A Precise Measurement of the Omega Minus Magnetic Moment

E 756 → P800

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A Progress Report

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Introduction

Baryon magnetic moment measurements play a fundamental role in improving our understanding of the behavior of quarks in hadrons. The simplest quark models correctly predict baryon magnetic moments to within 10% of the experimental data which are measured to better than 2% (Table 1). The disagreement with the data is significant and one must ask whether the differences can be understood in the framework of a standard quark model. More sophisticated quark models have introduced additional parameters to account for configuration mixing, relativistic corrections, and effective quark masses which are a function of their environment.[1] Even these models have difficulties in accommodating the precise hyperon measurements without losing their predictive power.

One expects the omega minus magnetic moment, μ_{Ω^-}, to be more amenable to calculation. It has as constituents three identical, spin parallel, relatively heavy quarks, thus making μ_{Ω^-} the most direct measurement of the strange quark magnetic moment. In the simplest quark models, μ_{Ω^-} is just three times the lambda magnetic moment, or -1.83 nuclear magnetons (n.m.). However, the corrections used in the more sophisticated models can destroy the equality between the lambda and the strange quark magnetic moments. With the effects needed to bring theory closer to the Σ and Ξ magnetic moment data, the best predictions for μ_{Ω^-} seem to be between -1.83 and -2.25 n.m.. Thus a measurement of μ_{Ω^-} at the ± 0.05 n.m. level is desirable to distinguish among contemporary theories. A 0.03 n.m. measurement, bringing the Ω^- precision into line with the other hyperons, should be sufficient for some time into the future.

The prerequisite to measuring a magnetic moment by spin precession is to have a polarized sample. The so-called "standard method" relies on the fact that hyperons produced by protons in inclusive reactions are polarized and that these hyperons live long enough to travel through a long, magnetic channel for spin precession.[2] This technique led to the precise set of hyperon magnetic moments measured by our group and others.[3] Prior to E756, no one had ever produced a polarized Ω^- beam. Thus we first proposed to try the "standard method". If the Ω^-'s were polarized, the experiment was designed to yield an error of less than 0.1 n.m. for the magnetic moment. We proposed to carry out a polarization analysis while data was being taken to determine the course of the experiment. If protons did not produce polarized Ω^-'s, we had devised alternative methods to produce the desired polarized sample.

During the 1987-88 fixed target run, the experiment proceeded as outlined in the proposal. Using a minimal statistically significant sample, we found the polarization of Ω^-'s produced directly by protons to be insufficient to accomplish the measurement. This result is in itself a major contribution to the understanding of the phenomena of inclusive hyperon polarization. In addition to the polarization results, this period of the experiment will yield the best measurement of the cascade minus magnetic moment (better than 1%), the best measurement of the weak decay parameter, α , for both the Ω^- and the Ξ^-, and the best measurement of the lifetime of both the Ω^- and the Ξ^-, good bread and butter physics.

With the enthusiastic assistance of the laboratory and its staff, we began implementing one of our alternate plans. From our previous experiments, we knew that a neutral beam produced at an angle was rich in polarized Λ's and Ξ^0's. Therefore we believed we could produce polarized Ω^- via spin transfer from a targeted polarized neutral hyperon beam. Because of the well designed optics of our proton beam, we had the flexibility of installing another targeting area and a neutral channel, just upstream of our charged hyperon channel. The laboratory very quickly built the simple neutral channel to our design and installed a target area capable of handling increased proton flux. While awaiting the installation of the new targeting scheme, which took about one month from request to delivery, we continued to take data, amassing the largest sample of Ω^-

events ever recorded (about 60,000) as well as significant numbers of antihyperons.

Our neutral beam was the first targeted polarized beam at the Tevatron and one of the few polarized high energy beams anywhere in the world. For the remainder of the fixed target run, about three calendar months, we collected about 20,000 Ω^-'s, enough to discover that the Ω^-'s were polarized and make the first statistically significant measurement of μ_{Ω^-} ($\pm$0.2 n.m.). In addition, measurements of the Ω^- and Ξ^- spin transfer from the polarized neutral hyperon beam will provide new information for particle production models. The stage is now set to accomplish the primary goal of the E756 proposal, a precise measurement of μ_{Ω^-}.

The results of E756 to date underscore the ability of smaller scale experiments to probe for new phenomena and to succeed when a "standard method" no longer works. Experiments such as ours need few laboratory resources but these are crucial. We appreciate the 'can do' attitude of the laboratory management and the individual efforts and flexibility of the laboratory personnel. Without this help and encouragement, the first run of E756 could not have paid off so handsomely in physics and pointed the way toward our goal.

The "Standard" Method

Our experiments have always emphasized simplicity with just enough redundancy to assure a successful measurement. We have always been more interested in the physics than in the apparatus. In keeping with this spirit, our current spectrometer is based on a 2mm MWPC system which we have used many times before. To this, we have added a set of silicon strip detectors and 1mm wire chambers to track Ω^- just before and after it decays. The setup of E756 is shown in Figure 1. The major subsystems of the spectrometer, PWC's, SSD's, and counters, all work well. The trigger for the experiment is S1.S2.VBAR.M.C12R.C13L where counter coincidences S1.S2.VBAR define the hyperon beam and the multiplicity counter ($2 \le M \le 4$) and chamber hit pattern (right-half of C12 and left-half of C13) ensure the correct decay topology ($\Omega^- \to \Lambda K^-$ or $\Xi^- \to \Lambda \pi^-$, $\Lambda \to p \pi^-$). The reconstructed yield of events which fit our three track, two vertex topology is typically 20% of the triggers.

For direct production of Ω^-'s, the primary proton beam was incident at production angles ±2.5 mr on a Be target located directly upstream of the hyperon magnet (see Figure 2). Typically 6000 three-track triggers were recorded per spill of 2×10^{10} protons with a livetime of about 70%. The trigger rate was limited by the singles rates of 0.75 MHz in the MWPC's. After track reconstruction and cuts, we will have a total of 5 million Ξ^-'s and 60,000 Ω^-'s. The mass plots for Ω^- and Ξ^- are shown in Figure 3, exhibiting the cleanliness of our sample.

These events were then analyzed for polarization. The preliminary polarization analysis of a small sample of Ξ^- events is shown in Figure 4. The good agreement between this data and our 400 GeV (E620) data gives us confidence in our Ω^- results. Using a sample of 28,000 Ω^-'s, our preliminary analysis indicates that the magnitude of the Ω^- polarization is 0.027 ± 0.017 (see Figure 4), too small to accomplish a high precision measurement of μ_{Ω^-} in a limited amount of time.

The Spin Transfer Method

In our alternate scheme for producing polarized Ω^-'s, the primary proton beam was incident at production angles ±2 mr on a one interaction length copper target. The target was located directly upstream of a shielded B2 magnet which contained a simple two piece collimator with a 3 mm x 3 mm defining aperature (see Figure 5). The primary proton beam and charged secondaries were swept away by the field of the B2. The resulting polarized neutral beam was then incident at 0 mr on another one interaction length copper target directly upstream of the charged hyperon magnet.

The rate at which we accumulated data was limited by the proton intensity that was allowed in our simple target area. Our requested intensity was 7×10^{11} per spill which yielded an average intensity during running days of 2×10^{11} per spill. This average intensity is derived from our data taking history from mid-November, 1987 until the end of January, 1988 when both the accelerator and our experiment were in routine running mode (see Figure 6). Our quoted average intensity is simply the number of protons we used to produce Ω^-'s (1.55×10^{16}) divided by the number of days the accelerator was up (48). We believe the factor of three and a half reduction from peak (requested) to average intensity is an accurate way to estimate running time from requested intensity. This empirical reduction factor takes into account short accelerator down times, accelerator instabilities, dead spills, short experiment down times, and the time required for necessary calibration runs. To estimate calendar time, another factor must be included to account for accelerator or experiment down times which are on the order of a day or longer. During this three month period, the factor from runnning time to calendar time was 1.5.

At a primary proton intensity of 7×10^{11} per spill and with the charged hyperon magnet operating at a field integral of 14.5 T-m, the trigger rate was 300 per spill and the experiment was 95% live. The charged particle flux through the spectrometer, which is a limiting factor at 0.75 MHz, was approximately 0.15 MHz. The yield of good Ξ^- and Ω^- events per trigger was slightly higher (30%) for the spin transfer method than for the direct production. The Ξ^- to Ω^- ratio for both methods was 75. For a requested proton intensity of 7×10^{11} per minute, the average Ω^- yield was about 15 per hour. The total number of Ω^-'s collected during the 56 calendar days of data taking was 20,000.

