Threshold resummation in direct photon production and its implications on the large-x gluon PDF

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Currently, the gluon distribution function is mainly constrained by jet data. Yet, its high-x behaviour is largely unknown. This kinematic region is important, for instance, for the understanding of the production of a massive state at forward rapidities at the LHC. In the past, single inclusive direct photon data from fixed target experiments was used to constrain the gluon distribution due to its dominant contribution from the $qg \rightarrow \gamma q$ subprocess in proton-proton collisions. Due to disagreement with its theoretical predictions at next-to-leading order (NLO) in perturbative QCD (pQCD), direct photon data have been excluded from global fits. This talk will discuss an improvement to such theoretical predictions by including threshold resummation at next-to-leading logarithmic accuracy (NLL) and its impact on gluon distribution at large-x using Bayesian reweighting technique.

PRESENTED AT

DPF 2013
The Meeting of the American Physical Society
Division of Particles and Fields
Santa Cruz, California, August 13–17, 2013

1Work supported by de-sc0010102 Dept of Energy.
1 Introduction

The theoretical predictions, of any process at hadron colliders depends on our knowledge of parton distribution functions (PDFs). These functions are currently not computable from first principles but instead they are extracted from data. Such task, commonly known as *global fits*, has been conducted by several collaborations that provide numerical tables for the distributions at different kinematical regions including central values as well as uncertainties that behave differently among the various parton species. In particular, the gluon distribution is unconstrained at high-$x$.

Historically, the information on high-$x$ gluon PDF was originally extracted from the data of single inclusive direct photon production at fixed target experiments. However, these data have largely been excluded from global fits due to disagreement with its theoretical description at NLO in pQCD. As today, the inclusive jet data from Tevatron experiment provides most of the information on the gluon PDF. Yet, its uncertainties at high-$x$ are still significantly large, so that any prediction of observables that are sensitive to the gluon PDF in this region are not reliable. More recently it was shown in Ref. [1] that isolated photon production from collider data can be consistently included in global fits and provides constraints on the gluon PDF in the region $x \sim 0.3$.

The disagreement between fixed target direct photon data and its theoretical calculation might be alleviated by improving the calculation beyond the NLO. One kind of improvement is called *threshold resummation*. Beyond the leading order in pQCD, near partonic threshold when the initial partons have just the enough energy to produce the high-$p_T$ photon, the phase space for extra gluon radiation is limited. As a consequence, the infrared cancellations between the virtual and real contributions are not exact, leaving logs of the form $\alpha_s^k \ln^{2k}(1-z)$ where $z = 1$ is the partonic threshold. The resummation of these threshold logs has been described in Ref. [2, 3] at NLL+NLO.

In this paper we present preliminary results on the potential impact of direct photon data from fixed target experiments on gluon PDF using the theoretical improvement mentioned above. To quantify such impact, we use a reweighting technique, based on Bayesian inference, following the ideas from Ref. [4, 5]. The document is organized as follow: in the next section a summary of the reweighting method is presented. A discussion of the preliminary results are given in Sec. 3. We present the conclusions in Sec. 4.
2 The reweighting method

We start by constructing $N = 100$ random PDFs distributed according to

$$f_k(x) = f_0(x) + \sum_j (f_j^\pm(x) - f_0(x)) |R_{kj}|,$$

(1)

where $f$ labels the various parton species. We will refer to members of the set $\{f_k\}$ as replicas. For simplicity we have dropped the implicit dependence of the PDFs on the factorization scale. The central values are given by $f_0$ and the confidence interval is encoded in the quantities $f_j^\pm$ (See for instance [5]). $R_{kj}$ are normally distributed random numbers with mean zero and variance one. The $\pm$ in $f_j^\pm$ is chosen according to the sign of $R_{kj}$. For each replica, we compute the theoretical predictions for the direct photon data and the corresponding $\chi^2_k$ using the $t_0$-method developed in Ref. [6].

Then, we assign weights of the form

$$w_k \propto \exp\left(-\frac{1}{2} \chi_k^2\right),$$

(2)

to each replica. The weights are normalized by demanding $N = \sum_k w_k$. The impact of direct photon data on gluon PDF can be quantified by computing the weighted expectation values and variances:

$$E[f(x)] = \frac{1}{N} \sum_k w_k f_k(x)$$

$$\text{Var}[f(x)] = \frac{1}{N} \sum_k w_k (f_k(x) - E[f(x)])^2.$$  

(3)

The corresponding quantities without reweighting (or equivalently unweighted) are obtained by setting all the weights equal to one.

3 Preliminary results

Here, we present the impact of the UA6 experiment ($pp \rightarrow \gamma + X \sqrt{s} = 24.3$ GeV) [7] on the Cteq6m gluon PDF [8]. In Fig. [1] we have plotted the invariant cross section (ICS) as a function of $p_T$. The plot also includes the theory predictions from the replicas and the corresponding unweighted and weighted expectation values labeled as E[ICS] and E[ICS|UA6] respectively. The renormalization and factorization scales have been set equal to $p_T$. The fact that the expectation values are close to each other implies a good agreement between the UA6 data and its theoretical predictions at NLO+NLL.
In Fig. 2 we present the gluon PDF uncertainty band (before and after the reweighting) at $Q = 10$ GeV as a function of $x$. In both cases we normalized respect to the expectation value from the unweighted results. Clearly a significant reduction in the uncertainty band is observed due to the presence of the UA6 data (the kinematic coverage is shown in the plot as a shaded region). The sensitivity of gluon PDF with direct photon data is expected since its production in proton-proton collisions is dominated by the $qg \rightarrow \gamma q$ subprocess. In Fig. 3 we have plotted a similar figure as Fig. 2 for the up quark distribution. In this case, since the up quark distribution is relatively well constrained in the kinematic region of UA6 data, the latter does not provide new information on the up quark PDF.

Figure 1: Invariant cross section (ICS) vs. $p_T$. The grey curves are the predictions from the replicas. The best replica (the one with the highest weight) is plotted as dashed magenta curve. $E[ICS]$ and $E[ICS|UA6]$ are the expectation values for the unweighted and weighted replicas respectively.
Figure 2: Top: Gluon PDF uncertainty bands normalized to the expectation value of unweighted gluon PDF. The grey band corresponds to the region of UA6 direct photon data. Bottom: ratio of reweighted variance ($\sigma_{rw}$) over unweighted variance ($\sigma_{uw}$).

4 Conclusion

We have presented a preliminary results on Cteq6m gluon PDF reweighting using the data of single inclusive direct photon production from the UA6 experiment. The theoretical predictions for the data has been computed using threshold resummation at NLL+NLO in pQCD. After reweighting, a significant reduction in gluon PDF uncertainty is observed. Further analysis exploring other PDFs sets will be presented in a future work (in preparation).
Figure 3: Same as Fig. 2 for Up quark PDF.

References

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