

Study of ISR process $e^+e^- \rightarrow \gamma_{\text{ISR}}\Lambda\bar{\Lambda}$ and two-photon process
 $\gamma^{(*)}\gamma^{(*)} \rightarrow \omega\omega$ via untagged method.

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October 11, 2026

Outline

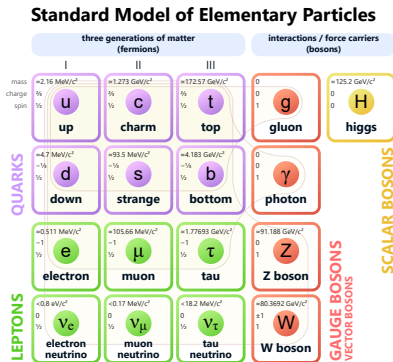
1. Introduction
2. Untagged Analysis of $e^+e^- \rightarrow \gamma_{\text{ISR}}\Lambda\bar{\Lambda}$
3. Untagged Analysis of $\gamma^{(*)}\gamma^{(*)} \rightarrow \omega\omega$
4. Summary and Prospects

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Quantum Chromodynamics (QCD)

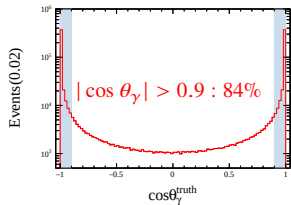
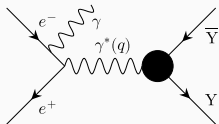
- ▶ The Standard Model describes three fundamental interactions, including the **strong interaction** governed by Quantum Chromodynamics (QCD).
- ▶ At low energies, the strong interaction exhibits significant **nonperturbative effects**, making precise theoretical predictions challenging.
- ▶ **Experimental measurements** of diverse processes and observables at e^+e^- colliders provide important probes of QCD and **hadron structure**.



Forward Physics

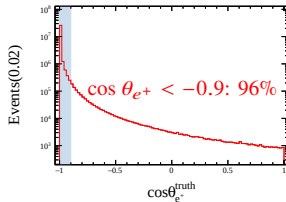
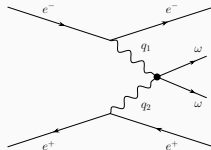
At e^+e^- colliders, particles **emitted at small angles** relative to the beam axis may escape detection through the beam pipe, motivating **untagged analyses**.

Untagged ISR: $e^+e^- \rightarrow \gamma_{\text{ISR}} X$

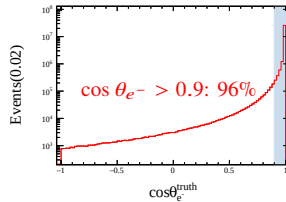


ISR photon: peaked at $|\cos \theta_\gamma| \rightarrow 1$.

Untagged Two-Photon: $e^+e^- \rightarrow e^+e^- X$



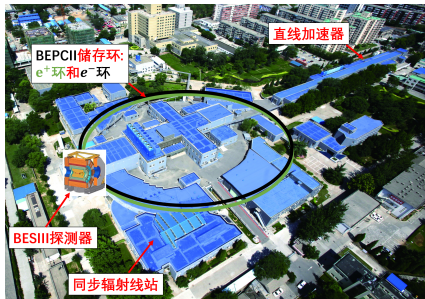
Scattered beam leptons: peaked at $|\cos \theta_{e^\pm}| \rightarrow 1$.



Untagged: Reconstruct only X , **enhancing acceptance, extending kinematic reach, and increasing statistics.**

BEPCII and BESIII

► BEPCII



$$E_{cm} = 1.84 \sim 4.95 \text{ GeV}$$

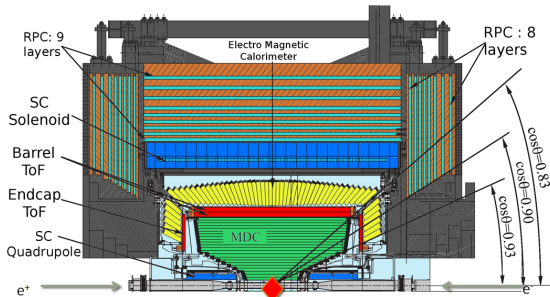
Peaking luminosity:

$$1.1 \times 10^{33} \text{ cm}^{-2} \text{s}^{-1} @ 3.773 \text{ GeV}$$

Crossing angle: $2 \times 11 \text{ mrad}$

Circumference: 237.53 m

► BESIII



MDC: Small cell, 43 layers, $\sigma_{xy} = 130 \mu\text{m}$, $dE/dx \sim 6\%$, $\sigma_p/p = 0.5\% @ 1 \text{ GeV}$.

