# K\* and D\* Decays in pi-N Scattering Strangeness production in pi-N and K-N scattering

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Ref. PRC 91, 065208 (2015), PRC 89, 025206 (2014), PRC 85, 042201 (2012) PRC 95, 055206 (2017)

### **HYPERON SPECTRUM** significance on Ξ resonances has been added since our 1988

### Missing hyperons and quantum numbers For a detailed earlier review, see Meadows [1]. Table 1. The status of the status of the status of the European Company of the European Company of the European

entirely from bubble chamber experiments, where the numbers of the numbers of the numbers of the numbers of th<br>And the numbers of t



- spin-parity known  $\blacksquare$  spin-parity know!

Conference on Baryon Resonances (Toronto, 1980),

20 N<sup>\*</sup> and 20 ∆<sup>\*</sup>

## HYPERON SPECTRUM

### Model-dependence of hyperon spectrum

### Ground state baryons For a detailed earlier review, see Meadows [1]. are not enough. We need more data!

entirely from bubble chamber experiments, where the numbers

of events are small, and only in the 1980's did electronic exper-

iments make any significant contributions. However, nothing of

significance on Ξ resonances has been added since our 1988

 $T$ 

status Ξπ ΛK ΣK Ξ(1530)π Other channels

mation is desirable and/or quantum numbers, branching fractions,

 $\mathbb{R}^n \times \mathbb{R}^n \times \mathbb{R}^n$  are interesting in

Table 1. Low-lying  $\Xi$  and  $\Omega$  baryon spectrum of spin 1/2 and 3/2 predicted by the non-relativistic quark model of Chao *et al.* (CIK), relativized quark model of Capstick and Isgur (CI), Glozman-Riska model (GR), large *Nc* analysis, algebraic model (BIL), and QCD sum rules (SR). The recent quark model prediction (QM) and the Skyrme model results (SK) are given as well. The mass is given in the unit of MeV.





↑ The 3<sup>rd</sup> lowest state  $\frac{1}{2}$  Existence ranges from very likely to certain, but further confirmation, but further confirmation, but further confirmation,  $\frac{1}{2}$ 

etc. are not well determined.

∗ Evidence of existence is only fair.

## $KN \rightarrow K\Xi$

- **Difficulties** 
	- Mostly, the decay distributions are used
	- Ground state: no strong decay
	- Remove model-dependence
- We need a model-independent method (based on symmetries only)
	- use the anti-kaon beam: larger cross sections
	- define  $\hat{\mathbf{n}}_1 \equiv (\mathbf{q} \times \mathbf{q}') \times \mathbf{q}/|(\mathbf{q} \times \mathbf{q}') \times \mathbf{q}|$  $\tilde{\mathbf{h}}_2 \equiv (\mathbf{q} \times \mathbf{q}')/|\mathbf{q} \times \mathbf{q}'|$   $\qquad \qquad \bar{K}(q)N(p) \to K(q') \Xi(p')$
	- choose  $\hat{\mathbf{q}} = \hat{\mathbf{z}}, \quad \hat{\mathbf{n}}_1 = \hat{\mathbf{x}}, \quad \hat{\mathbf{n}}_2 = \hat{\mathbf{y}}$

 $\hat{\mathbf{q}}$  and  $\hat{\mathbf{n}}_1$  form the reaction plane

### $\bar{K}N \to K\Xi$

### The general spin-structure of the reaction amplitude

$$
\begin{aligned} \hat{M}^+ &= M_0 + M_2 \boldsymbol{\sigma} \cdot \hat{\mathbf{n}}_2, \\ \hat{M}^- &= M_1 \boldsymbol{\sigma} \cdot \hat{\mathbf{n}}_1 + M_3 \boldsymbol{\sigma} \cdot \hat{\mathbf{n}}_3, \end{aligned}
$$

for positive parity  $\Xi$ for negative parity  $\Xi$ 

$$
\Rightarrow \hat{M} = \sum_{m=0}^{3} M_m \sigma_m
$$

where  $M_1 = M_3 = 0$  for positive parity  $\Xi$ and  $M_0 = M_2 = 0$  for negative parity  $\Xi$ 

### **o** The cross section

$$
\frac{d\sigma}{d\Omega} = \frac{1}{2} \operatorname{Tr} \left( \hat{M} \hat{M}^{\dagger} \right) = \sum_{m=0}^{3} |M_m|^2
$$

$$
\bar{K}N\to K\Xi
$$

(Diagonal) spin-transfer coefficient  $\circ$ 

$$
\frac{d\sigma}{d\Omega}K_{ii} = \frac{1}{2}\operatorname{Tr}\left(\hat{M}\sigma_i\hat{M}^\dagger\sigma_i\right) = |M_0|^2 + |M_i|^2 - \sum_{k\neq i}|M_k|^2
$$

$$
K_{ii} = \frac{d\sigma_i(++) - d\sigma_i(+-)}{d\sigma_i(++) + d\sigma_i(+-)}
$$

- Therefore, when *i=y*,  $K_{ii} = \pi_{\Xi} (= \pm 1)$
- Double polarization observable
	- The Ξ is self-analyzing, so we need polarized nucleon target only
	- should be possible to measure at J-PARC
- **o** Generalization to  $E^*$  resonances and to  $E$  photoproduction is also possible  $\pi_{\Xi} =$  $K_{yy}$

⌃ Nakayama, YO, Haberzettl, PRC **85** (2012) 042201(R)

### $KN \rightarrow K\Xi$

Target Nucleon asymmetry  $\blacksquare$ 

> $d\sigma$  $\frac{dS}{d\Omega}T_i \equiv$ 1 2  $\mathrm{Tr}\left(M\sigma_{i}M^{\dagger}\right)=2\mathrm{Re}[M_{0}M_{i}^{*}]+2\mathrm{Im}[M_{j}M_{k}^{*}]$

Recoil Cascade asymmetry  $\blacksquare$ 

> $d\sigma$  $\frac{dS}{d\Omega}P_i \equiv$ 1 2  $\mathrm{Tr}\left( MM^\dagger \sigma_i \right) = 2\mathrm{Re}[M_0 M_i^*]-2\mathrm{Im}[M_j M_k^*]$

### Positive parity Cascade Negative parity Cascade

 $d\sigma$  $\frac{dQ}{dQ}(T_y + P_y) = 4\text{Re}[M_0 M_2^*]$  $d\sigma$  $\frac{dQ}{d\Omega}(T_y - P_y) = 0$ 

$$
\frac{d\sigma}{d\Omega}(T_y + P_y) = 0
$$
  

$$
\frac{d\sigma}{d\Omega}(T_y - P_y) = 4\text{Im}[M_3M_1^*]
$$

More details for the kinematics of spin-1/2 and  $3/2 \text{ E}$  baryon productions  $\blacksquare$ can be found in Jackson, YO, Haberzettl, Nakayama, PRC 89 (2014) 025206

