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## The Bevalac Beam 40 Spectrometer

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# The Bevalac Beam 40 Spectrometer

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## I. Introduction

The 0 Degree Beam 40 Spectrometer at the Lawrence Berkeley Laboratory Bevalac can deliver a controlled beam of **ANY** particle stable nucleus at energies from a few MeV to a few GeV per nucleon. It is extremely useful in providing a controlled source of high energy nuclei equivalent to a laboratory Cosmic Ray source which can be used to study the physics and biology of highly ionizing radiation. The 0 degree spectrometer is used to study nuclear fragmentation processes at all energies (1), to study atomic processes in few electron systems (2), to probe the biological effects of heavily ionizing radiation (3), and to perform NASA related detector development and satellite calibrations. This note contains a short description of how the system is used.

## II.Technical aspects

The primary heavy ion beams are extracted from the Bevalac (4) synchrotron and transported through Channel I to the Beam 40 spectrometer (see Fig.1). Typical beam parameters are:

| | |
|---|---|
| Fluence: | $10^6(U) - 10^{10}(C)$ per second |
| Energy range: | 0.01 to 2.1 GeV per nucleon |
| Focus: | spot size $<$ 1 cm diameter |
| Emittance: | Hor = 50 mm mrad , ver = 100 mm mrad |
| Pulse: | spill duration 0.4-1.2 sec with 4-6 sec period |

Note that the maximum energy depends on the ion accelerated. The limit is set by the maximum rigidity that can be contained in the machine, $R_{max} \approx 6GV$. Charge state distributions at injection limit the maximum energy for heavy beams to $\approx$1 GeV/nuc.

Particles are injected into the synchrotron from any of five sources, three remote sources at the HILAC and two local. Injection energy varies up to ≈8.5 MeV/nucleon. This is sufficient to fully strip ions of low atomic number (Z), but most high Z beams are injected into the synchrotron and accelerated in a partially stripped state. At the exit of the synchrotron they can be stripped again or delivered to the spectrometer in their partially stripped state. The heaviest beams can be fully stripped only at the highest energies available.

Beams are injected and accelerated as single isotopes. However, once they exit the synchrotron they can be fragmented to form virtually any isotope. Single isotopes can be selected from the fragmentation reactions by a combination of collimating slits and energy absorbing foils in the transport beam line. Beams of any isotope can then be delivered to the spectrometer area.

## III. Nuclear Fragmentation Studies

When high energy nuclei pass through matter they often undergo strong interactions with the nuclei of the medium they are traversing. The majority of these nuclear interactions are "peripheral" and result in the fragmentation of the incident nucleus into smaller nuclei, typically a large fragment with mass near the mass of the incident nucleus accompanied by a few light isotopes. These nuclear fragments emerge from the interaction with nearly the same velocity as the incident nucleus and a small perpendicular momentum imparted by the collision process. The "persistence of velocity" is useful in making secondary isotope beams. The Beam 40 spectrometer is used to study the systematics of the nuclear fragmentation process.

For low energy fragmentation experiments the line and spectrometer act as a versatile beam preparation system (see Fig.2). Primary or secondary beams (produced by upstream fragmentation) can be brought to a focus at F4, transported through a target inside the spectrometer tank and brought to a focus at F5 along the spectrometer "rail". In these experiments the tank acts simply as a scattering chamber.

A 16 element solid state detector telescope can be mounted on a rail inside or outside the tank to collect fragments produced at any angle from 0 to 20 degrees with respect to the incident beam direction. Position sensitive solid state detectors at the front of the telescope determine the incident angle of the fragment. This detector system is capable of identifying any fragment whose total range is less than $18 g/cm^2$ of Si, provided it doesn't undergo a nuclear interaction enroute.

For fragmentation measurements using high energy light ions such as C, N, or O, a target is located at F4 and acts as the source point for the spectrometer (see Fig.3). The primary beam is clipped upstream to $< 1 mrad$ divergence. The downstream quadrupole currents are adjusted to transport particles of rigidity R (=pc/z) emitted w/i 10*mrad* of the primary beam direction from the F4 target to a focus at D on the spectrometer rail. The M2M3 current is held constant, to facilitate beam monitoring, delivering uninteracted primary beam ( rigidity $R_0$ ) to position $D_0$ on the external rail. The maximum rigidity of particles that can be focused at F5 is 7 GV/c.

The charge of each fragment is determined by its signal in a transmission solid state detector telescope located at position D on the external rail. Two position sensitive detectors in front of the telescope provide accurate determination of R through the relation between rigidity and bend angle (position), $R = R_0 D_0 / D$. Fragment velocities are determined by time-of-flight, by cherenkov detectors, or by nuclear fragmentation systematics (see Fig.4). Different rigidities are covered by moving the telescope to different locations along the external rail. This method is not useful for measuring absolute cross sections whenever $< P_{perp} / P_{parallel} >$ is comparable to the acceptance of the spectrometer.

IV. Atomic Physics

Forces between charged particles of atomic number $Z_1$ and $Z_2$ typically scale like the Born parameter, $\alpha Z_1 Z_2$, where $\alpha$=1/137. For fully stripped heavy ions passing through heavy targets, this expansion parameter is greater than 1. Even for simple ion-electron interactions, $\alpha Z$ becomes large. Thus, Lamb shifts become large and higher order terms ( order 3 and above in Born approximation calculations) become important.

By selecting an appropriate stripping foil at the synchrotron exit, and using the beam line as a rigidity filter, we can deliver heavy beams in almost any charge state to the spectrometer. The electron attachment and stripping processes are "very gentle" in that they effect the momentum of the incident ion very little. Thus, such beams can be delivered with essentially the emittance characteristics of the extracted beam. These beams are then used to measure attachment and stripping cross sections (processes affecting the transport of Cosmic Rays as well), energy loss effects, and QED of few electron high Z systems.

