NAL PROPOSAL No. 176

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PROPOSAL FOR AN EXPERIMENT AT THE NATIONAL ACCELERATOR LABORATORY

NUCLEAR LEVELS AS ANALYZERS OF HIGH ENERGY INTERACTIONS

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Abstract

We propose to study diffractive phenomena caused by 100 BeV pions, using a new technique, which consists in associating with the high energy interaction, the detection of photons resulting from the de-excitation of nuclear levels. Knowledge of the quantum numbers both for the ground state and the nuclear levels of the nuclei used, adds information as to the type of interaction. In particular, the use of the 4.4 MeV level of Carbon guarantees that the exchange quantum has isotopic spin 0. In addition, evidence resulting from our tests at Berkeley seems to further encourage the notion that this level selects to a good extent phenomena of the diffractive type.

We ask for 150 hours of running on a 100 BeV/c pion beam.

Experimenters: B. Babcock, P. Kirk, J. Marraffino, W. Mehlhop, S. Murty, O. Piccioni

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We assume our Letter of Intent to be the first part of the present proposal.

In our work in Beam 19 of the Berkeley Bevatron, we have by now added the following information, concerning the technique of studying gamma rays emitted by nuclei in association with high energy phenomena:

From the analysis of the pictures we can see that the distribution of events plotted as a function of the angle θ between the momentum exchange $\vec{q}$ (difference between the incoming 3 BeV/c momentum and the outgoing pion momentum; $\vec{q}$ is therefore practically perpendicular to the incoming momentum) and the direction of the photon, follows closely, considering the statistics, a $(\sin 2\theta)^2$ dependence, which would be expected for a scattering amplitude without spin flip.

This information seems to show that our method tends to select the diffraction-produced events, in a stronger way than supposed just on the basis that the isotopic spin change of the nucleus is 0. This experimental result is shown in the included four histograms, which are obtained in the following way: since the angle θ can assume all values between 0 and 360 degrees, and since the function $(\sin 2\theta)^2$ has obviously the period of 90°, the full range of 360° has been divided in 4 quadrants, and all the four quadrants have been superimposed. The resulting composite quadrant has been further divided in four ranges, and the pulse height histogram for each of the 4 ranges is reproduced in the 4 figures. Taking into account that the angular resolution of the sodium iodide crystal is itself about as large as each of the sectors, one concludes that the $(\sin 2\theta)^2$ dependence is well demonstrated.

More data on the same line have been taken, but we have not yet analyzed the pictures. We hope to have them ready at the time of our presentation.

We have searched for the excitation of the 15.1 MeV state of Carbon (isotopic spin 1, while the ground state is isotopic spin 0) but have not found it excited. Even at the momentum of .4 BeV/c, same as for the work at CERN by Stroot and others, we do not find evidence for such a gamma emission. After some meditation, we conclude that we are not in contradiction with the CERN work because their resolution did not allow them to distinguish between several states grouping around 15.1 MeV (they measured only the momentum of the outgoing pions, without detecting the photon).

The Experiment at NAL

We propose to study the diffractive interaction of pions at energies of 30, 60 and 100 BeV/c. To emphasize the distinction between diffractive interactions and non-diffractive ones, we propose to make a comparative study of the interaction of the pions in a Carbon target, when a 4.4 MeV photon is emitted, and the interaction in a light nucleus, preferably a Deuteron, without any demand for an excited state. We will study all possible events which can be recognized by the apparatus described in the next section. We will collect data on inclusive reactions, as well as on multiparticle production. Depending upon technical feasibility, we might or might not undertake a study of elastic scatterings as well. Note that by the word elastic we mean here that the energy of the secondary is the same as that of the primary within the experimental error, while of course knowing that it must have lost an energy equal to the energy of the excited level.

Events for which the total momentum of the secondary will add up, within the error, to an absolute value equal to that of the incoming particles, will deserve special attention. For those events, in fact, we could impose the requirement that the momentum transfer to the nucleus should be less than a few hundred MeV/c. This requirement will be of help in reducing background events, for instance when neutrons resulting from the disintegration of the Carbon produce a pulse in the crystal, of comparable height to that expected for the 4.4 MeV photon. Thus, the signal to background ratio will be better for these selected events than for others. However, on the basis of our Bevatron tests, we expect that such ratio will be adequate for a good investigation at any arbitrary high energy, even for events when the total momentum of the secondaries cannot be measured because some of them are missing from the picture.

