Formation of $\bar{K}$-nucleus systems at J-PARC

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Introduction

- Kaonic Nuclei

  -- ^{12}C, ^{16}O Theor. : Yamagata, Nagahiro, Hirenzaki(Structure, Reaction)
  : Mares, Friedman, Gal (Structure)
  Exp. : Kishimoto, Hayakawa -- Osaka Group

  -- ^{4}He Theor. : Akaishi, Yamazaki, Dote (Structure)
  Exp. : Iwasaki, Suzuki -- RIKEN Group

Many Subcomponents
Large Widths

➔ It seems difficult to observe clear signals for these kaonic nuclei.

J-PARC

- $^{3}He(K^{-},n)K^{-}pp$ J-PARC E15, Iwasaki, Nagae
  -- Signals for kaonic nuclei ? (even with large width?)
  (only a few subcomponents)
- Many Theoretical Studies for $K^{-}pp$ bound states.

We want to know the shapes of the spectra
for the formation of $\bar{K}NN$ states!!

In today's talk…

Yamagata, Nagahiro, Okumura, Hirenzaki, PTP114(05)301 ; Errata 114(05)905
Yamagata, Nagahiro, Hirenzaki, PRC74(06)014604
Yamagata, Hirenzaki, EPJA31(07)255
Yamagata, Nagahiro, Kimura, Hirenzaki PRC76(07)045204

1. Light Kaonic Nuclei ($\bar{K}NN$ systems)
   - (Bound states by solving Klein-Gordon equation)
   - Formation spectra in Green's function method

T. Koike, T. Harada , PLB 652(07)262

Main Part

novelty !!

- $\bar{K}$ - NN optical potential based on chiral amplitudes
- Consider all possible two nucleons and $\bar{K}$ systems
- Include the contributions from $\bar{K}^0$ initiated process.

$^3\mathrm{He}(K^-,n)$	$^3\mathrm{He}(K^-,p)$	$t(K^-,n)$	$t(K^-,p)$
K^-pp	K^-pn	K^-pn	K^-nn
$\bar{K}^0pn$		$\bar{K}^0nn$	

We show the missing mass spectra accompanied by the particle emissions due to Kbar absorption in nucleus.

2. Deeply bound kaonic atoms

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Yamagata, Nagahiro, Okumura, Hirenzaki,
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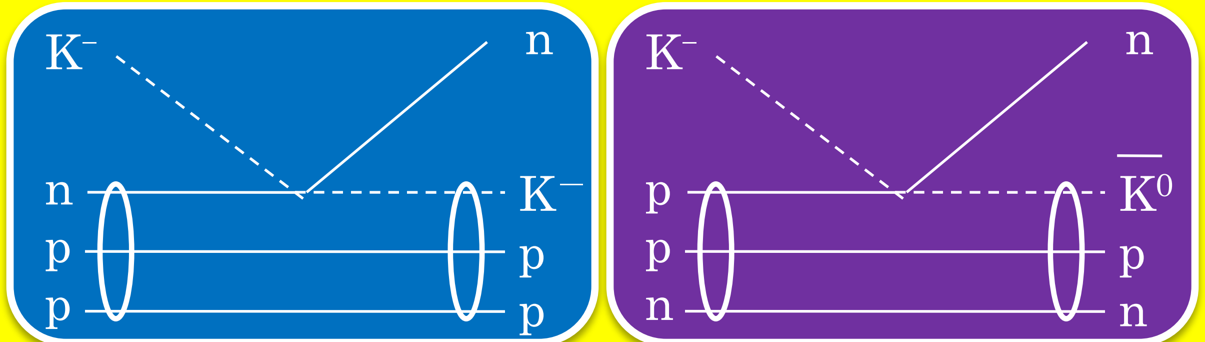
Part

novelty !!



- Include t… …ributions from $\bar{K}^0$ initiated process.

$^3\mathrm{He}(K^-,n)$	$^3\mathrm{He}(K^-,p)$	$t(K^-,n)$	$t(K^-,p)$
K^-pp	K^-pn	K^-pn	K^-nn
$\bar{K}^0pn$		$\bar{K}^0nn$	

We show the missing mass spectra accompanied
by the particle emissions due to Kbar absorption in nucleus.

2. Deeply bound kaonic atoms

Our theoretical tools

- Bound state by solving Klein-Gordon equation

selfconsistent with energy

E. Oset and L. L. Salcedo, J. Comput. Phys. 57 (85) 361

$$[-\vec{\nabla}^2 + \mu^2 + 2\mu V_{\rm opt}(r,\omega)]\phi(\vec{r}) = [\omega - V_{\rm coul}(r)]^2\phi(\vec{r})$$

- Formation spectra in Green's function method

O. Morimatsu, K. Yazaki, NPA435(85)727, NPA483(88)493

$$\frac{d^2\sigma}{dEd\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{\bar{K}N\to N\bar{K}} \sum_{\alpha} -\frac{1}{\pi}{\rm Im}\int d\vec{r}d\vec{r}'\, f_\alpha^*(\vec{r}')G(E;\vec{r}',\vec{r})f_\alpha(\vec{r})$$

$\left(\frac{d\sigma}{d\Omega}\right)_{\bar{K}N\to N\bar{K}}$: Elementary cross section (Exp. data)