V.Detector development and calibration

For detector development and calibration runs the spectrometer is used to prepare beams to specific energy, spot size and composition requirements. A remote controlled variable absorber ( 16 independent positions holding Cu foils from 0.003 to $90 g/cm^2$ thick and/or $CH_4$ from 0.5 to $10 g/cm^2$ thick) located at F4 is used to vary beam energy and composition through dE/dx and fragmentation. The quadrupole and dipole magnets may be tuned to deliver specific rigidity particles to specific locations in the cave or may be turned off to bathe the 0 degree location in fragmentation products. Primary beam spot size can be varied from $<1 cm$ dia. to uniform (+/-20%) illumination of $>20 cm$. diameter circle.

A detector development/calibration run generally involves two or more groups taking data for two or more primary beams at a variety of energies. Detectors may be placed side by side along the rail or in line along any radius from the center of M2M3, depending on rigidity/purity requirements (see Fig.5). Bevatron timing signals ( spill begin/end, etc.) are available for gating and triggering. The type of calibration data available by passing the primary beam through a thick CH4 target while cycling variable thicknesses of Cu into the beam is shown in Fig.6.

VI.Standard equipment available

The following hardware is available at Beam 40 without any special arrangements.

1. beam monitors (scintillators, ionization chambers)

2. beam energy degraders *

3. CH beam fragmenters *

4. 8 position target wheel at F4 *

5. internal 12 position target wheel

6. satellite size package positioner *

7. remote controlled cart on external rail for small detector systems *

8. Signal and high voltage cables from cave to house

These are described in detail in the appendix.

VII. Software

A standard data collection system is available at the facility (5). Advance preparation must be made for its use, however. Typically at least 1 week is required to arrange use of the CPU and to test code. The present system is based on VME to CAMAC system communication. The VME CPU controls CAMAC operations and sends data over a dedicated ethernet to a VAX cluster where it is taped and made available to online user routines. Multiple CAMAC crate experiments can be accomodated.

There are also dedicated ports on a VAX 780 and a VAX 8600 cluster available, as well as a DEC Vaxstation II on which users can run on/off-line analysis and

* CAMAC and manual control available. See hardware appendix.

data logging processes. Among the useful code available on these machines are

1. LULU analysis system (6)

2. Spectrometer operation programs (See Fig.7)

3. Range energy routines (see Fig.8)

4. Fragmentation prediction routines (see Fig.9)

5. Monte Carlo Fragmentation code

These are reasonably user friendly and have been tested in many situations.

VIII. Conclusions

The LBL Bevalac Beam 40 Spectrometer is a versatile facility used to study nuclear, atomic, and biological effects of high energy heavy nuclei. It is also used extensively by NASA to perform instrument development and balloon and satellite calibrations. The facility has a variety of supported hardware and software that make it particularly easy for the community to perform experiments using nuclear beams of energy from 10 to 2100 MeV/nucleon.

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## Figure Captions

1.Plan view of Beam 40 line from exit of Bevatron (F1) to cave area (F5).

2.Layout of spectrometer area for low energy fragmentation experiments. Beam is focused at F4, transported through target in tank, and focused on beam monitors at F5.

3.Layout of spectrometer for high energy light ion fragmentation experiments. Beam is focused on targets at F4. Q1A and B are tuned to deliver specific rigidity fragments to telescope at F5 on external rail. M2 and M3 currents are held constant to deliver uninteracted beam to center of beam steering scintillators at rail. Scope is moved along rail and Q1A,B tuned appropriately to measure flux of secondaries at different rigidities.

4.Spectrum of C fragments from $^{16}O$ as measured at external rail. The uninteracted beam is delivered to 200cm deflection on rail. Scope is moved from 160 to 290cm in 5cm steps and the number of fragments of each charge is recorded at each location. The spectrum shown represents the intensity of charge 6 fragments at each location normalized to constant incident beam fluence for each step of the scope.

5.Plan view of cave and house showing dimensions relevant to planning an experiment at Beam 40.

6.Data from calibration run of ISEE-C HKH instrument showing separate isotope lines for each charge. Lines were populated by fragmenting incident Fe beam and continuously changing beam energy using computer controlled absorbers.

7.Main menus for the Beam 40 Spectrometer programs MAGS and SPECT. These are used to set up the spectrometer for various experimental conditions.