Typical differences expected by the theorists between diffractive and nondiffractive events are such as indicated in the table, which we have taken from the review article of Frazer, et al. in Reviews of Modern Physics - April, 1972.

However, the main motive of our research lies not so much in the hope of nailing down some differences that are expected today, as it does on the hope that, availing ourselves of a new method, we might possibly open a new door in the investigation of high energy phenomena, which may give results not foreseen as of today.

After the first phase of the experiment, we would analyze our results, and probably add to our experimental apparatus few more spark chambers, with the intent to observe some particular reactions, which could not be easily recognized with the apparatus that we propose at present.

One such reaction could be, for instance, the diffraction dissociation of a pion into a pair of nucleon antinucleon. Obviously, in that case one of the nucleons must be uncharged. One would need therefore to have enough matter interposed in the spark chambers at the end of our apparatus, to recognize such a neutral particle. Another interesting reaction would be that of the diffraction dissociation of a pion into a charged and uncharged kaon.

Experimental Arrangement

Figures 1, 2, and 3 describe the arrangement of spark chambers and counters. The counters B_1, B_2, and B_3 identify any incoming high energy pions. The anticoincidence counter A guarantees that a noninteracting pion should not cause a trigger. The hodoscope of counters H, can be arranged logically in several ways to ask for one or more secondaries traversing the last spark chamber S_8. The target assembly, including the sodium iodide crystals looking at the target, is shown in detail in Figure 3. The crystal is surrounded by anticoincidence scintillation counters to reduce background. To trigger the system it will be required that a beam particle crosses the beam counters, produces a pulse in one or more counters in the Hodoscope, without any charged particle crossing any of the anticoincidence counters. The spark chambers are of the optical type, and their picture is taken by a camera 27 feet higher than beam level. The photographic frame will be on 35 mm film, and will have a length of 70 mm. We are already in possession of a fast camera of our own construction which can move that amount of film in 40 milliseconds or less. Taking into account the size of the spark chambers, one can readily see that there will be no trouble in achieving a resolution better than 1 millimeter in actual space. In turn, this means that the direction of a particle seen before the magnet, or after the magnet, will be known with an error less than $\pm$ .35 mr. Thus, the deflection of a particle going through the magnet will be known at better than $\pm$ .5 mr. To make a comparison with the angular deflection produced by the magnet itself, note that the magnet will give to any particle a transverse momentum of at least .6 BeV/c. Therefore a secondary of momentum as high as 50 BeV/c will undergo a deflection of 12 mr, and its momentum will be known with an accuracy of $\pm$ 4%. This should be sufficient for most of the purposes we have in mind. However, we anticipate that if in a future development of the experiment, we should find need for higher precision, the possibility exists of using two separate cameras, one before the magnet and another one after the magnet, and correspondingly placing the spark chambers apart by a greater distance than that shown in the present drawings, with substantial improvement in the accuracy of the momentum measurement. As to the angular acceptance for the secondaries, the present apparatus accepts secondaries of a momentum as low as 5 BeV/c, if produced at the target with an angular spread of $\pm$ 96 mr , in the horizontal plane, and about one half as much in the vertical plane. We assume that the pion beam can be obtained with an angular divergence of $\pm$ .5 mr, which corresponds to an uncertainty of transverse momentum of $\pm$ 50 MeV/c for an incoming momentum of 100 BeV/c.

The data will be taken by running at the same time a photographic camera and a tape unit commanded by a PDP8 computer. The tape will contain the information of the pulse height in the 8-inch diameter, 10-inches long sodium iodide crystal, the pulse height in the 5-inches thick sodium iodide anti-coincidence crystal, which protects the main crystal itself, and the time of flight between the pulse in the main crystal and the arrival of the beam particle. This last information, coupled with the information of the pulse height in the main crystal, is useful in excluding events due to neutrons of energies of a few MeV.

Rate of Useful Events

We assume that when a diffractive interaction occurs on the periphery of the Carbon nucleus, the probability of exciting the 4.4 MeV level is the same regardless of the particular type of that diffractive interaction.