$G(E;\vec{r}',\vec{r})$: Green function for K interacting with the nucleus

1-1. Optical Potential

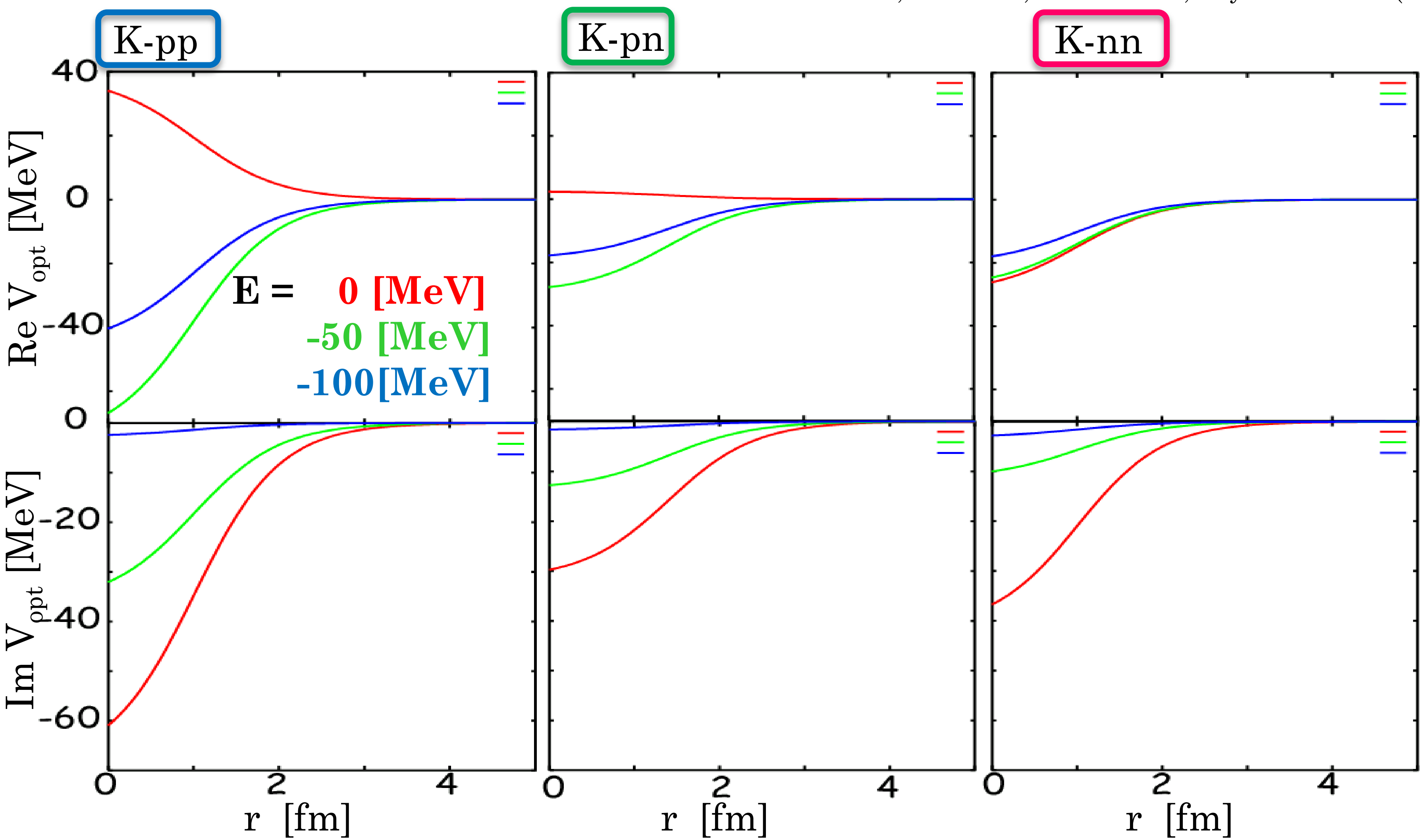
- Chiral Unitary Model

$T\rho$ approximation.

$\frac{A-1}{A}$ factor (To avoid double counting)

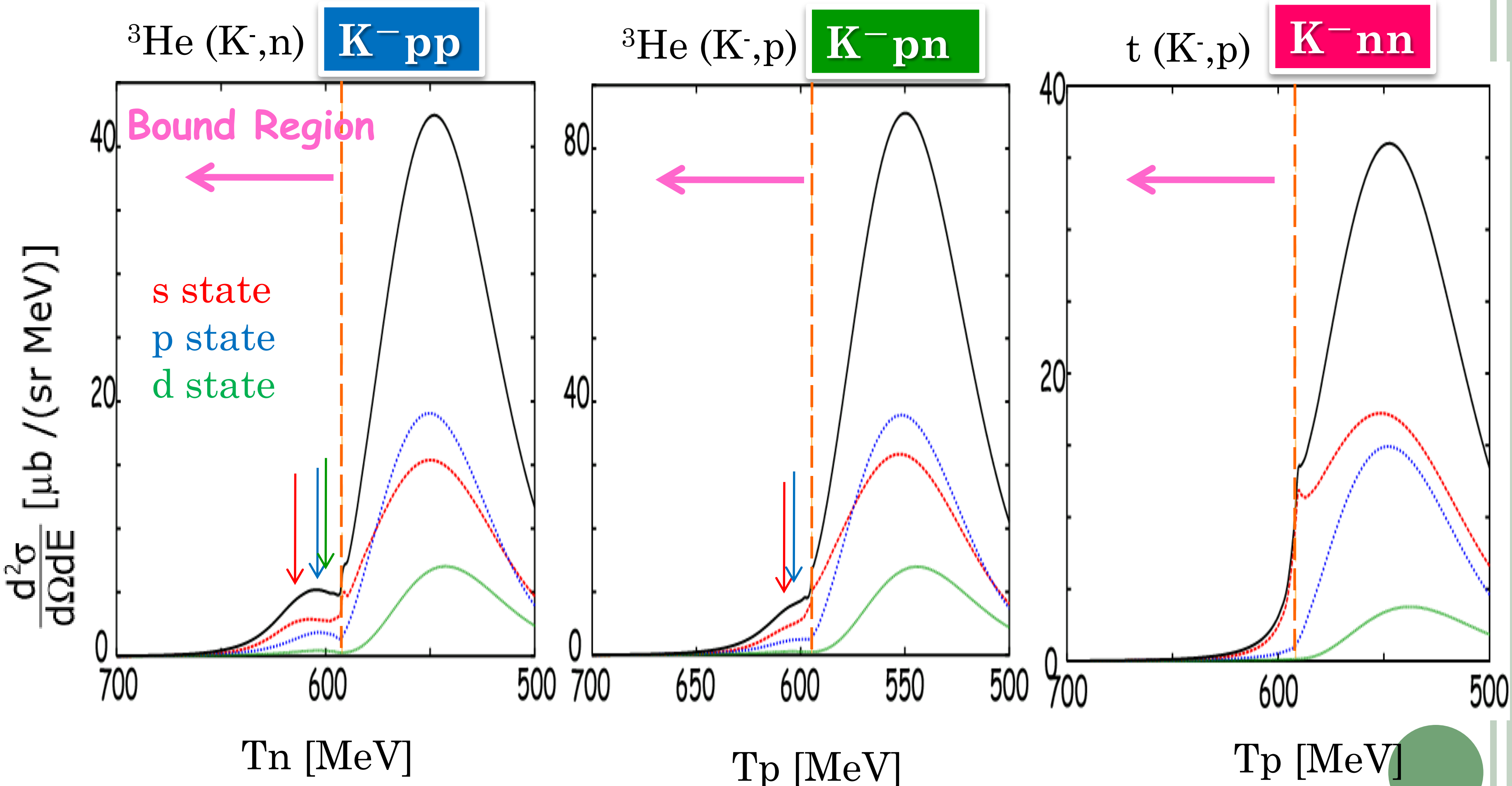
only **1 body absorption**.

E. Oset, A. Ramos, Nucl. Phys. A635 (98)99
E. Oset, A. Ramos, C. Bennhold, Phys. Lett. B527(02)99



1-2. Results -- Formation Spectra

- Formation Spectra -- Chiral Unitary -- T(ρ=0,E)ρ(r) Linear density

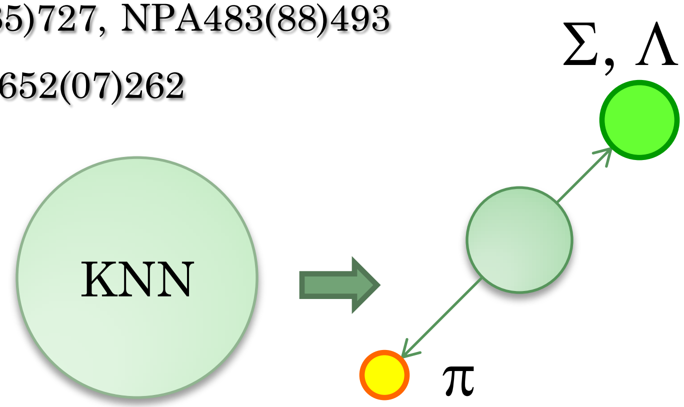


We may observe the contributions from the formation of $\bar{K}$NN systems!!

