Production of tensor glueball in reaction $\gamma\gamma \to G_2 \pi^0$

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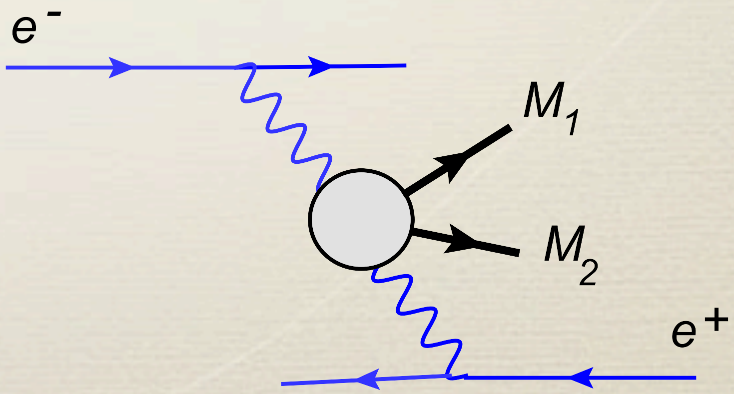
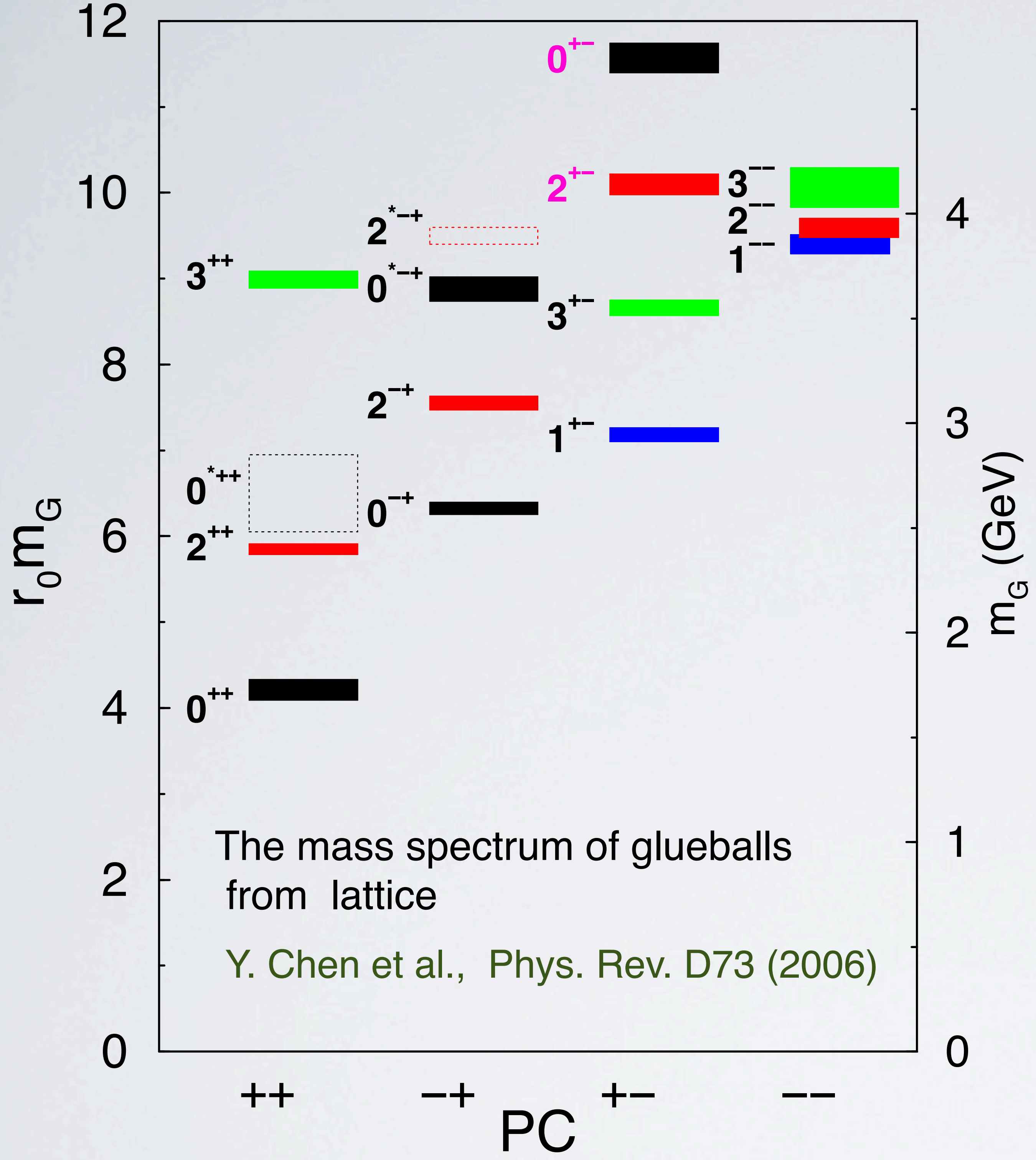
based on Phys.Lett. B781 (2018)
arXiv:1712.04285



Outline

- Motivation. Glueballs $G(2^{++})$: experimental evidence, predictions and models (9 slides)
- The process $\gamma+\gamma\to G(2^{++})+\pi^0$ as an opportunity to study tensor glueball (12 slides)
- Conclusion

Glueballs gg-state



J^{PC}	M_G (GeV/c^2)
0^{++}	1.710(.050)(.080)
2^{++}	2.390(.030)(.120)
0^{-+}	2.560(.035)(.120)

The lightest glueballs have J^{PC} quantum numbers of normal mesons and would appear as an SU(3) singlet state. If they are near a nonet of the same J^{PC} 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

Experimental evidence for tensor glueballs

PDG JPC=2++ and with masses 2.0−2.5 GeV $I^G(J^{PC}) = 0^+(2^{++})$

		f_2(2010) DECAY MODES	Fraction (Γ_i/Γ)
$f_2(2010)$	Mass $m = 2011^{+60}_{-80}$ MeV Full width $\Gamma = 202 \pm 60$ MeV	$\phi\phi$	seen
		$K\overline{K}$	seen
$f_2(2150)$	$Mass\ m = 2157 \pm 12\mathrm{MeV}$ OMITTED FROM SUMMARY TABLE	$\eta\eta$	seen
		$K\overline{K}$	seen
		$f_2(1270)\eta$	seen
		$a_2(1320)\pi$	seen
		$p\overline{p}$	seen
$f_2(2300)$	Mass $m = 2297 \pm 28$ MeV Full width $\Gamma = 149 \pm 40$ MeV	$\phi\phi$	seen
		$K\overline{K}$	seen
		$\gamma\gamma$	seen
$f_2(2340)$	Mass $m = 2339 \pm 60$ MeV Full width $\Gamma = 319^{+80}_{-70}$ MeV	$\phi\phi$	seen
		$\eta\eta$	seen
$f_J(2220)$	$Mass\ m = 2231 \pm 3.5\mathrm{MeV}$ OMITTED FROM SUMMARY TABLE	$\eta\eta'(958)$	seen

