

Search for J/ψ Weak Decay

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Anshan, Liaoning

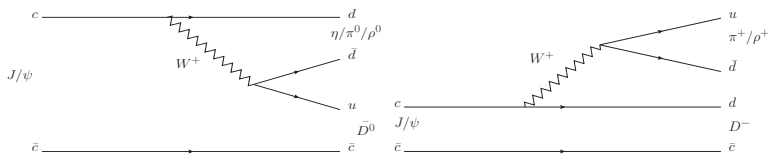
Motivation

- Hadronic, electromagnetic, and radiative decays of the J/ψ have been widely studied, weak decays seldom before, especially for $c \rightarrow d$ hadronic process.
- Kinematically, the J/ψ cannot decay to a pair of charmed D mesons, but can decay to a single D meson.
- The weak decays of charmonium are rare decays. Searching for weak decays of charmonium to single D mesons provides tests of standard model theory and serve as a probe of new physics.

▼ Weak decays			
Γ_{229}	$D^- e^+ \nu_e + \text{c.c.}$	$< 1.2 \times 10^{-5}$	CL=90% 984
Γ_{230}	$\bar{D}^0 e^+ e^- + \text{c.c.}$	$< 1.1 \times 10^{-5}$	CL=90% 987
Γ_{231}	$D_s^- e^+ \nu_e + \text{c.c.}$	$< 1.3 \times 10^{-6}$	CL=90% 923
Γ_{232}	$D_s^{*-} e^+ \nu_e + \text{c.c.}$	$< 1.8 \times 10^{-6}$	CL=90% 828
Γ_{233}	$D^- \pi^+ + \text{c.c.}$	$< 7.5 \times 10^{-5}$	CL=90% 977
Γ_{234}	$\bar{D}^0 \bar{K}^0 + \text{c.c.}$	$< 1.7 \times 10^{-4}$	CL=90% 898
Γ_{235}	$\bar{D}^0 \bar{K}^{*0} + \text{c.c.}$	$< 2.5 \times 10^{-6}$	CL=90% 670
Γ_{236}	$D_s^- \pi^+ + \text{c.c.}$	$< 1.3 \times 10^{-4}$	CL=90% 916
Γ_{237}	$D_s^- \rho^+ + \text{c.c.}$	$< 1.3 \times 10^{-5}$	CL=90% 663

Motivation

- $c \rightarrow u/s$ process such as $J/\psi \rightarrow D^0 e^+ e^-$, $J/\psi \rightarrow D^0 K^0$, $J/\psi \rightarrow D_s^- \rho^+$ and $J/\psi \rightarrow D^0 K^{*0}$ have been studied at BESII/BESIII
- More $c \rightarrow d$ process such as $J/\psi \rightarrow \bar{D}^0 \pi^0(\eta)(\rho^0)$, $D^- \pi^+(\rho^+)$ have not reported yet
- Multiple models¹²³ predict the order of branching fraction at $10^{-10} \sim 10^{-12}$.



¹EPJC55 607

²Int. J. Mod. Phys. A 14, 937(1997)

³Int. J. Mod. Phys. A30, 1550094 (2015)

Data sample and software version

- Data set(part blind):

- data (2009): J/ψ @3.097 GeV (225.3 ± 2.8) M
- MC (2009): J/ψ @3.097 GeV 225 M
- BOSS version: 664p01
- Signal MC: 600K for each signal channel
- Signal MC: $J/\psi \rightarrow \rho^+ \pi^-$, $J/\psi \rightarrow \rho^0 \pi^0$, $J/\psi \rightarrow \pi^+ \pi^0 \pi^-$ and $J/\psi \rightarrow \gamma \phi \phi$

- Decay Chain

- $J/\psi \rightarrow \bar{D}^0 M$
- $\bar{D}^0 \rightarrow K^+ e^- \bar{\nu}_e$
- $M \rightarrow \pi^+ \pi^- (\rho^0), \gamma \gamma (\pi^0, \eta)$
- $J/\psi \rightarrow D^- M$
- $D^- \rightarrow K_S^0 e^- \bar{\nu}_e$
- $M \rightarrow \pi^+ \pi^- (\rho^+), \pi^+$

- Compared with the hadronic final states, electron provide an effective "tag"

- Fully reconstruct the detectable final states
- Information of semi-leptonic decay is examined by $U_{\text{miss}} = E_{\text{miss}} - P_{\text{miss}}$, where $E_{\text{miss}} = E_{\text{CM}} - \sum_i E_i$, $P_{\text{miss}} = |-\sum_i \vec{p}_i|$, i denotes the final states
- Signal observable is recoiling mass of the light meson

- Charged track criteria:
 - $|\cos\theta| < 0.93$, $|R_z| < 10.0\text{cm}$, $|R_{xy}| < 1.0\text{cm}$
- PID:
 - pion, $\text{prob}(\pi) > \text{prob}(K)$, $\text{prob}(\pi) > 0$
 - kaon, $\text{prob}(K) > \text{prob}(\pi)$, $\text{prob}(K) > 0$
 - e, $\text{prob}(e) > \text{prob}(K)$, $\text{prob}(e) > \text{prob}(\pi)$, $\text{prob}(e) > 0.001$, $\text{EOP} > 0.8$
 - measurements: dE/dx , Tof, EMC(for e)
- γ :
 - $0 \leq t_{TDC} \leq 14$,
 - photon from barrel ($|\cos\theta| < 0.8$) : $E > 0.025\text{GeV}$.
 - photon from endcap ($0.86 < |\cos\theta| < 0.92$): $E > 0.05\text{GeV}$
- π^0 :
 - $0 \leq t_{TDC} \leq 14$,
 - photon from barrel ($|\cos\theta| < 0.8$) : $E > 0.025\text{GeV}$.
 - photon from endcap ($0.86 < |\cos\theta| < 0.92$): $E > 0.05\text{GeV}$
 - 1C: $\chi^2 < 200$, for bachelor π^0 , $\chi^2 < 20$

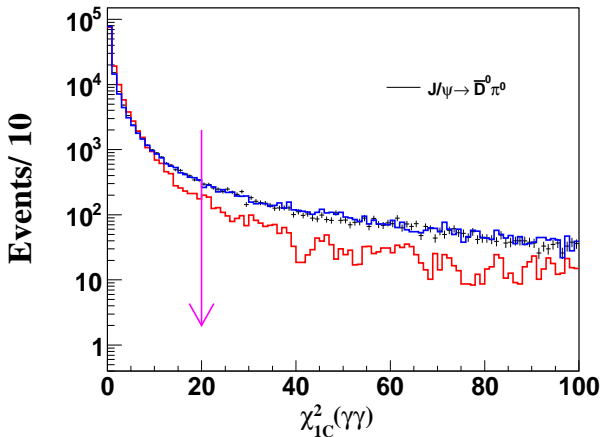
- η :
 - $0 \leq t_{TDC} \leq 14$,
 - photon from barrel ($|\cos\theta| < 0.8$) : $E > 0.025 \text{ GeV}$.
 - photon from endcap ($0.86 < |\cos\theta| < 0.92$): $E > 0.05 \text{ GeV}$
 - At most one photon from endcap.
 - 1C: $\chi^2 < 20$
- K_S :
 - $|\cos\theta| < 0.93$, $|R_z| < 30.0 \text{ cm}$ for tracks from K_S
 - no PID for pion
 - $m_{\pi^-\pi^+}$ lies in $(0.487, 0.511) \text{ GeV}/c^2$
 - Primary vertex fit: $\chi^2 < 100$
 - Second vertex fit : $L/\sigma > 2$
- ρ^{+0} : $(0.62, 0.95) \text{ GeV}/c^2$

Event Selection for $J/\psi \rightarrow \bar{D}^0 \pi^0$

Event Selection

$$J/\psi \rightarrow \bar{D}^0 \pi^0$$

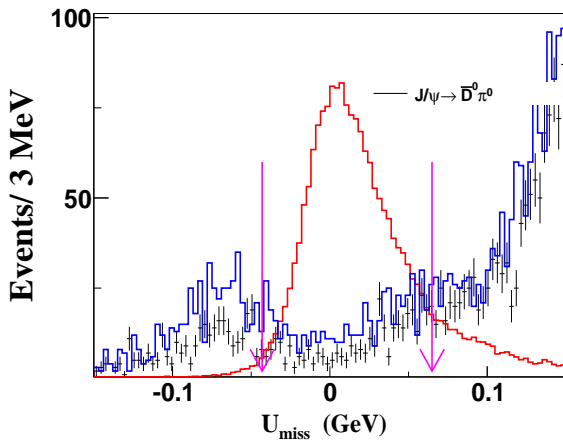
Dot with error bar is data, black line is inclusive MC, red line is signal MC.



