Charm Production & Life in Nuclear Matter

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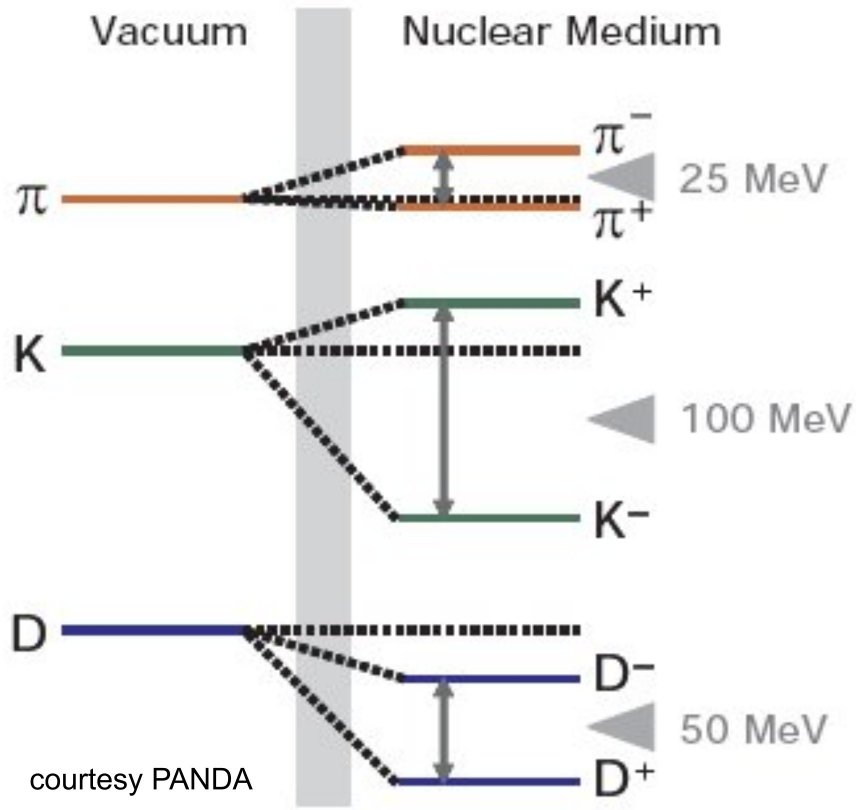
Mesons with Charm in Vakuum: Dyson-Schwinger—Bethe-Salpeter
Mesons with Charm in Medium: QCD Sum Rules
Hadrons with Charm: Production in p p_bar

dedicated research for PANDA & CBM (FAIR)

*) with T. Hilger, S. Leupold, S. Dorkin, L. Kaptari, H. Schade, A. Titov



pA:
Scheinast et al.
(KaoS), PRL 2006

pA: CBM, 2019
p_bar A: PANDA, 2019

like Stark & Zeeman effects in QM:
understanding hadronic part of QCD

Charming Mesons in Vacuum

Dyson-Schwinger – Bethe-Salpeter approach

Alkofer
Fischer
Krassnigg
Roberts
Tandy
...

guess for gluon propagator D
→ DS eq. for quark propagator (Euclidean, rainbow approx.):

$$S_q^{-1}(p) = i\gamma \cdot p + \tilde{m} + \frac{4}{3}\int \frac{d^4 l}{(2\pi)^4}\left[g^2 D(p-l)\right]_{\mu\nu}\gamma_\mu S_q(l)\gamma_\nu$$

arbitrary (cov. of BS)

BS eq. in rainbow-ladder approx. (Euclidean): $k_+ = k + \xi P,\ k_- = k + (\xi - 1)P$

$$\Gamma(P,p) = (-\frac{4}{3})\int \frac{d^4 k}{(2\pi)^4}\gamma_\mu S(k_+)\Gamma(P,k)S(k_-)\gamma_\nu (g^2 D(p-k))_{\mu\nu}$$

4 x 4 matrix: tricky expansion → ang. integration:

$g_i^k(p) = \int_0^\infty \frac{dk k^3}{4\pi^2}\sum A_{ij}^{km}(p,k) g_j^m(k)$ → g = K g → det (K – 1) = 0: bound states

gluon propagator: ansatz

Roberts et al., Eur. Phys. J. ST 140 (2007) 53 (4.44)

$$g^2(k^2)D_{\mu\nu}(k^2) = \left(\underbrace{\frac{4\pi^2 D k^2}{\omega^2} e^{-k^2/\omega^2}}_{\text{IR}} + \underbrace{\frac{8\pi^2 \gamma_m F(k^2)}{ln[\tau + (1 + \frac{k^2}{\Lambda^2_{QCD}})]}}_{\text{neglect}} \right) \left(\delta_{\mu\nu} - \frac{k_\mu k_\nu}{k^2} \right)$$

$\omega = 0.5$ GeV

$D = 16$ GeV^{-2}

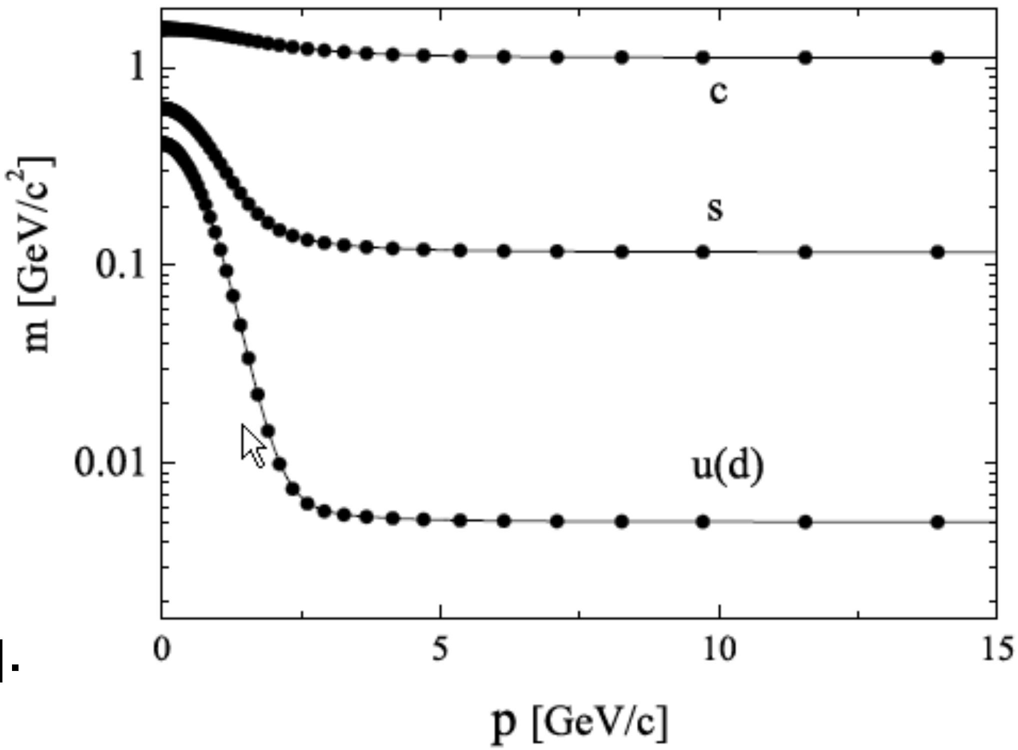
quark propagator:

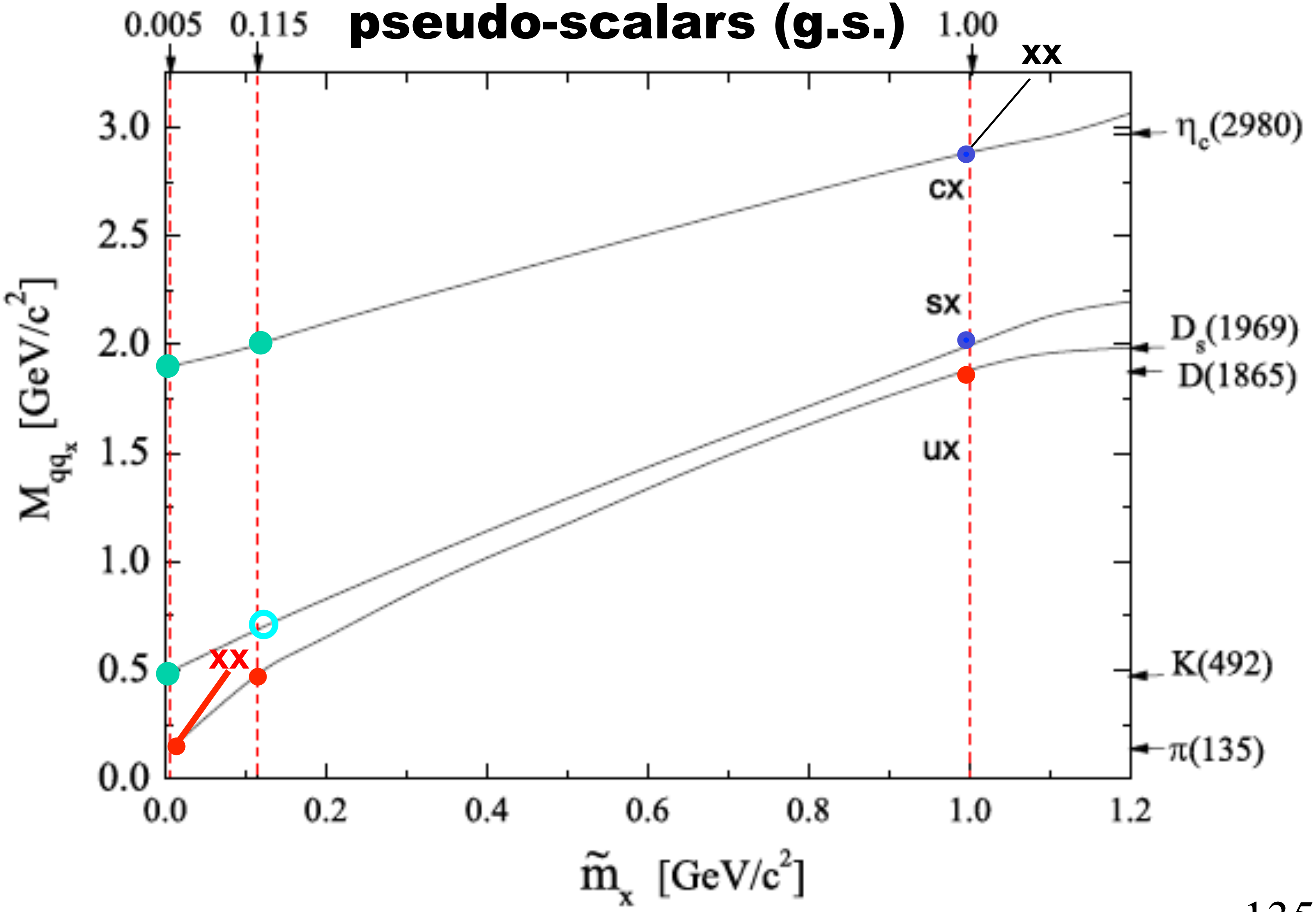
$$S_q^{-1}(p) = i\gamma \cdot pA(p) + B(p)$$

m(p) = B(p) / A(p)

$$\tilde{m} = m(p \to \infty)$$

→ input for Bethe-Salpeter eq.





pi: m_u = 0.005 GeV

K: m_s = 0.115 GeV

D: m_c = 1.0 GeV

135 MeV: pi

497 MeV: K

1870 MeV: D±

1970 MeV: D±s

2980 MeV: eta_c

under construction: scalar, vector, axial-vector channels

excited states: pi(1300)~1080 MeV,

non-zero T, mu: method = ?

Charming Mesons in Nuclear Matter

$$\Pi(q) = \mathrm{i} \int \mathrm{d}^4x \, \mathrm{e}^{\mathrm{i}qx} \langle\langle T\left[j(x) j^\dagger(0)\right]\rangle\rangle$$

→ OPE: QCD condensates (T,n)

$$\Pi(q) = \frac{1}{\pi} \int_{-\infty}^{+\infty} \mathrm{d}s \frac{\Delta\Pi(s, |\vec{q}|)}{s - q_0}$$

→ hadron spectral funct.

