Study of the $e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}J/\Psi$ production cross section

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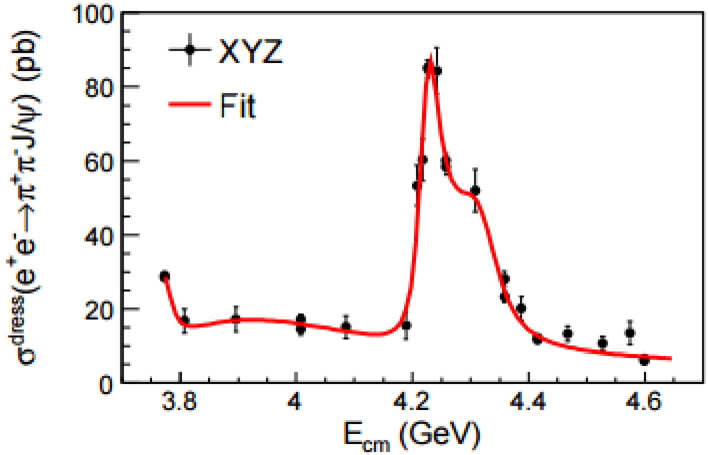
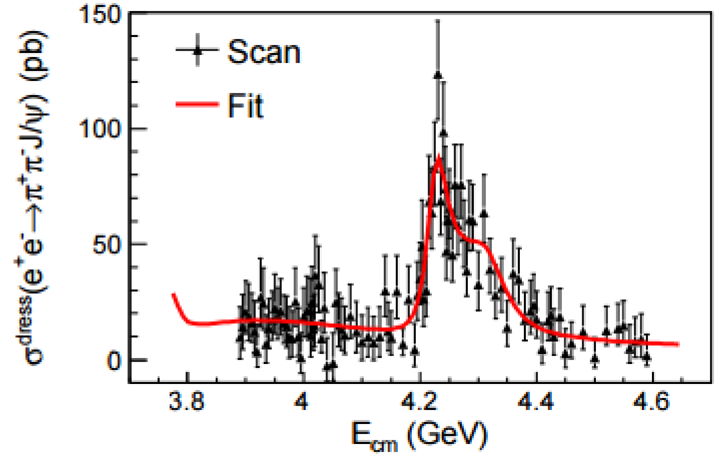
Introduction

From Zhiqing Liu'u work, we can that the minimum cross section of $\boldsymbol{e^+e^- \to \pi^+\pi^- J/\Psi}$ may around 4180MeV point. We have accumulated about 3160pb−1 data at this energy point .

We use the 4180MeV data sample to do detail background analysis. And we can use the same criteria to the new XYZ data to get more purity data sample to analyze the intermediate state, like $Z_c(3900)$.





Datasets and Boss version

- Data samples

4180 data sample (about $3000pb^{-1}$).
XYZ data samples (8 energy points, about $3700pb^{-1}$ in total).

- MC samples

Using KKMC and BesEvtgen to simulate the signal events.
We simulate 0.2M events with each channel of each energy point.

- Boss version

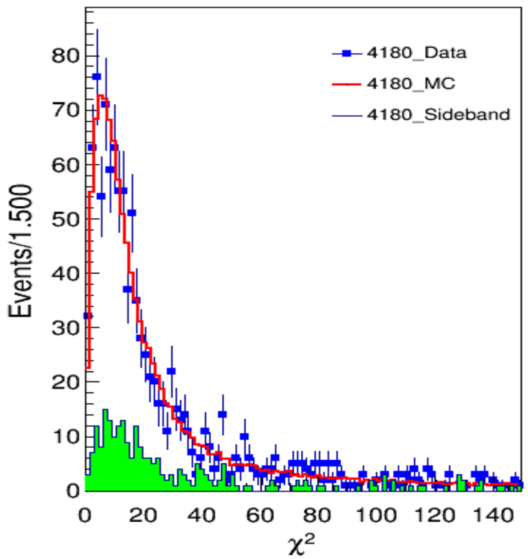
BOSS 7.0.2.p01 (4180 data sample)
BOSS7.0.3(new XYZ data samples)

Event selection

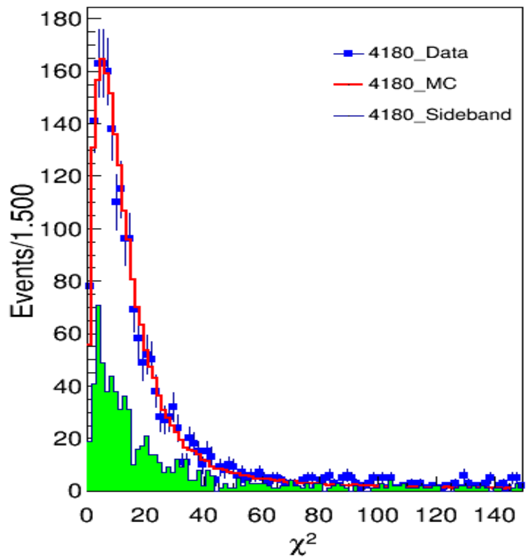
- $|V_z| < 10.0cm$
- $V_r < 1.0cm$
- Four charged tracks
- Total charges = 0
- 4C fit chisq<60

From the EMC deposit energy distribution, we can distinguish the electron and muon. And from the distribution of momentum, we can distinguish pion and leptons(electron and muon).

◆ 4C fit χ^2



4180:Ee channel

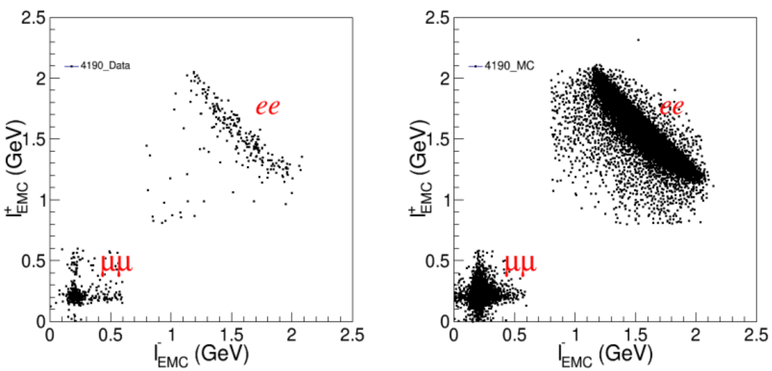


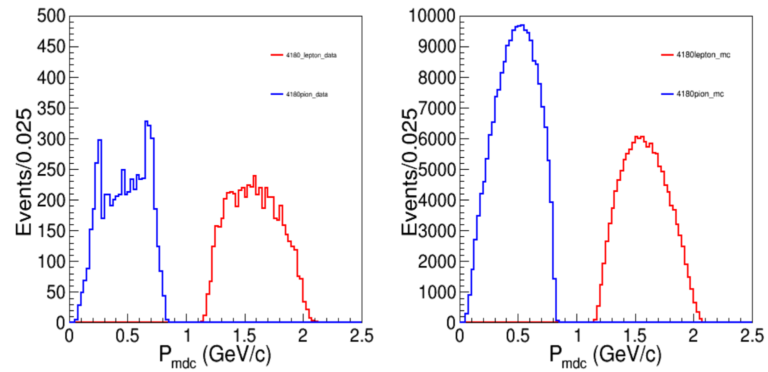
4180:Mm channel

Four-constraint (4C) kinematic fits are performed with the four charged tracks to improve resolution and help to suppress background. The $\chi^2 < 60$ is needed.

◆ Selected π and leptons

The distribution of EMC deposited energy and momentum. From the distribution we can see that the leptons distinguish will use same criteria, EMC_mu<0.40GeV and EMC_e>1.15GeV. And the momentum distinguish criteria will change with the energy.





4180:
EMC_mu<0.40GeV andEMC_e>1.15GeV

4180:
P_pion<0.82GeV/c, P_lepton>1.12GeV/c

Summary:

EMC_mu<0.40GeV, EMC_e>1.15GeV

Energy	4180	4190	4200	4210	4220	4237	4246	4270	4280
P_pion (GeV/c)	0.82	0.83	0.84	0.85	0.86	0.87	0.88	0.89	0.90

◆ Background Analysis

Because of the low cross section and a big data sample of 4180, we can do detail analysis of the background.

For ee channel,

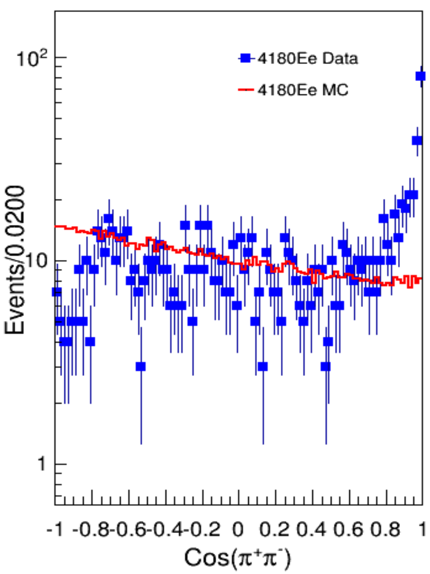
I. Gamma-conversion events
II. Misidentifying of electron and pion (low momentum pion)
III. The $ee\mu\mu$ of two-photon process

For $\mu\mu$ channel,

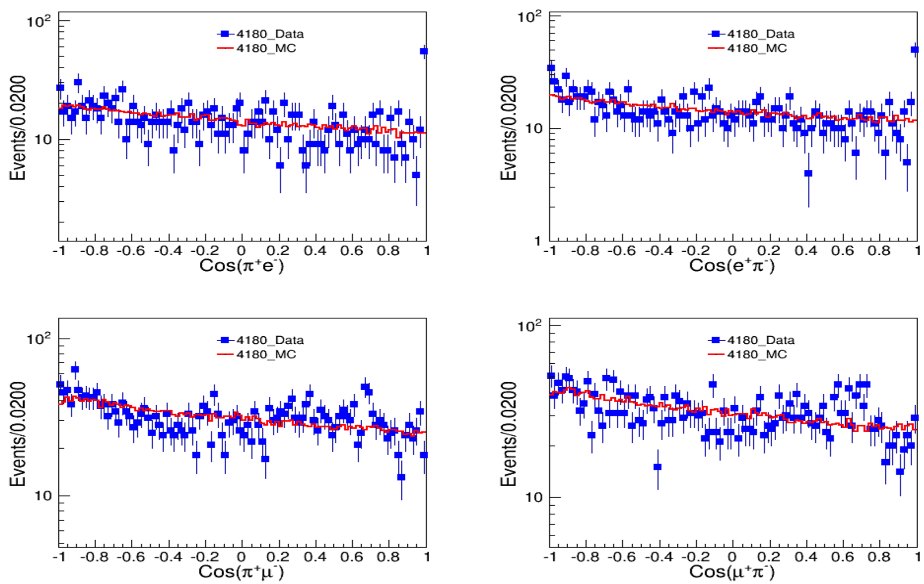
I. Misidentifying of muon and pion
II. 4pion(main $a_2^{\pm}\pi^{\mp}$ and $\rho^0\pi^+\pi^-$)

◆ Gamma-conversion events

The cosine value of $\pi^+\pi^-$



The cosine value of π and lepton



From the distribution of cosine, we can see clearly difference between data and MC at -1.0, and the background is from Gamma-conversion events.

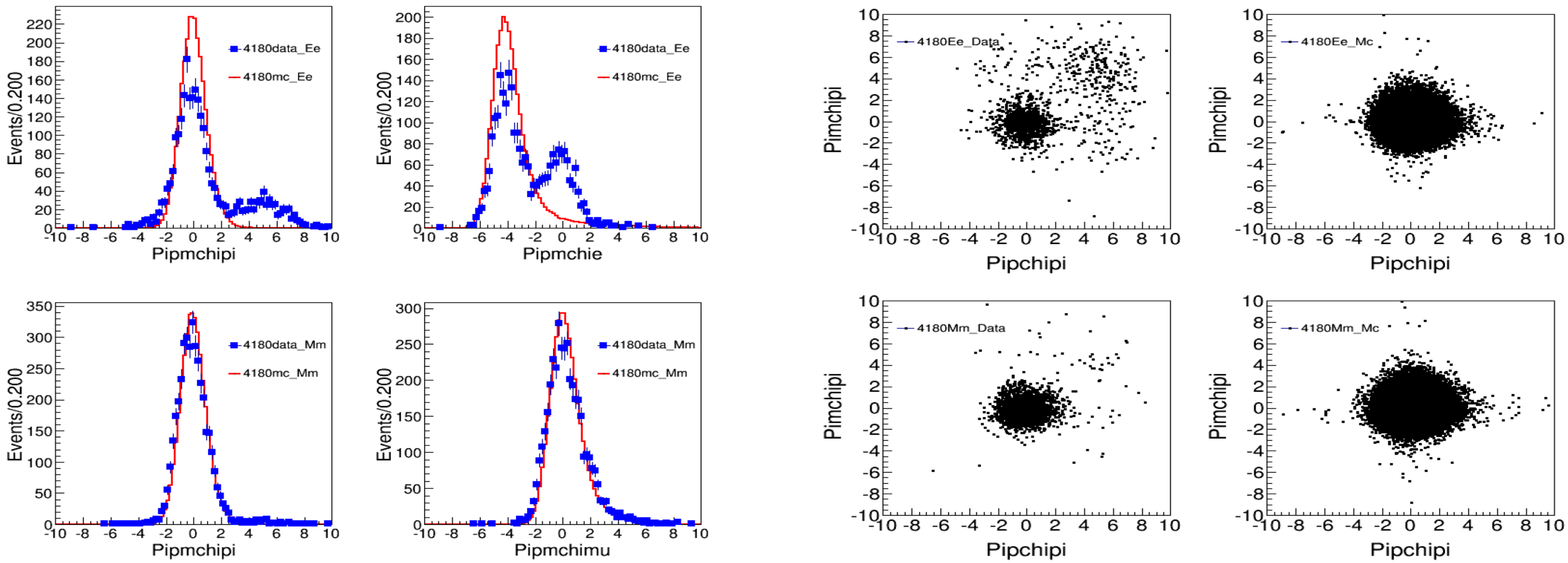
Cut criteria:

Ee channel: $\cos(\pi^+\pi^-) < 0.98 \&\& \cos(\pi^+e^-) < 0.98 \&\& \cos(e^+\pi^-) < 0.98$

Mm channel: $\cos(\pi^+\pi^-) < 0.98$

◆ Misidentifying of leptons and pion

From the dE/dX chi distribution, we can see clearly misidentification of pion and leptons. For ee channel is the low momentum electron misidentify to pion. And for mm chanel is low momentum muon misidentify to pion.