8. Main menu from the range-energy program RANEN used to predict energy loss phenomena.

9. Main menu from the program FRAG used to predict the response of detector systems to various fragmentation scenarios.

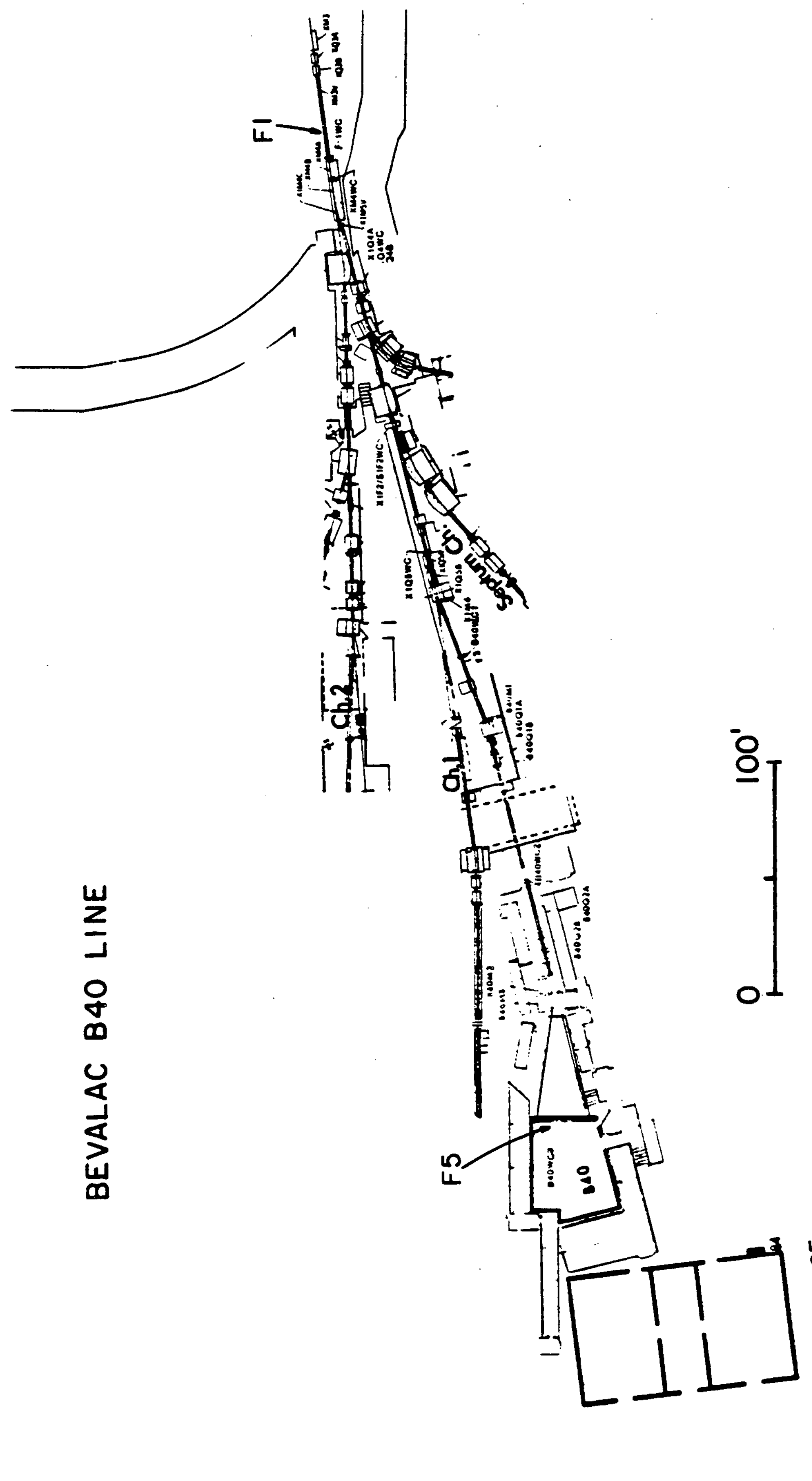


Fig 1

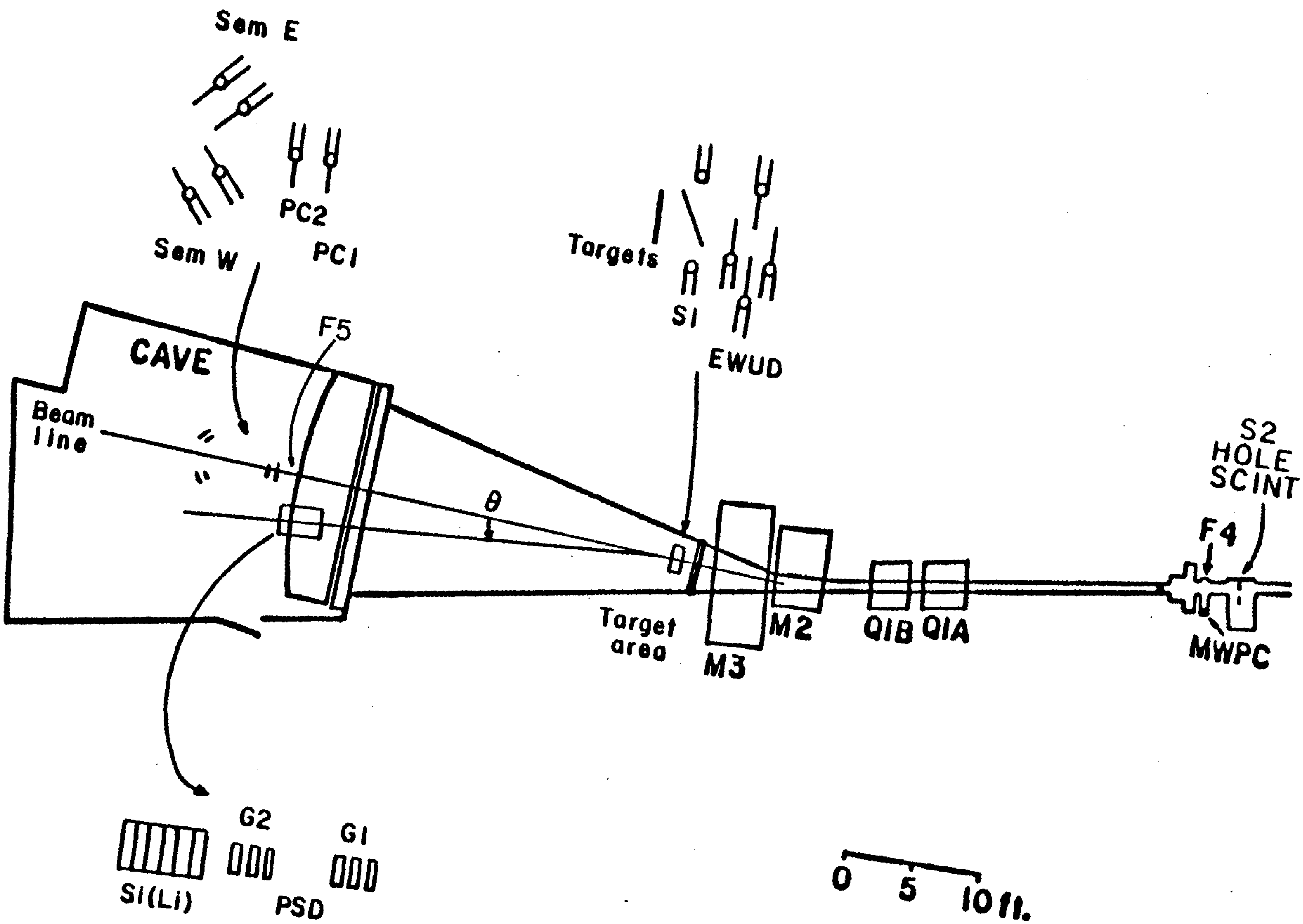
Sem E
PC2
PC1
Sem W
Targets
S1
EWUD
CAVE
F5
Beam line
θ
Target area
M3
M2
Q1B
Q1A
S2 HOLE SCINT
F4
MWPC
G2
G1
Si(Li)
PSD
0
5
10 ft.

