Prediction for several narrow *N** and Λ^* resonances with hidden charm around 4 GeV

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Outline

- Introduction
- Theory for the new bound states
- Width and Coupling constant of these states
- The prediction for PANDA
- Summary

Introduction

- The Chiral Unitary Approach has been a very fruitful scheme to study the nature of many hadron resonances. The poles showed by the analysis of meson baryon scattering amplitudes are identified with existing baryon resonances.

- In the many resonances, such as N*(1535), Λ*(1405), it suggests that there are large strange quark components.

Introduction

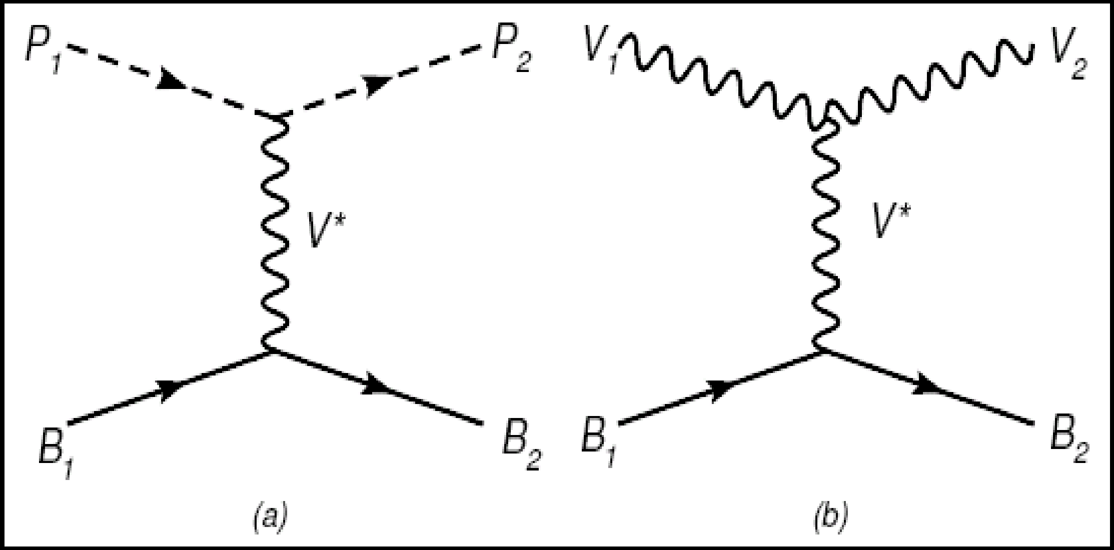
- The Chiral Unitary Approach has been a very fruitful scheme to study the nature of many hadron resonances. The poles showed by the analysis of meson baryon scattering amplitudes are identified with existing baryon resonances.

$\Rightarrow$ SU(3) $\Rightarrow$ SU(4)

- In the many resonances, such as N*(1535), Λ*(1405), it suggests that there are large strange quark components.

$\Rightarrow$ Put the Charm quarks in the resonances.

Theory for the Potential V



$$L_{VVV} = ig\left\langle V^{\mu}\left[V^{\nu},\partial_{\mu}V_{\nu}\right]\right\rangle$$

$$L_{PPV} = -ig\left\langle V^{\mu}\left[P,\partial_{\nu}P\right]\right\rangle$$

$$L_{BBV} = g\left\langle \bar{B}\gamma_{\mu}\left[V^{\mu},B\right]\right\rangle + g\left\langle \bar{B}\gamma_{\mu}B\right\rangle\left\langle V^{\mu}\right\rangle$$

SU(3) {

- $P_1\ P_2$: π, K , η, η'
- $V_1\ V_2$: ρ, K*, ω, ϕ
- $B_1\ B_2$: n, p , Σ, Ξ
- V^* : ρ, K*, ω, ϕ

⇒

- $\bar{D}$, D^- , D_s^-
- $\bar{D}^*$, D^{*-}, D_s^{*-}
- $\Lambda_c, \Sigma_c, \Xi_c, \Xi'_c, \Omega_c$
- ρ, K*, ω, ϕ

} SU(4)

E. Oset and A. Ramos Eur. Phys. J. A 44 445(2010)

Theory for the Potential V

From the Lagrangians, we can get the potential:

$$V_{ab(P_1B_1\to P_2B_2)} = \frac{C_{ab}}{4f^2}(E_{P_1} + E_{P_1})$$

$$V_{ab(V_1B_1\to V_2B_2)} = \frac{C_{ab}}{4f^2}(E_{V_1} + E_{V_2})$$

Here f=93MeV is the pion decay constant.