From our analysis, we found that the cut on two dimensional distribution of Pipchipi and Pimchipi will get a better results.

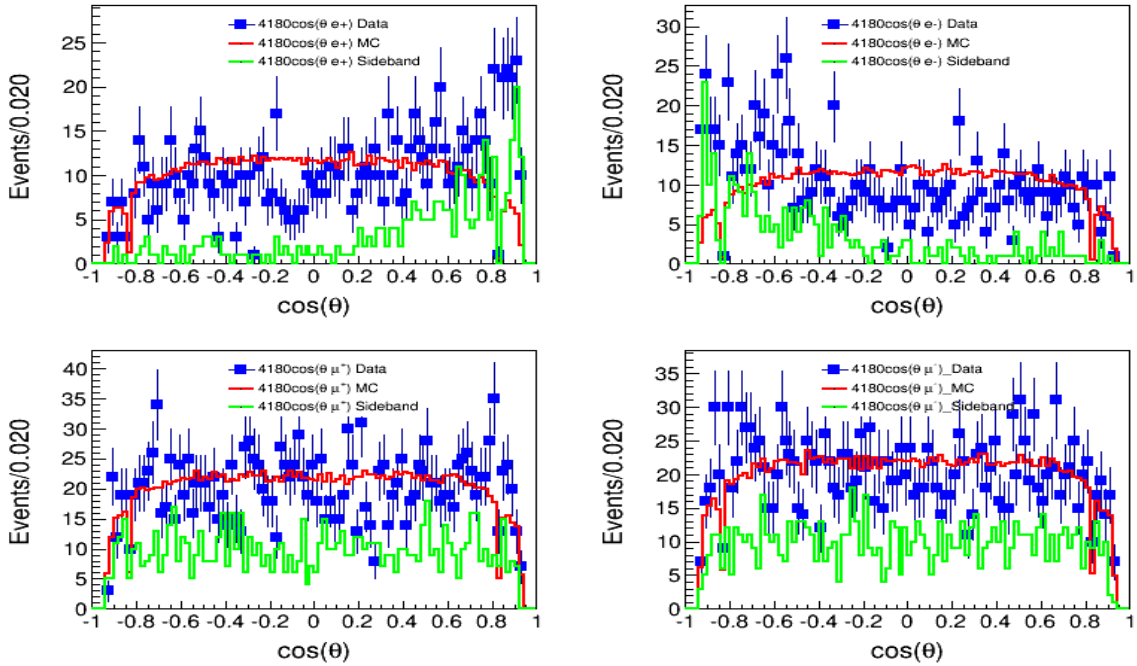
Cut criteria:

Ee channel: Pipchipi<2.8&&Pimchipi<3.0

Mm channel: Pipchipi<3.2&&Pimchipi<4.1

◆ The $ee\mu\mu$ of two-photon process

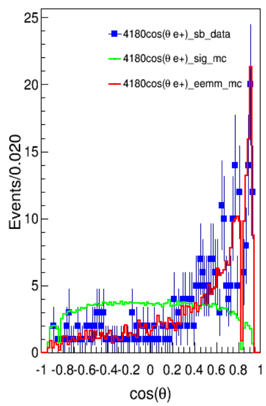
After exclude the background we know, there are still amount of unknown events. But it has a character of angle distribution. The plot shows the distribution of the angle between z-axis.

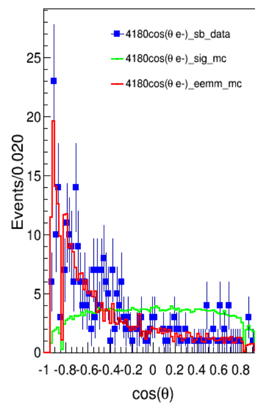


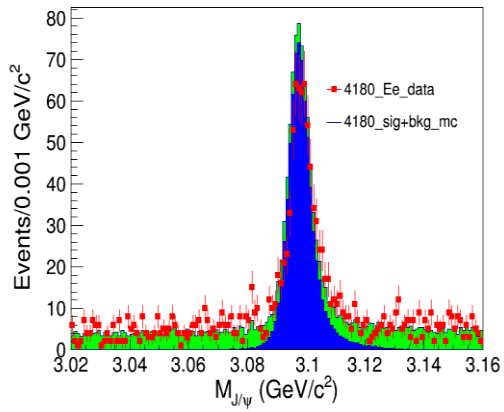
We have do much work to analyze this unknown background and find it is the $ee\mu\mu$ of two-photon process. And we will use BDT method to exclude it, we have no better directly cut to do this.

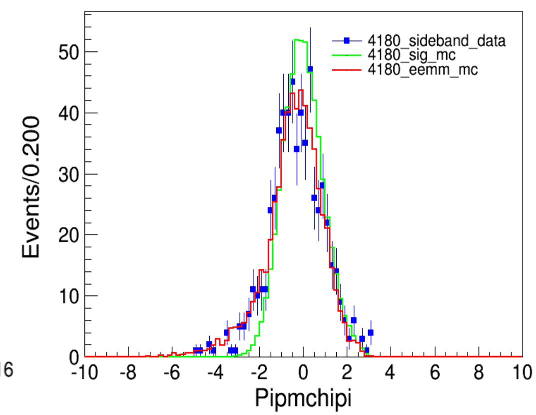
◆ The ee$\mu\mu$ of two-photon process

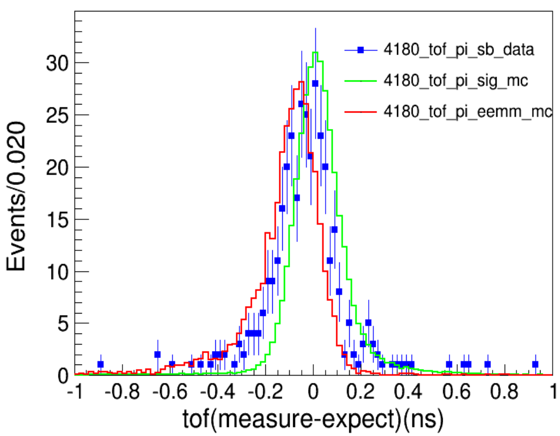
Thanks for Guo Yuping to offer us the generator so that we can do the following work. We will use the discrepant variables to do BDT analysis.

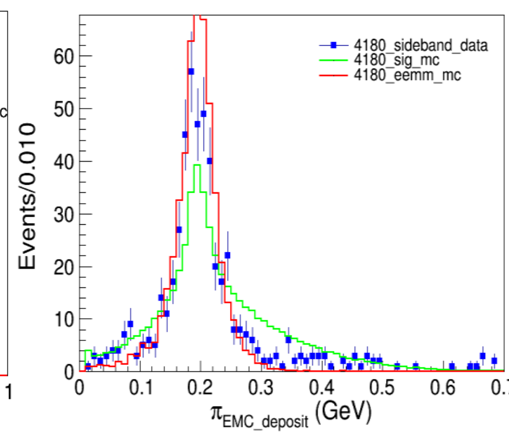


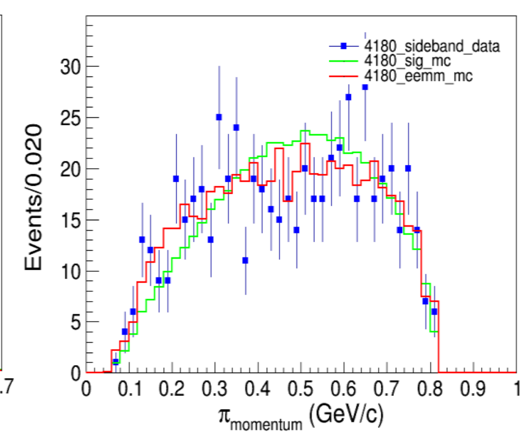






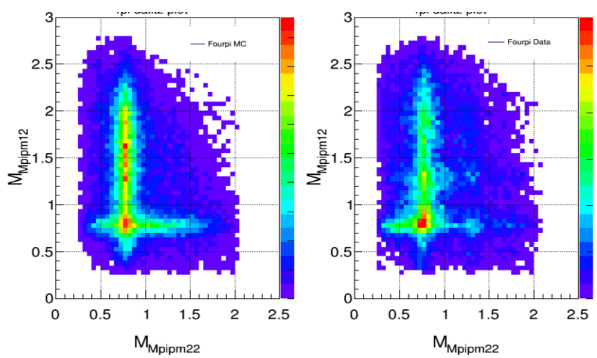


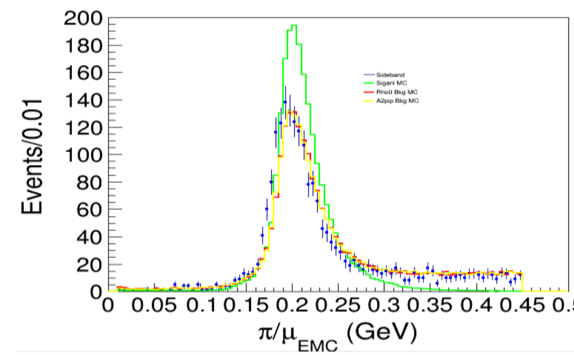


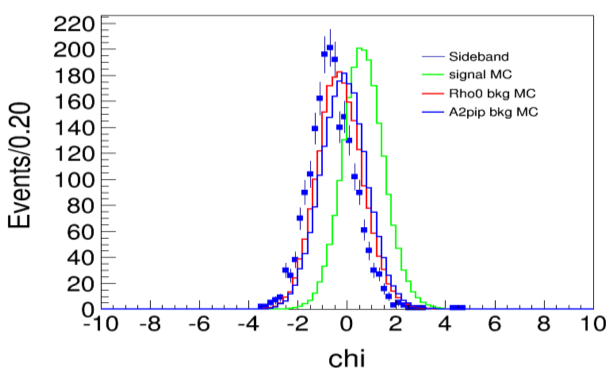


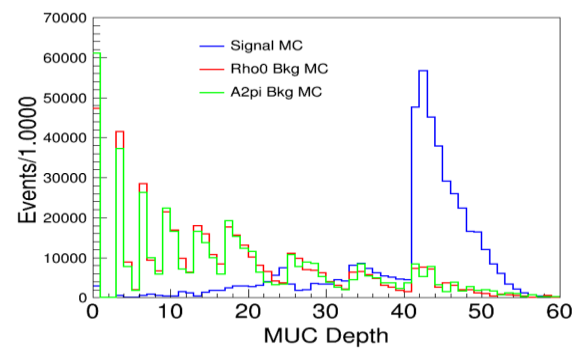
◆ 4pion background in $\mu\mu$ channel

From the combination of four pi, the 4 pion background comprise $a_2^{\pm}\pi^{\mp}$ and $\rho^0\pi^+\pi^-$ processes, and no peak in signal area. The distribution of EMC, dE/dX and MUC depth are the similar respectively. But the MUC has some serious problem, and we can't do correction now.





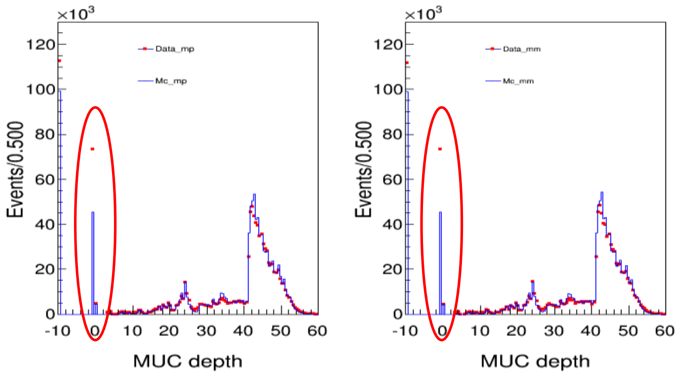




◆ Some problems

We have analyze the MUC problem for a long time, we find that there are about 4.0% muon not be recorded. And because of the angle distribution relevance and the MUC's structure character, we can't find a control sample to correct the efficiency.

For more information about the MUC problem, you can turn to the backup or the report by Tang Guangyi.

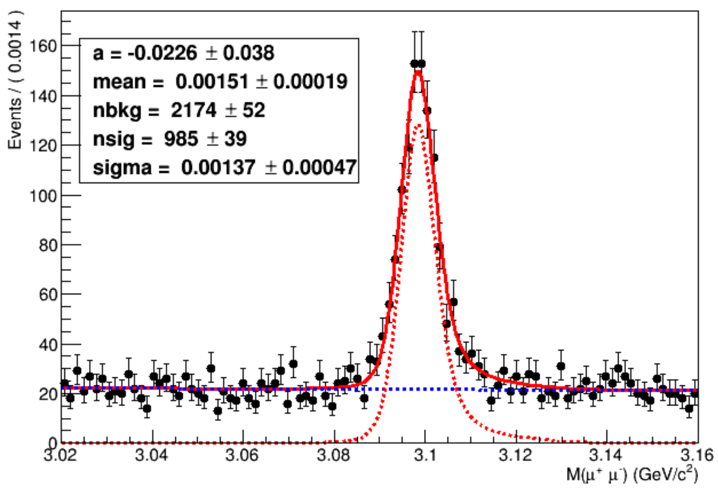


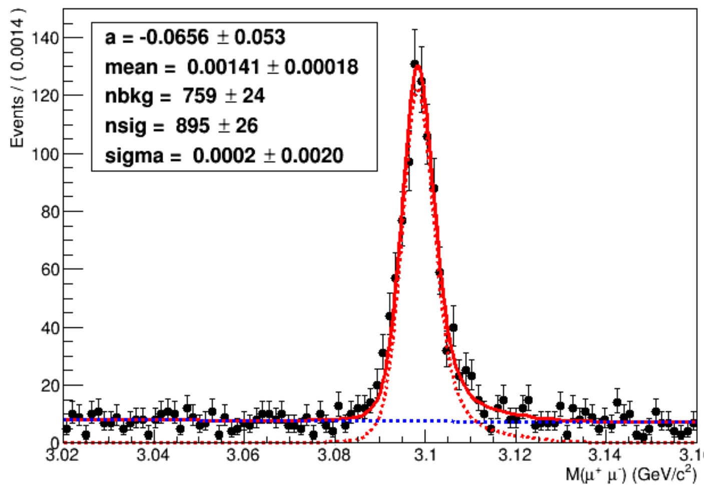
4237 Dimu events
MUC depth of $\mu^+\mu^-$

https://indico.ihep.ac.cn/event/7447/session/8/contribution/23/material/slides/0.pdf

◆ Some problems

In spite of the MUC efficiency problem, we can still use the MUC depth information in PWA analysis. And it will exclude the 4pi background effectively.



