DIS 2019

TORINO

XXVII International Workshop on Deep Inelastic Scattering and Related Subjects

8 - 12April 2019, Torino, Italy

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Working Groups:

WG1: Structure Functions and Parton Densities
WG2: Small-x and Diffraction
WG3: Higgs and BSM Physics in Hadron Collisions
WG4: Hadronic and Electroweak Observables
WG5: Physics with Heavy Flavours
WG6: Spin and 3D structure
WG7: Future of DIS

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Effect of flavor-dependent partonic transverse momentum on the determination of the W mass at hadron colliders

Marco Radici
INFN - Pavia

In collaboration with

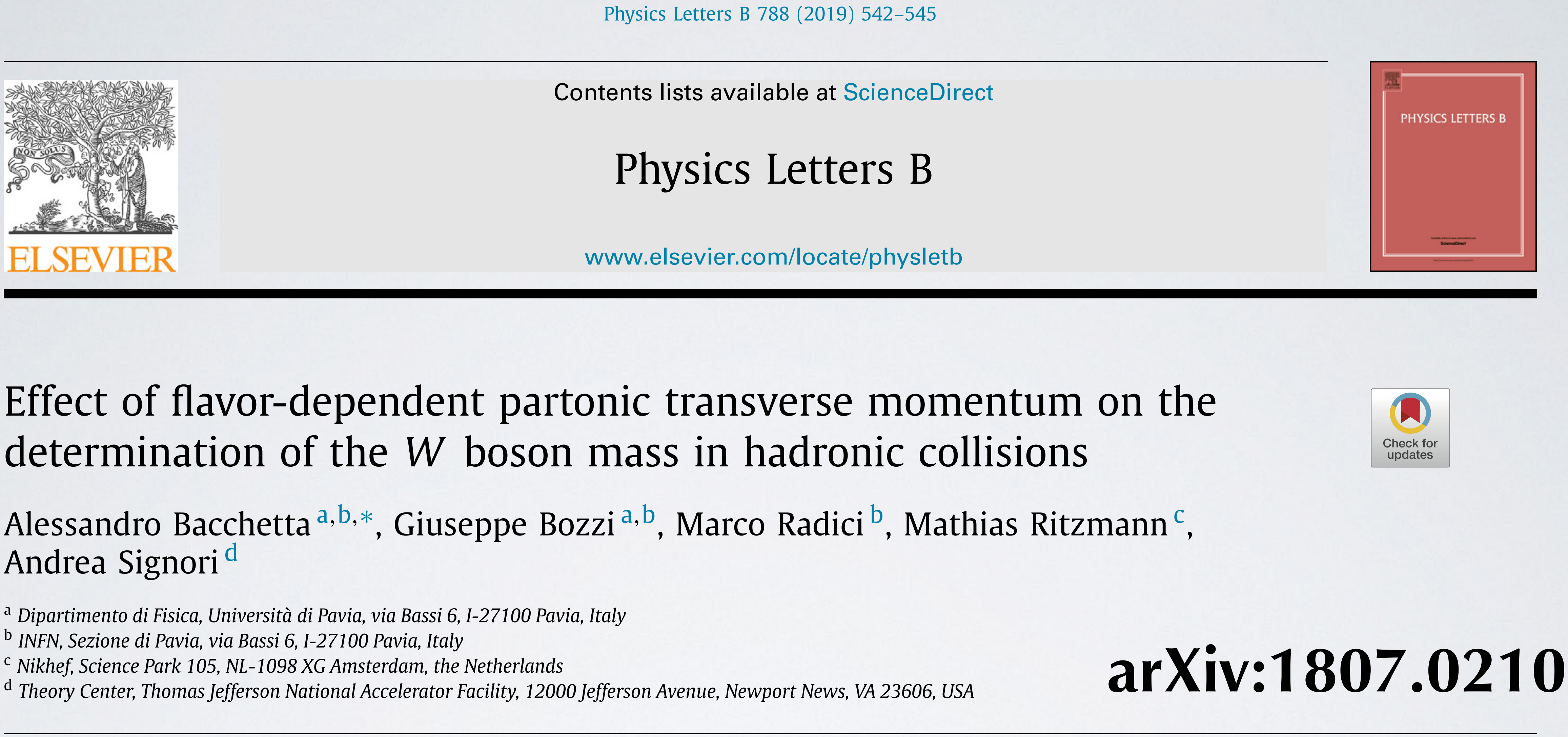
A. Bacchetta G. Bozzi	Univ. Pavia
A. Signori	Argonne Nat. Lab.

European Research Council

MAPPING THE PROTON IN 3D

HAS QCD
HADRONIC STRUCTURE AND QUANTUM CHROMODYNAMICS

Our findings



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

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arXiv:1807.02101

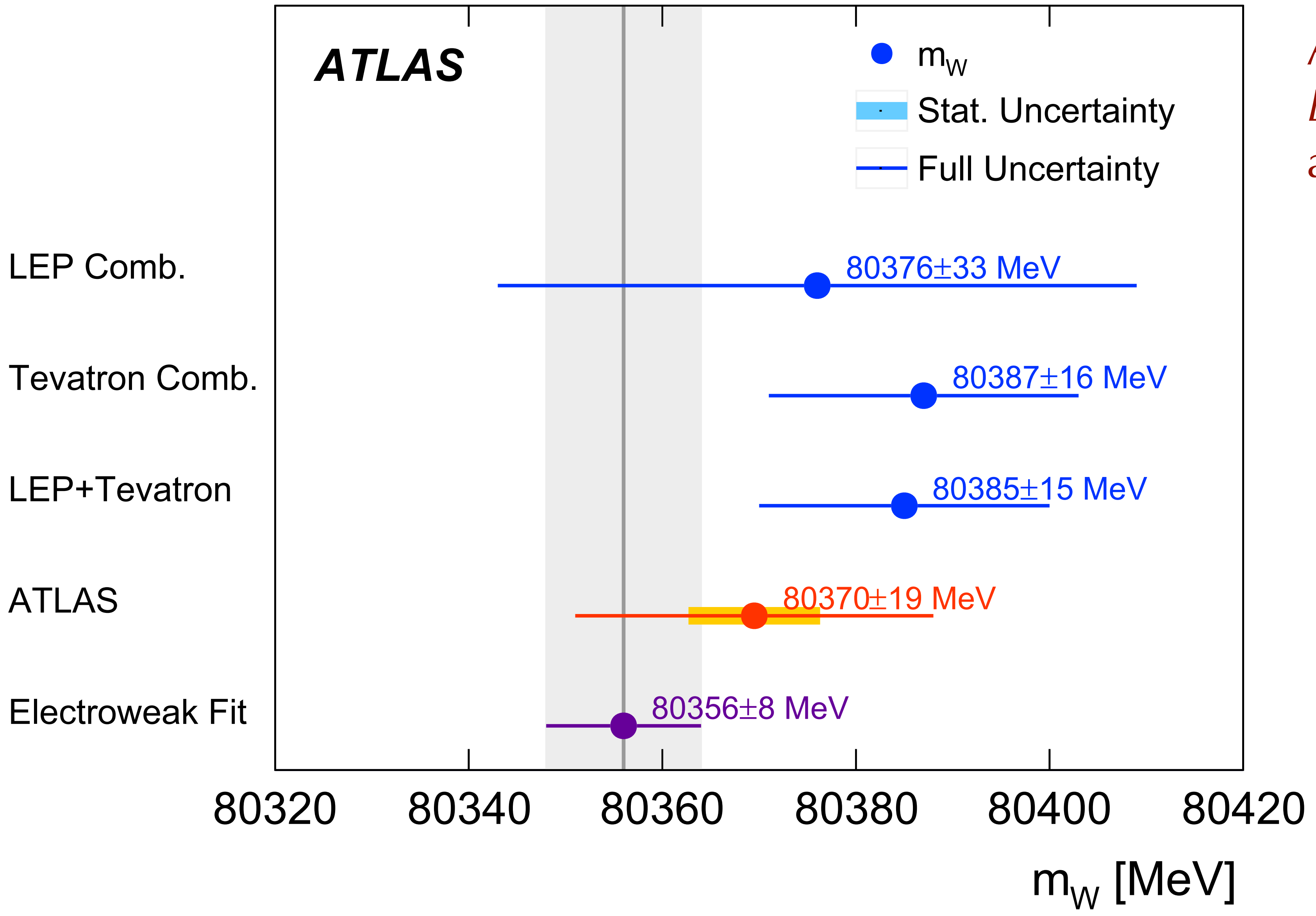
quark intrinsic transverse momentum can be flavor dependent
→ additional uncertainty on m_W, not considered so far.

