Glueball Identification in Baryonic B decays

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PLB727, 168 (2013)

Outline:

- Introduction
- Formalism
- Results
- Summary

What is glueball?

● gluon

⋆ as force carrier:

bind quarks to form $M(q\bar{q})$, $B(qqq)$

⋆ with color:

glue themselves to be a bound state: G(gg), G(ggg)

● unique

⋆ without quarks

⋆ massless $\Rightarrow$ massive

● Not confirmed yet!

Three lightest glueballs

• scalar glueball $J^{PC} = 0^{++}$

$m_G = 1.5$ or 1.7 GeV (LQCD)

$f_0(1370)$, $f_0(1500)$, $f_0(1710)$

mixture of G, $\bar{n}n$, $\bar{s}s$ $[\bar{n}n = (\bar{u}u + \bar{d}d)/\sqrt{2}]$

X.G. He *et al.*, PRD73, 051502 (2006)

unclear glueball identification

$\star$ $B^- \to f_0(1370, 1500, 1370) e^- \bar{\nu}_e$ can be useful.

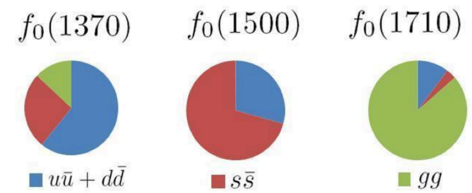
$\mathcal{B}_{f_0(1370)} = (2.3 - 2.6) \times 10^{-5}$

$\mathcal{B}_{f_0(1500)} \simeq (2 - 3) \times \mathcal{B}_{f_0(1710)}$ $(m_G \simeq 1.5$ GeV$)$

$\mathcal{B}_{f_0(1500)} \simeq (7 - 8) \times \mathcal{B}_{f_0(1710)}$ $(m_G \simeq 1.7$ GeV$)$

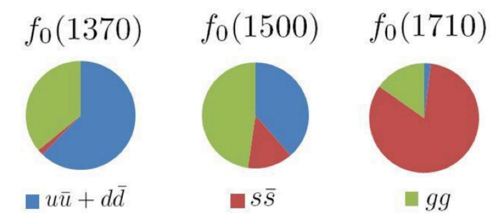
Y.K. Hsiao, C.C. Lih, C.Q. Geng, PRD89, 077501 (2014)

Cheng *et al* [PRD**74**, 094005 (2006)]



$M_{n\bar{n}} < M_{s\bar{s}} < M_{gg}$

Close and Kirk [PLB**483**, 345 (2000)]



$M_{n\bar{n}} < M_{gg} < M_{s\bar{s}}$

Vincent Mathieu

- **tensor glueball** $J^{PC} = 2^{++}$

$m_G \simeq 2.4$ GeV (LQCD)

$f_J \equiv f_J(2220)$ ($J = 2$ or 4), the candidate

$\star$ $\mathcal{B}(J/\Psi \to \gamma f_J) > 2.50 \times 10^{-3}$

$c\bar{c} \to gg\gamma$, gluon-rich process

$\star$ other possibilities, not excluded:
$f_2(2340)$
$f_2(1270)$, $f_2'(1525)$
the MIT bag model ($M(2^{++}) = 1.3$ GeV)

$\star\ \mathcal{B}(\bar{B}^0_s \to J/\psi p\bar{p}) = 3.0 \times 10^{-6}$ (LHCb)

(studied by Y.K. Hsiao and C.Q. Geng)

OZI rule in $\bar{B}^0_s \to (c\bar{c})(s\bar{s}) \to J/\psi p\bar{p}$:

with $s\bar{s} \to p\bar{p}$, $\mathcal{B}(\bar{B}^0_s \to J/\psi p\bar{p}) \leq 10^{-9}$

$\star$ resonant $\bar{B}^0_s \to J/\psi(f_J \to)p\bar{p}$ as the solution

$m_{p\bar{p}}$: 1.88-2.27 GeV

$f_J(2220) \to p\bar{p}$ found in $p\bar{p}$ scatterings

- **pseudoscalar glueball** $J^{PC} = 0^{-+}$

$m_G \simeq 2.6$ GeV (LQCD)