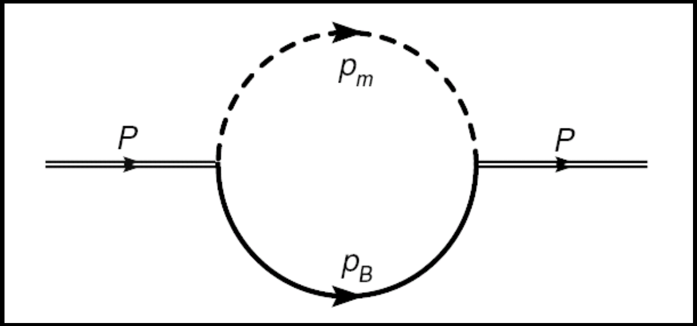
C_{ab} are calculated by the SU(4) Clebsch Gordan Coefficients.

E. M. Haacke, J. W. Moffat and P. Savaria

J. Math. Phys. 17, 2041 (1976).

Theory for the G function

$$G_{(m,B)} = i2M_B \int \frac{1}{(P-p_m)^2 - M_B^2 + i\varepsilon} \frac{1}{p_m^2 - M_m^2 + i\varepsilon} \frac{d^4 p_m}{(2\pi)^4}$$



$$G1_{(m,B)} = \int_0^{\Lambda} \frac{p^2 dp}{4\pi^2} \frac{2M_B(w_m + w_B)}{w_m w_B (P^2 - (w_m + w_B)^2 + i\varepsilon)}$$

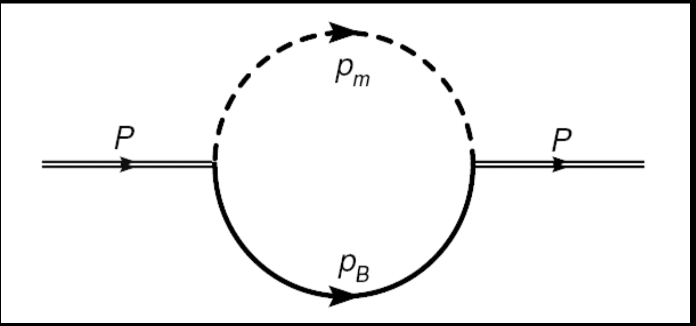
Free Parameter, Around the mass of $\rho(770)$.

$$G2_{(m,B)} = \frac{2M_B}{16\pi^2}\{a_\mu + \ln\frac{M_B^2}{\mu^2} + \frac{M_m^2 - M_B^2 + s}{2s}\ln\frac{M_m^2}{M_B^2} + \frac{q}{\sqrt{s}}[\ln[s-(M_m^2 - M_B^2) + 2q\sqrt{s}] + \ln[s+(M_m^2 - M_B^2) + 2q\sqrt{s}] - \ln[-s-(M_m^2 - M_B^2) + 2q\sqrt{s}] - \ln[-s+(M_m^2 - M_B^2) + 2q\sqrt{s}]]\}$$

