Measurements of cross section for $\eta\phi$ production above 4.0 GeV

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Updating

- Boss version : 6.6.5.p01 → 7.0.3 .
- Add data points.
- Checked the generator model of ConExc at $\sqrt{s} = 2.125 GeV$.

Outline

- Motivation
- Data set
- Event selection
- Data analysis
- Born cross section
- Systematic uncertainty
- Summary

Motivation

➢ Perturbative QCD theory fails to describe this energy region. Therefore it is vitally important to gain sufficient information from experiment to be used as input for various QCD-based theoretical models.

➢ In particular, precise measurements of light hadron production cross section is mandatory for getting knowledge about vacuum polarization effects, so that the hadronic contribution to the running fine-structure constant α(s) can be estimated, and further to extend to the Z–boson mass point and to get the value $\alpha(^{M^2}_{Z})$, which is a key value to precisely test on standard model.

➢ The cross sections are used to extract the resonance parameters for excited ρ and ϕ states. Recently, charmonium-like states, such as the Y(4260), Y(4360) and so on, have been observed in e^+e^-collisions, and measurements of their decay modes, masses and widths are desirable.

Data set

➢BOSS version: 7.0.3.

➢Signal MC : $e^+e^- \to \eta\phi, \phi \to K^+K^-, \eta \to \gamma\gamma$(500000 for each energy point).

➢ISR MC : $e^+e^- \to \phi\gamma_{ISR}$, $\phi \to K^+K^-$ (500000 for each energy point).

➢ Data Sets : The search of $e^+e^- \to \eta\phi$ based on data samples collected with the BESIII detector at center-of-mass energy above 4 GeV.

Table 1: Data sets used in this analysis and corresponding integrated luminosity

$\sqrt{s}$ (GeV)	Luminosity(pb^{-1})	$\sqrt{s}$ (GeV)	Luminosity(pb^{-1})	$\sqrt{s}$ (GeV)	Luminosity(pb^{-1})
4.009	481.96	4.237	530.6	4.360	539.84
4.090	52.63	4.245	55.59	4.390	55.18
4.180	3189.00	4.246	537.40	4.420	1073.56
4.190	522.50	4.260	824.67	4.470	109.94
4.200	524.60	4.270	825.67	4.530	109.98
4.210	518.10	4.280	175.50	4.575	47.67
4.220	514.30	4.310	44.90	4.600	566.93
4.230	1091.74				

```
Decay   vpho
1.0     eta     phi     ConExc 23;
Enddecay

Decay  eta
1.0    gamma    gamma    PHSP;
Enddecay

Decay phi
1.0     K+      K-      AngSam 1 -1;
Enddecay
```

We checked the generator model of ConExc at $\sqrt{s}$ =2.125GeV. The angle distribution and momentum distribution of it shown in backups.

Event selection

➢Charged Tracks :

- $|V_{xy}|$<1.0 cm $|V_r|$<10.0 cm
- $|cos\theta|$<0.93
- N_{good} >= 2 && $\sum Q_i$=0
- N(+) = 1 && N(-) = 1

➢Neutral Tracks :

- E_{min} > 25 MeV for $|cos\theta|$< 0.8
- E_{min} > 50 MeV for 0.86< $|cos\theta|$< 0.92
- TDC : 0 ≤ t ≤ 14 (with a unit of 50 ns)
- N_{good} >= 2

➢PID

- Only Kaon

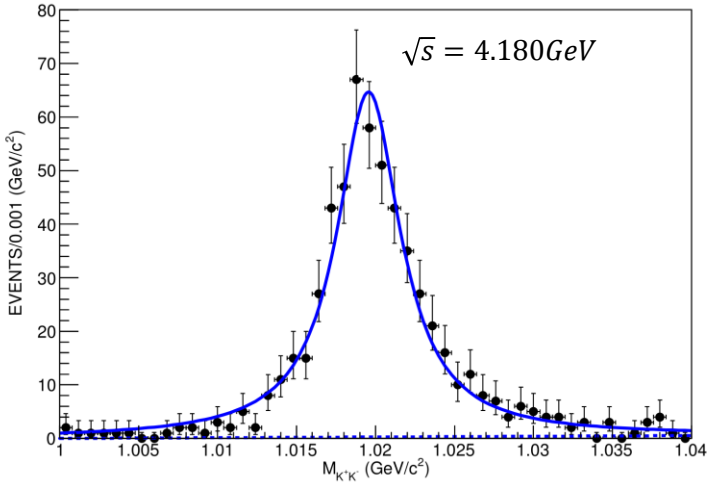
➢ϕ :

- mass : $|m_{kk} - 1.019|$<$2\sigma_{m_{kk}}$

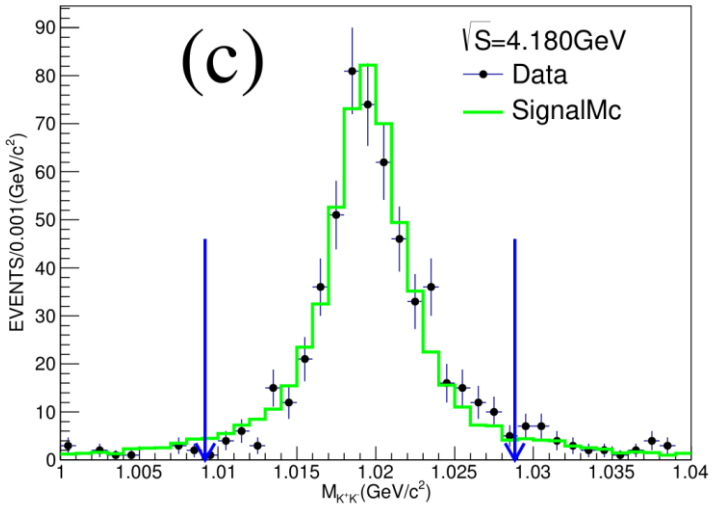
➢η :

- mass : 0.4 < $M_{\gamma\gamma}$ < 0.7 GeV/c^2
- $\theta_{\gamma\gamma}$: $\theta_{\gamma\gamma}$ < 1.5 radian

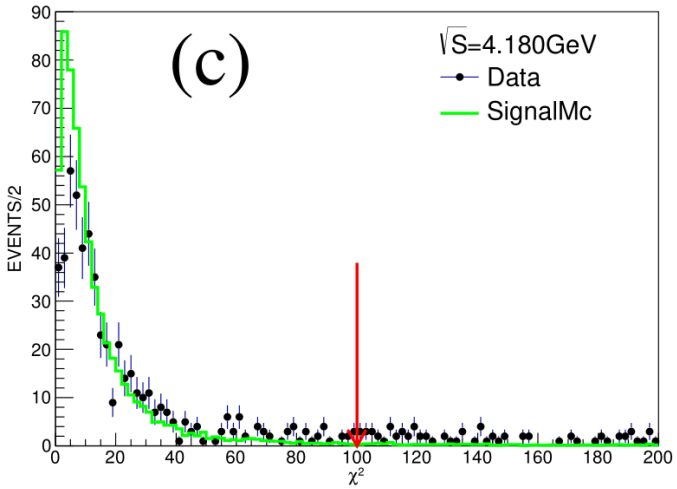
Event selection



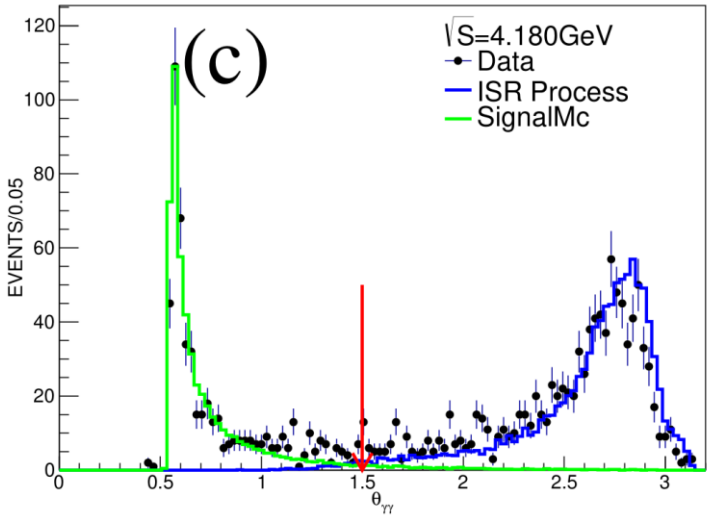
Fit results of $M_{K^+K^-}$. We get the $\sigma_{m_{kk}}$=$4.91 \pm 0.35 MeV$.



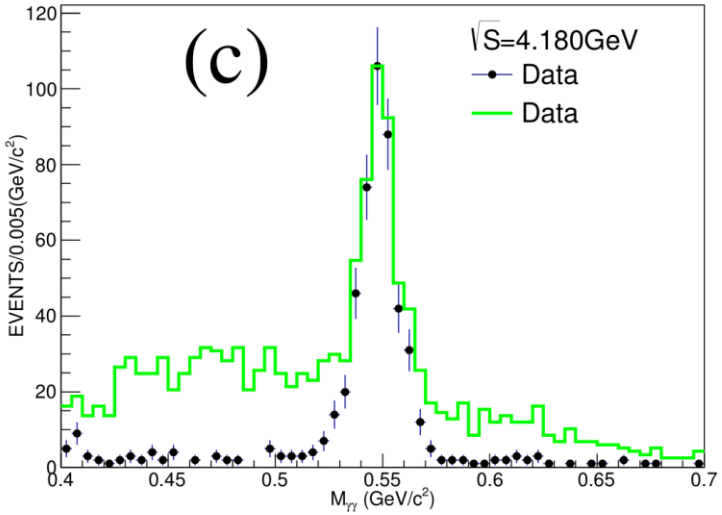
The distribution of $M_{K^+K^-}$.



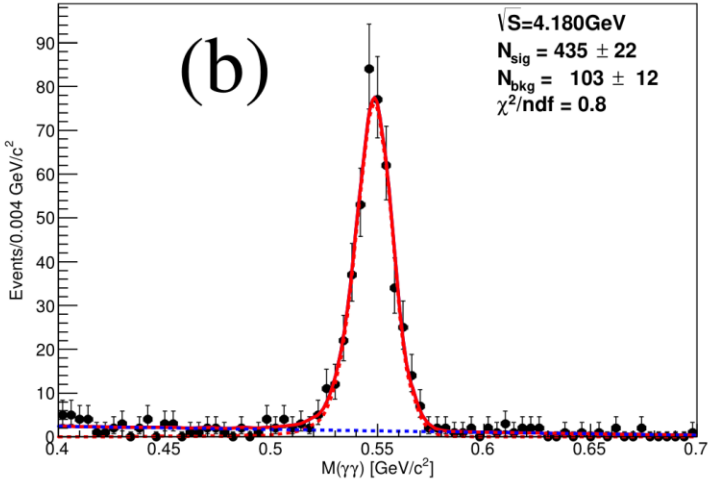
x^2_{4C} distribution



The distribution of $\theta_{\gamma\gamma}$.