$\eta(1405)$, the favorite candidate

$\star\ \mathcal{B}(J/\Psi \to \gamma\eta(1405)) \simeq 10^{-3}$

$\star$ the unseen in $\gamma\gamma$ reactions

$\circ$ out of range

$\circ$ mixture of G, $\bar{n}n$, $\bar{s}s$

H.Y. Cheng, H.n. Li, K.F. Liu, PRD79, 014024 (2009)

Glueball with m_G >3 GeV

- many glueballs with m_G >3 GeV have been predicted
- Clear identification

no mesons around (too fat for their existence), no mixing

- PANDA experiment:

scan heavy G's with masses < 5.4 GeV, not ready until 2018

- $M(c\bar{c})$ decays, such as $\psi(2S)$

in the range of 3.0-3.7 GeV

- B decays can be useful:

unlike $J/\psi(c\bar{c})$ decays $\Rightarrow ggg,\ gg\gamma$

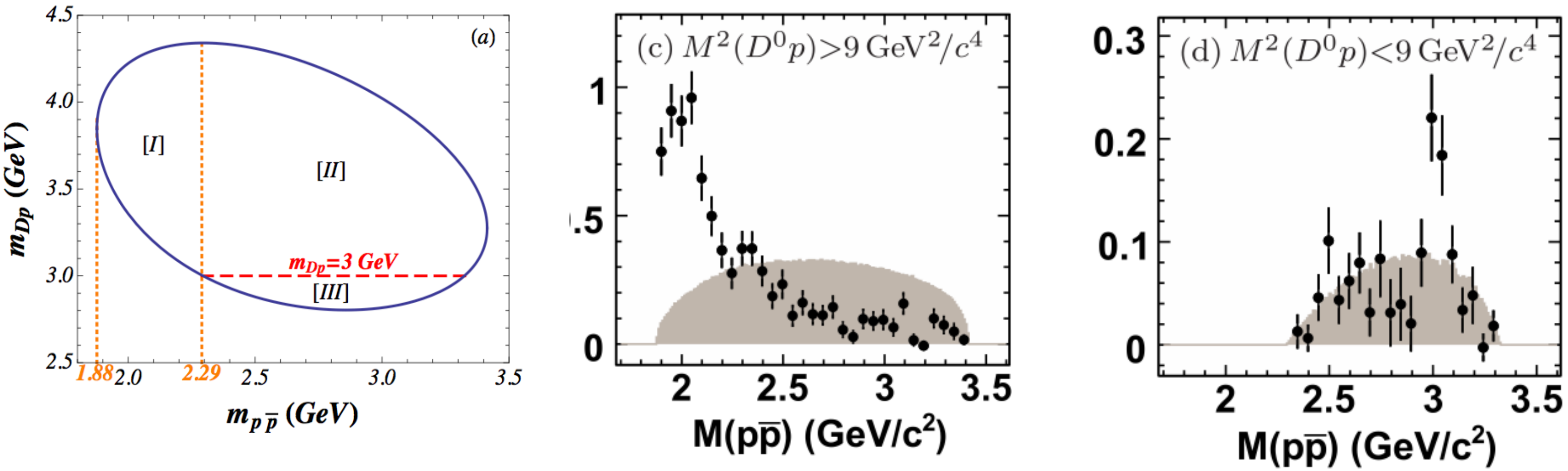
not regarded as a gluon-rich process

- $B \to p\bar{p}M$ decays: $B \to (G \to p\bar{p})M$

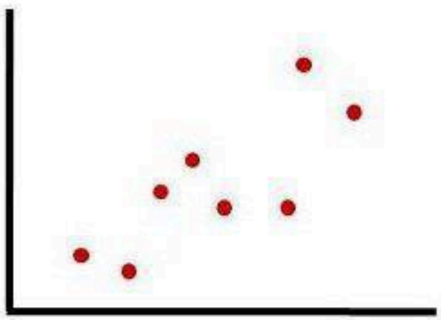
m_B, heavy $\Rightarrow$ a wider range to scan $m_{p\bar{p}}$ spectrum

- An unknown peak in $\bar{B}^0 \to p\bar{p}D^0$, Glueball?

