NAL PROPOSAL NO. 229

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A Proposal for Testing a Transition Radiation Detector at NAL

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The objectives of this study are (1) to measure the yield of transition radiation and to study the relativistic rise effect in ionization loss using a large number of multiwire proportional chambers, and (2) to measure the yield of transition radiation with a NaI counter with a beam hole, at NAL. This investigation will give us information to design a practical transition radiation detector to distinguish pions from kaons or kaons from protons. It should be possible to use the present device as it is for particle separation at 400 GeV.

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I. Physics Justification

Introduction

The commonly encountered requirements in elementary particle research are to determine accurately the momenta and masses of particles involved in a specific reaction, and to be able to detect and identify these particles individually. As particles reach relativistic energies, their velocities approach the velocity of light. The existing detection techniques, most of which rely on the velocity differences to identify these particles, would in general not be able to give satisfactory results at the extreme relativistic energies. It is desirable that entirely different approaches of particle detection be fully investigated. One approach to this problem is to use transition radiation for particle identification.

Transition radiation is produced when a charged particle traverses the boundary between two media of different dielectric constants. The intensity of x-ray transition radiation is linearly proportional to the Lorentz factor, γ, of the charged particle. Therefore, it is expected that a detector based on x-ray transition radiation can be used to determine the γ values of charged particles at very high energies.

Our study on transition radiation so far has been carried out using electron beams.[1] In the following we discuss the expected results from the experiments using the muons at NAL, based on experimental results using electrons and theoretical calculations. It is certain that a transition radiation detector is useful at high energy ($\sim$ 400 GeV), but since the maximum energy of a muon beam is 230 GeV, we present electron data relevant to this beam energy.

Our objectives in this investigation are:

1. To measure the yield of transition radiation from muons with a large number of multiwire proportional chambers and compare with the theory, and to obtain information to design a transition radiation detector which can be used at 400 GeV beam. It is desirable to measure transition radiation from heavier particles than electrons. Although the measurements have been made with electrons with the same γ values, the bremsstrahlung background

and multiple Coulomb scattering are smaller for heavier particles. This would allow us to measure transition radiation in the absence of these effects and will aid the interpretation of the result.

2. To study, using multiwire proportional chambers, the relativistic rise effect. This technique could also be used to identify the particles.

3. To measure the yield of transition radiation using a NaI crystal with a central beam hole. The primary particles generate transition radiation and pass through the beam hole. Such a system in a beam can be used to tag different particles, without using a sweeping magnet.

Experimental Arrangement for Chambers

The experimental arrangement is shown in Fig. 1. The detector consists of a large number of multiwire proportional chambers (10 to 30 chambers) and transition radiators. Each chamber has an active area of 6" x 6" and thickness of 2.2 cm. The sense wires are joined together to give a single signal output from a chamber. The chamber is filled with argon or xenon gas. Transition radiators consist either of 100 foils of ½ mil mylar with air spacing of ~ 30 mil or of ~ 4" styrofoam (density is 0.025 g/cm^3).

The beam goes through a thin scintillation counter telescope, transition radiators, and multiwire proportional chambers. The proportional chambers detect x-ray transition radiation, ionization due to the primary charged particle, and background radiation. Signals from the chambers are combined to give a geometric mean or an arithmetic mean and are stored in a pulse height analyzer. The measurement is repeated with a background radiator consisting of a solid block of the same material as the transition radiator with the same thickness, but without the multitude of interfaces. The yield of x-ray transition radiation is obtained by comparing these two measurements.

In Fig. 2 observed spectra for electrons and pions at 1.0 GeV/c are shown. The γ value for electrons is ~ 2000, which corresponds to muons of 200 GeV. Twenty chambers filled with argon are used. Radiators of 4" of styrofoam are placed between chambers. There is a separation between the two spectra for transition radiation and the background radiation. This separation will be improved by using xenon gas instead of argon. See the discussion for Fig. 4.

In Fig. 3 observed spectra for electrons and pions at 2.7 GeV/c ($\gamma \sim 5400$) are shown for the same experimental configuration as in Fig. 2. The improvement of transition radiation signal with increasing γ is clearly demonstrated. This makes the use of transition radiation for particle separation in the 400 GeV region promising.

In Fig. 4 the expected results for 100 and 200 GeV muons are shown. The spectra are calculated in the following way. Curve A is the expected background spectrum for muons for the chambers. This curve is obtained by appropriate extrapolation of the measured electron data. The thickness of each chamber is equivalent to 0.35 cm of Xe. For example this is achieved using 1 cm thick chambers filled with a mixture of 35% of Xe and 65% of He, because the construction of thin chambers is more difficult than changing the gas mixture. Curve B is the convolution of curve A and the calculated transition radiation spectrum for 100 GeV muons using transition radiators of 100 foils of ½ mil Mylar spaced at 60 mil. Curve C is the expected result for 200 GeV muons. We plan to confirm this result by our measurement at the AGS with electrons of 0.5 and 1.0 GeV. According to these calculated spectra, we expect that we can get good transition radiation signals from 100 or 200 GeV muons.