## $\bar{K} \overline{X}^{NP} = K \Xi^P + V \overline{X}^B$ 667 $\overline{C}$ Alcul $M$ uon $M_c$ *r |Fr*i*Sr*h*Fr|* ! *M<sup>s</sup>*

*T <sup>P</sup>*

 $\sim$  X



#### TOOLS *g*!#*Kc* = −*g*<sup>8</sup> *,* (A5d) **13** *L*<sup>3</sup>*/*2(±) !"*Kc* = *L*<sup>3</sup>*/*2(±) · **ι** respective excited states with spin up to 7*/*2. In the following  $\Omega$ use the isodoublet fields for the isodoublet fields for the isodoublet fields for the isodoublet fields for the isodoublet fields of the isodoublet fields for the isodoublet fields for the isodoublet fields for the is not only the spin-1*/*2 ground state " and # but also their respective excited states with spin up to 7*/*2. In the following

*L*<sup>3</sup>*/*2(±) #*NK* =

> *f* ' *p*2

*L*<sup>1</sup>*/*2(±)

*<sup>r</sup> ,mr,*"*<sup>r</sup>*

"*NK* <sup>≡</sup> *<sup>g</sup>*"*NK* "¯

(

*mK*

 $\equiv$   $\sim$ 

are constructed. We follow Refs. [23,24,72–74] and consider

$$
\mathcal{L}_{NNK}^{3/2(\pm)} = \frac{g_{\Lambda NK}}{m_K} \bar{\Lambda}^v (D_{\nu}^{3/2(\pm)} \bar{K}) N + \text{H.c.}, \qquad \text{(A6a)} \qquad \mathcal{L}_{NNK}^{5/2(\pm)} = \frac{g_{\Lambda NK}}{m_K^2} \bar{\Lambda}^{\mu\nu} (D_{\mu\nu}^{5/2(\pm)} \bar{K}) N + \text{H.c.}, \qquad \text{(A7a)}
$$
\n
$$
\mathcal{L}_{\Sigma NK}^{3/2(\pm)} = \frac{g_{\Sigma NK}}{m_K} \bar{\Sigma}^v \cdot (D_{\nu}^{3/2(\pm)} \bar{K}) \tau N + \text{H.c.}, \qquad \text{(A6b)} \qquad \mathcal{L}_{\Sigma NK}^{5/2(\pm)} = \frac{g_{\Sigma NK}}{m_K^2} \bar{\Sigma}^{\mu\nu} \cdot (D_{\mu\nu}^{5/2(\pm)} \bar{K}) \tau N + \text{H.c.}, \qquad \text{(A7b)}
$$
\n
$$
\mathcal{L}_{\Sigma AK}^{3/2(\pm)} = \frac{g_{\Sigma KK}}{m_K} \bar{\Xi} (D_{\nu}^{3/2(\pm)} K_c) \Lambda^v + \text{H.c.}, \qquad \text{(A6c)} \qquad \mathcal{L}_{\Sigma K K}^{5/2(\pm)} = \frac{g_{\Sigma K K}}{m_K^2} \bar{\Xi} (D_{\mu\nu}^{5/2(\pm)} K_c) \Lambda^{\mu\nu} + \text{H.c.}, \qquad \text{(A7c)}
$$
\n
$$
\mathcal{L}_{\Sigma K K}^{3/2(\pm)} = \frac{g_{\Sigma K K}}{m_K} \bar{\Xi} \tau (D_{\nu}^{3/2(\pm)} K_c) \cdot \Sigma^{\nu} + \text{H.c.}, \qquad \text{(A8a)} \qquad \mathcal{L}_{\Sigma K K}^{5/2(\pm)} = -\Gamma^{(\pm)} \left( \pm i\lambda + \frac{1 - \lambda}{m_H \pm m_B} \right) \,, \qquad \text{(A3a)}
$$
\n
$$
\mathcal{L}_{\Sigma K K}^{7/2(\pm)} = \frac{g_{\Sigma NK}}{m_K^3} \bar{\Sigma}^{\mu\nu\rho} \cdot (D_{\mu\nu\rho}^{7/2(\pm)} K_c) \Lambda^{\mu\nu\rho} + \text{H.c.}, \q
$$

The effective Lagrangians for spin-1*/*2 hyperons " and #

'

*D*<sup>1</sup>*/*2(±) !#*<sup>K</sup> Kc*

 $\overline{\phantom{a}}$ 

· ! + H.c.*,* (A4d)

\**n*

*L*<sup>1</sup>*/*2(±)

!#*Kc* <sup>=</sup> *<sup>g</sup>*!#*Kc* !¯ <sup>τ</sup>

*g*!"*Kc* = −*g*<sup>8</sup>

we use the notations for the isotopic fields for the isotopic fields of the isotopic fields of the isotopic fields of the interest of the inte

*g*!"*Kc*

1 − 4α

√3

*,* (A5c)

(a) 
$$
\mathcal{L}_{\Lambda N K}^{5/2(\pm)} = \frac{g_{\Lambda N K}}{m_K^2} \bar{\Lambda}^{\mu \nu} (D_{\mu \nu}^{5/2(\pm)} \bar{K}) N + \text{H.c.}, \quad (A7a)
$$
  
(b) 
$$
\mathcal{L}_{\Sigma N K}^{5/2(\pm)} = \frac{g_{\Sigma N K}}{m_K^2} \bar{\Sigma}^{\mu \nu} \cdot (D_{\mu \nu}^{5/2(\pm)} \bar{K}) \tau N + \text{H.c.}, \quad (A7b)
$$

τ*N* + H.c. *,* (A6b)

*s*- and *u*-channel amplitudes, *Ms* and *Mu* discussed in Sec. II,

are constructed. We follow Refs.  $\alpha$  and  $\alpha$   $\mathbb{Z}$  and consider  $\mathbb{Z}$ 

 $\sim$   $\frac{1}{4}$ 

*,* (A3a)

where *mK* denotes the kaon mass. For spin-5*/*2 hyperons

And, for spin-7*/*2 hyperons, we have [24,75]