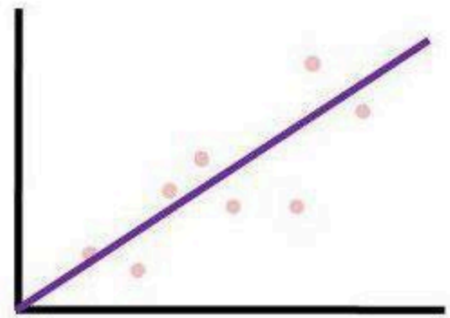
BABAR, PRD85, 092017 (2012)



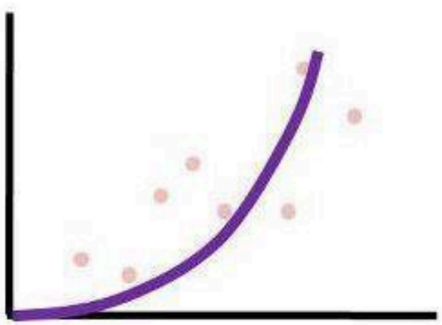
Actual data



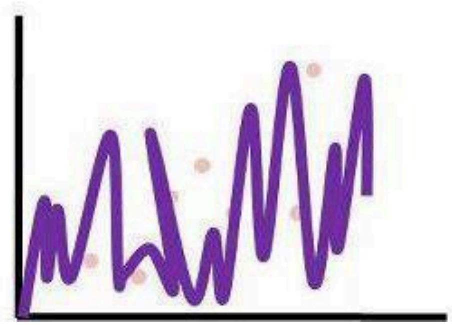
How you saw it:
Perfectly linear, as expected

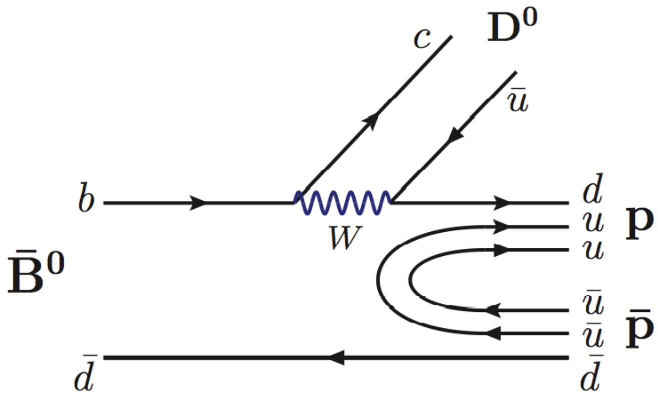


How your supervisor saw it:
Perfectly exponential, amazing new stuff



How the referee saw it:
Pure noise





$$\mathcal{A}(\bar{B}^0 \to p\bar{p}D^0) = \frac{G_F}{\sqrt{2}} V_{cb} V_{ud}^* a_2 \langle D^0 | (\bar{c}u)_{V-A} | 0 \rangle \langle p\bar{p} | (\bar{d}b)_{V-A} | \bar{B}^0 \rangle$$

$$\langle D^0 | (\bar{c}u)_{V-A} | 0 \rangle = i f_D p^\mu$$

$$\langle p\bar{p} | \bar{d}\gamma_\mu b | \bar{B}^0 \rangle = \bar{u}[g_1\gamma_\mu + g_2 i\sigma_{\mu\nu}p^\nu + g_3 p_\mu + g_4 q_\mu + g_5(p_{\bar{p}} - p_p)_\mu]\gamma_5 v$$

$$\langle p\bar{p} | \bar{d}\gamma_\mu\gamma_5 b | \bar{B}^0 \rangle = i\bar{u}[f_1\gamma_\mu + f_2 i\sigma_{\mu\nu}p^\nu + f_3 p_\mu + f_4 q_\mu + f_5(p_{\bar{p}} - p_p)_\mu] v$$

