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SOLENOIDAL DETECTOR NOTES

RAY TRACING STUDY FOR MAGNET STYLE SELECTION

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Ray Tracing Study for Magnet Style Selection

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1. Introduction

In order to evaluate the calorimeter performance, it is best to simulate EM and hadronic showers and eventually relate the simulation results to the physics goals. However, these simulations require fair amount of computing time. A much simpler method, ray-tracing, was introduced by M.Strovink et al.[1] This method is extremely useful to pin-point cracks, dead material as well as calorimeter depth, all of which are intimately related to the calorimeter performance. One of us (Asai) has developed a program of ray-tracing in the framework of widely-used Geant. Once one enters input parameters for any kind of detector geometries according to the Geant, the program calculates integral and differential radiation length as well as absorption length on a straight line specified by η and ϕ. We have used this program to ray-trace four possible calorimeter configurations in order to evaluate the magnet style dependence on calorimetry.

2. Calorimeter configurations

In the present study, four different cases are considered depending on calorimeter types and magnet styles:

	Solenoid style	Calorimeter type
Case-1	long	non-LA
Case-2	long	LA
Case-3	short	non-LA
Case-4	short	LA

where LA stands for liquid argon calorimeter and non-LA includes rest of calorimeter types, warm-liquid, scintillating plate and scintillating fiber calorimeters. This is because it is known from on-going design studies on liquid argon calorimeter that non-negligible amount of space and material is required in front of active calorimeter region for cryostat. It is not clear how much material and space are necessary in the case of other calorimeter types at present. We assumed no space and zero materials in front of active region, as an extreme case.

The actual geometry of calorimeter for each case is determined according to the following guidelines ;

1. inner tracking volume : r = 1.85m, half z length = 4.5m,
2. coil thickness : 35cm physical and 1.15 radiation length,
3. calorimeter depth : > $25X_0$ for EM and >9 λ_0 for total,
4. space for cabling and/or tracker support :
   - long solenoid : 10cm filled with Al-equivalent material of average density of 1.0g/cm^3,
   - short solenoid : 20cm filled with Al-equivalent material of average density of 0.5g/cm^3,
5. calorimeter material and density

	EM part	Had part
non-LA type :	Pb 95.6%	Pb 97.8%
	Scintillator 4.4%	Scintillator 2.2%
	$\langle\rho\rangle$ = 7.9 g/cm^3	$\langle\rho\rangle$ = 9.3 g/cm^3
LA type :	Pb 81%	Pb 93%
	Argon 19%	Argon 7%
	$\langle\rho\rangle$ = 4.8 g/cm^3	$\langle\rho\rangle$ = 7.5 g/cm^3.

6. Thickness and density of liquid argon cryostat
   - Case-2 : 10 cm thick, $\langle\rho\rangle$ = 1.6 (barrel), 1.0 (endcap)
   - Case-4 : 10 cm thick, $\langle\rho\rangle$ = 1.6 (barrel inner face)

12 cm thick, $\langle\rho\rangle = 1.6$ (barrel endplates)
17 cm thick, $\langle\rho\rangle = 1.6$ (endcap front face).

These numerical numbers specified here are inferred either from existing experience on CDF, VENUS and other detectors and/or from currently going calorimeter design.

Figs.1-4 show the cross sections of the detector quadrant in the z-r plane. Although some of detector details are somewhat drawn arbitrarily, the main geometries are of natural consequence of the guidelines stated above.