The coupling constants in the above Lagrangians corre-

sponding to " and # resonances are free parameters adjusted

 $\mathbf{r}$ 

$$
\mathcal{L}_{\Xi\Lambda K_c}^{5/2(\pm)} = \frac{g_{\Xi\Lambda K_c}}{m_K^2} \, \bar{\Xi} \big( D_{\mu\nu}^{5/2(\pm)} K_c \big) \Lambda^{\mu\nu} + \text{H.c.} \,, \quad \text{(A7c)}
$$

$$
\mathcal{L}_{\Sigma\Sigma K_c}^{5/2(\pm)} = \frac{g_{\Sigma\Sigma K_c}}{m_K^2} \bar{\Xi} \tau \left( D_{\mu\nu}^{5/2(\pm)} K_c \right) \cdot \Sigma^{\mu\nu} + \text{H.c. (A7d)}
$$

$$
D_{B'BM}^{1/2(\pm)} \equiv -\Gamma^{(\pm)} \bigg( \pm i\lambda + \frac{1-\lambda}{m_{B'} \pm m_B} \partial \bigg), \quad \text{(A3a)}
$$

$$
D_{\nu}^{3/2(\pm)} \equiv \Gamma^{(\mp)} \partial_{\nu}, \tag{A3b}
$$

$$
D_{\mu\nu}^{5/2(\pm)} \equiv -i\,\Gamma^{(\pm)}\partial_{\mu}\partial_{\nu}\,,\tag{A3c}
$$

$$
D_{\mu\nu\rho}^{7/2(\pm)} \equiv -\Gamma^{(\mp)} \partial_{\mu} \partial_{\nu} \partial_{\rho} , \qquad (A3d)
$$

$$
\Gamma^{(+)} \equiv \gamma_5 \text{ and } \Gamma^{(-)} \equiv 1
$$

*D*<sup>1</sup>*/*2(±) "*NK <sup>K</sup>*¯ *n*"<sup>4</sup> *r*

interpolate between the pseudovector  $\mathbb{R}^n$  and the pseudovector  $\mathbb{R}^n$ 

doscalar (λ = 1) couplings. Note that in the above equations of the above equations

(

the order of the subscript indices in *D*<sup>1</sup>*/*2(±)

*,* (A9)

∂*µ*∂ν *,* (A3c)

∂*µ*∂ν ∂ρ *,* (A3d)

*BM* is important, i.e.,

## RESULTS



FIG. 4. (Color online) Total cross-section results with individual resonances switched off (a) for  $K^- + p \rightarrow K^+ + \Xi^-$  and (b) for  $K^- +$  $p \to K^0 + \mathbb{E}^0$ . The blue (gray) lines represent the full result shown in Figs. 2 and 3. The red (gray) dashed lines which almost coincide with the blue lines represent the result with  $\Lambda(1890)$  switched off. The green (gray) dash-dotted lines represent the result with  $\Sigma(2030)$  switched off and the magenta (dark gray) dash-dash-dotted lines represent the result with  $\Sigma(2250)5/2^-$  switched off.

$$
\boxed{\Lambda(1890), \quad \Sigma(2030), \quad \Sigma(2250)}
$$

production are fewer and less accurate than for the charged production are fewer and less accurate than for the charged production are the charged production and the charged production are the charged production and the ch

 $T$  , and results for differential cross sections in  $\mathcal{L}$  , and  $\mathcal{L}$  and  $\mathcal{L}$ **F** *p p k*<sup>2</sup> + *p k*<sup>2</sup> + *k*<sup>2</sup> shape at backward angles. It is clear from Figs. 5(a) and 5(b) Jackson, YO, Haberzettl, Nakayama, PRC 91 (2015) 065208

contact amplitude contact amplitude contributions are backward-angle peaked by the contributions are backward-angles

#### RESULTS we have the total cross sections, the data for the data for the data for the data for the neutral  $\sim$ production are fewer and less accurate than for the charged contact amplitude contributions are backward-angle peaked  $\mathbf{r} = \mathbf{r}$ and, as the energy increases, get smaller at forward angles. In

for both backward and forward scattering angles (more

*W* = 2*.*8 GeV for the former and up to *W* = 2*.*5 GeV for the



FIG. 5. (Color online) Kaon angular distributions in the center-of-mass frame (a) for  $K^- + p \rightarrow K^+ + \Xi^-$  and (b) for  $K^- + p \rightarrow$  $K^0 + \Xi^0$ . The blue (gray) lines represent the full model results. The red (gray) dashed lines show the combined  $\Lambda$  hyperon contributions. The magenta (dark gray) dash-dotted lines show the combined  $\Sigma$  hyperon contributions. The green (gray) dash-dash-dotted line corresponds to the contact term. The numbers in the upper right corners correspond to the centroid total energy of the system *W*. Note the different scales used. The experimental data (black circles) are the digitized version as quoted in Ref. [50] from the original work of Refs. [31–34,36,37] for the  $K^- + p \rightarrow K^+ + \Xi^-$  reaction and of Ref. [30,36,37,40] for the  $K^- + p \rightarrow K^0 + \Xi^0$  reaction.



To gain some insight into the angular dependence exhibited

 $\frac{1}{2}$ 

by the fig. 10, we express the  $\mathcal{L}$ 

in terms of partial waves with *L* ! 2, which gives

 $2 \times 10^{-4}$ 

1 + **a** 

 $\blacksquare$ 

and differential cross section given by Eq. (15) is the sign

change of the terms involving β*L*. These terms are, however, proportional to sin<sup>2</sup> θ. Therefore, this spin observable behaves

like the differential cross section at very forward and backward

angles, where  $\mathbf{S} = \mathbf{S}$ 

flip amplitude. Now, if we ignore the *P*-wave contribution—

which is relatively very small in the neutral  $\mathbb{R}$ 

nearly over the entire energy region considered as seen in

 $\mathbb{F}_q$  , and the Eq. (16a) involves only seen that Eq. (16a) involves only seen that Eq. (16a) involves only seen that  $\mathbb{F}_q$ 

 $t_{\rm eff}$  are symmetric about  $\mathbf{R}$ 

*<sup>d</sup>*"*Kxz*, Eq. (16b) reveals a rather complicated angular

*<sup>d</sup>*"*Kxx* exhibits roughly this symmetry.

For *<sup>d</sup>*<sup>σ</sup>

2, which is a *P*-wave contribution in the spin-

2 + α1β

Note that the only difference between *<sup>d</sup>*<sup>σ</sup>

FIG. 9. (Color online) The recoil asymmetry multiplied by the cross section,  $P \frac{d\sigma}{d\Omega}$ , for both the  $K^- + p \rightarrow K^+ + \Xi^-$  and  $K^- +$  $p \to K^0 + \Xi^0$  reactions. The blue (gray) solid lines represent the full results of the current model. Data are from Refs. [33,37].

## **RESULTS (PREDICTIONS)** *KN→K*Ξ(1320) : *model results (prediction)*



## $\pi^- p \to K^{*0} \Lambda, \qquad \pi^- p \to D^{*-} \Lambda_c$

- \* Motivation
- Reactions close to threshold: nonperturbative approaches
- \* Effective Regge exchanges
	- \* QGSM (Quark Gluon String Model): Kaidalov et al.
	- \* usually vector exchange only is assumed because of large intercept of the trajectory
	- \* but the coupling is not known
	- \* it is needed to check the dominance of vector exchanges.



