Istituto Nazionale di Fisica Nucleare

MARIE CURIE ACTIONS

SQUHADRON

Andrea Signori

University of Pavia & INFN

Status and prospects for TMD phenomenology

Transversity 2022 - Almo Collegio Borromeo, Pavia

May 24, 2022

Outline

1. **Introduction and motivation**
2. **TMD phenomenology**
3. **“Applications” of hadron structure: Mw determination**

Mw determination - CDF II

https://www.science.org/doi/10.1126/science.abk1781

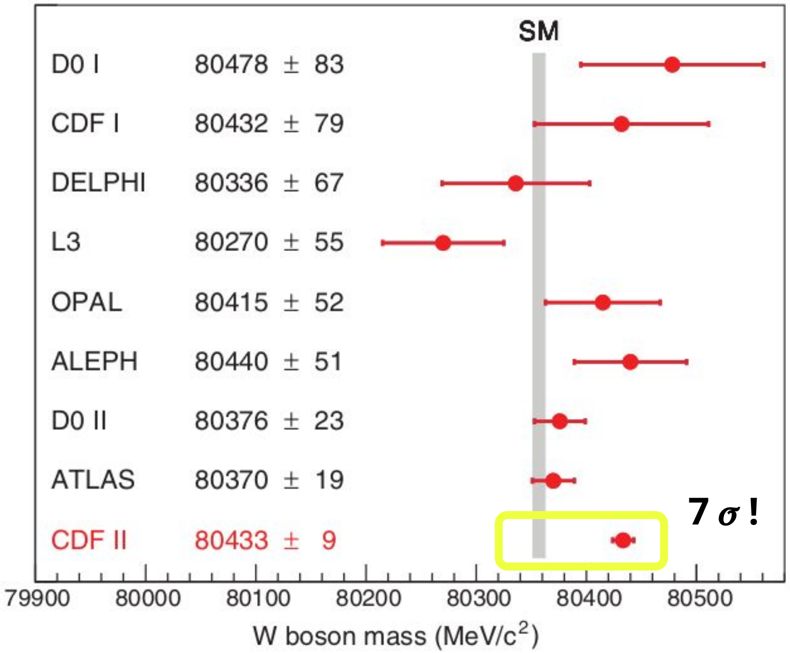

Table 2. Uncertainties on the combined M_W result.

Source	Uncertainty (MeV)
Lepton energy scale	3.0
Lepton energy resolution	1.2
Recoil energy scale	1.2
Recoil energy resolution	1.8
Lepton efficiency	0.4
Lepton removal	1.2
Backgrounds	3.3
p_T^Z model	1.8
p_T^W/p_T^Z model	1.3
Parton distributions	3.9
QED radiation	2.7
W boson statistics	6.4
Total	9.4

SM expectation (PDG): $M_W = 80357 \pm 6\ \mathrm{MeV}$

Connecting "low" and "high" energy physics

Structure of hadrons in 1D and 3D momentum space!

Table 2. Uncertainties on the combined M_W result.

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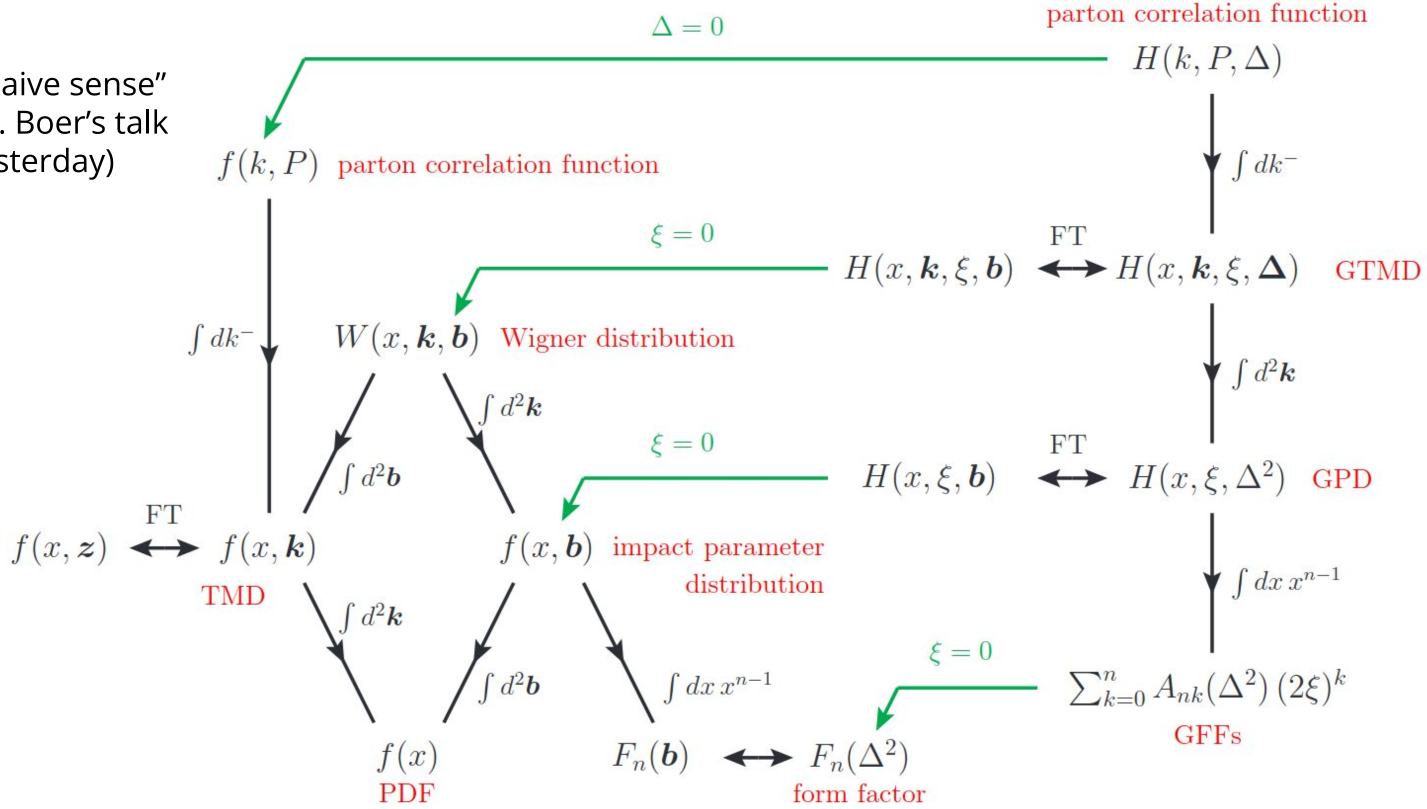
"The aim of science is not to open the door to infinite wisdom, but to set some limit to infinite error" - B. Brecht, "Galileo"

The hadron structure landscape

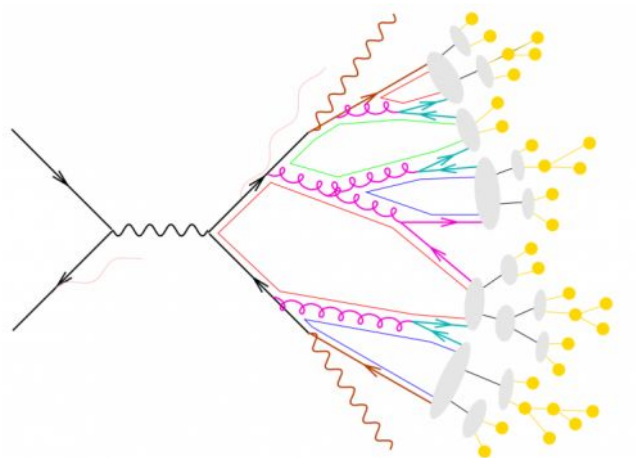
“in a naive sense”
(see D. Boer’s talk
yesterday)



Credit picture: M. Diehl - [arXiv 1512.01328]

Hadronization and fragmentation functions (FFs)

"Maps" of hadron formation in momentum space



See e.g. next talk by R. Seidl

$D_1^h(z)$	single-hadron collinear FF
$D_1^h(z, P_T^2)$	single-hadron TMD FF
$D_1^{h_1\,h_2}(z, \zeta)$	di-hadron FF
$J(s)$	inclusive jet FF
$\mathcal{G}^h(s, z)$	in-jet FF

SIDIS coverage

$$\ell(l) + N(P) \to \ell(l') + h(P_h) + X$$

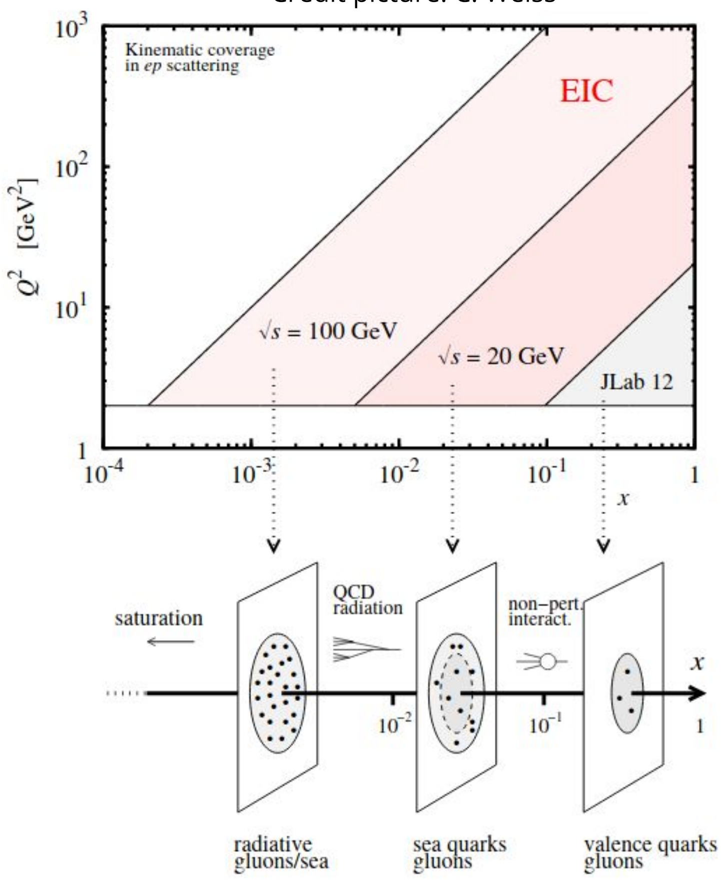
from JLab 12 GeV, Hermes, Compass
to the EIC

zooming into hadron structure

Importance of
complementary experiments

See H. Avakian's talk on Wednesday

Credit picture: C. Weiss



Precision 3D imaging of protons and nuclei

An Electron-Ion Collider will take three-dimensional precision snapshots of the internal structure of protons and atomic nuclei.

