ResBos2

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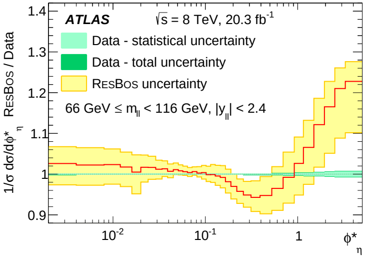
Motivation

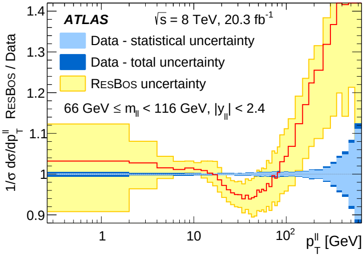
- Precise predictions modify the efficiencies for predictions
- Better understand sensitive kinematical distributions
- Understand difference between q_T resummation schemes
- Large Logs $\rightarrow$ Perturbation Theory breaks down

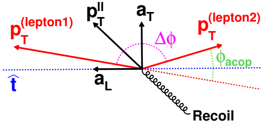
$$
\begin{aligned}
\frac{d\sigma}{dq_T^2} \propto \frac{1}{q_T^2} \big(&\alpha_s(L+1) + \alpha_s^2(L^3+L^2) + \cdots) \\
+ &\qquad\qquad (\alpha_s^2(L+1) + \alpha_s^3(L^3+L^2) + \cdots) \\
+ &\cdots \big)
\end{aligned}
$$

Motivation (Cont.)

$$\phi^*_\eta = \tan\left(\frac{\pi - \Delta\phi}{2}\right)\sqrt{1 - \tanh\left(\frac{\eta_1 - \eta_2}{2}\right)} \approx \frac{Q_T}{Q}\sin\phi_{CS}$$







Vesterinen and Wyatt et al.

CSS vs. CFG Formalism

Resummation

$$\sigma \int \frac{d^2b}{(2\pi)^2} e^{i\vec{q}_T\cdot\vec{b}}\tilde{W} + Y, \tilde{W} = e^{-S(b)}e^{-S_{NP}(b)} C \otimes f(x_A) C \otimes f(x_B)$$

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

CSS Formalism:

- Resummation process dependent (B and C Coefficients)
- What is implemented in ResBos and will be in ResBos2

CFG Formalism:

- Resummation process independent (B and C Coefficients)
- More in line with TMD
- What will be implemented in ResBos2

CSS vs. CFG (Cont.)

All Orders Conversion

$$A^{CSS} = A^{CFG}$$

$$B^{CSS} = B^{CFG} - \beta\left(\alpha_s\right)\frac{d\ln H\left(\alpha_s\right)}{d\ln\alpha_s}$$

$$C^{CSS} = \left[H\left(\alpha_s\right)\right]^{1/2} C^{CFG}$$

CSS vs. CFG (Cont.)

Conversion between CSS and CFG (Hard Factors):

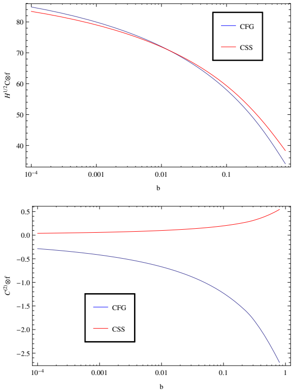
Conversion

$$C_{ab}^{(1)CSS}(z) = C_{ab}^{(1)CFG}(z) + \delta_{ab}\delta(1-z)\frac{1}{2}H_a^{(1)}$$

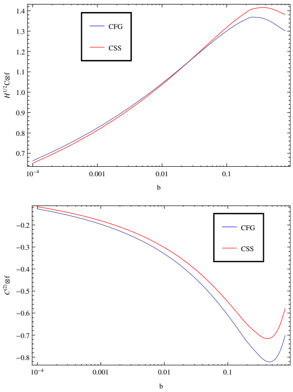
$$C_{ab}^{(2)CSS}(z) = C_{ab}^{(2)CFG}(z) + \frac{1}{2}H_a^{(1)}C_{ab}^{(1)CFG}(z) + \delta_{ab}\delta(1-z)\frac{1}{2}\left(H_a^{(2)} - \frac{1}{4}\left(H_a^{(1)}\right)^2\right)$$

Effects of $C^{(2)}$ on Drell-Yan

$q\bar{q}$ Channel



qg Channel



Note: $x = 0.01$

CSS vs. CFG (Cont.)

