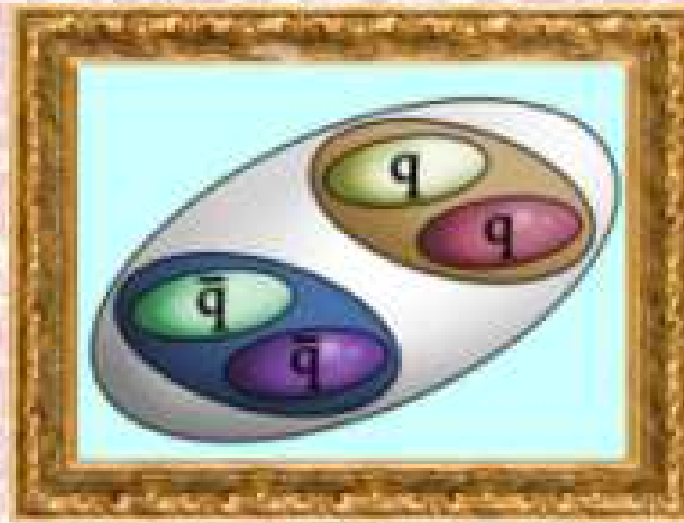
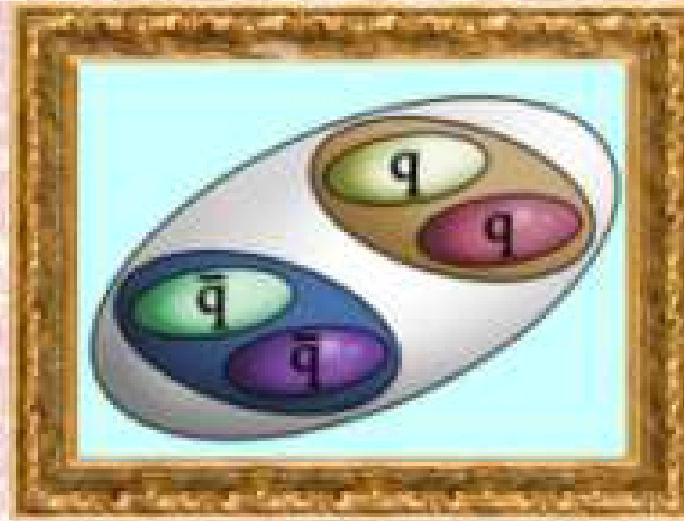


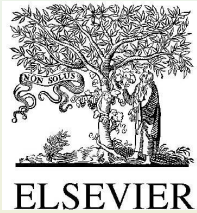




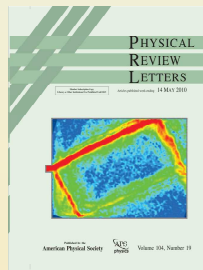
Tetraquarks - Evidence Grows!

Ahmed Ali (DESY)

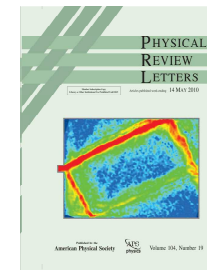
underlying work



A. Ali, C. Hambrock, I. Ahmed and M. J. Aslam,
“A case for hidden $b\bar{b}$ tetraquarks based on $e^+e^- \rightarrow b\bar{b}$
cross section between $\sqrt{s} = 10.54$ and 11.20 GeV,”
Phys. Lett. B **684** (2010) 28



A. Ali, C. Hambrock and M. J. Aslam,
“Tetraquark interpretation of the BELLE data on the anomalous
 $\Upsilon(1S)\pi^+\pi^-$ and $\Upsilon(2S)\pi^+\pi^-$ production near the $\Upsilon(5S)$
resonance,” Phys. Rev. Lett. **104**, 162001 (2010)



A. Ali, C. Hambrock and S. Mishima
”Tetraquark-based analysis and testes in e^+e^- annihilation near
the $\Upsilon(5S)$ ” DESY Report 10-076 (work in progress)



Overview

- Production and decays of $J^{PC} = 1^{--}$ $b\bar{b}$ tetraquarks
- tetraquarks in BaBar data!
- tetraquarks in Belle data!
- conclusion and outlook

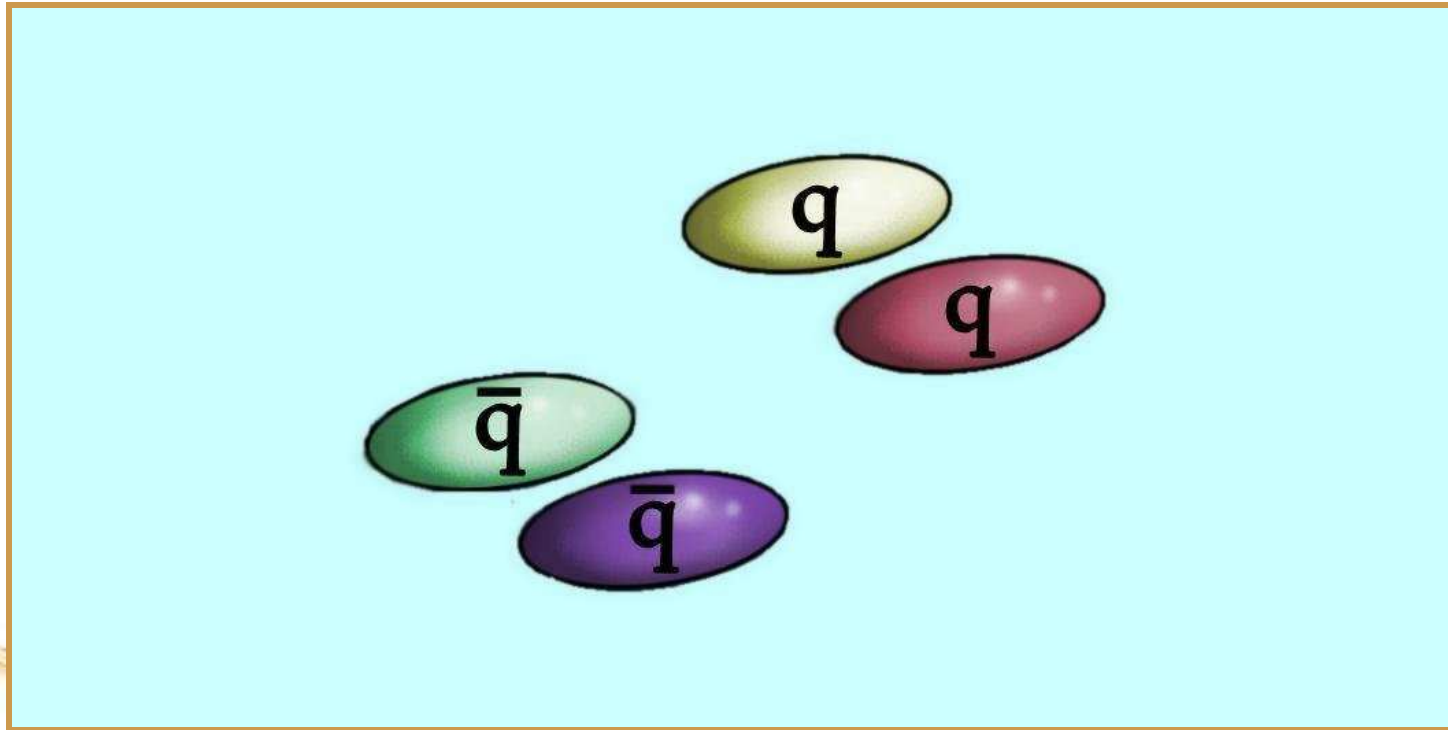
tetraquark constituents

the building blocks of tetraquarks are



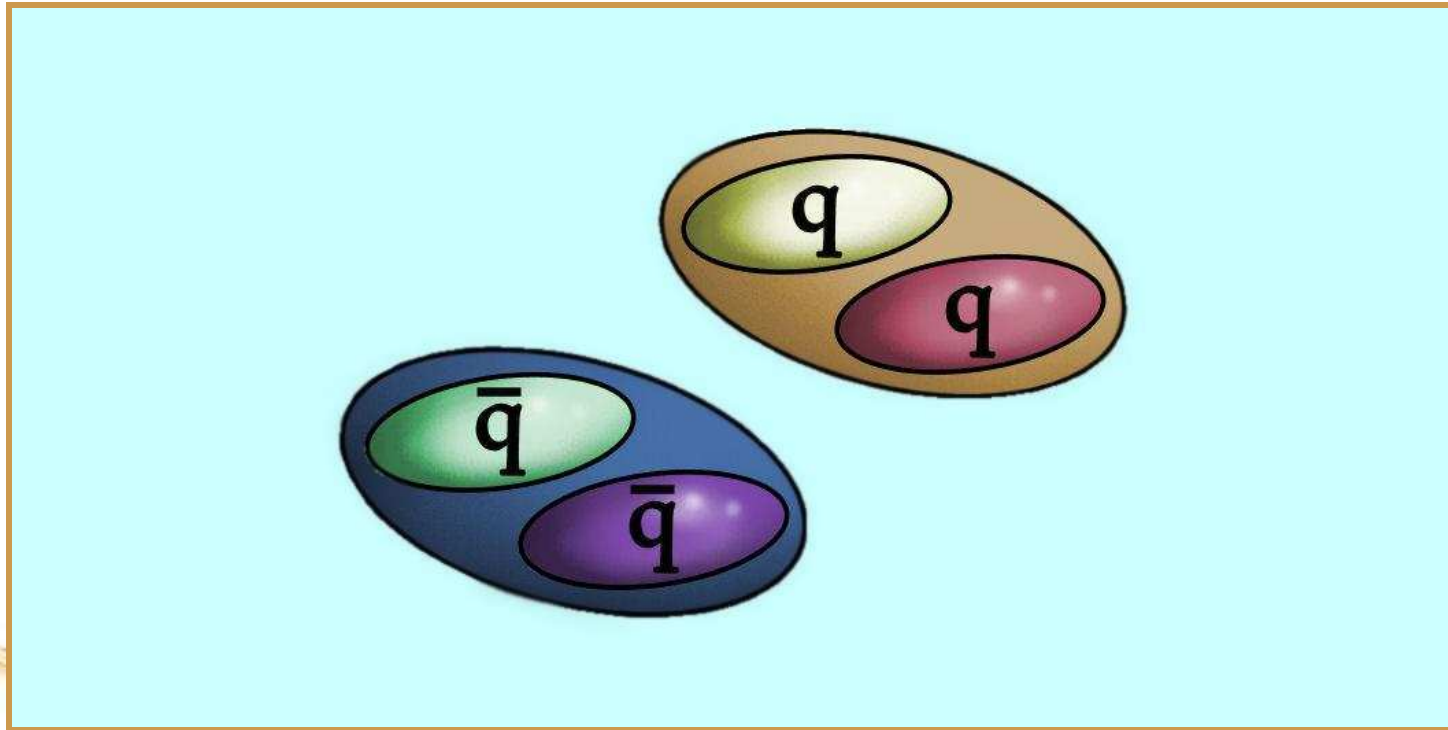
tetraquark constituents

4 quarks



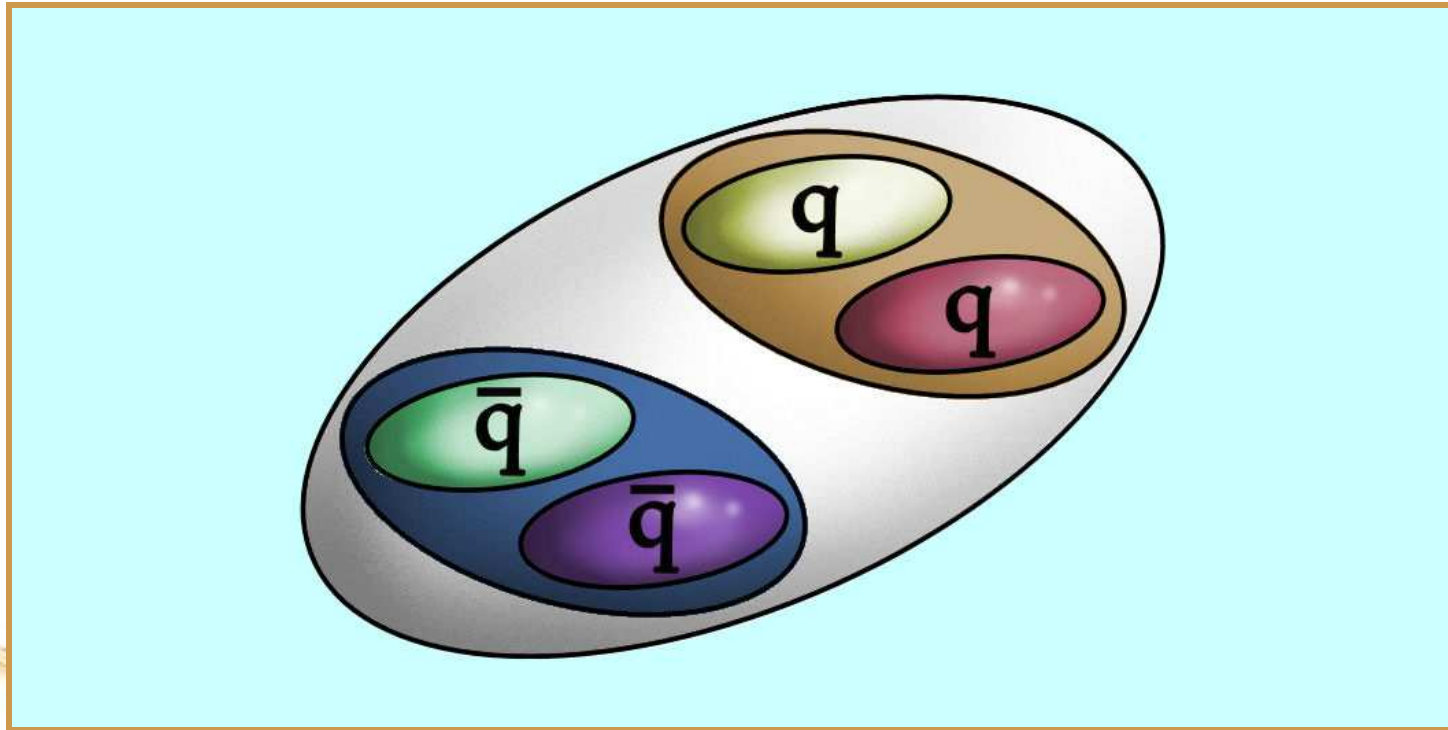
tetraquark constituents

forming a pair of diquarks and antidiquarks

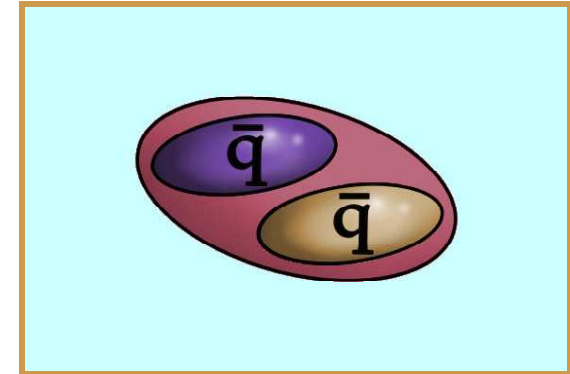


tetraquark constituents

the diquarks and antidiquarks form a tetraquark

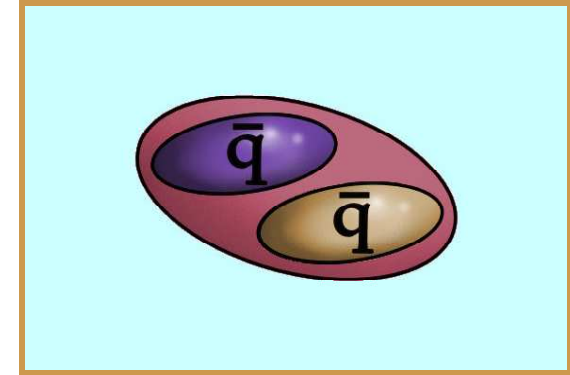


diquarks: color representation



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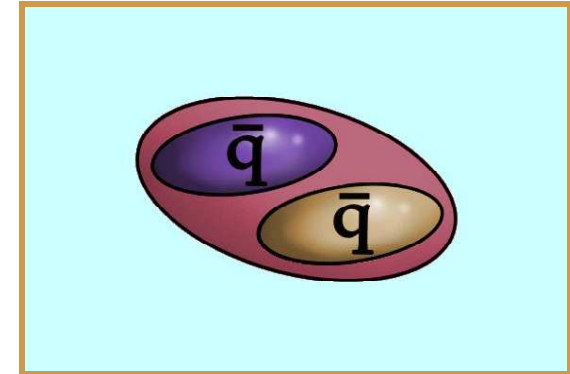
$$\bar{\mathbf{3}} \otimes \bar{\mathbf{3}} = \bar{\mathbf{6}} \oplus \mathbf{3}$$



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From one gluon exchange model
results [R. Jaffe, Phys. Rep., 409 (2005) 1]:



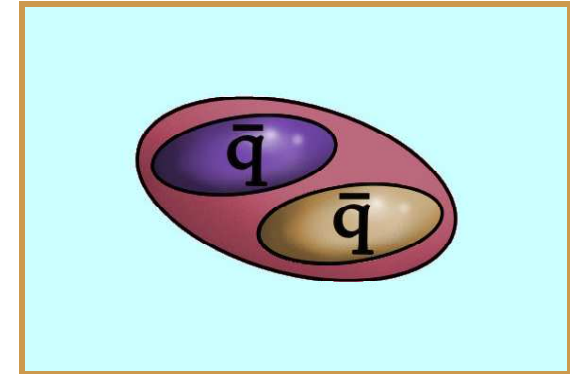
$D = A \otimes B$	$\mathbf{1}$	$\mathbf{3}$	$\bar{\mathbf{6}}$	$\mathbf{8}$
I	$-4/3$	$-2/3$	$1/3$	$1/6$



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The discriminator I

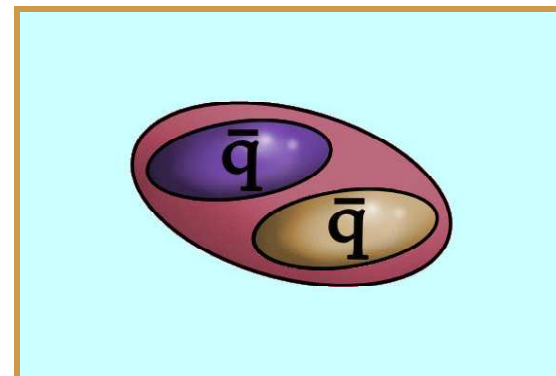
$$I = \frac{1}{2}(C(D) - C(A) - C(B)),$$

is the sum of the product of $SU(3)_C$ charges. **Attractive forces** (like in electromagnetism) exist for **negative signs** ($C(X)$: casimir invariant of representation X).