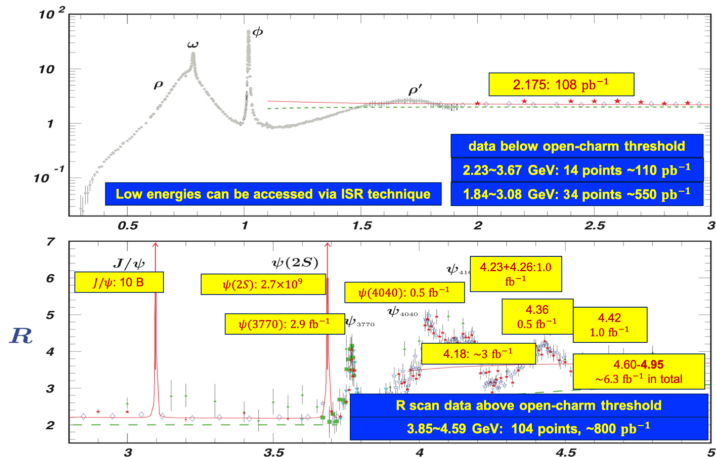
TOF: Plastic scintillator, $\sigma_T = 68 \text{ ps}$ (barrel), 110 ps (endcap); MRPC: 60 ps.

EMC: CsI(Tl), $L = 28 \text{ cm}$, $\sigma_E = 2.5\%$ (barrel), 5.0% (endcap).

MUC: RPC, 9/8 layers (barrel/endcap), $\sigma_{\text{spatial}} = 1.48 \text{ cm}$.

BESIII data sets

BESIII detector records symmetric e^+e^- collisions in the τ -charm region(1.84–4.95 GeV).



- Ideal environment to study QCD and hadron structure: both energy scan and ISR methods.
- The following analyses use large data samples at high energies ($\sqrt{s} = 3.773\text{--}4.288$ GeV).

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Motivation

- ▶ **Electromagnetic form factors (EMFFs)** probe baryon structure and non-perturbative strong interaction dynamics.
- ▶ In the time-like region, the EMFFs are **complex quantities**, where the electric (G_E) and magnetic form factors (G_M) contain both magnitude and phase information.
- ▶ The cross section of $e^+e^- \rightarrow \Lambda\bar{\Lambda}$ provides access to G_E and G_M :

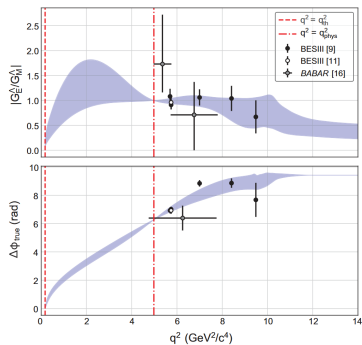
$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2 \beta C}{4q^2} \left[|G_M(q^2)|^2 (1 + \cos^2 \theta) + \frac{1}{\tau} |G_E(q^2)|^2 \sin^2 \theta \right].$$

- ▶ The self-analyzing weak decays of hyperons provide access to polarization and spin correlations, enabling measurements of $|G_E/G_M(q^2)| \equiv R(q^2)$ and the relative phase $\Delta\Phi(q^2)$.

Complete EMFF determination requires cross section, $|G_E/G_M|$, and phase $\Delta\Phi$.

ISR measurement of Λ EMFFs

- ▶ Previous Λ EMFF measurements are mainly based on energy scan data^[1,2], which provide discrete center-of-mass energies.
- ▶ With large statistics of $\psi(3770)$ and XYZ datasets at BESIII, **initial-state radiation (ISR)** method provides:
 - wide q^2 coverage through ISR;
 - simultaneous measurement of complete EMFFs;
 - complementary information to scan measurements.
- ▶ The lack of previous ISR studies highlights the importance of developing a dedicated fitting method for parameter extraction.



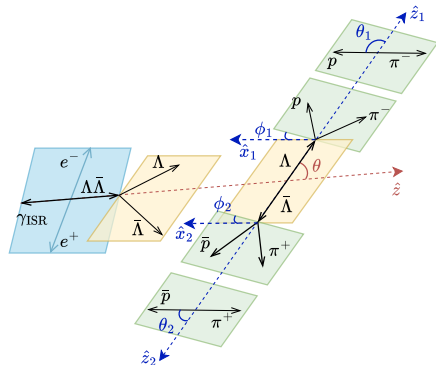
[1] PRL 123, 122003 (2019)

[2] PRL 135, 191902 (2025)

Kinematics and angular definitions

For ISR production $e^+e^- \rightarrow \gamma_{\text{ISR}}\Lambda\bar{\Lambda}$, with the self-analyzing decays $\Lambda \rightarrow p\pi^-$ and $\bar{\Lambda} \rightarrow \bar{p}\pi^+$, the angular variables are defined as:

- ▶ θ : polar angle of Λ in the $\Lambda\bar{\Lambda}$ rest frame, with $\hat{z}$ opposite to the ISR photon.
- ▶ (θ_1, ϕ_1) : proton polar and azimuthal angles in the Λ helicity frame.
- ▶ (θ_2, ϕ_2) : antiproton polar and azimuthal angles in the $\bar{\Lambda}$ helicity frame.



The angles $(\theta, \theta_1, \phi_1, \theta_2, \phi_2)$ fully describe the polarization observables.

