Photon Pair Production

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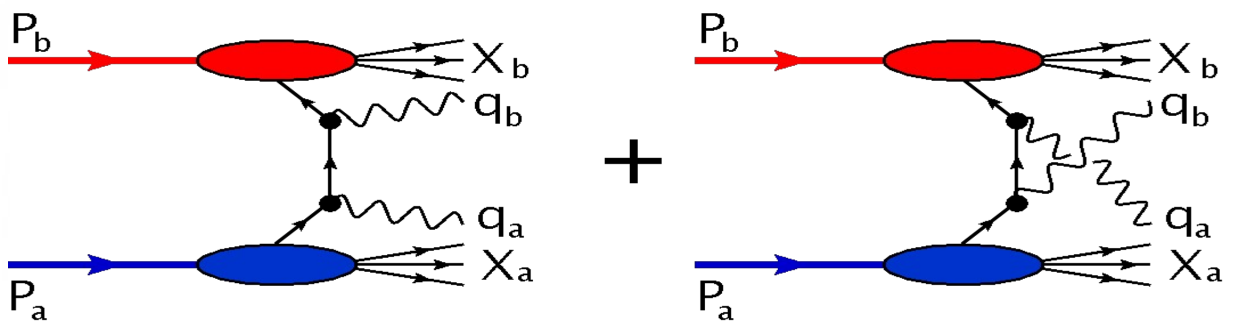
Summary:
The photon pair production process in proton collision is discussed as a complementary process to the Drell-Yan process in the context of TMD-factorization. It is argued that gluon TMDs can be extracted from photon pair production at RHIC. Estimates are given for the gluonic Boer-Mulders and Sivers effects.

Photon Pairs from $q\bar{q}$-channel

Parton model tree-level at $O(\alpha_s^0) \rightarrow$ quark-TMDs!



Only relevant at very small q_T: $\Lambda_{QCD} \sim q_T \ll Q$

$$\boxed{\left(\frac{d\sigma}{d^4q\,d\Omega}\right) \propto \int d^2k_{aT} \int d^2k_{bT}\,\delta^{(2)}(\vec{k}_{aT}+\vec{k}_{bT}-\vec{q}_T)\,\mathrm{Tr}\Big[\Phi(x_a,\vec{k}_{aT})\,H(x_a,x_b,q_a,q_b)\,\bar{\Phi}(x_b,\vec{k}_{bT})\,H^\dagger\Big] + \mathcal{O}(\tfrac{M}{Q})}$$

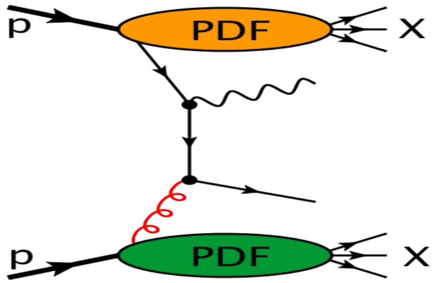
***k_T* - correlator:** $$\boxed{\Phi_{ij}(x,\vec{k}_T) = \int \frac{dz^- d^2z_T}{(2\pi)^2}\,\mathrm{e}^{ik\cdot z}\langle P,S|\,\bar{q}_j(0)\,\mathcal{W}^{?/DY}[0\,;\,z]\,q_j(z)\,|P,S\rangle\Big|_{z^+=0}}$$

Main result of the TMD tree-level formalism:

$$\boxed{\left(\frac{d^6\sigma^{hh\to\gamma\gamma X}}{dy\,dQ^2\,d^2q_T\,d\Omega}\right)(\Lambda \sim q_T \ll Q) = \frac{2}{\sin^2\theta}\left(\frac{d\sigma^{hh\to l^+l^-X}}{dy\,dQ^2\,d^2q_T\,d\Omega}\right)(\Lambda \sim q_T \ll Q\,|\,e_q \to e_q^2)}$$

