



Study of two-photon process $\gamma\gamma \rightarrow X$ at BESIII

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Thesis proposal report
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Outline

➤ Works on $\gamma\gamma \rightarrow X$ at BESIII

- Introduction
- Study of $\gamma\gamma^* \rightarrow p\bar{p}$ through single-tag method
- Study of $\gamma\gamma \rightarrow p\bar{p}$ through un-tag method
- Extending to other baryon or meson pairs $\gamma\gamma \rightarrow \Lambda\bar{\Lambda}, K_S K_S$

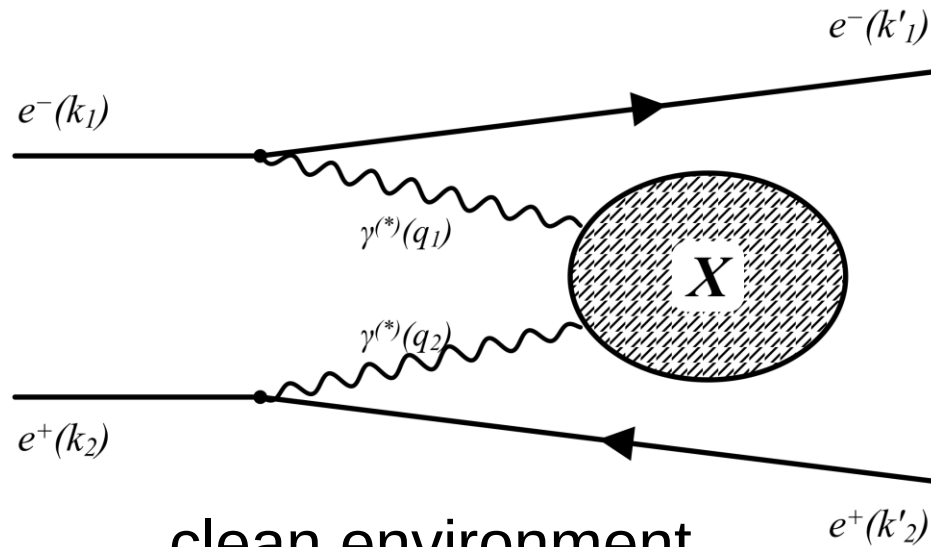
➤ Other work

- Polarization study of $e^+e^- \rightarrow \Lambda\bar{\Sigma}^0 + c.c.$ at 3.773GeV

➤ Summary and prospects

Tow-photon collisions as a probe of hadron structure

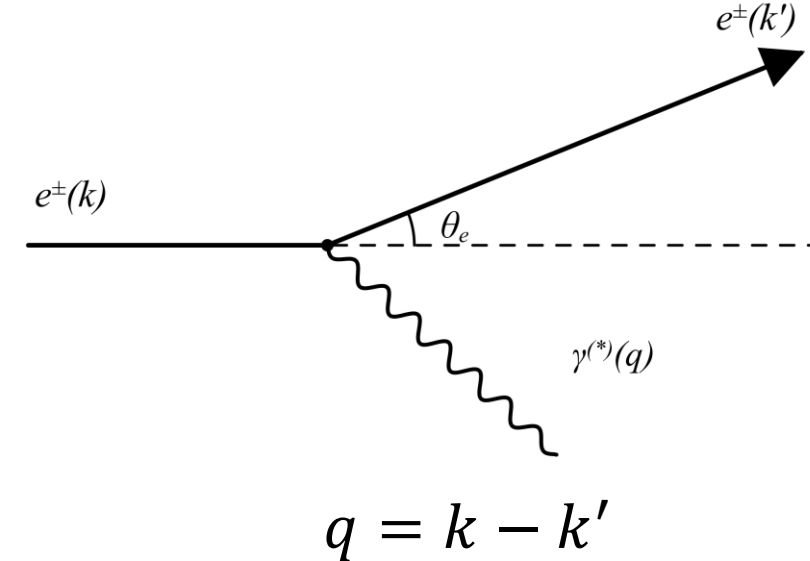
Feynman Diagram of two photon process:



clean environment

C=+ system

Photon radiation by electrons:



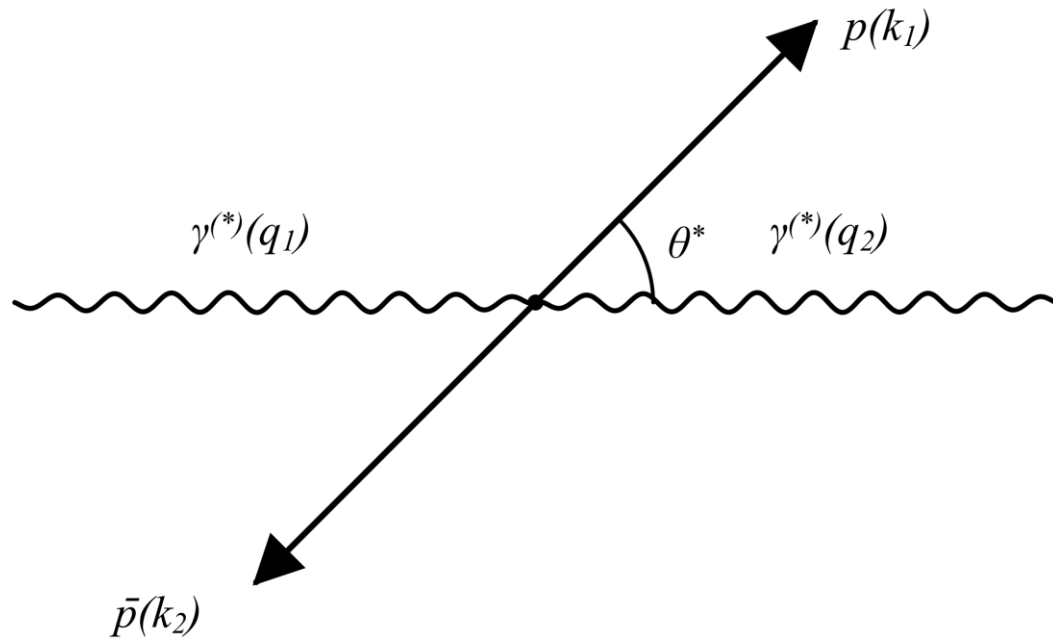
$$Q^2 = -q^2 \approx PP'(1 - \cos\theta_e)$$

Un-tag: collisions of two quasi-real photons, highest production

Single-tag: cleaner signal, full reconstruction of Q^2 information

Double-tag: Full reconstruction, very low statistics

Kinematics in the two-photon center-of mass system



Main physical observables:

$$Q_1^2 = -q_1^2, Q_2^2 = -q_2^2$$

$$W^2 = (q_1 + q_2)^2 = (k_1 + k_2)^2$$

$$|\cos\theta^*| = |\hat{k}_1 \cdot \hat{q}_1|$$

Amplitude:

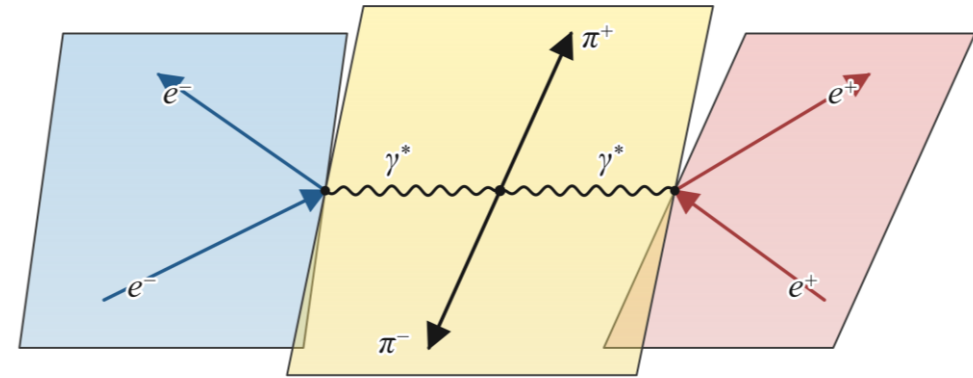
$$M_{\lambda_1, \lambda_2; \lambda_p, \lambda_{\bar{p}}} = M(W, Q_1^2, Q_2^2, \cos\theta^*)$$

$$N_{ee \rightarrow p\bar{p}} = \int \mathcal{L}_{int} \times \frac{dL_{\gamma\gamma}(W_{\gamma\gamma}, E_{cms}, Q^2)}{dW_{\gamma\gamma}} dW_{\gamma\gamma} \times \sigma_{\gamma\gamma \rightarrow p\bar{p}}(W_{\gamma\gamma}, Q^2, \cos\theta^*)$$

The lepton-side determines the virtuality and polarization of the photons.

The hadron-side describes the dependence of production on Q^2 , W and $|\cos\theta^*|$.

Azimuthal modulation and photon-helicity interference



A quasi-real photon with linear polarization along ϕ direction:

$$|\gamma(\phi)\rangle = \frac{1}{\sqrt{2}}(e^{-i\phi}|+\rangle + e^{i\phi}|-\rangle)$$

The coupling of the two photons yields:

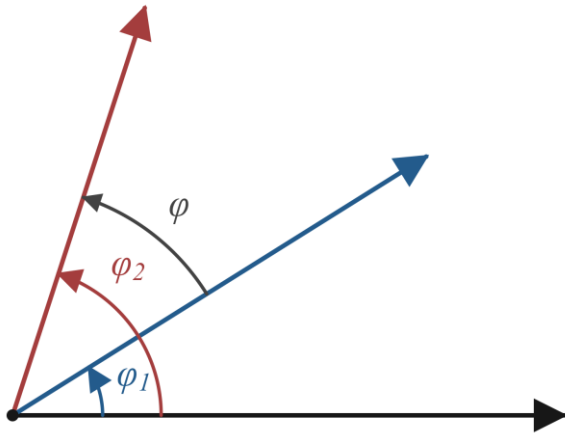
$$\mathcal{M}(\phi_1, \phi_2)$$

$$= \frac{1}{2} [e^{-i(\phi_1+\phi_2)} M_{++} + e^{-i(\phi_1-\phi_2)} M_{+-} + e^{i(\phi_1-\phi_2)} M_{-+} + e^{i(\phi_1+\phi_2)} M_{--}]$$

When virtual photons or non-zero spin particles exist:

$$M = \sum M_{\lambda_1 \lambda_2; \lambda'_1 \lambda'_2}$$

Where $\lambda_{1,2} = 0, \pm 1$ and $\lambda'_{1,2}$ denotes the spin of final particles.



Azimuthal modulation and photon-helicity interference

$$\frac{d\sigma}{d^2\mathbf{p}_{1\perp}d^2\mathbf{p}_{2\perp}dy_1dy_2} = \frac{1}{16\pi^2Q^4} \int d^2\mathbf{k}_{1\perp}d^2\mathbf{k}_{2\perp} \times \delta^2(\mathbf{q}_{\perp} - \mathbf{k}_{1\perp} - \mathbf{k}_{2\perp})x_1x_2$$

$$\times \left\{ \frac{1}{2}(|M_{+-}|^2 + |M_{++}|^2)f(x_1, k_{1\perp}^2)f(x_2, k_{2\perp}^2) - \cos(2\phi_1)\text{Re}[M_{++}M_{+-}^*]f(x_2, k_{2\perp}^2)h_1^{\perp}(x_1, k_{1\perp}^2) \right.$$

$$- \cos(2\phi_2)\text{Re}[M_{++}M_{+-}^*]f(x_1, k_{1\perp}^2)h_1^{\perp}(x_2, k_{2\perp}^2)$$

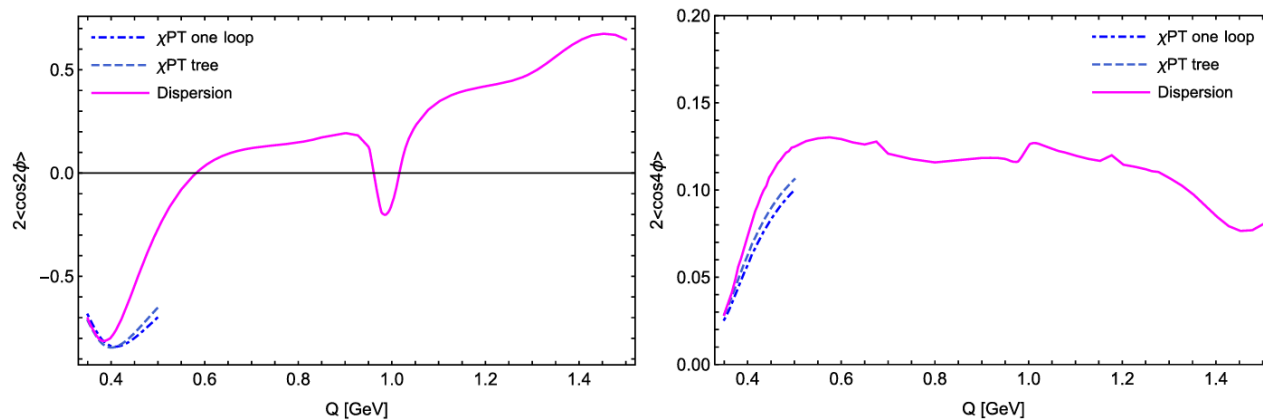
$$\left. + \frac{1}{2}[\cos 2(\phi_1 - \phi_2)|M_{++}|^2 + \cos 2(\phi_1 + \phi_2)|M_{+-}|^2]h_1^{\perp}(x_1, k_{1\perp}^2)h_1^{\perp}(x_2, k_{2\perp}^2) \right\}, \quad PRL 134, 141901(2025)$$

Term 1: only this term contributions to the total integrated cross section.