1-3. Conversion Part

O. Morimatsu, K. Yazaki, NPA435(85)727, NPA483(88)493

T. Koike, T. Harada , Phys. Lett. B 652(07)262



- Green's function method

*** Total Spectra**

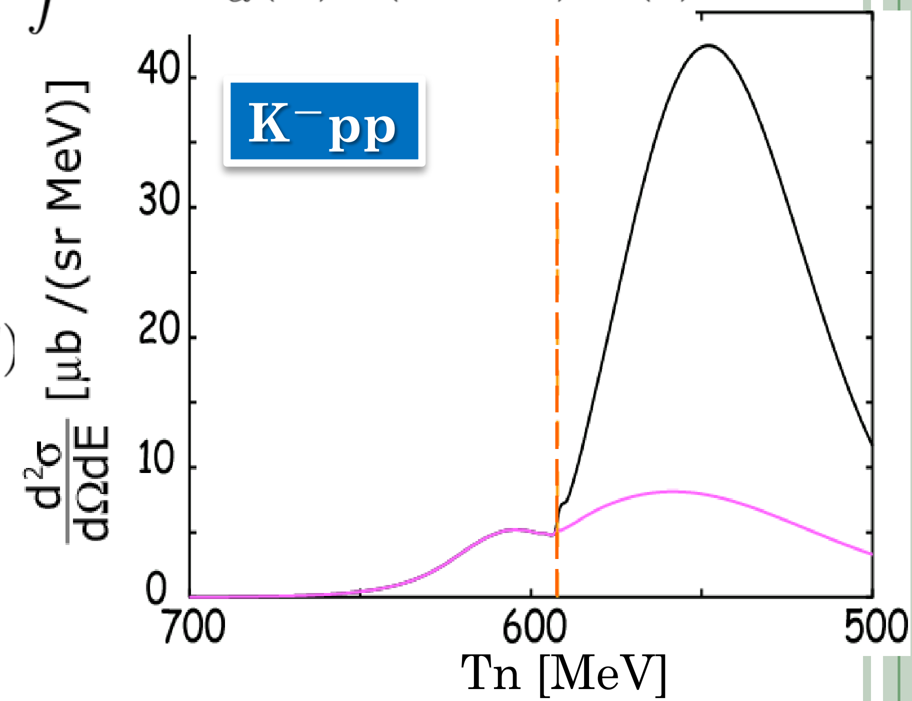
$$\left(\frac{d^2\sigma}{dEd\Omega}\right)_{\rm tot} = \frac{1}{\pi}\left(\frac{d\sigma}{d\Omega}\right)_{\bar K N\to\bar K N} S_{\rm tot}(E)$$

$$S_{\rm tot}(E) = -\tilde f\, {\rm Im} G\, f = -\sum_\alpha {\rm Im}\int d\mathbf{r}\, d\mathbf{r}'\, f^*_\alpha(\mathbf{r}')\, G(E;\mathbf{r}',\mathbf{r})\, f_\alpha(\mathbf{r})$$

*** Conversion Part**

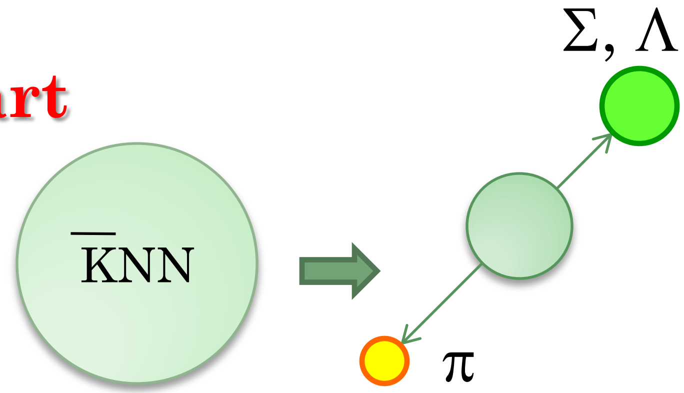
$$\left(\frac{d^2\sigma}{dEd\Omega}\right)_{\rm con} = \frac{1}{\pi}\left(\frac{d\sigma}{d\Omega}\right)_{\bar K N\to\bar K N} S_{\rm con}(E)$$

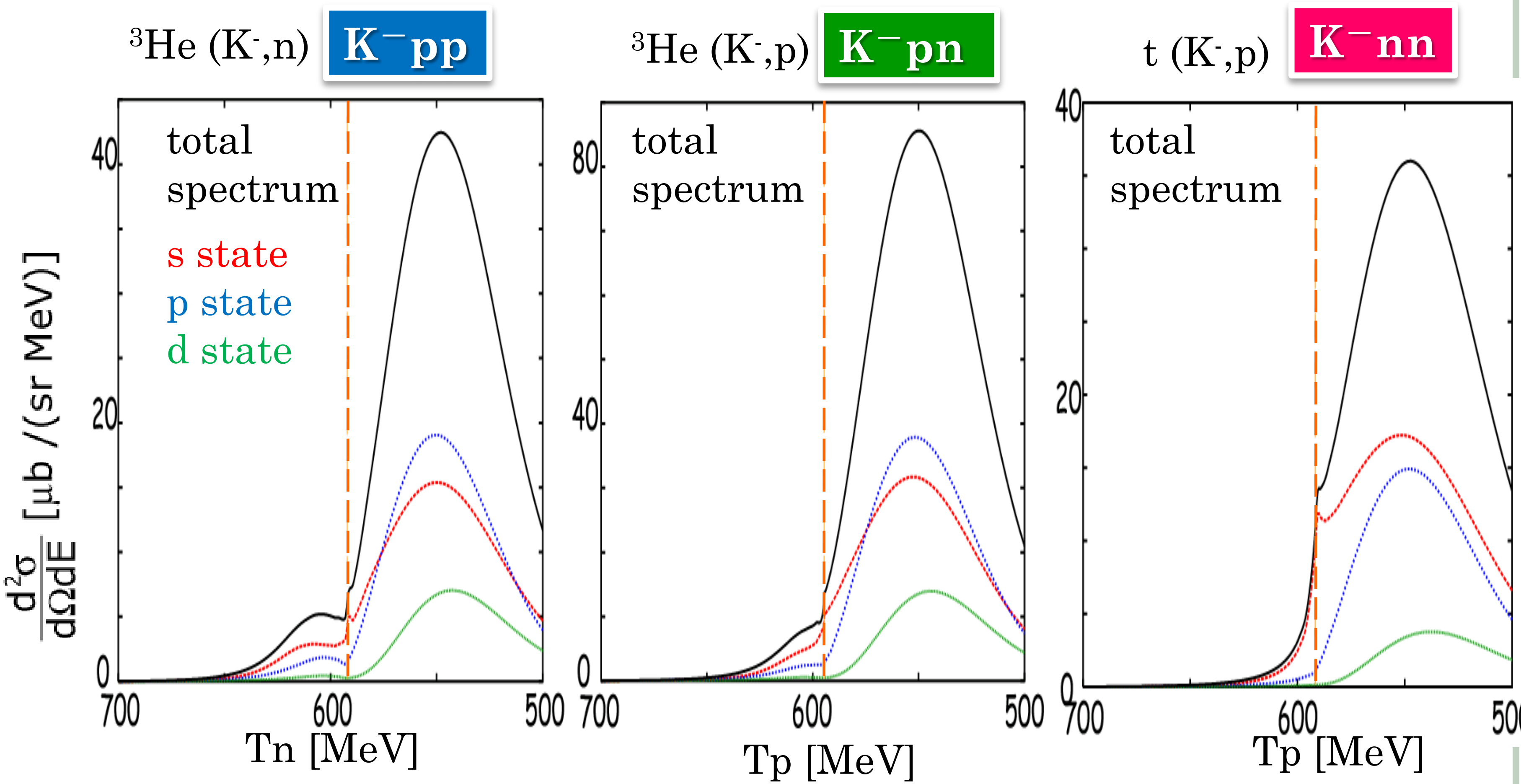
$$S_{\rm con}(E) = -\tilde f\, G^+ {\rm Im} U\, G\, f$$



1-4. Results -- Conversion Part

- If we can observe contributions from 1 body absorption process…





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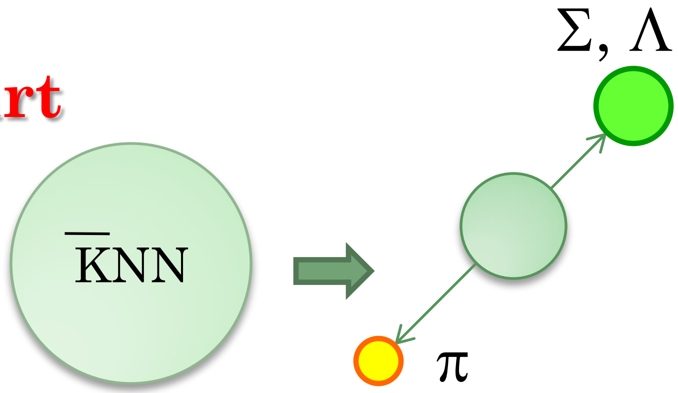

