



QCD k_t - smearing and Drell-Yan dilepton production

Gabriela Slipek

INSTITUTE OF NUCLEAR PHYSICS
POLISH ACADEMY OF SCIENCES
IFJ PAN



Plan of the talk

- Introduction
- Formalism
- Unintegrated parton distributions
- Results and discussion
- Conclusions

in collaboration with A. Szczurek

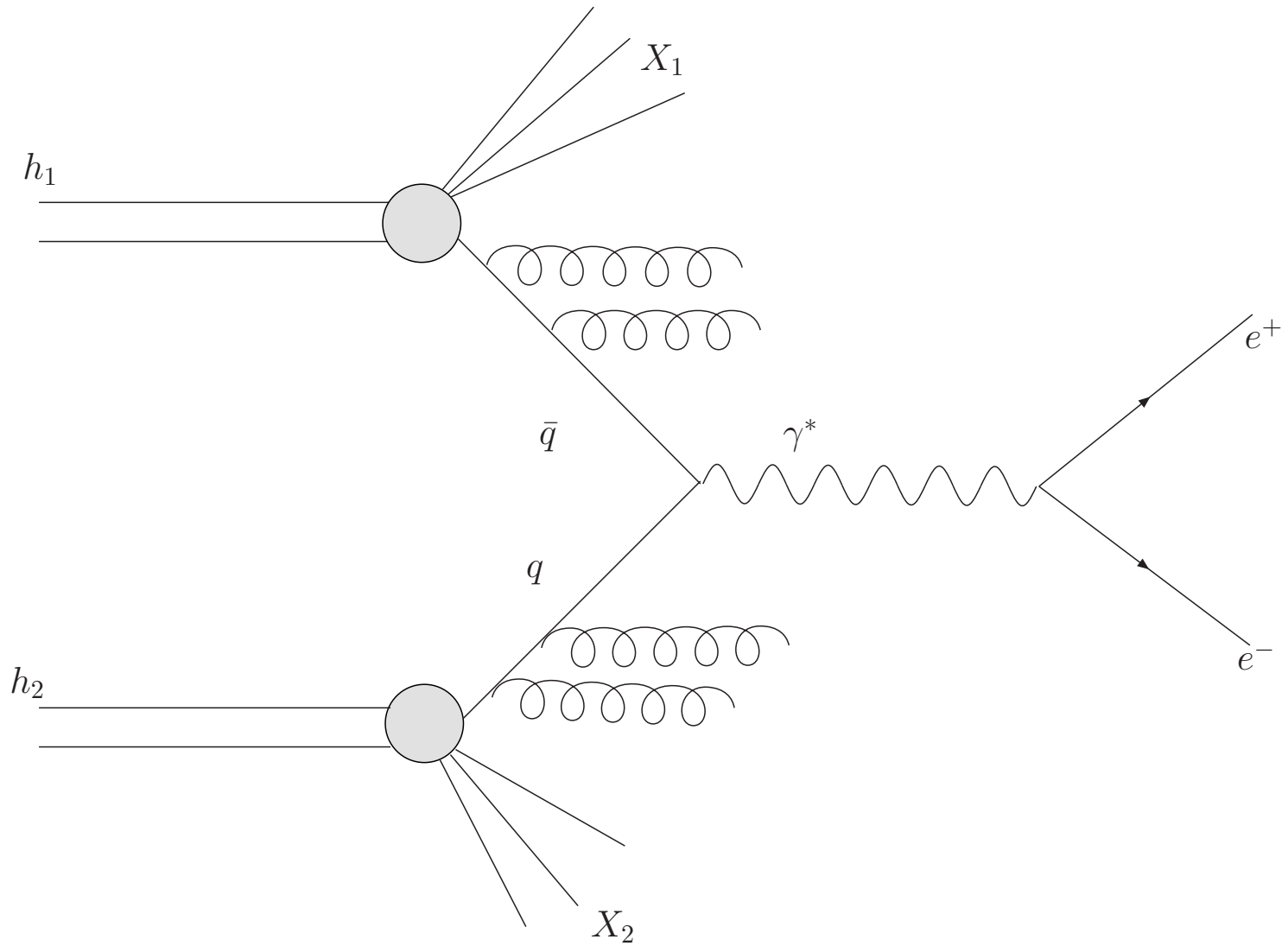


Introduction

- Standard collinear approach does not include **transverse momenta** of initial partons
- In LO collinear approximation:
 $d\sigma/d p_{t\text{pair}} \propto C_1 \delta(p_t)$
 $d\sigma/d\varphi_{e^+e^-} \propto C_2 \delta(\varphi_{e^+e^-} - \pi)$
- The method to include transverse momenta:
 - naive Gaussian smearing (often used in the literature)
 - **k_t - factorization (PDF \rightarrow UPDF or GDF \rightarrow UGDF)**
- our k_t -smearing includes:
 - primordial distribution of partons (**Fermi motion**)
 - QCD evolution
- Experimentally
 $d\sigma/d p_{t\text{pair}}$ depends on \sqrt{s} and $M_{e^+e^-}$