See H. Gao's talk later today

00 home
01 about
02 goals
03 design
04 benefits
05 status
06 news

Solving the Mystery of Proton Spin

An EIC would reveal how the teeming quarks and gluons inside the proton combine their spins to generate the proton's overall spin.

Search for Saturation

A unique form of matter, the color glass condensate, may be produced for study for the first time by an EIC, providing deeper insight into gluons and their interactions.

Quark and Gluon Confinement

Experiments at an EIC would cast fresh light on the mystery of why quarks or gluons can never be observed in isolation but must remain confined within protons and nuclei.

Electron-Ion Collider (EIC)

https://www.jlab.org/eic

more

A fixed-target program at the LHC

See P. di Nezza's talk on Friday

Contents lists available at ScienceDirect

ELSEVIER

journal homepage: www.elsevier.com/locate/physrep

PHYSICS REPORTS

High-x partonic content of nucleons and nuclei

Spin structure of (un)polarized nucleons

A fi… pro… d astroparticle studies

Check for updates

Heavy-Ion collisions at large rapidities

C. Hadjidakis [1,a], D. K… M.G. Echevarria [3,4,b], … A. Signori [11,3,12,b], B. … F. Donato [18], E.G. Ferreiro [19,20], I. Hrivnacova [1], A. Klein [17], A. Kurepin [21], C. Lorcé [22], F. Lyonnet [23], Y. Makdisi [24], S. Porteboeuf Houssais [25], C. Quintans [8], A. Rakotozafindrabe [26], P. Robbe [1], W. Scandale [27], N. Topilskaya [21], A. Uras [28], J. Wagner [29], N. Yamanaka [1,32,30,31], Z. Yang [33], A. Zelenski [24]

https://doi.org/10.1016/j.physrep.2021.01.002

Hadronization studies at Belle

see next talk by R. Seidl

Opportunities for precision QCD physics in hadronization at Belle II – a Snowmass whitepaper

A. Accardi,[1,2] Y.-T. Chien,[3,4,5,6] D. d'Enterria,[7] A. Deshpande,[5,3,8] C. Dilks,[9] P. A. Gutierrez Garcia,[10] W. W. Jacobs,[11] F. Krauss,[12] S. Leal Gomez,[13] M. Mouli Mondal,[5,3] K. Parham,[9] F. Ringer,[4] P. Sanchez-Puertas,[14] S. Schneider,[9] G. Schnell,[15,16] I. Scimemi,[10] R. Seidl,[17,18] A. Signori,[19,20] T. Sjöstrand,[21] G. Sterman,[5,3,4] and A. Vossen[9,2,*]

https://inspirehep.net/literature/2063309

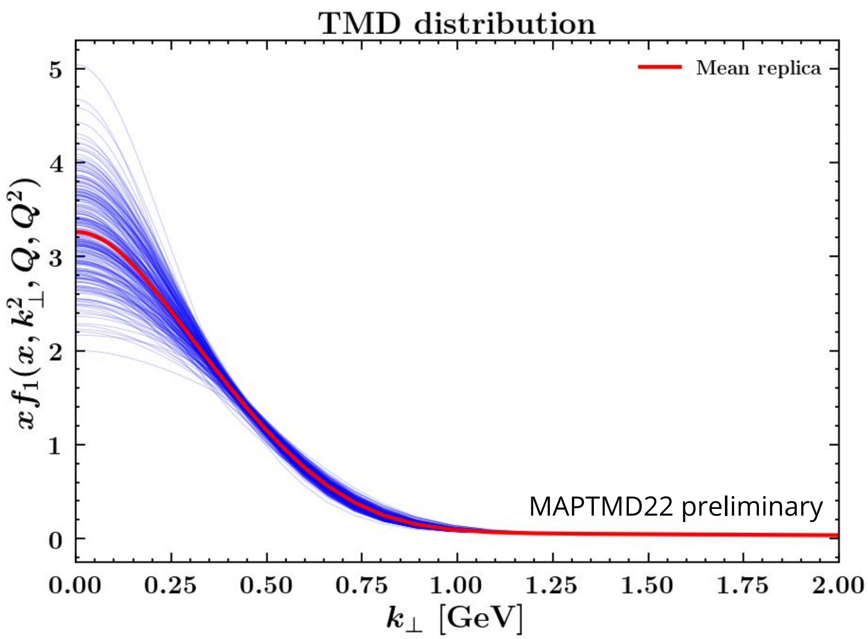
https://inspirehep.net/literature/2087635

Snowmass 2021 White Paper
Upgrading SuperKEKB with a Polarized Electron Beam: Discovery Potential and Proposed Implementation

April 13, 2022

US Belle II Group [1]
and
Belle II/SuperKEKB e- Polarization Upgrade Working Group [2]

TMD phenomenology



TMD PDF of the u at Q = 2 GeV and x = 0.001

TMD PDFs for quarks in nucleon

quark pol.

nucleon pol.	U	L	T
U	f_1		$h_1^\perp$
L		g_{1L}	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	$h_1,\ h_{1T}^\perp$

$$\Phi_{ij}(k,P) \;=\; \mathrm{F.T.}\,\langle P \big| \overline{\psi_j}(0)\, U\, \psi_i(\xi) \big| P\rangle$$

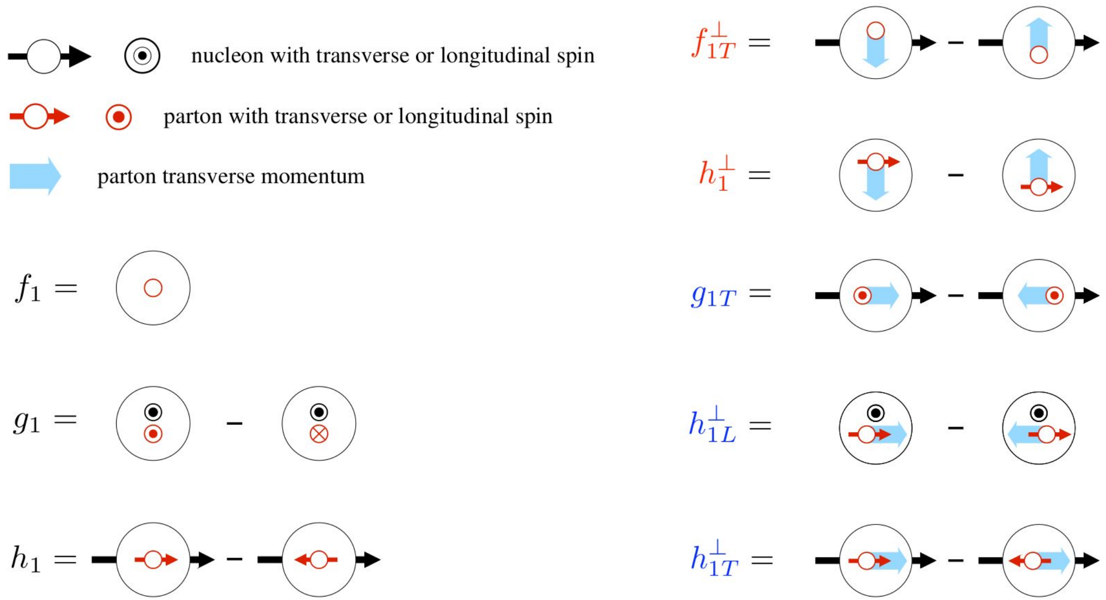
At leading twist: 8 TMD PDFs

(similar classification for gluons and for fragmentation functions)

- **Black**: time-reversal even AND collinear
- **Blue**: time-reversal even
- **Red**: time-reversal odd (*process dependence*)

The **symmetries of QCD** play a crucial role in this classification

Mulders' traffic lights



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nucleon pol.

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T	$f_{1T}^\perp$	g_{1T}	$h_1,\ h_{1T}^\perp$

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At leading twist: 8 TMD PDFs

(similar classification for gluons and for fragmentation functions)

- **Transversity** and **Sivers** : discussed yesterday
- Today: unpolarized TMD PDF f1 (and one among its applications)
- Unfortunately no time for polarization, higher-twists, fragmentation functions, ...

