The effect of a flavor-dependent intrinsic k_T on the determination of W mass at hadron colliders

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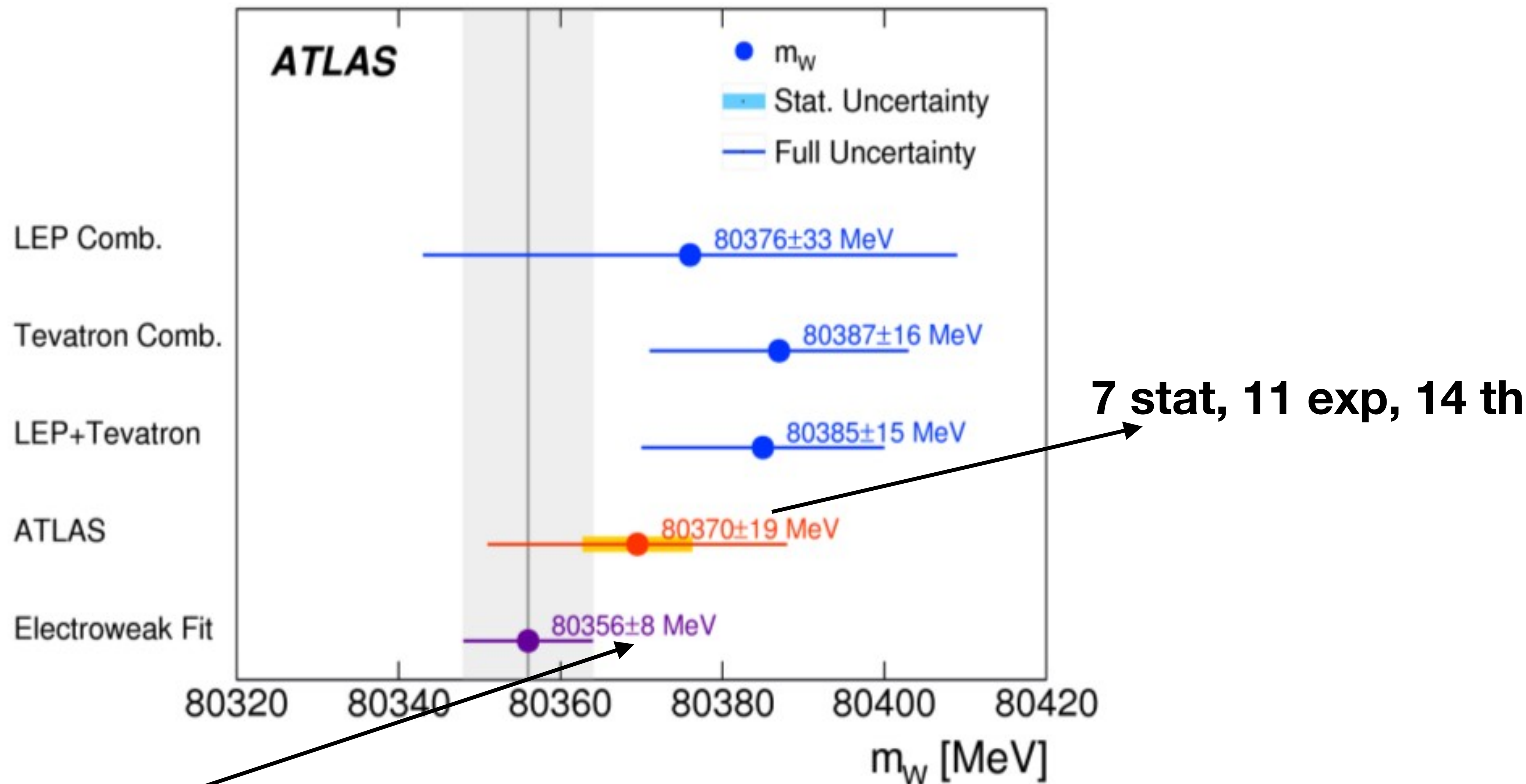
The W mass



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)

