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$K^{-}pp$-$\bar{K}^{0}np$ coupled-channel DWIA calculation for (K^{-}, n) reaction spectrum

Takahisa Koike & Toru Harada,

Osaka Electro-Communication Univ.

Akinobu Dote,

KEK Theory Center, IPNS, KEK

◆ Introduction

- **J-PARC E15 experiment;**
  search for "$K^{-}pp$" by ^{3}He(in-flight K^{-}, n)

  --- the analysis is under progress.

- **Calculation of ^{3}He(in-flight K^{-}, n) missing-mass spectra by DWIA using Green's function method;**

  - **Koike & Harada, PLB652 (2007) 262 / PRC80 (2009) 055208.**
    $K^{bar}NN$ (I=1/2) in isospin base

  - **Yamagata-Sekihara *et al*., PRC80 (2009) 045204.**
    $K^{-}pp$, $K^{0bar}np$ in charge base w/o coupling

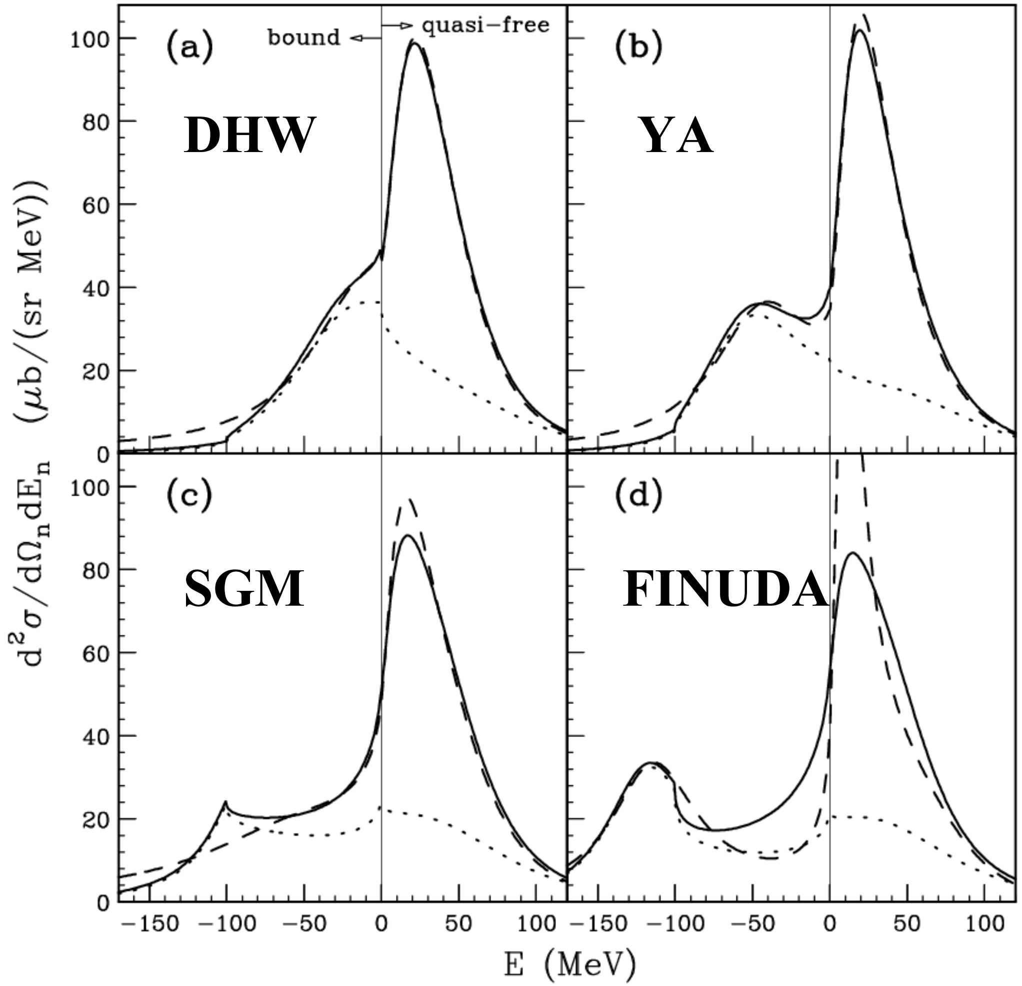
--- the further improvements of the calculations would be needed for the precise comparison with experimental data.

◆ Our previous calculation

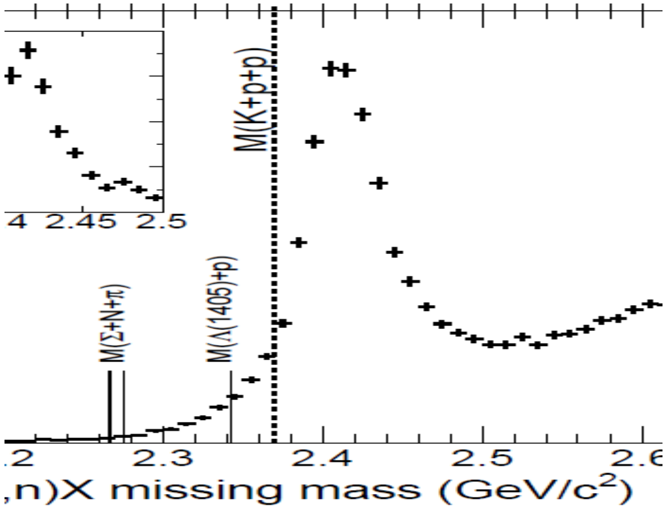
Koike & Harada, PRC80 (2009) 055208.

