N^3LO_{SV}+N^3LL Perturbative QCD Calculations for Drell-Yan at LHC

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Motivation

- NNLO corrections for DY are complete known long back.
- How to improved the NNLO corrections.
- First step SV corrections at three-loops. Captures dominant distributions and delta part at threshold ($z \to 1$) computed few years back by Ravi and co.
- Other way of improving the NNLO result: At threshold one can resum large threshold logs at all orders. NNLO+NNLL is available by Moch, Catani etc.
- In this work we improve existing N^3LO_{sv} result by performing N^3LL resummation.

Theoretical Formalism

The hadronic cross-section for DY production at the LHC can be written as

$$\sigma = \sigma^{(0)} \sum_{ab=q,\bar{q},g} \int_0^1 dx_1 \int_0^1 dx_2 \, f_a(x_1,\mu_f^2) \, f_b(x_2,\mu_f^2) \int_0^1 dz \; \Delta_{ab}(z,q^2,\mu_f^2) \delta(\tau - z x_1 x_2) \,,$$

- $\sigma = \frac{d\sigma}{dQ}\left(\tau, q^2\right)$ for DY production.
- $f_a(x_1,\mu_f^2)$ and $f_b(x_2,\mu_f^2)$ are the non-perturbative parton distribution functions.
- $\Delta_{ab}(z,q^2,\mu_f^2)$ is partonic coefficients.
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$$\sigma^{(0)}_{DY} = \frac{2\pi}{n_c}\left[\frac{Q}{S}\mathcal{F}^{(0)}\right]$$

$$\sigma^{(0)}_{Z} = \frac{2\pi}{n_c}\left[\frac{\pi\alpha}{8 s_w^2 c_w^2 S}\right]$$

$$\sigma^{(0)}_{W^\pm} = \frac{2\pi}{n_c}\left[\frac{\pi\alpha}{4 s_w^2 S}\right]$$

Theoretical Formalism

$$\mathcal{F}^{(0)} = \frac{4\alpha^2}{3q^2}\Bigg[Q_q^2 - \frac{2q^2(q^2-M_Z^2)}{\left((q^2-M_Z^2)^2+M_Z^2\Gamma_Z^2\right)c_w^2 s_w^2} Q_q g_e^V g_q^V$$
$$+ \frac{Q^4}{\left((q^2-M_Z^2)^2+M_Z^2\Gamma_Z^2\right)c_w^4 s_w^4}\left((g_e^V)^2+(g_e^A)^2\right)\left((g_q^V)^2+(g_q^A)^2\right)\Bigg].$$

The partonic coefficient function can be written as

$$\Delta_{ab}(z,q^2,\mu_f^2) = \Delta_{ab}^{(\mathrm{sv})}(z,q^2,\mu_f^2) + \Delta_{ab}^{(\mathrm{reg})}(z,q^2,\mu_f^2)$$

The soft-virtual coefficient function can be written as

$$\Delta^{\mathrm{sv}}(z,q^2) = C_0(q^2)\otimes \mathcal{C}e^{G_+\left(z,q^2\right)}$$

$$C_0(z,q^2) = \exp\left(\mathcal{L}_{\mathcal{F}}^{\mathrm{fin}} + 2\Phi_\delta^{\mathrm{fin}} - 2\mathcal{L}_{\Gamma\delta}^{\mathrm{fin}}\right)\delta(1-z)$$

$$G_+(z,q^2) = \left(\frac{1}{1-z}\left[\int_{\mu_f^2}^{q^2(1-z)^2}\frac{d\mu^2}{\mu^2}2A(a_s(\mu^2)) + D(a_s(q^2(1-z)^2))\right]\right)_+$$

Status of DY

- A complete calculation of the order α_s^2 correction to the Drell-Yan K factor

  R. Hamberg, W. L. van Neerven and T. Matsuura,Nucl. Phys. B359 (1991) 343.

- Drell-Yan production cross section at $\mathrm{N}^3\mathrm{LO}_{SV}$ QCD :

  T. Ahmed, M. Mahakhud, N. Rana and V. Ravindran, Phys. Rev. Lett.113(2014)212002 [1404.6504].

- Drell-Yan production cross section at NNLL QCD :

  Marco Bonvini, Stefano Forte, Giovanni Ridolfi, Nucl.Phys. B847 (2011) 93-159

Resummation

The general formula for resummation

$$\hat{\sigma}_N(q^2) = \int_0^1 dz z^{N-1} \Delta^{\rm sv}(z,q^2)$$
$$= \overline{g}_0(q^2) \exp\left(G_{\overline{N}}(q^2)\right), \qquad (1)$$

$$\lim_{N\to\infty} \int_0^1 dz z^{N-1} G_+(z,q^2) = \overline{G}_0(q^2) + G_{\overline{N}}(q^2), \quad \text{with} \quad G_{\overline{N}}(q^2)\Big|_{\overline{N}=1} = 0$$

where $\overline{N} = N \exp(\gamma_E)$ and γ_E is E-M constant.

