Looking for the Phase Interference between strong and EM in J/ψ decays

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(on behalf of BESIII-LNF(INFN) group)

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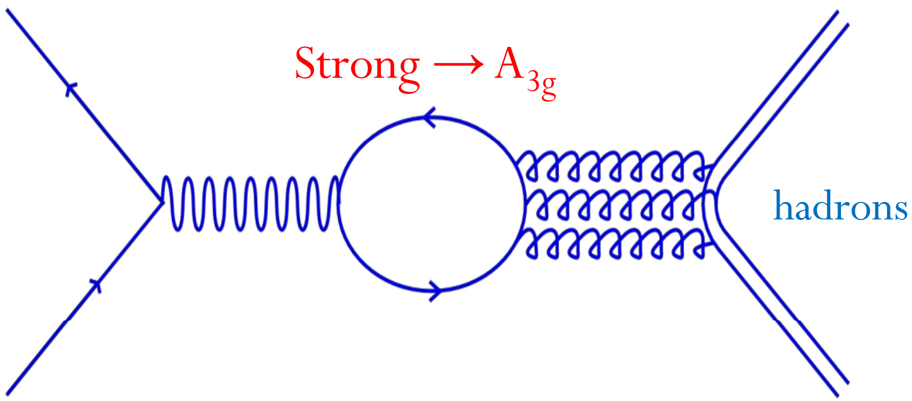
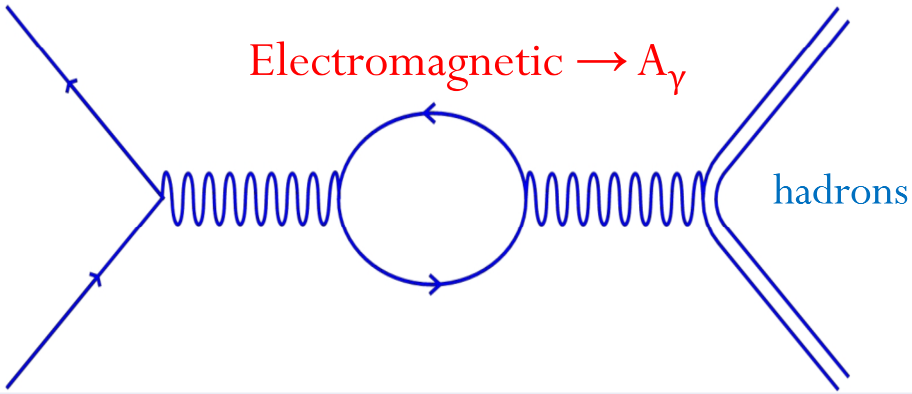
Outline

- Motivation
- A brief introduction on BESIII.
- Analysis on J/ψ decays to $\mu^+\mu^-$, $2(\pi^+\pi^-)$ and $2(\pi^+\pi^-)\pi^0$.
- Summary

J/ψ Strong and Electromagnetic Decay Amplitudes





$$\text{cross section} \sim |A_\gamma + A_{3g}|^2 = |A_\gamma|^2 + |A_{3g}|^2 + 2\,\mathrm{Re}[A_\gamma^* A_{3g}]$$

Resonant contributions

$\Gamma_{J/\psi} \sim 93\text{KeV}$ → pQCD

pQCD: both amplitudes almost real [1,2]

QCD does not provide sizeable imaginary amplitudes → $\phi \sim 10^\circ$ [1]

A_γ and A_{3g} must interfere ($\phi \sim 0^\circ$ / 180°)

Experimental results:

$J/\psi \rightarrow NN$ ($\frac{1}{2}^+\frac{1}{2}^-$) $\phi = 89^\circ \pm 9^\circ$

$J/\psi \rightarrow VP$ (1^-0^-) $\phi = 106^\circ \pm 10^\circ$

$J/\psi \rightarrow PP$ (0^-0^-) $\phi = 89.6^\circ \pm 9.9^\circ$

$J/\psi \rightarrow VV$ (1^-1^-) $\phi = 138^\circ \pm 37^\circ$

No interference?

[1] J. Bolz and P. Kroll, WU B 95-35.
[2] S.J. Brodsky, G.P. Lepage, S.F. Tuan, Phys. Rev. Lett. 59, 621 (1987).

J/ψ Strong and Electromagnetic Decay Amplitudes

Take J/ψ → ppbar / nnbar as a result

Initial-state isospin is 0, A_{3g}(ppbar) = A_{3g}(nnbar).

Like magnetic moments, A_{EM}(ppbar) = $-A_{EM}$(nnbar).

According to pQCD,

$$R = \frac{Br(J/\psi \to n\bar{n})}{Br(J/\psi \to p\bar{p})} = \left|\frac{A_{3g} + A_{\gamma}^{n}}{A_{3g} + A_{\gamma}^{p}}\right|^2 = \frac{1}{2}$$

$A_{3g}, A_{\gamma} \in \Re$ R<<1

$A_{3g} \perp A_{\gamma}$ R ≈1

But the BR are almost equal according to BESIII[1]:

BR(J/ψ → ppbar) = (2.112 ± 0.004 ± 0.027)•10^{-3}

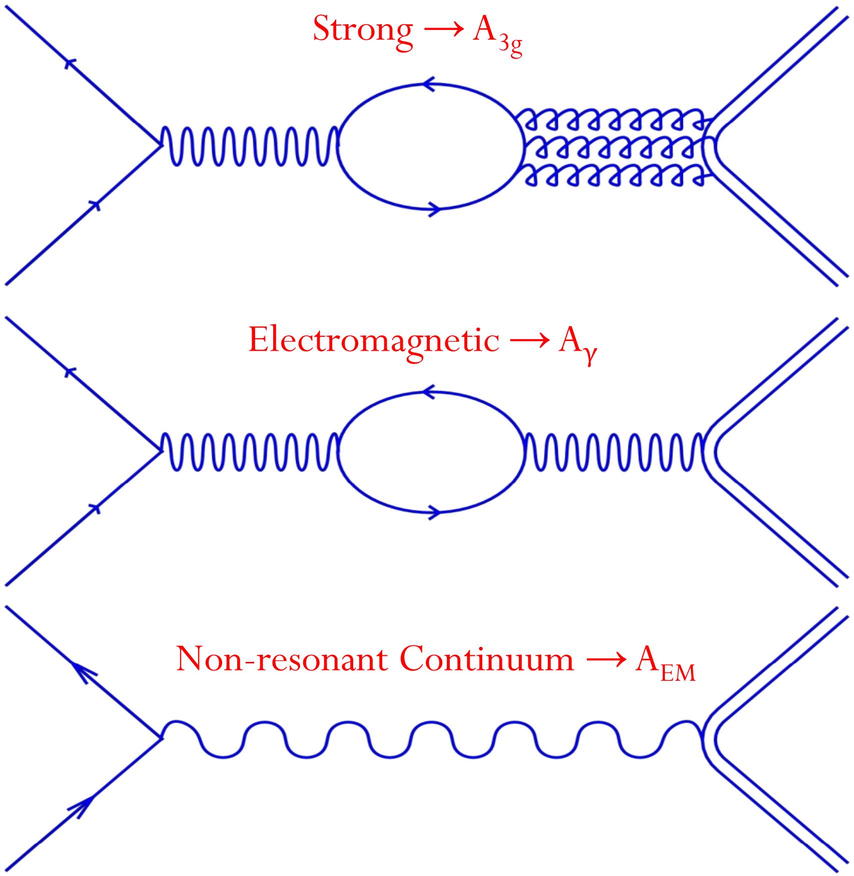
BR(J/ψ → nnbar) = (2.07 ± 0.01 ± 0.14)•10^{-3}

- Suggests 90° phase

Measurement from J/ψ decays has assumptions.