- $f_j(g_j) = D_{f_j(g_j)}/t^3, t = m_{p\bar{p}}^2$

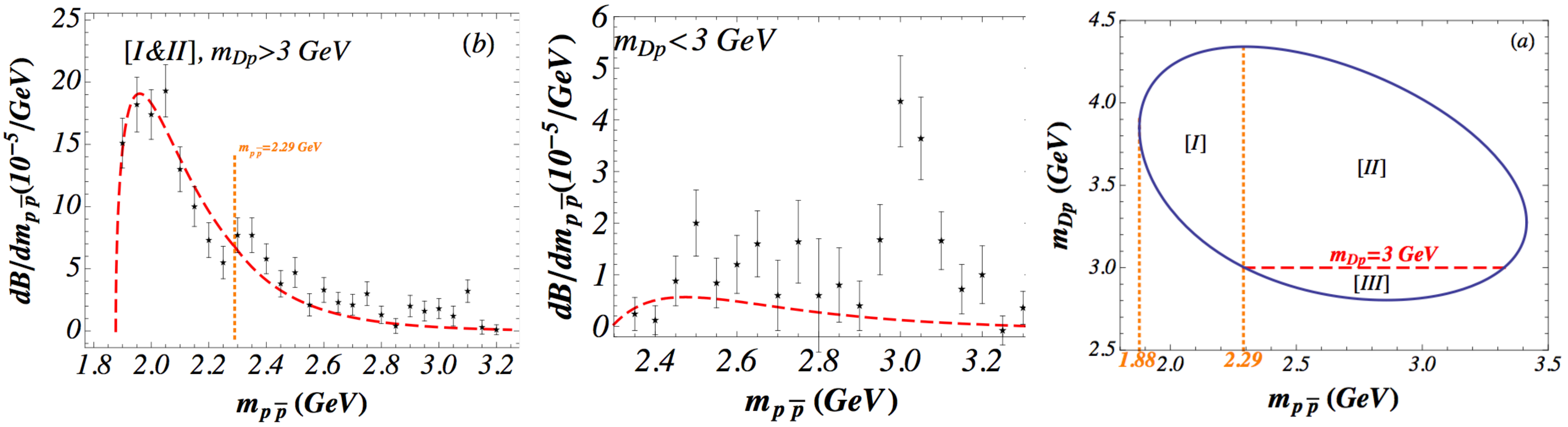
★ $\mathcal{B}(\bar{B}^0 \to p\bar{p}D^{(*)0})$, $\mathcal{B}(B^- \to \Lambda\bar{p}J/\psi)$ well explained

★ predictions for $\mathcal{B}(B^- \to \Lambda\bar{p}D^{(*)0})$, $\mathcal{B}(\bar{B}^0 \to \Sigma^0\bar{\Lambda}D^0)$ approved to agree with later measurements

$\Rightarrow$ trustworthy!

decay mode	our result	data
$10^6\mathcal{B}(B^- \to \Lambda\bar{\Lambda}K^-)$	2.8 ± 0.2	$3.38^{+0.41}_{-0.36} \pm 0.41$
$10^6\mathcal{B}(\bar{B}^0 \to \Lambda\bar{\Lambda}\bar{K}^0)$	2.5 ± 0.3	$4.76^{+0.84}_{-0.68} \pm 0.61$
$10^7\mathcal{B}(B^- \to \Lambda\bar{\Lambda}\pi^-)$	1.7 ± 0.7	< 9.4
$\mathcal{A}_{cp}(B^- \to p\bar{p}K^{*-})$	$0.22^{+0.04}_{-0.03} \pm 0.01 \pm 0.01$	0.21 ± 0.16
$10^5\mathcal{B}(B^- \to \Lambda\bar{p}D^0)$	1.14 ± 0.26	$1.43^{+0.28}_{-0.25} \pm 0.18$
$10^5\mathcal{B}(B^- \to \Lambda\bar{p}D^{*0})$	3.23 ± 0.32	$1.53^{+1.12}_{-0.85} \pm 0.47$ (< 4.8)
$10^5\mathcal{B}(\bar{B}^0 \to \Sigma^0\bar{\Lambda}D^0)$	1.8 ± 0.5	$1.5^{+0.9}_{-0.8}$

- Resonant state appears!



