ZGS EXTERNAL PROTON BEAM*

L. G. Ratner, T. de Parry, A. M. Glowacki
Argonne National Laboratory
Argonne, Illinois

Summary

Extraction methods, diagnostic equipment, and external beam lines are described. By the use of special targets and magnet field shapes, we have extracted beam at energies between 4.0 GeV/c and 13.4 GeV/c. Slow and fast extractions have been accomplished with efficiencies greater than 30 percent and 50 percent, respectively. A parasitic beam has been extracted with 20 percent efficiency. Extracted beams of up to 7 x 10^{11} protons/pulse with a 2.2 s repetition rate have been obtained for a neutrino experiment. To date, spill durations from 40 µs to 500 ms have been achieved.

A compact secondary emission detector having a very short radiation length has been designed and operated. The multiple scattering introduced into the beam by this chamber is less than 1/2 milliradian. TV systems with scintillators and sodium iodide matrices have been used to line up the beam.

In the external beam line, three target stations have been set up. The first is for a neutrino experiment, the second station for three experiments, and at the third station there are two experimental setups.

Extraction Methods

For extraction in the range of 1 ms to 500 ms, the Zero Gradient Synchrotron (ZGS) makes use of the standard technique of an energy loss target with lip. At 1 ms the maximum measured extraction efficiency is about 35 percent and drops to about 25 percent for long spills. For short spills in the µs range, a beam bumper magnet is used to displace the equilibrium orbit onto an energy loss target. This latter system is described in "A New Scheme of Beam Extraction of the Argonne ZGS," by J. Martin, T. Novey, A. Yokosawa, and S. Suwa.

Additionally, extraction with an efficiency of 20 percent can be obtained from a suitably placed target which can also provide for a beam of secondary particles into another area. As shown in Fig. 1, targeting for both the external proton beam and secondary beams is done in the same straight section. By placing a target about 60-in into the octant and at about 2.3-in radially in from the straight section centerline, a negative secondary particle beam goes down the 17-3/4° channel and the noninteracting protons lose sufficient energy to enter the extraction magnet chain. A 3.75-in beryllium target with lip has been used to produce a 20 percent extraction efficiency. The number of secondaries produced is down by a factor of two compared with a similar length target of copper.

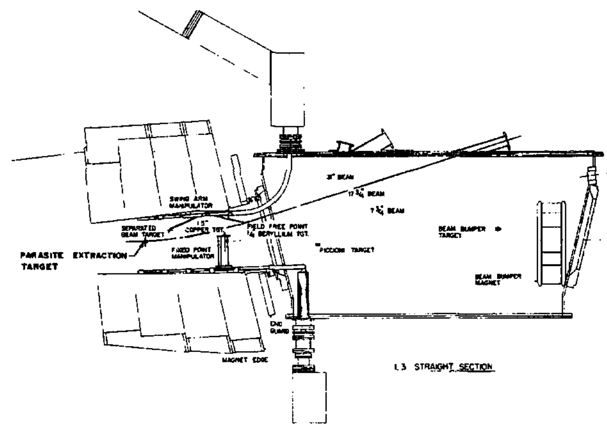

Figure 1 Targeting Straight Section Showing Parasite Extraction Target Position for Proton Beam Extraction and for Secondary Beam Down 17-3/4° Channel.

Another mode of operation which has turned out extremely efficient is the use of a "front porch field." By use of the ZGS central programmer, the ZGS magnet field program can be changed so that an additional flat-top or sequences of flat-tops can be produced at any desired energies. An experiment on p-p scattering was performed in which the proton beam was extracted at 51 different energies. By preprogramming the necessary parameters in an unused portion of the memory, the machine operators could change the "front porch" flat-top in one machine pulse without disturbing the other experiments going on with the full energy beam. Extraction has been accomplished with an average 25 percent efficiency over the range from 5.0 to 13.4 GeV/c.

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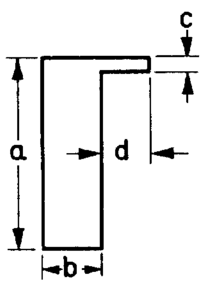
Since the extraction system uses fixed position magnets, it is necessary to change target lengths in order to eject beam at other than design ZGS energy. We are able to move the radial position of the extraction target, so that a given target length will be suitable for a range of ZGS energies. Calculations[1] for the above energy range showed that four targets were necessary for performing the desired extraction. These are shown in Fig. 2.



