CDF/ANAL/ELECTROWEAK/CDFR/xxxx
12June 2010

Plans for Analysis of Drell-Yan A_{fb} with electrons and muons

J.-Y. Han, A. Bodek, Y.S. Chung, K.S. McFarland, and W.K. Sakumoto
University of Rochester

ABSTRACT
A plan for the analysis of Drell-Yan A_{fb} with electrons and muons is outlined. The plan is to use about 6 fb^{-1} of data for each channel and perform an analysis which is not sensitive to efficiencies and acceptance. The plan works for both electrons and muons and for both Tevatron and LHC data. This study will be for the purpose of a CDF publication, and will be repeated for CMS.

.

1 Executive Summary

We propose to do the analysis of A_{fb} in two phases. We would like to collaborate with the muon group so that we can compare the results in the electron and muon channel. We want to do the analysis in a way that is not sensitive to details of CDF time dependent efficiencies and acceptance. If we use the angle event weighting technique, most of the acceptance and efficiencies cancel, and the analysis can be done immediately and yield results very quickly (called phase 1). This is the quickest way to search for a Z' in the asymmetry and dN/dM A more sophisticated analysis using event weighting angle and y is even less sensitive to the acceptance and efficiencies, but required much more work. However, it is directly applicable to CMS and the LHC. There are three goals.

1. Asymmetry and dN/dM(Born level and Quark level) in fine bins to search for Z', and also determine the sine of the electroweak mixing angle. Note for the case of destructive interference, a Z' can yield a dip in dN/dM in the region where the asymmetry has a dip followed (or preceded) by a small peak in the region where the asymmetry has a slight rise.

2. Asymmetry and dN/dM (Born level and Quark level) for two $|y|$ bins, $|y| < 1$ and $|y| > 1$ to get a constraint on the antiquarks in the nucleons and PDFs.

3. Asymmetry and dN/dM (Born level and Quark level, and Physical Asymmetry) to extract quark couplings,

CDF bins	$< M >$	*Dzero bins*	$< M >$	*comment*
50-60	45.5	50-60	45.5	1 same
60-70	64.5	60-70	64.5	2 same
70-75	72.6	70-75	72.6	3 same
75-81	78.3	75-81	78.3	3 same
81-86.5	84.4	81-86.5	84.4	5 same
86.5-89.5	88.4	86.5-89.5	88.4	5 same
89.5-92	90.9	89.5-92	90.9	6 same
92-97	93.4	92-97	93.4	7 same 5 GeV
97-105	99.9	97-105	99.9	8 same 7 GeV
105-115	109.1	105-115	109.1	9 same 10 GeV
115-130	121.3	115-130	121.3	10 same 15 GeV
115-130	121.3	115-130	121.3	11 same 15 GeV
130-150	≈140	130-180	147.5	12 different 20 GeV
150-175	≈162.5			13 different 25 GeV
175-200	≈187.5	180-250	206.5	14 different 25 GeV
200-225	≈212.5			15 different 25 GeV
225-250	≈237.5			16 different 25 GeV
250-275	≈262.5			17 different 25 GeV
275-300	≈287.5	250-500	310.5	18 different 25 GeV
300-325	≈312.5			19 different 25 GeV
325-350	≈337.5			20 different 25 GeV
350-400	≈375			21 different 50 GeV
500-600	≈550			22 different 100 GeV
600-700	≈650			23 different 100 GeV
700-800	≈750			25 different 100 GeV
800-900	≈850			25 different 100 GeV
900-1000	≈950			26 different 100 GeV
1000-1200	≈1100			28 different 200 GeV
1200-1400	≈1300			29 different 200 GeV
1400-1600	≈1500			30 different 200 GeV
1600-1800	≈1700			31 different 200 GeV
1800-2000	≈1900			32 different 200 GeV
2000-2500	≈2250			33 different 500 GeV
2500-3000	≈2750			34 different 500 GeV

Table 1: Proposed binning for CDF and CMS in GeV.

2 Proposed Binning

We propose to use the same bins as in the Dzero paper (with $1fb^{-1}$) for ease of comparison, except about 130 GeV where we propose 25 GeV bins till 350 GeV, and then a 50 GeV bin and then 100 GeV bins. The results for the quark level asymmetry for CMS could be directly copmared to CDF.

3 Theory

We define several types types of A_{fb} for Drell-Yan interactions.