[$\bar{K}$ × {NN} $_{I=1}$] $_{I=1/2}$ single channel in isospin basis

phenomenological potentials simulating various cases



J-PARC E15
T. Hashimoto et al.,
PETP 2015, 061D01

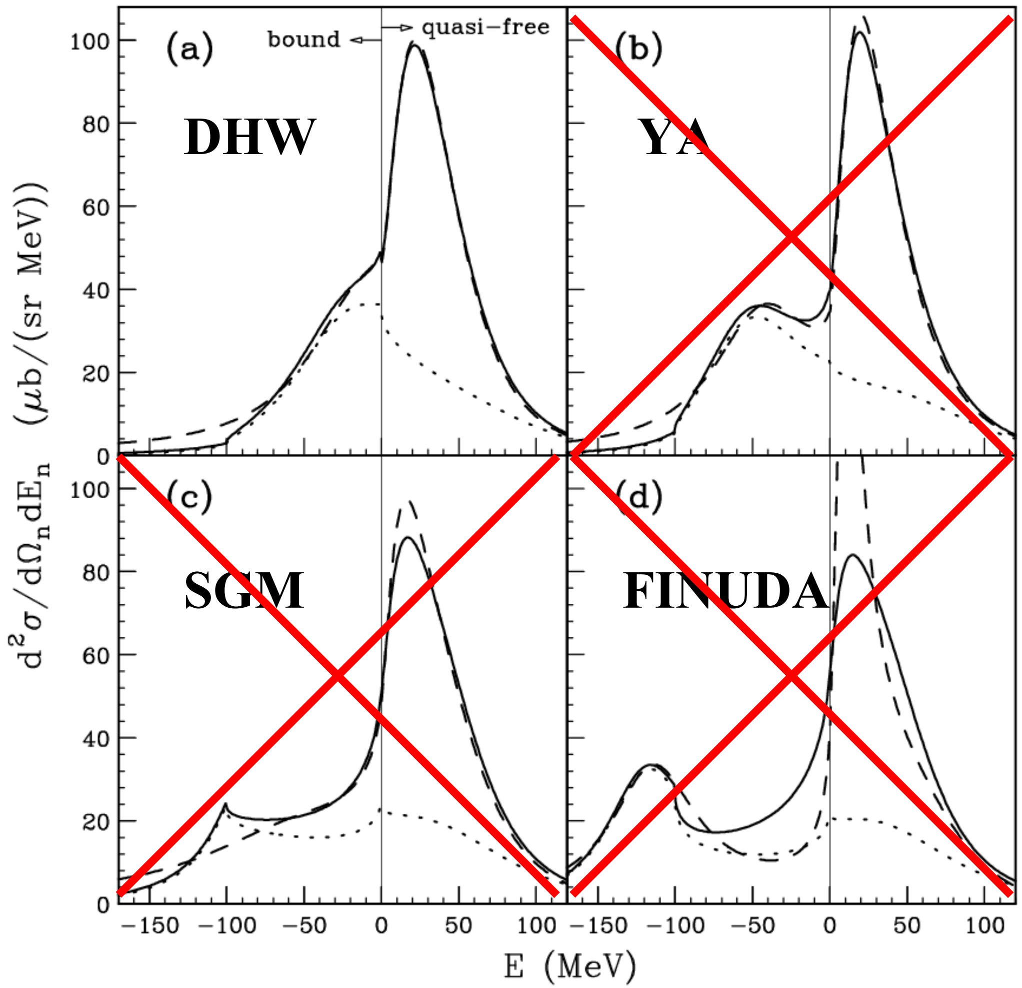


◆ Our previous calculation

Koike & Harada, PRC80 (2009) 055208.

[$\bar{K} \times \{NN\}_{I=1}$] $_{I=1/2}$ single channel in isospin basis

phenomenological potentials simulating various possibilities



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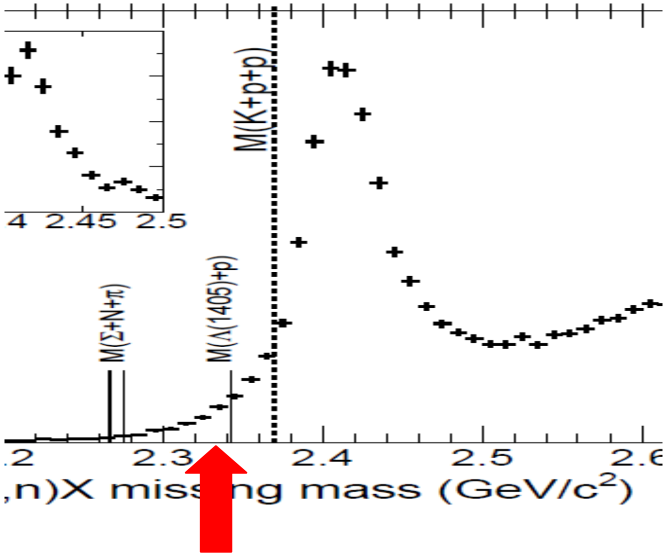


