Meson-induced pentaquark productions

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supported by Global Center of Excellence Program
"Nanoscience and Quantum Physics"

2012, Nov. 17th

Exotic hadrons in QCD

Θ^+ : **strangeness** $S = +1$, **baryon number** $B = 1$
minimal quark content ~ $uudd\bar{s}$ **: exotic!**

D. Diakonov, V. Petrov, M.V. Polyakov, Z. Phys. A359, 305 (1997)
T. Nakano, *et al.*, Phys. Rev. Lett. 91, 012002 (2003)

c.f. $\Lambda(1405)$ **~** $uud\, s\bar{u}$, $Z(4430)$ **~** $c\bar{c}d\bar{u}$ **: crypto-exotic hadrons**

Exotic hadrons are

- **not well established in experiments (~300 normal hadrons).**
- **not excluded in QCD.**
- **easily constructed in effective models.**

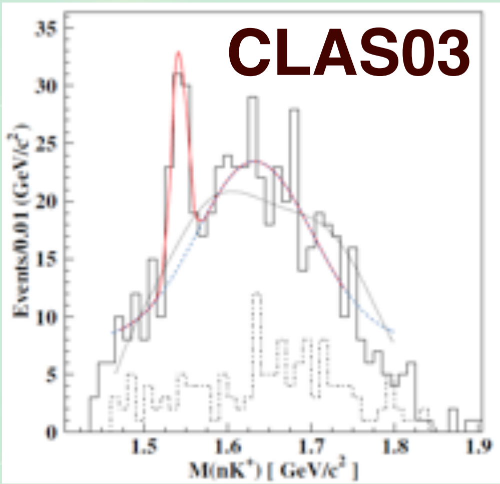
(Non)existence of exotic hadrons : Saturation?

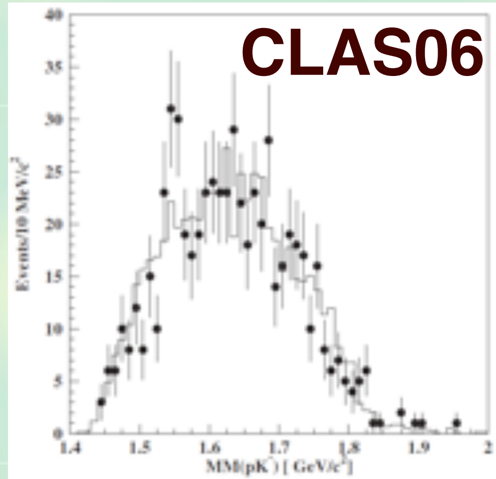
c.f. nucleus: Coulomb repulsion, drip line, ...
hydrogen molecule: covalent bond, ...

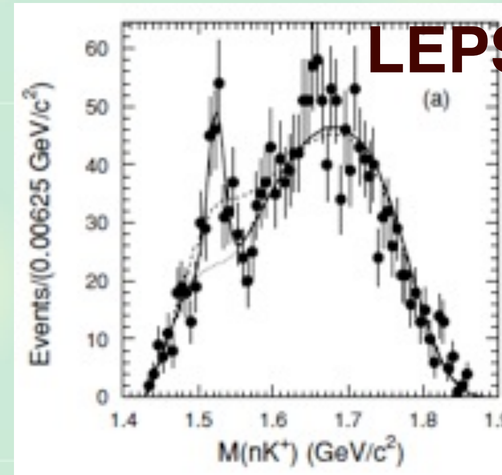
Exotic hadrons --> quark binding mechanism (confinement)

