Correction to TOF Time and Resolution

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December 19, 2000

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- PID using TOF
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1 Motivation

- The importance of TOF at BESΠ

  TOF has been improved at BESΠ, the resolution is about 180ps(for Bhabha events). Comparing to BESI(330ps for Bhabha events),it have been improved too much. It can identify particles well. The advantages of PID using TOF is obvious.

  Because the calibration is performed with bhabha events,and when doing the reconstruction ,time is corrected by hit point z,and pluse amplitude e.t , Of course the dependence of the $cos\theta$,pluse amplitude and momentum for the electron is well,but how about for the hadrons??We must do some study.

- How to do PID using TOF

  From the TOF and DEDX information, and using the kinematic formula :

$$T^i_{exp} = \frac{L\sqrt{P^2 + m_i^2}}{0.3P}$$

where

L : the path of particles flight

P : the momentum of particles

m_i : the mass of particle i

We can get the time expectation T^i_{exp} of particle i. Then we can define χ_i :

$$\chi_i = \frac{T_{mea} - T^i_{exp}}{\sigma}$$

Where

T_{mea} : the measured time

T^i_{exp} : the expected time of particle i

σ : the resolution of particles.

We can get the χ_i^2 for all kinds of particles. Then the particle with the least χ_i^2 is assumed to be the correct one.

- The problems

1. The distribution of χ should be N(0,1).
2. The centre of χ shift—it mean Time offset(fig.1).
3. Resolution should depend on the counter number, $cos\theta$,pulse amplitude and momentum.
4. It will affect the identification efficiency.
5. It makes difference between the MC data and the real data.—More systematic error

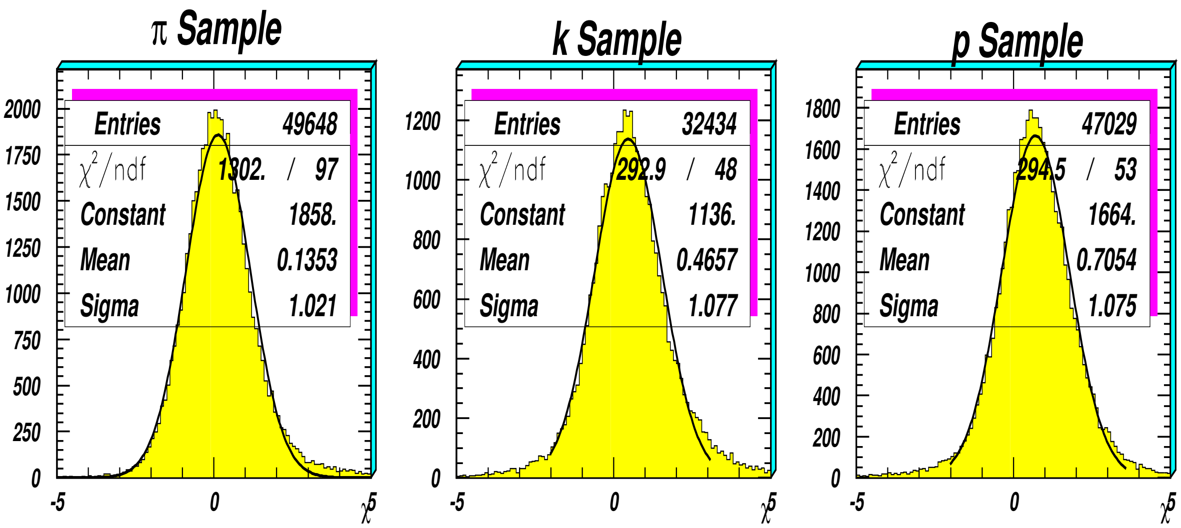

Fig.1 χ Distribution of π,K,P

2 How to do the correction

- **Sample selection**

In order to study TOF well ,we must get a pure samples as can as possible.For we will use the samples to study TOF, so we must obey the rule belowing when we get the samples.

1. Do not use TOF information .

2. Use the four-constraint kinematic fits .
3. The samples had better come from the decay of a resonance
   .

♠ π **sample**

We select π from the decay cannel:

$$J/\psi \to \rho\pi \to \pi^+\pi^-\pi^0$$

♠ **K sample**

We select K sample from the decay cannel:

$$J/\psi \to K^{*\pm}K^{\mp} \to K^{\pm}K^{\mp}\pi^0$$

and

$$J/\psi \to \phi\pi\pi \to KK\pi\pi$$

♠ **p sample**

We select K sample from the decay cannel:

$$J/\psi \to \pi^0 p^+ p^-$$

$$J/\psi \to p^+ p^-$$

♠ **e and u sample**

We select electron from e and u from decay cannel:

$$J/\psi \to \gamma e^+ e^-$$

$$J/\psi \to e^+ e^-$$

$$J/\psi \to u^+ u^-$$

From the Dalitz diagram and the invariant mass distribution of resonances(show at last)that we can see that we have go a relative pure sample.

• How to do the correction

♠ Time Offset

We have known χ is not a normal distribution,the centre shifted,it mean time offset,and the time measurement have systematic error.So we must do some correction for time.

We can get the time offset $\triangle T = T_{mea} - T_{exp}$ distribution when $cos\theta$ in a small range. fit $\triangle T$ with gaussion function.the mean of $\triangle T$ distribution is time offset.Then we can get time offset vary with $cos\theta$. Also we can get time offset vary with pluse amplitude and momentum for all kinds particles.

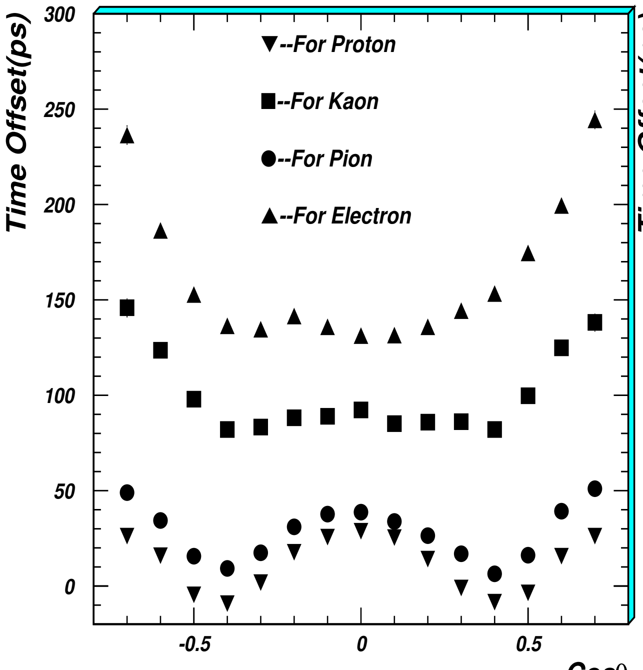

Fig.2 Time offset VS cosθ

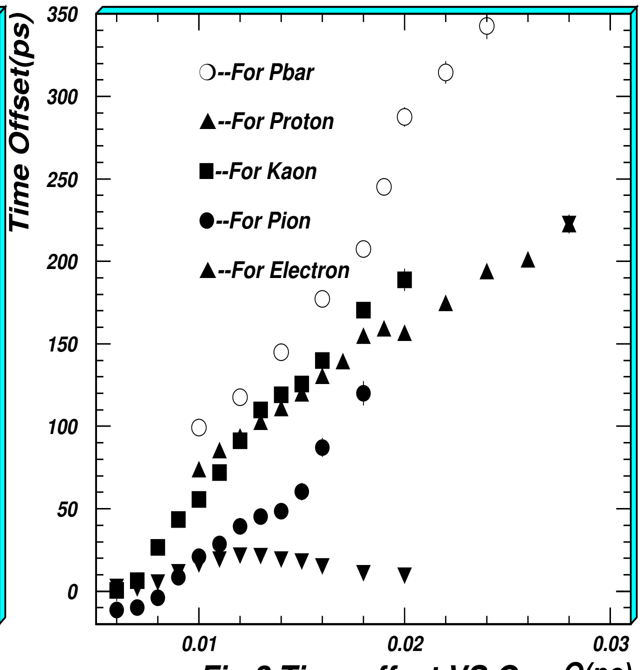

Fig.3 Time offset VS Q

From our study,we can find :

1. The time offset depend on pulse amplitude,momentum and $cos\theta$(Fig.2,3,4).Further the dependence is different for each kinds of particles.
2. The time offset is oscillation when it vary with $cos\theta$. Also the oscillation is different for all kind of particles (Fig.2)