$$\chi^2(\pi^0) < 20$$

Event Selection

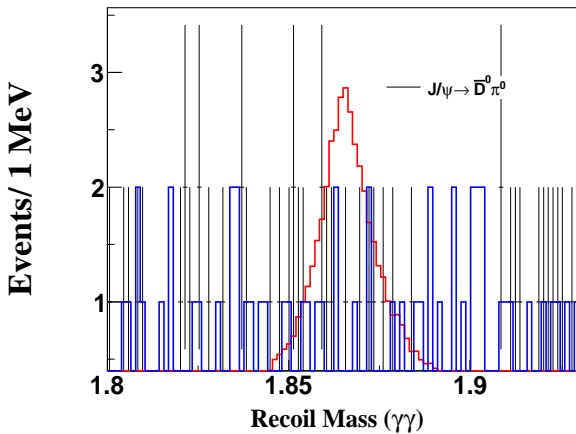
$$J/\psi \rightarrow \bar{D}^0 \pi^0$$



$$U_{\text{miss}} \in (-0.043, 0.065) \text{ GeV}$$

Event Selection

$$J/\psi \rightarrow \bar{D}^0 \pi^0$$



Background Check From Inclusive MC

$$J/\psi \rightarrow \bar{D}^0 \pi^0$$

No.	decay chain	final states	iTopology	nEvt	nTot
0	$J/\psi \rightarrow K^* K^0, K^* \rightarrow K^- \pi^+, K_S \rightarrow \pi^0 \pi^0$	$K^- \pi^0 \pi^0 \pi^+$	8	5	5
1	$J/\psi \rightarrow \gamma \pi^+ \pi^- \pi^0 \pi^0$	$\pi^- \pi^0 \pi^0 \pi^+ \gamma$	6	3	8
2	$J/\psi \rightarrow K^{*+} K^-, K^{*+} \rightarrow K^0 \pi^+, K_S \rightarrow \pi^0 \pi^0$	$K^- \pi^0 \pi^0 \pi^+$	4	3	11
3	$J/\psi \rightarrow \pi^- a_1^+, a_1^+ \rightarrow \rho^+ \pi^0, \rho^+ \rightarrow \pi^+ \pi^0$	$\pi^- \pi^0 \pi^0 \pi^+$	17	3	14
4	$J/\psi \rightarrow \pi^- \pi^0 \rho^+, \rho^+ \rightarrow \pi^+ \pi^0$	$\pi^- \pi^0 \pi^0 \pi^+$	10	2	16
5	$J/\psi \rightarrow \gamma K^+ K^-$	$K^- \gamma K^+$	3	2	18
6	$J/\psi \rightarrow a_2^+ \pi^-, a_2^+ \rightarrow \rho^+ \pi^0, \rho^+ \rightarrow \pi^+ \pi^0, \pi^+ \rightarrow \mu^+ \nu_\mu$	$\mu^+ \pi^- \pi^0 \pi^0 \nu_\mu$	21	2	20
7	$J/\psi \rightarrow K^0 K^- \pi^+, K_S \rightarrow \pi^0 \pi^0$	$K^- \pi^0 \pi^0 \pi^+$	23	2	22
8	$J/\psi \rightarrow a_2^- \pi^+, a_2^- \rightarrow \rho^- \pi^0, \rho^- \rightarrow \pi^- \pi^0$	$\pi^- \pi^0 \pi^0 \pi^+$	26	2	24
9	$J/\psi \rightarrow \rho^+ \pi^-, \rho^+ \rightarrow \pi^+ \pi^0$	$\pi^- \pi^0 \pi^+$	27	2	26
10	$J/\psi \rightarrow \gamma f_4(2050), f_4(2050) \rightarrow \pi^0 \pi^0$	$\pi^0 \pi^0 \gamma$	28	2	28
11	$J/\psi \rightarrow \gamma \eta \pi^0, \eta \rightarrow \gamma e^+ e^-$	$e^+ e^- \pi^0 \gamma \gamma$	11	1	29
12	$J/\psi \rightarrow \phi \pi^0 \pi^0, \phi \rightarrow K^+ K^-$	$K^- \pi^0 \pi^0 K^+$	12	1	30
13	$J/\psi \rightarrow K^* \bar{K}^0, K^* \rightarrow K^+ \pi^-, K_S \rightarrow \pi^0 \pi^0$	$\pi^- \pi^0 \pi^0 K^+$	13	1	31

$$J/\psi \rightarrow \bar{D}^0 \pi^0$$

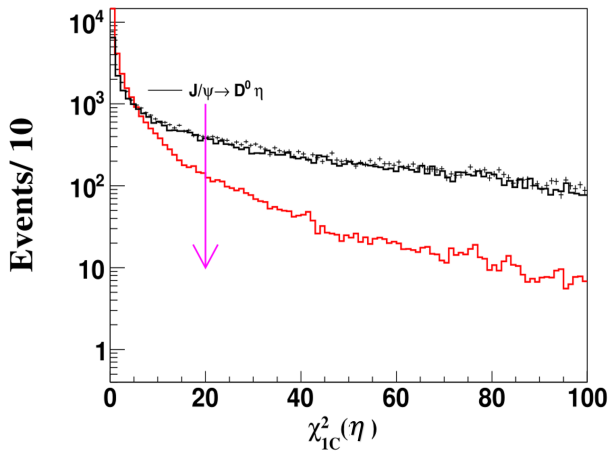
Selecton criteria:	Number	Absolute ratio (%)	Relative ratio (%)
Total Number	600000	100.0	100.0
Charged Track	483915	80.7	80.7
π/K PID	427082	71.2	88.3
Photon Selection	369846	61.6	86.6
e PID	294276	49.0	79.6
$\chi^2_{\gamma\gamma}$ Cut	285988	47.7	97.2
U_{miss} Cut	232539	38.8	81.3
Recoil Mass ($\gamma\gamma$) Range	220286	36.7	94.7

Event selection for $J/\psi \rightarrow \bar{D}^0 \eta$

Event Selection

$$J/\psi \rightarrow \bar{D}^0 \eta$$

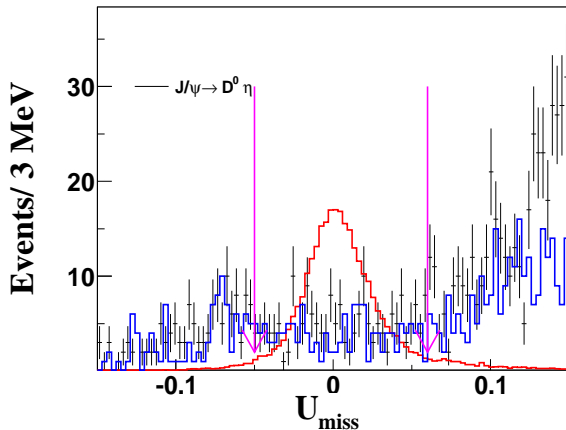
Dot with error bar is data, black line is inclusive MC, red line is signal MC.



$$\chi^2(\eta) < 20$$

Event Selection

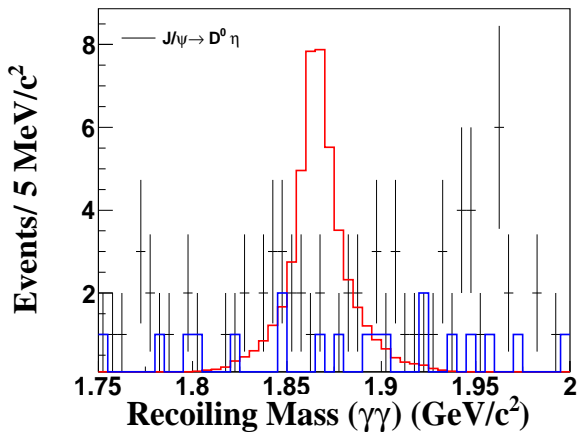
$$J/\psi \rightarrow \bar{D}^0 \eta$$



$$U_{\text{miss}} \in (-0.05, 0.06) \text{ GeV}$$

Event Selection

$$J/\psi \rightarrow \bar{D}^0 \eta$$



Background Check From Inclusive MC

$$J/\psi \rightarrow \bar{D}^0 \eta$$

No.	decay chain	final states	iTopology	nEvt	nTot
0	$J/\psi \rightarrow K^+ K^- \pi^0, \pi^0 \rightarrow \gamma\gamma$	$K^- \pi^0 K^+$	3	2	2
1	$J/\psi \rightarrow K^{*+} K_2^{*-}, K^{*+} \rightarrow K^0 \pi^+, K_2^{*-} \rightarrow K^- \pi^0, \pi^0 \rightarrow \gamma\gamma$	$K^- \pi^0 K^0 \pi^+$	1	1	3
2	$J/\psi \rightarrow \gamma \eta \pi^+ \pi^-, \eta \rightarrow \pi^0 \pi^0 \pi^0, \pi^0 \rightarrow \gamma\gamma$	$\pi^- \pi^+ \pi^0 \pi^0 \pi^0 \gamma$	2	1	4
3	$J/\psi \rightarrow \gamma K^+ K^{*-}, K^{*-} \rightarrow K^- \pi^0, \pi^0 \rightarrow \gamma\gamma$	$K^- \pi^0 \gamma K^+$	0	1	5
4	$J/\psi \rightarrow \gamma \bar{K}^* K^0, \bar{K}^* \rightarrow K^- \pi^+, K^0 \rightarrow K_L$	$K^- K_L \pi^+ \gamma$	4	1	6
5	$J/\psi \rightarrow \gamma \eta', \eta' \rightarrow \eta \pi^+ \pi^-, \eta \rightarrow \gamma\gamma$	$\gamma \gamma \gamma \pi^+ \pi^-$	5	1	7
6	$J/\psi \rightarrow \gamma \eta_2(1870), \eta_2(1870) \rightarrow a_0^+ \pi^-, a_0^+ \rightarrow \eta \pi^+, \eta \rightarrow \gamma\gamma$	$\gamma \gamma \gamma \pi^+ \pi^-$	6	1	8
7	$J/\psi \rightarrow K^+ K^- \pi^0 \pi^0, \pi^0 \rightarrow \gamma\gamma$	$K^- \gamma \gamma \gamma K^+$	7	1	9
8	$J/\psi \rightarrow \eta \rho^- \pi^+, \eta \rightarrow \gamma\gamma, \rho^- \rightarrow \pi^- \pi^0, \pi^0 \rightarrow \gamma\gamma$	$\pi^- \pi^+ \gamma \gamma \gamma$	8	1	10
9	$J/\psi \rightarrow \gamma K^- K^+$	$K^- \gamma K^+$	9	1	11
10	$J/\psi \rightarrow \gamma K_2^{*0} \bar{K}^0, \bar{K}^0 \rightarrow K^+ \pi^-, \gamma \rightarrow \gamma\gamma$	$\pi^- \gamma \gamma \gamma K_S K_2^{*0}$	10	1	12
11	$J/\psi \rightarrow K^+ \pi^0 K^{*-}, \pi^0 \rightarrow \gamma\gamma, K^{*-} \rightarrow \bar{K}^0 \pi^-$	$\bar{K}^0 \gamma \pi^- \gamma K^+$	11	1	13
12	$J/\psi \rightarrow \rho^- \pi^+ \eta, \rho^- \rightarrow \pi^- \pi^0, \eta \rightarrow \gamma\gamma, \pi^0 \rightarrow \gamma\gamma$	$\pi^- \pi^- \gamma \gamma \gamma$	12	1	14
13	$J/\psi \rightarrow K^- K^* \pi^+, K^* \rightarrow K^0 \pi^0, \pi^0 \rightarrow \gamma\gamma, K^0 \rightarrow K_S^0, K_S^0 \rightarrow \pi^+ \pi^-$	$\pi^- \pi^+ \pi^+ \gamma \gamma K^-$	13	1	15
14	$J/\psi \rightarrow \gamma \pi^+ \pi^- \pi^0 \pi^0, \pi^0 \rightarrow \gamma\gamma$	$\pi^- \pi^+ \gamma \gamma \gamma \gamma$	14	1	16
15	$J/\psi \rightarrow K^+ \bar{K}^0 \rho^-, \rho^- \rightarrow \pi^- \pi^0, \pi^0 \rightarrow \gamma\gamma$	$\pi^- \bar{K}^0 \pi^0 \gamma \gamma K^+$	15	1	17
16	$J/\psi \rightarrow \gamma K^- K_0^{*+}, K_0^{*+} \rightarrow K^+ \pi^0, \pi^0 \rightarrow \gamma\gamma$	$K^- K^+ \gamma \gamma$	16	1	18
17	$J/\psi \rightarrow a_2^- \rho^+, a_2^- \rightarrow \eta \pi^-, \rho^+ \rightarrow \pi^+ \pi^0, \eta \rightarrow \pi^0 \pi^0 \pi^0, \pi^0 \rightarrow \gamma\gamma$	$a_2^- \pi^+ \gamma \gamma \gamma \gamma$	17	1	19

