Diffractive Production of Heavy Flavors

Boris Kopeliovich
Ivan Schmidt
QCD factorization in Diffraction

Ingelman-Schlein picture of diffraction.

DIS on a proton (inclusive $\gamma^* + p \rightarrow X$) provides the distribution of partons in the proton.

Therefore, DIS on the Pomeron (diffraction $\gamma^* + p \rightarrow X + p$) provides the distribution of partons in the Pomeron.

Once the parton densities in the Pomeron are known, one can predict the cross section of any hard hadronic reaction. For instance (A.Donnachie & P.Landshoff),

$$\sigma_{sd}^{DY}(pp \rightarrow \bar{\ell}\ell\ X\ p) = G_{\bar{\ell}}/p \otimes F_{\bar{\ell}}/\bar{\ell} \otimes F_{\ell}/p \otimes \hat{\sigma}(\bar{q}q \rightarrow \bar{\ell}\ell).$$
QCD factorization in Diffraction

Breakdown of factorization.

This naive picture fails due to composite-ness of the Pomeron (J.Collins, L.Frankfurt & M.Strikman). The usual assumption that only one parton participates in the hard interaction, while other partons in the hadron are spectators, apparently is not correct for the Pomeron which may interact as a whole.

The full calculation of relevant graphs (F.Yuan & K.-T.Chao) misses, however, the interaction with the spectator partons which leads to:

- Dependence of hard diffraction on the hadronic size;
- Leading twist behavior, $1/Q^4 \Rightarrow 1/Q^2$. 
Heavy Flavors

Bremsstrahlung and Production mechanisms in inclusive production of heavy flavors by a projectile parton (quark or gluon)

\[ M_{Br} = M_1 + M_2 + \frac{Q^2}{M^2 + Q^2} M_3 \]

\[ M_{Pr} = \frac{M^2}{M^2 + Q^2} M_3 + M_4 + M_5 \]
Diffractive Heavy Flavors

Higher twist bremsstrahlung mechanism in diffraction: radiation of a $\bar{Q}Q$ pair by an isolated parton.

\[ \sigma \sim \frac{1}{m_Q^4} \]

Higher twist

Leading twist bremsstrahlung mechanism in diffraction:

\[ \sigma \sim \frac{1}{m_Q^2} \]

Leading twist
Diffractive Heavy Flavors

Production mechanism in diffraction:

\[ \sigma \propto \frac{1}{m_Q^2} \]

Leading twist
Diffractive Heavy Flavors

Previous calculations missed the leading twist contribution $\sigma \propto 1/m_Q^2$, resulting from interaction with spectator partons.

The distance between the spectator parton and the heavy pair is large, $\tilde{\rho} \sim 1/\Lambda_{QCD}$, while the $\bar{Q}Q$ separation is very small $r \sim 1/m_Q$. Thus, two gluons (blue) in the figure are soft, and only one (red) is hard. The leading twist behavior results from interference of the two sizes.

Similar situation occurs in heavy flavor production in diffractive DIS: the heavy quarks are created far away from the electron.
Data

- Measurements at ISR led to an amazingly large (probably incorrect) cross section of diffractive charm production (K.L. Giboni et al. 1979), $\sigma \sim 10 - 60 \mu b$. This experiment was an order of magnitude above the subsequent data for inclusive charm production.

- The E653 experiment found no diffractive charm in $p - Si$ collisions at 800 GeV. There is almost no $A$-dependence between hydrogen and silicon, so $\sigma \leq 26 \mu b$
Data

- Measurements at ISR led to an amazingly large (probably incorrect) cross section of diffractive charm production (K.L. Giboni et al. 1979), \( \sigma \sim 10 - 60 \mu\text{b} \). This experiment was order of magnitude above the subsequent data for inclusive charm production.

- The E653 experiment found no diffractive charm in \( p - Si \) collisions at 800 GeV. There is almost no \( A \)-dependence between hydrogen and silicon, so \( \sigma \leq 26 \mu\text{b} \)

- The E690 experiment reported the diffractive charm cross section at \( \sigma = 0.61 \pm 0.12 \pm 0.11 \mu\text{b} \) at 800 GeV. Agrees well with our calculations.
The CDF experiment measured the fraction of diffr activel y produced beauty, at approximately $R_{diff/tot}^{b\bar{b}} = (1 \pm 0.5)\%$, at $\sqrt{s} = 1.8$ TeV. The total cross section of beauty production at this energy has not been measured so far. If to rely on the theoretical prediction based on dipole model calculations, $\sigma_{tot}^{b\bar{b}} = 140$ mb, then $\sigma_{diff}^{b\bar{b}} \approx 1.4 \pm 0.7$ mb. This estimate agrees rather well with our results, but contradicts by an order of magnitude the higher twist mass dependence $\sigma_{diff}^{b\bar{b}} \propto 1/m_Q^4$. 
Results

\[ \sigma_{\text{diff}} (\mu b) \]

\[ \sqrt{s} \text{ (GeV)} \]

- charm
- beauty
- top
$x_1 = p_c^+ / p_p^+$
Results

![Graph showing the relationship between $d\sigma / dp_T^2$ (µb/GeV²) and $p_T^2$ (GeV²) for charm particles at different energies (500 GeV, 2000 GeV, 1400 GeV).]
Results

\[ \frac{d\sigma}{dp_T^2} \text{ (} \mu\text{b}/\text{GeV}^2) \]

- beauty
- 1400 GeV
- 2000 GeV
- 500 GeV

\[ p_T^2 \text{ (GeV}^2) \]

\[ 40 \quad 80 \quad 120 \quad 160 \quad 200 \]
Results

![Graph showing the relationship between $d\sigma / dp_T^2$ (µb/GeV²) and $p_T^2$ (GeV²) for different energies: 1400 GeV and 2000 GeV. The graph indicates a decrease in $d\sigma / dp_T^2$ as $p_T^2$ increases.]
pA collisions

\[
\sigma^{pA}_{sd}(pA \rightarrow X\bar{Q}QA) = A_{\text{eff}} \sigma^{pp}_{sd}(pA \rightarrow X\bar{Q}Qp)
\]

\[
A_{\text{eff}} = 16\pi B_{sd} \int d^2b \ T_A^2(b) \left\langle e^{-\sigma_{ri}T_A(b)/2} \right\rangle_{r_i}^2
\]

\[B_{sd} = 12 \text{ GeV}^{-2}\]

\[A_{\text{eff}} \approx 10.\]
Conclusions

- Novel leading twist mechanism of heavy flavor diffractive production.
- Factorization broken.
- Two mechanisms identified: bremsstrahlung and production.
- Interaction with spectators is important.
- Available data agree with our calculations.
- Straightforward application to high-pt jets.