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Polarization of  $\{\Omega\}^{\{-\}}$  Hyperons Produced in 800 GeV Proton-Beryllium Collisions

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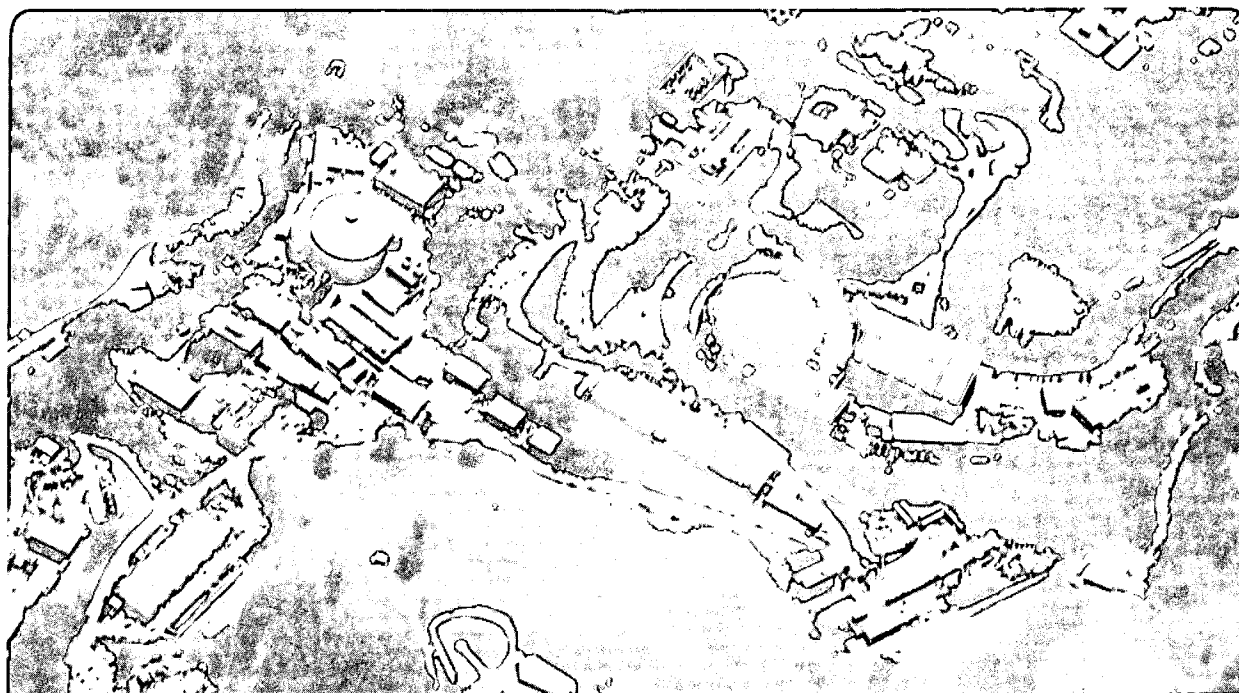
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August 1992



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**Polarization of  $\Omega^-$  Hyperons Produced in 800 GeV  
Proton-Beryllium Collisions**

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## Polarization of $\Omega^-$ Hyperons Produced in 800 GeV Proton-Beryllium Collisions

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### Abstract

The polarization of 103,211  $\Omega^-$  hyperons produced in 800 GeV proton-beryllium inclusive reaction has been measured. Between  $0.3 < x_F < 0.7$  and  $0.5 \text{ GeV}/c < p_t < 1.3 \text{ GeV}/c$ , the  $\Omega^-$  polarization is found to be consistent with zero, with a mean value of  $-0.01 \pm 0.01$  at  $\langle x_F \rangle = 0.5$  and  $\langle p_t \rangle = 0.95 \text{ GeV}/c$ . This behaviour is similar to that of  $\bar{\Lambda}^0$ , which also does not have any quarks in common with the incident proton, but is different from  $\bar{\Xi}^+$  which is significantly polarized in the same kinematic region.