The quality of the spin transfer data is represented by the cleanliness of the Ξ^- and Ω^- mass plots shown in Figure 7. These data were taken with the same trigger and have the same cuts applied as for those produced directly by protons. A comparison of Figures 3 and 7 shows no deterioration in quality using the neutral beam technique and our better understanding of the spectrometer as we proceeded. These data were analyzed for polarization as before, and both Ξ^-'s and Ω^-'s were found to be polarized (see Figure 8). At long last we have produced a beam of polarized Ω^-'s with a polarization, approximately 6%, sufficient to do a precision magnetic moment measurement. Data were also taken at higher magnetic fields of the charged hyperon channel to help plan a strategy for the next run. Higher magnetic fields correspond to higher average momenta (higher X_f). The Ξ^- polarization at the higher fields is also shown on Figure 8 and confirms a definite trend toward larger polarization (larger spin transfer) at higher momenta.

The 1989 Run Plan

The error in μ_{Ω^-}, $\delta(\mu_{\Omega^-})$, in units of n.m., is determined by the error in the polarization measurement and is given by

$$\delta(\mu_{\Omega^-}) = \left(\frac{2m_pS}{e}\right)\frac{\sqrt{3}}{\alpha_\Lambda P_\Lambda \int Bdl\ \sqrt{N}}$$

$$= \frac{16.2}{\alpha_\Lambda P_\Lambda \int Bdl\ \sqrt{N}}$$

where S is the spin of the Ω^-, m_p is the mass of the proton, e is the electric charge of the proton, $\int Bdl$ is the field integral of the charged hyperon magnet in units of T-m, $\alpha_\Lambda P_\Lambda$ is the measured asymmetry of the daughter lambda decay, and N is the number of Ω^-'s in the final sample. For the 1987-88 fixed target run, the $\int Bdl$ was 14.4 T-m, $\alpha_\Lambda P_\Lambda$ was 0.04±0.01, and N was 20,000, giving an error in μ_{Ω^-} of 0.2 n.m. (see Table 2, column 1). We propose to lower this error by about a factor of four during the first half of the next fixed target run in a straightforward manner as described below.

The largest factors we will employ in reducing the error in the magnetic moment measurement come from using an increased primary proton intensity, running for a longer time, and increasing the magnetic field in the charged hyperon magnet. We wish to increase the average primary proton intensity from a request of 7×10^{11} (2×10^{11} average) in the current run to 4.5×10^{12} (1.5×10^{12} average) in the 1989 run. This will be possible with an upgrading of the target area. At that intensity, the charged particle rate through our chambers will still be 0.4 MHz which is lower than our limit. By running for the first half of the next fixed target running cycle, we will also increase the data taking time from the 2 months (3 months calendar time) to 3 months (4.5 months calendar time).

We will also operate the hyperon magnet at its highest operating current which gives a field integral of 25.0 T-m. At the same time, the channel curvature will be changed to accept an average Ω^- momentum of 400 GeV. From the Ξ^- data, we expect the average Ω^- polarization to be about 10% at that momentum. The effect of the lower yield of Ω^- per incident proton on the magnetic moment precision at this higher momentum (see Figure 9) should be offset by the increased Ω^- polariation, giving no net loss. However, this lower yield is also true for pions in the negative beam. As a result, the charged particle flux through our chambers is also reduced, allowing us to run at the increased proton intensities required. To summarize, we want to collect 100,000 Ω^-'s taken at 25 T-m. This will be possible if we are given a total number of 2×10^{17} protons on target in the 1989 fixed target run.

These reasonably simple steps will result in improving the 0.2 n.m. error achieved in the 1987-1988 run to 0.03-0.06 n.m. for the next run, depending on the precise value of the Ω^- polarization. Other, smaller gains can probably be achieved by increasing the spatial acceptance of both the neutral and charged hyperon channels, using a beryllium target to produce the neutral beam with a higher average momentum, and additional background rejection by using spectrometer elements which were not needed in the exploratory phase of this experiment.

We emphasize that virtually no modifications to our existing spectrometer and beamline are necessary to make a measurement of this precision. Only the target area and the charged hyperon channel will be changed. With the long down time, including at least one summer before the next fixed target run, routine maintainance can easily be handled without disturbing the most important characteristic of our spectrometer which is that it is now ready for data taking. (See Figure 10 for our proposed startup schedule). Since no changes to online software or logic timing are planned, we can test the readiness of the spectrometer without beam. We feel confident that we can come up in a data taking mode in approximately 2 weeks after the beam first appears at our experiment.

Conclusion

We have shown both in this run and in the past that our group possesses both the understanding and the ability to make hyperon polarization measurements. By any definition, E756 was a success during the 87-88 fixed target run. Not only did we discover the effect which will allow us to fulfill our primary goal, but we will also extract much physics along the way. We request the opportunity to achieve the goal which is now within our grasp.

References

1. See for examples:
   - L. Brekke and J. Rosner, University of Chicago preprint EFI 87-80 (1987),
   - A. Mahohar and H. Georgi, Phys. Lett. 132B, 183(1983),
   - H. J. Lipkin, Nucl. Phys. B241, 477(1984), and Nucl. Phys. B214, 136(1983),
   - G. Brown and S. Myrher, Phys. Lett. 128B, 229(1983),
   - J. Franklin, Phys. Rev. D30, 1542(1984).

2. G. Bunce et al, Phys. Rev. Lett. 36, 1113(1976)

3. L. Schachinger et al, Phys. Rev. Lett. 41, 1348(1978),
   P. T. Cox et al, Phys. Rev. Lett. 46, 877(1981),
   C. Ankenbrandt et al, Phys. Rev. Lett. 51, 863(1983),
   R. Rameika et al, Phys. Rev. Lett. 52, 581(1984),
   G. Zapalac et al, Phys. Rev. Lett. 57, 1526(1986),
   C. Wilkinson et al, Phys. Rev. Lett. 58, 855(1987).

	experiment	exact SU(6)	broken SU(6)
p	2.794	input	input
n	-1.913	-1.86	input
Λ	-0.613±0.005	-0.93	input
Σ^+	2.38±0.02 2.479±0.025	2.79	2.67
Σ^0		0.93	0.79
Σ^-	-1.166±0.017	-0.93	-1.09
$\Sigma \to \Lambda$	-1.59±0.09	-1.63	1.42
Ξ^0	-1.250±0.014	-1.86	-1.44
Ξ^-	-0.69±0.04	-0.93	-0.49
Ω^-		-2.79	-1.84

