Special needs from flavor factories on MC

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Outline

Special needs on the MC for flavor factories

Exclusive process

MC in case of interference

Summary

Introduction

Current flavor factories, like SLAC and KEK B-factory, as well as BEPC-II/BES-III, accumulate large number of events. It requires high precision Monte Carlo simulation. Not only higher order of radiative corrections must be included, there are also some special needs.

In my work in BaBar, BELLE and BES experiments on the radiative corrections and related Monte Carlo simulation, I feel particularly hard pressed by two aspects:

- Add more exclusive final states into the MC programs
- Simulation in case of interference between resonance and non-resonance continuum

In the measurement of exclusive modes, both from ISR process, on top of the resonance and off-resonance continuum, MC simulation with higher order radiative corrections are needed.

The MC programs, like KKMC (for inclusive measurement), PHOKHARA (for ISR), BABAYAGA and MCGPJ (both for on top of the resonance and off-resonance continuum) come at the right time.

KKMC has been used by both BaBar and BELLE for inclusive hadronic states as well as $\mu^+\mu^-$ and $\tau^+\tau^-$. It will be used in BES-III.

PHOKHARA has been used by BaBar and BELLE sucessfully for their ISR analysis and publications.

For the exclusive processes, it is impossible for the authors of the original programs to include all possible exclusive final states into the programs. There will be too many of them. It is difficult to foresee which final states will draw the physics interests in the near future.

From the experiment point of view, it is desirable to have the programs which provide a frame, extra final states can be easily added into the programs.

As a matter of fact, BaBar has used PHOKHARA besides the original 9 final states in their published works. BELLE will do so too.

In general, PHOKHARA is written in a way that extra final states can be added easily. The authors of MCGPJ (by a Novosibirsk group) also try to achieve this goal. We hope BABAYAGA can be written this way too.

It is desirable that the programs leave the the hadronic tensor and hadronic current into a seperate subprogram. For example, in PHOKHARA, we hope both one-photon and two-photon emission call the same subprograms for hadronic tensors. Or call the same subprograms for hadronic current. It is preferable to have both the options: write the hadronic tensor or hadronic current. Since for final states involving fermions or vector mesons, it is more convenient to sum over the polarization, so the hadronic tensor is derived.

For many, if not most of the final states, the coupling of the hadronic current to the virtual photon is not well known to our present theoretical knowledge.

In the actual experiments, one needs to try different couplings, or more often, different combinations of couplings and compare the Monte Carlo with the experimental data, to yield the best simulation.

An example is the process

$$e^+e^- \to \gamma\gamma J/\psi\pi^+\pi^-$$

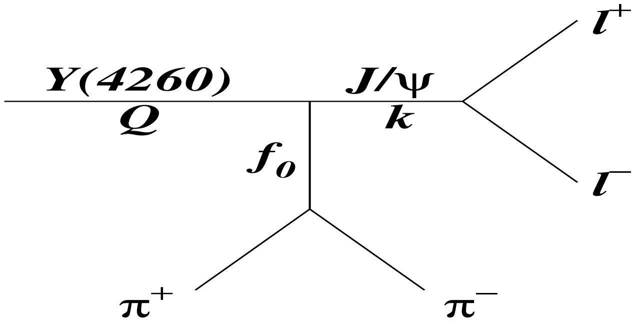
On B factories, this process is to measure the braching fractions of many charmonium states to $\pi^+\pi^- J/\psi$ by ISR process. These branching fractions are predicted by potential model.

It is also the final state in which Y(4260) has been found.

In this process, we either need to output the polarization of J/ψ, or alternatively, (and better off) we may write J/ψ to $\mu^+\mu^-$ and e^+e^- into the program, since experiments usually tag J/ψ by their decays into $\mu^+\mu^-$ and e^+e^-.

In some experiments, like BELLE and BES, the simulation software has no place for the polarization of the vector mesons. To get better simulation, one needs to write their decays explicitly into the Monte Carlo.

From data, it indicates that the $\pi^+\pi^-$ are in S wave. As a first order of approximation, we may consider the coupling of virtual photon to $\pi^+\pi^- J/\psi$ and then $J/\psi \to \mu^+\mu^-$ as



$$\langle \pi^+\pi^-\mu^+\mu^-|H^\mu|0\rangle \sim T(Q^2)(g^{\mu\nu} - \frac{Q^\mu Q^\nu}{Q^2})T(k^2)\Gamma^\nu(J/\psi \to \mu^+\mu^-) \quad (1$$

In this final state, there are both mesons and fermions. How do we implement it in PHOKHARA?