Fig. 2

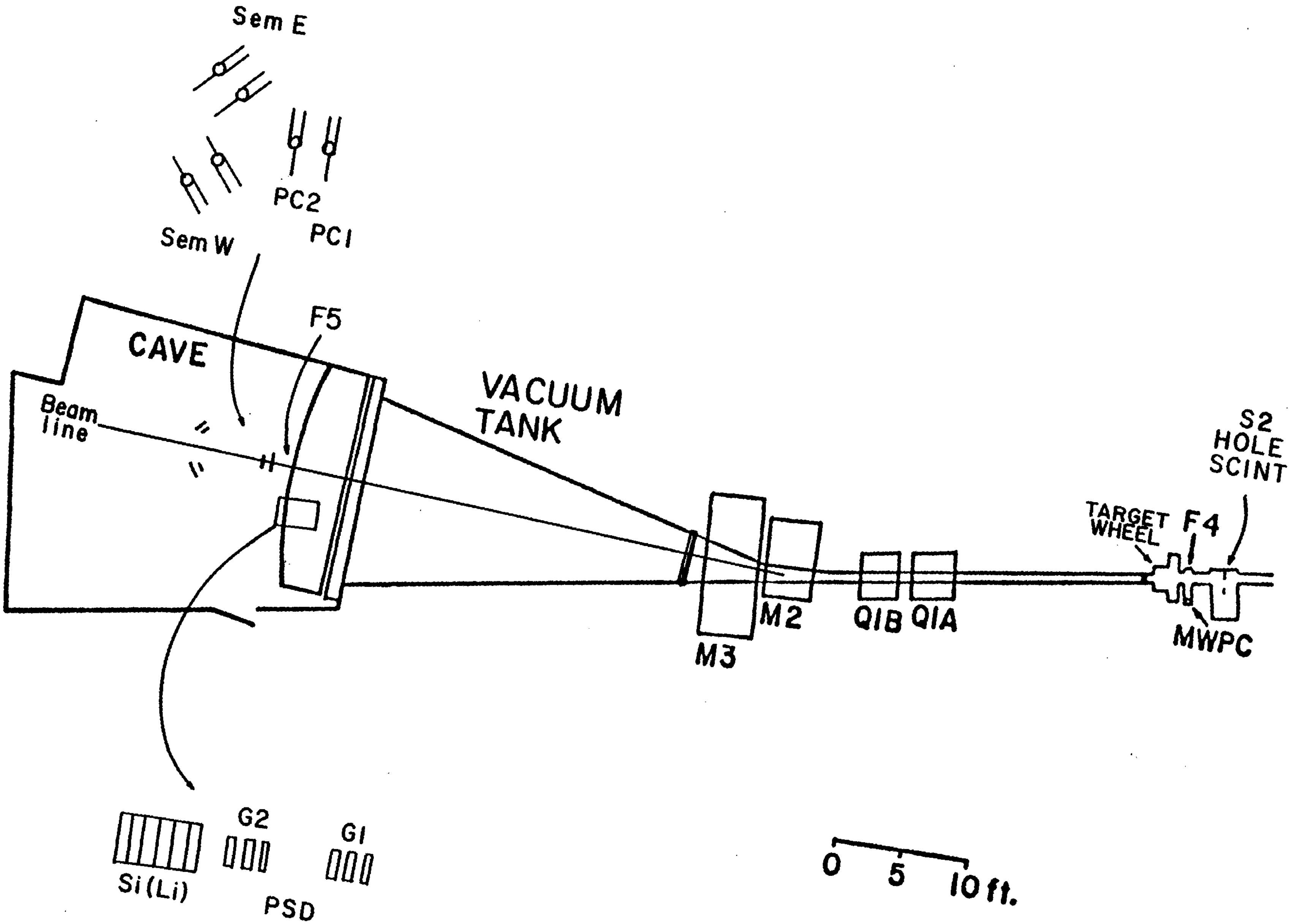
Sem E
Sem W
PC2
PC1
F5
CAVE
VACUUM
TANK
Beam
line
M3
M2
Q1B
Q1A
TARGET
WHEEL
F4
S2
HOLE
SCINT
MWPC
Si(Li)
G2
G1
PSD
0
5
10 ft.