Since the discovery that  $\Lambda^0$  hyperons produced by protons were polarized at high energies,<sup>1</sup> polarization measurements have been made on most of the stable baryons. A non-zero polarization was also observed for the  $\Xi^0$ ,  $\Xi^-$ ,  $\Sigma^+$ ,  $\Sigma^0$ , and  $\Sigma^-$  hyperons.<sup>2-7</sup> As required by parity conservation in strong interactions, the resulting polarization is in the direction perpendicular to the production plane of the hyperon. Typically the magnitude of the polarization is of the order of 10% at  $x_F$  of 0.5 and  $p_t$  of 1 GeV/c. A polarization consistent with zero was found for the  $\bar{\Lambda}^0$  in the same kinematic region.<sup>8</sup>

Since the  $\bar{\Lambda}^0$  does not have any valence quarks of the incident proton, its zero production polarization agrees with models in which the hyperon polarization is a consequence of the recombination of at least one leading quark from the projectile with the sea quarks.<sup>9</sup> However, the recent discovery that  $\bar{\Xi}^+$  antihyperons created by protons exhibit a polarization comparable to that of  $\Xi^-$  has cast doubts on the validity of polarization models that incorporate the leading quark effect.<sup>10</sup> The  $\Omega^-$  is a baryon, yet like the antihyperons, does not have any valence quarks in common with the incoming protons. Determining the polarization of  $\Omega^-$ 's produced by protons should improve our understanding of the quark production process via the strong interaction. This paper reports the first statistically significant measurement of the  $\Omega^-$  polarization.

The result is based on a sample of 103,211 reconstructed  $\Omega^-$ 's produced by 800 GeV protons incident on a beryllium target at Fermilab. The  $\Omega^-$  hyperons were detected through the  $\Omega^- \rightarrow \Lambda^0 + K^-$  and  $\Lambda^0 \rightarrow p + \pi^-$  decay sequence. The apparatus of this experiment, E-756, has been described in some detail elsewhere.<sup>11</sup> After emerging from the target, the  $\Omega^-$ 's passed through a 7.3 m long bending magnet, M1. The  $\Omega^-$ 's and their decay products were then detected by a spectrometer consisting of silicon microstrip detectors, multiwire proportional chambers, scintillators and an analysis magnet, M2. Data were taken with a vertical production angle of 2.4 mrad at five different M1 field integrals. The production angle was reversed regularly to change the sign of any possible polarizations in order to minimize

the effects of any apparatus asymmetries. The field of the momentum analyzing magnet was also reversed periodically for the same reason.

Event selection was based on both geometric and kinematic criteria in the off-line analysis. Invariant masses of each event were calculated under the  $\Lambda^0$ - $\pi^-$  and  $\Lambda^0$ - $K^-$  hypotheses. Most of the reconstructed events were  $\Xi^- \rightarrow \Lambda^0 + \pi^-$  decays that were recorded along with the  $\Omega^-$  decays in a ratio of about 75 to 1. By requiring the  $\Lambda^0$ - $\pi^-$  invariant mass of the event to be greater than  $1.345 \text{ GeV}/c^2$ , more than 99% of the  $\Xi^- \rightarrow \Lambda^0 + \pi^-$  decays were rejected. Additional requirements imposed on the data for selecting  $\Omega^- \rightarrow \Lambda^0 + K^-$  events are described in detail elsewhere.<sup>12</sup> The  $\Lambda^0$ - $K^-$  invariant mass distribution of the final data sample is shown in Figure 1. Only events with the  $\Lambda^0$ - $K^-$  invariant mass between  $1.657 \text{ GeV}/c^2$  and  $1.687 \text{ GeV}/c^2$  were used in the polarization analysis. The estimated background in the selected mass region was about 3%. These background events were primarily  $\Omega^- \rightarrow \Xi^0 + \pi^-$  decays or poorly reconstructed  $\Xi^- \rightarrow \Lambda^0 + \pi^-$  decays.