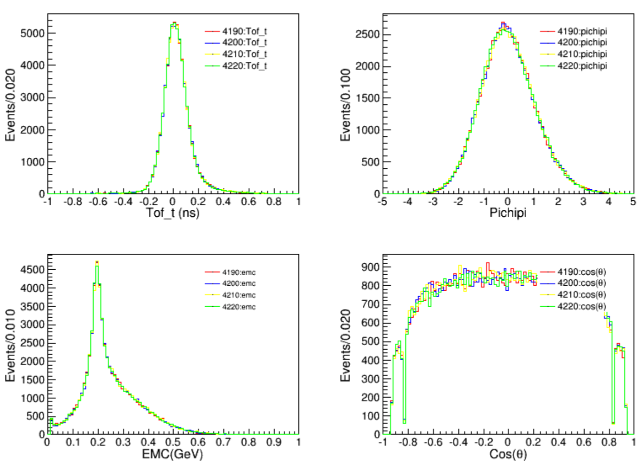


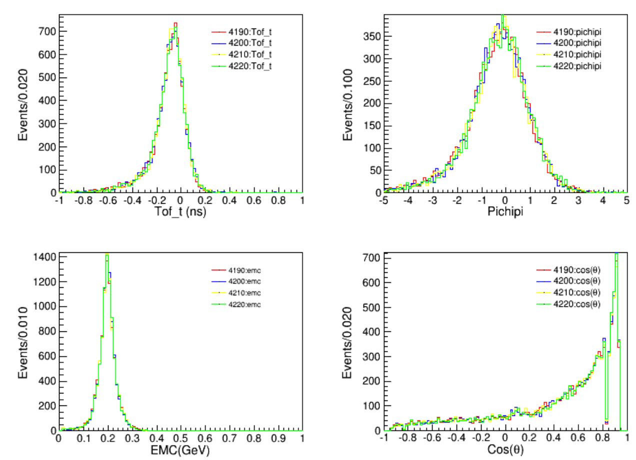
depth_mp>20 or depth_mm>20

We use the MC shape convolute Gaussian to fit the invariant mass of $\mathrm{M}_{\mu\mu}$, and compare the results with and without the cut, about 65% background will be exclude and only loss 9% signal events.

◆ Using BDT to exclude the background

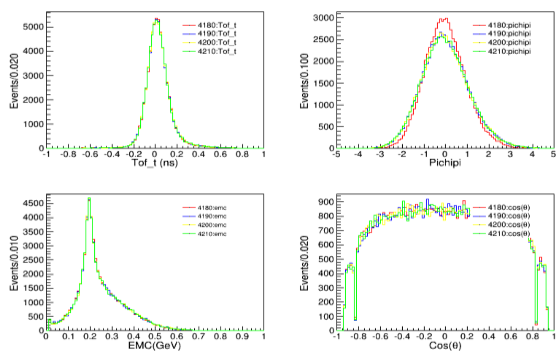
According to the analysis ahead, we can use BDT method to exclude the $ee\mu\mu$ of two-photon process background. And we find the variables are used in BDT have the similarity distribution of the new XYZ data respectively, but the 4180 sample is difference because of the boss version with dE/dX chi distribution.
So we will use two BDT models to 4180 data and new XYZ data.

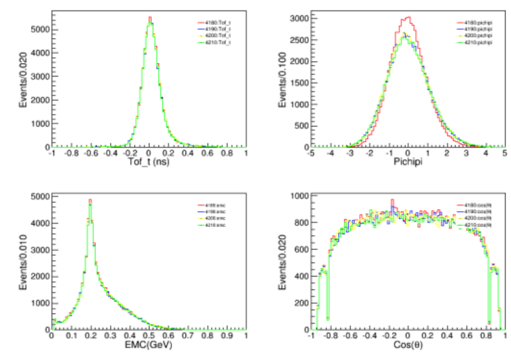




◆ dE/dX chi distribution

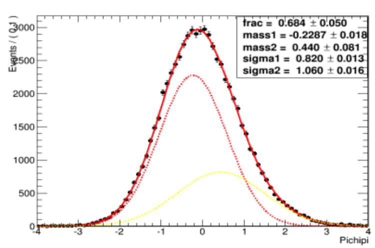
4180 data has been reconstructed in Boss703, but the dE/dX is not recalibrated. We fit the distribution with double Gaussian and the MC are conform to the data in two Boss version respectively.

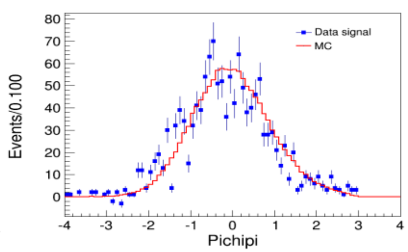


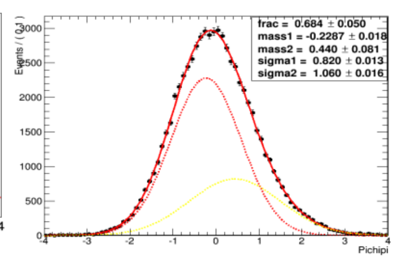


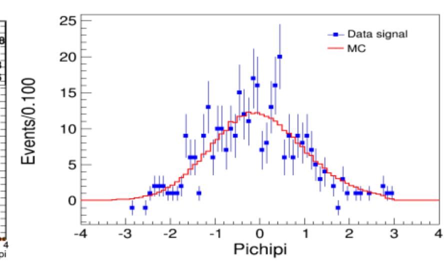
702p01

703



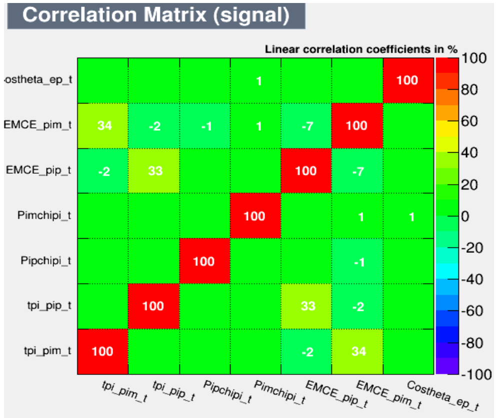


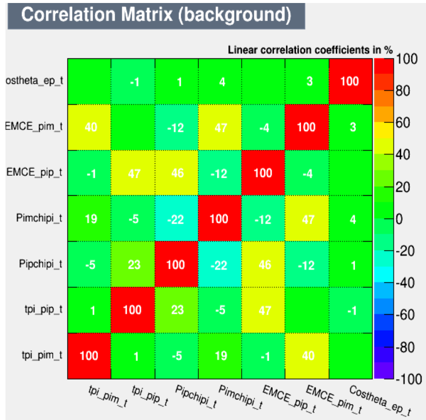


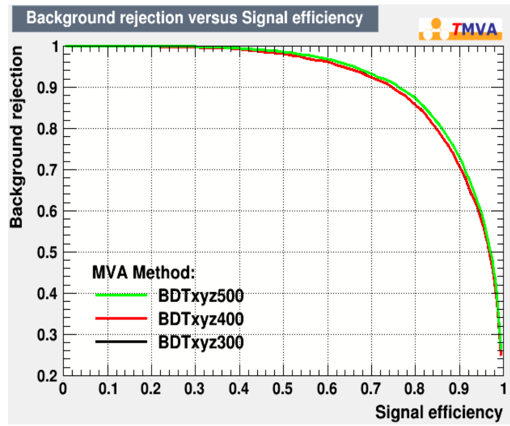


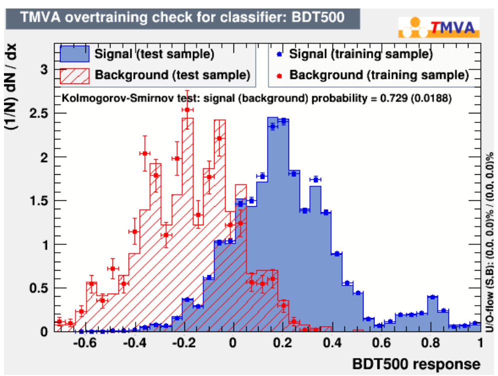
◆ Using BDT to exclude the background

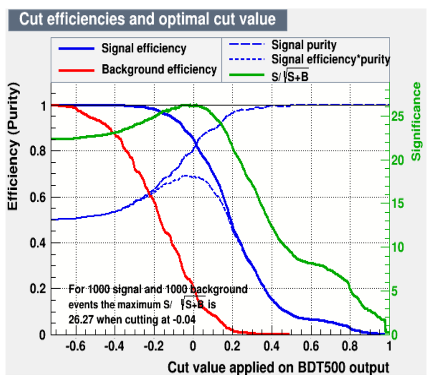
We use the tof, EMC, dE/dX and the costheta as the BDT variable, and they have weak correlation. For many tests, we use 500 trees to get a better ROC curve, and the train sample will accord with the test sample better.











◆ Using BDT to exclude the background

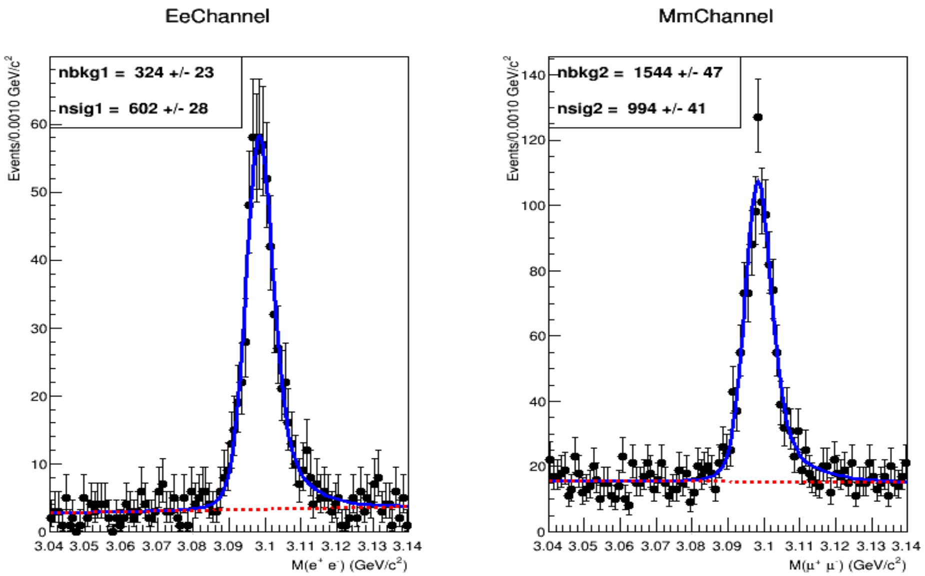
For the signal events number(Sig) and background events number(Bkg) used in BDT, we use the signal area events and the sideband events as estimation.

The BDT method will give the maximum S/sqrt(S+B) and the corresponding cut value, also the cut efficiency.

Energy	4180	4190	4200	4210	4220	4237	4246	4270	4280
Sig	637	140	246	330	539	677	624	488	147
Bkg	215	42	39	43	34	41	38	41	16
BDT(cut)	23.213 (-0.1370)	10.9135 (-0.1118)	14.9058 (-0.1421)	17.3851 (-0.1673)	22.6497 (-0.2042)	25.4046 (-0.2247)	24.3872 (-0.2247)	21.4156 (-0.1871)	11.6703 (-0.1819)
Effsig	0.9574	0.962	0.9754	0.9834	0.9914	0.9942	0.9942	0.9882	0.9871
Effbkg	0.3738	0.4195	0.4921	0.5564	0.6542	0.7047	0.7047	0.6056	0.5932

◆ Fitting method

After all cuts, we get our final results and use simultaneous_fit to constraint the two channels. We use the MC shape convolute Gaussian to describe the signal and Chebyshev polynomial to describe the background.



◆ The cross section

$$\sigma = \frac{N^{sig}}{\mathcal{L}_{int}(1+\delta)\mathcal{E}\mathcal{B}}$$

$$\mathcal{B}_e = (5.971 \pm 0.032)\%$$
$$\mathcal{B}_\mu = (5.961 \pm 0.033)\%$$

Energy	Events_ee	Events_mm	Ee_efficiency	Mm_efficiency	1+delta	Luminosity(pb-1)	Cross_section_ee(pb)	Cross_section_mm(pb)
4180	602+/-28	994+/-41	30.92%	47.98%	0.8301	3194.5 ±0.2 ±31.9	12.30+/-0.57	13.11+/-0.54
4190	139+/-13	221+/-19	31.96%	48.85%	0.8266	522.5±0.1±3.4	16.86+/-1.58	17.57+/-1.5
4200	234+/-17	355+/-22	32.74%	49.29%	0.8221	524.6±0.1±2.5	27.76+/-2.02	28.02+/-1.74
4210	343+/-20	577+/-27	32.75%	49.01%	0.8137	518.1±0.1±1.8	42.09+/-2.4	46.85+/-2.19
4220	555+/-24	840+/-32	33.26%	49.56%	0.8119	514.3±0.1±1.9	66.93+/-2.89	68.1+/-2.59
4237	681+/-27	1104+/-37	34.17%	50.57%	0.8057	530.6±0.1±2.4	78.08+/-3.10	85.67+/-2.87
4246	638+/-27	969+/-34	33.96%	50.59%	0.8092	537.4±0.1±2.6	72.35+/-3.06	73.89+/-2.59
4270	489+/-24	745+/-31	33.69%	50.41%	0.8235	529.7±0.1±2.8	55.73+/-2.74	56.84+/-2.37
4280	150+/-13	249+/-18	32.70%	49.50%	0.8238	175.5±0.1±0.9	53.13+/-4.61	58.37+/-4.22

◆ Next work

System error

I. Tracking
II. BDT
III. Others

PWA analysis

I. Give the cross section of Z_c(3900)
II. And so on

Summary

We will check our method and give the cross section of the nine energy points. And more important we will use PWA method to give the intermediate state information, like Z_c(3900) cross section.

