Non perturbative flavour-dependent effects due to intrinsic k_T and their impact on the determination of M_W

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in collaboration with
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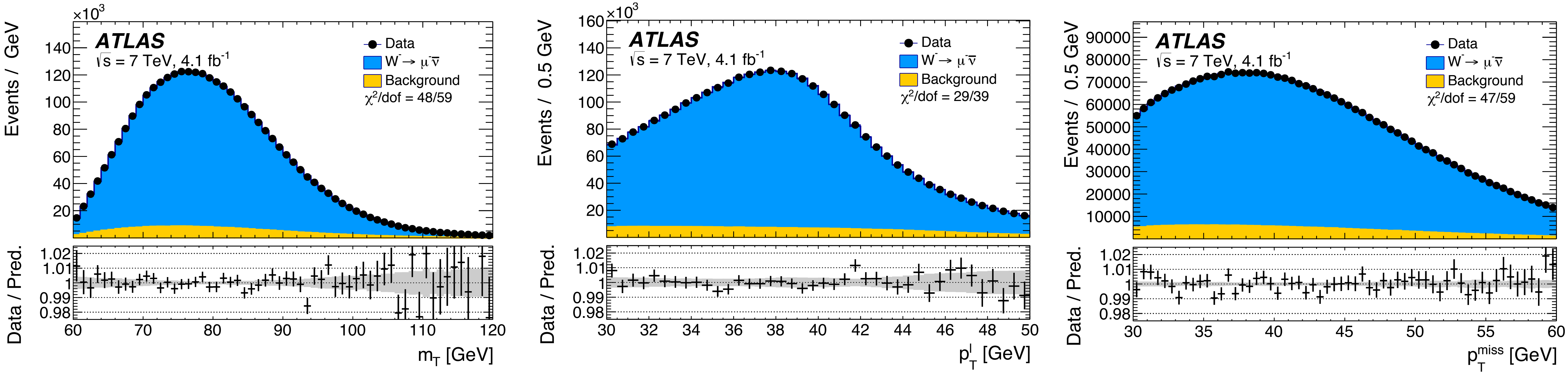
Observables and techniques



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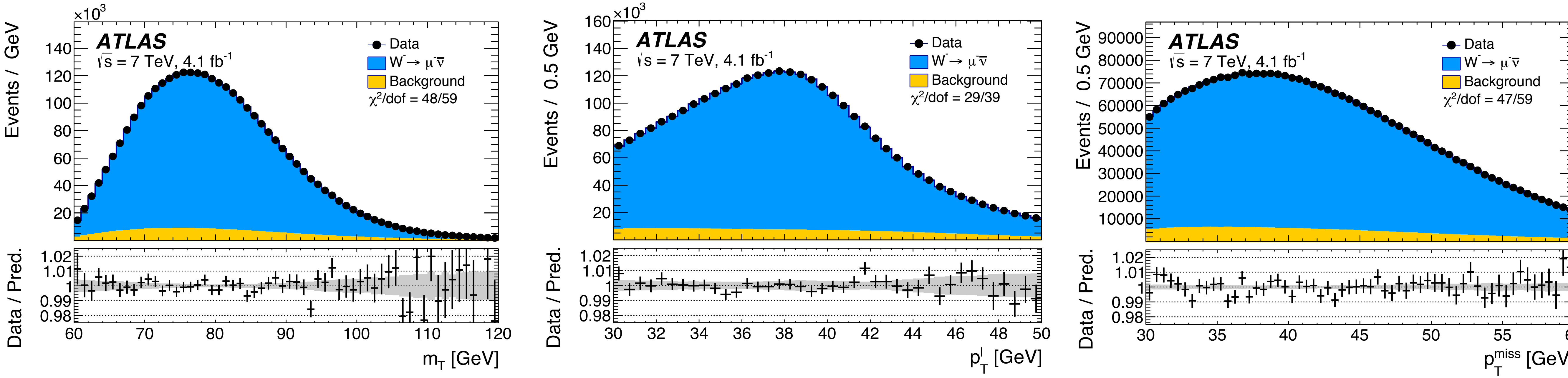

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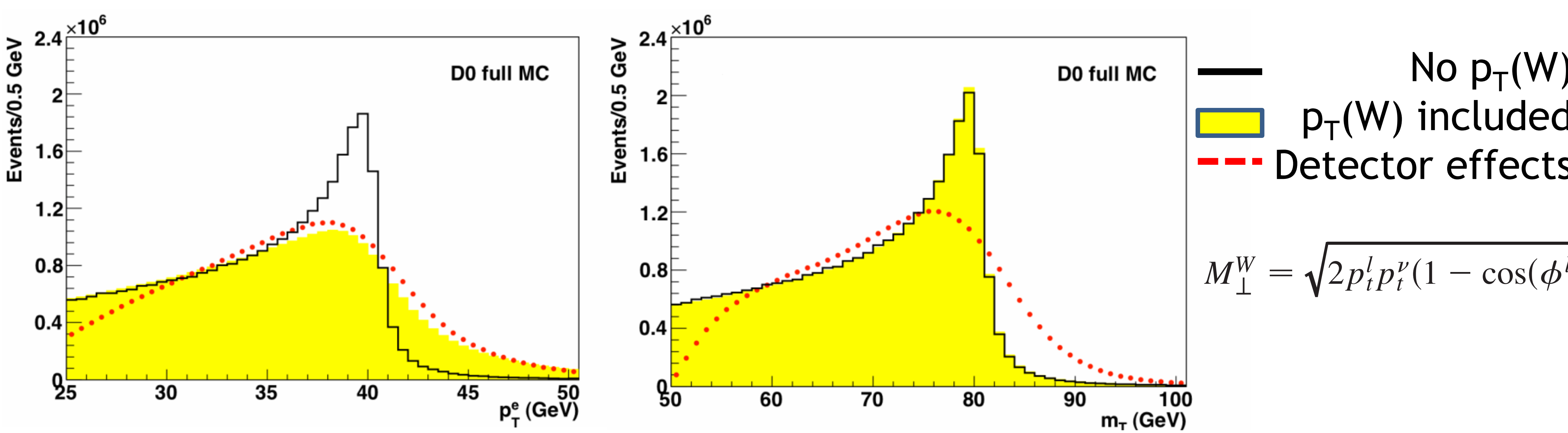

$$M_{\perp}^{W} = \sqrt{2 p_t^l p_t^\nu (1 - \cos(\phi^l - \phi^\nu))},$$

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

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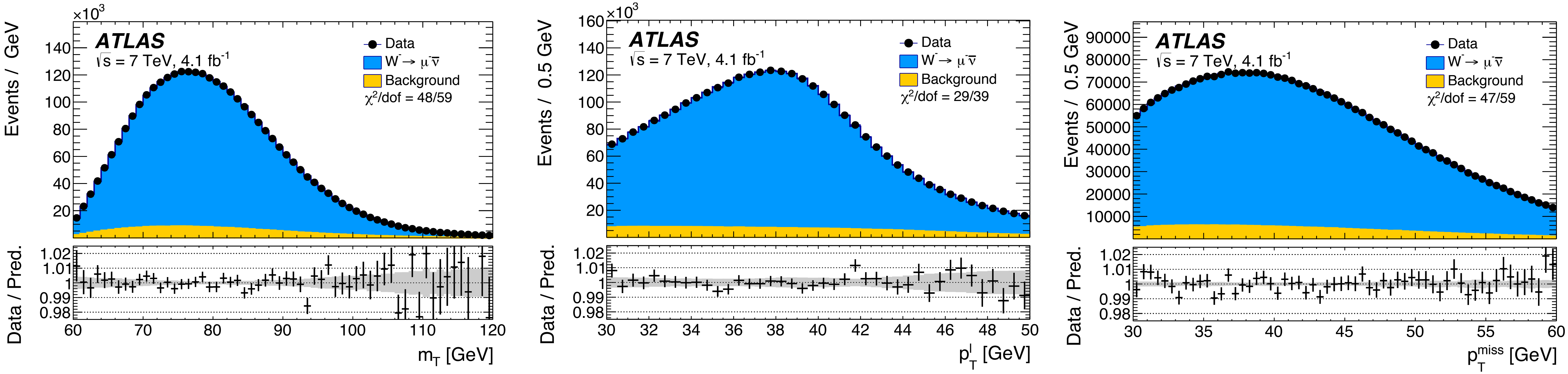

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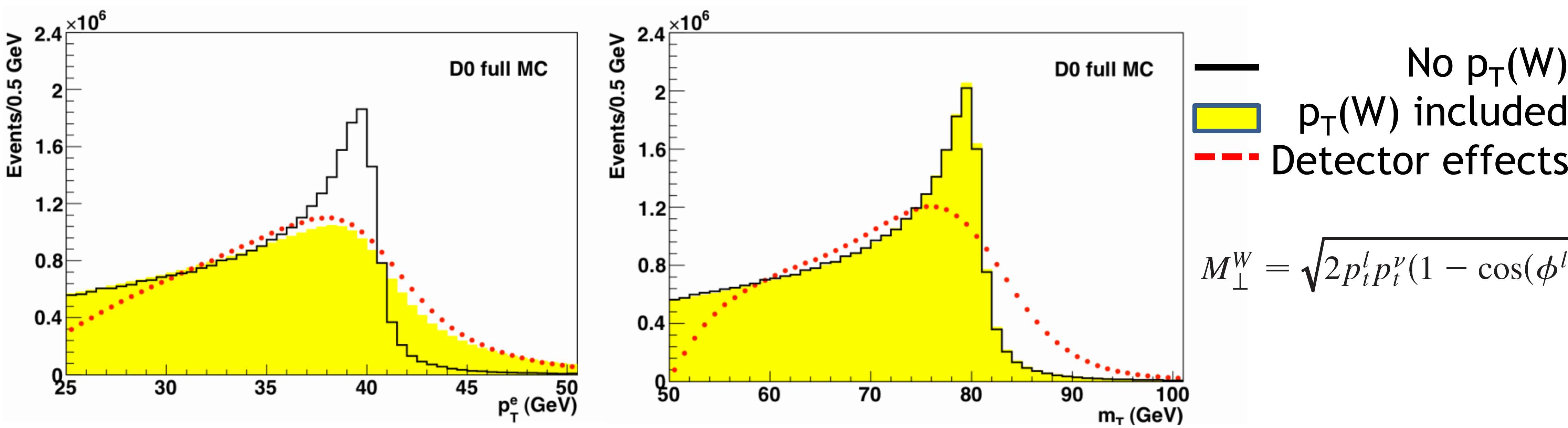

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p_{TW} modelling depends on flavour and all-order treatment of QCD corrections

Observables and techniques

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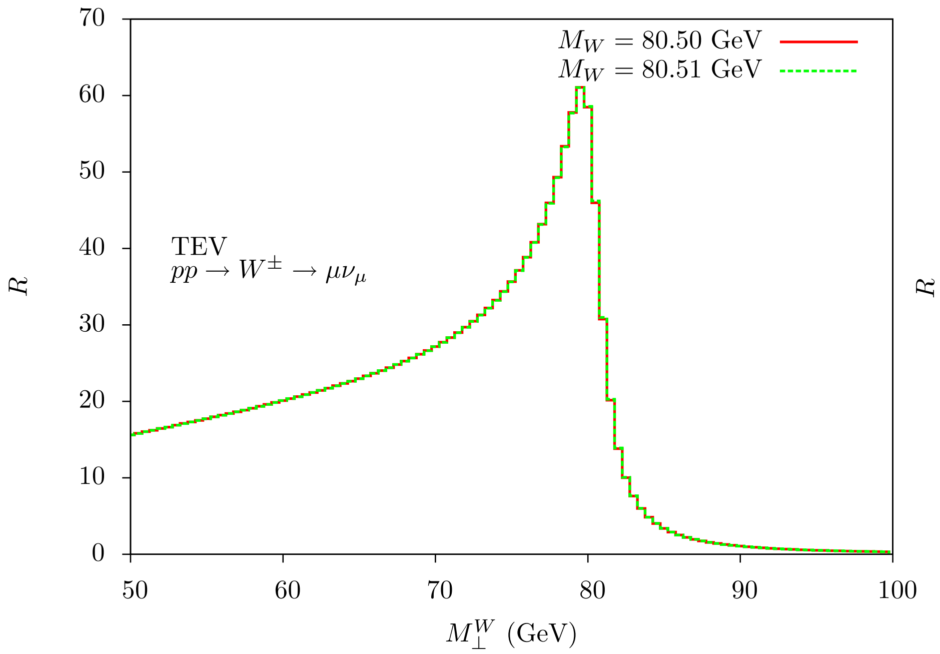

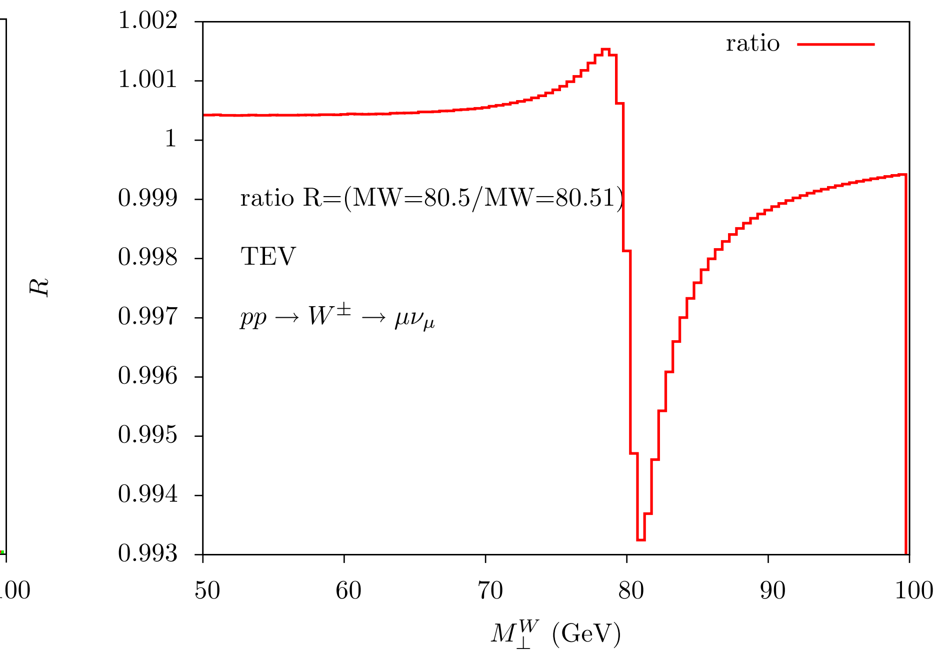

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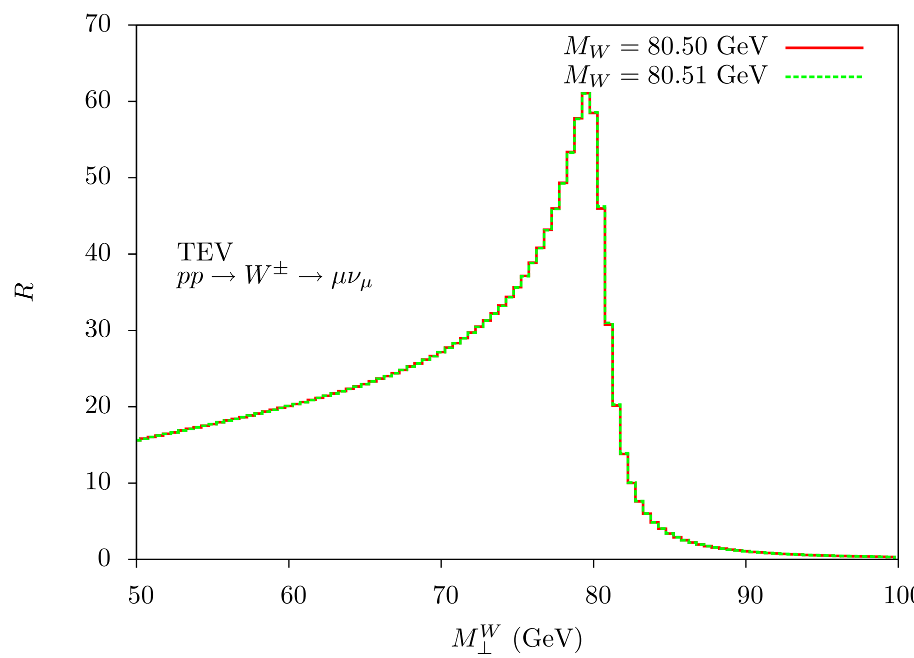

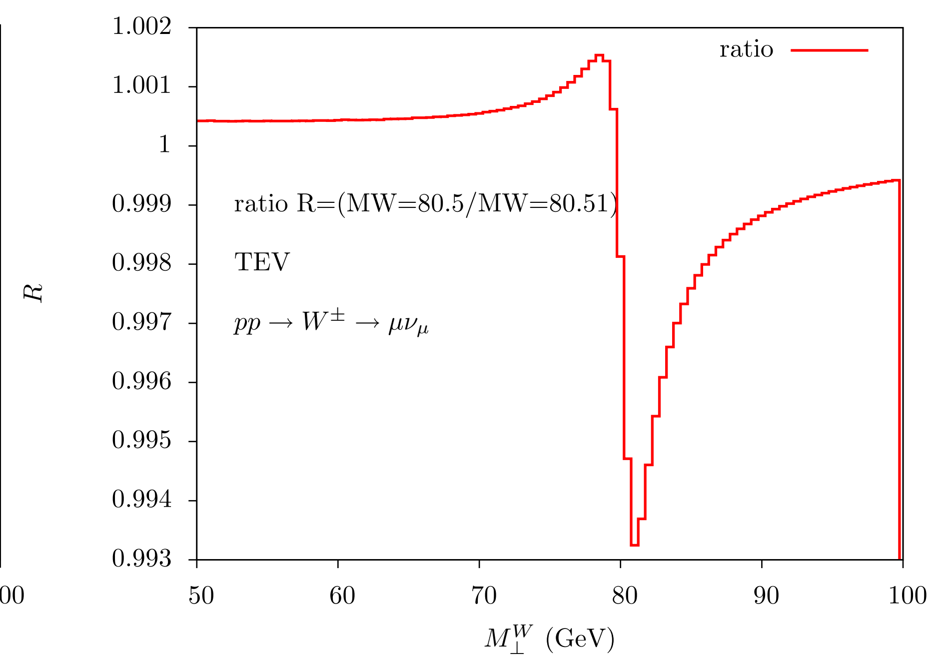

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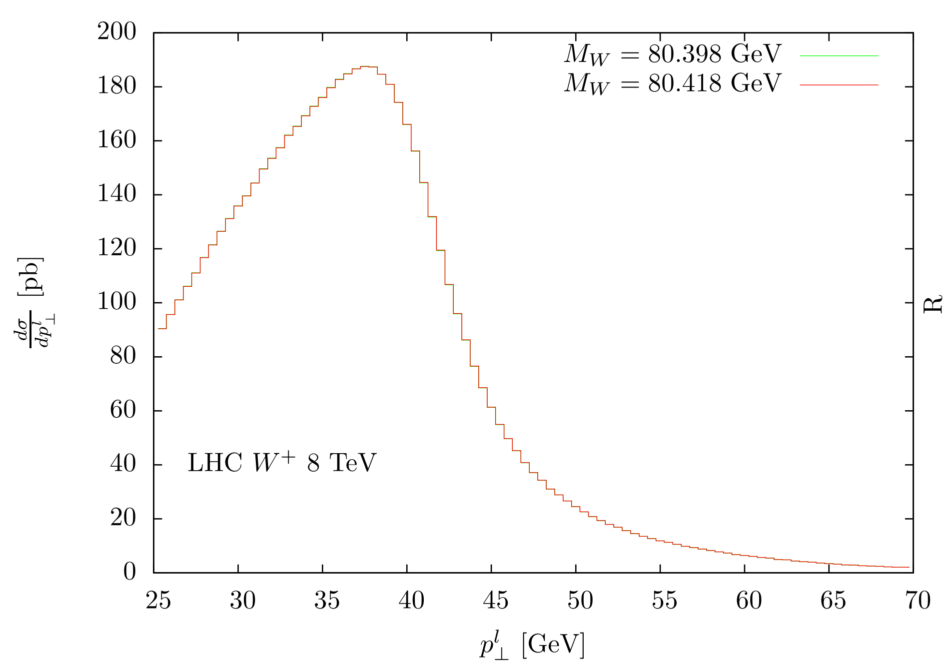