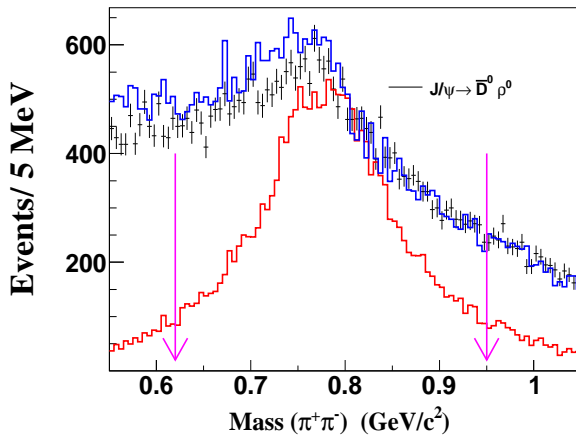
$$J/\psi \rightarrow \bar{D}^0 \eta$$

Selecton criteria:	Number	Absolute ratio (%)	Relative ratio (%)
Total Number	600000	100.0	100.0
Charged Track	480773	80.1	80.1
π/K PID	425416	70.9	88.5
Photon Selection	349208	58.2	82.1
e PID	264579	44.1	75.8
$\chi^2_{\gamma\gamma}$ Cut	236300	39.4	89.3
Missing U Cut	209371	34.9	88.6
Recoil Mass ($\gamma\gamma$) Range	201498	33.9	96.8

Event selection for $J/\psi \rightarrow \bar{D}^0 \rho^0$

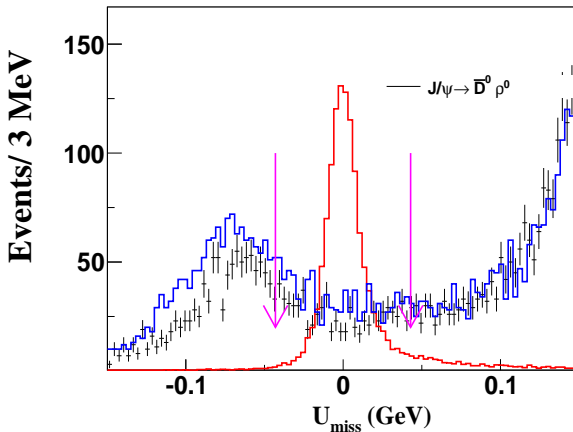
Event Selection

$$J/\psi \rightarrow \bar{D}^0 \rho^0$$



Event Selection

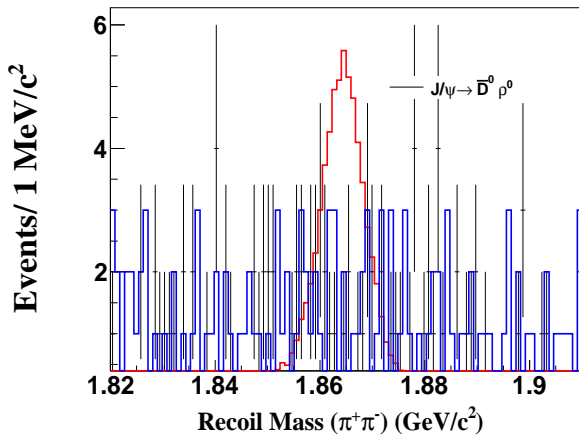
$$J/\psi \rightarrow \bar{D}^0 \rho^0$$



$$U_{\text{miss}} \in (-0.04, 0.05) \text{ GeV}$$

Event Selection

$$J/\psi \rightarrow \bar{D}^0 \rho^0$$



Background Check From Inclusive MC

$$J/\psi \rightarrow \bar{D}^0 \rho^0$$

No.	decay chain	final states	iTopology	nEvt	nTot
0	$J/\psi \rightarrow \pi^+ \pi^- \pi^+ \pi^- \pi^0, \pi^0 \rightarrow \gamma\gamma$	$\pi^- \pi^- \pi^0 \pi^+ \pi^+$	3	8	8
1	$J/\psi \rightarrow \omega \pi^+ \pi^-, \omega \rightarrow \pi^- \pi^+ \pi^0, \pi^0 \rightarrow \gamma\gamma$	$\pi^- \pi^- \pi^0 \pi^+ \pi^+$	7	8	16
2	$J/\psi \rightarrow b_1^- \pi^+, b_1^- \rightarrow \omega \pi^-, \omega \rightarrow \pi^- \pi^+ \pi^0, \pi^0 \rightarrow \gamma\gamma$	$\pi^- \pi^0 \pi^+ \pi^- \pi^+$	2	3	19
3	$J/\psi \rightarrow \omega f_2(1270), f_2(1270) \rightarrow \pi^- \pi^+ \pi^0, \pi^- \rightarrow \pi^+ \pi^-, \pi^0 \rightarrow \gamma\gamma$	$\pi^- \pi^0 \pi^+ \pi^+ \pi^-$	8	3	22
4	$J/\psi \rightarrow a_2^0 \rho^0, a_2^0 \rightarrow \rho^- \pi^+, \rho^- \rightarrow \pi^+ \pi^-, \pi^0 \rightarrow \gamma\gamma$	$\pi^- \pi^- \pi^0 \pi^+ \pi^+ \gamma$	0	2	24
5	$J/\psi \rightarrow \pi^- \pi^0 a_2^+, \pi^0 \rightarrow \gamma\gamma, a_2^+ \rightarrow \rho^0 \pi^+, \rho^0 \rightarrow \pi^+ \pi^-$	$\pi^- \pi^- \pi^0 \pi^+ \pi^+$	1	2	26
6	$J/\psi \rightarrow a_2^+ \pi^-, a_2^+ \rightarrow \eta \pi^+, \eta \rightarrow \pi^- \pi^+ \pi^0, \pi^0 \rightarrow \gamma\gamma$	$\pi^- \pi^0 \pi^+ a_2^+ \gamma \eta$	20	2	28
7	$J/\psi \rightarrow \bar{a}_2^- \rho^+, \bar{a}_2^- \rightarrow \rho^0 \pi^-, \rho^+ \rightarrow \pi^+ \pi^0, \rho^0 \rightarrow \pi^+ \pi^-, \gamma \rightarrow \gamma\gamma$	$\pi^- \bar{a}_2^- \pi^0 \pi^+ \pi^+ \gamma$	34	2	30
8	$J/\psi \rightarrow a_2^0 \rho^0, \rho^0 \rightarrow \rho^+ \pi^- \gamma FSR, \rho^+ \rightarrow \pi^+ \pi^-, \pi^- \rightarrow \pi^+ \pi^0, \pi^0 \rightarrow \gamma\gamma$	$\pi^- \pi^0 \pi^+ \pi^+ \pi^- \pi^-$	5	1	31

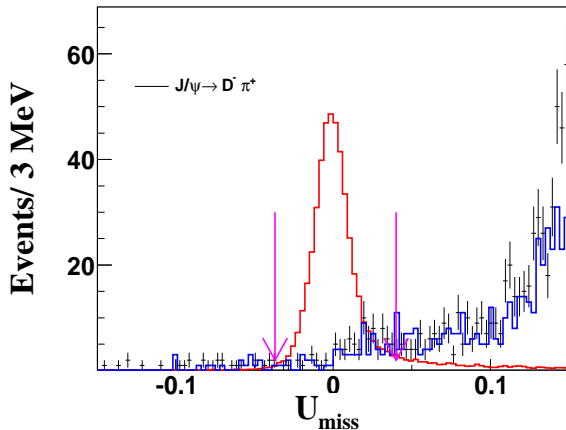
$$J/\psi \rightarrow \bar{D}^0 \rho^0$$

Selecton criteria:	Number	Absolute ratio (%)	Relative ratio (%)
Total Number	600000	100.0	100.0
Charged Track	435385	72.6	72.6
π/K PID	427225	71.2	98.1
Photon Selection	377946	63.0	88.5
e PID	278935	46.5	73.8
$\chi^2_{\gamma\gamma}$ Cut	232970	38.8	83.5
Mass ($\pi^+\pi^-$) Cut	202860	33.8	87.1
Missing U Cut	200961	33.5	99.1

