Production of D and B mesons and their semileptonic decays

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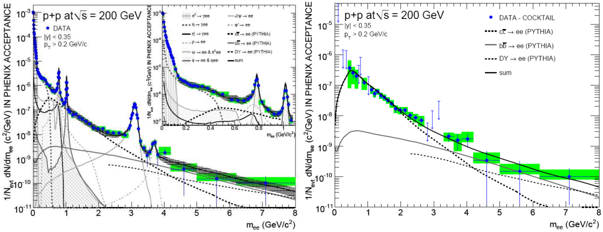
Cracow, Poland, 2010

Plan of the talk

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



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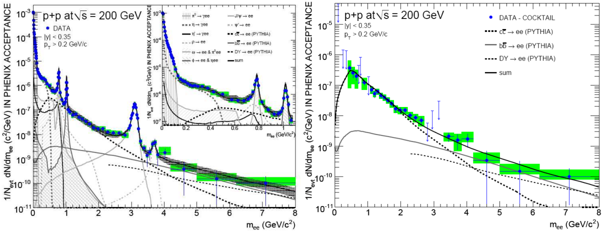

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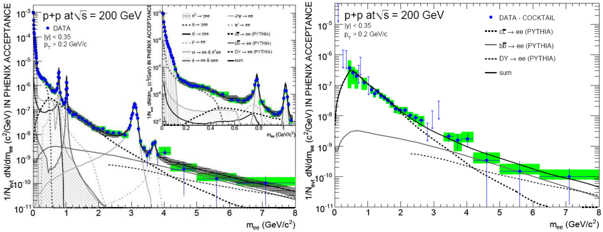
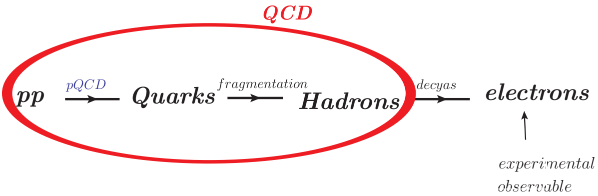


- dielectron mass spectrum dominated by semileptonic decays of charm and bottom mesons → nonphotonic electrons
- charm and bottom production → standard measurements of single leptons (PHENIX. STAR) and pQCD calculations (NLO, FONLL)
- alternative method → dielectron correlations
- a new tool for testing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

Nonphotonic electrons predictions



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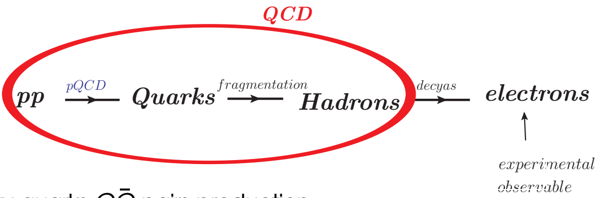

1. Heavy quarks $Q\bar{Q}$ pairs production
   - $m_c = 1.5$ GeV, $m_b = 4.75$ GeV $\longrightarrow$ perturbative QCD

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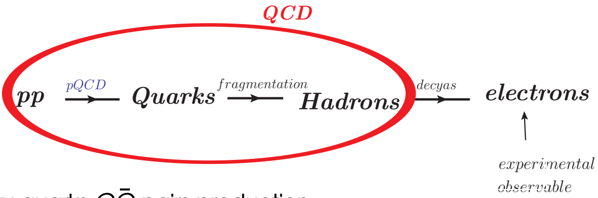

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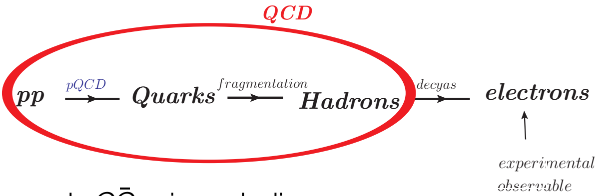

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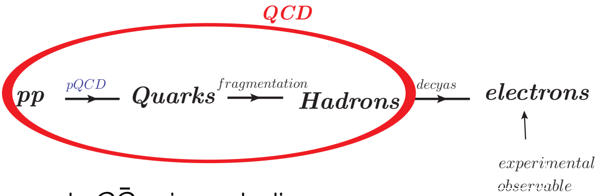

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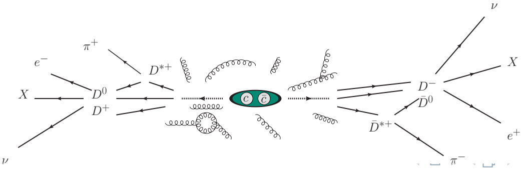
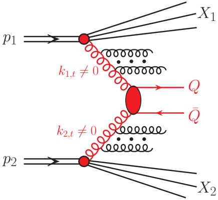
$$\frac{d\sigma^e}{dyd^2p} = \frac{d\sigma^Q}{dyd^2p} \otimes D_{Q\rightarrow H} \otimes f_{H\rightarrow e}$$



