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SHARP

# TMD impact on $W$ mass

Exploring how parton dynamics influence precision measurements at LHC

With the MAP collaboration

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7.02101v2 [hep-ph] 3 Aug 2018

# Effect of flavor-dependent partonic transverse momentum on the determination of the $W$ boson mass in hadron collisions

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(Dated: Monday 9<sup>th</sup> August, 2021)

Within the framework of transverse-momentum-dependent factorization we study for the first time the impact of a flavor-dependent intrinsic transverse momentum on the determination of  $W^\pm$  bosons in proton-proton collisions at  $\sqrt{s} = 7$  TeV. We estimate the value of the  $W$  boson mass  $M_W$  induced by different choices of flavor-dependent intrinsic quark transverse momentum by means of a template fit to the lepton transverse momentum distributions of the  $W$ -decay products. We find  $M_W = 80.36 \pm 0.10$  MeV and  $-4 \leq \Delta M_{W^-} \leq 3$  MeV with a statistical uncertainty of 0.1 MeV. For more detailed investigations of flavor-dependent nonperturbative structure at hadron colliders.

PACS numbers: 14.70.Fm, 13.85.Qk, 12.38.-t

## Introduction and motivation.

Nonperturbative effects in transverse-momentum-dependent (TMD) phenomena are a central topic in the hadronic physics community with potentially important applications to high-energy physics. The study of nonperturbative corrections originates from the work of Parisi and Petronzio [1] and Collins, Soper, and Sterman [2], which focused on the role of the hard scale of the process compared to the infrared scale of QCD. TMD factorization and evolution have been extensively studied in the literature [3–6], together with the matching to collinear factorization [2, 7–12]. Despite the limited amount of data available and the many open theoretical questions, in the past years we started gaining phenomenological information about TMD parton distribution functions (PDFs) with increasing level of precision.

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# UNIVERSITÀ DI PAVIA

Dipartimento di Fisica

Corso di laurea magistrale in Scienze fisiche

## Impact of quark transverse momentum on the extraction of the $W$ boson mass

Tesi per la laurea di:  
**Sara Pontina**

# Introduction

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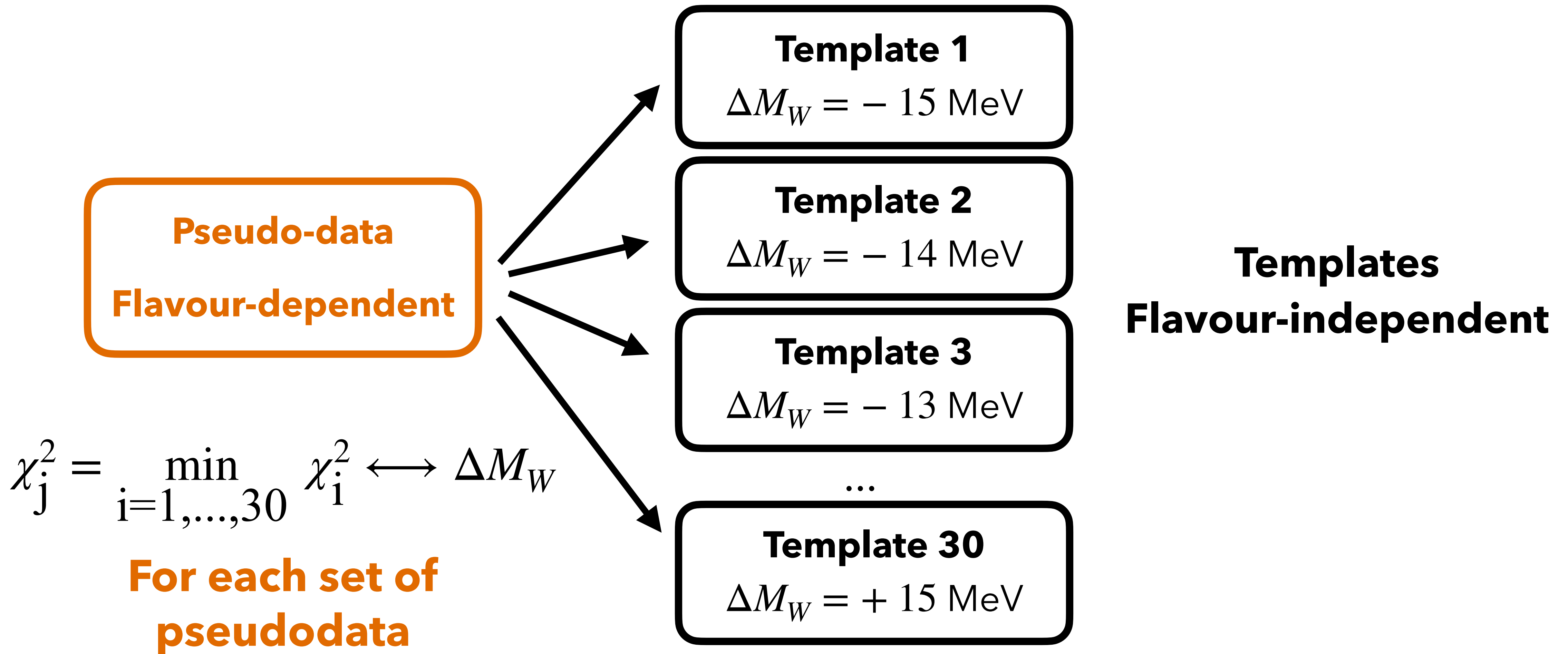
# 2018 study