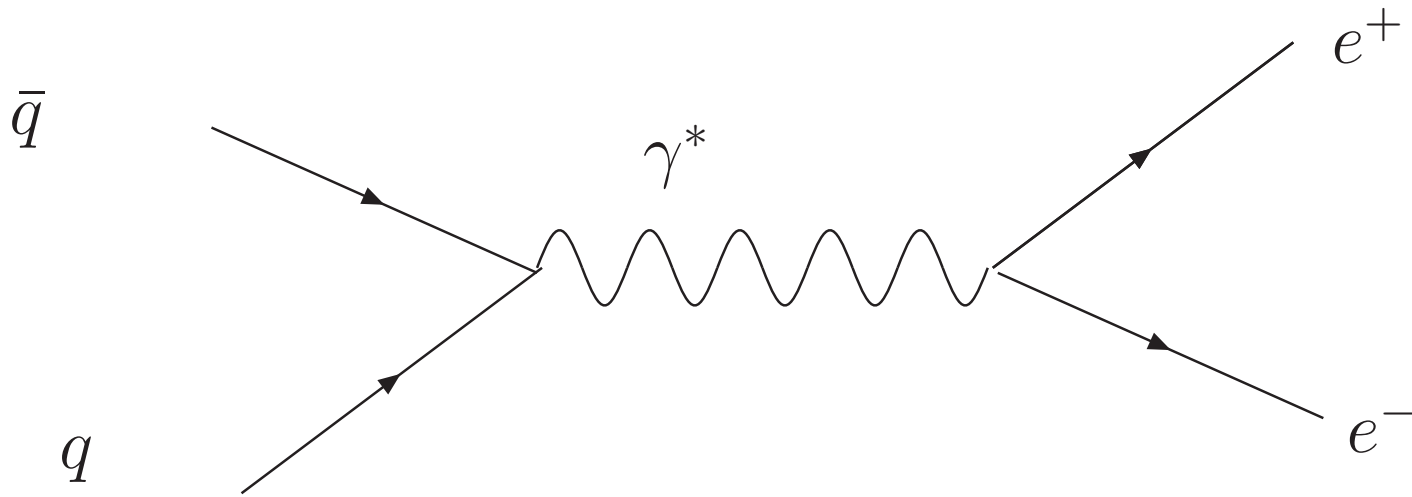


Dominant mechanism



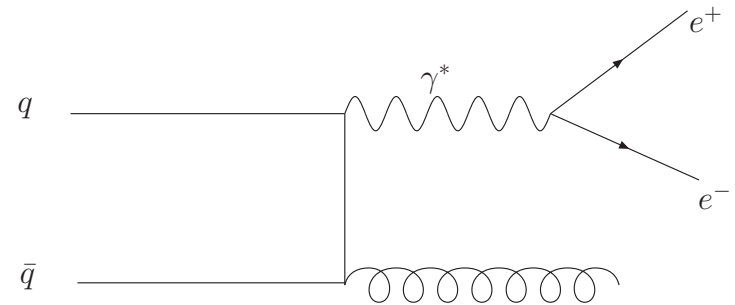
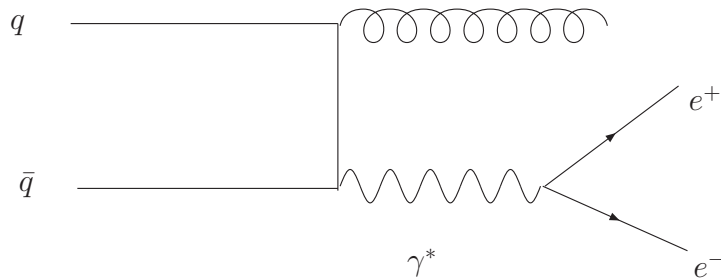
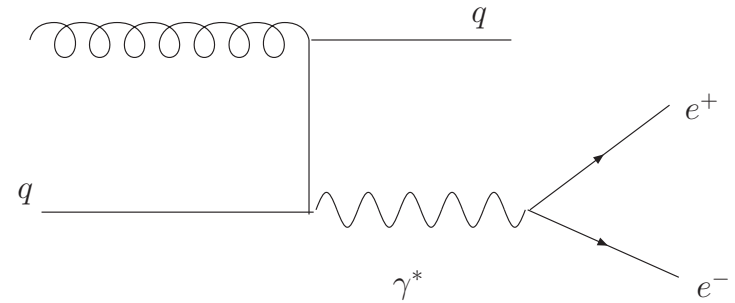
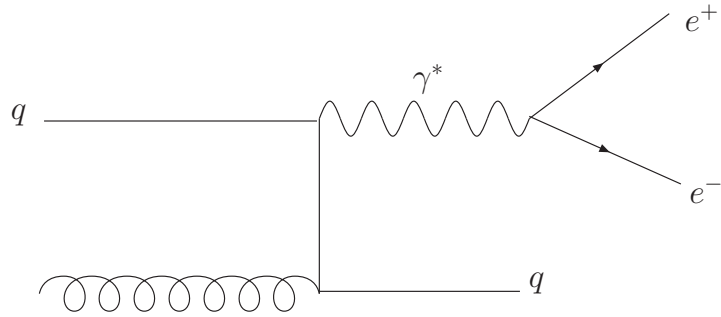


LO diagram for the Drell-Yan pair production





NLO diagrams for the Drell-Yan pair production





Lowest order $q\bar{q} \rightarrow e^+e^-$

- In collinear approach

$$\frac{d\sigma}{dy_1 dy_2 d^2 p_t} = \frac{1}{16\pi^2 \hat{s}^2} \sum_f [x_1 q_f(x_1, \mu^2) x_2 \bar{q}_f(x_2, \mu^2) \overline{|M(q\bar{q} \rightarrow e^+e^-)|^2} + x_1 \bar{q}_f(x_1, \mu^2) x_2 q_f(x_2, \mu^2) \overline{|M(\bar{q}q \rightarrow e^+e^-)|^2}]$$

$$p_{1t} = p_{2t} = p_t$$

$$y_1 = y(e^+)$$

$$y_2 = y(e^-)$$

$$x_1 = \frac{m_t}{\sqrt{s}} (\exp(y_1) + \exp(y_2)) \quad x_2 = \frac{m_t}{\sqrt{s}} (\exp(-y_1) + \exp(-y_2))$$