TMD factorization

$$pp \longrightarrow \gamma^{\cdot} \,/\, Z \longrightarrow l\,\bar{l} + X$$

$$\frac{d\sigma}{dq_T} \sim \mathcal{H}\, f_1(x_a, k_{T\,a}, Q, Q^2)\, f_1(x_b, k_{T\,b}, Q, Q^2)\, \delta^{(2)}(q_T - k_{T\,a} - k_{T\,b}) \; + \mathcal{O}(q_T/Q) \; + \; \mathcal{O}(\Lambda/Q)$$

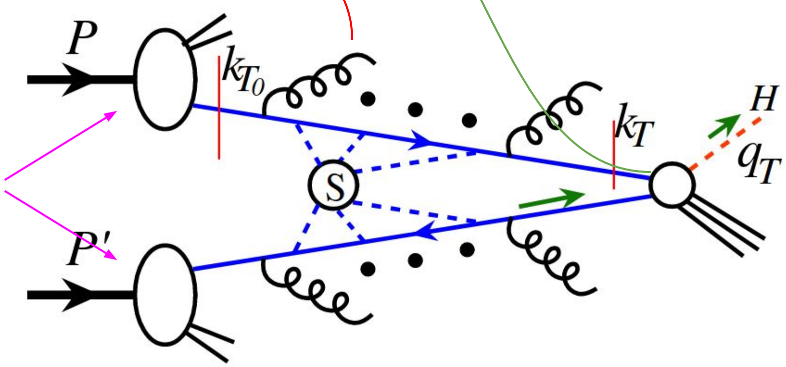
Experimental measurements

Perturbative contributions

Large qT corrections

Low Q corrections

Non-perturbative parts



$$\boxed{q_T \ll Q}$$

TMD factorization

$$pp \longrightarrow \gamma^{\cdot} \,/\, Z \longrightarrow l\,\bar{l} + X$$

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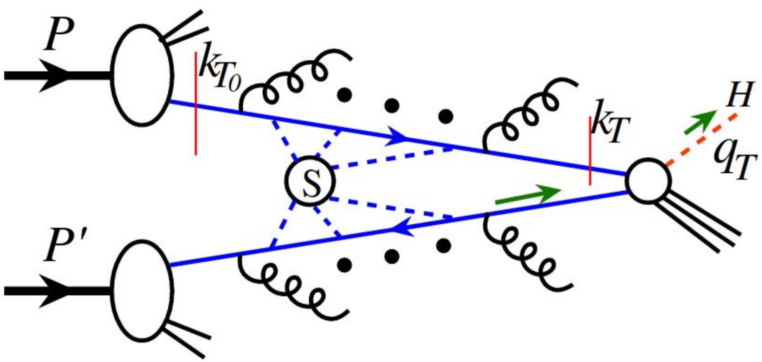
- TMDs & partonic cross section:
same **IR poles** = same non-perturbative physics

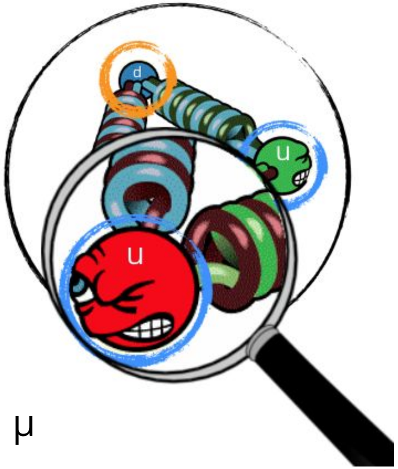
- **observed transverse momentum** :
handle on transverse momenta of **quarks**

- quark transverse momentum :
radiative (perturbative) and **intrinsic** (non-perturbative) components

- Renormalization = **evolution** equations tell us how to distinguish between the two



QCD evolution of a TMD PDF



$$F_a(x, b_T^2; \mu, \zeta) = F_a(x, b_T^2; \mu_0, \zeta_0)$$ → TMD distribution at initial scales

$$\times \quad \exp\left[\int_{\mu_0}^{\mu} \frac{d\mu'}{\mu'} \gamma_F\left(\alpha_s(\mu'), \frac{\zeta}{\mu'^2} \right) \right]$$ → evolution in μ

Calculable in pQCD

$$\times \quad \left(\frac{\zeta}{\zeta_0} \right)^{-D(b_T \mu_0, \alpha_s(\mu_0)) + g_K(b_T; \lambda)}$$ → evolution in ζ

Non-pert. corrections (large bT)

$$F_a(x, b_T^2; \mu_0, \zeta_0) = \sum_b C_{a/b}(x, b_T^2, \mu_0, \zeta_0) \otimes \underline{f_b(x, \mu_0)} F_{NP}(b_T; \lambda)$$

Prior knowledge assumed (?)

See J.C. Collins' book and many other references, e.g. https://inspirehep.net/literature/1393670

Non-perturbative TMD parts

$$F_a(x, b_T^2; \mu, \zeta) = F_a(x, b_T^2; \mu_0, \zeta_0)$$

$$\exp\left[\int_{\mu_0}^{\mu} \frac{d\mu'}{\mu'} \gamma_F\left(\alpha_s(\mu'), \frac{\zeta}{\mu'^2}\right)\right]$$

$$\left(\frac{\zeta}{\zeta_0}\right)^{-D(b_T\mu_0, \alpha_s(\mu_0)) \boxed{+ g_K(b_T; \lambda)}}$$

Non-pert. corrections (large bT)

$$F_a(x, b_T^2; \mu_0, \zeta_0) = \sum_b C_{a/b}(x, b_T^2, \mu_0, \zeta_0) \otimes f_b(x, \mu_0) \boxed{F_{NP}(b_T; \lambda)}$$

Intrinsic transverse momentum, potentially flavor dependent

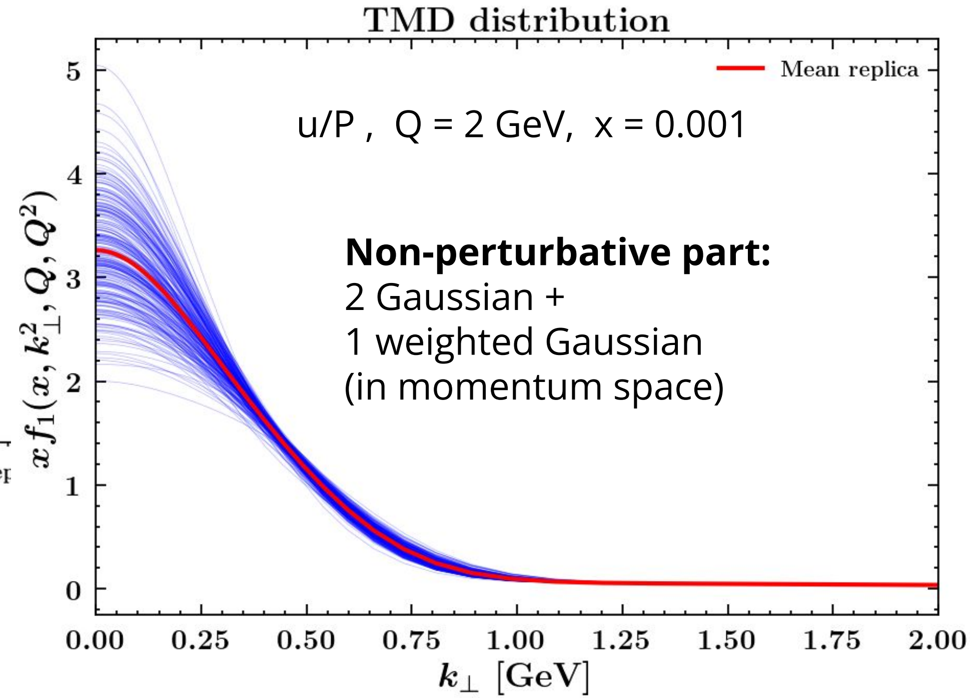
See M. Zurita’s talk later today

Unpolarized TMDs: a selection of past fits

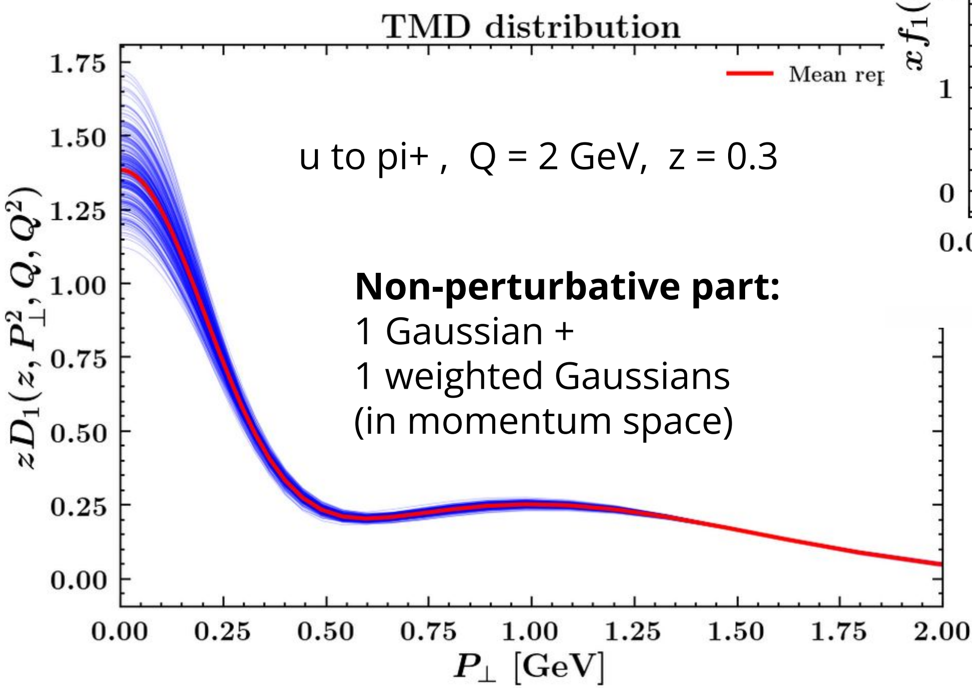
		Framework	HERMES	COMPASS	DY	Z production	N of points	χ^2/N_{points}
global	Pavia 2017 arXiv:1703.10157	NLL	✔	✔	✔	✔	8059	1.55
	SV 2017 arXiv:1706.01473	NNLL'	✘	✘	✔	✔	309	1.23
	BSV 2019 arXiv:1902.08474	NNLL'	✘	✘	✔	✔	457	1.17
global	SV 2019 arXiv:1912.06532	N3LL	✔	✔	✔	✔	1039	1.06
	Pavia 2019 arXiv:1912.07550	N3LL	✘	✘	✔	✔	353	1.02

