# MISSING-MASS TECHNIQUE FOR DIFFRACTION DISSOCIATION STUDIES

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## ABSTRACT

We have looked at the fundamental limitations of the missing-mass technique for surveys of coherently produced resonances. We have concluded that such experiments are natural thin-target experiments which will require high-intensity secondary beams--typically $10^8$ particles per pulse. Although the rates are low, we find them encouraging, and we conclude that it would be a mistake to give up on this technique.

## I. INTRODUCTION

Diffraction dissociation of beam particles[1] will be one of the basic classes of inelastic reactions to be studied at high energies. A complete survey of such processes is well known to require very large and precise apparatus and, especially when there are missing neutrals, it will be very difficult to establish a sufficiently precise energy and momentum balance from the kinematic information of the dissociation products alone.

The coherent dissociation of a beam particle (mass m, incident momentum $p_0$, energy $E_0$) into a state of mass M is supposed to leave the recoiling target nucleus (mass A) intact. One would really need to measure only the forward momentum component $q_{||}$ of the recoil and its kinetic energy T, in order to obtain the missing mass M

$$\frac{M^2 - m^2}{2p_0} = q_{||} - T\,\frac{E_0 + A}{p_0} , \qquad (1)$$

and the four-momentum transfer -t

$$-t = 2\,AT. \qquad (2)$$

Such a measurement would seem to be a natural way to make an initial survey of these processes.

A fundamental difficulty with this technique is that the recoil is very slow and hard to extract from the target for a precise measurement of its momentum $q = (q_{\parallel}, q_{\perp})$. For a missing mass M there is a minimum momentum $q_{\parallel}(\min)$

$$q_{\parallel}(\min) = \frac{M^2 - m^2}{2p_0} . \tag{3}$$

But to insure that the nucleus has a reasonable chance to stay intact one should also have

$$q_{\parallel}(\max) < (140\ \mathrm{MeV/c})/A^{1/3}.$$

Where the cross sections are reasonably high ($\sim$ 0.1 mb) namely for masses M corresponding to $q_{\parallel}(\min) << q_{\parallel}(\max)$ the recoils have an energy of only a few MeV. For higher masses, on the other hand, where the recoil would be easier to extract from the target, the cross sections dwindle below 1 microbarn.

The problem boils down to a matter of rates: one must make the target thin enough so that the recoils can easily escape in the forward direction, and one must accept the resulting rate limitations. The missing-mass survey is a thin-target experiment requiring recoil detection apparatus appropriate for low-energy physics research.

In this note we conclude that the rates are encouraging for a missing-mass search. We propose a conceptually very simple recoil spectrometer using a magnetic solenoid and solid-state detectors. We note that the incident beam need not be of high quality but that there must be plenty of it. We do not discuss the other apparatus needed to identify the forward dissociation products since such apparatus is likely to be available as a general laboratory facility. Also we would not necessarily advocate performing an initial missing-mass search together with a study of the decay channels.

## II. RATES

Let us restrict the target thickness to 10% of the range at the minimum recoil momentum $q_{\parallel}(\min) = (M^2 - m^2)/2p_0$. This should assure a relatively unobstructed escape of the recoil from the target and permit a momentum measurement to an accuracy of the order of one percent. The permissible target thickness would thus increase rapidly as the mass M increases, but the cross sections would decrease at the same time. Event rates are estimated assuming $10^7$ particles per pulse incident

($10^3$ pulses per hour) at momenta of 30 and 120 GeV/c for cross sections of 100 and 1 μb. They are displayed in Fig. 1 for protons, deuterons, and $\alpha$ particles as target nuclei. For heavier target nuclei the targets would have to be so thin that the rates look very discouraging. Heavier recoils with $q_{\parallel} < q$ (max) would have an appreciable chance to pick up electrons before escaping from the target.