1. The first is A_{qq} which is A_{fb} at the quark level. This quantity is the asymmetry which is most sensitive to new resonances such as Z' bosons. In order to extract this asymmetry, we need to correct for events which originate from sea antiquarks, The interactions of sea antiquarks in the proton with sea quarks in the antiproton have the opposite asymmetry and therefore dilute the experimentally measured asymmetry. The quark level asymmetry is extracted f by correcting the measured asymmetry for detector acceptance, resolution and efficiencies, as well as correcting for radiative and EW effects, and also correcting for the antiquark dilution of the asymmetry. This asymmetry depends very weakly on the rapidity y, and is primarily dependent on the invariant mass of the final state dilepton (the weak y dependence is due to the fact that the ratio of d and u quarks in the proton is a function of x, and the d and u quarks have different asymmetries). We will be extracting the quark level asymmetries averaged overaged over all y.

2. The second asymmetry is $A_{Born} = A_{QCD}$ which is A_{fb} with all antiquark, gluon and QCD effects, but without any radiation of initial or final state photons and without electroweak effects. This is the one boson exchange asymmetry, which his similar to the Born level radiatively corrected lepton scattering structure functions. This asymmetry is obtained by radiatively correcting the experimentally measured asymmetry. It should be used to compare with QCD calculations. The y dependence of this asymmetry is sensitive to the antiquark dilution. This asymmetry depends both on the invariant mass of the final state dilepton and also on the rapidity y. One of the theoretical studies that we should do is find out how different the Born level asymmetry predictions for different programs (ResBos, VBO, POWHEG, mc@nlo etc) and for different PDFs (for the same value of the electroweak mixing angle). If we fix the electroweak parameters, this asymmetry can be used to test QCD calculations, and the y dependence can be used to test the antiquark fraction of different PDFs. Since this is a Born level cross section, it can also be used to extract a value for the effective electroweak mixing angle (under the assumption that the quark couplings are the same as the SM coupling). This is what has been done by the Dzero collaboration with $1fb^{-1}$ of data in the electron channel.

3. The third asymmetry is $A_{QCD+FSR+EW}$ (=$A_{physical}$) which is the physically measured A_{fb} including the photon radiation from the initial and final state quarks, and EW loop corrections. For electron-positron final states it depends on the experimental definition of a clustered electron (since some final state photons can be include in the electron cluster in the calorimeter). This asymmetry will be different for electrons and muons, because of of the effect of the clustering of final state photons. Photons which are close to the electron will be added to the energy of the electron, but not the muon. Therefore, a comparison of muon and electron asymmetry is of interest, and is an important constraint on how well we are applying radiative corrections. This asymmetry should be used if we want to measure the quark couplings by comparing the acceptance corrected measured $A_{QCD+FSR+EW}$ with a calculation which includes both QCD and photon and EW effects. This asymmetry depends both on the invariant mass of the final state dilepton and also on the rapidity y.

4. The fourth asymmetry is the experimentally measured asymmetry. This is $A^{reconstructed}_{QCD+FSR+EW}$. It depends on acceptance and experimental resolution. Therefore, it depends on the modeling of the acceptance of detector and efficiencies. The acceptance also depends on the physics model used in the acceptance calculation since we need to correct for missing phase space (e.g. limited coverage of $\cos\theta$ and limited coverage in y). Physics model assumptions include both QCD related parameters (e.g. PDFs and NLO corrections which affect the acceptance in y and determine dN/dM), EW radiative corrections (which affect the acceptance in $\cos\theta$ and combined QCD and EW effects (e.g. the mass shift resulting from final state photon emission).

Previous analysis by $Dzero$ corrected the $A^{reconstructed}_{QCD+FSR+EW}$ for acceptance and resolution of the detector to obtain $A_{QCD+FSR+EW}$, followed by applying a radiative correction to obtain $A_{born} = A_{QCD}$. They published a table of the Born level asymmetry. They also compared the reconstructed asymmetry to a MC model which includes all of these effects and extracted a value for the effective electroweak mixing angle.

Previous analyses by $Dzero$ and CDF corrected for FSR using a matrix method, and then applied an EW correction. Both radiative corrections rely on modeling the cross sections and asymmetry as a function of mass. The previous analyses have used matrix inversion method (using Pythia in EW leading order) to unfold the effect of FSR radiation and extract the Born level asymmetry as a function of mass. The matrix method reduces the insensitivity to the assumed model of the cross section and A_{fb}. However, this method increases the statistical errors, and does not account for higher order EW effects.

A full EW/FSR correction includes emissions by photons both in the initial and final states as well as virtual loop corrections. It is not possible to theoretically separate FSR, photon ISR and EW loop corrections. The only way to determine a the full EW/FSR correction is to use a model for A_{Born}. Therefore, the matrix inversion method cannot be used if we want to look for small deviations from standard model predictions.

This was the case in the early electron scattering experiments in the 1960's. The measured cross sections were corrected for radiative photon emission by unfolding the raw data in a way similar to the Matrix method. A few years later this method was abandoned since it could not be used for higher order radiative corrections. In addition, the structure functions were already well know, so that getting the higher order radiative correction correctly was more important. The current process in the lepton scattering experiments is to extract the Born level structure functions using a model input to the radiative corrections, and them use the new measurement of the structure functions to improve the model and iterate.

