Measurement of B Hadron Correlations Using Displaced Secondary Vertex Information in Run I CDF Data

Text for the blessed web page – CDF note 6354

The CDF Collaboration

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Abstract

We present a measurement of B hadron correlations using displaced secondary vertex information. Specifically, we measure $\Delta\phi$, the transverse opening angle between the B hadrons. This analysis uses events from the inclusive electron and muon data samples in which at least two displaced secondary vertices are reconstructed. Once mistagged events are statistically subtracted, we obtain a combined electron and muon sample of approximately 17,000 events with a $b\bar{b}$ purity of greater than 90%. After correcting for relative detector efficiencies, we obtain

$$\text{Fraction of } B \text{ hadron pairs with } \Delta\phi < 90^\circ \text{ is } 28.8 \pm 1.0(stat) \pm 3.1(syst)\%$$

This measurement establishes the importance of higher order $b\bar{b}$ production mechanisms and is useful for studies of B flavor tagging for mixing and CP violation measurments.

1 Description

Bottom quark production diagrams can be divided into three classes: flavor creation, flavor excitation, and gluon splitting. Flavor creation consists of $b\bar{b}$ production through quark-antiquark annihilation or gluon-gluon fusion. Flavor excitation occurs when a b quark in the initial state of one of the beam particles is scattered into the final state through a hard interaction with a parton from the other beam. In gluon splitting, the $b\bar{b}$ pair arises as part of the fragmentation and shower development in the event.

Correlations between b quarks (or alternatively between the B hadrons resulting from $b\bar{b}$ production) probe the effective contribution from each $b\bar{b}$ production mechanism. For this analysis, we examine the transverse opening angle between the B hadrons, $\Delta\phi$, which is the angle between the B hadron measured in the plane perpendicular to the proton and antiproton beams. For flavor creation, the $\Delta\phi$ spectrum is peaked in the back-to-back region, while flavor excitation and gluon splitting have significant contributions at small opening angle. By measuring the $\Delta\phi$ distribution, especially the component at small opening angles, we can establish the relative importance of the higher order $b\bar{b}$ production mechanisms.

For this measurement, we use the 90 pb^{-1}data sample taken at CDF during the 1994-1995 run (Run Ib). We create a sample with enhanced $b\bar{b}$ content by requiring the presence of an electron or muon trigger. We then tag secondary vertices by searching for intersections of two or more tracks significantly displaced from the primary $p\bar{p}$ interaction vertex. We keep only events containing at least two displaced secondary vertices for the final sample. Events containing mistags (random combinations of tracks that are incorrectly reconstructed as displaced vertices) are removed statistically using the signed, two-dimensional decay distance, L_{xy}, described below. After mistag subtraction, we have a sample of 10,097 vertex-tag pairs from electron-triggered events and 7,092 vertex-tag pairs from muon-triggered events.

The raw mistag subtracted data distributions are compared to Pythia and Herwig Monte Carlo samples that have been passed through a detector simulation and treated as data. Three different Pythia samples, differing in the amount of initial state radiation, are used

- `PARP(67)` = 4.0: More initial state radiation, default for Pythia before version 6.138.
- `PARP(67)` = 3.0: Intermediate amount of intial state radiation
- `PARP(67)` = 1.0: Less initial state radiation, default for Pythia after version 6.138.

Only one Herwig sample was generated with mostly default parameters. For these comparisons, the relative normalizations of three production mechanisms are determined in two different ways:

Fixed: The relative normalizations of the three production mechanisms are fixed according to the Monte Carlo predictions for the cross sections of the production mechanisms.

Floating: The relative normalizations of the three production mechanisms are floated in a fit to get the best match to the data.

These Monte Carlo samples are also used to correct the data for backgrounds and detector effects.

The sources of background for this analysis include mistags, tags of prompt charm, and sequential double tags:

- Mistags occur when tracks that are not from the decay of a long lived particle are mistakenly reconstructed to form a secondary vertex. Mistags are subtracted statistically using the L_{xy} distributions of the tags in a procedure similar to side-band subtraction. L_{xy} is defined as the distance between the reconstructed secondary vertex and the primary vertex in the plane perpendicular to the beams. It is signed based on whether the p_T vector of the displaced vertex is pointed away from the primary ($L_{xy} > 0$) or towards the primary ($L_{xy} < 0$). Genuine tags for heavy flavor decays should have positive L_{xy}, while the L_{xy} distribution for mistags is symmetric around zero. Tags from the negative portion of the L_{xy} distribution can be used to statistically subtract mistags from the sample.

- Backgrounds from prompt charm can come either from exclusive $c\bar{c}$ production resulting in two long-lived D hadrons which are both tagged, or from multiple heavy flavor production ($b\bar{b} + c\bar{c}$) where a B hadron from the $b\bar{b}$ production yields one tag and a D hadron from the $c\bar{c}$ yields the other. The contribution from this background is estimated to be less than 10% and is corrected for using Monte Carlo.

- Sequential double tags occur when the same B hadron decay is tagged with two seperate displaced vertices. This can occur either through decays like $B \rightarrow D$ where the D hadron has a long enough liftime to be tagged seperately from the B, or through misreconstruction of the vertices. The contribution from this background is estimated to be neglible using Monte Carlo.

2 Blessed Numbers

This section summarizes the numbers that have been blessed for this analysis.

After correcting the data for backgrounds and Monte Carlo effects, we can calculate a "towards fraction" or fraction of the tag pairs with $\Delta\phi < 90°$.

2.1 Electron Towards Fraction

For the electron data, with the following B hadron cuts

- Trigger B: $p_T > 14\text{GeV}/c^2$, and $|\eta| < 1$

- Other B: $p_T > 7.5\text{GeV}/c^2$, and $|\eta| < 1$, we calculate a towards fraction of

$$29.8 \pm 1.3(stat) \pm 2.9(syst)\%$$

2.2 Muon Towards Fraction

For the muon data, with the following B hadron cuts

- Trigger B: $p_T > 14\text{GeV}/c^2$, and $|\eta| < 0.6$
- Other B: $p_T > 7.5\text{GeV}/c^2$, and $|\eta| < 1$,

we calculate a towards fraction of

$$26.4 \pm 1.7(stat) \pm 3.7(syst)\%$$

2.3 Combined Towards Fraction

For the combined electron and muon data, with the following B hadron cuts

- Trigger B: $p_T > 14\text{GeV}/c^2$, and $|\eta| < 1$
- Other B: $p_T > 7.5\text{GeV}/c^2$, and $|\eta| < 1$,

we calculate a towards fraction of

$$28.8 \pm 1.0(stat) \pm 3.1(syst)\%$$

3 Blessed Figures

The following figures have been blessed for the B hadron correlation measurement. More text can be found in CDF note 6354.

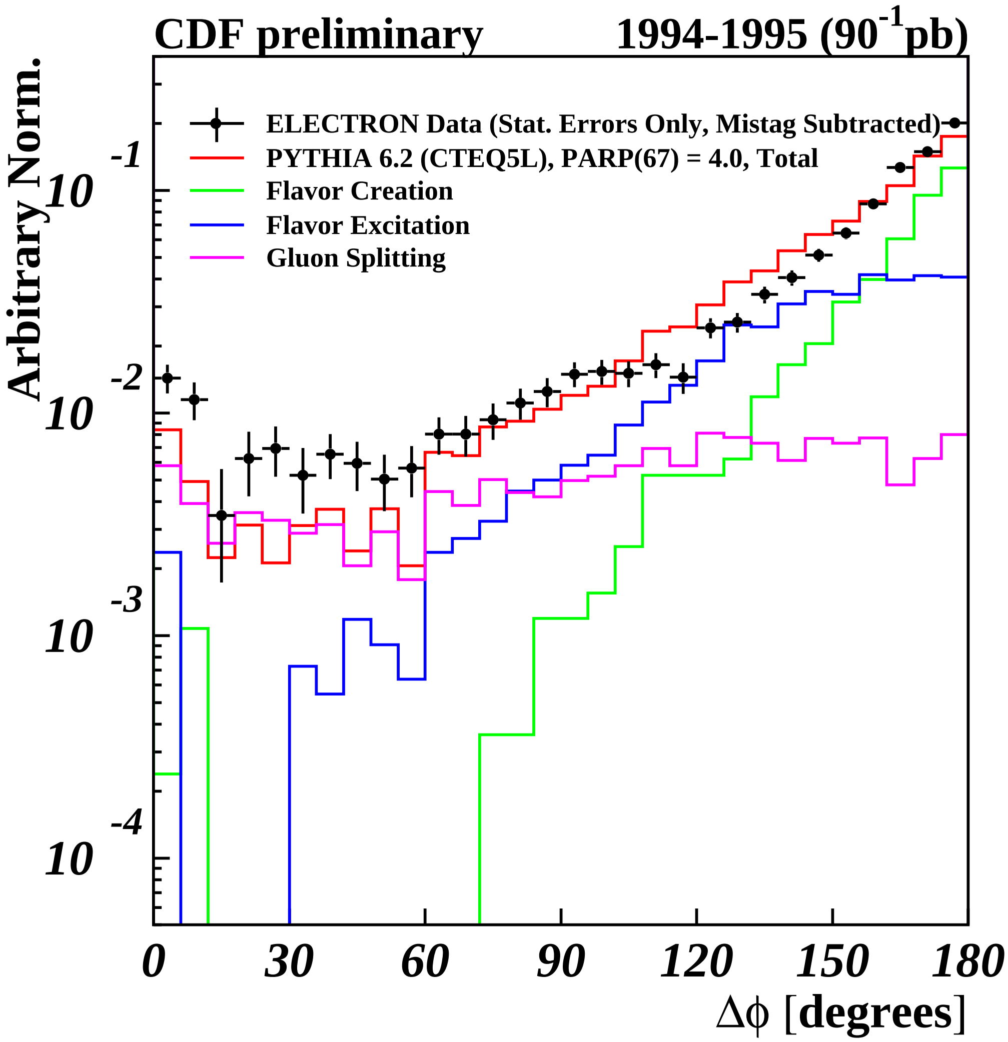

Figure 1: A comparison between the $\Delta\phi$ distribution for electron data and Pythia with PARP(67) $= 4.0$ (more initial state radiation, default before Pythia version 6.138). The data is mistag subtracted but not corrected for other backgrounds or detector effects. The Monte Carlo has been passed through a detector simulation and treated as data. The data is normalized to unit area. The overall Monte Carlo normalization is set to give the best shape match to the data. The relative normalizations of the three production mechanisms for the Monte Carlo distribution are fixed based on the Pythia prediction for the cross sections of the different production mechanisms.

