Production of $d_{N\Omega}$ dibaryon in kaon induced reactions

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Outline

- **BACKGROUND**
- **PRODUCTION PROCESSES**
- **NUMERICAL RESULTS AND DISCUSSIONS**
- **SUMMARY**

BACKGROUND

dibaryon — ***B = 2***, **six quarks** → **deuteron** — **proton**, **neutron** ↓

binding energy

2.22 MeV.

SU(6) theory	Phys. Rev. Lett. 13(26), 815817
quark model	Phys. Rev. D 37, 154-158
quark-cluster	Phys. Rev. D 38, 298
Skyrme	Nucl. Phys.A 549, 485-497
quark potential	Phys. Rev. C 51, 3411
quark delocalization and color screening	Phys. Rev. C 53, 1161-1166, Phys. Rev. Lett. 69, 2901-2904
…	…

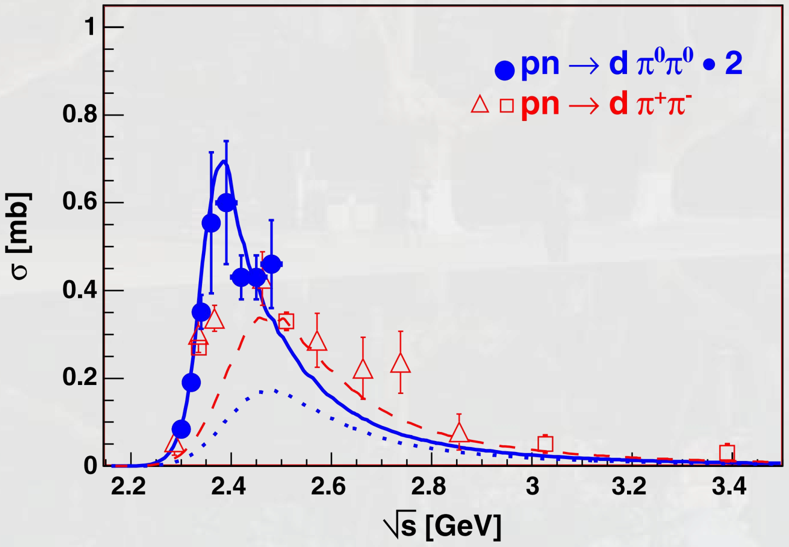
$N\Xi'$, $N\Xi_c$, $N\Xi_{cc}$, $\Xi_{cc}\Xi_{cc}$ $N\Omega$ $\Delta\Omega$

