Partial Wave Analysis of $J/\psi \to \gamma K^+ K^- (\gamma K_S^0 K_S^0), \gamma \pi^+ \pi^-$

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A) Question from Referees

B) What has been done after that

C) Problems and Outlook

- **Question from Refrerees (August)**
  - 0. Both approaches(global fit and bin-by-bin fit) will be pursued
  - 1. Using total 50M J/ψ (@BES annual meeting?)
  - 2. Perform bin-by-bin fit and use helicity amplitudes
  - 3. Start random and error (not symmetric)
  - 4. Acceptance correction
  - 5. $\gamma K_s K_s, +\gamma\pi^+\pi^-, \gamma K^+K^-$ 3 channels
  - 6. Vary cuts and PID to see the results if changed?

- 7. In $\gamma\pi^+\pi^-$ channel,including $\rho\pi$ events and the generateor?

- 8. Particale ID check

- 9. Background of γK^+K^-; W_K, W_e,W_π

- 10. α_{π^0} and π^0 bkgds rejecting.

- 11. Branching ratio and statistics of M.C.($ln\mathcal{L} - ln\mathcal{L}_b$)

A) What has been done after Hadron01

(actually from the end of Oct. focus on Data reconstruction and SIMBES)

Question I: 50M,namely two data sets comparions

- 1) summarize of the main cuts (modified)
  - $\sum Q_i = 0, N_{chrg} = 2$ (after VC,MDC ID), MFIT=2,$|cos\theta| < 0.80$
  - $U_{miss} \in (-0.01, 0.02)$GeV, for $\gamma\pi^+\pi^-$, $U_{miss} \in (-0.02, 0.02)$ GeV
  - $P_{tr}^2 < 0.0020$ GeV^2
  - $\chi^2_{\gamma K^+K^-} < 10, \chi^2_{\gamma\pi^+\pi^-} > \chi^2_{\gamma K^+k^-}, \chi^2_{\gamma\pi^+\pi^-} > 10$
  - $\Theta_{col} < 175^o$
  - ESC1,2 < 1.0 GeV

- PID:useing Penghp's correction and TOF information at least on kaon be identified. No PID for $\gamma\pi^+\pi^-$. (answered question 9)

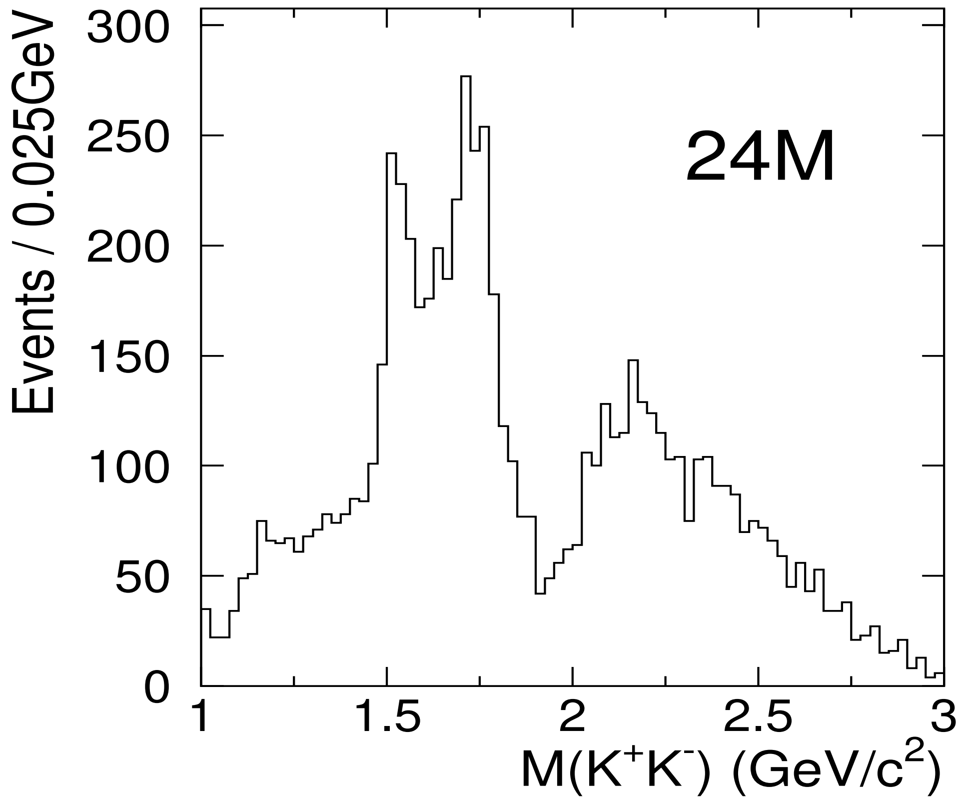
  In γK^+K^-,Data: $\sigma_t \sim$ 220ps. M.C.$\sigma_t \sim$ 210ps (Question 8). V103

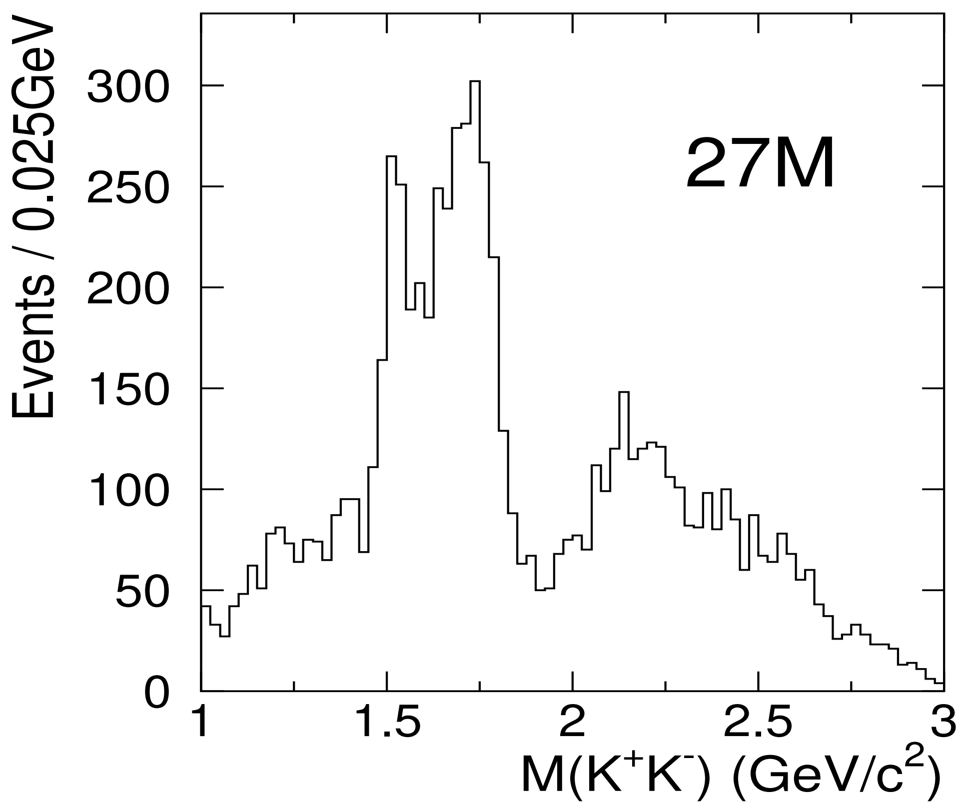
- to remove π^0,if $\chi^2_{\gamma\gamma\pi^+\pi^-} < 10, |m_{\gamma\gamma}\text{-}m_{\pi^0}| <$ 50MeV. if$\chi^2_{\gamma\gamma K^+K^-} < 10, |m_{\gamma\gamma}\text{-}m_{\pi^0}| <$ 50MeV (Answered Question 10)

