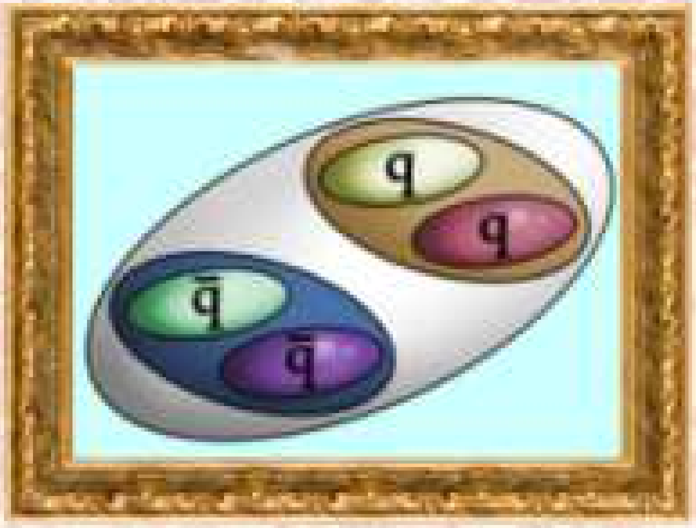
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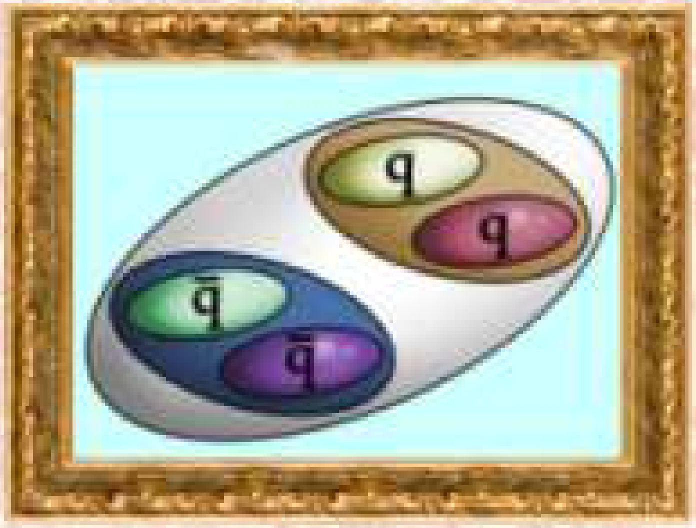

Tetraquarks - Evidence Grows!

Ahmed Ali (DESY), Tuesday, 29.06.2010

underlying work

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A. Ali, C. Hambrock, I. Ahmed and M. J. Aslam,
"A case for hidden $b\bar{b}$ tetraquarks based on $e^+e^- \to b\bar{b}$ cross section between $\sqrt{s} = 10.54$ and 11.20 GeV,"
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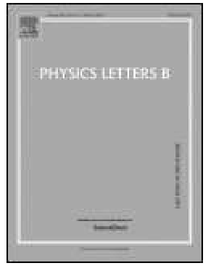

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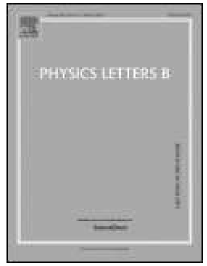

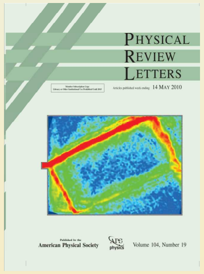

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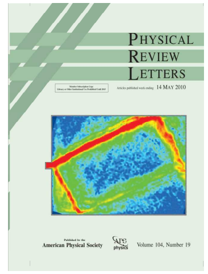

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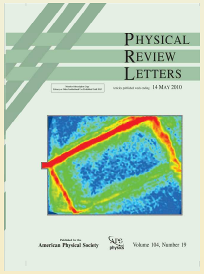

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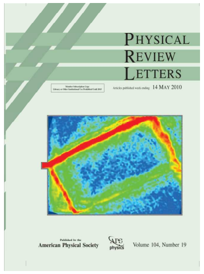

A. Ali, C. Hambrock and S. Mishima
"Tetraquark-based analysis of R_b and $\sigma(e^+e^- \to \Upsilon(1S)\pi^+\pi^-$, $\Upsilon(2S)\pi^+\pi^-$, $\Upsilon(3S)\pi^+\pi^-)$ near the $\Upsilon(5S)$"
(work in progress)

Overview

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- what are tetraquarks?

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- tetraquarks in Belle data!
- conclusion and outlook

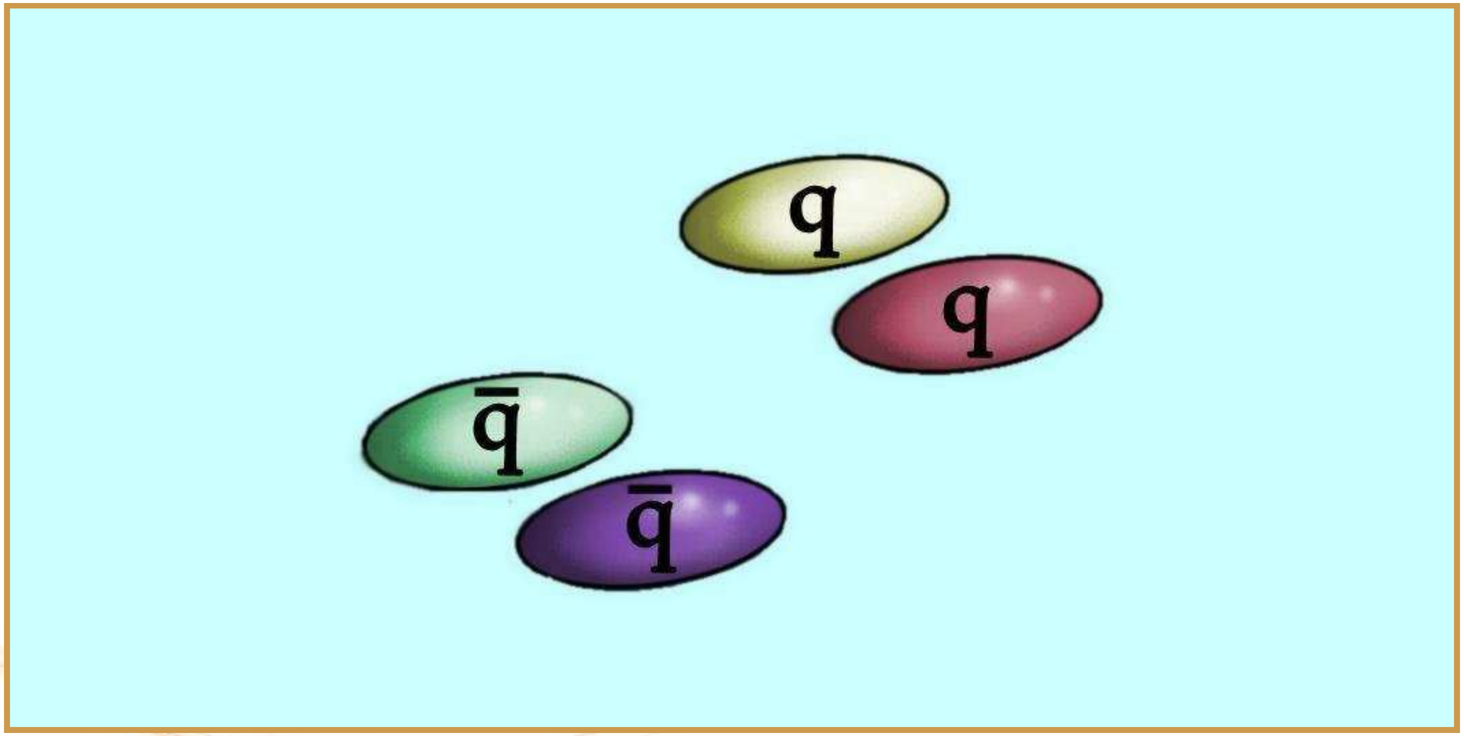
what are tetraquarks?

tetraquark constituents

the building blocks of tetraquarks are

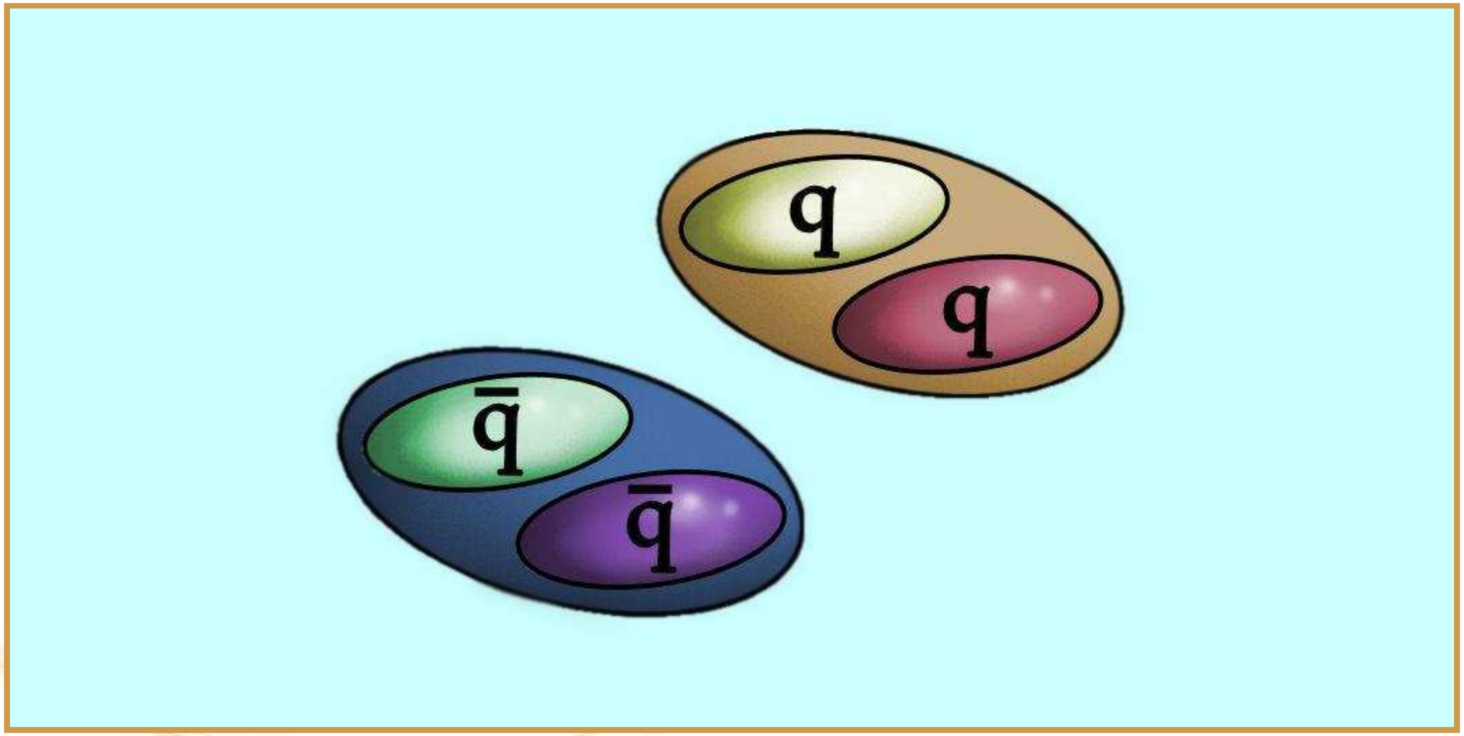
tetraquark constituents

4 quarks



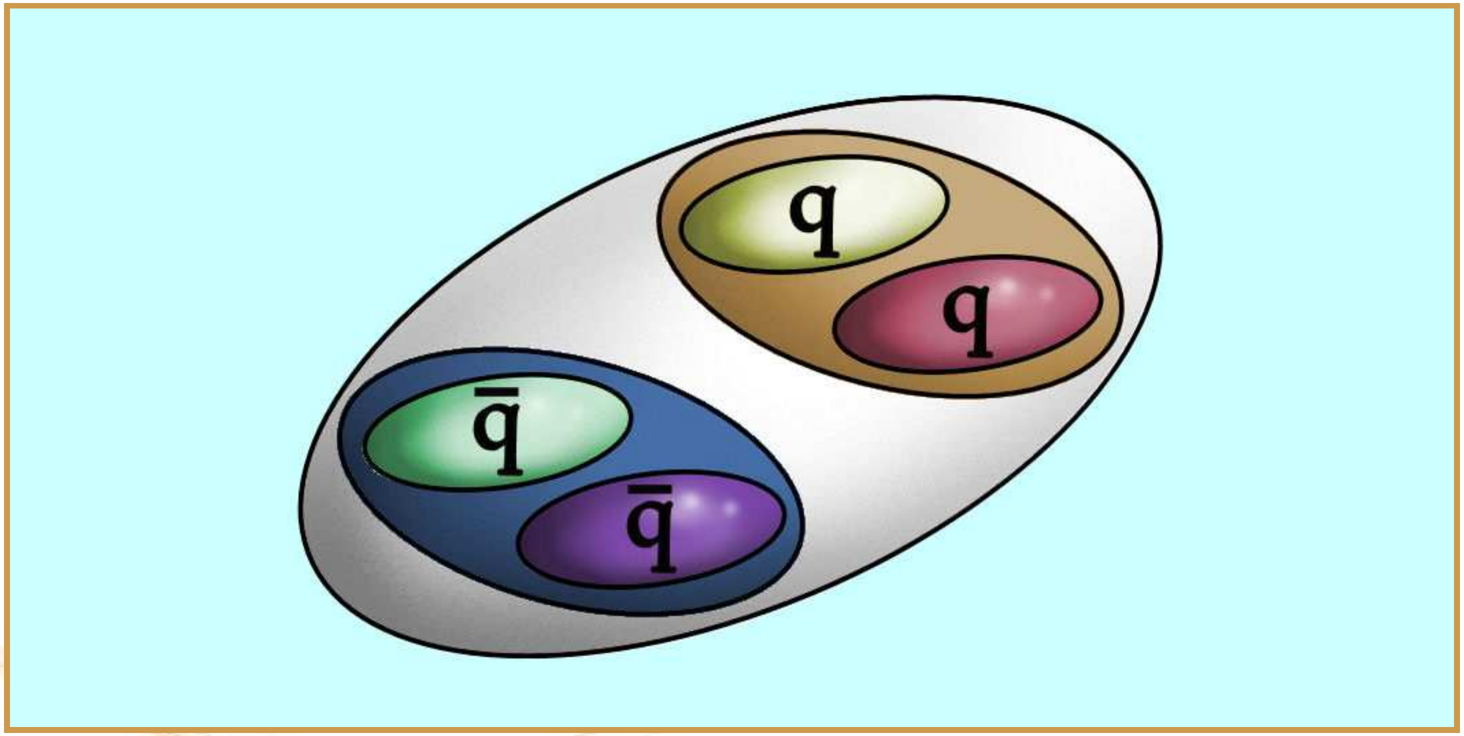
tetraquark constituents

forming a pair of diquarks and antidiquarks

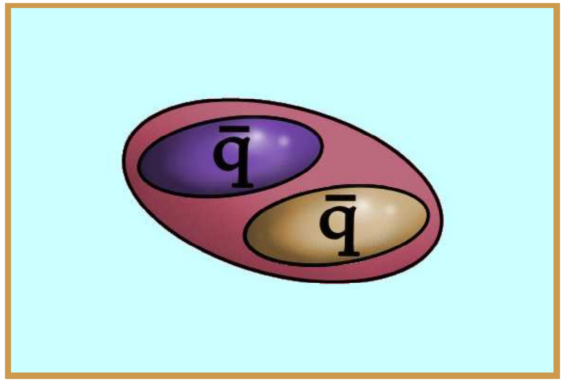


tetraquark constituents

the diquarks and antidiquarks form a tetraquark



diquarks: color representation



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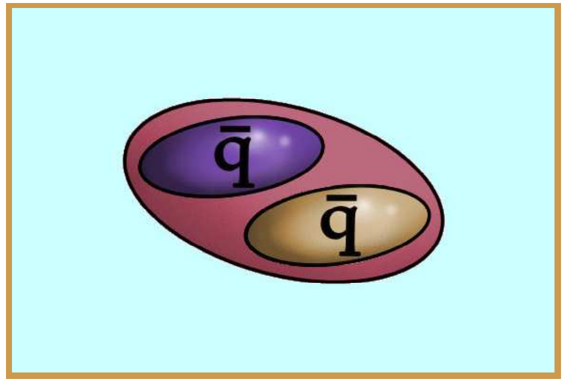
$$\bar{\mathbf{3}} \otimes \bar{\mathbf{3}} = \bar{\mathbf{6}} \oplus \mathbf{3}$$



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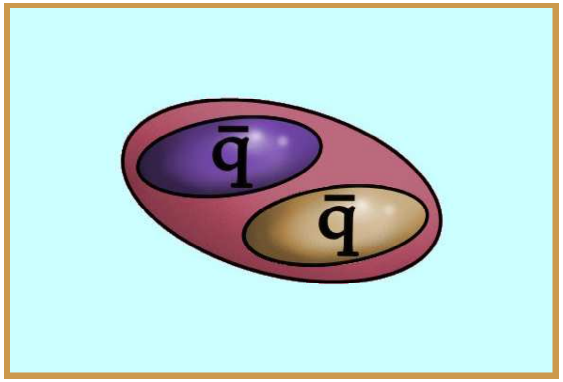

From one gluon exchange model results [R. Jaffe, Phys. Rep., 409 (2005) 1]:

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

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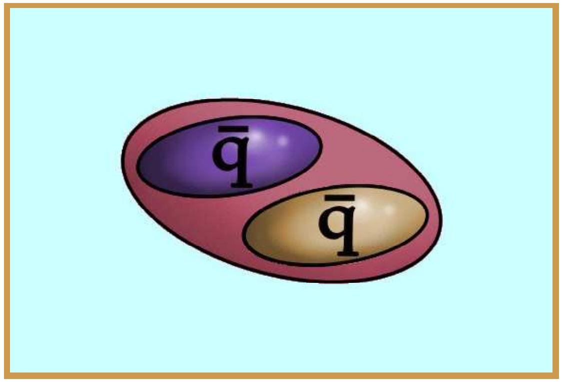

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The discriminator I

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

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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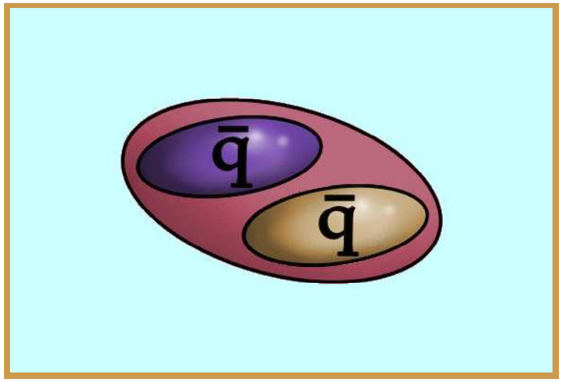

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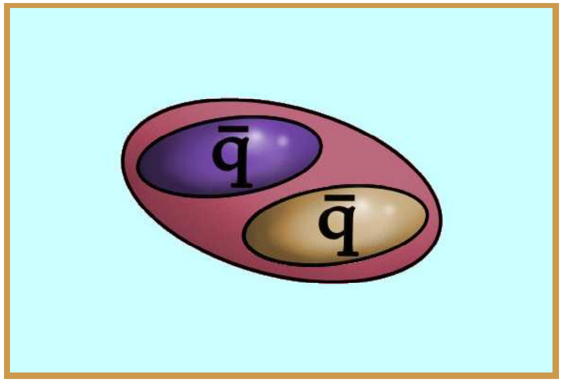

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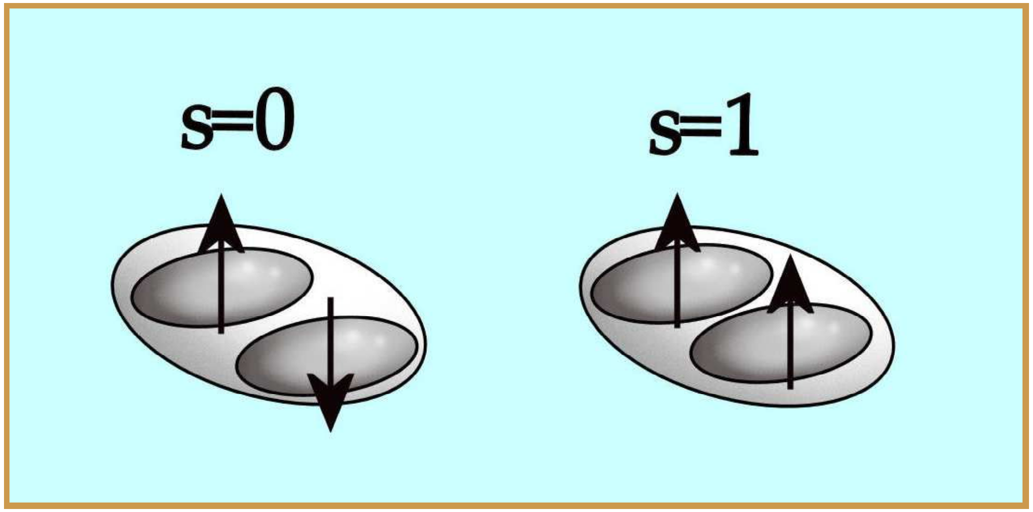

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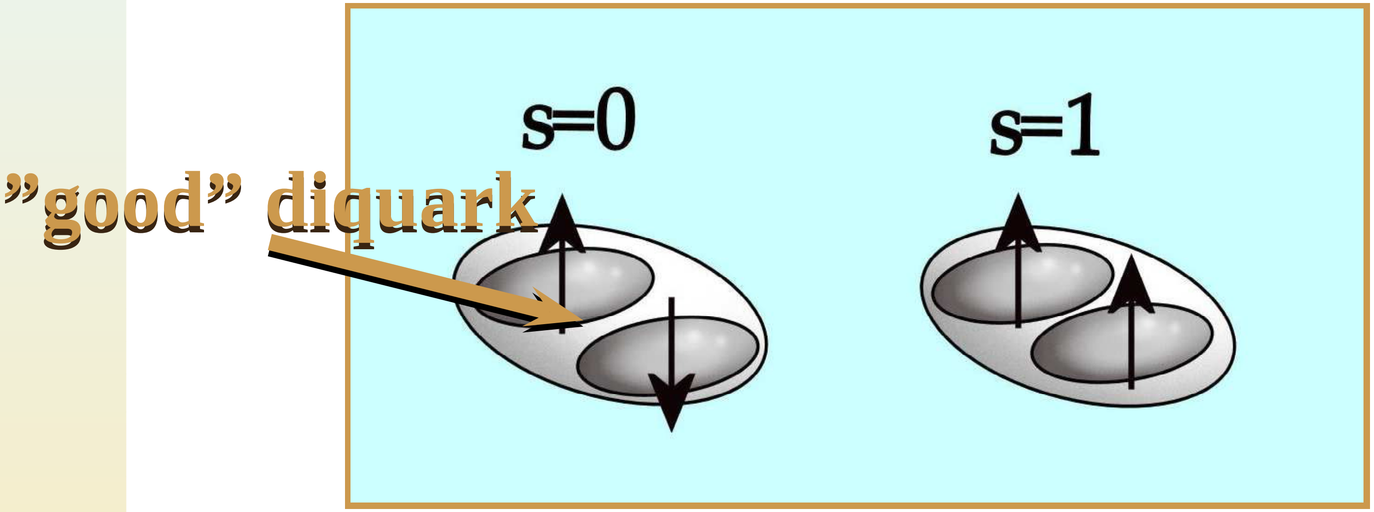