3. The pulse amplitude also depend on momentum and $cos\theta$(Fig.5).

4. The actions of proton and antiproton in TOF are different.

5. The actions of lepton in TOF is well than hadron except oscillation.

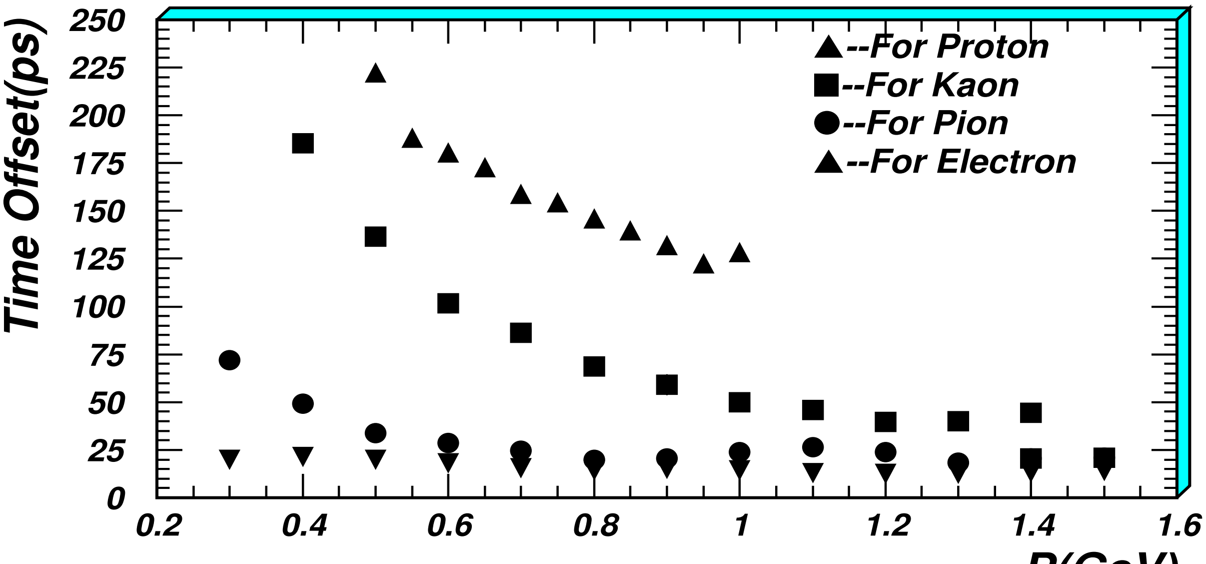

Fig.4 Time offset VS P

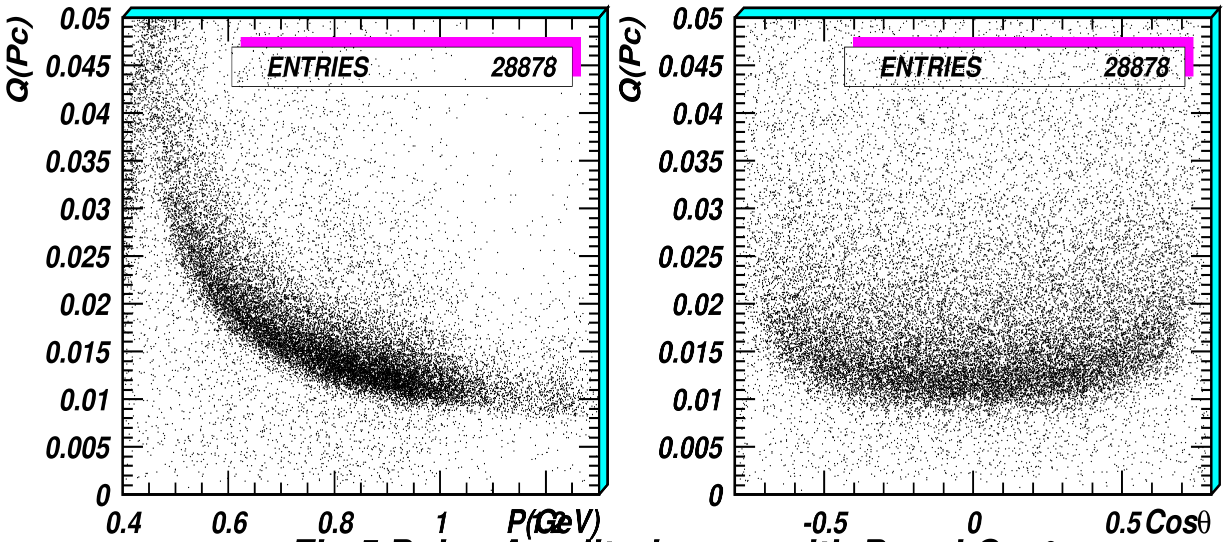

Fig.5 Pulse Amplitude vary with P and Cosθ

First we study the time offset oscillation when it very with $cos\theta$ with electron sample. We can get the time offset vary with momentum and pluse amplitude when abs($cos\theta$) in a small range(Fig.6,7). We can see time offset is flat when $cos\theta$ in a small range. Further time offset is in different level when $cos\theta$ is in different range. It mean that the oscillation does not depend on momentum and pulse amplitude. We also can statistic the measured time and expected time in a very small range, then we can get expected time and measured time vary with $cos\theta$, because electron momentom is about 1.5 Gev, we can know the path in the MDC is almost straight, so we can fit measured time and expected time with function $T = A/sin\theta$,we can see that the expected time fitting is better than measured time fitting. We also subtract expected time fitting resule from the expect time and measured time. then we can see time oscillation is come from the measured time(Fig.8). But we do not get the reason of oscillation now.

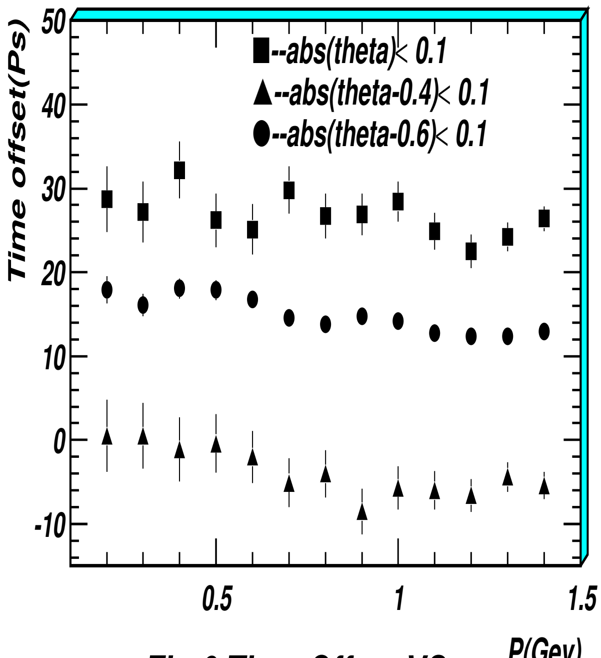

Fig.6 Time Offset VS p

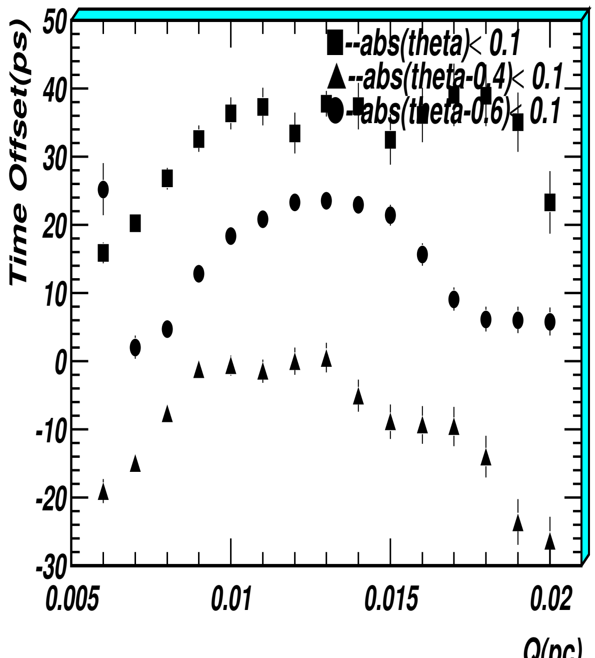

Fig.7 Time offset VS Q

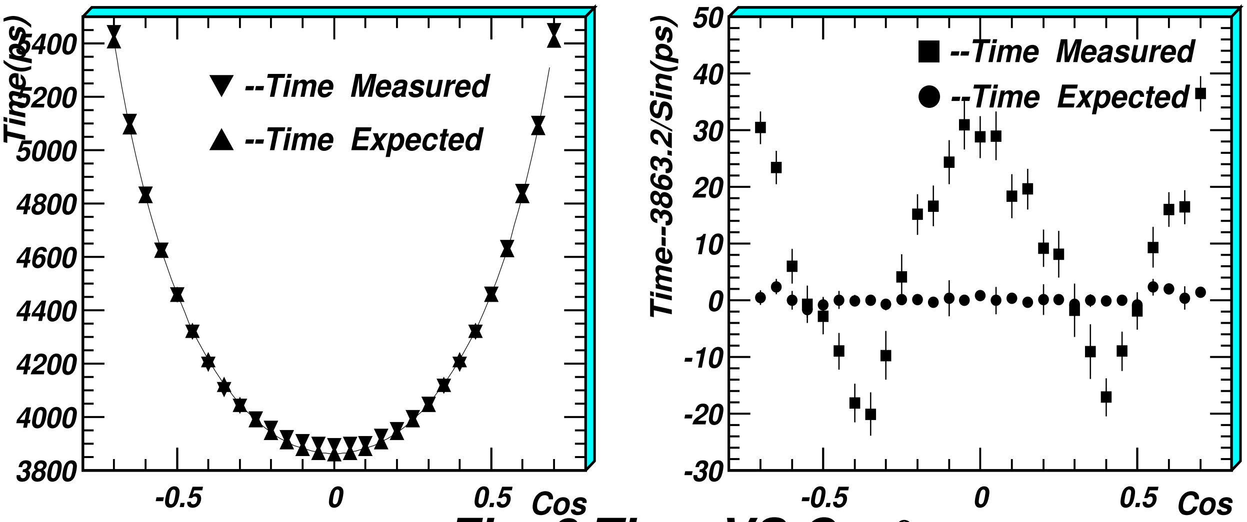

Fig. 8 Time VS Cosθ

We have known time offset depend on pulse amplitude,momentum and $cos\theta$,and the pulse amplitude also depend on momentum and $cos\theta$. in order to study the relation , we study proton sample carefully.

1. $cos\theta$ **dependence**

   First we can study time offset vary with $cos\theta$ when the momentum and the pulse amplitude in a small range(Fig.9). we also can compare the time offset vary with momentum when the pulse amplitude in a small range but $cos\theta$ inside or outside $-0.3-0.3$ range(Fig.10). Last we also can get the time offset vary with pulse amplitude when the momentum in a small range and $cos\theta$ inside or outside $-0.3-0.3$ range(Fig.11),From the study we see the $cos\theta$ dependence is not too much.

