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Forward Backward Asymmetry for Λ, Ξ and Ω baryons

Brad Abbott*
University of Oklahoma
E-mail: abbott@nhn.ou.edu

We measure the forward backward asymmetries A_{FB} for Λ, $\Xi^{\pm}$ and $\Omega^{\pm}$ baryons produced in $p\bar{p}$ collisions by the D0 detector at the Fermilab Tevatron collider at $\sqrt{s}$=1.96 TeV. The forward backward asymmetry is measured as a function of rapidity and we find the asymmetries for charged Ξ and Ω baryons are consistent with zero while the $\bar{\Lambda}/\Lambda$ production ratio is a universal function of "rapidity loss", the rapidity difference between the beam proton and the Λ.

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*Speaker.

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1. Introduction

We present a measurement of the forward backward asymmetry of Λ, $\Xi^{\pm}$ and $\Omega^{\pm}$ baryons produced in $p\bar{p}$ collisions by the D0 detector at the Fermilab Tevatron collider at $\sqrt{s}$=1.96 TeV. The full dataset of 10.4 fb^{-1} is analyzed to determine if the studied baryons retain some memory of the direction of the original proton and anti-proton beams. We consider a picture where a strange quark can coalesce with a diquark remnant of the beam to produce a lambda baryon with the probability of coalescence increasing as the rapidity difference between the proton and the lambda decrease. In this picture we expect to see an asymmetry in Λ-$\bar{\Lambda}$ production but no asymmetry for charged Ξ and Ω baryons since they do not share a diquark with the proton. The Λ, Ξ^- and Ω^- baryons are defined as forward if their longitudinal momentum p_z points in the proton direction and backwards if their p_z points in the anti-proton direction. The directions are reversed for $\bar{\Lambda}$, Ξ^+ and Ω^+.

The forward backward asymmetry A_{FB} for Λ baryons is defined as:

$$A_{FB} \equiv \frac{\sigma_F(\Lambda) - \sigma_B(\Lambda) + \sigma_F(\bar{\Lambda}) - \sigma_B(\bar{\Lambda})}{\sigma_F(\Lambda) + \sigma_B(\Lambda) + \sigma_F(\bar{\Lambda}) + \sigma_B(\bar{\Lambda})}$$

where σ_F and σ_B are the cross sections for forward and backward Λ or $\bar{\Lambda}$ production. A similar forward backward asymmetry can similarly be defined for Ξ and Ω production. i.e

$$A_{FB} \equiv \frac{\sigma_F(\Xi^-) - \sigma_B(\Xi^-) + \sigma_F(\Xi^+) - \sigma_B(\Xi^+)}{\sigma_F(\Xi^-) + \sigma_B(\Xi^-) + \sigma_F(\Xi^+) + \sigma_B(\Xi^+)}$$

2. Detector and Data

The D0 detector is described in detail elsewhere, see Refs. [1, 2, 3, 4, 5]. The D0 detector is well suited to measure forward backward asymmetries due to the initial state being $p\bar{p}$ (CP symmetric) and the solenoid and toroid magnetic fields being reversed periodically (canceling many important systematics). For many asymmetry measurements no other experiment has comparable sensitivity.

For the study of the Λ asymmetry, three data sets are studied (i) $p\bar{p} \to \Lambda(\bar{\Lambda})X$, (ii) $p\bar{p} \to \mu^{\pm}\Lambda(\bar{\Lambda})X$, and (iii) $p\bar{p} \to J/\psi\Lambda(\bar{\Lambda})X$. This allows a study of samples collected with a minimum bias trigger (i) and an increased statistical sample taken with single muon triggers (ii) and a sample containing reconstructed J/ψ candidates (iii). Additionally control samples where no asymmetry is predicted with the Λ or $\bar{\Lambda}$ replaced with a K_s^0 are studied. The K_s^0 control samples are used to show that there are no additional corrections necessary due to north-south asymmetries since $K_s^0 \to \pi^+\pi^-$ does not distinguish its parent K^0 or $\bar{K^0}$. Since the K_S^0 does not distinguish between the proton and anti-proton directions, it provides a powerful control sample to study any detector effects.

