$\pi^- \, p \to D^- \, \Lambda_c^+$ within the Generalized Parton Picture

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The Outline

1. Introduction
2. Reaction Mechanism
3. Results
4. Summary and Outlook

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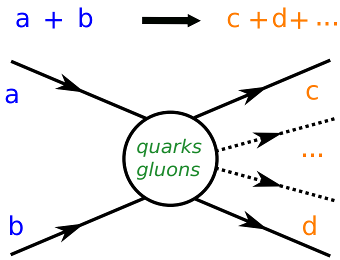

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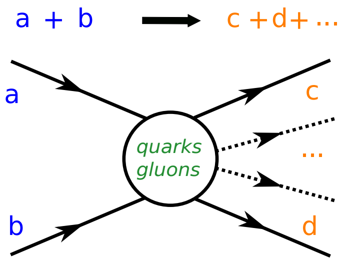

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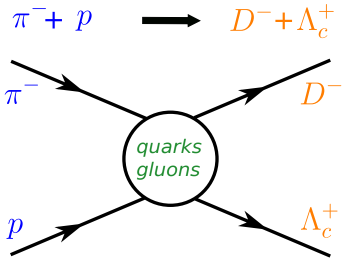

low counting rates in exclusive processes $\Rightarrow$ experiments are very challenging

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- further application/test of $p \to \Lambda_c^+$- transition generalized parton distributions (GPDs) introduced in
  Goritschnig A.T., Kroll P. and Schweiger W., Eur. Phys. J. A42 (2009)
  - originally: $\bar{p} \; p \to \bar{\Lambda}_c^- \; \Lambda_c^+$
  - also: $\gamma \; p \to \overline{D}^0 \; \Lambda_c^+$
    Goritschnig A.T., KS and Schweiger W., PoS (2014)

Why should we study $\pi^- \ p \to D^- \ \Lambda_c^+$?

- In general, production of charmed hadrons is interesting: Different models on the market which give different results.

$\Rightarrow$ What is the dominant production mechanism?

Double Handbag Mechanism

We use a *handbag* mechanism:

- expected to dominate in the intermediate energy region,
- minimal number of partons take part in the hard scattering,
- used to describe DIS, DVCS, wide-angle CS, TCS, $\bar{p}\,p$ annihilation into (heavy) baryons/mesons.

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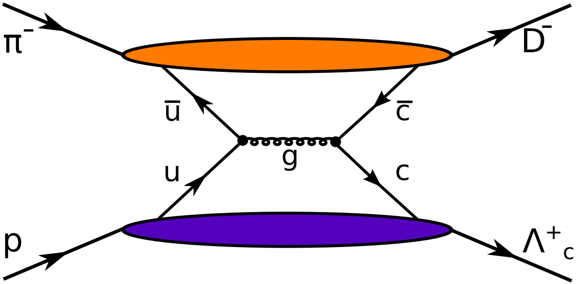
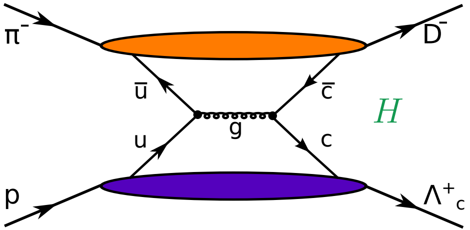


Process Amplitude

$$\mathscr{M} = FT\ \langle \Lambda_c^+ |\ \overline{\Psi}^c \Psi^u\ | p \rangle \times FT\ \langle D^- |\ \overline{\Psi}^u \Psi^c\ | \pi^- \rangle \times H$$



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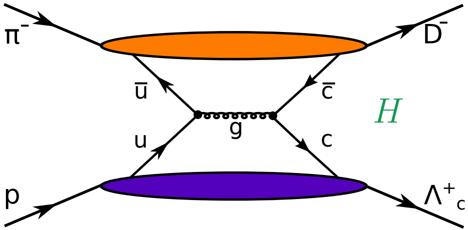

factorization in the sense that

- hard part contains highly virtual partons: $k_g^2 \geq 4m_c^2$
  H on tree level → 1 Feynman diagram
- hadronic matrix elements embody *soft scales*
  - restrictedparton virtualities: $|k|^2$ and $|k^2 \ - mc^2| \leq \Lambda^2$
  - restricted intrinsic parton transverse momenta: $\mathbf{k}_\perp^2/x \leq \Lambda^2$