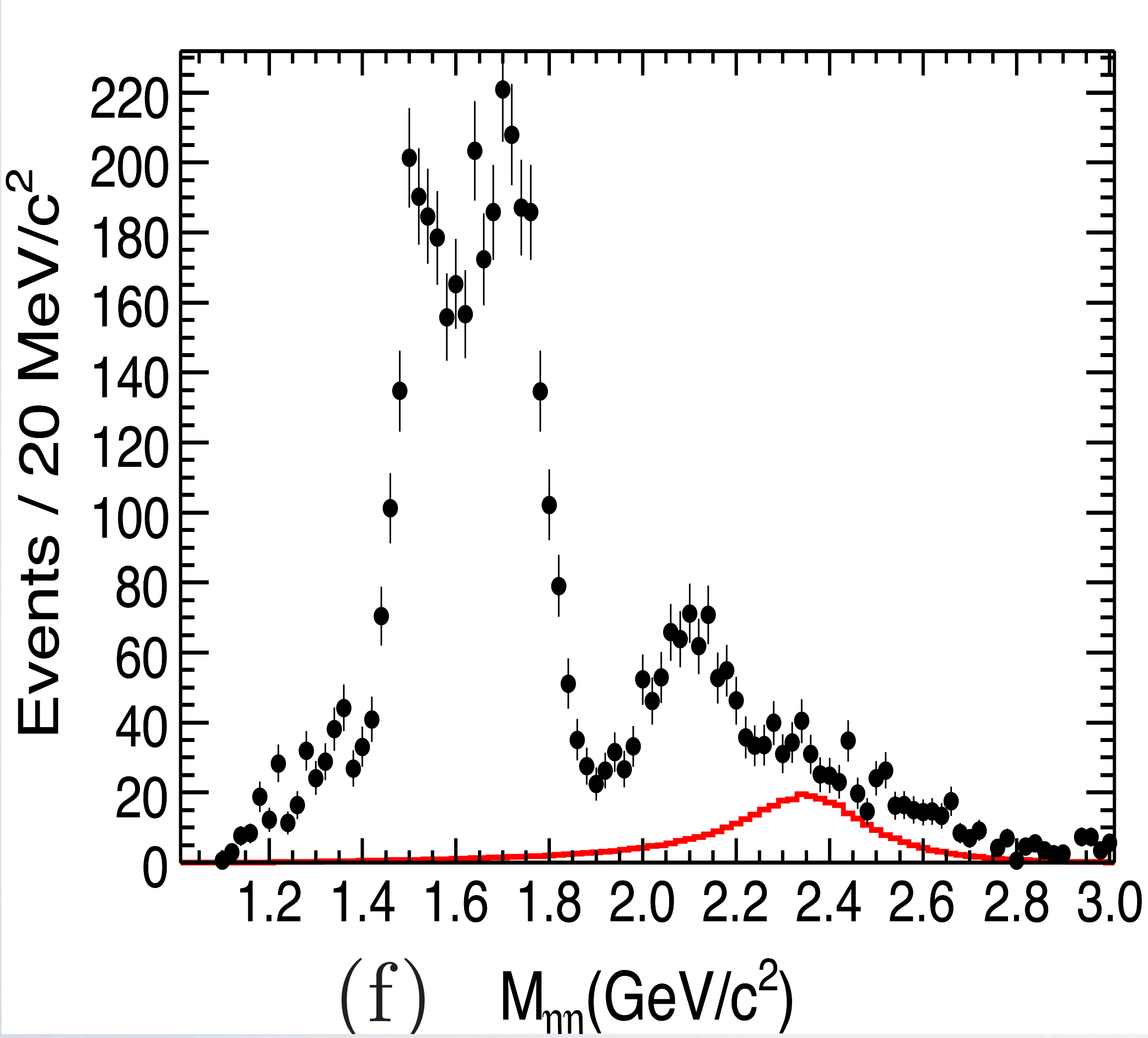
Experimental evidence for tensor glueballs

lattice prediction   Chen et al, PRL 111(2013) $Br[J/\psi \to \gamma G_2] \simeq 1.1\%$

$$M_{G_2} = 2.37\text{MeV}$$

Experiment   BES III, Ablikim et al, PRD 87(2013)

Resonance	Mass(MeV/c^2)	Width(MeV/c^2)	$\mathcal{B}(J/\psi \to \gamma X \to \gamma\eta\eta)$	Significance
$f_2(2340)$	$2362^{+31+140}_{-30-63}$	$334^{+62+165}_{-54-100}$	$(5.60^{+0.62+2.37}_{-0.65-2.07}) \times 10^{-5}$	7.6 σ



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

dots with error bars are data with the background events subtracted

Contribution of $f_2(2340)$ to the data according to PWA

Experimental evidence for tensor glueballs

Experiment BES III, Ablikim et al, PRD 93(2016)

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.

Resonance	M(MeV/c^2)	Γ(MeV/c^2)	B.F.($\times 10^{-4}$)	Sig.
$f_2(2010)$	2011	202	$(0.35 \pm 0.05^{+0.28}_{-0.15})$	$9.5\ \sigma$
$f_2(2300)$	2297	149	$(0.44 \pm 0.07^{+0.09}_{-0.15})$	$6.4\ \sigma$
$f_2(2340)$	2339	319	$(1.91 \pm 0.14^{+0.72}_{-0.73})$	$11\ \sigma$

The masses and widths are taken from PDG

Etkin et al, PRL(1978), PLB(1985), PLB(1988) $\pi^- + p \to \phi\phi n$

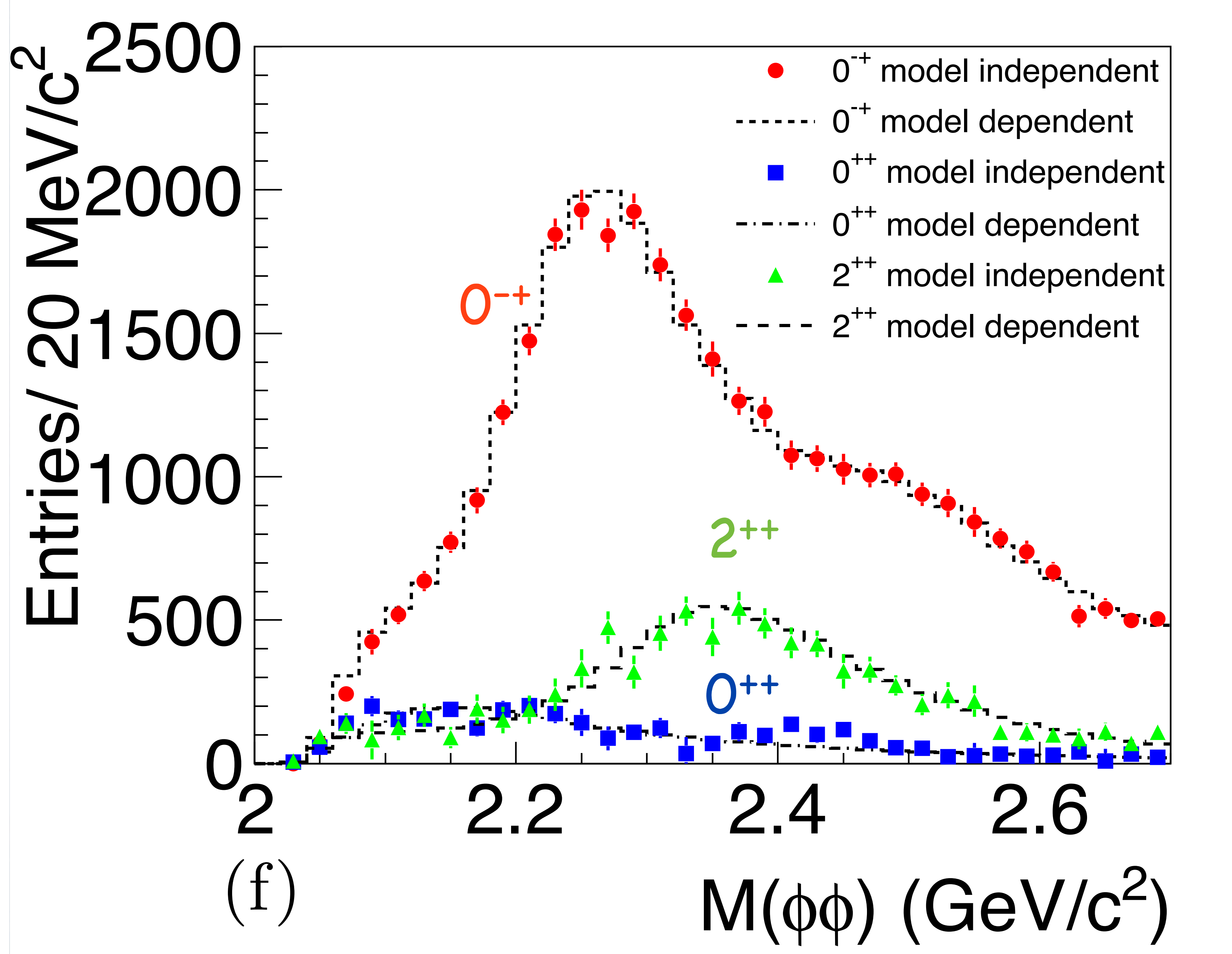
Uehara et al (BELLE), PTEP (2013) $\gamma\gamma \to K^0_S K^0_S$