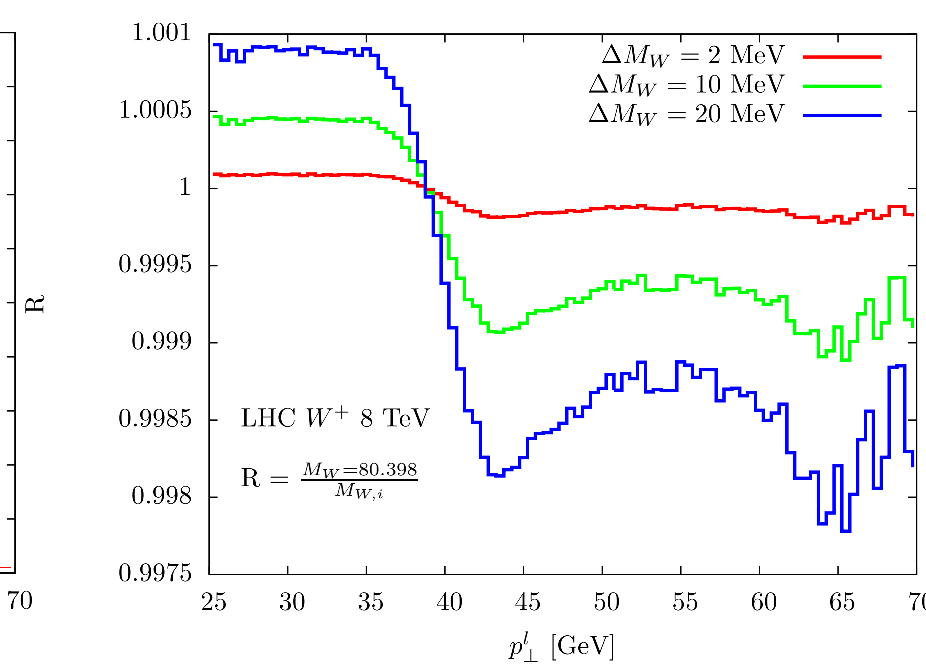

Uncertainties on M_W due to p_{TW}

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			
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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
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	W^+		W^-		Combined	
Kinematic distribution	p_T^ℓ	m_T	p_T^ℓ	m_T	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
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—> *different Gaussian factors for different flavours*

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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 $g^a_{_{NP}} = 0.4\ \mathrm{GeV}^2$

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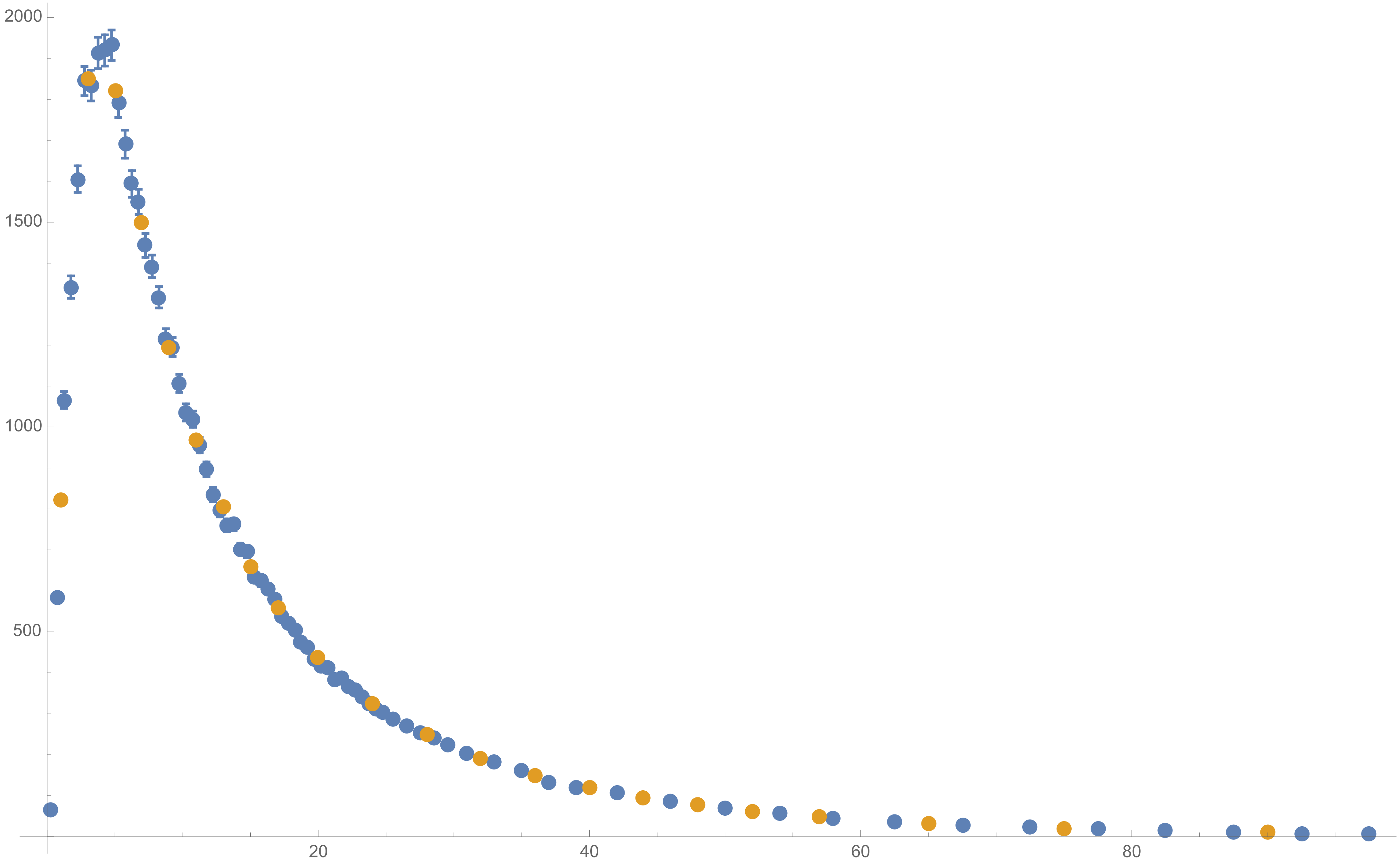

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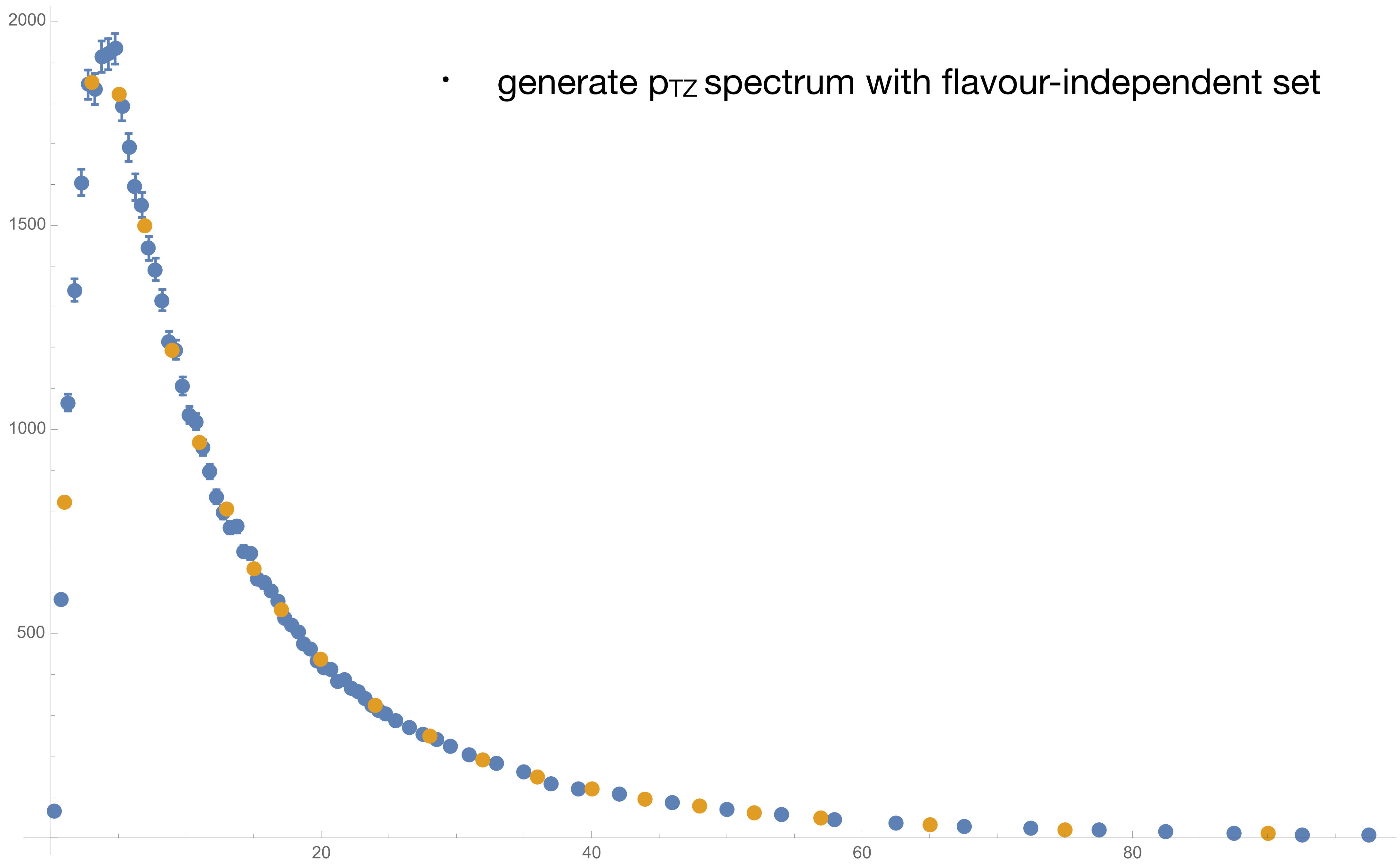

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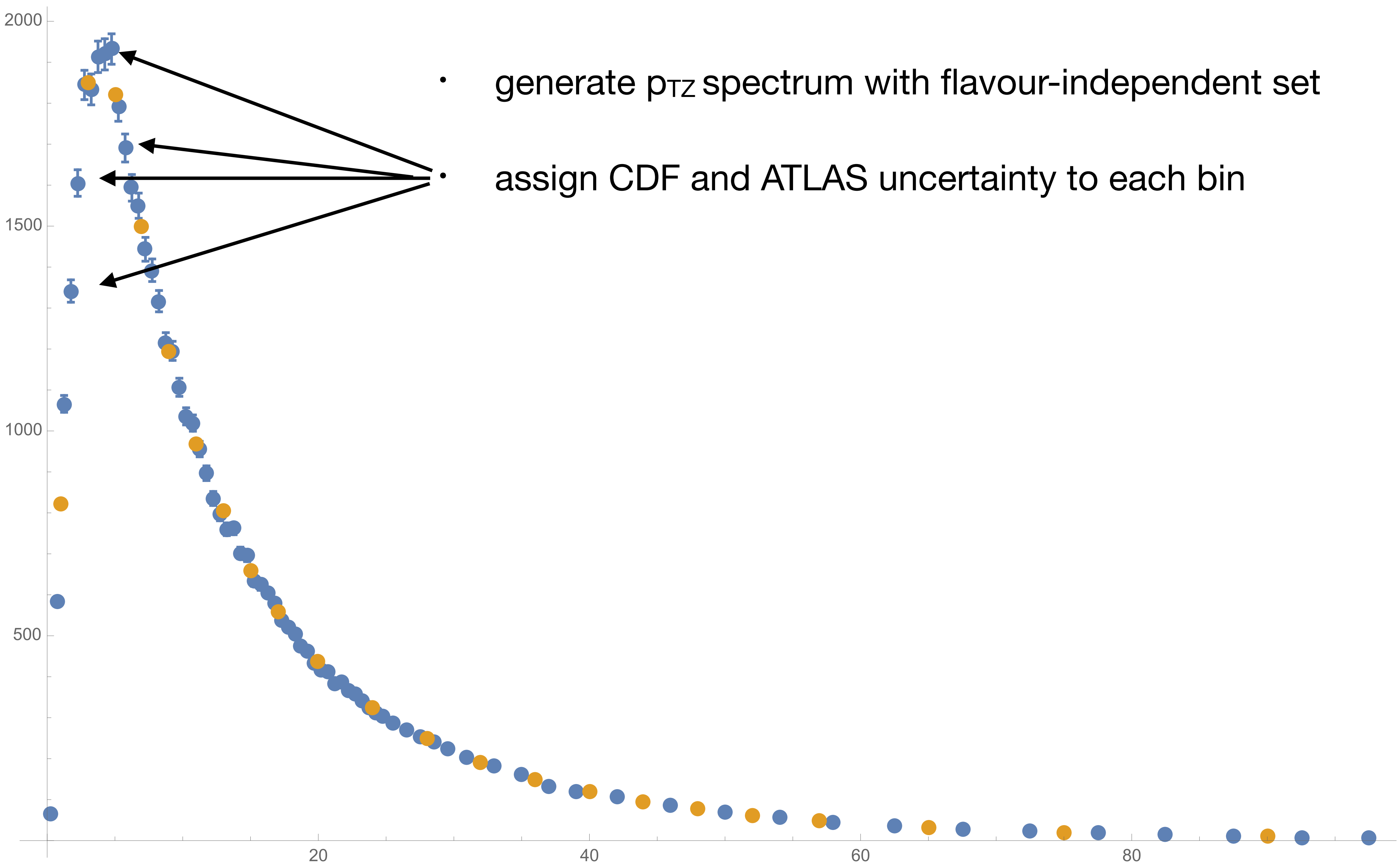

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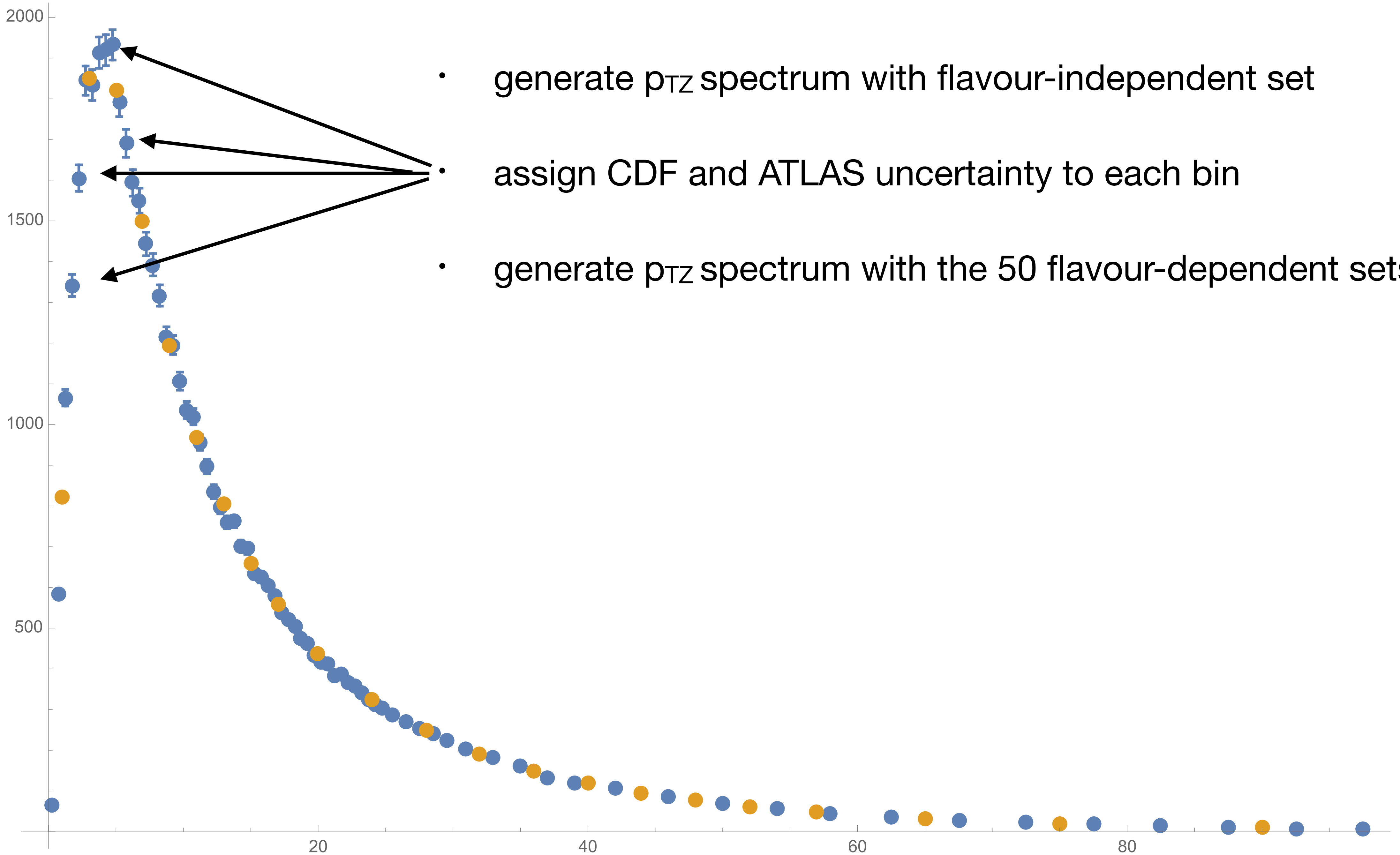