The Λ and $\bar{\Lambda}$ baryons as well as the K_s mesons are reconstructed from oppositely charged tracks that have a common vertex. For the Λ and $\bar{\Lambda}$ reconstruction, the proton mass is assigned to the daughter track with the larger momentum. These reconstructed V_o's are required to have a transverse momentum p_T between 2 and 25 GeV and pseudorapidity $|\eta|$<2.2. Figure 1(a) shows an example of the invariant mass distribution for $\Lambda \to p\pi^-$ for the $p\bar{p} \to \mu^{\pm}\Lambda(\bar{\Lambda})X$ data set. The

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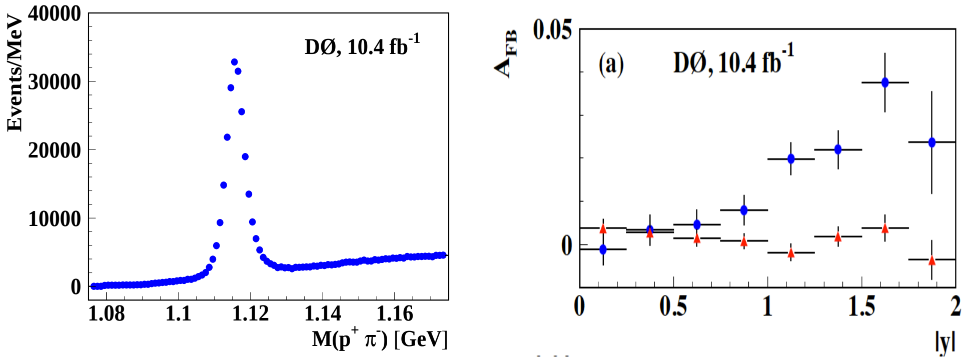
Data set	Number of candidate events
$p\bar{p} \to \Lambda(\Lambda)X$	5.85×10^5
$p\bar{p} \to J/\psi\Lambda(\bar{\Lambda})X$	2.50×10^5
$p\bar{p} \to \mu^{\pm}\Lambda(\bar{\Lambda})X$	1.15×10^7
$p\bar{p} \to K_s^0 X$	2.33×10^6
$p\bar{p} \to J/\psi K_s^0 X$	6.55×10^5
$p\bar{p} \to \mu^{\pm} K_s^0 X$	5.34×10^7

Table 1: Number of reconstructed candidate $\Lambda + \bar{\Lambda}$ or K_s^0 with p_T>2.0 GeV.

K_s samples are analyzed identically as the Λ and $\bar{\Lambda}$ samples except the pion mass is assigned to the larger momentum track.

Table 1 shows the number of candidate events collected for each data sample.

The solenoid and toroid polarities are reversed approximately every two weeks such that four different solenoid-toroid polarity combinations with approximately the same number of events are collected. The events are weighted for the different polarity combinations to remove any forward backward geometrical effects. Figure 1(b) shows the forward backward asymmetry as a function of rapidity for Λ and K_s. A significant asymmetry is seen in the Λ sample while the asymmetry is consistent with zero for the K_s sample. The K_s asymmetry shows that no additional corrections are necessary for any north-south asymmetries.



(a) (b)

Figure 1: (a) Invariant mass distribution of $\Lambda \to p\pi^-$. (b) A_{FB} as a function of rapidity for reconstructed candidate Λ and $\bar{\Lambda}$ (blue circles) and K_s^0(red triangles)

Figure 2 compares the asymmetry measured by various experiments that have studied $pZ \to \Lambda(\bar{\Lambda})X$ for different target Z=$p, \bar{p}$, Be, and Pb. To compare to these results we plot $[\sigma_B(\Lambda) + \sigma_B(\bar{\Lambda})]/[\sigma_F(\Lambda) + \sigma_F(\bar{\Lambda})]$=$(1-A_{FB})/(1+A_{FB})$. We find that the $\bar{\Lambda}/\Lambda$ production ratio is approximately a universal function of the "rapidity loss" $\Delta y \equiv y_p - y$, independent of the target Z or $\sqrt{s}$, where y_p is the rapidity of the proton beam and y is the rapidity of the Λ or $\bar{\Lambda}$.