Similarly, how do we simulate $\psi(nS) \to \pi^+\pi^- J/\psi$ and $\Upsilon(nS) \to \pi^+\pi^-\Upsilon(1S)$ by BABAYAGA or MCGPJ?

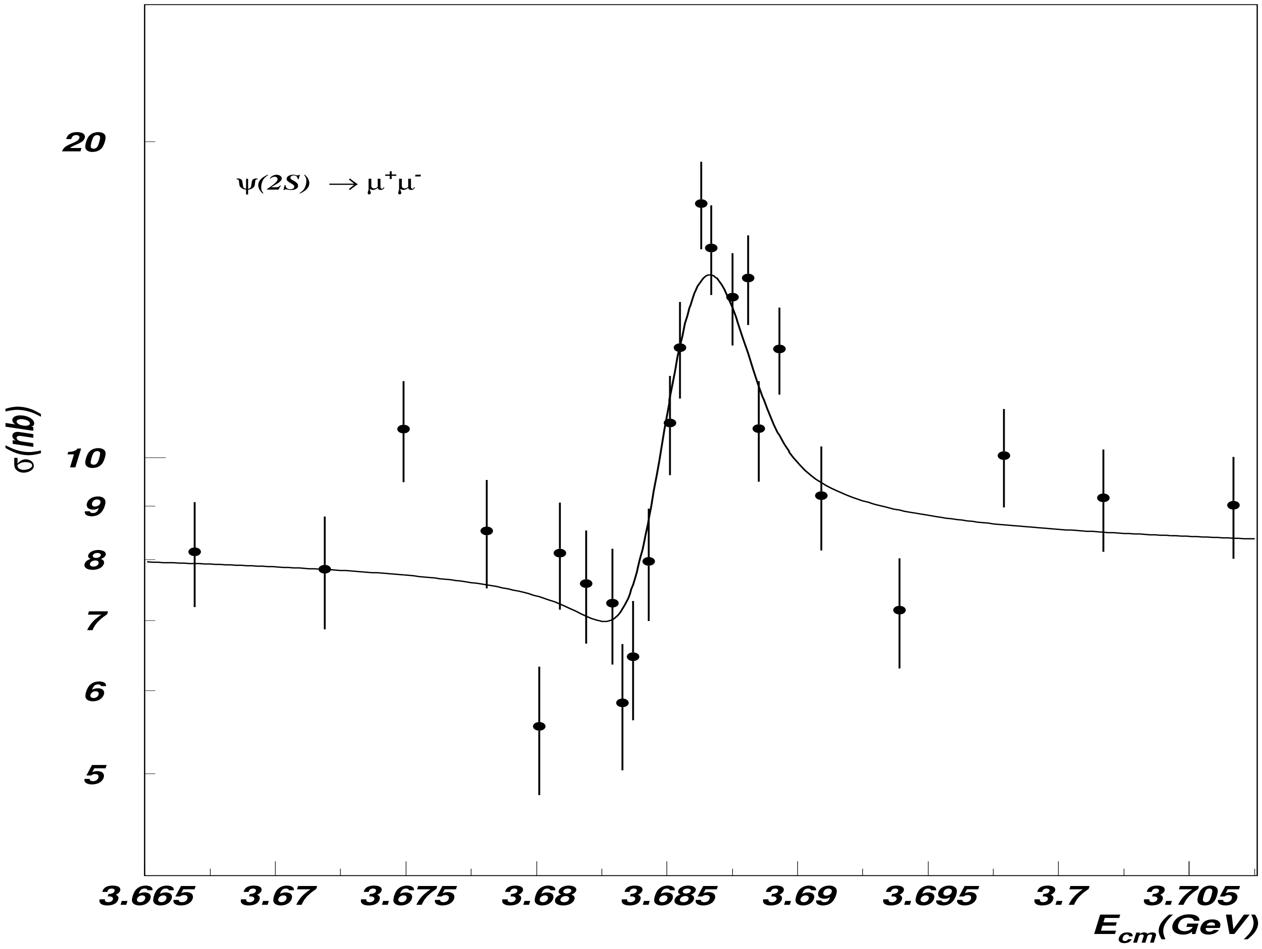
Simulation in case of inteference

Another important need from experiments is the simulation in case of significant interference between resonance and non-resonance continuum amplitudes.

Both τ/charm and B factories are e^+e^- colliders. In these experiments, besides resonances, there are non-resonance continuum amplitude which may have significant contribution.

