A Search For Fractionally Charged Particles at the Tevatron

27 February 1984

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Summary

We propose to search for production of fractionally charged particles (FCPs) produced from 1 Tev protons on a fixed target. Most FCPs (if produced) will be slowed down and stopped either in the target itself or in ten liquid freon collection tanks (total mass 13.4 tons). If the FCP stops in the collection tanks it will drift by the force of an electric field to the appropriate polarity collector wire. These wires will be removed at the conclusion of the experiment and will be distributed to existing bulk matter quark search experiments. In addition the target itself will also be distributed to these groups for analysis. One part of the target will be high purity mercury which will be distilled in order to concentrate the FCPs into a much smaller volume (and mass) before analysis. Our projected sensitivity to FCP production is up to one part in 10^{13} proton interactions, for an irradiation of 10^{15} protons on target. This limit will be roughly independent of the mass, charge, and production mechanism of the FCP.

Introduction

Whenever a new accelerator achieves higher energy and/or higher beam intensity as compared to existing accelerators one is obligated to search for free fractionally charged particles (FCPs). The total center-of-mass (CM) energy available at the Tevatron for a p-nucleon collision is approximately 44 Gev. This is about a factor of 2 larger than previous fixed target experiments.[1] Previous ISR collider experiments[2] lacked sufficient beam intensity to set stringent limits on FCP production although their CM energy was up to forty percent higher than the Tevatron. Furthermore all the previous limits have varying degrees of dependency upon assumptions concerning the mass, charge and production mechanism of the FCP. In addition the colliders are limited (at present) to p-p (or p-p) collisions whereas the fixed target experiment can look for the interactions where an significant fraction of an entire nucleus might be collectively involved in the collision. Under these conditions where a quark-gluon plasma might exist over a distance scale of 10 fm, FCP might escape the strong color forces.[3]

We propose an experiment in which it should be possible to achieve a sensitivity of up to one FCP per 10^{13} proton-nucleus interactions while remaining reasonably insensitive to the mass, charge, or production mechanism. We do this by slowing and stopping a significant fraction of all strongly-interacting particles produced in p-nucleus collisions in approximately ten tons of liquid material surrounding the target. Any stable FCPs (of any charge or mass) are then concentrated by a factor of up to 10^{6} from stopping material. The methods of concentration include either electrostatic attraction onto thin wires or by distillation of the bulk liquid. Within the next year at least six groups will be operating bulk matter quark search experiments. These experiments range from automated Millikan oil drop experiments to charged-particle low-energy accelerator experiments.[4] They can handle amounts of material ranging from the milligram to the (projected) gram levels. Our goal is to provide these bulk matter experiments with reasonably small amounts of material which have been exposed at an accelerator and have the exciting possibility of being enriched in FCPs. We emphasize the variety of different experimental techniques used by this experiment as well as by the individual bulk matter experiments. The different sets of systematics would justify this experiment even if our projected limits for FCP production were not as great as previous limits since the potential payoff is so enormous. A similar type of experiment[5] has already been run at the Bevalac at Lawrence Berkeley Laboratory.

Design Considerations

We speculate that the FCP is produced either in a p-nucleon (or q-q) hard collision or by the creation of a hot nuclear core in the target by a multiple interaction of the incident proton within the nucleus. In the former case the FCP laboratory energy is primarily given by the p-nucleon CM velocity and the FCP emitted primarily in the forward direction. In the latter case, the FCP is produced in a much slower effective CM, hence large laboratory angles are possible. Figures 1-4 are Monte Carlo scatter plots of the production angles and momenta for several different scenarios. In order to take into account most possibilities, we have surrounded the target by tanks of liquid whose purpose is to slow, stop, and then collect all stable strongly-interacting particles. The dimensions of the collecting tanks were chosen to give a reasonable stopping power (typically 60% for "normal strength" strongly interacting particles). Figures 5-8 show the projected stopping percentages as a function of collecting tank radius and length as calculated from a Monte Carlo simulation for several different FCP masses and production schemes. The Monte Carlo assumptions are described in Appendix A.

Some theoretical biases would suggest that the FCP might have a stronger interaction than the typical hadron and thus a shorter range in matter. In addition, one should note that, by definition, a FCP cannot be produced singly. Presumably the other FCP will be produced asymmetrically so that one of the two will have a smaller laboratory velocity. Finally the FCP may be part of a larger nuclear fragment. In all these cases, the FCP might not be able to exit the target. We take this possibility into account by having the target itself made out of materials which can be analyzed by the bulk matter experiments.

Once stopped, a negatively charged FCP will cascade electromagnetically (like a negative muon) to its lowest energy state and form a stable fractionally charged atom (FCA). The final overall charge of the FCA is unknown since one or more electrons may have been shaken-off in the cascade which would result in an overall positively charged FCA. On the other hand a positively charged FCP may remain isolated, or attach an electron, or bind itself to one of the atoms or molecules in the liquid. As in the negative charge case the overall FCA charge may be plus or minus, but in both cases it will not be neutral. We exploit this feature in both of our concentration schemes. If an electric field is introduced in the liquid by charged wires the FCA will drift toward the appropriate polarity wire. As it nears the wire (at about 25 to 50 Angstroms) its image charge begins to have a significant attraction. Once at the surface of the wire the binding energy associated with the image charge is

an order of magnitude stronger than the thermal energy and therefore the FCA is fixed to the wire. In addition if the exchange of an electron occurs in this region (reversing the sign of the FCA), the image charge field strength will still be stronger than that of the external applied electric field thus holding the FCA to the wire. The second scheme involves distilling the collecting liquid itself (high purity mercury) into a much smaller amount (milligrams). Again the image charge prevents the FCA from leaving the mercury surface during the distillation process. This process also has the advantage of different systematics than the wire collection scheme.

Experimental Details

A sketch of the target and collection tank system is shown in figure 9.

The target is approximately one interaction length of total material (mainly lead) and located just between the first pair of upstream tanks. The material itself will be a combination of indium, copper, and lead. All provide large nuclear targets for central collisions. The materials will be formed into 2.5 cm diameter by 3 mm thick wafers. Each wafer is separated by a 3mm air gap which facilitates cooling but more importantly allows low-energy wide-angle particles to escape the target and enter the collection tanks. Indium and copper have been chosen since they can be used directly in the Livermore and Caltech bulk matter experiments respectively.

The collection tank system is composed of ten individual tanks, each 1.2 meters height by 1.2 meters length by 0.6 meter width, arranged in two rows of five tanks. These two rows are placed approximately 1/2 to 1 inch on either side of the center beam line . Each tank will be filled with Freon 113 ($C_2Cl_3F_3$), a room temperature liquid (freezing point -35.0 °C, boiling point +47.6 °C) . Its physical properties are given in appendix B. Of particular value is its density (1.57 g/cm^3).The total volume of liquid is 8.6 m^3 weighing 13.5 metric tons. Within each tank will be two vertical one-meter length wires of opposite polarity (5000 V). The specific wire material will be gold (LBL and SFSU), copper (Caltech and Toronto), tungsten (Rochester) and indium (Livermore). The electrode configuration is designed to give the most efficient FCP sweep out of the volume. The tanks will be constructed out of 10 gauge mild steel sheet. It will be necessary to provide atmospheric venting of the tanks to prevent any dangerous pressure buildup (and to keep the tank construction costs within reason). This may be done by connecting neoprene tubing from the tank vents to the outside environment.

Finally 200 kg of mercury (14 cm width by 14 cm height by 80 cm length) will be placed immediately after the last pair of downstream tanks, directly in line with the beam. Its purpose is to act as both target and stopping material. Concentration will be effected by distillation and the residue analyzed by the San Francisco State bulk matter experiment.

Collection and Analysis

A FCA formed in the collector tank will drift in an applied electric field. The drift velocity is given by the formula

$$v = fE ,$$

where f is the ion mobility. This quantity has been measured for both positive and negative ions in cyclohexane and 2,2,4-trimethylpentane [4]. We scale this value to Freon 113 by using the relative viscosities of the liquids. The value thus obtained is $5*10^{-4}$ $cm^2V^{-1}s^{-1}$. The maximum drift time in the collection tanks depends upon several quantities which will vary from tank to tank (such as wire diameter), but will be on the order of an hour assuming a 5000V potential on the collecting wires.

At the conclusion of the running period the high voltage will be removed from the wires and the wire assembly will be pulled from the tank and placed into its storage container. This process relies on the image charge holding the FCA to the wire and the fact that the fluid flow over the wire (as it is removed from the tank) is laminar. We are considering storing the wires at dry ice temperature which should enhance the retention over a period of time of the FCA on the wire (Freon 113 is a solid at this temperature). The individual wires will then be shipped to the bulk matter experiments.

The pieces of the upstream target will also be distributed to the bulk matter experiments when they have radioactively cooled enough to allow convenient handling and shipping.The downstream mercury target will be shipped to San Francisco State University to undergo distillation before analysis.

Within reasonable limits some other target materials can be incorporated to accommodate any additional bulk matter experimental groups who wish to participate in this experiment.

Beam Requirements

We request 10^{15} protons on target at the NE1 site. A rate of 10^{11} protons/beam pulse would allow a convenient one week run. We estimate a week setup and another week dismantling time. If approved the setup could take place during the 1984 summer-fall shutdown. Since the only interference to the beam are the targets, these could be easily inserted just before the run and removed immediately after. The beam spot should be as small as possible to enable the collection tanks to cover the small forward angles as well as the large angles.