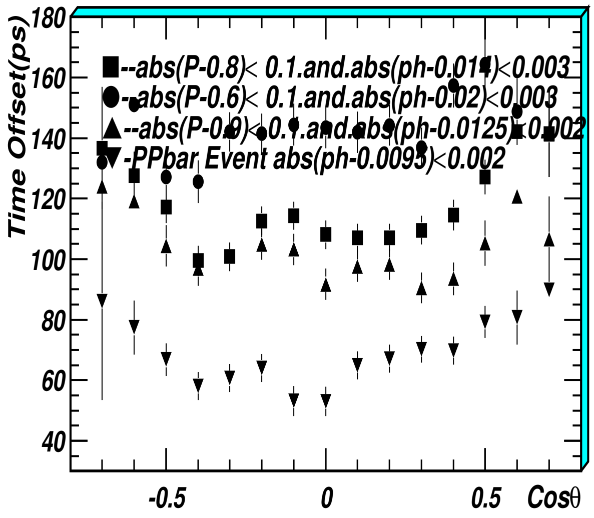

Fig. 9 Time Offset Vs Cosθ of Proton

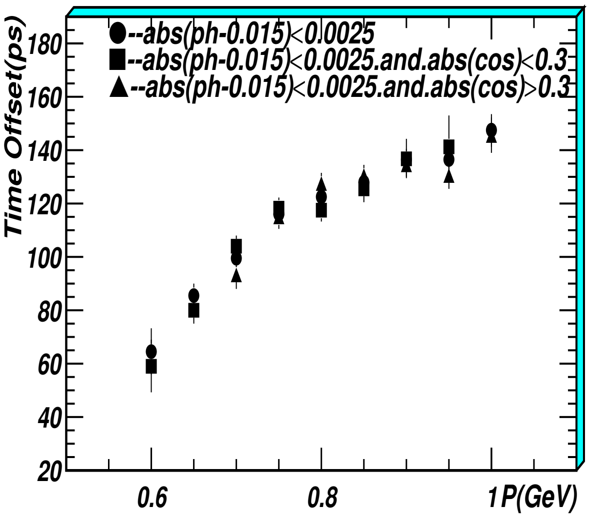

Fig. 10 Time Offset Vs P of proton

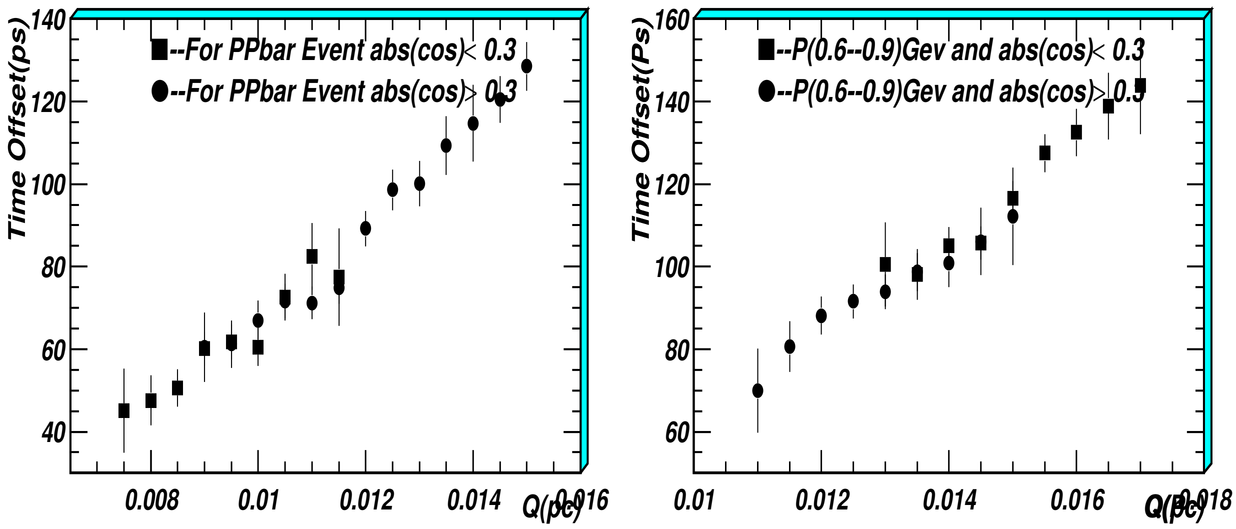

Fig.11 Time Offset Vs Q of Proton Sample

2. **Momentum dependence**

We also study the time offset vary with mometum when the pulse amplitude in a small range(Fig.12).Then we can see time offset changed tendency is different when pulse amplitude in all range or in a small range.It mean that the pluse amplitude dependence is more large than momentum dependence, the momentum dependence is coverd when the pluse amplitude in a large range.

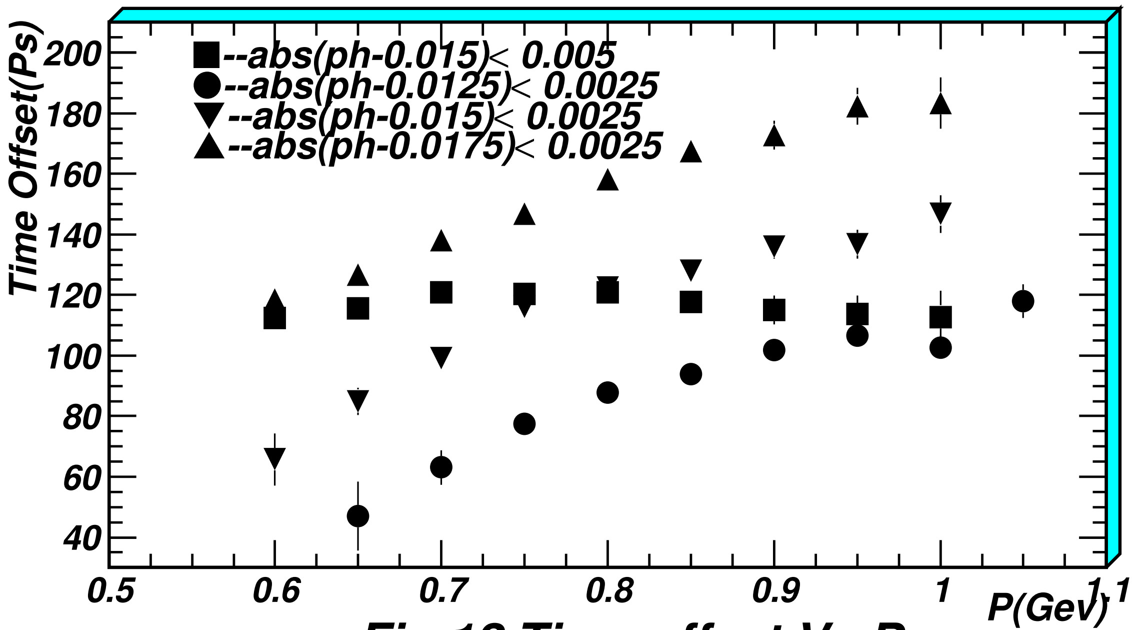

Fig.12 Time offset Vs P

3. **Pluse Amplitude dependence**

   We study the time offset vary pluse amplitude (Fig.3),we can see the time offset depend on pluse amplitude too much, because the statistics is finite, we can not do for some detail.

4. **Time Correction**

   Compare time offset dependence of pulse amplitude, $cos\theta$ and momentun, we can find the dependence of pulse amplitude is largest than the other two. and the $cos\theta$ dependence is smallest. So we can correct time step by step.

   (a) Do pulse amplitude correction.

   We can fit Fig.3 with polynomial, and get $\triangle T1 = A + B * Q + C * Q^2$,then we can define $\triangle T2 = T_{mea} - T_{exp} - \triangle T1$,and get $\triangle T2$ vary with momentum(Fig.13).

   (b) Do momentum correction.

Fit Fig.13 with polynomial, and get $\triangle T2 = A + B * p + C * p^2$,and we also can define $\triangle T3 = T_{mea} - T_{exp} - \triangle T1 - \triangle T2$.and get $\triangle T3$ vary with $cos\theta$(Fig.14).

(c) Do $cos\theta$ correction.

Last we fit Fig.14 with $\triangle T3 = A + B * cos^2\theta + C * cos^4\theta$.and get $\triangle T3$ vary with $cos\theta$.

Then the totle time correction is

$$\triangle T_{tot} = \triangle T1 + \triangle T2 + \triangle T3$$

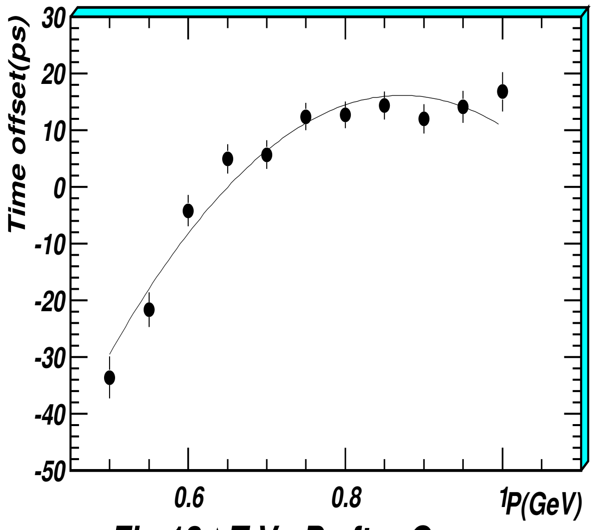

Fig.13 ΔT Vs P after Q corr

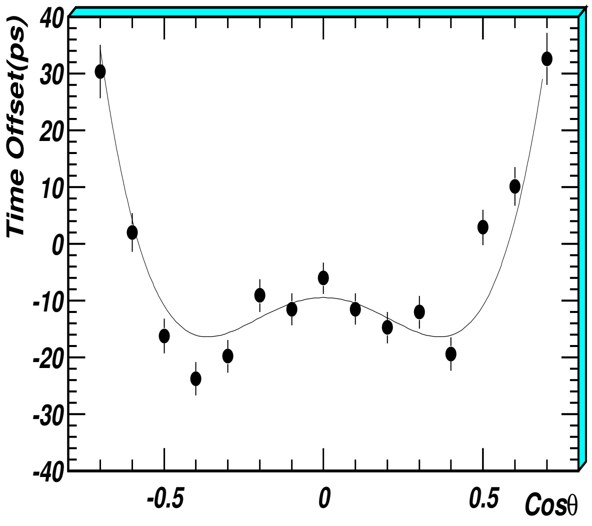

Fig.14 ΔT Vs cosθ after P corr

♠ TOF resolution

As we know ,TOF is composed of 48 block scintillation counters. Due to some difference of the scintillation counters, the resolution is different for each other.After particle hits the TOF, the photon will take some time to be transmited to the PMT,and some of them will be lost , therefore the resolution will depend on the hit point ,so it should change with the θ direction.Also the resolution will depend on momentum and pulse amplitude .

1. **Counter numbers dependence**

(a) Getting time offset $\Delta T = T_{mea} - T_{exp} - \Delta T_{tot}$ distribution for all the particles hitting the same scintilator.

(b) Fit ΔT with Gaussian .

(c) The σ is the resolution of the block of scintilator(Fig.15).

From the plot we can find resolution is very different for each block scintilator.

2. **The $cos\theta$ dependence**

(a) Dividing $cos\theta$ into several slices .

(b) Getting ΔT distribution in each slice .

(c) Getting the resolution varying with $cos\theta$(Fig.16) .

we can fit the plot with formula :

$$\sigma_{cos\theta} = P1 + P2 * \cos^2\theta$$

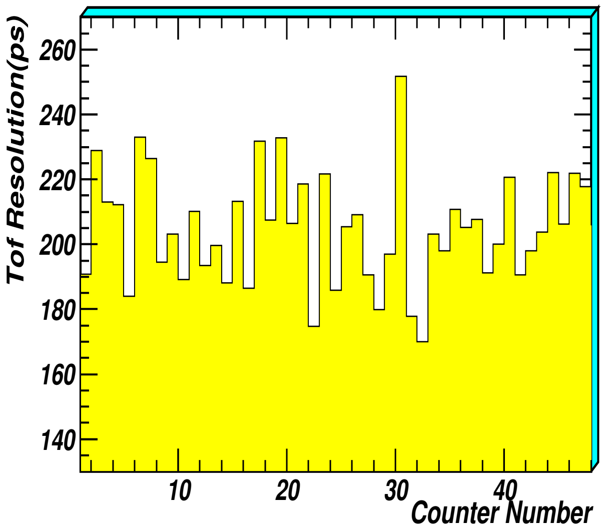

Fig.15 Resolution Vs Counter Mun

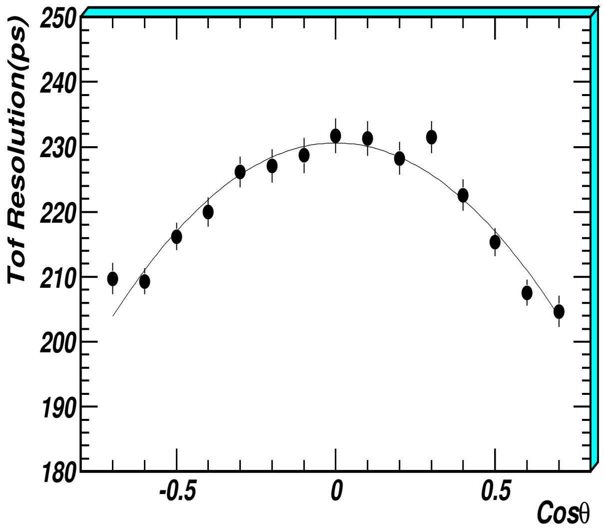

Fig.16 Resolution Vs Cosθ

3. **The pulse amplitude dependence**

(a) Dividing pulse amplitude into several slices .

