Studies of the relative phase between strong and electromagnetic decay amplitudes of psi(2S)

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Charmonium weekly meeting, Apr. 10
Outline

• Introduction

• MC generator

• Data vs MC

• Results
Introduction

LONG TIME AGO, IN A GALAXY FAR, FAR AWAY...
Relative phase of charmonia

Hadronic cross section around charmonia can be described with three diagrams

Experimental and theoretical agreement around EM contributions

Still questions around the strong ($A_{3g}$) amplitude:
- pQCD predicts almost real
- experiments have different results for $J/\psi$, pointing towards 90° relative phase
An additional motivation

From the experimental point of view, based on SU(3)$_F$ and isospin breaking violation models:

- At $J/\psi$
  - VP ($1^-$0$^-$) (e.g. $J/\psi \rightarrow \rho\pi$) phase = $106^\circ \pm 10^\circ$
  - PP (0$^-$0$^-$) (e.g. $J/\psi \rightarrow \pi\pi$) phase = $89.6^\circ \pm 9.9^\circ$
  - BB ($\frac{1}{2}$ $\frac{1}{2}$) (e.g. $J/\psi \rightarrow p\bar{p}$) phase = $89^\circ \pm 8^\circ$

- At $\psi(2S)$
  - VP (1$^-$0$^-$) phase = $159^\circ \pm 12^\circ$
  - PP (0$^-$0$^-$) phase = $95^\circ \pm 11^\circ$

Experiments points towards a non univocal phase for $\psi(2S)$ (but highly model dependent)
An additional motivation

From the experimental point of view, based on SU(3)$_F$ and isospin breaking violation models:

- At J/$\psi$
  - VP (1·0$^-$) (e.g. J/$\psi$ → $\rho\pi$) phase = 106° ± 10°
  - PP (0·0$^-$) (e.g. J/$\psi$ → $\pi\pi$) phase = 89.6° ± 9.9°
  - BB (½ ½) (e.g. J/$\psi$ → $p\bar{p}$) phase = 89° ± 8°

- At $\psi$(2S)
  - VP (1·0$^-$) phase = 159° ± 12°
  - PP (0·0$^-$) phase = 95° ± 11°

Possible explanation of $\rho\pi$ puzzle?

Experiments points towards a non univocal phase for $\psi$(2S) (but highly model dependent)
An(other) motivation

At Changsha workshop Rinaldo presented a model to explain the value of the relative phase in charmonium.

The Sounds of Silence
An attempt to explain the anomalous $J/\psi$ strong decay phase $\delta$

An(other) motivation

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An(other) motivation

At Changsha workshop, Rinaldo presented a model to explain the value of the relative phase in charmonium

This set of analysis can test this model.

| \( Q\bar{Q} \text{bar} \) | \(|\delta(M)|_{\text{exp}}\) | \( \mu^2 \approx \Lambda^2 \) | \( \mu^2 \approx M_{\Phi}^2 \) |
|-----------------|-----------------|-----------------|-----------------|
| \( \Phi \)      | \( 163 \pm 7 \degree \delta \) | -170.           | -170.           |
| \( J/\psi \)    | \( 85 \pm 4 \degree \)         | -66.            | -84.            |
| \( \psi(3686) \) | (?)                           | -61.            | -81.            |
| \( \Upsilon(1S) \) | \( \sim 64 \degree \)       | -44.            | -68.            |
Status of J/psi analyses

Several analyses are on-going:

- Yadi Wang’s $\mu^{+}\mu^{-}$ and $5\pi$ study has been published
- Marco Destefanis $p\bar{p}$ study is in Memo stage, ready for a newer version of the memo: results are consistent with other BESIII measurements
- Francesca De Mori $K^{+}K^{-}$ study is finalizing the memo after finding consistent results in $\psi(2S) \rightarrow \pi^{+}\pi^{-}$ J/psi $\rightarrow \pi^{+}\pi^{-}$ $K^{+}K^{-}$ study of the branching ratio
- I started once $\Lambda\bar{\Lambda}$ analysis, it can be helpful to verify if some differences arise when hyperon are considered (but very little effort)
Which channels?

- Plan to measure the relative phase in the largest number of channels possible to extract the relative phase in a “inclusive approach”
  - Unfortunately, our possibility are very limited by time and manpower constraints
- Golden channel:
  - $\pi\pi J/\psi$
  - $\rho\pi$
  - $\mu\mu$
  - $p\bar{p}$
  - $K^*K^0$
Phase in $\tau^+\tau^-$?