- 2) B-W fit of K^+K^- spectrum: $f_2(1270)(PDGM, \Gamma)+$ $f_2'(1525 + f^0(1710)+$legend functions

$M1525(GeV)$	$set1(24M)$ 1.531 ± 0.004	$set2(27M)$ 1.525 ± 0.003	$51M$ 1.528 ± 0.002	PDG 1.525 ± 0.005
$\Gamma 1525(MeV)$	80.8 ± 12.7	67.6 ± 11.1	73.6 ± 8.9	76 ± 10
$B(J/\psi \to \gamma f_2' \to \gamma K^+K^-)(10^{-4})$	1.55 ± 0.22	1.34 ± 0.20	1.43 ± 0.16	$2.1^{+0.3}_{-0.2}$
M1717	1.723 ± 0.004	1.710 ± 0.004	1.716 ± 0.003	1.712
$\Gamma(1710)$	160.0 ± 16.2	171.4 ± 13.2	167.9 ± 10.4	133
$B(J/\psi \to \gamma f_0' \to \gamma K^+K^-)(10^{-4})$	3.80 ± 0.34	4.50 ± 0.32	4.19 ± 0.24	4.25

efficiency is calculated by SOBER


24M
Events / 0.025GeV
M(K$^+$K$^-$) (GeV/c^2)


27M
Events / 0.025GeV
M(K$^+$K$^-$) (GeV/c^2)

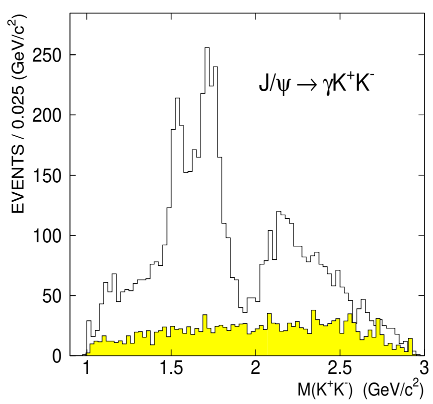


Fig. 11. K^+K^- mass spectrum after final cuts.

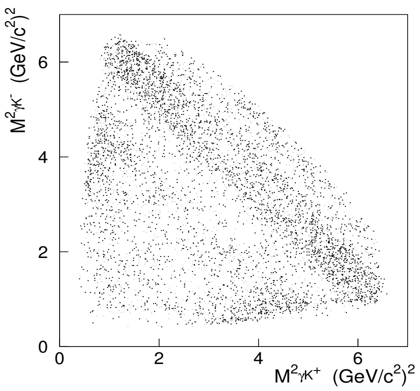
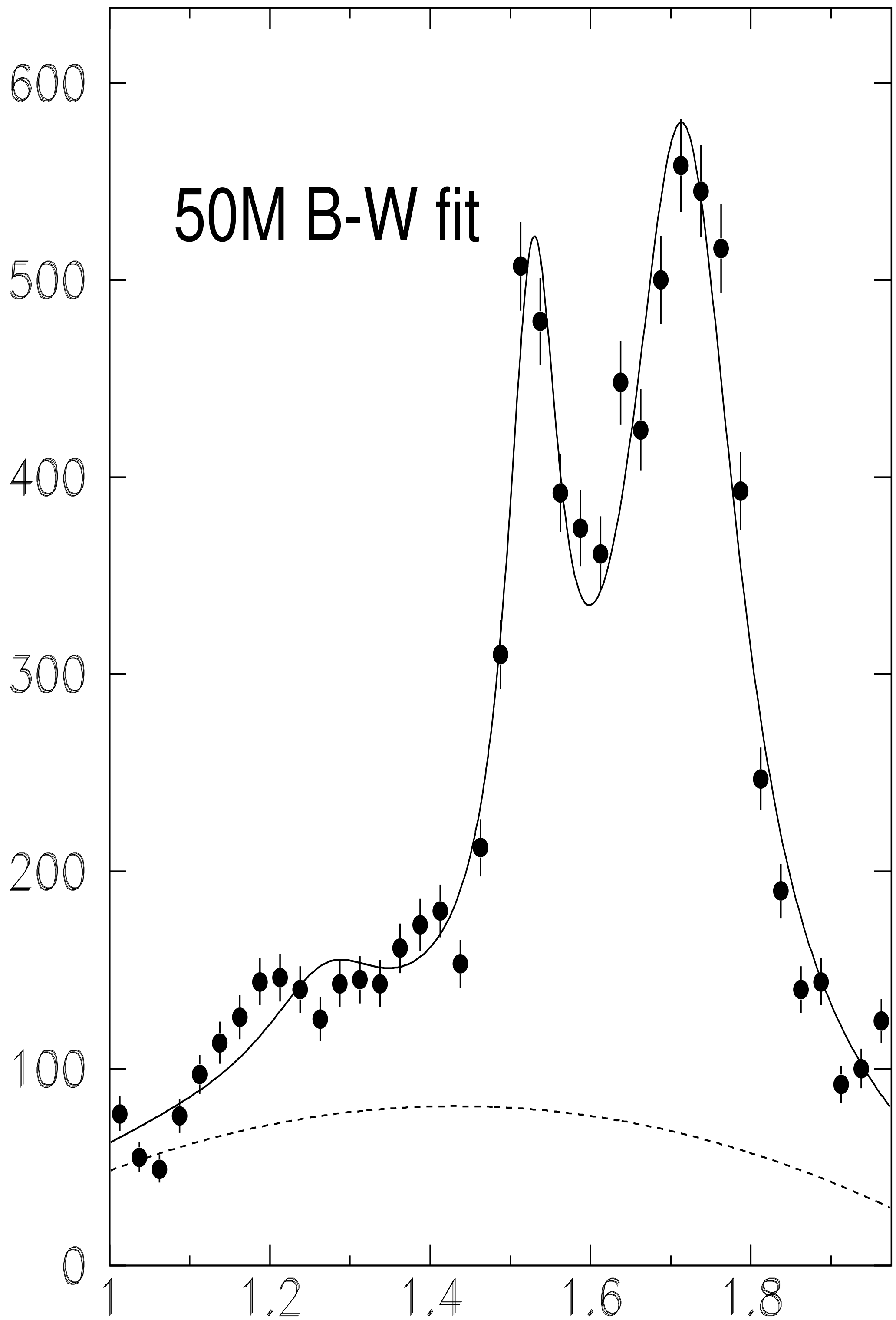


Fig. 12. γK^+K^- Dalitz plot.

