Search for Electromagnetic Dalitz decay

$J/\psi \to \mu^+\mu^-\eta'$

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Outline

- Motivation
- Data Set
- Basic Event Selection
- Background analysis
- Further event selection
- TMVA method
- Summary and Next to do

Motivation

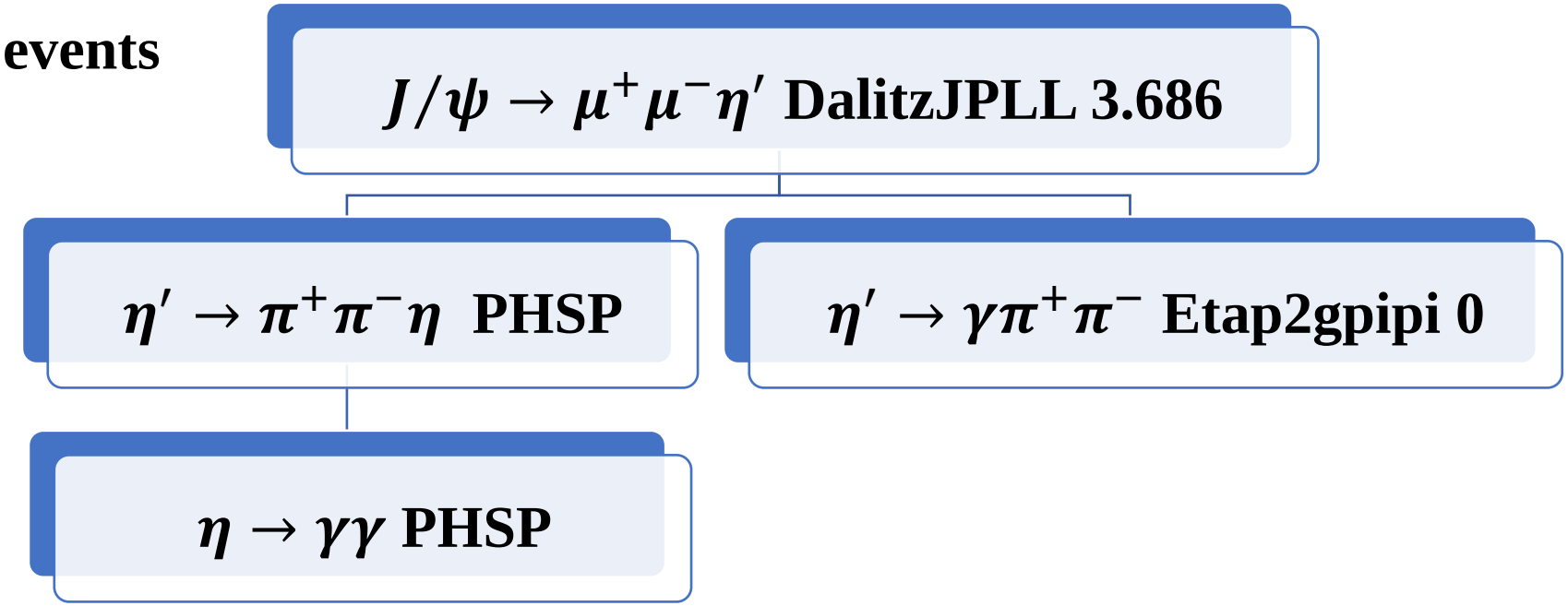
- The Electromagnetic Dalitz decays of $J/\psi \to \mu^+\mu^- P$ $\left(P = \pi^0, \eta, \eta'\right)$ have not been studied so far, due to the difficulty from the identification between pion and muon, especially for the soft muon.
- Based on 10 billion J/ψ events collected by BESIII, we search for the Electromagnetic Dalitz decay $J/\psi \to \mu^+\mu^-\eta'$, 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^-	$\mu^+\mu^-$
$\psi \to \pi^0 l^+ l^-$	$(3.89^{+0.37}_{-0.33}) \times 10^{-7}$	$(1.01^{+0.10}_{-0.09}) \times 10^{-7}$
$\psi \to \eta l^+ l^-$	$(1.21 \pm 0.04) \times 10^{-5}$	$(0.30 \pm 0.01) \times 10^{-5}$
$\psi \to \eta' l^+ l^-$	$(5.66 \pm 0.16) \times 10^{-5}$	$(1.31 \pm 0.04) \times 10^{-5}$

[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**



Basic Event Selection criteria

☐ Good charged track selection

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

☐ Particle identification (PID)

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

☐ Good photon

- $0 \leq TDC \leq 14$ (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 $N_\gamma \geq 2$.

PID	The good charged track			
	1th	2th	3th	4th
χ^2_{PID1}	μ^+	μ^-	π^+	π^-
χ^2_{PID2}	μ^+	π^-	π^+	μ^-
χ^2_{PID3}	π^+	π^-	μ^+	μ^-
χ^2_{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} .

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

4C kinematic fit

- Choose the best photon with the least χ^2_{4C} .

The best candidate in an event

- select the best combination with the minimum value of $\chi^2_{tot} = \chi^2_{\text{PID}} + \chi^2_{\text{vertex}} + \chi^2_{4C} + \left(\chi^2_{1C}(\eta \to \gamma\gamma)\right)$ from the four combinations of $\mu^+, \mu^-, \pi^+, \pi^-$.

Background analysis

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

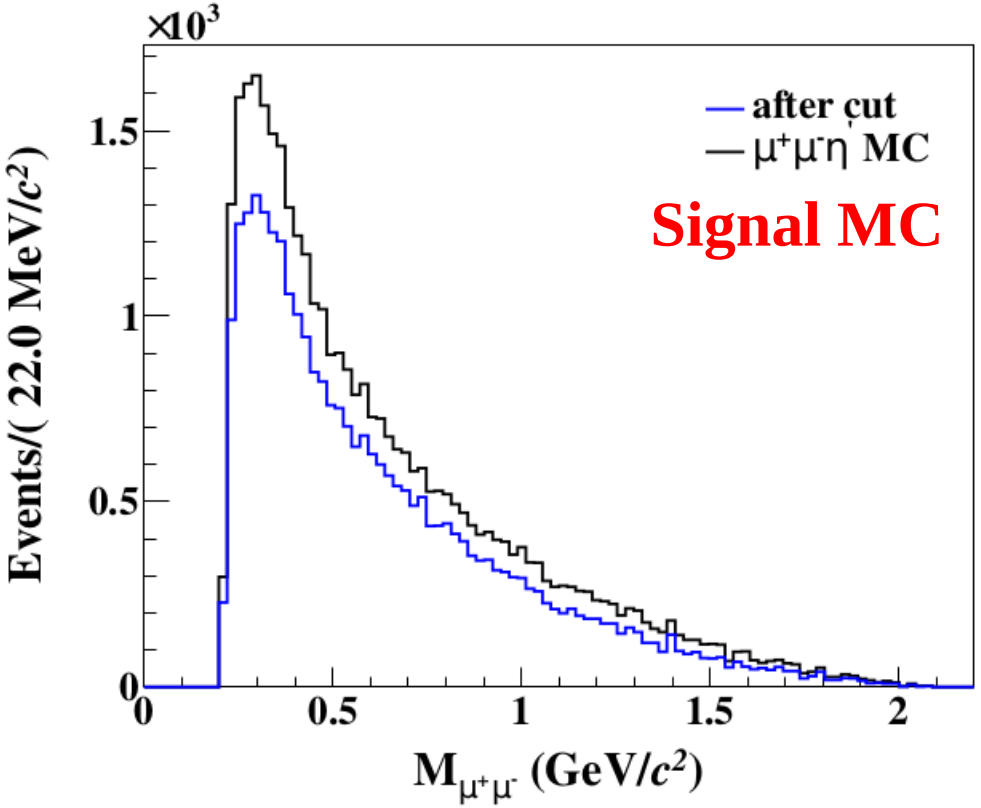
Table 1: Event trees and their respective initial-final states.

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	$e^+e^- \to J/\psi, J/\psi \to \rho^0\eta', \rho^0 \to \pi^+\pi^-\gamma_{FSR}, \eta' \to \pi^+\pi^-\eta, \eta \to \gamma\gamma$ $(e^+e^- \to \pi^+\pi^+\pi^-\pi^-\gamma\gamma\gamma_{FSR})$	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

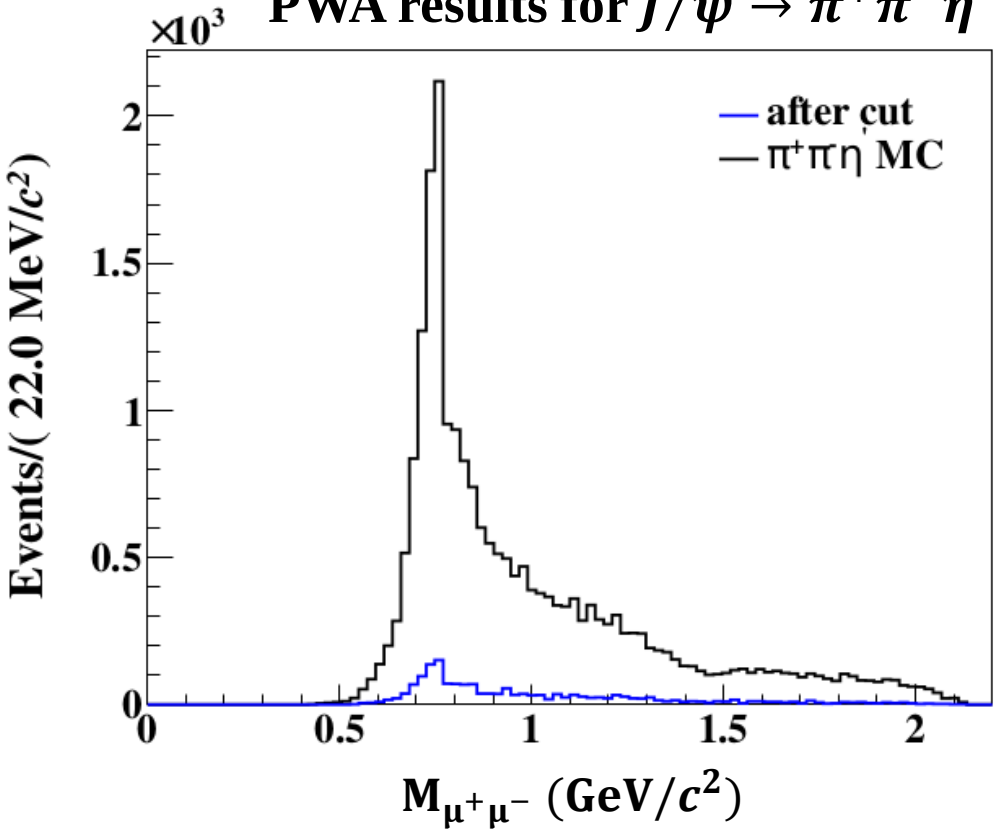
For $\eta' \to \pi^+\pi^-\eta$ case

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



80% of the signal events survived.