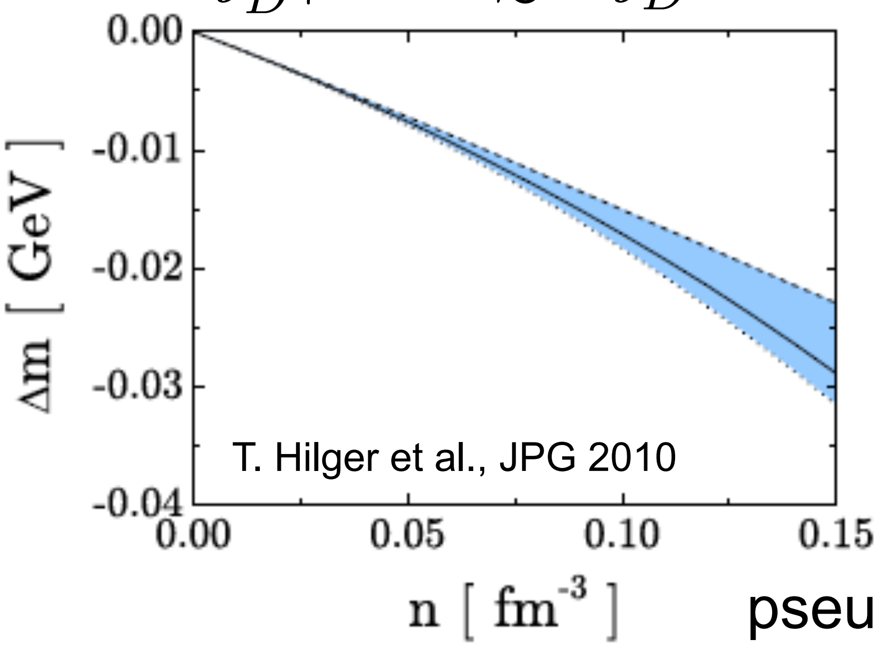
$$S_n(M) \equiv \int_{s_0^-}^{s_0^+} \mathrm{d}s \, s^n \Delta\Pi(s) \mathrm{e}^{-s^2/M^2}$$

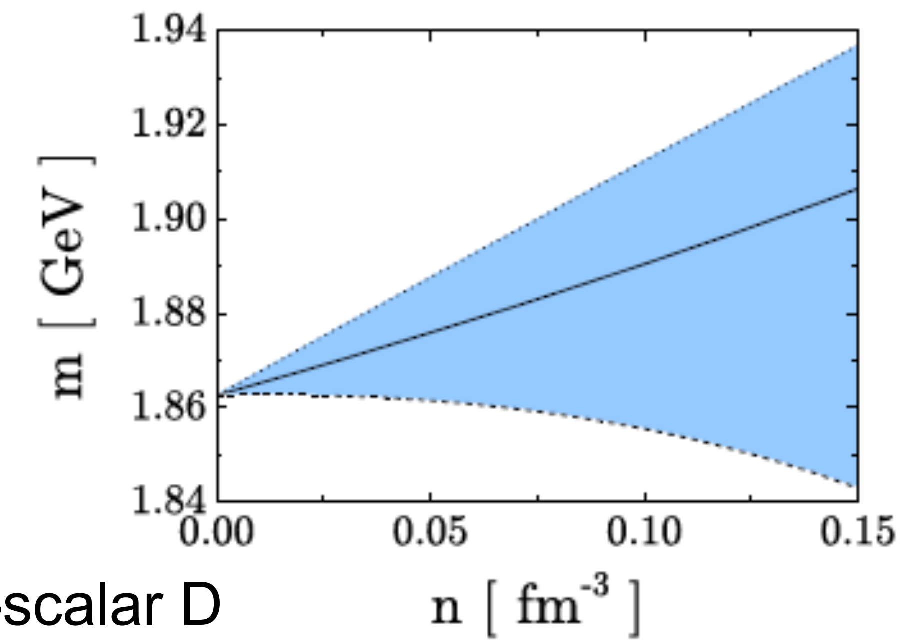
$$\Delta m \equiv \frac{1}{2} \frac{S_1 S_2 - S_0 S_3}{S_1^2 - S_0 S_2},$$

$$m_+ m_- \equiv -\frac{S_2^2 - S_1 S_3}{S_1^2 - S_0 S_2},$$

$$m^2 \equiv \Delta m^2 + m_+ m_-,$$

$$j_{D^+} = i\bar{d}\gamma_5 c, \; j_{D^-} = i\bar{c}\gamma_5 d$$

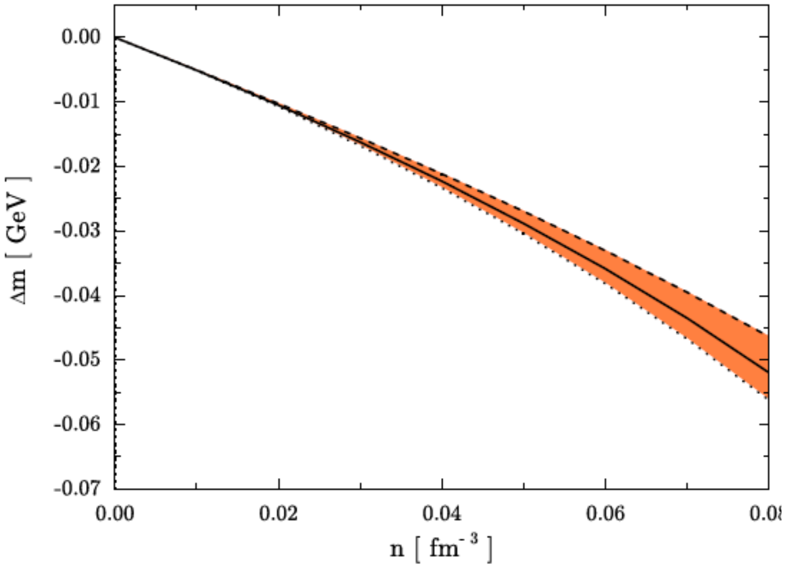


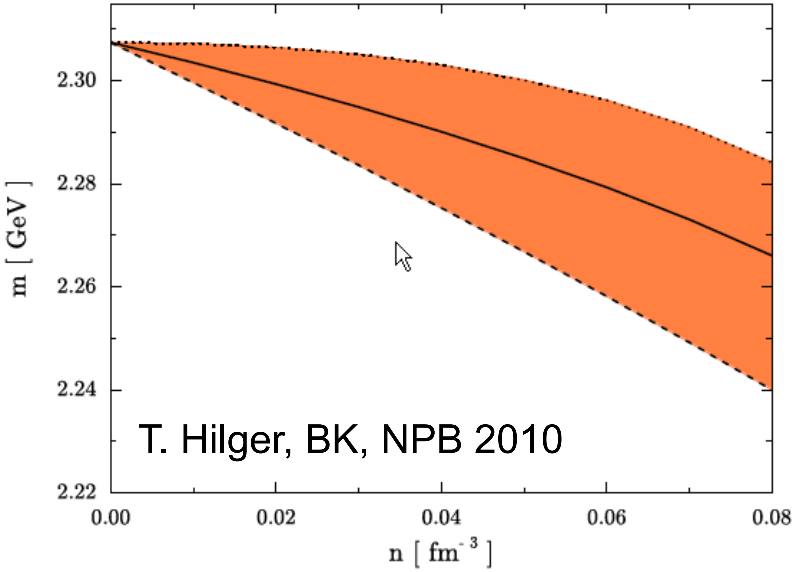


pseudo-scalar D

scalar $D^* - \bar{D}^*$

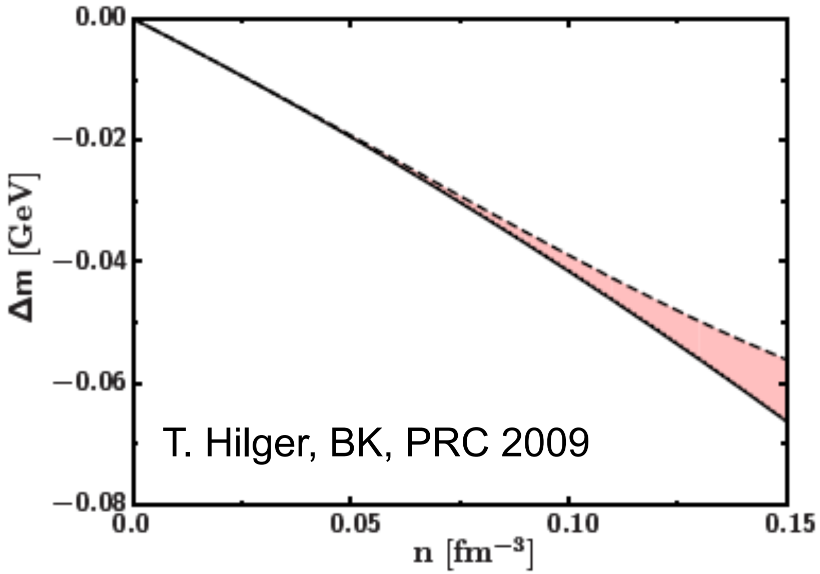
$j_{D^*} = \bar{d}c,\ j_{\bar{D}^*} = \bar{c}d$

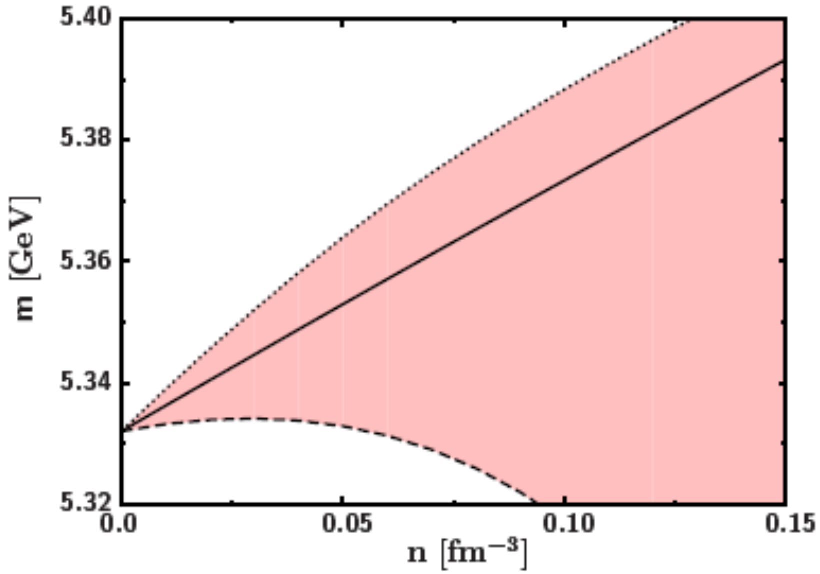




pseudo-scalar $B - \bar{B}$

$j_{B^+} = i\bar{b}\gamma_5 u,\ j_{B^0} = i\bar{b}\gamma_5 d$





condensate	vacuum value $\langle \cdots \rangle_{vac}$	density dependent part $\langle \cdots \rangle_{med}$
$\langle \overline{q} q \rangle$	$(-0.245\ \mathrm{GeV})^3$	$45/11\, n$
$\langle \frac{\alpha_s}{\pi} G^2 \rangle$	$(0.33\ \mathrm{GeV})^4$	$-0.65\ \mathrm{GeV}\, n$
$\langle \overline{q} g \sigma \mathcal{G} q \rangle$	$0.8\ \mathrm{GeV}^2 \times (-0.245\ \mathrm{GeV})^3$	$3\, n\ \mathrm{GeV}^2$
$\langle q^\dagger q \rangle$	0	$1.5\, n$
$\langle \frac{\alpha_s}{\pi} \left(\frac{(vG)^2}{v^2} - \frac{G^2}{4} \right) \rangle$	0	$-0.05\ \mathrm{GeV}\, n$
$\langle q^\dagger i D_0 q \rangle$	0	$0.18\ \mathrm{GeV}\, n$
$\langle \overline{q} \left[D_0^2 - \frac{1}{8} g \sigma \mathcal{G} \right] q \rangle$	0	$-0.3\ \mathrm{GeV}^2\, n$
$\langle q^\dagger D_0^2 q \rangle$	0	$-0.0035\ \mathrm{GeV}^2\, n$
$\langle q^\dagger g \sigma \mathcal{G} q \rangle$	0	$0.33\ \mathrm{GeV}^2\, n$