Exploratory studies investigated the **impact of flavour-dependent TMDs** on the **W boson mass**.

A simple **Gaussian ansatz** was used for the non-perturbative TMDs.

The methodology adopted was the **template fitting**.

# Template fit technique



# 2018 findings

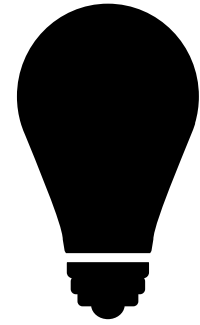
**Observed shifts** in  $M_W$  from flavour-dependent TMDs:

$$-6 \leq \Delta M_{W^+} \leq 9 \text{ MeV}$$

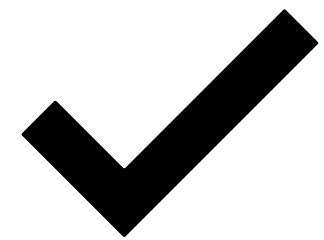
$$-4 \leq \Delta M_{W^-} \leq 3 \text{ MeV}$$

 These effects may be **not negligible**: further investigations are required.

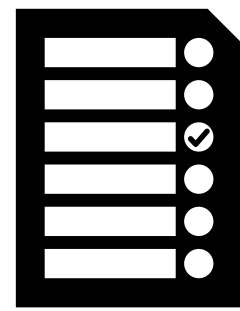
# Master thesis project



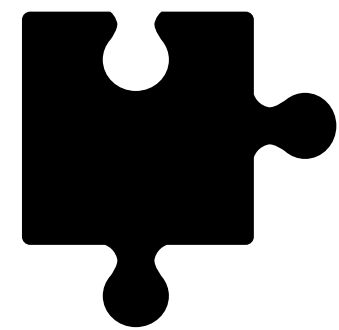
Inspired by previous works



Adopted same methodology as a starting point



Extended with new modifications and improvements



Extended to consider different TMDs extractions

# Main modifications

DYqT, DYRes



Gaussian ansatz



**MAP 2022 and 2024 TMDs**

# TMDs

<b>Global TMD fits</b>	<b>Accuracy</b>	<b>PDF uncertainty</b>	<b>Flavour dependent</b>	<b>SIDIS</b>	<b>Drell-Yan</b>	<b>#points</b>	<b>chi2/ #points</b>
<b>Pavia 2017</b> arXiv:1703.10157	NLL	✗	✗	✓	✓	8059	1.55
<b>SV 2019</b> arXiv:1912.06532	N3LL-	✗	✗	✓	✓	1039	1.06
<b>MAP22</b> arXiv:2206.07598	N3LL-	✗	✗	✓	✓	2031	1.06
<b>MAP24</b> arXiv:2405.13833	N3LL	✓	✓	✓	✓	2031	1.08
<b>ART25</b> arXiv:2503.11201	N4LL-	✓	✓	✓	✓	1209	1.05

# Main modifications

DYqT, DYRes



Gaussian ansatz



**MAP 2022 and 2024 TMDs**

Hadron colliders  
pseudodata



Focus on kinematics and  
statistics of **ATLAS**

# The ultimate goal

The final goal of this project would be to **collaborate with the experimental community** in order to include these effects in the  $W$  boson mass measurements.