PWA results for $J/\psi \to \pi^+\pi^-\eta'$ MC [1].

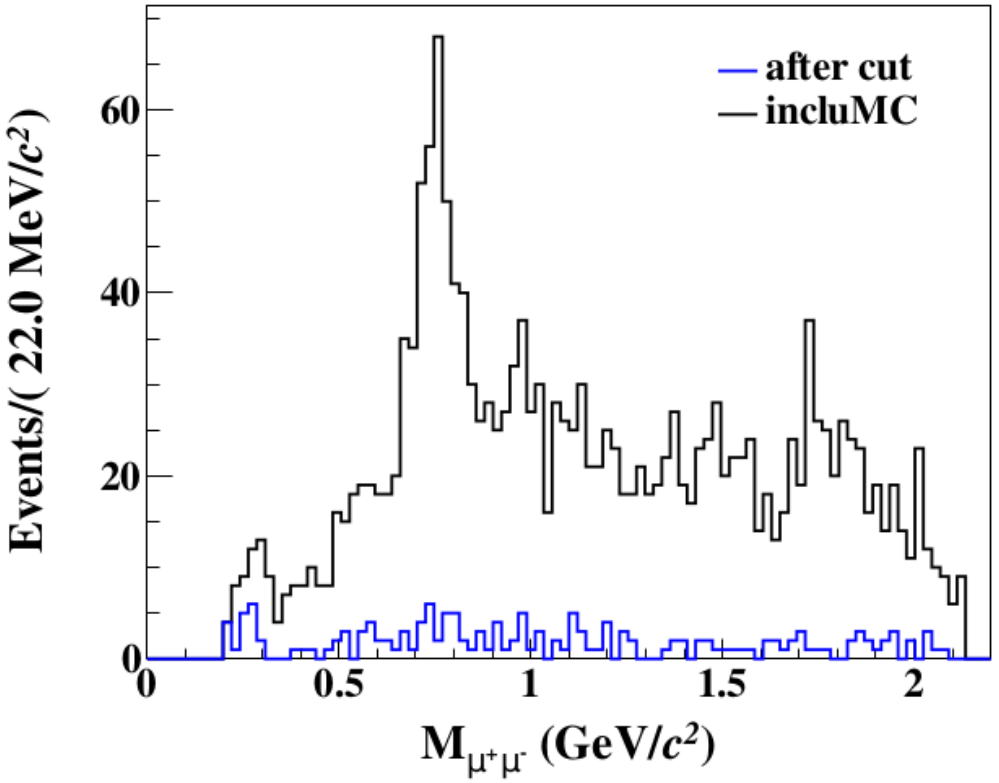


The background of $J/\psi \to \pi^+\pi^-\eta'$ can be suppressed by 92.2%.

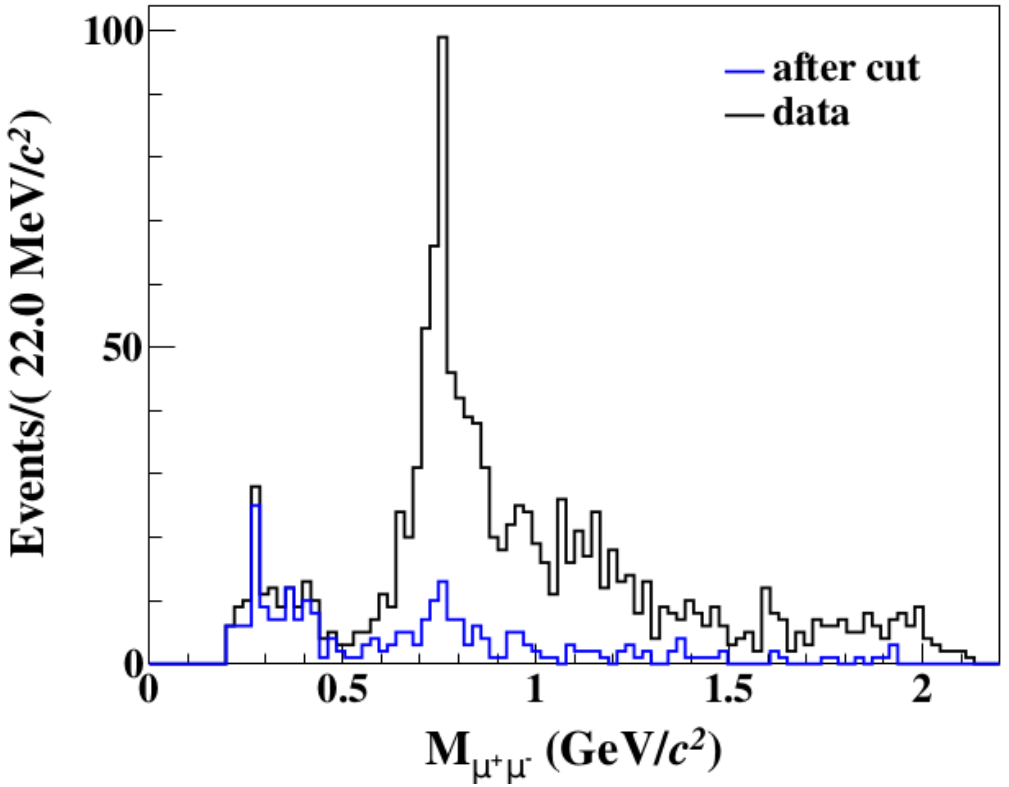
[1] M. Ablikim et al. (BESIII Collaboration), Phys. Rev. D 96, 112012 (2017).