Production density matrix

For the reaction $\gamma^* \rightarrow \Lambda \bar{\Lambda}$, the spin structure of the $\Lambda \bar{\Lambda}$ pair is described by the **production density matrix**^[1].

$$\rho_{\Lambda \bar{\Lambda}}(\theta; q^2) = \frac{1}{4} \sum_{\mu, \nu=0}^3 C_{\mu\nu}(\theta; q^2) \sigma_{\mu}^{\Lambda} \otimes \sigma_{\nu}^{\bar{\Lambda}},$$

where σ_0 is the identity and $\sigma_{1,2,3}$ are the Pauli matrices along the $(\hat{x}_i, \hat{y}_i, \hat{z}_i)$ axes of the helicity frames of the Λ and $\bar{\Lambda}$. The coefficient matrix is

$$C_{\mu\nu} \equiv 2 \begin{pmatrix} 1 + \alpha \cos^2 \theta & 0 & \beta \sin \theta \cos \theta & 0 \\ 0 & \sin^2 \theta & 0 & \gamma \sin \theta \cos \theta \\ -\beta \sin \theta \cos \theta & 0 & \alpha \sin^2 \theta & 0 \\ 0 & -\gamma \sin \theta \cos \theta & 0 & -(\alpha + \cos^2 \theta) \end{pmatrix}.$$

^[1]PRD 99, 056008 (2019).

Joint angular distribution

The production parameters at each q^2 are

$$\alpha(q^2) = \frac{\tau - R^2}{\tau + R^2}, \quad \beta(q^2) = \sqrt{1 - \alpha^2} \sin \Delta\Phi, \quad \gamma(q^2) = \sqrt{1 - \alpha^2} \cos \Delta\Phi.$$

For a finite interval $B = [q_1^2, q_2^2]$: $(\langle\alpha\rangle, \langle\beta\rangle, \langle\gamma\rangle) = \frac{\int_B dq^2 w(q^2)(\alpha(q^2), \beta(q^2), \gamma(q^2))}{\int_B dq^2 w(q^2)}.$

Here, $w(q^2)$ is the weight function, including the ISR radiator and the line-shape.

Energy-scan measurement: fixed q^2

$$\alpha^2(q^2) + \beta^2(q^2) + \gamma^2(q^2) = 1$$

$\Downarrow$

Two independent parameters $(\alpha, \Delta\Phi)$

ISR measurement: finite q^2 interval

$$\langle\alpha\rangle^2 + \langle\beta\rangle^2 + \langle\gamma\rangle^2 \leq 1$$

$\Downarrow$

Three averaged coefficients $(\langle\alpha\rangle, \langle\beta\rangle, \langle\gamma\rangle)$

Joint angular distribution

The production parameters at each q^2 are

$$\alpha(q^2) = \frac{\tau - R^2}{\tau + R^2}, \quad \beta(q^2) = \sqrt{1 - \alpha^2} \sin \theta$$

For a finite interval $B = [q_1^2, q_2^2]$: $(\langle \alpha \rangle, \langle \beta \rangle, \langle \gamma \rangle) = \frac{1}{w(B)} \int_B w(q^2) (\alpha, \beta, \gamma) dq^2$

Here, $w(q^2)$ is the weight function, including the ISR

Why does averaging give ≤ 1 ?

For any $u = \alpha, \beta, \gamma$,

$$\langle (u - \langle u \rangle)^2 \rangle = \langle u^2 \rangle - \langle u \rangle^2 \geq 0$$

which gives

$$\langle u \rangle^2 \leq \langle u^2 \rangle.$$

Summing over $u = \alpha, \beta, \gamma$,

$$\langle \alpha \rangle^2 + \langle \beta \rangle^2 + \langle \gamma \rangle^2 \leq \langle \alpha^2 + \beta^2 + \gamma^2 \rangle = 1.$$

Energy-scan measurement: fixed q^2

$$\alpha^2(q^2) + \beta^2(q^2) + \gamma^2(q^2) = 1$$

$\Downarrow$

Two independent parameters $(\alpha, \Delta\Phi)$

ISR measurement: finite q^2 interval

$$\langle \alpha \rangle^2 + \langle \beta \rangle^2 + \langle \gamma \rangle^2 \leq 1$$

$\Downarrow$

Three averaged coefficients $(\langle \alpha \rangle, \langle \beta \rangle, \langle \gamma \rangle)$

Data Sample and Event Selection

Data Sets: $\sqrt{s} = 3.773$ and 4.008–4.288 GeV, total luminosity: 30.9 fb^{-1}

► Good charged tracks:

- $|\cos \theta| < 0.93$, $V_r < 1 \text{ cm}$, $|V_z| < 10 \text{ cm}$
- $N_{\text{good}} \geq 4$

► PID (dE/dx + TOF):

- $p(\bar{p})$: $\text{prob}(p) > \text{prob}(K, \pi)$
- $\pi^\pm$: $\text{prob}(\pi) > \text{prob}(p, K)$
- $n_p \geq 1$, $n_{\bar{p}} \geq 1$, $n_{\pi^+} \geq 1$, $n_{\pi^-} \geq 1$

► Vertex fit:

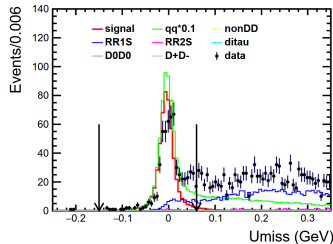
- Perform vertex fits for all $p\pi^-$ and $\bar{p}\pi^+$ pairs.
- Select the combination with minimum $\chi^2_{\text{total}} = \chi^2_{\text{Pri}} + \chi^2_{\text{Sec}}$.