We propose to do the same by extracting the Born level asymmetry and Born level dN/dM and iterating.

A model for A_{Born} and dN/dM is already needed to correct for acceptance, efficiencies and detector resolution effects. Therefore, it is impossible to have a model independent measurement of the asymmetry since both acceptance, resolution and higher order EW corrections require a good model of the Born cross section. The predictions of the standard model for A_{Born} are known much better than the measured values of A_{Born} as a function of mass. A large contribution to the experimental errors originate from acceptance/effiency corrections and detector resolution. These corrections depends both on A_{Born} and on modeling the detector and time dependent efficiencies. If there is new physics beyond the SM, the predictions for the Born cross sections will not be correct (since they may have a peak e.g. from new Z' boson).

If we apply a dilution correction to A_{born} ($= A_{QCD}$) we obtain A_{qq}.

As described in reference 1, the event weighting techniques uses weights which depend on the measured values of $\cos\theta$ and y for each event. These weights are used to extract A_{fb} at the quark level. This technique is not sensitive to modeling of the acceptance and efficiencies of the detector. The only remaining correction that needs to be applied is the correction for detector resolution effects. In addition to the reduced sensitivity to detector modeling, the event weighting technique reduced the statistical errors by 20% for $p\bar{p}$ and up to 40% for pp.

We will use both the simple standard technique and the event weighting technique to extract A_{qq}, A_{Born}, and $A_{born+FSR/EW}$ from the measured events. For the event weighting technique we will be using the expressions from reference 1.

4 Simple Analysis

We first discuss the simple standard way of doing the asymmetry analysis. First we extract the raw experimental asymmetry from the data. Here, the simple analysis $A_{raw}(M)$ is just a ratio $(N^+ - N^-)/(N^+ + N^-)$. For the reconstructed we use the same formula We can compare data and MC reconstructed in the same way as shown in figure 1.

We can also multiply $A_{raw}(M)$ by an acceptance plus efficiency plus resolution correction as determined from the CDF $PYTHIA$ Monte Carlo. The acceptance/efficieny/resoltuion correction is $C(M) = \frac{A^{P\ generated}_{qq+\bar{q}\bar{q}+ISR+FSR}}{A^{P\ reconstructed}_{qq+\bar{q}\bar{q}+ISR+FSR}}$. This correction is used to extract $A_{physical}$,

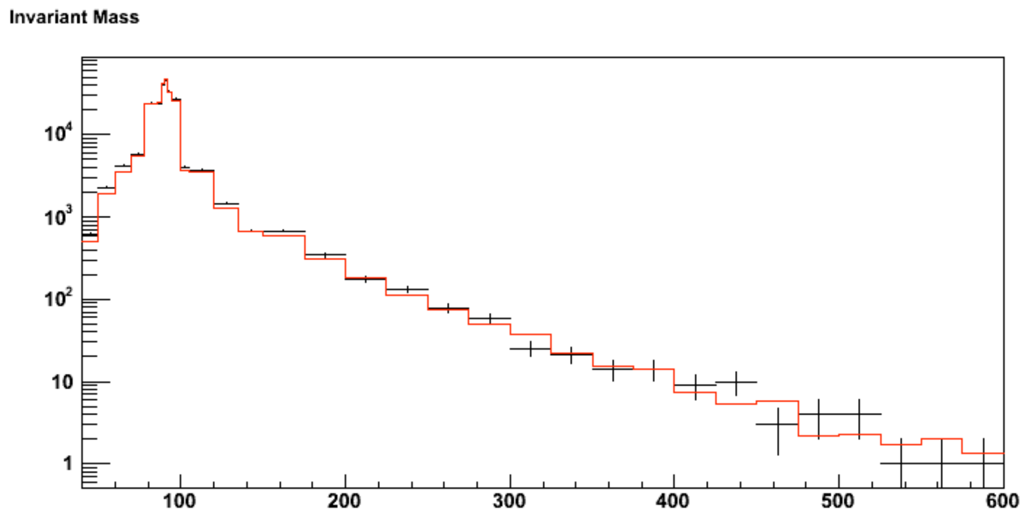

Figure 1: Preliminary CDF results: dN/dm for $e+e-$ final states with $4.1fb^{-1}$ using the standard simple analysis. Shown are reconstructed data and reconstructed CDF Pythia MC.

