Fermilab Proposal 661

Scientific Spokesman: Hans H. Gutbrod
GSI, Darmstadt
address: Lawrence Berkeley Lab
Bldg 70A
Berkeley, CA 94720
phone: FTS-486-5770

Energy and Momentum Dissipation in Nuclei in High Energy Hadron Nucleus Interactions

Submitted by scientists from:

Gesellschaft für Schwerionenforschung, Darmstadt, West Germany
Lawrence Berkeley Laboratory, Berkeley, California
Argonne National Laboratory, Argonne, Illinois

Names of the Experimenters

GSI: H.H. Gutbrod
H. Löhner
M.R. Maier
H.G. Ritter
H. Stelzer
R. Stock
F. Weik
H. Wieman

LBL: A.M. Poskanzer
A. Warwick

Argonne: D.J. Henderson
S.B. Kauffmann
E.P. Steinberg
B.D. Wilkins

I. Abstract

We propose to study hadron-nucleus interactions by measuring correlations in the target rapidity region between fast charged particles (e.g. $E_{proton} > 25$ MeV) and slow nuclear fragments. The slow fragments are identified as to their mass, charge and energy in a double TOF apparatus and by the ΔE-E technique with a total of 40 fragment telescopes. The events are characterized by the multiplicity of associated fast charged particles, as measured in an array of 80 scintillators.

The following problems will be studied:

a) Is there a transverse momentum transfer from the incident hadron to the whole nucleus? The observation of non-trivial effects requires the experimental capacity of ruling out recoils due either to Fermi jets or to the Coulomb forces in fission-like events.

b) Are there different event classes for different fragment masses? The associated charged particle multiplicity can be considered to be an indication of the amount of energy deposition and its distribution in phase space (violent or nonviolent reactions).

c) How much energy can be deposited in a nucleus, what "temperatures" are achieved, and what are the deformation and Coulomb effects of the emitting system? With the added feature of twofold correlation measurements, a) with other slow fragments and b) with fast charged particles, this experiment will improve substantially the understanding of these questions.

d) Is there a scaling observable dependent on the number of constituents in the hadron? The comparison of events from pion and proton interactions may reflect a difference between a two or three quark system. A scaling has been observed in relativistic nuclear collisions at the Bevalac where the constituents are the nucleons. There the shape of the slow fragment spectra and their associated charged particle multiplicity were only dependent on the total incident kinetic energy.

The request is for one target only (Au) and focuses on the protons first. Later the target mass dependence may be studied.

<u>Request</u>: 1×10^7 events with ≈ 50 GeV protons
1×10^7 events with ≈ 400 GeV protons
1×10^6 events with ≈ 200 GeV negative pions.

This results in an estimated running time of ≈ 700 hrs. We ask for an additional 100 hrs of tune up time.

II. Physics Motivation

Previous studies with 1 to 400 GeV protons have established that a change in reaction mechanism occurs above about 3 GeV bombarding energy. In this energy region, production cross sections become nearly constant, angular distributions of products become sideward rather than forward peaked in the laboratory frame of reference, and forward momentum transfer to the target decreases (as evidenced by forward-to-backward recoil ratios of products). These findings are based mainly on single particle inclusive data. Most of the underlying general physics questions are well described in the Fermilab proposal #591 (ref. 1). We therefore limit this discussion to the complementary aspects of our approach and to the physics we have studied at much lower incident projectile velocities (ref. 2,3,4).

Above 30 GeV few studies of hadron nucleus collisions have been made in the target rapidity region. This region contains the information on the intranuclear cascade of hadrons that are produced from the decay of low energy hadronic constituents. Obtaining information about the liftime of these constituents would be an exciting possibility.[8]

Energy Deposition:

Correlation data have been taken at Bevalac energies in studies of proton, ^{4}He and ^{20}Ne interactions with nuclei[2,3,4]. Besides the fragments spectra, associated charged particle multiplicities have been measured. It was found that the multiplicity of charged particles and the spatial multiplicity pattern provide a strong insight into the event classification. Data on the multiplicity patterns associated with π^+, p, d, and t emission at 90^o to the beam have been obtained in previous experiments[2] at the Bevalac. Proton, ^4He, ^{20}Ne, and ^{40}Ar bombardments of targets fron ^{27}Al to ^{238}U at bombarding energies from 250 MeV/A to 2.1 GeV/A were carried out.

