Measurement of the center-of-mass energy for the new XYZ data

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◆ Introduction

From December 2016 to June 2019, we had taken about 7.5 pb^{-1} data with 16 energy points at the center-of-mass energies from 4.13 GeV to 4.44 GeV . Those data samples are used to study XYZ particles.

And a precise measurement of center-of-mass energy (E_{cms}) is essential for most physics analyses. We use the process $e^+e^- \rightarrow \gamma_{ISR}/\gamma_{FSR}\mu^+\mu^-$ to measure the E_{cms}. Finally, we will give the distribution of E_{cms} run by run to check the stability of beam energy.

We use 4190MeV data as analysis example.

2017XYZ	Run Number	ExpLum(pb^{-1})	2019XYZ	Run Number	ExpLum(pb^{-1})
4190	47543-48170	500	4130	59163-59573	400
4200	48172-48713	500	4160	59574-59896	400
4210	48714-49239	500	4290	59902-60363	500
4220	49270-49787	500	4315	60364-60805	500
4237	49788-50254	500	4340	60808-61242	500
4246	50255-50793	500	4380	61249-61762	500
4270	50796-51302	500	4400	61763-62285	500
4280	51305-51498	175	4440	62286-62823	570

◆ Dataset and BOSS version

➢ Data samples

2017 XYZ data samples (8 energy points)
2019 XYZ data samples (8 energy points)

➢ MC samples

$\gamma_{ISR}\ J/\psi$ sample use the BesEvtgen (1million each energy point)
Dimu sample use the BaBayaga 3.5 (1million each energy point)

➢ Boss version

2017 XYZ: BOSS 7.0.2.p01 & BOSS 7.0.3
2019 XYZ: BOSS 7.0.4

◆ Analysis Method

For the process $e^+e^- \to \mu^+\mu^-$, we get

$$E_{cms} = M_0(\mu^+\mu^-).$$

But there will be ISR and FSR process, see $e^+e^- \to \mu^+\mu^-\gamma_{ISR}/\gamma_{FSR}$, so

$$E_{fit} = M\ (\mu^+\mu^-).$$

Then we use this mothed to get the E_{cms}, that's

$$E_{cms} = M(\mu^+\mu^-) + \Delta M,\ \ \Delta M = M_0(\mu^+\mu^-) - \mathrm{M}(\mu^+\mu^-).$$

For $\mathrm{M}(\mu^+\mu^-)$
We use $\gamma_{ISR}\mathrm{J}/\psi$ process as control sample to check the momentum calibration.

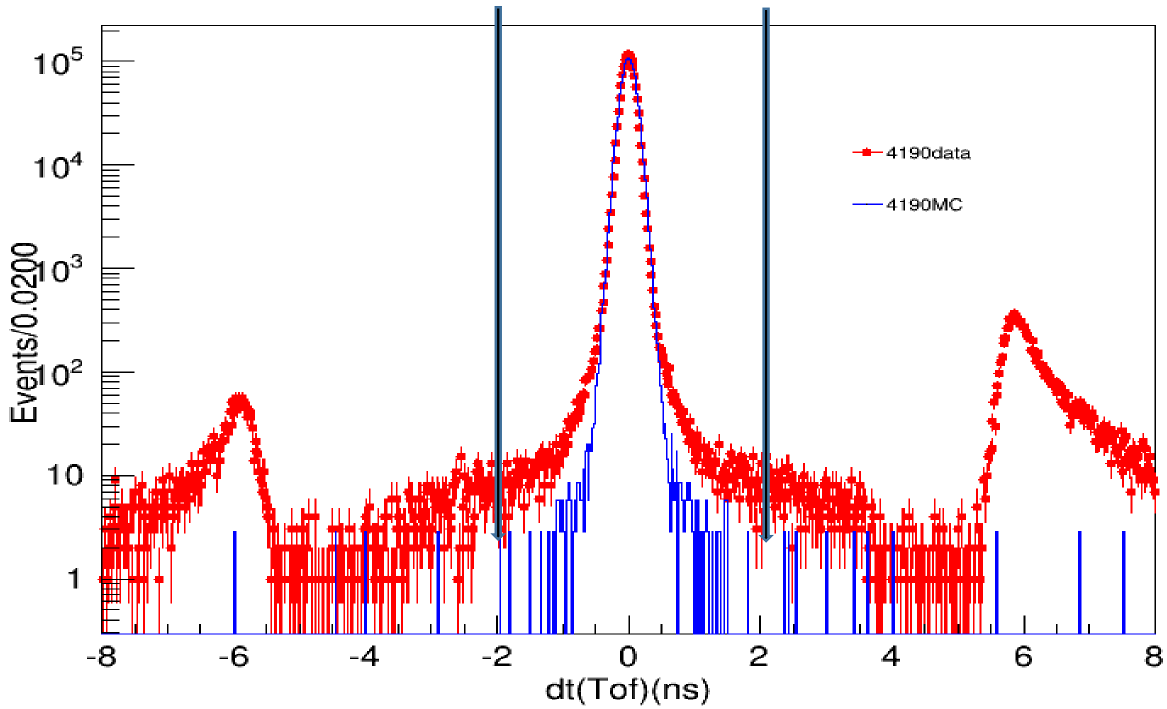
For ΔM
We use the MC simulation of Dimu events with or without ISR and FSR to estimate the ΔM , which is version-independent

➢ Event selection

- $|V_z|$<10.0cm
- V_r<1.0cm
- |cosθ|<0.8   (only barrel)
- Two charged tracks
- Total charges = 0
- TOF |Δt|<2ns
- $\cos(\mu^+\mu^-)<$-0.9997(only dimu)
- EMC<0.4GeV

➢ Event selection

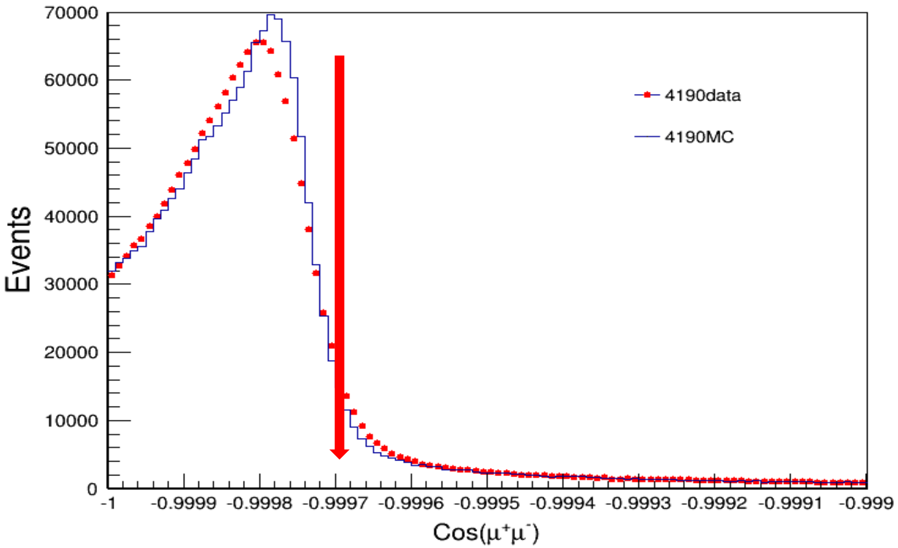
- The TOF difference (Δt) of $\mu^{+}\mu^{-}$