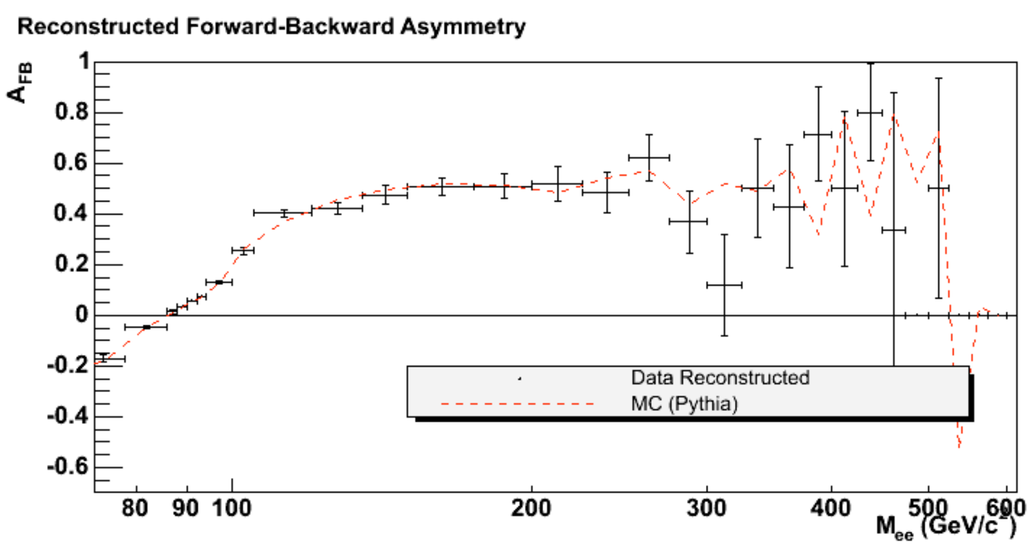

Figure 2: Preliminary CDF results: A_{fb} for $e+e-$ final states with $4.1fb^{-1}$ using the standard simple analysis. Shown are reconstructed data and reconstructed CDF Pythia MC.

which is the measured asymmetry with all acceptance, efficiency and resolution smearing corrections. The physical asymmetry can be compared to the $ZGRAD$ predictions and used extract quark couplings from the data. Since $ZGRAD$ doe not include the effects of quark transverse momentum, we correct the $ZGRAD$ predictions for QCD effects by using $A^{theory}_{physical} = A^{Z}_{qq+\bar{q}\bar{q}+FSR+EW} \times \frac{A_{QCD}}{A^{Z}_{qq+\bar{q}\bar{q}}}$.

The factor multiplying the $ZGRAD$ asymmetry accounts for the effect of the quark transverse momentum. Here, A_{QCD} is the Born cross section from a NLO program such as VPB, $ResBos$ or $POWHEG$ predicted using a NLO PDF such as CTEQ6.6, and $A^{Z}_{qq+\bar{q}\bar{q}}$ is the Born cross section from $ZGRAD$ (which does not include the effecds of quark transverse momentum) for the same NLO PDF.

We will use superscript P for $PYTHIA$, superscript Z for ZGRAD, and superscript NLO or $ResBos$ or VBP or $POWHEG$ for a specific NLO program.

In summary, the following are integrated asymmetries over all values of y using the simple standard analysis.

If we use only $PYTHIA$ we get.

1. $A^{measured}_{physical}(M) = A^{measured}_{raw}(M) \times \frac{A^{P\ generated-cteq5L}_{qq+\bar{q}\bar{q}+ISR+FSR}}{A^{P\ reconstructed-cteq5L}_{qq+\bar{q}\bar{q}+ISR+FSR}}$

2. $A^{measured}_{Born}(M) = A^{measured}_{raw}(M) \times \frac{A^{P\ generated-cteq5L}_{qq+\bar{q}\bar{q}+ISR}}{A^{P\ reconstructed-cteq5L}_{qq+\bar{q}\bar{q}+ISR+FSR}}$

3. $A^{theory}_{Born}(M) = A^{NLO-cteq66}_{QCD}$ from and NLO program.with a given NLO PDF.

4. $A^{measured}_{qq}(M) = A^{measured}_{raw}(M) \times \frac{A^{P\ generated-cteq5L}_{qq}}{A^{P\ reconstructed-cteq5L}_{qq+\bar{q}\bar{q}+ISR+FSR}}$

5. $A^{theory}_{qq}(M) = A^{Pythia-cteq5L}_{qq} (or A^{P-cteq66}_{qq})$

If we use combined $PYTHIA$ and NLO and $ZGRAD$ to include EW radiative corrections.