Equipment Costs

1.	Ten collection tanks @ $1000	$10000
2.	13.42 metric tons Freon 113 @ $2.60/kg	$35100
3.	200 kg triply distilled Hg	$ 6000
4.	LeCroy 7kV high voltage supply	$ 8150
5.	VT100 terminal	$ 1900
6.	Miscellaneous equipment	$ 5000
	total	$66150

We expect that Fermilab would provide beam monitoring equipment as well as a modest amount of electronics (ie an oscilloscope, some Nim scalers, and a Nimbin).

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   D.Antreasyan et.al, Phys. Rev. Lett. 39, 513 (1977)
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   b. G.Hirsch, Lawrence Berkeley Laboratory and Hewlett-Packard
   c. C.D.Hendricks and C.Wuest, Lawrence Livermore Laboratory

   Accelerator experiments include:
   a. K.H.Chang et.al., University of Toronto
   b. D.Elmore et.al., University of Rochester
   c. R.McKeown et.al., California Institute of Technology
5. M.A.Lindgren et.al. ,Phys.Rev.Lett.51, 1621 (1983)
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Appendix A. Monte Carlo

The size of the collection tanks is estimated from the generation of FCP in the target. The production has been run for cases where the effective target mass has ranged from 1 Gev/c^2 (p-nucleon type interaction) to 100 Gev/c^2 (p-Nucleus "hot-core" type interaction). The FCP mass was allowed to vary from (0.5-10.0) Gev/c^2. The FCP was assumed to be produced isotropically in the center-of-mass (cm) with an average perpendicular momentum, $a=\langle k^2\rangle^{1/2}$ = 0.5 Gev/c. The distribution is

$$N(k)d^3k = Aexp(-k/a)k^2dkd\Omega.$$

The FCP is then followed allowing both strong and EM interactions with the liquid (density=1.5). The ionization loss is calculated from the Bethe-Block equation (assuming Q_{FCP} =1/3 e). The strong interactions are calculated by assuming cross sections of 20 (normal), 10, and 5 mb. Once the FCP interacts the energy loss is calculated by assuming the FCP populates uniformly a rapidity distribution of width no greater than 3 units. If the maximum rapidity is less than 3 units then the new rapidity ranges from 0 to the maximum. The rms perpendicular momentum is chosen =0.3 Gev/c for k>1 Gev/c, and =0.2 Gev/c for k<1 Gev/c. The FCP is assumed to be stopped if its velocity <.03c.

Appendix B. Physical properties of Freon 113

1,1,2-TRICHLORO-1,2,2-TRIFLUOROETHANE

DESCRIPTION – 1,1,2-Trichlorotrifluoroethane (denoted henceforth as TTE) is a water-white, noncorrosive, nonflammable, volatile liquid. TTE has little odor in low concentrations; in high concentrations, its odor is ethereal and similar to carbon tetrachloride. It is shipped as a liquid in drums and cans.

SPECIFICATIONS – TTE has a minimum purity of 99.0% with the following additional specifications:

Component	Specifications
Maximum water content	0.0025% (by wt.)
Maximum high-boiling impurities	0.05% (by vol.)
Chloride content	none

USES – TTE is used as a refrigerant, as a heat transfer medium, as a selective solvent for oils and gums, as an effective film processing solvent for both machine and hand use, and as an intermediate in the manufacture of chlorotrifluoroethylene.

TOXICITY – TTE has relatively low toxicity. It is considerably less toxic than carbon tetrachloride. It is classified according to the rating system devised by Underwriters' Laboratories as much less toxic than Group 4 (which includes methyl chloride and ethyl bromide) and somewhat more toxic than group 5 (which includes carbon dioxide and butane). However, prolonged breathing of the vapor should be avoided, and TTE should be used preferably in areas having adequate ventilation. Prolonged contact of TTE with the skin should be avoided, since it has a drying effect by dissolving the fats and oils from the skin. The 1968 American Conference of Governmental Industrial Hygienists has recommended a threshold limit value of 1000 p.p.m. for TTE (concentration in air to which nearly all workers may be exposed, day after day, without adverse affects).

PRECAUTIONS IN HANDLING AND STORAGE – Since TTE is a relatively nontoxic and nonflammable liquid of low vapor pressure, the usual precautions associated with the handling of compressed gases are not applicable. However, TTE should be handled in an adequately ventilated area. When the hands are to be exposed to liquid TTE for any extended period, it is desirable to wear rubber or neoprene gloves.

MATERIALS OF CONSTRUCTION – The commonly used metals, such as steel, cast iron, brass, copper, tin, lead, and aluminum, can be used satisfactory with TTE under normal conditions of use. At high temperatures, however, some of the metals may act as catalysts for the decomposition of TTE. The tendency of metals to promote thermal decomposition of TTE is in the following general order: (least decomposition) inconel < 18-8 stainless steel < nickel < copper < 1340 steel < aluminum < bronze < brass < silver (most decomposition).

Magnesium alloys and aluminum containing more than 2% magnesium are not recommended for use in systems containing TTE where water may be present. Zinc is not recommended for use with TTE.

Plastics and polymers, in general, are little affected by TTE.

Synthetic rubber such as Neoprene-GN or Hycar-OR-15 is essentially unaffected, although there is a small amount of swelling of natural rubber.

CYLINDER AND VALVE DESCRIPTION – TTE is supplied in D.O.T. approved drums. Drums have a ¾ inch I.P.S. female outlet.

RECOMMENDED CONTROLS – Because of the low pressure, it is recommended that the drum be used either with an ordinary globe or gate valve, or drum spigot valve.

SHIPPING REGULATIONS – TTE is shipped as a nonflammable chemical and does not require any D.O.T. shipping labels.

COMMERCIAL PREPARATION – Numerous fluorination procedures are described in the patent literature for the preparation of TTE, most of which concern catalytic fluorination of perhalo-olefins or alkanes with hydrogen fluroide. TTE has also been prepared by electrolysis of bromotrichloroethylene, lithium fluoride, and calcium fluoride in liquid hydrogen fluoride.

CHEMICAL PROPERTIES – TTE is nonflammable and nonexplosive at ordinary temperatures. The apparent ignition temperature is 1256°F., but the combustion is very weak and the flame does not propagate through the vapor-air mixture. The rate of hydrolysis of TTE in pure water at 86°F. and 1 atm. is 0.005 g./liter of water/year; its hydrolysis rate in water in the presence of steel at saturation pressure and 112°F. is 40 g./liter of water/year. With respect to thermal stability, a maximum temperature of 225°F. is recommended for continuous TTE exposure in the presence of oil, steel, and copper. The rate of decomposition of TTE at 400°F. in steel is 6% per year. In quartz, the temperature for the first trace of decomposition of TTE is at about 570°F. (at an exposure time of 30 seconds).

PHYSICAL DATA

Thermodynamic Data

See Tables 1 and 2.

VAPOR PRESSURE – Vapor pressures for TTE are given in Table 1 on Thermodynamic Properties of Saturated 1,1,2-Trichloro-1,2,2-trifluoroethane and the vapor pressure curve, Figure 1.

REFERENCES

[1] *The Thermodynamic Properties of "Freon-113"*, 1938, "Freon" Products Division, E.I. DuPont de Nemours & Co., reprinted by permission.

1,1,2-TRICHLORO-1,2,2-TRIFLUOROETHANE

(Synonyms: Freon-113®, Genetron-113®, Isotron-113®, and Ucon-113®)

[Formula: CCl_2FCClF_2]

PHYSICAL CONSTANTS

Molecular Weight	187.38
Vapor Pressure @ 70° F.	5.5 p.s.i.a. (0.39 kg./cm.^{2} absolute)
Boiling Point @ 1 atm.	117.7° F. (47.6° C.)
Freezing Point @ 1 atm.	−31.0° F. (−35.0° C.)
Density, Gas @ b.p.	7.38 g./l.
Density, Liquid @ 30° C.	1.553 g./ml.
Critical Temperature	417.4° F. (214.1° C.)
Critical Pressure	495.4 p.s.i.a. (33.7 atm.) (34.8 kg./cm.^{2} absolute)
Critical Density	0.576 g./ml.
Specific Heat, Liquid @ 30° C.	0.218 cal./(g.) (° C.)
Specific Heat, Gas @ 60° C., 1 atm., *Cp*	0.161 cal./(g.) (° C.)
Specific Heat Ratio, Gas @ 60° C., 1 atm., *Cp/Cv*	1.080
Latent Heat of Vaporization @ b.p.	35.07 cal./g.
Refractive Index, n_D^{25}	1.354
Thermal Conductivity @ 30° C.	
Liquid	0.0_3215 cal./(sec.) (cm^2.) (° C./cm.)
Gas, 0.5 atm.	0.0_4186 cal./(sec.) (cm^2.) (° C./cm.)
Viscosity @ 30° C.	
Liquid	0.619 centipoise
Gas, 0.1 atm.	0.0104 centipoise
Surface Tension @ 25° C.	19 dynes/cm.
Relative Dielectric Strength @ 23° C., 0.4 atm. (N_2 = 1)	2.6
Dielectric Constant, Liquid @ 30° C.	2.44
Solubility in Water @ 25° C., @ Saturation Pressure	0.017% (by weight)
Solubility in Water in Freon-113	
@ 30° C.	0.013% (by weight)
@ 0° C.	0.0036% (by weight)

TRADEMARKS®

Freon-113® – E.I. duPont de Nemours and Co., Inc.

Genetron-113® – General Chemical Division, Allied Chemical Corp.

Isotron-113® – Pennsalt Chemical Corp.

Ucon-113® – Union Carbide Corp.