μ=1GeV and let a_μ is Free Parameter

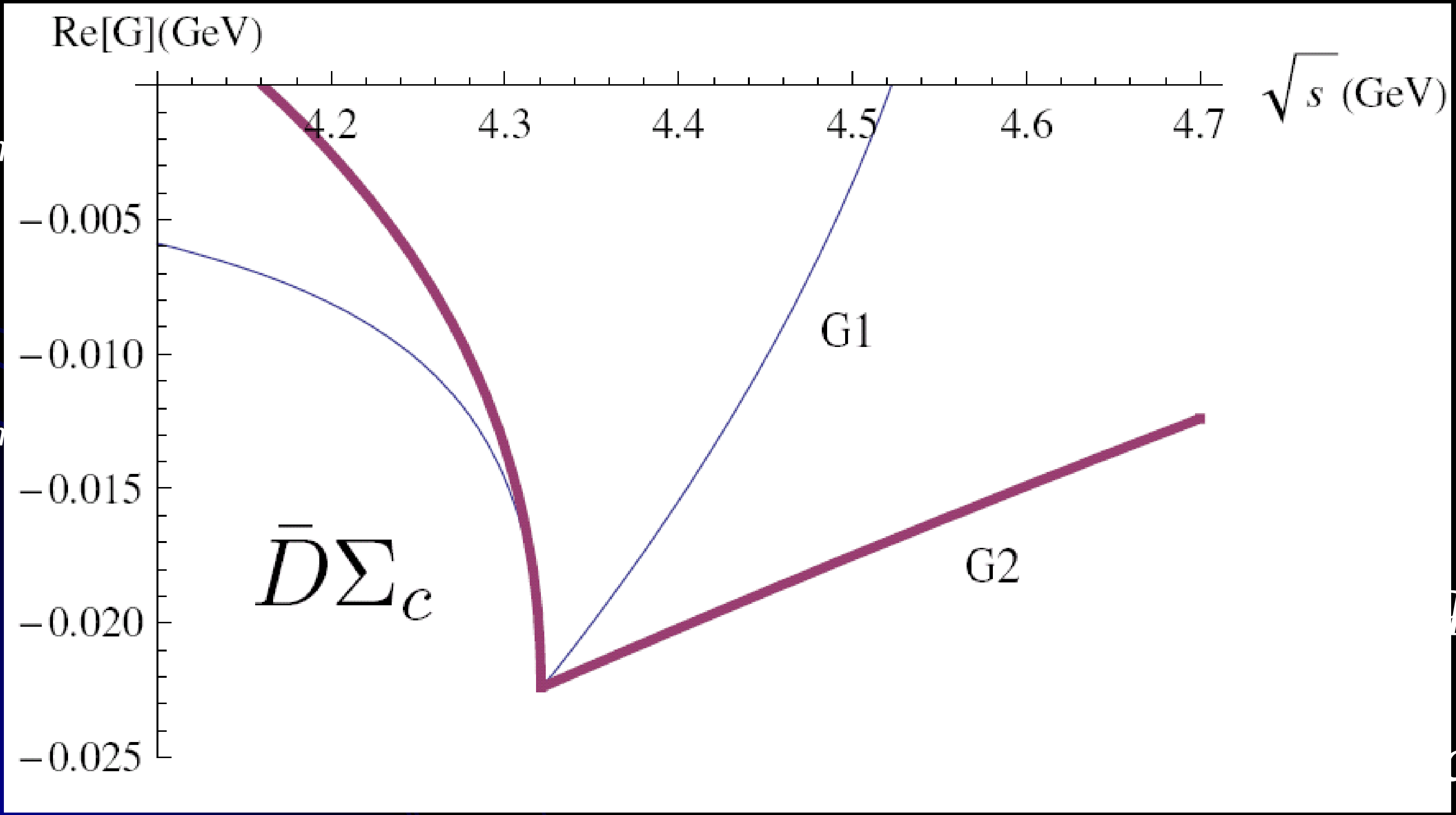
Theory for the G function

$$G_{(m,B)} = i2M_B \int \frac{1}{(P-p_m)^2 - M_B^2 + i\varepsilon} \frac{1}{p_m^2 - M_m^2 + i\varepsilon} \frac{d^4 p_m}{(2\pi)^4}$$



$G1_{(m}$

$G2_{(m}$



$q\sqrt{s}]-$

$q\sqrt{s}]]\}$

Theory for the T matrix

- We get the potential V and the G function.
- The unitary T amplitudes can be obtained by solving the coupled channels Bethe-Salpeter equation:

$$T = [1 - VG]^{-1} V$$

From the *T*, we can find some poles by using different G functions and parameters.

The Pole position

I, S	$\alpha=-2.2(\Lambda=0.7)$ Pole Position	$\alpha=-2.3(\Lambda=0.8)$ Pole Position	$\alpha=-2.4(\Lambda=0.9)$ Pole Position	
1/2, 0	4291(4273)	4269(4236)	4240(4187)	$\bar{D}\Sigma_c$
0, -1	4247(4120)	4213(4023)	4170(3903)	$\bar{D}_s\Lambda_c^+$ $\bar{D}\Xi_c$
	4422(4394)	4403(4357)	4376(4308)	$\bar{D}\Xi'_c$

TABLE I: Pole position from $PB \to PB$ with the two G functions. The unit is MeV

I, S	$\alpha=-2.2(\Lambda=0.7)$ Pole Position	$\alpha=-2.3(\Lambda=0.8)$ Pole Position	$\alpha=-2.4(\Lambda=0.9)$ Pole Position	
1/2, 0	4438(4410)	4418(4372)	4391(4320)	$\bar{D}^*\Sigma_c$
0, -1	4399(4256)	4370(4155)	4330(4030)	$\bar{D}_s^*\Lambda_c^+$ $\bar{D}^*\Xi_c$
	4568(4532)	4550(4493)	4526(4441)	$\bar{D}^*\Xi'_c$

TABLE II: Pole position from $VB \to VB$ with the two G functions. The unit is MeV

There are 6 bound states.