1. $A^{measured}_{physical}(M) = A^{measured}_{raw}(M) \times \frac{A^{P\ generated-cteq5L}_{qq+\bar{q}\bar{q}+ISR+FSR}}{A^{P\ reconstructed-cteq5L}_{qq+\bar{q}\bar{q}+ISR+FSR}}$

2. $A^{measured}_{Born}(M) = A^{measured}_{physical}(M) \times \frac{A^{Z-cteq66}_{qq+\bar{q}\bar{q}+FSR+EW}}{A^{Z-cteq66}_{qq+\bar{q}\bar{q}}}$.

3. $A^{measured}_{qq}(M) = A^{measured}_{physical}(M) \times \frac{A^{Z-cteq66}_{qq+\bar{q}\bar{q}+FSR+EW}}{A^{P-cteq66}_{qq+\bar{q}\bar{q}}}$.

4. $A^{theory}_{physical}(M) = A^{Z}_{qq+\bar{q}\bar{q}+FSR+EW} \times \frac{A^{NLO-cteq66}_{QCD}}{A^{Z-cteq66}_{qq+\bar{q}\bar{q}}}$.

5. $A^{theory}_{Born}(M) = A^{NLO-cteq66}_{QCD}$ from a NLO program (e.g. Resbos, VBP or Powheg) with a given NLO PDF.

6. $A^{theory}_{qq}(M) = A^{Pythia-cteq66}_{qq} (= A^{P-cteq66}_{qq})$

In addition, we extract dN/dM which is discussed at the end of this note.

5 Quarks bound in a nucleon

When quarks are bound in the nucleon, the dilepton can be produced with non-zero transverse momentum. This is described in detail in appendix A. For $p\bar{p}$ or pp collisions the angular distribution of γ^*/Z vector bosons decaying to e^+e^- or $\mu^+\mu^-$ pairs is given by:

$$\frac{d\sigma}{d(\cos\theta)} = A[1+\cos^2\theta + h(\theta)] + B\cos\theta \tag{1}$$

$$h(\theta) = \frac{1}{2}A_0(M_{\ell\ell}, P_T)(1-3\cos^2\theta) \tag{2}$$

The $q\bar{q}$ center of mass frame is well defined when the lepton pair has zero transverse momentum (P_T). For a non-zero transverse momentum of the dilepton pair, the $q\bar{q}$ center of mass frame is approximated by the Collins-Soper frame[2].

The term $h(\theta, M_{\ell\ell}, P_T)$ is a small QCD correction term which is zero when the transverse momentum of the dilepton pair is zero. The $h(\theta, M_{\ell\ell}, P_T)$ term integrates to zero when the cross section is integrated over all $\cos^2\theta$. For quark-antiquark annihilation the angular coefficient A_0 is only a function of the dilepton mass ($M_{\ell\ell}$) and transverse momentum (P_T) and is given by:

$$A_0 = \frac{P_T^2/M_{\ell\ell}^2}{1+P_T^2/M_{\ell\ell}^2} \tag{3}$$

6 Phase 1: The angle event weighting technique

Each event has a measured value of $|c_j| = |\cos\theta_j|$. The expressions for combining events with different $|c_j| = |\cos\theta_j|$ and values to yield the *Born* level asymmetry are derived in Ref. 1. The expressions are:

$$\begin{aligned}
z_{1,j} &= \frac{1}{2}\frac{c_j^2}{(1+c_j^2+h(\theta,P_T))^3} \\
z_{2,j} &= \frac{1}{2}\frac{|c_j|}{(1+c_j^2+h(\theta,P_T))^2} \\
N_{total} &= \sum_{all-events}[1] \\
A_1 &= \sum_{forward-events}[z_{1,j}] \\
A_2 &= \sum_{back-events}[z_{1,j}] \\
B_1 &= \sum_{forward-events}[z_{2,j}] \\
B_2 &= \sum_{back-events}[z_{2,j}]
\end{aligned} \tag{4}$$

$$
\begin{aligned}
[\Delta A_1]^2 &= \sum_{forward-events} \left[z_{1,j}^2\right] \\
[\Delta A_2]^2 &= \sum_{back-events} \left[z_{1,j}^2\right] \\
[\Delta B_1]^2 &= \sum_{forward-events} \left[z_{2,j}^2\right] \\
[\Delta B_2]^2 &= \sum_{back-events} \left[z_{2,j}^2\right] \\
A &= A_1 + A_2 \\
B &= B_1 - B_2 \\
[A_{fb}]^{total} &= \frac{3}{8}\frac{B}{A} = \frac{3}{8}\frac{B_1 - B_2}{A_1 + A_2} \\
\Delta A_1 &= \Delta B_1 \cdot \frac{A1}{B1} \\
\Delta A_2 &= \Delta B_2 \cdot \frac{A2}{B2} \\
\left[\Delta A_{fb}^{total}\right]^2 &= \left[\frac{3}{8}\right]^2 \frac{1}{(A_1 + A_2)^4} \left[E_1^2 + E_2^2\right] \\
E_1^2 &= \frac{[\Delta B_1]^2}{B_1^2} (A2B1 + A1B2)^2 \\
E_2^2 &= \frac{[\Delta B_2]^2}{B_2^2} (A2B1 + A1B2)^2
\end{aligned}
$$

Note that since we add up the forward and backwards events in separate sums, the weighting factors $z_{1,j}$ and $z_{2,j}$ are functions of the absolute value $|\cos\theta|$.