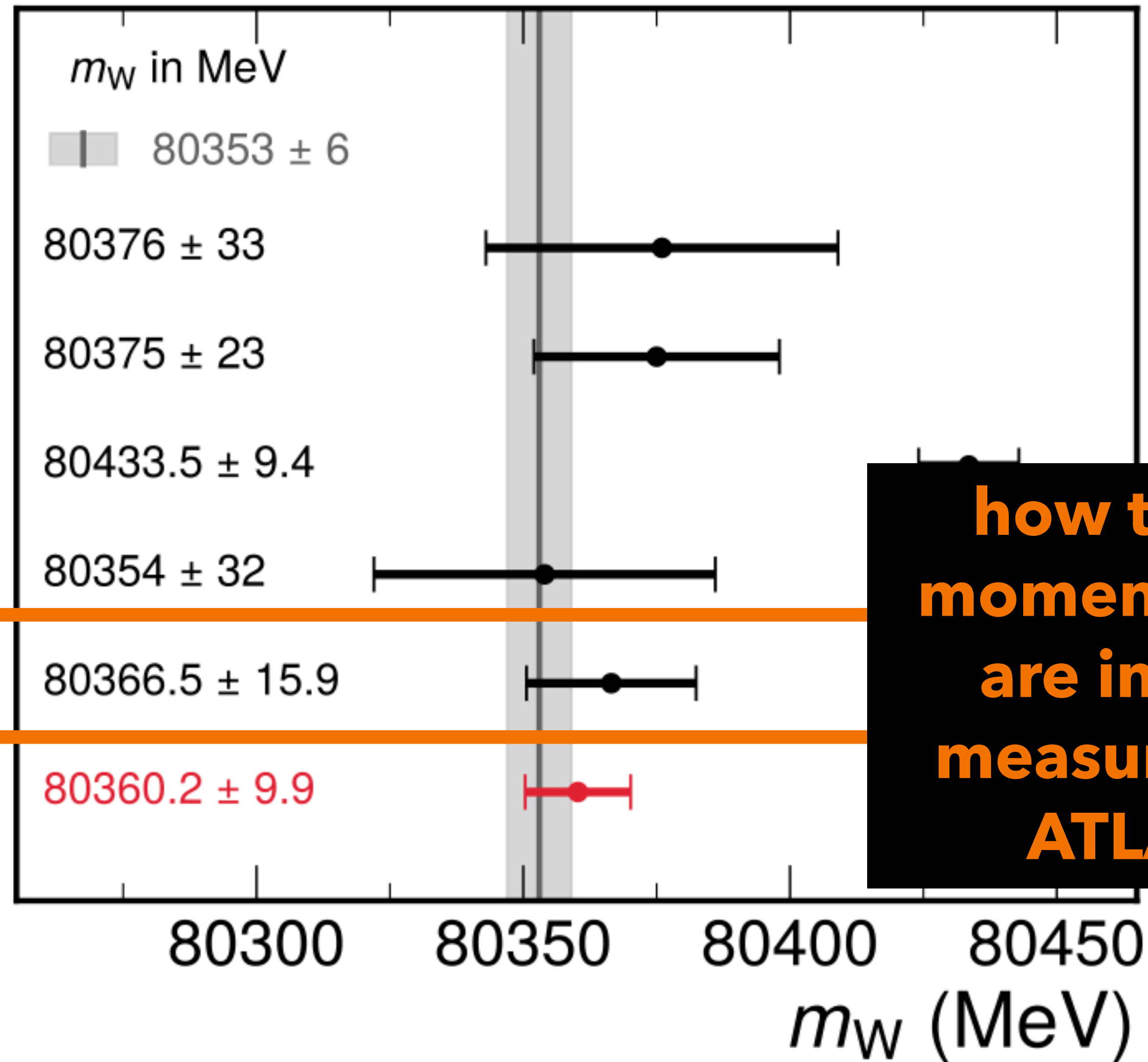


# Measurements of $M_w$

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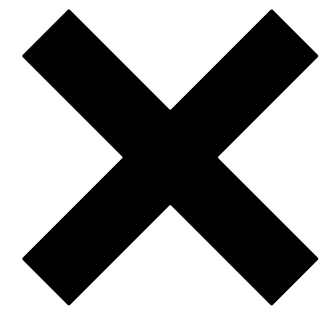
# $M_W$ measurements summary

Electroweak fit  
PRD 110 (2024) 030001  
LEP combination  
Phys. Rep. 532 (2013) 119  
D0  
PRL 108 (2012) 151804  
CDF  
Science 376 (2022) 6589  
LHCb  
IHEP 01 (2022) 036  
**ATLAS**  
EPJC 84 (2024) 1309  
**CMS**  
Nature 652 (2026)

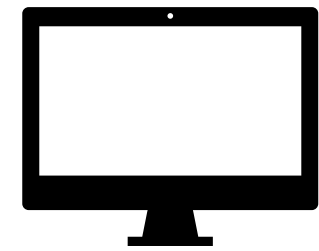


how transverse momentum effects are included in measurements like ATLAS one?