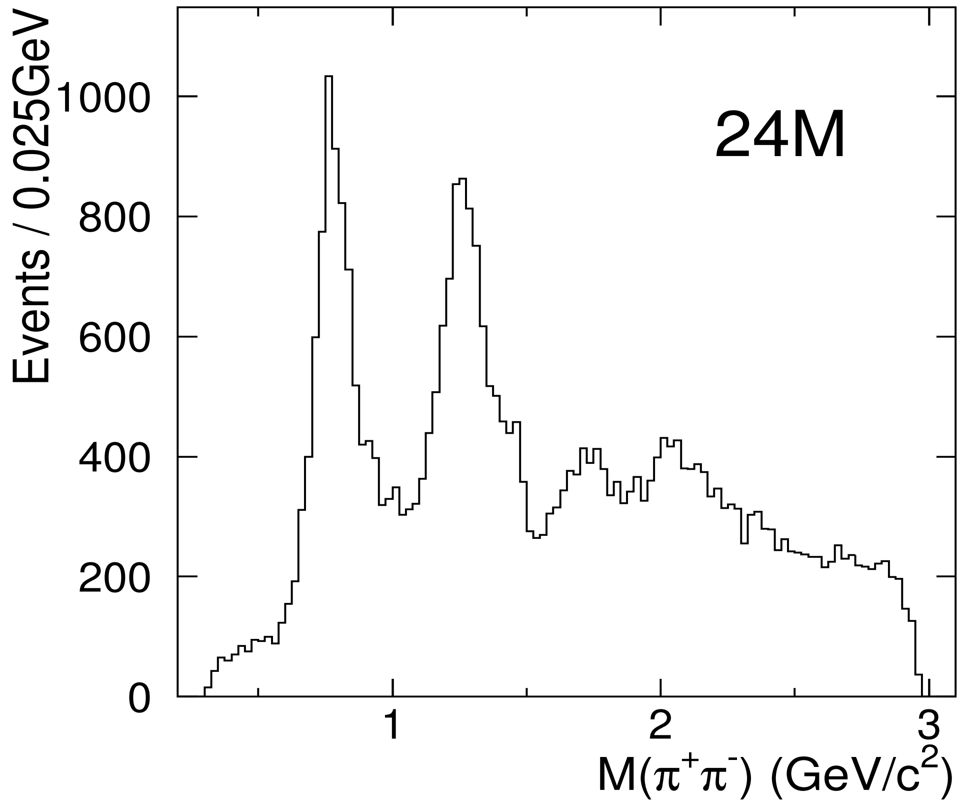
Fig. 11 shows the K^+K^- mass spectrum after final cuts, and Fig. 12 the Dalitz plot. The resonant structures in the mass regions of the $f_2'(1525)$ and the $f_0(1710)$ are very clearly visible in both figures and a bump at $m_{K^+K^-} \sim$ 2.1 GeV is present over the background. In Fig. 12, Vertical and horizontal bands along the axes are due to the K^*K and $\rho\pi$ backgrounds. The genuine radiative events form diagonal bands. The shaded region in Fig. 11 indicates the estimated backgrounds which will be studied in the following part.

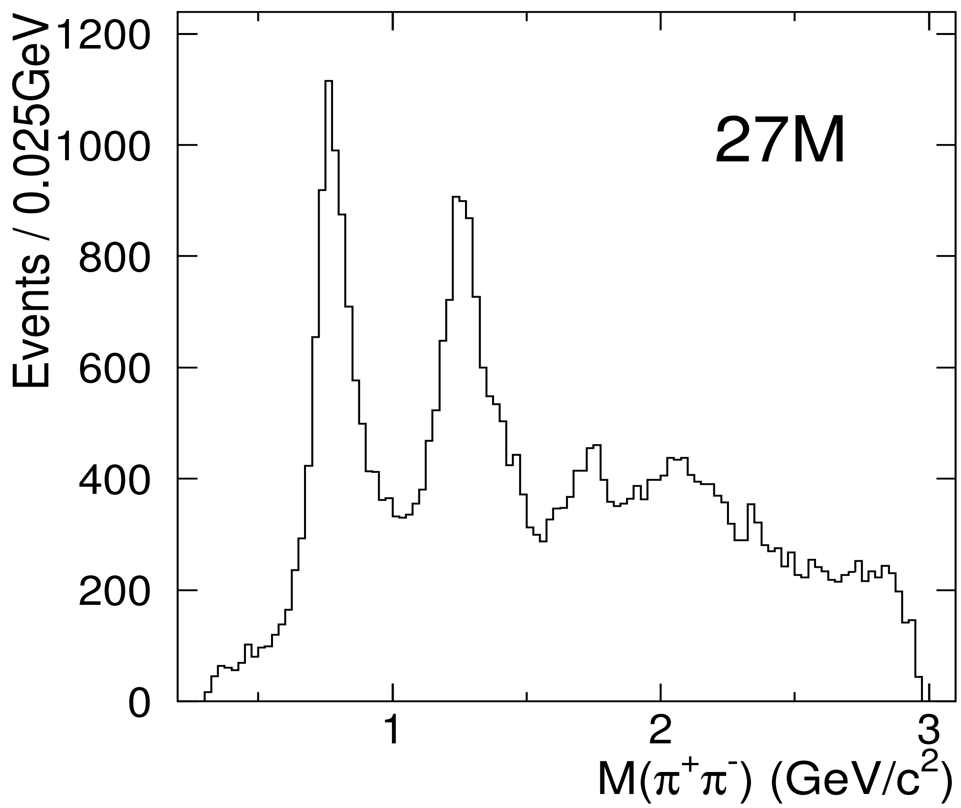
Detection Efficiency

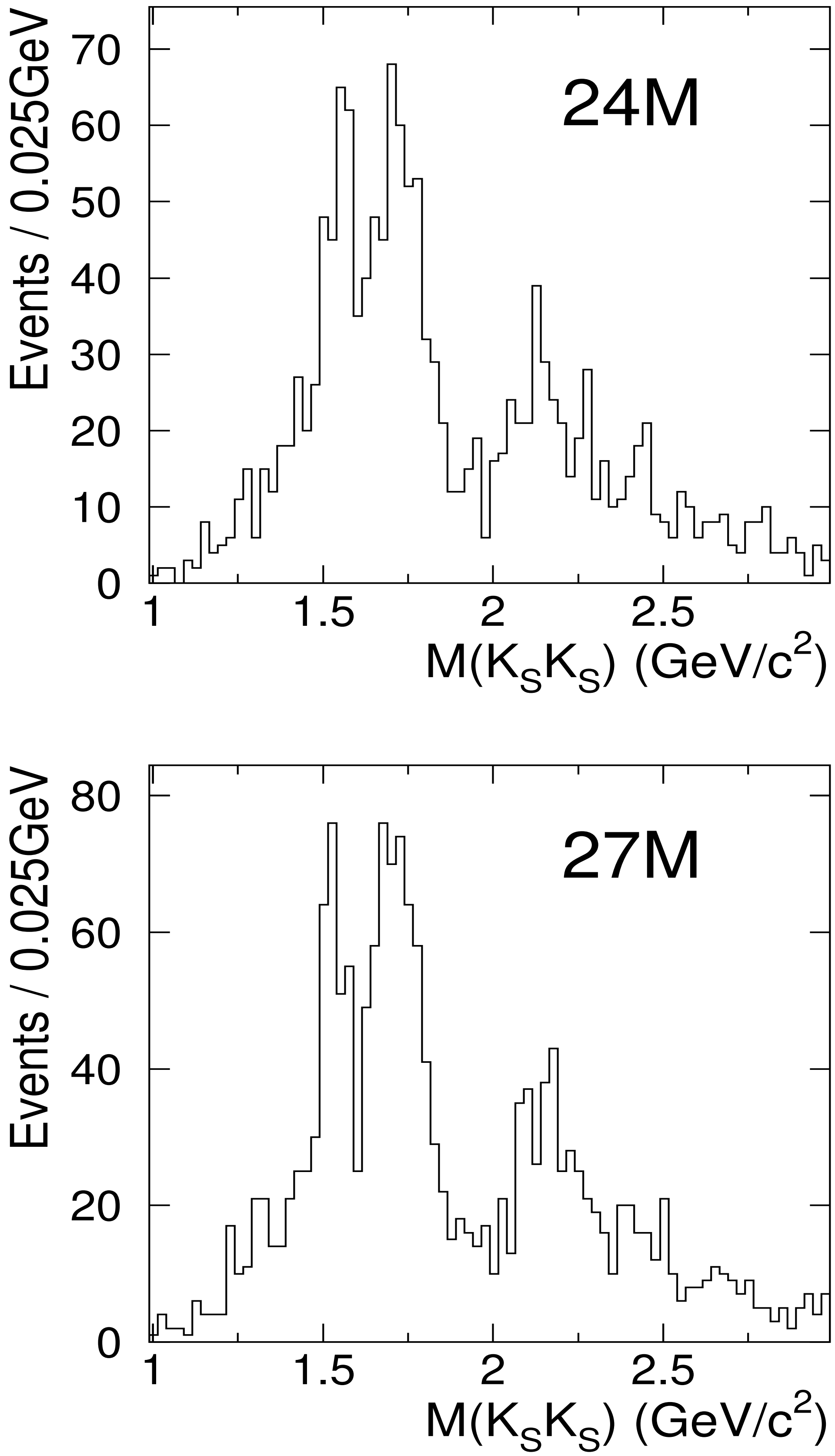
The detection efficiencies, averaged over a phase space production model, are shown in Fig. 13 and 14 respectively. They have a slight dependance on the invariant masses: almost constant up to 2 GeV/c^2 and then decreasing smoothly to 2.9 GeV/c^2. The fall-off at high mass is a consequence of the acollinearity cut.

