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Production of D and B mesons and their semileptonic decays

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11th International Workshop on Meson Production, Properties and Interaction,

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Cracow, Poland, 2010

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Plan of the talk

Introduction

Open Charm and Bottom and nonphotonic electrons

- Heavy quarks pair production
- Fragmentation into heavy mesons
- Semileptonic decays of D and B mesons

3 Related processes

- Drell-Yan dileptons
- QED $\gamma\gamma \rightarrow e^+e^-$ in p+p scattering





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Inclusive measurements of e^+e^- pairs

• e^+e^- pair invariant mass spectrum (0 - 8 GeV) PHENIX, p+p @ $\sqrt{s} = 200$ GeV, A. Adare, et al., Phys. Lett. **B 670** (2009), 313-320



 dielectron mass spectrum dominated by semileptonic decays of charm and bottom mesons → nonphotonic electrons



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- charm and bottom production → standard measurements of single leptons (PHENIX. STAR) and pQCD calculations (NLO, FONLL)



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Inclusive measurements of e^+e^- pairs

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- dielectron mass spectrum dominated by semileptonic decays of charm and bottom mesons → nonphotonic electrons
- charm and bottom production → standard measurements of single leptons (PHENIX. STAR) and pQCD calculations (NLO, FONLL)
- alternative method → dielectron correlations
- a new tool for testing pQCD techniques, fragmentation functions and semileptonic decays of D and B mesons



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Nonphotonic electrons predictions





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Nonphotonic electrons predictions





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Nonphotonic electrons predictions





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Semileptonic decays of D and B mesons



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Nonpho	ptonic electrons prediction	S		
	$\begin{array}{c} QCD\\ pp & \xrightarrow{pQCD} Quarks \stackrel{fragmentation}{\longrightarrow} Had\\ \end{array}$ Heavy quarks $Q\bar{Q}$ pairs production	lrons decyas el	ectrons t xperimental bservable	
	• $m_c = 1.5 { m GeV}, m_b = 4.75 { m GeV}$	\longrightarrow perturbative	e QCD	
2	Heavy quarks hadronization (fragmen	tation)		
3	Semileptonic decays of D and B mesc	ns		
	$rac{d\sigma^{ extsf{e}}}{dyd^2p} = rac{d\sigma^{ extsf{e}}}{dyd^2p}\otimes D_{ extsf{e}}$	$_{Q ightarrow H}\otimes f_{H ightarrow e}$) ν	
	X D^{0} D^{++}	α α α D ⁺ D ⁺ D ⁺ D ⁺	X e ⁺	(E) E OQC

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Heavy quarks pair production

Dominant mechanism and the k_t -factorization approach



- charm and bottom quarks production at high energies
 → gluon-gluon fusion
- QCD collinear approach → only inclusive one particle distributions, total cross sections
- LO k_t -factorization approach $\longrightarrow \kappa_{1,t}, \kappa_{2,t} \neq 0$ $\Rightarrow Q\bar{Q}$ correlations, p_t -distributions (Łuszczak, Szczurek)



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• multi-differential cross section $\frac{d\sigma}{dy_1 dp_{1t} dy_2 dp_{2t} d\phi} = \sum_{l,j} \int \frac{d^2 \kappa_{1,t}}{\pi} \frac{d^2 \kappa_{2,t}}{\pi} \frac{1}{16\pi^2 (x_1 x_2 s)^2} \overline{|\mathcal{M}_{lj \to \Theta \overline{\Theta}}|^2}$ $\times \delta^2 \left(\vec{\kappa}_{1,t} + \vec{\kappa}_{2,t} - \vec{p}_{1,t} - \vec{p}_{2,t} \right) \mathcal{F}_l(x_1, \kappa_{1,t}^2) \mathcal{F}_j(x_2, \kappa_{2,t}^2)$



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major part of NLO corrections automatically included

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Heavy quarks pair production

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- major part of NLO corrections automatically included
- $\mathcal{F}_{i}(x_{1}, \kappa_{1,t}^{2}) \mathcal{F}_{j}(x_{2}, \kappa_{2,t}^{2})$ unintegrated parton distributions

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

 $x_2 = \frac{m_{1,t}}{\sqrt{s}} \exp(-y_1) + \frac{m_{2,t}}{\sqrt{s}} \exp(-y_2),$ where $m_{l,t} = \sqrt{p_{l,t}^2 + m_Q^2}.$



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Heavy quarks pair production