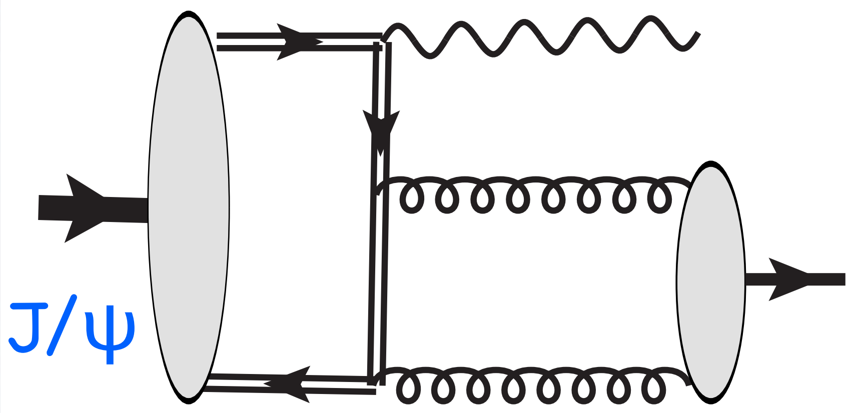
Abe et al (BELLE), EPJ (2004) $e^+e^- \to e^+e^- K^+K^-$

Experimental evidence for tensor glueballs

Experiment BES III, Ablikim et al, PRD 93(2016)

Intensities of individual J^{PC} components.





0^{-+}

$\eta(2225)$ $\eta(2100)$

2^{++}

$f_2(2010)$, $f_2(2300)$, $f_2(2340)$

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 $p\bar{p} \to \pi\pi, \eta\eta, \eta\eta'$ in the mass region 1990–2400 MeV Crystal Barrel

$\gamma\gamma \to K_S K_S$ $\gamma\gamma \to \pi^+\pi^-\pi^0$ L3 collaboration

Five 2^{++} resonanses are introduced to describe $p\bar{p}$ data

are supposed to be

$f_2(1920)$, $f_2(2240)$ $^3P_2$ $q\bar{q}$ states $f_2(2120)$, $f_2(2410)$ $^3P_2$ $s\bar{s}$ states

$f_2(2020)$, $f_2(2300)$ $^3F_2$ $q\bar{q}$ states $f_2(2340)$ $^3P_2$ $s\bar{s}$ state $s\bar{s}$ partner remains to be discovered

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

Experimental evidence for tensor glueballs

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

L.Burakovsky, P.R. Page 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 $q\bar{q}$-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)

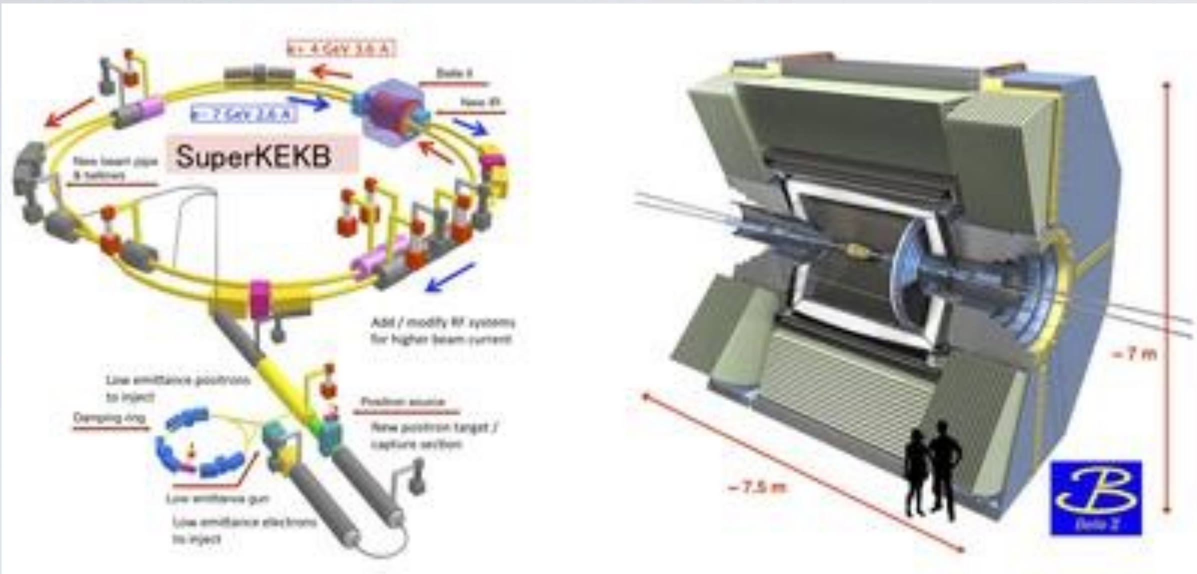
special case spin-2: there is the gluonic DA which does not mix with quarks

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 Q^2

Can one measure the cross section in BELLE II?



e^+e^- asymmetric collider

KEKB — instantaneous luminosity of 2.11×10^{34} cm^{-2} s^{-1}.