[1] J.M. Bian, J/ψ -> ppbar and J/ψ -> nnbar measurement by BESIII, accepted for pubblication PRD

Including the effect of continuum ($A_{cont.}$)



Resonant contributions

$\Gamma_{J/\psi} \sim 93\text{KeV}$ → pQCD

pQCD: all amplitudes almost real [1,2]

QCD does not provide sizeable imaginary amplitudes → $\phi \sim 10^\circ$ [1]

A_γ and A_{3g} must interfere ($\phi \sim 0^\circ$ / 180°)

Non-resonant continuum

pQCD regime

$A_{EM} \in \Re$

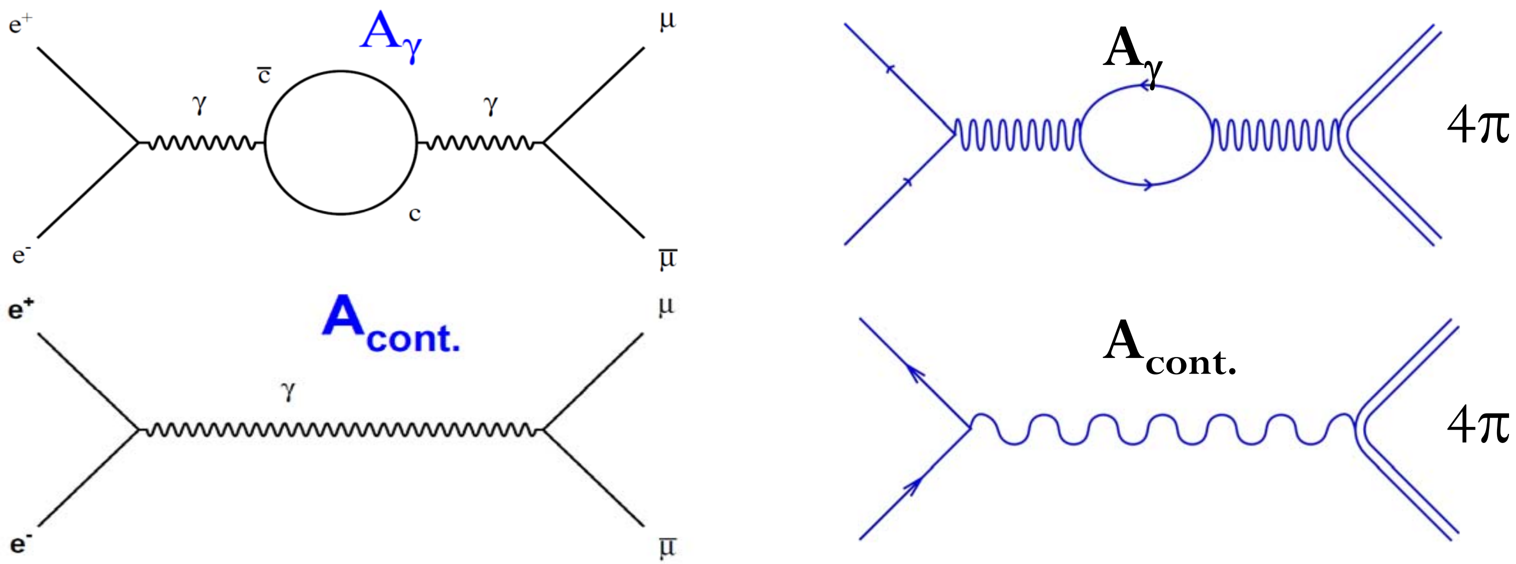
$$\sigma \sim |A_{3g} + A_\gamma + A_{cont}|^2$$

If A_γ and A_{cont} has the same phase,

$$\sigma \sim |A_{3g} + A_{EM}|^2 = |A_{3g}|^2 + |A_{EM}|^2 + 2\mathrm{Re}[A_{3g}^* A_{EM}]$$

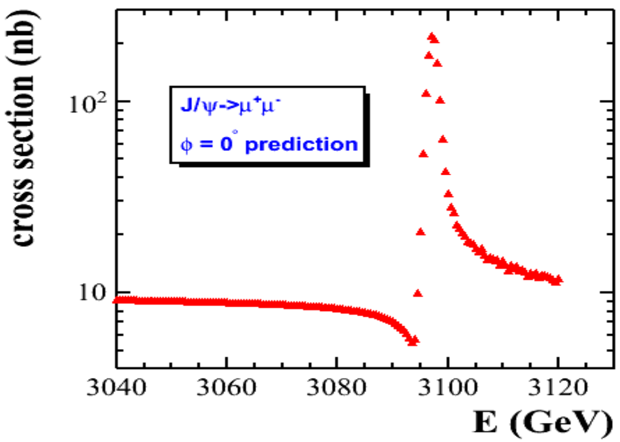
Expected Full Interferences in $e^+e^- \rightarrow \mu^+\mu^-/2(\pi^+\pi^-)$

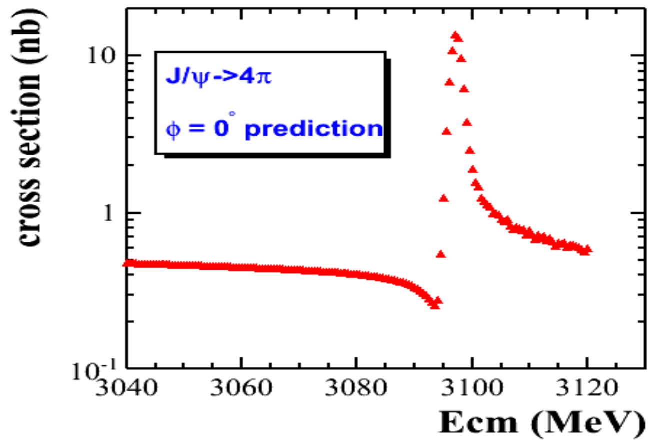
- Due to leptonic decay or G-parity, only A_γ and $A_{cont.}$ contribute in $e^+e^- \rightarrow \mu^+\mu^-$ and $e^+e^- \rightarrow 2(\pi^+\pi^-)$



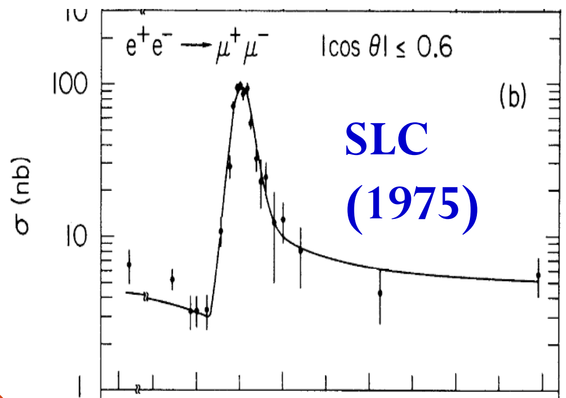
- $\sigma_{tot} \sim |A_\gamma + A_{cont.}|^2 = |A_\gamma|^2 + |A_{cont.}|^2 + 2Re[A_\gamma^* A_{cont.}]$
- $A_{cont.}$ has the same phase as $A_\gamma \rightarrow \phi \sim 0^o$.

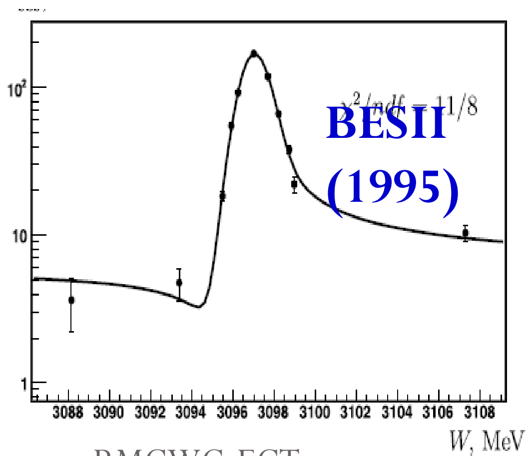
- Theoretical prediction when $\phi=0^o$. **An obvious dip below J/ψ.**

