Study of $e^+e^- \rightarrow \gamma^*\gamma^* \rightarrow e^+e^-\omega\omega$ with untagged mthod

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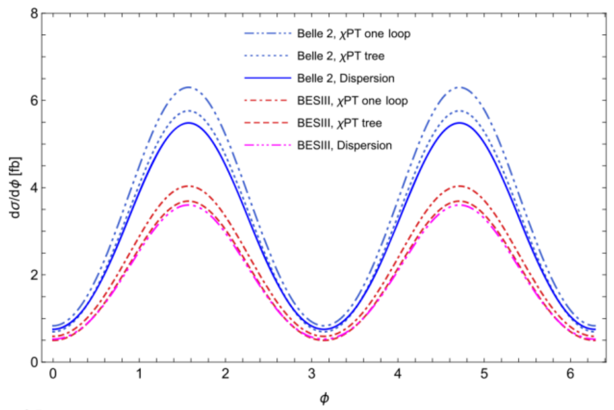
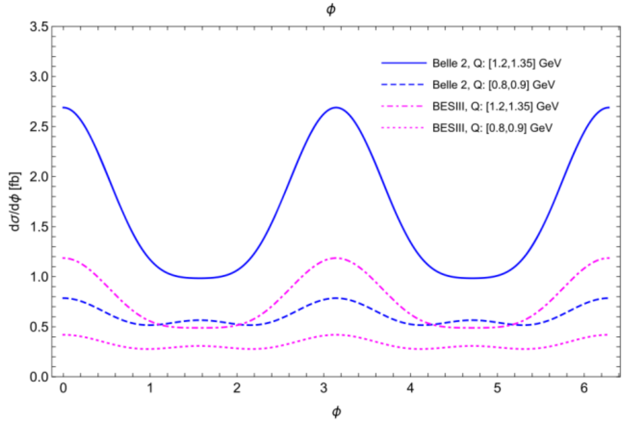
Motivation

- An azimuthal asymmetry is predicted within the Tranverse-Momentum-Dependent factorization theory in the process $e^+e^- \to e^+e^-\pi^+\pi^-$[1].
- The differential cross section with respect to azimuthal angle ϕ shows some oscillation structure.
  - ϕ is the angle between $\overrightarrow{\mathbf{P_T}}(\boldsymbol{\pi}^+) + \overrightarrow{\mathbf{P_T}}(\boldsymbol{\pi}^-)$ and $\overrightarrow{\mathbf{P_T}}(\boldsymbol{\pi}^+) - \overrightarrow{\mathbf{P_T}}(\boldsymbol{\pi}^-)$.
- Same oscillation phenomenon should also exist in the $\gamma\gamma \to VV$ process.
- The clear and simple background pollution of $e^+e^- \to e^+e^-\omega\omega$ process is an ideal channel to study the azimuthal asymmetry.