UPDFs - unintegrated parton distribution functions

- k_t -factorization \rightarrow replacement: $p_k(x, \mu_F^2) \longrightarrow \mathcal{F}_k(x, \kappa_t^2, \mu_F^2)$
- UPDFs needed in less inclusive measurements which are sensitive to the transverse momentum of the parton
- several models: BFKL, GBW, Ivanov-Nikolaev, Kharzeev-Levin, KMR, Kutak-Stasto, Kwiecinski
- Kwiecinski UPDFs:

from CCFM evolution equations

$$\begin{aligned} \mathcal{F}_{k}(x,\kappa_{t}^{2},\mu_{F}^{2}) &= \int_{0}^{\infty} db \ bJ_{0}(\kappa_{t}b)\tilde{\mathcal{F}}_{k}(x,b,\mu_{F}^{2}) \\ \tilde{\mathcal{F}}_{k}(x,b,\mu_{F}^{2}) &= \int_{0}^{\infty} d\kappa_{t} \ \kappa_{t}J_{0}(\kappa_{t}b)\mathcal{F}_{k}(x,\kappa_{t}^{2},\mu_{F}^{2}) \end{aligned}$$

● PDFs → UPDFs

$$xp_k(x,\mu_F^2) = \int_0^\infty d\kappa_t^2 \mathcal{F}(x,\kappa_t^2,\mu_F^2)$$



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Fragmentation into heavy mesons						

Simulation of hadronization process



- phenomenology \rightarrow fragmentation functions extracted from e^+e^- data
- often used: Braaten et al., Kartvelishvili et al., Peterson et al.
- Peterson et al. $D_{Q \to M}(z) = \frac{N}{z[1-(1/z)-\varepsilon_Q/(1-z)]}$ $\varepsilon_c = 0.06, \varepsilon_b = 0.006$ from PDG
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- numerically performed by rescalling transverse momentum at a constant rapidity (angle)
- from heavy quarks to heavy mesons:

$$\frac{d\sigma(y_1, p_{1t}^M, y_2, p_{2t}^M, \phi)}{dy_1 dp_{1t}^M dy_2 dp_{2t}^M d\phi} \approx \int \frac{D_{Q \to M}(z_1)}{z_1} \cdot \frac{D_{\bar{Q} \to \bar{M}}(z_2)}{z_2} \cdot \frac{d\sigma(y_1, p_{1t}^Q, y_2, p_{2t}^Q, \phi)}{dy_1 dp_{1t}^Q dy_2 dp_{2t}^Q d\phi} dz_1 dz_2$$

where:
$$p_{1t}^{Q} = \frac{p_{1t}^{M}}{z_{1}}$$
, $p_{2t}^{Q} = \frac{p_{2t}^{M}}{z_{2}}$ and $z_{1}, z_{2} \in (0, 1)$

• approximation:

 y_1, y_2, ϕ - unchanged in the fragmentation process



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Semileptonic decays of D and B mesons						

Simple model of semileptonic decays



- CLEO $e^+e^- \rightarrow \Psi(3770) \rightarrow D\bar{D} \rightarrow Xev$ $BR(D^+ \rightarrow e^+v_eX)=16.13\pm0.20(stat.)\pm0.33(syst.)\%$ $BR(D^0 \rightarrow e^+v_eX)=6.46\pm0.17(stat.)\pm0.13(syst.)\%$
- **BABAR** $e^+e^- \rightarrow \Upsilon(10600) \rightarrow B\overline{B} \rightarrow Xev$ BR $(B \rightarrow ev_eX)=10.36\pm0.06(stat.)\pm0.23(syst.)\%$



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- Monte Carlo ⇒ directions and lengths of outgoing leptons momenta
- Our input \implies experimental decay functions: $f_{CLEO}(p), f_{BABAR}(p)$





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- Monte Carlo =>> directions and lengths of outgoing leptons momenta
- Our input \implies experimental decay functions: $f_{CLEO}(p)$, $f_{BABAR}(p)$



• approximation: $D \text{ mesons } (D^{\pm}, D^{0}, \overline{D^{0}}, D_{S}^{\pm}, D^{*0}, D^{*\pm}, D_{S}^{*\pm})$ $B \text{ mesons } (B^{\pm}, B^{0}, \overline{D^{0}}, B_{S}^{0}, \overline{B_{S}^{0}}, B^{*}, B_{S}^{*})$ $BR(D \text{ and } B \longrightarrow X e v \approx 10\%)$