We have observed that, at 3 BeV/c, the elastic scattering, which is essentially all diffractive, produces the 4.4 MeV level with a cross section of 2 mb. On the other hand, the elastic cross section of 3 BeV/c, on nucleons is about 8 mb, and all diffractive multiple pion phenomena at 100 BeV/c occur, on nucleons, with a cross section which is not significantly different from 8 mb. Thus the cross section for diffractive multiple pion production on Carbon with excitation of the 4.4 MeV level should also be essentially equal to 2 mb.

Taking into account that the total efficiency for the crystal to detect a photon under the peak is approximately 2%, and that we can use a 3 inches thick Carbon (6×10^{23} atoms/cm^2) we expect that for one million incoming pions, we will obtain about 24 good events. For a half million pions per pulse, and assuming 10 pulses per minute, we should then expect 7300 good events per hour.

The definition of good events so far only means, however, that they are truly associated with the excitation of the 4.4 MeV level in Carbon, but does not contain any selection as to any peculiarity of the high energy interaction. To take into account of the geometrical efficiency of the magnet spectrometer itself, and of the triggering counters, we will divide the previous rate by a factor of 4 reducing it to 1800 events per hour. The rate for the run without the sodium iodide would perhaps be not much higher, because of the limit represented by the dead time for the camera, estimated to be 40 milliseconds.

We then estimate that a meaningful run could be done with 25 hours per setting. For 3 energies, and 2 alternatives, with crystal and without crystal (this second alternative should preferentially have a deuterium target) we arrive to the total of <u>150 hours</u>.

NAL Contribution

We would hope that it will be possible for NAL to provide us with a deuterium target. The size of the target should be some two feet in the direction of the beam, and have a diameter of at least 6 inches. The spectrometer magnet 48 D48 with 30 inches vertical aperture should of course be available as well as some shielding blocks to be placed around the sodium iodide crystal and the target assembly.

Depending on the availability, we will find it convenient to use electronic equipment furnished by the Laboratory. However, our proposal does not make it as an essential requirement that the Laboratory furnishes us with any electronic instrumentation.

COMPLETE DATA BERKELEY EXCITATION SCATTERING

HISTOGRAM OF PH   I   LOCATED AT WD(S) 12

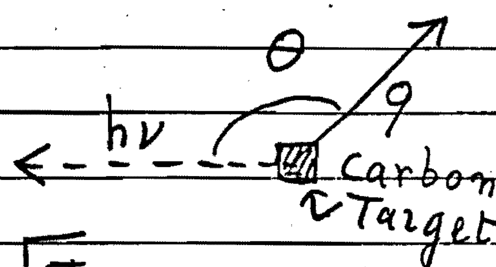
TEST 48

$\theta\ \phi = 0$ to 22.5

\+ 90 to 112.5

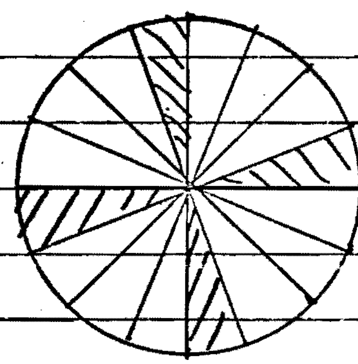
\+ 180 to 202.5

\+ 270 to 292.5



Incoming beam is perpendicular to paper (3 BeV/c)

↑ θ $|q| \sim .3\ \frac{BeV}{c}$



4.4 MeV ↓

```
  50
  49
  48
  47
  46
  45
  44
  43
  42
  41
  40
  39
  38
  37
  36
  35
  34
  33
  32
  31
  30
  29
  28
  27
  26
  25
  24
  23
  22
  21
  20
  19
  18
  17
  16
  15
  14
  13
  12
  11
  10
   9
   8
   7  X               X
   6  X       X  X  X X
   5  X       X  XX X X
   4  X       X XXX XXXX
   3  X  X  X XXXXXXXXXX
   2  XX X  X XXXXXXXXXX XX
   1  XX X  XXXXXXXXXXXXXXXXX
     123456789+123456789+123456789+123456789+
INTVL NOS     10        20        30        40
```