The extraction of physical quantities

Observables

- accessible via counting experiments: cross sections and asymmetries

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

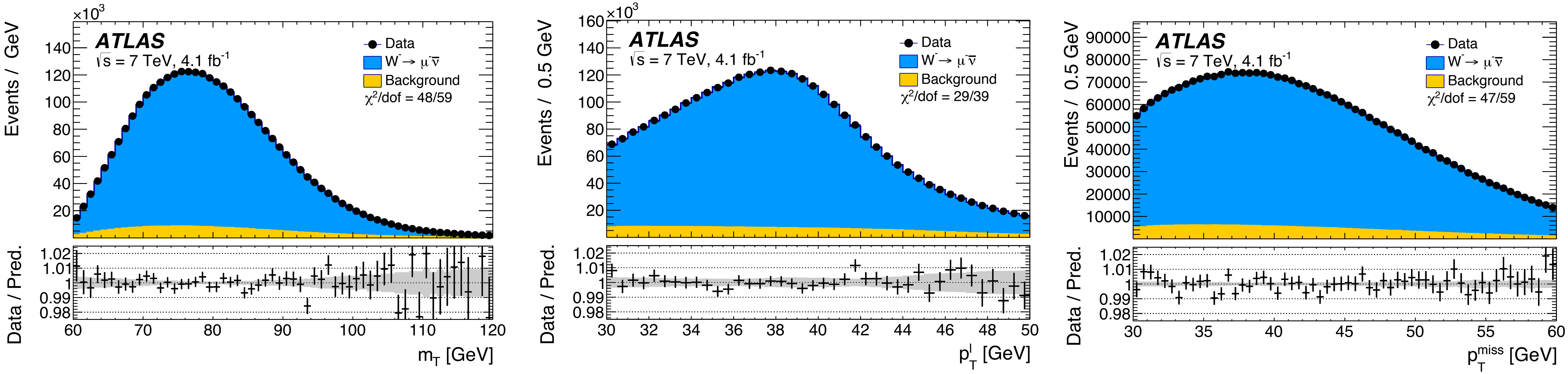
Template fit

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

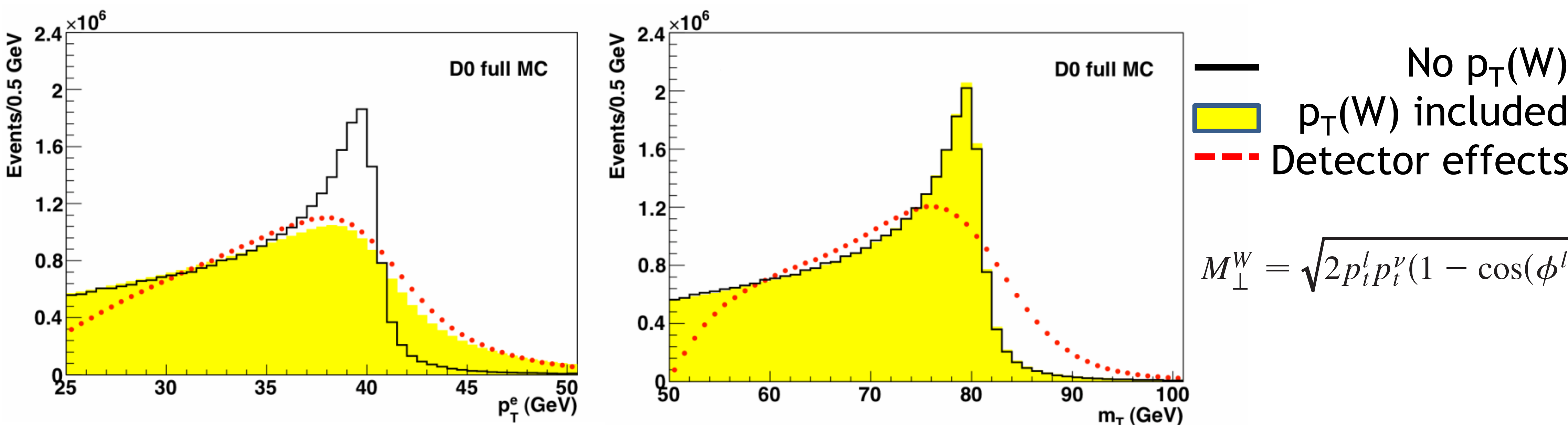
➡ these hypotheses should be treated as theoretical systematic errors

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



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

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

TMD factorisation

- The q_T-distribution of a generic **high-mass (Q)** system produced in hadronic collisions has **two** main regimes:

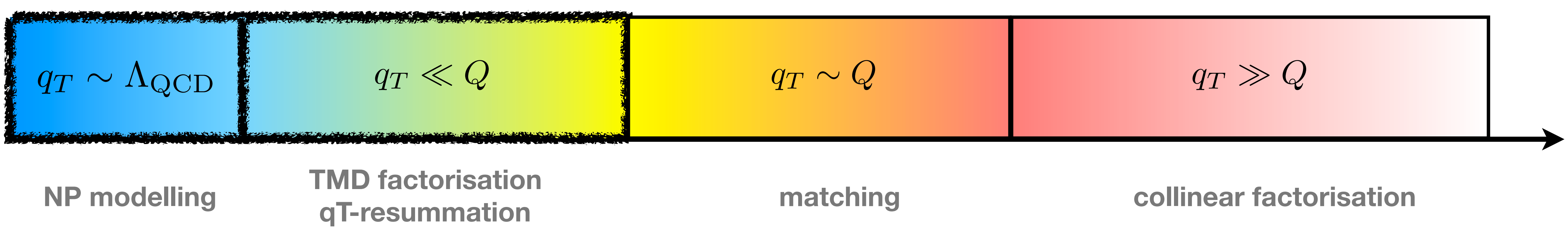
  - for $q_T \gtrsim Q$ **collinear factorisation** at fixed perturbative order is appropriate:

$$\left(\frac{d\sigma}{dq_T}\right)_{\rm f.o.} = \int_0^1 dx_1 \int_0^1 dx_2 f_1(x_1,Q) f_2(x_2,Q) \frac{d\hat{\sigma}}{dq_T} + \mathcal{O}\left[\left(\frac{\Lambda_{\rm QCD}}{Q}\right)^n\right]$$

  - for $q_T \ll Q$ **transverse-momentum-dependent (TMD) factorisation** at fixed logarithmic accuracy is appropriate:

$$\left(\frac{d\sigma}{dq_T}\right)_{\rm res.} \overset{\rm TMD}{=} \sigma_0 H(Q) \int d^2\mathbf{b}_T e^{i\mathbf{b}_T\cdot\mathbf{q}_T} F_1(x_1,\mathbf{b}_T,Q,Q^2) F_2(x_2,\mathbf{b}_T,Q,Q^2) + \mathcal{O}\left[\left(\frac{q_T}{Q}\right)^m\right]$$

$$\overset{q_T-\rm res.}{=} \sigma_0 \int d^2\mathbf{b}_T e^{i\mathbf{b}_T\cdot\mathbf{q}_T} e^{-S(\mathbf{b}_T,Q)} \left[\mathcal{C}\otimes f_1\right](x_1,\mathbf{b}_T,Q) \left[\mathcal{C}\otimes f_2\right](x_2,\mathbf{b}_T,Q) + \mathcal{O}\left[\left(\frac{q_T}{Q}\right)^m\right]$$



TMD Evolution

$$F_{f/P}(x, \mathbf{b}_T; \mu, \zeta) = \sum_j C_{f/j}(x, b_*; \mu_b, \zeta_F) \otimes f_{j/P}(x, \mu_b) \quad : A$$

$$\times \exp\left\{ K(b_*; \mu_b) \ln \frac{\sqrt{\zeta_F}}{\mu_b} + \int_{\mu_b}^{\mu} \frac{d\mu'}{\mu'} \left[\gamma_F - \gamma_K \ln \frac{\sqrt{\zeta_F}}{\mu'} \right] \right\} \quad : B$$

$$\times \exp\left\{ g_{j/P}(x, b_T) + g_K(b_T) \ln \frac{\sqrt{\zeta_F}}{\sqrt{\zeta_{F,0}}} \right\} \quad : C$$

- matching to the collinear region at $b_T \ll 1/\Lambda_{QCD}$,
- factorises as *hard* (perturbative) and *longitudinal* (*i.e.* collinear, non-perturbative).

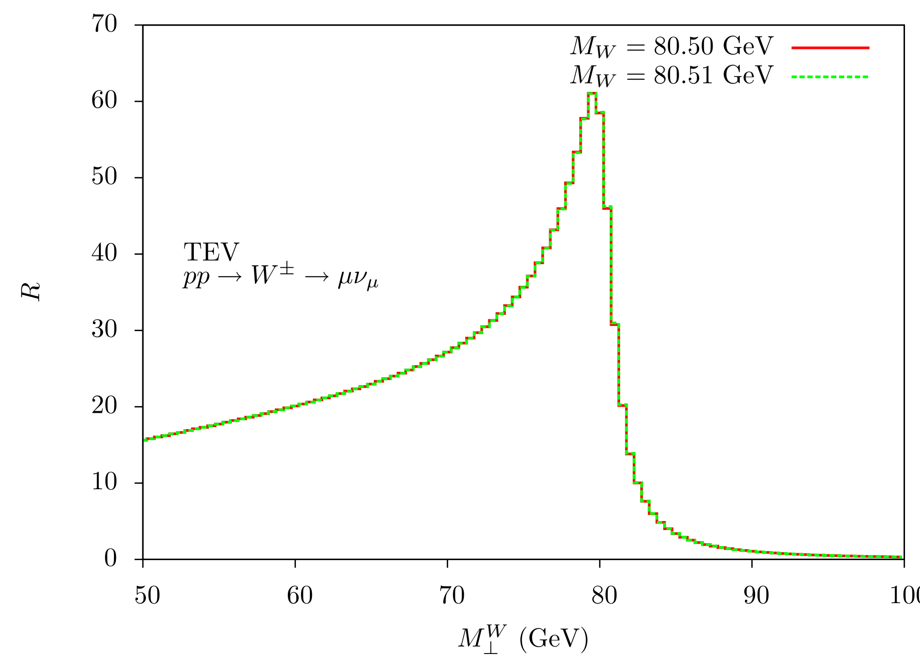
- avoid the Landau pole,
- f_{NP} accounts for the introduction of b_*,
- f_{NP} is non-perturbative thus **fit** to data.