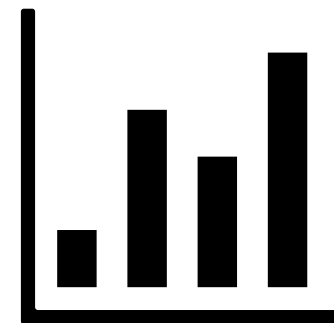
# Transverse momentum uncertainty



No direct use of global TMD fits



Parton shower generators



Only Drell-Yan processes



Flavour-dependence is not included

# Transverse momentum uncertainty

**ATLAS**  
measurement

Table 4: Uncertainty components for the  $p_T^\ell$ ,  $m_T$  and combined  $m_W$  measurements using the CT18 PDF set. The first columns give the total, statistical and overall systematic uncertainty in the measurements. The following columns show the contributions of modelling and experimental systematic uncertainties, grouped into categories.

Unc. [MeV ]	Total	Stat.	Syst.	PDF	$A_i$	Backg.	EW	$e$	$\mu$	$u_T$	Lumi	$\Gamma_W$	PS
$p_T^\ell$	16.2	11.1	11.8	4.9	3.5	1.7	5.6	5.9	5.4	0.9	1.1	0.1	1.5
$m_T$	24.4	11.4	21.6	11.7	4.7	4.1	4.9	6.7	6.0	11.4	2.5	0.2	7.0
Combined	15.9	9.8	12.5	5.7	3.7	2.0	5.4	6.0	5.4	2.3	1.3	0.1	2.3

# Results at NLL

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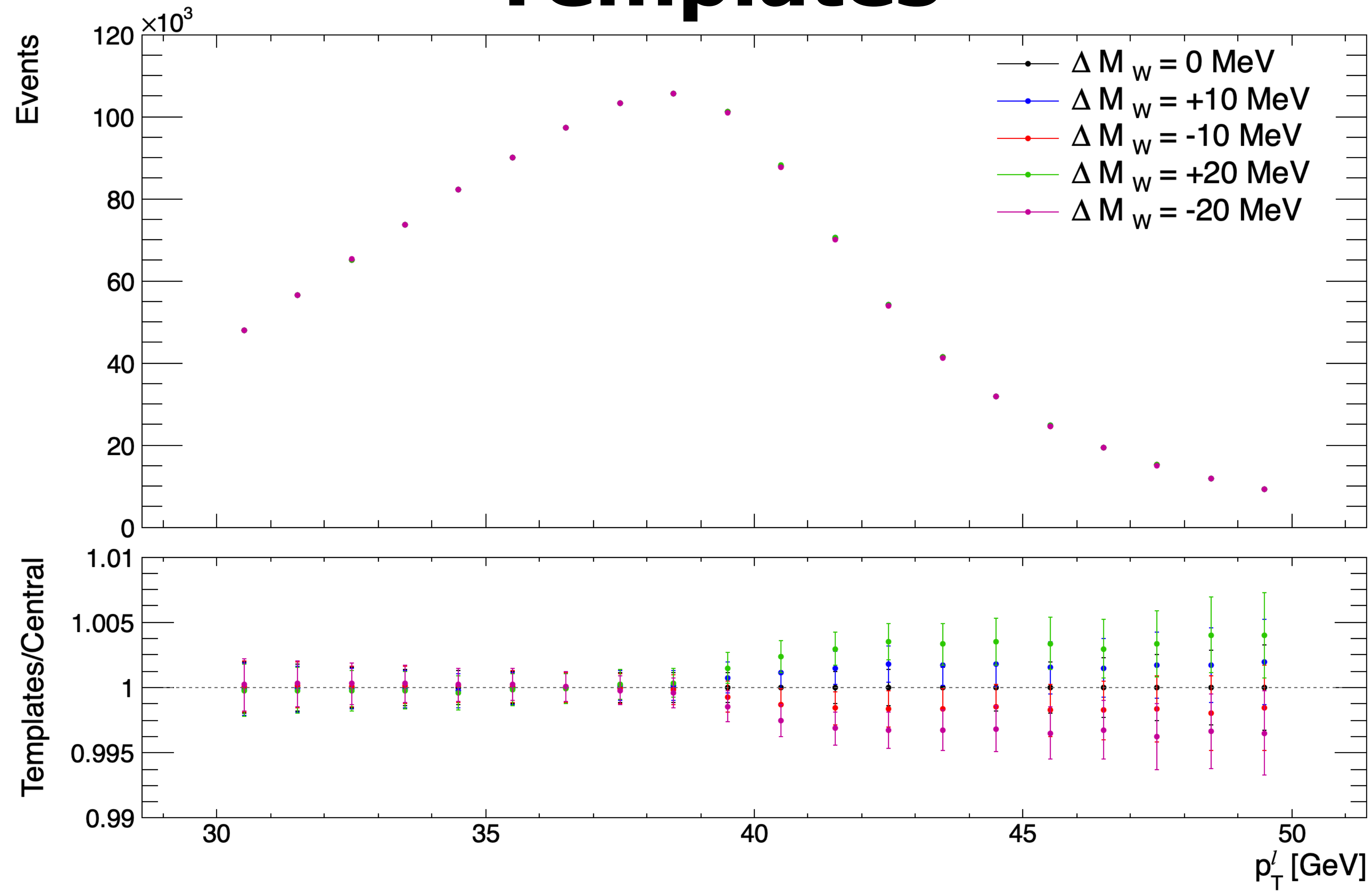
# Generation of the templates