Term 2 and 3: integration over $k_{i\perp}$ leaves a $\cos 2\phi$ modulation term.

Term 4: integration over $k_{i\perp}$ leaves a $\cos 4\phi$ modulation term.

Theoretical prediction for the observable $\langle \cos 2\phi \rangle$, $\langle \cos 4\phi \rangle$:

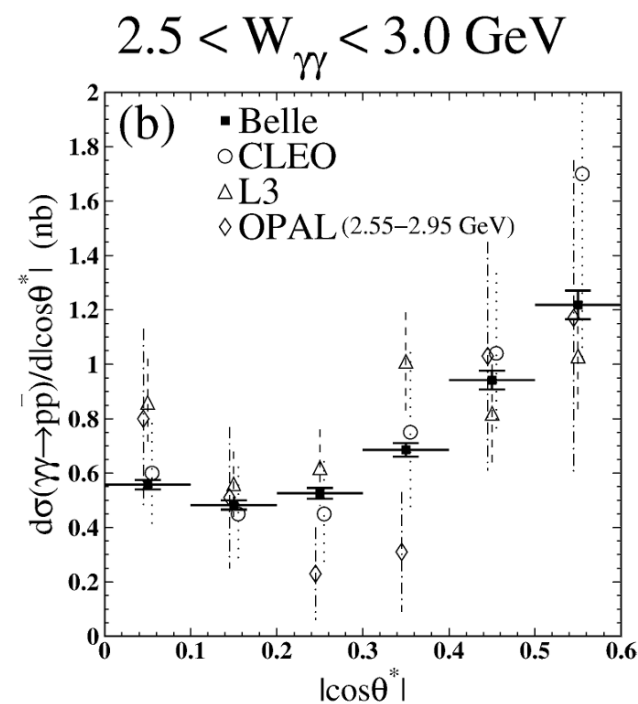
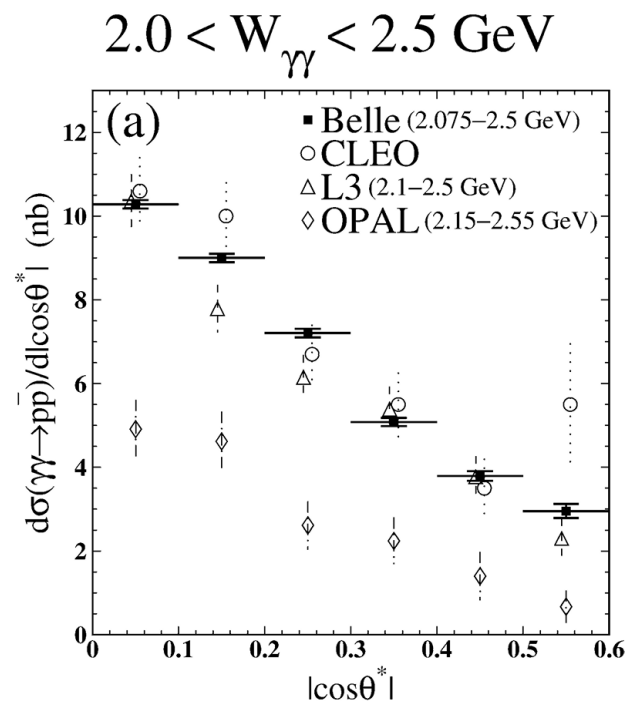
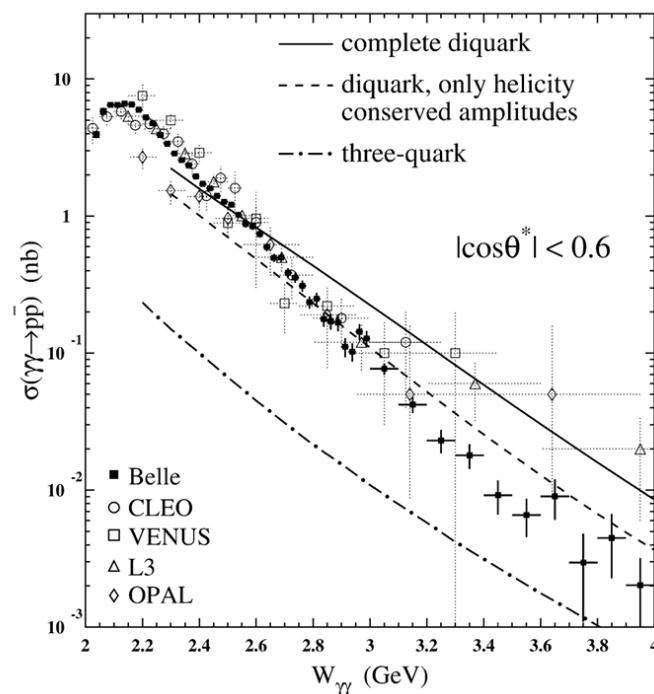


Future investigations may also include studying azimuthal asymmetries in other channels, such as $\gamma\gamma \rightarrow p\bar{p}$, $\gamma\gamma \rightarrow \rho\rho$, and $\gamma\gamma \rightarrow \gamma\gamma$, both in e^+e^- collisions and UPCs.

PRL 134, 141901(2025)

Experimental status of $\gamma\gamma \rightarrow p\bar{p}$

Many experiments have studied the $\gamma\gamma \rightarrow p\bar{p}$ process, among which Belle has reported the most precise results through UT method.

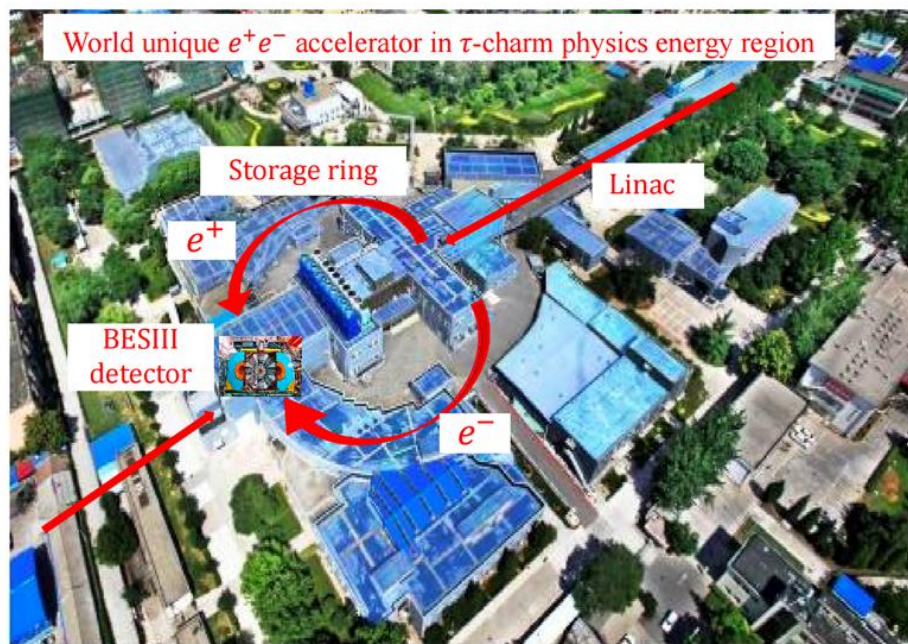


PLB 621(2005)41-55

By combining the UT and ST methods:

- Supplements the cross-section near the threshold
- Adds two observable dimensions, Q^2 and ϕ

BEPCII and BESIII



Double rings

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

Peak luminosity @ $E_{cm} = 3.773 \text{ GeV}$:

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

Circumference: 237.53 m

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

Electromagnetic Calorimeter

CsI(Tl): $L=28 \text{ cm}$

Barrel $\sigma_E=2.5\%$

Endcap $\sigma_E=5.0\%$

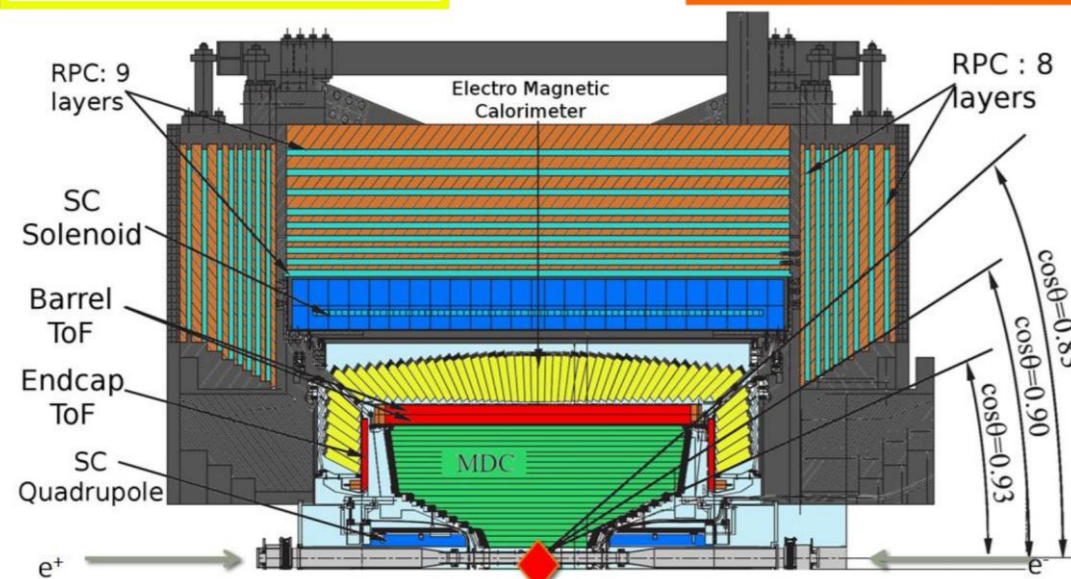
Muon Counter

RPC

Barrel: 9 layers

Endcap: 8 layers

$\sigma_{\text{spatial}}: 1.48 \text{ cm}$



Main Drift Chamber

Small cell, 43 layer

$\sigma_{xy}=130 \mu\text{m}$

$dE/dx \sim 6\%$

$\sigma_p/p = 0.5\%$ at 1 GeV

Time Of Flight

Plastic scintillator

$\sigma_T(\text{barrel}): 68 \text{ ps}$

$\sigma_T(\text{endcap}): 110 \text{ ps}$

(update to 60 ps with MRPC)

Signal MC generation and iteration

➤ HadroTOPS Generator

$$N_{ee \rightarrow p\bar{p}} = \int \mathcal{L}_{int} \times \frac{dL_{\gamma\gamma}(W_{\gamma\gamma}, E_{cms}, Q^2)}{dW_{\gamma\gamma}} dW_{\gamma\gamma} \times \sigma_{\gamma\gamma \rightarrow p\bar{p}}(W_{\gamma\gamma}, Q^2, \cos\theta^*)$$

The theoretical calculation of the $\gamma\gamma$ luminosity and the manual input of the hadronic cross section are performed separately for different polarization states of two photons.