$-15 \leq \Delta m_{W^+} \leq 9$ MeV

$-10 \leq \Delta m_{W^-} \leq 10$ MeV

The state of the art

The W mass (in numbers)

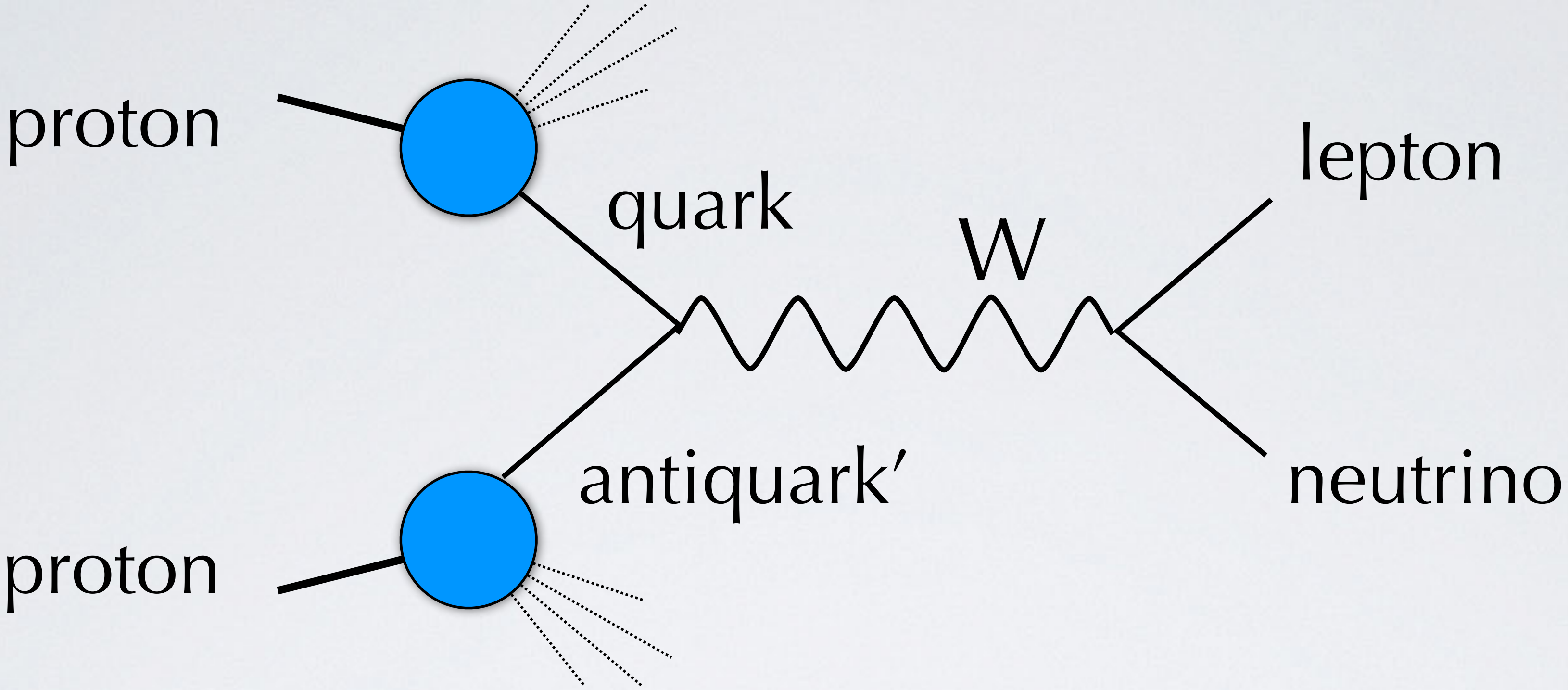


ATLAS Collaboration,
*EPJ **C78** (18) 110*
arXiv:1701.07240

$$m_W = 80370 \ \pm 7 \text{ (stat)} \ \pm 11 \text{ (exp syst)} \ \pm 14 \text{ (mod syst)} \text{ MeV}$$
$$= 80370 \ \pm 19 \text{ MeV}$$

$$m_{W+} - m_{W-} = -29 \pm 28 \text{ MeV}$$

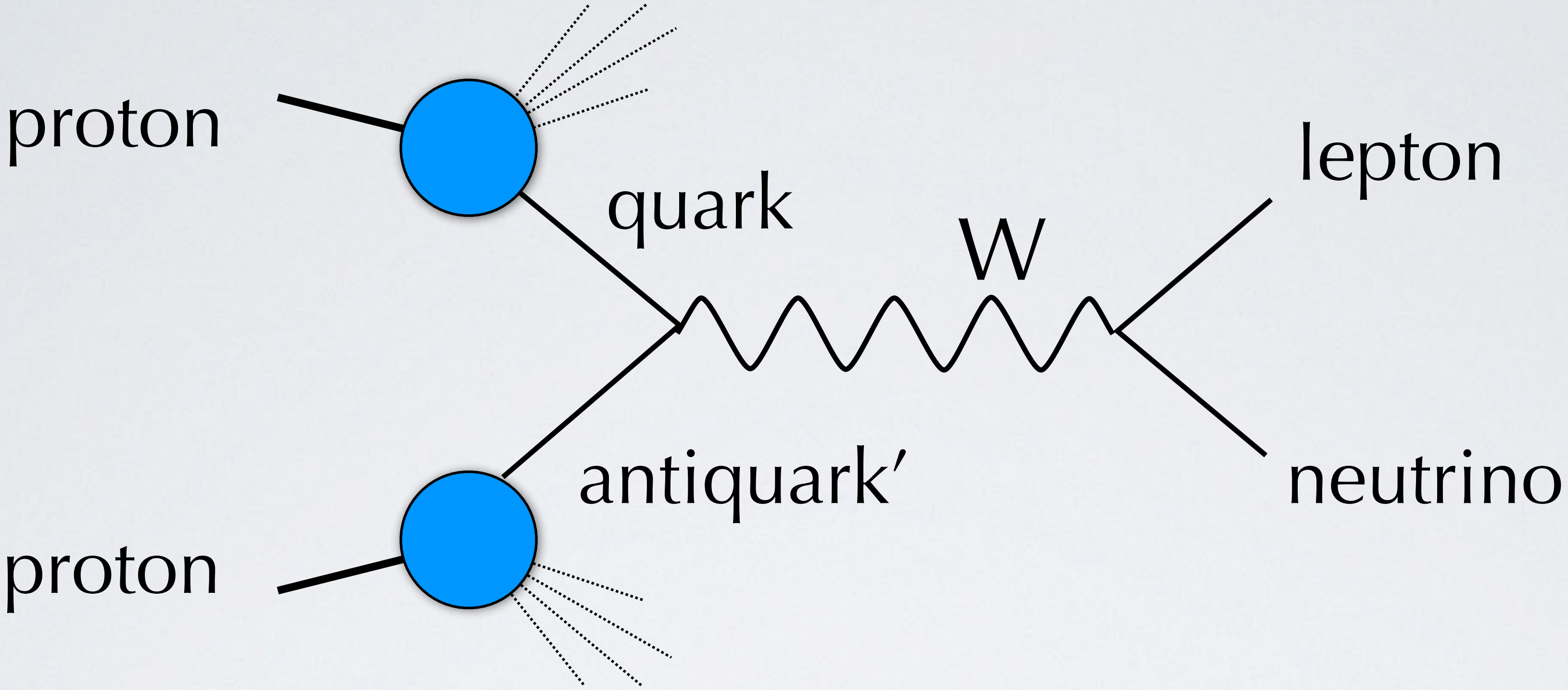
How is the W mass determined ?



4-momentum of neutrino difficult to determine
→ extract m_W from studying the shape of :

- lepton transverse mom. p_T^l
- transverse mass $m_T = \sqrt{2\, p_T^l\, p_T^\nu\, (1 - \cos(\phi^l - \phi^\nu)\,)}$
- missing transverse mom. p_T^{miss}

How is the W mass determined ?



4-momentum of neutrino difficult to determine
→ extract m_W from studying the shape of :

- lepton transverse mom. p_T^l ⬅
- transverse mass $m_T = \sqrt{2\, p_T^l\, p_T^\nu\, (1 - \cos(\phi^l - \phi^\nu))}$ difficult (only 16% of ATLAS sample)
- missing transverse mom. p_T^{miss} difficult (ATLAS does not reconstruct it)