Conversion between CSS and CFG (Sudakov Factors):

Conversion

$$B^{(1)CSS} = B^{(1)CFG}$$

$$B^{(2)CSS} = B^{(2)CFG} + \beta_0 H^{(1)}$$

$$B^{(3)CSS} = B^{(3)CFG} + \beta_1 H^{(1)} + 2\beta_0 \left(H_a^{(2)} - \frac{1}{2} \left(H_a^{(1)} \right)^2 \right)$$

B^3 for Drell-Yan

See Huaxing Zhu's Talk for "straightforward" calculation details

CSS

$$B^{(3)} = 114.982 - 11.2737 n_f + 0.321798 n_f^2$$
$$B^{(3)}_{n_f=5} = 66.66$$
$$\frac{B^{(3)}\frac{\alpha_s}{\pi}}{B^{(2)}} = 1.32$$

CFG

$$B^{(3)} = -16.185 - 0.011592 n_f + 0.11379 n_f^2$$
$$B^{(3)}_{n_f=5} = -13.416$$
$$\frac{B^{(3)}\frac{\alpha_s}{\pi}}{B^{(2)}} = 1.03$$

Non-Perturbative Effects

- Depends on scheme and on the order of A, B, and C.
- Fixed by data from low energy Drell-Yan through Tevatron data
- Mainly effects the small q_T region (up to about 10 GeV)
- Almost no effect on LHC data

Two Main Forms Used in ResBos2:

- BLNY ($b_{Max} = 1.5$)

$$S_{NP} = g_1 b^2 + g_2 b^2 \log\left(\frac{Q}{2Q_0}\right) + g_3 b^2 \log\left(100 x_1 x_2\right)$$

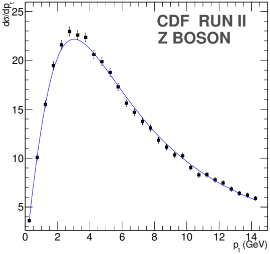
- SIYY ($b_{Max} = 1.5$)

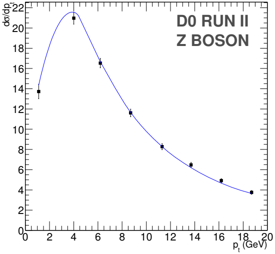
$$S_{NP} = g_1 b^2 + g_2 \log\left(\frac{b}{b_*}\right) \log\left(\frac{Q}{Q_0}\right) + g_3 b^2 \left(\left(\frac{x_0}{x_1}\right)^\lambda + \left(\frac{x_0}{x_2}\right)^\lambda\right)$$

$$b_* = \frac{b}{\sqrt{1 + \frac{b^2}{b_{max}^2}}}, \qquad Q_0 = 1.55, \qquad \lambda = 0.2, \qquad x_0 = 0.01$$

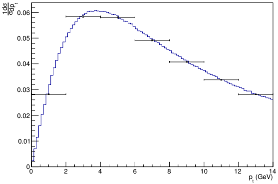
See 1406.3073 for details

Non-pert Function

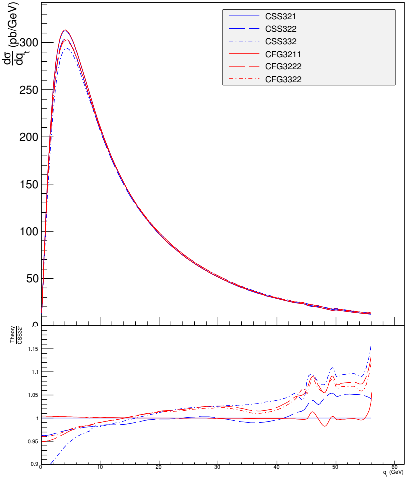




ATLAS



Comparison Between CSS and CFG



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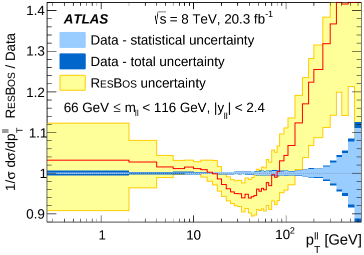
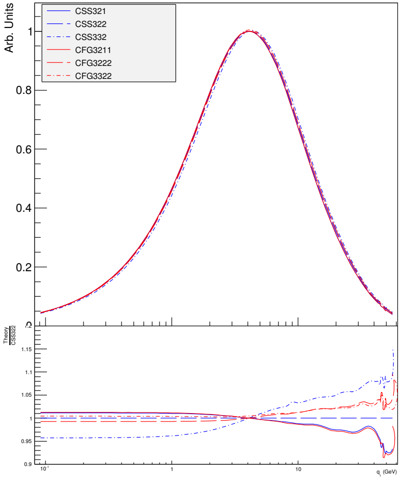




Asymptotic Expansion

$$\frac{d\sigma}{dq_t^2}_A = \sigma \sum_{i,j} \sum_{n,m} \left(\frac{\alpha_s(\mu)}{\pi}\right)^n {}_nC_m^{(ij)} \ln^m\left(\frac{Q^2}{q_T^2}\right)$$

First term that is different between the CSS and CFG Formalism in the asymptotic expansion is:

$$\frac{d\sigma}{dq_t^2}_A \subset \alpha_s^4 \ln\frac{Q^2}{Q_T^2}\left[A^{(4)} f_i f_j + \left(A^{(1)}\left(C^{(3)} \otimes f_i\right) f_j + A^{(1)}\left(C^{(3)} \otimes f_j\right) f_i\right)\right]$$