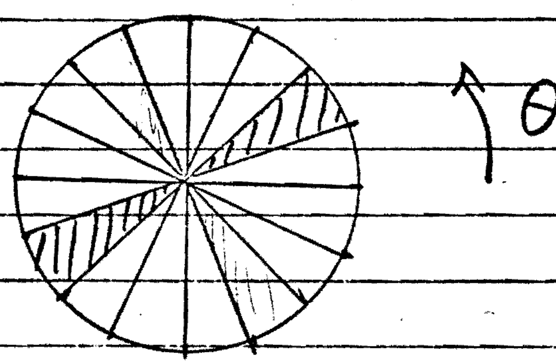
THESE NUMBERS REFER TO THE INTERVAL NUMBERS BELOW

COMPLETE DATA BERKELEY EXCITATION SCATTERING

HISTOGRAM OF PH 2 LOCATED AT WD(S) 12

TEST 49

θ = 22.5 to 45
+ 112.5 to 135
+ 202.5 to 225
+ 292.5 to 315



4.4 MeV ↓

```
  50
  49
  48
  47
  46
  45
  44
  43
  42
  41
  40
  39
  38
  37
  36
  35
  34
  33
  32
  31
  30
  29
  28
  27
  26
  25
  24
  23
  22
  21                 X
  20                 X
  19                 X
  18                 X
  17                 X
  16                 X
  15                 XX
  14                 XX
  13   X             XXX
  12   X             XXX
  11   X    X        XXX
  10   X    X  X X   XXX
   9   X    X  X X  XXXX
   8   X    X  X X  XXXX
   7   X    X  X X  XXXX    X
   6   X    X XX XX XXXX    XX
   5   X    XXXXXXXXXXXXX   XX
   4   X   XXXXXXXXXXXXXX   XX
   3   XX  XXXXXXXXXXXXXX   XX
   2   XX XXXXXXXXXXXXXXX X XX
   1   XX XXXXXXXXXXXXXXX XXXX
      123456789+123456789+123456789+123456789+
INTVL NOS      10        20        30        40
```

THESE NUMBERS REFER TO THE INTERVAL NUMBERS BELOW

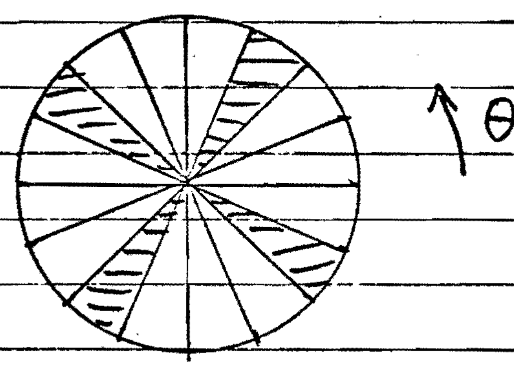
COMPLETE DATA BERKELEY EXCITATION SCATTERING

```
HISTOGRAM OF PH     3                    LOCATED AT WD(S)  12
TEST 50
  50
  49
  48
  47
  46
  45
  44
  43
  42
  41
  40
  39
  38
  37
  36
  35
  34
  33
  32
  31
  30
  29
  28
  27
  26
  25
  24
  23
  22                    X
  21                    X
  20                    X
  19                    X
  18                   XX
  17                   XX
  16          X        XX
  15          X       XXX
  14          X       XXX
  13          X       XXX
  12          X       XXX
  11          X   X   XXX
  10          XXX XX  XXX
   9          XXX XXX XXX
   8          XXX XXX XXX
   7    X     XXXXXXX XXX
   6    X    XXXXXXXX XXXX
   5    X    XXXXXXXXXXXXX
   4    X    XXXXXXXXXXXXX    X
   3    X   XXXXXXXXXXXXXX  X X
   2    XX  XXXXXXXXXXXXXXXXX X
   1   XXXXXXXXXXXXXXXXXXXXXX XX  X X
       123456789+123456789+123456789+123456789+
INTVL NOS      10        20        30        40
```

