Study of charmed baryons in $\pi p \to D^* \Lambda_c$ reaction

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4. Summary

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Proposal P50 is submitted :

"Charmed Baryon Spectroscopy via the (π^-, D^{*-}) reaction"

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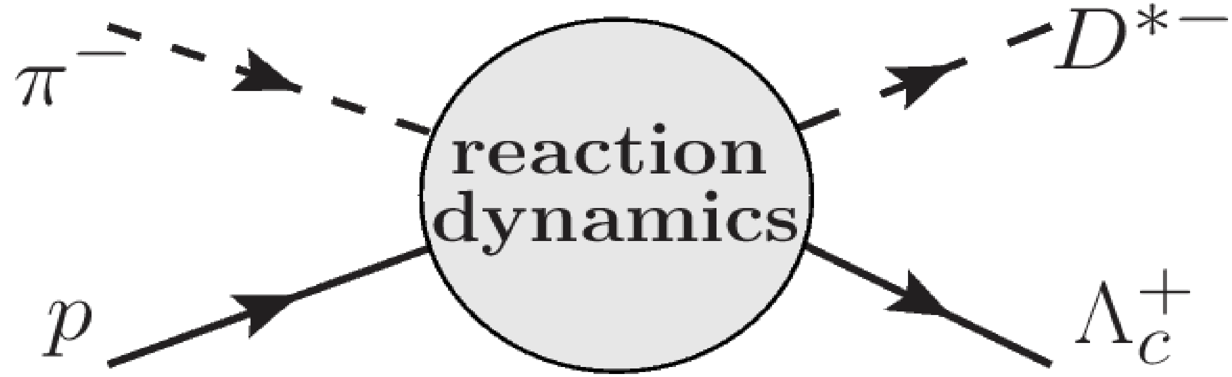
Executive Summary

We propose the spectroscopic study of charmed baryons via the (π, D^{*-}) reactions at the high-momentum (high-p) beam line of J-PARC to investigate the diquark degree of freedom in a hadron. The good diquark correlation is due to the color-spin interaction whose strength is proportional to the inverse of a quark mass. Therefore, there would be only one good diquark pair in a charmed baryon, which makes the study of excited charmed baryons unique and interesting.

We will supplement the high-p beam line with the dispersive ion optical elements so that a high-intensity pion beam with a resolution of $\Delta p/p$=0.1 % can be delivered. A new large acceptance spectrometer for the D^{*-} detection is designed to achieve a missing mass resolution of ∼5 MeV. Charmed baryons from the ground state to highly excited states of $E_x \sim 1$ GeV will be identified in a missing mass spectrum of the $p(\pi, D^{*-})$ reaction. In addition to the masses and widths of charmed baryons, the spectrometer enables us to measure some of the decay branching ratios of an excited baryon by detecting decay products.

Here, we propose new charmed baryon spectroscopy by means of the missing mass method to shed lights on the diquark.



Feynman model

The contribution of the particle of the ground state

Good at describing Low energy(threshold) behavior

Parameters : coupling constants,
cut off masses
in form factors

Regge model

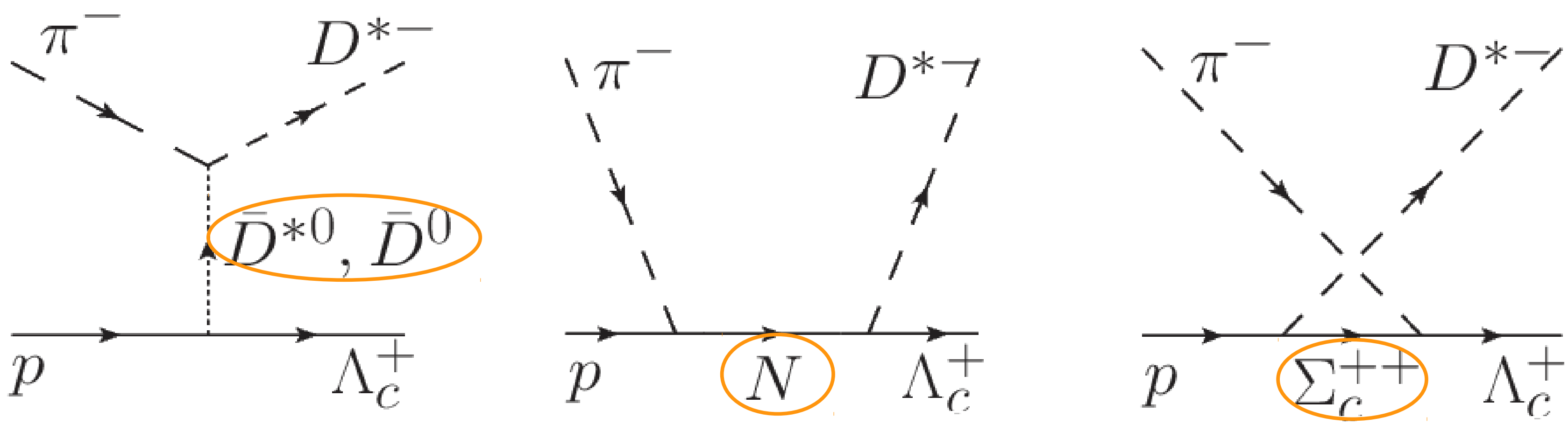
The contribution of the particles of both the ground and excited states which lie on the same trajectory