Event selection for $J/\psi \rightarrow \bar{D}^- \pi^+$

Event Selection

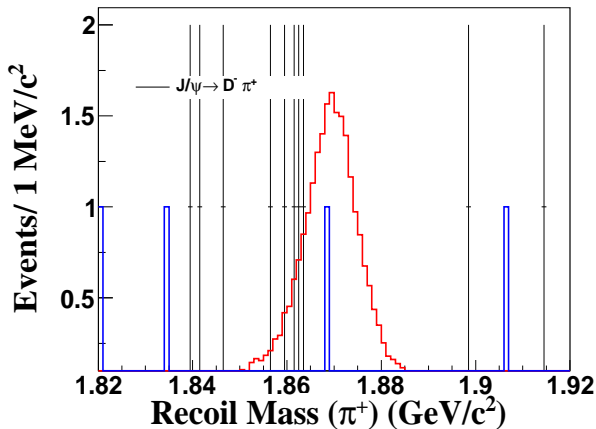
$$J/\psi \rightarrow D^- \pi^+$$



$$U_{\text{miss}} \in (-0.037, 0.04) \text{ GeV}$$

Event Selection

$$J/\psi \rightarrow D^- \pi^+$$



Background Check From Inclusive MC

$$J/\psi \rightarrow D^- \pi^+$$

No.	decay chain	final states	iTopology	nEvt	nTot
0	$J/\psi \rightarrow K_S K_L, K_S \rightarrow \pi^+ \pi^-$	$\pi^- \pi^+ K_L$	0	1	1
1	$J/\psi \rightarrow \bar{K}^0 K^0, \bar{K}^0 \rightarrow \pi^+ \pi^-, K^0 \rightarrow \pi^+ \pi^-$	$\pi^- \pi^- \pi^+ \pi^+$	1	1	2
2	$J/\psi \rightarrow \bar{K}^* K^0, \bar{K}^* \rightarrow K^- \pi^+, K^0 \rightarrow \pi^+ \pi^-$	$K^- \pi^+ \pi^+ \pi^-$	2	1	3
3	$J/\psi \rightarrow \omega \pi^+ \pi^-, \omega \rightarrow \pi^- \pi^+ \pi^0, \pi^0 \rightarrow \gamma \gamma$	$\pi^- \pi^- \pi^+ \gamma \gamma$	3	1	4

Cut Flow

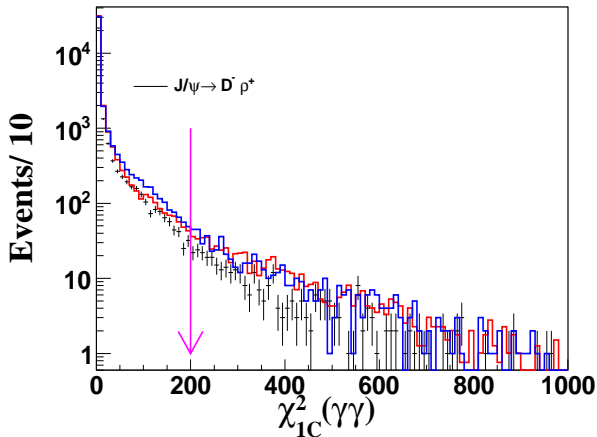
$$J/\psi \rightarrow D^- \pi^+$$

Selecton criteria:	Number	Absolute ratio (%)	Relative ratio (%)
Total Number	600000	100.0	100.0
Charged Track	434339	72.4	72.4
π/K PID	341258	56.9	78.6
K_S^0 Selection	304543	50.8	89.2
e PID	241117	40.2	79.2
Missing U Cut	211907	35.3	87.9
Recoil Mass (π^+) Range	210887	35.1	99.5

Event selection for $J/\psi \rightarrow D^- \rho^+$

Event Selection

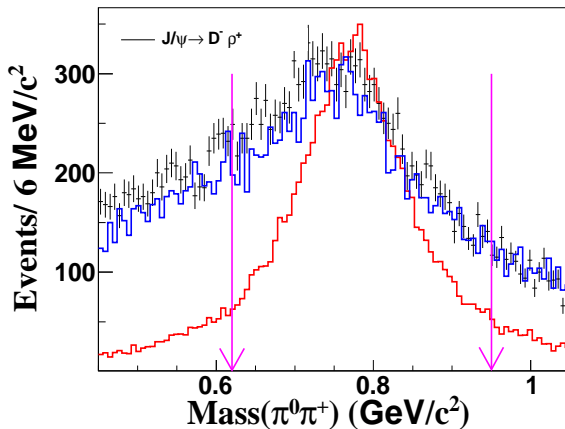
$$J/\psi \rightarrow D^- \rho^+$$



$$\chi^2(\pi^0) < 200$$

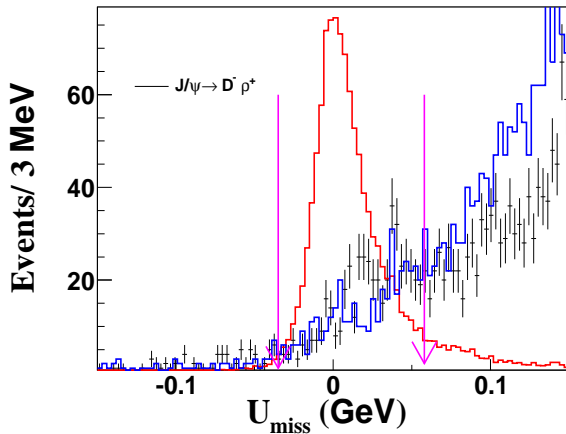
Event Selection

$$J/\psi \rightarrow D^- \rho^+$$



Event Selection

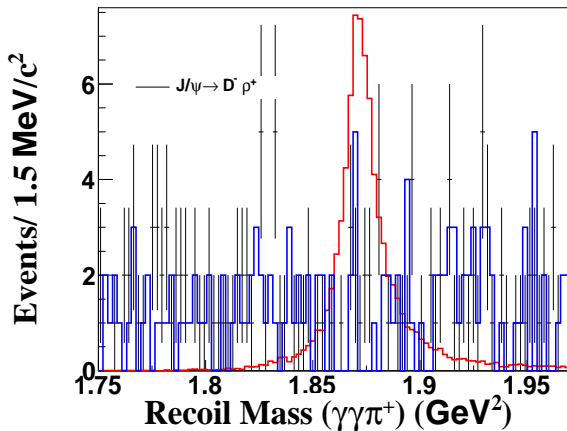
$$J/\psi \rightarrow D^- \rho^+$$



$$U_{\text{miss}} \in (-0.058, 0.074) \text{ GeV}$$

Event Selection

$$J/\psi \rightarrow D^- \rho^+$$



$$J/\psi \rightarrow D^- \rho^+$$

Selecton criteria:	Number	Absolute ratio (%)	Relative ratio (%)
Total Number	600000	100.0	100.0
Charged Track	398156	66.4	66.4
π PID	397329	66.2	99.8
Photon Selection	293669	48.9	73.9
K_S^0 Selection	199284	33.2	67.9
e PID	151457	25.2	76.0
χ_η^2	149177	24.9	98.5
Mass ($\pi^+ \pi^0$) cut	121871	20.3	81.7
Missing U Cut	101635	16.9	83.4
Recoil Mass ($\pi^+ \pi^0$) Range	91431	15.2	90.0

Background Check From Inclusive MC

$$J/\psi \rightarrow D^- \rho^+$$

No.	decay chain	final states	iTopology	nEvt	nTot
0	$J/\psi \rightarrow \bar{K}^* K^0, K^* \rightarrow K^- \pi^+, K^0 \rightarrow \pi^+ \pi^-$	$\pi^- \pi^+ K^- \pi^+$	5	2	2
1	$J/\psi \rightarrow K^0 \bar{K}^0 \pi^0, \pi^0 \rightarrow \gamma\gamma, K_S^0 \rightarrow \pi^+ \pi^-$	$\pi^- \pi^- \pi^+ \gamma \gamma \pi^- \pi^+$	1	1	3
3	$J/\psi \rightarrow \bar{K}^0 \rho^0 K^0, K_S \rightarrow \pi^+ \pi^-, K_L \rightarrow \gamma\gamma, \rho^0 \rightarrow \pi^+ \pi^-$	$\pi^- \pi^+ \pi^- \pi^+ \gamma \gamma$	3	1	5
4	$J/\psi \rightarrow \bar{K}^0 K^0 \rho^0, K_S \rightarrow \pi^+ \pi^-, K_L \rightarrow \gamma\gamma, \rho^0 \rightarrow \pi^+ \pi^-$	$\pi^- \pi^+ \pi^- \pi^+ \gamma \gamma$	4	1	6
5	$J/\psi \rightarrow \pi^+ b_1^- \pi^0, b_1^- \rightarrow \omega \pi^-, \pi^0 \rightarrow \gamma\gamma, \omega \rightarrow \pi^- \pi^+ \pi^0, \pi^0 \rightarrow \gamma\gamma$	$\pi^- \pi^+ \pi^- \pi^+ \gamma \gamma \gamma \gamma$	7	1	9
6	$J/\psi \rightarrow \rho^- K^+ \bar{K}^0, \rho^- \rightarrow \pi^- \pi^0, \pi^0 \rightarrow \gamma\gamma, K_S \rightarrow \pi^+ \pi^-$	$\pi^- \pi^+ \pi^- K^+ \gamma \gamma$	8	1	10
7	$J/\psi \rightarrow \pi^+ K^0 K_0^{*-}, K_0^{*-} \rightarrow \bar{K}^0 \pi^-, K_L \rightarrow \gamma\gamma, K_S \rightarrow \pi^+ \pi^-$	$\pi^- \pi^+ \pi^- \pi^+ \gamma \gamma$	11	1	13
8	$J/\psi \rightarrow K_0^{*-} K^+, K_0^{*-} \rightarrow \bar{K}^0 \pi^-, K_S \rightarrow \pi^+ \pi^-$	$\pi^- \pi^+ K^- \pi^+$	12	1	14
9	$J/\psi \rightarrow K^* \bar{K}^0, K^* \rightarrow K^0 \pi^0, \pi^0 \rightarrow \gamma\gamma, K_S \rightarrow \pi^+ \pi^-$	$\pi^- \pi^+ \pi^- \pi^+ \gamma \gamma$	15	1	17
10	$J/\psi \rightarrow \pi^+ K^0 K^{*-}, K^{*-} \rightarrow \bar{K}^0 \pi^-, K_L \rightarrow \gamma\gamma, K_S \rightarrow \pi^+ \pi^-$	$\pi^- \pi^+ \pi^- \pi^+ \gamma \gamma$	19	1	21
11	$J/\psi \rightarrow K^0 K^- \pi^+, K_S \rightarrow \pi^+ \pi^-$	$\pi^- \pi^+ K^- \pi^+$	20	1	22