Fig. 3

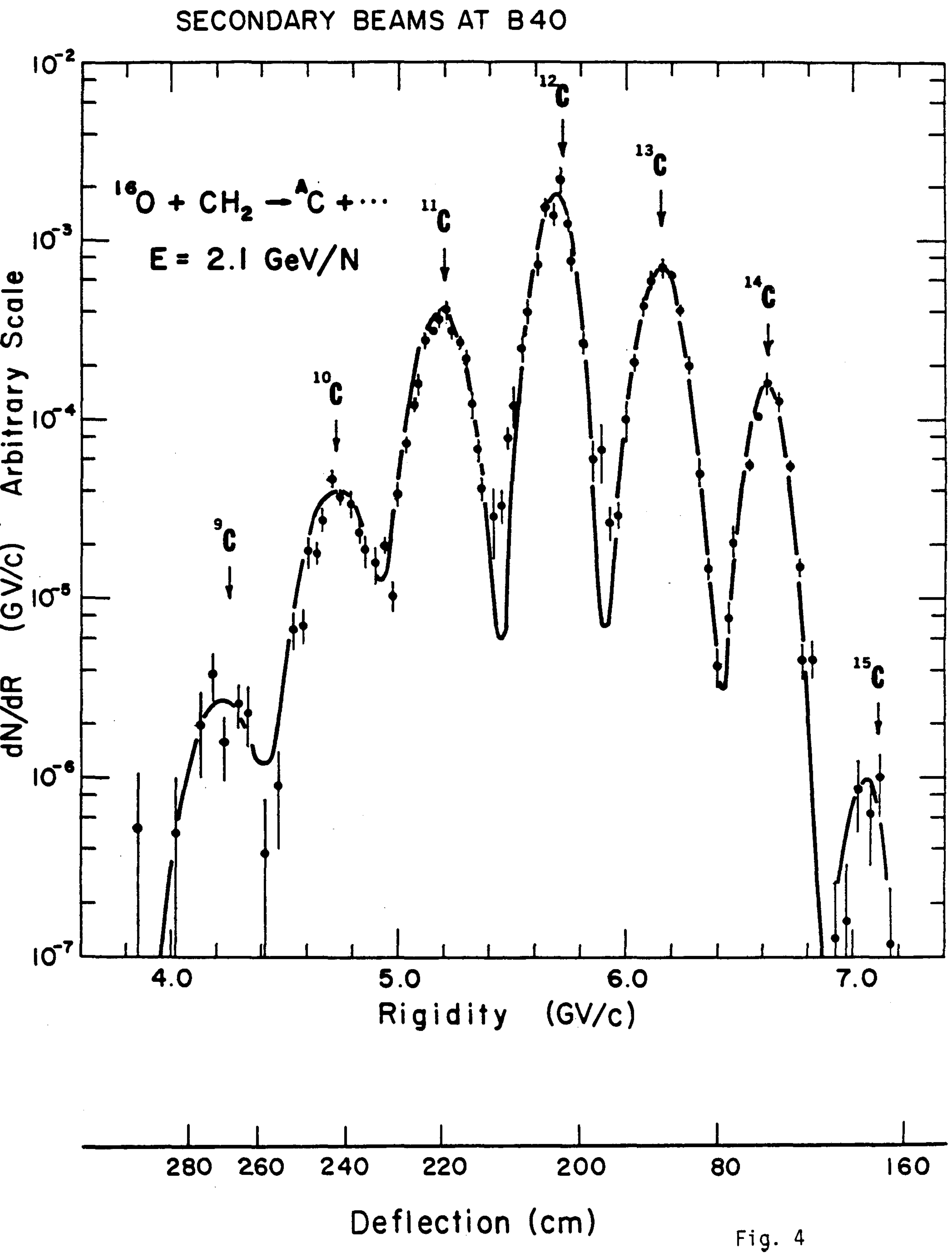
SECONDARY BEAMS AT B40
$^{16}O + CH_2 \rightarrow {}^{A}C + \cdots$
E = 2.1 GeV/N
$^{9}C$
$^{10}C$
$^{11}C$
$^{12}C$
$^{13}C$
$^{14}C$
$^{15}C$
dN/dR (GV/c)$^{-1}$ Arbitrary Scale
10$^{-2}$
10$^{-3}$
10$^{-4}$
10$^{-5}$
10$^{-6}$
10$^{-7}$
4.0
5.0
6.0
7.0
Rigidity (GV/c)
280
260
240
220
200
80
160
Deflection (cm)

