Multi-GeV Charmonium Mesons

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Resonance and Charmonium Studies

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Motivation

- Explicit glue tests QCD's non-perturbative gluonic interactions
- Spectroscopy of the new states of matter (gluonic hadrons) essentially unknown
- Charmonium hybrids and glueballs under better theoretical control and experimentally cleaner than light flavour hybrids

Kinematics

p rest

$\bar{p}$ energy E

Centre of mass energy W

$$W^2 = 2m_p\,(m_p + \sqrt{m_p^2 + E^2})$$

$$E < 10\ GeV \quad \Rightarrow \quad W < 4500\ MeV$$

Hybrid Charmonium

Many quenched lattice QCD mass predictions

Decay selection rule:
(non-relativistic quarks, spin 1 pair creation)

P.R. Page, *Phys. Lett.* **B402** (1997) 183

Hybrid charmonium $\overset{not}{\rightarrow}$ $D\bar{D}$, $D^*\bar{D}^*$
$\overset{small}{\rightarrow}$ $D^*\bar{D}$

$J^{PC} = 0^{+-} \overset{not}{\rightarrow} D\bar{D},\ D^*\bar{D}^*,\ D^*\bar{D}$

Width 0^{+-}, $1^{-+} = \mathcal{O}\ (5,\ 20)$ MeV

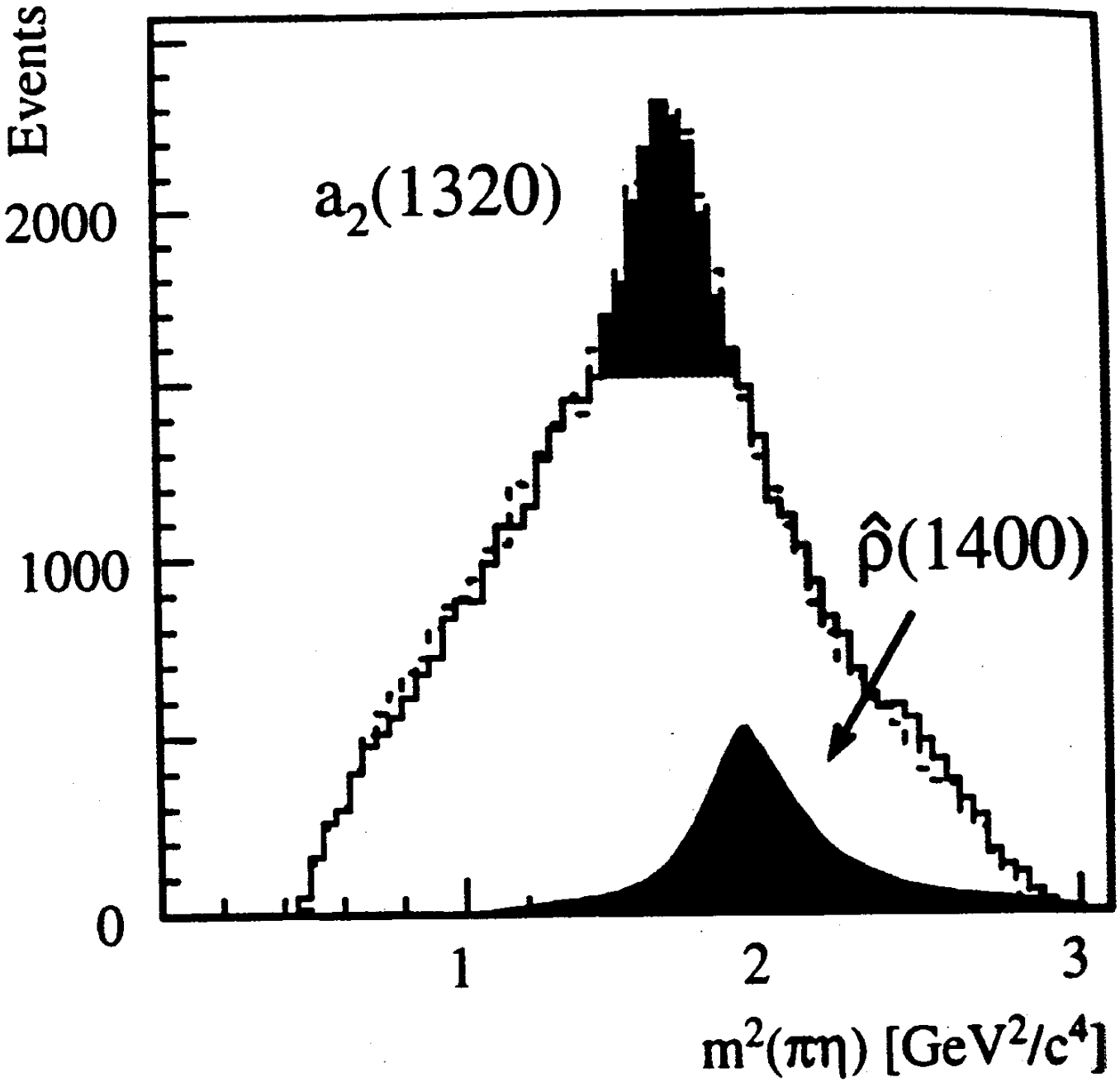
F.E. Close *et al.*, *Phys. Rev.* **D57** (1998) 5653