3. Calorimeter shape and weight

It is clear from Figs.1-4 that there is a distinct difference in calorimeter shape. In the case for long solenoid, the barrel calorimeter must be stretched out to >8.5 m in half length in order to maintain the required calorimeter depth, while the endcap calorimeter can be compact and small. The length of barrel calorimeter has an impact on the dimensions of the muon system as well as the accessibility to inside. We have calculated weight of calorimeter for each case;

	Case-1	Case-2	Case-3	Case-4
barrel calorimeter	4194 t	4902 t	2742 t	2914 t
end calorimeter	2 x 374 t	2 x 137 t	2 x 907 t	2 x 1100 t
total weight	4856 t	5176 t	4556 t	5114 t

It is noted that, in spite of the stretched shape of calorimeter for long solenoid, total weights of the calorimeter are surprisingly close to those of short coil. The difference is at most 300 tons. Other features that manifest significant differences between two styles are as follows:

	short solenoid	long solenoid
1. barrel calorimeter	9 m long	≥ 17 m long
2. endcap/plug calorimeter	~ 8m high	small and compact
3. barrel muon system	~ 8.5m long	~ 10m long
4. movement for access	1~2m	≥ 5m

5. inner tracker support	short and radial	long and cylindrical
6. cabling	radial at z =4.5m	axial along the coil
7. magnetic field (barrel)	0 or < 1T	0
8. magnetic field (endcap/plug)	2T or <1T	2T

These differences arise from the calorimeter geometries and the way of magnetic flux return. Although it is difficult to make any "definitive" preference from the list shown above, especially since details depend on calorimeter technology, one can say that the short coil is favored in items 1,3,4,5 and 6, while the long type has advantages in items 2 and 7. Therefore in general, the short type is favored as far as calorimeter geometry is concerned.

4. Ray-tracing results

By inserting all the relevant input parameters into Geant, we get Geant pictures as shown in Fig.5 for Case-3. The inner tracking part is based on silicon-wire EoI configuration. Intermediate angle trackers are assumed to consist of 6 straw superlayers. One of immediate output from the present ray tracing program is the radiation thickness of inner tracking system as shown in Fig.6. Note that tracker support structure is yet to be included in this calculation.

Figs.7-10 are the plots of the radiation thickness as a function of pseudo-rapidity. The plots indicate accumulated radiation length from the interaction point. It is better to have less radiation thickness in front of active EM calorimeter for better energy resolution and for better electron identification. Qualitatively, however, it is known that there is no significant degradation of energy resolution even with a few radiation length in front of the EM calorimeter. With a special massless gaps, it is possible to apply a correction to recover lost energy in front material up to about $5X_0$ with moderate energy resolution[2]. As a measure for evaluation, we take a rapidity interval in which the thickness of front material exceeds $3X_0$ (gray EM area) and $5X_0$ (bad EM area).

	case-1	case-2	case-3	case-4
type	long,nonLA	long,LA	short,nonLA	short,LA
gray EM area	0.1	0.8	0.1	0.45
bad EM area	0.0	0.2	0.0	0.15

Figs.11-14 are similar plots in terms of absorption length. One can see distinct differences in the rapidity region in which the barrel to endcap(plug) transition occurs, η~1.2-1.4 for short magnet while ~1.7-2.0 in the case of long type. If the central region is dominantly important relative to the end (intermediate angle) region, long magnet is preferred due to uniform calorimeter up to η~1.75. On the other hand, if energy measurement up to η of 3 is required for hermeticity for example, then the difference of break position does not matter. For the sake of evaluation, we take two measures in this case. One is the total area of dead material (in unit of $\eta \times \lambda_0$) in the first 5 interaction length. The other is the rapidity interval in which total dead material exceeds $1\lambda_0$ inside the region of first 5 interaction length.

	case-1	case-2	case-3	case-4
type	long, nonLA	long, LA	short, nonLA	short, LA
dead area*	0.85	1.91	0.69	1.23
bad region+	0.14	0.55	0.0	0.32

(* in unit of $\eta \times \lambda_0$, + in unit of η)

It is clear from these measures for EM as well as hadronic calorimetry that case-2 is the worst and case-4 is the 2nd worst. In this note we are comparing not calorimeter types (LA vs non-LA) but magnet styles (long vs short). Calorimeter must be chosen by considering many other factors in addition to the present ray tracing results. Therefore our conclusion on style preference is

non-LA case : short magnet is preferred (case-3 better than case-1)
LA case : short magnet is preferred (case-4 better than case-2)

according to above four criteria. Whatever the calorimeter type is, short solenoid is preferred.