Actual event rates in an experiment depend,of course, on the configuration of the detector. Further below we shall suggest an apparatus which will detect about 10% of the events on targets heavier than protons, and perhaps 1% of the events on proton targets. At this point let us just note as a rough rule-of-thumb that one will need beam intensities of the order of $10^8$ particles per pulse to detect 10 to 100 events per hour at the foreseeable cross sections.

## III. MEASUREMENT

In order to establish the missing mass M to a precision of a few percent one needs to know the incident momentum $p_0$, the forward momentum $q_{\parallel}$, and the kinetic energy T of the recoil. The incident beam could have a momentum bite of about one percent, and it could have an angular divergence of several milliradians. For the very small momentum transfers characteristic of coherent production on nuclei heavier than protons,the term $q_{\parallel}$ in Equation (1) predominates and one wants to measure it with a precision of about one percent. Generally it is desirable to measure the kinetic energy T quite precisely to get the momentum transfer. Below we propose to measure $q_{\parallel}$ by employing the uniform magnetic field of a solenoid, and to measure T by means of solid-state detectors.

The charge and the mass of the recoil need to be verified and one needs to know as much as possible about its trajectory and its time of flight between target and detector. For the very small energies considered here a fundamental limitation on the measurement appears: the recoil trajectory can be measured at only two points--target and detector--because any conceivable detector would absorb the particle. Thus either the charge or the mass of the recoil may remain ambiguous after analysis of an event if a magnetic field is employed. A third point could be defined by a narrow aperture at a heavy sacrifice in rates and presumably one would do this only after promising candidates have been identified in an initial survey. At any rate the time-of-flight between target and detector together with the crude geometrical constraints in the apparatus will help to resolve the ambiguity at least for the simple nuclei up to $\alpha$ particles.

It will sometimes be hard to prove that the target nucleus was not left in a quasi-stable excited state after the collision. As far as the missing-mass measurement is concerned an excitation of a few MeV would introduce an error of only a few percent. Unfortunately, however, it would remove the constraints of selection rules for coherent production (exchange of $J^P = 0^+$) which help to restrict the possibilities for the quantum numbers of the state M.

Finally there remains the possibility of appreciable background from the formation of $N^*$ at the target vertex. One would not expect of this background the type of structure that one expects to see for genuine diffraction dissociation. At this point we have no accurate judgment on how serious this problem will be and whether or not one might be able to veto such events by detecting other slow particles or slow $\pi^0$'s. This will depend very much on the exact geometry chosen and needs to be evaluated for specific designs.

## IV. APPARATUS

Of several possible experimental approaches we discuss an apparatus which would be most appropriate for very small momentum transfers. It is particularly well suited for coherent production on light nuclei heavier than protons where the average transverse momentum is small.

The incident beam is focused to a clean spot (a few mm in diameter) on a very thin target, typically $10^{-4}$ to $10^{-3}$ g/cm$^2$. The beam proceeds in the z-direction, and the x - y plane contains the target (coordinates $x = y = 0$) and a two-dimensional array of solid-state detectors (coordinates $x > 0$). A uniform magnetic field is applied in the y-direction, and the target and the detector plane are in the magnetic field. Figure 2 shows typical trajectories between target and detector of recoils escaping in the forward direction. The whole magnetic volume is under vacuum.

Recoils from events with a certain missing mass M will make an excellent focus in the x-coordinate on the detector even for angles as large as 60° or 70° from the forward direction and irrespective of the initial azimuth $\phi$. This is so because the magnetic field produces an exact focus in x for constant $q_{\parallel}$, and $q_{\parallel}$ in turn depends practically only on the missing mass M, the kinetic energy term in Eq. (1) being generally small. At any rate, regardless of the quality of the focus, a measurement of the x-coordinate giving $q_{\parallel}$, and of the kinetic energy T in a total absorption solid-state counter, gives the exact value of the missing mass and of the momentum transfer, provided that one is sure that the slow recoil is the original target nucleus. Time-of-flight will help discriminate against recoils of the wrong mass (e.g. against slow $\pi$'s or K's) and pulse-height information would eliminate particles which do not range out in the counter.