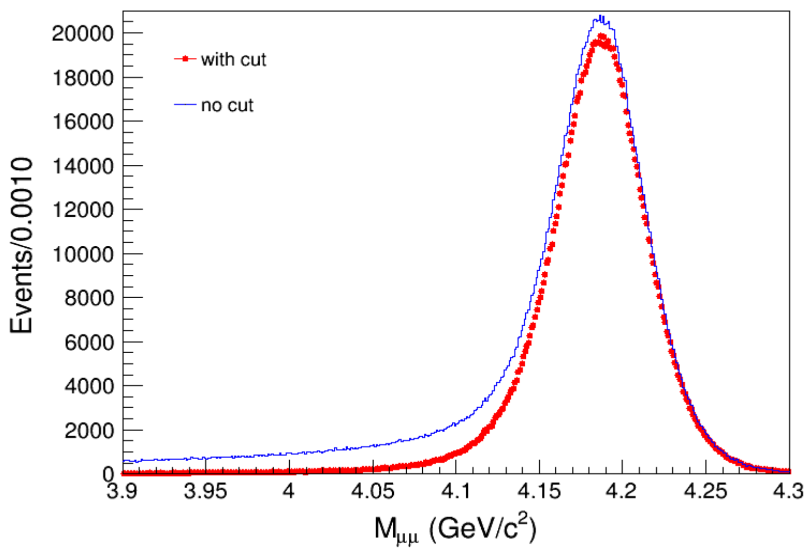


Choosing two tracks that are both in barrel and absolute value of the time difference ($|\Delta t|=|t_1 - t_2$)(ns)) is less than 2ns to exclude the cosmic ray.

➢ Event selection

- $\cos(\mu^+\mu^-)$ <-0.9997



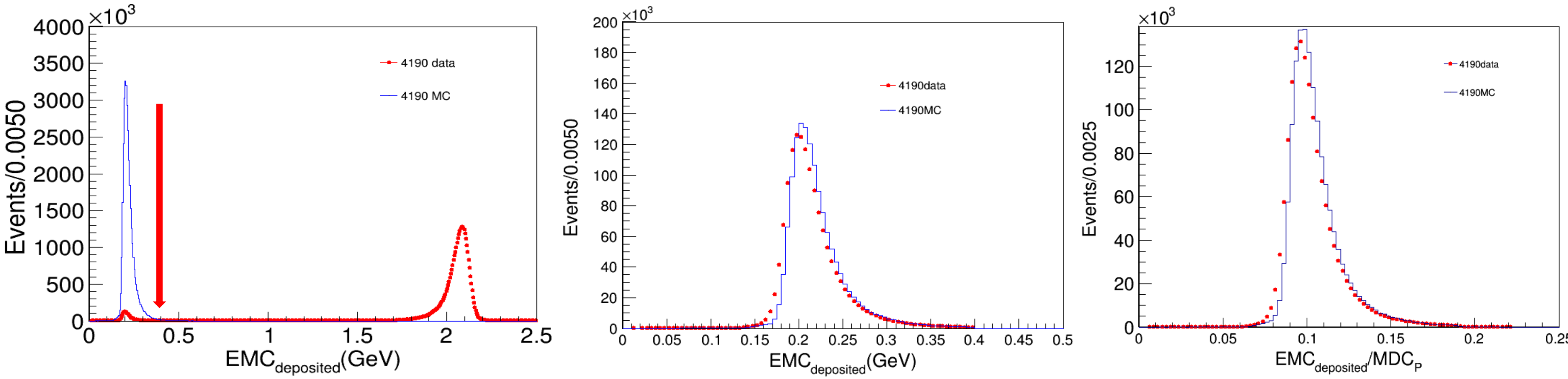


With or without $\cos(\mu^+\mu^-)$ <-0.9997

To suppress the events with large radiation, a constraint of $\cos(\mu^+\mu^-)$ <-0.9997 is needed.

➢ Event selection

- EMC<0.4GeV

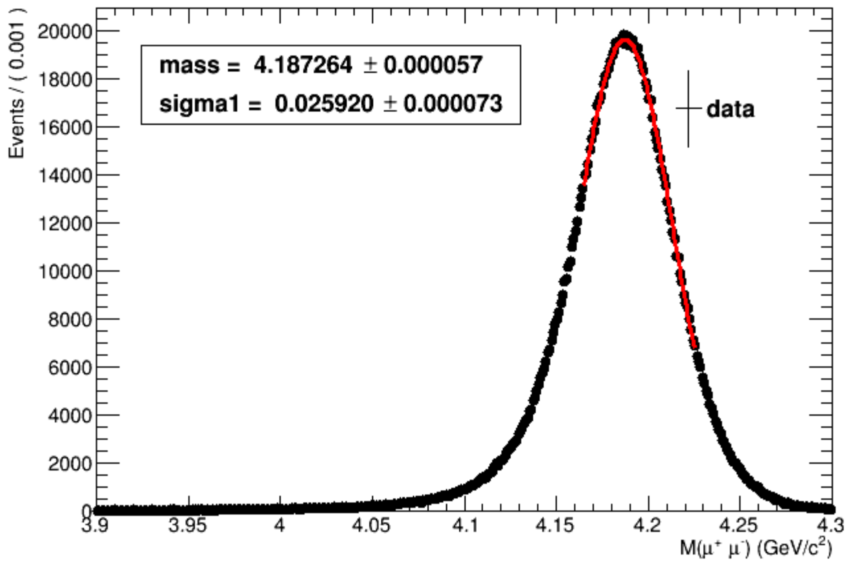


With EMC<0.4GeV

The deposited energy of μ is less than 0.4GeV from MC simulation. The data E/P distribution is consistent with the MC simulation.

➢ Fitting method

- Fitting Dimu ($M(\mu^+\mu^-)$)



Fit chi2/ndf: 1.90

$M(\mu^+\mu^-)$ = 4187.26 $\pm$ 0.06 MeV

Fitting range(4.165,4.225)

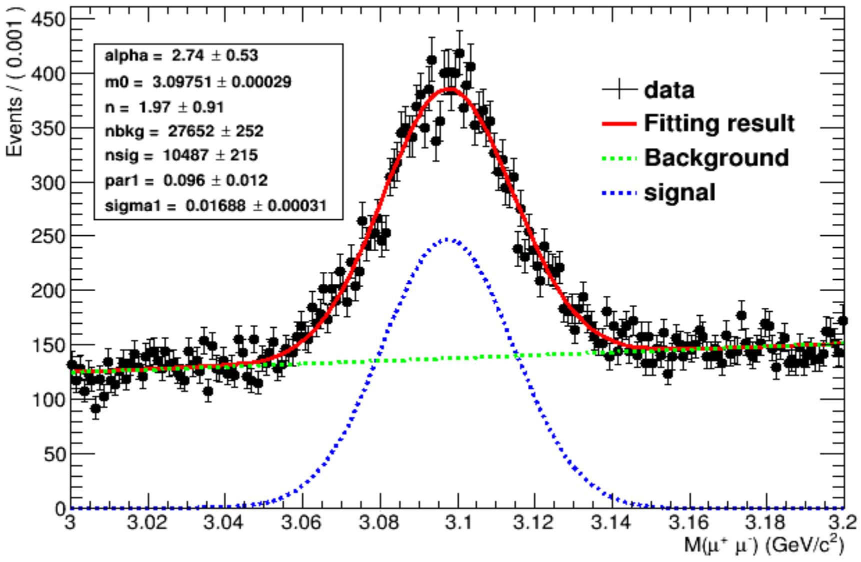
Firstly, we used a Gaussian function to fit the Dimu peak with a reasonable range to get the sigma and mean value.