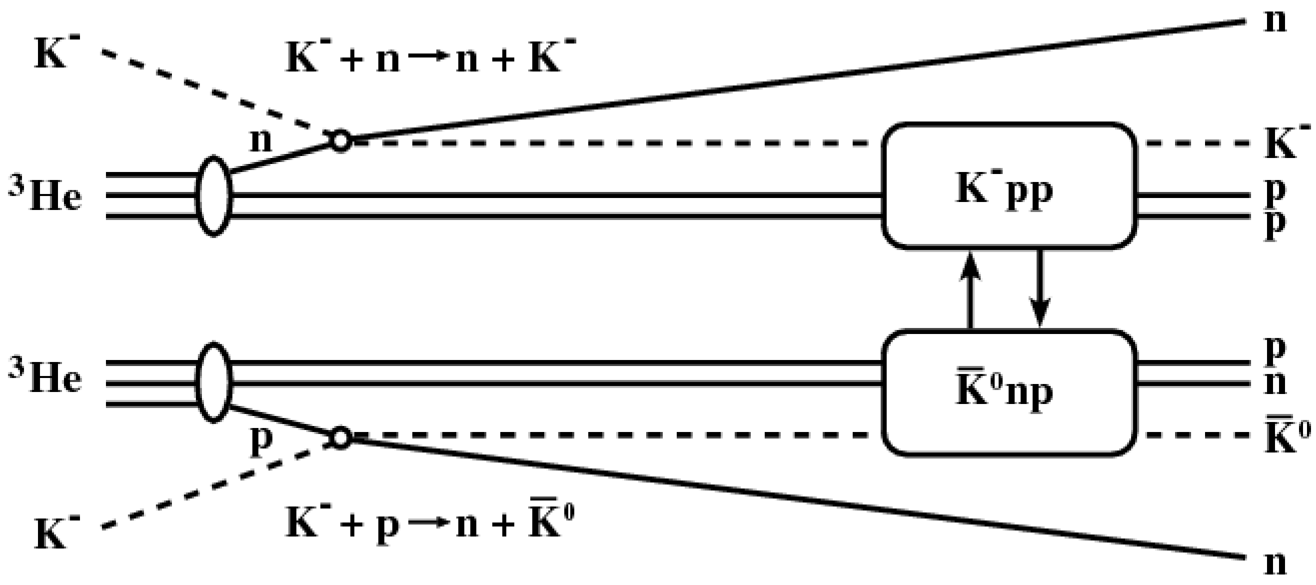
No peak
in bound-state region

◆ Purpose of this talk

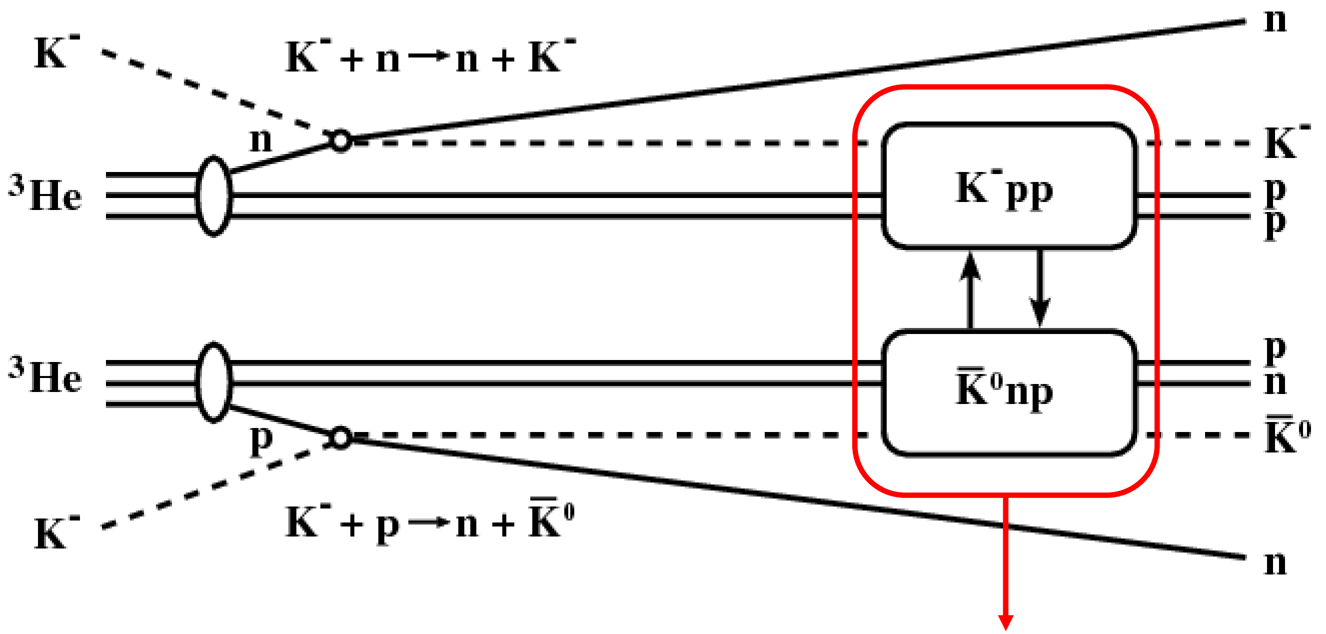
We report the new results of ^{3}He(in-flight K^{-}, n) reaction spectrum by DWIA calculation with following improvements;

present approach	previous approach
$K^{-}pp$ – $\bar{K}^{0}np$ coupled-channel Green's function method in charge base (I=1/2 & 3/2)	$\bar{K}NN$ (I=1/2) single-channel Green's function method in isospin base
Microscopic G-matrix folding potential with chiral SU(3) interaction	Phenomenologial potential using phase space factor
Adding $\bar{K}^{0}d$ S = 1 contribution	Only S = 0 contribution

◆ Reaction diagram



◆ Reaction diagram



$[\,\overline{K} \times \{NN\}_{I=1,\,S=0}\,]_{I=1/2}$

symbolically represented as "K⁻pp"

◆ DWIA framework using Green's function method

$$\frac{d^2\sigma}{d\Omega_n dE_n} = \beta\,(-)\frac{1}{\pi}\,Im\left[F^\dagger G F\right]$$

where,

$$F = -\chi_N^{(-)*}\chi_{K^-}^{(+)}\,\bar{f}_{K^-n\to nK^-}\,\langle\alpha|\hat{\psi}_n|\Psi_A\rangle + \chi_N^{(-)*}\chi_{K^-}^{(+)}\,\frac{1}{\sqrt{2}}\,\bar{f}_{K^-p\to n\bar{K}^0}\,\langle\alpha|\hat{\psi}_p|\Psi_A\rangle$$

neutron hole   proton hole

$$\equiv -\bar{f}_{K^-n\to nK^-}\,\tilde{F}_1 + \frac{1}{\sqrt{2}}\,\bar{f}_{K^-p\to n\bar{K}^0}\,\tilde{F}_2$$

