Measurement of cross-sections of $e^+e^- \to \phi\eta, \omega\pi^0, \omega\eta$ for energies around J/ψ peak

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Motivation

- Initially this work was inspired by the study of the phase between strong and electromagnetic amplitudes in J/ψ decays.
  The energy shape of cross-section in the region close to J/ψ production is determined by interference between
  - resonant production: $e^+e^- \to J/\psi \to 3gluons \to hadrons$
    $e^+e^- \to J/\psi \to \gamma \to hadrons$
  - non-resonant production: $e^+e^- \to \gamma \to hadrons$
- Meanwhile there are no precise data on the measurement of cross-sections of processes:
  $e^+e^- \to \phi\eta$,
  $e^+e^- \to \omega\eta$,
  $e^+e^- \to \omega\pi^0$
  in the region of energy $\sim 3\text{GeV}/c$.

Data Sets

Requested Energy (MeV)	List of runs	BEMS (MeV)	Int.Lum. (pb^{-1})
3050.0	28312 - 28346	3050.213±0.026	14.919±0.161
3060.0	28347 - 28381	3059.257±0.028	15.060±0.161
3080.0	28241 - 28266	3080.195±0.023	17.393±0.193
3083.0	28382-28387; 28466-28469	3083.060±0.043	4.769±0.055
3090.0	28388-28416; 28472-28475	3089.418±0.022	15.558±0.165
3093.0	28417-28453; 28476-28478	3092.324±0.025	14.910±0.160
3094.3	28479 - 28482	3095.261±0.084	2.143±0.025
3095.2	28487 - 28489	3095.994±0.081	1.816±0.021
3095.8	28490 - 28492	3096.390±0.075	2.135±0.025
3096.9	28493 - 28495	3097.777±0.076	2.069±0.026
3098.2	28496 - 28498	3098.904±0.075	2.203±0.026
3099.0	28499 - 28501	3099.606±0.093	0.756±0.011
3101.5	28504 - 28505	3101.923±0.106	1.612±0.021
3105.5	28506 - 28509	3106.144±0.090	2.106±0.025
3112.0	28510 - 28511	3112.615±0.093	1.720±0.021
3120.0	28512 - 28513	3120.442±0.115	1.264±0.016
3080.0	39355 - 39618	—	126.210±0.896

Data

Data Sets:

- We use DST for J/ψ-scan 2012 reconstructed using BOSS 6.6.4
- for R-scan 2015 – BOSS 6.6.5

BEMS – beam energy measurement system:

- We used the measurements of BEMS as described in `http://docbes3.ihep.ac.cn/DocDB/0002/000249/003/RelPhase_Energy_03.pdf`
- There are no BEMS measurements for R-scan data 3080MeV and we used $\mathbf{3080 \pm 1 MeV}$
- The energy values were further shifted by -0.55 ± 0.03MeV;
  see "Phase between strong and EM amplitudes in the lineshape of J/ψ resonance" (BAM-00128) and "Measurement of J/ψ resonance parameters through scan data" (BAM-00268)

Data

Integrated Luminosity Measurements:

- We used luminosity from BAM-00157: "Measurement of luminosity for R scan", $e^+e^- \to \gamma\gamma$ process
- Luminosity for R-scan data (2015) are taken from `http://docbes3.ihep.ac.cn/cgi-bin/DocDB/ShowDocument?docid=653`

Monte Carlo

- Monte-Carlo are simulated and reconstructed under BOSS 6.6.4

Signal

We used modified version of MCGPJ (Monte-Carlo Generator of Photon Jets - Eur.Phys.J.C 46,2006,p.689)

- The program allows to take into account ISR photons with an accuracy better than 1%
- We changed MCGPJ by adding the studied processes and the possibility of describing the interference between resonant and not-resonant production
- 150K events in each energy point

Background

- Inclusive MC for J/ψ-decays (3097MeV)
- KKMC generation for energy 3080MeV

$e^+e^- \to \phi\eta$

$(\phi \to K^+K^-;\ \eta \to \gamma\gamma)$

Event Selection

Two opposite charged tracks:

- $|R_{xy}| \leq 1$ cm; $|R_z| \leq 10$ cm
- $cos(\Theta) \leq 0.93$
- PID: $Prob(K) > Prob(\pi)||Prob(proton); Prob(K) > 0.001$

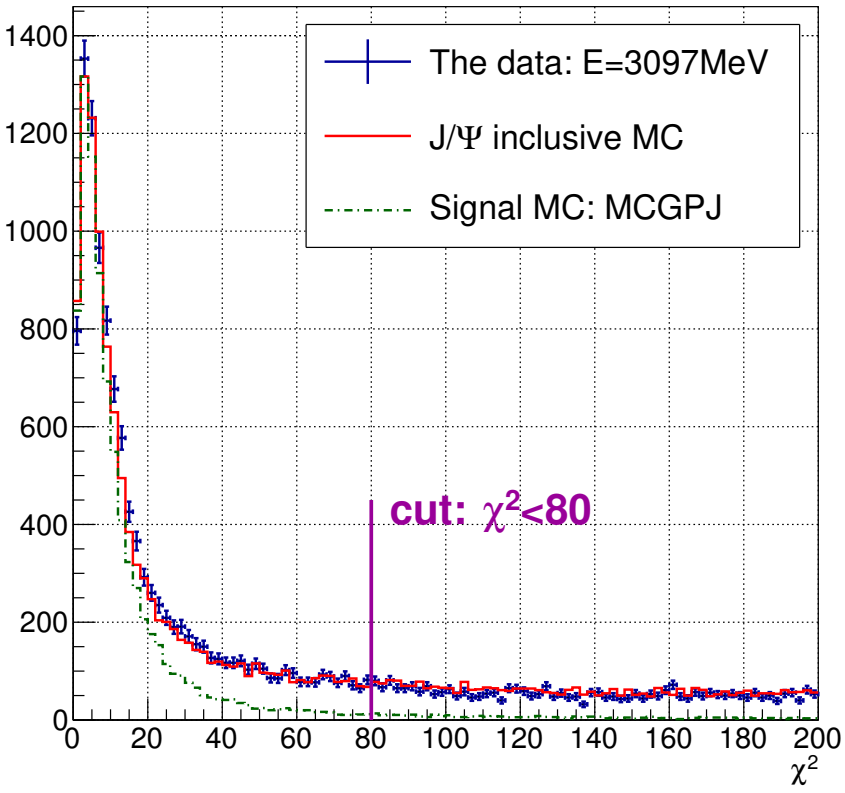
At least two photons:

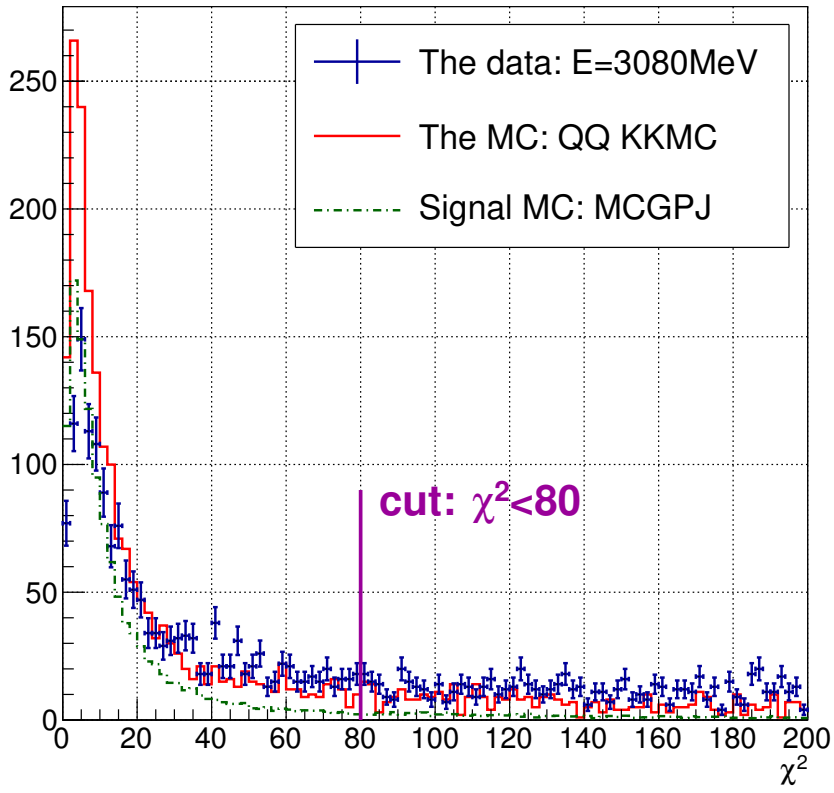
- $E_\gamma > 25$ MeV (barrel EMC) or $E_\gamma > 50$ MeV (end-cap EMC)
- $\alpha_\gamma > 10^o$ - the angle relative to the nearest charged track

4C kinematic fit under $K^+K^-\gamma\gamma$ hypothesis:

- Choosing the two best photons with the smallest $\chi^2(4C)$
- $\chi^2(4C) < 80$