A new global fit: MAPTMD22

(in preparation)



TMD PDF of the u at $Q = 2$ GeV and $x = 0.001$

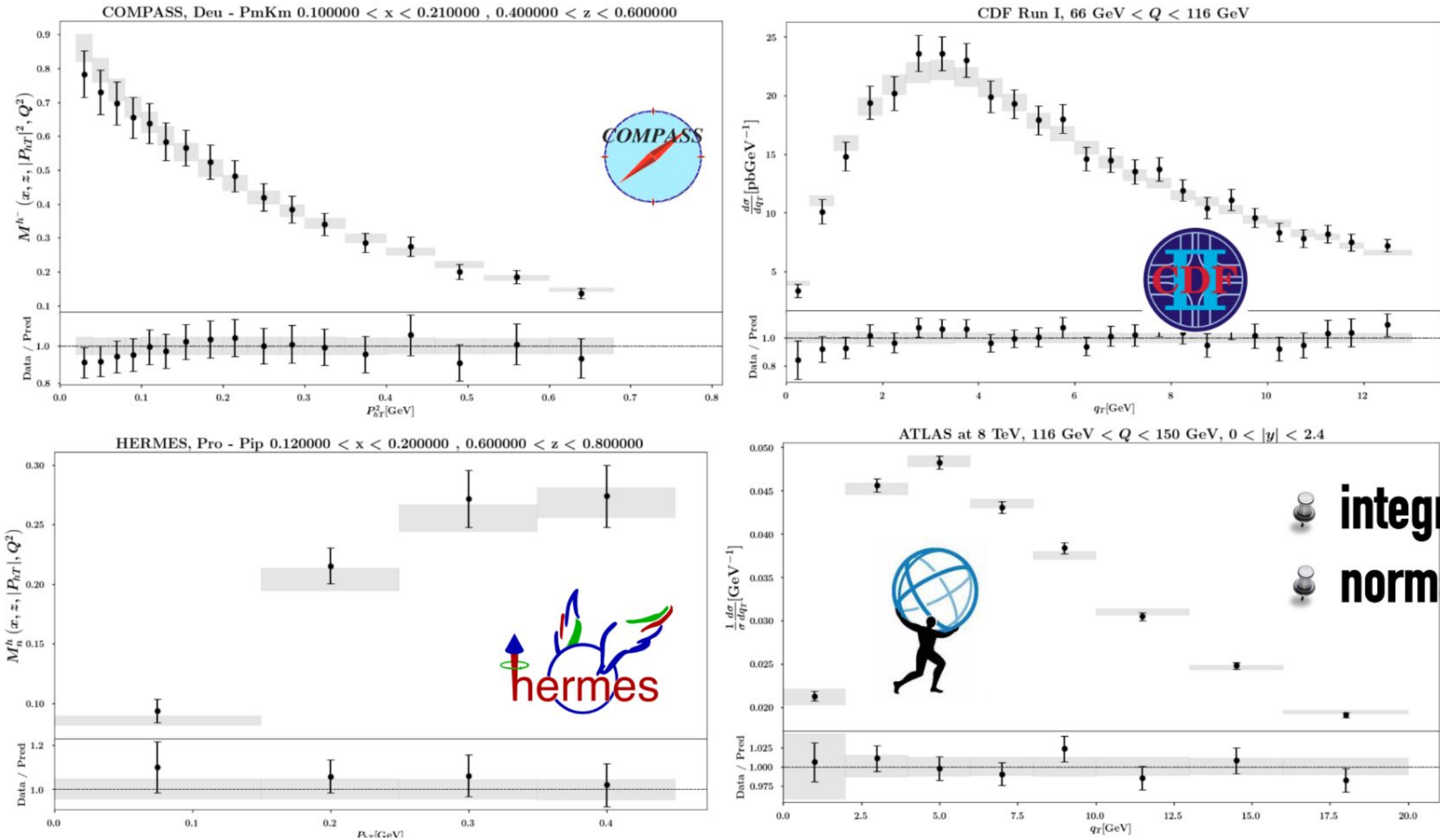


TMD FF of $u \to \pi^+$ at $Q = 2$ GeV and $z = 0.3$

- DY/Z and Semi-Inclusive DIS (“global”)
- N3LL accuracy
- chi2/dof ~ 1

No TMD flavor dependence yet..!

(computationally much more demanding)



$\chi^2 \sim 1$

- integration over bins
- normalization for SIDIS

For more details see V. Bertone's talk later today and/or:

- M. Cerutti (DIS 2022) : https://indico.cern.ch/event/1072533/contributions/4761767/
- C. Bissolotti (QCD evolution 2022) : https://conference.phys.virginia.edu/indico/event/7/session/1/contribution/63

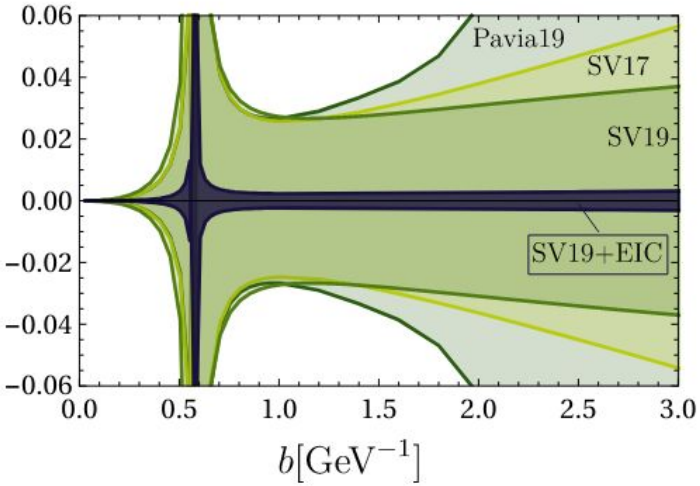
EIC impact studies: TMD evolution (SV19)

$$\left(\frac{\zeta}{\zeta_0}\right)^{-D(b_T\mu_0,\alpha_s(\mu_0))\boxed{+g_K(b_T;\lambda)}}$$

→ evolution in ζ

Non-pert. corrections (large bT)

EIC YR: https://inspirehep.net/literature/1851258

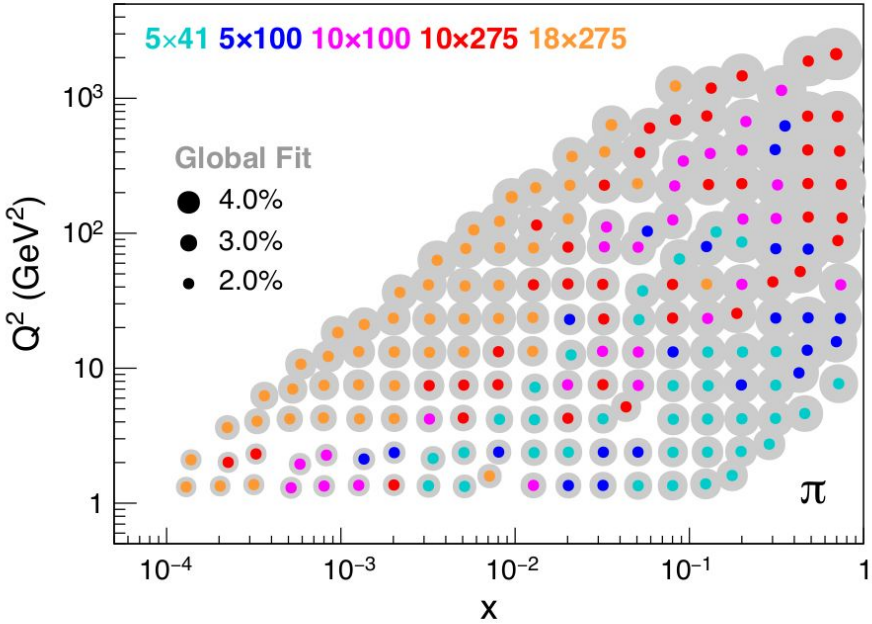


Huge impact of EIC SIDIS program on **non-perturbative TMD evolution**

SV19 extraction: https://inspirehep.net/literature/1770788

EIC impact studies: SIDIS cross section (PV17)

Projected uncertainties for **unpolarized SIDIS cross section**



Grey: uncertainty from PV17 extraction of TMD PDFs (mainly from TMD evolution)

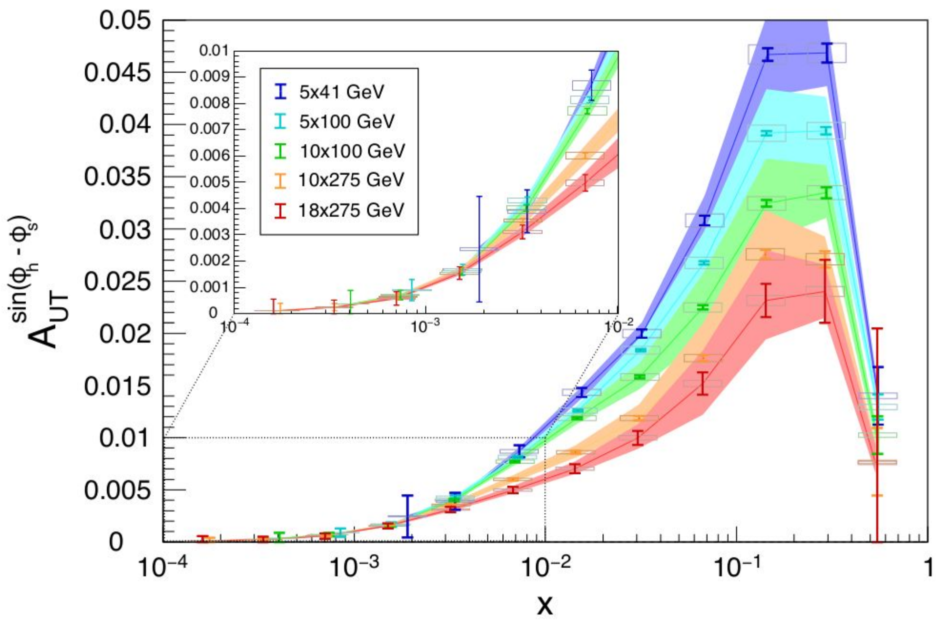
Colors: projected experimental uncertainty on ATHENA pseudo-data

