Charmonium

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"Charmonium"

$n\,^{2s+1}\ell_J$	J^{PC}	I = 0 $c\bar{c}$
$1\,^1S_0$	0^{-+}	$\eta_c(1S)$
$1\,^3S_1$	1^{--}	$J/\psi(1S)$
$1\,^1P_1$	1^{+-}	$h_c(1P)$
$1\,^3P_0$	0^{++}	$\chi_{c0}(1P)$
$1\,^3P_1$	1^{++}	$\chi_{c1}(1P)$
$1\,^3P_2$	2^{++}	$\chi_{c2}(1P)$
$1\,^3D_1$	1^{--}	$\psi(3770)$
$2\,^1S_0$	0^{-+}	$\eta_c(2S)$
$2\,^3S_1$	1^{--}	$\psi(2S)$
$2\,^3P_{0,1,2}$	$0^{++}, 1^{++}, 2^{++}$	

- $C\bar{C}$ meson states
- Parity

$$(-1)^{L+S}$$

- C-parity

$$(-1)^{L+1}$$

Charmonium Hybrids

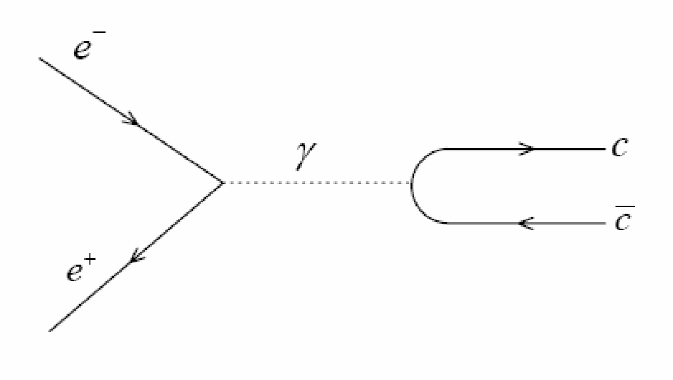
- Quasi-relativistic system
- OGE (one gluon exchange)

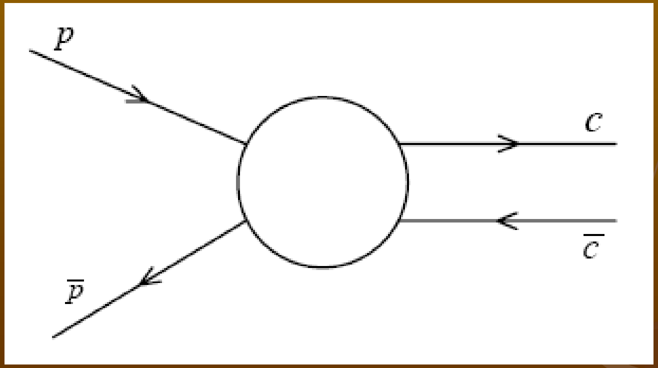
$$V_{c\bar{c}}(r) = -\frac{4}{3}\frac{\alpha_s}{r} + br$$

- Hybrids ($q\bar{q}g, q^3g...$)
- J^{pc} is forbidden (exotic states) for

$$0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, 3^{-+}...$$

Proton ANtiproton annihilation experiment at DArmstadt





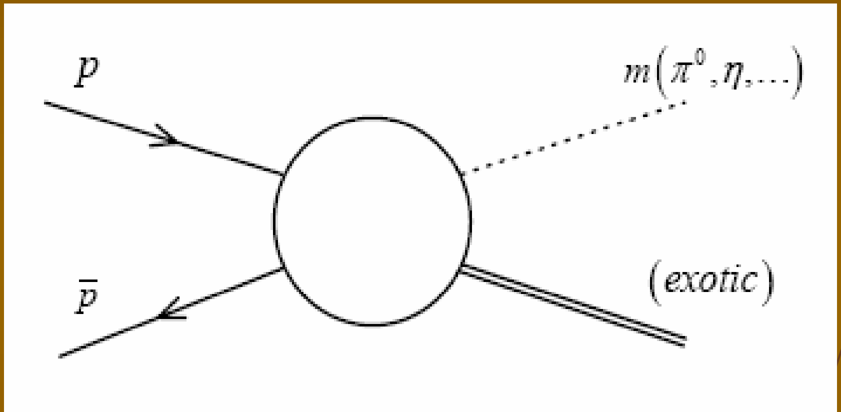
- electron-positron

$$J^{pc} = 1^{--}$$

- proton-antiproton

all nonexotic J^{pc}

PANDA for exotic meson



- The associated state could have exotic quantum number
- How large is the cross section?