The coupling constants

$$T_{ab} = \lim_{\sqrt{s} \to z_R} \frac{g_a g_b}{\sqrt{s} - z_R}$$

$$|g_a|^2 = \lim_{\sqrt{s} \to z_R} T_{aa}(\sqrt{s} - z_R)$$

$$g_b = \lim_{\sqrt{s} \to z_R} \frac{g_a T_{ab}}{T_{aa}}$$

I, S	Pole Position	Coupling Constant of Channels		
1/2, 0		$\bar{D}\Sigma_c$	$\bar{D}\Lambda_c^+$	
	4269	2.85	0	
0, -1		$\bar{D}_s\Lambda_c^+$	$\bar{D}\Xi_c$	$\bar{D}\Xi_c'$
	4213	1.37	3.25	0
	4403	0	0	2.64
1/2, 0		$\bar{D}^*\Sigma_c$	$\bar{D}^*\Lambda_c^+$	
	4418	2.75	0	
0, -1		$\bar{D}_s^*\Lambda_c^+$	$\bar{D}^*\Xi_c$	$\bar{D}^*\Xi_c'$
	4370	1.23	3.14	0
	4550	0	0	2.53

The width of New bound states

These bound states can decay by two types:

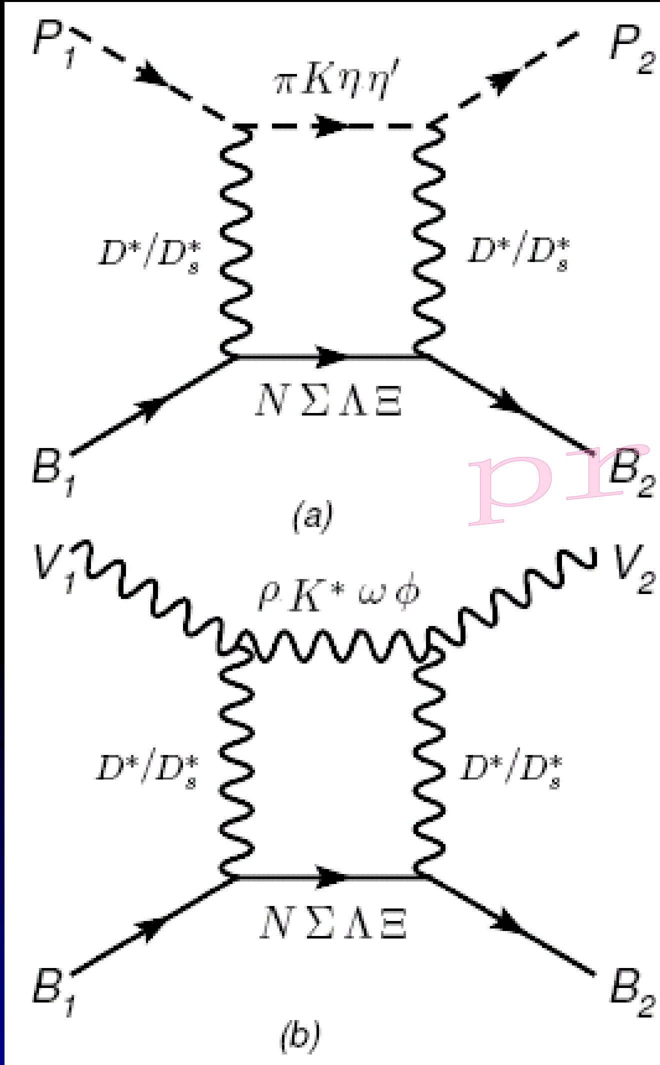
1. Decay to the light meson and baryon channels without charm quark.

