ResBos2 and
the CDF W Mass measurement

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In collaboration with Josh Isaacson and Yao Fu

CTEQ – Tung et al. (TEA)
in memory of Prof. Wu-Ki Tung

Outline

- What's ResBos for?
- ResBos2 is the Version 2 of ResBos
- Higher order effects to the measurement of W mass at CDF II

ResBos
(Resummation for Bosons)

Initial state QCD soft gluon resummation
and
Final state QED corrections

In collaboration with

Csaba Balazs, Alexander Belyaev, Ed Berger,
Qing-Hong Cao, Chuan-Ren Chen, Josh Isaacson,
Zhao Li, Steve Mrenna, Pavel Nadolsky, Jian-Wei Qiu,
Carl Schmidt, Peng Sun, Bin Yan and Feng Yuan

hep-ph/9704258
hep-ph/0401026
hep-ph/1205.4311
arXiv:2205.02788
etc.

What's ResBos for?

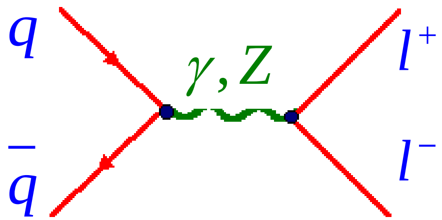
Precision Electroweak Physics at Hadron Colliders

Physics of Drell-Yan, *W*, *Z* and Higgs Bosons

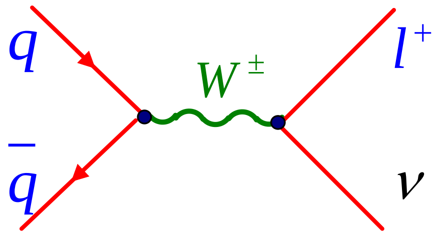
What's it for? An Example

- Transverse momentum of

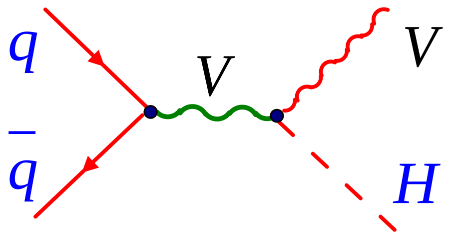
Drell-Yan



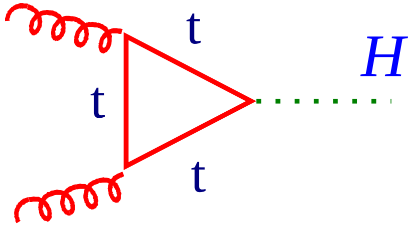
$W^\pm$



V H



$g\,g \to H$



including initial state QCD Resummation
(and final state QED radiation)

- Kinematics of Leptons from the decays
(Spin correlation included)

W-boson physics

❶ W-boson production and decay at hadron collider

❷ How to measure W-boson mass and width?

❸ High order radiative corrections:

☞ QCD (NLO, NNLO, Resummation)

☞ EW (QED-like, NLO)

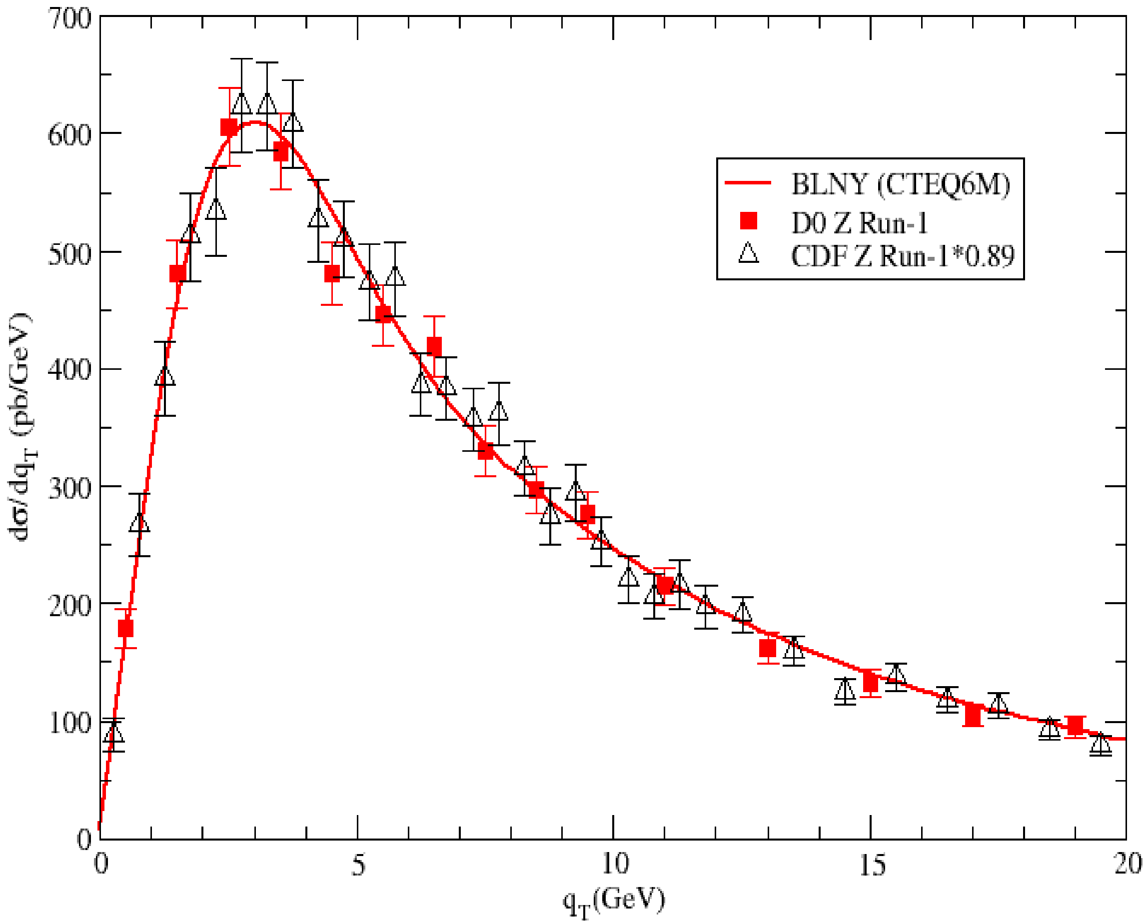
❹ ResBos and ResBos-A

Resummation calculations agree well with data

$P\bar{P} \rightarrow Z$ @ Tevatron

Predicted by ResBos:

A program that
includes the effect of
multiple soft gluon emission
on the production of
W and Z bosons
in hadron collisions.



Transverse momentum of the charged lepton

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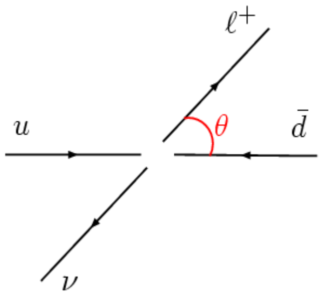
- In (ud) c.m. system,

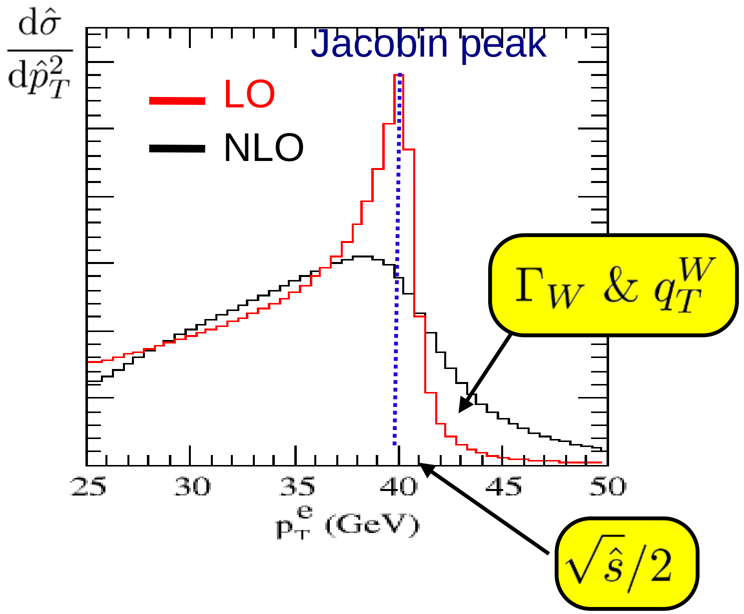


$$\hat{p}_T^2 = \frac{1}{4}\hat{s}\sin^2\theta$$

Jacobin factor

$$\frac{\mathrm{d}\cos\theta}{\mathrm{d}\hat{p}_T^2} = -\frac{2}{\hat{s}}\frac{1}{\sqrt{1-\frac{4\hat{p}_T^2}{\hat{s}}}}$$