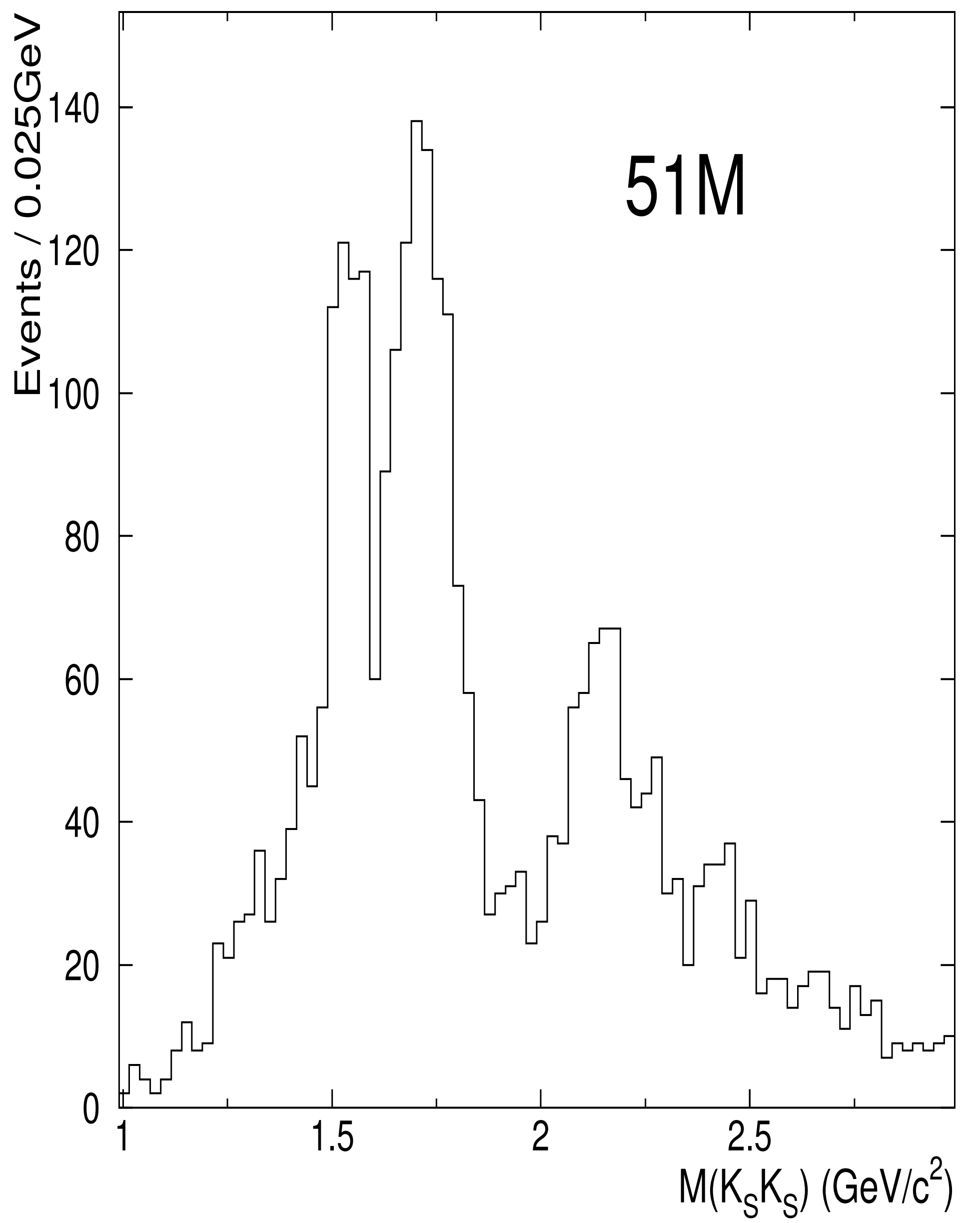


50M B-W fit
600
500
400
300
200
100
0
1
1.2
1.4
1.6
1.8

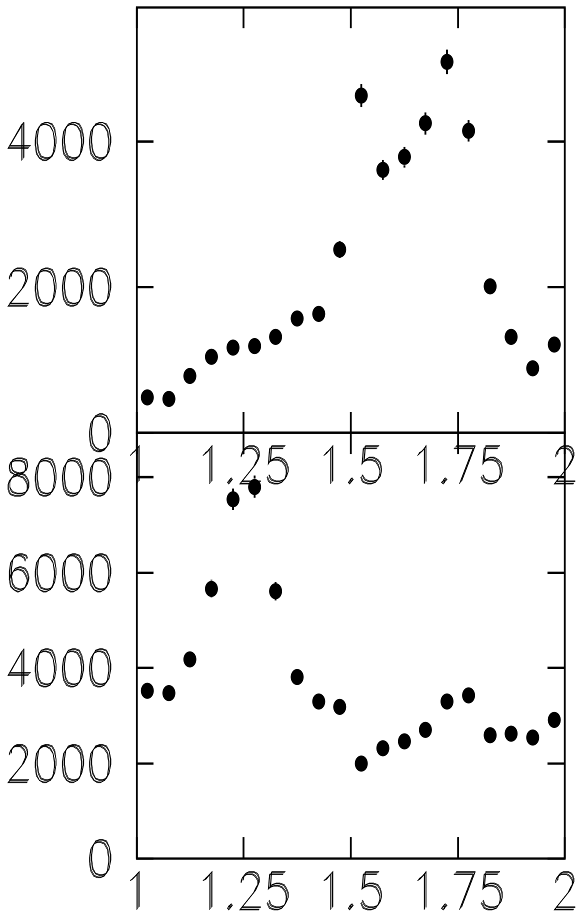

24M
Events / 0.025GeV
0
200
400
600
800
1000
1
2
3
M($\pi^+\pi^-$) (GeV/c^2)


27M
Events / 0.025GeV
0
200
400
600
800
1000
1200
1
2
3
M($\pi^+\pi^-$) (GeV/c^2)


24M
Events / 0.025GeV
M(K_SK_S) (GeV/c^2)
27M
Events / 0.025GeV
M(K_SK_S) (GeV/c^2)



Events / 0.025GeV
140
120
100
80
60
40
20
0
1
1.5
2
2.5
51M
M(K_S K_S) (GeV/c^2)



4000
2000
0
2000
1500
1000
500
0
1
1.25
1.5
1.75
2
8000
6000
4000
2000
0
3000
2000
1000
0
1
1.25
1.5
1.75
2
1
1.25
1.5
1.75
2

- After the efficiency correction,the peaks of 1525/1710 of BES and MK3:$\sim 1:1.2-1.3$ Now BES working on SIMBES (Which uses GEANT3)to do the M.C,Hope to get the right answer(Answered question 11)higher $\sim 10-20\%$(I estimate)

  Anyway the consistency of the two data sets is good.