Table 1. THERMODYNAMIC PROPERTIES OF SATURATED 1,1,2-TRICHLORO-1,2,2-TRIFLUOROETHANE[1]

Temp. °F.	Pressure p.s.i.a.	Specific Volume Liquid cu. ft./lb.	Specific Volume Vapor cu. ft./lb.	Enthalpy (Base -40°F.) Liquid BTU/lb.	Enthalpy (Base -40°F.) Vapor BTU/lb.	Latent Heat BTU/lb.	Entropy (Base -40°F.) Liquid BTU/(lb.)(°F.)	Entropy (Base -40°F.) Vapor BTU/(lb.)(°F.)	Temp. °F.
-30	0.2987	0.00947	82.26	1.97	74.65	72.68	0.0047	0.1738	-30
-20	0.4288	0.00953	58.61	3.96	76.05	72.09	0.0092	0.1732	-20
-10	0.6046	0.00959	42.48	5.96	77.47	71.51	0.0137	0.1728	-10
0	0.8377	0.00966	31.31	7.98	78.89	70.92	0.0182	0.1725	0
10	1.142	0.00972	23.45	10.00	80.32	70.32	0.0225	0.1723	10
20	1.534	0.00979	17.81	12.03	81.75	69.72	0.0268	0.1722	20
30	2.031	0.00987	13.71	14.08	83.20	69.12	0.0310	0.1722	30
40	2.655	0.00994	10.68	16.16	84.65	68.50	0.0352	0.1723	40
50	3.427	0.01002	8.426	18.24	86.11	67.87	0.0393	0.1725	50
60	4.374	0.01010	6.713	20.35	87.57	67.22	0.0434	0.1728	60
70	5.523	0.01018	5.404	22.48	89.04	66.56	0.0475	0.1731	70
80	6.902	0.01026	4.392	24.63	90.51	65.88	0.0515	0.1736	80
90	8.545	0.01035	3.600	26.80	91.98	65.18	0.0555	0.1741	90
100	10.48	0.01044	2.976	28.99	93.45	64.46	0.0594	0.1746	100
110	12.76	0.01053	2.477	31.22	94.93	63.71	0.0634	0.1752	110
120	15.40	0.01063	2.078	33.48	96.41	62.93	0.0673	0.1758	120
130	18.45	0.01073	1.754	35.75	97.89	62.14	0.0712	0.1765	130
140	21.93	0.01083	1.491	38.05	99.36	61.31	0.0750	0.1773	140
150	25.93	0.01094	1.273	40.38	100.82	60.44	0.0789	0.1780	150
160	30.44	0.01105	1.094	42.74	102.29	59.55	0.0827	0.1788	160
170	35.53	0.01116	0.9442	45.12	103.74	58.62	0.0865	0.1796	170
180	41.22	0.01128	0.8193	47.53	105.19	57.66	0.0903	0.1804	180
190	47.60	0.01140	0.7134	49.97	106.63	56.66	0.0940	0.1813	190
200	54.66	0.01153	0.6241	52.45	108.07	55.62	0.0978	0.1821	200
210	62.50	0.01166	0.5477	54.96	109.50	54.54	0.1015	0.1830	210
220	71.07	0.01179	0.4827	57.49	110.92	53.43	0.1052	0.1839	220

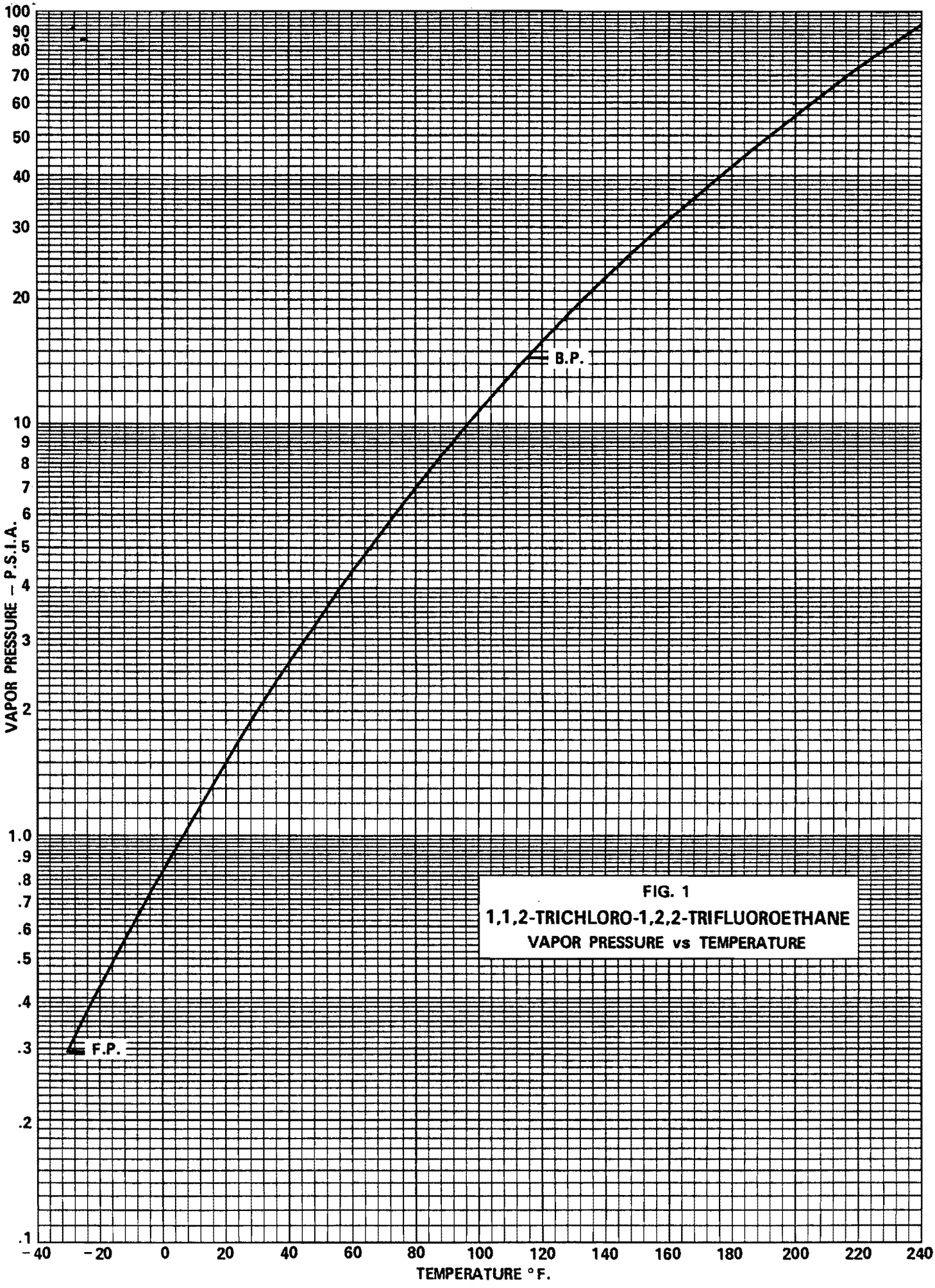


FIG. 1

1,1,2-TRICHLORO-1,2,2-TRIFLUOROETHANE

VAPOR PRESSURE vs TEMPERATURE

Figure Captions

Fig.(1-4) Scatter plots of FCP production angle (degrees) vs FCP laboratory momentum (GeV/c).

Fig.(5-8) Stopping positions of FCPs for various assumptions of FCP mass and the effective target mass. In all cases we have assumed a normal strength strong interaction. For the (a) figures the radial coordinate has been integrated to 1.2 meters, while for the (b) figures the length coordinate has been integrated to 10 meters. Since there is only a weak correlation between the radial and length coordinates, an approximate efficiency for intermediate detector sizes may be easily inferred from these graphs.

Fig. 9 Schematic representation of the experimental apparatus. The tanks are filled with Freon 113 (a room temperature liquid). The "+" and "-" refer to the polarity of the high voltage collection wires (not shown in side view). The target is located just within the first pair of upstream tanks and is made up of lead, indium, and copper pieces in approximately the shape shown. Not shown is the downstream mercury target (approximately a 10 cm cube) which serves as an additional target and collection tank. This will be placed just after the last two downstream collection tanks.