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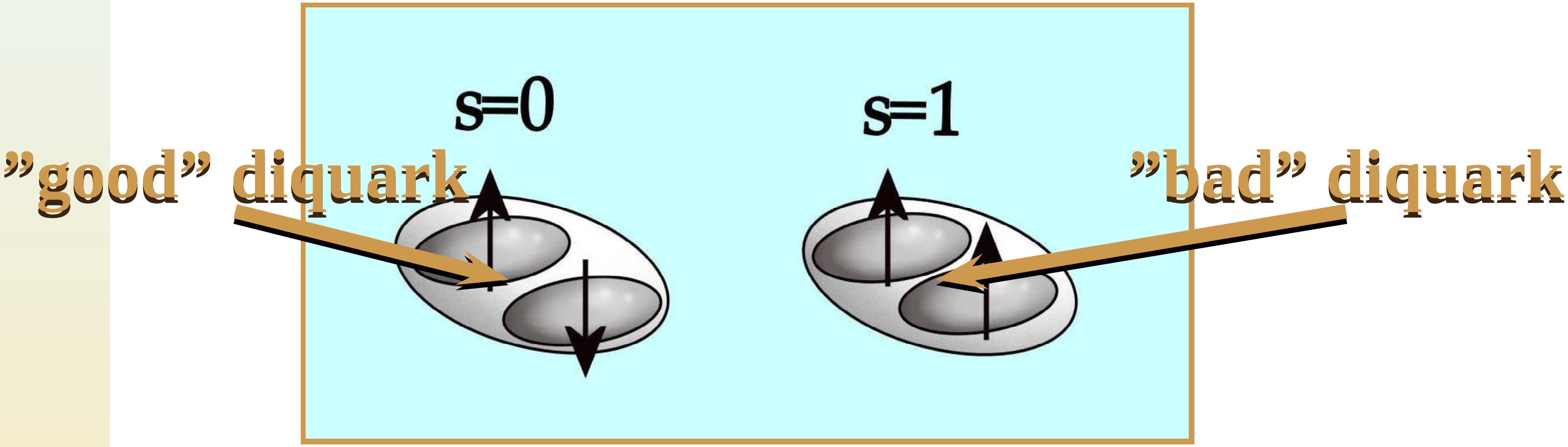

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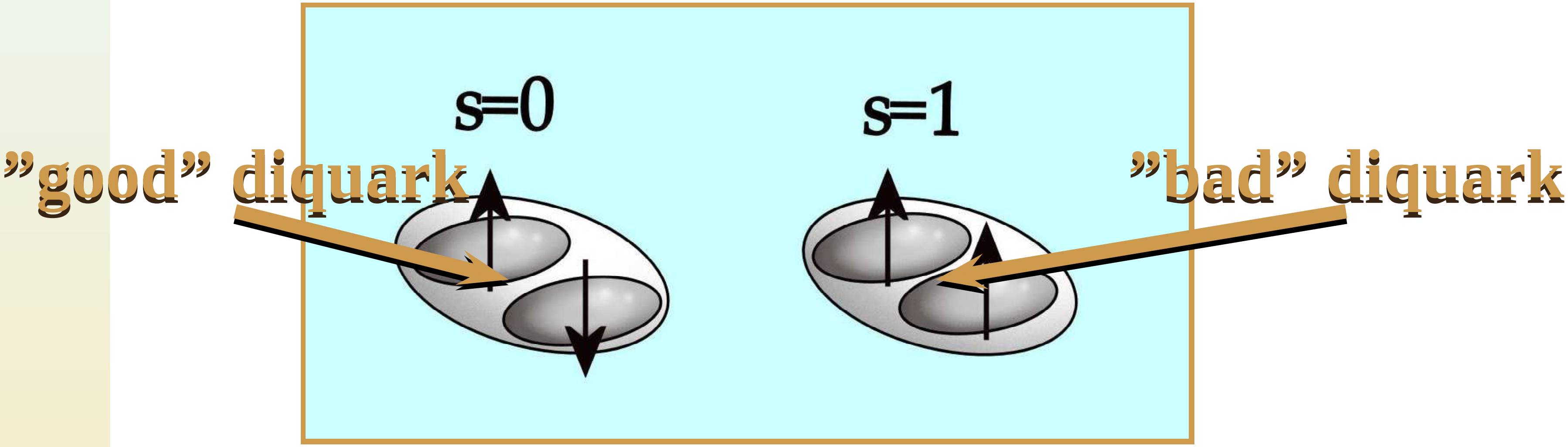

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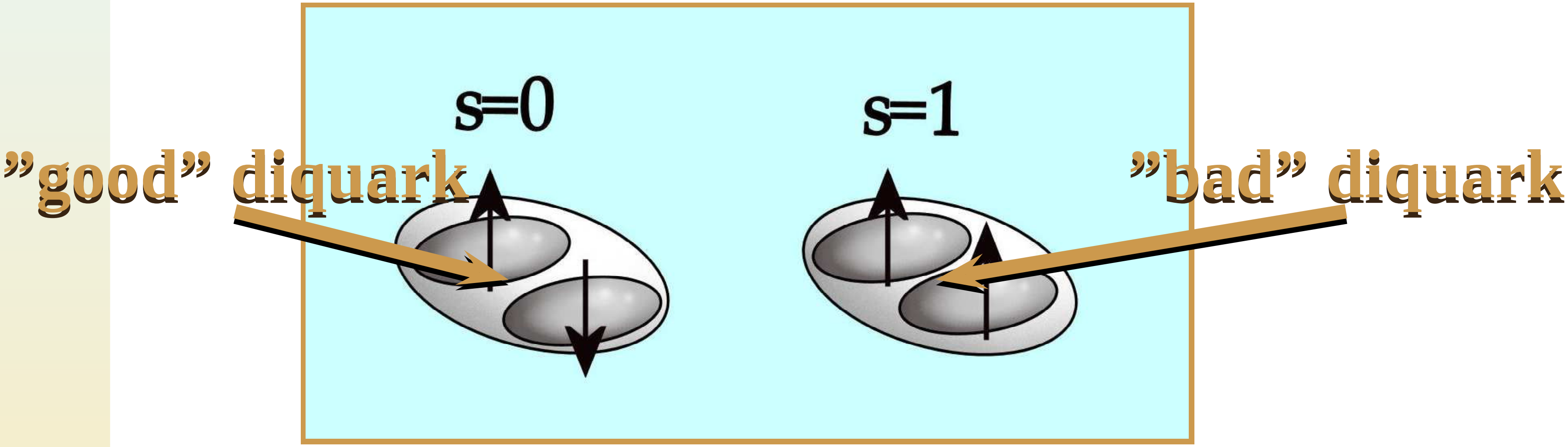

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- less binding for "bad" spin 1 diquarks

now: closer look at lattice results

In the Heavy-Quark-Limit spin decoupling should allow for both cases to exist.

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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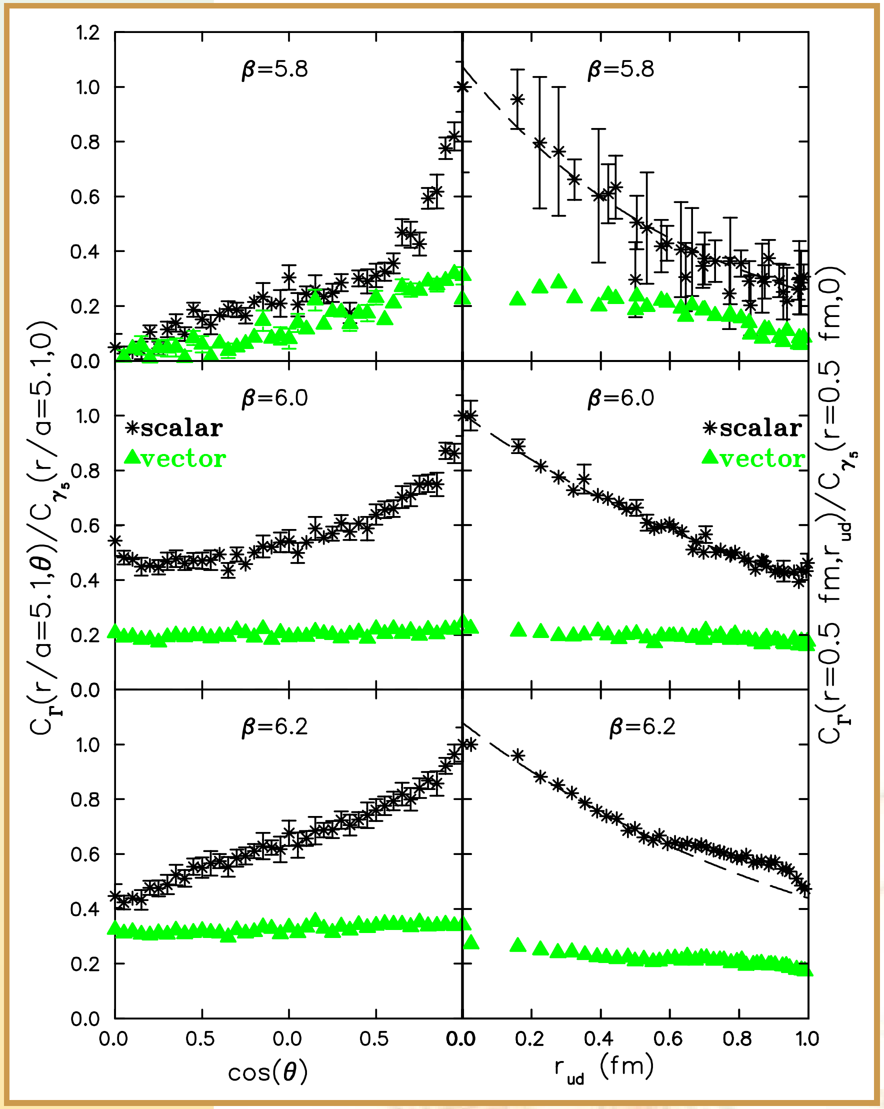
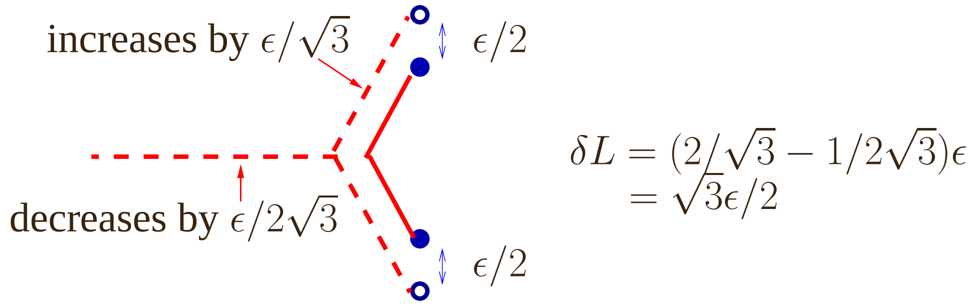
1^+:	$\Gamma = \gamma_i$	diquark size:	$r_0(r)$

diquarks: evidence in lattice QCD





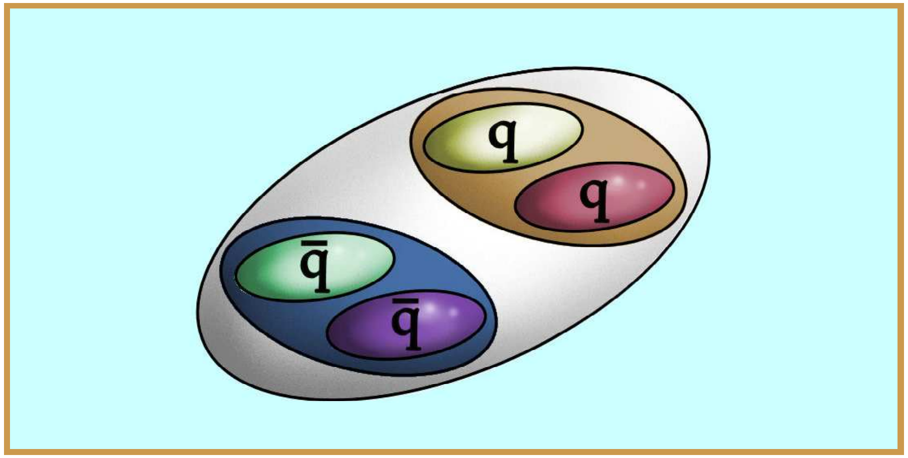
$$\kappa = \frac{K_{[qq][\bar{q}\bar{q}]}}{K_{q\bar{q}}} = \sqrt{3}/2,$$

$K_{[qq][\bar{q}\bar{q}]}$ $(K_{q\bar{q}})$ being the string tension of the tetraquark (meson).

tetraquark vs. hadronic molecule

tetraquark vs. hadronic molecule

- A tetraquark is a strongly bound QCD object consisting of colored constituents, the diquarks and antidiquarks:



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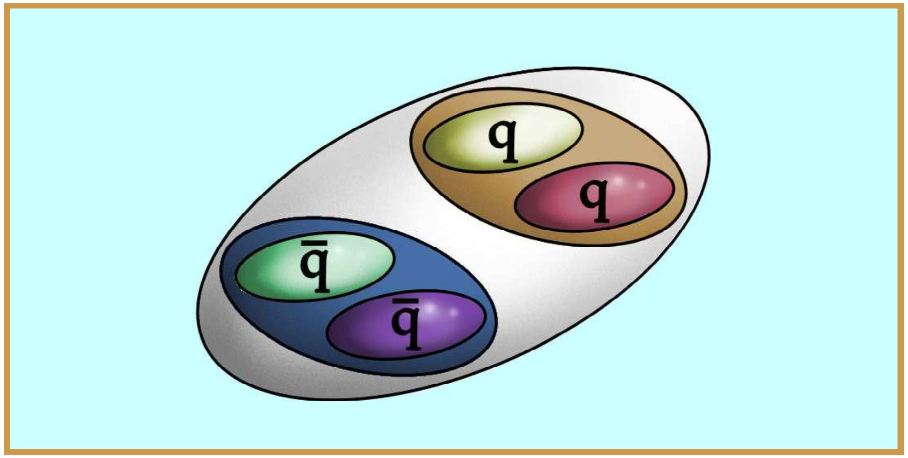
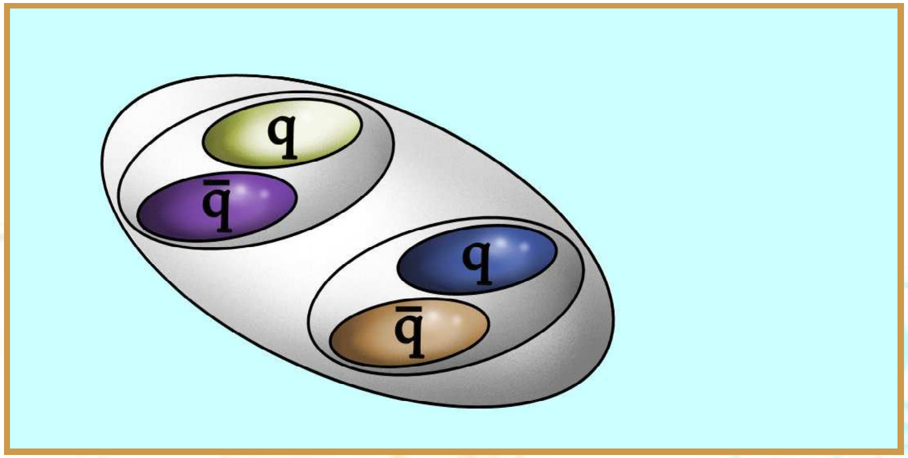


- In contrast to a hadronic molecule, which is bound by the exchange of pions :



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^{--}	$\phi f_0(980)$	e^+e^- (ISR) $J/\psi \to \eta Y_s(2175)$	BaBar, BESII
$X(3872)$	3871.4 ± 0.6	< 2.3	1^{++}	$\pi^+\pi^- J/\psi$, $\gamma J/\psi$,$D\bar{D}^*$	$B \to KX(3872)$, $p\bar{p}$	BaBar CDF, D0,
$X(3915)$	3914 ± 4	28^{+12}_{-14}	$0/2^{++}$	$\omega J/\psi$	$\gamma\gamma \to X(3915)$	
$Z(3930)$	3929 ± 5	29 ± 10	2^{++}	$D\bar{D}$	$\gamma\gamma \to Z(3940)$	
$X(3940)$	3942 ± 9	37 ± 17	$0^{?+}$	$D\bar{D}^*$ (not $D\bar{D}$ or $\omega J/\psi$)	$e^+e^- \to J/\psi X(3940)$	
$Y(3940)$	3943 ± 17	87 ± 34	$?^{?+}$	$\omega J/\psi$ (not $D\bar{D}^*$)	$B \to KY(3940)$	BaBar
$Y(4008)$	4008^{+82}_{-49}	226^{+97}_{-80}	1^{--}	$\pi^+\pi^- J/\psi$	e^+e^-(ISR)	
$X(4160)$	4156 ± 29	139^{+113}_{-65}	$0^{?+}$	$D^*\bar{D}^*$ (not $D\bar{D}$)	$e^+e^- \to J/\psi X(4160)$	
$Y(4260)$	4264 ± 12	83 ± 22	1^{--}	$\pi^+\pi^- J/\psi$	e^+e^-(ISR)	BaBar, CLEO
$Y(4350)$	4361 ± 13	74 ± 18	1^{--}	$\pi^+\pi^- \psi'$	e^+e^-(ISR)	BaBar
$X(4630)$	4634^{+9}_{-11}	92^{+41}_{-32}	1^{--}	$\Lambda_c^+\Lambda_c^-$	e^+e^-(ISR)	
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$Z(4050)$	4051^{+24}_{-23}	82^{+51}_{-29}	?	$\pi^\pm \chi_{c1}$	$B \to KZ^\pm(4050)$	
$Z(4250)$	4248^{+185}_{-45}	177^{+320}_{-72}	?	$\pi^\pm \chi_{c1}$	$B \to KZ^\pm(4250)$	
$Z(4430)$	4433 ± 5	45^{+35}_{-18}	?	$\pi^\pm \psi'$	$B \to KZ^\pm(4430)$	
$Y_b(10890)$	$10,890 \pm 3$	55 ± 9	1^{--}	$\pi^+\pi^- \Upsilon(1,2,3S)$	$e^+e^- \to Y_b$	

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

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^{--}	$\phi f_0(980)$	e^+e^- (ISR) $J/\psi \to \eta Y_s(2175)$	BaBar, BESII
$X(3872)$	3871.4 ± 0.6	< 2.3	1^{++}	$\pi^+\pi^- J/\psi$, $\gamma J/\psi$,$D\bar{D}^*$	$B \to KX(3872)$, $p\bar{p}$	BaBar CDF, D0,
$X(3915)$	3914 ± 4	28^{+12}_{-14}	$0/2^{++}$	$\omega J/\psi$	$\gamma\gamma \to X(3915)$	
$Z(3930)$	3929 ± 5	29 ± 10	2^{++}	$D\bar{D}$	$\gamma\gamma \to Z(3940)$	
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our (hidden bottom) tetraquark candidate

calculating tetraquark masses

- QCD Sum Rules [Wang, Eur. Phys. J. C **67**, 411 (2010)]
- Relativistic Quasipotential model [Ebert et al., Mod. Phys. Lett. A **24**, 567 (2009)]
- Constituent quark model [Drenska et al., arXiv:1006.2741 [hep-ph]]

- Estimates presented here are based on [Ali et al., Phys. Lett. B **684**, 28 (2010)]

tetraquarks as mathematical objects

- interpolating oparators of the diquarks:

”good”: 0^+ $\mathcal{Q}_{i\alpha} = \epsilon_{\alpha\beta\gamma}(\bar{b}_c^\beta \gamma_5 q_i^\gamma - \bar{q}_{i_c}^\beta \gamma_5 b^\gamma)$

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states

Tetraquark states are characterized by the spin $s_{\mathcal{Q}}$ of the diquark coupling to total angular momentum J:

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$$\begin{aligned}
\left|0_{\mathcal{Q}}, 0_{\bar{\mathcal{Q}}};\ 0_J\right\rangle &= \Gamma^0 \otimes \Gamma^0, \\
\left|1_{\mathcal{Q}}, 1_{\bar{\mathcal{Q}}};\ 0_J\right\rangle &= \frac{1}{\sqrt{3}}\Gamma^i \otimes \Gamma_i, \\
\left|0_{\mathcal{Q}}, 1_{\bar{\mathcal{Q}}};\ 1_J\right\rangle &= \Gamma^0 \otimes \Gamma^i, \\
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\end{aligned}$$

hamiltonian

The previously defined states need to diagonalize the hamiltonian:

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

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with

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qq **spin coupling**

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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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example 1^{++}

- giving the 1^{++}, $[\bar{b}\bar{q}][bq]$ state as example:

$$|1^{++}\rangle \;=\; \frac{1}{\sqrt{2}}\left(|0_{\mathcal{Q}}, 1_{\bar{\mathcal{Q}}};\; 1_J\rangle + |1_{\mathcal{Q}}, 0_{\bar{\mathcal{Q}}};\; 1_J\rangle\right)$$

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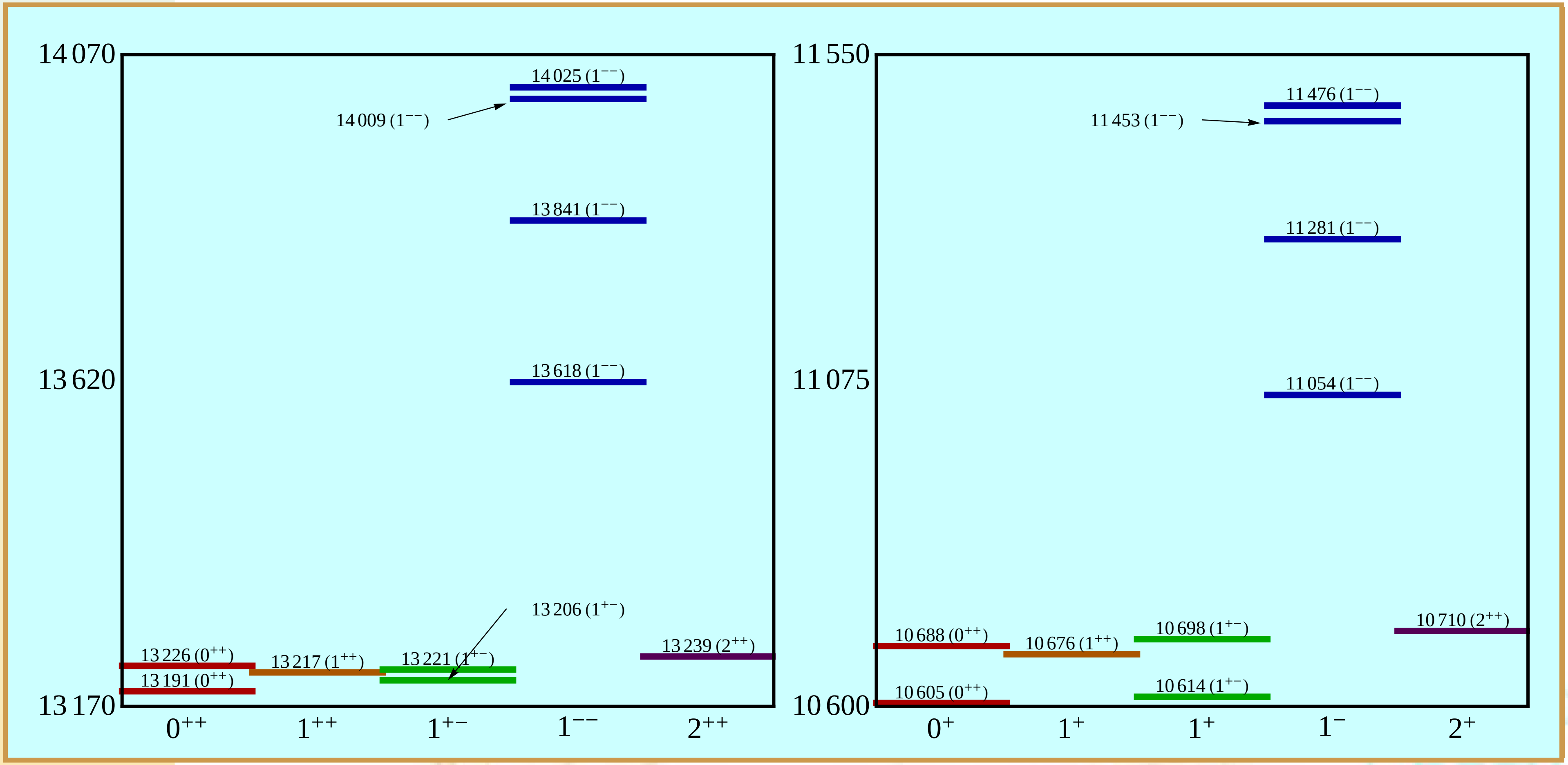
$m_{[bq]}$	$(\mathcal{K}_{bq})_{\bar{3}}$	$\mathcal{K}_{b\bar{q}}$	$\mathcal{K}_{q\bar{q}}$	$\mathcal{K}_{b\bar{b}}$
5250 MeV	6 MeV	6 MeV	80 MeV	9 MeV

tetraquark mass spectrum



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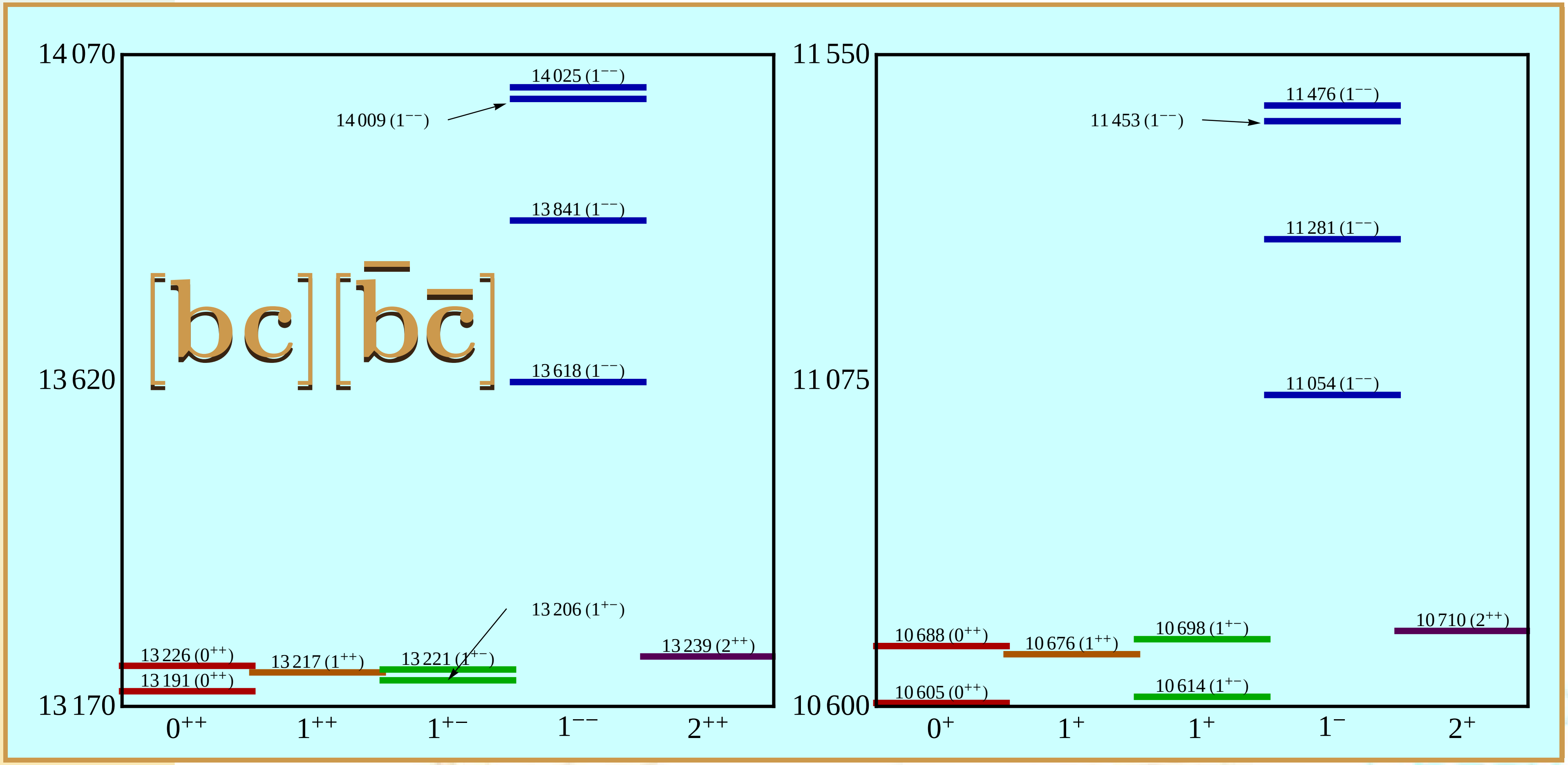