P.R. Page, *Acta Phys. Polon.* **B29** (1998) 3387

Decay to charmonium + light hadrons signal
$c\bar{c}$ nature of initial state. ψ easiest to detect

Production: LEAR: $\hat{\rho}(1405)$, $\hat{\rho}(1600)(?)$, $\rho(1450)$

CRYSTAL BARREL



Glueballs

- No light flavour conventional mesons $\gtrsim 3100 \pm 110$ MeV

  M.M. Brisudová, L. B., T. G., *Phys. Rev.* **D61** (2000) 054013

- Mixing with charmonium small
- Most glueballs $\stackrel{n\alpha t}{\rightarrow}$ two glueballs

$\Longrightarrow$ Glueball could be very narrow!

(if light flavour hybrid meson mixing small)

Production: LEAR: $f_0(1500)$, $f_J(2220)$

Subprogram of hybrid charmonium: Distinguish by charmonium + light hadrons decay

Contents

J^{PC} exotics	J^{PC} unknown
Need PWA	Not need PWA
Fixed $\bar{p}$ energy	Vary $\bar{p}$ energy
Low σ	High σ

J^{PC} Exotics

Conventional charmonium not J^{PC} exotic

J^{PC} exotic $\Rightarrow$ hybrid $c\bar{c}$, glueball (four–quark)

- Need angular distributions / PWA

+ Cannot mix with conventional charmonium

Hybrid $c\bar{c}$: Mass (MeV)

Quenched Lattice QCD:

1^{-+}	0^{+-}	Ref.
$4410^{+60}_{-150} + \text{sys}$	$4560^{+110}_{-100} + \text{sys}$	[1]
$4290^{+110}_{-190} + \text{sys}$	$4560^{+80}_{-110} + \text{sys}$	[1]
$4390 \pm 80 \pm 200$	$4610 \pm 110 \pm 200$	[2]