$P_{GeV/c}$	a in	b in	c in	d in
13.4 -10.6	2.50	0.5	0.54	0.324
10.20- 8.60	2.00	0.5	0.020	0.40
8.20- 6.60	1.50	0.5	0.017	0.50
6.20- 5.00	1.10	0.5	0.014	0.82

Figure 2 Plan View of Extraction Targets (All targets were 1/8-in in vertical extent)

Beam Diagnostics

Scintillators and TV cameras are used to line up the extracted beam. We have also used a 4-in x 4-in screen made up of 0.4-in x 0.4-in x 1-1/4-in Na I crystals. This gives a good visual response at lower intensities ($\leq 10^8$ protons/cm^2). For quantitative measurements, a Secondary Emission Monitor (SEM) has been constructed.

One of the important properties of this device, which was first designed by Tautfest and Fechter,[2] is its freedom from saturation effect, which is common in the case of ionization chambers for presently achievable beam intensities. The sensitivity range of a SEM device at the lower beam intensities is dependent on the number of electrodes contained in this unit, electrode materials, and the sensitivity range of the electrometer measuring the collected charges. Presently available chopper electrometers are capable of measuring charges of about 10^{-16} coulombs.[3]

The choice of materials and the number of electrodes of a SEM device through which the beam of charged particles passes, are limited by the maximum tolerable scattering angle of these particles which interact with the matter. The SEM described in this paper was designed and built in accordance with the above stated comments.

In Fig. 3, a general schematic diagram of the complete monitoring system is indicated. As it may be seen, the secondary electrons produced by the electrodes of the SEM are measured by the electrometer. The resultant potential difference appearing at the output terminal of the electrometer is fed into a voltage-to-frequency converter from which the ac signal is conveyed to a frequency counter for optical display. If desired, the counter output can also be fed into a computer for storage or simultaneous utilization of the digitized data.

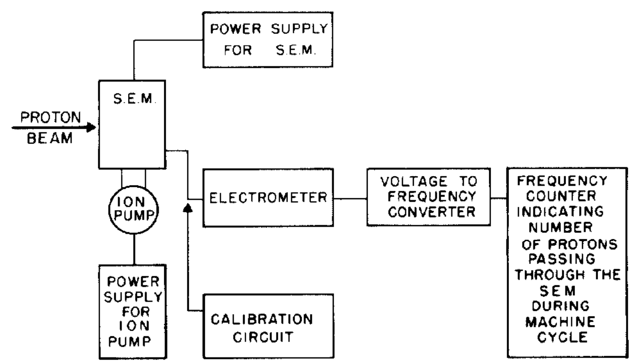


Figure 3 Schematic Diagram of Secondary Emission Monitor System

A generalized presentation of the SEM device is given in Fig. 4. The unit has 15 aluminum electrodes each 1.25×10^{-3} cm thick; the active diameter of each electrode is 15 cm. The aluminum foil of each electrode is sandwiched between a pair of stainless steel stiffener rings, which are point welded at several locations along their circumferences. All electrodes are supported by means of high quality ceramic spacers. The chamber body of the SEM is provided with an entrance and exit window made of 0.025 cm thick titanium foil which is electron beam welded to the window frames.

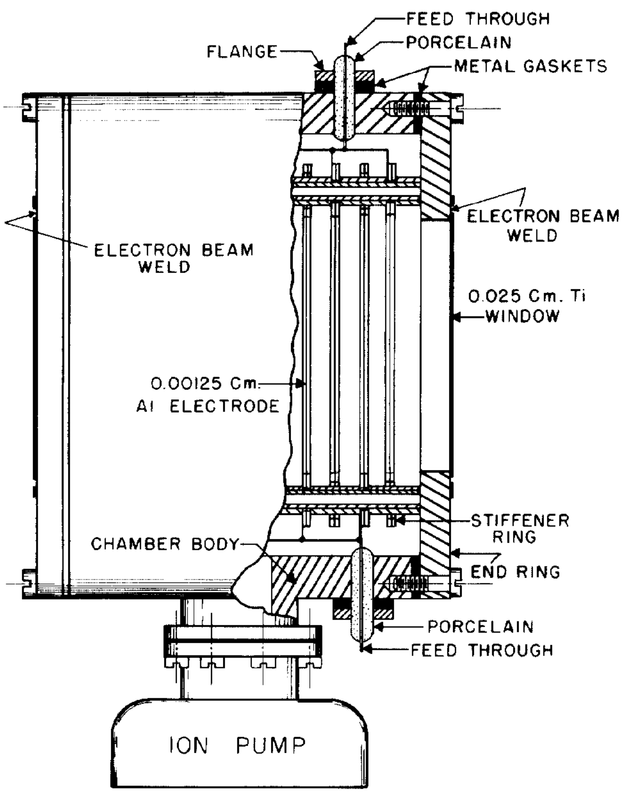


Figure 4. Secondary Emission Chamber and Vacuum Pump

To allow a bake-out of the assembled unit at about 250° C, all employed vacuum gaskets in the assembly are metal-type components.