Weinberg type sum rules for chiral partners of heavy-light mesons

$m_c \quad m_q \to 0$

$$\frac{1}{\pi}\int_{-\infty}^{+\infty} d\omega\, \omega\, \Delta\Pi_{P-S}(\omega) = -\,2m_c\langle\bar{q}q\rangle\ ,$$

$$\frac{1}{\pi}\int_{-\infty}^{+\infty} d\omega\, \omega^3\, \Delta\Pi_{P-S}(\omega) = -\,2m_c^3\langle\bar{q}q\rangle + m_c\langle\bar{q}g\sigma\mathscr{G}q\rangle - m_c\,\langle\Delta\rangle$$

$$\frac{1}{\pi}\int_{-\infty}^{+\infty} d\omega\, \omega^5\, \Delta\Pi_{P-S}(\omega) = -\,2m_c^5\langle\bar{q}q\rangle + 3m_c^3\langle\bar{q}g\sigma\mathscr{G}q\rangle - 3m_c^3\,\langle\Delta\rangle + \ldots$$

$$\frac{1}{\pi}\int_{-\infty}^{+\infty} d\omega\, \omega\, \Delta\Pi_{V-A}(\omega) = 8m_c\langle\bar{q}q\rangle\ ,$$

$$\langle\bar{q}g\sigma\mathscr{G}q\rangle - 8\langle\bar{q}D_0^2q\rangle \equiv \langle\Delta\rangle$$

zero in vacuum

$$\frac{1}{\pi}\int_{-\infty}^{+\infty} d\omega\, \omega^3\, \Delta\Pi_{V-A}(\omega) = 8m_c^3\langle\bar{q}q\rangle + 4m_c\langle\Delta\rangle$$

$$\frac{1}{\pi}\int_{-\infty}^{+\infty} d\omega\, \omega^5\, \Delta\Pi_{V-A}(\omega) = 8m_c^5\langle\bar{q}q\rangle - 4m_c^3\langle\bar{q}g\sigma\mathscr{G}q\rangle - 12m_c^3\langle\Delta\rangle + \ldots$$

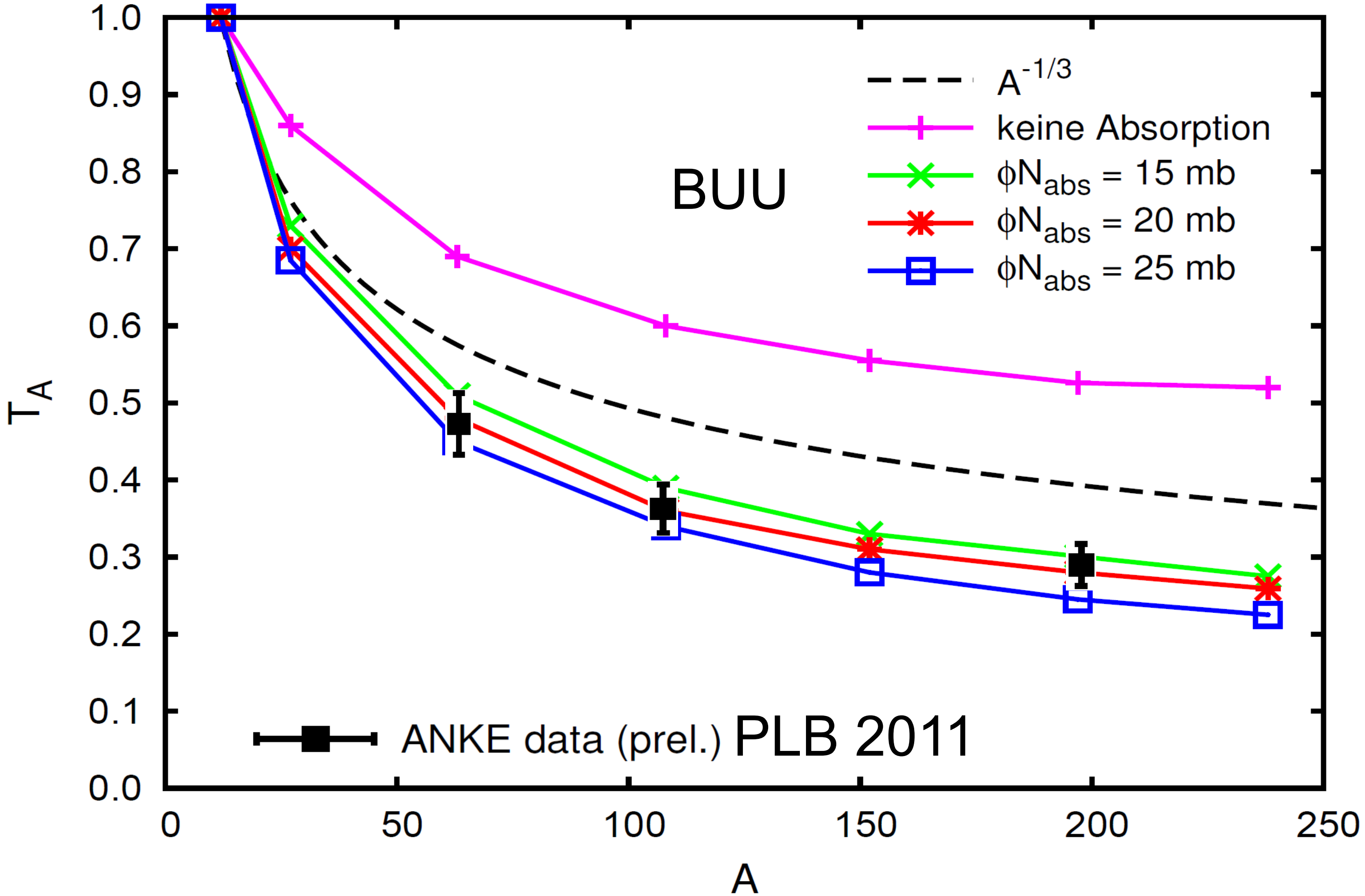
heavy-quark symmetry: $\Pi_{(1)} = \frac{1}{3}\left(\frac{q^\mu q^\nu}{q^2} - g^{\mu\nu}\right)\Pi_{\mu\nu}$

l.o. in $|q^2|/m_c \ll 1$: $\Pi_{(1)}^{V-A} = \Pi^{P-S} = \frac{-2}{m_c}\langle\bar{q}q\rangle$

Aside: Width of Strangeonium

$pA \to X\phi$: Tansparency Ratio $T_A = \frac{\sigma_{pA\to\phi X}}{A} \frac{C}{\sigma_{pC\to\phi X}}$

$\quad \llcorner\!\to K^+K^-$



$\Gamma_\phi = 45 - 73$ MeV in Valencia – Paryev models

Glauber eikonal type approach

p = projectile

abs

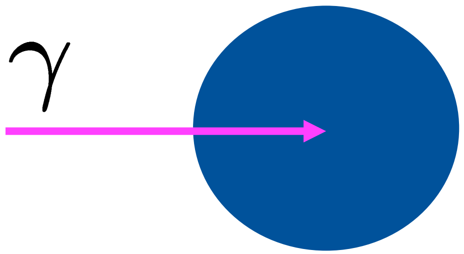
$c\bar{c}$

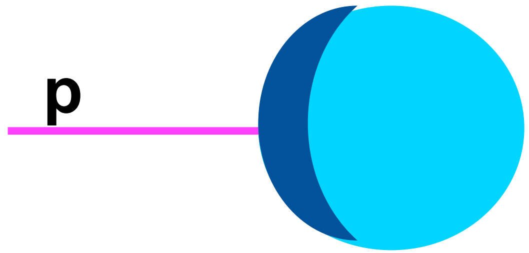
$$\sigma_{pA\to\phi X} = \sigma_{pN\to\phi X} \int d^2b \int_{-\sqrt{R^2-b^2}}^{\sqrt{R^2-b^2}} dz\; n(\vec{b}, z)$$

$$\times \exp\left\{ -\sigma_{pN}^{\rm tot} \int_{-\sqrt{R^2-b^2}}^{z} dz'\; n(\vec{b}, z') - \sigma_{\phi N}^{\rm tot} \int_{z}^{\sqrt{R^2-b^2}} dz'\; n(\vec{b}, z') \right\}$$

attenuation of projectile **absorption of ejectile**

photo (electro) production: „illumination“ of whole nucleus
proton (p_bar) induced production: „illumination“ of front side

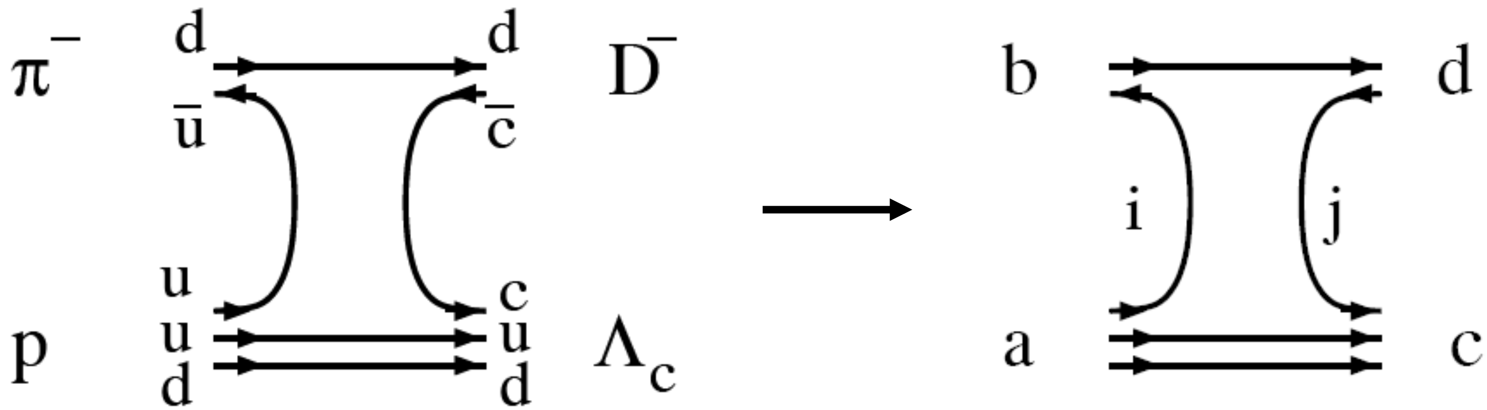




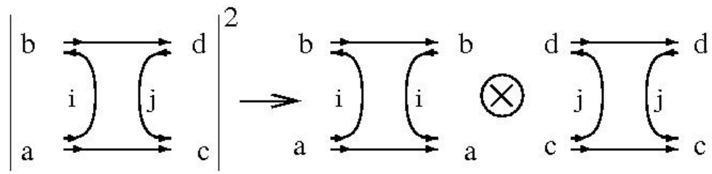
Exclusive Associate Charm Production in p p_bar*

Regge approach à la Kaidalov et al.