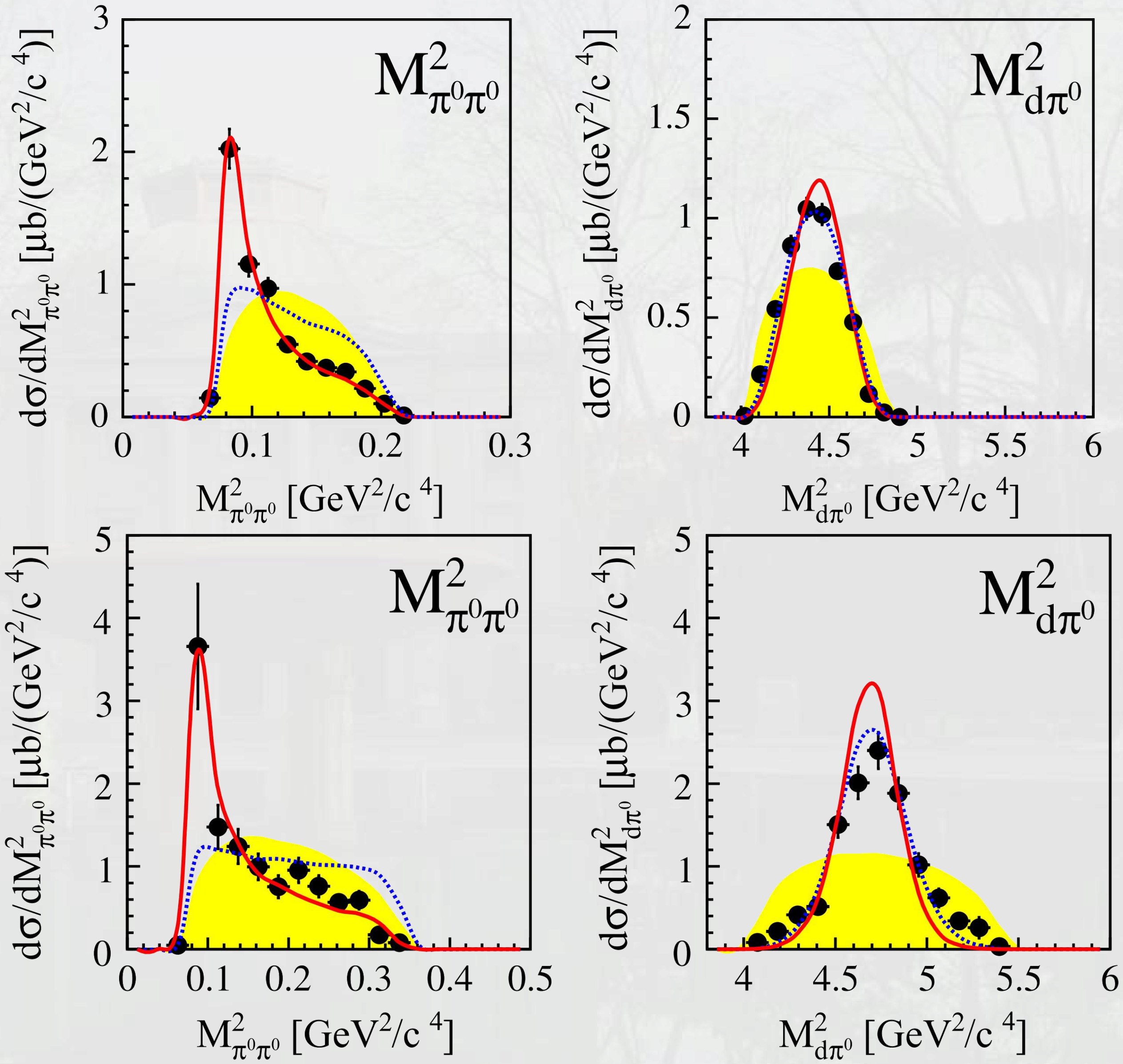
BACKGROUND

the first breakthrough

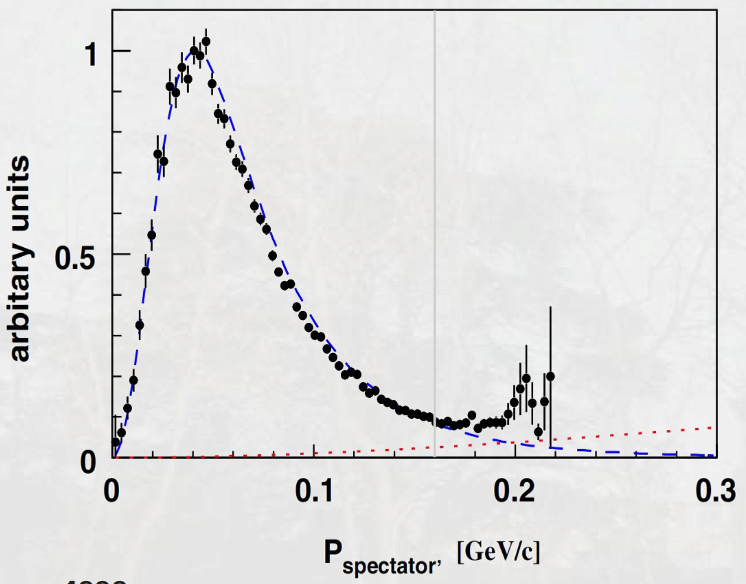
$d^*(2380)$

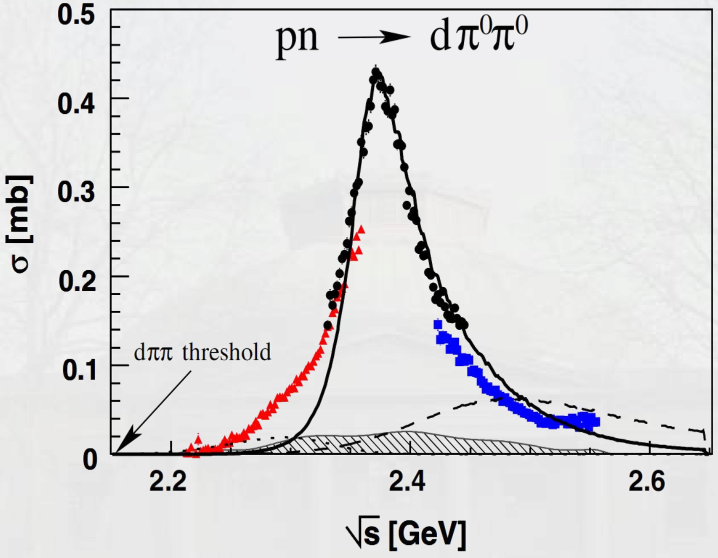
CELSIUS/WASA Collaboration
Phys.Rev. Lett.102,052301
$np \to d\pi^0\pi^0$