Throughout this note we have emphasized the smallest possible momentum transfers by focusing the attention on the escape of the recoil from the target in the forward direction (say within about 70° of forward). The proposed apparatus is optimized for forward recoils. It would detect an appreciable fraction of the events from target nuclei which have a narrow diffraction peak, while it is not optimized to detect the recoils near 90° prevalent for proton targets which have a wider diffraction peak. In either case it will serve well for a missing-mass search, even though it will cover only a small fraction of the interesting transverse momenta for proton events.

Typically one expects to catch about 10% of the deuterium events (~ 1% of the proton events) on a reasonable detector. To do this one would typically use a 20-kG solenoidal field over a cylindrical volume of diameter 0.7 meters and a height of, say, one meter. If one measures the position x with a resolution of a few mm, one could measure $q_{\parallel} < 200$ MeV/c to an accuracy of a few percent. The detector would have an area of roughly $0.3 \times 1\mathrm{m}^2$. This large detector may present the largest practical problems.

## V. SUMMARY

We have looked at the fundamental limitations of the missing-mass technique for surveys of coherently produced resonances. We propose a conceptually simple experiment which will provide a missing mass and transverse momentum measurement in a reasonably optimal way. We have concluded that these experiments are natural thin target experiments which will require high-intensity secondary beams--typically $10^8$ particles per pulse. These beams need not be of the highest quality: a momentum resolution of ~ 1% and an angular divergence of several milliradians would give excellent precision. The missing-mass experiments will be difficult because of the low rates. But we believe that, for the purpose of a general survey, the large and expensive systems for detecting the forward dissociation products have such severe limitations that it would be a mistake to give up on the missing-mass technique.

## REFERENCE

[1] M. L. Good and W. D. Walker, Phys. Rev. 120, 1857 (1960).