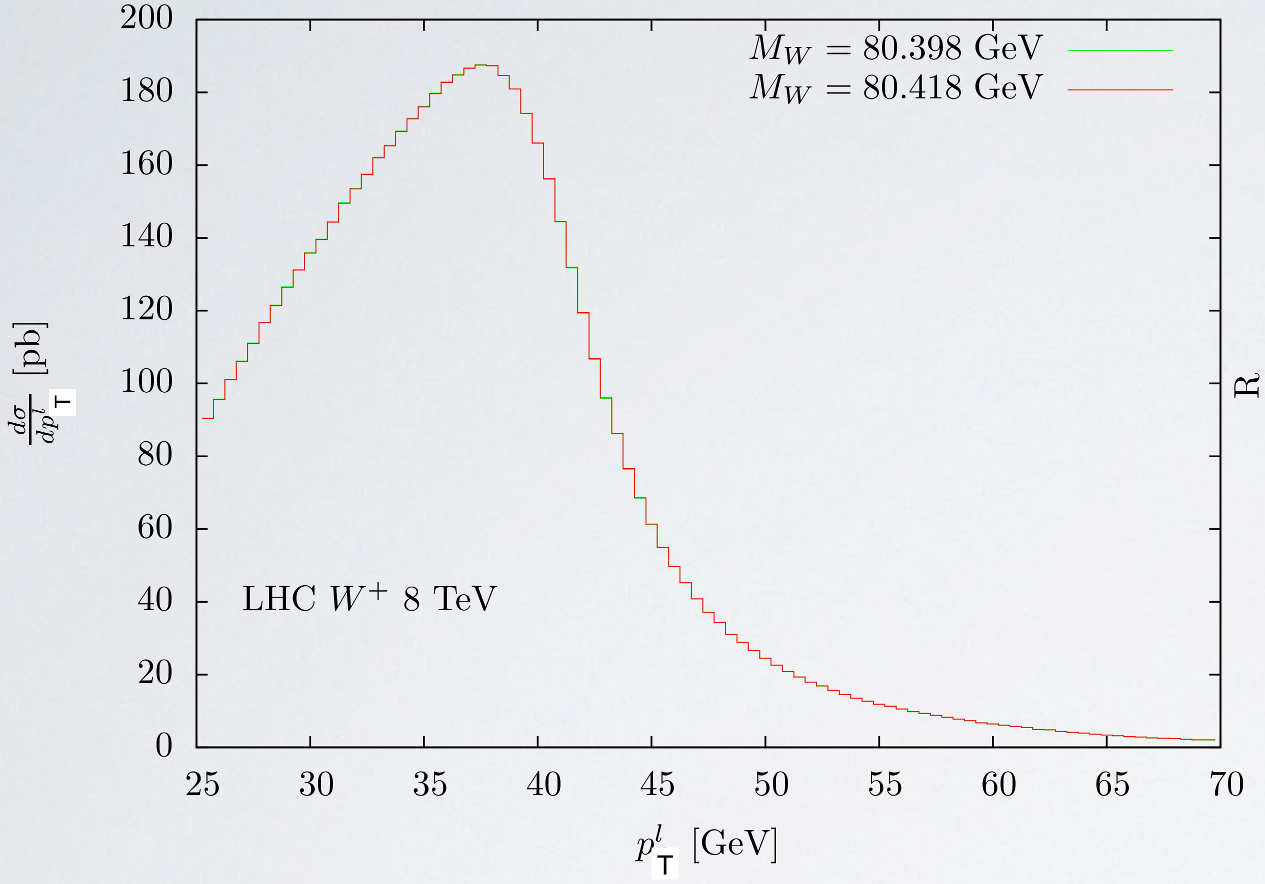
The template - fit technique

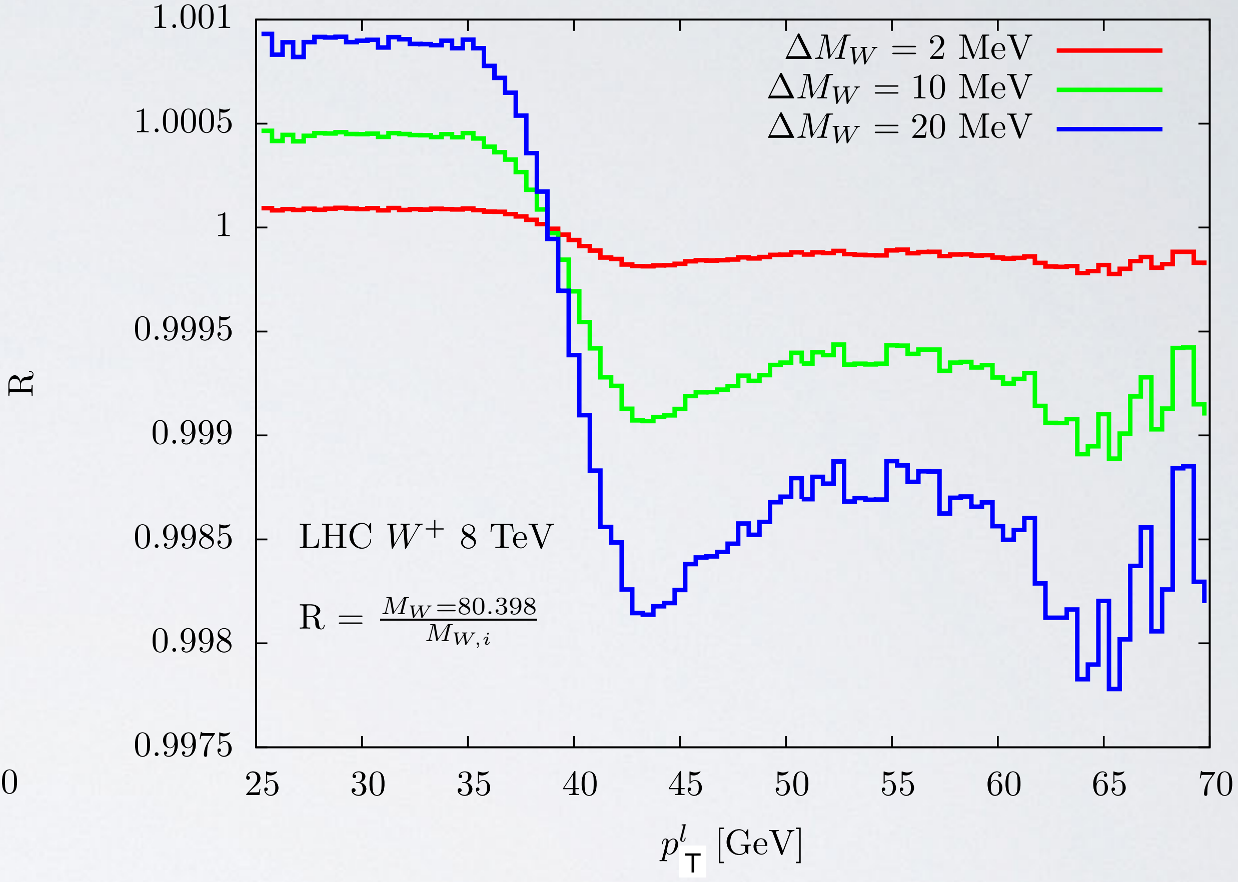
- using Monte Carlo generators with the best of theoretical accuracy and of realism in detector simulation, produce several high-statistics histograms (“templates”) with different m_W
- the template that best fits the measured p_T^l (and m_T) shapes selects the preferred value for m_W
- hypotheses used to build templates (choice of PDFs, scales, nonperturbative parameters, prescriptions,…) are treated as theoretical systematic errors (“mod syst”)

Challenging measurement

Bozzi, Rojo, Vicini, *PRD* ***83*** *(11)* arXiv:1104.2056

….





a distortion at the **per mille level** of the p$_T^l$ distribution induces a shift of *O*(**10 MeV**) in the W mass m$_W$!

$$R = \frac{m_W^0 = 80.398}{m_W^0 + 0.002}$$

$$R = \frac{m_W^0 = 80.398}{m_W^0 + 0.010}$$

$$R = \frac{m_W^0 = 80.398}{m_W^0 + 0.020}$$

How to estimate systematic uncertainties

Example: the current largest uncertainty comes from PDFs

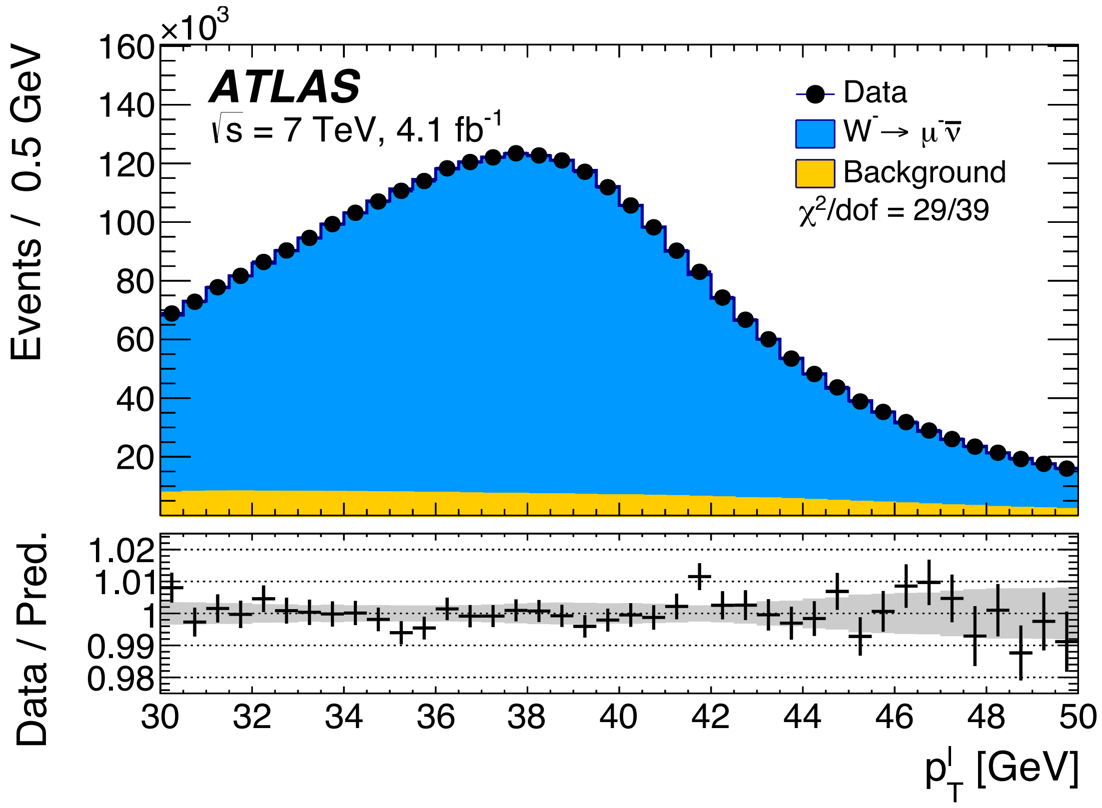
- use Monte Carlo generators to produce pseudodata with known fixed m_W^0 and different PDF sets

- using the same generator, create templates with fixed PDF set and varying m_W around m_W^0

- apply template-fit on pseudodata: the $[(\text{best } m_W) - m_W^0]$ gives the uncertainty δm_W coming from PDFs only

