Role of the screening gluon in dijet CEP

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Central exclusive production

The main interest in CEP is the possibility to observe the light Higgs boson at the LHC in a very clean environment:

$$pp \to p + H(\to b\bar{b}) + p\,.$$

But CEP of other systems is also important:

- QCD $b\bar{b}$ CEP is an irreducible background for the Higgs signal;
- dijet (gg) CEP has much larger cross section; it offers an important check of theoretical calculations of CEP.

Calculating CEP

Standard four-step scheme for CEP production of system X:

1. Calculate partonic-level $qq \to q + X + q$;
2. Put quarks into protons by introducing unintegrated gluon densities;
3. Take into account double-log enhanced high-order corrections via the Sudakov factor;
4. Account for rescattering corrections by introducing gap survival probability;

An additional step for dijet production: convert gg into jj.

Calculating CEP (cont.)

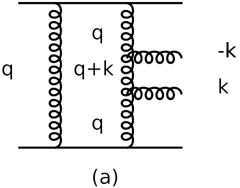
Most of the works on CEP are devoted to the rescattering corrections and the gap survival probability, while the other steps are usually believed to be under control. In fact, this is not so. Our previous study shows that:

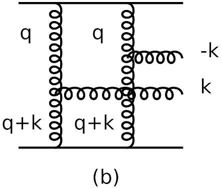
- roughly half of the cross section comes from soft region $\rightarrow$ strong sensitivity to the parametrization of the unintegrated gluon densities.
- log^2-terms, log-terms and constant terms in the Sudakov logarithm are of the same order;

But what I will discuss here is the possibility that even the partonic-level description of CEP might be more tricky than usually assumed.

Lowest order diagrams for $qq \to qqgg$

Consider CEP of color-singlet gg pair.





Consider the lower order diagrams that contribute to the imaginary part of the amplitude. For the sake of illustration, I focus only on the forward quark scattering.

gg are produced in midrapidity, $E_T \approx |\mathbf{k}| \sim \sqrt{s_{gg}}$.

Lowest order diagrams for $qq \to qqgg$ (cont.)

Diagram A:

$$\text{Im}\ M_A = C\frac{s}{\mathbf{k}^2}\int\frac{d^2\mathbf{q}}{(\mathbf{q}^2)^2}\sum_{\lambda_1'\lambda_2'} e^{-i(\lambda_1'-\lambda_2')\phi_{\mathbf{q},\mathbf{k}}}\cdot A(\lambda_1'\lambda_2'\to\lambda_1\lambda_2)\,,$$

where $A(\pm,\pm\to\pm,\pm) = 1$,
$A(\pm,\mp\to\pm,\mp) = (u_{gg}/s_{gg})^2$,
$A(\pm,\mp\to\mp,\pm) = (t_{gg}/s_{gg})^2$.
A rough estimate:

$$\text{Im}\ M_A \propto \frac{s}{\mathbf{k}^2}\cdot\frac{1}{\mu^2}\,,\quad \lambda_1=\lambda_2\,.$$

where μ^2 is a (moderately) soft scale.

Lowest order diagrams for $qq \to qqgg$ (cont.)

Diagram B:

$$\text{Im } M_B = C \frac{s}{\mathbf{k}^2} \int \frac{d^2\mathbf{q}}{\mathbf{q}^2(\mathbf{q}+\mathbf{k})^2} e^{-i(\lambda_1+\lambda_2)\phi_{\mathbf{q},\mathbf{q}+\mathbf{k}}} \,,$$

where $\phi_{\mathbf{q},\mathbf{q}+\mathbf{k}}$ is the azimuthal angle between $\mathbf{q}$ and $\mathbf{q}+\mathbf{k}$.

- It has an extra $\mathbf{k}^2$ suppression,
- but it is enhanced by an extra log;
- and it has a very different helicity structure.

Lowest order diagrams for $qq \to qqgg$ (cont.)

Transverse momentum integral

$$\int \frac{d^2\mathbf{q}}{\mathbf{q}^2(\mathbf{q}+\mathbf{k})^2} \to \frac{1}{\mathbf{k}^2}\log\frac{\mathbf{k}^2}{\mu^2}\,.$$

When unintegrated gluon densities are inserted, one gets:

$$\int \frac{d^2\mathbf{q}}{\mathbf{q}^2(\mathbf{q}+\mathbf{k})^2}\mathcal{F}(x,\xi,\mathbf{q})\mathcal{F}(\bar{x},\bar{\xi},\mathbf{q}+\mathbf{k})$$
$$\to \frac{1}{\mathbf{k}^2}G(x,\xi,\mathbf{k})\mathcal{F}(\bar{x},\bar{\xi},\mathbf{k})\,.$$

NB: these off-forward distributions are in the region $x < \xi$ as all the gluons are emitted from the protons. To reliably estimate gluon distribution in this regime is an additional non-trivial task.

