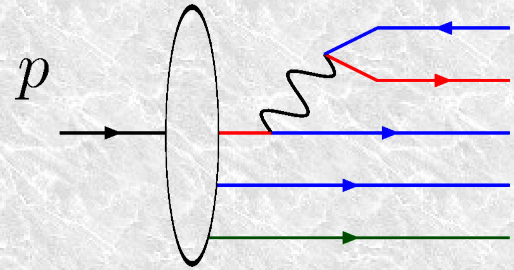
Intrinsic vs. radiative charm

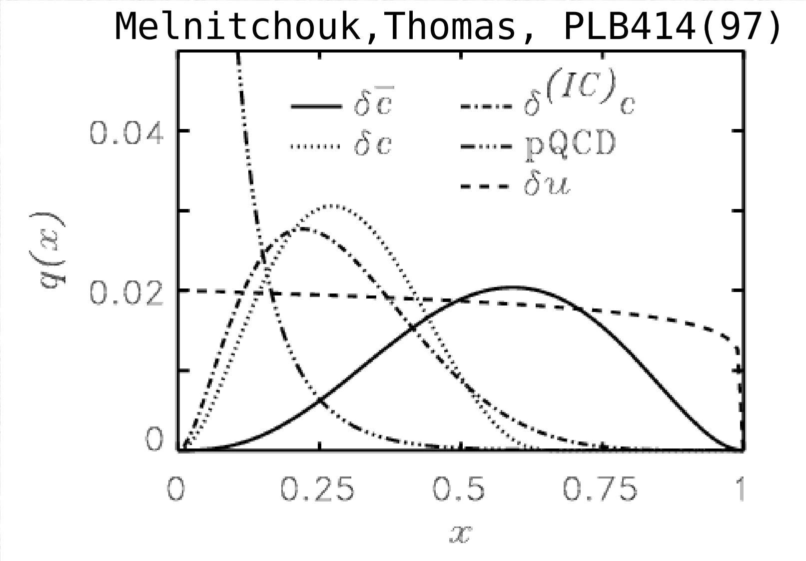
- Usual assumption in global fits: at threshold

Pumplin, PRD73(06),
Brodky et al., PRD73(06)
+ references teherein

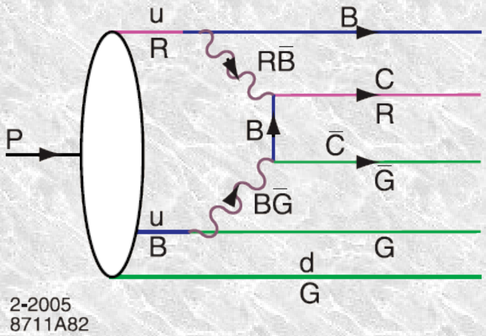
$$c(x, Q_c \approx m_c) = 0$$

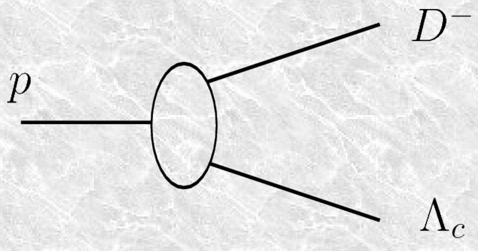
  - charm generated during DGLAP evolution





- but QCD predicts intrinsic charm





  - a c-cbar pair fluctuation already exists, peaked at large x~0.4
  - fully participates in DGLAP evolution
  - *c, cbar* asymmetry: small @ NLO (pQCD) or large (nonpert. models)

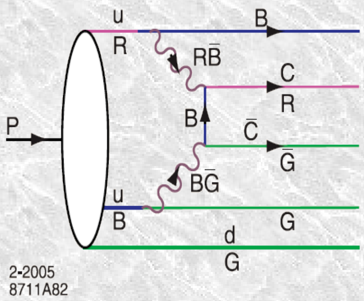
Indications from global fits

[Pumplin, Lai, Tung, PRD75(07)]

- 3 models at $\mu = m_c$
  [see Pumplin PRD 73(06) for review of models]

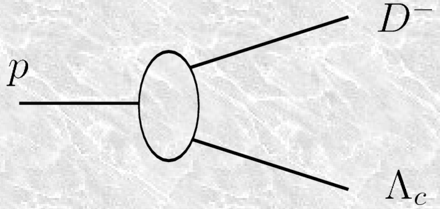
1) Brodsky-Hoyer-Peterson-Sakai [PLB 93 (80)]

$$c(x) = \bar{c}(x)$$
$$= A\,x^2\left[6x(1+x)\ln x + (1-x)(1+10x+x^2)\right]$$



2) meson-cloud model
[Navarra et al '96, '98;
Melnitchouk,Steffens,Thomas '97,'99]

$$c(x) = Ax^{1.897}(1-x)^{6.095}$$
$$\bar{c}(x) = \bar{A}x^{2.511}(1-x)^{4.929}$$