In coupled channel scheme,

Factrized form

$$\frac{d^2\sigma}{d\Omega_n dE_n}$$

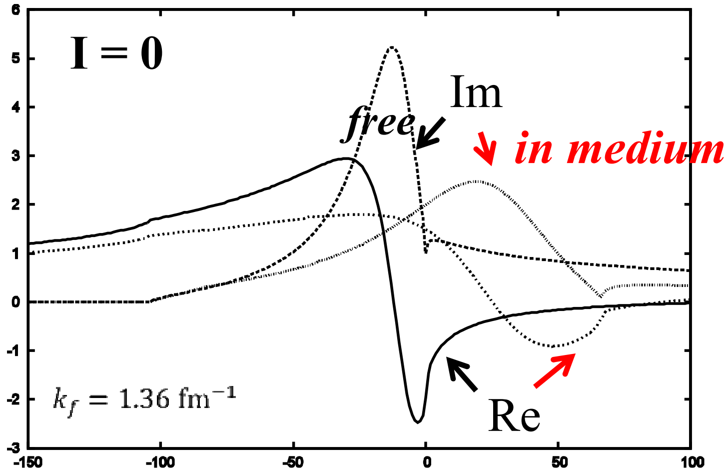
$$= \beta\,|\bar{f}_{K^-n\to nK^-}|^2\,(-)\frac{1}{\pi}\,Im\left[\tilde{F}_1^\dagger G_{11}\tilde{F}_1\right] \longrightarrow \beta\left\langle\frac{d\sigma}{d\Omega}\right\rangle_{K^-n\to nK^-} S_1(E)$$

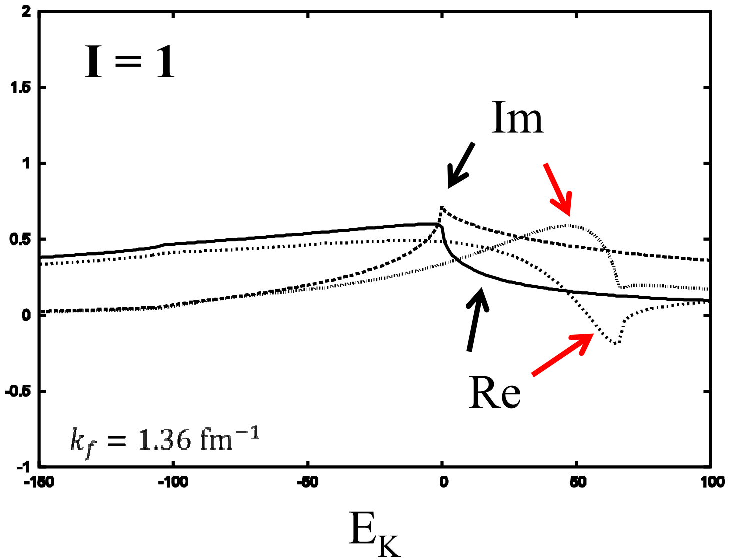
$$+\,\beta\,\frac{1}{2}\,|\bar{f}_{K^-p\to n\bar{K}^0}|^2\,(-)\frac{1}{\pi}\,Im\left[\tilde{F}_2^\dagger G_{22}\tilde{F}_2\right] \longrightarrow \beta\,\frac{1}{2}\left\langle\frac{d\sigma}{d\Omega}\right\rangle_{K^-p\to n\bar{K}^0} S_2(E)$$

$$-\,\beta\,\sqrt{2}\,Re(\bar{f}_{K^-n\to nK^-}\bar{f}^*_{K^-p\to n\bar{K}^0})(-)\frac{1}{\pi}\,Im\left[\tilde{F}_1^\dagger G_{12}\tilde{F}_2\right] \longrightarrow \text{(interference term)}$$

◆ G-matrix folding potentials for $\bar{K}$-"NN" system

$K^{bar}N$ Scattering amplitude





- **$K^{bar}N$-πΣ(-πΛ) interaction**

Chiral SU(3) + $K^{bar}N$ Scattering length

$$\hat{V}_{MB}^{\mathrm{NRv2}} = \sum_{\alpha,\beta} -\frac{C^I_{\alpha\beta}}{8f_\pi^2}(\omega_\alpha+\omega_\beta)\sqrt{\frac{1}{m_\alpha m_\beta}}\, g^I_{\alpha\beta}(r)$$

NRv2: Dote et al., NPA912(2013)66.

- **G-matrix in nuclear medium**

$$g = v + v\frac{Q_N}{E_{\bar{K}} - Q_N T Q_N} g$$

Parameters: E_{st} = -20 MeV, k_f = 1.36 fm^{-1}

- **Folding model potential**

$$U_{\alpha\alpha'} = \langle\phi_\alpha|\sum_i \bar{g}|\phi_{\alpha'}\rangle(1-\kappa_{NN})$$