   Such as πN, ηN, η'N, KN

2. Decay to the $\bar{c}c$ meson and baryon channels with charm quark.

   Such as J/ψ N, η_c N,

Light Meson and Baryon channel

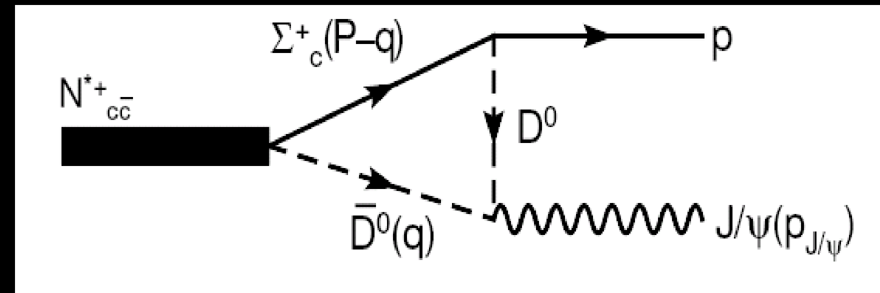


I, S	Pole Position	real axis Mass	real axis Width	Width of Decay Channel				
1/2, 0				πN	ηN	$\eta' N$	$K\Sigma$	
	4269	4267	34.3	3.8	8.1	3.9	17.0	
0, -1				$\bar{K}N$	$\pi\Sigma$	$\eta\Lambda$	$\eta'\Lambda$	$K\Xi$
	4213	4213	26.4	15.8	2.9	3.2	1.7	2.4
	4403	4402	28.2	0	10.6	7.1	3.3	5.8
1/2, 0				ρN	ωN	$K^*\Sigma$		
	4418	4416	28.4	3.2	10.4	13.7		
0, -1				$\bar{K}^*N$	$\rho\Sigma$	$\omega\Lambda$	$\phi\Lambda$	$K^*\Xi$
	4370	4371	23.3	13.9	3.1	0.3	4.0	1.8
	4550	4549	23.7	0	8.8	9.1	0	5.0

The widths are all very narrow.

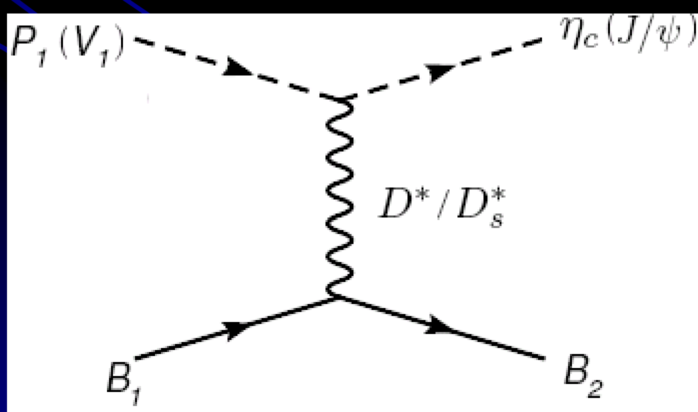
$\bar{c}c$ Meson and Baryon channel

1. The potentials of VB⇔PB are very small. When they exchange pseudo-scalar meson, the BBP vertex is very small; when they exchange vector meson, the VVP vertex is very small.



$$\Gamma_{N^*_{c\bar{c}} \to J/\psi N} = 0.01 MeV$$

2. The bound states from the PB channels only can decay to the η_cB , and the bound states from the VB channels only can decay to the J/ψB.