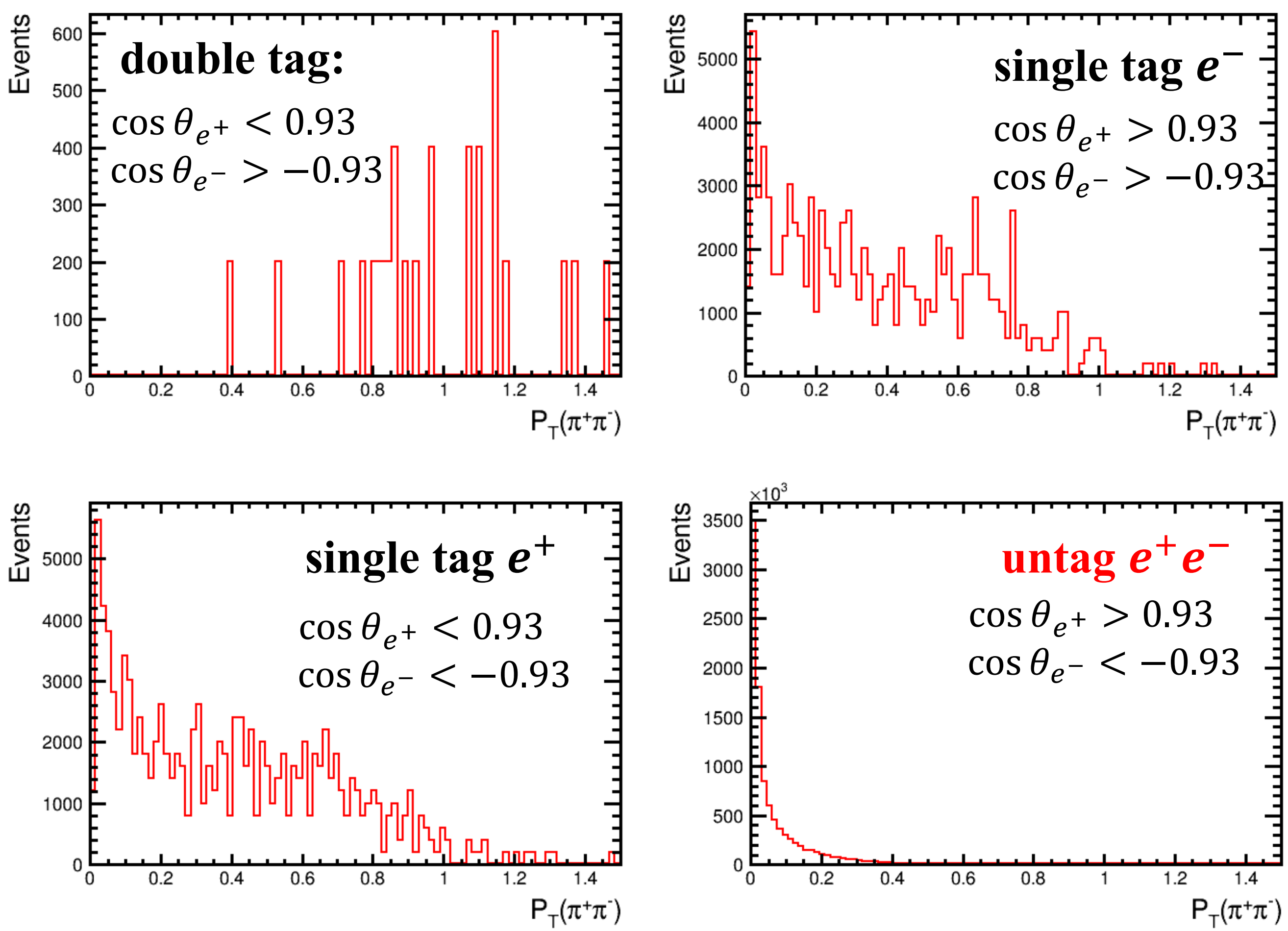




[1] PRL 134, 141901 (2025)

Motivation

➢ The TMD factorization theory is based on the quasireal photons emitted off e^+ and e^-, which leads to a requirement of $P_T(\pi^+\pi^-) < 0.1$ GeV/c.



method	statistic ratio	$P_T < 0.1$ ratio
double tag	0%	0%
single tag e^-	1%	18%
single tag e^+	1%	20%
untag e^+e^-	**98%**	**80%**

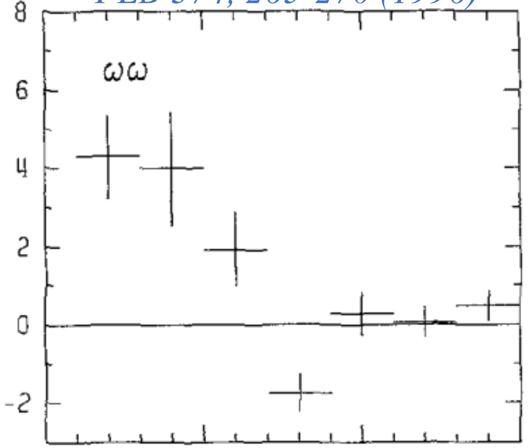
✓ **98%** two-photon events comes from untag region!

✓ **80%** events from untag region statisfy $P_T(\pi^+\pi^-) < 0.1$ GeV/c.

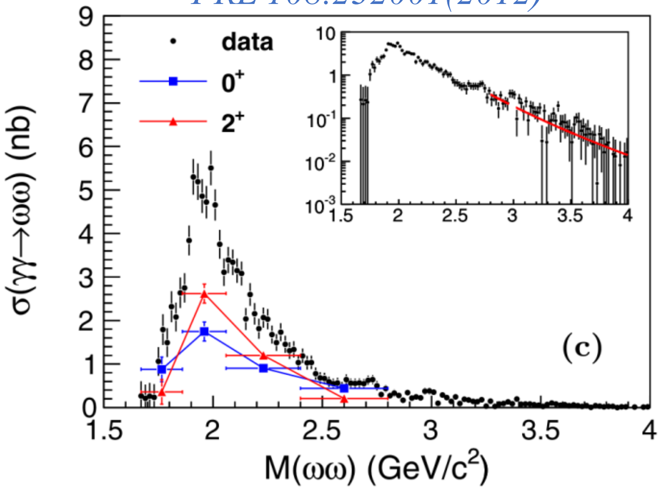
Motivation

➢The cross section of two-photon process $e^+e^- \to e^+e^-\omega\omega$ is studied by ARGUS[1] and Belle[2] experiment. Two resonant structures below charmonium threshold are found by Belle experiment.

PLB 374, 265-270 (1996)



PRL 108.232001(2012)



➢With the large data sets collected by BESIII, the process of $e^+e^- \to e^+e^-\omega\omega$ can be studied with BESIII data for the first time.

