Theoretical Studies of LHC Physics in the Context of Exact Amplitude-Based Resummation Realized by MC Methods

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Contents

Introduction

- Successful running of the LHC during 2010-2012 has resulted in accumulation of large samples of data on SM standard candle processes.
- Announcement of Brout-Englert-Higgs boson candidate.

This has brought along the era of prediction of QCD processes at sub-1% precision tag.
In order to obtain the desired level of accuracy the IR-improved DGLAP-CS theory realization with Herwiri1.031 was done by implementing the set of IR-improved DGLAP-CS kernels in Herwig6.5. The process gives better than 1% theoretical precision. The comparison with the ATLAS and the CMS data was encouraging. In what follows we review these comparisons and extend the results to the LHCb data.

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Precision QCD for LHC

This approach is exact as opposed to the other existing approaches. To show this we point out that in the threshold resummation methods the non singular contributions to the cross sections at $z \longrightarrow 1$ are dropped in resumming the logs in $n-$Mellin space using

$$|\int_0^1 dz z^{n-1} f(z)| \leq (\frac{1}{n}) max_{z\in[0,1]}|f(z)| \tag{1}$$

In the SCET theory, the terms of $\mathcal{O}(\lambda)$ are dropped at the amplitude level. There $\lambda = \sqrt{\frac{\Lambda}{Q}}$ with $\Lambda \sim .3GeV$ so that $\lambda \cong 5.5\%$ with $Q \sim 100GeV$. So these approaches can only be used as a guide to the non-Abelian residuals $\hat{\hat{\beta}}_{n,0}$, that are developed for the (sub-)1% precision regime.

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The above estimate holds also for the following result:
the differential cross section for the p_T distribution for the heavy guage boson production in hadron-hadron collisions, which we specialize here to the case of the Drell-Yan γ^* production for definiteness

$$\frac{d\sigma}{dQ^2 dy dQ_T^2} \sim \frac{4\pi^2\alpha^2}{9Q^2 s}\left\{\int \frac{d^2 b}{(2\pi)^2} e^{i\vec{Q_T}.\vec{b}} \tilde{W}(b; Q, x_A, x_B) + Y(Q_T; Q, x_A, x_B)\right\}. \tag{2}$$

Here, $y = \frac{1}{2}\ln(\frac{Q^+}{Q})$ such that $x_A = e^y \frac{Q}{\sqrt{s}}$ and $x_B = e^{-y}\frac{Q}{\sqrt{s}}$.

Precision QCD for LHC

To link the experimental results with the theoretical predictions we give the fully differential representation of a hard LHC scattering process:

$$d\sigma = \sum_{i,j} \int dx_1 dx_2 F_i(x_1) F_j(x_2) d\hat{\sigma}_{res}(x_1 x_2 s) \tag{3}$$

where $\{F_j\}$ and $d\hat{\sigma}_{res}$ are the parton densities and the reduced hard differential cross section respectively.
The theoretical precision can be written as

$$\Delta\sigma_{th} = \Delta F \oplus \Delta\hat{\sigma}_{res}. \tag{4}$$

It should fulfill the condition $\Delta\sigma_{th} \leq f\Delta\sigma_{expt}$ where $f \lesssim \frac{1}{2}$.

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The master formula for the QCD $\otimes$ QED resummation theory is given by

$$d\bar{\sigma}_{res} = e^{SUM_{IR}(QCED)} \sum_{n,m=0}^{\infty} \frac{1}{n!m!} \int \prod_{j_1=1}^{n} \frac{d^3 k_{j_1}}{k_{j_1}} \prod_{j_2}^{m} \frac{d^3 k'_{j_2}}{k'_{j_2}} \int \frac{d^4 y}{(2\pi)^4} e^{iy\cdot(p_1+q_1-p_2-q_2-\sum_j k_j)+D_{QCED}} * \tilde{\bar{\beta}}_{n,m}(k_1,\ldots,k_n;k'_1,\ldots,k'_m)\frac{d^3 p_2}{p_2^0}\frac{d^3 q_2}{q_2^0}. \quad (5)$$