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

09 inclusive MC



09 data



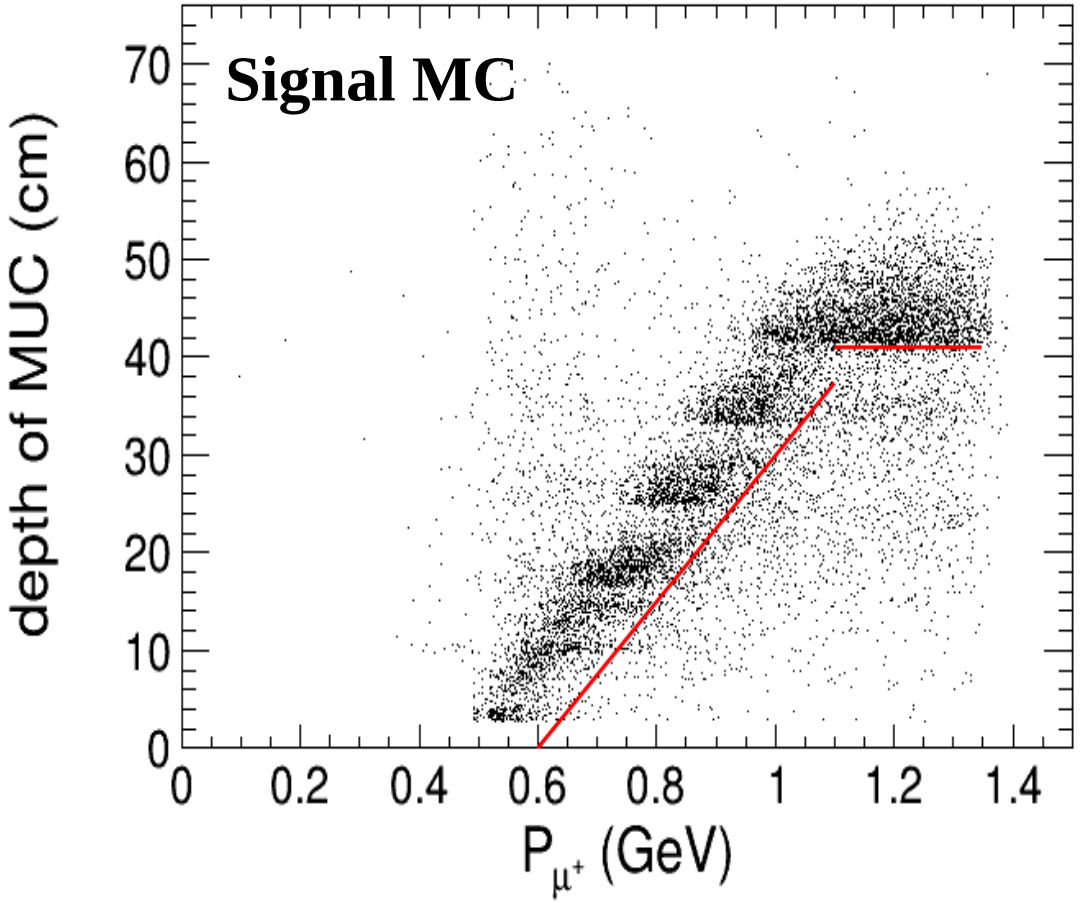
Events: 157/1893=8.2%

Events: 254/1223=20%

☐ The depth for μ^+ or μ^- in MUC

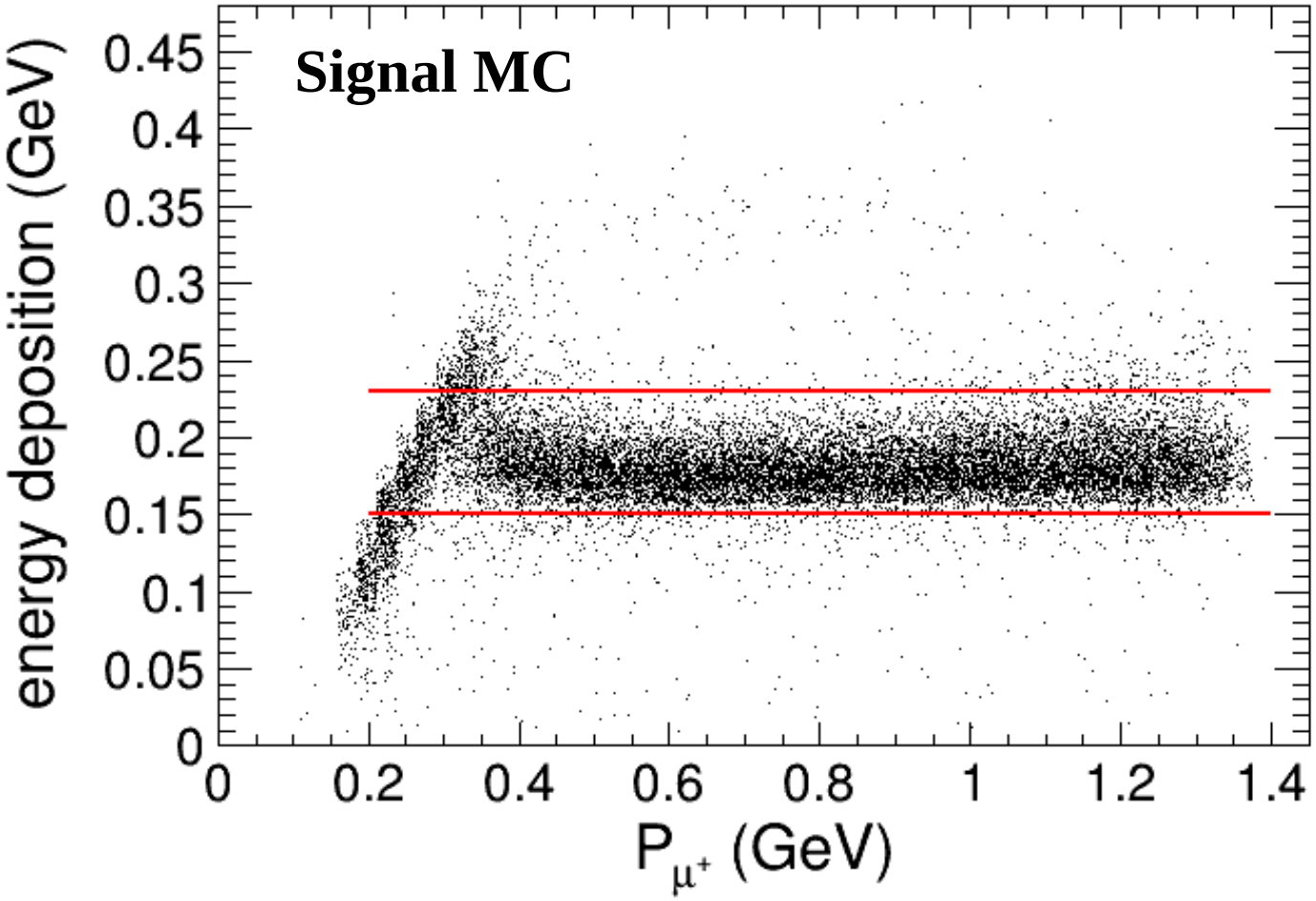
The momentum (p) of μ^+/μ^- (GeV/c)	The depth (L) in MUC (cm)
$p < 0.6$	No cut
$p \in [0.6, 1.1)$	$L > (-37.4 + 68 \times p)$
$p > 1.1$	$L > 42$

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



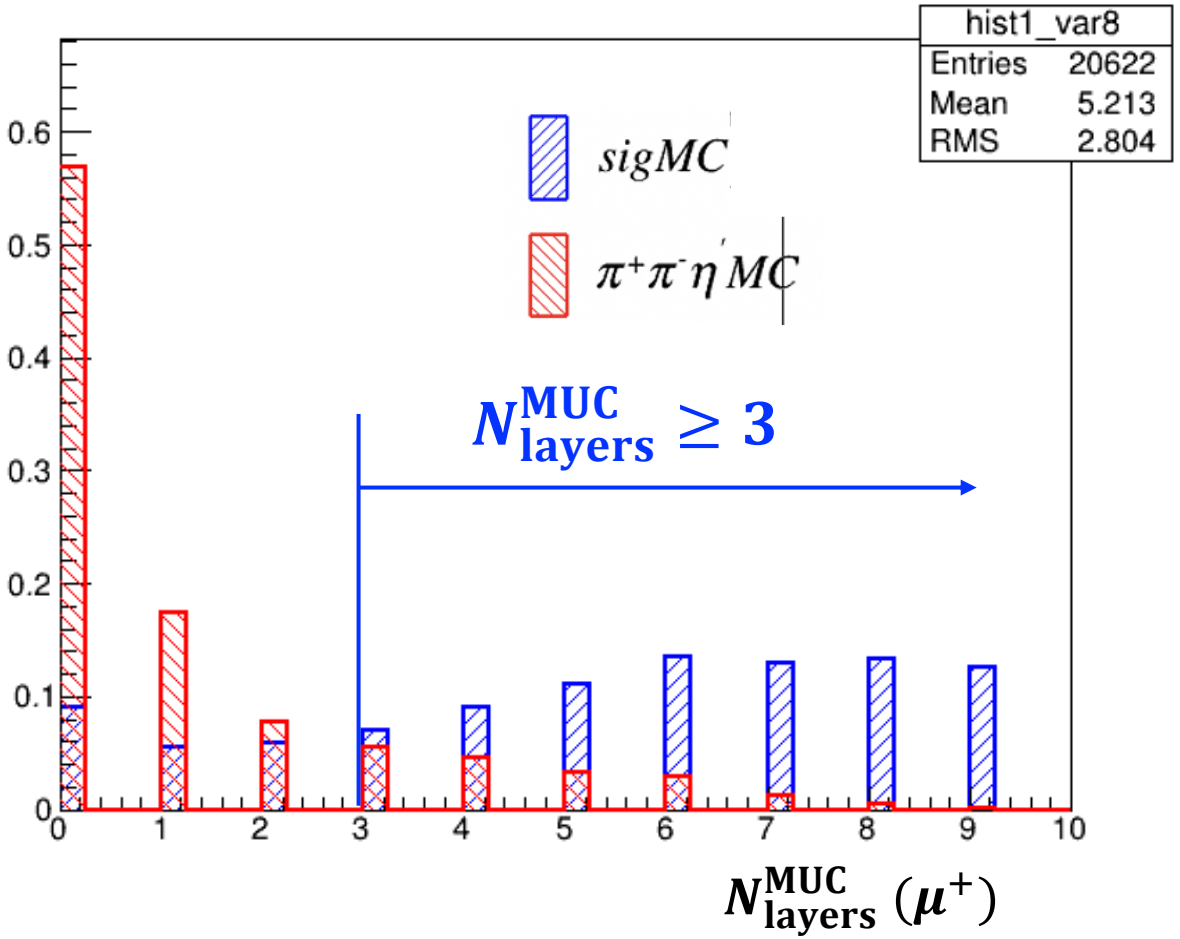
- $E_{\mathrm{EMC}}(\mu^{\pm}) \in [0.15, 0.23]$ GeV

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



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

The number of hit layers in MUC for μ^+



☐ Summary of the event selection criteria so far

- $\chi^2_{5c} < 50$;
- $\chi^2_{\rm tot}(\mu^+\mu^-\eta') < \chi^2_{\rm tot}(\pi^+\pi^-\eta')$;
- **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 < p < 1.1 GeV/c, the depth in MUC should be greater than $-37.4+ 68\times p$ (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!)