SuperKEKB — instantaneous luminosity of 8×10^{35} cm^{-2} s^{-1}

larger by a factor 40

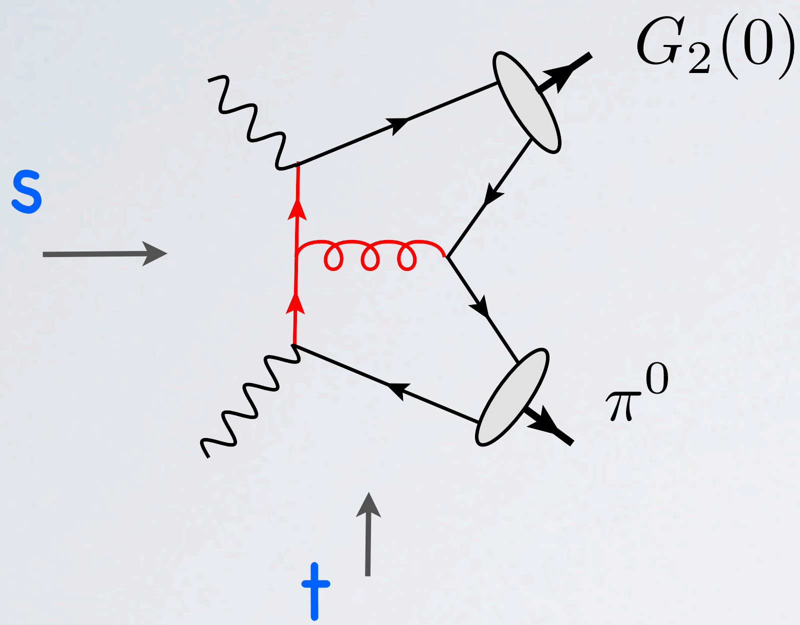
The ambitious goal is to accumulate an integrated luminosity of 50 attob^{-1} (10^{-18}) by the mid of next decade, which is 50 times more data than the previous Belle detector acquired

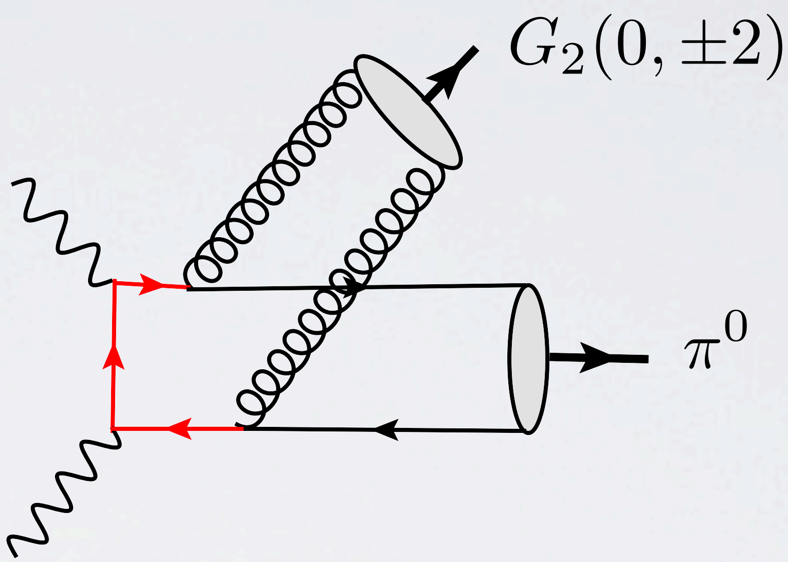
$\gamma\gamma \to \pi^-\pi^+$ $\gamma\gamma \to K^+K^-$	$2.4\,\mathrm{GeV} < \sqrt{s} < 4.1\,\mathrm{GeV}$	H. Nakazawa et al., **Phys.Lett. B615 (2005)**
$\gamma\gamma \to \pi^0\pi^0$	$0.6 < \sqrt{s} < 4.1$	S. Uehara et al., Phys. Rev. D 79 (2009)
$\gamma\gamma \to K_S^0\bar{K}_S^0$	$1.0 \le \sqrt{s} \le 4.0$	S. Uehara et al., PTEP 2013 (2013)
$\gamma\gamma \to \eta\eta$	$1.1 < \sqrt{s} < 3.8$	S. Uehara et al., Phys. Rev. D 82 (2010)

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

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

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





all terms are of order α_s

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

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

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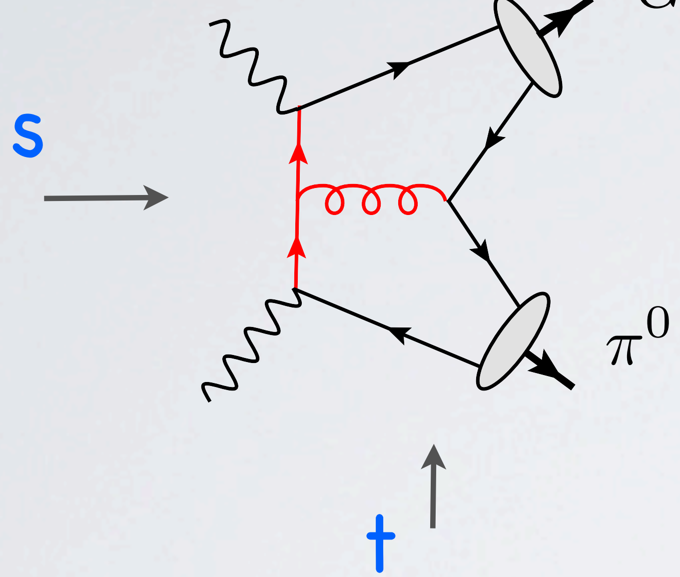
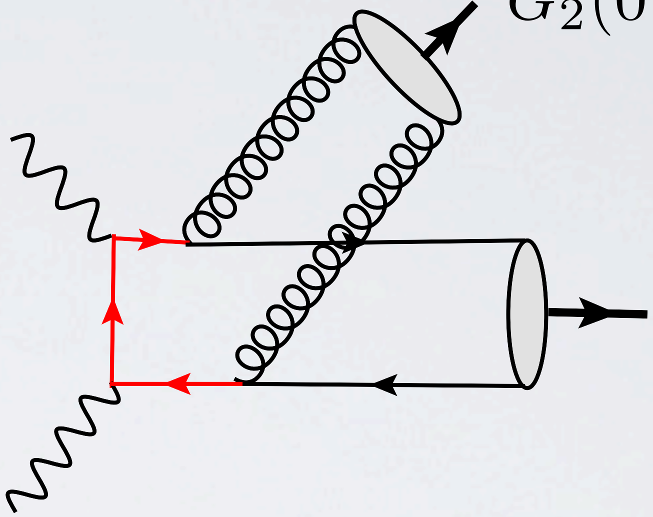




$$\frac{d\sigma_{\gamma\gamma}[\pi^0 G_2]}{d\cos\theta} = \frac{1}{64\pi} \frac{s + m_G^2}{s^2} \left(|\overline{A_{++}}|^2 + |\overline{A_{+-}}|^2 \right)$$