The **TMD** parameters are **fixed** (central replica of MAP24 flavour blind)

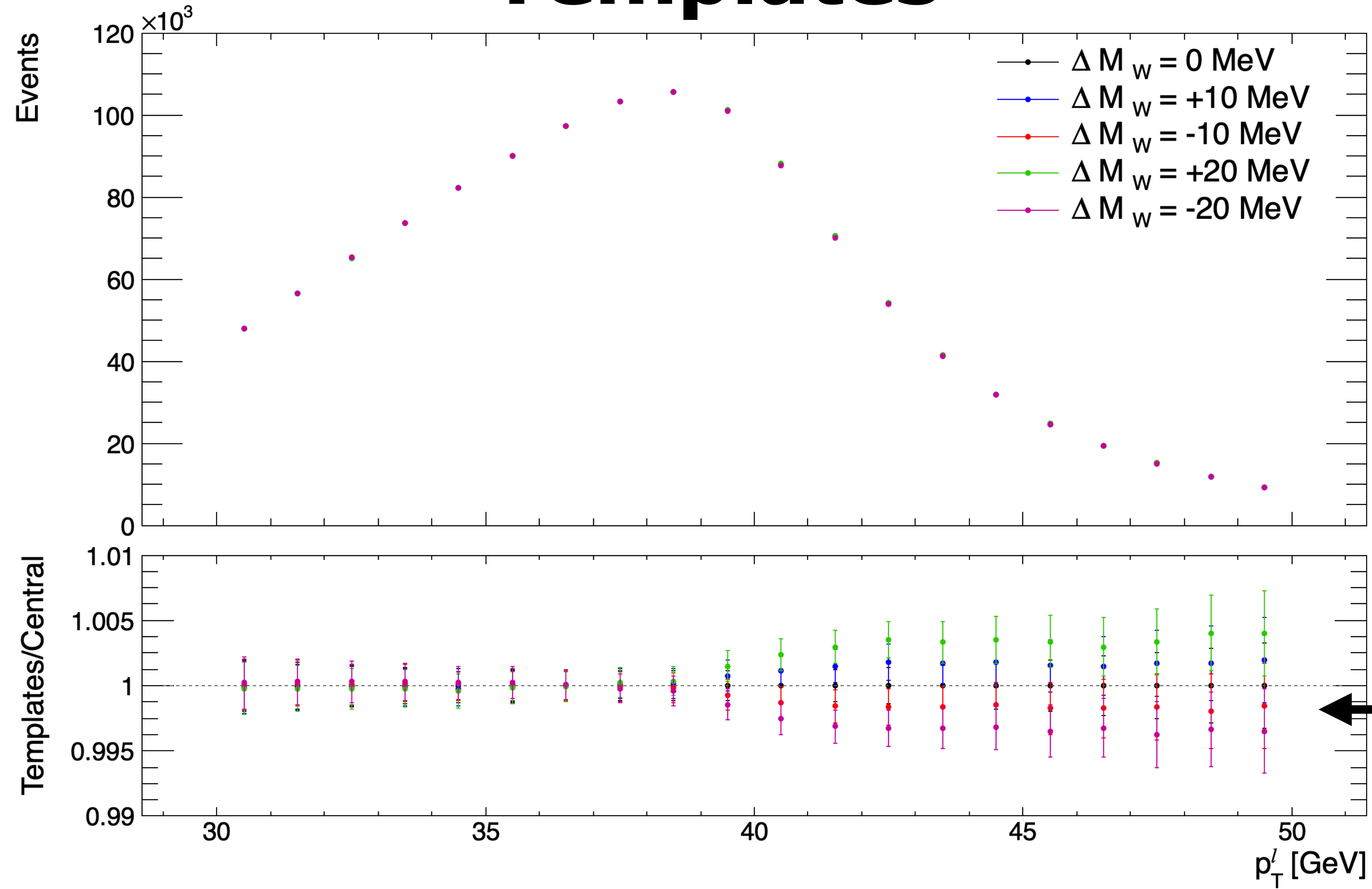
Templates are generated with **higher statistics** (i.e. smaller errors)