Baryon Magnetic Moments

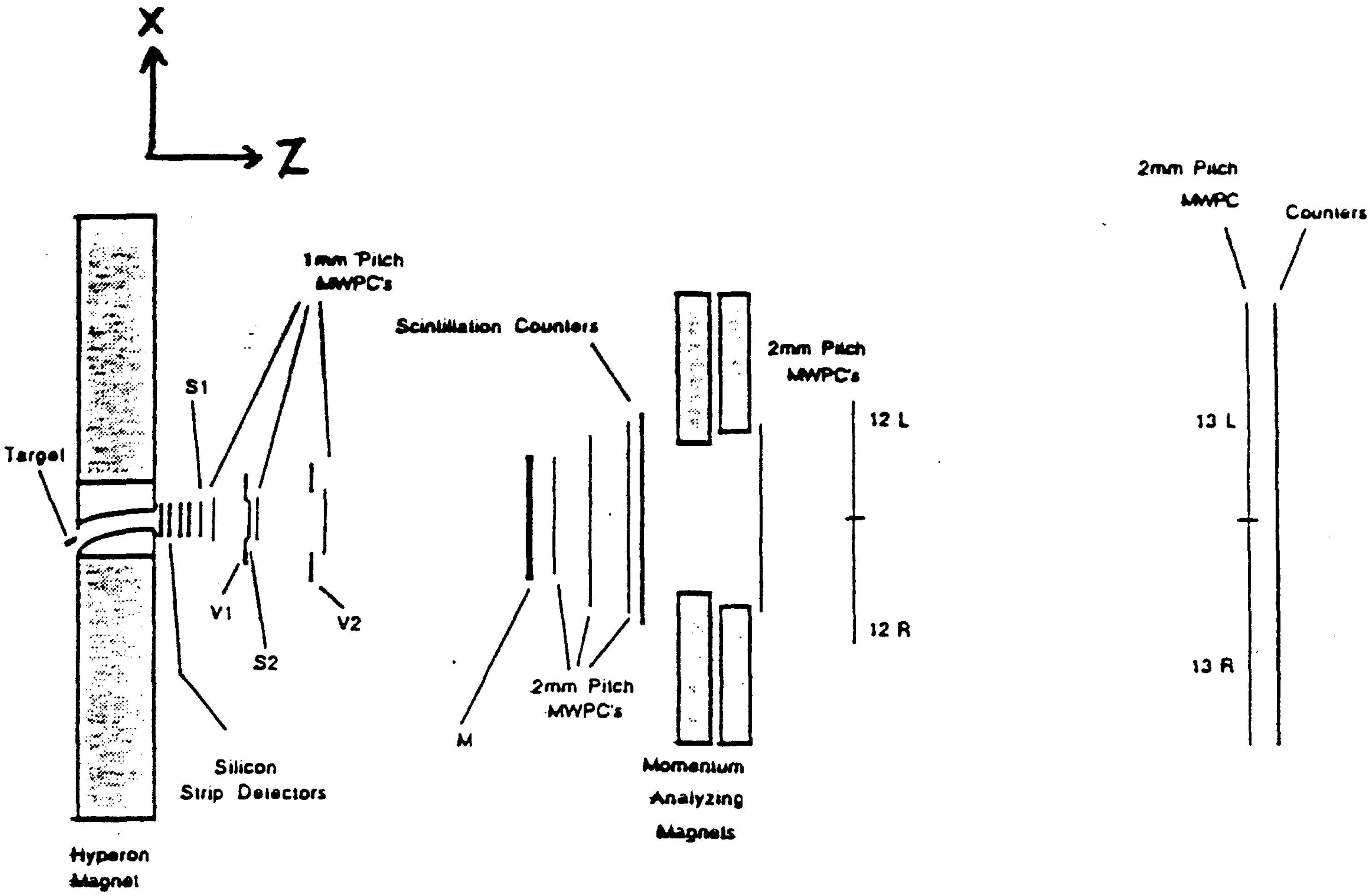
TABLE 1 Current experimental determinations of the hyperon magnetic moments along with predictions for the simplest quark models.

$$\delta\mu_{\Omega^-} = \frac{16.2}{(\alpha P)\int Bdl\sqrt{N}}$$

	'87-'88	proposed
$\int Bdl$	14.5	25.0
(αP)	0.04	0.06
N	20000	100000
ΔT	2 months	4 months
$\langle I \rangle$	4×10^{11}	2×10^{12}
$\delta\mu_{\Omega^-}$	**0.2 n.m.**	**0.03 n.m.**

Error in Magnetic Moment Measurement

TABLE 2 - We show the factors which go into determining the error in the magnetic moment. In order to obtain 100000 events we need a total integrated intensity of 2E17 protons on target. The Delta T and average I shown are way to achieve this, however one must be careful when interpreting the T and I.

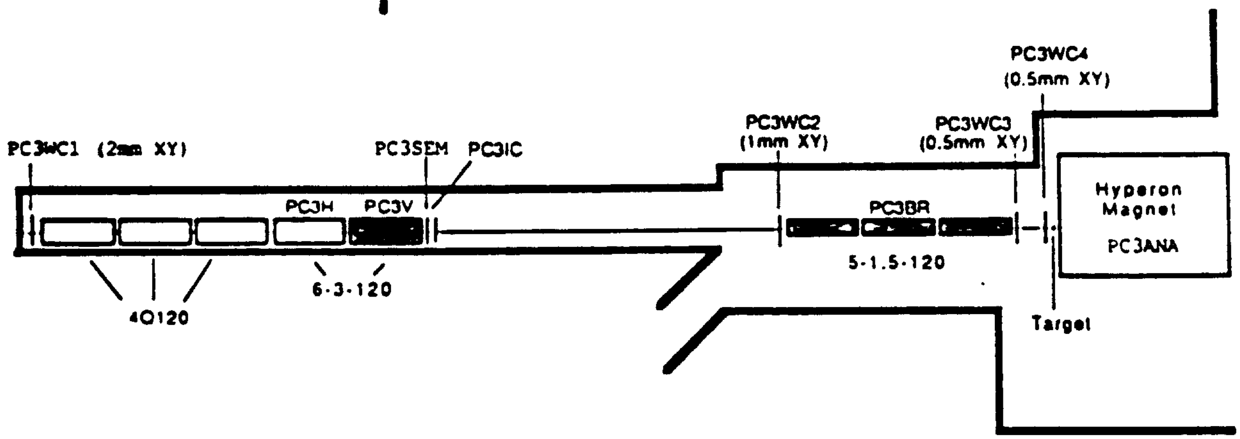


Plan View of E756 Spectrometer (not to scale)

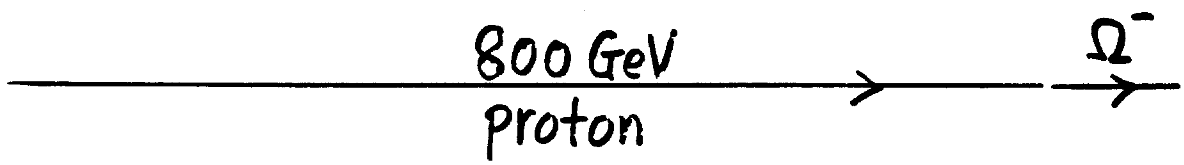
FIGURE 1

Part I

$p + Be \rightarrow \Omega^- + x$



Plan view



Elevation view

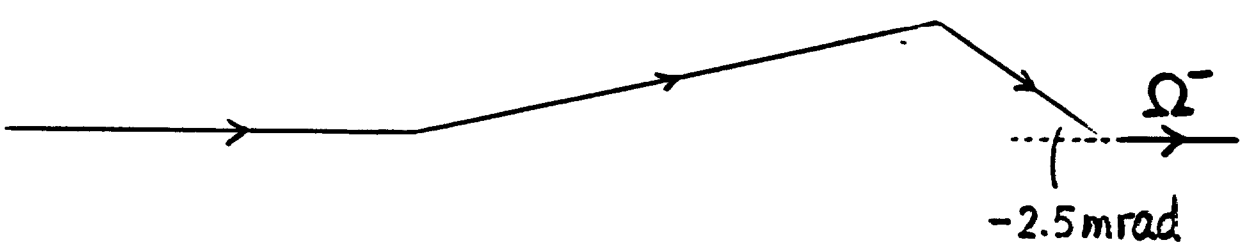


FIGURE 2 - Layout of PC3 pre-target area for E756 when producing Omegas directly from protons.

