J-PARC hadron physics in 2016

Open charm production in exclusive reactions at PANDA-FAIR and J-PARC energy region

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The aim of our discussion is qualitative/quantitative estimation of

open charm production in $\bar{p}p$ reactions with one flavor exchange

$\bar{p}p \to \bar{\Lambda}\Lambda(\Sigma)$ and $\bar{p}p \to \bar{\Lambda}_c\Lambda_c(\Sigma_c)...$

$\bar{p}p \to \bar{K}K$ and $\bar{p}p \to D\bar{D}...$ (PANDA)

$\bar{p}p \to \bar{K}K^*$ and $\bar{p}p \to D\bar{D}^*...$

and reactions with two flavor exchange

$\bar{p}p \to \bar{\Xi}\Xi$ and $\bar{p}p \to \bar{\Xi}_c\Xi_c$

open charm production in πp reactions

$\pi^- p \to D^{*-}\Lambda_c$ (J-PARC)

also in pp reactions, like

$pp \to \Lambda_c\bar{D}^o p$ and $pp \to \Lambda_c\bar{D}^o X$

mainly in forward production (large x)

Charmed and strange hadrons

$c\bar{u}$ (D^0) (1864) or (D^{*0})(2007) $\rightarrow s\bar{u}$ (K^-) (494) or (K^{*-})

$c\bar{d}$ (D^+) (1869) or (D^{*+})(2010) $\rightarrow s\bar{d}$ $(\bar{K}^0)$ (498) or $(\bar{K}^{*0})$

$c\bar{c}$ (J/ψ) (3096) $\rightarrow s\bar{s}$ (ϕ) (1020)

$\bar{c}u$ $(\bar{D}^0)$ (1864) or $(\bar{D}^{*0})$ $\rightarrow \bar{s}u$ (K^+) (494) or $(\bar{K}^{*+})$

$\bar{c}d$ (D^-) (1869) or (D^{*-}) $\rightarrow \bar{s}d$ (K^0) (498) or (K^{*0})

cuu (Σ_c^{++}) (2452) $\rightarrow suu$ (Σ^+)

cud (Λ_c^+) (2286) or (Σ_c^+) (2451) $\rightarrow sud$ (Λ) or (Σ^0)

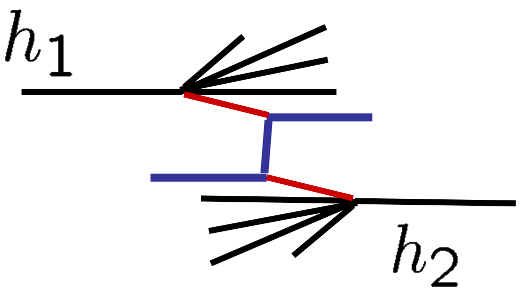
cdd (Σ_c^0) (2452) $\rightarrow sdd$ (Σ^-)

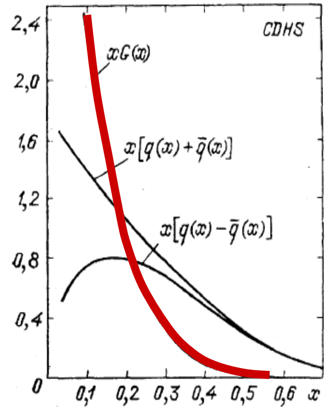
csu (Ξ_c^+) (2467) $\rightarrow ssu$ (Ξ^0) (1315)

csd (Ξ_c^0) (2470) $\rightarrow ssd$ (Ξ^-) (1322)

Challenges of some utilized models

Open charm at high energy and pQCD models





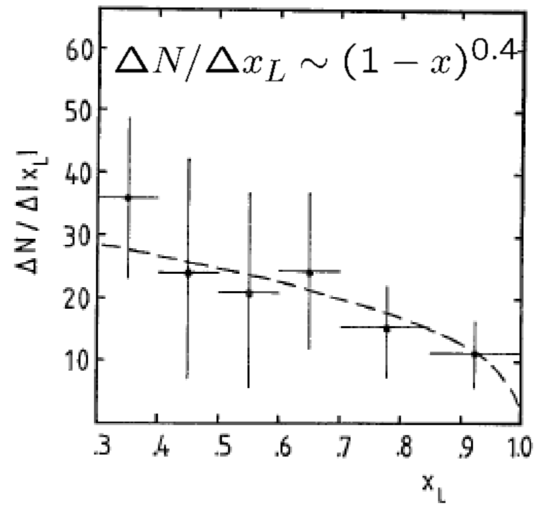
$$d\sigma_{H_c} \sim xG(x)$$

$$xG(x)|_{x\to 1} \sim (1-x)^5$$

with $x \simeq 1$

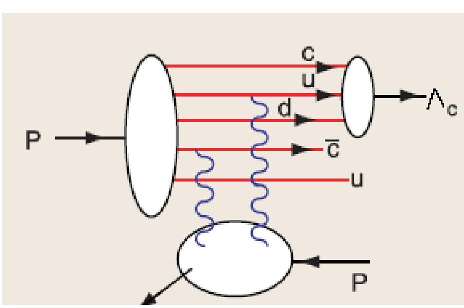
M. Basile *et al*., Lett. Nuovo Cim. 30, 487 (1981)

$$p + p \to \Lambda_c + X, \quad \sqrt{s} = 62\text{GeV}$$



"Intrinsic charm model"

Brodsky *et al*, PLB**93** (1980)

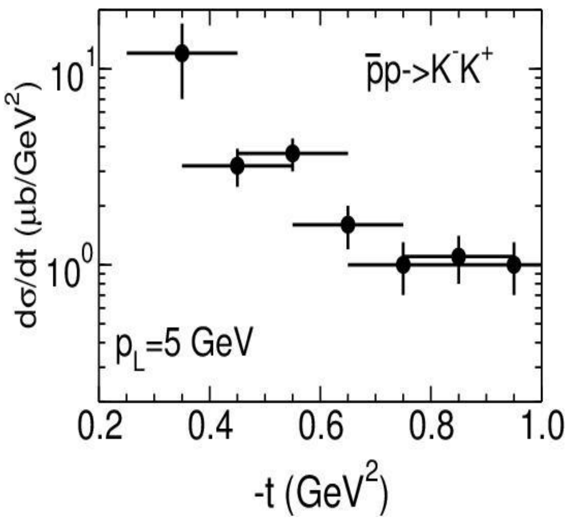


$\sim 1\%\ [c\bar{c}]$ in proton

Effective Lagrangian Models

Heidenbauer, Krein et al., (1993-2015) $\bar{p}p \to \bar{Y}Y$
⋮
Shyam&Lenske,(2015) $\bar{p}p \to \bar{M}M$
⋮

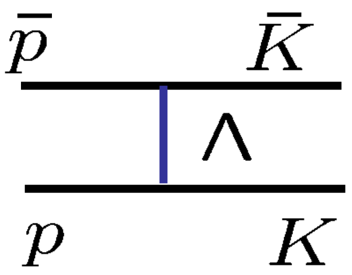
Example: $\bar{p}p \to K^- K^+$

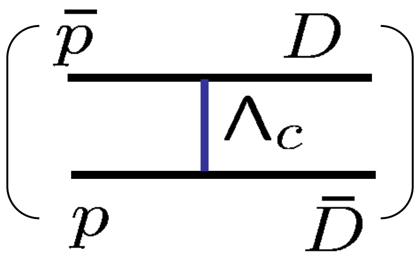


A. Eide *et al*., Nucl. Phys. **B**60,173 (1973)

(LEAR)

Definite enhancement at forward production angles encourage for t-exchange channels

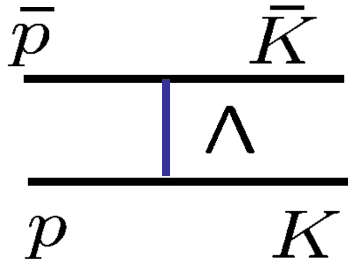




$$\mathcal{L}_{NYK} = -i\bar{N}\gamma_5 YK + \text{h.c.}\ ,$$

$$\mathcal{L}_{NYD} = -i\bar{N}\bar{D}\gamma_5 Y_c + \text{h.c.}\ ,$$

Amplitude and cross sections



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

$$A^{\bar{p}p \to \bar{K}K}_{m_i n_i}(s,t) = \frac{\bar{v}_{n_i}\,(p_Y \cdot \gamma - M_Y)\, u_{m_i}}{t - M^2}\, g^2_{KNY}\, f^2(t)$$

$f(t)-$ form factor

$$\frac{d\sigma}{dt} = \frac{1}{16\pi s(s - 4M_N^2)} \mathrm{Tr}[AA^\dagger]; \qquad \sigma_{\text{tot}} = \frac{1}{32\pi s} \frac{p_f}{p_i} \int_{-1}^{1} d\cos\theta\, \mathrm{Tr}[AA^\dagger]$$

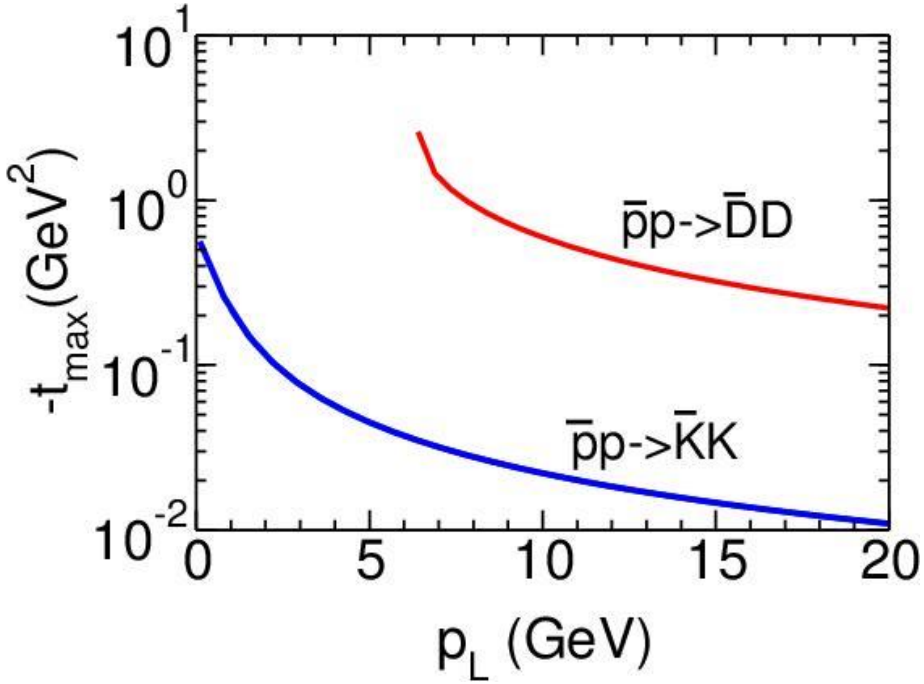
$$\mathrm{Tr}[AA^\dagger] = \frac{g^4_{KNY}\, f^4(t)}{(t - M_Y^2)^2} F^2(s,t)$$

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

Kinematics: momentum transfers

$$t = 2M_p^2 - 2E_pE_K + 2p_pp_K \cos\theta$$

$$-t_{\mathrm{max}} \equiv |-t|_{\mathrm{max}} = -2M_p^2 + 2E_pE_K - 2p_pp_K$$



$$\frac{d\sigma(\bar{D}D)}{dt} \ll \frac{d\sigma(\bar{K}K)}{dt}$$

$$\sigma_{\rm tot} \propto {\rm Tr}[AA^\dagger] = \frac{1}{s}\frac{g^4_{KNY}\, f^4(t)}{(t-M_Y^2)^2} F^2(s,t)$$

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

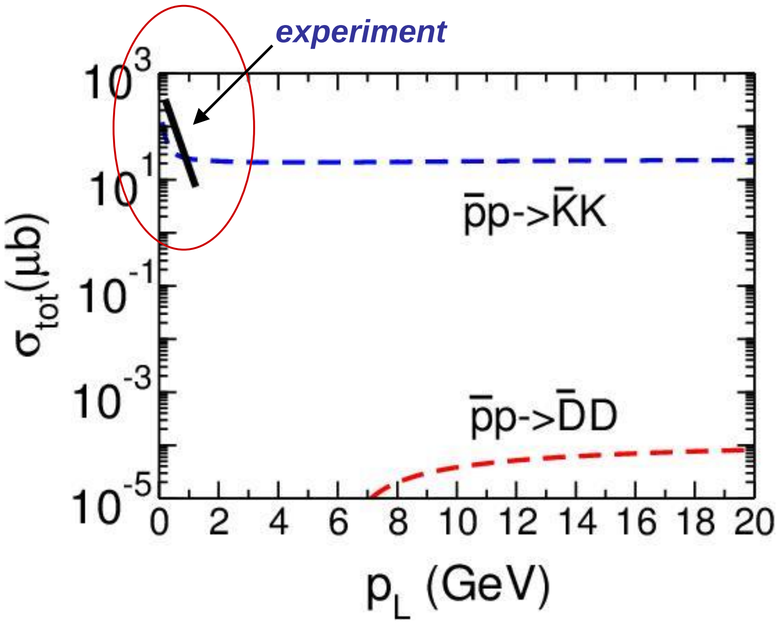
$$\sigma_{\rm tot} \approx {\rm Constant} \quad {\rm at} \quad s \ll M_i^2, |t|$$

experiment

$$\sigma_{\rm tot} \approx C \left(\frac{s}{s_0}\right)^{-\gamma} \; {\rm with}\; \gamma \gg 1$$

$$\frac{\sigma_{\bar{D}D}}{\sigma_{\bar{K}K}} \le 10^{-5}$$

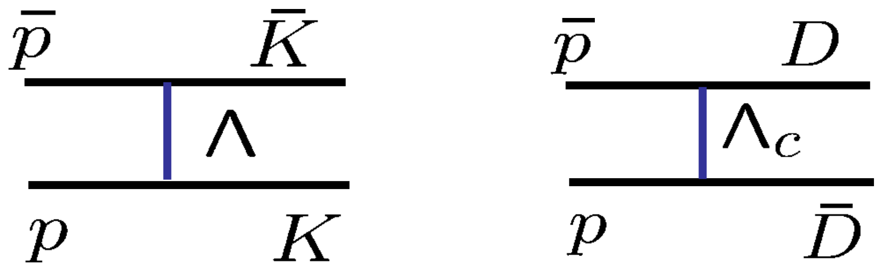
Limited region of application



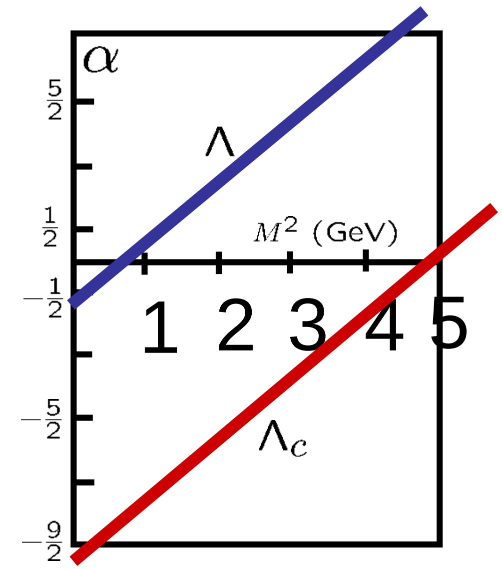
Wrong energy dependence

Contrary to the hadron-exchange models,Regge approaches are work satisfactorily for strangeness production

Similarity of $\bar{p}p \longrightarrow \bar{K}K$ *and* $\bar{p}p \longrightarrow D\bar{D}$ *motivates for utilizing the Regge models for charm production*



internal lines are associated with Regge trajectories



$$T_{Regge} \sim \left(-\frac{s}{s_{\mathcal{R}}}\right)^{\alpha_R(t)-\frac{1}{2}}$$

$$\alpha_R(t) \simeq \alpha_R(0) + \alpha'_R\, t \rightarrow$$ *linear trajectories* → *small yields of charm*

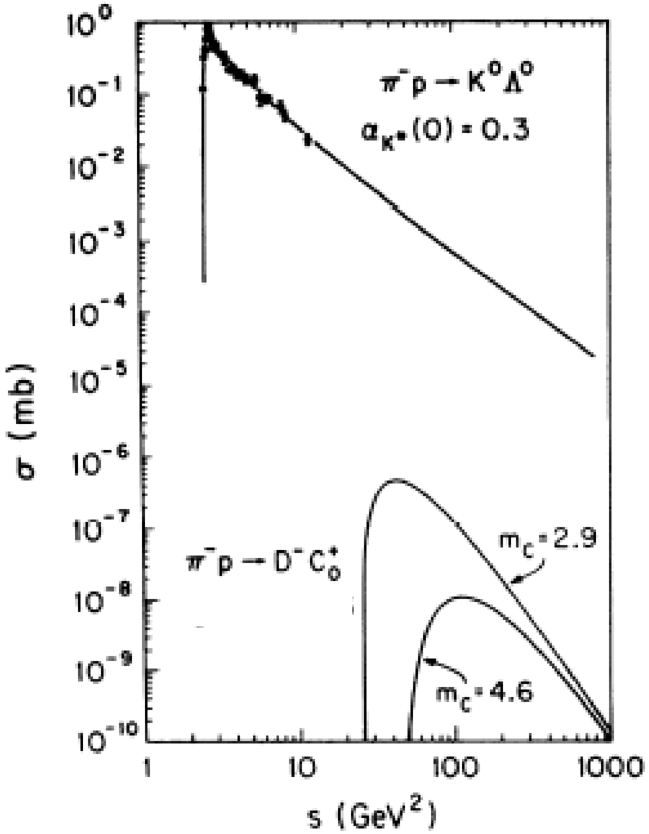
$$R = \Lambda_c, \Sigma_c, D^* \ldots$$

Therefore, there are doubts:

(1) trajectories $\alpha(t)$ *non-linear?*

Chew-Frautschi plot

(2) what is a value of scale parameters $s_{\mathcal{R}}$



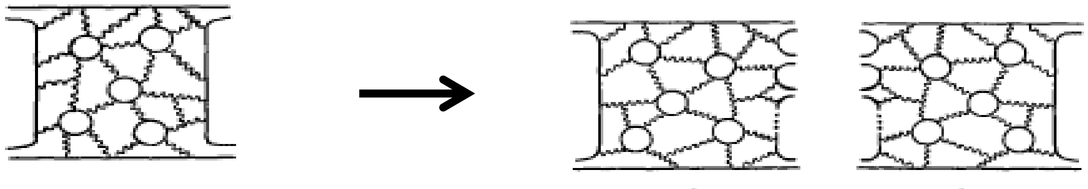
V. Barger, R.Phillips, PRD 12 (1975)

$$\frac{\text{charm}}{\text{strangeness}} < 10^{-6} \ldots 10^{-7}$$

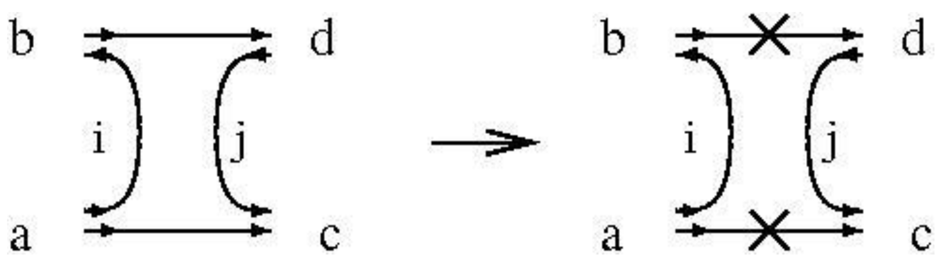
***Possible solution is an approach based on non-perturbative quark-gluon string model discussed for the firrst time by S.Nussinov**, (PRL**34**(1975) and **F.Low** ,PRD**12** (1975))*

Essentially, they discussed formation and decay of a $q\bar{q}$ ***color tube***

with complicated intermediate (multi-particle) states

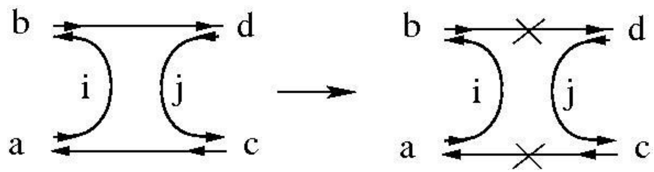


The method of evaluation of observables based on utilizing the planar diagram for two body amplitude and it's cutting In s-channel

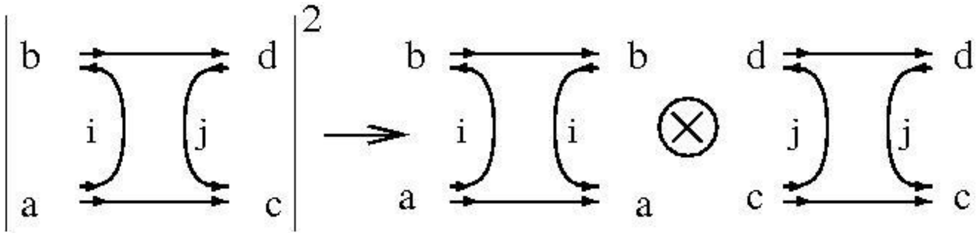


was elaborated by Kaidalov (almost 10 years later) [Z.Phys. C **12** (1982)] *and developed by Kaidalov et al. (in 1983-2005*) *and other groups: A.T., Kampfer(2008), A.Khojiamirian et al.(2012), G.Lykasov et al.(2010)… V. Grishina et al.(2005)(strangeness), Kim, Hosaka & et al., (2015) …. …*

(In particularly for two-body exclusive processes!!)



$$\mathrm{Im} T_{ab \to cd} \sim \sum_X T_{ab \to X} \cdot T^{\dagger}_{cd \to X}$$

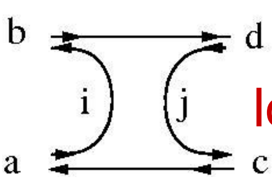


the use of optical theorem ⟶ factorization:

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

probabilities of elastic scattering

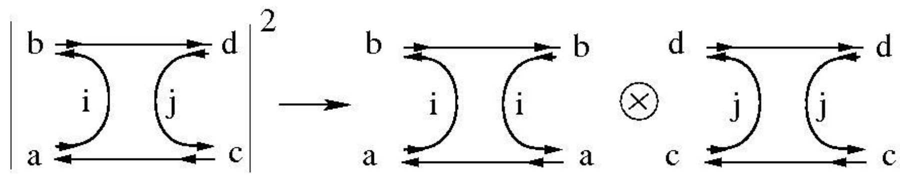
required diagram (amplitude)



looks like “Regge trajectory” with an effective “ij” Reggeon

The main advantage of Kaidalov's approach based on

(i) *factorization:*



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

(ii) *Regge type of the individual and the "required amplitude":*

$$A_{ij} \sim \Gamma(1-\alpha_{ij}(t)) \left(-\frac{s}{s_{ij}}\right)^{\alpha_{ij}(t)-1}$$

A.Kaidalov, Z.Phys.C12, 62 (1982)

is a derivation of the consistent equations for $\alpha_{ij}(t)$ and s_{ij} :

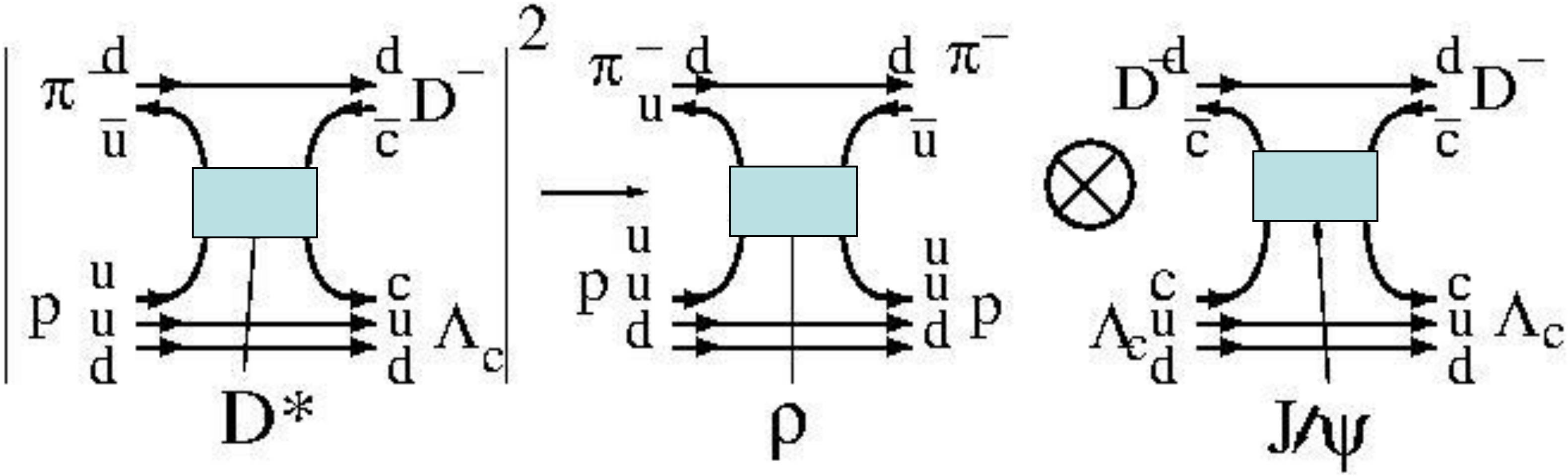
(1) $$2\alpha_{\bar{i}j}(0) = \alpha_{\bar{i}i}(0) + \alpha_{\bar{j}j}(0) \ ,$$

(2) $$2/\alpha'_{\bar{i}j} = 1/\alpha'_{\bar{i}i} + 1/\alpha'_{\bar{j}j} \ ,$$ ***and***

(3) $$(s_{ab:cd})^{2(\alpha_{ij}-1)} = (s_{ab})^{\alpha_{ii}(0)-1} \times (s_{cd})^{\alpha_{jj}(0)-1} \ .$$

$$s_{ab} = \left(\sum_i^{n_a} M_{i\perp}\right)\left(\sum_j^{n_b} M_{j\perp}\right)$$ with $M_{u,d\perp} \simeq 0.5$ GeV, $M_{s\perp} \simeq 0.6$ GeV, $M_{c\perp} \simeq 1.6$ GeV

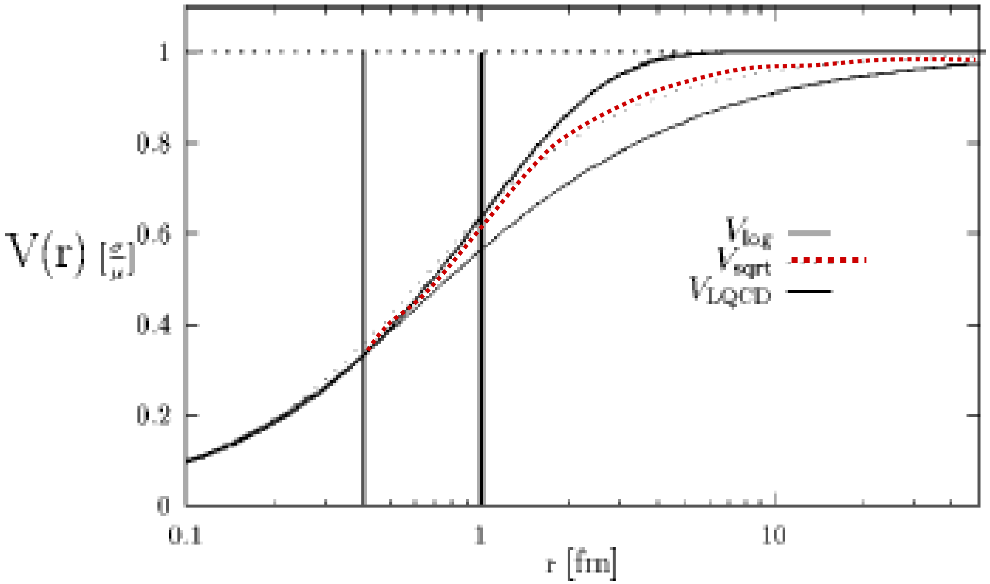
Example: $\pi^- p \to D^- \Lambda_c$

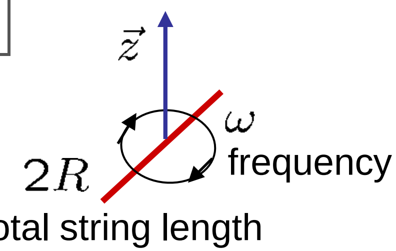


$$w^2_{\pi p \to D^- \Lambda_c} \sim w_{\pi^- p \to \pi^- p} \times w_{D^- \Lambda_c \to D^- \Lambda_c}$$

[$\rho\,(q\bar{q})$ trajectory $J/\psi\,(c\bar{c})$ trajectory]

Non-linear trajectory reflects behavior of QCD motivated $\bar{q}q$ *potential* $V(\rho)$





string tension $\sigma(\rho) = \frac{dV(\rho)}{d\rho}$

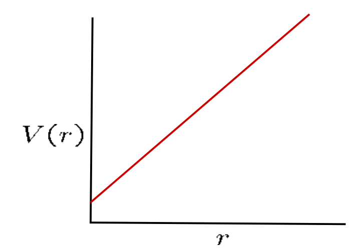
$$E = 2\int_0^R \frac{d\rho\,\sigma(\rho)}{\sqrt{1-(\rho\omega)^2}};$$

string energy

$$J = 2\int_0^R \frac{d\rho\,\sigma(\rho)\rho^2\omega}{\sqrt{1-(\rho\omega)^2}},$$

string spin momentum

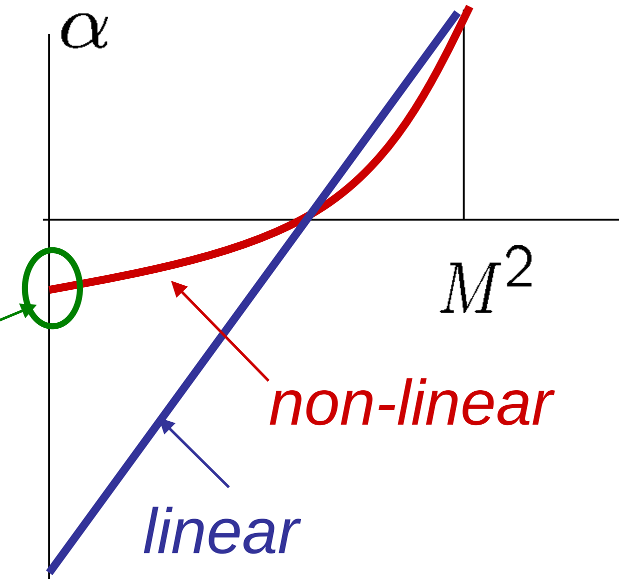
$$V(\rho) = \frac{a}{\pi\mu}\arctan(\pi\mu\rho) \longrightarrow J = \frac{1}{\pi\mu}(a/\sigma) - \sqrt{(a/\sigma) - E^2}$$



$$J = c_1 + c_2 E^2$$

Non-linear Regge trajectories for diagonal channels in a square root form

Brisudova, Burakovsky, and Goldman PRD **61**, (2000).



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

with $T \gg 1\text{GeV}^2$

In the diffractive region with $-t \ll T$,

$$\alpha(t) \simeq \alpha(0) + \frac{\gamma t}{2\sqrt{T}} \simeq \alpha(0) + \alpha' t$$

$$\alpha' = \gamma / 2\sqrt{T}$$

where $\gamma = 3.65\ \text{GeV}^{-1}$ ⟷ from $\alpha_\rho(t)$

universal value

$$\alpha_\rho,\ M_{K^*},\ M_{K_3^*},\ M_{J/\psi},\ M_{D^*}$$

are taken as input

$$\alpha_\rho(0) = 0.55, \qquad \sqrt{T_\rho} = 2.46 \text{ GeV}, \qquad \alpha'_\rho \simeq 0.742 \text{ GeV}^{-2} ,$$

$$\alpha_{K^*}(0) = 0.414, \qquad \sqrt{T_{K^*}} = 2.58 \text{ GeV}, \qquad \alpha'_{K^*} \simeq 0.71 \text{ GeV}^{-2} ,$$

$$\alpha_\phi(0) = 0.28, \qquad \sqrt{T_\phi} \simeq 2.70 \text{ GeV}, \qquad \alpha'_\phi \simeq 0.676 \text{ GeV}^{-2} ,$$

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

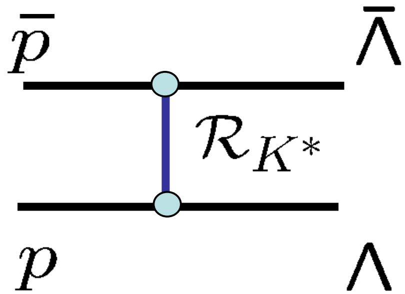
$$\alpha_{J/\psi}(0) = -2.60, \qquad \sqrt{T_{J/\psi}} \simeq 5.36 \text{ GeV}, \qquad \alpha'_{J/\psi} \simeq 0.34 \text{ GeV}^{-2} ,$$

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

$$\alpha_{dc}(0) \simeq -2.09, \qquad \alpha'_{dc} \simeq 0.557 \,\text{GeV}^{-2} ,$$

$$s_{\bar{p}p:D\bar{D}} \simeq 3.59 \,\text{GeV}^2 .$$

Reaction $\bar{p}p \to \bar{Y}Y, \; Y = \Lambda, \Sigma, \Lambda_c, \Sigma_c ...$