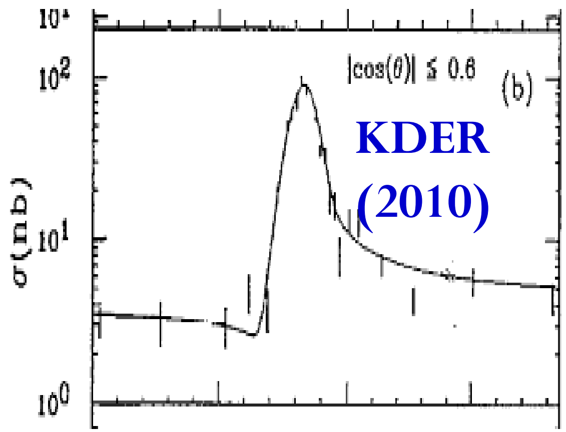




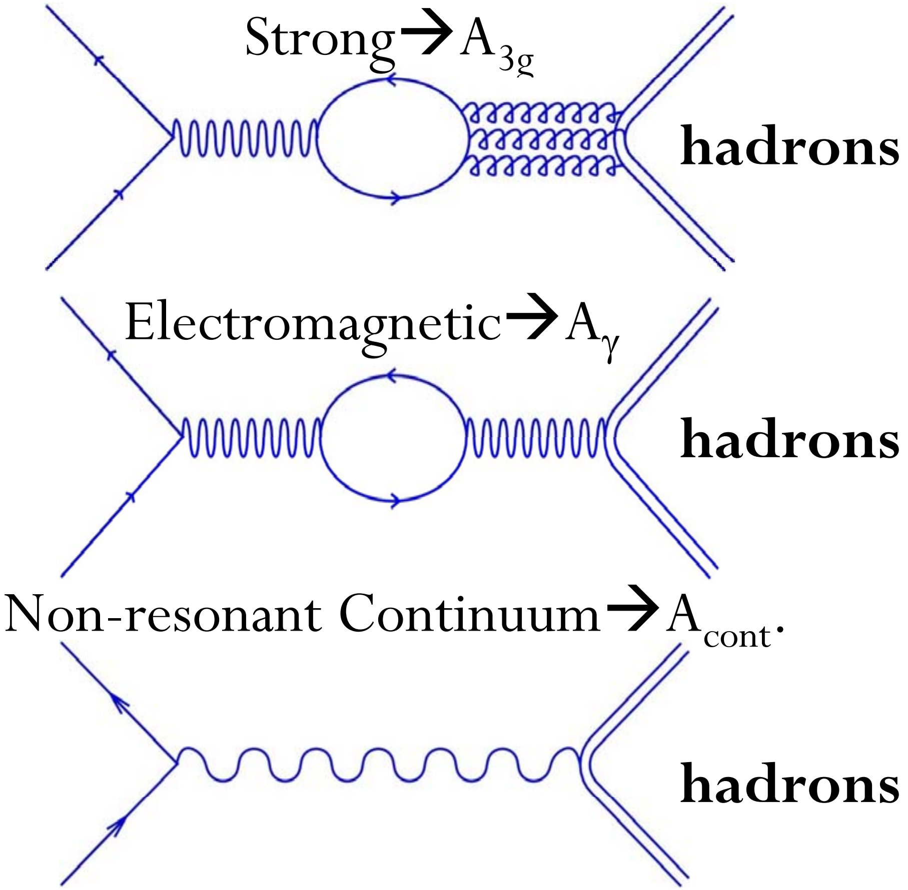
- The interference pattern between $J/\psi \to \mu^+\mu^-$ and the non-resonant amplitudes has been firstly found @ SLAC [PRL 33,1406], BES-II [PLB 355,374] and KEDR [PLB 685,134].







Interference in strong mechanism $J/\psi \rightarrow 5\pi$



G-parity conserved.

A_{3g} contributes.

$$\sigma \sim |A_{3g}+A_{EM}|^2 = |A_{3g}|^2 + |A_{EM}|^2 + 2\mathrm{Re}[A_{3g}{}^* A_{EM}]$$

How about the lineshape of J/ψ in $e^+e^- \rightarrow 5\pi$?

In $\phi \rightarrow \pi^+\pi^-\pi^0$ @ Novosibirsk

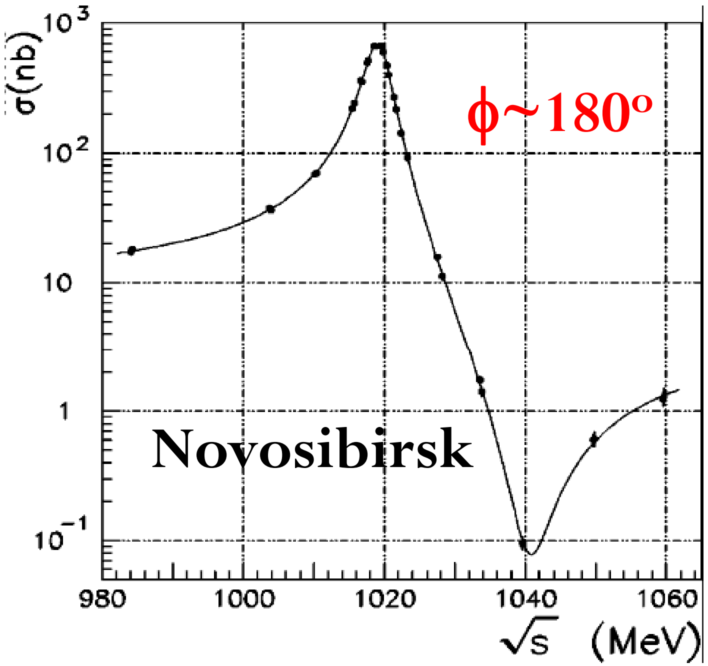
- $\sigma \sim |A_{3g}+A_{EM}|^2 = |A_{3g}|^2+|A_{EM}|^2+2\mathrm{Re}[A_{3g}{}^*A_{EM}]$

- The dip above ϕ peak indicates full interference $\phi \sim 180^o$.

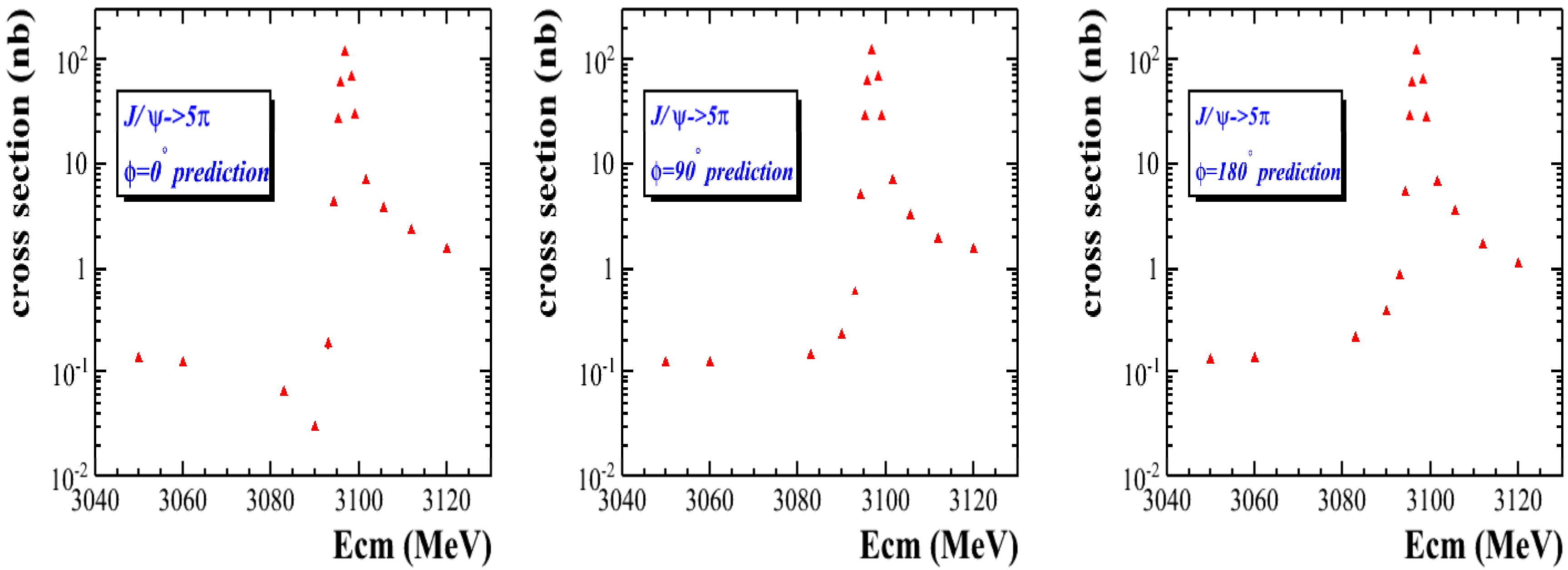
- ϕ decays is in agreement with pQCD
- Both A_{3g} and A_{EM} are real, opposite signs