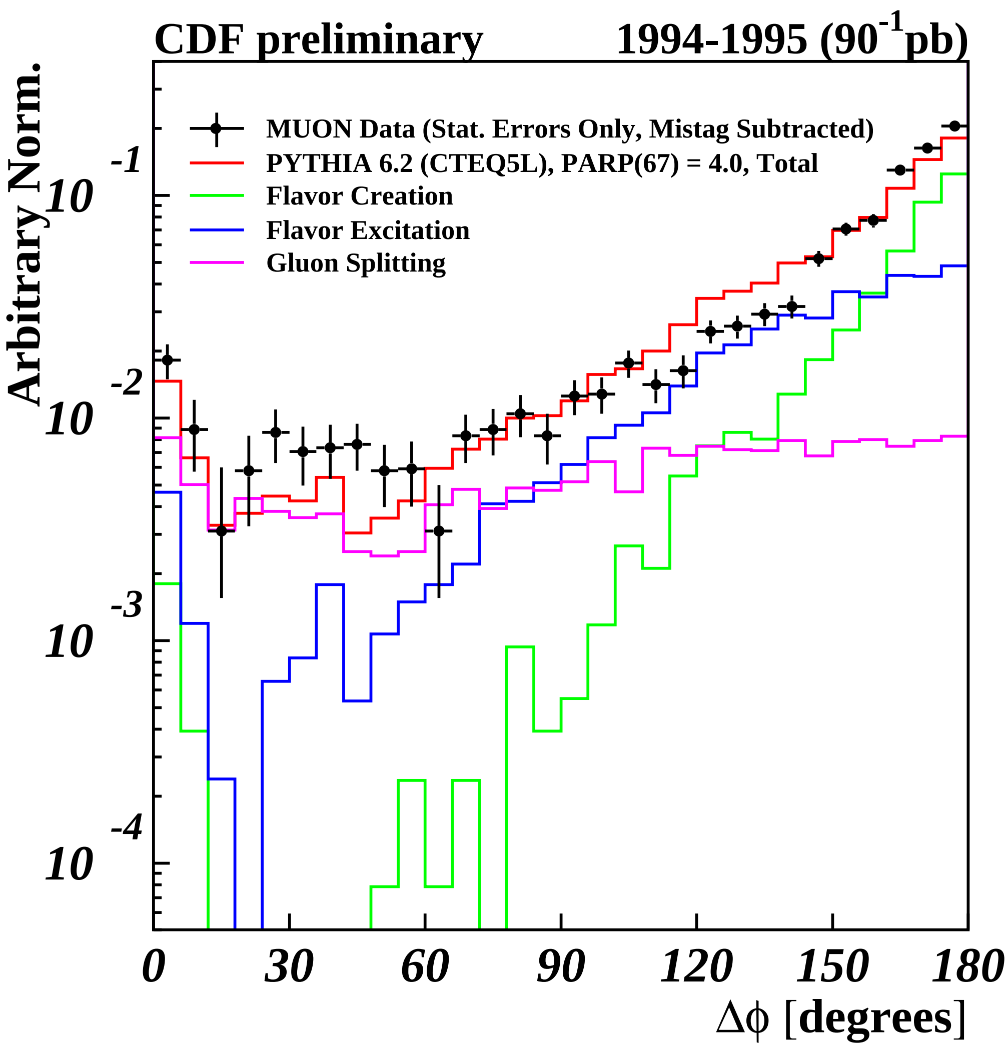

Figure 2: A comparison between the $\Delta\phi$ distribution for muon data and Pythia with PARP(67) $= 4.0$ (more initial state radiation, default before Pythia version 6.138). The data is mistag subtracted but not corrected for other backgrounds or detector effects. The Monte Carlo has been passed through a detector simulation and treated as data. The data is normalized to unit area. The overall Monte Carlo normalization is set to give the best shape match to the data. The relative normalizations of the three production mechanisms for the Monte Carlo distribution are fixed based on the Pythia prediction for the cross sections of the different production mechanisms.

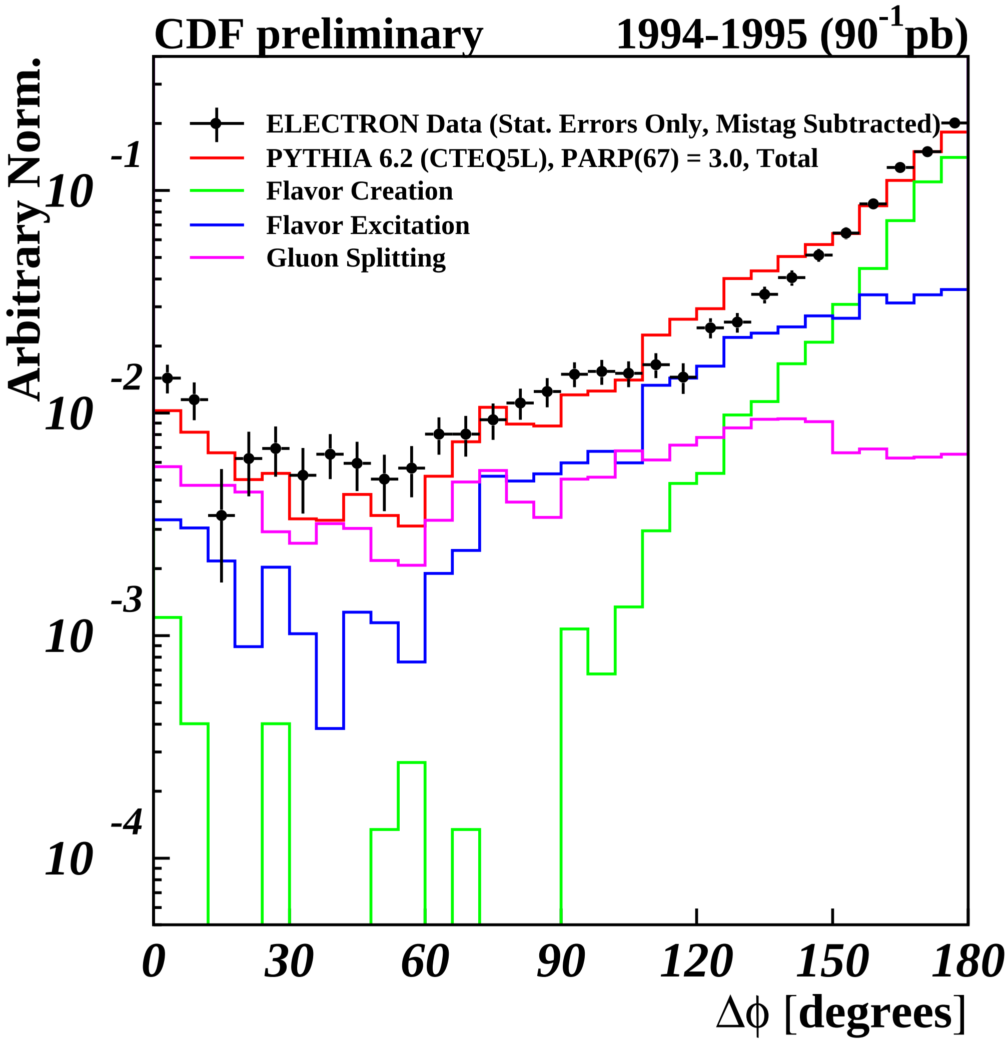

Figure 3: A comparison between the $\Delta\phi$ distribution for electron data and Pythia with `PARP(67)` = 3.0 (intermediate initial state radiation). The data is mistag subtracted but not corrected for other backgrounds or detector effects. The Monte Carlo has been passed through a detector simulation and treated as data. The data is normalized to unit area. The overall Monte Carlo normalization is set to give the best shape match to the data. The relative normalizations of the three production mechanisms for the Monte Carlo distribution are fixed based on the Pythia prediction for the cross sections of the different production mechanisms.