peripheral collisions: small momentum transfer/forward angles



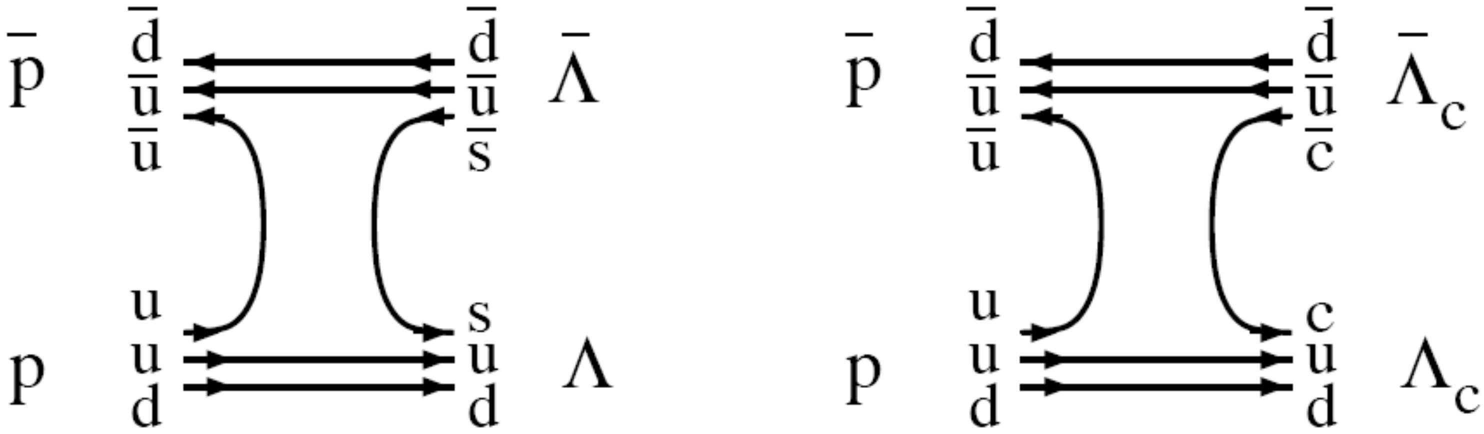
consistency of a b → a b, c d → c d

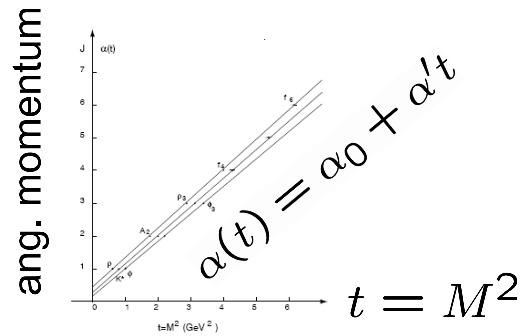


shopping list: $\bar{p}p \rightarrow \bar{\Lambda}\Lambda, \bar{\Lambda}_c\Lambda_c, \bar{K}K, \bar{D}D, \bar{D}D^*\ldots$

*) work by A.I. Titov: Open Charm Physics at PANDA, Mainz, Oct. 19-20, 2009

Baryon Pairs in Exit Channel





cross section: $$\frac{d\sigma}{dt} = \frac{1}{16\pi(s-4M_N^2)^2}|T_{fi}|^2$$

Regge pole amplitude with K* dominance:

K^* trajectory

$$T^{\bar{p}p\rightarrow\bar{\Lambda}\Lambda}_{m_f n_f;m_i,n_i} = C(t)\mathcal{M}^{\bar{p}p\rightarrow\bar{\Lambda}\Lambda}_{m_f n_f;m_i,n_i}(s,t)\frac{g^2_{K^*N\Lambda}}{s_0}\Gamma(1-\alpha_{\bar{s}q}(t))\left(-\frac{s}{s_{\bar{p}p:\bar{\Lambda}\Lambda}}\right)^{\alpha_{\bar{s}q}(t)-1}$$

fit (universal) — spin — 1 GeV

Brisudova, Burakovsky, Goldman, PRD 2000: non-linear Regge trajectories

$$\alpha(t) = \alpha(0) + \gamma(\sqrt{T} - \sqrt{T-t})$$

-t << T: $\alpha(t) = \alpha(0) + \alpha' t, \quad \alpha' = \gamma/2\sqrt{T}.$

additivity:

$$2\alpha_{\bar{s}q}(0) = \alpha_{\bar{q}q}(0) + \alpha_{\bar{s}s}(0) \quad (1)$$

$$2/\alpha'_{\bar{s}q} = 1/\alpha'_{\bar{q}q} + 1/\alpha'_{\bar{s}s} \quad ,(2)$$

$$\sqrt{T_\rho} = 2.46 \text{ GeV}, \qquad \alpha'_\rho \simeq 0.742 \text{ GeV}^{-2} ,$$

$$\sqrt{T_{K^*}} = 2.58 \text{ GeV}, \qquad \alpha'_{K^*} \simeq 0.71 \text{ GeV}^{-2}$$

$$\sqrt{T_\phi} \simeq 2.70 \text{ GeV}, \qquad \alpha'_\phi \simeq 0.676 \text{ GeV}^{-2} ,$$

$\rho \qquad \phi$

$$w^2_{ab\to cd} \simeq w_{ab\to ab} \times w_{cd\to cd}$$

diagonal transitions $\bar{p}p \to \bar{p}p$, $(s_{\bar{p}p})$ and $\bar{\Lambda}\Lambda \to \bar{\Lambda}\Lambda$, $(s_{\bar{\Lambda}\Lambda})$:

$$\left(s_{\bar{p}p:\bar{\Lambda}\Lambda}\right)^{2(\alpha_{K^*}(0)-1)} = \left(s_{\bar{p}p}\right)^{\alpha_\rho(0)-1} \times \left(s_{\bar{\Lambda}\Lambda}\right)^{\alpha_\phi(0)-1} \quad (3)$$

$$s_{ab} = \left(\sum_i^{n_a} M_{i\perp}\right)\left(\sum_j^{n_b} M_{j\perp}\right)$$

$$M_{q\perp} \simeq 0.5 \text{ GeV}, \; M_{s\perp} \simeq 0.6 \text{ GeV}, \text{ and } M_{c\perp} \simeq 1.6 \text{ GeV}$$

spin amplitude: $\mathcal{M}^{\bar{p}p\to\bar{\Lambda}\Lambda}_{m_f n_f; m_i n_f}(s,t) = \mathcal{N}(s,t)\,\Gamma^{(p)\,\mu}_{m_f m_i}\;\Gamma^{(\bar{p})\,\nu}_{n_f n_i}\;(-g_{\mu\nu} + \frac{q_\mu q_\nu}{q^2})$

from $\mathcal{L}_{K^*NY} = -\bar{Y}\left(\gamma_\mu - \frac{\kappa_{K^*NY}}{M_N + M_Y}\sigma_{\mu\nu}\right) N \partial^\nu K^{*\mu} + \text{h.c.}$

$$\Gamma^{(p)}_\mu = \bar{u}_\Lambda \left((1+\kappa_{K^*N\Lambda})\gamma_\mu - \kappa_{K^*N\Lambda}\frac{(p_p + p_\Lambda)_\mu}{M_N + M_\Lambda}) \right) u_p$$

$$\Gamma^{(\bar{p})}_\mu = \bar{v}_{\bar{p}} \left((1+\kappa_{K^*N\Lambda})\gamma_\mu + \kappa_{K^*N\Lambda}\frac{(p_{\bar{p}} + p_{\bar{\Lambda}})_\mu}{M_N + M_\Lambda}) \right) v_{\bar{\Lambda}}$$

$$\mathcal{N}(s,t) = \frac{F_\infty(s)}{F(s,t)}, \qquad F_\infty(s) = 2s\ ,$$

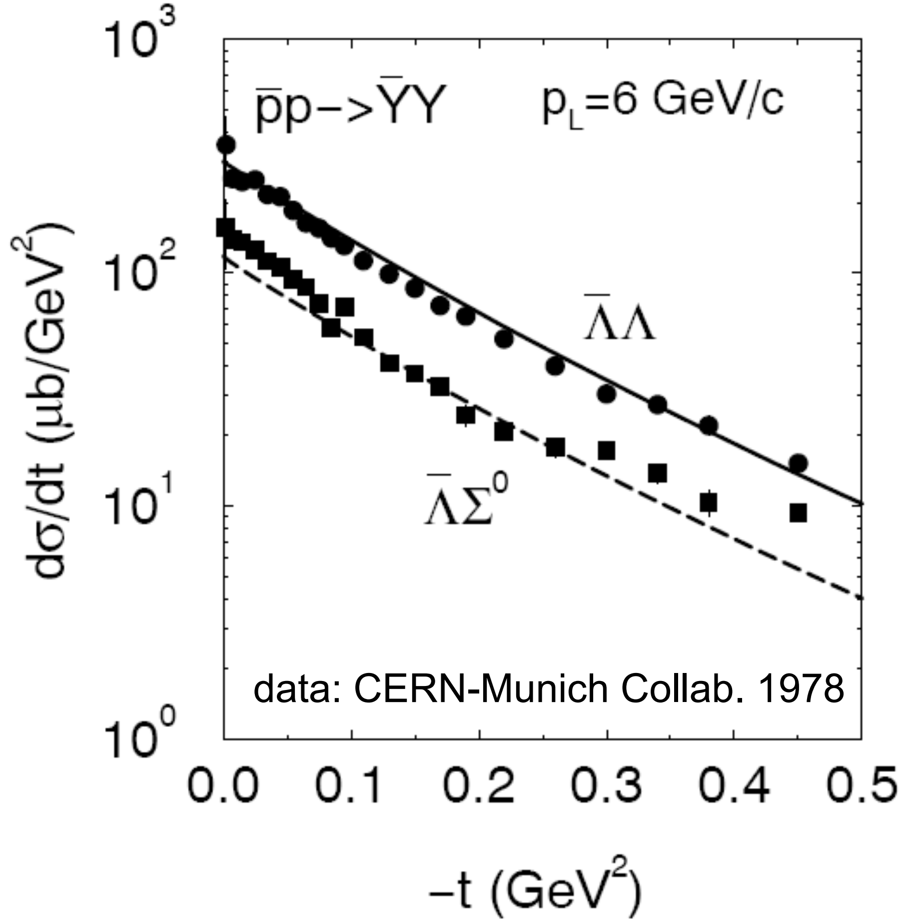
$$F^2(s,t) = \mathrm{Tr}\left(\Gamma^{(p)\,\mu}\Gamma^{(p)\,\mu'\,\dagger}\right)\mathrm{Tr}\left(\Gamma^{(\bar{p})\,\nu}\Gamma^{(\bar{p})\,\nu'\,\dagger}\right)(g_{\mu\nu} - \frac{q_\mu q_\nu}{q^2})(g_{\mu'\nu'} - \frac{q_{\mu'} q_{\nu'}}{q^2})$$