$e^+e^- \rightarrow \pi^+\pi^-\pi^0$ around ϕ

Phys. Rev. D 63, 072002



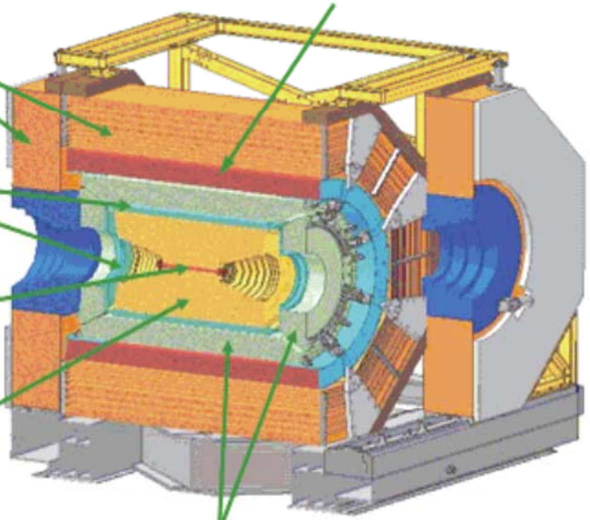
Theoretical prediction on J/ψ→5π



ISR effect and energy spread of beam energy have been considered.

BESIII Experiment

The BESIII Detector



Beam energy: 1.0 – 2.3 GeV

Peak Luminosity:

Design: 1×10^{33} $cm^{-2}s^{-1}$

Achieved: 0.65×10^{33} $cm^{-2}s^{-1}$

Datasets already got:

2009: 106 M $\psi(2s)$ 4xCLEOc

225M J/ψ 4xBESII

2010-11: 2.9 fb^{-1} $\psi(3770)$ 3.5xCLEOC

2011: 0.5 fb^{-1} @4.01GeV (Ds, XYZ)

2012: 0.4 B $\psi(2S)$

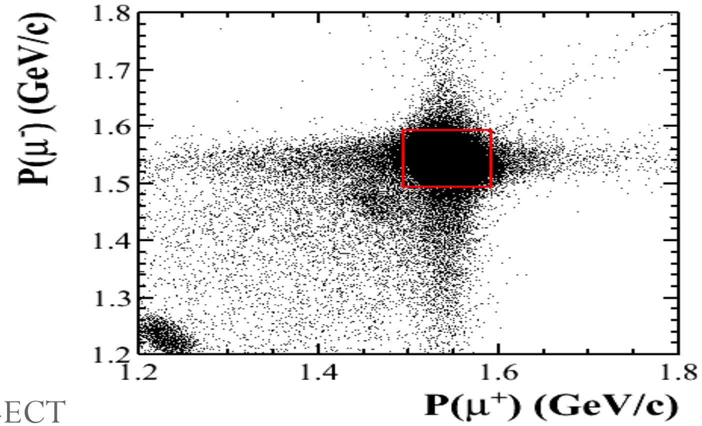
1.0 B J/ψ and J/ψ lineshape fine scan for phase measurement

R scan @ 2.4, 2.8, 3.4 GeV

201: 515 pb^{-1} @ 4260 MeV

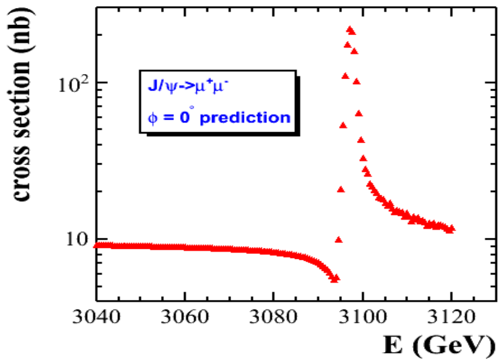
Analysis on $e^+e^- \to \mu^+\mu^-$

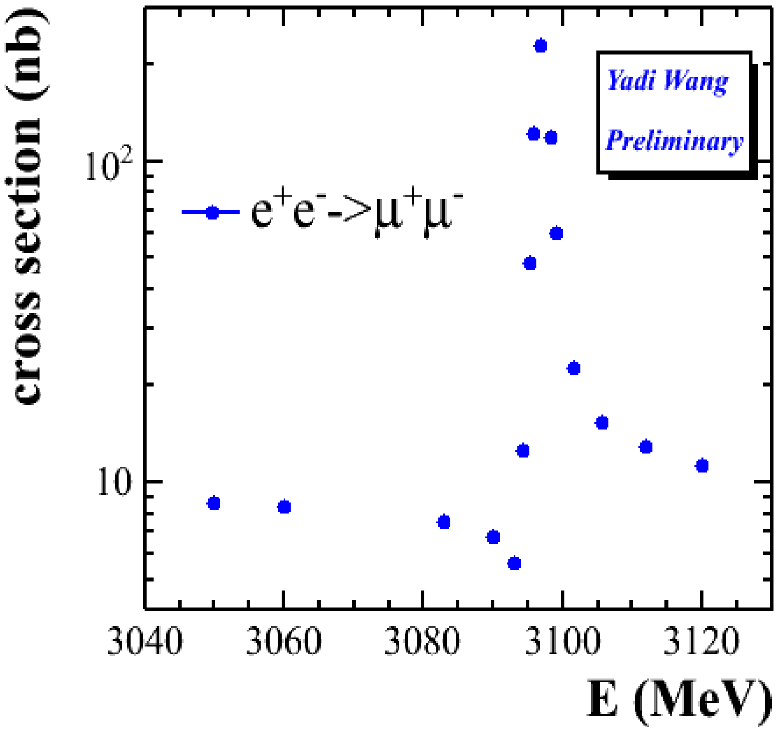
- 2 good charged tracks:
  - $|Rxy|<1cm$, $|Rz|<10cm$;
  - $|\cos\theta|<0.8$.
- No good neutral tracks in EMC:
  - $0<T<14$ (x50 ns)
  - $E_\gamma>25MeV$ ($|\cos\theta|<0.8$), $E_\gamma>50$ MeV ($0.86<|\cos\theta|<0.92$)
  - $\theta_{\gamma,charged}<10^o$.
- Vertex fit to impove the momentum resolution:
  - $\chi^2_{vertex}<100$.
- Veto e^+e^-:
  - Each charged track has an energy deposit in EMC;
  - $E/p<0.25$.
- Veto cosmic rays:
  - $\Delta T=|Tof(\mu^+)-Tof(\mu^-)|<0.5$
- Momentum window cut:
  - $|p_{\mu\pm}-p_{the}|<3\sigma$



Preliminary result

Energy (GeV)	Nevts	ϵ (%)	L (pb^{-1})	Cross section (nb)
3.0500	73731 ± 271.5	~ 57.7	$14.895 \pm 0.029 \pm 0.165$	$8.579 \pm 0.032 \pm 0.096$
3.0600	73092 ± 270.4	~ 57.7	$15.056 \pm 0.030 \pm 0.168$	$8.414 \pm 0.031 \pm 0.095$
3.0830	20777 ± 144.1	~ 57.7	$4.759 \pm 0.017 \pm 0.053$	$7.566 \pm 0.052 \pm 0.088$
3.0900	60878 ± 246.7	~ 57.7	$15.552 \pm 0.030 \pm 0.172$	$6.784 \pm 0.027 \pm 0.076$
3.0930	49262 ± 222.0	~ 57.7	$15.249 \pm 0.030 \pm 0.169$	$5.599 \pm 0.025 \pm 0.063$
3.0943	15493 ± 124.5	~ 57.7	$2.145 \pm 0.011 \pm 0.025$	$12.518 \pm 0.101 \pm 0.160$
3.0952	50952 ± 225.7	~ 57.7	$1.819 \pm 0.010 \pm 0.021$	$48.546 \pm 0.215 \pm 0.621$
3.0958	152043 ± 389.9	~ 57.7	$2.161 \pm 0.011 \pm 0.029$	$121.937 \pm 0.313 \pm 1.750$
3.0969	276861 ± 526.2	~ 57.7	$2.097 \pm 0.011 \pm 0.03$	$228.817 \pm 0.435 \pm 3.487$
3.0982	152109 ± 390.0	~ 57.7	$2.210 \pm 0.012 \pm 0.031$	$119.285 \pm 0.306 \pm 1.794$
3.0990	26110 ± 161.6	~ 57.7	$0.759 \pm 0.007 \pm 0.009$	$59.620 \pm 0.369 \pm 0.896$
3.1015	21293 ± 145.9	~ 57.7	$1.614 \pm 0.010 \pm 0.018$	$22.864 \pm 0.157 \pm 0.292$
3.1055	18767 ± 137.0	~ 57.7	$2.106 \pm 0.011 \pm 0.024$	$15.444 \pm 0.113 \pm 0.194$
3.1120	12765 ± 113.0	~ 57.7	$1.719 \pm 0.010 \pm 0.02$	$12.870 \pm 0.114 \pm 0.167$
3.1200	8261 ± 90.9	~ 57.7	$1.261 \pm 0.009 \pm 0.015$	$11.354 \pm 0.125 \pm 0.158$