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

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

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

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

$$\mathcal{N}^2(s,t) = \frac{1}{F^2(s,t)},$$

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

$C(t)$

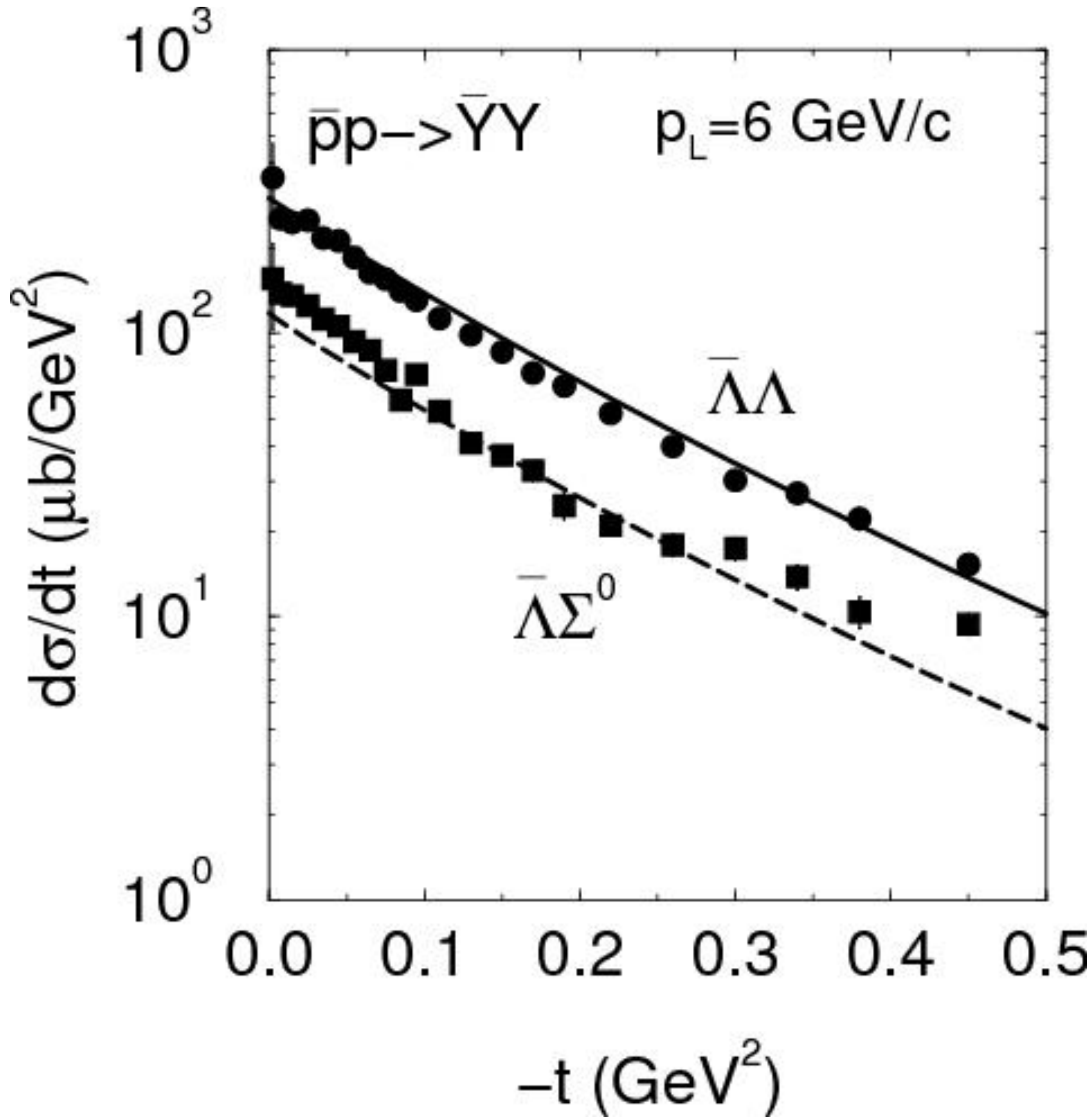
unknown residual function

$g_{KNY}, g_{K^*NY}, \kappa_{K^*NY}$ - from hyper-nucleon physics (Nijmegen potential)

SU(4) $\longrightarrow g_{DNY_c}(g_{D^*NY_c}) = g_{KNY}(g_{K^*NY})$

Stoks & Rijken PRC, **59**, 3009 ('99)

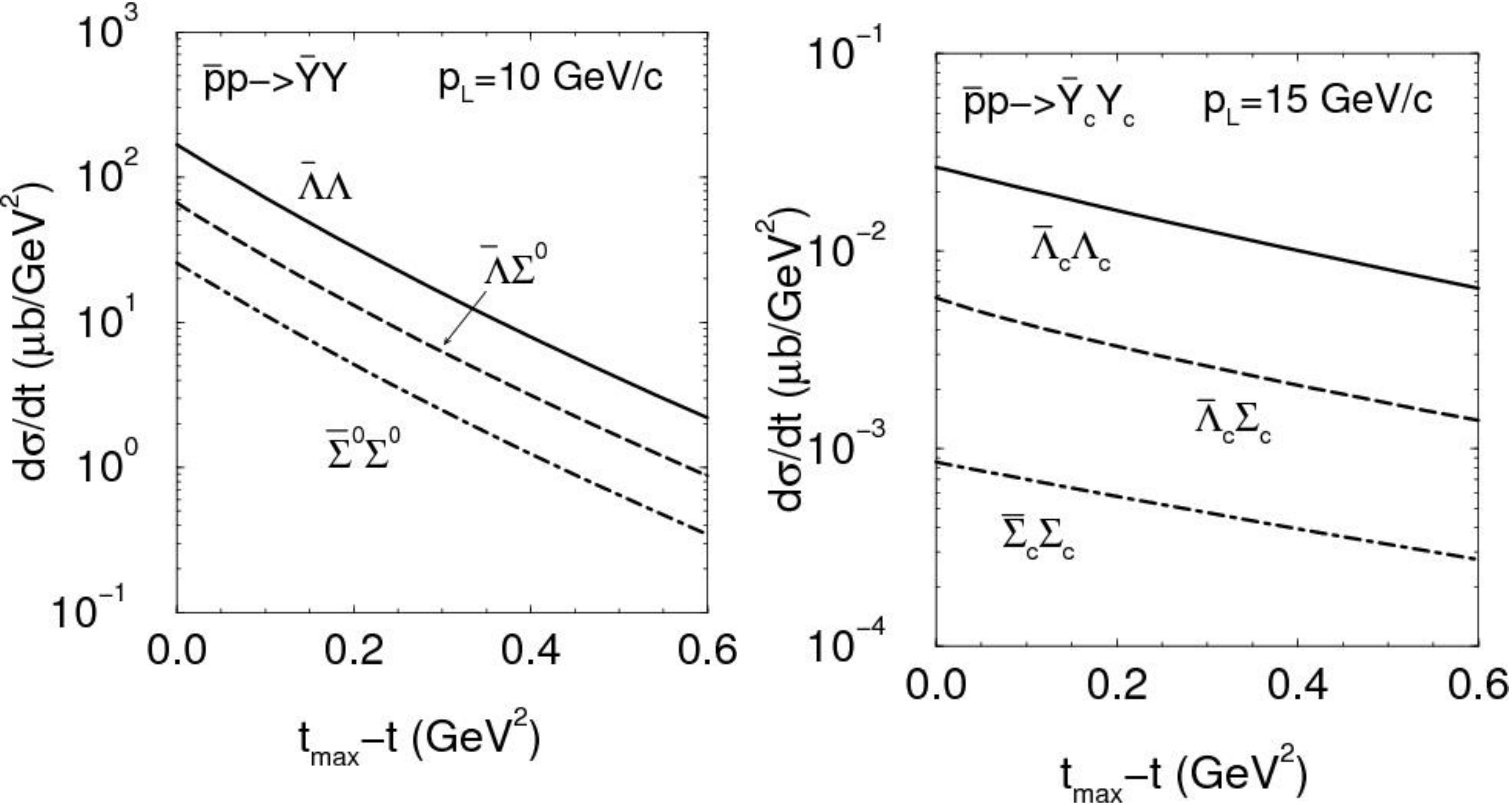
important note: for unpolarized case $\sum_{\text{spins}} \mathcal{M}\mathcal{M}^\dagger = 1$



$$C(t) = \frac{0.54}{(1 - t/1.15)^2}$$

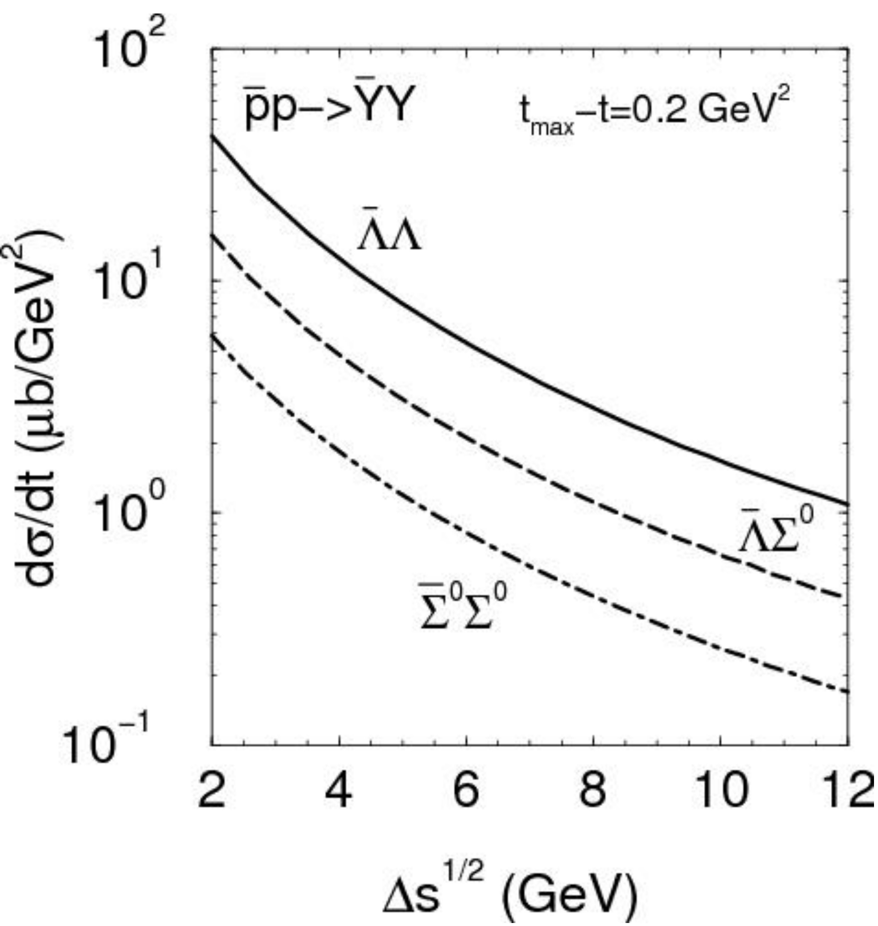
Reactions $\bar{p}p \to \bar{Y}Y,\ Y = \Lambda, \Sigma^o\ (\Lambda_c, \Sigma_c^o)$

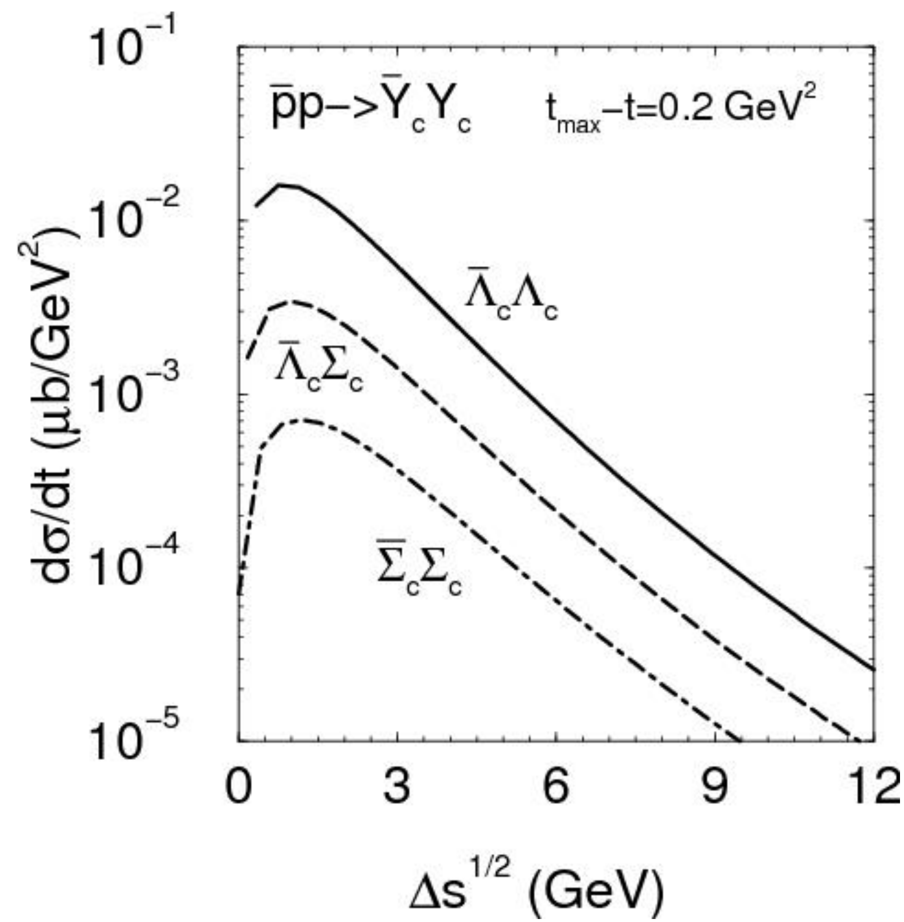
t - dependence



Reactions $\bar{p}p \to \bar{Y}Y,\ Y = \Lambda, \Sigma^o\ (\Lambda_c, \Sigma_c^o)$

energy dependence

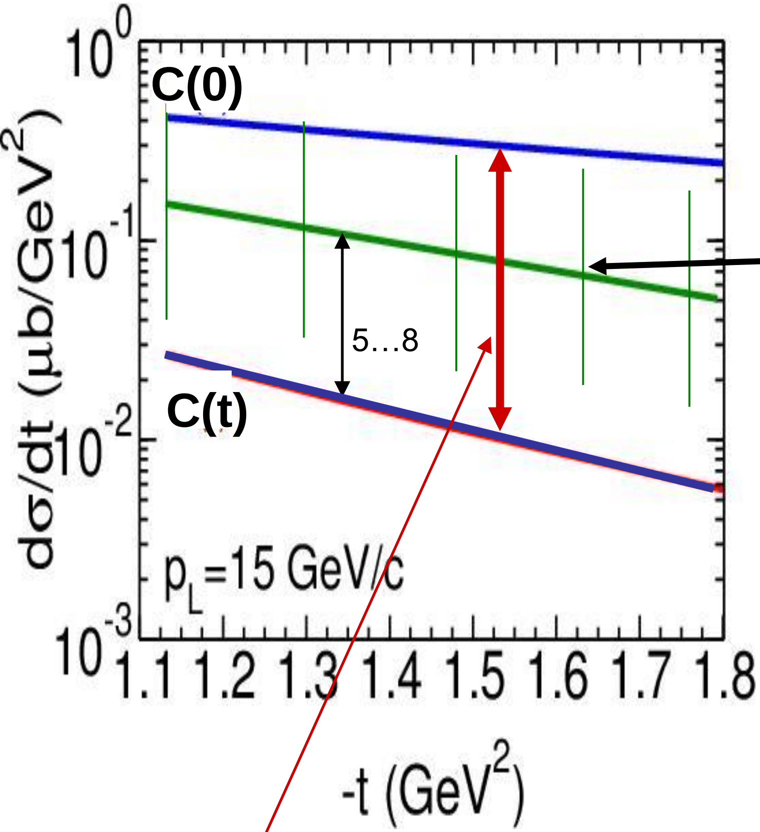




Comparison of two realization of QGSM for $\bar{p}p \to = \bar{\Lambda}_c \Lambda_c$

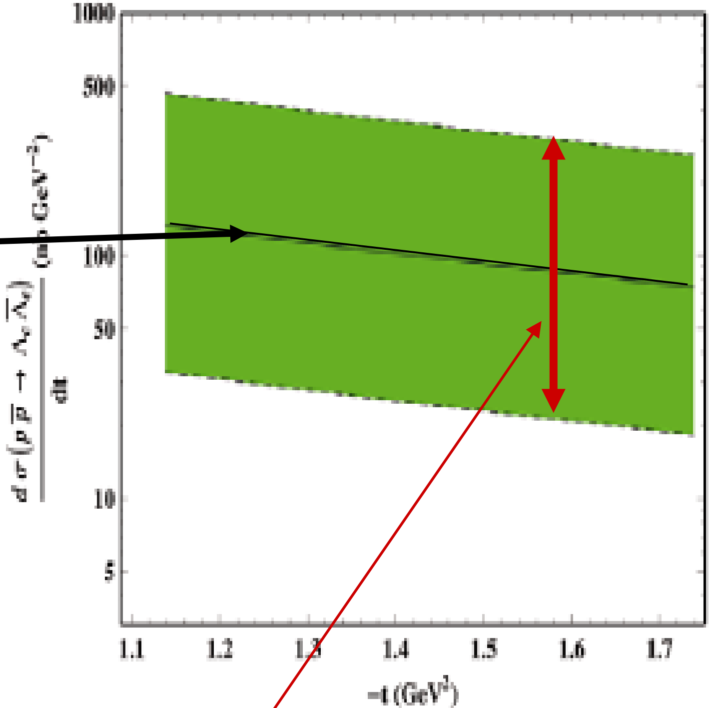
A.T., B. Kämpfer

Phys. Rev. C78,025291 (2008)