= 0.3

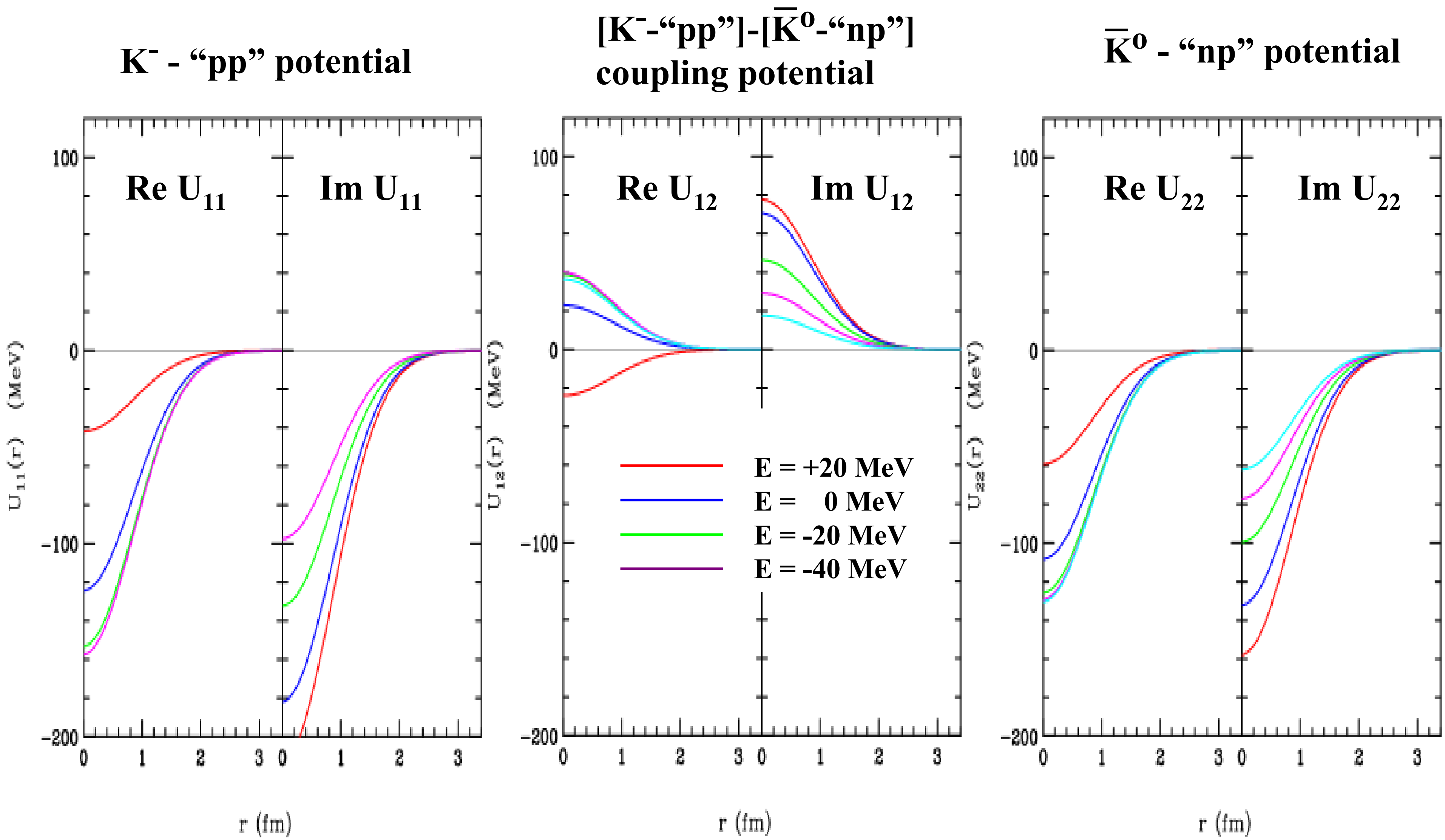
rearrangement effects

ϕ_α **: NN w.f. gaussian (r.m.s) = 2.8 fm**

◆ Calculated $\bar{K}$-"NN" potentials

B.E. = 15 MeV, *Γ* ~ 120 MeV

Approximation;
- No "NN" shrinking effect



◆ Coupled-channel Green's function

- **Ch.1; K^-pp = K^- + $\{pp\}_{s=0}$ core,**
- **Ch.2; K^0np = $\bar{K}^0$ + $\{np\}_{s=0}$ core,**

$$\begin{bmatrix} E_1 - T_1^{(l)} - U_{11}(r) & -U_{12}(r) \\ -U_{21}(r) & E_2 - T_2^{(l)} - U_{22}(r) \end{bmatrix} \begin{bmatrix} G_{11}^{(l)}(E;r,r') & G_{12}^{(l)}(E;r,r') \\ G_{21}^{(l)}(E;r,r') & G_{22}^{(l)}(E;r,r') \end{bmatrix} = \begin{bmatrix} \delta(r'-r) & 0 \\ 0 & \delta(r'-r) \end{bmatrix}$$