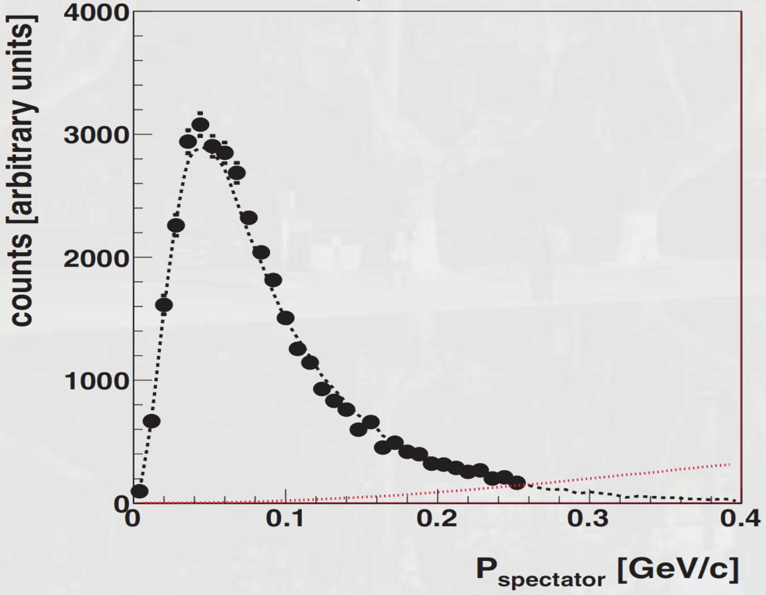


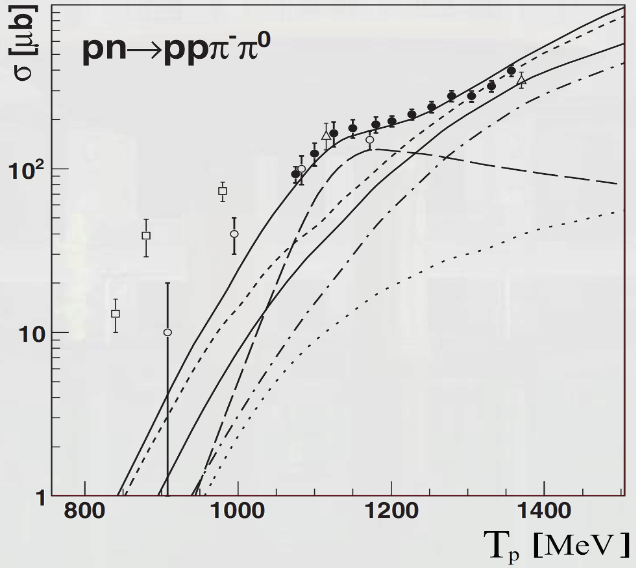


BACKGROUND









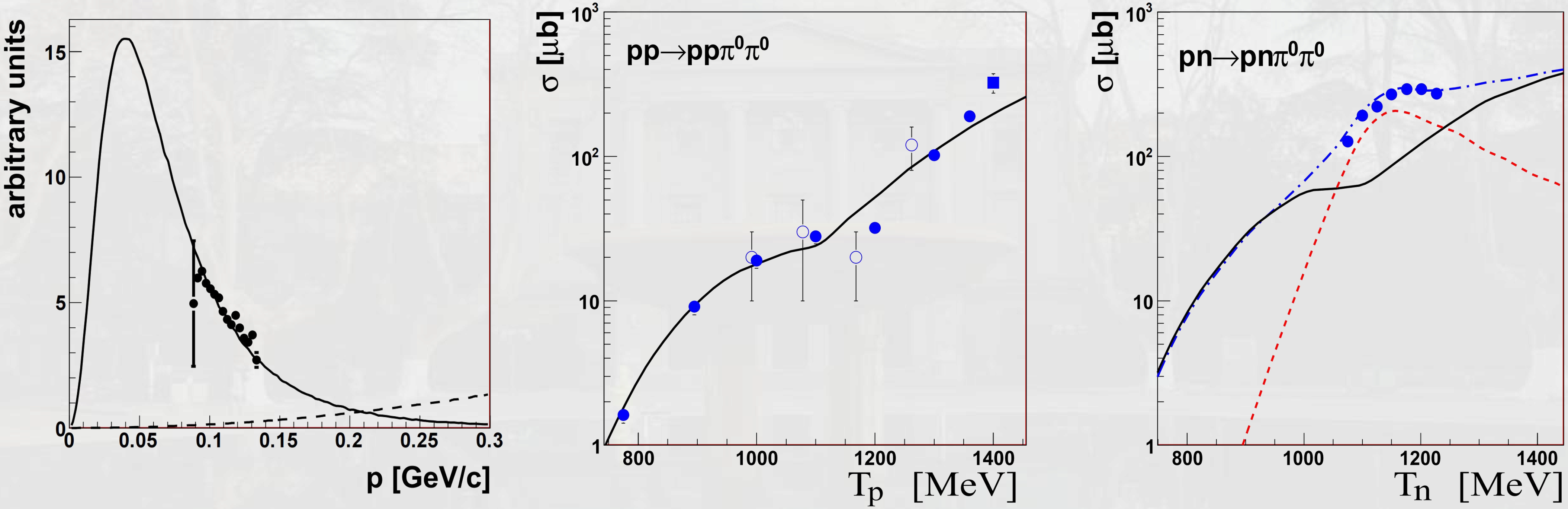
WASA-at-COSY Collaboration

Phys. Rev. Lett. 106, 242302	$np \rightarrow d\pi^0\pi^0$
Phys. Rev. C 88(5), 055208	$np \rightarrow pp\pi^-\pi^0$

BACKGROUND

WASA-at-COSY Collaboration

Phys. Lett. B 743, 325-332	$np \rightarrow np\pi^0\pi^0$



theoretical research

- **three-body hadronic model**

  $N\Delta$ and $\Delta\Delta$ dibaryon states

  Nucl. Phys. A 928, 73-88

- **pion exchange potential model**

  H-like $\Lambda_c\Lambda_c$, Λ_cN dibaryons

  Phys. Lett. B 704, 547-550 Phys. Rev. D 85, 014015

- **the quark delocalization color screening model**

  $N\Sigma_{c,b}$ $\Lambda_c\Lambda_c/\Lambda_b\Lambda_b$ dibaryons

  Phys. Rev. C 89(3),035201 Phys. Rev. C 87(3),034002

  $\Delta^0\Delta^0$, $\Omega\Omega$, $\Xi\Xi$ Phys. Rev. D 105(3),034006, Phys. Rev. C102(4),045202 , Chin. Phys.C45(4), 041002, Phys. Rev. D 105(9), 094021

…

BACKGROUND

- **QCD sum rule** Phys. Rev. D 103, 094011

  NΩ dibaryon bound state