$$\begin{aligned} \frac{d^3\sigma}{dW dQ_1^2 dQ_2^2} &= \frac{d^3L_{TT}}{dW dQ_1^2 dQ_2^2} \sigma_{TT} + \frac{d^3L_{LL}}{dW dQ_1^2 dQ_2^2} \sigma_{LL} + \frac{d^3L_{TL}}{dW dQ_1^2 dQ_2^2} \sigma_{TL} \\ &+ \frac{d^3L_{LT}}{dW dQ_1^2 dQ_2^2} \sigma_{LT} + \frac{d^3\tilde{L}_{TT}}{dW dQ_1^2 dQ_2^2} \tau_{TT} + \frac{d^3\tilde{L}_{TL}}{dW dQ_1^2 dQ_2^2} \frac{1}{2} (\tau_0 + \tau_1) \end{aligned}$$

The initial signal MC includes only TT-polarized $\gamma\gamma$ states, with interference neglected. The hadronic cross section depends only on W , using Belle results.

$$\frac{\partial \sigma_{TT}}{\partial Q^2} = 0, \quad \frac{\partial \sigma_{LL}}{\partial \cos\theta^*} = 0, \quad \sigma_{LL}(W) = \sigma(\gamma\gamma \rightarrow p\bar{p})_{Belle}$$

Data set and Event selection for ST

➤ Data and MC samples:

BOSS: 712

Data set: full data sat at 3.773GeV, 20.3fb⁻¹

IncMC sample: Hadron Hybrid; 0.25x Bhabha; 15x dimu; 1x $\gamma\gamma \rightarrow ee, \mu\mu, \pi\pi, KK, \eta, \eta'$

ExcMC sample: 1M $\gamma\gamma \rightarrow p\bar{p}$ TT-only, 10M $e^+e^- \rightarrow p\bar{p}$

➤ Event selection:

- Good charged track:

$$|V_{xy}| < 1cm, |V_z| < 10cm, |\cos\theta| < 0.93$$

$$N_{good} = 3, N_{charge} = \pm 1$$

- PID:

p: prob(p) > prob(e, μ , π , K), 0.001

e: prob(e) > prob(μ , π , K, p), 0.001

$$N_p = N_{\bar{p}} = N_e = 1$$

- Vertex Fit:

Vertex fit for $p\bar{p}e$, success;

- Other:

$\cos\theta_{miss} \times \text{sign}(e) < 0$;

- Good Photon

10 degree away from charged tracks and 20 for $\bar{p}$

Further Event selection for ST

Further selection performed based on the kinematic features of ST:

- Constrain the angles of missing system:

$$\cos\theta_{\text{miss}} * \text{sign}(e) < -0.99;$$

- Veto Bhabha background:

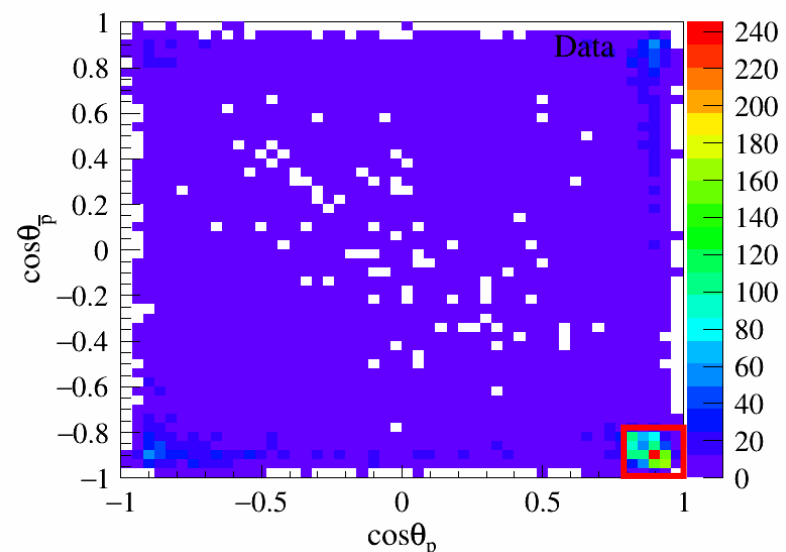
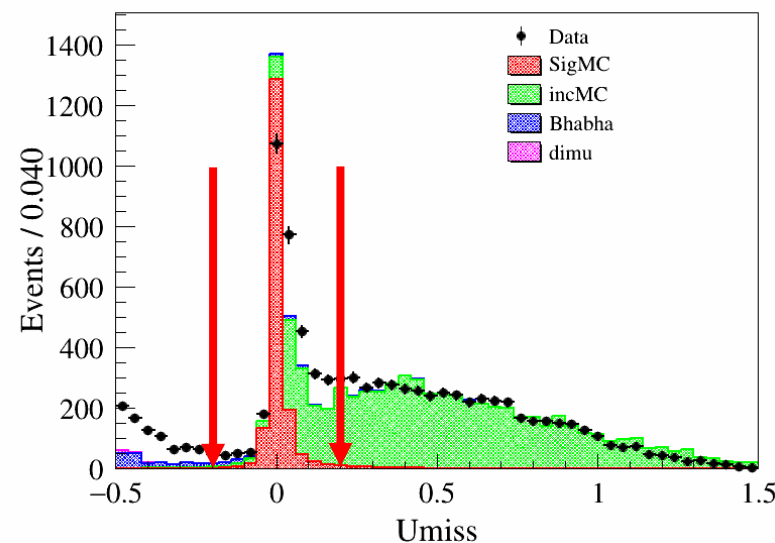
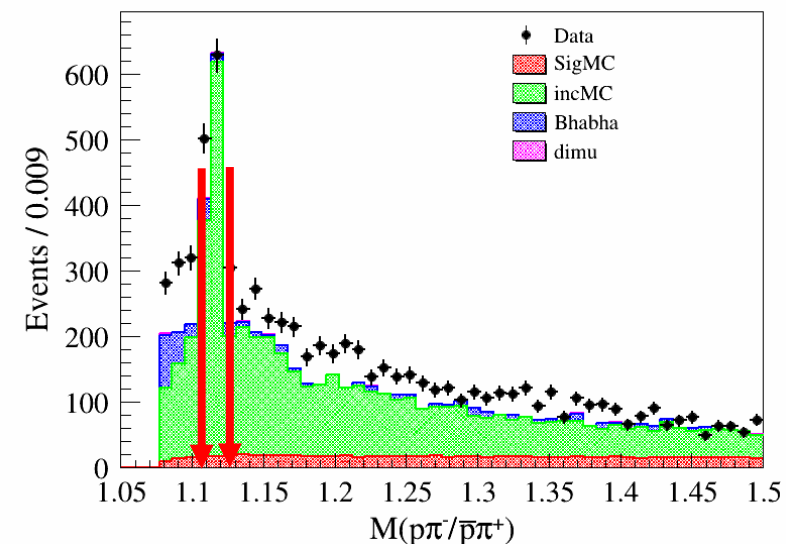
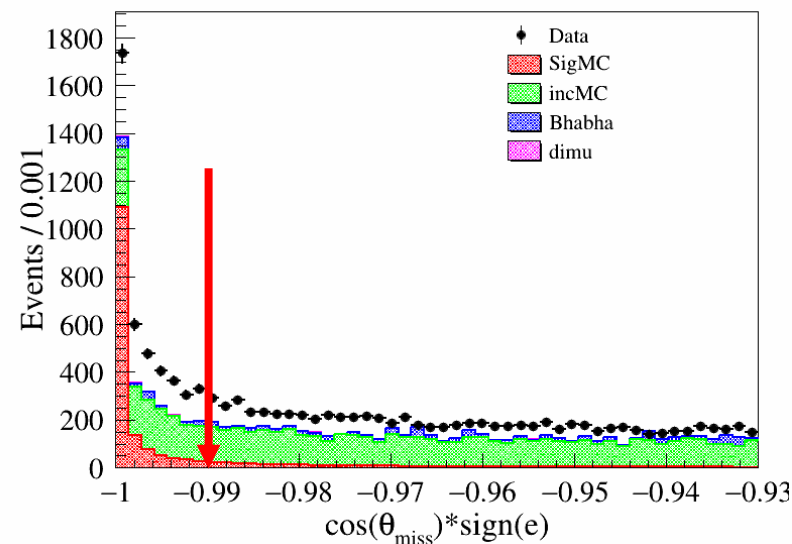
$$\text{Reject } \cos\theta_p > 0.8 \text{ \& } \cos\theta_{\bar{p}} < -0.8$$

- Veto Λ included background:

$$\text{Reject } |M(p\pi^-/\bar{p}\pi^+) - M(\Lambda)| < 10\text{MeV}$$

- Signal region is selected as:

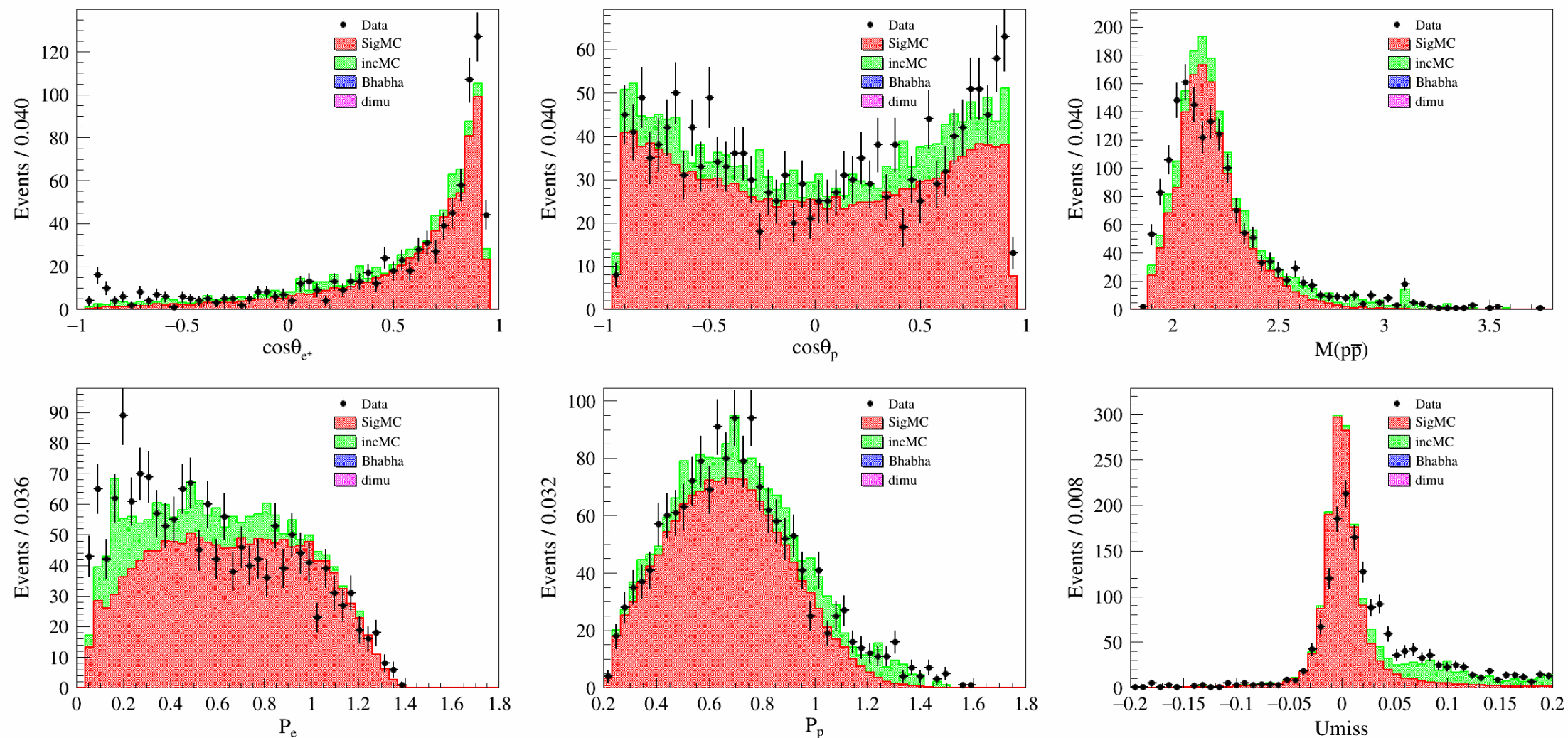
$$|U_{\text{miss}}| < 0.2$$



Previous result for ST

$$N_{sig}^{obs} \sim 1350, N_{bkg} \sim 300$$

The data shows good agreement with MC for most spectra.