A.Khodjamirian,C. Klein, T.Mannel and Y.-M. Wang

Eur.Phys.J.A.48,31(2012)



the uncertainties caused
by the residual function C(t)

the uncertainties caused
by LCSR of strong couplings

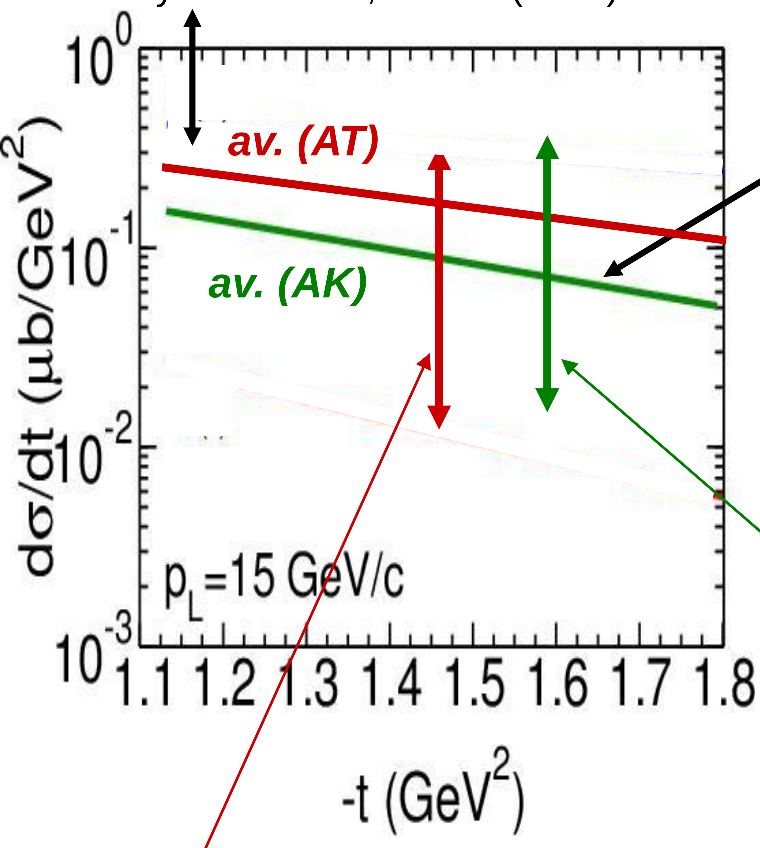
Comparison of two realization of QGSM (average values)

A.T., B. Kämpfer

Phys. Rev. C78,025291 (2008)

A.Khodjamirian,C. Klein, T.Mannael and Y.-M. Wang

Eur.Phys.J.A.48,31(2012)

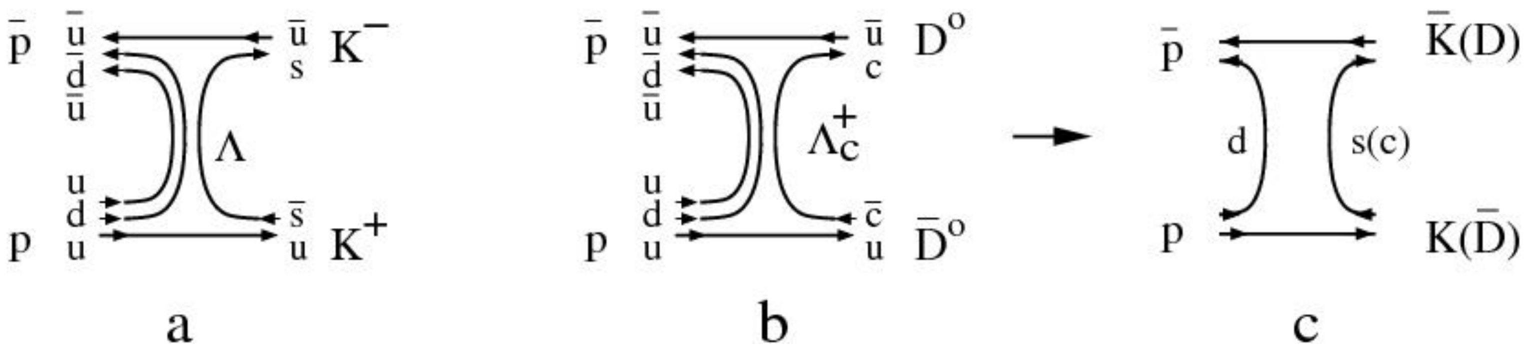


the uncertainties caused by the residual function C(t)

the uncertainties caused by LCSR of strong couplings

for the average values both predictions are consistent with each other within a factor of 2

Reaction $\bar{p}p \to \bar{K}K\,(D\bar{D})$



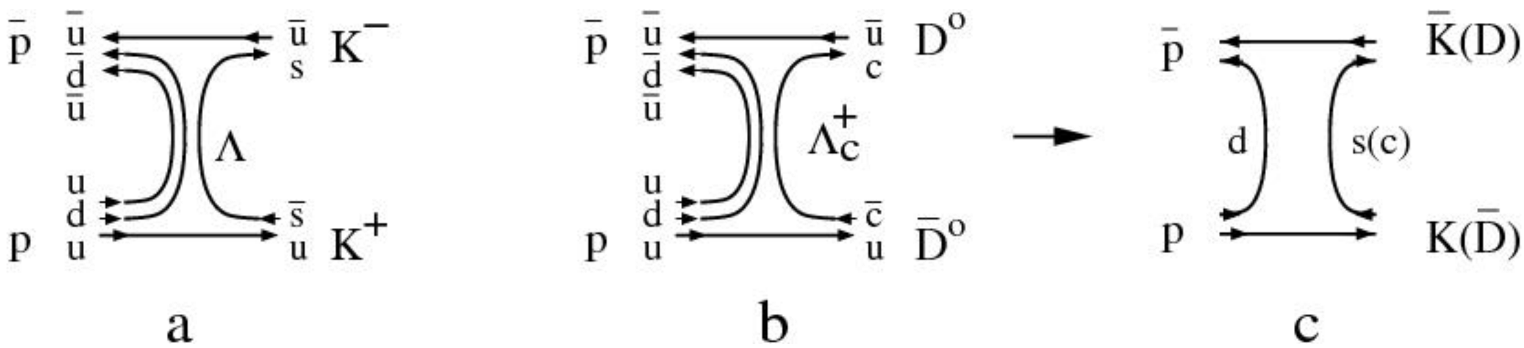
$$T^{\bar{p}p\to\bar{K}K}_{m_i,n_i} = C'(t)\frac{g^2_{KN\Lambda}M_Y\sqrt{s}}{s_0}\Gamma(\frac{1}{2}-\alpha_{\bar{s}q}(t))\left(-\frac{s}{s_{\bar{p}p:\bar{\Lambda}\Lambda}}\right)^{\alpha_{\bar{s}q}(t)-\frac{1}{2}} \otimes \mathcal{M}^{\bar{p}p\to\bar{K}K}_{m_i;n_i}(s,t)$$

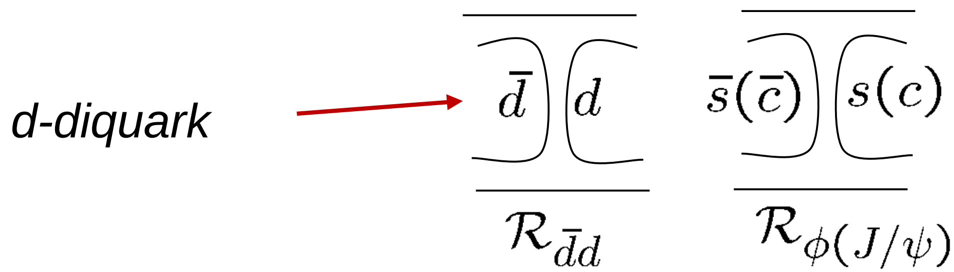
$$\mathcal{M}^{\bar{p}p\to\bar{K}K}_{m_i n_i}(s,t) = \mathcal{N}(s,t)\,\left[\bar{v}_{n_i}\,(\not{p}_Y - M_Y)\,u_{m_i}\right]\ ,$$

$$\mathcal{N}^2(s,t) = \frac{1}{F^2(s,t)},$$

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

Reaction $\bar{p}p \to \bar{K}K\,(D\bar{D})$





How to evaluate the di-quark trajectory?

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

$$\alpha_{sd}(t) \equiv \alpha_{\Lambda}(t) = -0.65 + 0.94\,t$$

is taken as input [cf. K.Storrow Phys. Rep. 103,135(1984)]

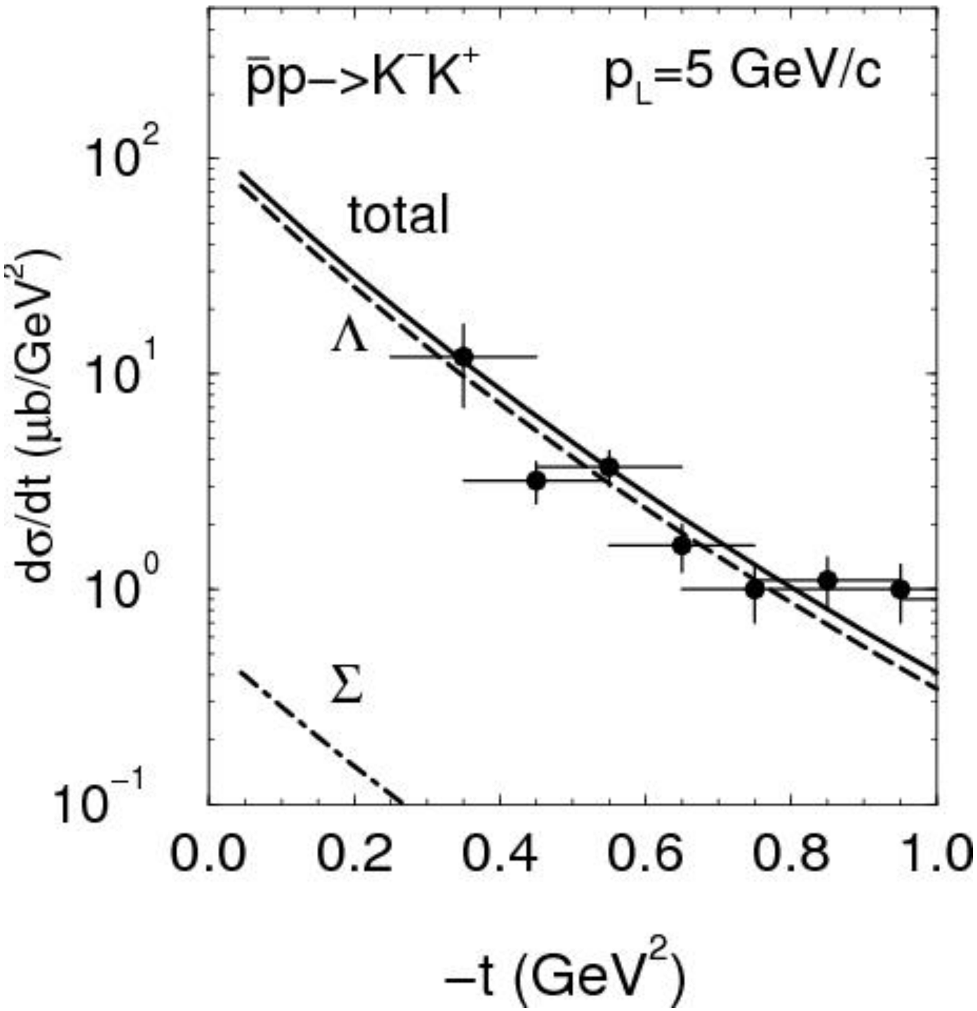
then

$$\alpha_{dd}(t) = -1.58 + 1.542\,t$$

and allows to identify trajectory of Λ_c

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

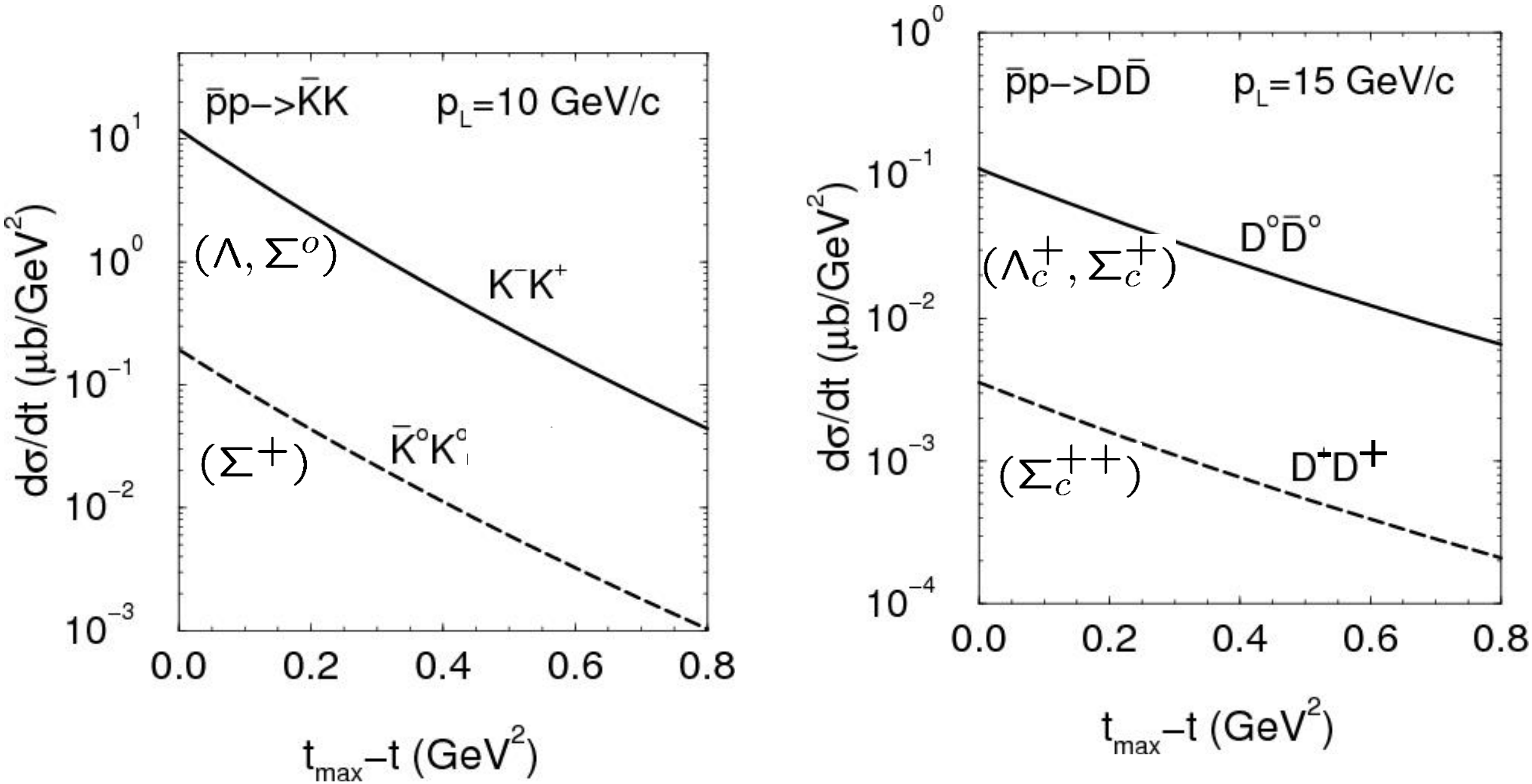
$$\alpha_{dc}(t) \equiv \alpha_{\Lambda_c}(t) = -2.09 + 0.557\,t$$



