Analysis of γγ→J/ψγ

Y.Seino (Niigata Univ), H.Miyata (Niigata Univ) for the Belle collaboration

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Abstract: Many models to describe the nature of the heavy quarkonia have been proposed and we can test such models by analyzing charmonium states produced in two-photon collisions through measuring their two-photon decay width($\Gamma_{\gamma\gamma}$) and the angular distribution since they provide us information on properties and internal structure of charmonium states. In this analysis, we use the decay channel $\gamma\gamma \to X \to J/\psi\gamma$, $J/\psi \to l^+l^-$ (l = e or μ) in the 980.4 fb^{-1} Belle data sample, where X is a charmonium state. Previously, Belle and CLEO collaborations have reported the measurement of $\gamma\gamma \to \chi_{c2}(1P) \to J/\psi\gamma$, $J/\psi \to l^+l^-$ using 32.6fb^{-1} and 14.4fb^{-1} samples, respectively. By analyzing an about 30 times larger data sample, we can make a more precise measurement of $\chi_{c2}(1P)$ and other rare charmonium states including a new charmonium(-like) state. In this presentation, we discuss the purpose and method of the analysis and show the result of the feasibility study using Monte Carlo (MC) samples of $\gamma\gamma \to X \to J/\psi\gamma$.

Belle Experiment

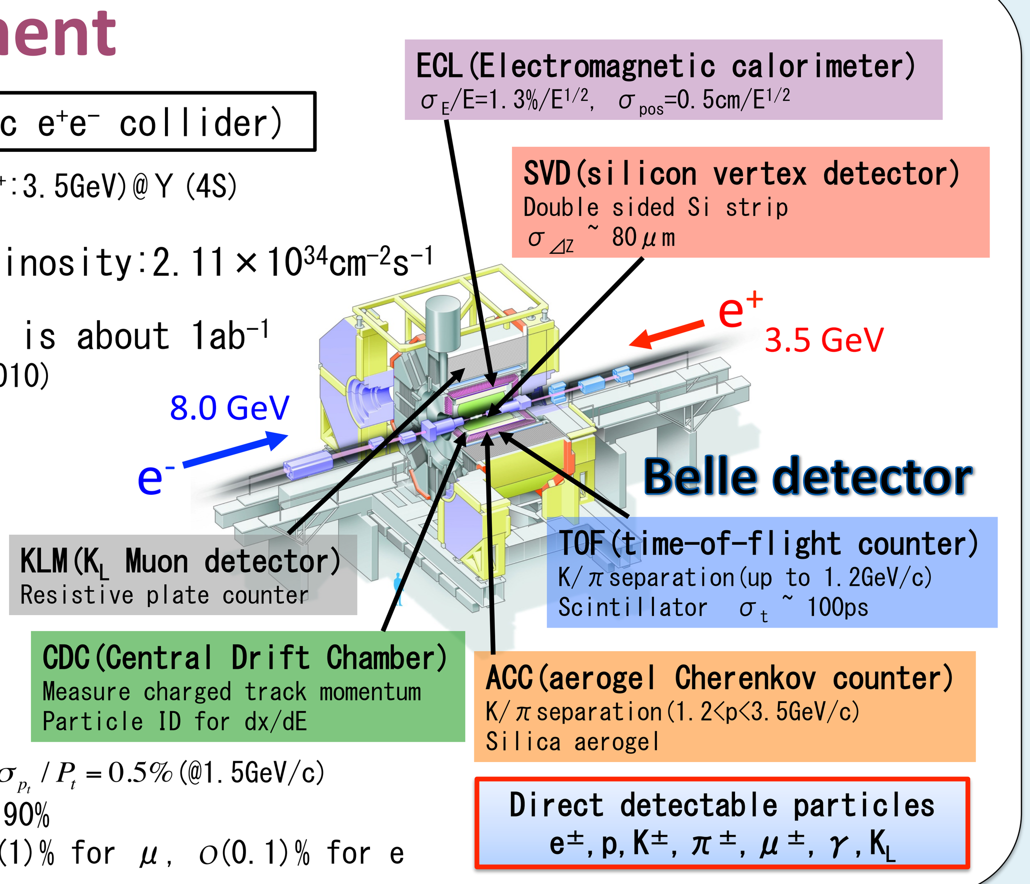
KEKB collider (Asymmetric e⁺e⁻ collider)