- $\gamma K^{+}K^{-}$ backgrounds and in the PWA fit:

  $lnL = lnL_{data} - lnL_{bkgds}$, and lnL_{bkgds} from M.C $\pi^{0}K^{+}K^{-}$(phase space) ${K^{*}}^{\pm}K^{\mp}$(two body decay with special anguar distribution)

  generator:$\rho\pi, K^{*}K$ (answered question 7)

- Bin-by-bin fit

  $C_1C_2C_3->x,y,b(independent)+\phi_0\phi_x\phi_y->$ $|A_0|^2,|A_1|^2,|A_2|^2;|B|^2$

  Where

  $$|A_1|^2=|A_0|^2x^2$$

  $$|A_2|^2=|A_0|^2y^2$$

  $$|B|^2=|A_0|^2b^2$$

  $$|A_0|^2+|A_1|^2+|A_2|^2+5|B|^2=Nevent$$

  from M.C,γK^+k^- : $1,020,000$ phase space data (SOBER) $\gamma\pi^+\pi^-$: $1,020,000$ phase space data

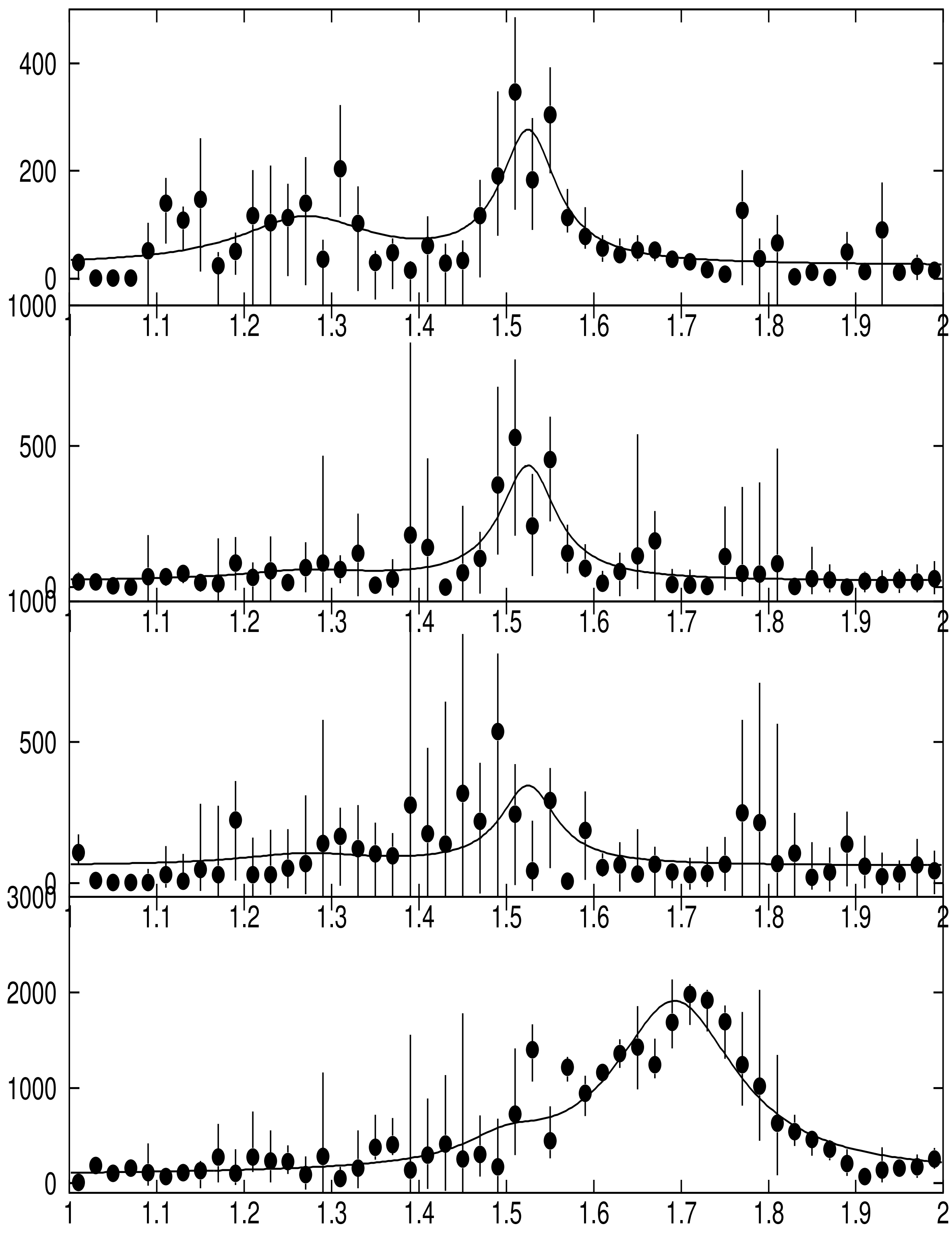
  20MeV/bin,MC Events number $\sim$ 2000/bin: may not enough?(Question 11)

- During the fit,Start from Random initial values,and very few multi-solutions (only at large $\rho\pi$ background range of $\gamma\pi^+\pi^-$ and K^*K of γK^+K^-) : averaged and included in errors.

- for $\gamma\pi^+\pi^-$,the M.C Simulation is Not good. e.x. the ρ^0 signal at low mass from M.C is lower ($\sim$ 4/5) and narrower than the one observed in data. To reduce the effect of bkgds,use the cut: $M^2_{\gamma\pi^+} > 1.0$ and $M^2_{gamma\pi^-} > 1.0$

  If Simbes OK in the futrue,keep all the bkgds.