$$C'(t) = \frac{0.38}{(1-t/1.15)^2}$$

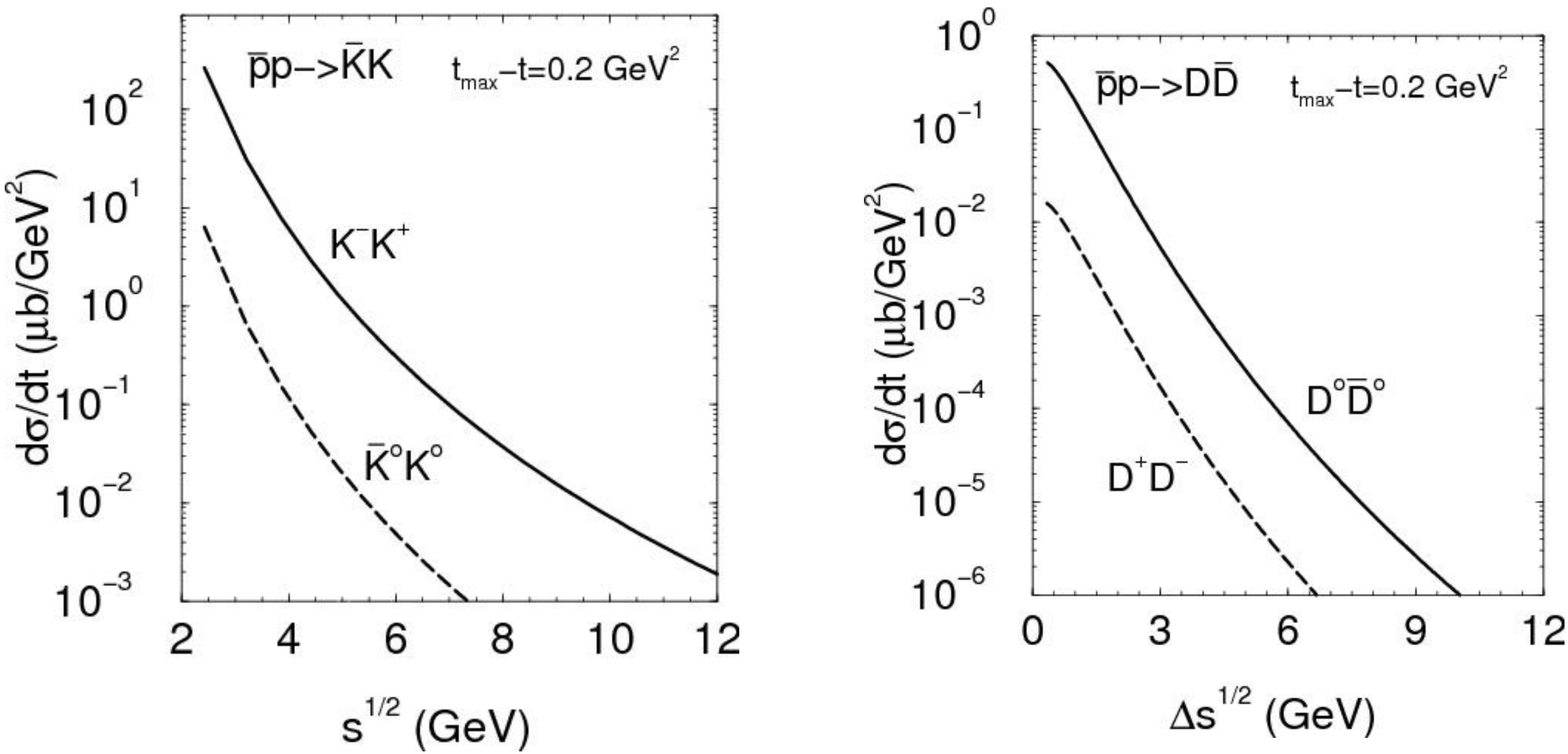
Reactions $\bar{p}p \to \bar{K}K\,(D\bar{D})$

t-dependence



Reactions $\bar{p}p \to \bar{K}K\,(D\bar{D})$

s-dependence

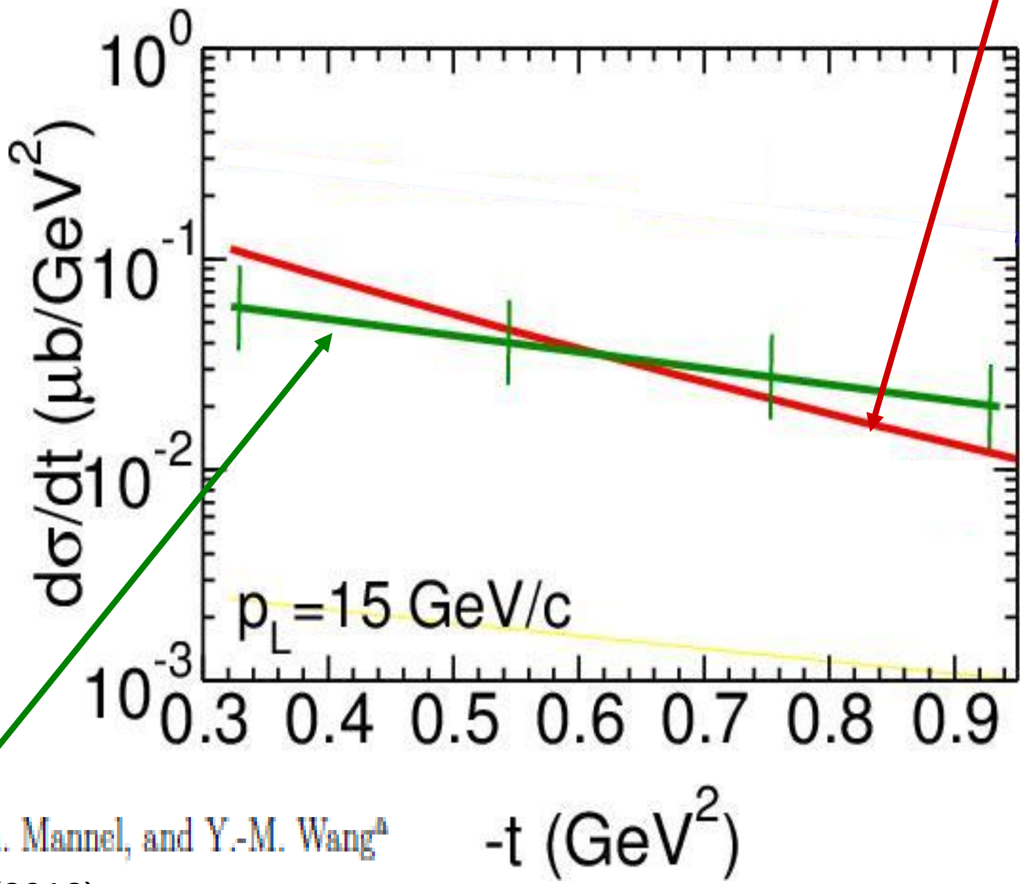


"J-PARC hadron physics in 2016"

Comparison of two realization of QGSM for $\bar{p}p \to D\bar{D}$

A.T., B. Kämpfer

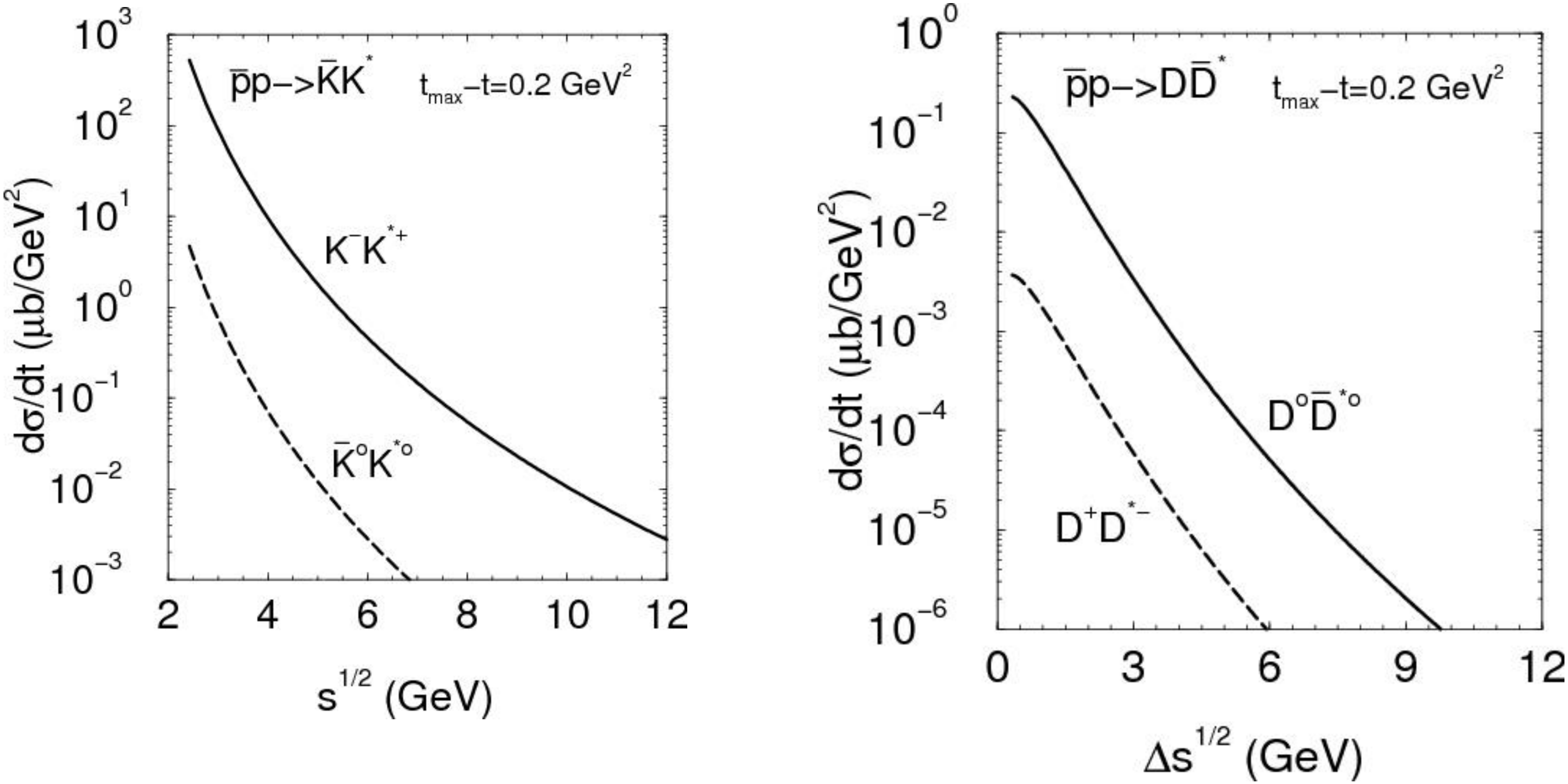
Phys. Rev. C78,025291 (2008)



A. Khodjamirian, Ch. Klein, Th. Mannel, and Y.-M. Wang[a]

Eur. Phys. J.A48, 31(2012)

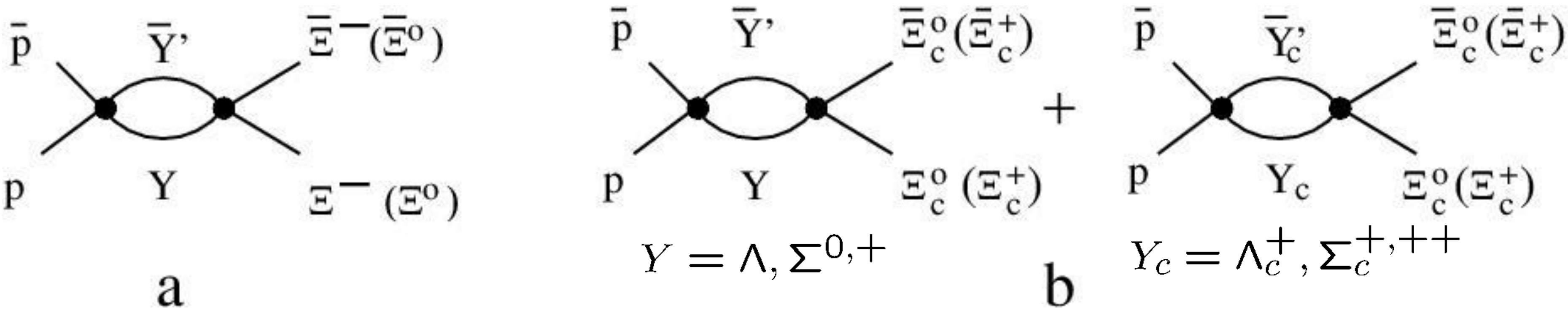
Reaction $\bar{p}p \to \bar{K}K^*$



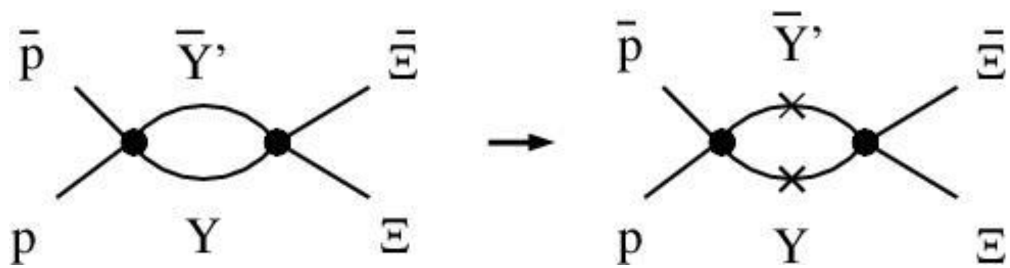
$$d\sigma^{KK^*} \simeq (2 \div 3)\, d\sigma^{KK}$$

$$\frac{\text{charm}}{\text{strangeness}} \sim 10^{-3} \ldots 10^{-4} \ldots$$

Double flavor exchange: and $\bar{\Xi}_c \Xi_c$ in $\bar{p}p$ collisions



Cut (pole) diagrams

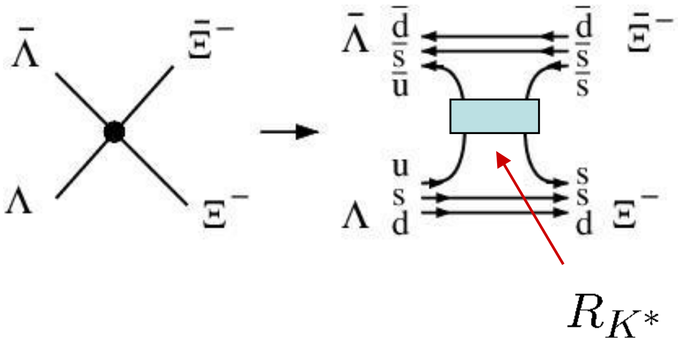


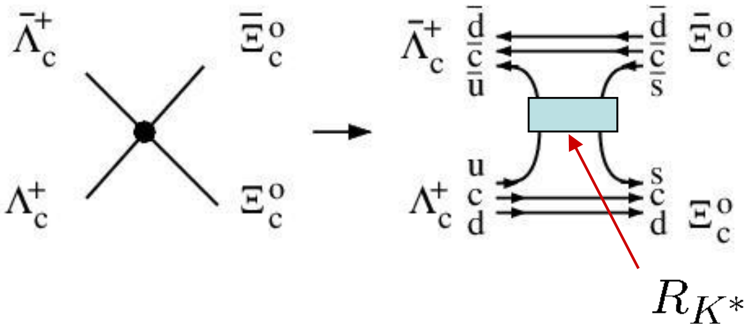
Cutkosky cutting rule

$$T^{\bar{p}p\to\bar{\Xi}\Xi} \simeq T_{\text{cut}}^{\bar{p}p\to\bar{\Xi}\Xi}$$

$$= -i\frac{\sqrt{1-4M_Y^2/s}}{16\pi}\int\frac{d\Omega_Y}{4\pi}\sum_{\text{spins }\bar{Y}'Y} T^{\bar{p}p\to\bar{Y}'Y}\,T^{\bar{Y}'Y\to\bar{\Xi}\Xi}$$

The vertex amplitudes: “effective region exchange”





The amplitude of $\bar{p}p \to \bar{Y}'Y \to \bar{\Xi}^0 \Xi^0$ *transition is a coherent sum with*

$$\bar{Y}'Y = \bar{\Lambda}\Lambda,\ \bar{\Sigma}^0\Sigma^0,\ \bar{\Sigma}^+\Sigma^+,\ \bar{\Sigma}^0\Lambda,\ \bar{\Lambda}\Sigma^0$$

intermediate states

SU(3) predicts

$$g_{K^*\Lambda\Xi^0} * g_{K^*\Sigma^0\Xi^0} < 0$$

$$T^{\bar{p}p \to \bar{\Xi}^0\Xi^0} = g_\Lambda^4 \left(1 + \frac{1}{9} + \frac{4}{9} - \frac{2}{3}\right) T_0 = \frac{8}{9} g_\Lambda^4 \underline{T_0}$$

coupling constant independent amplitude

for $\bar{p}p \to \bar{Y}'Y \to \bar{\Xi}^-\Xi^-$, one has $\bar{Y}'Y = \bar{\Lambda}\Lambda,\ \bar{\Sigma}^0\Sigma^0,\ \bar{\Sigma}^0\Lambda,\ \bar{\Lambda}\Sigma^0$

$$[g_{K^*\Lambda\Xi^-} * g_{K^*\Sigma^0\Xi^-}] > 0$$

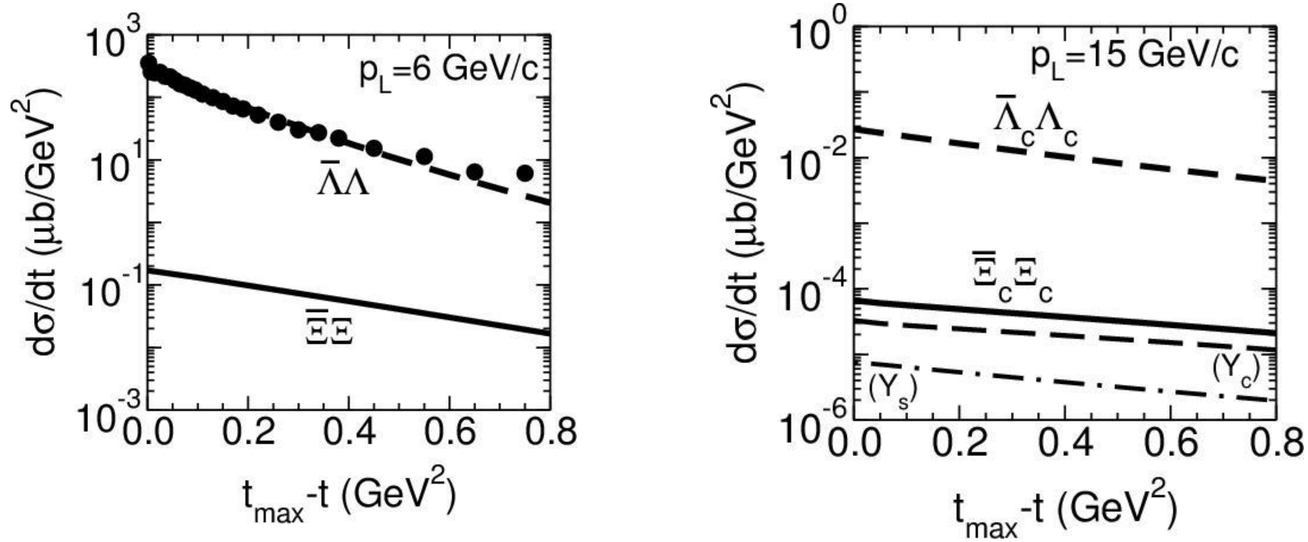
the ratio of cross sections looks as

$$\frac{\sigma^{\bar{p}p \to \bar{\Xi}^-\Xi^-}}{\sigma^{\bar{p}p \to \bar{\Xi}^0\Xi^0}} \simeq \frac{\sigma^{\bar{p}p \to \bar{\Xi}_c^0\Xi_c^0}}{\sigma^{\bar{p}p \to \bar{\Xi}_c^+\Xi_c^+}} \simeq 4.$$