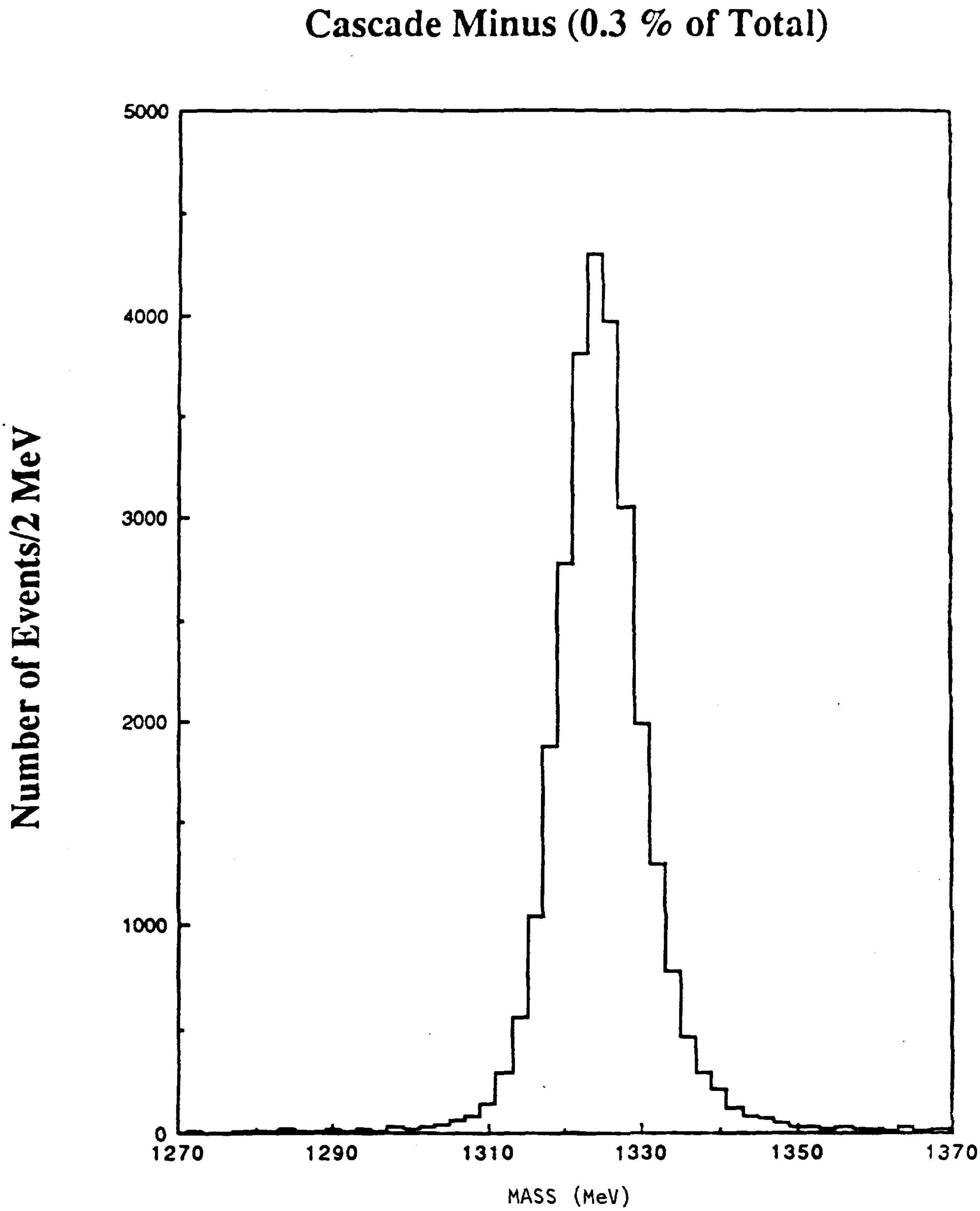


Figure 3a - Mass plot for a small sample of Cascades produced by protons

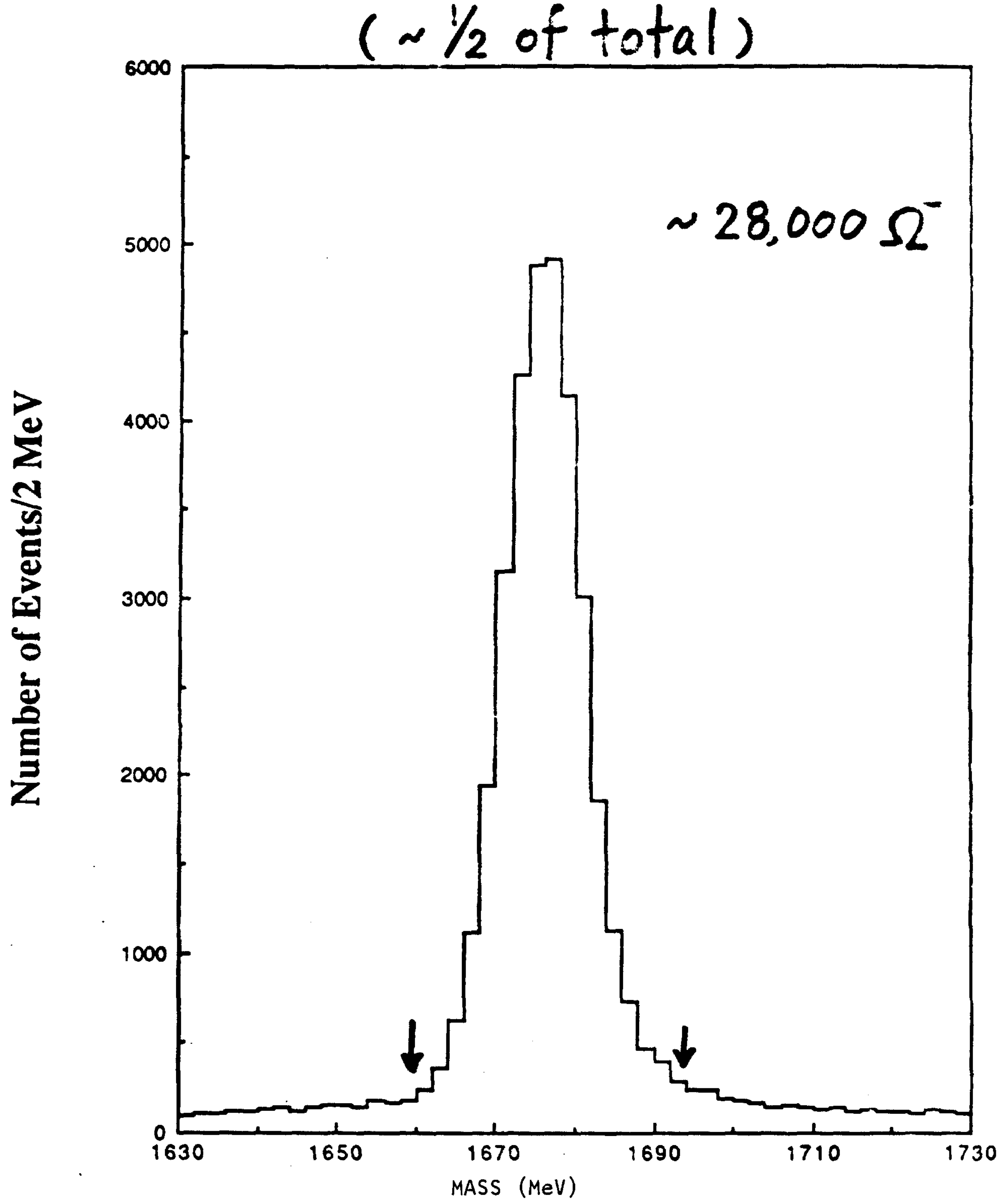


Figure 3b - Mass plot for 28000 Omegas produced by protons. The arrows indicate where the data was cut for the polarization analysis.