$$\Longrightarrow \quad \frac{\mathrm{d}\hat{\sigma}}{\mathrm{d}\hat{p}_T^2} \sim \frac{\mathrm{d}\hat{\sigma}}{\mathrm{d}\cos\theta} \times \frac{1}{\sqrt{1-4\hat{p}_T^2/\hat{s}}}$$



sensitive region for measuring

M_W : $p_T^e \sim 30 - 45$ GeV

Γ_W : not a good observable

Transverse mass of the W-boson

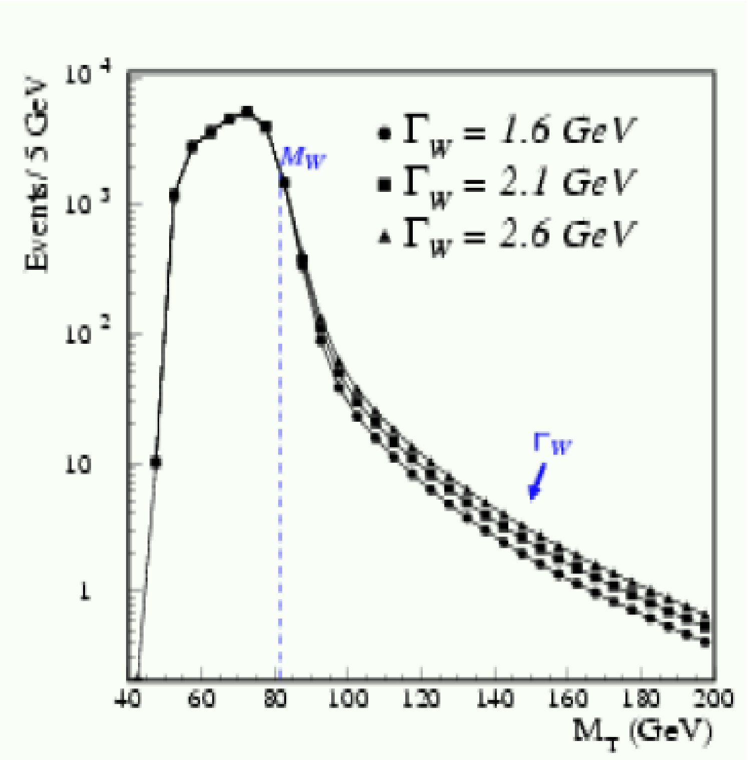
C T E Q

- Definition:

$$m_T^2(\ell,\nu) = 2\, p_T^\ell\, p_T^\nu (1-\cos\phi_{\ell\nu})$$

from overall p_T imbalance

$$\Longrightarrow \frac{d\hat{\sigma}}{dm_T^2} \sim \frac{1}{\sqrt{1-m_T^2/\hat{s}}}$$



- unaffected by longitudinal boosts of $\ell\nu$ system
- not sensitive to q_T^W
- tail knows about Γ_W (direct measurement)

sensitive region:

M_W : $M_T \sim 60 - 100$ GeV

Γ_W : $M_T > 100$ GeV

What's QCD Resummation?

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- Perturbative expansion

$$\frac{d\hat{\sigma}}{dq_T^2} \sim \alpha_S \left\{ 1 + \alpha_S + \alpha_S^2 + \cdots \right\}$$

- The singular pieces, as $\frac{1}{q_T^2}$ (1 or log's)

$$\frac{d\hat{\sigma}}{dq_T^2} \sim \frac{1}{q_T^2} \sum_{n=1}^{\infty} \sum_{m=0}^{2n-1} \alpha_S^{(n)} \ln^{(m)}\left(\frac{Q^2}{q_T^2}\right)$$

$$\sim \frac{1}{q_T^2} \left\{ \alpha_S \left(\underline{L+1}\right) + \alpha_S^2 \left(\underline{L^3 + L^2} + \underline{L+1}\right) + \alpha_S^3 \left(\underline{L^5 + L^4} + \underline{L^3 + L^2} + \underline{L+1}\right) + \cdots \right\}$$

$$L \equiv \ln\left(\frac{Q^2}{q_T^2}\right)$$

Resummation is to reorganize the results in terms of the large Log's.

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Resummed results:

$$\frac{d\sigma}{dq_T^2} \sim \frac{1}{q_T^2}\Big\{ [\alpha_S (L+1) \quad +\alpha_S^2 (L^3+L^2) + \alpha_S^3 (L^5+L^4) \quad +\cdots]$$

$$+[\qquad +\alpha_S^2 (L+1) \quad +\alpha_S^3 (L^3+L^2) \quad +\cdots]$$

$$+[\qquad\qquad +\alpha_S^3 (L+1) \quad +\cdots]$$

$$+\cdots \Big\}$$

Determined by $A^{(1)}$ and $B^{(1)}$

Determined by $A^{(2)}$ and $B^{(2)}$

Determined by $A^{(3)}$ and $B^{(3)}$

→ QCD Resummation

In the formalism by Collins-Soper-Sterman, in addition to these perturbative results, the effects from physics beyond the leading twist is also implemented as

[non-perturbative functions].

CSS Resummation Formalism

$$\frac{d\sigma}{dq_T^2\, dy\, dQ^2} = \frac{\pi}{S}\sigma_0 \delta\left(Q^2 - M_W^2\right) \cdot$$

$$\left\{ \frac{1}{(2\pi)^2} \int d^2 b \quad e^{i\vec{q}_T \cdot \vec{b}} \tilde{W}\left(b, Q, x_A, x_B\right) \cdot \text{[Non-perturbative functions]} \right.$$

$$\left. + Y\left(q_T, y, Q\right) \right\}$$

$$\sum_j \int_{x_A}^1 \frac{d\xi_A}{\xi_A} C_{qj}\left(\frac{x_A}{\xi_A}, b, \mu\right) \cdot f_{j/A}\left(\xi_A, \mu\right)$$

$$\tilde{W} = e^{-S(b)} \cdot C \otimes f\left(x_A\right) \cdot C \otimes f\left(x_B\right)$$

$$\sum_k \int_{x_B}^1 \frac{d\xi_B}{\xi_B} C_{qk}\left(\frac{x_A}{\xi_A}, b, \mu\right) \cdot f_{k/B}\left(\xi_B, \mu\right)$$

Sudakov form factor $S(b) = \int_{\left(\frac{b_0}{b}\right)^2}^{Q^2} \frac{d\bar{\mu}^2}{\bar{\mu}^2} \left[\ln\left(\frac{Q^2}{\bar{\mu}^2}\right) A(\bar{\mu}) + B(\bar{\mu}) \right]$

[Non-perturbative functions] are functions of (b, Q, x_A, x_B) which include QCD effects beyond Leading Twist.

[non-perturbative function] is a function of (b, Q, x_A, x_B), implemented to include effects beyond Leading Twist.

Until we know how to calculate QCD non-perturbatively, (Lattice Gauge Theory?), these functions can only be parameterized. However, the same functions should describe Drell-Yan, $W^{\pm}$, Z^0 data.

- Test QCD in problems involving multiple scales.
- Measuring these non-perturbative functions may help in understanding the non-perturbative part of QCD.

[non-perturbative functions] , dependent of Q, b, x_A, x_B, is necessary to describe q_T – distribution of Drell-Yan, $W^{\pm}$,Z^0 events.

$$\exp\left[-g_1 b^2 - g_2 b^2 \ln\left(\frac{Q}{2Q_0}\right) - g_1 g_3 b^2 \ln\left(100 x_A x_B\right)\right]$$

New term with x-dependence

BLNY parametrization

hep-ph/0212159

The coefficients g_1, g_2, g_3 need to be determined by existing data.

- Example: for $W^{\pm}$

$$\sigma_0 = \left(\frac{4\pi^2\alpha}{3} \sum_{jj'} Q_{jj'}^{(W)} \right), \qquad Q_{jj'}^{(W)} = \frac{1}{4\sin^2\theta_W} \left(kM \right)_{jj'}^2$$

The couplings of gauge bosons to fermions are expressed in the way to include the dominant electroweak radiative corrections. The propagators of gauge bosons also contain energy-dependent width, as done in LEP precision data analysis.