Dominant mechanism and the k_t-factorization approach



- charm and bottom quarks production at high energies $\longrightarrow$ gluon-gluon fusion
- QCD collinear approach $\rightarrow$ 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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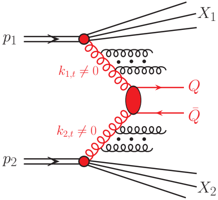

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- multi-differential cross section

$$\frac{d\sigma}{dy_1 dp_{1t} dy_2 dp_{2t} d\phi} = \sum_{i,j} \int \frac{d^2\kappa_{1,t}}{\pi} \frac{d^2\kappa_{2,t}}{\pi} \frac{1}{16\pi^2 (x_1 x_2 s)^2} \overline{|\mathcal{M}_{ij \to Q\bar{Q}}|^2}$$
$$\times \; \delta^2 \left(\vec{\kappa}_{1,t} + \vec{\kappa}_{2,t} - \vec{p}_{1,t} - \vec{p}_{2,t} \right) \mathcal{F}_i(x_1, \kappa_{1,t}^2) \, \mathcal{F}_j(x_2, \kappa_{2,t}^2)$$

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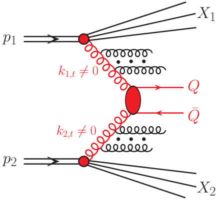

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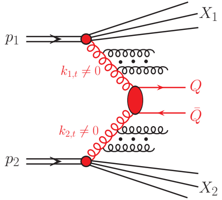

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- $\mathcal{F}_i(x_1, \kappa_{1,t}^2)\, \mathcal{F}_j(x_2, \kappa_{2,t}^2)$ - unintegrated parton distributions
- $x_1 = \frac{m_{1,t}}{\sqrt{s}} \exp(y_1) + \frac{m_{2,t}}{\sqrt{s}} \exp(y_2)$,

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

UPDFs - unintegrated parton distribution functions

- k_t-factorization → 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**

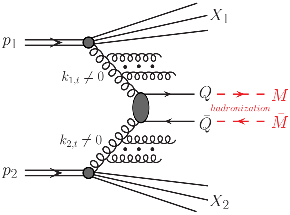
$$\mathcal{F}_k(x,\kappa_t^2,\mu_F^2) = \int_0^\infty db\; bJ_0(\kappa_t b)\tilde{\mathcal{F}}_k(x,b,\mu_F^2)$$

$$\tilde{\mathcal{F}}_k(x,b,\mu_F^2) = \int_0^\infty d\kappa_t\; \kappa_t J_0(\kappa_t b)\mathcal{F}_k(x,\kappa_t^2,\mu_F^2)$$

- PDFs ⟶ UPDFs

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

Simulation of hadronization process



- phenomenology $\longrightarrow$ 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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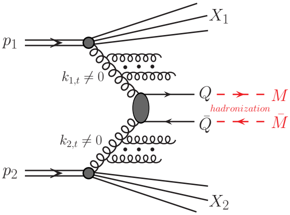

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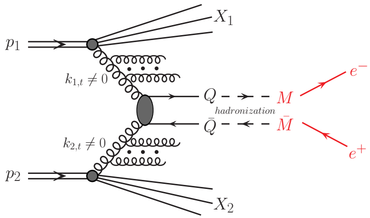
- from heavy quarks to heavy mesons:

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

  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

Simple model of semileptonic decays



- **CLEO** $e^+e^- \to \Psi(3770) \to D\bar{D} \to Xe\nu$
  BR$(D^+ \to e^+\nu_e X)$=16.13±0.20(stat.)±0.33(syst.)%
  BR$(D^0 \to e^+\nu_e X)$=6.46±0.17(stat.)±0.13(syst.)%
- **BABAR** $e^+e^- \to \Upsilon(10600) \to B\bar{B} \to Xe\nu$
  BR$(B \to e\nu_e X)$=10.36±0.06(stat.)±0.23(syst.)%

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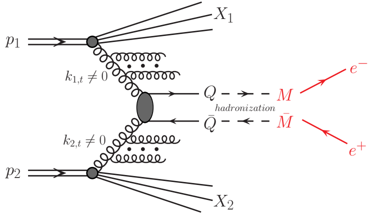

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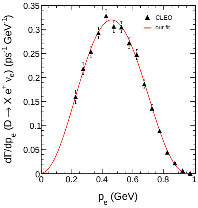
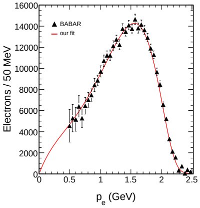
- Monte Carlo $\Longrightarrow$ directions and lengths of outgoing leptons momenta
- Our input $\Longrightarrow$ experimental decay functions: $f_{CLEO}(p)$, $f_{BABAR}(p)$