The associated charged particle multiplicity in reactions with various projectiles from protons to ^{40}Ar on a U target rises steadily as the incident total energy is increased to 42 GeV, the maximum energy in a 2.1 GeV/u ^{20}Ne bombardment studied so far (fig. 1).

An extension of the above experiment was made to include the detection and measurement of the correlation angle between slow fragments in coincidence with a particle (ΔE-E) telescope.[3,4] The data exhibit three distinct particle multiplicity distributions (fig. 2). Events associated with fission-like fragments at 90^o to the beam show a maximum probability at zero multiplicity; events associated with a proton[2] at 90^o exhibit a reasonable number of zero as well as high multiplicity events with a maximum multiplicity near twelve; and events associated with an oxygen[3,4] fragment at 90^o display a very low probability for zero multiplicity and the highest mean multiplicity.

Due to their associated charged particle multiplicity distributions low-energy target fragments with $4 < Z < 12$ observed at 90^o to the beam are interpreted as providing a signature for central collisions. On heavy targets, the light fragment spectra are characterized by a "Coulomb peak", its energy being dependent on the charged particle multiplicity observed. The multiplicity associated with these light fragments has been found to be determined only by the total incident kinetic energy rather than by mass or velocity of the projectile or the amount of particle production (fig. 3). The deformation of the nuclear system in the last stages of the interaction can be studied by measuring the correlation between this Coulomb energy and the associated charged particle multiplicity.

All these studies were done in an energy region where cascading dominates the reaction, whereas, for example, with 70 GeV incident protons on Pb[5] approximately 6% of all interactions lead to total disintegration of the nucleus.

In the proposed experiment it is our goal to compare the "nuclear explosion" caused by high-energy protons with our studies at the Bevalac, in order to investigate the mechanisms of energy deposition into a nucleus up to incident energies where the nuclear transit time becomes shorter than the primary interaction time and quark-plasma effects in the nucleus may play a dominant role (ref. 6).

Momentum Transfer:

Symmetric and asymmetric multiplicity patterns have been observed[3,4] in our Bevalac experiments (fig. 4). The former were associated with a detected oxygen-like fragment and the latter with fragments of high Z (e.g., Fe). The asymmetric multiplicity pattern was peaked in the reaction plane in the hemisphere opposite the heavy fragment. This proves that there is a perpendicular momentum transfer between the incident projectile and the target nucleus up to $p_{\perp}$ values of >2 GeV/c. The long-range Coulomb interaction can easily produce these momentum values, as it is known to do in fission-like processes. Experiments which measure the associated charged particle multiplicity pattern and the additional correlation of the fission-like partners, if present, give a much clearer understanding of the reaction mechanisms. In the absence of fission-like partners the heavy fragments are considered to be accelerated by the "pressure" produced in the reaction zone.

In the proposed experiment the high-energy proton-nucleus interaction could leave a nucleus "wounded", or with a hot spot[7], which would cool down via particle emission into and out of the nucleus. This could lead to a large recoil of the target nucleus associated with a broad jet of nucleons in the opposite direction. The detection of the target residue would be achieved in the TOF detectors and the associated jet of fast nucleons from the "hot spot" would be detected opposite the telescope in the multiplicity array.

Of special interest would be fragments close to the target mass with large transverse momenta but no high associated charged particle multiplicity in the target rapidity region and no coincident second heavy fragment. This would correspond to a rather "cold" process with little energy dissipation in the nucleus but rather large momentum transfer, facilitated by the removal of a few nucleons from the high momentum region of the Fermi distribution. Those events, if detected, could yield information on the tails of the momentum distribution of the nuclear constituents (ref. 9).

III. Experimental Details

The experimental apparatus to be used has been successfully employed at the Bevalac in the recent experiment 489H. It consists of 1) a vacuum scattering chamber which houses a total of 40 detector telescopes and 2) an 80-scintillator multiplicity array surrounding the chamber. Fig. 5 shows the layout of the apparatus.