THESE NUMBERS REFER TO THE INTERVAL NUMBERS BELOW

θ = 45 to 67.5
+ 135 to 157.5
+ 225 to 247.5
+ 315 to 337.5

4.4 MeV ↓



CONPLETE DATA BERKELEY EXCITATION SCATTERING

```
HISTOGRAM OF PH     4                LOCATED AT WD(S)  12
TEST 30
 50
 49
 48
 47
 46
 45
 44
 43
 42
 41
 40
 39
 38
 37
 36
 35
 34
 33
 32
 31
 30
 29
 28
 27
 26
 25
 24
 23
 22
 21
 20
 19
 18
 17
 16
 15
 14
 13                  X
 12                  X
 11                  X
 10                  X
  9              X  X X
  8   X        X X  X X
  7   X        X X  X X
  6   X      XXXXX  X X
  5   X    X XXXXX  XXXX X
  4   X   XXXXXXXX XXXXX X  X
  3   X   XXXXXXXXXXXXXX X  X
  2   XXXXXXXXXXXXXXXXXX X  X
  1   XXXXXXXXXXXXXXXXXX XXXXX
     123456789+123456789+123456789+123456789+
INTVL NOS     10        20        30        40
```

THESE NUMBERS REFER TO THE INTERVAL NUMBERS BELOW

θ = 67.5 to 90
+ 157.5 to 180
+ 247.5 to 270
+ 337.5 to 360

4.4 MeV ↓

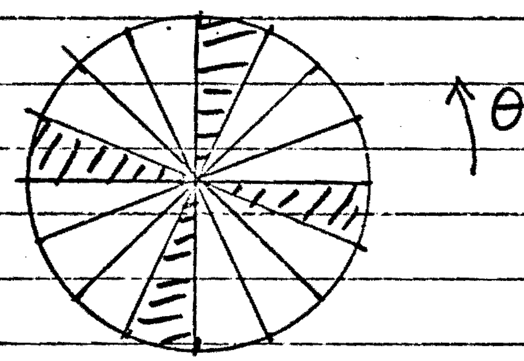


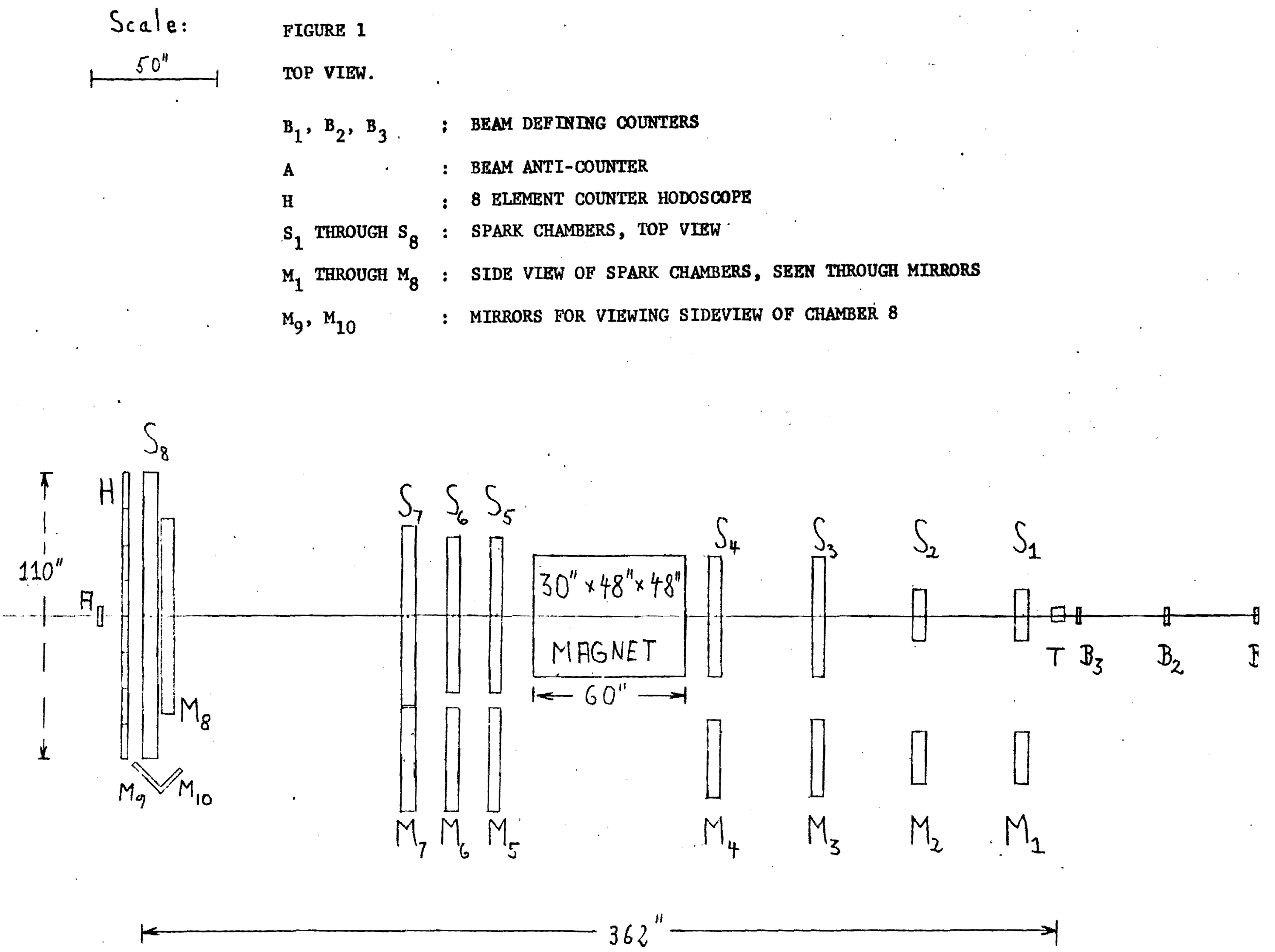
TABLE 4.1 Summary of models, types of experiments, and the predictions made by various models.