When averaged over the sample, it can be shown that the polarization of the  $\Omega^-$ ,  $\bar{P}_\Omega$ , is related to the daughter  $\Lambda^0$  polarization,  $\bar{P}_\Lambda$ , by the following equation:<sup>12</sup>

$$\bar{P}_\Lambda = \frac{1}{2(j+1)} [ 1 + (2j+1)\gamma ] \bar{P}_\Omega \quad (1)$$

where  $\gamma$  is the decay parameter of the  $\Omega^- \rightarrow \Lambda^0 + K^-$  decay and is taken to be +1, since  $\beta$  is assumed to be zero,<sup>13</sup>  $\alpha \approx 0$ ,<sup>12,14</sup> and the decay is predominantly parity conserving,<sup>15</sup>  $j$  is the spin of the  $\Omega^-$  and is assumed to be  $3/2$ . In the rest frame of the  $\Lambda^0$ ,  $\bar{P}_\Lambda$  can be measured by examining the distribution of the decay proton along a spatial axis  $i$  which is given by

$$\frac{dN}{d \cos\theta_i} = \frac{1}{2} ( 1 + \alpha_\Lambda P_{\Lambda i} \cos\theta_i ) \quad (2)$$

where  $\theta_i$  is the angle between the momentum of the proton and the axis  $i$ . In practice this distribution is modified by the acceptance of the spectrometer which was unfolded with a hybrid Monte Carlo method.<sup>16</sup>



The measured signal is a sum of the polarization,  $\alpha_\Lambda P_\Lambda$ , and any bias which results from a combination of the apparatus and the reconstruction of events not fully reproduced in the Monte Carlo simulation (e.g. events with small opening angles). Because a parity conserving polarization must be perpendicular to the production plane ( $\vec{p}_p \times \vec{p}_{\Omega^-}$ ), it reverses when the production angle changes sign, but the bias will remain unchanged. Data taken with positive and negative production angles can thus be used to determine both the polarization signal and the bias. Table 1 shows the components of the polarization,  $\alpha_\Lambda P_\Lambda$ , and bias as a function of the momentum of the  $\Omega^-$ . Most of the biases were less than two standard deviations from zero. As shown in Figure 2, the y-components of the polarization were consistent with zero, with a mean of  $0.00 \pm 0.01$ , as required by parity conservation. The other two polarization components were also not significantly different from zero. Since the results of the samples with an equal and opposite M2 field agreed to the precision of the measurement, they were combined in the following analysis.

The polarization at the target,  $P_\Omega$ , is related to the x and z components of the polarization measured in the spectrometer by  $P_x = P_\Omega \cos\phi$  and  $P_z = P_\Omega \sin\phi$ , where  $\phi$  is the spin precession angle relative to the  $\Omega^-$  momentum in the magnetic field of M1,

$$\phi = \frac{2}{\beta} \left( \mu_\Omega - \frac{q_\Omega}{2m_\Omega c} \right) \int B dl \quad (3)$$

where  $q_\Omega$  and  $m_\Omega$  are the charge and the mass of  $\Omega^-$  respectively,  $\beta = v/c \approx 1$  in this experiment,  $\mu_\Omega$  is the  $\Omega^-$  magnetic moment given in nuclear magnetons (n.m.), and  $\int B dl$  is the field integral of M1 in units of T-m. With  $\mu_\Omega$  constrained to  $-1.94 \pm 0.22$  n.m.,<sup>17</sup> a fit using the measured asymmetries yielded  $P_\Omega$  and the biases as a function of momentum.<sup>18</sup> The chi-square for this procedure was 8.7 for four degrees of freedom. The  $\Omega^-$  polarization at the target as a function of momentum is shown in Table 2.<sup>19</sup> The average  $\Omega^-$  polarization was determined to be  $-0.01 \pm 0.01$  at a mean  $x_F$  of 0.5 and  $p_t$  of 0.95 GeV/c. The biases determined with this method were consistent with zero. The mean helicity was  $-0.00 \pm 0.01$ , again

