Production of tensor glueball in reaction $YY\rightarrow G_2\Pi^0$

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Outline

Motivation. Glueballs G(2++): experimental evidence, predictions and models (9 slides)

> The process $y+y \rightarrow G(2^{++})+ \pi^0$ as an opportunity to study tensor glueball (12 slides)

> > Conclusion

The lightest glueballs have JPC quantum numbers of normal mesons and would appear as an SU(3) singlet state. If they are near a nonet of the same JPC quantum numbers, they will appear as an extra f-like state. While the fact that there is an extra state is suggestive, the decay rates and production mechanisms are also needed to unravel the quark content of the observed mesons.

Crede, Mayer, 2009 appear as an extra i-like state. Wrille the fact that there is an extra $\frac{1}{3}$ are near a n

Experimental evidence for tensor glueballs *K*∗(892)*K*∗(892) seen 387 Experimental evidence for tensor gluebe η η seen 803 *Examental evidence for tensor glueballs Fxperimental evidence for tensor alueballs* π π (17*.*0*±*1*.*5) % 1003 **Perimental evidence for tensor glaeballs** references in the following data for a team of the following data for a second team of the following data for
The following data for a second team of the following data for a second team of the following data for a second $\overline{\mathbf{S}}$ Penson Stacharts Mass m = 2297 ± 28 MeV ensor glueballs = 149 meters

 $\mathcal{L}^{\mathcal{L}}$, which is a set of seen $\mathcal{L}^{\mathcal{L}}$, where $\mathcal{L}^{\mathcal{L}}$, we see that $\mathcal{L}^{\mathcal{L}}$

PDG $JPC=2++$ and with masses $2.0-2.5$ GeV **K K** \mathbf{K} is the second function of \mathbf{K} is the second function of \mathbf{K} . The second function of \mathbf{K} is the second function of \mathbf{K} is the second function of \mathbf{K} is the second function of $\mathbf{$ **masses 2.0-2.5 GeV** $I^G(J^{PC}) = 0^+(2^{++})$ *f*4(2050) *^IG*(*JPC*)=0+(4 + +) Mass *m* = 2025 *±* 10 MeV (S = 1.8) Mass *m* = 2025 *±* 10 MeV (S = 1.8) PDG $JPC=2++$ and with masses 2.0-2.5 GeV $I^G(J^{PC})=0$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ $\frac{1}{2}$ and with masses 2.0 2.5 Jev 1 (3) = 0 $M = \sqrt{G}(\sqrt{PC})$ e + $\sqrt{9}$ $eV = \int_{0}^{1} (f(t))^2 dt = 0$ $\frac{1}{2}$ $1503B631$ $150B1$ $2.0-Z.5$ GeV $P'(J' \circ) = 0^+(2^{T-1})$ $f(2) = 2560$ $f(3)(P^2) = 0+(2^{2}+1)$ -2.5 GeV $I^G(J^{PC}) = 0^+(2^{++})$

f

OMITTED FROM SUMMARY TABLE $\left(\frac{m \omega}{m} \right)$ = $\frac{m \omega}{m} = 2201 \pm 0.0$ m $\left(\frac{m \omega}{m} \right)$ $Mass \ m = 2231 \pm 3.5$ MeV $\eta \eta$ (956) **2130 THE SONGO SUMMAN FIABLE** $f_J(2220)$ $Mass m = 2231 \pm 3.5$ MeV OMITTED FROM SUMMARY TABLE Γ⁷ φφ not seen $\overline{\mathcal{M}}$

 \mathbb{R}^n derived from an analysis of neutrino-oscillation experiments. The second contribution experiments. The second contribution experiments of \mathbb{R}^n