PV17 extraction: https://inspirehep.net/literature/1520011

(from ATHENA detector proposal)

EIC impact studies: Sivers asymmetry (PV20)

Projected uncertainties for **Sivers asymmetry in SIDIS**



Bands: uncertainty from PV20 extraction of Sivers TMD PDF

Points: projected experimental uncertainty on ATHENA pseudo-data

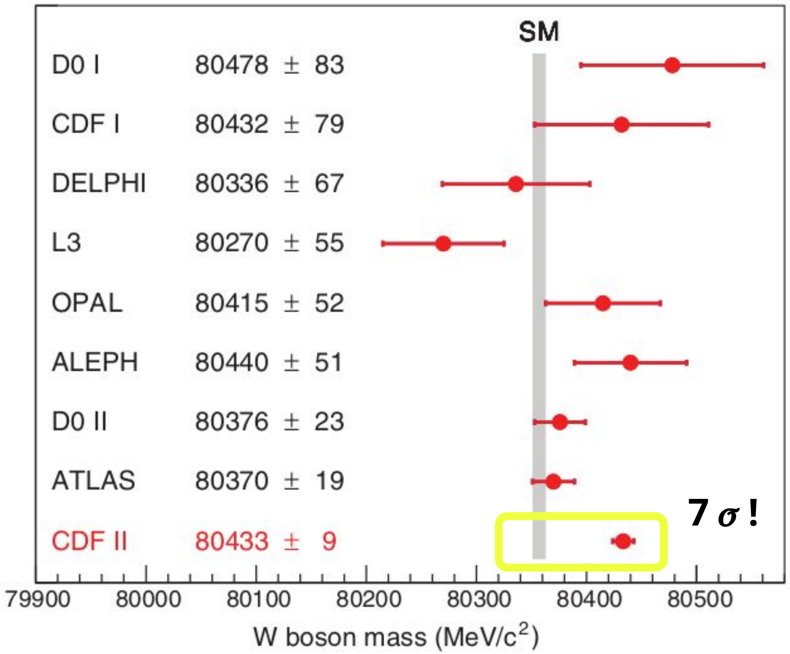
PV20 extraction: https://inspirehep.net/literature/1793441

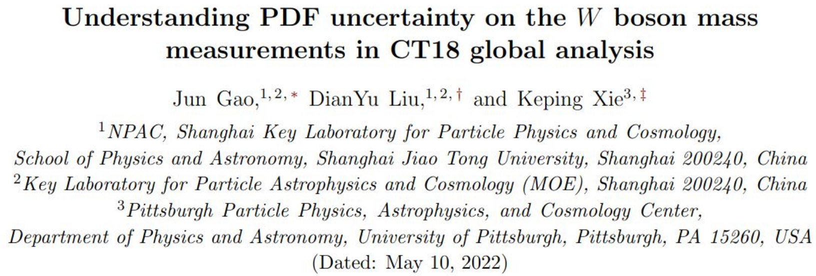
(from ATHENA detector proposal)

CDF-II measurement : role of 1D hadron structure

1. Role of **collinear PDFs**: https://inspirehep.net/literature/2078769

"… find that spread of predictions from different PDF sets can be much larger than the PDF uncertainty predicted by a specific PDF set."





Understanding PDF uncertainty on the W boson mass measurements in CT18 global analysis

Jun Gao,[1,2,*] DianYu Liu,[1,2,†] and Keping Xie[3,‡]
[1] *NPAC, Shanghai Key Laboratory for Particle Physics and Cosmology, School of Physics and Astronomy, Shanghai Jiao Tong University, Shanghai 200240, China*
[2] *Key Laboratory for Particle Astrophysics and Cosmology (MOE), Shanghai 200240, China*
[3] *Pittsburgh Particle Physics, Astrophysics, and Cosmology Center, Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, PA 15260, USA*
(Dated: May 10, 2022)

See E. Nocera's talk on Thursday on collinear hadron structure

See also A. Vicini's talk on Thursday on Mw determination

CDF-II measurement : role of <u>3D</u> hadron structure

2. Role of **resummation** accuracy: https://inspirehep.net/literature/2077581

ResBos2 and the CDF W Mass Measurement

Joshua Isaacson,[1,*] Yao Fu,[2] and C.-P. Yuan[3]
[1] *Theoretical Physics Department, Fermi National Accelerator Laboratory, P.O. Box 500, Batavia, IL 60510, USA*
[2] *Department of Modern Physics, University of Science and Technology of China, Jinzhai Road 96, Hefei, Anhui, 230026, China*
[3] *Department of Physics and Astronomy, Michigan State University, 567 Wilson Road, East Lansing, MI 48824, USA*

"... using higher order corrections would result in a <u>decrease</u> in the value reported by CDF by <u>at most 10 MeV</u>."

3. Use a tool with **state of the art treatment of TMDs** (perturbative and non-perturbative)

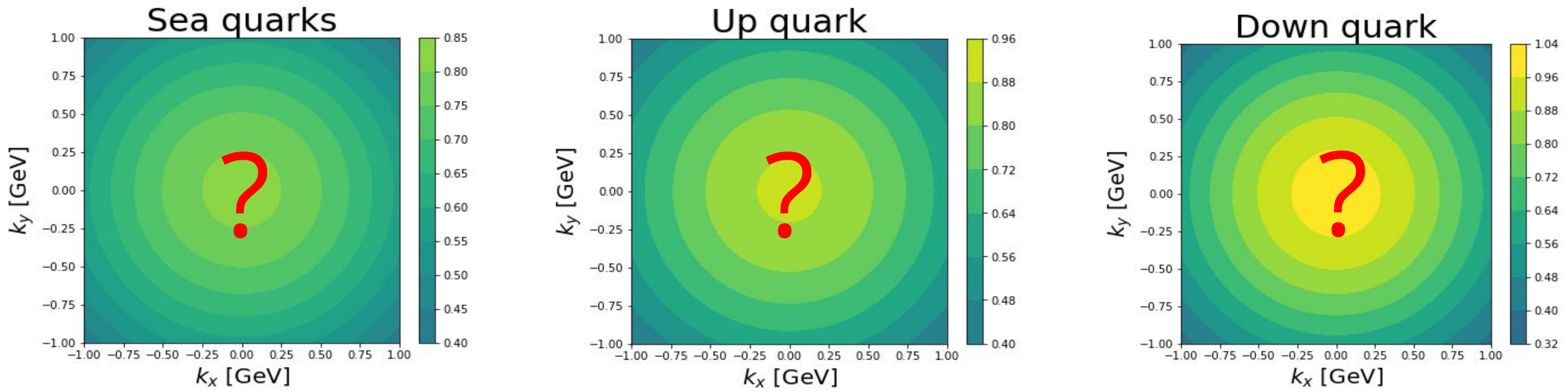
4. Study the **role of TMD flavor effects**

CDF-II measurement : role of <u>3D</u> hadron structure

4. **role of TMD flavor** effects: for ATLAS 7 TeV kinematics up to <u>9 MeV of shift</u>

https://inspirehep.net/literature/1681006

- Different kinematics with respect to LHC = **different relevance of non-perturbative corrections**
- **Proton-antiproton** : two valence quarks involved in W production



Take home message for our QCD community

*“ […] The **model-dependent nature** of the analysis*

implies that future improvements or corrections

*in any relevant **theoretical modeling***

*can be used to **update** our measurement **quantifiably**”*

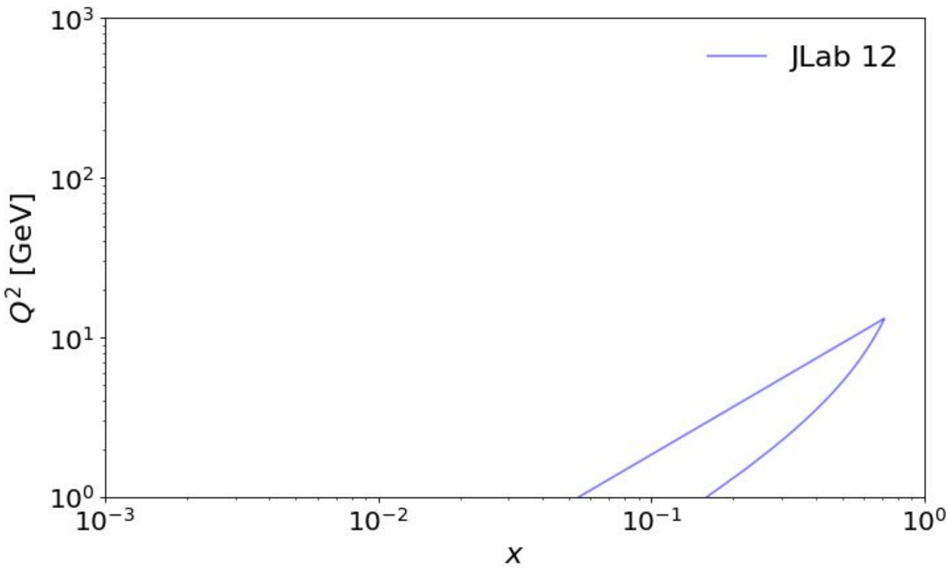
High precision measurements of the W boson mass with the CDF II detector:
https://www.science.org/doi/10.1126/science.abk1781

Backup

Kinematics

"inelasticity": $y = \frac{P \cdot q}{P \cdot l} = \frac{E_\gamma}{E_\ell}$ $\qquad y_{\min} < y < y_{\max}$

Invariant mass hadronic final states: $W^2 = (P+q)^2 = M^2 + y\,s\,(1-x)$ $\qquad W^2 > W^2_{cut}$



PROs

- Rich territory for non-perturbative effects

- sensitivity to higher twist

- valence region (focus for flavor, spin, etc.)