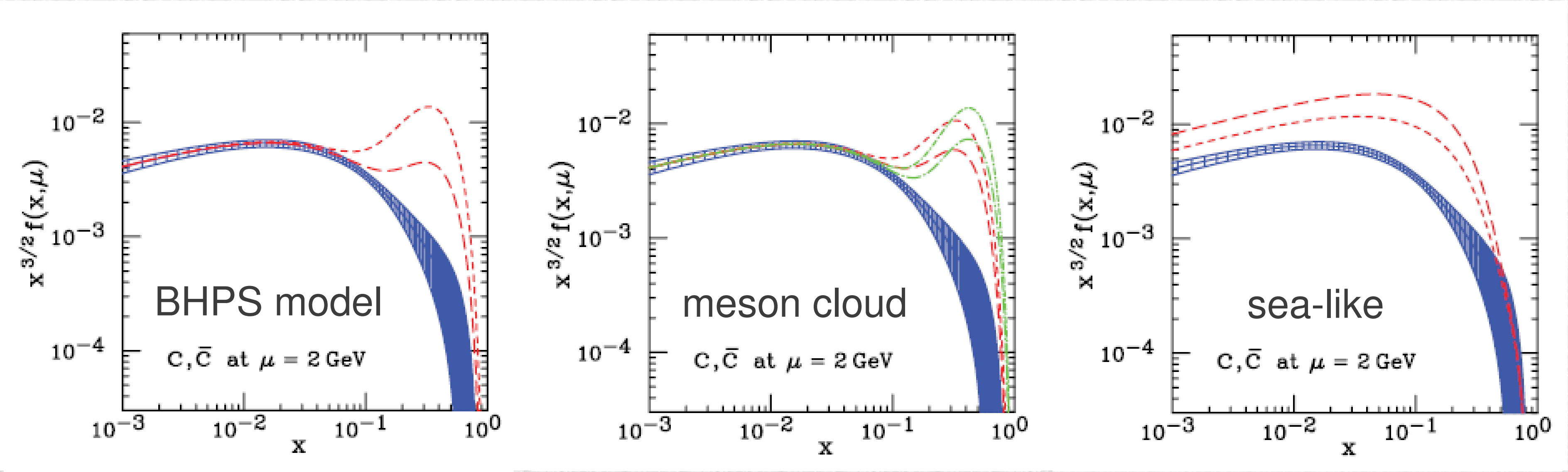
3) phenomenological “sea-like”

$$c(x) = \bar{c}(x) \propto \bar{d}(x) + \bar{u}(x)$$

Indications from global fits

[Pumplin, Lai, Tung, PRD75(07)]

- All models allow **IC = 0-3% intrinsic charm**
  - Evolution redistributes IC to lower *x*, but large-*x* peak persists
  - sea-like spread out over *x*