Simulation in case of inteference

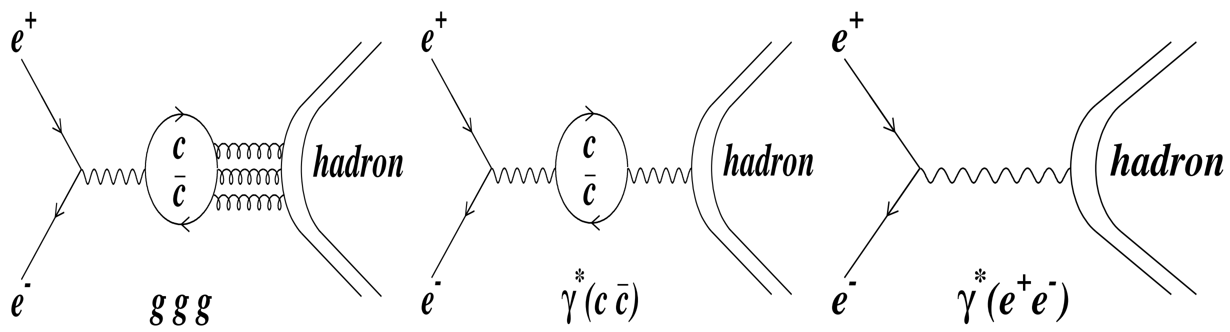
The contribution of non-resonance continuum amplitude can be seen from the scanned curve of $\mu^+\mu^-$ around ψ' resonance.



Digression to physics

In the charmonium decays, there are both strong and EM interactions.

Together with the non-resonace continuum amplitude, there are three diagrams which contribute.



Digression to physics

It has been known that in J/ψ decays, the three gluon amplitude a_{3g} and one-photon amplitude a_γ are orthogonal for

- 1^+0^- 90° M. Suzuki, Phys. Rev. **D63**, 054021 (2001)
- 1^-0^- $(106 \pm 10)^\circ$ J. Jousset *et al.*, Phys. Rev. **D41**, 1389 (1990); D. Coffman *et al.*, Phys. Rev. **D38**, 2695 (1988); J. Jousset *et al.*, *Phys. Rev.* D **41**, 1389 (1990); A. Bramon, R. Escribano and M. D. Scadron, *Phys. Lett.* B **403**, 339 (1997); M. Suzuki, *Phys. Rev.* D **58**, 111504 (1998); N.N.Achasov, Talk at Hadron2001; G. López Castro *et al.*, in CAM-94, Cancum, Mexico.
- 1^-1^- $(138 \pm 37)^\circ$ L. Köpke and N. Wermes, Phys. Rep. **174**, 67 (1989).
- 0^-0^- $(89.6 \pm 9.9)^\circ$ M. Suzuki, Phys. Rev. **D60**, 051501(1999); G. López Castro *et al.*, ibid; L. Köpke and N. Wermes, ibid.
- $N\overline{N}$ $(89 \pm 15)^\circ$ R. Baldini, *et al.* Phys. Lett.**B444**, 111 (1998); G. López Castro *et al.*, ibid.

Digression to physics

Mahiko Suzuki summarized the experimental situation of the two-boday J/ψ decays. Phys. Rev. **D63**, 054021(2001) The existing data strongly favor large relative phase close to 90° between the gluon and the photon decay amplitudes for 1^-0^-, 0^-0^-, 1^-1^- and $N\overline{N}$, and are consistent with a large phase for 1^+0^-.

He then reached the conclusion:

The relative phase between the gluon and the photon decay amplitudes are universally large for all two-body decays of J/ψ.

Digression to physics

Based on the analysis of experimental data from BES, we have found that this orthogonality holds in ψ' and ψ'' decays too and we know the sign is negative, i.e. $-90°$.

P. Wang, C. Z. Yuan, X. H. Mo, Phys. Rev. **D** 69; 057502 (2004);

P. Wang, C. Z. Yuan, X. H. Mo, Phys. Lett. **B** 567; 73 (2003);

P. Wang, C. Z. Yuan, X. H. Mo, Phys. Lett. **B** 574; 41 (2004)

This conclusion has been supported by more recent measurements by CLEO on $\psi' \to 0^-0^-$ and $\psi'' \to 1^-0^-$ decays.

(CLEO collaboration, S.Dobbs et al, hep-ex/0603020;

CLEO collaboration, G.S.adams et al, Phys.Rev.D73:012002,2006.)

This universality of the phase is likely to be true for the decays of all charmonium (quarkonium) 1^{--} states.

Digression to physics

If the continuum amplitude is parametrized as $\frac{1}{s}$ which is real, then the EM decay amplitude can be parametrized as $\frac{B(s)}{s}$, with

$$B(s) \equiv \frac{3\sqrt{s}\Gamma_{ee}/\alpha}{s - M^2 + iM\Gamma_t}.$$

On top of the resonance, $B(s) = -i3B_{ee}/\alpha$ with phase of -90°.

