The analysis of $J/\psi \to \gamma\eta\pi^+\pi^-$

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I. Motivation

The radiative decay of $J/\psi \to \gamma\eta\pi\pi$ is interestings for several resons:

1. About the 1.3 GeV signal in $\eta\pi\pi$ invariant mass distribution

♡ The branching ratio of $J/\psi \to \gamma f_1(1285)$ from Mark3 and DM2 is quite different with the result from PDG (see table 1).
♡ Mark3 and DM2 thought that the 1.3 GeV signal was $f_1(1285)$,but they did not give the exactly spin-parity, that means is that they could not distinguish between $f_1(1285)$ and $\eta(1295)$.

Resonance Parameters and Branching Ratios for $J/\psi \to \{\gamma, \omega, \phi\}\eta\pi\pi$

J^{pc}	Object	Observed in	Mass (MeV)	Width (MeV)	Br($\times 10^{-4}$)	Exp.
1^{++} ?	$f_1(1285)$?	$J/\psi \to \gamma\eta\pi^+\pi^-(a)^*$	1282 (fixed)	24 (fixed)	$2.6 \pm 0.28 \pm 0.58$	Mark3
1^{++} ?	$f_1(1285)$?	$J/\psi \to \gamma\eta\pi^+\pi^-(b)^*$	1283 (fixed)	26 (fixed)	$4.8 \pm 1.7 \pm 0.4$	Mark3
?	$f_1(1285)$?	$J/\psi \to \gamma\eta\pi^+\pi^-(a)$	1264 ± 8	44 ± 20	$2.6 \pm 0.4 \pm 0.4$	DM2
1^{++}	$f_1(1285)$?	$J/\psi \to \omega\eta\pi^+\pi^-(a)$	$1283 \pm 6 \pm 10$	$14 \pm^{19}_{14} \pm 10$	$4.3 \pm 1.2 \pm 1.3$	Mark3
1^{++} ?	$f_1(1285)$?	$J/\psi \to \phi\eta\pi^+\pi^-(a)$	$1283 \pm 6 \pm 10$	$24 \pm^{20}_{14} \pm 10$	$1.6 \pm^{0.6}_{0.5} \pm 0.4$	Mark3
1^{++} ?	$f_1(1285)$?	$J/\psi \to \gamma\eta\pi^+\pi^-(a)$			1.83 ± 0.6	DM2
0^{-+}	X(1400)	$J/\psi \to \gamma\eta\pi^+\pi^-(a)^*$	1400 ± 6	47 ± 13	$3.38 \pm 0.33 \pm 0.64$	Mark3
0^{-+}	X(1400)	$J/\psi \to \gamma\eta\pi^+\pi^-(b)^*$	1400 ± 7	69 ± 23	$7.8 \pm 2.7 \pm 0.7$	Mark3
0^{-+} ?	X(1400)	$J/\psi \to \gamma\eta\pi^+\pi^-(a)$	1398 ± 6	53 ± 11	$7.0 \pm 0.6 \pm 1.1$	DM2
0^{-+} ?	X(1400)	$J/\psi \to \gamma\eta\pi^+\pi^-(a)^*$			$5.6 \pm 0.7 \pm 0.9$	DM2
1^{++} ?	$f_1(1420)$	$J/\psi \to \omega\eta\pi^+\pi^-(a)$	$1421 \pm 8 \pm 10$	$45 \pm^{32}_{23} \pm 15$	$9.2 \pm 2.4 \pm 2.8$	Mark3
0^{-+} ?	$\iota(1440)$	$J/\psi \to \gamma\eta\pi^+\pi^-(a)$			$< 17(90\% C.L)$	Cry.-ball
?	X(1700)	$J/\psi \to \gamma\eta\pi^+\pi^-(a)$	1770 ± 45	520 ± 110	$39 \pm 2 \pm 7$	Cry.-ball
?	X(1700)	$J/\psi \to \gamma\eta\pi^0\pi^0(a)$			$26 \pm 4 \pm 8$	Cry.-ball
2^{-+}	X(1900)	$p\overline{p} \to \eta\pi^0\pi^0\pi^0$	1850 ± 30	225 ± 50		Cry.-barrel
2^{-+}	X(1900)	$e^+e^- \to e^+e^-\eta\pi^0\pi^0(a)$	$1876 \pm 35 \pm 50$	$228 \pm 90 \pm 34$		Cry.-ball
?	X(1900)	$J/\psi \to \gamma\eta\pi^+\pi^-(a)^*$	~ 1900			Mark3