$\sqrt{s}$=10.58GeV (e⁻:8.0GeV, e⁺:3.5GeV) @ Υ(4S)

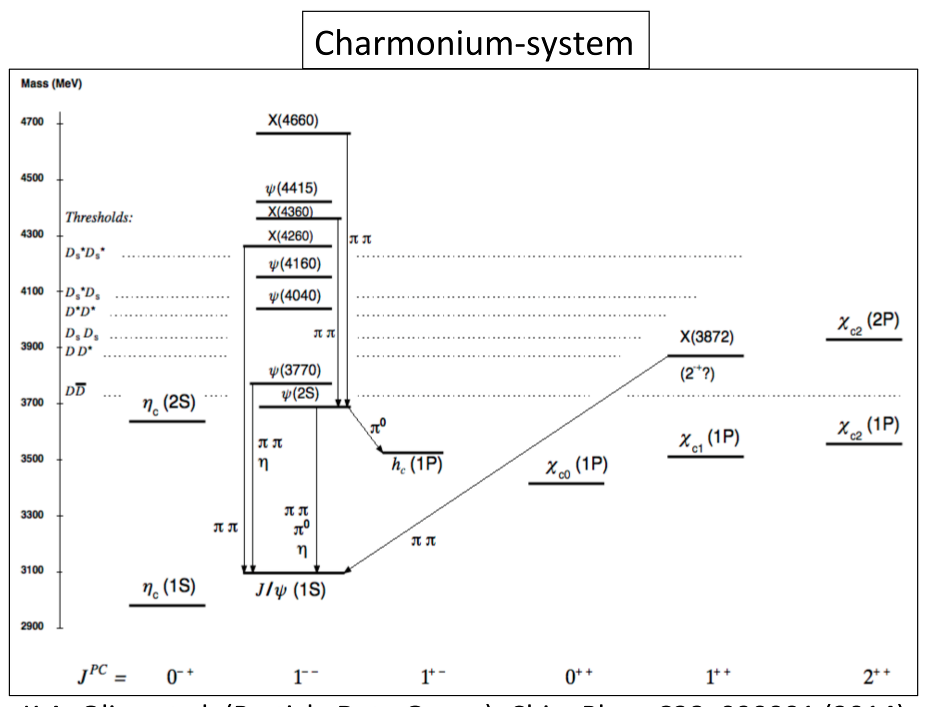
- The world-highest luminosity: 2.11×10^{34}cm^{-2}s^{-1}
- Integrated luminosity is about 1ab^{-1}
  (Operation period: 1999～2010)
  Υ(4S): 711fb^{-1}
  Υ(5S): 121fb^{-1}
  Υ(3S): 3fb^{-1}
  Υ(2S): 24fb^{-1}
  Υ(1S): 5.7fb^{-1}
  Off-resonance: 87fb^{-1}

Belle detector

- Complex detector
  →Track reconstruction: $\sigma_{p_t}/p_t = 0.5\%$ (@1.5GeV/c)
  →Lepton ID: Efficiency ≥ 90%
  Fake rate: $O(1)$% for μ, $O(0.1)$% for e

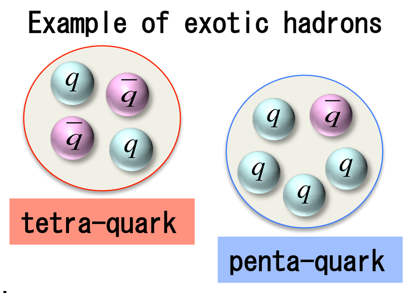


Analysis Motivation (Analysis of Charmonium(-like) States)