Note:

$$A \equiv \sum_{n=1}^{\infty} \left(\frac{\alpha_S}{\pi} \right)^n \cdot A^{(n)}, \qquad B \equiv \sum_{n=1}^{\infty} \left(\frac{\alpha_S}{\pi} \right)^n \cdot B^{(n)},$$

$$C \equiv \sum_{n=0}^{\infty} \left(\frac{\alpha_S}{\pi} \right)^n \cdot C^{(n)}$$

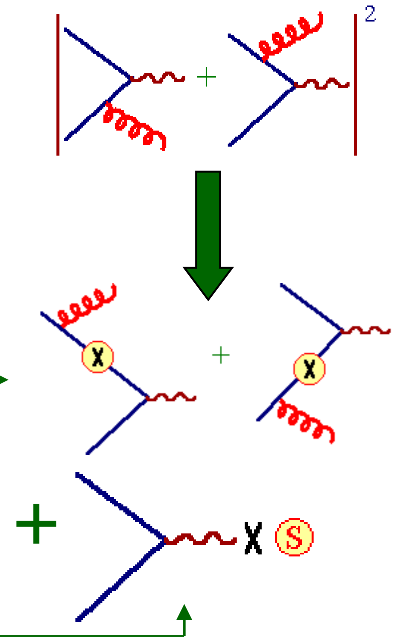
As $q_T \to 0$

$$\frac{d\sigma}{dq_T^2\, dy\, dQ^2}\Bigg|_{q_T\to 0} = \left(\frac{\pi}{s}\sigma_0\right)\cdot\delta\left(Q^2 - M_W^2\right)\cdot\left(\frac{1}{2\pi q_T^2}\right)\left(\frac{\alpha_s(Q)}{\pi}\right)$$

$$\cdot\Big\{ f_{q/A}(x_A,Q)\left[P_{\bar{q}\leftarrow\bar{q}}\otimes f_{\bar{q}}\right]_{x_B,Q} + \left[P_{q\leftarrow q}\otimes f_q\right]_{x_A,Q} f_{\bar{q}/B}(x_B,Q)$$

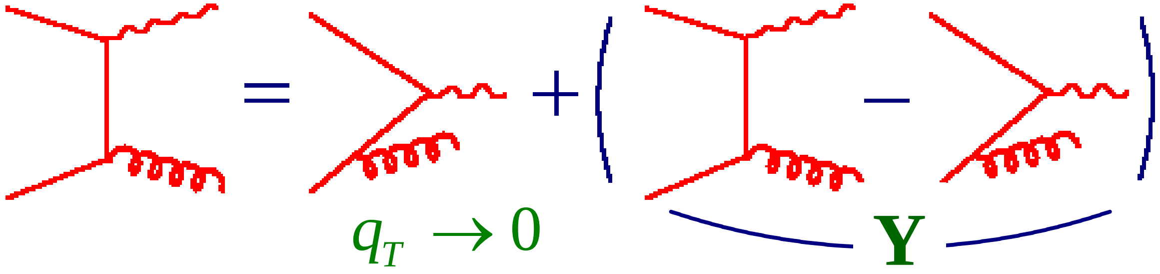
$$+ f_{q/A}(x_A,Q) f_{\bar{q}/B}(x_B,Q)\cdot\left[2\left(\frac{4}{3}\right)\ln\left(\frac{Q^2}{q_T^2}\right) + 2(-2)\right]\Big\}$$

Diagramatically,

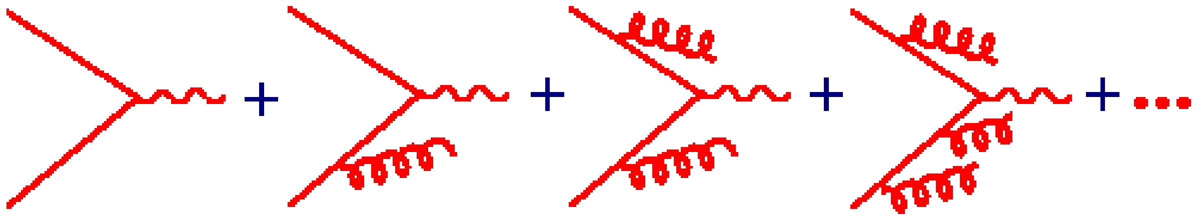


Exponentiate

To preserve transverse momentum conservation, we have to go to the impact parameter space (b-space) to perform resummation.



Diagramatically, Resummation is doing



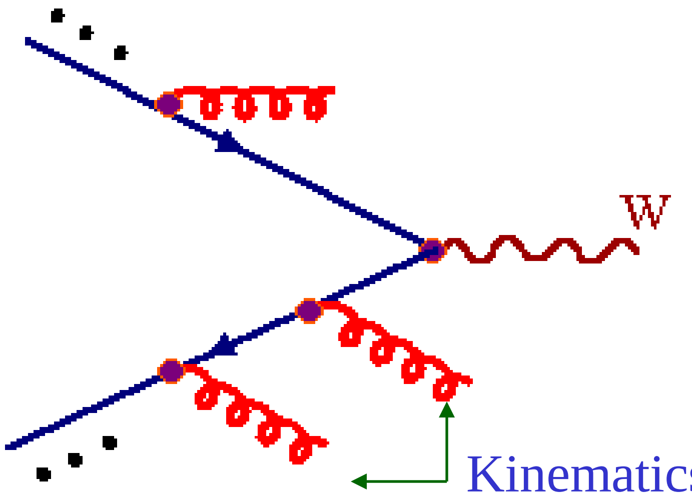
→ Resum large $\alpha_S^n \ln^m\left(\frac{Q^2}{q_T^2}\right)$ terms

$$\left.\frac{d\sigma}{dq_T^2\,dy}\right|_{q_T \to 0} \sim \frac{1}{q_T^2}\sum_{n=1}^{\infty}\sum_{m=0}^{2n-1}\alpha_S^n \ln^m\left(\frac{Q^2}{q_T^2}\right)\cdot C_m^n$$

Monte-Carlo programs ISAJET, PYTHIA, HERWIG contain these physics.

(Note: Arbitrary cut-off scale in these programs to affect the amount of Backward radiation , i.e. Initial state radiation.)

Monte-Carlo Approach



Backward Radiation
(Initial State Radiation)

Kinematics of the radiated gluon, controlled by Sudakov form factor with some arbitrary cut-off. (In contrast to perform integration in impact parameter space, i.e., b space.)

The shape of q_T (w) is generated. But, the integrated rate remains the same as at Born level (finite virtual correction is not included).

* Recently, there are efforts to include part of higher order effect in the event generator.

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Event Generators (PYTHIA, HERWIG)

Note that the integrated rate is the same as the Born level rate ($\alpha_S^{(0)}$) even though the q_T – distribution is different (i.e., not $\delta\left(q_T^2\right)$ any more).

$$\sigma = \int \mathrm{d}q_T^2 \frac{\mathrm{d}\sigma}{\mathrm{d}q_T^2} \sim \int \mathrm{d}^2 b \underbrace{\int e^{i\vec{q}_T\cdot\vec{b}}\,\mathrm{d}^2 q_T}_{\delta^2(b)}\, \sigma_0 e^{-S(b)}$$

$$= \int \mathrm{d}^2 b\, \delta^2(b)\cdot\sigma_0\cdot e^{-S(b)} \quad \rightarrow \quad 1 \text{ at } b=0$$

$$= \sigma_0$$

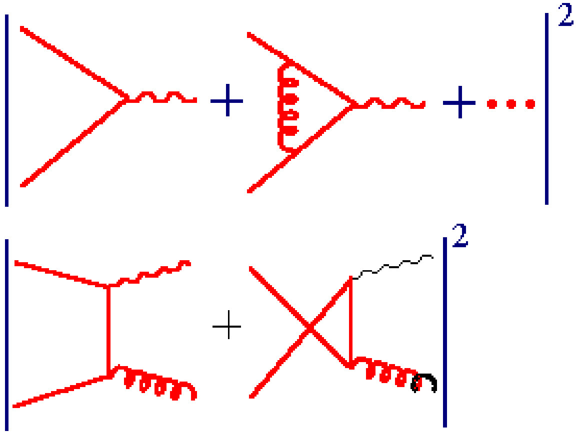
For C-Function = $\delta\left(1-\frac{x_A}{\xi_B}\right)$