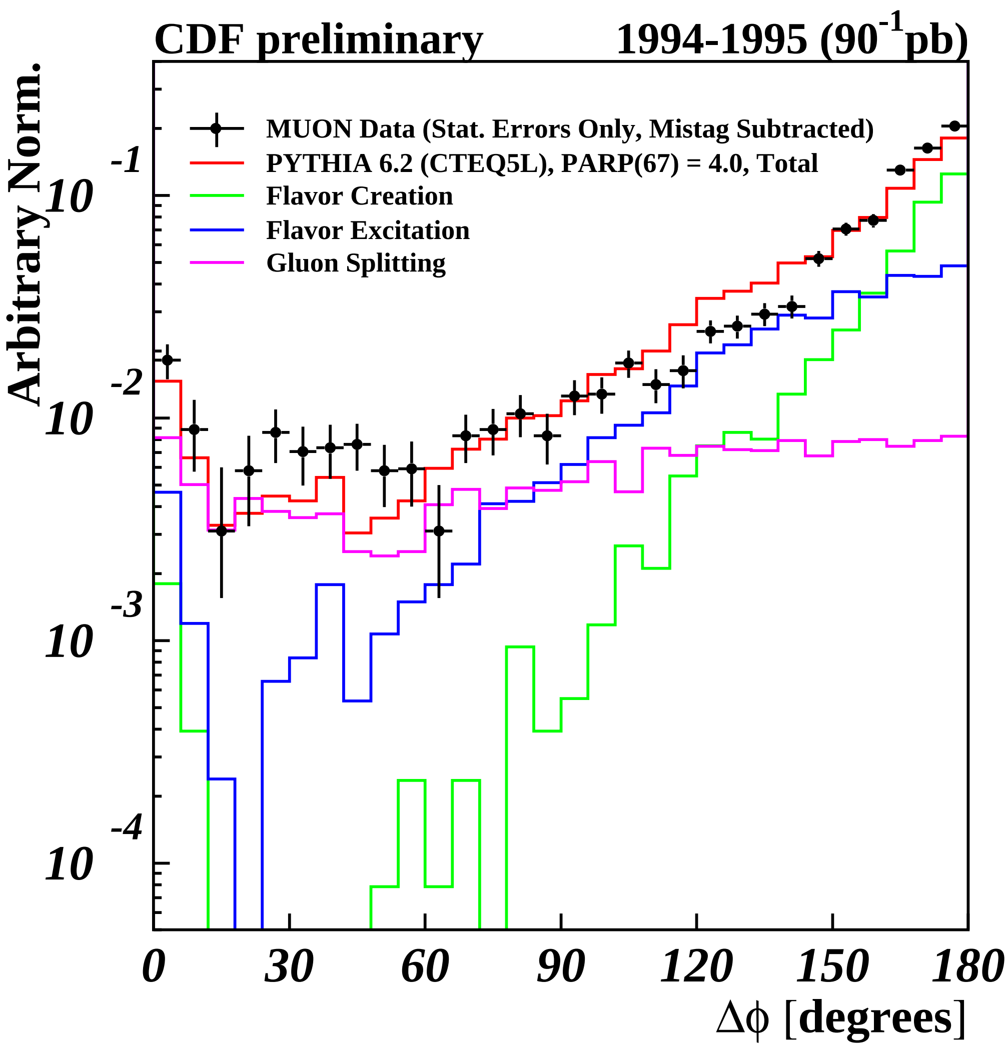

Figure 4: A comparison between the $\Delta\phi$ distribution for muon data and Pythia with PARP(67) = 3.0 (intermediate initial state radiation). The data is mistag subtracted but not corrected for other backgrounds or detector effects. The Monte Carlo has been passed through a detector simulation and treated as data. The data is normalized to unit area. The overall Monte Carlo normalization is set to give the best shape match to the data. The relative normalizations of the three production mechanisms for the Monte Carlo distribution are fixed based on the Pythia prediction for the cross sections of the different production mechanisms.

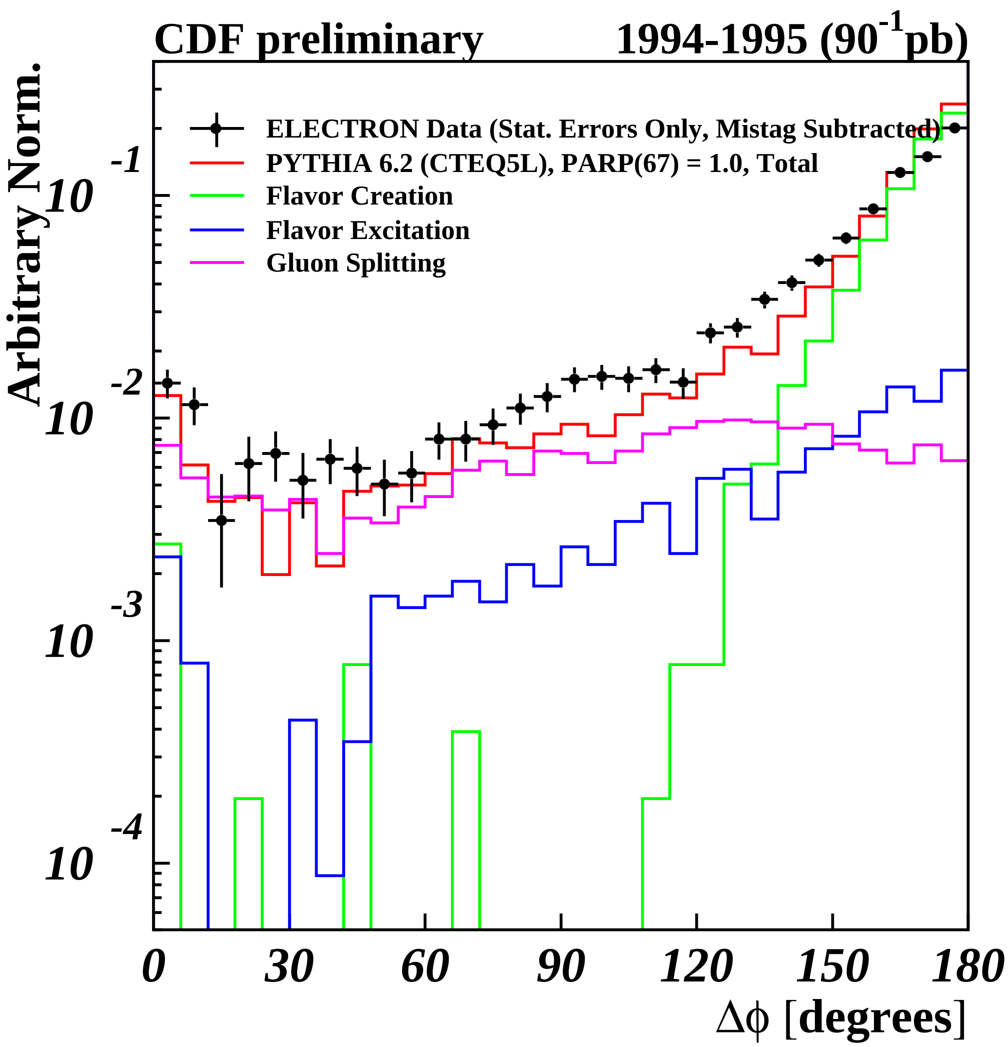

Figure 5: A comparison between the $\Delta\phi$ distribution for electron data and Pythia with PARP(67) = 1.0 (less initial state radiation, default after Pythia version 6.138). The data is mistag subtracted but not corrected for other backgrounds or detector effects. The Monte Carlo has been passed through a detector simulation and treated as data. The data is normalized to unit area. The overall Monte Carlo normalization is set to give the best shape match to the data. The relative normalizations of the three production mechanisms for the Monte Carlo distribution are fixed based on the Pythia prediction for the cross sections of the different production mechanisms.

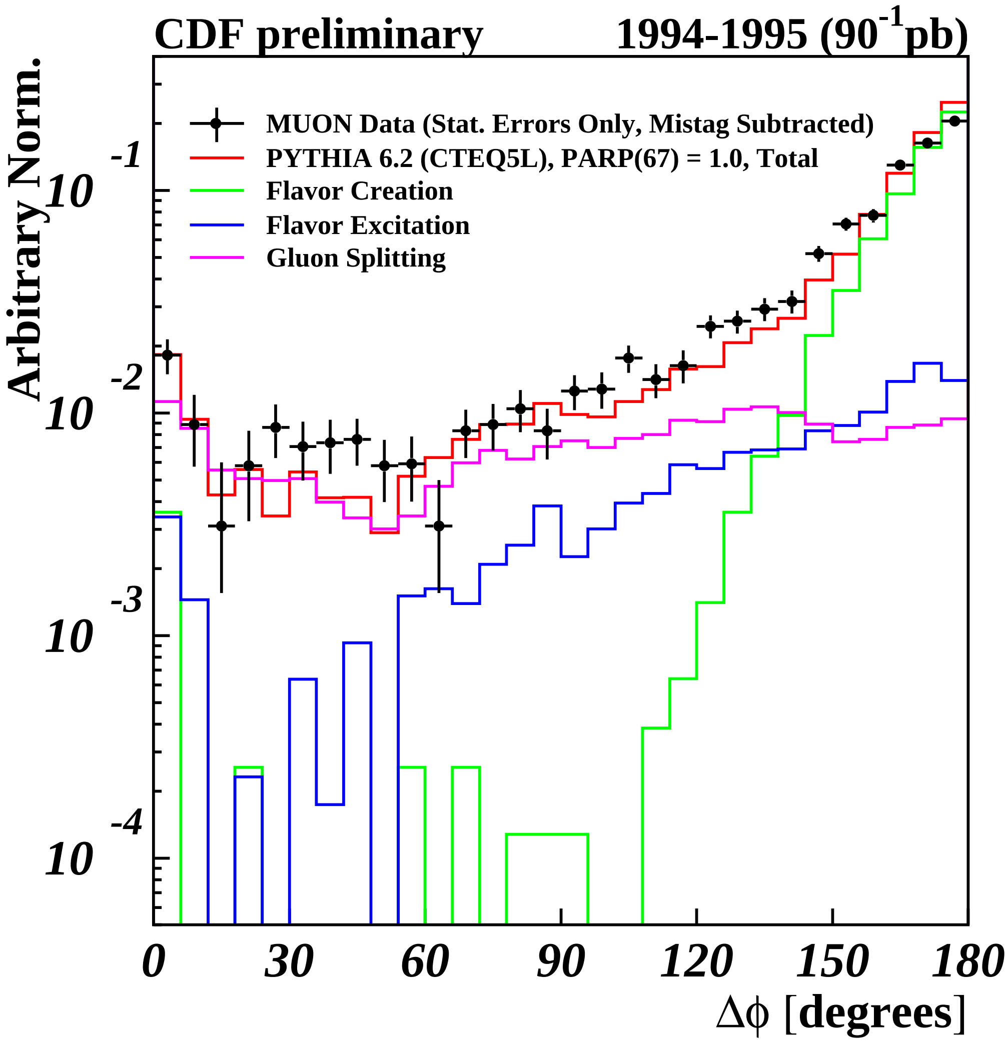

Figure 6: A comparison between the $\Delta\phi$ distribution for muon data and Pythia with `PARP(67)` = 1.0 (less initial state radiation, default after Pythia version 6.138). The data is mistag subtracted but not corrected for other backgrounds or detector effects. The Monte Carlo has been passed through a detector simulation and treated as data. The data is normalized to unit area. The overall Monte Carlo normalization is set to give the best shape match to the data. The relative normalizations of the three production mechanisms for the Monte Carlo distribution are fixed based on the Pythia prediction for the cross sections of the different production mechanisms.