Good at describing
High energy behavior

Parameters : coupling constants,
Regge trajectories,
scale parameters

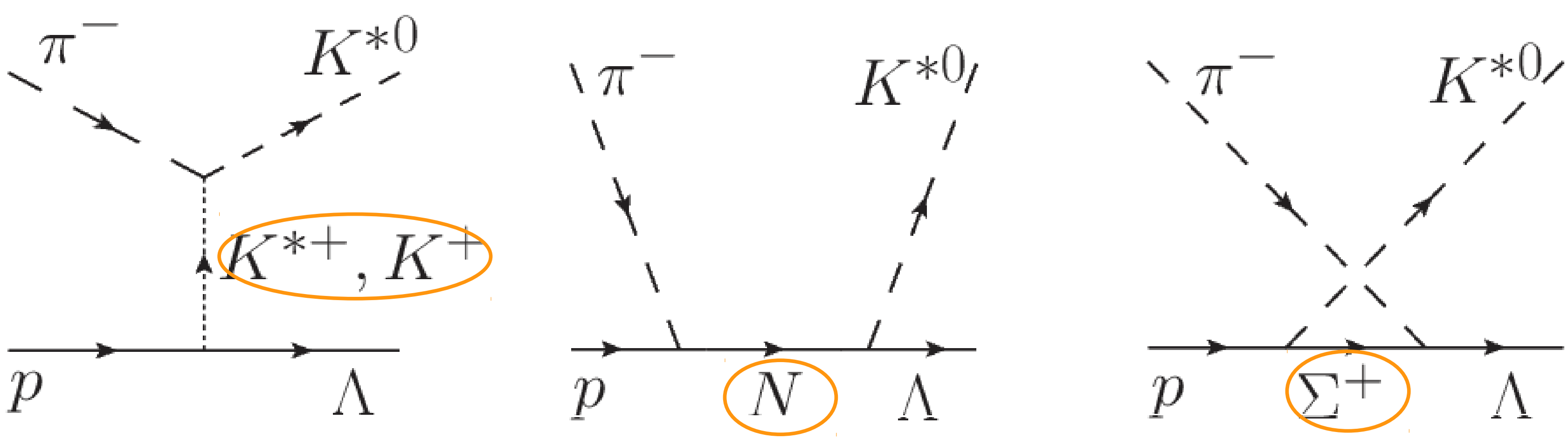
1.Feynman Model

$$\pi^- p \to D^{*-}(1870)\Lambda_c^+(2286)$$



c quark

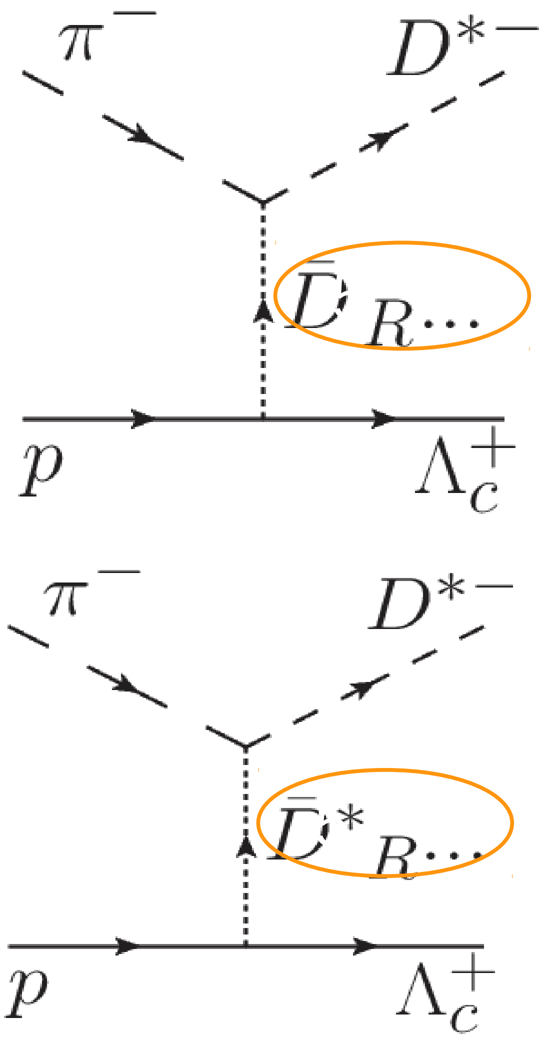
$$\pi^- p \to K^{*0}(892)\Lambda(1116)$$