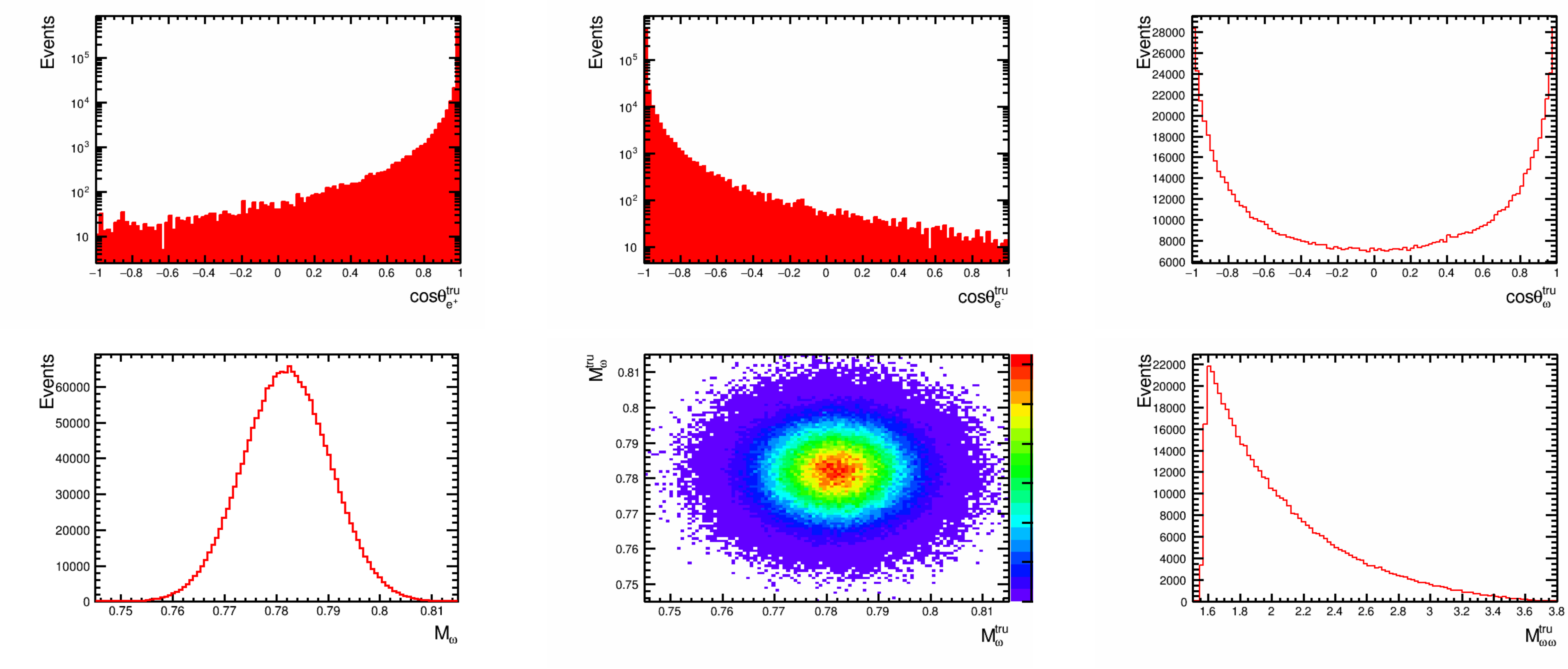
[1] PLB 374, 265-270 (1996) [2] PRL 108.232001(2012)

Data sets and MC sample

- **Data sets: 20.3 fb^{-1} $\psi(3770)$**
- **Signal MC:**
  - 1 million MC generated by **CppGamGam generator**.[1]
- **Inclusive background:**
  - Hadrons background generated by R-QCD group by Weiping Wang.
  - /besfs5/offline/data/tauqcd/bes3gen/712/psipp/
- **Exculsive background MC:**
  - 1 million $e^+e^- \rightarrow e^+e^-\omega\pi^+\pi^-\pi^0$ MC generated by CppGamGam generator.