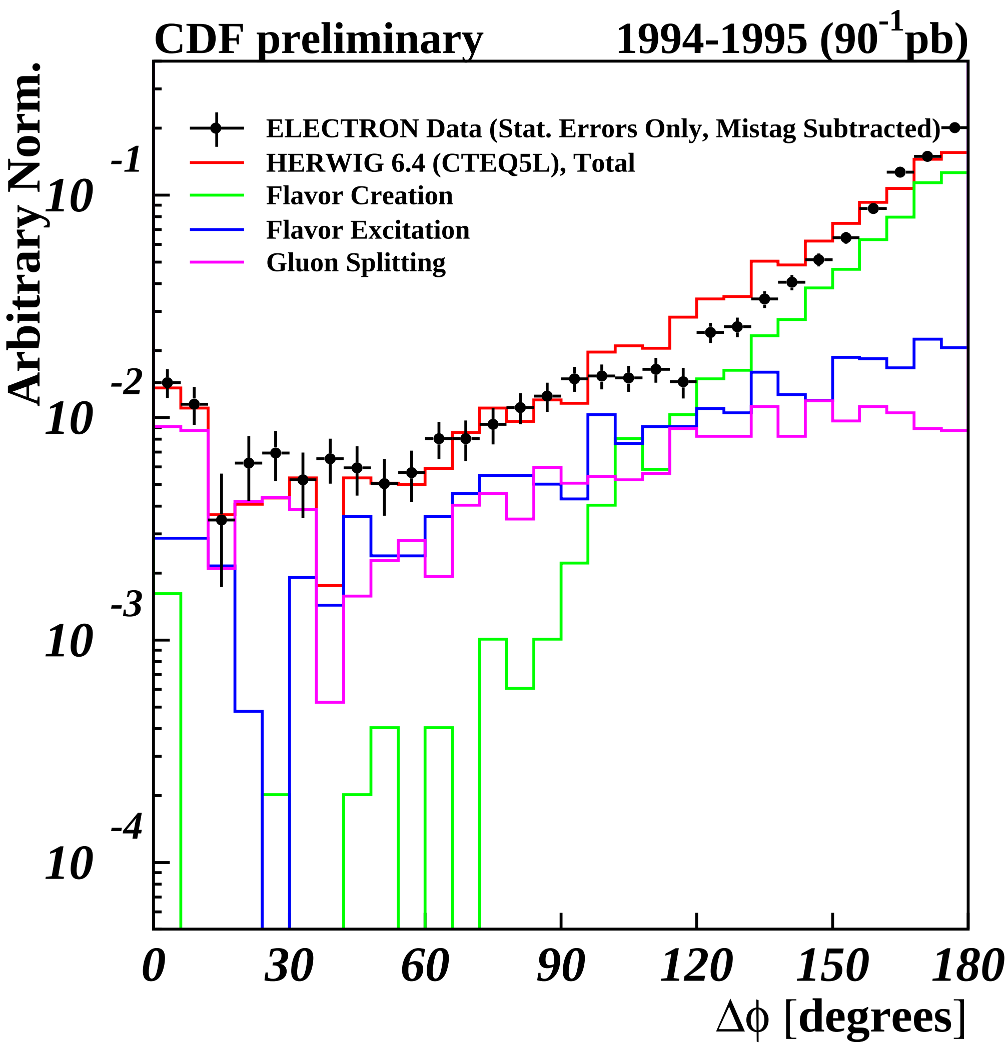

Figure 7: A comparison between the $\Delta\phi$ distribution for electron data and HERWIG. The data is mistag subtracted but not corrected for other backgrounds or detector effects. The Monte Carlo has been passed through a detector simulation and treated as data. The data is normalized to unit area. The overall Monte Carlo normalization is set to give the best shape match to the data. The relative normalizations of the three production mechanisms for the Monte Carlo distribution are fixed based on the HERWIG prediction for the cross sections of the different production mechanisms.

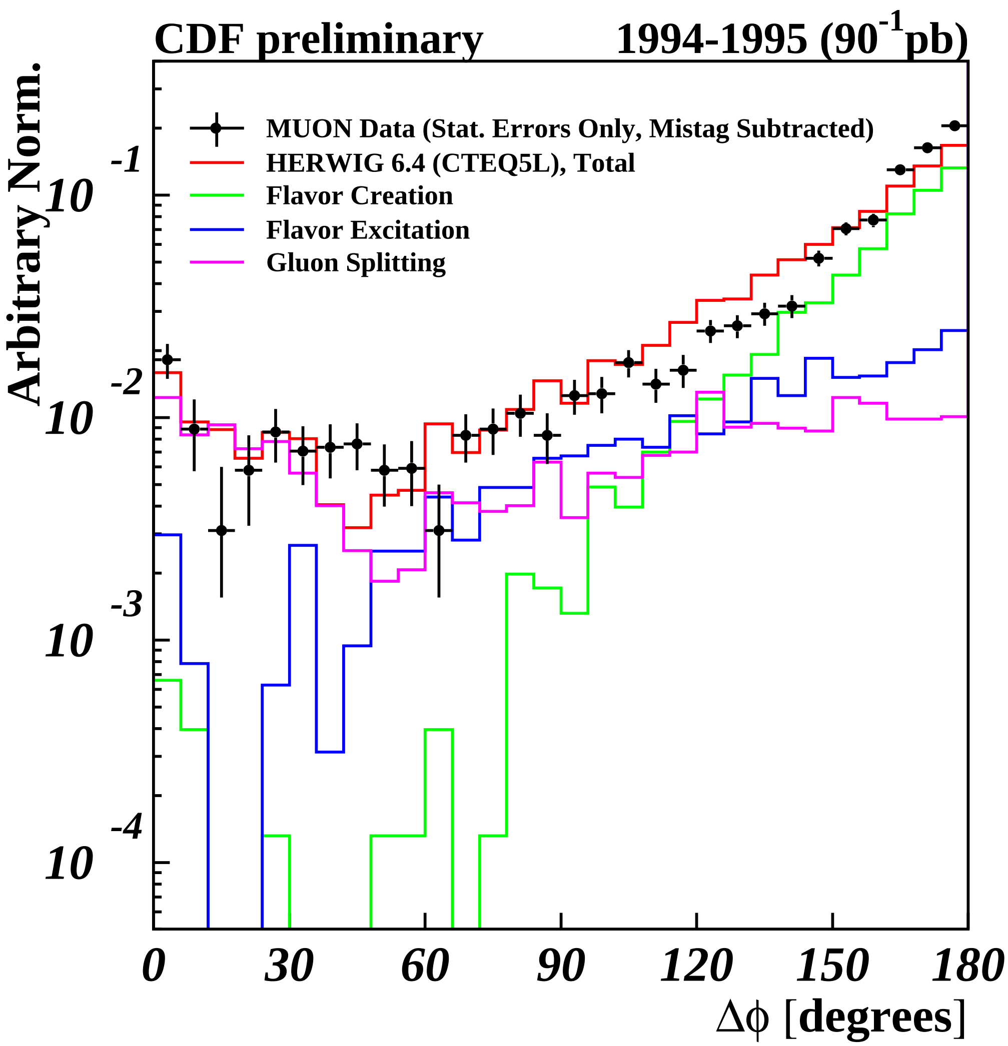

Figure 8: A comparison between the $\Delta\phi$ distribution for muon data and Herwig. The data is mistag subtracted but not corrected for other backgrounds or detector effects. The Monte Carlo has been passed through a detector simulation and treated as data. The data is normalized to unit area. The overall Monte Carlo normalization is set to give the best shape match to the data. The relative normalizations of the three production mechanisms for the Monte Carlo distribution are fixed based on the Herwig prediction for the cross sections of the different production mechanisms.

