Calculations on Λ_c-$\overline{\Lambda}_c$ and D-$\overline{D}$ production

W. Schweiger

Karl-Franzens-Universität Graz

Collaborators:

A.T. Goritschnig, S. Kofler (Univ. Graz),
P. Kroll (Univ. Wuppertal), B. Pire (Ecole Polytech. Palaiseau)

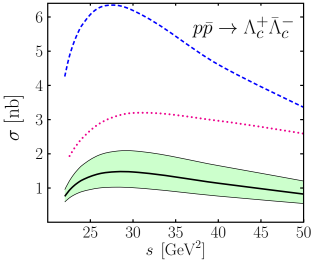
(June 11^{th}, 2014, PANDA XLIX. Coll. Meeting, GSI)

Theoretical Situation

Outcome of theoretical descriptions of $p\bar{p} \longrightarrow \Lambda_c \overline{\Lambda}_c$ rather controversial!

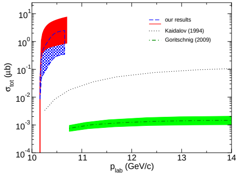
pQCD:

A. Goritschnig, P. Kroll, W. Schweiger:
Eur. Phys. J. A 42 (2009) 43

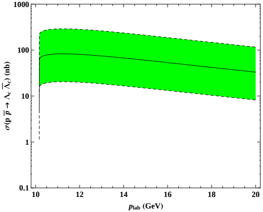


Hadronic models:

J. Haidenbauer and G. Krein:
Phys. Lett. B 687 (2010) 314



A. Khodjamirian et al: Eur.Phys.J. A 48 (2012) 31

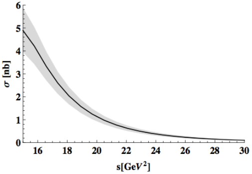


Theoretical Situation

Outcome of theoretical descriptions of $p\bar{p} \longrightarrow D\bar{D}$ also controversial!

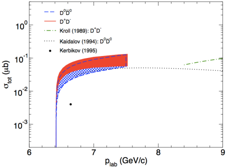
pQCD:

A. Goritschnig, B. Pire, W. Schweiger:
Phys. Rev. D 87 (2013) 014017;
D 88 (2013) 079903(E)

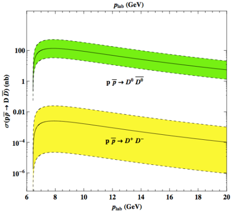


Hadronic models:

J. Haidenbauer and G. Krein:
arXiv: 1404.4174 [hep-ph]



A. Khodjamirian et al: Eur.Phys.J. A48 (2012) 31

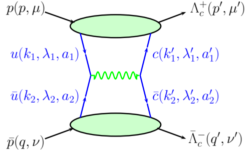


Theoretical Situation

Production mechanisms, assumptions and ingredients

pQCD:

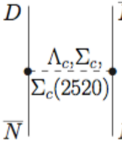
- Handbag mechanism



- intrinsic charm in p neglected
- charm created perturbatively via $u\bar{u} \to c\bar{c}$
- Λ_c and D LC-wfs strongly peaked at $x_0 = m_c/m_{H_c}$
- $p \to \Lambda_c$ transition GPDs and $p \to D$ TDAs unknown $\Rightarrow$ modelling
- valid well above production threshold (ξ small)

Hadronic models:

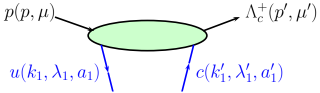
- Hadron (Reggeon) exchange



- charm created non-perturbatively via $H_c^{(*)}$ (Regge) exchange
- intrinsic charm in p crucial
- $B_c p M_c^{(*)}$-couplings unknown $\Rightarrow$ $SU(4)_f$-relations, LC sum rules
- initial and final state interaction (partly) taken into account
- vertex form factors not uniquely determined
- valid from production threshold on

Features of the Handbag Mechanism

- Analysis of soft hadronic matrix element



$\Rightarrow$ 8 $p \to \Lambda_c$ transition GPDs H, E, $\tilde{H}$, $\tilde{E}$, H_T, E_T, $\tilde{H}_T$, $\tilde{E}_T$

- Peaking approximation ($\bar{x}_i \to x_0$ in hard-scattering amplitude) $\Rightarrow$ $\bar{x}$-integrals over GPDS $\Rightarrow$ 8 transition form factors

$$\int \frac{d\bar{x}_1}{\sqrt{\bar{x}_1^2 - \xi^2}} \mathcal{H}^{cu}_{\mu'\mu} = \bar{u}\left(p',\mu'\right)\left[R_V(\xi,t)\,\gamma^+ + R_T(\xi,t)\,\frac{i\sigma^{+\nu}\Delta_\nu}{M+m}\right] u(p,\mu)$$