Experimental Arrangement for NaI

The second phase of this investigation is to measure transition radiation using a NaI crystal with a beam hole. The experimental arrangement is shown in Fig. 5. The primary particle generates transition radiation at a radiator and passes through a central hole in the NaI. Our present NaI crystal is 3" diameter with 1" diameter hole. Transition radiation has an angular distribution with respect to the particle, will be displaced from the particle at certain distances, and will be detected by a NaI. The peak of the angular distribution is at $\sim 1/\gamma$. Since different particles of the same momentum have different angular distributions, such a system can identify particles in the beam. It is essential to test this type of arrangement with muons, since, for electrons at the same γ, the angular distribution is greatly affected by multiple Coulomb scattering.

The angular distribution of transition radiation from 100 and 200 GeV muons are shown in Fig. 6. The NaI crystal will detect 70% of transition radiation, if the detector is placed at 60' from the transition radiator, and 65% at 30' for 100 GeV muons. The detected signals at different distances for 100 and 200 GeV muons are shown in Table I.

TABLE I

Calculated intensity and number of photons to be detected. Radiator is 500 foils of ½ mil mylar with 30 mil spacing. N is the number of photons per incident particle and I is the intensity per incident particle.

Muon Energy (GeV)	Total		Distance between Radiator and NaI							
			15'		30'		60'		120'	
	N	I (keV)	N	I	N	I	N	I	N	I
100	0.816	10.8	0.082	1.08	0.531	7.03	0.570	7.57		
200	2.31	36.4	~ 0.15	~ 2.0	0.42	6.55	0.93	14.6	1.73	27.2

In the present investigation, the detector will give an indication of transition radiation, even if the allowed space is only ~ 15'.

Other related results can be found in References 1 and 2.

II. Apparatus

The layout of the apparatus for chambers is shown in Fig. 7. Each chamber has an active area of 6" x 6" and has a 3" wide frame of G-10. All chambers and radiators are mounted on a stand which has wheels. The stand contains the power supplies for the chambers and counters, some logic units and so on. Other apparatus like the electronics racks, a PHA, teletype, cabinets, and gas system is located near the wall away from the beam line. Only signal cables, an ac cord and gas hoses run between two systems of the detector and electronics racks.

The space of 10 to 15 feet along the beam line and 6 feet wide for the detector is required. It is certainly better if we can have a longer space along the beam line.

The layout for the NaI system is similar except that the chambers are replaced by a helium bag containing the NaI and a transition radiator.

All the apparatus will be provided by proposers and will be ready by the beginning of September. The entire system is valued about $70,000.

The manpower needed from NAL is small except that we prefer to have one collaborator.

III. Scope of the Experiment

The system will be tested at the AGS of Brookhaven National Laboratory before it is moved to NAL. The chamber system has been extensively used at the AGS and will be further tested to optimize the yield of transition radiation expected from muons at the NAL energies.

Beam Line

The muon beam in the Neutrino Area is satisfactory. We understand that the space is available without affecting the on-going experiments. However, if space is available, the pion beam in the Meson Area or the bubble chamber beam in the Neutrino Area is even more suitable.

Beam Requirements

1. The beam energy is greater than 100 GeV, possibly 200 GeV.
2. The momentum bite is 10 to 20%.
3. We can use beam rates of up to 10^4 μ/sec.
4. One particular beam energy is all right, although several different beam energies will give us more information.

Machine Time

The setup time required without beam is about two weeks. The total running time requested with the beam is four days. We prefer to have two running periods to analyze data taken in the first period and make modifications for the second. A few days between two runs are sufficient.

Time Scale

Most of the apparatus is ready at the present time. The whole system will be operational by the beginning of September.

Running Procedure

The detector will be mounted on wheels as mentioned. It will be tested using stray muons and will be moved into the beam line to take data. On the other hand, the chamber system has a very small amount of material (up to

0.1 radiation length) in the central region, and can be placed from beginning in the beam line without affecting the experiments downstream.

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2. F. Harris, T. Katsura, S.I. Parker, V.Z. Peterson, R.W. Ellsworth, G.B. Yodh, W.W.M. Allison, C.B. Brooks, J.H. Cobb, and J.H. Mulvey, Nucl. Instr. & Meth. (in press).

Figure Captions

Fig. 1 The experimental arrangement for multiwire proportional chambers.

Fig. 2 Pulse height distributions for electrons and pions at 1.0 GeV/c. Twenty chambers of 2.2 cm thick filled with Ar are used. Radiator is 4" foam. Geometric mean unit is used.