CONs

- Low Q: applicability of collinear and TMD formalism ?

- Low Q: separation of fragmentation regions?

Kinematics

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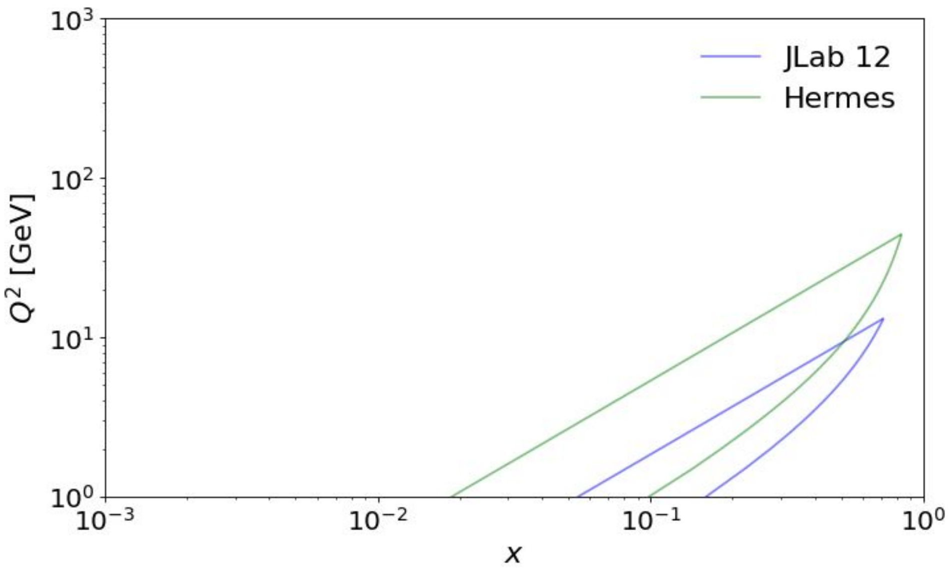

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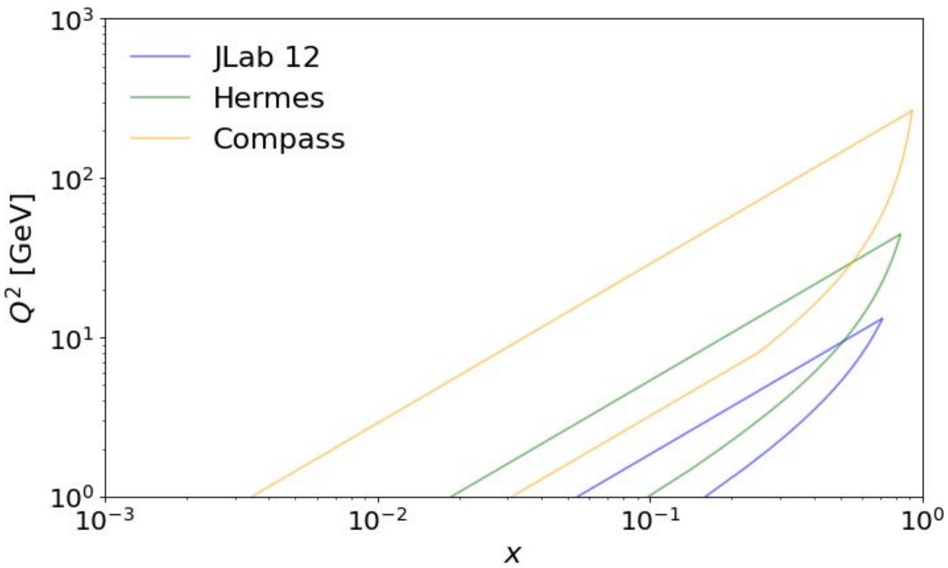

With the ***limited gain in Q*** from JLab 11 to Hermes and Compass we still experience the same “**problems**” related to the ***presence of power corrections to the TMD formalism***

Kinematics

"inelasticity": $$y = \frac{P \cdot q}{P \cdot l} = \frac{E_\gamma}{E_\ell}$$ $$y_{\min} < y < y_{\max}$$

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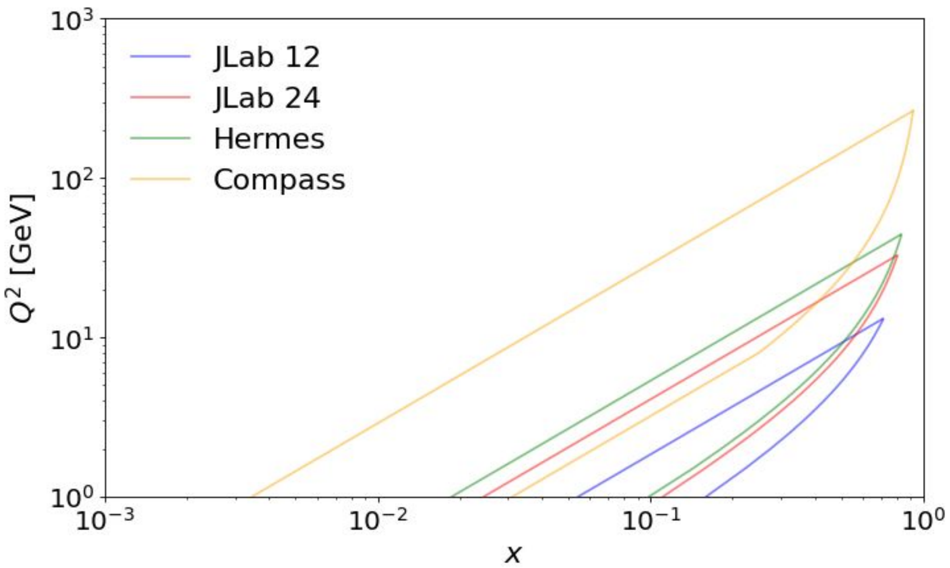


The motivations for adding "**JLab 24**" should rely on the power of this data to *"**enrich**" the picture, but not to "**clean**" it* from the point of view of the formalism

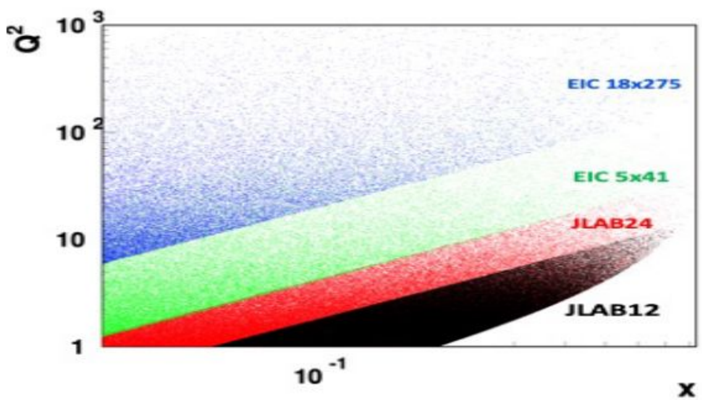
Fundamental insights into:
- non-pert. large x region
- polarization
- flavor separation
- collinear distributions (?)
- ...

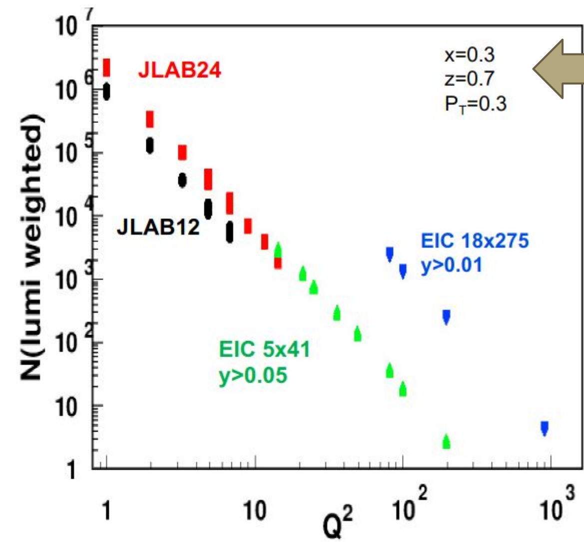
But same "complications" as the other fixed-target experiments

Kinematics and statistics

see Harut's talk at CPHI 2022 (and next presentation)

A crucial role is played by the available statistics *within* the kinematic coverage



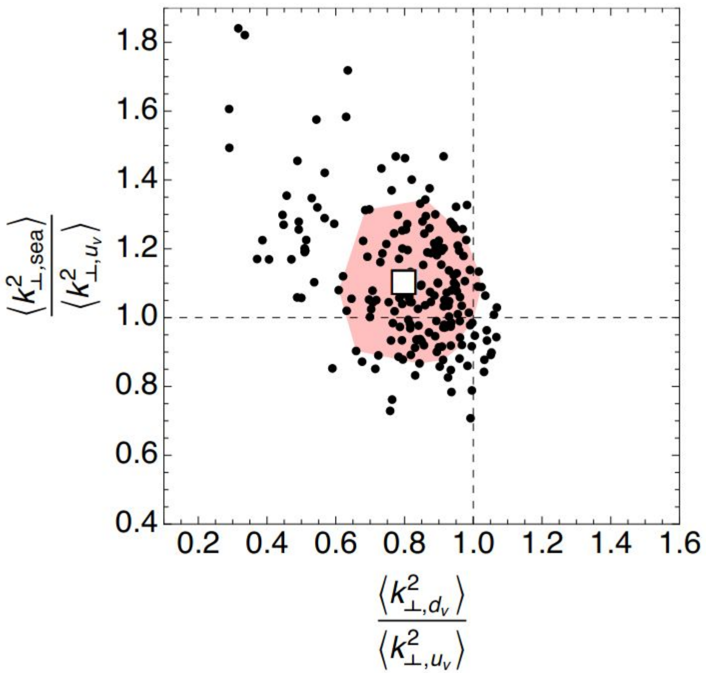


large x

NEED IMPACT STUDIES!