Experimental evidence for tensor glueballs 2 \mathbf{r} 200

 M_{\odot} : M_{\odot} results, including the mass and widths for resonances, branching ratios of M_{\odot} $-$ 9.37M uttice prediction ction chan at al DDI 111(2013) $Br(J/\psi)$ Events / 20 MeV/c lattice prediction chen et al, PRL 111(2013) $Br[J/\psi \rightarrow \gamma G_2] \simeq 1.1\%$ $M_{G_2} = 2.37$ MeV

obtained according to the changes of the log likelihood. ′ 2(1525) 1513±5+4 Experiment BES III, Ablikim et al, PRD 87(2013) −36 273+27+70 × 10−23 (1.13+0.09+0.109+0.09+0.109+0.109+0.109+0.109+13.9 cm f −10 750 74, 10 11.11111 01 al, 11.0 01 1002 **D** cross section of the cross
The contract of the cross section of the cross section of the cross section of the cross section of the cross
T

Resonance Mass(MeV/ c^2) Width(MeV/ c^2) $\mathcal{B}(J/\psi \to \gamma X \to \gamma \eta \eta)$ Significance 0 \sim

 $f_2(2340)$ $2362^{+31+140}_{-30-63}$ $^{+31+140}_{-30-63}$ $334^{+62+165}_{-54-100}$ $-32^{+31+140}_{-30-63}$ $334^{+62+165}_{-54-100}$ $(5.60^{+0.62+2.37}_{-0.65-2.07}) \times 10^{-5}$ 7.6 σ $\frac{J2(2540)}{2002-30-63}$ $\frac{0.04}{2004}$ -63 004 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8 3.0 $\frac{1002}{1}$

.

40

$$
J/\psi\to\gamma X\to\gamma\eta\eta
$$

dots with error bars are data ↓ ^{II} ↓ The detection of the detection events subtracted

> Contribution of $f_2(2340)$ to the data according to PWA i hırti on o ϵ (2340)
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Experimental evidence for tensor glueballs where ni and one of the stream of whole die iniental evidence for tensor glaeballs serimental evidence for tensor clueballs the first expedition. The second or second or second ones are second only of the second ones are second on the second ones are secon

Experiment BES III, Ablikim et al, PRD 93(2016) rim of the second state of the second state of the second state of the second state state of the second state o Experiment

TABLE I. Mass, width, $\mathcal{B}(J/\psi \to \gamma X \to \gamma \phi \phi)$ (B.F.) and significance (Sig.) of each component in the baseline solution. The first errors are statistical and the second ones are systematic. $\frac{1}{2}$ $\overline{\text{ors are stati}}$ stical and the second ones are $\frac{y}{2}$ $+18$ \mathbb{R}_6

The masses and widths are taken from PDG Etkin et al, PRL(1978), PLB(1985), PLB(1988) $\pi^- + p \to \phi \phi n$ hara et al (BELLE), PTEP (2013) $\gamma\gamma\to K^0_SK^0_S$ Abe et al (BELLE), EPJ (2004) $e^+e^- \rightarrow e^+e^-K^+K^-$ The masses and widths are taken from PDG $Uehara et al (BELLE), PTEP (2013)$ $\gamma\gamma \rightarrow K_S^0 K_S^0$ Δ be at al (RELLE). FOT (2007) Δ statistically the Δ process at (DEELE), EPJ (2004) by either Abe et al (BELLE), EPJ (2004) e+e−→ e+e−K+K−

Experimental evindence for tensor glueballs $Experiment - 0.55 III, $Ablikim 0.5a$, $PPD 13(2016)$$ $\text{COS}\theta(\phi)$ 1 cosθ(φ Experiment Intensities of individual JPC components.

1000 C

 $\eta(2225)$ $\eta(2100)$ O^{-+} 2++ $f₂(2010)$, $f₂(2300)$, $f₂(2340)$

Experimental evidence for tensor glueballs

One more conjecture

reanalysis of BNL data $\pi^-p \to \phi \phi n$ Lindenbaum, Longacre, PRD(2004)