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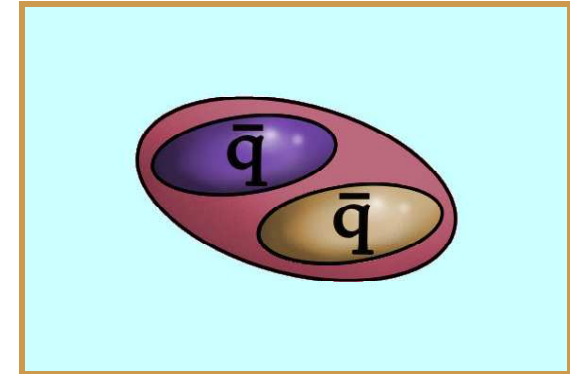
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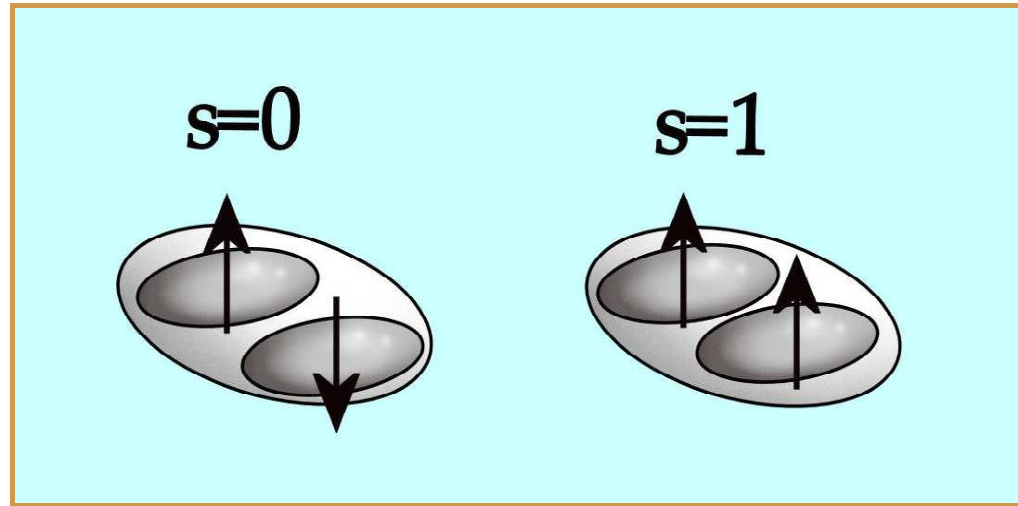
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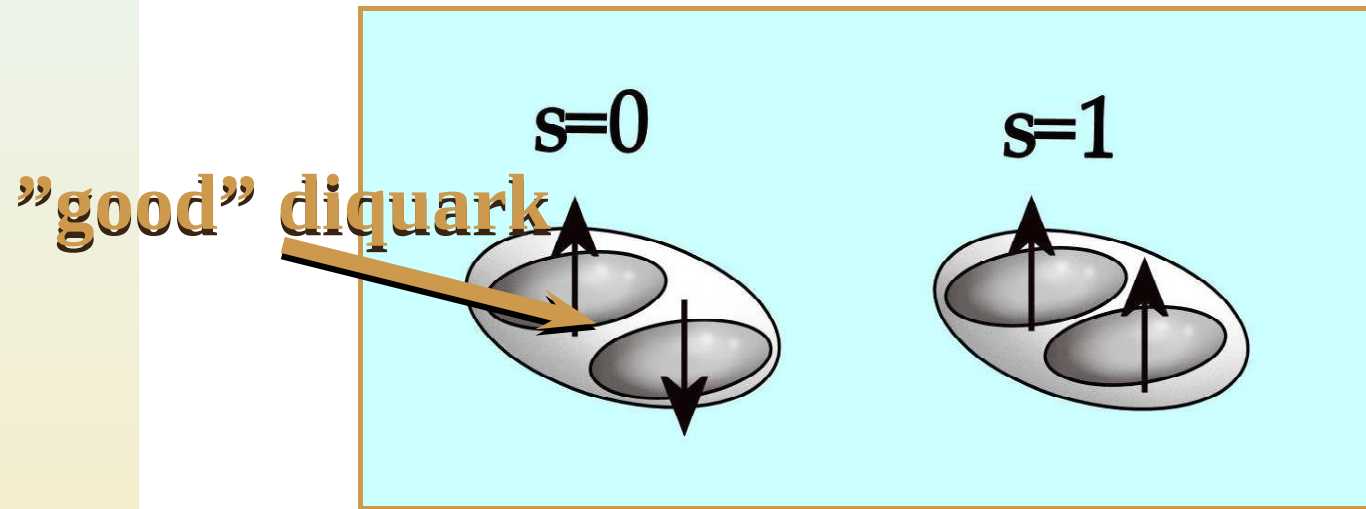
diquarks: spin representation



lattice simulations [Alexandrou et al., Phys. Rev. Lett. **97**, 222002 (2006)]
show in the light quark sector:



diquarks: spin representation

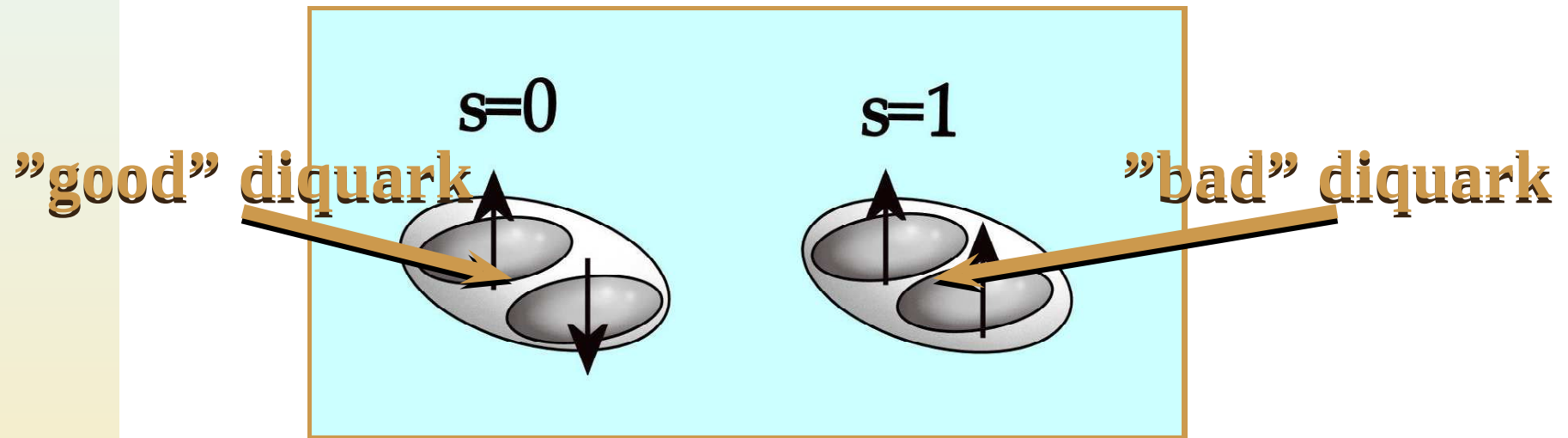


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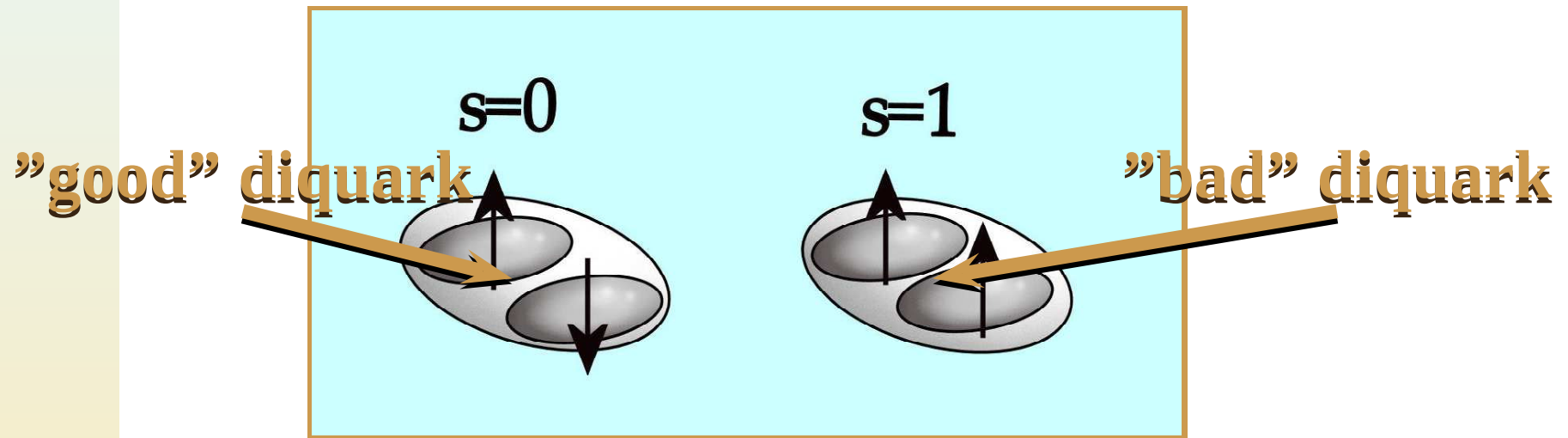


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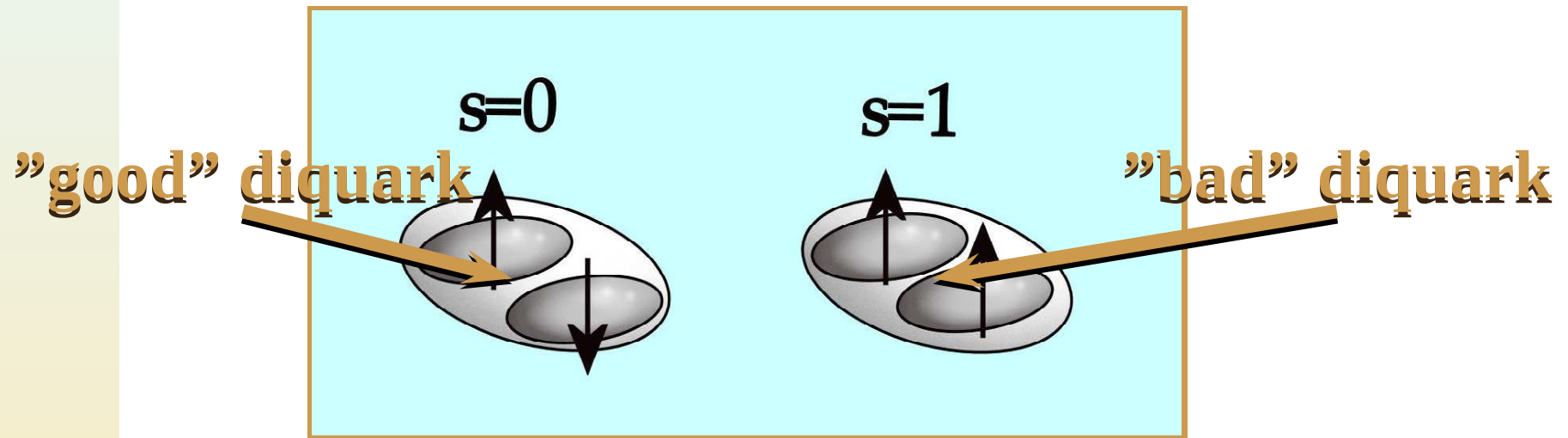
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In the Heavy-Quark-Limit **spin decoupling** should allow
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diquarks: spin representation



lattice simulations [Alexandrou et al., Phys. Rev. Lett. **97**, 222002 (2006)]
show in the light quark sector:

- binding **now: closer look at** lattice results
- less binding for "bad" spin 1 diquarks

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diquarks: evidence in lattice QCD

gauge invariant two-density correlators:

$$C_{\Gamma}(\mathbf{r}_u, \mathbf{r}_d, t) \equiv \langle 0 | J_{\Gamma}(\mathbf{0}, 2t) J_0^u(\mathbf{r}_u, t) J_0^d(\mathbf{r}_d, t) J_{\Gamma}^{\dagger}(\mathbf{0}, 0) | 0 \rangle$$



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correlator: $C_{\gamma_5}(r, r_{ud}) \propto e^{-r_{ud}/r_0(r)}$

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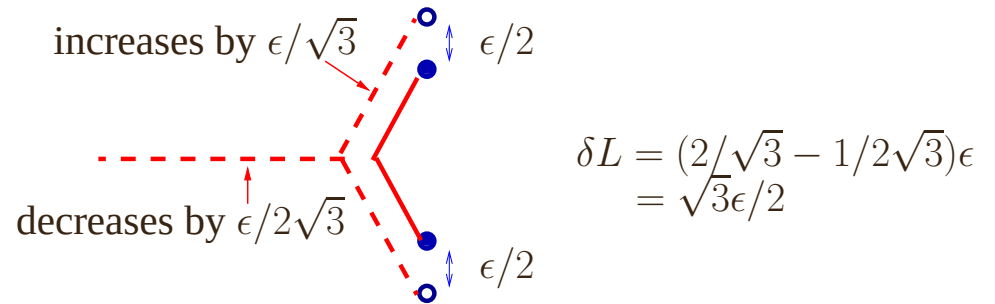
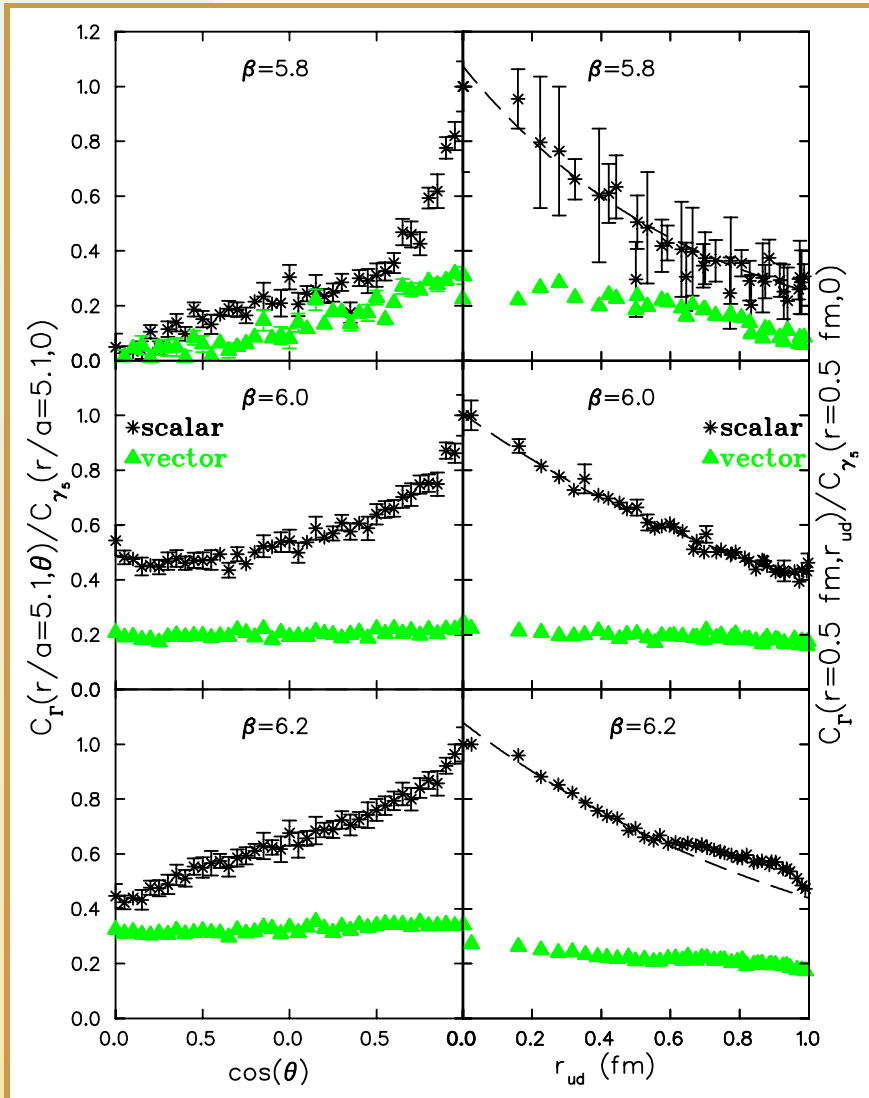
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diquarks: evidence in lattice QCD



$$\kappa = \frac{K_{[qq][\bar{q}\bar{q}]}(K_{q\bar{q}})}{K_{q\bar{q}}} = \sqrt{3}/2,$$

being the string tension of the tetraquark (meson).



states observed by Belle

Summary of new states observed by Belle. [arXiv:0910.3404 [hep-ex]]

State	M (MeV)	Γ (MeV)	J^{PC}	Decay Modes	Production Modes	Also observed by
$Y_s(2175)$	2175 ± 8	58 ± 26	1^{--}	$\phi f_0(980)$ $\pi^+\pi^- J/\psi$,	e^+e^- (ISR) $J/\psi \rightarrow \eta Y_s(2175)$	BaBar, BESII BaBar
$X(3872)$	3871.4 ± 0.6	< 2.3	1^{++}	$\gamma J/\psi, D\bar{D}^*$	$B \rightarrow K X(3872), p\bar{p}$	CDF, D0,
$X(3915)$	3914 ± 4	28^{+12}_{-14}	$0/2^{++}$	$\omega J/\psi$	$\gamma\gamma \rightarrow X(3915)$	
$Z(3930)$	3929 ± 5	29 ± 10	2^{++}	$D\bar{D}$ $D\bar{D}^*$ (not $D\bar{D}$)	$\gamma\gamma \rightarrow Z(3940)$	
$X(3940)$	3942 ± 9	37 ± 17	$0^{?+}$	or $\omega J/\psi$	$e^+e^- \rightarrow J/\psi X(3940)$	
$Y(3940)$	3943 ± 17	87 ± 34	$?^{?+}$	$\omega J/\psi$ (not $D\bar{D}^*$)	$B \rightarrow KY(3940)$	BaBar
$Y(4008)$	4008^{+82}_{-49}	226^{+97}_{-80}	1^{--}	$\pi^+\pi^- J/\psi$	e^+e^- (ISR)	
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$Z(4250)$	4248^{+185}_{-45}	177^{+320}_{-72}	$?$	$\pi^\pm \chi_{c1}$	$B \rightarrow K Z^\pm(4250)$	
$Z(4430)$	4433 ± 5	45^{+35}_{-18}	$?$	$\pi^\pm \psi'$	$B \rightarrow K Z^\pm(4430)$	
$Y_b(10890)$	$10,890 \pm 3$	55 ± 9	1^{--}	$\pi^+\pi^- \Upsilon(1, 2, 3S)$	$e^+e^- \rightarrow Y_b$	

recent theoretical review: [Drenska et al., arXiv:1006.2741 [hep-ph]]

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our (hidden bottom) tetraquark candidate

hamiltonian

The previously defined states need to diagonalize the hamiltonian:

$$H = 2m_Q + H_{SS}^{(qq)} + H_{SS}^{(q\bar{q})} + H_{SL} + H_{LL}$$



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hamiltonian

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$$H_{SS}^{(qq)} = 2(\mathcal{K}_{bq})_{\bar{3}}[(\mathbf{S}_b \cdot \mathbf{S}_q) + (\mathbf{S}_{\bar{b}} \cdot \mathbf{S}_{\bar{q}})]$$