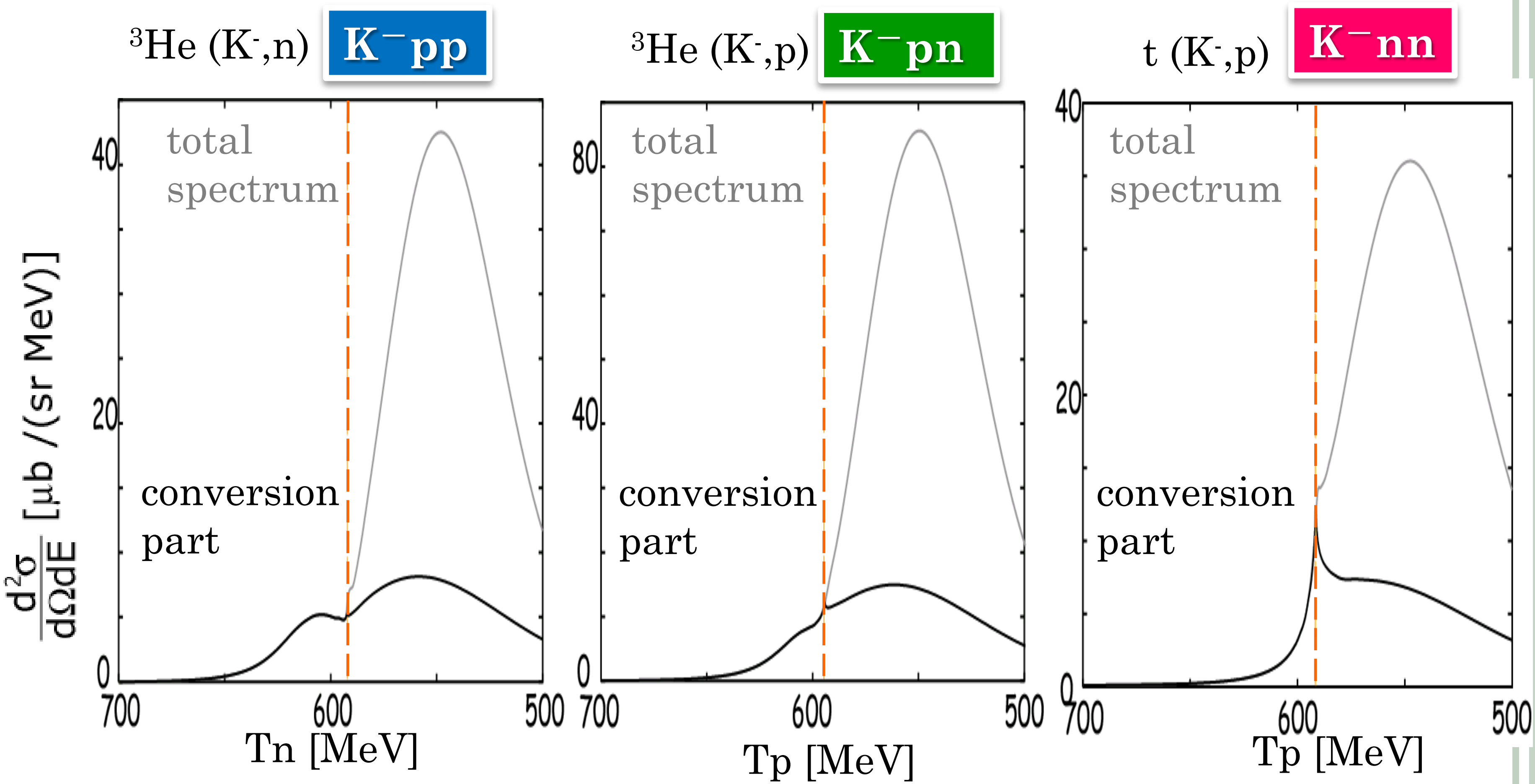

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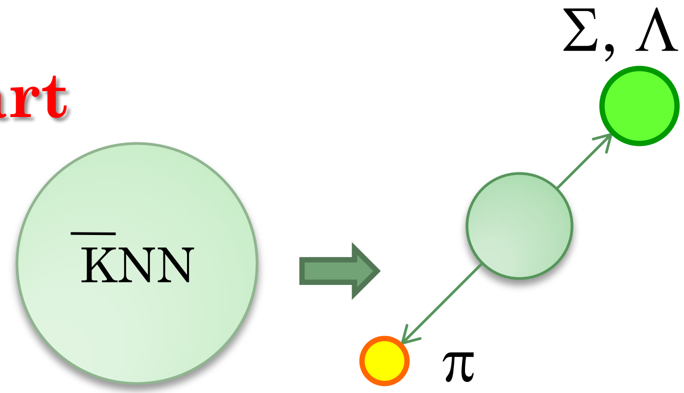