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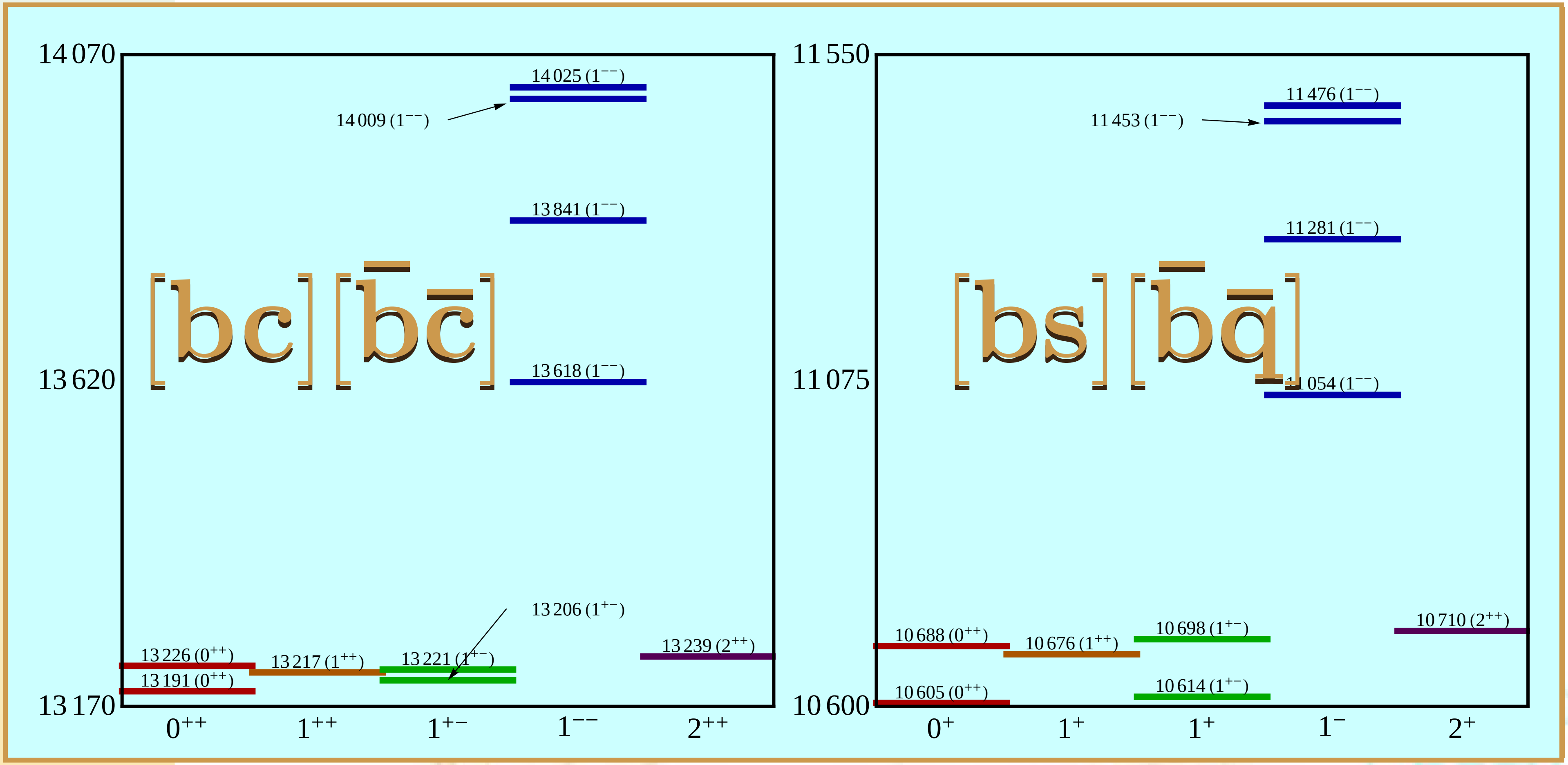

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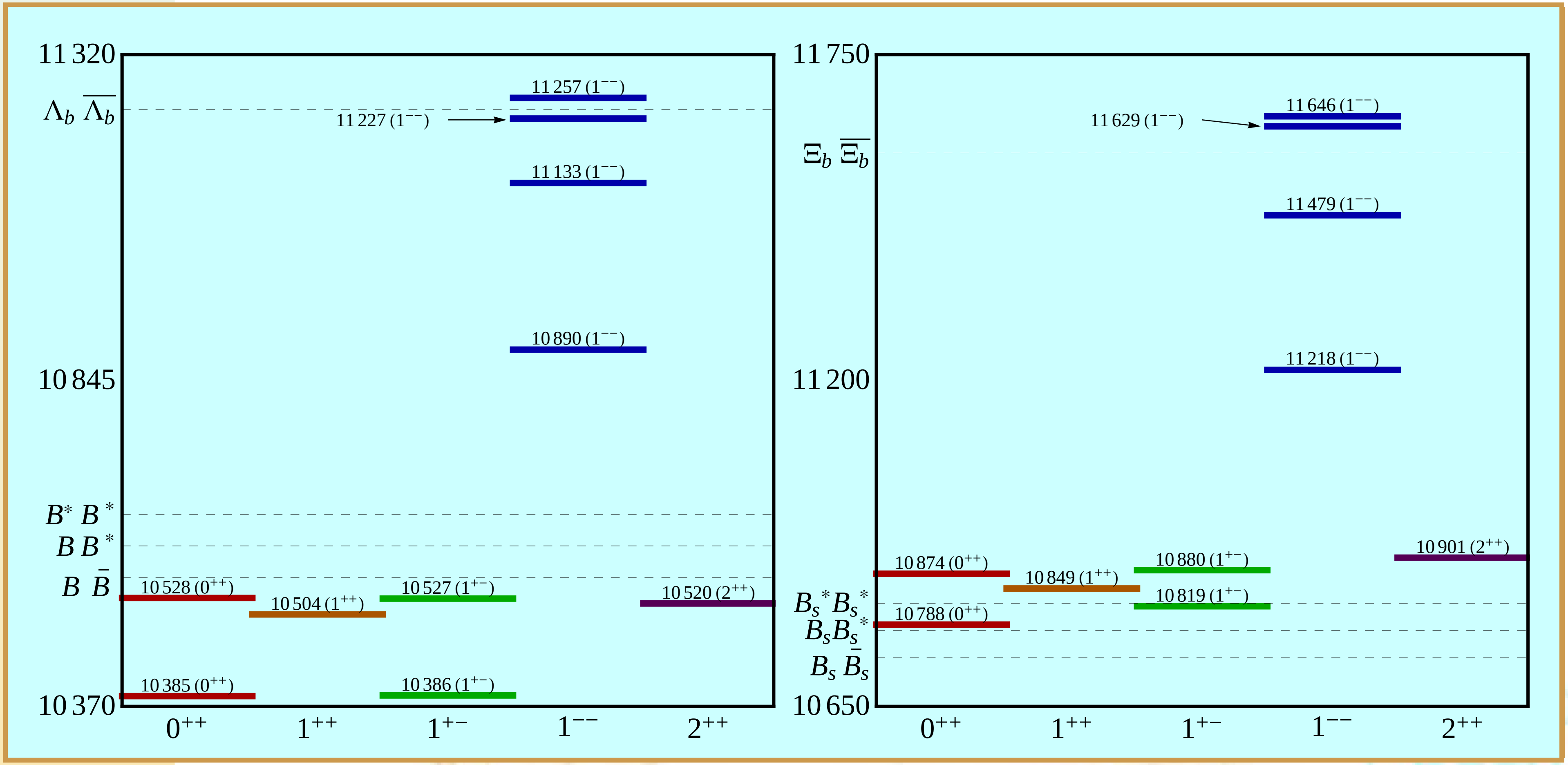

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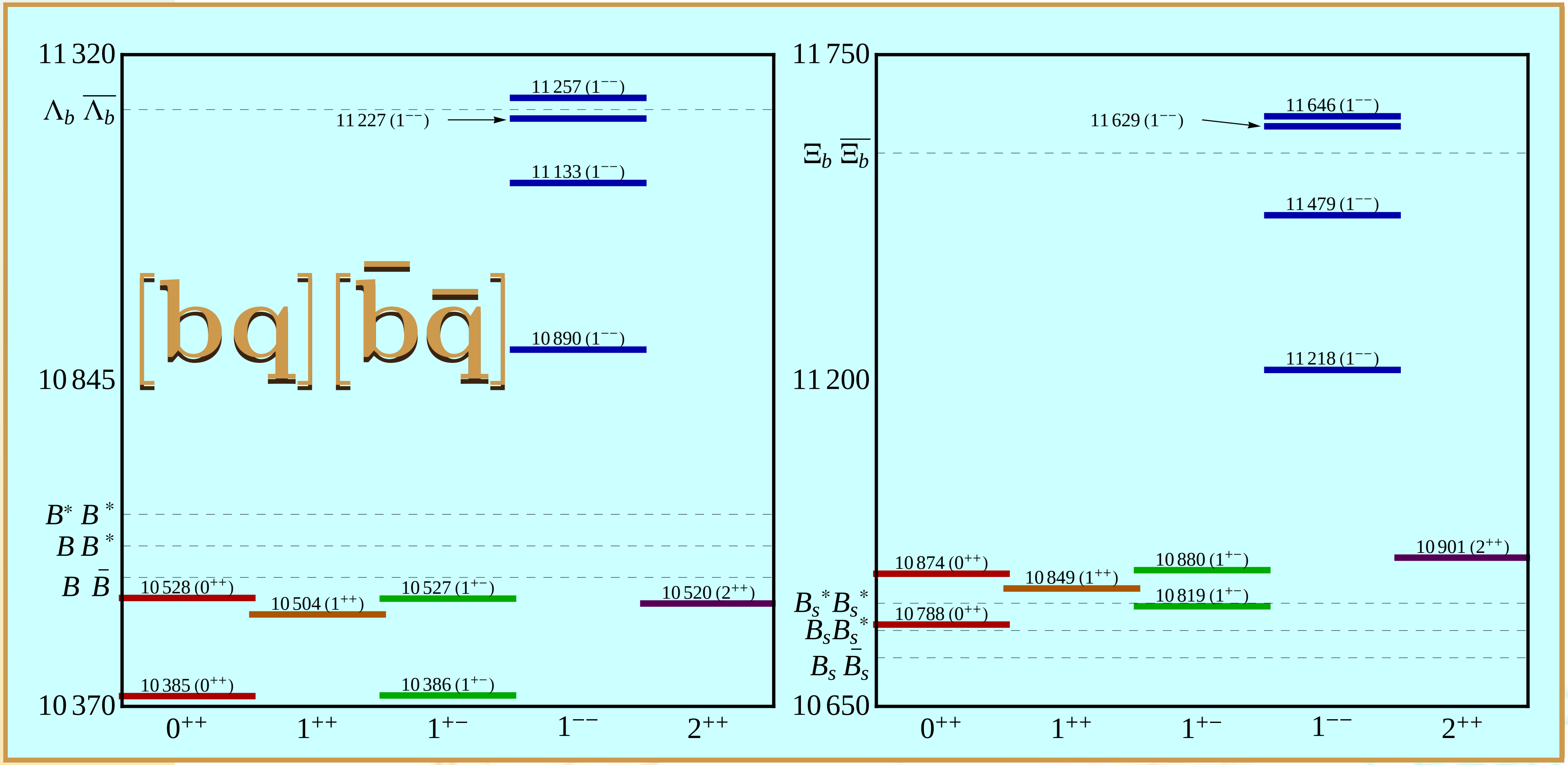

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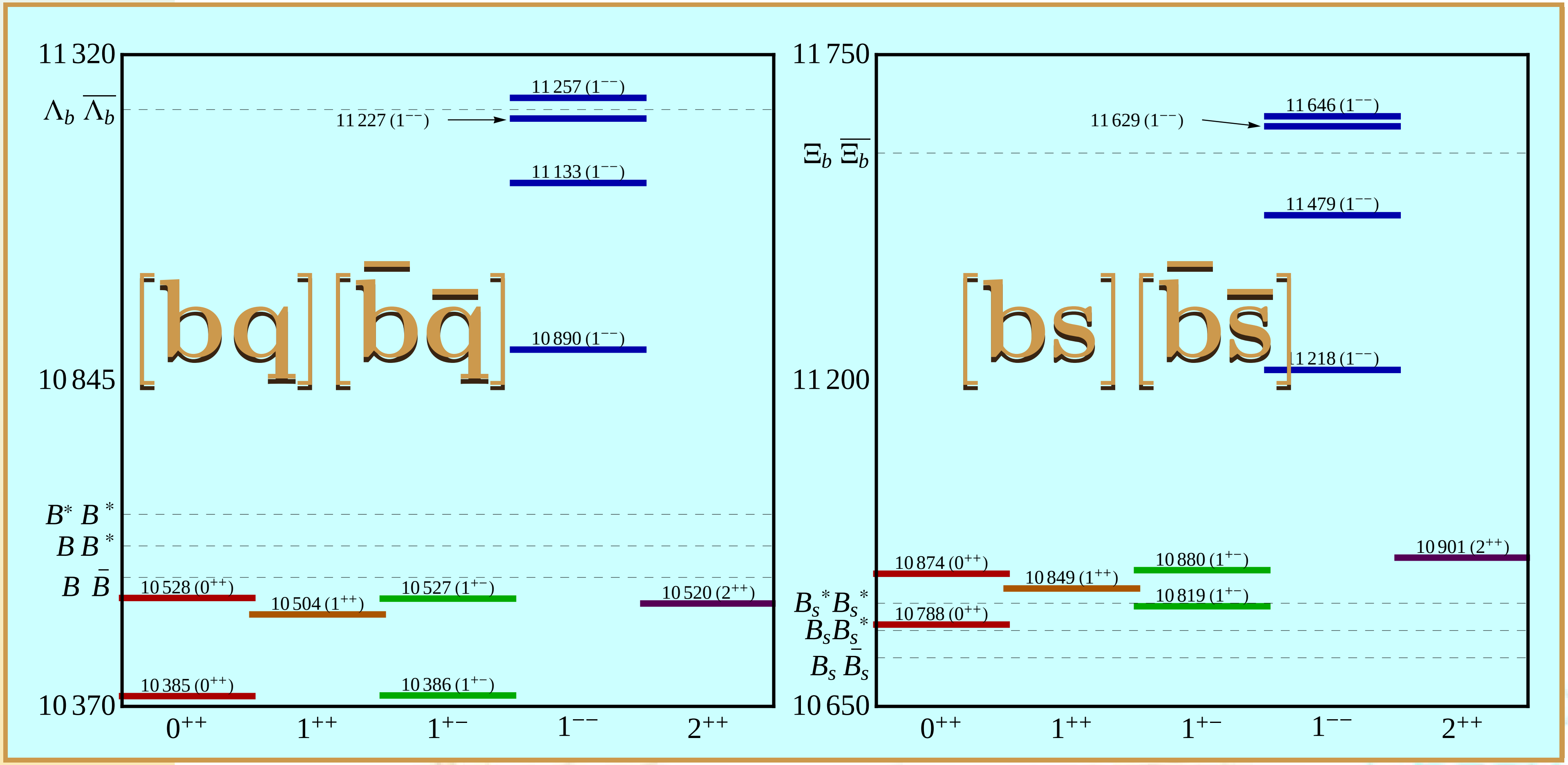

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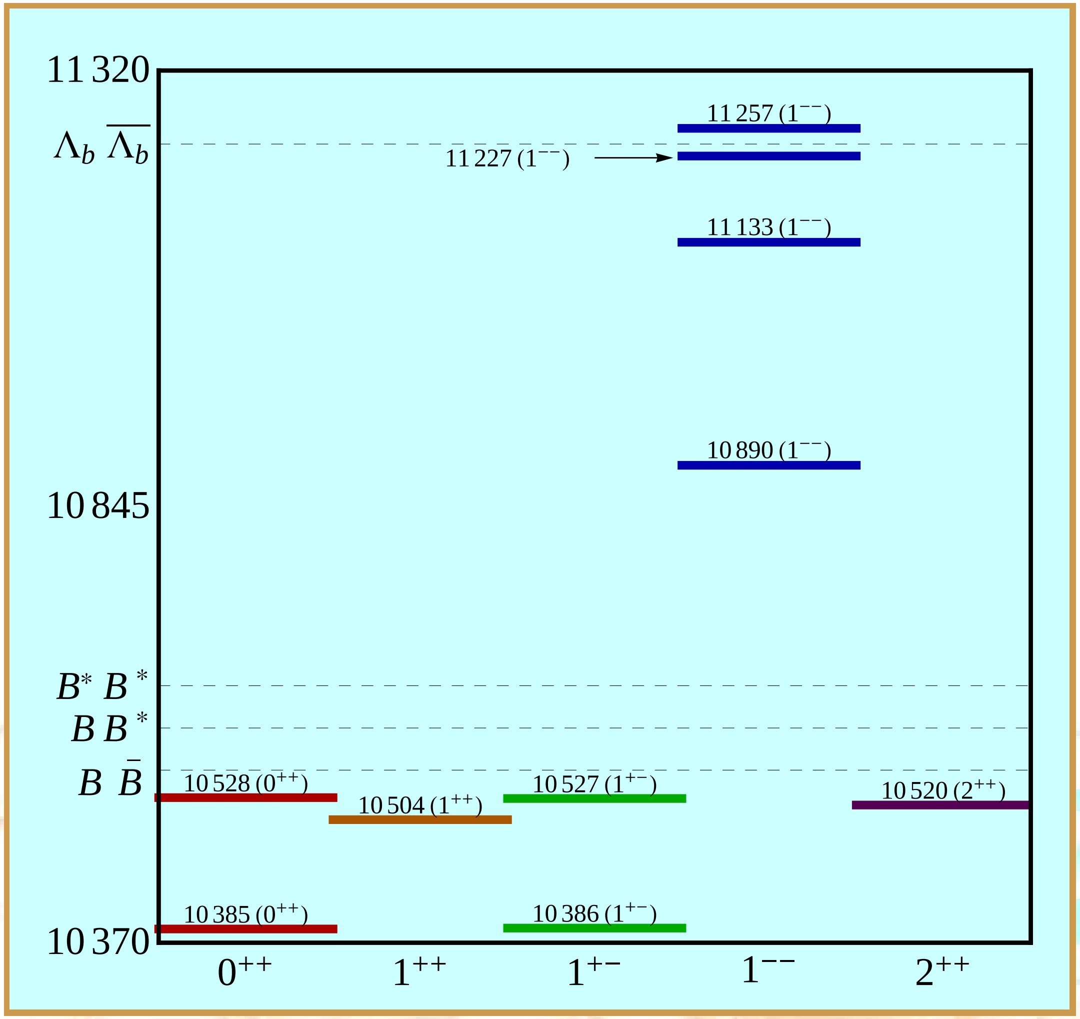
- they will give rise to 80 mass eigenstates if isospin breaking is taken into account
- most of them are hard to find due to typically large widths and mixing with the ordinary hadrons

possible observable states

which states are accessible in todays experiments?

possible observable states

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



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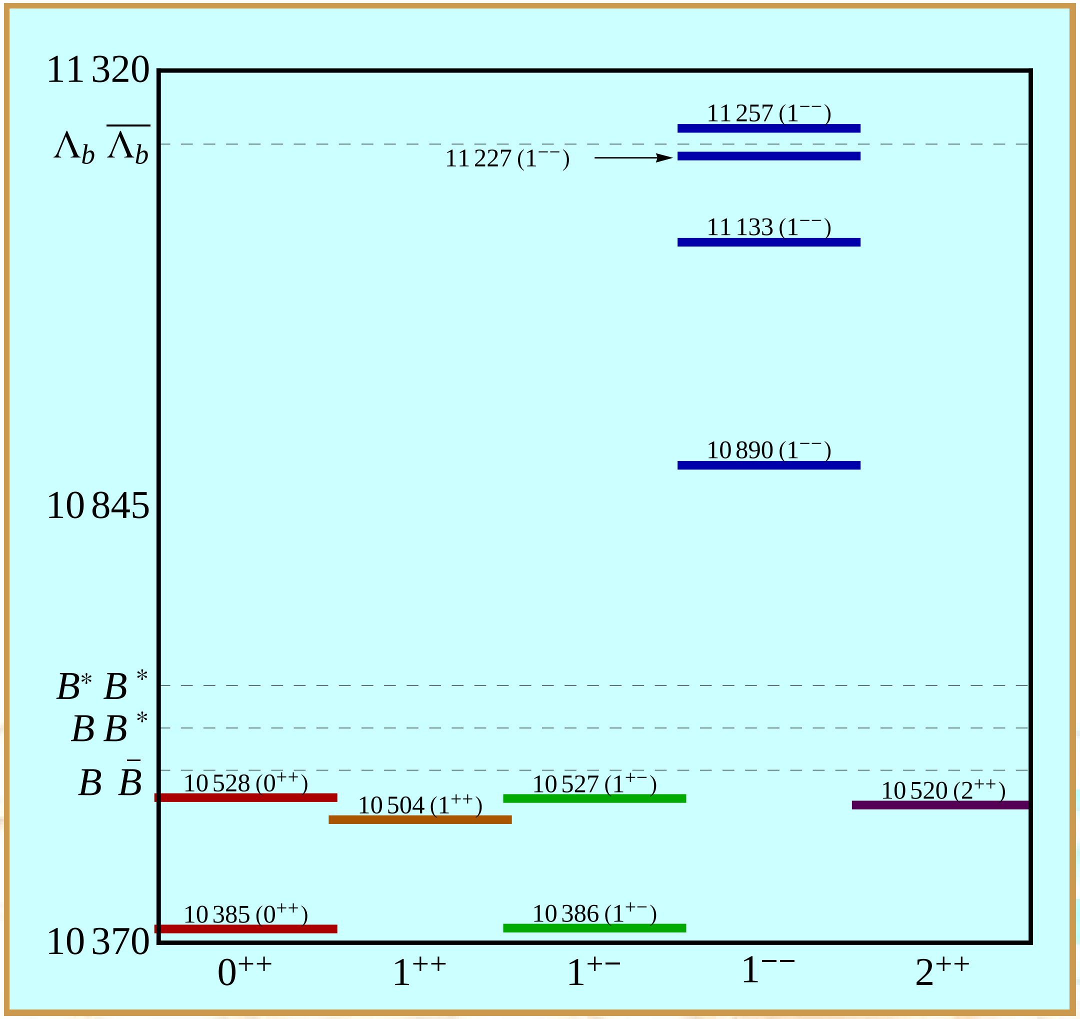