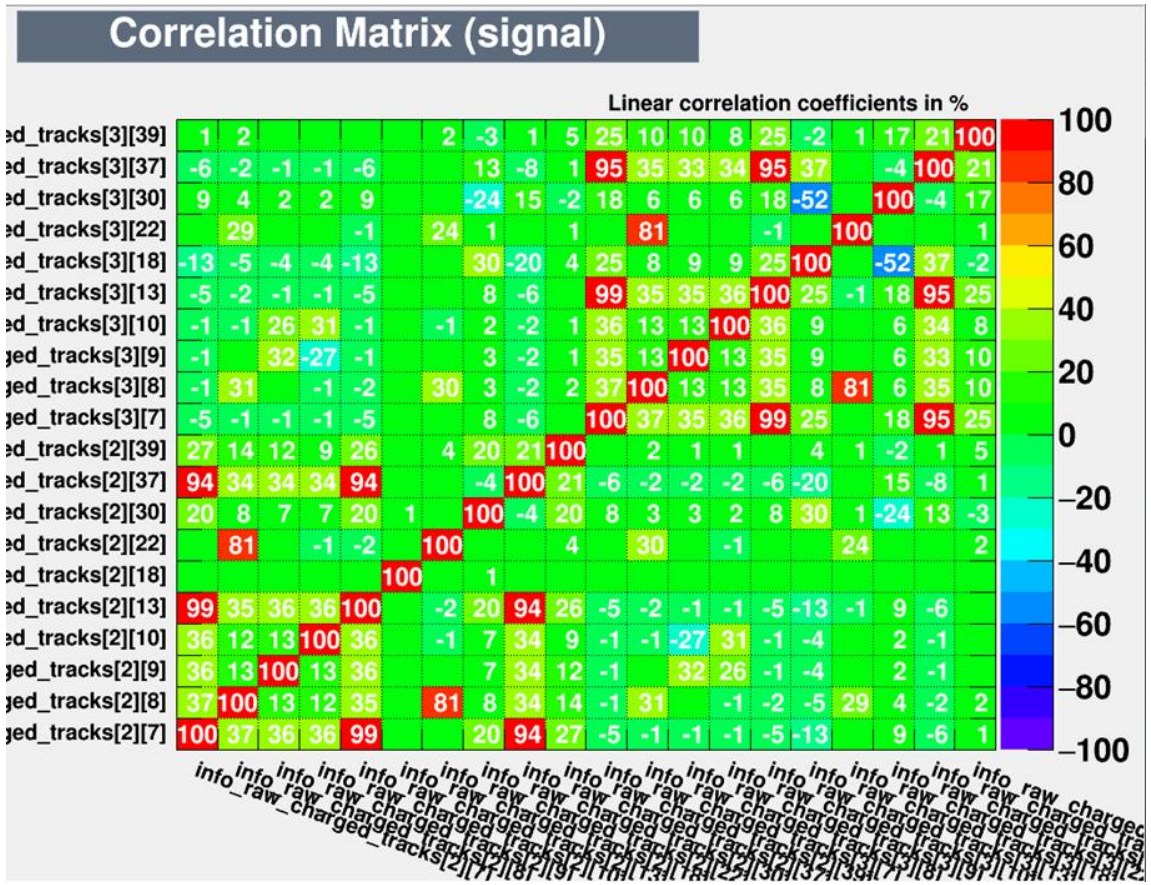
The first TMVA

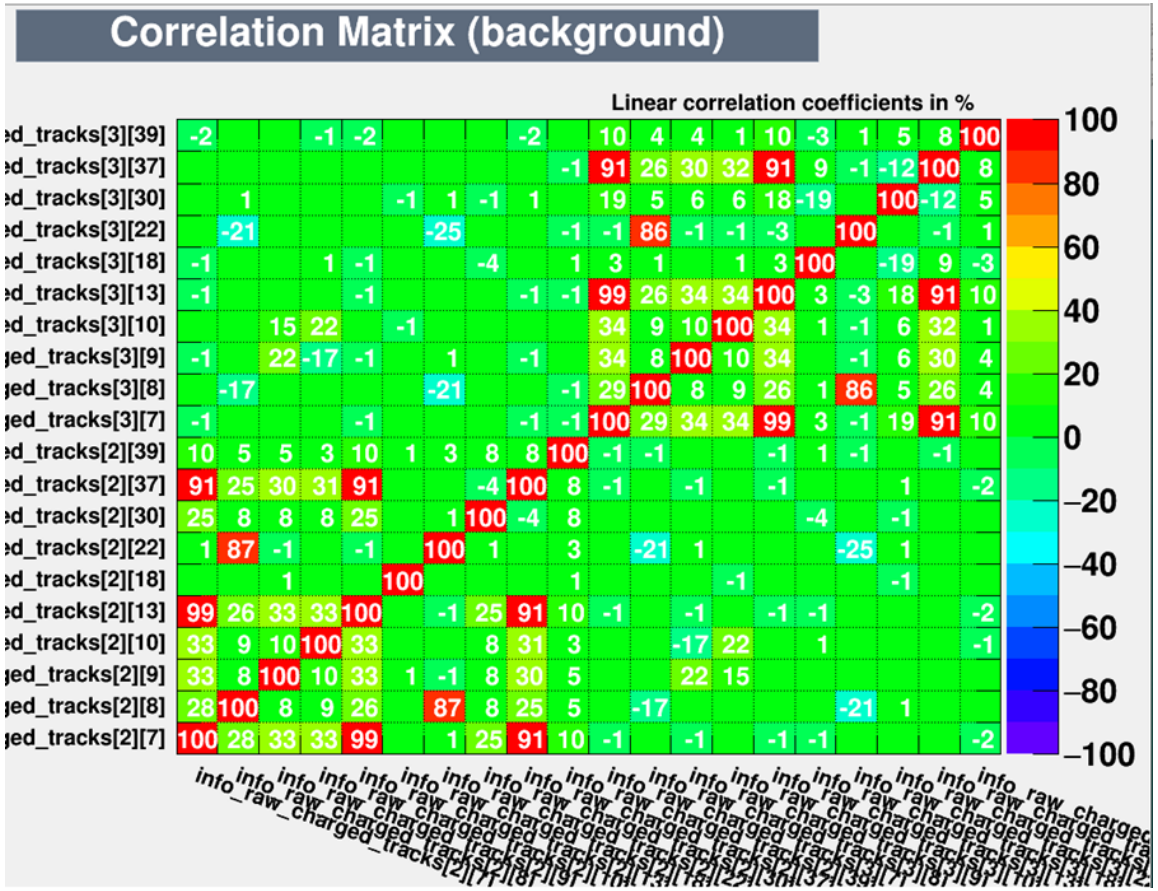
	Input variables for μ^+	
1	info_raw_charged_tracks[2][7]	The energy deposited in EMC of μ^+
2	info_raw_charged_tracks[2][8]	The P_x in EMC of μ^+
3	info_raw_charged_tracks[2][9]	The P_y in EMC of μ^+
4	info_raw_charged_tracks[2][10]	The P_z in EMC of μ^+
5	info_raw_charged_tracks[2][13]	The θ in EMC 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 μ^+
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 θ 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

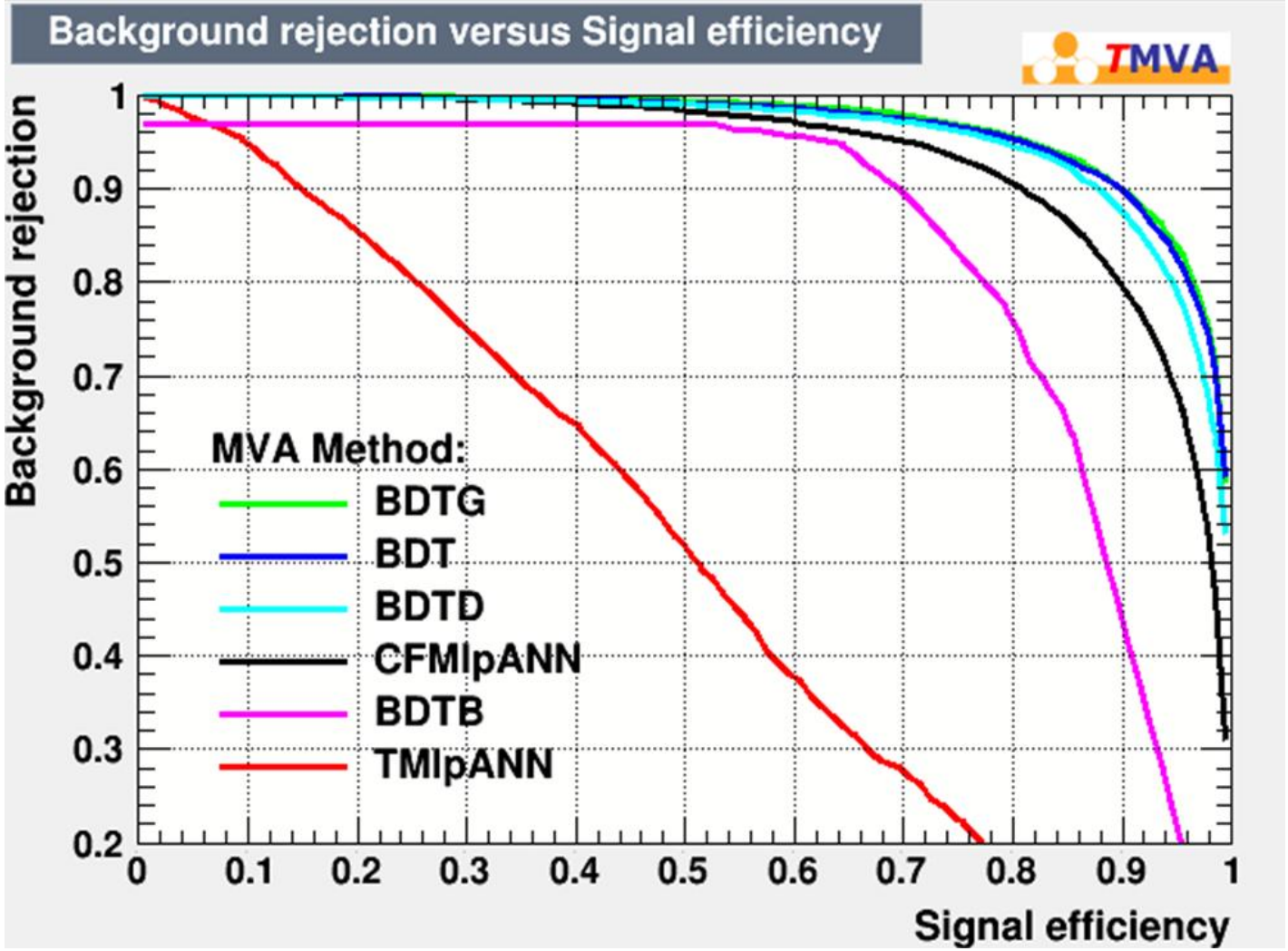
The large correlations between some input variables happen.