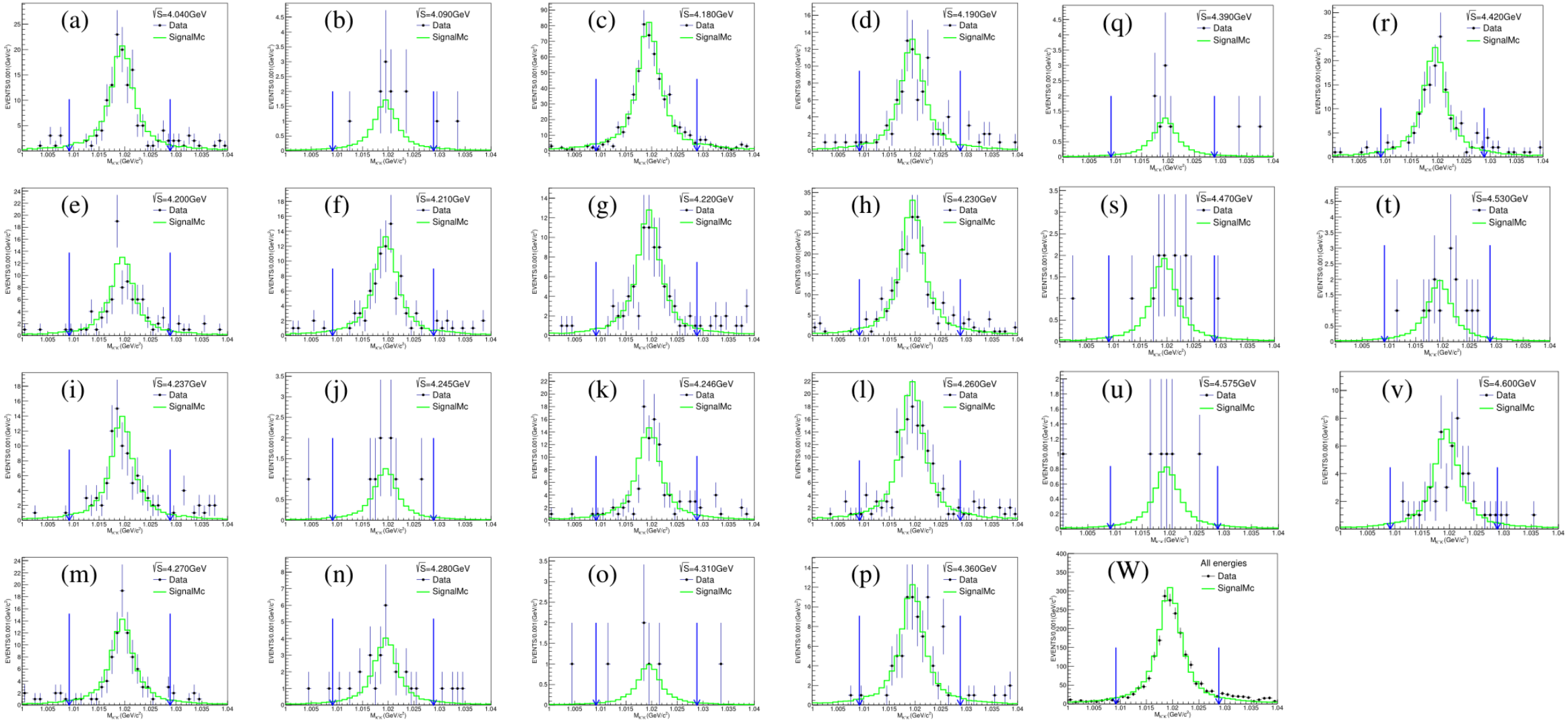
The distribution of $M_{\gamma\gamma}$.



Fit results of $M_{\gamma\gamma}$.

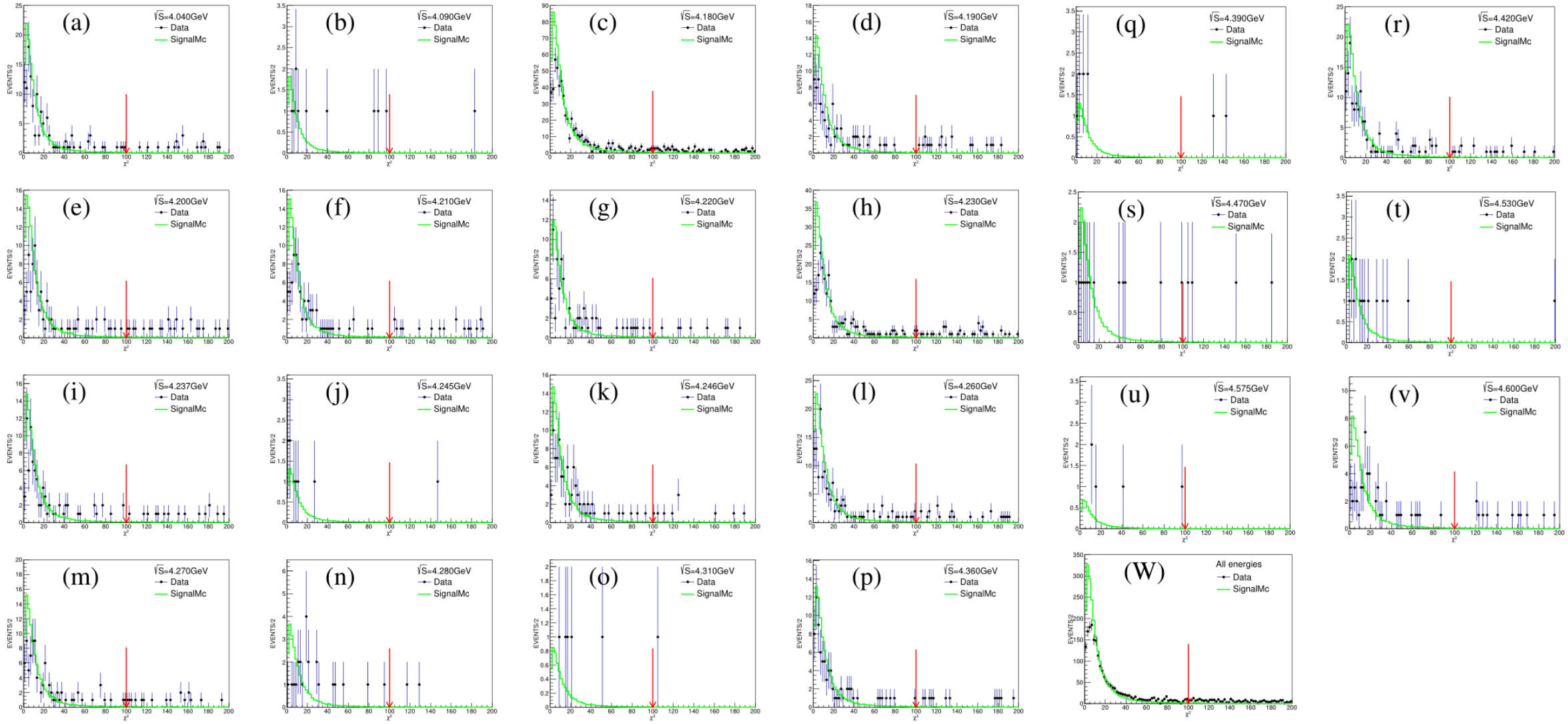
Event selection

The distribution of invariant mass of ϕ ($|m_{kk} - 1.019| < 2\sigma_{m_{kk}}$)



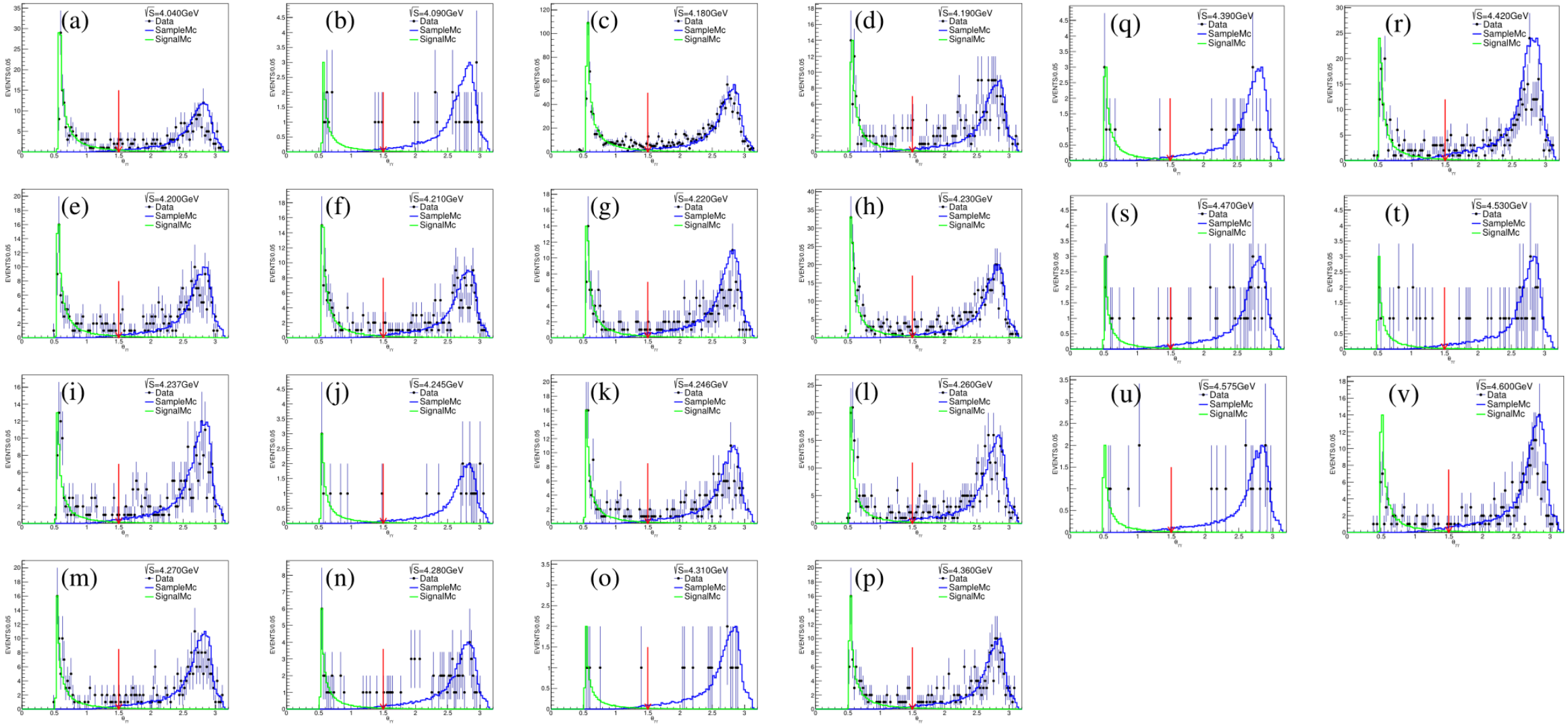
Event selection

x^2_{4C} distribution (x^2_{4C}<100)