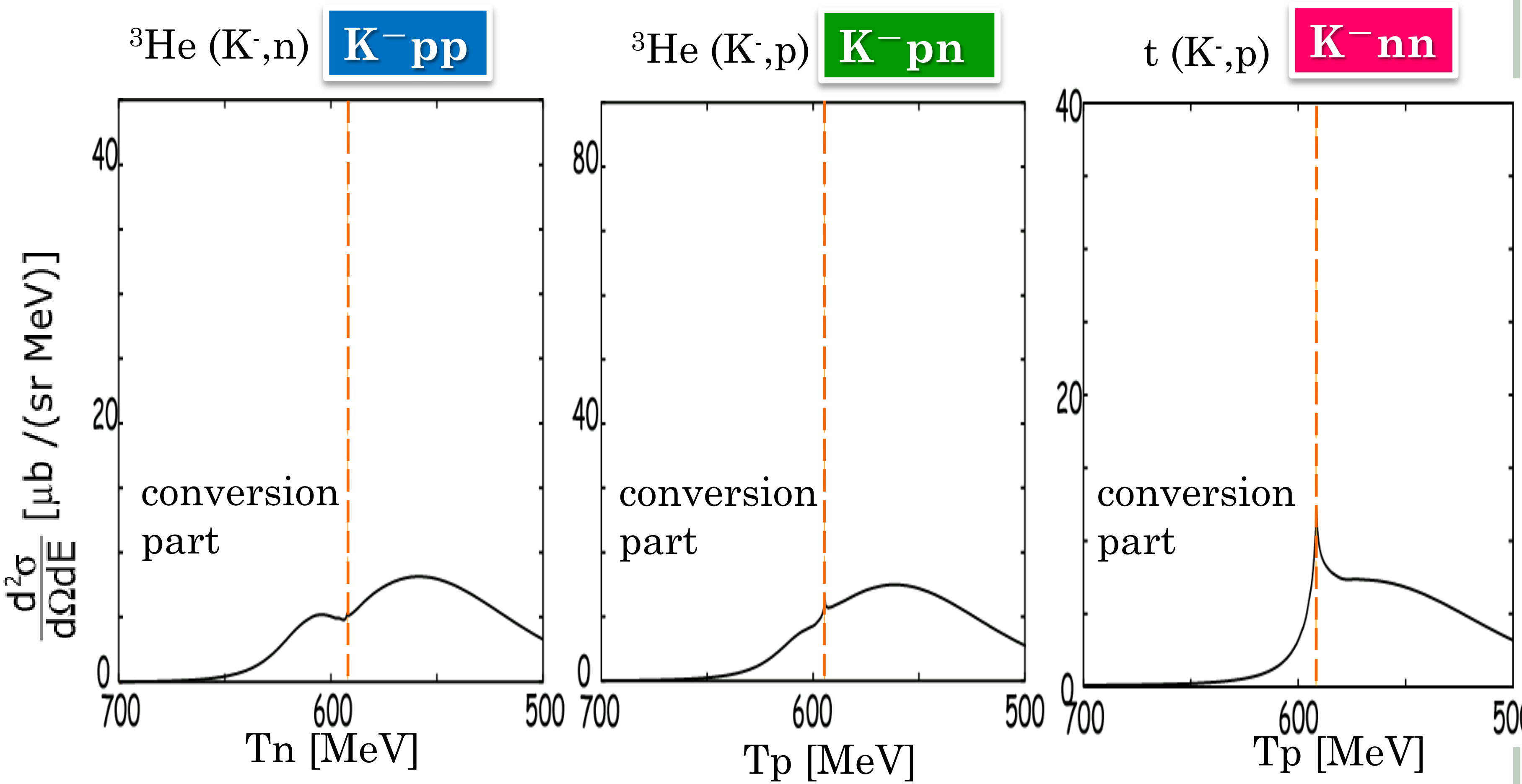

1-4. Results -- Conversion Part

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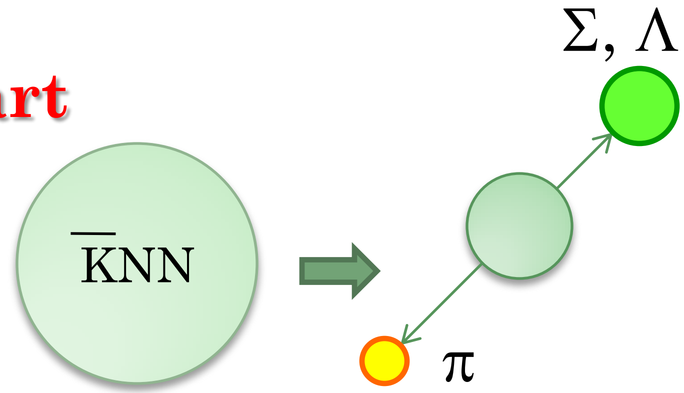
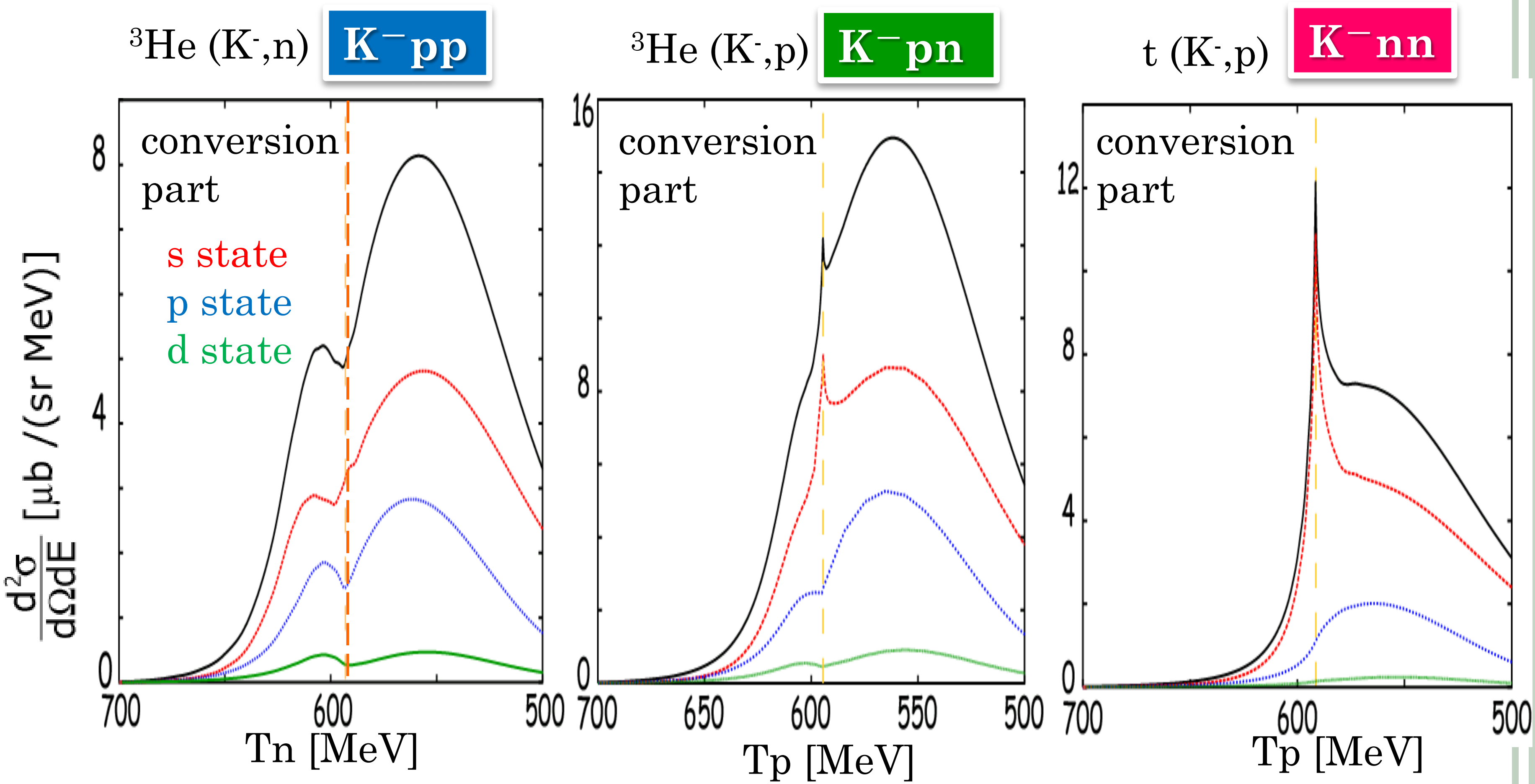
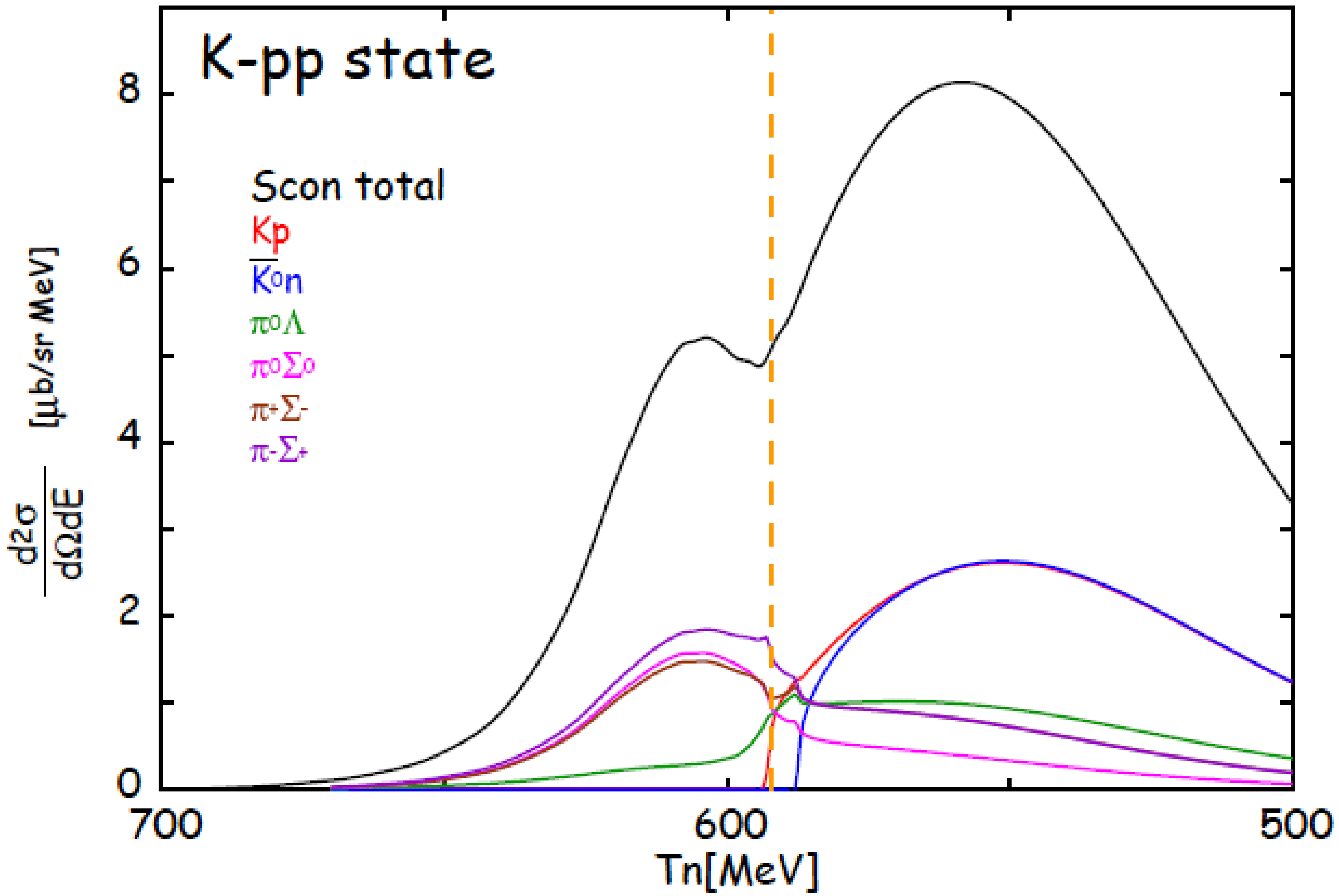




