The BNL Multiparticle Spectrometer (MPS) Program*

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by

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A. THE MPS

In the past several years many of the large accelerator laboratories have constructed or have begun construction of large solid angle spectrometer systems (CERN's Omega, SLAC's LASS, Rutherford's RMS). At Brookhaven this effort is called MPS (for Multi-Particle Spectrometer) and is being operated as a user facility by members of the Physics and Accelerator Departments with considerable assistance from the university user community. The list of people and institutions involved in the work reported here is given in Table I. The spectrometer consists of a large C magnet located in one corner of the EEBA building at the end of one branch of the Medium Energy Separated Beam (MESB). I will proceed to describe the state of the spectrometer as of April 1975, although considerable augmentation and improvement is projected for the near future.

I. The magnet (Figs. 1 and 2) is a C with poles 1.83 m wide by 4.57 m long with a vertical separation of 1.22 m. Except for 3-20 cm diameter stainless steel columns, the west side is open to provide access for detectors and egress for particles.

The top pole and yoke have 12 slots 12.7 cm X the full width of the pole for the introduction of chamber modules whose magnetostrictive read-out lines are located in the low field region above the magnet.

II. The MESB is designed to separate K's and π's up to about 5 GeV/c and p up to the maximum transportable momentum, which is about 8.7 GeV/c. The
final spot size H x V at the MPS hydrogen target was 1.2 cm x 2.6 cm at 8.7 GeV/c and 1.8 cm x 4.0 cm at 4.0 GeV/c, the two momenta used for the last run.

III. The hydrogen target in use for the last run was 4.44 cm diameter x 30 cm long mounted on an adjustable carriage with horizontal position and angle about a vertical axis remotely adjustable.

IV. Detectors

a. The beam was instrumented with 12 gaps of proportional wire chambers with 1 mm wire spacing providing 1/4% fwhm momentum resolution with $\approx$ 1 mr fwhm angular and $\approx$ 3 mm position resolutions at the hydrogen target. A single threshold Cerenkov counter, about 99% efficient for pions, was adequate for the conditions under which we ran the separated beam for this run.

b. Magnetostrictive chamber modules were installed in slots numbered 3, 5, 6, 7, 8, 9, 10 (Fig. 2). Each module consisted of two x gaps (with vertical wires) separated by a u and a v gap (wires $\pm$ 15° to vertical). Y magnetostrictive chamber modules (with two gaps of horizontal wires) were inserted through the open side of the magnet in front of slots 4, 5, 6, 8, 9, 10 and 11. Each chamber has a sensitive area 1.8 m x 1.2 m and a position resolution of about 1 mm fwhm. This is about twice as large as we achieved in the MKI chambers outside the magnetic field and the cause is under investigation. Behind the magnet were located two modules from the old spectrometer, the "I" (3 m x 1 m) and the "E" (4.3 m x 1.6 m) each with 2 x and 2 y gaps. In the I module there is also a w gap with wires at 45°.
In all then there were 102 magnetostrictive lines reading coordinates from \( \sim 180,000 \) spark chamber wires (a total of 320 km of wire).

c. In front of slot \#3 and under slot \#4 were located two large proportional wire chambers TPX1 and TPX2, 1.2 m and 1.6 m wide, respectively, each with vertical wires 1.2 m long with .25 cm separation. These were part of the event triggering system.

d. Surrounding the hydrogen cell was a composite scintillation counter consisting of two half-cylinders. The downstream end of the cylinder is closed by a 10 cm diameter scintillator. Downstream is a scintillation counter hodoscope H4 consisting of 45 vertical counters 5.4 cm wide and a hodoscope H5 in the shape of a flattened Vee with 112 counters 6.5 cm wide.

e. Between the two counter hodoscopes was a Cerenkov hodoscope (20 cells, 18 actually in use) operated with Freon 114 at atmospheric pressure with a threshold at 3 to 3.5 GeV/c for pions.

f. Toward the end of the run four of the plane chamber "R" modules intended to be used beside the hydrogen target for Experiment 557 were installed beside the hydrogen target near the open side of the MPS magnet. Each module has four spark chamber gaps, two with vertical wires (x gaps), two with wires arranged \( \pm 10^\circ \) to the horizontal, read out by a diode capacitor circuit on each wire.

