



Search for Electromagnetic Dalitz decay $J/\psi \rightarrow \mu^+ \mu^- \eta'$

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Motivation

- The Electromagnetic Dalitz decays of $J/\psi \rightarrow \mu^+\mu^- P(P = \pi^0, \eta, \eta')$ have not been studied so far, due to the difficulty from the identification between pion and muon, especially for the soft muon.
- Based on 10 billion J/ψ events collected by BESIII, we search for the Electromagnetic Dalitz decay $J/\psi \rightarrow \mu^+ \mu^- \eta'$, and try to study the transition factor of J/ψ decays to η' .
- The predicted branching fractions of $J/\psi \to \mu^+\mu^- P\left(P = \pi^0, \eta, \eta'\right)$ [1] are listed in the Table.

Decay mode	e^+e^-	$\mu^+\mu^-$
$\psi ightarrow \pi^0 l^+ l^-$	$(3.89^{+0.37}_{-0.33}) \times 10^{-7}$	$(1.01^{+0.10}_{-0.09}) \times 10^{-7}$
$\psi ightarrow \eta l^+ l^-$	$(1.21 \pm 0.04) \times 10^{-5}$	$(0.30 \pm 0.01) \times 10^{-5}$
$\psi ightarrow \eta' l^+ l^-$	$(5.66 \pm 0.16) \times 10^{-5}$	$(1.31 \pm 0.04) \times 10^{-5}$

[1] J. L. Fu, H. B. Li, X. S. Qin, and M. Z. Yang, Mod. Phys. Lett. A, 27, 1250223 (2012).

Data Set

> BOSS version : BOSS 708

> Data sample : J/ψ data in 2009

> Inclusive MC : J/ψ MC in 2009

➢ Signal MC : 0.225 million events

vents

$$J/\psi \rightarrow \mu^+\mu^-\eta'$$
 DalitzJPLL 3.686
 $\eta' \rightarrow \pi^+\pi^-\eta$ PHSP
 $\eta' \rightarrow \gamma\pi^+\pi^-$ Etap2gpipi 0
 $\eta \rightarrow \gamma\gamma$ PHSP

Basic Event Selection criteria

Good charged track selection

- $|cos\theta| < 0.93$
- $|R_{xy}| < 1 \text{ cm}, |R_z| < 10 \text{ cm}$
- $N_{\text{Good}} = 4$, $\sum Q_{\text{net}} = 0$

D Particle identification (PID)

- Use dE/dx+TOF+EMC;
- Obtain the χ^2_{PID} value for each assumed combination of

 $\mu^+, \mu^-, \pi^+, \pi^-.$

Good Good photon

- $0 \leq TDC \leq 14 \text{ (x50ns)}$
- Barrel : $|\cos\theta| < 0.8, E_{\gamma} > 25$ MeV;
- End cap : $0.86 < |\cos\theta| < 0.92$, $E_{\gamma} > 50$ MeV;

•
$$N_{\gamma} \geq 1$$
, or $N_{\gamma} \geq 2$.

DID	The good charged track								
ΓID	1th	2th	3th	4th					
$\chi^2_{\rm PID1}$	μ^+	μ^-	π^+	π^-					
$\chi^2_{\rm PID2}$	μ^+	π^{-}	π^+	μ^-					
$\chi^2_{\rm PID3}$	π^+	π^{-}	μ^+	μ^-					
$\chi^2_{\rm PID4}$	π^+	μ-	μ^+	π^-					

• For $\eta' \to \pi^+\pi^-\eta$, $\eta \to \gamma\gamma$ case

5C kinematic fit

- The invariant mass of the two good photons is constrained into the η mass in PDG.
- Choose the best two photons with the least χ^2_{5C} .
- **The best candidate in an event**
 - select the best combination with the minimum value of $\chi^2_{tot} = \chi^2_{PID} + \chi^2_{vertex} +$

 $\chi^2_{4C} + (\chi^2_{1C}(\eta \to \gamma \gamma))$ from the four combinations of $\mu^+, \mu^-, \pi^+, \pi^-$.

• For $\eta' \to \pi^+ \pi^- \gamma$ case

4C kinematic fit

• Choose the best photon with the

least χ^2_{4C} .

Background analysis

The main ones: the pion mis-identified as muon.

