Meson-induced pentaquark productions

Tetsuo Hyodo$^a$, Atsushi Hosaka$^b$, and Makoto Oka$^a$

Tokyo Institute of Technology$^a$  RCNP, Osaka$^c$

supported by Global Center of Excellence Program “Nanoscience and Quantum Physics”

2012, Sep. 11th
Introduction

**Pentaquark Θ+**

Θ+ : strangeness $S = +1$, baryon number $B = 1$

minimal quark content $\sim uudd\bar{s}$ : exotic!


$\gamma d \rightarrow K^{+}K^{-}pn$ reaction

New results from LEPS

Y. Kato, Talk at FB20

- $K^+$, $K^-$ detected. momentum of $n$ is determined by MMSA.
- significance of the peak in new data: 1.6-1.9 $\sigma$
- event selection by start counter: peak grows
Experiment at J-PARC

J-PARC E19: $\pi^- p \rightarrow K^- X$, first result from J-PARC hadron hall

12pSL-10 M. Moritsu, et al.,

- Cross section $< 0.26 \mu b/sr$

Impact on the existence of $\Theta^+$? --&gt; theoretical analysis
Meson-induced $\Theta^+$ production

Theoretical study of reactions

Meson-induced $\Theta^+$ production: relatively simple

Effective Lagrangian approach $\rightarrow$ upper limit of $\Gamma_\Theta$

We examine isospin $I=0$, spin-parity $J^P=1/2^\pm$, $3/2^\pm$ cases.

- Born terms (must exist if $\Theta^+$ decays into $KN$)

- Other possible contributions: unknown couplings

Born terms only $\rightarrow \sigma$ is proportional to $\Gamma_\Theta$
**Meson-induced Θ+ production**

**Interference with other contributions**

Our aim: upper limit of cross section --> upper limit of $\Gamma_\Theta$

- Destructive interference --> underestimation

\[
\sigma \propto |T_{\text{Born}}|^2 = \left| \bar{T}_{\text{Born}} \sqrt{\Gamma_\Theta} \right|^2 < 1
\]

\[
\sigma \propto \left| \bar{T}_{\text{Born}} \sqrt{\Gamma_\Theta} + T_{\text{other}} \right|^2 < 1
\]

Interference pattern in general depends on the reaction.

- Negative result in *various* low energy reactions
  \((\pi^-p \rightarrow K^-X, \ K^+p \rightarrow \pi^+X, \ pp \rightarrow \Sigma^+X, \ \gamma p \rightarrow K^0X, ...\)

It is unnatural that all the negative results are explained by destructive interference.

--> Born diagrams will provide a **conservative upper limit**.
Meson-induced $\Theta^+$ production

**Total cross sections**

Theoretical uncertainties:
- two schemes of meson-baryon coupling (PV, PS)
- two types of hadron form factor (Fs, Fc)

Total cross sections with $J^P=1/2^+$ case ($\Gamma_\Theta = 1$ MeV)

- Threshold behavior of PS is different from PV.  
  --> chiral low energy theorem
Meson-induced Θ+ production

**Total cross sections for various quantum numbers**

Upper limit in experiments (isotropic production)
- J-PARC E19: $\pi^- p \rightarrow K^- \Theta^+ \sigma \lesssim 10^{-1} \text{ mb}$
- KEK E559: $K^+ p \rightarrow \pi^+ \Theta^+ \sigma \lesssim 10^0 \text{ mb}$

Total cross sections at experimental energies ($\Gamma_\Theta = 1 \text{ MeV}$)

<table>
<thead>
<tr>
<th>$J^P$</th>
<th>$\pi^- p \rightarrow K^- \Theta^+$</th>
<th>$K^+ p \rightarrow \pi^+ \Theta^+$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$= 1/2^+$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>static</td>
<td>PS</td>
<td>PV</td>
</tr>
<tr>
<td>covariant</td>
<td>9.2 $^{+1.4}_{-1.3}$</td>
<td>0.51 $^{+0.07}_{-0.08}$</td>
</tr>
<tr>
<td></td>
<td>5.3 $^{+2.8}_{-2.0}$</td>
<td>0.29 $^{+0.16}_{-0.11}$</td>
</tr>
<tr>
<td>$= 1/2^-$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>static</td>
<td>PV</td>
<td>PS</td>
</tr>
<tr>
<td>covariant</td>
<td>0.18 $^{+0.02}_{-0.03}$</td>
<td>0.40 $^{+0.06}_{-0.06}$</td>
</tr>
<tr>
<td></td>
<td>0.10 $^{+0.06}_{-0.04}$</td>
<td>0.23 $^{+0.12}_{-0.09}$</td>
</tr>
<tr>
<td>$= 3/2^+$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>static</td>
<td>PS</td>
<td>PV</td>
</tr>
<tr>
<td>covariant</td>
<td>10 $^+2_{-1}$</td>
<td>94 $^{+11}_{-11}$</td>
</tr>
<tr>
<td></td>
<td>5.9 $^{+3.1}_{-2.2}$</td>
<td>478 $^{+12}_{-14}$</td>
</tr>
<tr>
<td>$= 3/2^-$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>static</td>
<td>PV</td>
<td>PS</td>
</tr>
<tr>
<td>covariant</td>
<td>5.5 $^{+0.8}_{-0.8}$</td>
<td>8572 $^{+1019}_{-992}$</td>
</tr>
<tr>
<td></td>
<td>3.2 $^{+1.6}_{-1.2}$</td>
<td>40544 $^{+1511}_{-1824}$</td>
</tr>
</tbody>
</table>

If we consider the width should be larger than 0.1 MeV; --> spin 3/2 cases are ruled out.
Differential cross section at $P_{\text{lab}} = 1.92$ GeV ($\Gamma_\Theta = 1$ MeV)

Comparison with J-PARC data

- Angular dependence is not so strong.
  - J-PARC E19 experiment: $K^+$ detected in forward angles.

J-PARC experiment --> upper limit of $\Gamma_\Theta$

- (narrow width of $1/2^-$ is theoretically unreasonable)
We study pentaquark productions in meson-induced reactions with Born diagrams.

Cross sections for $J^P = 1/2^\pm, 3/2^\pm$ cases.

Spin $3/2$ cases --> large cross section

$\Gamma_\Theta << 0.1$ MeV: unlikely for hadrons

Spin $1/2$ cases may be possible.

upper limit of $\Gamma_\Theta$ with J-PARC exp.