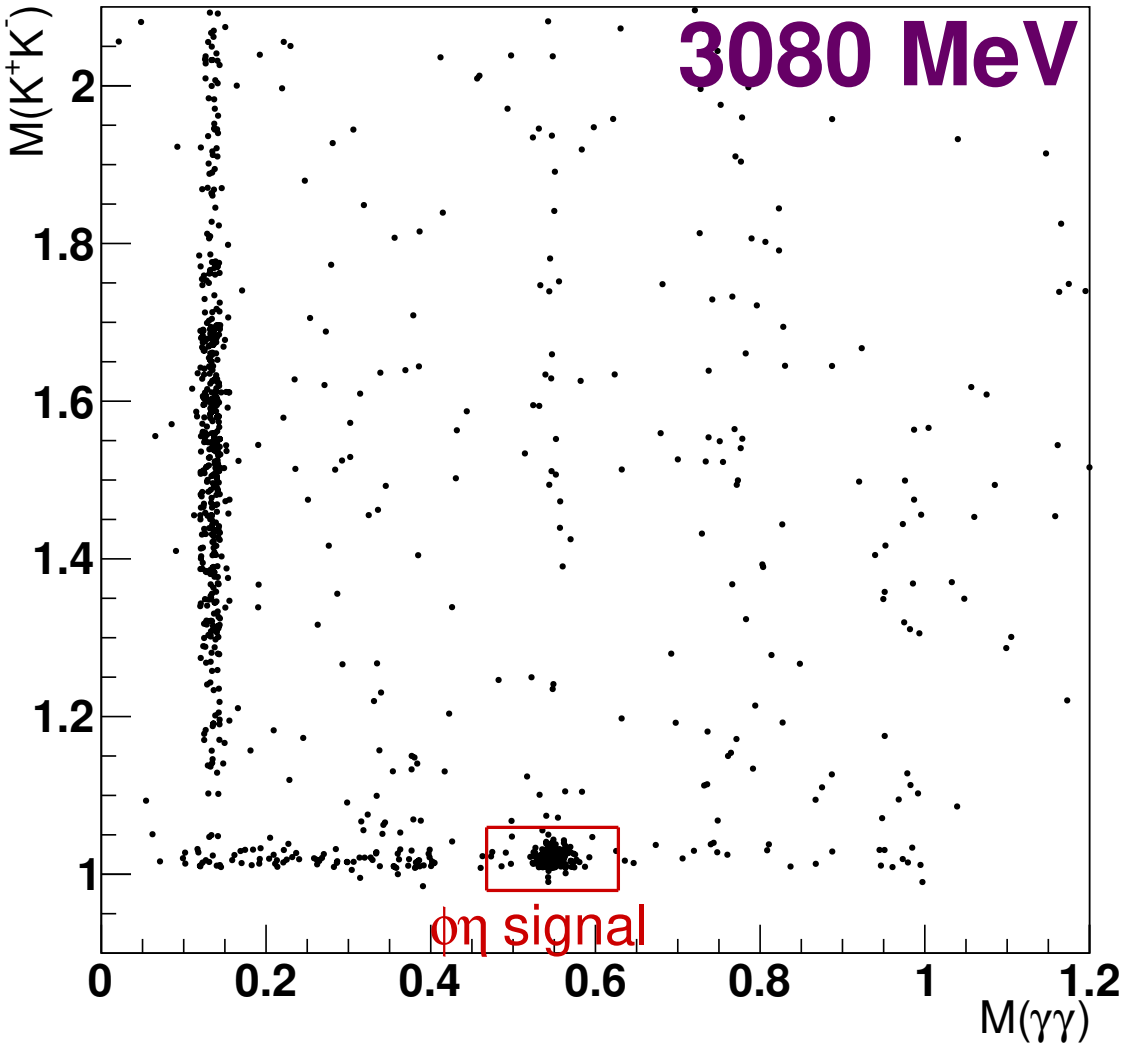
4C – Kinematic fit: χ^2 Data vs MC



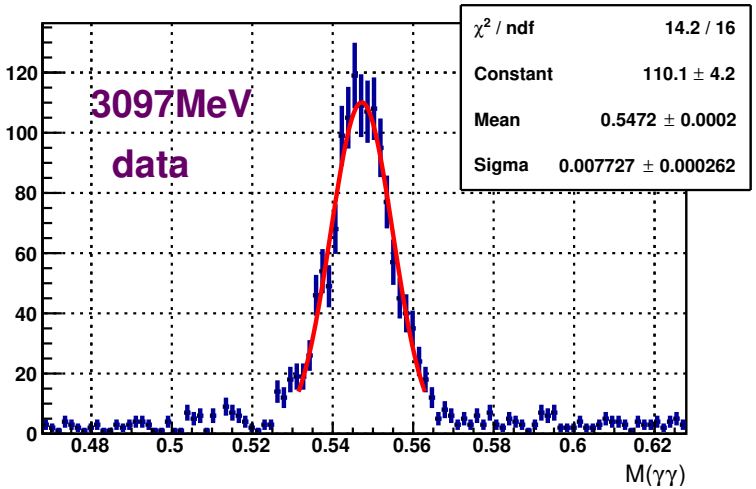


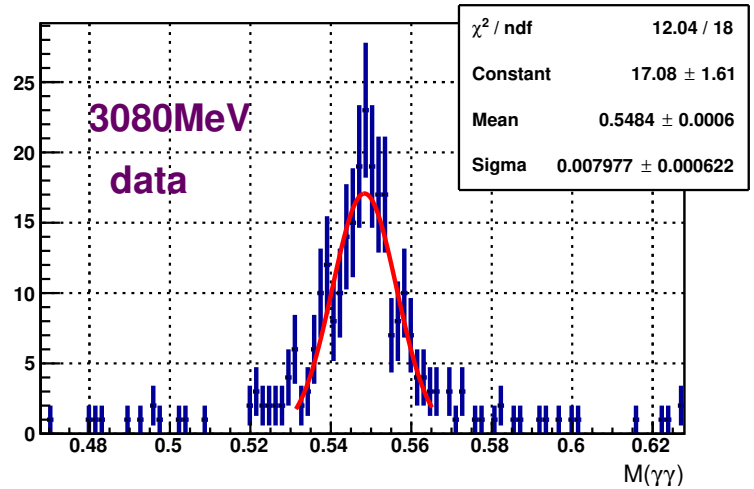
- Good agreement between data and inclusive MC for 3097MeV
- Signal MC shows that cut $\chi^2 < 80$ removes the background tail

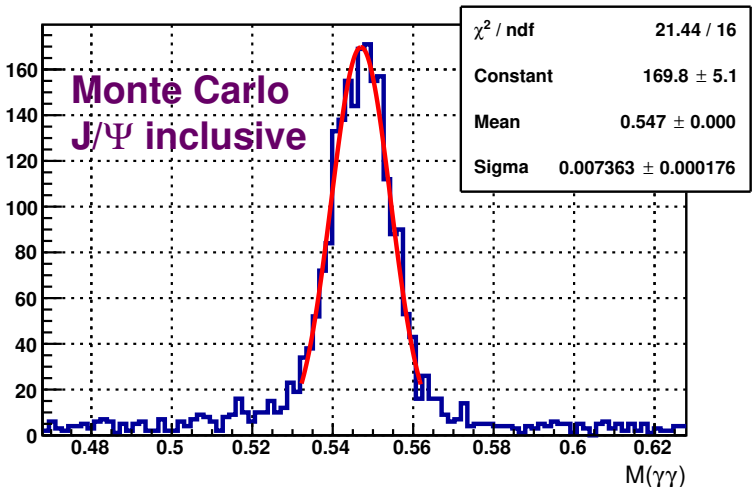
Invariant masses of η and ϕ

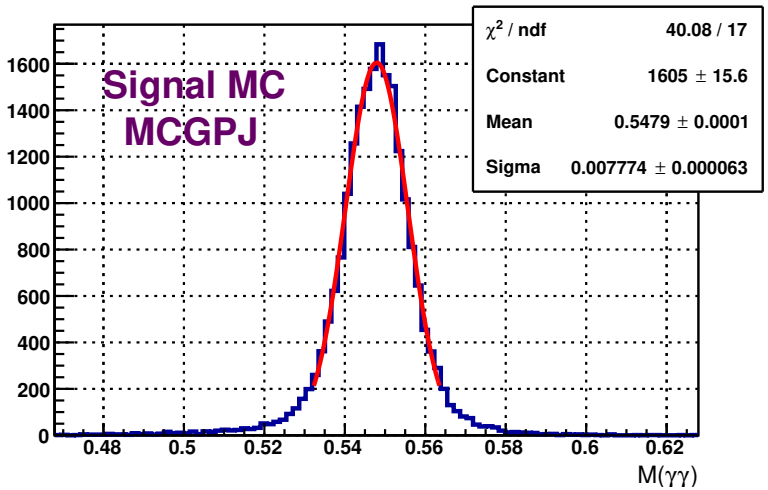


Invariant mass of $\eta \to \gamma\gamma$









- The distributions fit with Gauss ($\sigma(\eta) \sim 8$ MeV) independent of beam energy

Event Selection (continue)

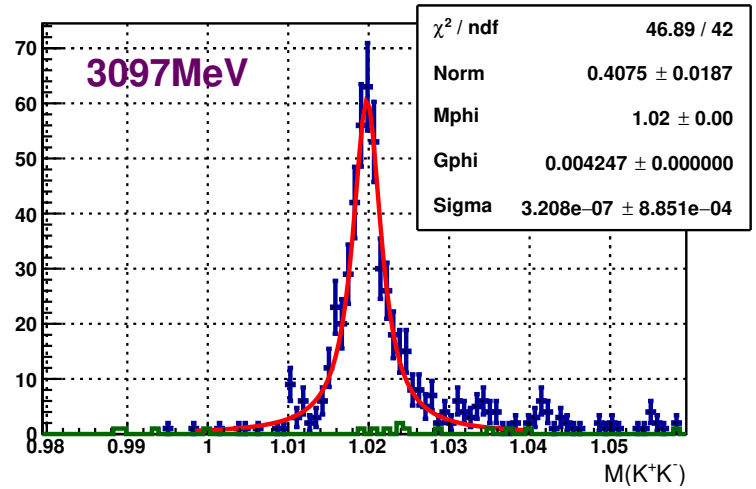
Side-band subtraction for $M(\gamma\gamma)$

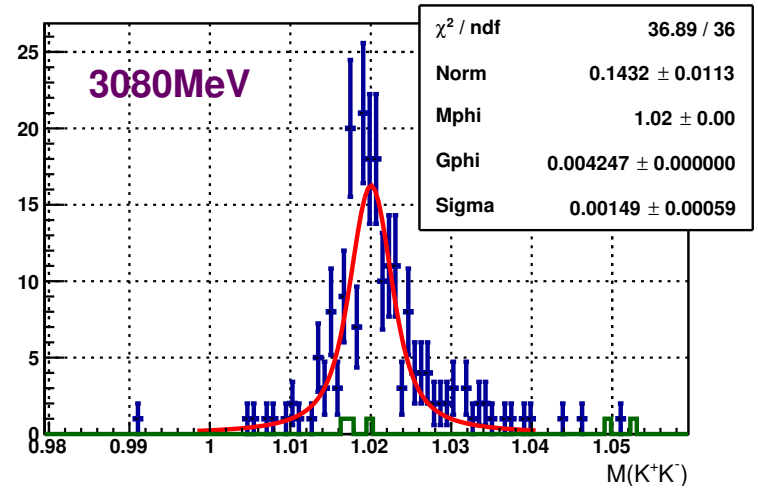
- The central part is
$$|M(\gamma\gamma) - M_\eta)| < 3\sigma(\eta)$$
- The background is estimated as the sum of the side band regions:
$$4\sigma(\eta) < |M(\gamma\gamma) - M_\eta)| < 7\sigma(\eta)$$
- $\sigma(\eta) = 8$ MeV