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Table 1: Event trees and their respective initial-final states.

index	event tree (event initial-final states)	iEvtTr	iEvtIFSts	nEvts	nCmltEvts
1	$e^+e^- \to J/\psi, J/\psi \to \pi^+\pi^-\eta', \eta' \to \pi^+\pi^-\eta, \eta \to \gamma\gamma$ $(e^+e^- \to \pi^+\pi^+\pi^-\pi^-\gamma\gamma)$	0	0	1000	1000
2	$e^+e^- \to J/\psi, J/\psi \to \rho^0 \eta', \rho^0 \to \pi^+\pi^-, \eta' \to \pi^+\pi^-\eta, \eta \to \gamma\gamma$ $(e^+e^- \to \pi^+\pi^+\pi^-\pi^-\gamma\gamma)$	1	0	433	1433
3	$e^+e^- \to J/\psi, J/\psi \to \pi^+\pi^+\pi^-\pi^-\eta, \eta \to \gamma\gamma$ $(e^+e^- \to \pi^+\pi^+\pi^-\pi^-\gamma\gamma)$	5	0	254	1687
4	$e^+e^- \to J/\psi, J/\psi \to \eta_c \gamma, \eta_c \to \pi^+\pi^-\eta', \eta' \to \pi^+\pi^-\eta, \eta \to \gamma\gamma$ $(e^+e^- \to \pi^+\pi^+\pi^-\pi^-\gamma\gamma\gamma)$	14	3	32	1719
5	$e^+e^- \to J/\psi, J/\psi \to \pi^+\pi^-\eta\gamma, \eta \to \pi^0\pi^+\pi^- (e^+e^- \to \pi^+\pi^+\pi^-\pi^-\gamma\gamma\gamma)$	6	3	26	1745
6	$e^+e^- \to J/\psi, J/\psi \to \pi^+\pi^-\eta\gamma, \eta \to \pi^+\pi^-\gamma \\ (e^+e^- \to \pi^+\pi^+\pi^-\pi^-\gamma\gamma)$	2	0	22	1767
7	$e^+e^- \to J/\psi, J/\psi \to \eta'\gamma, \eta' \to \pi^+\pi^-\eta, \eta \to \gamma\gamma$ $(e^+e^- \to \pi^+\pi^-\gamma\gamma\gamma)$	7	4	20	1787
8	$e^+e^- \to J/\psi, J/\psi \to \pi^+\eta b_1^-, \eta \to \gamma\gamma, b_1^- \to \pi^-\omega, \omega \to \pi^+\pi^- (e^+e^- \to \pi^+\pi^+\pi^-\pi^-\gamma\gamma)$	18	0	17	1804
9	$e^+e^- \to J/\psi, J/\psi \to \omega\eta', \omega \to \pi^+\pi^-, \eta' \to \pi^+\pi^-\eta, \eta \to \gamma\gamma$ $(e^+e^- \to \pi^+\pi^+\pi^-\pi^-\gamma\gamma)$	16	0	10	1814
10	$e^+e^- \to J/\psi, J/\psi \to \pi^-\eta b_1^+, \eta \to \gamma\gamma, b_1^+ \to \pi^+\omega, \omega \to \pi^+\pi^- (e^+e^- \to \pi^+\pi^+\pi^-\pi^-\gamma\gamma)$	11	0	8	1822
11	$e^+e^- \to J/\psi, J/\psi \to \rho^0 \eta', \rho^0 \to \pi^+\pi^-\gamma_{FSR}, \eta' \to \pi^+\pi^-\eta, \eta \to \gamma\gamma$ $(e^+e^- \to \pi^+\pi^+\pi^-\pi^-\gamma\gamma\gamma\gamma_{FSR})$	15	5	8	1830
12	$e^+e^- \to J/\psi, J/\psi \to \pi^+\pi^-\eta'\gamma_{FSR}, \eta' \to \pi^+\pi^-\eta, \eta \to \gamma\gamma$ $(e^+e^- \to \pi^+\pi^+\pi^-\pi^-\gamma\gamma\gamma_{FSR})$	17	5	7	1837
13	$e^+e^- \to J/\psi, J/\psi \to \eta' \rho(1700)^0, \eta' \to \pi^+\pi^-\eta, \rho(1700)^0 \to \pi^+\pi^-, \eta \to \gamma\gamma \\ (e^+e^- \to \pi^+\pi^+\pi^-\pi^-\gamma\gamma)$	8	0	7	1844
14	$e^+e^- \to J/\psi, J/\psi \to \pi^+\pi^-\eta', \eta' \to \pi^+\pi^-\eta\gamma_{FSR}, \eta \to \gamma\gamma$ $(e^+e^- \to \pi^+\pi^+\pi^-\pi^-\gamma\gamma\gamma_{FSR})$	10	5	5	1849
15	$e^+e^- \to J/\psi, J/\psi \to \pi^0 \pi^+ \pi^- \eta, \eta \to \pi^+ \pi^- \gamma (e^+e^- \to \pi^+ \pi^+ \pi^- \pi^- \gamma \gamma \gamma)$	24	3	4	1853
16	$e^+e^- \to J/\psi, J/\psi \to \pi^0\pi^0\pi^+\pi^+\pi^-\pi^- \\ (e^+e^- \to \pi^+\pi^+\pi^-\pi^-\gamma\gamma\gamma\gamma)$	29	6	4	1857
17	$e^+e^- \to J/\psi, J/\psi \to \pi^+\pi^-h_1(1170)\gamma, h_1(1170) \to \pi^0\rho^0, \rho^0 \to \pi^+\pi^- (e^+e^- \to \pi^+\pi^+\pi^-\pi^-\gamma\gamma\gamma)$	22	3	2	1859

