BESII MDC dE/dX Correction and PID using dE/dX

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1 Motivation

• Introduction

The BESΠ detector[1] is a large general purpose solenoidal detector at BEPC, the wide range of physics that can be studied require the detector to have good momentum resolution and particle identification for charged. Of course the PID using TOF can be well used, but in order to improve the confidential level of PID, we also can use dE/dX information to identify particle especially in a low momentum range.

The main drift chamber(MDC) is designed to measure the momenta of charged particles, ionization energy loss(dE/dX) of charged particles in the gas of the chamber, and provide information for the trigger. by combining the momenta of charged particle and its dE/dX in the working gas of the MDC, the mass of the particle can be determined. The goal of charged particle identification using dE/dX in the $BES\Pi$ is to seperate $\pi/K/P$ in a low momentum range.

• The Ionization loss of charged particle in the gas

When the unit charged particle passes through a medium with a thickness of t[g/cm^2], the loss energy due to ionization collision with the bound electrons of the medium. the most probable ionization energy loss is given by LANDAU formula[2]:

$$dE/dx|_{prob} = \frac{2\pi ne^4t}{m_ev^2\rho}[ln(\frac{2m_ev^2(2\pi ne^4t/m_ev^2\rho)}{I^2(1-\beta^2)})-\beta^2+0.198-\sigma] \qquad (1)$$

where n denote the electron desity of the medium, ρ is the density, I is the mean ionization potential, e is the electron charge, m_e is the electron mass, v is the velocity of the charged particle and the σ is the density correction due to the polarization effect. For the three components working gas mixture($89\% Ar + 10\% CO_2 + 1\% CH_4$),Eq.(1) can be simplified into

$$dE/dx|_{prob} = \frac{125x}{\beta^2}(8.226 + lnx + 2ln\gamma - \beta^2 - \sigma) \qquad (2)$$

Where the x is the thickness of dE/dX sampling in centimeter. Fiting the real data, we obtain a dependence of the σ on the vilosity of the charged track to be[3]:

$$\sigma = 0 \qquad y < 0.7$$

$$\sigma = 0.3329 - 0.9141 * y + 0.7790 * y^2 \qquad 0.7 \leq y \leq 3.6$$

$$\sigma = -9.3115 + 4.6y \qquad y > 3.6$$

Where $y = log_{10}(\beta\gamma)$

Eq.(2) is a function of $\beta\gamma$ universal for all unit-charged particles. Fig.1(left) show the most probable ionization energy loss of the 5 different kinds of particles passing through unit centimeter gas as a function of momenta, which is calculated with Eq.(2) and combined with density correction. Fig.1(right) show the measurement of the dE/dX varying with momenta. Since the different kinds of particles have different values of $\beta\gamma$ for a given momentum, each of their most probable energy loss are different from each other. By measuring the momemta of a particle and it most probable energy loss, the mass of the particle can be determined.

- ## dE/dX reconstruction and systematic errect correction.

In the standard gas thinkness 1 cm per dE/dX sample, the energy loss approximately follows the Landua distribution.

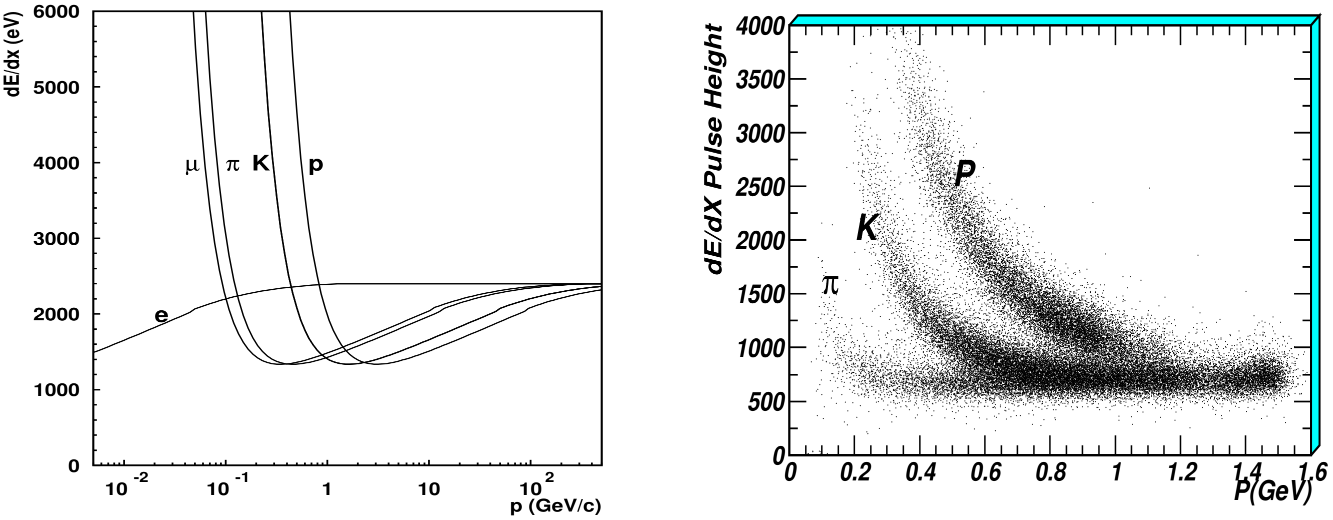


Figure 1: Theoretical calculation and $BES\Pi$ MDC Measurement dE/dX .Vs. Momentum

In oder to remove the occasiocal events with a larger energy transfer due to σ electrons, and to improve the dE/dX resolution and the ability of the particle identification, the method of truncated mean is applied when doing dE/dX reconstruction[4]. and the dE/dX pulse height also be corrected by seven systematic errect items[5].

• PID using dE/dX and Particle Separation

In order to identify particles, first we can get the most probable energy loss $(dE/dX)_{meas}$ from MDC, we also can get the momenta of particle from MDC information, then from the calculation according to the LANDAU formula, we can get most probable energy loss of each kind of particle $(dE/dX)^i_{exp}$ for a given momenta, then we can defined χ_i:

$$\chi_i = \frac{(dE/dX)_{meas} - (dE/dX)^i_{exp}}{\sigma_i}$$

where σ_i is the resolution of energy loss of particle i. then the particle with least χ^2 is assumed to be the correct one.

In order to describe the separated ability of MDC for particle A and particle B, the power of two particle seperation by dE/dX measurement is defined as:

$$SPRT = \frac{(dE/dX)_A - (dE/dX)_B}{\sigma_B}$$

where the $(dE/dX)_A$ and $(dE/dX)_B$ are the most probable energy loss of particle A and particle B, respectively. The σ_B is the standard deviation of distribution of the most probable energy loss of particle B. Fig.2 show the particle seperation as a function of momenta.

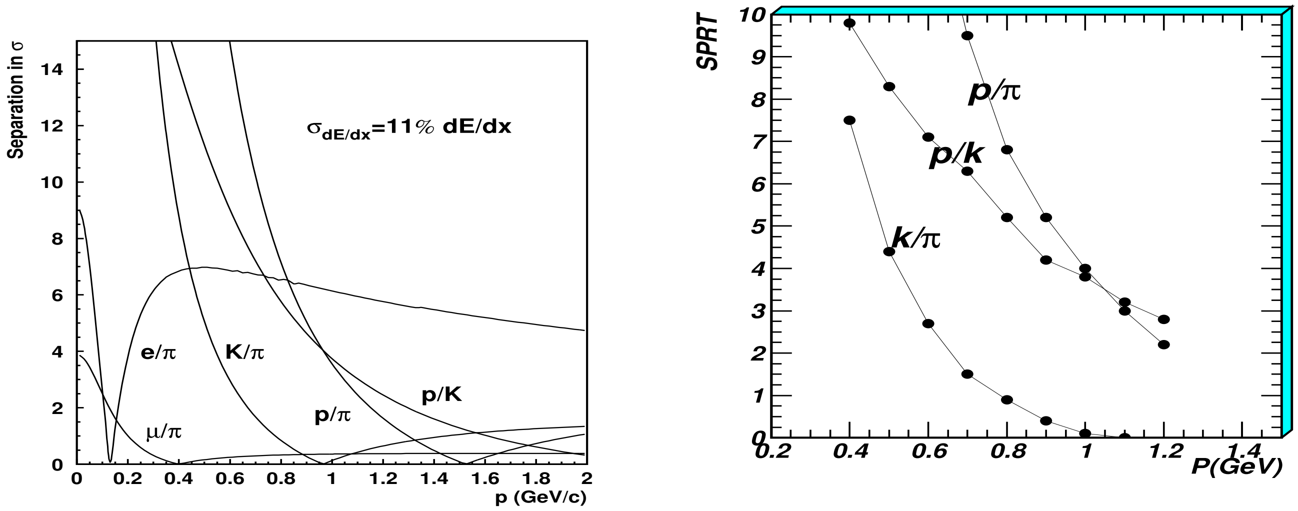


Figure 2: Theoretical calculation and $BES\Pi$ MDC Measuremen SPRT .Vs. Mometum

- **The Problems**

According to the define of χ_i, the distributon of χ_i should be a normal N(0,1) distribution for correct identified particles. However from the study we can see the χ is not a N(0,1) distribution especially for hadron samples(Fig.3). The mean of χ shift, it means the measurement of dE/dX pulse height has systematic error. and the σ does not equate 1, it reflects the resolution determination has some problems. The reason is that we select Bhabha events to do calibration, the momentum of electrons is about 1.5 GeV. From the plot of the most probable energy loss , we can see electrons are in the relativistic rising range. Of course the calibration parameters can describe well when the particle's momenta is in the relativistic rising range. Though the dE/dX pulse height have seven items systematic correction, but the calibrated parameters can not describe the act of the energy loss very well when the momentum is in the low range. Because $dE/dX \propto 1/\beta^2$, the change of energy loss pulse height is steep when the momentum is small. Furthermore the resolution of the energy loss is different from each kinds of particles.

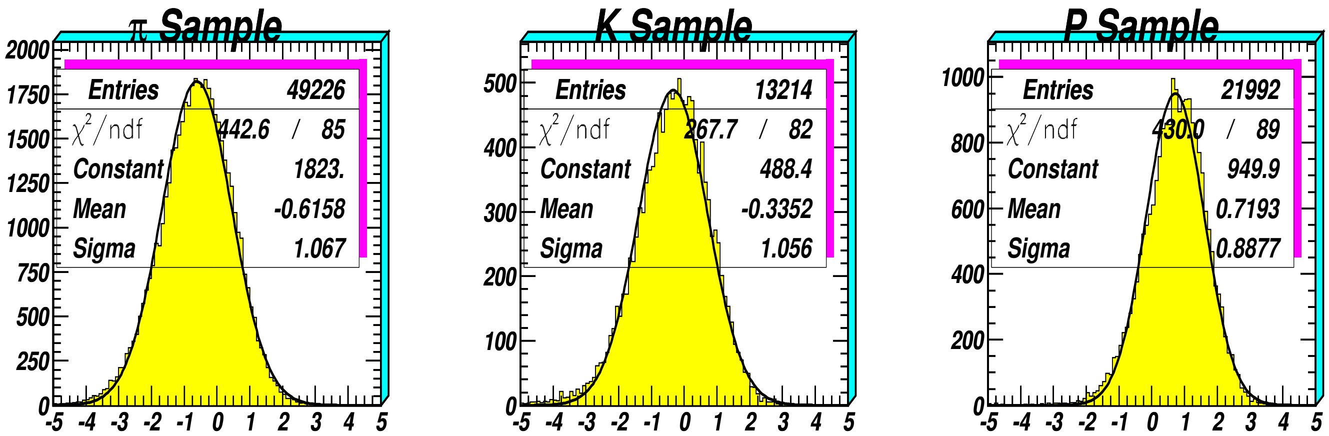


Figure 3: The χ distribution for each kinds of particles without correction

We know the measurement of dE/dX pulse height has systematic error, if we do not do some correction ,there will make different between the real data and the M.C. data , and it will increase more systematic error for the physical result, and it also will affect the identification efficiency. So we must do some correction.

2 Sample Selection

In order to study MDC energy loss well ,we must get a pure samples as possible as we can. For we will use the samples to study MDC, so we must obey the rules following when we get the samples:

1. Do not use MDC information .
2. Using TOF information.
3. Using the four-constraint kinematic fits .
4. The samples had better come from the decay of a resonance.

- **π sample**

  We select π from the decay channel:

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

  Cut Condition:

  a. $|M_{\pi^0} - 0.135| < 0.015GeV$

  b. $|M_{\rho^0} - 0.770| < 0.15GeV.or.|M_{\rho^+} - 0.770| < 0.15GeV.or.|M_{\rho^-} - 0.770| < 0.15GeV$

  c. $\chi_\pi < \chi_K.and.\chi_\pi < \chi_P.and.\chi_\pi < 15$

  d. Two tracks are identified as π with TOF

  Fig.4 show some plots of cut condition for π sample selection.

- **K sample**

  We select K sample from the decay channel:

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

  Cut condition :

  a. Two tracks are identified as K with TOF

  b. $|M_{\pi^0} - 0.135| < 0.02GeV$

  c. $\chi_K < \chi_\pi.and.\chi_K < \chi_P.and.\chi_K < 15$

  d. $|M_{K^{*+}} - 0.892| < 0.1GeV.or.|M_{K^{*-}} - 0.892| < 0.1GeV$

  Fig.5 show some plots of cut conditions for K sample selection.

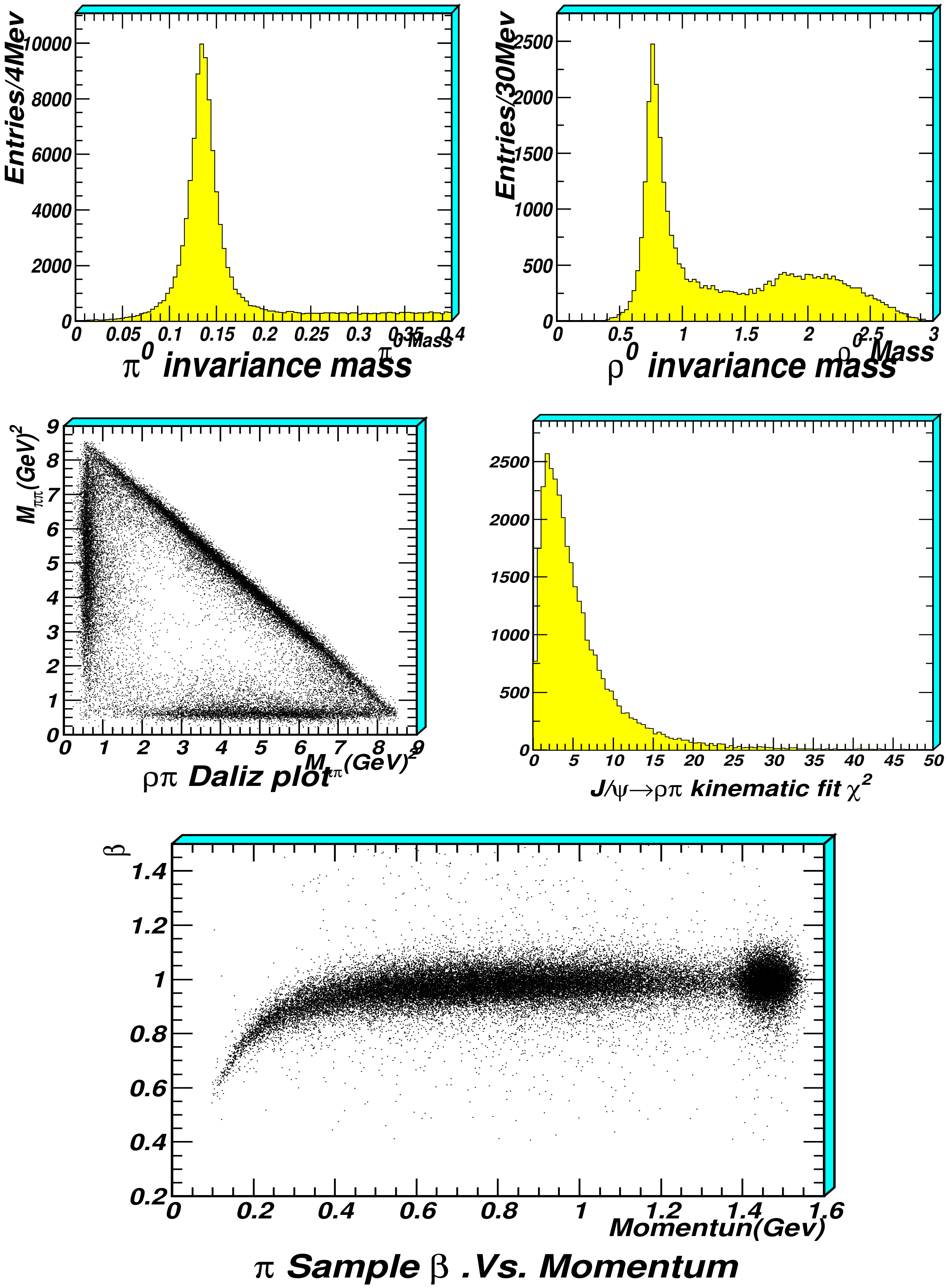


Figure 4: some plot of cut condition for π samples selection

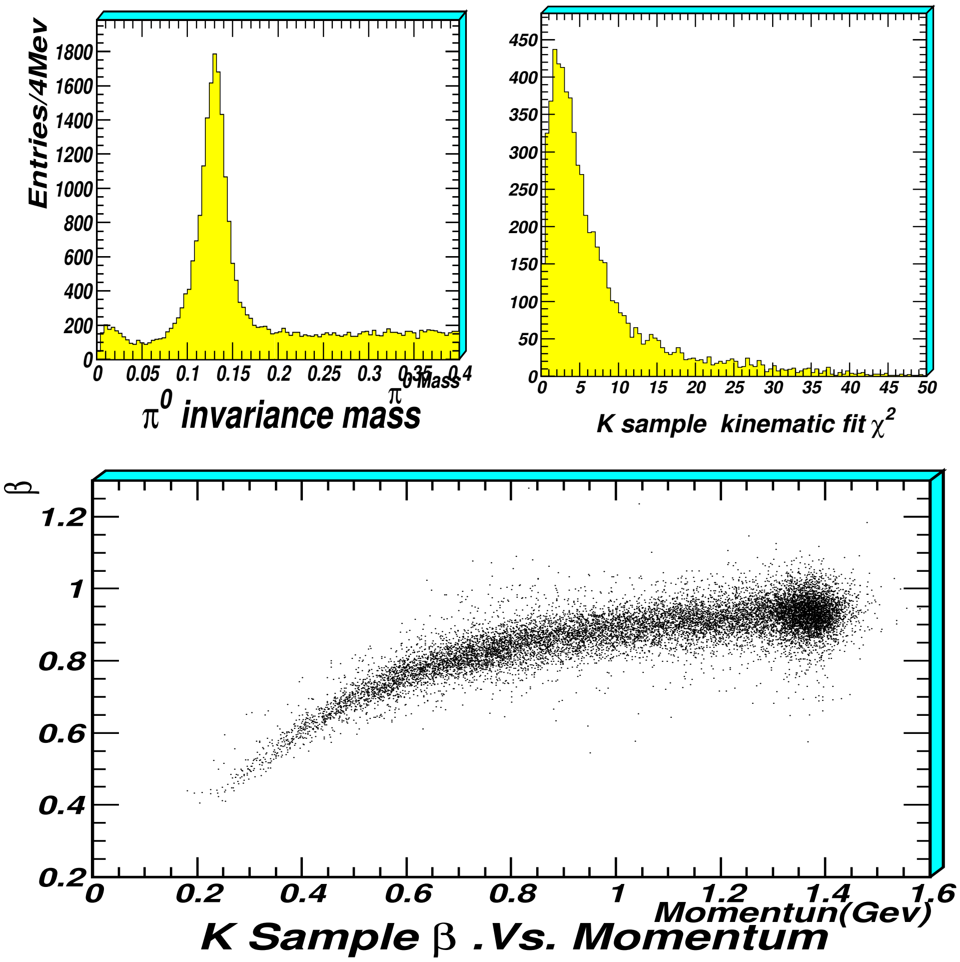


Figure 5: some plot of cut condition for K samples selection

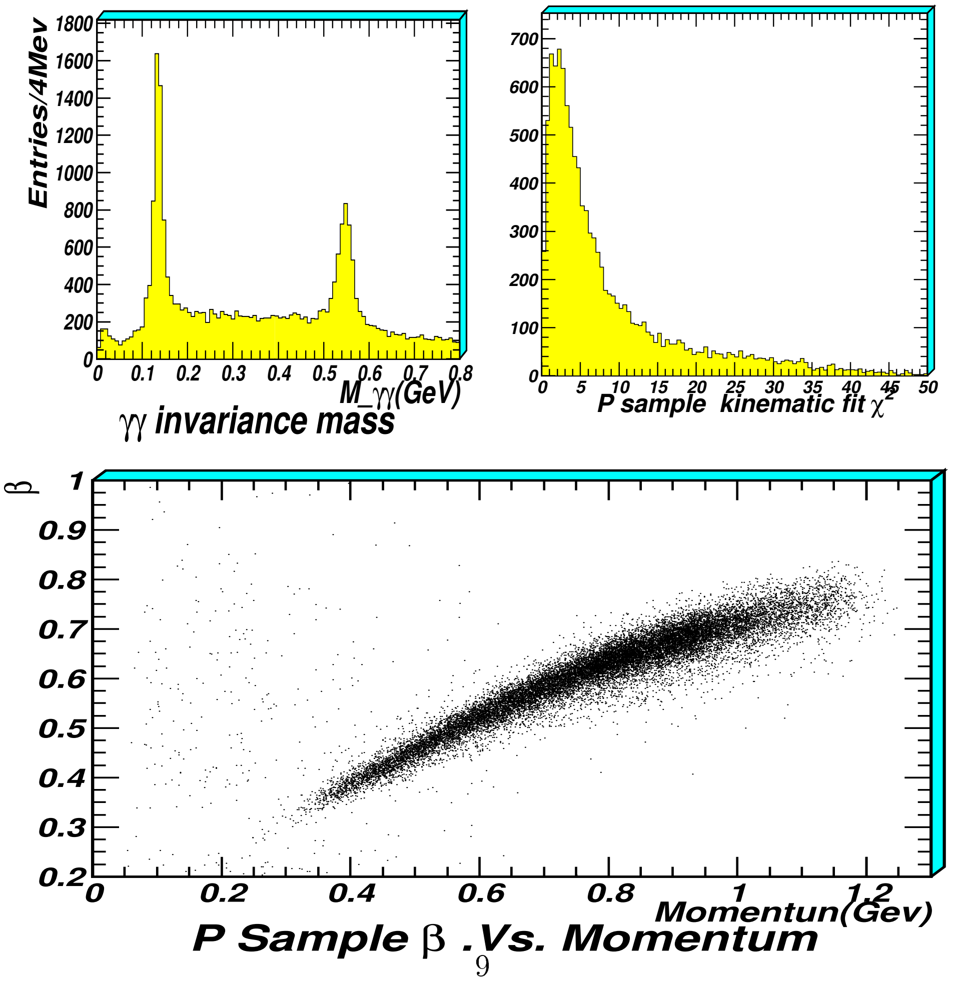


Figure 6: some plot of cut condition for P samples selection

- **P sample**

  We select P sample from the decay channel:

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

$$J/\psi \rightarrow \eta^0 p^+ p^-$$

  Cut comdition :

  a. Two tracks are identified as P with TOF

  b. $|M_{\gamma\gamma} - 0.135| < 0.03GeV.or.|M_{\gamma\gamma} - 0.547| < 0.04GeV$

  c. $\chi_P < \chi_\pi.and.\chi_P < \chi_K.and.\chi_P < 15$

  Fig.5 show some plots of cut conditions for P sample selection.

From the Dalitz diagram and the invariant mass distribution of resonances we can see that we has got a relative pure sample.

3 How to do the correction

According to LANDAU formula, we can see the most probable energy loss is a function of the $\beta\gamma$, which does not depend on the mass of the particle, so first we can get the energy loss offset and resolution as a function of $\beta\gamma$. The most probable energy loss is estimated by taking the 30% truncated mean of the corrected ionization samples, so the influence of path length of each sample is very important, because the path is the helix geometric, the path length may depend on direction cosine. So we will check the dependence between the energy loss and cosine. Also the energy loss resolution may depend on the number of samples, so we will check the energy loss depend on the number of hit wires. In this memo, we only correct the most probable energy loss with $\beta\gamma$ and direction cosine items. and we will check the the dependence between energy loss and the number of hit wires.

- **Energy loss offset correction**

  The mean of χ distribution does not equate 0, it means that the measurement of energy loss has systematic error. In order to study the energy loss offset, we must get the dependence between χ and $\beta\gamma$, we can:

  a. Dividng $log(\beta\gamma)$ into sevel slices for each kind of particle

  b. Geting the χ distribution for a given $log(\beta\gamma)$

  c. Fiting the χ with gaussion function

  d. Geting the mean of χ as function of $log(\beta\gamma)$(Fig.7)

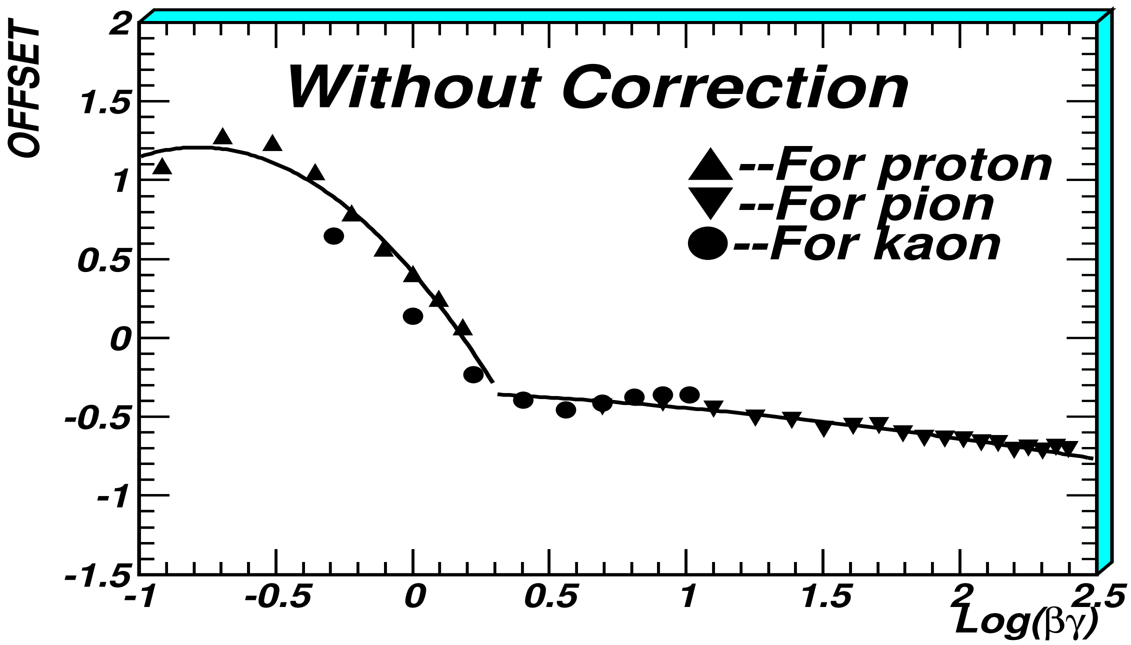


Figure 7: The mean of χ .Vs. $log(\beta\gamma)$ without correction

We also can get the dependence between the χ and $cos\theta$, then we can get the change of χ as function of $cos\theta$(Fig.8).

Comparing the Fig.7 and Fig.8, we can see the dependence between the mean of χ and $log(\beta\gamma)$ is a continuous function, and it does not depend on the particle, it only is a function of $log(\beta\gamma)$. About the dependence between the mean of χ and $cos\theta$, it also is a continuous function for each kind of particle, but the values of dependence are in the different level for each

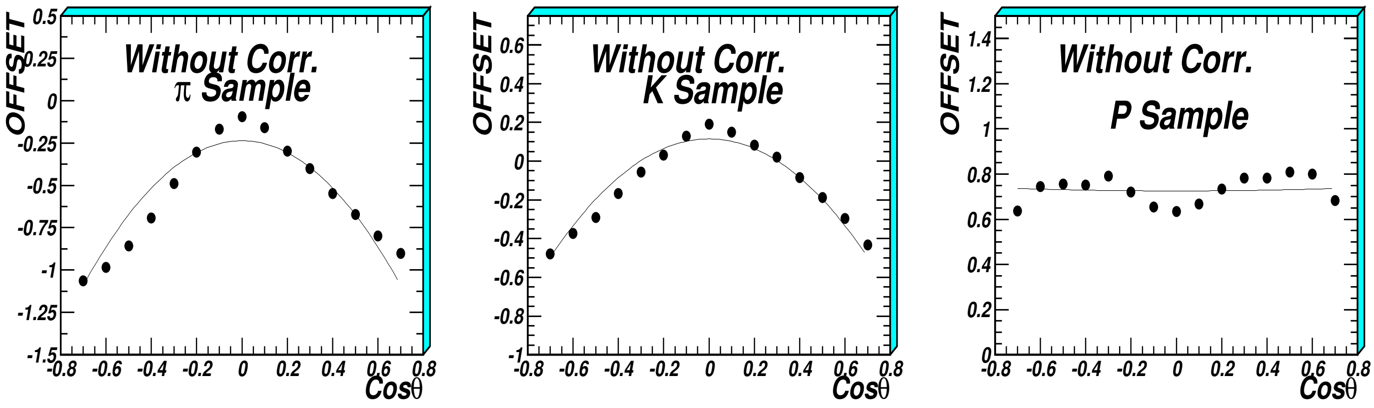


Figure 8: The mean of χ .Vs. $cos\theta$ without correction

kind of particle. Considering the continuity and the number of corrected parameters, we decide to do $log(\beta\gamma)$ correction firstly, then to do $cos\theta$ correction.

1. **Log($\beta\gamma$) Correction**

   We will do log($\beta\gamma$) correction. The function between χ and $log(\beta\gamma)$ is continuous, But we can see a turning point near $log(\beta\gamma) = 0.4$(Fig.7), it can be explained that when $log(\beta\gamma) < 0.4$, the energy loss $dE/dX \propto 1/\beta^2$, the change of energy loss is steep. But when the $log(\beta\gamma) > 0.4$, it is in a relativistic rising range, the energy loss is stable. We can fit the plot with two polynomial in different range respectively. We can get the result:

$$\Delta\chi_1 = \begin{cases} 0.450 - 2.15 * x - 1.51 * x^2 & x < 0.4 \\ -0.330 - 0.074 * x - 0.0405 * x^2 & x > 0.4 \end{cases}$$

$$x = log(\beta\gamma)$$

2. **Cosθ Correction**

   After doing log($\beta\gamma$) correction, we can define $\chi_1 = \chi - \Delta\chi_1$, and then we can get χ_1 as a function of $cos\theta$(Fig.9), From the plot, we can see the shape of the dependence between the χ_1 and $cos\theta$ is same especially for π and K, the average of χ_1 in all range of $cos\theta$ is about 0 for each kind of particles, and the dependence's shape of P sample is flat.

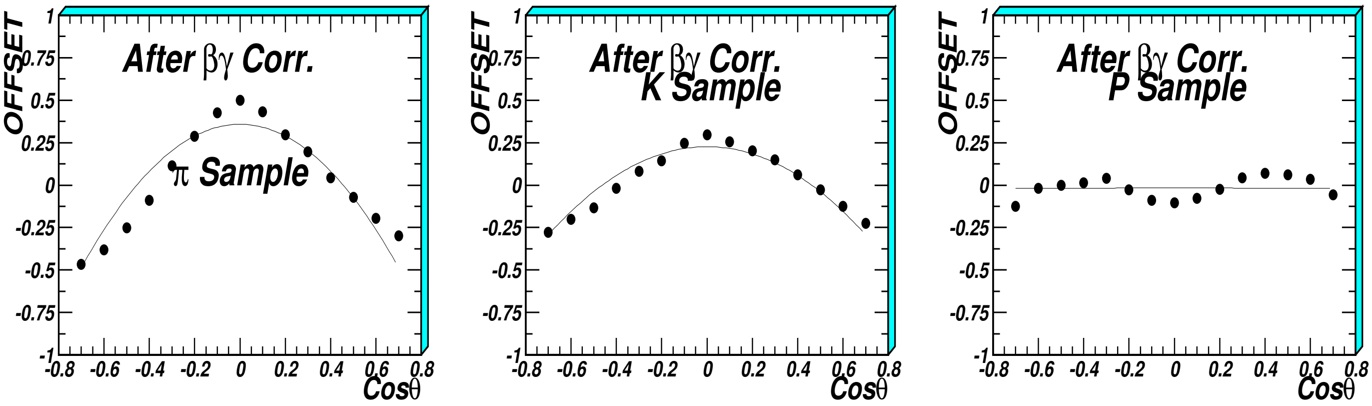


Figure 9: The mean of χ_1 .Vs. $cos\theta$ after $\log(\beta\gamma)$ correction

We can fit the three plots with the function $\chi_1 = p_i(1 + k * cos^2\theta)$, where k is same for each kinds of particle, it reflect the curvature of the plot, and p_i reflects the value of the dependenc for each kind of particles. We can get the result:

$$\Delta\chi_1 = 0.36096 * (1 - 4.68693 * cos^2\theta) \qquad For\pi$$

$$\Delta\chi_1 = 0.22631 * (1 - 4.68693 * cos^2\theta) \qquad For K$$

$$\Delta\chi_1 = 0.0 \qquad For P$$

- **Energy loss resolution correction**

We have known the σ of χ does not equate 1, the measurement of the energy loss resolution has some problem. After doing the $cos\theta$ correction to χ, we can define the $\chi_2 = \chi - \Delta\chi - \Delta\chi_1$, then we can study the σ of χ_2, Fig.10 and Fig.11 show the σ of χ_2 as a function of $log(\beta\gamma)$ and $cos\theta$ respectively.

From the plot, we can see σ shape is flat when it varies with $cos\theta$, but it also has a turning point near $log\beta\gamma = 0.4$ in the Fig.10, the reason is the same as the energe loss offset. So for the resolution of energy loss, we only do $log(\beta\gamma)$ correction. we can fit Fig.10 with two polynomial. and get the result:

$$\sigma = \begin{cases} 0.87144 + 0.39996 * x + 0.33695 * x^2 & x < 0.4 \\ 1.0173 + 0.0044 * x - 0.0043 * x^2 & x > 0.4 \end{cases}$$

$$x = log(\beta\gamma)$$

After the resolution correction, we can define the χ_3 as:

$$\chi_3 = \frac{\chi - \Delta\chi_1 - \Delta\chi_2}{\sigma}$$

then χ_3 should be a normal distribution.

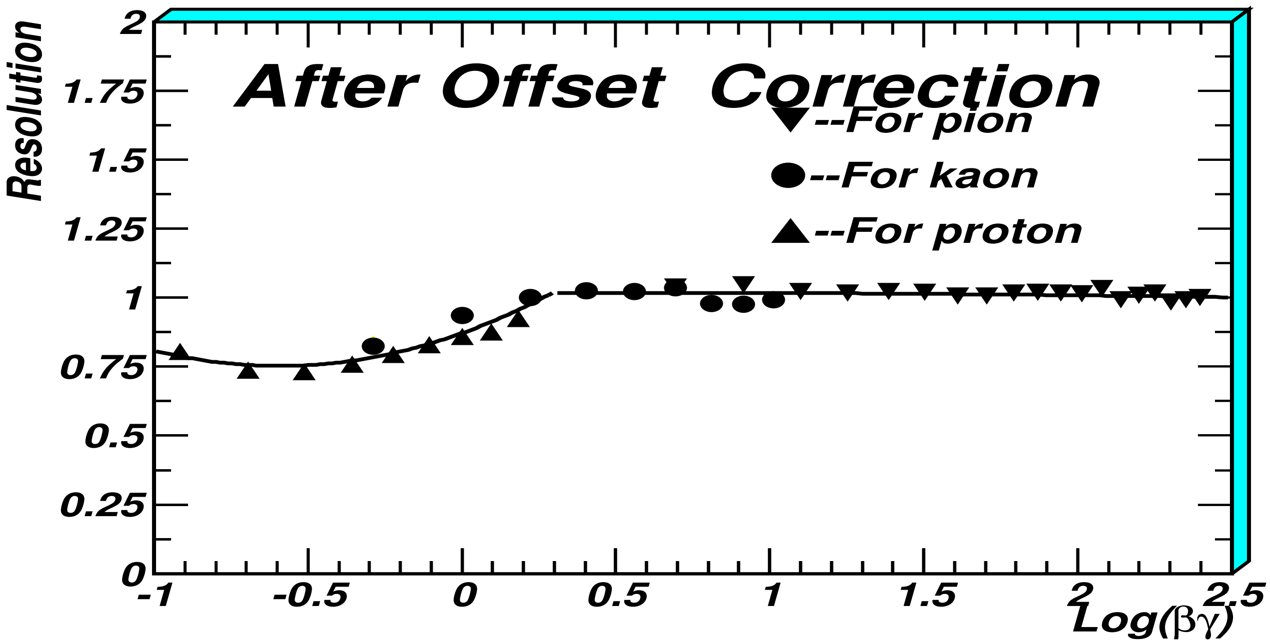


Figure 10: The σ_2 of χ_1 .Vs. $log(\beta\gamma)$ after offset correction

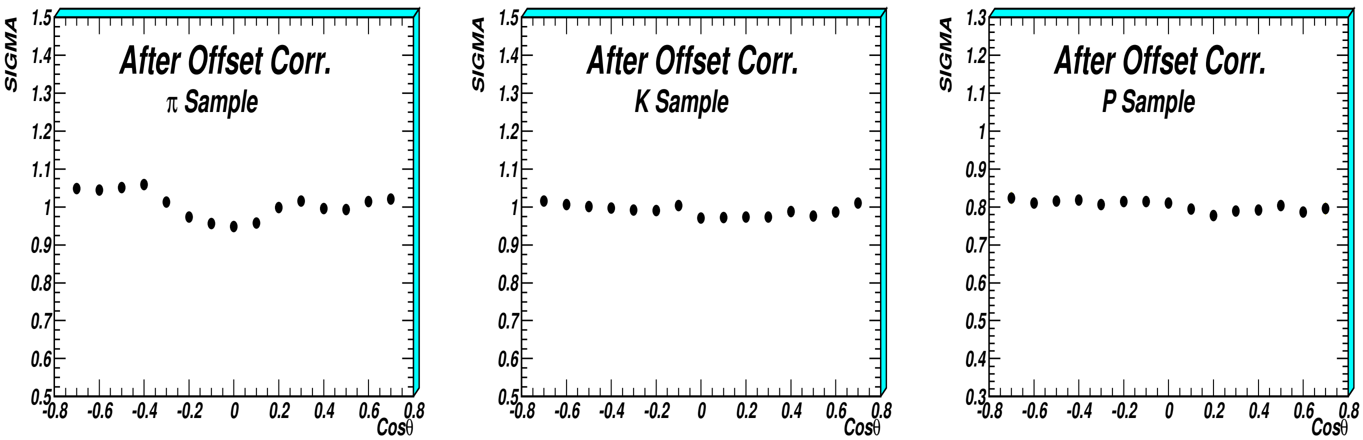


Figure 11: The mean of χ_1 .Vs. $cos\theta$ after log($\beta\gamma$) correction

4 For M.C.data

In order to reduce the difference between the M.C. data and real data, lower the systematic error, we must do correction for M.C data as for real data. Fig.12 and Fig.13 show the mean of χ as a function of $log(\beta\gamma)$, $cos\theta$ without correction respectively for M.C data.

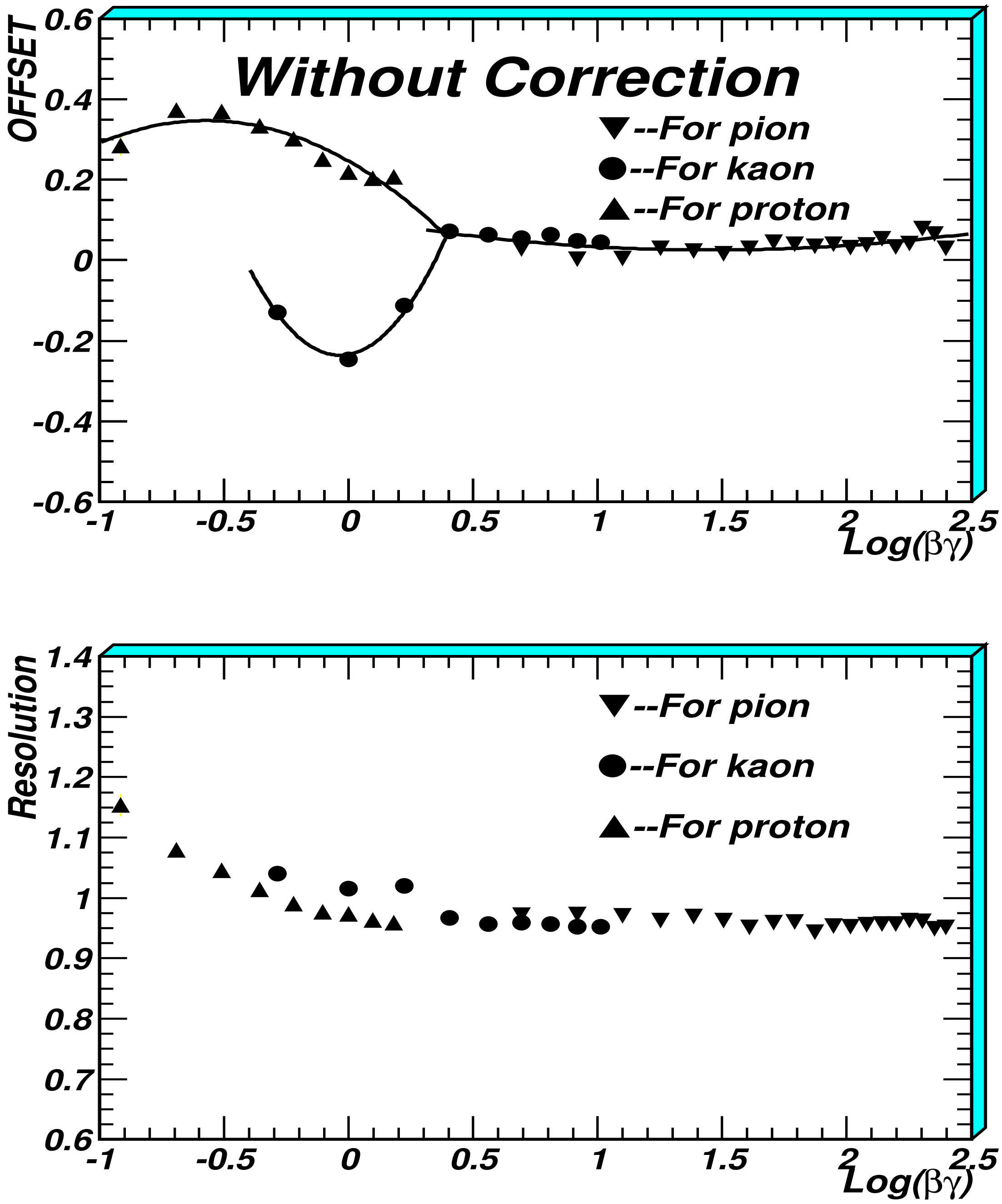


Figure 12: The distribution of χ .Vs. $log\beta\gamma$ for M.C. data without correction

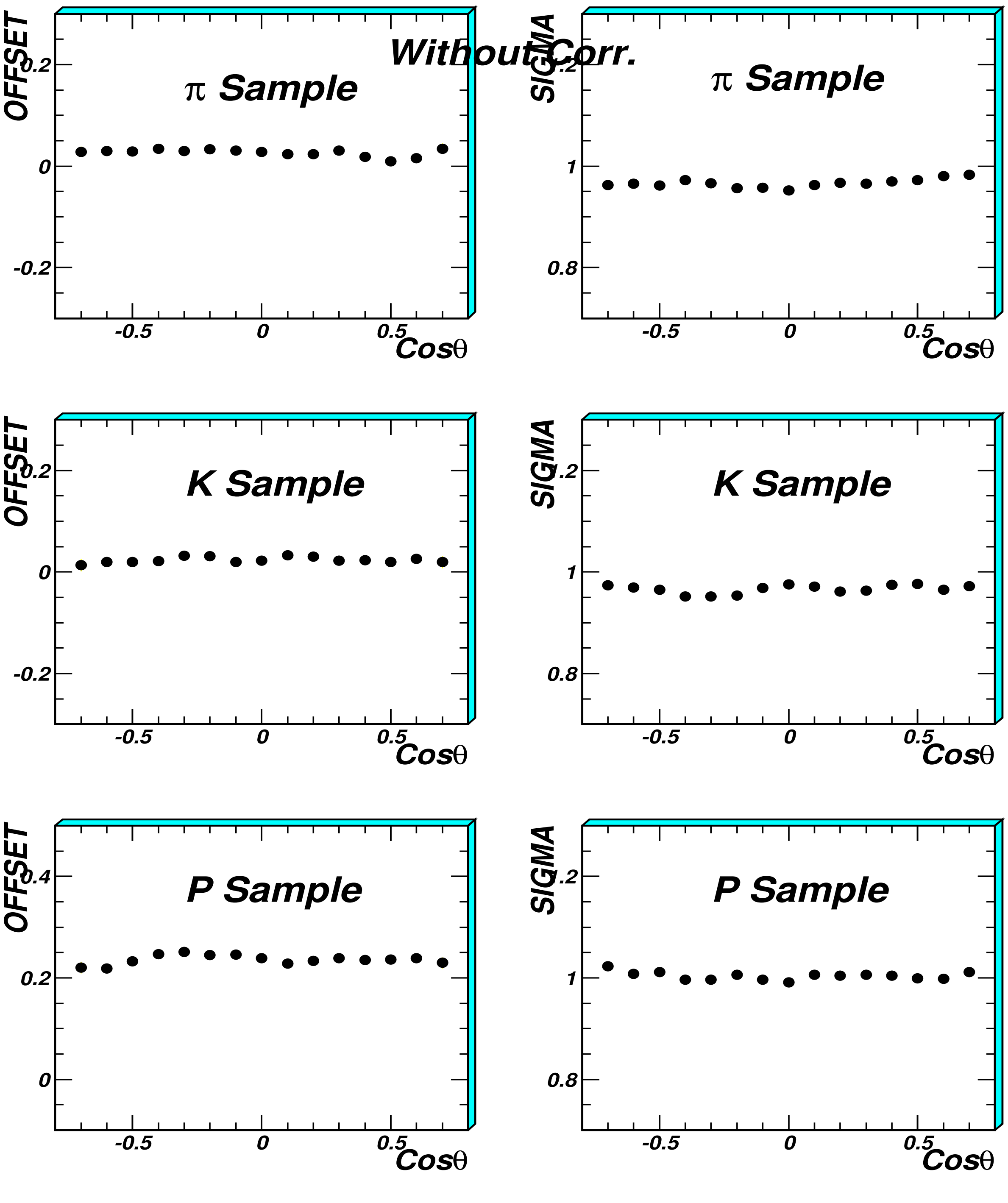


Figure 13: The distribution of χ .Vs. $cos\theta$ for M.C. data without correction

Of course the M.C. data is better than real data, from the plot we can see the distribution of mean and σ is flat when it varies with $cos\theta$, it means that the energy loss does not depend on the $cos\theta$ for the M.C. data, but the distribution of χ still depends on $\log(\beta\gamma)$. So we will only consider the $\log(\beta\gamma)$ correction for the energy loss including offset and resolution.

- **Offset correction**

We will do the $log(\beta\gamma)$ correction for the mean of χ, from the plot we also can see a turning point near log($\beta\gamma$).eq.0.4, the changed tendency of M.C data is the same as real data when $log(\beta\gamma)$ is in high range. but in the low range, the changed tendency depends on the kind of particle. So we will correct the mean of χ with a polynomial when the $log(\beta\gamma) > 0.4$. In the range of $log(\beta\gamma) < 0.4$ we also fit the plot with polynomial, but we must do the correction for each kind of particle respectively. then we can get the result:

$$\Delta\chi = \begin{cases} 0.1054 - 0.11 * x + 0.0378 * x^2 & x \geq 0.4 \\ -0.234 + 0.1127 * x + 1.620 * x^2 & x < 0.4 \quad for K \\ 0.2457 - 0.3525 * x - 0.3071 * x^2 & x < 0.4 \quad for P \end{cases}$$

$$x = log(\beta\gamma)$$

- **Resolution correction**

We only will do the $log\beta\gamma$ correction for the resolution of the energy loss, We can define the $\chi_2 = \chi - \Delta\chi$ after the offset corretion, then we can get the σ of χ_2 as a functin of $log\beta\gamma$(Fig.14), we fit the plot with a polynomail, and get the result:

$$\sigma = 1.0014 - 0.069288 * x + 0.023099 * x^2$$

$$x = log\beta\gamma$$

After doing all the correction to the χ of the M.C. data, we can define the χ' as:

$$\chi' = \frac{\chi - \Delta\chi}{\sigma}$$

where $\Delta\chi$ and σ is the offset and the factor of resolution correction we have got. Then χ' should be a normal distribution.

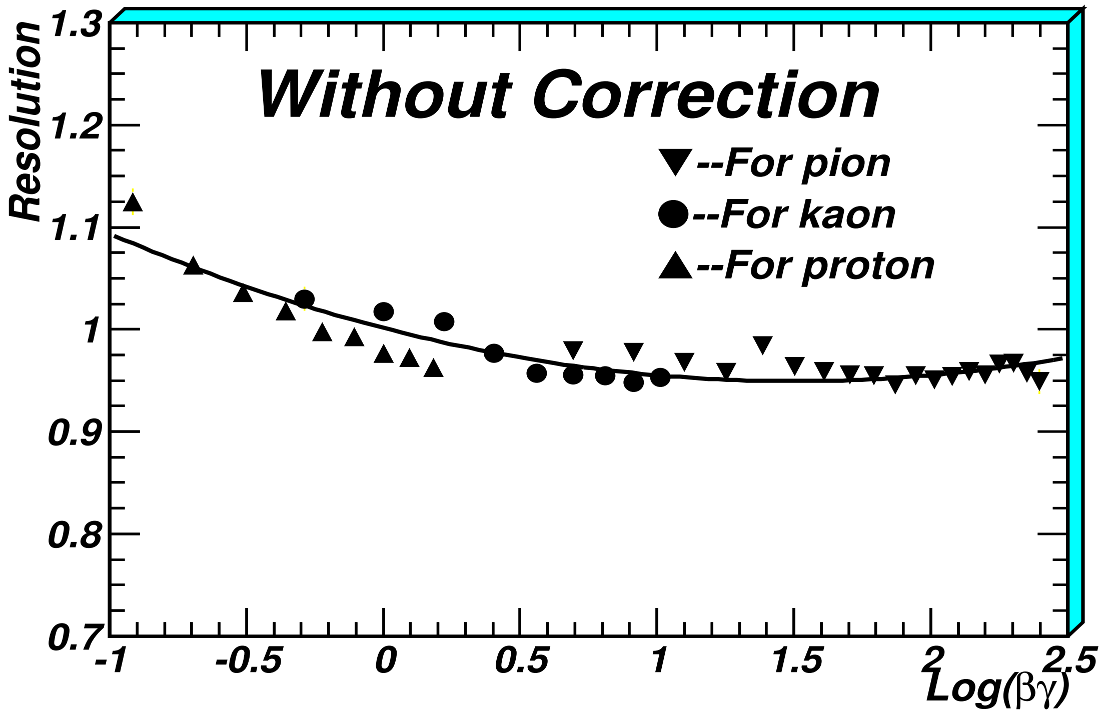


Figure 14: The σ of χ .Vs. $log\beta\gamma$ for M.C. data after offset correction

5 Check the Result

After doing the correction, the distribution of $\chi_2 = (\chi - \Delta\chi)/\sigma$ should be a N(0,1) distribution. Now we can check the result for real data and M.C data respectively.

• Check the Real data

1. **Log($\beta\gamma$) dependence**

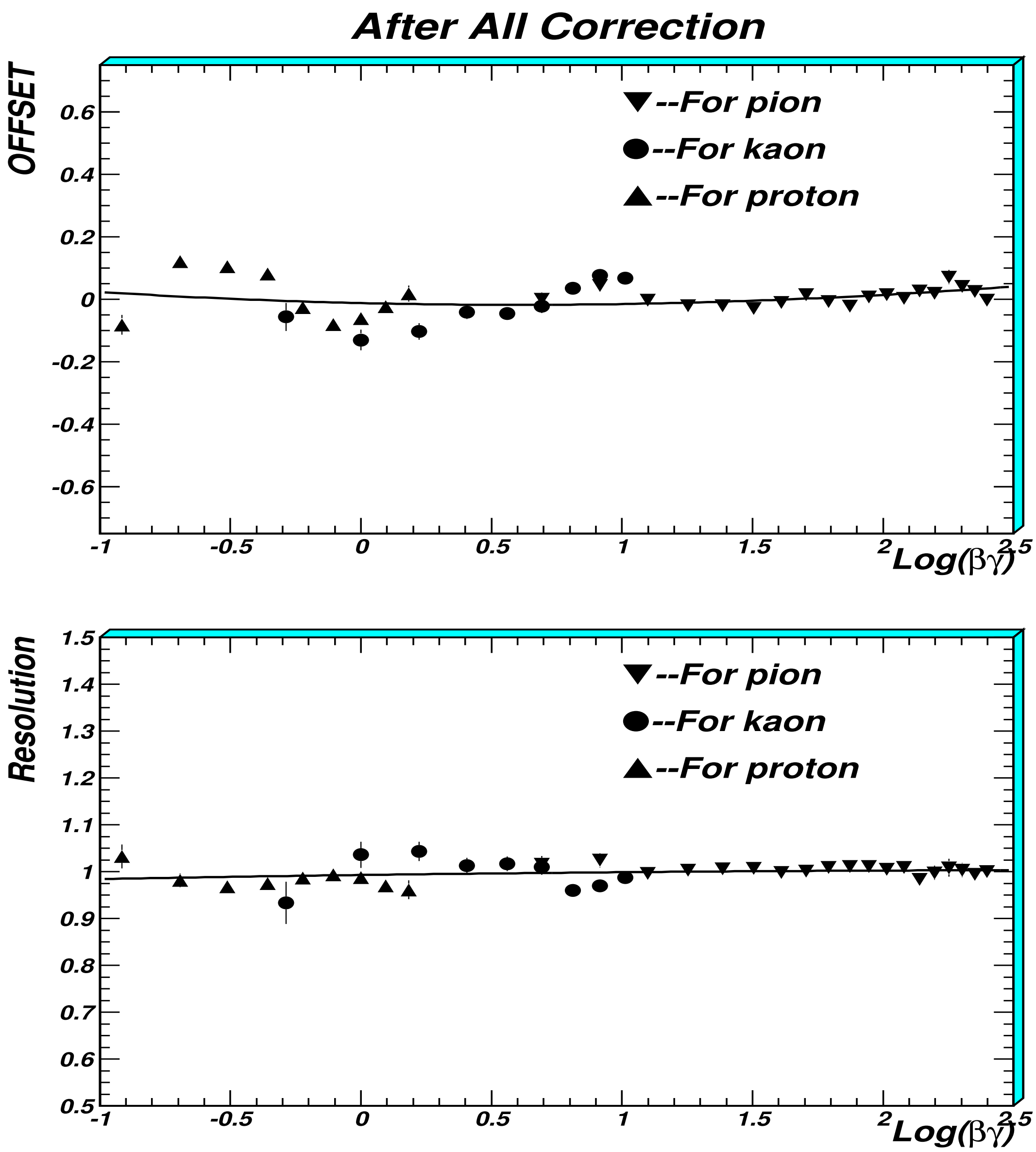


Figure 15: The distribution of χ .Vs. $log(\beta\gamma)$ after correction

2. **Cosθ dependence**

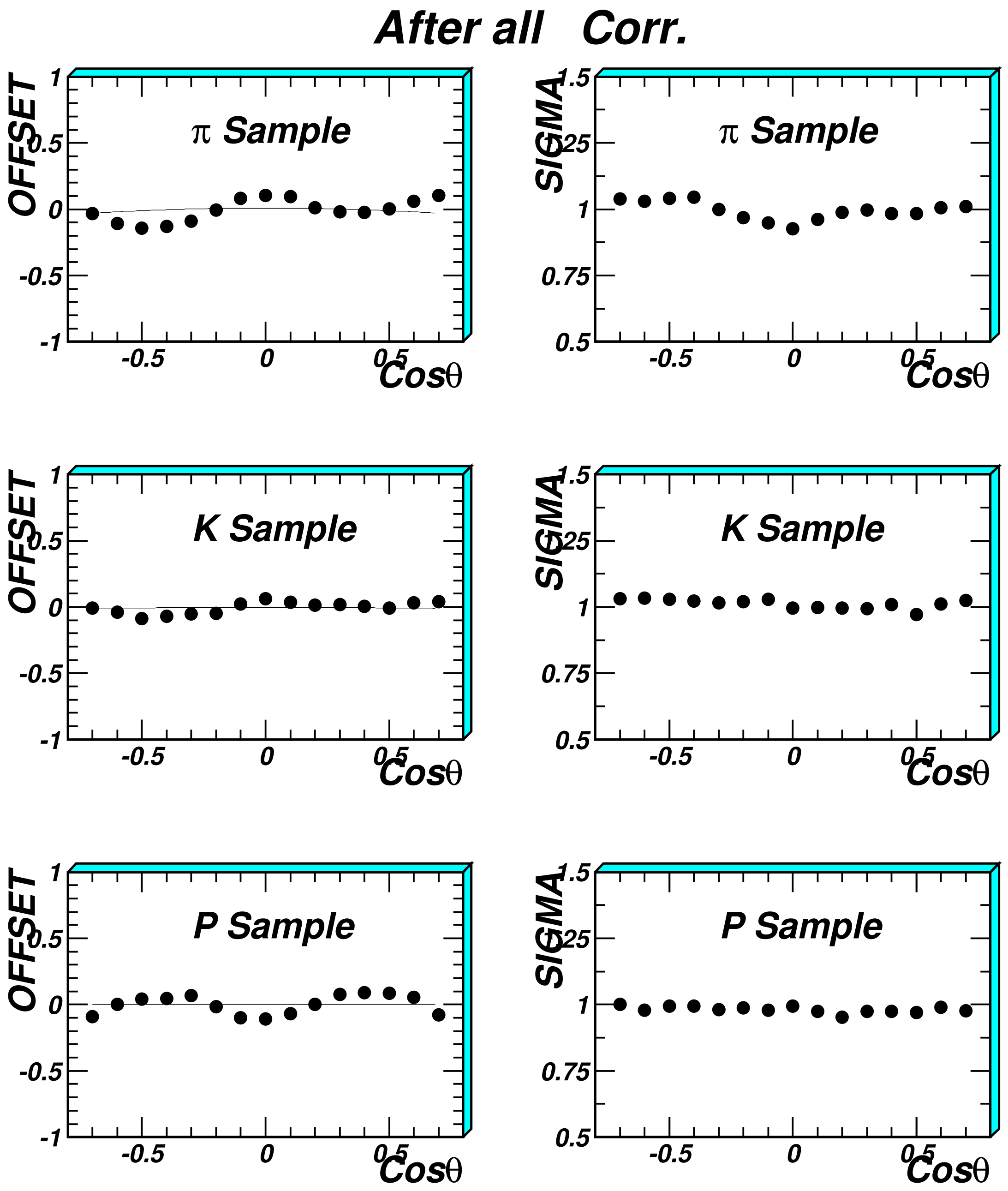


Figure 16: The distribution of χ .Vs. $cos\theta$ after correction

3. **Hited number dependence**

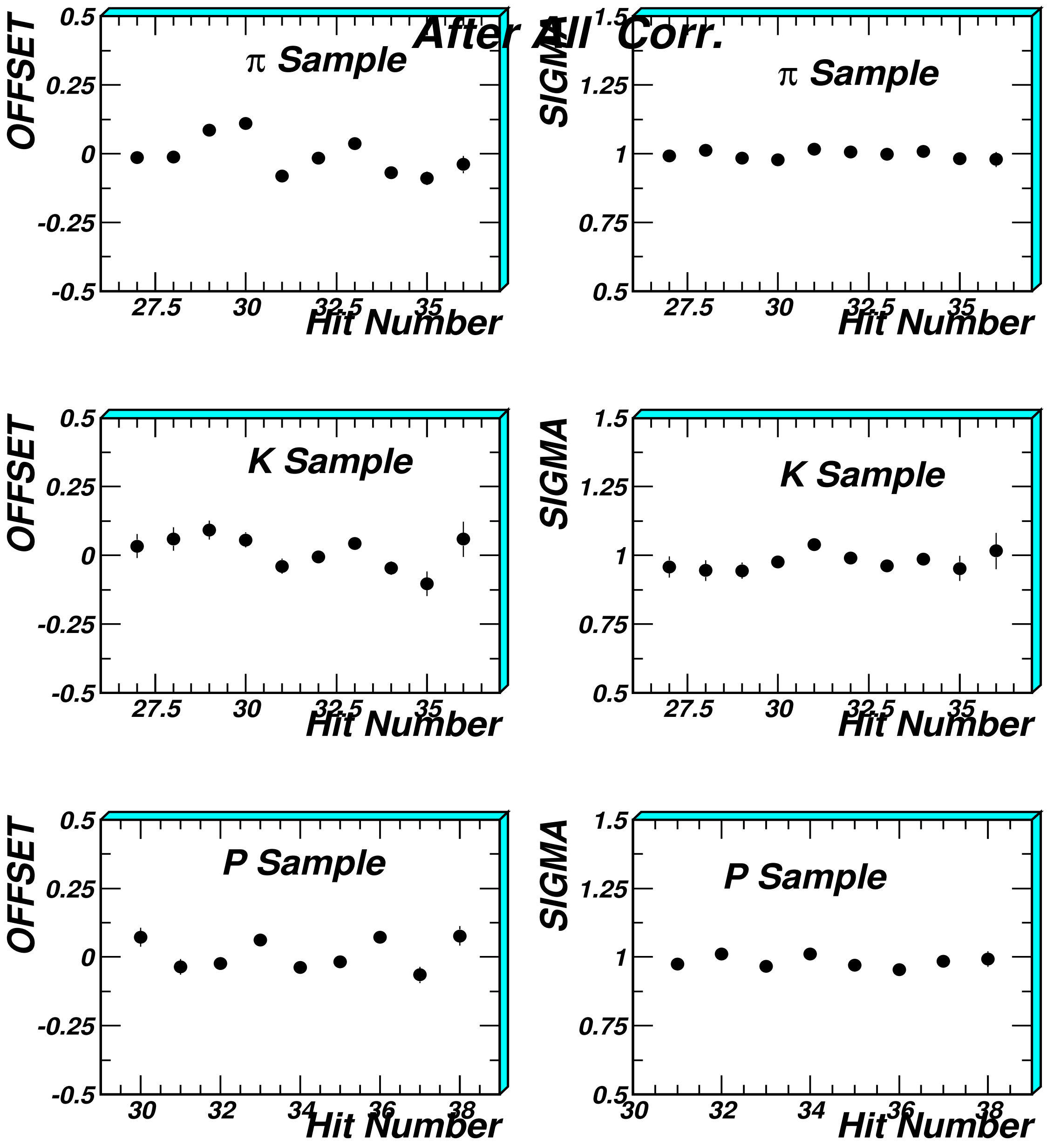


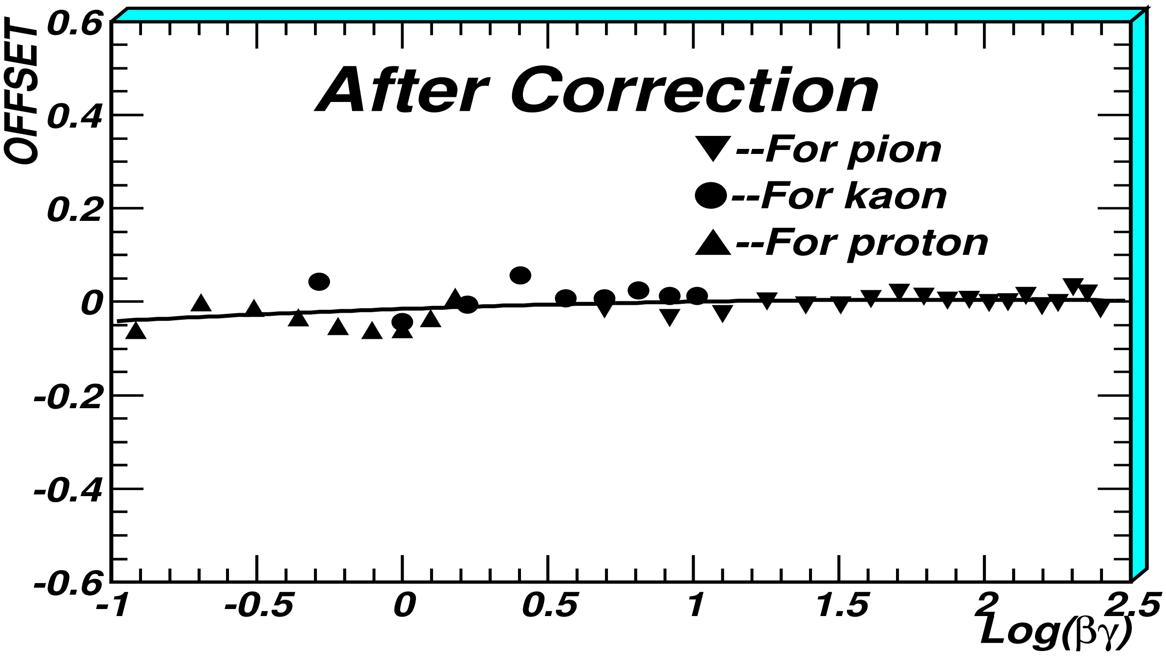
Figure 17: The distribution of χ .Vs. Hited number after correction

From the plot, we can see the χ is a normal distribution when it varies with $log\beta\gamma$, $cos\theta$ and hited number after correction.

- **Check the M.C. data**

Now we check χ distribution of M.C. data after correction.

1. **Log($\beta\gamma$) dependence**



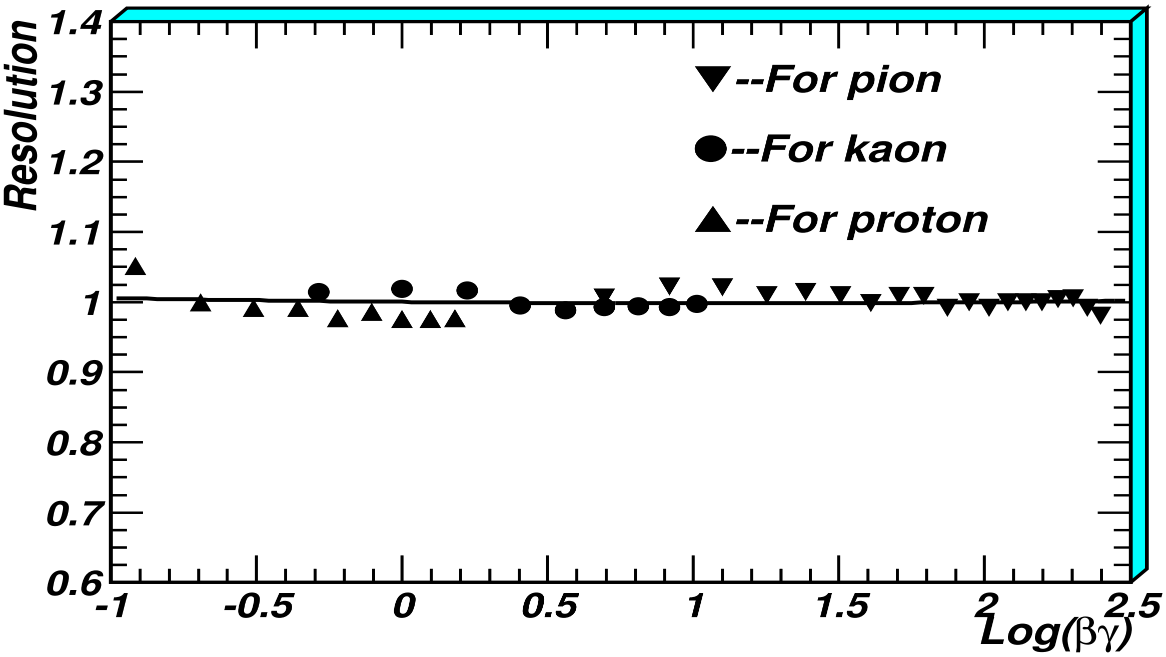


Figure 18: The distribution of χ .Vs. $log\beta\gamma$ after correction for M.C. data

2. **Cosθ dependence**

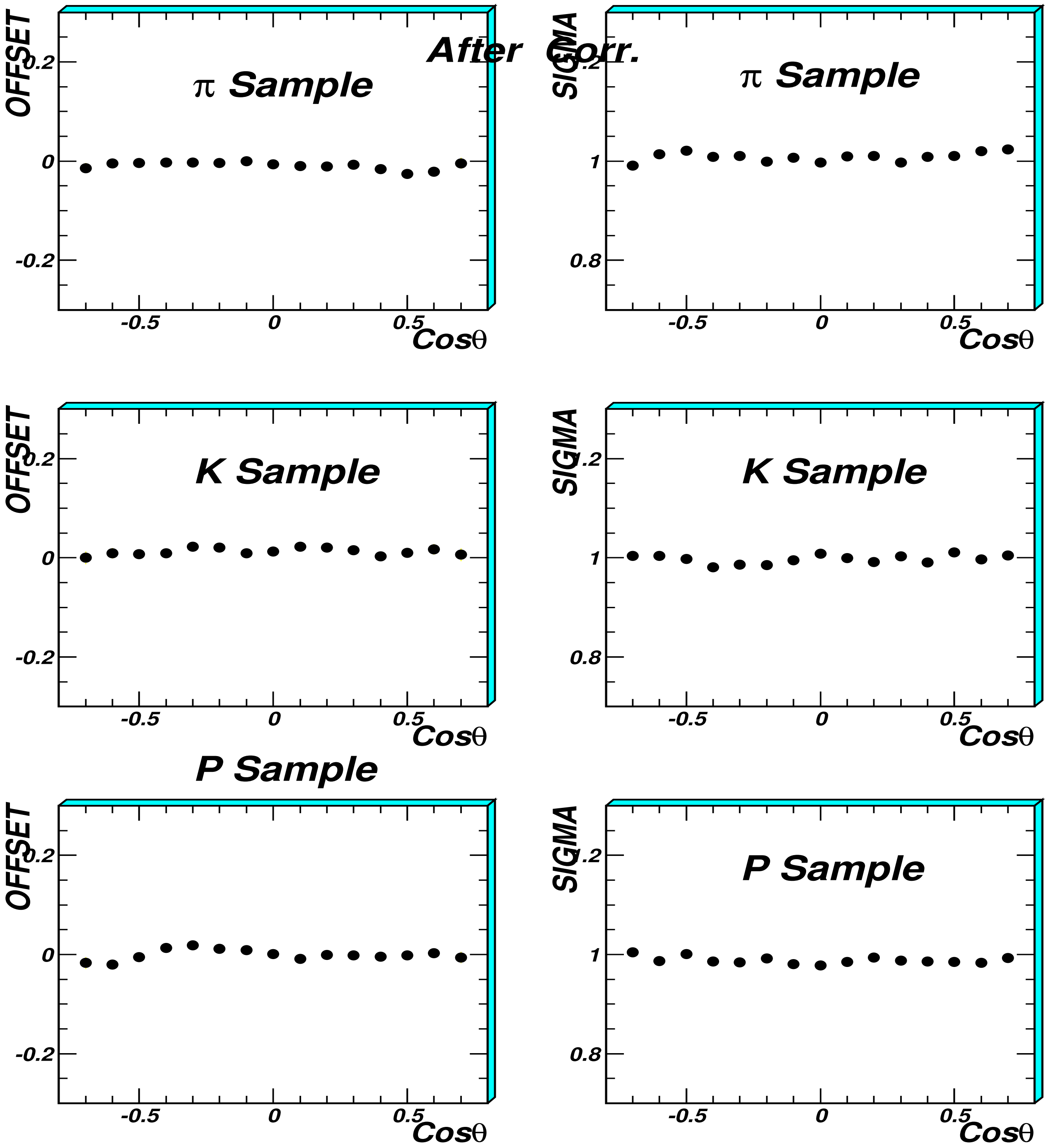


Figure 19: The distribution of χ .Vs. $cos\theta$ after correction for M.C. data

3. **Hited number dependence**

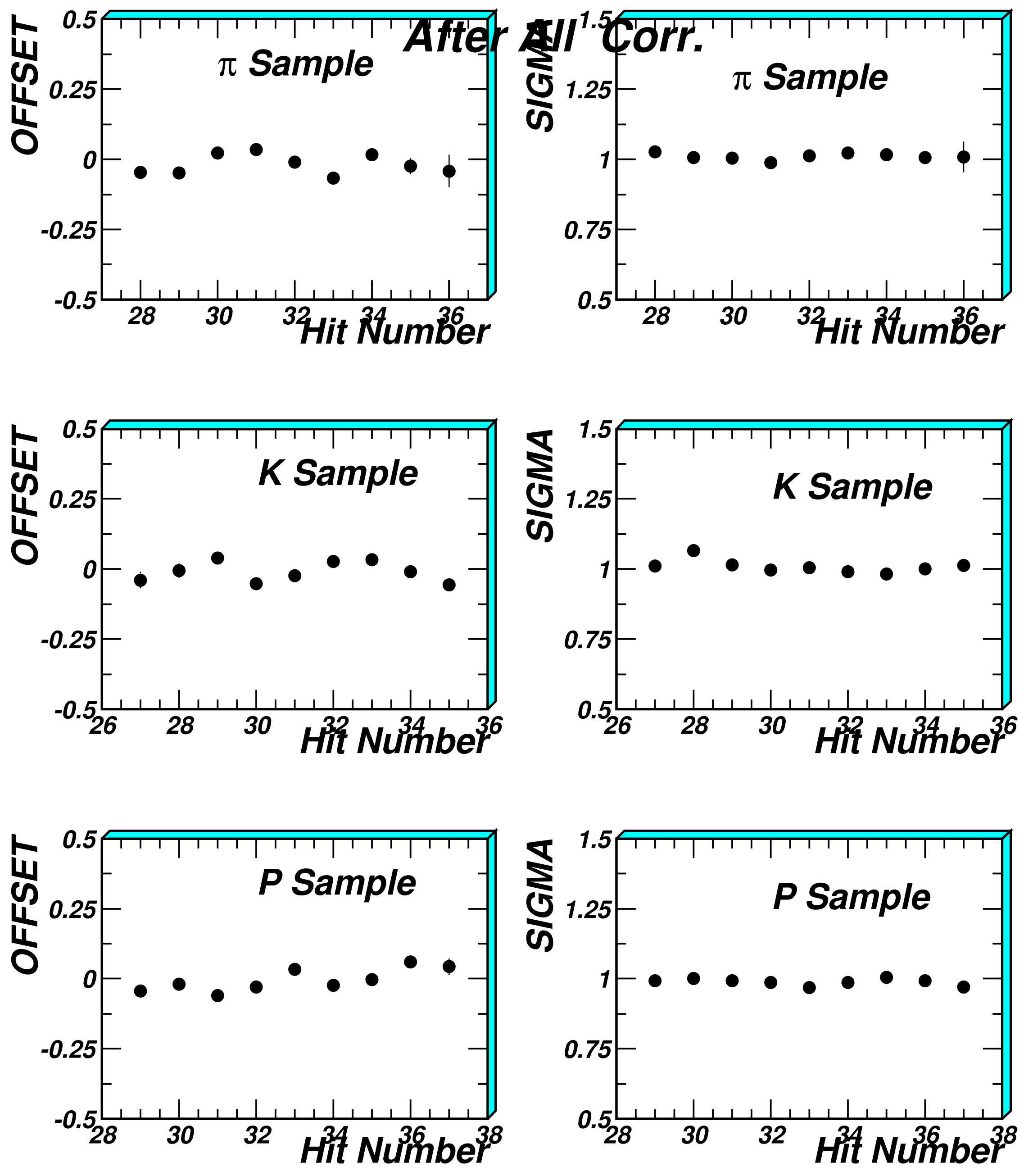


Figure 20: The distribution of χ .Vs. hit number after correction for M.C. data

From the plot we can see the distribution of χ is a normal distribution after the correction.

6 PID using dE/dX

Because each kind of particle has diffrent values of $\beta\gamma$ for a given momenta, according to LANDAU formula, the most probable energy loss is different from each other, we will use the energy loss dE/dX to identify particle. We can get the particle momenta from MDC information, then we can get the most probable energy loss $(dE/dX)^i_{exp}$ according to LANDAU formula for each kind of particle , we also can get the measured $(dE/dX)_{meas}$ values from MDC information, Using the define of χ:

$$\chi_i = \frac{(dE/dX)_{meas} - (dE/dX)^i_{exp}}{\sigma_i}$$

we can get the χ for each kind of particle, the particle with the least χ^2 should be the correct one . We will use the corrected χ^2 to identify particle.

From the calculated and measured plot of the most probable energy loss and the ability of particle seperation, we can see it is difficult to seperate particle using dE/dX when the momentum in high range for hadrons. Because we do not use the dE/dX information to select the sample, so we can get the identification efficiency for each kind of particle from the samples. Fig.21 show the identification efficiency for the hardon particle before and after correction. Fig.22 show the M.C data identification efficiency. From the plot, we can get the identification efficiency is better after correction, K and π can be identificated well when mementa less than 0.6 GeV, and proton can be well seperated using dE/dX information.

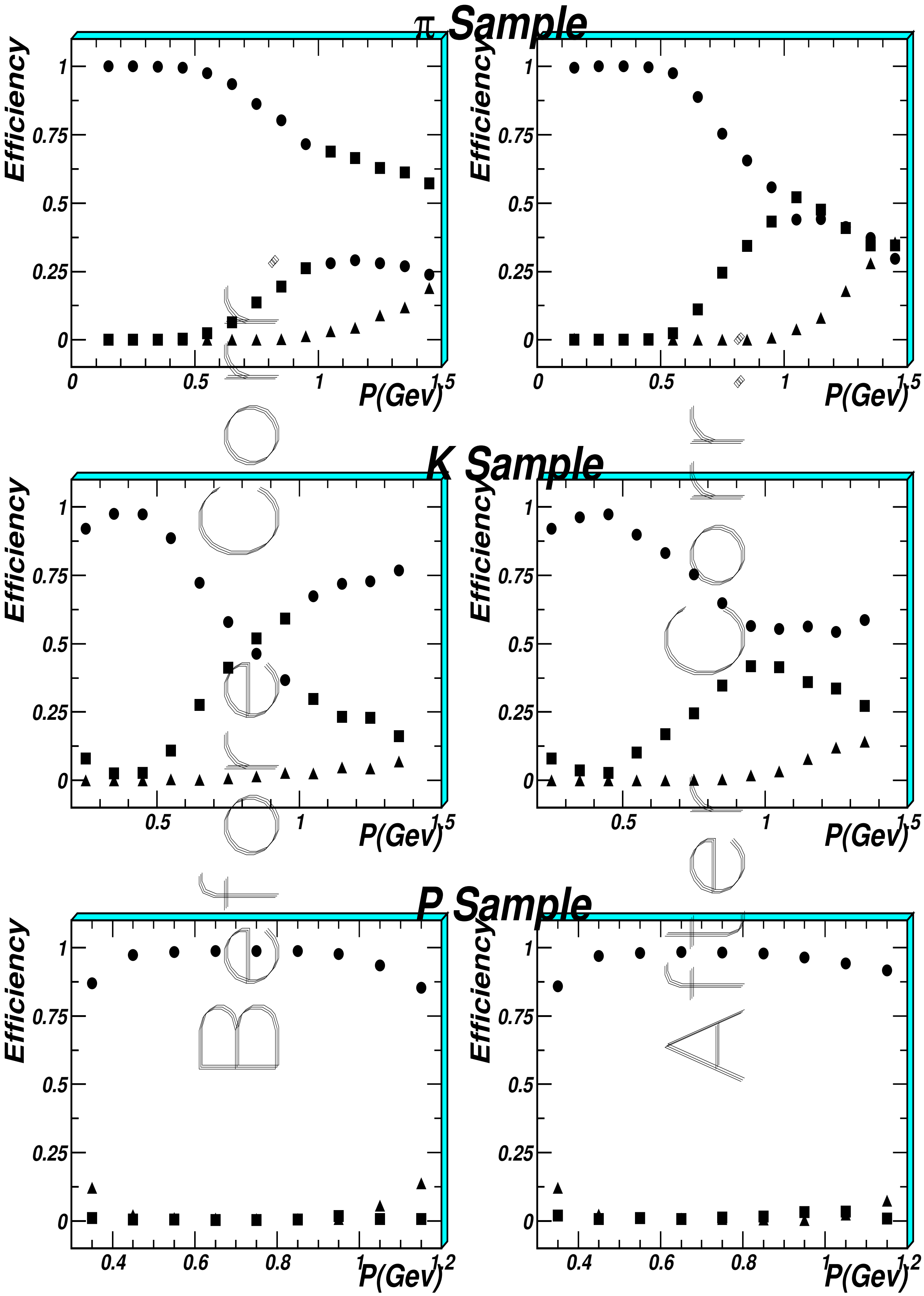


Figure 21: The identification efficiency before and after correction for real data

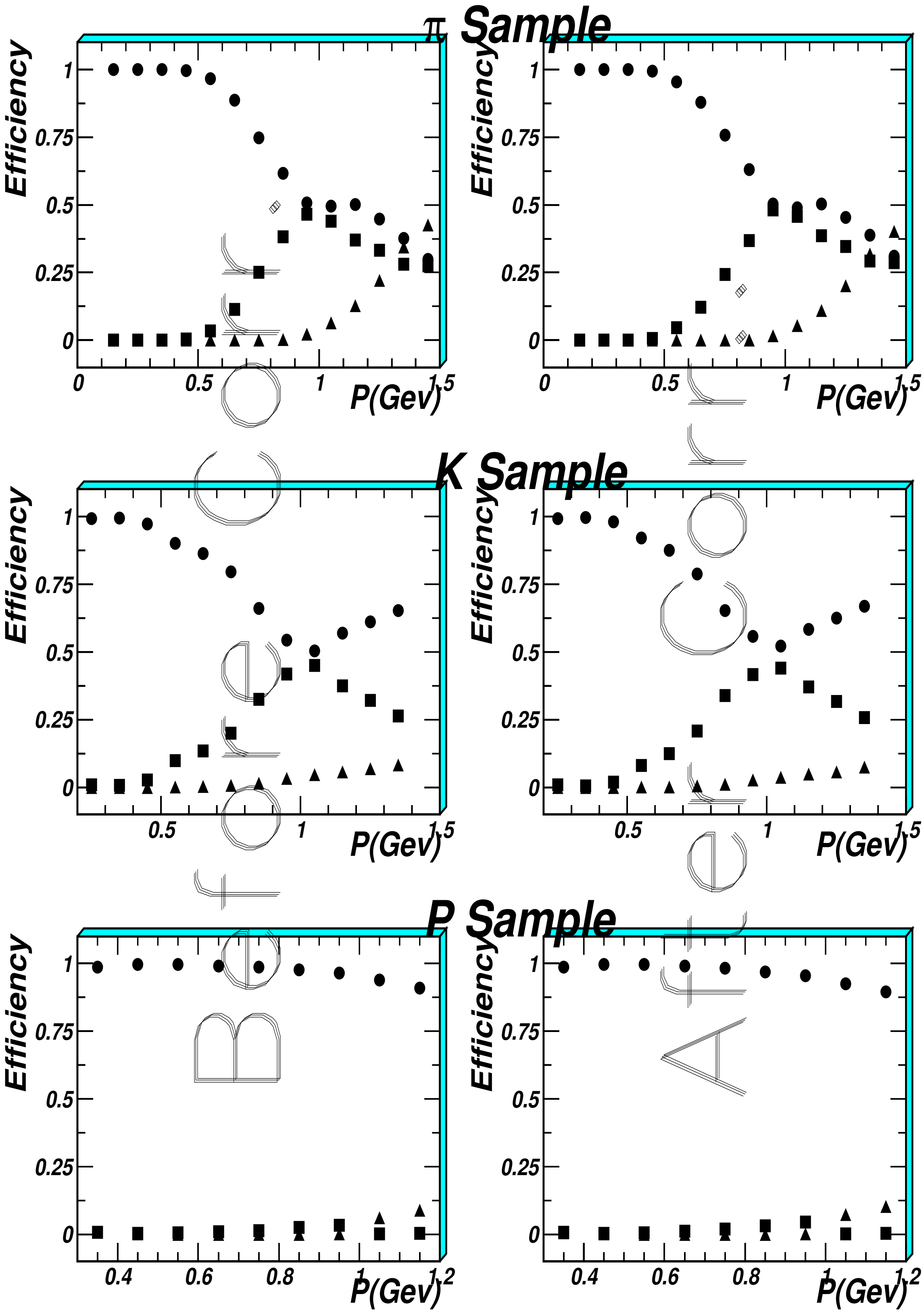


Figure 22: The distribution of χ .Vs. hit number after correction for M.C. data

7 PID using dE/dX and TOF information

BES is a large general purpose solenoidal detector, it has two sub-detectors to identify particle especially for hardons–TOF and dE/dX.

TOF has been improved at BESΠ, it's resolution is about 180ps for Bhabha event, the seperation ability is greater than 3σ when particle momenta less than 0.8GeV for K/π. Since the measured time has offset and the resolution determination has some promblems, we have done some correction for TOF information(see my memo). In order to improve the confidential level of particle identification, we will combine TOF and dE/dX information to identify particle after correction.

Here we desrcibe the PID using TOF briefly, we can get the particle momenta and length of path, then we can get the expected time for each kinds of particle from the kinematic formula. also we can get the measured time, then define χ^i_{TOF}:

$$\chi^i_{TOF} = \frac{T_{meas} - T_{exp}}{\sigma}$$

the particle with the least χ^2 is the correct one.

Now we combine the TOF and dE/dX information to identify particle. Since the seperation ability of dE/dX is not very well when the particle momenta is greater than 1.0GeV, we only use TOF information to do PID when the momenta is higher than 1.0GeV, of course if one of the two sub-detectors has not information, we only use another one to do PID. When we combine TOF and dE/dX information to do PID, we can get the χ^2 of TOF and dE/dX for each kind of particle respectively. then we can get the sum of $\chi^2 = \chi^2_{TOF} + \chi^2_{dE/dX}$, and the particle with least χ^2 is the correct one.

8 Conclusion

- The most probable energy loss obey the LANDAU formula as a function of $\beta\gamma$.
- The most probable energy loss dE/dX informtion have systematic error without correction, the distribution of χ is not a normal distribution.
- dE/dX offset and resolution has been corrected with the $log\beta\gamma$ and $cos\theta$.
- dE/dX offset and resolution of M.C. data also has been corrected as real data.
- The χ is a normal distribution when it varies with $log\beta\gamma$ and $cos\theta$ and hit number after correction.
- Particle K and π can be well identified when the momenta less than 0.6GeV after correction, and Proton can be well identify using dE/dX information.
- We has finished the code of PID using combined information of TOF and dE/dX after correction

References

[1] J.Bai et at,the BES detector,Nucl.Inst,&Meth A344(1994)319-334

[2] R.M.Sternheimer,R.F. Peierls,Phys Rev.,B3(1971) 3681

[3] J.H.Cobb et al.,Nucl.Instr.Meth. 133,315(1976)

[4] Rong.G.,Software correction for systematic Effect of the BES MDC dE/dX,the 4th chinese national Conference on High Energy Experimental Physics,Beijing,Oct.1991.Study and application of a Method for Systematic Efficts of BES MDC dE/dX,Internal Report.IHEP.Nov.1992.

[5] Rong.G.,Charged Particle Identification Using dE/dX measurement in BESΠ MDC,The 7th BES annual Meeting,June,1998,Datong,Shanxi

[6] Sun.S.J. et at ,Particle Identification Using dE/dX in BES Detector,The 7th BES annual Meeting,July 1995, Beijing

[7] Yuan Changzheng PH.D thesis