Heavy hadron production for the study of their structure

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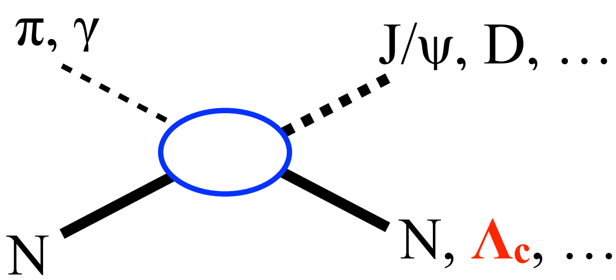
1. Introduction
   Background and resonances in binary reactions
2. How abundantly are charms produced?
3. What we can learn about the structure?
4. Productions of P_c

1. Introduction

Binary reactions: for the study of Λ^* and P_c



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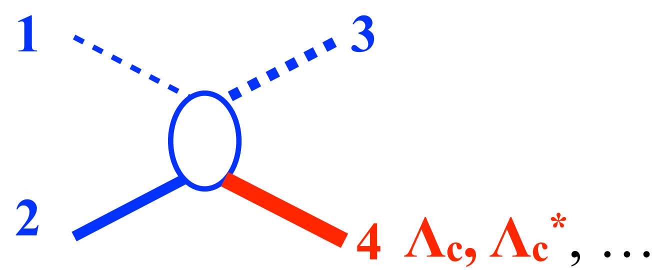
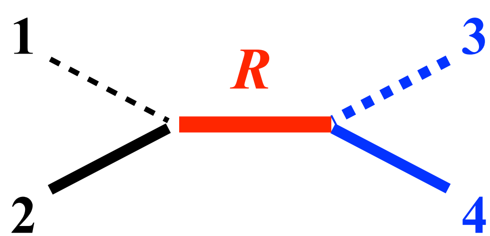
$\pi N \to D^* N, DN$
$\gamma N \to J/\psi\ N$

Background



Missing mass of **1,2,3** for the study of **4**
Λ_c, Λ_c^*, Σ_c^*, …

Resonance



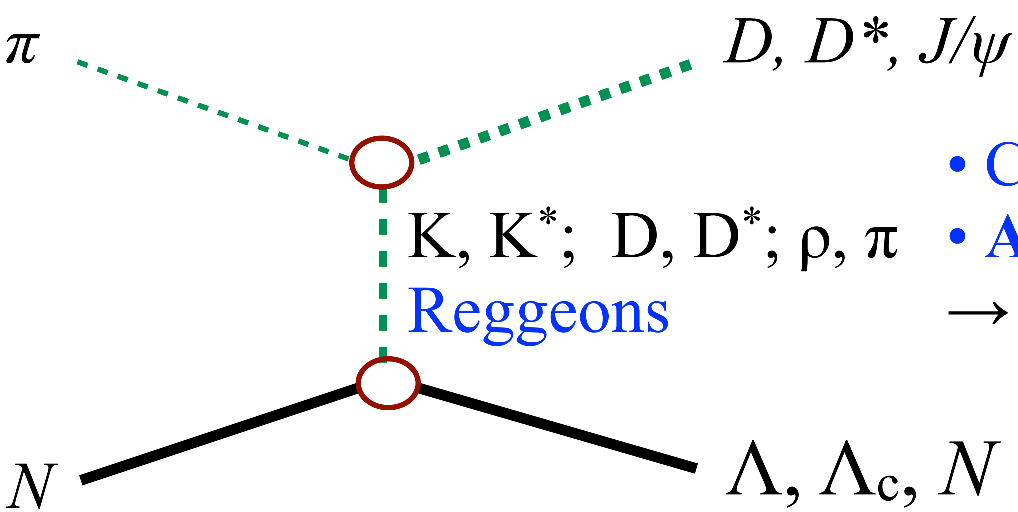
Energy (s) dep. and B.R. **3, 4** for the study of resonance, P_c

Questions: 1. How **abundantly** are charms produced?
2. What we can learn about the **structure**?

2. How abundantly are charms produced?

Pion induced reactions @ J-PARC

A.B. Kaidalov and P.E. Volkovitsky, Z. Phys. C 63, 517 (1994)



- Correct **large *s* behavior**
- **Absolute value** not determined

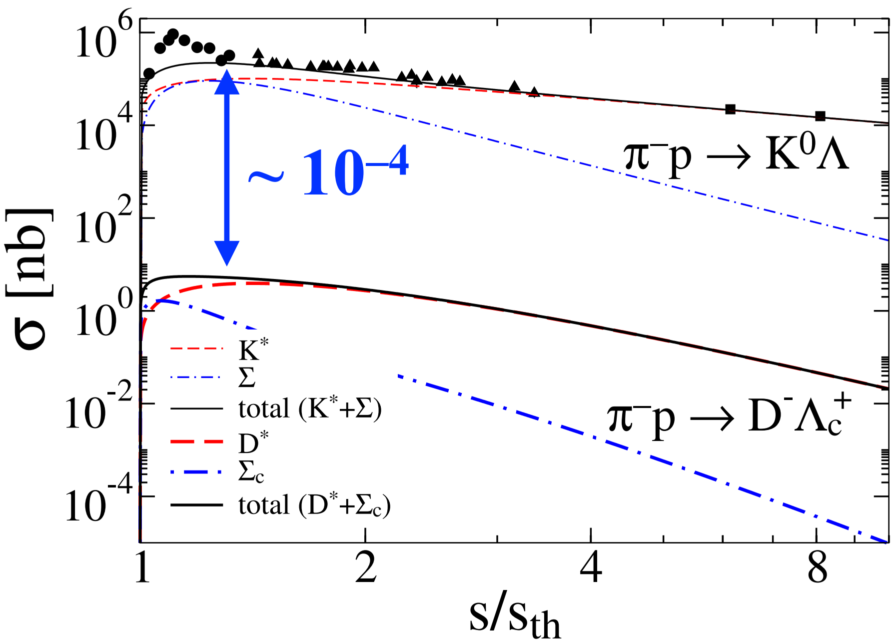
→ Fit to strangeness production and **predict for charm**