$$G_{\overline{N}}(q^2) = \ln \overline{N}\, \overline{g}_1(\overline{N},q^2) + \overline{g}_2(\overline{N},q^2) + a_s\, \overline{g}_3(\overline{N},q^2) + a_s^2\, \overline{g}_4(\overline{N},q^2) + \cdots .$$

$$\overline{g}_0(q^2) = \exp\left(\mathcal{L}_{\mathcal{F}}^{\rm fin} + 2\Phi_\delta^{\rm fin} - 2\mathcal{L}_{\Gamma\delta}^{\rm fin} + \overline{G}_0(q^2)\right)$$

$$\overline{g}_0(q^2) = 1 + \sum_{n=1}^{\infty} a_s^i \overline{g}_{0i}(q^2).$$

Resummation

- One can reshuffle of γ_E between $\overline{g}_0$ and $G_{\overline{N}}$, all the above equations will be remain same but $\overline{N}$ will be replaced by N and $\overline{G}_0(q^2)$ will be replaced by $G_0(q^2)$.
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$$G_{\overline{N}}^{\rm Soft} = G_{\overline{N}} + 2\Psi_{\delta}^{\rm fin} - 2\mathcal{L}_{\Gamma\delta}^{\rm fin}$$

$$\hat{\sigma}_N(q^2) = g_0^{\rm Soft}(q^2) \exp\left(G_{\overline{N}}^{\rm Soft}(q^2)\right).$$

$$G_{\overline{N}}^{\rm Soft}(q^2) = \ln \overline{N}\, g_1^{\rm Soft}(\overline{N}, q^2) + g_2^{\rm Soft}(\overline{N}, q^2) + a_s\, g_3^{\rm Soft}(\overline{N}, q^2) + a_s^2\, g_4^{\rm Soft}(\overline{N}, q^2) + \cdots$$

$$g_0^{\rm Soft}(q^2) = 1 + \sum_{n=1}^{\infty} a_s^i g_{0i}^{\rm Soft}(q^2).$$

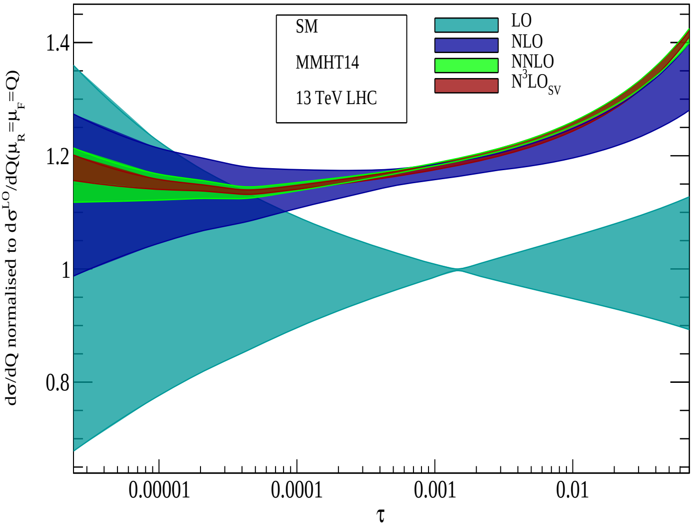
Matching

$$\sigma_V^{N^nLO+N^nLL} = \sigma_V^{N^nLO} + \sigma_V^{(0)} \sum_{ab\in\{q,\bar{q}\}} \int_{c-i\infty}^{c+i\infty} \frac{dN}{2\pi i}(\tau)^{-N}\delta_{a\bar{b}} f_{a,N}(\mu_f^2) f_{b,N}(\mu_f^2)$$

$$\times \left(\hat{\sigma}_N \Big|_{N^nLL} - \hat{\sigma}_N \Big|_{trN^nLO} \right).$$

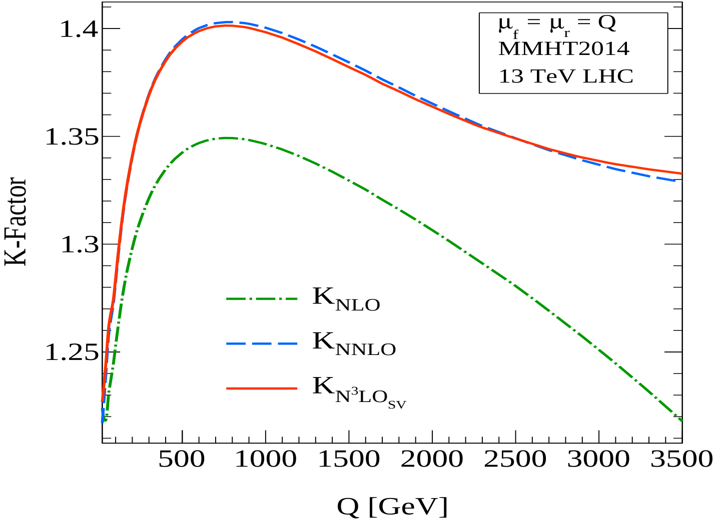
- $\sigma_V^{N^nLO}$ fixed order cross section in z space.
- $f_{i,N}$ is parton distribution function in N space.
- $\hat{\sigma}_N \Big|_{trN^nLO}$ is SV part in N space.