"Gatchina group" Anisovich, Sarantsev, Matveev, Nyiri (2005)

based on analysis $pp^- \rightarrow \pi \pi$, ηη, ηη' in the mass region 1990–2400 MeV $\gamma\gamma \rightarrow K_S K_S$ $\gamma\gamma \rightarrow \pi^+\pi^-\pi^0$ L3 collaboration Crystal Barrel

are supposed to be Five 2⁺⁺ resonanses are introduced to describe pp data f2(1920), f2(2240) 3P2 qq states $\overline{}$ $f_2(2020)$, $f_2(2300)$ $3F_2$ $q\overline{q}$ states \overline{a} states f2(2340) $\overline{3P_2 s\overline{s}}$ state ss⁻ partner remains to be discovered f₂(2120), f₂(2410) 3P₂ ss states \overline{a} $\frac{1}{2}$

Glueball $f_2(2000)$ $M = 2010 \pm 30$ MeV $\Gamma = 495 \pm 35$ MeV

Experimental evidence for tensor glueballs

More conjectures: $f_J(2220)$ have been proposed to be a tensor glueball candidate

[L.Burakovsky,](http://inspirehep.net/author/profile/Burakovsky%2C%20Leonid?recid=527964&ln=en) [P.R. Page](http://inspirehep.net/author/profile/Page%2C%20Philip%20R.?recid=527964&ln=en) PRD62, 2000

F. Giacosa, Th. Gutsche, V. E. Lyubovitskij and Amand Faessler PRD72, 2005

More experimental data are required in order to distinguish the conventional qq-scenario from other possible exotic configurations

Is it possible to suggest a prescription which allows one to clearly distinguish gluonic state from the quark state?

Potentially this can be done by studying of meson production in the hard processes since the latter are sensitive to the lowest Fock wave functions

The glueballs must have strong overlap with the physical states through the gluon operators

Can we learn smth about glueballs from hard exclusive reactions?

Advantages the amplitude sensitive to the wave functions (distribution amplitudes) strong coupling to gluonic component of WF must be observed mixing with quarks is well understood (QCD evolution) special case spin-2: there is the gluonic DA which does not mix with quarks

Disadvantages

mixing still can be problematic for interpretation if hadron is qq and gg state (it depends on the concrete process)

small cross sections at large hard scale \mathbb{Q}^2

Can one measure the cross section in BELLE II?

KEKB

e+e- asymmetric collider

instantaneous luminosity of $2.11x10^{34}$ cm⁻² s⁻¹.

SuperKEKB instantaneous luminosity of 8x1035 cm–2 s–1 larger by a factor 40

The ambitious goal is to accumulate an integrated luminosity of 50 attob-1 (10-18) by the mid of next decade, which is 50 times more data than the previous Belle detector acquired

$$
\gamma \gamma \rightarrow \pi^{-} \pi^{+}
$$
\n
$$
\gamma \gamma \rightarrow K^{+} K^{-}
$$
\n2.4GeV $\langle \sqrt{s} \times 4.1 \text{GeV}$ H. Nakazawa et al., Phys. Lett. B615 (2005)
\n
$$
\gamma \gamma \rightarrow \pi^{0} \pi^{0}
$$
\n0.6 $\langle \sqrt{s} \times 4.1$ S. Uehara et al., Phys. Rev. D 79 (2009)
\n
$$
\gamma \gamma \rightarrow K^{0}_{S} \bar{K}^{0}_{S}
$$
\n1.0 $\leq \sqrt{s} \leq 4.0$ S. Uehara et al., PTEP 2013 (2013)
\n3. Uehara et al., PTEP 2013 (2010)
\n4.1 $\langle \sqrt{s} \times 3.8$ S. Uehara et al., Phys. Rev. D 82 (2010)

also transition FFs $\gamma^* \gamma \to \pi^0$ $\gamma^* \gamma \to f_0(980)$ $\gamma^* \gamma \to f_2(1270)$

One more way to study tensor glueball: $\gamma\gamma\to\pi^0G(2^{++})$

wide angle scattering $s \sim -t \sim -u \gg \Lambda^2$

all terms are of order α_s

 Wakely and Carlson, Phys. Rev. D 45 (1992) Earlier $\gamma\gamma \rightarrow G_0(0^{-+})\pi^0$

> Ichola and Parisi, Z. Phys. C 66 (1995) 653 $\gamma\gamma\to G_0(0^{-+},0^{++},2^{++})\pi^0$