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$q\bar{q}$ spin coupling

$$H_{SS}^{(qq)} = 2(\mathcal{K}_{bq})_{\bar{3}}[(\mathbf{S}_b \cdot \mathbf{S}_q) + (\mathbf{S}_{\bar{b}} \cdot \mathbf{S}_{\bar{q}})]$$

$$H_{SS}^{(q\bar{q})} = 2(\mathcal{K}_{b\bar{q}})(\mathbf{S}_b \cdot \mathbf{S}_{\bar{q}} + \mathbf{S}_{\bar{b}} \cdot \mathbf{S}_q) \\ + 2\mathcal{K}_{b\bar{b}}(\mathbf{S}_b \cdot \mathbf{S}_{\bar{b}}) + 2\mathcal{K}_{q\bar{q}}(\mathbf{S}_q \cdot \mathbf{S}_{\bar{q}})$$



hamiltonian

The previously defined states need to diagonalize the hamiltonian:

$$H = 2m_Q + H_{SS}^{(qq)} + H_{SS}^{(q\bar{q})} + H_{SL} + H_{LL}$$

with

$L S$ coupling

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$$H_{SL} = 2A_Q(\mathbf{S}_Q \cdot \mathbf{L} + \mathbf{S}_{\bar{Q}} \cdot \mathbf{L})$$



hamiltonian

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$$H_{SL} = 2A_Q(\mathbf{S}_Q \cdot \mathbf{L} + \mathbf{S}_{\bar{Q}} \cdot \mathbf{L})$$

$$H_{LL} = B_Q \frac{L_{Q\bar{Q}}(L_{Q\bar{Q}} + 1)}{2}$$



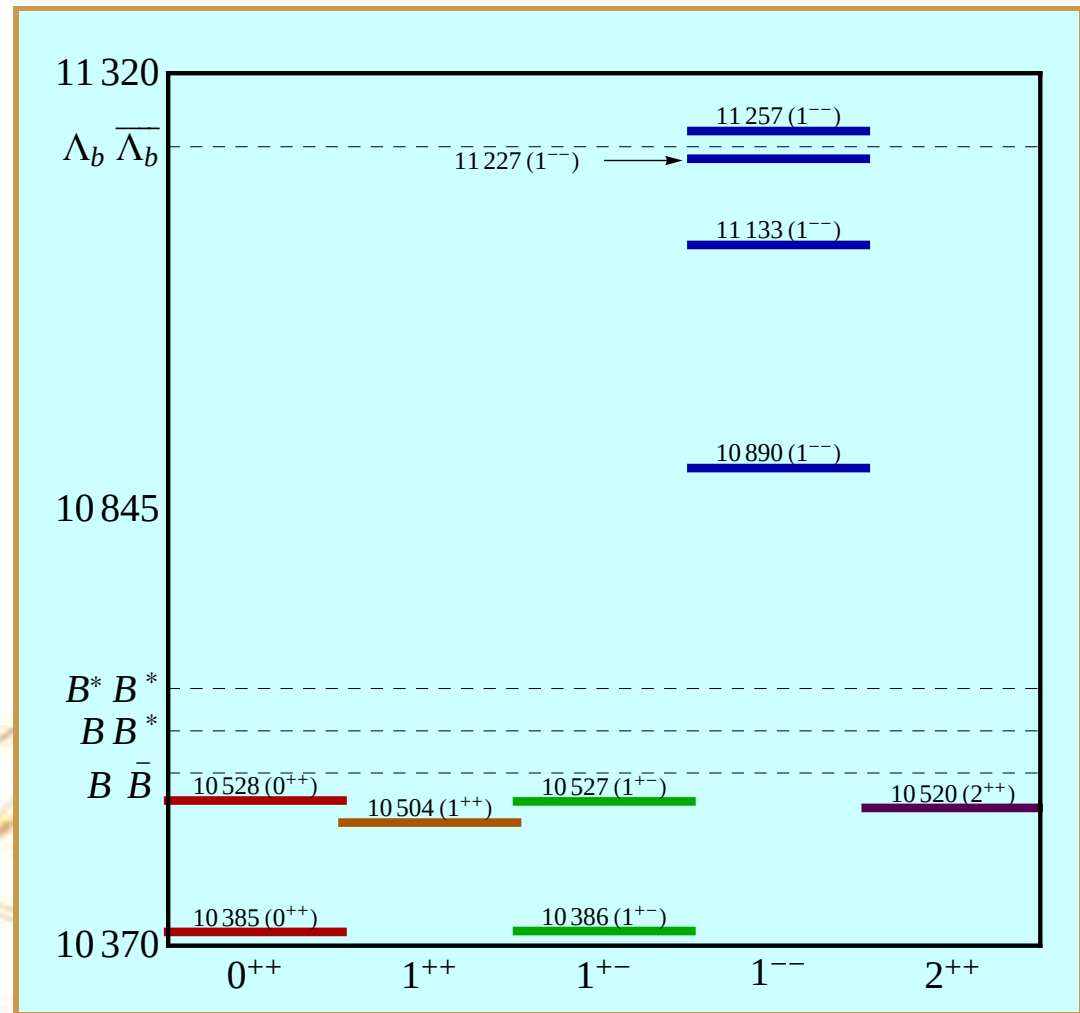
possible observable states

which states are accessible in today's experiments?



possible observable states

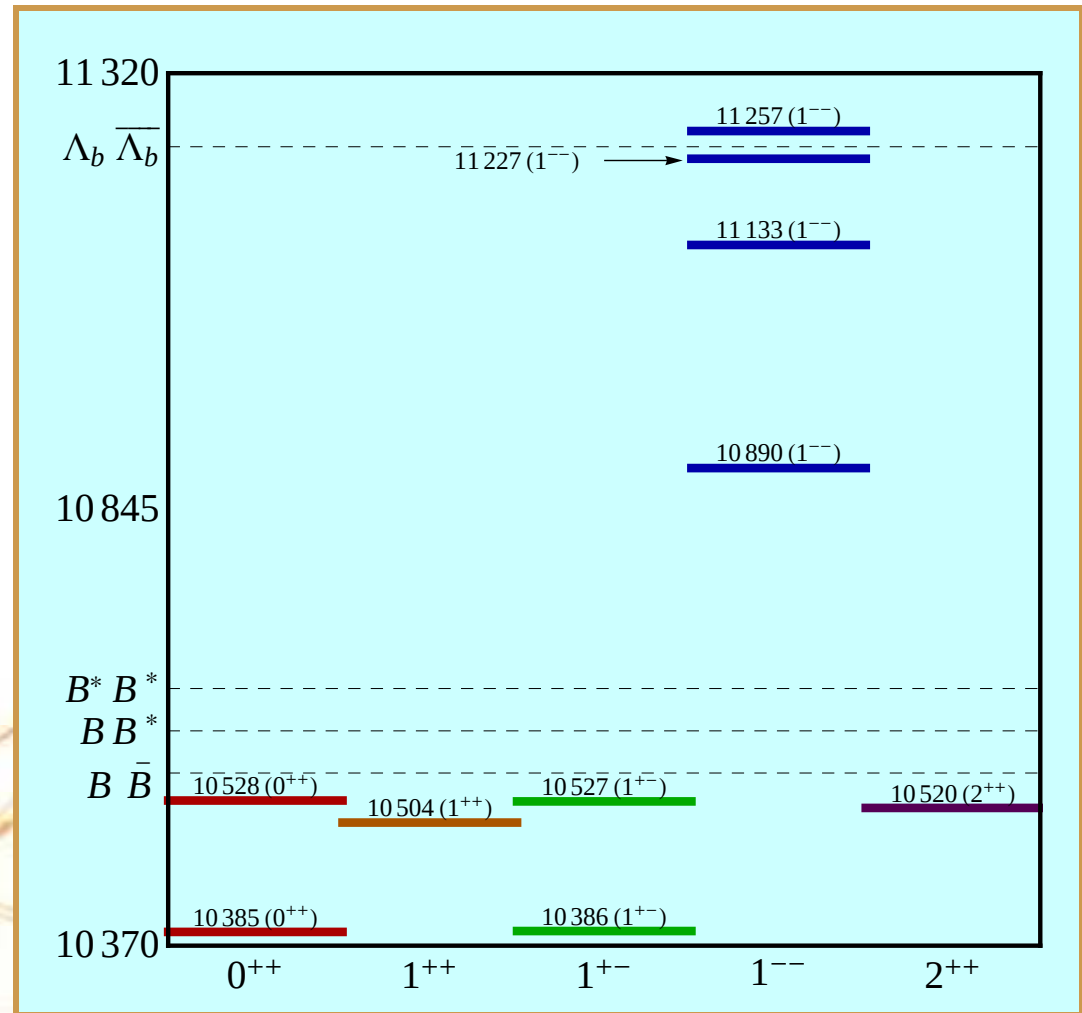
closer look at the light $[bq][\bar{b}\bar{q}]$ tetraquarks:



possible observable states

closer look at the light $[bq][\bar{b}\bar{q}]$ tetraquarks:

- The 1^{--} states, we call Y_b , have the right quantum numbers to be produced in e^+e^- annihilation.

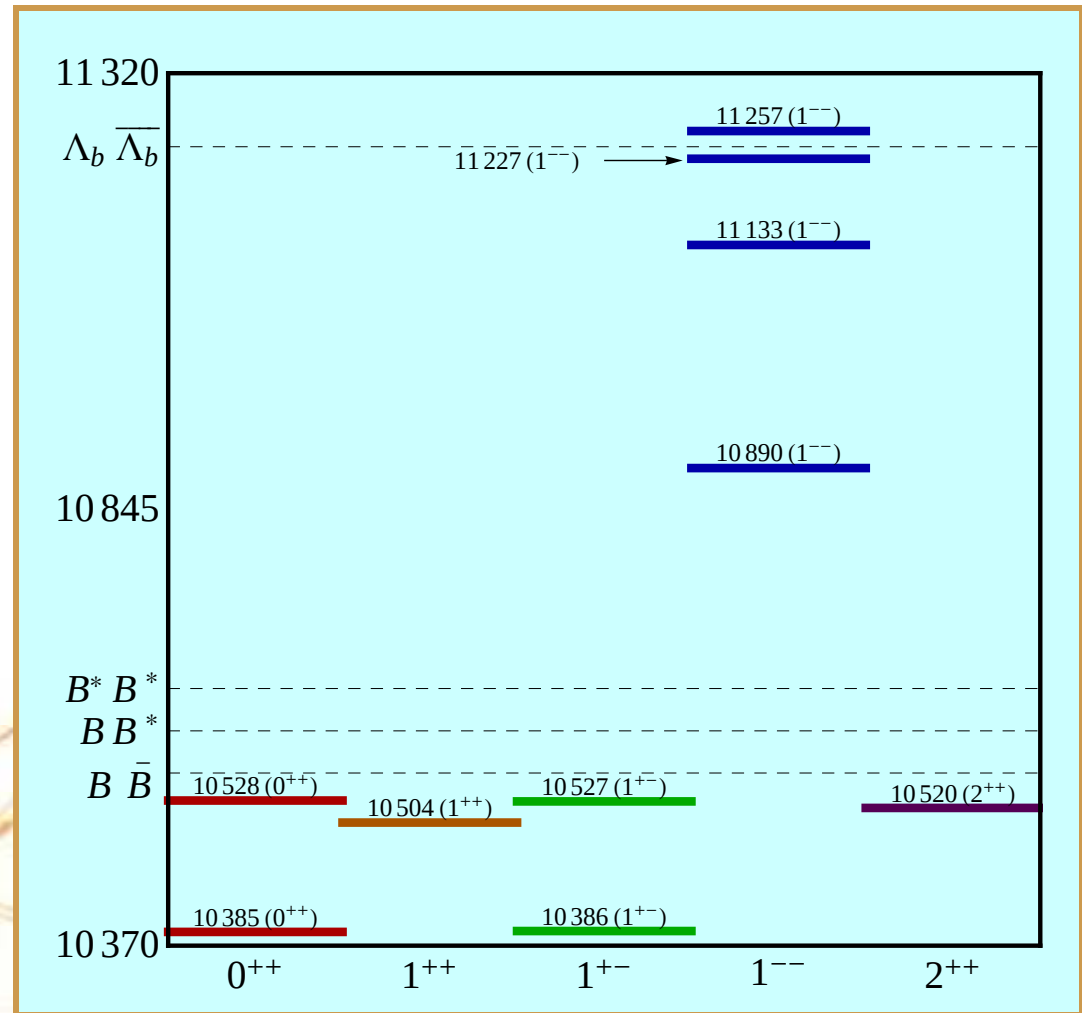


possible observable states

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■ The 1^{--} states, we call Y_b , have the right quantum numbers to be produced in e^+e^- annihilation.

■ Two of them are in the range of the BaBar and Belle center of mass energies.

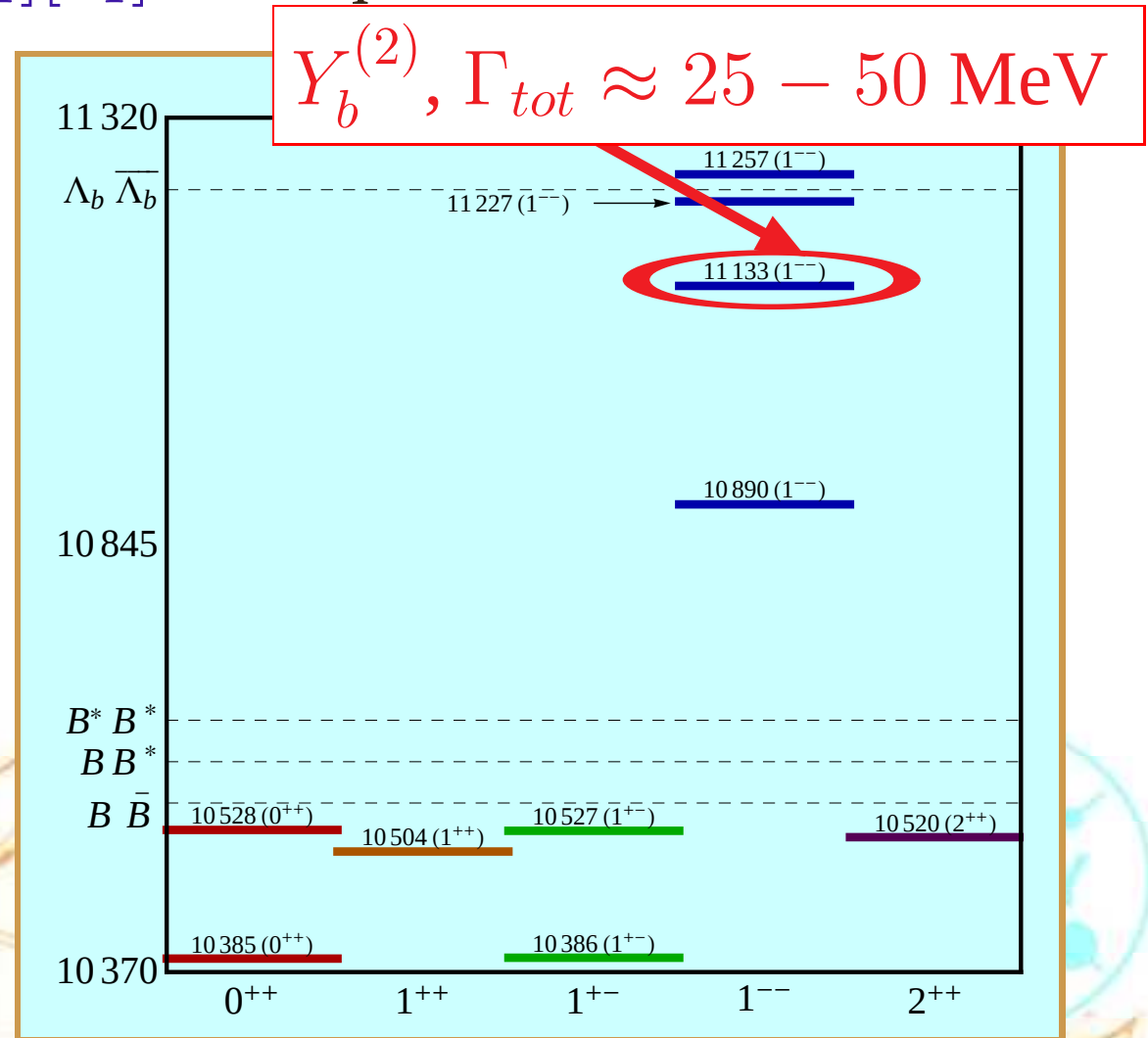


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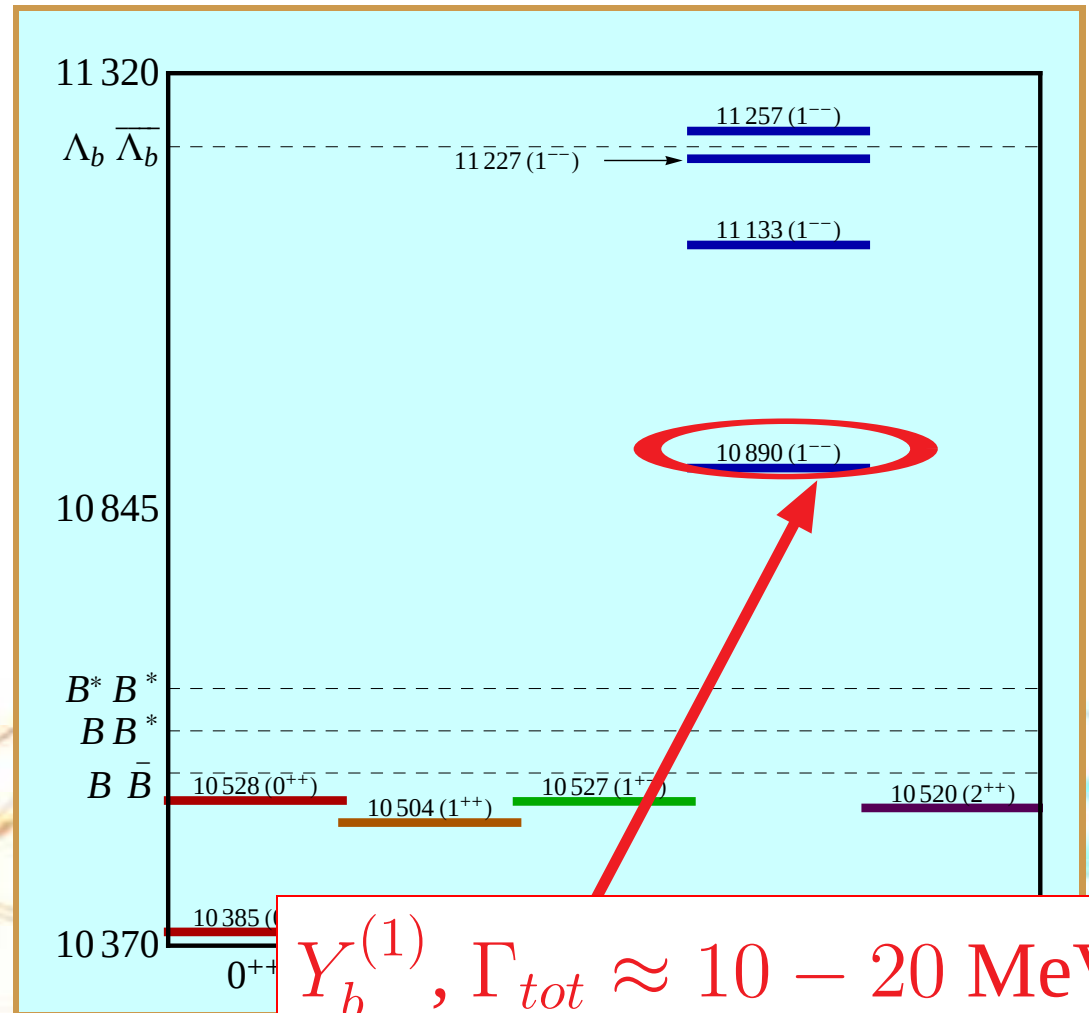


possible observable states

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$Y_b^{(1)}, \Gamma_{tot} \approx 10 - 20 \text{ MeV}$

isospin breaking

Y_b mass eigenstates

$$\begin{aligned} Y_{[b,l]} &= \cos \theta Y_{[bu]} + \sin \theta Y_{[bd]}, \\ Y_{[b,h]} &= -\sin \theta Y_{[bu]} + \cos \theta Y_{[bd]}. \end{aligned}$$

with isospin mass breaking

$$M(Y_{[b,h]}) - M(Y_{[b,l]}) = (7 \pm 3) \cos(2\theta) \text{ MeV}.$$

and charge

$$\begin{aligned} Q_{Y_{[b,l]}} &= \frac{1}{3} \cos \theta - \frac{2}{3} \sin \theta, \\ Q_{Y_{[b,h]}} &= -\frac{1}{3} \sin \theta - \frac{2}{3} \cos \theta. \end{aligned}$$