- **chiral SU(3) quark model** arXiv:nucl-th/0606056

  may exist NΩ and ΔΩ dibaryons weakly bound systems

- **phenomenological Lagrangian approach** Phys. Rev. D 101,114032

  dynamical coalescence mechanism

  constituents and the strong decays of $d_{N\Omega}$

- **HAL QCD Collaboration** Nucl. Phys. A 928, 89-98

  near the physical point binding energy of pΩ became 2.46 MeV

…

The possibility of dibaryons with **strangeness -3** $\boxed{d_{N\Omega}}$

BACKGROUND

Searching $d_{N\Omega}$

The key point of producing the $d_{N\Omega}$ is the production of the Ω baryon

abtain Ω baryon

- **high energy heavy-ion collision**
- ***pp* collision processes**
- $K^- p \to \boxed{\Omega^-} K^+ \bar{K}^{(*)0}$ $\qquad J(J^P) = \frac{1}{2}(2^+)$

  $\Omega^- d \to \Xi^- \Lambda p$ $\to$ **$d_{N\Omega}$ invariant mass spectrum**

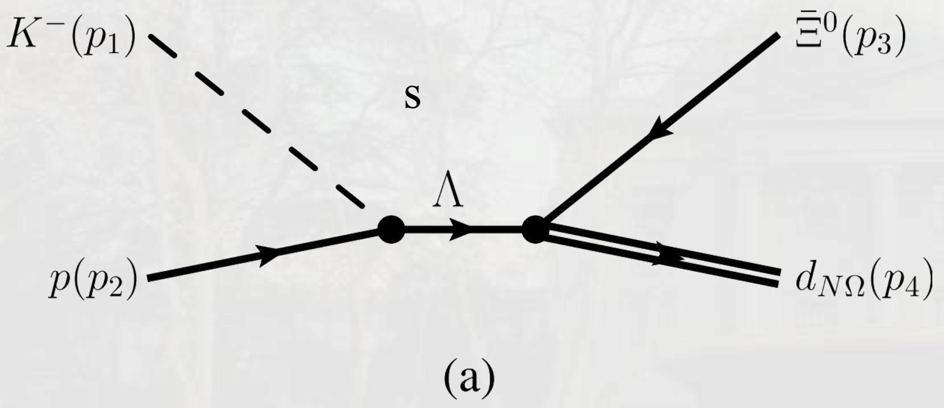
abtain kaon beam

- **J-PARC** Nucl. Phys. A 805, 486
- **COMPASS** EPJ Web Conf. 37, 01016
- **OKA@U-70** Nucl. Part. Phys. Proc. 273-275, 1330
- **SPS@CERN** Nucl. Part. Phys. Proc. 273-275, 2720