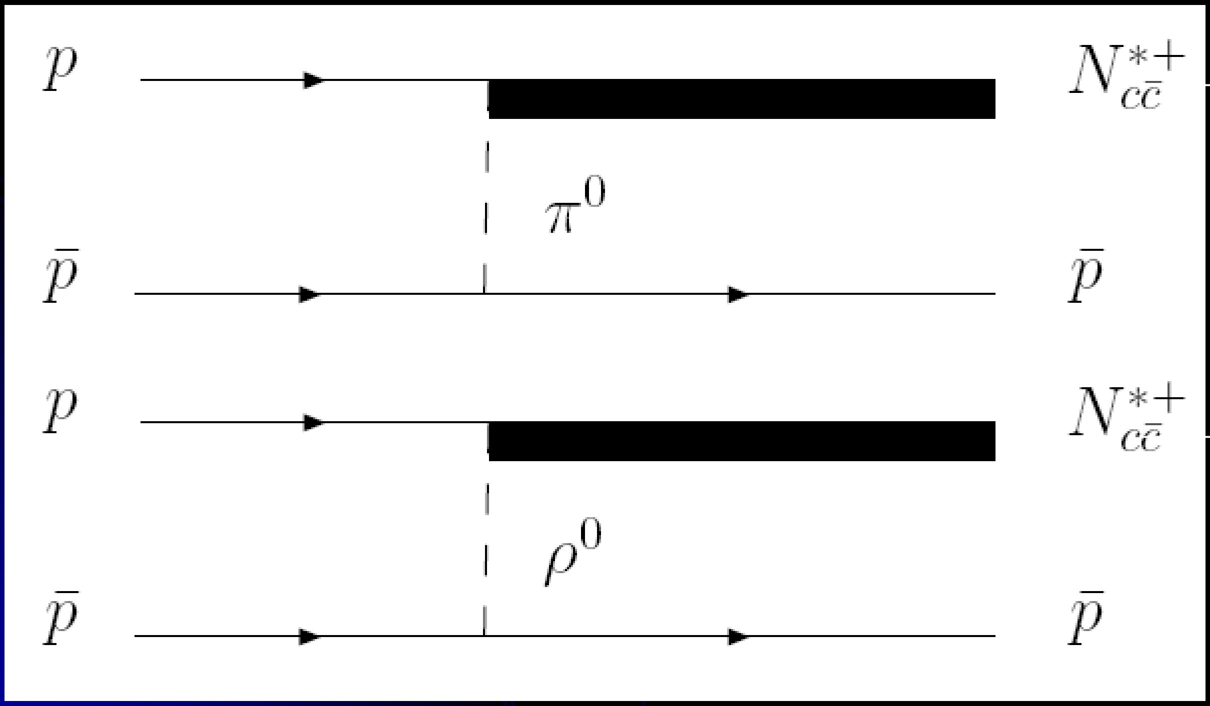


preliminary

I, S	real axis Mass	Width	Width of Decay Channel
1/2, 0	4261	56.9	$\eta_c N$ 23.4
0, -1	4209	32.4	$\eta_c \Lambda$ 5.8
	4394	43.3	16.3
1/2, 0	4412	47.3	$J/\psi N$ 19.2
0, -1	4368	28.0	$J/\psi \Lambda$ 5.4
	4544	36.6	13.8

The prediction for PANDA

The $\bar{p}$ beam of 15 *GeV* one has the invariant mass of C.M. about 5470 *MeV* , which allows one to observe resonances in $\bar{p}X$ production up to a mass *M*= 4538 *MeV* .