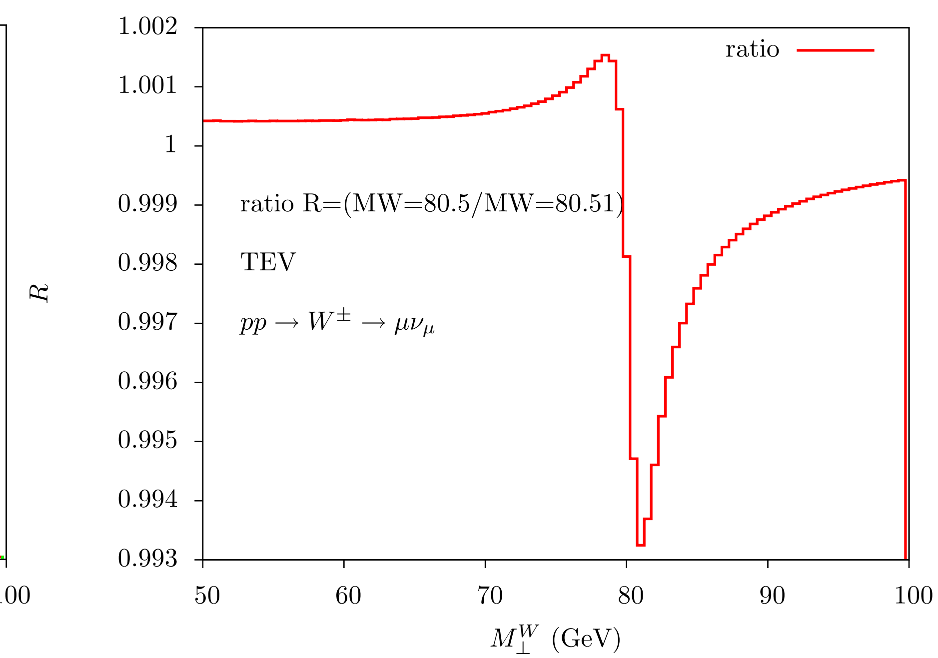
- CS and RGE evolution,
- evolution to large b_T,
- perturbative.

Observables and techniques

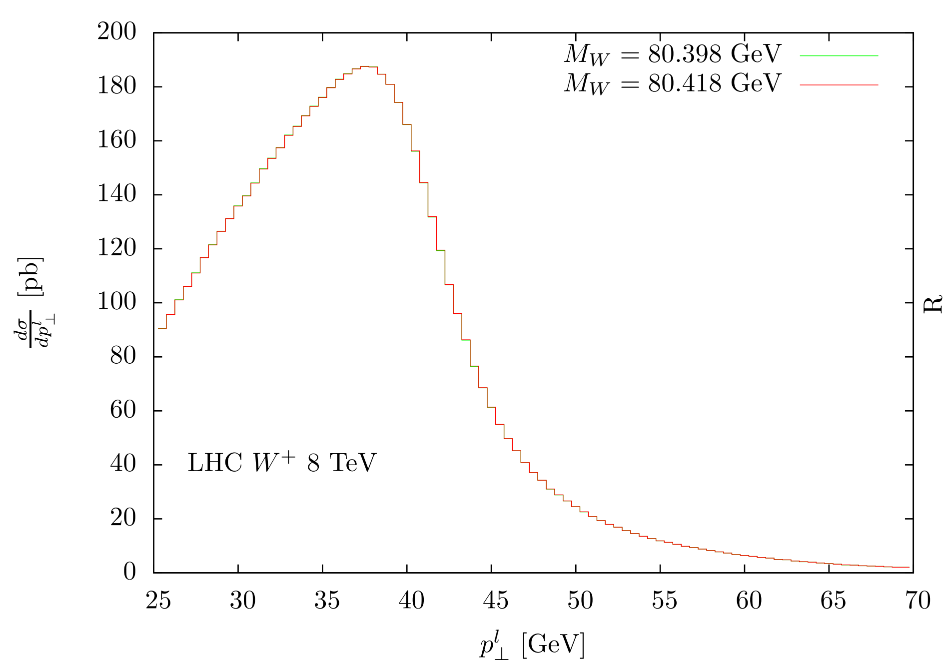
Challenging shape measurement: a distortion at the few per mille level of the distributions yields a shift of O(10 MeV) of the M_W value