Systematic Uncertainty

Sources	$J/\psi \rightarrow \bar{D}^0 \eta$ (%)	$J/\psi \rightarrow \bar{D}^0 \pi^0$ (%)	$J/\psi \rightarrow \bar{D}^0 \rho^0$ (%)	$J/\psi \rightarrow D^- \rho^+$ (%)	$J/\psi \rightarrow D^- \pi^+$ (%)
Tracking	2.0	2.0	4.0	4.0	4.0
PID	2.0	2.0	4.0	2.0	2.0
Photon Efficiency	2.0	2.0	-	2.0	-
ρ^+/ρ^0 Mass Cut	-	-	2.4	5.1	-
U_{miss} Cut	0.5	0.4	0.5	0.4	0.9
Model:	16.1	12.5	5.7	10.3	8.6
BR Errors	0.9	0.8	0.8	1.5	1.5
J/ψ Numbers	1.2	1.2	1.2	1.2	1.2
Total	16.5	13.1	8.5	12.6	9.9

Systematic Errors Study

- $J/\psi \rightarrow \gamma\phi\phi$: U_{miss} Cut
- $J/\psi \rightarrow \rho\pi$: $\rho^{0/+}$ mass window cut

Selection of $J/\psi \rightarrow \gamma\phi\phi$

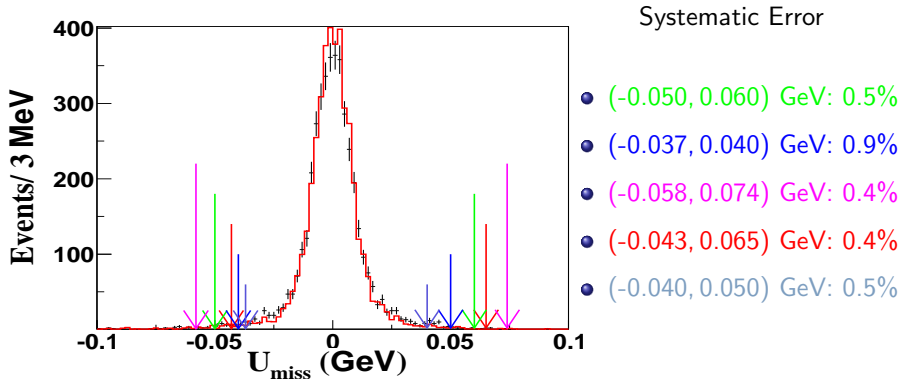
- Charged Track Selection : Same as $D^- \rho^+$ Selection
- Photon Selection: Same as $D^- \rho^+$ Selection
- Particle ID Selection: Same as $D^- \rho^+$ Selection
- For U_{miss} Studying
 - Choose smallest ($|M_{K_1^+ K_1^-} - M_\phi| + |M_{K_2^+ K_2^-} - M_\phi|$)
 - $M_{K_1^+ K_1^-} / M_{K_2^+ K_2^-} \in (1.01, 1.03)$ GeV/c^2
 - $|M_{\gamma\phi\phi} - M_{J/\psi}| < 0.4 \text{GeV}/c^2$
 - 4C: $\chi^2 < 50$

Bkgs. Level: About 1.3%

$J/\psi \rightarrow \phi\eta$

No.	decay chain	final states	iTopology	nEvt	nTot
0	$J/\psi \rightarrow \gamma\phi\phi, \phi \rightarrow K^+K^-, \phi \rightarrow K^+K^-$	$K^-K^-\gamma K^+K^-$	0	2678	2678
1	$J/\psi \rightarrow \gamma\eta(2250), \eta(2250) \rightarrow \phi\phi, \phi \rightarrow K^+K^-, \phi \rightarrow K^+K^-$	$K^-K^-\gamma K^+K^-$	1	808	3486
2	$J/\psi \rightarrow \gamma\eta_c, \phi \rightarrow \phi\phi, \phi \rightarrow K^+K^-, \phi \rightarrow K^+K^-$	$K^-K^-\gamma K^+K^-$	2	270	3756
3	$J/\psi \rightarrow f_1(1420)\phi, f_1(1420) \rightarrow K^+K^-\pi^0, \phi \rightarrow K^+K^-, \gamma \rightarrow \gamma\gamma$	$K^-K^-\gamma K^-\gamma K^+$	5	16	3772
4	$J/\psi \rightarrow \gamma\phi K^-K^+, \phi \rightarrow K^+K^-$	$K^-\gamma K^+K^+K^-$	6	14	3786
5	$J/\psi \rightarrow \phi f_1(1420), \phi \rightarrow K^+K^-, f_1(1420) \rightarrow K^+K^-\pi^0, \pi^0 \rightarrow \gamma\gamma$	$K^-K^-\gamma\gamma K^+K^-$	4	7	3793
6	$J/\psi \rightarrow \phi K^{*+}K^-, \phi \rightarrow K^+K^-, K^{*+} \rightarrow K^+\pi^0, \pi^0 \rightarrow \gamma\gamma$	$K^-\gamma\gamma K^+K^+K^-$	11	5	3799
7	$J/\psi \rightarrow \gamma K^-K^+\phi, \phi \rightarrow K^+K^-$	$K^-K^-\gamma K^+K^-$	8	2	3801
8	$J/\psi \rightarrow \phi K^{*-}K^+, \phi \rightarrow K^+K^-, K^{*-} \rightarrow K^-\pi^0, \pi^0 \rightarrow \gamma\gamma$	$K^-K^-\gamma\gamma K^+K^-$	7	2	3803
9	$J/\psi \rightarrow K_0^{*+}\phi K^-, K_0^{*+} \rightarrow K^+\pi^0, \phi \rightarrow K^+K^-, \pi^0 \rightarrow \gamma\gamma$	$K^-K^-\gamma\gamma K^+K^+$	9	1	3804
10	$J/\psi \rightarrow h_1(1380)K^+K^-, h_1(1380) \rightarrow K^{*+}K^-, K^{*+} \rightarrow K^+\pi^0, \pi^0 \rightarrow \gamma\gamma$	$K^-K^-\gamma\gamma K^+K^-$	10	1	3805
11	$J/\psi \rightarrow \gamma\phi\phi, \phi \rightarrow K^+K^-, \phi \rightarrow K^+K^-\gamma_{FSR}$	$K^-K^-\gamma K^+K^-\gamma_{FSR}$	3	1	3806
Total					3815

U_{miss} Distribution

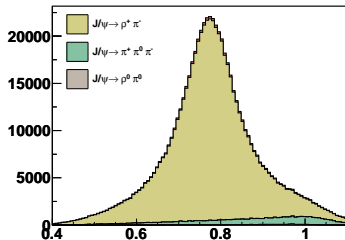


Selection of $J/\psi \rightarrow \rho\pi$

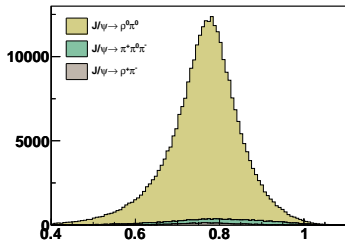
- Charged Track Selection : Same as $J/\psi \rightarrow D\rho$ Selection
- Photon Selection: Same as $J/\psi \rightarrow D\rho$ Selection
- Particle ID Selection: Same as $J/\psi \rightarrow D\rho$ Selection
- For ρ mass window cut:
 - $|M_{\pi^+\pi^0\pi^-} - M_{J/\psi}| < 0.04 \text{ GeV}/c^2$
 - 1C kinematic fit on π^0 : $\chi^2 < 20$
 - $J/\psi \rightarrow \rho^+\pi^-$: $M_{\pi^+\pi^-} > 0.95 \text{ GeV}/c^2$
 - $J/\psi \rightarrow \rho^0\pi^0$: $M_{\pi^+\pi^0}/M_{\pi^-\pi^0} > 0.95 \text{ GeV}/c^2$

Background Check

$$J/\psi \rightarrow \rho^+ \pi^-$$



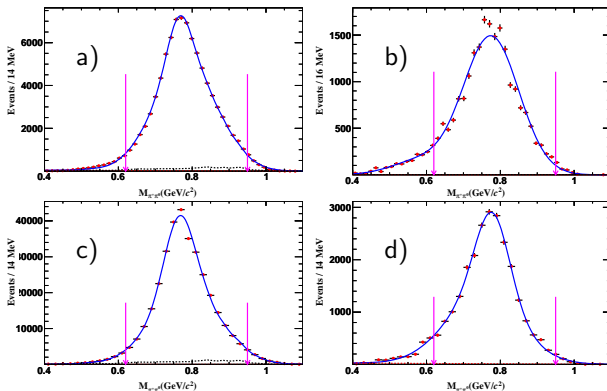
$$J/\psi \rightarrow \rho^0 \pi^0$$



Other backgrounds level is less than 0.3%, can be negligible

Systematic uncertainty on ρ mass window requirement

data: Double Gaussian + polynomial function + $J/\psi \rightarrow \pi^+\pi^0\pi^-$
MC: Double Gaussian + polynomial function

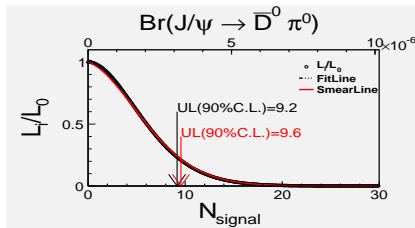
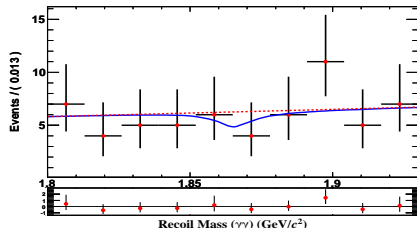


Systematic uncertainty, ρ : 2.8%, ρ^+ : 5.1%

Results

Distribution of Mass

$$J/\psi \rightarrow \bar{D}^0 \pi^0 + c.c.$$

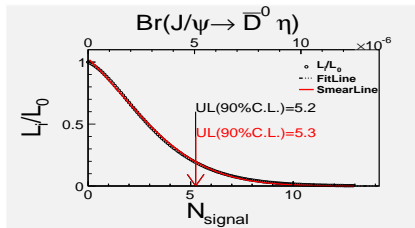
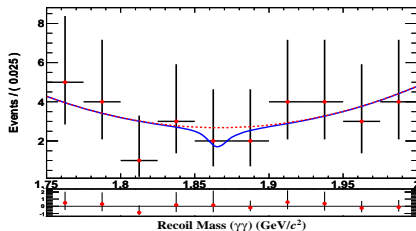