1-4. Results -- Conversion Part

- If we can observe contributions
  from 1 body absorption process… ^{3}He (K$^-$,n) **K$^-$pp**



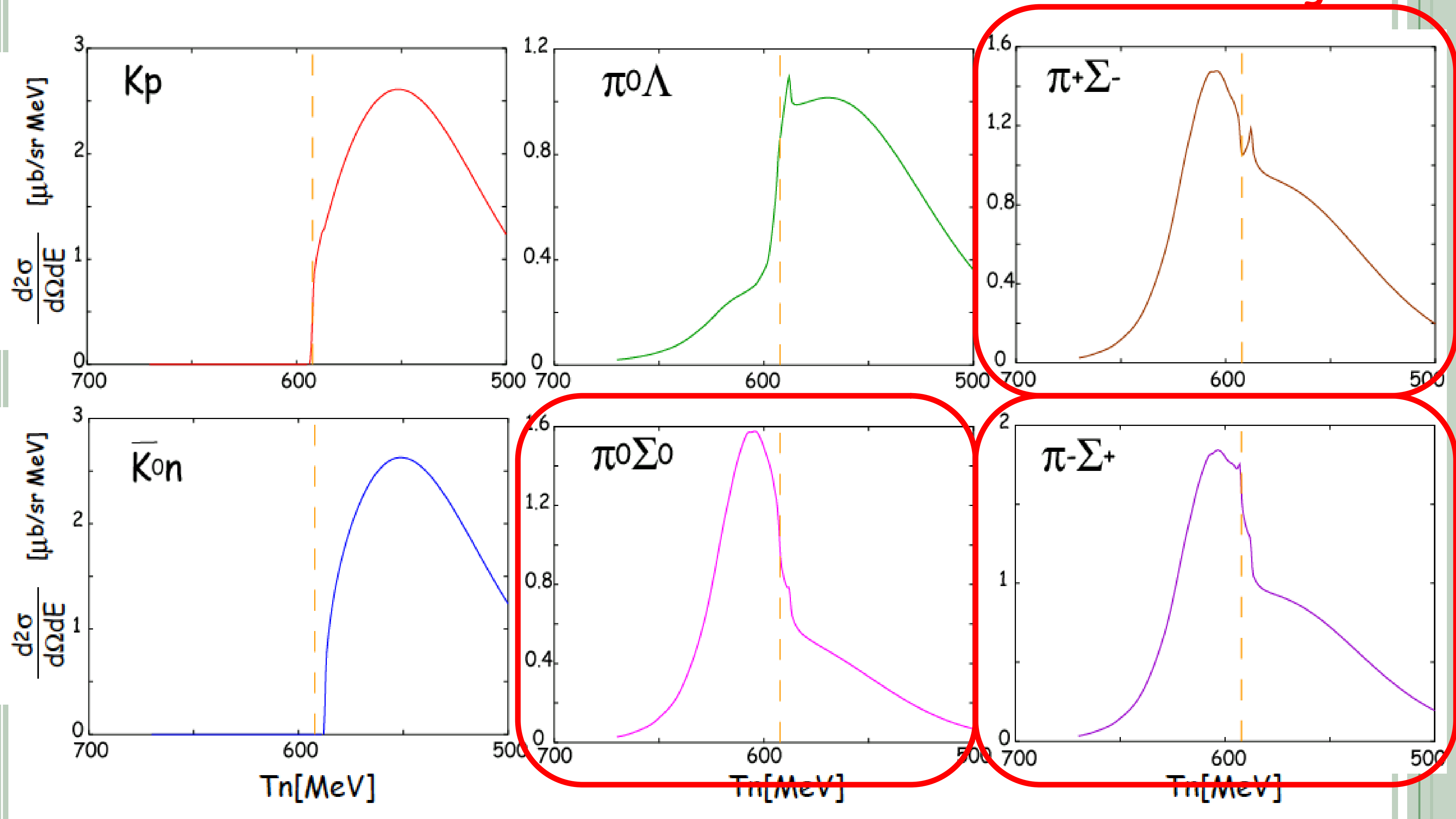
1-4. Results -- **Conversion Part**

$^3He\ (K^-,n)$

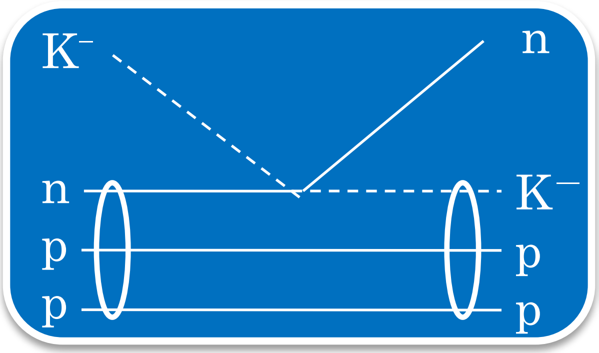
K^-pp

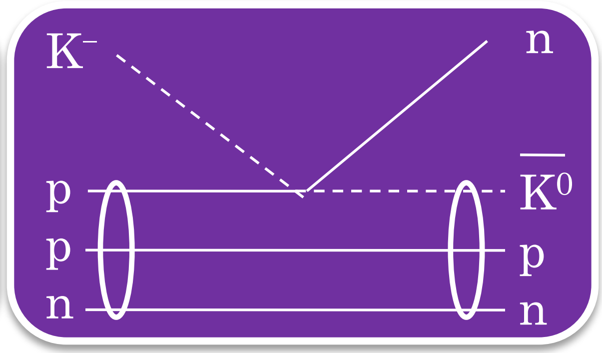
not include the contribution from $\Sigma(1385)$