PRODUCTION PROCESSES

approach: effective Lagrangian   cross-section

A. The $K^- p \to d_{N\Omega}\bar{\Xi}^0$ process



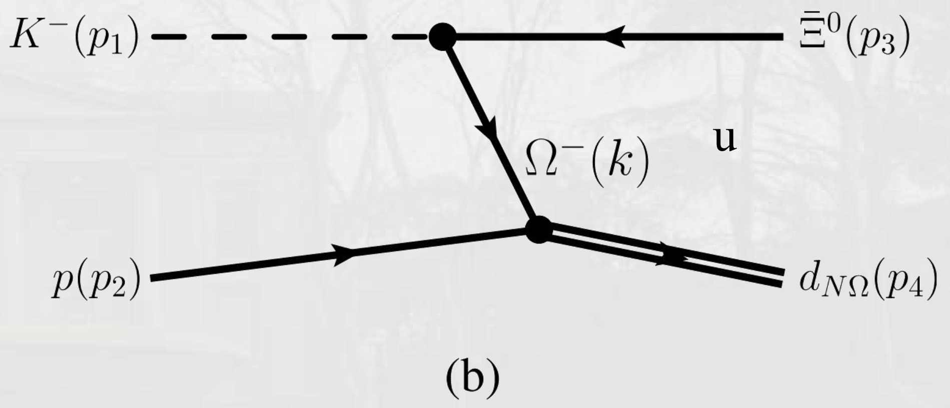


Fig. 1. (color online) Diagrams contributing to the process of $K^- p \to d_{N\Omega}\bar{\Xi}^0$, where the $d_{N\Omega}$ is considered as a S-wave $N\Omega$ dibaryon with $J^P = 2^+$.

The effective Lagrangian for the interaction reads:

$$\mathcal{L}_{d_{N\Omega}N\Omega} = g_{d_{N\Omega}N\Omega} d^{\mu\nu^\dagger}_{N\Omega} \bar{\Omega}_\mu \gamma_\nu N^c + \mathrm{H.c.} \qquad \mathcal{L}_{\Omega\Xi K} = \frac{g_{\Omega\Xi K}}{m_\pi} \partial_\beta K \bar{\Omega}^\beta \Xi + \mathrm{H.c.}.$$

$$\mathcal{M} = \frac{g_{\Omega\Xi K}}{m_\pi} \left(-i p_{1\beta}\right) g_{d_{N\Omega}N\Omega}\, d^{\mu\nu}_{N\Omega} F(k^2, m_\Omega^2) \left[\bar{u}^c(p_2, m_2)\gamma_\nu S(k, m_\Omega)_{\mu\beta} v(p_3, m_3)\right]$$

cross-section formula:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta} = \frac{1}{32\pi s}\frac{|\vec{p}_f|}{|\vec{p}_i|}\left(\frac{1}{2}\overline{|\mathcal{M}|^2}\right)$$

s is the center of mass energy and θ is the scattering angle

$$\mathrm{d}\sigma = \frac{1}{8(2\pi)^4}\frac{1}{\Phi}|\mathcal{M}|^2\mathrm{d}p_5^0\mathrm{d}p_3^0\mathrm{d}\cos\theta\mathrm{d}\eta$$

the propagator of the Ω baryon and $d_{N\Omega}$:

$$S(k, m_\Omega)_{\mu\beta} = i\frac{\not{k} + m_\Omega}{k^2 - m_\Omega^2}\left[-g_{\mu\beta} + \frac{1}{3}\gamma_{\mu\beta} + \frac{2k_\mu k_\beta}{3m_\Omega^2} + \frac{\gamma_\mu k_\beta - \gamma_\beta k_\mu}{3m_\Omega}\right]$$

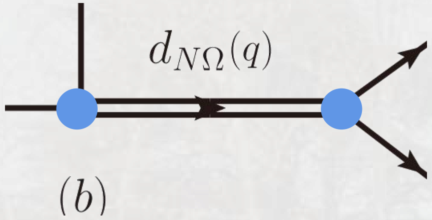
$$\mathcal{P}_{d_{N\Omega}}^{\mu\nu\lambda\omega}(q, m_{d_{N\Omega}}, \Gamma_{d_{N\Omega}}) = \frac{\mathrm{i}}{q^2 - m_{d_{N\Omega}}^2 + \mathrm{i}m_{d_{N\Omega}}\Gamma_{d_{N\Omega}}}$$