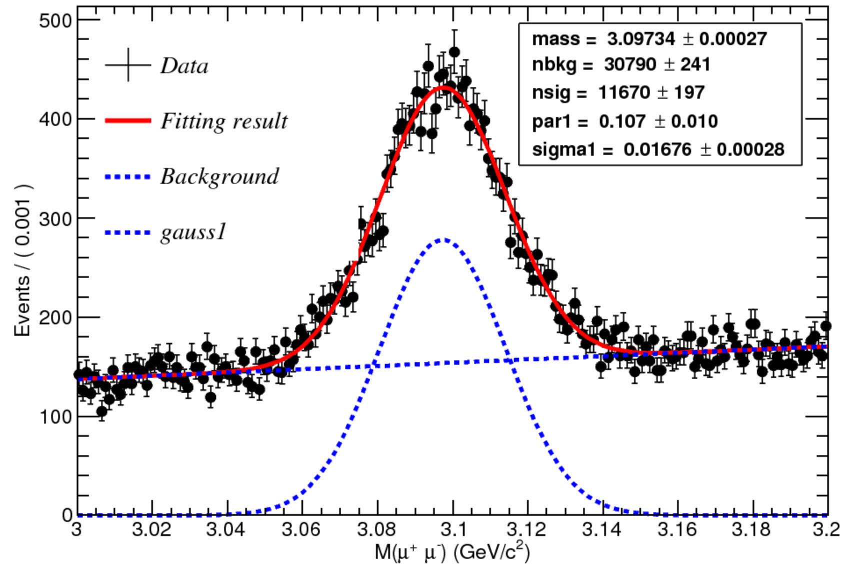
Then we get the experienced fitting range:

(mean-1.0sigma, mean+1.5sigma)

For change the fitting range within 0.5sigma the difference will less than 0.1 MeV and will consider as a system error.

● Fitting $\gamma_{ISR}J/\psi(M(\mu^+\mu^-))$





Crystal ball + 1st-order polynomial
$M(\mu^+\mu^-)$ = 3097.51 $\pm$0.29 MeV

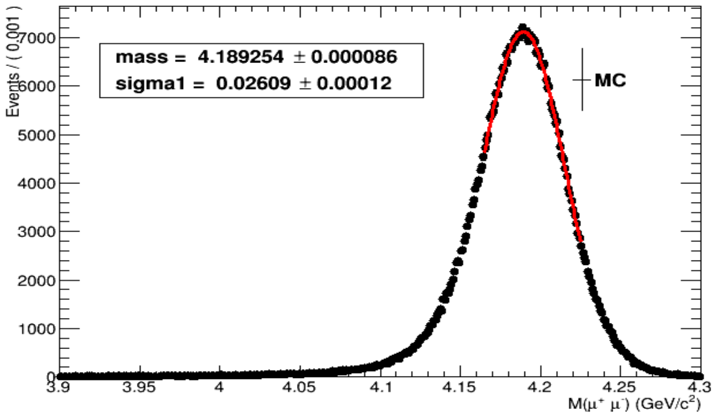
Gauss + 1st-order polynomial
$M(\mu^+\mu^-)$ = 3097.52 $\pm$ 0.29 MeV

The fitting results showing the consistency of the two methods. And we choose the crystal-ball function to describe the signal.

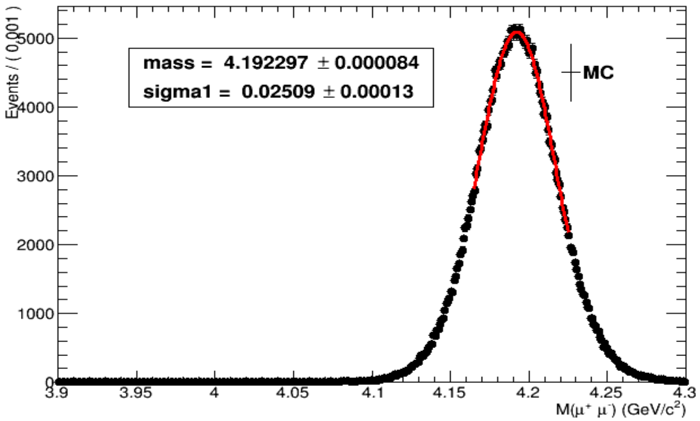
Radiation correction(ΔM)

✓ Radiation correction for Dimu process

We generated the Dimu MC with ISR and FSR turned on or off and take the difference (ΔM) of $M(\mu^+\mu^-)$ as radiation correction, which is version-independent.



$M(\mu^+\mu^-)$_on =4189.254 $\pm$ 0.086MeV

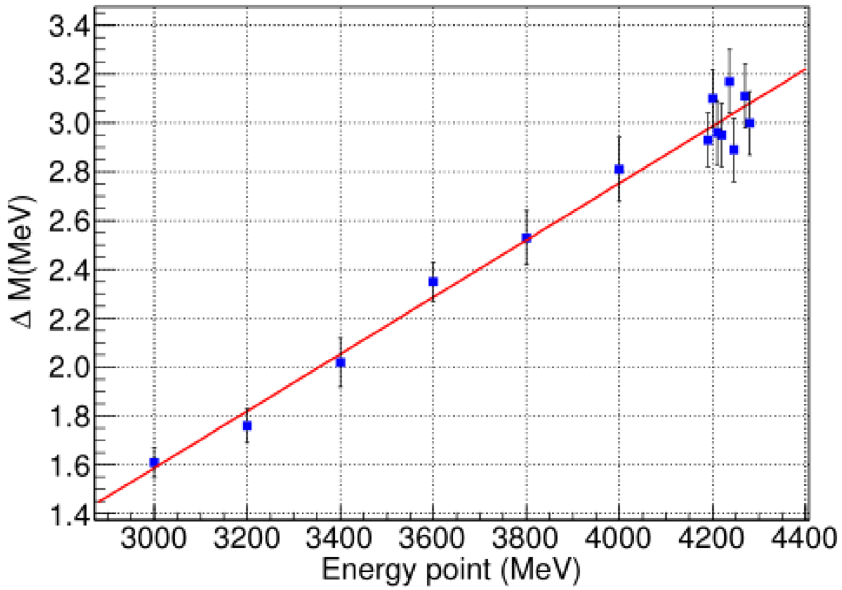


$M(\mu^+\mu^-)$_off =4192.297 $\pm$ 0.084MeV

ΔM=3.043 $\pm$ 0.120MeV

- Radiation correction for Dimu process

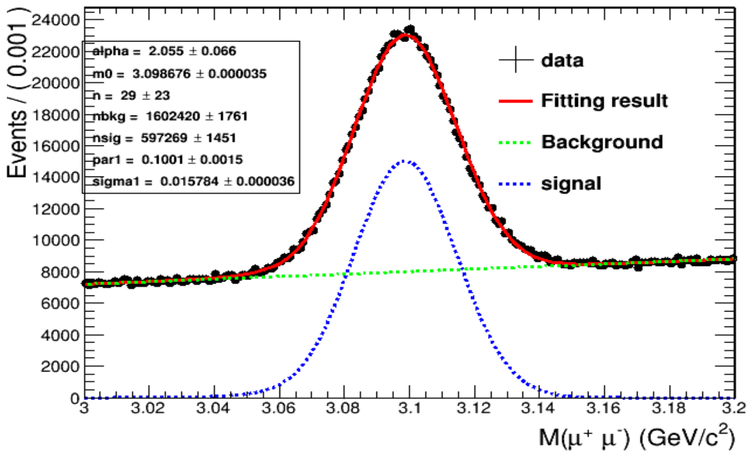
To reduce the fluctuation of statistic, we generate a group of samples and get the distribution of ΔM. we fit it with a first-order polynomial.