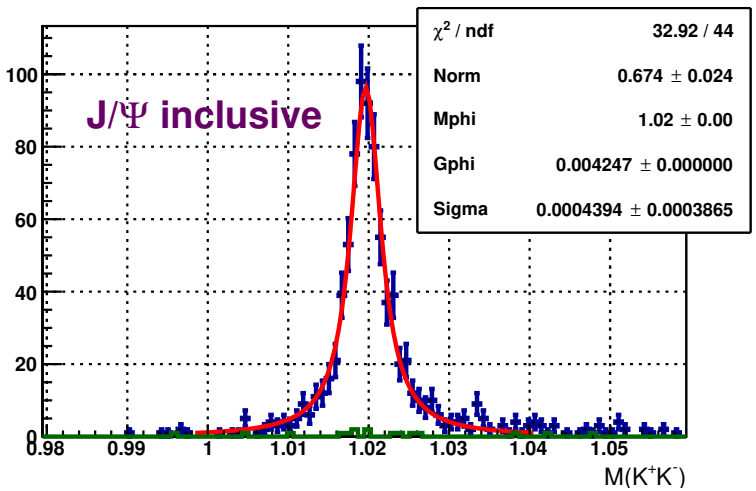
Selection of $M(K^+K^-)$ (see next slide)

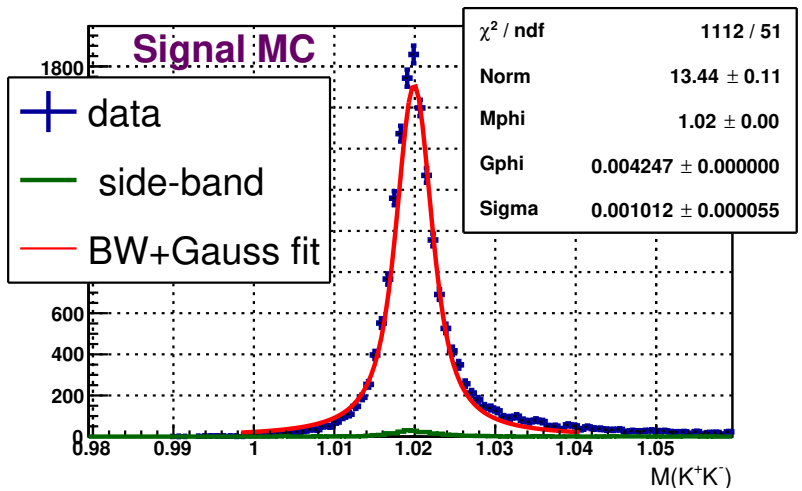
- We use loose selection criteria:
$$|M(K^+K^-) - M_\phi)| < 5 \times \Gamma_\phi$$
- $\Gamma_\phi = 4.247$ MeV