The Model of $p\bar{p} \to \psi\pi^0$

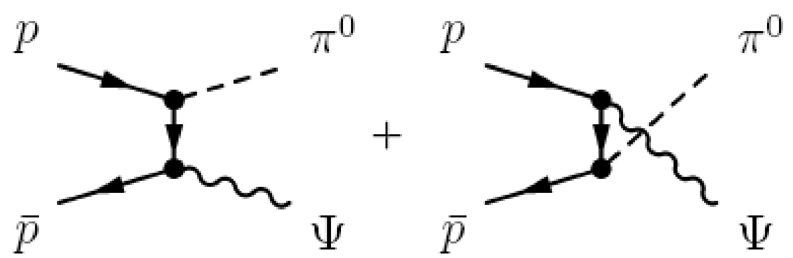


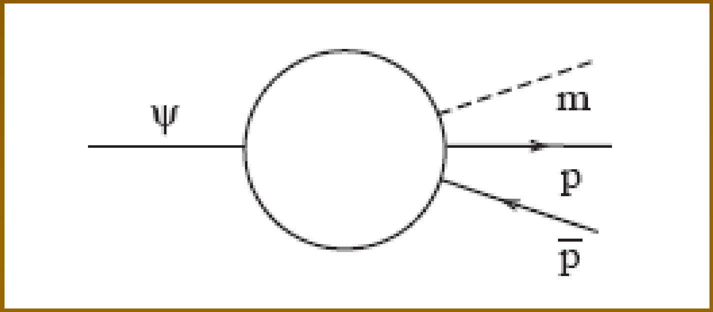
FIG. 1: Feynman diagrams assumed in this model of the generic reaction $p\bar{p} \to \pi^0\Psi$.

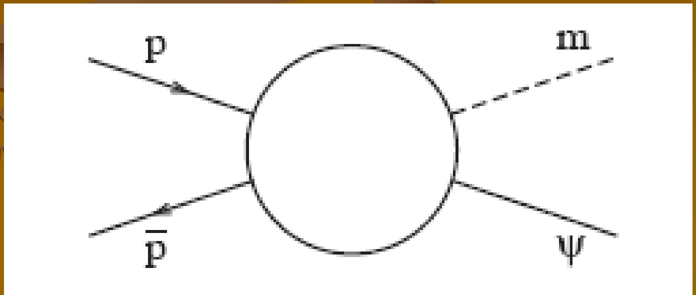
$$\mathcal{M} = i g_\pi g_\Psi \bar{v}_{\bar{p}\bar{s}} \left[\Gamma \frac{(\not{p} - \not{k} + m)}{(t - m^2)} \gamma_5 + \gamma_5 \frac{(\not{k} - \not{\bar{p}} + m)}{(u - m^2)} \Gamma \right] u_{ps}$$

- two vertex in this diagram

$g_{p\bar{p}\pi} \approx 13.5$ $\quad$ $g_{p\bar{p}\psi} = ?$

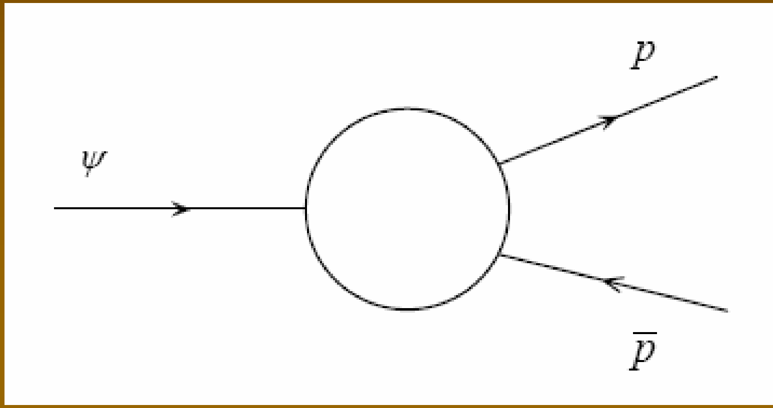
Why this model works?