Our analysis method can be used in other experiments. If we have the right MUC information, we can also use BDT method in $\mu\mu$ channel.

In our work, we have study all the background in pipijpsi(ee/$\mu\mu$) process.

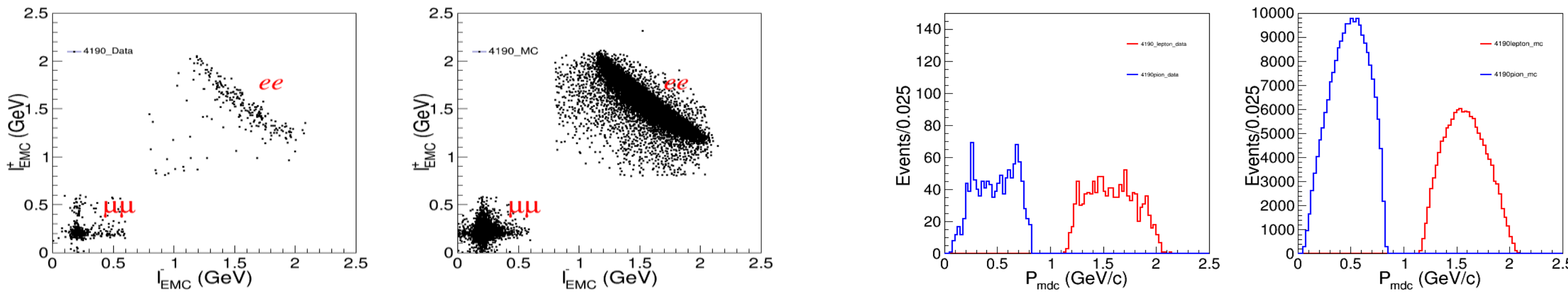
Thank you!

Backup

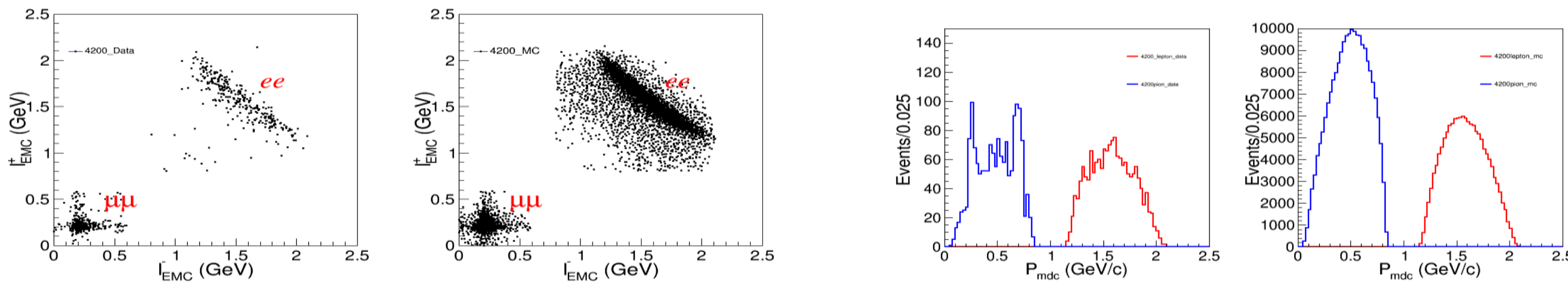
we have do detailed analysis in 4180 energy point and we can use same criteria to the new XYZ data. It may be not the optimization criteria for other energy points, but will also lead to good results.

And the next plots show the same information of the new XYZ data in 4180 analysis.

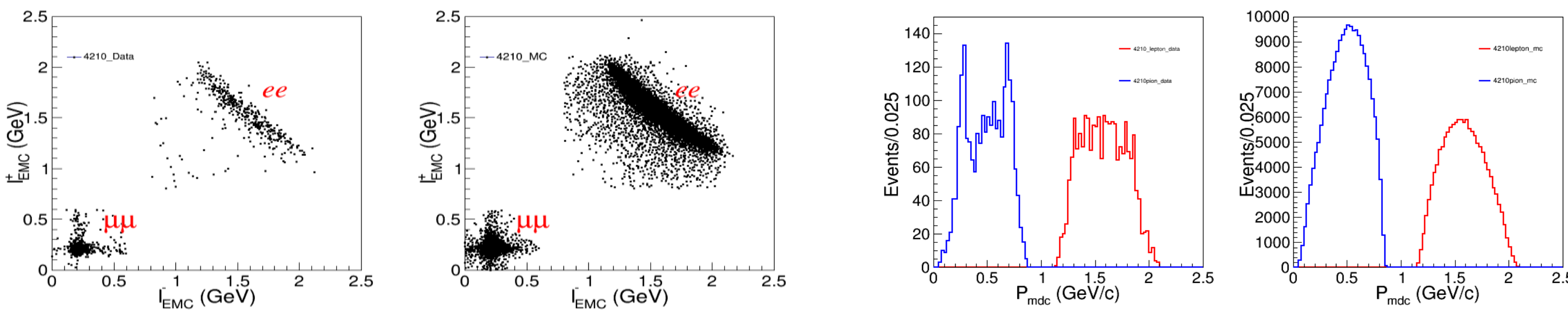
◆ Selected π and leptons



4190:P_pion<0.83, P_lepton>1.12

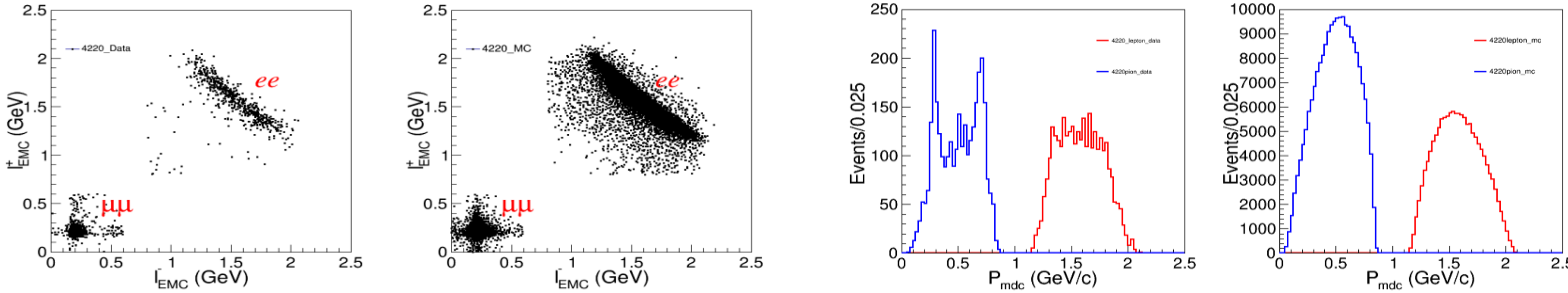


4200:P_pion<0.84, P_lepton>1.12

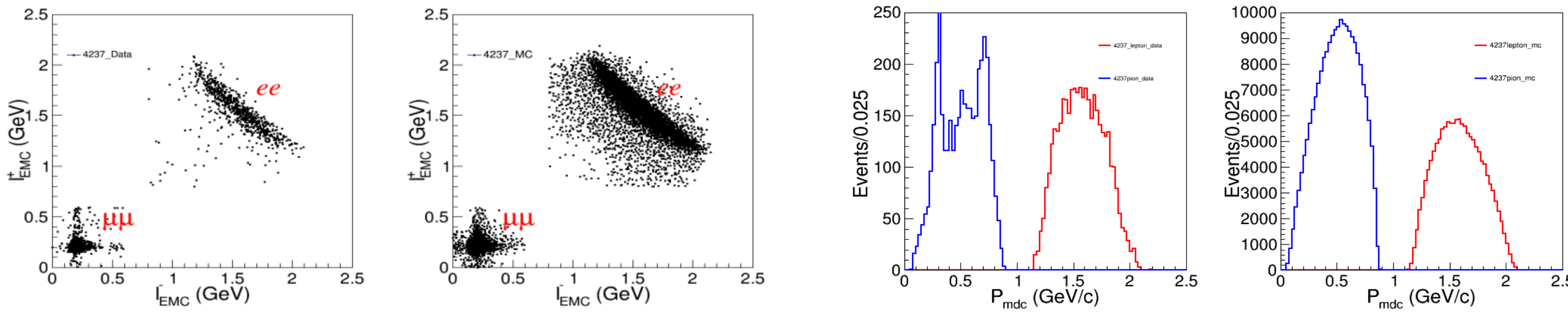


4210:P_pion<0.85, P_lepton>1.12

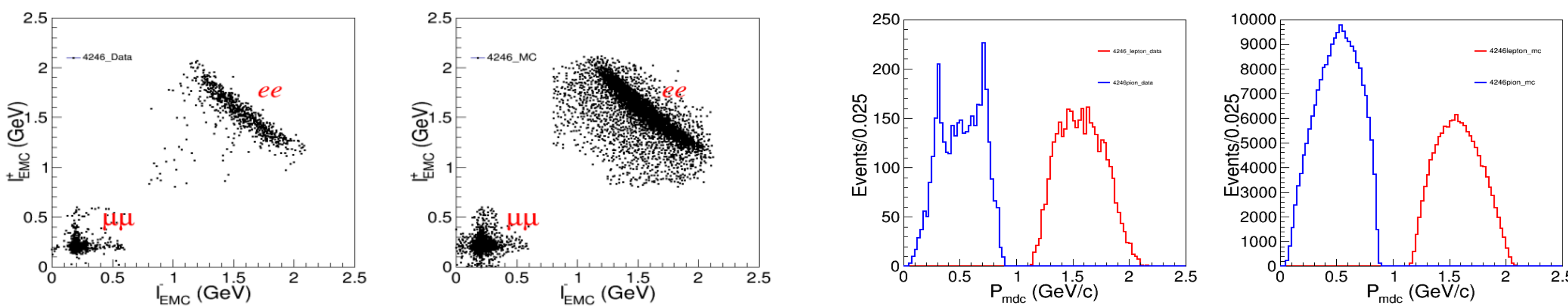
◆ Selected π and leptons



4220:P_pion<0.86, P_lepton>1.12

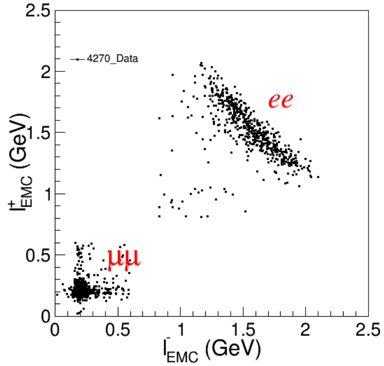


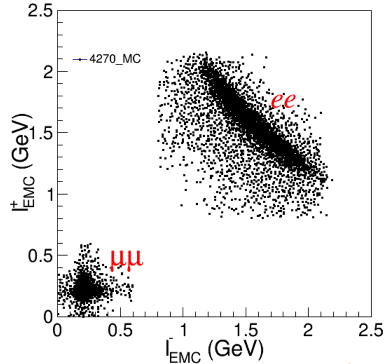
4237:P_pion<0.87, P_lepton>1.12

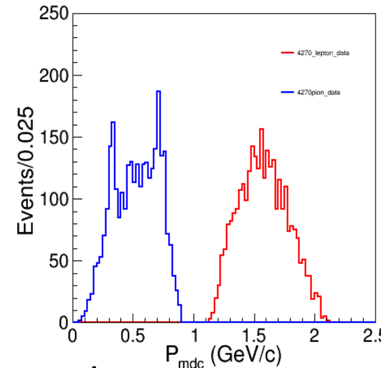


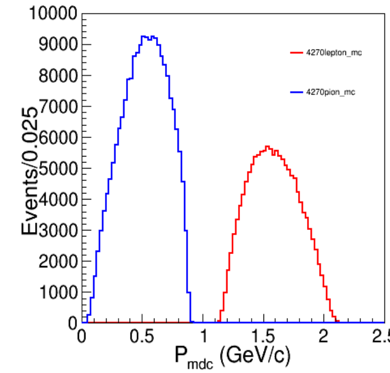
4246:P_pion<0.88, P_lepton>1.12

◆ Selected π and leptons

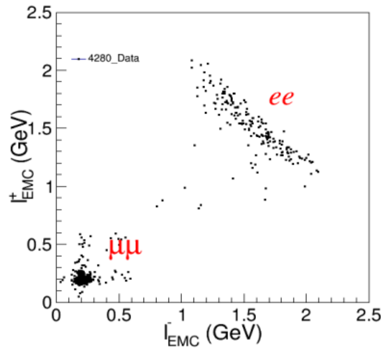


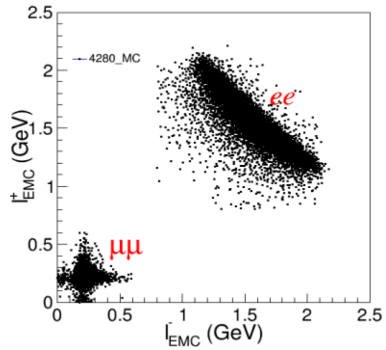


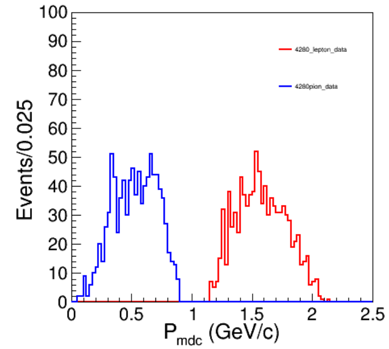


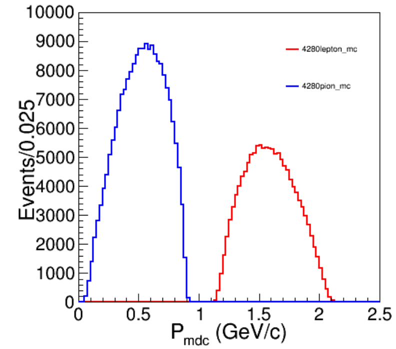


4270:P_pion<0.89, P_lepton>1.12



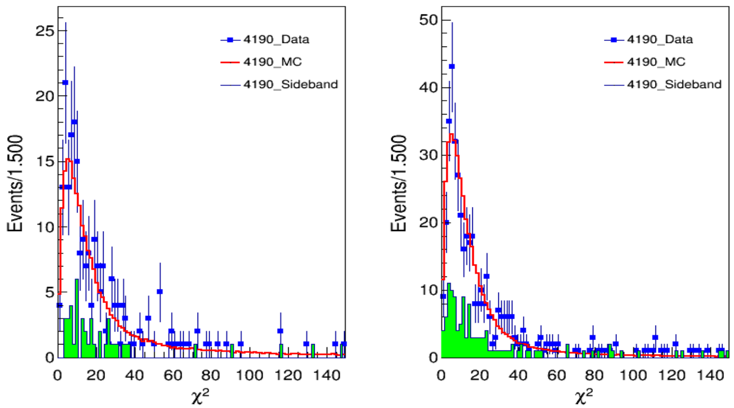






4280:P_pion<0.90, P_lepton>1.12

◆ 4C fit chisq



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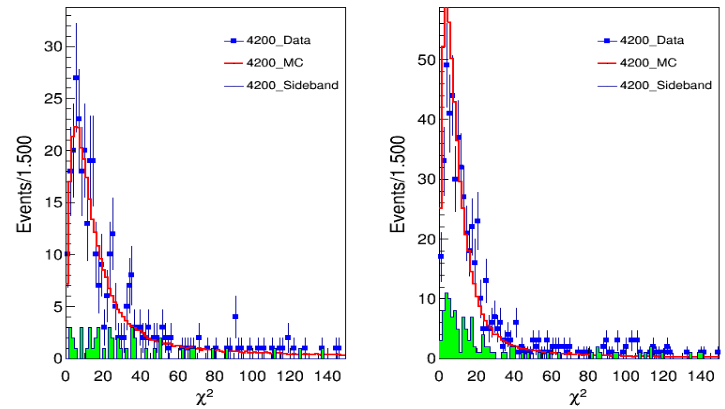