Y_b production

- We have derived the Van Royen-Weisskopf formula for the electronic widths of the 1^{--} tetraquark, made up of point-like diquarks [A. Ali, C. Hambrock and S. Mishima] :



Y_b production

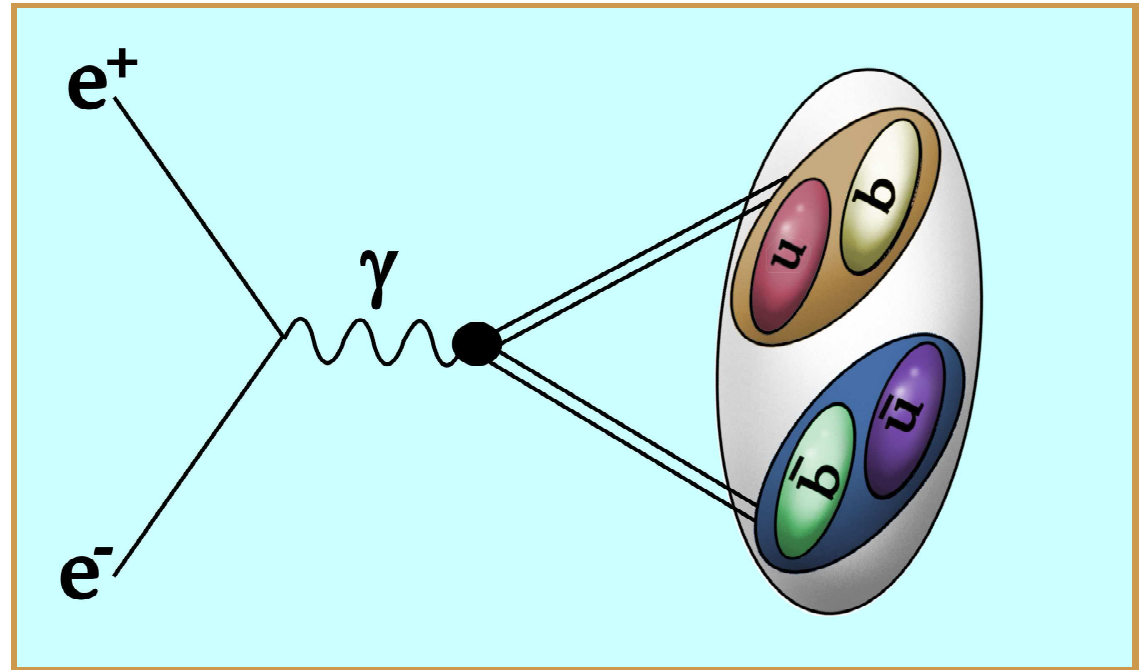
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$$\Gamma_{ee}(Y_{[b,l/h]}) = \frac{24\alpha^2 Q_{[b,l/h]}^2}{M_{Y_{[b,l/h]}}^4} \kappa^2 \left| R_{11}^{(1)}(0) \right|^2$$



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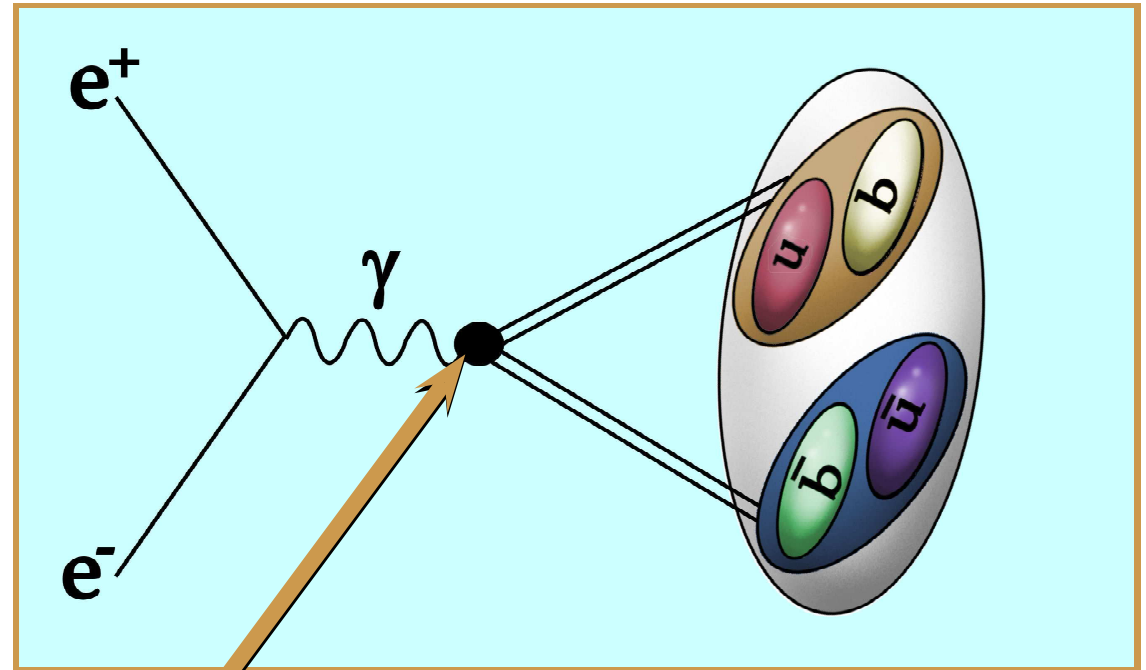


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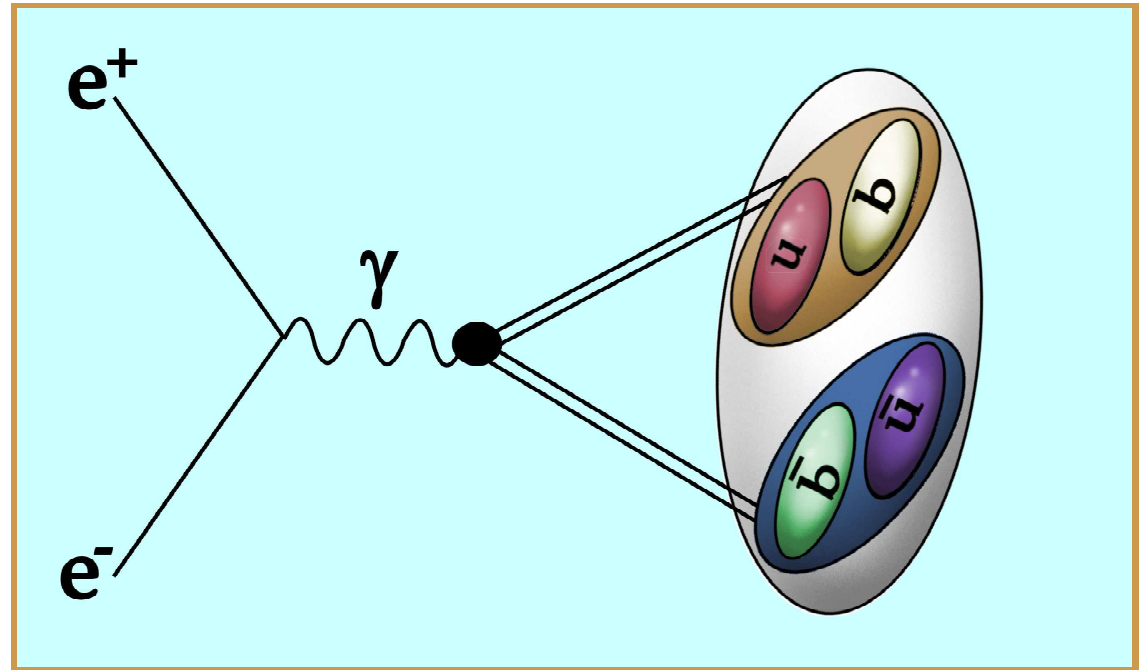
diquark charge

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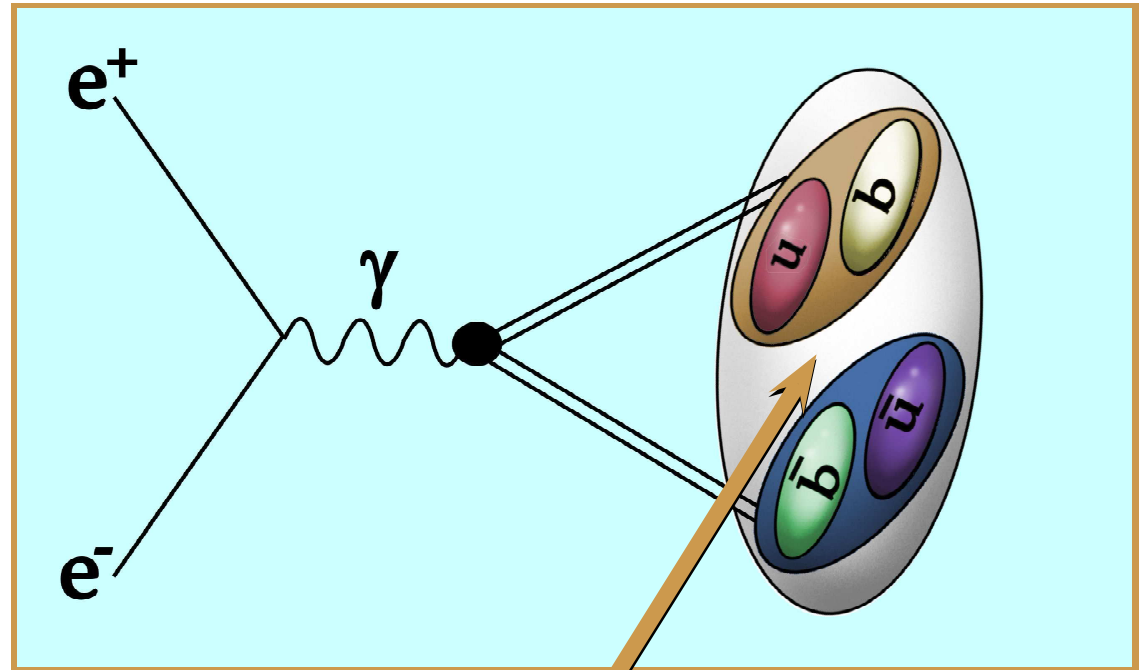
hadronic size parameter

$$\Gamma_{ee}(Y_{[b,l/h]}) = \frac{24\alpha^2 Q_{[b,l/h]}^2}{M_{Y_{[b,l/h]}}^4} \kappa^2 \left| R_{11}^{(1)}(0) \right|^2$$



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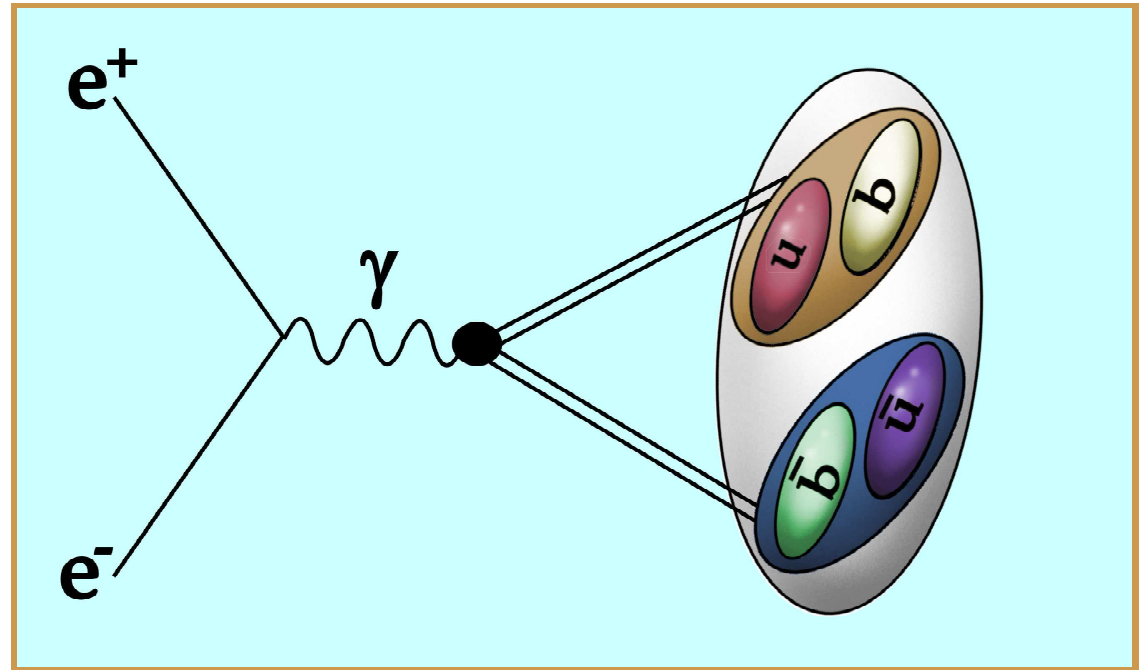
radial tetraquark wave function at origin

$$\Gamma_{ee}(Y_{[b,l/h]}) = \frac{24\alpha^2 Q_{[b,l/h]}^2}{M_{Y_{[b,l/h]}}^4} \kappa^2 \left| R_{11}^{(e)}(0) \right|^2$$



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$$\Gamma_{ee}(Y_{[b,l/h]}) = \frac{24\alpha^2 Q_{[b,l/h]}^2}{M_{Y_{[b,l/h]}}^4} \kappa^2 \left| R_{11}^{(1)}(0) \right|^2$$

- Production ratio: $R_{ee} = \frac{\Gamma_{Y[b,l]}}{\Gamma_{Y[b,h]}} = \left(\frac{1-2\tan\theta}{2+\tan\theta} \right)^2$ ($1/4 \leq R_{ee} \leq 4$).



Y_b decay

Γ_{tot} is dominated by two-body decays ($B\bar{B}$, $B\bar{B}^*$, $B^*\bar{B}^*$):



Y_b decay

channel

$B\bar{B}$

$B\bar{B}^*$

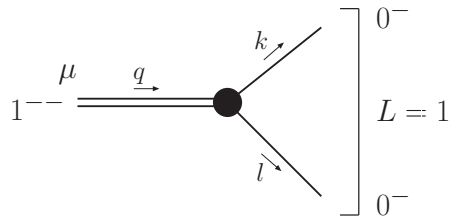
$B^*\bar{B}^*$



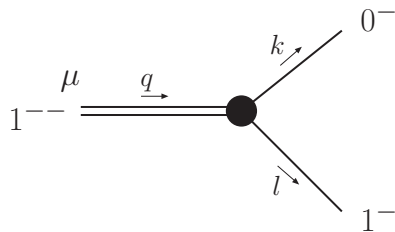
Y_b decay

channel diagram

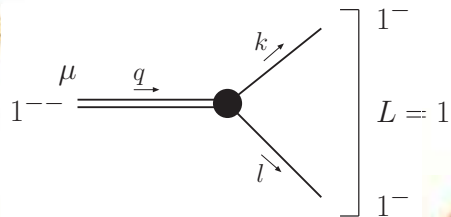
$B\bar{B}$



$B\bar{B}^*$



$B^*\bar{B}^*$



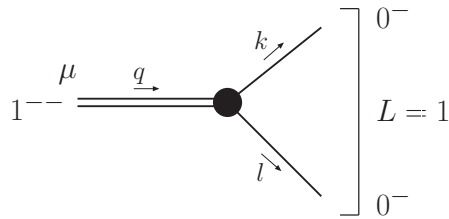
Y_b decay

channel

diagram

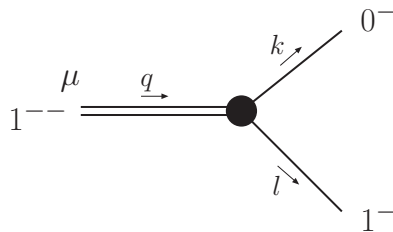
vertex

$B\bar{B}$



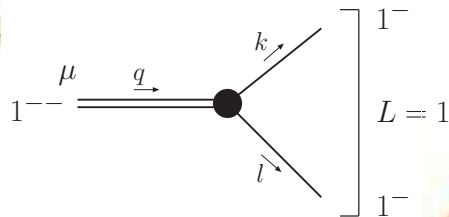
$$\cong F(k^\mu - l^\mu)$$

$B\bar{B}^*$



$$\cong \frac{F}{M} \epsilon^{\mu\nu\rho\sigma} k_\rho l_\sigma$$

$B^*\bar{B}^*$



$$\cong F(g^{\mu\rho}(q+l)^\nu - g^{\mu\nu}(k+q)^\rho + g^{\rho\nu}(q+k)^\mu)$$



Y_b decay

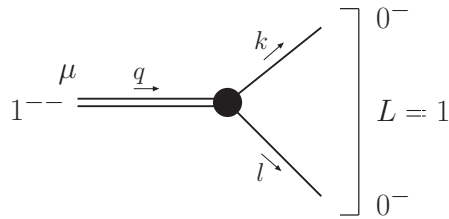
channel

diagram

vertex

width

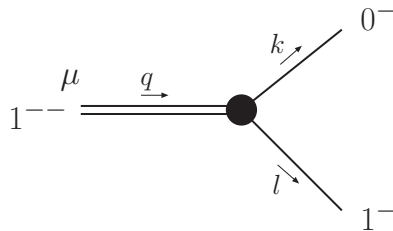
$B\bar{B}$



$$\cong F(k^\mu - l^\mu)$$

$$\Rightarrow \Gamma = \frac{F^2 |\vec{k}|^3}{2M^2 \pi}$$

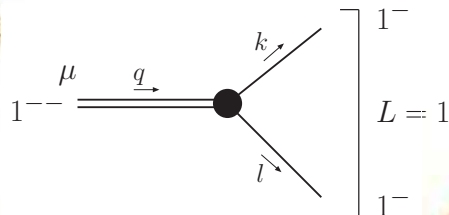
$B\bar{B}^*$



$$\cong \frac{F}{M} \epsilon^{\mu\nu\rho\sigma} k_\rho l_\sigma$$

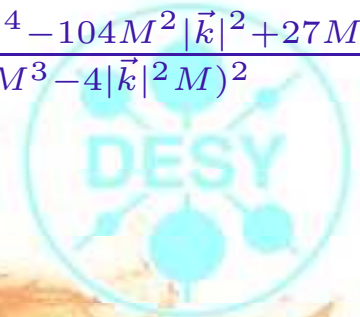
$$\Rightarrow \Gamma = \frac{F^2 |\vec{k}|^3}{4M^2 \pi}$$