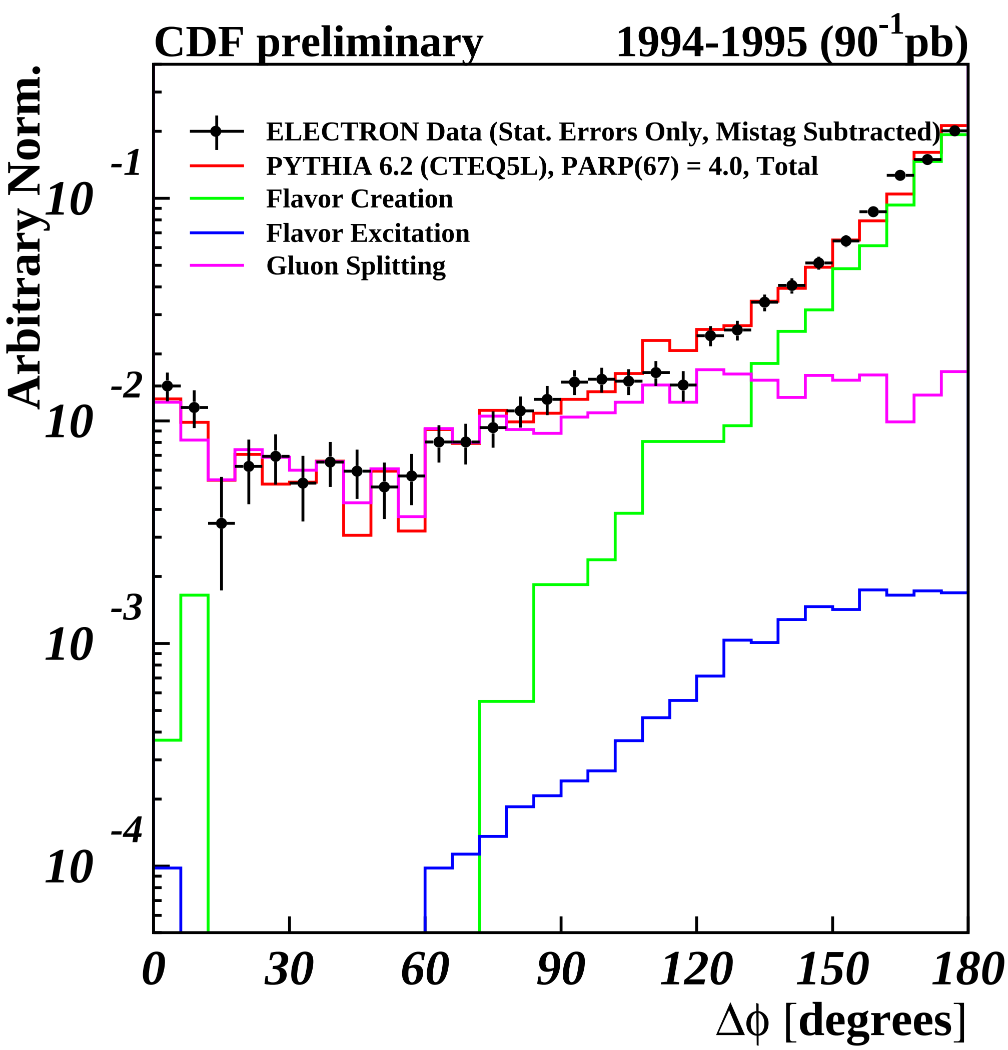

Figure 9: A comparison between the $\Delta\phi$ distribution for electron data and PYTHIA with PARP(67) = 4.0 (more initial state radiation, default before PYTHIA version 6.138). The data is mistag subtracted but not corrected for other backgrounds or detector effects. The Monte Carlo has been passed through a detector simulation and treated as data. The data is normalized to unit area. The normalizations of the three production mechanisms for the Monte Carlo distribution are allowed to float in a fit to produce the best match to the data.

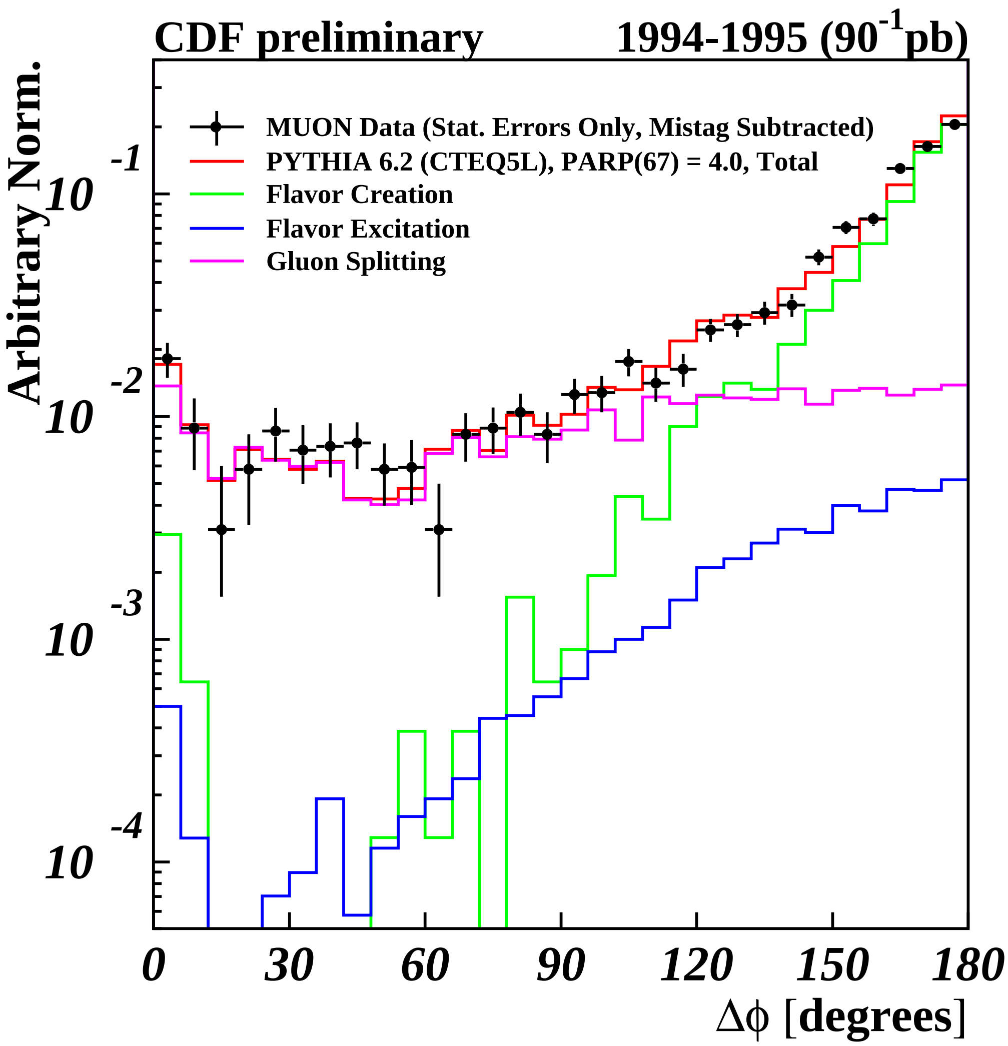

Figure 10: A comparison between the $\Delta\phi$ distribution for muon data and PYTHIA with PARP(67) = 4.0 (more initial state radiation, default before PYTHIA version 6.138). The data is mistag subtracted but not corrected for other backgrounds or detector effects. The Monte Carlo has been passed through a detector simulation and treated as data. The data is normalized to unit area. The normalizations of the three production mechanisms for the Monte Carlo distribution are allowed to float in a fit to produce the best match to the data.

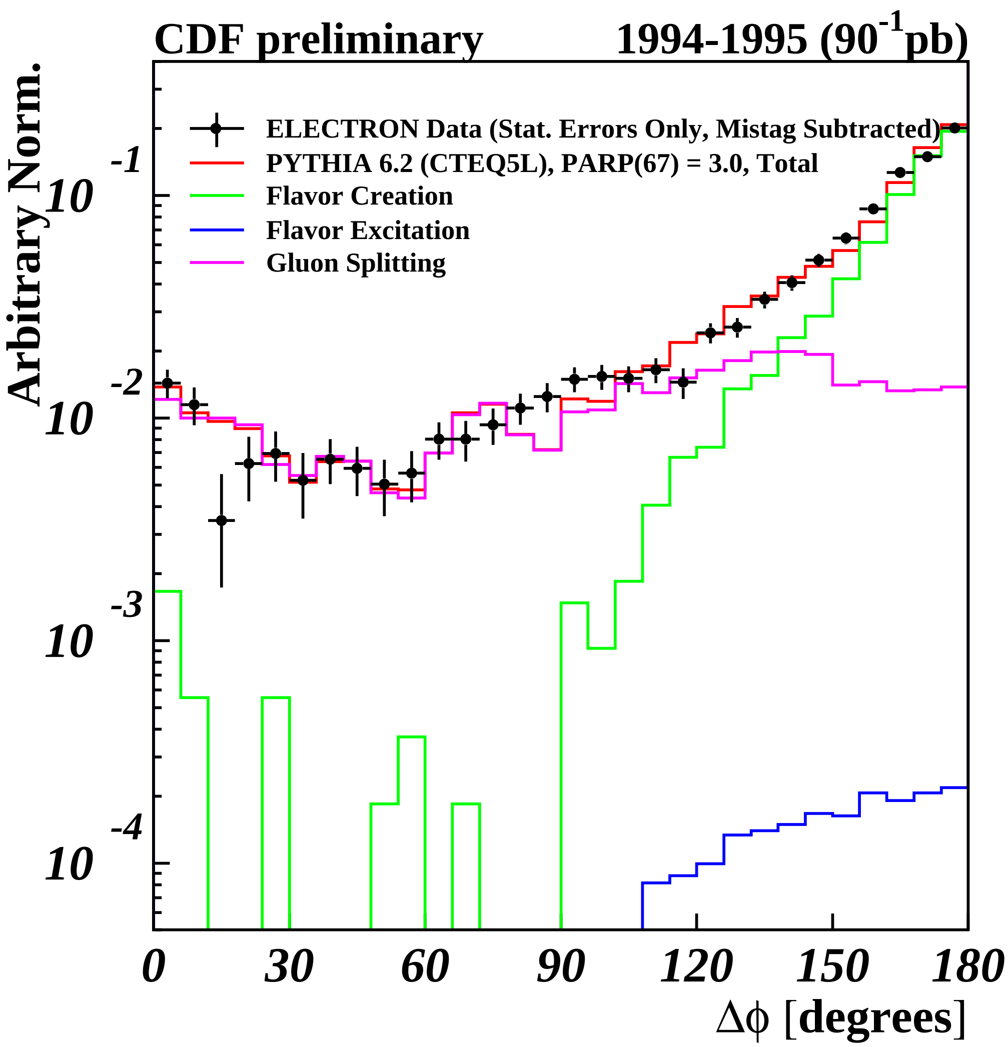

Figure 11: A comparison between the $\Delta\phi$ distribution for electron data and PYTHIA with PARP(67) $= 3.0$ (intermediate initial state radiation). The data is mistag subtracted but not corrected for other backgrounds or detector effects. The Monte Carlo has been passed through a detector simulation and treated as data. The data is normalized to unit area. The normalizations of the three production mechanisms for the Monte Carlo distribution are allowed to float in a fit to produce the best match to the data.