(b) Getting ΔT distribution in each slice .

(c) Getting the resolution vary with The pulse amplitude (Fig.17)

Fit Fig.17 with polynomail :

$$\sigma_Q = A + B * Q + C * Q^2$$

4. **The momentum dependence**

   (a) Dividing momentum into several slices .

   (b) Getting ΔT distribution in each slice .

   (c) Getting the resolution varying with momentum(Fig.18).

   Fit Fig.18 with polynomail :

$$\sigma_p = A + B * p + C * p^2$$

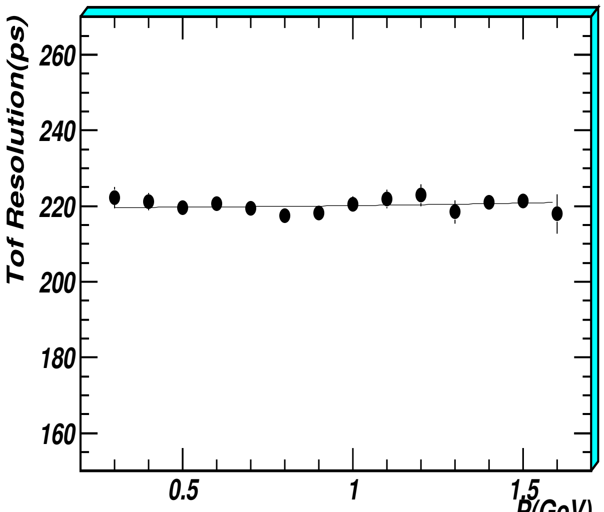

Fig.17 Resolution Vs P

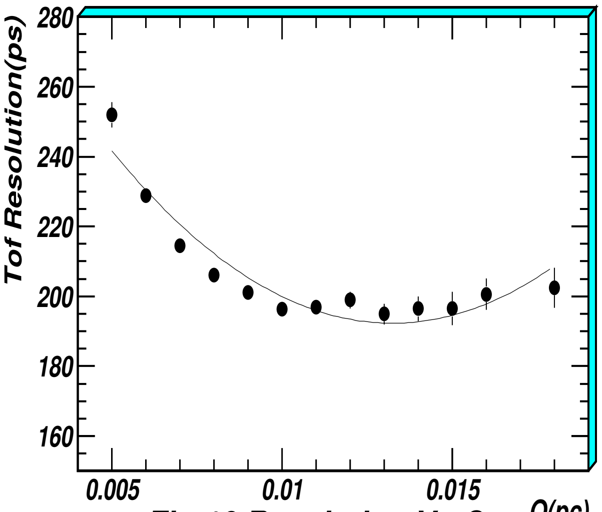

Fig.18 Resolution Vs Q

5. **TOF Resolution**

   From our study,we get the dependence between resolution and counter number,$cos\theta$,momentum and pulse amplitude.then we can get the resolution:

$$\sigma = \sigma_i * \frac{\sigma_{cos\theta}}{\sigma_{ave}} * \frac{\sigma_p}{\sigma_{ave}} * \frac{\sigma_Q}{\sigma_{ave}}$$

where

σ_i: The resolution of No. i block scintillator.

σ_p: The resolution vary with momentum.

$\sigma_{cos\theta}$: The resolution vary with $cos\theta$.

σ_q: The resolution vary with pulse amplitude.

σ_{ave}: The average resolution of particle i.

Also the resolution is different for all kinds of particles. so we must get the resolution for all kinds of particles.

3 PID using TOF

We have finished PID process using TOF information after correction. veryone can call the process at bespcfarm.The direct is /mnt/raid/home/penghp/bes/tof/corr/

In the process,we defined χ value :

$$\chi = \frac{T_{mea} - T_{exp} - \triangle T}{\sigma}$$

Particle with the least χ^2 value is assumed to the correct one.

The variables used in the process are :

Input : IITRK , The track # of the particle

Output : A integer value. 1 is for K, 2 for π,3 for p

In order for users to use the process freely, we also define a common block in the file tofwgt.inc. It includes some useful valiables such as weight, probability, and relative weight between K and π.

4 Check the code

First we can check χ distribution after correction, Fig.19 show the mean of χ vary with counter number , $cos\theta$,momentum and pulse amplitude.Fig.20 show the σ vary with counter number ,$cos\theta$,momentum and pulse amplitude.From the plot we can see χ is a normal distribution after correction.

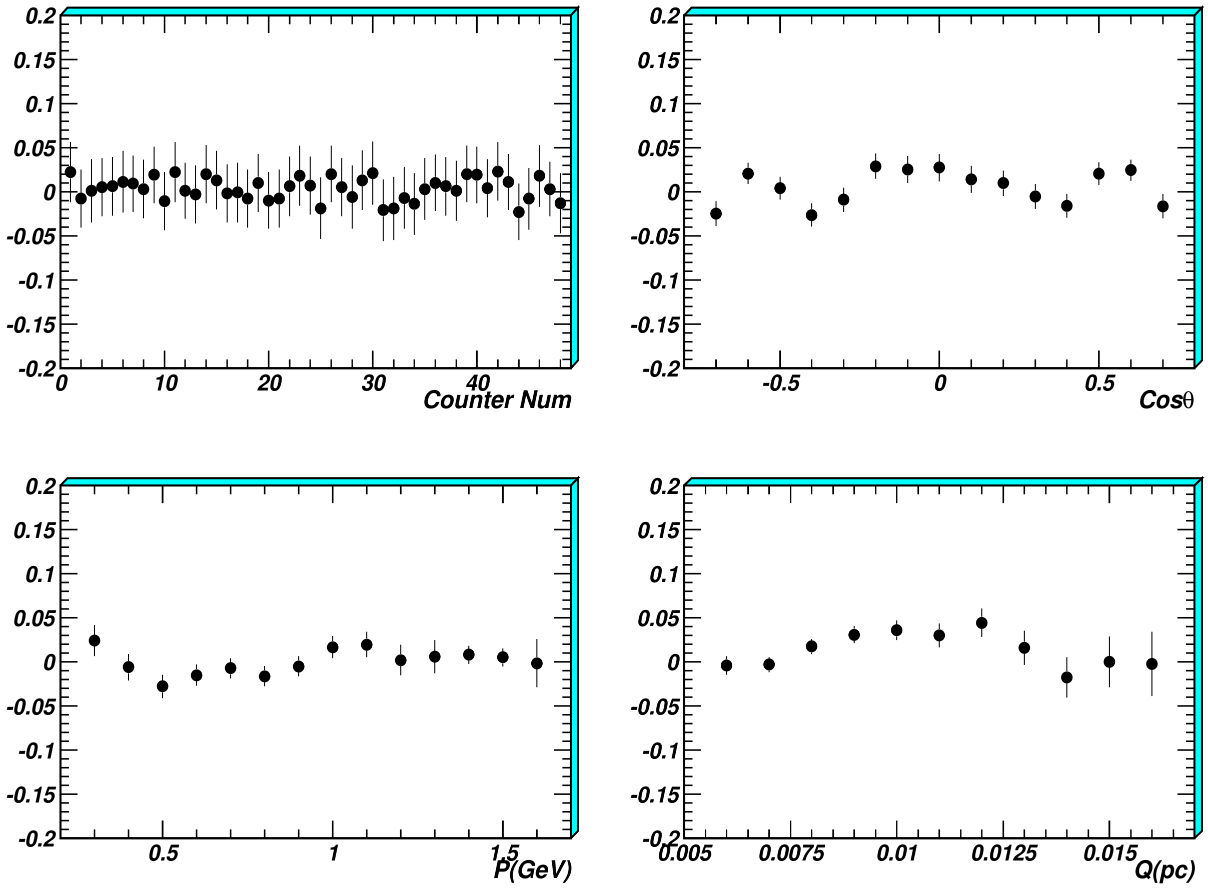

Fig.19 The mean of χ Distribution after Corr

Second we give the identification efficiency for the K and π. Fig.21 and Fig.22 show π and K identification efficiency before and after correction. from the plot we can see the identification efficiency of π is increased and K identification efficiency alse have a small improve. Fig.23 show K and π identification efficiency after correction. Fig.24 show relative weight between K and π. Also we give the β distribution of TOF for all kinds of particles(Fig.24.B).