Experiment	Model: (a) Mueller analysis	(b) Multiperipheral	(c) Diffractive fragmentation	(d) Statistical thermodynamical	(e) Cheng-Wu	Beam energy region
(1) Average multiplicity $\langle n(E)\rangle$	$\langle n(E)\rangle = a \ln E + b$		No prediction; can accommodate any reasonable behavior	$\langle n\rangle$ grows faster than ln E	$\langle n\rangle \propto s^a$, $a>0$	$E>E_p$
(2) Multiplicity distribution $P(n)$	No prediction	Roughly Poisson	$P(n) \propto n^{-2}$ if $\langle n\rangle \propto \ln E$	No prediction	?	$E>E_p$
Partial cross sections $\sigma_n(E)$	No prediction	$(K \ln s)^{n-2} s^{-K}/(n-2)!$, $K=2-2\alpha_M(0)\approx 1$	Constant	No prediction	?	$E>E_p$
(3) One-particle spectra: limiting fragmentation?	Yes	Yes	Yes	Yes	No; $\rho(\mathbf{q}) \propto s^a$	$E>E_f$
(4) One-particle spectra: central plateau?	Yes	Yes	No prediction; can be accommodated	Not in present version; can be accommodated	Yes	$E>E_p$
(5) One-particle spectra: factorization in fragmentation regions	Yes	Yes	?	No prediction	?	$E>E_f$
(6) One-particle spectra: factorization in plateau region	Yes	Yes	No	No prediction	?	$E>E_p$
(7) Two-particle spectra: correlations?	Only short-range correlations, if Regge poles≫Regge cuts.		No prediction	No prediction	?	$E>E_f$
(8) Diffraction dissoc. into high missing mass	$\propto g_{PPP}^2$, triple Pomeron coupling	g_{PPP} small or zero	"Favored"	No prediction	?	
(9) $\sigma_{tot}(E)$	$\sigma \propto$ const. or $s^{-\epsilon}$, $\epsilon \ll 1$.		Constant	No prediction	$\sigma \propto \ln^2 s$	

FIGURE 1

TOP VIEW.

B_1, B_2, B_3	:	BEAM DEFINING COUNTERS
A	:	BEAM ANTI-COUNTER
H	:	8 ELEMENT COUNTER HODOSCOPE
S_1 THROUGH S_8	:	SPARK CHAMBERS, TOP VIEW
M_1 THROUGH M_8	:	SIDE VIEW OF SPARK CHAMBERS, SEEN THROUGH MIRRORS
M_9, M_{10}	:	MIRRORS FOR VIEWING SIDEVIEW OF CHAMBER 8



Scale: 50"