Pentaquark Θ+

γd --> K+K-pn reaction



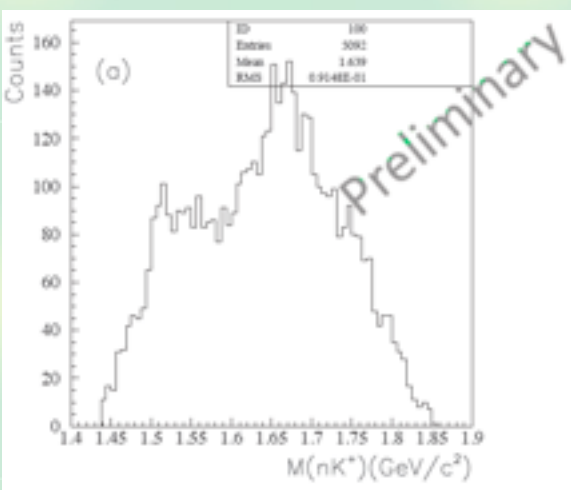


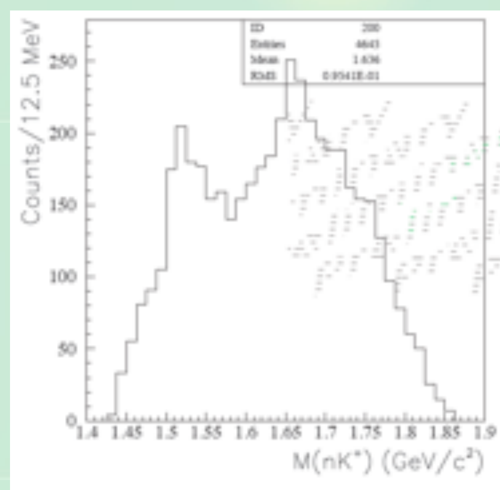


New results from LEPS

Y. Kato, Talk at FB20, M. Niiyama, Talk at HYP12

- K+, K- detected. momentum of n is determined by MMSA.