[1] C. Bernard *et al.* (MILC Collab.), LATTICE'98, hep-lat/9809087

[2] *ibid., Phys. Rev.* **D56** (1997) 7039

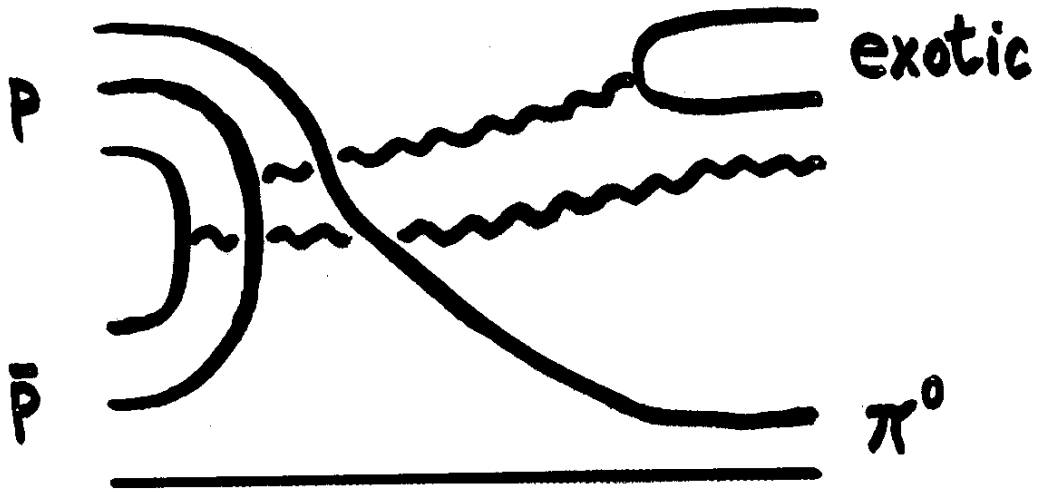
$D^{**}D$ threshold: 4290 MeV

2^{+-}, 0^{--} exotics: probably above $D^{**}D$

Hybrid $c\bar{c}$: Production

Formation: $p\bar{p} \overset{not}{\rightarrow}$ exotic

$$p\bar{p} \rightarrow \text{exotic}\,(\pi^0,\ \pi\pi,\ \pi\pi\pi,\ \eta, \ldots)$$



$\Rightarrow$ Fixed $\bar{p}$ energy

$$E < 10\ GeV \quad \Rightarrow \quad m_{\text{exotic}} < 4360\ MeV$$

Hybrid $c\bar{c}$: Decay

$$1^{-+} \to \psi\,(\omega, \phi, \gamma) \to e^+e^-e^+e^-,\ e^+e^-\gamma$$

[small]

$$0^{+-} \to \psi\,(\pi\pi)_S\ \ [\psi\pi^0\pi^0] \to e^+e^-\gamma\gamma\gamma\gamma$$

[background]

Missing mass:

Detect π^0 and ψ in $p\bar{p} \to$ exotic $\pi^0 \to \psi X \pi^0$

J^{PC}	Open charm	Hidden charm	Light hadrons
0^{+-}	Quantum	$J/\psi\{f_{\{0,1,2\}}, (\pi\pi)_S\}$	$a_{\{0,1,2\}}\rho;\ a_{\{1,2\}}\{b_1, \gamma\}$
	numbers	$h_c\eta;\ \eta_c h_1$	$b_1\pi;\ h_1\eta^{(\prime)}$
	forbid	$\chi_{c0}\omega$	$\{(\pi\pi)_S, f_0\}\{\omega, \phi\}$
	$D^{(*)}D^{(*)}$	$\chi_{c\{1,2\}}\{\omega, h_1, \gamma\}$	$f_{\{1,2\}}\{\omega, h_1, \phi, \gamma\}$
0^{--}	D^*D	$h_c(\pi\pi)_S$	$a_{\{0,1,2\}}b_1;\ a_{\{1,2\}}\{\rho, \gamma\}$
		$J/\psi\{f_{\{1,2\}}, \eta^{(\prime)}\}$	$\rho\pi$
		$\chi_{c0}h_1;\ \eta_c\{\omega, \phi\}$	$f_0h_1;\ \eta^{(\prime)}\{\omega, \phi\}$
		$\chi_{c\{1,2\}}\{\omega, h_1, \gamma\}$	$f_{\{1,2\}}\{\omega, h_1, \phi, \gamma\}$
1^{-+}	$D^*D,\ D^*D^*$	$\chi_{c\{0,1,2\}}(\pi\pi)_S$	$a_{\{0,1,2\}}a_{\{0,1,2\}};\ a_{\{1,2\}}\pi$
		$\eta_c\{f_{\{1,2\}}, \eta^{(\prime)}\}$	$f_{\{0,1,2\}}f_{\{0,1,2\}};\ f_{\{1,2\}}\eta^{(\prime)}$
		$\chi_{c\{1,2\}}\eta$	$\{\rho, \gamma\}\{\rho, b_1\};\ b_1b_1$
		$\{h_c, J/\psi\}\{\omega, h_1, \phi, \gamma\}$	$\{\omega, h_1, \phi, \gamma\}\{\omega, h_1, \phi, \gamma\}$
2^{+-}	$D^*D,\ D^*D^*$	$\{h_c, J/\psi\}\{f_{\{0,1,2\}}, (\pi\pi)_S\}$	$a_{\{0,1,2\}}\{\rho, b_1, \gamma\}$
		$\{h_c, J/\psi\}\eta^{(\prime)}$	$\{\rho, \gamma, b_1\}\pi$
		$\{\eta_c, \chi_{c\{0,1,2\}}\}\{\omega, h_1, \phi, \gamma\}$	$\{\eta^{(\prime)}, f_{\{0,1,2\}}\}\{\omega, h_1, \phi, \gamma\}$

Hybrid $c\bar{c}$: Cross-section

LEAR: similar to charmonium: 130 pb

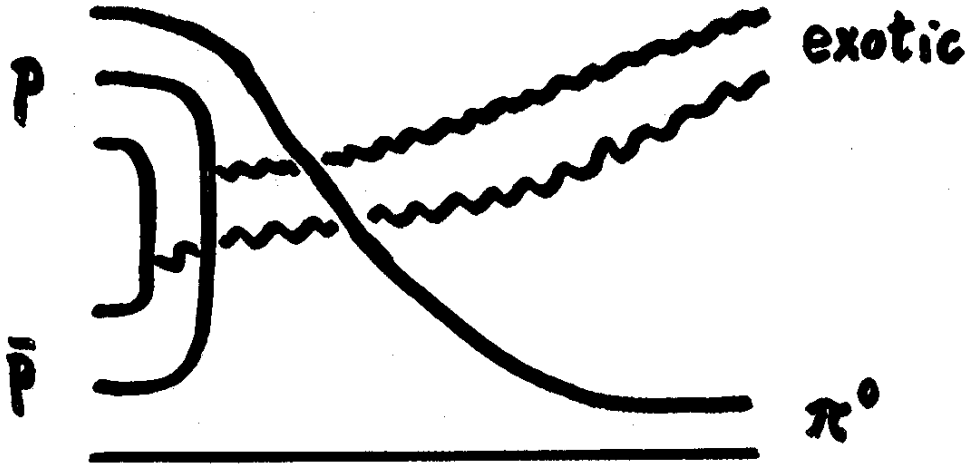
$\sigma(p\bar{p} \to \psi\pi^0) = 130 \pm 25$ pb. from R. Cester, Workshop on Physics at SuperLEAR (Zurich, Oct. 1991), Inst. of Physics Conf. Series No. 124, p. 91

$\mathcal{L} = 10^{32}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$ 50% efficiency

$BR(\text{exotic} \to \psi\omega) = 1\%$

$\Rightarrow$ 1 event/day

Glueballs



+ Large σ

- Many decay channels: light hadrons

2^{+-} $4140 \pm 50 \pm 200$ MeV [lightest]

0^{+-} $4740 \pm 70 \pm 230$ MeV [too heavy]