consistent with zero as required by parity conservation. In addition, if  $\mu_{\Omega}$  were also determined from the fit, its value of  $-0.60 \pm 0.16$  n.m., with a chi-square of 2.2 for three degrees of freedom, was significantly different from the measured value of  $-1.94 \pm 0.22$  n.m., while the mean value of the  $\Omega^-$  polarization did not change.

Figure 3 is a comparison of the polarizations of  $\Omega^-$ ,  $\bar{\Lambda}^0$ ,  $\Xi^+$  and  $\Xi^-$  when produced by protons in inclusive reactions as a function of the transverse momentum.<sup>4,8,10</sup> The  $\bar{\Lambda}^0$  data, taken at 400 GeV/c, cover a similar  $x_F$  range as the  $\Omega^-$ ,  $\Xi^-$  and  $\Xi^+$  results from this experiment. Even though  $\Omega^-$  is a baryon, it has no valence quarks in common with the proton. Its zero polarization seems to indicate that having at least one quark in common with the beam, like  $\Xi^-$ , is necessary to produce a polarized particle. This agrees with the zero polarization measured for the  $\bar{\Lambda}^0$ , but is distinctly different from the non-zero polarization of  $\Xi^+$ . The conflicting behaviour of the production polarization among the  $\Omega^-$ ,  $\bar{\Lambda}^0$ , and  $\Xi^+$  is puzzling. As far as we know, no existing model of particle production can accommodate the  $\Omega^-$ ,  $\bar{\Lambda}^0$ , and  $\Xi^+$  results.

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- <sup>19</sup> If  $\gamma$  is -1, the polarizations of  $\Omega^-$  at the target and their uncertainties should be multiplied by a factor of -5/3.

## List of tables

Table 1: Mean  $\Omega^-$  momentum, components of the polarization, and biases as a function of the M1 field integral, and the field polarity of M2.

Table 2:  $\Omega^-$  polarization at target as a function of momentum. The decay parameter,  $\gamma$ , is taken to be +1.