$$T_D(s,t) = \underline{\mathcal{M}_D(s,t)} \underline{\left(\frac{s}{s_D}\right)^{\alpha_D(t)} \Gamma[-\alpha_D(t)] \frac{\alpha'_D}{P^{\mathrm{F}}_D(t)}},$$

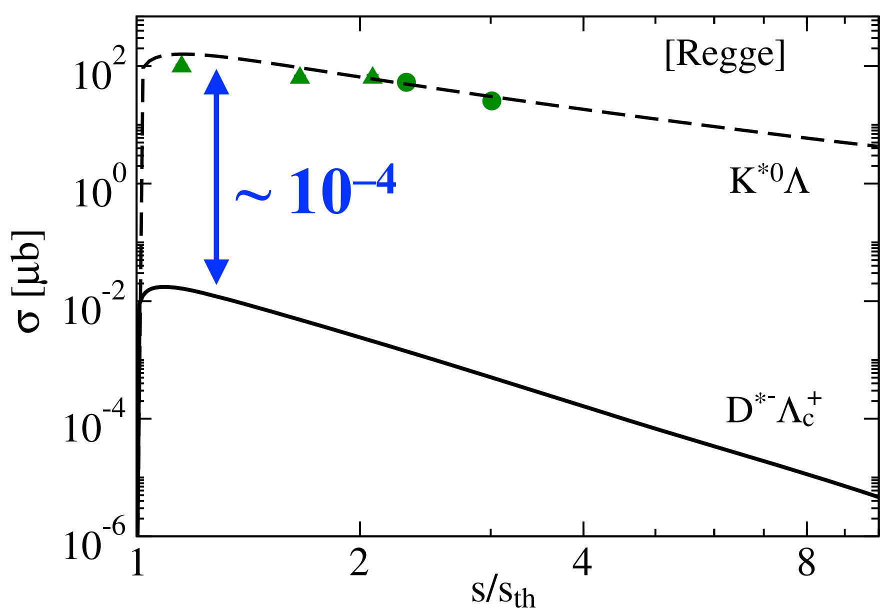
Total cross sections

Kim, AH, Kim,
Phys.Rev. D92 no.9, 094021 (2015); D94, no. 9, 094025 (2016)