- generate p_{TZ} spectrum with flavour-independent set
- assign CDF and ATLAS uncertainty to each bin
- generate p_{TZ} spectrum with the 50 flavour-dependent sets

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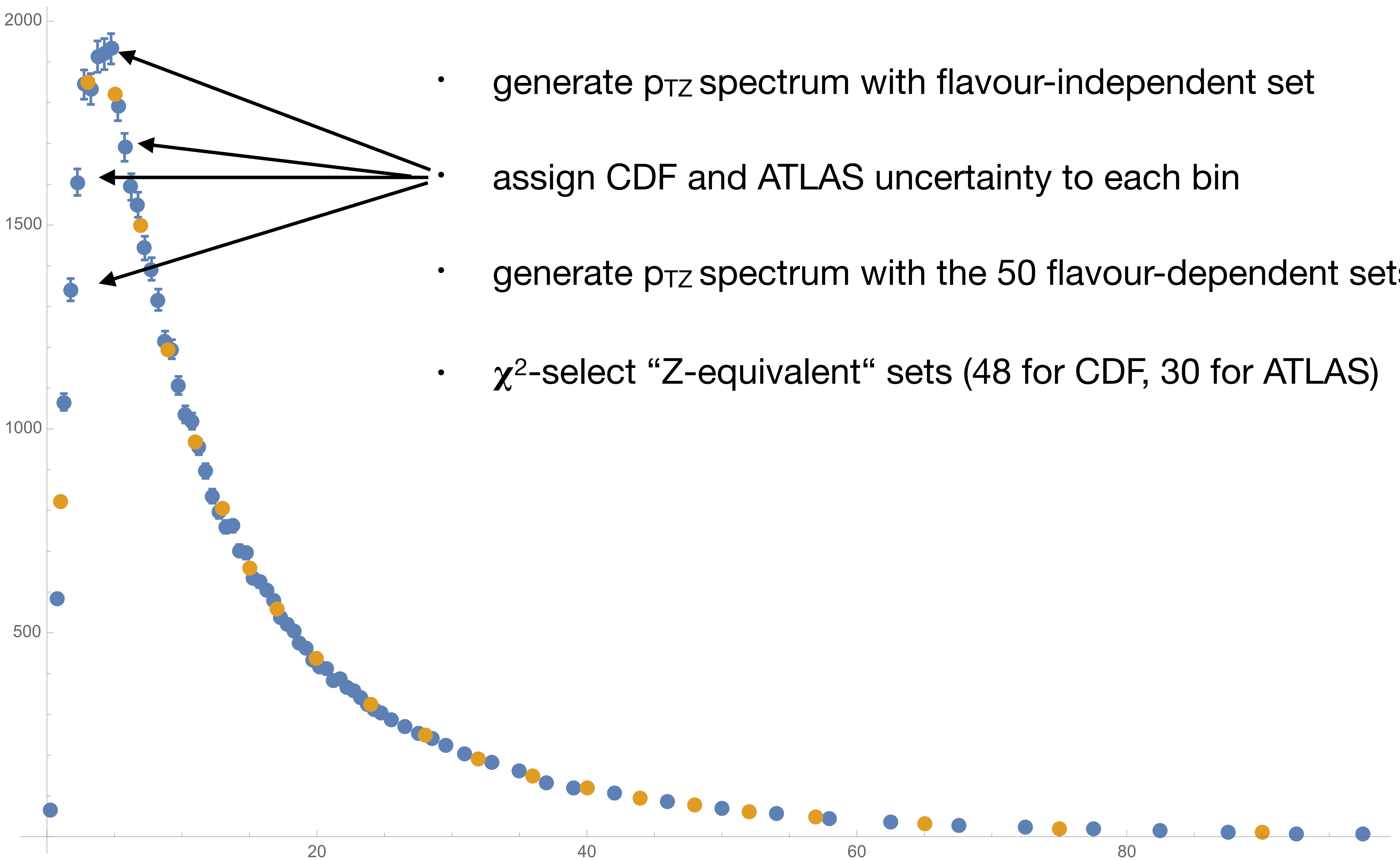

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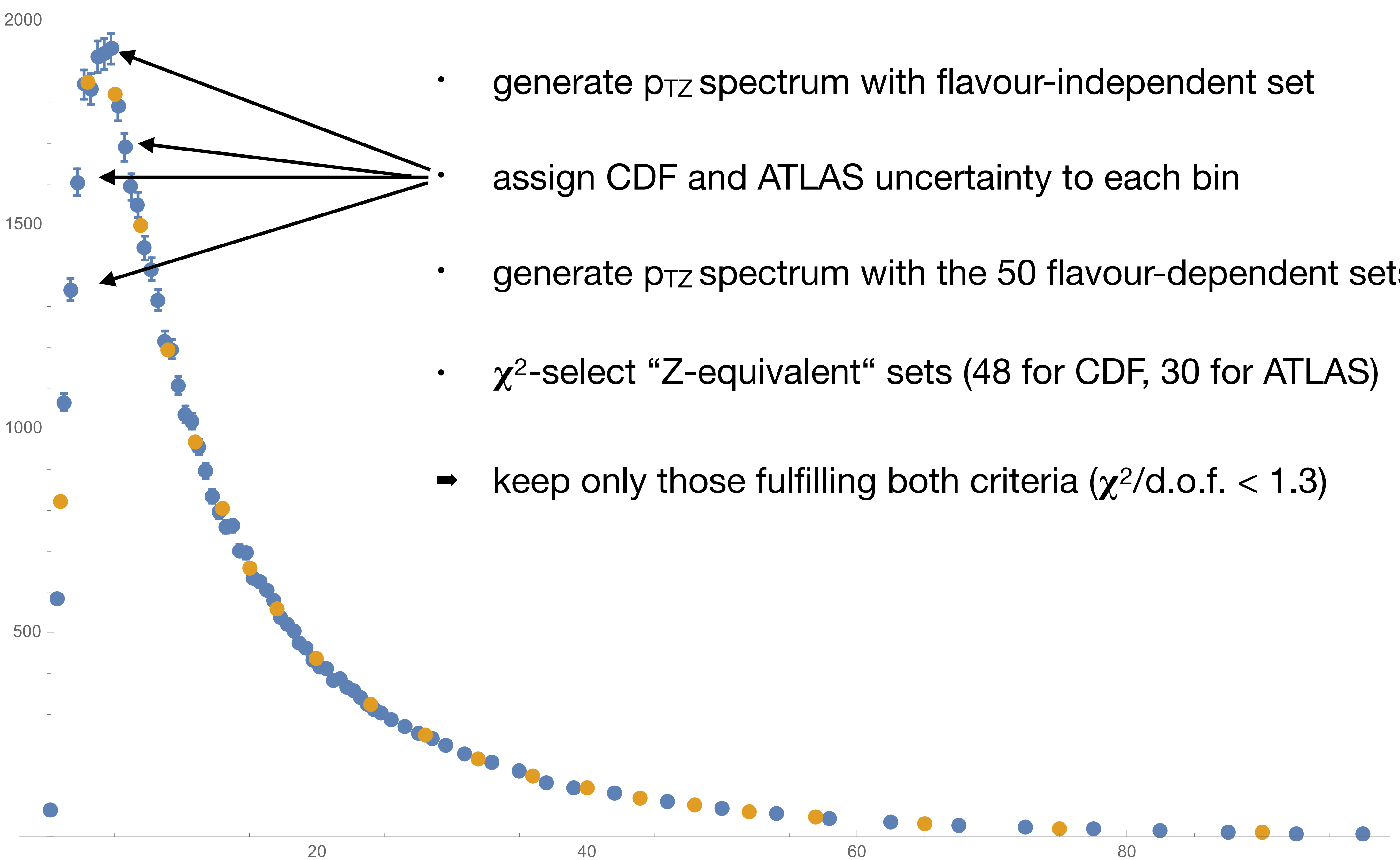

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W^+

Set	m_T	p_{Tl}
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2	-2	-3
3	-2	-9
4	0	-10
5	1	6
6	-2	-7
7	1	-8
8	-2	-15
9	1	-15
10	-3	0

W^-

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

NLL+LO QCD analysis obtained through a modified version of the **DYRes** code [Catani, deFlorian, Ferrera, Grazzini (2015)]
(LHC 7 TeV, ATLAS acceptance cuts)

Impact on the determination of M_W: preliminary results

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  ➡ these are our **pseudodata**

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

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- **perform the template fit procedure and compute the shifts induced by flavour effects**

- transverse mass: few MeV shifts, generally favouring lower values for W^- (preferred by EW fit)

W^+

Set	m_T	p_{Tl}
1	0	-1
2	-2	-3
3	-2	-9
4	0	-10
5	1	6
6	-2	-7
7	1	-8
8	-2	-15
9	1	-15
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- lepton pt: quite important shifts, generally favouring lower values (envelope: up to **21 MeV**)

W^+

Set	m_T	p_{Tl}
1	0	-1
2	-2	-3
3	-2	-9
4	0	-10
5	1	6
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  "Flavour creation is performed by a specially trained scientist called a **"flavorist"**, whose job combines scientific knowledge with creativity to develop new and distinctive flavours. The flavour creation begins when the flavorist receives a brief from the **client**. In the brief, the clients attempt to communicate exactly what type of flavour they seek, in what application it will be used, and any special requirements. The **communication barrier** can be quite difficult to overcome since most people are not experienced at describing flavours. The flavorist uses his or her knowledge to create a formula and compound it. The flavour is then submitted to the client for testing. **Several iterations, with feedback from the client, may be needed before the right flavour is found.**"

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

Backup slides

The W mass

ATLAS, EPJC 78, 110 (2018)

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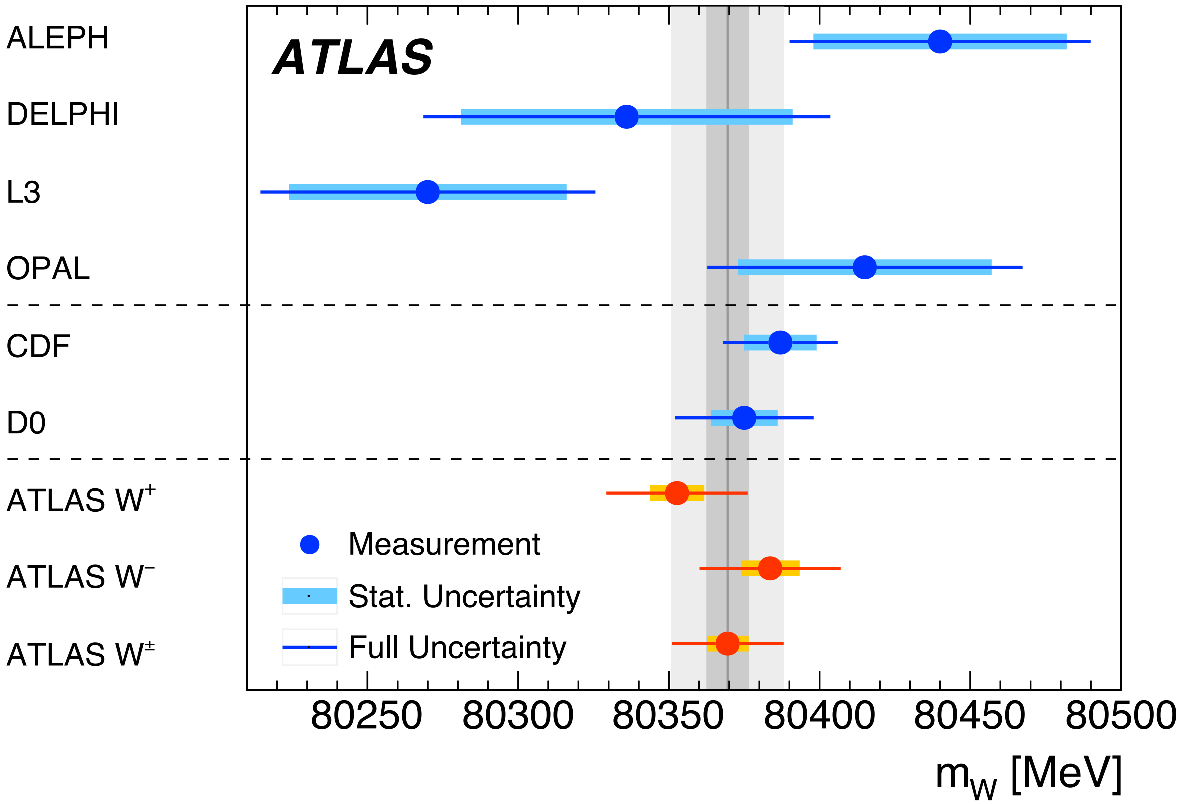

Experimental measurements

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

(7 stat, 11 exp, 14 th)

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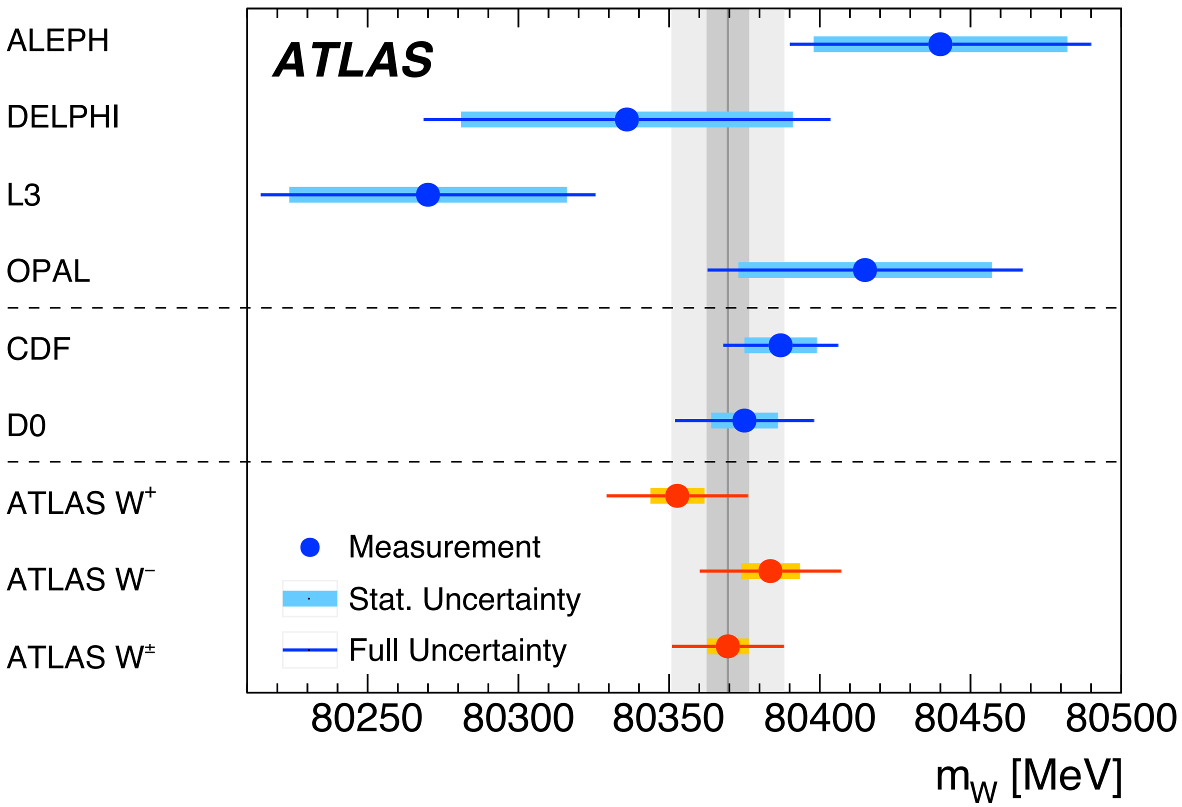