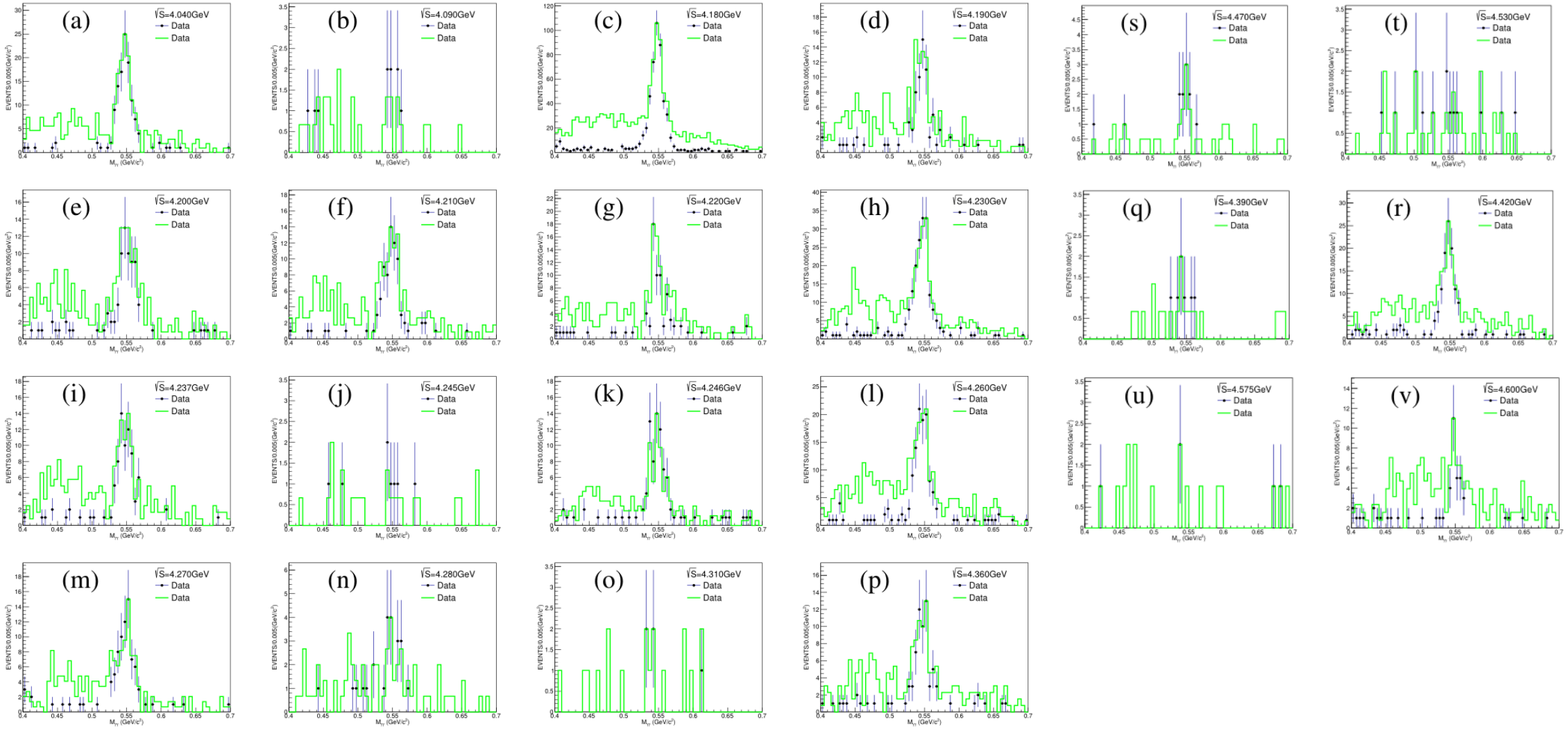
Event selection

The distribution of θ between γ and γ (angle < 1.5 radian)



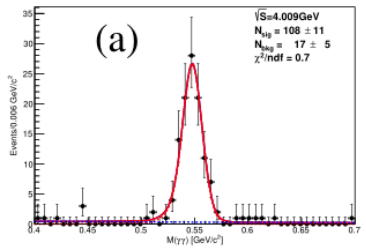
Event selection

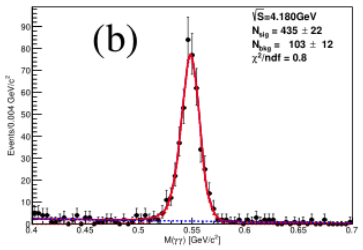
The distribution of invariant mass of η (with and without requirement of the cut on the two photon open angle for the data)

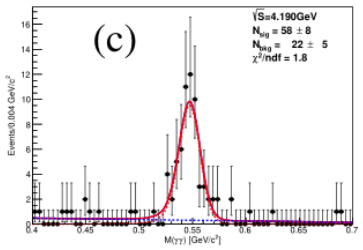


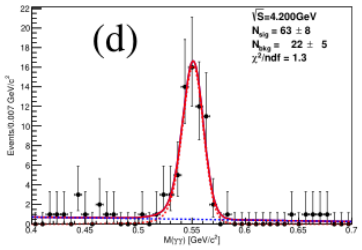
Data analysis

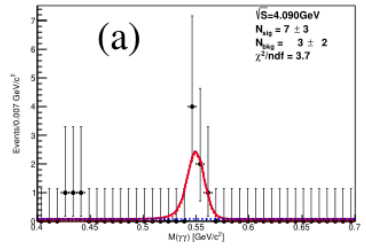
The fitting result of $m_{\gamma\gamma}$(The signal shape : the signal MC line shape convolving with a Gaussian function. The background shape : taken as a first order Chebychev function.)

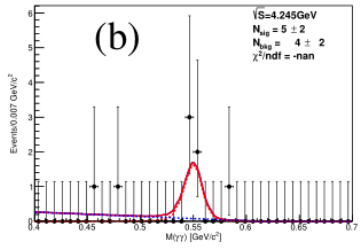


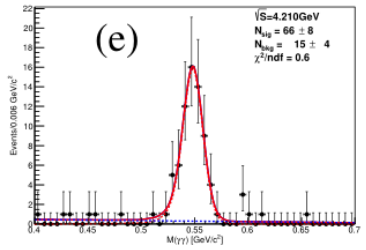


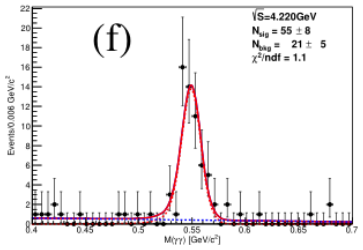


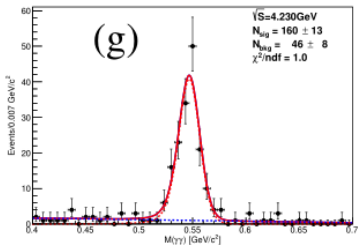


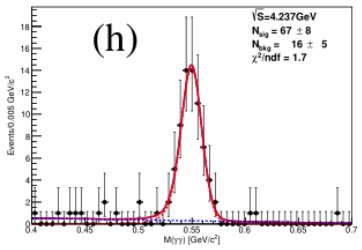


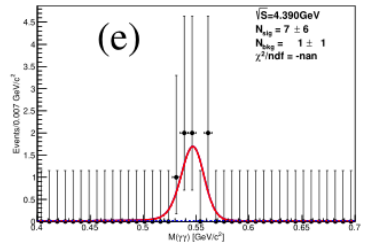


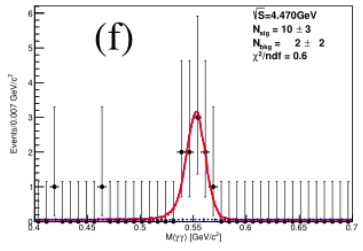


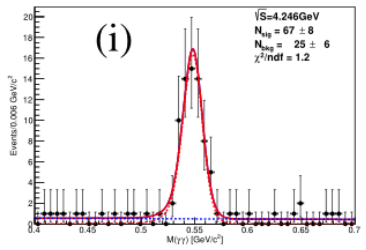


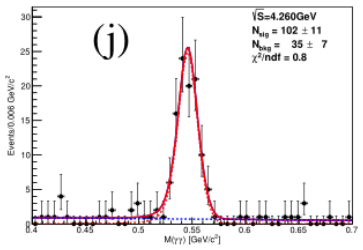


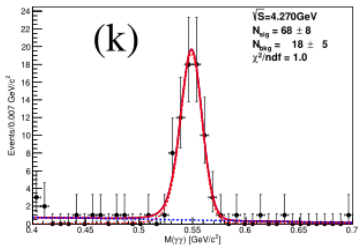


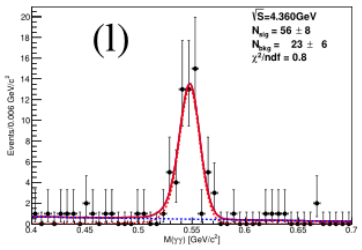


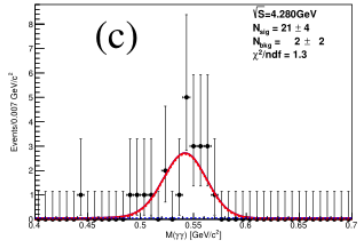


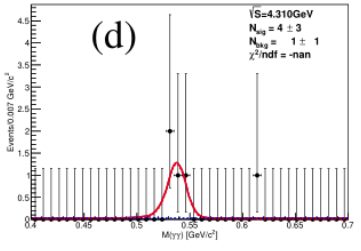


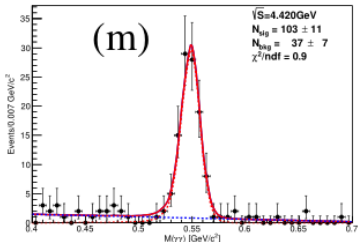


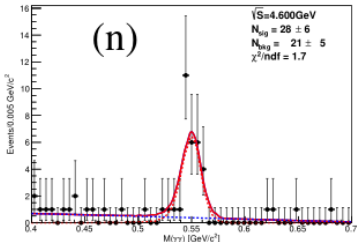


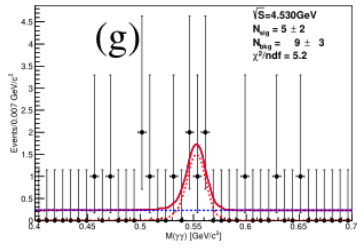


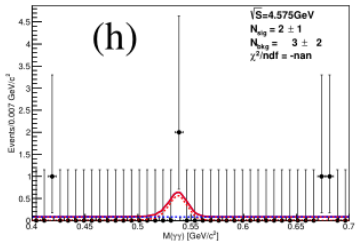












Summary of fitting

Summary of signal yield and the statistical significance

$\sqrt{s}$ (GeV)	signal yields	significance	$\sqrt{s}$ (GeV)	signal yields	significance
4.009	108 ± 11	12.73σ	4.260	102 ± 11	11.34σ
4.090	$7 \pm 3(< 13)$	2.54σ	4.270	68 ± 8	9.39σ
4.180	435 ± 22	25.50σ	4.280	$21 \pm 4(< 34)$	4.06σ
4.190	58 ± 8	8.30σ	4.310	$4 \pm 3(< 9)$	1.76σ
4.200	63 ± 8	8.69σ	4.360	56 ± 8	8.02σ
4.210	66 ± 8	9.48σ	4.390	$7 \pm 6(< 13)$	2.77σ
4.220	55 ± 8	8.30σ	4.420	103 ± 11	11.75σ
4.230	160 ± 13	14.53σ	4.470	$10 \pm 3(< 16)$	3.15σ
4.237	67 ± 8	9.39σ	4.530	$5 \pm 2(< 11)$	1.07σ
4.245	$5 \pm 2(< 10)$	1.88σ	4.575	$2 \pm 1(< 6)$	0.56σ
4.246	67 ± 8	9.11σ	4.600	28 ± 6	5.36σ

Born cross section

$$\sigma_{Born} = \frac{N}{L_{int} \cdot \varepsilon \cdot Br(\eta \to \gamma\gamma) \cdot Br(\phi \to K^+K^-) \cdot (1+\delta) \cdot \delta^{vac}},$$

$$(1+\delta) \cdot \delta^{vac} = \frac{\sigma^{obs}}{\sigma^{B}} = \frac{1}{\sigma^{B}(s)} \int \frac{\sigma^{B}(s(1-x))}{1+\Pi(s)} F(x,s)dx,$$

- $(1+\delta) \cdot \delta^{vac}$: radiative correction factor.
- $\Pi(s)$: the vacuum polarization contribution.
- $F(x, s)$: radiator function taken from QED calculation with accuracy 0.1%.
- $\sigma^{B}(s)$: Born cross section.