$\pi N \to K\Lambda$, $D\Lambda c$

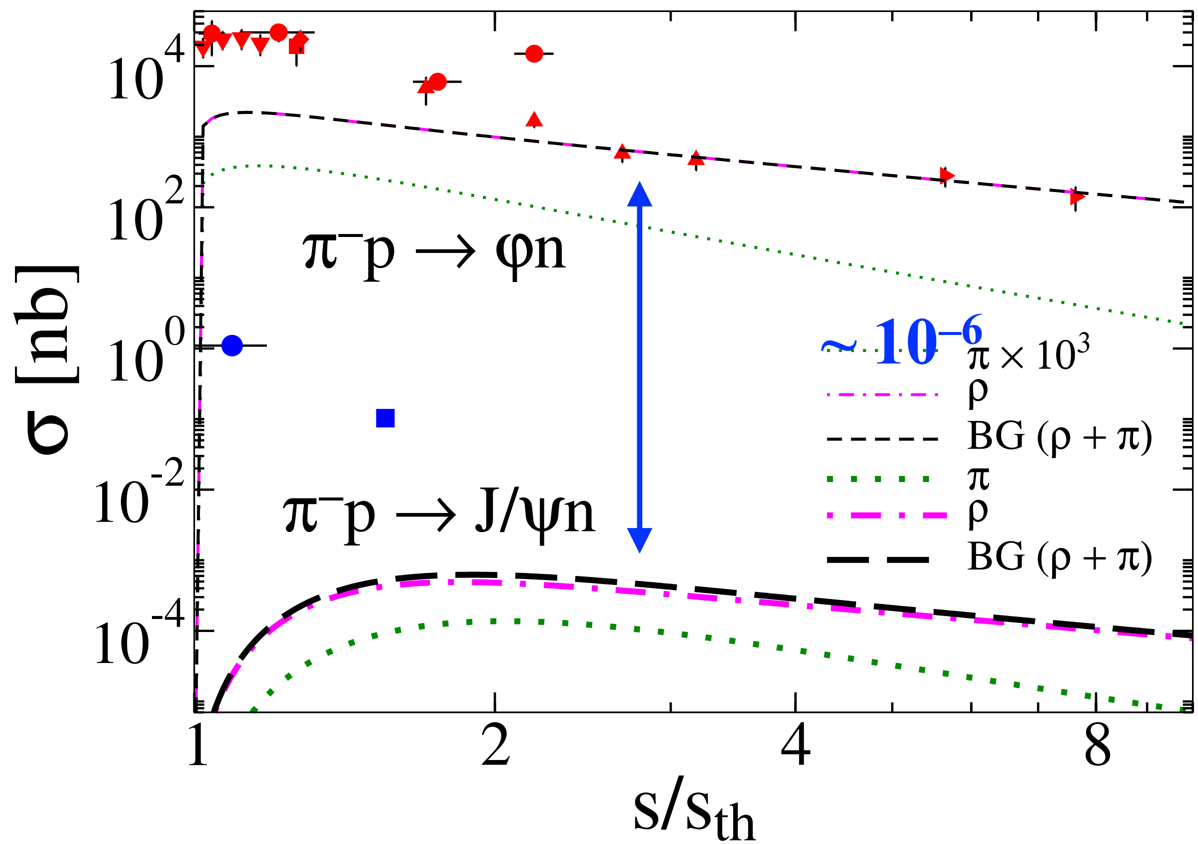


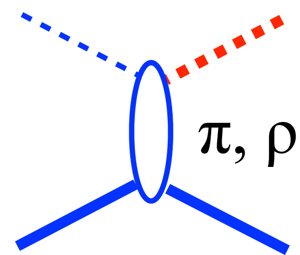
$\pi N \to K^*\Lambda$, $D^*\Lambda c$



Kim, AH, Kim, Phys.Rev. D92 no.9, 094021 (2015)