(a) $\eta \to \gamma\gamma$, (b) $\eta \to \pi^+\pi^-\pi^0$, *) $a_0(980)\pi$

2. About the $\iota/\eta(1440)$

♡ The first observation of $\eta(1440)$ was made in $p\overline{p} \to K\overline{K}3\pi$ annihilations at rest. The $\eta(1440)$ was reported to decay into $K\overline{K}\pi$, equally through $a_0(980)\pi$ and $K^*(892)\overline{K}$.
♡ The $\eta(1440)$ has since also been in a partial wave analysis of the $K\overline{K}$ system, in 6GeV $p\bar{p}$ annihilations, and in nonperipherally selected $\pi^- p \to K_s^0 K_s^0 \pi^0 n$.
♡ The $\eta(1440)$ is also seen as a broad enhancement in J/ψ radiative decay.
♡ All these results, together with RATH 89 and BERTIN 95, suggest the existence of two overlapping pseudoscalar states, one around 1400 MeV, the other one around 1480 MeV.

3. About the Axial-vector mesons (1^{++})

♡ The $q\bar{q}$ model predicts a nonet that includes two isoscalar 1^3P_1 states with masses below about 1.6GeV. Three such 1^{++} states are know, the $f_1(1285)$, the $f_1(1420)$, and the $f_1(1530)$, with suggests that one of these is a non-$q\bar{q}$ meson. The $f_1(1420)$ is the most likely candidate.

4. About 2^{-+} *resonance around 1.9 GeV*

♡ Two Isospin I=0 1^1D_2 $q\bar{q}$ resonances are expected in the vicinity of 1.7GeV and 1.9GeV. Crystal-barrel data on $p\bar{p} \to \eta\pi^0\pi^0\pi^0$ at 1.94 GeV/c reveal two new I=0 $J^{PC} = 2^{-+}$ resonances in $\eta\pi\pi$. The first, at 1650 ± 15 MeV, it may be interpreted as the $q\bar{q}$ 1^1D_2 partner of $\pi_2(1670)$. The second, at 1850 ± 30 MeV, but it seems could not be putted into the 1^1D_2 $q\bar{q}$ states.
♡ A 2^{-+} hybrid was also predicted by theory around 1.9 GeV.
♡ Several groups have been reported the existence of the 1.9 GeV resonance, but we have not see the report in $J/\psi \to \gamma\eta\pi^+\pi^-$ decay mode about this resonance in detail.

Suggested by $q\bar{q}$ Quark-model Assignment for Meson nonets

$N^{2s+1}L_J$	J^{PC}	$u\overline{d}, u\overline{u}, d\overline{d}$ I=1	$u\overline{u}, d\overline{d}, s\overline{s}$ I=0	$\overline{s}u, \overline{s}d$ I=1/2
1^1S_0	0^{-+}	π	$\eta,\eta\prime$	K
1^3P_1	1^{++}	$a_1(1260)$	$f_1(1285), f_1(1510)$	K_{1A}
1^1D_2	2^{-+}	$\pi_2(1670)$	? , ?	$K_2(1770)$
2^1S_0	0^{-+}	$\pi(1300)$	$\eta(1295), ?$	$K(1460)$
3^1S_0	0^{-+}	$\pi(1770)$	$\eta(1760), ?$	$K(1830)$