C T E Q

To recover the "K-factor" in the NLO total rate

To include the C-Functions

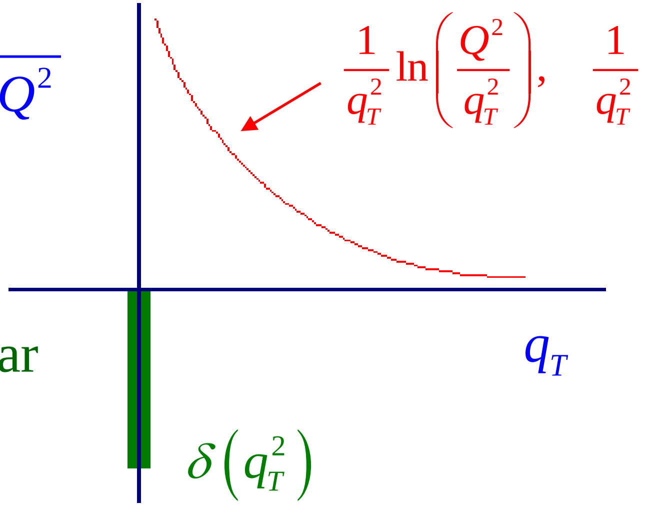
$$\frac{d\sigma}{dQ^2 dy} :$$

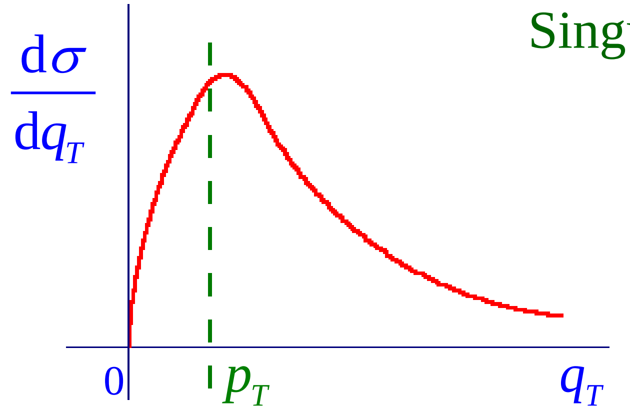


Finite +

$$\frac{d\sigma}{dq_T\, d\,y\, dQ^2}$$

Singular





The area under the q_T – curve will reproduce the total rate at the order $\alpha_S^{(1)}$ if Y term is calculated to $\alpha_S^{(1)}$ as well.

Include NNLO in high q_T region

- To improve prediction in high q_T region
- To speed up the calculation, it is implemented through K-factor table which is a function of (Q, q_T, y) of the boson, not just a constant value.

→ ResBos predicts both rate and shape of distributions.

Precision measurements require accurate theoretical predictions

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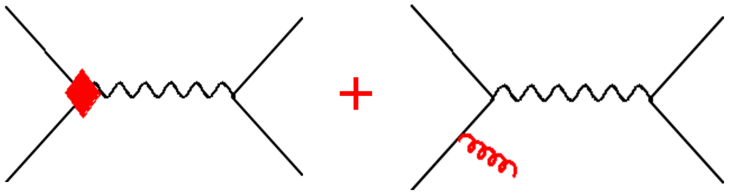
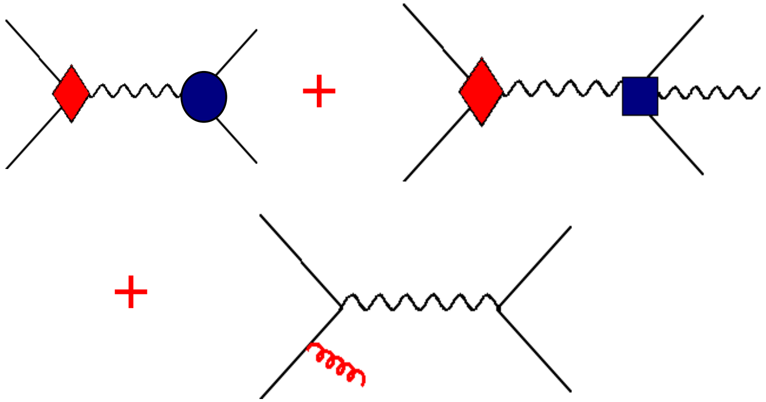
- ResBos-A: improved ResBos by including final state NLO QED corrections to W and Z production and decay

hep-ph/0401026

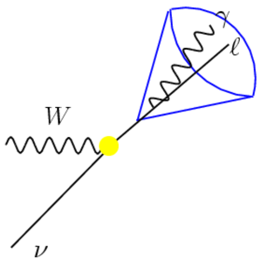
Qing-Hong Cao and CPY

Resum+Born	Resum+NLO
	

● and ■ denote FQED radiation corrections, which dominates the W mass shift.

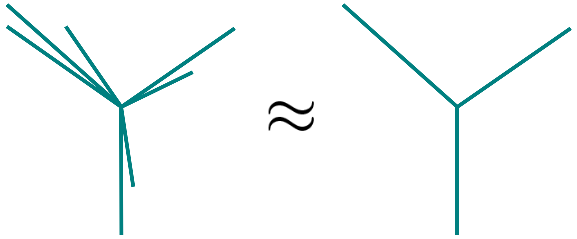
Need to consider the recombination effect

- Experimental: difficult to discriminate between electrons and photons with a small opening angle



- Theoretical: to define infra-safe quantities which are independent of long-distance physics

Essential feature of a general IRS physical quantity:
The observable must be such that it is insensitive to whether n or n+1 particles contributed if the n+1 particles has n-particle kinematics.

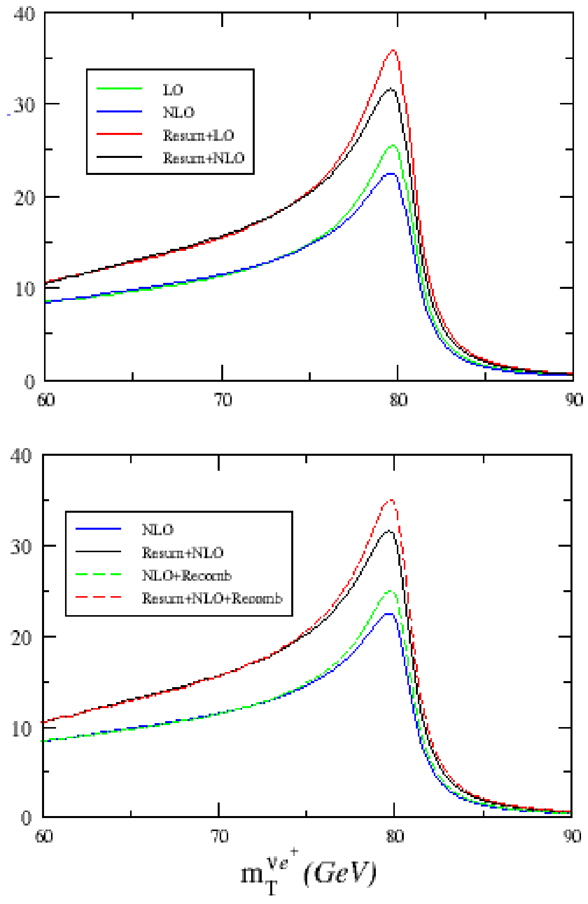


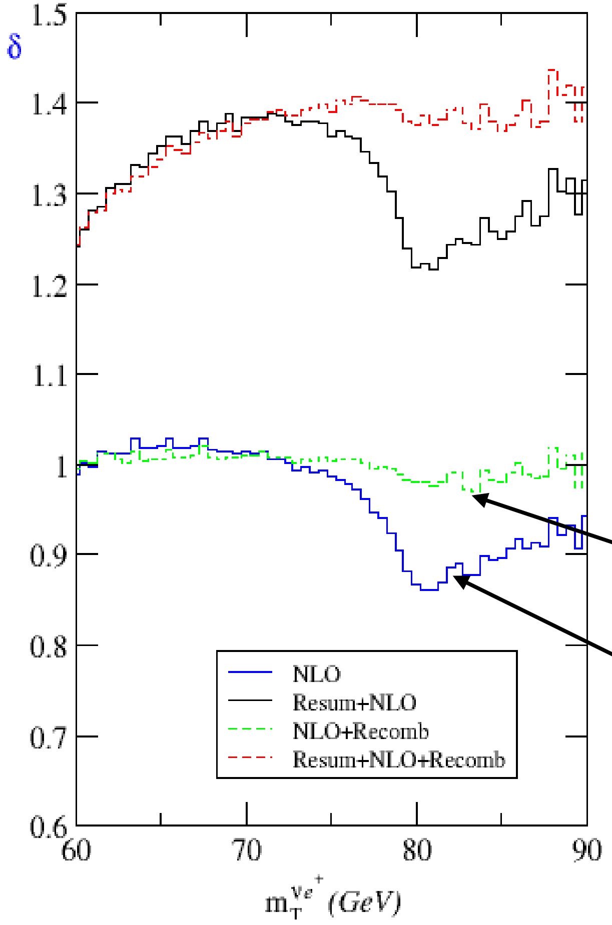
- Procedure @ Tevatron (for electron)