Invariant mass of $\phi \to K^+K^-$



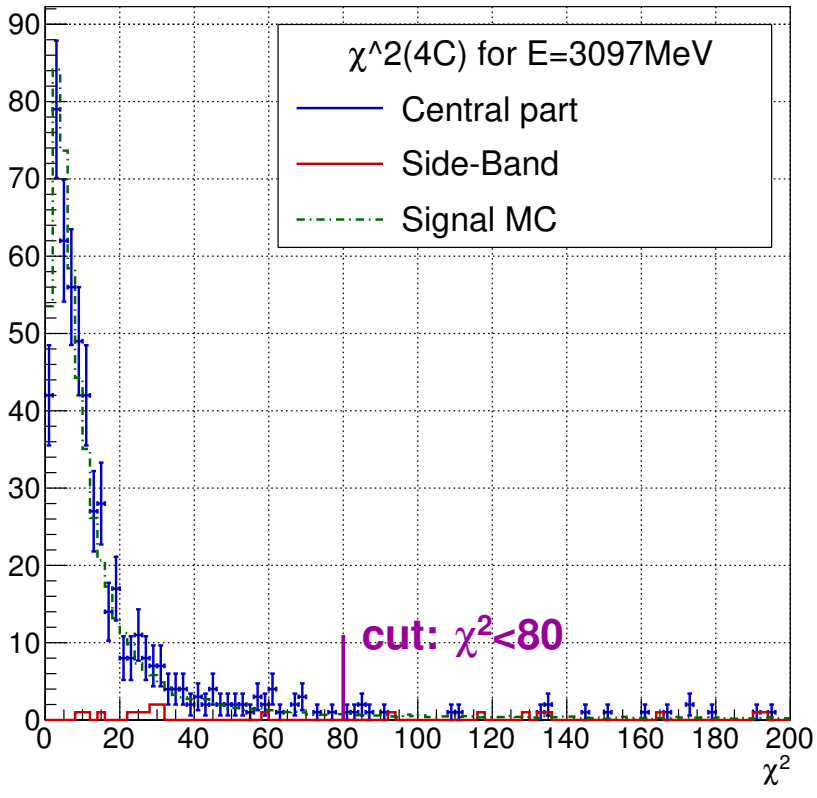


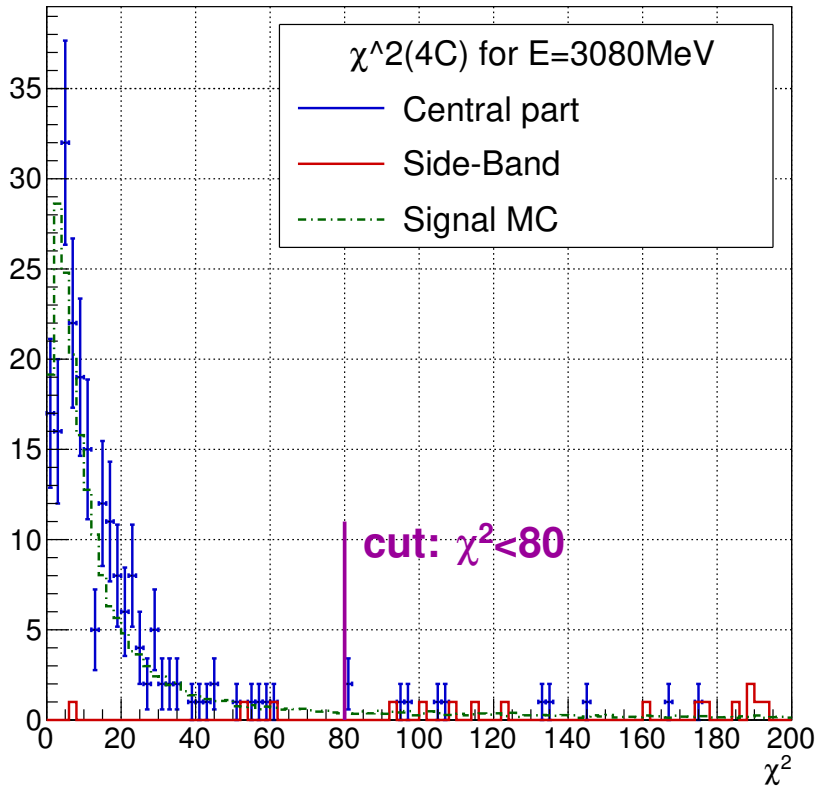




- The distributions fit with Breit-Wignre convoluted with Gauss
- The width of Γ_ϕ fixed on PDG value (4.247 MeV)
- The side-band method shows there is no peaking background

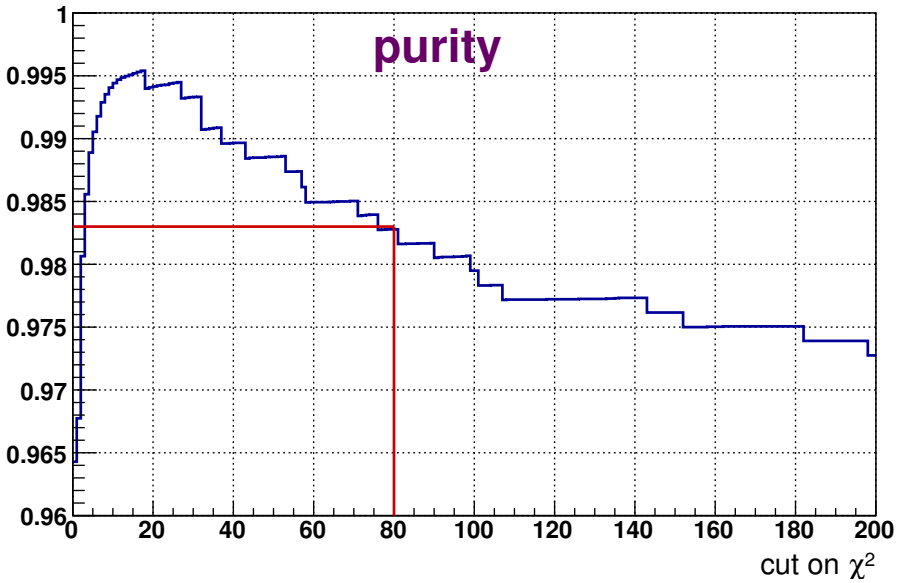
$\chi^2(4C)$ for Side-Band events

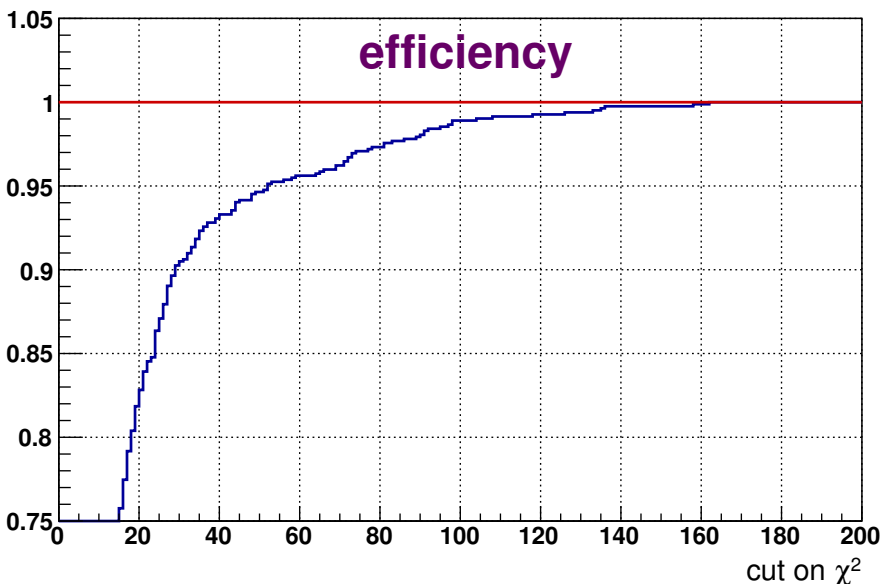




- Good agreement between data and signal MC
- Backgrounds estimated by side-band events are small

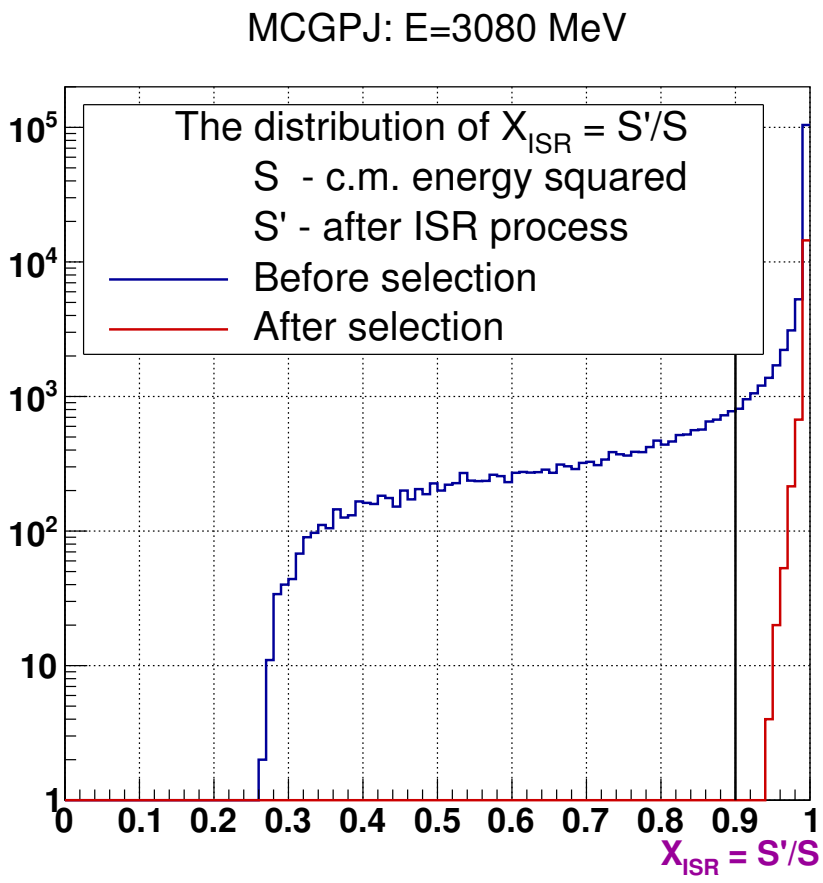
Background study (3097 MeV; inclusive J/ψ MC)