► Recoil against the ISR photon (untagged):

- $P_{\text{miss}} = P_{\text{c.m.}} - P_\Lambda - P_{\bar{\Lambda}}$

► Further selection:

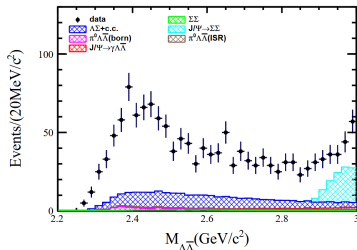
- $1.109 \text{ GeV}/c^2 \leq M_{\Lambda(\bar{\Lambda})} \leq 1.122 \text{ GeV}/c^2$
- $|\cos \theta_{\text{miss}}| \geq 0.99$
- $-0.15 \text{ GeV} \leq U_{\text{miss}} \leq 0.06 \text{ GeV}$
($U_{\text{miss}} \equiv E_{\text{miss}} - p_{\text{miss}}$)



Background Analysis

- ▶ After event selections, there are **1422** events for the dataset at $\sqrt{s} = 3.773$ GeV and **371** events for the dataset at $\sqrt{s} = 4.008\text{--}4.288$ GeV.
- ▶ The main backgrounds are investigated by **MC estimation** and **data-driven methods**.
- ▶ The results are summarized below, taking the $\psi(3770)$ data sample as an example.

Channels	N_{bkg}	Ratio(%)
$e^+e^- \rightarrow \gamma_{\text{ISR}}\Lambda\bar{\Sigma}^0 + c.c.$	227.22 ± 1.03	15.98
$e^+e^- \rightarrow \gamma_{\text{ISR}}J/\psi(\rightarrow \Sigma^0\bar{\Sigma}^0)$	69.19 ± 0.83	4.87
$e^+e^- \rightarrow \pi^0\Lambda\bar{\Lambda}$	22.52 ± 0.16	1.58
$e^+e^- \rightarrow \gamma_{\text{ISR}}\Sigma^0\bar{\Sigma}^0$	14.95 ± 0.18	1.05
$e^+e^- \rightarrow \gamma_{\text{ISR}}\pi^0\Lambda\bar{\Lambda}$	14.05 ± 0.28	0.99
$e^+e^- \rightarrow \gamma_{\text{ISR}}J/\psi(\rightarrow \gamma\Lambda\bar{\Lambda})$	12.67 ± 0.34	0.89
Non(semi)- $\Lambda\bar{\Lambda}$	9.50 ± 1.54	0.67



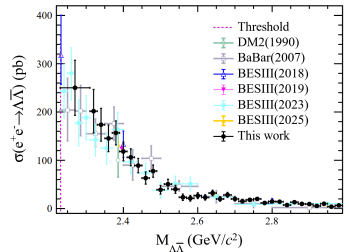
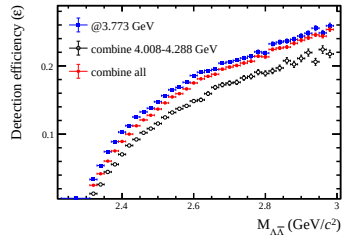
- ▶ **Main backgrounds:** $e^+e^- \rightarrow \gamma_{\text{ISR}}\Lambda\bar{\Sigma}^0 + c.c.$ and $e^+e^- \rightarrow \gamma_{\text{ISR}}J/\psi \rightarrow \gamma_{\text{ISR}}\Sigma^0\bar{\Sigma}^0$.

Cross section results

- ▶ According to the $M_{\Lambda\bar{\Lambda}}$ resolution and $M_{\Lambda\bar{\Lambda}}$ distribution of data, divide up $M_{\Lambda\bar{\Lambda}}$ to 35 bins from 2.23 to 2.99 GeV/ c^2 .
 - From 2.23-2.31 GeV/ c^2 , bin size is 80 MeV; (the low untag-ISR efficiency near the threshold)
 - From 2.31 to 2.99 GeV/ c^2 , every 20 MeV one bin, 34 bins
- ▶ In each interval, the dressed cross section is calculated by

$$\sigma_{\Lambda\bar{\Lambda}}^B(M_{\Lambda\bar{\Lambda}}) = \frac{dN_{sig}/dM_{\Lambda\bar{\Lambda}}}{\varepsilon \cdot BR(\Lambda \rightarrow p\pi^-) \cdot BR \rightarrow \bar{p}\pi^+ \cdot d\mathcal{L}_{int}/dM_{\Lambda\bar{\Lambda}}},$$