The Mounting of the Chamber:

This is simple and will be discussed after the exact beamline location has been established. An area of 4m width and 10m length with the beam centered is required in the target area.

Vacuum Requirements:

A vacuum of $\sim 10^{-5}$ Torr is maintained inside the chamber to protect the silicon surface barrier detectors. Vacuum beam line is required at least to the entrance aperture of the chamber to avoid the need for windows. If necessary we will provide the diffusion pump, which would require a liquid nitrogen feeder system and a large roughing pump. We need two gate valves in the beamline, one upstream and one downstream of the chamber.

Flammable Gases:

The avalanche detector runs on small amounts of isobutane ($\sim$6 Torr) and the gas ionization chamber on methane (30 Torr) in a flow through mode. Two small roughing pumps are needed on loan, equipped with appropriate exhaust connections.

Electronics:

Standard CAMAC electronic will be used and the whole data acquisition is based on the Fermilab-Multi-Program. The software for this experiment is ready and fieldproven. We would like to borrow a PDP-11-45 computer and have some support of the PREP for the CAMAC system.

Data Analysis:

Since this proposal is based on our 489H experiment at the Bevalac, the analysis will follow the same lines. The software developed for the LBL-CDC-7600 and the GSI 370/168 systems will be used for the Fermilab data. This should allow a fast and efficient analysis of these data.

Target:

We require a heavy target and gold is chosen to allow comparisons to be made with our heavy-ion data and to avoid large numbers of low deposition energy fission events.

Readiness:

Upon approval of this proposal the equipment could be set up at Fermilab in late spring of 1981 with preliminary testing of background conditions, if necessary, during May or June 1981. The experiment would be ready to take data starting October 1, 1981. Other commitments of the GSI-LBL collaborators are the experiment 488H with the Plastic Ball Spectrometer at the Bevalac which is scheduled for the spring of 1981.

Beamtime Considerations:

For protons the intensities on target must be such as to avoid chance coincidences and pileup in the counters, at the same time allowing the event rate to reach the limit of the data acquisition system. During the spill we require a flux of approximately 6 x 10^{10} protons/sec which corresponds to an average beam intensity of approximately 6 x 10^{9} protons/sec, depending on the particular repetition rate. With an effective target thickness of 2mg cm^{-2} the maximum readout rate is achieved. The readout time is approximately 7 m sec per event, giving a data rate of approximately 100 accepted events per spill with an estimated dead-time of 10-20%. A minimum of 10^{7} events is needed to measure cross sections for a particular fragment mass down to 0.1 μb sr^{-1} MeV^{-1}. Estimated on the basis of previous studies at the Bevalac, this sensitivity corresponds to measurements up to $p_{\perp}$ of 6 GeV/c for a mass bin of 20 units centered around ^{60}Ni fragments. We estimate the beamtime necessary to obtain these data for a given proton energy to be about 300 hrs. Since we ask for two proton energies, this adds up to 600 hrs. For the pion-nucleus interactions an additional 100 hrs is requested in a high flux negative pion beam.

Since the whole experiment has already been proven in the field at Berkeley, the tuneup time of 100 hrs would be used to adapt to the new environment and to adjust timing, etc. Since most of the collaboration are not in residence near Fermilab we would like large blocks of beamtime, scheduled to minimize traveling expenditures. None of us are restricted by teaching.

Other Commitments:

The collaborators from GSI and LBL are committed to the Plastic Ball spectrometer at the Bevalac. This takes most of their time through June 1981, leaving enough time, however, to get fully ready for the subsequent Fermilab activity. The NAL collaborators are close to Fermilab and are committed strongly to another Fermilab proposal which utilizes the same experimental apparatus presented here but with a different emphasis.

Funding:

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Figure Captions:

Figure 1

Total kinetic energy dependence of the mean observed associated charge particle multiplicity <M> from events induced by projectiles ranging in mass from protons to ^{40}Ar.

Figure 2

Observed associated charged particle multiplicity distributions, as measured with the 80 counter multiplicity array, plotted as a probability.