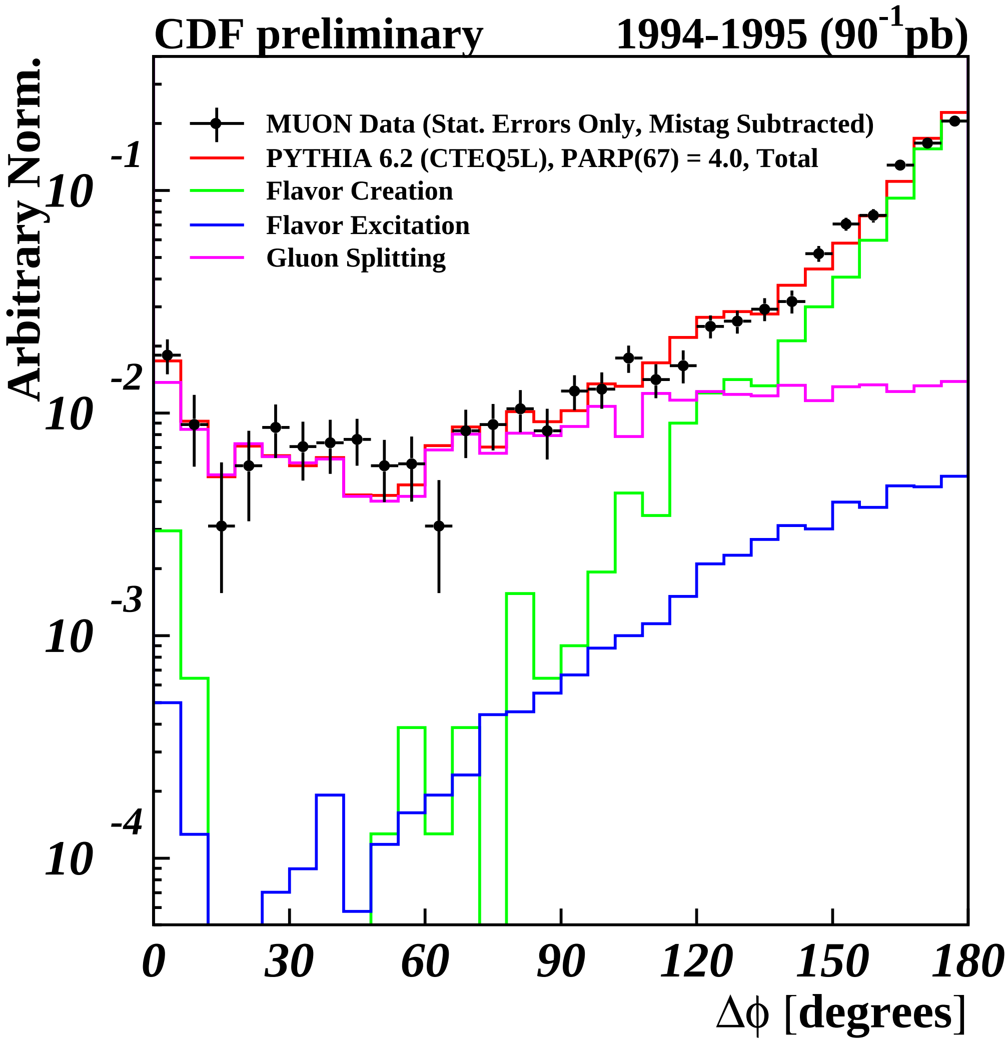

Figure 12: A comparison between the $\Delta\phi$ distribution for muon data and PYTHIA with PARP(67) $= 3.0$ (intermediate initial state radiation). The data is mistag subtracted but not corrected for other backgrounds or detector effects. The Monte Carlo has been passed through a detector simulation and treated as data. The data is normalized to unit area. The normalizations of the three production mechanisms for the Monte Carlo distribution are allowed to float in a fit to produce the best match to the data.

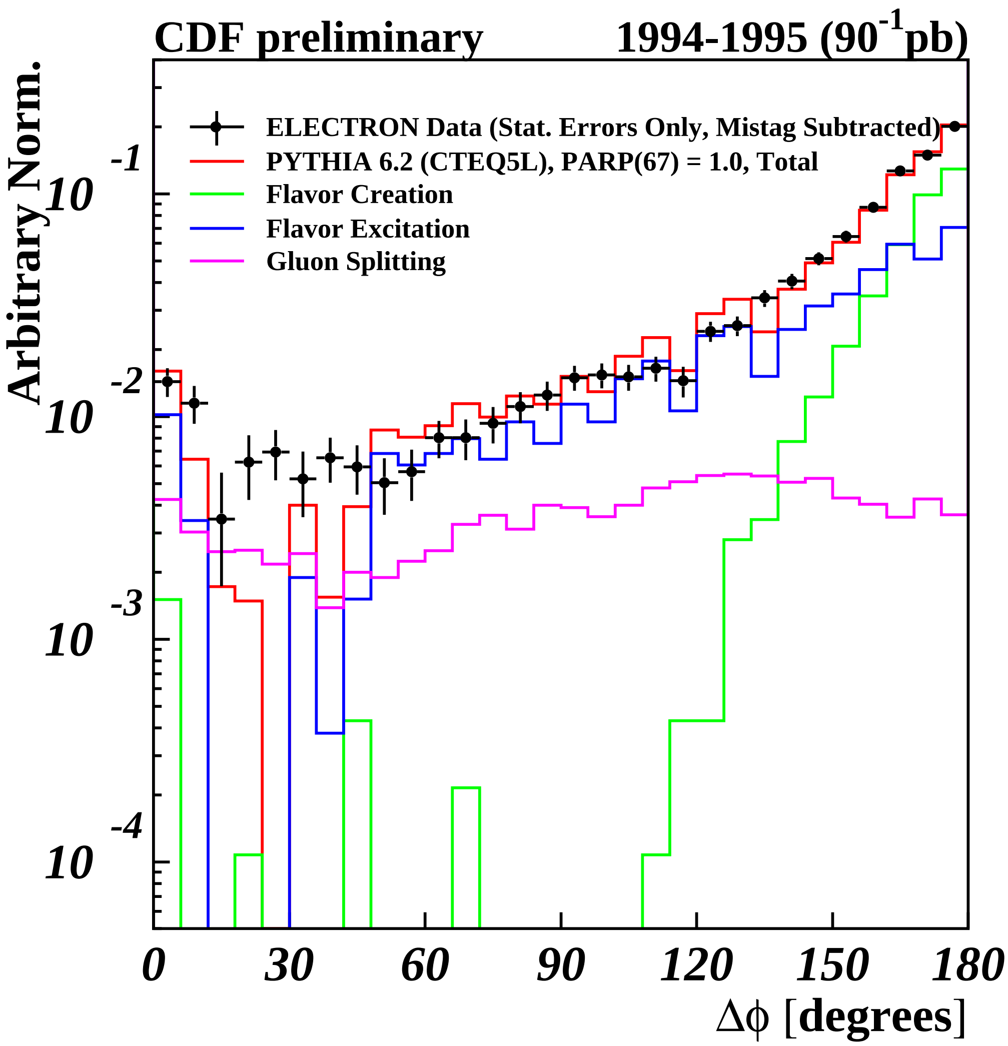

Figure 13: A comparison between the $\Delta\phi$ distribution for electron data and Pythia with PARP(67) = 1.0 (less initial state radiation, default after Pythia version 6.138). The data is mistag subtracted but not corrected for other backgrounds or detector effects. The Monte Carlo has been passed through a detector simulation and treated as data. The data is normalized to unit area. The normalizations of the three production mechanisms for the Monte Carlo distribution are allowed to float in a fit to produce the best match to the data.

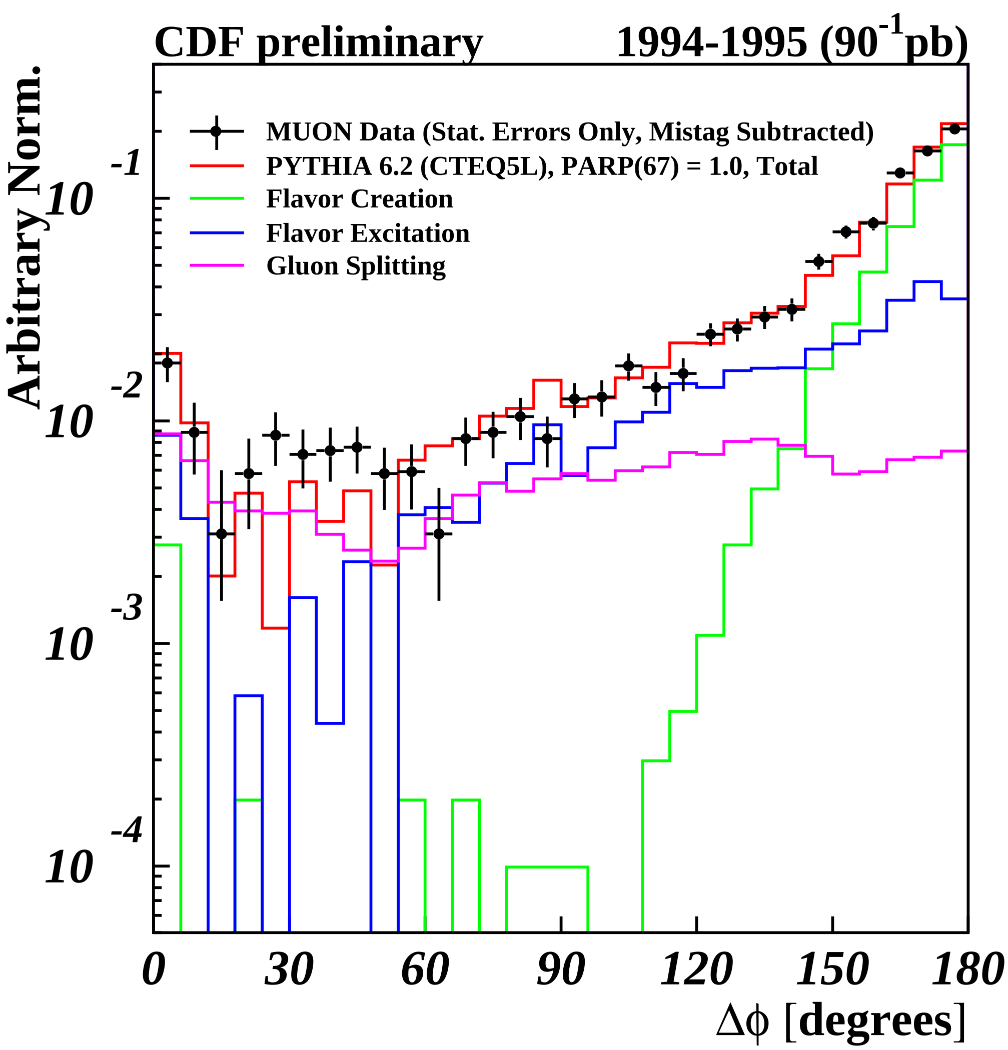

Figure 14: A comparison between the $\Delta\phi$ distribution for muon data and Pythia with PARP(67) = 1.0 (less initial state radiation, default after Pythia version 6.138). The data is mistag subtracted but not corrected for other backgrounds or detector effects. The Monte Carlo has been passed through a detector simulation and treated as data. The data is normalized to unit area. The normalizations of the three production mechanisms for the Monte Carlo distribution are allowed to float in a fit to produce the best match to the data.