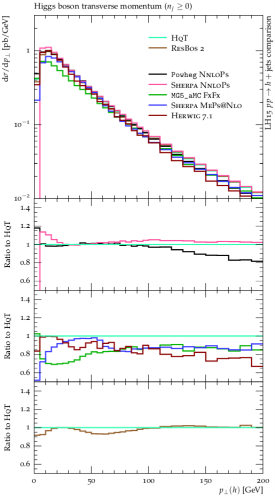
Using ZFITTER as EW input for ResBos

LHC 13 TeV	$\sigma_Z[\mathrm{pb}]$
ATLAS	$1981 \pm 7 \pm 38 \pm 42$
CMS	$1910 \pm 10 \pm 40 \pm 90$
FEWZ CT14 (CMS)	1900^{+50}_{-50}
DYNNLO CT14 (ATLAS)	$1890^{+50}_{-50} \pm 30 \pm 30$
RESBOS(CMS ZFITTER)	1872
FEWZ/RESBOS	1.01496
RESBOS(ATLAS ZFITTER)	1845
DYNNLO/RESBOS	1.02439

ATLAS: $66\text{GeV} < M_{ll} < 116\text{GeV}$
CMS: $60\text{GeV} < M_{ll} < 120\text{GeV}$
Use Improved Born Approximation:
$g_V^f = \sqrt{\rho_f}\left(t_{3L}^{(f)} - 2Q_f\kappa_f \sin^2\theta_W^{eff}\right)$
$g_A^f = \sqrt{\rho_f} t_{3L}^{(f)}$
$\sin^2\theta_W^{eff} = \kappa_f \sin^2\theta_W$
(Captures dominate EW effects at the Z pole, and are taken at the scale $\sqrt{s}$)

Note: This is in the CSS Scheme and does not include $B^{(3)}$ or $C^{(2)}$

Higgs Boson Comparisons



B^3 for Higgs

CSS

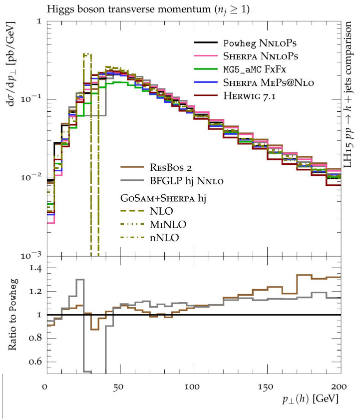
$$B^{(3)} = 548.98 - 114.236 n_f + 4.578 n_f^2$$
$$-(13 + 2.875 n_f - 0.222 n_f^2) \ln\left(\frac{m_t^2}{m_H^2}\right)$$
$$B^{(3)}_{n_f=5} = 78.3$$
$$\frac{B^{(3)}\frac{\alpha_s}{\pi}}{B^{(2)}} = 0.11$$

See the talk by Huaxing Zhu

ResBos 2: Coming Soon

ResBos2:

- Higgs + Jet Predicitons (See Peng Sun's Talk)
- $W/Z/\gamma$ + Jet Predictions (Coming Soon)
- Z'/W' Predictions
- Completely Public (No grids needed)
- Plus all calculations currently in ResBos



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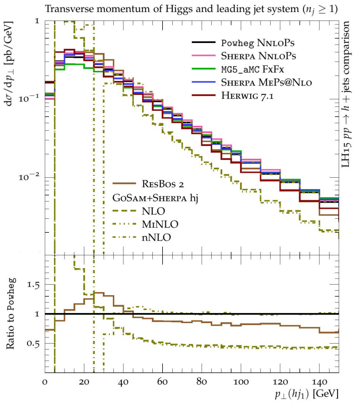

Processes in ResBos2

Process	$A^{(i)}$	$B^{(i)}$	$C^{(i)}$	Pert Order	In ResBos(321)?
$W^+ \to l^+ + \nu + X$	3	3	2	NNLO	Y
$W^- \to l^- + \bar{\nu} + X$	3	3	2	NNLO	Y
$Z^0 \to l^+ + l^- + X$	3	3	2	NNLO	Y
$Z^0/\gamma^* \to l^+ + l^- + X$	3	3	2	NNLO	Y
$\gamma^* \to l^+ + l^- + X$	3	3	2	NNLO	Y
$H^0 \to \gamma\gamma + X$	3	3	2	NNLO	Y
$H^0 \to Z^0Z^0/W^+W^- \to 4l + X$	3	3	2	NNLO	Y
$W^{+*} \to W^+H^0 + X$	3	3	2	NNLO	Y
$W^{-*} \to W^-H^0 + X$	3	3	2	NNLO	Y
$Z^{0*} \to Z^0H^0 + X$	3	3	2	NNLO	Y
$q\bar{q} \to \gamma\gamma + X$	3	3	2	NLO	Y
$gg \to \gamma\gamma + X$	3	2	1	NLO	Y
$q\bar{q} \to Z^0Z^0 + X$	3	2	1	NLO	Y
$W^+W^- + X$	3	2	1	NLO	N
$W' \to l^- + n\bar{u} + X$	3	3	2	NNLO	N
$Z' \to l^- + l^+ + X$	3	3	2	NNLO	N
$H + j$	2	1	1	NLO	N
$Z/\gamma + j$ (coming soon)	2	1	1	NLO	N
$W + j$ (coming soon)	2	1	1	NLO	N