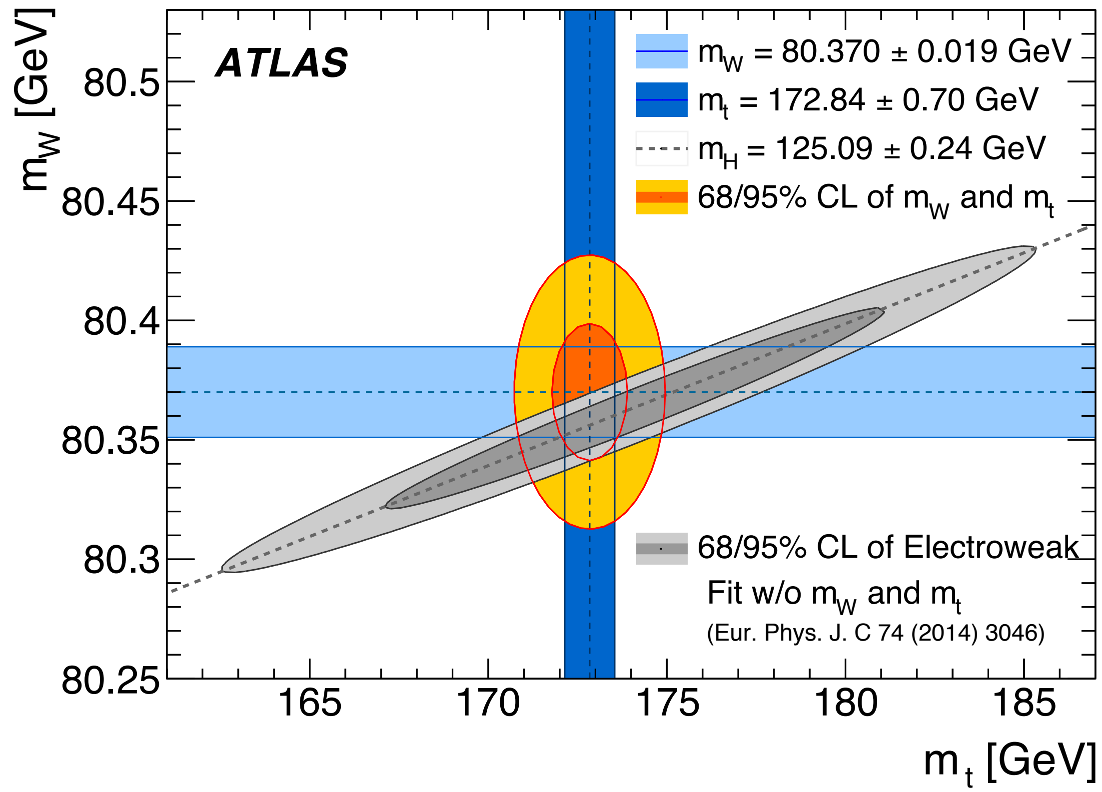

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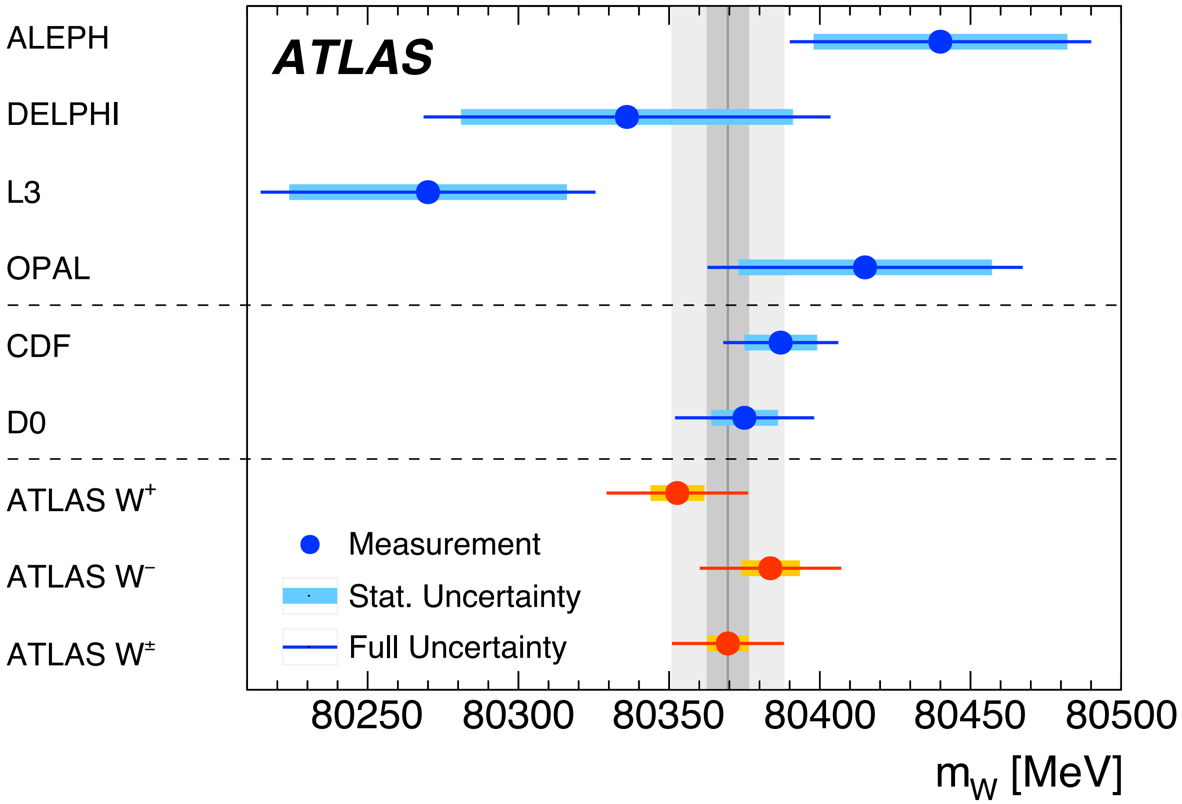

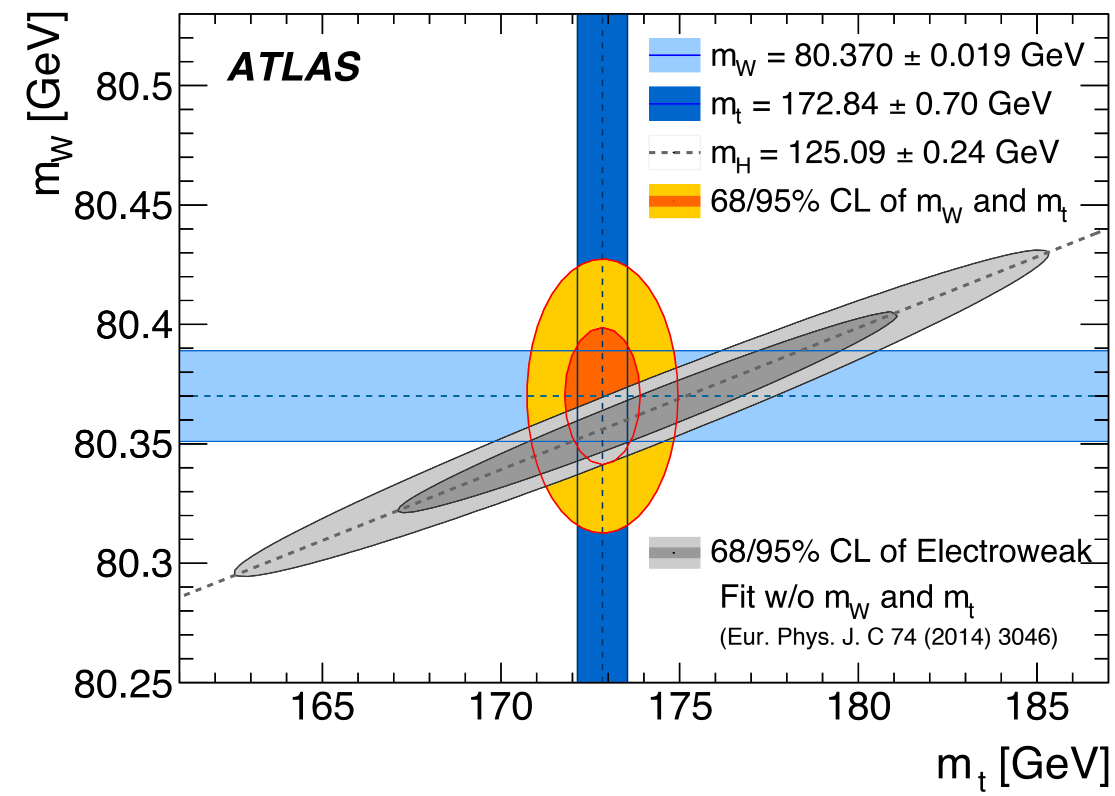

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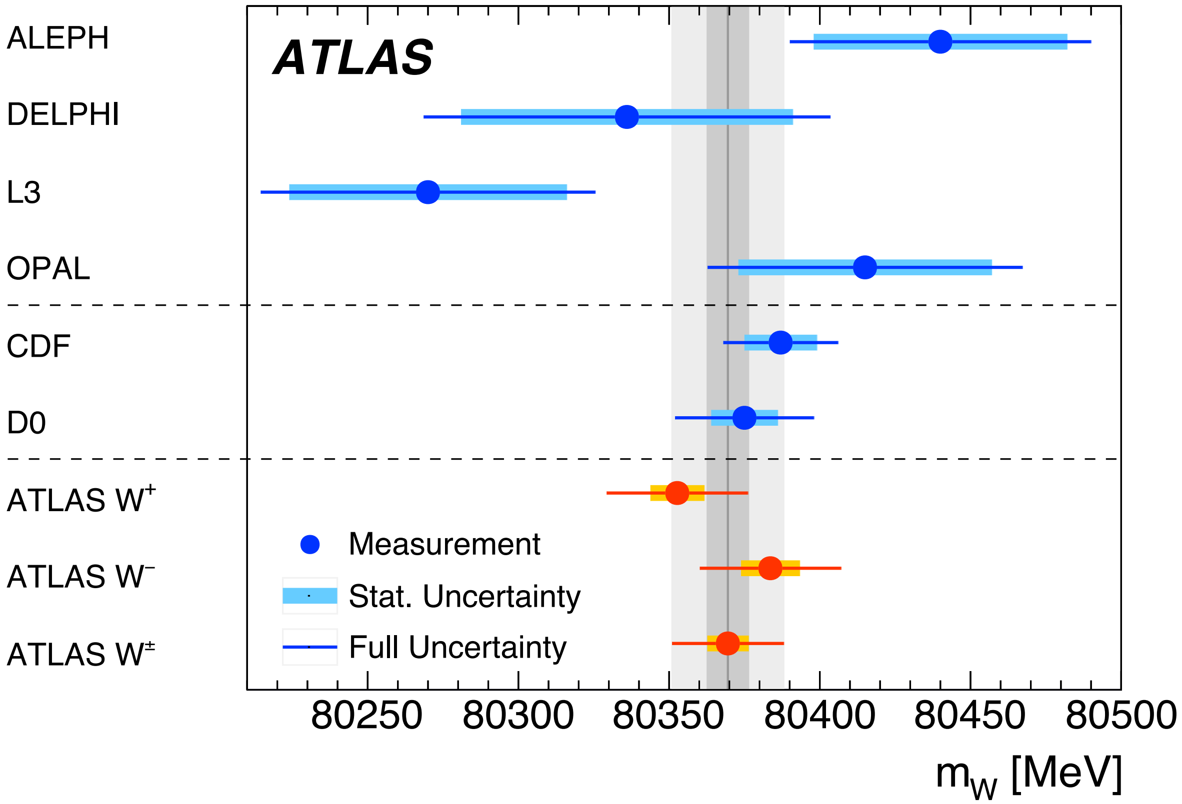

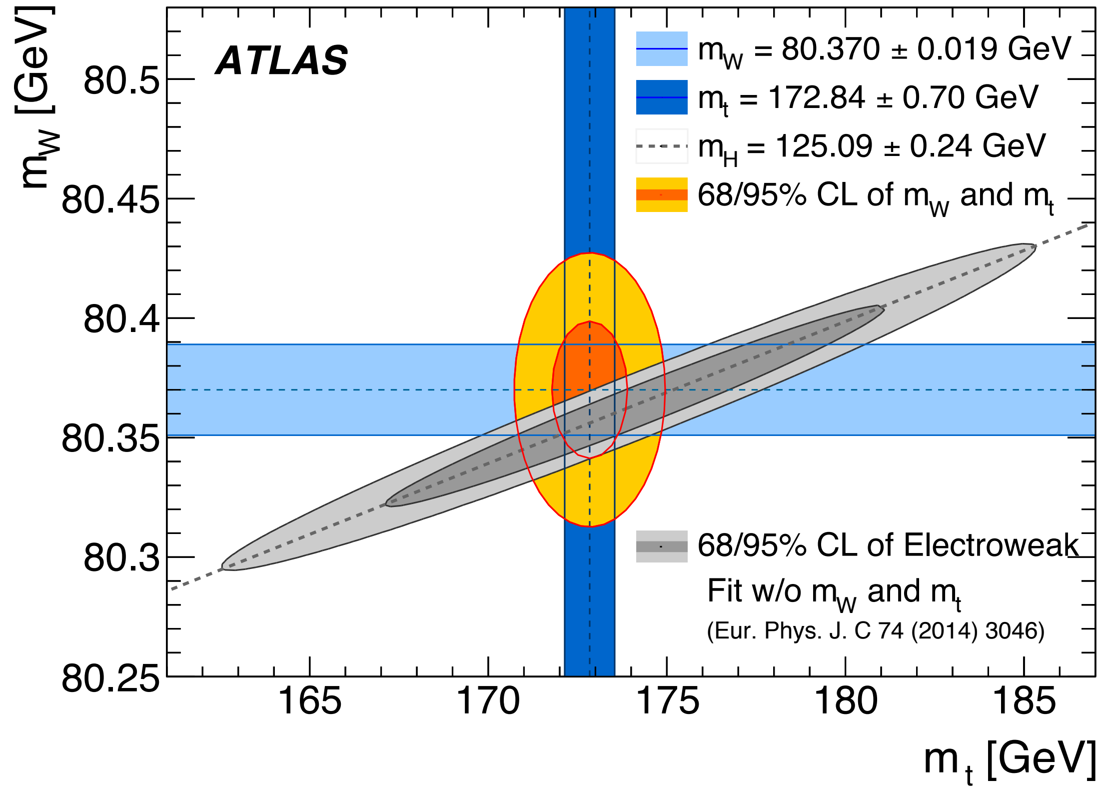

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The extraction of physical quantities

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Observables

- accessible via counting experiments: cross sections and asymmetries

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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
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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

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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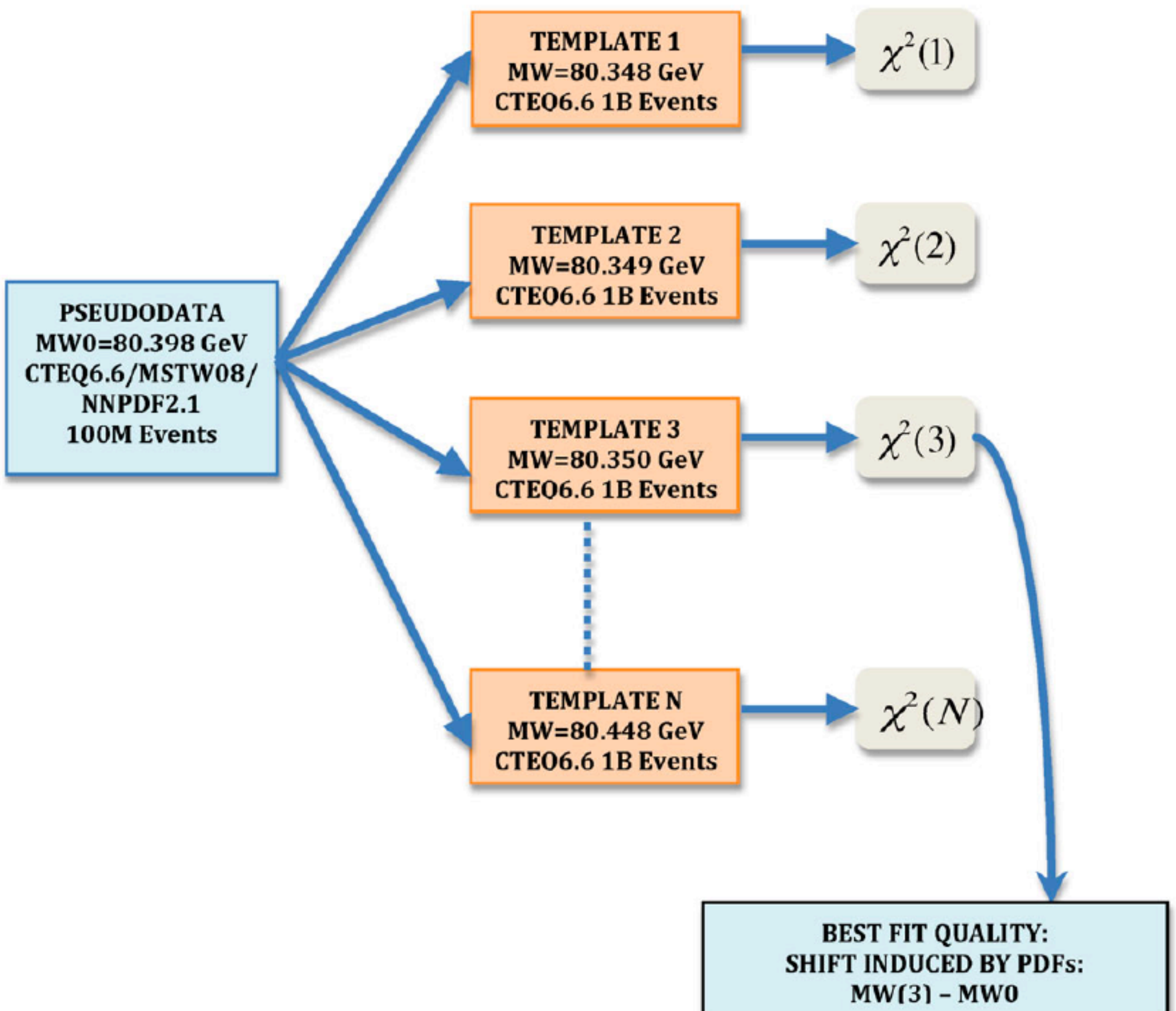
- same code used to generate both pseudodata and templates → only effect probed is the PDF one