K.A. Olive et al. (Particle Data Group), Chin. Phys. C38, 090001 (2014)

- In this century, heavy quarkonium spectroscopy has been developed from the result of many experiments.
- For establishing theory of hadron formation from quarks, we have to research properties, internal structure of the hadrons and discover more new hadrons.
- In 2003, X(3872) which is considered as exotic hadron, was discovered at Belle experiment. After that, many particles which may be exotic have been discovered at various experiments. Exotic hadrons become a popular field at the moment.



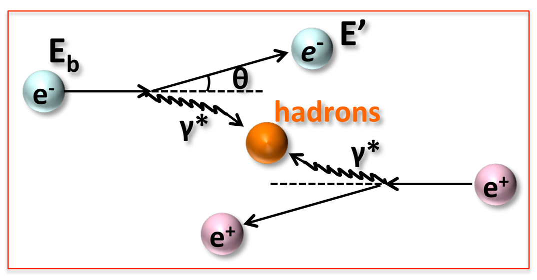
- We will analyze charmonium states and Charmonium-like (candidate of exotic charmonium("XYZ" states)) states to develop heavy quarkonium spectroscopy.

Analysis of γγ → J/ψγ (two-photon process)

Two-photon process

- At an e⁺e⁻ collider We can observe a hadronic system from collisions of virtual or quasi-real photons from beams.
- Radiative photon from the beam is virtual. Virtual $Q^2(=-q^2$: q is 4-momentum of virtual photon) is expressed by below formula.

$$Q^2 = 4E_bE'\sin^2\frac{\theta}{2}$$

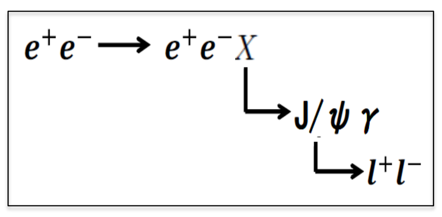


Hadron production from two-photon process

- In the case of P_t-balance(θ≈0) requirement of the hadronic system, we can measure the single resonance formation from the quasi-real photons collision(Q≈0).
- Assuming a quasi-real photons collision, there are constraints on quantum numbers of the resonance.
  (neutral meson, C-parity=+, J^P=(even)$^\pm$ or (odd≠1)$^+$)
- Observing the quasi-real photons collision, we can measure two-photon decay width($\Gamma_{\gamma\gamma}$) from cross-section of the produced meson. $\Gamma_{\gamma\gamma}$ gives information of internal structure of produced meson.

The contents of analysis

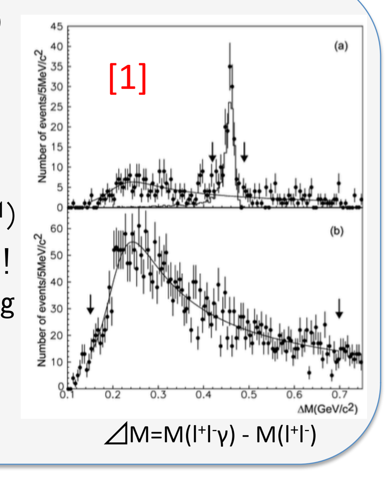
- In order to measure properties and internal structure of charmonium(-like) states, we analyze the channel of $\gamma\gamma \to J/\psi\gamma$, $J/\psi \to l^+l^-$ (l=e or μ).
- We plan to perform the following:
  ① More precise measurement of χ_{c2}(1P). (Update of the Belle result[1])
  ② Search for new charmonium(-like) states.
  ③ Analysis with bad-P_t-balance.



Analysis channel

If possible, we like to try analyzing it. The details will be discussed later.