The $|\cos\theta|$ event weighting takes care of most of the $|\cos\theta|$ acceptance and efficiencies. However, it does not correct for resolution smearing, radiative corrections and the fact that the asymmetry is a function of y and the acceptance of the detector is a function of y. Therefore, although it is smaller then in the simple technique, a correction for acceptance and radiative effects still needs to be made.

The rest of the analysis follows in the same way as for the simple standard analysis, except for the fact that both the "measured" and MC "reconstructed" asymmetries in the expression given above (section on simple analysis) now use the angle event weighting technique.

7 Phase 2: Combined angle and dilution event weighting technique

In pp or $p\bar{p}$ collisions each event is can be characterized by a *misID* factor $w_i(|y_i|)$ which is related to the quark and antiquark distribution ($x_{1,2} = (M_{\ell\ell}/\sqrt{s})e^{\pm|y|}$) at its value of $|y_i|$. In addition, each event has a measured value of $|c_j| = |\cos\theta_j|$. The expressions for combining events with different $|c_j| = |\cos\theta_j|$ and *misID* w_i values to yield the *quark* level asymmetry are derived in Ref. 1. The expressions are:

$$
\begin{aligned}
k_{A,i} &= k_{1,i} - k_{2,i} = (1-2w_i)^2 \\
k_{B,i} &= k_{1,i} + k_{2,i} = (1-2w_i) \\
N_{total} &= \sum_{all-events} [1] \\
z_{1,j} &= \frac{1}{2}\frac{c_j^2}{(1+c_j^2+h(\theta))^3} \\
z_{2,j} &= \frac{1}{2}\frac{|c_j|}{(1+c_j^2+h(\theta))^2} \\
A_1 &= \sum_{for-events} [z_{1,j}k_{A,j}] \\
A_2 &= \sum_{back-events} [z_{1,j}k_{A,j}] \\
B_1 &= \sum_{for-events} [z_{2,j}k_{B,j}] \\
B_2 &= \sum_{back-events} [z_{2,j}k_{B,j}] \\
[\Delta A_1]^2 &= \sum_{for-events} \left[z_{1,j}^2 k_{A,j}^2\right] \\
[\Delta A_2]^2 &= \sum_{back-events} \left[z_{1,j}^2 k_{A,j}^2\right] \\
[\Delta B_1]^2 &= \sum_{for-events} \left[z_{2,j}^2 k_{B,j}^2\right] \\
[\Delta B_2]^2 &= \sum_{back-events} \left[z_{2,j}^2 k_{B,j}^2\right] \\
A &= A_1 + A_2 \\
B &= B_1 - B_2 \\
[\Delta A_1] &= [\Delta B_1] \cdot \frac{A1}{B1} \\
[\Delta A_2] &= [\Delta B_2] \cdot \frac{A2}{B2} \\
A_{fb}^{total} &= \frac{3}{8}\frac{B}{A} = \frac{3}{8}\frac{B_1 - B_2}{A_1 + A_2} \\
\left[\Delta A_{fb}^{total}\right]^2 &= \left[\frac{3}{8}\right]^2 \frac{1}{(A_1+A_2)^4}\left[E_1^2 + E_2^2\right] \\
E_1^2 &= \frac{[\Delta B_1]^2}{B_1^2}(A2B1 + A1B2)^2 \\
E_2^2 &= \frac{[\Delta B_2]^2}{B_2^2}(A2B1 + A1B2)^2
\end{aligned}
\tag{5}
$$

The above expressions yield a quark level asymmetry which has not been corrected for effect of resolution smearing nor FSR/EW radiative corrections. We can correct for these effects by including them in a modified effective $misID$ factor $w(M,|y_i|)$.

Table 1 shows the various asymmetries that can be extracted $PYTHIA$, NLO and $ZGRAD$. If we wish to neglect EW radiative corrections we can use a pure LO $PYTHIA$ based analysis. If we wish to include EW radiative corrections and QCD NLO, we need to use a combination of results from $PYTHIA$, $ZGRAD$ and a Born level NLO asymmetry (from a $ResBos$, VBP or $POWHEG$)

If we define $R(M,|y_i|) = \frac{1}{(1-2w(M,|y_i|)}$ then if we use $PHYTIA$ we define :

1. $R_0^P(M,|y_i|) = \frac{A_{qq+\bar{q}\bar{q}+ISR}^{P-cteq5L}}{A_{qq}^{P-cteq5L}}$ (yields $w_0^P(M,|y_i|)$ which only corrects for antiquark dilution and P_T from ISR). If we use $w_0(M,|y_i|)$ to extract the asymmetry, we will need to apply further corrections for detector resolution smearing and radiative corrections. Therefore, we will not use $R_0(M,|y_i|)$ or $w_0(M,|y_i|)$ in our analysis.