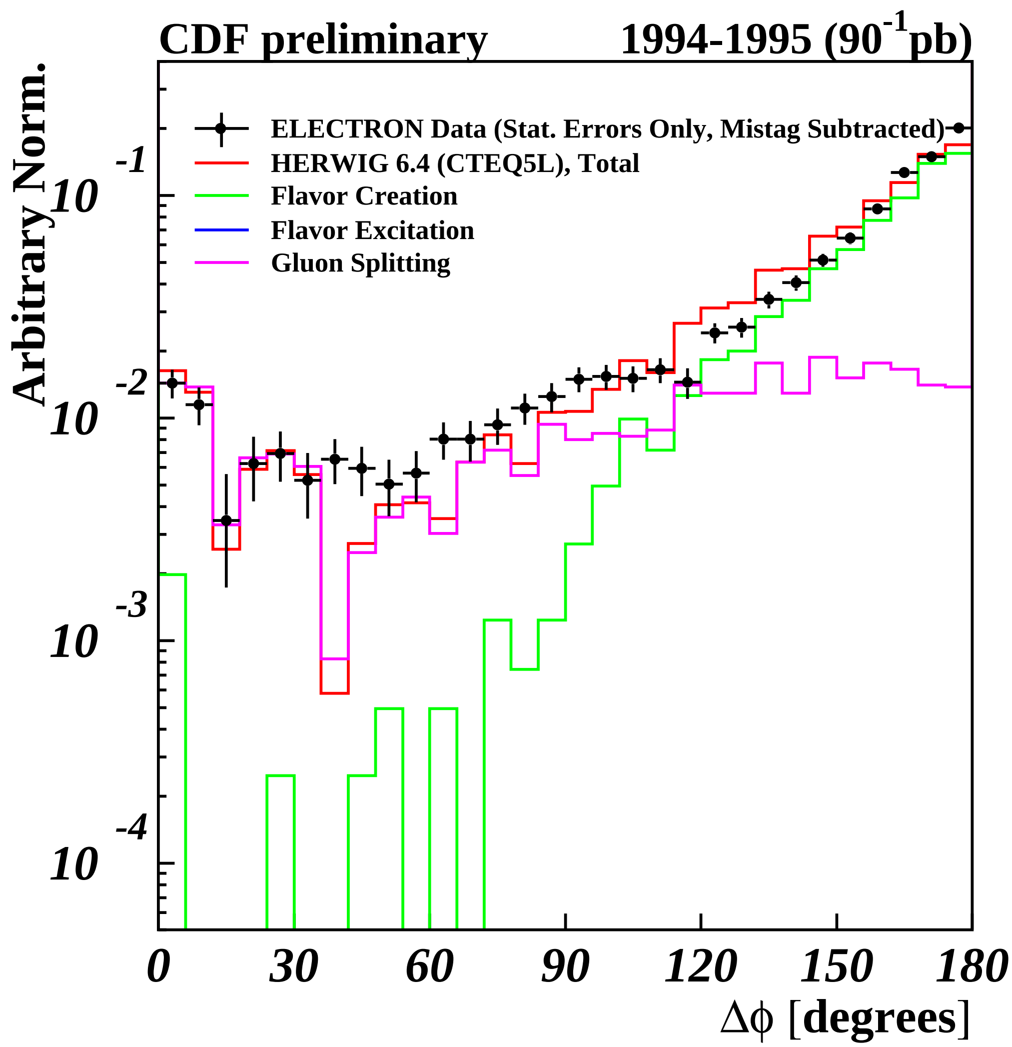

Figure 15: A comparison between the $\Delta\phi$ distribution for electron data and HERWIG. The data is mistag subtracted but not corrected for other backgrounds or detector effects. The Monte Carlo has been passed through a detector simulation and treated as data. The data is normalized to unit area. The normalizations of the three production mechanisms for the Monte Carlo distribution are allowed to float in a fit to produce the best match to the data. Note, the fit has set the flavor excitation normalization to zero.

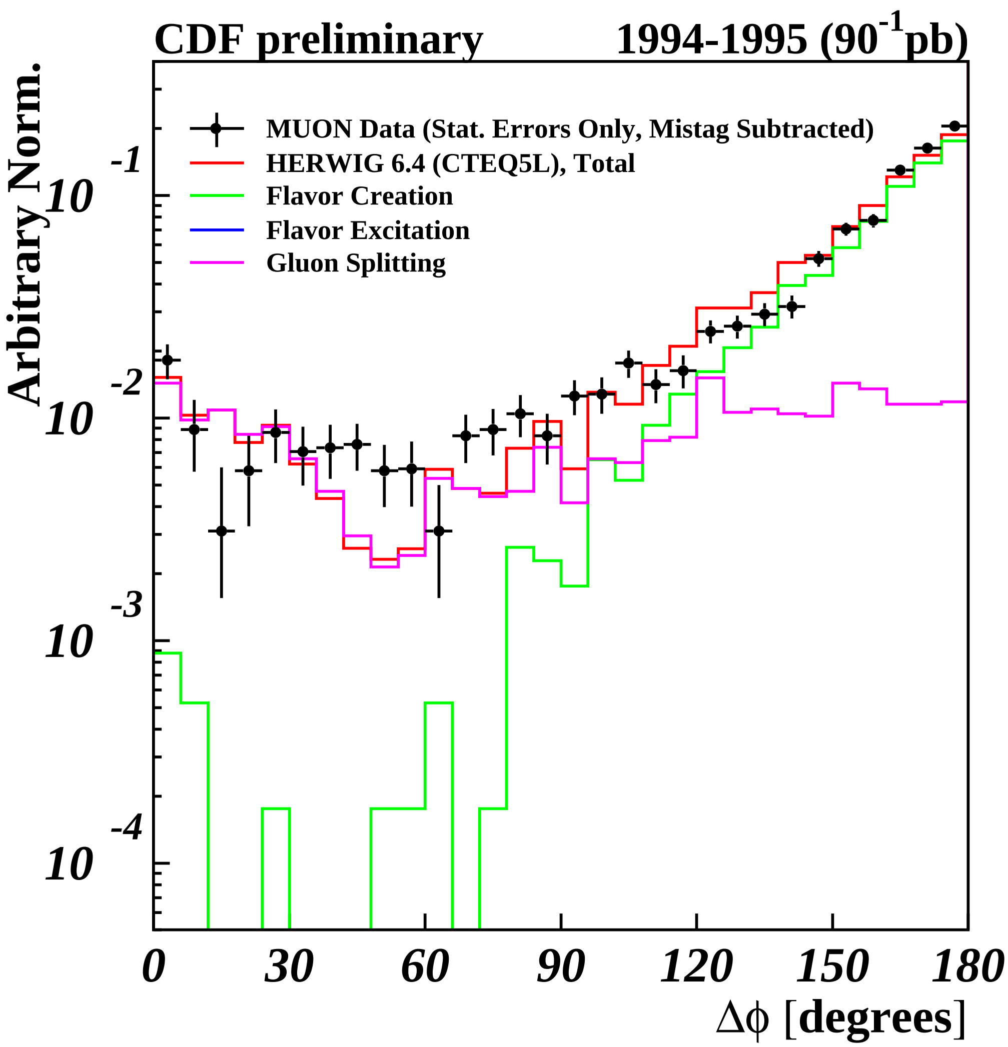

Figure 16: A comparison between the $\Delta\phi$ distribution for muon data and HERWIG. The data is mistag subtracted but not corrected for other backgrounds or detector effects. The Monte Carlo has been passed through a detector simulation and treated as data. The data is normalized to unit area. The normalizations of the three production mechanisms for the Monte Carlo distribution are allowed to float in a fit to produce the best match to the data. Note, the fit has set the flavor excitation normalization to zero.

