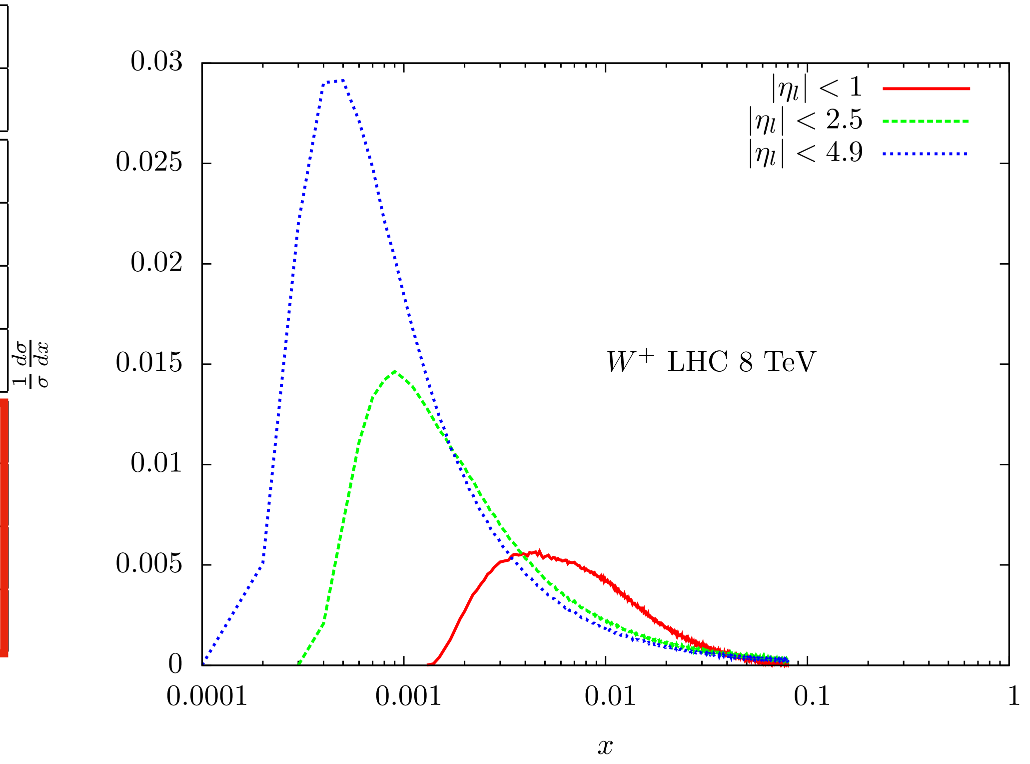

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