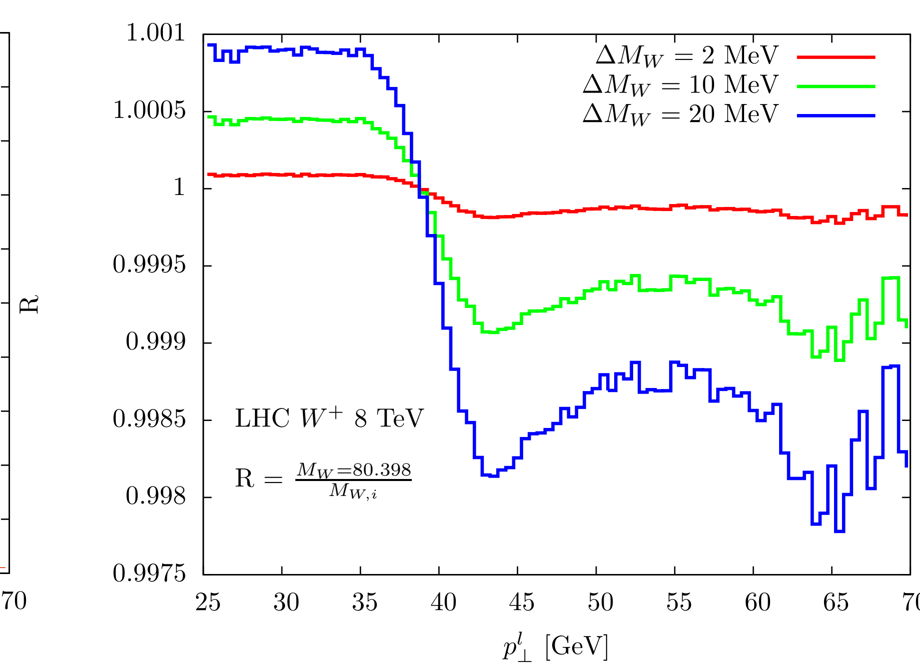
m_T





p_{Tl}

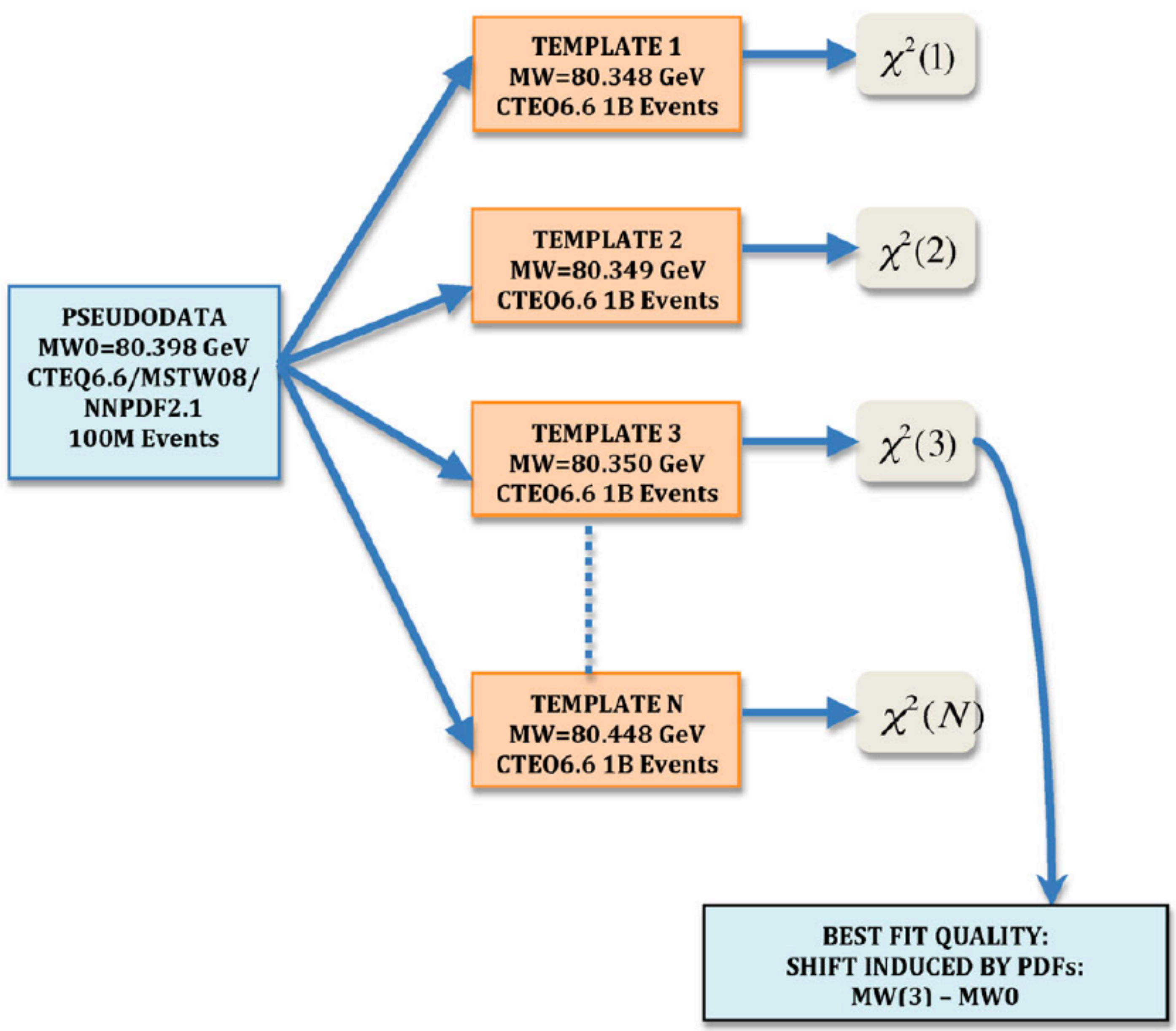




Template-fit estimate of theoretical uncertainties (ex:PDF)

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)

- **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



p_{TW} and the modelling of intrinsic k_T

- $p_{Tl} \Leftarrow p_{TW} \Leftarrow$ 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

Choice of NP parameters

$$\frac{d\sigma}{dq_T} \sim \mathrm{FT}\ \exp\{-g_{_{NP}} b_T^2\}$$ ⟶ Fit to Z/γ^* Tevatron data: $g_{_{NP}} \sim 0.8\ \mathrm{GeV}^2$

[Guzzi, Nadolsky, Wang (2014)]

<u>For each TMD:</u> $0.4\ \mathrm{GeV}^2 \sim g^a_{_{NP}} \longrightarrow g_{evo} \ln\left(\frac{Q^2}{Q_0^2}\right) + g_a$ ⟶ *variation range for g_a*

Fit to SIDIS/DY/Z data: $g_{evo} \ln\left(\frac{Q^2}{Q_0^2}\right) \in [0.17, 0.39]\ \mathrm{GeV}^2$

