jet $P_T^{\text{jet}}$ and the photon $P_T^\gamma$:

$$A = \frac{P_T^{\text{jet}} - P_T^\gamma}{P_T^\gamma}$$  \hspace{1cm} (2)

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

$$\Delta A = \sqrt{\left(\frac{\partial A}{\partial P_T^{\text{jet}}}\right)^2 \Delta P_T^{\text{jet}} + \left(\frac{\partial A}{\partial P_T^\gamma}\right)^2 \Delta P_T^\gamma}$$  \hspace{1cm} (3)

if assuming the $P_T^{\text{jet}}$ and $P_T^\gamma$ are not correlated, then

$$\Delta A = \sqrt{\frac{\Delta P_T^{\text{jet}}}{P_T^{\text{jet}}} \Delta P_T^\gamma + \frac{\Delta P_T^\gamma}{P_T^\gamma} \Delta P_T^{\text{jet}}}$$  \hspace{1cm} (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 $(\Delta P_T^{\text{jet}}/P_T^{\text{jet}}) \Delta P_T^\gamma$ term is small enough and can be neglected, with respect to the contribution from $\Delta P_T^{\text{jet}}$ term. After neglecting the photon term, We have:

$$\Delta A = \frac{\Delta P_T^{\text{jet}}}{P_T^{\text{jet}}}$$  \hspace{1cm} (5)

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

$$\frac{\Delta P_T^{\text{jet}}}{P_T^{\text{jet}}} = \frac{\Delta P_T^{\text{jet}}}{P_T^\gamma} \cdot \frac{\langle P_T^\gamma \rangle}{\langle P_T^{\text{jet}} \rangle}$$  \hspace{1cm} (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 $P_T^\gamma$ to $P_T^{\text{jet}}$ 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 value $A$ 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 $\langle P_T^\gamma \rangle/\langle P_T^{\text{jet}} \rangle$ in each photon $P_T$ bins to get the correct jet energy resolution $\Delta P_T^{\text{jet}}/P_T^{\text{jet}}$.

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 corresponding 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 the size of 5 GeV to 20 GeV interval. For each bin, the $P_T$ distribution in each photon bin is 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 $\sigma_{jet}^2/(\langle P_T^{jet} \rangle^2)$. Here $\langle P_T^{jet} \rangle$ is the average jet $P_T$ in each photon $P_T$ bin.

**Di-jets like balancing [4]** The direct measurement of jet $P_T$ distribution in each photon bin will have large statistical error because the shape of jet distribution highly relies on the number of events in each bin and the size of the bins. Although the di-jets like balancing method also rely much on the statistics, what we will use this method is to compare the results of 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 $P_T$ and the bisection direction $\vec{r}_b = \frac{\vec{P}_T^b + \vec{P}_T^{jet}}{2}$ which lies the vectors $P_T^b$ projects on $\vec{r}$ direction and $P_T^{jet}$ projects on $\vec{r}$ direction. These two components are sensitive to the difference sources[2][3]. $P_T^b$ is related to calorimeter energy resolution, QCD, gluon emission, etc. (It is not a constant term with respect to the photon $P_T$.) However, $P_T^{jet}$ is a relative constant as a function of photon $P_T$. This component is related to jet angular resolution, QCD hard and soft gluon emission, etc. To get the calorimeter resolution for the jets, we can use $\sigma_{P_T}^b$ to subtract by $\sigma_{P_T}^{jet}$ to remove the effects from $\sigma_{P_T}^{jet}$ term to jet energy resolution. That is

$$\sigma_{jet} = \sqrt{\sigma_{P_T}^b - \sigma_{P_T}^{jet}}$$

where we use $\sigma_{P_T}^{jet}$.

The jet energy resolution is then expressed by $\sigma_{jet}/\langle P_T^{jet} \rangle$. 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+jet Monte Carlo simulated samples generated with $(MB)=0.5$, 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, 2 K PtGt80 events passed.

* If the jet and photon are approximately back-to-back,

**What do the 16 K events come from?**

---

1. [Note 1]
2. [Note 2]
3. [Note 3]
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 photons 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>
<thead>
<tr>
<th>Trigger Name</th>
<th>Min $P_T$ cut</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEM5</td>
<td>20 GeV</td>
</tr>
<tr>
<td>CEM10</td>
<td>15 GeV</td>
</tr>
<tr>
<td>CEM12</td>
<td>30 GeV</td>
</tr>
<tr>
<td>CEM15</td>
<td>30 GeV</td>
</tr>
<tr>
<td>CEM20</td>
<td>35 GeV</td>
</tr>
<tr>
<td>EM.Hi</td>
<td>25 GeV</td>
</tr>
<tr>
<td>EM.HL.CEM10</td>
<td>35 GeV</td>
</tr>
<tr>
<td>CEM5CF..LBX</td>
<td>75 GeV</td>
</tr>
</tbody>
</table>

Table 1: The triggers and correspondent minimum $P_T$ cut turn-on curves to show?

No jet trigger will be used in processing data.

2.4 The Cuts and Events Selection

In the p10.15 version of RECOAnalyze, the $\eta$ region of photon is only processed up to $|\eta| \leq 0.8$. In this note, we will set the photon detector $\eta$ region at $|\eta| \leq 0.8$, and the jets detector $\eta$ 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 $z_{\text{vertex}} < 50cm$. We also remove any photon within the azimuthal ($\phi$) crack region of the calorimeter if $\Delta \phi_{\text{crack}} < 0.01$. Here $\Delta \phi_{\text{crack}}$ is defined as:

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

To select the photon candidates, only EM object with EM ID=±10 or ±11 will be considered as a photon candidate. EM ID correction software em.util version v00-02-40
3. Results

Figure 1 shows the asymmetry plots of the photonic jet sample. The asymmetry plots are

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Figure 1: The "Photon+Jets" asymmetry plots from $\pi^{0,15}$ data.

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 is only one jet and one photon, so the jet and photon's momentum will be balanced in transverse 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 $\sigma_A$ will be multiplied by a factor of $(P_T^j)/(P_T^{\gamma})$ to get the correct expression of jet energy resolution. Why?

Figure 3 shows the jet energy resolution in CC region ($|\eta| < 0.8$ for photon and 0.7
Figure 3: The jet energy resolution from p10.15 "Photon+Jets" data

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 diamond is from photon+jets sample using direct measurement of jet width in photon $p_T$ bins.

Explain the curve in this plot. On take it out if it is not needed.
Figure 4: Compare the resolutions from p10.15 Monte Carlo di-jets sample with p10.11 photon+jets Monte Carlo sample. Curve is ...
The resolution is then fitted by equation:

$$\frac{\sigma_{ET}}{ET} = \sqrt{\frac{N^2}{ET^2} + \frac{S^2}{ET} + C^2} \quad (10)$$

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 obtained from the two methods to cross check the consistency. The fitting results for CC region is $N=0.9 \pm 1.085$, $S=0.933 \pm 0.149$, $C=0.138 \pm 0.003$, which is the same as the result from di-jets QCD samples within the statistical error regions [8]. If we fit the $\sigma_{E_T}^2$ instead of resolution, by using the equation:

$$\sigma_{E_T}^2 = N^2 + S^2 P_T + C^2 P_T^2 \quad (11)$$

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

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: $N=0.795$, $S=1.099 \pm 0.025$, $C=0.106 \pm 0.005$.

The results from Monte Carlo "Photon+Jets" samples are used to check the consistency 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 nonlinearity 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 $N=-3.68 \pm 0.218$, $S=0 \pm 0.302$, $C=0.123 \pm 0.0017$.

4 Acknowledgements

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References