H, $E \to R_V$, R_T, $\tilde{H}$, $\tilde{E} \to R_A$, R_P, H_T, $\tilde{H}_T$, E_T, $\tilde{E}_T \to S_T$, S_S, S_{V1}, S_{V2}

- Suppression of FFs which require quark orbital angular momentum $\Rightarrow |R_V|, \quad |R_A|, \quad |S_T| \quad >> \quad |R_T|, \quad |R_P|, \quad |S_{V1}|, \quad |S_{V2}|$
- $\bar{x} > \xi$ (DGLAP region) $\Rightarrow$ overlap representation of GPDs and FFs in terms of valence-quark LC-wavefunctions feasible
- s-wave wave functions $\to R_V \approx R_A \approx S_T$

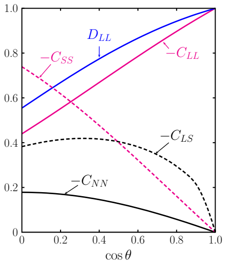
Features of the Handbag Mechanism

Spin Correlation Parameters

Single polarization observables vanish, but non-vanishing correlators:

- initial spin correlations: A_{ij}
- polarization transfer $p \to \Lambda_c$: D_{ij}
- final spin correlations: C_{ij}
- polarization correlation between p and Λ_c: K_{ij}

with $i, j =$ L (helicity), N (normal to scatt. plane) and
S (sideways direction, within scattering plane but $\perp$ to momentum).



If $\mu_{\Lambda_c} = \mu_c \Rightarrow R_V = R_A = S_T$, then

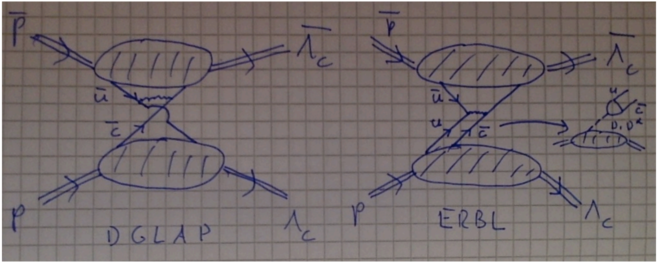
$$\mathcal{O}\left(p\bar{p} \to \Lambda_c\bar{\Lambda}_c\right) = \mathcal{O}\left(u\bar{u} \to c\bar{c}\right),$$

which is independent of model for baryon wave functions!

Extension of the Handbag Mechanism

Intrinsic (non-perturbative) charm in p

- Requires (at least) $|uudc\bar{c}>$ Fock component in p
- Is c-quark distribution in p peaked at small x (typical for light sea quarks), or concentrated at larger x (typical for LC-wf models)?
- In addition to DGLAP region also the ERBL region ($|x| < |\xi|$) may become important



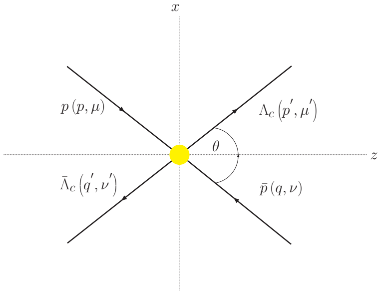
- Knowledge on intrinsic (non-perturbative) charm in p still poor

  J. Pumplin, H.L. Lai and W.K. Tung: Phys. Rev. D75 (2007) 054029

  T.J. Hobbs, J.T. Londergan and W. Melnitchouk: Phys. Rev. D89 (2014) 074008

Conclusions

- pQCD, i.e. generalized parton picture, applied to $p\bar{p} \to \Lambda_c \overline{\Lambda}_c$ and $p\bar{p} \to D^0 \overline{D^0}$ (p treated as $uS[ud]$ state)
- Occurring GPDs and TDAs modeled by overlap of (valence Fock state) LC wave functions
- Predictions for integrated $p\bar{p} \to \Lambda_c \bar{\Lambda}_c$ and $p\bar{p} \to D^0 \overline{D}^0$ cross sections between 1 and 10 nb
- pQCD provides characteristic behavior of spin correlations for $p\bar{p} \to \Lambda_c \overline{\Lambda}_c \Rightarrow c$-quark spin directly accessible via Λ_c spin?
- Integrated cross sections from pQCD 1-3 orders of magnitude smaller than from hadrodynamical models
- Hadrodynamical models require (non-perturbative) intrinsic charm in proton
- Experiment in favor of hadrodynamical models
  $\Rightarrow$ intrinsic charm in p has to be considered
  $\Rightarrow$ important information about c-quark distribution in p
- Intrinsic charm in proton can be accommodated within generalized parton picture, but requires additional modeling and has not yet been attempted