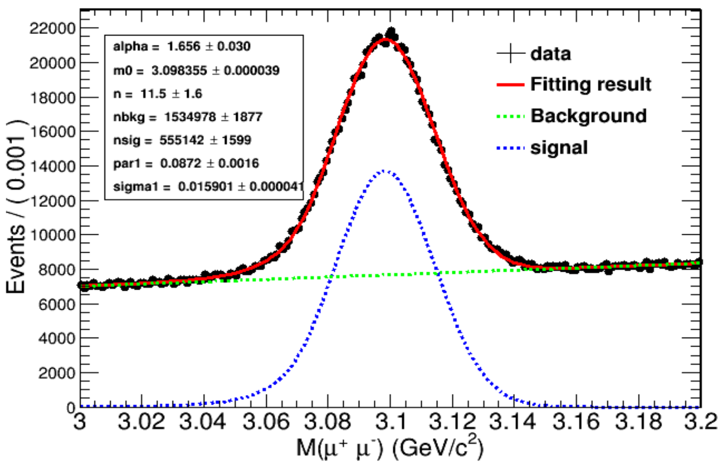


$$\Delta M = (1.167 \pm 0.054) * 10^{-3} * X + (-1.914 \pm 0.199)(MeV)$$

- FSR correction for $\gamma_{ISR}\ J/\psi$ process

Consider the influence of background in $\gamma_{ISR}\ J/\psi$ process, we extract the shape and ratio of background from data and generate the MC.





$M(\mu^+\mu^-)$_on = 3098.68$\pm$ 0.04 MeV

$M(\mu^+\mu^-)$ _off= 3098.36 $\pm$ 0.04 MeV

FSR = 0.32 $\pm$ 0.05MeV

- FSR correction for $\gamma_{ISR}\, J/\psi$ process

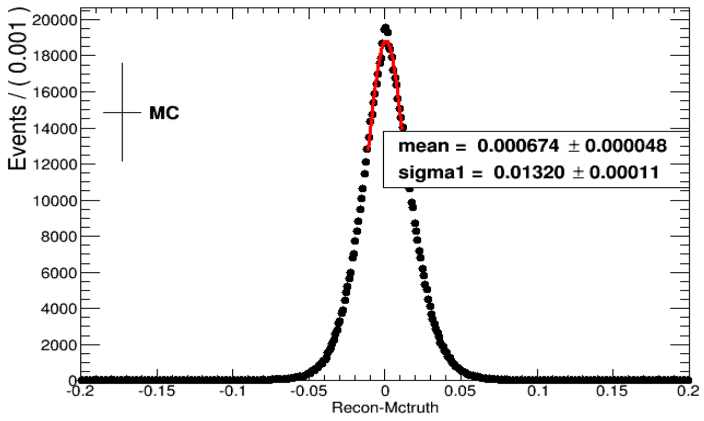
(PDG: 3096.92 $\pm$ 0.01 MeV)

2017XYZ	FSR	$\gamma_{ISR}J/\psi_{data}$	diff	2019XYZ	FSR	$\gamma_{ISR}J/\psi_{data}$	diff
4190	0.31 ± 0.05	3100.02 ± 0.30	3.64 ± 0.30	4130	0.31 ± 0.05	3100.02 ± 0.30	3.64 ± 0.30
4200	0.17 ± 0.05	3099.68 ± 0.29	3.16 ± 0.29	4160	0.17 ± 0.05	3099.68 ± 0.29	3.16 ± 0.29
4210	0.32 ± 0.05	3099.55 ± 0.28	3.18 ± 0.28	4290	0.32 ± 0.05	3099.55 ± 0.28	3.18 ± 0.28
4220	0.19 ± 0.05	3099.46 ± 0.30	2.96 ± 0.30	4315	0.19 ± 0.05	3099.46 ± 0.30	2.96 ± 0.30
4237	0.29 ± 0.05	3099.15 ± 0.29	2.75 ± 0.29	4340	0.29 ± 0.05	3099.15 ± 0.29	2.75 ± 0.29
4246	0.29 ± 0.05	3099.09 ± 0.30	2.65 ± 0.30	4380	0.29 ± 0.05	3099.09 ± 0.30	2.65 ± 0.30
4270	0.32 ± 0.05	3099.89 ± 0.31	3.52 ± 0.31	4400	0.32 ± 0.05	3099.89 ± 0.31	3.52 ± 0.31
4280	0.31 ± 0.05	3097.12 ± 0.49	0.51 ± 0.49	4440	0.31 ± 0.05	3099.59 ± 0.29	2.90 ± 0.29

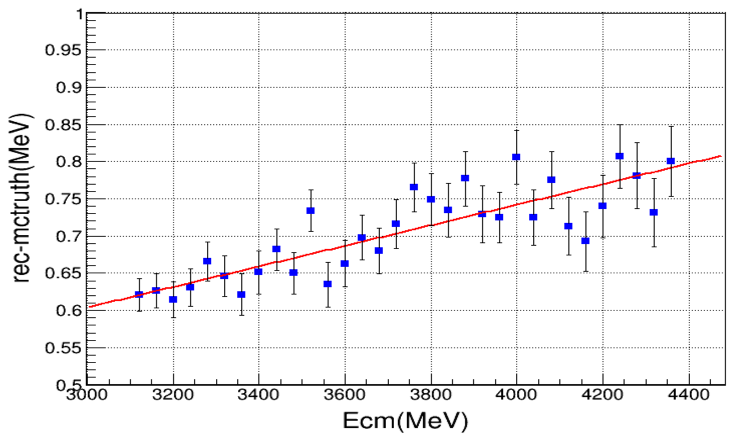
After FSR correction, we find there exist some bias between data and PDG of the invariant mass of J/ψ, and which are because of momentum calibration.

➢ I/O check

To get the bias of reconstruction, we generate a group MC samples of Dimu process without radiative from 3120 MeV to 4360 MeV.