If the phase between strong and EM amplitudes is -90°, then the relative phase between strong and non-resonance continuum amplitudes is either 180° or 0°, depending on the extra minus sign from the charges of the constituent quarks.

ψ' decays

For example, in $\psi' \to 1^-0^-$ decays, we have

H. E. Haber and J. Perrier, Phys. Rev. **D32**, 2961 (1985)

$$\begin{aligned} A_{\omega\pi^0} &= 3(a_\gamma + a_c) \quad , \\ A_{\rho\pi} &= a_{3g} + a_\gamma + a_c \quad , \\ A_{K^{*+}K^-} &= a_{3g} + \epsilon + a_\gamma + a_c \quad , \\ A_{K^{*0}\overline{K^0}} &= a_{3g} + \epsilon - 2(a_\gamma + a_c) \quad . \end{aligned}$$

Here a_{3g}, a_γ and a_c are amplitudes due to strong, EM and non-resonance continuum; ϵ is a SU(3) breaking parameter.

So the relative phase between strong and non-resonance continuum amplitudes is 180° for $\rho\pi$ and $K^{*+}K^-$, but 0° for $K^{*0}\overline{K^0}$.

Simulation in case of inteference

Destructive interference between resonance and continuum means that the observed cross section at the resonance can be smaller than the off resonance cross section measured at nearby energy and scaled for s dependence. The experimental results on ψ'' demonstrate this interference pattern.

CLEO reported the measured cross sections of many final states at 3.67GeV and ψ'' peak. CLEO collaboration, G.S.adams et al, Phys.Rev.D73:012002,2006

Simulation in case of inteference

Channel	σ(3.67 GeV) [pb]	σ(3.77 GeV) [pb]
	VP	
$\rho^+\pi^-,\ \rho^-\pi^0,\ \rho^-\pi^+$	$8.0^{+1.7}_{-1.4} \pm 0.9$	$4.4 \pm 0.3 \pm 0.5$
$\omega\pi^0$	$15.2^{+2.8}_{-2.4} \pm 1.5$	$14.6 \pm 0.6 \pm 1.5$
$\phi\pi^0$	< 2.2	< 0.2
$\rho\eta$	$10.0^{+2.2}_{-1.9} \pm 1.0$	$10.3 \pm 0.5 \pm 1.0$
$\omega\eta$	$2.3^{+1.8}_{-1.1} \pm 0.5$	$0.4^{+0.2}_{-0.2} \pm 0.1$
$\phi\eta$	$2.1^{+1.9}_{-1.2} \pm 0.2$	$4.5 \pm 0.5 \pm 0.5$
$\rho\eta'$	$2.1^{+4.7}_{-1.6} \pm 0.2$	$3.8^{+0.9}_{-0.8} \pm 0.4$
$\omega\eta'$	< 17.1	$0.6^{+0.8}_{-0.3} \pm 0.6$
$\phi\eta'$	< 12.6	$2.5^{+1.5}_{-1.1} \pm 0.4$
$K^{*0}\overline{K^0},\ \overline{K}^{*0}K^0$	$23.5^{+4.6}_{-3.9} \pm 3.1$	$23.5 \pm 1.1 \pm 3.1$
$K^{*+}K^-,\ K^{*-}K^+$	$1.0^{+1.1}_{-0.7} \pm 1.8$	< 0.6
	AP	
$b_1\pi$	$7.9^{+3.1}_{-2.5} \pm 1.8$	$6.3 \pm 0.7 \pm 1.5$

ψ'' data

Among these channels, $\omega\pi^0$, $\rho\eta$, $\rho\eta'$ and $\pi^+\pi^-$ go only via electromagnetic interaction and the a_γ can be neglected For ψ''. But for other final states which have contributions from both strong and electromagnetic interactions, there could be interference between a_{3g} and a_c as well as between a_{3g} and a_γ. Since for the ψ'', a_γ is very small compared to a_c, so only the interference between a_{3g} and a_c could be important. Based on the analysis of the experimental data, we have suggested that the phase θ_g is universally -90° in quarkonium decays.