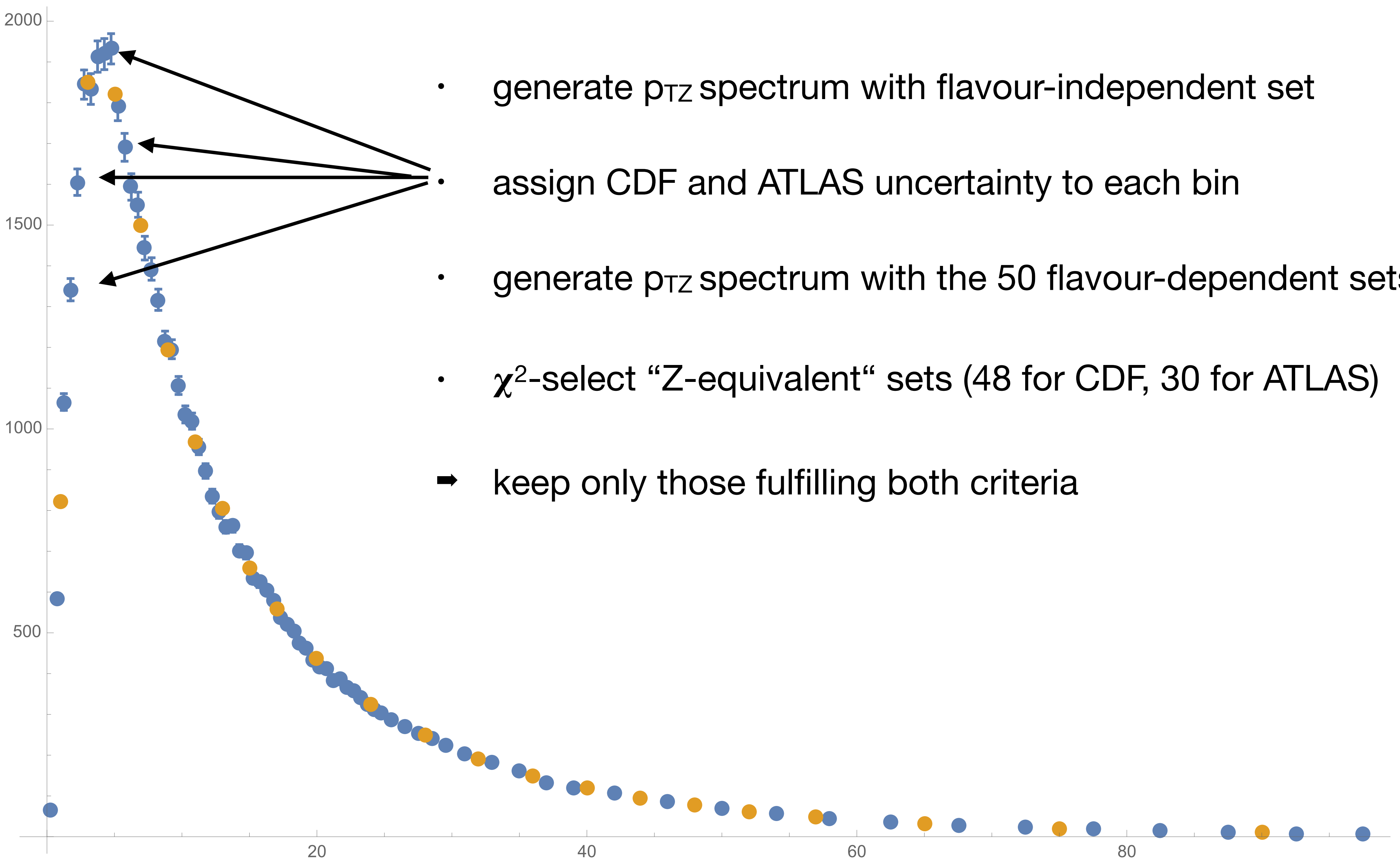
[Bacchetta, Delcarro, Pisano, Radici, Signori (2017)]

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

“Z-equivalent” sets



- 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
- χ^2-select “Z-equivalent“ sets (48 for CDF, 30 for ATLAS)

➡ keep only those fulfilling both criteria

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)

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**

- 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

  ➡ **templates**

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

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

- lepton pt: quite important shifts (envelope **up to 15 MeV**)