To get *more precise* information on TMDs ***should we aim at more statistics (JLab 24) or higher Q2 (EIC) ?***

Flavor dependent TMD PDFs



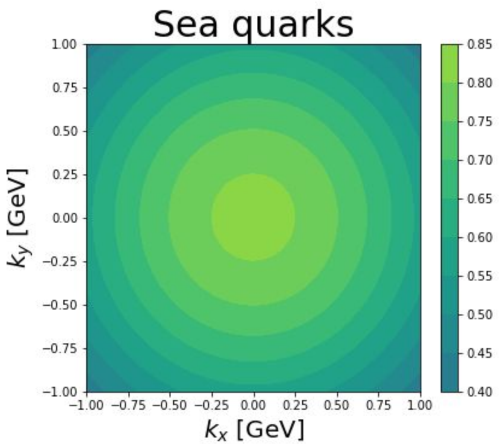
"**PV13**" analysis

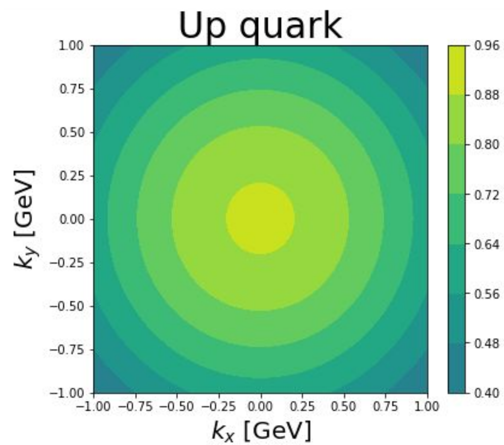
Parton model fits of HERMES data

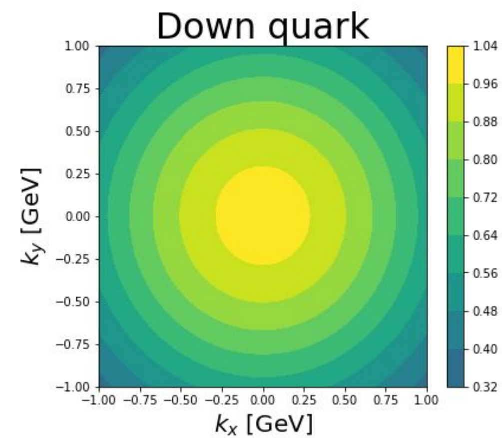
$$\langle k^2_{\perp,\mathrm{sea}}\rangle$$
$$\vee$$
$$\langle k^2_{\perp,\mathrm{u}_v}\rangle$$
$$\vee$$
$$\langle k^2_{\perp,\mathrm{d}_v}\rangle$$

https://inspirehep.net/literature/1254070

Flavor dependent TMD PDFs







This can be **relevant** when **comparing** processes with

different “flavor content”, e.g. **Z and W boson production**

Different frameworks, same observable

$$
\left(\frac{d\sigma}{dq_T}\right)_{\text{res.}}
\begin{array}{ll}
\overset{q_T-\text{res.}}{\underset{\text{PB}}{\propto}} & e^{2S}\left[f_1 \otimes \mathcal{H} \otimes f_2\right] \\[2ex]
\overset{\text{TMD}}{\propto} & H \times F_1 \times F_2 \\[2ex]
\overset{\text{SCET}}{\propto} & H \times B_1 \times B_2 \times S
\end{array}
+ \mathcal{O}\left[\left(\frac{q_T}{Q}\right)^m\right]
$$

$$\mathcal{H} = HC_1C_2$$

$$F_i = e^S C_i \otimes f_i$$

$$F_i = \sqrt{S} \times B_i$$

Dictionary to compare different factorization frameworks

“equivalent” to the extent of describing TMD physics

G. Bozzi at SarWors 2021 - https://agenda.infn.it/event/27742/

Codes

SCETlib
[https://confluence.desy.de/display/scetlib]

CuTe
[https://cute.hepforge.org/]

SCET

DYRes/DYTurbo, DYqT, etc.
[https://gitlab.cern.ch/DYdevel/DYTURBO]

ReSolve
[https://github.com/fkhorad/reSolve]

ResBos
[https://resbos.hepforge.org/]

qT resummation

TMD factorization

arTeMiDe
[https://teorica.fis.ucm.es/artemide/]

Nanga Parbat (MAPTMD22 analysis)
[https://github.com/MapCollaboration/NangaParbat]

Parton branching

RadISH
[https://arxiv.org/pdf/1705.09127.pdf]

PB-TMDs
[https://arxiv.org/pdf/1906.00919.pdf]

G. Bozzi at SarWors 2021 - https://agenda.infn.it/event/27742/

Codes

Excellent accuracy **BUT** *only unpolarized and leading twist*!

Basic ingredients **common** to all codes

LHC EWWG "Benchmark"

i.e., compare

- accuracy (easy)
- differences (hard)
- uncertainties (harder)

Main **differences**:

- "Space": position vs momentum space
- Perturbative QCD: PDF evolution, scale variation, matching with fixed-order
- Non-perturbative QCD: treatment of Landau pole, intrinsic-kT

G. Bozzi at SarWors 2021 - https://agenda.infn.it/event/27742/

Event generators

Based on TMDs:

- Cascade (PB TMDs)
  [https://cascade.hepforge.org/]

- gmctrans/TMDgen
  - parton model level TMDs
  - includes polarization and higher twist, but no evolution: too primitive for EIC?
  - semi-inclusive
  [https://wiki.bnl.gov/eic/index.php/Gmc_trans
  Hermes collaboration + independent work]

Exclusive generators with transverse momentum effects

- Pythia [https://pythia.org/]
- Herwig [https://herwig.hepforge.org/]
- Geneva [https://stash.desy.de/projects/GENEVA]
- ...

TMDs & W boson mass determination

References:

1. Bacchetta, Bozzi, Radici, Ritzmann, Signori - https://inspirehep.net/literature/1681006
2. Bozzi, Signori - https://inspirehep.net/literature/1712178

... and more work in progress (also related to the recent CDF measurement)

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www.elsevier.com/locate/physletb

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

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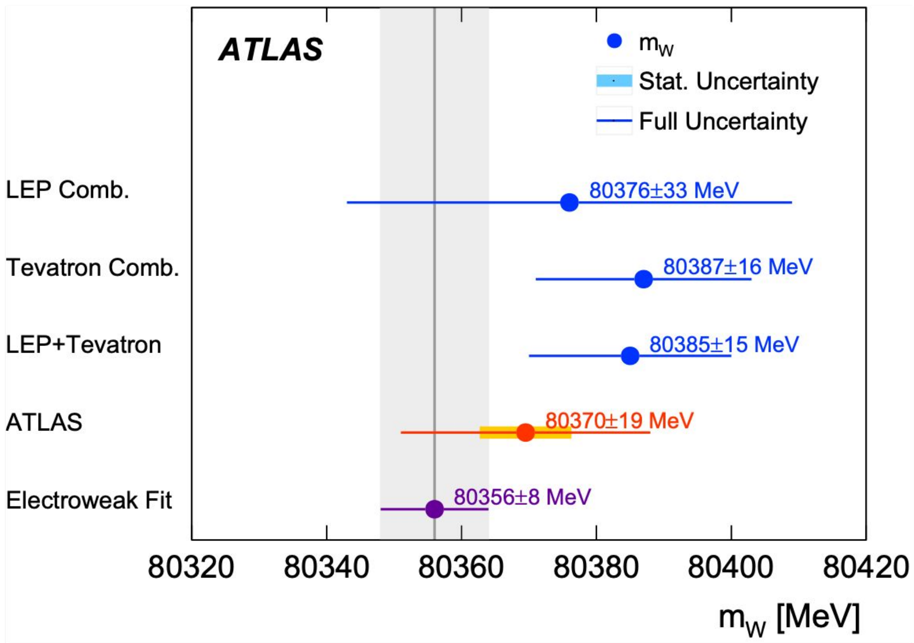
ATLAS determination

https://inspirehep.net/literature/1510564



Possibly underestimated ?

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

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

Breakdown of uncertainties

https://inspirehep.net/literature/1510564

ATLAS EXPERIMENT

Possibly underestimated ?