$M_{q\bar{q} \rightarrow e^+e^-}$ - text book formula



Lowest order $q\bar{q} \rightarrow e^+e^-$

- In k_t - factorization

$$\frac{d\sigma}{dy_1 dy_2 d^2p_{1,t} d^2p_{2,t}} = \sum_{i,j} \int \frac{d^2\kappa_{1,t}}{\pi} \frac{d^2\kappa_{2,t}}{\pi} \frac{1}{16\pi^2(x_1 x_2 s)^2}$$

$$\delta^2(\vec{\kappa}_{1,t} + \vec{\kappa}_{2,t} - \vec{p}_{1,t} - \vec{p}_{2,t}) [f_{q_f}(x_1, \kappa_{1,t}^2) f_{\bar{q}_f}(x_2, \kappa_{2,t}^2) \overline{|M(q\bar{q} \rightarrow e^+e^-)|^2} \\ + f_{\bar{q}_f}(x_1, \kappa_{1,t}^2) f_{q_f}(x_2, \kappa_{2,t}^2) \overline{|M(q\bar{q} \rightarrow e^+e^-)|^2}]$$

- $f_i(x_1, \kappa_{1,t}^2)$ unintegrated parton distributions

$$x_1 = \frac{m_{1,t}}{\sqrt{s}} \exp(y_1) + \frac{m_{2,t}}{\sqrt{s}} \exp(y_2), \quad x_2 = \frac{m_{1,t}}{\sqrt{s}} \exp(-y_1) + \frac{m_{2,t}}{\sqrt{s}} \exp(-y_2).$$

$$m_t = \sqrt{p_t^2 + m^2} \text{ - transverse mass}$$

- standard collinear formula

$$f_i(x_1, \kappa_{1,t}^2) \rightarrow x_1 p_i(x_1) \delta(\kappa_{1,t}^2) \quad f_j(x_2, \kappa_{2,t}^2) \rightarrow x_2 p_j(x_2) \delta(\kappa_{2,t}^2)$$



Higher order $qg \rightarrow e^+e^-q$ and $gq \rightarrow e^+e^-q$

● k_t -factorization

Standard trick:

$$qg \rightarrow e^+e^-q \implies qg \rightarrow (e^+e^-)_{Me e} q$$

$$gq \rightarrow e^+e^-q \implies gq \rightarrow (e^+e^-)_{Me e} q$$

effectively $2 \rightarrow 2$ process

$$\frac{d\sigma}{dy_1 dy_2 d^2p_{1,t} d^2p_{2,t}} = \sum_{i,j} \int \frac{d^2\kappa_{1,t}}{\pi} \frac{d^2\kappa_{2,t}}{\pi} \frac{1}{16\pi^2 (x_1 x_2 s)^2}$$

$$\delta^2(\vec{\kappa}_{1,t} + \vec{\kappa}_{2,t} - \vec{p}_{1,t} - \vec{p}_{2,t}) [f_g(x_1, \kappa_{1,t}^2) f_{q_f}(x_2, \kappa_{2,t}^2) \overline{|M(gq \rightarrow (l^+l^-)q)|^2} + f_{q_f}(x_1, \kappa_{1,t}^2) f_g(x_2, \kappa_{2,t}^2) \overline{|M(qg \rightarrow (l^+l^-)q)|^2}]$$

$$\bullet \overline{|M(qg \rightarrow l^+l^-q)|^2} = \frac{\alpha_{em}}{3\pi M_{ee}^2} \overline{|M(qg \rightarrow \gamma^*q)|^2}$$

$$\bullet \overline{|M(gq \rightarrow l^+l^-q)|^2} = \frac{\alpha_{em}}{3\pi M_{ee}^2} \overline{|M(gq \rightarrow \gamma^*q)|^2}$$



Interrelation via Fourier-Bessel transform

$$f_k(x, k_t^2, \mu^2) = \int_0^\infty db \, b J_0(k_t b) \tilde{f}_k(x, b, \mu^2)$$
$$\tilde{f}_k(x, b, \mu^2) = \int_0^\infty dk_t \, k_t J_0(k_t b) f_k(x, k_t^2, \mu^2)$$