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Drell-Yan dileptons						

Drell-Yan processes in the k_t -factorization



- A. Szczurek, G. Ślipek, Phys. Rev. D 78 (2008) 114007
- k_t -factorization approach with Kwiecinski UPDFs

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- 0-th and 1-st order qq
 -anihilation and 1-st order Compton scattering
- O-th order Drell-Yan cross section

$$\begin{aligned} \frac{d\sigma}{dy_1 dy_2 d^2 p_{1t} d^2 p_{2t}} &= \sum_t \int \frac{d^2 \kappa_{1t}}{\pi} \frac{d^2 \kappa_{2t}}{\pi} \frac{1}{16\pi^2 (x_1 x_2 s)^2} \ \delta^2 \left(\vec{\kappa}_{1t} + \vec{\kappa}_{2t} - \vec{p}_{1t} - \vec{p}_{2t}\right) \\ & \left[\mathcal{F}_{q_t} (x_1, \kappa_{1t}^2, \mu_F^2) \ \mathcal{F}_{\bar{q}_t} (x_2, \kappa_{2t}^2, \mu_F^2) \ \overline{|M(q\bar{q} \to e^+e^-)|^2} \right. \\ & \left. + \mathcal{F}_{\bar{q}_t} (x_1, \kappa_{1t}^2, \mu_F^2) \ \mathcal{F}_{q_t} (x_2, \kappa_{2t}^2, \mu_F^2) \ \overline{|M(q\bar{q} \to e^+e^-)|^2} \right] \end{aligned}$$

unintegrated quark distributions



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QED $\gamma\gamma \rightarrow e^+e^-$ in p+p scattering						

Elastic and inelastic reactions

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$$pp \rightarrow ppe^+e^-$$



- exact momentum space calculations with 4-body phase space
- consistent with LPAIR Monte Carlo package

• $pp \rightarrow X_1 X_2 e^+ e^-$



- collinear kinematics
- MRST 2004

(Martin-Roberts-Stirling-Thorne) photon distributions in nucleon



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Dilepton invariant mass spectrum





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Image: A math a math

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Uncertainties - μ_F , μ_R scale dependence





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Uncertainties - quark mass dependence





Image: A matrix and a matrix

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Sensitivity of fragmentation functions parameters ϵ_c , ϵ_b





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Transverse momenta correlations





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Azimuthal and $p_{t,sum}$ correlations



 azimuthal angle between outgoing leptons • $\overrightarrow{p_{t,sum}} = \overrightarrow{p_{1t}} + \overrightarrow{p_{2t}}$

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Model:

 Theoretical description of nonphotonic and Drell-Yan dilepton production in proton-proton collisions in the framework of the k_t-factorization approach



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Model:

• Theoretical description of nonphotonic and Drell-Yan dilepton production in proton-proton collisions in the framework of the *k*_t-factorization approach

Succes:

• Well description of the PHENIX dilepton invariant mass spectrum



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Model:

• Theoretical description of nonphotonic and Drell-Yan dilepton production in proton-proton collisions in the framework of the *k*_t-factorization approach

Succes:

• Well description of the PHENIX dilepton invariant mass spectrum

New possibilieties:

• Kinematical correlations between outgoing leptons



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Thank You for attention!



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Backup





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Image: A math a math

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Backup

$$\begin{array}{c} c \xrightarrow{0.246} D^+ \xrightarrow{0.161} e^+ \\ \xrightarrow{0.565} D^0 \xrightarrow{0.066} e^+ \\ \xrightarrow{0.224} D^{*+} \xrightarrow{0.677} \pi^+ D^0 \xrightarrow{0.066} e^+ \\ \xrightarrow{0.307} \pi^0 D^+ \xrightarrow{0.161} e^+ \\ \xrightarrow{0.016} \gamma D^+ \xrightarrow{0.161} e^+ \\ \xrightarrow{0.213} D^{*0} \xrightarrow{0.619} \pi^0 D^0 \xrightarrow{0.066} e^+ \\ \xrightarrow{0.381} \gamma D^0 \xrightarrow{0.066} e^+ \\ \xrightarrow{0.381} \gamma D^0 \xrightarrow{0.066} e^+ \\ \xrightarrow{0.061} D_S^+ \xrightarrow{0.942} \gamma D_S^+ \xrightarrow{0.08} e^+ \\ \xrightarrow{0.058} \pi^0 D_S^+ \xrightarrow{0.08} e^+ \end{array}$$

Future:

- explicite calculations of decays $c \to D^* \to D^{0,+} \to e^+$
- different fragmentation functions



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