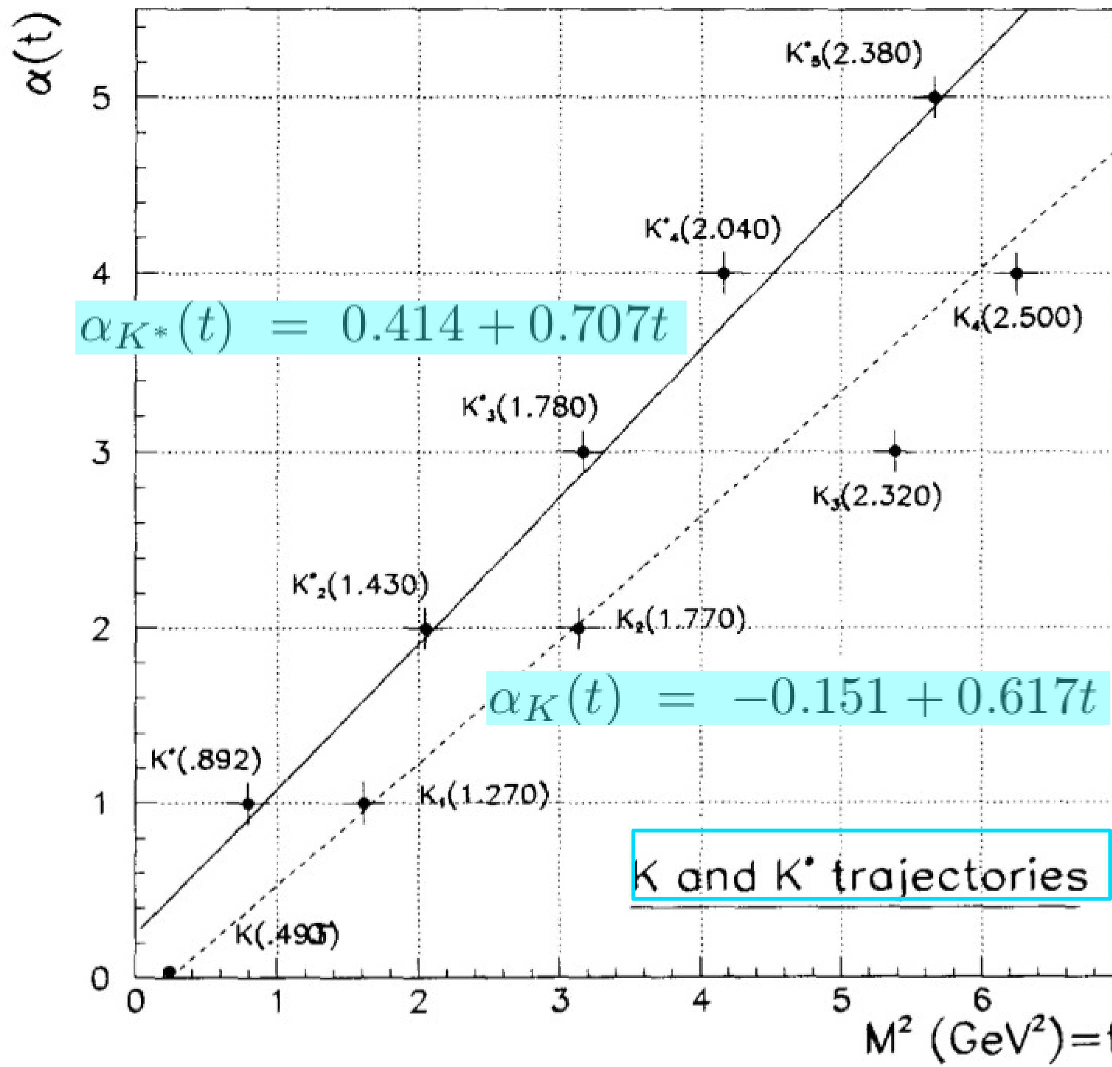
s quark

2.Regge Model

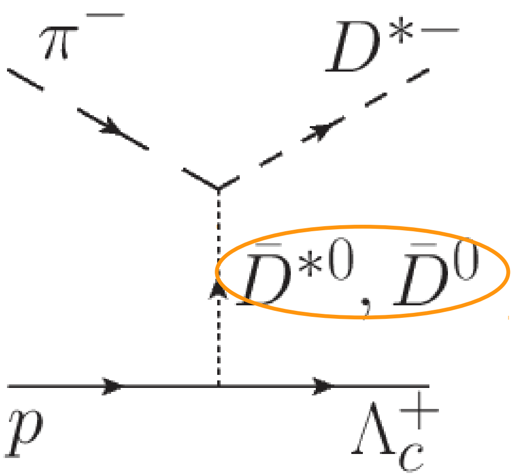
$$\pi^- p \to D^{*-}(1870)\Lambda_c^+(2286)$$



$$\alpha(t) = \alpha(0) + \alpha' t$$



Effective Lagrangians



t-channel

D -

$$\mathcal{L}_{\pi D D^*} = -g_{\pi D D^*} D^*_\mu \left(\bar{D}\partial^\mu \pi - \partial^\mu \bar{D}\pi\right)$$

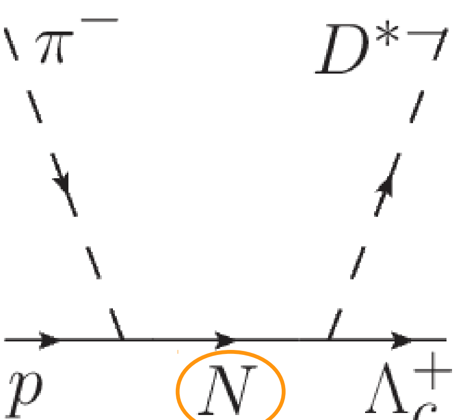
$$\mathcal{L}_{D N \Lambda_c} = -i g_{D N \Lambda_c} \bar{N}\gamma_5 \Lambda_c D + \text{h.c.}$$

D* -

$$\mathcal{L}_{\pi D^* D^*} = -g_{\pi D^* D^*} \varepsilon^{\mu\nu\alpha\beta} \partial_\mu D^*_\nu \pi \partial_\alpha \bar{D}^*_\beta$$
$$(\text{or } \; g_{\pi D^* D^*} \varepsilon^{\mu\nu\alpha\beta} \partial_\mu D^*_\nu \partial_\alpha \pi \bar{D}^*_\beta)$$

$$\mathcal{L}_{D^* N \Lambda_c} = -g_{D^* N \Lambda_c} \bar{N}\left[\gamma_\mu \Lambda_c - \frac{\kappa_{D^* N \Lambda_c}}{2M_N}\sigma_{\mu\nu}\Lambda_c \partial^\nu\right] D^{*\mu} + \text{h.c.}$$

$$g_{D^* D \pi} \equiv g_{D^{*+} D^0 \pi^+} = -\sqrt{2} g_{D^{*+} D^+ \pi^0} = \sqrt{2} g_{D^{*0} D^0 \pi^0}$$
$$= -g_{D^{*0} D^+ \pi^-} \; .$$

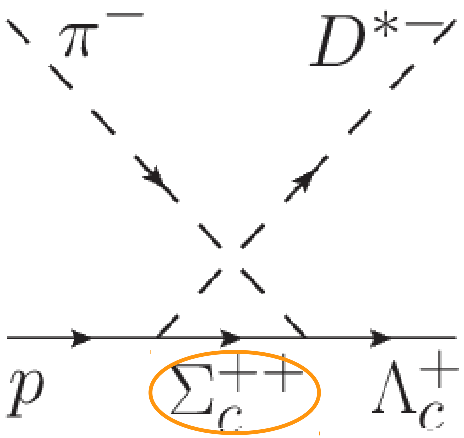


s-channel

N -

$$\mathcal{L}_{\pi N N} = -i g_{\pi N N} \bar{N}\gamma_5 \boldsymbol{\tau} \cdot \boldsymbol{\pi} N$$