During the normal operation, the SEM chamber is remotely positioned into the path of the extracted proton beam of the ZGS machine. Experimental evidence indicates[4, 5, 6] that the performance reliability of a SEM depends very much on the chemical properties of the surfaces emitting secondary electrons. To avoid these undesirable chemical changes of the electrode surfaces, the SEM built at ANL has been provided (see Fig. 4) with a permanently attached ion pump of 15 liters/s capacity which prevents undesirable contaminants from entering the unit and keeps the pressure within the chamber at a desirable level of about 10^{-7} Torr. The minimum thickness of the window foil to be used in a vacuum system is dependent on its tolerable inflection under atmospheric pressure which is given by the following relationship.[7]

$$W_{max} = 0.662\, p(Pp/Ed)^{1/3} \qquad (1)$$

where

W_{max} = maximum inflection (cm)

P = atmospheric pressure (kG/cm^2)

p = radius of the window (cm)

d = thickness of the foil (cm)

E = modulus of elasticity (kG/cm^2) .

In our case using:

$P = 1\ kG/cm^2$

$p = 7.5$ cm

$d = 0.025$ cm

$E = 1.2 \times 10^6\ kG/cm^2$ (for titanium) ,

we get

$$W_{max} = 0.32\ cm \quad .$$

The proton beam scattering caused by the two titanium windows $(228\ mg/cm^2)$ and by the 15 aluminum electrodes $(51.44\ mg/cm^2)$ may be obtained from the following relationship:[8]

$$\left\langle \theta^2 \right\rangle = \frac{21^2}{(P_{MeV}\,\beta)^2}\,\frac{t_x}{X_o} \qquad (2)$$

where

$$\frac{1}{X_o} = \frac{4}{137}\, Z(Z+1)\,\frac{N}{A}\, z^2 r_e^2 \ln\left(\frac{183}{Z^{1/3}}\right) \frac{cm^2}{g}$$

t_x = mass of the energy absorbing matter (g/cm^2)

z = charge of the bombarding particles

Z = atomic number (Al → Z = 13; Ti → Z = 22)

A = atomic weight (Al → A = 277; Ti → A = 46)

N = Avogardo's number (6.02×10^{23})

r_e = classical radius of electron $(2.8176 \times 10^{-13}\ cm)$

P = 13.41×10^3 MeV/c (for 12.5 GeV proton beam)

β = 0.99756 (for 12.5 GeV proton beam) .

Substituting pertinent values into Eq. (2) yields the total divergence angle:

$$\theta = 0.246 \quad \text{mr} \quad .$$

The approximate coefficient of secondary electron emission Y (i.e., the ratio of the secondary electrons to the bombarding primary particles as given by Tautfest and Fechter[2]) has the following relationship:

$$Y = \frac{4 \pi r_e^2 NZ}{A K \beta^2} t_x^{1/2} \qquad (3)$$

where

K = constant in the range energy relationship ($K = 1.38\ mC^2 - cm/g^{1/2}$ for aluminum)

t_x = thickness of the emitting foil (g/cm^2).

Substituting corresponding values into Eq.(3) yields for 7 emitting electrodes:

$$Y = 0.0815 \quad . \qquad (4)$$

The same order of magnitude for the yield factor was also observed at ANL a few years ago using an experimental SEM which was connected to an oil diffusion pump. Contamination of the electrode surfaces by oil vapor and oxidation caused this yield factor to vary by as much as 60 percent.

The yield factor of the SEM described in this paper will be determined more accurately by measurements performed under better known and controlled operation conditions.

Assuming a number of primary charged particles traversing the SEM to be 10^8/machine cycle, then the produced secondary charge will be

$$Q = Y \times N \times 1.6 \times 10^{-19}$$
$$= 1.3 \times 10^{-12} \text{ coulomb} \quad . \qquad (5)$$

For practical reasons, it is desirable to obtain at least 1 mV signal with the help of this charge. Hence, the required capacity value across which this voltage should appear should be about:

$$C = \frac{Q}{V} = \frac{1.3 \times 10^{-12}}{10^{-3}} = 1300 \text{ pF} \quad . \qquad (6)$$

From the geometry of the SEM, the theoretical capacity of this unit will be about:

$$C = \epsilon_o \frac{A}{d}\left[0.08842 \frac{\pi \times 18.5^2}{0.6} \text{ pF}\right] 7 = 1100 \text{ pF}. \quad (7)$$

At the present time, the SEM is being evaluated. The experimental results gathered for this system will be presented at a later date.