One more way to study tensor glueball: $\gamma\gamma\to\pi^0G(2^{++})$

wide angle scattering $s \sim -t \sim -u \gg \Lambda^2$

$$
\frac{d\sigma_{\gamma\gamma}[\pi^0 G_2]}{d\cos\theta} = \frac{1}{64\pi} \frac{s + m_G^2}{s^2} \left(|\overline{A_{++}}|^2 + |\overline{A_{+-}}|^2 \right)
$$

At LO

 $A_{\pm\pm} : \gamma(\pm) \gamma(\pm) \to G_2(\pm 2)$ tensor gluon DA

 $A_{\pm\mp}:\gamma(\pm)\gamma(\mp)\rightarrow G(0)$ quark & gluon DAs

Amplitude and cross section

$$
\frac{d\sigma_{\gamma\gamma}[\pi^0 G_2]}{d\cos\theta} \simeq \frac{\alpha_{em}^2 \alpha_s^2}{s} \left(\left| \frac{f_\pi f_g^T}{s} I_g^{++}(\cos\theta) \right|^2 + \left| \frac{f_\pi f_g^S}{s} I_g^{+-}(\cos\theta) + \frac{f_\pi f_g}{s} I_q^{+-}(\cos\theta) \right|^2 \right)
$$

 $f_{\pi} = 131 \text{ MeV}$ $f_g^{T,S}, f_q$ unknown

$$
I_g^{++}(\cos \theta) = \int_0^1 dy \frac{\phi_\pi(y)}{y\bar{y}} \int_0^1 dx \frac{\phi_g^T(x)}{x\bar{x}} \frac{(-2)}{(1 - \cos \theta)x\bar{y} + (1 + \cos \theta)y\bar{x}}
$$

Light-cone distribution amplitudes

$$
\begin{aligned}\n\begin{aligned}\n\begin{aligned}\nxp &\longrightarrow \\
\downarrow \left\downarrow \right. &\downarrow \quad p \\
\end{aligned}\n\end{aligned}\n\qquad \sim \int_{|k_{\perp}| < \mu} d^2 k_{\perp} \Psi_{BS}(x, k_{\perp}) = \phi(x, \mu)
$$

describes the momentum-fraction distribution of partons at zero transverse separation in a 2-particle Fock state

suppressed by powers of 1/Q:

multiparticle states: qqq -qq with orbital momentum

 $V_{+} = V_{0} \pm V_{3}$

$$
\langle G_2(p,\lambda)|\bar{\psi}(z)\rlap{/} \psi(0)|0\rangle\Big|_{z_+=z_\perp=0}=m^2\frac{z_-}{p_+}e_{++}^{(\lambda)*}\int_0^1dx\,e^{ixz_-p_+}f_q\phi_q(x)
$$

normalization
constant

$$
\langle G_2(p,\lambda) | \bar{\psi} \left[\gamma_{\mu} i \stackrel{\leftrightarrow}{D}_{\nu} + \gamma_{\nu} i \stackrel{\leftrightarrow}{D}_{\mu} \right] \psi | 0 \rangle = f_q m^2 e^{(\lambda)*}_{\mu\nu}
$$

Light-cone distribution amplitudes

scalar gluons: mix with the quark operator (QCD evolution)

$$
\langle G_2(p,\lambda) | z^{\alpha} z^{\beta} G^a_{\alpha\mu}(z) G^a_{\beta\mu}(0) | 0 \rangle \Big|_{z_-=z_{\perp}=0} = m^2 e_{++}^{(\lambda)*} \int_0^1 dx \, e^{ixp-z_+} f_g^S \phi_g^S(x)
$$

normalization constant

$$
\langle G_2(p,\lambda)|G^a_{\alpha\beta}(0)G^a_{\mu\nu}(0)|0\rangle = \frac{1}{2}f_g^Sm^2 \left\{ \left[g_{\alpha\mu}e^{\lambda\}\ast}_{\beta\nu} - (\alpha \leftrightarrow \beta) \right] - (\mu \leftrightarrow \nu) \right\}
$$

$$
+ f_g^T \left\{ \left[(p_\alpha p_\mu - \frac{1}{2}m^2 g_{\alpha\mu}) e^{\lambda\}\ast}_{\beta\nu} - (\alpha \leftrightarrow \beta) \right] - (\mu \leftrightarrow \nu) \right\}
$$