Further Event Selection criteria for muon/pion identification

For $\eta' \rightarrow \pi^+ \pi^- \eta$ case





 $\Box \chi^2_{\text{tot}}(\mu^+\mu^-\eta') < \chi^2_{\text{tot}}(\pi^+\pi^-\eta')$



Events: 157/1893=8.2%



Events: 254/1223=20%

\Box The depth for μ^+ or μ^- in MUC



The depth for μ^+ in MUC vs. its momentum

$\Box E_{\text{EMC}}(\mu^{\pm}) \in [0.15, 0.23] \text{ GeV}$

The energy deposited in EMC (E_{EMC}) for μ^+ vs. its momentum



$\square N_{\text{layers}}^{\text{MUC}} \geq 3 \text{ for } \mu^+ \text{ or } \mu^-$

The number of hit layers in MUC for μ^+



Summary of the event selection criteria so far

- $\chi^2_{5c} < 50;$
- $\chi^2_{\text{tot}}(\mu^+\mu^-\eta') < \chi^2_{\text{tot}}(\pi^+\pi^-\eta');$
- The number of hit layers in MUC is at least three;
- The energy deposition in EMC can be in the range of 0.15 GeV to 0.23 GeV;
- If $0.6 GeV/c, the depth in MUC should be greater than <math>-37.4 + 68 \times p$ (cm);
- If p > 1.1 GeV/*c*, the depth in MUC should be bigger than 42 cm.

Next, use TMVA method to further reduce the mis-

identification between muon and pion.

(Thanks for the help from Dr. Yilong Wang!)

The first TMVA

	Input variables for μ^+										
1	info_raw_charged_tracks[2][7]	The energy deposited in EMC of μ^+									
2	info_raw_charged_tracks[2][8]	The P_x in EMC of μ^+									
3	info_raw_charged_tracks[2][9]	The P_y in EMC of μ^+									
4	info_raw_charged_tracks[2][10]	The P_z in EMC of μ^+									
5	info_raw_charged_tracks[2][13]	The $ heta$ in EMC of μ^+									
6	info_raw_charged_tracks[2][18]	The last hit layers in MUC of μ^+									
7	info_raw_charged_tracks[2][22]	The P_z of μ^+									
8	info_raw_charged_tracks[2][30]	latMoment of μ^+									
9	info_raw_charged_tracks[2][37]	e3x3/e5x5 of <i>µ</i> ⁺									
10	info_raw_charged_tracks[2][39]	dedxnumGoodHits of μ^+									

	Input Variables for µ ⁻										
11	info_raw_charged_tracks[3][7]	The energy deposited in EMC of μ^-									
12	info_raw_charged_tracks[3][8]	The P_x in EMC of μ^-									
13	info_raw_charged_tracks[3][9]	The P _y in EMC of μ^-									
14	info_raw_charged_tracks[3][10]	The P_z in EMC of μ^-									
15	info_raw_charged_tracks[3][13]	The $ heta$ in EMC of μ^-									
16	info_raw_charged_tracks[3][18]	The last hit layers in MUC of μ^-									
17	info_raw_charged_tracks[3][22]	The P_z of μ^-									
18	info_raw_charged_tracks[3][30]	latMoment of μ^-									
19	info_raw_charged_tracks[3][37]	e3x3/e5x5 of μ^-									
20	info_raw_charged_tracks[3][39]	dedxnumGoodHits of μ^-									

The first TMVA results on the correlation matrix

The large correlations between some input variables happen.