The differential cross section is then written as

*mi,mf ,*λ*<sup>V</sup> ,*λ′

× *Y*<sup>1</sup>λ*<sup>V</sup>* (0*<sup>f</sup>* ) *Y* <sup>∗</sup>

*dt d*0*<sup>f</sup>*

*<sup>W</sup>*(0*<sup>f</sup>* ) <sup>=</sup> #

FIG. 2. Diagrammatic representation of the effective  $\pi^- + p \rightarrow$  $K^{*0} + \Lambda$  and  $\pi^- + p \to D^{*-} + \Lambda_c^+$  reactions.

#### $$ respectively. In the strangeness sector, *Y* = "(1116*,*1*/*2+), sector, *Y* = "*c*(2286*,*1*/*2+), *V* = *D*∗(2010*,*1−), and *P* =  $an \lambda$ Refs. [13–19]. The QGSM is based on the planar quark 2, where *p*<sup>π</sup> , *pp*, *pV* , and *pY* are the four momenta of the  $s_{1,2}$ decomposition for the *K*∗" production with substitution of the *J/*ψ trajectory by the φ meson trajectory. The details can of vector mesons produced in π−p collisions. We summarize in π−p collisions. We summarize in most summarize in<br>We summarize in the produced in π−p collisions. We summarize it is a summarize in the product in the summarize **MALISM** produced through the decays of *K*<sup>∗</sup> → *K* + π and *D*<sup>∗</sup> →  $\mathsf{FORMALISM}$  $p \sim$  Kittles structure of the reaction and  $r \sim$  $\overline{\phantom{a}}$ for the case of recoil polarization. Here, we made use of the showled by the determined by the comparison with experimental by the comparison with experimental  $\alpha$ MAI IS*N* <sup>2</sup>*/*4<sup>π</sup> <sup>=</sup> <sup>0</sup>*.*796 for the vector meson trajectory  $\epsilon$ the intercept of the *K*<sup>∗</sup> (*D*∗) vector meson, for instance, is larger than that of the corresponding pseudoscalar *K* (*D*) meson trajectory [21]. However, other mechanisms cannot  $\Gamma$ UKMALIJM

to test the validity of the dominance of vector meson trajectory

reaction, which leads to *g*<sup>2</sup>

fully evaluated in the framework of the QGSM suggested

with parameters completely determined by the nonlinear  $\rho$ 

spin-density matrix elements, and decay angular distributions

<sup>0</sup> */*4π ≃ 0*.*796.

*J/*ψ meson trajectories as found from the meson spectroscopy

by Kaidalov [11,12] and later developed and refined in

diagram decomposition and unitary conditions  $\mathbb{R}^n$  .

the so-called planar diagram decomposition. An example of

with parameters completely determined by the nonlinear  $\mu$ 

 $T$  , the corresponding cross section for  $\mathcal{A}$ 

pseudoscalar exchange mechanism is expected to be small,

where *Tf i* is the invariant amplitude for the production

hyperon, respectively. The solid angle and the magnitude of magnitude of magnitude of magnitude of magnitude of

Depending on the polarization state of the initial and final

the pseudoscalar-type Reggeon exchange exhibit a similar *t*

κ*<sup>K</sup>*∗*p*" = κ*<sup>D</sup>*∗*p*"*<sup>c</sup>* as in Ref. [25]. The normalization factor *N* in Eq. (7) is introduced to compensate for the artificial *s* and *t*

Recent studies of strangeness and charm production at a

 $\mathbb{F}_q$  ,  $\mathbb{F}_q$ 

Diagrammatic representations of the effective π<sup>−</sup> + *p* →

*<sup>N</sup> ,s*) is the Källén function defined

 $F = \frac{1}{\sqrt{2\pi}}\int_{0}^{\infty} \frac{1}{\sqrt{2\pi}}\left( \frac{1}{\sqrt{2\pi}}\right) \frac{1}{\sqrt{2\pi}}\left( \frac{1}{\sqrt{2\pi}}\right)$ 

*<sup>c</sup>* , where it is assumed

laboratory frame is chosen to be *p*<sup>π</sup>

ρ *J/*Ψ

*<sup>c</sup>* reactions are shown in

ρ0

determined by experimental data.

purpose, we adjust the value of *g*PS

The decay probabilities are expressed in terms of the

spin-density matrix elements ρλλ′ , where λ*<sup>V</sup>* is abbreviated

pseudoscalar exchange mechanism is expected to be small,

we consider two extreme cases, namely, vector-exchange

dominance and pseudoscalar-exchange dominance. For this

that *<sup>d</sup>*σ(PS)*/dt* <sup>=</sup> *<sup>d</sup>*σ(V)*/dt* at zero vector meson production

course, the realistic case is between these two extreme cases,

and the relative strength of the two mechanisms should be

production are exhibited in Figs. 3(a) and 3(b), respectively.

Throughout the present study, the initial pion momentum in the

production and 15 GeV*/c* for charm production. The V and

PS Reggeon exchanges are shown by the solid and dashed

curves, respectively, together with available experimental data

of Ref. [26] for *K*<sup>∗</sup> production. Although the energy scale is

different, it turns out that the cross section of charm production

is suppressed compared with that of strangeness production,

which is consistent with the observation made in Ref. [18].

One can see that both the vector-type Reggeon exchange and

the pseudoscalar-type Reggeon exchange exhibit a similar *t*

dependence in differential cross sections. This resemblance

is clearly seen in the case of charm production, although the

available data seem to prefer the vector-type exchange in the

case of strangeness production. Therefore, the *t* dependence of

cross sections cannot clearly distinguish the two exchanges. As

we see in the next subsections, however, the situation changes

for spin-density matrix elements and the angular distributions

of *K*<sup>∗</sup> → *K*π and *D*<sup>∗</sup> → *D*π decay, where the difference

as λ, which are determined by the amplitudes of Eq. (12).

Depending on the polarization state of the initial and final

(ii) the recoil polarization case, when the spin of the

The obtained differential cross sections for *K*<sup>∗</sup> and *D*<sup>∗</sup>

kinds of spin-density matrices defined as

outgoing hyperon (") is determined by their decay

distribution using that it is self-analyzing. Then, de-

pending on the spin state of the hyperon, we have two

 $H \to \mathbb{R}$ 

or helicity of the produced hyperon is *mf* = +<sup>1</sup>

Denoting the polar and the azimuthal angles of the outgoing

pseudoscalar *K* (or *D*) mesons by 1 and 2, respectively, the

decay angular distributions can be expressed in terms of the

2In the case of vector meson photoproduction, the former is called

the helicity frame, while the latter corresponds to the Gottfried-

states, we are interested in the following two cases:

 $\frac{1}{2}$ 

*<sup>c</sup>* reactions are shown in

3

4π

− √

= (*p*<sup>π</sup> −

spin-density matrix elements as

*,* (1)

 $\mathbb{Z}$  , respectively.