Fig. 4

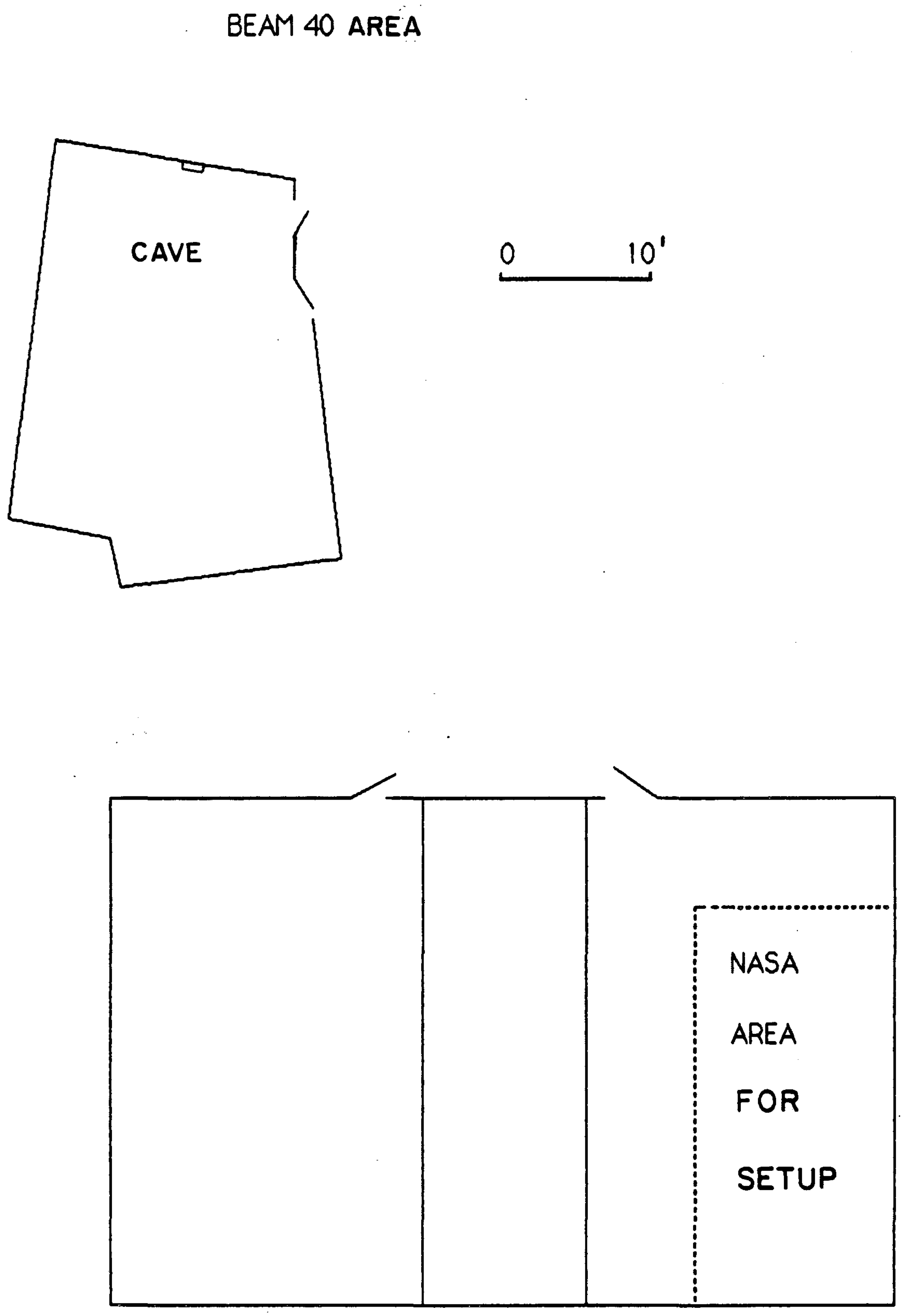


Fig. 5

SATELLITE CALIBRATIONS - ISEE CLASS ($\Delta A \leq 0.2$ amu)