5. Summary

A ray-tracing program is developed in the framework of Geant. We have used this program to perform ray-tracing the possible calorimeters in order to evaluate the magnet style dependence on calorimetry.

Based on EoI geometry, two magnet styles, long and short, are combined with two different calorimeter technologies, liquid argon and non-liquid argon, resulting four different calorimeter-magnet configurations. We have compared differences in various aspects that arise from difference in calorimeter shape. Although it is difficult to make any "definitive" preference from these differences, the short magnet appears to count more favored points as far as calorimeter geometry is concerned.

We have shown the results on ray-tracing for all four cases as a function of rapidity. Among others, the radiation thickness of materials in front of EM calorimeter as well as the non-active hadronic part up to 5 interaction length are taken as measures of evaluation for calorimeter performance. For both cases of liquid argon and non-liquid argon, short magnets are preferred in terms of these measures.

References

[1] M.Strovink, W.J.Womersley, and G.E.Forden, Invited talk at the Workshop on Calorimetry for the Super Collider, University of Alabama, SSC-SDC-14, 1989.

[2] H.Hirayama, Proceedings of the International Workshop on Solenoidal Detectors for the SSC, KEK, April 23-25,1990, pp.360-365.

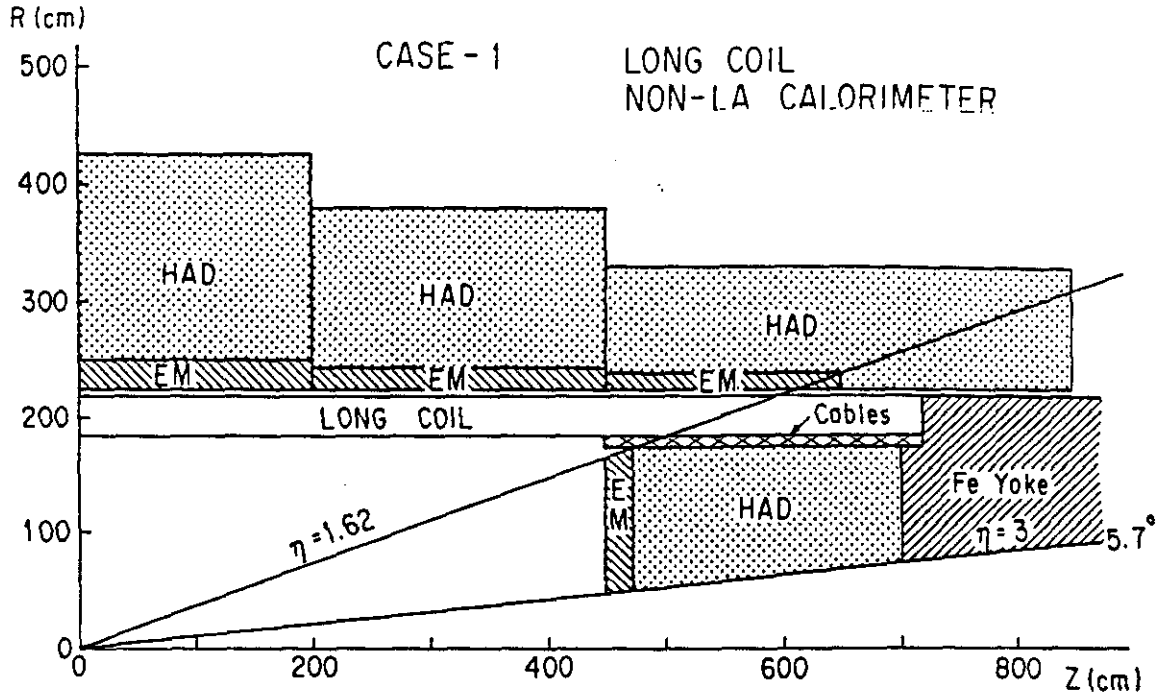

Fig. 1 Configuration of case-1 : long coil and non-liquid argon calorimeter.