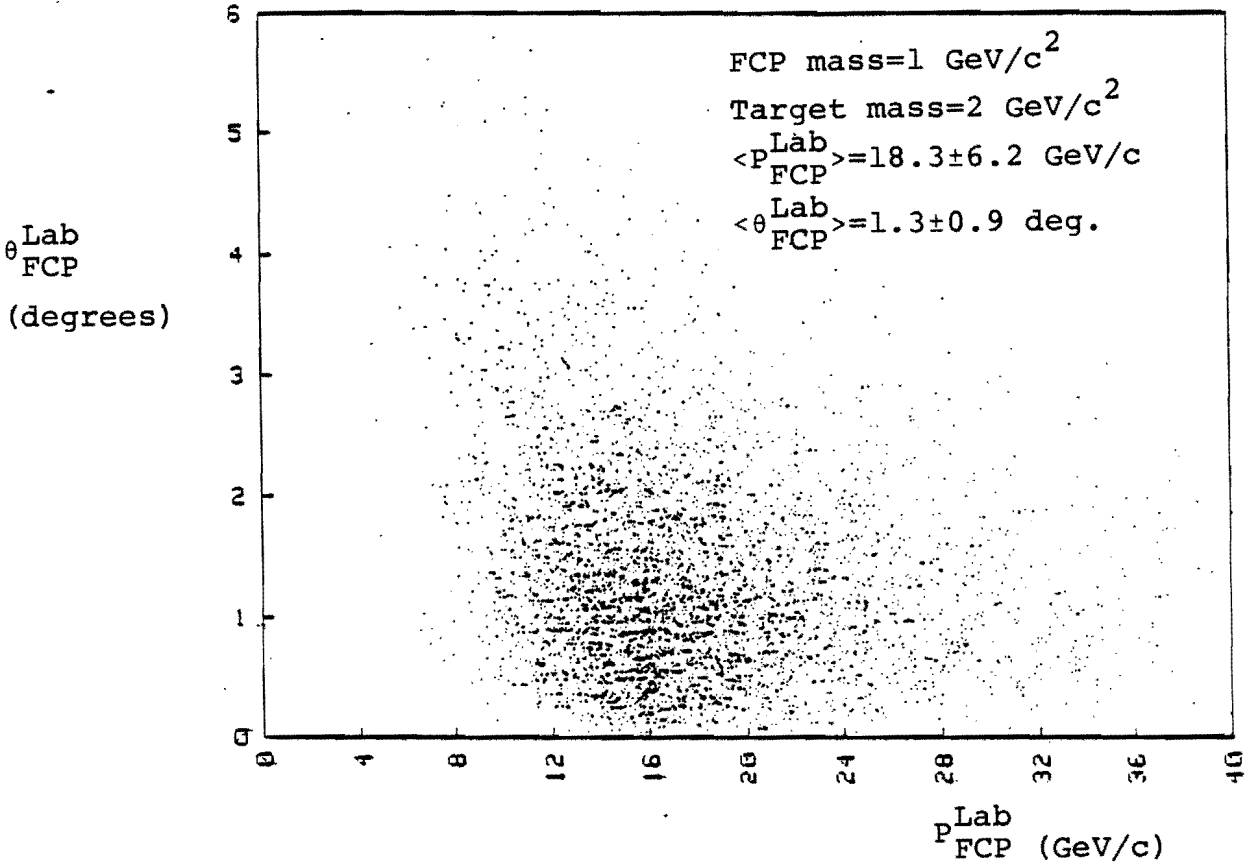

FCP mass=1 GeV/c^2
Target mass=2 GeV/c^2
$\langle P^{Lab}_{FCP} \rangle$=18.3±6.2 GeV/c
$\langle \theta^{Lab}_{FCP} \rangle$=1.3±0.9 deg.
θ^{Lab}_{FCP} (degrees)
P^{Lab}_{FCP} (GeV/c)

Fig.1

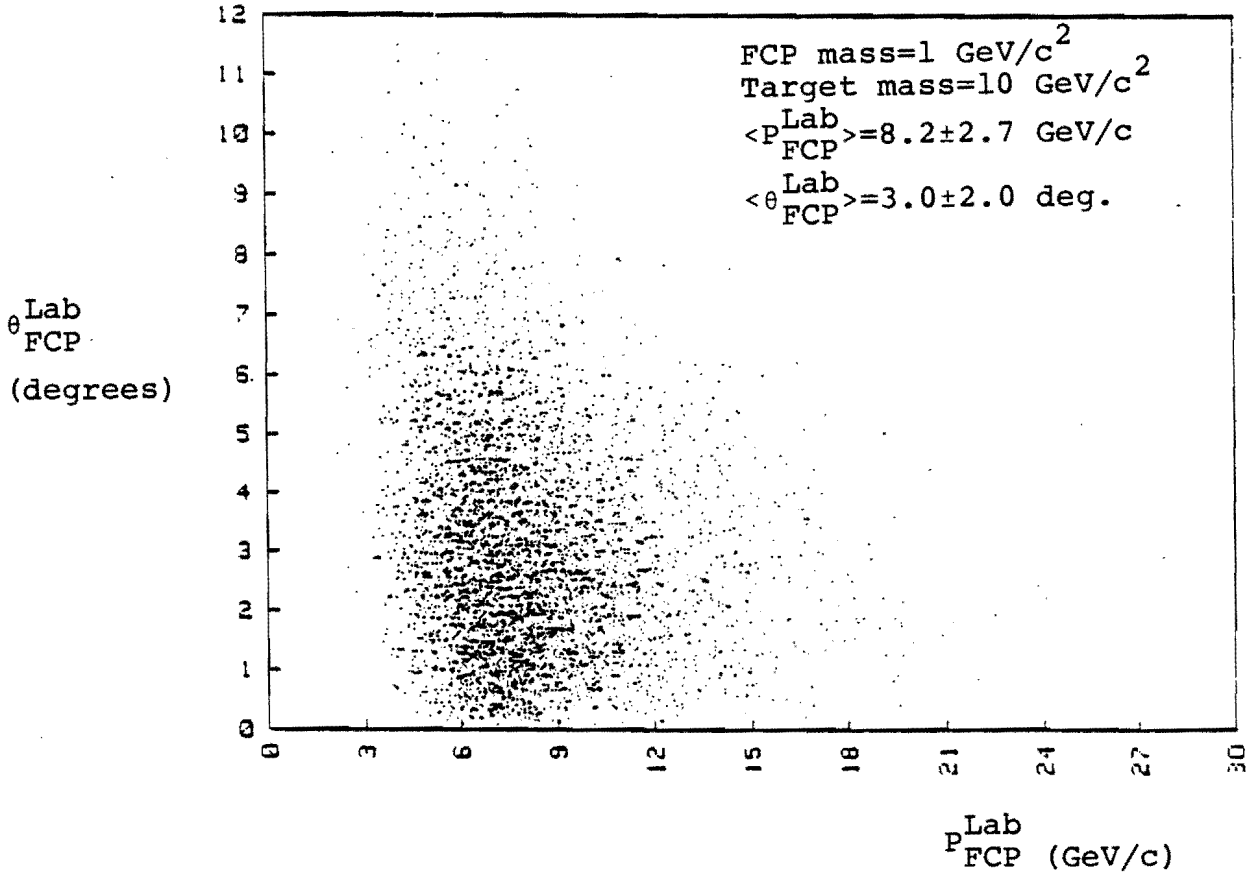

FCP mass=1 GeV/c^2
Target mass=10 GeV/c^2
$\langle P^{Lab}_{FCP} \rangle$=8.2±2.7 GeV/c
$\langle \theta^{Lab}_{FCP} \rangle$=3.0±2.0 deg.
θ^{Lab}_{FCP} (degrees)
P^{Lab}_{FCP} (GeV/c)

Fig.2

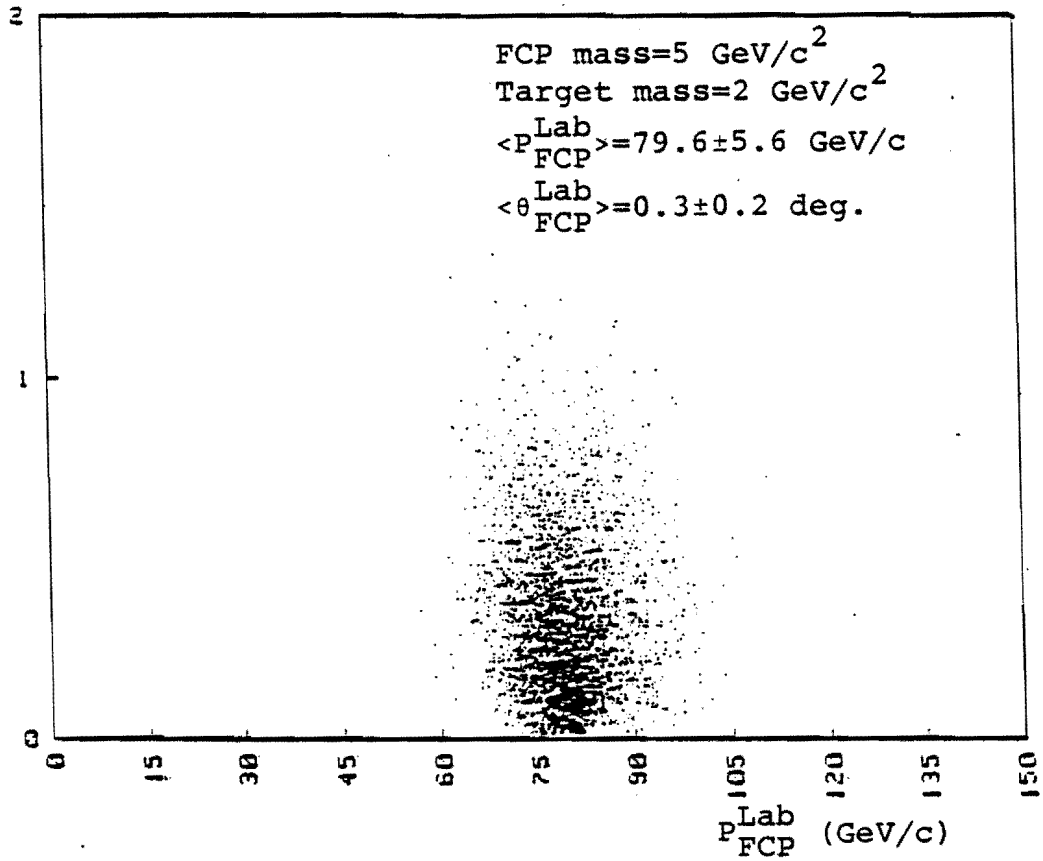

FCP mass=5 GeV/c^2
Target mass=2 GeV/c^2
<P^{Lab}_{FCP}>=79.6±5.6 GeV/c
<θ^{Lab}_{FCP}>=0.3±0.2 deg.
θ^{Lab}_{FCP} (degrees)
P^{Lab}_{FCP} (GeV/c)
0
1
2
0
15
30
45
60
75
90
105
120
135
150