600 MeV/nuc $^{56}Fe + CH_2 \rightarrow F + X$

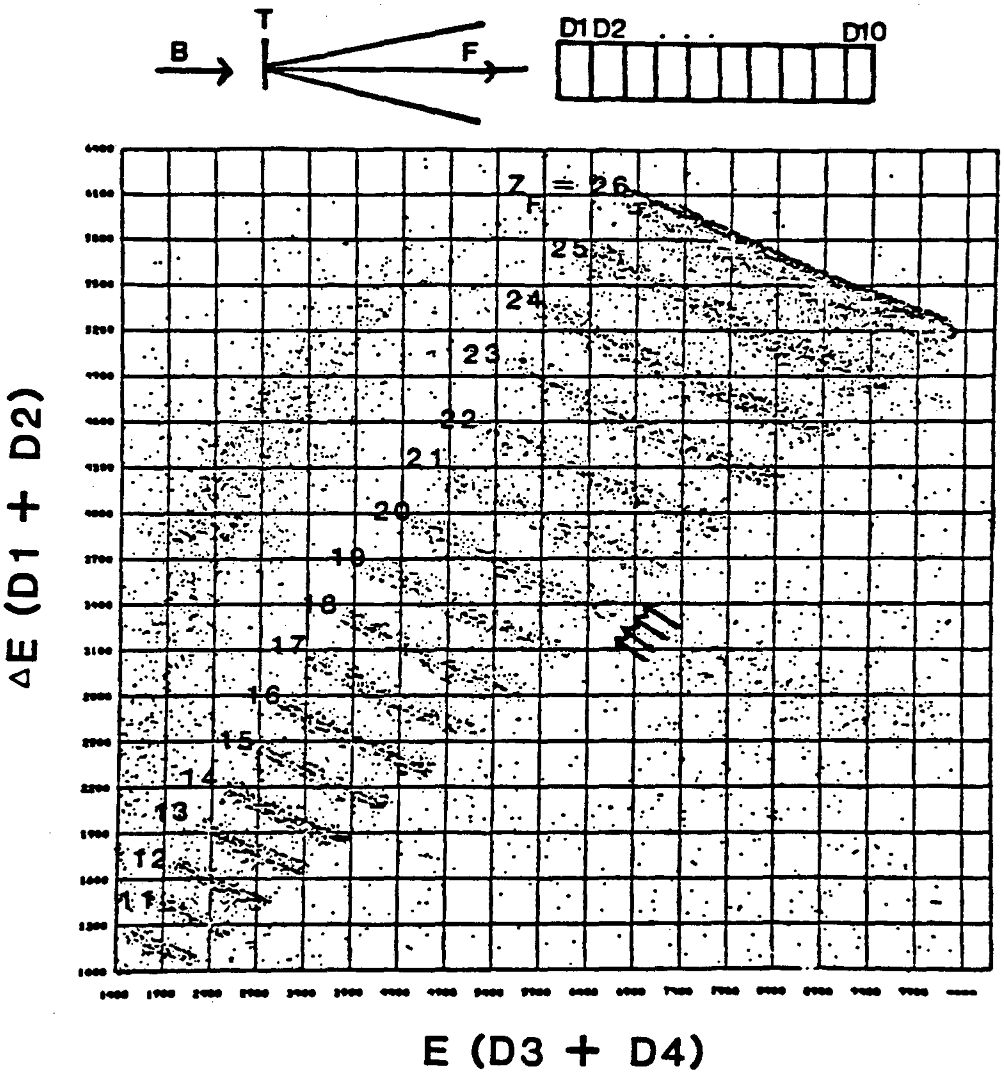


Fig. 6

```
sub commands         **** Beam40 Spect Program *****
beam z,a,q    Zb =   26.       Ab =   56.     Qb =   24.
bev  B   Bev   B = 6585.      R = 3011.0     E =  660.0
strp n   Fl strip : now yes :  R = 2760.3 in line
         n=1=>new, gt.2=>Z in line
s0io n   S0 in/out: now  in   1=new, 2=old
d0   d   position for energy measurement, now  = 200.0cm
         predicted R = 2754.1 E/A=  650.5 (no targ/abs)
         predicted     m23=   19.95 Q2A=   21.27 Q2B=   19.03
mags     measured      m23=   19.95 Q2A=   21.27 Q2B=   19.03
         measured  R = 2754.13 E/A=  650.52 (no targ/abs)

abso   1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16: range in Cu=  21.536
       0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0   total Cu= 0.00000E+00
targ   1  2  3  4  5  6  7  8                         : range in CH2=  15.284
       0  0  0  0  0  0  0  0                          total CH2= 0.00000E+00
 In spect           : R= 2754.13 E/A=  650.52 beta=0.80827
posi dd   to place beam at  200.0cm on rail:
         predicted    m23=   19.95 q2a=   21.27 q2b=   19.03
 ***  in cave  ***                E/A=  645.48 beta=0.80690
```

```
B40 magnets--  Exp.__________
beam,zb,ab,qb       26.   56.   24.        B= 6585.
ener eb                  660.00
strp   strip at fl so B (eff) = B (Q) -- now yes
       Q in line =   26. E in line :   652.80
s0io   in now yes
ntrp   interpolate from tables -- now off
R (Z) = 2779.4   R (qb)= 3011.0   B (bev)= 6584.9

 -- in line   : E =    652.80 B (eff) = 6036.5 --

q5a=      16.73 mv ;   1003.60 amps:__________________
q5b=      17.43 mv ;   1045.79 amps:__________________
m6 =      10.36 mv ;    621.33 amps:__________________
m1 =      15.88 mv ;    635.40 amps:__________________
q1a=      20.82 mv ;   1249.47 amps:__________________
q1b=      20.04 mv ;   1202.27 amps:__________________

 --- in spect : E =    650.50 B (eff) =   6023.04 ---

q2a=      20.99 mv ;   1259.67 amps:__________________
q2b=      19.01 mv ;   1140.40 amps:__________________
m23=      19.95 mv ;    798.17 amps:__________________
```

Fig. 7

```
BEAM40 :: RANGE-ENERGY Calculations for E<2000 MeV/nuc
 1 zb   projectile charge              26.
 2 ab   projectile mass(amu)           56.
 3 zt   targ at.num (-1 for comp)       6.
 4 at   target mass(amu)               12.
 5 tht  target thickness(g/cm2)     1.0000
 6 adji ionization potential(ev)       79.

 7 eb   energy (mev/nuc)            650.00
        beta  =  0.80813      gamma =  1.6978
        range (g/cm2)               16.162
                de/dx (mev/g/cm2)           1495.4
        delta e in target   1507.2    MeV :   26.914      MeV/nuc
        residual range (g/cm2)      15.162     E rem.   623.09

 8 rp   range for projectile       0.00000E+00 g/cm**2
        energy for this range      0.00000E+00 MeV/nuc
-1      exit     -2 = print
```

Fig. 8

```
BEAM40 :: FRAGGEN to study projectile fragmentation
 1.beam ---- Z= 26. ---- A=  56.
 3.beam energy (mev/nuc)  E=  650.00    rigidity R=  2752.8
   beta in:  b= 0.80813      gamma in: g=  1.6978
   range in target material   16.162
   out:  E=  623.09       R=  2680.7      b= 0.80060      g=  1.6689
 4.beam position on rail            200.00
 ...
 5.target--- Z=  6. ---- A=  12. ..6..rad len  42.639
 7.target thickness (g/cm2)         1.0000      --theta rms  0.97065E-03
   fraction destroyed   0.76116E-01 destruction CS(mb)  1577.3
 ...                    mfp=   12.631      g/cm2)
 8.fragment- Z= 24. ---- A=  50. thnuc= 0.19880E-02
   fraction made = 0.18111E-02 production CS(mb)=  37.530
10.shifts/nuc--p=-0.48107      E (lab)=-0.64258      wid=  2.4744
  energy--    low    619.15       high    627.11     dif   7.9606
   target only-- low   623.09       high   624.33     dif   1.2392
  rigidity--  low    2582.7       high    2603.4     mean   2593.0
  peak position   206.76      lo  207.6 hi  205.9
 ...
11.show scope  .....12.fill scope random from elo to ehi
13.frac.accepted  0.00000E+00 (angl_acept, area)  0.000E+00  0.000E+00
-1=exit -2=print page   20=toggle menu  cr=go
```

Fig. 9

# HARDWARE APPENDIX.

The standard equipment available at Beam 40 is described below. The list in VI above is repeated with some self-explanatory items deleted.