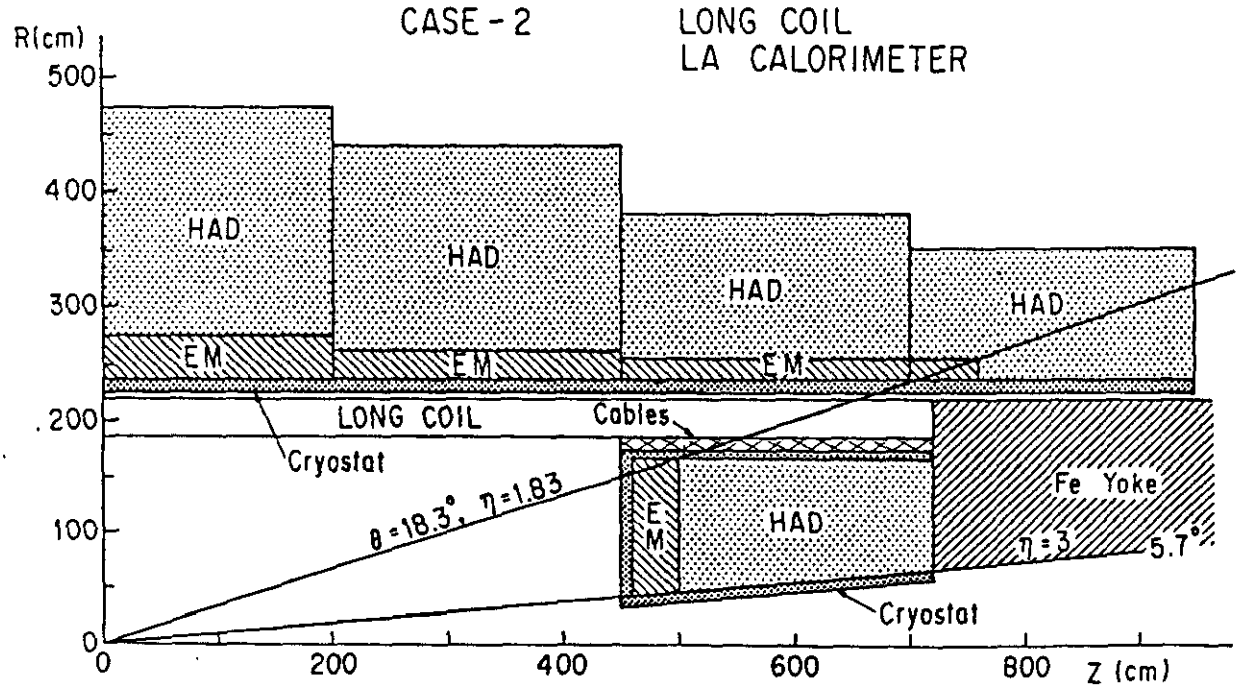

Fig. 2 Configuration of case-2 : long coil and liquid argon calorimeter.