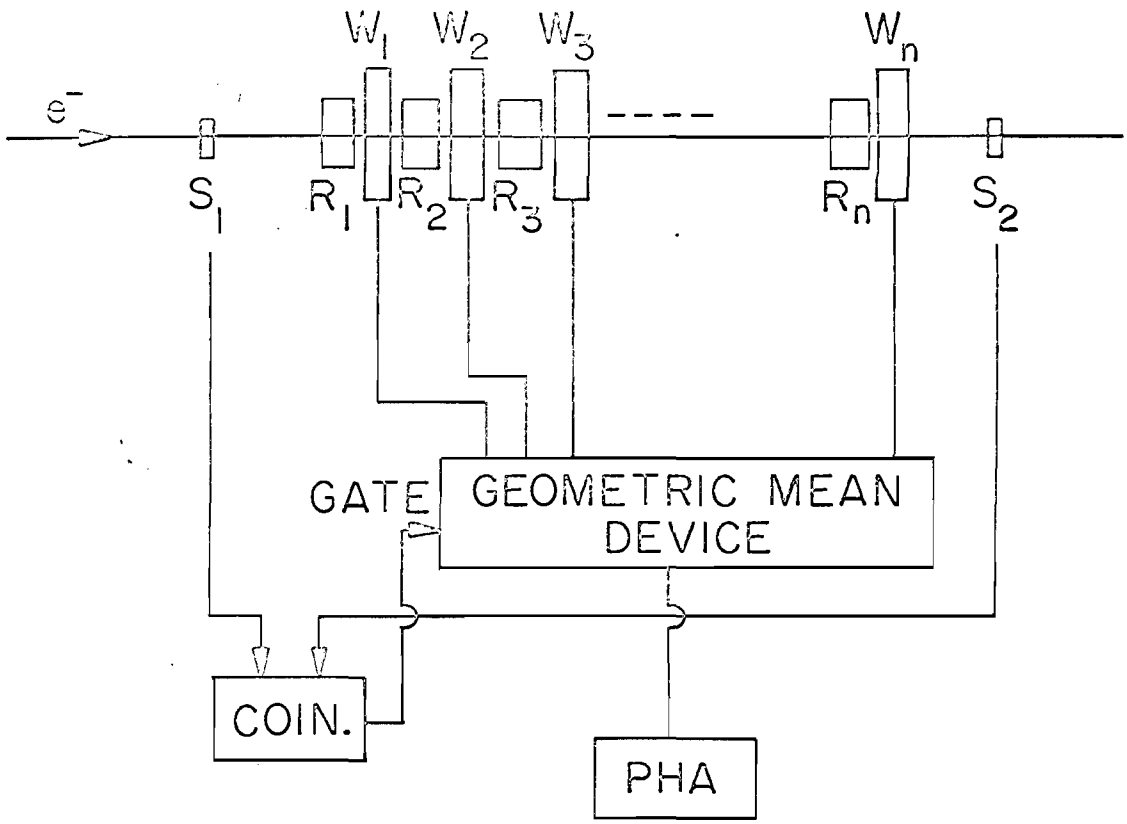
Fig. 3 Pulse height distributions for electrons and pions at 2.7 GeV/c. Twenty chambers of 2.2 cm thick filled with Ar are used. Radiator is 4" foam. Geometric mean is used.

Fig. 4 Expected transition radiation spectra from 100 and 200 GeV muons. These spectra are calculated for ten chambers filled with 0.35 cm of Xe. Radiator is 100 foils of ½ mil Mylar with 30 mil spacing. Curve A, background distribution; Curve B, 100 GeV muon; Curve C, 200 GeV muon.

Fig. 5 The experimental arrangement for a NaI crystal with a beam hole.

Fig. 6 Angular distributions of transition radiation from 100 and 200 GeV muons. Radiator is 500 foils of ½ mil Mylar with 30 mil spacing.

Fig. 7 Layout of the apparatus.