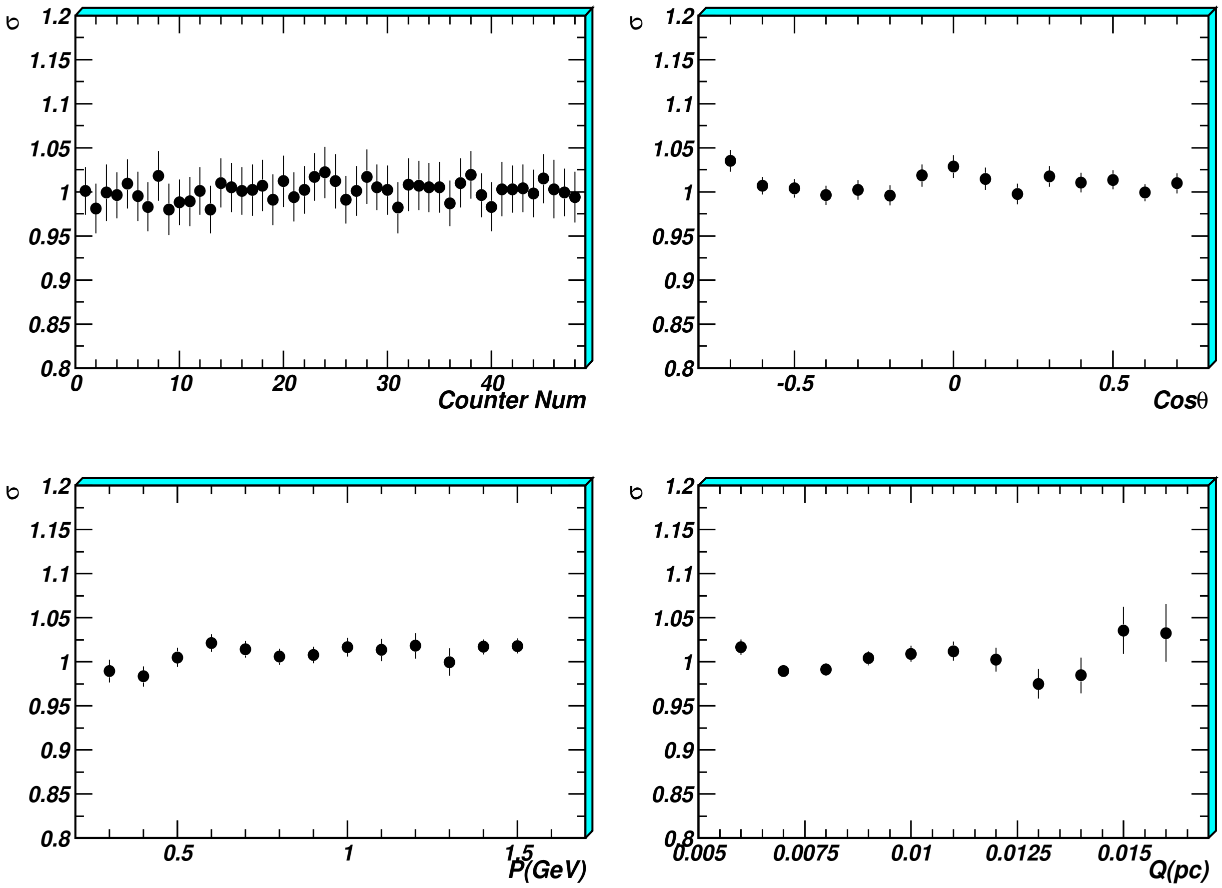

Fig.20 The σ of χ Distribution after Corr

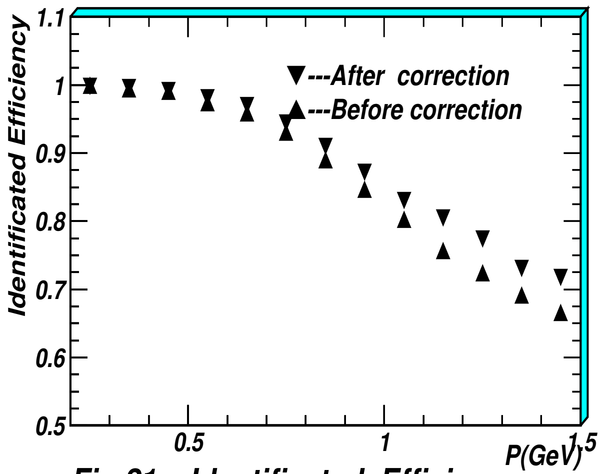

Fig.21 π Identificated Efficiency

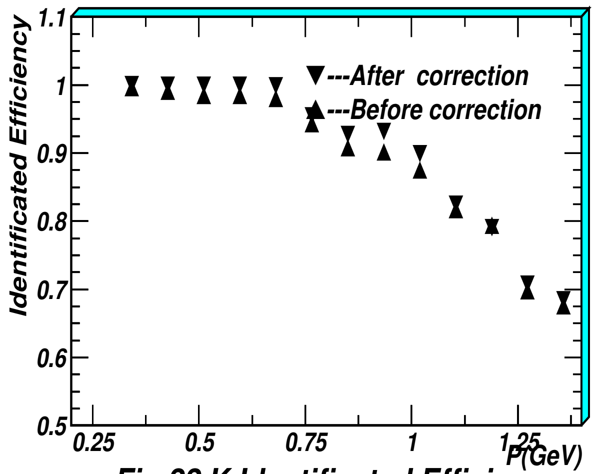

Fig.22 K Identificated Efficiency

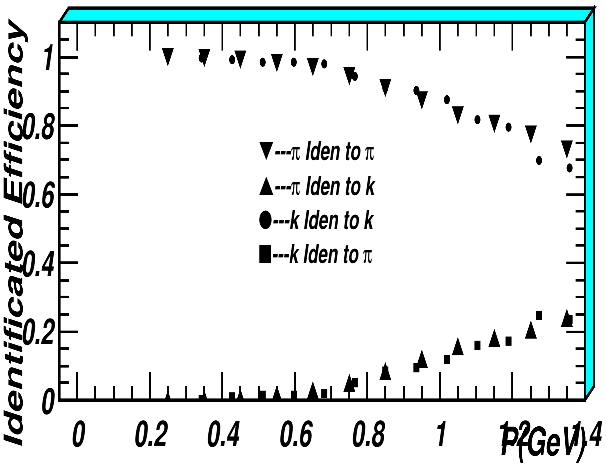

Fig.23 Identificated Efficiency after Corr

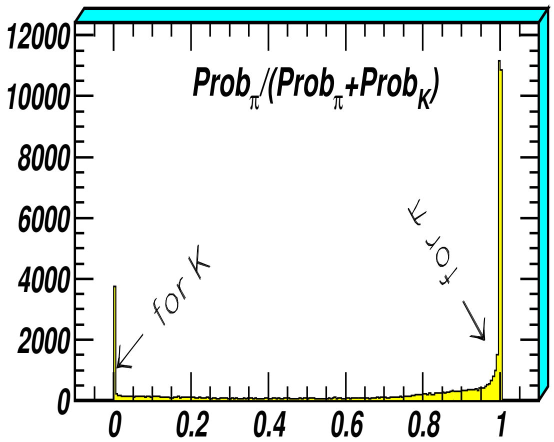

Fig.24 Relative Prob Between K and π

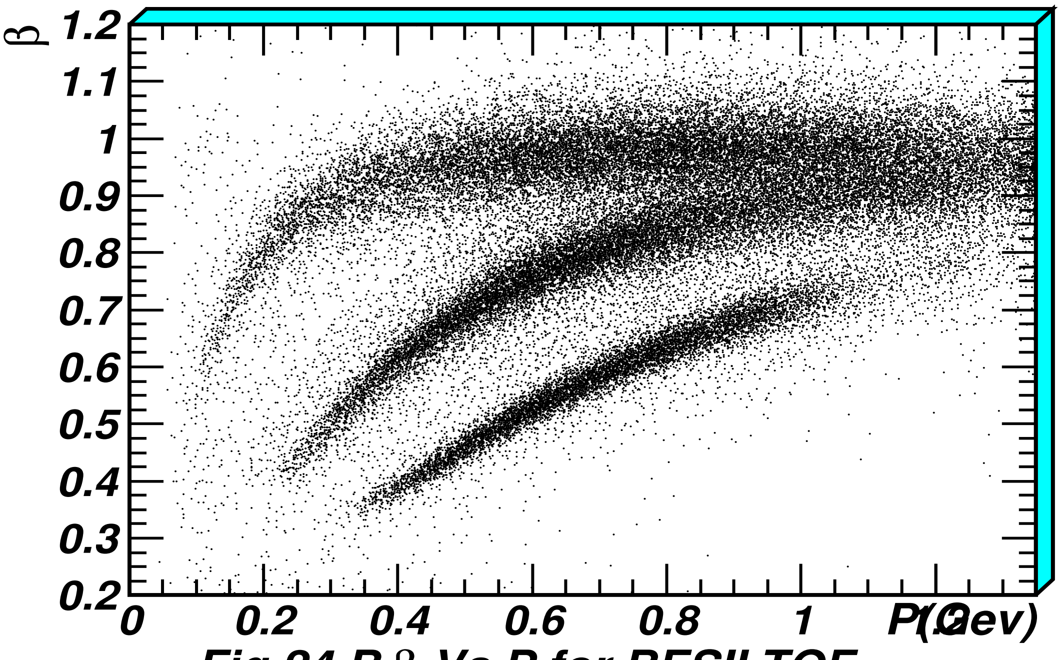

Fig.24.B β Vs P for BESII TOF

Last we check the code from the J/ψ decay channel:

$$J/\psi \to \phi\pi\pi \to KK\pi\pi$$

$$J/\psi \to \omega kk \to \pi^+\pi^-\pi^0 kk$$

From the distribution of ϕ ,ω mass(Fig.25,Fig.26),we can see the select efficiency is increased after correction

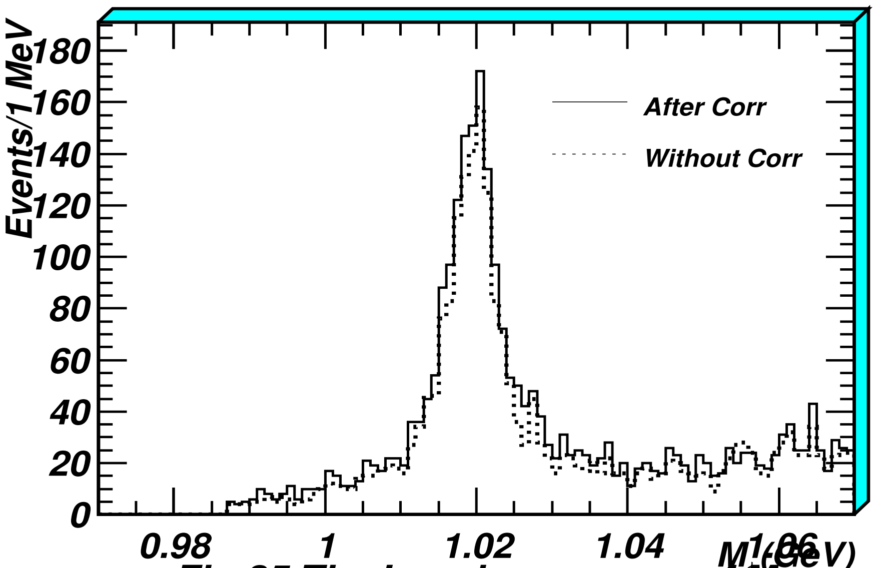

Fig.25 The Invariance mass of M_ϕ

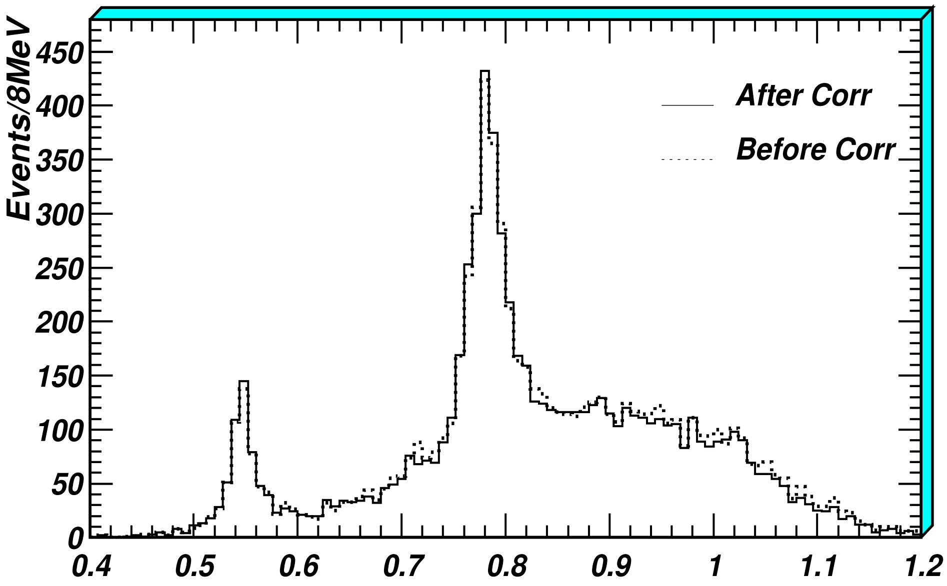

Fig.26 Invariant Mass of ω M_ω(GeV)

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5 For M.C data

Inorder to reduce the difference between real data and M.C. data,we must do the same correction to M.C. data. We use HOWL generater to generate J/ψ decay channel:

$$J/\psi \to \pi^+\pi^-\pi^0$$

$$J/\psi \to k^+k^-\pi^0$$

$$J/\psi \to p^+p^-\pi^0$$

to get π,k,and p sample.