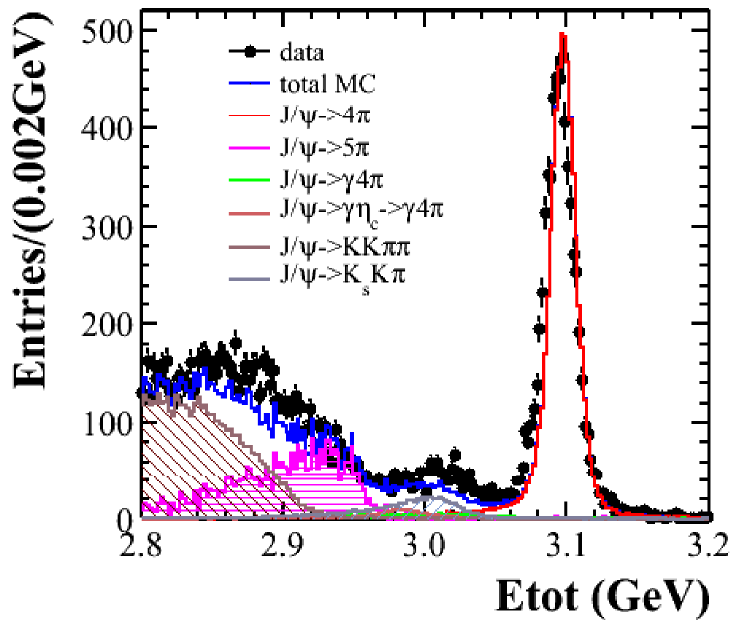




A dip just below J/ψ peak, which is consistent with $\phi=0^o$ case.

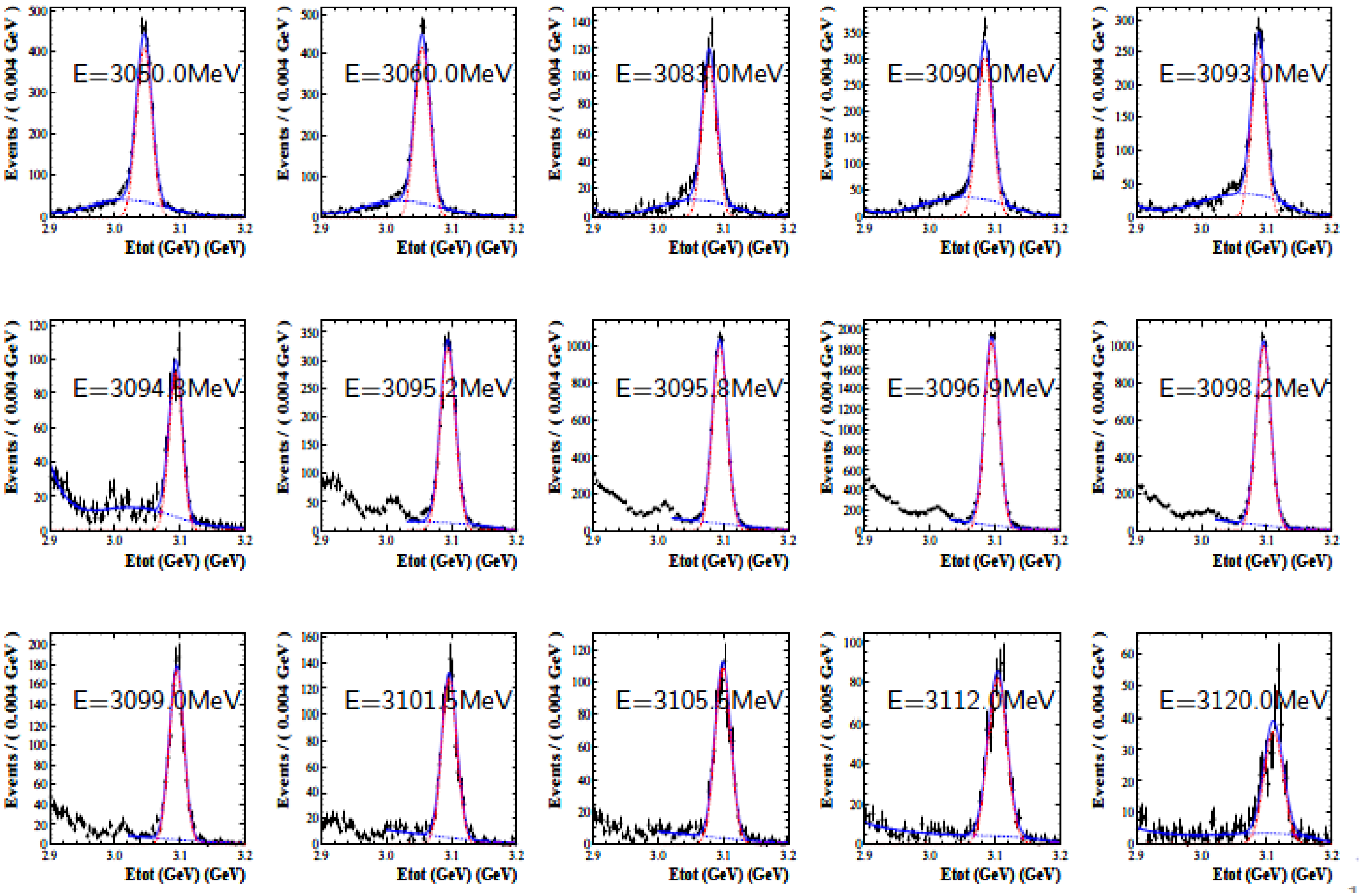
Analysis on $e^+e^- \rightarrow 2(\pi^+\pi^-)$

- 4 good charged tracks:
  - $|Rxy|<1cm$, $|Rz|<10cm$.
- Vertex fit to improve the momentum resolution.
- Veto bkg from γ-conversion ($2(e^+e^-)$):
  - All angles between π^+ and π^-, $10^o<\theta_{\pi+\pi-}<170^o$.
- Veto events which have multi-tracks:
  - Minimum angle between $(\pi^+\pi^-)$ pairs: $\theta(\pi^+\pi^-,\pi^+\pi^-)>170^o$.



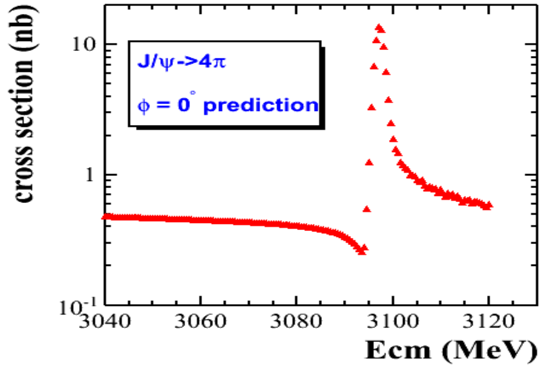
Distribution of total energy from J/ψ data.