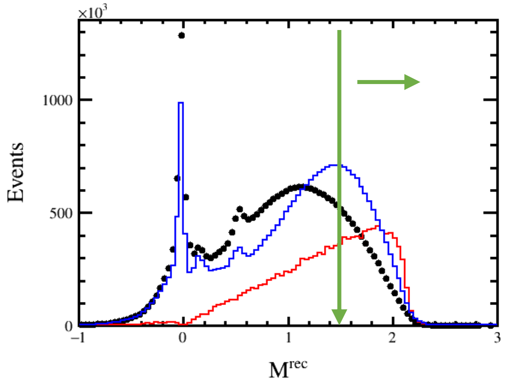
[1]BAM-636

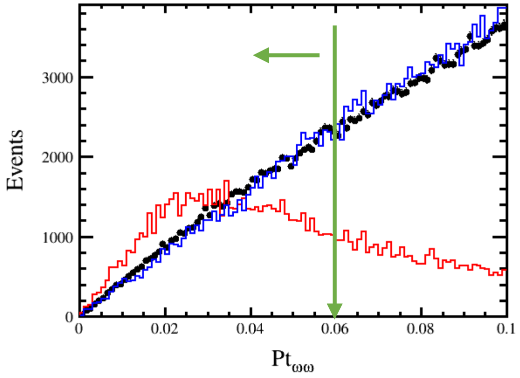
MC truth distribution

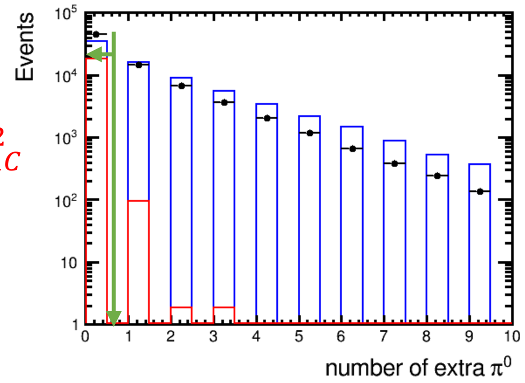


Event selection: $e^+e^- \rightarrow e^+e^-\omega\omega \rightarrow e^+e^-2(\pi^+\pi^-\pi^0)$

- **Good charged track**
  - $V_r < 1$ cm, $|V_z| < 10$ cm, $|\cos\theta| < 0.93$, $N_{good} = 4$
- **PID (dE/dx+TOF)**
  - $Prob(\pi) > Prob(p/K)$, $N(\pi^+) = N(\pi^-) = 2$
- **Vertex Fit:** SUCCESS
- **Good photons:**
  - $|\cos\theta_\gamma| < 0.8$ or $0.86 < |\cos\theta_\gamma| < 0.92$
  - $E_\gamma \geq 25$ MeV $(barrel)$, $E_\gamma \geq 50$ MeV $(endcaps)$
  - $EMC\ time$: $0\sim700\ ns$
  - $\theta(\gamma,\pi) > 10°$
  - $N_\gamma \geq 4$
- **Good π^0 list:**
  - $0.115 \leq M_{\gamma\gamma} \leq 0.150$ GeV/c^2
  - $\chi^2_{1C} < 20$
  - $Helicity < 0.95$
  - $N_{\pi^0} \geq 2$
  - Choose the $2\pi^0$ combination with minimum sum of χ^2_{1C}
- **Further requirement:**
  - Recoil mass > 1.5 GeV/c^2
  - $P_T < 0.06$ GeV/c
  - Number of extra $\pi^0 = 0$





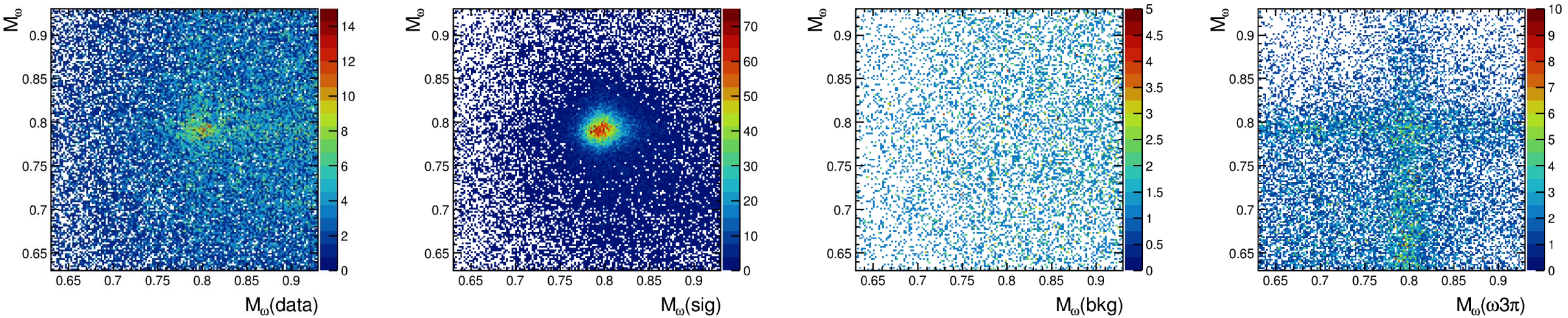


— Hadrons
— Signal
-●- Data

	Efficiency	
	Absolute(%)	Relative(%)
Total	1	
nGood=4	46.07	46.07
PID	41.75	90.61
Vtxfit	41.36	99.05
Good Photon	19.38	46.86
Good pi0	10.78	55.61
Recoil mass	5.15	47.75
P_T cut	2.19	42.51
Extra π^0	2.18	99.46