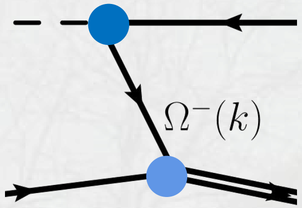
$$\times\left[\frac{1}{2}\left(\tilde{g}_{\mu\lambda}\tilde{g}_{\nu\omega} + \tilde{g}_{\mu\omega}\tilde{g}_{\nu\lambda}\right) - \frac{1}{3}\tilde{g}_{\mu\nu}\tilde{g}_{\lambda\omega}\right]$$

PRODUCTION PROCESSES

- **Form factor**

internal structures and offshell effects of the exchanging particle



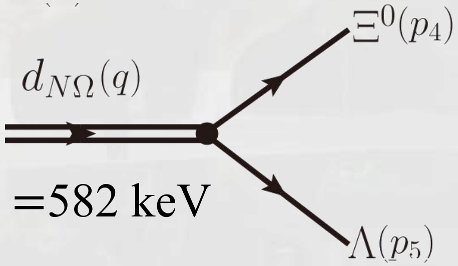


$$F(q^2, m^2) = \frac{\Lambda^4}{(m^2 - q^2)^2 + \Lambda^4}$$

- **coupling constants**

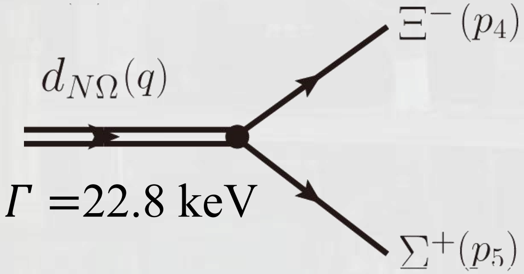
partial decay widths

$$\Gamma_{d_{N\Omega}\to\ldots} = \frac{1}{(2J+1)8\pi}\frac{|\vec{k}_f|}{M_{d_{N\Omega}}^2}|\overline{\mathcal{M}_{d_{N\Omega}\to\ldots}}|^2$$