Fig.3

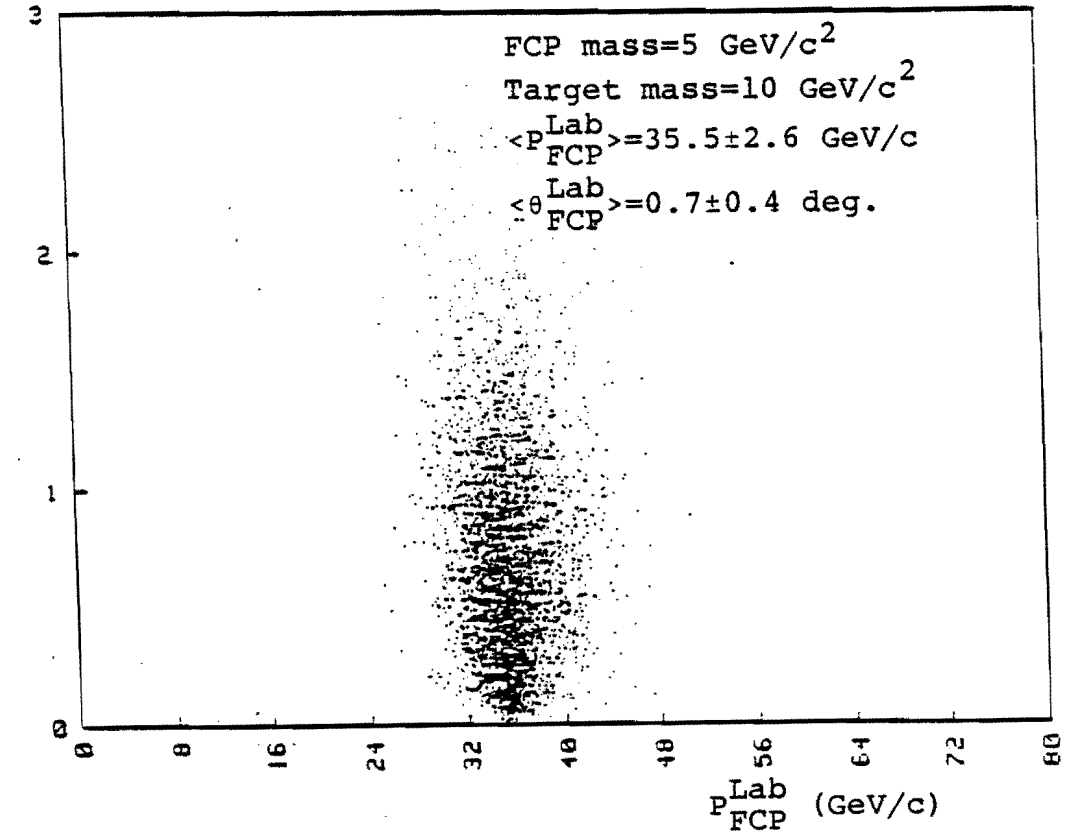

FCP mass=5 GeV/c^2
Target mass=10 GeV/c^2
<P^{Lab}_{FCP}>=35.5±2.6 GeV/c
<θ^{Lab}_{FCP}>=0.7±0.4 deg.
θ^{Lab}_{FCP} (degrees)
P^{Lab}_{FCP} (GeV/c)
0
1
2
3
0
8
16
24
32
40
48
56
64
72
80

Fig.4

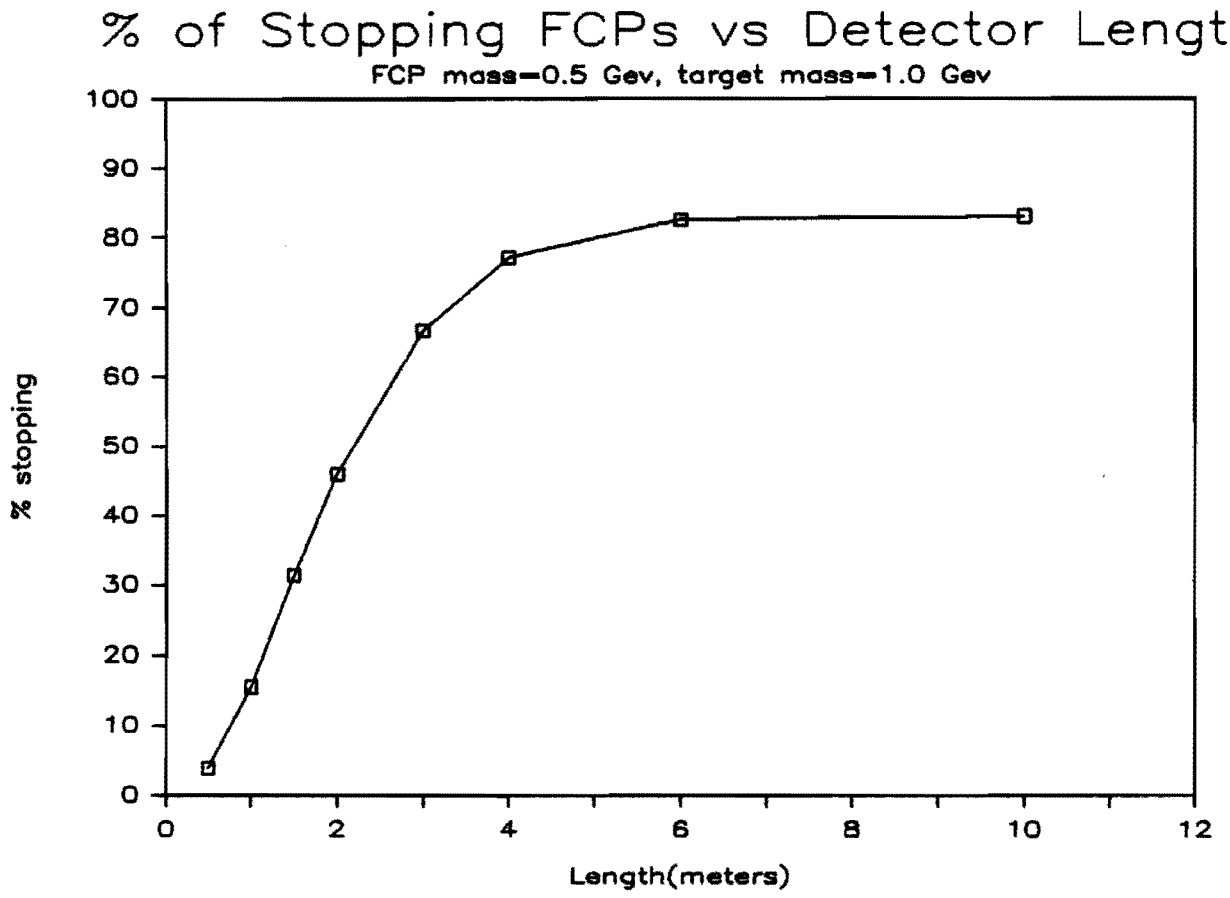

% of Stopping FCPs vs Detector Length
FCP mass=0.5 Gev, target mass=1.0 Gev
% stopping
Length(meters)
0
10
20
30
40
50
60
70
80
90
100
0
2
4
6
8
10
12