The **W mass** is **varied** across the templates, spanning the range -20 MeV to +20 MeV

# Templates



# Templates



Same TMD replica,  
**different masses**

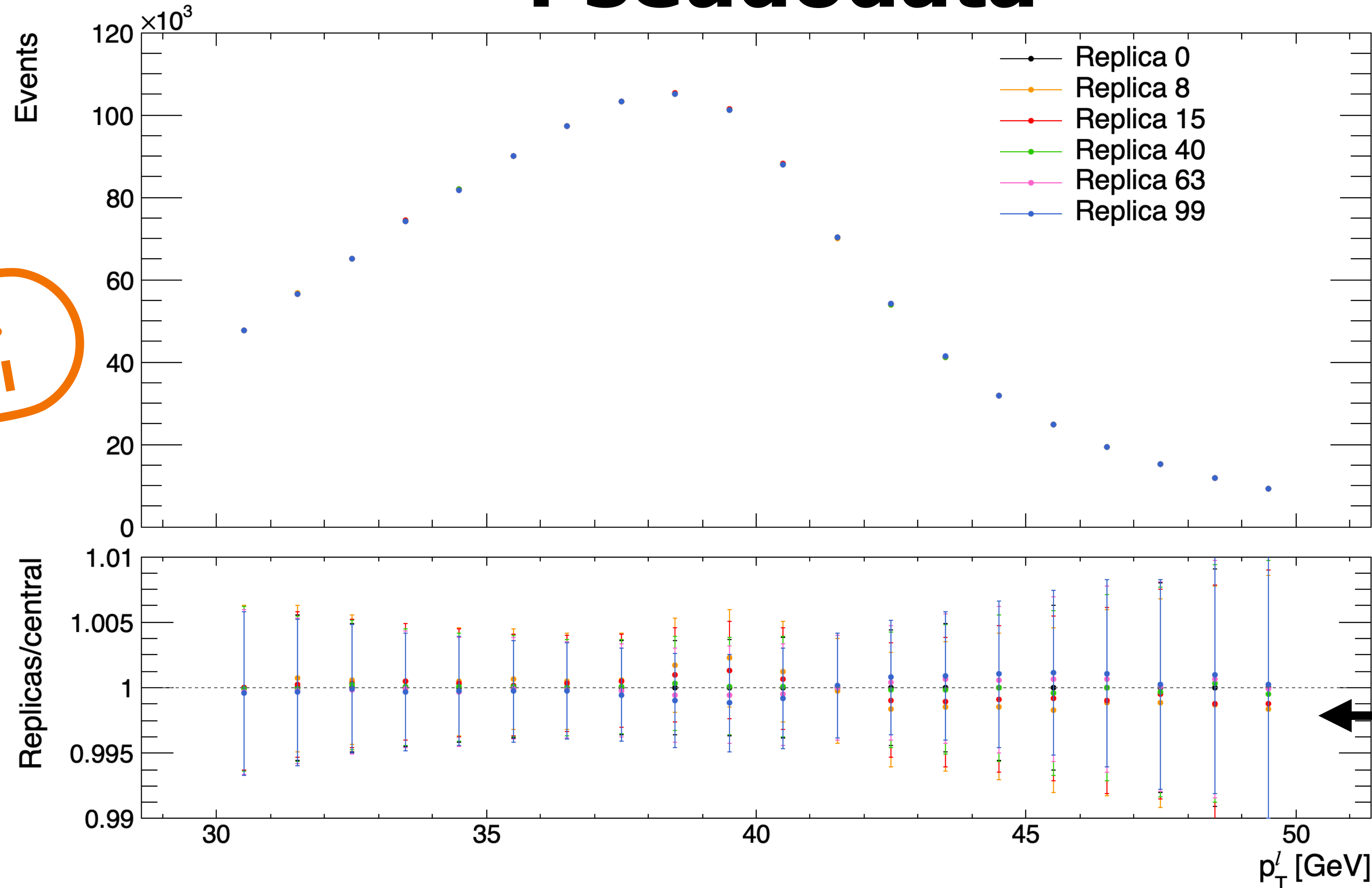
# Generation of the pseudodata

The **TMD** parameters are **varied**, generating **MAP24** and **MAP22** replicas

In this preliminary work only the  **$W^+$  process** is investigated

The **W mass** is **fixed** at the central value (80355 MeV)