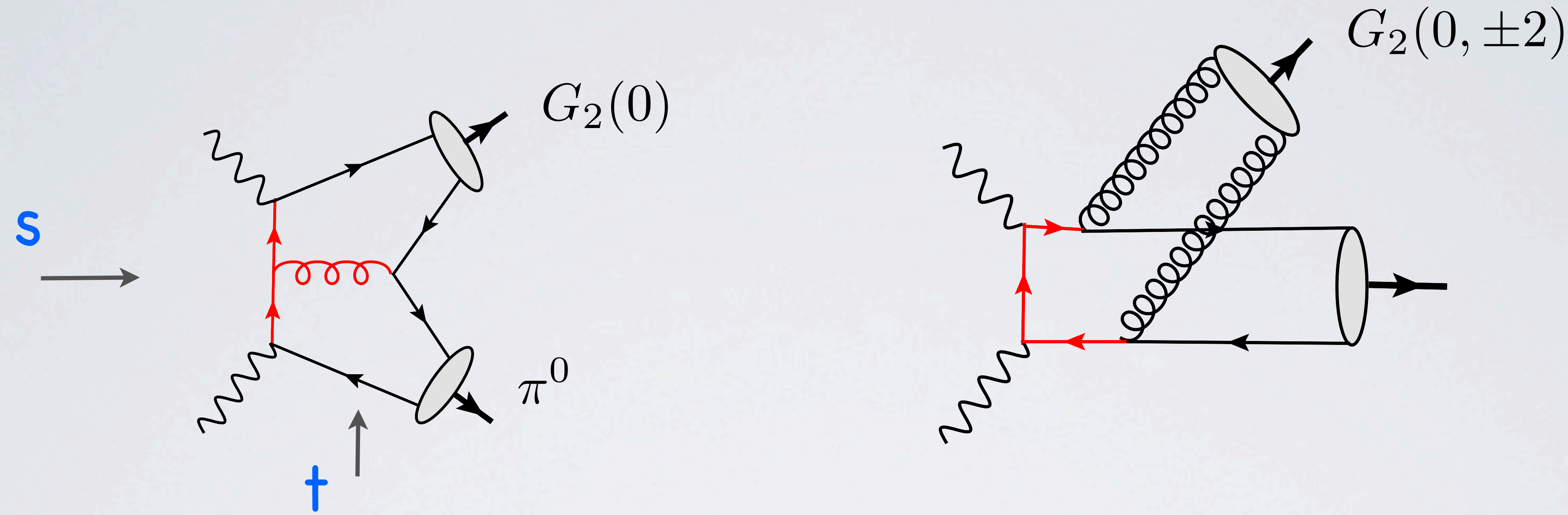
At LO

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

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

Amplitude and cross section

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

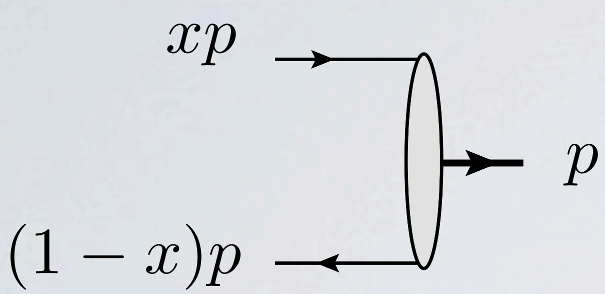


$$\frac{d\sigma_{\gamma\gamma}[\pi^0 G_2]}{d\cos\theta} \simeq \frac{\alpha_{em}^2 {\alpha_s}^2}{s}\left(\left|\frac{f_\pi f_g^T}{s} I_g^{++}(\cos\theta)\right|^2 + \left|\frac{f_\pi f_g^S}{s} I_g^{+-}(\cos\theta) + \frac{f_\pi f_q}{s} I_q^{+-}(\cos\theta)\right|^2\right)$$

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



$$\sim \int_{|k_\perp|<\mu} d^2k_\perp \Psi_{BS}(x, k_\perp) = \phi(x, \mu)$$

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: $q\bar{q}g$

$q\bar{q}$ with orbital momentum

$$V_\pm = V_0 \pm V_3$$

$$\langle G_2(p,\lambda)|\bar\psi(z)\not{z}\psi(0)|0\rangle\Big|_{z_+=z_\perp=0} = m^2 \frac{z_-}{p_+} e^{(\lambda)*}_{++} \int_0^1 dx\, e^{ixz_-p_+} f_q\phi_q(x)$$

normalization constant

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

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

$$\begin{aligned}\langle G_2(p,\lambda)| G^a_{\alpha\beta}(0) G^a_{\mu\nu}(0)|0\rangle &= \frac{1}{2} f_g^S m^2 \left\{\left[g_{\alpha\mu} e^{(\lambda)*}_{\beta\nu} - (\alpha \leftrightarrow \beta)\right] - (\mu \leftrightarrow \nu)\right\} \\ &+ f_g^T \left\{\left[\left(p_\alpha p_\mu - \frac{1}{2} m^2 g_{\alpha\mu}\right) e^{(\lambda)*}_{\beta\nu} - (\alpha \leftrightarrow \beta)\right] - (\mu \leftrightarrow \nu)\right\}\end{aligned}$$

Light-cone distribution amplitudes

only for tensor polarisation $\lambda = \pm 2$

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

such component does not mix with quarks

$$\langle G_2(p,\lambda)|\bar\psi(z) \overleftrightarrow{D}_{\{\perp\mu} \overleftrightarrow{D}_{\perp\nu\}} \not{z} \psi(0)|0\rangle \quad \Rightarrow \quad \sim \frac{\Lambda^2}{Q^2}$$