Sensitivity to W transverse momentum

p_T^l (lepton transv. mom.) distribution



ATLAS Collaboration,
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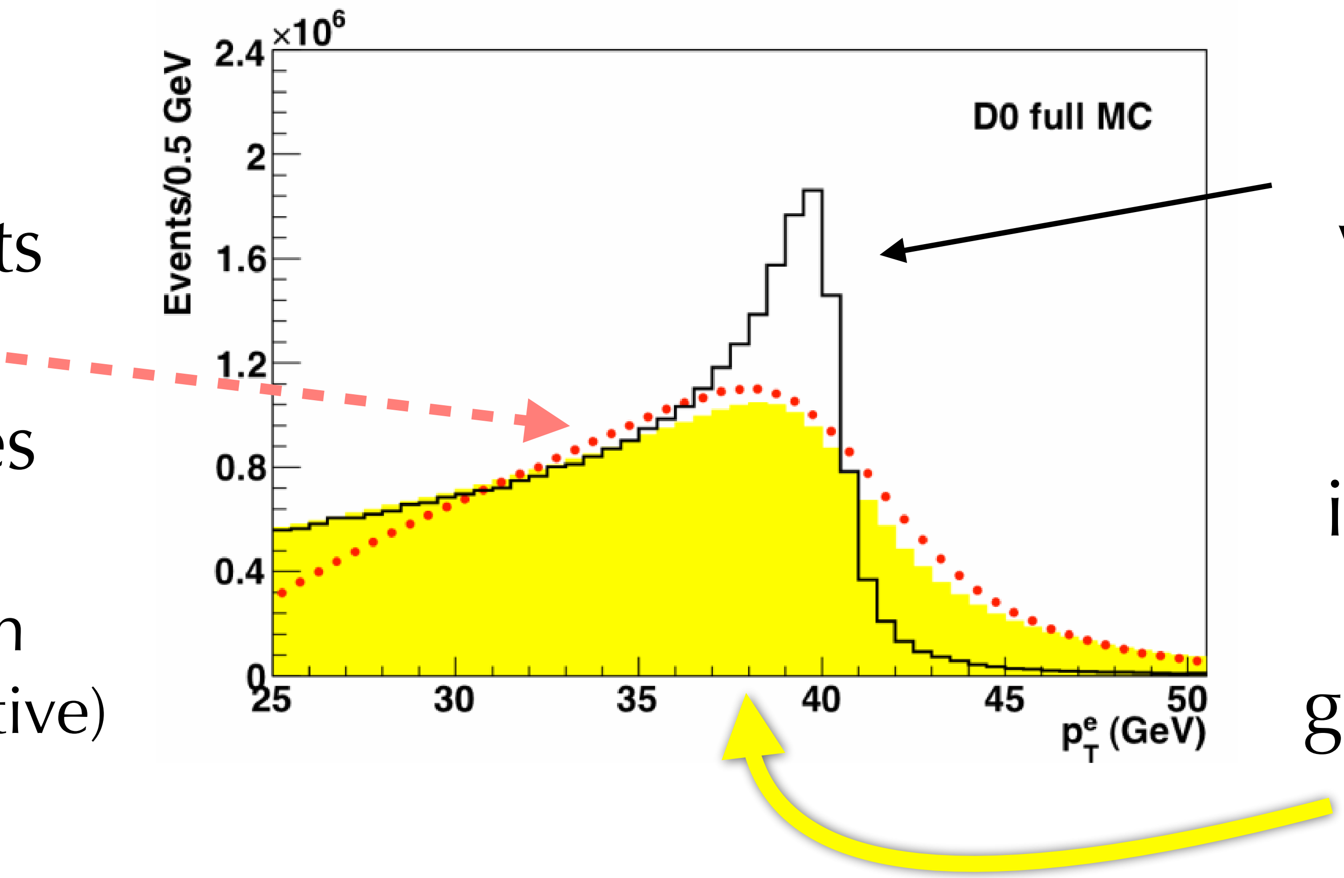
arXiv:1701.07240

detector effects cause minor changes

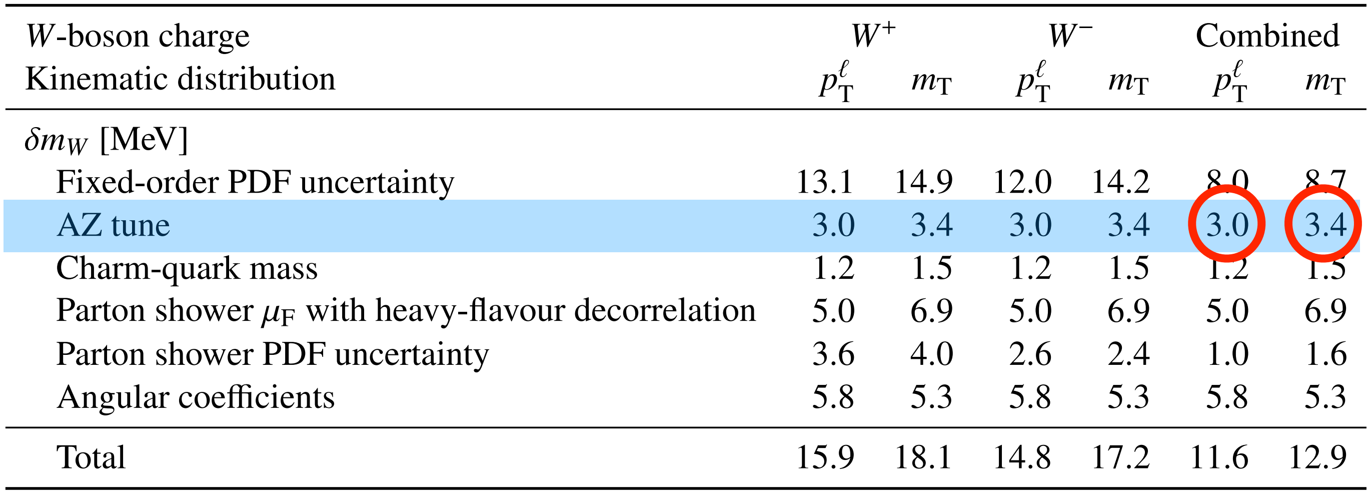
(m_T distribution much more sensitive)



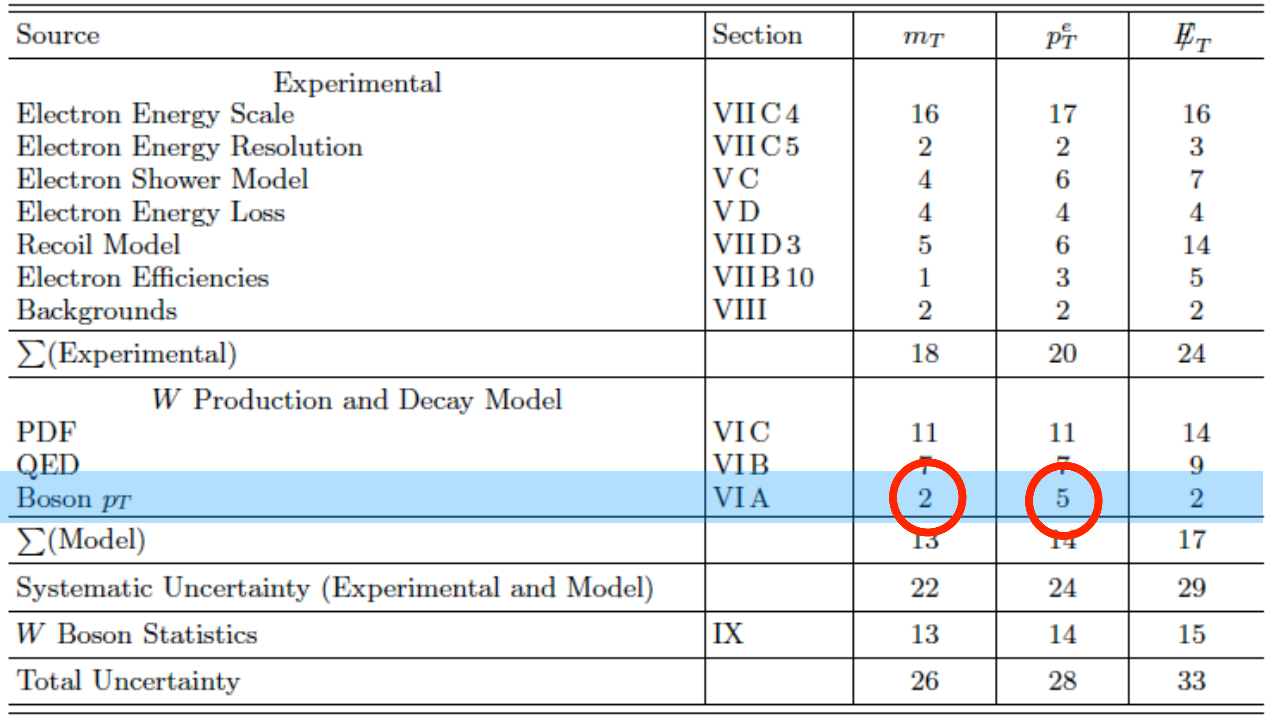
if $p_T^W=0$,
the p_T^l distribution
would look like this

if $p_T^W\neq0$ is included,
the p_T^l distribution
gets modified like this

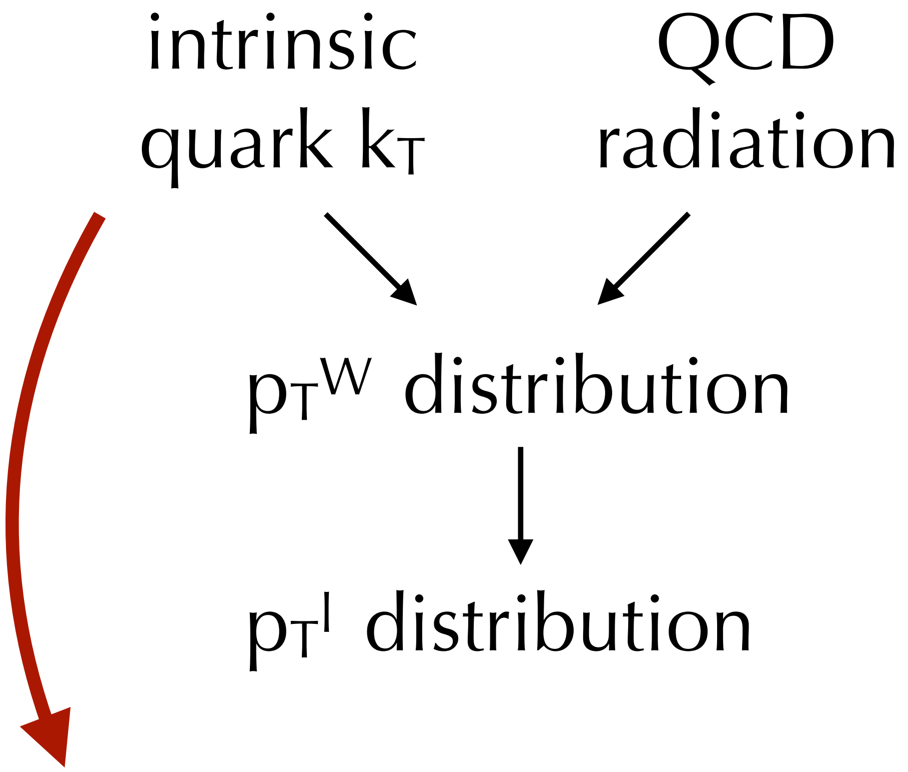
Uncertainty on m_W due to p_T^W



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
Total	15.9	18.1	14.8	17.2	11.6	12.9