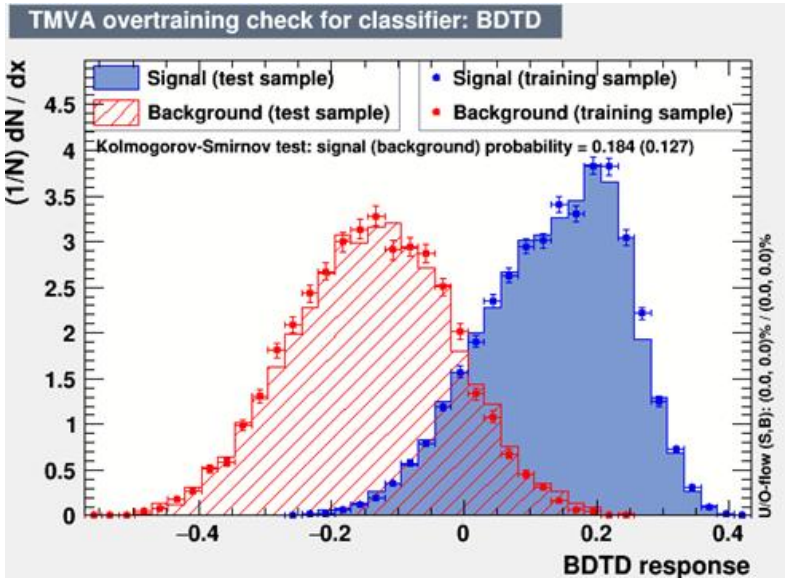
The first TMVA results for ROC curve

ROC curve: the background rejection vs. signal efficiency

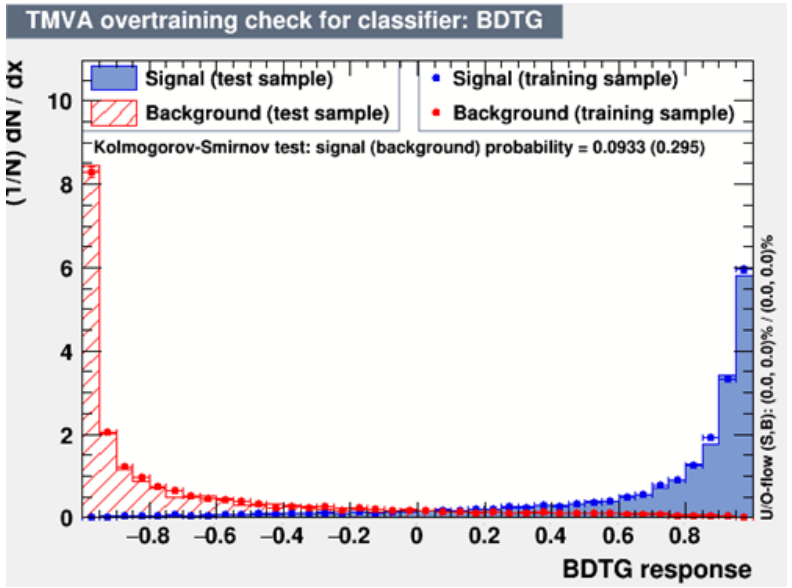


The First TMVA results on the response for each method

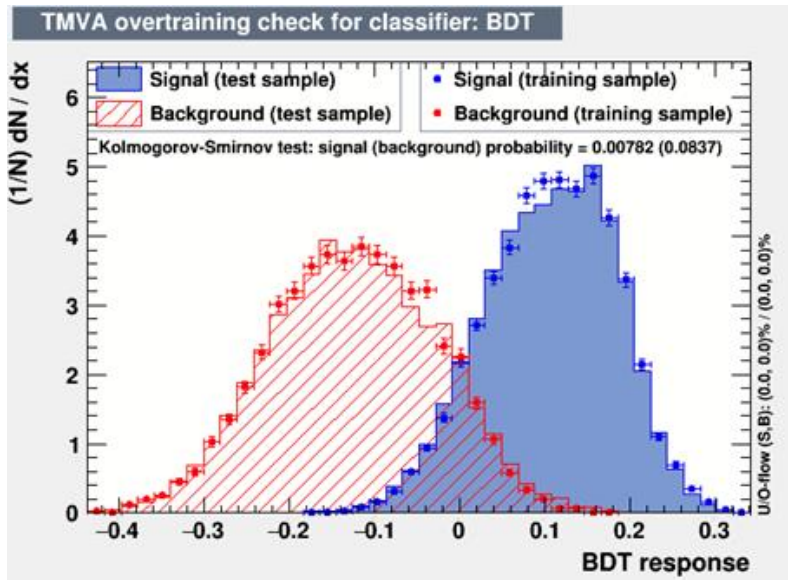
The Classifier Output Distributions



BDTD method



BDTG method



BDT method

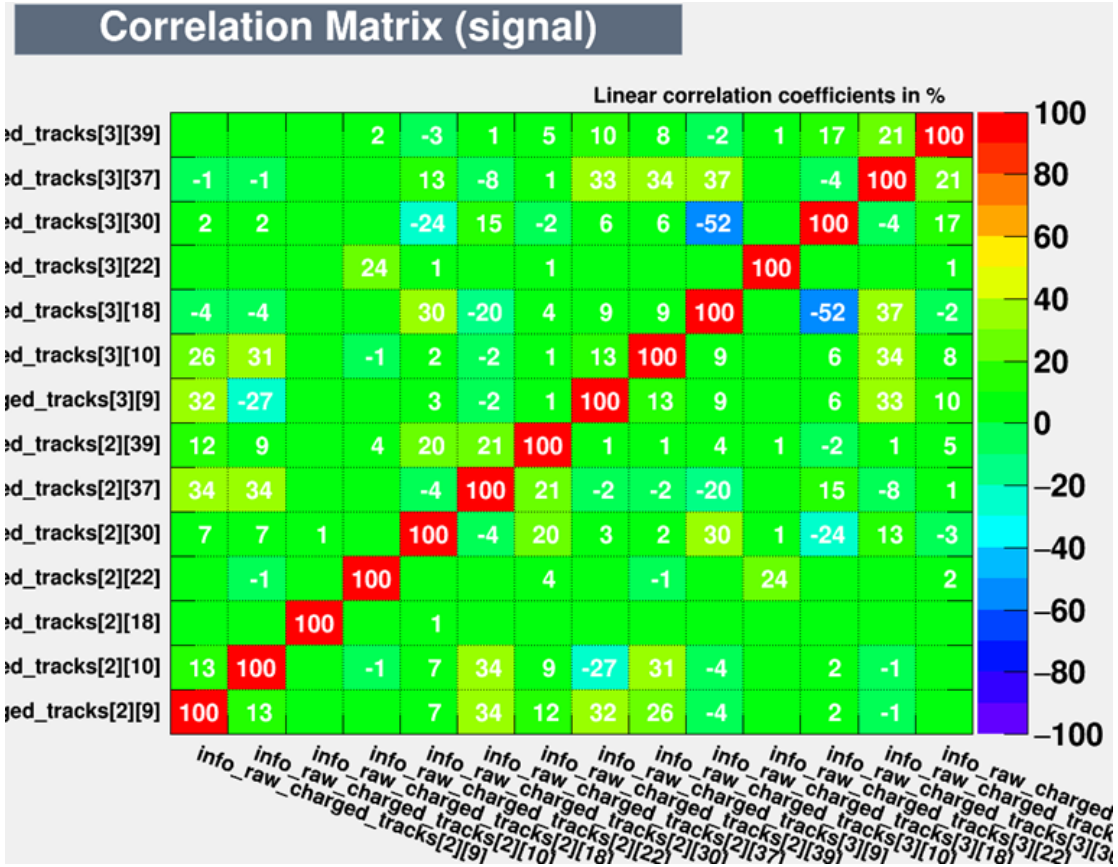
☐ The second TMVA

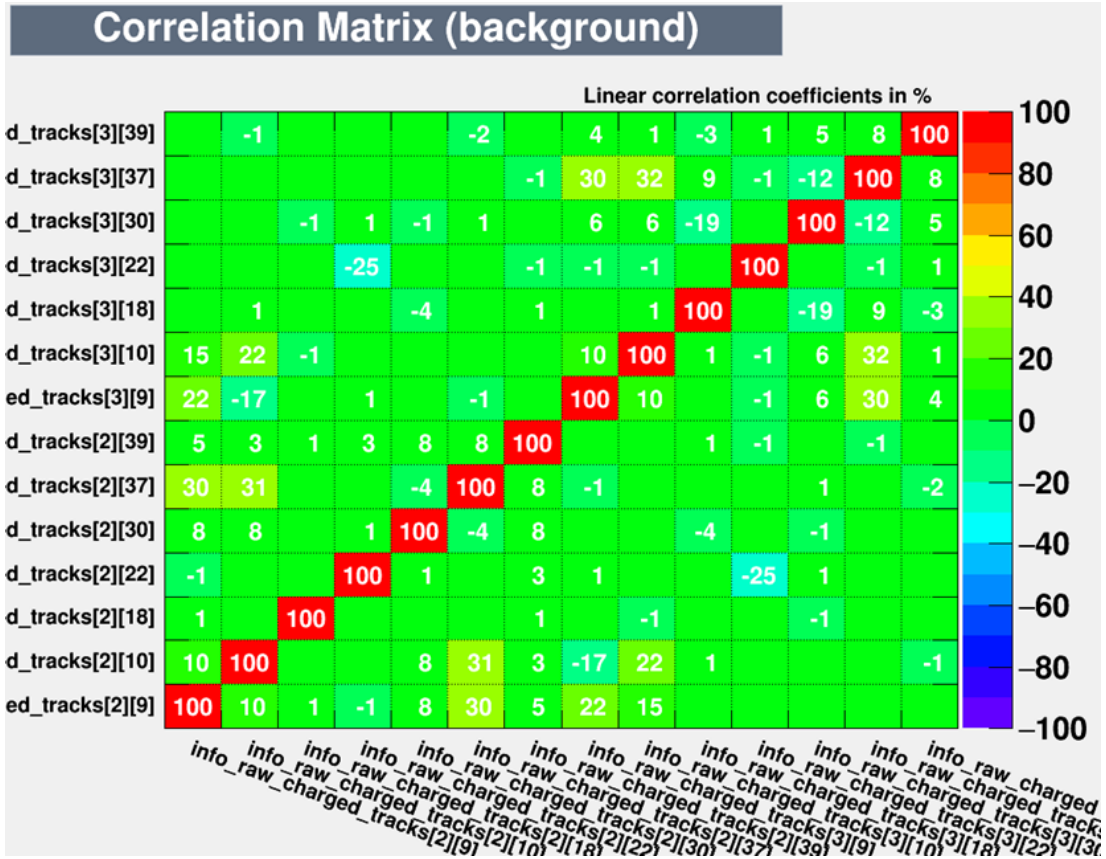
	Input variables for μ^+	
1	info_raw_charged_tracks[2][9]	The P_y in EMC of μ^+
2	info_raw_charged_tracks[2][10]	The P_z in EMC of μ^+
3	info_raw_charged_tracks[2][18]	The last hit layers in MUC of μ^+
4	info_raw_charged_tracks[2][22]	The P_z of μ^+
5	info_raw_charged_tracks[2][30]	latMoment of μ^+
6	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 results on the correlation matrix