UPDFs in the impact factor representation

$$\tilde{f}_k(x, b = 0, \mu^2) = \frac{x}{2} p_k(x, \mu^2)$$

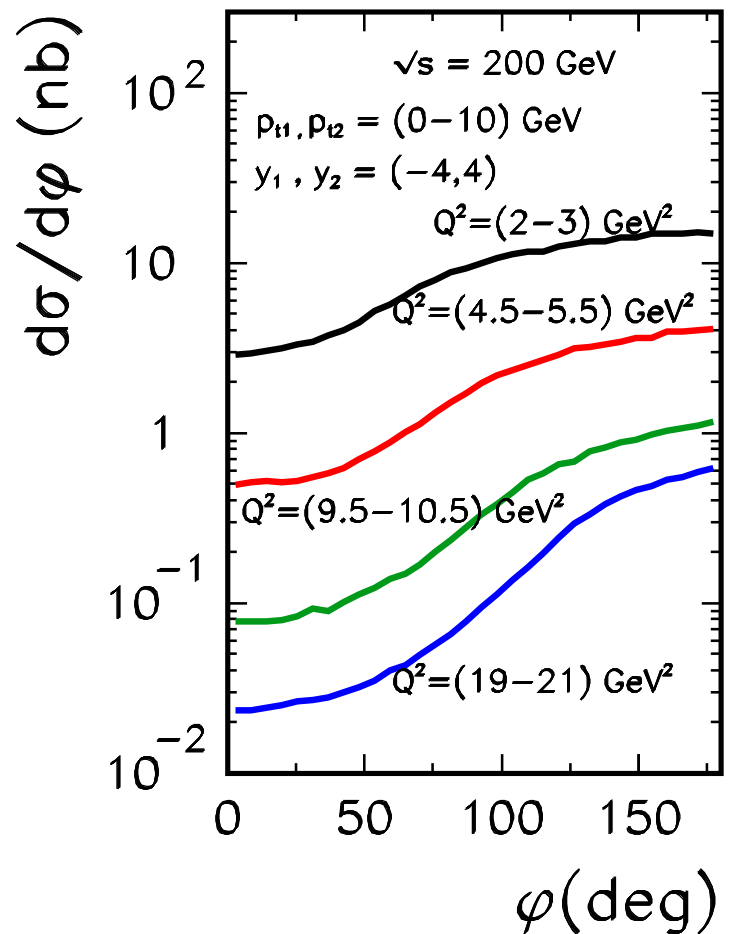
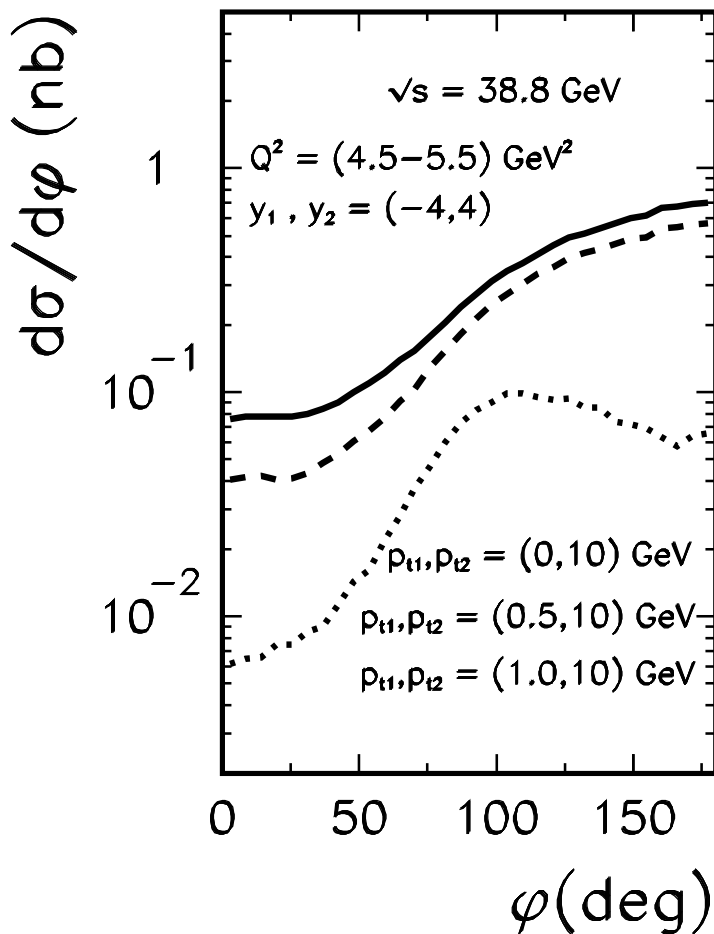
transverse momentum dependent UPDFs

$$xp_k(x, \mu^2) = \int_0^\infty dk_t^2 \, f_k(x, k_t^2, \mu^2) .$$



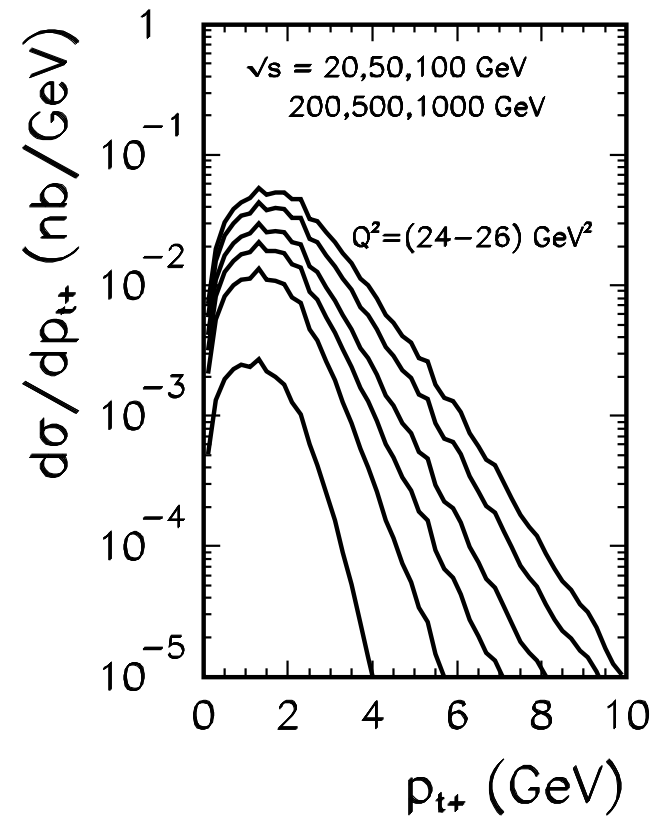
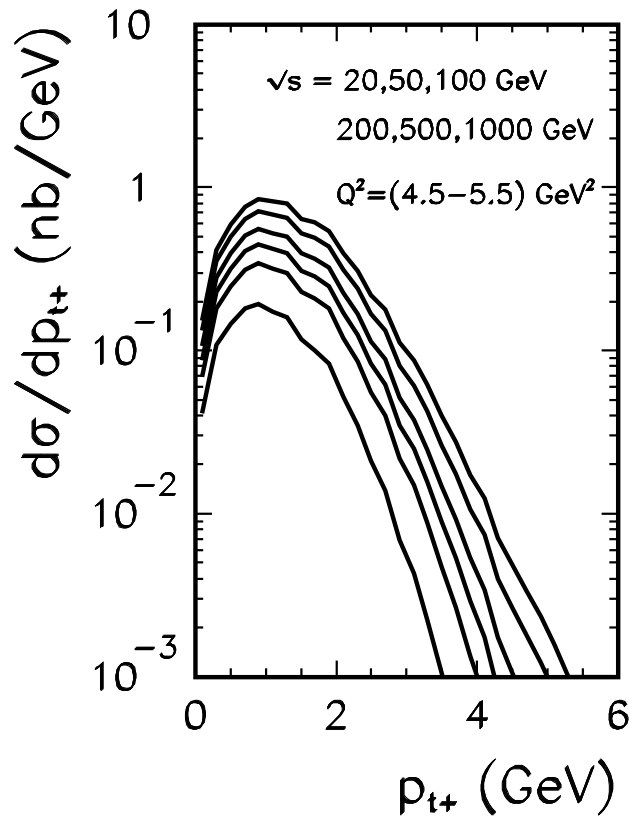
Azimuthal correlations between e^+e^-