From our study ,we found the M.C. data is better than the real data,Fig.31 show the time offset distribution with correction, Fig.32 show the resolution distribution.

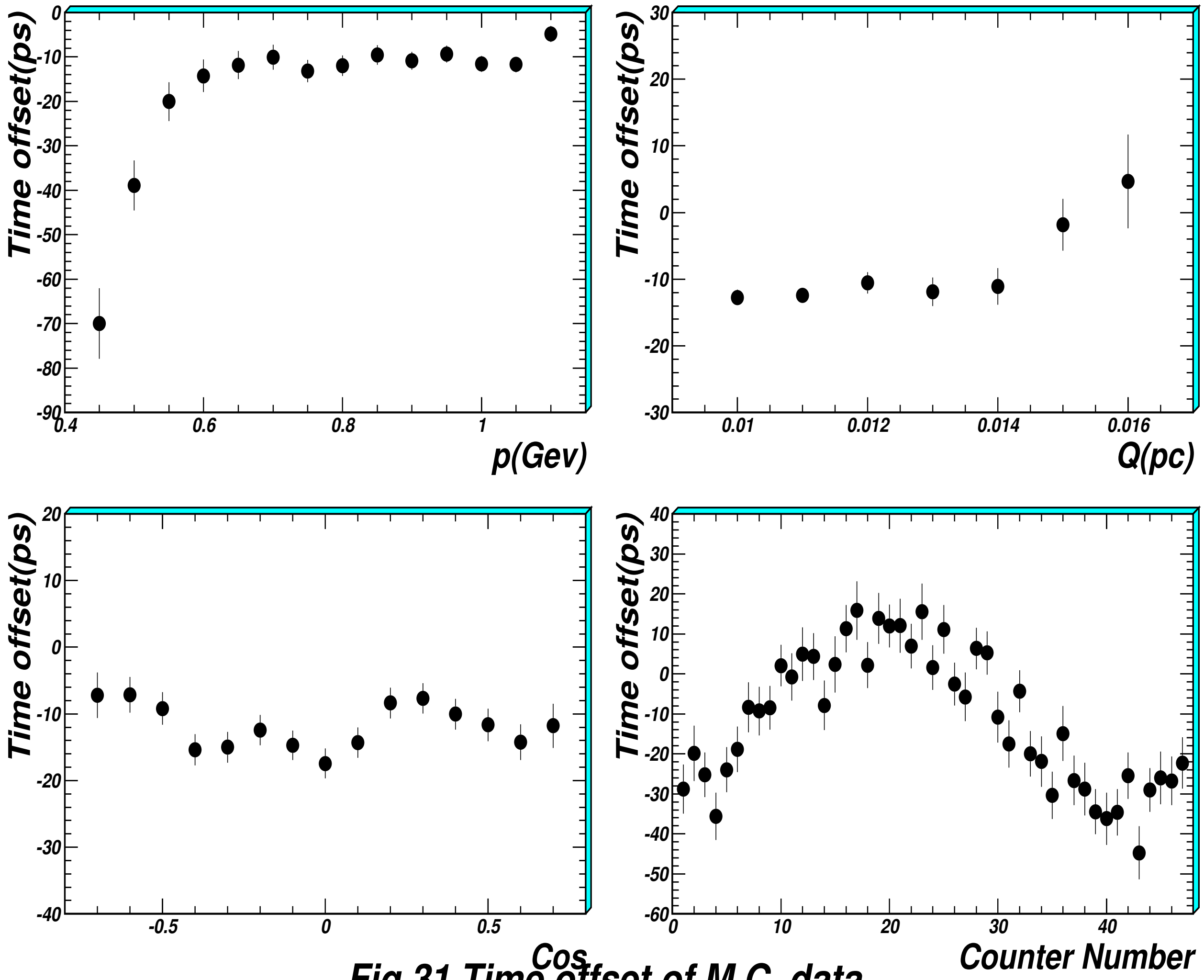

Fig.31 Time offset of M.C. data

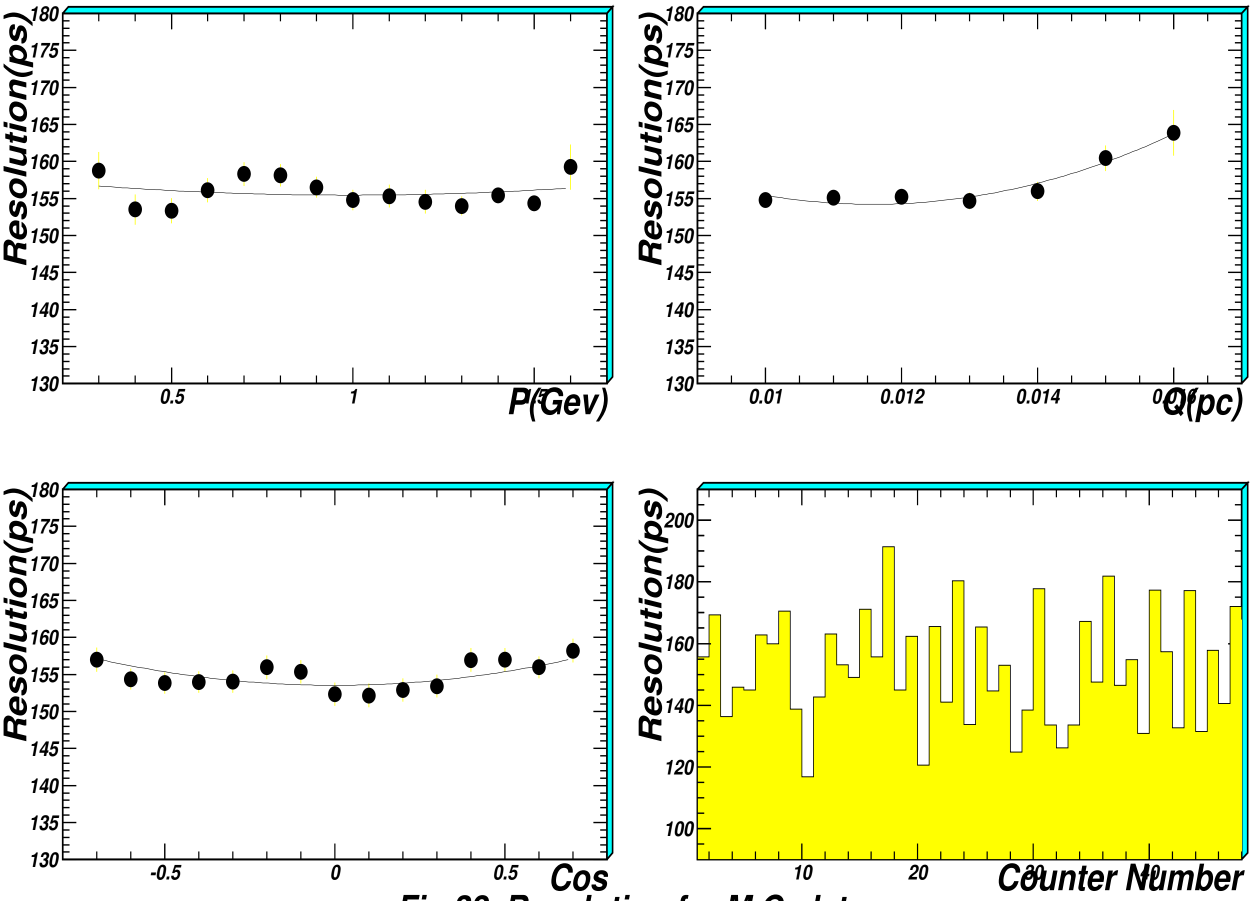

Fig.32. Resolution for M.C. data

For the time offset ,we only do momentum correction .After do momentum correction we check the time offset vary with $cos\theta$,pulse amplitude . we found $\Delta T = T_{mea} - T_{exp} - \Delta T_p$ is very close 0(Fig.33).

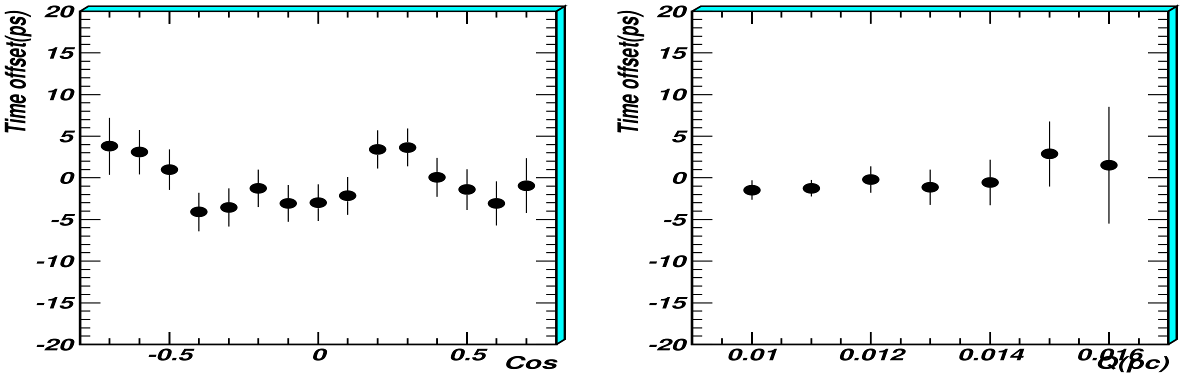

Fig.33 Time Offset after Momentum Corr of M.C. data

For the resolution,we do the same correction as real data.