Lowest order diagrams for $qq \to qqgg$ (cont.)

Helicity structure

$$\int \frac{d^2\mathbf{q}}{\mathbf{q}^2(\mathbf{q}+\mathbf{k})^2} \cdot \exp[-i(\lambda_1+\lambda_2)\phi_{\mathbf{q},\mathbf{q}+\mathbf{k}}]\,.$$

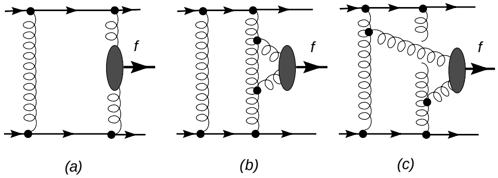
The above estimate was for the dominant contribution of $\lambda_1 = -\lambda_2$, i.e. total helicity-2 state.
Total helicity-0 contribution is suppressed:

$$\int \frac{d^2\mathbf{q}}{\mathbf{q}^2(\mathbf{q}+\mathbf{k})^2} \cos(2\phi_{\mathbf{q},\mathbf{q}+\mathbf{k}}) = 0\,.$$

If gluon propagators are regularized at soft scale μ^2, then

$$\int \frac{d^2\mathbf{q}}{(\mathbf{q}^2)_R(\mathbf{q}+\mathbf{k})^2_R} \cos(2\phi_{\mathbf{q},\mathbf{q}+\mathbf{k}}) \sim \frac{\mu^2}{\mathbf{k}^4}\,.$$

CEP via an intermediate gg^* production

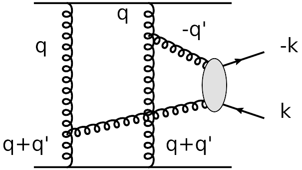


If system f can be produced in CEP via the "standard" mechanism (a,b), it can also be produced via an intermediate gg^* production in multi-Regge-kinematics.

- (a) standard mechanism;
- (b) one-loop Sudakov correction;
- let's focus on diagram such as (c).

$q\bar{q}$ CEP via intermediate gg^*

Let us focus on $q\bar{q}$ CEP.



Again, we look at the imaginary part of the amplitude.
One of the intermediate gluons is set on-shell by taking a residue for an integral over one of the lightcone variable.

$q\bar{q}$ CEP via intermediate gg^* (cont.)

Schematic expression:

$$\mathrm{Im}\ M \quad \propto \quad \alpha_s \frac{s}{s_{gg}} \sum_{\lambda_1,\lambda_2} \int \frac{d^2\mathbf{q}\ d^2\mathbf{q}'}{[\mathbf{q}^2(\mathbf{q}+\mathbf{q}')^2]^2} \int_0^1 \frac{d\xi}{\xi}$$
$$\times C_1^\mu e_\mu^*(\lambda_1) \cdot C_2^\nu e_\nu^*(\lambda_2) \cdot M(g_{\lambda_1} g^*_{\lambda_2} \to q\bar{q})\,.$$

Helicities: $\lambda_1 = \pm$, $\lambda_2 = \pm, 0$.
ξ and $1-\xi$ are the fractions of lightcone variable of $q\bar{q}$ carried by the colliding gluons.
Virtuality of g^* is $Q^2 \approx s_{gg}\xi$.

Non-local vertex for g^* emission (C_2^ν) from a t-channel gluon can still be used (with $\alpha_2\beta_2 s \neq \mathbf{q}'^2$) thanks to strong longitudinal ordering.

Example of $q\bar{q}$ CEP

Standard contribution to $q\bar{q}$ CEP is strongly suppressed by small quark mass: due to $\lambda_1 = \lambda_2$ rule, the standard amplitude is of order

$$\frac{s}{\mathbf{k}^2} \cdot \frac{m_q}{|\mathbf{k}|} \,.$$

Let's check contribution of various helicities in the new diagram with massless quarks.