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



intrinsic quark k_T

QCD radiation

p_T^W distribution

p_T^l distribution

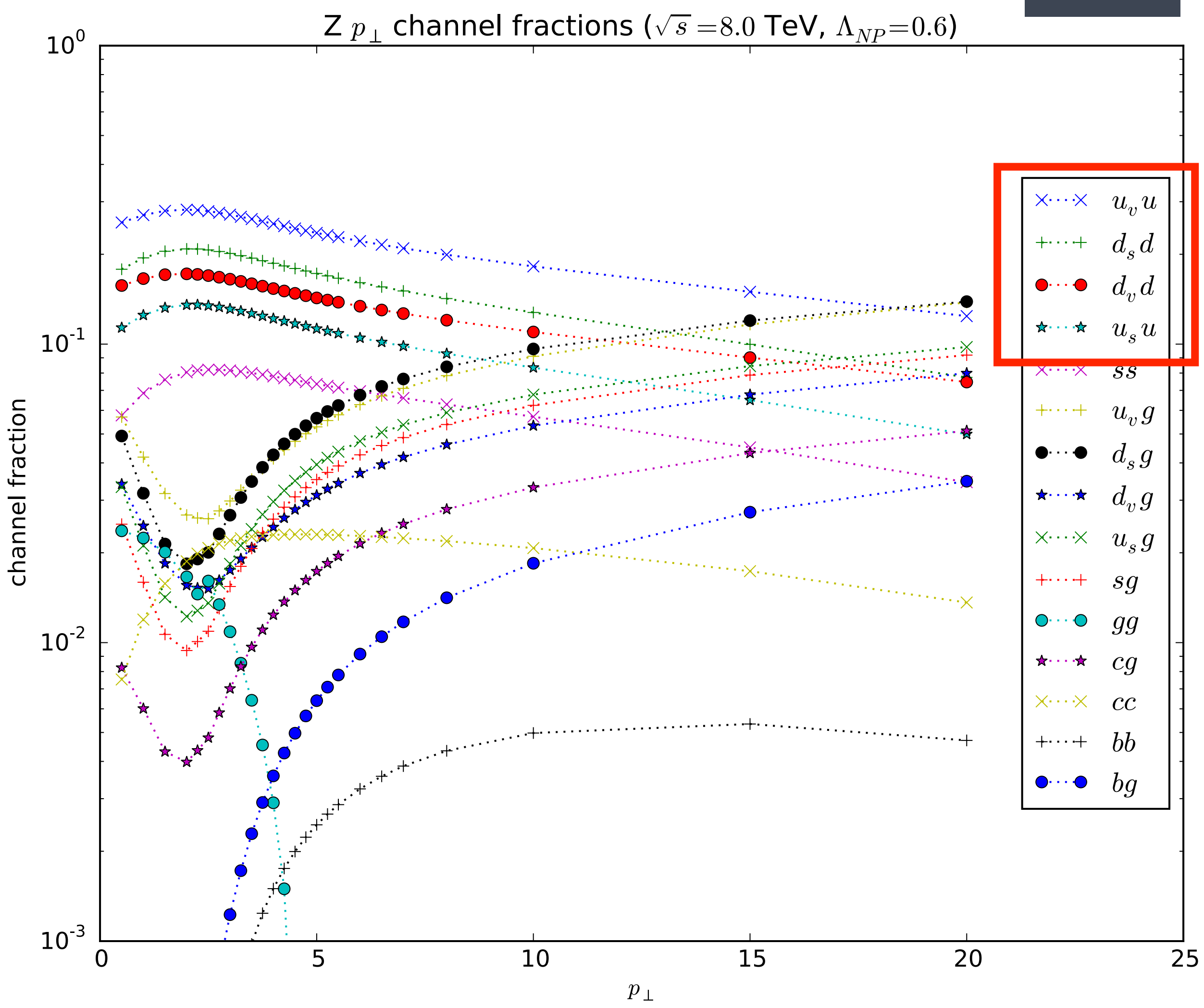
assumed universal and flavor-independent

Monte Carlo generators are tuned to describe Z-boson data …

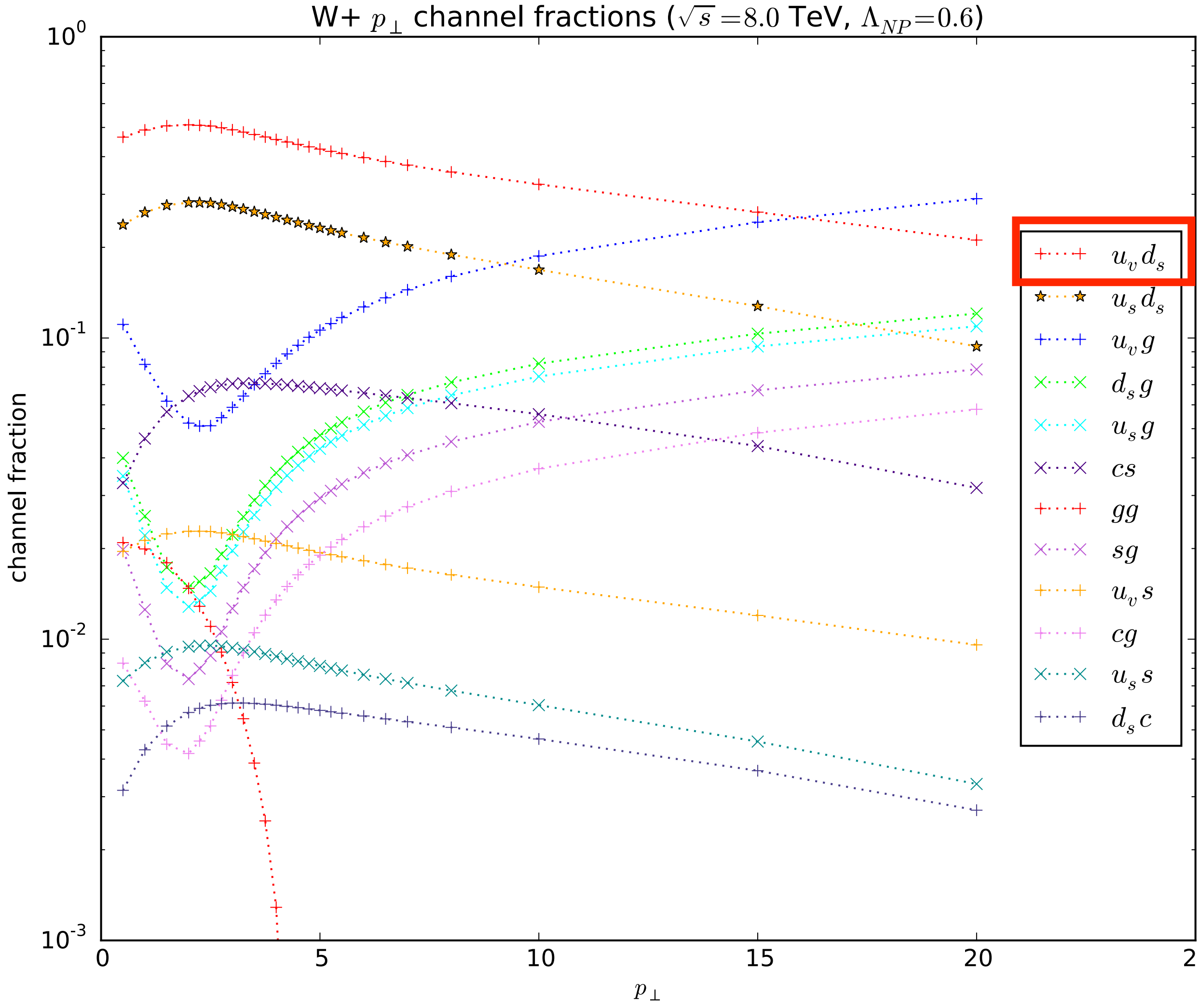
Z and W production involve different flavor combinations

Flavor contributions

Z



W+



uū and dd̄ are the most important channels

ud̄ is the most important channel

Our work

Monte Carlo generator

- we use a modified version of **DYRes**

Catani, De Florian,
Ferrera, Grazzini (2015)

- we implement into the cross section an explicit dependence on quark intrinsic k_T through Transverse Momentum Distributions (TMD)

Collins, “Foundations of Perturbative QCD”
(Cambridge, 2011)

$$f_1^q(x, k_T; \mu^2) = \frac{1}{2\pi} \int d^2 b_T \, e^{-i b_T \cdot k_T} \, \widetilde{f}_1^q(x, b_T; \mu^2)$$

nonperturbative part

$$\widetilde{f}_1^q(x, b_T; \mu^2) = \sum_i \left(\widetilde{C}_{q/i} \otimes f_1^i \right) (x, b_*; \mu_b^2) \, e^{\widetilde{S}(b_*; \mu_b, \mu)} \, f_{1\mathrm{NP}}^q(x, b_T)$$