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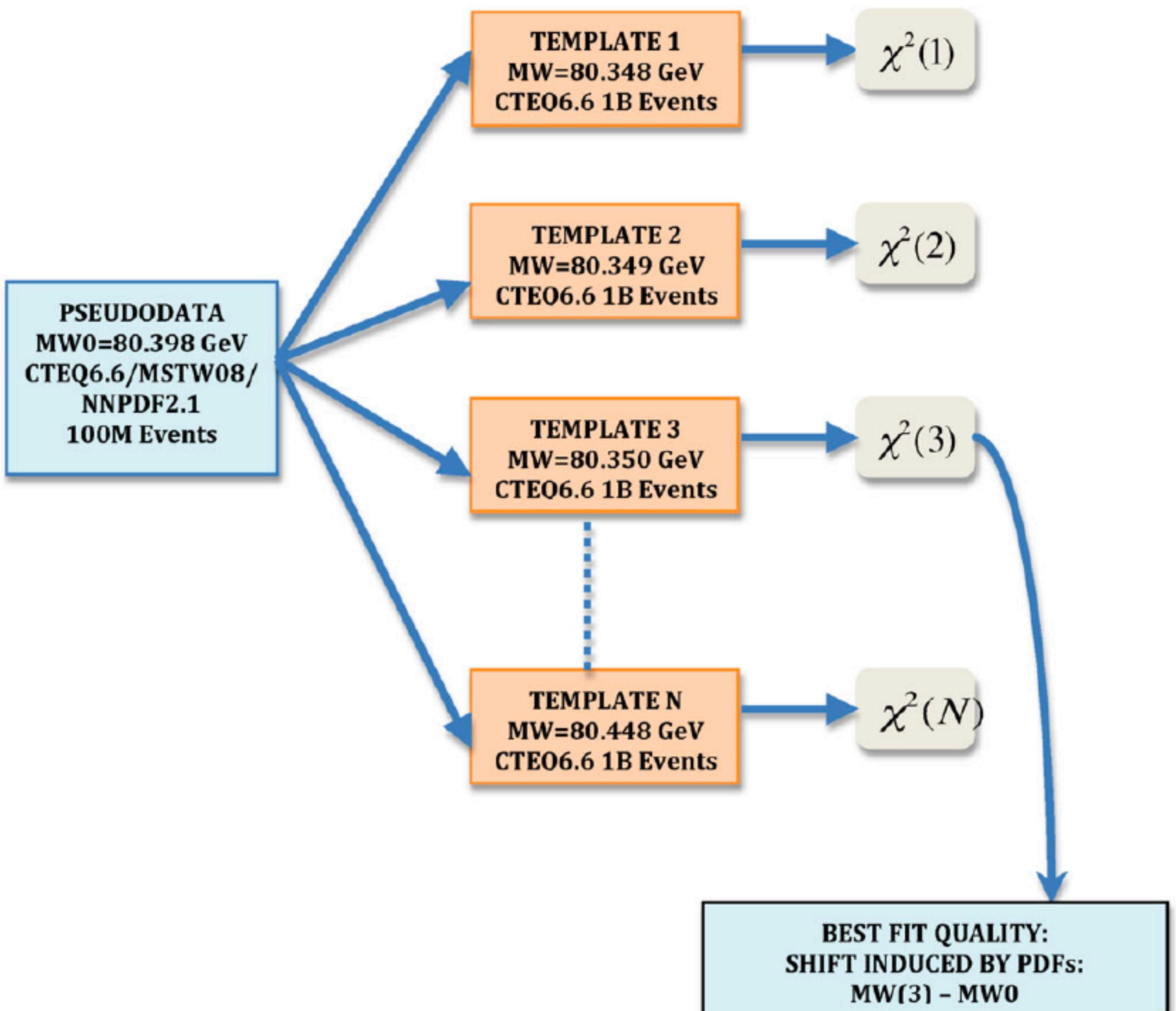

- PDF error = combination of different M_W results from each replica, according to the formulae recommended by the PDF collaborations

Hessian: CTEQ, MSTW

$$\sigma_X^2 = \frac{1}{4}\sum_{k=1}^{N}[X(S_k^+) - X(S_k^-)]^2$$

Montecarlo: NNPDF

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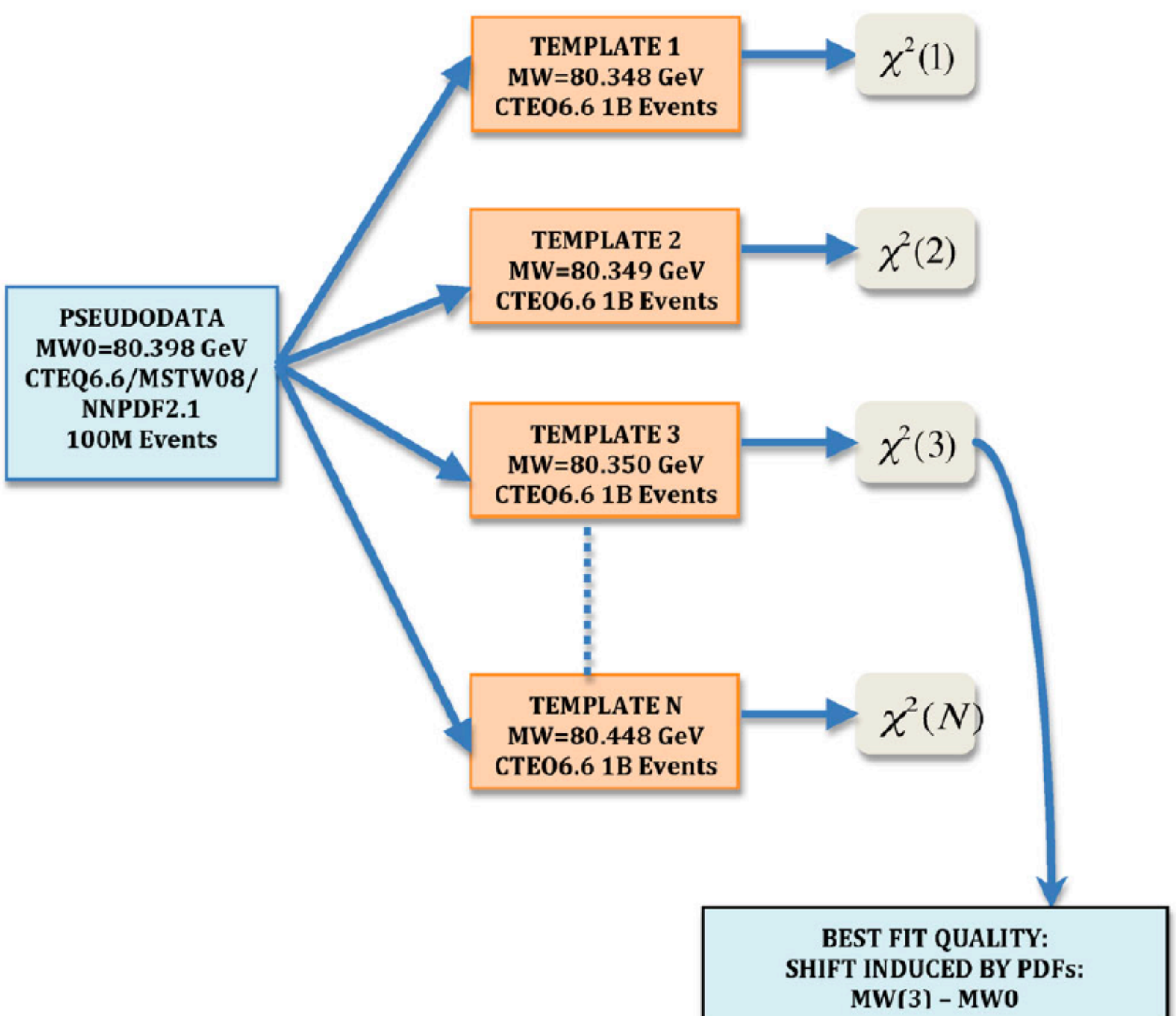

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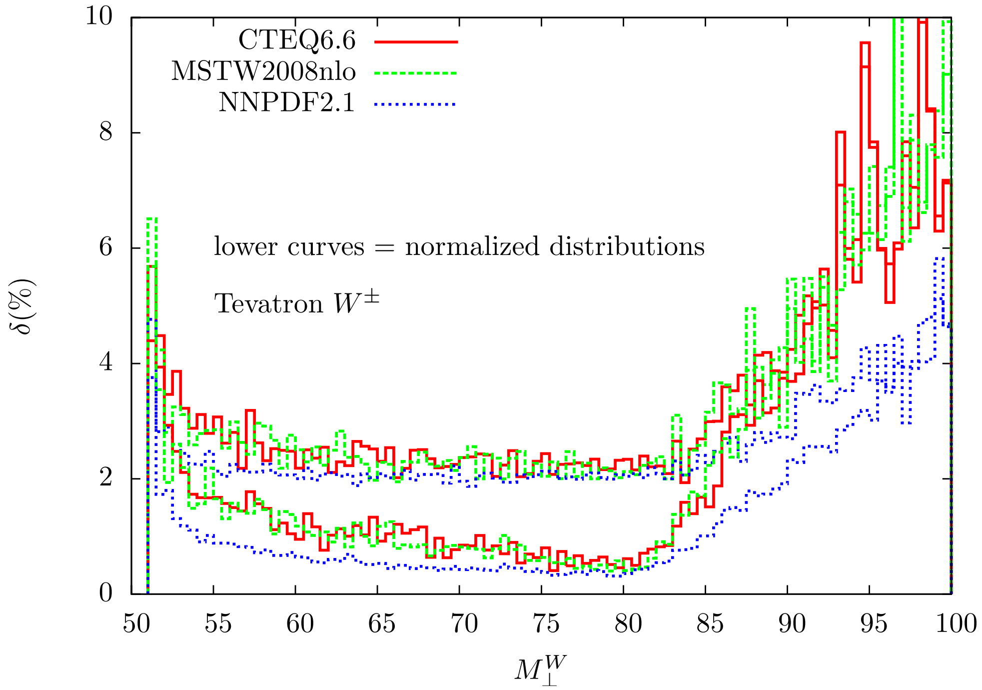
- M_W shift = distance between the PDF set under study and the reference set

Effects on transverse mass



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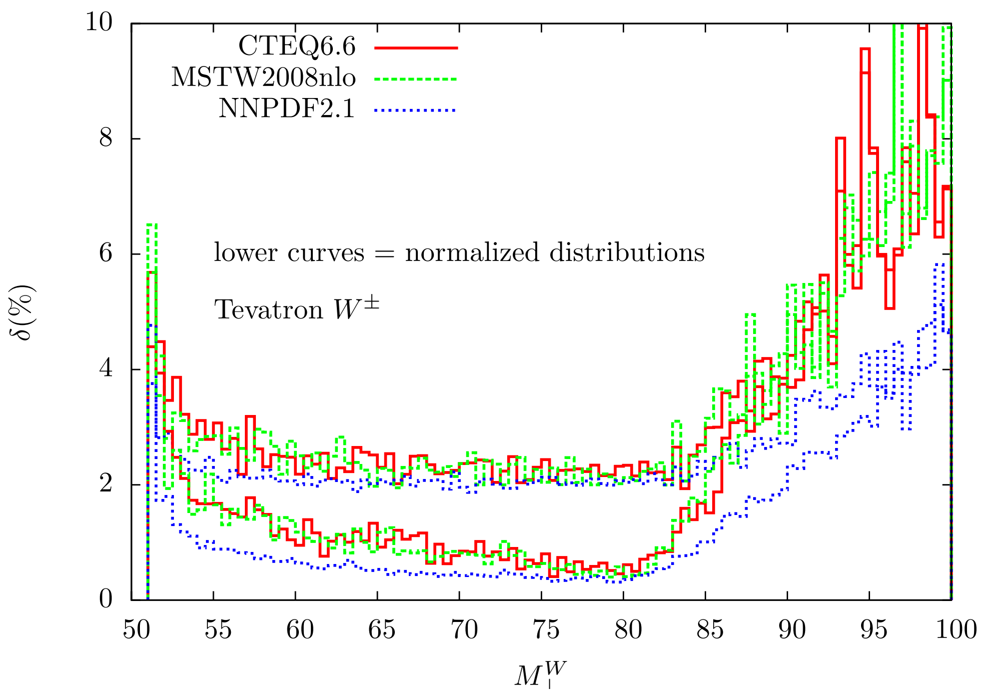

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	$m_W \pm \delta_{\rm pdf}$	$\langle\chi^2\rangle$	$m_W \pm \delta_{\rm pdf}$	$\langle\chi^2\rangle$	$m_W \pm \delta_{\rm pdf}$	$\langle\chi^2\rangle$	$\delta_{\rm pdf}^{\rm tot}$
Tevatron, $W^\pm$	80.398 ± 0.004	1.42	80.398 ± 0.003	1.42	80.398 ± 0.003	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
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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
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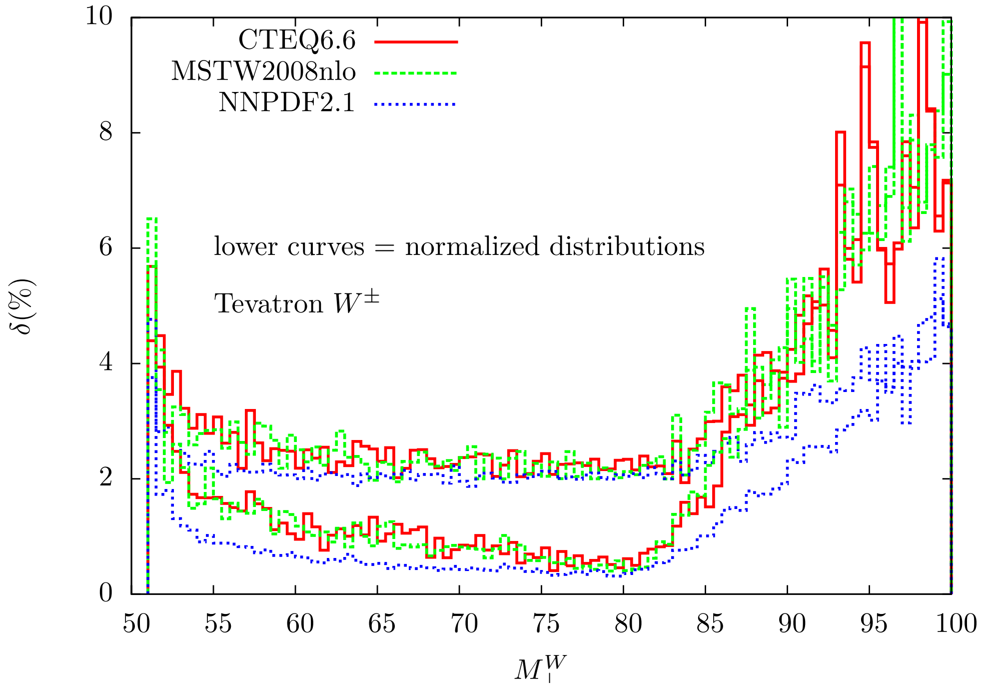

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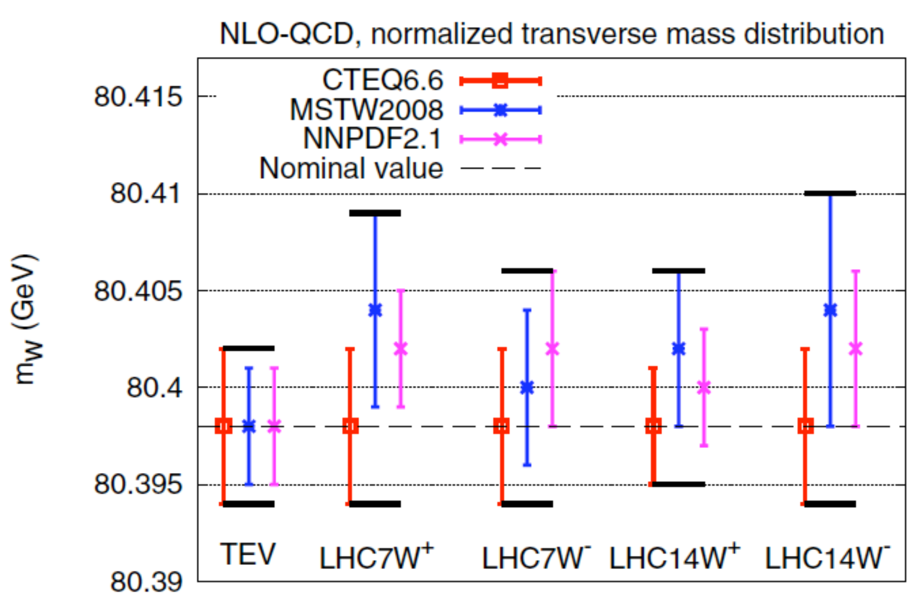

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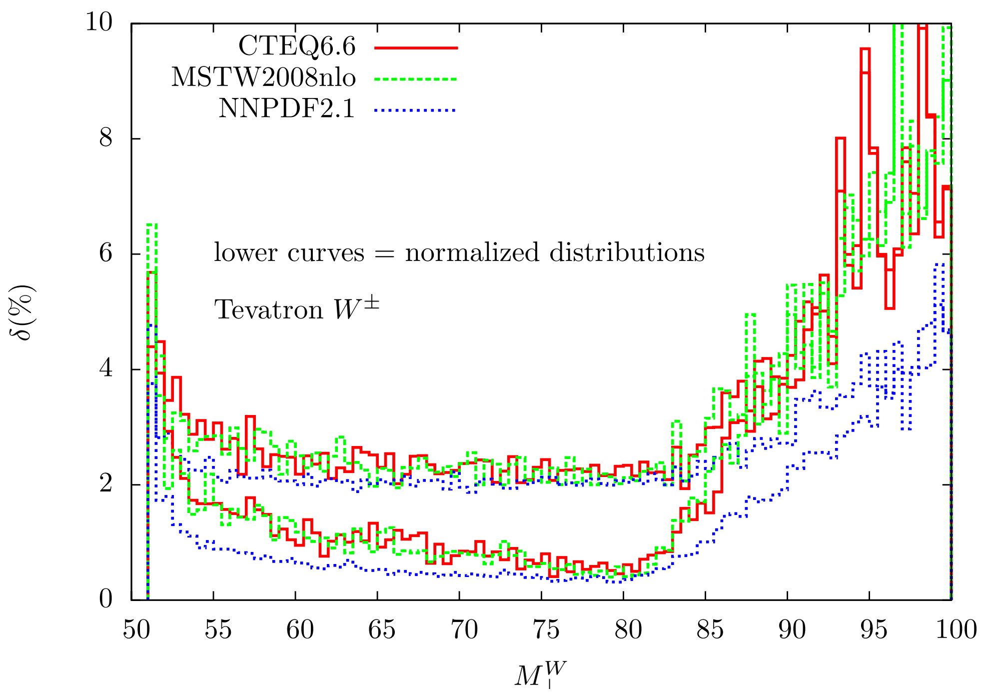