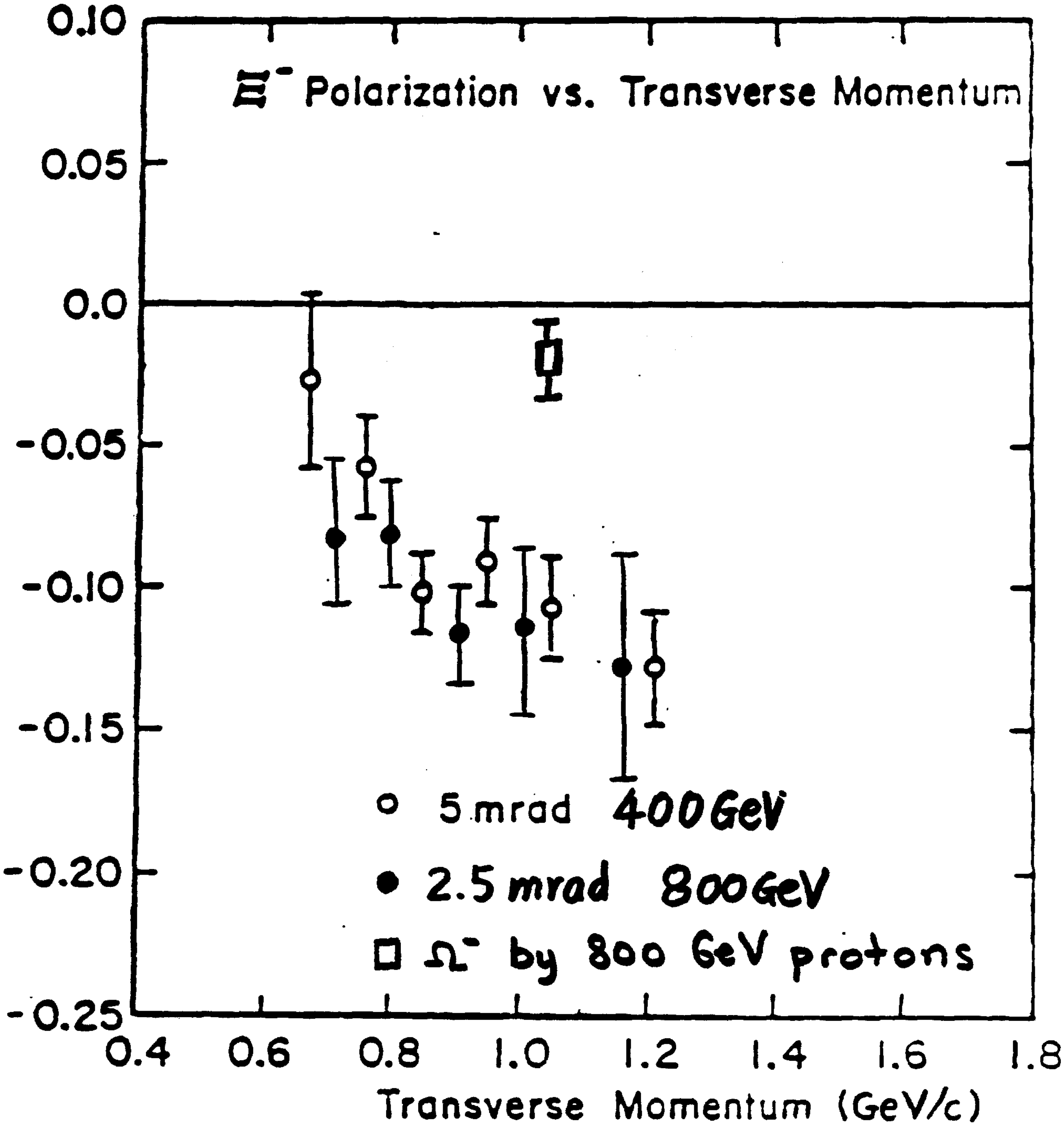
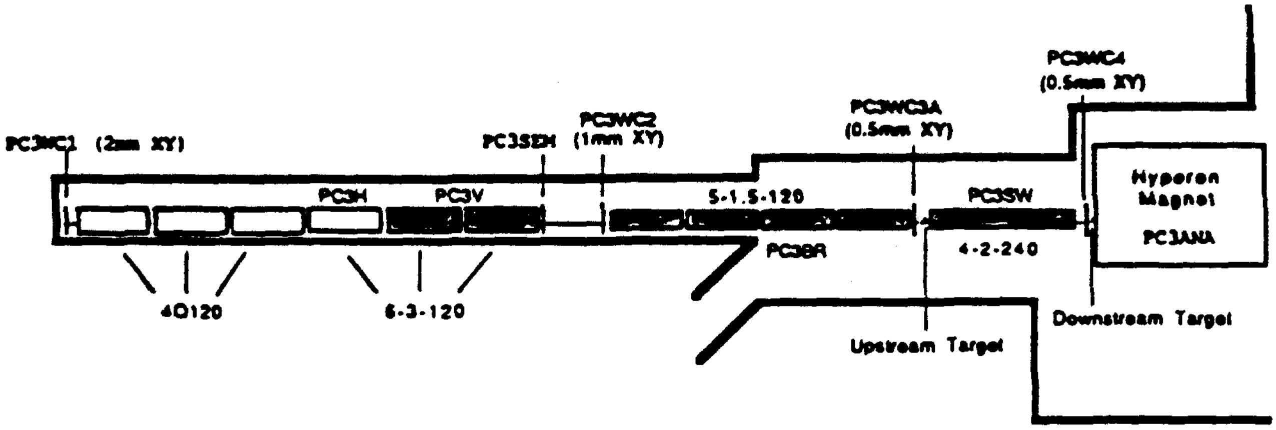


FIGURE 4 - Preliminary polarization results for a small sample of Cascades from E756 is shown with cascade polarization measured in E620 (400 GeV). The polarization result for 28000 Omegas (produced by protons) is also shown.

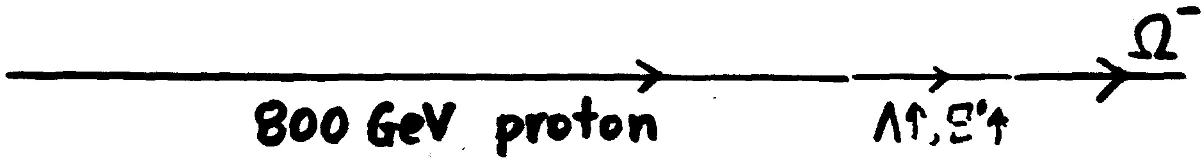
Part II

$p + Cu \rightarrow \Lambda\uparrow, \Xi^0\uparrow$

$\Lambda\uparrow, \Xi^0\uparrow + Cu \rightarrow \Omega^- + X$



Plan View



Elevation View

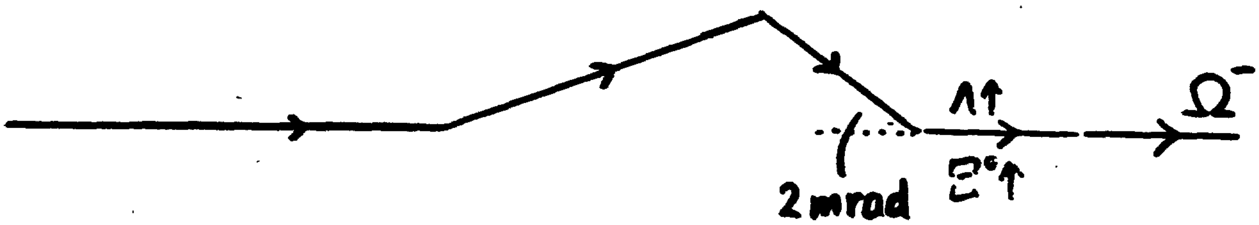


FIGURE 5a - The PC3 pre-target area is shown for the neutral beam targeting scheme.