$W_1, W_2 \ldots W_n$; MULTIWIRE PROPORTIONAL CHAMBERS

$R_1, R_2 \ldots R_n$; TRANSITION RADIATORS

S_1, S_2; PLASTIC SCINTILLATION COUNTERS

Fig. 1

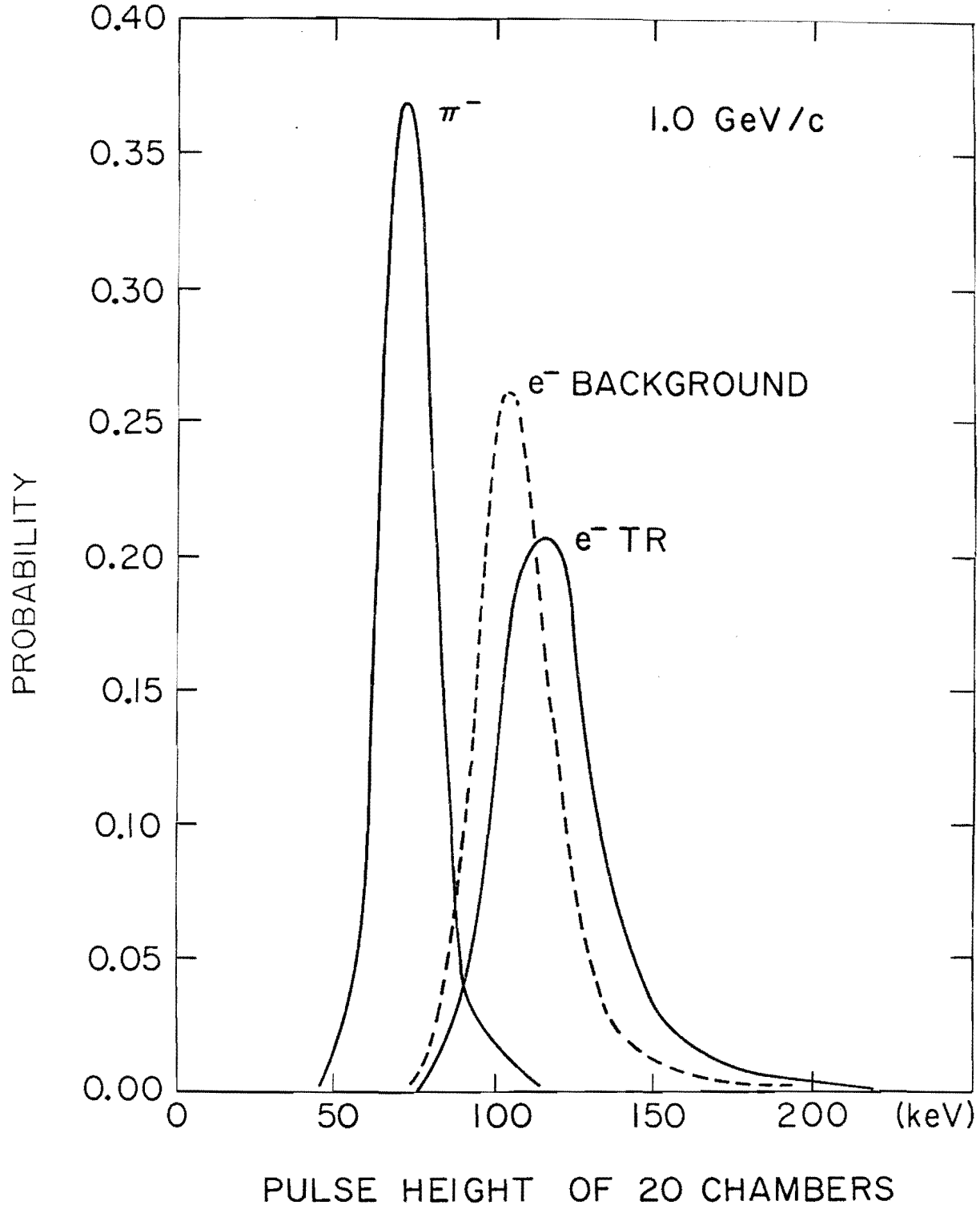

0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
PROBABILITY
π⁻
1.0 GeV/c
e⁻ BACKGROUND
e⁻ TR
0
50
100
150
200
(keV)
PULSE HEIGHT OF 20 CHAMBERS