Effective Lagrangians



u-channel

Σc -

$$\mathcal{L}_{\pi\Sigma_c\Lambda_c} = -ig_{\pi\Sigma_c\Lambda_c}\bar{\Lambda}_c\gamma_5\boldsymbol{\tau}\cdot\boldsymbol{\pi}\Sigma_c + \text{h.c.}$$

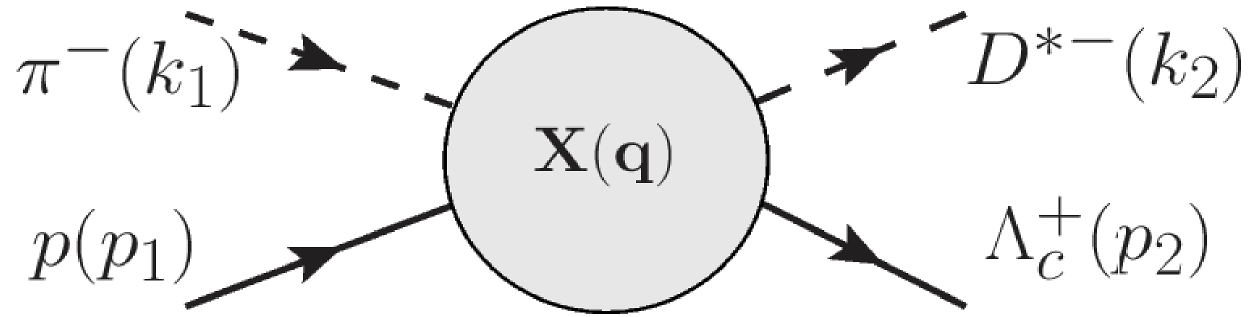
$$\mathcal{L}_{D^*N\Sigma_c} = -g_{D^*N\Sigma_c}\bar{N}\left[\gamma_\mu\Sigma_c - \frac{\kappa_{D^*N\Sigma_c}}{2M_N}\sigma_{\mu\nu}\Sigma_c\partial^\nu\right]D^{*\mu} + \text{h.c.}$$

Coupling Constants

Strong coupling (charmed)	LCSR estimate	Strong coupling (strange)	LCSR estimate	Ratio of couplings $\left(\frac{\text{charmed}}{\text{strange}}\right)$	LCSR estimate
$g_{\Lambda_c N D}$	$10.7^{+5.3}_{-4.3}$	$g_{\Lambda N K}$	$7.3^{+2.6}_{-2.8}$	$\frac{g_{\Lambda_c N D}}{g_{\Lambda N K}}$	$1.47^{+0.58}_{-0.44}$
$g^V_{\Lambda_c N D^*}$	$-5.8^{+2.1}_{-2.5}$	$g^V_{\Lambda N K^*}$	$-6.1^{+2.1}_{-2.0}$	$\frac{g^V_{\Lambda_c N D^*}}{g^V_{\Lambda N K^*}}$	$0.95^{+0.35}_{-0.28}$
$g^T_{\Lambda_c N D^*}$	$3.6^{+2.9}_{-1.8}$	$g^T_{\Lambda N K^*}$	$12.8^{+5.8}_{-5.2}$		
$\frac{g^T_{\Lambda_c N D^*}}{g^V_{\Lambda_c N D^*}}$	$-0.63^{+0.16}_{-0.28}$	$\frac{g^T_{\Lambda N K^*}}{g^V_{\Lambda N K^*}}$	$-2.1^{+0.5}_{-0.6}$		
$g_{\Sigma_c N D}$	$1.3^{+1.0}_{-0.9}$	$g_{\Sigma N K}$	$1.1^{+0.6}_{-0.5}$		
$g^V_{\Sigma_c N D^*}$	$1.0^{+1.3}_{-0.6}$	$g^V_{\Sigma N K^*}$	$1.7^{+0.9}_{-0.8}$	$\frac{g^V_{\Sigma_c N D^*}}{g^V_{\Sigma N K^*}}$	$0.56^{+0.42}_{-0.20}$
$g^T_{\Sigma_c N D^*}$	$2.1^{+1.9}_{-1.0}$	$g^T_{\Sigma N K^*}$	$3.6^{+1.5}_{-1.2}$		
$\frac{g^T_{\Sigma_c N D^*}}{g^V_{\Sigma_c N D^*}}$	2.1 ± 0.5	$\frac{g^T_{\Sigma N K^*}}{g^V_{\Sigma N K^*}}$	$2.1^{+0.6}_{-0.3}$		

Khodjamirian et al, EurPhysJ.A.48.31(2012)

1. Feynman Amplitude



$$\mathcal{M} = \bar{u}_{\Lambda_c}\,\mathcal{M}_X\,u_N$$

$$\begin{aligned}
\mathcal{M}_D &= \frac{1}{t-M_D^2} 2 g_{\pi D D^*} g_{DN\Lambda_c} \gamma_5 (\varepsilon_\mu^* k_1^\mu) \\
\mathcal{M}_{D^*} &= \frac{1}{t-M_{D^*}^2} g_{\pi D^* D^*} g_{D^* N \Lambda_c} \epsilon^{\mu\nu\alpha\beta} \\
&\times \left[\gamma_\sigma - \frac{i\kappa_{D^*N\Lambda_c}}{2M_N}\sigma_{\sigma\lambda} q^\lambda\right] \left[g^{\sigma\mu} - \frac{q^\sigma q^\mu}{M_{D^*}^2}\right] \varepsilon^{*\nu} k_1^\alpha k_2^\beta \\
\mathcal{M}_N &= \frac{1}{s-M_N^2} i g_{\pi NN} g_{D^*N\Lambda_c} \varepsilon_\mu^* \left[\gamma^\mu - \frac{i\kappa_{D^*N\Lambda_c}}{2M_N}\sigma^{\mu\nu} k_{2\nu}\right] (\not{q} + M_N)\gamma_5 \\
\mathcal{M}_{\Sigma_c} &= \frac{1}{s-M_{\Sigma_c}^2} i g_{\pi\Sigma_c\Lambda_c} g_{D^*N\Sigma_c} \gamma_5 (\not{q} + M_{\Sigma_c}) \varepsilon_\mu^* \left[\gamma^\mu - \frac{i\kappa_{D^*N\Lambda_c}}{2M_N}\sigma^{\mu\nu} k_{2\nu}\right]
\end{aligned}$$