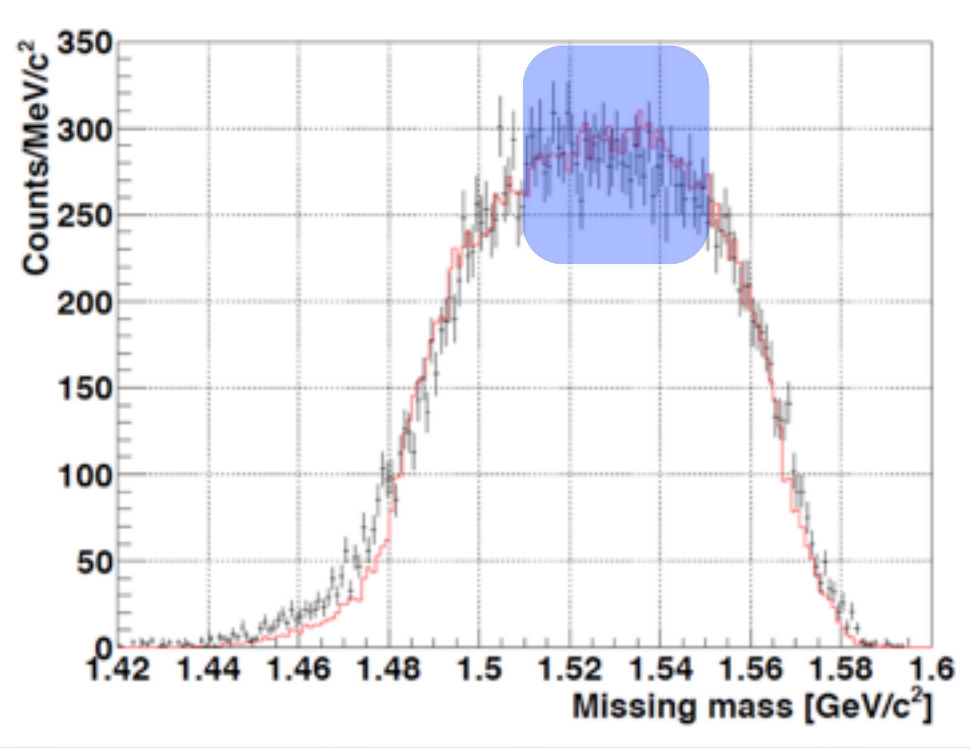


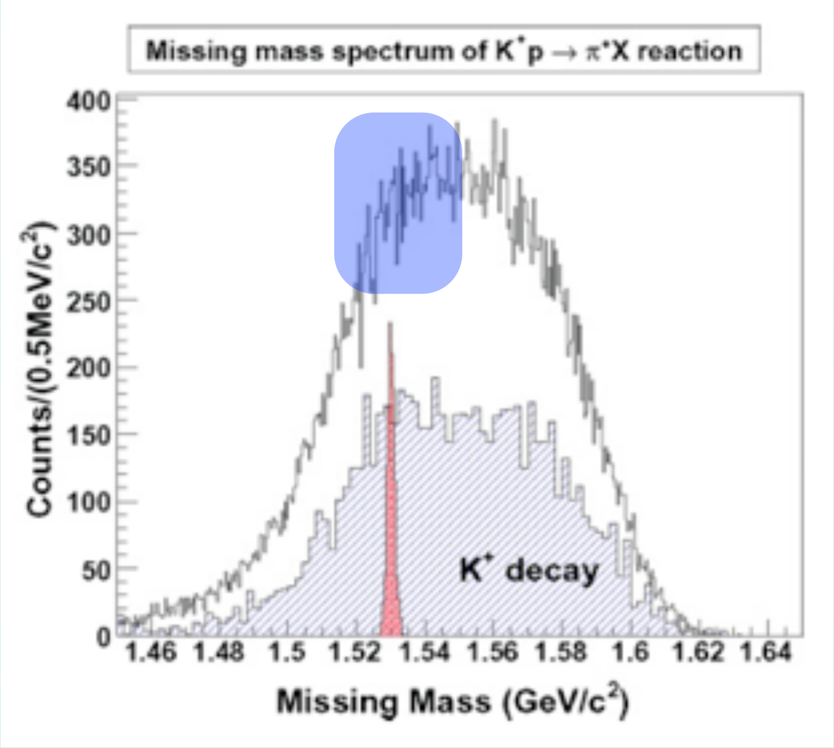
proton rejected, summed data

Meson-induced experiments

π-p --> K-X : **J-PARC E19,** K+p --> π+X : **KEK E559**

K. Shirotori, *et al.*, Phys. Rev. Lett. 109, 132002 (2012)
K. Miwa, *et al.*, Phys. Rev. C77, 045203 (2008)





- upper limit (averaged over detected angles)
< 0.26 μb/sr for π-p --> K-X, **< 3.5 μb/sr for** K+p --> π+X