Models for DAs

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

Asymptotic shapes for glueball DAs

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

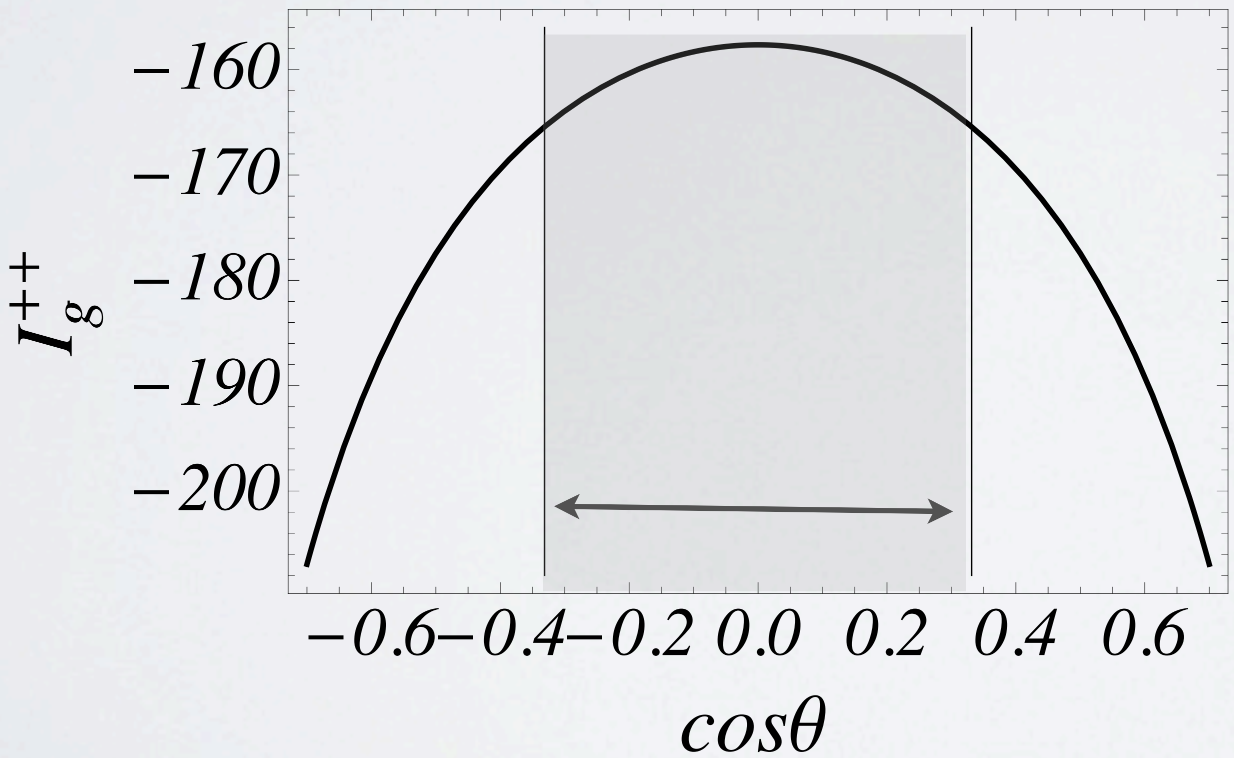
$$\phi_g^T(x) = 30x^2\bar x^2$$

Angular behaviour

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

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

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



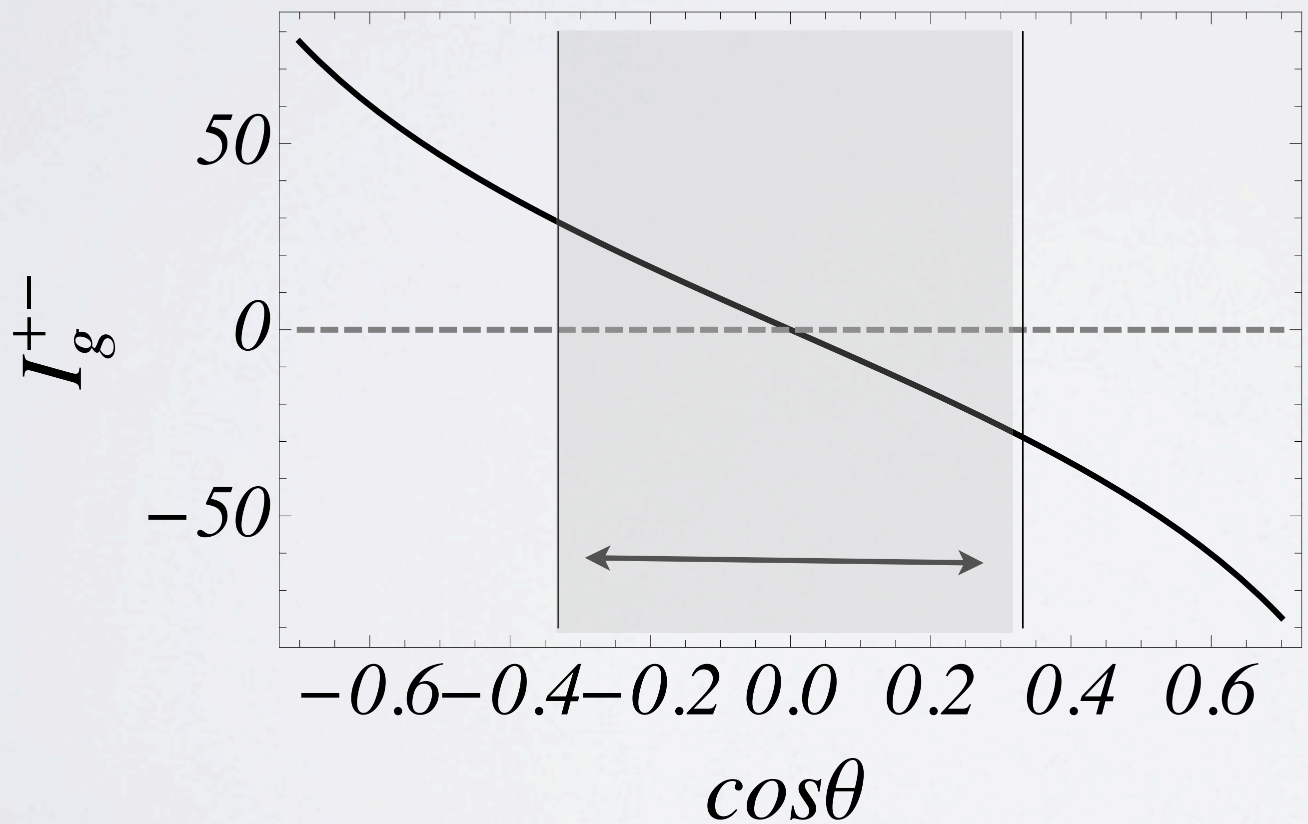
$$s \sim -t \sim -u \gg \Lambda^2$$

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

Angular behaviour

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

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



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

$|u|, |t| \geq 2.5\text{GeV}^2$

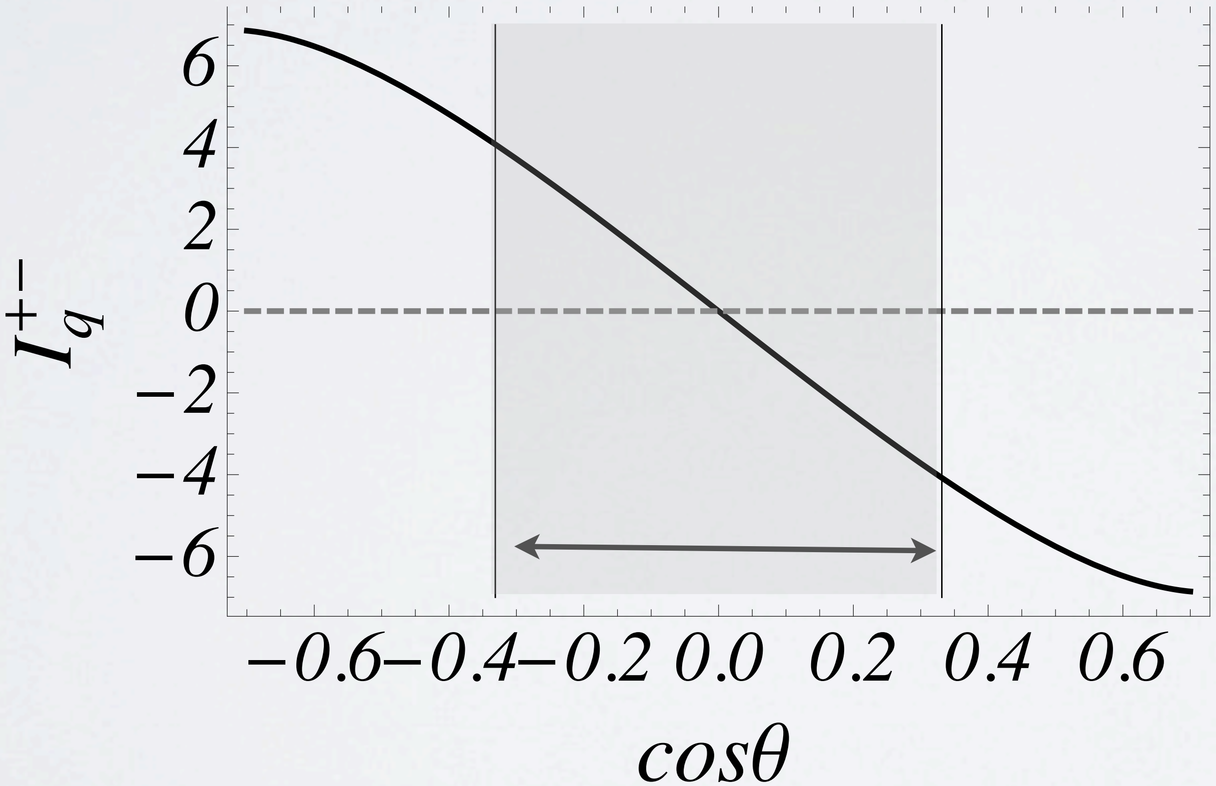
☛ $|I_g^{++}| \gg |I_g^{+-}|$

s = 13GeV²

Angular behaviour

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

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



☛ $|I_g^{++}| \gg |I_g^{+-}| \gg |I_q^{+-}|$

at large angles G_2 is dominantly produced in the tensor polarization

Summary of the nonperturbative input

Models for DAs

$$f_\pi = 131 \text{ MeV}$$

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

$$a_2(\mu = 1\text{GeV}) = 0.20$$

Asymptotic shapes for glueball DAs

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

Low energy couplings

$$\mu = 1\text{GeV}$$

$$f_g^S \simeq 100 \text{ MeV} \qquad f_q \simeq 10 - 100 \text{ MeV}$$

$$f_g^T \simeq 50 - 150\text{MeV}$$

Compare with

$$\langle G(0^{-+})|G_{+\mu}\tilde{G}_{+\mu}|0\rangle = f_G$$

Wakely and Carlson, Phys. Rev. D 45 (1992)