2. Regge Propagator

PS meson(D) : $$\frac{1}{t-M_D^2} \to P_{Regge}^{D} = \left(-\frac{s}{s_{\pi p;D^*\Lambda_c}}\right)^{\alpha_D(t)} \Gamma(-\alpha_D(t))\frac{1}{s_0}$$

V meson(D*) : $$\frac{1}{t-M_{D^*}^2} \to P_{Regge}^{D^*} = \left(-\frac{s}{s_{\pi p;D^*\Lambda_c}}\right)^{\alpha_{D^*}(t)-1} \Gamma(1-\alpha_{D^*}(t))\frac{1}{s_0}$$

Regge trajectories : $\alpha(t) = \alpha(0) + \alpha' t$
Energy scale parameter : $s_0^{\pi N \to D^* \Lambda_c}$
=> determined by using Quark-Gluon-String Model(QGSM)

Universal scale parameter : s_0
=> determined phenomenologically between 1 and 3 Gev

3. Regge Parameters

The intercept and the slope of the trajectory for the nondiagonal transition are related to the corresponding parameters for the diagonal transitions :

$$\alpha(t) = \alpha(0) + \alpha' t \ ?$$

$$2\alpha_{ij} = \alpha_{\bar{i}i}(0) + \alpha_{\bar{j}j}(0) \qquad 2/\alpha'_{ij} = 1/\alpha'_{\bar{i}i} + 1/\alpha'_{\bar{j}j}$$

$$\pi^- p \to D^{*-}\Lambda_c^+$$

$$\begin{aligned}
\alpha_{\bar{u}u}(t) = \alpha_\pi(t) &= -0.0118 + 0.647t \\
\alpha_{\bar{c}c}(t) = \alpha_{\eta_c}(t) &= -3.2103 + 0.332t \\
\alpha_{uc}(t) = \alpha_D(t) &= -1.6115 + 0.439t
\end{aligned}$$

$$\begin{aligned}
\alpha_{\bar{u}u}(t) = \alpha_\rho(t) &= 0.55 + 0.742t \\
\alpha_{\bar{c}c}(t) = \alpha_{J/\Phi}(t) &= -2.60 + 0.340t \\
\alpha_{uc}(t) = \alpha_{D^*}(t) &= -1.02 + 0.467t
\end{aligned}$$

$$\pi^- p \to K^{*0}\Lambda$$

$$\begin{aligned}
\alpha_{\bar{u}u}(t) = \alpha_\pi(t) &= -0.0118 + 0.647t \\
\alpha_{\bar{s}s}(t) = \alpha_{\eta_s}(t) &= -0.291 + 0.606t \\
\alpha_{us}(t) = \alpha_K(t) &= -0.151 + 0.617t
\end{aligned}$$

$$\begin{aligned}
\alpha_{\bar{u}u}(t) = \alpha_\rho(t) &= 0.55 + 0.742t \\
\alpha_{\bar{s}s}(t) = \alpha_\phi(t) &= 0.27 + 0.675t \\
\alpha_{us}(t) = \alpha_{K^*}(t) &= 0.414 + 0.707t
\end{aligned}$$

Brisudova et al, PRD 61.054013(2000)

3. Regge Parameters

The energy scale parameter is related to the corresponding parameters for the diagonal transitions :

$$\pi^- p \to D^{*-}\Lambda_c^+$$

$$s_0^{\pi N \to D^* \Lambda_c} = \left(s_0^{\pi N}\right)^{\frac{\alpha_\rho(0)-1}{2(\alpha_{D^*}(0)-1)}} \left(s_0^{D^*\Lambda_c}\right)^{\frac{\alpha_{J/\Psi}(0)-1}{2(\alpha_{D^*}(0)-1)}}$$

$$\alpha(t) = \alpha(0) + \alpha' t$$

$$m_u \approx 0.5, m_s \approx 0.6\ [\mathrm{GeV}]$$

$$s_0^{\pi N} \approx 1.5, s_0^{D\Lambda_c} \approx 5.46\ [\mathrm{GeV}^2]$$

$$s_0(D) = 4.25, s_0(D^*) = 4.75$$

$$\pi^- p \to K^{*0}\Lambda$$

$$s_0^{\pi N \to K^* \Lambda} = \left(s_0^{\pi N}\right)^{\frac{\alpha_\rho(0)-1}{2(\alpha_{K^*}(0)-1)}} \left(s_0^{K^*\Lambda}\right)^{\frac{\alpha_\phi(0)-1}{2(\alpha_{K^*}(0)-1)}}$$

$$\alpha(t) = \alpha(0) + \alpha' t$$

$$m_u \approx 0.5, m_c \approx 1.6\ [\mathrm{GeV}]$$

$$s_0^{\pi N} \approx 1.5, s_0^{K\Lambda} \approx 1.76\ [\mathrm{GeV}^2]$$

$$s_0(K) = 1.64, s_0(K^*) = 1.66$$

Brisudova et al, PRD 61.054013(2000)

Total Cross Section $\pi^- p \to K^{*0}\Lambda$

1. Feynman model

$$\left(\frac{d\sigma}{d\Omega}\right)_{\rm CM} = \frac{1}{64\pi^2 s}\frac{\mathbf{p}_{out}}{\mathbf{k}_{in}}\frac{1}{2}\sum_{s,s'}|\mathcal{M}|^2$$

$$\mathcal{M} = \mathcal{M}_K \cdot F_K + \mathcal{M}_{K^*} \cdot F_{K^*} + \mathcal{M}_N \cdot F_N + \mathcal{M}_\Sigma \cdot F_\Sigma$$

$$F = \frac{\Lambda^4}{\Lambda^4 + (p^2 - M_{ex}^2)^2}$$

How to determine the cutoff masses, Λ ?