1. Counter number correction
2. $Cos\theta$ correction
3. Momentum correction
4. Pulse amplitude correction

Then we can get the resolution:

$$\sigma = \sigma_i * \frac{\sigma_{cos\theta}}{\sigma_{ave}} * \frac{\sigma_p}{\sigma_{ave}} * \frac{\sigma_Q}{\sigma_{ave}}$$

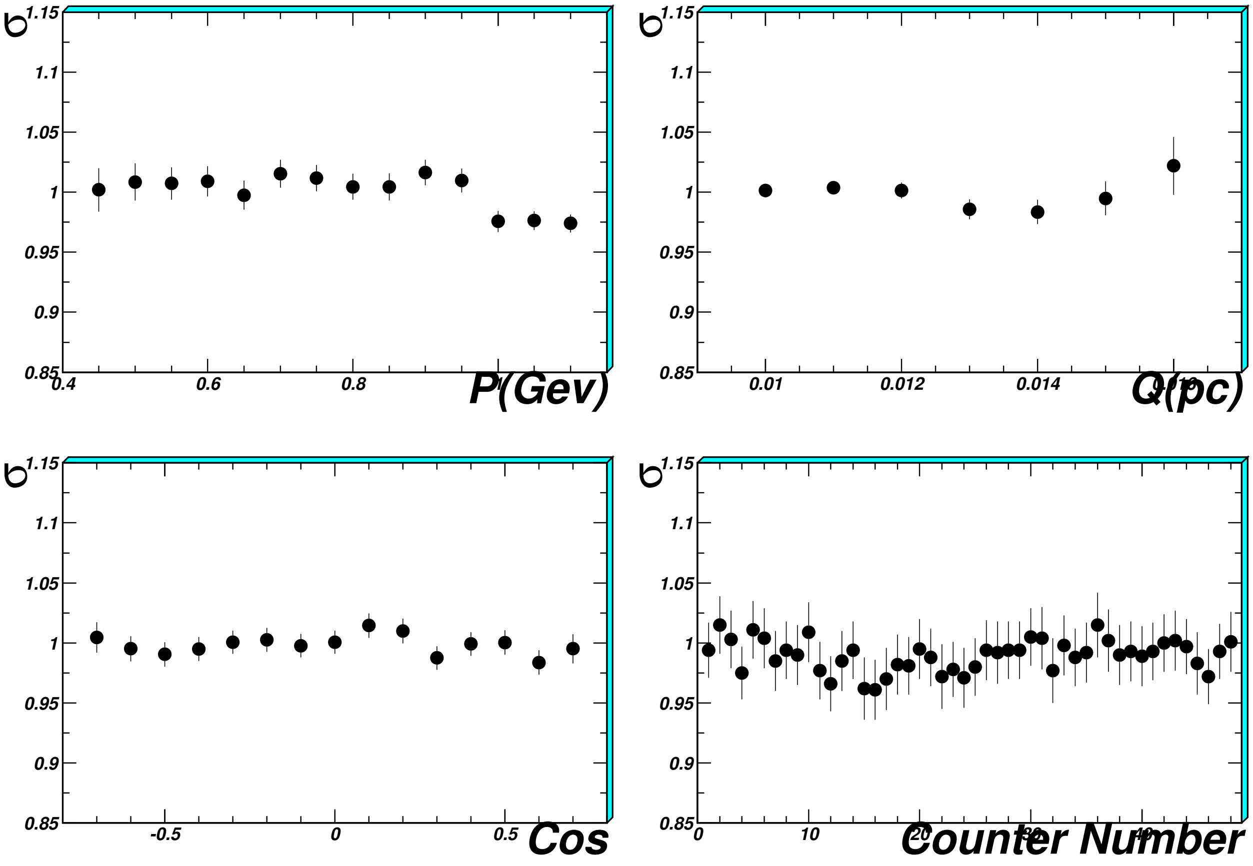

Fig.34 The σ of χ Distribution of M.C. data after Corr

After do the correction ,we also define the $\chi = \frac{T_{mea} - T_{exp} - \Delta T_p}{\sigma}$, and check χ vary with counter number,$cos\theta$, momentum and pulse amplitude,found it is a normal distribution(Fig.34.35). Also we generate π sample using RHOPI generater and use the same correction result which have get from HOWL generater to check χ, we also get χ is a normal distribution when it vary with counter number,$cos\theta$, momentum and pulse amplitude.It was said that the correction of M.C. data do not depend on generater.

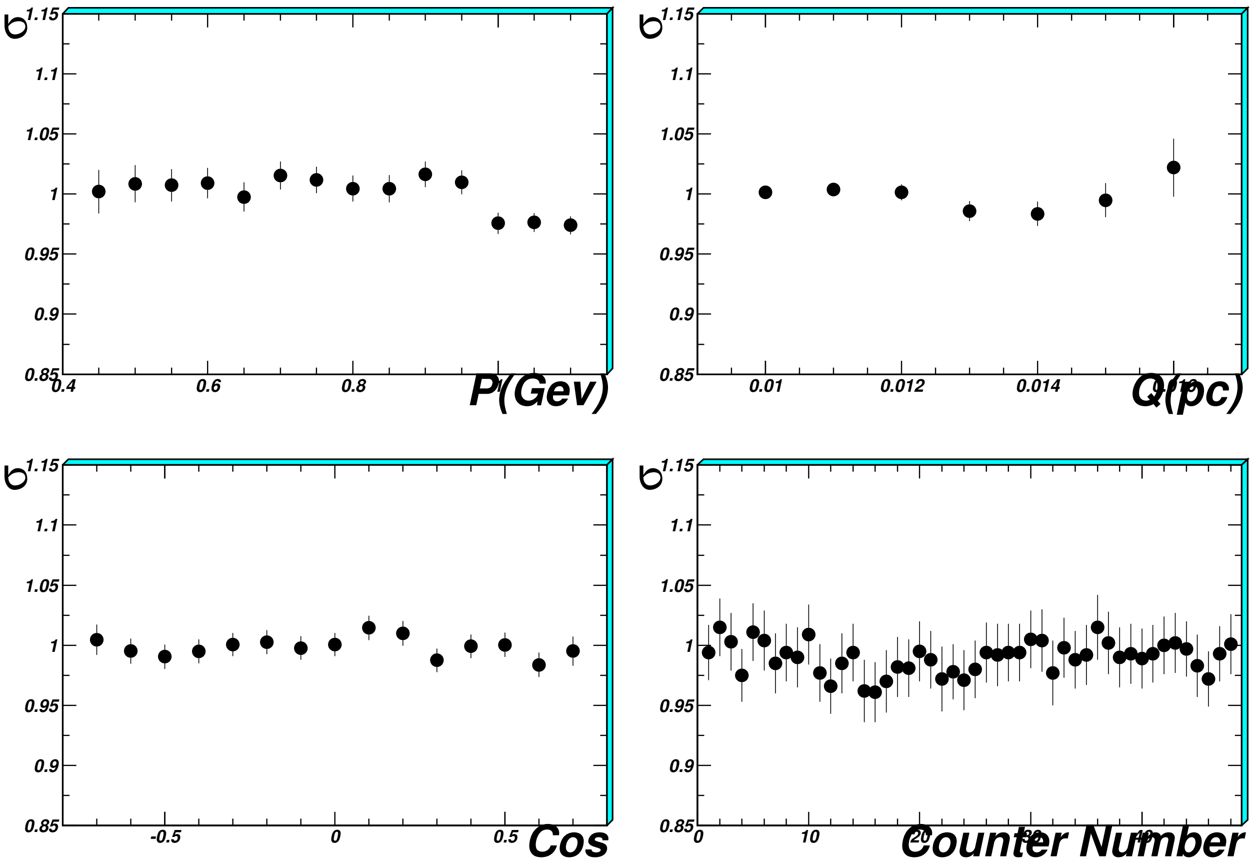

Fig.34 The σ of χ Distribution of M.C. data after Corr

6 Compare M.C. data and real data

After do all correction to real data and M.C. data. the different between real data and M.C data should been reduced.but from our study,we found resolution still have some problem. Fig.27 show the resolution very with coumter number. it can see that the M.C. data resolution is much better than real data.also we study the resolution vary with $cos\theta$(Fig.28), we found the charge tendency is very different between real data and M.C. data. Fig.29 and Fig.30 show the identification effi-

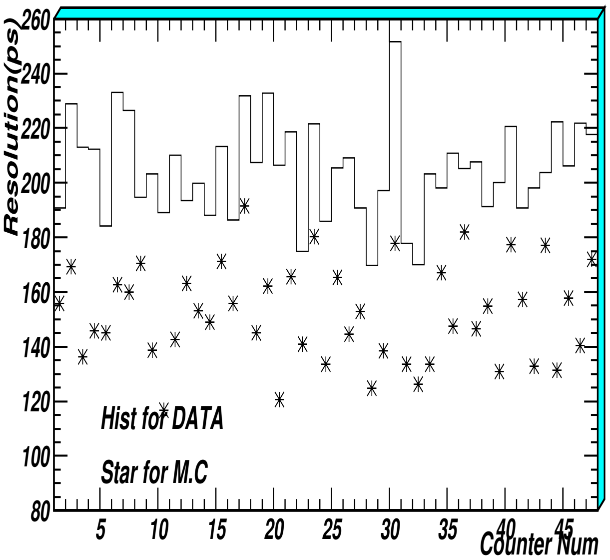

Fig.27 Resolution Vs Counter Num

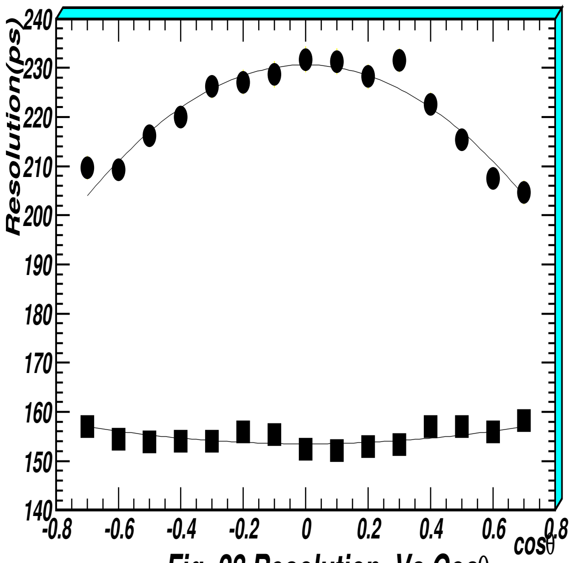

Fig. 28 Resolution Vs Cosθ

ciency vary with momentum, we can see the M.C. identification efficiency is higher than read data,the reason is that the real data resolution is much bigger than M.C. data. so it will make a systematic error.