$\sqrt{s}$ (GeV)	N	L_{int} (pb^{-1})	ε (%)	$(1+\delta) \cdot \delta^{vac}$	σ_{Born} (pb)
4.009	108 ± 11	481.96	3.27	7.43	4.79 ± 0.49
4.090	7 ± 3 (< 13)	52.63	3.23	7.40	2.89 ± 1.24 (< 5.36)
4.180	435 ± 22	3189.00	3.33	7.10	2.99 ± 0.15
4.190	58 ± 8	522.50	3.40	7.06	2.40 ± 0.33
4.200	63 ± 8	524.60	3.42	7.03	2.59 ± 0.33
4.210	66 ± 8	518.10	3.41	6.99	2.77 ± 0.34
4.220	55 ± 8	514.30	3.42	6.96	2.33 ± 0.34
4.230	160 ± 13	1091.74	3.46	6.92	3.18 ± 0.26
4.237	67 ± 8	530.60	3.48	6.89	2.69 ± 0.33
4.245	5 ± 2 (< 10)	55.59	3.48	6.83	1.96 ± 0.79 (< 3.92)
4.246	67 ± 8	537.40	3.55	6.85	2.66 ± 0.32
4.260	102 ± 11	825.67	3.49	6.80	2.70 ± 0.29
4.270	68 ± 8	529.70	3.54	6.76	2.79 ± 0.33
4.280	21 ± 4 (< 34)	175.50	3.52	6.72	2.62 ± 0.50(< 4.24)
4.310	4 ± 3 (< 9)	44.90	3.59	6.61	1.95 ± 1.46 (< 4.38)
4.360	56 ± 8	539.84	3.69	6.42	2.27 ± 0.32
4.390	7 ± 6 (< 13)	55.18	3.74	6.32	2.78 ± 2.39(< 5.17)
4.420	103 ± 11	1073.56	3.77	6.23	2.12 ± 0.23
4.470	10 ± 3 (< 16)	111.09	3.83	6.07	2.03 ± 0.61(< 3.25)
4.530	5 ± 2 (< 11)	112.12	3.95	5.90	1.01 ± 0.40(< 2.23)
4.575	2 ± 1 (< 6)	48.93	4.00	5.78	0.94 ± 0.47(< 3.77)
4.600	28 ± 6	566.93	4.05	5.71	1.11 ± 0.24

Systematic uncertainty I

➢Photon reconstruction : 1% .

➢Tracking Efficiency and PID for kaon : Determined to be 1% and 2% per track, respectively.

➢Event selection criteria

- Kinematic fit : By the track-parameter-corrected method.
- ϕ mass window : enlarging its width by one standard deviation.
- $\theta_{\gamma\gamma}$ window : changing to 1.3, 1.4, 1.6 and 1.7 radian.

The uncertainties in the Born cross sections are estimated with: $$\delta = \frac{|\sigma'_{Born} - \sigma_{Born}|}{\sigma_{Born}},$$

where Born cross section difference, σ'_{Born} - σ_{Born}, correspond to the change of the differences.

Systematic uncertainty II

➢ Fitting : Due to the difference between the signal yields and the nominal ones.

➢ Integrated luminosity : Determined to be 1.1% at $\sqrt{s}$ =4.040 GeV, 1.0% at other energy points.

➢ Radiative correction factor : Associating with radiative correction factor is estimated with different parametrization of input cross sections.

➢ Branching fraction : The total uncertainty from the two branching fractions comes to be 1.14% for all the energy points.

Summary of systematic uncertainties(%) I

PR, TE, KF, ϕMW, BS, FR, IL, RCF and BR is photon reconstruction, tracking efficiency, kinematic fit, ϕ mass window, background shape, fitting range, integrated luminosity, radiative correction factor and branching ratio, respectively.

$\sqrt{s}$ (GeV)	PR	TE	PID	KF	ϕ MW	$\theta_{\gamma\gamma}$	BS	FR	IL	RCF	BR	Total
4.009	2.00	2.00	4.00	0.15	0.21	3.34	0.00	1.25	1.10	0.84	1.14	6.32
4.180	2.00	2.00	4.00	0.00	1.00	1.34	0.00	0.67	1.00	0.33	1.14	5.45
4.190	2.00	2.00	4.00	0.15	2.50	2.92	1.67	2.08	1.00	1.25	1.14	7.06
4.200	2.00	2.00	4.00	0.44	0.39	3.86	6.56	1.54	1.00	0.39	1.14	9.33
4.210	2.00	2.00	4.00	0.00	0.36	2.53	2.89	0.36	1.00	1.81	1.14	6.68
4.220	2.00	2.00	4.00	0.15	3.00	3.43	3.86	3.86	1.00	0.86	1.14	8.81
4.230	2.00	2.00	4.00	0.58	0.31	2.20	1.26	0.31	1.00	0.31	1.14	5.78
4.237	2.00	2.00	4.00	0.00	1.49	4.09	1.49	1.49	1.00	0.37	1.14	7.06
4.246	2.00	2.00	4.00	0.14	1.88	1.88	3.38	0.38	1.00	0.00	1.14	6.70
4.260	2.00	2.00	4.00	0.00	0.00	1.11	0.00	0.37	1.00	0.74	1.14	5.31
4.270	2.00	2.00	4.00	0.14	1.43	4.30	2.87	1.79	1.00	0.36	1.14	7.64
4.360	2.00	2.00	4.00	0.14	5.29	2.20	1.76	0.44	1.00	2.20	1.14	8.20
4.420	2.00	2.00	4.00	0.13	2.83	0.94	0.94	1.42	1.00	0.94	1.14	6.24
4.600	2.00	2.00	4.00	0.12	1.80	5.41	7.21	3.60	1.00	0.90	1.14	10.65

Summary of systematic uncertainties(%) II

$\sqrt{s}$ (GeV)	4.090	4.245	4.280	4.310	4.390	4.470	4.530	4575
Photon reconstruction	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Tracking efficiency	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
PID	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Kinematic fit	0.00	0.00	0.14	0.00	0.00	0.13	0.13	0.13
ϕ mass window	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67
$\theta_{\gamma\gamma}$	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77
Background shape	Ignore							
Fitting range	Ignore							
Integrated luminosity	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Radiative correction factor	0.35	0.51	12.98	0.51	0.00	0.99	0.99	0.00
Branching ratio	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14
Total	5.48	5.49	14.08	5.49	5.47	5.56	5.56	5.47

Cross section for $e^+e^- \to \eta\phi$

➢ To extract the Born cross section for the resonance Y(4220) or Y(4260) production in this decay mode, the measured cross sections around 4.2196 GeV or 4.230 GeV are assumed due to the continuum process and the Y(4220)/Y(4260) resonance.

➢ We fit the distribution of Born cross sections measured at these energy points with the following formula, with the orbit angular momentum L = 1 between the final state ϕ and η particles:

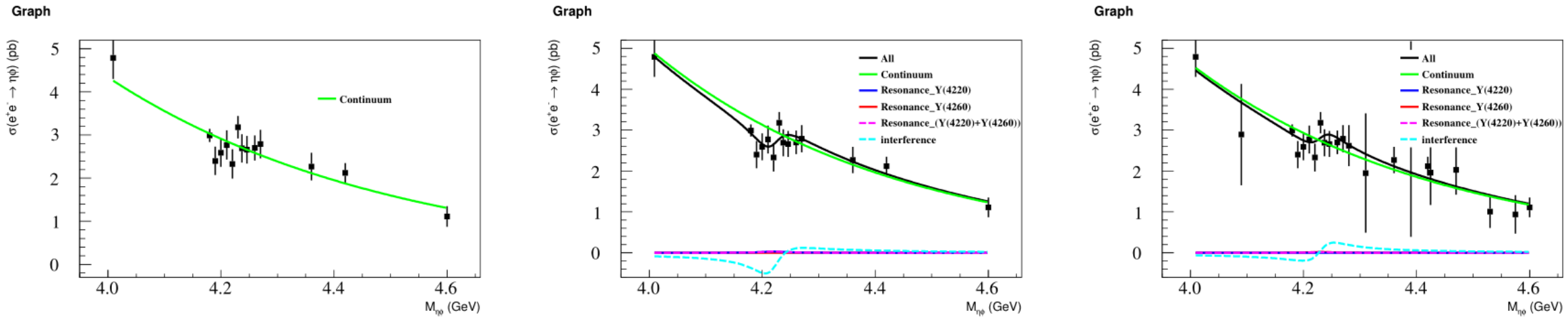
$$\sigma(\sqrt{s}) = \left|\frac{c_0}{s}e^{-a\sqrt{s}} + c_1 e^{i\phi_1} BW_1(\sqrt{s}) + c_2 e^{i\phi_2} BW_2(\sqrt{s})\right|^2 P^3(s),$$

$$\text{with} \qquad BW_i(\sqrt{s}) = \sqrt{12\pi\Gamma_i}/(s - M_i^2 + iM_i\Gamma_i)$$

where c_i are taken as real constants, which imply that the phase angles ϕ_1 and ϕ_2 for two resonances are relative to the continuum component. M_i and Γ_i fixed to the masses and widths of Y(4220) or Y(4260) resonances, respectively, the ϕ is the relative phase angle between the Breit-Wigner function and exponential function. P(s) is the magnitude of ϕ momentum in e^+e^- CM system.

Cross section for $e^+e^- \to \eta\phi$

➢ Fit results of the distribution for Born cross section.



The left shows fit results with continuum alone. The middle plot show the fitting results of Born cross sections with significance larger than 5σ (points with error bars). The right plot show the fit to all measured cross sections, include energy points with significance less than 5σ.

➢ The Born cross section of Y(4220) at 4.2196 GeV is determined to be σ_1 ($\sqrt{s}$ = 4.22) = (3.20 ± 3.18) × 10^{-2} pb with phase angle $\emptyset_1$= (5.63 ± 0.39) radian; the Born cross section of Y(4260) at 4.230 GeV is σ_2 ($\sqrt{s}$ = 4.26) = (0.00 ± 9.34) × 10^{-3} Pb with phase angle $\emptyset_2$ = (0.19±4.75) radian with statistical significance of resonance 1.20σ.

Next to do

- Continue answering questions and updating the memo.
- Run the process of $e^+e^- \to \eta\phi$, $\phi \to K^+K^-$, $\eta \to \pi^+\pi^-\pi^0$ and $e^+e^- \to \eta\phi$, $\phi \to K^+K^-$, $\eta \to \pi^0\pi^0\pi^0$.

Thanks for your attention!

Backups

Checked the generator model of ConExc

Event selection

➢ In order to check the reliability of the generator model of ConExc on the measurements of cross section For $\eta\phi$ production, we use data taken at 2.125 GeV and to compare various distribution between the data and Monte Carlo simulation.