- **χ^2 fitting**

1. right panel: $\chi^2/d.o.f = 3.95$, in which

0.96 arises from the non-peaking data points

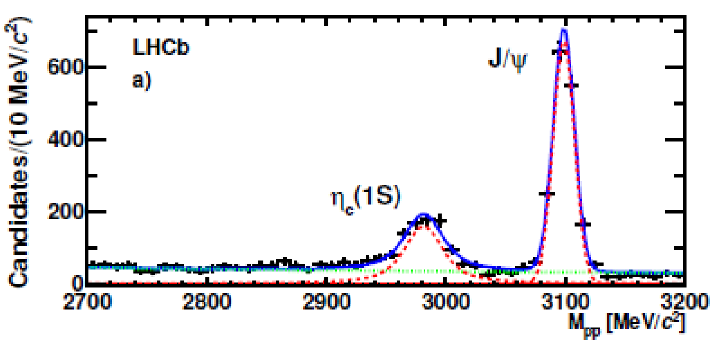
2.99 from the 6 peaking data points

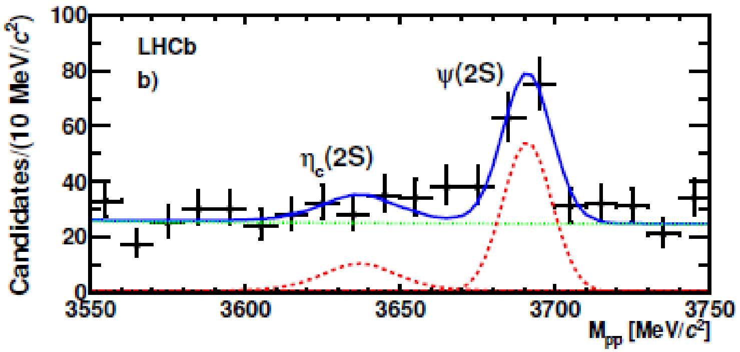
at (2.95, 3.00, 3.05, 3.10, 3.15, 3.20) GeV

$\bar{B}^0 \to (M(c\bar{c}) \to p\bar{p})D^0$

- $m_{J/\psi}, m_{\eta_c} \simeq 3$ GeV
- In $B^- \to p\bar{p}K^-$, the $M(c\bar{c})$ states are observed.

LHCb, Eur. Phys. J. C73, 2462 (2013)





- $\mathcal{B}(\bar{B}^0 \to (J/\psi \to p\bar{p})D^0) \simeq \mathcal{B}(\bar{B}^0 \to J/\psi D^0)\mathcal{B}(J/\psi \to p\bar{p})$

$\mathcal{B}(\bar{B}^0 \to (J/\psi \to p\bar{p})D^0) = 8 \times 10^{-6}$ (data)

$\mathcal{B}(J/\psi \to p\bar{p}) = 2 \times 10^{-3}$ (pdg)

$\Rightarrow \mathcal{B}(\bar{B}^0 \to J/\psi D^0) = 4 \times 10^{-3} \gg [< 1.3 \times 10^{-5}$ (pdg)],

- $\Gamma(data) \simeq$ 100-200 MeV $\gg \Gamma(J/\psi) = 93$ KeV
- Similarly, $\eta_c \to p\bar{p}$ can't work.

× $M(c\bar{c})$

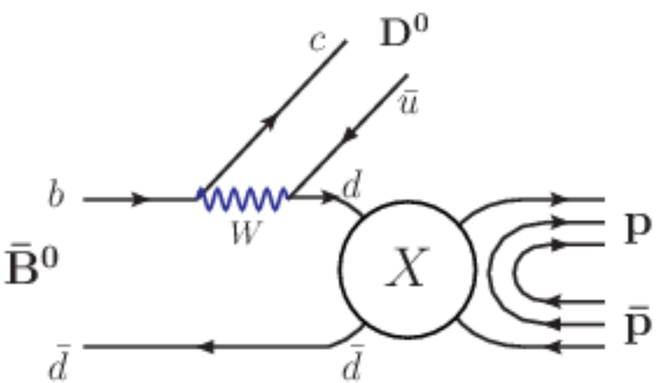
$\bar{B}^0 \to (X \to p\bar{p})D^0$, $X = M(d\bar{d})$ **or** G?