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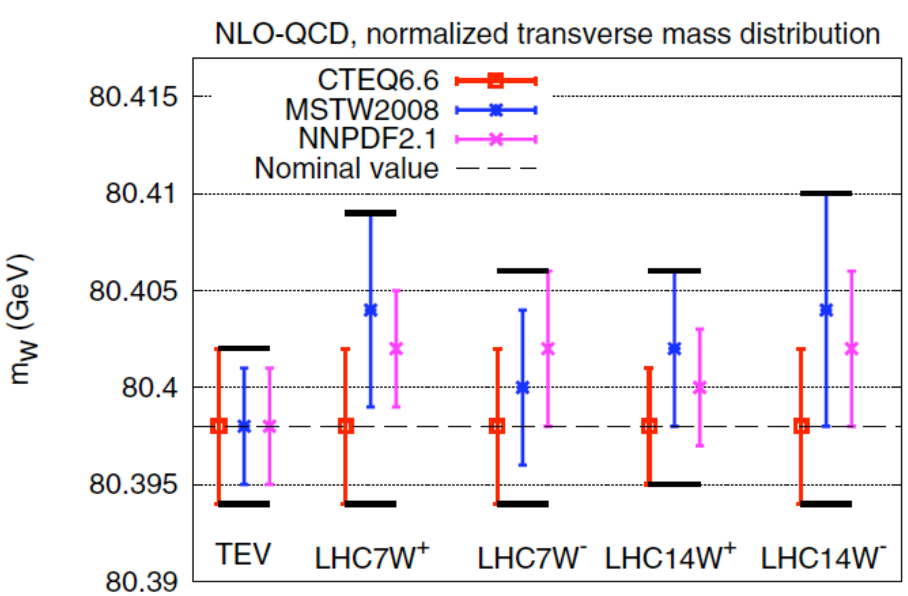
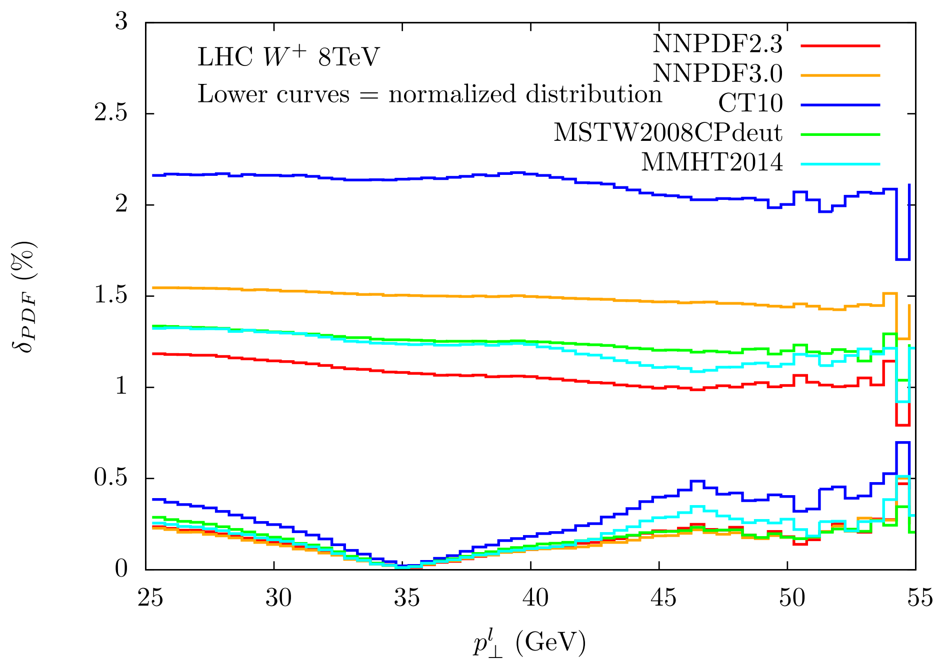


- Accuracy of templates essential: highly demanding computing task!
- For transverse mass distribution, a fixed-order NLO-QCD analysis is sufficient to assess this PDF uncertainty
- PDF error is moderate at the Tevatron but also at the LHC

Effects on lepton p_T



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

- Conservative estimate of the PDF uncertainty: CC-DY channel alone
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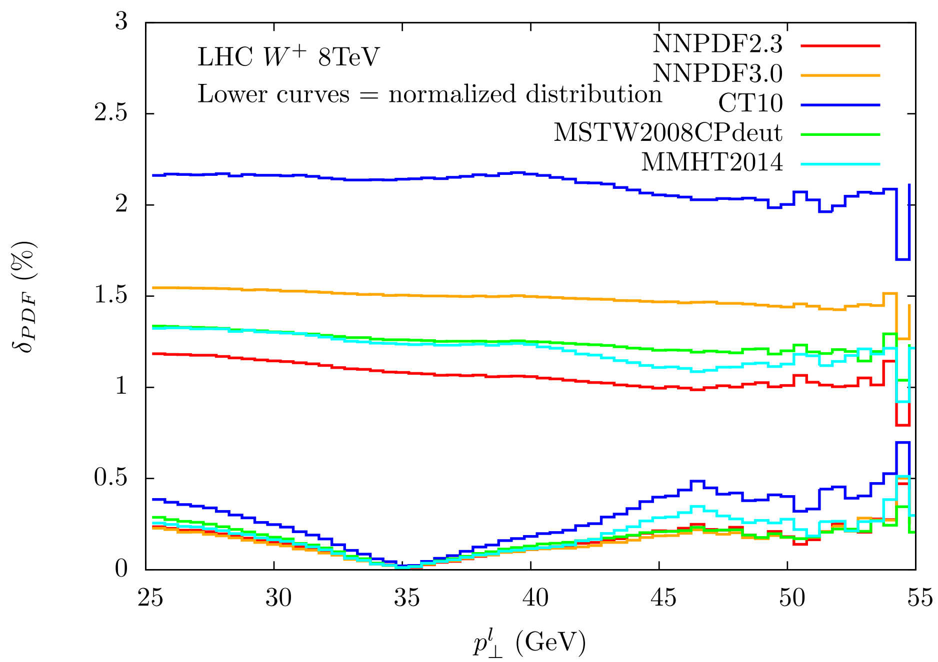

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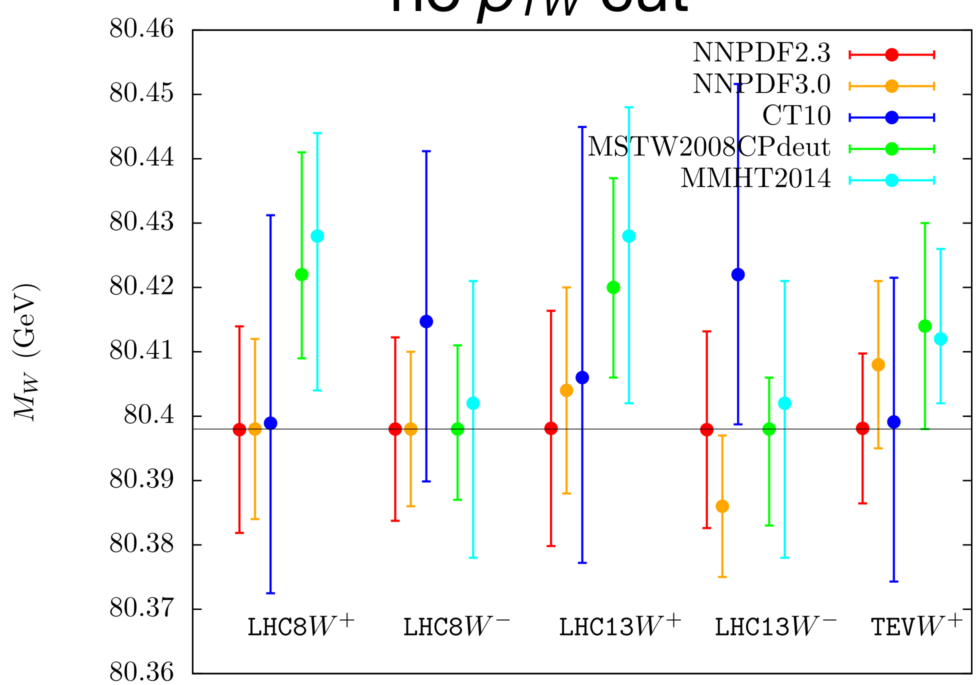
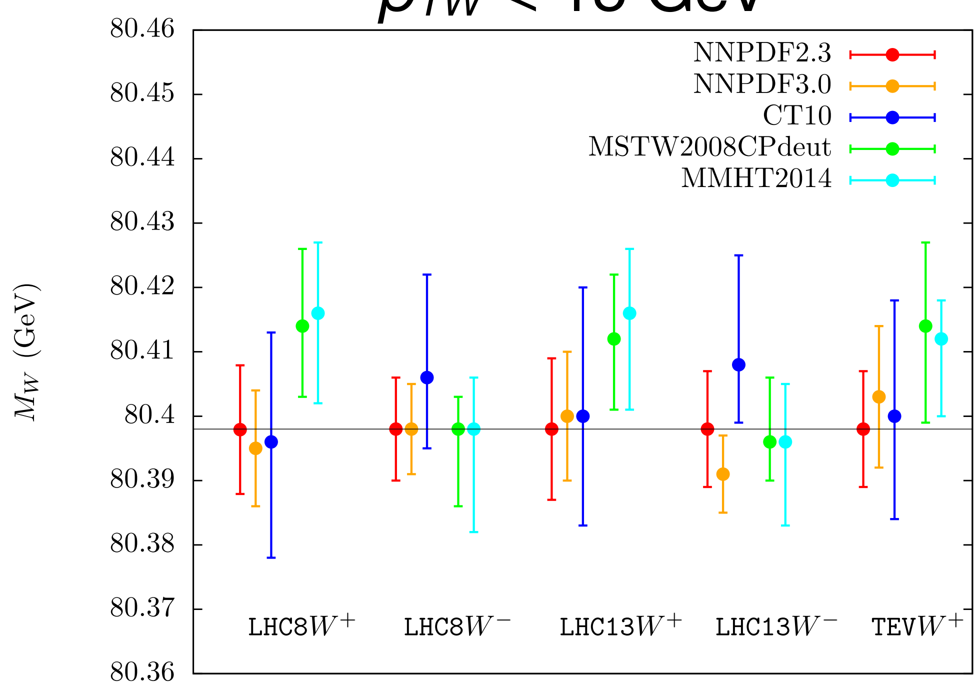
	no $p_\perp^W$ cut		$p_\perp^W < 15$ GeV	
	δ_{PDF} (MeV)	Δ_{sets} (MeV)	δ_{PDF} (MeV)	Δ_{sets} (MeV)
Tevatron 1.96 TeV	27	16	21	15
LHC 8 TeV W^+	33	26	24	18
W^-	29	16	18	8
LHC 13 TeV W^+	34	22	20	14
W^-	34	24	18	12

- 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



Acceptance cuts: interesting insights

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normalized distributions			
cut on $p_\perp^W$	cut on $\lvert\eta_l\rvert$	CT10	NNPDF3.0
inclusive	$\lvert\eta_l\rvert < 2.5$	$80.400 + 0.032 - 0.027$	80.398 ± 0.014
$p_\perp^W < 20$ GeV	$\lvert\eta_l\rvert < 2.5$	$80.396 + 0.027 - 0.020$	80.394 ± 0.012
$p_\perp^W < 15$ GeV	$\lvert\eta_l\rvert < 2.5$	$80.396 + 0.017 - 0.018$	80.395 ± 0.009
$p_\perp^W < 10$ GeV	$\lvert\eta_l\rvert < 2.5$	$80.392 + 0.015 - 0.012$	80.394 ± 0.007
$p_\perp^W < 15$ GeV	$\lvert\eta_l\rvert < 1.0$	$80.400 + 0.032 - 0.021$	80.406 ± 0.017
$p_\perp^W < 15$ GeV	$\lvert\eta_l\rvert < 2.5$	$80.396 + 0.017 - 0.018$	80.395 ± 0.009
$p_\perp^W < 15$ GeV	$\lvert\eta_l\rvert < 4.9$	$80.400 + 0.009 - 0.004$	80.401 ± 0.003
$p_\perp^W < 15$ GeV	$1.0 < \lvert\eta_l\rvert < 2.5$	$80.392 + 0.025 - 0.018$	80.388 ± 0.012

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$p_\perp^W < 15$ GeV	$\|\eta_l\| < 2.5$	$80.396 + 0.017 - 0.018$	80.395 ± 0.009
$p_\perp^W < 10$ GeV	$\|\eta_l\| < 2.5$	$80.392 + 0.015 - 0.012$	80.394 ± 0.007
$p_\perp^W < 15$ GeV	$\|\eta_l\| < 1.0$	$80.400 + 0.032 - 0.021$	80.406 ± 0.017
$p_\perp^W < 15$ GeV	$\|\eta_l\| < 2.5$	$80.396 + 0.017 - 0.018$	80.395 ± 0.009
$p_\perp^W < 15$ GeV	$\|\eta_l\| < 4.9$	$80.400 + 0.009 - 0.004$	80.401 ± 0.003
$p_\perp^W < 15$ GeV	$1.0 < \|\eta_l\| < 2.5$	$80.392 + 0.025 - 0.018$	80.388 ± 0.012

strong p_{TW} cut reduces M_W uncertainty

Acceptance cuts: interesting insights

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

normalized distributions			
cut on $p_\perp^W$	cut on $\lvert\eta_l\rvert$	CT10	NNPDF3.0
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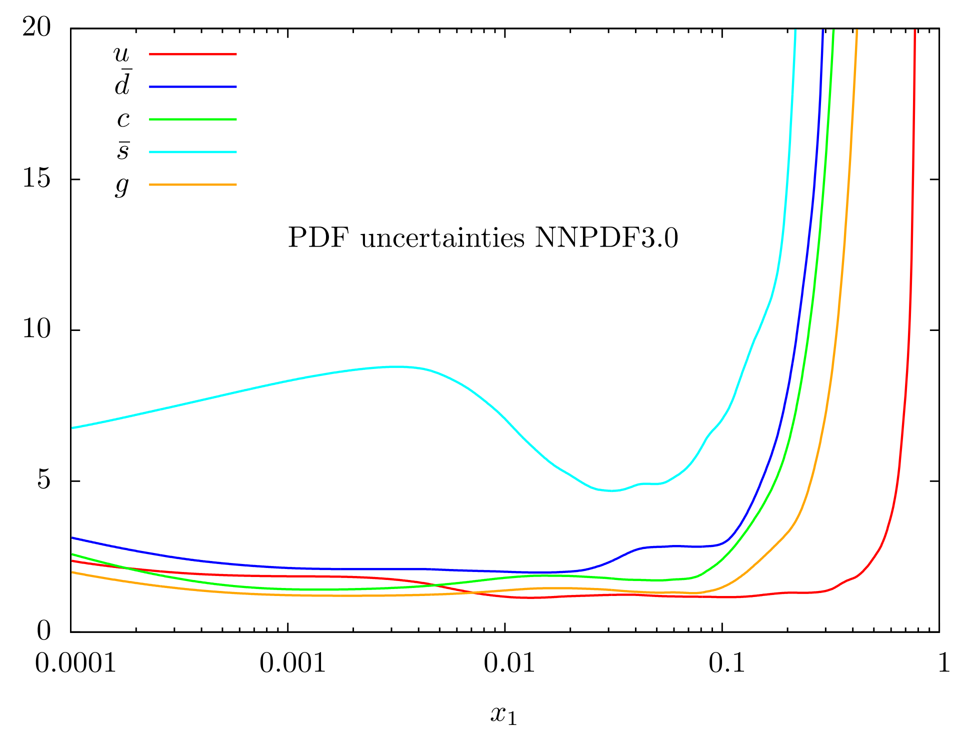

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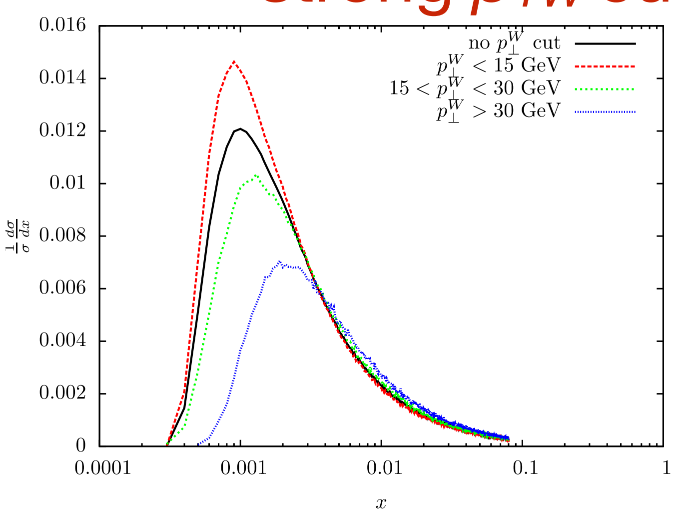

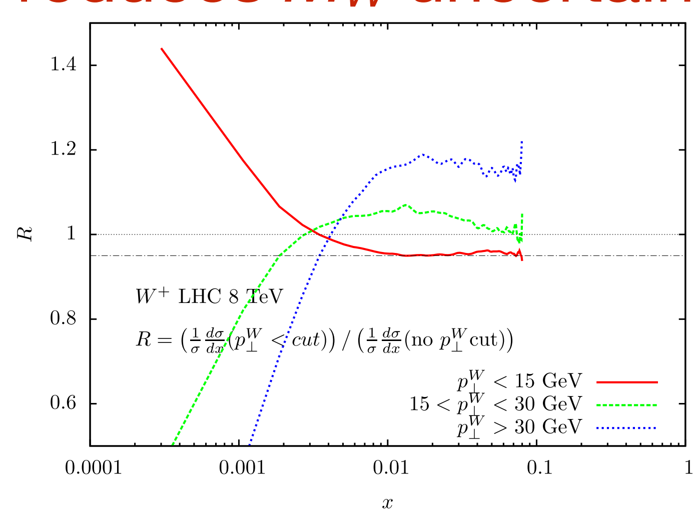

suppression of the large-x region

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

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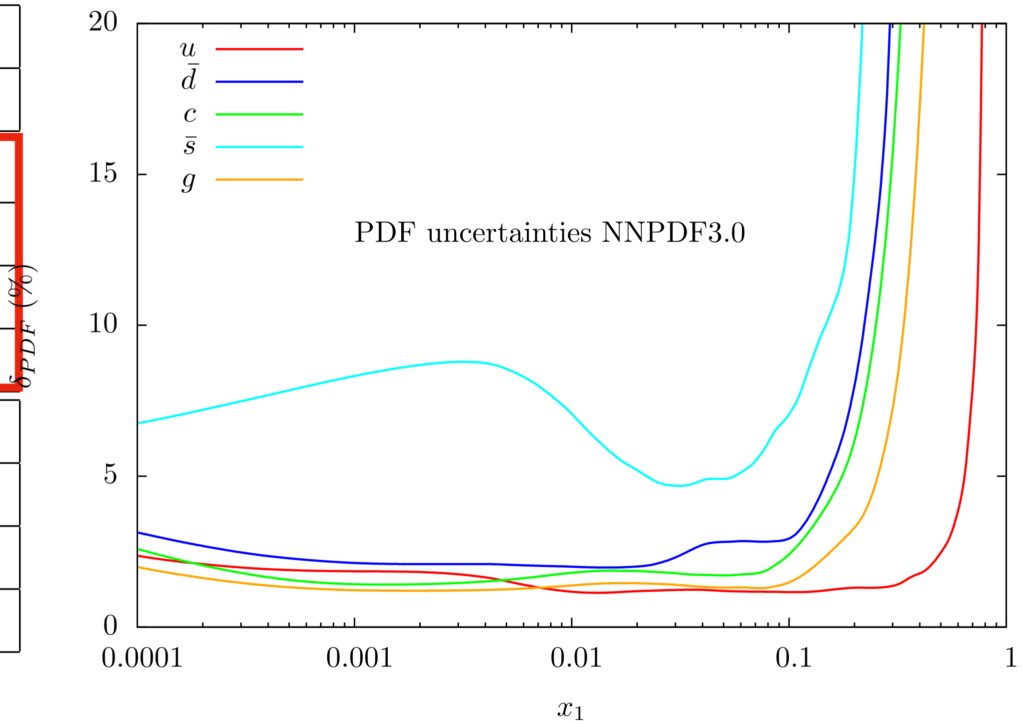