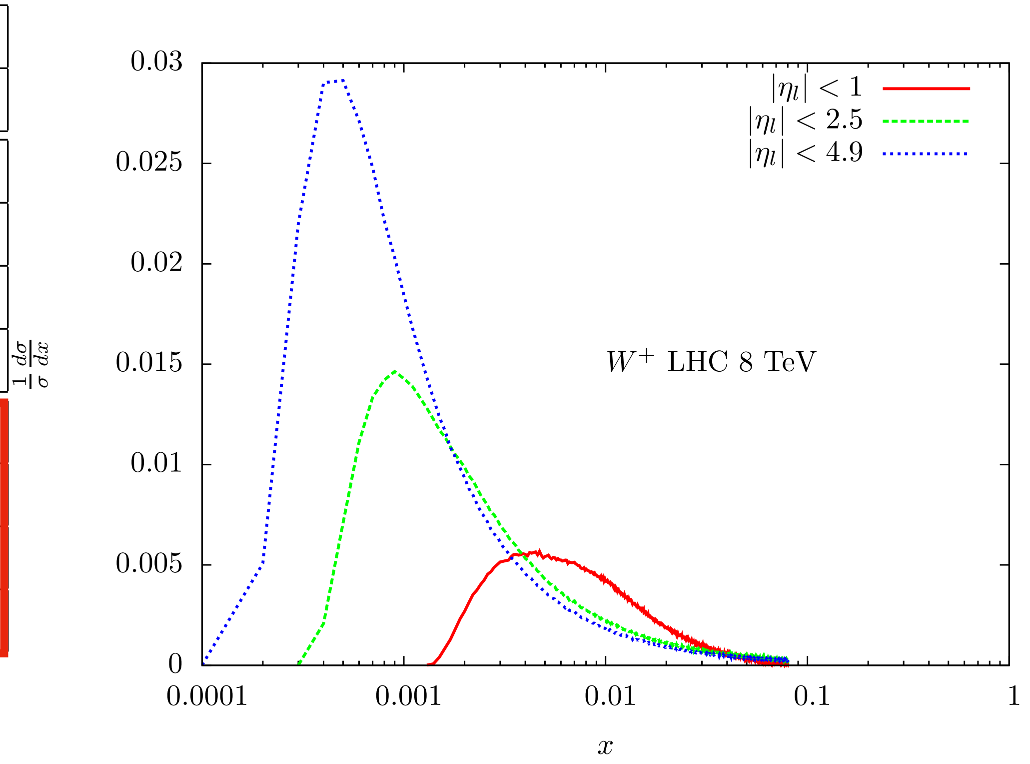
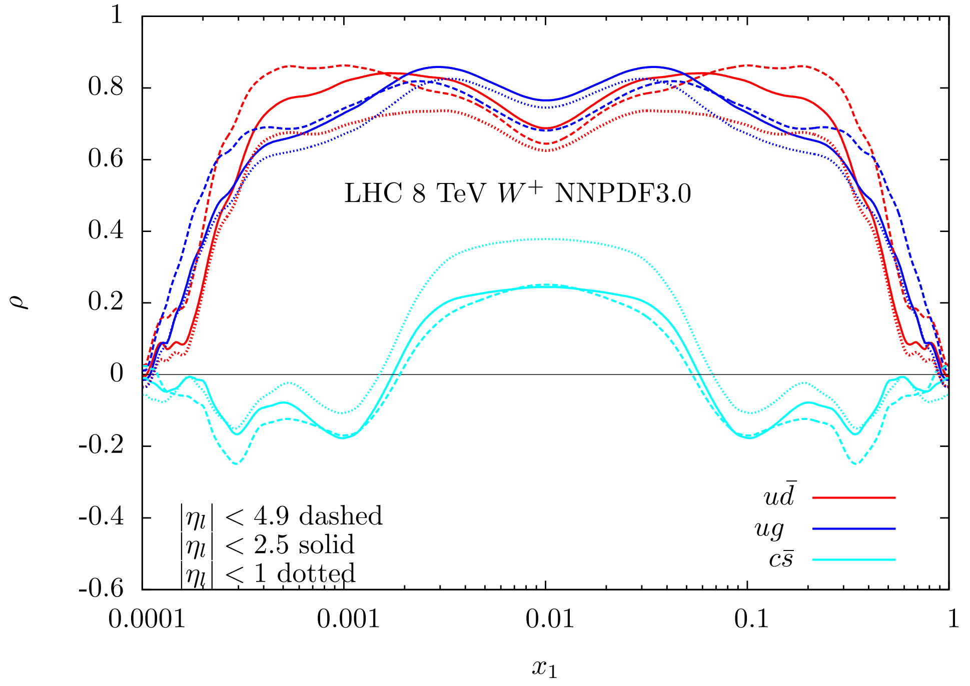