- Bayesian approaches
- 130 times unbinned fits
- Exclusive MC signal shape + 2-nd order chebychev polynomial

Number of signal: < 9.6 (CL=90%)

Distribution of Mass

$$J/\psi \rightarrow \bar{D}^0 \eta + c.c.$$

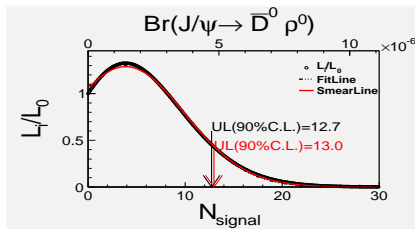
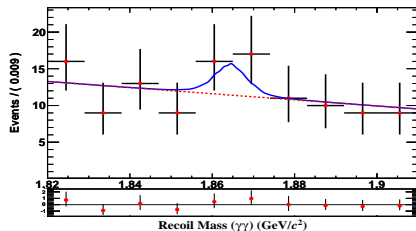


- Bayesian approaches
- 130 times unbinned fits
- Exclusive MC signal shape + 2-nd order chebychev polynomial

Number of signal: < 5.3 (CL=90%)

Distribution of Mass

$$J/\psi \rightarrow \bar{D}^0 \rho^0 + c.c.$$

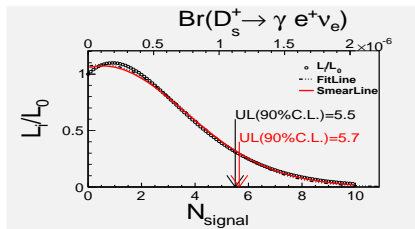
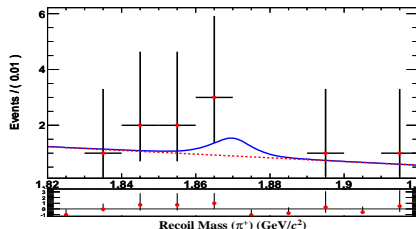


- Bayesian approaches
- 300 times unbinned fits
- Exclusive MC signal shape + 2-nd order chebychev polynomial

Number of signal: < 13.0 (CL=90%)

Distribution of Mass

$$J/\psi \rightarrow D^- \pi^+ + c.c.$$

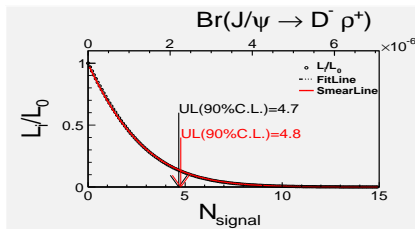
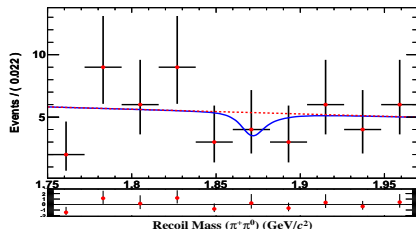


- Bayesian approaches
- 100 times unbinned fits
- Exclusive MC signal shape + 2-nd order chebychev polynomial

Number of signal: < 5.7 (CL=90%)

Distribution of Mass

$$J/\psi \rightarrow D^- \rho^+ + c.c.$$



- Bayesian approaches
- 150 times unbinned fits
- Exclusive MC signal shape + 2-nd order chebychev polynomial

Number of signal: < 4.8 (CL=90%)

Final results

- $J/\psi \rightarrow \bar{D}^0 \pi^0 + c.c.:$ $BR < 3.2 \times 10^{-6}$
- $J/\psi \rightarrow \bar{D}^0 \eta + c.c.:$ $BR < 5.3 \times 10^{-6}$
- $J/\psi \rightarrow \bar{D}^0 \rho^0 + c.c.:$ $BR < 4.8 \times 10^{-6}$
- $J/\psi \rightarrow D^- \pi^+ + c.c.:$ $BR < 1.2 \times 10^{-6}$
- $J/\psi \rightarrow D^- \rho^+ + c.c.:$ $BR < 2.3 \times 10^{-6}$

- First search for J/ψ weak decay $J/\psi \rightarrow \bar{D}^0 \pi^0 / \eta / \rho^0 + c.c.$ and $J/\psi \rightarrow D^- \rho^+ + c.c.$
- The order of $\mathcal{B}_{J/\psi \rightarrow D^- \pi^+ + c.c.}$ decay are improved
- We have studied the data/MC difference of efficiency on U_{miss} and ρ mass window requirements

Thank you for attention!

Backup

Input branching fractions

- $J/\psi \rightarrow \bar{D}^0 \pi^0$: a) 10^{-6} , b) 2×10^{-6} , c) 5×10^{-6} , d) 10×10^{-6}
- $J/\psi \rightarrow \bar{D}^0 \eta$
- $J/\psi \rightarrow \bar{D}^0 \rho^0$
- $J/\psi \rightarrow D^- \pi^+$
- $J/\psi \rightarrow D^- \rho^+$

$$J/\psi \rightarrow \bar{D}^0 \pi^0$$

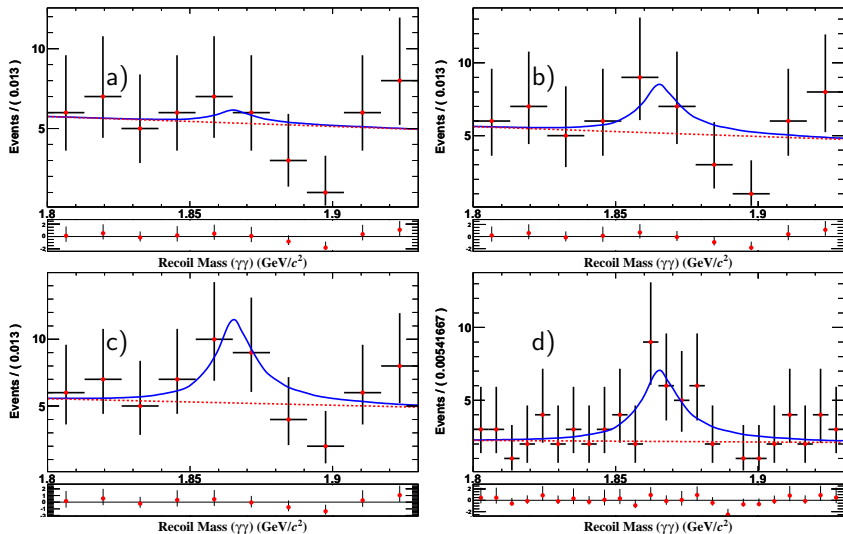
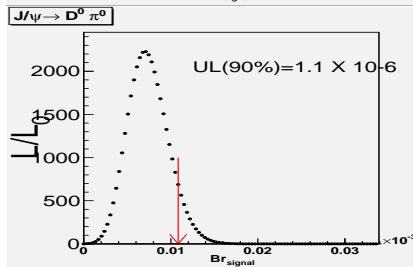
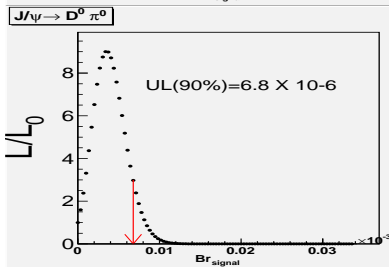
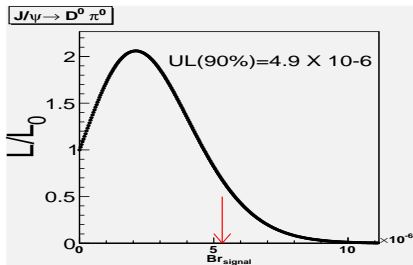
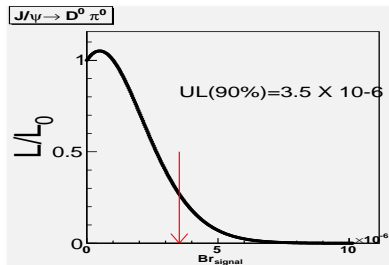


Figure: a) $(5.2 \pm 19.2) \times 10^{-7}$, b) $(2.2 \pm 2.1) \times 10^{-6}$, c) $(4.0 \pm 2.3) \times 10^{-6}$, d) $(0.8 \pm 0.3) \times 10^{-5}$

$$J/\psi \rightarrow \bar{D}^0 \pi^0$$



$$J/\psi \rightarrow \bar{D}^0 \eta$$

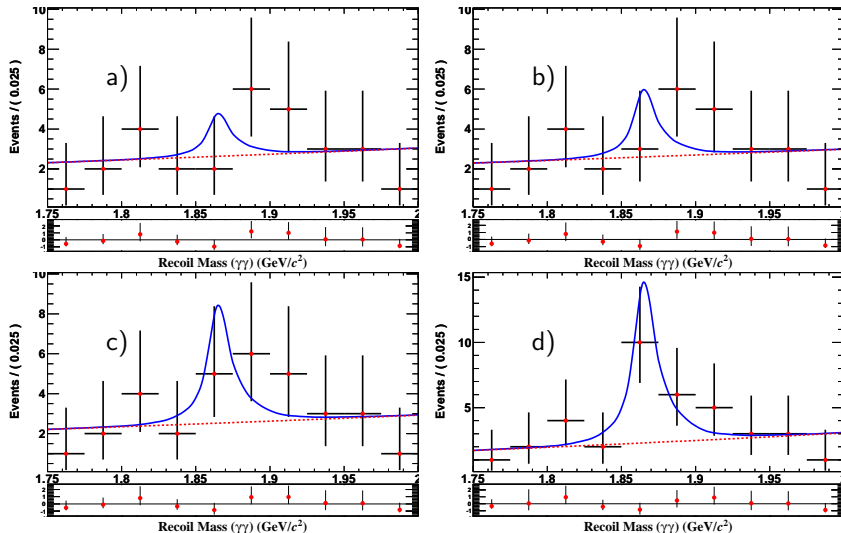
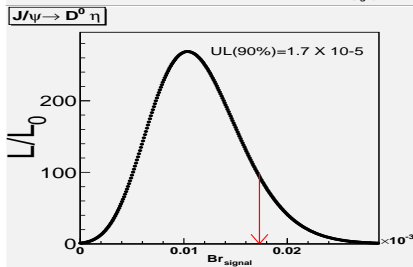
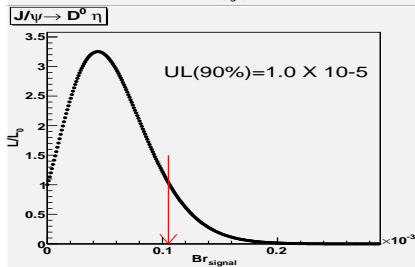
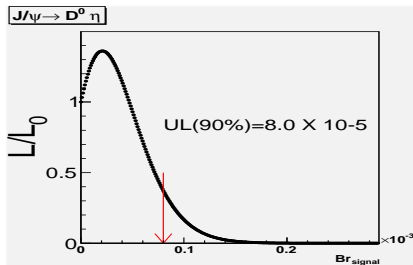
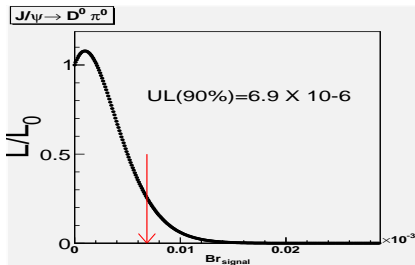