V. All the data generated by the detectors described is recorded in a computer memory device (data box) with a capacity of 16384 18-bit words. Between AGS pulses this device writes magnetic tape records of the events, and in parallel, transmits some events to the PDP10 of the On-Line Data
Facility. This small sample of data events, along with regular readings of a rapid cycling digital voltmeter, is processed by the "on-line" program. Special events are included in the data to monitor the efficiency and position accuracy of the magnetostrictive chambers. Data triggers are processed through pattern recognition and abbreviated geometry-kinematics routines "on-line" to provide nearly full analysis of a small statistics sample. CRT displays of detector performance, effective mass histograms, reconstruction of events, etc. are available at the touch of a teletype key. Teletype warning messages of poor detector performance were delivered to the MPS Control Room.

The magnetic tapes were carried to the BNL Central Scientific Computing Facility for processing by a CDC 7600 computer. Processing times were typically 6-8 minutes for a tape containing 10,000 mixed events.

B. EXPERIMENT 654

There were four separate groups approved to do experiments with four substantially different configurations of detectors in the MPS. Members of all four groups were actively engaged in developing and testing equipment and computer programs for these experiments when the joint announcement of the J and ψ prompted an immediate reappraisal. The four groups decided to coalesce and propose a single experiment, using the equipment already in hand, to investigate the new phenomenon. It was immediately apparent that the coupling of the "Jipsy" to any hadron production channel would be too small to collect many events in MPS, especially since the MESB had an upper limit of about 8.7 GeV/c. The assumption that the new phenomenon was the first manifestation of the existence of "CHARM" was
then considered to offer the best chance for a meaningful measurement. The J itself was clearly not "charmed" but could be a bound state of the charmed quark and its anti-quark. The crucial experiments would be the production of charmed objects. In fact, an MPS proposal to search for such objects with a high energy beam had already been submitted. The MESB again seemed too low in energy for much hope but a certain amount of $\pi^-p$ running at the top energy was included to search for associated production of a charmed meson-baryon final state. The second possibility lay in the fact that if the J was, in fact, "orthocharmonium," a spin one bound state of $c\bar{c}$, then the corresponding spin zero bound state "paracharmonium" should be near it in mass and, on various grounds, should couple much more strongly to hadrons. We thus planned a "formation" experiment $\bar{p}p + n_c +$ final state, tuning the total c.m. energy of the $\bar{p}p$ system to lie near and just below the J mass to search for the existence of a narrow peak ($J^{PC} = 0^{-+}$, $\Gamma \sim$ several MeV). To maximize the chance of seeing a small cross section signal we looked for places where normal strong interaction cross sections were themselves quite small. The final states planned were quasi-inclusive $\Lambda$, $\Lambda$ and $K^0$ production and $\pi^+\pi^-$ and backward $p\bar{p}$ elastic scattering.

Data were thus recorded with three separate energies of the incident $\bar{p}$ beam covering the range of 3.7 to 4.2 GeV/c momentum corresponding to $\sqrt{s} = M_{n_c} = 2.99$ to $3.14$ GeV/c$^2$. Two triggering systems were used simultaneously, the $0+2$ trigger (no count in the target scintillator, two clusters in TPX2) attempting to detect the decay of strange neutrals and a $\Delta Q = 2$ trigger detecting a forward high momentum positive particle by triggering an appropriate combination of counters in H4 and H5.
Figure 3 is a plot of the effective mass of the neutral vee's reconstructed for the lowest energy run using the $\Lambda$ and $\bar{\Lambda}$ hypotheses (there is no kinematic overlap between these). As expected, since the trigger is on forward neutrals there are about 17 times as many $\bar{\Lambda}$'s as $\Lambda$'s produced. The width of the $\bar{\Lambda}$ peak is about 4 MeV (fwhm), consistent with spark chamber resolution, but there are clearly substantial "tails" to this distribution. One contribution to this worse resolution is the drift of charge deposited in the chambers before the spark formation. We have monitored this effect and know that it varied with time during this run. We hope to substantially reduce this variation by better regulation of the composition of the spark chamber gas. Figure 4 is a plot of the missing mass squared distribution for the $\bar{\Lambda}$ events. Although the mass scale is slightly off, the usual clear peaks due to peripheral processes $\bar{p}p \rightarrow \bar{\Lambda}Y, \bar{\Lambda}Y^*$ are there.