☞ $p'_e = p_e + p_\gamma$
- $\Delta R(e,\gamma) < 0.2$
- $E_\gamma < 0.15 E_e$ for $0.2 < \Delta R(e,\gamma) < 0.3$

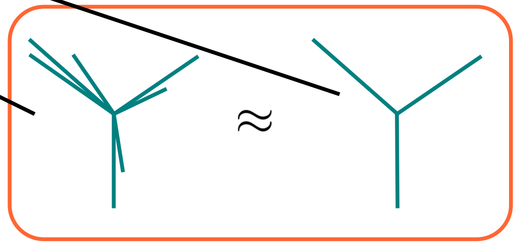
☞ rejection
- $E_\gamma > 0.15\ E_e$ for $0.2 < \Delta R(e,\gamma) < 0.4$

Recombination Effects for detecting electrons





Effects of QED correction decrease significantly after recombination.



infrared-safe

ResBos2

Version 2 of ResBos
(matched to NNLO in total inclusive rate)

Josh Isaacson, Yao Fu and CPY; arXiv:2205.02788

Collins-Soper-Sterman Formalism

Resummation

$$\frac{d\sigma_{\text{res}}}{dQ^2 d^2\vec{q}_T dy d\Omega} = \sigma \int \frac{d^2b}{(2\pi)^2} e^{i\vec{q}_T\cdot\vec{b}}\tilde{W},$$

$$\tilde{W} = e^{-S(b)} C \otimes f(x_A, C_3/b) C \otimes f(x_B, C_3/b)$$

$$S(b) = \int_{\frac{C_1^2}{b^2}}^{C_2^2 Q^2} \frac{d\bar{\mu}^2}{\bar{\mu}^2}\left[\ln\left(\frac{C_2^2 Q^2}{\bar{\mu}^2}\right) A(\bar{\mu}) + B(\bar{\mu})\right]$$

- Sudakov factor
- Collinear factors
- Perturbative Coefficients (A, B, C)

[Collins, Soper, Sterman, '85] [...]

ResBos vs. ResBos2

ResBos → NNLL (+ NLO)

ResBos2 → N^3LL (+ NNLO)

Order	Boundary Condition (C)	Anomalous Dimension γ_i (B)	Γ_{cusp} (A)	Fixed Order Matching (Y)
LL	1	-	1-loop	-
NLL	1	1-loop	2-loop	-
NLL' (+ NLO)	α_s	1-loop	2-loop	α_s
NNLL (+ NLO)	α_s	2-loop	3-loop	α_s
NNLL' (+ NNLO)	α_s^2	2-loop	3-loop	α_s^2
N^3LL (+ NNLO)	α_s^2	3-loop	4-loop	α_s^2
N^3LL' (+ N^3LO)	α_s^3	3-loop	4-loop	α_s^3
N^4LL (+ N^3LO)	α_s^3	4-loop	5-loop	α_s^3

TABLE I. The definitions for the accuracy of the resummation calculation. The accuracy used by CDF was NNLL + NLO, while the state-of-the-art is N^3LL + NNLO.

Josh Isaacson, Yao Fu and CPY; arXiv:2205.02788

CDF W mass measurement

C T E Q

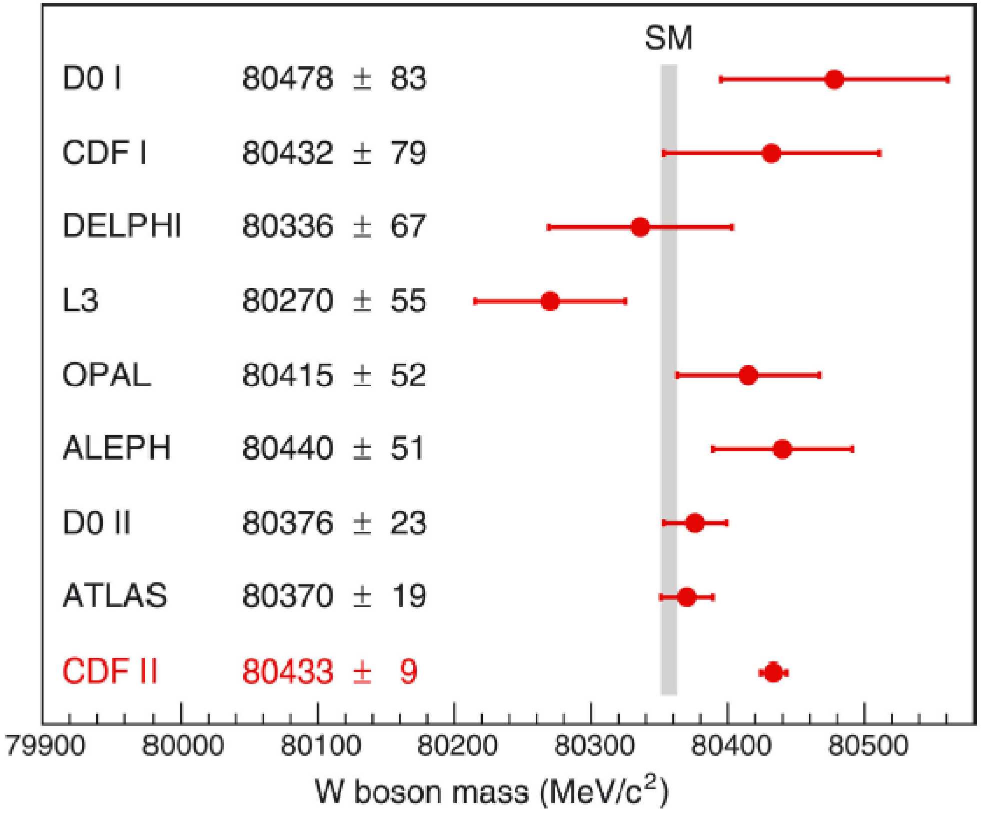


Figure reproduced from CDF-II measurement (Science 376, 170).

- Missing LHCb result: 80,354 ± 36 MeV

Quoted from CDF paper (Science 367, 170)

Simulated experiments are used to evaluate the statistical correlations between fits, which are found to be 69% (68%) between m_T and p_T^ℓ (p_T^ν) fit results and 28% between p_T^ℓ and p_T^ν fit results (*43*). The six individual M_W results are combined (including correlations) by means of the best linear unbiased estimator (*66*) to obtain $M_W = 80{,}433.5 \pm 9.4$ MeV, with χ^2/dof = 7.4/5 corresponding to a probability of 20%. The m_T, p_T^ℓ, and p_T^ν fits in the electron (muon) channel contribute weights of 30.0% (34.2%), 6.7% (18.7%), and 0.9% (9.5%), respectively. The combined result is shown in Fig. 1, and its associated systematic uncertainties are shown in Table 2.

Study the impact of higher order effects:
from NNLL+NLO
to NNNLL+NNLO

FROM RESBOS TO RESBOS2
FROM W(321)+Y TO W(432)+YK(R)

Shorthand notation:
W(321)=W(321)+Y
W(432)=W(432)+YK(R)

from NNLL+NLO to NNNLL+NNLO

- Generate pseudodata, including pT(Z), pT(W), mT, pT(e), pT(nu), using W(432) and CT18 NNLO central set PDF.
- Fit the pT(Z) pseudodata with W(321) calculation and CT18 NNLO central set PDF, in which the g2 and α_s values are the fitting parameters. This is called tuned W(321) prediction.