External Proton Beam (EPB) Line

The external beam has been set up to run in two modes. The first is for neutrino experiments in which the production target is placed in the interior tunnel adjacent to the ZGS ring. The second mode is for the proton beam to be brought out through the main shielding wall and to hit targets in the experimental area.

The neutrino mode had the first pair of quadrupole magnets (5 Q 36) installed with a space between them for monitoring equipment, whereas the placement of the magnets adjacent to each other was the ideal arrangement for the EPB. The supports were bridged and movement between the two positions was obtained by attaching DU glacier plate to magnet support structure and flat plate, and simple guide to base. In this manner, elevations were kept within magnet support adjustment. Movement was facilitated with a light duty ratchet chain hoist. Because the two positions were not variable, their location was pinned and checking of elevations after movement comprised the major portion of the work. The movement of approximately 4 ft and survey check was accomplished in approximately 3 hours.

The proton beam exits from the interior tunnel adjacent to the Ring Building proper through 12 ft of steel shielding assembled from plates 4- to 6-in thick. A 13-in square opening was burned in each plate for insertion of a 9-1/2-in OD vacuum transport. Irregularities in cutting and elevation further reduced the net clear through opening. By laying a vinyl protective sheet on the bottom half of this opening and creating a vinyl jacket around the vacuum transport tube and filling it with water, the irregular void space between the shielding and tube was completely filled.

A radiation safety system was installed for the exterior proton tunnel based on the two modes of operation, selection of which is determined in the main control room by use of Kirk key interlocks. For the neutrino mode, the Kirk key interlocks in the main and experimental control rooms must be in proper position and power supply for the switching magnet (XB4) energized in the proper polarity.

In the EPB mode, in addition to the above, all doors and emergency switches are closed in the exterior tunnel and the first pair of quadrupole magnets (XBC 1 and XBC2) must have their power supplies energized. When the above is satisfied, the circuitry of the interlocks ultimately permits operation by the removal of a uranium plug from blocking position, the plunging of the Piccioni target, and increasing power supply current from minimum for the switching magnet.

Helium and vacuum are the major portion of beam transport. The helium transport is comprised of 22-in diameter 20-mil vinyl terminated on machined flanges by banding. Valves on the flange permit introduction of helium as well as purging. Flanges are designed for mounting of windows separately, hence a 3-mil mylar is generally used. This combines the quality of a thin window and heavy-duty container for minimum losses. Where an upstream window is in the main beam and the downstream window in a branch beam, 5-mil windows have been bonded in the wall opening made in the 22-in diameter enclosure to permit beam exit with minimum scattering.

A recent typical setup of the EPB is shown in Fig. 5. The first focus of the EPB is produced at a thin target for the p-p scattering experiment E-102. The beam is well enough focussed to then be used by E-31, a nuclear chemistry setup with a scattering chamber, and then hit a thick target for producing kaons for experiment E-36. Alternatively, if E-36 is not running, the proton beam can then be refocussed by the next two downstream quadrupoles and hit a target which can simultaneously supply secondary particles for experiments E-21 and E-42. The beam, after this target, plows into the beam stop outside the Proton Building.

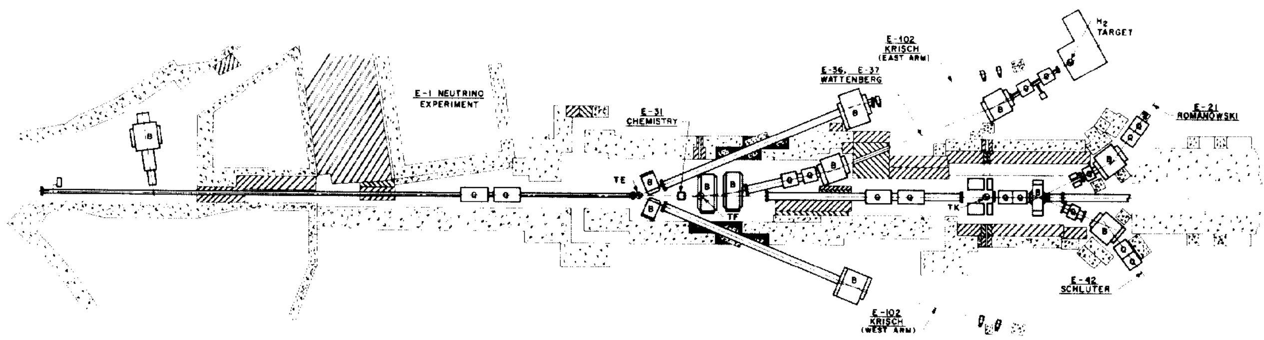


Figure 5 Typical Experimental Setup in Proton Area

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