It is also possible to use the $\tau$ mass selection to extract the phase in another pure EM decay

Profit of the experience of the Chinese and Russian colleagues
Final tables of runs

Thanks to Zhang Jianyong and BEMS, precise measurements of the beam energies are available.

<table>
<thead>
<tr>
<th>Requested Energy (MeV)</th>
<th>Requested Luminosity (nb⁻¹)</th>
<th>Run number</th>
<th>Energy (MeV)</th>
<th>Spread (MeV)</th>
<th>Luminosity (nb⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3580</td>
<td>85</td>
<td>55375-55461</td>
<td>3581.543 ± 0.060</td>
<td>1.493 ± 0.060</td>
<td>85665.6</td>
</tr>
<tr>
<td>3670</td>
<td>85</td>
<td>55462-55541</td>
<td>3670.158 ± 0.063</td>
<td>1.410 ± 0.053</td>
<td>84719.7</td>
</tr>
<tr>
<td>3681</td>
<td>85</td>
<td>55542-55635</td>
<td>3680.144 ± 0.061</td>
<td>1.517 ± 0.060</td>
<td>84814.5</td>
</tr>
<tr>
<td>3683</td>
<td>55</td>
<td>55636-55662</td>
<td>3682.752 ± 0.115</td>
<td>1.710 ± 0.104</td>
<td>28668.3</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>55663-55690</td>
<td>3684.224 ± 0.119</td>
<td>1.547 ± 0.122</td>
<td>28651.6</td>
</tr>
<tr>
<td>3685.5</td>
<td>25</td>
<td>55691-55716</td>
<td>3685.264 ± 0.105</td>
<td>1.478 ± 0.114</td>
<td>25982.8</td>
</tr>
<tr>
<td>3686.6</td>
<td>25</td>
<td>55717-55737</td>
<td>3686.496 ± 0.120</td>
<td>1.594 ± 0.117</td>
<td>25055.1</td>
</tr>
<tr>
<td>3690</td>
<td>70</td>
<td>55738-55795</td>
<td>3691.363 ± 0.075</td>
<td>1.541 ± 0.074</td>
<td>69374.6</td>
</tr>
<tr>
<td>3710</td>
<td>70</td>
<td>55796-55859</td>
<td>3709.755 ± 0.074</td>
<td>1.460 ± 0.075</td>
<td>70326.7</td>
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</table>

Reconstructed data:
/bes3fs/offline/data/704-1/psipscan1805/dst

All data also available in Torino servers
/media/bespanda/dati_bes/dati_scan/phasepsipscan/
/home_bes009/mdestefa/lists/psip_phase
MC generators
J/ψ case

- For J/ψ we can use Babayaga, a permille level ISR generator
- We have applied some modifications both on Babayaga and BOSS
  - It was quite a long process
  - But we are successful
- Slow generation of ISR once
- Fast fitting routine
  - available in fortran and C++, results are compatible
BESIII generator

- KKMC + BesEvtGen
- ConExc
- Babayaga
- Phokhara
- Etim
BESIII generator

- KKMC + BesEvtGen
- ConExc
- Babayaga
- Phokhara
- Etim

Cannot reproduce all the interesting final states
Etim

• Created by Rinaldo

• Advantage:
  – We know exactly what is inside (if you can read fortran)
  – We have already tested at J/psi that the prediction are in good agreement

• Main disadvantage:
  – It is custom, not official, need lot of counterchecks from the review!
ConExc

• Extract the ISR contribution from an iterative study of the lineshape of the cross section:
  - Start with flat lineshape
  - Iterate until variation of the i-1th and ith step is below a certain threshold (0.1 %), that is assumed also as systematic error

• It can be quite time-demanding
• But has all the final states already included

• Ping RongGang is always very willing to help
  - I haven't directly spoken with him about this yet

谢谢！
KKMC + BesEvtGen

• Advantage: it is official

• A recent version allow to save the information for the ISR/FSR generation, set the maximum ISR energy
  – We need: weight + energy after ISR
  – Then we can repeat the same procedure as for Babayaga!

• Unfortunately it seems to work only around Y(4220)
  – I have spoken with Sun Zhentian in Changsha, he is very willing to collaborate!