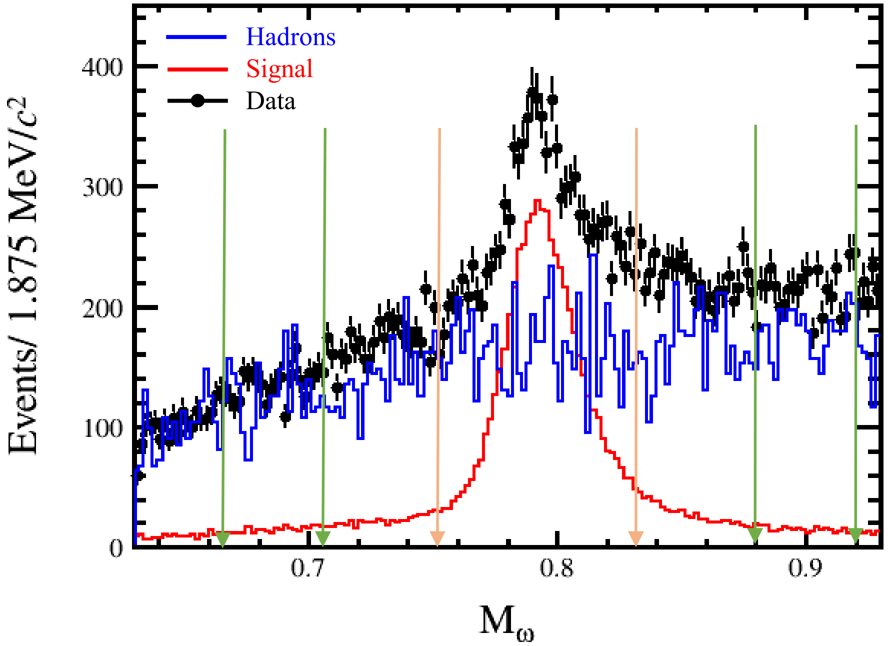
Extraction of $\omega\omega$ signal

- Every event has 4 pairs of $\omega\omega$ combinations.
  - $\pi_1^0\pi_1^+\pi_1^-$, $\pi_2^0\pi_2^+\pi_2^-$
  - $\pi_1^0\pi_1^+\pi_2^-$, $\pi_2^0\pi_2^+\pi_1^-$
  - $\pi_1^0\pi_2^+\pi_1^-$, $\pi_2^0\pi_1^+\pi_2^-$
  - $\pi_1^0\pi_2^+\pi_2^-$, $\pi_2^0\pi_1^+\pi_1^-$
- Require $\left|M_{\omega_{1,2}} - m_\omega^{PDG}\right| < 0.15\ \text{GeV}/c^2$ at least one of this four combination.
  - Relative effciencicy is 99.81% for signal MC.



Extraction of $\omega\omega$ signal

➢Require the oppsite ω mass within PDG mass $\pm$ 40MeV, and we can obtain the M_ω mass spectrum:



Signal region:

- 0.752~0.832

Sideband region:

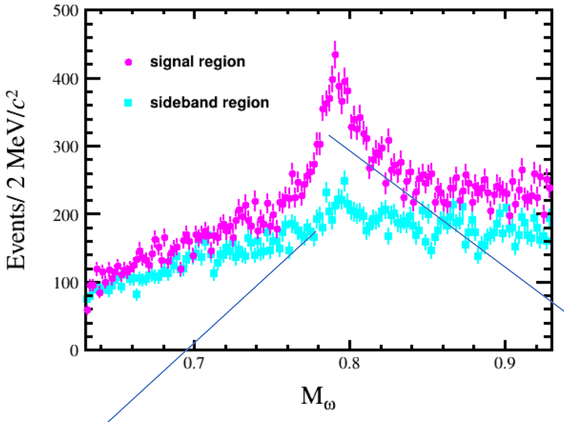
- 0.664~0.704
- 0.880~0.920

➢Sideband region has the same interval width with signal region. ⇒ scale factor = 1

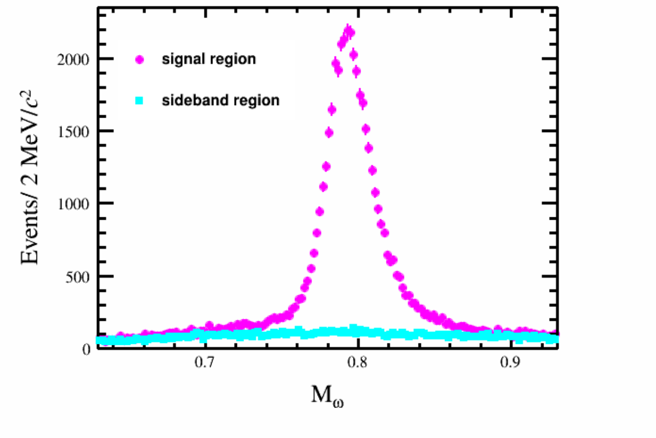
➢Clear $\omega\omega$ signals can be observed and no peaking background from hadrons background.