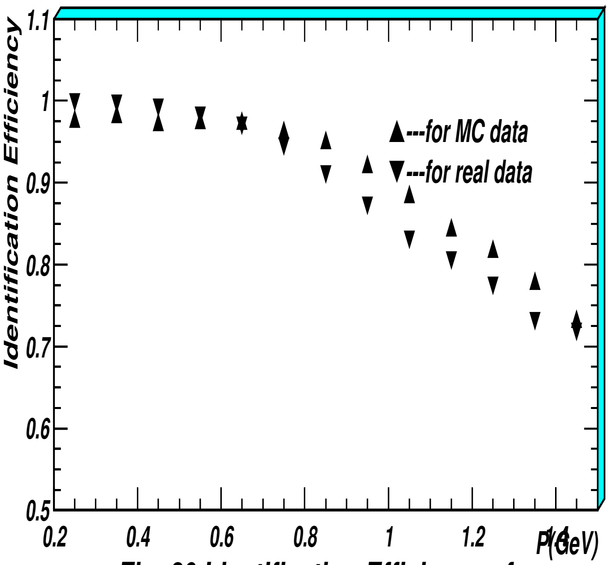

Fig. 29 Identification Efficiency of π

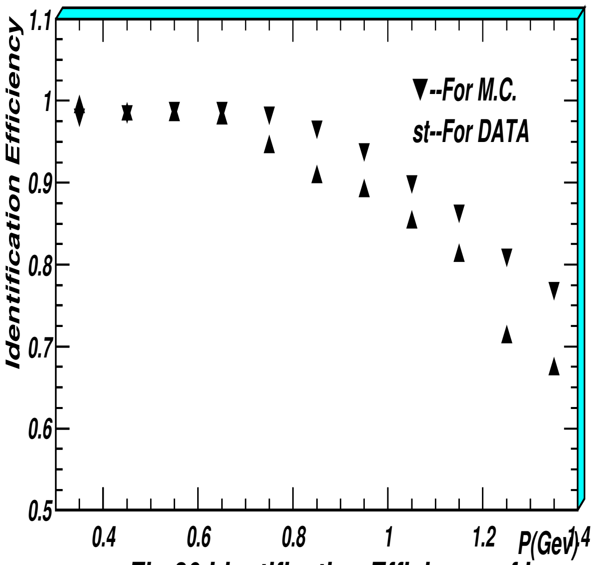

Fig.30 Identification Efficiency of k

7 Conclusion

1. **What has been done**
   (a) Correction for TOF time and resolution for real data.
   (b) Correction for TOF time and resolution for M.C. data.
   (c) PID using TOF information code and check the code.
   (d) Give the identification efficiency.
2. **How about the effect**
   (a) The χ distribution is N(0,1) after correction .
   (b) The identification efficiency is increased for real data, and event select efficiency also is increased.
   (c) The most importance is that **the correction can minimize the difference between MC data and real data**, and the systematic error will be much reduced.
3. **The problem**
   (a) Why does the time offset oscillation when it vary with $cos\theta$
   (b) Why does the action of all kinds of particles is different so much at TOF, especially between lepton and hadron.
   (c) The resolution of M.C. data is better than real data, must do some modify at simulation.
   (d) Hope to get a set of same parameters to do correction for all kinds of particles.
   (e) Can we calibration with hadron such as proton????

$J/\psi \longrightarrow \rho\pi \longrightarrow \pi^+\pi^-\pi^0$

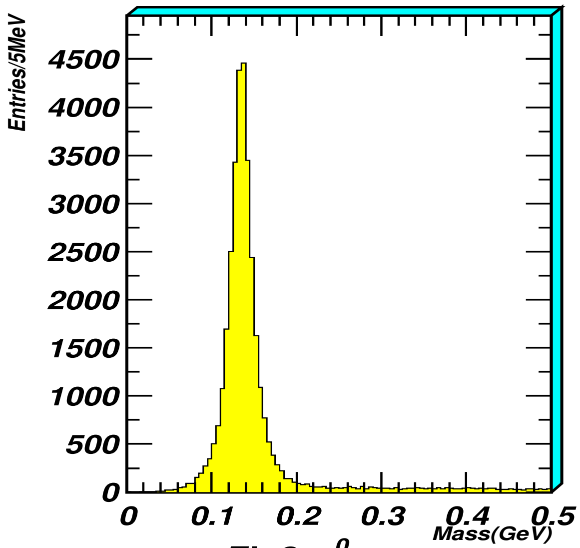

Fig2. π^0 mass

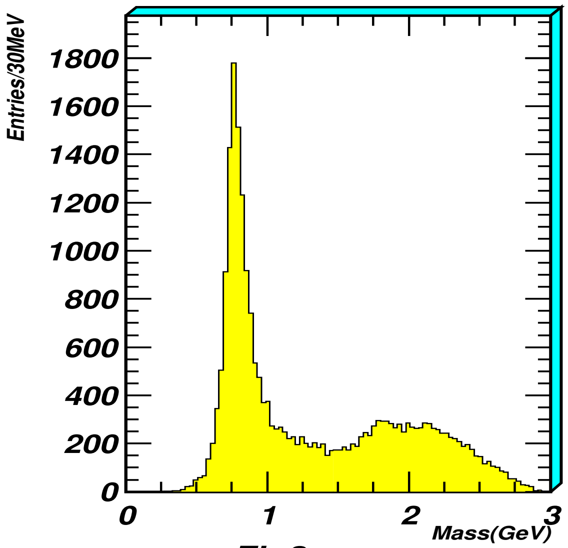

Fig3. ρ mass

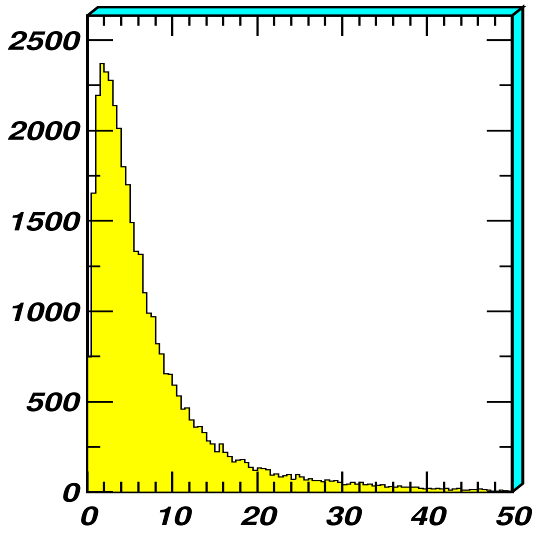

Fig4 . χ^2 of 4-C fit

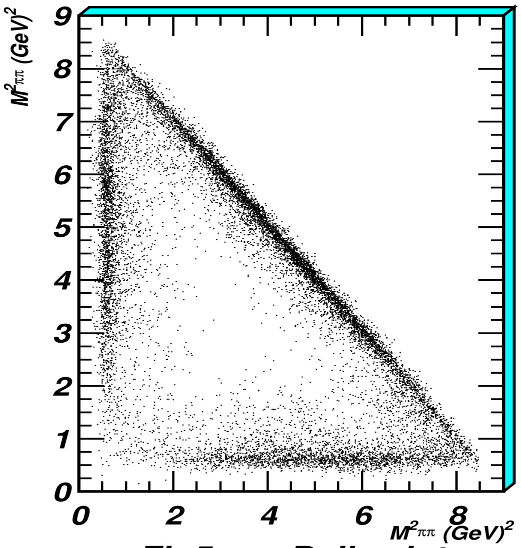

Fig5. $\pi\rho$ Daliz plot

$J/\psi \rightarrow K^{*}K \rightarrow KK\pi^{0}$

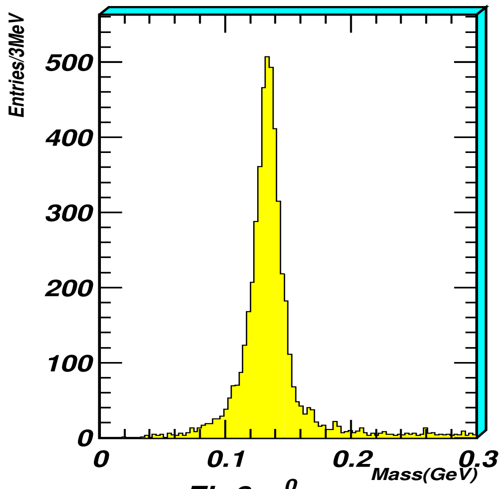

Fig6. π^{0} **mass**

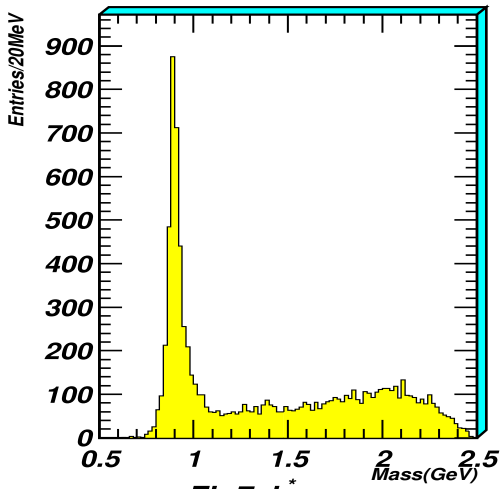

Fig7. k^{*} **mass**

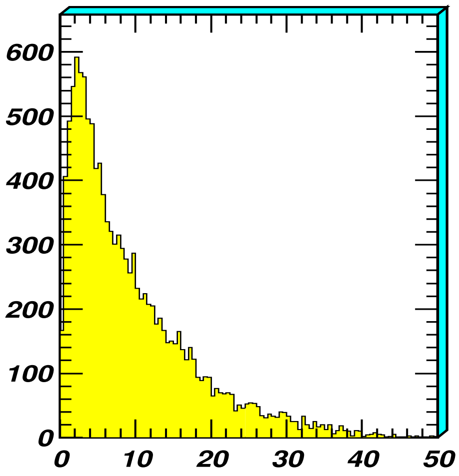

Fig8 . χ^{2} **of 4-C fit**

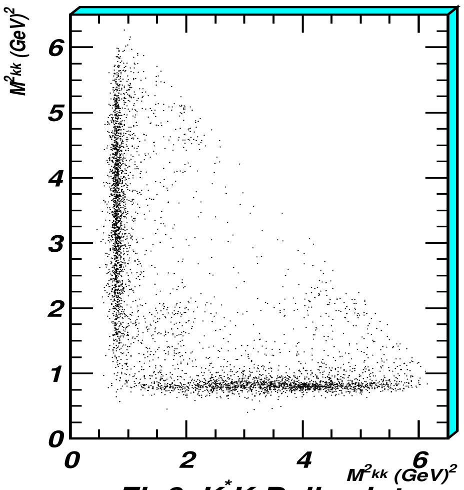

Fig9. $K^{*}K$ **Daliz plot**

$J/\psi \rightarrow \phi\pi\pi \rightarrow KK\pi\pi$

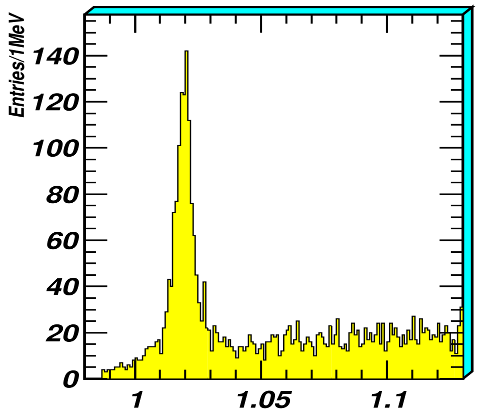

Fig9. ϕ **mass** M_{χ}(GeV)

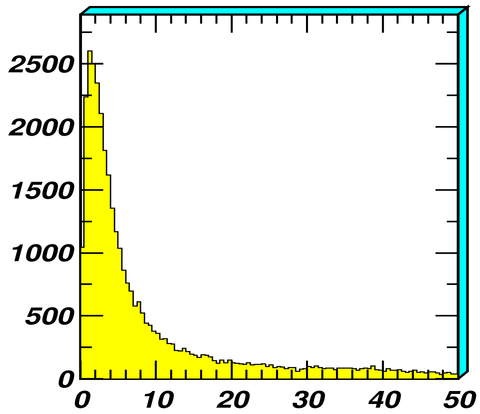

Fig10. χ^{2}