C.J. Morningstar, M. Peardon, *Phys. Rev.* **D60** (1999) 034509

J^{PC} Unknown

+ PWA not necessary $\Rightarrow$ bump hunting

- Can be conventional charmonium

+ Narrowness or decay modes distinctive

+ Small conventional charmonium mixing, except for mass coincidences $[1^{--}]$

S.B. Gerasimov, *Proc. of 11th Int. Conf. on Problems of Quantum Field Theory* (July 1998, Dubna, Russia), hep-ph/9812509

F.E. Close, P.R. Page, *Phys. Lett.* **B366** (1996) 323

Hybrid $c\bar{c}$: Mass

8 low–lying hybrids [5 non-exotic]:

$1^{--}, (0,1,2)^{-+} < 1^{++}, (0,1,2)^{+-}$

K.J. Juge, J. Kuti, C.J. Morningstar, hep-lat/9909165

T. Manke, *et al.*, *Phys. Rev.* **D57** (1998)3829

Splittings (MeV)

J^{PC}	Gluon exchange [1]	Confinement [2]
0^{-+}	-180	8
1^{-+}	-50	4
1^{--}	60	0
2^{-+}	210	-4

[1] P. R. Page, *D. Phil. thesis* (Univ. of Oxford, 1995)

[2] J. Merlin, J. Paton, *Phys. Rev.* **D35** (1987) 1668

Hybrid $c\bar{c}$: Production

Formation: $p\bar{p} \rightarrow$ non-exotic $\quad W < 4500$ MeV

$\Rightarrow$ Energy scan

Hybrid $c\bar{c}$: Decay

$p\bar{p} \rightarrow$ non-exotic $\rightarrow \psi X$. ψ detected. X from missing mass. $X = \eta,\ \eta',\ \omega,\ \phi,\ \pi\pi,\ K\bar{K}, \ldots$

[conventional charmonium suppressed]

$\psi\eta \qquad 1^{--},\ 1^{+-}$

$\psi\omega \qquad 0^{-+},\ 2^{-+},\ 1^{++}$

non-exotic $\rightarrow e^+e^-,\ \mu^+\mu^-,\ \tau^+\tau^-,\ \gamma\gamma$ small

S. Ono *et al.*, *Z. Phys.* **C26** (1984) 307; *Phys. Rev.* **D34** (1986) 186; P.R. Page, *Nucl. Phys.* **B495** (1997) 268

Hybrid $c\bar{c}$: Cross-section

Form. $\sigma = 0.1\ \mu$b. Similar to charmonium

F.E. Close, SuperLEAR Workshop, p. 63; K. Königsmann, p. 71

$\mathcal{L} = 10^{32}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$ 50% efficiency

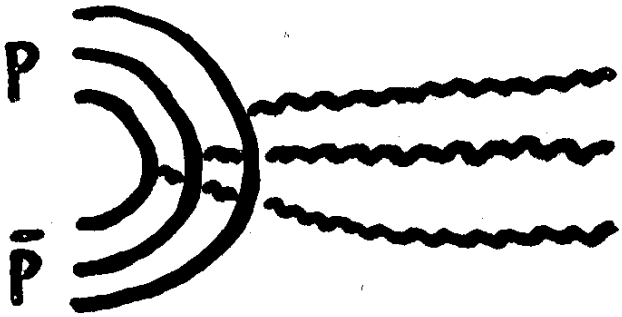
$BR(\text{exotic} \rightarrow \psi\eta) = 1\%$