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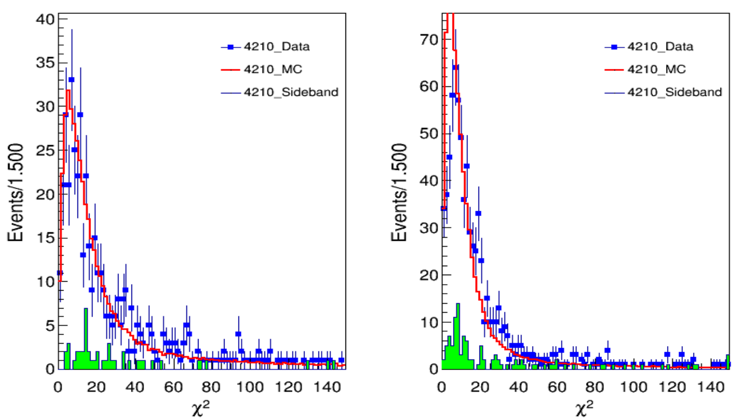

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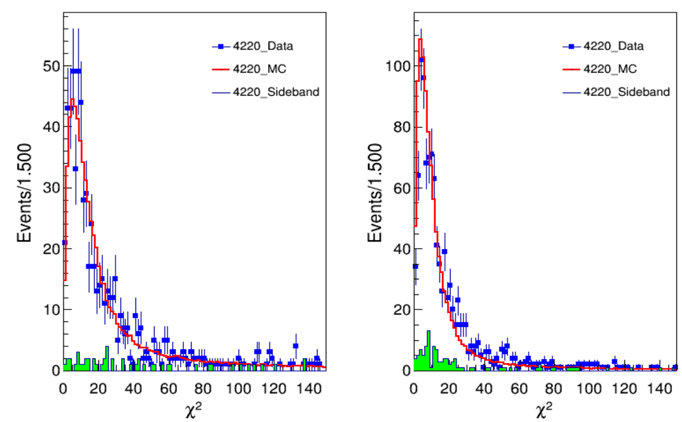
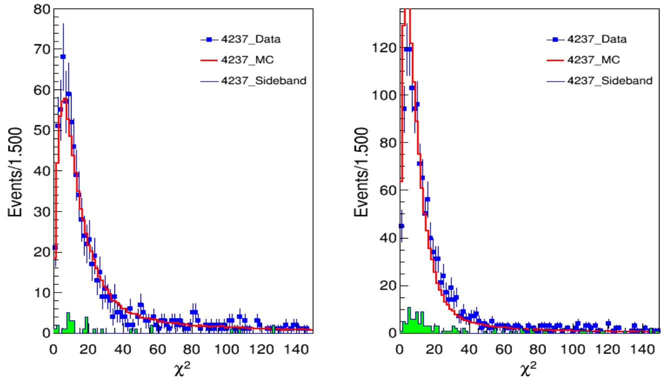


4220

◆ 4C fit chisq



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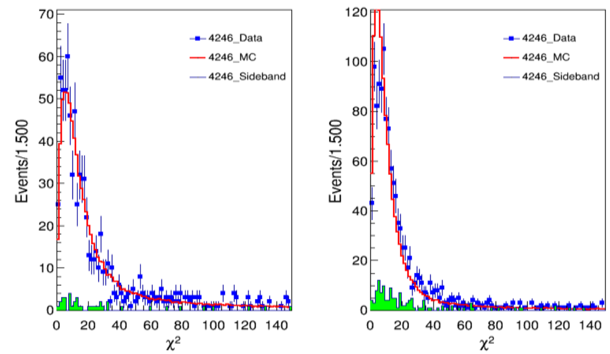

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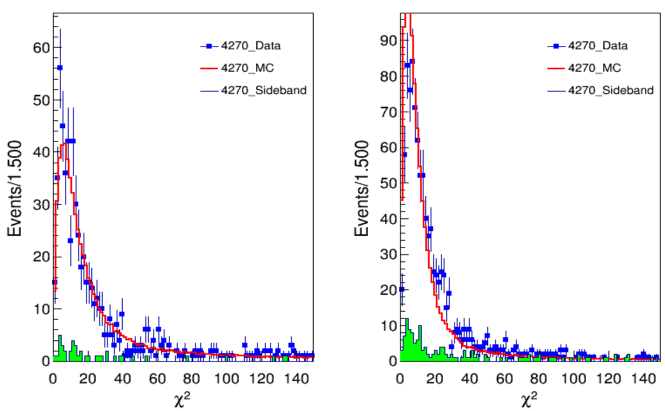

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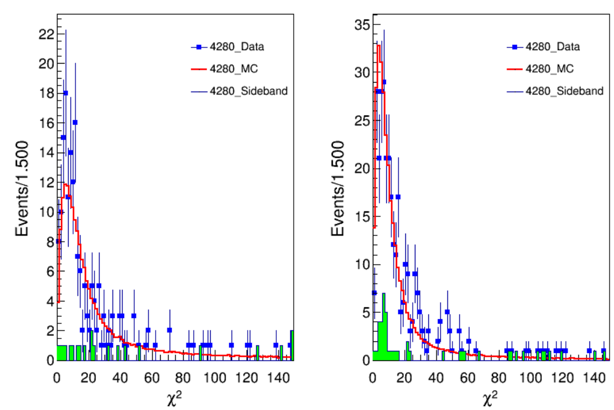
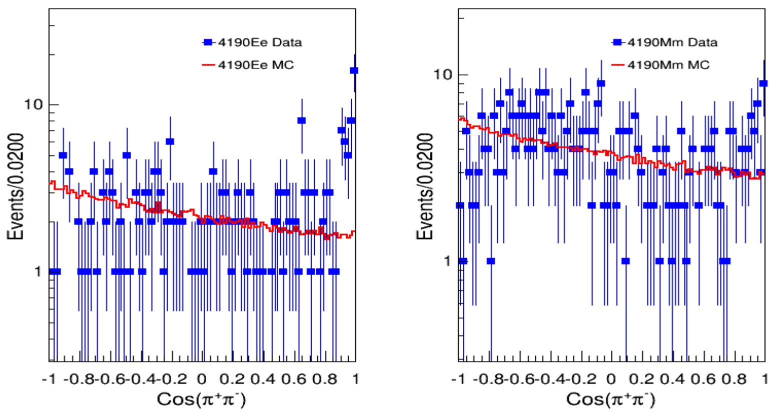


4280

◆ Gamma-conversion events

The cosine value of $\pi^+\pi^-$



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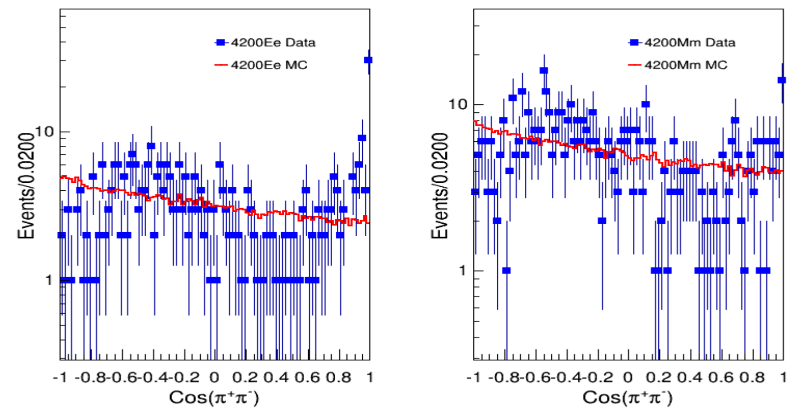

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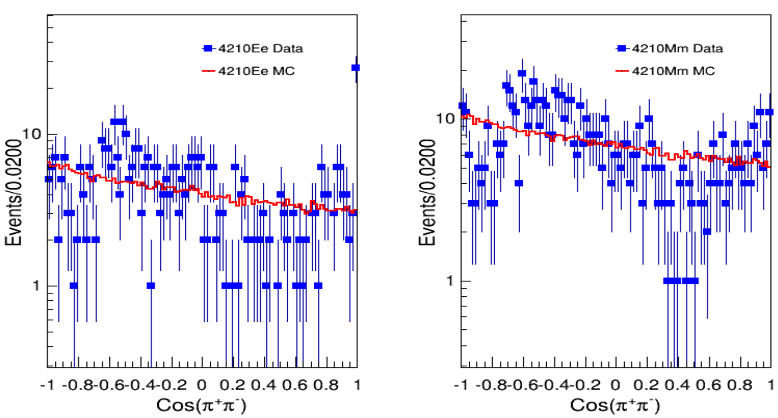

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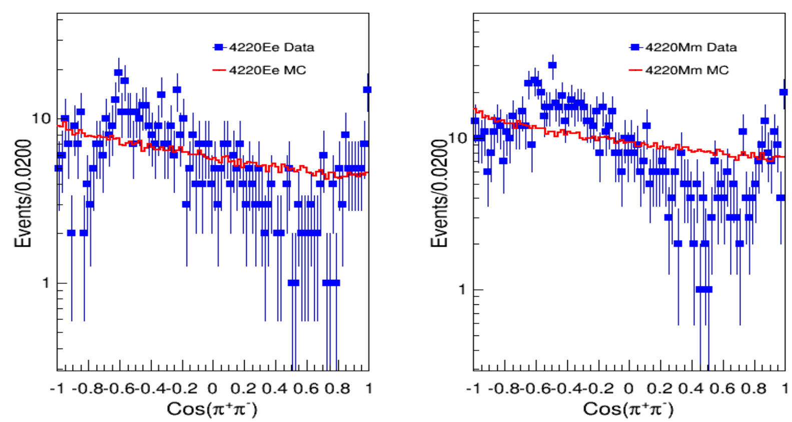
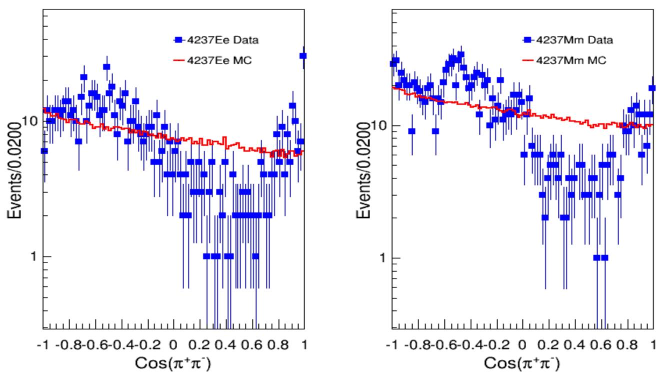


4220

◆ Gamma-conversion events



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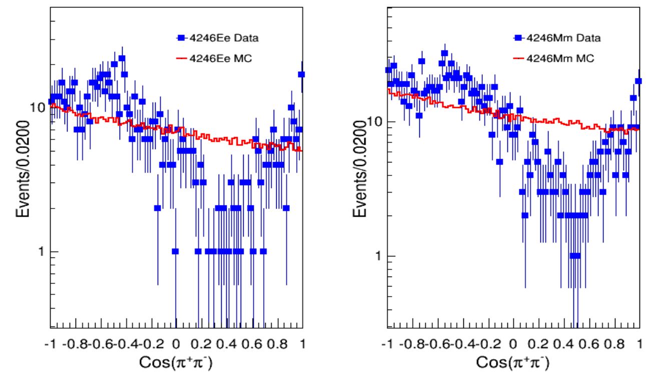

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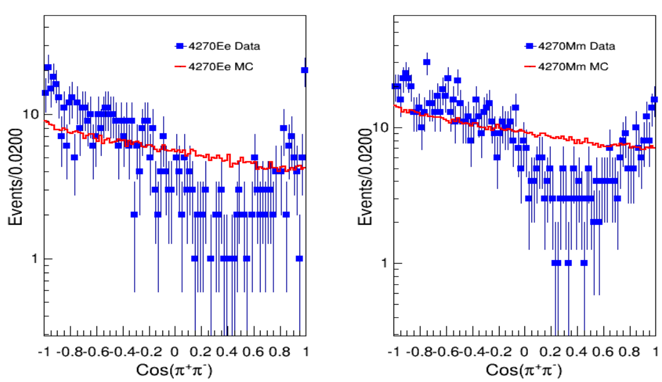