➢Charged Tracks :

- $|V_{xy}|$<1.0 cm $|V_r|$<10.0 cm
- $|cos\theta|$<0.93
- N_{good} >= 2 && $\sum Q_i$=0
- N(+) = 1 && N(-) = 1

➢Neutral Tracks :

- E_{min} > 25 MeV for $|cos\theta|$< 0.8
- E_{min} > 50 MeV for 0.86< $|cos\theta|$< 0.92
- TDC : 0 ≤ t ≤ 14 (with a unit of 50 ns)
- N_{good} >= 2

➢PID

- Only Kaon

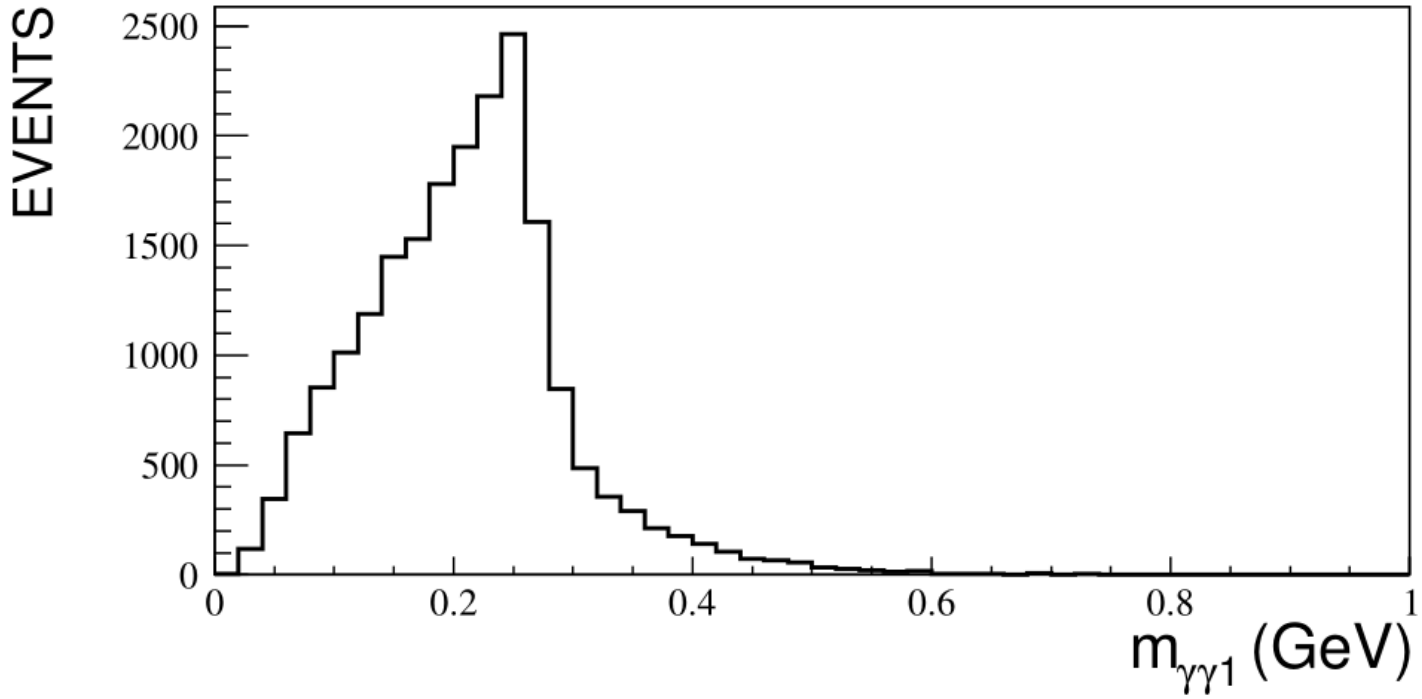
➢ϕ :

- mass : $|m_{kk} - 1.019| < 0.030$GeV
- 4C kinematic fit : $x^2_{4C} < 100$

Checked the generator model of ConExc

Event selection

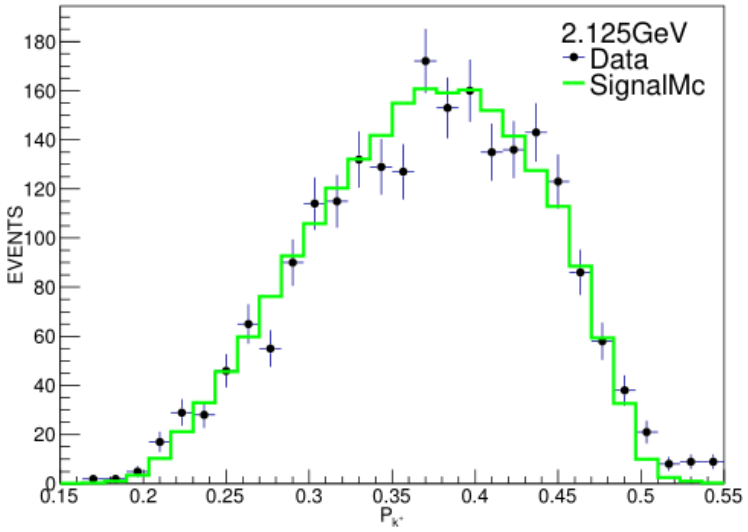
➢ We generate MC samples for $e^+e^- \to \phi\gamma_{ISR}$ process, containing 5×10^5 events for this energy point, with generator model VECTORISR, but only 20 events by the event selection.

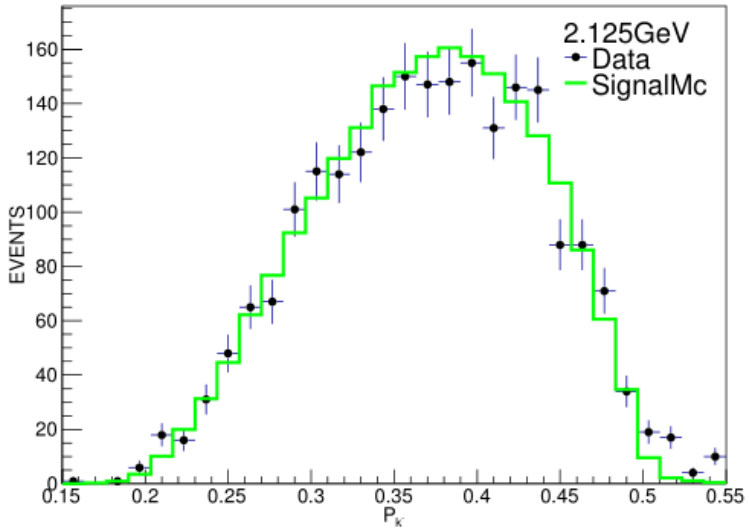


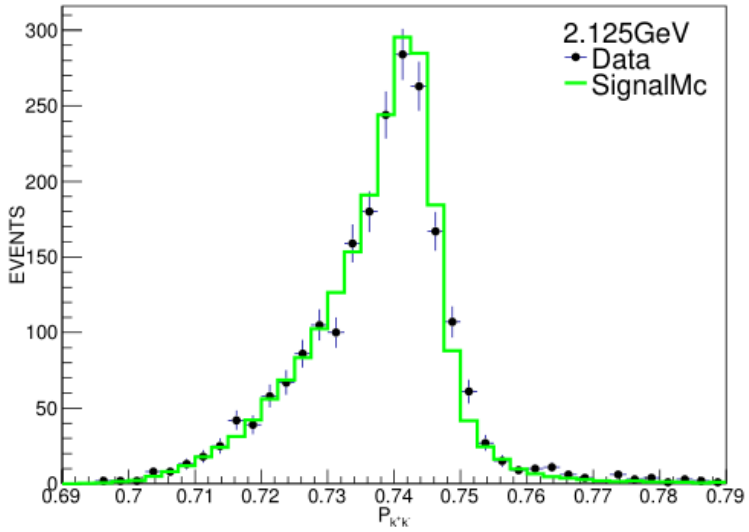
The $\gamma\gamma_1$ invariant mass spectrum of MC events for for $e^+e^- \to \phi\gamma_{ISR}$ at 2.125 GeV.

Checked the generator model of ConExc

Data/MC comparison for selection criteria



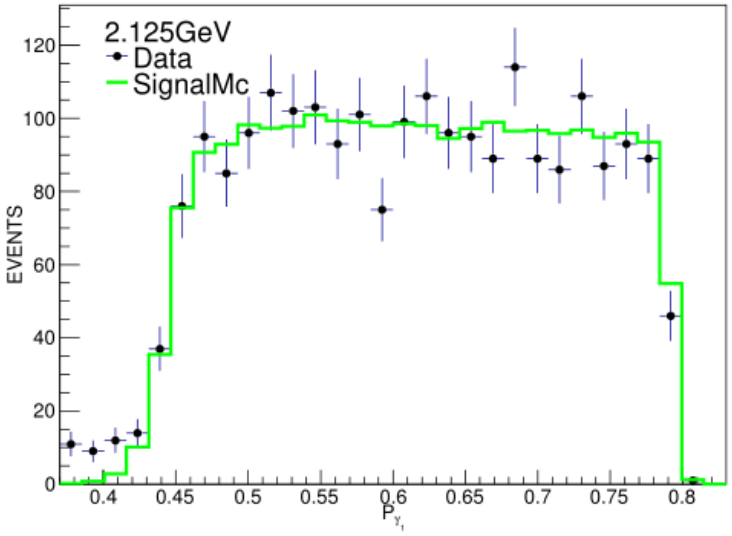


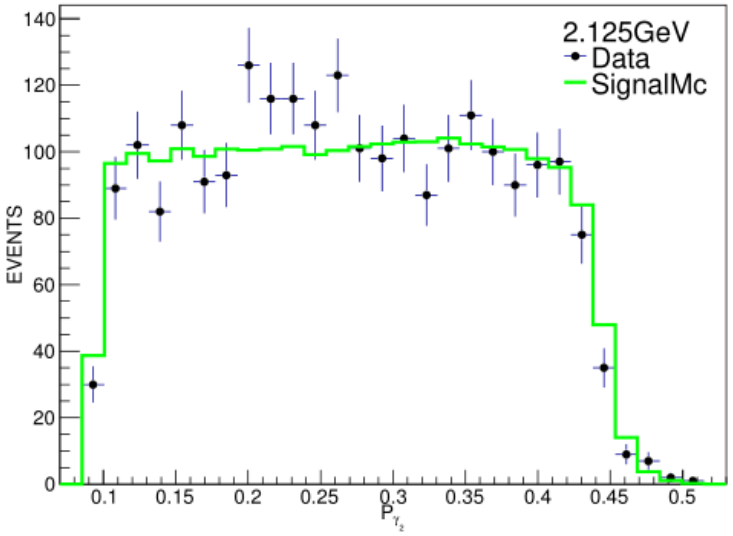


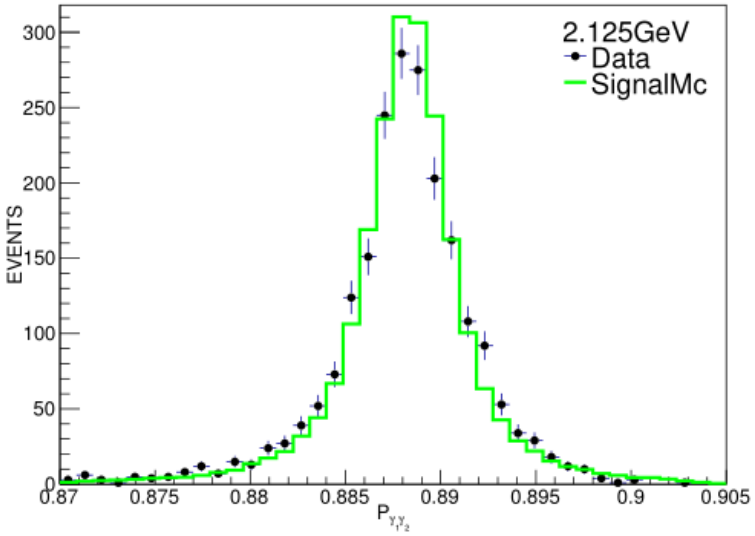
Momentum of K ± and ϕ distribution at the e^+e^- center-of-mass.