- $\bar{B}^0 \to p\bar{p}$ transition:

$$\langle p\bar{p}|(\bar{d}b)_{V-A}|\bar{B}^0\rangle = \langle p\bar{p}|X\rangle \frac{i}{(t-m_X^2)+im_X\Gamma_X}\langle X|(\bar{d}b)_{V-A}|\bar{B}^0\rangle$$

- Resonant amplitude:

$$\mathcal{A}_R(\bar{B}^0 \to (X \to p\bar{p})D^0) = \frac{G_F}{\sqrt{2}}V_{cb}V_{ud}^* a_2 \frac{f_D}{(t-m_X^2)+im_X\Gamma_X}\bar{u}(a+b\gamma_5)v$$



(b)

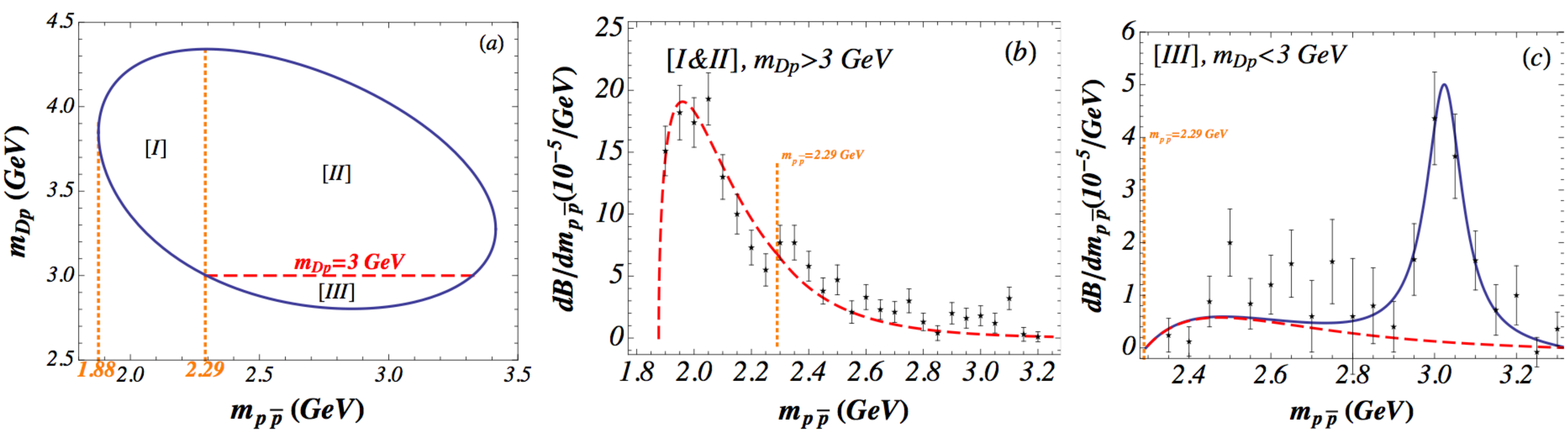
- $\mathcal{A} = \mathcal{A}(\bar{B}^0 \to p\bar{p}D^0) + \mathcal{A}_R(\bar{B}^0 \to (X \to p\bar{p})D^0)$

$\chi^2/d.o.f = 1.17$

$|a| = |b| = 4.4 \pm 1.0$

$(m_X,\ \Gamma_X) = (3020 \pm 8,\ 107 \pm 30)$ MeV

$\mathcal{B}(\bar{B}^0 \to p\bar{p}D^0) \simeq 1 \times 10^{-4}$



$M(n\bar{n})$ $[(u\bar{u}+d\bar{d})/\sqrt{2}]$, **not likely!**

For the normal mesons $M(n\bar{n})$, $M(s\bar{s})$:

- no observations heavier than $f_6(2510)$ (PDG)
- no QCD predictions heavier than 2.8 GeV

PRD83, 111502 (2011)

- hadronic Regge trajectories give the mass limits–

$M(n\bar{n})$: (2.86 ± 0.11) GeV

$M(s\bar{s})$: (3.10 ± 0.11) GeV

PRD 61, 054013 (2000)

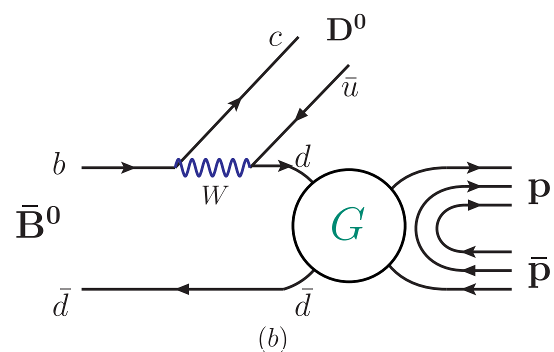
When you have eliminated the impossible, whatever remains, however improbable, must be the truth.