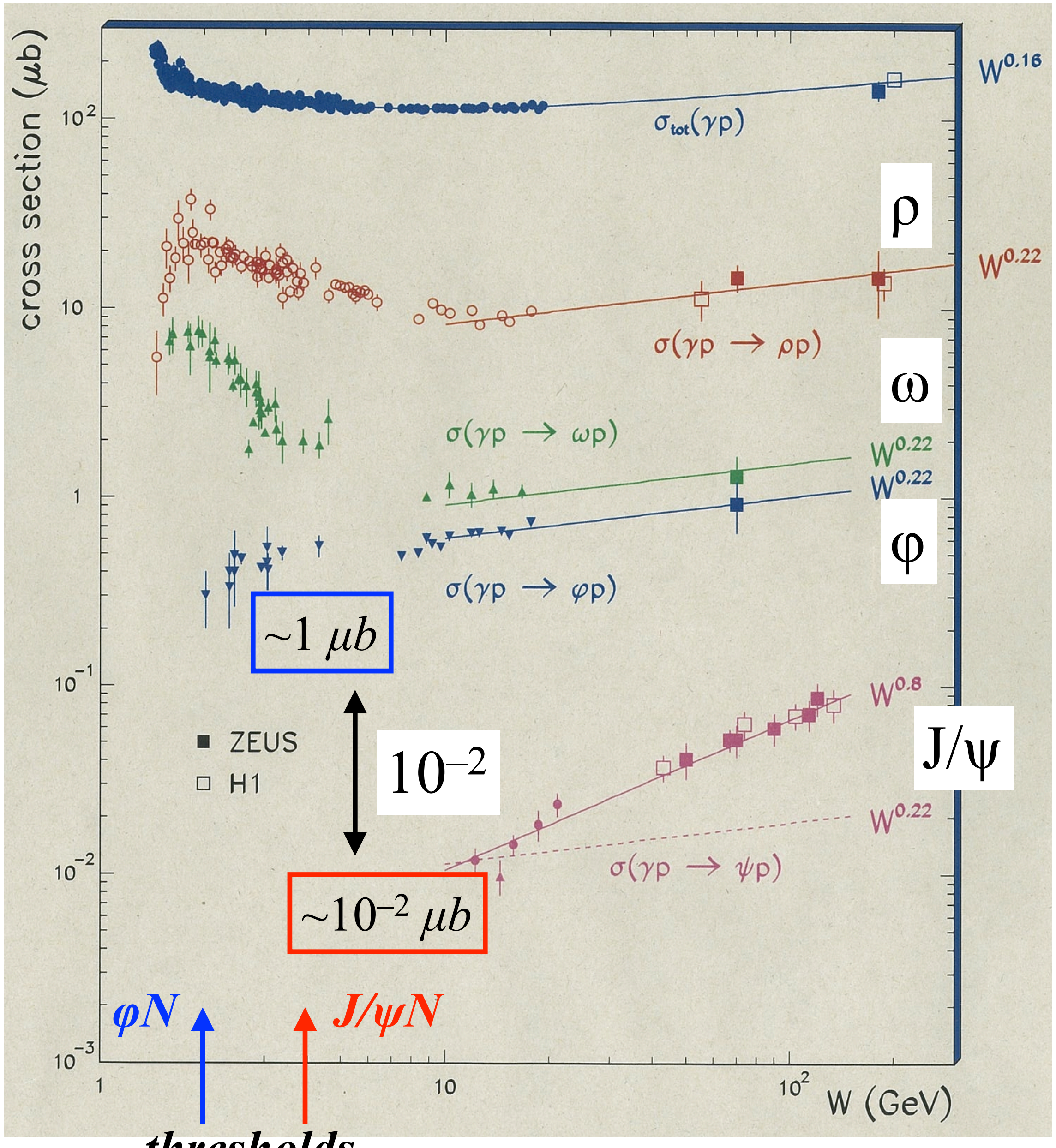
$\pi N \to \varphi N$, $J/\psi N$





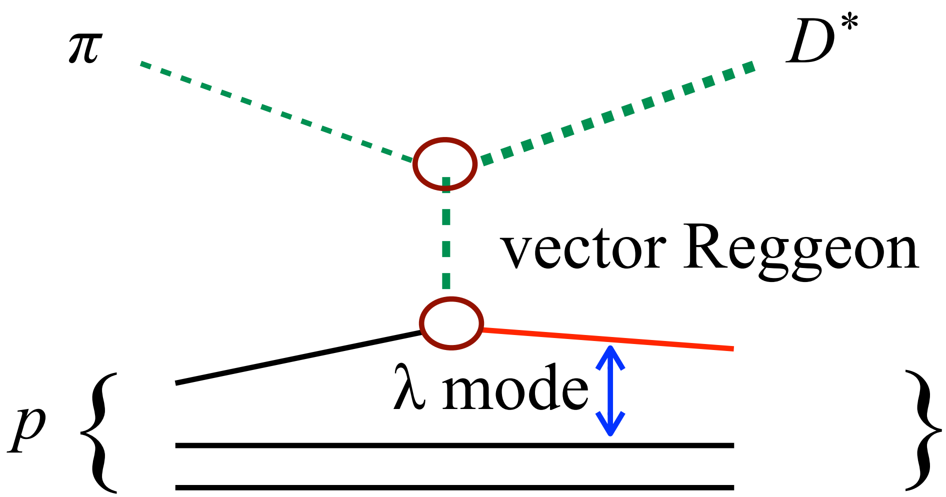
- ρπ Reggeon model reproduces the ***large s behavior of ϕ***
- J/ψ production is largely suppressed by ~ $\mathbf{10^{-6}}$ $g_{\pi\rho\phi} \gg g_{\pi\rho J/\psi}$
- Wish to see more data