II. Event Selections

$J/\psi \to \gamma\eta\pi^+\pi^-$ $(3\gamma\pi^+\pi^-)$

♠ $P_{miss} = \sqrt{(\sum P_x)^2 + (\sum P_y)^2 + (\sum P_z)^2}$

The selection of "good" γ

♡ $3 \leq N_{neu} \leq 15$

♡ $E_\gamma \geq 0.07$ GeV

♡ $cos\theta_{\gamma q} \leq 0.99$

♡ $cos\theta_{\gamma\eta} \leq 0.99$

The selection of charged particles

♡ $\sqrt{x_0^2 + y_0^2} < 0.8cm$, $|z_0| < 14cm$

♡ **Two charged particles, and** $\sum Q = 0$

♡ **MFIT=2 or -19 for every charged particles**

♡ **At least one π track per event**

Kinematic fit

♡ $0.1 \leq P_{miss} \leq$ **1.2 GeV/c**

♡ $\chi^2_{J/\psi\to 3\gamma\pi\pi} < \chi^2_{J/\psi\to 3\gamma KK}$

$\chi^2_{J/\psi\to 3\gamma\pi\pi} < \chi^2_{J/\psi\to 4\gamma\pi\pi}$

$\chi^2_{J/\psi\to 3\gamma\pi\pi} \leq$ **20**

♡ $|M_{\gamma\gamma} - M_\eta| \leq$ **0.1 GeV**

♡ $\chi^2_{5c} \leq 15$

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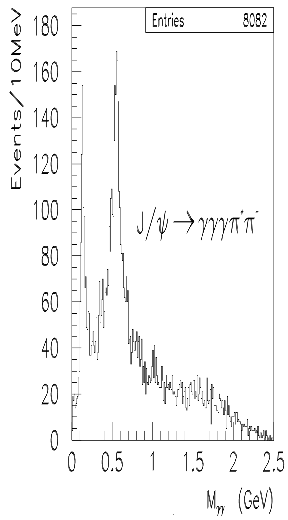

Figure 1: The invariant mass spetrum of $\gamma\gamma$ after 4C-fit.

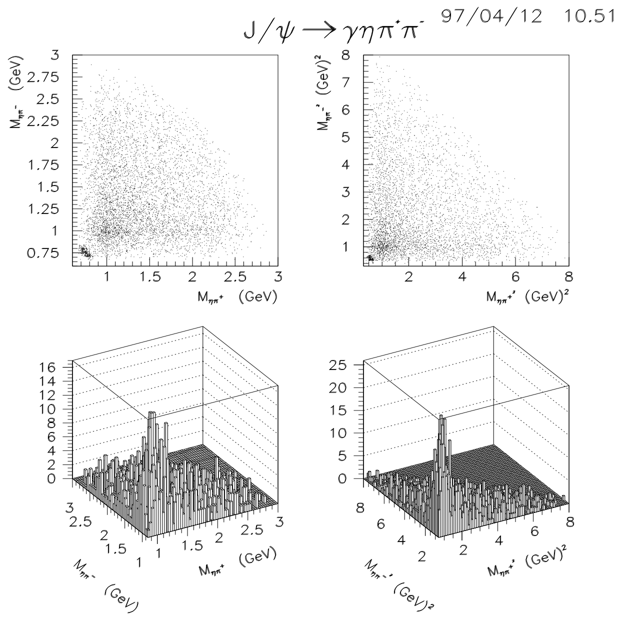

Figure 2: The Delatz plot of $\eta\pi^{\pm}$

Final selection

♡ $|M_{\eta\pi^+} - M_{a_0(980)}| \leq$ **0.11GeV or** $|M_{\eta\pi^-} - M_{a_0(980)}| \leq$ **0.11GeV**

♡ $M_{\eta\pi^{\pm}} \geq$ **1391 MeV or** $M_{\eta\pi^{\pm}} \leq$ **1237 MeV**

♡ $M_{\pi^+\pi^-} \leq$ **1.0 GeV or** $M_{\pi^+\pi^-} \geq$ **1.4 GeV**

Backgrounds

Decay mode	**Final states**	**Events of MC gen.**	**Events after cut**	
			1.0 ∼ 3.1 GeV	**1.0 ∼ 2.2 GeV**
$J/\psi \to \rho\pi^0$	$2\gamma\pi^+\pi^-$	**70000**	**0**	**0**
$J/\psi \to \gamma\eta K^+K^-$	$3\gamma K^+K^-$	**40000**	**6**	**0**
$J/\psi \to \omega\eta$	$4\gamma\pi^+\pi^-$	**13000**	**26**	**16**
$J/\psi \to a_2(1320)\rho$	$4\gamma\pi^+\pi^-$	**12000**	**15**	**9**
$J/\psi \to \rho\eta$	$2\gamma\pi^+\pi^-$	**10000**	**1**	**0**
$J/\psi \to \omega\pi^+\pi^-$	$3\gamma\pi^+\pi^-$	**5000**	**44**	**0**
$J/\psi \to \omega\pi^0$	$4\gamma\pi^+\pi^-$	**3300**	**17**	**17**
$J/\psi \to \gamma f_2(1270)\eta$	$3\gamma\pi^+\pi^-$	**3000**	**11**	**1**
$J/\psi \to \gamma a_2(1320)^{\pm}\pi^{\mp}$	$3\gamma\pi^+\pi^-$	**3000**	**5**	**5**
$J/\psi \to b_1(1235)^{\pm}\pi^{\mp}$	$3\gamma\pi^+\pi^-$	**2000**	**54**	**0**
$J/\psi \to \omega f_2(1270)$	$3\gamma\pi^+\pi^-$	**1600**	**3**	**0**