1D Fit: MC shape

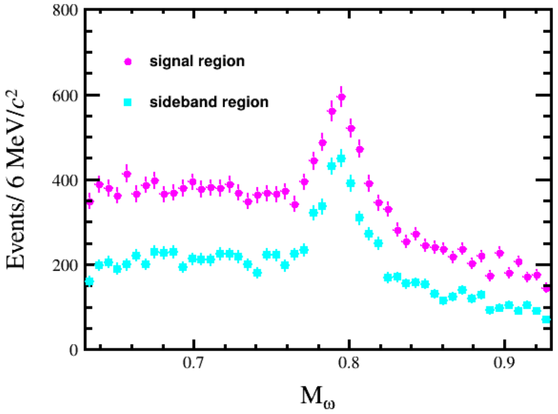
M_ω^{data}



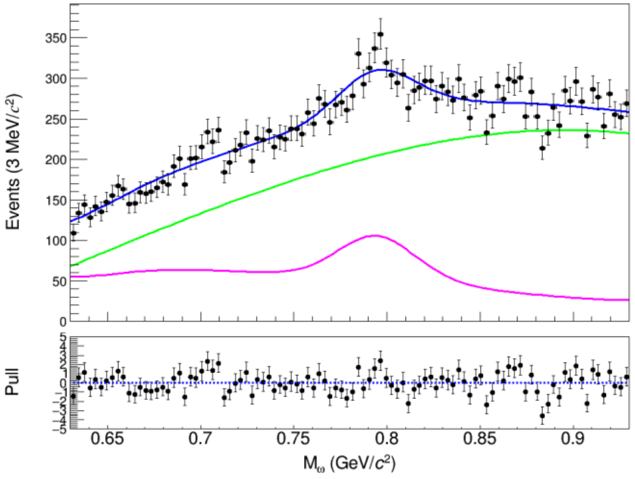
M_ω^{signal}



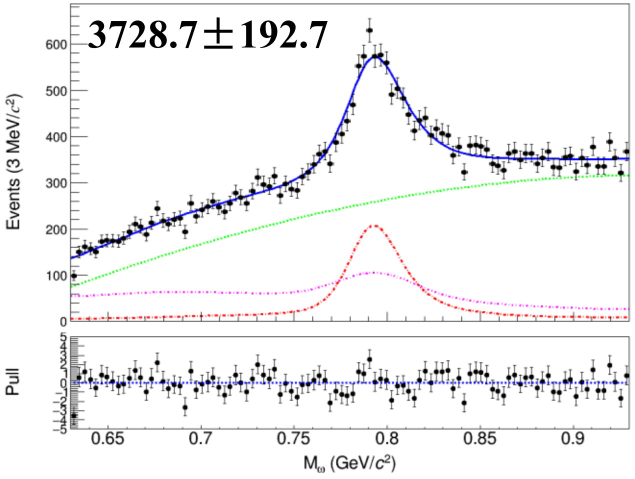
$M_\omega^{\omega 3\pi}$



chebychev + $\omega 3\pi$-bkg shape (sideband region)



signal MC shape + 3rdCheby + fixed bkg shape



Here, the signal events are counted as twice.

$N_{sig} \sim 1864$

1D Fit: MC shape

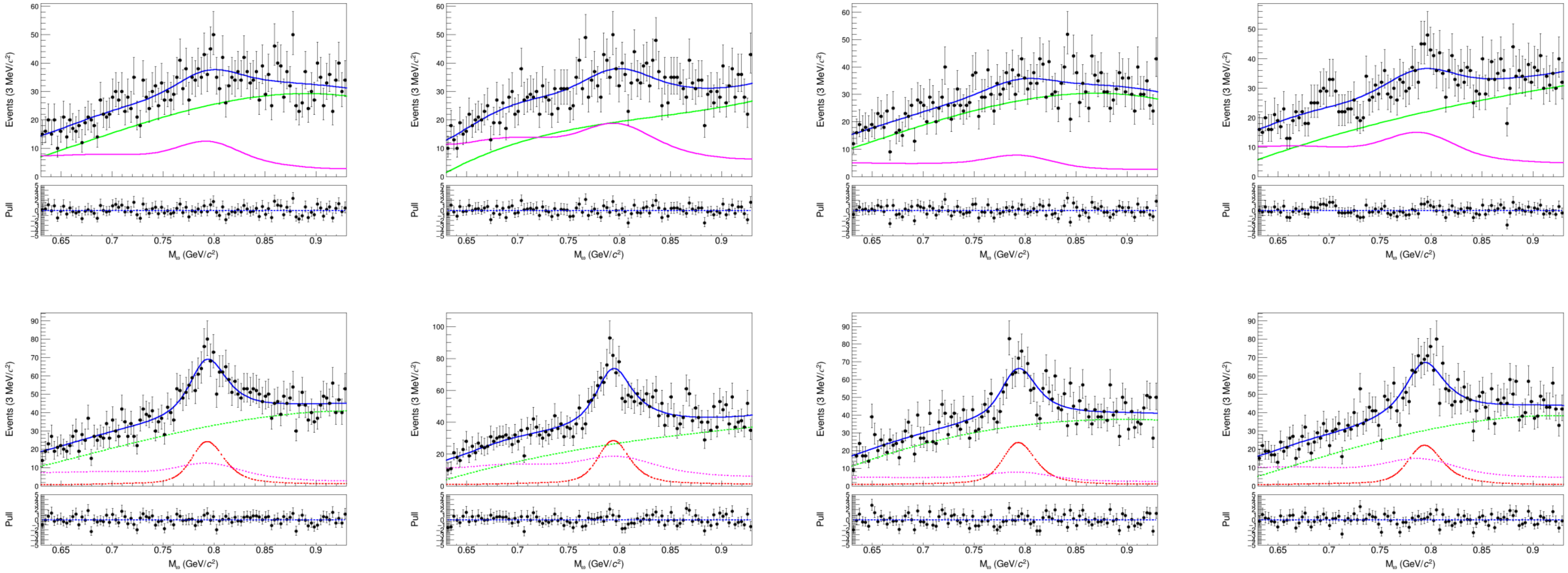
ϕ = Angle$(\overrightarrow{P_T}(\pi^+) + \overrightarrow{P_T}(\pi^+), \overrightarrow{P_T}(\pi^+) - \overrightarrow{P_T}(\pi^+))$