SV Result

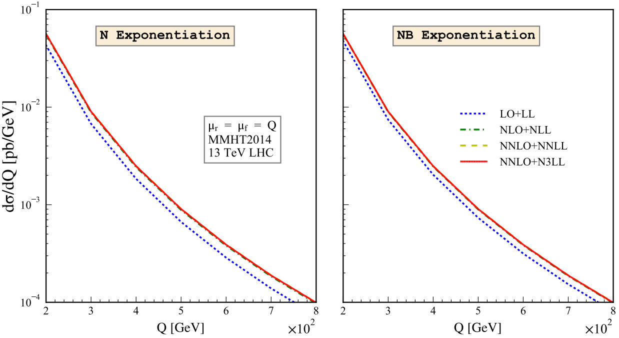


SM
MMHT14
13 TeV LHC
LO
NLO
NNLO
N3LOSV
1.4
1.2
1
0.8
0.00001
0.0001
0.001
0.01
τ
dσ/dQ normalised to dσLO/dQ(μR=μF=Q)

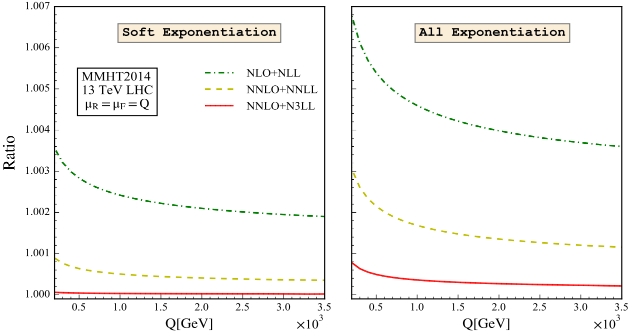
SV Result


$\mu_f = \mu_r = Q$
MMHT2014
13 TeV LHC
K-Factor
1.4
1.35
1.3
1.25
500
1000
1500
2000
2500
3000
3500
Q [GeV]
K_{NLO}
K_{NNLO}
$K_{N^3LO_{SV}}$

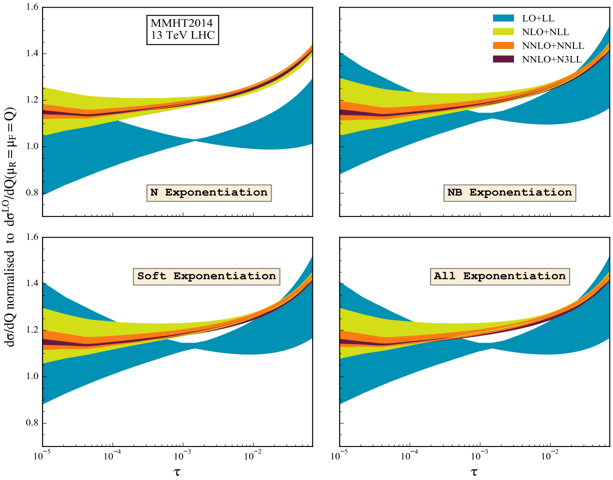
Resum Result



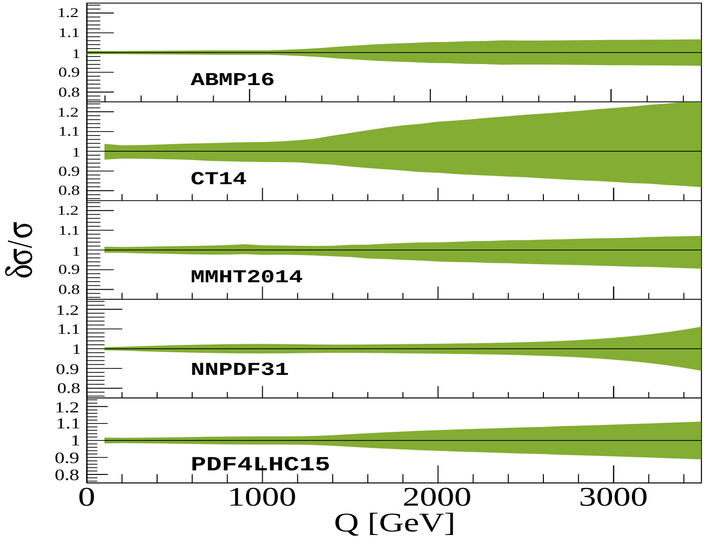
Resum Result



Resum Result



Resum Result



Conclusion

- We have computed N^3LO_{SV}+N^3LL QCD correction for DY process at LHC.
- For standard $\overline{N}$ prescription, we found scale uncertainty reduces to 2%.
- Numerically we studied different prescription for resummation and we find more and more terms exponentiation gives better scale uncertainty.
- We studied the intrinsic PDF uncertainty for five different PDFs.