Fig. 2

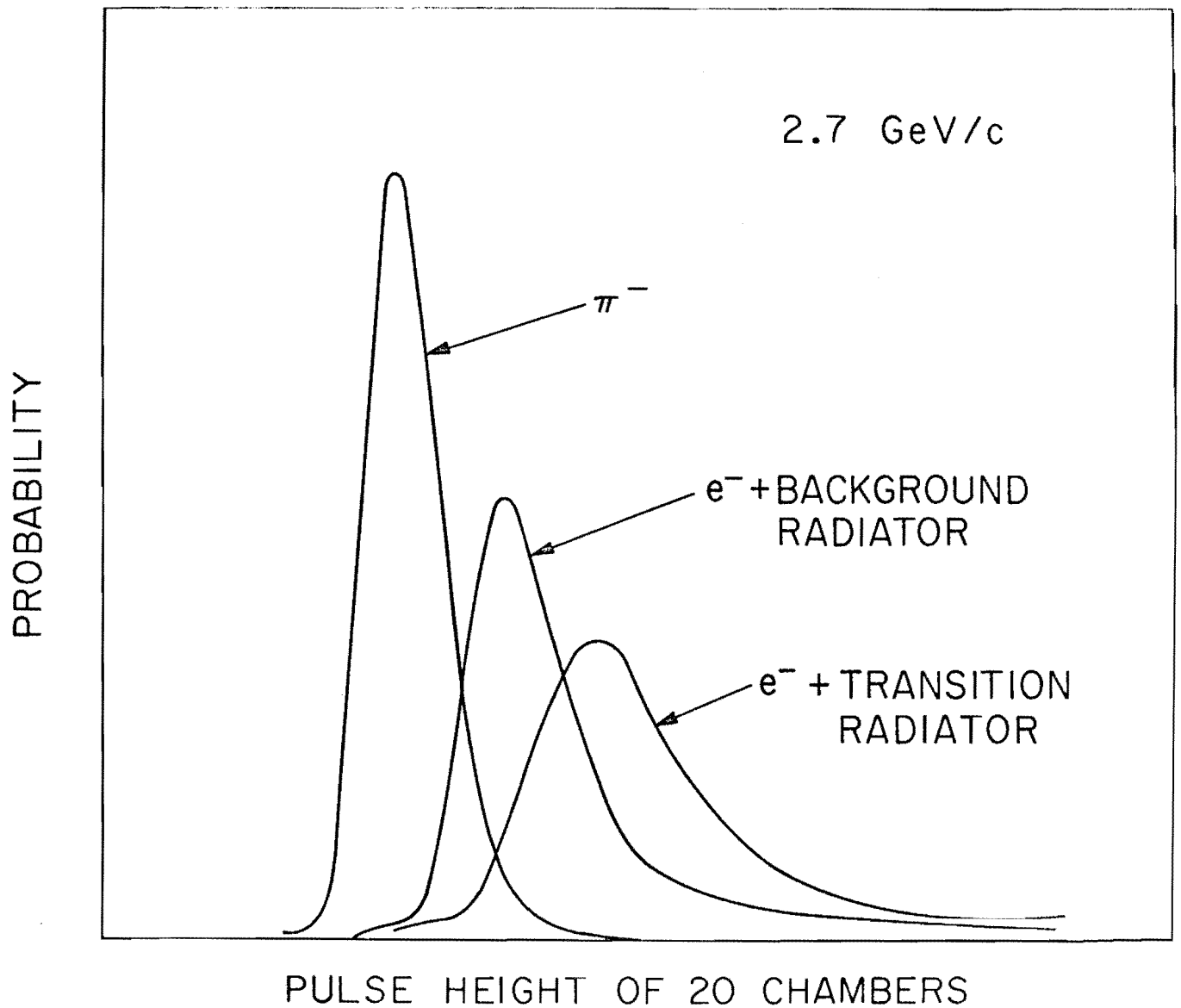

2.7 GeV/c
π^-
e^- + BACKGROUND RADIATOR
e^- + TRANSITION RADIATOR
PROBABILITY
PULSE HEIGHT OF 20 CHAMBERS

Fig. 3

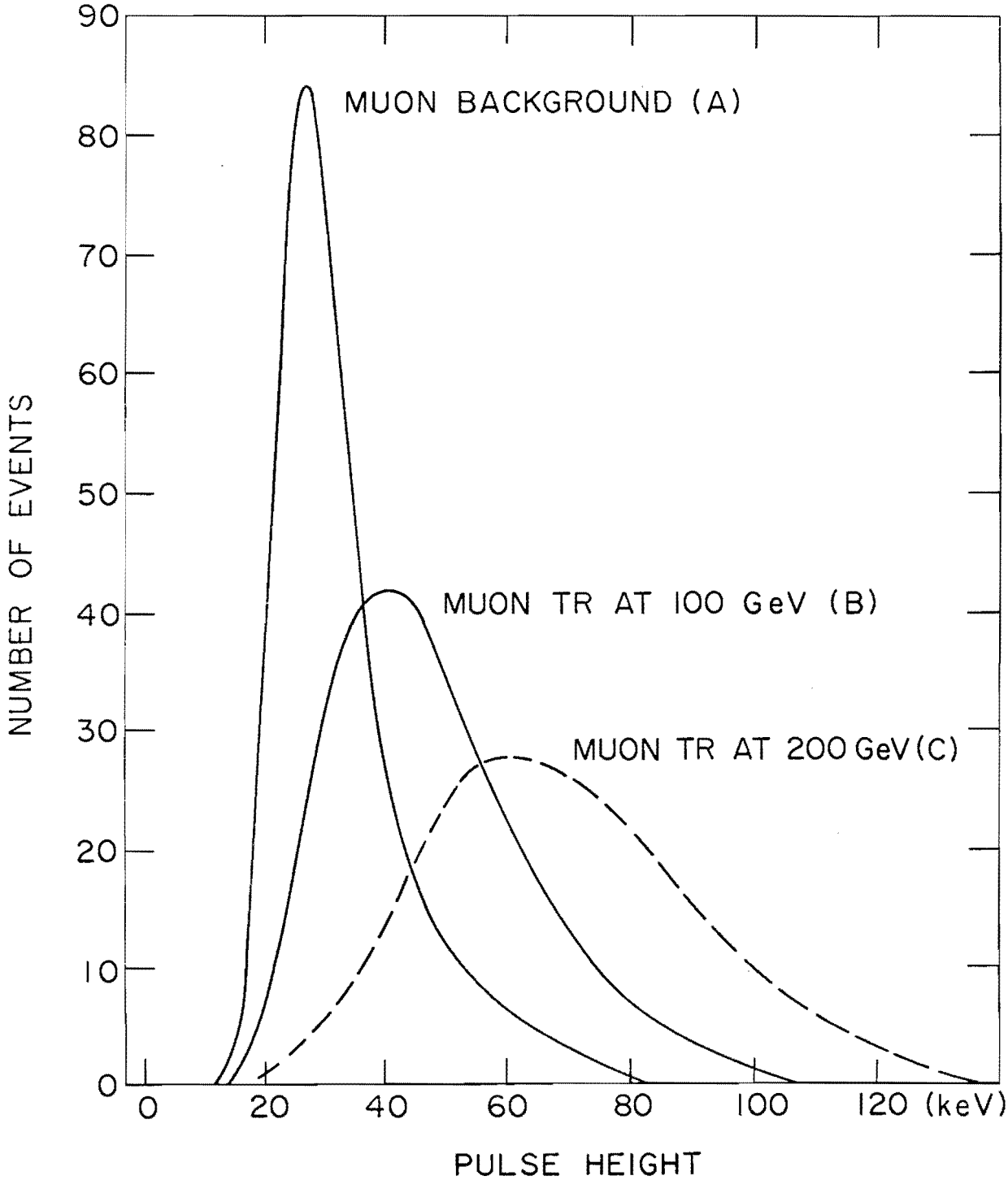