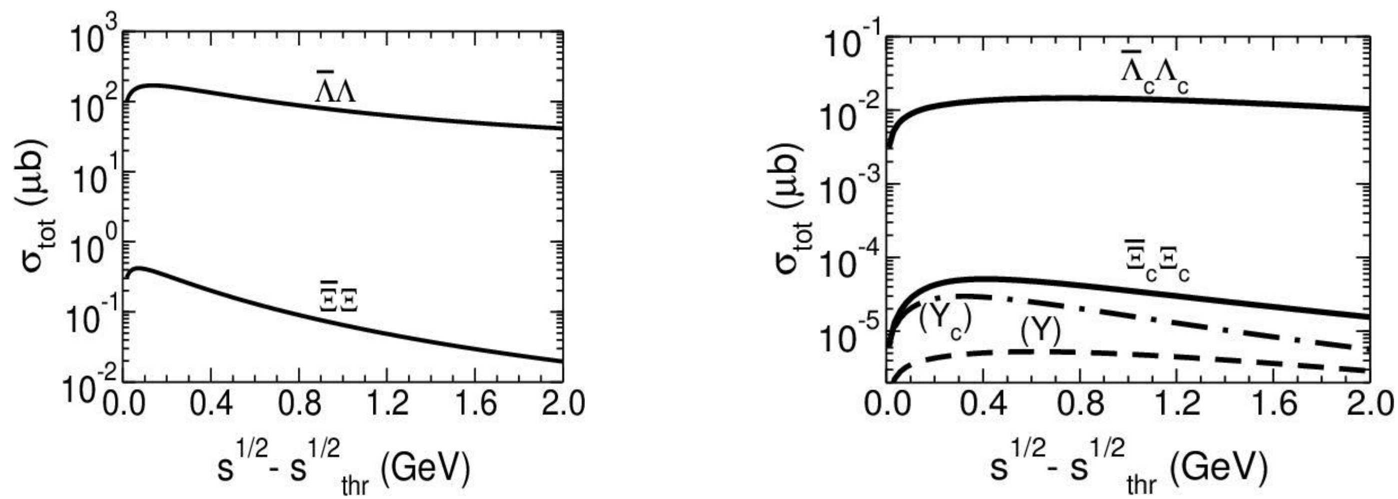
Ξ^- *and* Ξ_c^o

Cross sections

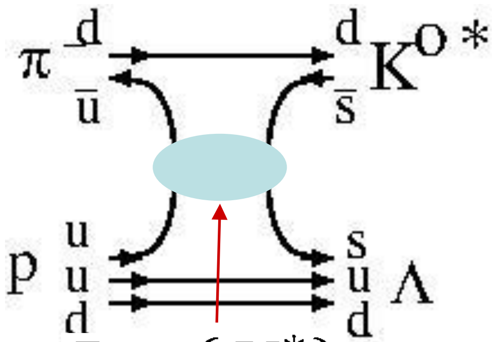
differential



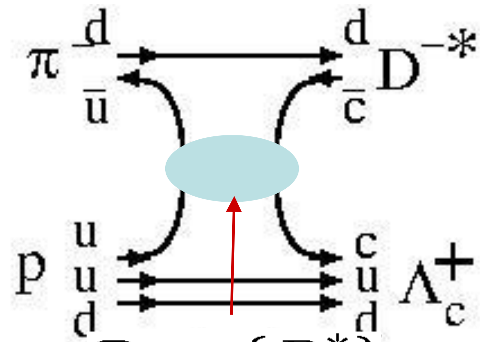
total



Exclusive $\pi p \to M^* \Lambda;\ M^* = K^{o,*},\ D^{-*}$ reactions



$\mathcal{R}_{p\Lambda}\{K^*\}$



$\mathcal{R}_{p\Lambda_c}\{D^*\}$

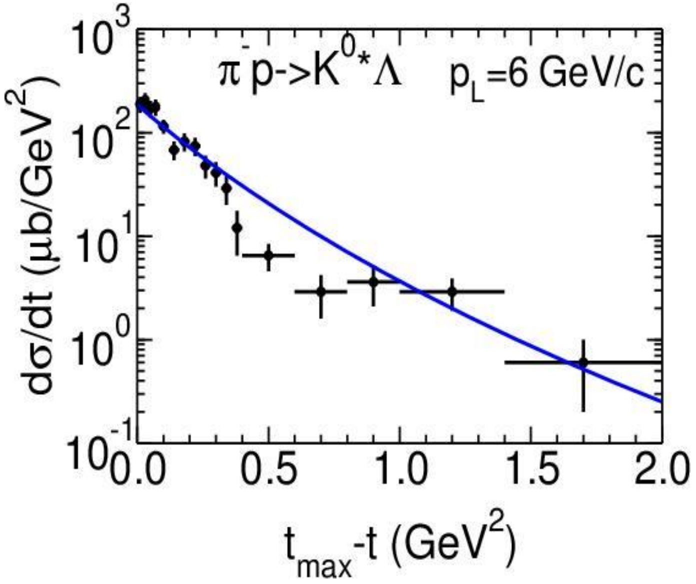
$$T^{\pi p \to \Lambda M^*} \simeq g_0^2 \frac{s}{\bar{s}} \Gamma(1 - \alpha_{\mathcal{R}_{p\Lambda(\Lambda_c)}}(t)) \left(\frac{s}{s_0^{\mathcal{R}}}\right)^{2(\alpha_{\mathcal{R}_{p\Lambda(\Lambda_c)}}(t)-1)}$$

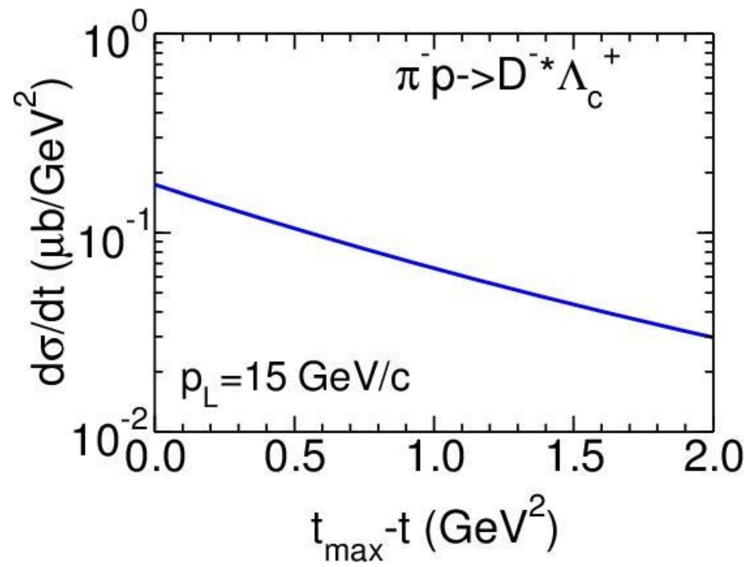
$\alpha_{\mathcal{R}_{p\Lambda_c}}(t) = 0.414 + 0.71t$ $\qquad$ $\alpha_{\mathcal{R}_{p\Lambda_c}}(t) = -1.02 + 0.47t$

$s^{\mathcal{R}_{p\Lambda}} \simeq 1.59\ \text{GeV}^2$ $\qquad$ $s^{\mathcal{R}_{p\Lambda_c}} \simeq 4.75\ \text{GeV}^2$

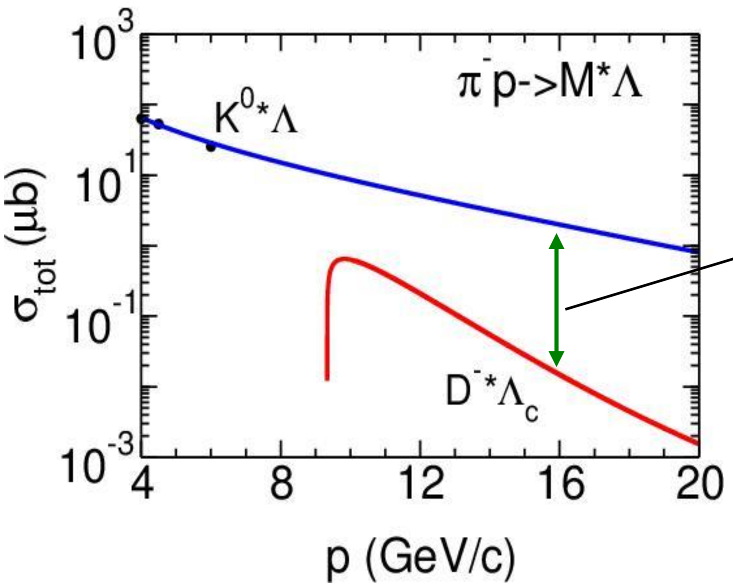
$\frac{g_0^2}{4\pi} \simeq 0.8, \quad \bar{s} \simeq 1\text{GeV}^2$

Differential cross sections





Total cross sections

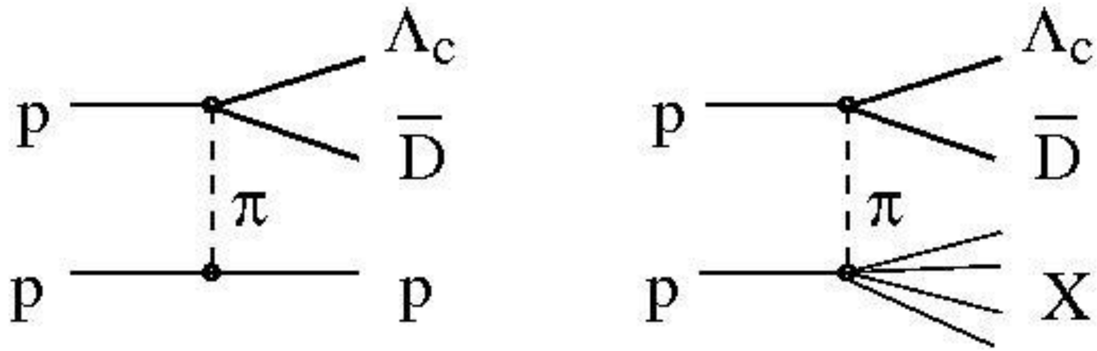


[cf. K. Boreskov, A.Kaidalov, Sov.J. Nucl.Phys. 37 (1982)]

$$\frac{c}{s} \simeq 10^{-2\ldots-3} \text{ vs. } \frac{c}{s} \simeq 10^{-6}$$

[cf. V. Barger, R.Phillips, PRD 12 (1975)]

Reactions $pp \to \Lambda_c \bar{D}\, p$ and $pp \to \Lambda_c \bar{D}\, X$



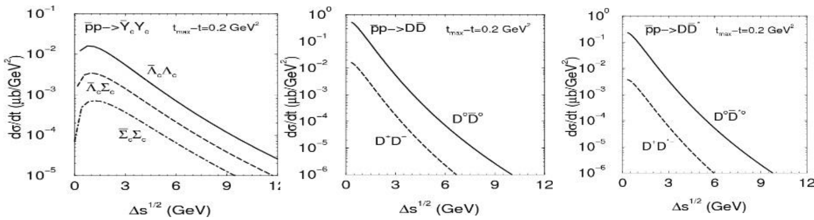
$$d\sigma^{pp \to \Lambda_c \bar{D}\, p(X)} \sim \frac{d\sigma^{\pi p \to \Lambda_c \bar{D}}}{dt} \otimes \sigma^{\pi N}_{\rm tot}\; d[PS]$$

For high energy cf. K. Boreskov, A.Kaidalov, Sov.J. Nucl.Phys. 37 (1982)

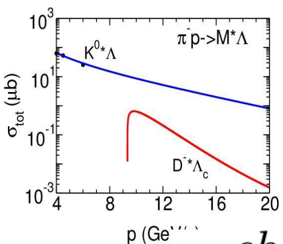
For J-PARC energies our work is in a progress

Summary

- *We have evaluated the cross sections for* $\bar{p}p \to \bar{Y}_c Y_c,\ D\bar{D},\ D^*\bar{D},\ \ldots$ *reactions, including double flavor exchange,*



- *and for* $\pi p \to D^* \Lambda_c$ *reactions at* $E_{\rm lab} \leq 20\ \mathrm{GeV}$



$$\frac{charm}{strangeness} \sim 10^{-4}$$

ambiguity with residual function!!

$$\frac{charm}{stsangeness} \sim 10^{-2}$$

- *This result may be used for design of PANDA detector and "charm" program at JPARC*

- *And for further development of the theoretical approaches in "charmed physics"*

THE END

Thank you very much for attention !

BACKUP

Longitudinal asymmetries

$$\mathcal{A}(s,t) = \frac{d\sigma^A - d\sigma^P}{d\sigma^A + d\sigma^P},$$

where $d\sigma^A \equiv d\sigma^{\rightleftarrows}$ $d\sigma^P \equiv d\sigma^{\rightrightarrows}$

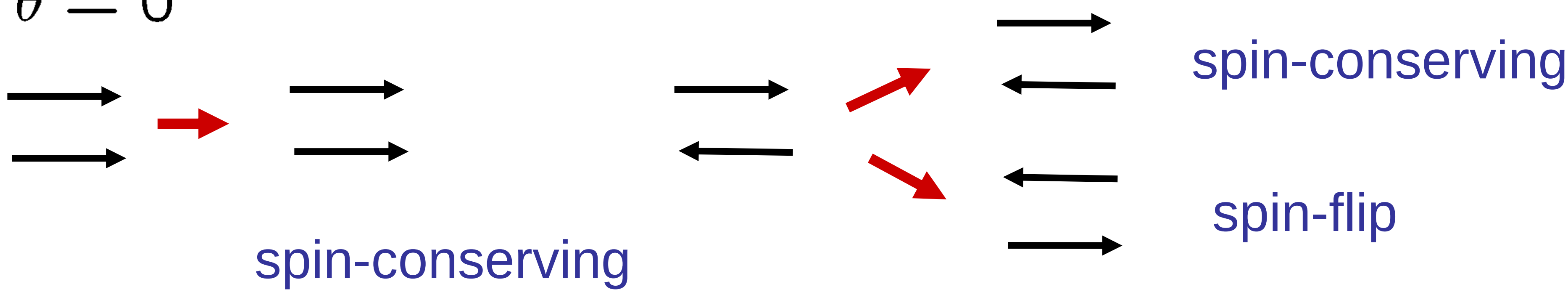
Polarized Antiproton EXperiment (PAX)

http://www.fz-juelich.de/ikp/pax/

Longitudinal asymmetry

$$\mathcal{A} = \frac{d\sigma^A - d\sigma^P}{d\sigma^A + d\sigma^P}, \qquad d\sigma^A \equiv d\sigma^{\rightleftarrows}, \quad d\sigma^P \equiv d\sigma^{\rightrightarrows}$$

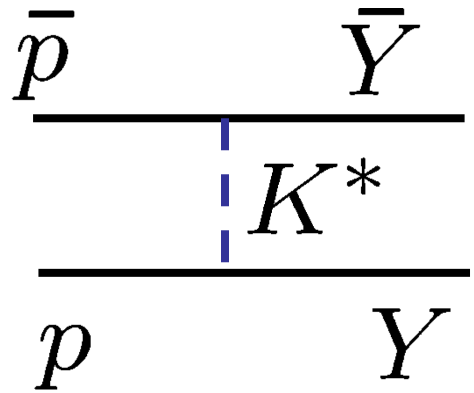
$\theta = 0$



$$T_{m_f n_f; m_i, n_i} \sim A(s)\, \delta_{m_i m_f}\, \delta_{n_i n_f} + \frac{1}{\sqrt{2}} B(s)\, (1 - 4 m_i m_f)\, \delta_{-m_i m_f} \delta_{-n_i n_f}$$