Checked the generator model of ConExc

Data/MC comparison for selection criteria



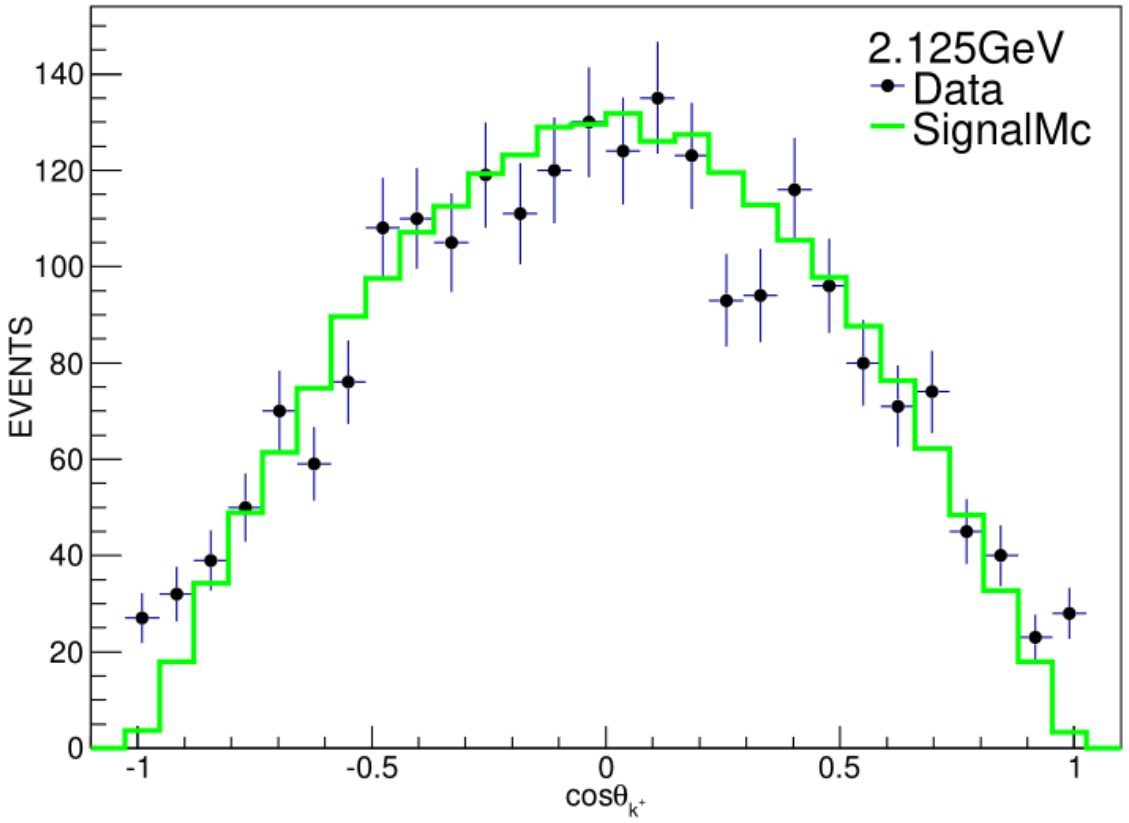


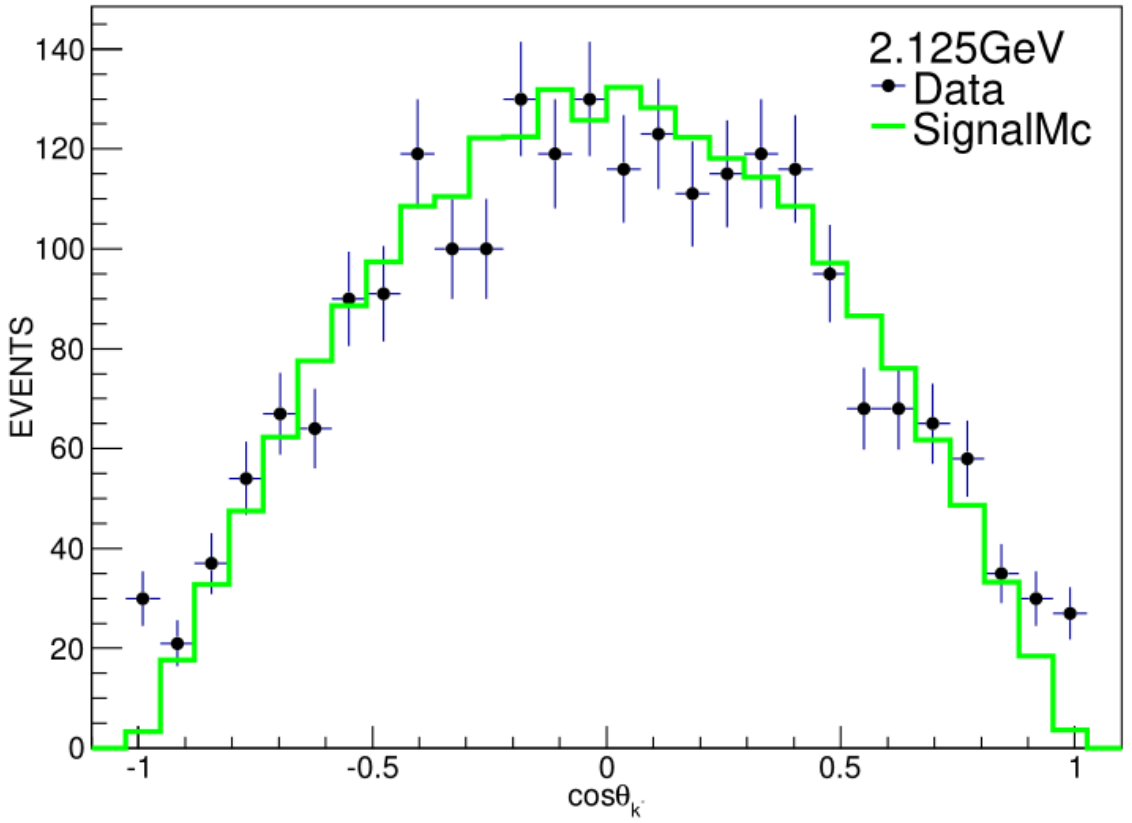


Momentum of γ distribution at the e^+e^- center-of-mass, γ_1 , γ_2 and γγ, respectively.

Checked the generator model of ConExc

Data/MC comparison for selection criteria

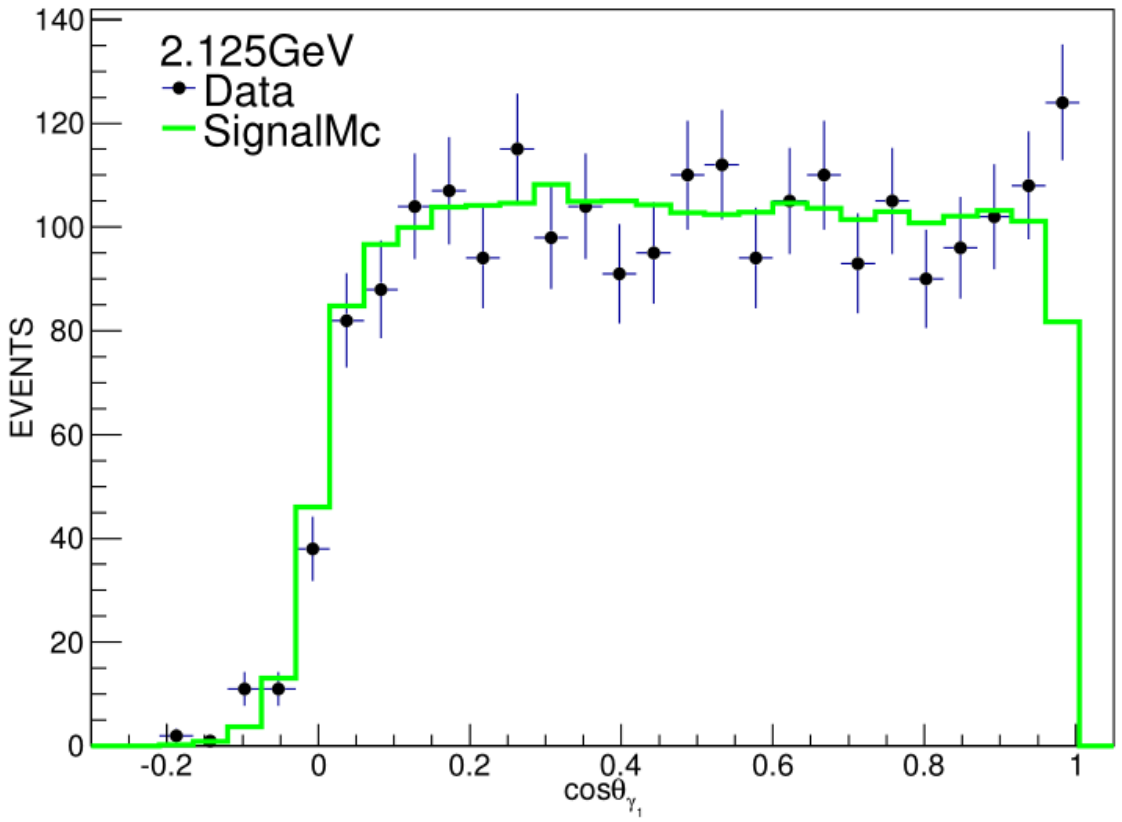


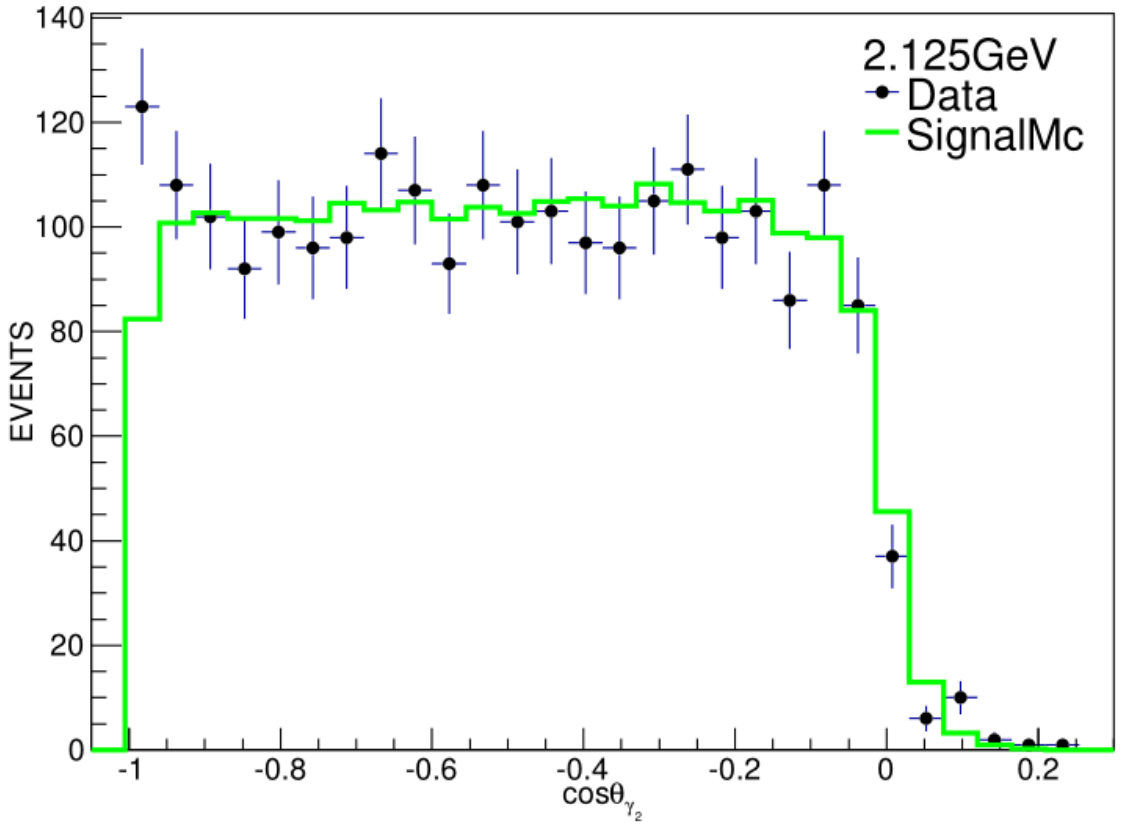


Helicity angle of $\cos\theta_K$ distribution.