ρ *J/*Ψ

 $Cross$  section for (two-body  $\rightarrow$  three-body) thro  $\overline{ }$  cross section is allows the produced particle *calculus* of the produced purtles Cross section for (two-body **→** three-body) through the decay of the produced particle  $h(x) = h(x)$  and the solid angle  $C$ ross section for (two-body  $\rightarrow$  three-body) thro be found in Ref. [15].  $\begin{array}{|c|c|c|}\hline \textbf{b} & \textbf{c} & \textbf{c} & \textbf{c} \end{array}$   $\begin{array}{|c|c|c|}\hline \textbf{c} & \textbf{c} & \textbf{c} & \textbf{c} \end{array}$ **II. THE MODEL DECAY ANGULAR DISTRIBUTION** CHICLE DUCKY CHICAGO CHIC QUAL DI LITE PICQUELLE distinguish different production mechanisms. It can be done by ree-body) through the decay of the produced particle  $\ddot{b}$  the unpolarized case, where the spin- $\Gamma$  Cross section for (two-body  $\rightarrow$  three-k Have the sum rule (two-body → filtee-reserved) both the strangeness and charm production processes as we do y) through the decay of the produced partic  $\mathsf{dv} \rightarrow \mathsf{three}\text{-}\mathsf{body}$ ) through the decav of the produced particle structure of the production mechanisms. In fact, as we see for the production of *K*<sup>∗</sup> and *D*<sup>∗</sup> mesons, respectively. Of  $\overline{a}$  and  $\overline{b}$  we elaborate on the angular distribution on the angular distribution on the angular distribution of  $\overline{a}$ tions of pseudon for the decay *ihree-hody*) through the decay of the produced pa and the *Dody*, through the decay of the produced pa

$$
d\sigma = \left(\frac{1}{16\pi\lambda_i}|T_{fi}|^2dt\right)\left(\frac{k_f d\Omega_f dM_V}{16\pi^3}\right) \qquad \pi^- + p \to V + Y \to (P + \pi) + Y
$$

$$
T_{fi} = A_{m_f, \lambda_V; m_i} \frac{1}{p_V^2 - M_0^2 + i M_0 \Gamma_{\text{tot}}} \mathcal{D}_{\lambda_V}(\Omega_f) \qquad \mathcal{D}_{\lambda} = 2c \sqrt{\frac{4\pi}{3}} Y_{1\lambda}(\Omega_f)
$$

are flavored baryon, vector meson, and pseudoscalar meson,

respectively, and we use *MV* for the vector meson mass. The

SANG-HO KIM, YONGSEOK OH, AND ALEXANDER I. TITOV PHYSICAL REVIEW C **95**, 055206 (2017)

respectively, and we use *MV* for the vector meson mass. The **Mandelstam variables for the production produ a** \* vector exchange be excluded, and the contribution from such mechanisms  $\star$  vector exchange \* vector exchange

*<sup>K</sup>*∗<sup>0</sup> <sup>+</sup> " and <sup>π</sup><sup>−</sup> <sup>+</sup> *<sup>p</sup>* <sup>→</sup> *<sup>D</sup>*∗− <sup>+</sup> "<sup>+</sup>

− ρ<sup>±</sup>

<sup>1</sup>−<sup>1</sup> sin2 \$ cos 2%

following Hermitian conditions: ρ−11 = ρ10, ρ01 = ρ10, ρ01 = ρ10, αρ10 = ρ10, αρ10 = ρ10, αρ10 = ρ10, αρ10, αρ

<sup>−</sup>1*.*<sup>02</sup> <sup>+</sup> <sup>0</sup>*.*<sup>467</sup> *<sup>t</sup>*,*s<sup>V</sup>*

The reactions under considerations under considerations under consideration in the present work of the present

with αPS

and *s*PS

conditions ρ<sup>0</sup>

that the vector meson trajectory exchange model needs to be the vector model needs to be the vector model needs to be the vector model of the vector model in the vector model in the vector model in the vector model in the

under consideration in the present work are the two-step

$$
\mathcal{A}_{fi}^V = g_0^2 \frac{s}{\bar{s}} \Gamma \left( 1 - \alpha_R^V(t) \right) \left( \frac{s}{s_{0R}^V} \right)^{\alpha_R^V(t)-1} \n\qquad\n\mathcal{A}_{fi}^V = g_0^2 \frac{s}{\bar{s}} \Gamma \left( 1 - \alpha_R^V(t) \right) \left( \frac{s}{s_{0R}^V} \right)^{\alpha_R^V(t)-1} \n\times \left[ (1 + \kappa_{K^* p\Lambda}) \gamma_\nu - \kappa_{K^* p\Lambda} \frac{(p_p + p_\Lambda)_\nu}{M_p + M_\Lambda} \right] u_{m_i}(p)
$$

 $\star$  pseudoscalar exchange with α*<sup>V</sup> <sup>R</sup>p*" (*t*) <sup>=</sup> <sup>0</sup>*.*<sup>414</sup> <sup>+</sup> <sup>0</sup>*.*<sup>707</sup> *<sup>t</sup>*, *<sup>s</sup><sup>V</sup>* 0*Rp*" ↑ *pseudoscalar exchange* independent amplitude reads those in the vector meson exchange case so that *s*PS meson productions. All the theoretical tools to investigate the **and** *P* and *D* mesons control by the *P* mesons produced by the *P* sequence of *R*  $\mu$  mesons produced by the *P* sequence of *R*  $\mu$  mesons produced by the *P* sequence of *R*  $\mu$  mesons produced by the *P* sequenc \* pseudoscalar exchange

$$
\mathcal{A}_{fi}^{\rm PS} \simeq g_0^2 \,\Gamma\big(-\alpha_{\mathcal{R}}^{\rm PS}(t)\big) \bigg(\frac{s}{s_{0\mathcal{R}}^{\rm PS}}\bigg)^{\alpha_{\mathcal{R}}^{\rm PS}(t)} \qquad S_{m_f,\lambda_V;m_i}^{\rm PS} = \varepsilon_{\mu}^*(\lambda_V) \, q^{\mu} \bar{u}_{m_f}(\Lambda) \gamma_5 u_{m_i}(p)
$$

 $\alpha$ <sub>Strangeness</sub> – 1 *p*<sub>2</sub> + *i*m<sub>0</sub>  $\rho$ <sub>2</sub> + *p*<sub>1</sub>  $\alpha_{\rm charm}^V = -1.02 + 0.467 t$  $\alpha_{\text{strangeness}} = -0.151 \pm 0.011 l$   $\alpha_{\text{charm}} =$  $p = 0.420 +$ *d s*  $\frac{1}{2}$  =  $\frac{1}{2}$  +  $\frac{1}{2}$  +  $\frac{1}{2}$  $\ddot{\phantom{0}}$ = (*pV* + *pY* )  $p_{n} = -1.611 + 0.439 t$ pion, the proton, the produced (virtual) vector meson, and the factor *g*<sup>0</sup> is determined in the next section by comparison with  $\alpha_{\text{strangeness}}^{V} = -0.414 + 0.707 t$ *reaction strangeness*  $PS$  and  $\Omega$  and  $\Omega$  angular mesons of  $P$ **produced the decay of**  $\alpha_{\text{strangeness}} = -0.131 + 0.017t$  $= 1.02 \pm 0.4674$  $t_{\text{rms}} = -1.02 \pm 0.02$ The decay probabilities are expressed in terms of the  $s_{\text{arm}} = -1.611 + 0.439 t$  $\alpha_{\text{obs}}^V = -1.02 + 0.467 t$  $m_{\text{charm}}$   $1.02 \pm 0.101 \text{ m}$  $\alpha^{PS} = -1611 + 0439t$  $\alpha_{\text{charm}} = -1.011 + 0.439 l$  $\alpha^V$  = −0*.*414 + 0.707 *t*  $\alpha^V$  $\alpha_{\text{strangeness}}^{V} = -0.414 + 0.707 t$   $\alpha_{\text{charm}}^{V} = -1.02 + 0.467 t$ flavor content of the vertices are assumed to be the same as  $\alpha_{\text{strangness}}^{PS} = -0.151 + 0.617$  $\alpha_{\text{strangeness}}^{PS} = -0.151 + 0.617 t \qquad \alpha_{\text{cha}}^{PS}$ <sup>0</sup>*Rp*(*<sup>c</sup>* <sup>=</sup> *<sup>s</sup><sup>V</sup>*  $d_{\rm m} = -1.02 + 0.467 t$  $\alpha_{\text{obs,}}^{PS} = -1.611 + 0.439 t$ One can see that both the vector-type Reggeon exchange and **II. RESULTS AND DISCUSSION** In this section, we present numerical results on different numerical results on different numerical results on  $\mathbb{R}^n$ angular distributions of *K* and *D* mesons in π*N* scattering. of vector mesons produced in π−*p* collisions. We summarize  $1.02 + 0.40$  $\overline{1}$  $161$ with Br = &*<sup>f</sup> /*&tot when &tot ≪ *MV* .  $\frac{PS}{\text{charm}} = -1.611 + 0.439 t$ 

, and *<sup>s</sup>*¯*p*"*<sup>c</sup>* <sup>=</sup> 1 GeV2 for

and outgoing baryons, respectively, and λ*<sup>V</sup>* represents the

**D** +  $\frac{1}{2}$  and  $\frac{1}{2}$  depend on the spin of the spin of the participating  $\frac{1}{2}$ particles, the spin structure of the reaction amplitudes of Eq. (6)

## DIFFERENTIAL CROSS SECTIONS

![](_page_16_Figure_1.jpeg)

pseudoscalar (dashed curves) Register exchanges. The experimental data for  $\rho$  +  $\rho$  + vector exchange

In the case of vector-type Reggeon exchange, the matrix

*t-*frame

*s-*frame

 $\frac{1}{2}$ 

model, which are calculated in the *s* and *t* frames. Our results numerically confirm the symmetry pseudoscalary properties, *ρ*ουαιος της προσ to the spin structure ϵ*<sup>µ</sup>*ναβ *qµpV* <sup>α</sup>ε<sup>∗</sup> pseudoscalar exchange **produced rest frame, where**  $p$   $\blacksquare$ 

**Example 10** Both exchanges are normalized to the differential cross sections at the forward angle Both exchanges are normalized to the differential cross sections at the forward angle.

*s*-frame

<sup>β</sup> (λ*<sup>V</sup>* ) of the amplitude

(*MV ,*0*,*0*,*0) and *q* = − *p*<sup>π</sup> , this factor is proportional to the

vector product of ε∗(λ*<sup>V</sup>* ) × *p*<sup>π</sup> . In the *s* frame and small-

*t*-frame

#### SPIN-DENSITY MATRIX ELEMENTS  $\overline{C}$ IN COIN DENSITY M **OFFITS PROTHER** (*MV ,*0*,*0*,*0) and *q* = − *p*<sup>π</sup> , this factor is proportional to the **VRIX FIFMENTS** momentum transfers, *p*<sup>π</sup> has a large *z* component and a small

to the spin structure ϵ*<sup>µ</sup>*ναβ *qµpV* <sup>α</sup>ε<sup>∗</sup>

<sup>β</sup> (λ*<sup>V</sup>* ) of the amplitude

model, which are calculated in the *s* and *t* frames. Our results

![](_page_17_Figure_1.jpeg)

frame, while those in panels (b), (d), (f), and (h) were obtained in the *t* frame.

## SPIN-DENSITY MATRIX ELEMENTS

![](_page_18_Figure_1.jpeg)

|λ|=1*,* |λ′

|=<sup>1</sup>. In the

that ρ<sup>0</sup>

<sup>1</sup>−<sup>1</sup> <sup>=</sup> 0 at *<sup>t</sup>* <sup>=</sup> *<sup>t</sup>*max. This is because of the relation

#### COMPARISON WITH DATA |  $\overline{A}$ *discussing frame* 1 M/ITLI DATA N WIIH DAIA

 $\lambda$ 

 $\mathbf{F}_{\mathbf{F}}=\mathbf{F}_{\mathbf{F}}+\mathbf{F}_{\mathbf{F}}+\mathbf{F}_{\mathbf{F}}+\mathbf{F}_{\mathbf{F}}+\mathbf{F}_{\mathbf{F}}+\mathbf{F}_{\mathbf{F}}+\mathbf{F}_{\mathbf{F}}+\mathbf{F}_{\mathbf{F}}+\mathbf{F}_{\mathbf{F}}+\mathbf{F}_{\mathbf{F}}+\mathbf{F}_{\mathbf{F}}+\mathbf{F}_{\mathbf{F}}+\mathbf{F}_{\mathbf{F}}+\mathbf{F}_{\mathbf{F}}+\mathbf{F}_{\mathbf{F}}+\mathbf{F}_{\mathbf{F}}+\mathbf{F}_{\mathbf{F}}+\mathbf{$ 