From the reaction of $\gamma p \to K^*\Lambda$, we found that
the values of Λ=0.65~0.75 GeV describe the data pretty well.
So the same values are used for our research.

Total Cross Section $\pi^- p \to K^{*0}\Lambda$

2. Regge model

$$\left(\frac{d\sigma}{d\Omega}\right)^{Regge}_{\mathrm{CM}} = \frac{1}{64\pi^2 s}\frac{\mathbf{p}_{out}}{\mathbf{k}_{in}}\frac{1}{2}\sum_{s,s'}|\mathcal{M}\cdot(t-M_{ex}^2)P^{ex}_{Regge}|^2$$

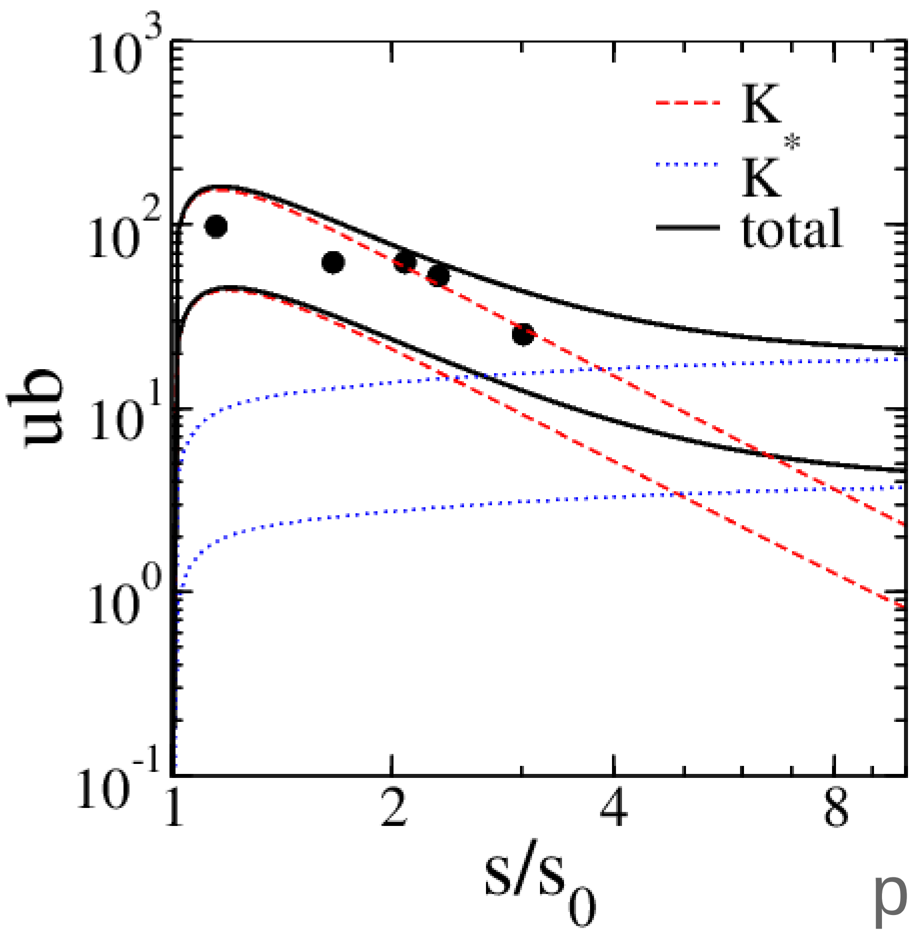
$$\left(\frac{d\sigma}{d\Omega}\right)^{Regge}_{K} = \frac{1}{64\pi^2 s}\frac{\mathbf{p}_{out}}{\mathbf{k}_{in}}\frac{1}{2}\sum_{s,s'}|\mathcal{M}_K|^2\left(\frac{s}{s_{\pi p;K^*\Lambda}}\right)^{2\alpha_K(t)}\Gamma(-\alpha_K(t))^2\frac{1}{s_0^2}$$

$$\left(\frac{d\sigma}{d\Omega}\right)^{Regge}_{K^*} = \frac{1}{64\pi^2 s}\frac{\mathbf{p}_{out}}{\mathbf{k}_{in}}\frac{1}{2}\sum_{s,s'}|\mathcal{M}_{K^*}|^2\left(\frac{s}{s_{\pi p;K^*\Lambda}}\right)^{2(\alpha_{K^*}(t)-1)}\Gamma(1-\alpha_{K^*}(t))^2\frac{1}{s_0^2}$$