$\Rightarrow$ 500 events/day

No PWA $\Rightarrow$ can detect all non-exotic $\rightarrow \psi X$

$\approx 25\% \Rightarrow$ 12500 events/day

Glueballs



+ Large σ

- Many decay channels: light hadrons

1^{--} $3850 \pm 50 \pm 190$ MeV

2^{-+} $3890 \pm 40 \pm 190$ MeV

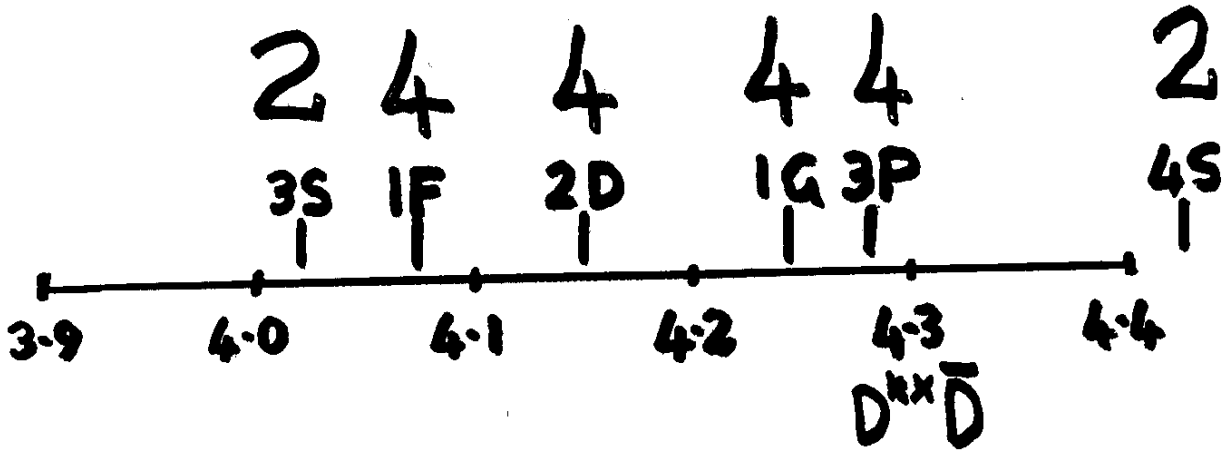
2^{--} $3930 \pm 40 \pm 190$ MeV

3^{--} $4130 \pm 90 \pm 200$ MeV

C.J. Morningstar, M. Peardon, *Phys. Rev.* **D60** (1999) 034509

non-exotic $\rightarrow e^+e^-$, $\mu^+\mu^-$, $\tau^+\tau^-$, $\gamma\gamma$ small

Bump Hunting



M.M. Brisudová, L. B., T. G., *Phys. Rev.* **D61** (2000) 054013
K. Heikkilä, N.A. Törnqvist, S. Ono, *Phys. Rev.* **D29** (1984) 110

18 conventional charmonia $\Rightarrow$

contiguous resonances if $c\bar{c}$ width ≈ 50 MeV

$\gtrsim$ 4 non-exotic glueballs

$\lesssim 5$ non-exotic hybrid charmonia

Given decay channel will be J^{PC} filter

Example: $\psi\eta$: 3 charmonia [S-, P-wave]

2 hybrid charmonia

2 glueballs [not preferred]

Need good understanding of conventional states so that new states stand out

Energy Scan 4.0 - 4.3 GeV region:

10 MeV bins $\Leftrightarrow$ $\bar{p}$ tuned 50 MeV $\Rightarrow$ 30 scans

30 MeV bins $\Leftrightarrow$ $\bar{p}$ tuned 150 MeV $\Rightarrow$ 10 scans

Lowest mass new flavoured baryons: Doubly charmed

$$W \gtrsim 2 \times 3650\ MeV \quad \Rightarrow \quad E \gtrsim 27\ GeV$$

Lowest mass new flavoured mesons: Bottom charm

$$W \geq 2 \times (6.40 \pm 0.39 \pm 0.13)\ GeV \Rightarrow E \gtrsim 86\ GeV$$

D.E. Groom *et al.*, *Eur. Phys. J.* **C15** (2000) 1

Competition

Proposed Glue / Charm - Factory @ GSI Darmstadt: $E < 15$ GeV

Conclusions

J^{PC} exotics	J^{PC} unknown
Need PWA	Not need PWA
Fixed $\bar{p}$ energy	Vary $\bar{p}$ energy
Low σ	High σ