Impact on the existence of Θ^+? --> theoretical analysis

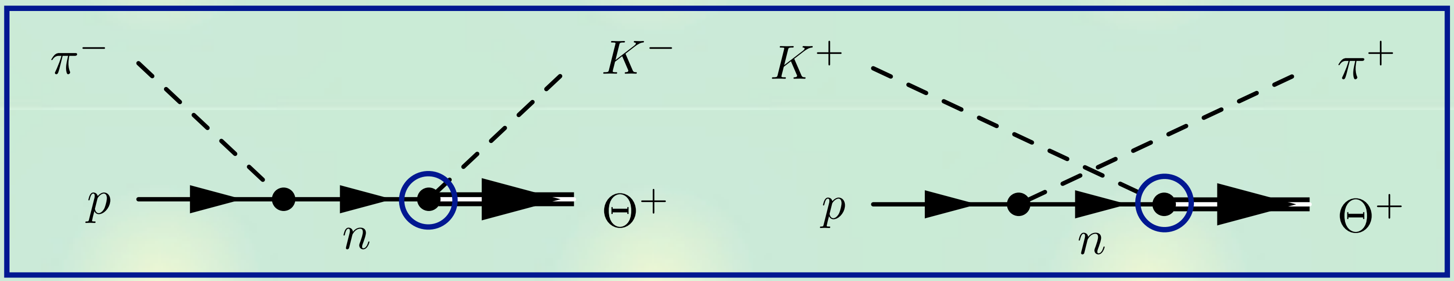
Theoretical study of reactions

Meson-induced Θ^+ production: relatively simple

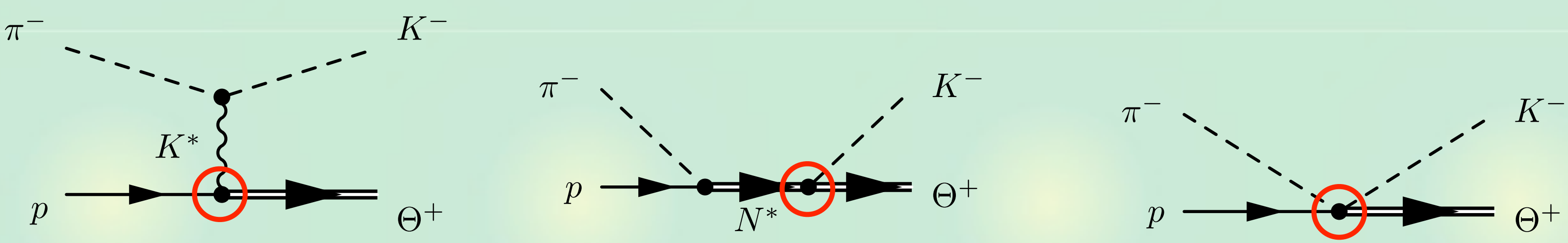
Effective Lagrangian approach --> upper limit of Γ_Θ

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

- Born terms (must exist if Θ^+ decays into KN)



- Other possible contributions: unknown couplings



Born terms only--> σ is proportional to Γ_Θ

Interference with other contributions

Our aim: upper limit of cross section --> upper limit of Γ_Θ

- Destructive interference --> underestimation

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

1

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

10 **-9**

Interference pattern in general depends on the reaction.

- Negative result in various low energy reactions

(π-p --> K-X, K+p --> π+X, pp --> Σ+X, γp --> K^0X, ...)

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

--> Born diagrams will provide a conservative upper limit.

Effective Lagrangians

Pseudoscalar (PS) scheme

$$\mathcal{L}_{KN\Theta}^{1/2^\pm} = g_{KN\Theta}^{1/2^\pm} \bar{\Theta}^+ \Gamma K N + \mathrm{h.c.} \qquad \Gamma = \begin{cases} i\gamma_5 & \text{(positive parity)} \\ 1 & \text{(negative parity)} \end{cases}$$

$$\mathcal{L}_{\pi NN} = i g_{\pi NN} \bar{N} \gamma_5 \boldsymbol{\pi} N$$

- coupling constants: decay width of Θ+

$$g_{KN\Theta}^{1/2^\pm} = \sqrt{\frac{2\pi M_\Theta \Gamma_\Theta}{|\boldsymbol{k}|(E \mp M)}}, \quad g_{\pi NN} = 13.5$$

Pseudovector (PV) scheme

$$\mathcal{L}_{KN\Theta}^{1/2^\pm} = \frac{-i g_A^{*\pm}}{2f} \bar{\Theta}^+ \gamma_\mu \Gamma \partial^\mu K N + \mathrm{h.c.}$$

$$\mathcal{L}_{\pi NN} = \frac{g_A}{2f} \bar{N} \gamma_\mu \gamma_5 \partial^\mu \boldsymbol{\pi} N$$