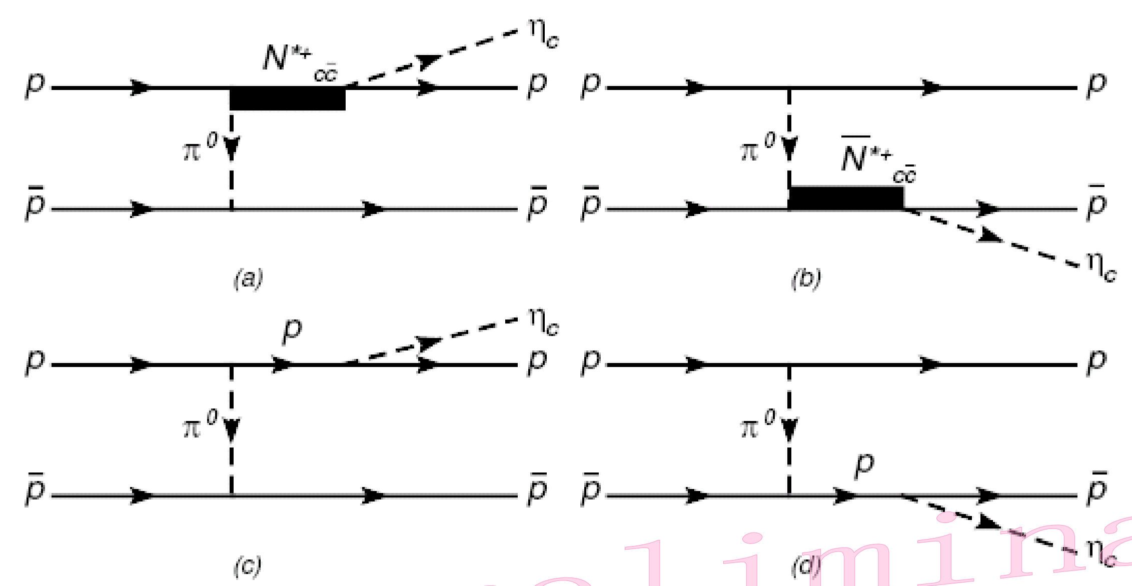
From PB

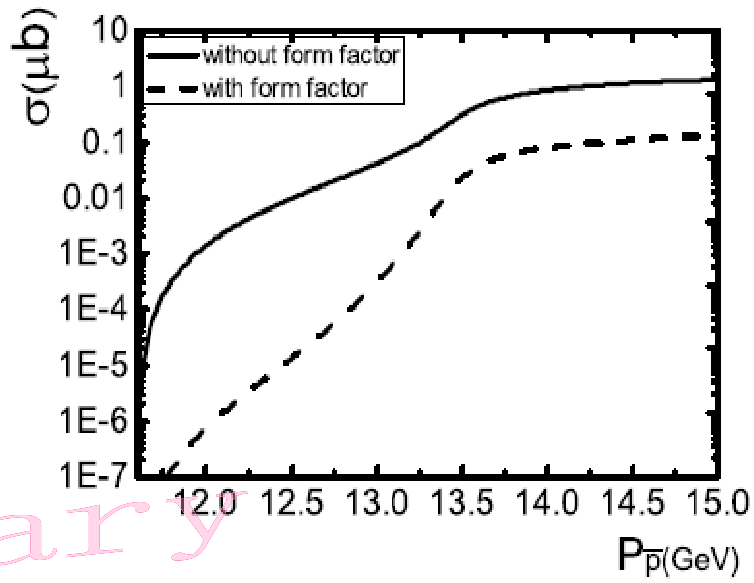
$$\left.\frac{d\sigma}{d\cos\theta\, dM^2_{N^*}}\right|_{\theta=0} = 0.7-1.9\mu b/\mathrm{GeV}^2$$

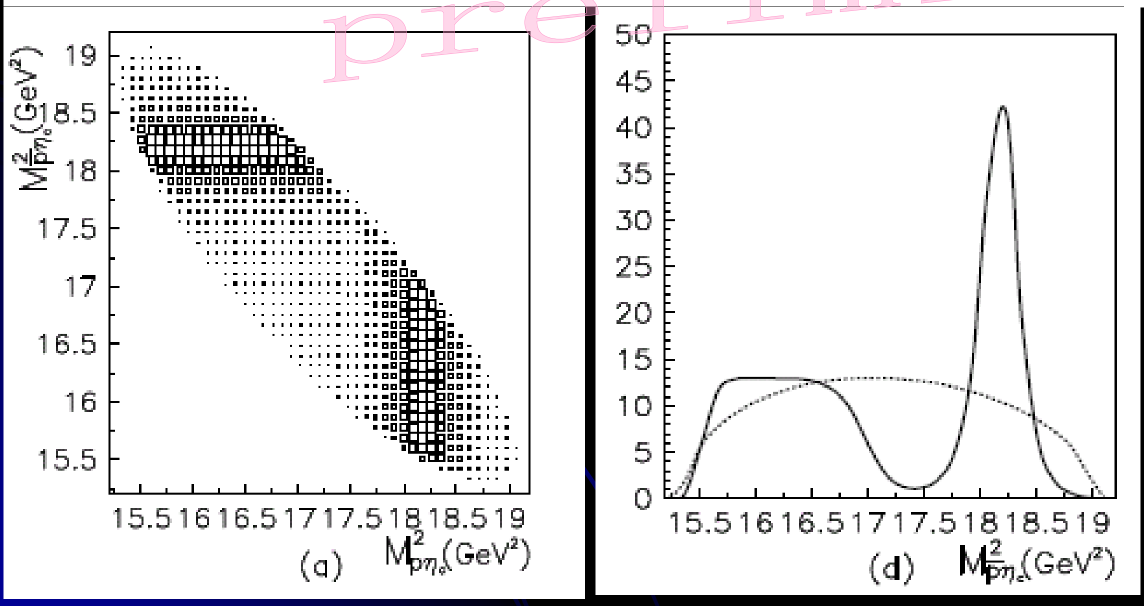
From VB

$$\left.\frac{d\sigma}{d\cos\theta\, dM^2_{N^*}}\right|_{\theta=0} = 0.015-0.12\mu b/\mathrm{GeV}^2$$