2. $R_1^P(M,|y_i|) = \frac{A_{qq+\bar{q}\bar{q}+ISR+FSR}^{P-cteq5L}}{A_{qq}^{P-cteq5L}}$ (yields $w_1^P(M,|y_i|)$ which includes corrections for antiquark dilution, P_T from ISR, and final state FSR, but does not include any corrections for detector resolution We will use $w_1(M,|y_i|)$ in our analysis to reconstruct a first iteration asymmetry, and add the effect of resolution iteratively using $w_2(M,|y_i|)$ as shown below.

3. $R_2^P(M,|y_i|) = R_1^P(M,|y_i|) \times \frac{A_{recon}^P(W_1^P)}{A_{qq}^{P-cteq5L}}$ (yields $w_3^P(M,|y_i|)$ which now includes corrections for antiquark dilution, P_T from ISR, and final state FSR and also a correction for experimental resolution and corrections for any deviations from the angular distribution, and y dependence assumed in this technique,

If we use $ZGRAD$ we define:

1. $R_0^Z(M,|y_i|) = \frac{A_{QCD}^{res-cteq66}}{A_{qq}^{P-cteq66}}$ ((yields $w_0^Z(M,|y_i|)$ which only corrects for antiquark dilution and P_T from ISR). If we use $w_0(M,|y_i|)$ to extract the asymmetry, we will need to apply further corrections for detector resolution smearing and radiative corrections. Therefore, we will not use $R_0(M,|y_i|)$ or $w_0(M,|y_i|)$ in our analysis.

2. $R_1^Z(M,|y_i|) = \frac{A_{QCD+ISR+FSR/EW}^{Z}}{A_{qq}^{P-cteq66}}$ (yields $w_1^Z(M,|y_i|)$ which includes corrections for antiquark dilution, P_T from ISR, and final state FSR, but does not include any corrections for detector resolution We will use $w_1(M,|y_i|)$ in our analysis to reconstruct a first iteration asymmetry, and add the effect of resolution iteratively using $w_2(M,|y_i|)$ as shown below.

3. We add a correction for experimental resolution using $R_2^Z(M,|y_i|) = R_1^Z(M,|y_i|) \times \frac{A_{recon}^P(W_1^P)}{A_{qq}^{P-cteq5L}}$. We must use $\frac{A_{recon}^P(W_1^P)}{A_{qq}^{P-cteq5L}}$ to correct for experimental resolution because only $PYTHIA$ is implemented in a full CDF MC which allows use to extract reconstructed variables in MC. (yields $w_3^Z(M,|y_i|)$ which now includes corrections for antiquark dilution, P_T from ISR, and final state FSR and also a

correction for experimental resolution and corrections for any deviations from the angular distribution, and y dependence assumed in this technique,

After we extract the measured quark level asymmetry versus M, we obtain the measured Born level asymmetry by multiplying by the ratio of the theoretical Born level asymmetry to the theoretical quark level asymmetry from either $PYTHIA$ for the PYTHIA based analysis or $ZGRAD$ for a $ZGRAD$ based analysis.

Similarly, we obtain the measured Physical asymmetry by by multiplying by the ratio of the theoretical physical asymmetry to the theoretical quark level asymmetry from either $PYTHIA$ for the PYTHIA based analysis or $ZGRAD$ for a $ZGRAD$ based analysis.

i.e. Using the entries in Table 1, If we use only $PYTHIA$ based analysis we get.

1. $A_{Born}^{measured}(M) = A_{qq}^{measured}(M) \times \frac{A_{qq+\bar{q}\bar{q}+ISR}^{P-cteq5L}}{A_{qq}^{P-cteq5L}}$

2. $A_{Born}^{theory}(M) = A_{QCD}^{NLO-cteq66}$ from and NLO program.with a given NLO PDF.

3. $A_{physical}^{measured}(M) = A_{qq}^{measured}(M) \times \frac{A_{qq+\bar{q}\bar{q}+ISR+FSR}^{P-cteq5L}}{A_{qq}^{P-cteq5L}}$

If we use combined $PYTHIA$ and NLO and $ZGRAD$ to include EW radiative corrections we get.