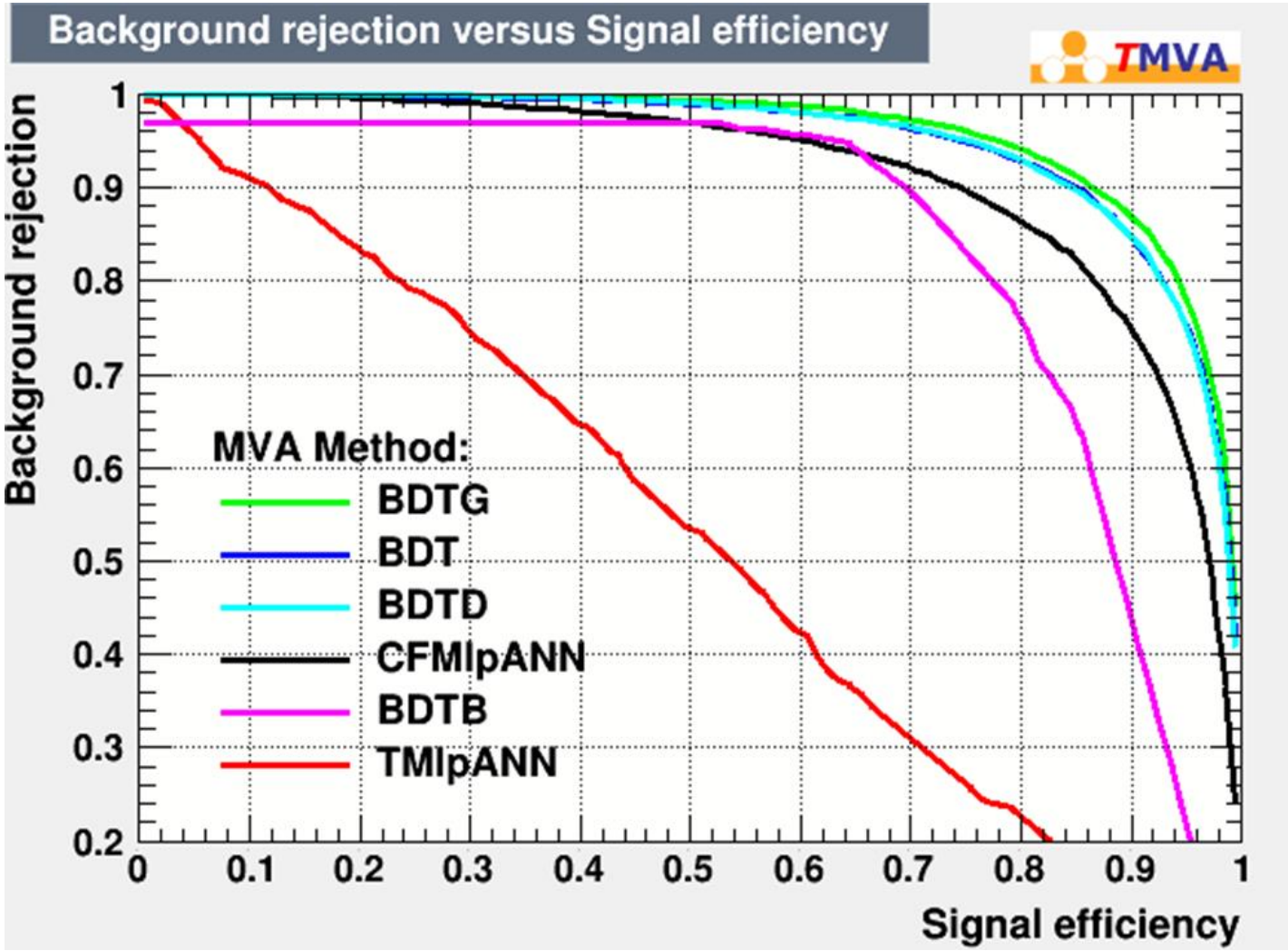
The second TMVA removes the positive (negative) correlation greater than 50%.





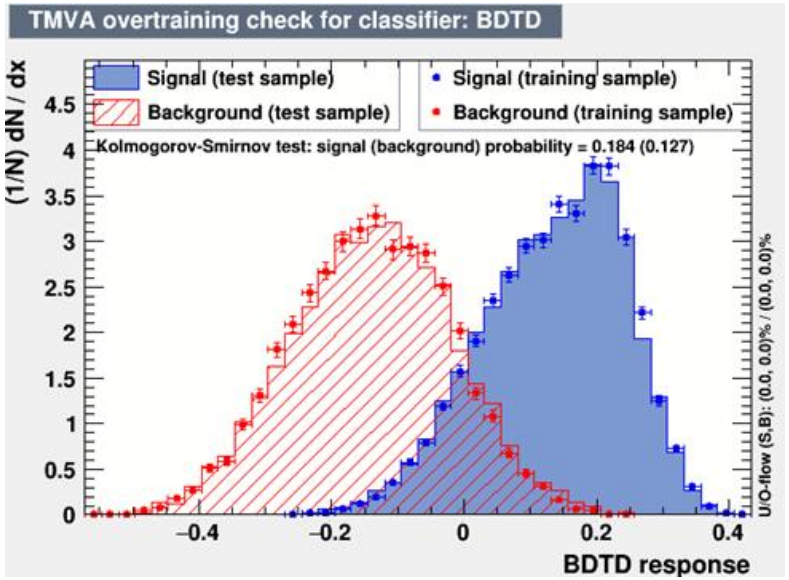
The Second TMVA results for ROC curve

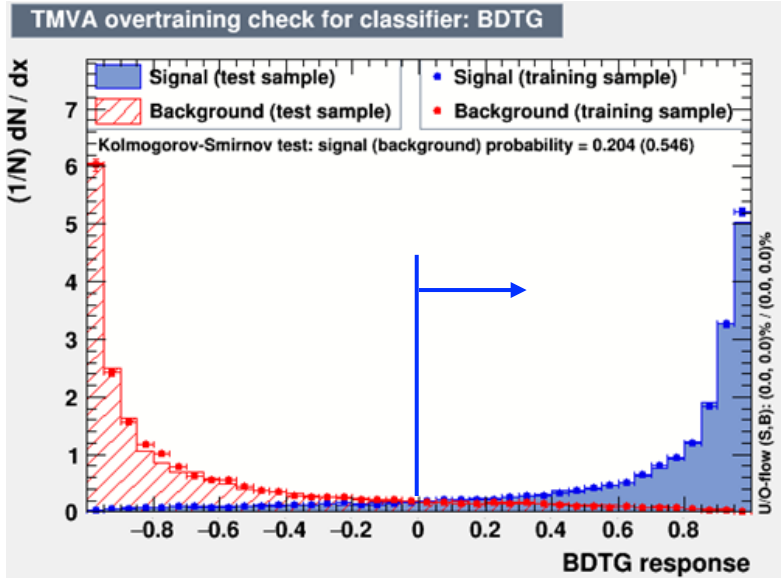
ROC curve: the background rejection vs. signal efficiency