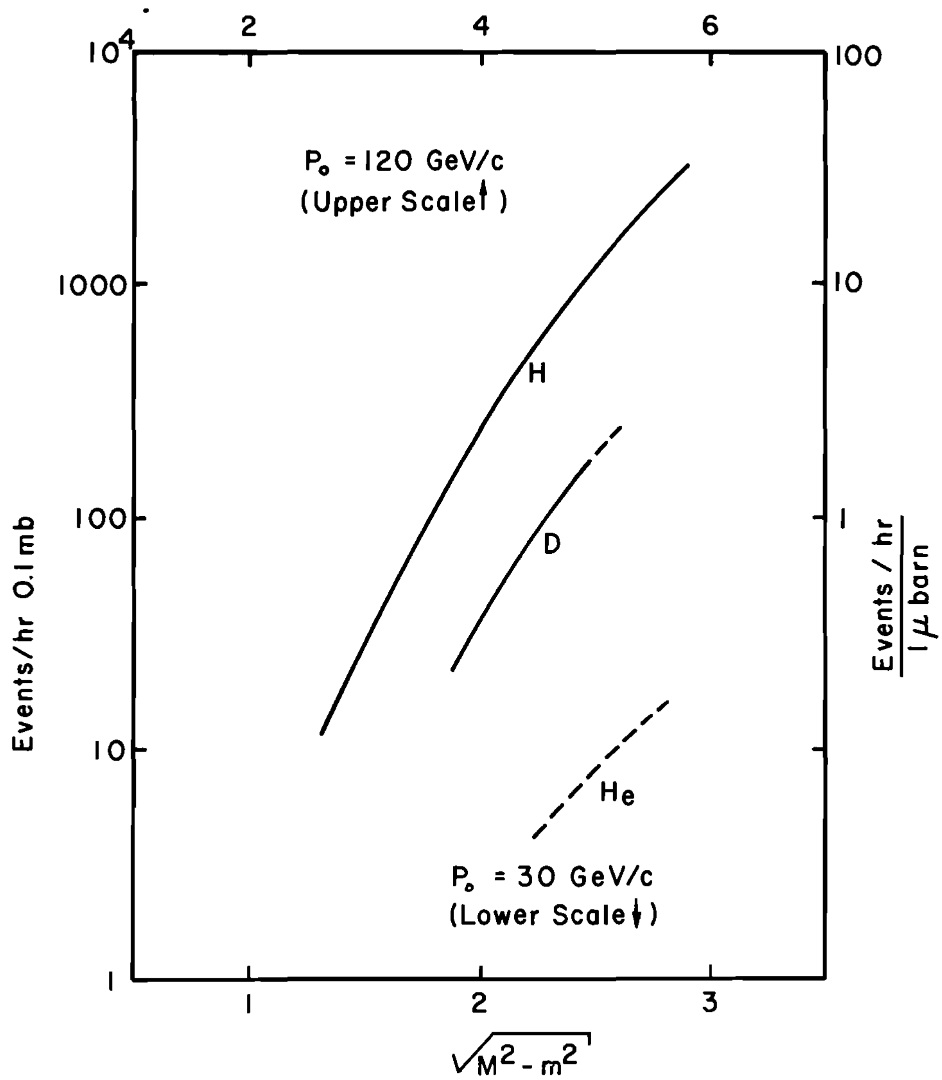


Fig. 1. Event rates for $10^7$ incident particles per pulse.

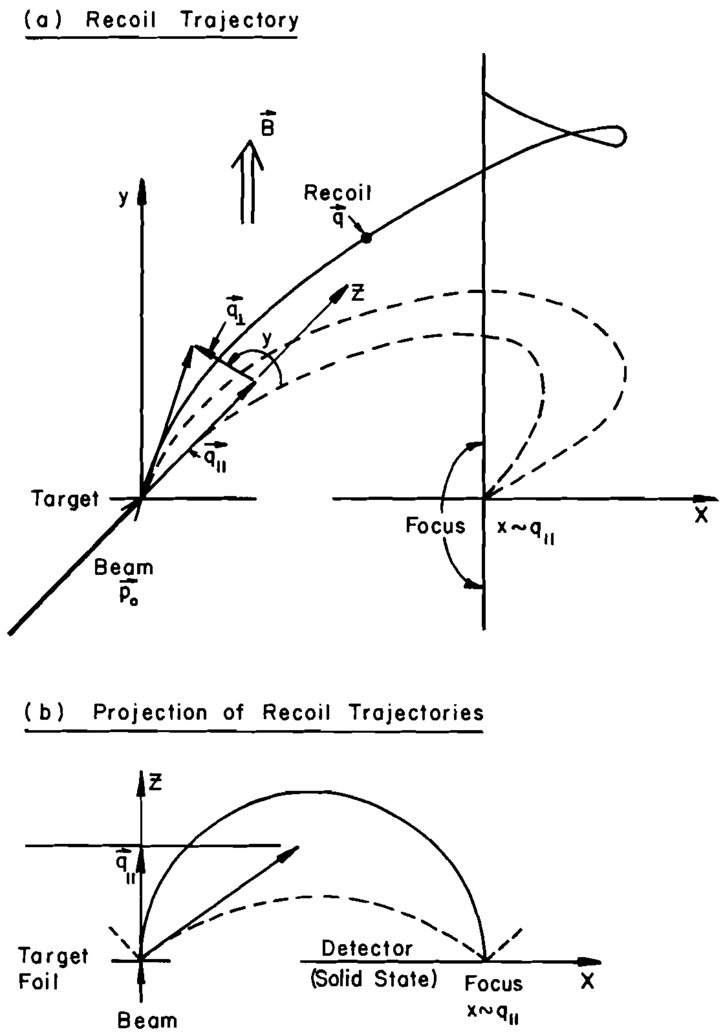


Fig. 2. Particle trajectories and focusing properties.