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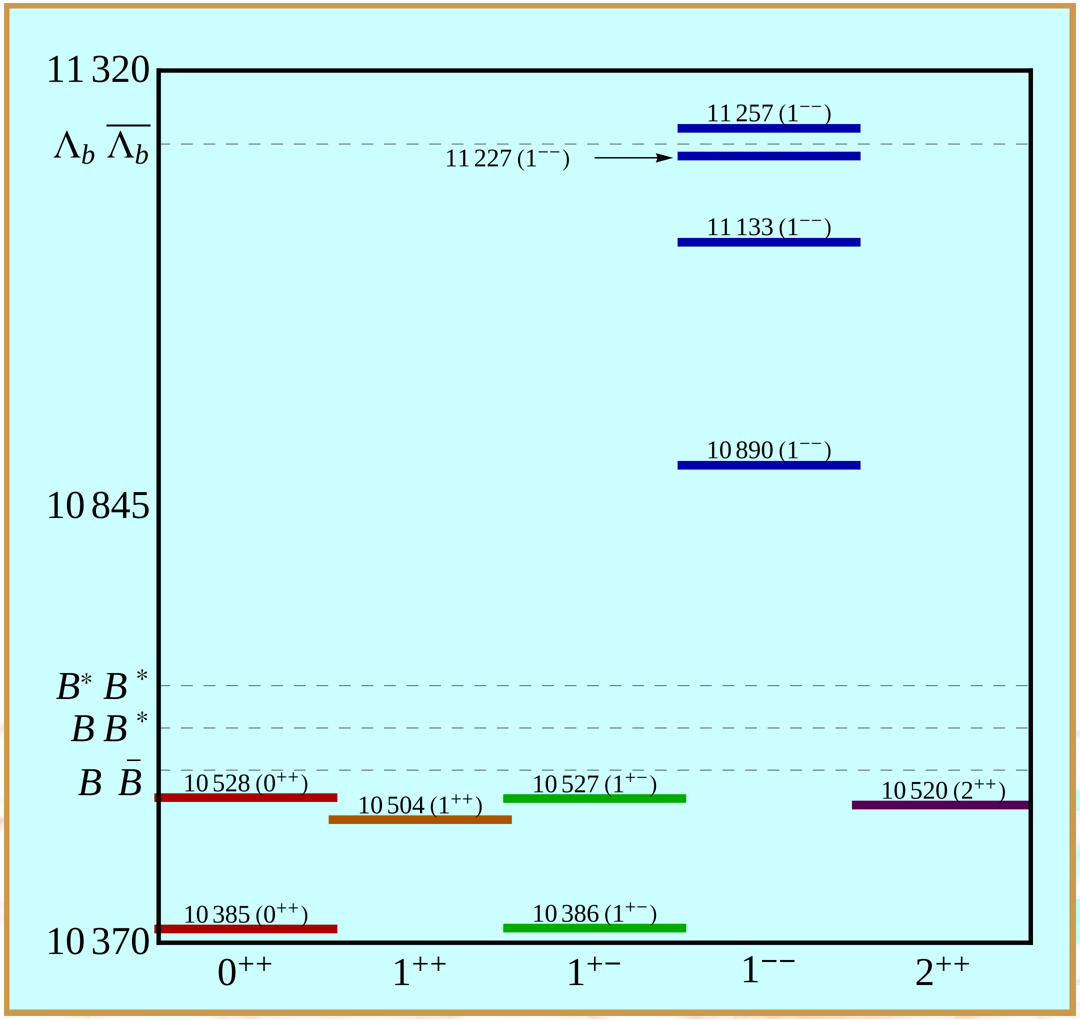
- Two of them are in the range of the BaBar and Belle center of mass energies.



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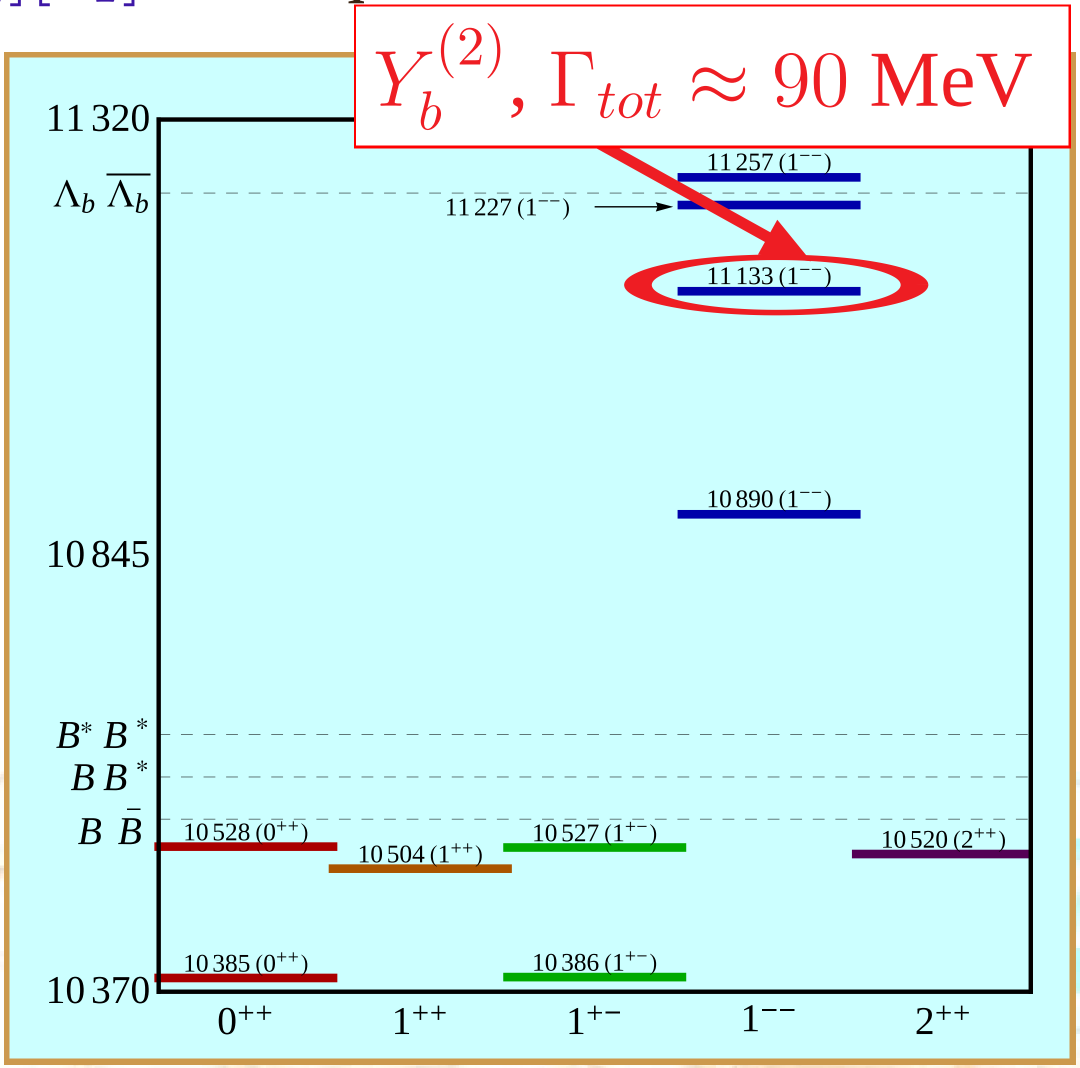

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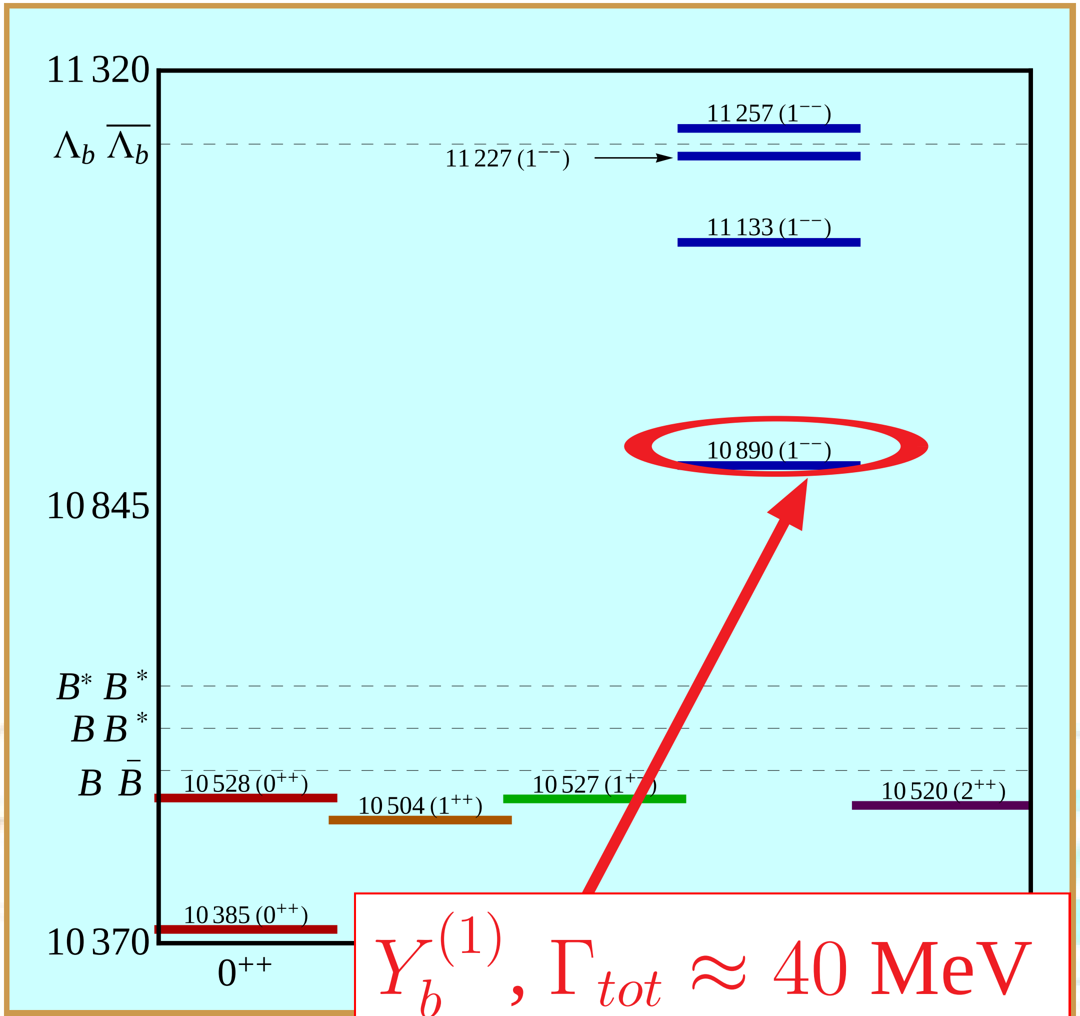

$Y_b^{(1)}$, $\Gamma_{tot} \approx 40$ MeV

isospin breaking

Y_b mass eigenstates

$$Y_{[b,l]} = \cos\theta \, Y_{[bu]} + \sin\theta \, Y_{[bd]},$$
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and charge

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- 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] :

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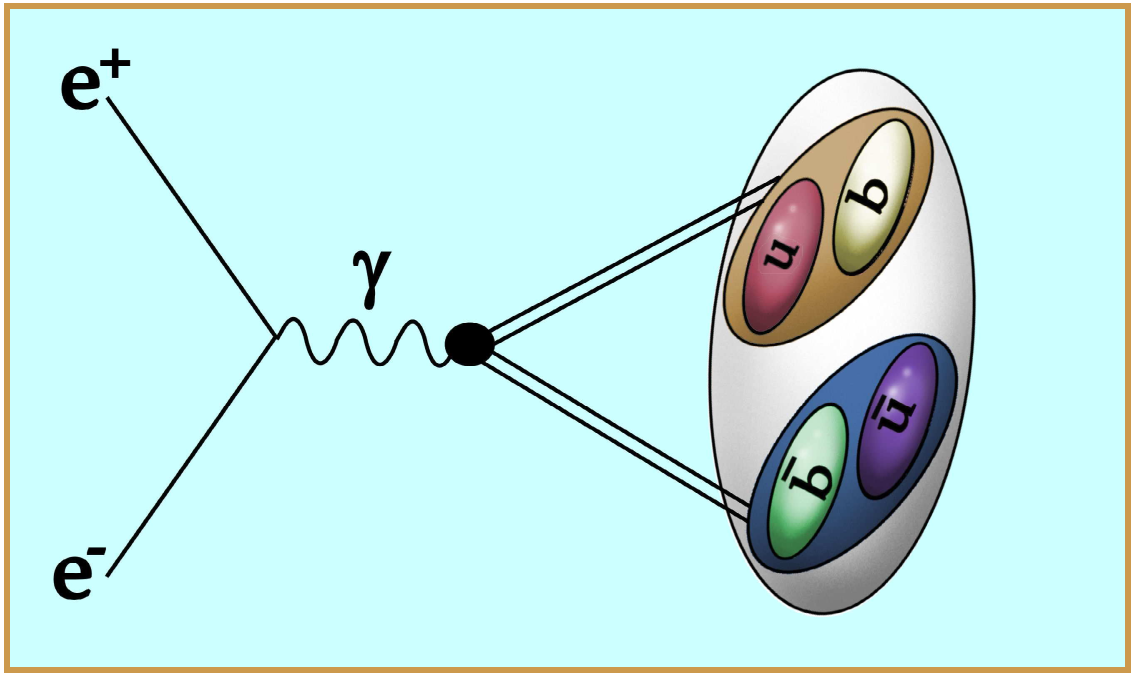

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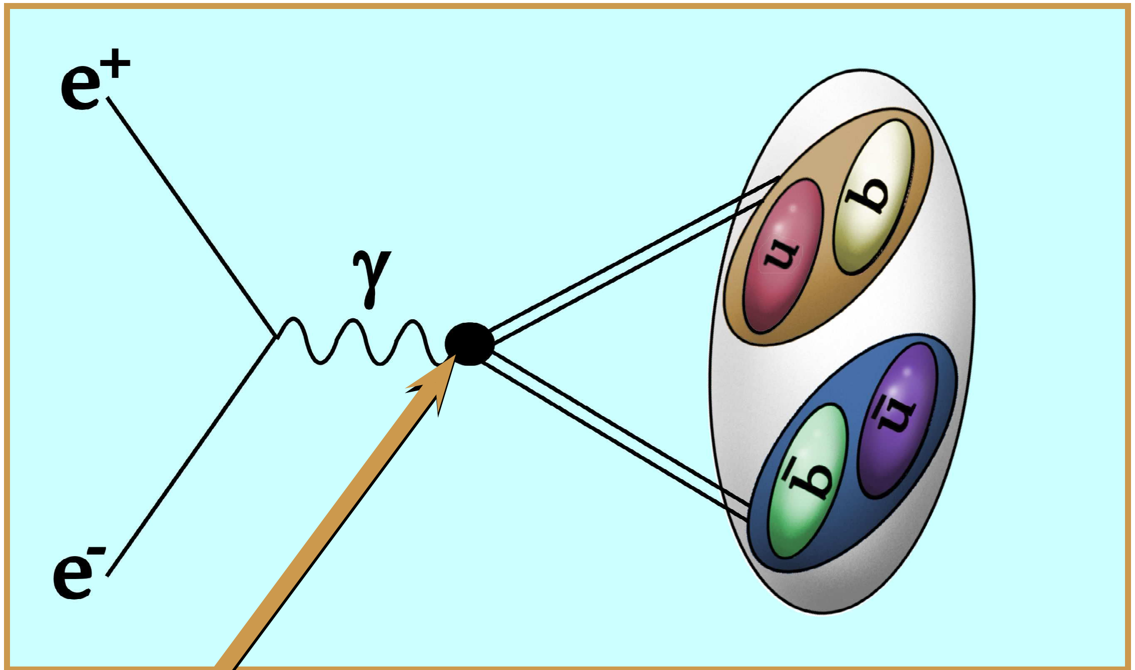

diquark charge

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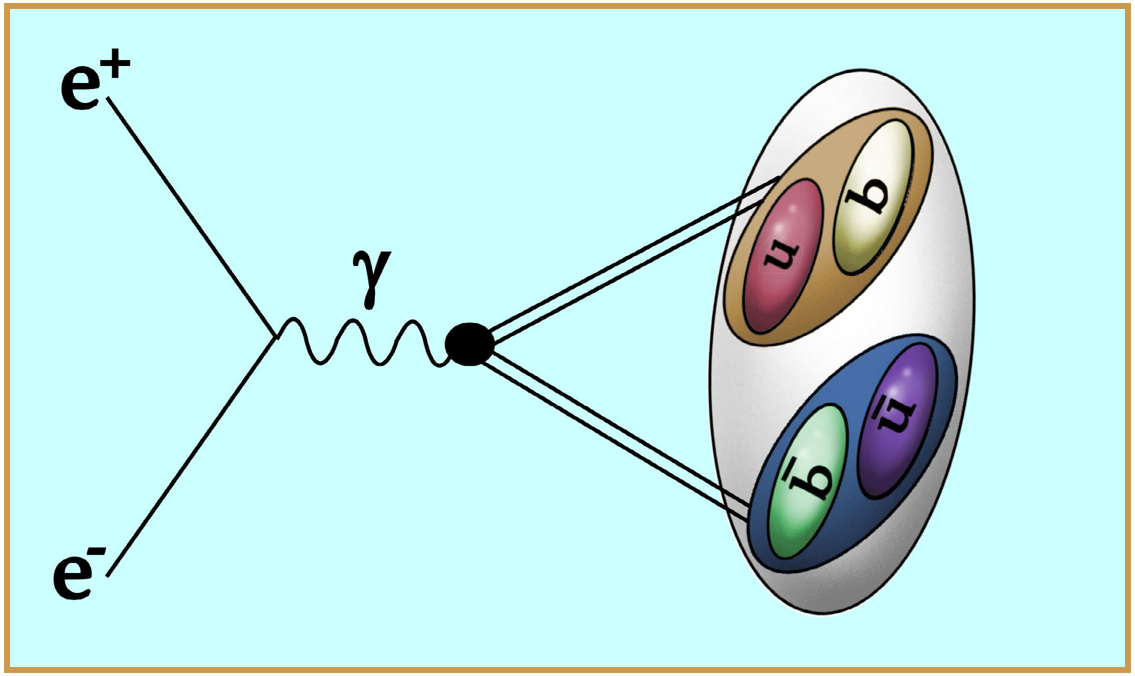

hadronic size parameter

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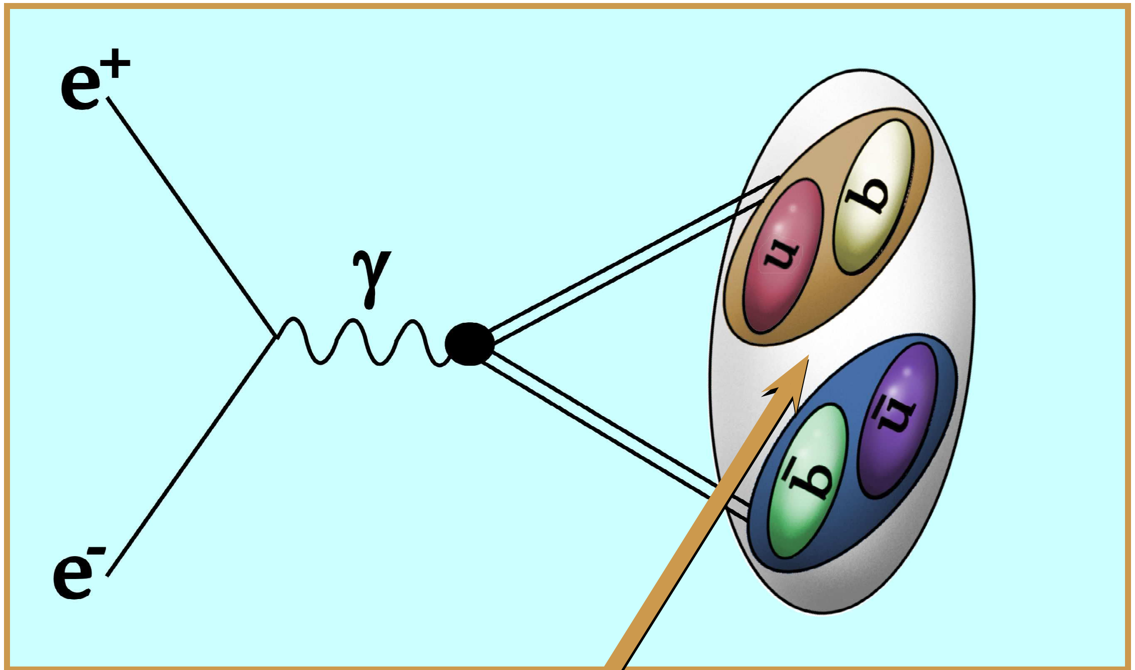

radial tetraquark wave function at origin

$$\Gamma_{ee}(Y_{[b,l/h]}) = \frac{24\alpha^2 Q^2_{[b,l/h]}}{M^4_{Y_{[b,l/h]}}}\,\kappa^2 \left|R^{(\ell)}_{11}(0)\right|^2$$

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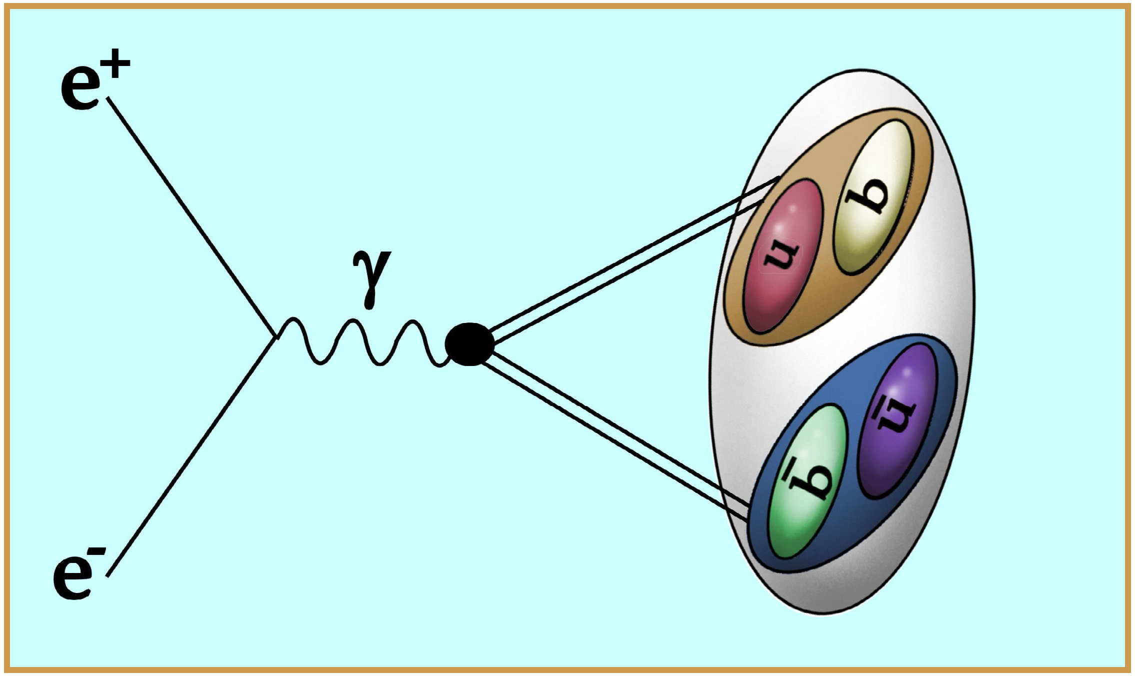


$$\Gamma_{ee}(Y_{[b,l/h]}) = \frac{24\alpha^2 Q^2_{[b,l/h]}}{M^4_{Y_{[b,l/h]}}} \kappa^2 \left| R^{(1)}_{11}(0) \right|^2$$