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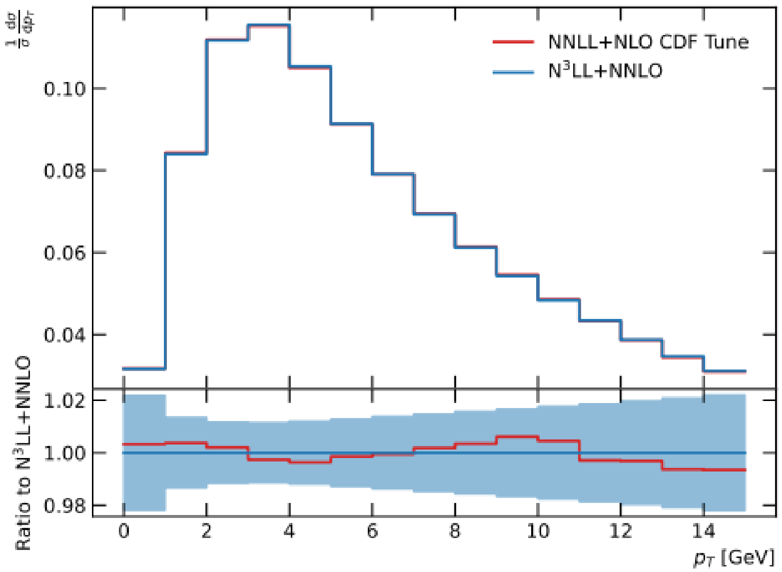
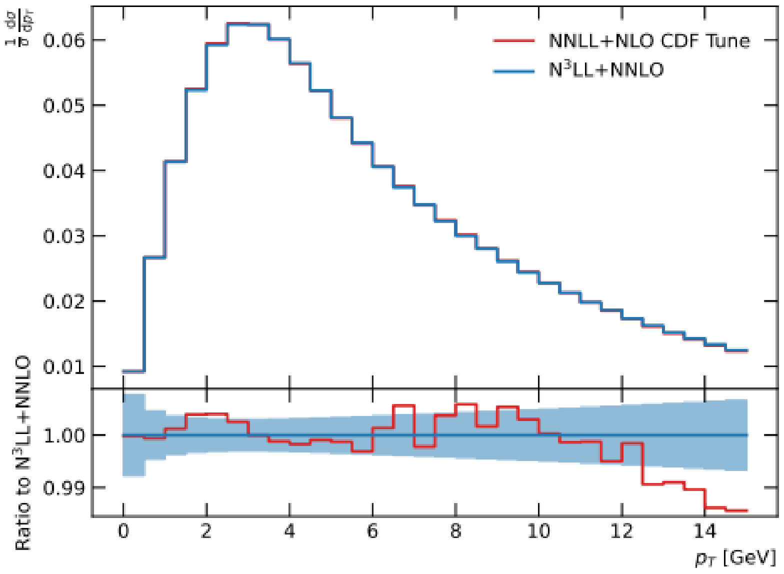
Comparison of tuned W(321) and pseudodata W(432)

$$\frac{1}{\sigma}\frac{d\sigma}{dp_T(Z)}$$



$$\frac{1}{\sigma}\frac{d\sigma}{dp_T(W)}$$



M_W template

- **Generate M_W template using the tuned W(321)**

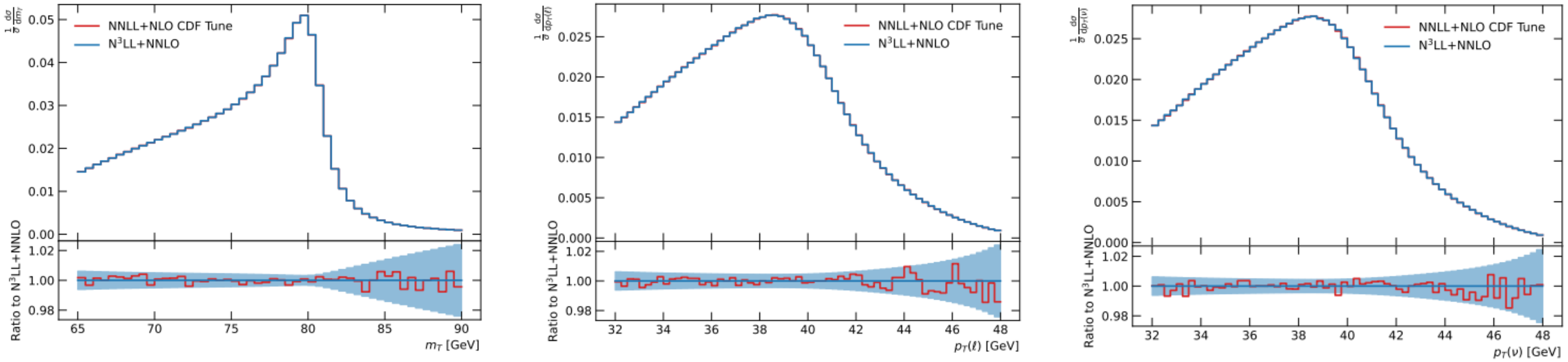
  Template: From 80.336 to 80.435, step is 0.001GeV

- **Shift M_W from W(432) to tuned W(321)**

  χ^2 fitting using normalized M_T, $p_T(l)$, $p_T(v)$ distribution to find the M_W

  Shift: $Fitted\ M_W - input\ M_W(80.385)$

Shift in M_W, when using the tuned W(321)



	Mass Shift [MeV]	
Observable	ResBos2	+Detector Effect+FSR
m_T	1.5 ± 0.5	0.2 ± 1.8 ± 1.0
$p_T(\ell)$	3.1 ± 2.1	4.3 ± 2.7 ± 1.3
$p_T(\nu)$	4.5 ± 2.1	3.0 ± 3.4 ± 2.2

Unc1: statistical uncertainty of generated samples
Unc2: uncertainty from different random seed of Gaussian smear. It is estimated by generating 100 different smeared pseudodata with different random seed, using the mean value to determine the average shift, using the RMS to determine the uncertainty.

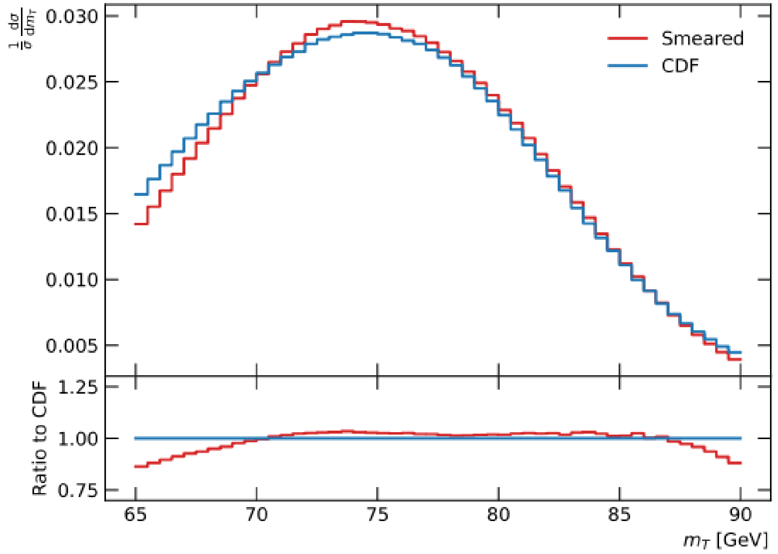
Another simple smear model is also used: 5% $on\ p_T(l)$ and 11% $on\ p_T(\upsilon)$, the conclusion is not changed.

Detector Resolution effect

- **Smear momentum on $p_T(l)$ and $pT(v)$**

$$\frac{\sigma}{E} = \frac{a}{\sqrt{E}} \oplus b \oplus \frac{c}{E},$$

Gaussian smear effect applied on $p_T(l)$ and $p_T(v)$



Same smearing was applied to both M_W template and tuned W(321) predictions

Angular correlation

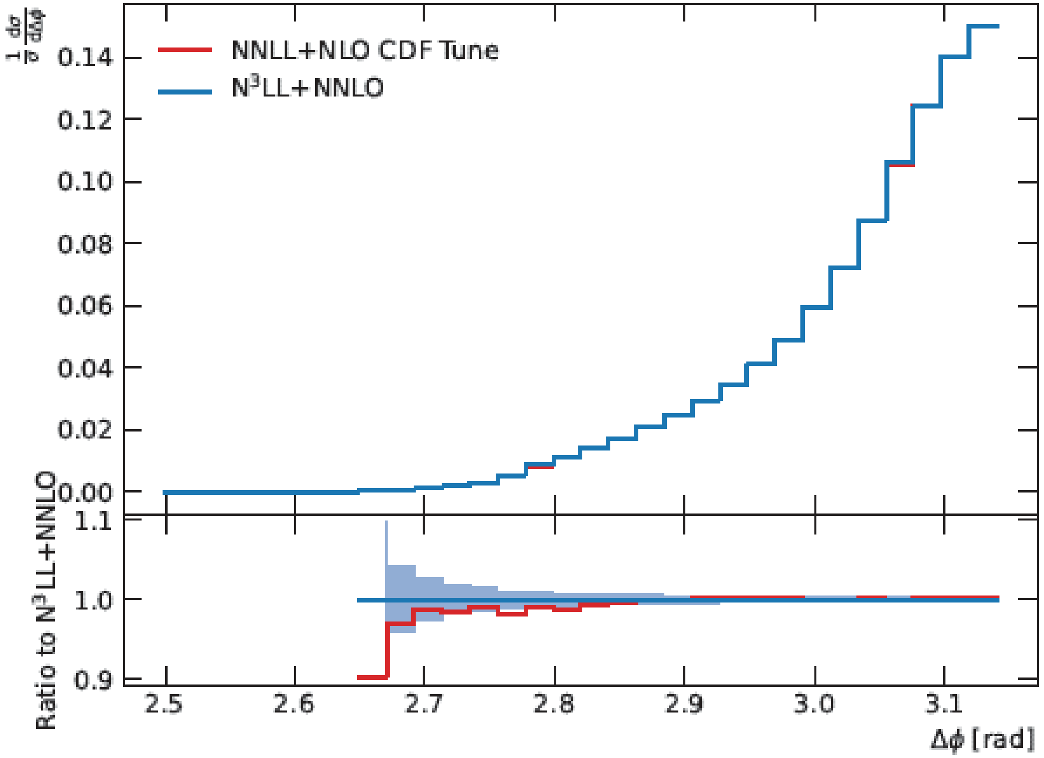


FIG. 7. Comparison of the generated pseudodata for $\Delta\phi$ using the N^{3}LL+NNLO calculation compared to the CDF tuned prediction at NNLL+NLO. The blue band represents the statistical uncertainty associated with the CDF measurement.