Figure 3

Observed mean multiplicity plotted against Z of the detected fragment. The multiplicity depends, for a given fragment Z, only on the total kinetic energy of the projectile.

Figure 4

Sample multiplicity patterns as detected in the 80 counter array, in coincidence with an oxygen fragment (upper half) and a Z = 26 fragment (lower half).

Figure 5

Scattering chamber and associated detectors.

References:

1) Fermilab-Purdue Collaboration, Fermilab proposal #581.

2) A. Sandoval, et al., Phys. Rev. C21 (1980) 1321.

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4) A. Baden, et al., contributed paper, ICNP, Berkeley, 1980.

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6) E.V. Shuryak, Academy of Sciences, Novosibirsk, preprint No. 80-92.

7) H. Bethe, Phys. Rev. 53 (1938) 675; R. Weiner and M. Weström, Nucl. Phys. A286 (1977) 282; H. Ho, et al., Z. Phys. A283 (1977) 235; P.A. Gottschalk and M. Weström, Phys. Rev. Lett. 39 (1977) 1250.

8) A. Bialas, Proc. First Workshop on Ultra Relativistic Nuclear Collisions, May 21-24, 1979, LBL 8757, US-346 CONF 7905107, p. 63, and references therein.

9) H. Frisch, ibid., p. 195, and private communications.

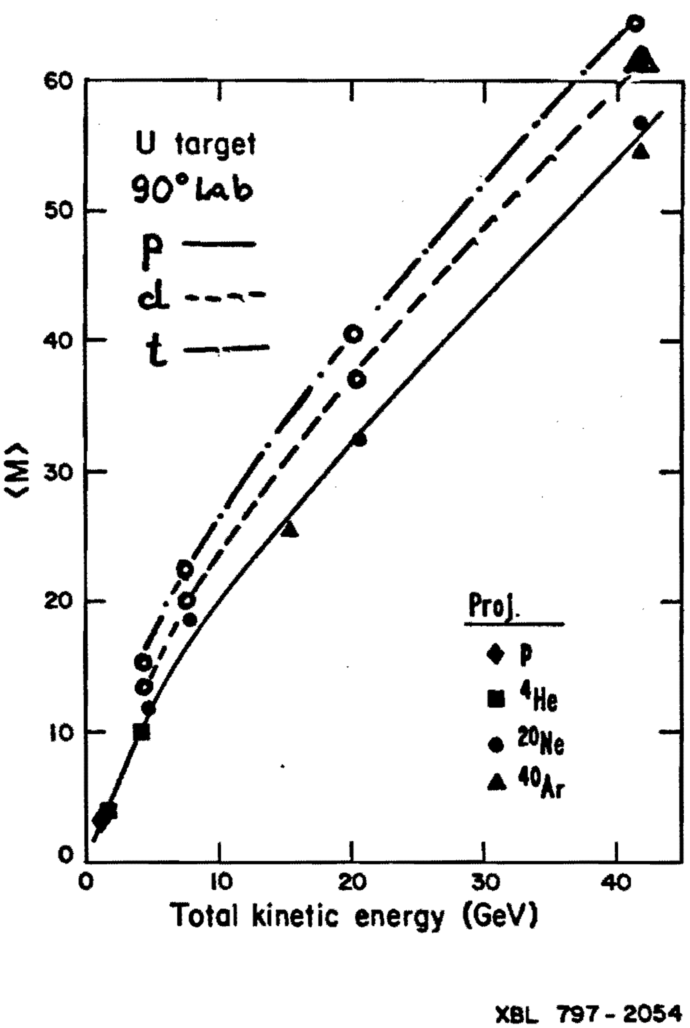

U target
90° Lab
p
d
t
Proj.
p
^{4}He
^{20}Ne
^{40}Ar
⟨M⟩
0
10
20
30
40
50
60
Total kinetic energy (GeV)
XBL 797-2054