$\mu_b \propto \frac{1}{b_*}$,

$b_*(b_T)$ smoothly connects between perturbative (low b_T) and nonperturbative (large b_T) domains

perturbative parts computed
at order α_S - NLL

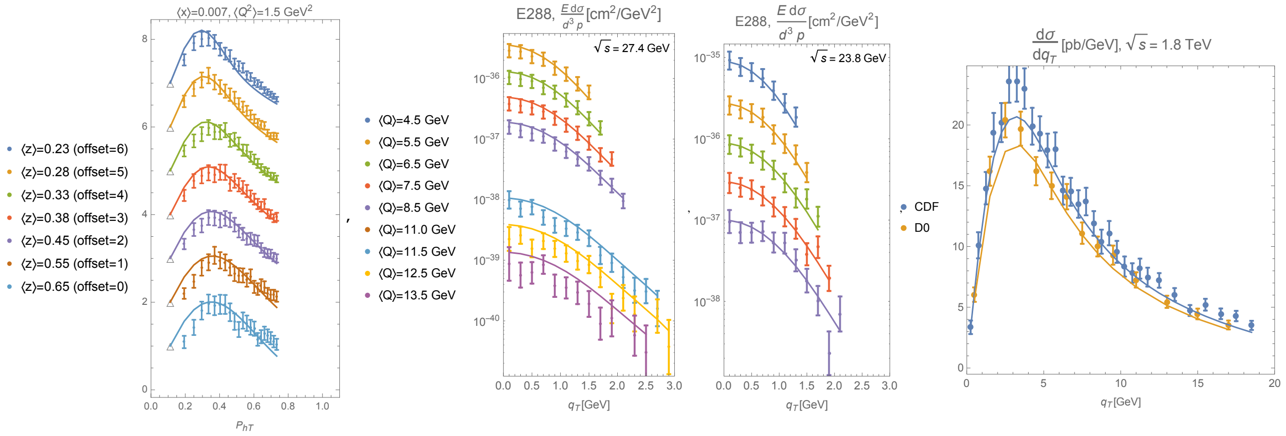
Nonperturbative part

$$f_{1\mathrm{NP}}^{q}(x,b_T) \approx f_{1\mathrm{NP}}^{q}(b_T) \propto e^{-\overbrace{\left[\underbrace{g_{evo}\;\log(Q^2/Q_0^2)}+g_q\right]}^{g_{NP}^{q}}\,b_T^2}$$

flavor-independent
(gluon radiation)

flavor-dependent

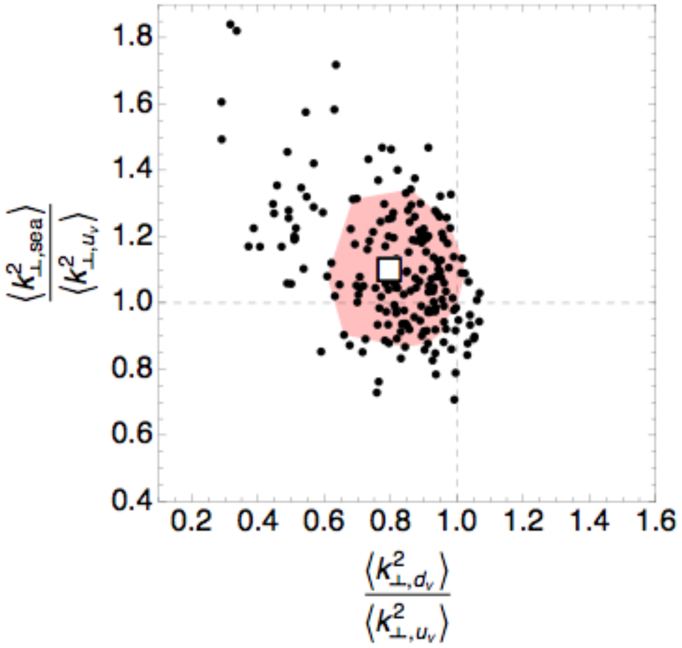
from fit of SIDIS / Drell-Yan / Z-boson data
it turns out ~ [0.2 - 0.4] GeV^2



Bacchetta, Delcarro, Pisano, Radici, Signori, *JHEP* ***1706*** *(17) 081*
arXiv:1703.10157

see also Guzzi, Nadolsky, Wang, PRD**90** (14) 014030

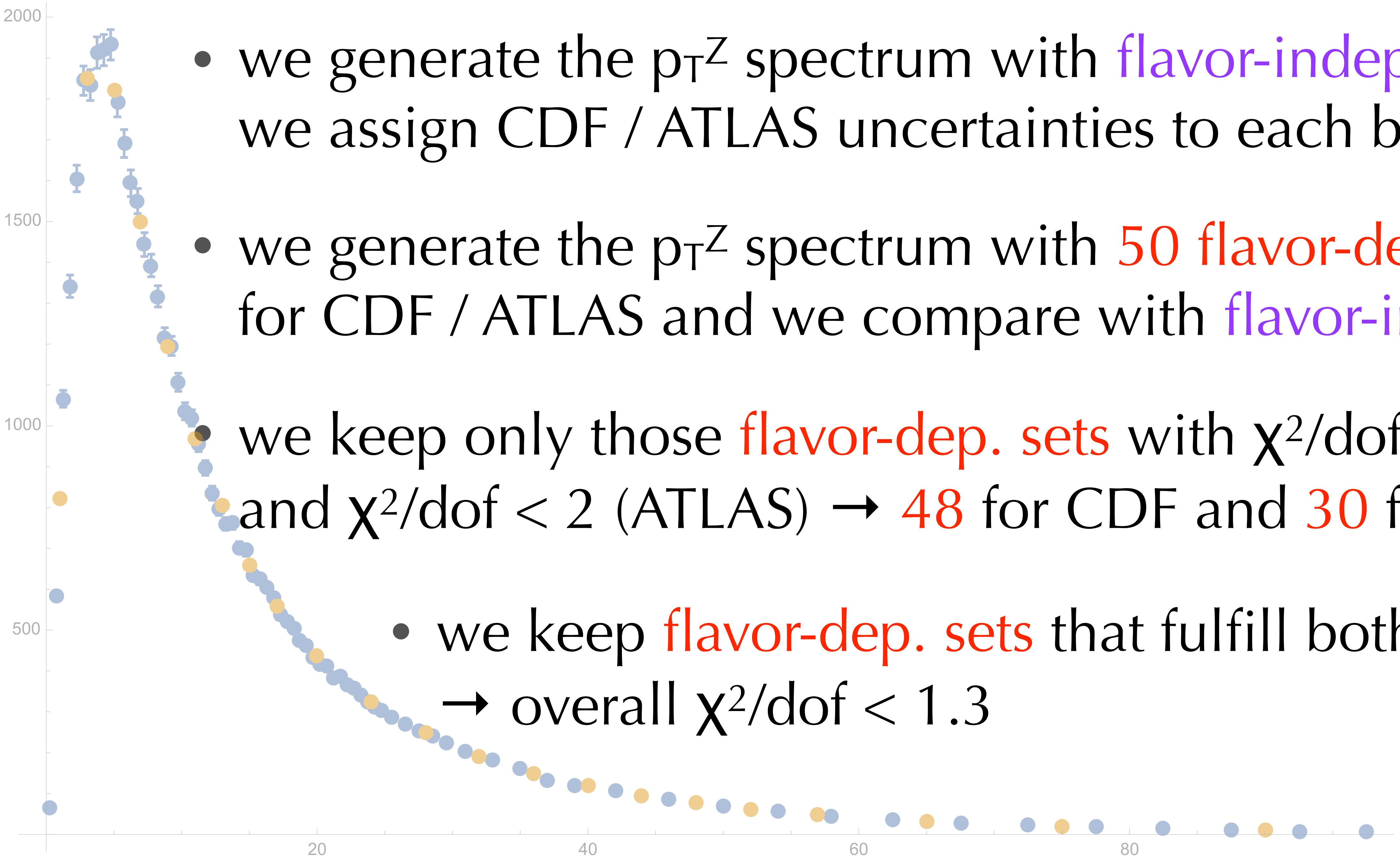
fit of SIDIS data
lot of room for flavor dependence



Signori, Bacchetta, Radici, Schnell, *JHEP* ***1311*** *(13)* 194
arXiv:1309.3507

Choice of "Z-equivalent" parameters

- we first select 50 flavor-dep. sets $g_{\mathrm{NP}}^{q} = \left\{ g_{\mathrm{NP}}^{u_v}, g_{\mathrm{NP}}^{d_v}, g_{\mathrm{NP}}^{u_{sea}}, g_{\mathrm{NP}}^{d_{sea}}, g_{\mathrm{NP}}^{s} \right\} \in [0.2 \div 0.4]$ and 1 flavor-indep. set $g_{\mathrm{NP}}^{q} = 0.4$



- we generate the p_T^Z spectrum with flavor-indep. set and we assign CDF / ATLAS uncertainties to each bin
- we generate the p_T^Z spectrum with 50 flavor-dep. sets for CDF / ATLAS and we compare with flavor-indep. one
- we keep only those flavor-dep. sets with χ^2/dof < 1.1 (CDF) and χ^2/dof < 2 (ATLAS) → 48 for CDF and 30 for ATLAS
  - we keep flavor-dep. sets that fulfill both criteria → overall χ^2/dof < 1.3

Template fit → shift of W mass

- using "Z-equivalent" flavor-dep. sets, generate p_T^l / m_T / p_T^{miss} distributions at $m_W^0 = 80.370$ GeV → pseudodata

- using flavor-indep. set, generate p_T^l / m_T / p_T^{miss} distributions at high statistics for 30 different m_W in ($m_W^0 \pm 0.015$ GeV) → templates