$B^* \bar{B}^*$



$$\cong \begin{aligned} & F(g^{\mu\rho}(q+l)^\nu \\ & - g^{\mu\nu}(k+q)^\rho \\ & + g^{\rho\nu}(q+k)^\mu) \end{aligned}$$

$$\Rightarrow \Gamma = \frac{F^2 |\vec{k}|^3 (48|\vec{k}|^4 - 104M^2 |\vec{k}|^2 + 27M^4)}{2\pi (M^3 - 4|\vec{k}|^2 M)^2}$$



Y_b decay

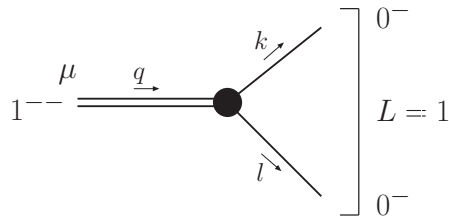
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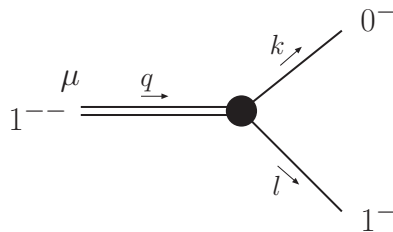
$B\bar{B}$



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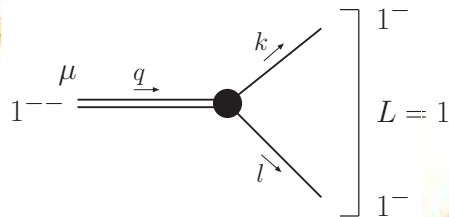
$B\bar{B}^*$



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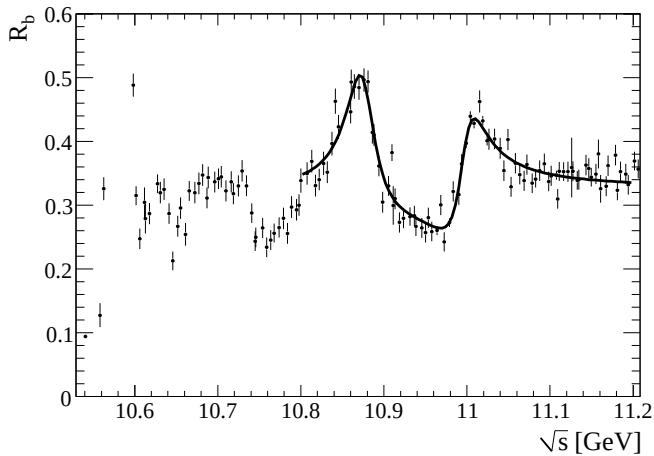


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- The couplings F are estimated from the measured widths of the $\Upsilon(5S)$ decays ($\Gamma_{tot}(Y_b^{(1)}) \approx 10 - 20$ MeV, $\Gamma_{tot}(Y_b^{(2)}) \approx 25 - 50$ MeV, ...)

BaBar fit



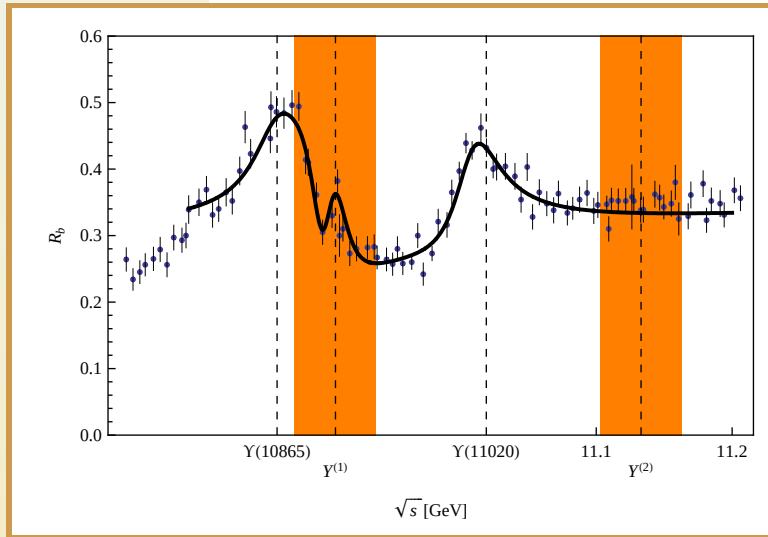
$$\begin{aligned}\sigma(e^+e^- \rightarrow b\bar{b}) = & |A_{nr}|^2 + |A_r + A_{10860}e^{i\phi_{10860}} \\ & \times BW(M_{10860}, \Gamma_{10860}) + A_{11020}e^{i\phi_{11020}} \\ & \times BW(M_{11020}, \Gamma_{11020})|^2\end{aligned}$$

$$\chi^2/\text{d.o.f.} \approx 2$$

[Phys. Rev. Lett. **102**, 012001 (2009)]



BaBar fit



$\chi^2/\text{d.o.f.} = 88/67$

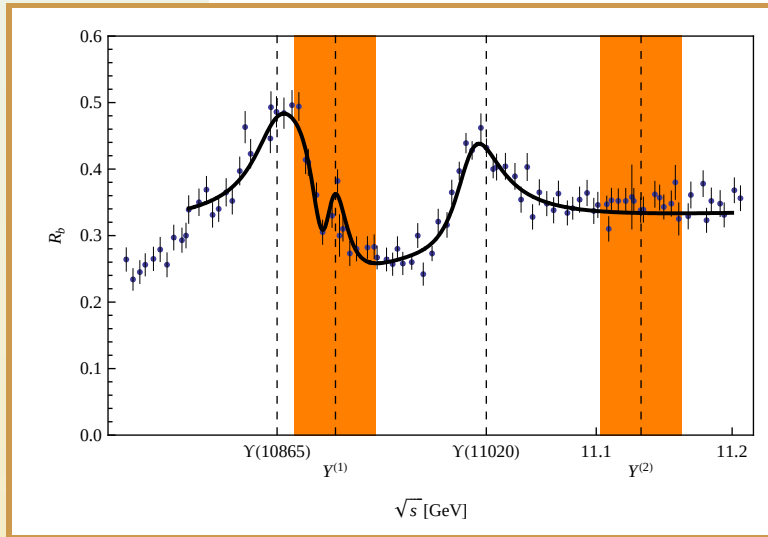
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add $A_{Y_{[b,l]}} e^{i\phi_{Y_{[b,l]}}} BW(M_{Y_{[b,l]}}, \Gamma_{Y_{[b,l]}})$

and $A_{Y_{[b,h]}} e^{i\phi_{Y_{[b,h]}}} BW(M_{Y_{[b,h]}}, \Gamma_{Y_{[b,h]}})$



BaBar fit



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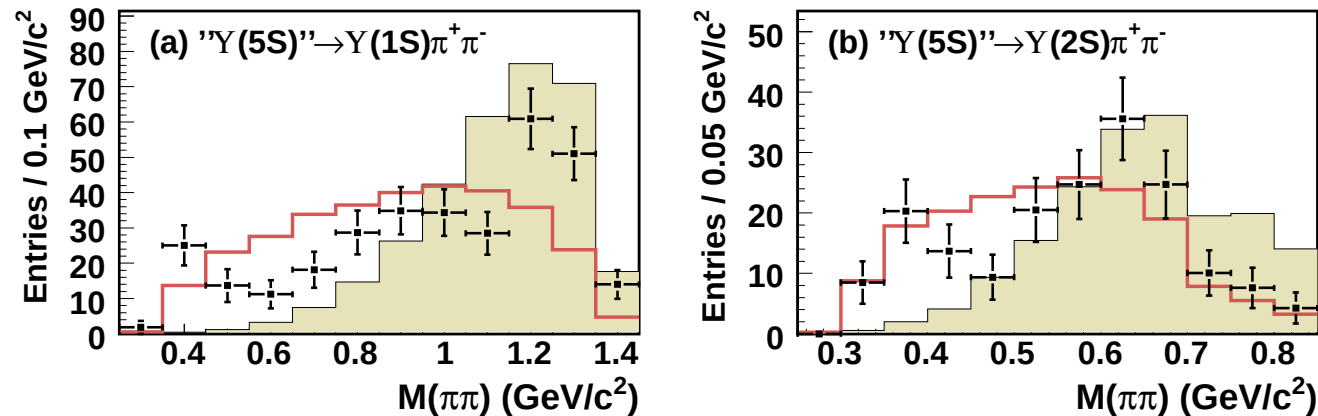
and $A_{Y_{[b,h]}} e^{i\phi_{Y_{[b,h]}}} BW(M_{Y_{[b,h]}}, \Gamma_{Y_{[b,h]}})$

	$M[\text{MeV}]$	$\Gamma[\text{MeV}]$	$\varphi [\text{rad.}]$
$\Upsilon(5S)$	10864 ± 5	46 ± 8	1.3 ± 0.3
$\Upsilon(6S)$	11007 ± 0.3	40 ± 2	0.88 ± 0.06
$Y_{[b,l]}$	$10900 - \Delta M/2 \pm 2$	28 ± 2	1.3 ± 0.2
$Y_{[b,h]}$	$10900 + \Delta M/2 \pm 2$	28 ± 2	1.9 ± 0.2

$\Delta M = 5.6 \pm 2.8 \text{ MeV}, \Gamma_{ee}(Y_{[b,l]}) = 0.045 \pm 0.015 \text{ keV}, \Gamma_{ee}(Y_{[b,h]}) = 0.04 \pm 0.015 \text{ keV}$



enigmatic Belle data



Phys. Rev. Lett. **100**, 112001 (2008)

$$\Gamma(\Upsilon(2S) \rightarrow \Upsilon(1S)\pi\pi) \approx 0.0060 \text{ MeV}$$

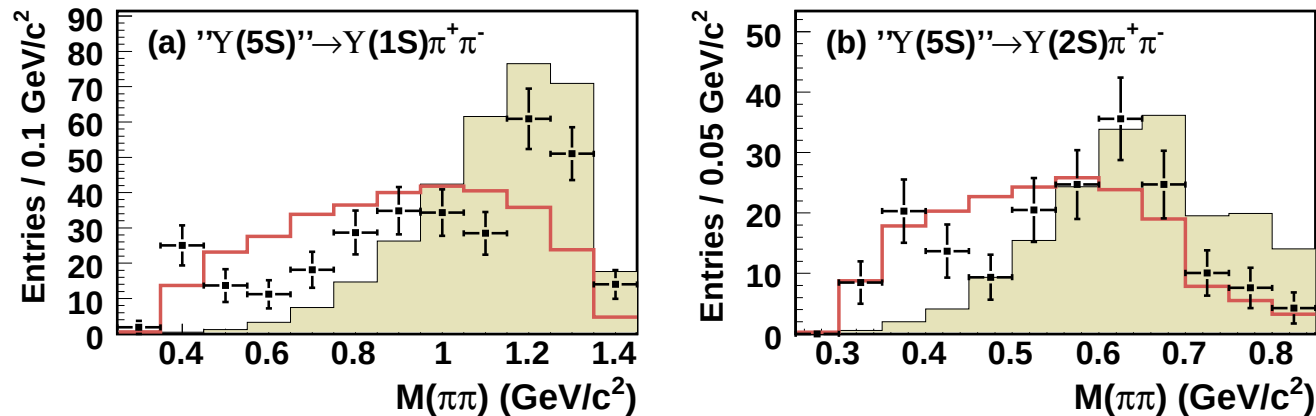
$$\Gamma(\Upsilon(3S) \rightarrow \Upsilon(1S)\pi\pi) \approx 0.0009 \text{ MeV}$$

$$\Gamma(\Upsilon(4S) \rightarrow \Upsilon(1S)\pi\pi) \approx 0.0019 \text{ MeV}$$

$$\Gamma(''\Upsilon(5S)'' \rightarrow \Upsilon(1S)\pi^+\pi^-) \approx 0.59 \text{ MeV}$$



enigmatic Belle data



Phys. Rev. Lett. **100**, 112001 (2008)

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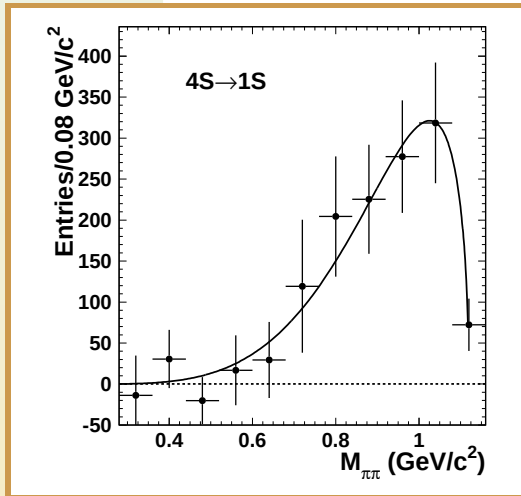
$$\Gamma(''\Upsilon(5S)'' \rightarrow \Upsilon(1S)\pi^+\pi^-) \approx 0.59 \text{ MeV}$$

differs by two orders of magnitude!



why is the belle data puzzling?

- typical $\Upsilon(nS) \rightarrow \Upsilon(1S)\pi\pi$ decays:

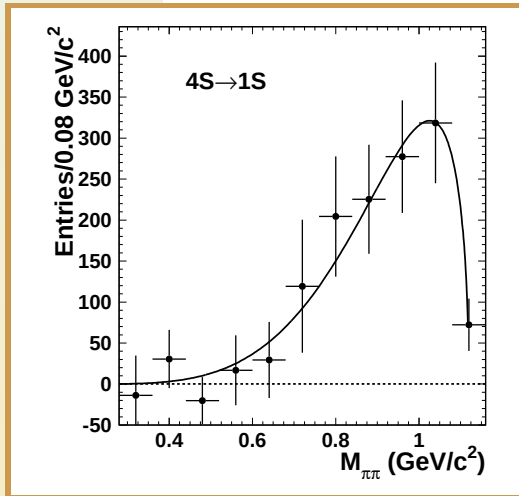


[Phys. Rev. D **79** (2009) 051103]

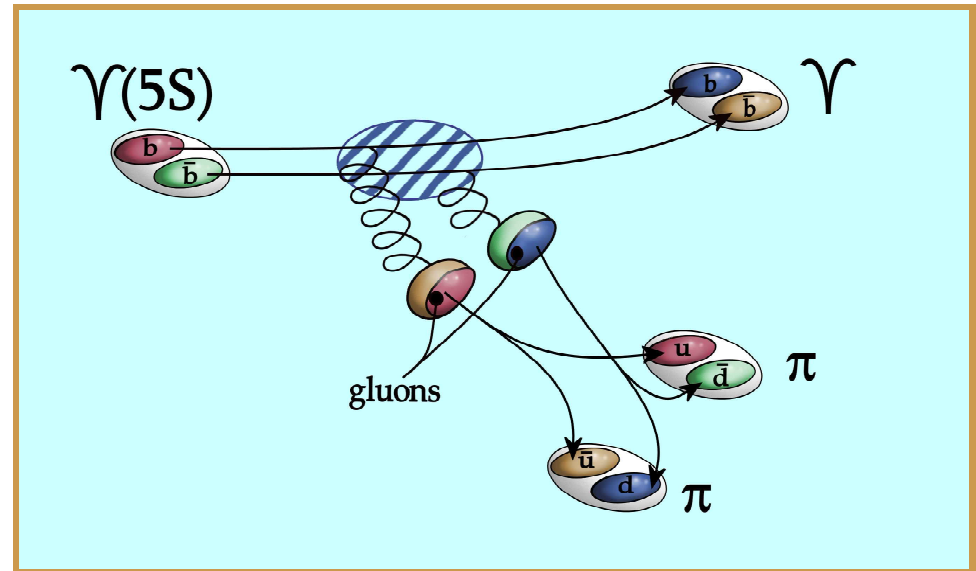


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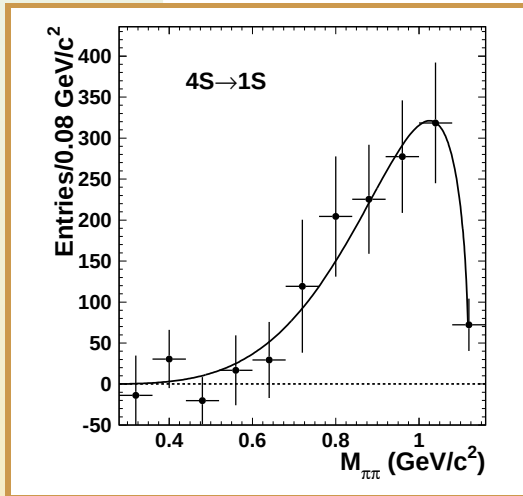


[Phys. Rev. D **79** (2009) 051103]

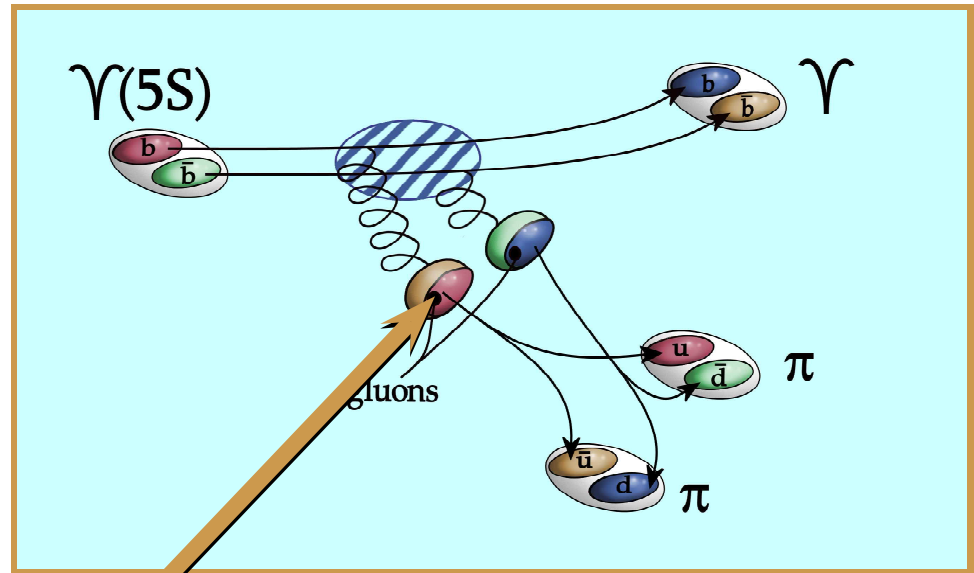


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[Phys. Rev. D **79** (2009) 051103]