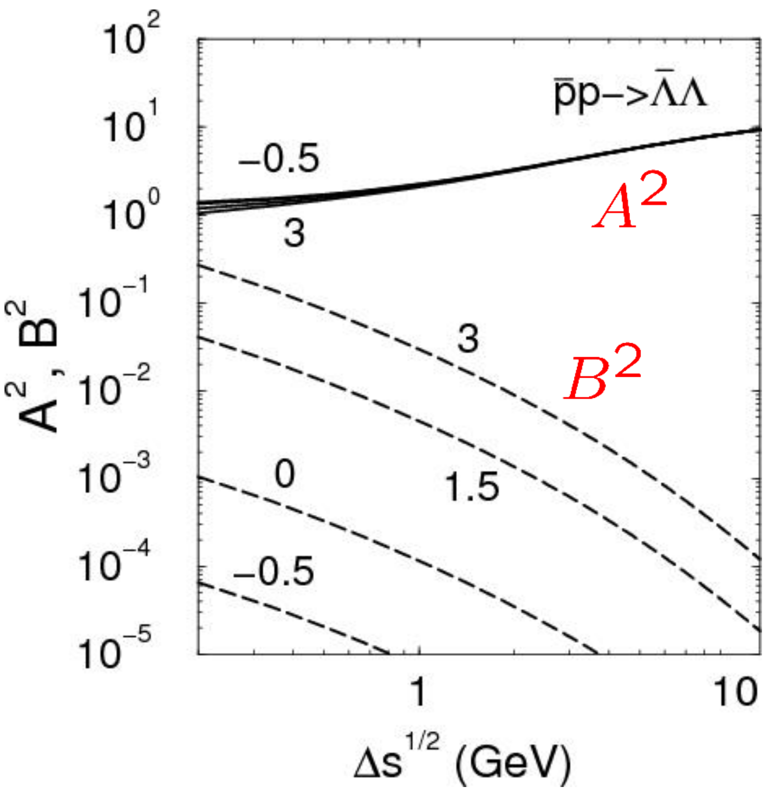
$$\boxed{\mathcal{A} = \frac{B^2(s)}{A^2(s) + B^2(s)}}$$

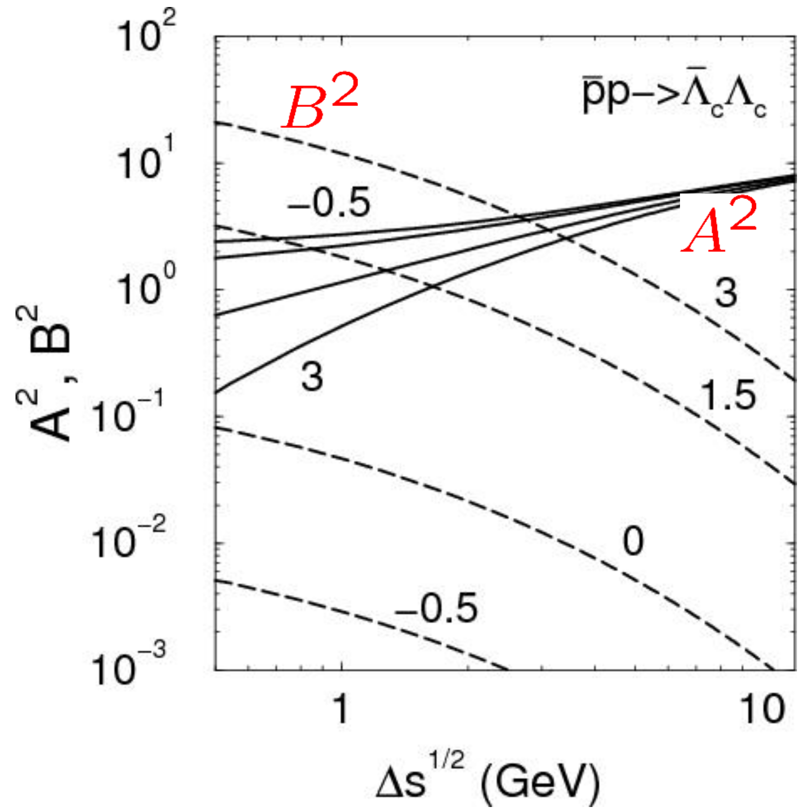
Structure of spin-flip amplitude



$$B(s) = -\sqrt{2}\left((1+\kappa)\left(\frac{\mathbf{p}_p}{E+M_N} - \frac{\mathbf{p}_Y}{E+M_Y}\right)\right)^2$$

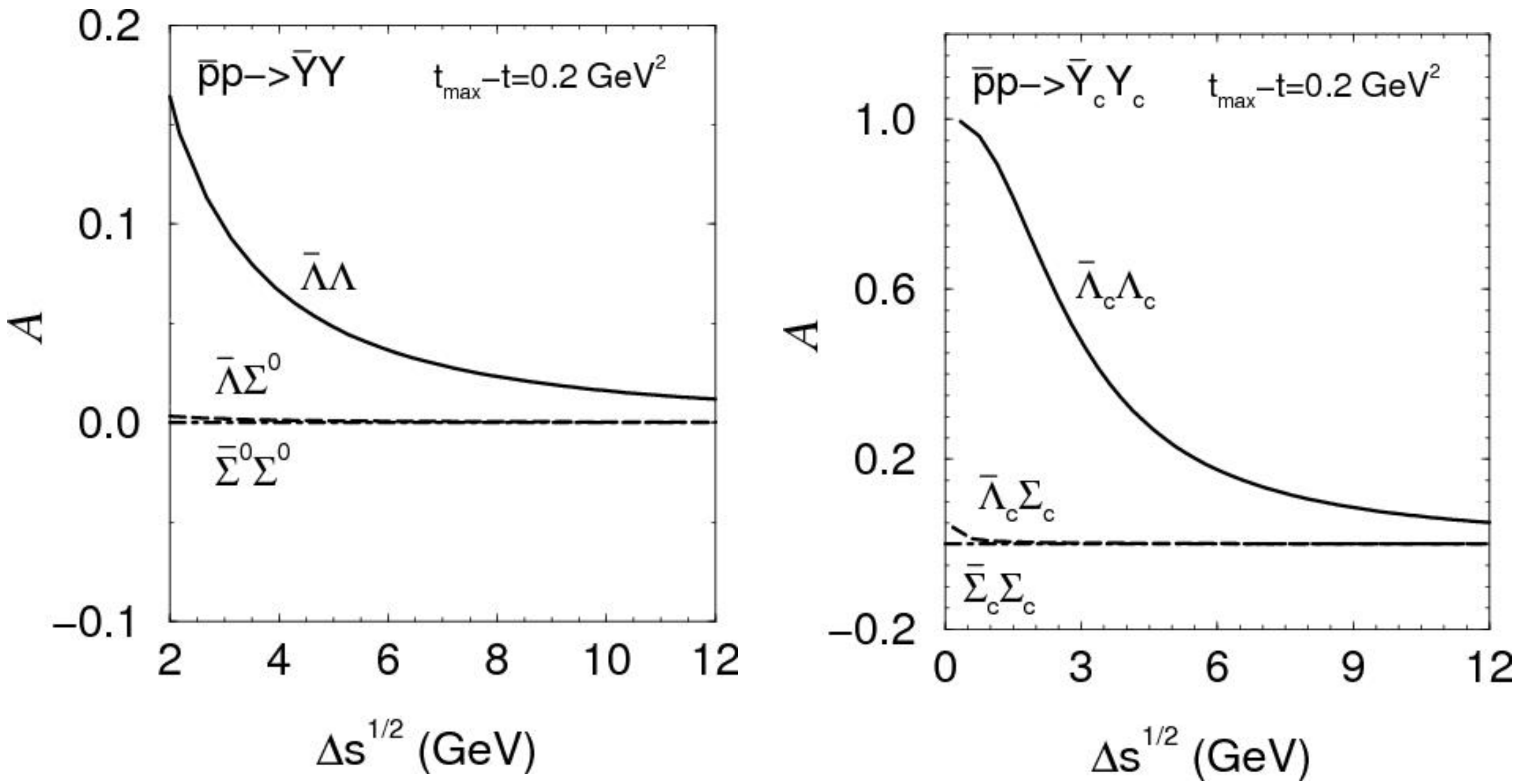
$$\mathcal{A} = \frac{B^2(s)}{A^2(s) + B^2(s)}$$





Asymmetry *s-dependence*

Reaction $\bar{p}p \rightarrow \bar{Y}Y$, $Y = \Lambda, \Lambda_c^+, \Sigma^o, \Sigma_c^+$

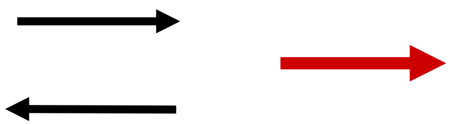


Longitudinal asymmetry

$$\bar{p}p \rightarrow \bar{K}K\,(D\bar{D})$$

$\theta = 0$

$J_{\text{final}} = 0$



0

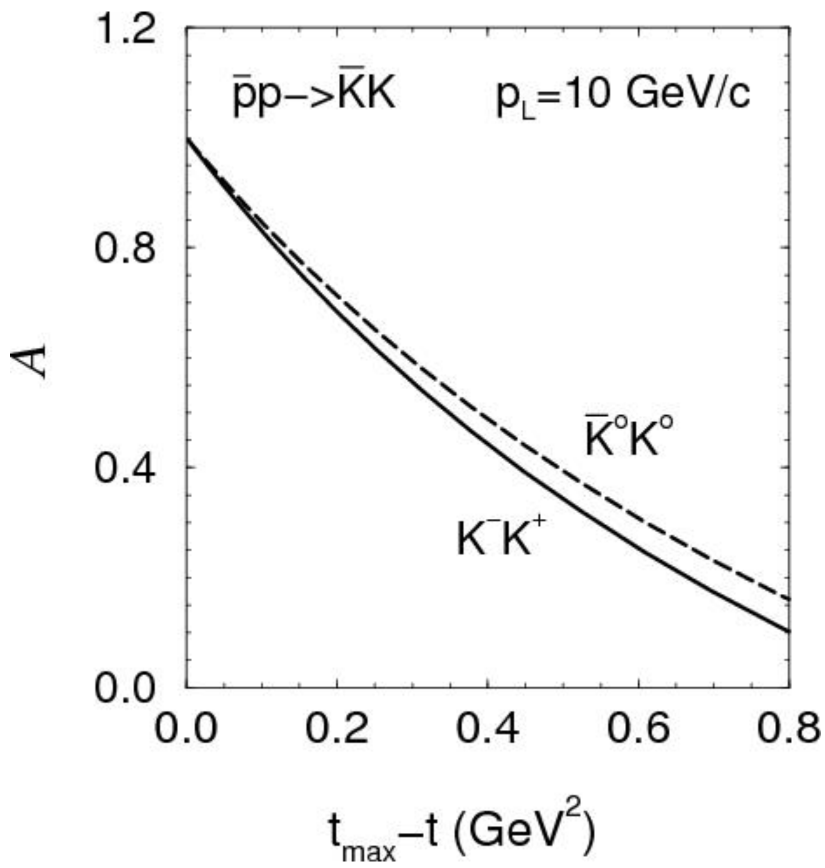
$$\mathcal{A} = \frac{d\sigma^A - d\sigma^P}{d\sigma^A + d\sigma^P},$$

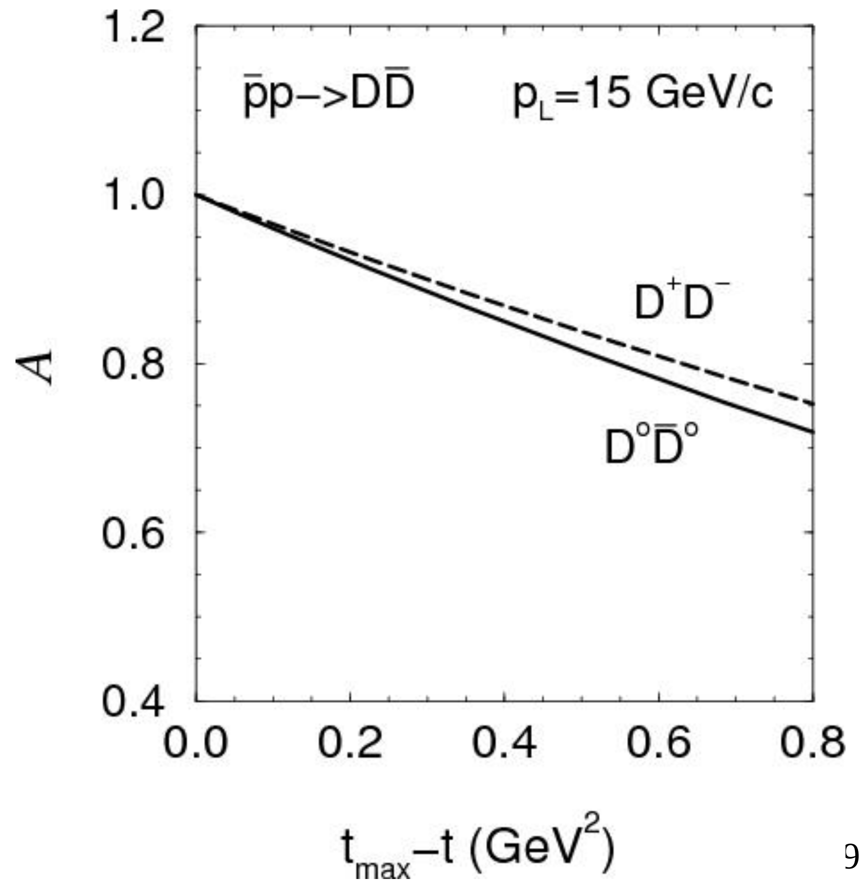
$$d\sigma^P \equiv d\sigma^{\rightrightarrows} \simeq 0$$

$$\mathcal{A} \simeq 1$$

Asymmetry *t-dependence*

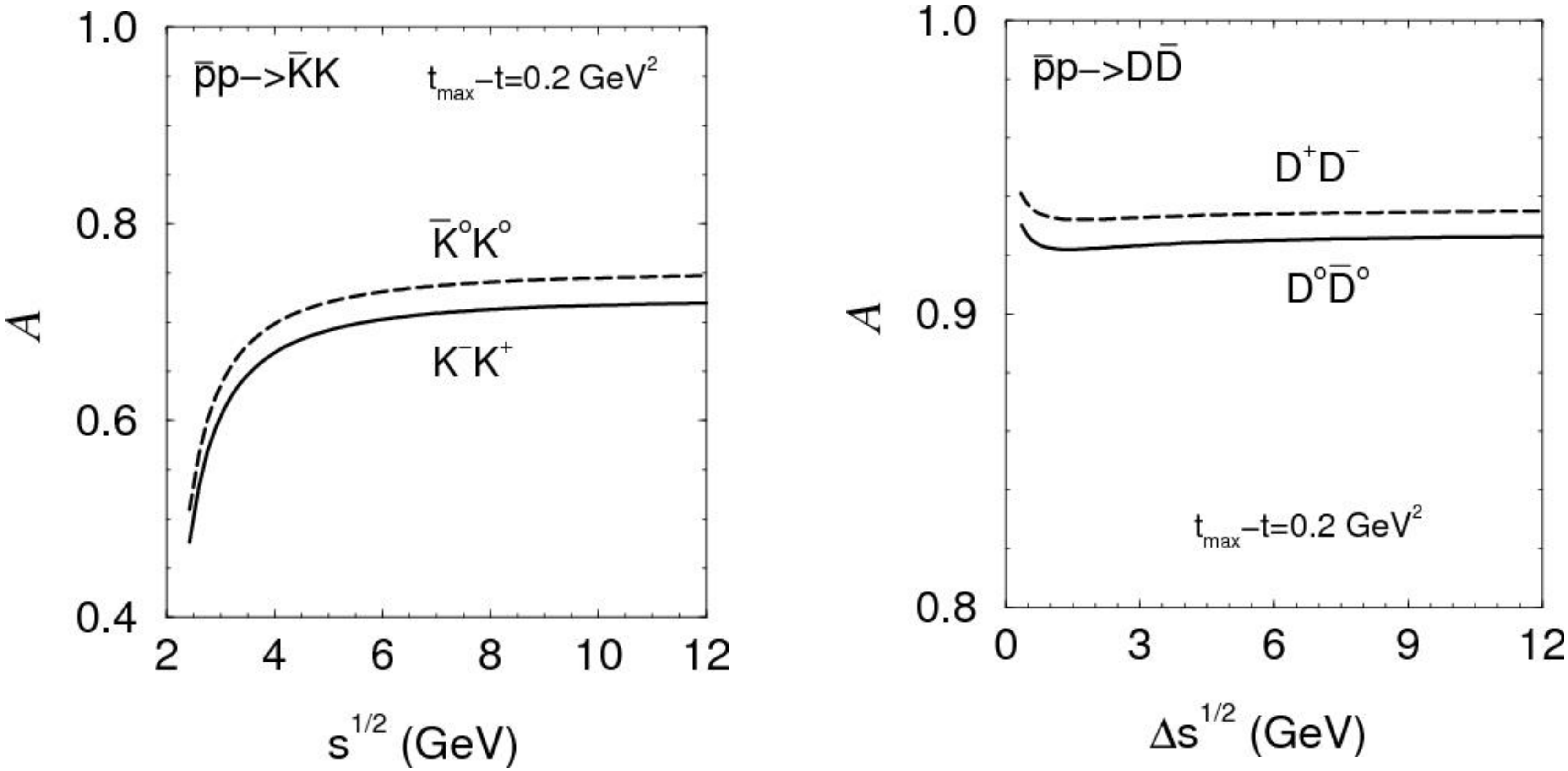
Reactions $\bar{p}p \to \bar{K}K,\ D\bar{D}$





Asymmetry *s-dependence*

Reactions $\bar{p}p \to \bar{K}K,\ D\bar{D}$



Longitudinal asymmetry

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

pure vector coupling!!!