Vector meson production: $\gamma\, p \to V\, p$



3. What we can learn about the structure?

Missing Mass study for $\pi N \to D^* \Lambda_c$



Λ_c, Λ_c^*, Σ_c^*, …

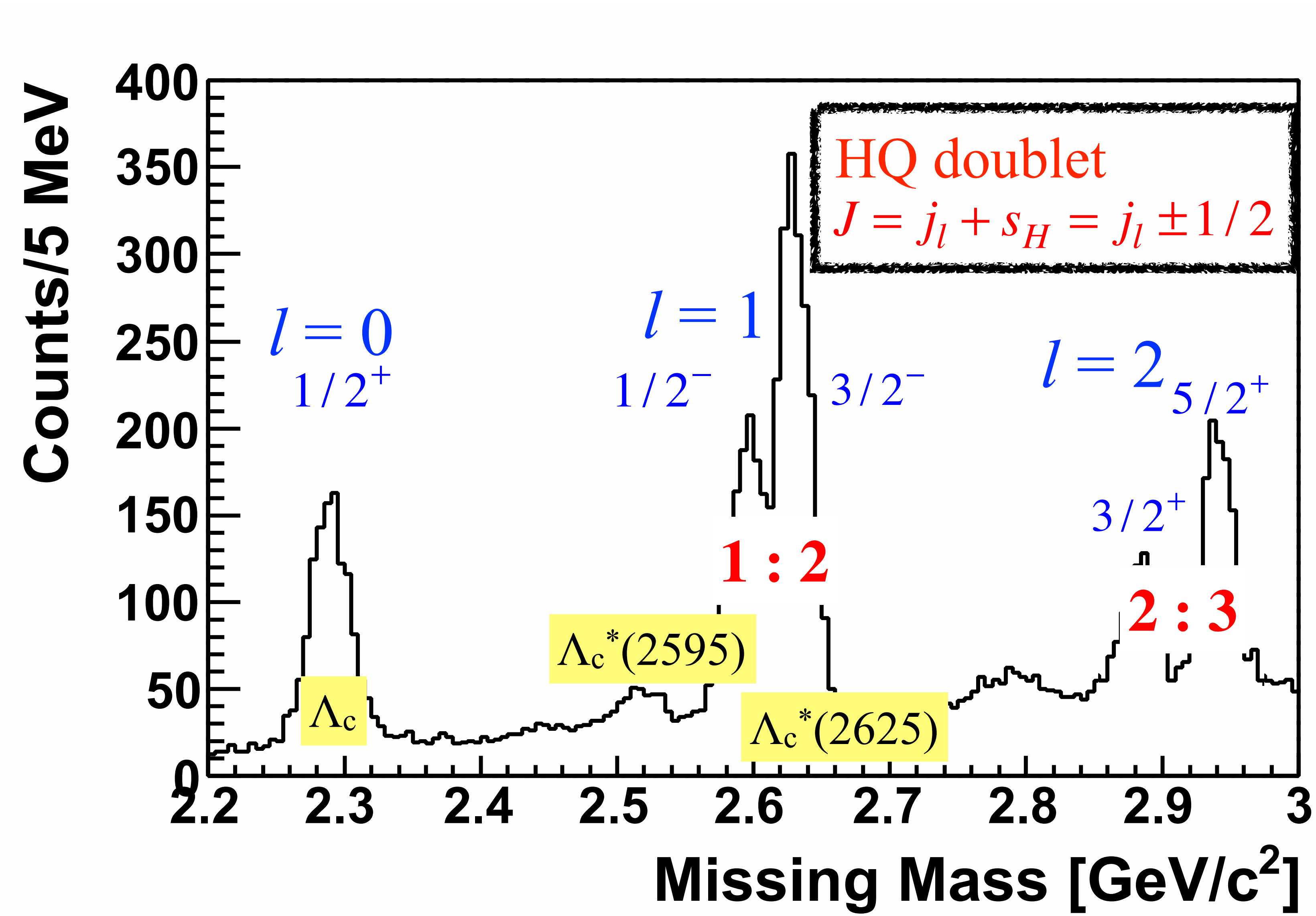
Quark model WF

$$\langle B_c(L\text{-wave})|\vec{e}_\perp \cdot \vec{\sigma} e^{i\vec{q}_{eff}\cdot\vec{x}}|N(\text{S-wave})\rangle_{radial} \sim \left(\frac{q_{eff}}{A}\right)^L \times \exp\left(-\frac{q_{eff}^2}{4A^2}\right)$$