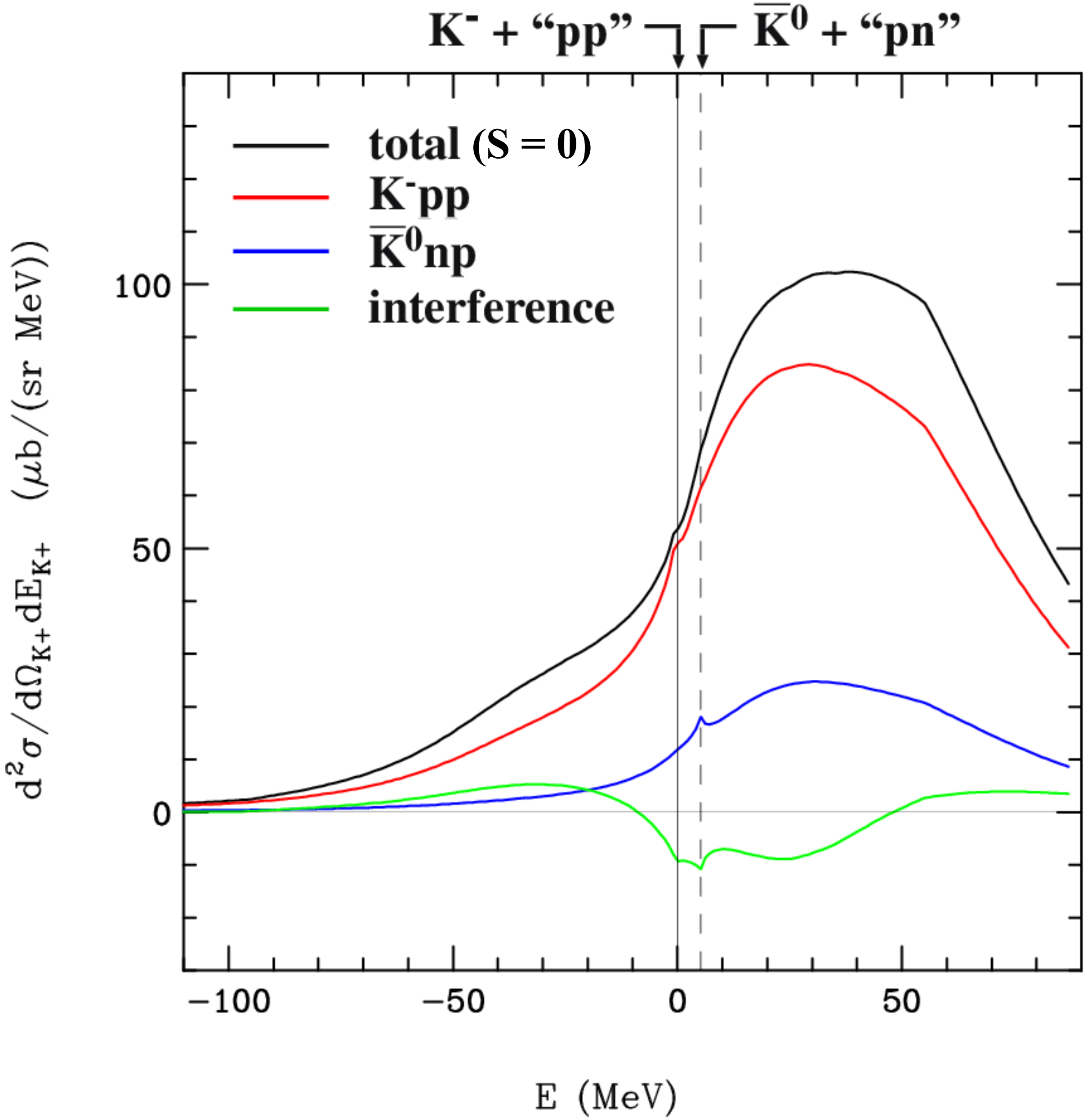
where

$$T_i^{(l)} = \frac{\hbar^2}{2\mu_i}\left(-\frac{\partial^2}{\partial r^2} + \frac{l(l+1)}{r^2}\right) \quad (i = 1, 2)$$

$$E_2 = E_1 + \Delta Q, \quad \Delta Q \equiv M(\bar{K}^0 + n + p) - M(K^- + p + p) = 5.23 \text{ MeV}$$

$$\begin{cases} U_{11}\text{: } K^-\text{-"}pp\text{" potential} \\ U_{12} = U_{21}\text{: coupling potential between } K^-\text{-"}pp\text{" and } \bar{K}^0\text{-"}np\text{"} \\ U_{22}\text{: } \bar{K}^0\text{-"}np\text{" potential} \end{cases}$$

◆ ^{3}He(K^{-}, n) inclusive spectrum at p_{K^-} = 1 GeV/c, $\theta_n = 0^o$



◆ Importance of $\bar{K}^0 d$ (S = 1) channel

Koike & Harada, Nucl. Phys. A804 (2008) 231.

$T\ (T_C)$	$S\ (S_C)$	$\sigma(K^-, n)$	
$\frac{1}{2}$ (0)	1 (1)	$\boxed{\frac{3}{2} \lvert f_{K^-p \to n\bar{K}^0} \rvert^2}$	$\bar{K}^0 d$
$\frac{1}{2}$ (1)	0 (0)	$\frac{2}{3} \lvert f_{K^-n \to nK^-} + \frac{1}{2} f_{K^-p \to n\bar{K}^0} \rvert^2$	
$\frac{3}{2}$ (1)	0 (0)	$\frac{1}{3} \lvert f_{K^-n \to nK^-} - f_{K^-p \to n\bar{K}^0} \rvert^2$	

$$\underbrace{\lvert f_{K^-n \to nK^-} \rvert^2}_{K^-\{pp\}_{s=0}} + \underbrace{\boxed{\frac{1}{2} \lvert f_{K^-p \to n\bar{K}^0} \rvert^2}}_{\bar{K}^0\{np\}_{s=0}} + \text{(interference)}$$ **in charge basis**

Production cross section $\boxed{\sigma(\bar{K}^0 d) \sim 3 \times \sigma(\bar{K}^0\{np\}_{s=0})}$