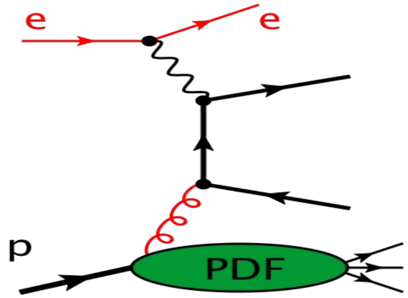
Gluon TMDs in photon pair production

<u>Gluon TMDs in pp-collisions with colored final state:</u>



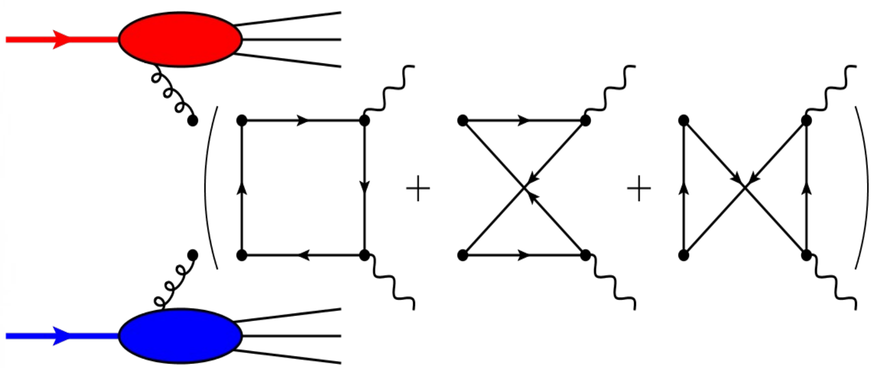
TMD-Factorization (?)

<u>Gluon TMDs in Heavy-quark production in ep-collisions:</u>



Wait for EIC

Feature of photon pair production → direct sensitivity to gluon TMDs at O($_s^2$)



- No colored final state
- Box diagrams finite
- Potentially large gluon distributions
- New Observables, e.g. Cos(4ϕ)

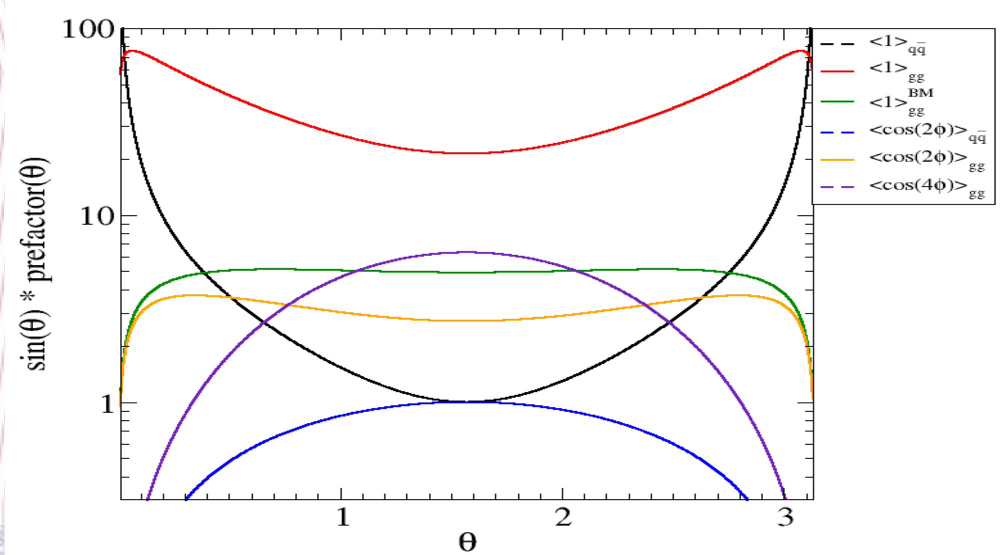
Unpolarized Cross Section

Six structures for the unpolarized cross section ($q_T << Q$)

$$\frac{\mathrm{d}\sigma_{UU}}{\mathrm{d}^4q\,\mathrm{d}\Omega} \sim \left(\frac{2}{\sin^2\theta}\right)\Big((1+\cos^2\theta)[f_1^q\otimes f_1^{\bar q}] + \cos(2\phi)\sin(2\theta)[h_1^{\perp q}\otimes h_1^{\perp\bar q}]\Big)$$

$$+\left(\frac{\alpha_s}{2\pi}\right)^2\Big(\mathcal{F}_1[f_1^g\otimes f_1^g] + \mathcal{F}_2[h_1^{\perp g}\otimes h_1^{\perp g}] + \cos(2\phi)\mathcal{F}_3[h_1^{\perp g}\otimes f_1^g + f_1^g\otimes h_1^{\perp g}] + \cos(4\phi)\mathcal{F}_4[h_1^{\perp g}\otimes h_1^{\perp g}]\Big)$$

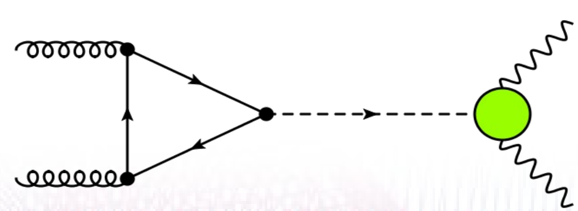
$\mathcal{F}_i$: non-trivial functions of sin(θ) and cos(θ) (Logarithms)



- $q\bar q$ singular for θ → 0, π
  → p_T (or θ)-cuts for each photon
- cos(4ϕ) induced by gluon BM- functions,
  → no corresponding quark / DY term.
- powerful in combination with DY
  → even gluon TMD f_1 unknown.
- cos(2ϕ) determines sign of gluon BM-function.
- Same angular structure found in collinear resummation formulas for higher qT.
  (Balazs et al., Catani & Grazzini)

LHC: Diphotons → main channel for Higgs-Prod.