- Cut on $\chi^2(4C)$ is the last cut
- The purity and efficiency as a function of $\chi^2(4C)$ cut
- The background is less than 2% for $\chi^2(4C) < 80$

Reconstruction of ISR events



- Only events with $X_{ISR} > 0.9$ pass selection cuts
- In the whole region we completely rely on the MCGPJ generator

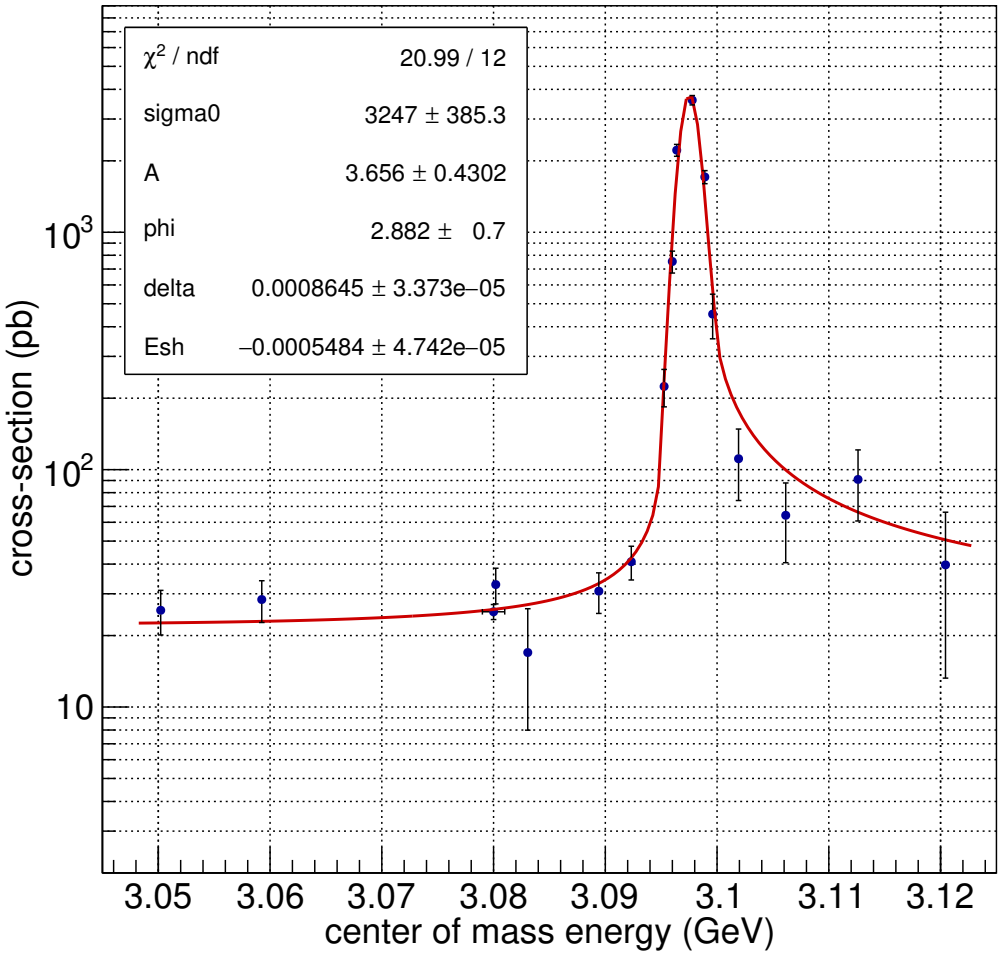
We choose $X_{ISR} > 0.9$ as a signal definition region

Cross Section of $e^+e^- \to \phi\eta$

$X_{ISR} > 0.9$

E(GeV)	Lum.(pb^{-1})	Signal	Eff.(%)	Cross Section(nb)
3.049663	14.919	23 ± 4.9	12.34	0.0256 ± 0.0054
3.058707	15.06	26 ± 5.2	12.45	0.0284 ± 0.0057
3.079645	17.393	35 ± 6.0	12.54	0.0328 ± 0.0056
3.082510	4.769	5 ± 2.6	12.64	0.0170 ± 0.0090
3.088868	15.558	30 ± 5.8	12.82	0.0308 ± 0.0060
3.091774	14.91	39 ± 6.3	13.07	0.0409 ± 0.0066
3.094711	2.143	32 ± 5.7	13.63	0.2241 ± 0.0402
3.095444	1.816	93 ± 9.8	13.91	0.7531 ± 0.0798
3.095840	2.135	320 ± 18.4	13.82	2.2174 ± 0.1278
3.097227	2.069	503 ± 22.9	13.80	3.6032 ± 0.1641
3.098354	2.203	255 ± 16.2	13.84	1.7103 ± 0.1084
3.099056	0.756	23 ± 4.9	13.76	0.4521 ± 0.0963
3.101373	1.612	12 ± 4.0	13.69	0.1112 ± 0.0371
3.105594	2.106	9 ± 3.3	13.61	0.0642 ± 0.0237
3.112065	1.72	10 ± 3.3	13.08	0.0909 ± 0.0302
3.119892	1.264	3 ± 2.0	12.22	0.0397 ± 0.0265
3.080000	126.21	195 ± 14.2	12.54	0.0252 ± 0.0018

Cross Section of $e^+e^- \to \phi\eta$



- We confirm the shift in energy: the fit result: -0.55 ± 0.05 MeV
- We use result of the fit in MCGPJ generator to describe the dependence of the cross section on the energy