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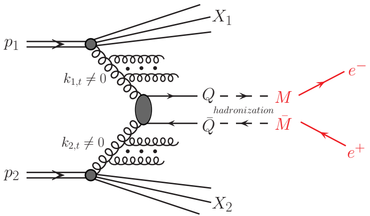

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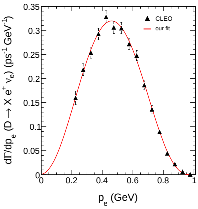
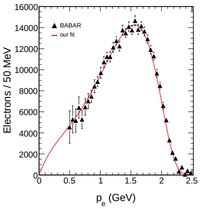
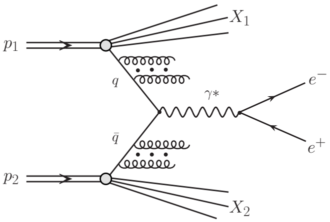




- approximation:
  D mesons $(D^\pm, D^0, \bar{D}^0, D_S^\pm, D^{*0}, D^{*\pm}, D_S^{*\pm})$
  B mesons $(B^\pm, B^0, \bar{D}^0, B_S^0, \bar{B}_S^0, B^*, B_S^*)$
  BR(D and $B \longrightarrow X\ e\ \nu \approx 10\%$)

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
- 0-th and 1-st order $q\bar{q}$-anihilation and 1-st order Compton scattering

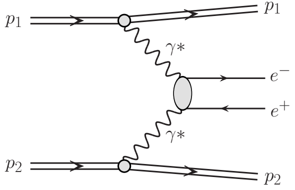
- 0-th order Drell-Yan cross section

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

- **unintegrated quark distributions**

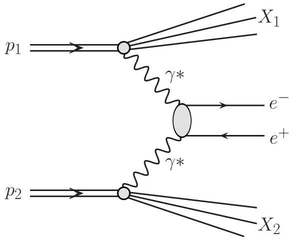
Elastic and inelastic reactions

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



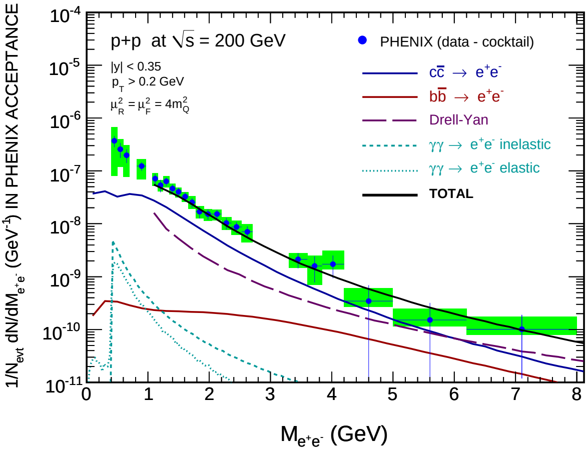
- exact momentum space calculations with 4-body phase space
- consistent with LPAIR Monte Carlo package

- $pp \to X_1X_2e^+e^-$

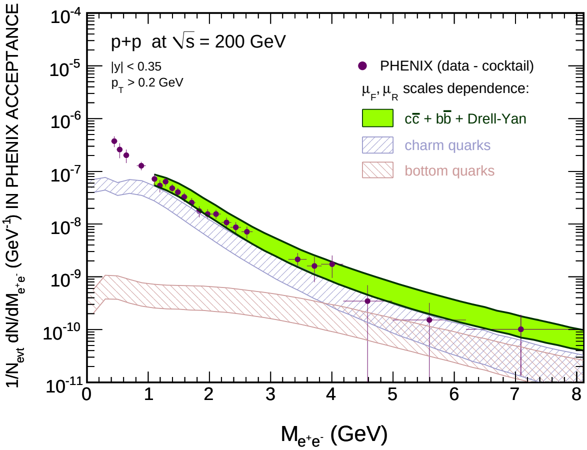


- collinear kinematics
- MRST 2004 (Martin-Roberts-Stirling-Thorne) photon distributions in nucleon