The prediction for PANDA







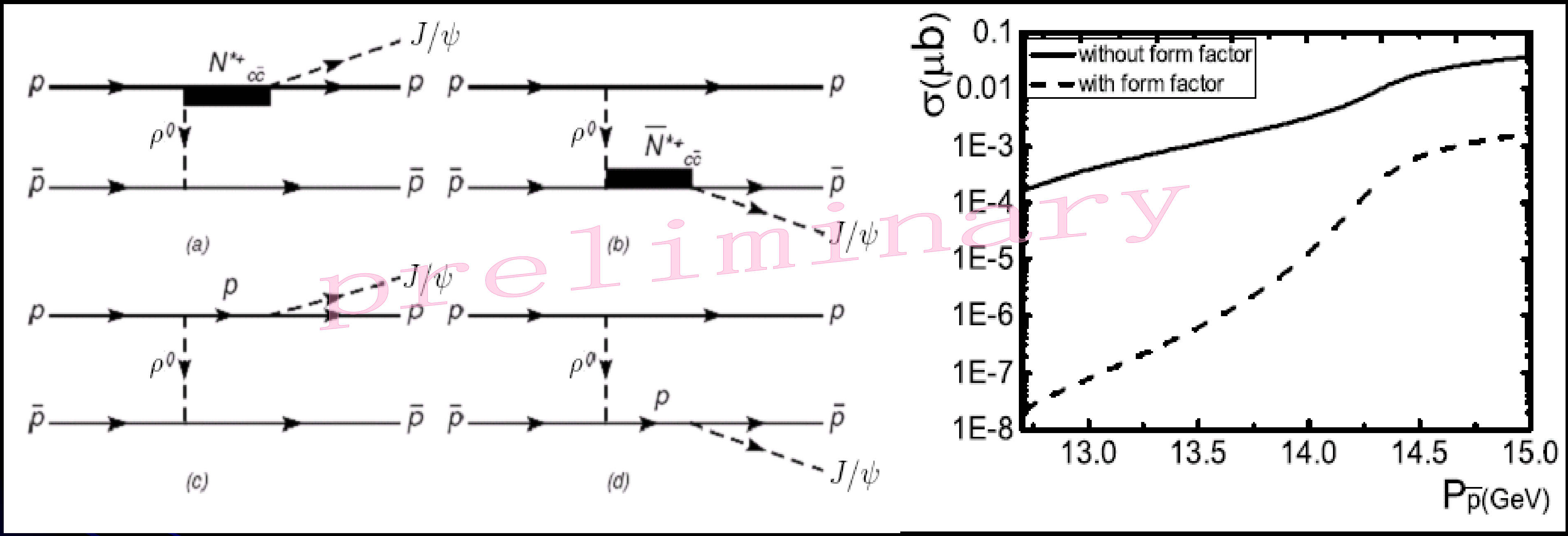
$$F=\frac{\Lambda_\pi^2-M_\pi^2}{\Lambda_\pi^2-p_\pi^2}$$

$$F=\frac{\Lambda_{N*}^4}{\Lambda_{N*}^4+(p_{N*}^2-M_{N*}^2)}$$

$\bar{p}p \rightarrow \eta c\ \bar{p}p$

0.13—1.3μb

The prediction for PANDA



$\bar{p}p \rightarrow J/\psi\ \bar{p}p$ 0.002 – 0.037μb

But the J/ψ is much easier to be detected by lepton channels than η_c.

Summary(1)

- We find 6 bound states by using the Chiral Unitary Approach. All of these bound states have hidden charm quarks.
- These states can decay to two types of channels:

1 light meson and baryon channels: about 1MeV—14MeV because of $\bar{c}c$ annihilation.

2 $\bar{c}c$ meson and baryon channels: about 20MeV because of small phase space.

These heavy states have narrow width.

Summary(2)

- The suggestion for PANDA
- These new states could be looked for in the reaction $\bar{p}p \to \eta_c\ \bar{p}p$ and $\bar{p}p \to J/\psi\ \bar{p}p$.
- $\bar{p}p \to \eta_c\ \bar{p}p$ 0.13 — 1.3 μb
- $\bar{p}p \to J/\psi\ \bar{p}p$ 0.002 — 0.037μb
- It can provide almost 110000 and 1700 events per day in PANDA by $L=10^{31}\ cm^{-2}s^{-1}$.

Thank you!