The difference of momentum between Reconstruction and MC truth

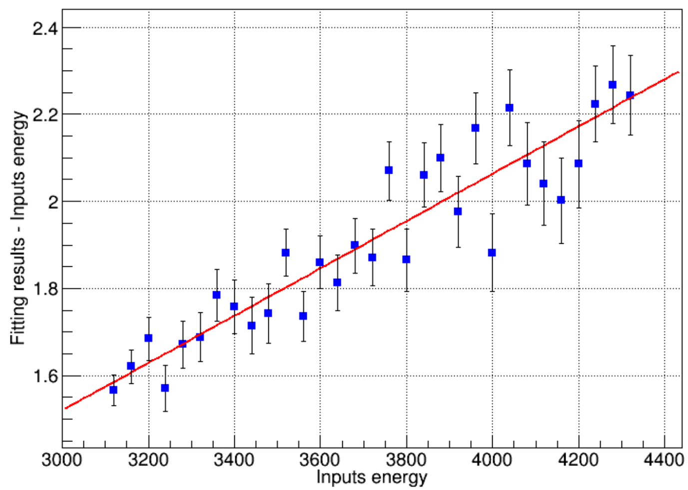


$$y = (1.38 \pm 0.16) * 10^{-4} x + (1.89 \pm 0.56)$$

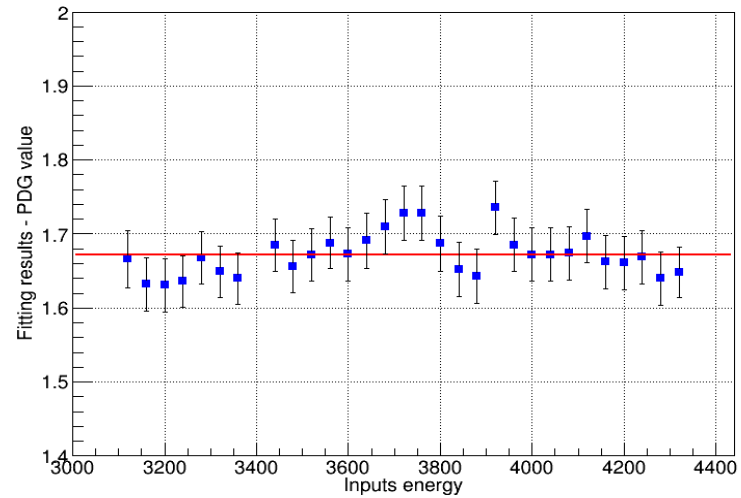
The momentum difference distribution with the E_{cms}. And we fit it with a first-order polynomial.

Momentum Calibration

For the distribution of I/O with Dimu process and $\gamma_{ISR}J/\psi$ process, We found the difference of I/O have the linear relationship with the energy.



Dimu process without radiation



$\gamma_{ISR}J/\psi$ process without FSR

$$Y(2017) = (5.44 \pm 0.33) * 10^{-4} X - (0.11 \pm 0.12)(MeV),$$

We use the slope from MC and the difference of J/ψ value between data and PDG as the intercept to correct the bias caused by momentum calibration.

Momentum Calibration

From the calibration are version-dependent and the two data sets have been reconstruction under two round calibration, respectively. And we used same method to obtain the correction formula.

$$\text{Momcal} = (Exp\ - 3096.92) * k + diff\ (MeV)$$

Here the Momcal is the momentum calibration correction value, the Exp is the energy point value, and the diff is the difference of $\mathrm{M}(J/\psi)$ between $\gamma_{ISR}\ J/\psi$ process and PDG value.

For 2017 XYZ data:
Round 1: k1 = $(5.44 \pm 0.33) * 10^{-4}$
Round 2 : k2 = $(6.24 \pm 0.44) * 10^{-4}$

◆ Systematic uncertainty

- Three sources:
  - ➢ Momentum calibration
  - ➢ Radiation correction(ΔM)
  - ➢ Fitting range

A summary of the E_{cms} with total systematic uncertainty.

Systematic uncertainty

$Ep(MeV)$	Momentum calibration	ΔM	Fitting method	Total
4190	0.29	0.30	0.10	0.43
4200	0.27	0.30	0.10	0.42
4210	0.30	0.30	0.10	0.44
4220	0.27	0.30	0.10	0.42
4237	0.26	0.30	0.10	0.41
4246	0.26	0.30	0.10	0.41
4270	0.27	0.30	0.10	0.42
4280	0.49	0.30	0.10	0.58

◆ Final results

The E_{cms} of each energy point after
1. Momentum calibration
2. Radiation correction.

(Ecm = fitting value – Momentum calibration + radiation correction)

Results in Round1 calibration:

2017XYZ	Run number	$M_{\mu^+\mu^-}$(MeV)	MomCal(MeV)	ΔM(MeV)	E_{cms}(MeV)
4190[1]	47543-48170	4187.26 ± 0.06	1.47 ± 0.29	2.98 ± 0.30	$4188.77 \pm 0.06 \pm 0.43$
4200[1]	48172-48713	4197.61 ± 0.06	1.70 ± 0.27	2.99 ± 0.30	$4198.90 \pm 0.06 \pm 0.42$
4210[1]	48714-49239	4207.10 ± 0.06	0.89 ± 0.30	3.00 ± 0.30	$4209.21 \pm 0.06 \pm 0.44$
4220[1]	49270-49787	4216.84 ± 0.06	1.11 ± 0.21	3.01 ± 0.30	$4218.74 \pm 0.06 \pm 0.42$
4237[1]	49788-50254	4233.68 ± 0.05	1.03 ± 0.26	3.03 ± 0.30	$4235.68 \pm 0.05 \pm 0.41$
4246[1]	50255-50793	4241.82 ± 0.05	1.07 ± 0.26	3.04 ± 0.30	$4243.79 \pm 0.05 \pm 0.41$
4270[1]	50796-51302	4265.39 ± 0.06	1.71 ± 0.27	3.07 ± 0.30	$4266.75 \pm 0.06 \pm 0.42$
4280[1]	51305-51498	4275.78 ± 0.11	1.15 ± 0.49	3.08 ± 0.30	$4277.71 \pm 0.11 \pm 0.58$

- Results in Round2 calibration

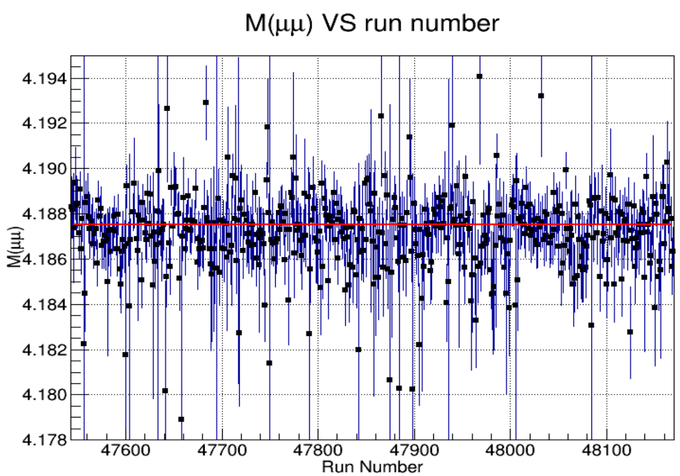
For different BossVersion the main difference is momentum calibration, i.e. the correction of Momcal and it’s version-dependent. The radiation correction is version-independent.