Fairly large contribution

◆ Adding $\bar{K}^0 d$ (S = 1) channel

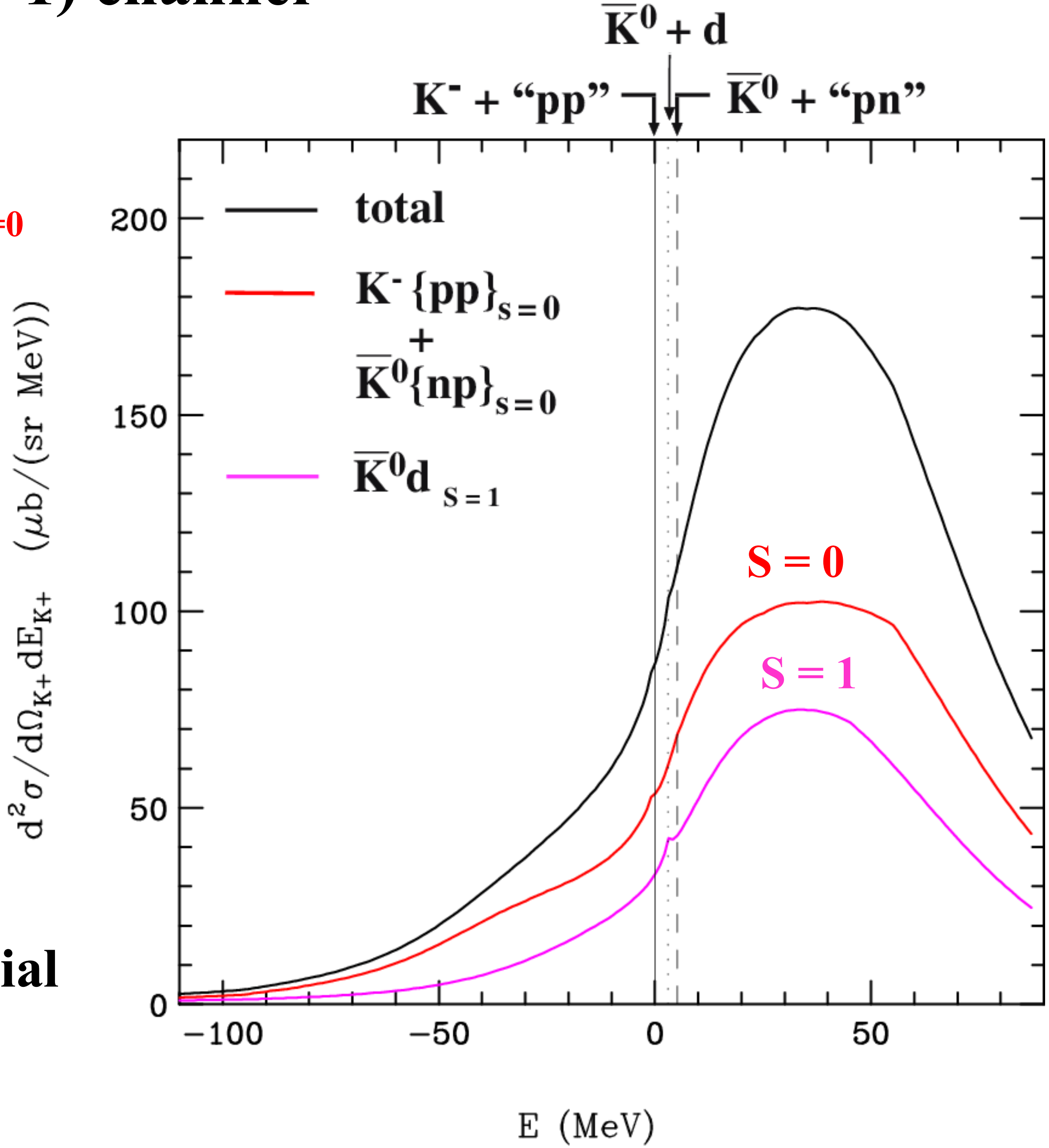
$K^- \{np\}_{S=0}$-$\bar{K}^0 \{np\}_{S=0}$