Checked the generator model of ConExc

Data/MC comparison for selection criteria

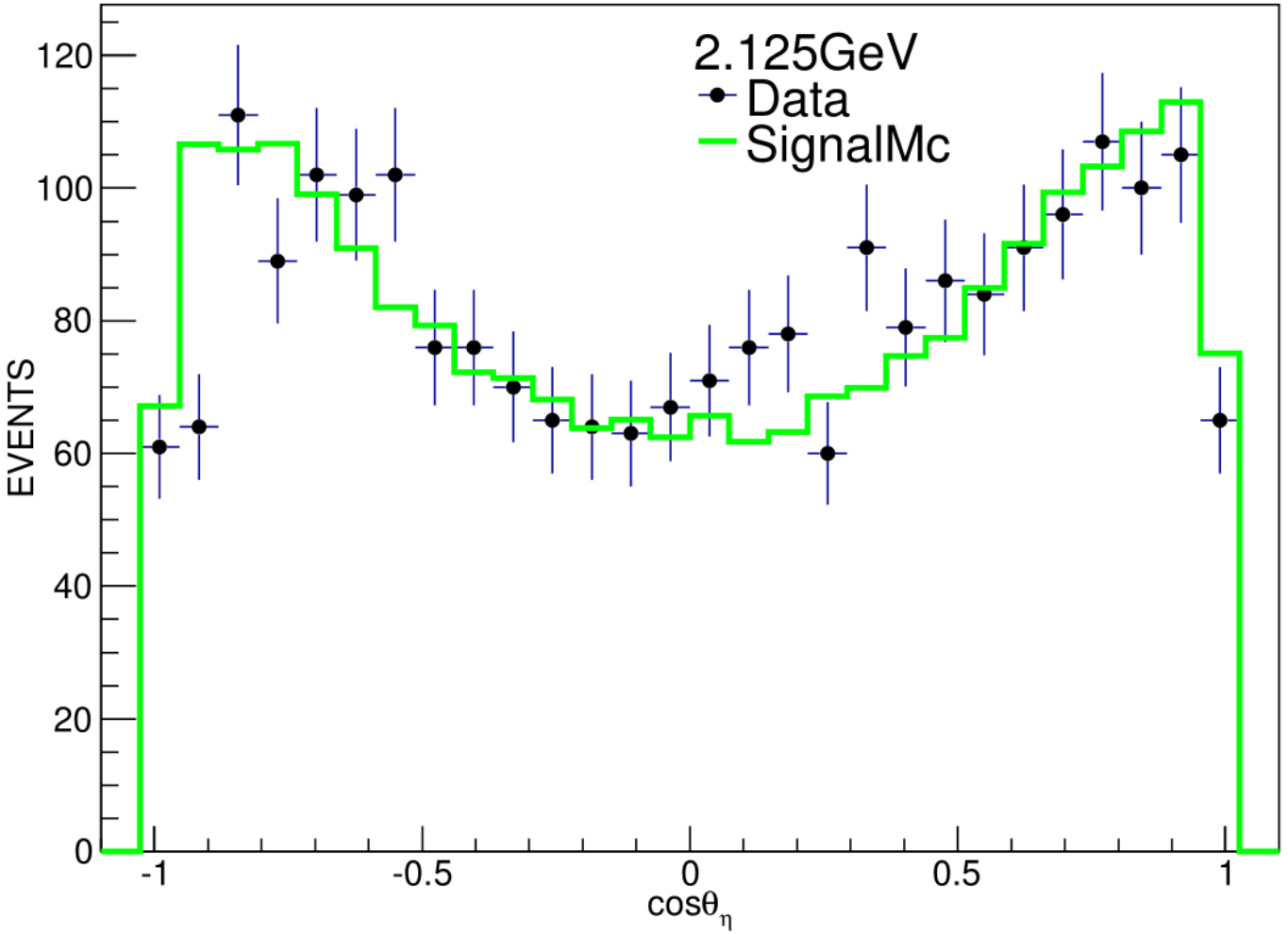




Helicity angle of $\cos\theta_\gamma$ distribution at the e^+e^- center-of-mass, γ_1 , γ_2 and $\gamma\gamma$, respectively.

Checked the generator model of ConExc

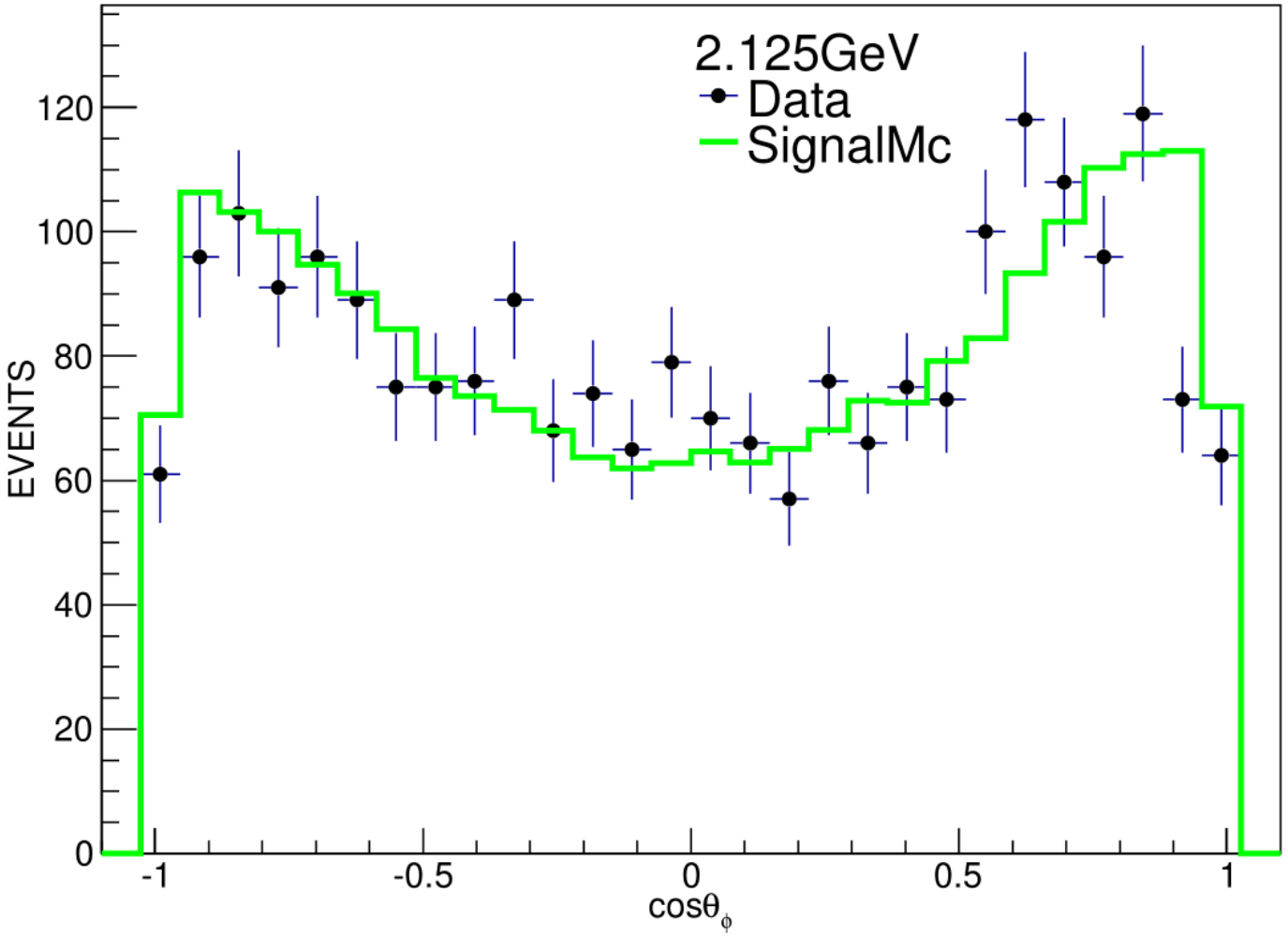
Data/MC comparison for selection criteria



Angular distribution of η meson, $\cos\theta_\eta$, at the e^+e^- center-of-mass.

Checked the generator model of ConExc

Data/MC comparison for selection criteria



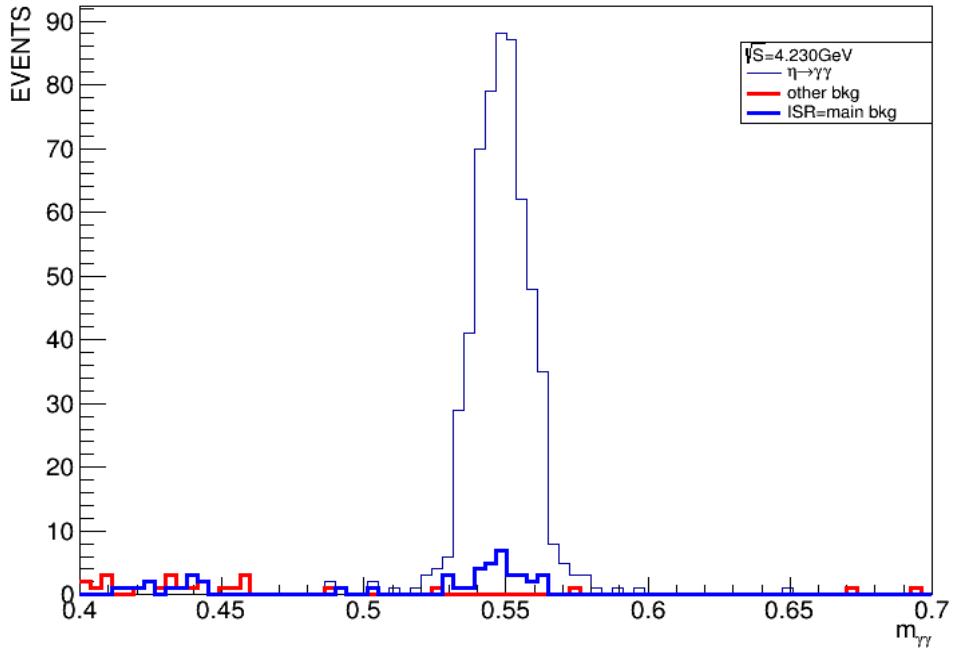
Angular distribution of ϕ meson, $\cos\theta_\phi$,at the e^+e^- center-of-mass.