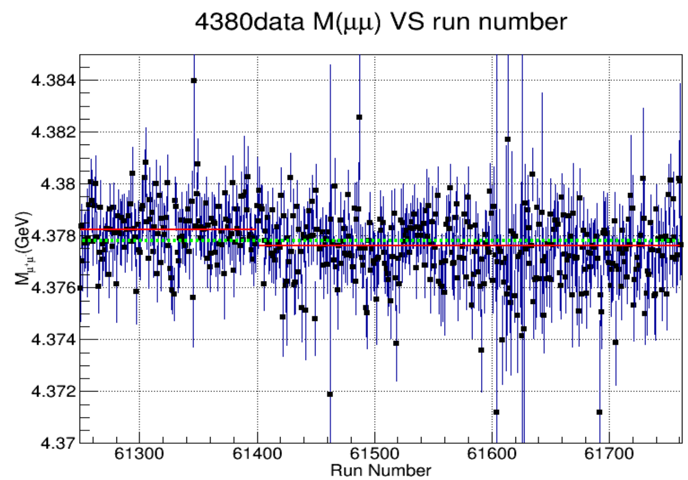
2017XYZ	Run number	$M_{\mu^+\mu^-}$(MeV)	MomCal(MeV)	ΔM(MeV)	E_{cms}(MeV)
4190	47543-48170	4187.67 ± 0.06	1.66 ± 0.28	2.98 ± 0.30	$4188.99 \pm 0.06 \pm 0.41$
4200	48172-48713	4197.97 ± 0.05	1.93 ± 0.28	2.99 ± 0.30	$4199.03 \pm 0.05 \pm 0.41$
4210	48714-49239	4207.43 ± 0.06	1.18 ± 0.29	3.00 ± 0.30	$4209.25 \pm 0.06 \pm 0.42$
4220	49270-49787	4217.12 ± 0.05	1.29 ± 0.26	3.01 ± 0.30	$4218.84 \pm 0.05 \pm 0.40$
4237	49788-50254	4233.94 ± 0.05	1.15 ± 0.24	3.03 ± 0.30	$4235.82 \pm 0.05 \pm 0.38$
4246	50255-50793	4242.04 ± 0.05	1.15 ± 0.24	3.04 ± 0.30	$4243.93 \pm 0.05 \pm 0.38$
4270	50796-51302	4265.63 ± 0.06	1.90 ± 0.26	3.07 ± 0.30	$4266.80 \pm 0.06 \pm 0.40$
4280	51305-51498	4276.03 ± 0.11	1.37 ± 0.48	3.08 ± 0.30	$4277.74 \pm 0.11 \pm 0.57$

From the results of two Bossversion, we can see they consistency with each other.

◆ Data quality check

To get better known the quality of our data over time, we have do some checks run by run.





4190： Value:4187.52 ± 0.06MeV

4380： Value1: 4378.23 ± 0.09MeV
Vaule2: 4377.82 ±0.05MeV

◆ Summary

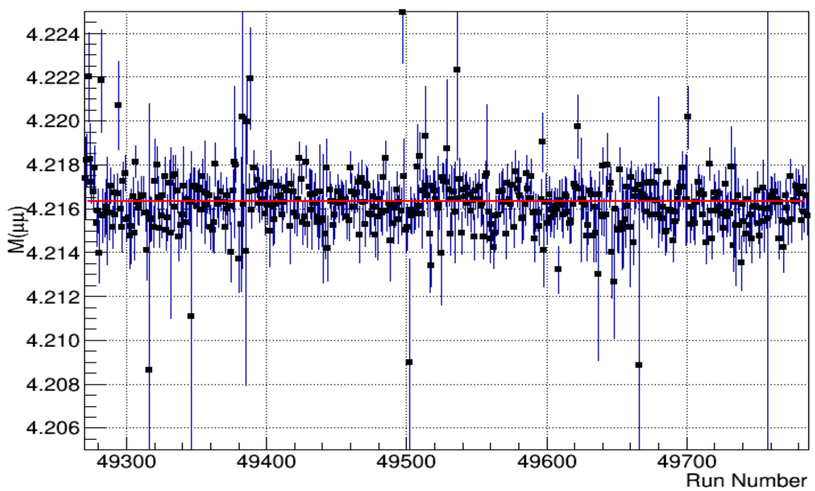
We have measured the E_{cms} of new XYZ data with Dimu process in different Boss version with same method and the results are consistent with echo other, and this prove the reliability of our method.

And from the run by run distribution, we can know our data are with a high-quality and stable for most of the time during the data taking

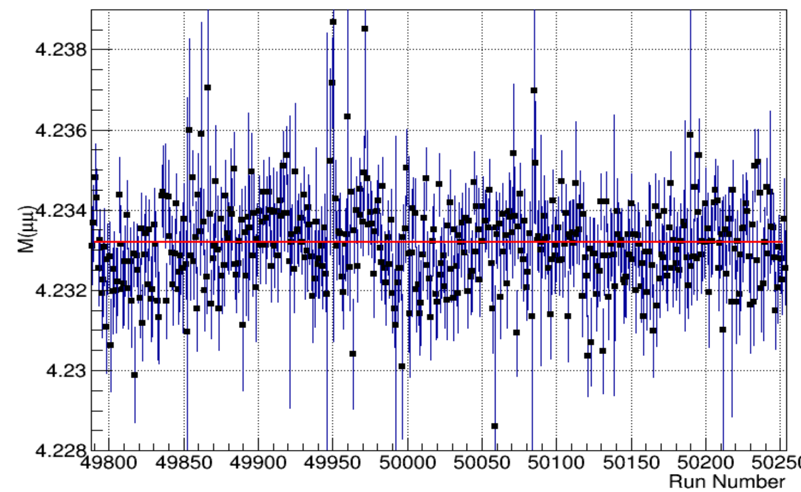
Thank you !!!