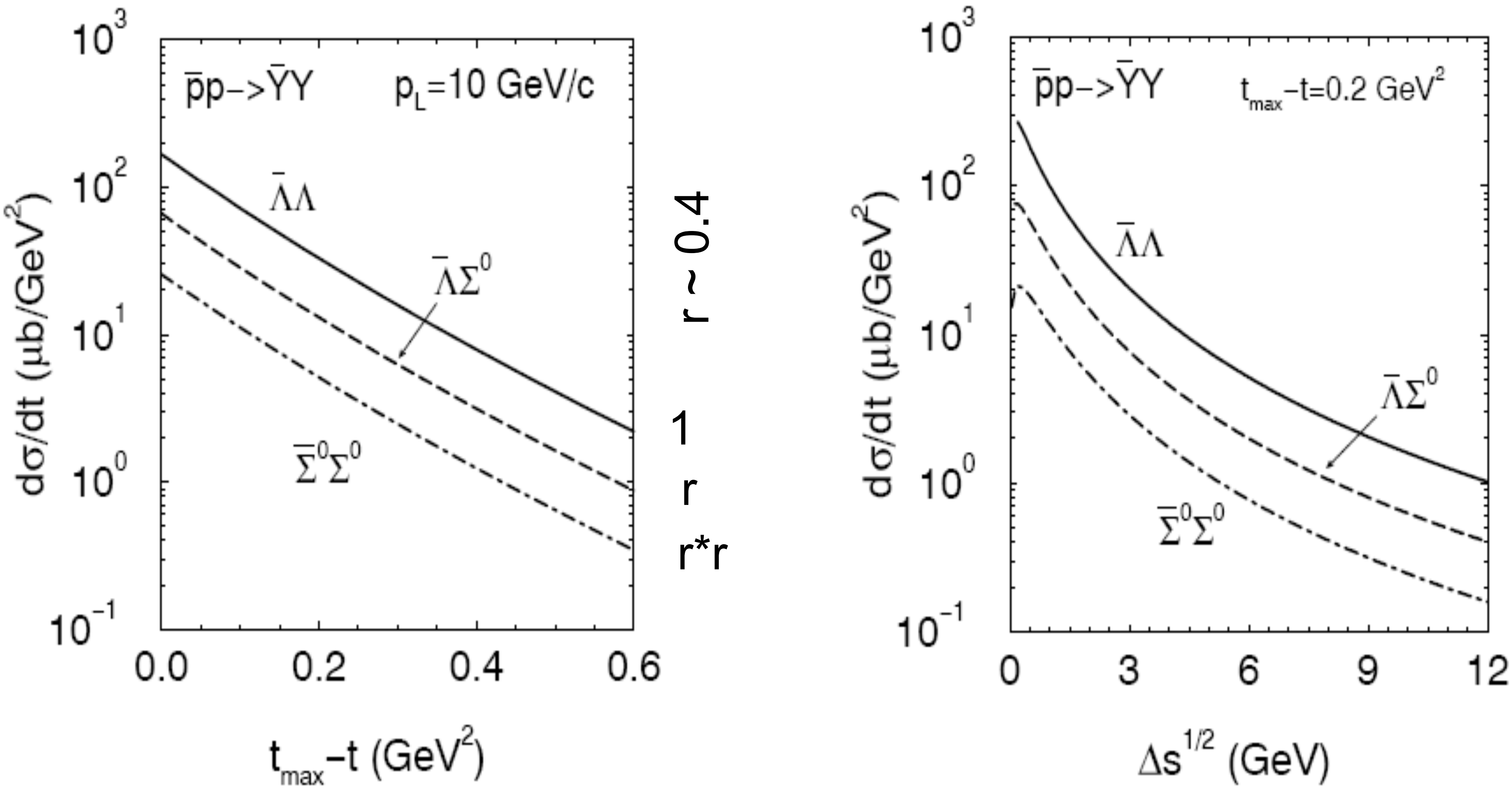
Nijmegen pot.:

$$g_{K^*NY} = -5.18, \kappa_{K^*NY} = 2.79 :\ Y = \Lambda$$

$$g_{K^*NY} = -3.29, \kappa_{K^*NY} = -0.91 :\ Y = \Sigma$$

fit: $$C(t) = \frac{0.37}{(1 - t/1.15)^2}$$





$\bar{p}p \to \bar{Y}Y$
p_L=10 GeV/c
$d\sigma/dt$ (μb/GeV^2)
$t_{max}-t$ (GeV^2)
$\bar{\Lambda}\Lambda$
$\bar{\Lambda}\Sigma^0$
$\bar{\Sigma}^0\Sigma^0$
r ~ 0.4
1
r
r*r
$\bar{p}p \to \bar{Y}Y$
$t_{max}-t$=0.2 GeV^2
$d\sigma/dt$ (μb/GeV^2)
$\Delta s^{1/2}$ (GeV)
$\bar{\Lambda}\Lambda$
$\bar{\Lambda}\Sigma^0$
$\bar{\Sigma}^0\Sigma^0$

$\Lambda \to \Lambda_c^+ \equiv \Lambda_c$

$\Sigma^0 \to \Sigma_c^+ \equiv \Sigma_c$

$K^* \to \bar{D}^*$

$\alpha_\phi \to \alpha_{J/\psi}$

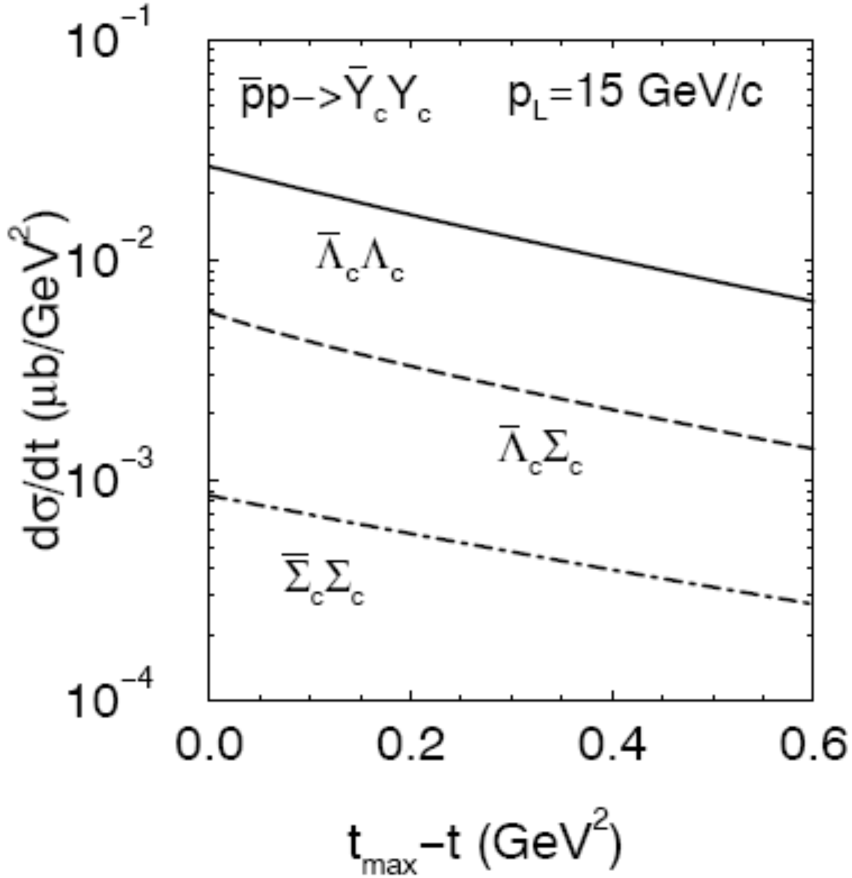
$$\alpha_{D^*}(0) = -1.02, \quad \sqrt{T_{D^*}} = 3.91 \text{ GeV}, \quad \alpha'_{D^*} \simeq 0.467 \text{ GeV}^{-2}$$

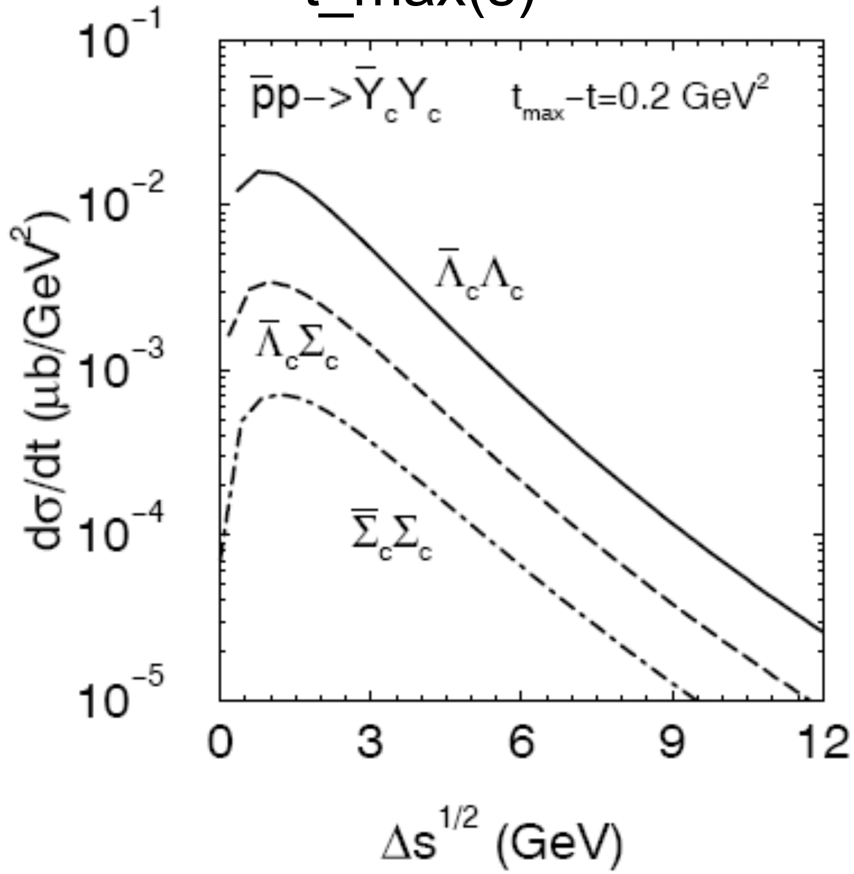
$$\alpha_{J/\psi}(0) = -2.60, \quad \sqrt{T_{J/\psi}} \simeq 5.36 \text{ GeV}, \quad \alpha'_{J/\psi} \simeq 0.34 \text{ GeV}^{-2}$$

$$s_{\bar{p}p:\bar{\Lambda}_c\Lambda_c} \simeq 5.98 \text{ GeV}^2.$$

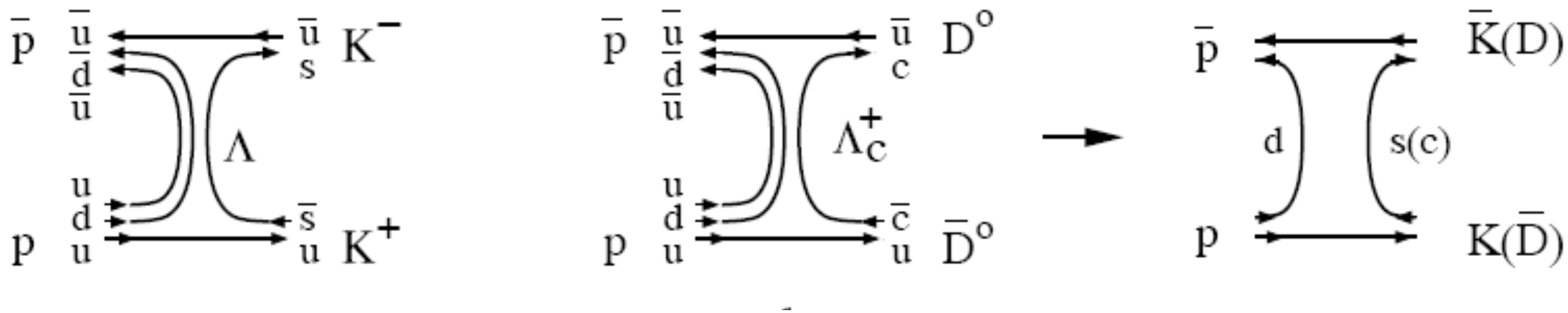
SU(4) symmetry: $g_{DNY_c} = g_{KNY}$, $g_{D^*NY_c} = g_{K^*NY}$

bumpy structure:
t_max(s)





Meson Pairs in Exit Channel



Λ exchange:

$$T^{\bar{p}p\to K^-K^+}_{m_i,n_i} = C'(t)\mathcal{M}^{\bar{p}p\to K^-K^+}_{m_i,n_i}(s,t)\frac{g^2_{KN\Lambda}}{s_0}\Gamma(\frac{1}{2}-\alpha_{ds}(t))\left(-\frac{s}{s_{\bar{p}p:\bar{K}K}}\right)^{\alpha_{ds}(t)-\frac{1}{2}}$$

(1) $$2\alpha_{ds}(0) = \alpha_{\bar{d}d}(0)+\alpha_{\bar{s}s}(0)$$

(2) $$2/\alpha'_{ds} = 1/\alpha'_{\bar{d}d}+1/\alpha'_{\bar{s}s}\ .$$

$$\alpha_{ds} = \alpha_\Lambda = -0.65+0.94t$$

$$\alpha_{\bar{d}d}(t) = -1.58+\alpha'_{\bar{d}d}t \ \text{ with } \alpha'_{\bar{d}d} = 1.542\ \text{GeV}^{-2}$$