- 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

$B\bar{B}$

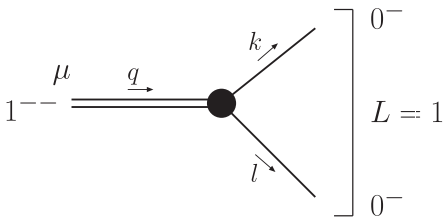
$B\bar{B}^*$

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

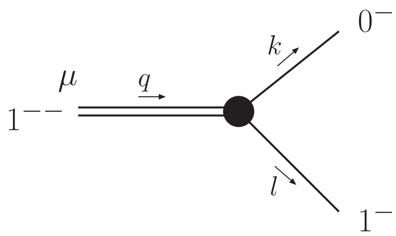
Y_b decay

channel | diagram

$B\bar{B}$



$B\bar{B}^*$



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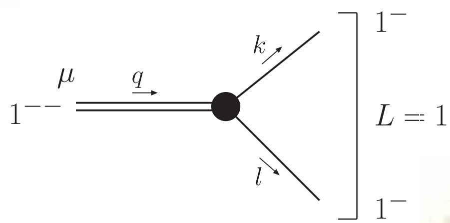
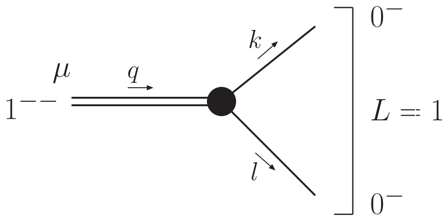
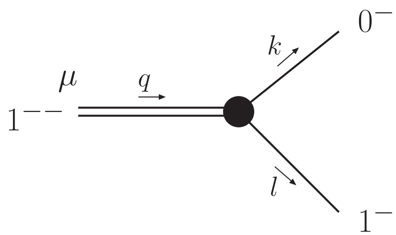
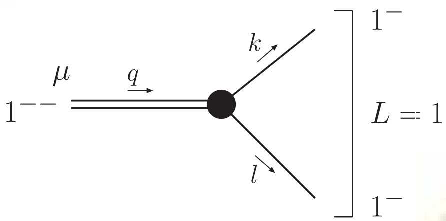
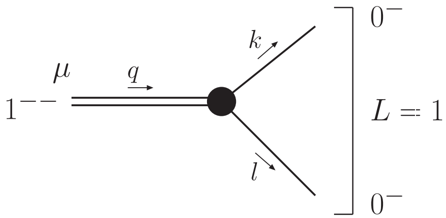
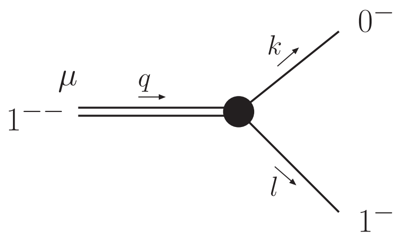
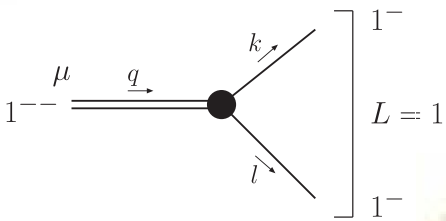


Y_b decay

channel	diagram	vertex
$B\bar{B}$		$\widehat{=} F(k^\mu - l^\mu)$
$B\bar{B}^*$		$\widehat{=} \frac{F}{M}\epsilon^{\mu\nu\rho\sigma}k_\rho l_\sigma$
$B^*\bar{B}^*$		$\widehat{=} F(g^{\mu\rho}(q+l)^\nu - g^{\mu\nu}(k+q)^\rho + g^{\rho\nu}(q+k)^\mu)$

Y_b decay

channel	diagram	vertex	width
$B\bar{B}$		$\widehat{=} F(k^\mu - l^\mu)$	$\Rightarrow \Gamma = \frac{F^2 \lvert\vec{k}\rvert^3}{2M^2\pi}$
$B\bar{B}^*$		$\widehat{=} \frac{F}{M}\epsilon^{\mu\nu\rho\sigma}k_\rho l_\sigma$	$\Rightarrow \Gamma = \frac{F^2 \lvert\vec{k}\rvert^3}{4M^2\pi}$
$B^*\bar{B}^*$		$\widehat{=} F(g^{\mu\rho}(q+l)^\nu - g^{\mu\nu}(k+q)^\rho + g^{\rho\nu}(q+k)^\mu)$	$\Rightarrow \Gamma = \frac{F^2\lvert\vec{k}\rvert^3(48\lvert\vec{k}\rvert^4 - 104M^2\lvert\vec{k}\rvert^2 + 27M^4)}{2\pi(M^3 - 4\lvert\vec{k}\rvert^2 M)^2}$

Y_b decay

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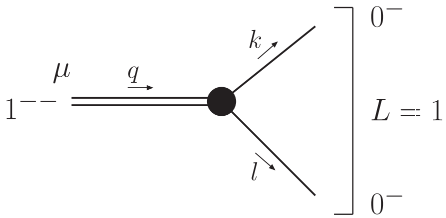
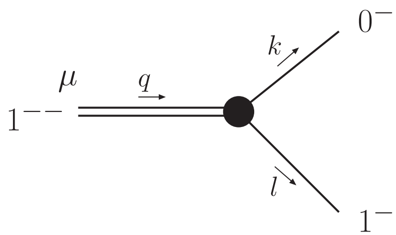
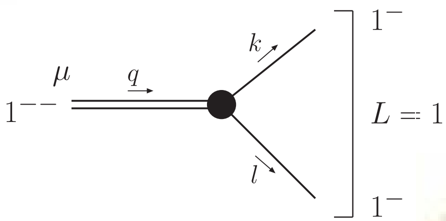
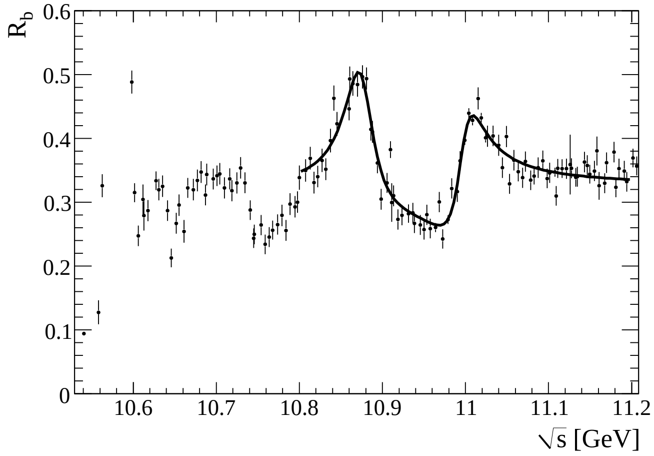
$B\bar{B}$		$\widehat{=} F(k^\mu - l^\mu)$	$\Rightarrow \Gamma = \frac{F^2 \lvert\vec{k}\rvert^3}{2M^2\pi}$
$B\bar{B}^*$		$\widehat{=} \frac{F}{M}\epsilon^{\mu\nu\rho\sigma}k_\rho l_\sigma$	$\Rightarrow \Gamma = \frac{F^2 \lvert\vec{k}\rvert^3}{4M^2\pi}$
$B^*\bar{B}^*$		$\widehat{=} F(g^{\mu\rho}(q+l)^\nu - g^{\mu\nu}(k+q)^\rho + g^{\rho\nu}(q+k)^\mu)$	$\Rightarrow \Gamma = \frac{F^2\lvert\vec{k}\rvert^3(48\lvert\vec{k}\rvert^4 - 104M^2\lvert\vec{k}\rvert^2 + 27M^4)}{2\pi(M^3 - 4\lvert\vec{k}\rvert^2 M)^2}$

- The couplings F are estimated from the measured widths of the $\Upsilon(5S)$ decays ($\Gamma_{tot}(Y_b^{(1)}) \approx 40$ MeV, $\Gamma_{tot}(Y_b^{(2)}) \approx 90$ MeV,...)

fit to BaBar data

BaBar fit

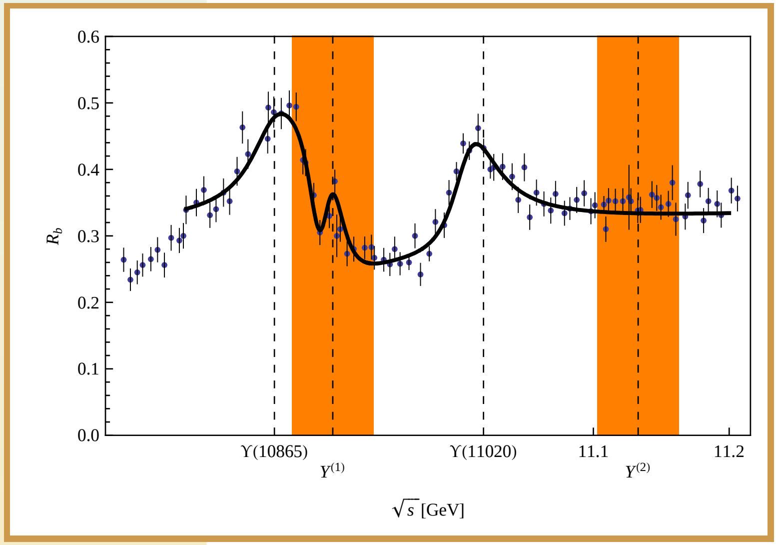


$$\sigma(e^+e^- \to b\bar{b}) =$$
$$|A_{nr}|^2 + |A_r + A_{10860}e^{i\phi_{10860}}$$
$$\times BW(M_{10860}, \Gamma_{10860}) + A_{11020}e^{i\phi_{11020}}$$
$$\times BW(M_{11020}, \Gamma_{11020})|^2$$

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

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

BaBar fit



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

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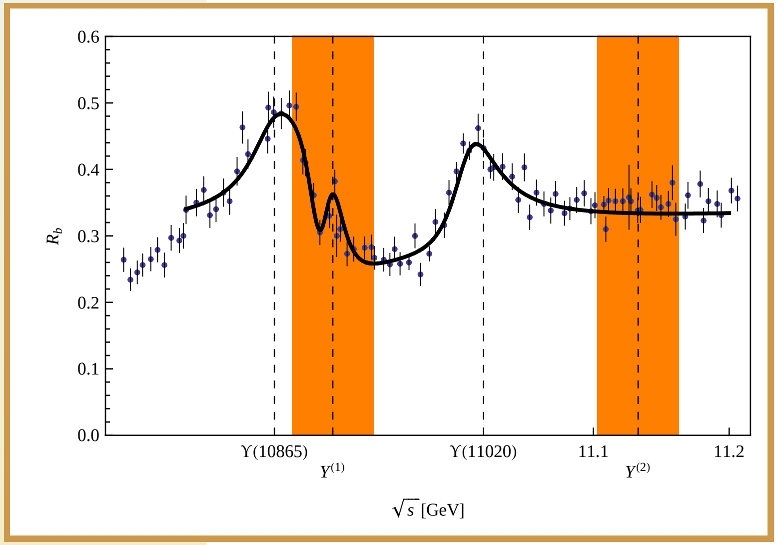

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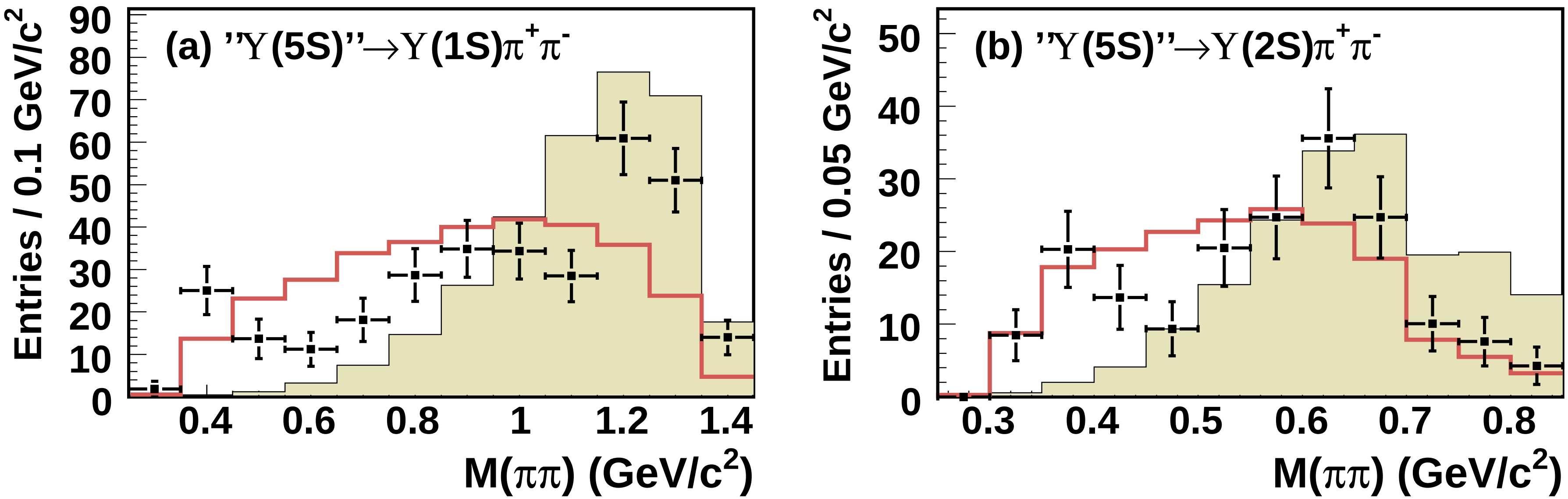
	M [MeV]	Γ [MeV]	φ [rad.]
$\Upsilon(5S)$	10864 ± 5	46 ± 8	1.3 ± 0.3
$\Upsilon(6S)$	11007 ± 0.3	40 ± 2	0.88 ± 0.06
$Y_{[b,l]}$	$10900 - \Delta M/2 \pm 2$	28 ± 2	1.3 ± 0.2
$Y_{[b,h]}$	$10900 + \Delta M/2 \pm 2$	28 ± 2	1.9 ± 0.2

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

Belle data, explanation and fitting

enigmatic Belle data



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

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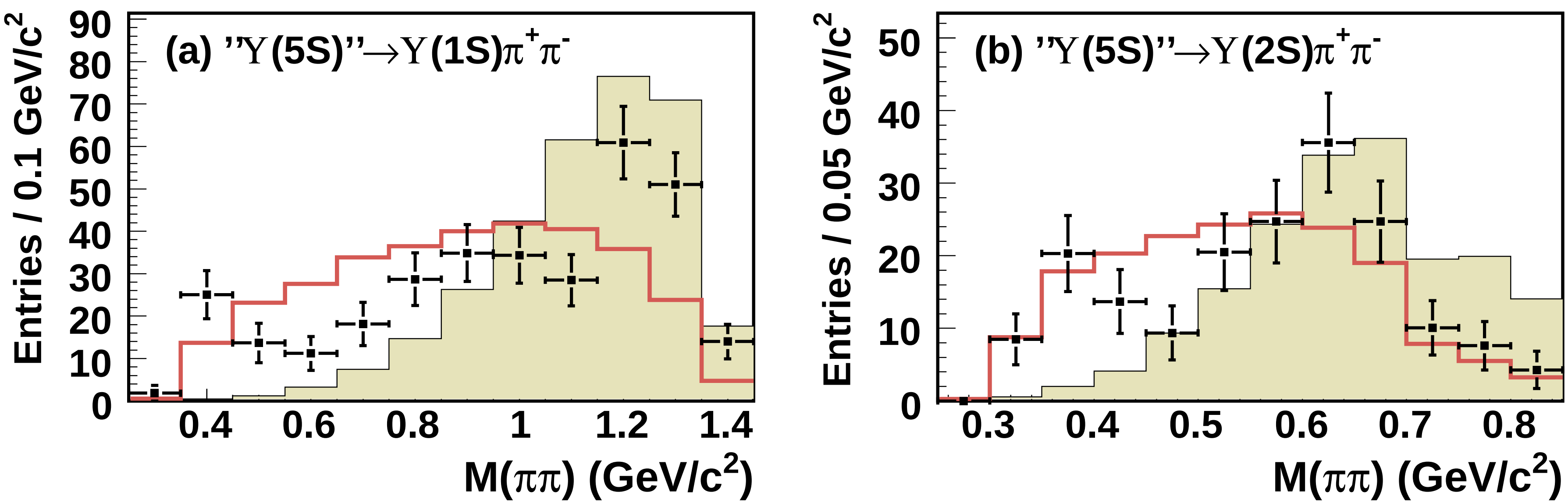

Phys. Rev. Lett. **100**, 112001 (2008)

reported partial decay width:

$$\Gamma(\text{"}\Upsilon(5S)\text{"} \to \Upsilon(1S)\pi^+\pi^-) = 0.59 \pm 0.04 \pm 0.09 \text{ MeV}$$
$$\Gamma(\text{"}\Upsilon(5S)\text{"} \to \Upsilon(2S)\pi^+\pi^-) = 0.85 \pm 0.07 \pm 0.16 \text{ MeV}$$

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differs by two orders of magnitude!

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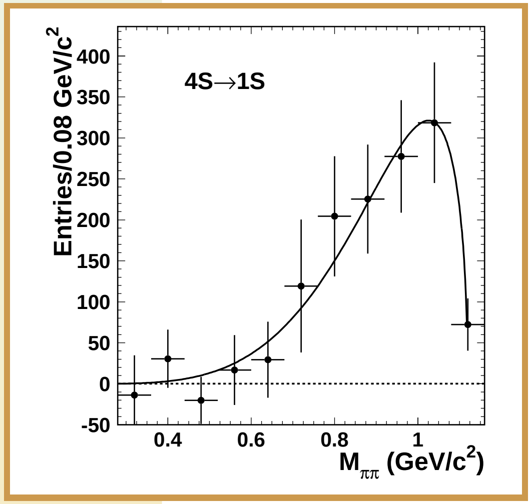

[Phys. Rev. D **79** (2009) 051103]

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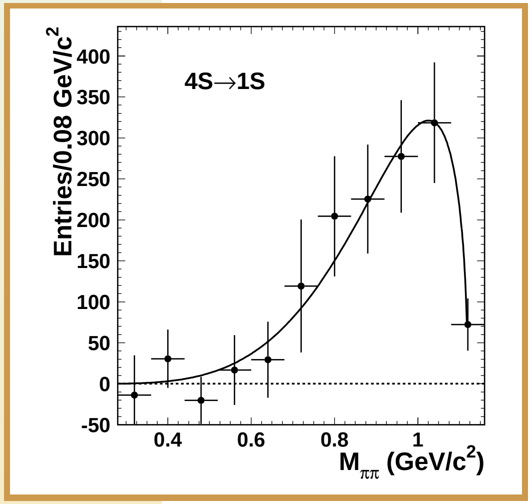

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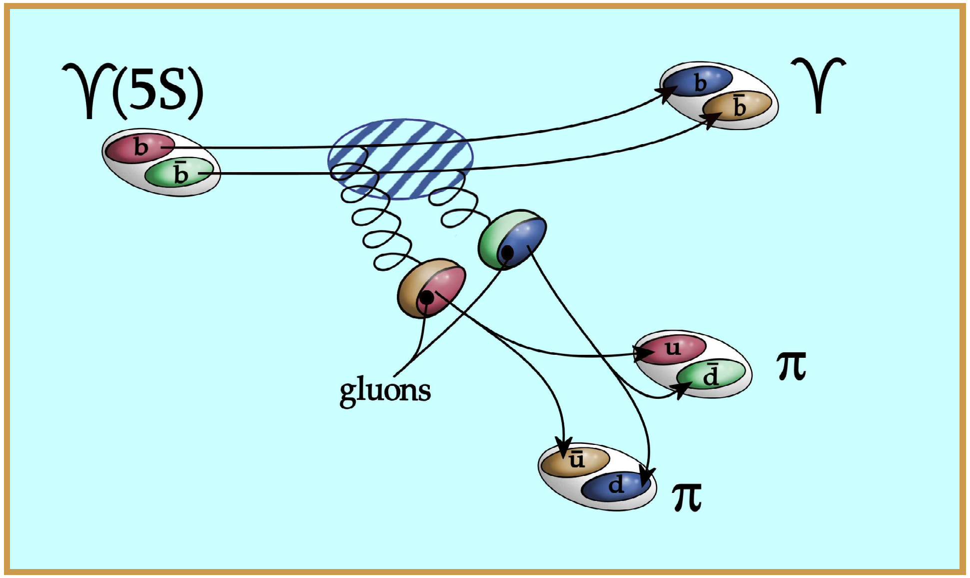

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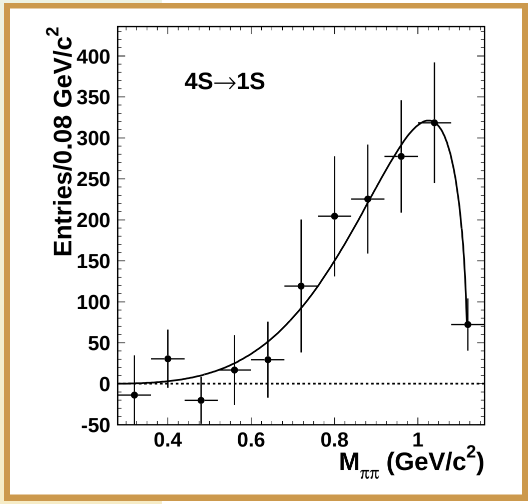

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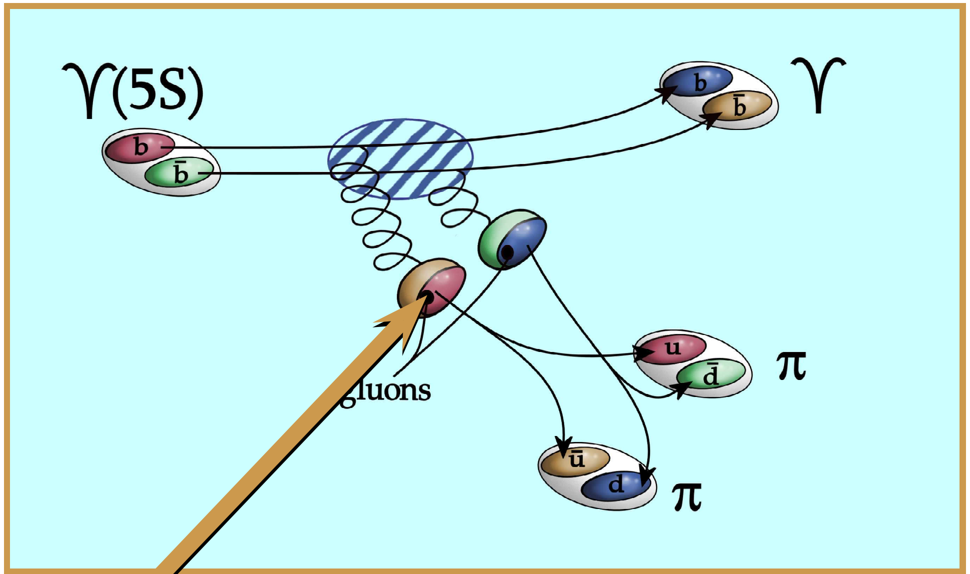

underlying process is

Zweig forbidden

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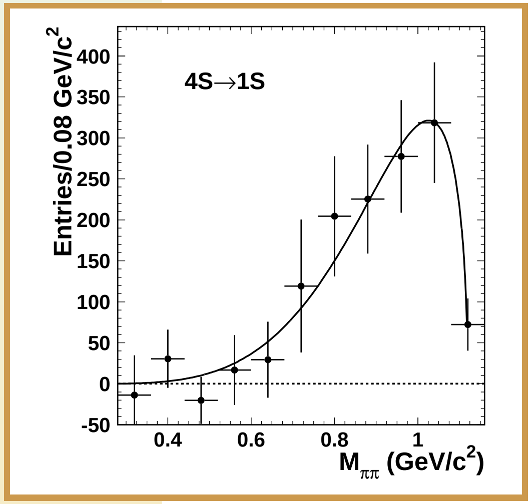