 $\pi^- p \to K^{*0} \Lambda$  (*s*-frame)

![](_page_19_Figure_2.jpeg)

FIG. 6. Spin-density matrix elements for *K*∗<sup>0</sup> production in the *s* frame. Panels (a), (b), and (c) correspond to ρ<sup>0</sup>  $\pi^- p \to K^{*0} \Lambda$  (*t*-frame)

![](_page_19_Figure_4.jpeg)

#### **DECAY ANGULAR DISTRIBUTION** the *Quantization and Quantization and AN* in the center-of-momentum frame of the production process **D** +  $\frac{1}{2}$  and  $\frac{1}{2}$  depend on the spin of the spin of the spin of the participating  $\frac{1}{2}$  $p_{\text{max}}$  $\mathsf{L}\mathsf{L}\mathsf{L}$ distinguish different production mechanisms. It can be done by  $\overline{D}$  and  $\overline{D}$  and  $\overline{D}$   $\overline{D}$  and  $\overline{D}$  and  $\overline{D}$  and  $\overline{D}$ states, we are interested in the following two cases:

spin-density matrix elements ρλλ′ , where λ*<sup>V</sup>* is abbreviated

*d*σ  $dt\,d\Omega_f$ = *d*σ *dt*  $W(\Omega_f)$  with  $W(\Omega_f) =$ convention of Ref. [26], the former is called the *s* frame and  $\frac{a\sigma}{2}$ .  $\frac{d}{dt} d\Omega_t = dt^{\prime\prime(\log t)}$ spin-density matrix elements ρλλ′ , where λ*<sup>V</sup>* is abbreviated *Sf i* that carries the symmetry of the exchanged Reggeon [15], = *Af i*  $\boldsymbol{t}$  $\frac{1}{2}$   $r = \nabla$ *mi*=± <sup>1</sup> <sup>2</sup> *, mf* =± <sup>1</sup> 2  $\frac{1}{4}$   $\ldots$ , when  $\ldots$ with  $W(\Omega_f) = \sum$  $m_i, m_f, \lambda_V, \lambda_V'$  $\mathcal{M}_{m_f, \lambda_V; m_i} \mathcal{M}_{m_f, \lambda'_V; m_i}^* Y_{1\lambda_V}(\Omega_f) Y_{1\lambda'_V}^*(\Omega_f)$ 

> *M*  $\star$  Define the density matrix el  $\mathcal{D}$  depending on the polarization state of the initial and final a **1**  $\bullet$  Define the density matrix \* Define the density matrix elements \*

The differential cross section is then written as

produced through the decays of *K*<sup>∗</sup> → *K* + π and *D*<sup>∗</sup> →

"dressing" the spin-independent amplitude by the spin factor

*mf ,mi,*λ*<sup>V</sup>*

*K∗0 → D≈π0 decays. As is a is well known as is well known as is well known***, and is well known, as is well known,** since the decay angular distribution of outgoing *K*<sup>+</sup> is analyzed in the virtual vector meson's rest frame, there is an

or the quantization axis may be defined to be parallel to the incoming pion, i.e., the initial beam direction. Following the

as λ, which are determined by the amplitudes of Eq. (12).

 $\mathcal{C}$  the unpolarized case, where the spin-density matrix is spin-density matrix is spin-density matrix is  $\mathcal{C}$ 

(ii) the recoil polarization case, when the spin of the

$$
\rho_{\lambda\lambda'}^0 = \sum_{m_i=\pm\frac{1}{2}, m_f=\pm\frac{1}{2}} \mathcal{M}_{m_f, \lambda; m_i} \mathcal{M}_{m_f, \lambda'; m_i}^*, \qquad \rho_{\lambda\lambda'}^{\pm} = \sum_{m_i=\pm\frac{1}{2}} \mathcal{M}_{m_f, \lambda; m_i} \mathcal{M}_{m_f, \lambda'; m_i}^*
$$

*n the cho* For definition of the interest with the spin of the interest of the spin of  $*$  Ambiquity in the choice of the qu pending on the spin state of the hyperon, we have two  $\frac{1}{2}$  + k<sub>n</sub> *M i M i M i*  $\frac{1}{2}$ :ne quantiza<sup>.</sup> \* Ambiguity in the choice of the quantization axis for VM decay

*<sup>K</sup>*∗<sup>0</sup> <sup>→</sup> *<sup>K</sup>*+π<sup>−</sup> and *<sup>D</sup>*∗− <sup>→</sup> *<sup>D</sup>*−π<sup>0</sup> decays. As is well known, **A** *s*-frame: antiparallel to the outgoing and in the production process ambiguity in choose the quantization and choose the quantization axis. One may choose the choice of the choice of the production process  $H = \frac{1}{2} \int_{0}^{2\pi} \frac{1}{2} \left[ \frac{1}{2} \left( \frac{1}{2} \right) \frac{1}{2} \right] \, d\theta$ **a** and the tensor constant of the ten tial [23,24]. The Dirac spinors of the initial baryon and the outgoing hyperon in the CM frame and derigoing ny pordit in the distribution *s*-frame: antiparallel to the outgoing hyperon in the CM frame

<sup>1</sup>−<sup>1</sup> sin2 <sup>1</sup> cos 2<sup>2</sup>

Jackson frame [27].

the quantization axis antiparallel to the outgoing hyperon *Y* in t-trame: parallel to the incoming pior or helicity of the produced hyperon is *mf* = +<sup>1</sup> t-frame: p the final baryon are denoted by *umi* and *umf* , respectively, **and is t-frame: parallel to** meson. Generalization to the case of charm production may *incoming* ion heam − √ *t*-frame: parallel to the incoming pion beam

or the quantization axis may be defined to be parallel to the

Denoting the polar and the azimuthal angles of the outgoing

11 sin2 1 no.<br>11 sin2 1 = po

pseudoscalar *K* (or *D*) mesons by 1 and 2, respectively, the decay angular distributions can be expressed in terms of the

incoming pion, i.e., the initial beam direction. Following the

convention of Ref. [26], the former is called the *s* frame and

00 cos2 1 + p<br>2 + post-cos2 = post-cos2

spin-density matrix elements as

' ρ0

(0*<sup>f</sup>* ) <sup>=</sup> <sup>3</sup>

be achieved by the substitutions *M*" → *M*"*<sup>c</sup>* , *MK*<sup>∗</sup> → *MD*<sup>∗</sup> , and so on. Because of the lack of information, we assume

κ*<sup>K</sup>*∗*p*" = κ*<sup>D</sup>*∗*p*"*<sup>c</sup>* as in Ref. [25]. The normalization factor *N* in Eq. (7) is introduced to compensate for the artificial *s* and *t*

The decay probabilities are expressed in the decay probabilities are expressed in the decay probabilities are expressed in the decay of the decay probabilities are expressed in the decay of the decay of the decay of the de

the latter the *t* frame.<sup>2</sup>

dependence generated by *Sf i*.