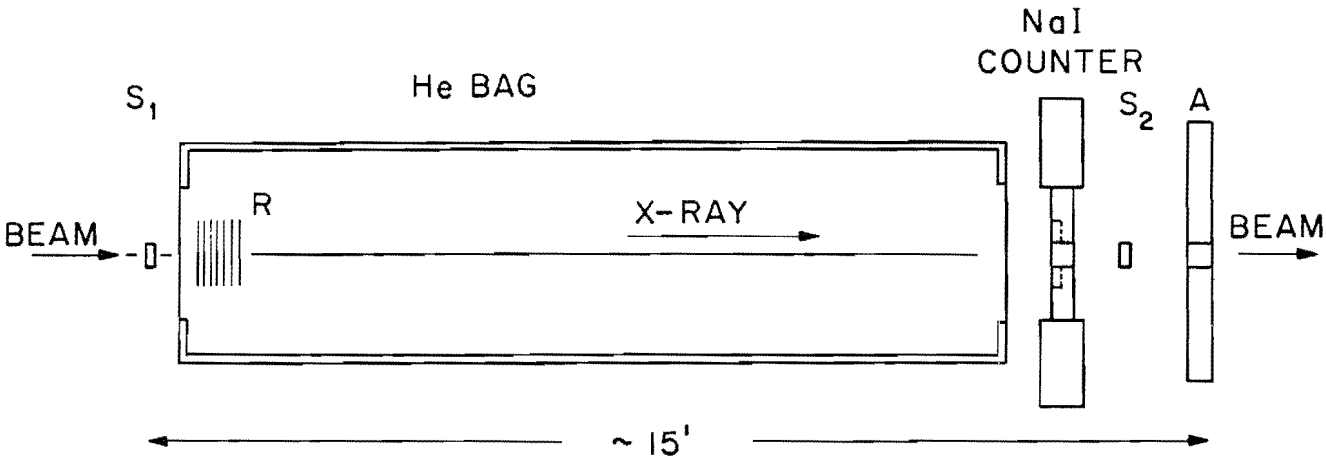

MUON BACKGROUND (A)
MUON TR AT 100 GeV (B)
MUON TR AT 200 GeV (C)
NUMBER OF EVENTS
PULSE HEIGHT
0
10
20
30
40
50
60
70
80
90
0
20
40
60
80
100
120 (keV)