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

	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

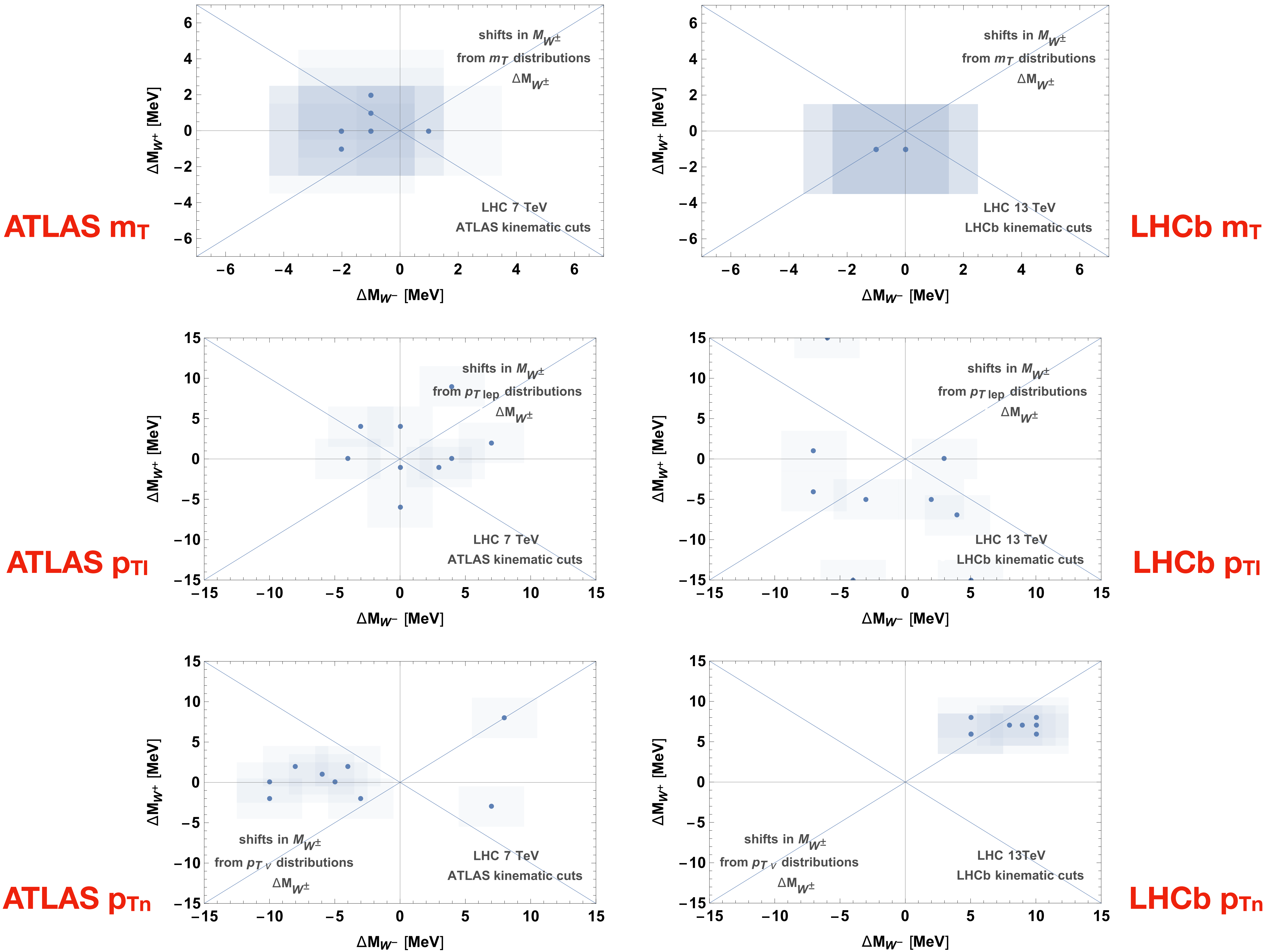
	ΔM_{W+}			ΔM_{W-}		
Set	m_T	$p_{T\ell}$	$p_{T\nu}$	m_T	$p_{T\ell}$	$p_{T\nu}$
1	-1	-5	7	-1	-3	8
2	-1	-15	6	0	5	10
3	-1	1	8	-1	-7	5
4	-1	-15	6	0	-4	5
5	-1	-4	6	-1	-7	5
6	-1	-5	7	0	2	9
7	-1	-15	6	-1	-6	5
8	-1	0	8	0	3	10
9	-1	-7	7	0	4	10

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



shifts in $M_{W^\pm}$
from m_T distributions
$\Delta M_{W^\pm}$
LHC 7 TeV
ATLAS kinematic cuts
ATLAS m_T
shifts in $M_{W^\pm}$
from m_T distributions
$\Delta M_{W^\pm}$
LHC 13 TeV
LHCb kinematic cuts
LHCb m_T
shifts in $M_{W^\pm}$
from $p_{T\,lep}$ distributions
$\Delta M_{W^\pm}$
LHC 7 TeV
ATLAS kinematic cuts
ATLAS p_{Tl}
shifts in $M_{W^\pm}$
from $p_{T\,lep}$ distributions
$\Delta M_{W^\pm}$
LHC 13 TeV
LHCb kinematic cuts
LHCb p_{Tl}
shifts in $M_{W^\pm}$
from $p_{T\,\nu}$ distributions
$\Delta M_{W^\pm}$
LHC 7 TeV
ATLAS kinematic cuts
ATLAS p_{Tn}
shifts in $M_{W^\pm}$
from $p_{T\,\nu}$ distributions
$\Delta M_{W^\pm}$
LHC 13TeV
LHCb kinematic cuts
LHCb p_{Tn}
ΔM_{W^-} [MeV]
ΔM_{W^+} [MeV]

Outlook

- First flavour-dependent study of the impact of intrinsic transverse momentum on the determination of the W mass
- Flavour effects are both important and detectable: no "flavour-blind" analysis allowed
- Explore other observables (ϕ^*, asymmetries, …)
- Better constraints for f_{NP} from flavour-sensitive processes (i.e., SIDIS @ JLab, Compass, EIC)

Thank you!