	Correlation Matrix (background)																							
													11	inear		rrela	tion		ffici	ente	in 9	6		
100	,	d tracks[3][39]	-2			-1	-2				-2		10	4	4	1	10	-3	1	5	8	100		100
	,	d tracks[3][37]										-1	91	26	30	32	91	9	-1	-12	100	8		
80	,	d tracks[3][30]		1				-1	1	-1	1		19	5	6	6	18	-19		100	-12	5		80
	,	d tracks[3][22]		-21					-25			-1	-1	86	-1	-1	-3		100		-1	1		~~
60	,	d_tracks[3][18]	-1			1	-1			-4		1	3	1		1	3	100		-19	9	-3		60
	,	d_tracks[3][13]	-1				-1				-1	-1	99	26	34	34	100	3	-3	18	91	10		
40	,	d_tracks[3][10]			15	22		-1					34	9	10	100	34	1	-1	6	32	1		40
	,	ed_tracks[3][9]	-1		22	-17	-1		1		-1		34	8	100	10	34		-1	6	30	4		00
20	,	ed_tracks[3][8]		-17					-21			-1	29	100	8	9	26	1	86	5	26	4		20
	,	ed_tracks[3][7]	-1				-1				-1	-1	100	29	34	34	99	3	-1	19	91	10		~
0	,	d_tracks[2][39]	10	5	5	3	10	1	3	8	8	100	-1	-1			-1	1	-1		-1			0
00	,	d_tracks[2][37]	91	25	30	31	91			-4	100	8	-1		-1		-1			1		-2		20
-20	,	d_tracks[2][30]	25	8	8	8	25		1	100	-4	8						-4		-1				-20
40	•	d_tracks[2][22]	1	87	-1		-1		100	1		3		-21	1				-25	1				40
-40	•	d_tracks[2][18]			1			100				1				-1				-1				-40
CO	•	d_tracks[2][13]	99	26	33	33	100		-1	25	91	10	-1		-1		-1	-1				-2		60
-60	,	d_tracks[2][10]	33	9	10	100	33			8	31	3			-17	22		1				-1		-00
00	,	ed_tracks[2][9]	33	8	100	10	33	1	-1	8	30	5			22	15								90
-00	1	ed_tracks[2][8]	28	100	8	9	26		87	8	25	5		-17					-21	1				-00
100	1	ed_tracks[2][7]	100	28	33	33	99		1	25	91	10	-1		-1		-1	-1				-2		100
-100			in	fo in	fo in	fo in	fo in	fo in	inf	in in	fo inf	in	in in	fo int	in	r in	ini	in	inf	ini	int	inf	6	-100
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Correlation Matrix (signal)

Linear correlation coefficients in %										100												
d_tracks[3][39]	1	2					2	-3	1	5	25	10	10	8	25	-2	1	17	21	100		100
d_tracks[3][37]	-6	-2	-1	-1	-6			13	-8	1	95	35	33	34	95	37		-4	100	21		90
d_tracks[3][30]	9	4	2	2	9			-24	15	-2	18	6	6	6	18	-52		100	-4	17		00
d_tracks[3][22]		29			-1		24	1		1		81			-1		100			1		60
d_tracks[3][18]	-13	-5	-4	-4	-13			30	-20	4	25	8	9	9	25	100		-52	37	-2		00
d_tracks[3][13]	-5	-2	-1	-1	-5			8	-6		99			36	100	25	-1	18	95	25		40
d_tracks[3][10]	-1	-1	26	31	-1		-1	2	-2	1	36	13	13	100	36	9		6	34	8		40
ed_tracks[3][9]	-1		32	-27	-1			3	-2	1	35	13	100	13	35	9		6	33	10		20
jed_tracks[3][8]	-1	31		-1	-2		30	3	-2	2	37	100	13	13	35	8	81	6	35	10		20
ed_tracks[3][7]	-5	-1	-1	-1	-5			8	-6		100	37	35		99	25		18	95	25		0
d_tracks[2][39]	27	14	12	9	26		4	20	21	100		2	1	1		4	1	-2	1	5		U
d_tracks[2][37]	94		34		94			-4	100	21	-6	-2	-2	-2	-6	-20		15	-8	1		20
d_tracks[2][30]	20	8	7	7	20	1		100	-4	20	8	3	3	2	8	30	1	-24	13	-3		-20
d_tracks[2][22]		81		-1	-2		100			4		30		-1			24			2		40
d_tracks[2][18]						100		1														-40
d_tracks[2][13]	99	35			100		-2	20	94	26	-5	-2	-1	-1	-5	-13	-1	9	-6			60
d_tracks[2][10]	36	12	13	100	36		-1	7	34	9	-1	-1	-27	31	-1	-4		2	-1			-00
ged_tracks[2][9]	36	13	100	13	36			7	34	12	-1		32	26	-1	-4		2	-1			00
ed_tracks[2][8]	37	100	13	12	35		81	8	34	14	-1	31		-1	-2	-5	29	4	-2	2		-00
ed_tracks[2][7]	100	37		36	99			20	94	27	-5	-1	-1	-1	-5	-13		9	-6	1		100
into into into into into into into into																						
		~_r	W re	1	1	1	1	K'a	10	K'a	K'a	K C	W C	K'a	K C	K C	10	K C	1/2	h c	K Ch	Ch-
				'arg	ied.	9ed	ied.	ied 9	ied.	9ed	ied s	led 9	led S	led.	ied 9	led.	ied 9	ied S	ied s	led 9	ed 9e	19ed 9
						- 4C	K\${2	NA		187	PAR.	ist?	NAS.	NSS.	NS 2	13/3	193	1943	183	183	PLAT	1318131