$$f_G = 105\text{MeV}$$

QCD sum rules

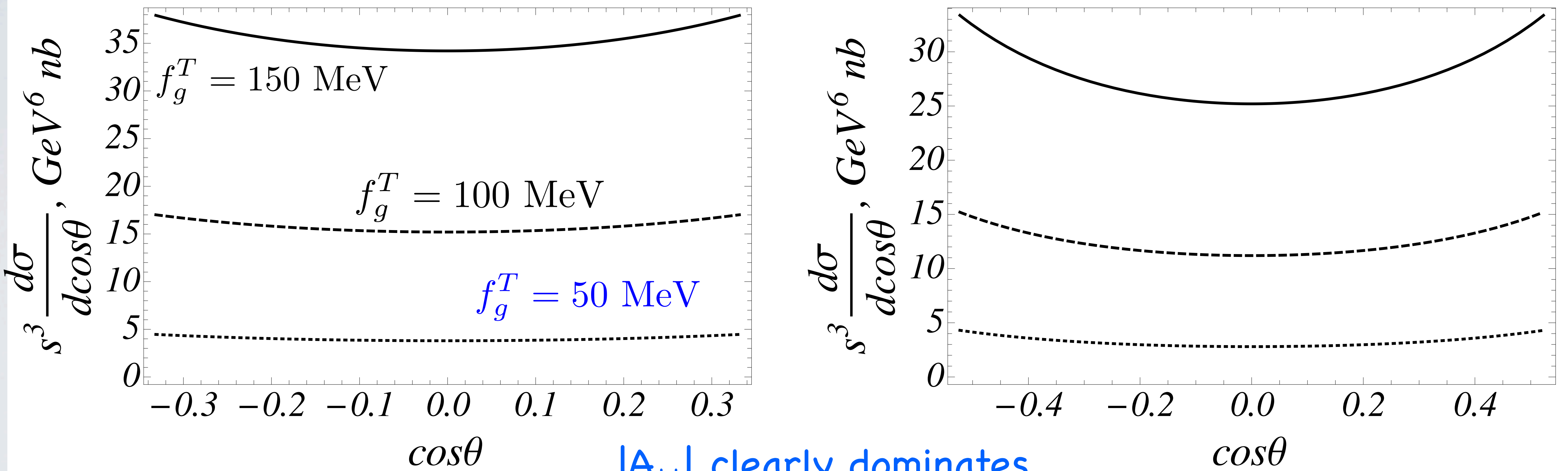
m_G = 2.3 GeV   s = 13, 16 GeV^2

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

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 = 13GeV² $|t| \,\&\, |u| > 2.5~\mathrm{GeV}^2$ s = 16GeV²



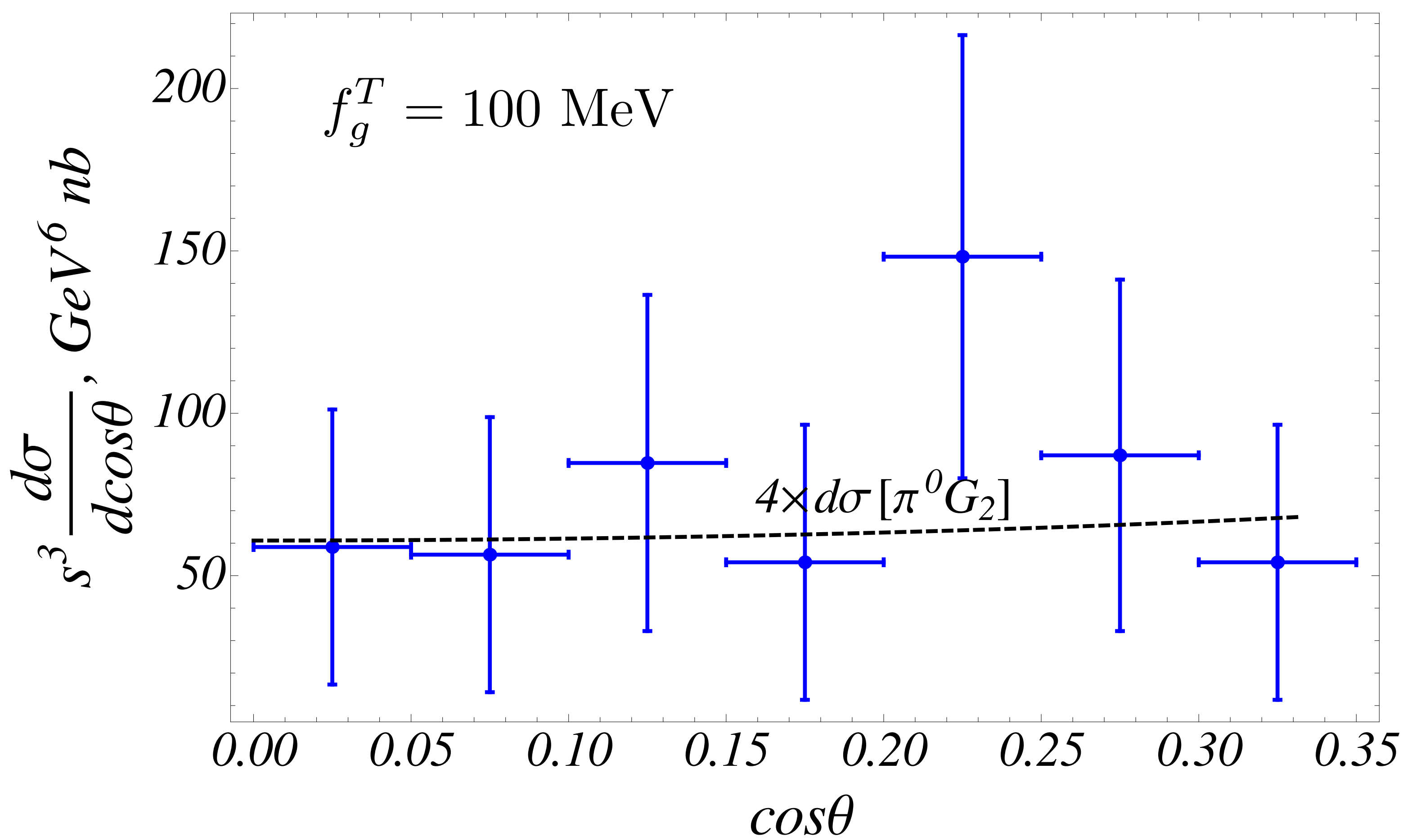
|A_{++}| clearly dominates

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

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

Can one measure the glueball cross section in BELLE II?