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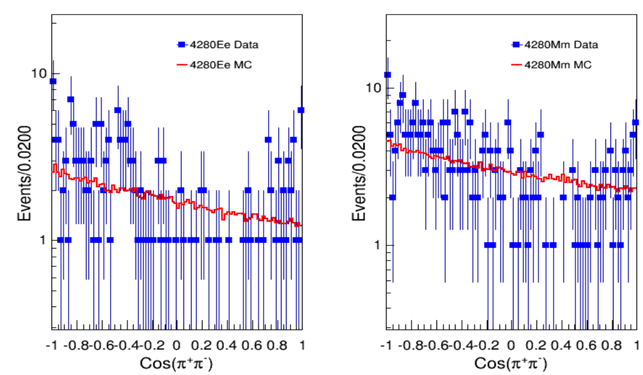
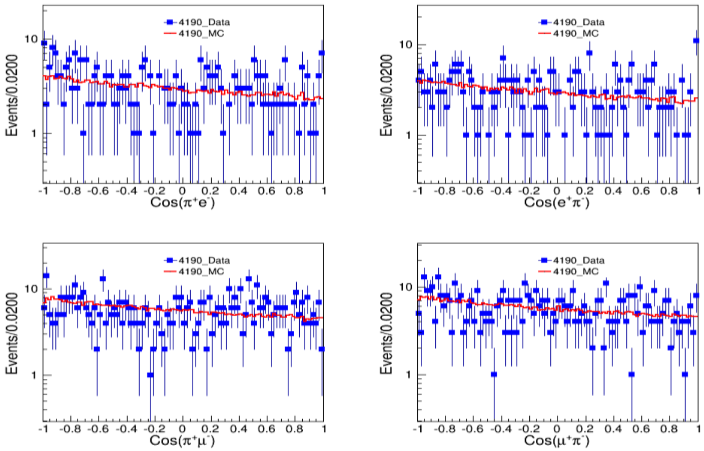


4280

◆ Gamma-conversion events

The cosine value of π and lepton



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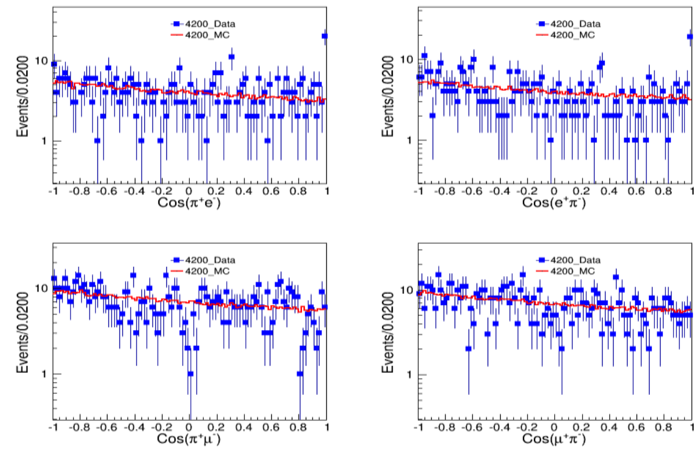

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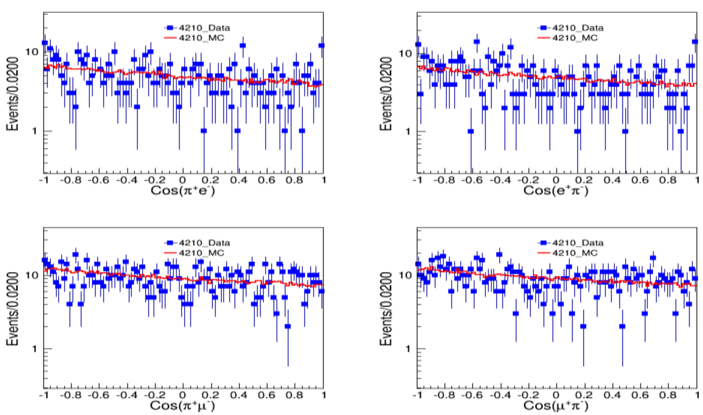

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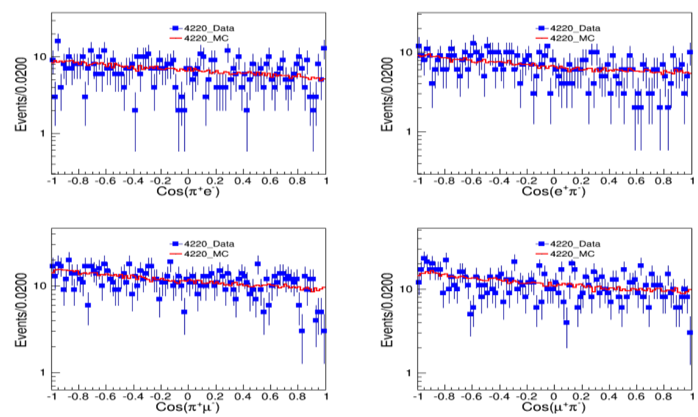
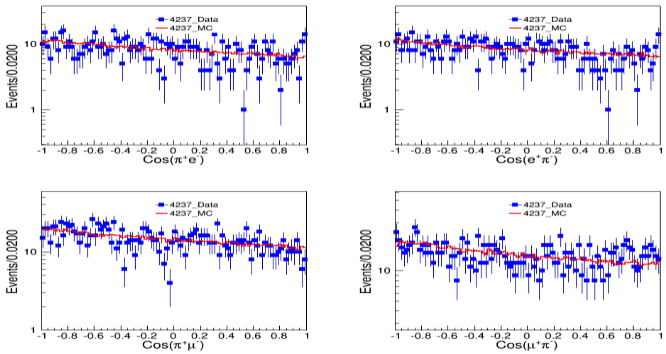


4220

◆ Gamma-conversion events



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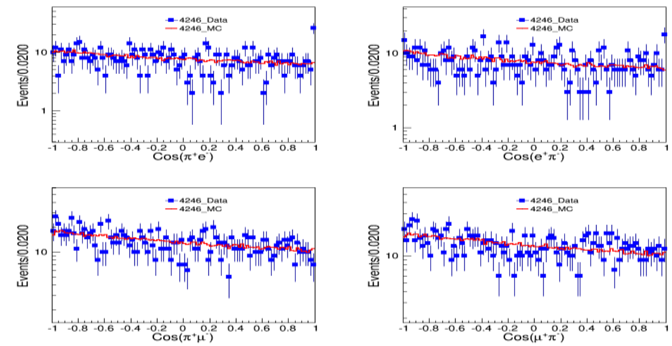

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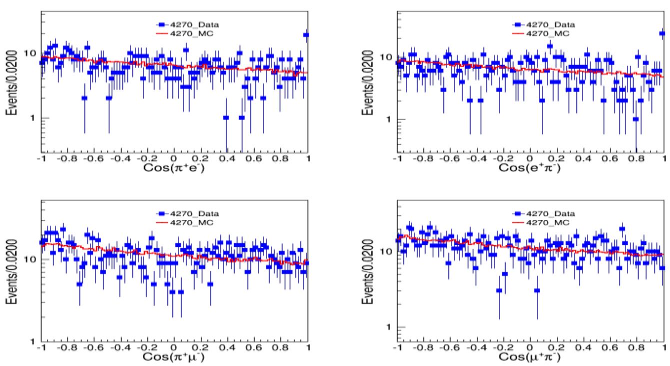

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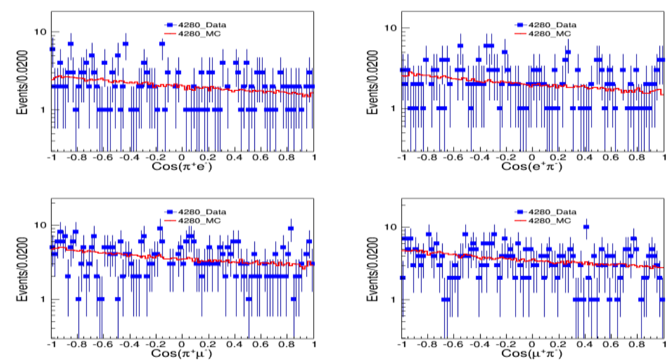
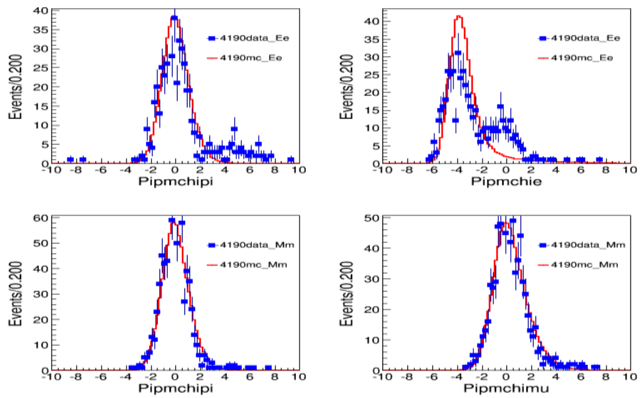


4280

◆ Misidentifying of leptons and pion



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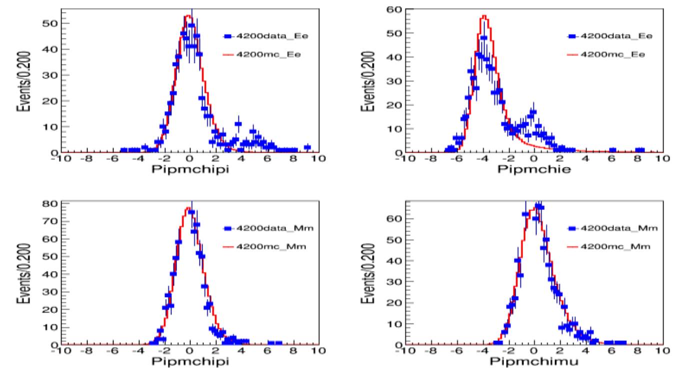

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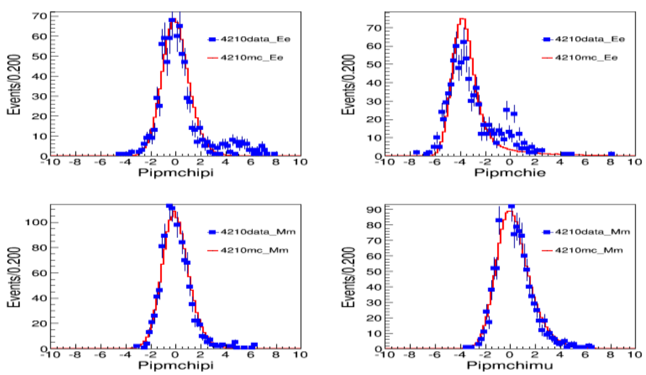

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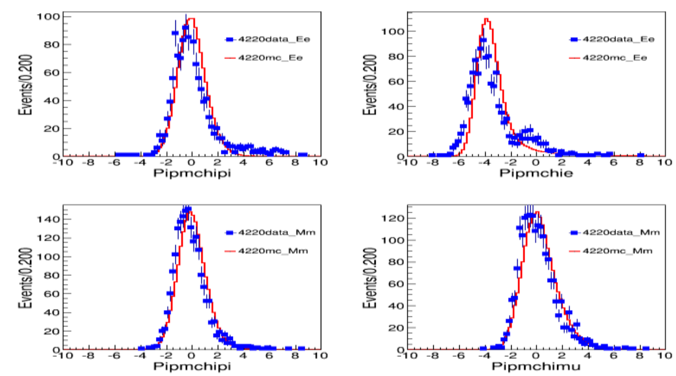
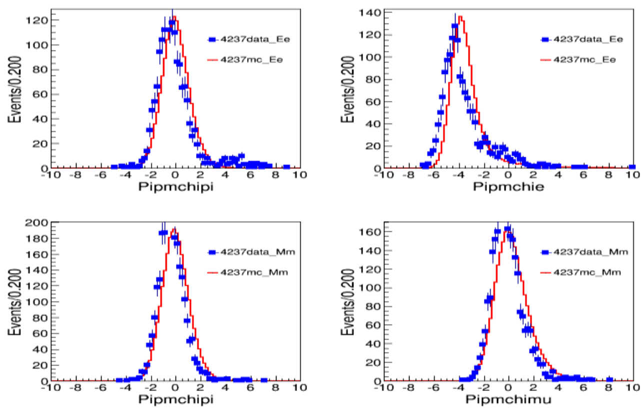


4220

◆ Misidentifying of electron and pion



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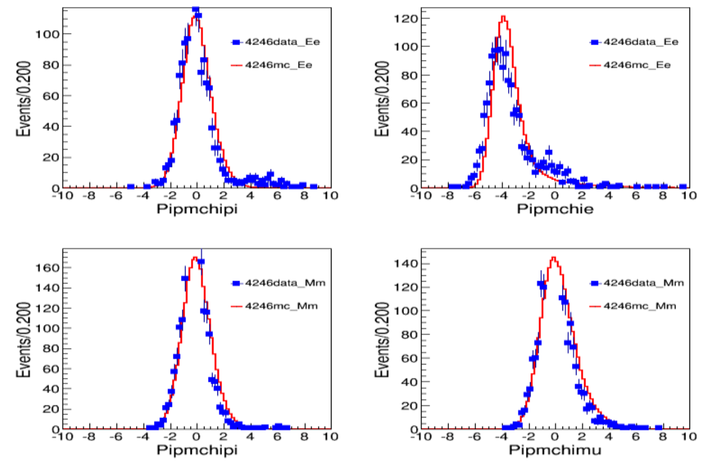

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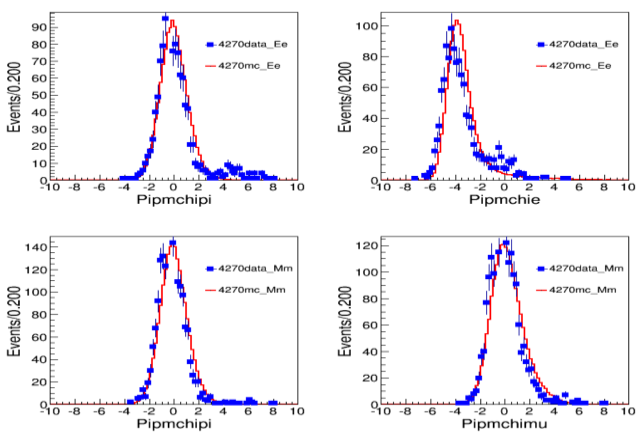