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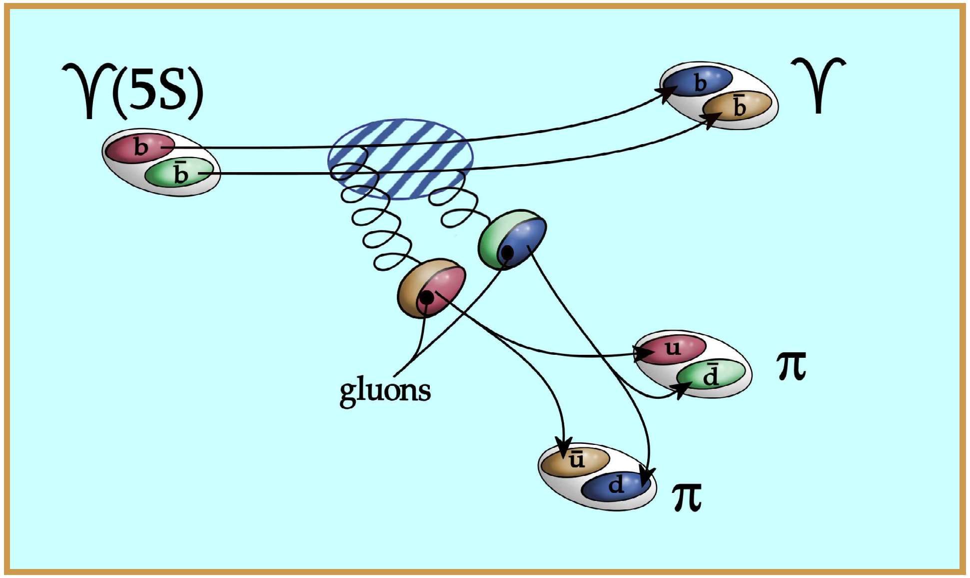

$$\mathcal{M}_{\mathbf{a}}^{\mu\nu} = g^{\mu\nu}\frac{F}{F_\pi^2}\Big[m_{\pi\pi}^2 - \beta(\Delta M)^2(1+\frac{2m_\pi^2}{m_{\pi\pi}^2}) + \frac{3}{2}\beta((\Delta M)^2 - m_{\pi\pi}^2)(1-\frac{4m_\pi^2}{m_{\pi\pi}^2})(cos^2\theta - \frac{1}{3})\Big]$$

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

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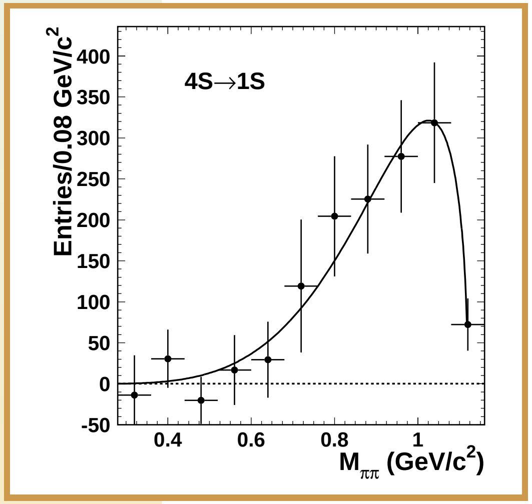

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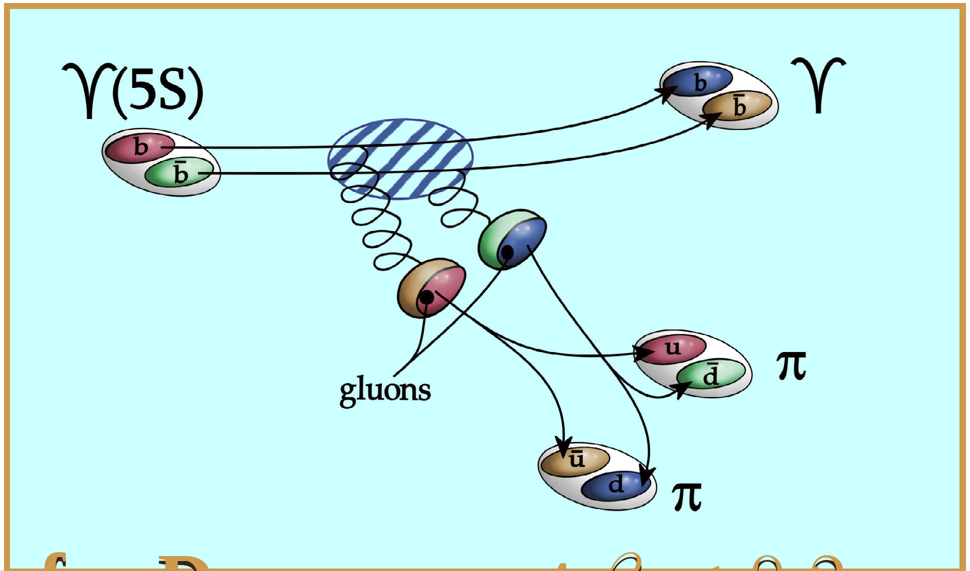

measure for D-wave part $\beta < 0.2$

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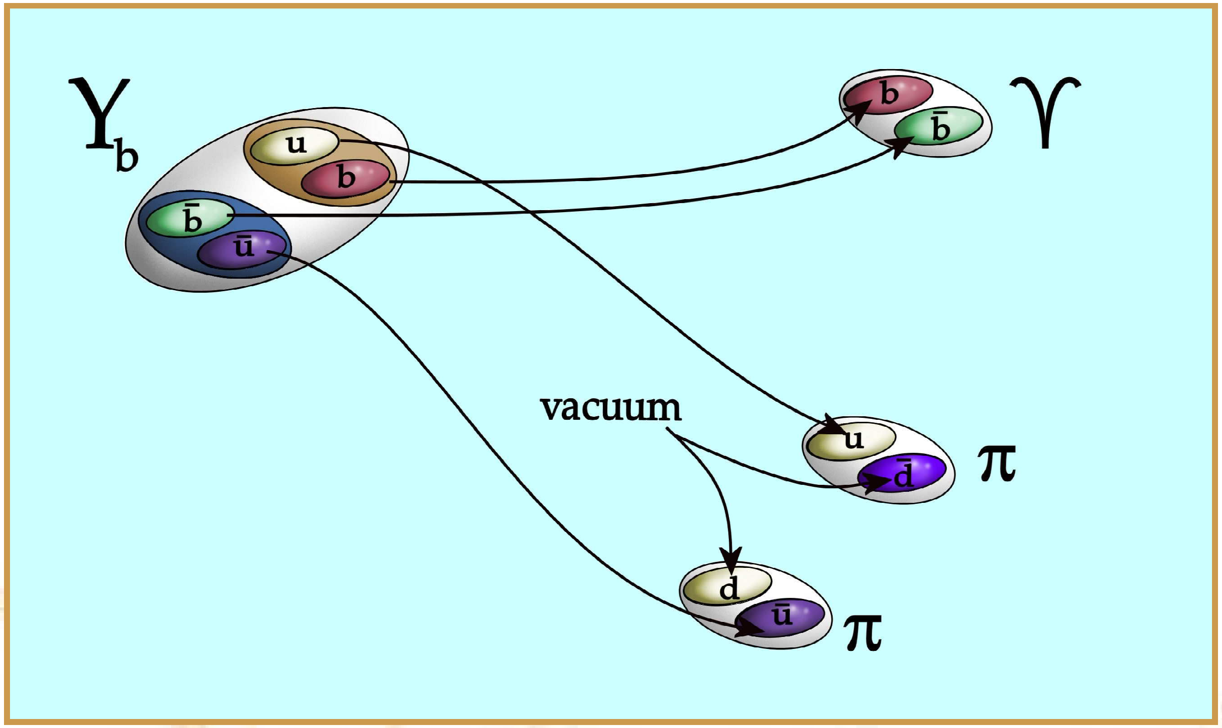
[Phys. Rev. Lett. **35**, 1 (1975)]

continuum contribution

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



short intermezzo: light tetraquarks

light tetraquarks

- From the light quark sector we have a full $SU(3)_F$ nonet of tetraquark resonances [t'Hooft et al., Phys. Lett. B **662**, 424 (2008)] :

light tetraquarks

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$$
\begin{aligned}
\sigma^{[0]} &= [ud][\bar{u}\bar{d}] \\
\kappa &= [su][\bar{u}\bar{d}];\ [sd][\bar{u}\bar{d}] \\
&\quad \text{(+conjugate doublet)} \\
f_0^{[0]} &= \frac{[su][\bar{s}\bar{u}]+[sd][\bar{s}\bar{d}]}{\sqrt{2}} \\
a_0 &= [su][\bar{s}\bar{d}];\ \ [sd][\bar{s}\bar{u}]; \\
&\quad \frac{[su][\bar{s}\bar{u}]-[sd][\bar{s}\bar{d}]}{\sqrt{2}}
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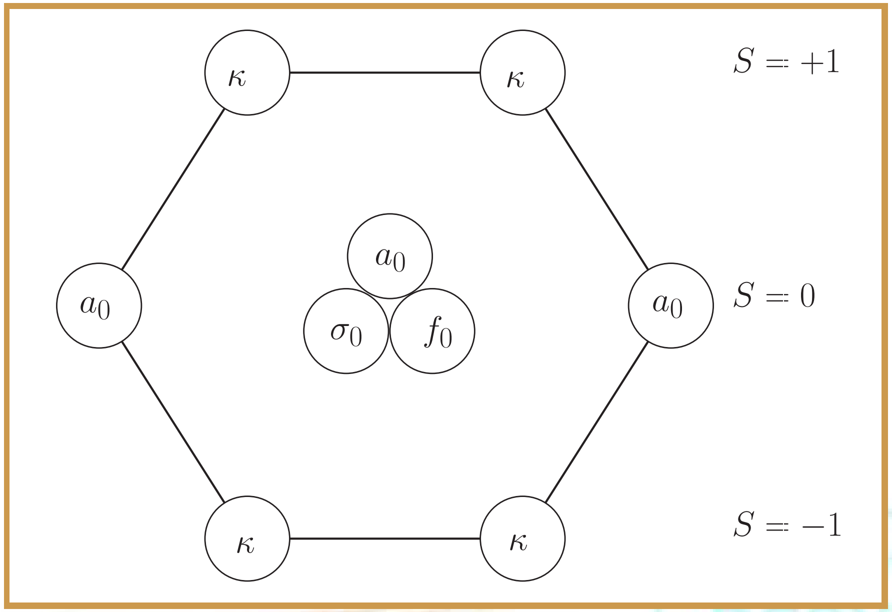

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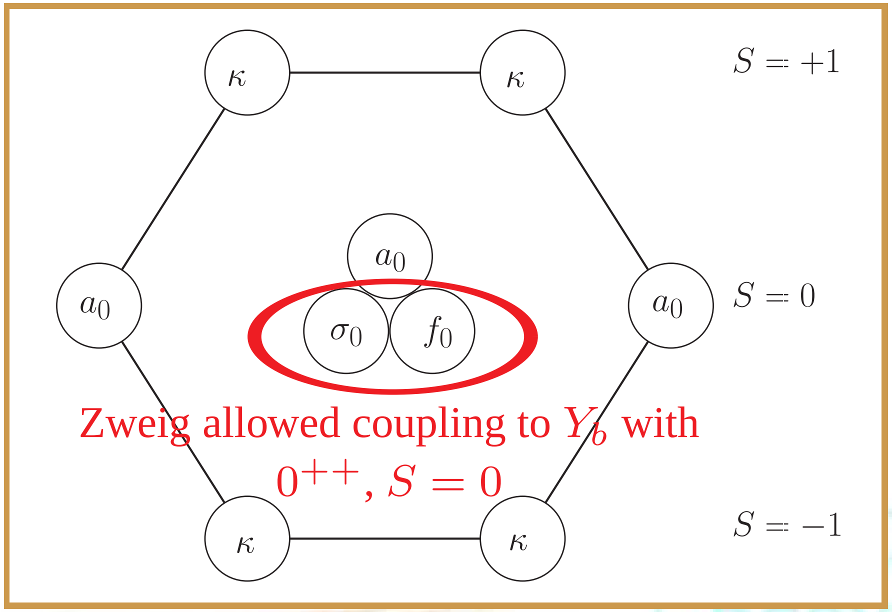

light tetraquark interactions

The effective Lagrangian ($i,\ j$ are flavor indices):

$$\mathcal{L} \propto \mathrm{Det}(Q_{LR})\ , \qquad (Q_{LR})^{ij} = \bar{q}^i_L q^j_R$$

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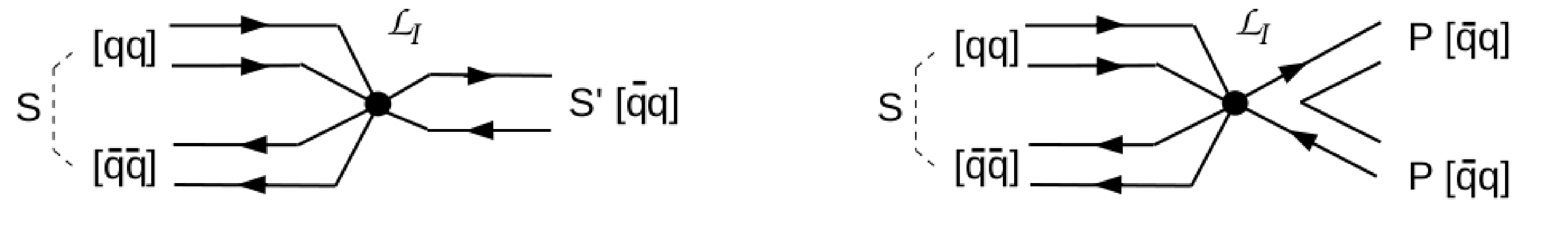
induces tetraquark-meson 6-quark interactions via

$$\text{Tr}(J^{[4q]} J^{2q}) \; , \quad \text{with} \quad J^{[4q]}_{ij} = [\bar{q}\bar{q}]_i [qq]_j \; , \qquad J^{2q}_{ij} = \bar{q}_j q_i$$



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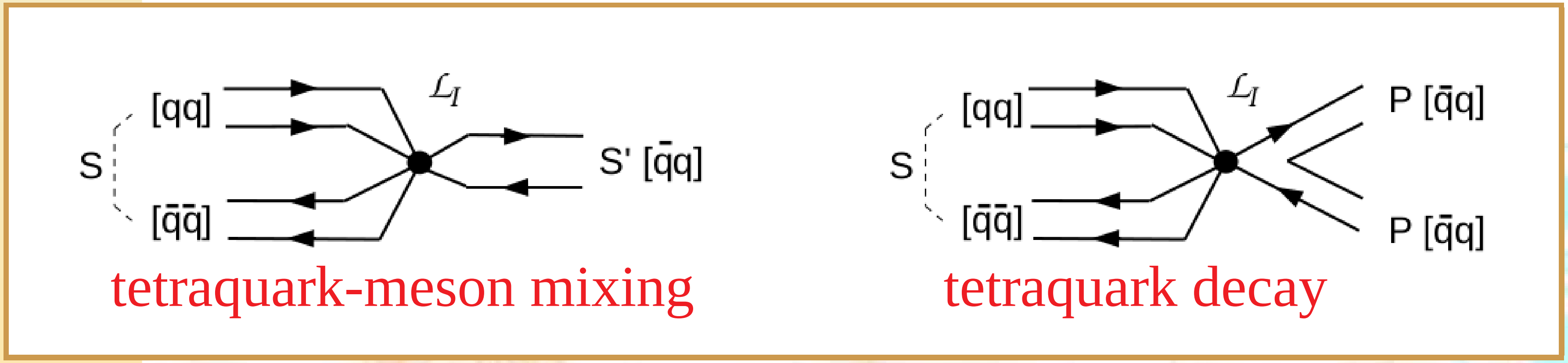
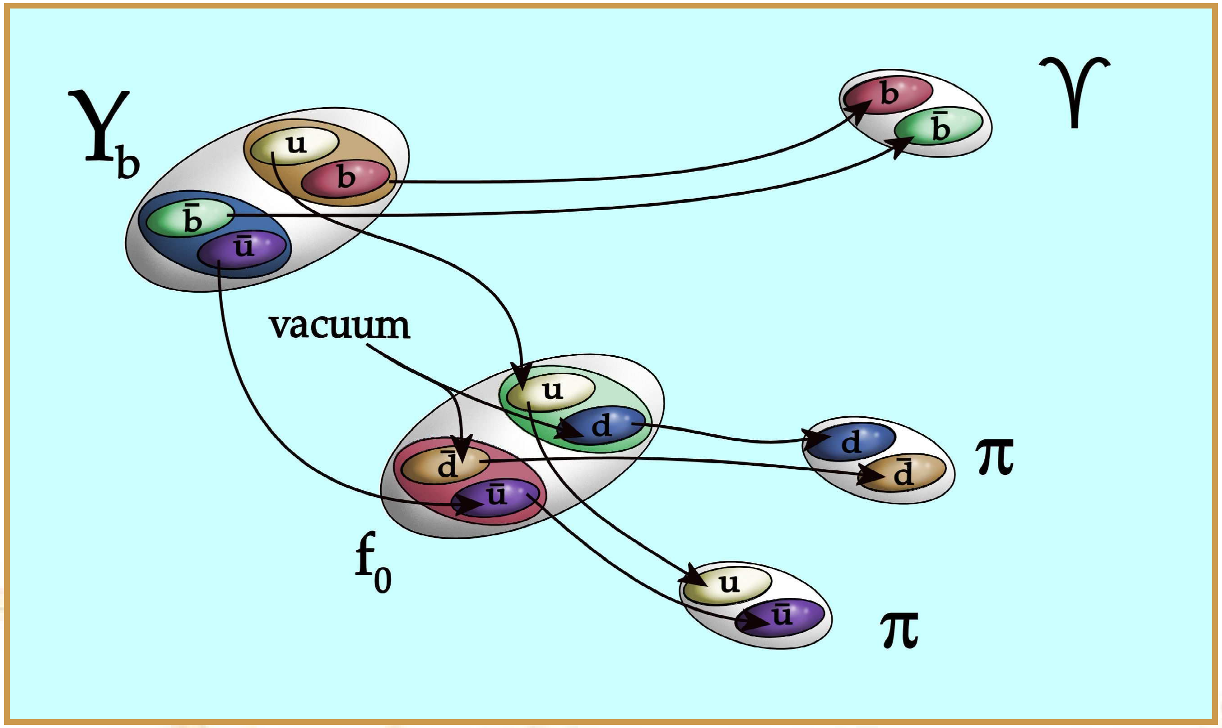