W(432) has the correct lepton angular correlations at NNLO, and W(321) at NLO.

M_W template for studying the shift due to various PDFs

- **Generate M_W template using the W(432)**

  Template: From 80.336 to 80.435, step is 0.001GeV, CT18NNLO central set

  Study the shift due to various PDFs in higher order calculation

- **Pseudodata generated by using W(432) + other PDFs**

  χ^2 fitting using normalized M_T, $p_T(l)$, $p_T(v)$ distribution to find the M_W

  Shift: $Fitted\ M_W - input\ M_W(80.385)$

M_W template for studying the shift due to various PDFs

- **Shift due to various PDFs**

	m_T		$p_T(\ell)$		$p_T(\nu)$	
PDF Set	NNLO	NLO	NNLO	NLO	NNLO	NLO
CT18	0.0 ± 1.3	1.8 ± 1.2	0.0 ± 15.9	2.0 ± 14.3	0.0 ± 15.5	2.9 ± 14.2
MMHT2014	1.0 ± 0.6	2.6 ± 0.6	6.2 ± 7.8	36.7 ± 7.0	3.9 ± 7.5	36.0 ± 6.7
NNPDF3.1	1.1 ± 0.3	2.1 ± 0.4	2.1 ± 3.8	13.5 ± 4.9	5.4 ± 3.7	10.0 ± 4.9
CTEQ6M	N/A	2.8 ± 0.9	N/A	19.0 ± 10.4	N/A	20.9 ± 10.2

pT(e) and pT(nu) are more sensitive to gluon PDF errors than mT(e,nu), hence, generate more shift in Mw.

PDF-induced correlations

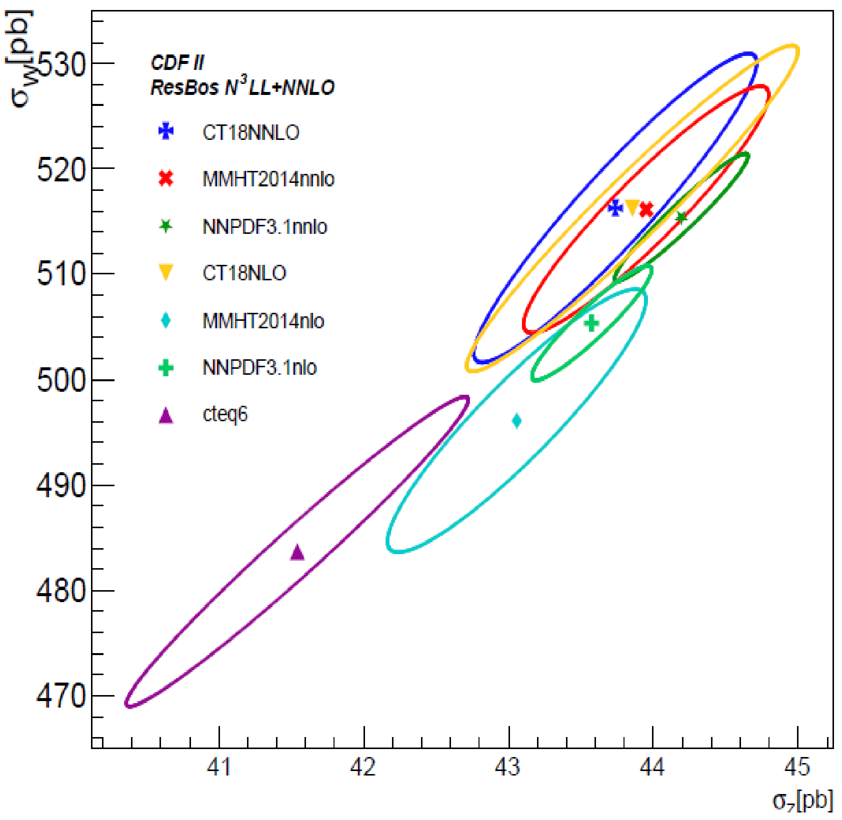


FIG. 10. PDF-induced correlation ellipses, at the 68% confidence level (C.L.), between the fiducial cross sections of W and Z boson production at the Tevatron Run II.

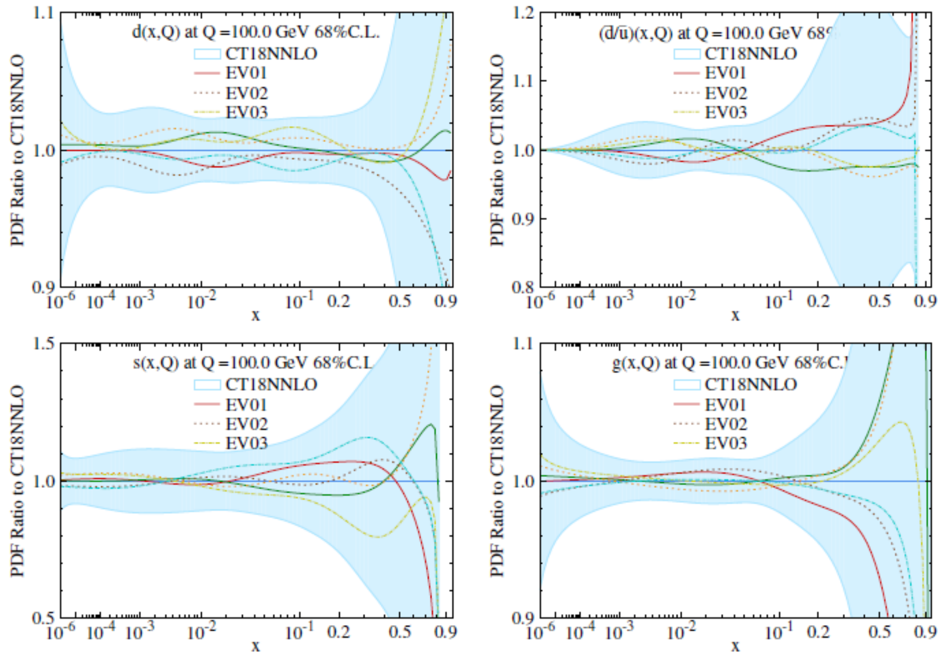
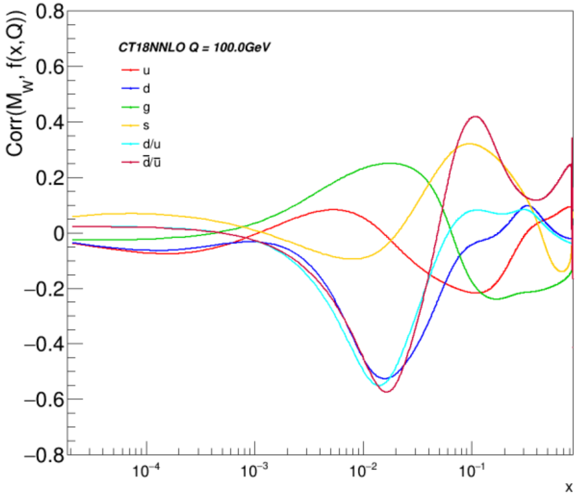


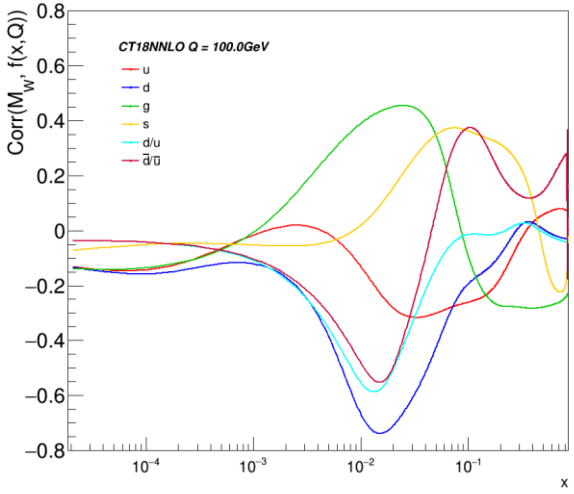
FIG. 13. Ratios of the top three pairs of eigenvector PDFs and the original CT18 NNLO error PDFs, at $Q = 100$ GeV, to the CT18 NNLO central value of d, $\bar{d}/\bar{u}$, s and g PDFs. These eigenvector PDFs were obtained after applying the ePump-optimization to the original CT18 NNLO PDFs with respect to the m_T distribution.