(3) $$(s_{\bar{p}p:\bar{K}K})^{2(\alpha_{ds}(0)-\frac{1}{2})} = (s_{\bar{p}p})^{\alpha_{\bar{d}d}(0)}\times(s_{\bar{K}K})^{\alpha_{\bar{s}s}(0)-1} \qquad s_{\bar{K}K} = 1.21\ \text{GeV}^2 \text{ and } s_{\bar{p}p} = 2.25\ \text{GeV}^2$$

$$\mathcal{M}^{\bar{p}p\to\bar{K}K}_{m_i n_i}(s,t) = \mathcal{N}(s,t)\,\left[\bar{v}_{n_i}\,(\not{p}_Y - M_Y)\,u_{m_i}\right]\ ,$$

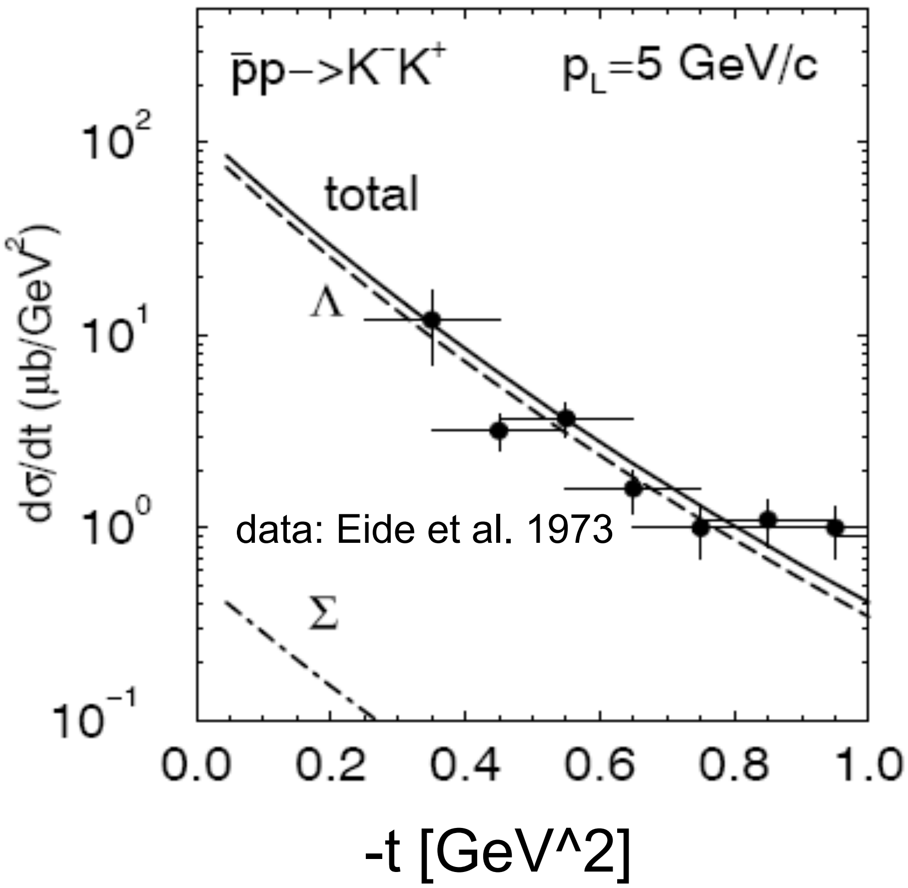
$$\mathcal{N}(s,t) = \frac{F_\infty(s)}{F(s,t)}, \qquad F^2_\infty(s) = s\,M_Y^2/2\ ,$$

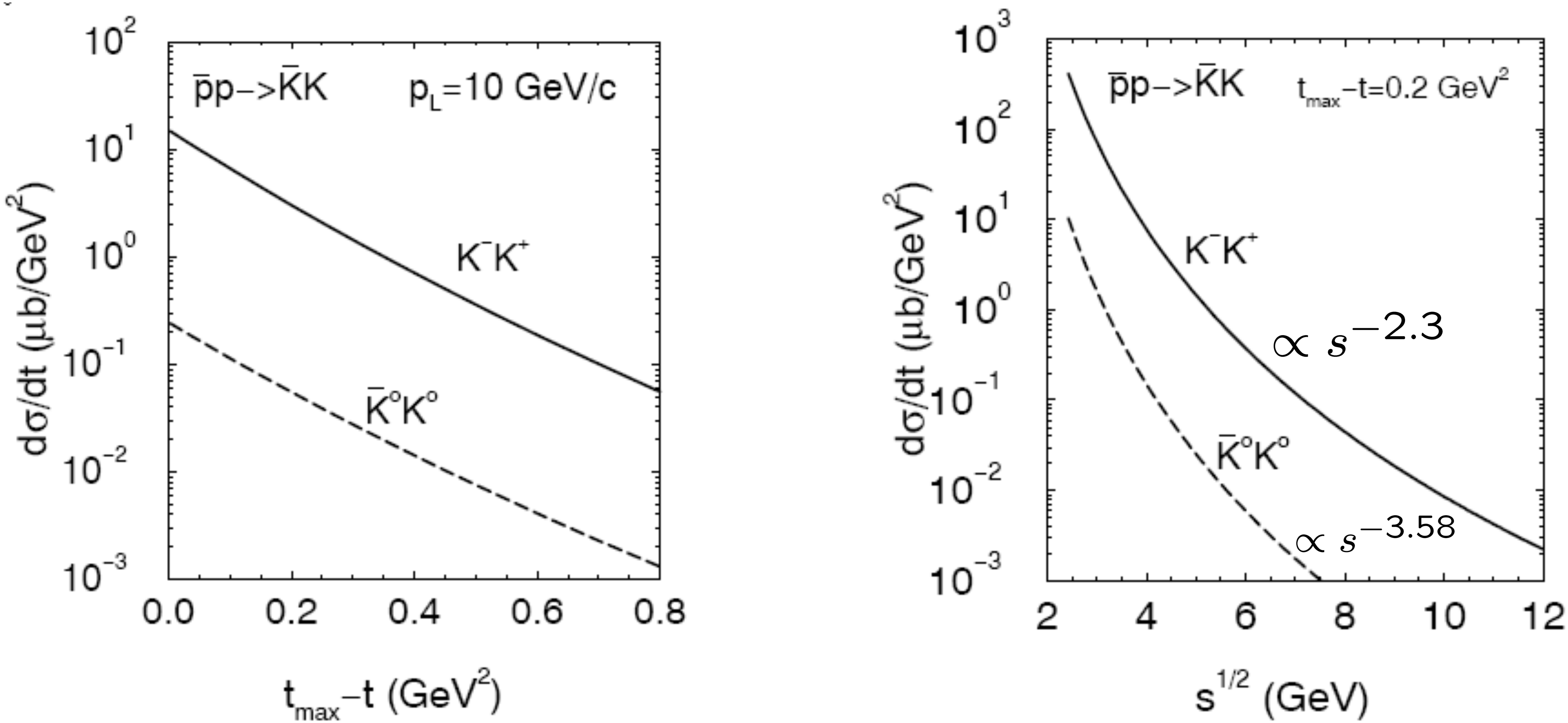
$$F^2(s,t) = \frac{1}{2}\,\big((s-2M_N^2)(M_Y^2-t) + 4M_N M_Y(M_N^2+M_K^2+t)$$

$$-(M_N^2-M_K^2+t)^2 - M_N^2(M_Y^2+t)\big)\ ,$$

from $\mathcal{L}_{NYK} = -i\bar{N}\,\gamma_5\,Y K + \text{h.c.}$

fit: $C'(t) = \dfrac{0.51}{(1-t/1.15)^2}$



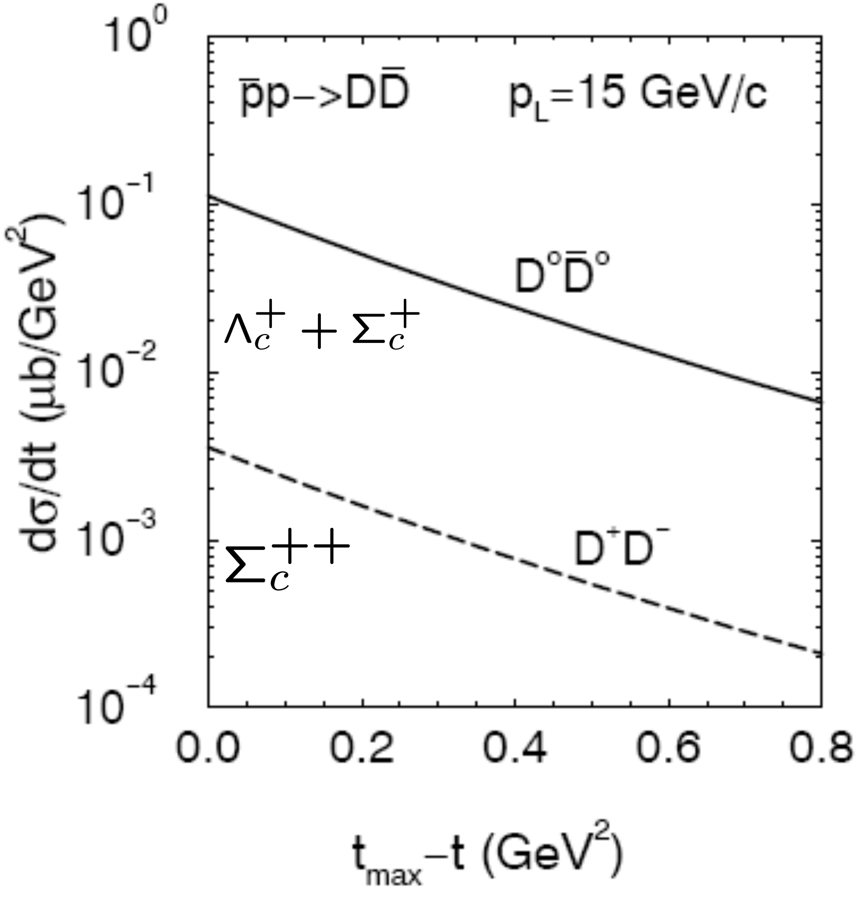


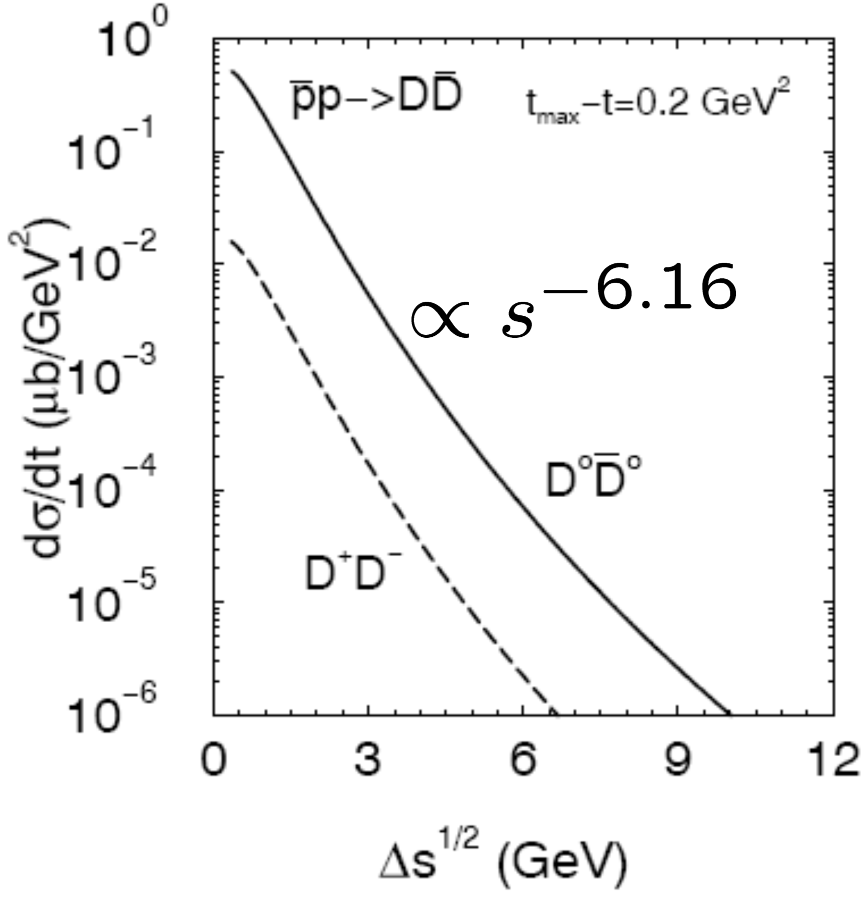
p̄p−>K̄K
p_L=10 GeV/c
K⁻K⁺
K̄°K°
dσ/dt (μb/GeV²)
t_max−t (GeV²)
0.0
0.2
0.4
0.6
0.8
10²
10¹
10⁰
10⁻¹
10⁻²
10⁻³
p̄p−>K̄K
t_max−t=0.2 GeV²
K⁻K⁺
∝ s^−2.3
K̄°K°
∝ s^−3.58
dσ/dt (μb/GeV²)
s^1/2 (GeV)
2
4
6
8
10
12
10³