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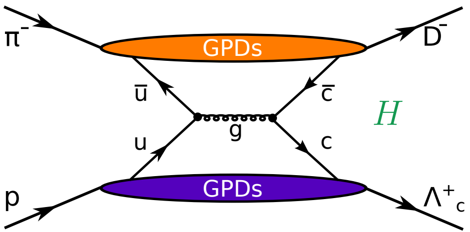

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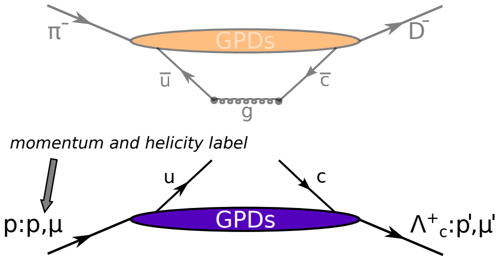

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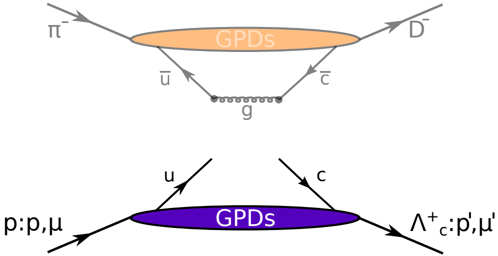

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project on different Dirac structures

- $\bar{\Psi}^c \; \gamma^+ \; \Psi^u$: 2 GPDs
- $\bar{\Psi}^c \; \gamma^+ \gamma_5 \; \Psi^u$: 2 GPDs
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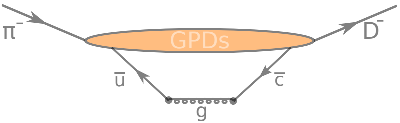

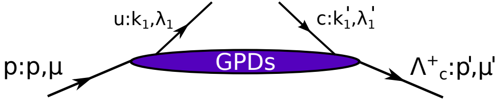

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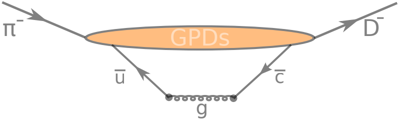

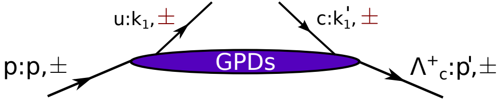

$$FT\ \langle \Lambda_c^+ : p', \pm |\ \underbrace{\bar{\Psi}^c\ \Psi^u}\ | p : p, \pm \rangle$$

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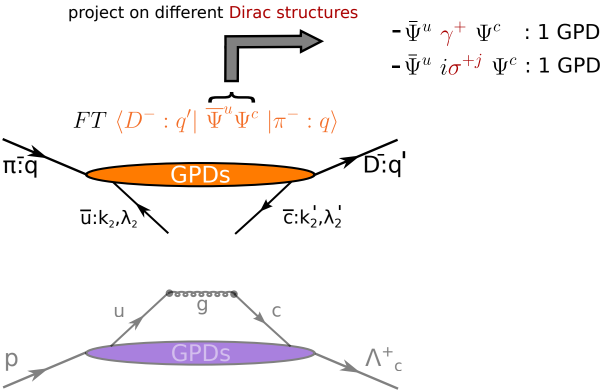
- (quark) GPDs: FT of a product of bilocal quark field operators sandwiched between non-diagonal hadronic matrix elements
- parton interpretation in light-cone (LC) quantization (LC-gauge)
- spin structure of the hadrons can be taken into account easily with GPDs

Generalized Parton Distributions II



- pseudoscalar meson to pseudoscalar meson transition simple: 2 GPDs

Overlap Representation of GPDs in terms of LCWFs

We employ the light-cone wave function (LCWF) representation of GPDs.
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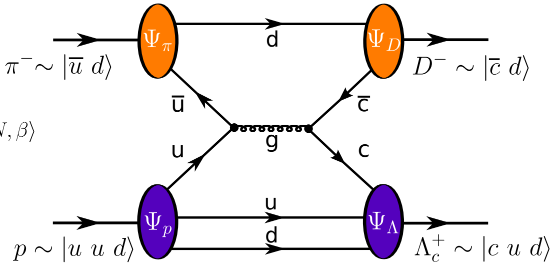
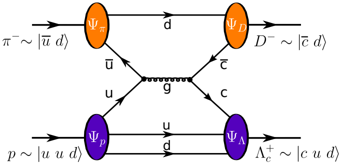