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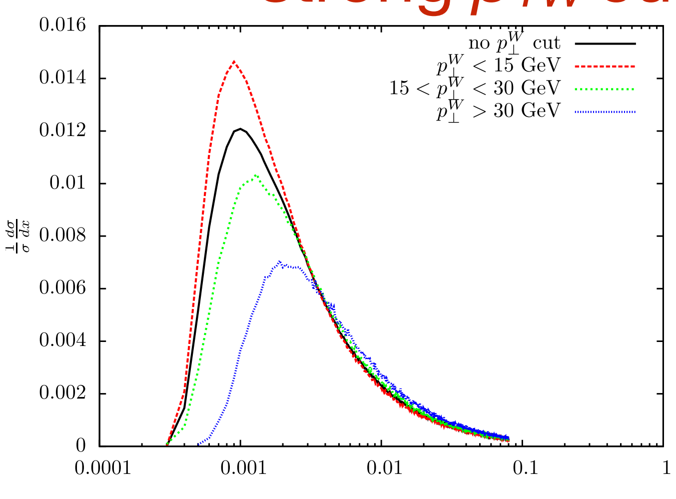

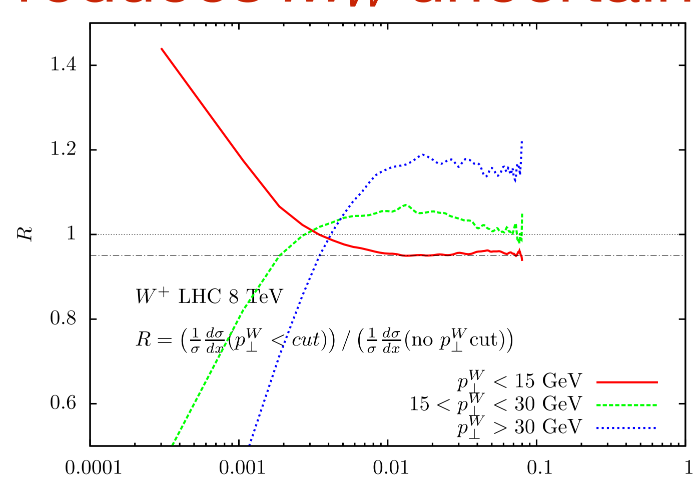

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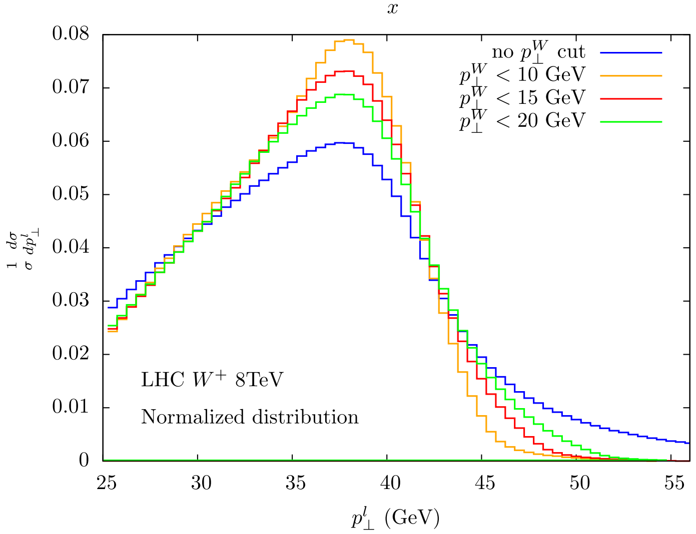

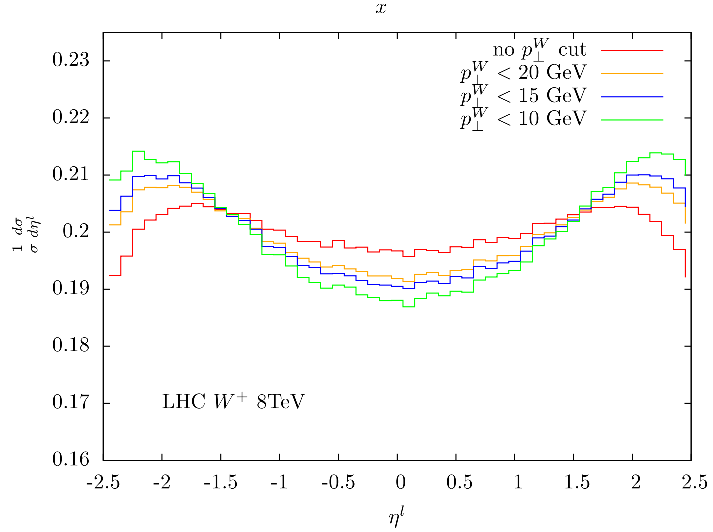

steeper shape of the p_{Tl} distribution

enhancement of high rapidity regions

Acceptance cuts: interesting insights

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

normalized distributions			
cut on $p_\perp^W$	cut on $\lvert\eta_l\rvert$	CT10	NNPDF3.0
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loose lepton pseudorapidity cut reduces M_W uncertainty

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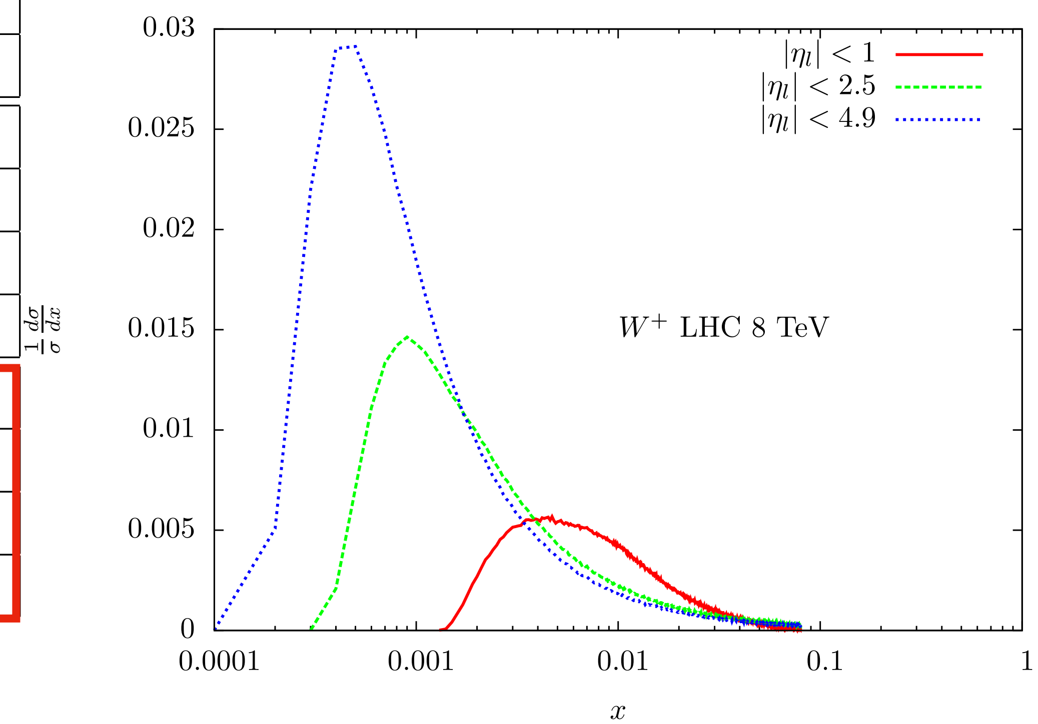

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Acceptance cuts: interesting insights

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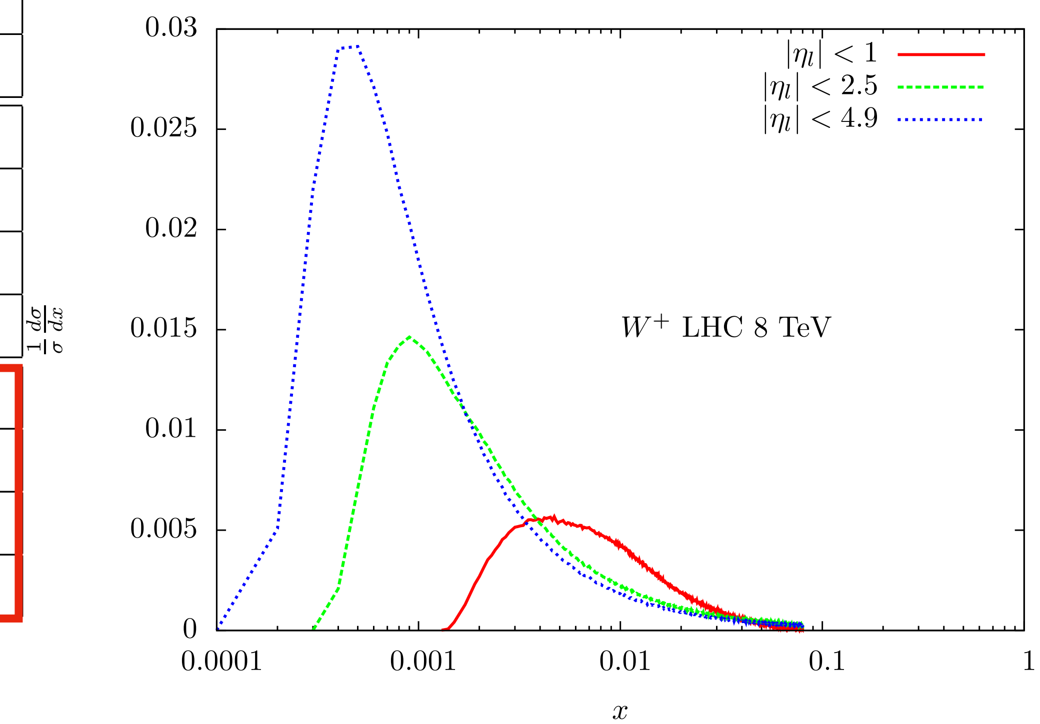

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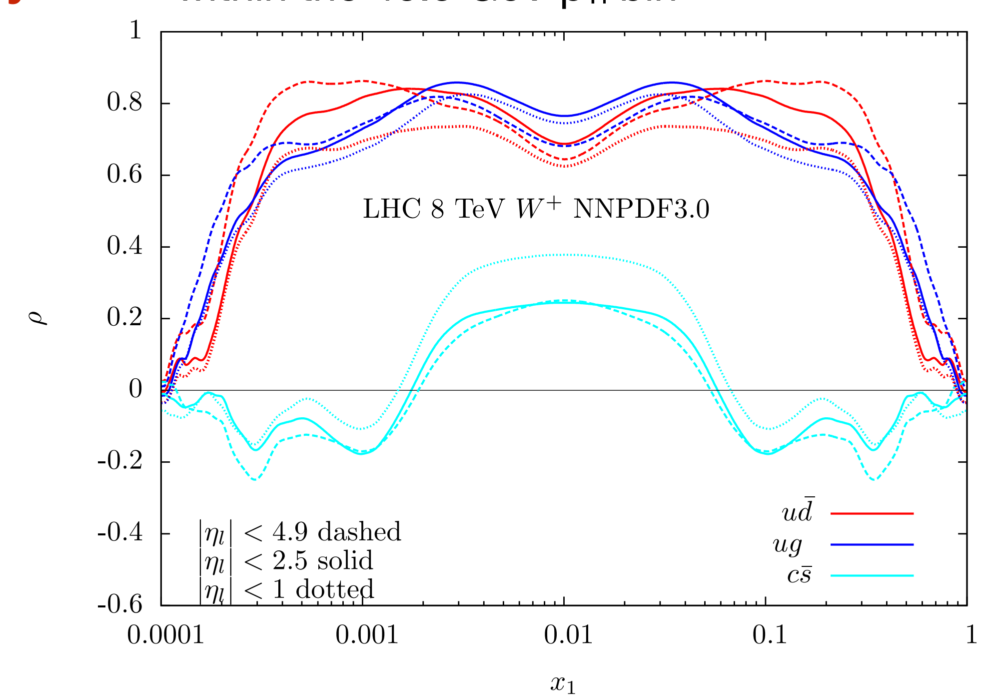
correlation of parton luminosities within the 40.5 GeV p_{Tl} bin



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

Acceptance cuts: interesting insights

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

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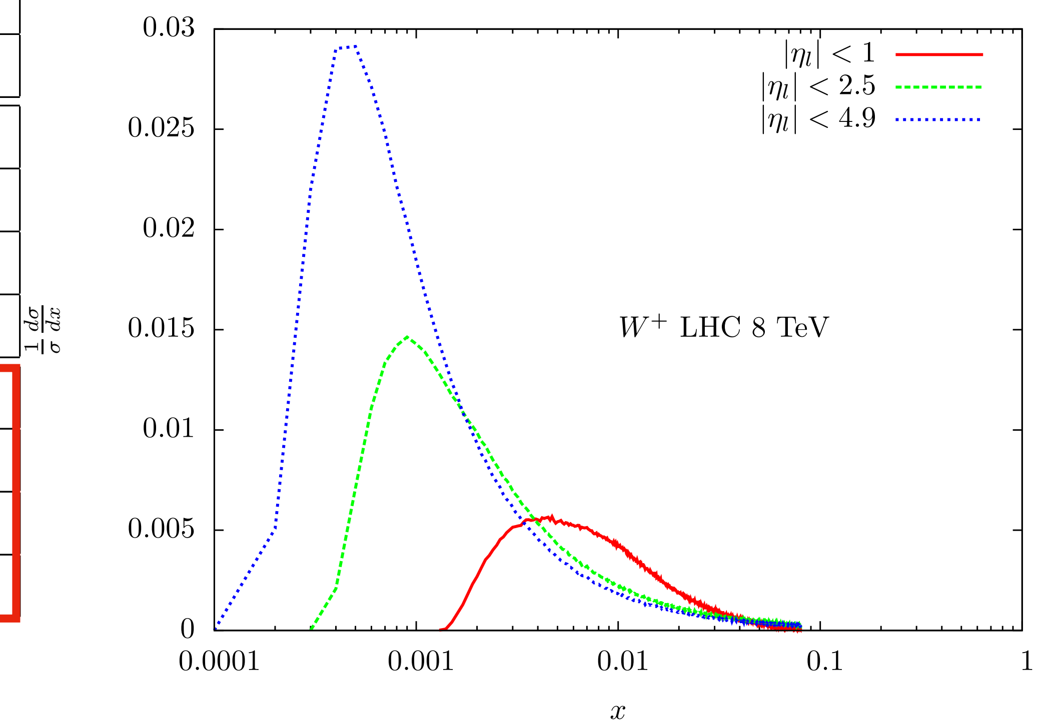
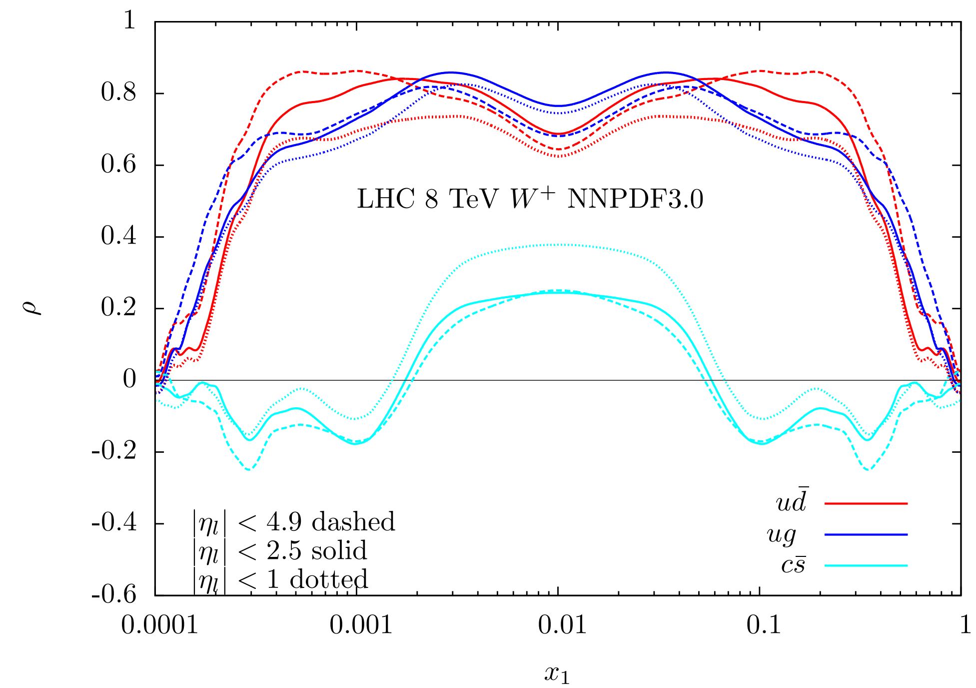


loose lepton pseudorapidity cut reduces M_W uncertainty

- 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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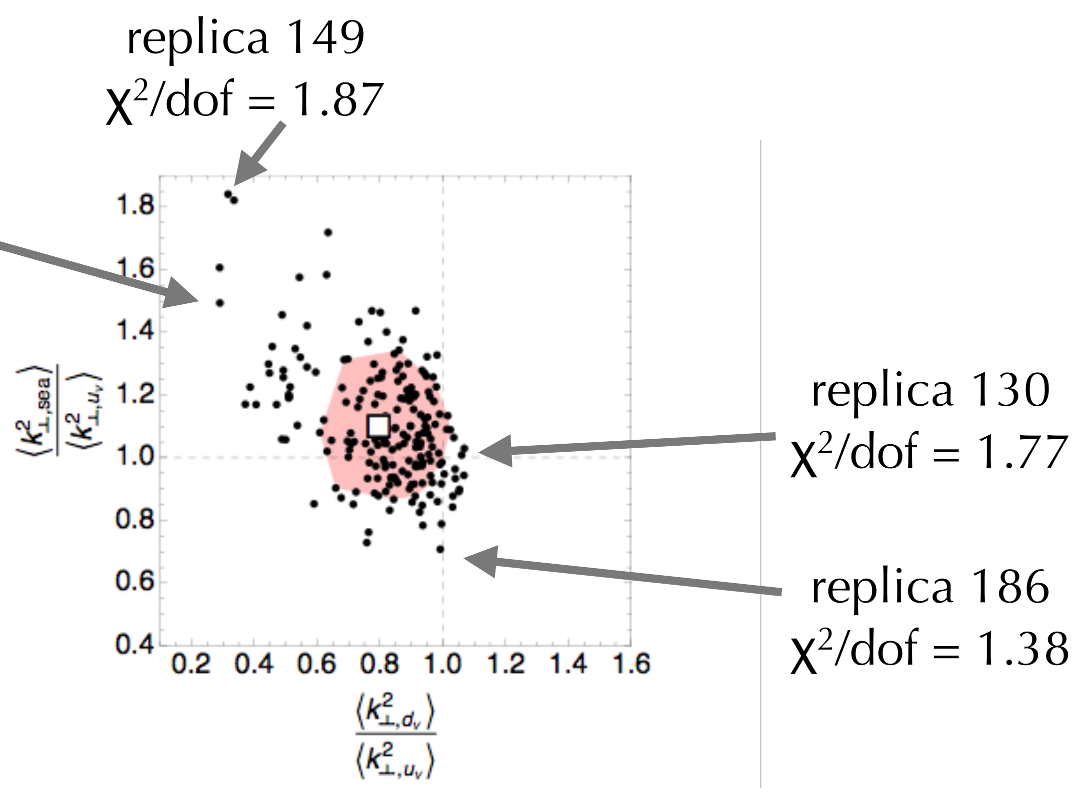
Extraction of parameters from SIDIS