→ Background process: diphotons via quark-box
→ gluon TMD (unpol., BM) feasible



(Maximal) Gluonic BM-effect at RHIC

Estimates at RHIC ($S^{½}$ = 500 GeV) → Gluon (and Quark!) TMDs unknown at RHIC energy

Saturation of Positivity bounds:

$$|h_1^{\perp,g}| \leq \frac{2M^2}{k_T^2} f_1^g \qquad |h_1^{\perp}, q| \leq \frac{M}{k_T} f_1^q$$

Gaussian Ansatz:

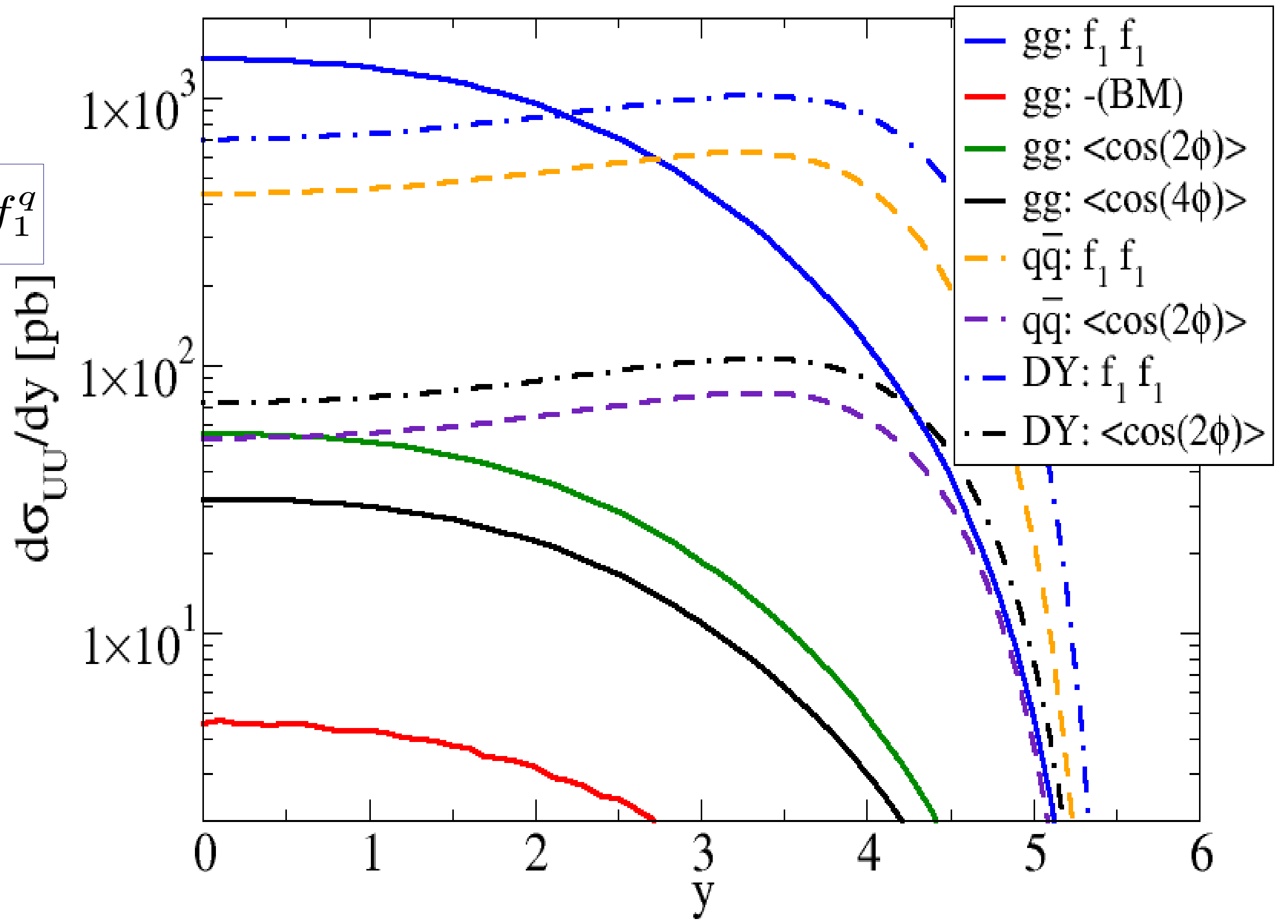
$$f_1^{q/g}(x, k_T^2) = f_1^{q/g}(x)\, e^{-k_T^2/\langle k_{T,q/g}^2 \rangle}$$