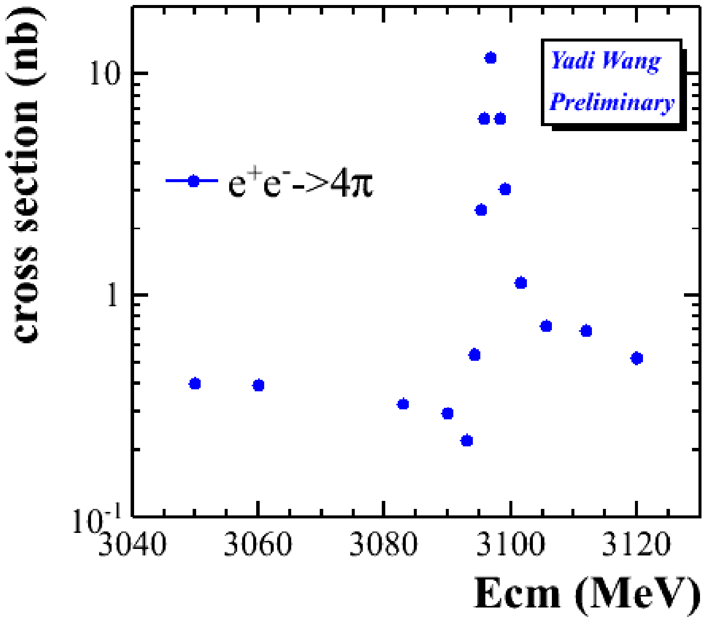
Preliminary result



Preliminary result

Energy (GeV)	Nevts	ϵ (%)	L (pb^{-1})	Cross section (nb)
3.0500	2984.2 ± 69.1	~ 50.1	$14.895 \pm 0.029 \pm 0.165$	$0.400 \pm 0.009 \pm 0.005$
3.0600	2988.2 ± 66.7	~ 50.1	$15.056 \pm 0.03 \pm 0.168$	$0.396 \pm 0.009 \pm 0.005$
3.0830	767.4 ± 36.6	~ 50.1	$4.759 \pm 0.017 \pm 0.053$	$0.322 \pm 0.015 \pm 0.004$
3.0900	2275.3 ± 59.9	~ 50.1	$15.552 \pm 0.03 \pm 0.172$	$0.292 \pm 0.008 \pm 0.003$
3.0930	1689.1 ± 56.9	~ 50.1	$15.249 \pm 0.03 \pm 0.169$	$0.221 \pm 0.007 \pm 0.002$
3.0943	583.5 ± 30.3	~ 50.1	$2.145 \pm 0.011 \pm 0.025$	$0.543 \pm 0.028 \pm 0.007$
3.0952	2250.0 ± 61.8	~ 50.1	$1.819 \pm 0.01 \pm 0.021$	$2.469 \pm 0.068 \pm 0.032$
3.0958	6793.2 ± 97.9	~ 50.1	$2.161 \pm 0.011 \pm 0.029$	$6.275 \pm 0.091 \pm 0.090$
3.0969	12356.6 ± 146.7	~ 50.1	$2.097 \pm 0.011 \pm 0.03$	$11.76 \pm 0.140 \pm 0.179$
3.0982	6964.0 ± 124.3	~ 50.1	$2.21 \pm 0.012 \pm 0.031$	$6.290 \pm 0.112 \pm 0.095$
3.0990	1153.1 ± 44.6	~ 50.1	$0.759 \pm 0.007 \pm 0.009$	$3.032 \pm 0.117 \pm 0.046$
3.1015	922.4 ± 36.1	~ 50.1	$1.614 \pm 0.01 \pm 0.018$	$1.141 \pm 0.045 \pm 0.015$
3.1055	770.4 ± 0.7	~ 50.1	$2.106 \pm 0.011 \pm 0.024$	$0.730 \pm 0.001 \pm 0.009$
3.1120	595.0 ± 28.8	~ 50.1	$1.719 \pm 0.01 \pm 0.02$	$0.691 \pm 0.033 \pm 0.009$
3.1200	327.8 ± 23.6	~ 50.1	$1.261 \pm 0.009 \pm 0.015$	$0.519 \pm 0.037 \pm 0.007$

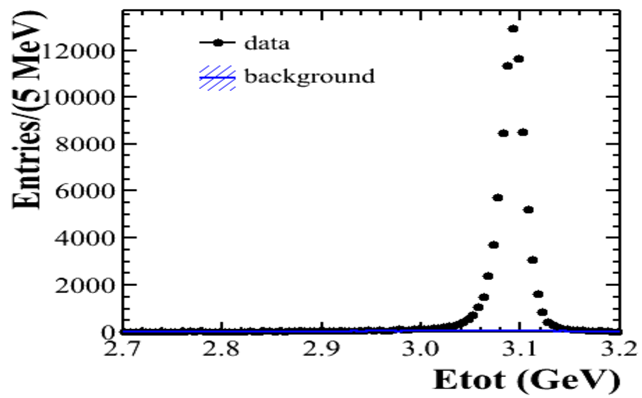




A dip just below J/ψ peak, which is consistent with φ=0° case.

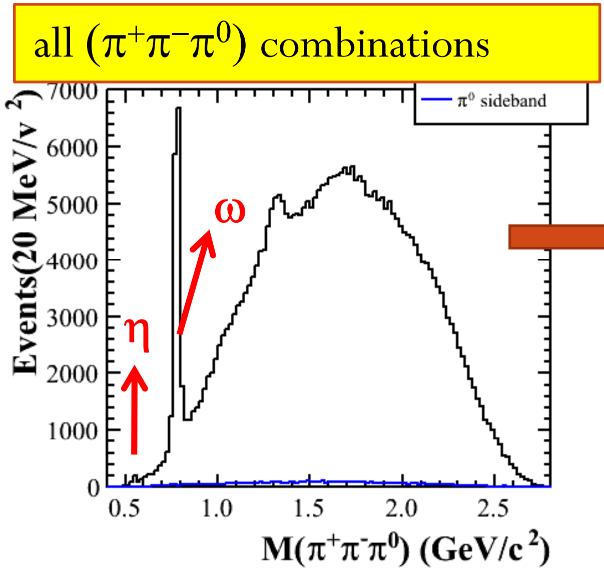
Analysis on $e^+e^- \rightarrow 2(\pi^+\pi^-)\pi^0$

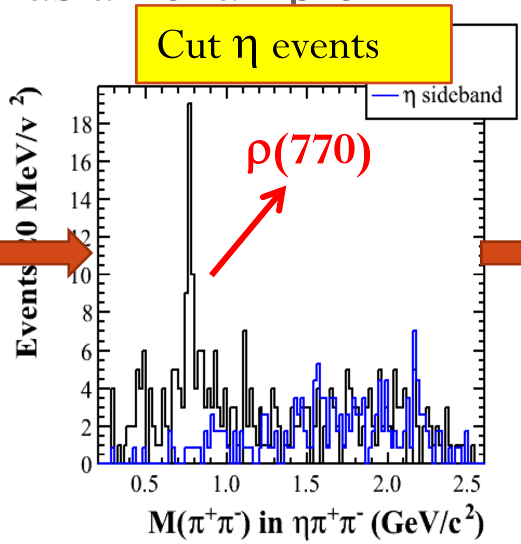
- 4 good charged tracks:
  - $|Rxy|<1cm$, $|Rz|<10cm$.
- At least 2 good neutral tracks in EMC:
  - $0<T<14$ (x50 ns);
  - $E_\gamma>25MeV$ ($|\cos\theta|<0.8$), $E_\gamma>50$ MeV ($0.86<|\cos\theta|<0.92$)
  - $\theta_{\gamma,charged}<10^o$.
- PID for each charged track:
  - $prob(\pi)>prob(K)$
- Vertex fit:
  - $\chi^2_{vertex}<100$.
- 3-C kinematic fit:
  - Loop all photons, choose the combination with the minimum $\chi^2_{3C}(<200)$.
- π^0 selection:
  - $|M(\gamma\gamma)-0.135|<0.02$ GeV/c2
  - $|\cos\theta(\pi^0)_{decay}| = \frac{|E_{\gamma1}-E_{\gamma2}|}{p_{\pi^0}} < 0.9$