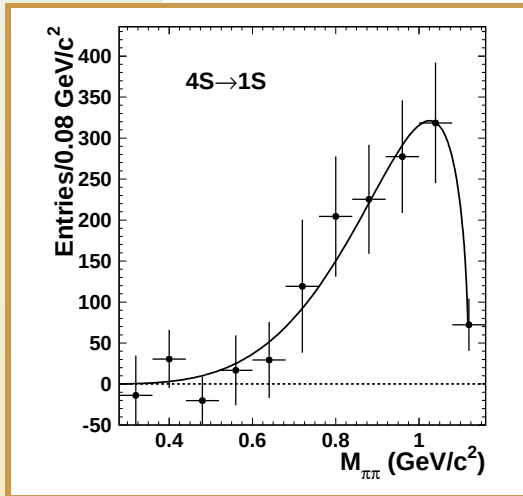
underlying process is

Zweig forbidden

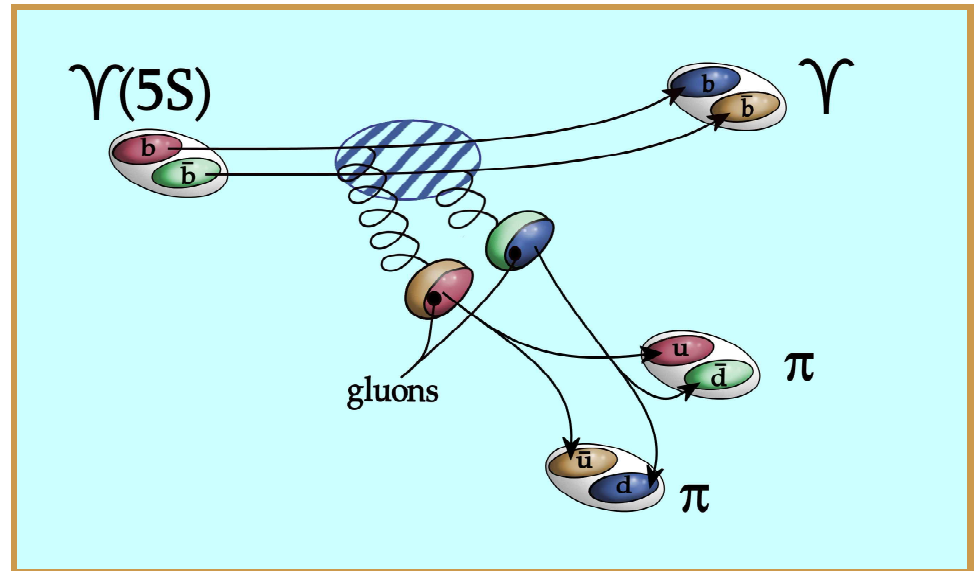


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[Phys. Rev. D **79** (2009) 051103]

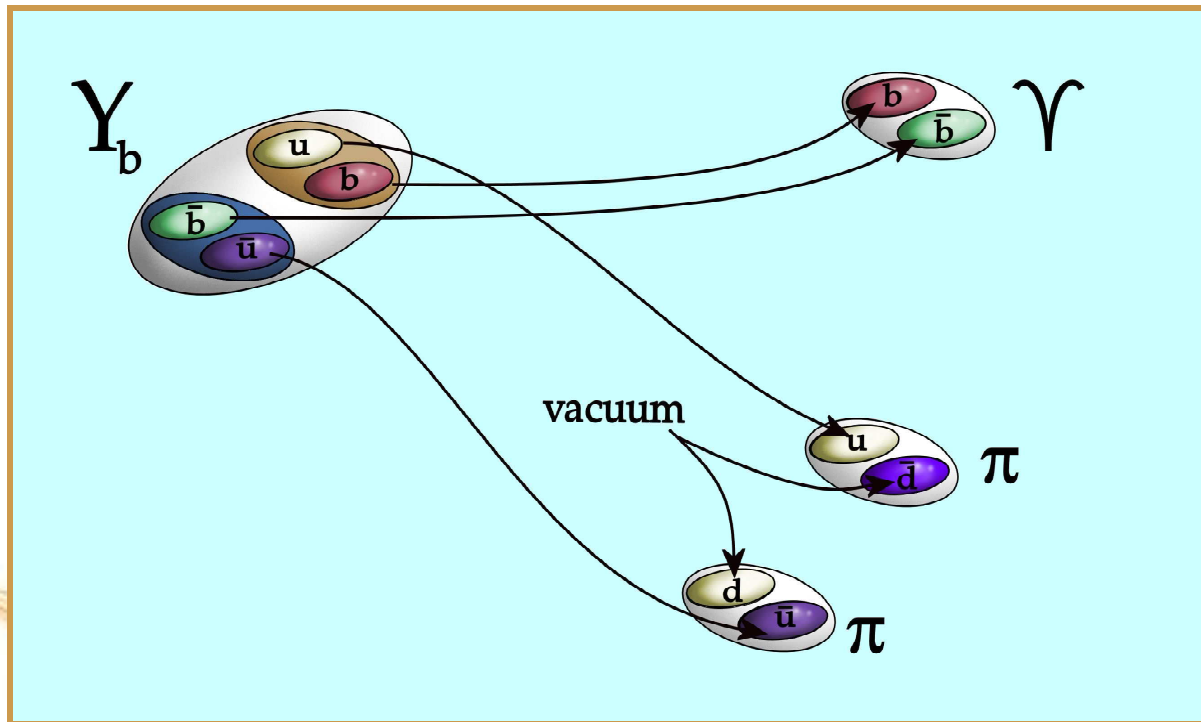


$$\mathcal{M}_a^{\mu\nu} = g^{\mu\nu} \frac{F}{F_\pi^2} \left[m_{\pi\pi}^2 - \beta(\Delta M)^2 \left(1 + \frac{2m_\pi^2}{m_{\pi\pi}^2} \right) + \frac{3}{2} \beta((\Delta M)^2 - m_{\pi\pi}^2) \left(1 - \frac{4m_\pi^2}{m_{\pi\pi}^2} \right) (\cos^2 \theta - \frac{1}{3}) \right]$$

[Phys. Rev. Lett. **35**, 1 (1975)]

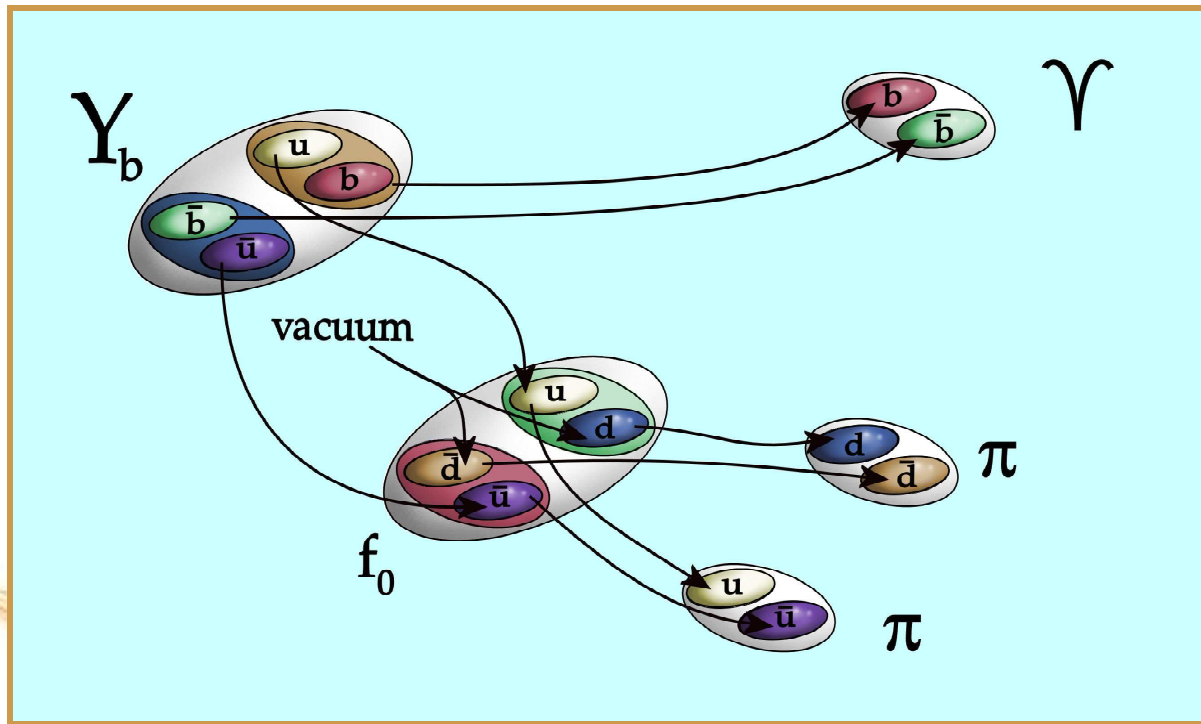
continuum contribution

- The tetraquark decay has a different **Zweig allowed** underlying process:

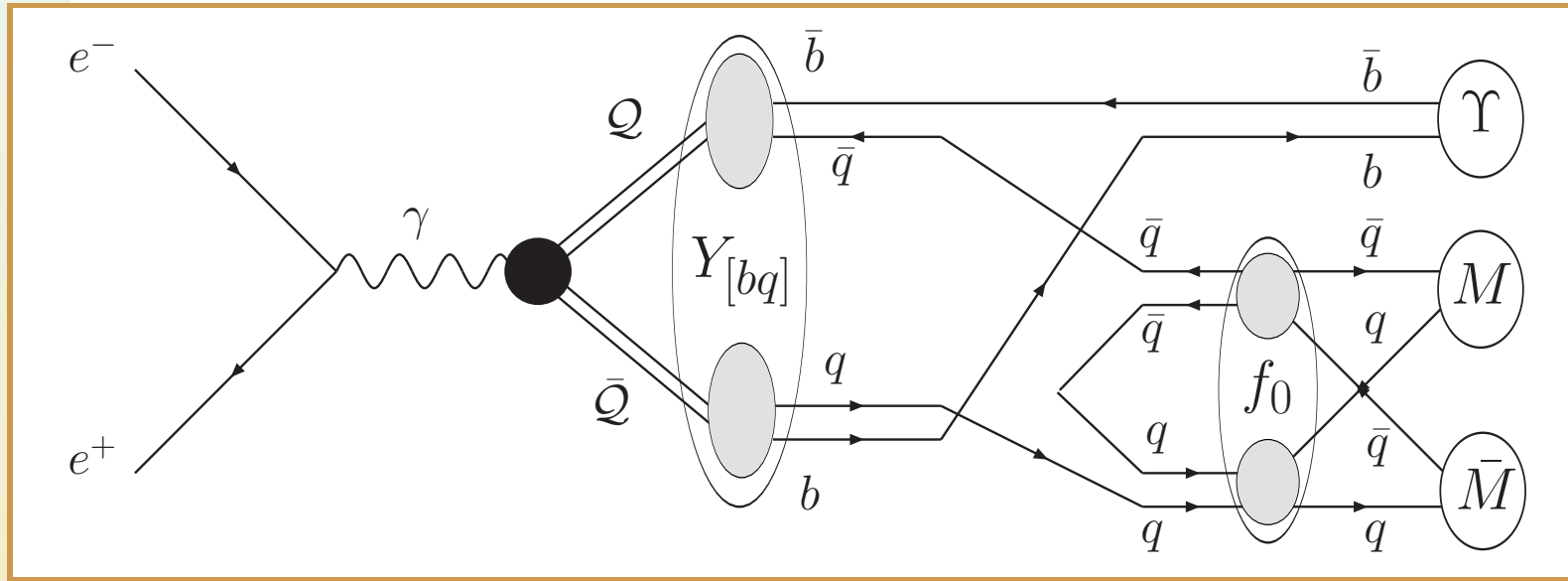


resonance contribution

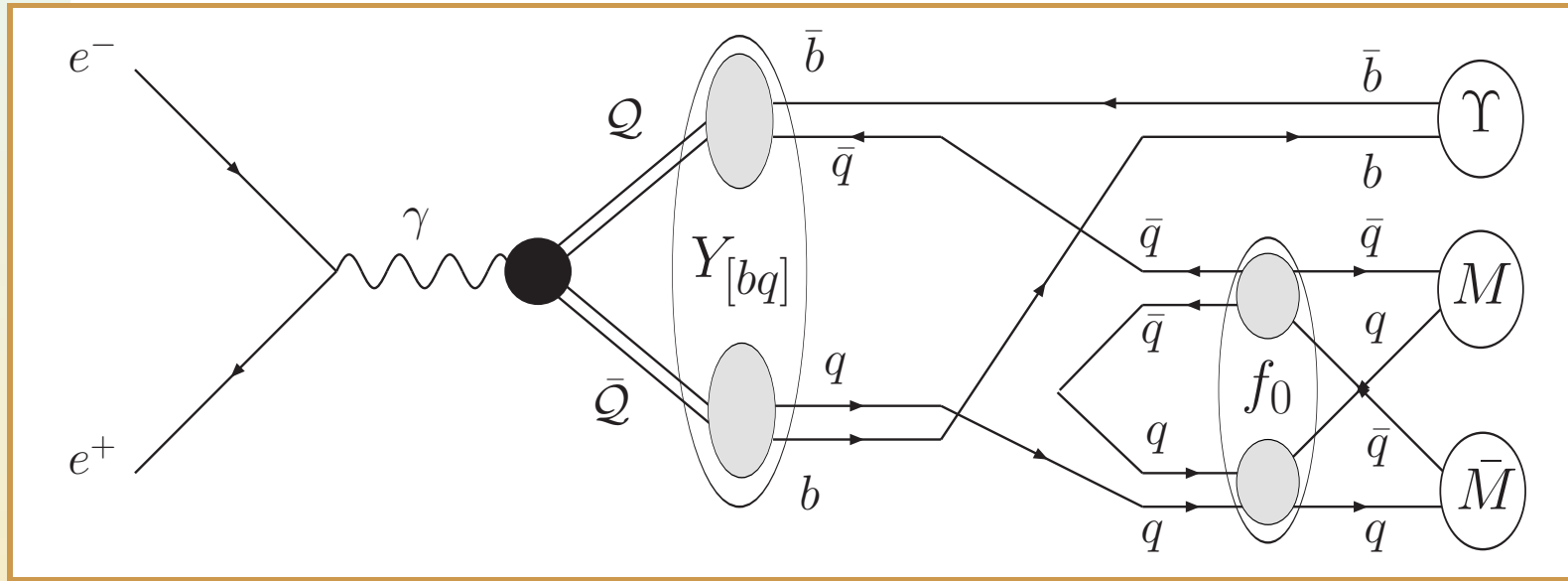
The tetraquark resonances can also account for **Zweig allowed** contributions in the decay process:



0^{++} resonance contribution



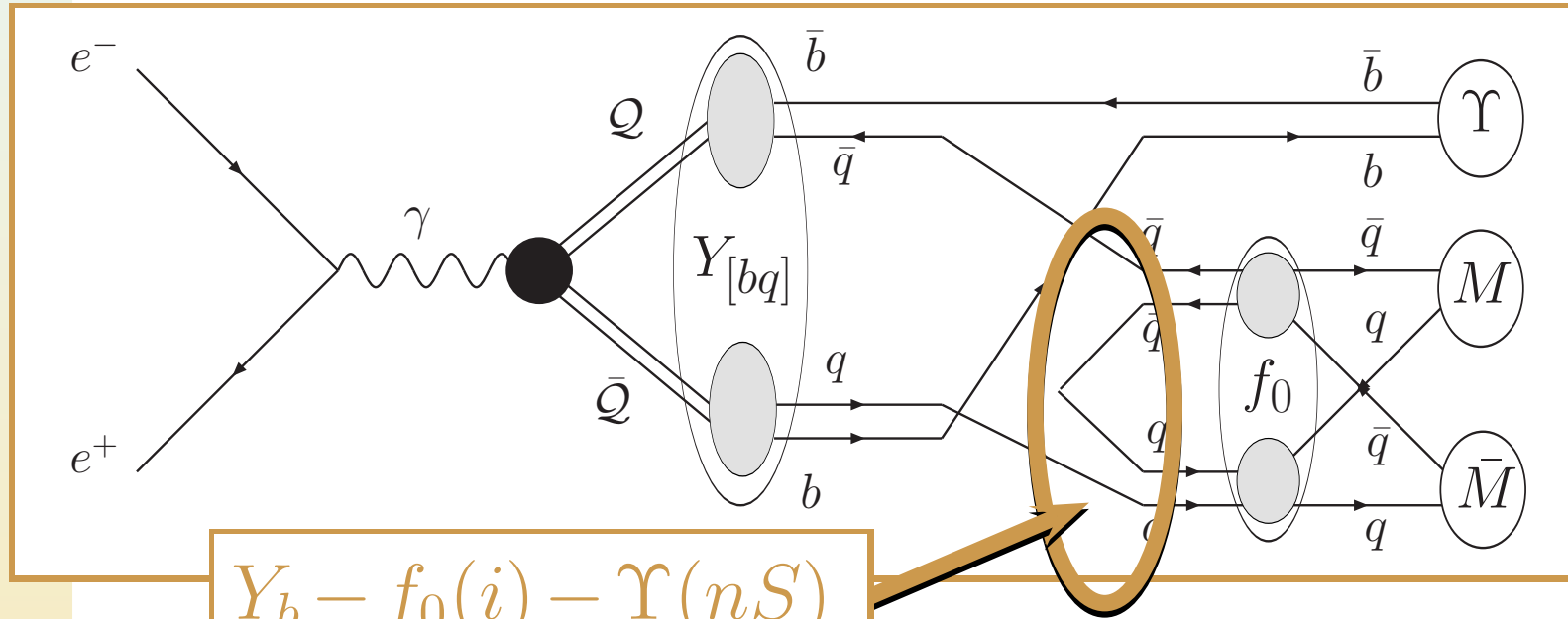
0^{++} resonance contribution



$$\mathcal{M}_{0^{++} \text{ resonance}} = \epsilon^Y \cdot \epsilon^\gamma \sum_i \frac{a_{f_0(i)} e^{i\varphi_{f_0(i)}} (m_{\pi\pi}^2 - 2m_\pi^2)/2}{m_{\pi\pi}^2 - m_{f_0(i)}^2 + im_{f_0(i)} \Gamma_{f_0(i)}(m_{\pi\pi})}$$