The missing mass squared spectrum for $\Lambda$ events (Fig. 5) however, shows considerable suppression of the quasi-elastic region and suggests that this process might be a good place to look for decay of the $c \bar{c}$. Fig. 6 shows our "scan" of forward $\Lambda$ production as a function of $\bar{p}$ momentum from 3.7 to 4.2 GeV/c (2.99 to 3.14 GeV/c$^2$ mass range). The $\bar{\Lambda}$ events serve as an excellent denominator, helping to remove any momentum dependent acceptance effects, although dividing by the incident beam spectrum provides a very similar plot. Within statistics no outstanding peak is seen. Each bin is 10 MeV/c which is about the resolution of the beam spectrometer and corresponds to about 3 MeV in mass. Since we are in the process of preparing this data for publication I will not quote a cross section limit except to say that it is in the region of a few microbarns.
Figure 7 is a spectrum of the $\pi^+\pi^-$ effective mass with the $\bar{\Lambda}$ and $\Lambda$ events removed. There is still some background but a clear $K^0$ signal is obtained (10 to 12 MeV fwhm) again with a low mass tail. The missing mass spectrum (Fig. 8) shows no $K^0$ or $K^*$ bump. Figure 9 is the ratio of the $K^0$ to $\Lambda$ production as a function of beam momentum. Again we see no obvious large narrow peak. Not wishing to leave the impression that the MPS is designed for two track events, we present in Fig. 10 a plot of the effective mass and missing mass for events with two neutral $K$‘s produced by 8.7-GeV/c $\pi^-$ on hydrogen.

C. THE FUTURE

New devices planned for the MPS this year include a set of 9 cylindrical spark chambers with magnetostrictive readout, designed to surround the hydrogen target with the beam passing down the cylinder axis with tails to bring the wires out of the magnetic field for readout. The chambers are 140 cm long with diameters ranging from 33 cm for #1 to 120 cm for #9. Each gap is formed by axial wires on the outside and wires spiraling at an angle of 45° to the axis on the inside.

As an alternative target region detector, the total compliment of capacitive readout chambers is to be 4L, 4R and 3D modules, a total of 42 gaps. A new proportional wire chamber to be located in the incident beam in front of the hydrogen target should substantially improve the accuracy of the determination of the direction and location of the beam particle and should also aid the alignment and $E \times B$ effect measurements.

A high energy (unseparated) beam has been designed using superconducting dipoles and should be installed by next year. By rotating the
MPS magnet this beam can be brought to the MPS hydrogen target without relocating anything mounted in the MPS proper. The beam should provide particles up to 25 GeV/c in momentum.

REFERENCES:

FIGURE CAPTIONS

Fig. 1  Perspective drawing of MPS magnet.

Fig. 2  Layout of MPS detectors – April 1975.

Fig. 3  Effective mass plots of neutral vees from 3.83 GeV/c \( \bar{p}p \) interactions. Proton-\( \pi^- \) and antiproton-\( \pi^+ \) mass hypotheses.

Fig. 4  Missing mass squared spectrum from anti-lambda production in 3.83 GeV/c \( \bar{p}p \) interactions.

Fig. 5  Missing mass squared spectrum from lambda production in 3.83 GeV/c \( \bar{p}p \) interactions.

Fig. 6  Ratio of \( \Lambda \) to \( \bar{\Lambda} \) production as a function of incident antiproton momentum.