谢谢！
In the meantime, we shall start to generate some events to perform data quality validation, first cuts.

How to proceed? As suggested to me long-ago by:

- Copy KKMC in the working area
- Modify the share files by setting the mass of psi(2S) to the central value of the energy considered
- Modify the decay card accordingly
- Add "GenerateJpsi = true" option in the jobOptions of the simulation
#include "SOFFLINEEVENTLOOPMGRROOT/share/OfflineEventLoopMgr_option.txt"

//**************job options for generator (KKMC)**************
#include "KKMCROOT/share/jobOptions_KKMC_3681.txt"

KKMC.CMSEnergy = 3.680144;
KKMC.BeamEnergySpread = 0.601517;
KKMC.NumberOfEventsPrinted = 1;
KKMC.GeneratePsiL = true;
KKMC.GeneratePsiLPrime = true;
KKMC.ThresholdCut = 3.37684;
KKMC.TagISR = 1;
KKMC.HVPS = 1;
//KKMC.ModeIndexExpXS = -2;

//**************job options for EvtGen**************
#include "SBESEVTGENROOT/share/BesEvtGen.txt"

evtDecay.userDecayTableName = "pipipilpsi.dec";

KKMC.ResParameterRh3 = [1.720e6, 250e-3, 0.0e-6];
// Omega(783)
KKMC.ResParameterOmega = [0.78265e0, 8.39e-3, 0.0e-6];
// Omega(1419) --&gt; omega'
KKMC.ResParameterOmega2 = [1.419e0, 174e-3, 0.00e-6];
// Omega(1649) --&gt; omega''
KKMC.ResParameterOmega3 = [1.649e0, 220e-3, 0.00e-6];
// Phi(1020)
KKMC.ResParameterPhi1 = [1.01942e0, 4.46e-3, 1.33e-6];
// Phi(1680) --&gt; Phi'
KKMC.ResParameterPhi2 = [1.680e0, 150e-3, 0.00e-6];
// J/Psi(3097)
KKMC.ResParameterPsi1 = [3.09916e0, 0.8929e-3, 5.55e-6];
// Psi(3686)
KKMC.ResParameterPsi2 = [3.680144e0, 0.304e-3, 2.35e-6];
// Psi(3770)
KKMC.ResParameterPsi3 = [3.77315e0, 27.2e-3, 0.262e-6];
These are the events you are searching for:

\[ e^+e^- \rightarrow \pi\pi J/\psi \]
\[ J/\psi \rightarrow e^+e^- \]
MC and BOSS version

- BOSS version: 7.0.4
- 20000 events for each energy value to estimate the efficiency and extract the event selection
  - Both real energy and spread are used in the simulation

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- Selection based on PipiJpsialg on BOSS repository:
  - We will move to our algorithm soon
Data – MC comparison @ 3681 MeV

Lepton momentum in the J/psi center of mass
Data – MC comparison @ 3681 MeV

$\rho_e$

$\rho_{\pi}$
Preliminary efficiencies

Fit to the $\pi\pi$ recoil mass

Energies before/on the peak

Energies above the peak

Voigtian distribution +
First order Chebychev

More complicated pattern
due to ISR return
Energy above the peak – ISR effect

ISR contribution shifts the peak of about the same difference between the center of mass energy and the nominal peak of $\psi(2S)$
Real data – Fit @ 3681 MeV

N_{sig} = 5.6e+3 + 0.1e3
N_{bkg} = 1.3e+3 + 0.1e3
Real data @ 3710 MeV – Full recoil spectrum

Good agreement between MC and data!
Possible to fit only the $J/\psi$ region to search for the signal
Real data @ 3710 MeV – Fit to J/ψ energy region

\[ N_{\text{sig}} = 6.4 \times 10^2 + 1.0 \times 10^2 \]
\[ N_{\text{bkg}} = 3.7 \times 10^3 + 0.1 \times 10^3 \]

Voigtian + Chebychev

Final number of events will be determined by fitting both peaks at the same time.
Next steps...

- Most urgent: define the proper generator
  - Final fitting routine will change based on this
- Refine the event selection (solve the ISR for events just above the peak) and finalize the cut for $J/\psi \rightarrow ee$
- Add the $J/\psi \rightarrow \mu\mu$ sample
- Analyse the background
- Final fit to extract the phase
- ...