χ_{c2}(1P) (nominal mass: 3.556GeV/c²) is one of charmonium states. In the previous research, the channel of $\gamma\gamma \to \chi_{c2}(1P) \to J/\psi\gamma$ was measured at Belle[1] and CLEO[2]. ([1]: 32.6fb^{-1}, [2]: 14.4fb^{-1}) Now we have much more statistics! Using about 980.4fb^{-1} and reducing systematic error, the parameters of χ_{c2}(1P) will be more precise measured than before.



⊿M=M(l⁺l⁻γ) - M(l⁺l⁻)

In the previous results([1],[2]), the statistics have not been sufficient to measure charmonium states except χ_{c2}(1P). In this analysis, 30 times larger statistics may enable us to measure the other charmonium states. We may be able to measure the other charmonium states. (For example, we expect that χ_{c2}(2P) can be measured.)

[1] Phys. Lett. B 540, 33 (2002).
[2] Phys. Lett. D 73, 071101 (2006).

MC study

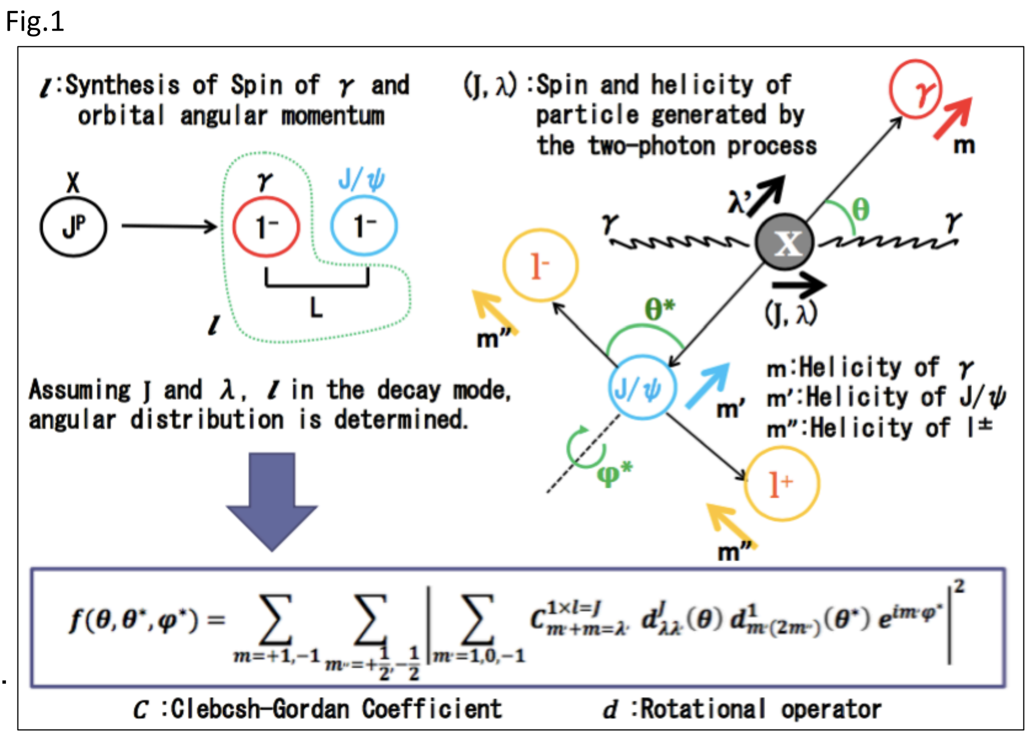
[3] S. Uehara, KEK Report 96-11 (1996).