- It is reasonable to identify $X(3020)$ as a glueball.
- no mixing with normal mesons
- predictions (in units of MeV)

$J^{PC} = 2^{-+}$	1^{--}	1^{+-}
$3100 \pm 30 \pm 150$	3200 ± 200	$2940 \pm 30 \pm 140$
$3040 \pm 40 \pm 150$	$3240 \pm 330 \pm 150$	$2980 \pm 30 \pm 140$
2950 ± 150	3020	3270 ± 340

⋆ 2^{-+}: gg

⋆ 1^{--}, 1^{+-}: ggg



- $\mathcal{O} - J/\psi$ mixing ($\mathcal{O}$: 1^{--} glueball)

Hou, Soni, 1983

solution to $\rho\pi$ puzzle:

$\mathcal{B}(J/\psi \to \rho\pi) = 1.7\%$, big

One of the scenarios gives

$\Gamma_{\mathcal{O}} < 120$ MeV

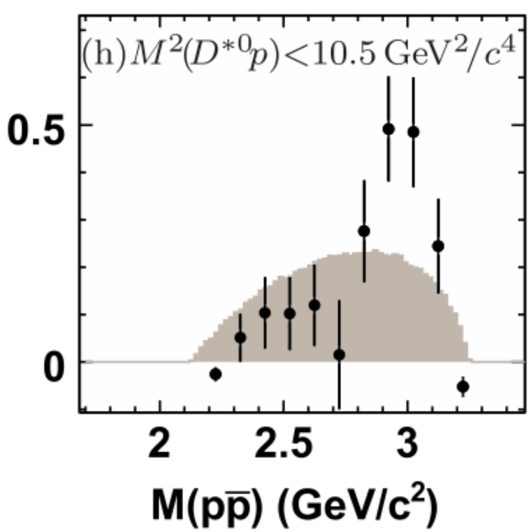
$|m_{\mathcal{O}} - m_{J/\psi}| < 80$ MeV

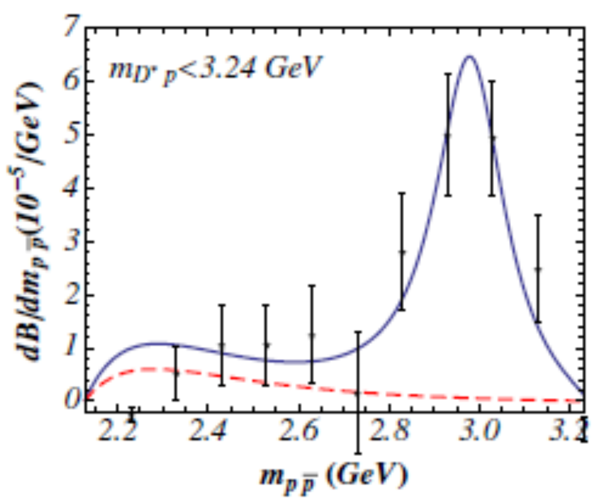
Hou, PRD55, 6952 (1997)

- $\bar{B}^0 \to p\bar{p}D^{*0}$

$\star$ $(m_X,\, \Gamma_X) = (2980 \pm 17,\, 187 \pm 71)$ MeV

$\star$ the combined data:
$(m_X,\, \Gamma_X) = (3013 \pm 7,\, 119 \pm 28)$ MeV





Bound state

- $N^*\bar{N}^*$ bound state with $N^* \equiv N(1440)$, $N(1520)$
- a working hypothesis

$\Lambda_c(2800)$, $\Lambda_c(2940)$ as DN and D^*p

$f_0(1370)$ and $f_0(1710)$

as two-vector meson bound states

- Unlike glueball, predicted in theory

Summary

- We have examined the nature of the unknown peak in the $m_{p\bar{p}}$ spectrum of the $\bar{B}^0 \to p\bar{p}D^0$ decay.

- The peak can be neither identified as η_c or J/ψ, nor classified as $M(d\bar{d})$.

- We conclude that it corresponds to a glueball fitted as $X(3020)$:
$(m_X,\ \Gamma_X) = (3020 \pm 8,\ 107 \pm 30)$ MeV