$$\psi \rightarrow N^{*+} + \overline{p} \rightarrow p + \overline{p} + \pi$$

$p\bar{p}\psi$ vertex



$$\Gamma(\eta_c \to p\bar{p}) = \alpha_{\eta_c}\beta M/2$$

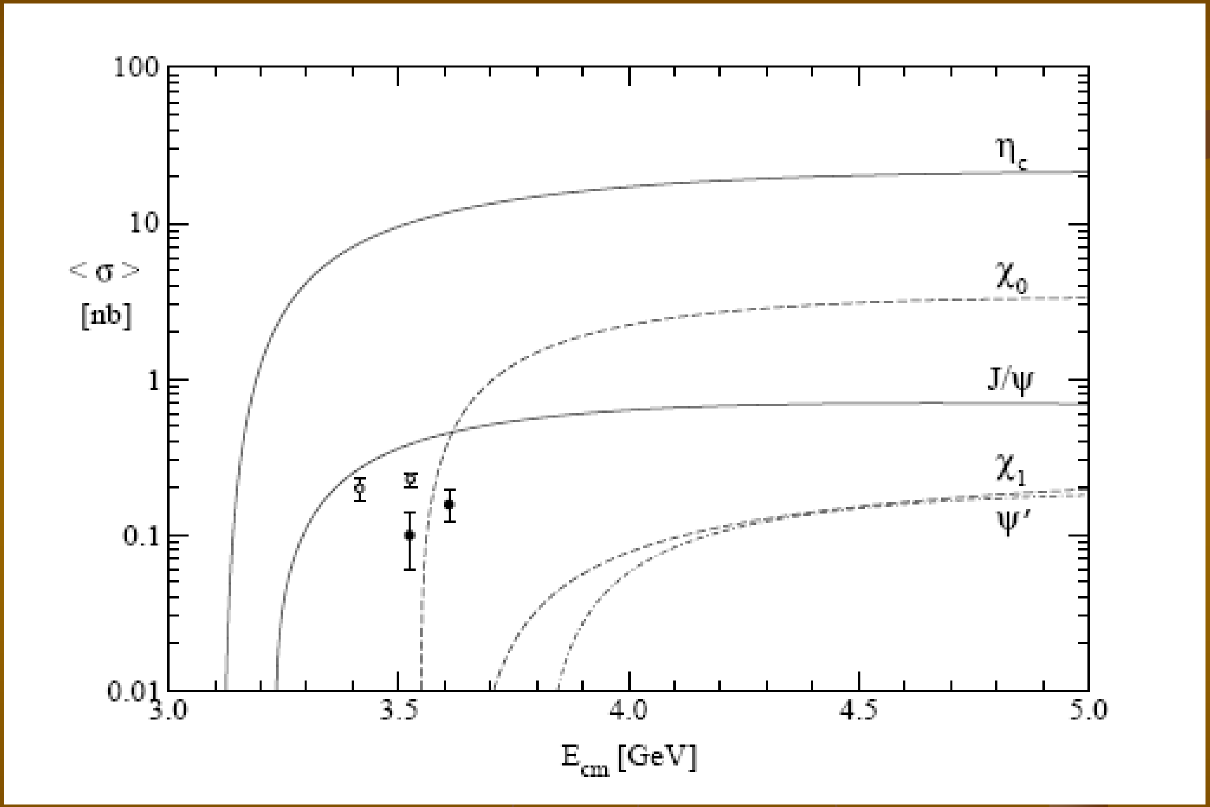
$$\Gamma(J/\psi \to p\bar{p}) = \alpha_{J/\psi}\beta(1+2/r_\Psi^2)M/3$$

