Produkcija fotona u visokoenergijskim proton-jezgra sudarima

Samostalni seminar iz istraživanja u fizici

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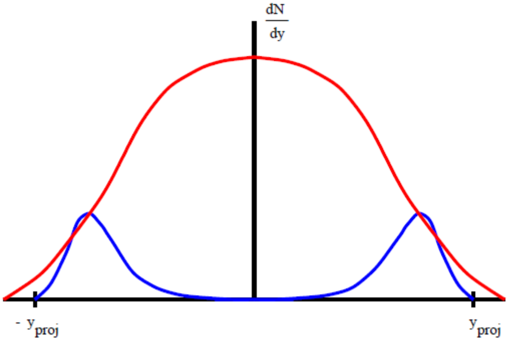
Fizika malog x

- distribucija proizvedenih čestica u hadron-hadron sudarima



Koordinate svjetlosnog stošca

- $x^\mu=(x^0,x^1,x^2,x^3)$
- Koordinate svjetlosnog stošca:

$$x^\pm = \frac{1}{\sqrt{2}}(x^0 \pm x^3) \tag{1}$$

- Skalarni produkt:

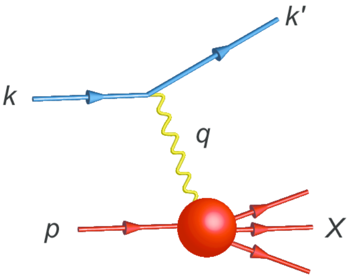
$$p \cdot x = p^- x^+ + p^+ x^- - \boldsymbol{p}_\perp \cdot \boldsymbol{x}_\perp \tag{2}$$

- $\eta_{\mu\nu}=diag(1,\text{-}1,\text{-}1,\text{-}1)$

Duboko neelastično raspršenje

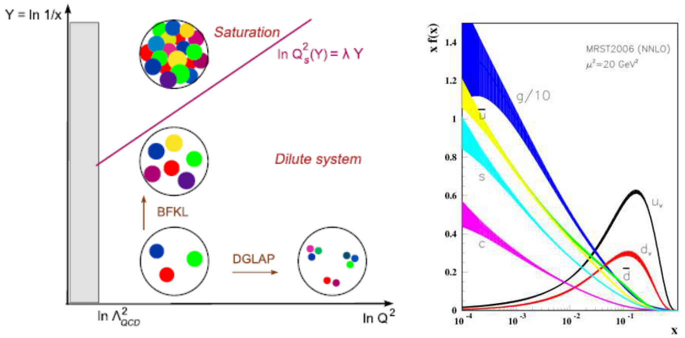
- varijable: x, Q^2, y, s

$$x = \frac{Q^2}{sy}$$



Fazni prostor hadrona

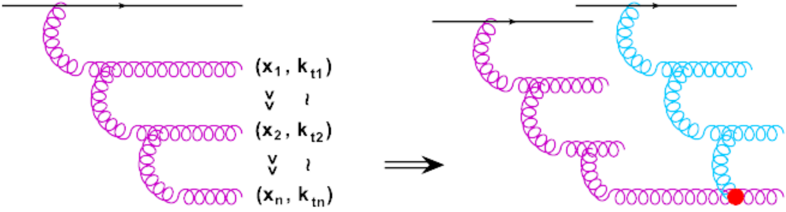
- Bjorkenov limes: fiks. x sa Q^2, $s \to \infty$
- Regge-Gribov limes: fiks. Q^2, $x \to 0$ i $s \to \infty$



Saturacija

- Saturacijska skala:

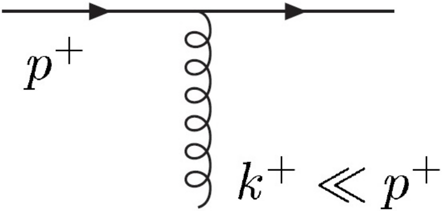
$$Q_s^2 \sim \frac{\alpha_s x G(x, Q_s^2)}{\pi R^2} \sim A^{1/3} \quad (3)$$



- $\alpha(Q_s^2) \ll 1$

Staklasti kondenzat boje

- Skala Λ_+ dijeli na:
- brze izvore boje ρ ($p^+ > \Lambda_+$) i dinamička polja A^μ gluona ($k^+ < \Lambda_+$)



Staklasti kondenzat boje

$$W_{MV}[\rho] \equiv \exp\left[-\int dx^- d^2x_\perp \frac{\rho_a(x^-, x_\perp)\rho^a(x^-, x_\perp)}{2\mu^2(x^-)} \right] \tag{4}$$

$$Q_s^2 = \frac{g^2 C_F}{2\pi} \mu_A^2 \tag{5}$$

$$\langle A[\rho] \rangle_\rho = \int [\mathcal{D}\rho]\, W[\rho]\, A[\rho] \tag{6}$$