| M1 field integral (T-m) | Field Polarity of M2 | Mean $\Omega^-$ momentum (GeV/c) | Comp. | $\alpha_{\Lambda} P_{\Lambda}$ | Bias             |
|-------------------------|----------------------|----------------------------------|-------|--------------------------------|------------------|
| -15.3                   | +                    | 316                              | x     | $-0.04 \pm 0.02$               | $0.03 \pm 0.02$  |
|                         |                      |                                  | y     | $-0.04 \pm 0.02$               | $0.00 \pm 0.02$  |
|                         |                      |                                  | z     | $0.00 \pm 0.03$                | $0.03 \pm 0.03$  |
|                         | -                    | 330                              | x     | $0.02 \pm 0.02$                | $-0.01 \pm 0.02$ |
|                         |                      |                                  | y     | $-0.01 \pm 0.02$               | $-0.00 \pm 0.02$ |
|                         |                      |                                  | z     | $0.07 \pm 0.03$                | $-0.02 \pm 0.03$ |
| -19.5                   | +                    | 379                              | x     | $0.00 \pm 0.01$                | $0.01 \pm 0.01$  |
|                         |                      |                                  | y     | $0.01 \pm 0.01$                | $-0.01 \pm 0.01$ |
|                         |                      |                                  | z     | $-0.01 \pm 0.02$               | $-0.03 \pm 0.02$ |
|                         | -                    | 389                              | x     | $-0.03 \pm 0.01$               | $-0.02 \pm 0.01$ |
|                         |                      |                                  | y     | $0.02 \pm 0.01$                | $-0.01 \pm 0.01$ |
|                         |                      |                                  | z     | $-0.01 \pm 0.01$               | $-0.02 \pm 0.01$ |
| -22.2                   | +                    | 418                              | x     | $-0.00 \pm 0.01$               | $0.01 \pm 0.01$  |
|                         |                      |                                  | y     | $-0.01 \pm 0.01$               | $0.00 \pm 0.01$  |
|                         |                      |                                  | z     | $-0.01 \pm 0.02$               | $-0.01 \pm 0.02$ |
|                         | -                    | 428                              | x     | $-0.00 \pm 0.02$               | $0.03 \pm 0.02$  |
|                         |                      |                                  | y     | $0.04 \pm 0.02$                | $-0.01 \pm 0.02$ |
|                         |                      |                                  | z     | $-0.03 \pm 0.02$               | $-0.01 \pm 0.02$ |
| -24.3                   | +                    | 452                              | x     | $-0.05 \pm 0.04$               | $0.04 \pm 0.04$  |
|                         |                      |                                  | y     | $0.02 \pm 0.04$                | $0.06 \pm 0.04$  |
|                         |                      |                                  | z     | $-0.00 \pm 0.04$               | $-0.02 \pm 0.04$ |
|                         | -                    | 459                              | x     | $0.01 \pm 0.03$                | $0.05 \pm 0.03$  |
|                         |                      |                                  | y     | $0.02 \pm 0.03$                | $-0.00 \pm 0.03$ |
|                         |                      |                                  | z     | $0.05 \pm 0.03$                | $0.01 \pm 0.03$  |
| -25.5                   | +                    | 465                              | x     | $0.02 \pm 0.03$                | $0.03 \pm 0.03$  |
|                         |                      |                                  | y     | $0.01 \pm 0.04$                | $-0.07 \pm 0.03$ |
|                         |                      |                                  | z     | $-0.02 \pm 0.04$               | $-0.02 \pm 0.04$ |
|                         | -                    | 473                              | x     | $0.03 \pm 0.02$                | $0.02 \pm 0.02$  |
|                         |                      |                                  | y     | $-0.03 \pm 0.02$               | $-0.07 \pm 0.03$ |
|                         |                      |                                  | z     | $-0.04 \pm 0.03$               | $-0.03 \pm 0.03$ |

Table 1

| Mean $\Omega^-$ momentum (GeV/c) | Number of Events | Mean transverse momentum (GeV/c) | $\Omega^-$ polarization at target |
|----------------------------------|------------------|----------------------------------|-----------------------------------|
| 323                              | 15,735           | 0.776                            | 0.01±0.02                         |
| 385                              | 47,722           | 0.925                            | -0.03±0.01                        |
| 424                              | 25,685           | 1.02                             | -0.01±0.02                        |
| 457                              | 5,976            | 1.10                             | 0.01±0.04                         |
| 471                              | 8,093            | 1.13                             | 0.02±0.03                         |

Table 2

## Figure Captions

FIG. 1.  $\Lambda^0$ - $K^-$  invariant mass of the final data sample. Events with mass between the arrows are used in the polarization analysis.

FIG. 2. Components of the polarization as a function of the field polarity of M2 and momentum of the  $\Omega^-$ .

FIG. 3. Comparison of the  $\Omega^-$  polarization with those of the  $\Xi^+$ ,  $\bar{\Lambda}^0$  and  $\Xi^-$  as a function of the transverse momentum. For a given transverse momentum, the average  $x_F$  of the  $\bar{\Lambda}^0$  is slightly lower than that of the  $\Omega^-$ . The  $\Xi^-$  and  $\Xi^+$  data are from this experiment (see references 4 and 10), and the 400 GeV/c  $\bar{\Lambda}^0$  results are taken from reference 8.