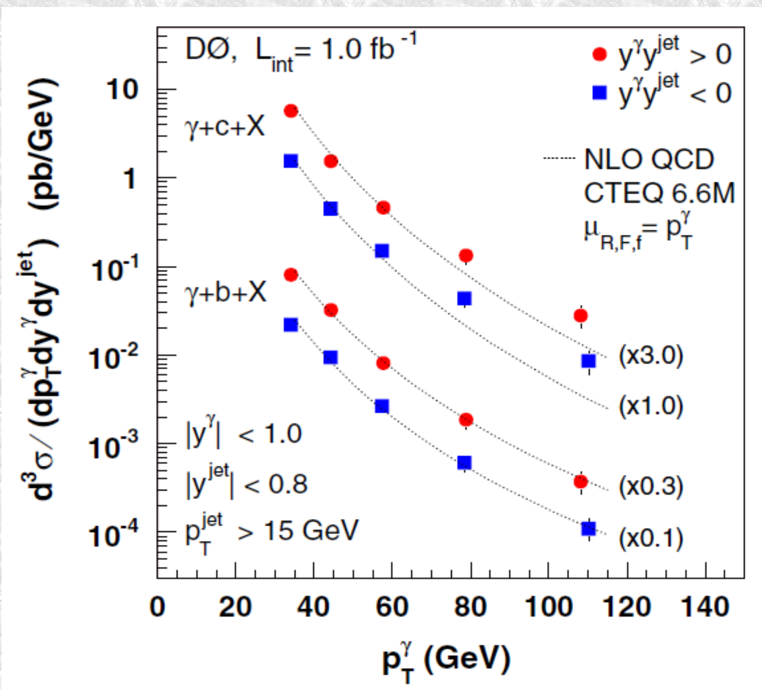


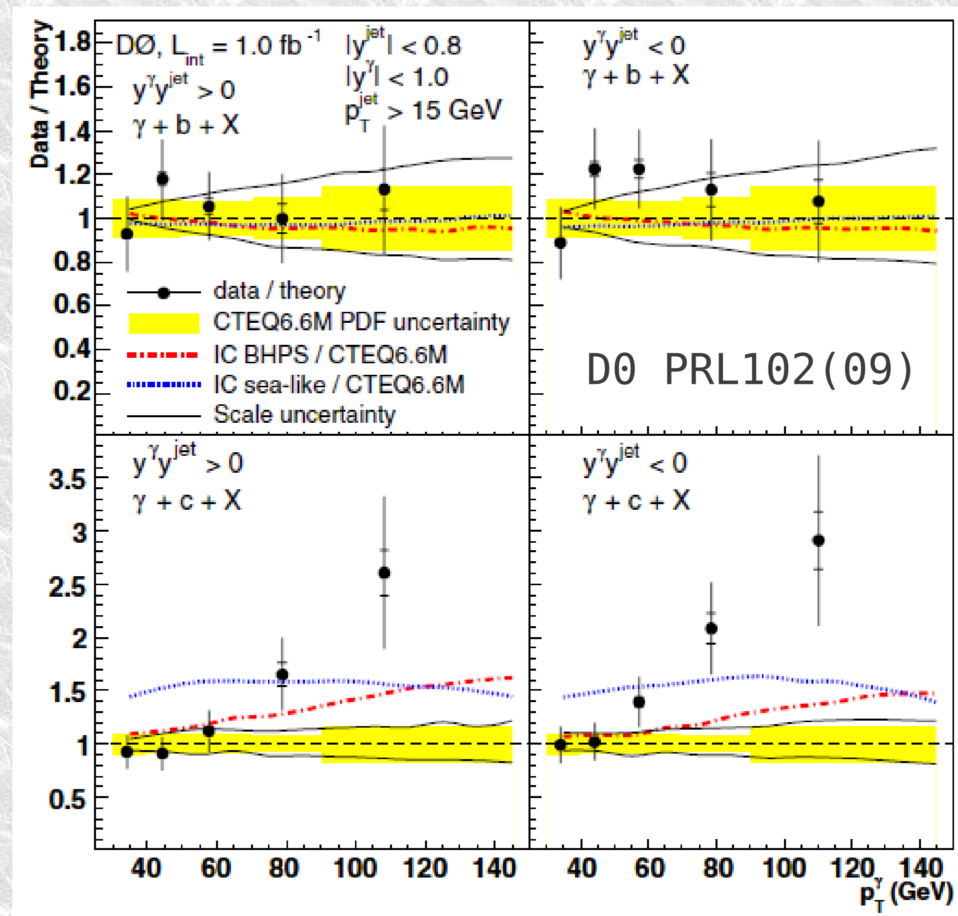
Experimental evidence - D0

- D0 measured excess of γ+charm jets compared CTEQ6.6 [D0, PRL102(09)]

$$g + Q \to \gamma/Z + Q$$

$$q + \bar{q} \to \gamma/Z + g \to \gamma/Z + Q\bar{Q}$$



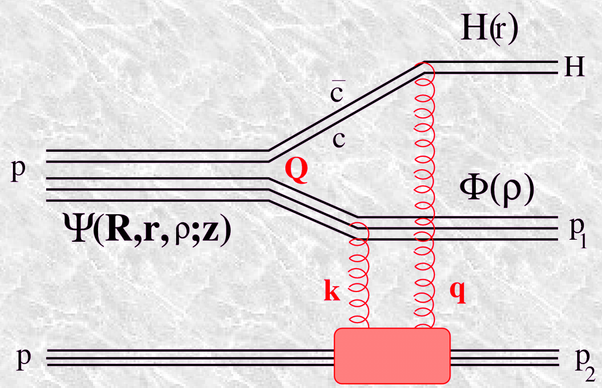


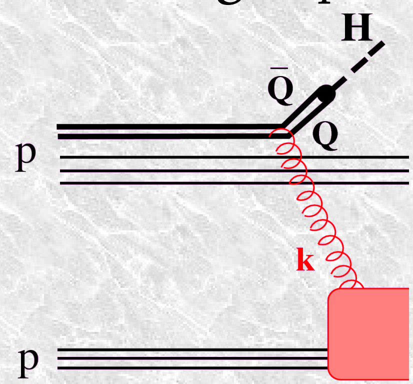
$0.01<x<0.3$ and $10^3<Q^2<10^4$

- Difference due to
  - intrinsic charm?
  - underestimate of $g \to c\bar{c}$?