Two datasets are studied for the $\Xi^{\pm}$ asymmetry, $p\bar{p} \to \Xi^{\pm}X$ and $p\bar{p} \to \mu\Xi^{\pm}X$. Due to the low statistics in the minimum bias data, only one dataset, $p\bar{p} \to \mu\Omega^{\pm}X$, is collected using single muon triggers for the $\Omega^{\pm}$ asymmetry. We reconstruct Ξ baryons through their decay $\Xi^- \to \Lambda\pi^-$

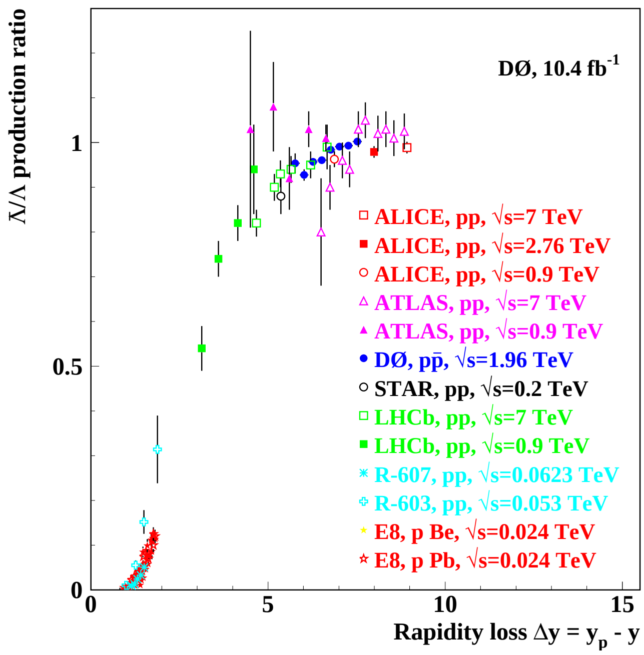


Figure 2: $\bar{\Lambda}/\Lambda$ production ratio as a function of rapidity loss $\Delta y = y_p - y$ for different experiments studying $pZ \to \Lambda(\bar{\Lambda})X$ where Z=$p\bar{p}$, Be or Pb. Results are for ALICE [6], ATLAS[7], D0 (this analysis), STAR [8], LHCb[9], ISR R-607 [10], ISR R-603 [11], and E8[12].

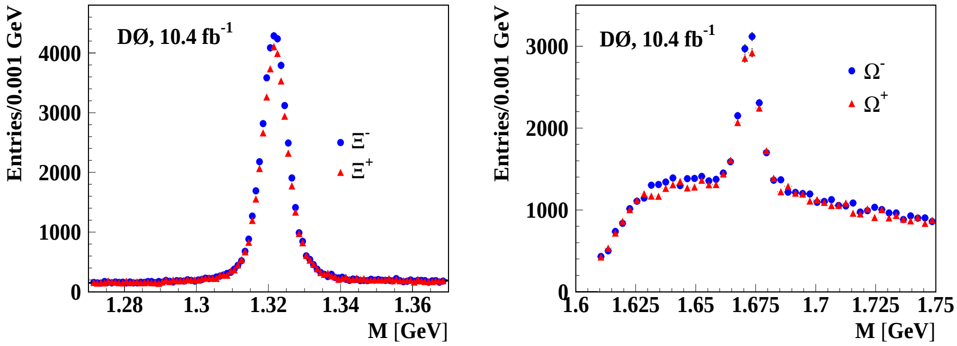
Data set	Number of events
$p\bar{p} \to \Xi^{\pm}X$	3.7×10^3
$p\bar{p} \to \mu^{\pm}\Xi^{\pm}X$	7.7×10^4
$p\bar{p} \to \mu^{\pm}\Omega^{\pm}X$	1.4×10^4