Fig. 7  Effective mass of neutral vees from 3.83 GeV/c \( \bar{p}p \) interactions. \( \pi^+\pi^- \) mass hypothesis.

Fig. 8  Missing mass plot from \( K^0 \) production in 3.83 GeV/c \( \bar{p}p \) interactions.

Fig. 9  Ratio of \( K^0 \) to \( \bar{\Lambda} \) production as a function of incident antiproton momentum.

Fig. 10 (a) Effective mass plot of \( K_{s}K_{s} \) events produced by 8.7 GeV/\( \pi^- \) on hydrogen. (b) Missing mass plot.
TABLE I

List of MPS Collaborators

Brandeis University
J. Bensinger, S. Jacobs, L. Kirsch and P. Schmidt

Brookhaven National Laboratory
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J. Russell

Syracuse University
M.A. Fainberg, P. Gauthier, M. Goldberg, N. Horwitz, I. Linscott
and G.C. Moneti
MPS MAGNET

<table>
<thead>
<tr>
<th>Weight</th>
<th>650 tons</th>
</tr>
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<tbody>
<tr>
<td>Gap</td>
<td>6' wide x 4' high x 15' long</td>
</tr>
<tr>
<td>Central Field</td>
<td>10kG</td>
</tr>
<tr>
<td>Coils</td>
<td>14 pancakes, 11 turns ea.</td>
</tr>
<tr>
<td>Power</td>
<td>10,000 A @ 240V</td>
</tr>
<tr>
<td>Cooling Water</td>
<td>400 GPM @ 20°C rise</td>
</tr>
<tr>
<td>Downward Force</td>
<td>550 tons (magnet powered)</td>
</tr>
<tr>
<td>at Midplane</td>
<td></td>
</tr>
<tr>
<td>Support</td>
<td>4 hydrostatic bearings, 30&quot; dia. on steel plates</td>
</tr>
<tr>
<td>Rotation</td>
<td>± 15°, pivot 18&quot; inside upstream end</td>
</tr>
</tbody>
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Figure 1
LIQUID HYDROGEN TARGET

7 XUVX MODULES IN SLOTS
7 YY MODULES BETWEEN SLOTS

TPX1, TPX2

LIQUID HYDROGEN TARGET

BEAM FROM MESB

ANTI COINCIDENCE COUNTERS

12Q30

SPARK CHAMBERS
ČERENKOV COUNTER-HODOSCOPE
HODOSCOPE
SCINTILLATION COUNTER-HODOSCOPIES
Figure 3

3.83 $\bar{p}p \rightarrow V^0$

$M(\rho \pi^-)$

$M(\bar{p} \pi^+)$

EFFECTIVE MASS (GeV)

EVENTS/0.4 MeV
Figure 5

$3.83 \text{ GeV/c}$

$\bar{p}p \rightarrow \Lambda + \text{MM}$

Events / 0.1 GeV$^2$

Missing Mass Squared (GeV$^2$)

$\bar{\Lambda}$
$\bar{\Sigma}$
$\Lambda(1405)$
$\bar{\Lambda}(1520)$
$\Sigma(1385)$

Figure 5
Figure 6
Figure 7

3.83 \bar{p}p \rightarrow V^0

M(\pi^+\pi^-)

EVENTS/MeV

EFFECTIVE MASS (GeV)
Figure 9

**Beam Momentum vs. $\frac{N(K^0)}{N(\bar{\Lambda})}$**

- 4.06 GeV/c
- 3.95 GeV/c
- 3.83 GeV/c

**Axes:**
- $x$: Beam Momentum (GeV/c)
- $y$: $\frac{N(K^0)}{N(\bar{\Lambda})}$

**Legend:**
- Lines represent data points and error bars indicate uncertainty.
Figure 10

(a) $\pi^- p \rightarrow K_s K_s + (nN)^0$

8.7 GeV/c

Events / 0.05 GeV

Effective Mass ($K_s K_s$) GeV

(b) Events / 0.06 GeV

Missing Mass ($K_s K_s$) GeV