♡ **In our interesting mass region** $(1.0 \sim 2.2GeV)$ **of** $a_0(980)\pi$ **invariant mass spectrum:**

Noise/Signal $\sim 5\%$

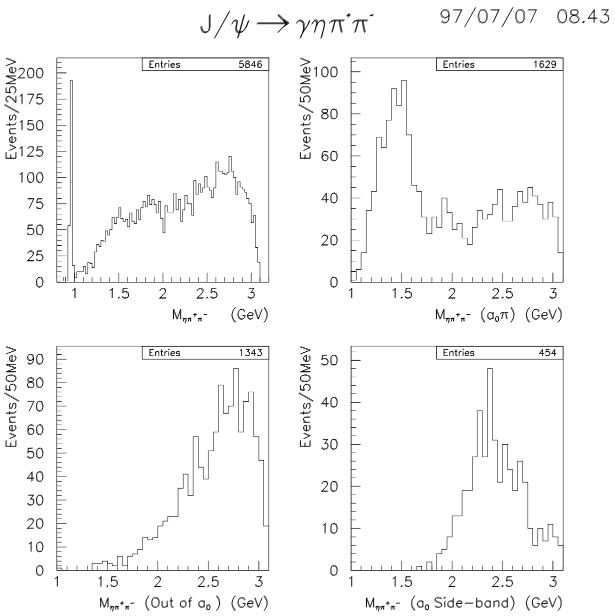

Figure 3: The invariant mass of $\eta\pi\pi$

III. Results and Discussions

1. Results around 1.1∼ 1.7 GeV Mass Region in $\eta\pi\pi$ Invariant Mass Spectrum

J^{PC}	**Mass (MeV)**	**Partial Width (MeV)**	**Br**$(J/\psi \to \gamma X)Br(X \to a_0(980)\pi)$ $Br(a_0(980) \to \eta\pi)(\times 10^{-4})$
0^{-+}	$1283 \pm 4 \pm 14$	$51 \pm 10 \pm 12$	$6.9 \pm 0.3 \pm 1.7$
	$1477 \pm 4 \pm 17$	$42 \pm 11 \pm 10$	$6.8 \pm 0.3 \pm 1.7$
1^{++}	$1413 \pm 3 \pm 15$	$25 \pm 20 \pm 10$	$2.6 \pm 0.5 \pm 1.0$
	$1540 \pm 2 \pm 21$	$41 \pm 12 \pm 18$	$3.1 \pm 0.7 \pm 1.4$

2. Result and Discussions about 1.9 GeV Resonance in $\eta\pi\pi$ Invariant Mass Spectrum

Using two methods (Moment and Helicity), we analysed its angular distributions. After compared these results, we think that it is a 2^{-+} resonance.
After the BW fit, we obtain:
$M = 1910 \pm 28 \pm$ **20 MeV**
$\Gamma = 125 \pm 65 \pm$ 31 MeV
$Br(J/\psi \to \gamma X)Br(X \to a_0\pi)Br(a_0 \to \eta\pi) = (2.1 \pm 1.1 \pm 0.5) \times 10^{-4}$

♡ **Whether the $\eta_2(1910)$ which we got it at here can put into the 1^1D_2 nonet ?**
If it can be put into there, it will be a rich $s\bar{s}$ state.
♡ Is the $\eta_2(1910)$ a rich $s\bar{s}$ state?
We analysed the $J/\psi \to \gamma K^+K^-\pi^0$, based on our statistics, we can NOT see the resonance around 1.9 GeV, so $\eta_2(1910)$ is $UNLIKELY$ the ninth member of the $q\bar{q}$ 1^1D_2