- ε is the selection efficiency;
- $d\mathcal{L}_{int}/dM_{\Lambda\bar{\Lambda}} = W(s, x) \cdot \mathcal{L}_{data}$



Systematic uncertainty of cross section measurement

1. **Luminosity uncertainty:** includes a 0.5% ISR uncertainty.
2. $\Lambda/\bar{\Lambda}$ **reconstruction:** referred to *Phys. Rev. D* **107**, 072005 (2023).
3. U_{miss} **and** $|\cos \theta_{\text{miss}}|$ **cuts:** evaluated using $e^+e^- \rightarrow \gamma_{\text{ISR}} J/\psi \rightarrow \gamma_{\text{ISR}} \Lambda \bar{\Lambda}$ at $\sqrt{s} = 3.773$ GeV.
4. **Background uncertainty:** uncertainties from minor backgrounds are neglected.

$e^+e^- \rightarrow \gamma_{\text{ISR}} (\Lambda \bar{\Sigma}^0 + \text{c.c.})$ (15.98%)	Line shape $\pm \sigma$
$e^+e^- \rightarrow \gamma_{\text{ISR}} J/\psi \rightarrow \gamma_{\text{ISR}} \Sigma^0 \bar{\Sigma}^0$ (4.87%)	Angle Sum MC generator
Neglected backgrounds	0.5%

5. **Angular distribution, polarization and spin correlations:**

Generate signal MC samples with the measured parameters varied by $\pm 1\sigma$.

6. **Branching fractions of $\Lambda(\bar{\Lambda}) \rightarrow p\pi^- (\bar{p}\pi^+)$:** 1.6% from PDG.

Total systematic uncertainty: 7.5% – 15.7%.

Extraction of EMFFs

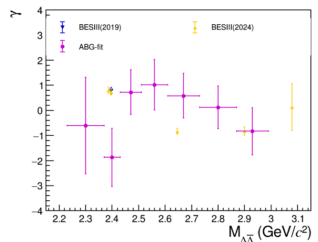
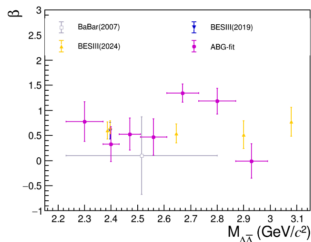
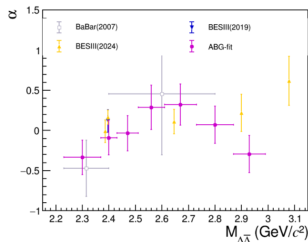
- ▶ The $M_{\Lambda\bar{\Lambda}}$ range of 2.23–2.99 GeV/ c^2 is divided into 7 bins with signal yields of 150–230 events.
- ▶ Define $\xi = (\theta, \theta_1, \phi_1, \theta_2, \phi_2)$. The averaged joint angular amplitude for $\gamma^* \rightarrow \Lambda(\rightarrow p\pi^-)\bar{\Lambda}(\rightarrow \bar{p}\pi^+)$:

$$\mathcal{W}(\xi) = \mathcal{F}_0(\xi) + \langle\alpha\rangle\mathcal{F}_5(\xi) - \alpha_\Lambda\langle\beta\rangle(\mathcal{F}_3(\xi) + \mathcal{F}_4(\xi)) - \alpha_\Lambda^2(\mathcal{F}_1(\xi) + \langle\gamma\rangle\mathcal{F}_2(\xi) - \langle\alpha\rangle\mathcal{F}_6(\xi)).$$

- ▶ The parameters $\langle\alpha\rangle$, $\langle\beta\rangle$, and $\langle\gamma\rangle$ are extracted in each interval by maximizing the likelihood:

$$-\ln \mathcal{L} = -\sum_{\text{data}} \ln \mathcal{W}(\xi_i; q_i^2) + \sum_{\text{bkg}} \ln \mathcal{W}(\xi_i; q_i^2) + (N_{\text{data}} - N_{\text{bkg}}) \ln \mathcal{N},$$

where $\mathcal{N}$ is the normalization factor and obtained from MC integration.



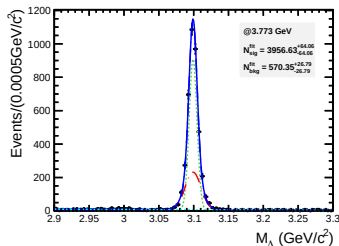
Validation with $e^+e^- \rightarrow \gamma_{\text{ISR}} J/\psi \rightarrow \gamma_{\text{ISR}} \Lambda \bar{\Lambda}$

Cross section validation

- ▶ With the **same event selections**, the branching fraction is extracted from:

$$\mathcal{B}(J/\psi \rightarrow \Lambda \bar{\Lambda}) = \frac{N_{J/\psi \rightarrow \Lambda \bar{\Lambda}}}{\epsilon N_{J/\psi}^{\text{prod}} \mathcal{B}^2(\Lambda \rightarrow p \pi^-)}.$$

- ▶ The measured result: $(1.83 \pm 0.10) \times 10^{-3}$, consistent with PDG: $(1.88 \pm 0.08) \times 10^{-3}$.