$q\bar{q} \rightarrow e^+e^-$ (leading order)





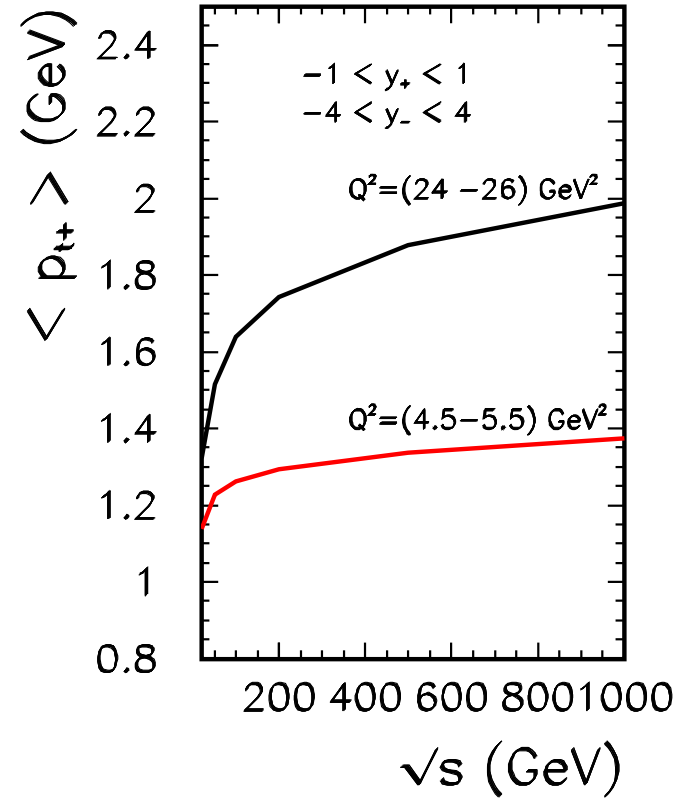
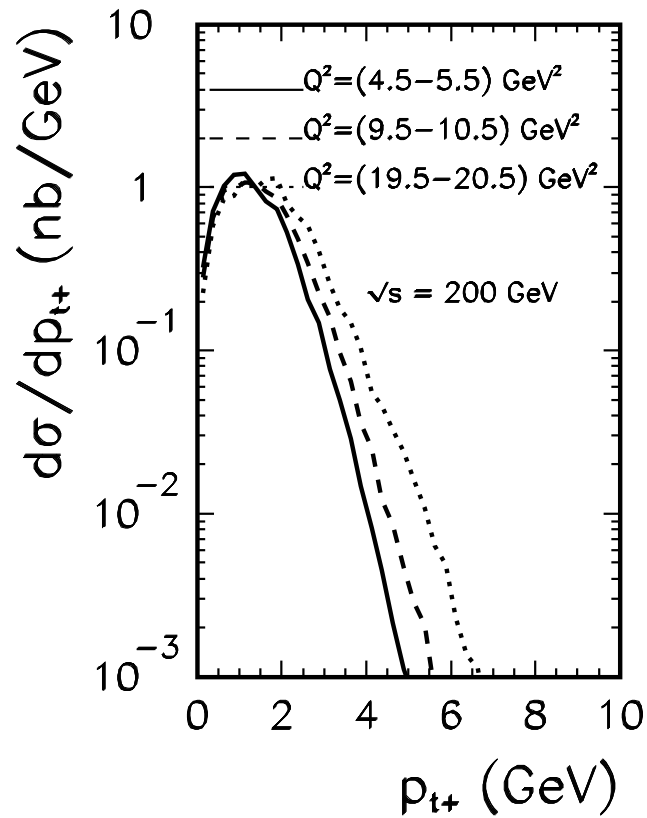
Transverse momentum of the electron pair