- properties of heavy hadrons are dominated by heavy valence quark: restriction on valence Fock states a good approximation
- LCWFs are the model input
- simple parton interpretation

Light Cone Wave Functions



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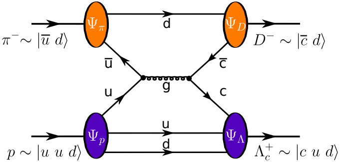

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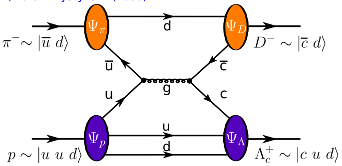

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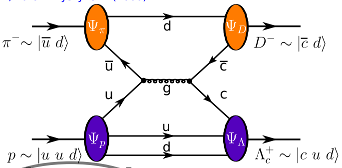

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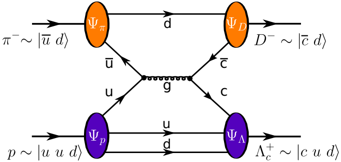

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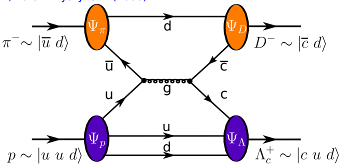

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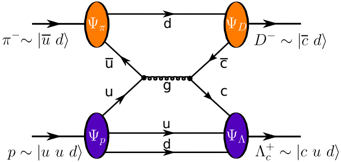

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both produce a peak at m_C/M_Λ

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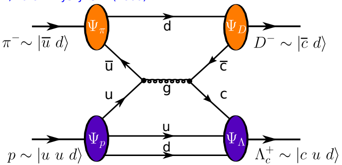

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every LCWF depend on 2 parameters:
- normalization constant N
- oscillator parameter a

proton and pion LCWF: good constraints at hand
Lambda and D LCWF: parameters fixed by physical conditions, e.g. valence Fock state prob., decay constant,...

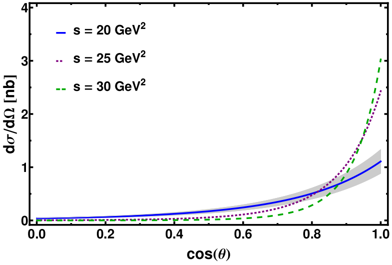
We have all pieces of our process amplitudes determined:

- hard partonic subprocess. . . Feynman diagram
- non-perturbative effects. . . contained in GPDs, which are modeled by an overlap of LCWFs

Let‘s have a look at our results.

Estimate of Differential Cross Section

KK mass exp.



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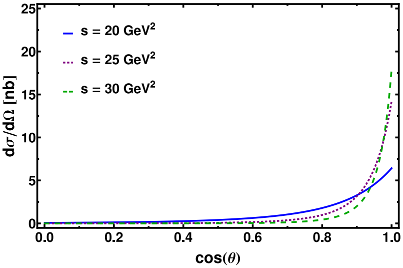
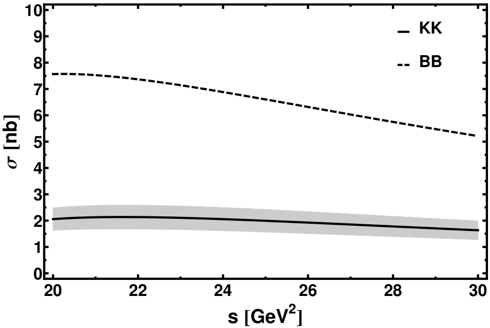


- diff. cross section (nb) vs. $\cos\theta$ for different values of Mandelstam s
- in the order of 1 nb
  - BB mass exp. produces a larger cross section
- shaded band: varied parameters of Λ/D LCWF

Estimate of Integrated Cross Section



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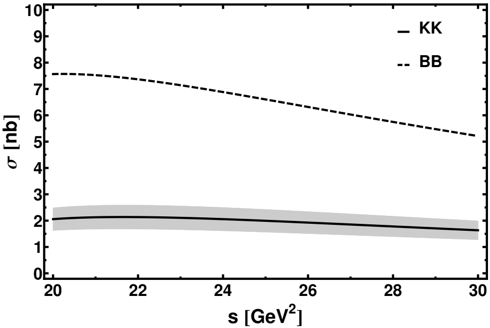