Correlation cosine between the uncertainty of the extracted M_W and that of parton density

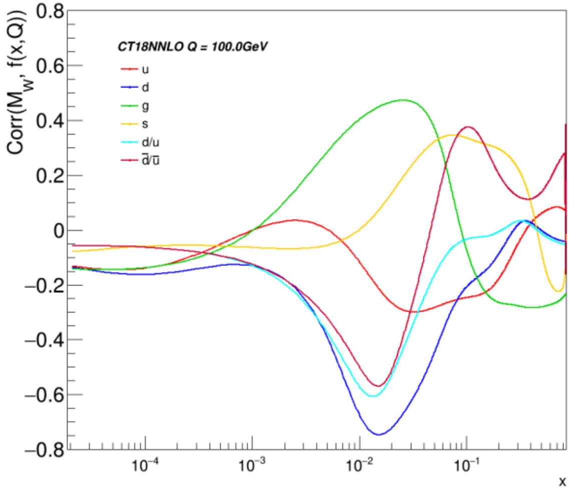
Extracted by $\frac{1}{\sigma}\frac{d\sigma}{dm_T}$



Extracted by $\frac{1}{\sigma}\frac{d\sigma}{dp_T(l)}$



Extracted by $\frac{1}{\sigma}\frac{d\sigma}{dp_T(\nu)}$



pT(e) and pT(nu) are more sensitive to gluon PDF errors than mT(e,nu), hence, generate more shift in Mw.

C T E Q

M_W template for studying the width effect

- **Generate M_W template using the W(432)**

  Template: From 80.336 to 80.435, step is 0.001GeV

  Width: 2.0895 GeV (used in CDF paper)

- **Changing the width of W boson**

  According to the uncertainty of the W boson width reported by PDG, which is 0.042GeV

  Three pseudodata are generated:

  $M_W = 80.385GeV, \Gamma_W = 2.0475GeV$
  $M_W = 80.385GeV, \Gamma_W = 2.1315GeV$
  $M_W = 80.385GeV, \Gamma_W$ is determined by NLO calculation, which is proportional to M_W^3

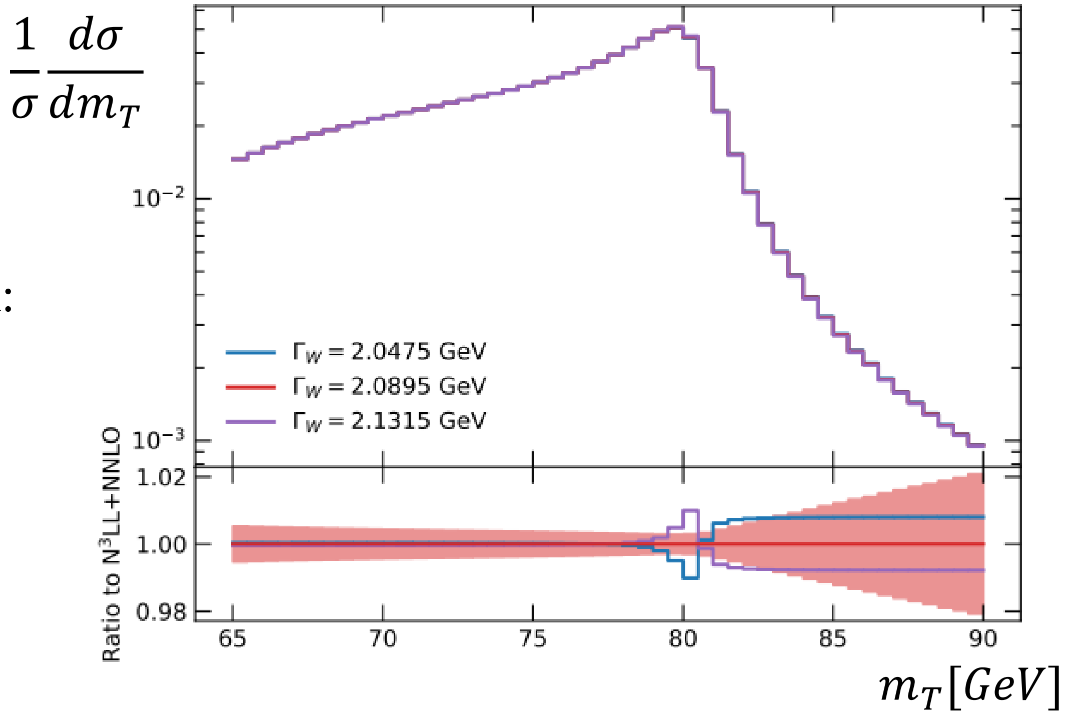
CTEQ

M_W template for studying the width effect

- Generate M_W template using the W(432)

Shift due to the different W boson width:

Width	Mass Shift [MeV]
2.0475 GeV	2.0 ± 0.5
2.1315 GeV	0.3 ± 0.5
NLO	1.2 ± 0.5



Learned from Joey Huston @ MSU

==== my answers to questions from Dr. Natascia Vignaroli =====

(1)

> What do you think about the CDF anomaly?

=>

Our paper only discussed the impact of higher order contributions to the extraction of M_W, based on CDF's data-driven method. We cannot answer the question about the difference observed by CDF between their data and SM prediction.

If it is not due to new physics effect, then one could ask:

— Could there be some common systematic(s) among all six of the CDF analyses?

— Would it be worthwhile to do a W-mass analysis of Z -> ee, \mu \mu, though it will be statistics limited?

(2)

> How about the ATLAS measurement?

=>

ATLAS has a much better detector, but as compared to CDF, it suffers from being "too energetic" — most W bosons are boosted (to both longitudinal and transverse directions)! CDF has smaller PDF uncertainties, smaller QCD radiation (Sudakov) effects, and smaller pileup, etc.

==

Lessons learned from W mass measurements

C T E Q

Experimentalists + Theorists

2017 Featured Story #1: Million-dollar gift establishes endowed professorship in honor of the late Dr. Wu-Ki Tung

Michigan State University
(1992-2009)

http://www.pa.msu.edu/node/5921

- Co-founder of CTEQ (**The Coordinated Theoretical-Experimental Project on QCD)** in 1989 – present
- Nowadays, many, like this Mini-Workshop, are doing precisely that.

Backup slides

Where is it?

- **ResBos**: http://hep.pa.msu.edu/resum/
- **Plotter**: http://hep.pa.msu.edu/wwwlegacy

ResBos-A (including final state NLO QED corrections)
http://hep.pa.msu.edu/resum/code/resbosa/
has not been updated.
Why? Because it was not used for Tevatron experiments.

The plan is to include final state QED resummation inside ResBos2.

Sorry, the website is temporary down and will be restored later.

Physical processes included in ResBos

$W^{\pm}$

γ, Z including gauge invariant set amplitude

H Including the full NNLO contribution

$\gamma\gamma, ZZ, WW$

New physics: W', Z', H^{+}, A^{0}, H^{0} …

Limitations of ResBos

- Any perturbative calculation is performed with some approximation, hence, with limitation.
- To make the best use of a theory calculation, we need to know what it is good for and what the limitations are.

It does not give any information about the hadronic activities of the event.

→ It could be used to reweight the distributions generated by (PYTHIA) event generator, by comparing the boson (and it decay products) distributions to ResBos predictions.

This has been done for W-mass analysis by CDF and D0)

Conclusion

- ResBos is a useful tool for studying electroweak gauge bosons and Higgs bosons at the Tevatron and the LHC.
- It includes not only QCD resummation for low q_T region but also higher order effect in high q_T region, with spin correlations included via gauge invariant set of matrix elements.