Fig.5a

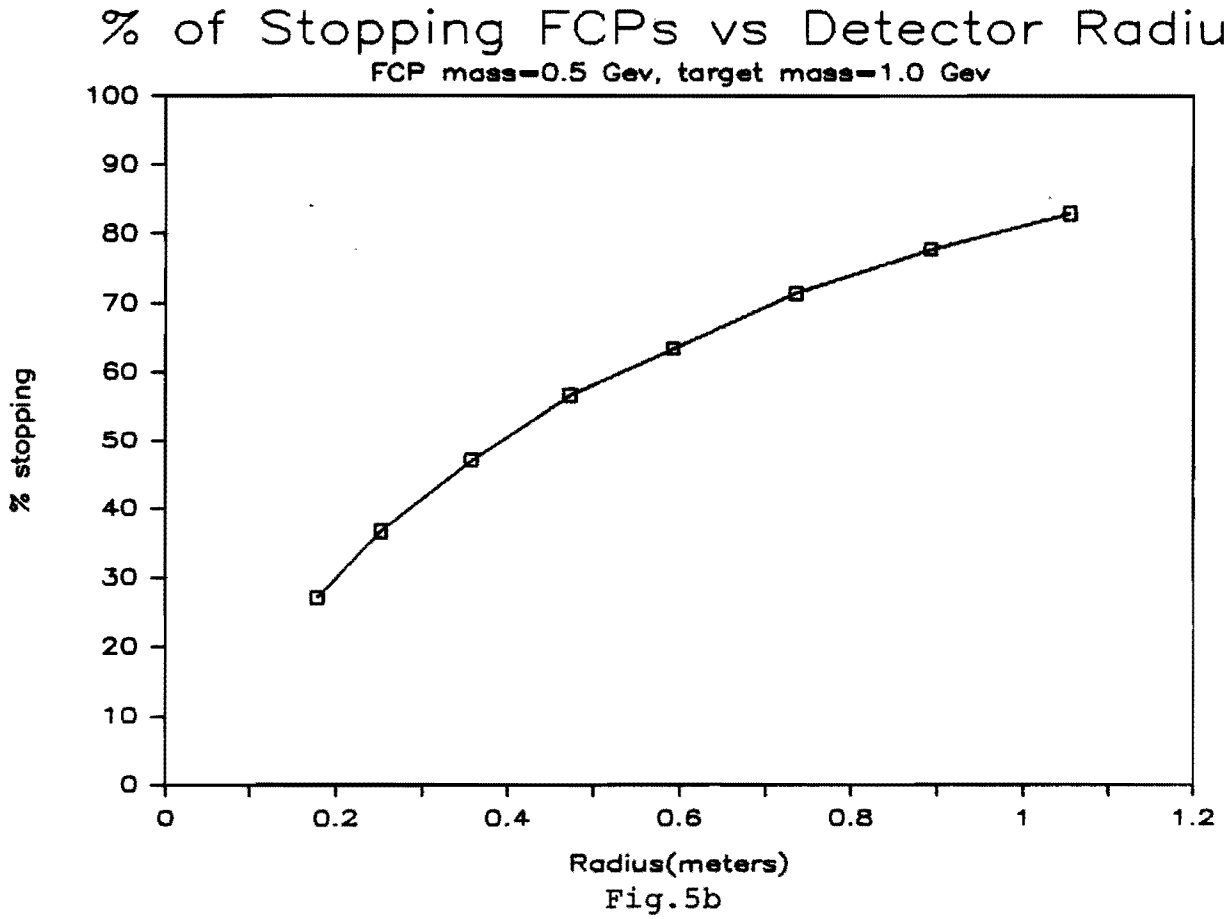
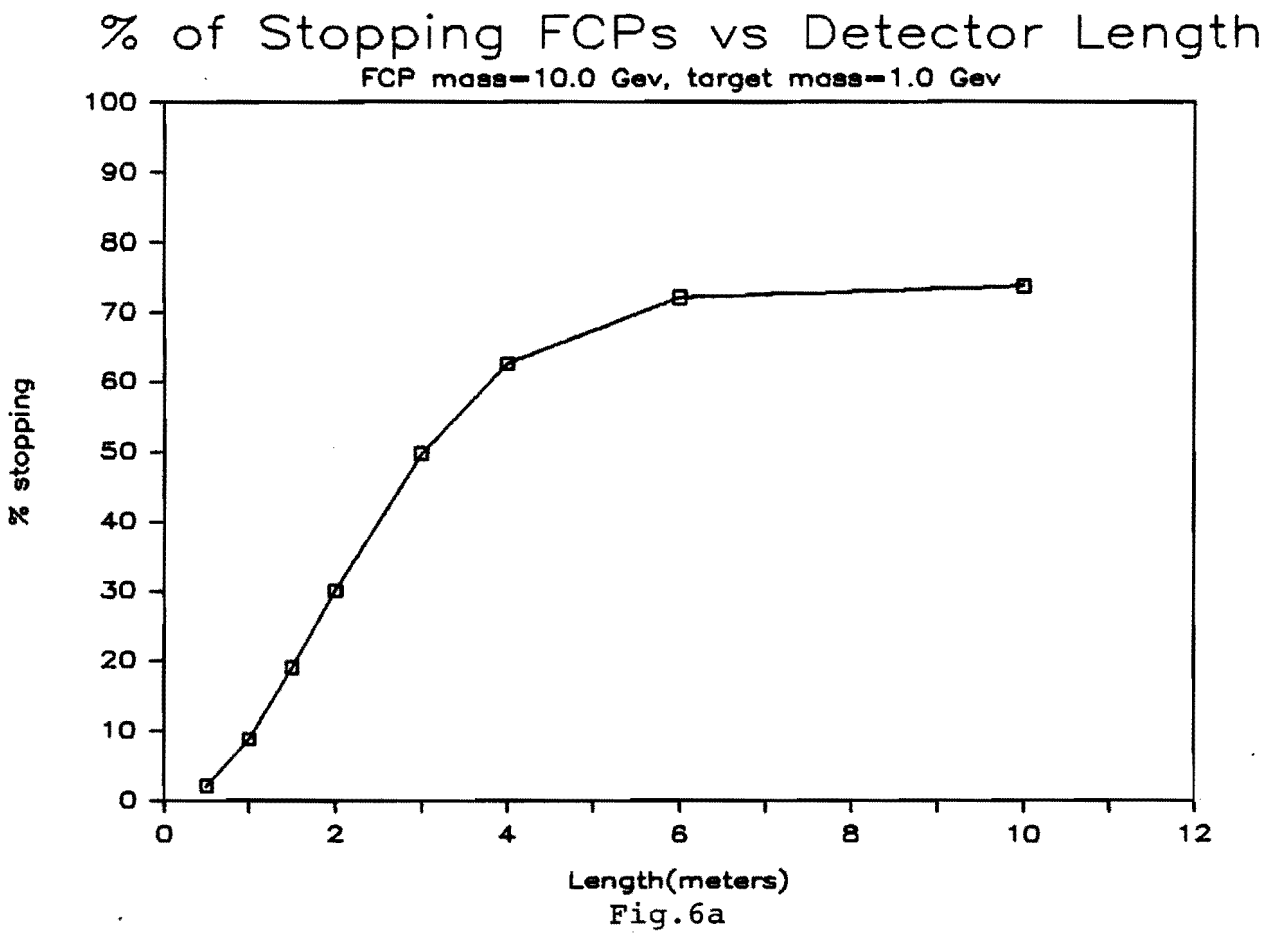
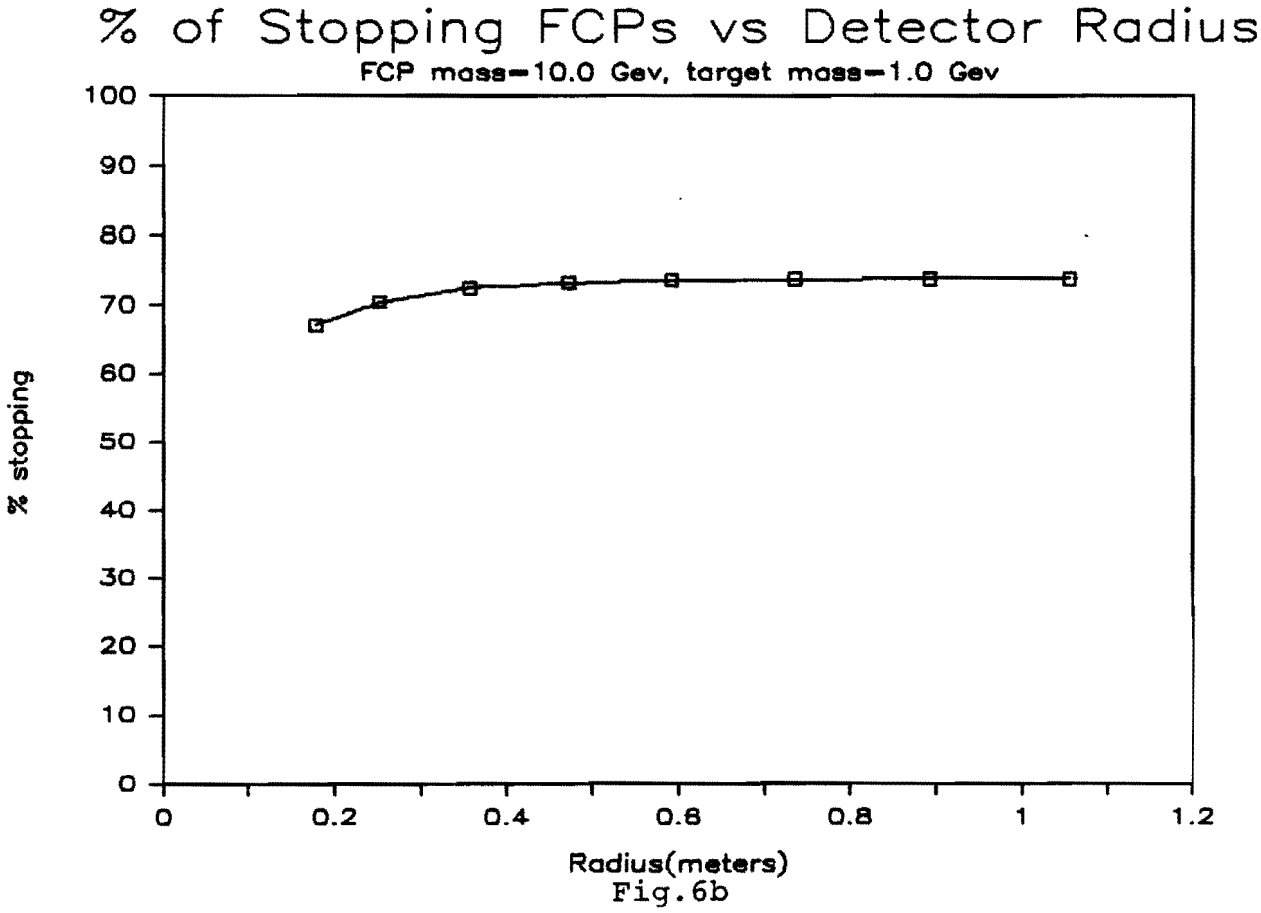

% of Stopping FCPs vs Detector Radius
FCP mass=0.5 Gev, target mass=1.0 Gev
% stopping
Radius(meters)
0
10
20
30
40
50
60
70
80
90
100
0
0.2
0.4
0.6
0.8
1
1.2

Fig.5b


% of Stopping FCPs vs Detector Length
FCP mass=10.0 Gev, target mass=1.0 Gev
% stopping
100
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10
12
Length(meters)
Fig.6a


% of Stopping FCPs vs Detector Radius
FCP mass=10.0 Gev, target mass=1.0 Gev
% stopping
100
90
80
70
60
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
1
1.2
Radius(meters)
Fig.6b