# Pseudodata

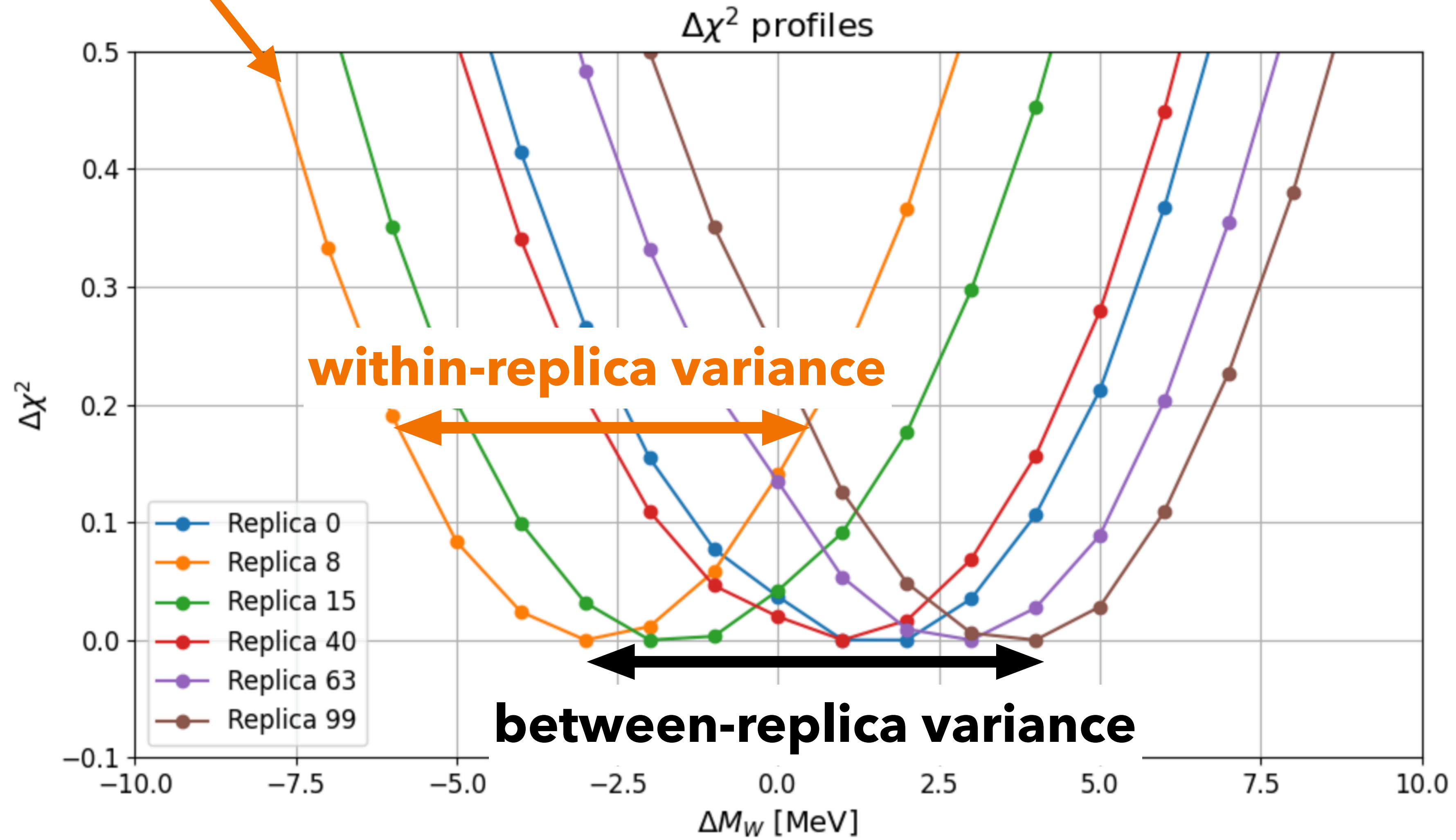


Example:  
MAP24 FI

**We have varied only TMD parameters: the PDF member has been fixed**

Same mass,  
**different TMD replicas**

one TMD replica



**Preliminary  
results**

# Outcome

<b>TMD parametrizations</b>	<b>Range of the shifts</b>	<b>Mean of the shifts</b>	<b>Within-replica error</b>	<b>Between- replica error</b>
<b>MAP24 flavour independent</b>	[-4,+7] MeV	1.6 MeV	7.5 MeV	2.2 MeV
<b>MAP24 flavour dependent</b>	[-5,+5] MeV	-1.6 MeV	7.5 MeV	1.6 MeV
<b>MAP22 Drell-Yan- only</b>	[-5,+20] MeV	-1.4 MeV	7.6 MeV	5.7 MeV

**Preliminary  
results**

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**Preliminary  
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**Preliminary  
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**flavour-dependence  
is expected to have a  
greater impact on  
comparing  $W^+$  and  
 $W^-$  cases**

**Preliminary  
results**

# Outcome

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**excluding DIS in the  
global fit increases  
the uncertainty**

5.7 MeV

**Work in progress**

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# The current goals

- Working on reproducing the procedure at **N3LL**
- Consider **both  $W^+$  and  $W^-$  channels**
- Clarify the interplay between PDFs and TMDs
- Produce also MAP24 Drell-Yan-only
- ...



**Thank you!**

**Backup**

# MAP implementation in

In order to use MAP22 and MAP24 parametrization in the template fitting, the **functional form** has been **implemented in the code**:

$$f_1(x, b_T; \zeta) = \exp\left[-g_2^2 \frac{b_T^2}{4} \ln \frac{\zeta}{Q_0^2}\right] \times \frac{g_1(x) e^{-g_1(x) \frac{b_T^2}{4}} + (\lambda)^2 (g_2(x))^2 \left(1 - g_2(x) \frac{b_T^2}{4}\right) e^{-g_2(x) \frac{b_T^2}{4}} + (\lambda_2)^2 g_3(x) e^{-g_3(x) \frac{b_T^2}{4}}}{g_1(x) + (\lambda)^2 (g_2(x))^2 + (\lambda_2)^2 g_3(x)}$$

And the corresponding **b \* -prescription** has been implemented, too:

$$\bar{b}_{MAP}^*(b_T) = b_{max} \left( \frac{1 - \exp(-b_T^4/b_{max}^4)}{1 - \exp(-b_T^4/b_{min}^4)} \right)^{1/4} \quad b_{max} = 2e^{-\gamma_E} \simeq 1.123 \text{ GeV}^{-1}$$
$$b_{min} = \frac{2e^{-\gamma_E}}{\mu}$$

# Transverse momentum uncertainty

Table A.2: Uncertainties in the W-like  $m_Z$  and  $m_W$  measurements, with contributions to the total uncertainty from individual sources separated according to the “nominal” [33] and “global” [105] definitions of the impacts.

Source of uncertainty	Impact (MeV)			
	Nominal		Global	
	in $m_Z$	in $m_W$	in $m_Z$	in $m_W$
Muon momentum calibration	5.6	4.8	5.3	4.4
Muon reco. efficiency	3.8	3.0	3.0	2.3
W and Z angular coeffs.	4.9	3.3	4.5	3.0
Higher-order EW	2.2	2.0	2.2	1.9
$p_T^V$ modeling	1.7	2.0	1.0	0.8
PDF	2.4	4.4	1.9	2.8
Nonprompt-muon background	—	3.2	—	1.7
Integrated luminosity	0.3	0.1	0.2	0.1
MC sample size	2.5	1.5	3.6	3.8
Data sample size	6.9	2.4	10.1	6.0
Total uncertainty	13.5	9.9	13.5	9.9

**CMS**  
measurement