Transverse spin of vector Reggeon

Angular momentum matching

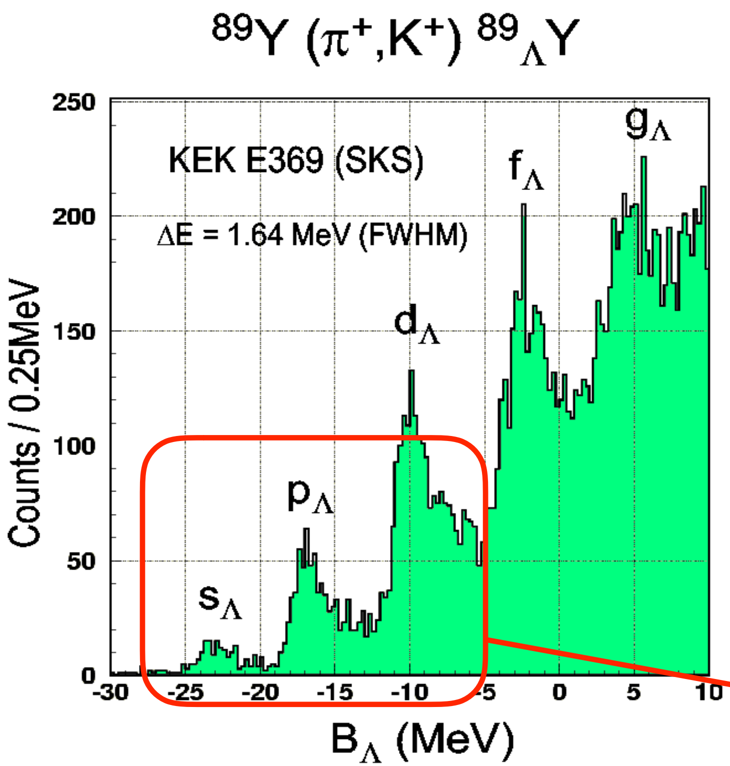
Spectrum simulation

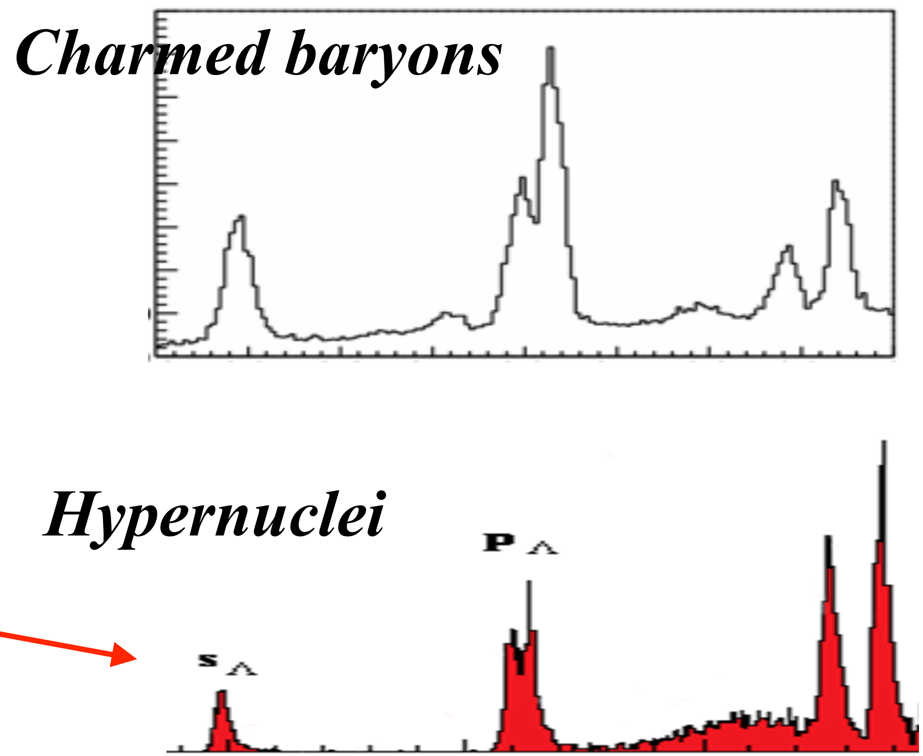


Similarity with hyper nuclei

Establishing single particle orbits: ^{89}Y

$^{89}Y\ (\pi^+, K^+)\ ^{89}{}_{\Lambda}Y$

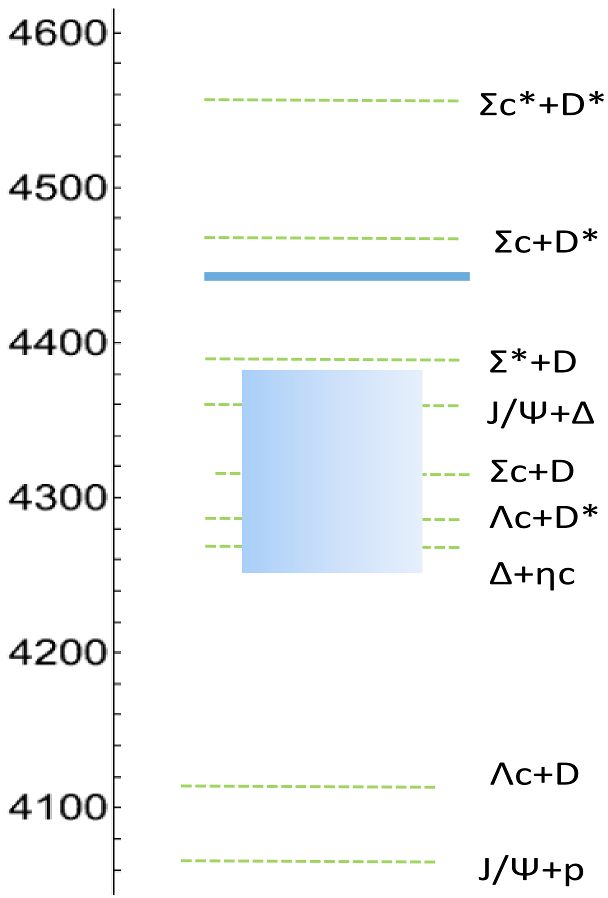




H. Hotch *et al.*,
Phys. Rev. C64, 044302(2001)

4. Productions of P_c

Not much is known except for masses and widths



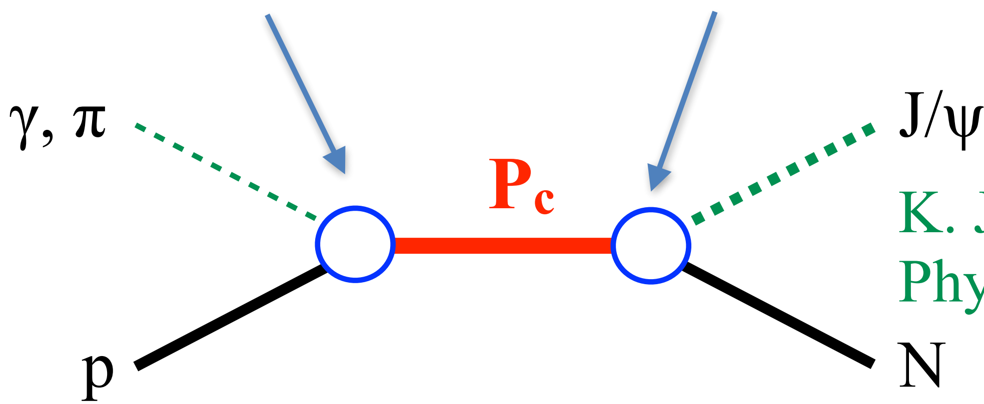
Pc(4450)
Γ = 39±5±19

Pc(4380)
Γ = 205±18±86

Estimation for the J/ψ production

Kubarovsky and Voloshin, PRD92, 031502(R) (2015)

$$\sigma(\pi + p \to P_c \to J/\psi + p)$$
$$= \frac{2J+1}{4}\frac{4\pi}{k^2}\frac{\Gamma^2/4}{(E-E_0)^2+\Gamma^2/4} \Bigg\} \xrightarrow{J=1/2} \textbf{600 } \boldsymbol{\mu b} \text{ at the resonance point}$$
$$\times \mathrm{Br}(P_c \to \pi + p)\mathrm{Br}(P_c \to J/\psi + p)$$



K. Jenkins et al.,
Phys. Rev. D 17, 52 (1978)

To be consistent with the available data of at most **~ 1 nb**,
the product of the BR's is ~ 10^{-6} or less

Open charm molecular states

Wu et al, PRL105, 232001 (2010)

J = 1/2⁻ DΛc, …

TABLE IV. Mass (M), total width (Γ), and the partial decay width (Γ_i) for the states from $PB \to PB$, with units in MeV.