Energy and invariant mass broadening



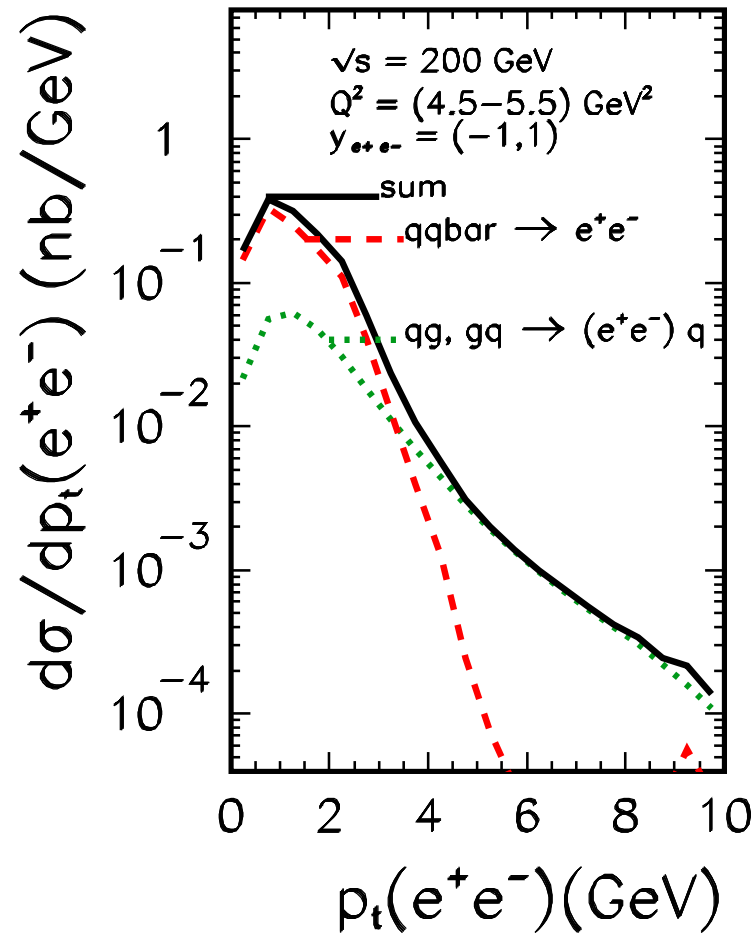
Transverse momentum broadening



renormalized!