Further assumption:

$$\langle k_{T,q}^2 \rangle = \langle k_{T,g}^2 \rangle = 0.5\,\mathrm{GeV}^2$$

P_T-cut for photons:

$$p_T^\gamma > 1\,\mathrm{GeV}$$



- Gluons at midrapidity, quarks at large rapidity
- BM-contribution to ϕ-indep. CS small
- <cos(4ϕ)> ≤ 1% (depend. on saturation)

Gluonic Sivers-effect at RHIC

Four structures for the ϕ-indep. transv. Single-Spin Asymmetry

$$\frac{d\sigma_{TU}}{d^4q\,d\Omega} \sim S_T \sin\phi_S \Big[\frac{2}{\sin^2\theta}(1+\cos^2\theta)\,[f_{1T}^{\perp,q}\otimes f_1^{\bar q}] + \Big(\frac{\alpha_s}{2\pi}\Big)^2 \Big(\mathcal{F}_1\,[f_{1T}^{\perp,g}\otimes f_1^g] + \mathcal{F}_2\,[h_1^g \otimes h_1^{\perp,g}] + \mathcal{F}_2\,[h_{1T}^{\perp,g}\otimes h_1^{\perp,g}]\Big)\Big] + \ldots$$

Positivity bounds:

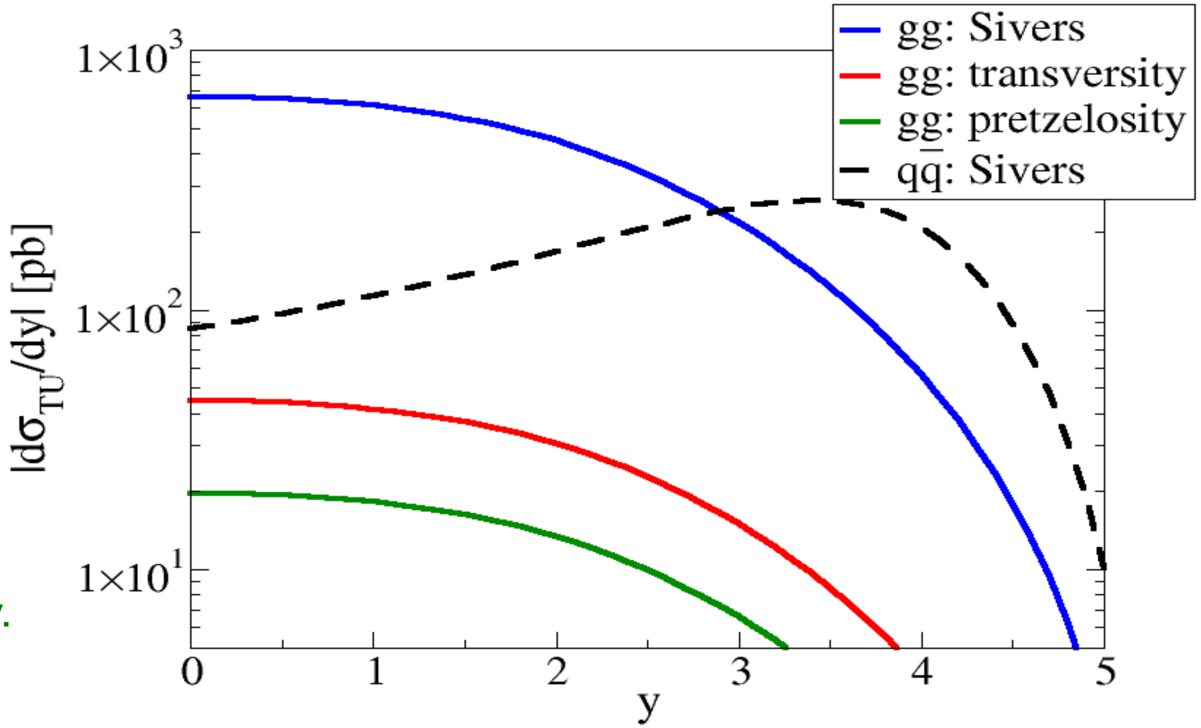
$$|f_{1T}^{\perp,q/g}| \le \frac{M}{k_T} f_1^{q/g}$$

$$|h_1^g| \le \frac{M}{k_T} f_1^g \qquad |h_{1T}^{\perp,g}| \le \frac{2M^3}{k_T^3} f_1^g$$

Flavor cancellation:

$$f_{1T}^{\perp,u} \sim -f_{1T}^{\perp,d}$$

$\rightarrow$ pos. pound given by u-quark only.



- Sign of Sivers function not predicted by positivity $\rightarrow$ quark and gluon effects could add.
- Gluonic effects at midrapidity, quark effects at large rapidities.
- Effects by gluon transversity / pretzelosity small.