Γ =582 keV

$$g_{d_{N\Omega}\Lambda\Xi} = 7.9\times 10^{-2}$$



Γ =22.8 keV

$$g_{d_{N\Omega}\Sigma\Xi} = 2.5\times 10^{-2}$$

Phys. Rev. D 101, 114032

Cross sections for $K^- p \to d_{N\Omega}\bar{\Xi}^0$

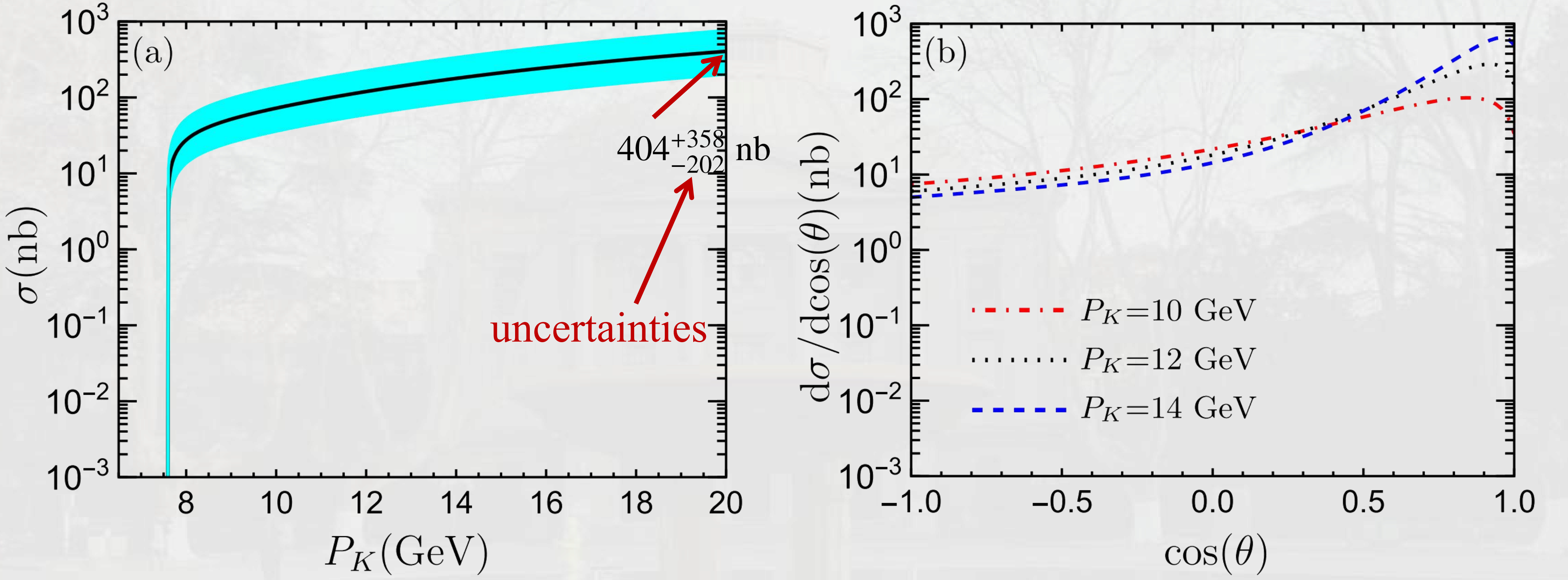
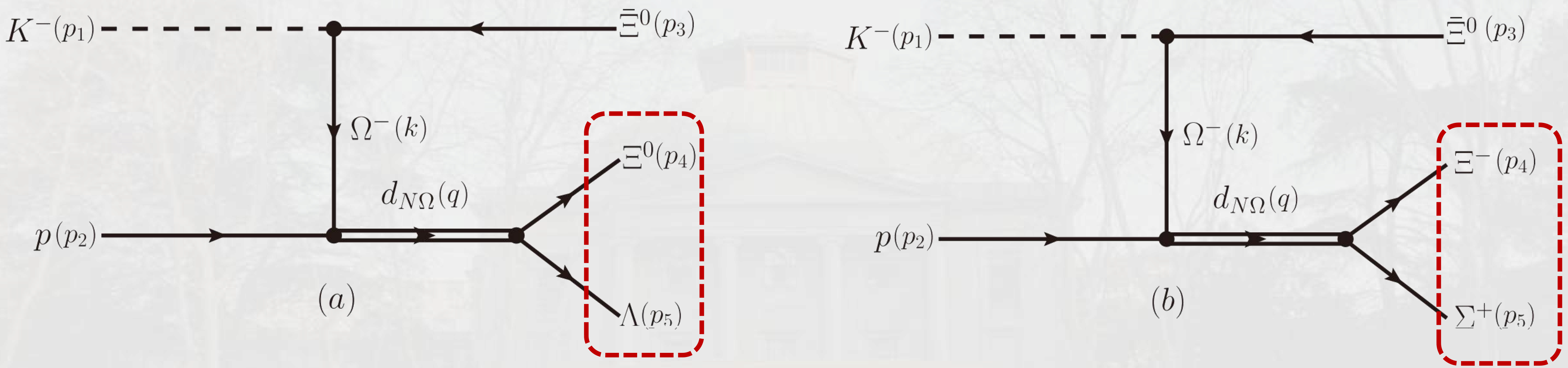


Fig. 3. (color online) Cross sections for the process $K^- p \to d_{N\Omega}\bar{\Xi}^0$ depending on the beam energy (diagram (a)), and differential cross sections depending on $\cos(\theta)$ (diagram (b)).

The cross sections increase sharply near the threshold and become very weakly dependent on the beam energy when the beam energy is greater than 9 GeV.

B. The $K^- p \to \Lambda \Xi^0 \bar{\Xi}^0$ and $K^- p \to \Sigma^+ \Xi^- \bar{\Xi}^0$ processes



$$\mathcal{L}_{d_{N\Omega}Y_1Y_2} = i\frac{G_{d_{N\Omega}Y_1Y_2}}{2M_{Y_1}}\bar{Y}_1^{\,c}\left(\gamma_\mu\partial_\nu + \gamma_\nu\partial_\mu\right)Y_2 d^{\mu\nu}_{N\Omega} + \frac{F_{d_{N\Omega}Y_1Y_2}}{(2M_{Y_1})^2}\partial_\mu\bar{Y}_1^c\partial_\nu Y_2 d^{\mu\nu}_{N\Omega} + H.c.$$