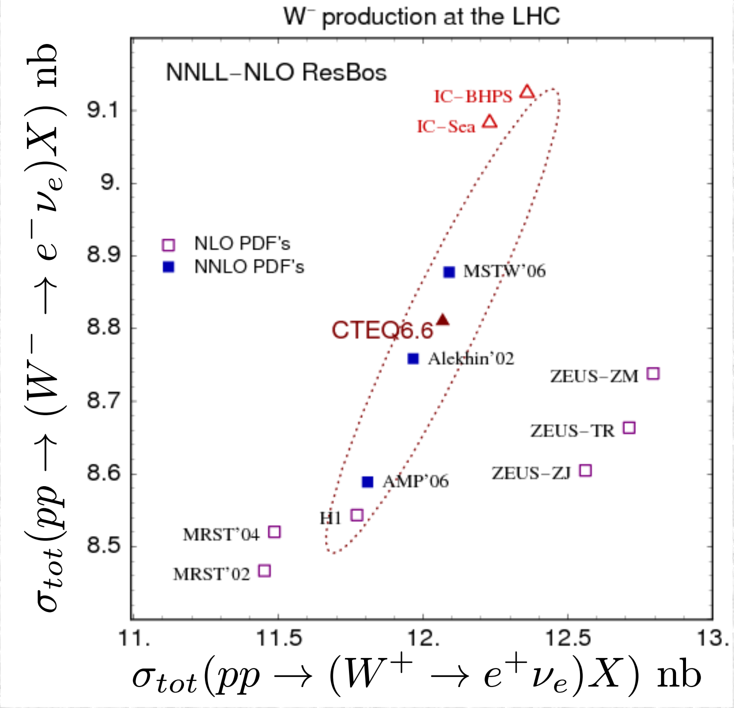
Phenomenological implications

- SM and beyond at **Tevatron and LHC**
  - Higgs and single top production sensitive to heavy quarks
  - Novel Higgs production mechanisms at large $x_F \approx 0.7\text{-}0.9$ [Brodsky et al. PRD73(06), NPB907(09)]





  - W production [Nadolsky et al. PRD78(08)]



How to measure – hadronic collisions

- **γ/Z + charm jet**
  - sensitive to $g + Q \to \gamma/Z + Q$ and $q + \bar{q} \to \gamma/Z + g \to \gamma/Z + Q\bar{Q}$
  - $y_\gamma y_{jet} > 0$ and $y_\gamma y_{jet} < 0$ sensitive to different x_1, x_2
  - allows constraints on Q, Qbar, and gluons
  - angular dependence to distinguish above sub-processes

- Also,

  - High x_F $pp \to J/\psi X$
  - High x_F $pp \to J/\psi J/\psi X$
  - High x_F $pp \to \Lambda_c X$
  - High x_F $pp \to \Lambda_b X$
  - High x_F $pp \to \Xi(ccd)X$ (SELEX)

PANDA Workshop
Turin June 17, 2009

Novel Anti-Proton QCD Physics
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Stan Brodsky
SLAC

How to measure – DIS

- **HERA charm and bottom events**
  - already included in the fits
  - most data at small *x*, where $\gamma\, g \to c\bar{c}$ dominates over $\gamma\, c \to c\, X$
  - **needs larger *x***

- **F_L/F_2 ratio** [Ivanov, NPB814(09)]

- **JLAB 6/12**
  - Ideally placed across the charm threshold
  - D+ vs. D- sensitive to c/cbar asymetry

- **EIC (LHeC ??)**
  - jet measurements are possible
  - larger Q^2 range

Target and heavy-quark mass corrections

- DIS in collinear factorization: [Accardi, Qiu JHEP '08]

$$F_{T,L}(x_B, Q^2, m_N) = \sum_f \int_{x_f^{min}}^{x_f^{max}} \frac{dx}{x}\, h^f_{T,L}\left(\frac{\xi_f}{x}, Q^2\right) \varphi_f(x, Q^2)$$

f parton mass

Nachtmann variable

$$\xi_f = \xi \left[1 - \frac{\xi^2}{x^2}\frac{m_f^2}{Q^2}\right]^{-1} \xrightarrow{m_f \to 0} \xi \xrightarrow{M_N \to 0} x_B$$

$$x_f^{min} = \xi \frac{Q^2 + (c-1)m_f^2 + \Delta[m_f^2, -Q^2, c m_f^2]}{2Q^2} \xrightarrow{m_f \to 0} \xi \xrightarrow{M_N \to 0} x_B$$

$$x_f^{max} = \xi \frac{Q^2/x_B + 3m_f^2 + \Delta[m_f^2, -Q^2, Q^2(1/x_B - 1)]}{2Q^2} \xrightarrow{m_f \to 0} \xi/x_B \xrightarrow{M_N \to 0} 1$$

$$\Delta[a,b,c] = \sqrt{a^2 + b^2 + c^2 - 2(ab + bc + ca)} \qquad \xi = 2x_B/\left(1 + \sqrt{1 + 4x_B^2 M_N^2/Q^2}\right)$$