  20 MeV/bin, 1.0 - 2.0 GeV



400
200
0
1000
500
0
1000
500
0
3000
2000
1000
0
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2

• Analysis results of $J/\psi \to \gamma k^+ k^-$(50M+24M)(very preliminary)
1) for $|a_{2,0}|^2$,$|a_{2,1}|^2$, $|a_{2,2}|^2$ fit, No obvious signal around 1.7GeV and 1525MeV, if free fit $+f_2$(1270)(PDG M Γ)

$$
\begin{array}{l}
|a_{2,0}|^2\text{:}\ M = 1.524 \pm 0.002 GeV\ \ \Gamma = 60.2 \pm 3.1 MeV \\
|a_{2,1}|^2\text{:}\ M = 1.519 \pm 0.001 GeV\ \ \Gamma = 69.8 \pm 3.2 MeV \\
|a_{2,2}|^2\text{:}\ M = 1.475 \pm 0.002 GeV\ \ \Gamma = 111.8 \pm 7.8 MeV
\end{array}
$$

(very poor)

If fix $f_2\prime(1525)$ as $m = 1525 MeV, \Gamma = 76 MeV$

	Events Number	$Br(J/\psi \to \gamma X \to \gamma k^+ k^-)(\times 10^{-4})$
$\lvert a_{2,0}\rvert^2$:	1396 ± 42	0.27 ± 0.01
$\lvert a_{2,1}\rvert^2$:	2328 ± 47	0.46 ± 0.01
$\lvert a_{2,2}\rvert^2$:	1613 ± 57	0.32 ± 0.01

$$x^2 = \frac{|a_{2,1}|^2}{|a_{2,0}|^2} = 1.71 \pm 0.04; y^2 = \frac{|a_{2,2}|^2}{|a_{2,0}|^2} = 1.16 \pm 0.05$$

L.D.Chen: $= 1.08 \pm 0.31$ $= 0.25 \pm 0.24$

other experimental average: $x = 0.86 \pm 0.07$; $y = 0.19 \pm 0.10$

Our global fit of 24M$\Rightarrow$ $x = 1.58 \pm 0.12; y = 1.07 \pm 0.23$

And $Br(J/\psi \to \gamma f_2\prime(1525) \to \gamma k^+ k^-) = (1.08 \pm 0.02) \times 10^{-4}$ PDG: $\sim 2.09 \times 10^{-4}$
our global fit $\Rightarrow (1.24 \pm 0.20) \times 10^{-4}$
W.Dunwoodie:$(4.0 \pm 0.8) \times 10^{-4}/2$

- If the bin 1520-1540 $MeV \uparrow$

this value will be consistent with our B-W fit of $k^+ k^-$spectrum.

• for $f_2(1270)$,input as PDG values of m, Γ
(very poor fit,affected by ρ^0 backgrounds)
$|a_{2,0}|^2$: $(2.13 \pm 0.08) \times 10^{-5}$
$|a_{2,1}|^2$: $(0.80 \pm 0.08) \times 10^{-5}$
$|a_{2,2}|^2$: $(0.96 \pm 0.12) \times 10^{-5}$
So, $\frac{|a_{2,1}|^2}{|a_{2,0}|^2} = 0.38 \pm 0.11$; $\frac{|a_{2,2}|^2}{|a_{2,0}|^2} = 0.45 \pm 0.14$
$\Rightarrow$ Not reliable
other experimental average: $x = 0.86 \pm 0.07, y = 0.19 \pm 0.10$

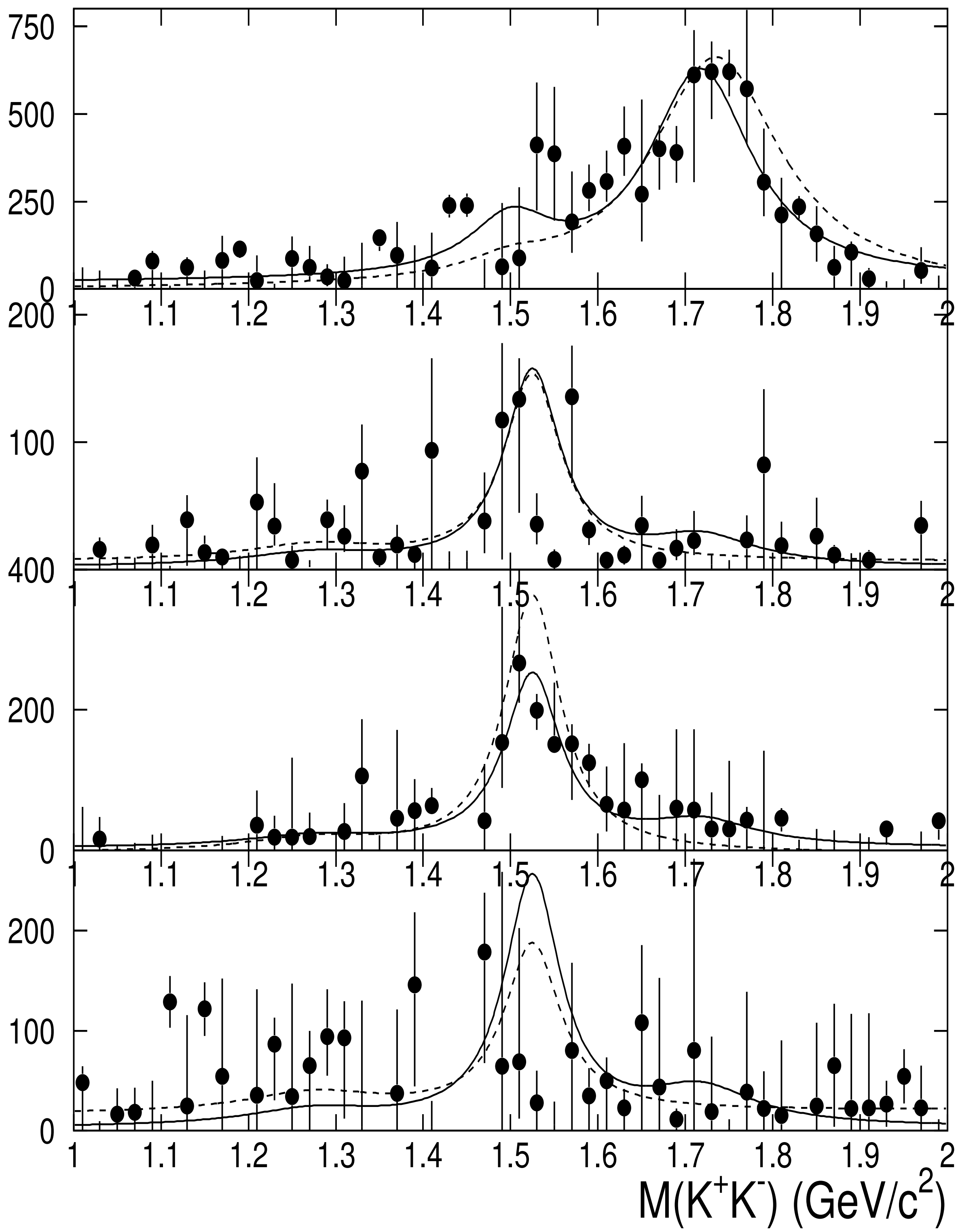
$Br(J/\psi \to \gamma f_2(1270) \to \gamma k^+ k^-) \sim (3.9 \pm 0.2) \times 10^{-5}$

PDG:$\sim 3.2 \times 10^{-5}$

• for the fit of $|a_{0,0}|^2$:
Input 1700+$f_0(1500)$($M = 1.693 \pm 0.002 GeV, \Gamma = 171 \pm 3 MeV$; $M = 1500 MeV, \Gamma = 112 MeV$)

$Br(J/\psi \to \gamma f_0(1710) \to \gamma k^+ k^-) \sim (4.21 \pm 0.05) \times 10^{-4}$ PDG:$\sim 4.25 \times 10^{-4}$
our global fit (24M):$(3.36 \pm 0.54) \times 10^{-4}$

Since the fit of bin-by-bin Not very stable, especially in the fit of phase, so Now we haven't performed the study of phase motion(also waiting for SIMBES and new data sample). I estimate the reasonable phase motion results in $\gamma\pi^+\pi^-$ is possible,but for γk^+k^-very difficult.