Equal helicities: $\lambda_1 = \lambda_2$.
$M(gg^* \to q\bar{q}) \propto Q^2/s_{gg} = \xi$. The amplitude is of order:

$$\alpha_s \frac{s}{\mathbf{k}^2} \int \frac{d^2\mathbf{q}\; d^2\mathbf{q}'}{\mathbf{q}^2\mathbf{q}'^2(\mathbf{q}+\mathbf{q}')^2} \cos(2\phi_{\mathbf{q},\mathbf{q}+\mathbf{q}'}) \int \frac{d\xi}{\xi} \cdot \xi \sim \alpha_s \frac{s}{\mathbf{k}^2} \frac{1}{\mu^2} \,.$$

Example of $q\bar{q}$ CEP (cont.)

Opposite helicities: $\lambda_1 = \lambda_2$.
$M(gg^* \to q\bar{q}) \sim 1$, but an additional azimuthal dependence appears.

$$\int \frac{d^2\mathbf{q}\ d^2\mathbf{q}'}{\mathbf{q}^2\mathbf{q}'^2(\mathbf{q}+\mathbf{q}')^2} \int \frac{d\xi}{\xi} \cdot |M(gg^* \to q\bar{q})| \cdot \cos(2\phi_{\mathbf{q}',\mathbf{k}})\,.$$

The azimuthal integration kills the leading power in $\mathbf{k}$. Correlation between $\mathbf{q}'$ and $\mathbf{k}$ is needed:

$$|M(gg^* \to q\bar{q})| \to \frac{\mathbf{q}'^2}{\mathbf{k}^2} \cos^2\phi_{\mathbf{q}',\mathbf{k}}\,.$$

The amplitude is of order

$$\alpha_s \frac{s}{\mathbf{k}^4} \int \frac{d^2\mathbf{q}}{\mathbf{q}^2} \frac{d^2\mathbf{q}'}{(\mathbf{q}+\mathbf{q}')^2} \int \frac{d\xi}{\xi} \sim \alpha_s \frac{s}{\mathbf{k}^4} \left(\log \frac{\mathbf{k}^2}{\mu^2}\right)^3 \,.$$

Example of $q\bar{q}$ CEP (cont.)

Longitudinal helicity: $\lambda_1 = 0$.

Potentially important: $M(gg^* \to q\bar{q}) \propto Q/\sqrt{s_{gg}} = \sqrt{\xi}$, but $C_\mu e_L^\mu \propto \sqrt{\xi s_{gg}} \gg C_\mu e_\pm^\mu$. Their product is $\xi\sqrt{s_{gg}}$.

However, $M(gg_L^* \to q\bar{q})$ does not depend on angles apart from $e^{-i\lambda_1\phi_{\mathbf{q}',\mathbf{k}}}$ factor $\to$ no extra correlation between $\mathbf{q}'$ and $\mathbf{k}$ compensates $e^{-i\lambda_1\phi_{\mathbf{q}',\mathbf{k}}}$.

$\to$ the longitudinal polarization does not contribute.

Example of $q\bar{q}$ CEP (cont.)

Overall comparison:

standard	new: $\lambda_1 = \lambda_2$	new: $\lambda_1 = -\lambda_2$
$\frac{m_q}{E_T}$	$\alpha_s \cdot \mathcal{O}(1)$	$\alpha_s \cdot \frac{\mu^2}{E_T^2} \log^3 \frac{E_T^2}{\mu^2}$

NB: for $E_T = 50$ GeV, $\mu \sim 0.5$ GeV, $\log(E_T^2/\mu^2) \approx 10$

- Even for $b\bar{b}$, the new contribution might be as large as the standard one.
- There is equally strong production of light quark pairs.
- Cannot be reduced by selecting forward protons.

These diagrams must be taken seriously when estimating $q\bar{q}$ CEP.

Role of the screening gluon in gg production

gg CEP

- gg CEP is not suppressed by the helicity selection rule $\longrightarrow$ the effect of the new diagrams is not as important as in $q\bar{q}$ production.
- Still, equal helicity configuration leads to a NLO single-log enhanced contribution $\longrightarrow$ can be viewed as an additional single-log contribution to the Sudakov form factor due to the presence of the screening gluon.
- Opposite helicity configuration leads to a NLO $\log^3$ term similar to $q\bar{q}$ CEP $\longrightarrow$ a double-log correction to diagram B in gg CEP.

Conclusions

- The screening gluon might play an active role in CEP if the leading diagram is suppressed, e.g. in $q\bar{q}$ production.
- Initial estimates show there are new contributions to the $b\bar{b}$ production, which might be as important as the standard diagrams.
- The similar class of diagrams leads also to an additional single-log correction to the Sudakov logarithm in gg CEP.
- Accurate numerical estimates of these contributions are going to be difficult, as they involve off-forward gluon distributions in the unusual domain $x < \xi$.