1. $A_{Born}^{measured}(M) = A_{qq}^{measured}(M) \times \frac{A_{QCD}^{res-cteq66}}{A_{qq}^{P-cteq66}}$

2. $A_{Born}^{theory}(M) = A_{QCD}^{NLO-cteq66}$ from and NLO program.with a given NLO PDF.

3. $A_{physical}^{measured}(M) = A_{qq}^{measured}(M) \times \frac{A_{qq+\bar{q}\bar{q}+FSR+EW}^{Z}}{A_{qq}^{P-cteq6L}} \times \frac{A_{QCD}}{A_{qq+\bar{q}\bar{q}}^{Z}}$

8 Preparing the MC data sets

We want to measure $A_{qq}(M)$, $A_{Born}(M) = A_{QCD}(M)$, and $A_{QCD+FSR/EW}(M)$ averaged over all y. As a check we want to measure $A_{qq}(M)$ (averaged over all y) by using data for $|y| < 1$ and for $|y| > 1$. These two measurement should agree with each other and provide a measure of how well we know the antiquark distribution. Around the Z peak, the fraction of events from the antiquarks is about 10% and 5%, for $|y| < 1$ and for $|y| > 1$, respectively.

$A_{qq}(M)$ and dN/dM will be used to search for deviations from the Standard Model (e.g. Z'). $A_{QCD+FSR/EW}(M)$ will be used to measure deviations of the quark coupling from the SM predictions.

In order to use the formulae above we need to know most of the asymmetries shown in Table 1 as a functions of mass and $|y|$. One way to do so is to make tables using large Monte Carlo statistics of these parameters in 12 bins of $|y|$ in steps of 0.25 in $|y|$ from 0 to 3. In addition, we need to determine the parameters in the table as a function of mass (integrated over y).

A_{fb} *sample*	$PHYTIA^P$ default QCD LO	$QCD-ResBos$ or VBP etc. QCD NLO	$ZGRAD^Z$ QCD LO	$ZGRAD+PYTHIA$ combined LO and NLO
$A_{qq}(M, all\ y)$	$A_{qq}^{P-cteq5L}(M)$	$A_{qq}^{P-cteq66}(M)$	$A_{qq}^{P-cteq66}(M)$	$A_{qq}^{P-cteq66}(M)$
$A_{qq+\bar{q}\bar{q}}(M, y)$	$A_{qq+\bar{q}\bar{q}}^{P-cteq5L}$	$not\ defined$	$A_{qq+\bar{q}\bar{q}}^{Zcteq6.6}$	$A_{qq+\bar{q}\bar{q}}^{Z-cteq6.6}$
$A_{Born}=A_{QCD}$	$A_{qq+\bar{q}\bar{q}+ISR}^{P-cteq5L}$	$A_{QCD}^{res-cteq66}$	$not-available$	$A_{QCD}^{res-cteq66}$
$A_{qq+q\bar{q}+FSR}$	$A_{qq+q\bar{q}+FSR}^{P-cteq5L}$	na	$not\ defined$	$not-defined$
$A_{qq+\bar{q}\bar{q}+FSR+EW}$	na	na	$A_{qq+\bar{q}\bar{q}+FSR+EW}^{Z-cteq66}$	$A_{qq+\bar{q}\bar{q}+FSR+EW}^{Z-cteq66}$
$A_{QCD+FSR}$	$A_{qq+\bar{q}\bar{q}+FSR+ISR}^{P-cteq5L}$	na	$not\ defined$	$not\ defined$
$A_{QCD+FSR+EW}$	na	na	na	$A_{QCD+FSR+EW}^{Z} = A_{qq+\bar{q}\bar{q}+FSR+EW}^{Z} \times \frac{A_{QCD}}{A_{qq+\bar{q}\bar{q}}^{Z}}$
corrected for	recon MC	recon Data	corrected for	recon Data
QCD	$A_{recon}^{p}(w_0^P)$	$A_{recon}^{data}(w_0^p)$	QCD	$A_{recon}^{data}(w_0^Z)$
QCD+FSR	$A_{recon}^{p}(w_1^P)$	$A_{recon}^{data}(w_1^p)$	QCD+EW	$A_{recon}^{data}(w_1^Z)$
QCD+FSR+res	$A_{recon}^{p}(w_2^P)$	$A_{recon}^{data}(w_2^p)$	QCD+EW+res	$A_{recon}^{data}(w_2^Z)$

Table 2:

References

[1] A simple event weighting technique for optimizing the measurement of the forward-backward asymmetry of Drell-Yan dilepton pairs at hadron colliders. Arie Bodek, Eur.Phys.J.C67:321-334,2010 e-Print: arXiv:0911.2850 [hep-ex]

[2] J.C. Collins and D.E. Soper, Phys. Rev. **D16**, 2219 (1977).