1. Beam Monitors. (Scintillators, Ionization Chambers.)

2. Beam Energy Degraders. *

3. Target Wheel at F4. *

4. Internal 12 position target wheel.

5. Satellite size package positioner. *

6. Remote Controlled cart on external rail with up/down (6") adjustment for small detectors systems.*

7. Balloon-package adjustable table.

* CAMAC or manual control

## 1. Beam Monitors.

The Beam 40 line has a set of scintillator-PMT counter in vacuum at F4, just downstream from the target wheel ( See Fig.1). This is called the $S_0$ Scintillator. There is also a set of steering scintillators called rail-east (RE), rail-west (RW), and rail-total (RT) , just downstream of the vacuum tank window. Both the $S_0$ and the rail scintillator arrangements are fixed in their position in the line, but they can be inserted into and retracted from the beam. This insertion and retraction is controlled by a single width NIM module that has duplicated circuitry for the independent control of these devices. (The $S_0$ scintillator is 1 mm and the RE,RW and RT scintillators are 6 mm thick.)

The front panel of the NIM module houses a pair of switches with IN-OUT positions plus a set of red LEDs to indicate that the scintillators are in the beam; there is also a set of green LEDs that indicate that the scintillators are out of the beam.

To complement the set of beam monitor scintillators, there is also a set of four portable counters ( portable-east (PE), west (PW), up (PU), down (PD)) mounted on a movable fixture that can be positioned anywhere in the cave. An additional 1"x1" ($6.5 cm^2$ ) scintillator is used for beam flux calibrations in doing large area exposures.

## 2. The Absorber Box (Lollipop Shover) and its CAMAC controller.

The absorber box at F4 houses 16 different absorbers which can be moved in and out of the beam by means of a CAMAC module which provides both manual and computer control. In the manual mode the operator 'sets' any one of the in/out toggle switches to the desired position and 'sends' the absorber the set positions by means of a 'send' push button switch. A set of LEDs monitors the last command given ('off' implies last command - i.e. position of the toggle switch - was OUT; 'on' means that the last command was to put the absorber IN the beam.) There are two more separate sets (16 each) of LEDs that monitor the position (in or out) of the absorbers.

3. Target Wheel at F4

The targe wheel at F4 can accomodate as many as 8 targets. Normally one position (0) is left blank for no-target operation. The wheel is controlled by a CAMAC module that allows both manual and computer control operation. The front panel houses two push-button switches for clockwise or CCW motion of the wheel. There are two seven-element digital displays labeled "target position" and "target destination" respectively. The target position display indicates the actual position of the wheel. The target destination display responds to the pressing of the CW or CCW push-button switches. If there is no match between these displays, the target wheel will go into motion until the "position" matches the "destination" at which point the wheel will remain motionless. The front panel also houses a fuse which is in series with the motor; the removal of this fuse is an effective way of preventing the wheel from moving.

WARNING. Clear commands to the crate send the wheel to the "0" position.

4. 12-Position Internal Target Wheel.

The spectrometer vacuum tank of the Beam 40 line can house a Geneva drive target wheel just down-stream from the bending magnets. There are actually two wheels, each one capable of holding six targets. The control units for these wheels are standard 19 inch rack assemblies 8 inches high. Position is monitored by a voltmeter that reads out an analog of the wheel position.

5. Satellite-size package positioner.

This device was designed to handle a satellite size package approximately a cubic foot in size and can support 50 pounds with the center of mass over the pivot point. Dubbed the "patient positioner", this device can move in three directions, (vertical, elevation, azimuth) thus its CAMAC controller has three independent channels to control its motion. The front panel of the controller has toggle switches to select manual or computer control and switches to select the direction of motion while in manual control. A set of LEDs indicate the limit positions and the "ready" condition. (i.e. The device has stopped moving because the desired position has been achieved.) The front panel also houses three separate LED numeric displays which monitor the position of the device. D.C. motors provide the motion and individual potentiometers provide the analog of the position. This signal is digitized and displayed in the front panel as well as made available to the CAMAC read bus.

6. Rail Carts.

The beam line can accomodate an internal rail (inside the pie shaped vacuum tank downstream from the bending magnets) which in turn can carry a small cart. (12"x12".) There is also an external rail wich in turn carries a bigger cart (16"x 48") capable of loads up to 200 pounds. Both the internal and external carts can be moved along the rails by remote control through the CAMAC cart controller.

The cart controller is a micro-processor (8085) based module that allows three modes of operations: host computer, (PDP-11) and two manual modes. These modes are selected by a 3-position toggle switch on the front panel. The host computer operation is selected with the "on line" position of the switch. The "manual" position enables another toggle switch (up-down) so that the cart can be moved in either direction along the rail by manipulating this switch. The third position of the mode switch is labeled "micro", and if selected, it enables a set of touch switches which in turn allows the operator to change the contents of the "destination" and "position" displays on the front panel. In the "micro" mode, if the position does not match the destination, upon the touching of the "send" button the micro-controller will read and compare the contents of the position and destination and proceed to move the cart in the appropiate direction until the position matches the destination.

In addition to the lateral movement along the rail, the external cart can be moved up and down both locally (in the cave) or remotely (in the house) via a NIM module. The NIM module has an up/down toggle switch, limit indicator LEDs, and a position indicator LED array. Additionally, the position can be encoded into a LeCroy 2249 ADC with an appropiate signal provided by this NIM module.

7. Balloon-size package table.

In order to accomodate large instruments, a roll-around table has been designed capable of supporting up to 500 pounds. The dimensions for the top are 16 inches by 48 inches. Additionally, this table has been designed to move its load up and down (about 10 inches of travel), as well as to tilt the load about 10 degrees in the front-to-back direction and in the sideways direction. These adjustments are possible because the top is independently supported at three points. These supports are motor driven by tree separate motors with three separate controls which allows the freedom of movement discribed above.

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