Figure: a) $(2.2 \pm 3.2) \times 10^{-6}$, b) $(3.6 \pm 3.5) \times 10^{-6}$, c) $(6.4 \pm 4.) \times 10^{-6}$, d) $(1.3 \pm 0.5) \times 10^{-5}$

$$J/\psi \rightarrow \bar{D}^0 \eta$$



$$J/\psi \rightarrow \bar{D}^0 \rho^0$$

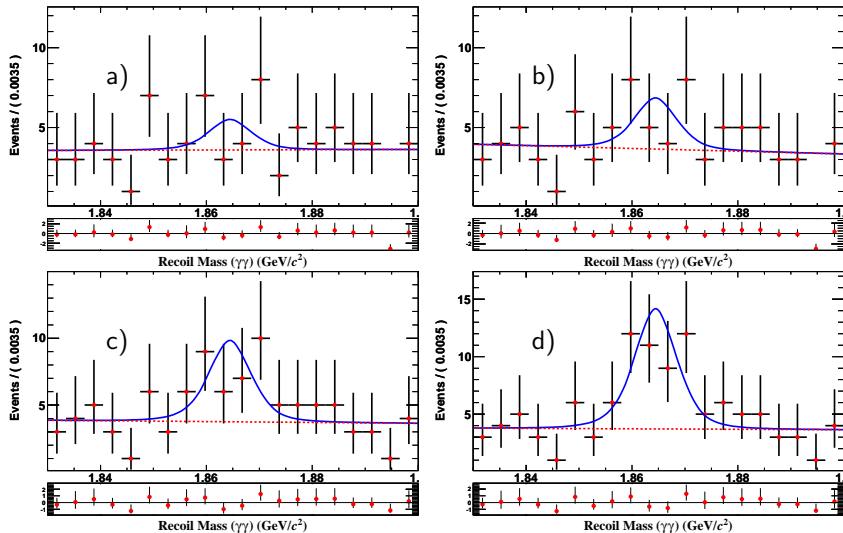
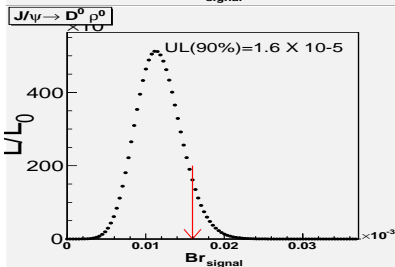
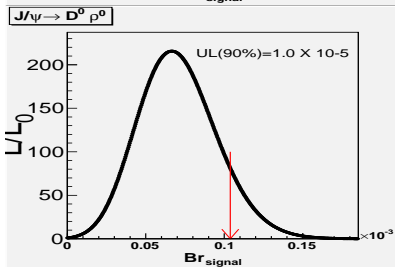
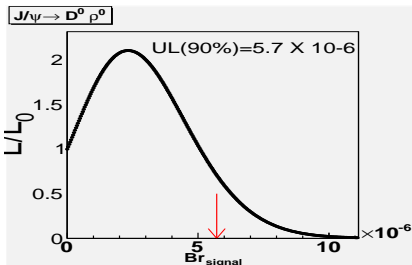
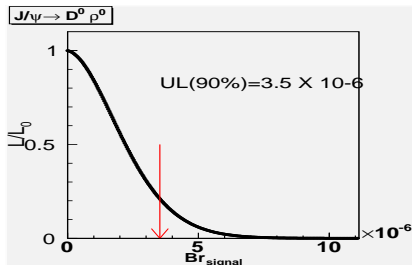


Figure: a) $(2.2 \pm 2.2) \times 10^{-6}$, b) $(3.7 \pm 2.3) \times 10^{-6}$, c) $(7.4 \pm 2.7) \times 10^{-6}$, d) $(1.2 \pm 0.3) \times 10^{-5}$

$$J/\psi \rightarrow \bar{D}^0 \rho^0$$



$$J/\psi \rightarrow D^- \pi^+$$

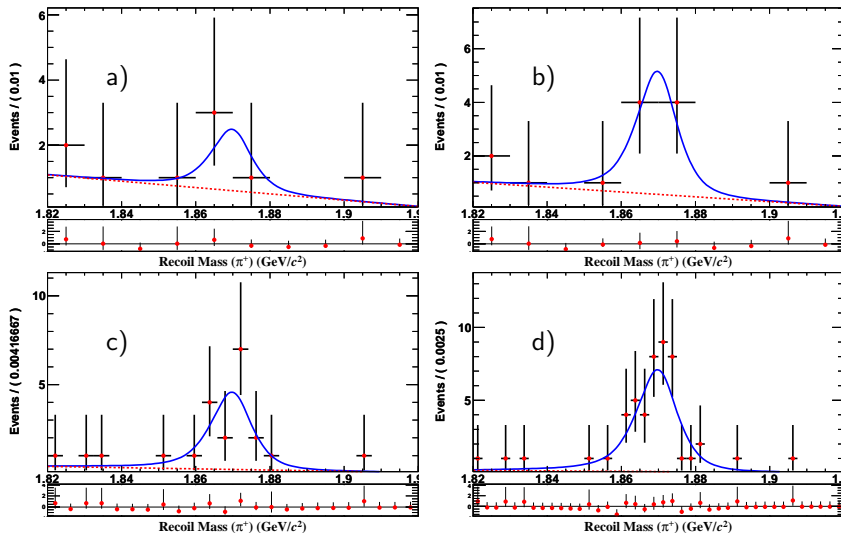
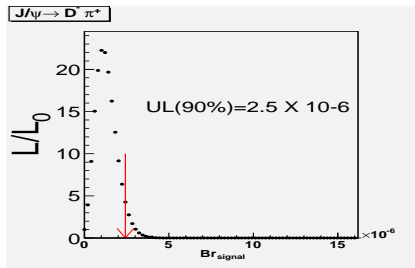
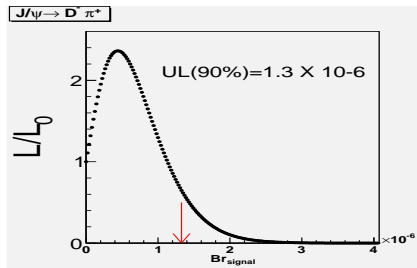


Figure: a) $(0.6 \pm 0.5) \times 10^{-7}$, b) $(1.5 \pm 0.6) \times 10^{-6}$, c) $(4.9 \pm 1.0) \times 10^{-6}$, d) $(9.2 \pm 1.4) \times 10^{-6}$

$$J/\psi \rightarrow D^- \pi^+$$



$$J/\psi \rightarrow D^- \rho^+$$

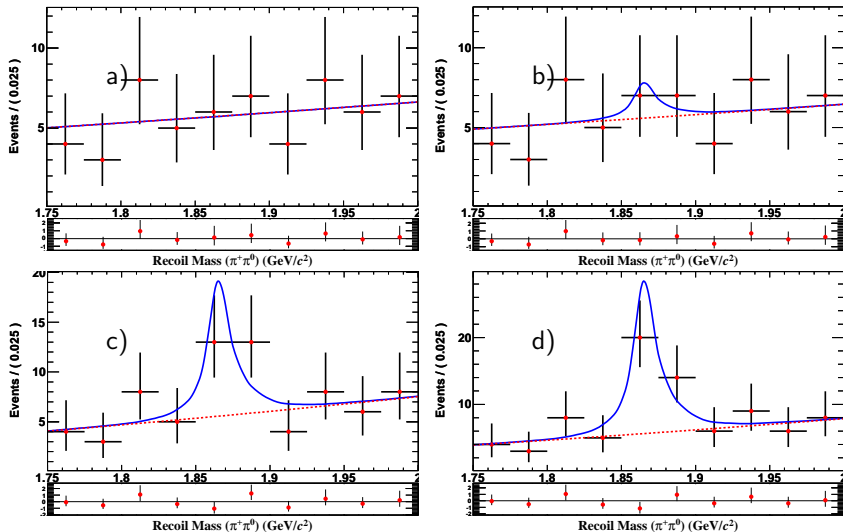
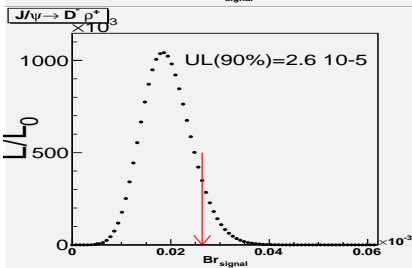
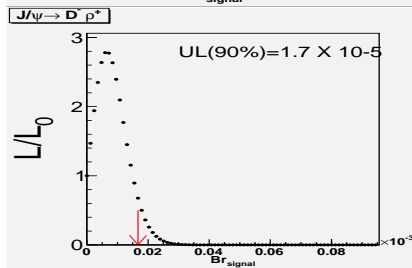
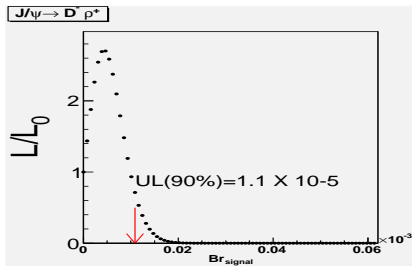
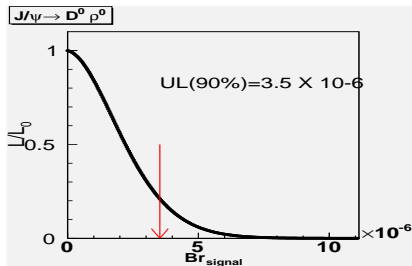
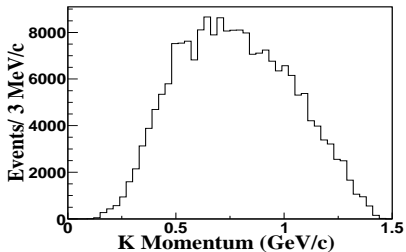
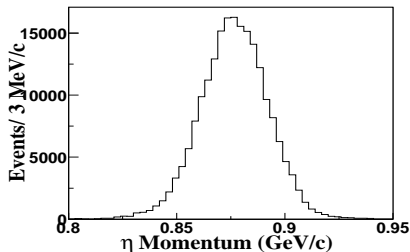
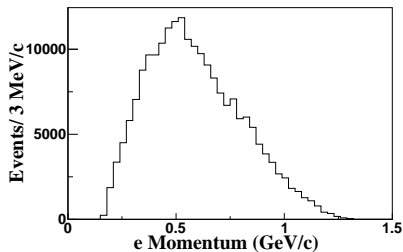