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

This contribution is determined fitting:
- the intrinsic transverse momentum of partons
- $\alpha_S(m_Z)$
- IR cutoff for ISR

Pythia tune to Z boson data
7 TeV

assuming no differences in flavor

Our findings

ATLAS 7 TeV

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

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

Statistical uncertainty: ±2.5 MeV

The fact that **quark intrinsic transverse momentum** can be **flavor dependent** leads to an **additional uncertainty** on mW, not considered so far

- the four-loop QCD corrections generates a shift of -2.2 MeV
- The expectation from missing higher orders is 4 MeV

Eur.Phys.J. C74 (2014) 3046 ("Global EW fit at NNLO")

We believe the theory systematics are underestimated

W qT spectrum

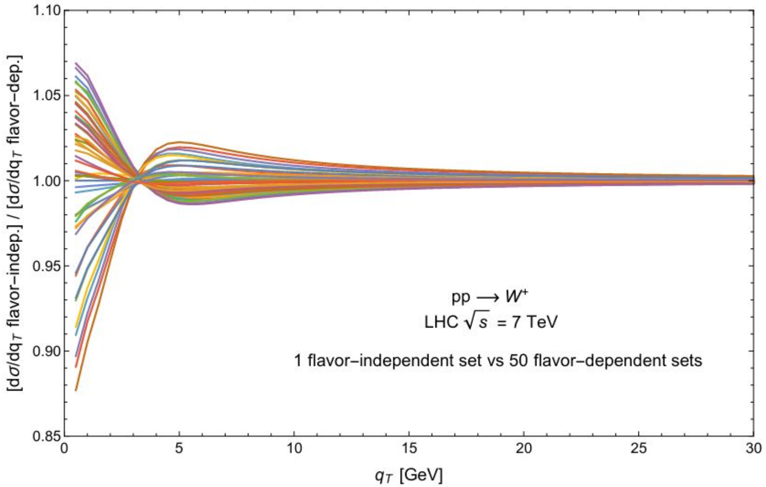
The flavor structure of the TMDs
can **affect the shape** of the **W qT spectrum**
up to 5%-10% at very low qT

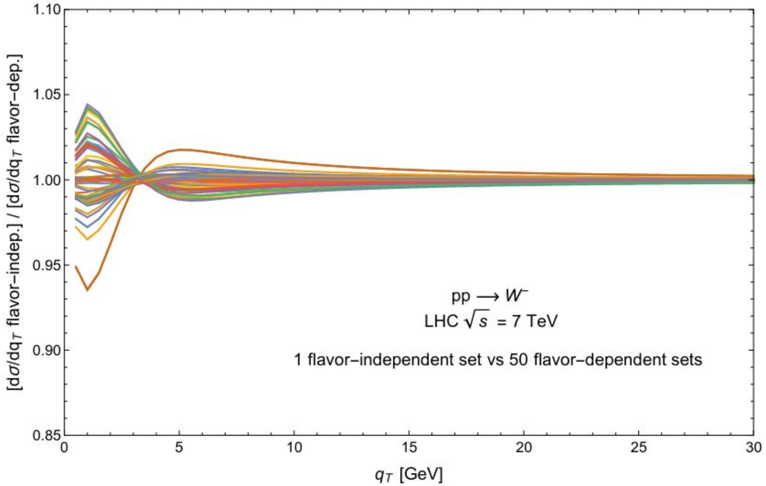
↓

Impact on lepton pT and mT

↓

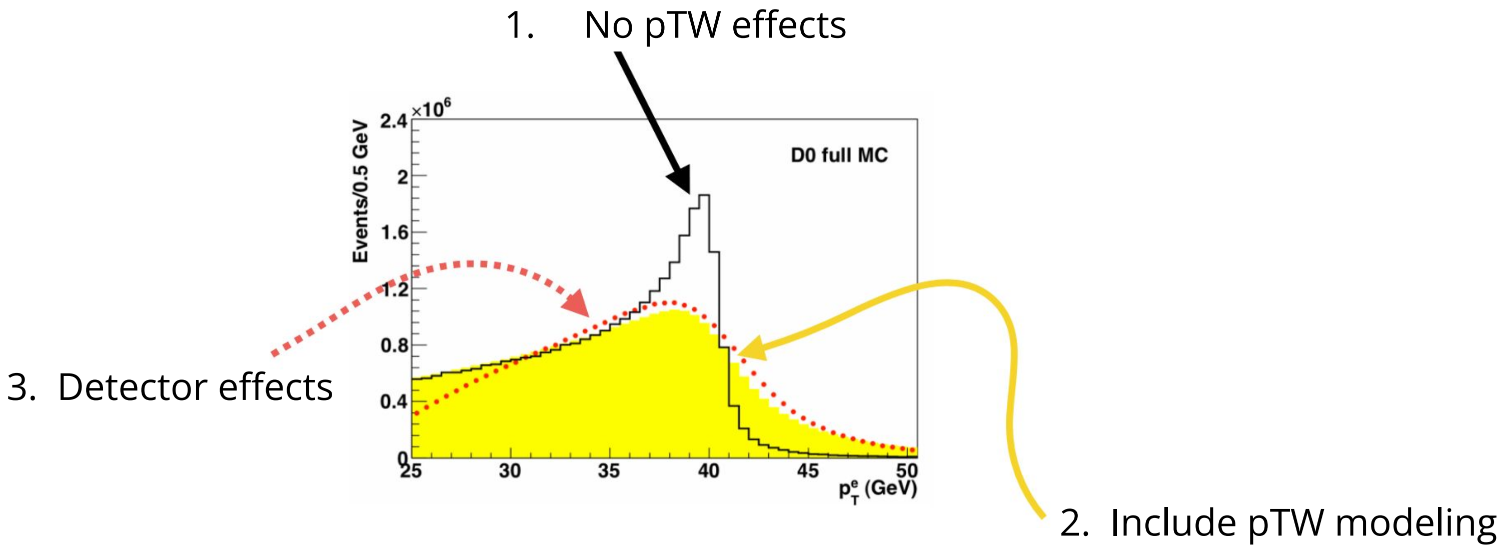
Impact on mW





https://inspirehep.net/literature/1712178

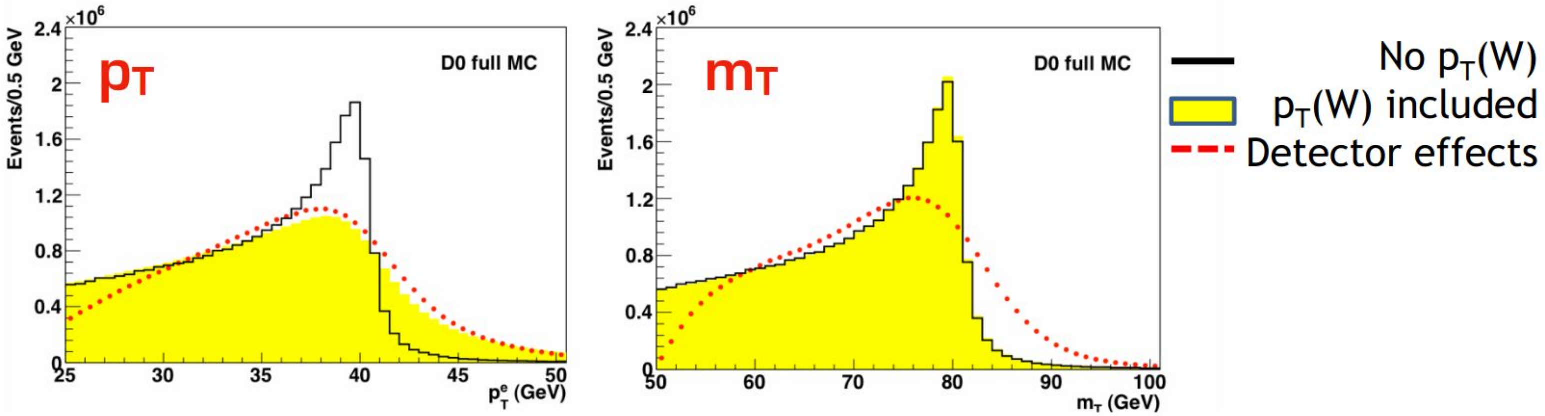
Lepton pT distribution



pTW modeling = treatment of **TMD PDFs**, including perturbative and non-perturbative parts

$$\frac{d\sigma}{dq_T} \sim \underline{\mathcal{H}\ f_1(x_a, k_{Ta}, Q)\ f_1(x_b, k_{Tb}, Q)\ \delta^{(2)}(q_T - k_{Ta} - k_{Tb})} + \mathcal{O}(q_T/Q) + \mathcal{O}(m/Q)$$

Lepton pT vs transverse mass



Transverse mass: important detector effects, weakly sensitive to pTW modeling

Lepton pT : **very sensitive to pTW modeling**, moderate detector effects

Template fit strategy

Additional uncertainties from the flavor structure of the pTW modeling can be **larger than** the ones quoted in the analysis (LHC kinematics)

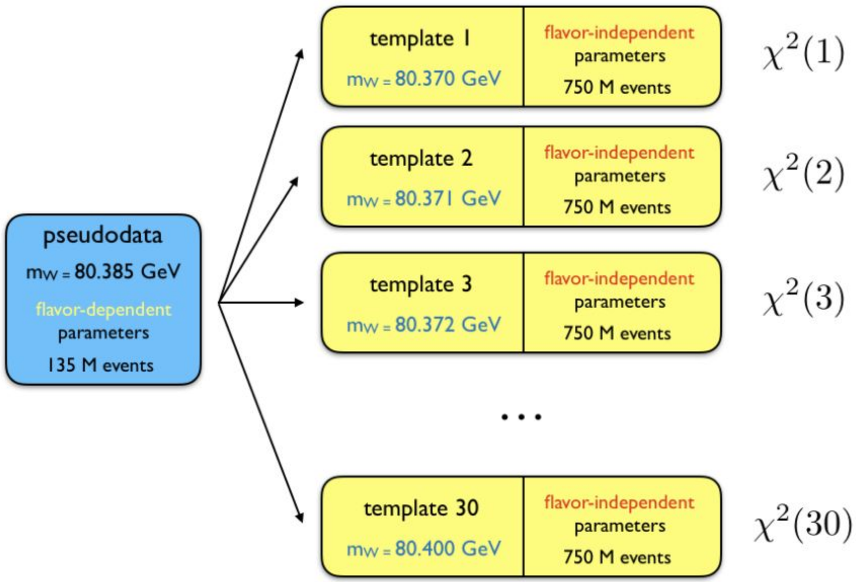


Table 2
Shifts in $M_{W^\pm}$ (in MeV) induced by the corresponding sets of flavor-dependent intrinsic transverse momenta outlined in Table 1 (Statistical uncertainty: 2.5 MeV).

Set	ΔM_{W^+}		ΔM_{W^-}	
	m_T	$p_{T\ell}$	m_T	$p_{T\ell}$
1	0	−1	−2	3
2	0	−6	−2	0
3	−1	9	−2	−4
4	0	0	−2	−4
5	0	4	−1	−3

Flavor dependence from PV13 analysis