ϕ is in the region [0°, 360°]. Every 45° one bin, divide ϕ into 8 intervals.

Bin-1 Bin-2 Bin-3 Bin-4

sideband

signal

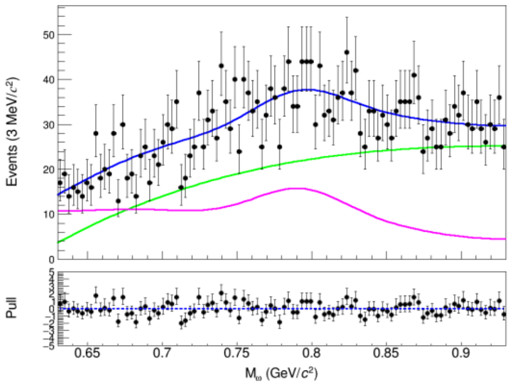


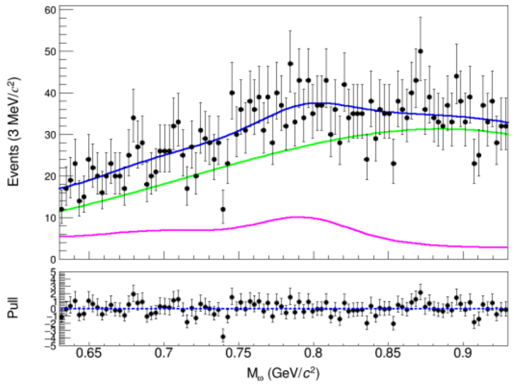
1D Fit: MC shape

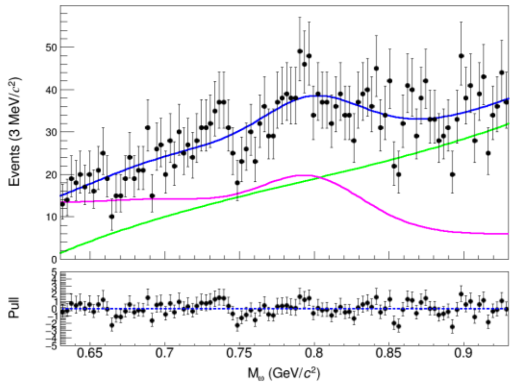
ϕ is in the region [0°, 360°]. Every 45° one bin, divide ϕ into 8 intervals.