- apply template-fit on pseudodata → get the W mass shift $(\delta m_W)_i = [(\text{best } m_W)_i - m_W^0]$ for each flavor-dep. set **i**

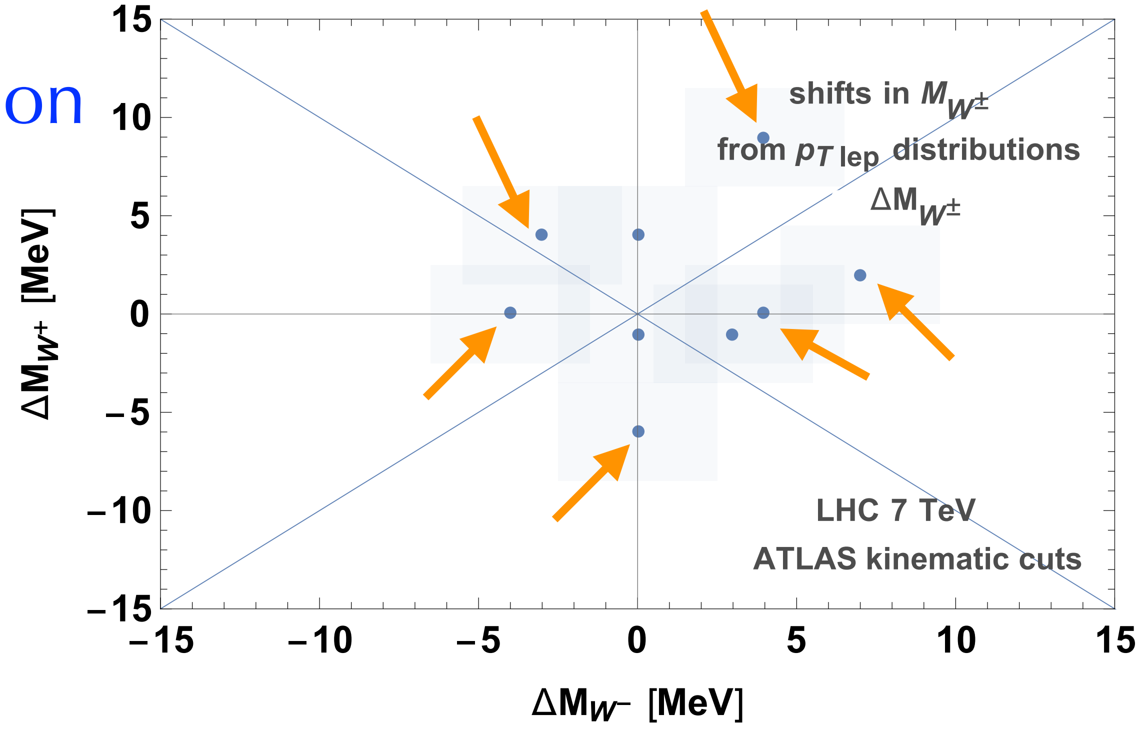
for each flavor-dep. set **i**, keep those templates for which $(\chi^2 - \chi^2_{min}) < 1$ → $(\delta m_W)_i \pm 2.5$ MeV (stat)