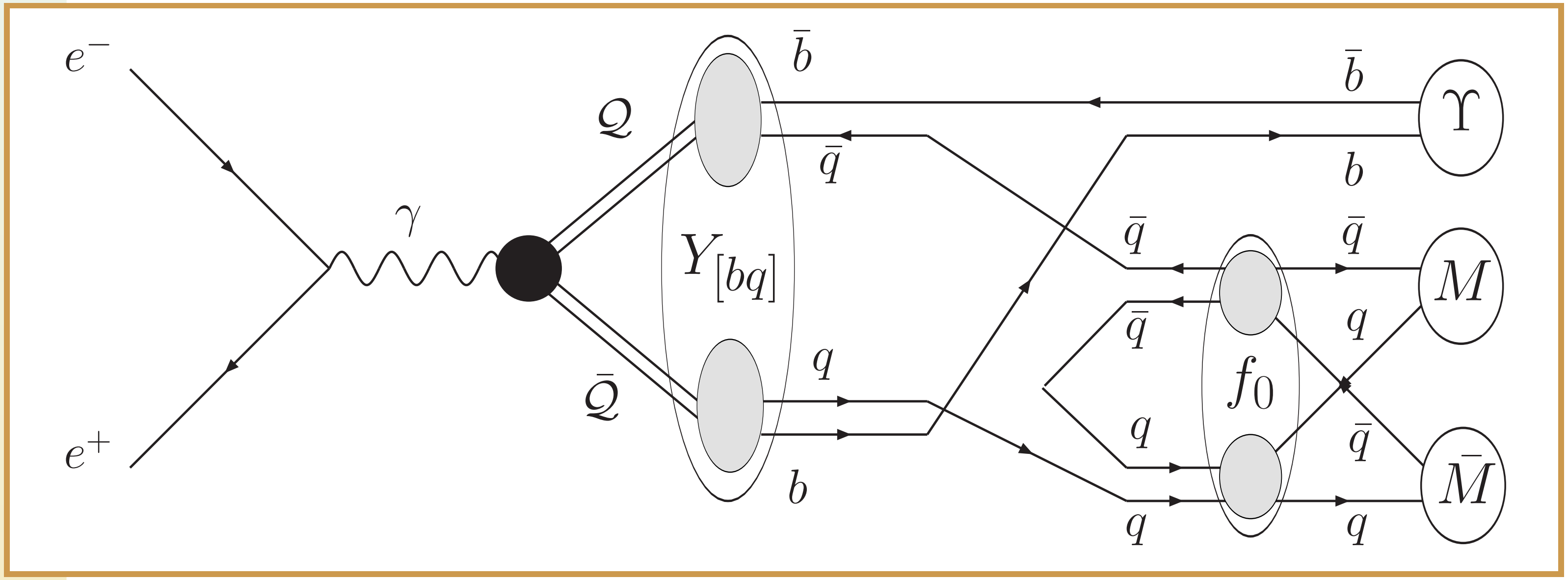
resonance contribution

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

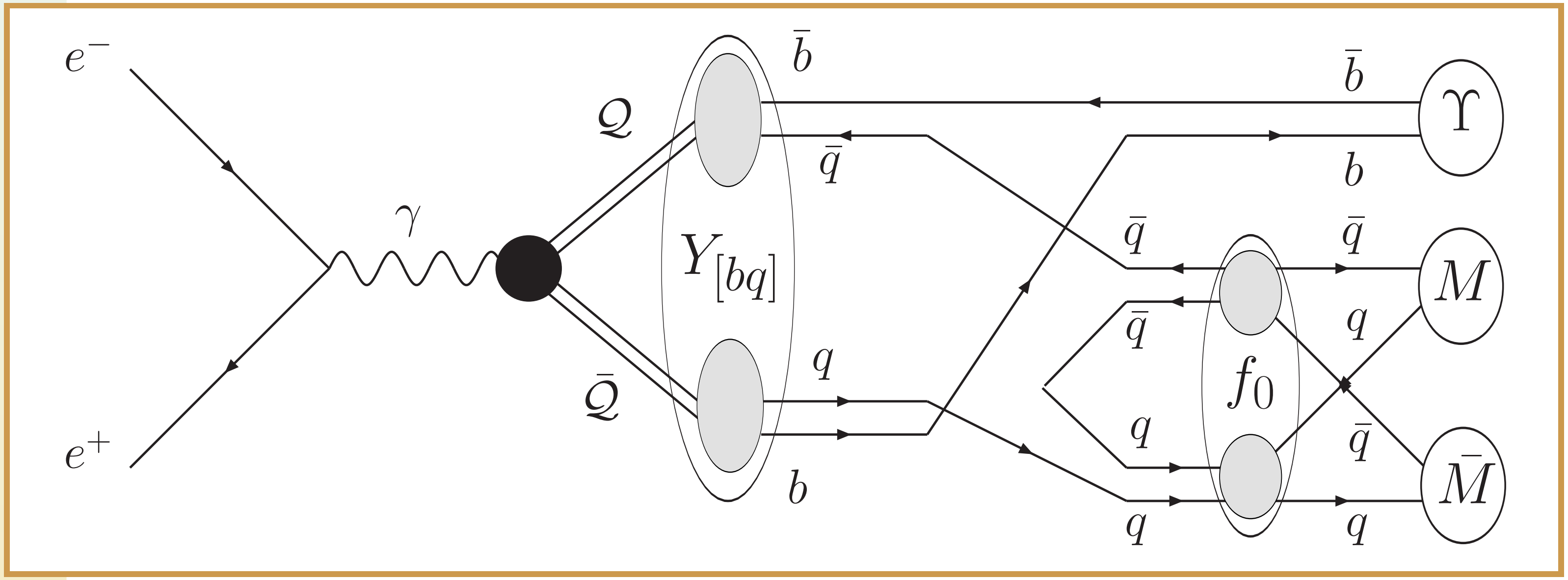


summing up contributions

0^{++} resonance contribution



0^{++} resonance contribution



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

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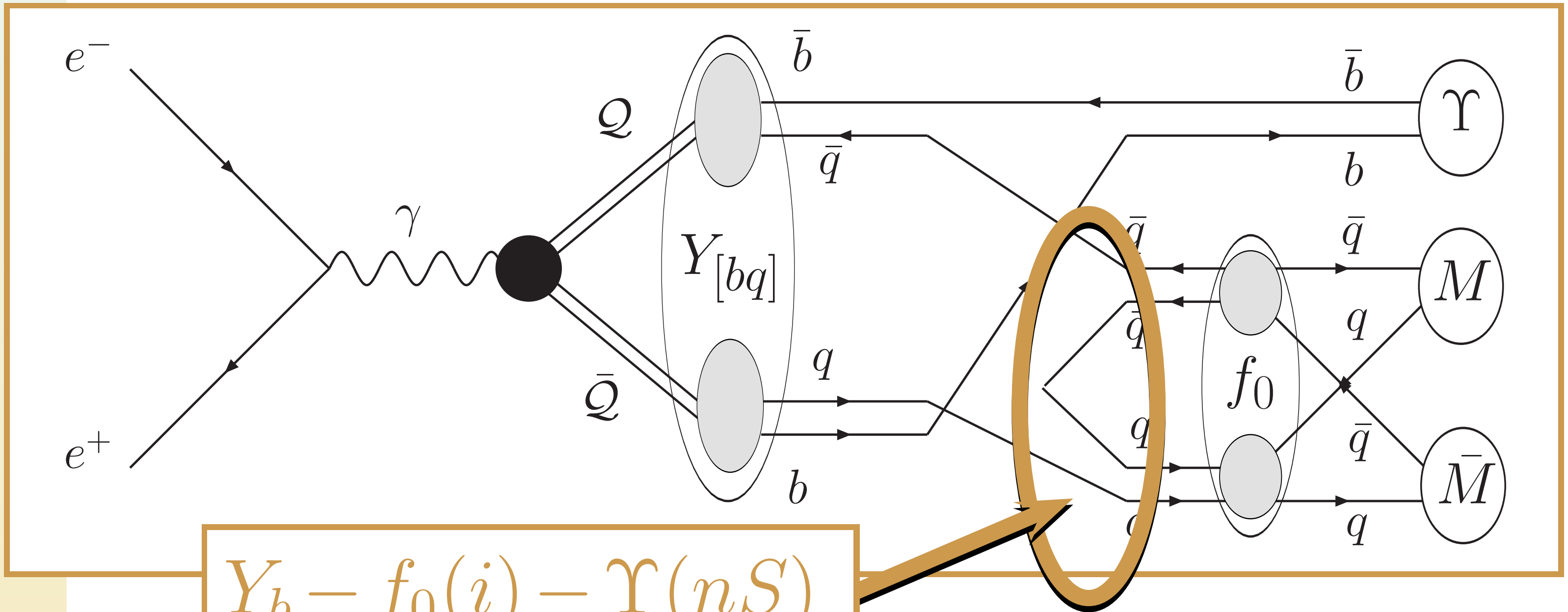
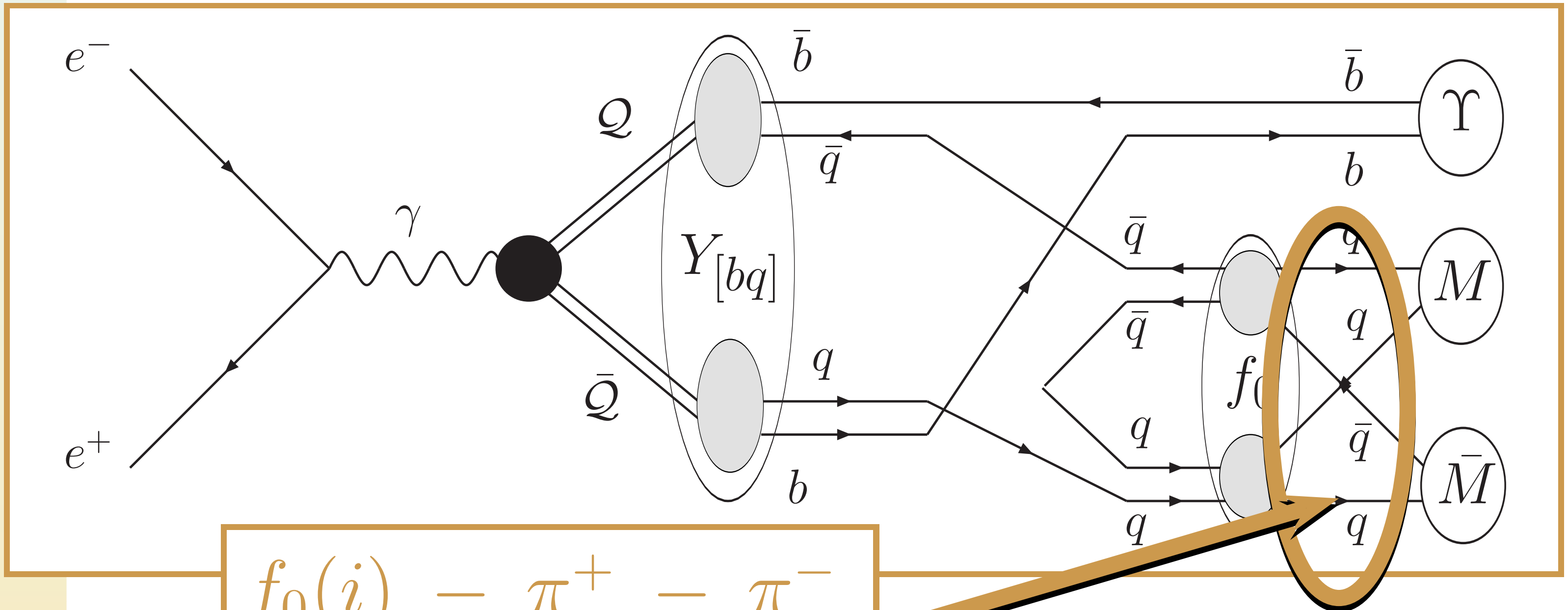


$Y_b - f_0(i) - \Upsilon(nS)$
coupling $F_{f_0(i)}$

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

0^{++} resonance contribution

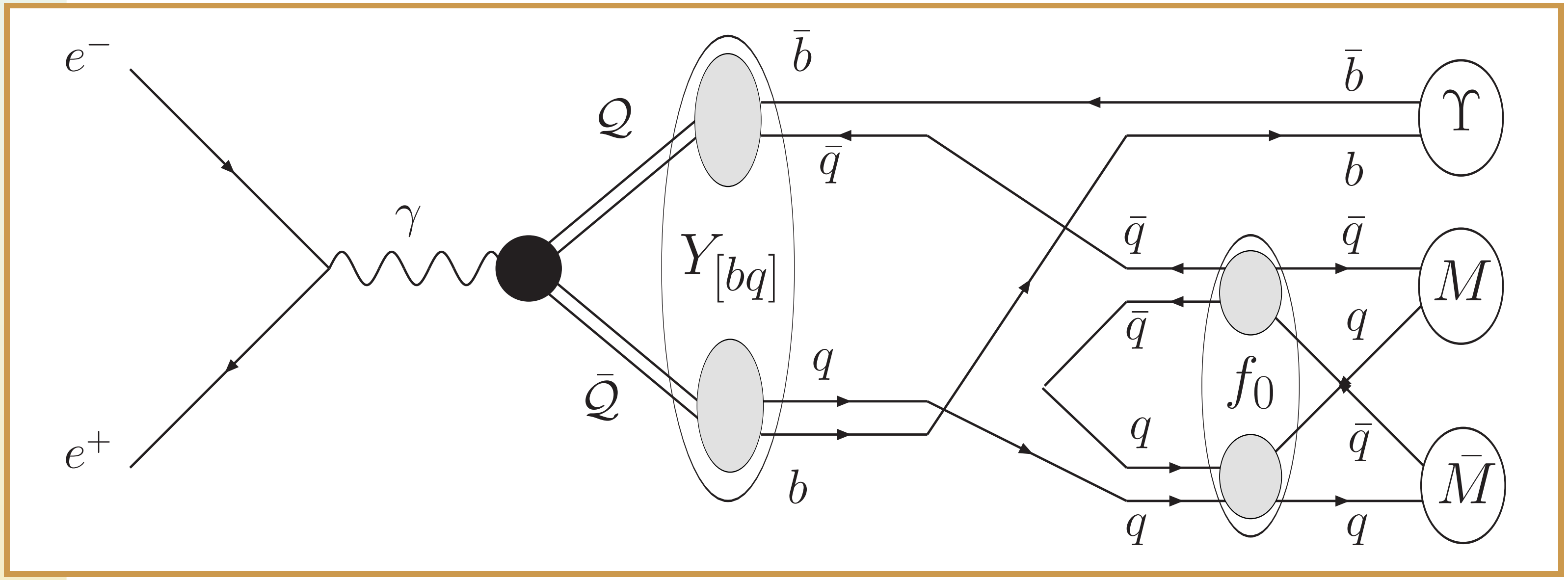


$f_0(i) - \pi^+ - \pi^-$

coupling $g_{f_0(i)\pi\pi}$

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

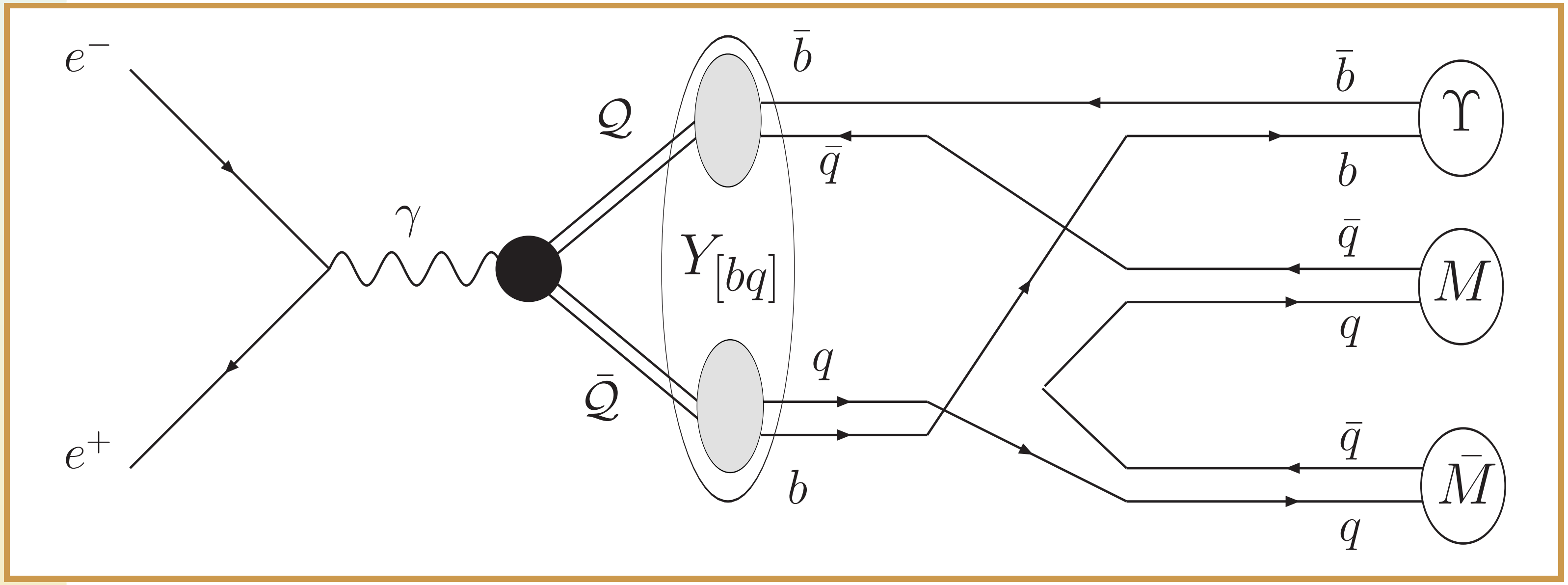
0^{++} resonance contribution



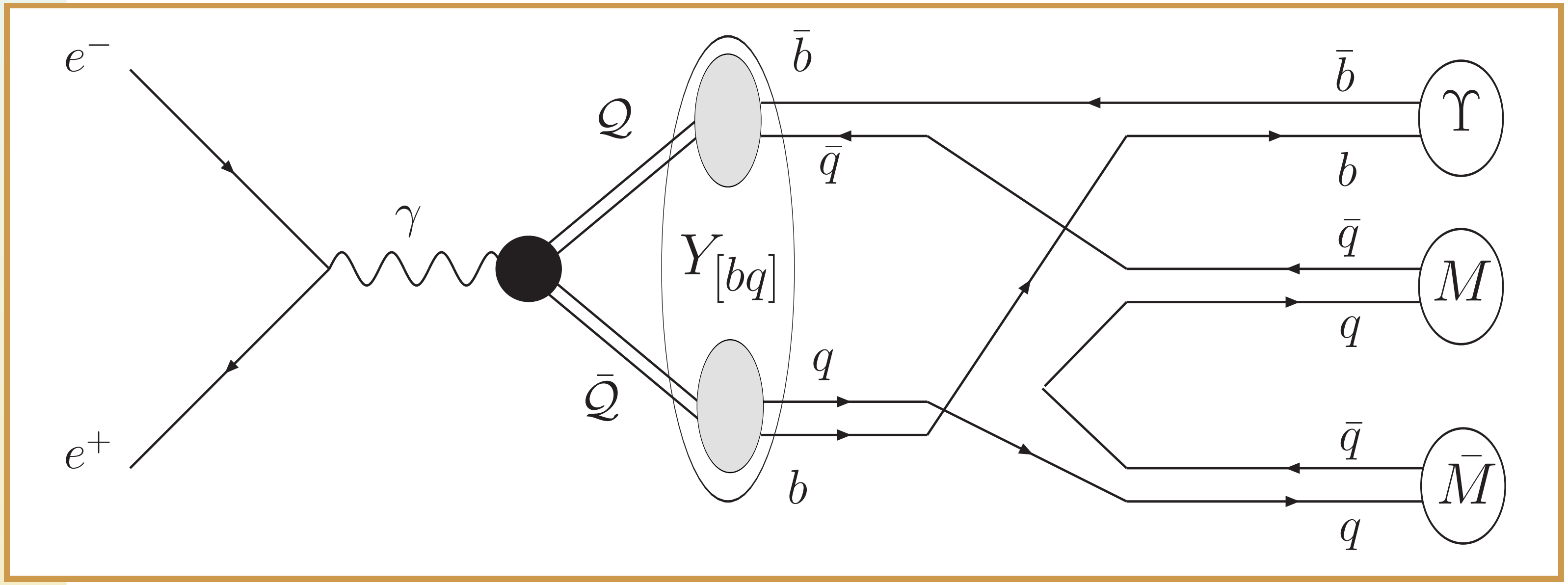
$$a_{f_0(i)} \propto F_{f_0(i)} \times g_{f_0(i)\pi\pi}$$

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

continuum contribution

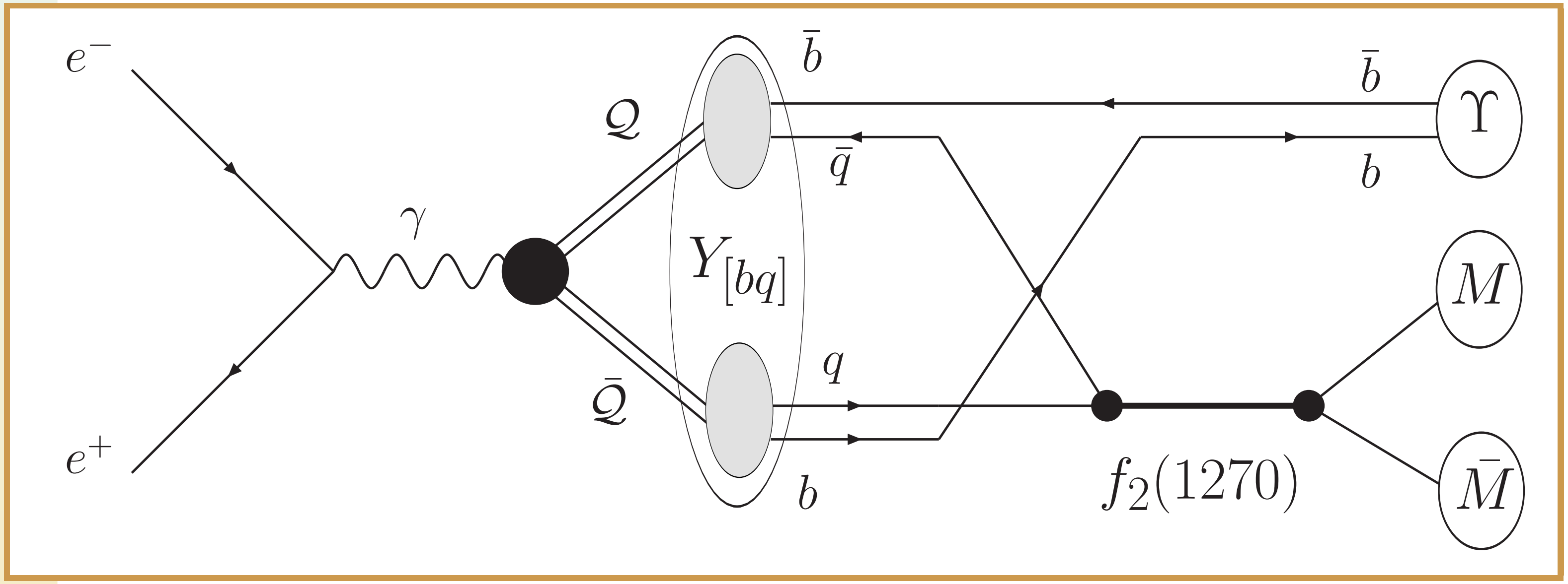


continuum contribution



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

D-wave 2^{++} contribution



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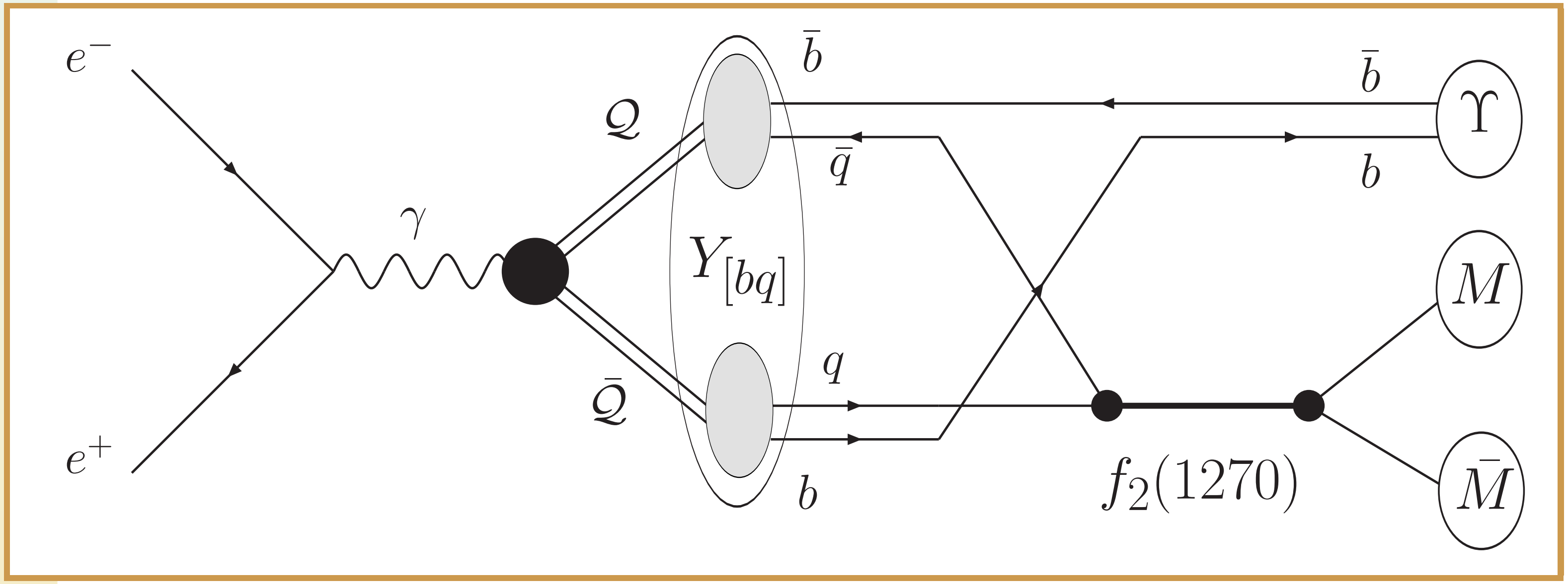
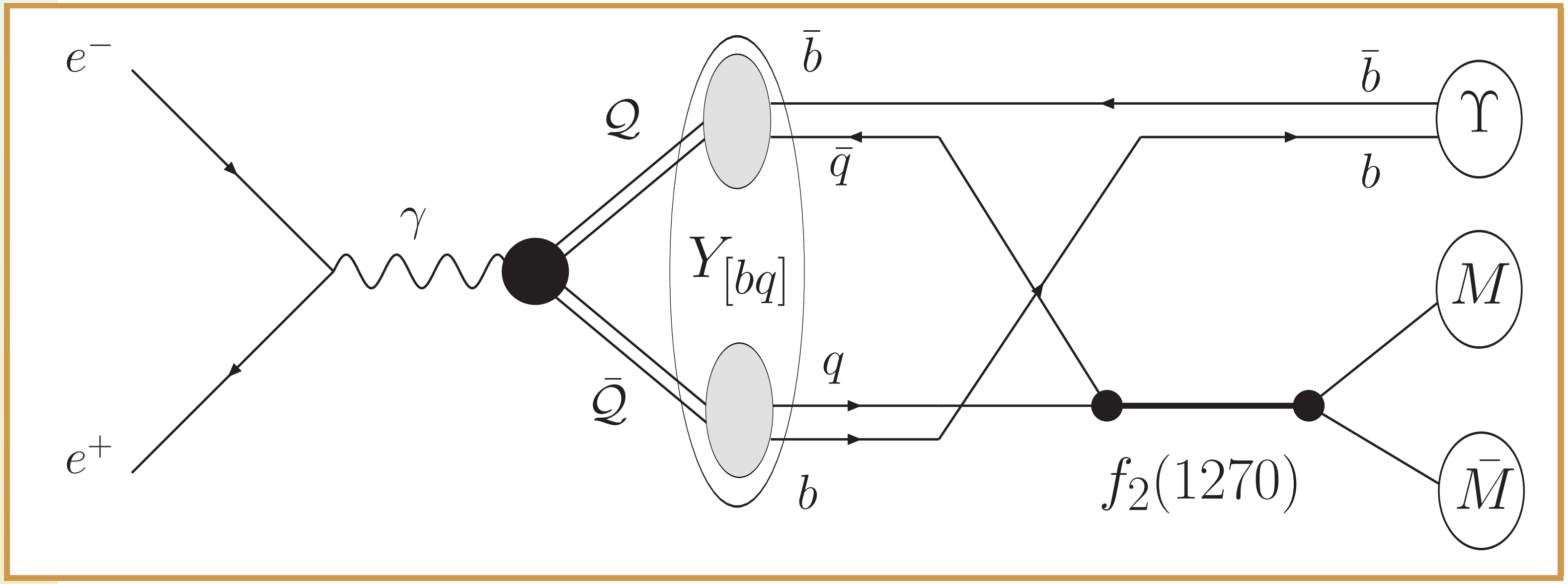


$$\mathcal{M}_{f_2(1270)} = \varepsilon^{Y}.\varepsilon^{\Upsilon} a_{f_2(1270)} e^{i\varphi_{f_2(1270)}} A_{f_2(1270)}$$