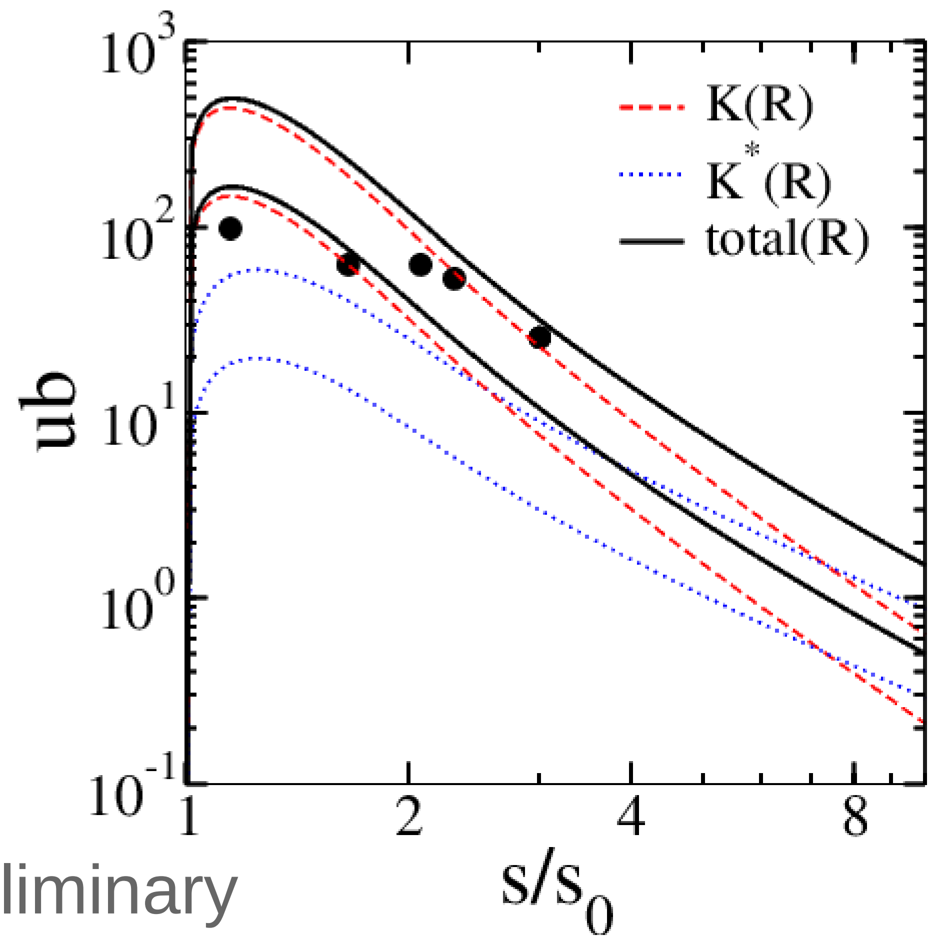
Except for the universal scale parameters, s_0, all the parameters are determined.

Total Cross Section $\pi^- p \rightarrow K^{*0}\Lambda$

1. Feynman model



2. Regge model



preliminary

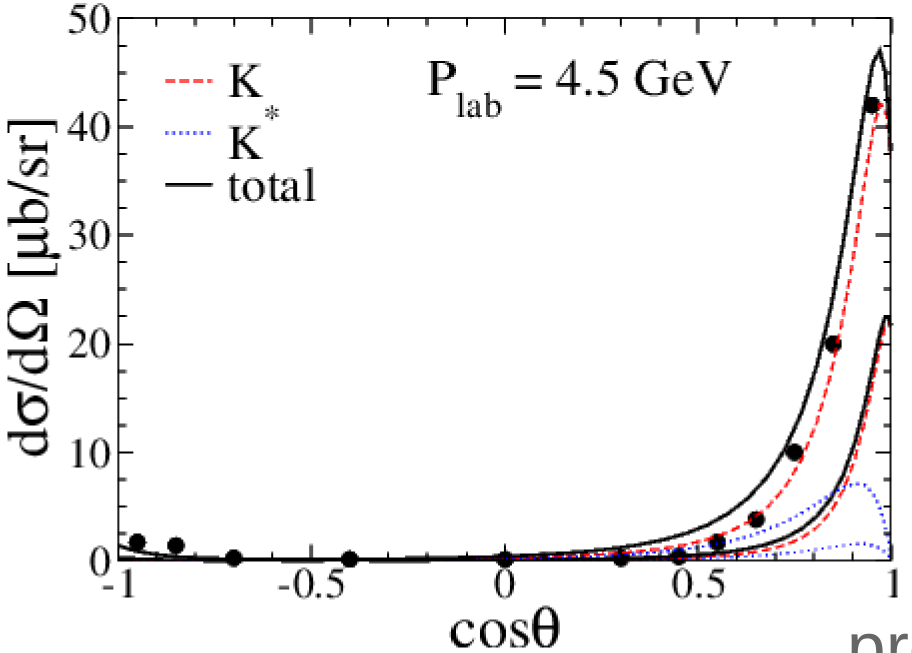
cutoff mass, Λ : 0.65 ~ 0.75 [GeV]

universal scale parameter, s0 : √3 ~ 3 [GeV^2]

Exp. Data : Dahl et al, PR 163.1377(1967) Crennell et al, PRD 6.1220(1972)

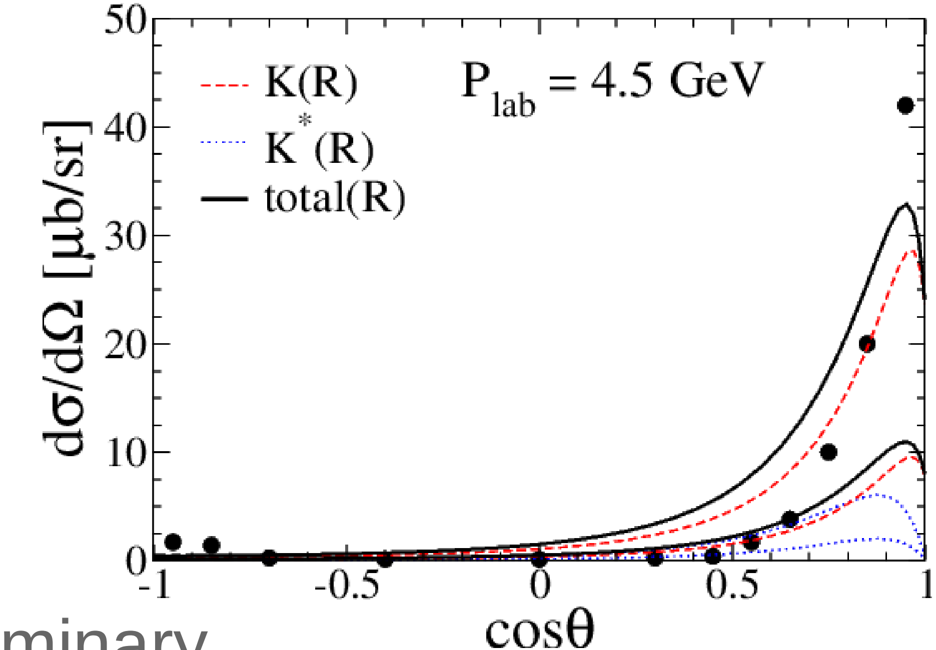
Differential Cross Section $\pi^- p \to K^{*0}\Lambda$