correlation of parton luminosities within the 40.5 GeV p_{Tl} bin



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

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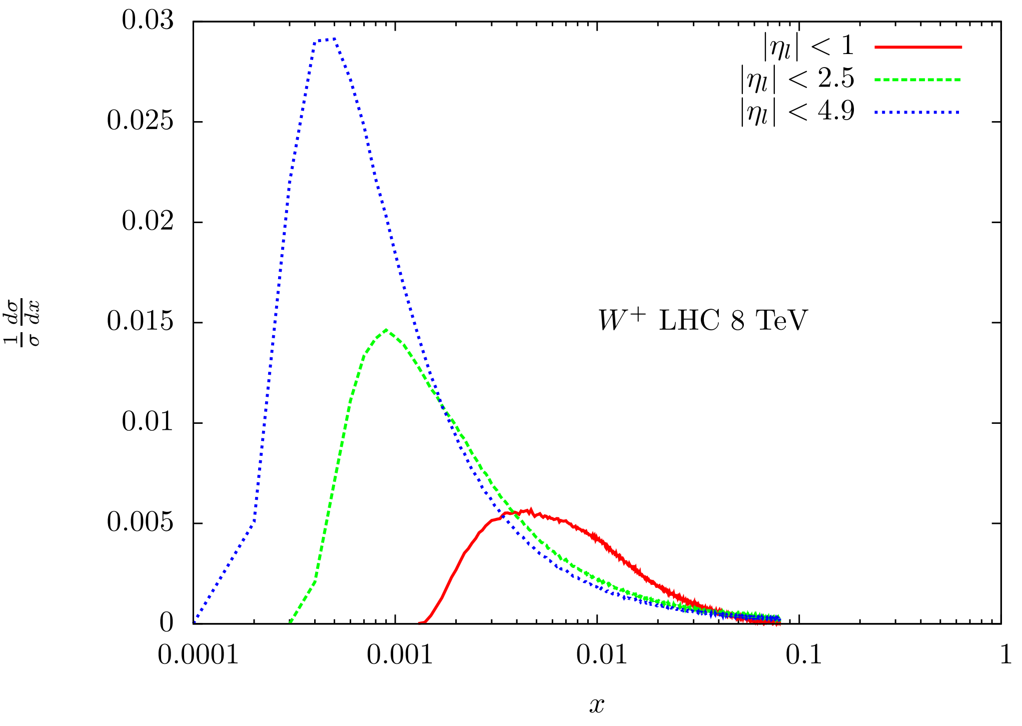

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- PDF sum rules → *non trivial compensations between different rapidity intervals among different flavours*

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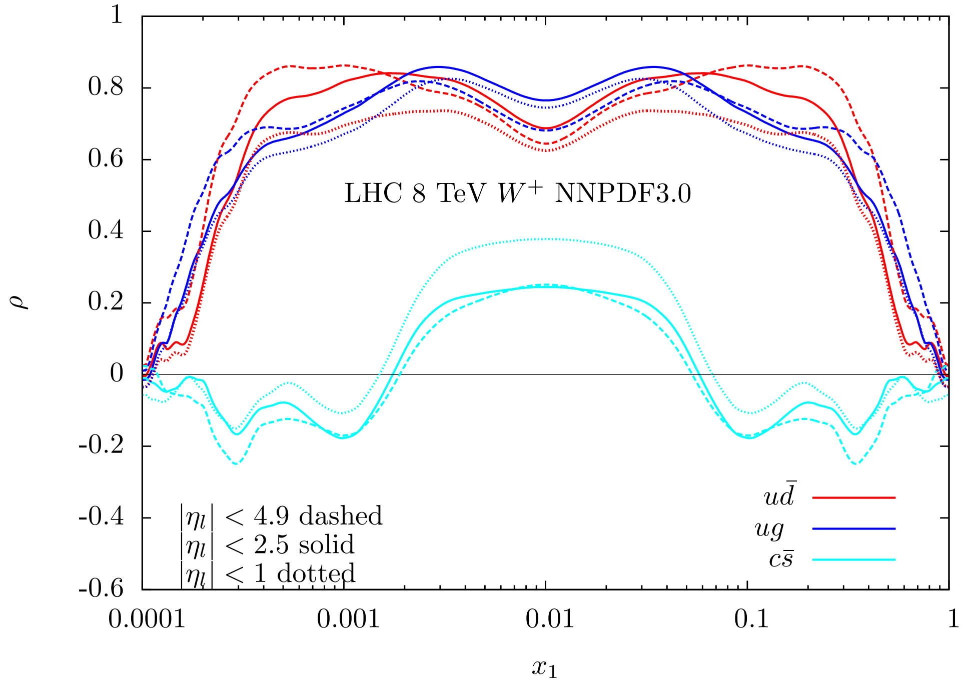