Symmetric CM frame

4-momenta in terms of LC-components:

$$p = \left[(1+\xi)\,\bar{p}^+,\, \frac{m^2 + \mathbf{\Delta}_\perp^2/4}{2\,(1+\xi)\,\bar{p}^+},\, -\frac{\mathbf{\Delta}_\perp}{2}\right]$$

$$p' = \left[(1-\xi)\,\bar{p}^+,\, \frac{M^2 + \mathbf{\Delta}_\perp^2/4}{2\,(1-\xi)\,\bar{p}^+},\, \frac{\mathbf{\Delta}_\perp}{2}\right]$$

$$q^{(\prime)} = \left[p^{(\prime)-},\, p^{(\prime)+},\, -\mathbf{p}_\perp^{(\prime)}\right]$$

Average 4-momentum:
$\bar{p} = \frac{1}{2}\,(p + p') \Rightarrow \bar{\mathbf{p}}$ parallel to $\mathbf{e}_z$

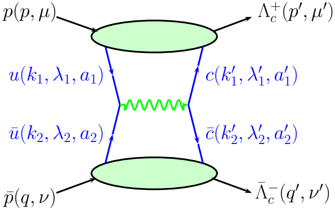
4-momentum transfer

$$\Delta = p' - p = q - q' = k_1' - k_1 = k_2 - k_2'$$

Skewness parameter:

$$\xi = \frac{p^+ - p'^+}{p^+ + p'^+} = -\frac{\Delta^+}{2\bar{p}^+}\,.$$

$(a^+, a^-, a_\perp)$ with $a^\pm = (a^0 \pm a^3)/\sqrt{2}$ and $a_\mu b^\mu = a^+ b^- + a^- b^+ - \mathbf{a}_\perp \mathbf{b}_\perp$.



Momenta of active partons

$$k_1 = \left[x_1 p^+,\, k_1^-,\, \mathbf{k}_{1\perp}\right]$$
$$k_1' = \left[x_1' p'^+,\, k_1'^-,\, \mathbf{k}_{1\perp}'\right]$$
$$k_2 = \left[k_2^+,\, x_2 q^-,\, \mathbf{k}_{1\perp}\right]$$
$$k_2' = \left[k_2'^+,\, x_2' q'^- . \mathbf{k}_{2\perp}'\right]$$

Average momentum fractions $\bar{x}_i$:

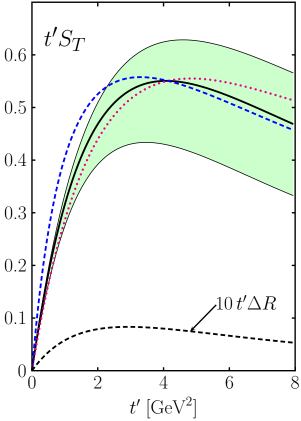
$$\bar{x}_1 = \frac{k_1^+ + k_1'^+}{p^+ + p'^+}\,, \quad \bar{x}_2 = \frac{k_2^- + k_2'^-}{q^- + q'^-}$$

Relation to individual parton momentum fractions $x_i^{(\prime)}$:

$$x_1 = \frac{\bar{x}_1 + \xi}{1+\xi}\,, \quad x_1' = \frac{\bar{x}_1 - \xi}{1-\xi}\,, \quad x_2 = \frac{\bar{x}_2 - \xi}{1+\xi}\,, \quad x_2' = \frac{\bar{x}_2 + \xi}{1-\xi}$$

$\rho \neq 0 \Longrightarrow R_{V/A} = S_T \mp \frac{1}{2}\Delta R$

($\rho = 2 \Longrightarrow \approx 10\%$ probability to find c with opposite helicity)



Scaled form factor $t'S_T$ $\left[\mathrm{GeV}^2\right]$ with $t' = t - t_0$ at $s = 30\mathrm{GeV}^2$.

- solid black: $f = f_{KK}$
- dashed blue: $f = f_{BB}$
- dotted red: $(1/\sqrt{x_0{}^2 - \xi^2}) \int d\bar{x}_1$ over GPDs

($a_p = a_\Lambda = 0.75$ GeV^{-1}, $N_p = 160.5$ GeV^{-2}, $N_\Lambda = 2117/3477\mathrm{GeV}^{-2}$ (KK/BB))