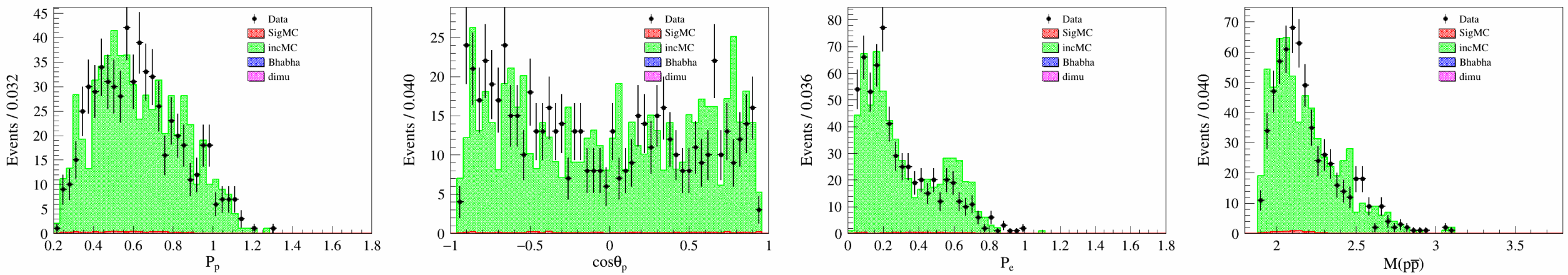
Background Analysis for ST

Background sources:

- Δ included process
- Misidentification of low-momentum e/π

Final states		N	Level
$p\bar{p}\pi\pi$	Non Δ	91	5.5%
	Δ included	144	8.7%
$p\bar{p}\pi K$		19	1.2%
$p\bar{p}\gamma/\pi^0$		46	2.8%
$p\bar{p}e^+e^-$		10	0.061%

The agreement between data and MC in sideband region $U_{miss} > 0.3$:

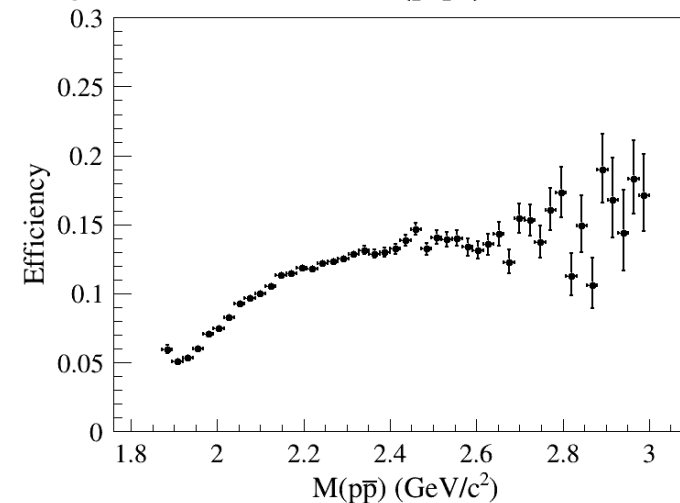


Efficiency for ST

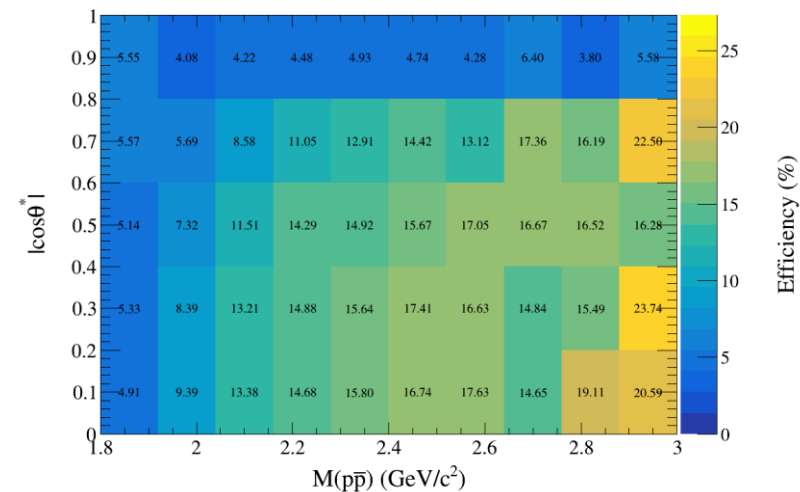
Efficiency and cutflow:

Selection	Event	Rel eff (%)
Total events	700000	\
$N_{good} = 3$	119398	17.1
Pass PID	97233	81.4
Pass Vtxfit	95475	98.2
$\cos\theta_{miss} * \text{sign}(e) < -0.99$	75148	78.7
Reject $\cos\theta_p > 0.8$ & $\cos\theta_{\bar{p}} < -0.8$	74762	99.5
Reject $ M(p\pi) - M(\Lambda) < 10\text{MeV}$	73362	98.1
$-0.2 < U_{miss} < 0.2$	72379	98.7
Total efficiency	10.3%	

Efficiency binned in $M(p\bar{p})$:

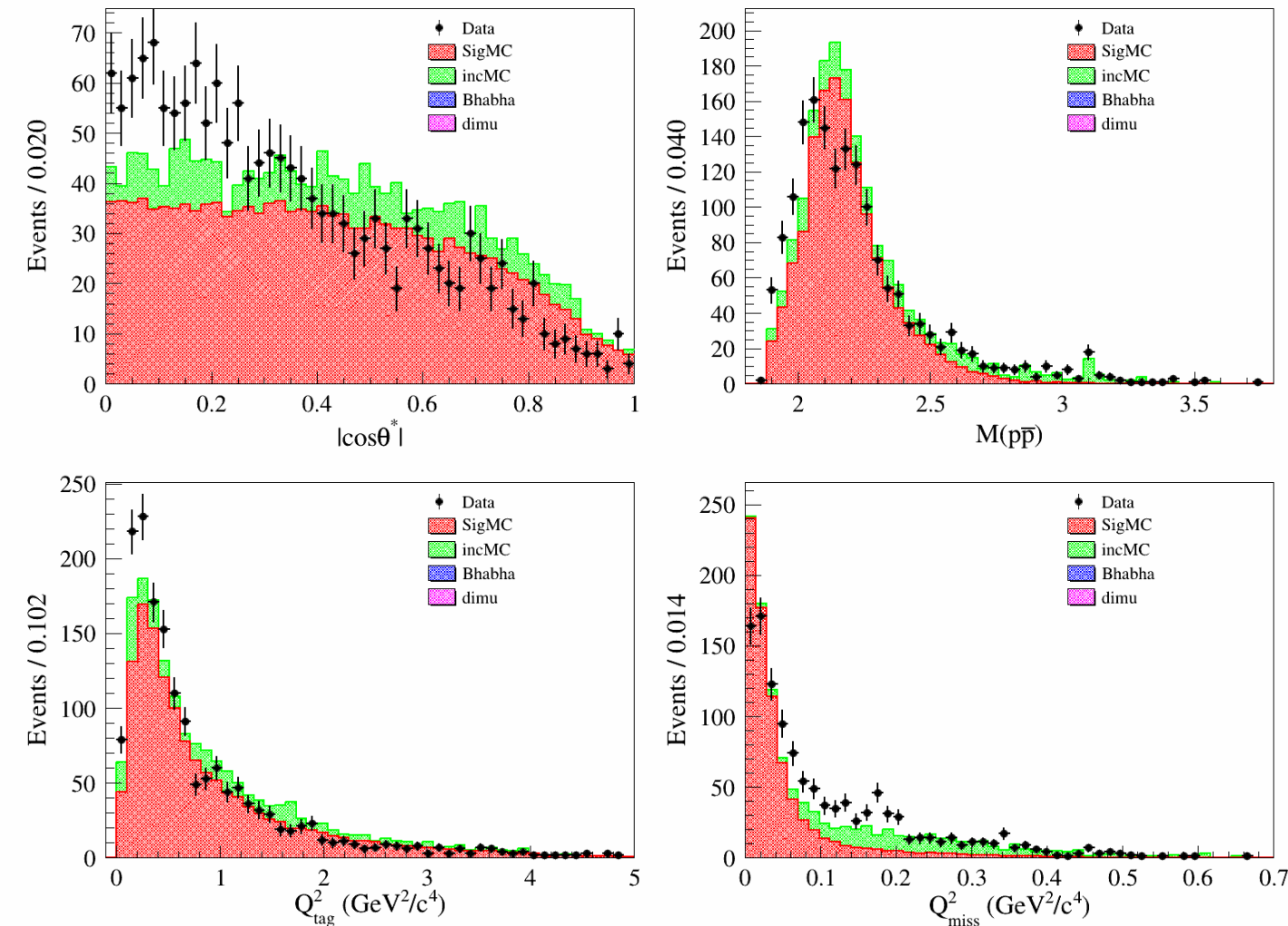


Efficiency binned in $M(p\bar{p})$ & $|\cos\theta^*|$:



Previous result for ST

Main physical observables:



Summary:

- Preliminary event selection completed
- Have been presented in collaboration

Next to do:

- More detailed background studies
- Iterate on signal MC
- Extract the cross section results
- Extract the ϕ modulation observables

Data set and Event selection for UT

➤ Data and MC samples:

BOSS: 712

Data set: full data sat at 3.773GeV, 20.3fb⁻¹

IncMC sample: Hadron Hybrid; 0.25x Bhabha; 15x dimu; 1x $\gamma\gamma \rightarrow ee, \mu\mu, \pi\pi, KK, \eta, \eta'$

ExcMC sample: 1M $\gamma\gamma \rightarrow p\bar{p}$ TT-only, 10M $e^+e^- \rightarrow p\bar{p}$

➤ Event selection:

- Good charged track:

$$|V_{xy}| < 1cm, |V_z| < 10cm, |\cos\theta| < 0.93$$

$$N_{good} = 2, N_{charge} = 0$$

- PID:

p: prob(p) > prob(e, μ , π , K), 0.001

e: prob(e) > prob(μ , π , K, p), 0.001

$$N_p = N_{\bar{p}} = 1$$

- Vertex Fit:

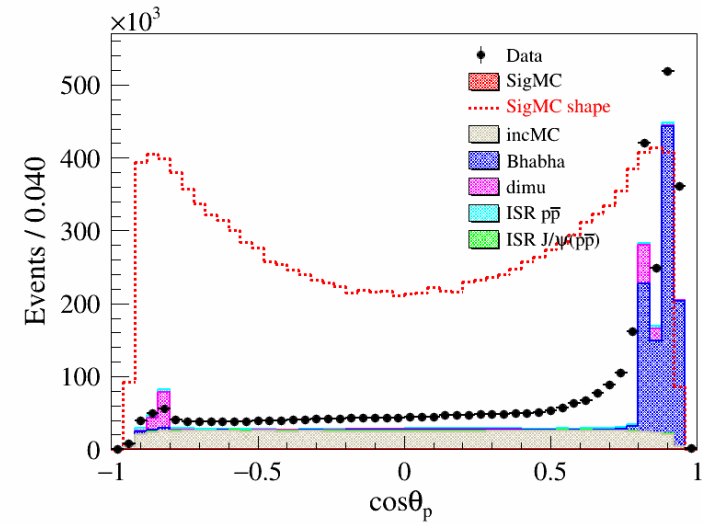
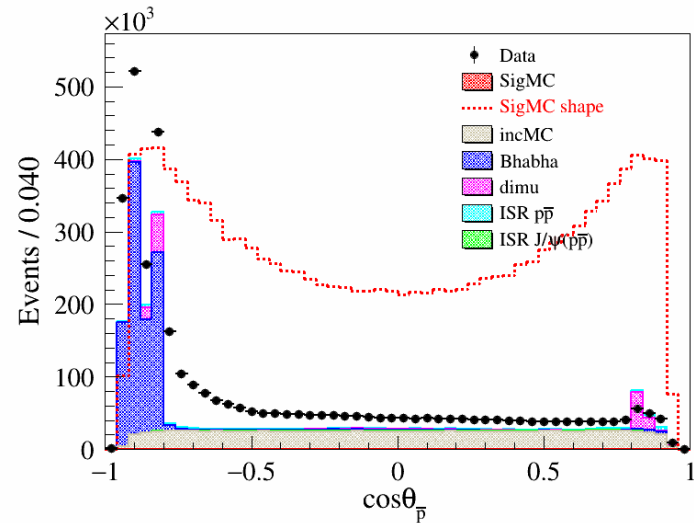
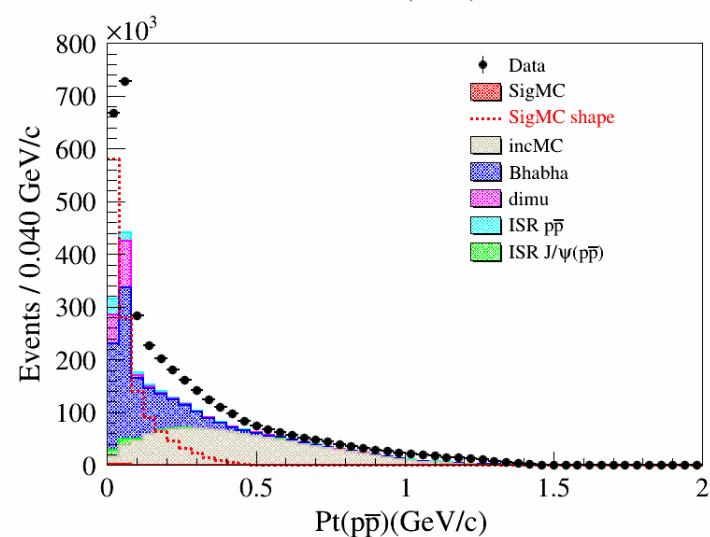
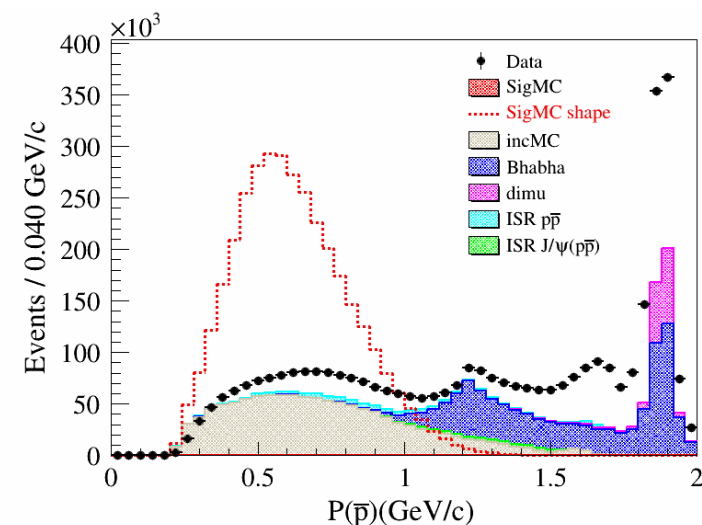
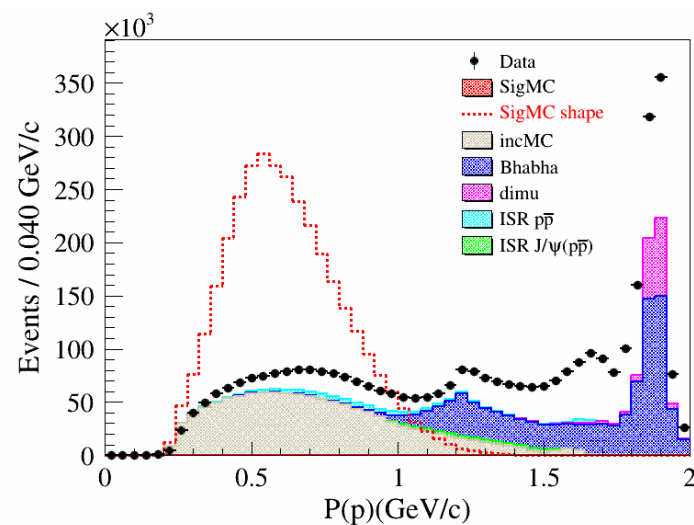
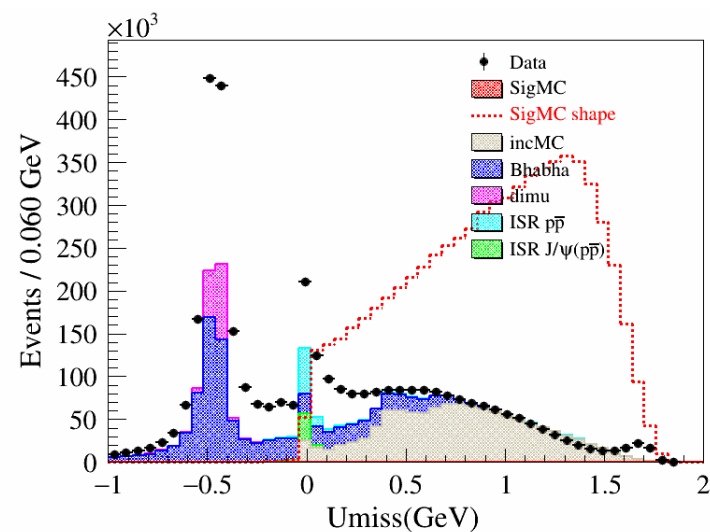
Vertex fit for $p\bar{p}$, success;

- Good Photon

10 degree away from charged tracks and 20 for $\bar{p}$

Further event selection for UT

Much more complex background than ST: 100x



Further event selection for UT

Further selection performed based on the kinematic features of UT:

- Constrain on the missing system:

$$U_{miss} > 0.1;$$

- Constrain on transverse momentum:

$$P_t(p\bar{p}) < 0.05 \text{ GeV}/c$$

- Constrain on the TOF information:

$$|t_{TOF}^p - t_{TOF}^{\bar{p}}| < 5$$

- Veto Bhabha background:

$$\text{Reject } \cos\theta_p > 0.8 \text{ \& } \cos\theta_{\bar{p}} < -0.8$$

- Constrain on EMC energy:

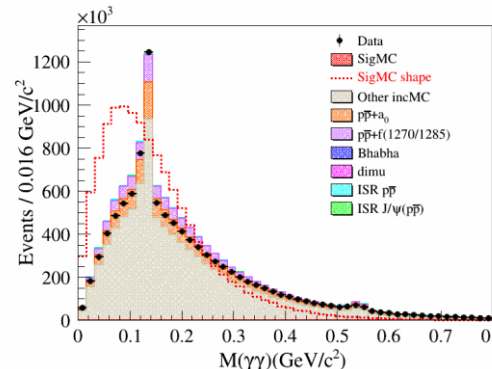
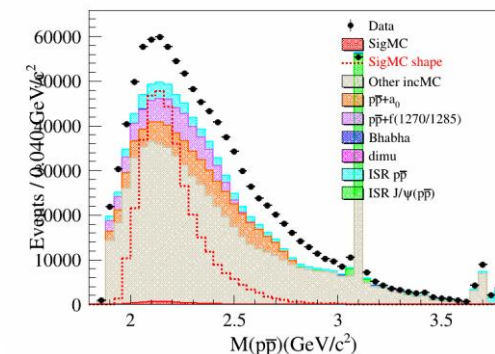
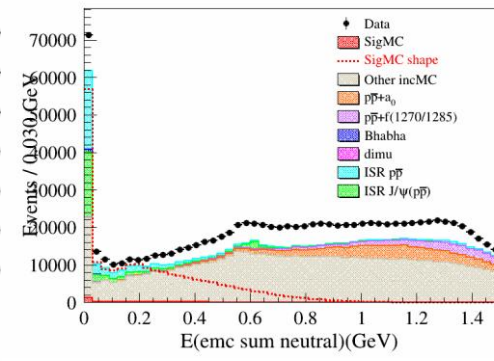
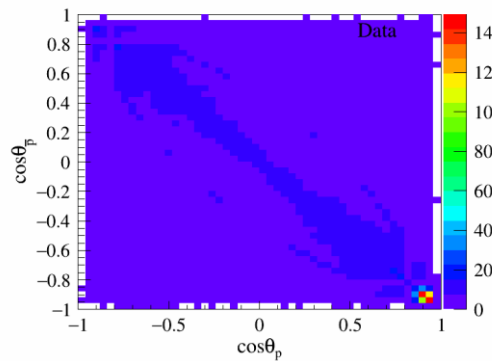
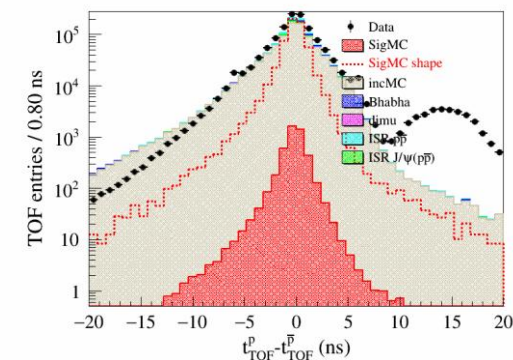
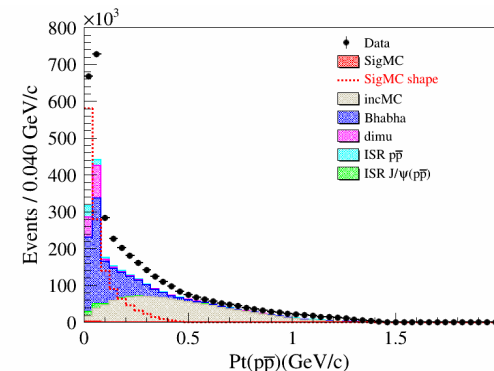
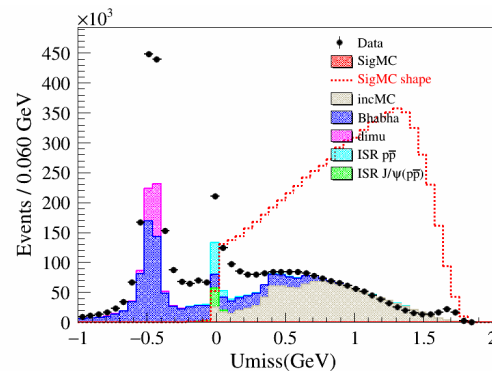
$$E(\text{emc neutral}) < 0.5$$

- Constrain on invariant mass of $p\bar{p}$:

$$M(p\bar{p}) < 3 \text{ GeV}/c^2$$

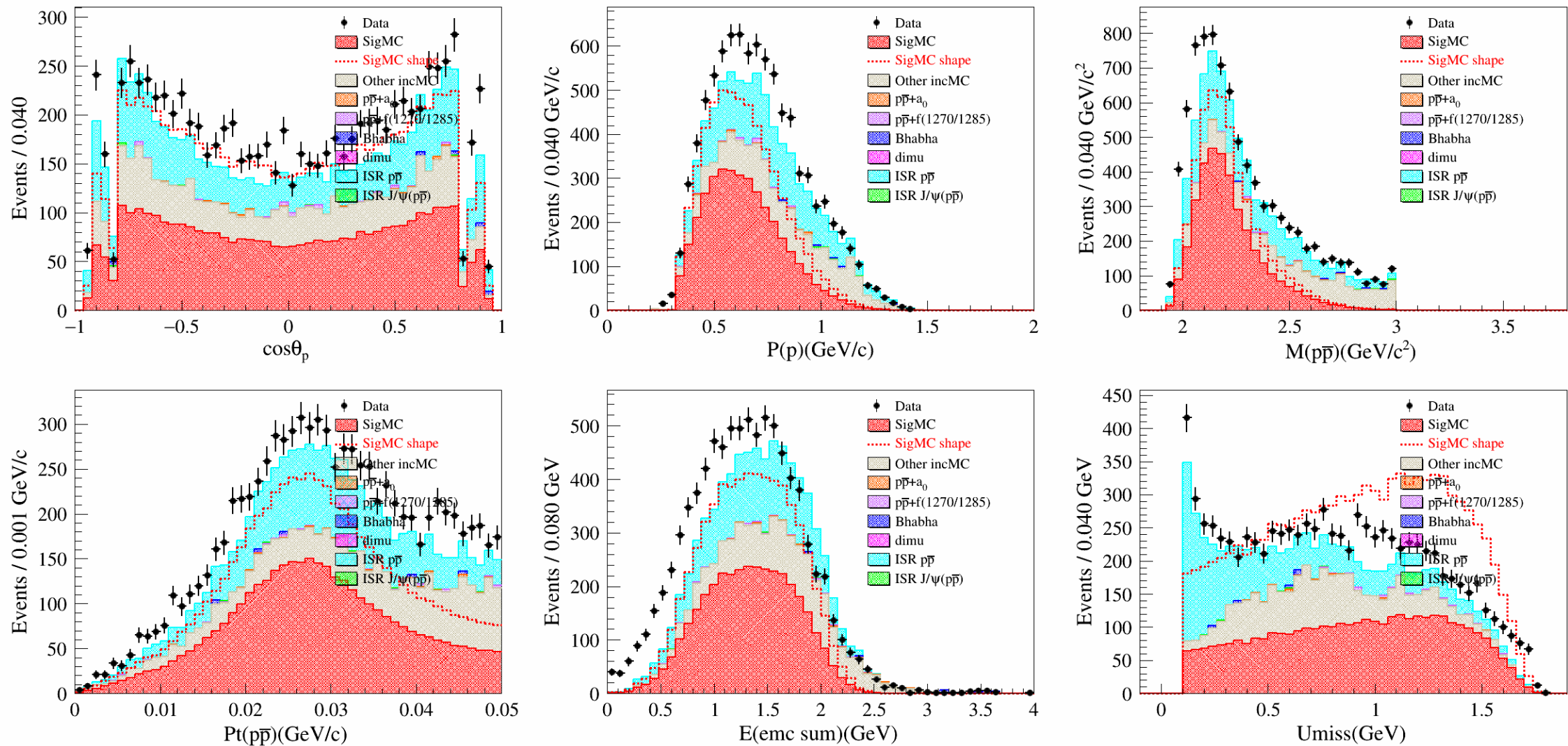
- Veto π^0 included background:

$$\text{Reject } |M(\gamma\gamma) - M(\pi^0)| < 15 \text{ MeV}$$



Previous result for UT

The signal is at same level to the background.