1. Feynman model



cutoff mass, Λ :
0.65 ~ 0.75 [GeV]

2. Regge model



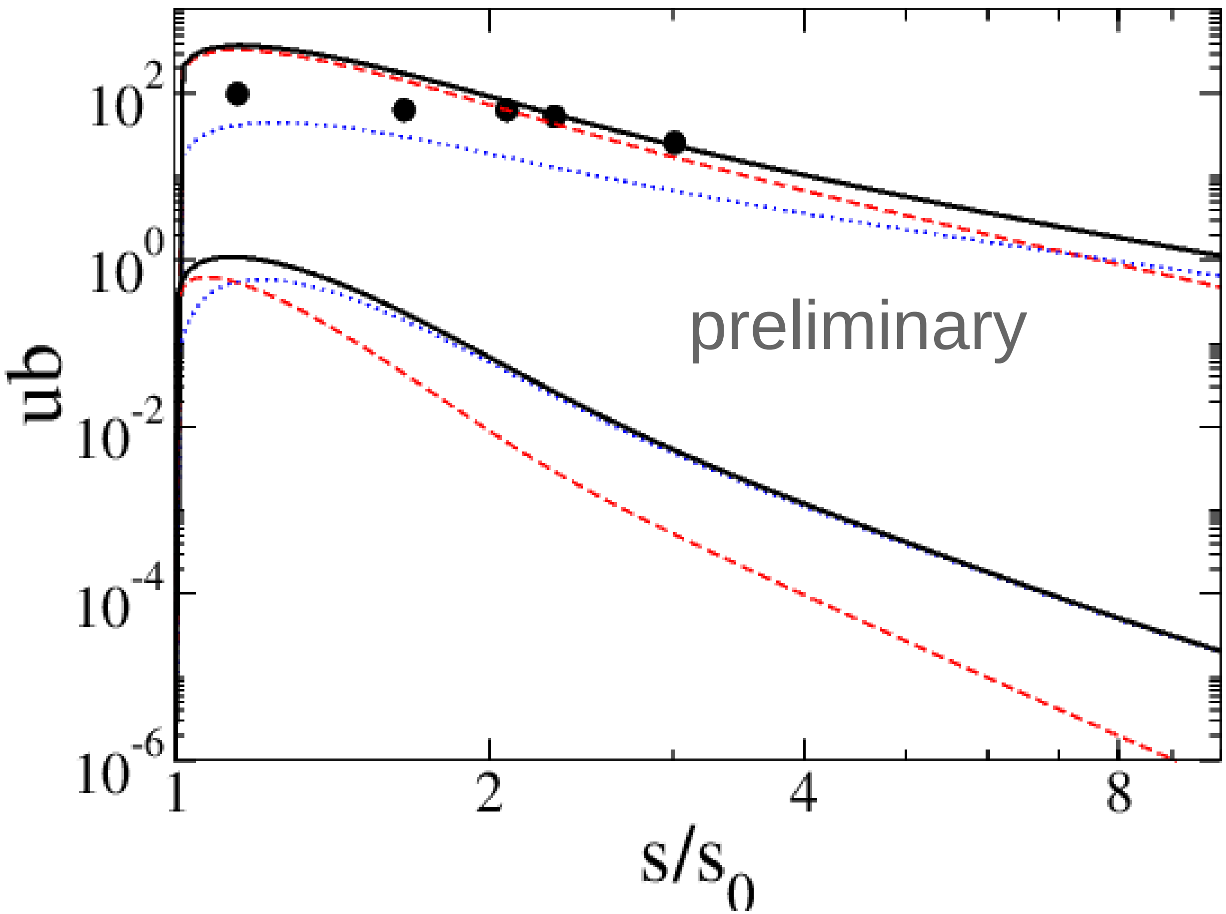
preliminary

universal scale parameter, s0 :
√3 ~ 3 [GeV^2]

K exchange is dominant. The contributions of
u- and s- channel exchanges are almost negligible.

Exp. Data : Crennell et al, PRD 6.1220(1972)

Total Cross Section (Regge Model)



$\pi^- p \to K^{*0}\Lambda$

$\pi^- p \to D^{*-}\Lambda_c^+$

Exp. Data : Dahl et al, PR 163.1377(1967) Crennell et al, PRD 6.1220(1972)

◇ We investigated pion induced production off the proton target,

($\pi p \rightarrow K^*\Lambda$, $\pi p \rightarrow D^*\Lambda_c$), within the Feynman and Regge model.

◇ In Feynman model, we take into account the contributions

of K(D), K*(D*), N, and $\Sigma(\Sigma_c)$ particles.

In Regge approach, the K(D) and K*(D*) trajectories are considered.

The parameters are fixed by using the Quark-Gluon-String Model(QGSM).

◇ It turned out that the total cross section of charm production ($\pi p \rightarrow D^*\Lambda_c$)

is 100~10000 times smaller than that of strange one($\pi p \rightarrow K^*\Lambda$).

◇ Future work :

We should normalize the amplitude for the case of K(D) exchange.

Feynman model for the charm reaction, $\pi p \rightarrow D^*\Lambda_c$ would be considered soon.