Figure: a) $(0.0 \pm 1.9) \times 10^{-7}$, b) $(1.1 \pm 2.1) \times 10^{-6}$, c) $(3.7 \pm 2.3) \times 10^{-6}$, d) $(6.8 \pm 2.8) \times 10^{-6}$

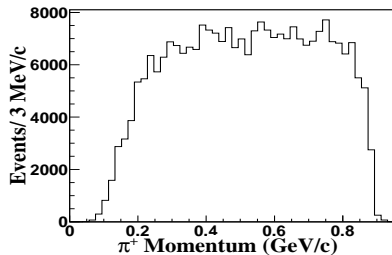
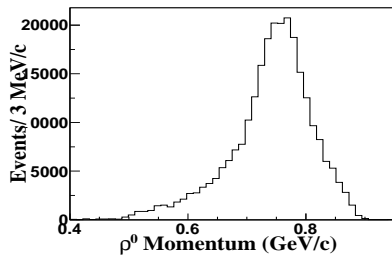
$$J/\psi \rightarrow D^- \rho^+$$



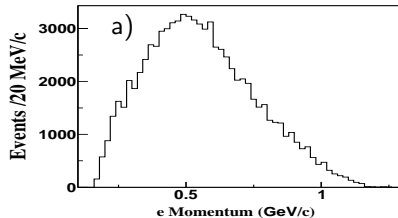
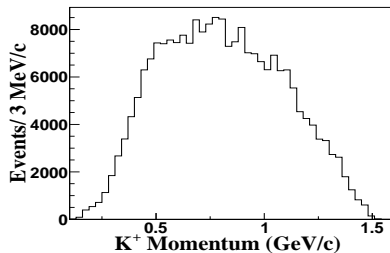
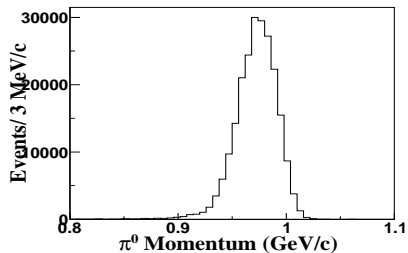
Momentum distribution from $J/\psi \rightarrow \bar{D}^0 \eta$



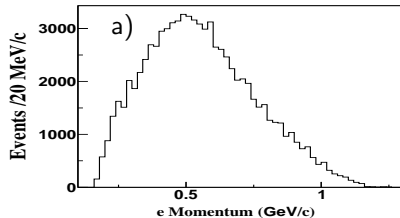
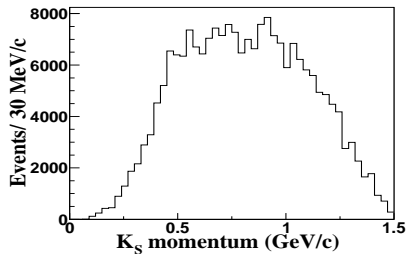
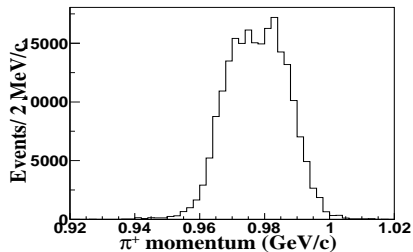
Momentum distribution from $J/\psi \rightarrow \bar{D}^0 \rho^0$



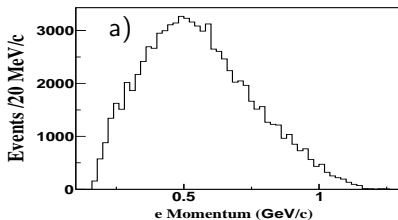
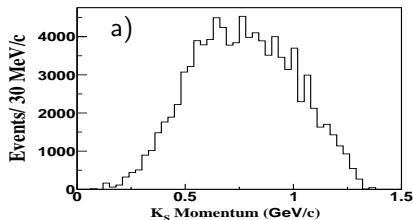
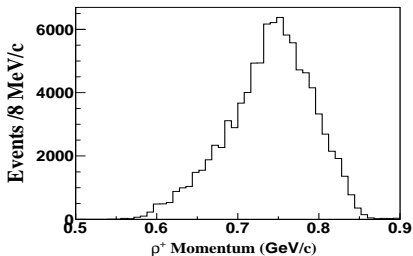
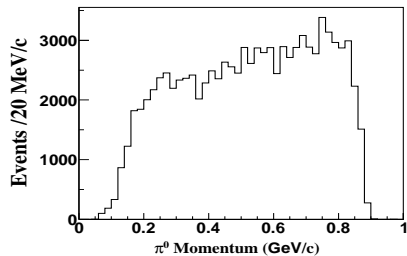
Momentum distribution from $J/\psi \rightarrow \bar{D}^0 \pi^0$



Momentum distribution from $J/\psi \rightarrow D^- \pi^+$



Momentum distribution from $J/\psi \rightarrow D^- \rho^+$

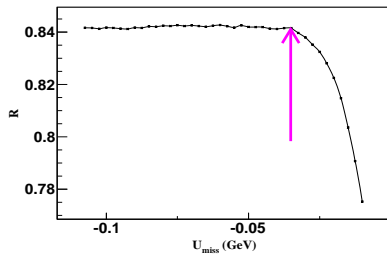
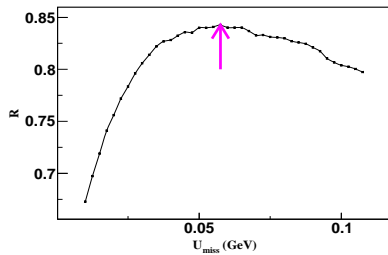


Optimization on U_{miss} Cut

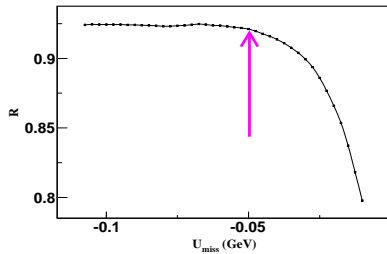
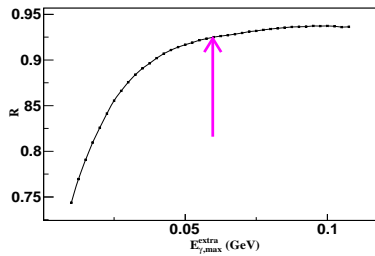
$$R = r_{\text{sig}} / \sqrt{r_{\text{sig}} + r_{\text{bkg}}},$$

where $r_{\text{sig}} = \frac{N_{\text{cut}}^{\text{sig}}}{N_{\text{tot}}^{\text{sig}}}$, $r_{\text{bkg}} = \frac{N_{\text{cut}}^{\text{bkg}}}{N_{\text{tot}}^{\text{bkg}}}$, $N_{\text{cut}}^i (i = \text{sig}, \text{bkg})$ is the number of events after applying U_{miss} cut

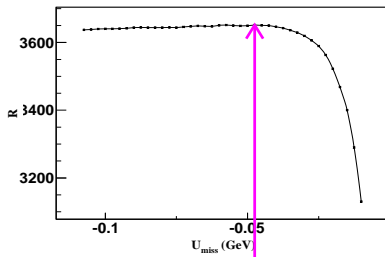
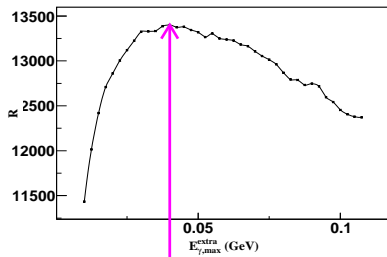
$$J/\psi \rightarrow \bar{D}^0 \pi^0 + c.c.$$



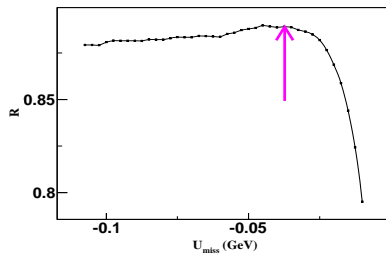
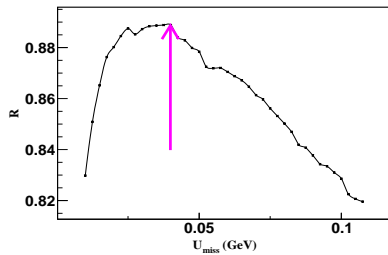
$$J/\psi \rightarrow \bar{D}^0 \eta + c.c.$$



$$J/\psi \rightarrow \bar{D}^0 \rho^0 + c.c.$$



$$J/\psi \rightarrow D^- \pi^+ + c.c.$$



$$J/\psi \rightarrow \rho\pi$$

- $J/\psi \rightarrow \rho^+\pi^-$: