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Jet Energy Resolutions using Photon+jets data

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Abstract

In this note we present jet energy resolution from P10.15 photon+jets samples. The resolutions measure from photon-jets P_T asymmetry method, dijets-like method and the jet width in photon+jets events are presented and discussed in detail. The resolutions from data are compared with Monte Carlo simulation and also the results from the di-jet data we obtained before. Our studies show the jet energy resolutions from photon+jets samples are compartiable with resolutions from di-jets samples. For the photon+jet samples, we found the results are $93\%/\sqrt{P_T}$ in data.

1 Introduction

Jet energy resolution can be measured using di-jets balance method. By measuring the asymmetry variable of the transverse momentum of the two jets and doing the Gaussian fit, we can calculate the jet energy resolution. But the jet triggers are less sensitive and not well understood as comparing with the EM triggers. In DØ experiment, the EM trigger is much more sensitive and faster than the jet triggers, espeically at low P_T level. The high turn-on P_T of jet triggers will also bias the jet resolution at the low P_T level. To verify and improve the resolution measurement at low P_T level, the results from photon+jets are very important to check the jet resolution measurement using di-jets balance method.

In this note, we will use three different ways to measure the jet energy resolutions using photon+jets data. First we will discuss the methods we used to measure the resolutions, then, we will explain what kinds of events cuts we will apply, and in the rest of note, we will use photon+jets data to determine the sampling term "S", and use the data from photon+jets events together with di-jets events to determine the jet energy resolutions.

The photon+jets samples and the di-jets samples we will use are both processed by *RECO* version p10.15, except the photon+jets Monte Carlo samples, which are produced by older *RECO* version p10.11 due to unavailability of p10.15 photon+jets Monte Carlo samples. Because there're no noise and nonlinearlity simulations in P10 version of Monte Carlo samples. The jet resolution obtained from measuring Monte Carlo sample and the real data are expected to be very different.

The jet energy resolution in DØ *RunI* was measured by applying Gaussian fit of di-jets asymmetry, in the CC resion of the calorimeter($|\eta|$ <0.5), the final *RunI* jet energy resolution is [7]:

$$\frac{\sigma_E}{E} == \sqrt{\frac{N^2}{E_T^2} + \frac{S^2}{E_T} + C^2} = \sqrt{\frac{2.652^2}{E_T^2} + \frac{0.685^2}{E_T} + 0.036^2} \quad (1)$$

Here sampling term "S" is the main contribution to the resolution, and "N" is the noise term of the calorimeter to the jets.

2 Events Selections

2.1 The methods

To compare the jet energy resolution from photon+jets samples, we will use "asymmetry","di-jets-like" and direct measurement of the jet width in photon P_T bins to study the resolution.

Asymmetry Here the asymmetry means the asymmetry of the transverse momentum between photon and the jets. Define the asymmetry between transverse momentum of jet P_T^{jet} and the photon P_T^{γ}:

$$A = \frac{P_T^{jet} - P_T^{\gamma}}{P_T^{\gamma}} \tag{2}$$

It is easy to find the uncertainty of asymmetry variable A by using the error propagation equation:

$$\Delta A = \sqrt{(\frac{\partial A}{\partial P_T^{jet}})^2 \Delta P_T^{jet2} + (\frac{\partial A}{\partial P_T^{\gamma}})^2 \Delta P_T^{\gamma 2}} \tag{3}$$

if assumming the P_T^{jet} and P_T^{γ} are not correleated,

$$\Delta A = \sqrt{\frac{P_T^{jet2}}{P_T^{\gamma 4}} \Delta P_T^{\gamma 2} + \frac{1}{P_T^{\gamma 2}} \Delta P_T^{jet2}} \tag{4}$$

In the DØ detector, the resolution of photon is is close to the resolution of the electron, which is about $10\%/\sqrt{E}$ [5] and is a small variable comparing with the jet resolution. In the rest of the calculation, we assume the contribution from $(P_T^{jet2}/P_T^{\gamma 4})\Delta P_T^{\gamma 2}$ term is small enough and can be neglected, with respect to the contribution from ΔP_T^{jet2} term. After neglecting the photon term, We have:

$$\Delta A = \frac{\Delta P_T^{jet}}{P_T^{\gamma}} \tag{5}$$

In order to obtain the jet energy resolution $\Delta P_T^{jet}/P_T^{jet}$ from ΔA, we do the following conversion:

$$\frac{\Delta P_T^{jet}}{P_T^{jet}} = \frac{\Delta P_T^{jet}}{P_T^{\gamma}} \cdot \frac{\langle P_T^{\gamma} \rangle}{\langle P_T^{jet} \rangle} \tag{6}$$

Here we use average transverse momentum $\langle P_T \rangle$, which is averaged in the photon bins to simplify the resolution calculation. When the ratio of the average value of P_T^{γ} to P_T^{jet} in each bins are equal or close to 1, that is, the response between photon and jets are well corrected, we can use the width of asymmetry valuse A obtained from the photon bins as the jet energy resolution in this bin directly. Otherwise, it is necessary to correct the width of asymmetry variable A with the ratio $\langle P_T^{\gamma} \rangle / \langle P_T^{jet} \rangle$ in each photon P_T bins to get the correct jet energy resolution $\Delta P_T^{jet}/P_T^{jet}$.

The Direct measurement of Jet width Since the accuracy of resolution measurement using asymmetry method very much relies on the jets and photon response correction, we try to compare with results from asymmetry to the other ways which will not rely on the correction of jets and EM response. The direct measurement of jet width in each photon P_T bins and di-jets like balancing methods are the other ways that are used to verify the resolution from asymmetry method.

In the method of direct measurement of jet width, we find the transverse momentum of the leading photon and the corresopndent jet P_T to this photon. The jet P_T distributions are plotted within the photon P_T bins, the transverse momentum of the bins are ranged from 25 GeV to 80 GeV, at size of 5 GeV to 10 GeV interval for each bins at different P_T. The jet P_T distribution in each bins is then fitted by a Gaussian function. In term of the width of the fitted Gaussian functions in the photon P_T bins, the jet energy resolution will be $\sigma^{jet}_{P_T}/\langle P^{jet}_T \rangle$. Here $\langle P^{jet}_T \rangle$ is the average jet P_T in each photon P_T bins.

Di-jets like balancing [4] The direct measurement of jet P_T distribution in each photon bins will have large statistical error because the shape of jet distribution highly relies on the number of events in each bins and the size of the bins. Although the di-jets like balancing method also very much relies on the statistics, what we will use this method is to compare the results from different methods and check the differences between these ways. The di-jets like balancing method was first introduced by the UA2 collaboration[1]. Define the imbalance vector between jet and photon P_T

$$\overrightarrow{P_T} = \overrightarrow{P^{\gamma}_T} + \overrightarrow{P^{jet}_T} \tag{7}$$

has the vectors $\overrightarrow{P^{\xi}_T}$ projects on $\hat{\xi}$ direction and $\overrightarrow{P^{\eta}_T}$ projects on $\hat{\eta}$ direction. These two components are sensitive to the difference sources[2][3]. $\overrightarrow{P^{\xi}_T}$ is releated to calorimeter energy resolution, QCD gluon emission, etc. It is not a constant term with respect to the photon P_T. However, $\overrightarrow{P^{\eta}_T}$ is a relative constant as a function of photon bins. This component is releated to jet angular resolution, QCD hard and soft gluon emission, etc. To get the calorimeter resolution for the jets, we can use $\sigma_{P^{\eta}_T}$ to subtract by $\sigma_{P^{\xi}_T}$ to remove the effects from $\sigma_{P^{\xi}_T}$ term to get jet energy resolution. That is

$$\sigma_{jet} = \sqrt{\sigma^2_{P^{\xi}_T} - \sigma^2_{P^{\eta}_T}} \tag{8}$$

The jet energy resolution is then expressed by $\sigma_{jet}/\langle P^{\gamma}_T \rangle$, The average photon transverse momentum in each photon P_T bins is used here.

2.2 The data and the Monte Carlo samples

P10.15 post-shutdown data is used to calculate the jet energy resolution. The p10.11 photon+jets Monte Carlo simulated samples generated with $\langle MB \rangle$=0.5, plate geometry and pythia generator are used to calculate resolution and check the results from the real data analysis.

Four Monte Carlo samples, which are PtGt20, PtGt40, PtGt80, PtGt160, are used in calculation. The first one has about 80 K events. The rest three, are about 50 K events each. After processed by all applied cuts, there're about 16 k PtGt20 events, 800 PtGt160 events, 10 K PtGt40 events and 2 K PtGt80 events passed.

The data samples were taken at or after June and processed by *RECO* version p10.15. The run numbers ranges from 145098 to 150570. The bad runs were removed according with JET/MET bad run list [9]. Additional bad runs were removed based on their missing ET (MET) distributions. There're about 1750 K events total, and about 352 K events passed all applied cuts.

2.3 The Triggers

The nine EM triggers were used to filter the p10.15 photon+jets photon data. We have set a minimum P_T cut for each trigger. Only photon with transverse momentum higher than the minimum P_T cut will be counted and processed. The values of minimum P_T cut are based on the trigger turn-on efficiency. We place the minimum P_T cut around the 90% efficiency of each correspondent trigger[6]. The triggers and their Minimum P_T cut listed in the table 1 below:

Table 1: The triggers and correspondent minimum P_T cut

Trigger Name	Min P_T cut
CEM5	20 GeV
CEM10	15 GeV
CEM12	30 GeV
CEM15	30 GeV
CEM20	35 GeV
EM_Hi	25 GeV
EM_HI_CEM10	35 GeV
CEM5CFT_LBX	75 GeV

No jet trigger will be used in processing data.

2.4 The Cuts and Events Selection

In the p10.15 version of RECOAnalyze, the η region of photon is only processed up to ± 0.8. In this note, we will set the photon detector η region at $|\eta| \leq 0.8$, and the jets detector η regions are limited at CC regions with $|\eta| \leq 0.7$ in events selection .

In each of the event, we require at least 3 tracks associate with the vertices, the distance Z_{vertex} < *50cm*. We also remove any photon within the azimuthal (ϕ) crack region of the calorimeter if $\Delta\phi_{cracker} < 0.01$. Here $\Delta\phi_{cracker}$ is defined as:

$$\Delta\phi_{cracker} = MOD(\frac{32}{2\pi}\phi_{cluster}, 1) \quad (9)$$

To select the photon candidates, only EM object with EM ID=$\pm$10 or $\pm$11 will be considerred as a photon candidate. EM ID correction software *em_util* version v00-02-40 is used to do the EM ID correction. Any events without EM cluster or valid EM candidate is then to be removed from analysis. Photon candidates with $0.95 < EMFrac < 1.05$ and $-0.05 < EMIso < 0.1$ are required. Only the photon with highest transverse momentum (leading photon) in the event will be selected and processed for photon+jets study.

The jets used in analysis are processed by JCCA cone algorithm (with $\Delta R = 0.7$). Any jet in one event is required to pass the jet quality cut, namely

$0.05 \leq EMFrac \leq 0.95$;

$HotFrac < 10$;

$N90 > 1$;

$CHF < 0.5$

If any events contains jet that fails the above quality cut, we will remove the whole event to avoid introducing the bias to the jet resolution. Because this fail is probabilly due to the problems of calorimeter instead of the problem from the single failed jet.

The jets-photon response is corrected with *JetCor* Version 2.2. The highest and next to highest P_T jets passed the cuts are selected if the jets are out of the ΔR <0.5 cone of the leading photon. To reduce the gluon radiation, only the event with the transverse momentum of the second highest jet less than 8 GeV are considered the good event and will be processed. Finally, a back-to-back of 2.8 between leading photon and the correspondent highest P_T jet is required to avoid introducing bias at small η region.

To remove the noise from the electron candidates, we set the minimum missing E_T (MET) requirement:

$MET/P_T^{\gamma} < 2$ ($P_T^{\gamma} < 15$)

$MET/P_T^{\gamma} < 1.2$ ($15 < P_T^{\gamma} < 25$)

$MET/P_T^{\gamma} < 0.8$ ($P_T^{\gamma} > 25$)

The same cuts and selection methods are used to process Monte Carlo samples, except the triggers and the minium P_T cuts for each triggers are not used in processing Monte Carlo samples. Because there's no trigger simulation in p10.11 Monte Carlo samples.

3 Results

Figure 1 shows the asymmetry plots of the photon+jets sample. The asymmetry plots are plotted at different photon P_T bins ranges from 25 GeV to 100 GeV at 5 or 10 GeV bin size. At low P_T bins we can see the asymmetry curves are distorted when the asymmetry variable is negative. This is due to the EM trigger's minimum transverse momentum cut-off. When the cut-off P_T is sent to lower these distortation will disappear but the resolution will be biased due to the low trigger efficiency. We've put the data passes all nine triggers listed in table 1 together. Figure 2 shows the jet P_T distribution at different photon P_T bins. We can find the same trigger minimum P_T cut-off distortion on the jet P_T distribution. From figure 1, and 2, it is easy to see at higher P_T bins, the statistics errors will be larger due to the totol number of events in the bins is smaller, especially

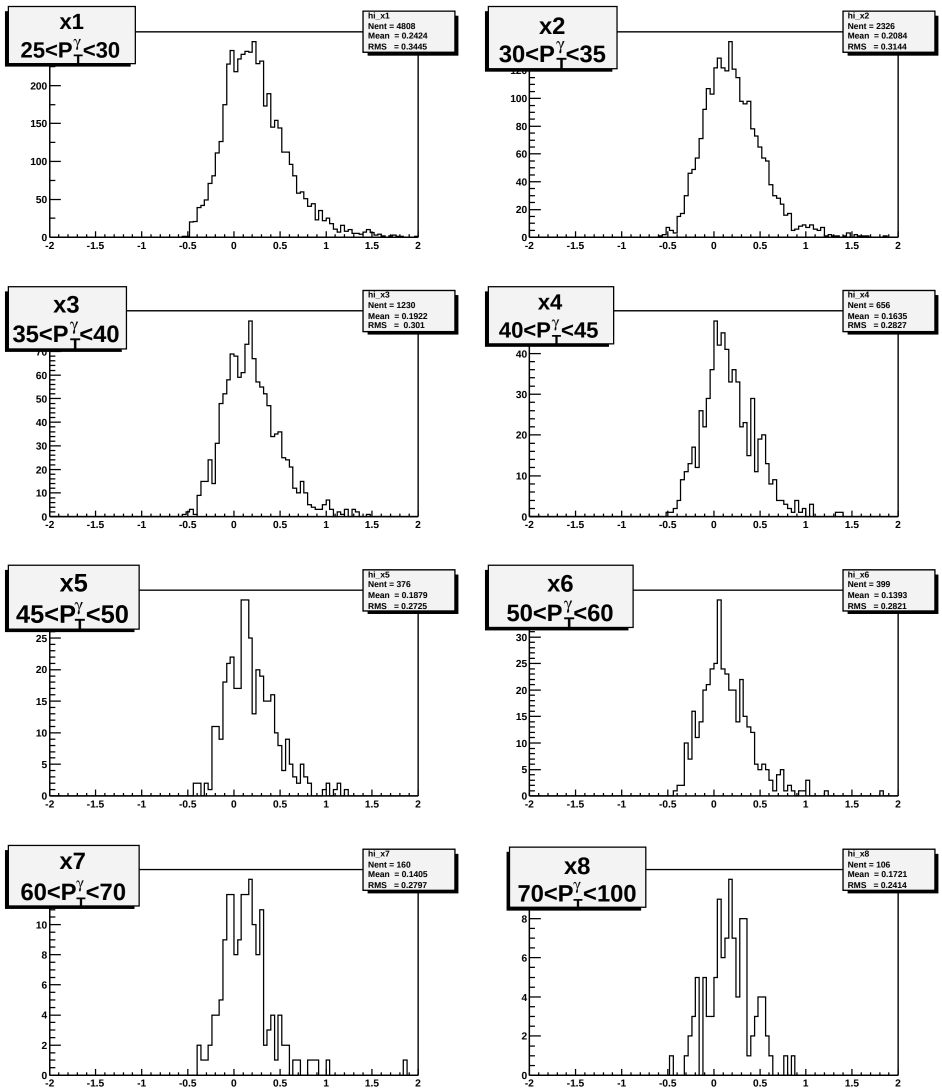

Figure 1: The "Photon+Jets" asymmetry plots

for the jet P_T distribution. This will introduce the large statistical errors to resolution when P_T is relative higher.

From Figure 1 we can also find the transverse momentum of photon and jets is not balanced very well after the response correction by using *JetCor*. The asymmetry method assumes there's only one jet and one photon, so the jet and photon's momentum will be balanced in transvese axis. but in reality there's always extra jets and the missing E_T. In this note, when we calculate resolution using the asymmetry, the σ_A will be multiplied by a factor of $\langle P_T^\gamma \rangle / \langle P_T^{jet} \rangle$ to get the correct expression of jet energy resolution.

Figure 3 shows the jet energy resolution in CC region ($|\eta| < 0.8$ for photon and 0.7

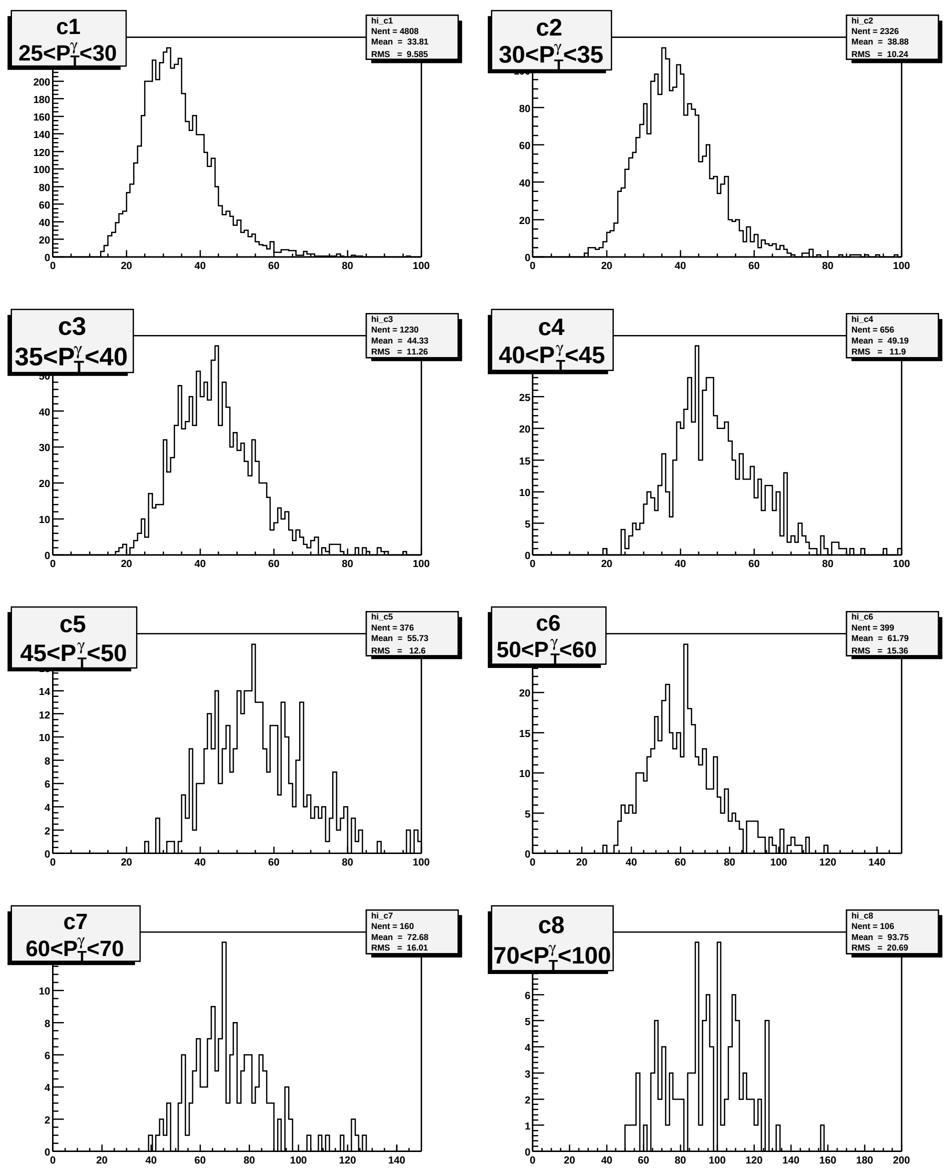

Figure 2: The jets P_T distribution at photon P_T bins

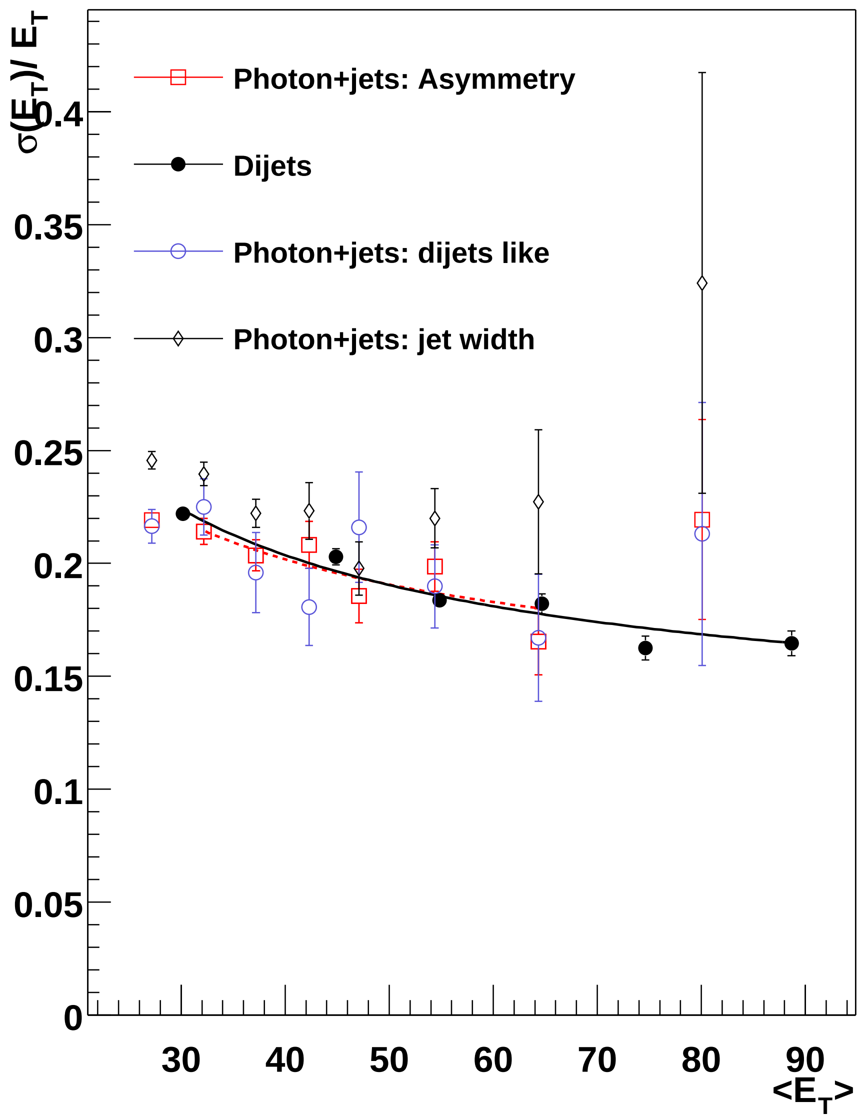

Figure 3: The jet energy resolution from p10.15 "Photon+Jets" data

for jets) obtained from different methods. The red square is from photon+jets sample using asymmetry method. The black dot is from the di-jets sample. Blue circle is from photon+jets sample using dijet-like method, and the black diamand is from photon+jets sample using direct measurement of jet width in photon P_T bins.

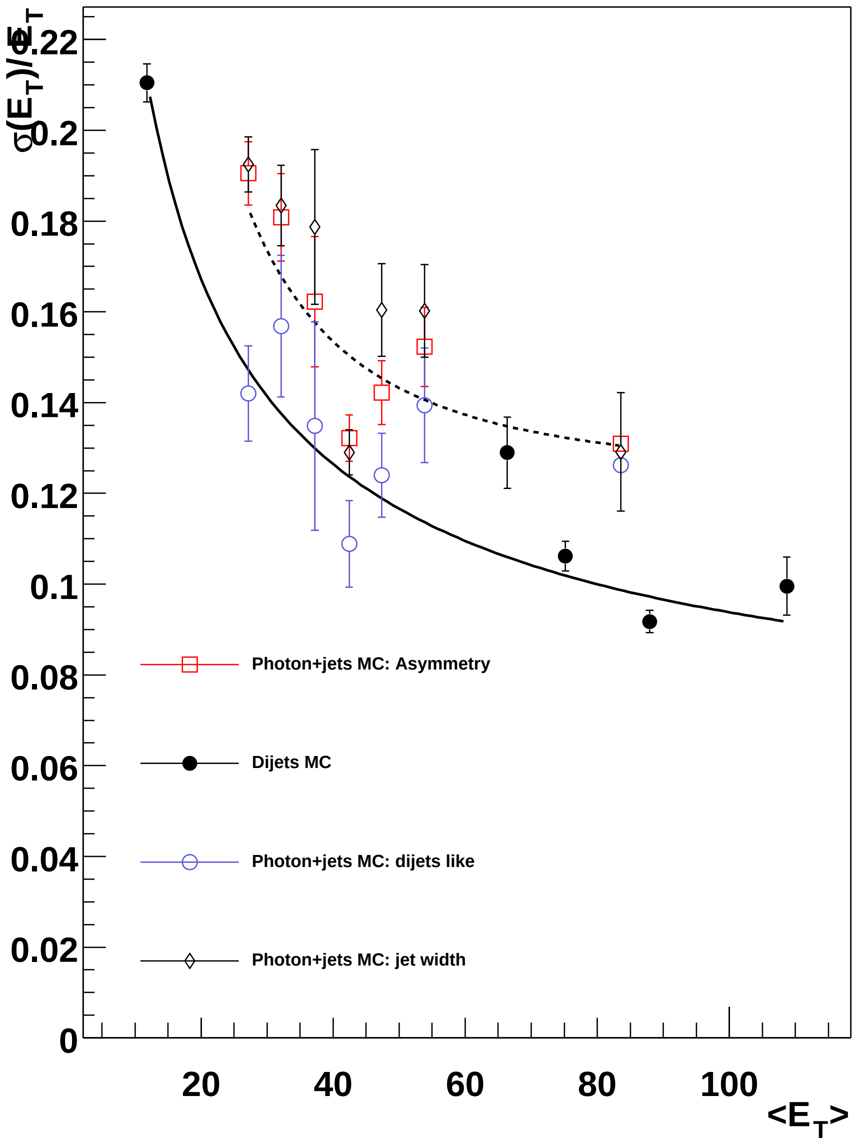

Figure 4: Compare the resolutions from p10.15 Monte Carlo di-jets sample with p10.11 photon+jets Monte Carlo sample

The resolution is then fitted by equation:

$$\frac{\sigma_{E_T}}{E_T} = \sqrt{\frac{N^2}{E_T^2} + \frac{S^2}{E_T} + C^2} \tag{10}$$

Here N, S and C are fitting parameters stand for noise term, sampling term and the constant term of the calorimeter. We will use P_T in the fitting instead of E_T.

We fitted the resolution based on asymmetry method, and use the data obtain from the rest methods to cross check the consistancy. The fitting results for CC region is N=0.± 1.085, S=0.933± 0.149, C=0.138±0.003, which is the same as the result from di-jets QCD samples within the statistical errors regions [8]. If we fit the $\sigma_{E_T}^2$ instead of resolution, by using the equation:

$$\sigma_{E_T}^2 = N^2 + S^2 P_T + C^2 P_T^2 \tag{11}$$

to cross check the consistancy of the fitting. Here we set the noise term N=0, the result is S=1.46±0.016, C=0.007± 1.52.

If we combine the points form photon+jets asymmetry and di-jets asymmetry, and fit the combined curve, the fitting result for the jet energy resolution will be: N=0.± 0.795, S=1.099± 0.025, C=0.106±0.005.

The results from Monte Carlo "Photon+Jets" samples are used to check the consistancy with the data's. We use the same method to calculate resolution in Monte Carlo as we used for the data, the only different is the photon+jets sample and di-jets sample are from the two different *RECO* versions, and there's no trigger, noise and nonlinearlty simulation in the Monte Carlo sample. The plots for the CC region ($|\eta| < 0.8$ for photon and 0.7 for jets) are shown at Figure 4 . The fitted results are N=-3.68±0.218, S=0±0.302, C=0.123±0.0017.

4 Acknowledgements

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