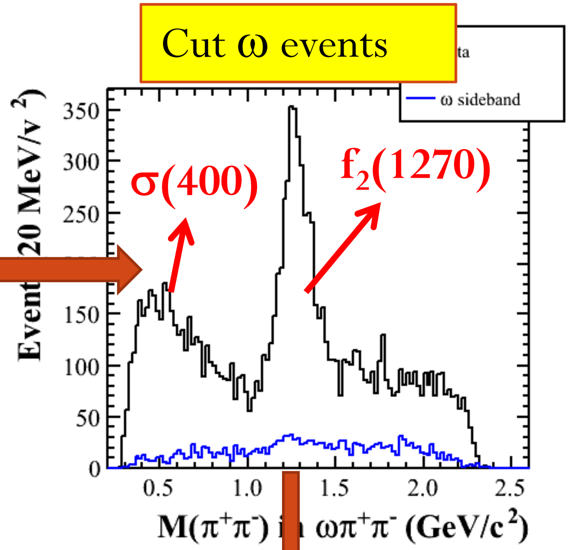


Multi-combinations in $2(\pi^+\pi^-)\pi^0$

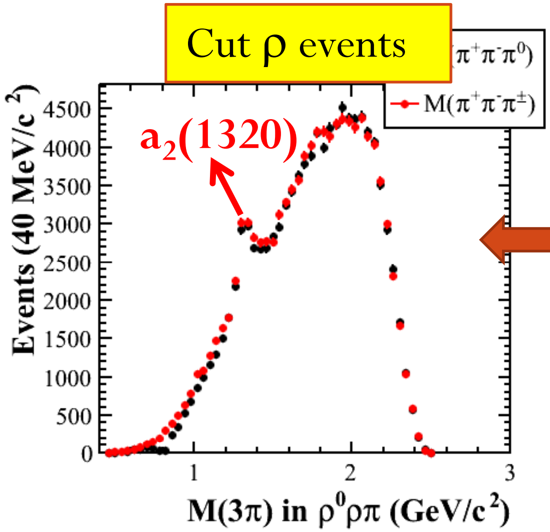
take data @ 3.0969GeV as an example

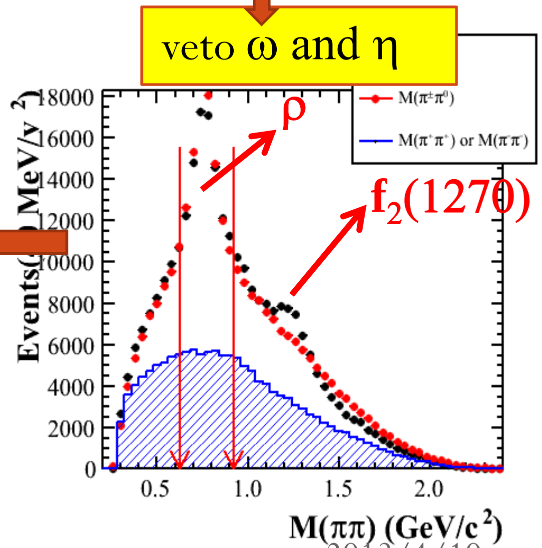






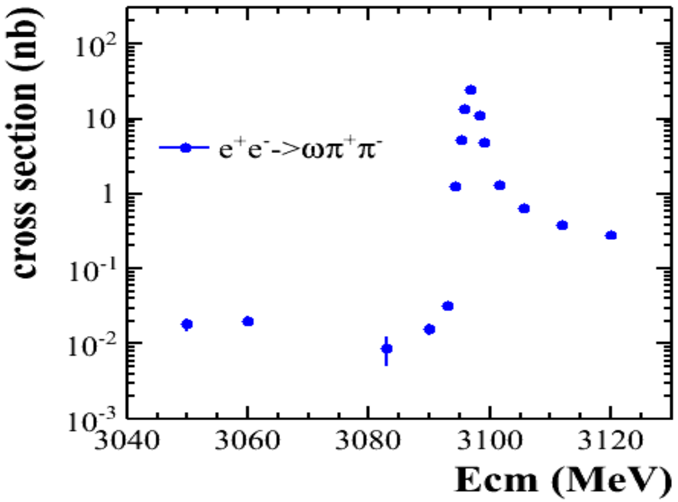
Possible intermediate processes:
$\omega\pi^+\pi^-$, $\omega\rightarrow\pi^+\pi^-\pi^0$;
$\eta\pi^+\pi^-$, $\eta\rightarrow\pi^+\pi^-\pi^0$
(G-parity violated);
$\rho^0\rho^\pm\pi^\pm$;
$\rho^\pm\pi^\pm f_2(1270)$.

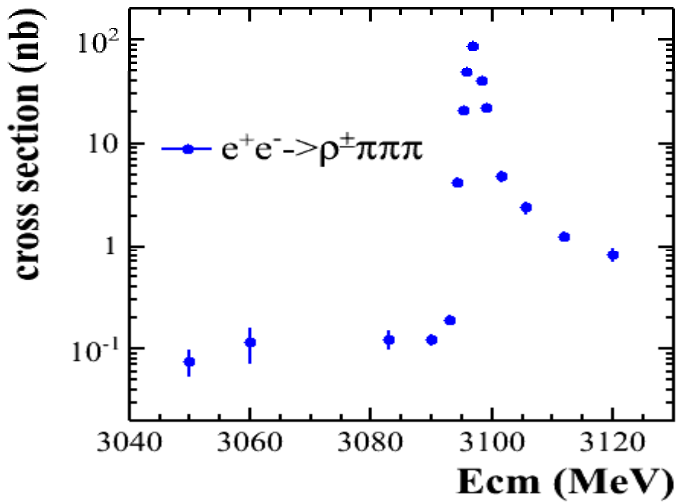


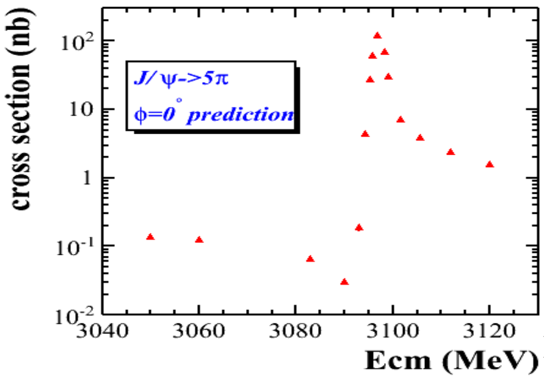


J/ψ lineshape from $\omega\pi^+\pi^-$ and $\rho^\pm$ events

The possible interference between intermediate resonances may affect the J/ψ lineshape.