- generalized GT relation

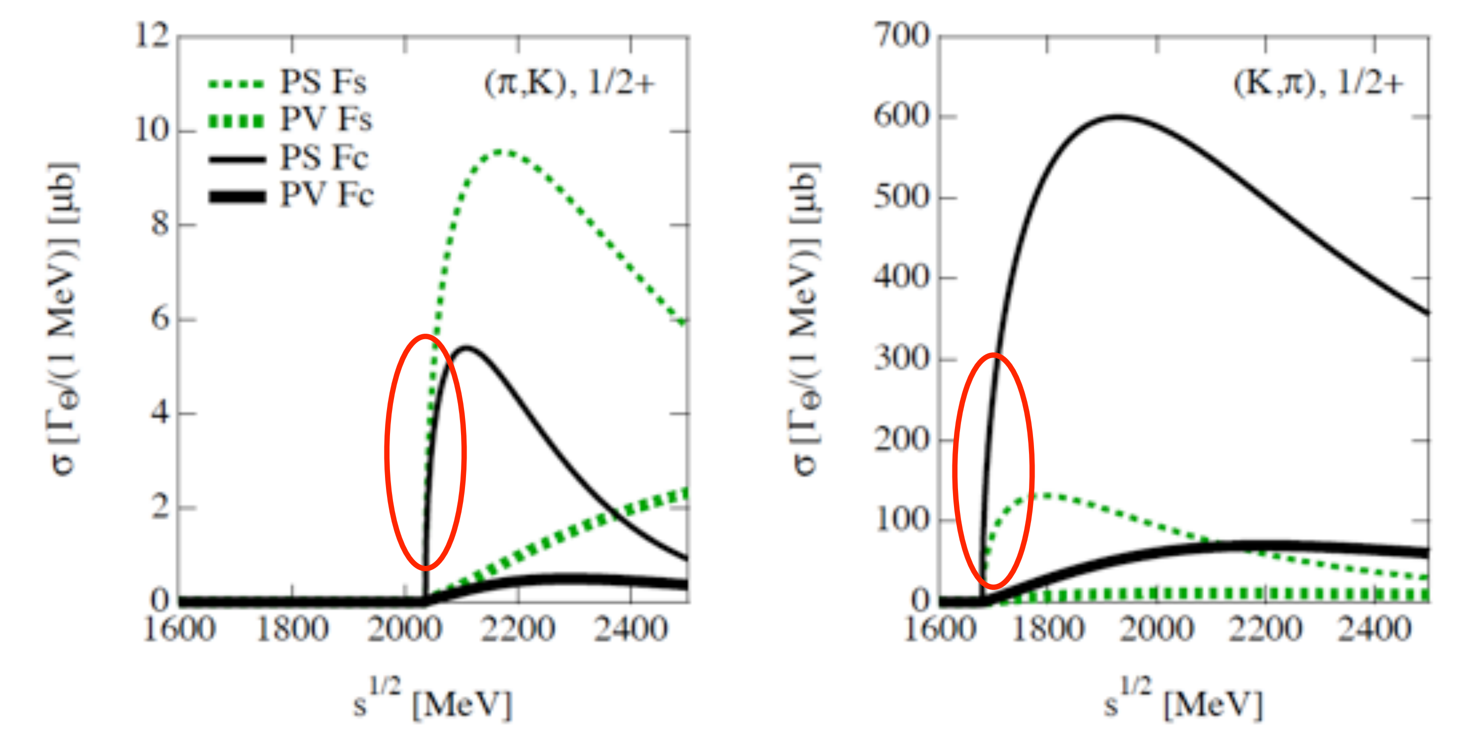
$$g_A^{*\pm} = \frac{2f}{M_\Theta \pm M_N} g_{KN\Theta}^{1/2^\pm}, \quad g_A = 1.25, \quad f = 93\ \mathrm{MeV}$$

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 (**Γ_Θ **= 1 MeV)**



- **Threshold behavior of PS is different from PV.**
  --> chiral low energy theorem

Total cross sections for various quantum numbers

Upper limit in experiments

- **J-PARC E19:** π-p --> K-X **$\sigma \lesssim 10^{-1}$ μb**
- **KEK E559:** K+p --> π+X **$\sigma \lesssim 10^{0}$ μb**