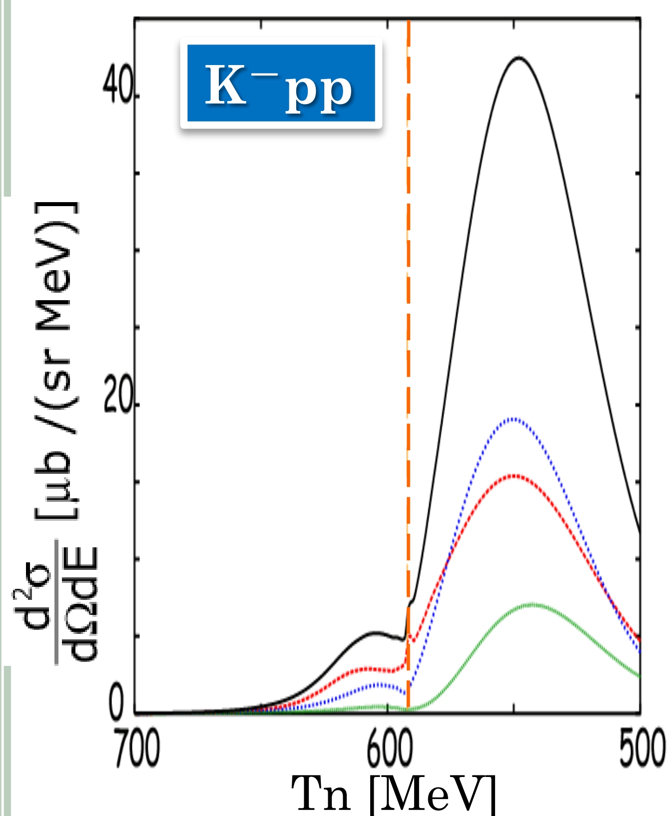
Dominant in bound region

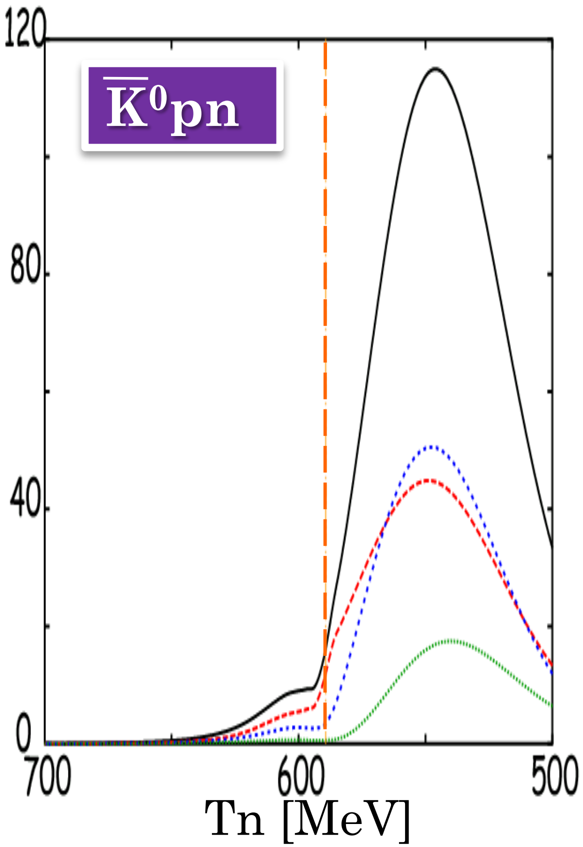


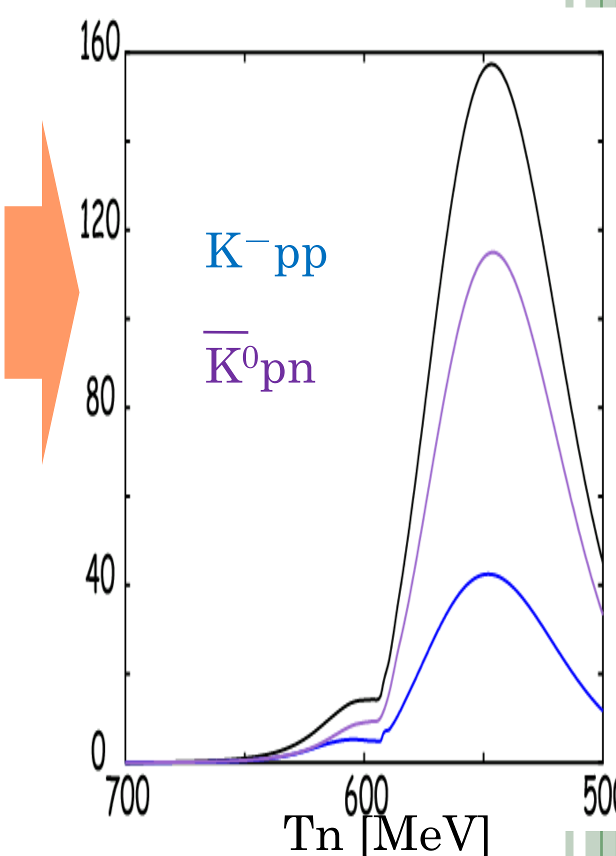
1-4. Results -- ^{3}He(K^-,n) -- possible final systems



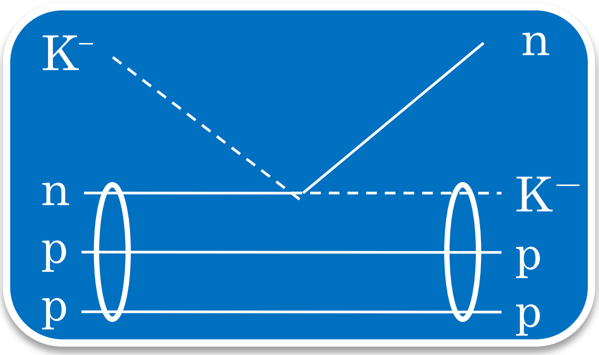


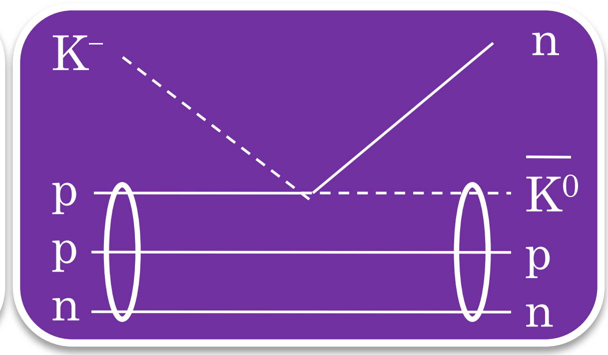




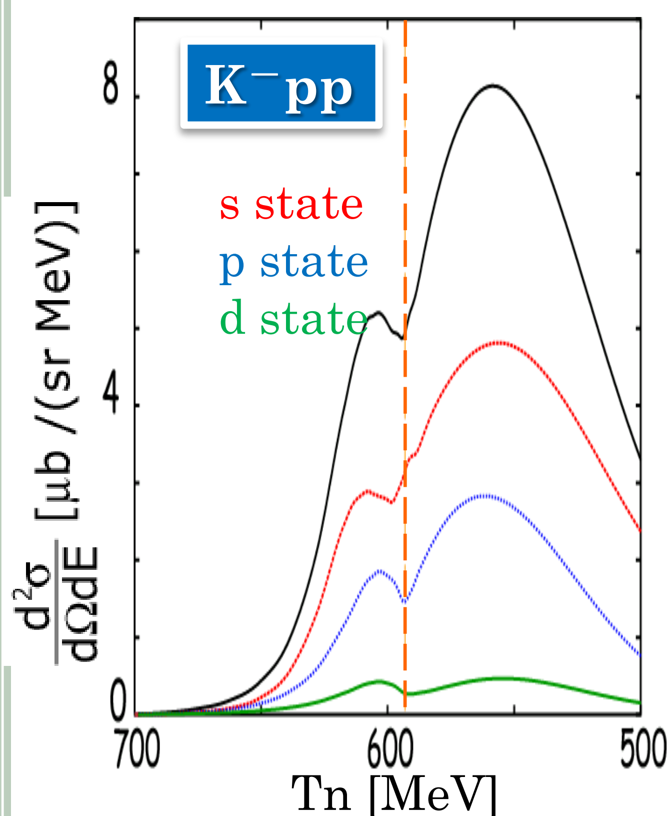


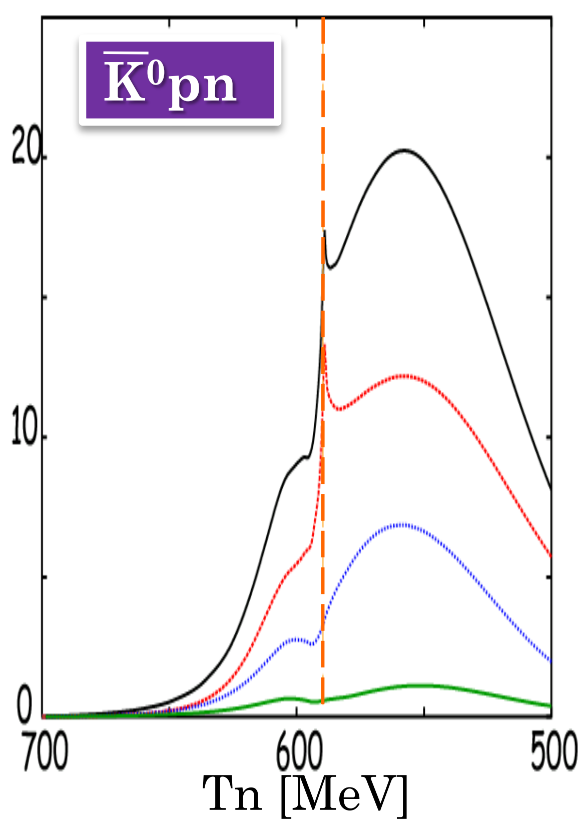
1-4. Results -- $^3He(K^-,n)$ -- possible final systems