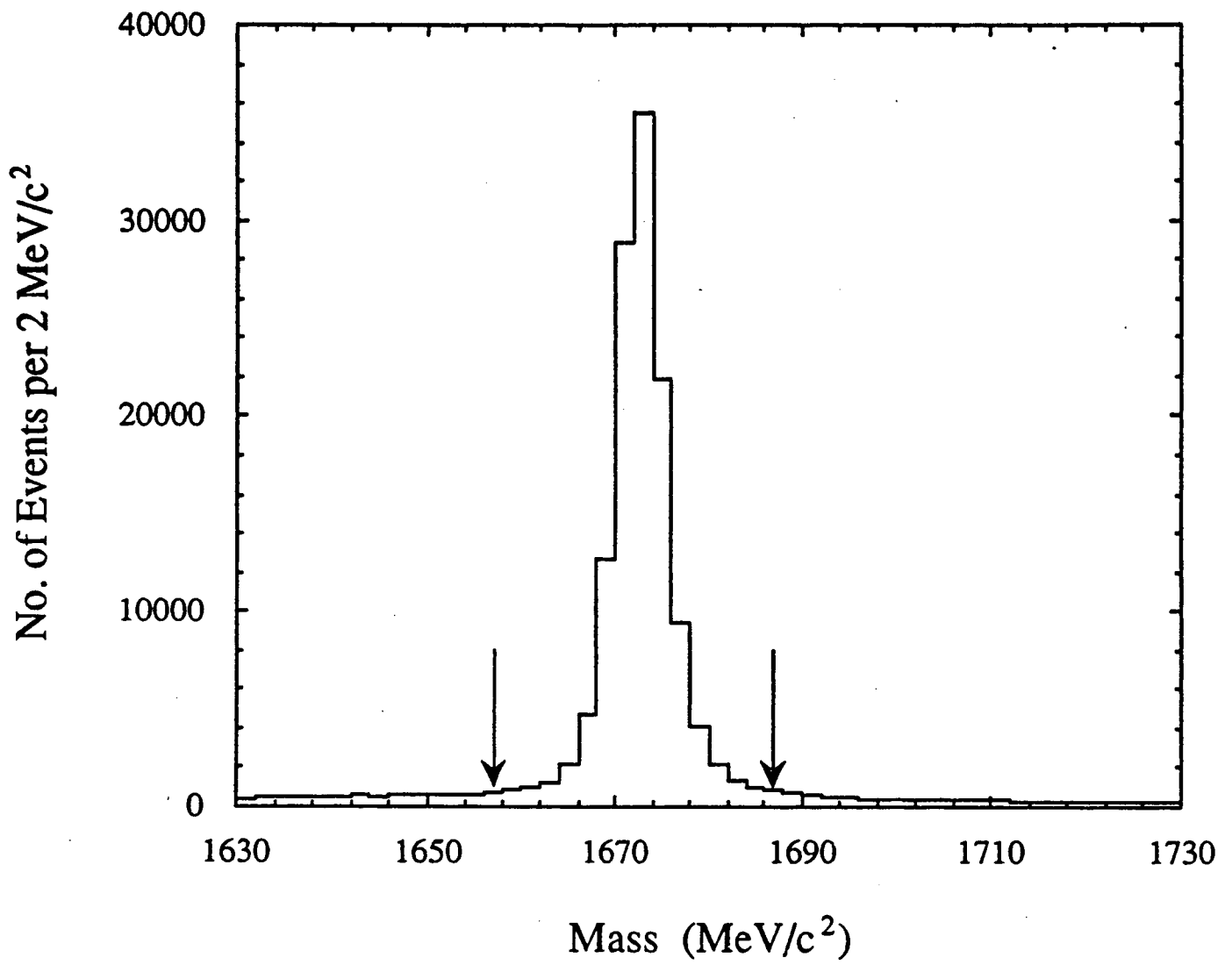


Figure 1