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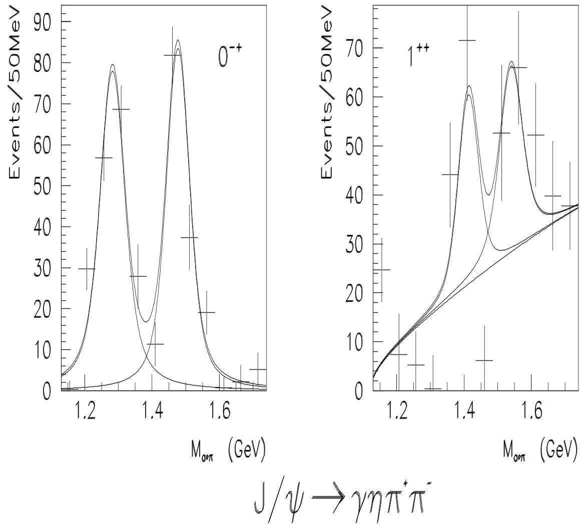

Figure 4: The BW fit of 0^{-+} and 1^{++} in 1.1~ 1.7 GeV mass region

(I=0) state.

♡ From $J/\psi \rightarrow \omega\eta\pi\pi$ and $J/\psi \rightarrow \phi\eta\pi\pi$ these J/ψ strong decays, we can see the signal around 1.9 GeV.

♡ We *MAY* say that $\eta_2(1910)$ was *PROBABLY* a *HYBRID*.

♡ Because of the low statistics , and the limit of the spin-parity analysis methods, the study of this state should be putted forward.

As compared with Crystal-barrel, we also analysed $J/\psi \rightarrow \gamma a_2(1320)\pi$ and $J/\psi \rightarrow \gamma f_2(1270)\eta$ channels. Results of our experiment and results of Crystal-barrel are more similarities then differences.

J^{PC}	Mass(MeV)	Width(MeV)	Decay modes	Exp.
2^{-+}	1650 ± 15	180 ± 75	$X \rightarrow a_2(1320)\pi$	Cry.-barrel
	$1691 \pm 21 \pm 19$	$189 \pm 50 \pm 26$	$X \rightarrow a_2(1320)\pi$	BES
2^{-+}	1850 ± 30	225 ± 50	$X \rightarrow f_2(1270)\eta$	Cry.-barrel
	$1905 \pm 9 \pm 26$	$68 \pm 52 \pm 44$	$X \rightarrow f_2(1270)\eta$	BES

IV. Summary

$$J/\psi \rightarrow \gamma a_0(980)\pi,\ a_0(980) \rightarrow \eta\pi$$

0^{-+} *states*

$M_1 = 1283 \pm 4 \pm 14$ MeV

$\Gamma_1 = 51 \pm 10 \pm 12$ MeV

$Br(J/\psi \rightarrow \gamma X)Br(X \rightarrow a_0\pi)Br(a_0 \rightarrow \eta\pi) = (6.9 \pm 0.3 \pm 1.7) \times 10^{-4}$