Angular fit validation

- ▶ The **same angular fit method** is applied to extract α , β , and γ .
- ▶ The results are **consistent with the J/ψ scan measurements**, and $\alpha^2 + \beta^2 + \gamma^2 = 1$ is satisfied within uncertainties.
- ▶ Only statistical uncertainty.

Parameter	This work	J/ψ scan result
α	0.39 ± 0.06	0.4748 ± 0.0038
β	0.59 ± 0.07	0.6013 ± 0.0052
γ	0.64 ± 0.19	0.6427 ± 0.0049
$\alpha^2 + \beta^2 + \gamma^2$	0.91 ± 0.27	1

Summary of the untagged process of $e^+e^- \rightarrow \gamma_{\text{ISR}}\Lambda\bar{\Lambda}$

Summary

- ▶ The **dressed cross section** of $e^+e^- \rightarrow \Lambda\bar{\Lambda}$ is measured in **35** $\Lambda\bar{\Lambda}$ mass intervals from threshold to $3.0 \text{ GeV}/c^2 \rightarrow$ **improved precision of the line shape**.
- ▶ A **dedicated fitting method** for extracting production parameters in ISR measurements is developed $\rightarrow$ **enabling future ISR-based studies of hyperon EMFFs**.
- ▶ The production parameters **$\langle\alpha\rangle$, $\langle\beta\rangle$, and $\langle\gamma\rangle$** of the Λ hyperon are measured in **7** mass intervals using ISR data. $\rightarrow$ **important input for theoretical studies**.

Future work

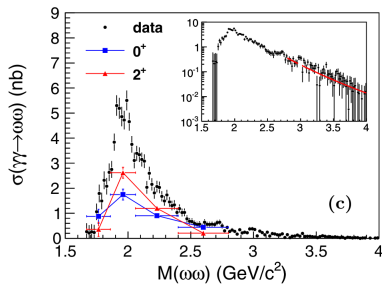
- ▶ Study the systematic uncertainties of the $\langle\alpha\rangle$, $\langle\beta\rangle$, and $\langle\gamma\rangle$ measurements.
- ▶ Update the analysis memo and paper draft.

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Motivation: Two-photon process $\gamma^{(*)}\gamma^{(*)} \rightarrow \omega\omega$

- ▶ The cross section of the two-photon process $\gamma^{(*)}\gamma^{(*)} \rightarrow \omega\omega$ has been studied by ARGUS^[1] and Belle^[2] experiments.
- ▶ **Two resonant structures** below the charmonium threshold were observed by Belle.
- ▶ With the large data samples collected by BESIII, the $\gamma^{(*)}\gamma^{(*)} \rightarrow \omega\omega$ process can be studied **for the first time** with BESIII data.

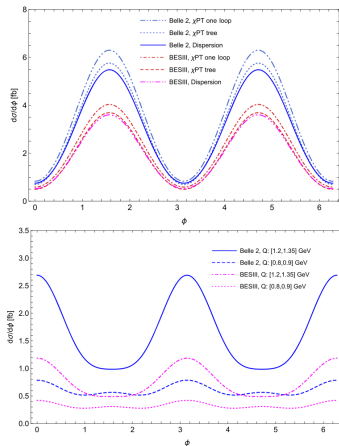


^[1] PLB 374, 265–270 (1996)

^[2] PRL 108, 232001 (2012)

Motivation: Azimuthal asymmetry in $\gamma\gamma \rightarrow VV$

- ▶ An **azimuthal asymmetry** is predicted within the Transverse-Momentum-Dependent factorization theory^[1] in the process $\gamma^{(*)}\gamma^{(*)} \rightarrow \pi^+\pi^-$.
- ▶ The differential cross section with respect to the azimuthal angle ϕ shows some **oscillation structure**.
 - ϕ is the angle between $\vec{P}_T(\pi^+) + \vec{P}_T(\pi^-)$ and $\vec{P}_T(\pi^+) - \vec{P}_T(\pi^-)$.
- ▶ The same oscillation phenomenon should also exist in the $\gamma^{(*)}\gamma^{(*)} \rightarrow VV$ process.
- ▶ The clean background environment of $\gamma^{(*)}\gamma^{(*)} \rightarrow \omega\omega$ makes it an **ideal channel** to study the azimuthal asymmetry.



^[1] PRL 134, 141901 (2025)

Data Sample and Event Selection

Data: $\sqrt{s} = 3.773 \text{ GeV}$, 20.3 fb^{-1} ; **Signal MC:** generated with CppGamGam.

Decay chain: $e^+e^- \rightarrow e^+e^-\omega\omega \rightarrow e^+e^-(\pi^+\pi^-\pi^0)(\pi^+\pi^-\pi^0)$, $\pi^0 \rightarrow \gamma\gamma \Rightarrow 2\pi^+2\pi^-4\gamma$.