Fig. 4



S_1, S_2 : SCINTILLATORS OF 1" DIAMETER

A : ANTI-COUNTER WITH 1" HOLE

R : FOIL RADIATOR

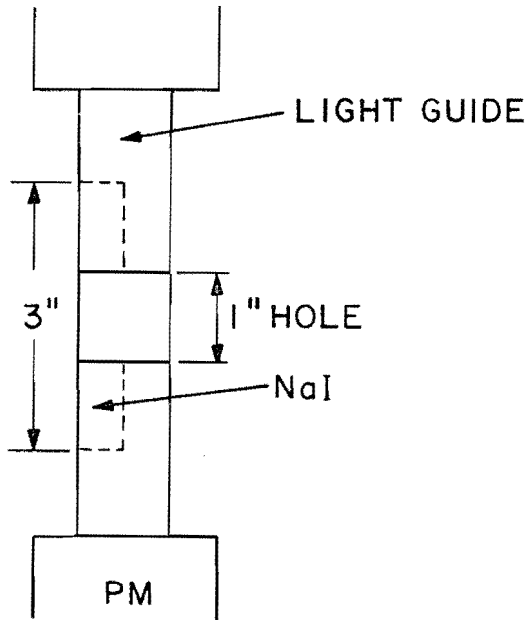


Fig. 5

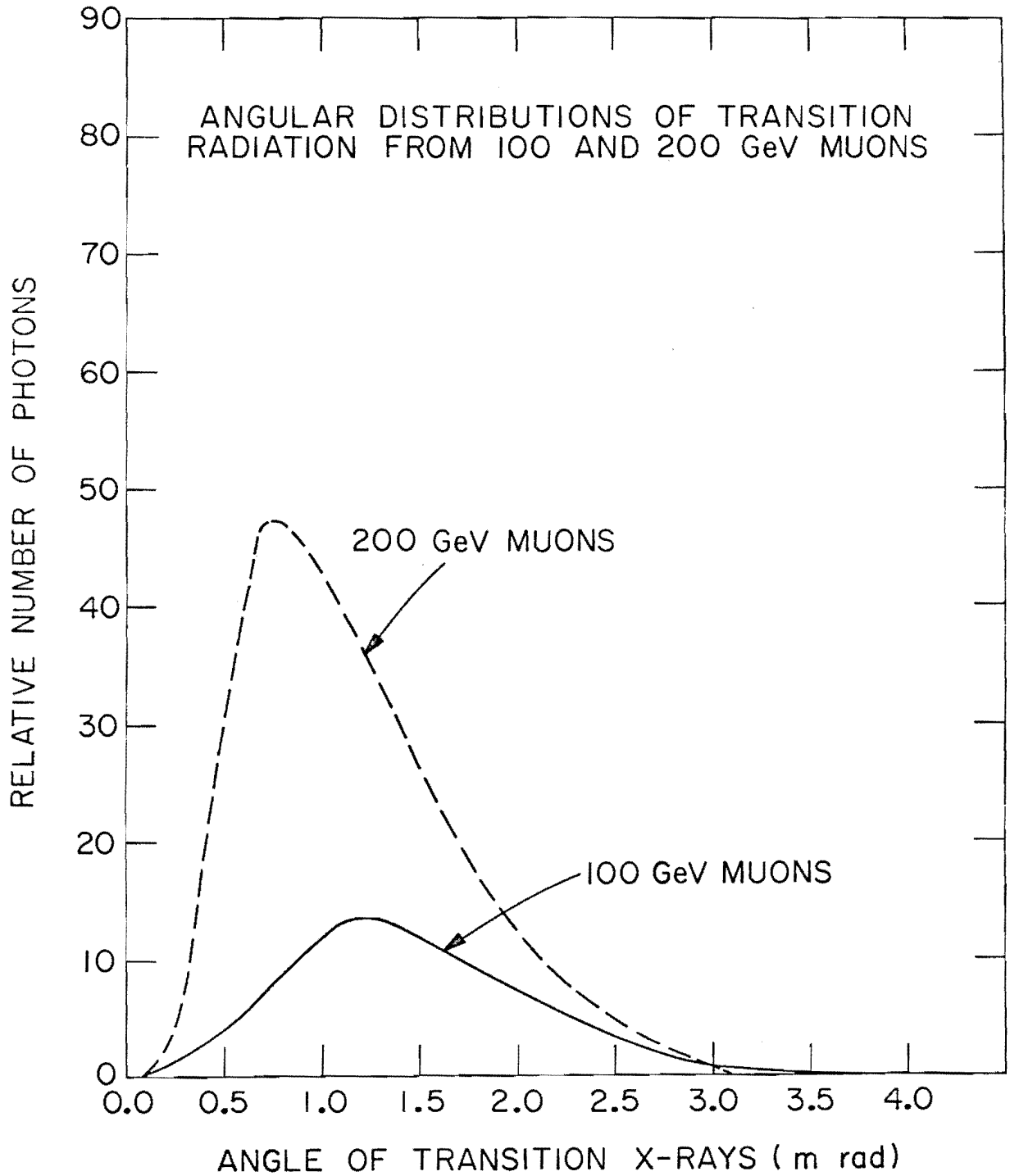

ANGULAR DISTRIBUTIONS OF TRANSITION RADIATION FROM 100 AND 200 GeV MUONS
RELATIVE NUMBER OF PHOTONS
90
80
70
60
50
40
30
20
10
0
200 GeV MUONS
100 GeV MUONS
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
ANGLE OF TRANSITION X-RAYS (m rad)