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



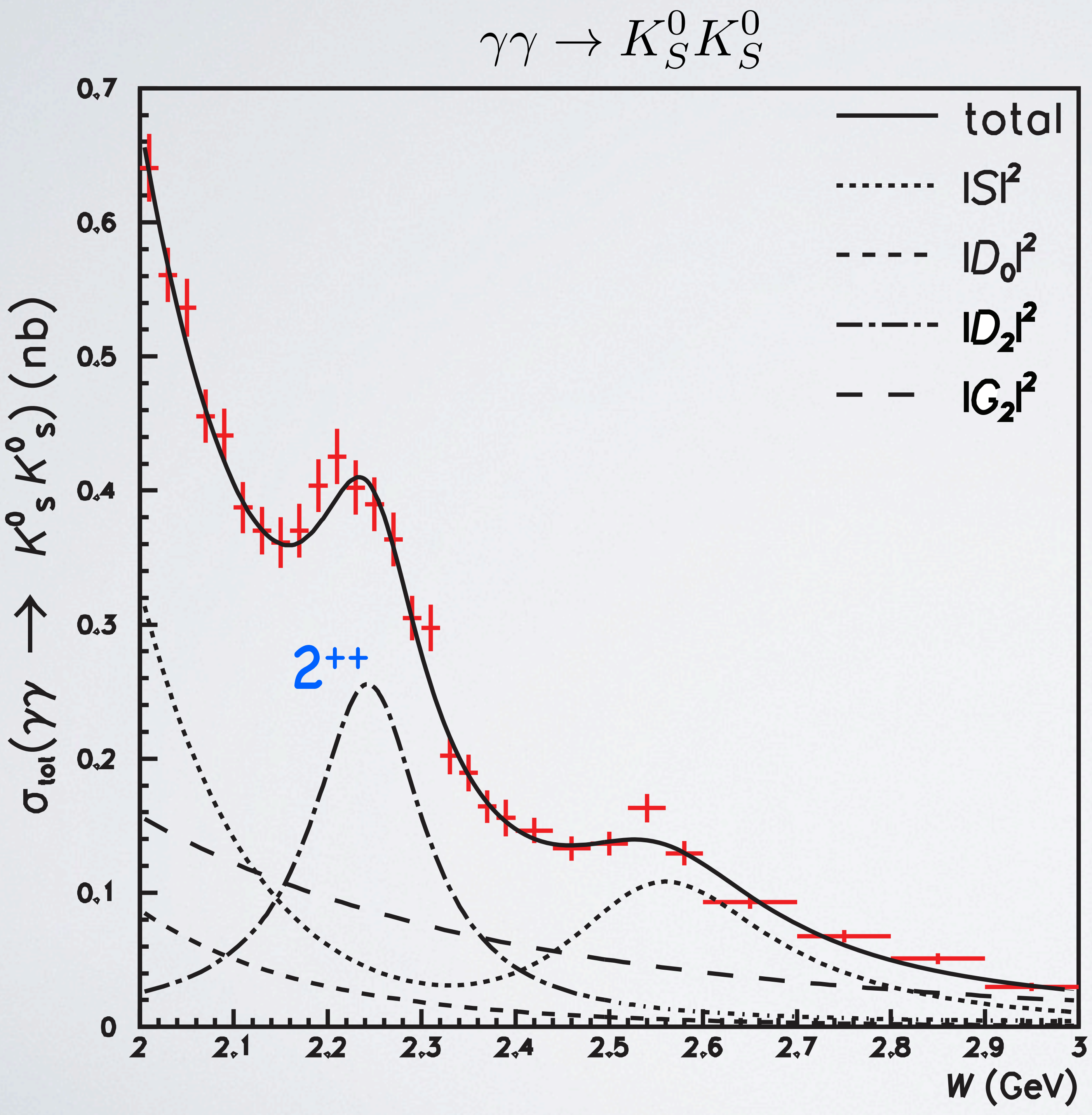
s = 13GeV^2

$$|t|\ \&\ |u| > 2.5\ \mathrm{GeV}^2$$

observable $\dfrac{d\sigma[\gamma\gamma \to \phi\phi\pi^0]}{d\cos\theta}$ 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 $q\bar{q}$-state of have large $q\bar{q}$-component

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

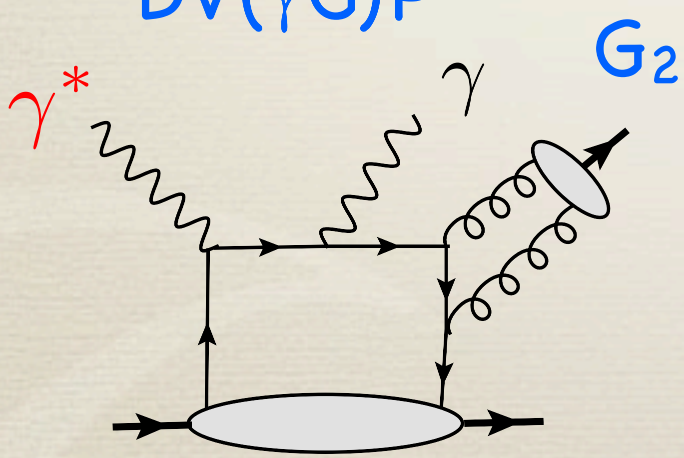
- Tensor 2^{++} glueball is especially interesting because of specific contribution with the gluon transversity (leading twist!)

- The cross section of $\gamma\gamma \to \pi^0 G(2^{++})$ is dominated by contribution with the gluon transversity which does not mix with the quarks, angular behaviour

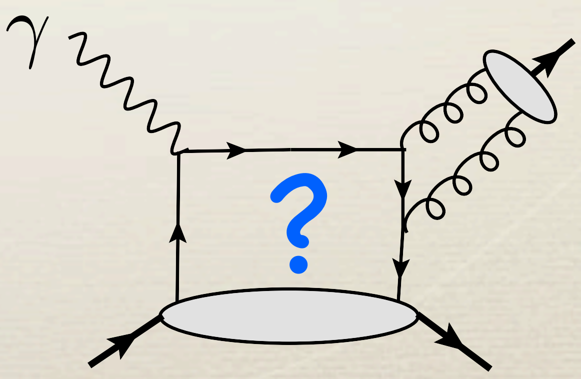
- Theoretical ambiguities: how large are power corrections?

- Other possible processes which can be sensitive to the gluon transversity

DV(γG)P



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



Thank you!

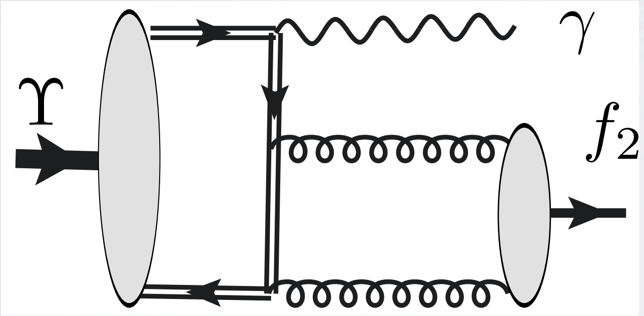
coupling to gluons: qq-state

Gluon DA:

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

rich gluon process

$\Upsilon(1S) \to \gamma f_2 \qquad M_\Upsilon = 9.5\text{GeV} \qquad m_b \simeq 4.5\text{GeV}$



$$\frac{Br[\Upsilon(1S)\to\gamma\ f_2]}{Br[\Upsilon(1S)\to e^+e^-]} = \frac{64\pi}{3}\frac{\alpha_s^2(4m_b^2)}{\alpha}\left(1-\frac{m_{f_2}^2}{M_\Upsilon^2}\right)\frac{\left[5f_g^S/4\right]^2}{m_b^2}$$

simplest model

$$\phi_g^S(x) = 30x^2(1-x)^2$$

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

coupling to gluons: qq-state

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

therefore this result compatible with

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

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

QCD evolution mixes f_q and f_g^S