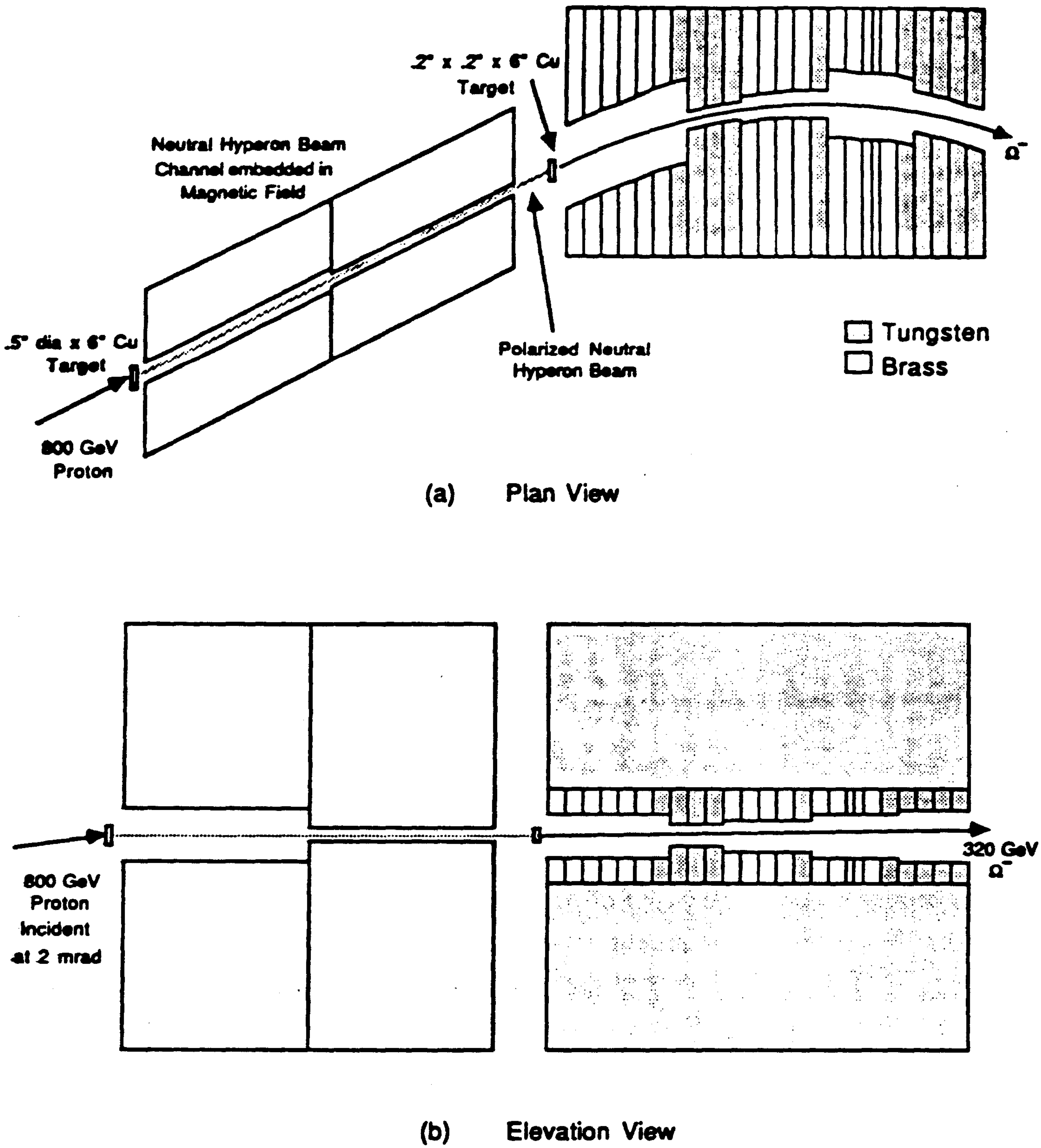


FIGURE 5b - Detail of the neutral beam channel imbedded in the B2 magnet, and the charged beam channel imbedded in the momentûm selecting, spin precession magnet.

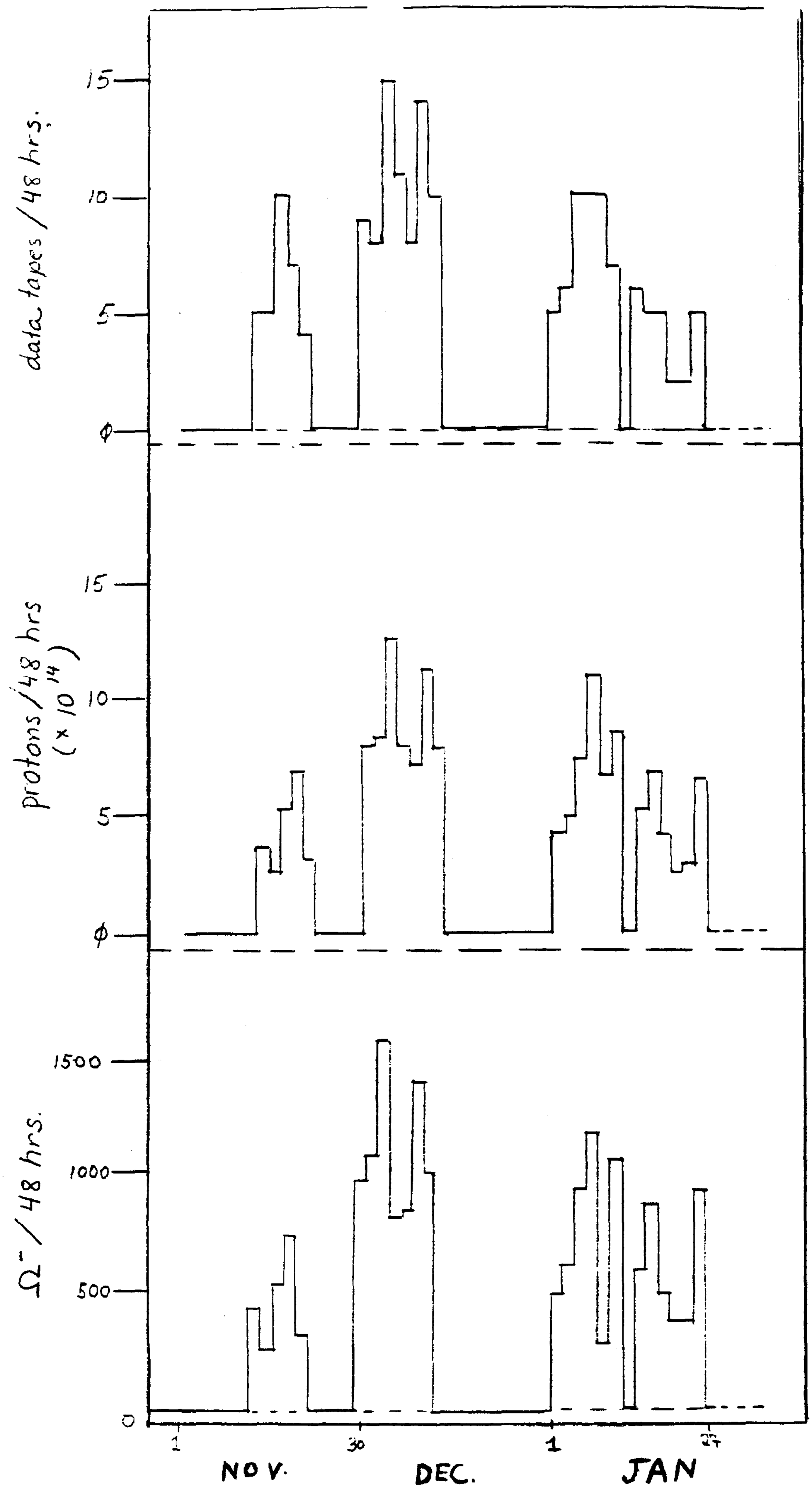


Figure 6 - E756 data taking history from Nov. 13, 1987 until January 27, 1988. This is the period during which all of the polarized Omega data was taken.

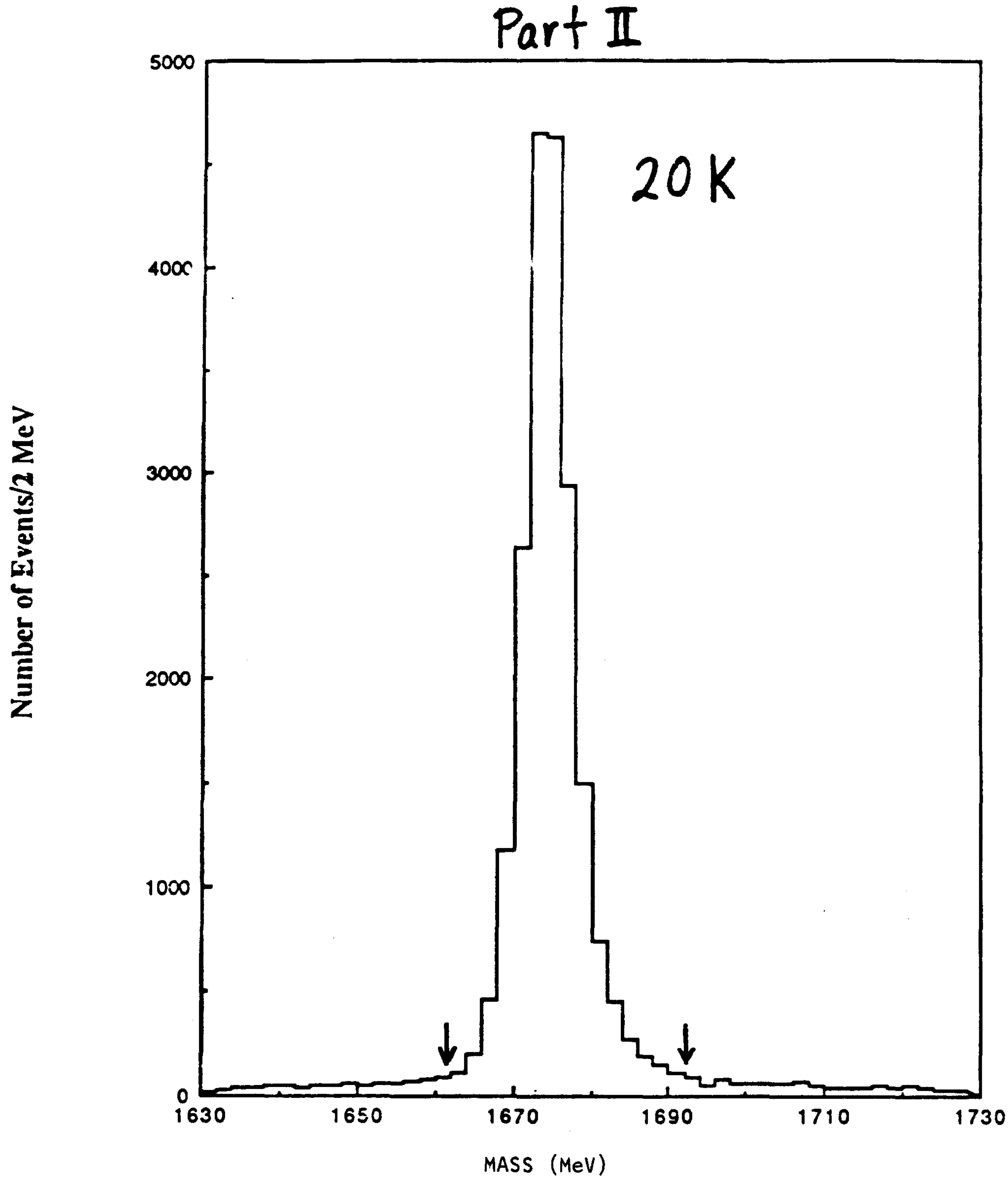


FIGURE 7b - Mass plot for Omegas produced by a neutral beam. Again the arrows indicate where the data were cut for use in the polarization analysis.