The first TMVA results for ROC curve

ROC curve: the background rejection vs. signal efficiency



The First TMVA results on the response for each method

The Classifier Output Distributions



	Input variables for μ^+									
1	info_raw_charged_tracks[2][9]	The P_y in EMC of μ^+								
2	info_raw_charged_tracks[2][10]	The P_z in EMC of μ^+								
3	info_raw_charged_tracks[2][18]	The last hit layers in MUC of μ^+								
4	info_raw_charged_tracks[2][22]	The P_z of μ^+								
5	info_raw_charged_tracks[2][30]	latMoment of μ^+								
6	info_raw_charged_tracks[2][37]	e3x3/e5x5 of μ^+								
7	info_raw_charged_tracks[2][39]	dedxnumGoodHits of μ^+								

	Input variables for μ^-									
8	info_raw_charged_tracks[3][9]	The P_y in EMC of μ^-								
9	info_raw_charged_tracks[3][10]	The P_z in EMC of μ^-								
10	info_raw_charged_tracks[3][18]	The last hit layers in MUC of μ^-								
11	info_raw_charged_tracks[3][22]	The P_z of μ^-								
12	info_raw_charged_tracks[3][30]	latMoment of μ^-								
13	info_raw_charged_tracks[3][37]	e3x3/e5x5 of μ^-								
14	info_raw_charged_tracks[3][39]	dedxnumGoodHits of μ^-								

The second TMVA removes the positive (negative) correlation greater than 50%.

Linear correlation coefficients in % 100 d_tracks[3][39] 100 80 d_tracks[3][37] 100 d tracks[3][30] 6 -52 100 60 d_tracks[3][22] 100 40 d_tracks[3][18] 30 -20 9 100 37 -52 9 d_tracks[3][10] -2 100 20 ed_tracks[3][9] 32 -27 0 d_tracks[2][39] 12 9 4 20 100 5 -20 d_tracks[2][37] -4 21 -8 100 d_tracks[2][30] 7 100 3 -40 d_tracks[2][22] 100 4 -60 d_tracks[2][18] 100 d_tracks[2][10] 13 100 -4 2 -80 ed_tracks[2][9] 100 13 2 -1 34 -4 -100 info raw charged track info_raw_charged info_raw_charged

Correlation Matrix (signal)

Correlation Matrix (background)



The Second TMVA results for ROC curve

ROC curve: the background rejection vs. signal efficiency



The Second TMVA results on the response for each method

The Classifier Output Distributions



BDTG method

BDT method

> Finally, the BDTG method is selected to suppress the pion mis-identification, and require the BDTG response to be greater than 0.

D Dalitz plot after applied above criteria





In the fit:

Signal: a double Gaussian function;

Background: Chebychev function;

 $M(\pi^+\pi^-\eta) \in [0.93, 0.98] \, \mathrm{GeV}/c^2$

D Two-dimentional fit on $M(\pi^+\pi^-\eta)$ and $M(\mu^+\mu^-)$

Need more checks



The number of events for each part is floated.

• By using $\chi^2_{tot}(\mu^+\mu^-\eta') < \chi^2_{tot}(\pi^+\pi^-\eta')$, we can effectively suppress the background

from pion mis-identification.

- The data from 2017,2018 will be added.
- More check on the 2D fit on $M(\mu^+\mu^-\eta)$ and $M(\mu^+\mu^-)$.
- Study the form factor of J/ψ transitions to η' .

Back up

