

Exploring Hadron Interactions and Gluonic Dynamics with Kaon and Antiproton Beams

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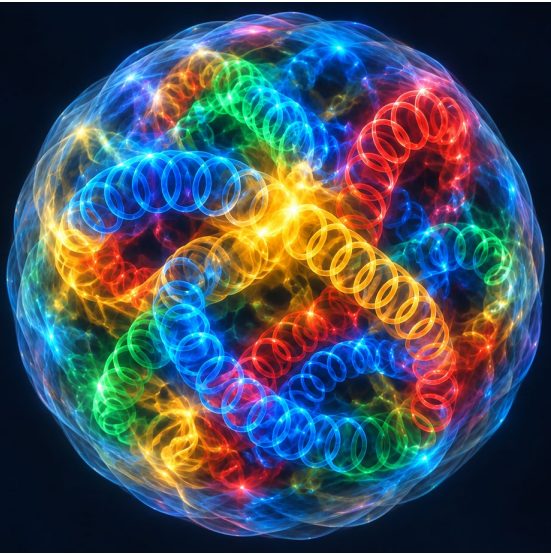
1. Kaon scattering
2. Gluonic spectroscopy
3. Polarized antiprotons

**1st J-PARC K10 Collaboration Meeting &
Workshop on K10 Physics and Detector Technology,
Korea University, 9 October 2026**

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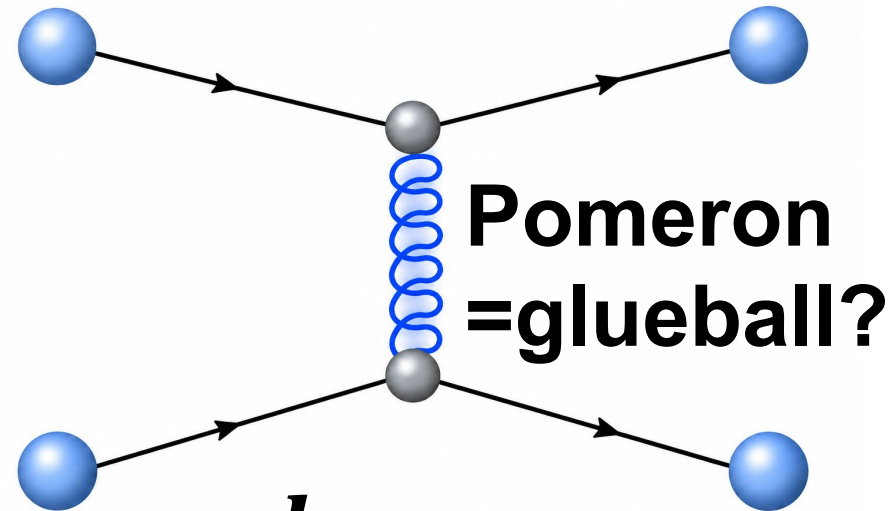


Gluonic dynamics



Glueballs

QCD states composed of gluons



$$\frac{d\sigma}{dt} \sim A(s) e^{B(s)t}$$





Physics opportunities at K10

From hadron scattering to gluonic and spin dynamics

1. What governs K^+p elastic scattering from a few to 10 GeV/ c ?
2. Can gluonic dynamics appear as resonant states in $\bar{p}p$ annihilation?
3. How can we produce **polarized antiprotons**?





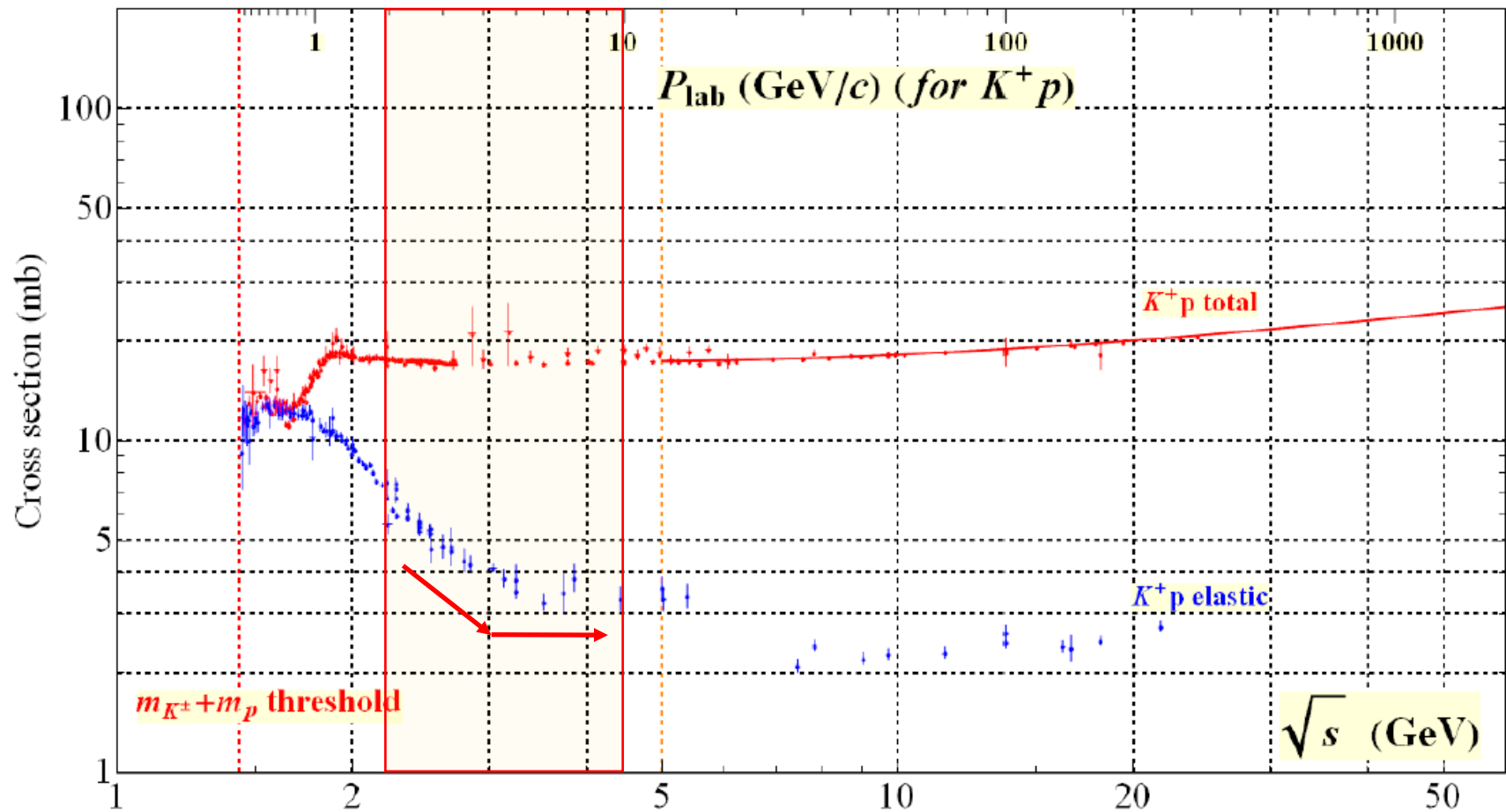
$K^+ p$ elastic scattering





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What is exchanged in $K^+p \rightarrow K^+p$



$P_K = 2 \sim 10 \text{ GeV}/c$ corresponding to
 $\sqrt{s} = 2.23 \sim 4.46 \text{ GeV}$



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9 October 2026



What is exchanged in $K^+p \rightarrow K^+p$

$K^+p \rightarrow K^+p: f_2$ reggeon + Pomeron
($p_K \geq 3 \text{ GeV}/c$)

B.-G. Yu and K.-J. Kong, PRC100, 065206 (2019);
V. Barger and M. Olsson, PR146, 1080 (1966).

Evolution of the Pomeron contribution

$$\frac{d\sigma}{dt} \sim A(s) e^{B(s)t}$$

Systematic measurements of $A(s)$ and $B(s)$ from 2 to 10 GeV/ c probe the transition from Reggeon exchange to Pomeron-dominated diffraction





From meson to Pomeron

$$\frac{d\sigma}{dt} \sim A(s) e^{B(s)t}$$

An energy scan can separate competing exchanges:

$$\mathcal{M}_i(s, t) \sim \beta_i(t) (s/s_0)^{\alpha_i(t)}$$

$\alpha_i(t) = \alpha_i(0) + \alpha'_i t$ gives

$$A_i(s) = \left. \frac{d\sigma}{dt} \right|_{t=0} \propto s^{2[\alpha_i(0)-1]}$$

$$B_i(s) = B_{0,i} + 2\alpha'_i \log(s/s_0)$$





From meson to Pomeron

Pomeron exchange

$$\alpha_P(t) = 1.08 + 0.25t$$

f -Reggeon exchange

$$\alpha_f(t) = 0.5 + 0.9t$$

$A(s)$: depending on $\alpha_i(0)$,
 f_2 suppression & Pomeron dominance
 $B(s)$: reflecting both Regge shrinkage
and the transverse spatial extent of the
interaction.





Why K^+p ?

Possible t -channel exchanges

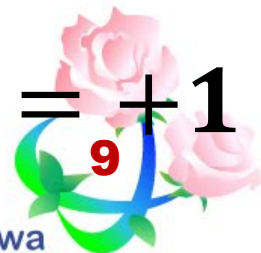
isovector

$$\mathcal{M}(K^\pm p) = f_0 + a_0 \bar{\pi} \phi + f_2 + a_2 + P$$
$$f_2 \simeq 1.27 \text{ GeV}, P_{2++} \simeq 1.92 \text{ GeV}$$

s -channel contribution

K^-p : highly excited Λ/Σ hyperons can be excited

K^+p : no established conventional $S = +1$ baryon resonances





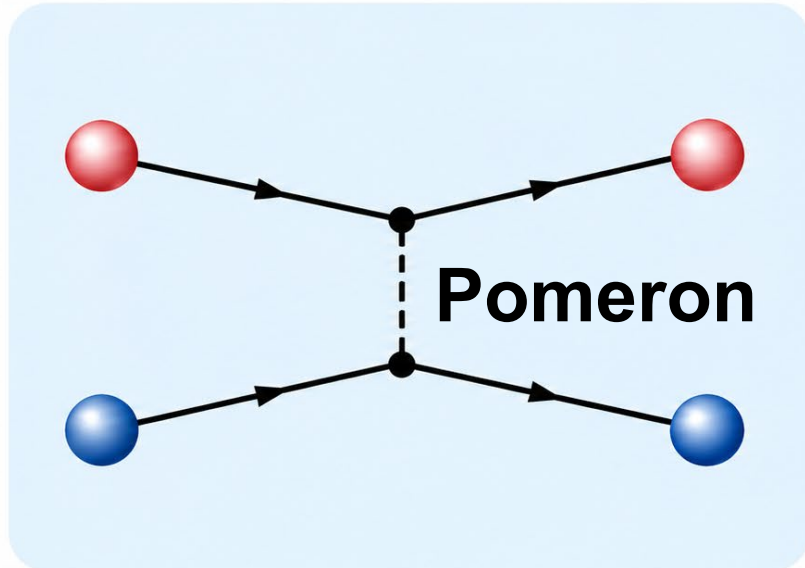
Gluonic spectroscopy in $\bar{p}p \rightarrow \bar{Y}Y$



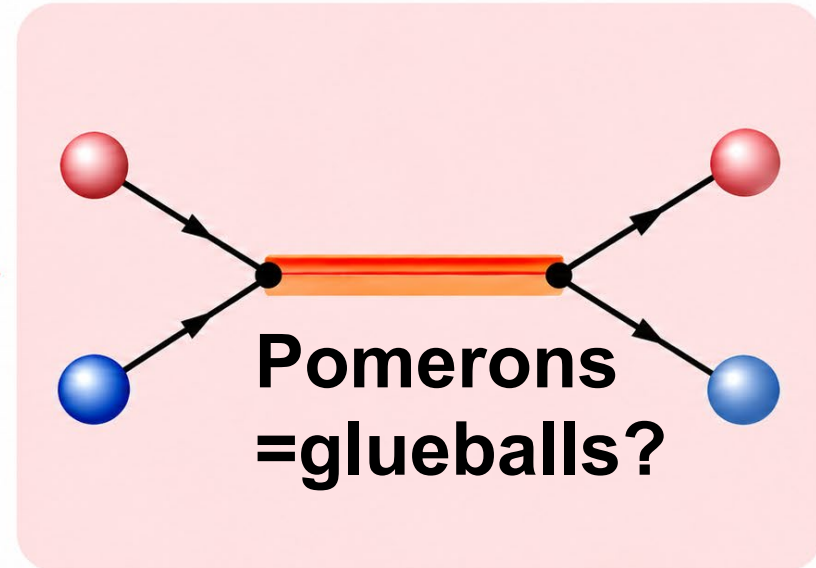


What is Pomeron?

spacelike exchange



timelike states



Does vacuum exchange have an observable timelike counterpart?

Does the Pomeron trajectory contain physical even- J^{++} glueball states?





4^{++} glueball search

$$\alpha_P(t) \simeq 1.08 + 0.25t/\text{GeV}^2$$

$$\alpha_P(M^2) = 4$$

$$M_{4^{++}} \sim 3.42 \text{ GeV}$$

$$p_{\bar{p}} \sim 5.20 \text{ GeV}/c$$

Energy scan for $\bar{p}p \rightarrow G_{4^{++}} \rightarrow \bar{Y}Y$

$$p_{\bar{p}} = 3.74 \sim 6.69 \text{ GeV}/c$$

$$\text{for } M_{\bar{p}p} = 3.0 \sim 3.8 \text{ GeV}$$

A search window motivated not by a precise full-QCD mass prediction but by the Pomeron trajectory.





Why hyperon pairs?

$\bar{Y}Y$ channels as a gluonic probe

$$\bar{p}p \rightarrow G_{4^{++}} \rightarrow \begin{cases} \bar{\Lambda}\Lambda, \bar{\Sigma}\Sigma, \bar{\Xi}\Xi \dots {}^3F_4, \dots \\ \bar{\Delta}\Delta, \bar{\Xi}^*\Xi^*, \bar{\Omega}\Omega \dots {}^7P_4, \dots \end{cases}$$

Mass and J^{PC} alone are not sufficient to establish a glueball

1. a common resonance pole and phase motion
2. Production and decay angular distributions consistent with a common J^{PC}





Why hyperon pairs?

Glueballs: flavor-singlet (flavor blind)
**coupling without a preferred quark flavor,
apart from phase-space and
hadronization effects.**

$\sqrt{s}$ (GeV)	$\sigma(\bar{\Sigma}\Sigma)/\sigma(\bar{\Lambda}\Lambda)$	$\sigma(\bar{\Xi}\Xi)/\sigma(\bar{\Lambda}\Lambda)$
3.0	1.52	0.18
3.2	1.81	0.37
3.4	2.01	0.56
3.6	2.17	0.73
3.8	2.28	0.87



$\bar{\Omega}\Omega$

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Other glueball candidates

BESIII collaboration, arXiv:2607.20366

$X(2370)$ with $0^{-+} \rightarrow K^* \bar{K}$

Quenched lattice calculations generally place the lightest 0^{-+} glueball at $2.3 \sim 3.0$ GeV

Other channels: $\pi\pi\eta'$, $K\bar{K}\eta'$, $K\bar{K}\pi$, $\pi\pi\eta$, ...

Close to $\Sigma\bar{\Sigma}$ threshold (molecule?)

In $\Lambda\bar{\Lambda}$ production, P_{Λ} , $P_{\bar{\Lambda}}$, $C_{ij}^{\Lambda\bar{\Lambda}}$ will be measured

$D_{ij}^{\bar{p} \rightarrow \Lambda}$ and $D_{ij}^{\bar{p} \rightarrow \bar{\Lambda}}$ can be also measured if we have polarized antiprotons.





Polarized antiprotons?





Why polarized antiprotons?

Cross sections: mainly constrain $|\mathcal{M}|^2$

Spin observables: access interference and relative phases

With a transversely polarized $\bar{p}$ beam

- 1. analyzing powers**
- 2. spin-transfer coefficients**
- 3. Stronger constraints on partial-wave amplitudes**





The key idea

Polarized antiprotons from $\bar{\Lambda}$ weak decay

1. Production of a primary $\bar{p}$ beam

Unpolarized

2. Production of $\bar{\Lambda}$ s from $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$

Polarized

3. Decay of $\bar{\Lambda}$ s into $\bar{p}$ s

Polarized





Decay of $\bar{\Lambda}$ s into $\bar{p}$ s

Decay angular distribution

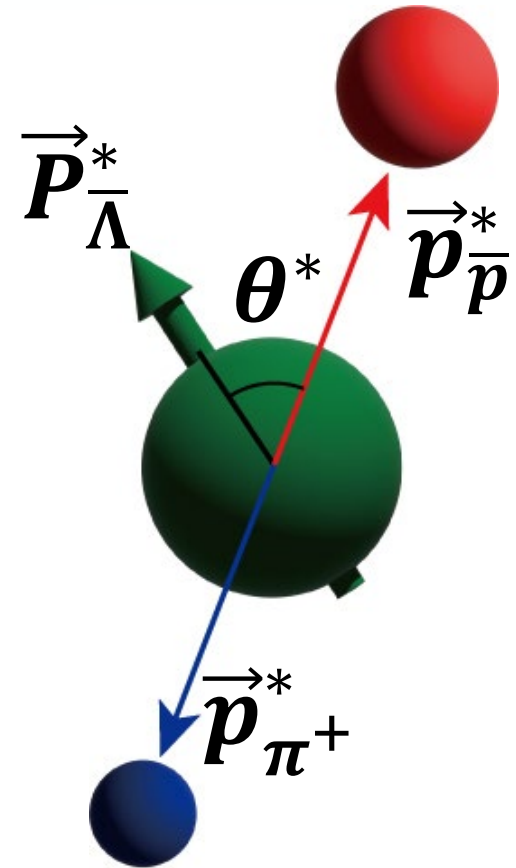
$$\frac{d\sigma}{d\Omega^*} = \frac{1}{4\pi} \left(1 + \alpha_{\bar{\Lambda}} \vec{P}_{\bar{\Lambda}}^* \cdot \hat{p}_{\bar{p}}^* \right)$$

in the $\bar{\Lambda}$ rest frame
with

$\alpha_{\bar{\Lambda}}$: decay parameter

$\vec{P}_{\bar{\Lambda}}^*$: $\bar{\Lambda}$ polarization vector

$\hat{p}_{\bar{p}}^*$: daughter antiproton direction
(unit vector)





Decay of $\bar{\Lambda}$ s into $\bar{p}$ s

Polarization vector of $\bar{p}$ s

Lee-Yang's equation:

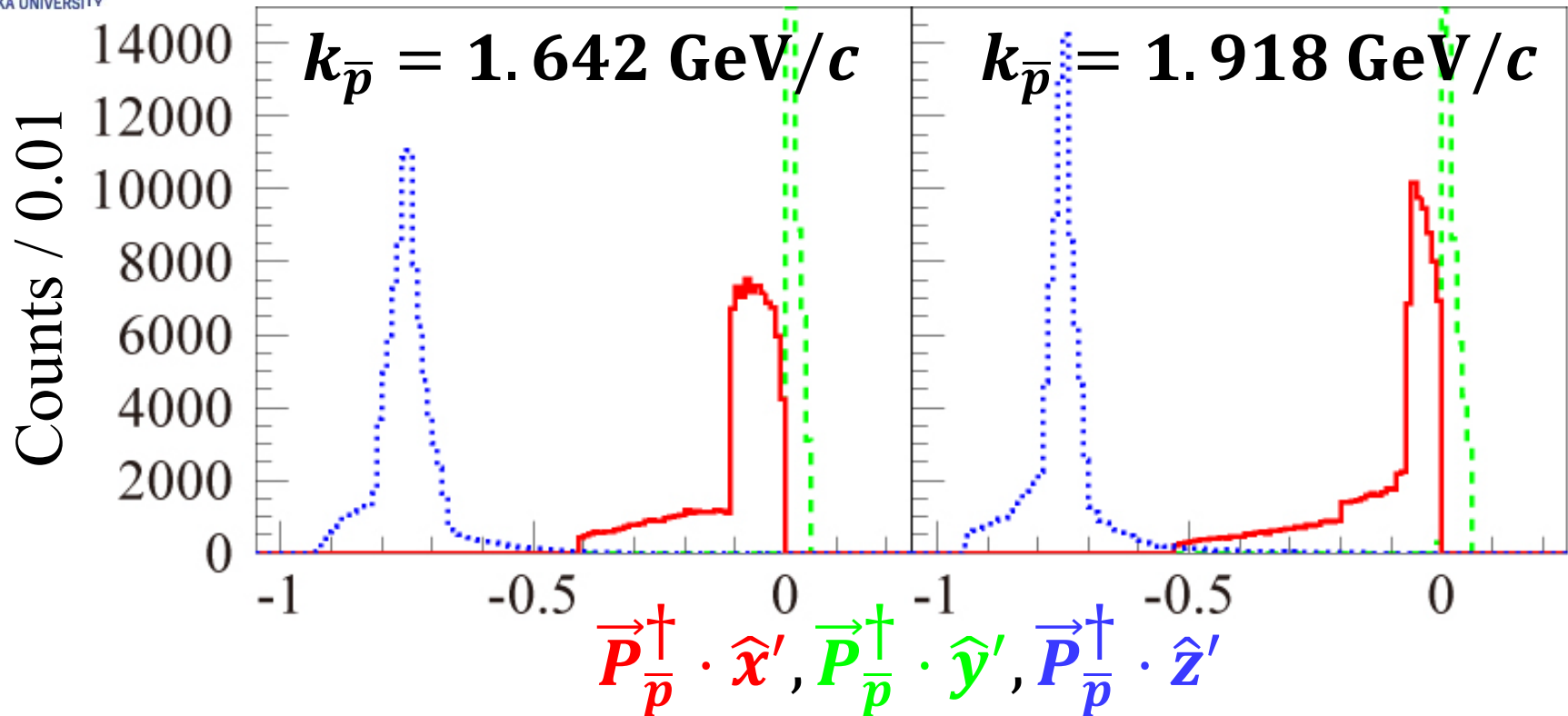
$$\begin{aligned} \vec{P}_{\bar{p}}^\dagger &= \frac{1}{1 + \alpha_{\bar{\Lambda}} \vec{P}_{\bar{\Lambda}}^* \cdot \hat{p}_{\bar{p}}^*} \left\{ \begin{aligned} &\text{self-polarization} \\ &(\alpha_{\bar{\Lambda}} + \vec{P}_{\bar{\Lambda}}^* \cdot \hat{p}_{\bar{p}}^*) \hat{p}_{\bar{p}}^* \\ &+ \beta_{\bar{\Lambda}} \vec{P}_{\bar{\Lambda}}^* \times \hat{p}_{\bar{p}}^* + \gamma_{\bar{\Lambda}} \hat{p}_{\bar{p}}^* \times (\vec{P}_{\bar{\Lambda}}^* \times \hat{p}_{\bar{p}}^*) \end{aligned} \right\} \end{aligned}$$

in the $\bar{\Lambda}$ rest frame





Decay of $\bar{\Lambda}s$ into $\bar{p}s$



sideways, normal, longitudinal

A large longitudinal polarization can be rotated into a sizable transverse polarization during momentum analysis.





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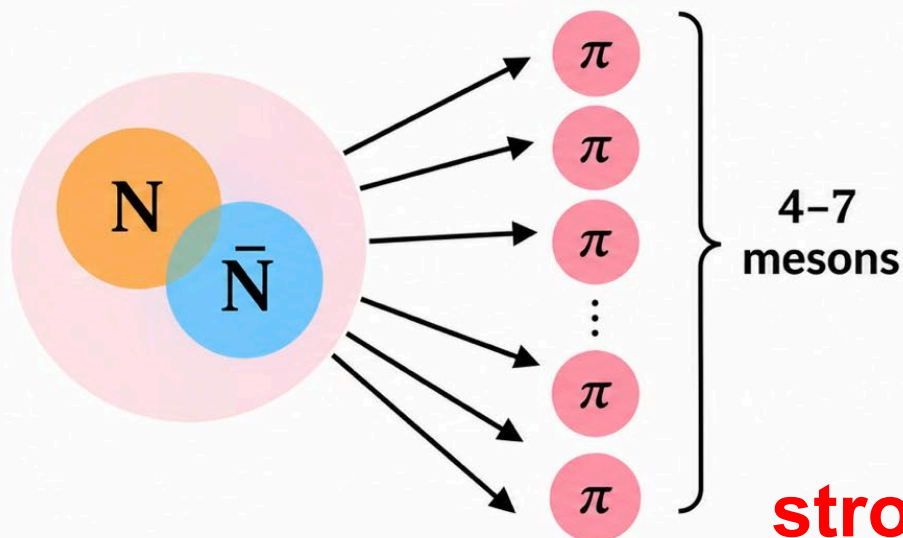
Other physics projects from our group



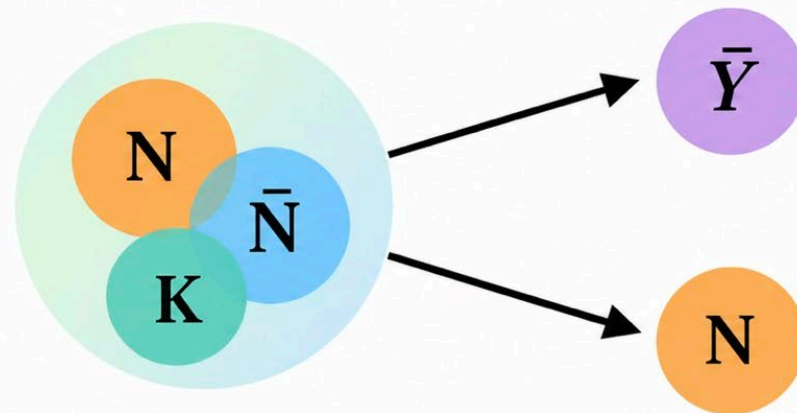
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Study of Kaonic Baryonium

$N\bar{N}$ (Baryonium)



$KN\bar{N}$ (Kaonic Baryonium)



strong attraction for $K\bar{N}$ and $N\bar{N}$
weak repulsion for KN

$$\bar{p}d \rightarrow Y(KN\bar{N})_{\text{b.s.}}$$

$$q_{\min} \sim 0.6 \text{ GeV}/c @ p_{\bar{p}} = 6 \text{ GeV}/c$$

1) antibaryon-baryon interaction

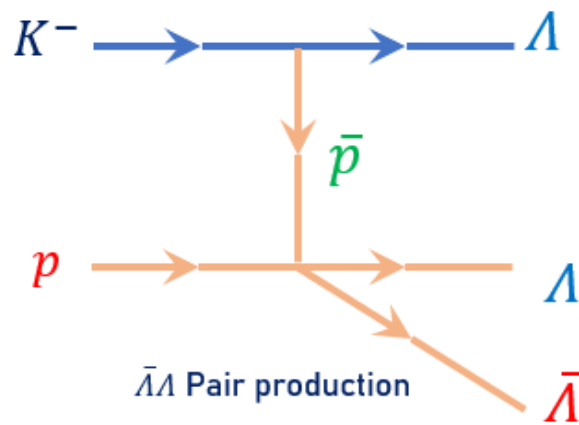
2) kaons in a nucleus

Ryo Kobayakawa

Multistrange Dibaryons in $(K^-, \bar{Y})$ Reactions

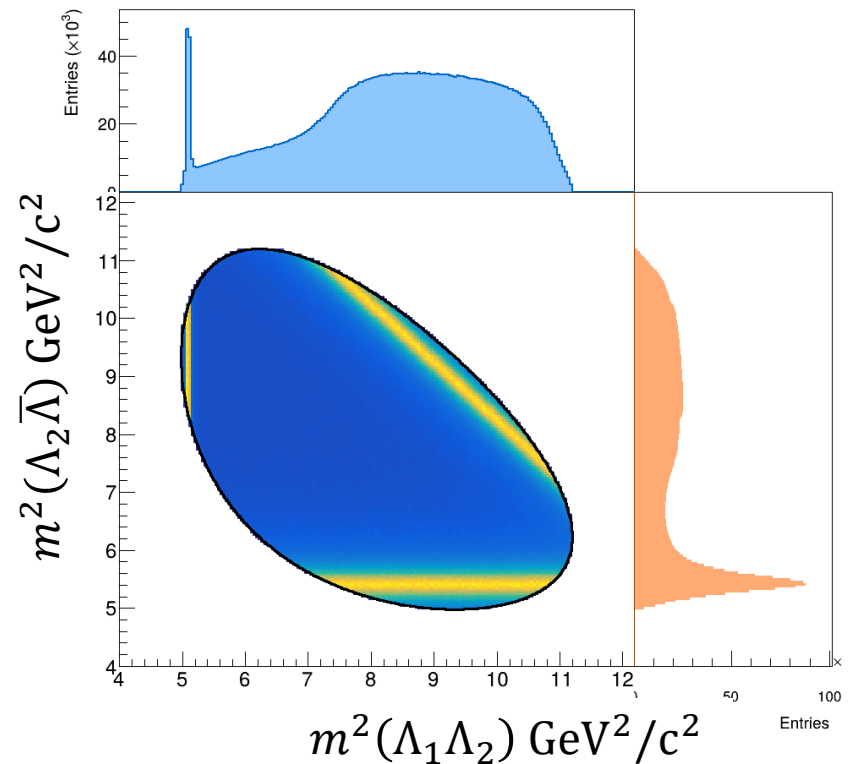
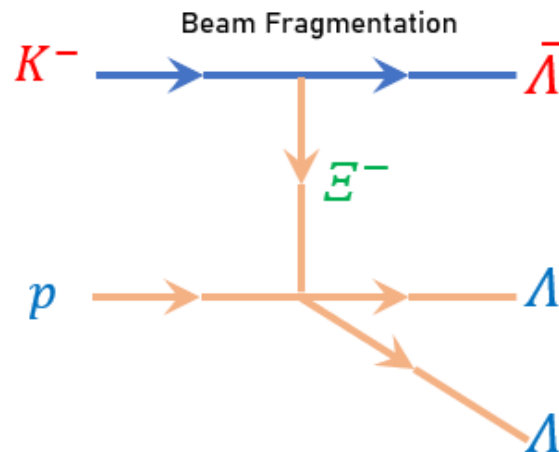
Sun Young Ryu

- $(K^-, \bar{\Lambda}(\bar{E}, \bar{\Omega}))$ reactions: open up clean kinematic phase spaces to map out three-body $YY\bar{Y}$ dynamics and provide unprecedented, clean YY scattering data.



$$\sigma(K^- p \rightarrow \bar{\Lambda} + X) \approx 0.08 \text{ mb}$$

E.L. Berger et al (CERN), CERN/D.Ph.II/Phys 74-9 (1974).



Hyperon- ^4He Scattering at K10

Does short-range repulsion change with strangeness?

Compact ^4He

$$\rho(0) \sim 2\rho_0$$

Same $^5_\Lambda\text{He}$ binding

Different cores

Direct $Y - ^4\text{He}$ scattering

$\Lambda\alpha$ first $\rightarrow \Xi\alpha$ next

Jinno et al., PRC 110, 014001 (2024)

Keigo Mizutani



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Summary



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Summary

K^+p elastic scattering

Map the transition from meson-Reggeon
to Pomeron exchange

$\bar{p}p \rightarrow \bar{Y}Y$ at around $p_{\bar{p}} \sim 5.2 \text{ GeV}/c$

Search for timelike gluonic dynamics
and a possible 4^{++} state

Polarized antiprotons

Open access to spin-dependent
annihilation amplitudes and $\bar{N}N$
interactions





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Backup



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Decay of $\bar{\Lambda}s$ into $\bar{p}s$

Polarization vector of $\bar{p}s$

$\vec{P}_{\bar{p}}^\dagger$: $\bar{p}$ polarization in the $\bar{p}$ rest frame

$\vec{P}_{\bar{\Lambda}}^*$: $\bar{\Lambda}$ polarization in the $\bar{\Lambda}$ rest frame

$\hat{p}_{\bar{p}}^*$: $\bar{p}$ direction in the $\bar{\Lambda}$ rest frame

$\bar{\Lambda}$ decay parameters

$$\alpha_{\bar{\Lambda}} = -\alpha_{\Lambda} = 0.748 \pm 0.008$$

$$\phi_{\bar{\Lambda}} = -\phi_{\Lambda} = +6.5^\circ \pm 3.5^\circ$$

$$\rightarrow \beta_{\bar{\Lambda}} = -\beta_{\Lambda} = 0.075, \gamma_{\bar{\Lambda}} = \gamma_{\Lambda} = +0.66$$

$$\alpha_{\Lambda}^2 + \beta_{\Lambda}^2 + \gamma_{\Lambda}^2 = 1$$

$$\tan\phi_{\Lambda} = \beta_{\Lambda}/\gamma_{\Lambda}$$