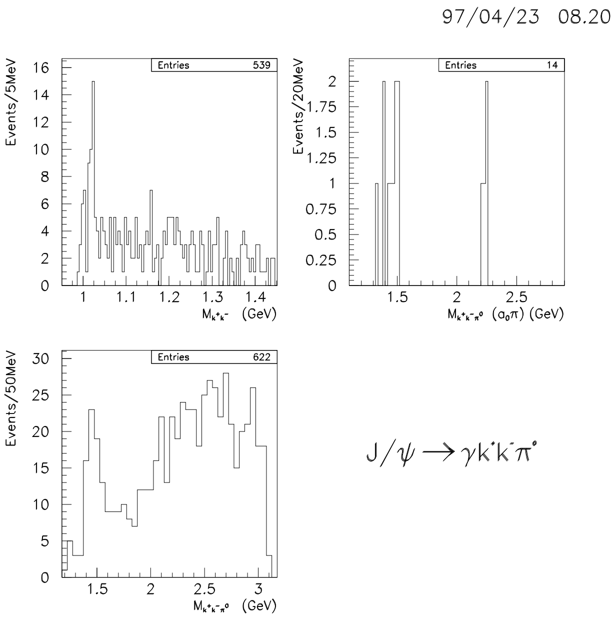

Figure 5: The invariant mass of $K^+K^-\pi^0$

Events $= 170 \pm 7$, 4σ

$M_2 = 1477 \pm 4 \pm 17$ MeV
$\Gamma_2 = 42 \pm 11 \pm 10$ MeV
$Br(J/\psi \to \gamma X)Br(X \to a_0\pi)Br(a_0 \to \eta\pi) = (6.8 \pm 0.3 \pm 1.7) \times 10^{-4}$
Events $= 169 \pm 7$, 6σ

1^{++} *states*
$M_1 = 1413 \pm 3 \pm 15$ MeV
$\Gamma_1 = 25 \pm 20 \pm 10$ MeV
$Br(J/\psi \to \gamma X)Br(X \to a_0\pi)Br(a_0 \to \eta\pi) = (2.6 \pm 0.5 \pm 1.0) \times 10^{-4}$
Events $= 65 \pm 13$, 6σ

$M_2 = 1540 \pm 2 \pm 21$ MeV
$\Gamma_2 = 41 \pm 12 \pm 18$ MeV
$Br(J/\psi \to \gamma X)Br(X \to a_0\pi)Br(a_0 \to \eta\pi) = (3.1 \pm 0.7 \pm 1.4) \times 10^{-4}$
Events $= 76 \pm 17$, 5σ

$$J/\psi \to \gamma a_0(980)\pi,\ a_0(980) \to \eta\pi$$

2^{-+} *states*
$M = 1910 \pm 28 \pm 20$ MeV

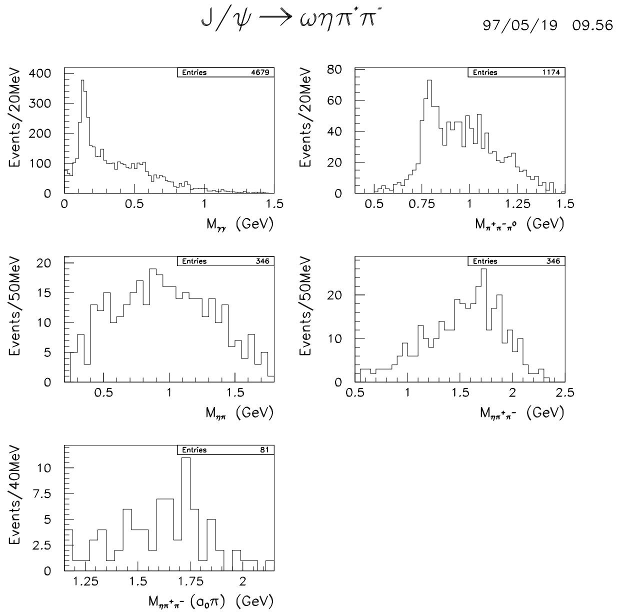

Figure 6: The invariant mass of $\eta\pi\pi$

$\Gamma = 125 \pm 65 \pm 31$ MeV
$Br(J/\psi \to \gamma X)Br(X \to a_0\pi)Br(a_0 \to \eta\pi) = (2.1 \pm 1.1 \pm 0.5) \times 10^{-4}$
Events $= 50 \pm 28,\ 3.8\sigma$

$$J/\psi \to \gamma f_2(1270)\eta,\ f_2(1270) \to \pi^+\pi^-$$

2^{-+} *states*
$M = 1905 \pm 9 \pm 26$ MeV
$\Gamma = 68 \pm 52 \pm 44$ MeV
$Br(J/\psi \to \gamma X)Br(X \to f_2\eta) = (3.0 \pm 2.2 \pm 1.9) \times 10^{-4}$
Events $= 11 \pm 8,\ 3.5\sigma$

$$J/\psi \to \gamma a_2(1320)\pi,\ a_2(1320) \to \eta\pi$$

2^{-+} *states*
$M = 1691 \pm 21 \pm 19$ MeV
$\Gamma = 189 \pm 50 \pm 26$ MeV
$Br(J/\psi \to \gamma X)Br(X \to a_2\eta) = (4.8 \pm 1.6 \pm 0.7) \times 10^{-3}$
Events $= 91 \pm 31,\ 8\sigma$