◆ Backup

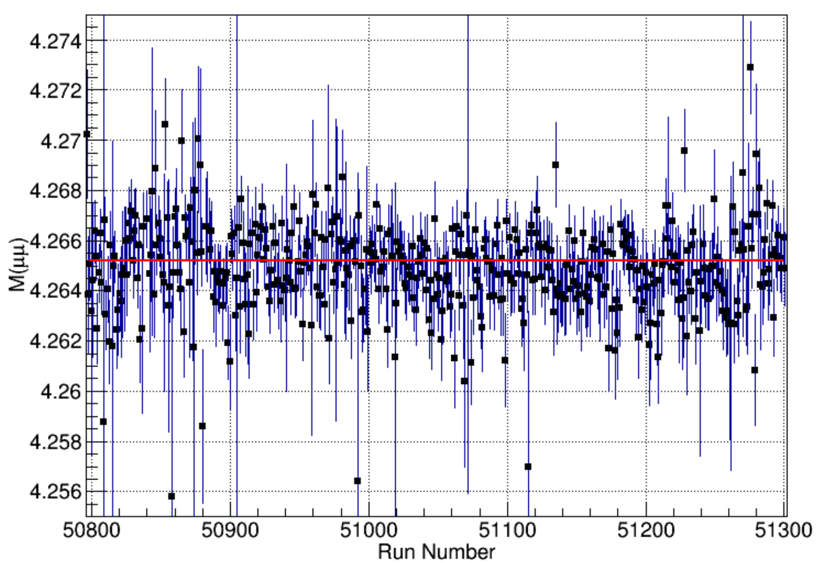
➢M(μμ) of data Run by Run



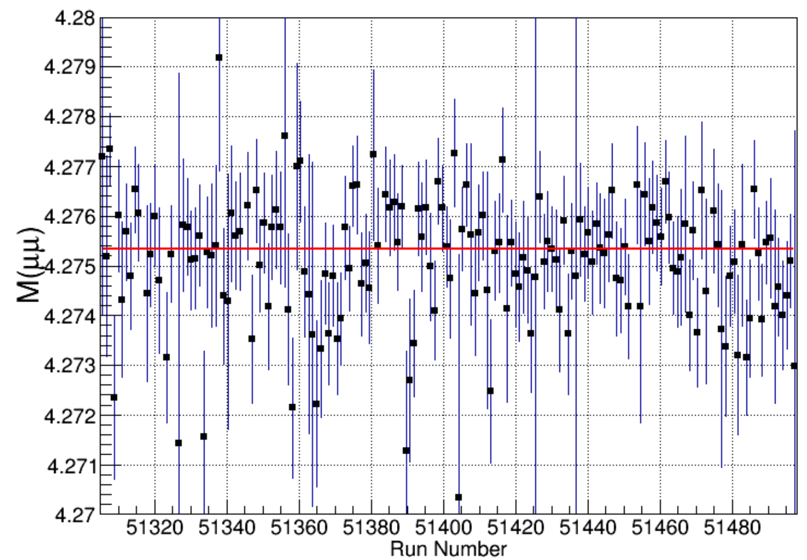
4220: Average: 4216.33±0.05 MeV



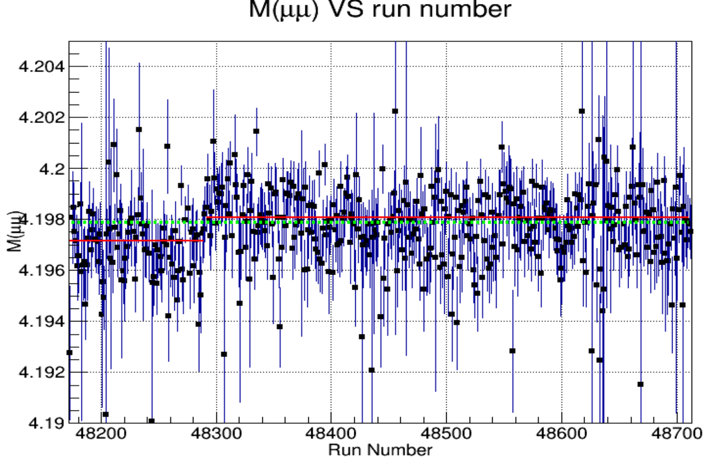
4237: Average: 4233.21 ± 0.04 MeV



4270: Average: 4265.20 ± 0.06 MeV



4280: Average: 4275.34± 0.009 MeV



4200

Range (48172, 48290)

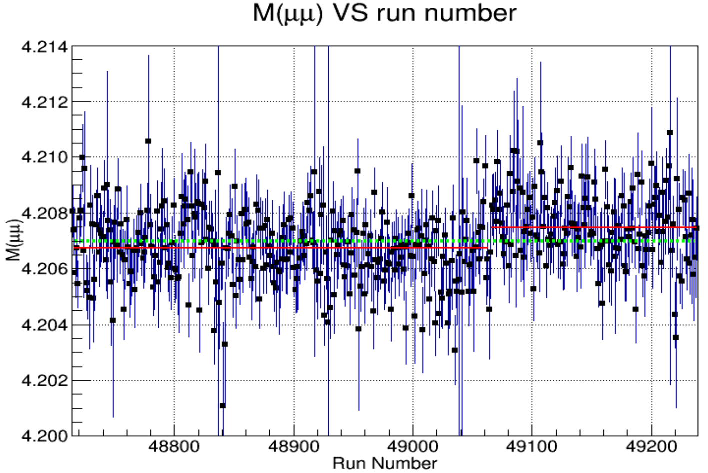
Average: 4197.14 ± 0.12 MeV

Range (48291, 48713)

Average: 4198.07 ± 0.06 MeV:

Range(48172,48713)

Average: 4197.88 ± 0.06 MeV



4210

Range (48174, 49065)

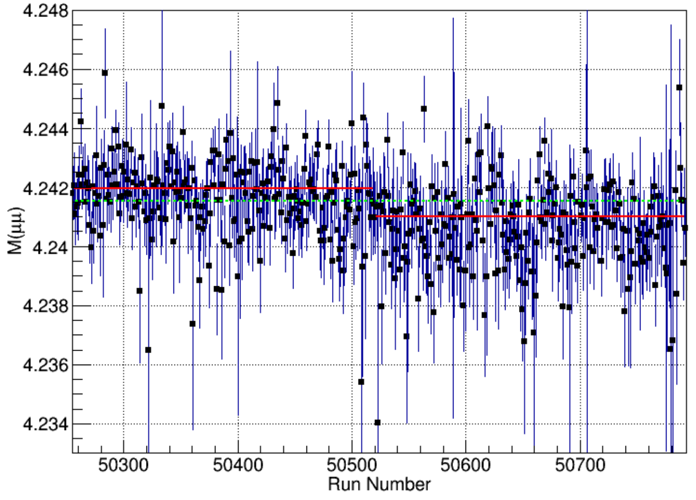
Average: 4206.75 ± 0.06 MeV

Range (49066, 49239)

Average: 4207.49 ±0.09 MeV

Range (48174, 49239)

Average: 4206.98 ± 0.05 MeV



4246

Range (50255,50520)

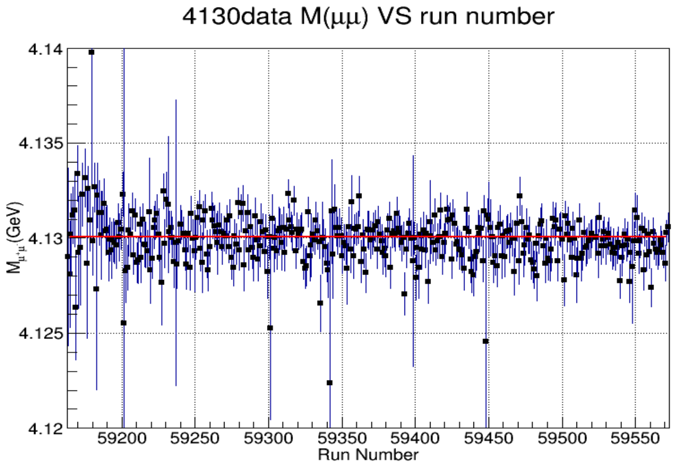
Average: 4241.01 ± 0.08 MeV

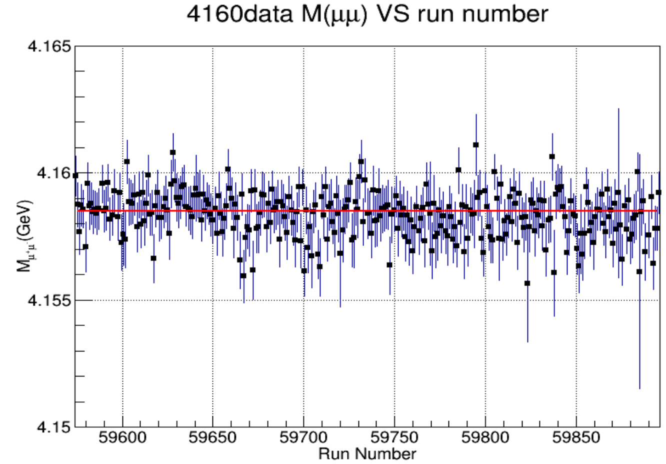
Range (50521,50793)

Average: 4241.55 ± 0.05 MeV

Range (50255,50793)