$$\theta = 0 \qquad s_f = 1, \lambda_V = 1, 0$$

$$T_{\lambda_i;m_i,n_i} \sim \left(A\,\delta_{m_i n_i} + B\;\delta_{-m_i n_i}\right)\delta_{\lambda_i \lambda_V}\;,$$

$$\lambda_i = m_i + n_i$$

$$A \simeq \sqrt{2}, \qquad B \simeq \frac{M_N}{M_V}\;,$$

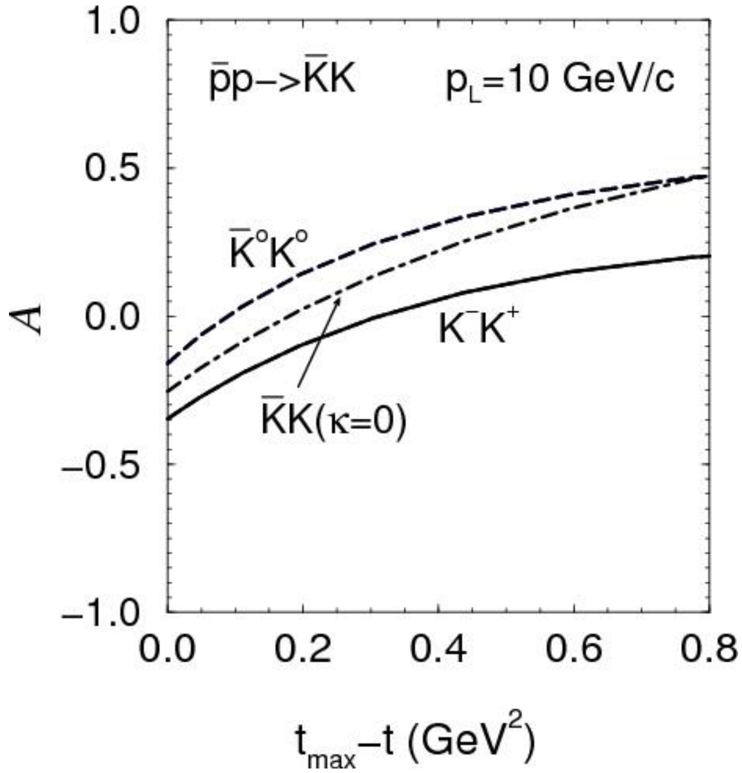
$$\mathcal{A} = \frac{M_N^2 - 2M_V^2}{M_N^2 + 2M_V^2}$$

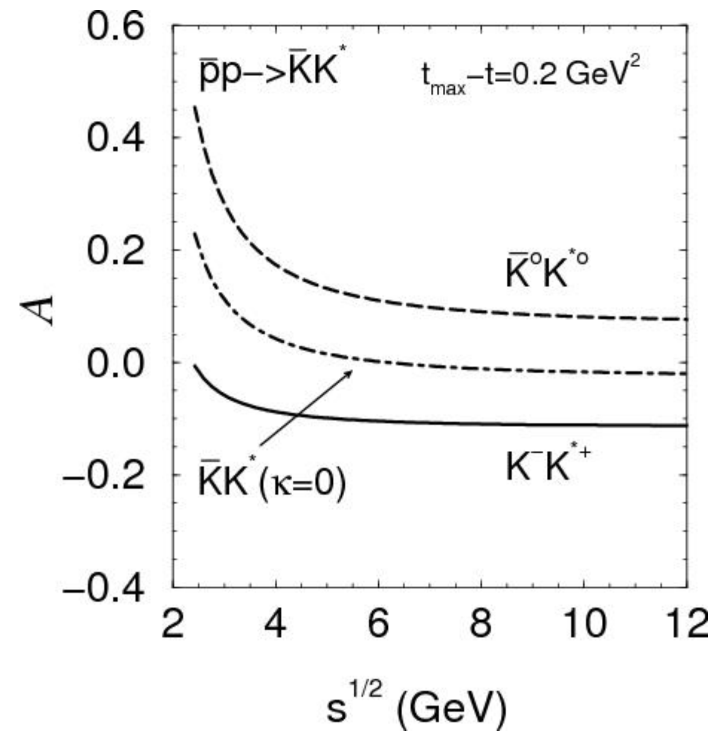
$\sim -0.3\,(\bar{K}K^*)$

$\sim -0.8\,(D\bar{D}^*)$

"J-PARC hadron physics in 2016"

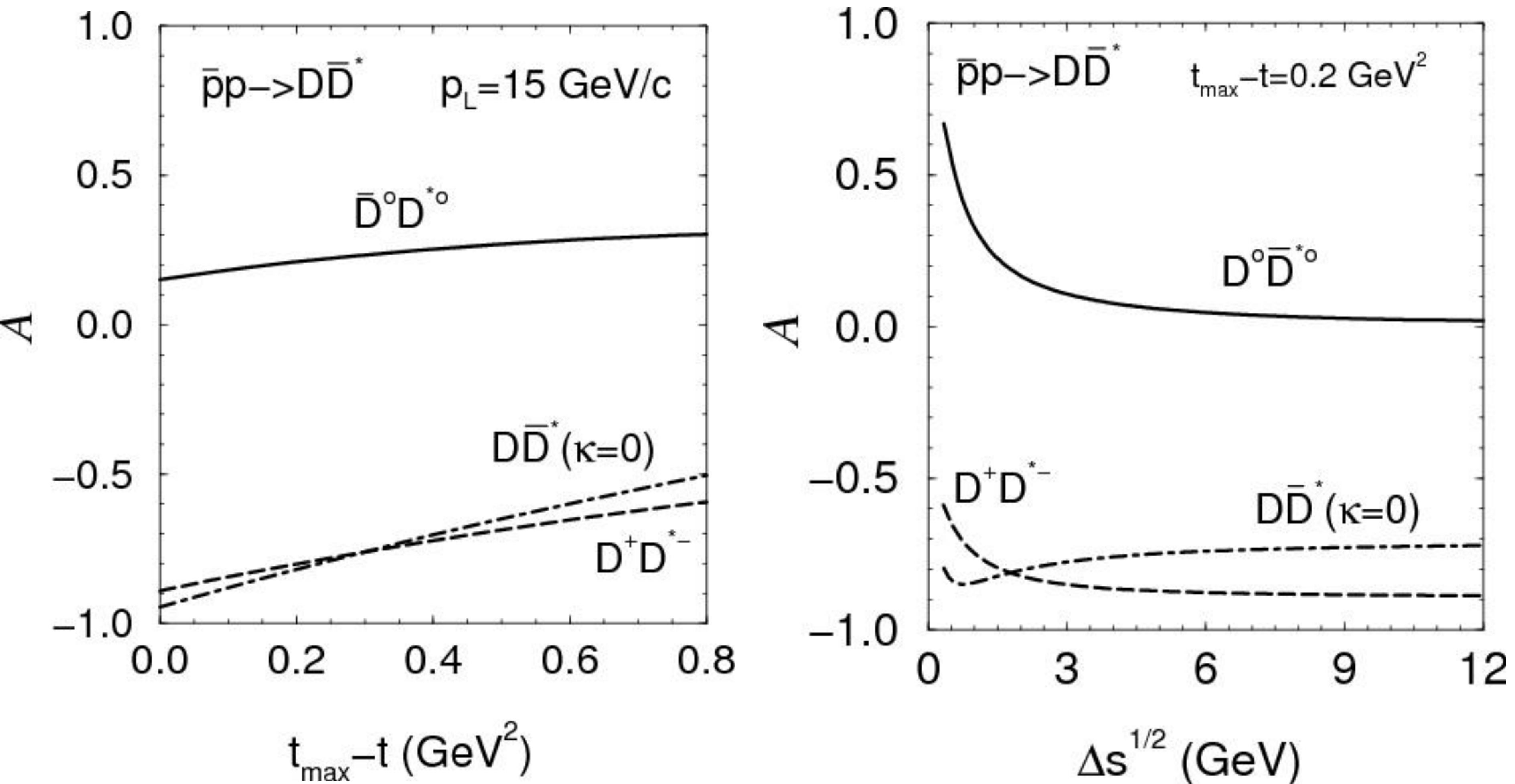
Reaction $\bar{p}p \to \bar{K}K^*$





"J-PARC hadron physics in 2016"

Reaction $\bar{p}p \rightarrow D\bar{D}^*$



J.Haindenbauer and J.Krein
Phys. Lett. **B 687** (2010)

OBE model

$$\frac{\text{charm}}{\text{strangeness}} \simeq 3 \cdot 10^{-2}$$

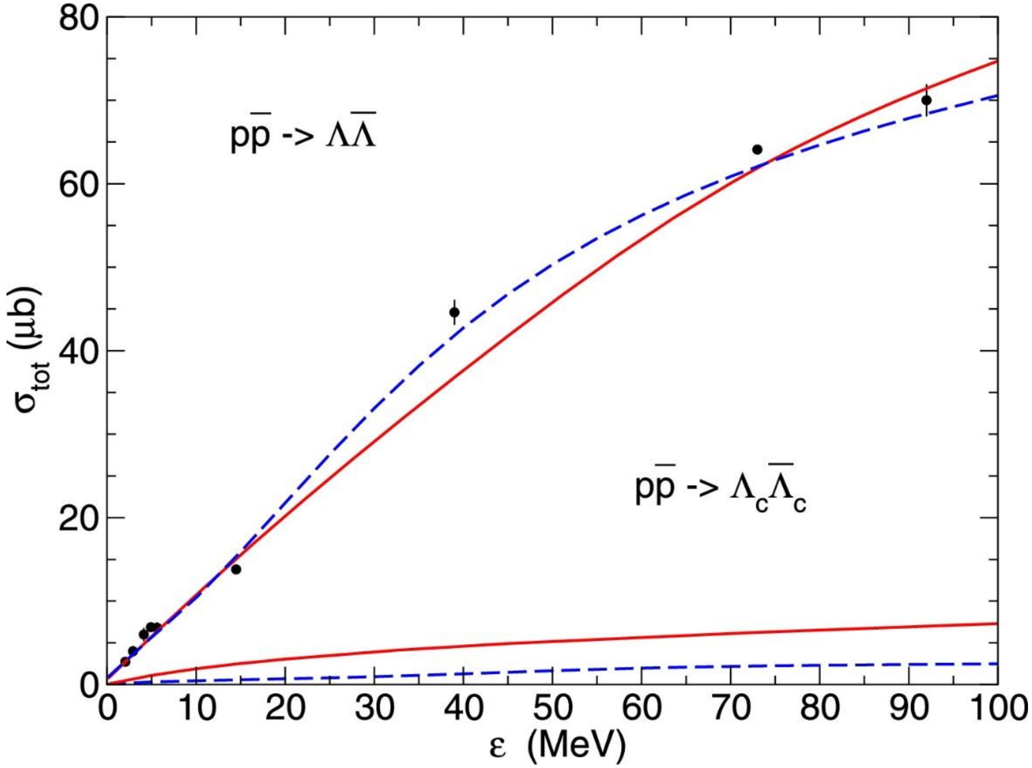


Fig. 2. Total reaction cross sections for $\bar{p}p \to \bar{\Lambda}\Lambda$ and $\bar{p}p \to \bar{\Lambda}_c^- \Lambda_c^+$ as a function of the excess energy ϵ. The results for $\bar{p}p \to \bar{\Lambda}\Lambda$ (upper curves) are taken from our work [7]. The solid curves are results for the meson-exchange transition potential while the dashed curves correspond to quark-gluon dynamics. The $\bar{p}p \to \bar{\Lambda}_c^- \Lambda_c^+$ results are obtained with the $\bar{p}p$ interaction C.

$$\frac{d\sigma}{d\Omega} = \frac{1}{64\pi^2} C(s, M_\Lambda) |T(s, M_\Lambda)|^2 \ ,$$

$$\sim |1/(t - M_V^2)|^2$$

$$\begin{aligned} -t_s &= 0.22 \ldots 0.50 \\ -t_c &= 3.54 \ldots 5.33 \end{aligned}$$

$$\frac{d\sigma^s}{d\sigma^c} \simeq 9.8 \times 54.4 \simeq 530$$

$$\frac{\text{charm}}{\text{strangeness}} \simeq 2 \cdot 10^{-4}$$

TABLE I. Parameters of the vector meson trajectories of the form (8). The intercept of the ρ trajectory was taken as an input.

	ρ	K^*	ϕ	
$\alpha(0)$	0.55	0.414 ± 0.006	0.27 ± 0.01	
$\sqrt{T}$, GeV	2.46 ± 0.03	2.58 ± 0.03	2.70 ± 0.07	
	D^*	D_s^*	J/ψ	
$\alpha(0)$	-1.02 ± 0.05	-1.16 ± 0.05	-2.60 ± 0.10	
$\sqrt{T}$, GeV	3.91 ± 0.02	4.03 ± 0.04	5.36 ± 0.05	
	B^*	B_s^*	B_c^*	Υ
$\alpha(0)$	-7.13 ± 0.17	-7.27 ± 0.17	-8.70 ± 0.18	-14.81 ± 0.35
$\sqrt{T}$, GeV	7.48 ± 0.02	7.60 ± 0.04	8.93 ± 0.03	12.50 ± 0.02

TABLE V. Parameters of the pseudoscalar meson trajectories of the form (8). (The parameters for the K trajectory were found using the mass of K_2 from [29]. If we instead use a mass of the corresponding *pure* $n\bar{s}$ state as found in Ref. [46], i.e., $M_{K_2}=1762\pm18$ GeV, the parameters change slightly: the intercept -0.153 ± 0.003, and the threshold 2.93 ± 0.07 GeV.)

	π	K	η_s	
$\alpha(0)$	-0.0118 ± 0.0001	-0.151 ± 0.001	-0.291 ± 0.003	
$\sqrt{T}$, GeV	2.82 ± 0.05	2.96 ± 0.05	3.10 ± 0.11	
	D	D_s	η_c	
$\alpha(0)$	-1.61105 ± 0.00005	-1.751 ± 0.001	-3.2103 ± 0.0001	
$\sqrt{T}$, GeV	4.16 ± 0.03	4.29 ± 0.06	5.49 ± 0.02	
	B	B_s	B_c	η_c
$\alpha(0)$	-7.41 ± 0.17	-7.54 ± 0.17	9.00 ± 0.17	-14.80 ± 0.34
$\sqrt{T}$, GeV	7.89 ± 0.16	8.01 ± 0.16	9.24 ± 0.12	12.98 ± 0.24

TABLE II. Comparison of the masses of the spin-1, spin-3 and spin-5 states given by ten vector meson trajectories of the form (8) with data. All masses are in MeV.

	$J=1$		$J=3$		$J=5$	
	This work	Ref. [29]	This work	Ref. [29]	This work	Ref. [29]
$\alpha_\rho(t)$	**769.0±0.9**	769.0±0.9	**1688.8±2.1**	1688.8±2.1	2124±19	
$\alpha_{K^*}(t)$	**896.1±0.3**	896.1±0.3	**1776±7**	1776±7	2215±21	
$\alpha_\phi(t)$	1015±17	1019.4	1863±31	1854±7	2305±42	
$\alpha_{D^*}(t)$	**2006.7±0.5**	2006.7±0.5	2721±23		3191±22	
$\alpha_{D_s^*}(t)$	2102±29	2106.6±2.1±2.7	2808±28		3279±30	
$\alpha_{J/\psi}(t)$	**3096.9**	3096.9	3753±41		4240±39	
$\alpha_{B^*}(t)$	**5324.9±1.8**	5324.9±1.8	5814±51		6217±46	
$\alpha_{B_s^*}(t)$	5411±58	5416.3±3.3	5901±53		6306±49	
$\alpha_{B_c^*}(t)$	6356±80		6853±72		7276±65	
$\alpha_\Upsilon(t)$	**9460.4±0.2**	9460.4±0.2	9906±91		10304±84	

TABLE VI. Comparison of the masses of the spin-0, spin-2 and spin-4 states given by ten pseudoscalar meson trajectories of the form (8) with data. (We take the error estimate on the η_b mass as 10% of the calculated splitting, in agreement with Fig. 2 of the second paper of Ref. [45].) All masses are in MeV.

	$J=0$		$J=2$		$J=4$	
	This work	Ref. [29]	This work	Ref. [29]	This work	Ref. [29]
$\alpha_\pi(t)$	**135**	135	**1677±8**	1677±8	2237±26	
$\alpha_K(t)$	**493.7**	493.7	**1773±8**	1773±8	2333±27	
α_{η_s}	698±14		1869±38	1854±20	2429±54	
$\alpha_D(t)$	**1864.1±1.0**	1864.1±1.0	2692±19		3228±22	
$\alpha_{D_s}(t)$	1971±19	1969.0±1.4	2786±26		3323±32	
$\alpha_{\eta_c}(t)$	**2979.8±2.1**	2979.8±2.1	3692±23		4217±25	
$\alpha_B(t)$	**5279.8±1.6**	5279.8±1.6	5830±89		6286±93	
$\alpha_{B_s}(t)$	**5369.6±2.4**	5369.6±2.4	5920±89		6376±93	
$\alpha_{B_c}(t)$	6283±79		6826±79		7287±80	
$\alpha_{\eta_b}(t)$	**9424±3.6**		9914±148		10353±150	