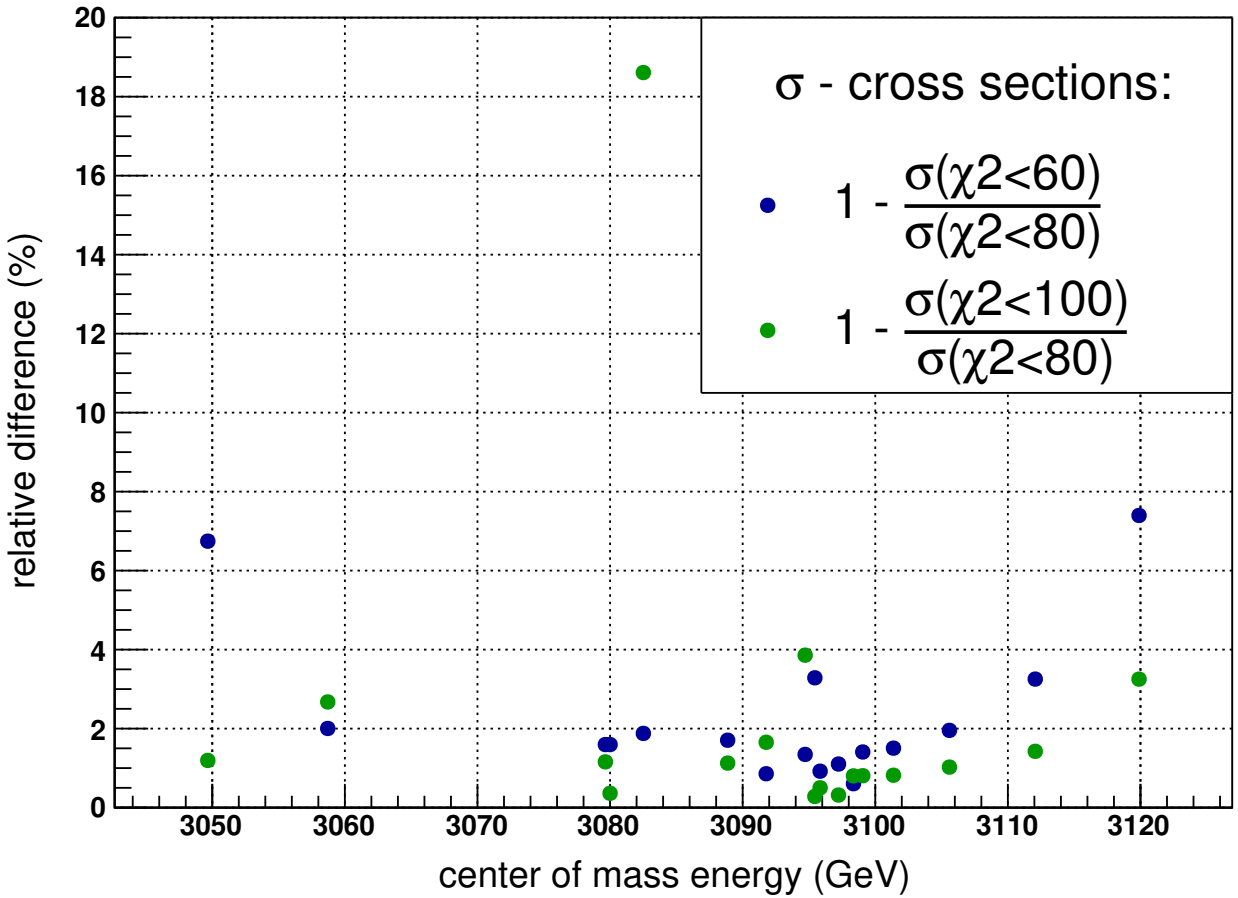
Comparison with BAM-269 results:

- We have common data point 3080 MeV but different selection criteria
- BAM-269 result is $\sigma(3080 MeV) = 29 \pm 2$ pb
- Our result calculated for full range of $X_{ISR} > 0$ is $\sigma(3080 MeV) = 28.6 \pm 2.1$ pb

Systematic uncertainties

- **Luminosity (BAM-00157):**
  - mainly by systematic error $\sim 1\%$
- **Track reconstruction:** $2 \times 1\%$
- **Photon reconstruction:** $2 \times 1\%$
- **Branching fractions (PDG):**
  $$\delta Br(\phi \to K^+K^-) \oplus \delta Br(\eta \to 2\gamma) = 1.1\%$$
- **Selection:**
  - varying $\chi^2 \pm 20$ cut: $\sim 2\%$
  - varying $M_{\gamma\gamma}$ window: Y%
- **MCGPJ:**
  Generator used measured cross section of $e^+e^- \to \phi\eta$ as input. Therefore statistical error of measured cross sections leads to systematic uncertainty: Z%

Varying χ^2 cut: 80 ± 20



- The relative errors are generally less than 2%
- The errors are up to 19% for low-statictical data (5 selected events becomes 6)

$e^+e^- \to \omega\pi^0$

$(\omega \to \pi^+\pi^-\pi^0;\ \pi^0 \to \gamma\gamma)$

Event Selection

Two opposite charged tracks:

- $|R_{xy}| \leq 1$ cm; $|R_z| \leq 10$ cm; $cos(\Theta) \leq 0.93$
- PID: $Prob(\pi) > 0.001$

At least 4 photons:

- $E_\gamma > 25$ MeV (barrel EMC) or $E_\gamma > 50$ MeV (end-cap EMC)
- $\alpha_\gamma > 20^o$ - the angle relative to the nearest charged track

Kinematic fits:

1. 4C-fit: we select four photons with the smallest $\chi^2(4C)$ among $\pi^+\pi^-4\gamma$ combinations
2. 5C-fit: additionally we required that one of the combination $\pi^+\pi^-2\gamma$ must give M_ω and $\chi^2(5C) < 90$
3. We consider the remaining two photon as π^0

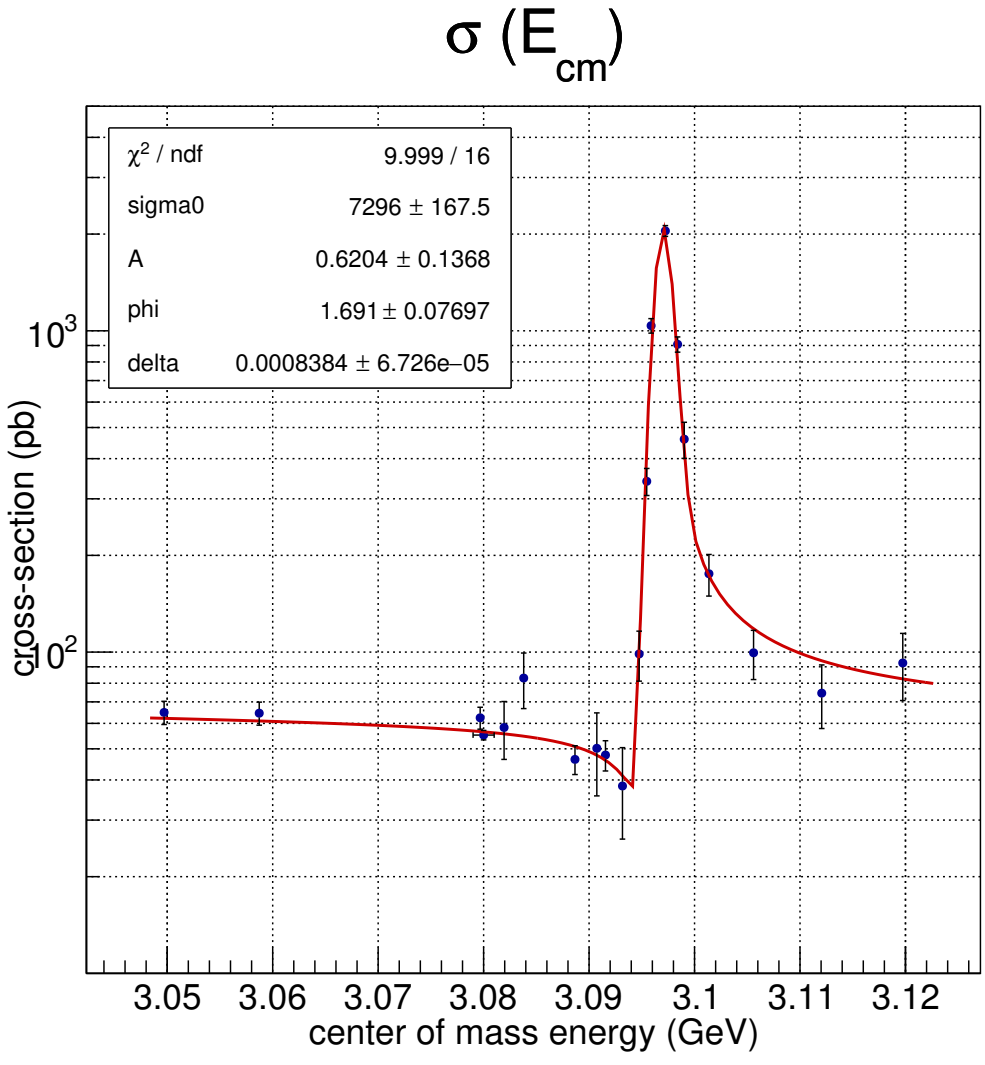
Event Selection (continue)