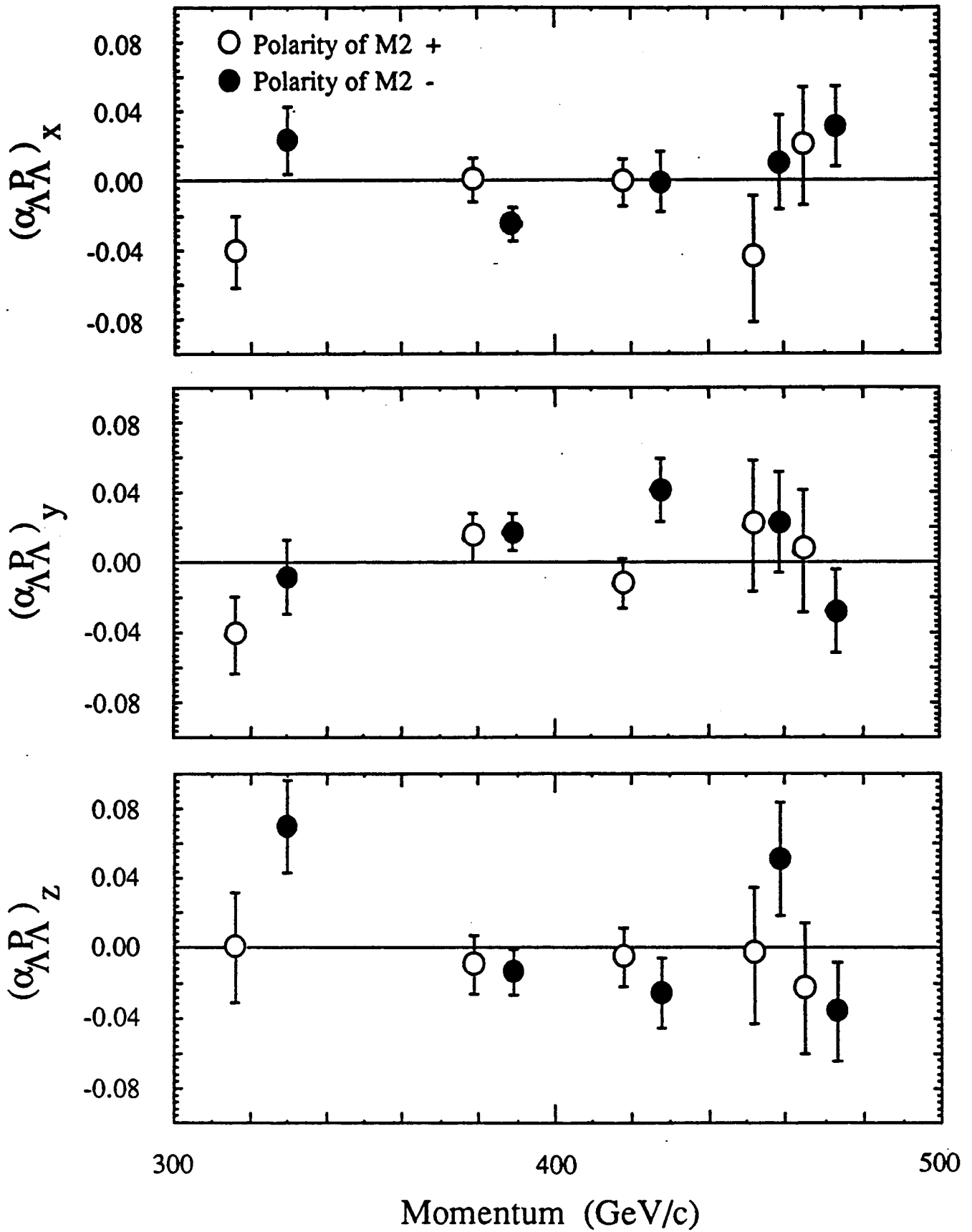


Figure 2

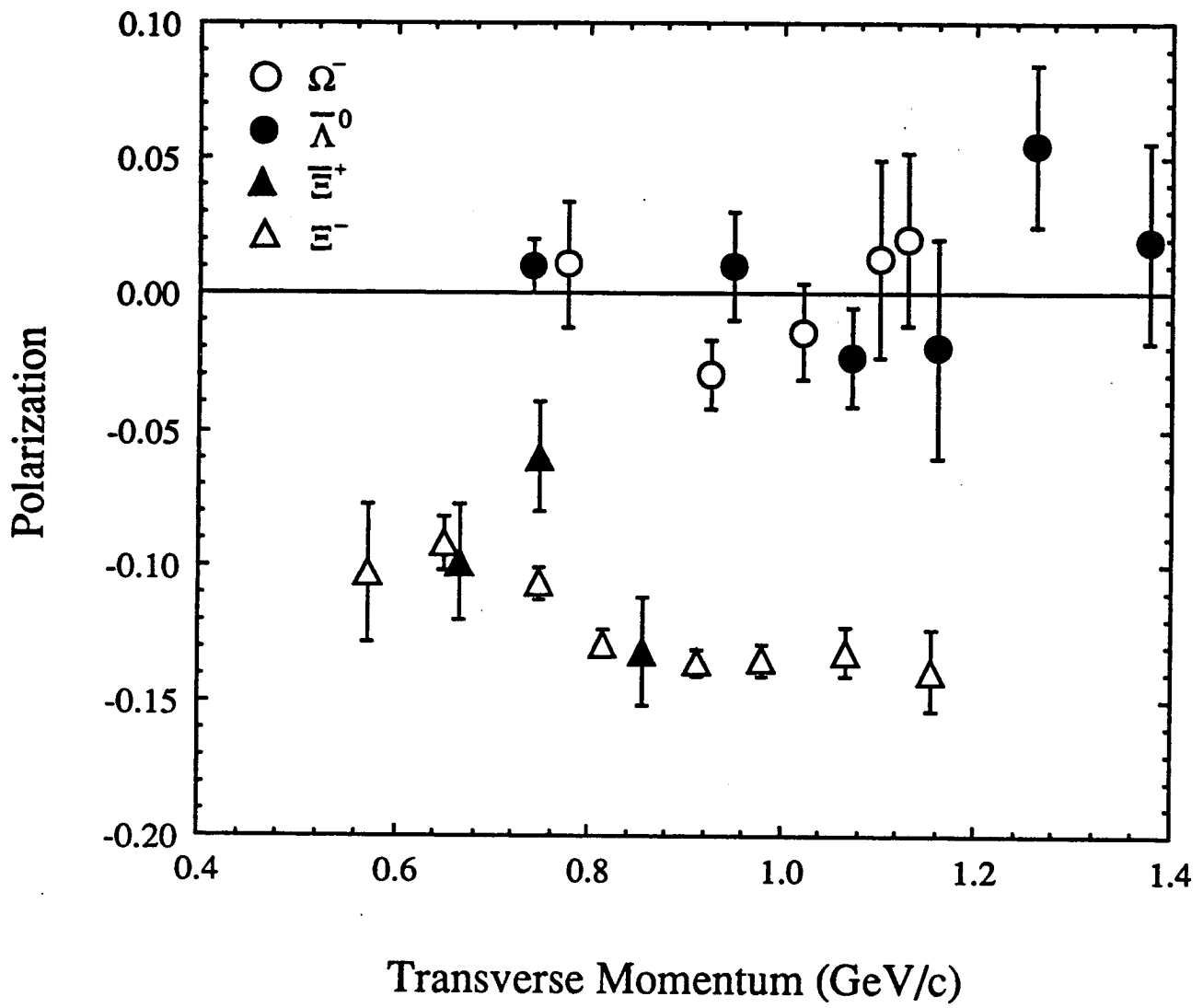


Figure 3

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