Fig. 1

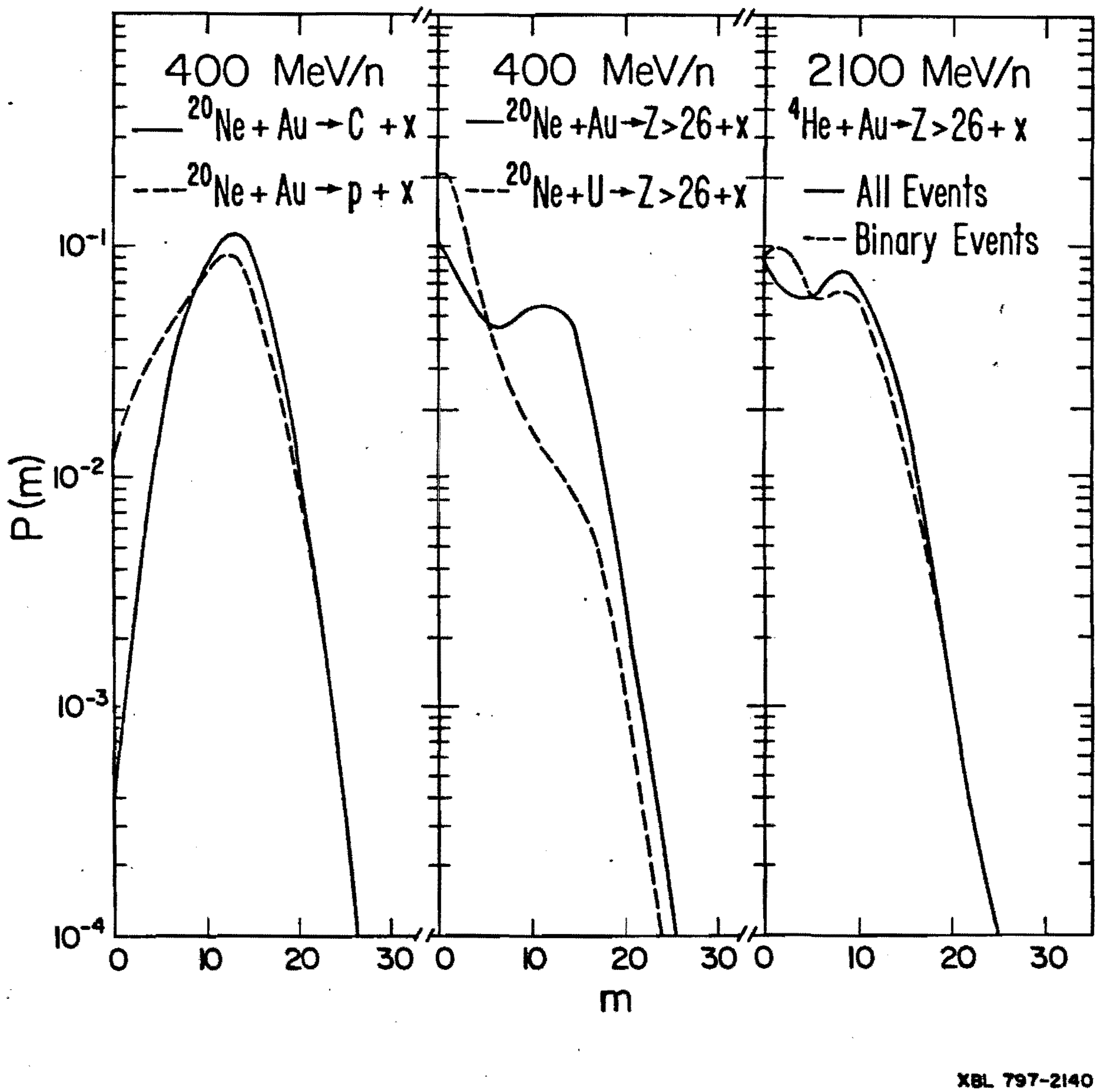

400 MeV/n
—— ^{20}Ne + Au → C + x
- - - ^{20}Ne + Au → p + x
400 MeV/n
—— ^{20}Ne + Au → Z > 26 + x
- - - ^{20}Ne + U → Z > 26 + x
2100 MeV/n
^{4}He + Au → Z > 26 + x
—— All Events
- - - Binary Events
P (m)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
10
20
30
m
XBL 797-2140