0^{++} resonance contribution

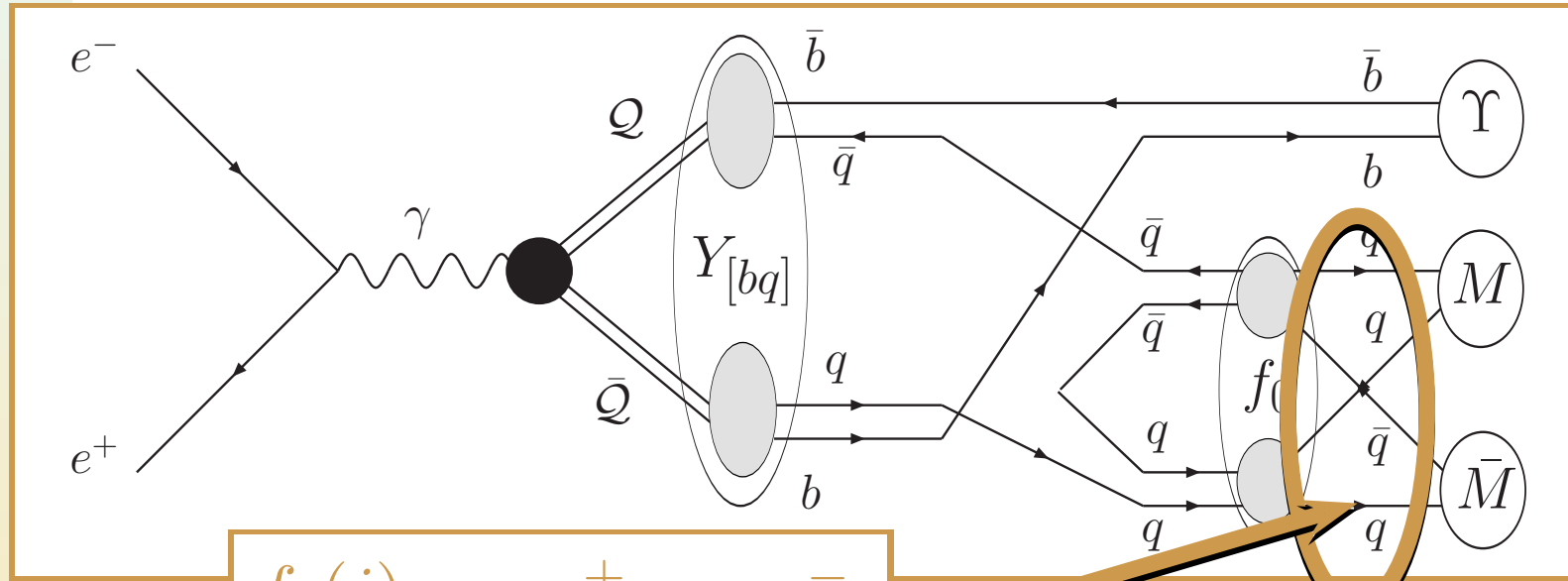


$Y_b - f_0(i) - \Upsilon(nS)$
coupling $F_{f_0(i)}$

$$\mathcal{M}_{0^{++} \text{ resonance}} = \epsilon^Y \cdot \epsilon^\Upsilon \sum_i \frac{a_{f_0(i)} e^{i\varphi_{f_0(i)}} (m_{\pi\pi}^2 - 2m_\pi^2)/2}{m_{\pi\pi}^2 - m_{f_0(i)}^2 + im_{f_0(i)} \Gamma_{f_0(i)}(m_{\pi\pi})}$$



0^{++} resonance contribution

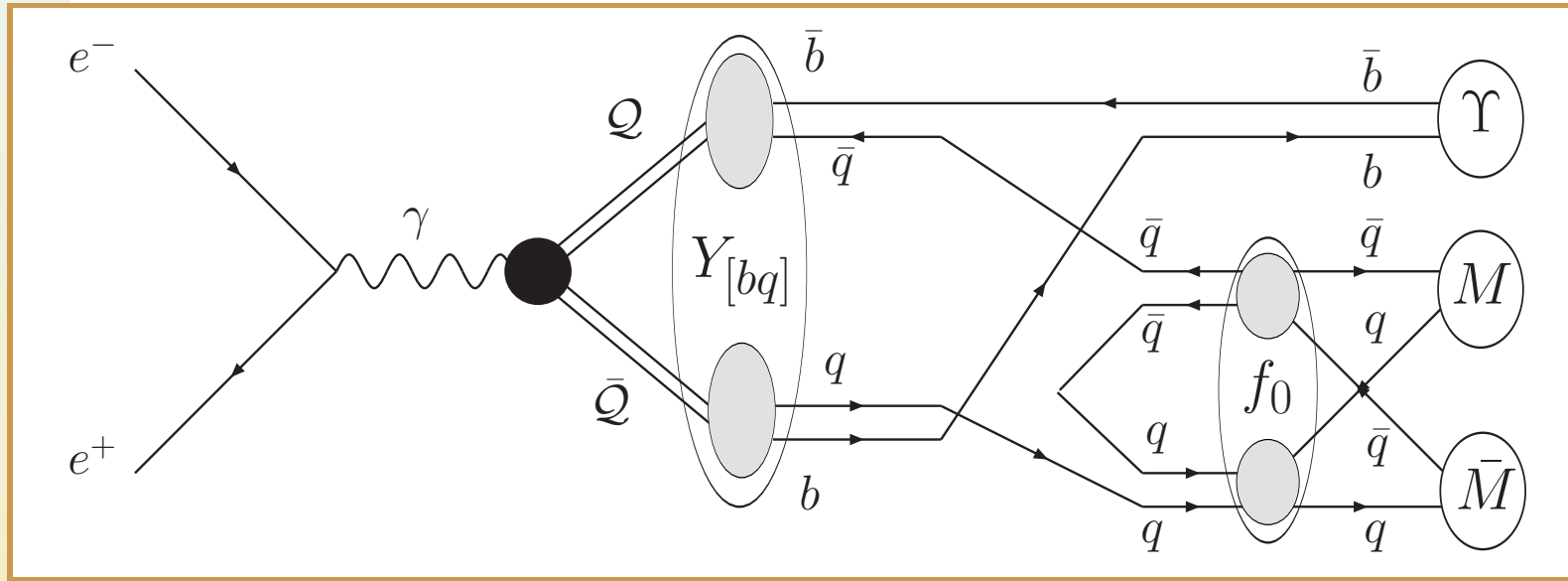


$f_0(i) \rightarrow \pi^+ \pi^-$
coupling $g_{f_0(i)\pi\pi}$

$$\mathcal{M}_{0^{++} \text{ resonance}} = \epsilon^Y \cdot \epsilon^\gamma \sum_i \frac{a_{f_0(i)} e^{i\varphi_{f_0(i)}} (m_{\pi\pi}^2 - 2m_\pi^2)/2}{m_{\pi\pi}^2 - m_{f_0(i)}^2 + i m_{f_0(i)} \Gamma_{f_0(i)}(m_{\pi\pi})}$$



0^{++} resonance contribution

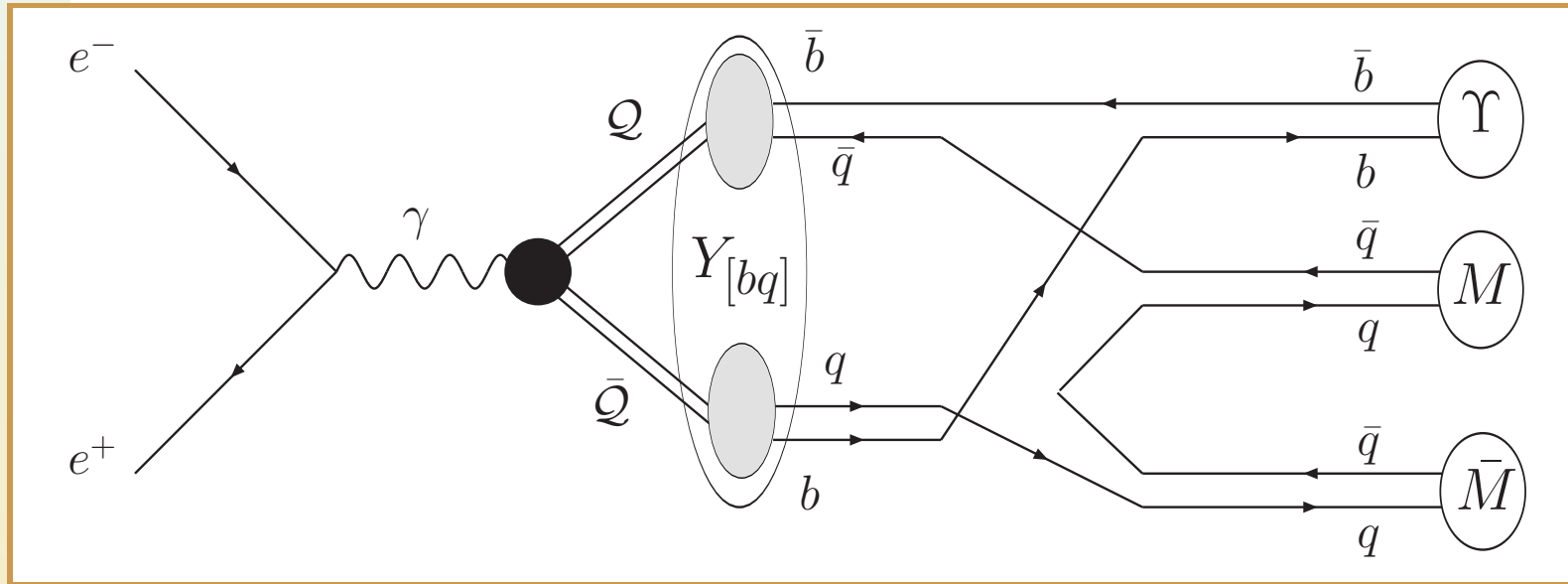


$$a_{f_0(i)} \propto F_{f_0(i)} \times g_{f_0(i)\pi\pi}$$

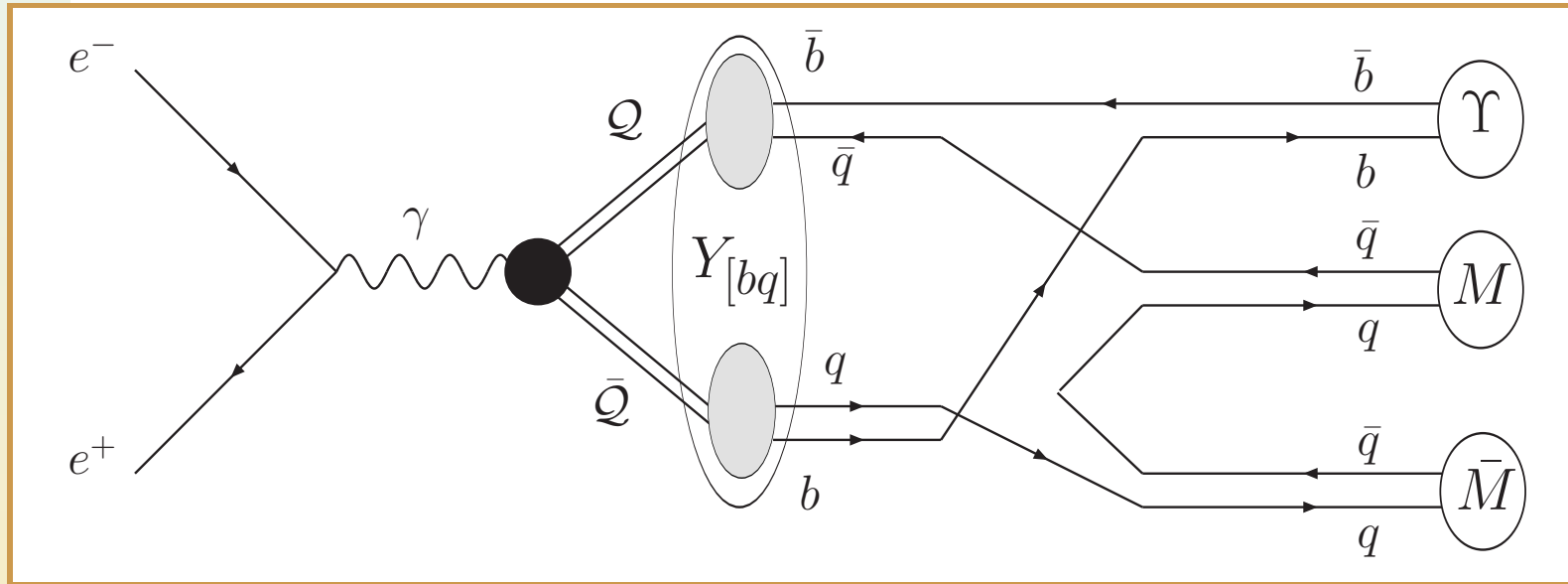
$$\mathcal{M}_{0^{++} \text{ resonance}} = \epsilon^Y \cdot \epsilon^\gamma \sum_i \frac{a_{f_0(i)} e^{i\varphi_{f_0(i)}} (m_{\pi\pi}^2 - 2m_\pi^2)/2}{m_{\pi\pi}^2 - m_{f_0(i)}^2 + im_{f_0(i)} \Gamma_{f_0(i)}(m_{\pi\pi})}$$



continuum contribution

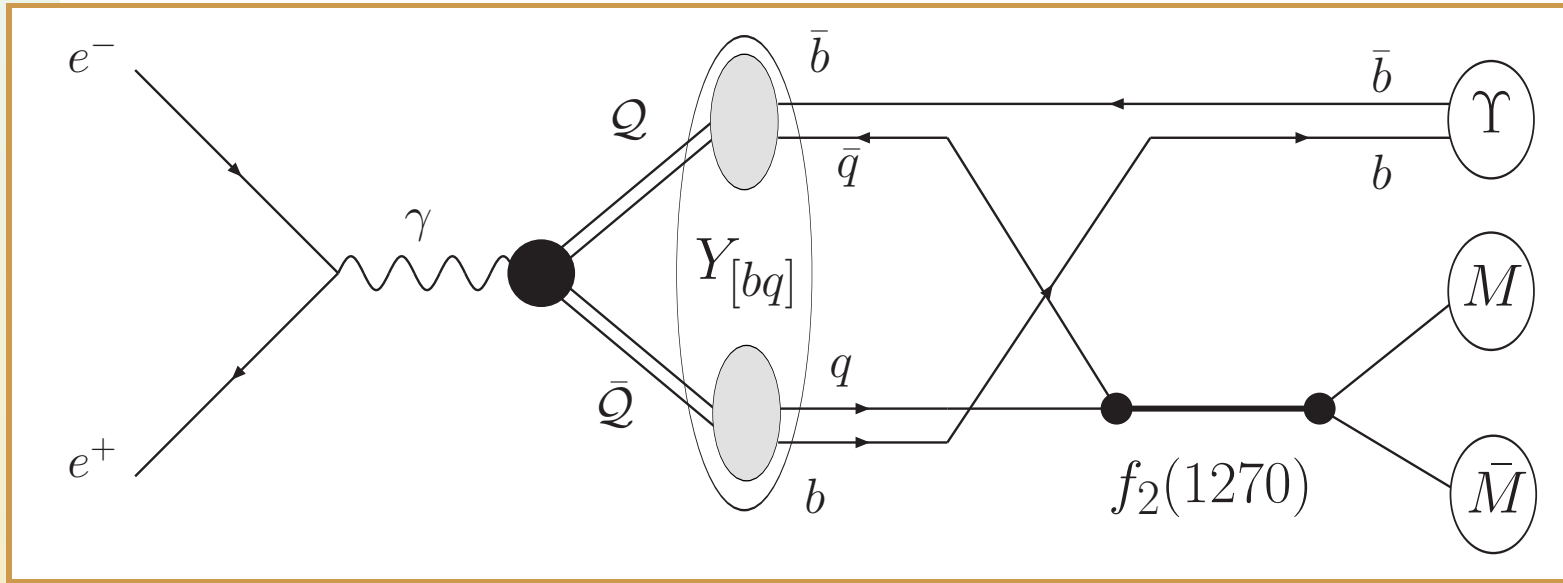


continuum contribution

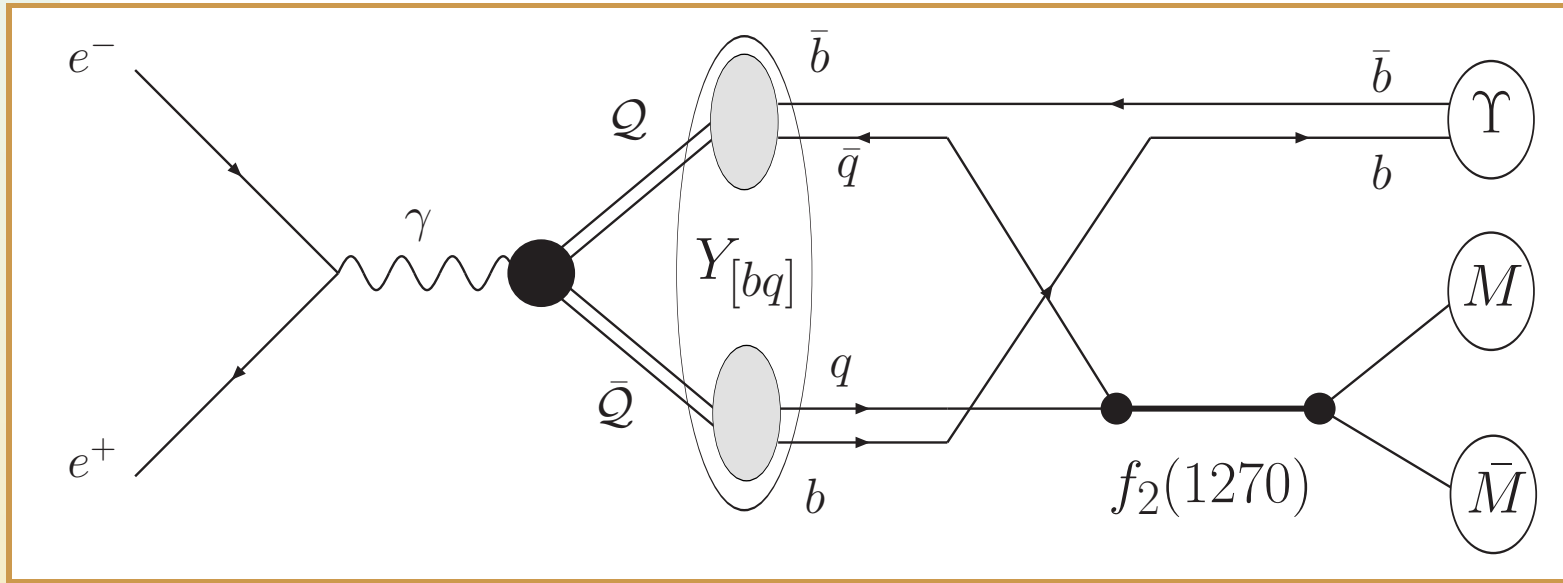


$$\mathcal{M}_{\text{continuum}} = \varepsilon^Y \cdot \varepsilon^\Upsilon \frac{F}{F_\pi^2} \left[m_{\pi\pi}^2 - \beta(\Delta M)^2 \left(1 + \frac{2m_\pi^2}{m_{\pi\pi}^2} \right) + \frac{3}{2} \beta((\Delta M)^2 - m_{\pi\pi}^2) \times \left(1 - \frac{4m_\pi^2}{m_{\pi\pi}^2} \right) (\cos^2 \theta - \frac{1}{3}) \right]$$