750
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400
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0
200
100
0
1
1.1
1.2
1.3
1.4
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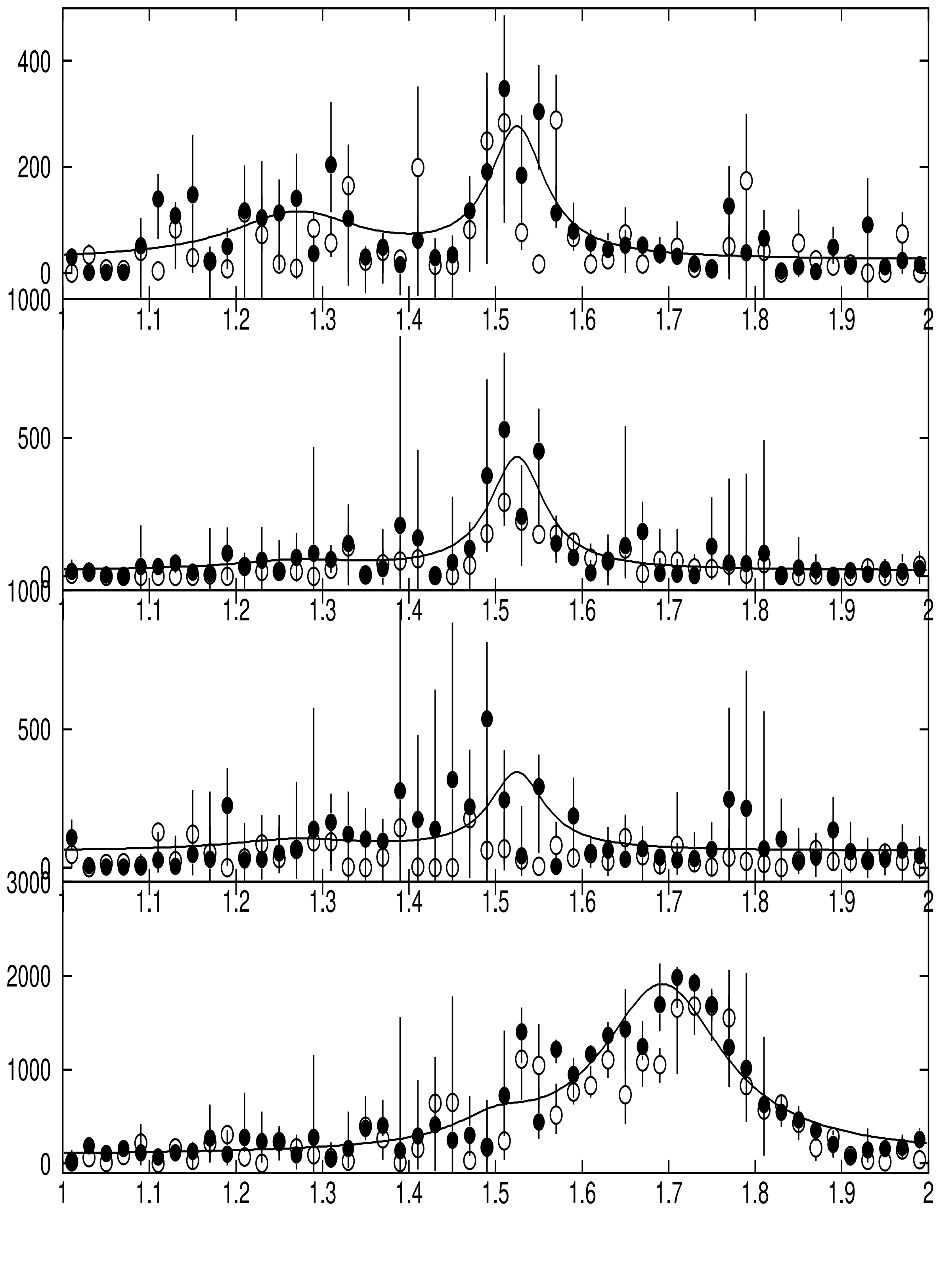
1.6
1.7
1.8
1.9
2
M(K+K-) (GeV/c2)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3000
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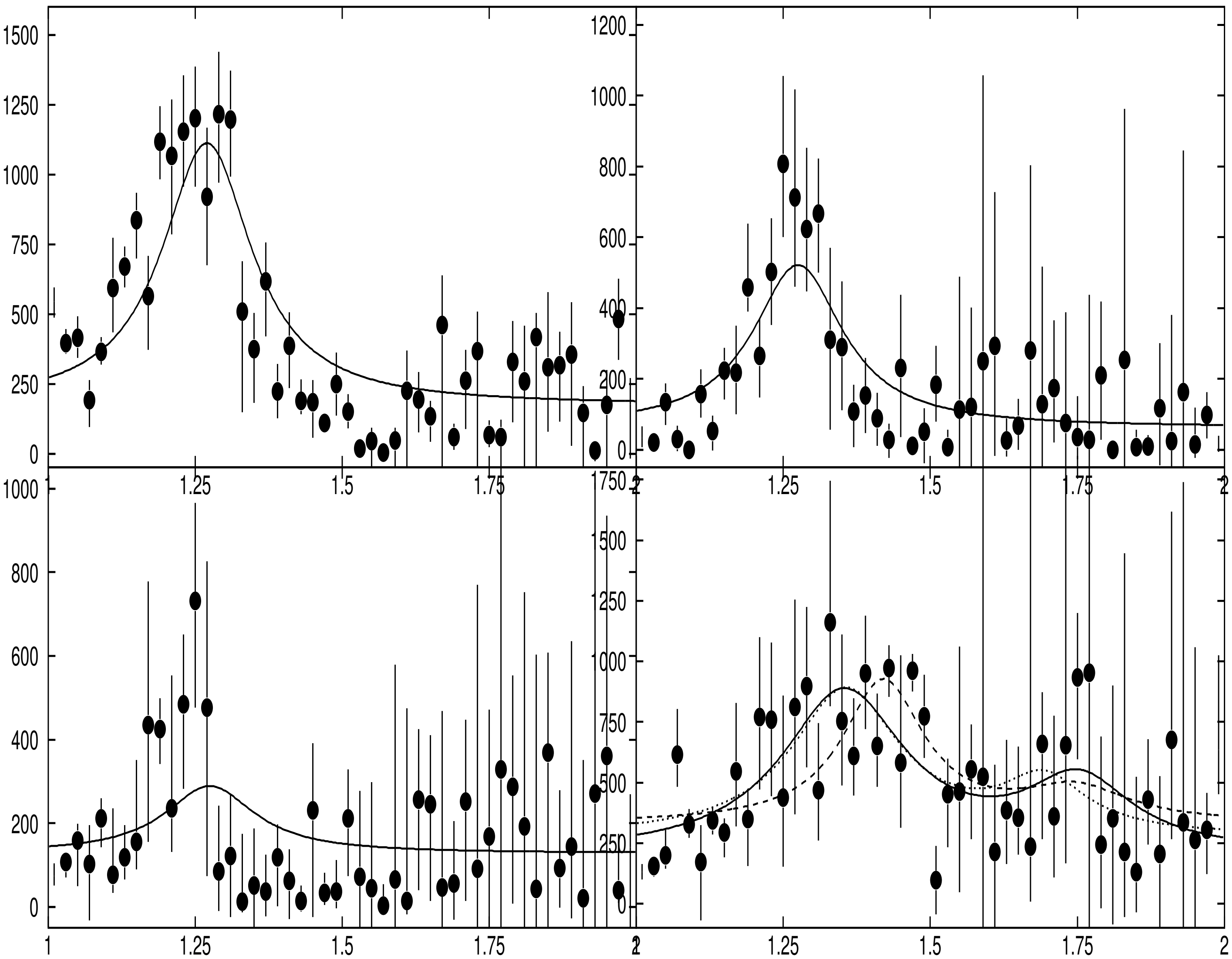
1.8
1.9
2



1500
1250
1000
750
500
250
0
1200
1000
800
600
400
200
0
1
1.25
1.5
1.75
2
800
600
400
200
0

Analysis results of $J/\psi \to \gamma\pi\pi$(50M+24M) (very preliminary)

• Fit of $|a_{2,0}|^2$,$|a_{2,1}|^2$,$|a_{2,2}|^2$: only obvious structure of $f_2(1270)$
And M, Γ free fit of $|a_{2,0}|^2$:gives reasonable $\Gamma \sim 170 MeV$,but low mass $\sim 1.25 GeV$
$|a_{2,1}|^2$:gives reasonable mass $\sim 1.27 GeV$, but narrow $\Gamma \sim 100 MeV$
the fit of $|a_{2,2}|^2$ very poor.