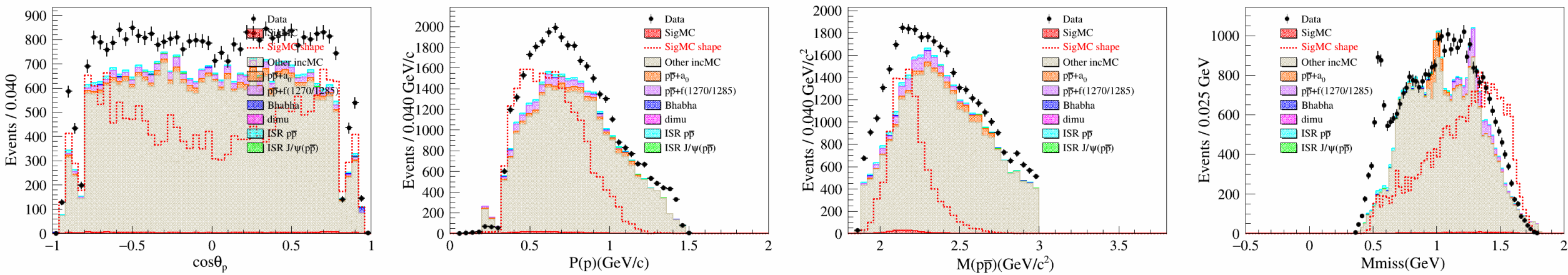
Background Analysis for UT

Background sources:

- All $p\bar{p}$ containing backgrounds
- Main background channel $e^+e^- \rightarrow p\bar{p}$
- Complex background processes

Final states	N	level
$ee \rightarrow p\bar{p}$	2565	29.3%
$e^+e^- \rightarrow p\bar{p}X$	1783	20.3%
non $p\bar{p}$	0	0%

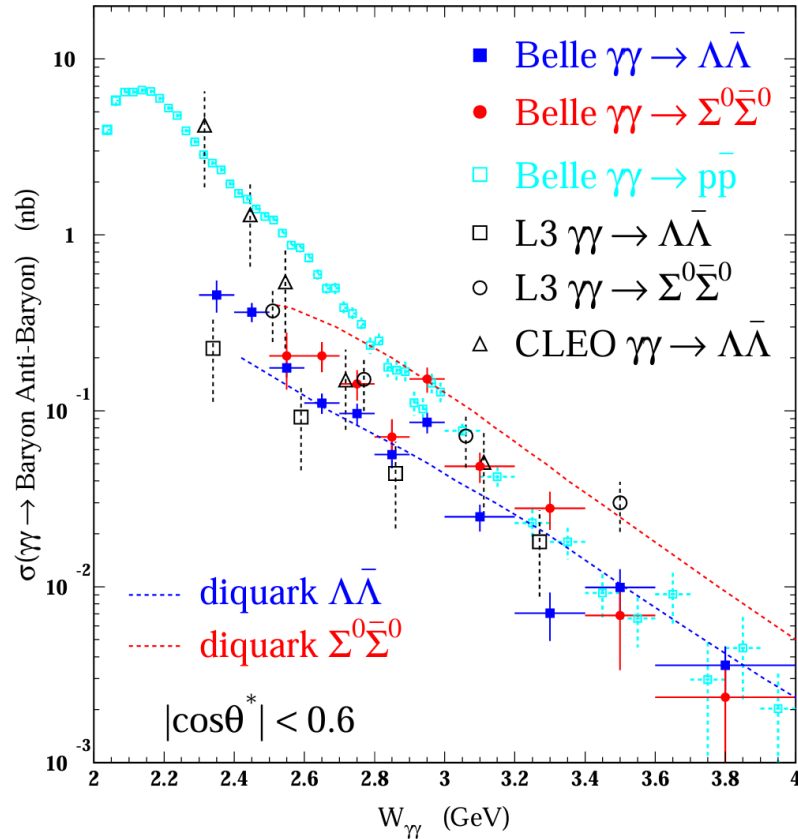
The agreement between data and MC in sideband region $Pt(p\bar{p}) > 0.3 GeV/c$:
The MC poorly describes the data; more refined and comprehensive studies are needed.



Extending to strange quarks baryon pairs $\gamma\gamma \rightarrow \Lambda\bar{\Lambda}$

Belle shows the most precise results through UT method: *arXiv:hep-ex/0609048*

Using 464 fb^{-1} of data collected at Belle, hundreds of events have been obtained for channel $\gamma\gamma \rightarrow \Lambda\bar{\Lambda}$.



Estimation the yield:

- Cross section an order smaller than $\sigma(\gamma\gamma \rightarrow p\bar{p})$
- Branching fraction of $\text{BF}(\Lambda \rightarrow p\pi) = 0.641 \pm 0.005$
- Lower reconstruction efficiency
- Higher production threshold

$$N_{obs}^{exp} \approx 500 \times 0.1 \times 0.4 \times 0.3 = 6$$

Extending to strange quarks baryon pairs $\gamma\gamma \rightarrow \Lambda\bar{\Lambda}$ ST

➤ Data set: full data at 3.773GeV

➤ Event selection:

- Good charged track:

$$|V_{xy}| < 10\text{cm}, |V_z| < 30\text{cm}, |\cos\theta| < 0.93$$

$$N_{\text{good}} = 5 N_{\text{charge}} = 1$$

- PID:

$$p: \text{prob}(p) > \text{prob}(e, \mu, \pi, K), 0.001$$

$$N_p = N_{\bar{p}} = 1$$

- Reconstruct Λ :

Vertex and second vertex fit for $p\pi$ combination

Select smallest $|M(p\pi) - M(\Lambda)|$

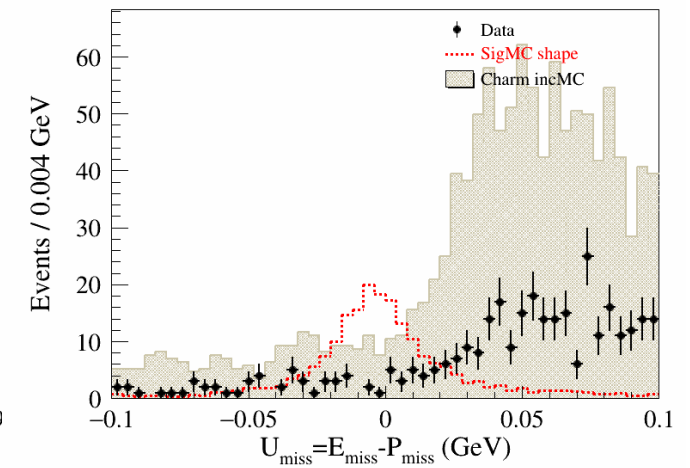
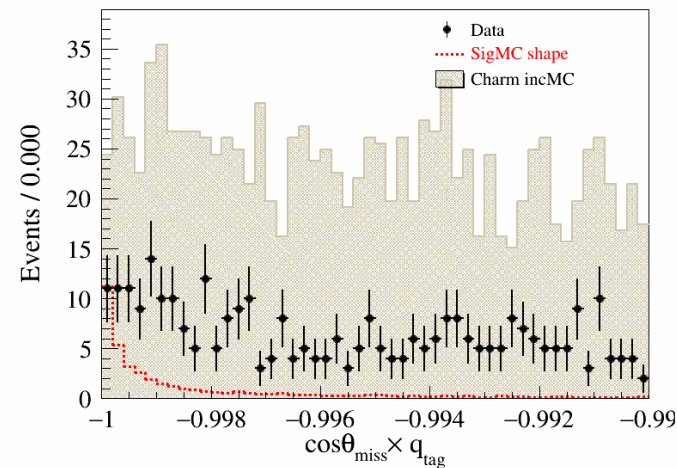
- Extra tracks regrad as e
- Vertex fit for $\Lambda\bar{\Lambda}e$

➤ Further selection:

$$\cos\theta_{\text{miss}} \times \text{Sign}(e) < -0.99$$

$$|U_{\text{miss}}| < 0.1$$

➤ Result:



The statistics are insufficient, data taken at higher energy points can be exploited.

Extending to meson pairs $\gamma\gamma \rightarrow K_S K_S$ ST

➤ Data set: 20.3fb^{-1} at 3.773GeV

➤ Event selection:

- Good charged track:

$$|V_{xy}| < 10\text{cm}, |V_z| < 20\text{cm}, |\cos\theta| < 0.93$$

$$N_{\text{good}} = 5 N_{\text{charge}} = 1$$

- PID:

$$e/\pi: \text{prob}(e/\pi) > \text{prob}(p, K), 0.001$$

- Reconstruct K_S :

Vertex and second vertex fit for $\pi^+\pi^-$ combination

$$\text{and } |M(\pi\pi) - M(K_S)| < 24\text{MeV}/c^2$$

Select smallest $|M(\pi\pi) - M(K_S)| + |M(\pi\pi) - M(K_S)|$

- Extra tracks regrad as e
- Vertex fit for $K_S K_S e$

➤ Further selection:

$$\cos\theta_{\text{miss}} \times \text{Sign}(e) < -0.99$$

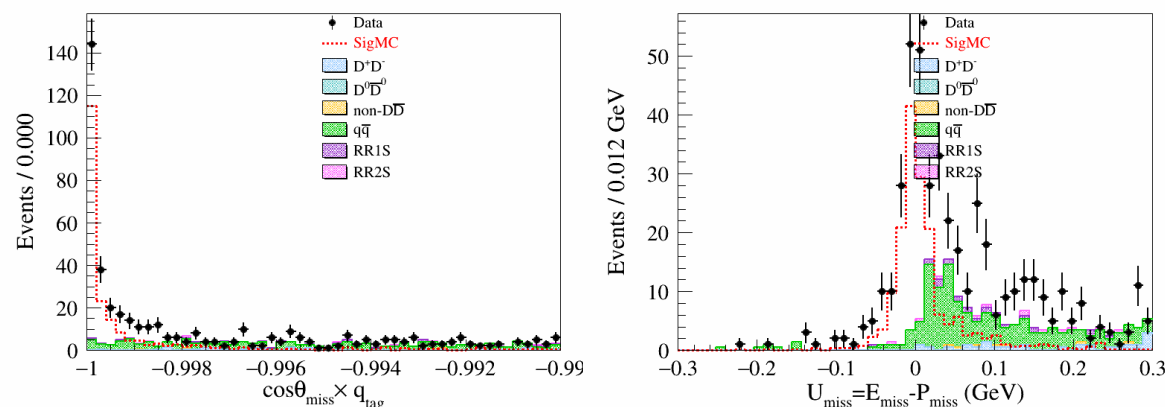
$$|U_{\text{miss}}| < 0.3$$

$$|M(\pi^+\pi^-) - M(K_S)| < 12\text{MeV}/c^2$$

$$L/\sigma(K_S) > 2$$

$$EOP(e) > 0.8$$

➤ Result: about 300 signal events



At low W (for KK), the UT yields about 13 times more events than the ST process

Extending to meson pairs $\gamma\gamma \rightarrow K_S K_S$ UT

➤ Data set: 4.19fb^{-1} at 3.773GeV

➤ Event selection:

- Good charged track:

$$|V_{xy}| < 10\text{cm}, |V_z| < 20\text{cm}, |\cos\theta| < 0.93$$

$$N_{\text{good}} = 4, N_{\text{charge}} = 0$$

- PID:

$$e/\pi: \text{prob}(e/\pi) > \text{prob}(p, K), 0.001$$

- Reconstruct K_S :