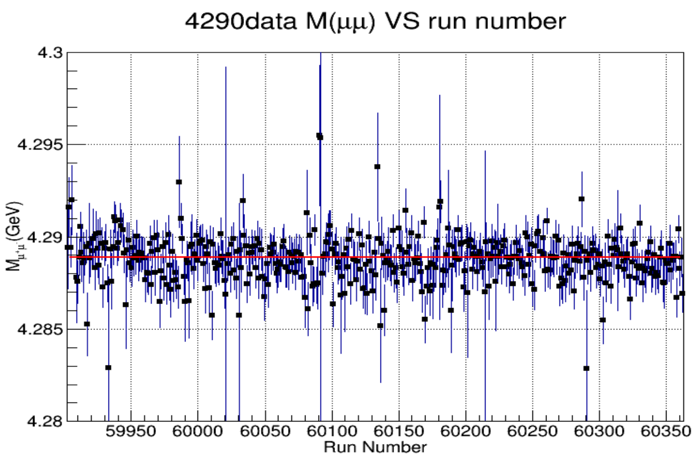
Average: 4241.95± 0.07 MeV

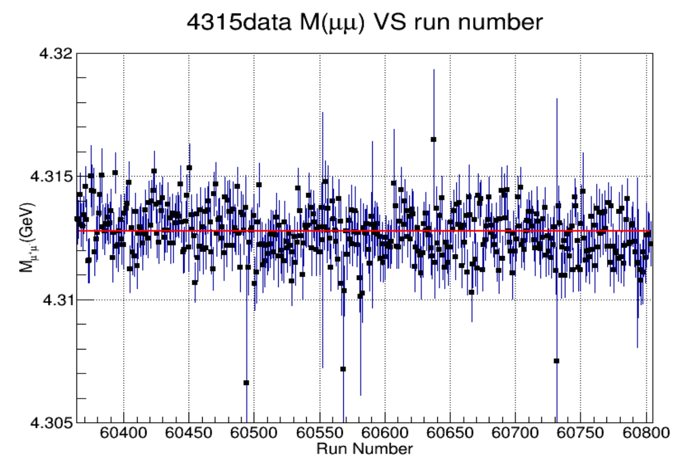




4130: Average: 4130.05$\pm$0.05 MeV

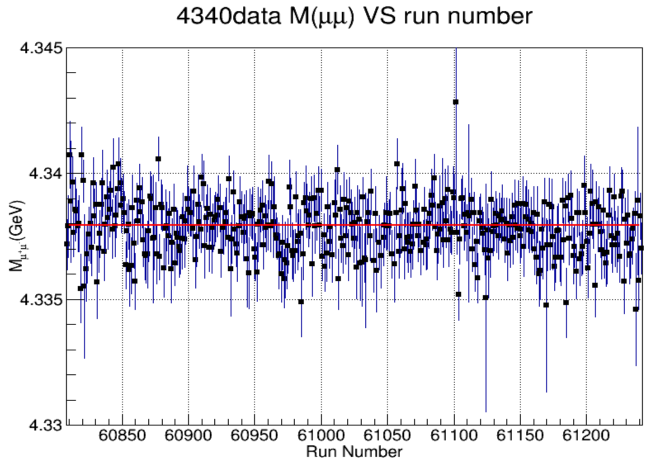
4160: Average: 4158.49$\pm$0.05 MeV



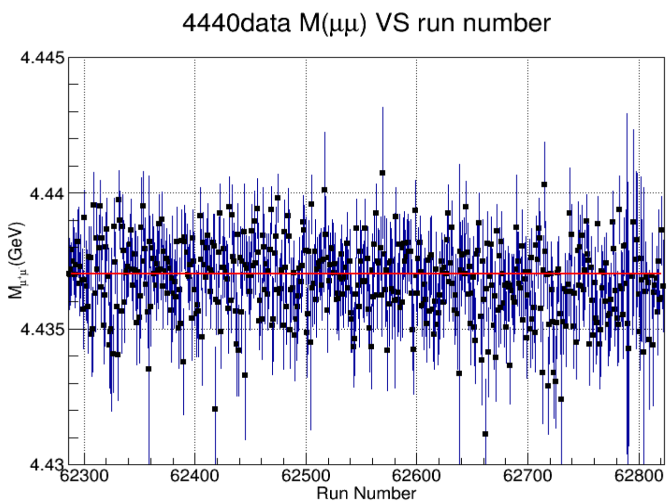


4290: Average: 4288.91$\pm$0.05 MeV

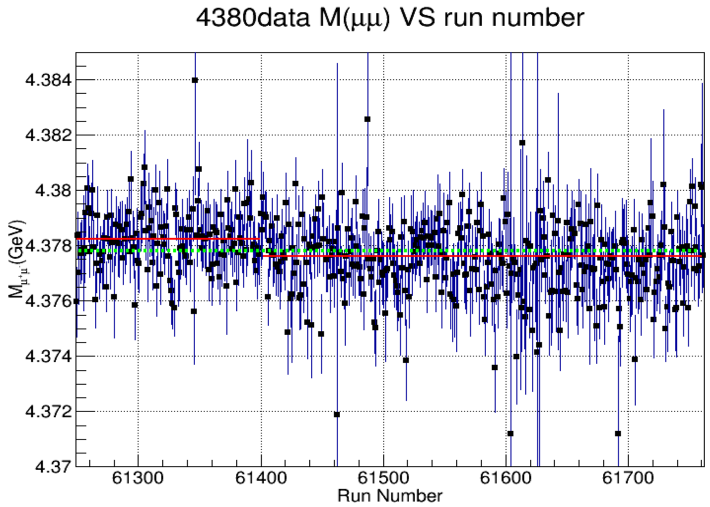
4315: Average: 4312.79$\pm$0.04 MeV



4340: Average: 4337.93± 0.05 MeV



4440: Average: 4437.01± 0.05 MeV



4380

Range (61249, 61400)

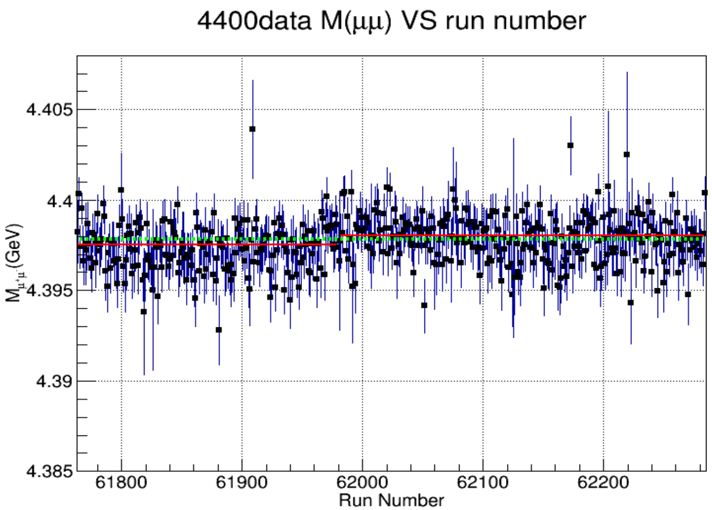
Average: 4378.23 ± 0.09 MeV

Range (61401, 61762)

Average: 4377.61 ± 0.06 MeV:

Range(61249, 61762)

Average: 4377.82 ± 0.05 MeV



4400

Range (61763, 61980)

Average: 4397.51 ± 0.08 MeV

Range (61981, 62285)

Average: 4398.06 ± 0.07 MeV:

Range(61763, 62285)

Average: 4397.83 ± 0.05 MeV