$$\Gamma(\chi_0 \to p\bar{p}) = \alpha_{\chi_0}\beta^3 M/2$$

$$\Gamma(\chi_1 \to p\bar{p}) = \alpha_{\chi_1}\beta^3 M/3.$$

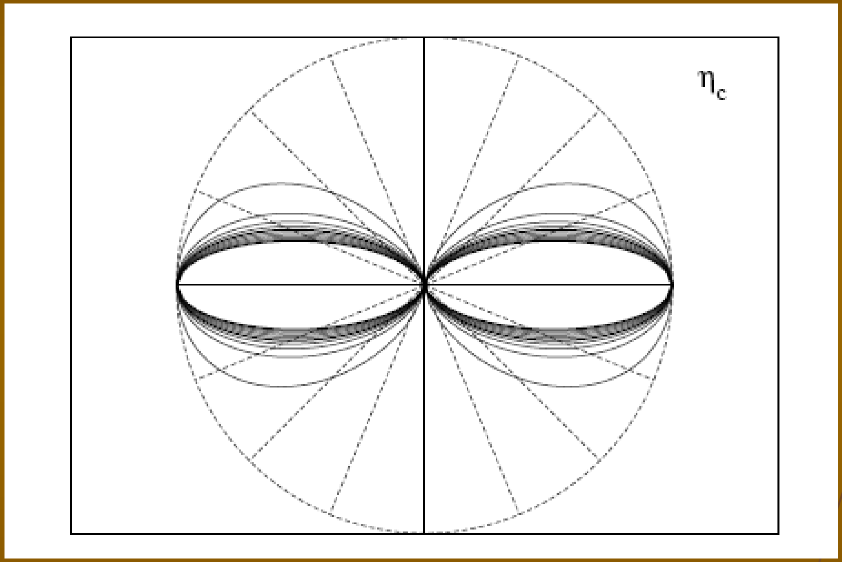
State Ψ	$B_{\Psi\to p\bar{p}}$	$\Gamma_\Psi^{tot.}$[MeV]	$10^3 \cdot g_{pp\Psi}$
η_c	$(1.3 \pm 0.4) \cdot 10^{-3}$	25.5 ± 3.4	19.0 ± 3.2
J/ψ	$(2.17 \pm 0.08) \cdot 10^{-3}$	0.0934 ± 0.0021	1.62 ± 0.03
ψ'	$(2.65 \pm 0.22) \cdot 10^{-4}$	0.337 ± 0.013	0.97 ± 0.04
χ_0	$(2.24 \pm 0.27) \cdot 10^{-4}$	10.4 ± 0.7	5.42 ± 0.37
χ_1	$(6.7 \pm 0.5) \cdot 10^{-5}$	0.89 ± 0.05	1.03 ± 0.07
χ_2	$(6.6 \pm 0.5) \cdot 10^{-5}$	2.06 ± 0.12	–

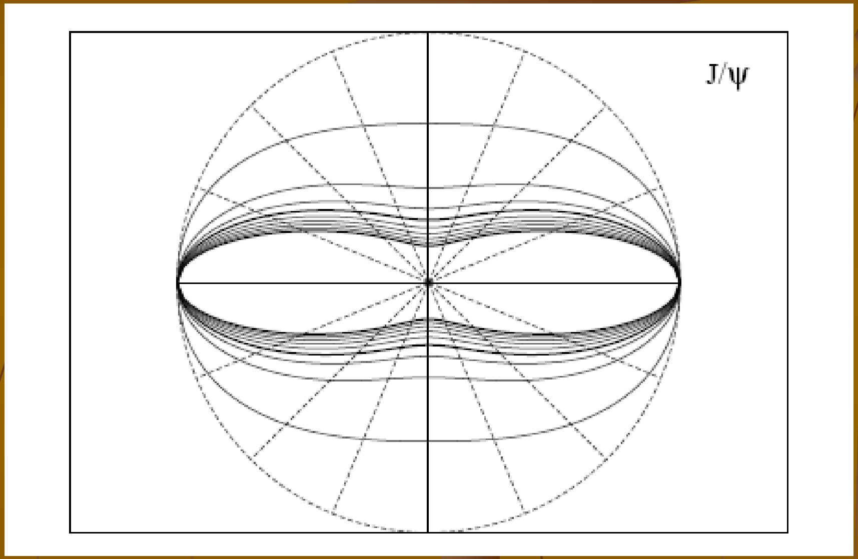
Cross Section result



- The data points are Fermilab measurements of the cross section for $p\bar{p} \rightarrow \pi^0 \, J/\psi$

angular distributions





E from 3.2 to 5.0 GeV by 0.2

E from 3.4 to 5.0 GeV by 0.2

Future

- polarization predictions
- include baryon resonances
- include $p\bar{p}\psi$ form factor
- calculate ppm coupling constant