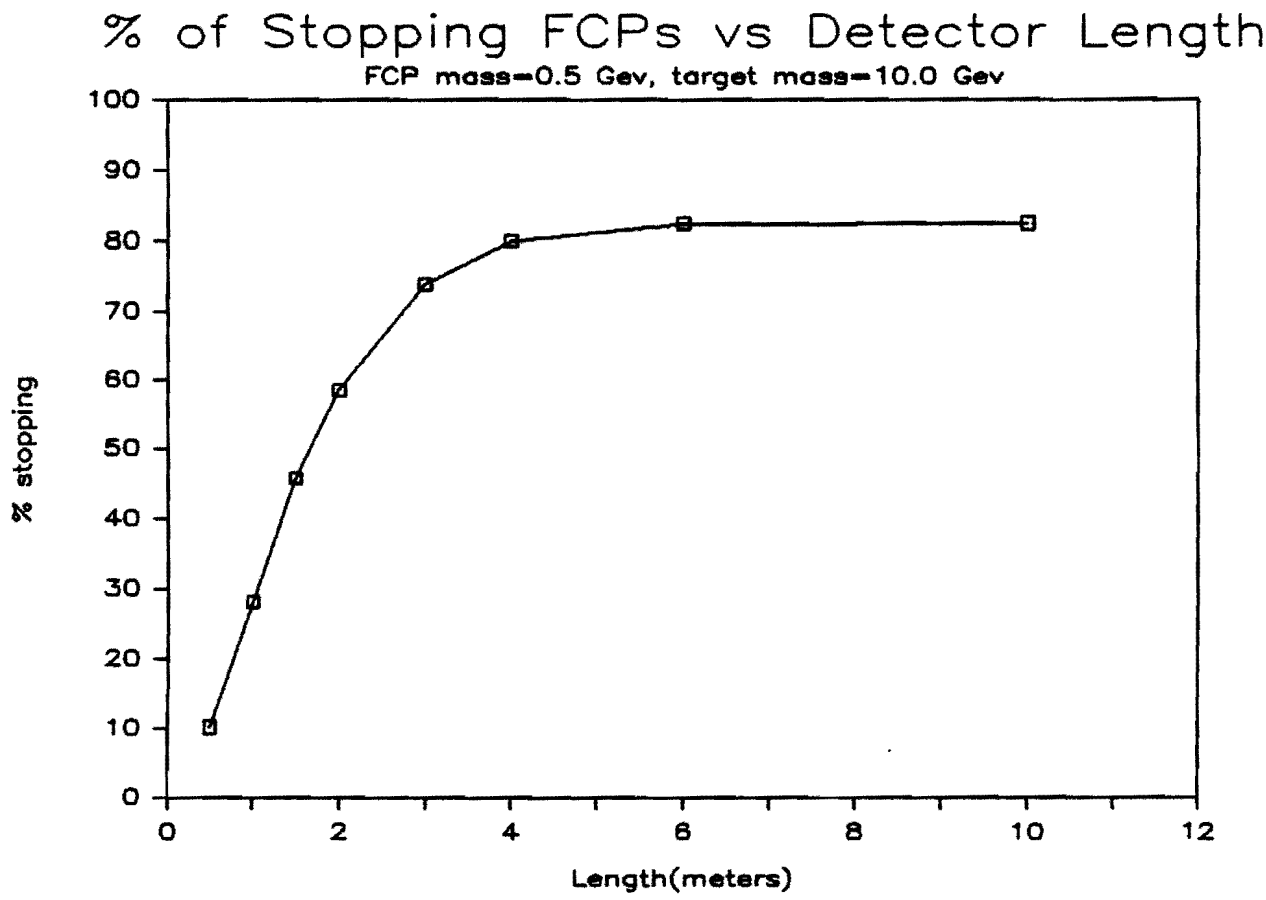

% of Stopping FCPs vs Detector Length
FCP mass=0.5 Gev, target mass=10.0 Gev
% stopping
100
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10
12
Length(meters)

Fig.7a

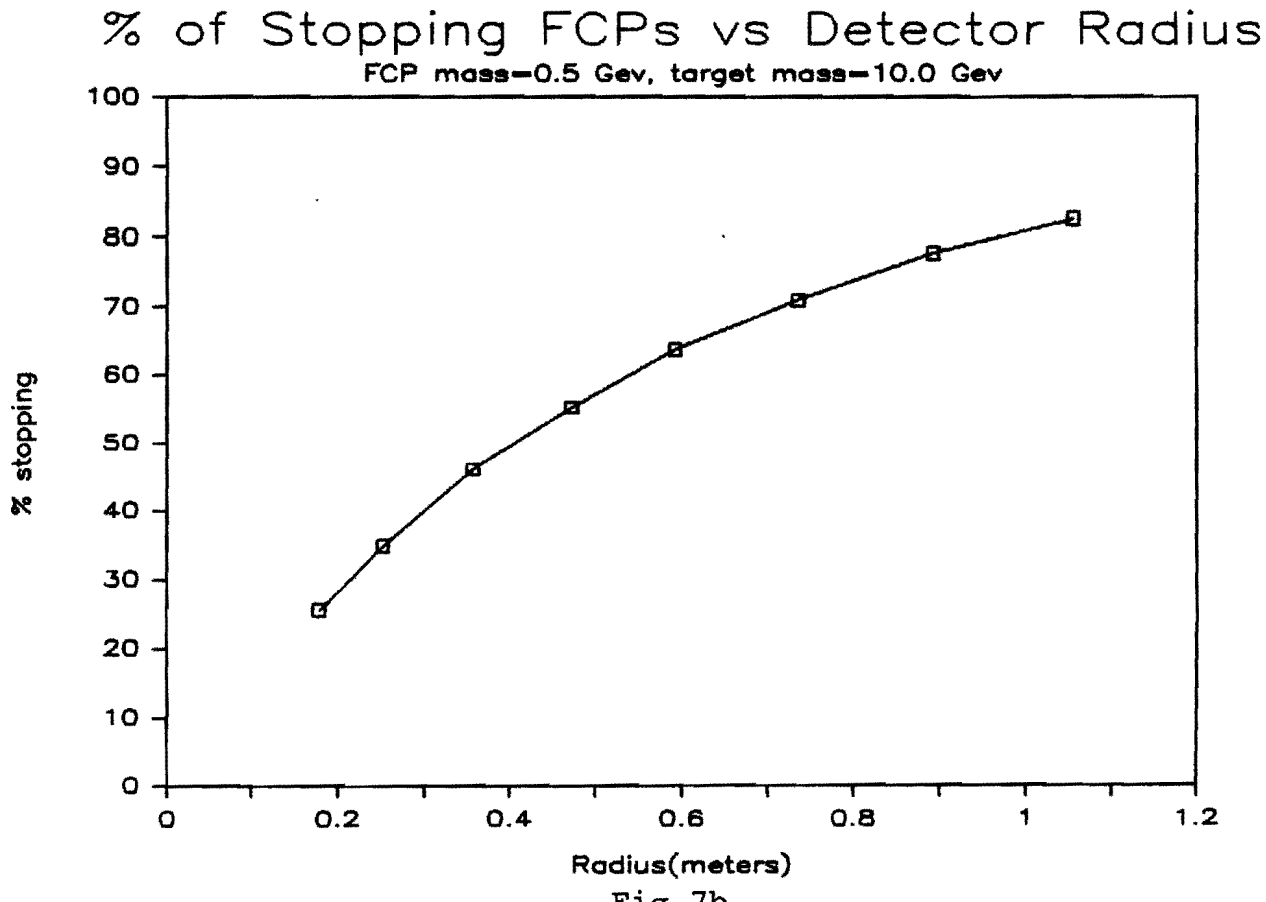

% of Stopping FCPs vs Detector Radius
FCP mass=0.5 Gev, target mass=10.0 Gev
% stopping
100
90
80
70
60
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
1
1.2
Radius(meters)