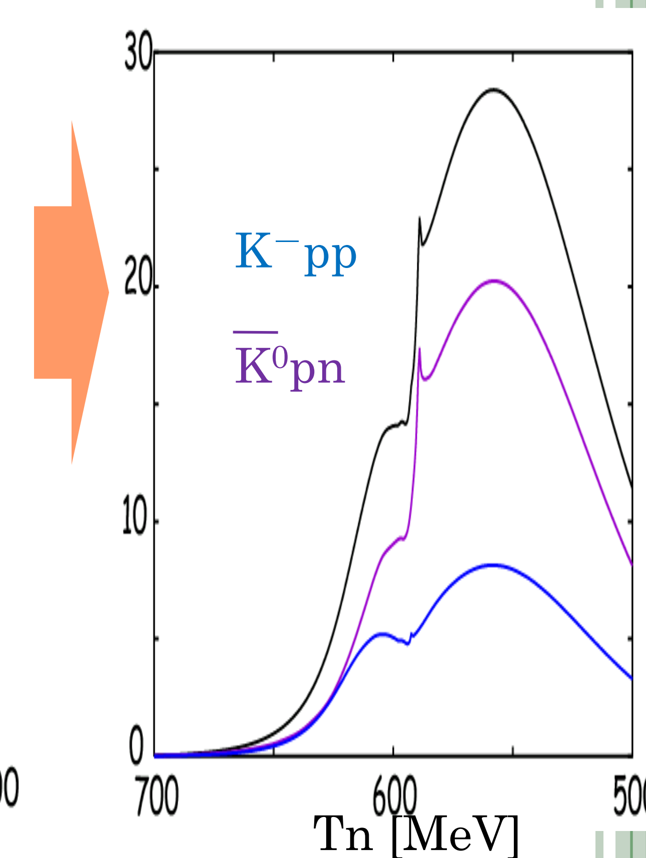




Conversion part







1-5. Comments on our calculation for $\bar{K}NN$

- We don't calculate structure as few body systems.
  (Optical potential description by Tρ approximation for very light system)
- We assume density distribution of NN system.
  (improvements are required)
- We need to evaluate 2 body absorption correctly.
  - Chiral Unitary Model T(ρ=0,E) --- only 1 body absorption

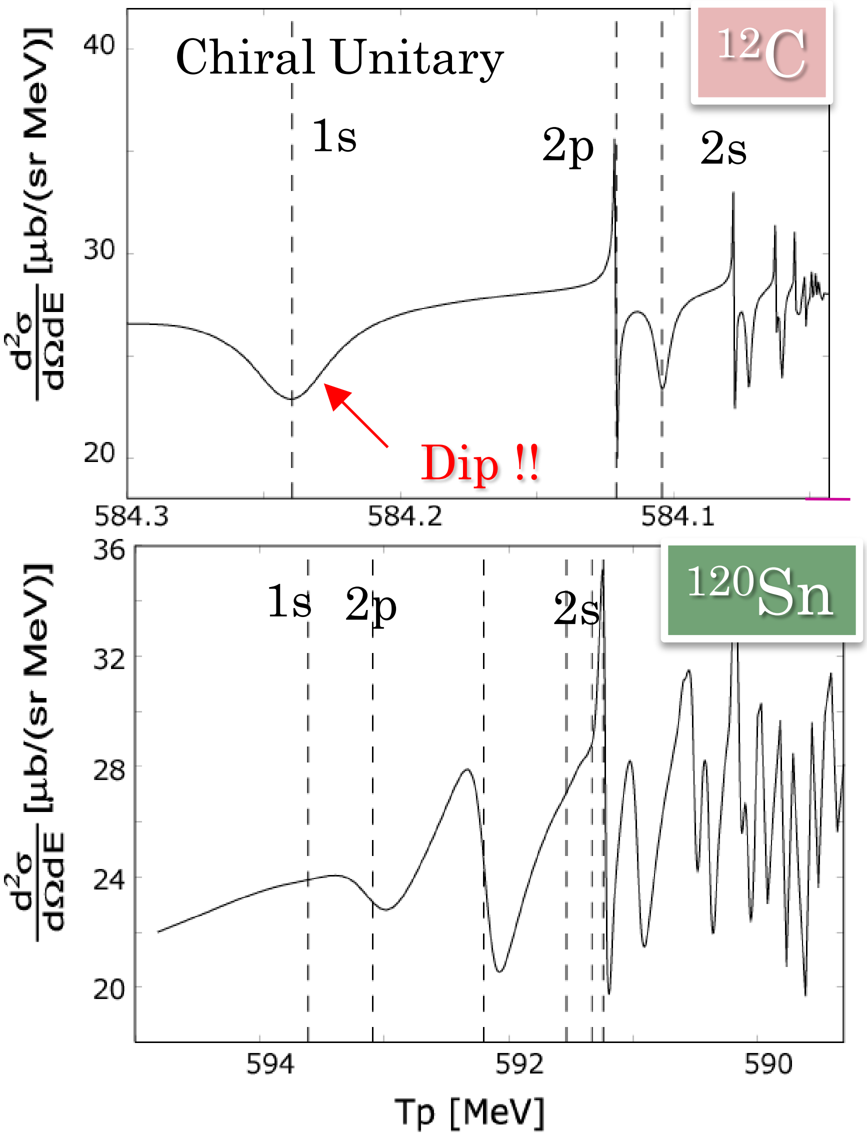
2. Deeply bound kaonic atoms

- the Coulomb assisted kaon-nucleus bound systems
- The lightly bound atomic states have been observed with X-ray spectroscopy.
  (ex. Iio san's talk (Hayano Group))
- BUT, the deeply bound states have never been observed yet !!

So, we calculated the formation spectra of kaonic atoms in (K-,p) reactions.

2. Deeply bound Kaonic Atoms

J. Yamagata, H. Nagahiro, R. Kimura and S. Hirenzaki, Phys. Rev. C76(07)045204



* The expected spectra show interesting structures with clear signals.
* The structures are very robust.

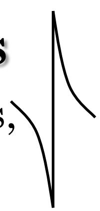
➔ Experimentally confirming the predicted structures is of great importance!!

* If an experiment with enough resolution did not find the predicted structures,

➔ this would cast serious doubt on the validity of the potentials which reproduce the existing lightly bound atomic data.

1-6. Summary

- We calculated various $\bar{K}NN$ systems.
  -- Some bound states exist in complex E plane
  -- We may observe the small structures at bound region.
- We also considered $\bar{K}^0 pn$ state in addition to $K^- pp$ state in ^{3}He(K-,n) reaction.
- We expect clearer signals in the conversion part.
  (Especially πΣ emission channels!!)
- We need to observe the emitted particles after kaon absorption in addition to forward nucleon in (K-,n) reactions.

- **Deeply bound kaonic atoms**
  - Not simple peak structure. But dips,  shapes etc.
  - The experimental investigations are very important !!
    → 'Robust prediction!' while 'Insensitive?'
    → Experimentally confirming the predicted structures is of great importance!!