The new non-Abelian residuals $\tilde{\bar{\beta}}_{n,m}$ allow rigorous shower/ME matching via their shower subtracted analogs: in the above equation we make replacement

$$\tilde{\bar{\beta}}_{n,m} \to \hat{\tilde{\bar{\beta}}}_{n,m}.$$

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The MC@NLO differential cross section is represented by

$$d\sigma_{MC@NLO} = [B + V + \int (R_{MC} - C)d\Phi_R]d\Phi_B[\Delta_{MC}(0) + \int (R_{MC}/B)\Delta_{MC}(k_T d\Phi_R)] + (R - R_{MC})\Delta_C(k_T)d\Phi_B d\Phi_R \quad (6)$$

and the Sudakov form factor is given by

$$\Delta_{MC}(p_T) = e^{[-\int d\Phi_R \frac{R_{MC}(\Phi_B,\Phi_R)}{B}\theta(k_T(\Phi_B,\Phi_R)-p_T)]} \quad (7)$$

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The resulting new resummed kernels, P_{AB}^{exp}, yield a new resummed scheme for the PDF's and the reduced cross section:

$$F_j, \hat{\sigma} \rightarrow F'_j, \sigma' \, for$$

$$P_{gq}(z) \rightarrow P_{gq}^{exp}(z) = C_F F_{YFS}(\gamma_q) e^{\frac{1}{2}\delta_q} \frac{1+(1-z)^2}{z} z^{\gamma_q}.$$

The new scheme gives the same value for σ with improved Monte Carlo simulation. Here the YFS infrared factor is $F_{YFS} = e^{-C_E a}/\Gamma(1+a)$ where C_E is the Euler's constant.

The coherent state of very soft massless quanta of the respective guage field generated by an accelerated charge makes it impossible to know which of the infinity of the possible states one has made in the splitting process.

$$q(1) \to q(1-z) + G \otimes G_1 ... \otimes G_l, l = 0, ..., \infty$$

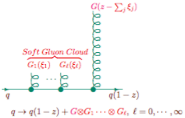

Figure 1: Bloch-Nordsieck soft quanta for an accelerated charge

Consistency Checks

Here we review the comparisons made between Herwiri1.031 and Herwig6.510, both with and without the MC@NLO exact $\mathcal{O}(\alpha_S)$ correction, in relation to the LHC data on the Z/γ^* production with decay to lepton pairs. The unimproved MC requires the very hard value of PTRMS $\cong$ 2.2 GeV to give a good fit to the p_T spectra as well as the rapidity spectra whereas the IR - improved calculation gives a good fit to both the spectra without the need of such a hard value of PTRMS.

Consistency Check

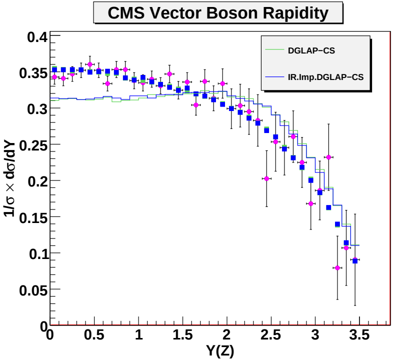

Figure 2: Comparison with the LHC data: CMS rapidity data on (Z/γ^*) production to e^+e^-, $\mu^+\mu^-$ pairs, the circular dots are the data, the green (blue) lines are HERWIG6.510 (HERWIRI1.031)

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Consistency Check

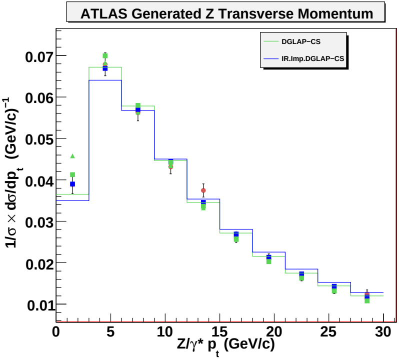

Figure 3: Comparison with the LHC data: ATLAS p_T spectrum data on (Z/γ^*) production to bare e^+e^- pairs, the circular dots are the data, the green (blue) lines are HERWIG6.510 (HERWIRI1.031)

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Consistency Checks

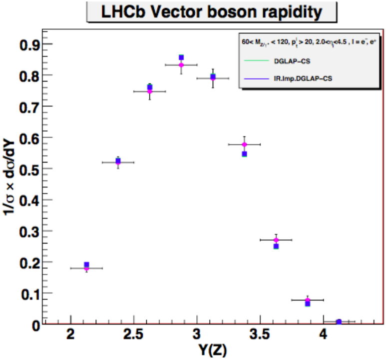

Figure 4: Comparison with the LHCb data: LHCb rapidity data on (Z/γ^*) production to e^+e^- pairs, the circular dots are the data, the green(blue) squares are MC@NLO/ HERWIG6.510 (PTRMS=2.2GeV) (MC@NLO/HERWIRI1.031).