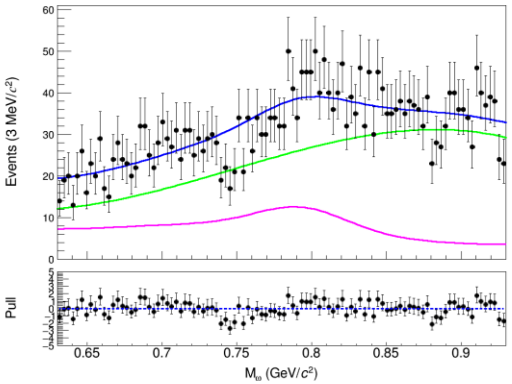
Bin-5 | Bin-6 | Bin-7 | Bin-8

sideband

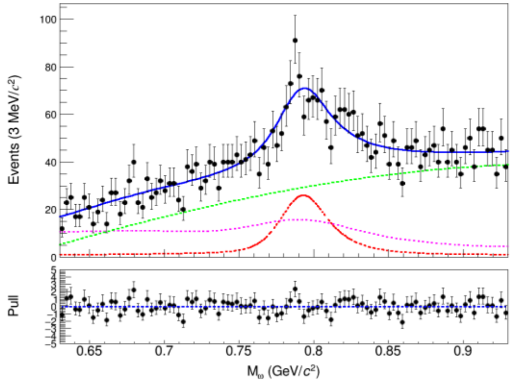


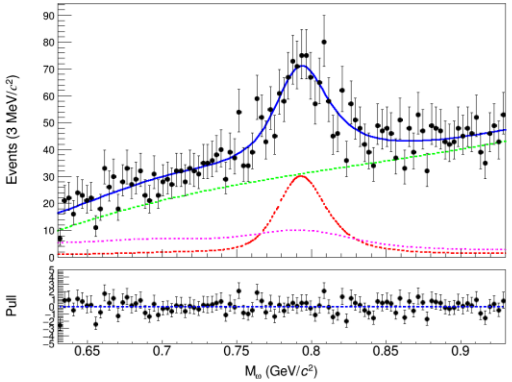


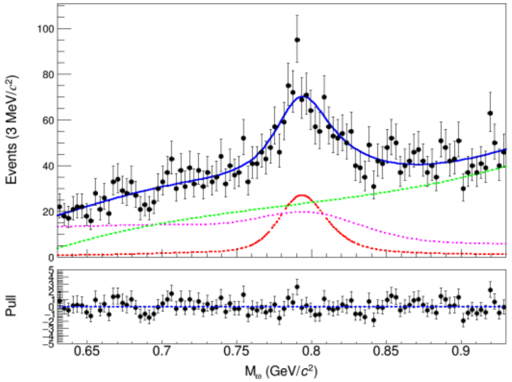


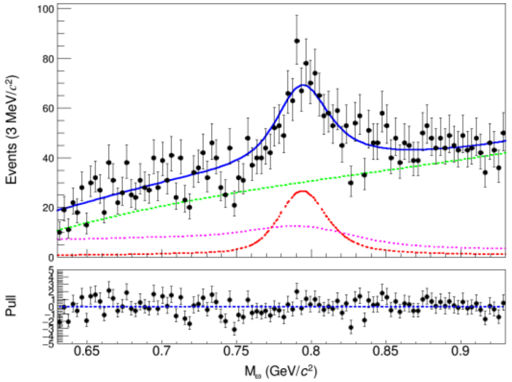


signal



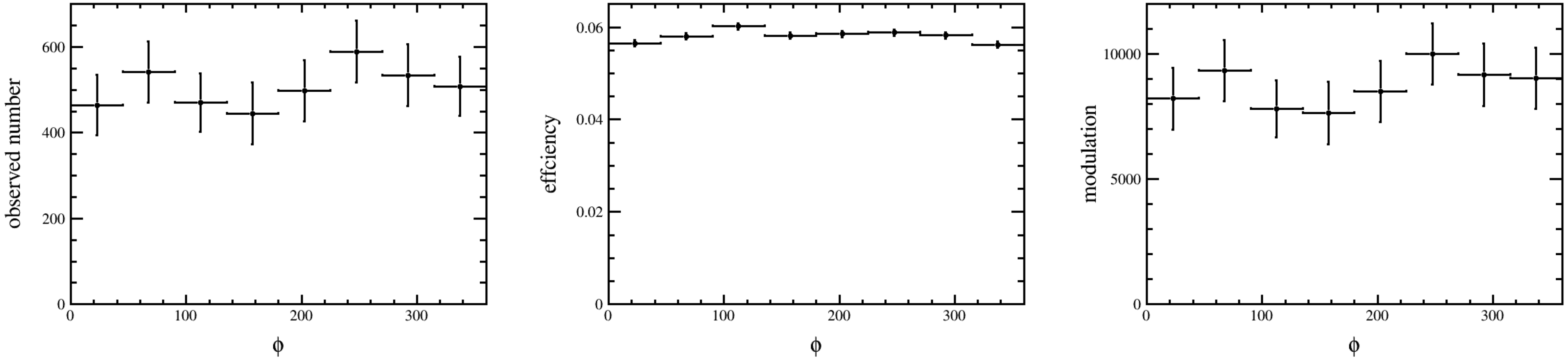






1D fit: MC shape

- ➢The observed signal events, efficiency curves and modulation of ϕ are shown below.
- ➢In the $e^+e^- \to e^+e^-\omega\omega$ process, modulation of ϕ shows some oscillation structures.



Summary and to do list

- Summary
  - ✓ About **1860** $\boldsymbol{e^+e^- \rightarrow e^+e^-\omega\omega}$ **signal events** are observed with **untagged method** at BESIII detector for the first time.
  - ✓ Divide ϕ into 8 intervals, and modulation of ϕ shows some oscillation structures.

- To do list
  - Try other fit methods, such as 2D fit.
  - Study the statistical uncertainty caused by double counting signal events.
  - Study the systematic uncertainties.
  - Observe the modulation of ϕ in $e^+e^- \rightarrow e^+e^-\pi^+\pi^-$ process with untagged method.

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