B.E. = 15 MeV
Γ ~ 120 MeV

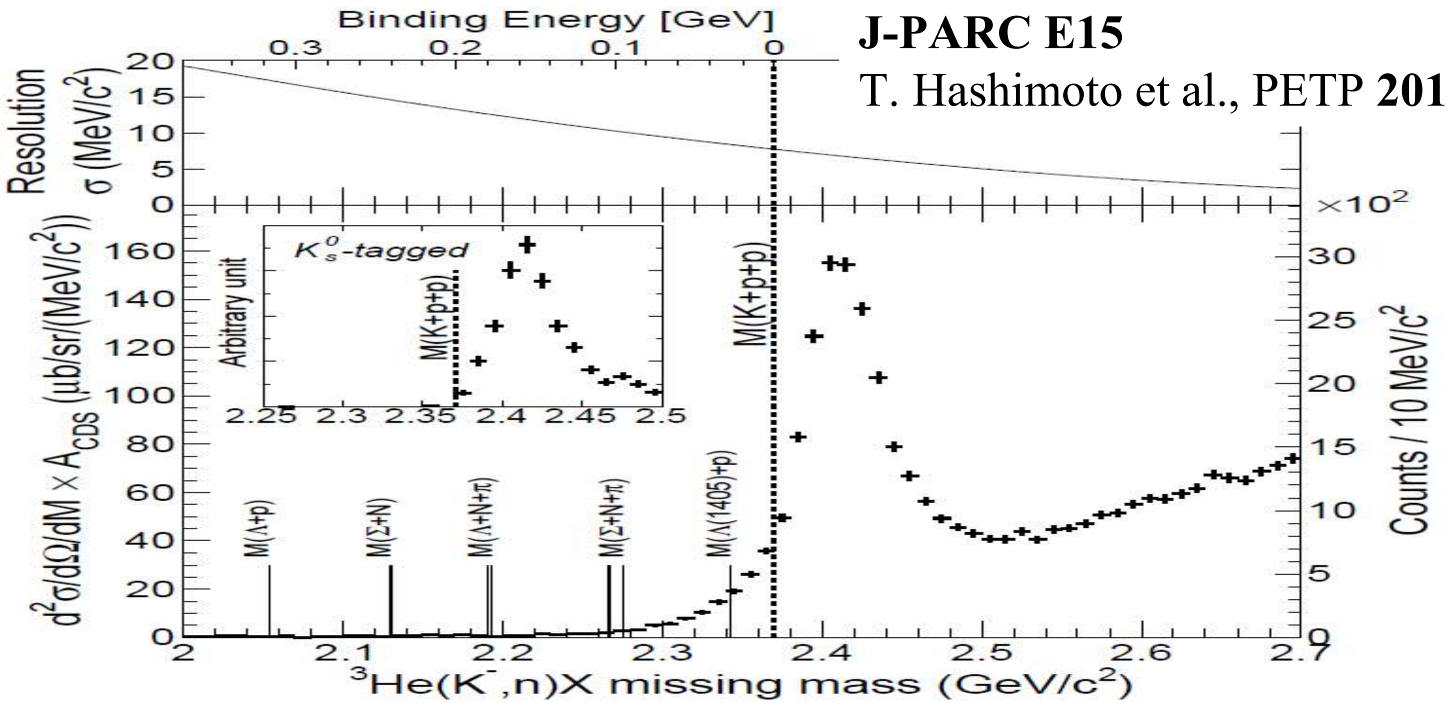
$\bar{K}^0 d_{S=1}$

B.E. ~ 0 MeV
Γ ~ 40 MeV

$\bar{K}^0$-d potential
~ $\bar{K}^0$-$\{np\}_{S=0}$ potential
w/o coupling

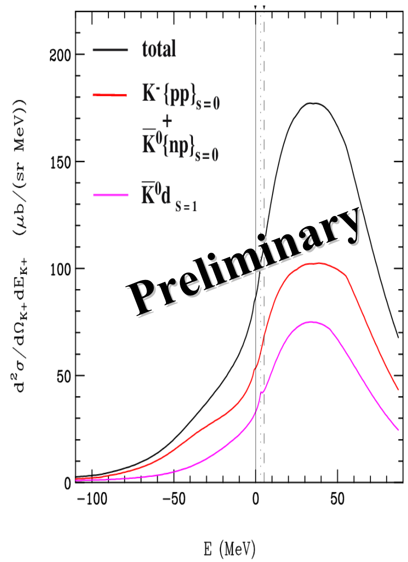


◆ Comparison with J-PARC data



J-PARC E15

T. Hashimoto et al., PETP **2015**, 061D01



Our calculation

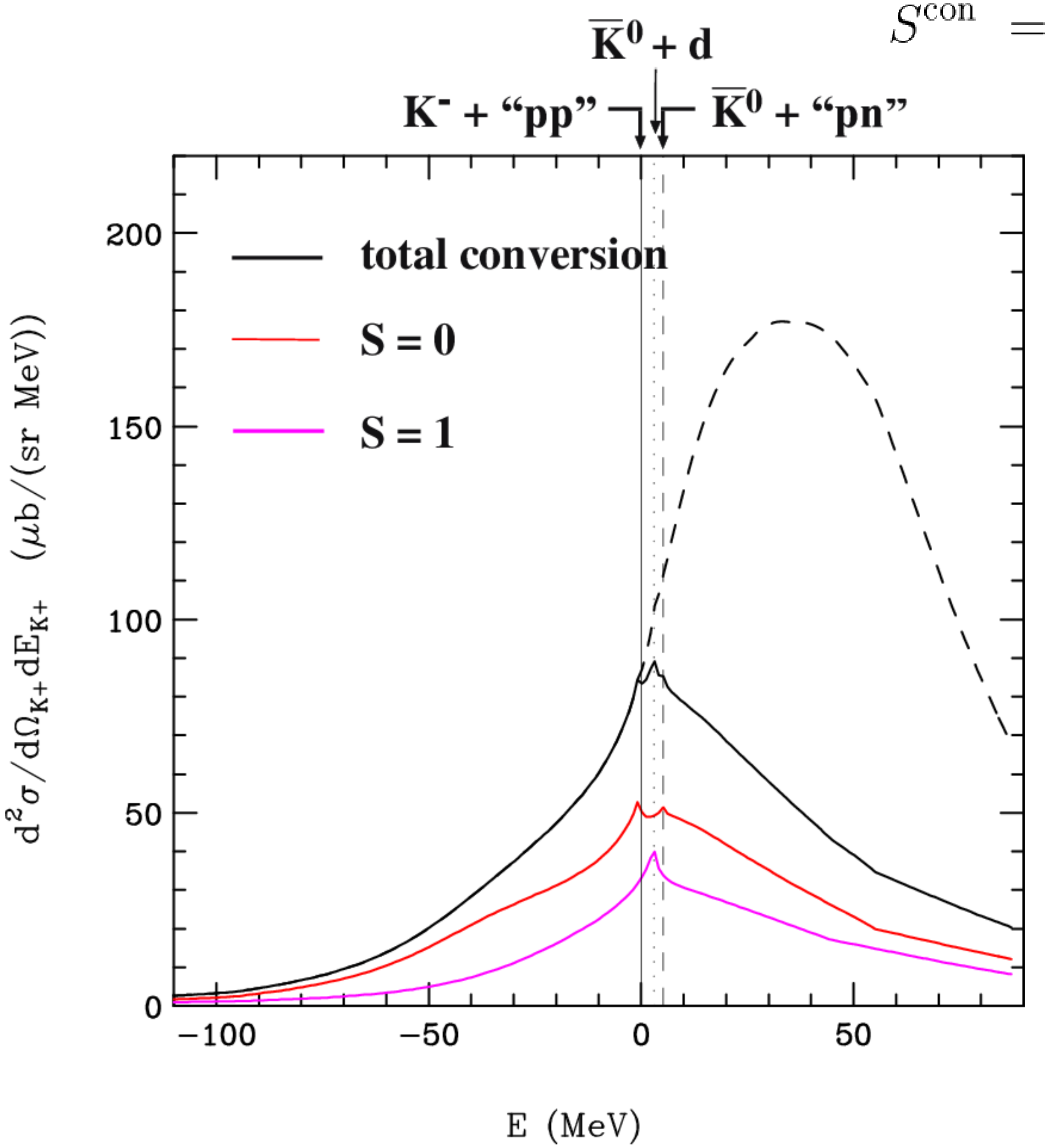
Caution:

No “NN” core-nuclear breakup

No QF-Λ(1405) formation

◆ Conversion spectrum

$$S^{\mathrm{con}} = -\frac{1}{\pi} F^\dagger G^\dagger (\mathrm{Im}\, U) G F$$



$\overline{K}NN$

→ $\pi\Sigma N$

→ $\pi\Lambda N$

→ ΣN

→ ΛN

◆ Summary and problems

- The bound state peak would not be visible due to the small B.E. and the large width.

  --- consistent with the preliminary experimental data.

- The contribution of $\bar{K}^0 d$ (S = 1) channel could be comparable with that of $K^- pp + \bar{K}^0 np$ (S = 0) in QF region.

- For more quantitative comparison with J-PARC data, we need;

  a. to include the "NN" core-nuclear breakup process and the QF-$\Lambda(1405)$ formation process.

  b. to decompose the inclusive spectrum into (semi-)exclusive spectra.