Fig. 2

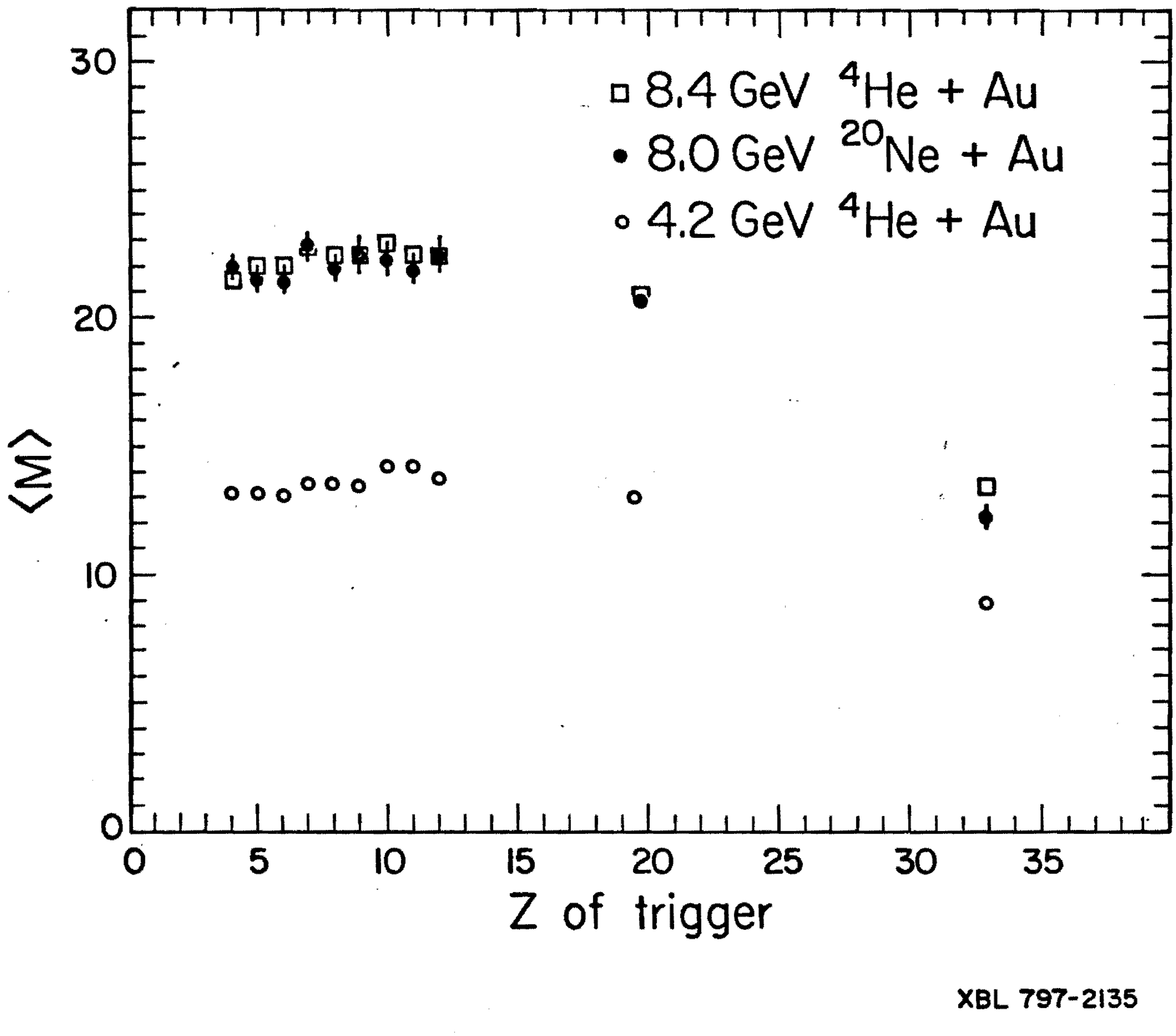