Consistency Check

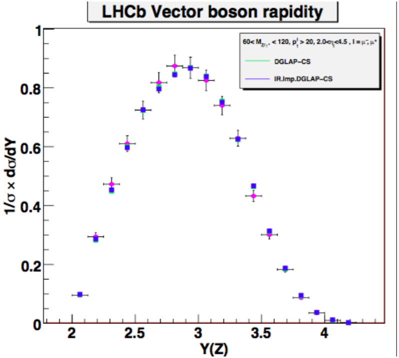

Figure 5: Comparison with the LHCb data: LHCb rapidity data on (Z/γ^*) production to bare $\mu^+\mu^-$ pairs, the circular dots are the data, the green(blue) squares are MC@NLO/HERWIG6.510 (PTRMS=2.2GeV) (MC@NLO/HERWIRI1.031).

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Consistency Check

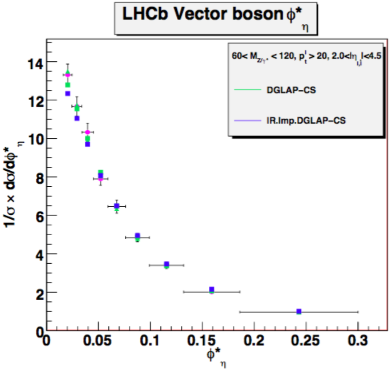

Figure 6: Comparison with LHCb data on ϕ^*_η for the $\mu^+\mu^-$ channel in single Z/γ^* production at the LHC. The legend for the plot is the same as the above figures.

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Consistency Check

In the above case $\phi^*_\eta = tan(\phi_{acop}/2)\sqrt{1 - tanh^2(\Delta\eta/2)}$, where $\Delta\eta = \eta^- - \eta^+$.

η^- is the negatively charged lepton pseudo rapidity and

η^+ is the positively charged lepton pseudo rapidity.

$\phi_a cop = \pi - \Delta\phi$

where $\Delta\phi$ is the azimuthal angle between the two leptons which have transverse momenta $\vec{p}_{iT}$, $i = 1, 2$.

The variable ϕ^*_η is not exactly the same as p_T of the produced Z/γ^* but is correlated with it.

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Consistency Check

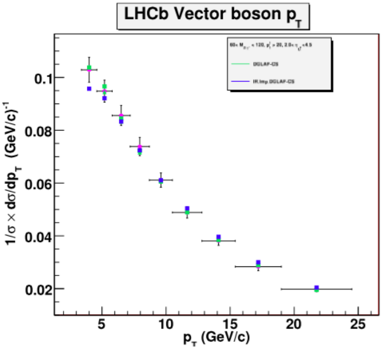

Figure 7: Comparison of the LHCb data on p_T for the $\mu^+\mu^-$ channel in single Z/γ^* production at the LHC. The legend for the plot is same as above.

Conclusion

- What we see in the comparison with the LHCb data is that the situation is similar to what we got for comparison with LHC CMS and ATLAS data where all three calculations give an acceptable fit.
- When we come to the case of ϕ_η^* variable, we see from the $\chi^2/d.o.f$ that curiously the MC@NLO / HERWIG6.5 (PTRMS=0 GeV) gives a better fit that MC@NLO / HERWIG6.5 (PTRMS=2.2 GeV). This underscores the difference between the variable ϕ_η^* and p_T.
- However, when we compare the p_T data, we see that HERWIRI1.031 gives a better fit to the data without the need of an ad hoc hard intrinsic PTRMS.

Conclusion

- We point out here as we have earlier, the fundamental description in MC@NLO / HERWIRI1.031 can be systematically improved to the NNLO parton shower / ME matched level.
- Our comparison with the LHCb data supports the proposition that our method should work in its region of the acceptance phase space as well as they do in the acceptance phase spaces for ATLAS and CMS.

THANK YOU