FIGURE 2

SIDE VIEW AND CAMERA GEOMETRY

T : TARGET

S1 THROUGH S8 : SPARK CHAMBERS, SIDEVIEW

M8 : SIDEVIEW OF S8, AS PRESENTED TO THE CAMERA THROUGH MIRRORS

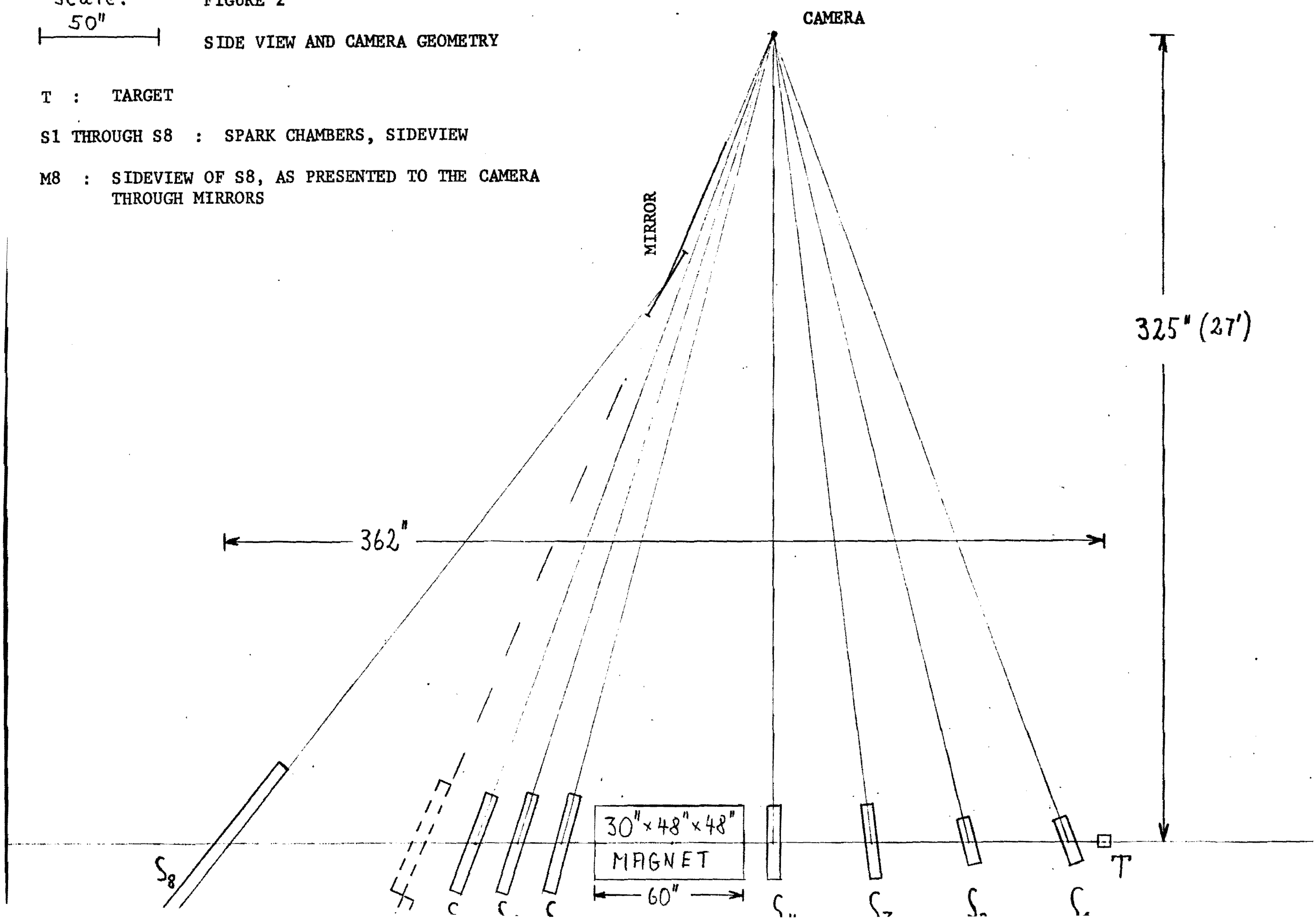


FIGURE 3

DETAILS OF TARGET ASSEMBLY AND GAMMA DETECTOR.

A_1, A_2 : ANTICOINCIDENCE COUNTERS (PLASTIC SCINTILLATOR)

A_3, A_4 : ANTICOINCIDENCE COUNTERS (NAI)

NaI : 8 INCH DIAMETER NAI CRYSTAL