D-wave 2^{++} contribution



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

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

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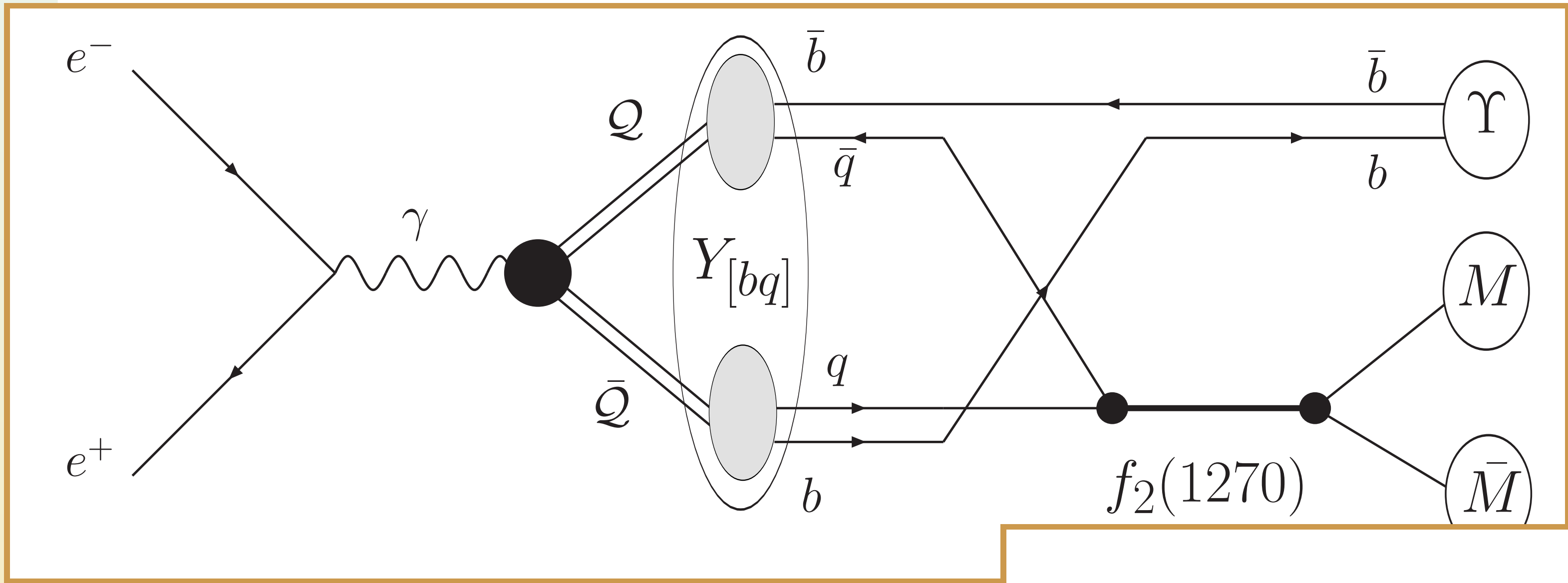

spherical harmonics:

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

$$\mathcal{M}_{f_2(1270)} \;=\; \varepsilon^{Y}.\varepsilon^{\Upsilon} a_{f_2(1270)}$$

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full amplitude

summing the single contributions leads to the full amplitude:

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

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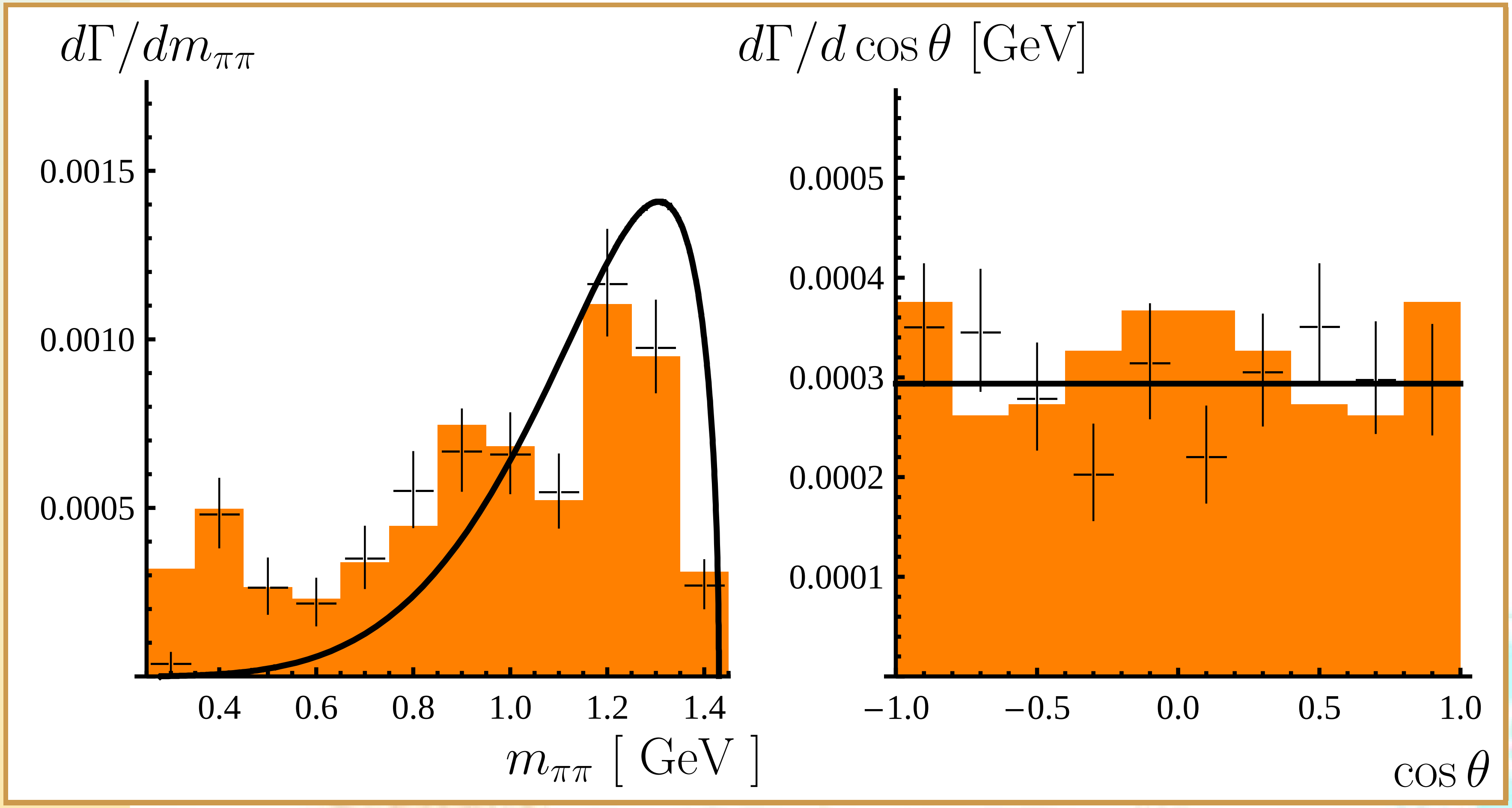
&\quad + a_{f_2(1270)} e^{i\varphi_{f_2(1270)}} A_{f_2(1270)}(m_{\pi\pi})\Big]
\end{aligned}
$$

differential partial decay width:

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

fit to Belle data

Fit for $Y_b \to \Upsilon(1S)\pi^+\pi^-$:



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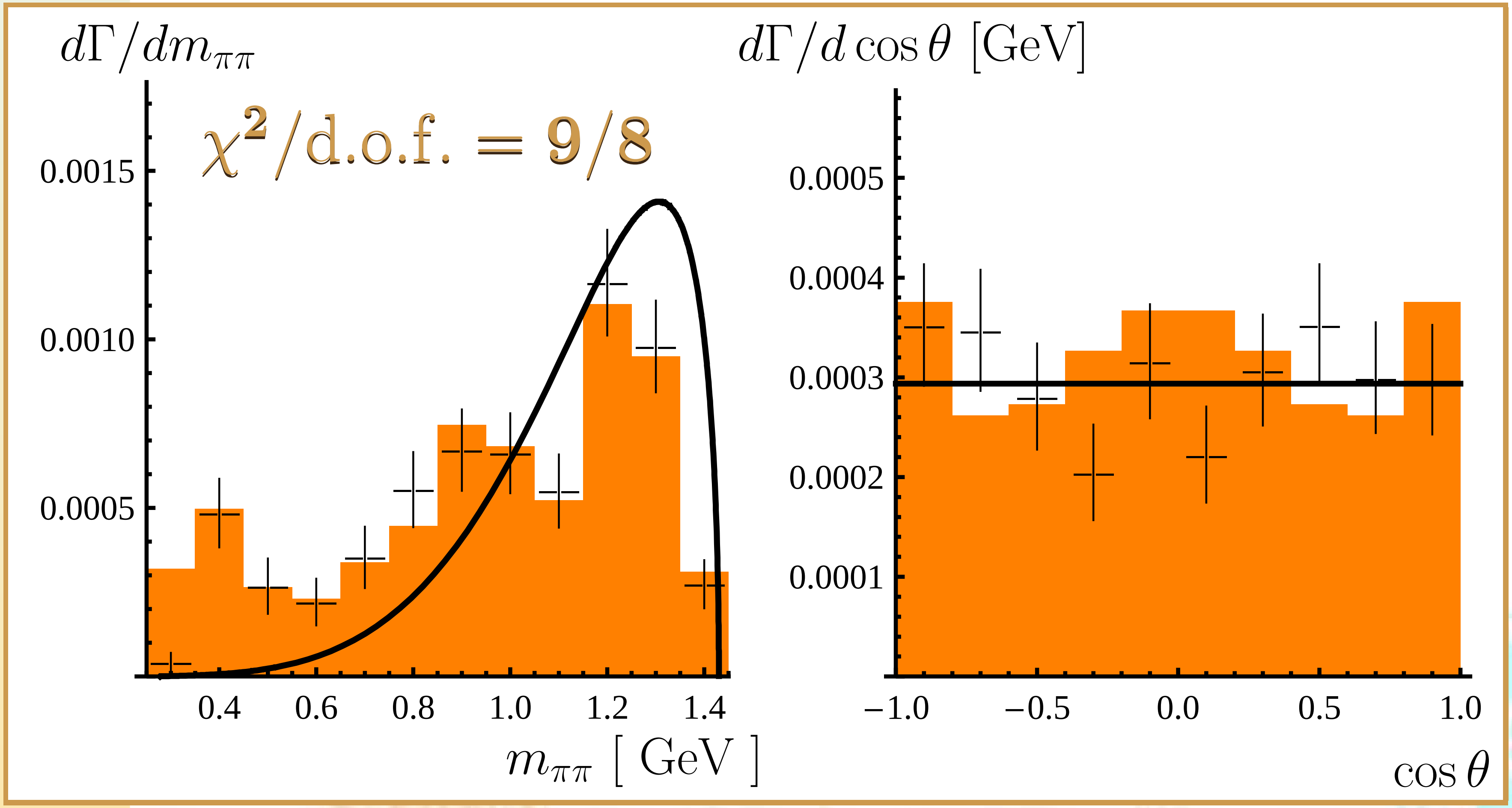
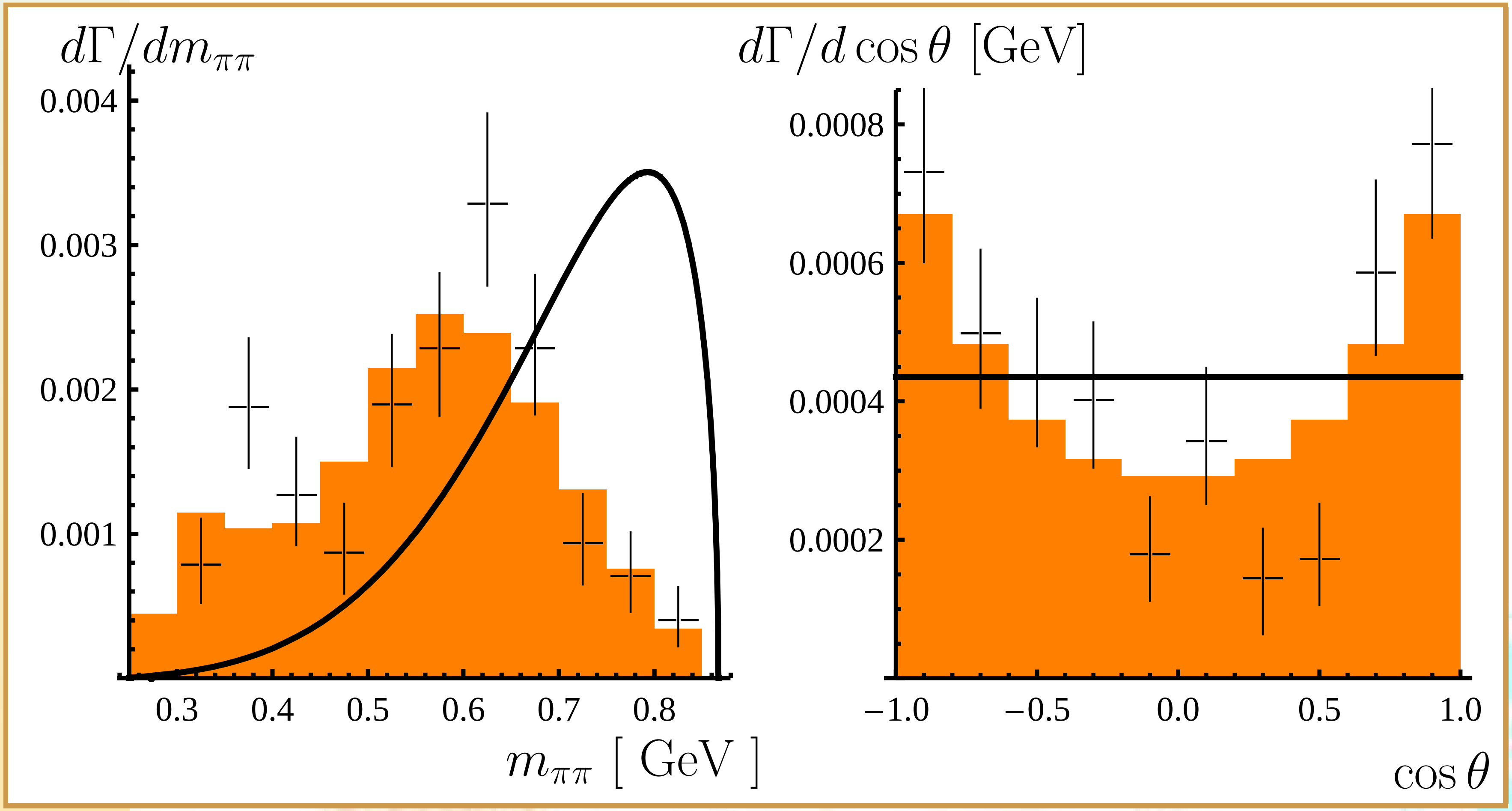


fit to Belle data

Fit for $Y_b \to \Upsilon(2S)\pi^+\pi^-$:



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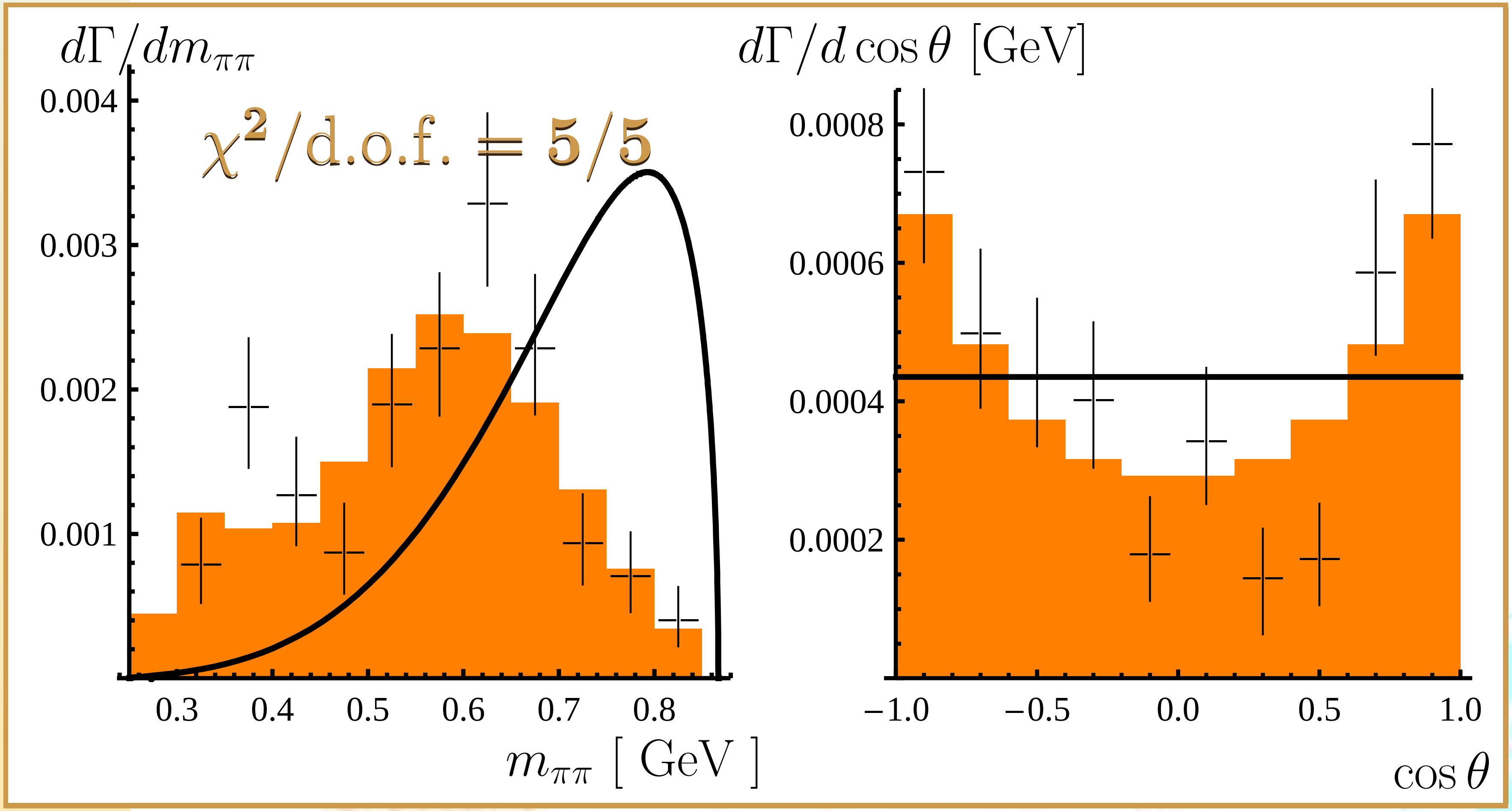
Fit for $Y_b \to \Upsilon(2S)\pi^+\pi^-$:



fit values

- fit values for $Y_b \to \Upsilon(1S)\pi^+\pi^-$:
  $F = 0.19 \pm 0.03$, $\beta = 0.54 \pm 0.12$,
  $a_{f_2(1270)} = 0.5 \pm 0.16$, $\varphi_{f_2(1270)} = 3.33 \pm 0.06$

	$a_{f_0(i)}$	$F_{f_0(i)}$	$\varphi_{f_0(i)}$ (rad.)
$f_0(600)$	3.6 ± 0.7	1.38 ± 0.27	1.14 ± 0.14
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- fit values for $Y_b \to \Upsilon(2S)\pi^+\pi^-$:
  $F = 0.86 \pm 0.34$, $\beta = 0.7 \pm 0.3$

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

outlook and conclusion

Summarizing:

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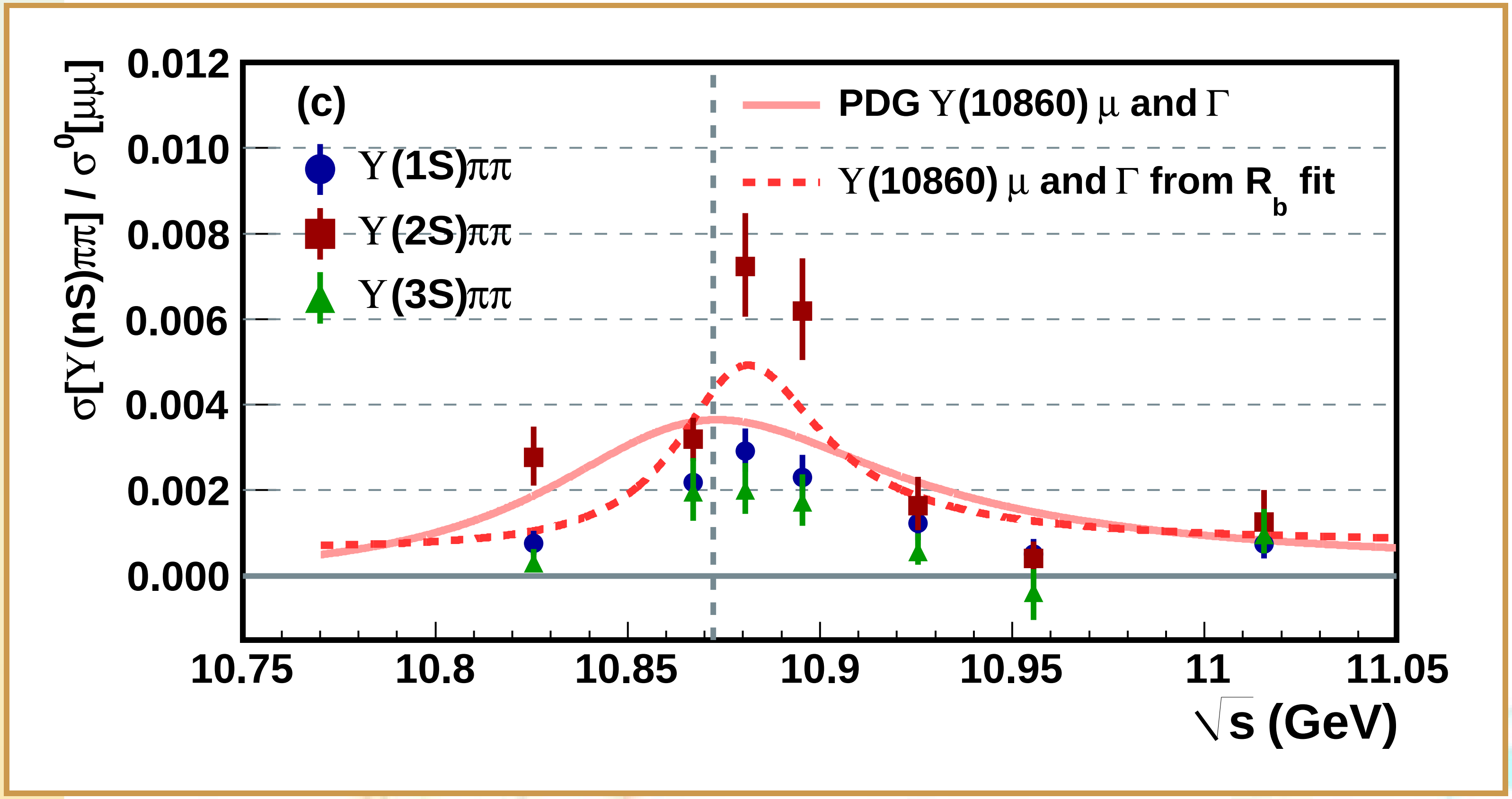
Summarizing:

- The $\Upsilon(5s) \to \Upsilon(1S)\pi^+\pi^-,\ \Upsilon(2S)\pi^+\pi^-$ decays are Zweig forbidden .
- The $Y_b \to \Upsilon(1S)\pi^+\pi^-,\ \Upsilon(2S)\pi^+\pi^-$ decays are Zweig allowed and can explain the observed decay width, larger by two orders of magnitude.
- The coupling to intermediate light quark resonances ($f_0(600)$, $f_0(980)$, $a_2(1270)$) can explain the shape of the invariant mass contribution (scalar meson dominance) .

new Belle data

fits under preparation



Belle data taking

- Spring 2010 run
  - Last Belle data king has started May 13 ("experiment 73")
  - Will take until June 30 (7 weeks)
  - 1 week startup
  - 3 weeks machine study for SuperKEKB
  - 4 weeks physics (Υ(5S), scan to search for the Ali tetraquark [PLB684, 28-39, 2010])

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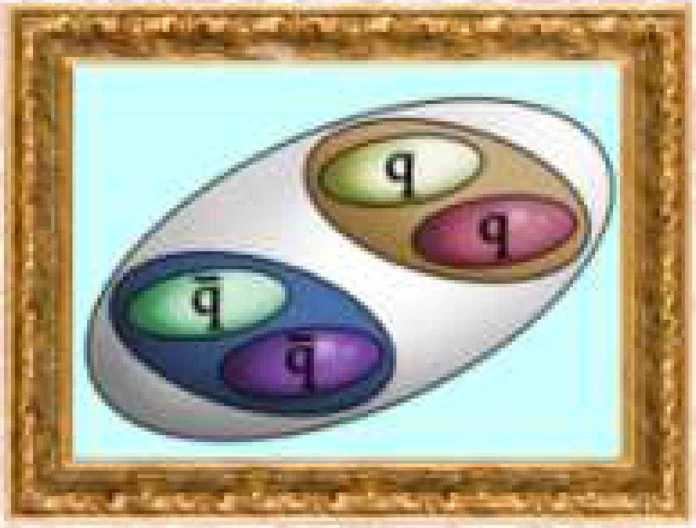
In conclusion
we hope for good news after the World Cup



thank you!