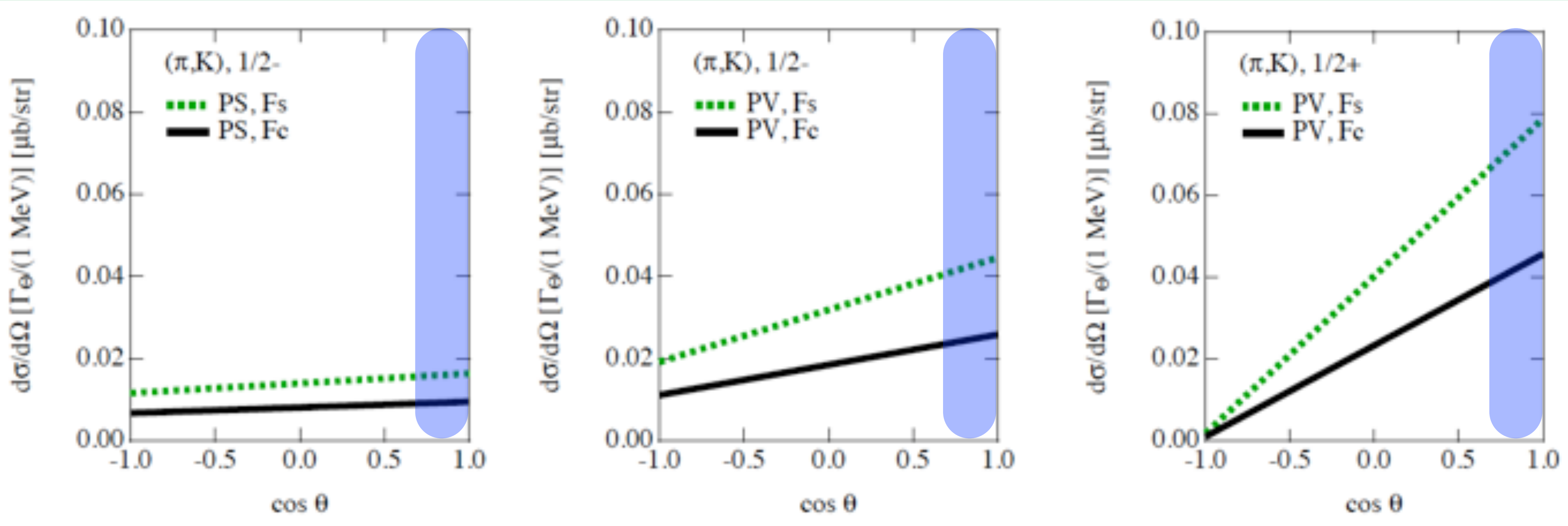
Total cross sections at experimental energies (Γ_Θ = 1 MeV)

	$\pi^- p \to K^- \Theta^+$		$K^+ p \to \pi^+ \Theta^+$	
$J^P = 1/2^+$	PS	PV	PS	PV
static	$9.2^{+1.4}_{-1.3}$	$0.51^{+0.07}_{-0.08}$	119^{+14}_{-14}	$9.6^{+1.1}_{-1.1}$
covariant	$5.3^{+2.8}_{-2.0}$	$0.29^{+0.16}_{-0.11}$	595^{+16}_{-20}	46^{+1}_{-2}
$J^P = 1/2^-$	PS	PV	PS	PV
static	$0.18^{+0.02}_{-0.03}$	$0.40^{+0.06}_{-0.06}$	$1.9^{+0.3}_{-0.2}$	$4.2^{+0.5}_{-0.5}$
covariant	$0.10^{+0.06}_{-0.04}$	$0.23^{+0.12}_{-0.09}$	$9.6^{+0.3}_{-0.3}$	20^{+1}_{-1}
$J^P = 3/2^+$				
static	10^{+2}_{-1}		94^{+11}_{-11}	
covariant	$5.9^{+3.1}_{-2.2}$		478^{+12}_{-14}	
$J^P = 3/2^-$				
static	$5.5^{+0.8}_{-0.8}$		8572^{+1019}_{-992}	
covariant	$3.2^{+1.6}_{-1.2}$		40544^{+1511}_{-1824}	

If we consider the width should be larger than 0.1 MeV;
--> spin 3/2 cases are ruled out.

Comparison with J-PARC data

Differential cross section at P_{lab} = 1.92 GeV (Γ_Θ = 1 MeV)



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

J-PARC experiment --> upper limit of Γ_Θ

- **(narrow width of** 1/2- **is theoretically unreasonable)**

Summary

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**

  Γ_Θ **<< 0.1 MeV: unlikely for hadrons**

- **Spin** 1/2 **cases may be possible.**

  upper limit of Γ_Θ **with J-PARC exp.**

T. Hyodo, A. Hosaka, M. Oka, Prog. Theor. Phys. 128, 523-531 (2012)