Fig.7b

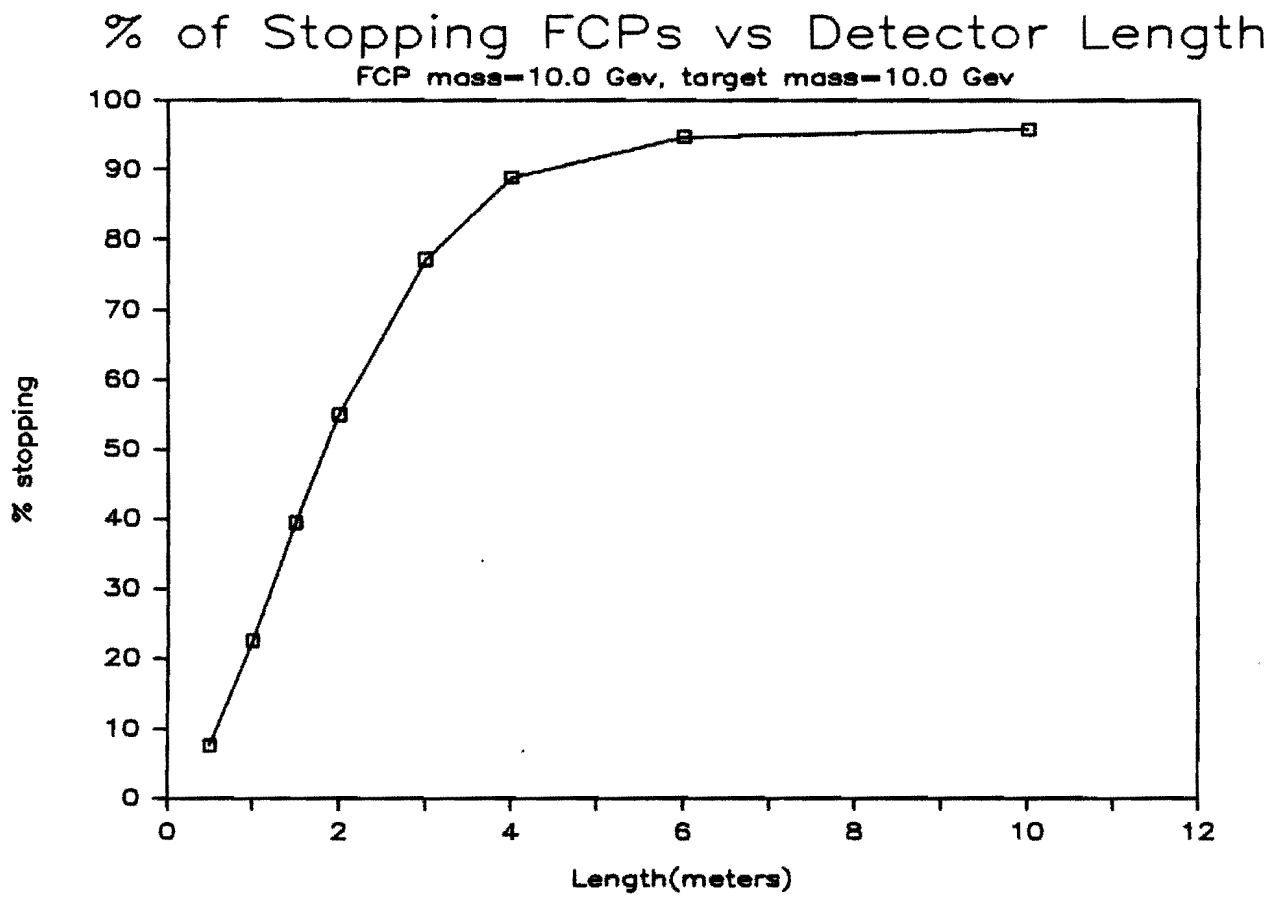

% of Stopping FCPs vs Detector Length
FCP mass=10.0 Gev, target mass=10.0 Gev
% stopping
Length(meters)
0
10
20
30
40
50
60
70
80
90
100
0
2
4
6
8
10
12

Fig.8a

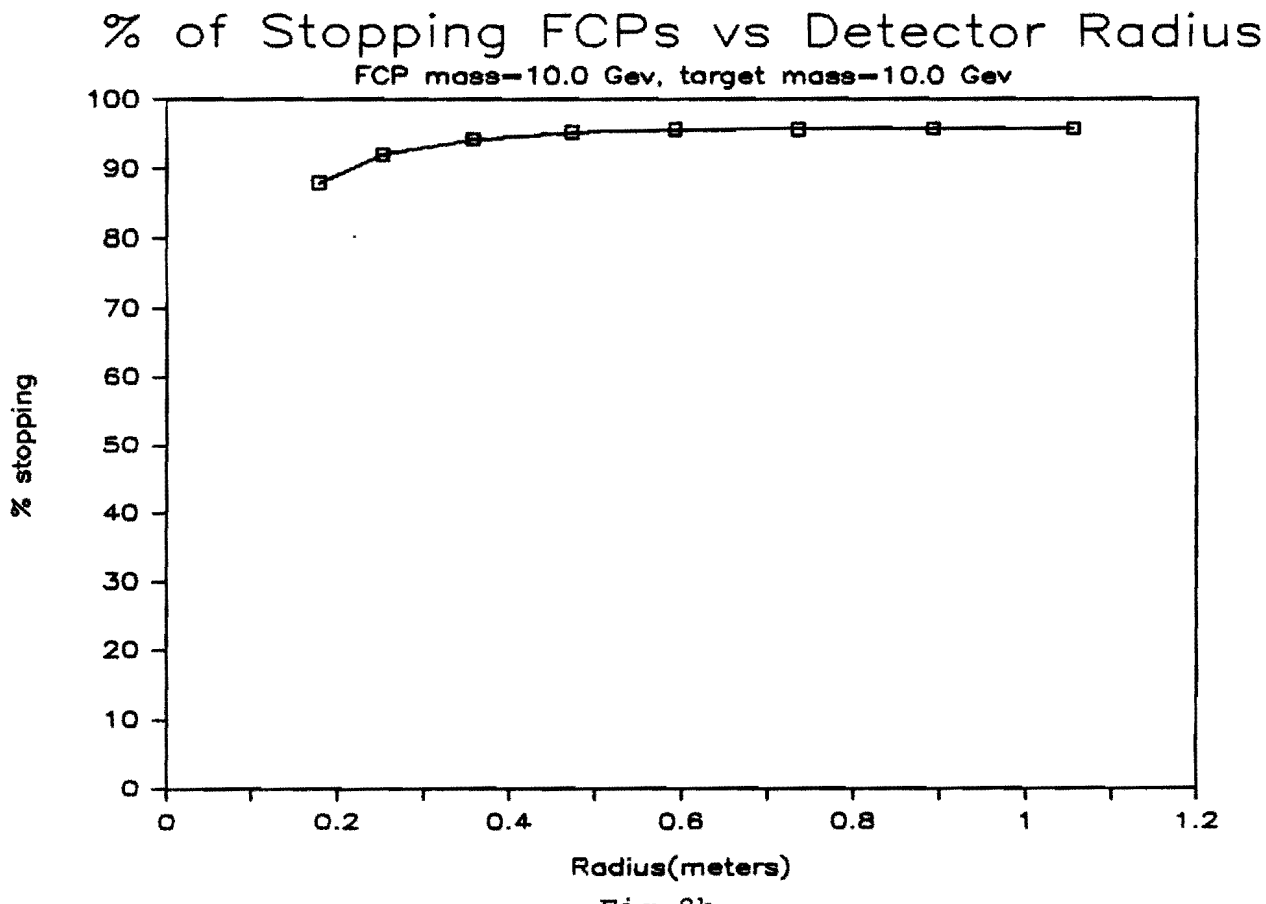

% of Stopping FCPs vs Detector Radius
FCP mass=10.0 Gev, target mass=10.0 Gev
% stopping
Radius(meters)
0
10
20
30
40
50
60
70
80
90
100
0
0.2
0.4
0.6
0.8
1
1.2

Fig.8b

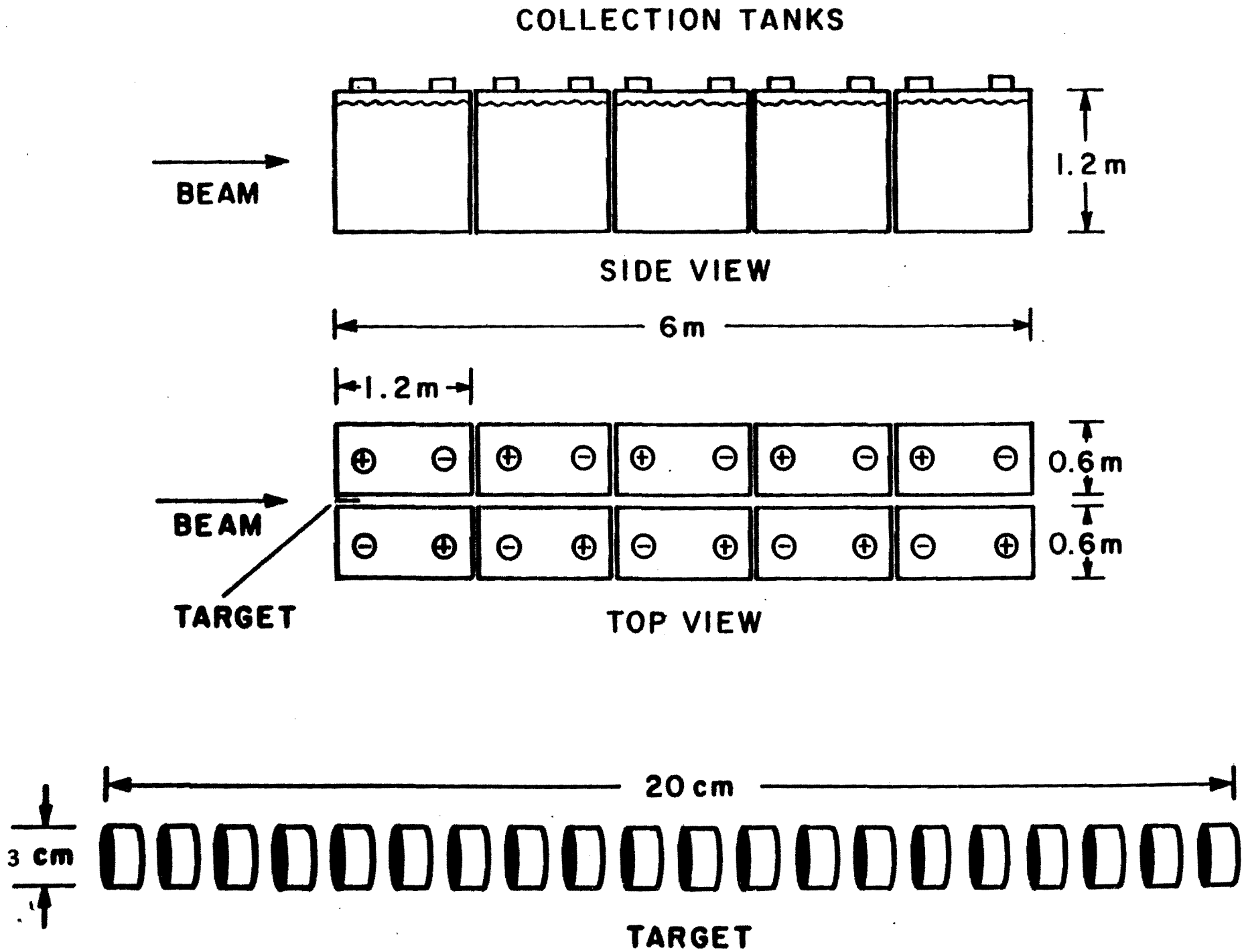

COLLECTION TANKS
BEAM
1.2 m
SIDE VIEW
6m
1.2m
0.6m
0.6m
BEAM
TARGET
TOP VIEW
20 cm
3 cm
TARGET

Fig.9