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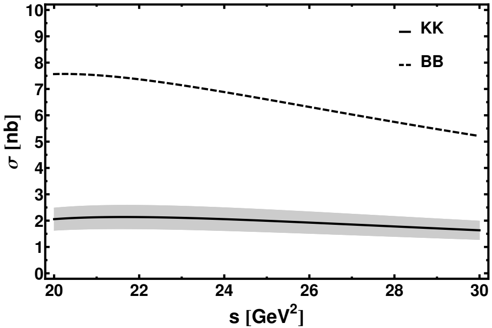
Estimate of Integrated Cross Section



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- *AGS-experiment: upper bound of* 15 *nb for integrated cross section*
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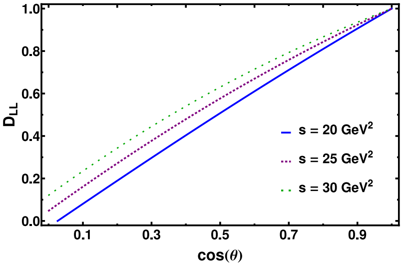
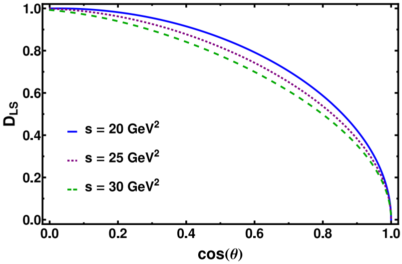
Spin Correlations





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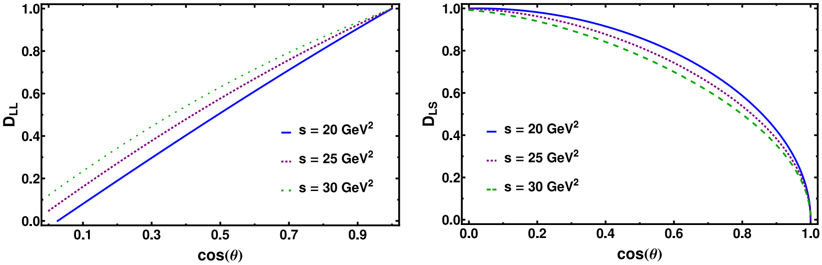

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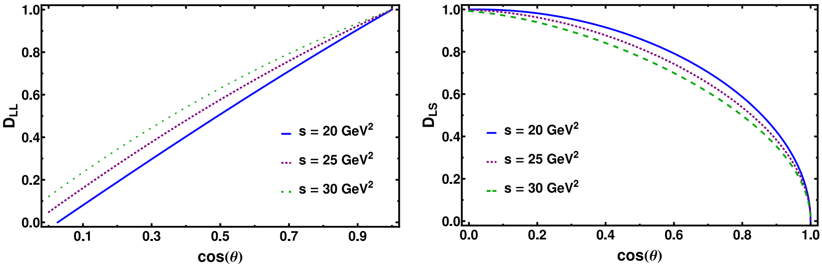

- 2 depolarisation observables for different Mandelstam s values vs. $\cos(\theta)$
- polarisation transfer from the proton to the Λ_c^+:
  - L ...longitudinal
  - S ...sideways
- mild energy dependence
- approximately independent of GPDs

$\Rightarrow$ *characteristic for handbag mechanism*

Exclusive Production of Charmed Hadrons

Within the collinear fac. approach, other reactions producing charmed hadrons have been investigated:

- integrated cross section in the order of 1 nb
  - $\bar{p}\, p \to \bar{\Lambda}_c^- \; \Lambda_c^+$
    Goritschnig A.T.,Kroll P. and Schweiger W.,Eur. Phys. J. A42 (2009)
  - $\bar{p}\, p \to D^0 \overline{D}^0$
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- integrated cross section in the order of < 1 nb
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Other approaches would be

- Regge models,
- hadronic exchange models.

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Different theoretical descriptions of $\bar{p}p \to \bar{\Lambda}_c^- \Lambda_c^+$ are controversial!