Table 2: Number of reconstructed $\Xi^{\pm}$ and $\Omega^{\pm}$ candidates with p_T>2.0 GeV.

and $\Xi^+ \to \bar{\Lambda}\pi^+$. The $\Lambda(\bar{\Lambda})$ candidate is combined with a positively (negatively) charged track that makes a good vertex with the $\Lambda(\bar{\Lambda})$ candidate and has at least a three standard deviation significance in the separation in the transverse plane from the primary vertex. The mass of the track is set to the pion mass for Ξ candidates and the kaon mass for Ω candidates. The transverse decay length of the Λ, and Ξ or Ω must exceed 4 mm. Table 2 shows the number of reconstructed candidates for each sample. Figures 3(a) and 3(b) show the reconstructed Ξ and Ω invariant mass distributions while Figures 4(a) and 4(b) show the forward backward asymmetry for the two samples.

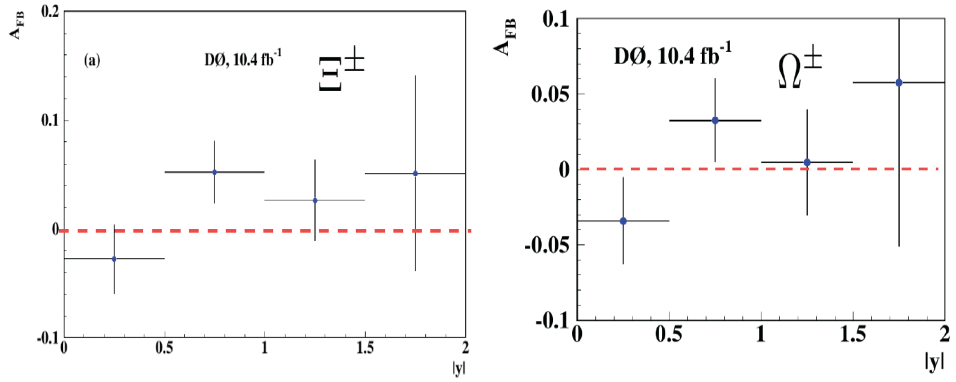
3. Conclusions

We present measurements of the forward backward asymmetry for Λ mesons, and Ξ and Ω baryons. The measured asymmetries for both the Ξ and Ω samples are consistent with zero within uncertainties. A previous measurement for charged B mesons yields $A_{FB}(B^{\pm}) = [-0.24 \pm 0.41(stat) \pm 0.19(syst)]\%$ [13]. In addition D0 has measured the forward backward asymmetry



(a) (b)

Figure 3: (a) Invariant mass distribution of $\Xi^- \to \Lambda\pi^-$ (blule circles) and $\Xi^+ \to \bar{\Lambda}\pi^+$ (red triangles) for $p\bar{p} \to \mu\Xi^\pm X$ data. (b) Invariant mass distribution of $\Omega^- \to \Lambda K^-$ (blue circles) and $\Omega^+ \to \bar{\Lambda}K^+$ (red triangles) for $p\bar{p} \to \mu\Omega^\pm X$ data.



(a) (b)

Figure 4: (a) Asymmetries of reconstructed Ξ^- and Ξ^+ candidates for the minimum bias sample $p\bar{p} \to \Xi^\pm X$. The uncertainties are statistical only. (b) Asymmetries of reconstructed Ω^- and Ω^+ candidates for the sample $p\bar{p} \to \mu\Omega^\pm X$. The uncertainties are statistical only.

for the Λ_b [14]. Combining all of these results show a consistent picture with the hypothesis that a strange or bottom quark produced in scattering can coalesce with a *ud* diquark remnant of the beam to produce a $\Lambda(\Lambda_b)$. The forward backward asymmetry for Λ, $\bar{\Lambda}$ show that the production ratio is approximately a universal function of rapidity loss that does not depend strongly on the total center of mass energy or the target. Further details on the analyses can be found at [15] and [16].

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