Generation and detector simulation of signal MCs

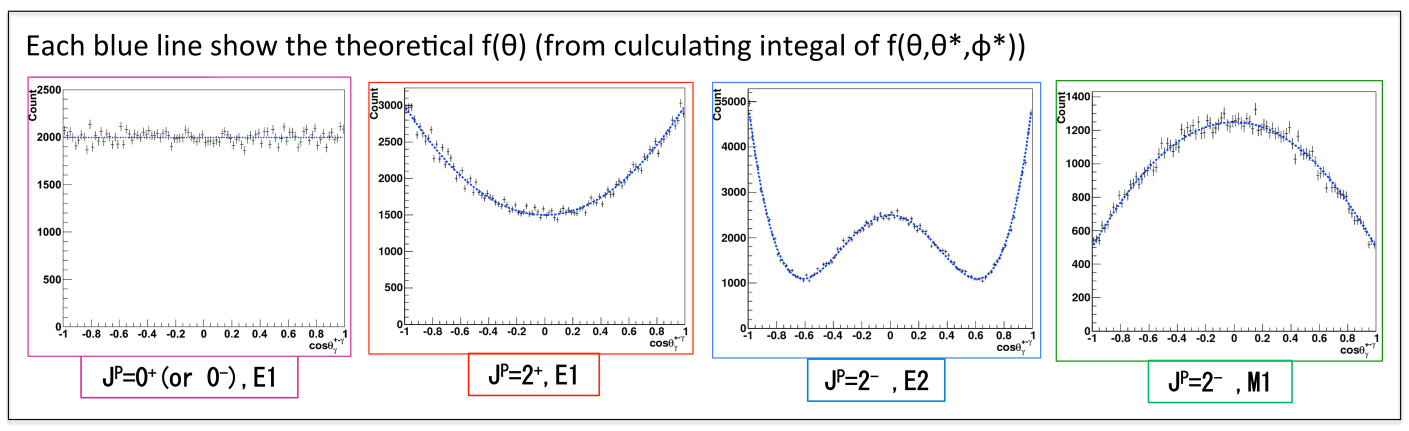
- We use MC samples $\gamma\gamma \to X$(Assumed charmonium state)$\to J/\psi\gamma$ to estimate the efficiency for the signal process. (The TREPS MC program[3] is used as an event generator.)
- As seen in Fig.1, the angular distribution of X(Assumed charmonium state) follows the parameters of J, λ and l in the decay mode. (by measuring the angular distribution of charmonium state, we get information on the quantum numbers of charmonium state.)
- To measure known charmonium state and search for new charmonium states, we generate the signal MC samples having 4 different type angular distributions and various charmonium states masses. (3.1-4.5GeV/c²)

(1) Generated particle is J^P=0⁺(or 0⁻) and l=1(E1 transition), λ=0
(2) Generated particle is J^P=2⁺ and l=1(E1 transition), λ=2
(3) Generated particle is J^P=2⁻ and l=1(M1 transition), λ=0
(4) Generated particle is J^P=2⁻ and l=2(E2 transition), λ=0

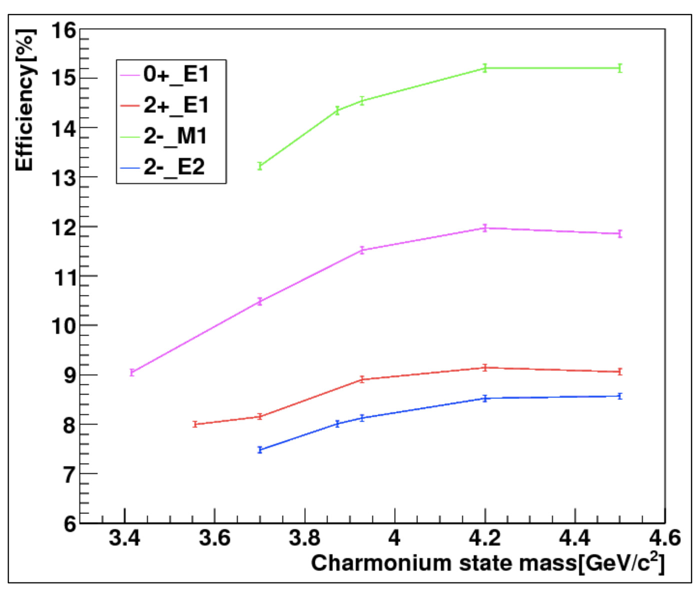
Fig.1



- Fig.2: Distribution of the polar angle(θ) of the photon in the l⁺l⁻γ c.m. frame for each type MC sample of 4.2GeV/c² charmonium state mass.