Yang-Mills jednadžba

- Yang-Mills jednadžba:

$$[D_\nu, F^{\nu\mu}] = J^\mu, \tag{7}$$

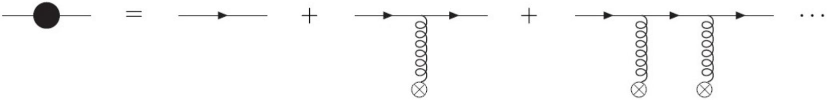
$$J^\mu(x^-, x_\perp) = \delta^{\mu +} g\rho(x^-, x_\perp) \tag{8}$$

- Rješenje:

$$A^i(x^-, x_\perp) = \theta(x^-)\frac{i}{g}U(x_\perp)\partial^i U^\dagger(x_\perp) \tag{9}$$

$$U(x_\perp) \equiv \mathrm{T}\exp\left\{-ig^2\int_{-\infty}^{\infty} dz^- \frac{1}{\nabla_\perp^2}\tilde{\rho}_a(z^-, z_\perp)t^a\right\} \tag{10}$$

Fermionski propagator u polju jezgre



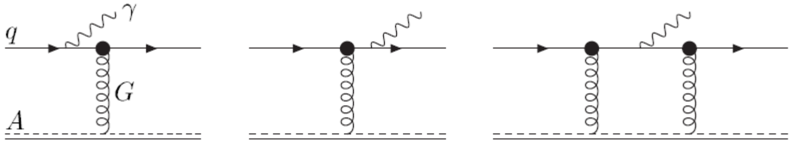
$$G_F(x,y) = i \int \frac{d^4 q}{(2\pi)^4} \frac{1}{q^2 - m^2 + i\epsilon} \sum_{s,a} \psi_q^{s,a}(x) \overline{\psi}_q^{s,a}(y) \qquad (11)$$

Amplituda

- Promatramo proces:

$$q(p) + A \to q(q)\gamma(k)A \tag{12}$$

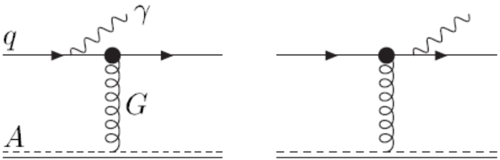
$$\begin{aligned} \langle q(q)\gamma(k)|q(p)\rangle = -e\overline{u}(q)\big[(2\pi)^4\delta^4(k+q-p)\not{\epsilon} \\ +\mathcal{T}_F(q,p-k)G_F^0(p-k)\not{\epsilon} + \not{\epsilon}\,G_F^0(q+k)\mathcal{T}_F(q+k,p) \\ \int \frac{d^4 l}{(2\pi)^4}\mathcal{T}_F(q,l)G_F^0(l)\not{\epsilon}\,G_F^0(k+l)\mathcal{T}_F(k+l,p)\big]\,u(p) \end{aligned} \tag{13}$$



Amplituda

- Konačan izraz za amplitudu:

$$\langle q(q)\gamma(k)|q(p)\rangle \sim \overline{u}(q)\left[\frac{\gamma^-(\not{p}-\not{k}+m)\not{\epsilon}}{(p-k)^2-m^2}+\frac{\not{\epsilon}(\not{q}+\not{k}+m)\gamma^-}{(q+k)^2-m^2}\right]u(p)$$
$$\times\, 2\pi\delta(q^-+k^--p^-)\int d^2x_\perp e^{i(q_\perp+k_\perp-p_\perp)\cdot x_\perp}(U(x_\perp)-1) \quad (14)$$



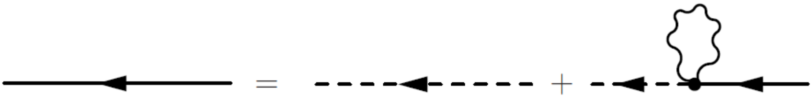
Spinski dio amplitude

$$L \equiv \overline{u}(q)\left[\frac{\gamma^{-}(\not{p}-\not{k}+m)\not{\epsilon}}{(p-k)^2-m^2}+\frac{\not{\epsilon}(\not{q}+\not{k}+m)\gamma^{-}}{(q+k)^2-m^2}\right]u(p) \tag{15}$$

$$\begin{aligned}\langle \mathrm{tr}(L^{\dagger}L)\rangle = -4m^2\left[\frac{p^{-2}}{(q\cdot k)^2}+\frac{q^{-2}}{(p\cdot k)^2}+\frac{k^{-2}}{(p\cdot k)(q\cdot k)}\right]\\ +8(p^{-2}+q^{-2})\left[\frac{p\cdot q}{(p\cdot k)(q\cdot k)}+\frac{1}{q\cdot k}-\frac{1}{p\cdot k}\right]\end{aligned} \tag{16}$$