(I, S)	M	Γ	Γ_i					
(1/2, 0)			πN	ηN	$\eta' N$	$K\Sigma$		$\eta_c N$
	4261	56.9	3.8	8.1	3.9	17.0		23.4
(0, −1)			$\bar{K}N$	$\pi\Sigma$	$\eta\Lambda$	$\eta'\Lambda$	$K\Xi$	$\eta_c\Lambda$
	4209	32.4	15.8	2.9	3.2	1.7	2.4	5.8
	4394	43.3	0	10.6	7.1	3.3	5.8	16.3

J = 1/2⁻, 3/2⁻ D*Λc, …

TABLE V. Mass (M), total width (Γ), and the partial decay width (Γ_i) for the states from $VB \to VB$ with units in MeV.

(I, S)	M	Γ	Γ_i					
(1/2, 0)			ρN	ωN	$K^*\Sigma$			$J/\psi N$
	4412	47.3	3.2	10.4	13.7			19.2
(0, −1)			$\bar{K}^*N$	$\rho\Sigma$	$\omega\Lambda$	$\phi\Lambda$	$K^*\Xi$	$J/\psi\Lambda$
	4368	28.0	13.9	3.1	0.3	4.0	1.8	5.4
	4544	36.6	0	8.8	9.1	0	5.0	13.8

$$Br(P_c \to \pi N) \sim 6\%$$

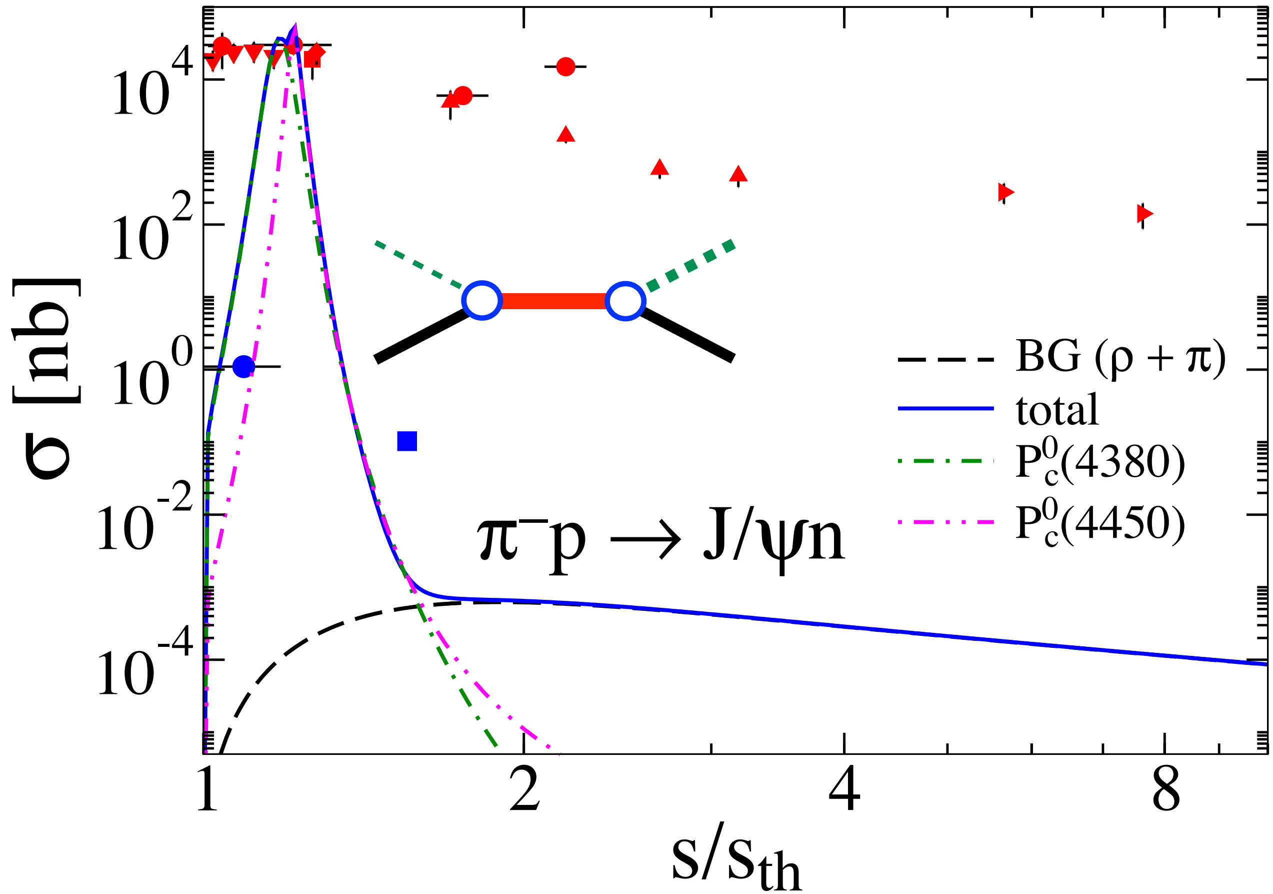
$$Br(P_c \to J/\psi\, N) \sim 40\%$$

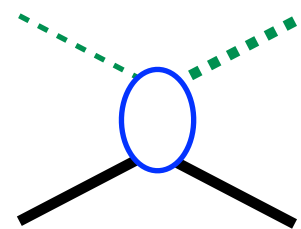
If 1/2⁻, physical *Pc* can be a mixture of them, and then