Light-cone distribution amplitudes !*0.6*!*0.4*!*0.2 0.0 0.2 0.4 0.6 cos*Θ !*0.6*!*0.4*!*0.2 0.0 0.2 0.4 0.6 cos*Θ !*0.6*!*0.4*!*0.2 0.0 0.2 0.4 0.6* \mathbf{i} ght-cone dist \mathcal{C} jbution amplitudes $cos\theta$ scale *^µ*² = 2*.*7GeV² . The area between the vertical lines corresponds to the region where *[|]u|, [|]t[|]* In the short value are convolution and the simple accession the symmetry properties of the symmetry properties

only for tensor polarisation $\lambda = \pm 2$ S_{in} for tensor polarisation $I = +2$ $\lambda = \pm 2$.7GeV2 . The area between the vertical lines $\lambda = \pm 2$ only for tensor polar

$$
\langle G(p,\lambda)|z^{\alpha}z^{\beta}G_{\alpha(\mu_{\perp}}(z)G_{\beta\nu_{\perp}})(0)|0\rangle\bigg|_{z_-=z_{\perp}=0}=e^{(\lambda)*}_{(\mu_{\perp}\nu_{\perp})}\int_0^1dx\,e^{ixp-z_+}f_g^T\phi_g^T(x)
$$

such component does not mix with quarks values for the low energy glueball couplings. I the following we assume that the state *f*2(2340) which has component does not mix with quarks we use the glueball state of α

In order to make n order to make numerical estimates we need to specify \mathcal{L}_n models for the DAS and provide numerical estimates \mathcal{L}_n

$$
\langle G_2(p,\lambda) | \bar{\psi}(z) \overleftrightarrow{D}_{\{\perp \mu} \overleftrightarrow{D}_{\perp \nu\}} \sharp \psi(0) | 0 \rangle \quad \Rightarrow \quad \sim \frac{\Lambda^2}{Q^2}
$$

Models for DAs with the second moment This value is close to many phenomenological estimates and lattice result \mathbb{R} .

 $\phi_{\pi}(y) \simeq 6y\bar{y} + 6a_2(\mu)y\bar{y}C_2^{3/2}(2y-1)$ $a_2(\mu = 1 \text{GeV}) = 0.20$

 A^s This value is close to many phenomenological estimates and lattice result \mathbb{R}^n . This can be a substitute result \mathbb{R}^n Asymptotic shapes for glueball DAs and λ

$$
\phi_g^S(x) = 30x^2 \bar{x}^2 \qquad \phi_q(x) = 30x\bar{x}(2x - 1)
$$

$$
\phi_g^T(x) = 30x^2 \bar{x}^2
$$

*a*2(*µ* = 1GeV) = 0*.*20*.* (21)

Angular behaviour

$$
\frac{d\sigma_{\gamma\gamma}[\pi^0 G_2]}{d\cos\theta} \simeq \frac{\alpha_{em}^2 \alpha_s^2}{s} \left(\left| \frac{f_\pi f_g^T}{s} \frac{64}{9} \pi^2 \sqrt{2} I_g^{++}(\cos\theta) \right|^2 + |A_{+-}|^2 \right)
$$

$$
\bar{x} \equiv 1
$$

$$
I_g^{++}(\cos\theta) = \int_0^1 dy \frac{\phi_\pi(y)}{y\bar{y}} \int_0^1 dx \frac{\phi_g^T(x)}{x\bar{x}} \frac{(-2)}{(1-\cos\theta)x\bar{y} + (1+\cos\theta)y\bar{x}}
$$

 $s \sim -t \sim -u \gg \Lambda^2$

 $-x$

Angular behaviour

$$
\frac{d\sigma_{\gamma\gamma}[\pi^0 G_2]}{d\cos\theta} \simeq \frac{\alpha_{em}^2 \alpha_s^2}{s} \left(|A_{++}|^2 + \left| \frac{f_\pi f_g^S}{s} \frac{8}{9} \pi^2 \sqrt{2} I_g^{+-}(\cos\theta) + \frac{f_\pi f_q}{s} \frac{32}{9} \pi^2 I_g^{+-}(\cos\theta) \right|^2 \right)
$$

$$
I_g^{+-}(\cos\theta) = \int_0^1 dy \frac{\phi_\pi(y)}{y\bar{y}} \int_0^1 dx \frac{\phi_g^S(x)}{x\bar{x}} \frac{-\cos\theta}{(1-\cos\theta)x\bar{y} + (1-\cos\theta)y\bar{x}}
$$

Angular behaviour

$$
\frac{d\sigma_{\gamma\gamma}[\pi^0G_2]}{d\cos\theta} \simeq \frac{\alpha_{em}^2{\alpha_s}^2}{s} \left(|A_{++}|^2 + \left| \frac{f_\pi f_g^S}{s} \frac{8}{9} \pi^2 \sqrt{2} I_g^{+-}(\cos\theta) + \frac{f_\pi f_q}{s} \frac{32}{9} \pi^2 I_g^{+-}(\cos\theta) \right|^2 \right)
$$

$$
I_q^{+-}(\cos\theta) = \int_0^1 dy \frac{\phi_\pi(y)}{y\bar{y}} \int_0^1 dx \frac{\phi_q(x)}{x\bar{x}} \frac{\cos\theta(1-\cos^2\theta)(y-x)(\bar{x}-y)^2}{[(\bar{x}-y)^2(1-\cos^2\theta)+4x\bar{x}y\bar{y}]}
$$

at large angles G₂ is dominantly produced in the tensor polarization Γ figure 3: The convolution integrals as a functions of cos Γ shaded area between the vertical lines of Γ $|I_g^{++}| \gg |I_g^{+-}| \gg |I_q^{+-}|$

In order to make numerical estimates we need to specify models for the DAs and provide numerical summary of the nonperturbative input following models of DAs. For pion DA we take Summary of the nonperturbative input

 $\alpha_s(m_\tau) = 0.251$ contribution will also from the amplitude **A**

Models for DAs

\n
$$
f_{\pi} = 131 \text{ MeV}
$$
\n
$$
\phi_{\pi}(y) \simeq 6y\bar{y} + 6a_2(\mu)y\bar{y}C_2^{3/2}(2y - 1)
$$
\n
$$
a_2(\mu = 1 \text{GeV}) = 0.20
$$
\nAsymptotic shapes for glueball DAs

\n
$$
\phi_g^T(x) = 30x^2\bar{x}^2 \qquad \phi_g^S(x) = 30x^2\bar{x}^2 \qquad \phi_q(x) = 30x\bar{x}(2x - 1)
$$
\nLow energy couplings

\n
$$
\mu = 1 \text{GeV}
$$
\nCompare with

\n
$$
\langle G(0^{-+})|G_{+\mu}\tilde{G}_{+\mu}|0\rangle = fg
$$
\n
$$
f_g^S \simeq 100 \text{ MeV}
$$
\n
$$
f_g^T \simeq 50 - 150 \text{MeV}
$$
\n
$$
f_g = 2.3 \text{ GeV}
$$
\n
$$
f_g = 13, 16 \text{ GeV}^2
$$
\nQCD sum rules

\n
$$
\alpha_s(m_\tau^2) = 0.297 \qquad \mu^2 = 3 - 4 \text{GeV}^2
$$

Cross section

$$
\frac{d\sigma_{\gamma\gamma}[\pi^0 G_2]}{d\cos\theta} = \frac{1}{64\pi} \frac{s + m_G^2}{s^2} \left(|\overline{A_{++}}|^2 + |\overline{A_{+-}}|^2 \right)
$$