Fig. 6

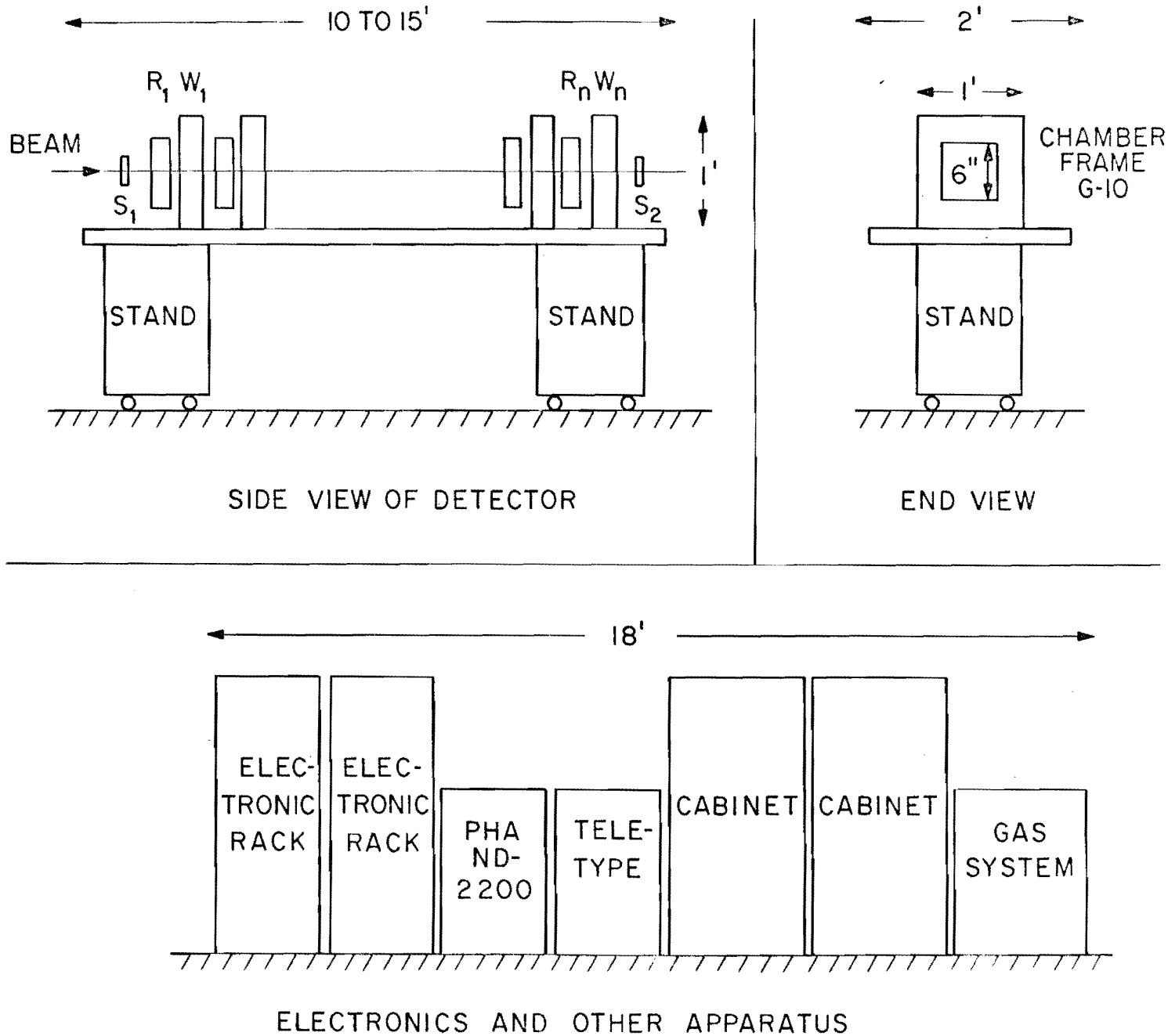

10 TO 15'
R1 W1
Rn Wn
BEAM
S1
S2
1'
STAND
STAND
SIDE VIEW OF DETECTOR
2'
1'
6"
CHAMBER
FRAME
G-10
STAND
END VIEW
18'
ELEC-
TRONIC
RACK
ELEC-
TRONIC
RACK
PHA
ND-
2200
TELE-
TYPE
CABINET
CABINET
GAS
SYSTEM
ELECTRONICS AND OTHER APPARATUS

Fig. 7