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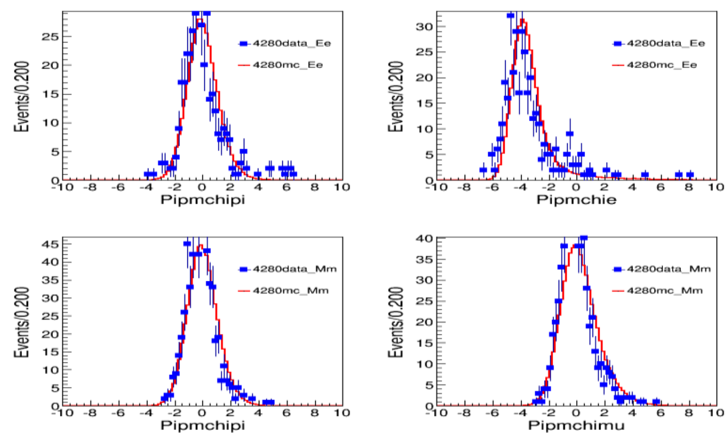
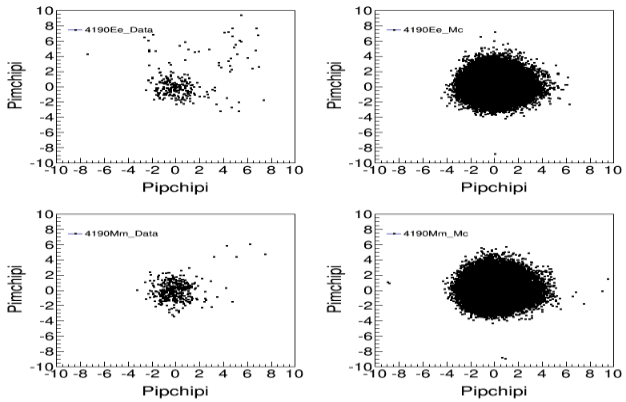


4280

◆ Misidentifying of electron and pion



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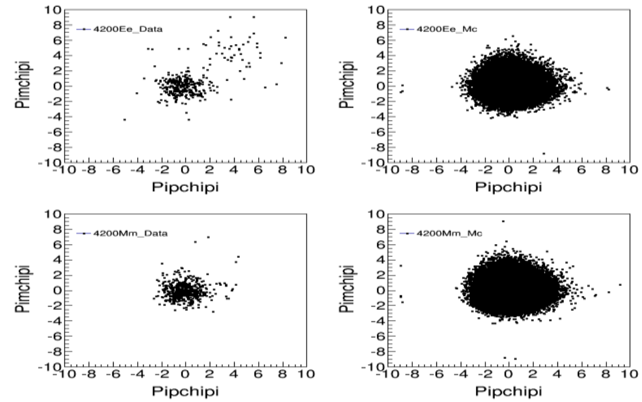

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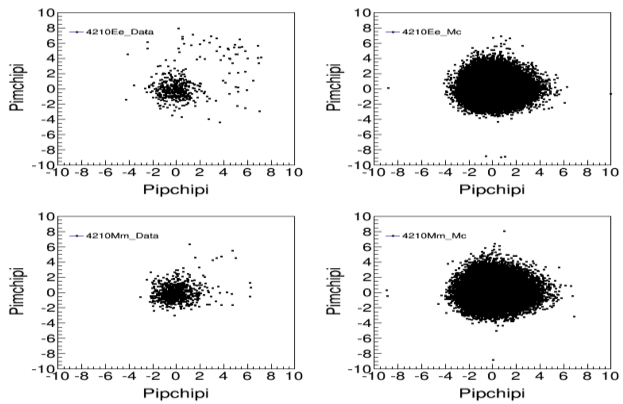

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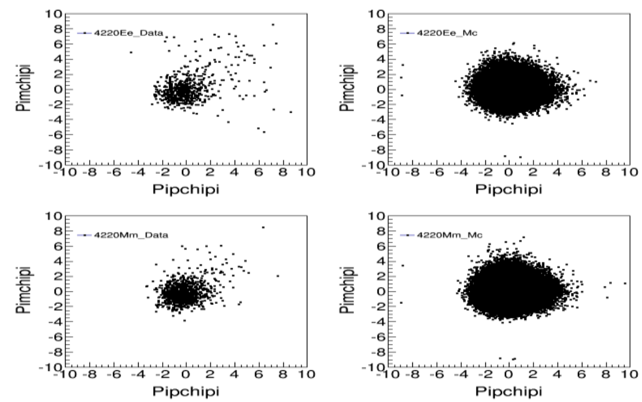
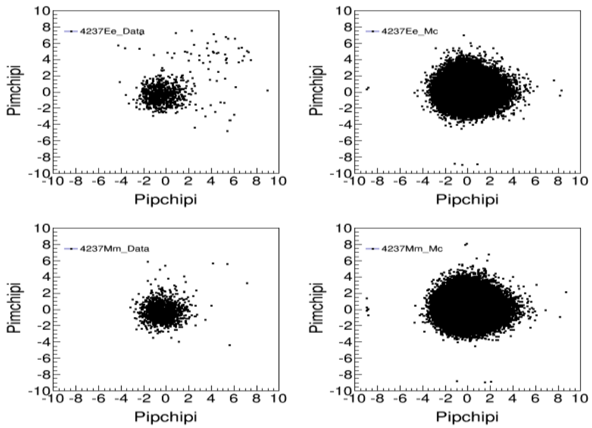


4220

◆ Misidentifying of electron and pion



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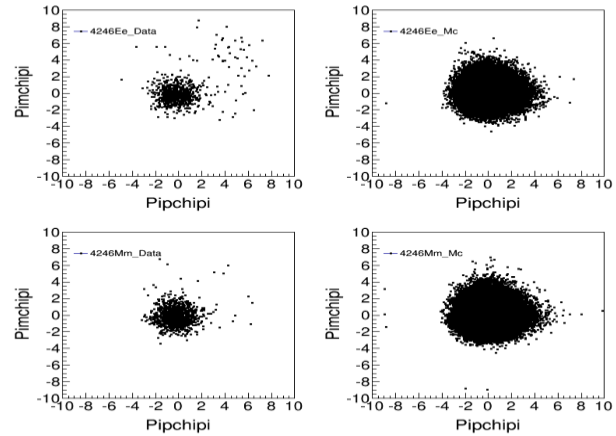

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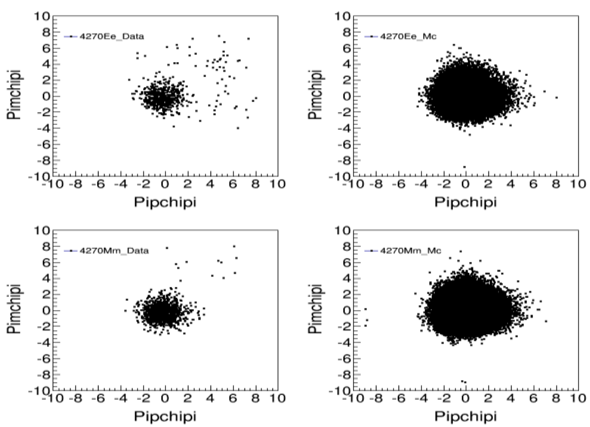

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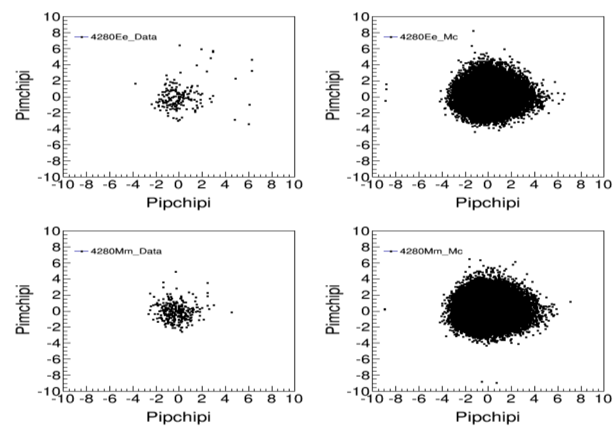
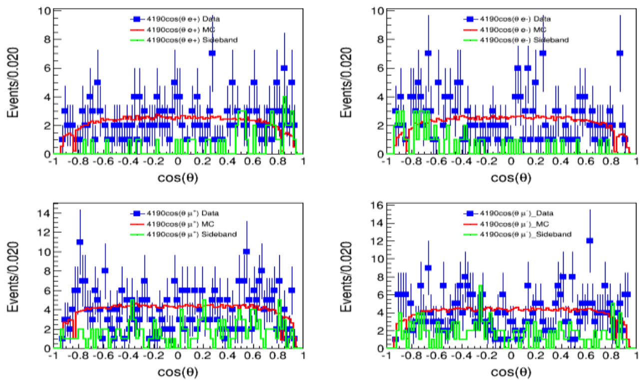


4280

◆ The ee$\mu\mu$ of two-photon process



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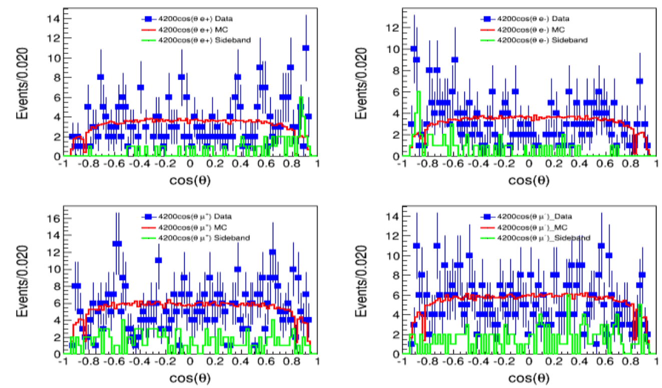

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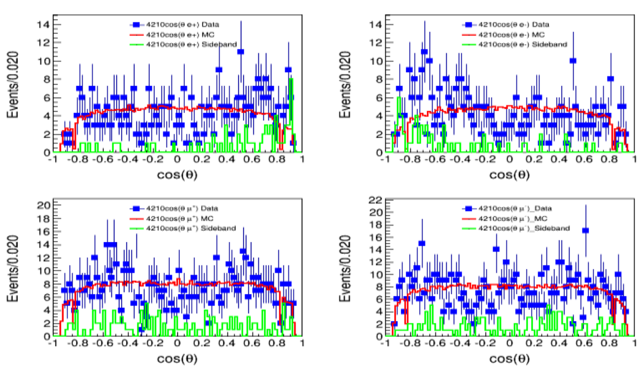

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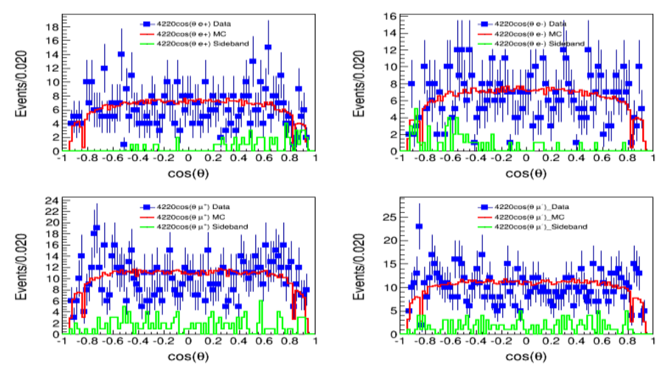

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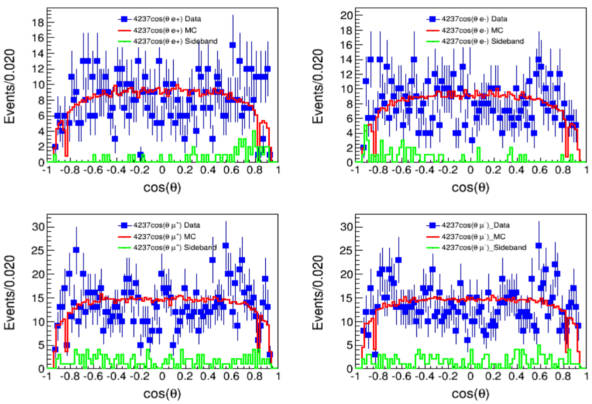
◆ The ee$\mu\mu$ of two-photon process



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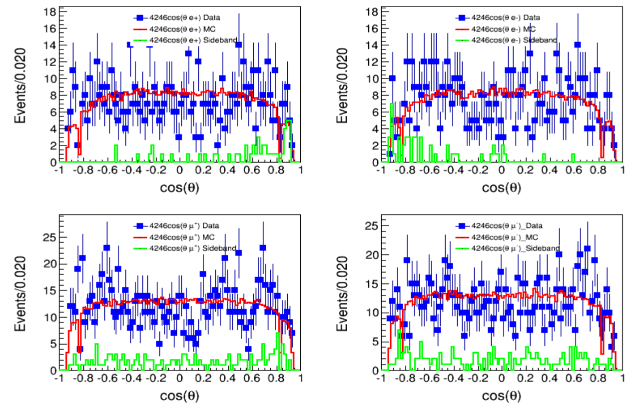

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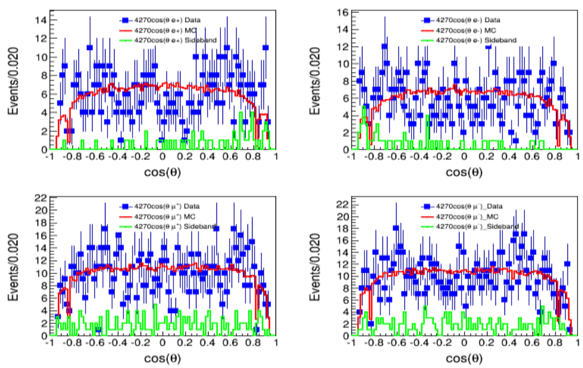