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$$\frac{d\sigma}{dq_T} \sim \text{FT}\ \exp\{-g_{_{NP}} b_T^2\} \longrightarrow$$

Fit to Z/γ^* Tevatron data: $g_{_{NP}} \sim 0.8\ \text{GeV}^2$

[Guzzi, Nadolsky, Wang (2014)]

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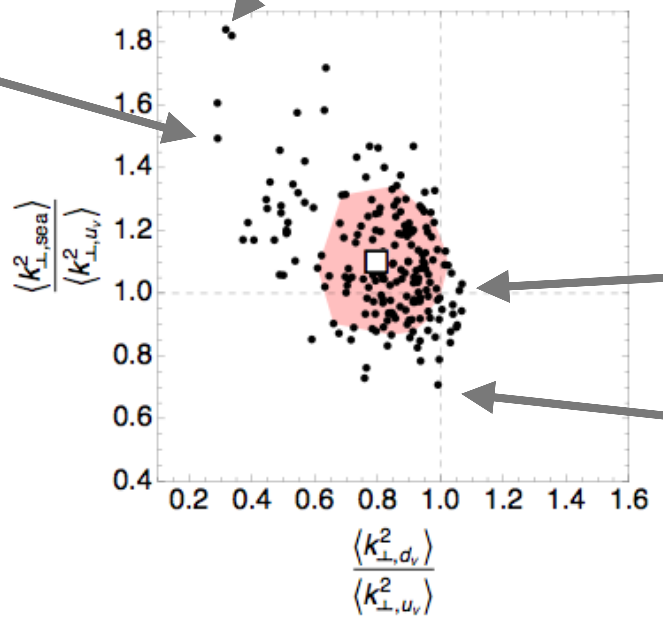
We consider :

- **50 flavour-dependent sets** $\{g^{u_v}_{_{NP}}, g^{d_v}_{_{NP}}, g^{u_s}_{_{NP}}, g^{d_s}_{_{NP}}, g^{s}_{_{NP}}\}$ with $g^a_{_{NP}} \in [0.2, 0.6]\ \mathrm{GeV}^2$
- **1 flavour-independent set** with $g^a_{_{NP}} = 0.4\ \mathrm{GeV}^2$

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
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replica 130
χ^2/dof = 1.77

replica 186
χ^2/dof = 1.38

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u_v width

point of
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d_v width < (mostly) u_v width

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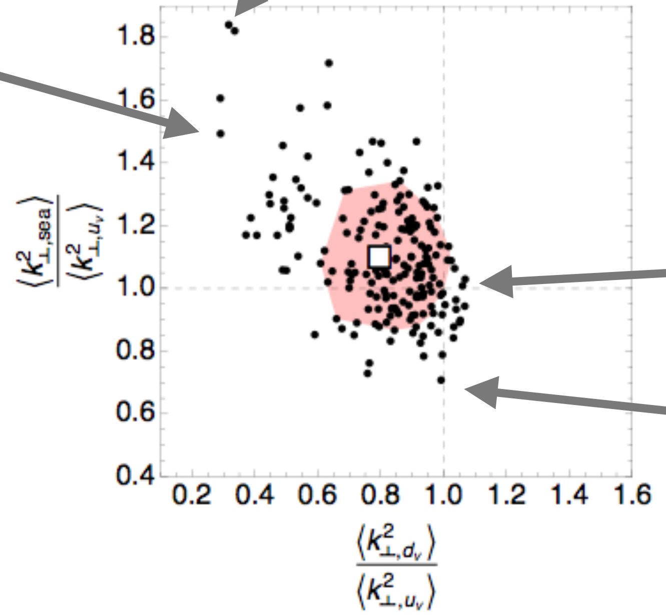

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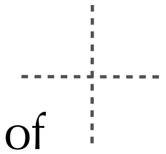

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On average, *sea > u_v > d_v*

flav-dep vs. flav-indep set