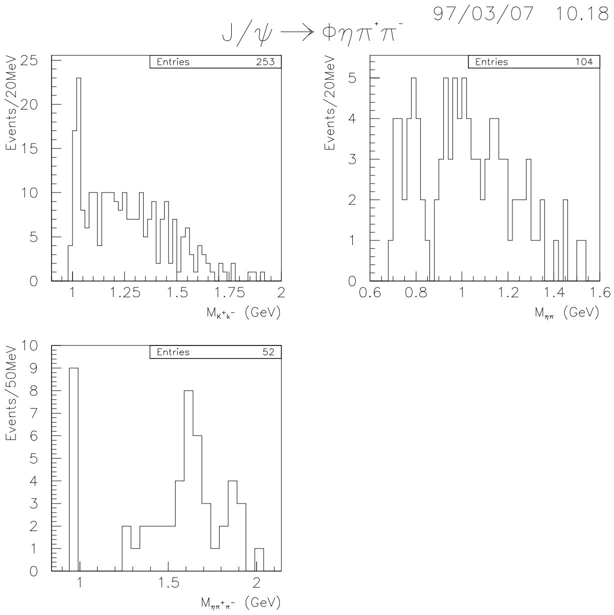

Figure 7: The invariant mass of $\eta\pi\pi$

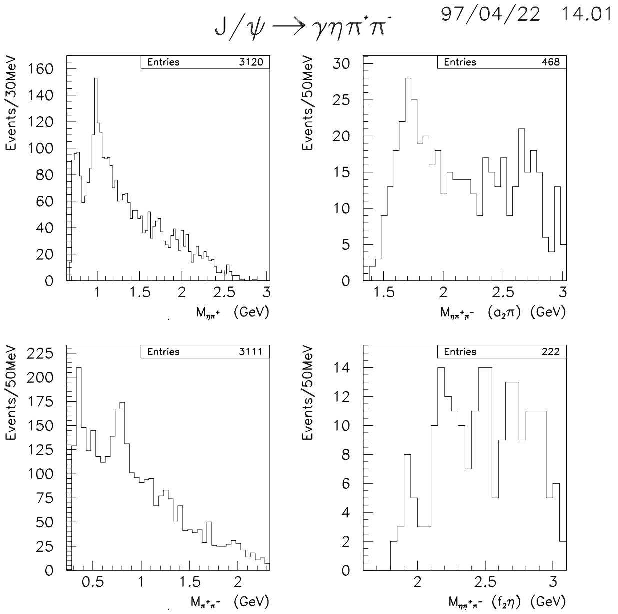

Figure 8: The invariant mass of $\eta\pi\pi$ after $a_2(1320)$ cut and $f_2(1270)$ cut

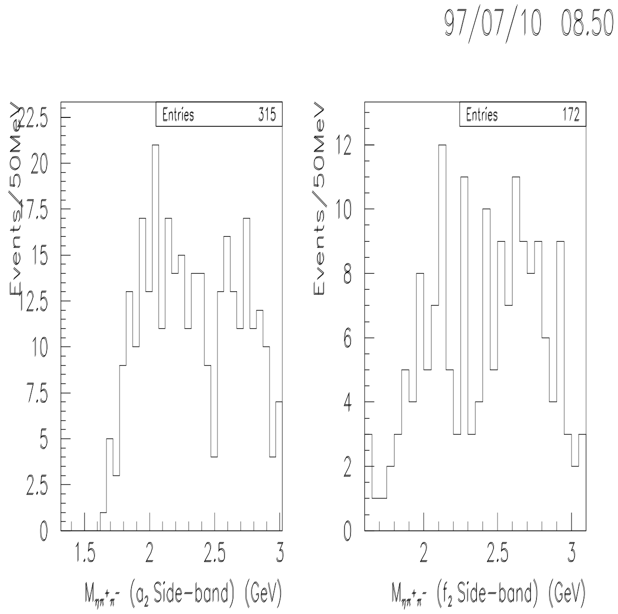

Figure 9: The $\eta\pi\pi$ invariant mass of $a_2(1320)$ side-band ans $f_2(1270)$ side-band