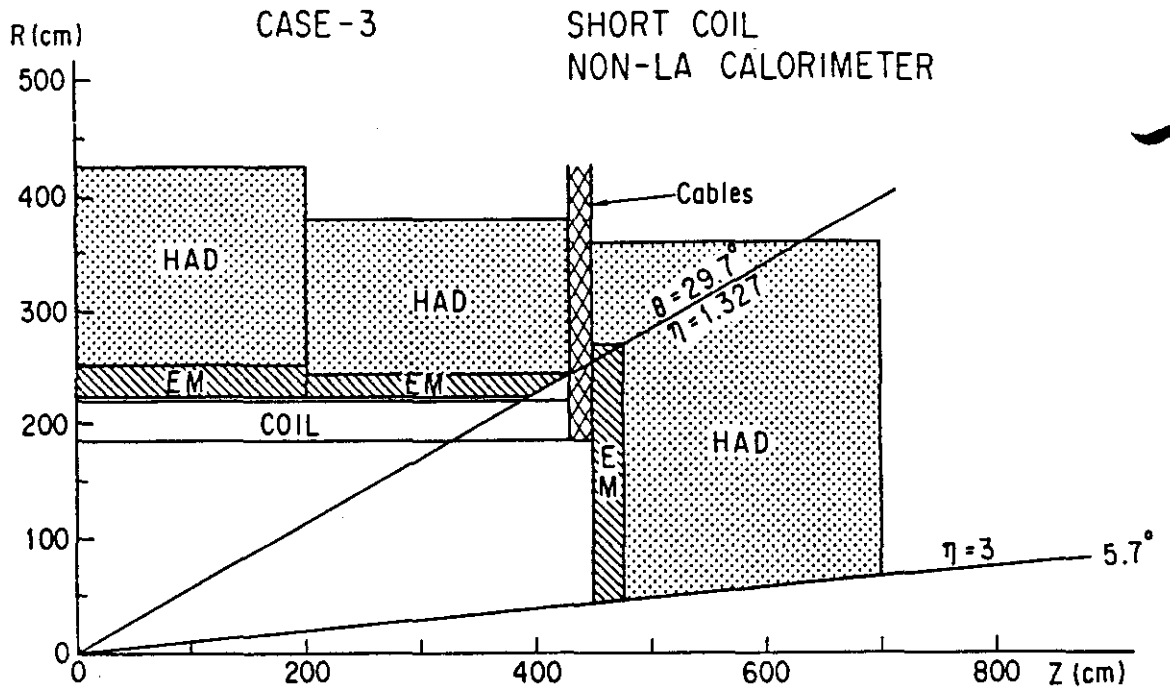

Fig. 3 Configuration of case-3 : short coil and non-liquid argon calorimeter.

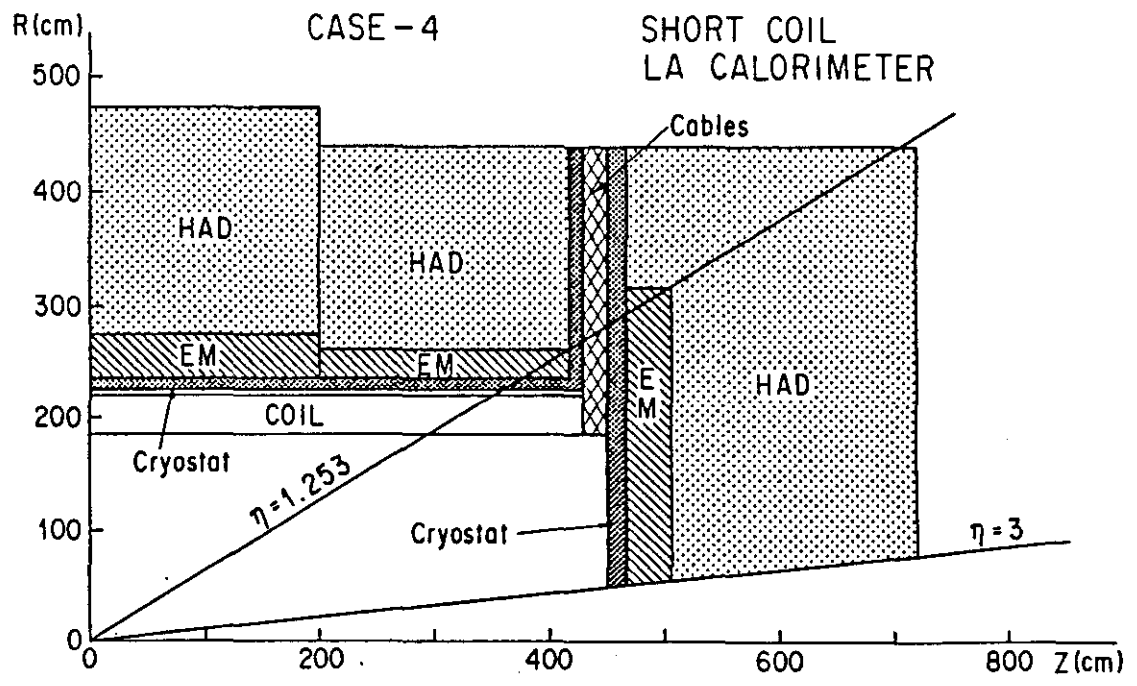

Fig. 4 Configuration of case-4 : short coil and liquid argon calorimeter.

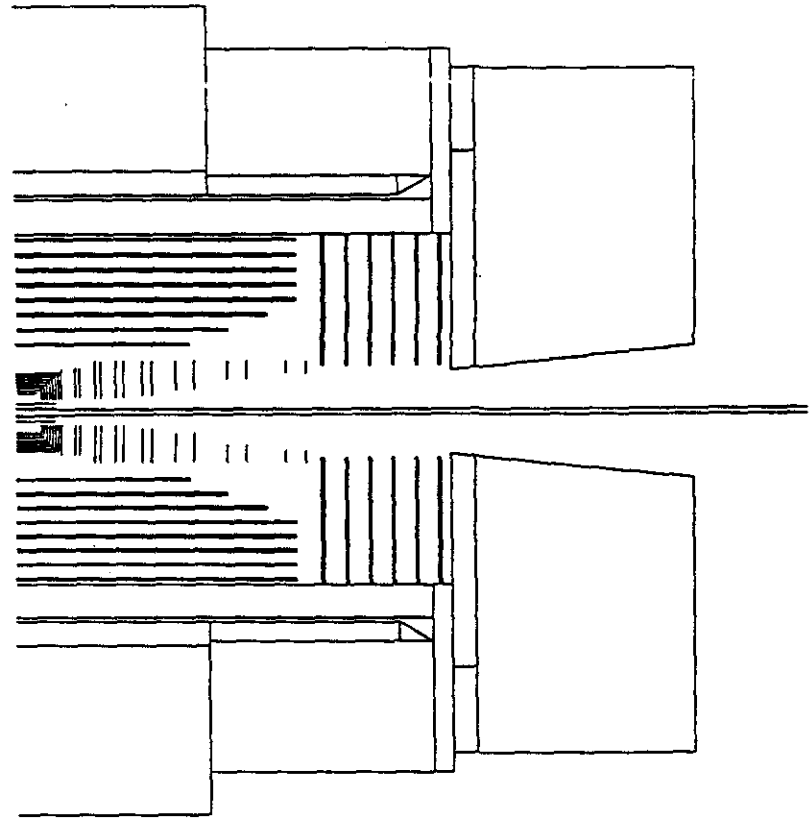

Fig.5 GEANT picture for the case-3.

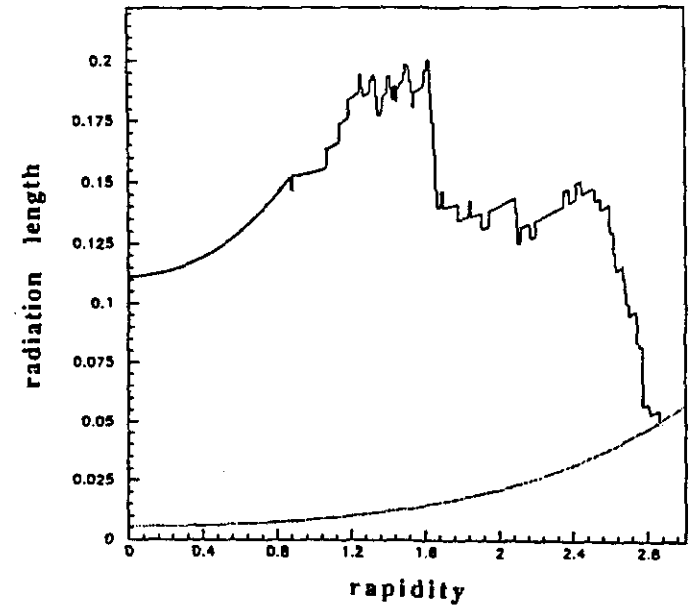

Fig.6 Total radiation length of inner tracker with silicon + wire system. Dotted line is contribution of the beam pipe.