$$\begin{aligned}\mathcal{M}_a &= \left[g_{d_{N\Omega}N\Omega}\bar{u}^c(p_2,m_2)\gamma^\nu S(k,m_\Omega)_{\mu\beta}v(p_3,m_3)\right] \\ &\times \left[\frac{g_{\Omega\Xi K}}{m_\pi}(-ip_{1\beta})\right]\mathcal{P}^{\mu\nu\lambda\omega}_{d_{N\Omega}}\left(q,m_{d_{N\Omega}},\Gamma_{d_{N\Omega}}\right)\left[i\frac{G_{d_{N\Omega}\Xi\Lambda}}{2m_\Xi}\bar{u}^c(p_5,m_5)\left(\gamma_\lambda(-ip_{4\omega})+\gamma_\omega(-ip_{4\lambda})\right)u(p_4,m_4)\right] \\ &\times F\left(k^2,m_\Omega^2\right)F\left(q^2,m^2_{d_{N\Omega}}\right)\end{aligned}$$

the branching ratio of $d_{N\Omega} \to \Xi^-\Sigma^+$ is sizable

Cross section for $K^- p \to \Xi^0 \Lambda \bar{\Xi}^0$ and $K^- p \to \Xi^- \Sigma^+ \bar{\Xi}^0$

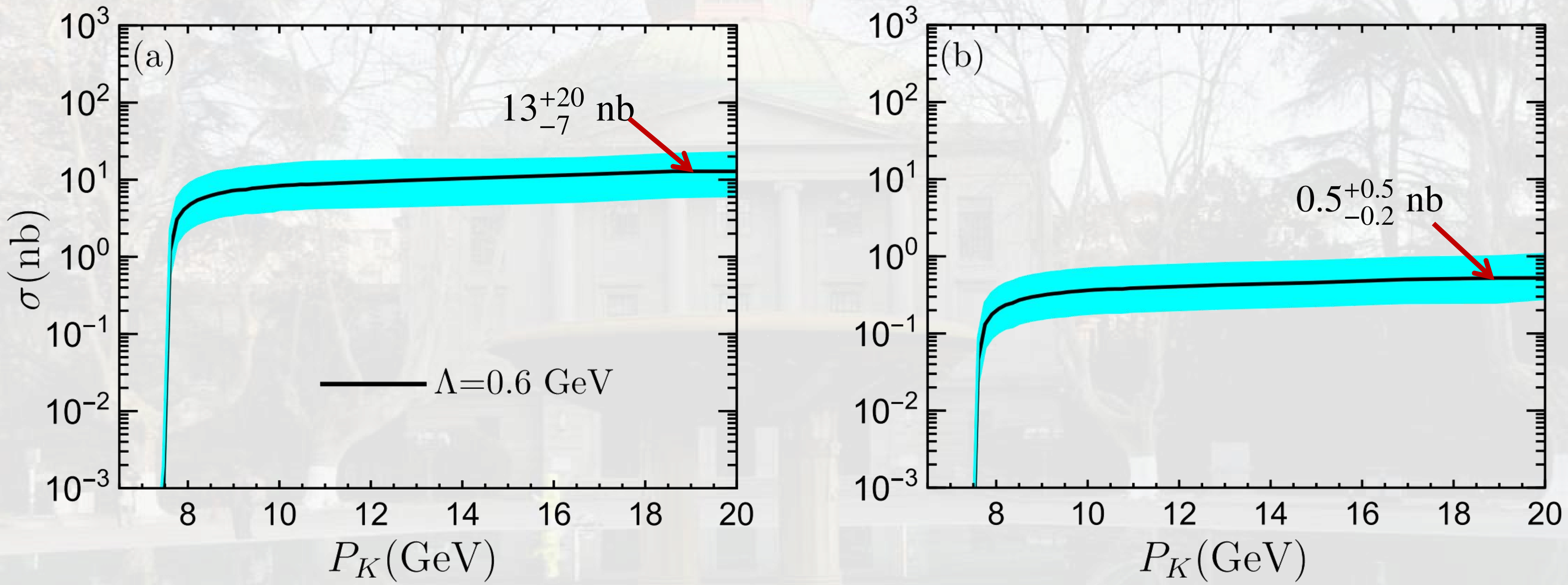


Fig. 4. (color online) Cross sections for $K^- p \to \Xi^0 \Lambda \bar{\Xi}^0$ (diagram (a)) and $K^- p \to \Xi^- \Sigma^+ \bar{\Xi}^0$ (diagram (b)) depending on the beam energy.

SUMMARY

- The production of the dibaryon is the crucial step for investigating its properties experimentally.
- The cross sections for $K^- p \to d_{N\Omega}\bar{\Xi}^0$ were estimated several hundreds nanobarns at P_K=20 GeV.
- The differential cross sections indicated that the produced $d_{N\Omega}$ dibaryons were concentrated in the forward angle area.
- $d_{N\Omega}$ dibaryon could be detected in the $\Xi^0\Lambda$ and $\Xi^-\Sigma^+$ invariant mass spectrum.

Thanks for your attention