► Good charged tracks:

- $|\cos\theta| < 0.93$, $V_r < 1 \text{ cm}$, $|V_z| < 10 \text{ cm}$
- $N_{\text{good}} = 4$

► PID (dE/dx + TOF):

- $\text{prob}(\pi) > \text{prob}(p, K)$
- $N_{\pi^+} = 2, N_{\pi^-} = 2$

► Vertex fit: successful

► Good photons:

- $|\cos\theta_\gamma| < 0.8$ or $0.86 < |\cos\theta_\gamma| < 0.92$
- $E_\gamma \geq 25 \text{ MeV}$ (barrel), $E_\gamma \geq 50 \text{ MeV}$ (endcaps)
- EMC time: $0 \sim 700 \text{ ns}$
- $\theta(\gamma, \pi) > 10^\circ$
- $N_\gamma \geq 4$

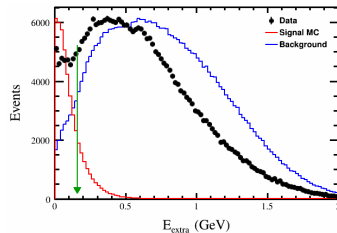
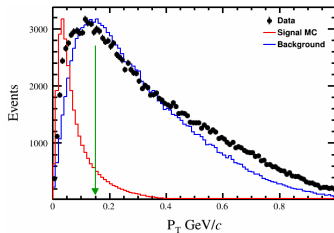
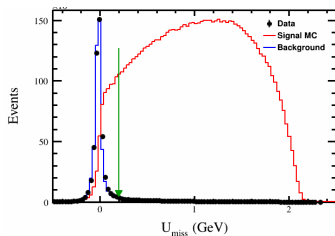
► Good π^0 list:

- $0.115 \leq M_{\gamma\gamma} \leq 0.150 \text{ GeV}/c^2$
- $\chi^2_{1C} < 20$
- Helicity < 0.95
- $N_{\pi^0} \geq 2$
- Select the $2\pi^0$ with minimum $\sum \chi^2_{1C}$

Selection	Absolute Eff. (%)	Relative Eff. (%)
Total	100	100
$N_{\text{Good}} = 4$	46.07	46.07
PID	41.75	90.61
Vtxfit	41.36	99.05
Good photons	19.38	46.86
Good π^0	10.78	55.61

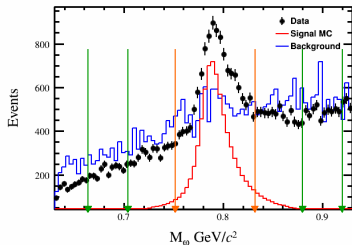
Further selection

- ▶ To suppress ISR and other hadronic backgrounds, we further require:
 - $U_{\text{miss}} > 0.2 \text{ GeV}$;
 - $P_T(\omega\omega) < 0.15 \text{ GeV}/c$;
 - $E_{\text{extra}} < 0.16 \text{ GeV}$ (Extra EMC deposited energy).



$\omega\omega$ Signal Selection

- ▶ 4 $\omega\omega$ combinations are reconstructed from the $2(\pi^+\pi^-\pi^0)$ final state.
- ▶ At least one combination is required to satisfy $|M_{\omega_{1,2}} - m_{\omega}^{\text{PDG}}| < 0.15 \text{ GeV}/c^2$.
- ▶ Requiring the opposite ω within $\pm 40 \text{ MeV}/c^2$ of the PDG mass, the remaining M_{ω} spectrum is used to define the signal and sideband regions.



Signal region:

$$0.752 < M_{\omega} < 0.832 \text{ GeV}/c^2$$

Sideband regions:

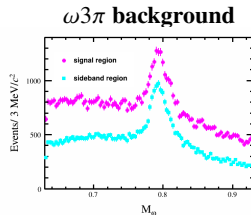
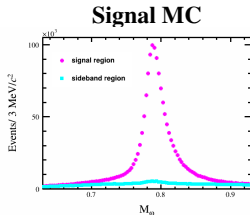
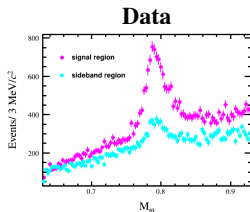
$$0.664 < M_{\omega} < 0.704 \text{ GeV}/c^2$$

$$0.880 < M_{\omega} < 0.920 \text{ GeV}/c^2$$

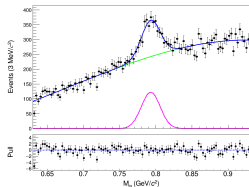
- ▶ No significant peaking hadronic background is observed in the M_{ω} spectrum.

Extraction of Signal Events

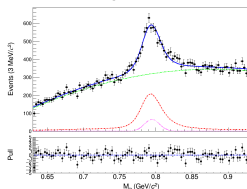
- The dominant peaking background is from $\gamma^{(*)}\gamma^{(*)} \rightarrow \omega 3\pi$.



