Forward Drell-Yan and backward jet production as a probe of the BFKL dynamics

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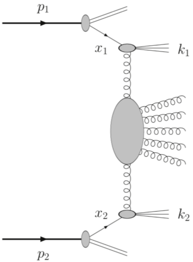
Plan

- Mueller-Navelet jets
- Motivation for DY+jet studies
- Presentation of the numerical results

- Two forward/backward jets separated by large rapidity interval ΔY



$$\frac{d\sigma^{MN}}{dY_1 dY_2 d^2k_1 d^2k_2} = f_{\text{eff}}(x_1,k_1) \otimes \Phi^{(J)}(x_1,k_1) \otimes G(k_1,-k_2,\Delta Y) \otimes \Phi^{(J)}(x_2,k_2) \otimes f_{\text{eff}}(x_2,k_2)$$

- $\Phi^{(J)}$ is jet impact factor and G is the BFKL Green function

$$G(k_1,-k_2,\Delta Y) = \left[C_0 + 2\sum_{m=1}^{\infty} \cos(m(\pi - \Delta\phi_{jj})\, C_M\right]$$

Azimuthal angle decorrelation

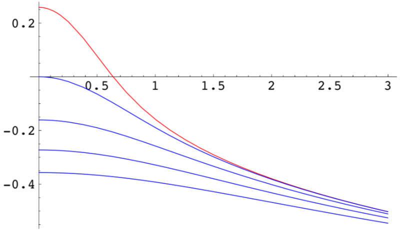
$$G(k_1, -k_2, \Delta Y) = \left[C_0 + 2 \sum_{m=1}^{\infty} \cos(m(\pi - \Delta\phi_{jj})\, C_M \right]$$

- Studies of decorrelation in the azimuthal angle between jets $\Delta\phi_{jj}$.

  Stirling, Del Duca, Schmidt, Kwieciński, Motyka, Martin, Bartels, Colferai, Vacca, Sabio Vera, Szymanowski, Walon, Ducloue, D. Yu. Ivanov, Papa, Capolare, Celiberto,. . .

- Fourier coefficients with BFKL equation kernel eigenvalues $\omega_m(\nu)$

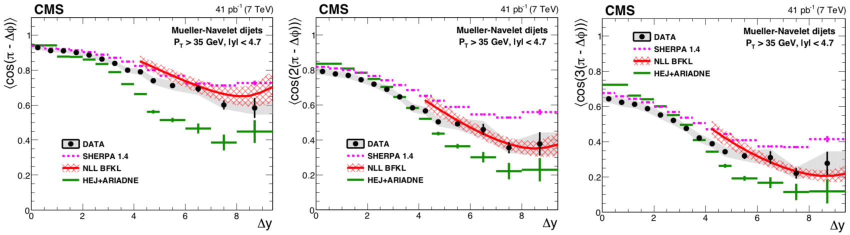
$$C_m(|k_1|, |k_2|, \Delta Y) = \int_0^{\infty} d\nu \, \exp(\omega_m(\nu)\Delta Y) \, \cos(\nu \ln(k_1^2/k_2^2))$$



- Angular decorrelation measured by CMS through

$$\frac{1}{\sigma^{MN}}\frac{d\sigma^{MN}}{d\Delta\phi} = \frac{1}{2\pi}\left\{1 + 2\sum_{m=1}^{\infty}\cos(m(\pi - \Delta\phi))\frac{C_m}{C_0}\right\}$$

$m = 1$ $\qquad$ $m = 2$ $\qquad$ $m = 3$

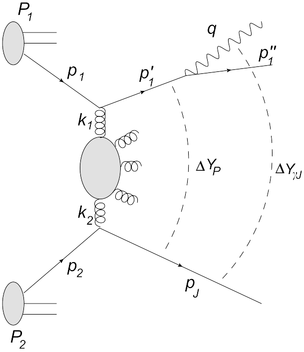


- Red curves from BFKL calculations of Ducloué, Szymanowski and Wallon.

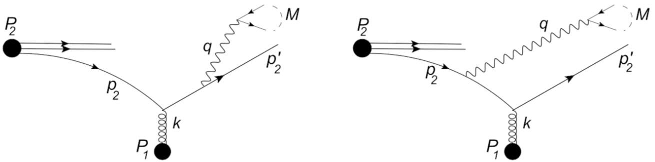
More in Alessandro Papa talk

Drell-Yan lepton pair + jet production

- Replace one of the jets by forward/backward DY lepton pair



- DY pair is more versatile probe than jet itself.

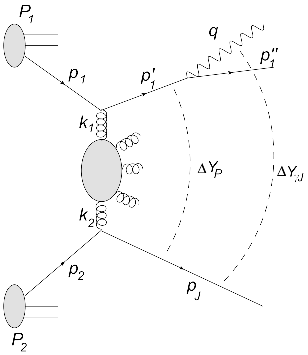


- Helicity structure functions from lepton pair angular dependence in its CM frame $\Omega = (\theta, \phi)$:

$$\left(\frac{d\sigma^{DY}}{d^4q\, d\Omega}\right)_{CM} \sim \Big[(1-\cos^2\theta) W_L + (1+\cos^2\theta) W_T + (\sin^2\theta\cos 2\phi) W_{TT} + (\sin 2\theta \cos\phi) W_{LT}\Big]$$

- Integration over leptonic angles gives Lorentz invariant combination

$$\frac{d\sigma^{DY}}{d^4q} \sim W_T + \frac{W_L}{2}$$



- ΔY_P is an argument of the BFKL kernel while $\Delta Y_{\gamma J}$ is measured

$$\Delta Y_P = \ln\left(\frac{z(1-z)x_1x_2S}{M^2(1-z)+q_T^2+z(k_{1\perp}^2-2\vec{k}_{1\perp}\cdot\vec{q}_T)}\right), \qquad z = \frac{p_{J\perp}\sqrt{M^2+q_T^2}}{x_1x_2S}\,e^{\Delta Y_{\gamma J}}$$

- Theoretical ΔY_P depends on measured $\Delta Y_{\gamma J}$.

DY+jet helicity structure functions

- Helicity structure functions for DY+jet are differential in jet variables

$$W_\lambda \;\to\; \frac{dW_\lambda}{d(\Delta Y_{\gamma J})\, d^2 p_J}\,, \qquad\qquad \lambda = T, L, TT, LT$$

- Explicitly

$$\frac{dW_\lambda}{d(\Delta Y_{\gamma J})\, d^2 p_J} = \frac{4\alpha_{em}^2\alpha_s^2}{(2\pi)^4}\,\frac{1}{M^2 p_J^2}$$
$$\times \int dx_1 \int \frac{dx_2}{x_2} \sum_f e_f^2 \Big\{ q_f(x_1, M_\perp) + \bar{q}_f(x_1, M_\perp) \Big\} f_{\text{eff}}(x_2, M_\perp)\, \theta(1-z)$$
$$\times \int \frac{d^2 k_1}{k_1^2}\, \Phi_\lambda^{(\gamma J)}(q_\perp, k_1, z)\, G(k_1, -p_J, \Delta Y_P)\, \Phi^{(J)}(p_J)$$

- $\Phi_\lambda^{(\gamma J)}$ are known LO γ+jet impact factors and $q_\perp$ is photon transverse momentum.
- G is the BFKL Green functions characterized by the eigenvalues $\omega_m(\nu)$.

Eigenvalues $\omega_m(\nu)$ - three cases considered

- The LLA solution

$$\omega_m(\nu) = \overline{\alpha}_s \left[2\psi(1) - \psi\left(\frac{m+1}{2} + i\nu\right) - \psi\left(\frac{m+1}{2} - i\nu\right)\right]$$

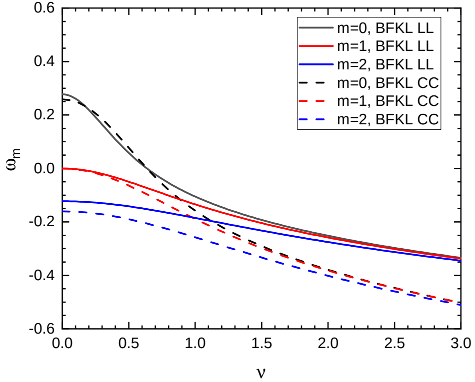
- Consistency constraint (CC) in BFKL kernel gives the equation for $\omega_m(\nu)$

$$\omega = \overline{\alpha}_s \left[2\psi(1) - \psi\left(\frac{m+\omega+1}{2} + i\nu\right) - \psi\left(\frac{m+\omega+1}{2} - i\nu\right)\right]$$

- The LO-Born approximation (two gluon exchange)

$$G(k_1, k_2) = |k_1|\,|k_2|\,\delta^2(k_1 + k_2)$$

BFKL solutions - $\omega_m(\nu)$



- For $\bar{\alpha}_s = 0.1$ for LL and $\bar{\alpha}_s = 0.15$ for CC, $\omega_0(0) \approx 0.27$
- Similar results for LL and CC solutions

Angular decorrelation in DY+jet process

- Cross section integrated over over lepton angles

$$\sigma(\phi_{\gamma J}) \equiv \frac{dW_T}{d(\Delta Y_{\gamma j})dp_J^2} + \frac{1}{2}\frac{dW_L}{d(\Delta Y_{\gamma j})dp_J^2}$$

where $\phi_{\gamma J}$ azimuthal angle between photon $q_\perp$ and jet $p_{J\perp}$

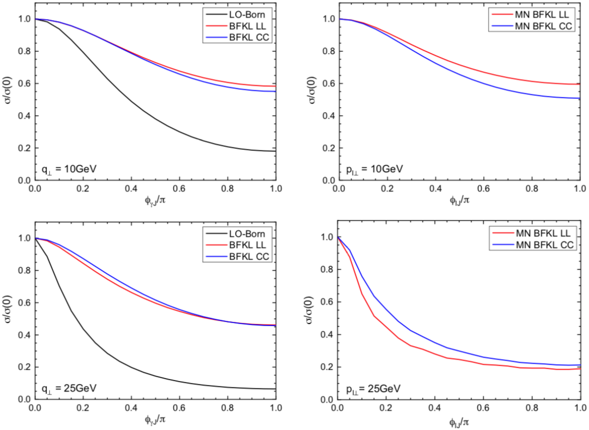
- We study the normalized ratio for the LHC $\sqrt{S} = 13\,\mathrm{TeV}$

$$\frac{\sigma(\phi_{\gamma J})}{\sigma(0)}$$

- Angular decorrelation - flat distribution in $\phi_{\gamma J}$

Angular decorrelation: DY+jet versus MN jets

DY+ j　　　　　　MN



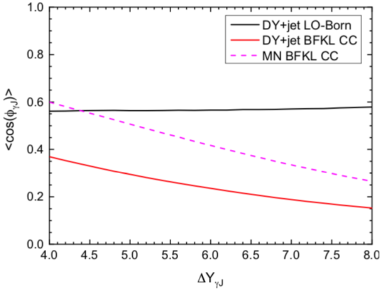
$$p_{J\perp} = 30\ \mathrm{GeV}, \quad M = 35\,\mathrm{GeV}, \quad \Delta Y_{\gamma J} = \Delta Y_{MN} = 7$$

- Stronger decorrelation for DY+j than for MN jets.

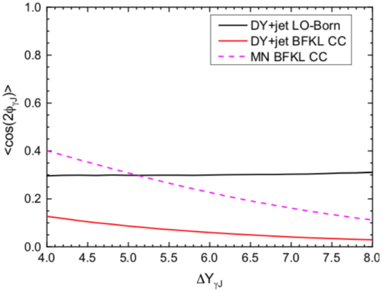
Angular decorrelation as a function $\Delta Y_{\gamma j}$

- Given in terms of mean cosines: $\langle \cos(m\phi_{\gamma J})\rangle = C_m/C_0$.
- Back-to-back: $C_m/C_0 = 1$. Angular decorrelation: $C_m/C_0 < 1$

$m = 1$



$m = 2$



$q_\perp = p_{l\perp} = 25\,\mathrm{GeV}, \qquad p_{J\perp} = 30\,\mathrm{GeV}, \qquad M = 35\,\mathrm{GeV}$

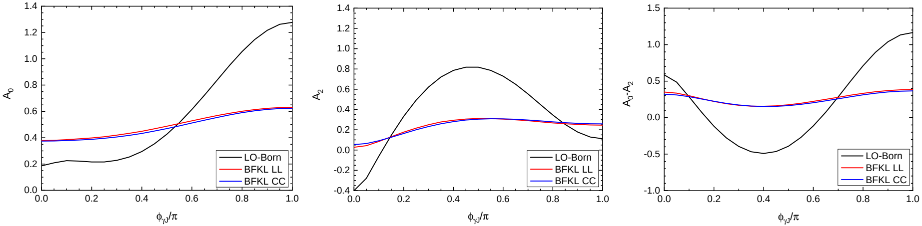
- Stronger decorrelation for DY+j than for MN jets.

DY+ jet helicity structure functions

- From angular dependence of DY lepton pair helicity structure functions

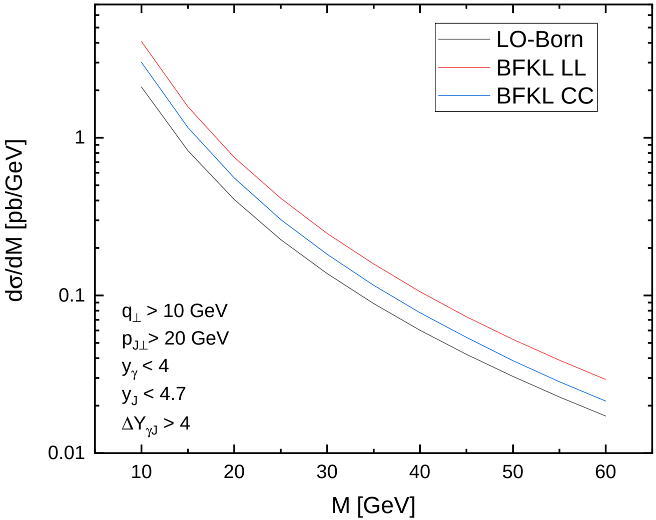
$$A_0(\phi_{\gamma j}) = \frac{W_L}{W_T + W_L/2}\,, \qquad A_1 = \frac{W_{LT}}{W_T + W_L/2}\,, \qquad A_2 = \frac{2W_{TT}}{W_T + W_L/2}$$

- Lam-Tung relation: $A_0 - A_2 = 0$



- Additional information about BFKL effects.

Total cross section



Summary and outlook

- We propose to study forward/backward DY+ jet to test BFKL dynamics
- More observables than for MN jets and cleaner experimental signature
- Angular decorrelation in γ^*–jet angle found stronger than for MN jets
- Angular coefficients of DY lepton pair strongly sensitive to BFKL dynamics
- Outlook: NLO/NLL analysis

Thank you!

Backup

Photon+jet impact factors in Gottfried-Jackson frame

- More complicated than the jet impact factor in the MN process

$$\Phi_L^{(\gamma J)} = 2\left[\frac{M(1-z)}{D_1} - \frac{M(1-z)}{D_2}\right]^2$$

$$\Phi_T^{(\gamma J)} = \frac{1+(1-z)^2}{2}\left[\frac{q_\perp}{D_1} - \frac{q_\perp - zk_{1\perp}}{D_2}\right]^2$$

$$\Phi_{LT}^{(\gamma J)} = -(2-z)\left(\frac{M(1-z)}{D_1} - \frac{M(1-z)}{D_2}\right)\left(\frac{q_\perp}{D_1} - \frac{q_\perp - zk_{1\perp}}{D_2}\right)\cdot e_x$$

$$\Phi_{TT}^{(\gamma J)} = \left\{\left[\left(\frac{q_\perp}{D_1} - \frac{q_\perp - zk_{1\perp}}{D_2}\right)\cdot e_x\right]^2 - \left[\left(\frac{q_\perp}{D_1} - \frac{q_\perp - zk_{1\perp}}{D_2}\right)\cdot e_y\right]^2\right\}$$

where

$$D_1 = (1-z)M^2 + q_\perp^2\,, \qquad D_2 = (1-z)M^2 + (q_\perp - zk_{1k_\perp})^2$$

and

$$z = q^+/p_1^+$$