So fix its $M = 1275$,$\Gamma = 185.5 MeV$ respectively

$|a_{2,0}|^2 \Rightarrow Br(J/\psi \to \gamma X \to \gamma\pi\pi = \sim (2.85 \pm 0.04) \times 10^{-4}$
$|a_{2,1}|^2$ $(1.44 \pm 0.02) \times 10^{-4}$
$|a_{2,2}|^2$ $(0.80 \pm 0.02) \times 10^{-4}$

$\Rightarrow \frac{|a_{2,1}|^2}{|a_{2,0}|^2} = 0.51 \pm 0.03$; $\frac{|a_{2,2}|^2}{|a_{2,0}|^2} = 0.28 \pm 0.02$
our global fit:$x = 0.66 \pm 0.14, y = 0.46 \pm 0.20$(good

consistent)
other experimental average:$x = 0.85\pm0.05, y = 0.02 \pm 0.05$
While $Br(J/\psi \to \gamma f_2(1270) \to \gamma\pi^+\pi^-) = (5.09\pm 0.05) \times 10^{-4}$

W.Dunwoodie: $\sim 8.8 \times 10^{-4}$

our globle fit:$\sim (7.96 \pm 0.96) \times 10^{-4}$ Why so low?
Since the fit of $f_2(1270)$ in $\gamma k^+k^-$is very poor,it's NOT meaningful to compare in $\gamma\pi^+\pi^+/\gamma k^+k^-$.

2)Fit of $|a_{0,0}|^2$

• Input two structures,one around $1.3-1.5GeV$, other around$1.7GeV$,free M, Γ fit,the first $\Rightarrow$ $M = 1.361 \pm 0.002GeV, \Gamma = 218.0 \pm 6.4MeV$
the second $\Rightarrow$ $M = 1.755 \pm 0.001GeV, \Gamma = 32MeV$
So test line1,line2,line3

• If we use$M = 1.750GeV, \Gamma = 220MeV$which is used in our global fit,then,$Br(J/\psi \to \gamma f_0 \to \gamma\pi^+\pi^-) = (6.5 \pm 0.2) \times 10^{-5}$
our global fit $Br(J/\psi \to \gamma f_0(1770) \to \gamma\pi^+\pi^-) = (5.2 \pm 1.9) \times 10^{-5}$(CONSISTENT)

- from line3's results (to compare $f_0(1710)$ in $\pi\pi$ and $k\bar{k}$)

$Br(J/\psi \to \gamma f_0(1710) \to \gamma\pi^+\pi^-) = (5.2\pm0.3)\times 10^{-5}$
and $\frac{Br(J/\psi\to\gamma f_0(1710)\to\gamma\pi^+\pi^-)}{Br(J/\psi\to\gamma f_0(171051ightarrow\gamma k\bar{k})} = (9.3\pm0.6)\%$

In our global fit ,analyticicity has been assumed which provides an additional contraint in the fit. The consistency of the global fit and Bin-by-Bin fit is GOOD.Since in the later,the fitted amplitudes are non-analytic,the fits Not Stable and difficult to control.So the problem in γk^+k^-'s bin 1.52-1.54 GeV and the $f_0(1500)$ in $\gamma\pi^+\pi^-$'s explaination are NOt surprised

• One problem:fit of the bin 1520-1540MeV in $\gamma k^+ k^-$

a) form or code wrong?

b) bin-by-bin fit large error and unstable? Statistics?

c) data favor 0^+in this bin really?

d) M.C. simulation Not good enough?

e) BG Not considered correct?

To check Question a) and b),we do
D.H.Zhang generated M.C.data 25,000
(I have sent to the referees our check on form using our global fit in this August,there M.C. checkseemed No problem)
$f_{2'}(1525) : x = 0.86, y = 0.19, N_{event} \sim 10,00$

$M = 1525MeV, \Gamma = 76MeV$

$f_0(1710)$: $N_{event} \sim 15000, M = 1710MeV, \Gamma = 150MeV$

Simply, we assumed $\phi_0 = \phi_x = \phi_y = 0$

And after BES detector and selection,5100 events remained,at the same level of data statistics.

We performed 6 bins around the peak of $f_2\prime(1525)$

	1.46 − 1.48	1.48 − 1.50	1.50 − 1.52	1.52 − 1.54	1.54 − 1.56	1.50 − 1.55
b	0.217 ± 0.116	0.284 ± 0.117	0.195 ± 0.080	0.285 ± 0.025	0.059 ± 0.126	0.086 ± 0.022
x	0.921 ± 0.158	0.859 ± 0.116	0.834 ± 0.084	0.809 ± 0.062	1.060 ± 0.130	0.857 ± 0.046
y	0.233 ± 0.328	0.369 ± 0.252	0.374 ± 0.220	0.178 ± 0.083	0.577 ± 0.395	0.297 ± 0.070
N_{0+}	13 ± 13	34 ± 23	29 ± 22	78 ± 12	2 ± 10	18 ± 9
N_{2+}	105 ± 13	155 ± 23	281 ± 22	326 ± 12	327 ± 10	873 ± 9

From this table, we can see that:

1) The input $x, y = 0.86, 0.19$,while the fitted x, y are consistent with them within the error quite well,so we know that the amplitude form and code are No problem.

2) The M.C. data are similiar to the real data from the m, Γ of the $f_2\prime(1525)$ and $f_0(1710)$,and statistics ,etc.and the results show that in

each bin 2^+ component is dominant and the fit ok.

3) In this mass region around 1525 MeV, b.g. events are few relatively,and will not change the ratio of 0^+ and 2^+.

So, c)and d) could be the reason or other ???

- Problems remained and outlook

Nearly answered all the questions,but still have some problems and work need to be solved:

1) What still Not done? $\gamma K_s K_s$ fit phase motion study $\gamma\pi^+\pi^-$ includeing all $\rho\pi$

2) what need to be improved? $f_0(1710)$'s M in γK^+K^- and $f_2(1270)$'s M and BR in $\gamma\pi^+\pi^-$ B-W fit of $|A_0|^2, |A_1|^2, |A_2|^2, b|B|^2$,and the errors.

3) One Puzzle:the bin 1520-1540 in γK^+K^- (must be studied carfully and make sure)

4) Basic material:

Data will be reconstructed again?

When will the SIMBES ok? Since the M.C data will affect the fit results both in γK^+K^- and $\gamma\pi^+\pi^-$ as metioned before. (select $\rho\pi$ and k^*K sample and compare carefully)

5) Other questions and suggestions?