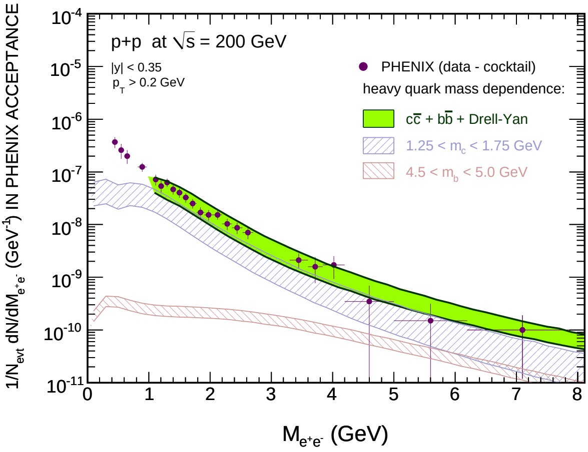
Dilepton invariant mass spectrum



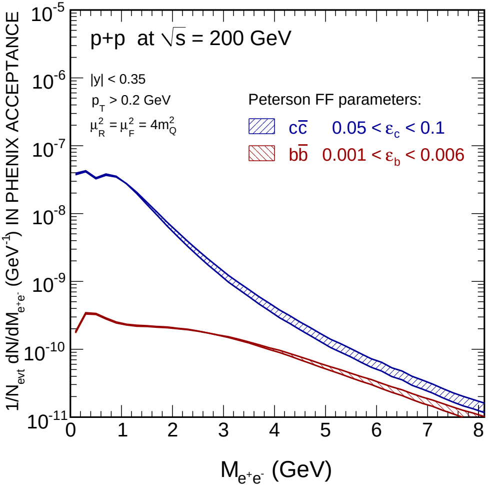
Uncertainties - μ_F, μ_R scale dependence



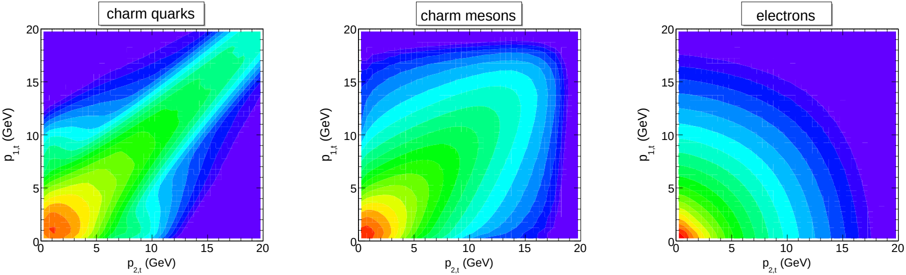
Uncertainties - quark mass dependence



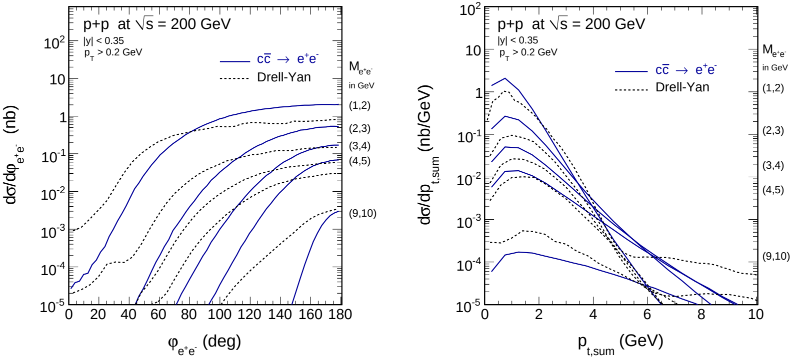
Sensitivity of fragmentation functions parameters ϵ_c, ϵ_b



Transverse momenta correlations



Azimuthal and $p_{t,sum}$ correlations



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

Summary

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Model:

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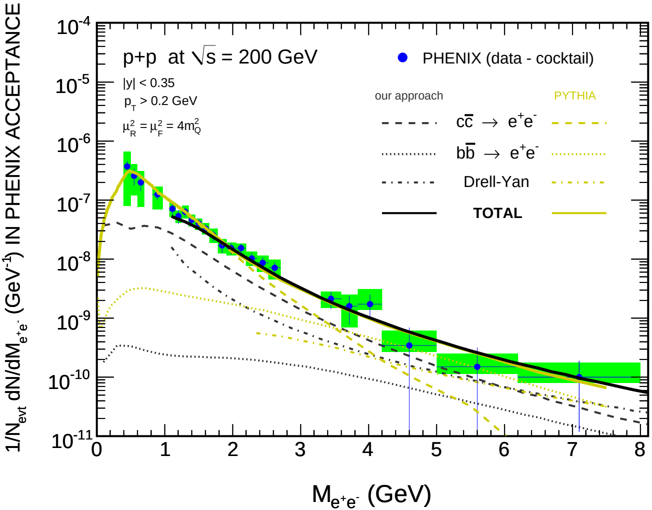
New possibilieties:

- Kinematical correlations between outgoing leptons

Thank You for attention!

Backup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|y| < 0.35
p_T > 0.2 GeV
μ²_R = μ²_F = 4m²_Q
PHENIX (data - cocktail)
our approach
PYTHIA
cc̄ → e⁺e⁻
bb̄ → e⁺e⁻
Drell-Yan
TOTAL
1/N_evt dN/dM_e+e- (GeV⁻¹) IN PHENIX ACCEPTANCE
M_e+e- (GeV)

Backup

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

Future:

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