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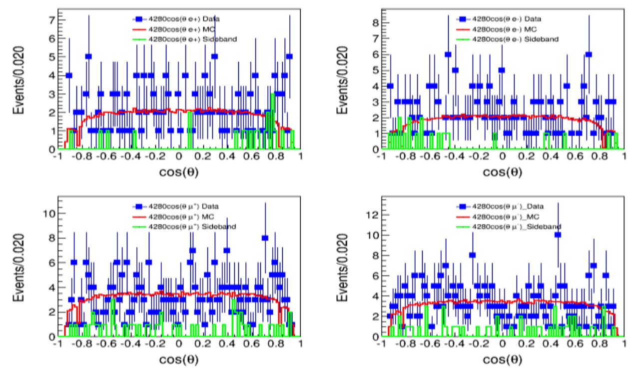
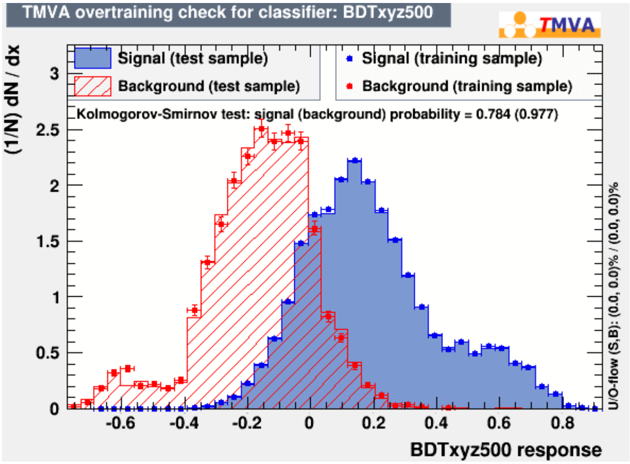
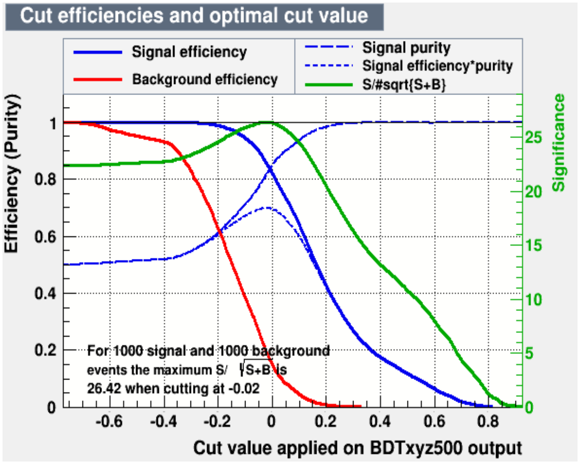


4280

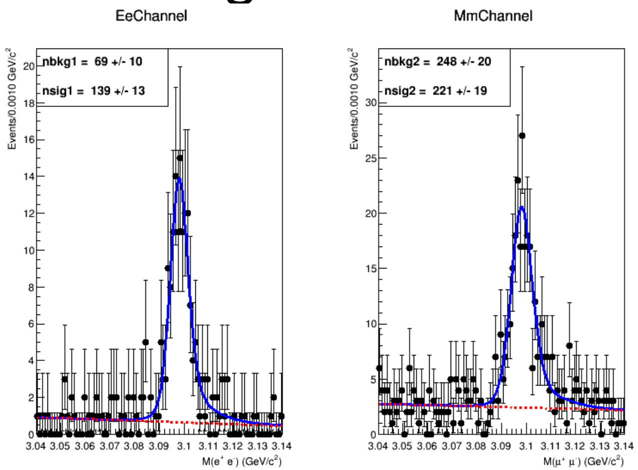
◆ Using BDT to exclude the background



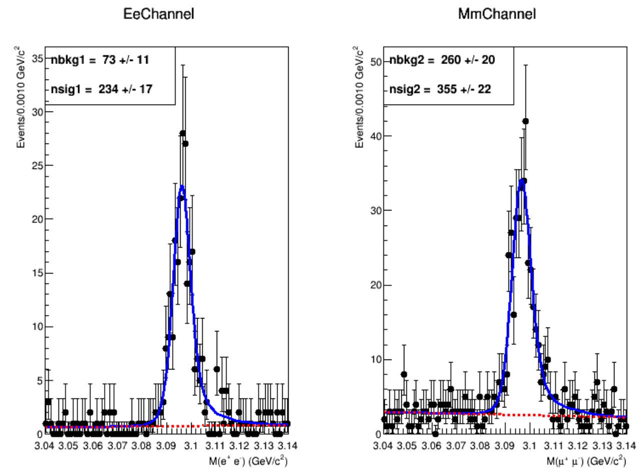


New XYZ MC sample:
We have product eight times MC sample of new XYZ sample than 4180 MC

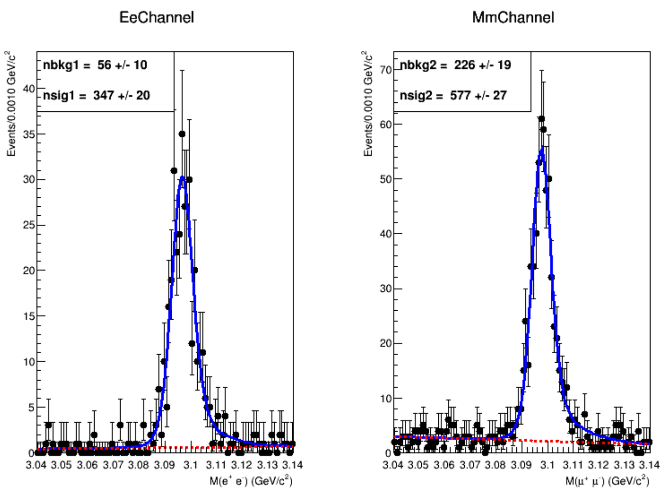
◆ Fitting method



4190



4200



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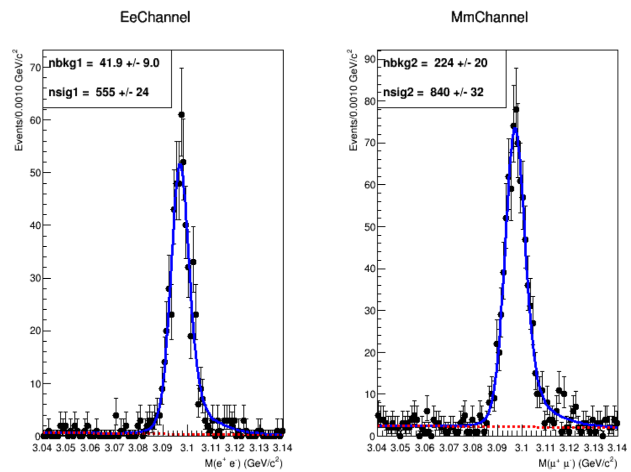

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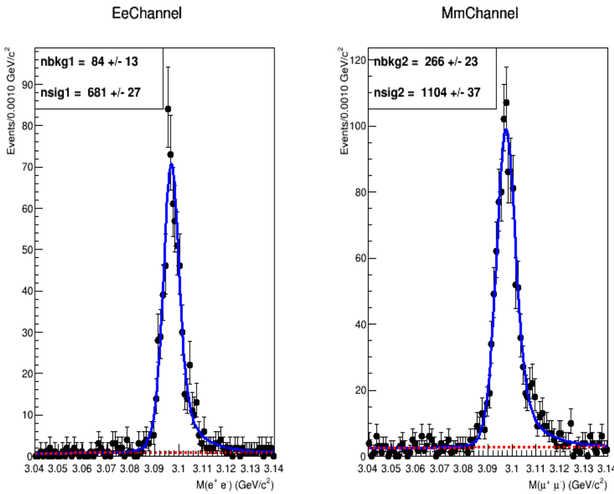

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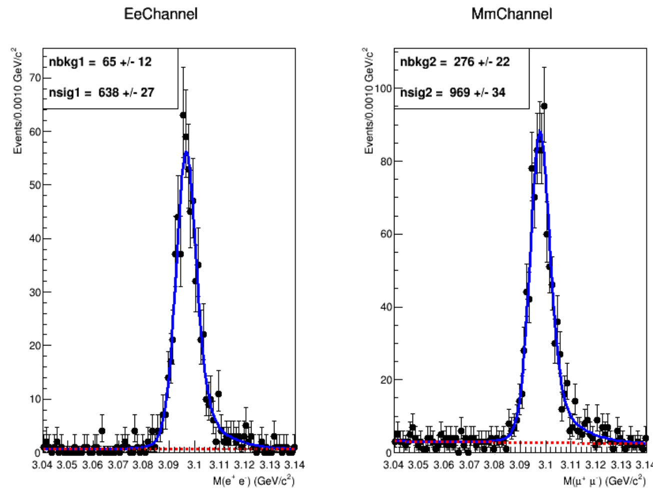

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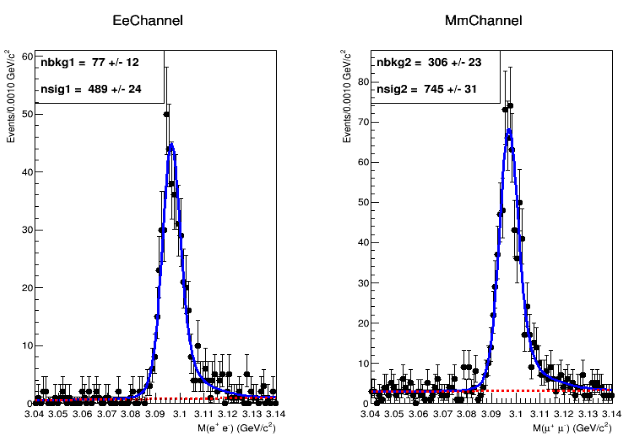

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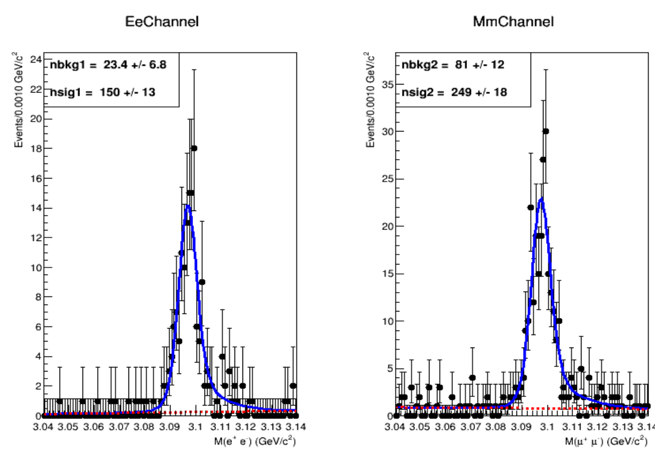
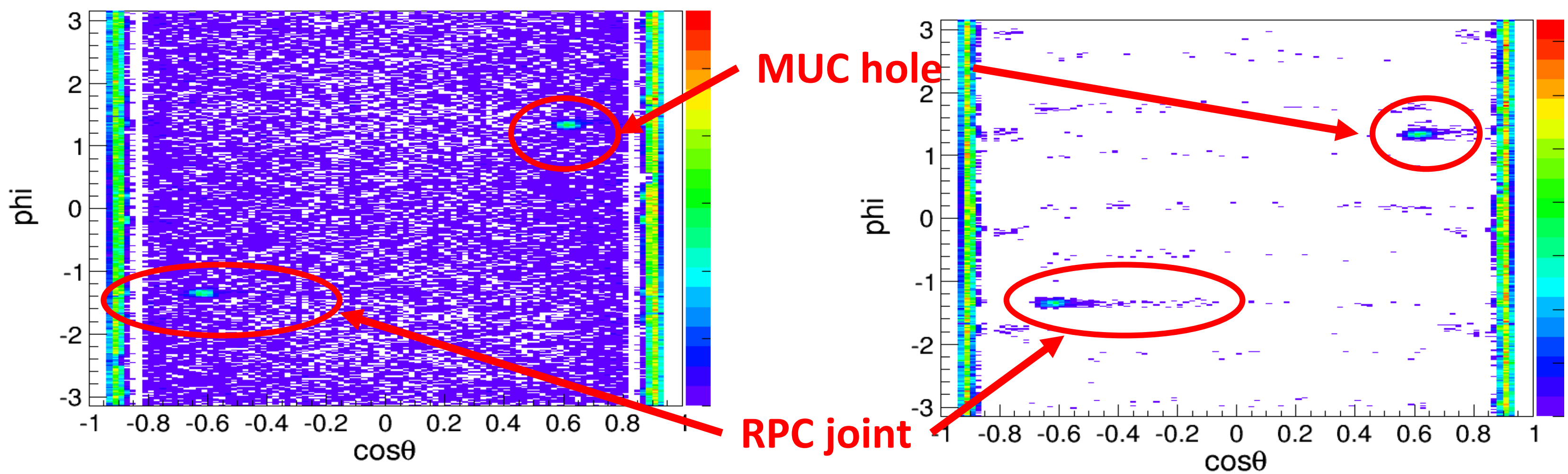


4280

◆The problem of MUC

Because of the correlation of Dimu events, when one muon track's position at the MUC hole, another track will be in the joint of two RPC.

But there is a uniform background with data, and also shows correlation with two tracks. We analyze those events in detail.



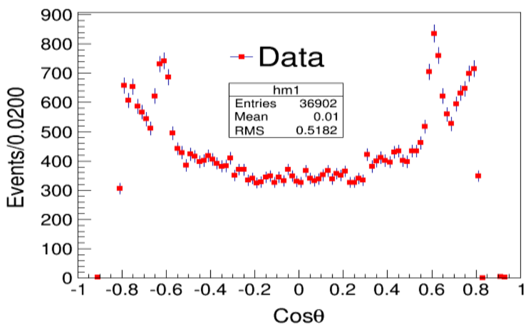
Data: depth= -1:(cost , phi)

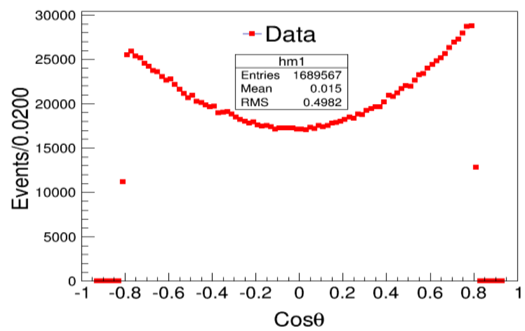
MC: depth =-1: (cost, phi)

From the plot, we can see clearly correlation of Dimu events with (cost, phi) distribution and that's reasonable with two tracks have no information, but the background of data is not.

◆The problem of MUC

We project the events with depth =-1 to costheta and with the range (-0.83, 0.83), and ignore the hole events(the ratio is about 0.10% of whole events). We give the ratio of the problem events with nine energy points.





	4180	4190	4200	4210	4220	4237	4246	4270	4280
N_bkg	213485	39145	39366	47019	64195	36902	37939	30660	19287
N_tot	10198530	1668197	1673681	1558494	1642808	1689567	1710211	1679803	556254
Ratio	2.09%	2.35%	2.35%	3.02%	3.91%	2.18%	2.22%	1.83%	3.47%

From the table, we know that the ratio is bigger than the probably background of Dimu events, and with a highly momentum(>1.2Gev/c), but not record with MUC.