$$\Lambda \to \Lambda_c^+ \equiv \Lambda_c$$
$$\Sigma^0 \to \Sigma_c^+$$
$$\Sigma^+ \to \Sigma_c^{++}$$
$$K^+ \to \bar{D}^0$$
$$\bar{K}^0 \to D^+$$

$$2\alpha_{dc}(0) = \alpha_{\bar{d}d}(0) + \alpha_{\bar{c}c}(0)$$
$$2/\alpha'_{dc} = 1/\alpha'_{\bar{d}d} + 1/\alpha'_{\bar{c}c} \ ,$$

$$\alpha'_{dc}(0) \simeq -2.09, \qquad \alpha'_{dc} \simeq 0.557\,\mathrm{GeV}^{-2}$$
$$s_{\bar{p}p:D\bar{D}} \simeq 3.59\,\mathrm{GeV}^2 \ .$$



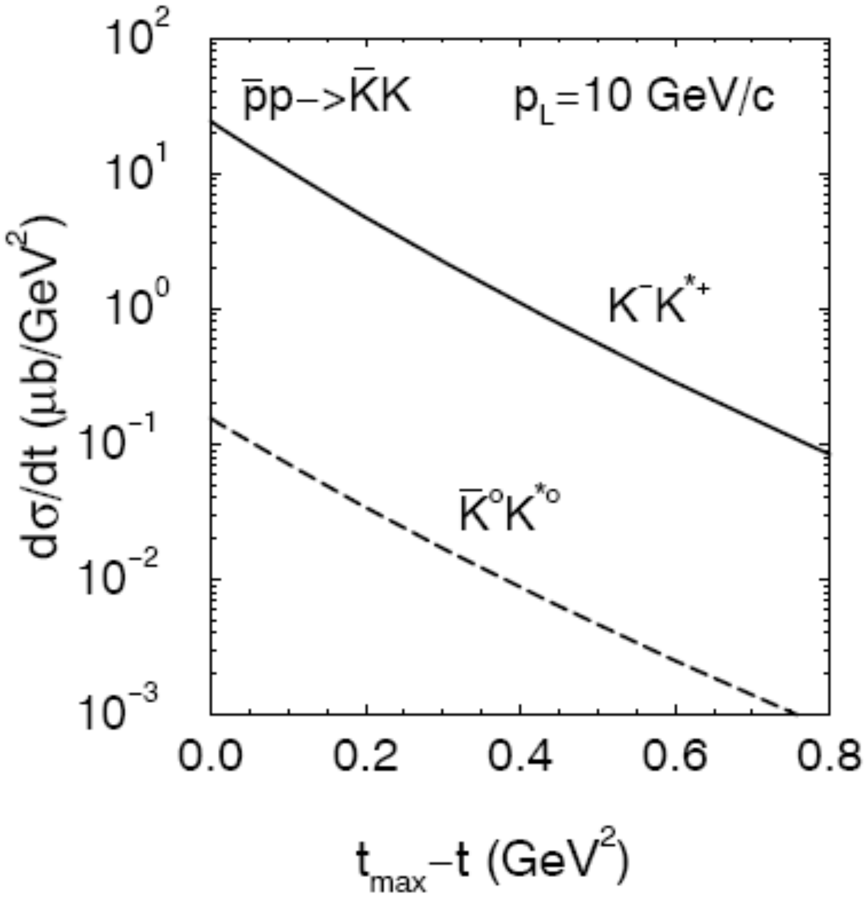


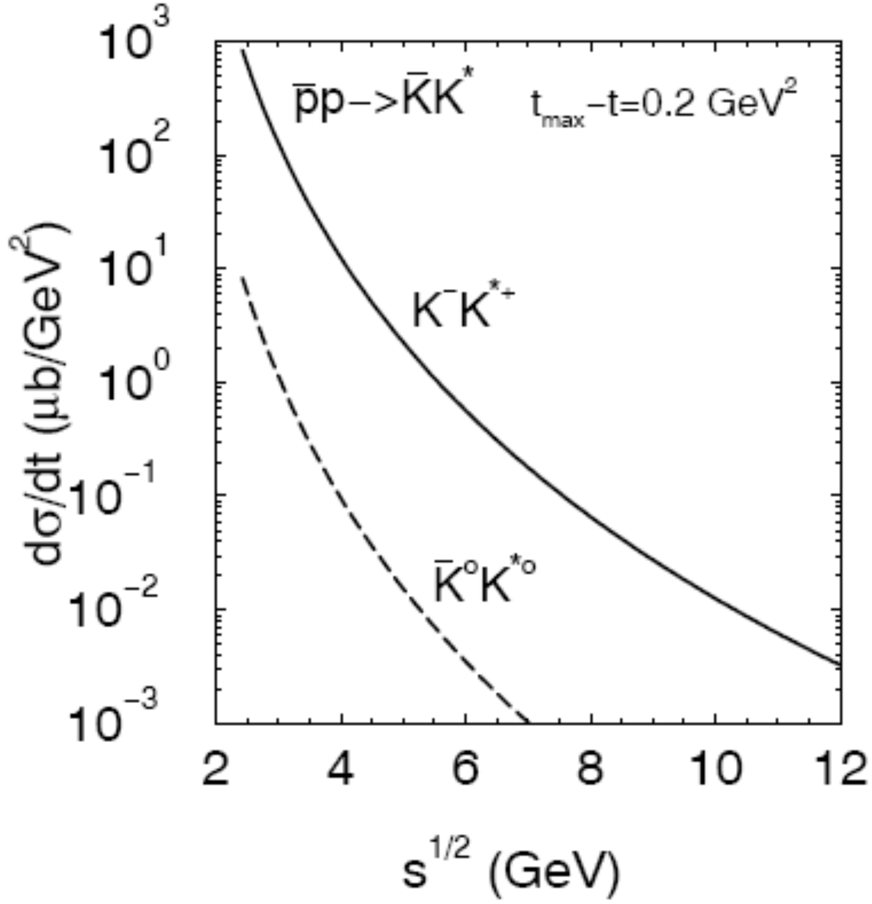
$$\bar{p}p \to \bar{M}\, M^*$$

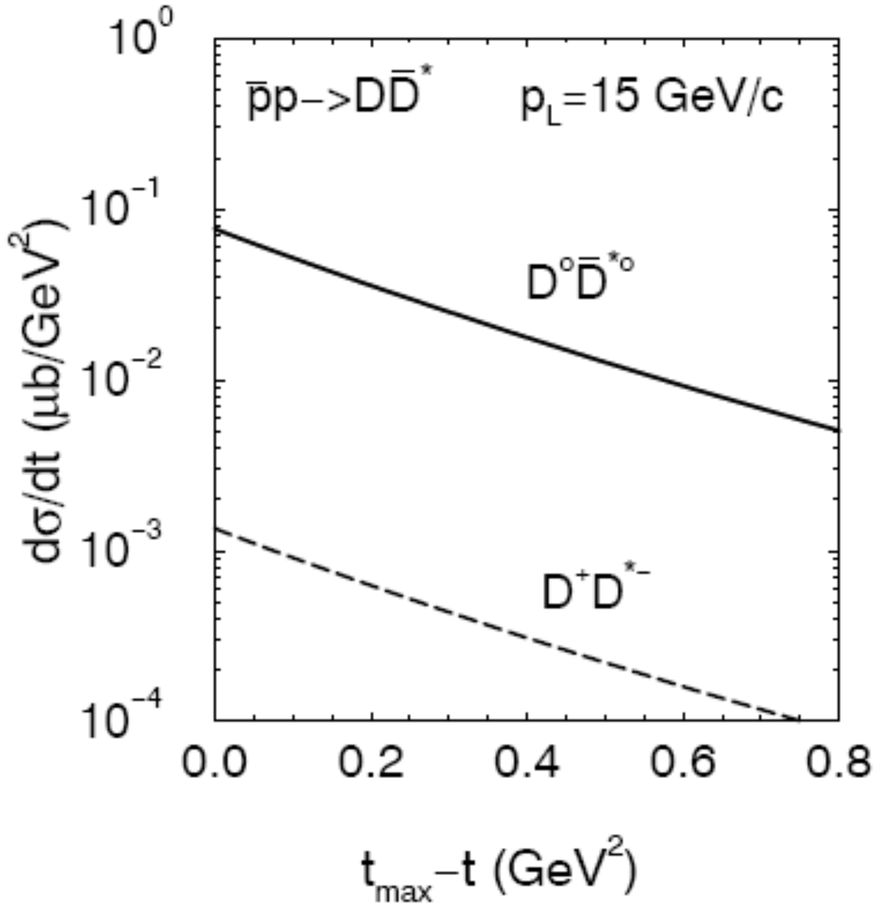
pseudo-scalar → $\bar{M}$; vector meson → M^*

$$T^{\bar{p}p\to\bar{K}^- K^{*+}}_{\lambda_f;m_i,n_i} = C'(t)\mathcal{M}^{\bar{p}p\to\bar{K}K}_{\lambda_f;m_i,n_i}(s,t)\frac{g_{K^*N\Lambda}g_{KN\Lambda}}{s_0}\Gamma(\frac{1}{2}-\alpha_{ds}(t))\left(-\frac{s}{s_{\bar{p}p:\bar{K}K^*}}\right)^{\alpha_{ds}(t)-\frac{1}{2}}$$

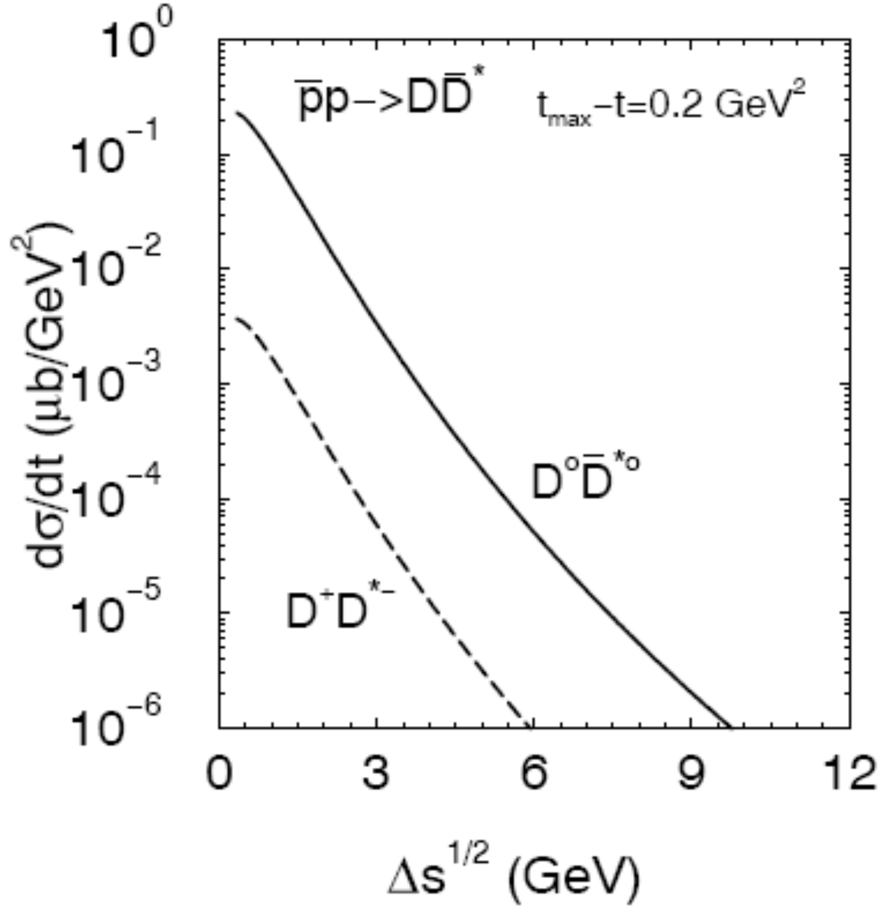
$$\mathcal{M}^{\bar{p}p\to\bar{K}K}_{\lambda_f;m_in_i}(s,t) = \mathcal{N}(s,t)\,\Gamma^{\mu}_{\lambda_f;m_in_i} \qquad \Gamma^{\mu}_{\lambda_f;m_in_i} = \bar{v}_{n_i}\left[\gamma_5\,(\not{p}_Y - M_Y)\,(\gamma^\mu + \frac{\kappa_{NYK^*}}{2(M_N+M_Y)}(\gamma^\mu\not{p}_{K^*} - \not{p}_{K^*}\gamma^\mu))\right]u_{m_i}\epsilon^{\mu *}_{\lambda_i}$$







$\bar{p}p \to D\bar{D}^*$
p_L=15 GeV/c
$D^o\bar{D}^{*o}$
D^+D^{*-}
dσ/dt (μb/GeV^2)
$t_{max}-t$ (GeV^2)

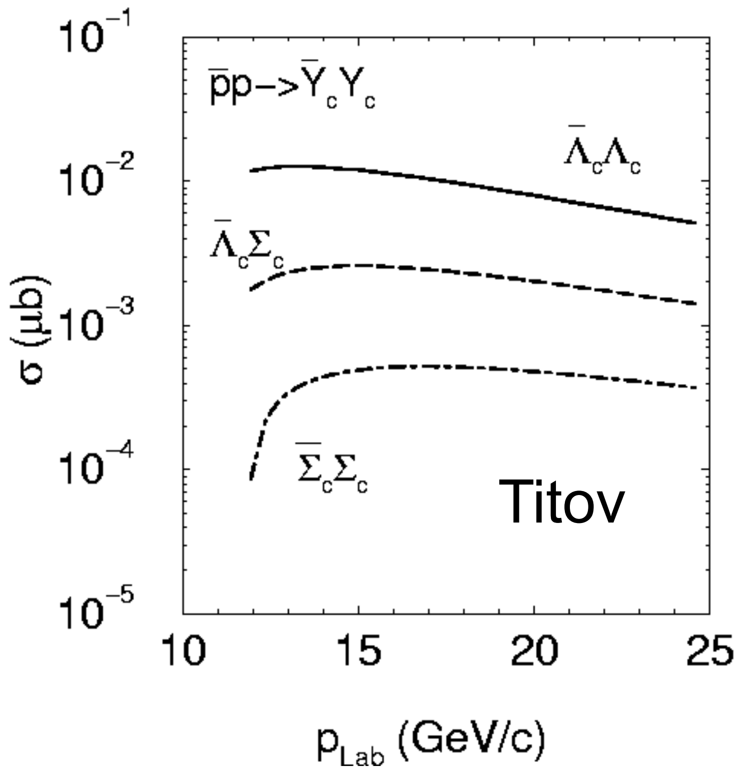


$\bar{p}p \to D\bar{D}^*$
$t_{max}-t$=0.2 GeV^2
$D^o\bar{D}^{*o}$
D^+D^{*-}
dσ/dt (μb/GeV^2)
Δs$^{1/2}$ (GeV)

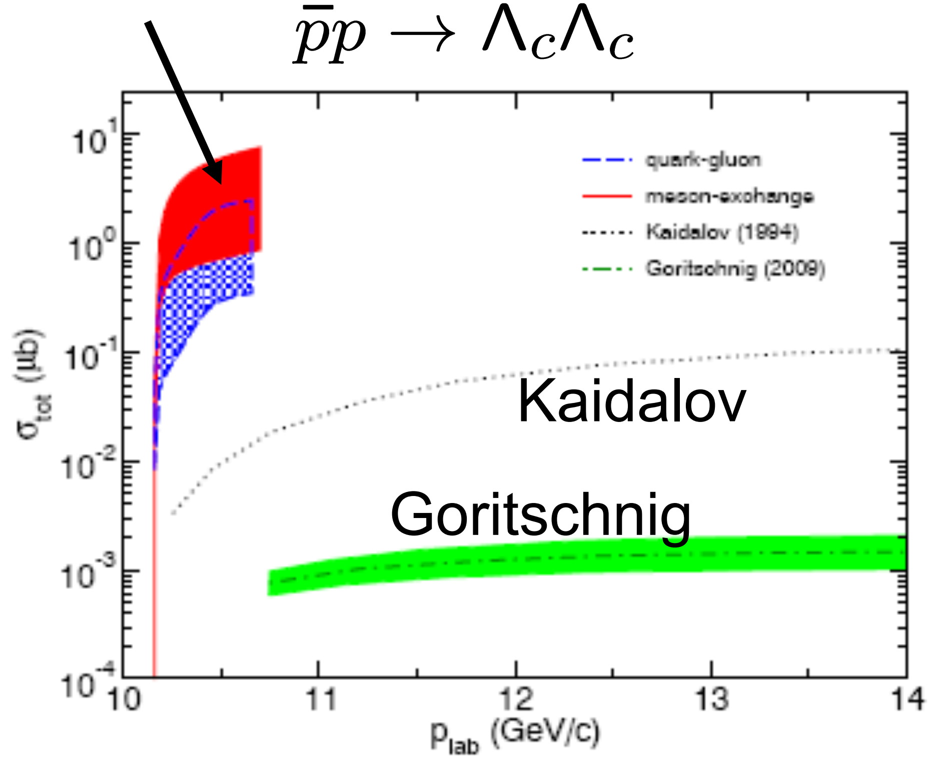
Longitudinal Asymmetries: cf. Titov, BK, PRC 78 (2008) 025201

$$\mathcal{A} = \frac{d\sigma^{\leftrightarrows} - d\sigma^{\rightrightarrows}}{d\sigma^{\leftrightarrows} + d\sigma^{\rightrightarrows}}$$ → PAX

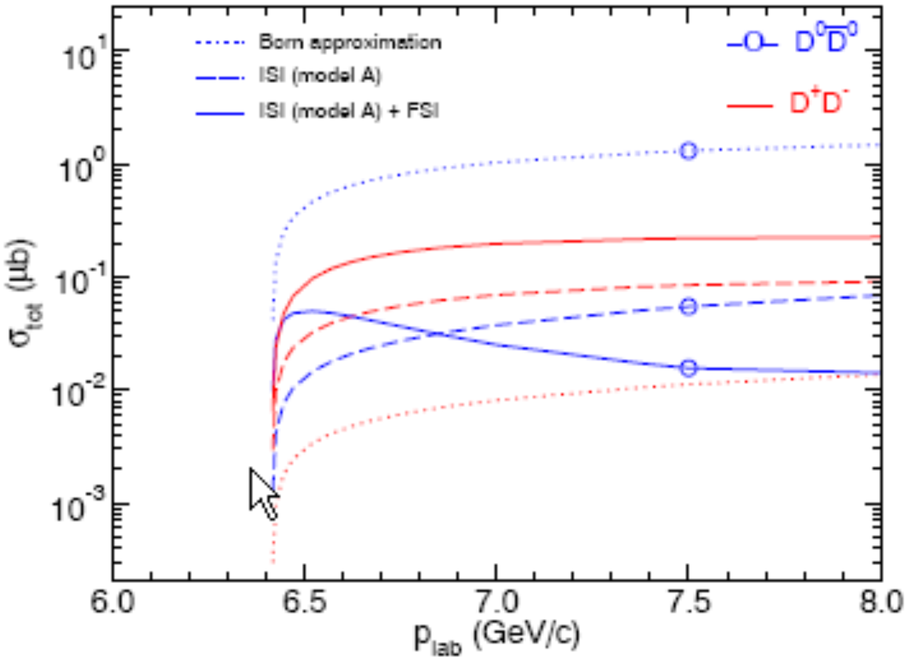
Very different predictions by Haidenbauer, Krein, PLB 687 (2010) 314

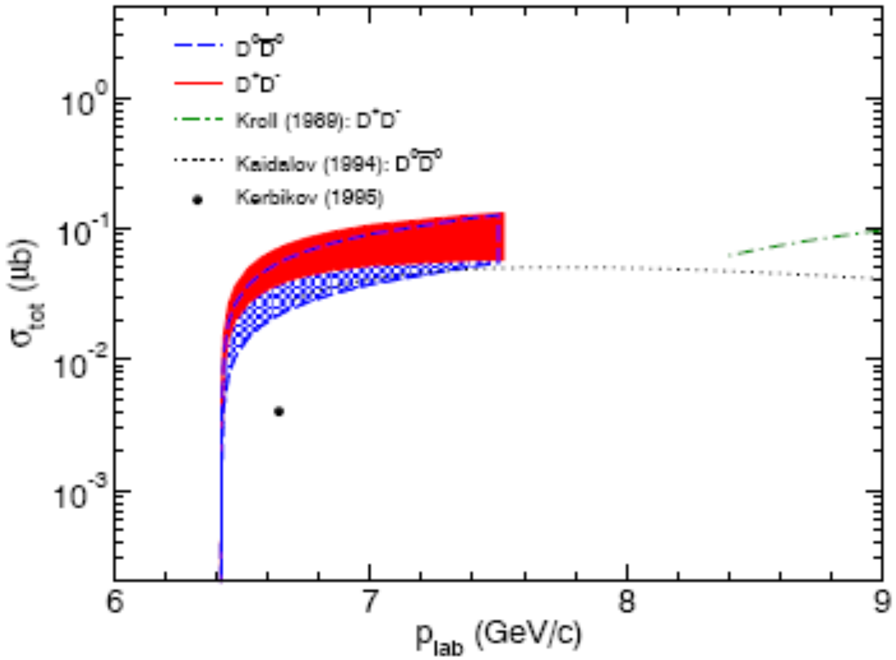


$\bar{p}p \to \bar{\Lambda}_c \Lambda_c$



„an impressive qualitative difference“





Artoisenet, Braaten, PRD 2009: inclusive charm production within parton model → factor 10 uncertainty due to variations of

$$m_c,\ \mu_r,\ \mu_f$$

Linnyk, Bratkovskaya, Cassing, IJMP 2008:
elementary charm Xsections from PYTHIA fits to high-energy data
→ Au + Au at 25 AGeV

much remains to be done!

Summary

- DS-BS: our first results are encouraging
  next: other channels, excited states
  goal: in medium
- QCD sum rules: fairly robust „mass splitting" of $D - \bar{D}$
  Weinberg type differences of heavy-light mesons
  → amplified chiral condensate
- Transparency ratio: width of charmonia (like phi)
- Regge type phenomenology for associate charm production
  in p p_bar: predictions for peripheral collisions