Sideband fit
 $\omega 3\pi$ shape + 3rd-order Chebychev



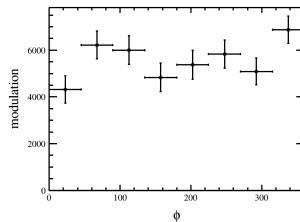
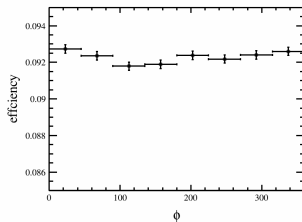
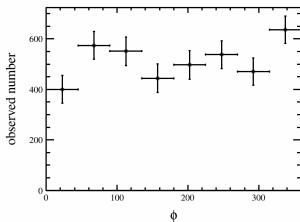
Signal-region fit
Signal MC + fixed bkg + 3rd-order Chebychev



- The fitted signal yield is $N_{\text{sig}} = 4115.35 \pm 156.31$.

Extraction of ϕ modulation

- ▶ $\phi \equiv \angle(\vec{P}_T(\omega_1) + \vec{P}_T(\omega_2), \vec{P}_T(\omega_1) - \vec{P}_T(\omega_2))$.
- ▶ ϕ is in the region $[0^\circ, 360^\circ]$: every 45° one bin, divide ϕ into 8 bins.
- ▶ For each bin, the signal is extracted by fitting the sideband and signal M_ω spectrum.



Summary of the untagged process of $\gamma^{(*)}\gamma^{(*)} \rightarrow \omega\omega$

Summary

- ▶ About 4000 $\gamma^{(*)}\gamma^{(*)} \rightarrow \omega\omega$ signal events are observed for the first time with the untagged method at BESIII.
- ▶ The ϕ -dependent modulation is investigated by dividing the data into 8 ϕ bins.

Future work

- ▶ Perform unfolding to reduce the detector resolution effect.
- ▶ Extract the cross section in different $M_{\omega\omega}$ bins.
- ▶ Evaluate the systematic uncertainties.
- ▶ Include additional higher-energy data samples.
- ▶ ...

Outline

1. Introduction
2. Untagged Analysis of $e^+e^- \rightarrow \gamma_{\text{ISR}}\Lambda\bar{\Lambda}$
3. Untagged Analysis of $\gamma^{(*)}\gamma^{(*)} \rightarrow \omega\omega$
4. Summary and Prospects

Summary and Prospects

► Study of $e^+e^- \rightarrow \gamma_{\text{ISR}}\Lambda\bar{\Lambda}$:

- ✓ Memo and draft have been submitted for collaboration review.
- Prepare the **methodology paper** about the ISR MLL fitting.
- Revise the **analysis draft** according to the referees' comments.

► Study of $\gamma^*\gamma^* \rightarrow \omega\omega$:

- ✓ ϕ **modulation** has been preliminarily extracted.
- Study the **cross section** and systematic uncertainties.
- Prepare the memo and draft.



Memo version 5.1

BESIII Analysis Memo

BAM-964

November 13, 2025

Measurement of $e^+e^- \rightarrow \Lambda\bar{\Lambda}$ from threshold to 3 GeV/ c^2 at BESIII via untagged-ISR method

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On the complete determination of hyperon time-like
electromagnetic form factors via ISR

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¹University of Science and Technology of China

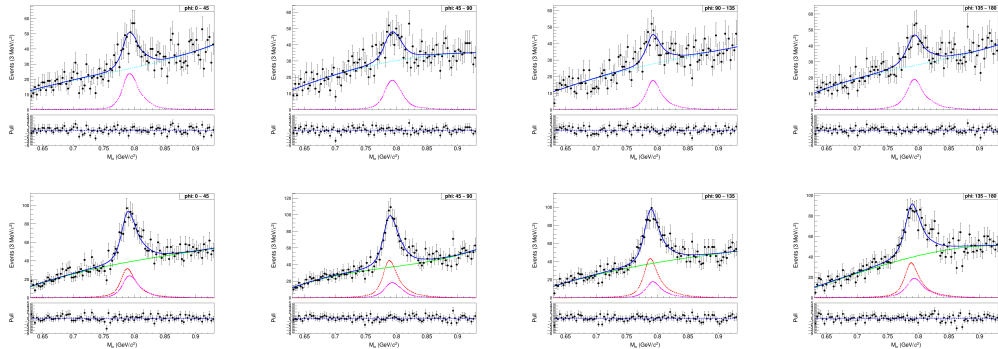
²Uppsala University

October 12, 2026

Abstract

Two complementary methods are presented to extract time-like baryon electromagnetic form factors (EMFFs) studied via the initial-state-radiation (ISR) process, in a finite q^2 interval where the EMFF ratio $|G_E/G_M|$ and the relative phase $\Delta\Phi$ have a non-negligible q^2 dependence. We first introduce a Taylor-expansion likelihood that keeps the local q^2 dependence of $|G_E/G_M|$ and $\Delta\Phi$ inside the interval. We then show analytically that the bin-integrated angular distribution is naturally described by three effective production parameters α_B , β_B , and γ_B , generalising the fixed-energy (α, β, γ) to a finite interval. The two approaches are compared and validated with toy MC studies, which demonstrate that the averaged-parameter fit yields approximately unbiased estimates even at low statistics.

Backup: Additional plots



Backup: Additional plots