#### than the pseudoscalar-exchange model, we can see that the vector-exchange model alone cannot successfully explain the m<br> $\overline{a}$ Φ) Then

(e) (f) (g) (h)

<sup>+</sup> <sup>π</sup><sup>−</sup>

1 2

 $\mathbf{I}$ 

In Figs. 6 and 7, we compare our results with the

available experimental data of Ref. [26] for *K*∗<sup>0</sup> production

in the *s* and *t* frames, respectively. Although the vectorexchange mechanism leads to a better agreement with the data

than the pseudoscalar-exchange model, we can see that the

vector-exchange model alone cannot successfully explain the data.<sup>3</sup> New experimental data for *K*<sup>∗</sup> production with higher

precision are, therefore, strongly desired. In *D*<sup>∗</sup> production, the difference is also large enough to be verified by experiments

and the analyses can be done at current or future experimental

The polar angle distributions of outgoing *K* and *D* mesons

are obtained by integrating *W*("*,* #) of Eqs. (15) and (16)

<sup>00</sup> = ρ<sup>+</sup>

$$
W^{0}(\Omega_{f}) = \frac{3}{4\pi} \Big[ \rho_{00}^{0} \cos^{2} \Theta + \rho_{11}^{0} \sin^{2} \Theta - \rho_{1-1}^{0} \sin^{2} \Theta \cos 2\Phi - \sqrt{2} \operatorname{Re}(\rho_{10}^{0}) \sin 2\Theta \cos \Phi \Big],
$$

words, the distribution functions functions for the vector trajectory of the vector trajectory of

exchange display a cosine function shape, while those of

the pseudoscalar trajectory exchange show a sine function

shape. This is a direct consequence of the spin-density matrix  $\mathbf{d}$  ,

The corresponding distributions are shown in Fig. 9 at

takes a positive value for vector-type exchange and a negative

value for pseudoscalar-type exchange. This difference means

exchange are out of phase. The amplitudes of the oscillations

in *W*<sup>0</sup> are found to be larger than those of *W*±, which reflects

pseudoscalar-Reggeon exchange in the *t* frame, ρ

<sup>2</sup> *,*#) of vector-type exchange and pseudoscalar-type

<sup>11</sup> shown in Figs. 4 and 5.

<sup>1</sup>−<sup>1</sup> cos 2#*,*

. In the *s* frame, the matrix element ρ<sup>0</sup>

1−1 and 5. For the Figs. 4 and 5.

−1

$$
W^{\pm}(\Omega_f) = \frac{3}{4\pi} \left[ \rho_{00}^{\pm} \cos^2 \Theta + \frac{1}{2} \left( \rho_{11}^{\pm} + \rho_{-1-1}^{\pm} \right) \sin^2 \Theta - \rho_{1-1}^{\pm} \sin^2 \Theta \cos 2\Phi - \frac{1}{\sqrt{2}} \text{Re} \left( \rho_{10}^{\pm} - \rho_{-10}^{\pm} \right) \sin 2\Theta \cos \Phi \right],
$$

Integration over the azimuthal angle gives over the azimuthal angle #, which gives production *ever* the eximit Integration over the azimuthal angle gives

*p* → *D*∗−Λ*<sup>c</sup>*

+

$$
\frac{2}{3} W^0(\Theta) = \rho_{00}^0 \cos^2 \Theta + \rho_{11}^0 \sin^2 \Theta,
$$
  

$$
\frac{2}{3} W^{\pm}(\Theta) = \rho_{00}^{\pm} \cos^2 \Theta + \frac{1}{2} (\rho_{11}^{\pm} + \rho_{-1-1}^{\pm}) \sin^2 \Theta.
$$

3We could confirm this conclusion through the comparison with the The azimuthal angle distributions at a fixed polar angle " **c** angles, the obtained from Eqs. (15). At fixed angles,

<sup>|</sup>*t*max <sup>−</sup> *<sup>t</sup>*| = <sup>0</sup>*.*1 GeV<sup>2</sup>

$$
\frac{4\pi}{3}W^0\left(\Theta = \frac{\pi}{2}, \Phi\right) = \rho_{11}^0 - \rho_{1-1}^0 \cos 2\Phi,
$$

$$
\frac{4\pi}{3}W^{\pm}\left(\Theta = \frac{\pi}{2}, \Phi\right) = \frac{1}{2}(\rho_{11}^{\pm} + \rho_{-1-1}^{\pm}) - \rho_{1-1}^{\pm} \cos 2\Phi.
$$

#### RESULTS (I) In the case of pseudoscalar-type Reggeon exchange, however, the situation is  $R \vdash S$ amplitude of this mechanism is proportional to the scalar  $\mathbf{S}$  and  $\mathbf{S}$  are the results for  $\mathbf{S}$ In this case, the spin alignment of the outgoing hyperon is fixed to be *mf* = +<sup>1</sup>  $2 \times 10^{-2}$  . The absolute values of  $2 \times 10^{-2}$

of ρ<sup>0</sup>

![](_page_22_Figure_1.jpeg)

![](_page_22_Figure_2.jpeg)

 $A$ l these observations hold also for the matrix element  $\rho$ 

![](_page_22_Figure_3.jpeg)

product, ε∗(λ*<sup>V</sup>* ) · *p*<sup>π</sup> , which leads to a strong enhancement

<sup>00</sup> <sup>=</sup> 1 and all the other <sup>ρ</sup><sup>0</sup>

<sup>00</sup> in the *t* frame, so that ρ<sup>0</sup>

## RESULTS (II)

![](_page_23_Figure_1.jpeg)

and decays of *<sup>K</sup>*<sup>∗</sup> and *<sup>D</sup>*<sup>∗</sup> mesons at <sup>|</sup>*t*max <sup>−</sup> *<sup>t</sup>*| = <sup>0</sup>*.*1 GeV<sup>2</sup>

in the numerators in Eqs. (13) and (14). The spin-density

## SUMMARY

- \* Spectrum of excited hyperons
	- \* very model-dependent
	- \* a new window for studying hadron structure
- \* **Ξ** production in Kbar-N scattering
	- $*$  intermediate  $\Lambda$  and  $\Sigma$  hyperons
	- \* more precise and accurate data are needed
	- \* complimentary to photoproduction processes
- \* K\*(D\*) production and decay in pi-N scattering
	- \* vector exchange vs pseudoscalar exchange
	- \* decay angular distribution will be useful to pin down the spin structure of the production amplitudes
- \* All these studies may be tested at current facilities.

Thank You