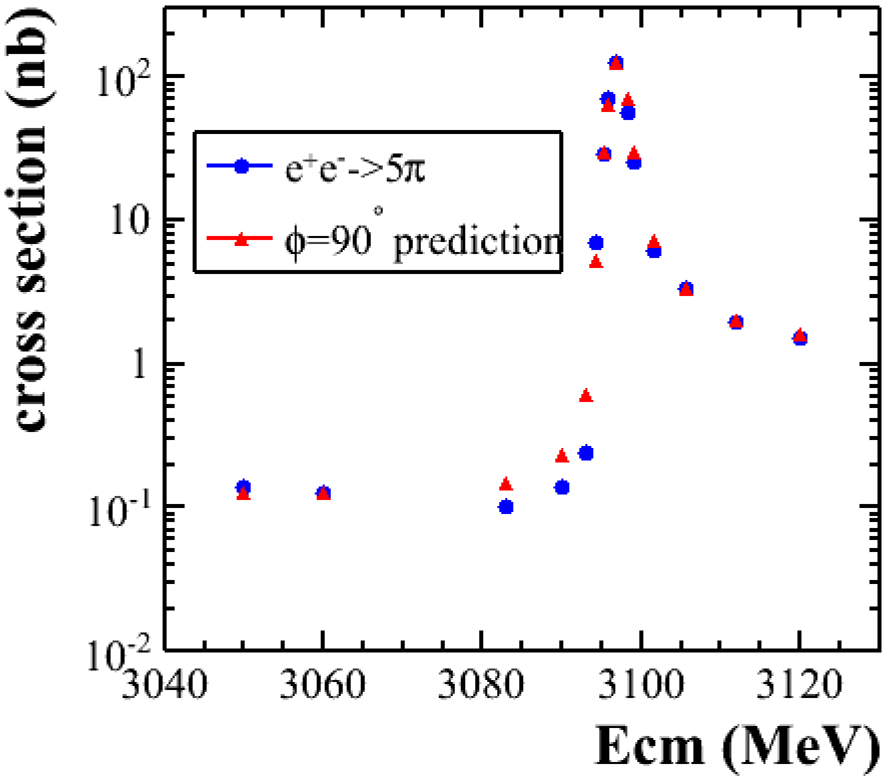


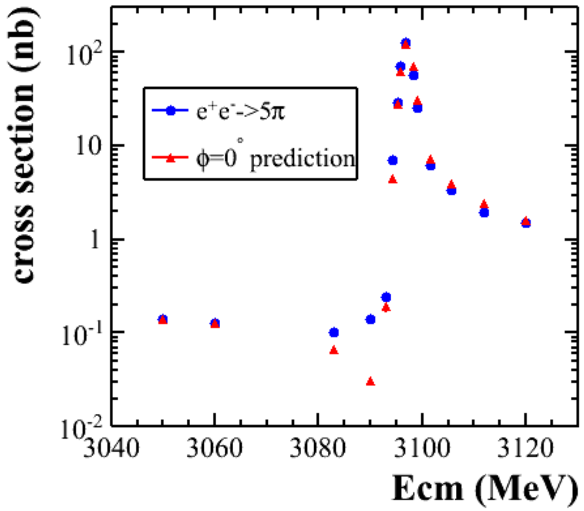


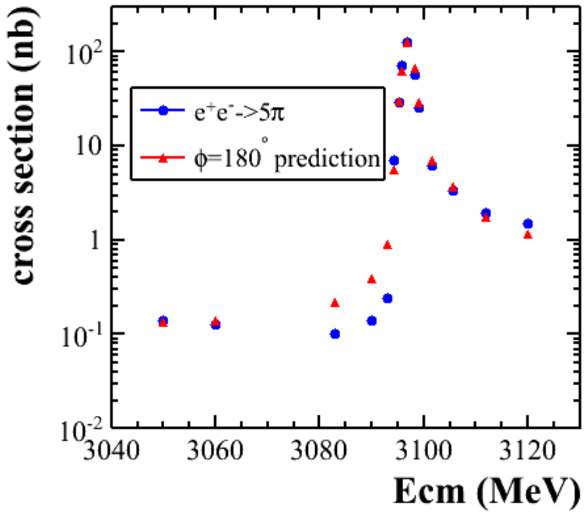


The behaviors of $\omega\pi^+\pi^-$ and $\rho^\pm$ events look similar. Neither of them is consistent with $\phi=0^o$ case.

J/ψ lineshape from $2(\pi^+\pi^-)\pi^0$ (veto $\eta\pi^+\pi^-$)



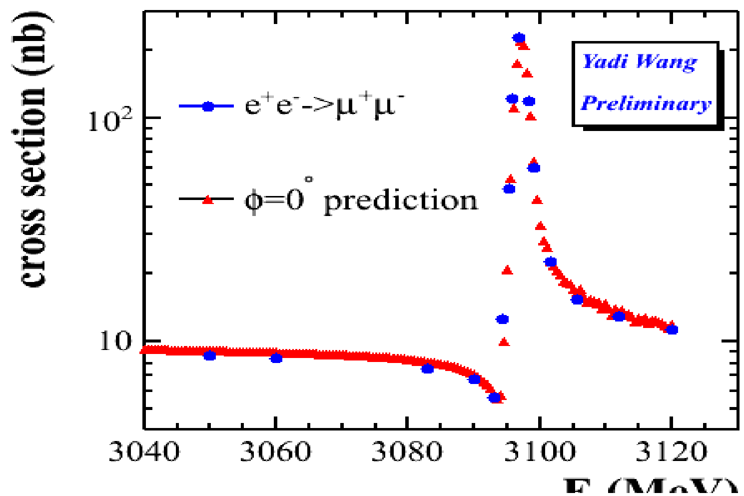


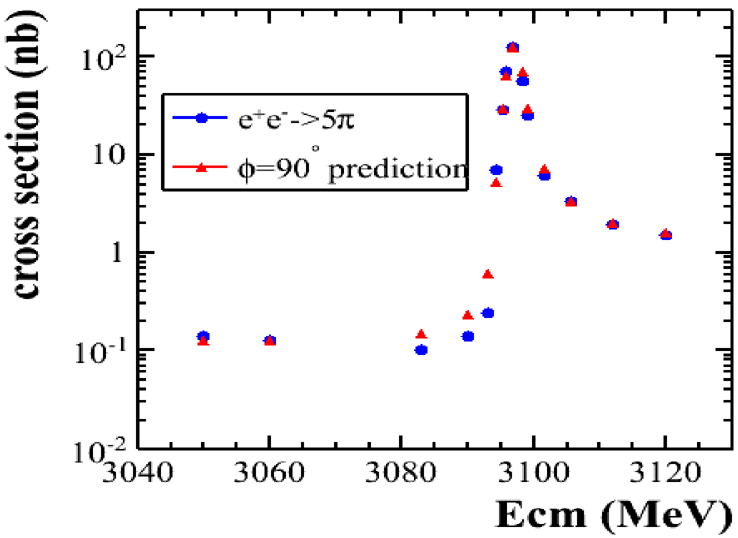


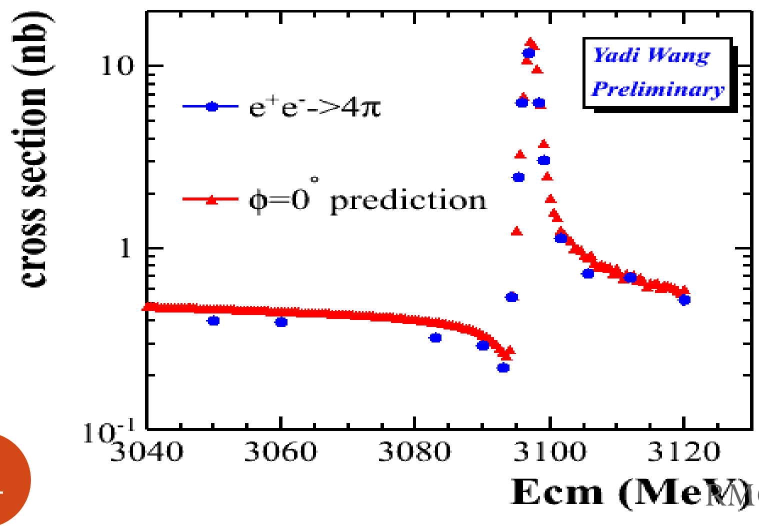
Different from $\mu^+\mu^-$ or $2(\pi^+\pi^-)$, the J/ψ lineshape is more consistent with $\phi=90^o$.

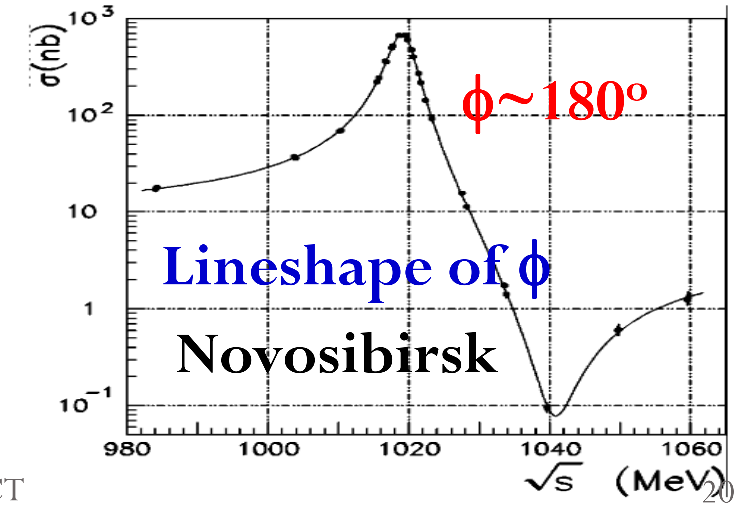
Summary of J/ψ lineshapes

Different lineshapes → A_{3g} is perpendicular to A_{EM}?









Next work

- More dedicate work on ISR;
- Precise evaluation of E_{cms} and of the correspondant uncertainties;
- Systematic errors studies;
- Fitting on the lineshapes to get the phase angle.
- Better understanding of the phase angle.
- More channels, i.e., $e^+e^- \rightarrow$ ppbar(under work by Marco Destefanis)/nnbar/6π

Thanks !