$$Br(P_c \to \pi N) \times Br(P_c \to J/\psi\, N) \le 0.006 \sim 10^{-2}$$

Implying that σ is about 10^4 larger

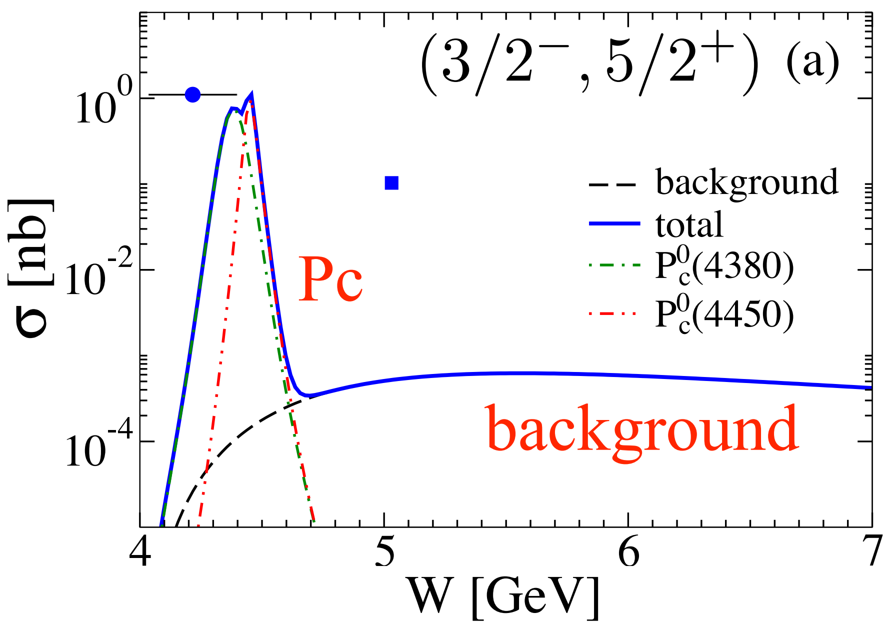
$\pi N \to J/\psi\ N$

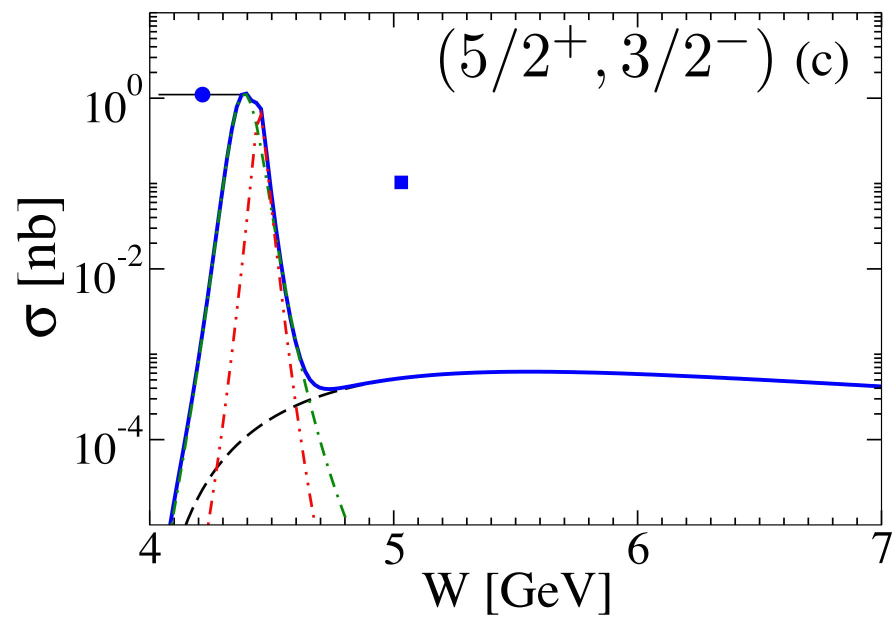




Resonance $\boldsymbol{P_c}$ contribution seems too large

With reduced branching ratio





Summary

- Binary reactions for strangeness and charm productions have been studied by Regge model

	Strangeness [μb]	Charm [μb]	Ratio
$\pi N \to D\Lambda c$, $\pi N \to D^*\Lambda c$	$\sim 10^2$	$\sim 10^{-2}$	$\sim 10^{-4}$ our predictions
$\pi N \to \varphi(J/\psi)N$	~ 1	$\sim 10^{-6}$	$\sim 10^{-6}$
$\gamma N \to K(D)\Lambda_{(c)}$	~ 1	$\sim 10^{-1}$ * $\sim 10^{-5}$ **	$\sim 10^{-1}$ $\sim 10^{-5}$
$\gamma N \to VN$	~ 1	$\sim 10^{-2}$	$\sim 10^{-2}$

* Prediction by Gustafsson et al, PRD69, 094015 (2004)
** by Goritschnig et al, POS (Photon 2013) 061

- For P_c, we need more data and realistic theory study

Coupled channel of MB and 5q configs