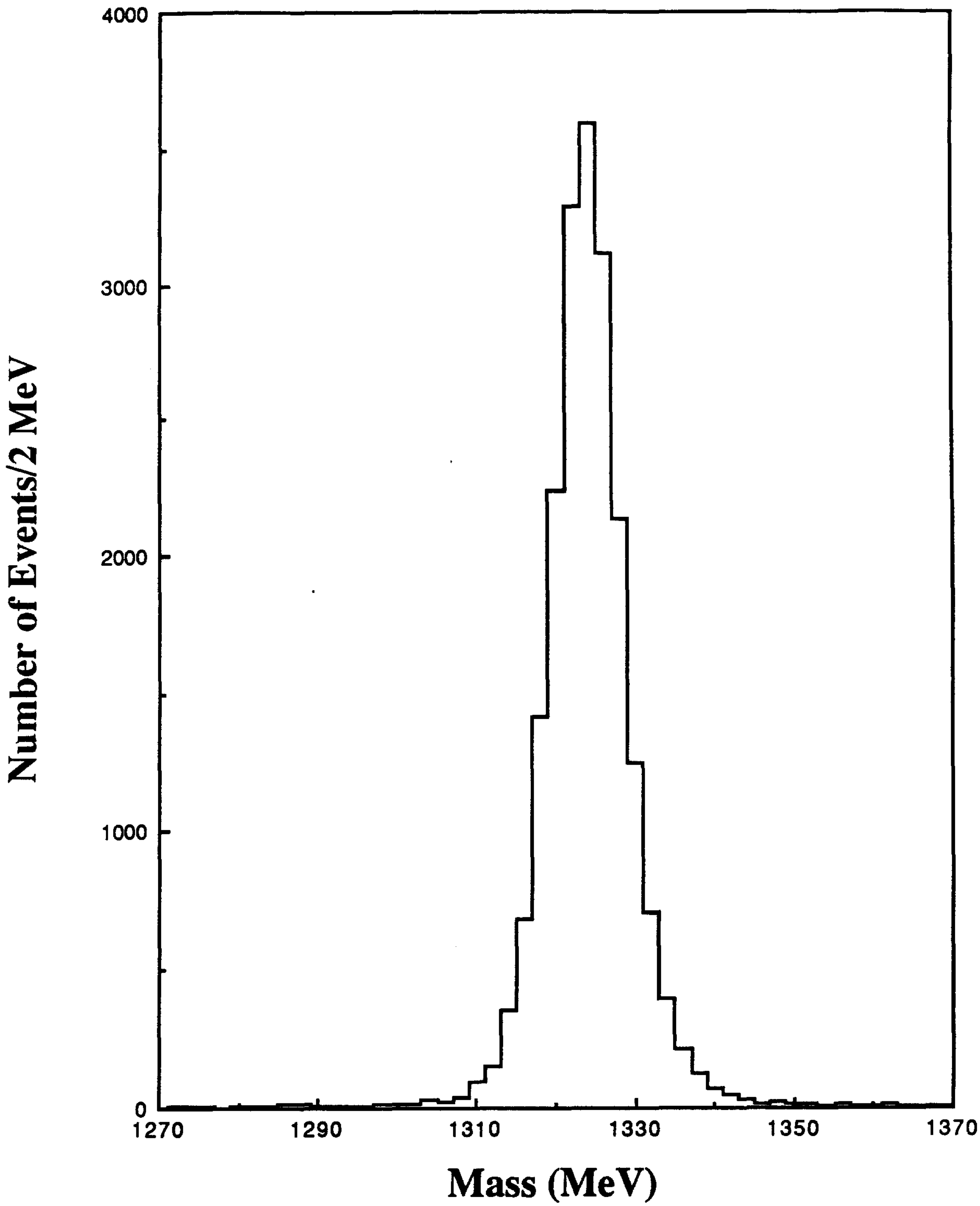


Figure 7a - Mass plot for a sample of Cascades
produced by the neutral beam.

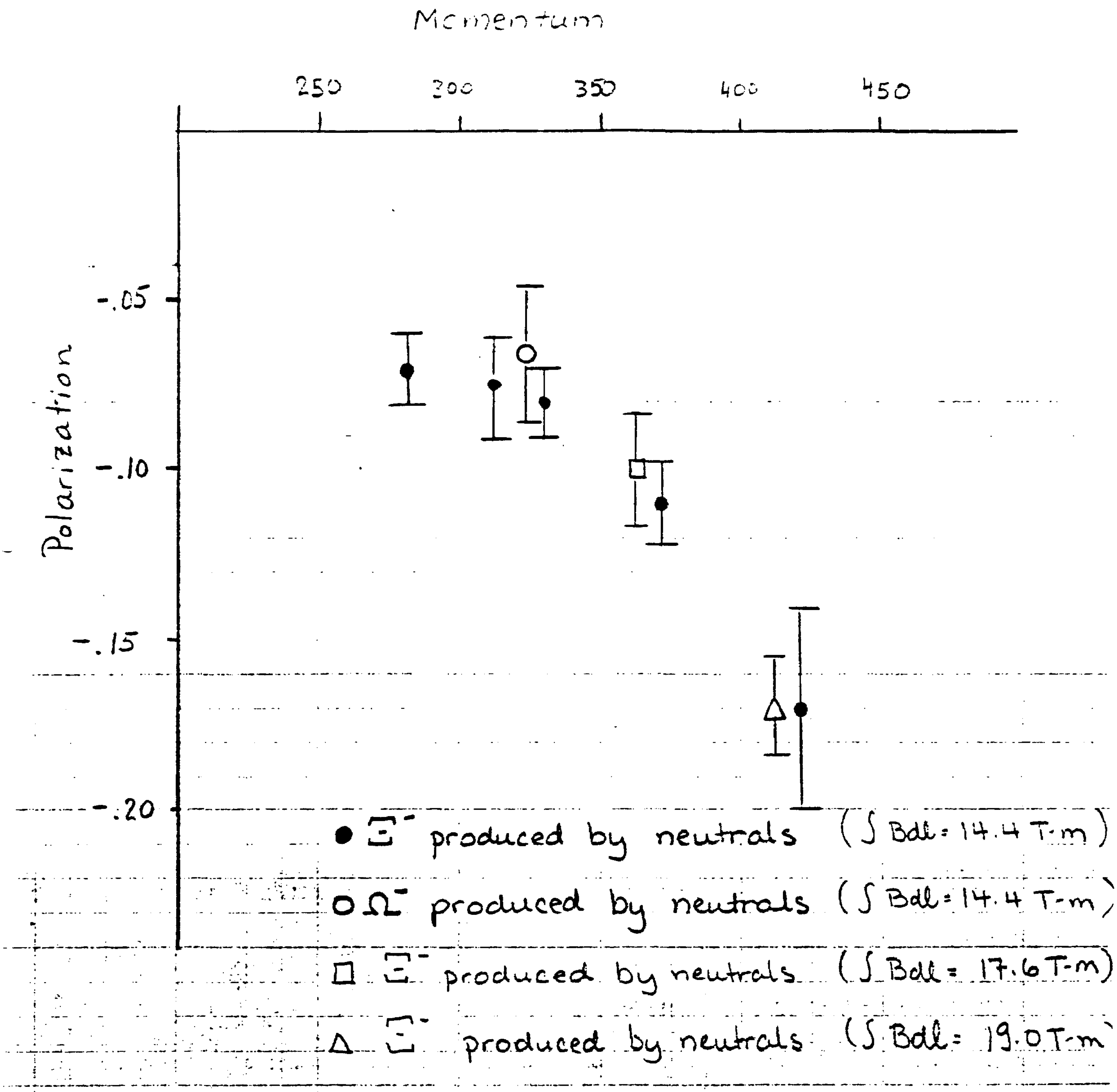


FIGURE 8. - PRELIMINARY results of polarization for neutral beam production of Cascades and Omegas.

E756

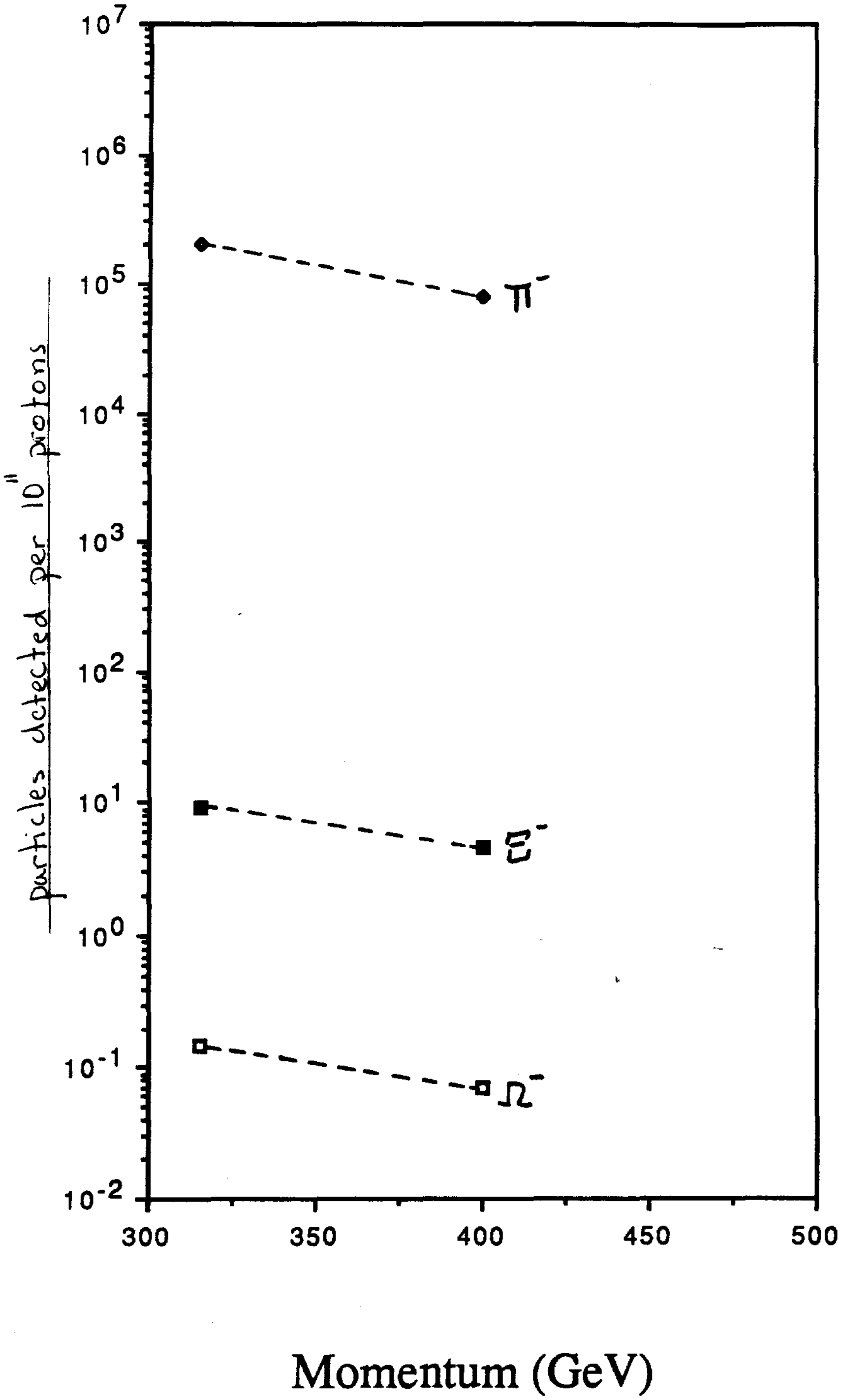


FIGURE 9 - Particle flux for pi's, cascades and omegas for neutral beam production. Note, the rates are per 1E11 protons on target.

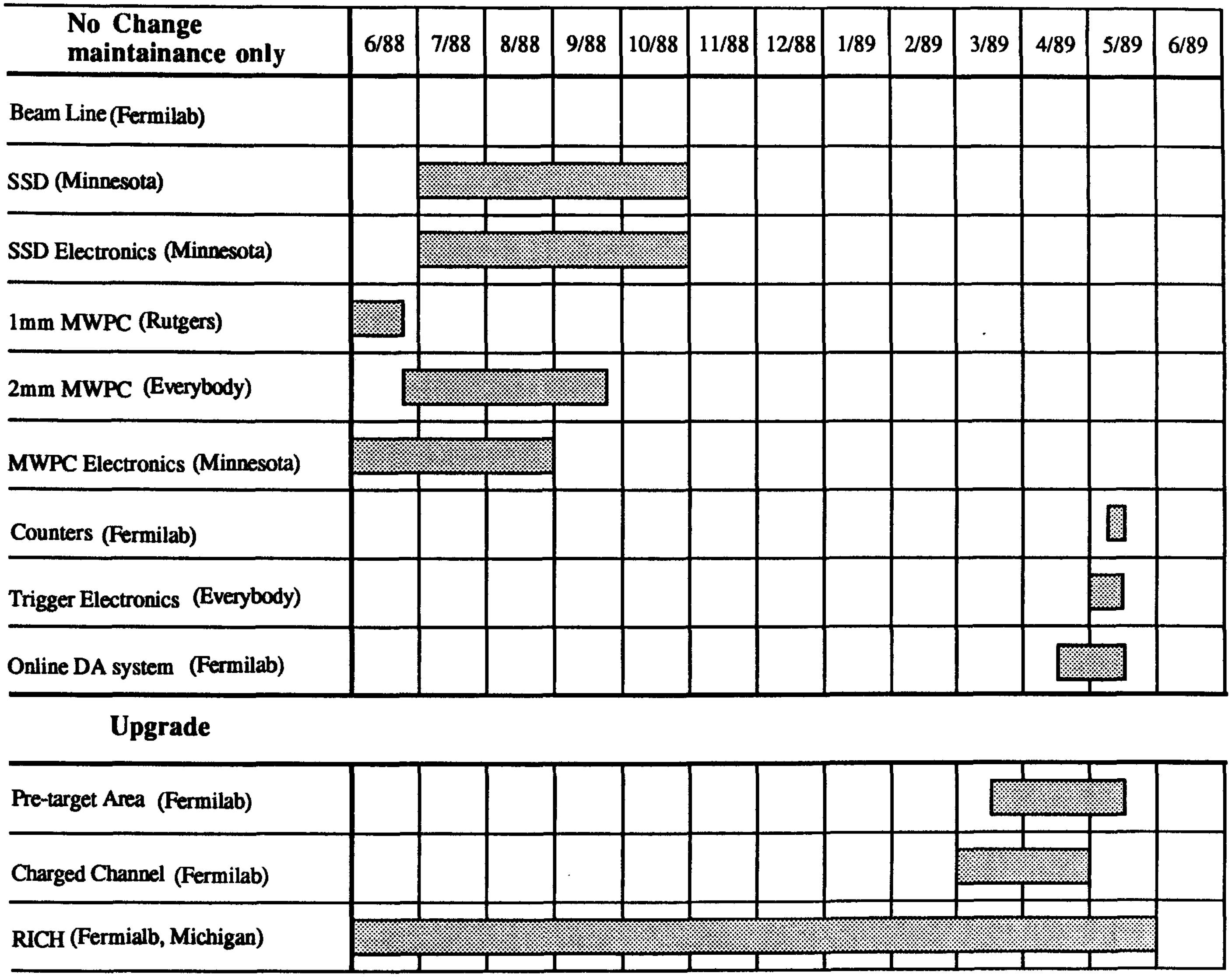


FIGURE 10 - **1989 Start-up Schedule of E756**