Cut on invariant masses:

- $|M(\pi^+\pi^- 2\gamma) - M_\omega| < 30$ MeV
- $|M(\gamma\gamma) - M_{\pi^0}| < 18$ MeV

Cross Section of $e^+e^- \to \omega\pi^0$

$X_{ISR} > 0.9$ is our signal definition region



Comparison with L.Yan presentation on BESIII collaboration meeting 16/06/2015

- The same data but different analysis
- L.Yan presentation: $\sigma(3080MeV) = 58.6 \pm 1.8$ pb
- Our result calculated for full range of $X_{ISR} > 0$ is $\sigma(3080MeV) = 56.8 \pm 1.9$ pb

$e^+e^- \to \omega\eta$

$(\omega \to \pi^+\pi^-\pi^0;\ \eta \to \gamma\gamma)$

Event Selection

Two opposite charged tracks:

- $|R_{xy}| \leq 1$ cm; $|R_z| \leq 10$ cm; $cos(\Theta) \leq 0.93$
- PID: $Prob(\pi) > 0.001$

At least 4 photons:

- $E_\gamma > 25$ MeV (barrel EMC) or $E_\gamma > 50$ MeV (end-cap EMC)
- $\alpha_\gamma > 20^o$ - the angle relative to the nearest charged track

Reconstruction $\eta \to \gamma\gamma$ and $\pi^0 \to \gamma\gamma$

- We use 4C kinematic fits for $\pi^+\pi^-4\gamma$ combinations and select four photons with the smallest $\chi^2(4C)$ satisfying $\chi^2(4C) < 100$
- Choosing two photons pairs such that $|M(\gamma_1\gamma_2) - M_\eta|$ is minimal if $|M(\gamma_3\gamma_4) - M_{\pi^0}| < 15$ MeV

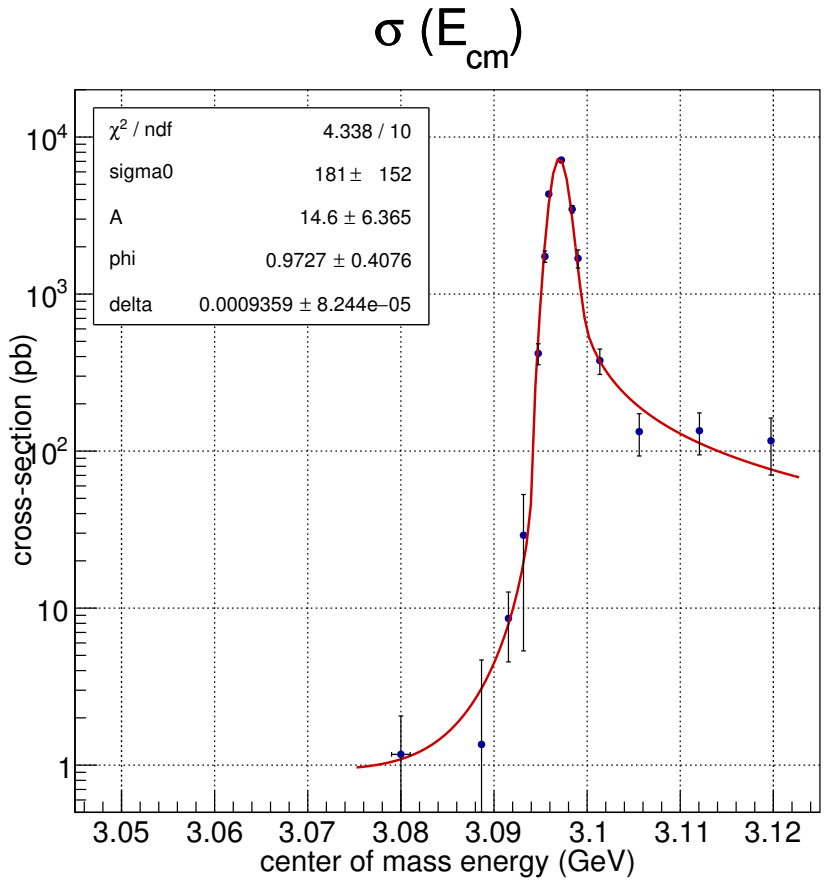
Event Selection (continue)

2D side-band subtraction:

- The central part is
  $|M(\gamma_1\gamma_1) - M_\eta)| < 3\sigma(\eta)$ and $|M(\pi^+\pi^-\gamma_3\gamma_4) - M_\omega)| < 3\sigma(\omega)$
- The background is estimated in the side band regions:
  bands for M_η: $4\sigma(\eta) < |M(\gamma_1\gamma_2) - M_\eta)| < 7\sigma(\eta)$
  bands for M_ω: $4\sigma(\omega) < |M(\pi^+\pi^-\gamma_3\gamma_4) - M_\omega)| < 7\sigma(\omega)$
- $\sigma(\eta) = 8$ MeV
  $\sigma(\omega) = 10$ MeV

Cross Section of $e^+e^- \to \omega\eta$

$X_{ISR} > 0.9$ is our signal definition region



- We have zero or negative number of events for $E < 3080$ MeV

Conclusion

- We measured the cross sections of $e^+e^- \to \phi\eta$, $e^+e^- \to \omega\pi^0$ and $e^+e^- \to \omega\eta$ in the region of energies around J/ψ
- We continue the work for estimation of systematic uncertainties
- We plan to write a memo in details describing this analysis