Vertex and second vertex fit for $\pi^+\pi^-$ combination

$$\text{and } |M(\pi\pi) - M(K_S)| < 24\text{MeV}/c^2$$

Select smallest $|M(\pi\pi) - M(K_S)| + |M(\pi\pi) - M(K_S)|$

- Vertex fit for $K_S K_S$

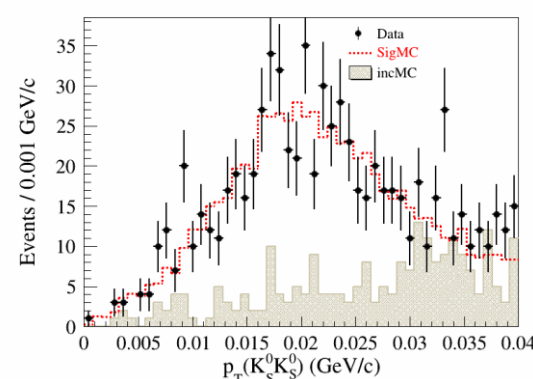
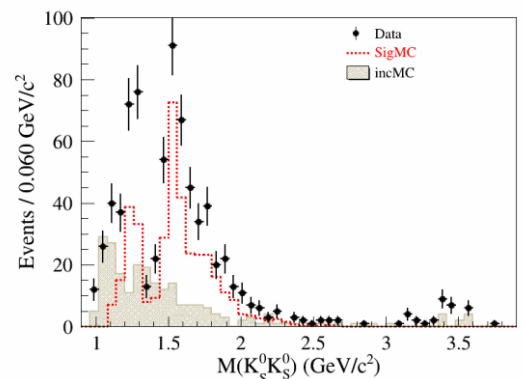
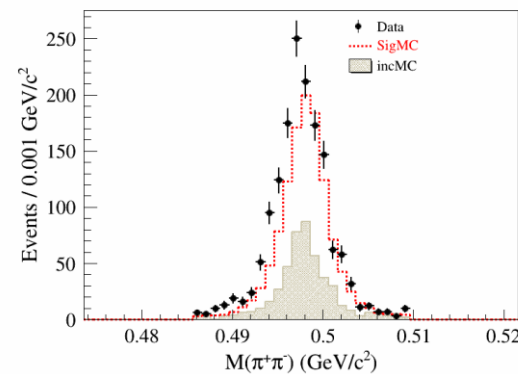
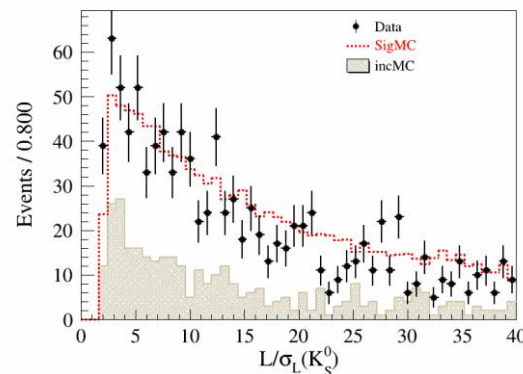
➤ Further selection:

$$|M(\pi^+\pi^-) - M(K_S)| < 12\text{MeV}/c^2$$

$$L/\sigma(K_S) > 2$$

$$Pt(K_S K_S) < 0.04\text{GeV}/c$$

➤ Result: about 500 signal events



Summary of study of two-photon process

Process	Method	Physics motivation	Status of analysis	Next to do
$\gamma\gamma \rightarrow p\bar{p}$	ST	Study the dependence of hadronic cross section on W , $\cos\theta^*$, Q^2 and ϕ modulation	Preliminary event selection completed; low background level	More detailed background studies; iteration of signal MC.
$\gamma\gamma \rightarrow p\bar{p}$	UT	Cross section measurement and study ϕ modulation	Event selection and background study are still on going.	Finish event selection and background study.
$\gamma\gamma \rightarrow \Lambda\bar{\Lambda}$	ST	Production of strange quark baryon pairs via two-photon collisions	No significant signal is observed at current energy point and statistics.	Data from higher energy points will be explored.
$\gamma\gamma \rightarrow K_S^0 K_S^0$	ST	Cross section measurement and resonance studies	A simple yield estimation was performed.	Finish event selection.
$\gamma\gamma \rightarrow K_S^0 K_S^0$	UT	Cross section measurement and resonance studies	A simple yield estimation was performed.	Finish event selection.

Begin with $\gamma\gamma \rightarrow p\bar{p}$, build up two photon studies covering different photon virtualities and final states.

Other work: Polarization study of $ee \rightarrow \Lambda\bar{\Sigma}^0$ at 3.773GeV

Motivation: Inner structure of hyperon (G_E and G_M)

- The modulus and phase of the ratio G_E/G_M in time-like region accessed directly from the measurement of the polarization.

➤ Introduce observables α and $\Delta\Phi$ constructed from G_E and G_M :

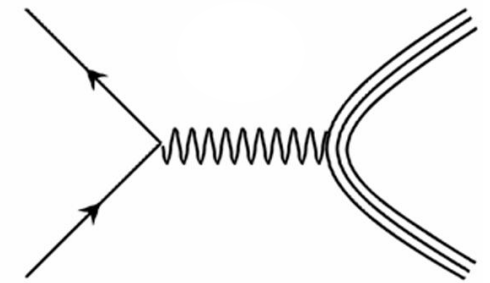
$$\alpha = \frac{s|G_M|^2 - 4M^2|G_E|^2}{s|G_M|^2 + 4M^2|G_E|^2} \rightarrow \frac{d\sigma}{d\cos\theta} \approx 1 + \alpha\cos^2\theta; \quad \frac{G_E}{G_M} = e^{i\Delta\Phi} \left| \frac{G_E}{G_M} \right| \xrightarrow{\Delta\Phi \neq 0} P_y(\cos\theta_Y) = \frac{\sqrt{1-\alpha^2}\cos\theta_Y\sin\theta_Y}{1+\alpha\cos^2\theta_Y} \sin(\Delta\Phi)$$

- Provide measurement results in higher energy region.

Dataset: $e^+e^- \rightarrow \Lambda\bar{\Sigma}^0 + c.c$ at 3.773GeV

- Highest integrated luminosity of 20.275 fb⁻¹.
- Dominant decay $\psi(3773) \rightarrow D\bar{D}$ + Isospin symmetry breaking, almost pure Born process.

Born process



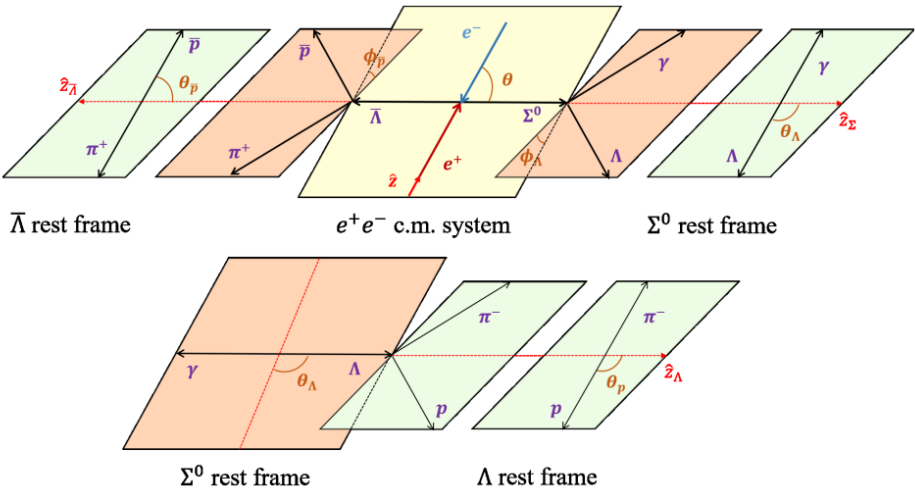
Other work: Polarization study of $ee \rightarrow \Lambda \bar{\Sigma}^0$ at 3.773 GeV

Decay Parameter Measurement:

- Helicity amplitude: $W(\xi, \Omega) \propto \text{Tr}(\rho_{\Sigma^0 \bar{\Lambda}}) \propto \sum_{\mu, \nu, i=0}^3 C_{\mu \nu} a_{\mu i}^{\Sigma^0} a_{i0}^{\Lambda} a_{\nu 0}^{\bar{\Lambda}}$
- Likelihood: $-\ln \mathcal{L} = -\sum_{i=1}^{N_{\text{tot}}} \ln W(\xi_i, \Omega) + N_{\text{tot}} \cdot \mathcal{N}(\Omega)$

Summary: The angular distribution parameter α , the relative phase of the form factor and the cross section is measured:

	$ee \rightarrow \Lambda \bar{\Sigma}^0$	$ee \rightarrow \bar{\Lambda} \Sigma^0$
α	$0.32 \pm 0.24_{\text{stat}} \pm 0.10_{\text{syst}}$	$0.60 \pm 0.18_{\text{stat}} \pm 0.11_{\text{syst}}$
$\Delta\Phi$	$0.64 \pm 0.37_{\text{stat}} \pm 0.16_{\text{syst}}$	$1.37 \pm 0.46_{\text{stat}} \pm 0.18_{\text{syst}}$
σ^B	$200 \pm 12_{\text{stat}} \pm 8_{\text{syst}}$	$186 \pm 11_{\text{stat}} \pm 6_{\text{syst}}$



This picture is from: Nat Commun 15, 8812 (2024).

Next to do: Finish collaboration internal review and publication process

Summary and prospect

- Study of $\gamma\gamma \rightarrow p\bar{p}$:
 - ✓ Event selection and background study
 - ❑ iteration of signal MC
 - ❑ Study the cross section and ϕ modulation
 - ❑ Prepare the memo and draft

- Study of $e^+e^- \rightarrow \Lambda\bar{\Sigma}^0 + c.c.:$
 - ✓ Memo have been submitted for collaboration review.
 - ❑ Prepare draft.

- Prospects:
 - ❑ Study of other $\gamma\gamma \rightarrow X$ process, e.g. $\gamma\gamma \rightarrow K_S^0 K_S^0$

BACK UP

➤ **Good Charged Tracks:**

$$|V_{xy}| < 10cm; |V_z| < 30cm; |\cos(\theta)| < 0.93;$$

$$N_{charged} \geq 4;$$

➤ **Charged Tracks Identification:**

$$p(\bar{p}): |P| > 0.7GeV/c; \pi^+(\pi^-): |P| < 0.7GeV/c$$

$$N_p, N_{\bar{p}}, N_{\pi^+}, N_{\pi^-} \geq 1$$

➤ **Good Photon:**

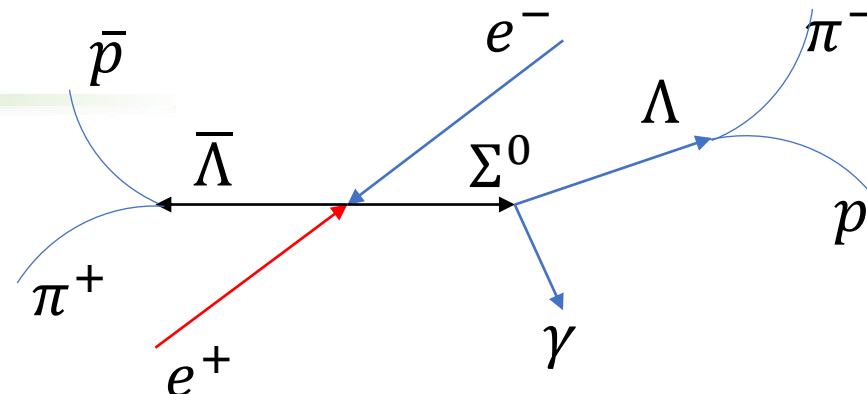
$$\text{Barrel: } E_\gamma > 25MeV;$$

$$\text{End cap: } E_\gamma > 50MeV;$$

$$\text{The EMC timing } t: 0ns < t < 700ns;$$

The direction of photon at least 10° away from $p\pi^+\pi^-$ and 20° away from $\bar{p}$.

$$N_{photon} \geq 1;$$



➤ **Vertex Fit:**

Vertex fit and second vertex fit applied to $p\pi^-$ and $\bar{p}\pi^+$, the one with minimum $|M_{p\pi} - M_\Lambda|$ is kept. And $|M_{p\pi} - M_\Lambda| < 12MeV/c^2$, $\chi^2_{sec} < 20$ and $L/\sigma_L > 0$ are required.