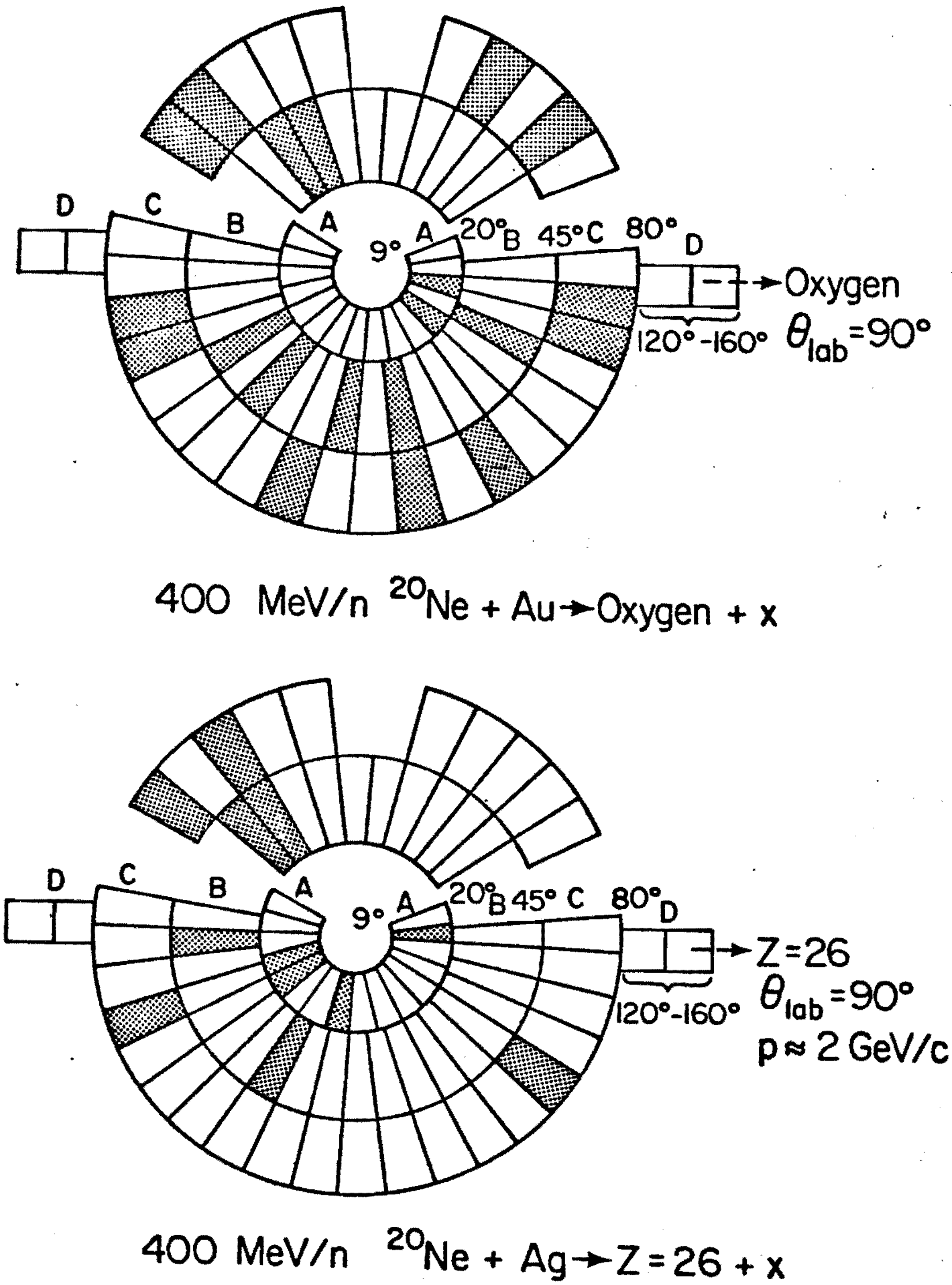