lowest vs higher order contributions in $p_t(\text{pair})$

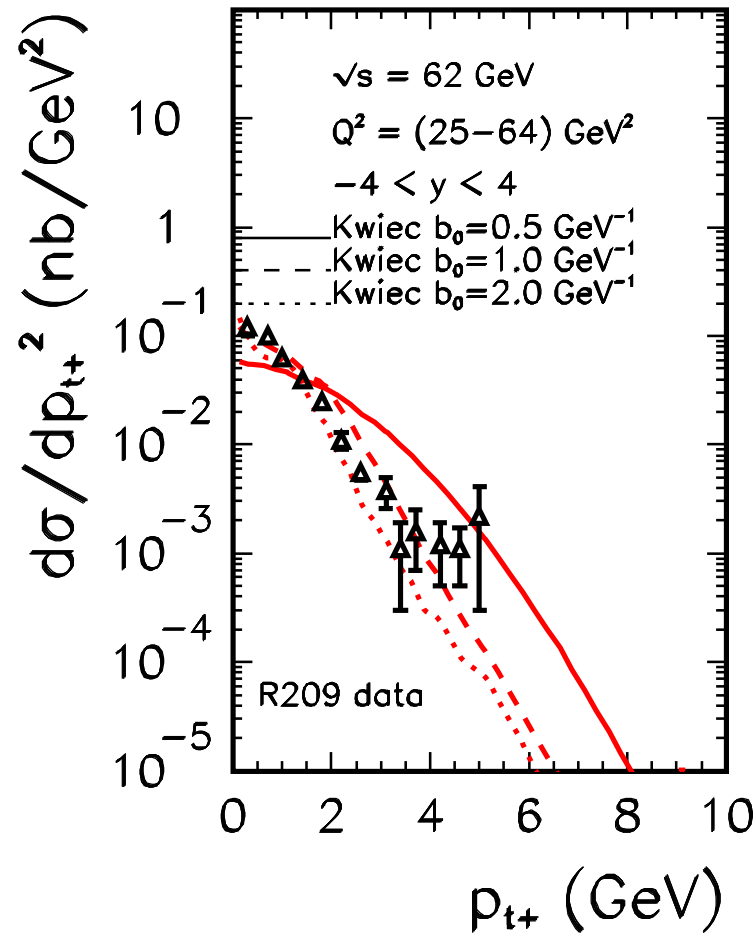


Dominance of lowest order for small $p_t(e^+e^-)$

Dominance of higher order for large $p_t(e^+e^-)$



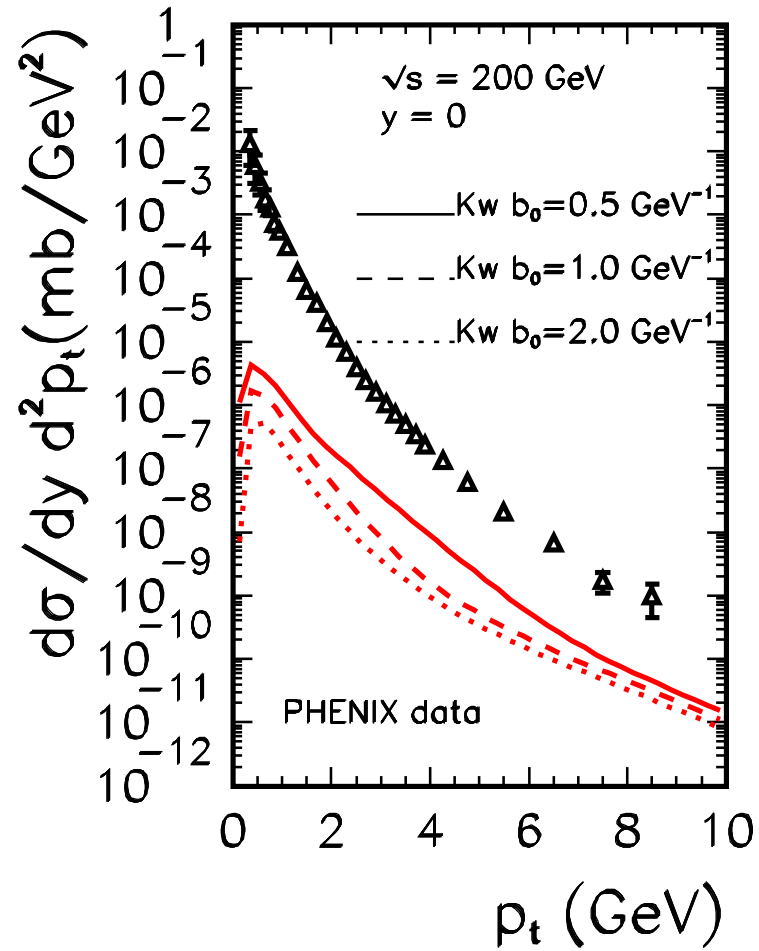
Comparison to experimental data



R209 collaboration data
Effect of Fermi motion



Comparison to experimental data

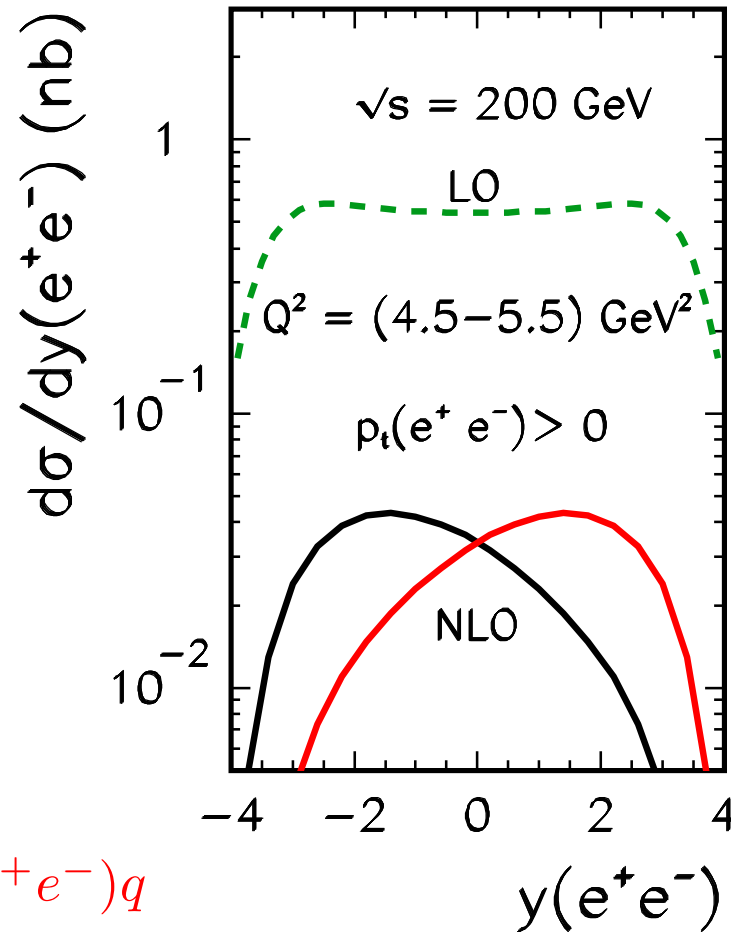


PHENIX data



Rapidity distribution of the lepton pair

$$\sqrt{s} = 200 \text{ GeV} \text{ and } Q^2 = 4.5 - 5.5 \text{ GeV}^2$$



$$qg \rightarrow (e^+e^-)q \quad gq \rightarrow (e^+e^-)q$$

Full range of rapidities

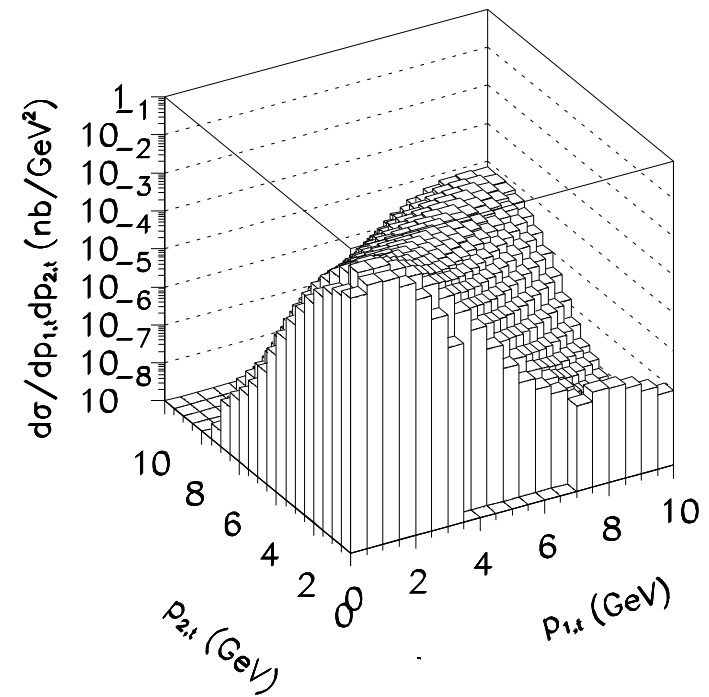
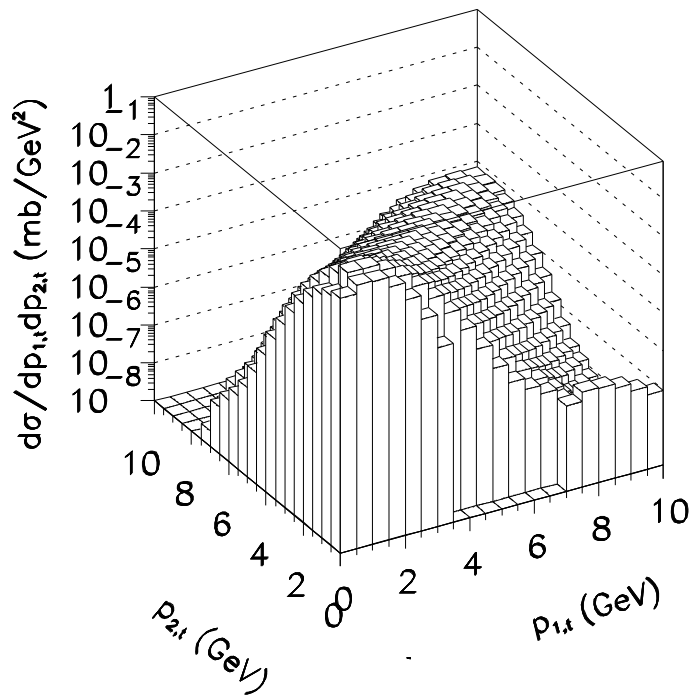