- Fig.3: Signal detection efficiency of each type MC samples depending on charmonium states.



Event Selection

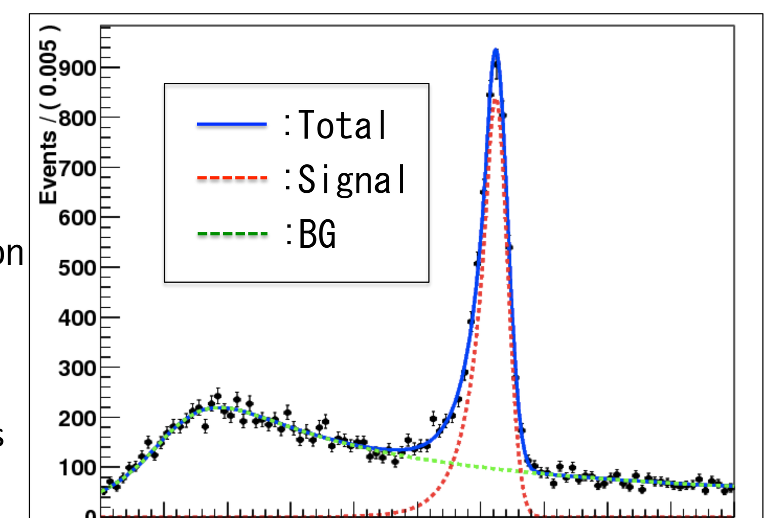
- Only two oppositely-charged particles from J/ψ
  - -0.47 ≤ cosθ ≤ 0.82
  - Pt ≥ 0.4[GeV/c]
  - |dr| ≤ 1[cm]
  - |dz| ≤ 3[cm]
  - |Δdz| ≤ 1[cm]
  - cos α > -0.997
  α: The opening angle of the two tracks
- Lepton PID (E:energy deposit on ECL P:momentum)
  Electron : E/P ≥ 0.8 Muon : 0.0 ≤ E/P ≤ 0.4
- Only one photon cluster with E_γ ≥ 0.2[GeV] at ECL
  - The total energy deposit on ECL is less than 6.0[GeV]
  - Cluster is isolated from the charged tracks by more than 18.2°
- Rejection of ISR process
  M^2_{reco} = $(E^*_{beam} - E^*_{J/\psi})^2 - P^{*2}_{J/\psi}$ ≥ 5.0[GeV]
- Reconstruction of J/ψ by two charged particles
  - $P_{J/\psi}$ ≤ 6.0[GeV/c]
  - $M_{J/\psi}$ ≤ 4.5[GeV/c²]
- Transverse momentum of total cut for two-photon process
  - $\Sigma_{\leftarrow}|Pt^*|$ > 0.10[GeV/c]
  - $\Sigma_{+-\gamma}|Pt^*|$ < 0.15[GeV/c]

Fitter test and expected value of $\Gamma_{\gamma\gamma}(\chi_{c2}(1P))$

- We perform a fitter test using the toy MC made from the PDFs defined by signal MC and the previous result[1]. Here the expected numbers of signals and backgrounds are estimated by an extrapolation from the previous result[1]. (the below table is summary of the toy MC.)