Background check from Inclusive MC

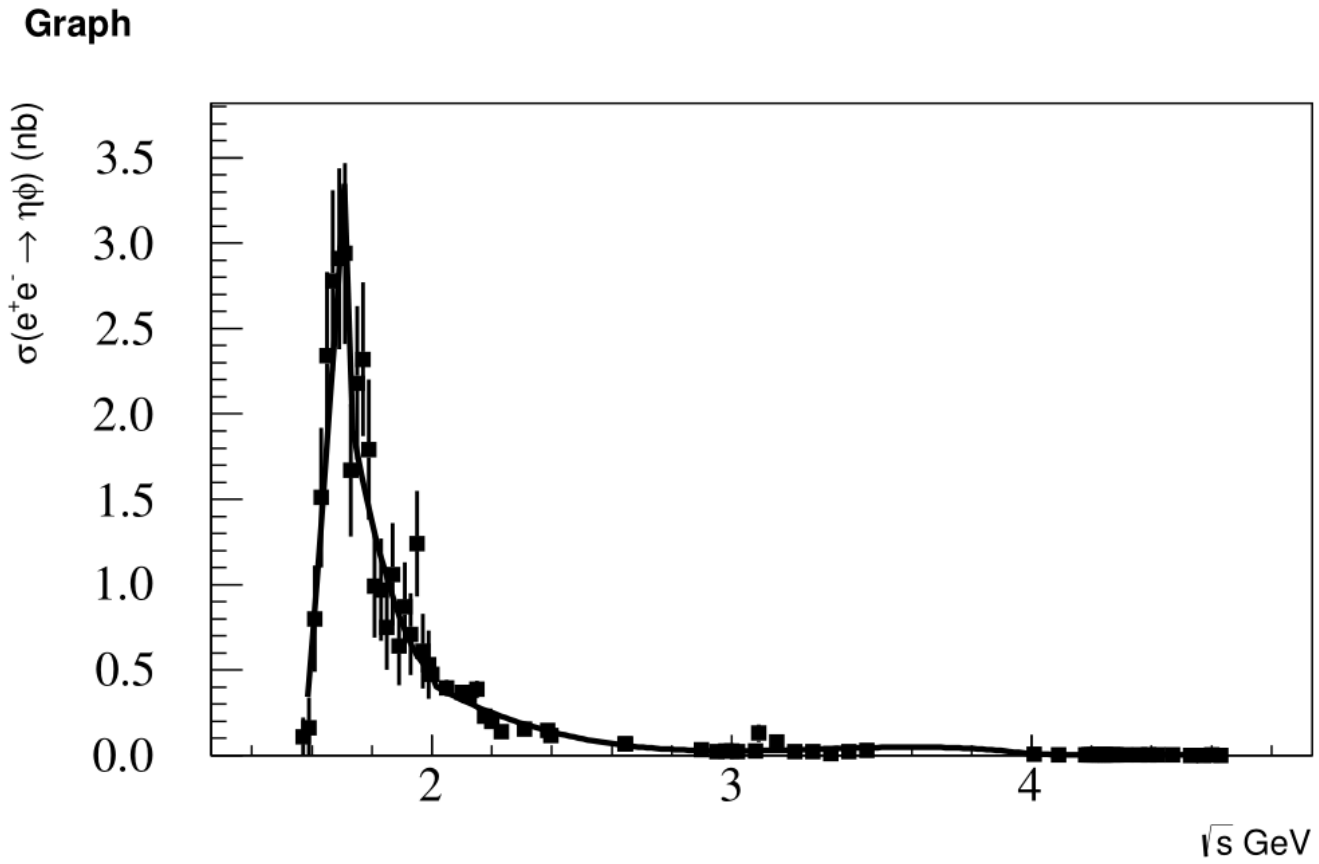
At 4.230GeV

No.	decay chain	final states	iTopo	nEvt	nTot
0	$e^+e^- \to \eta\phi,\ \eta \to \gamma\gamma,\ \phi \to K^-K^+,$	$e^+e^- \to \gamma\gamma K^+K^-$	0	429	429
1	$e^+e^- \to \gamma\gamma_v,\ \gamma_v \to \eta\phi,\ \eta \to \gamma\gamma,\ \phi \to K^-K^+,$	$e^+e^- \to \gamma\gamma\gamma K^+K^-$	1	152	581
2	$e^+e^- \to \gamma\gamma^*,\ \gamma^* \to K^-\eta K^+,\ \eta \to \gamma\gamma,$	$e^+e^- \to \gamma\gamma\gamma K^+K^-$	3	33	614
3	$e^+e^- \to \gamma\phi,\ \phi \to K^-K^+,$	$e^+e^- \to \gamma K^+K^-$	4	20	634
4	$e^+e^- \to \gamma\gamma_v,\ \gamma_v \to K^-K^+,$	$e^+e^- \to \gamma K^+K^-$	2	13	647
5	$e^+e^- \to \eta\phi,\ \eta \to \pi^0\pi^0\pi^0,\ \phi \to K^-K^+,$	$e^+e^- \to \gamma\gamma\gamma\gamma\gamma\gamma K^+K^-$	5	3	650
6	$e^+e^- \to \gamma\gamma_v,\ \gamma_v \to K^-K^{*+},\ K^{*+} \to \pi^0K^+,$	$e^+e^- \to \gamma\gamma\gamma K^+K^-$	7	2	652
7	$e^+e^- \to \gamma\omega,\ \omega \to \pi^-\pi^0\pi^+,$	$e^+e^- \to \gamma\gamma\gamma\pi^+\pi^-$	6	1	653
8	$e^+e^- \to \gamma\gamma_v,\ \gamma_v \to K^{*-}K^+,\ K^{*-} \to K^-\pi^0,$	$e^+e^- \to \gamma\gamma\gamma K^+K^-$	8	1	654
9	$e^+e^- \to \gamma\gamma_v,\ \gamma_v \to \pi^0\phi,\ \phi \to K^-K^+,$	$e^+e^- \to \gamma\gamma\gamma K^+K^-$	9	1	655

Table 1:



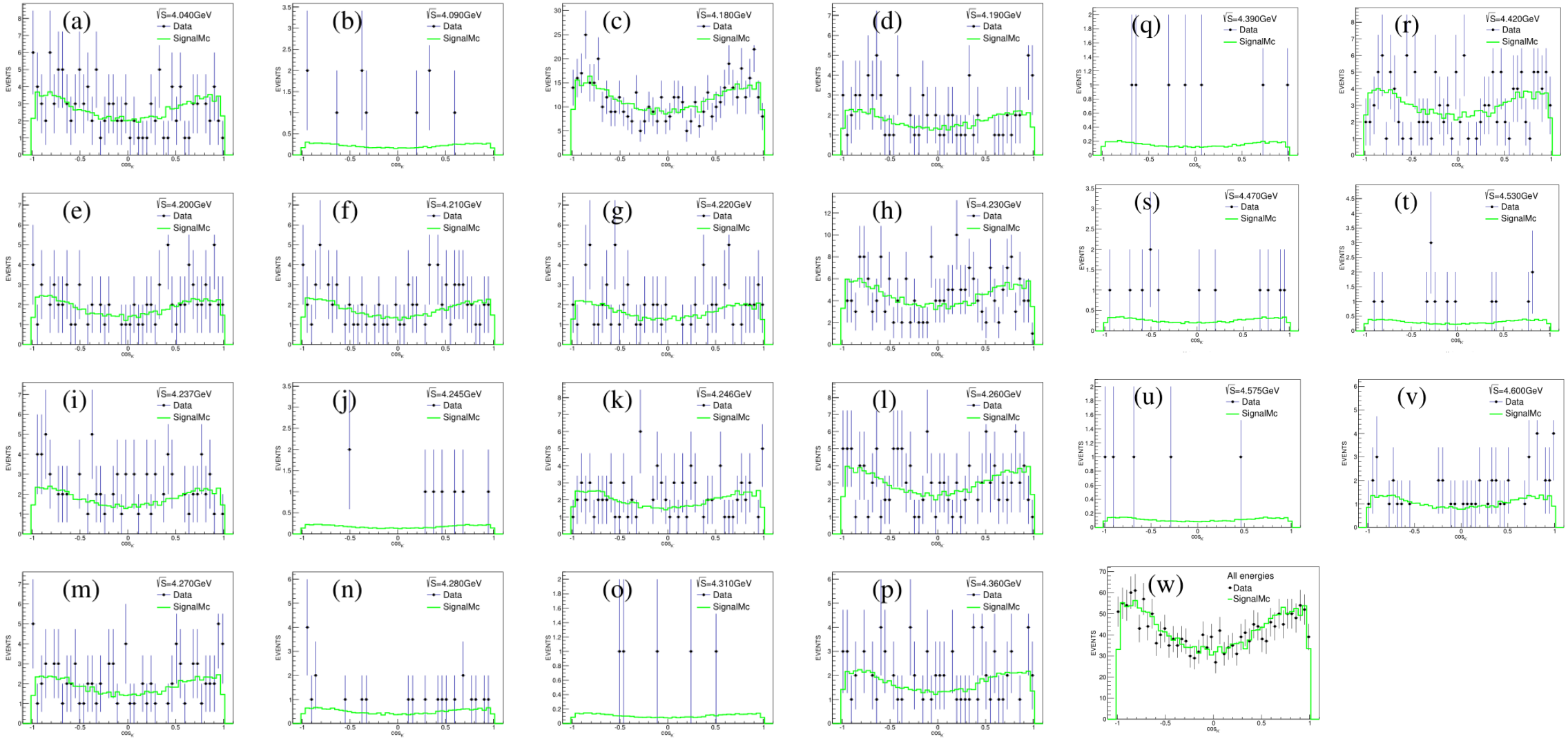
Parametrization of input cross sections



The fit results of cross section and used as input of ConExc model. The dots with errors are measured cross sections, and curve is the fitted result.

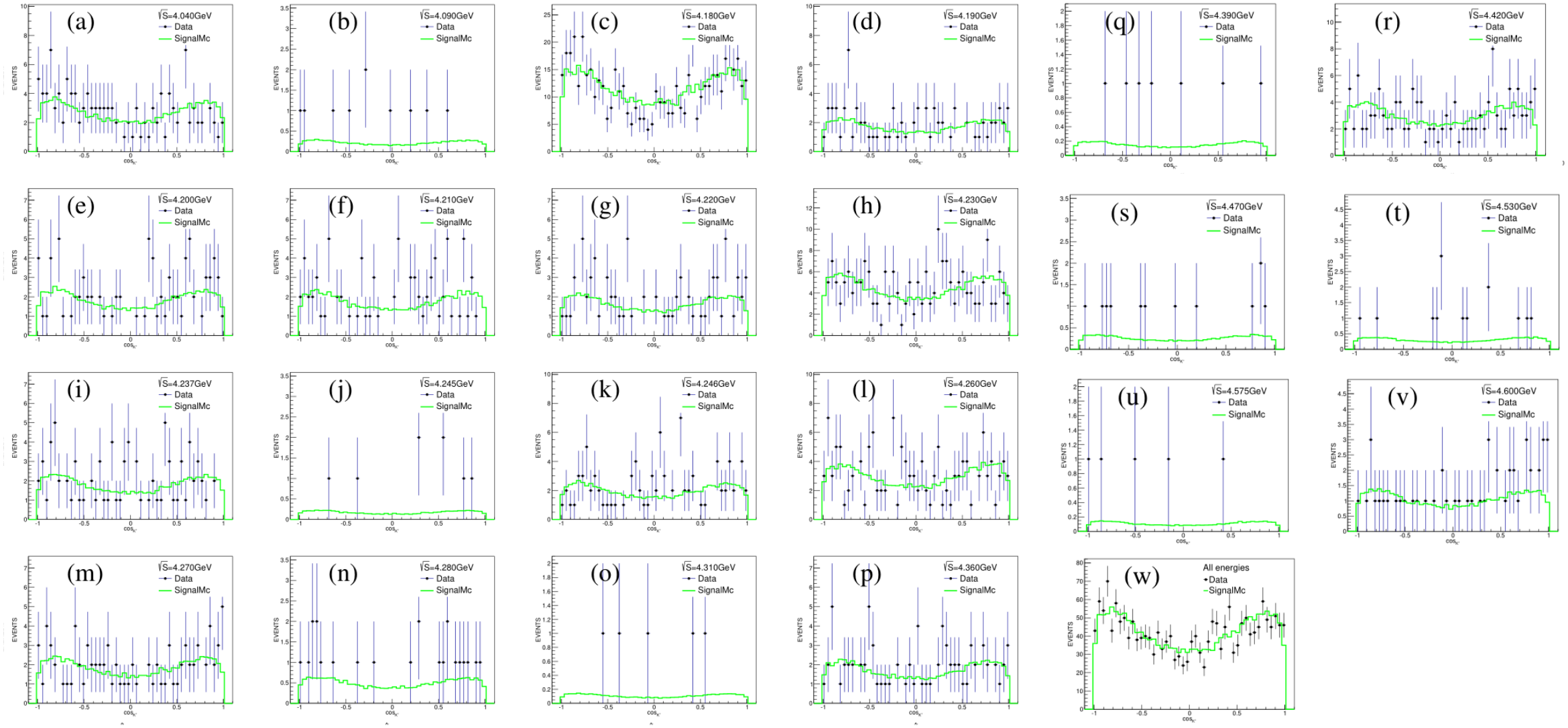
Event selection

The distribution of $cosK^-$



Event selection

The distribution of $cosK^+$



Event selection

The distribution of momentum of ϕ meson