Dilepton-quark correlation

$$\sqrt{s} = 200\text{GeV} \text{ and } Q^2 = 4.5 - 5.5\text{GeV}^2$$

$$qg \rightarrow (e^+e^-)q$$

$$gq \rightarrow (e^+e^-)q$$



QCD Compton only

Full range of rapidities

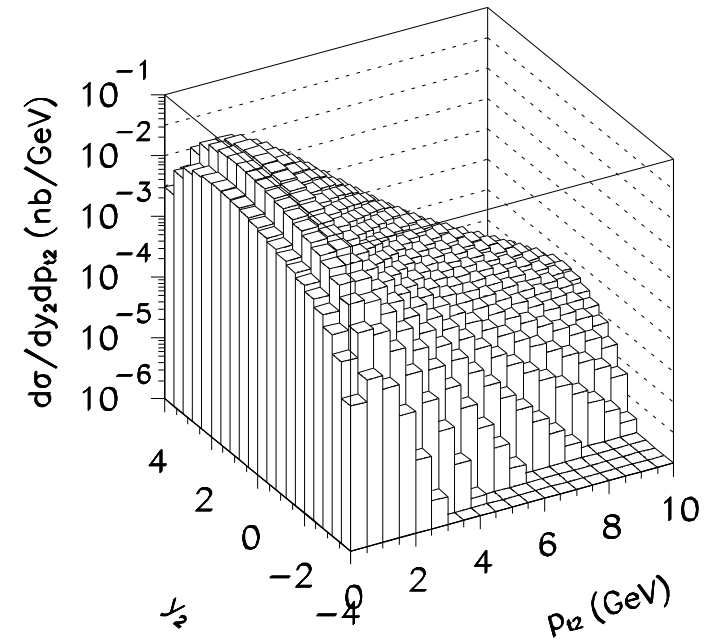
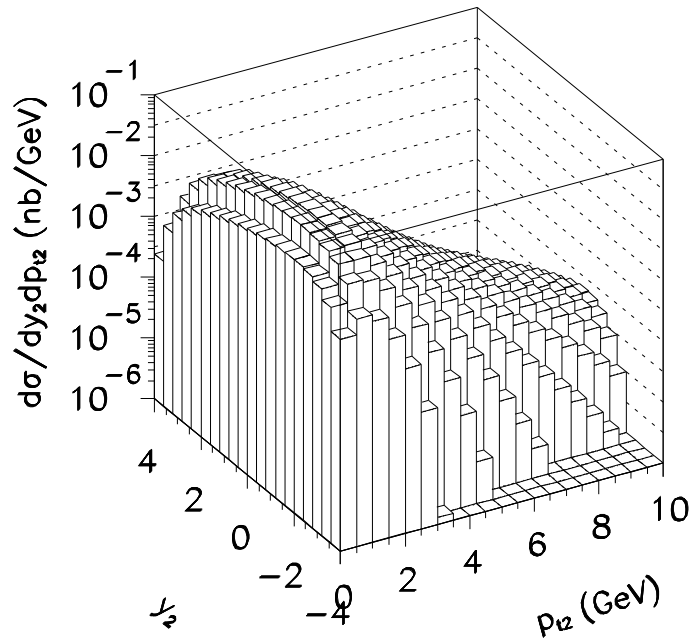


Dilepton pair distribution

$$\sqrt{s} = 200 \text{ GeV} \text{ and } Q^2 = 4.5 - 5.5 \text{ GeV}^2$$

$$qg \rightarrow (e^+e^-)q$$

$$gq \rightarrow (e^+e^-)q$$





SUMMARY

- I have presented results for Drell-Yan dilepton production in the k_t - factorization approach. Kwiecinski UPDF were used.
- Both lowest order and higher order were included.
- Both of them contribute to the momentum distribution of e^+e^- pair in contrast to some calculation in the literature.
- We find that the width of the transverse momentum distribution is both energy and $M_{e^+e^-}$ dependent.
- The Phenix collaboration measured the $\frac{e^+ + e^-}{2}$. Here the DY contribution is rather small.
- The R209 collaboration data for $\sqrt{s} = 62 GeV$ can be described nicely provided that the Fermi motion parameter is adjusted.