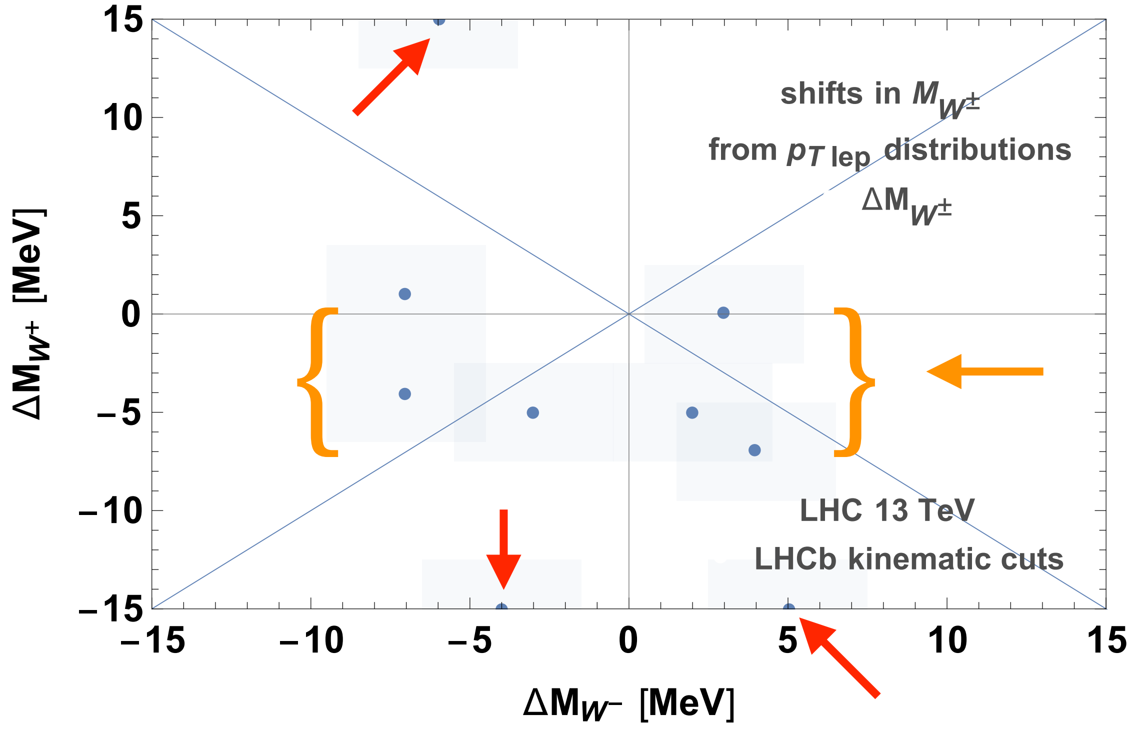
Resulting W mass shifts

LHC 7 TeV, ATLAS cuts

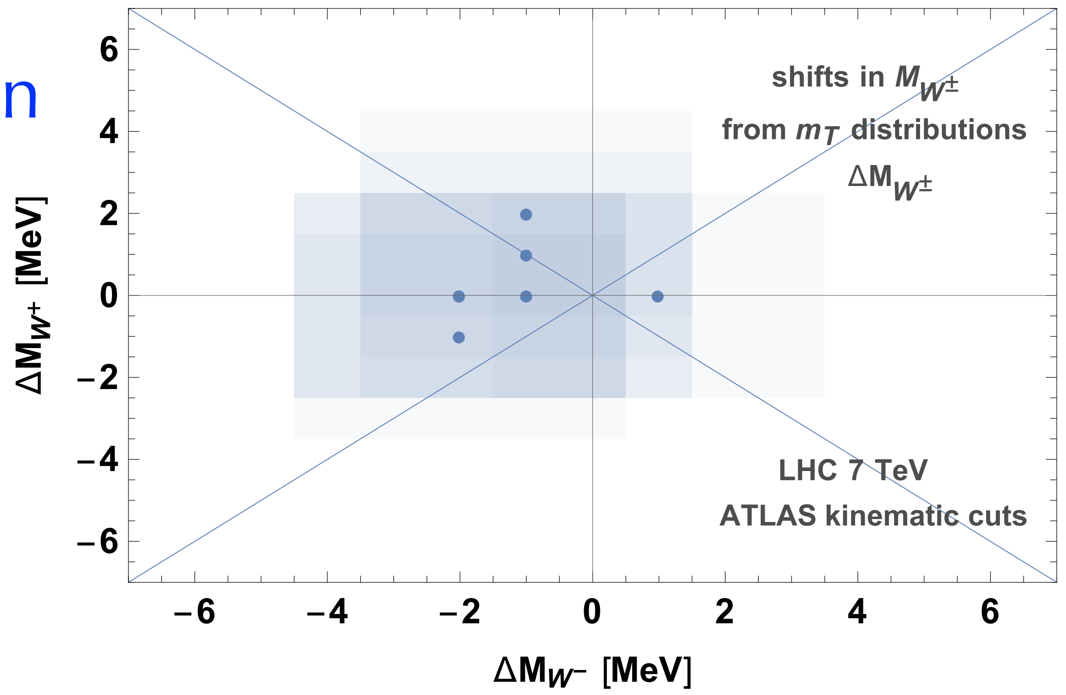
LHC 13 TeV, LHCb cuts

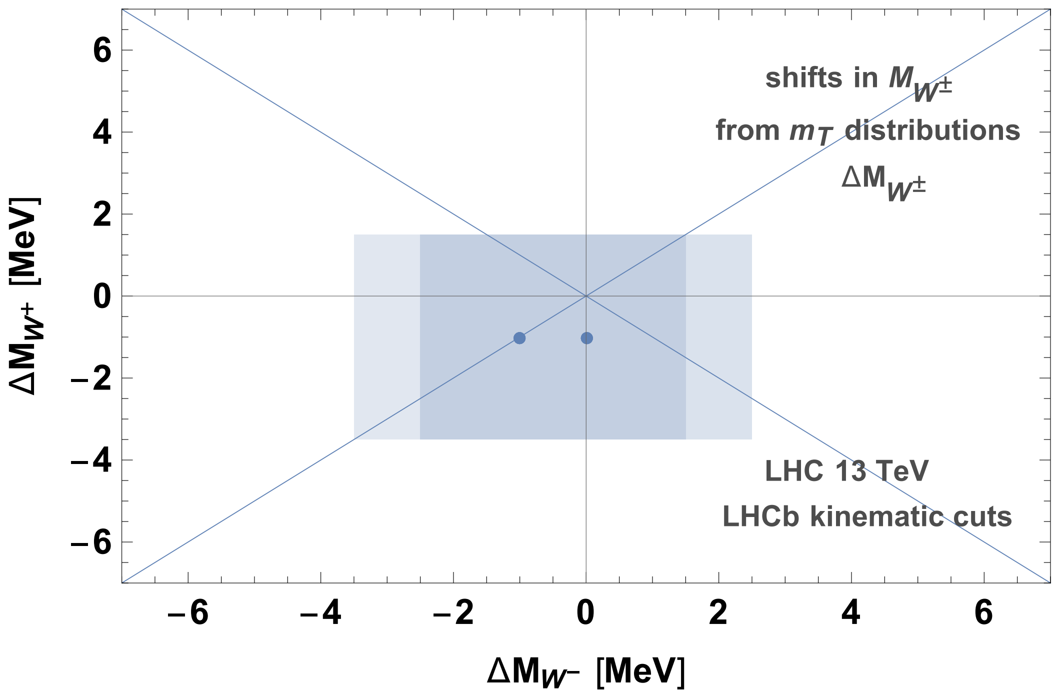
p_T^l distribution





m_T distribution





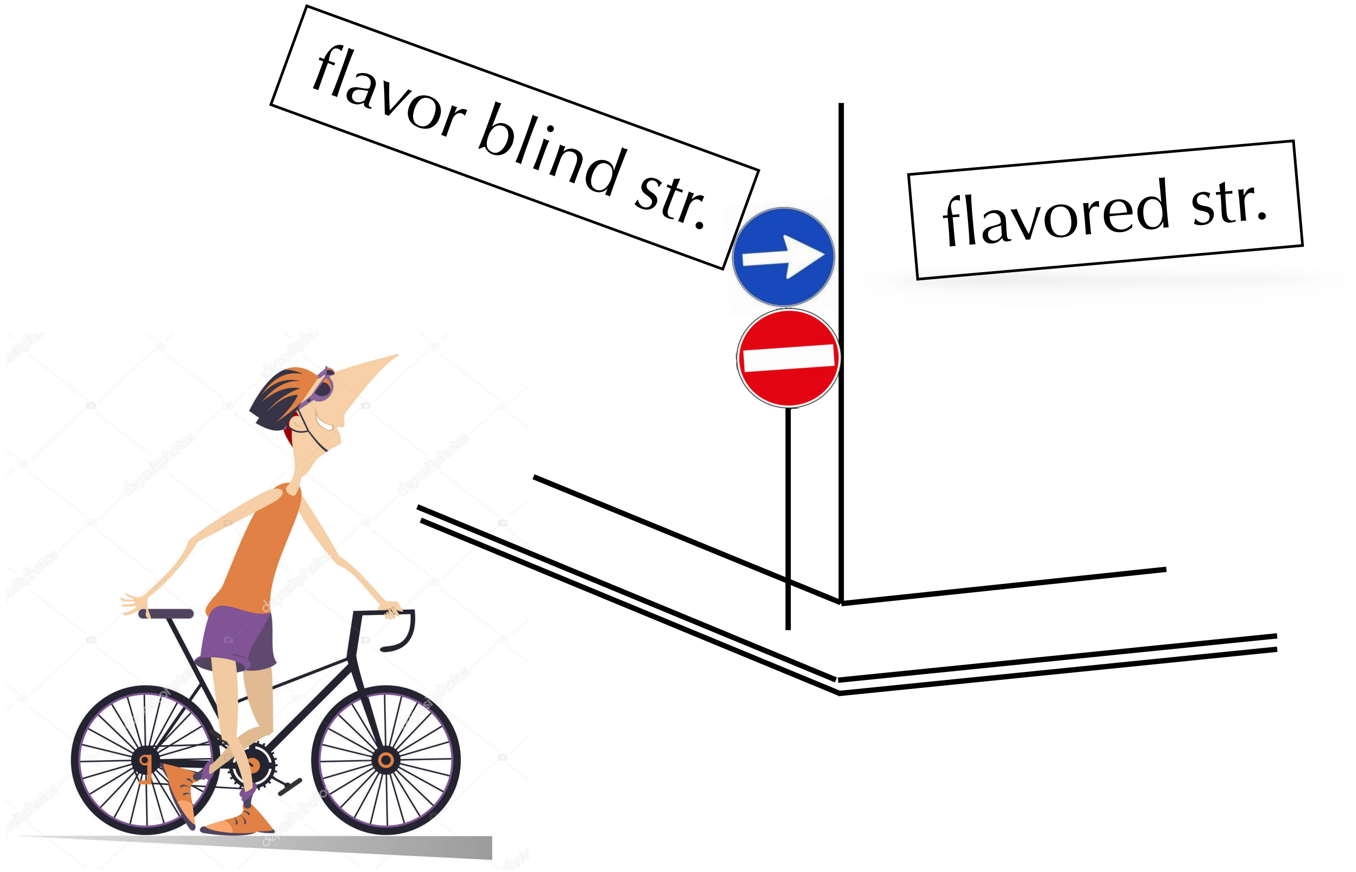
Interesting configurations

	valence		sea			ATLAS EXPERIMENT		LHCb	
Set	u_v	d_v	u_s	d_s	s	Δm_{W+}	Δm_{W-}	Δm_{W+}	Δm_{W-}
1	0.34	0.26	0.46	0.59	0.32	-1	+3	-5	-3
2	0.34	0.46	0.56	0.32	0.51	-6	0	-15	+5
3	0.55	0.34	0.33	0.55	0.30	+9	+4	+1	-7
4	0.53	0.49	0.37	0.22	0.52	0	-4	-15	-4
5	0.42	0.38	0.29	0.57	0.27	+4	-3	-4	-7
6	0.40	0.52	0.46	0.54	0.21	0	+4	-5	+2
7	0.22	0.21	0.40	0.46	0.49	-1	0	+15	-6
8	0.53	0.31	0.59	0.54	0.33	+2	+7	0	+3
9	0.46	0.46	0.58	0.40	0.28	+4	0	-7	+4

N.B. $W^+ \sim u\bar{d}$: larger u_v & d_s give $\Delta m_{W+} > 0$

Conclusions

Nonperturbative flavor dependence of
quark intrinsic transverse momentum
is important for precise determination of W mass



Please, take the right way….

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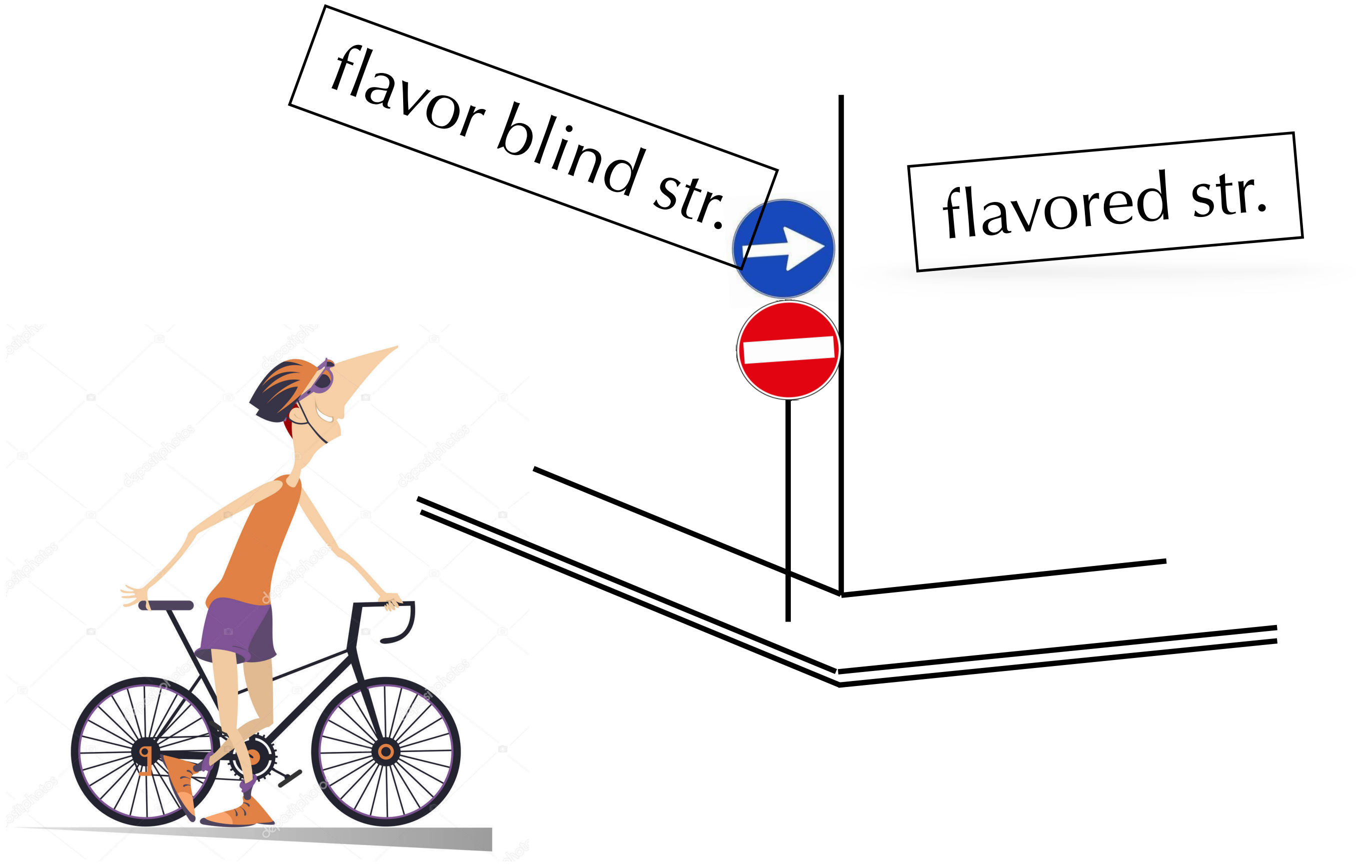

Please, take the right way….

it's harder, but rewarding…