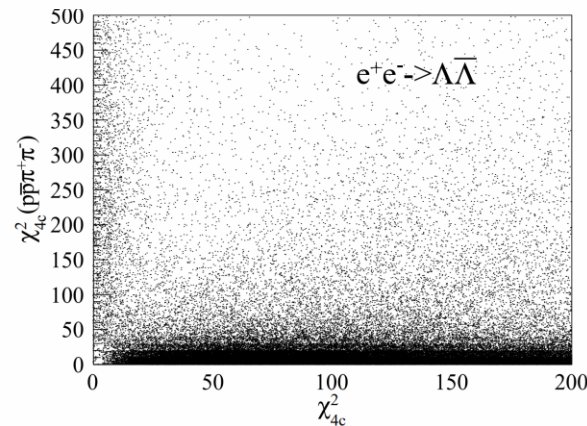
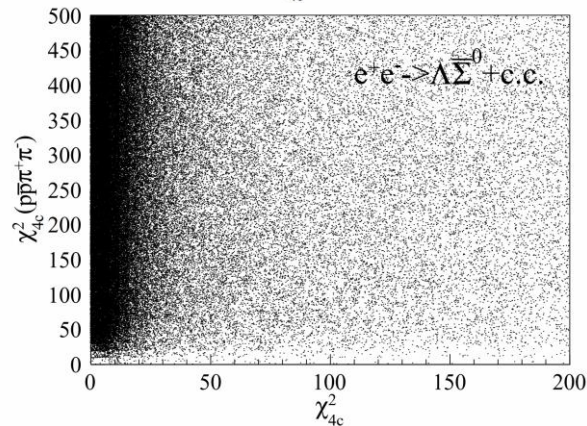
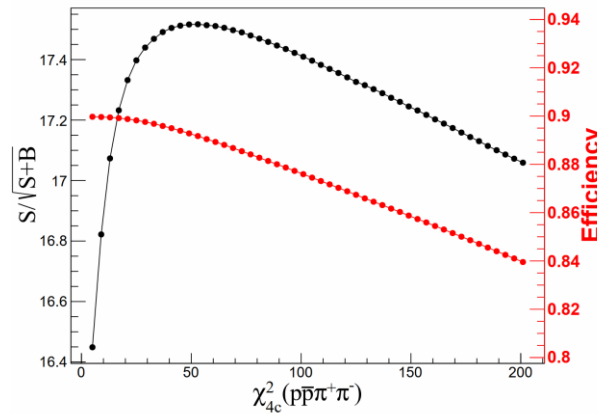
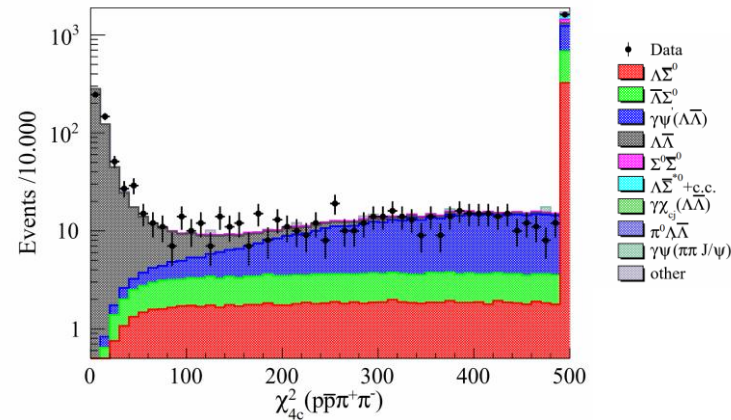
➤ **4C-Kinematic Fit**

Loop over all $\gamma\Lambda\bar{\Lambda}$ combinations with 4C fit and the one with minimum χ^2_{4C} and $\chi^2_{4c} < 200$ is retained; And $M(p\bar{p}\pi^+\pi^-) > 3.4GeV/c^2$ is required.

Event Selection

➤ To reject the background of $e^+e^- \rightarrow \Lambda\bar{\Lambda}$:

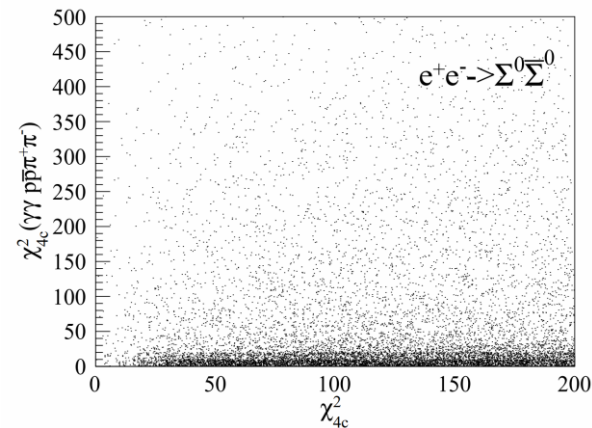
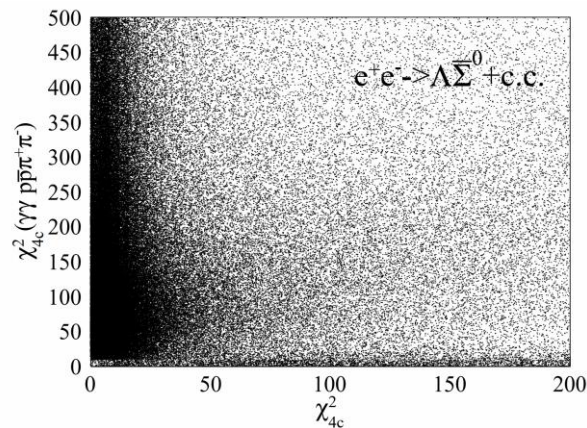
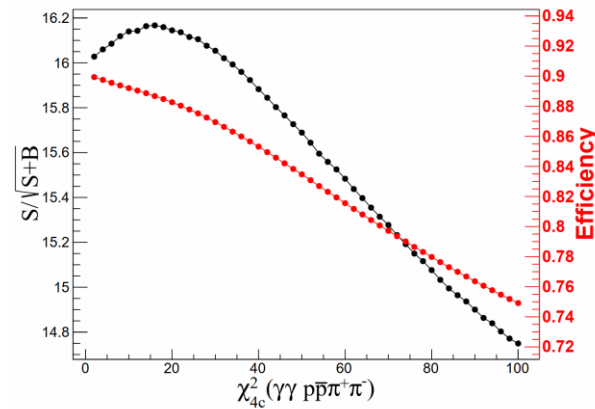
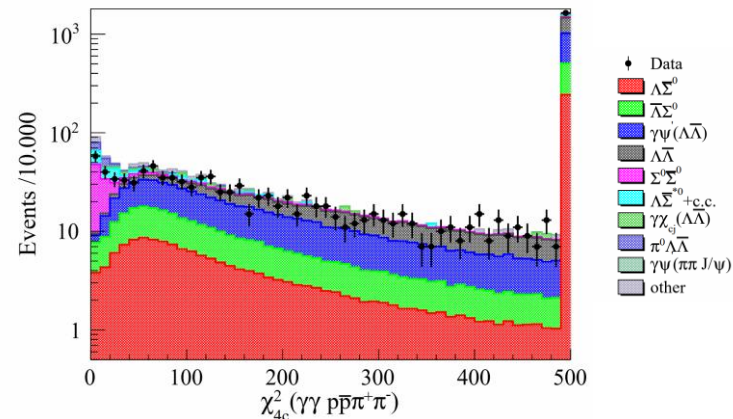
An additional 4C-fit under the hypothesis of $e^+e^- \rightarrow p\bar{p}\pi^+\pi^-$ is carried out and the corresponding distributions are shown here. A requirement $\chi^2_{4c}(p\bar{p}\pi^+\pi^-) > 50$ is preformed.



Event Selection

➤ To reject the background of $e^+e^- \rightarrow \Sigma^0 \bar{\Sigma}^0$:

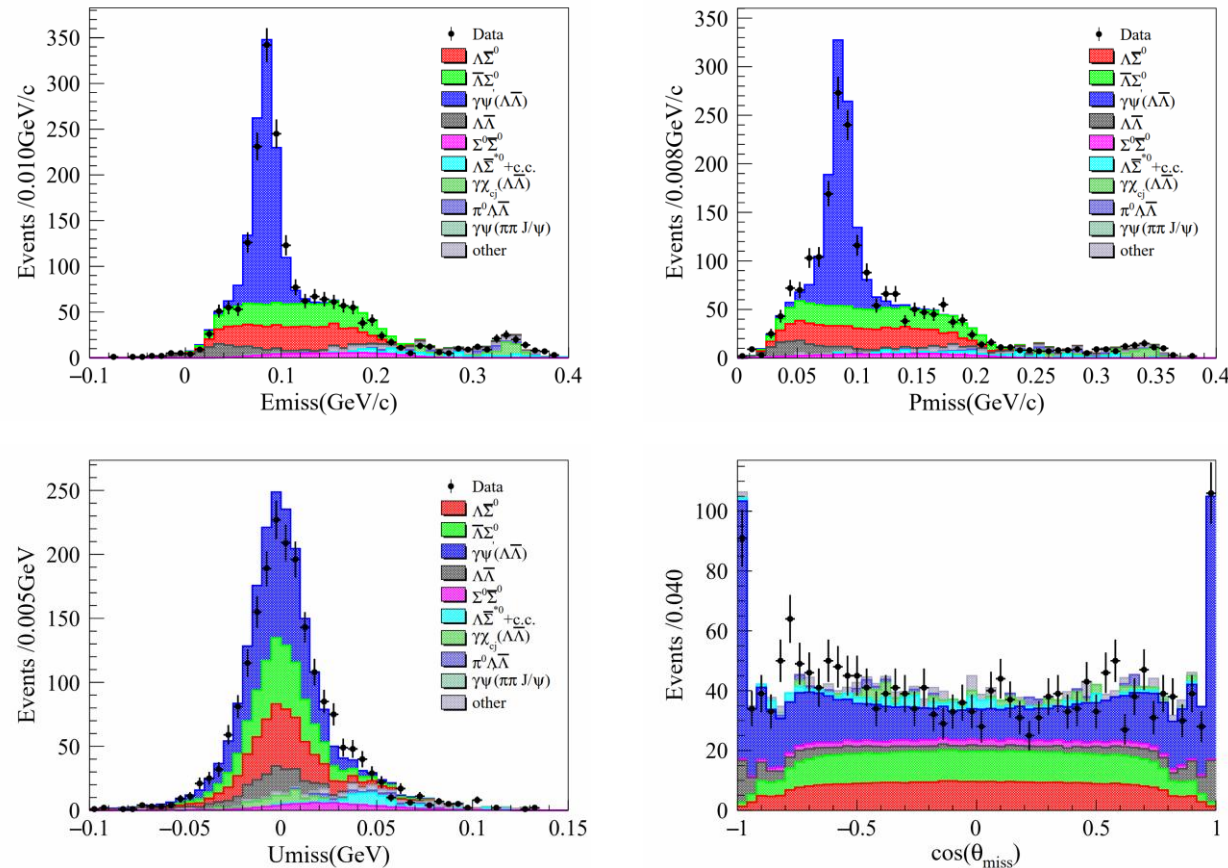
An additional 4C-fit under the hypothesis of $e^+e^- \rightarrow p\bar{p}\pi^+\pi^-\gamma\gamma$ is carried out and the corresponding distributions are shown here. A requirement $\chi^2_{4c}(p\bar{p}\pi^+\pi^-\gamma\gamma) > 20$ is preformed.



Event Selection

➤ To reject the background of $e^+e^- \rightarrow \psi(3686)\gamma_{ISR}$:

The corresponding distributions of the kinematic variables of the missing system recoiling against $\Lambda\bar{\Lambda}$ are shown here. A selection $|\cos\theta_{miss}| < 0.92$ is preformed.



Event Selection

➤ $\Lambda(\bar{\Lambda})$ and $\Lambda\bar{\Lambda}$ invariant mass requirement:

To minimize the background contribution, the requirement $|M_{p\pi} - M_{\Lambda}| < 6\text{MeV}/c^2$ (5 times of resolution) and $M(p\bar{p}\pi^+\pi^-) > 3.55\text{GeV}/c^2$ are performed.

➤ $\chi^2_{4c}(p\bar{p}\pi^+\pi^-\gamma)$ optimization:

To minimize the background contribution, the requirement $\chi^2_{4c}(p\bar{p}\pi^+\pi^-) < 100$ is further carried out.