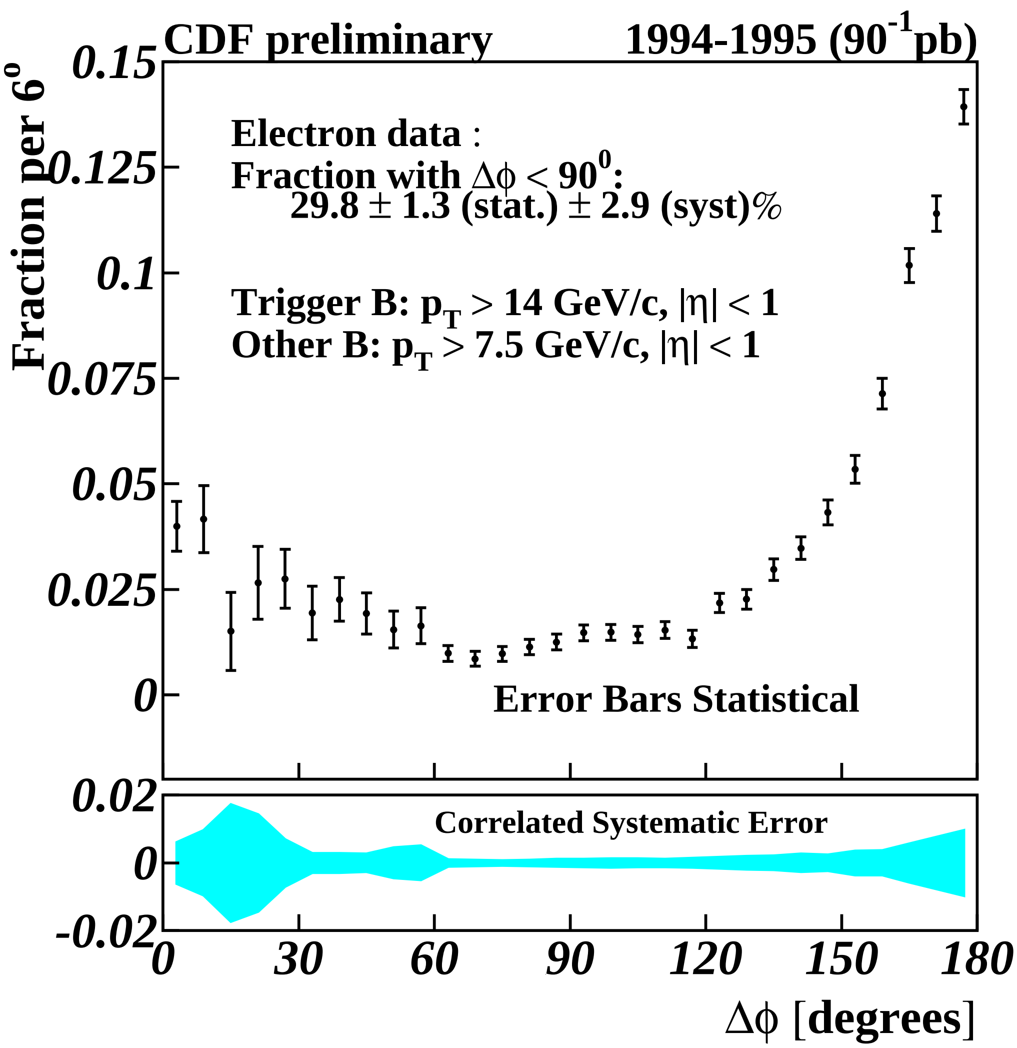

Figure 17: The corrected $\Delta\phi$ distribution for the electron data. The corrections include mistag subtraction, prompt charm subtraction, sequential removal, and the relative tagging efficiency correction. The systematic error is correlated from bin to bin.

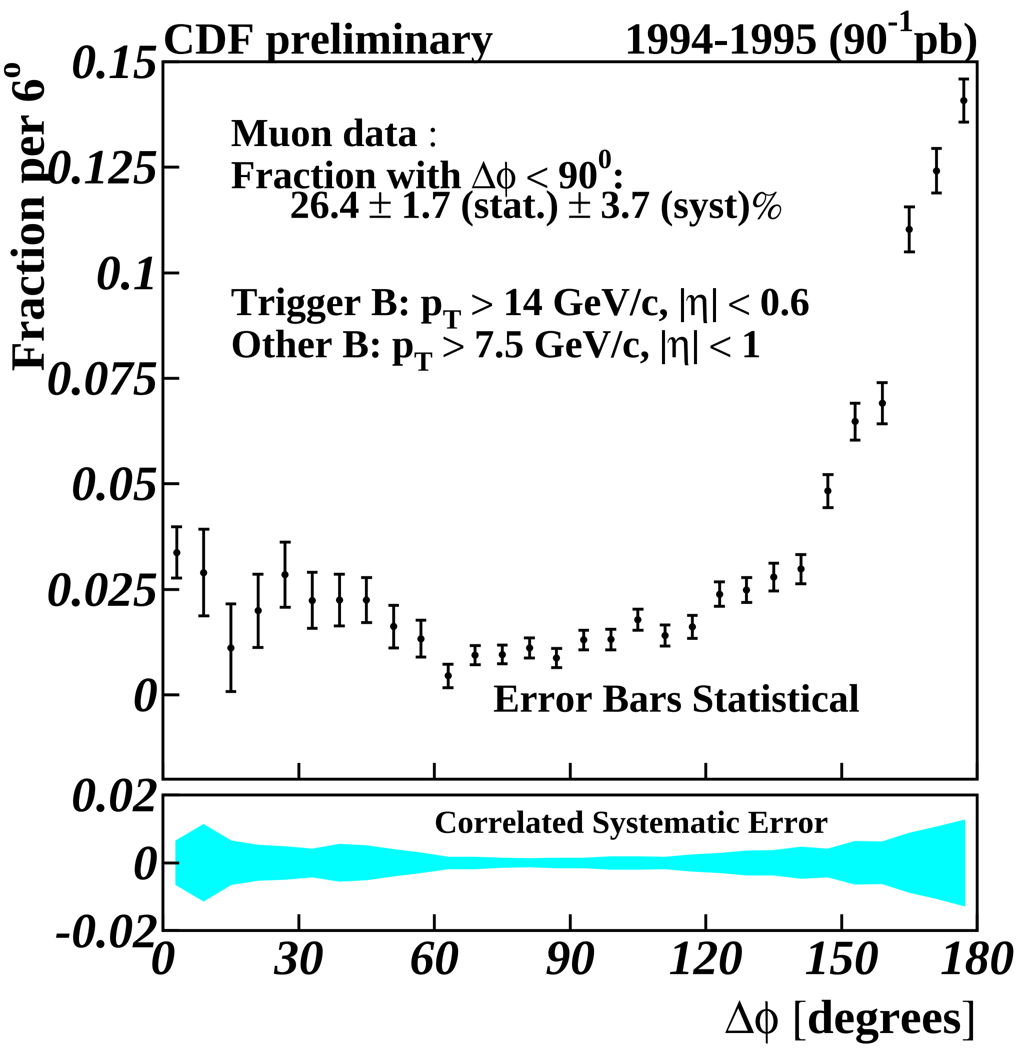

Figure 18: The corrected $\Delta\phi$ distribution for the muon data. The corrections include mistag subtraction, prompt charm subtraction, sequential removal, and the relative tagging efficiency correction. The systematic error is correlated from bin to bin.

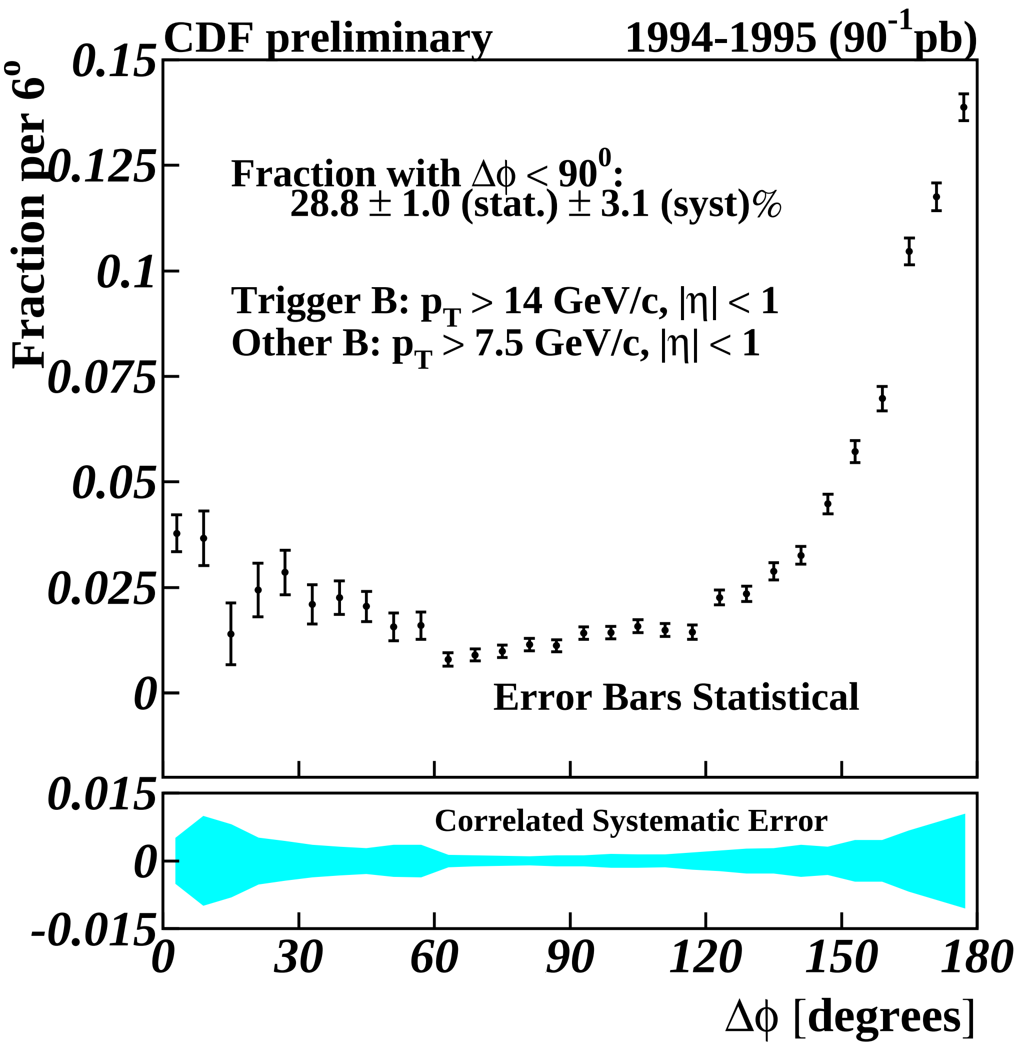

Figure 19: The corrected $\Delta\phi$ distribution for the combined electron and muon data samples. In combining these samples we have ignored the slight difference in η acceptance for the two triggers. The corrections include mistag subtraction, prompt charm subtraction, sequential removal, and the relative tagging efficiency correction. The systematic error is correlated from bin to bin.