8.4 GeV ^{4}He + Au
8.0 GeV ^{20}Ne + Au
4.2 GeV ^{4}He + Au
30
20
10
0
⟨M⟩
0
5
10
15
20
25
30
35
Z of trigger
XBL 797-2135

Fig. 3



XBL 797-2134

Fig. 4

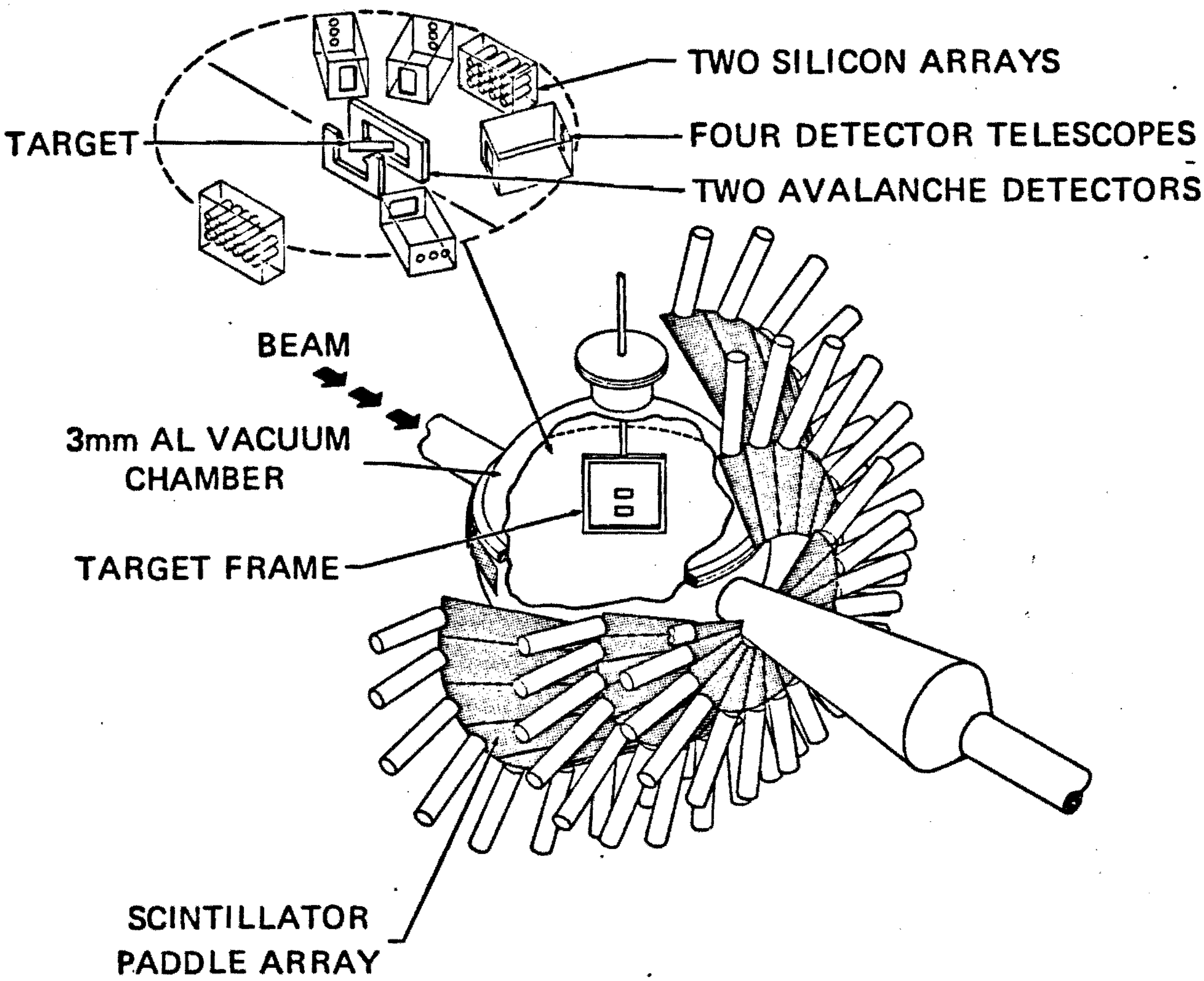

TWO SILICON ARRAYS
FOUR DETECTOR TELESCOPES
TWO AVALANCHE DETECTORS
TARGET
BEAM
3mm AL VACUUM
CHAMBER
TARGET FRAME
SCINTILLATOR
PADDLE ARRAY

Fig. 5