 $s = 13$ GeV² $|t| \& |u| > 2.5$ GeV² $s = 16$ GeV²

$$
\gamma \gamma \to G(0^{-+})\pi^0 \qquad \theta = 90^\circ \qquad s^3 \frac{d\sigma}{d\cos\theta} = 0.5 - 3.5 \qquad \text{Wakely and Carlson, Phys. Rev. D 45 (1992)}
$$

$$
\gamma \gamma \to f_{J=2}(2220)\pi^0 \quad 200\theta = 90^\circ \qquad s^3 \frac{d\sigma}{d\cos\theta} = 0.1 - 0.4 \qquad \text{Ichola and Parisi, Z. Phys. C 66 (1995) 653}
$$

Comparison with BELLE data $\gamma\gamma\to\pi^0\pi^0$ (only 25% of the collected data used)

 \mathcal{A}^{max} as a function as a function of cost \mathcal{A}^{max} and \mathcal{A}^{max} in the \mathcal{A}^{max} in the \mathcal{A}^{max}

 $s = 13$ GeV² $|t| \& |u| > 2.5 \text{ GeV}^2$

 $F_{\rm c}$ can be defined by the dashed line is the same as in $F_{\rm c}$ but scaled by \sim μ \sim μ $observedble \quad \frac{d\sigma[\gamma\gamma\to\phi\phi\pi^0]}{I}$ *d* cos θ is smaller $\frac{d\theta[\gamma\gamma \to \phi\phi\pi]}{d\cos\theta}$ is smaller

Experimental evidence for tensor glueballs

Experiment BELLE, Uehara et al, PTEP (2013)

*f*2(2300) $M = 2297 \pm 28$ MeV $\Gamma = 149 \pm 40$ MeV

Probably this indicates that this meson is qqstate of have large qqcomponent <u>.</u> .
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Conclusions

Hard exclusive processes are sensitive to the gluonic component of the wave function and this can be used for identification of glueballs

Experimental measurements are challenging because exclusive cross sections are quite small

- Tensor 2++ glueball is especially interesting because of specific contribution with the gluon transversity (leading twist!)
- The cross section of $\gamma\gamma\to\pi^0G(2^{++})$ is dominated by contribution with the gluon transversity which does not mix with the quarks, angular behaviour **O** Theoretical ambiguities: how large are power corrections?

Other possible processes which can be sensitive to the gluon transversity

 $s \sim -t \sim -u \gg \Lambda^2$

coupling to gluons: qq-state

Gluon DA:

$$
\langle f_2(P,\lambda) | z^{\alpha} z^{\beta} G^a_{\alpha\mu}(z) G^a_{\beta\mu}(0) |0\rangle |_{z=-z_{\perp}=0} \sim f_g^S \int_0^1 dx \, e^{ixp-z_+} \phi_g^S(x)
$$

rich gluon process

⌥(1*S*) ! *f*² *Br*[⌥(1*S*) ! *f*2] *Br*[⌥(1*S*) ! *e*⁺*e*] = 64⇡ 3 ↵2 *s*(4*m*² *b*) ↵ ¹ *^m*² *f*2 *M*² ⌥ ! ⇥ 5*f ^S ^g /*4 ⇤2 *m*² *b M*⌥ = 9*.*5GeV *m^b* ' 4*.*5GeV Figure 5. The leading contribution to the radiative decay Υ(1*S*) → γ*f*2(1270). *S ^g* (*x*) = 30*x*²(1 *^x*) 2simplest model

 $f_g^S(\mu^2=4m_b^2) = (14.9 \pm 0.8)\,\rm{MeV}$ m_b^2 γ*f*2(1270). The dominant contribution comes from the two-quark *QQ*¯ component of the

coupling to gluons: qq-state

QCD evolution mixes f_q and f_g^S

 $f_g^S(\mu^2 = 4m_b^2) = (14.9 \pm 0.8) \,\rm{MeV}$

therefore this result compatible with

 $f_g^S(1 \, \hbox{GeV}) \approx 0$

i.e. the meson consists from qq at low normalization point