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

template fit on HERMES data: distribution of parameters



sea width > (mostly) u_v width

point of no flavor dep.

d_v width < (mostly) u_v width

Extraction of parameters from SIDIS

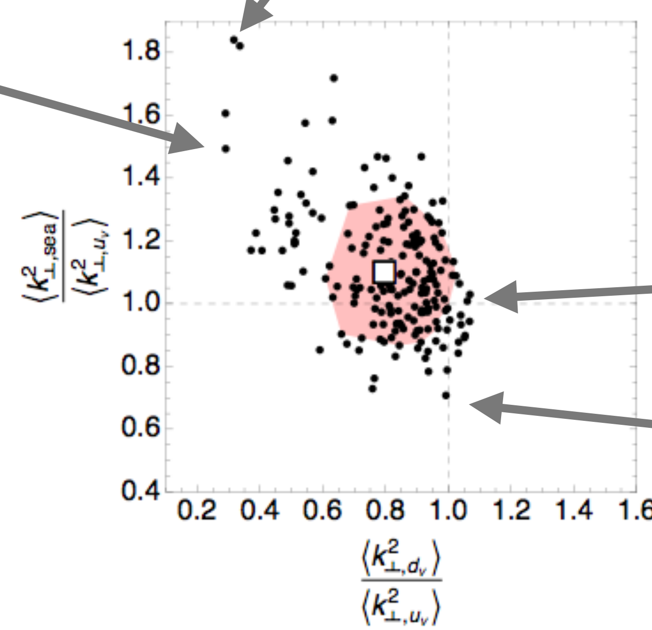
Signori, Bacchetta, Radici, Schnell, JHEP 1311, 194 (2013)

template fit on HERMES data: distribution of parameters

replica 149
χ^2/dof = 1.87

replica 73
χ^2/dof = 1.70

sea width
> (mostly)
u_v width



replica 130
χ^2/dof = 1.77

replica 186
χ^2/dof = 1.38

point of
no flavor dep.

d_v width < (mostly) u_v width

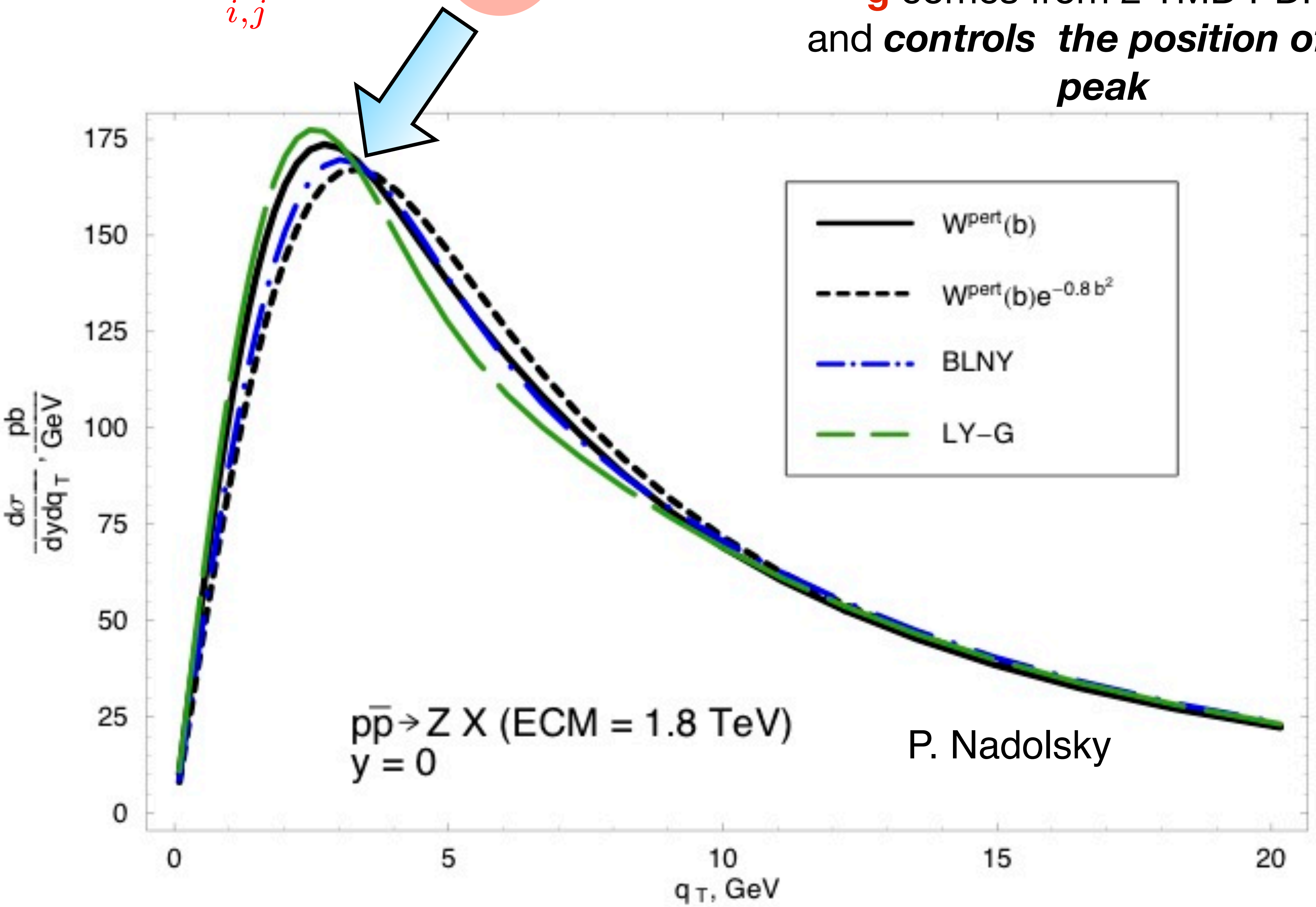
On average, *sea > u_v > d_v*

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

Application to *W/Z* p_T spectrum

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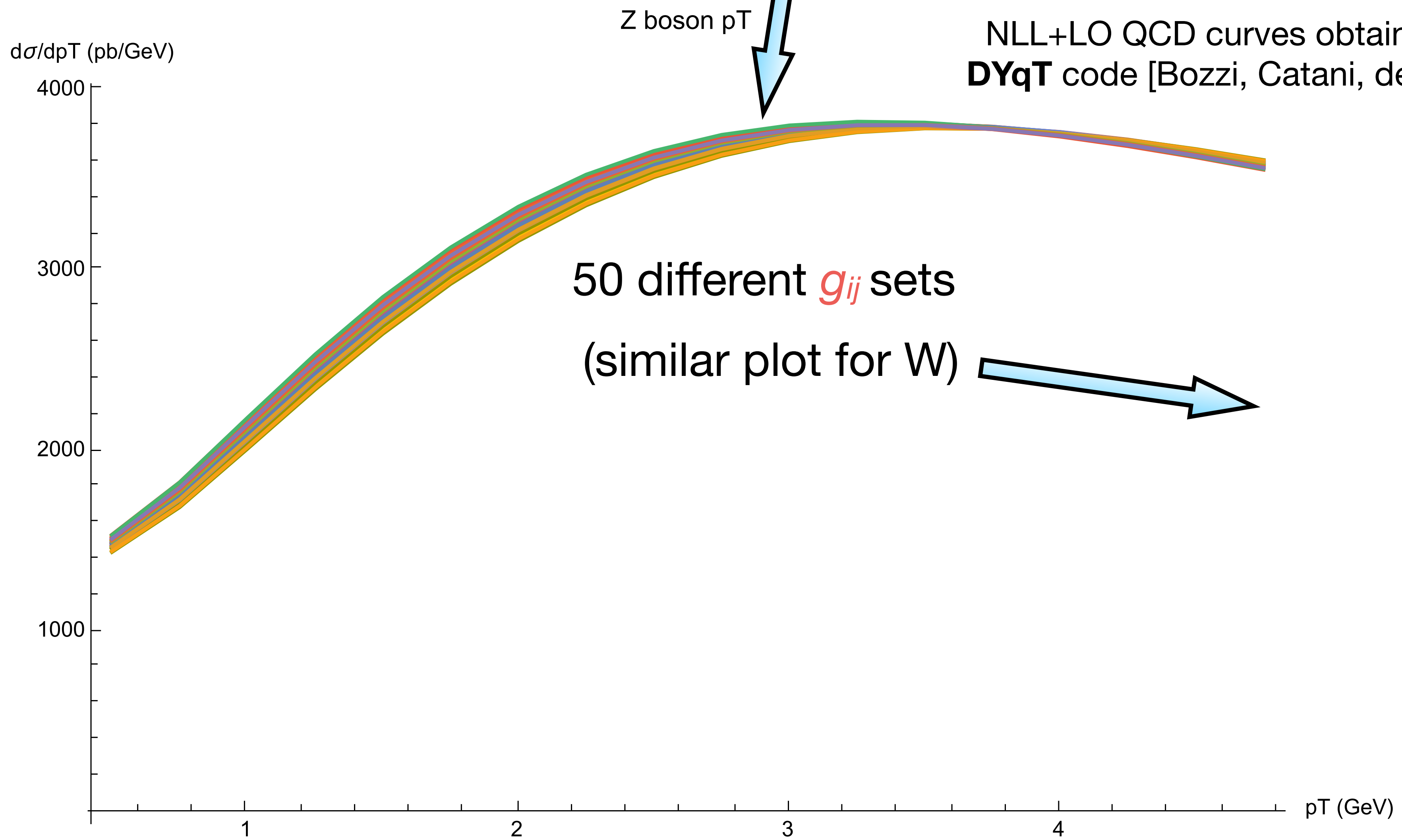
NLL+LO QCD curves obtained through a modified version of the **DYqT** code [Bozzi, Catani, deFlorian, Ferrera, Grazzini (2009,2011)]



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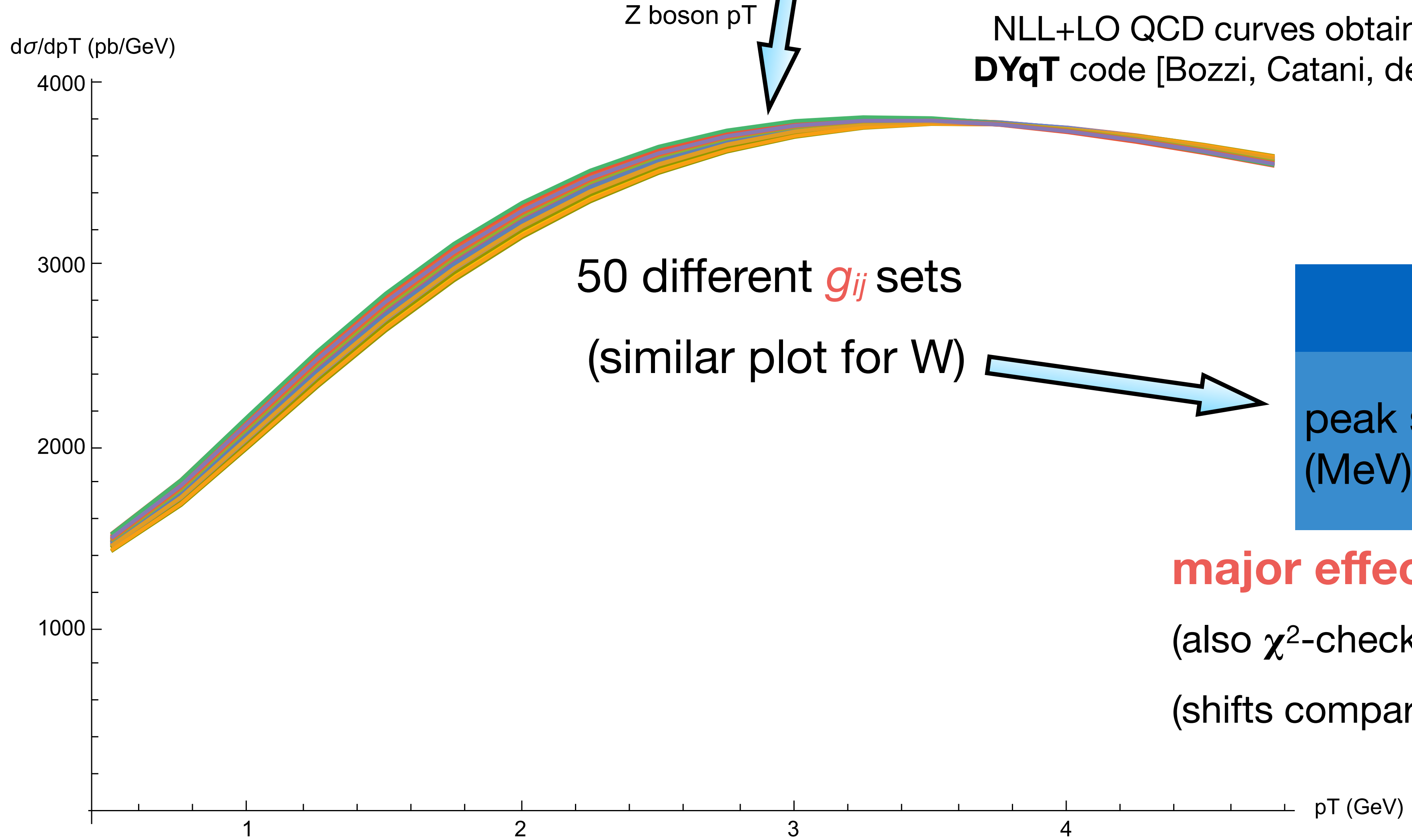

50 different g_{ij} sets

(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)

Application to W/Z p_T spectrum

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

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

	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

M_{W^-} shift (in MeV) induced by NP sets

Set	m_T	p_{Tl}	$p_{T\nu}$	mtw-χ^2_{min}	ptl-χ^2_{min}	ptn-χ^2_{min}
1	-2	-7	-4	0.923093	1.18601	2.16485
2	-4	-15	-5	0.953261	1.00702	1.50588
3	-2	-11	-5	0.817592	0.903778	1.72749
4	-2	-12	-5	0.73319	0.736835	1.38164
5	-4	-7	-5	0.774518	0.579344	1.4835
6	0	-10	-4	0.793141	1.22571	2.11026
7	-4	-6	3	0.585178	0.600643	1.59608
8	-3	-11	-3	0.841088	1.26592	2.4133
9	-3	-15	-2	0.772005	0.963561	1.65476
10	0	-14	-6	0.626776	1.00097	1.4415

"M_{W^+} shift (in MeV) induced by NP sets"

Set	m_T	p_{Tl}	$p_{T\nu}$	mtw-χ^2_{min}	ptl-χ^2_{min}	ptn-χ^2_{min}
1	0	-1	12	1.0194	0.84778	0.983719
2	-2	-3	9	1.18236	0.927213	1.31063
3	-2	-9	6	0.959932	0.620414	0.614995
4	0	-10	4	1.62317	1.07128	1.2164
5	1	6	6	0.972826	1.16398	1.28241
6	-2	-7	9	1.07171	0.615082	1.10561
7	1	-8	5	1.23286	0.882176	1.22056
8	-2	-15	9	0.963465	0.691639	0.901393
9	1	-15	3	0.581562	0.782452	0.888138
10	-3	0	14	1.47225	0.530928	0.392643

Set g uv us dv ds s c b

1{0.32108, 0.33778, 0.46095, 0.26013, 0.59112, 0.32108, 0.32108, 0.32108}

2{0.2705, 0.46733, 0.41929, 0.20787, 0.55902, 0.2705, 0.2705, 0.2705}

3{0.25811, 0.49448, 0.5694, 0.31138, 0.29115, 0.25811, 0.25811, 0.25811}

4{0.26528, 0.41526, 0.28755, 0.38483, 0.56529, 0.26528, 0.26528, 0.26528}

5{0.30474, 0.55162, 0.33049, 0.3366, 0.54924, 0.30474, 0.30474, 0.30474}

6{0.32215, 0.47848, 0.52228, 0.34218, 0.47273, 0.32215, 0.32215, 0.32215}

7{0.21369, 0.39747, 0.45974, 0.52346, 0.54212, 0.21369, 0.21369, 0.21369}

8{0.51104, 0.34282, 0.56302, 0.46376, 0.31644, 0.51104, 0.51104, 0.51104}

9{0.48917, 0.223, 0.3997, 0.20973, 0.46185, 0.48917, 0.48917, 0.48917}

10{0.51569, 0.52846, 0.37406, 0.49193, 0.21709, 0.51569, 0.51569, 0.51569}