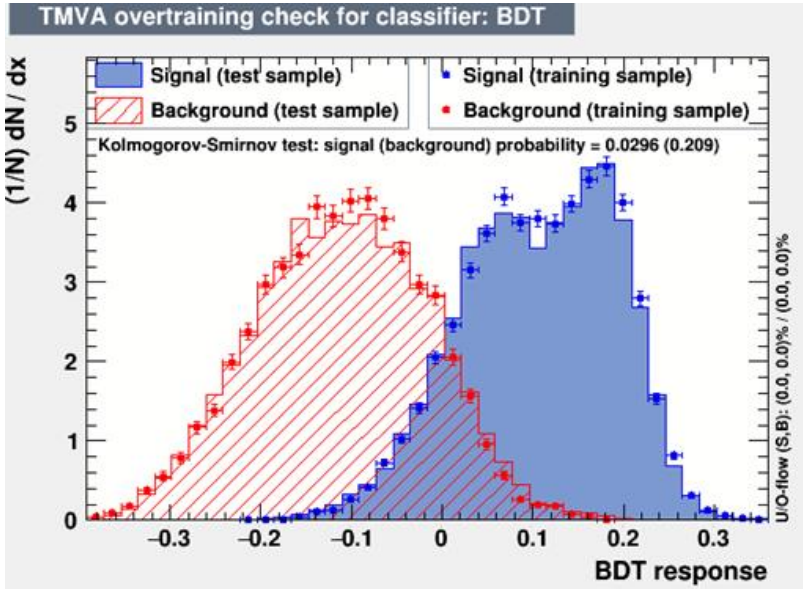


☐ The Second TMVA results on the response for each method

The Classifier Output Distributions







BDTD method

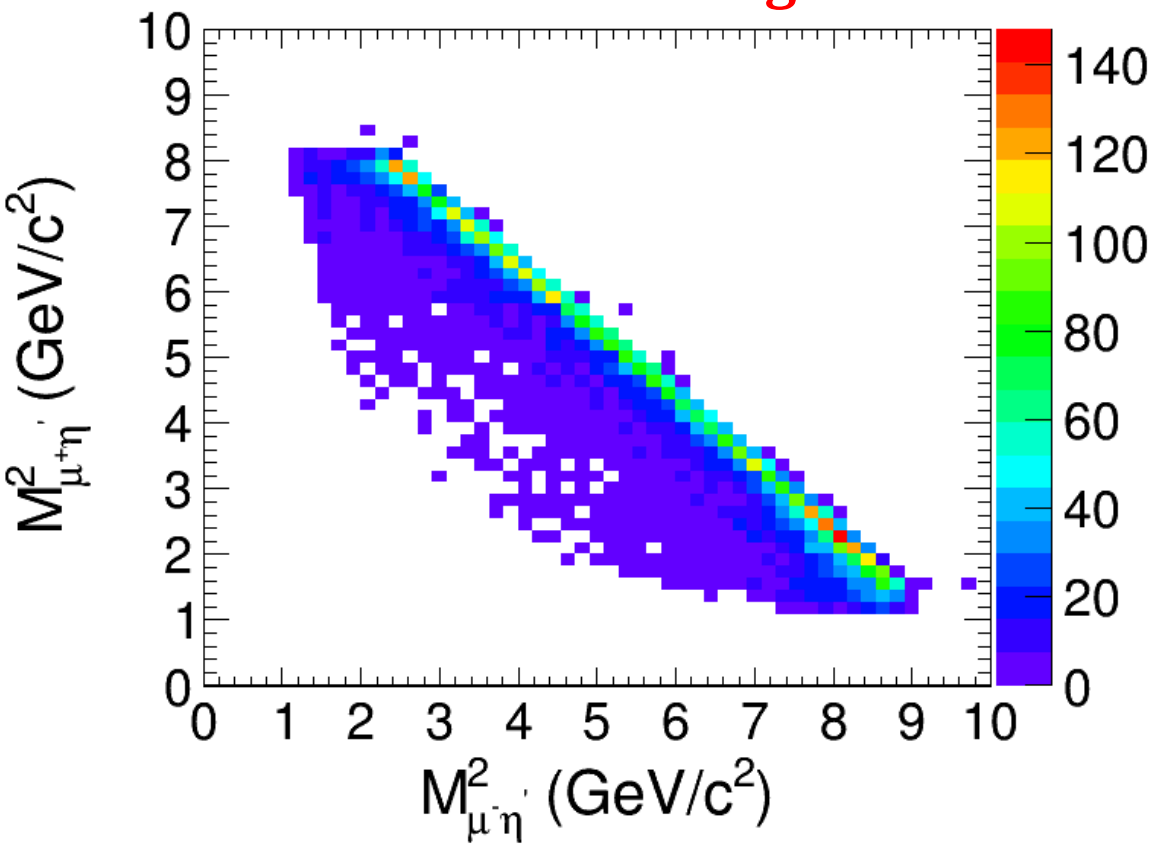
BDTG method

BDT method

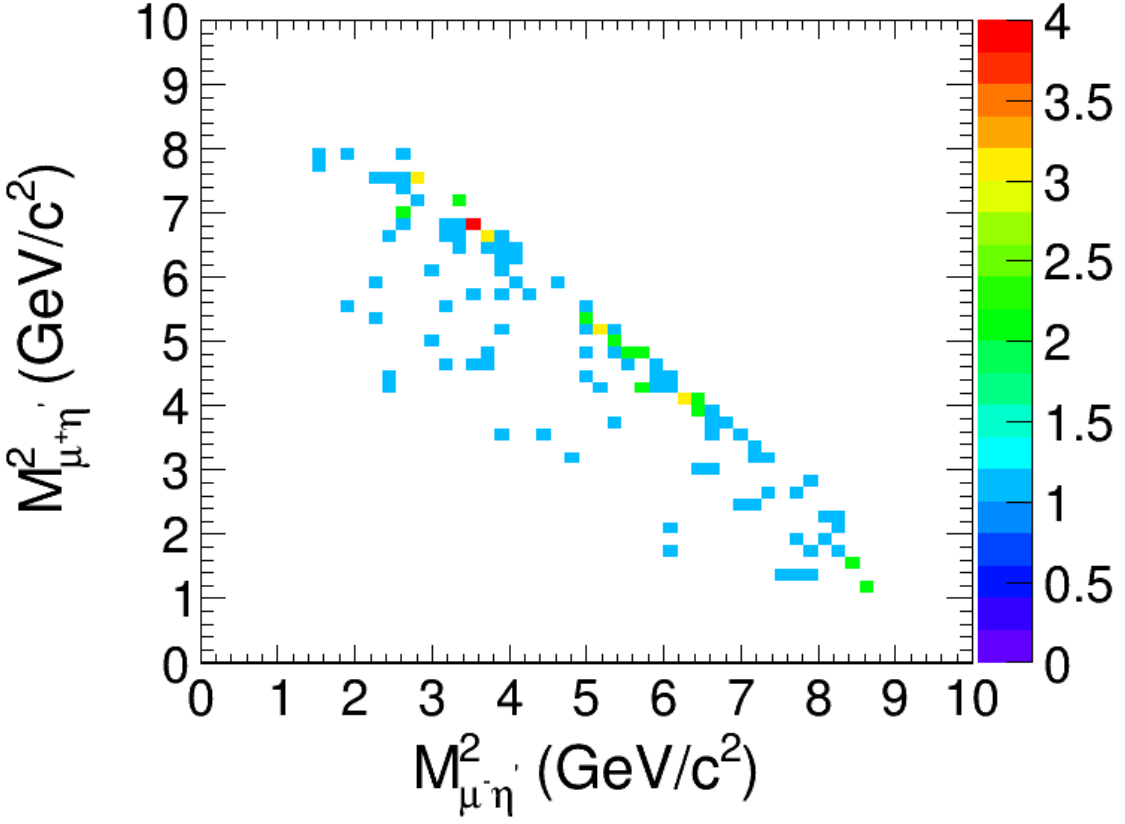
- **Finally, the BDTG method is selected to suppress the pion mis-identification, and require the BDTG response to be greater than 0.**

☐ Dalitz plot after applied above criteria

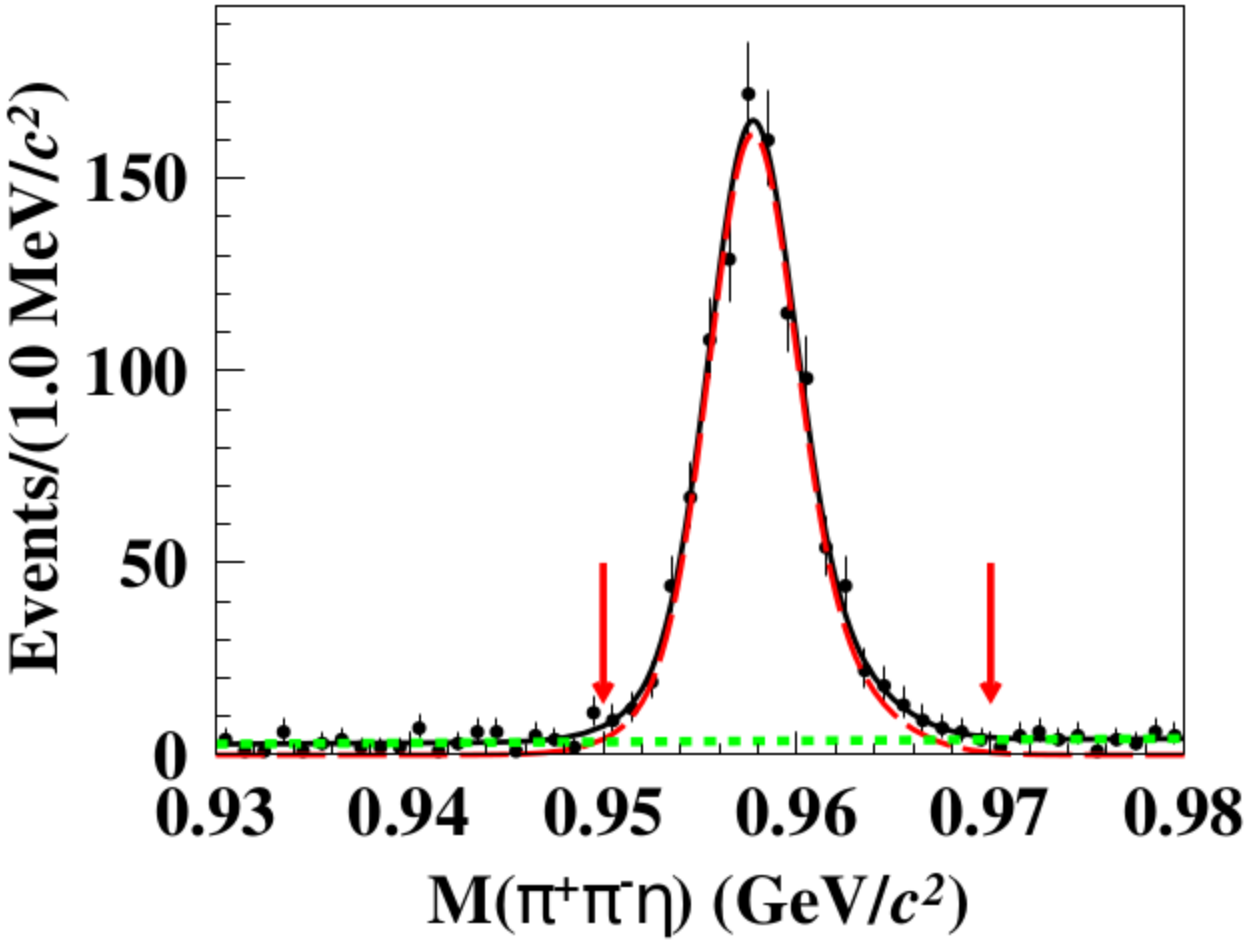
Signal MC



09data + small 17 data



Fit to $M(\pi^+\pi^-\eta)$



In the fit:

Signal: **a double Gaussian function;**

Background: **Chebychev function;**

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

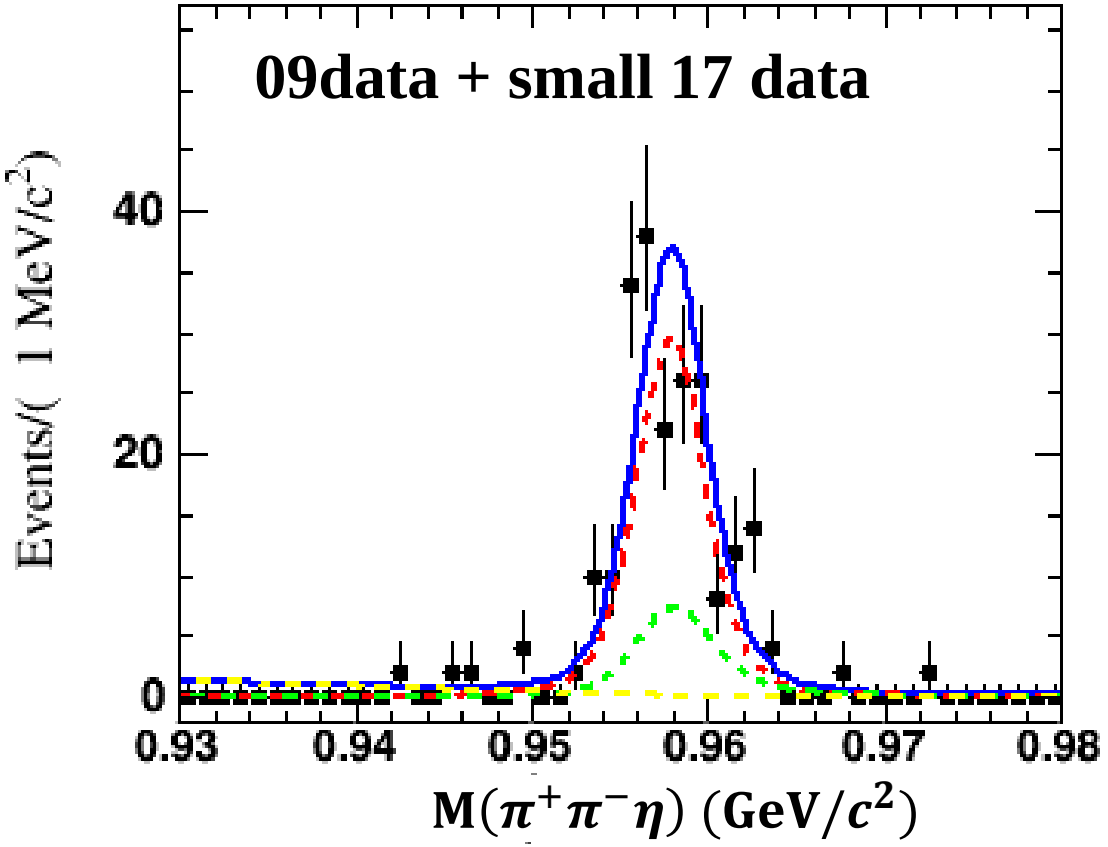
☐ Two-dimentional fit on $M(\pi^+\pi^-\eta)$ and $M(\mu^+\mu^-)$

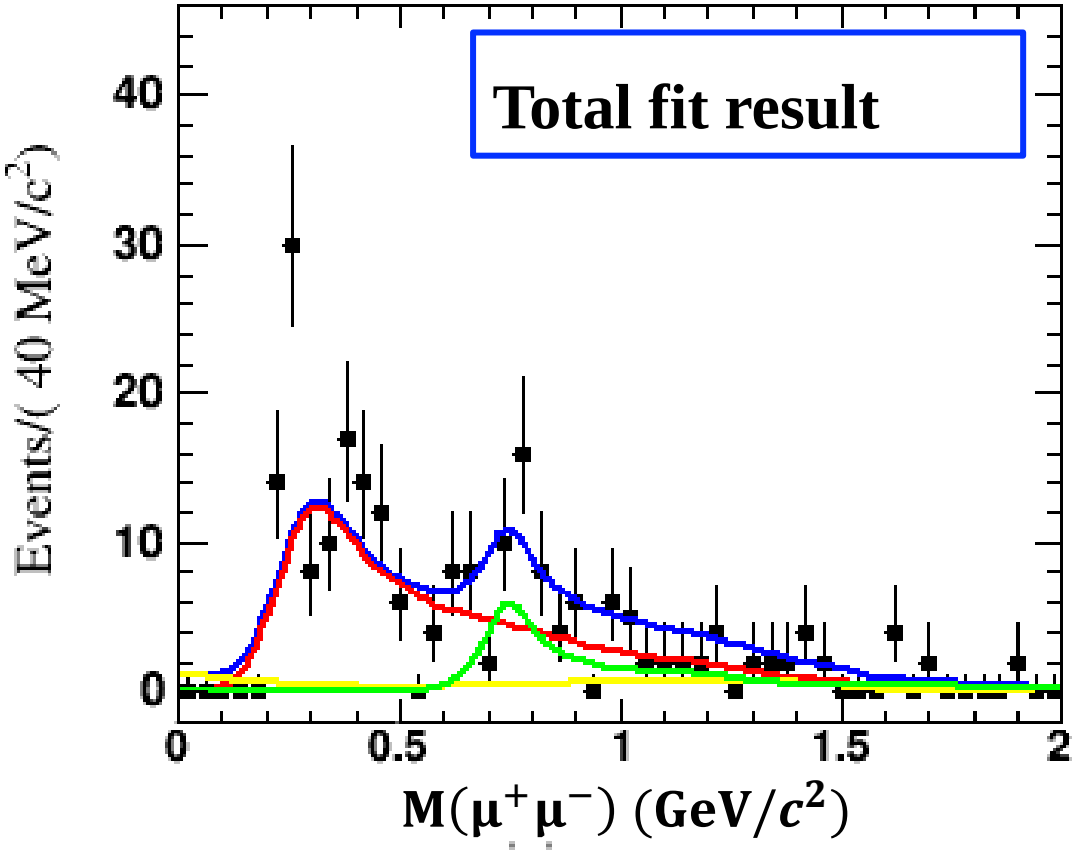
Need more checks

Signal $J/\psi \to \mu^+\mu^-\eta'$ MC

$J/\psi \to \pi^+\pi^-\eta'$ bkg MC

Other bkgs: Chebychev



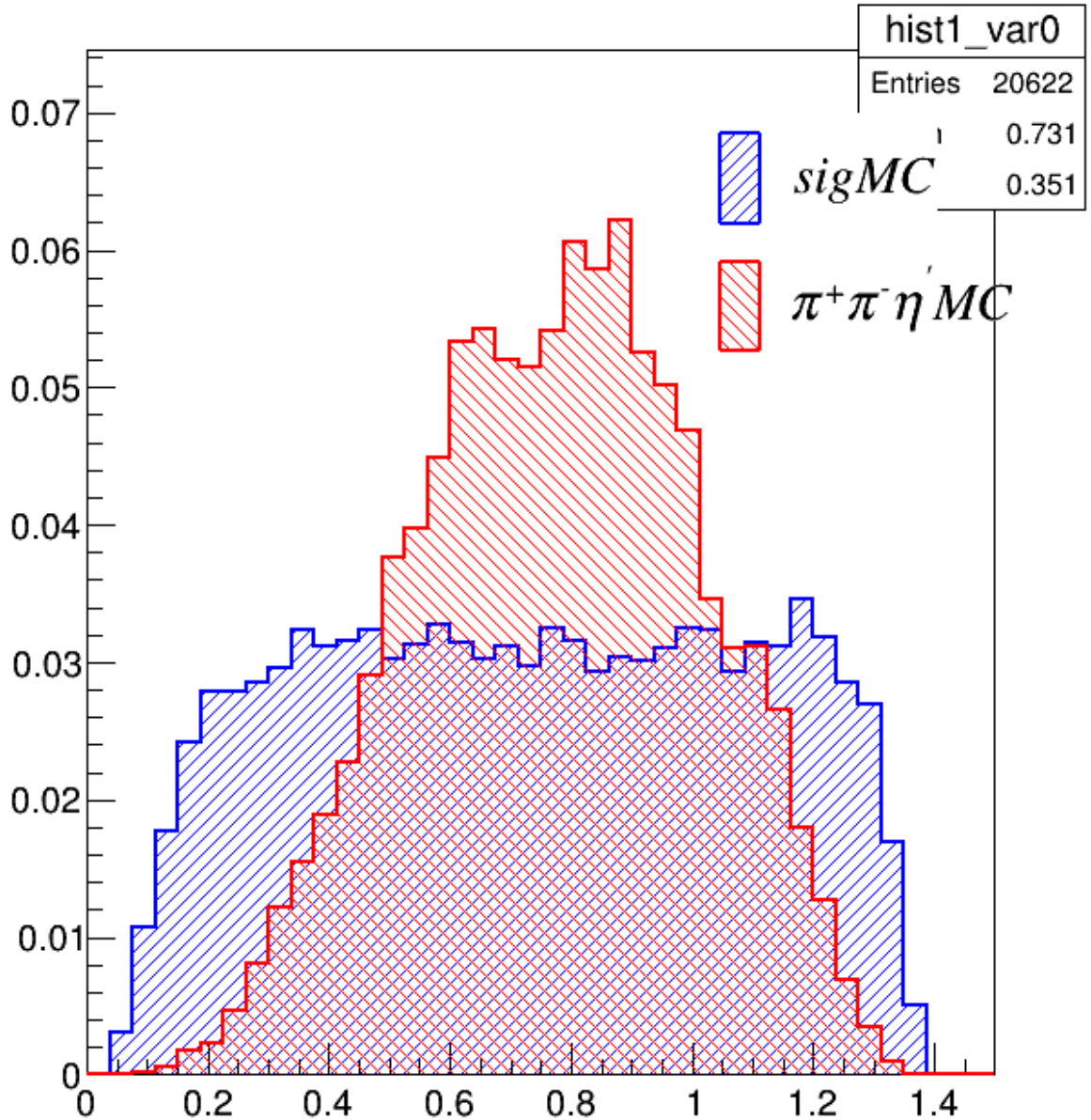


The number of events for each part is floated.

☐ Summary and next to do

- **By using $\chi^2_{\rm tot}(\mu^+\mu^-\eta') < \chi^2_{\rm tot}(\pi^+\pi^-\eta')$, 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



The momentum of μ +