Usrednjavanje po svim vrijednostima boje

- $\langle U(x_\perp) \rangle$

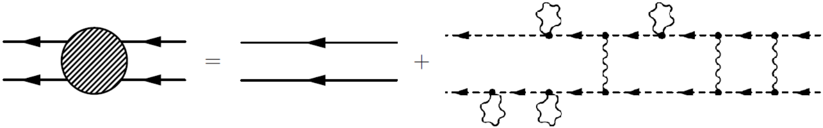


$$\langle U(x_\perp) \rangle = 1 - \mathcal{P}(x_\perp) + \mathcal{P}(x_\perp) e^{-B_1 x_\perp}, \tag{17}$$

$$B_1(x_\perp) \sim \frac{Q_S^2}{\Lambda_{QCD}^2} \tag{18}$$

Usrednjavanje po svim vrijednostima boje

- $\langle U^\dagger(x_\perp)U(y_\perp)\rangle$



$$\langle (U^\dagger(x_\perp)-1)(U(y_\perp)-1)\rangle = \mathcal{P}(x_\perp)\mathcal{P}(y_\perp)\left[1+e^{-B_2(x_\perp-y_\perp)}-2e^{-B_1}\right] \quad (19)$$

$$B_2(x_\perp - y_\perp) \approx \frac{Q_s^2(x_\perp - y_\perp)^2}{4\pi}\log\left(\frac{1}{|x_\perp - y_\perp|\Lambda_{QCD}}\right) \quad (20)$$

Diferencijalni udarni presjek

- $\delta(q^- + k^- - p^-) \to \delta(0^-)$
- Umjesto ravnim valom ulazni kvark pretstavljamo valnim paketom:

$$|\phi_{in}\rangle \equiv \int \frac{d^3 l}{(2\pi)^3} \frac{e^{ib \cdot l_\perp}}{\sqrt{2E_l}} \phi(l) |q(l)_{in}\rangle \tag{21}$$

- Normalizacija:

$$\langle \phi_{in} | \phi_{in} \rangle = 1 \quad \text{t.j} \int \frac{d^3 l}{(2\pi)^3} |\phi(l)|^2 = 1 \tag{22}$$

Diferencijalni udarni presjek

- Diferencijal vjerojatnosti interakcije između valnog paketa i jezgre:

$$dP(b) \equiv \frac{d^3k}{(2\pi)^3 2k_0}\frac{d^3q}{(2\pi)^3 2q_0}|\langle q(q)\gamma(k)|\phi_{in}\rangle|^2 \tag{23}$$

- Nakon integracije:

$$d\sigma = \int d^2b dP(b) \tag{24}$$

- Diferencijalni udarni presjek:

$$d\sigma = \frac{d^3k}{(2\pi)^3 2k_0}\frac{d^3q}{(2\pi)^3 2q_0}\frac{1}{2p^-}|\mathcal{M}(l|qk)|^2 2\pi\delta(p^- - q^- - k^-) \tag{25}$$

Inkluzivni udarni presjek

- $l_\perp \equiv q_\perp + k_\perp$

$$\frac{d\sigma_{incl}}{d^2 k_\perp} \sim \frac{1}{k_\perp^2} \int_{z_{min}}^{1} dz P_{q\to q\gamma}(z) \int d^2 l_\perp \frac{l_\perp^2 C(l_\perp)}{[l_\perp - k_\perp/z]^2} \tag{26}$$

- Korelator:

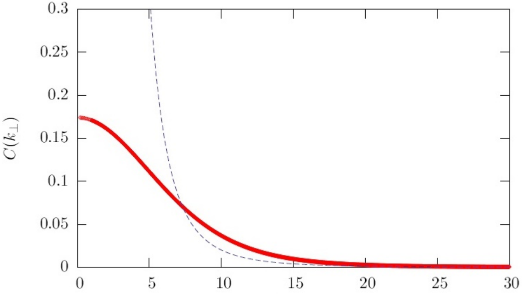
$$C(l_\perp) = \int d^2 l_\perp e^{-i\boldsymbol{l}_\perp \cdot x_\perp} e^{-B_2(x_\perp)} \tag{27}$$

Korelator

- perturbativna granica

$$C(l_\perp) \approx \frac{2Q_s^2}{l_\perp^4}. \quad (28)$$

$$\frac{d\sigma_{pert.}}{d^2k_\perp} \propto \frac{N_h}{k_\perp^2}\int_{z_{min}}^{1} dz P_{q\to q\gamma}(z)\int \frac{d^2 l_\perp}{l_\perp^2[l_\perp - k_\perp/z]^2} \quad (29)$$



Zaključak

- Pretstavljena teorija staklastog kondenzata boje
- Izračunat udarni presjek za produkciju fotona u pA sudarima
- zbog jakog polja jezgre O(1/g) bremsstrahlung dijagrami postaju dominantniji od $q\bar{q} \rightarrow g\,\gamma$

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