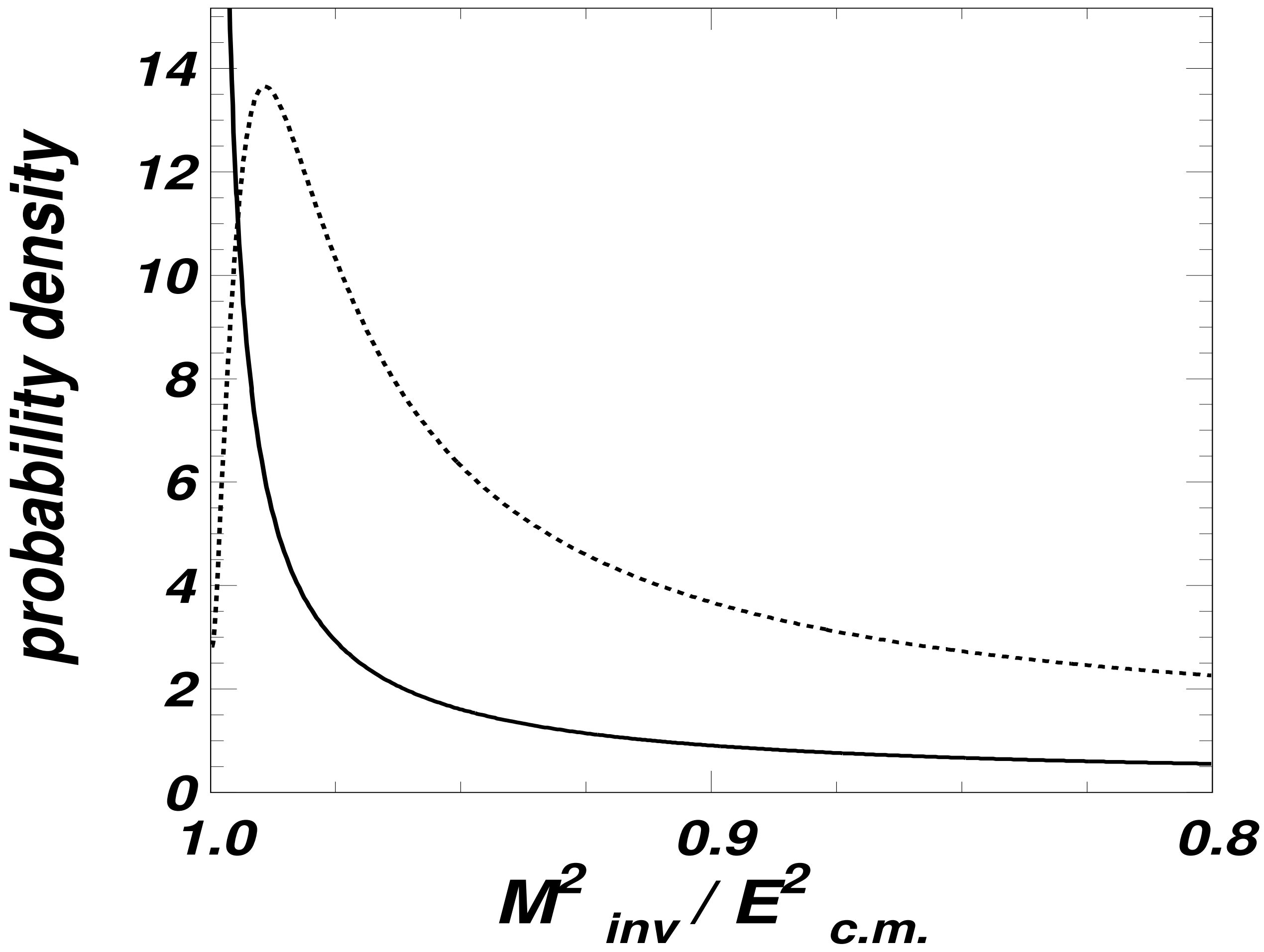
The relative phase between a_{3g} and a_c is either 180° or 0°, depending on whether the relative sign between g and e is plus or minus. The interference between a_{3g} and a_c is destructive for the final states $\rho\pi$, $\omega\eta$, $\omega\eta'$, $K^{*+}K^- + c.c.$, $b_1\pi$, and K^+K^-, but constructive for $\phi\eta$, $\phi\eta'$, and $K^{*0}\overline{K^0} + c.c.$

Simulation in case of inteference

The problem is: in the measurement of these final states, how do we simulate them by BABAYAGA and MCGPJ?

BABAYAGA and MCGPJ are written for off-resonace. If there is significant interference between resonance and non-resonance continuum, the distribution of invariant mass of the final state hadrons is changed, particularly such change is dramatic by destructive interference.

Simulation in case of inteference



Simulation in case of inteference

In BABAYAGA and MCGPJ, it is desirable to have a subprogram in which the distribution of the invariant mass of final state hadrons can be coded.

Similar needs is in the simulation of data scanned across a resonance.