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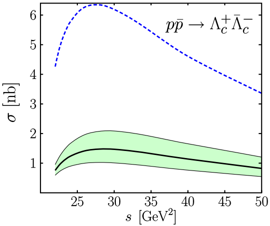

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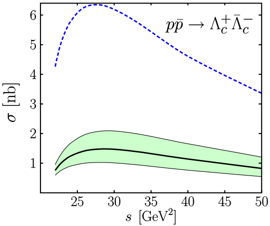

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hadronic models

hadron exchange

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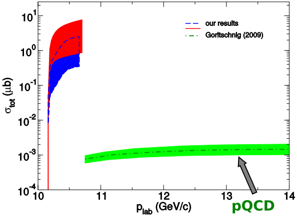

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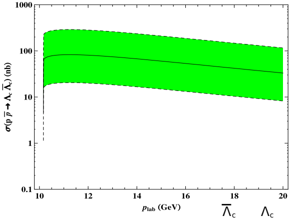

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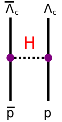

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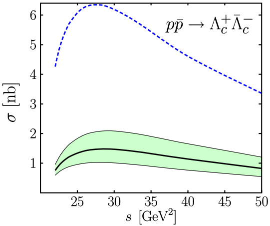

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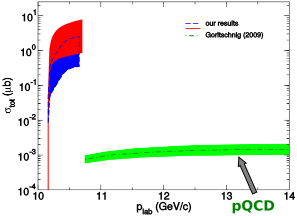

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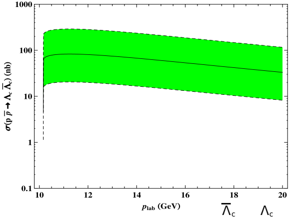

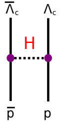

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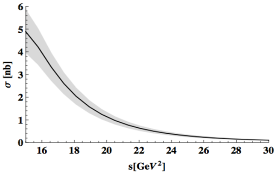

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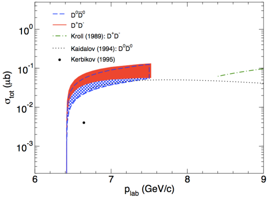

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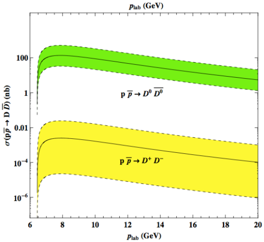

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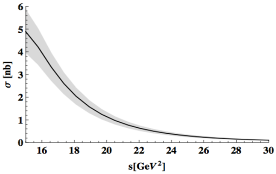

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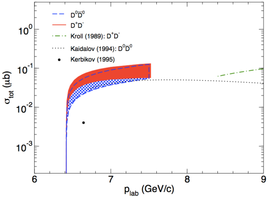

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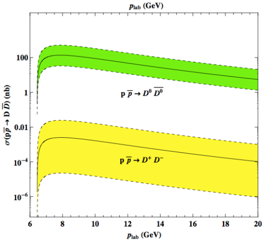

Also a difference of 2-3 orders of magnitude!

Can we understand these differences?

Our model:

- $SU(4)_f$ symmetry breaking on the level of the wave function
  e.g. $p \to \Lambda_c$ overlaps considerable diminished compared to $p \to \Lambda$
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Unreggeized model:
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vertex form factor
cutoff mass: m_M + 1 GeV

$$\sim \sum_{M=D,D^*} g^2_{N,\Lambda_c,M} \frac{F^2_{N,\Lambda_c,M}}{t - m^2_M}$$

SU(4)$_f$ symmetry

$$m_{M_s} \to m_{M_c} : \frac{m^2_{M_s}}{m^2_{M_c}} \approx \frac{1}{4}$$

$$\frac{\sigma\left(\bar{p}p \to \bar{\Lambda}\Lambda\right)}{\sigma\left(\bar{p}p \to \bar{\Lambda}_c\Lambda_c\right)} \approx 16$$

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Reggeized model:

Ahodjamirian A. et al, Eur. Phys. J. A48 (2012)

$$\sim \left(\frac{s}{s_0}\right)^{\alpha_{D^*}(t)-1}$$

- $SU(4)_f$ breaking in the scale parameter (and Regge residues)
- different Regge parameters lead to different results in charm/strange suppression

  for $\bar{p}p \to \bar{\Lambda}_c\Lambda$: difference of 2 order of magnitude as compared to pQCD
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Summary:

- Different models lead to different predictions.
- Differences in predictions up to 3 orders of magnitude.

Only the expriment can decide.
Interesting and excited times are ahead us.

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$$\pi^- \; p \to D^- \; \Lambda_c^+$$

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Thank you very much for your attention.