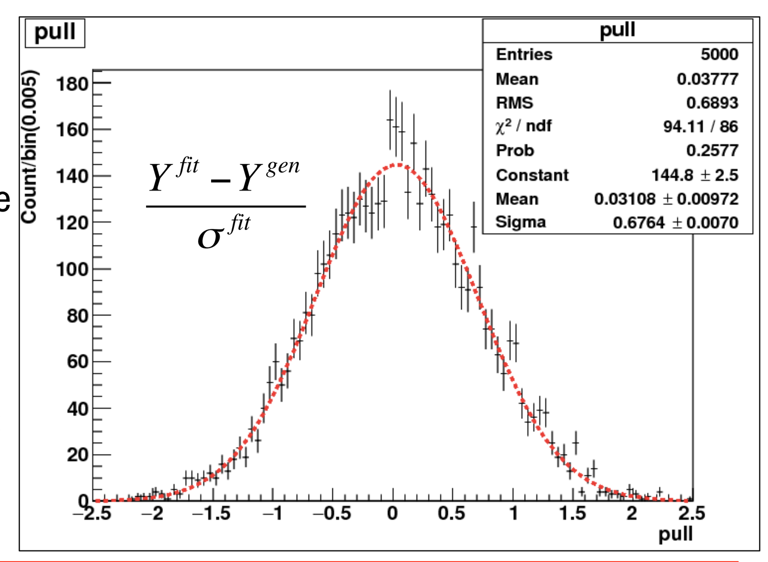
	Expected number (⊿M=0.15～1.45GeV)	PDF shape
Signal part	4941	Signal MC
Background part	18035	Previous result[1]

- Fig.4: The result of fit using our toy MC. Signal and background part are fitted with the Crystal Ball function (all of the parameters are floated) and a function of (⊿M-a)$^{-b}$/(1+exp(-c(⊿M-d))) (a, b, c, d are fixed with the previous result[1]), respectively.



- Fig.5: Pull distribution as a result of fitter test, where pull is defined as ($Y^{fit}-Y^{gen}$)/σ^{fit}, and we generate 5000 toy MC samples for fitter test.

Y^{fit}: yield of fit result
Y^{gen}: generated yield at toy MC
σ^{fit}: err of fit result



The expected result from the estimated efficiency and the fitter test:

$$\Gamma_{\gamma\gamma}(\chi_{c2})Br(\chi_{c2} \to J/\psi\gamma)Br(J/\psi \to l^+l^-) = 13.5 \pm 0.2(stat.) \pm 0.5(syst.)$$

Previous result[1]: $13.5 \pm 1.3(stat.) \pm 1.1(syst.)$

Here, we suppose that systematic error will be 4.0%.

Analysis with bad-P_t-balance

[4] G.A.Schuler et al., NP B523, 423 (1998).

- In the case of loose P_t-balance cut(bad-P_t-balance), production of charmonium(-like) state violating the constraints of quantum numbers by the quasi-real photons collision is expected[4].
- We may be able to report the first measurement of χ_{c1}(1P) (J^{PC}=1^{++}) in the two-photon process with the bad-P_t-balance thanks to the advantage of high statistics(980.4fb^{-1}).
- Because BelleⅡ experiment(the target of integrated luminosity is 50ab^{-1}) is prepared, we like to establish analysis with the bad-P_t-balance in advance.

Summary and next step

- To test models describing the nature of heavy quarkonia, we study $\gamma\gamma \to X \to J/\psi\gamma$, $J/\psi \to l^+l^-$ (l = e or μ) with the 980.4fb^{-1} Belle data sample. We will measure the two-photon decay widths($\Gamma_{\gamma\gamma}$) and the angular distribution of charmonium(-like) states.
- We estimate the efficiency of several charmonium(-like) states and confirm the stability of our fit by performing the fitter test. From them, we evaluate $\Gamma_{\gamma\gamma}(\chi_{c2}(1P))Br(\chi_{c2} \to J/\psi\gamma)Br(J/\psi \to l^+l^-)$. It turns out that the statistic error will be 1.5%. (the previous result[1]: 9.6%)
- After the MC study, we start the analysis using the data sample to measure and search charmonium(-like) states soon.