D-wave 2^{++} contribution

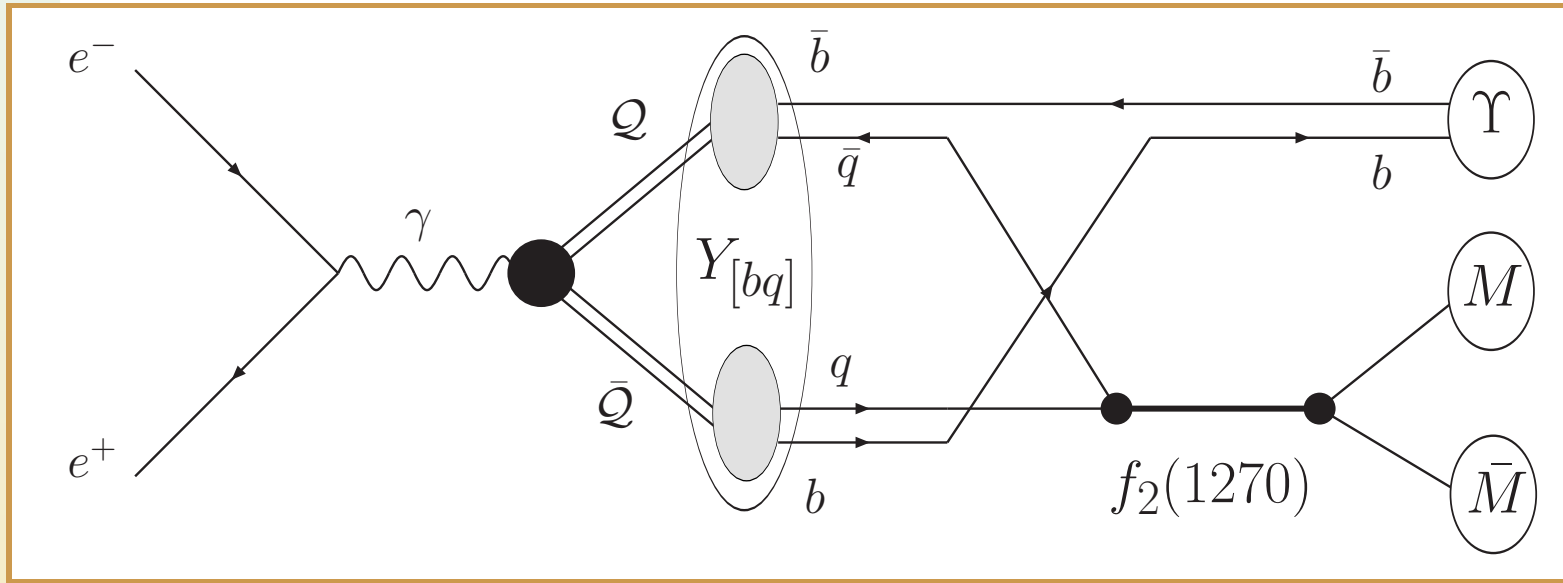


D-wave 2^{++} contribution



$$\mathcal{M}_{f_2(1270)} = \varepsilon^Y . \varepsilon^\Upsilon a_{f_2(1270)} e^{i\varphi_{f_2(1270)}} A_{f_2(1270)}$$

D-wave 2^{++} contribution

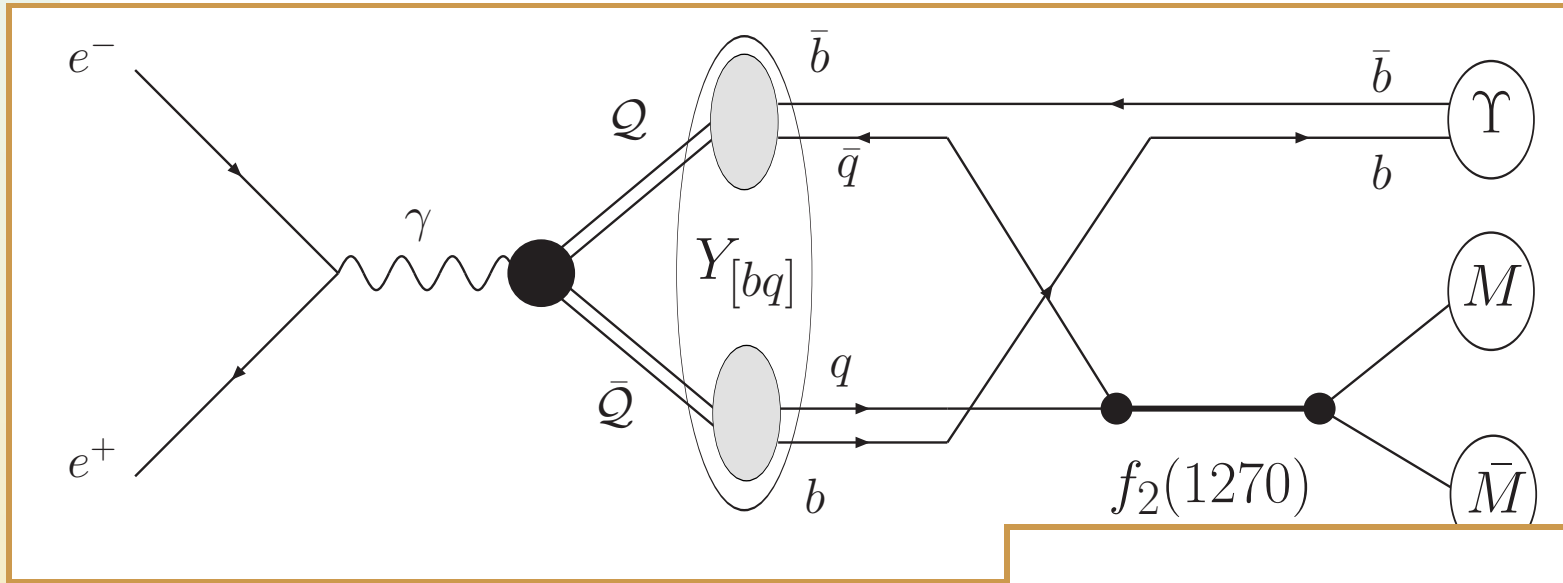


$$\mathcal{M}_{f_2(1270)} = \varepsilon^Y \cdot \varepsilon^\Upsilon a_{f_2(1270)} e^{i\varphi_{f_2(1270)}} A_{f_2(1270)}$$

$$A_{f_2(1270)} = \frac{\sqrt{8\pi(2J+1)}}{\sqrt{m_{\pi\pi}}} Y_2 \frac{a_{f_2(1270)} \sqrt{m_{f_2(1270)}}}{m_{f_2(1270)}^2 - m_{\pi\pi}^2 - im_{f_2(1270)} \Gamma_{f_2(1270)}}$$



D-wave 2^{++} contribution



spherical harmonics:

$$|Y_2^2| = \sqrt{\frac{15}{32\pi}} \sin^2 \theta$$

$$\mathcal{M}_{f_2(1270)} = \epsilon^Y \cdot \epsilon^\Upsilon a_{f_2(1270)}$$

$$A_{f_2(1270)} = \frac{\sqrt{8\pi(2J+1)}}{\sqrt{m_{\pi\pi}}} Y_2^2 \frac{a_{f_2(1270)} \sqrt{m_{f_2(1270)}}}{m_{f_2(1270)}^2 - m_{\pi\pi}^2 - i m_{f_2(1270)} \Gamma_{f_2(1270)}}$$

full amplitude

summing the single contributions leads to the full amplitude:

$$\begin{aligned} \mathcal{M} = & \varepsilon^Y . \varepsilon^Y \left[\frac{F}{F_\pi^2} \left[m_{\pi\pi}^2 - \beta (\Delta M)^2 \left(1 + \frac{2m_\pi^2}{m_{\pi\pi}^2} \right) \right. \right. \\ & + \left. \frac{3}{2} \beta ((\Delta M)^2 - m_{\pi\pi}^2) \left(1 - \frac{4m_\pi^2}{m_{\pi\pi}^2} \right) (\cos^2 \theta - \frac{1}{3}) \right] \\ & + \sum_i \frac{a_{f_0(i)} e^{i\varphi_{f_0(i)}} (m_{\pi\pi}^2 - 2m_\pi^2)/2}{m_{\pi\pi}^2 - m_{f_0(i)}^2 + i m_{f_0(i)} \Gamma_{f_0(i)}(m_{\pi\pi})} \\ & \left. + a_{f_2(1270)} e^{i\varphi_{f_2(1270)}} A_{f_2(1270)}(m_{\pi\pi}) \right] \end{aligned}$$

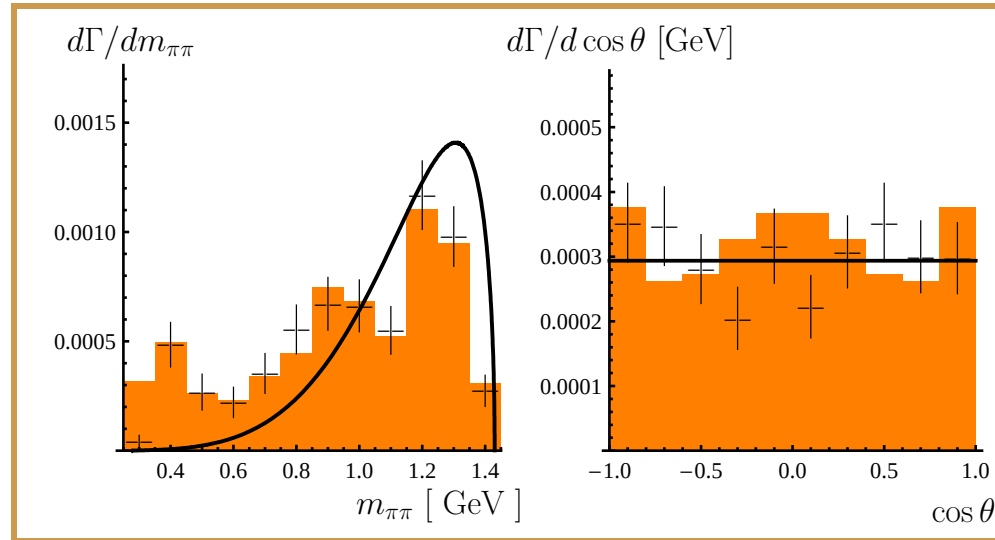
differential partial decay width:

$$d\Gamma = \frac{1}{(2\pi)^3} \frac{1}{32M_{Y_b}^3} |\mathcal{M}|^2 dm_{Y_\pi}^2 dm_{\pi\pi}^2$$



fit to Belle data

Fit for $Y_b \rightarrow \Upsilon(1S)\pi^+\pi^-$ with $\chi^2/\text{d.o.f.} = 5/5$:

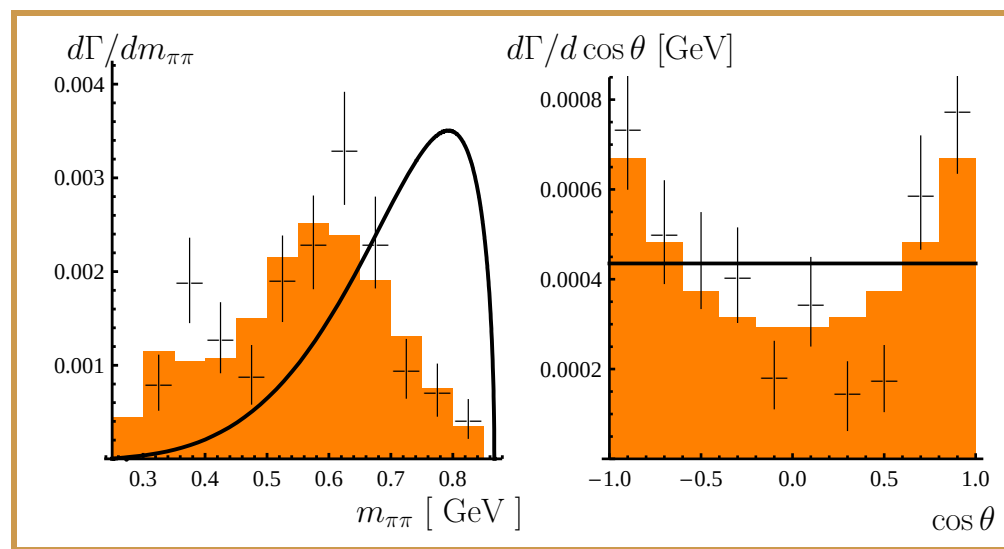


$$F = 0.19 \pm 0.03, \beta = 0.54 \pm 0.12, a_{f_2(1270)} = 0.5 \pm 0.16, \\ \varphi_{f_2(1270)} = 3.33 \pm 0.06$$

	$a_{f_0(i)}$	$F_{f_0(i)}$	$\varphi_{f_0(i)} \text{ (rad.)}$
$f_0(600)$	3.6 ± 0.7	1.38 ± 0.27	1.14 ± 0.14
$f_0(980)$	0.47 ± 0.02	1.02 ± 0.04	4.12 ± 0.3

fit to Belle data

Fit for $Y_b \rightarrow \Upsilon(2S)\pi^+\pi^-$ with $\chi^2/\text{d.o.f.} = 9/8$:



$$F = 0.86 \pm 0.34, \beta = 0.7 \pm 0.3$$

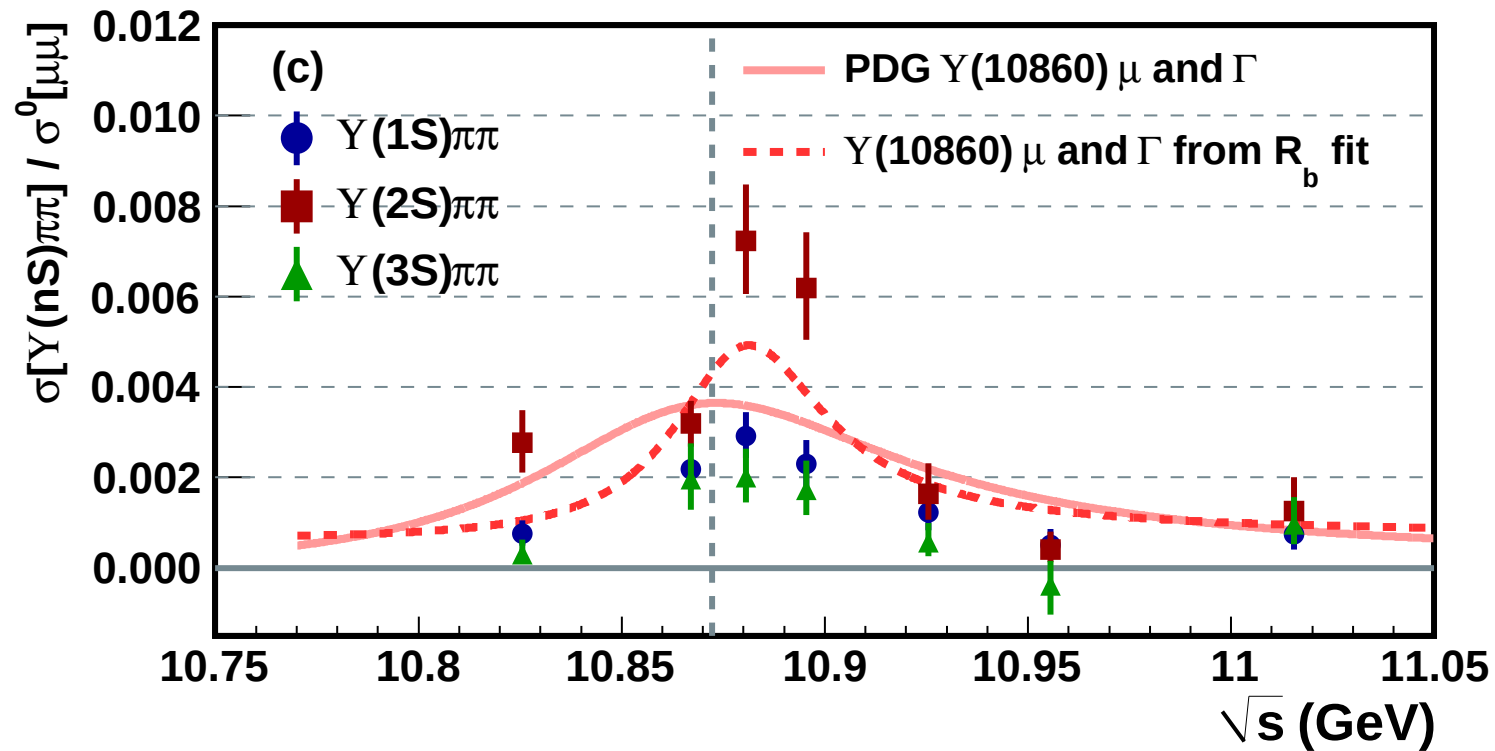
	$a_{f_0(i)}$	$F_{f_0(i)}$	$\varphi_{f_0(i)}$ (rad.)
$f_0(600)$	10.89 ± 2.4	4.19 ± 0.92	2.76 ± 0.22

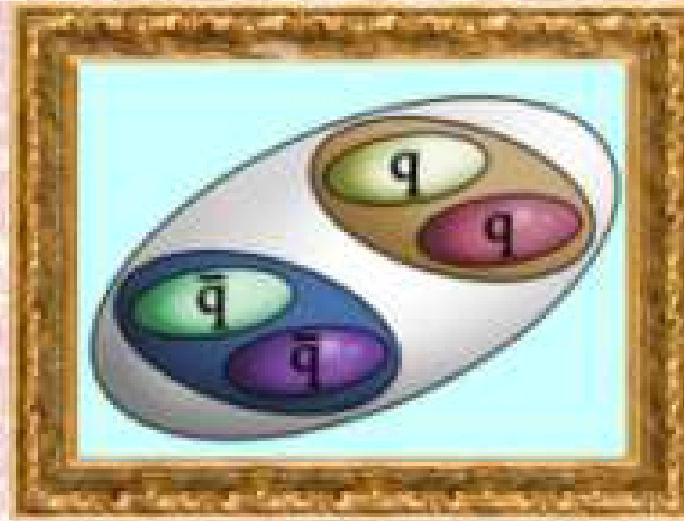
Summarizing:

- $\Upsilon(5S) \rightarrow \Upsilon(1S)\pi^+\pi^-$, $\Upsilon(2S)\pi^+\pi^-$ decays are **Zweig forbidden** .
- $Y_b \rightarrow \Upsilon(1S)\pi^+\pi^-$, $\Upsilon(2S)\pi^+\pi^-$ decays are **Zweig allowed** and can explain the large observed decay widths measured by Belle.
- The coupling to intermediate light quark resonances ($f_0(600)$, $f_0(980)$, $f_2(1270)$) can explain the shape of the invariant mass contribution (**scalar meson dominance**) .
- Crucial Tests:
 - Is there any sign of Y_b in Belle's R_b -scan?
 - Are the decays $Y_b \rightarrow \Upsilon(1S)K^+K^-$ ($\Upsilon(1S)\eta\pi^0$) dominated by the light tetraquarks $f_0(980)$ and $a_0(980)$?

new Belle data

fits under preparation





thank you!