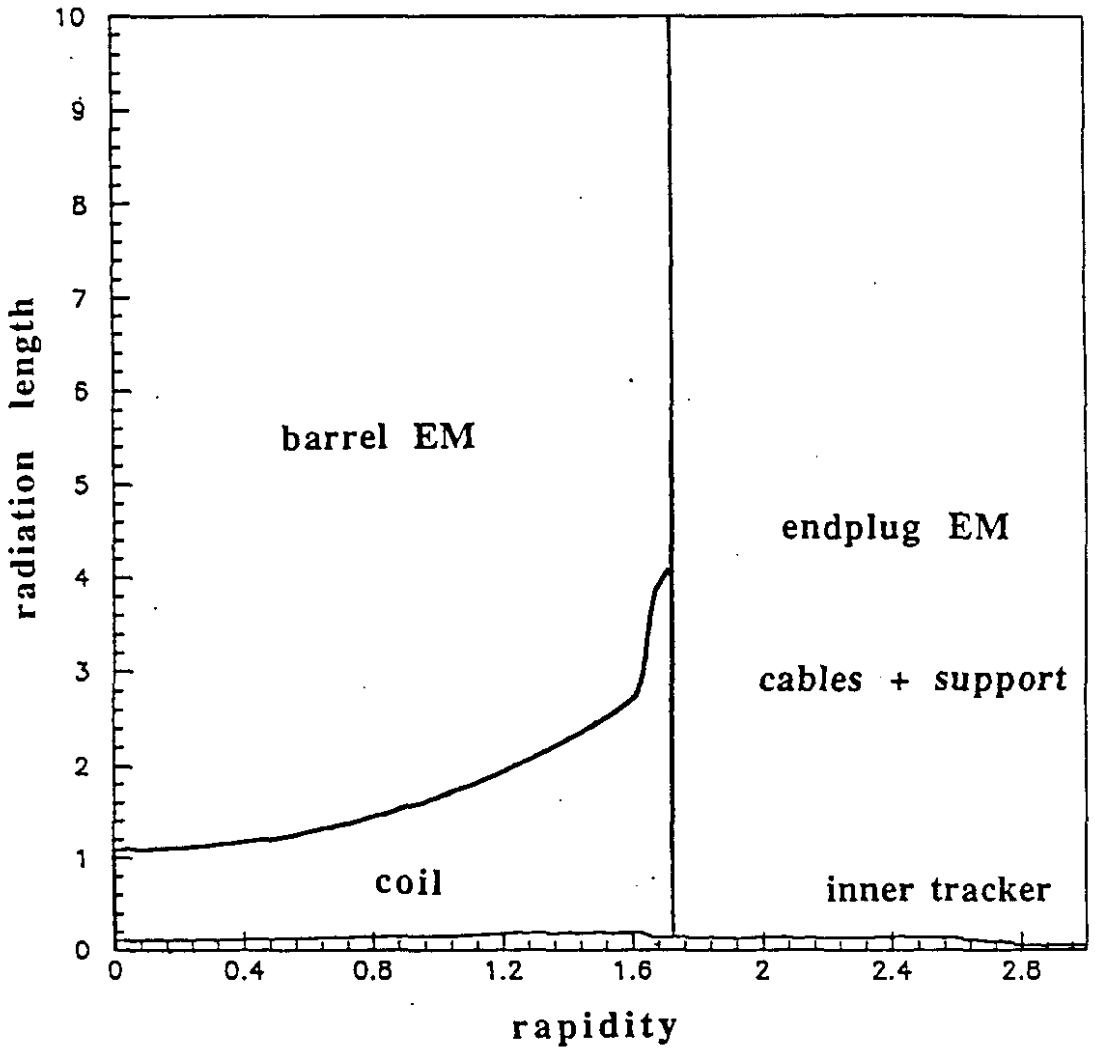

Fig.7 Rapidity dependence of radiation length for case-1 (long coil + non-liquid argon).

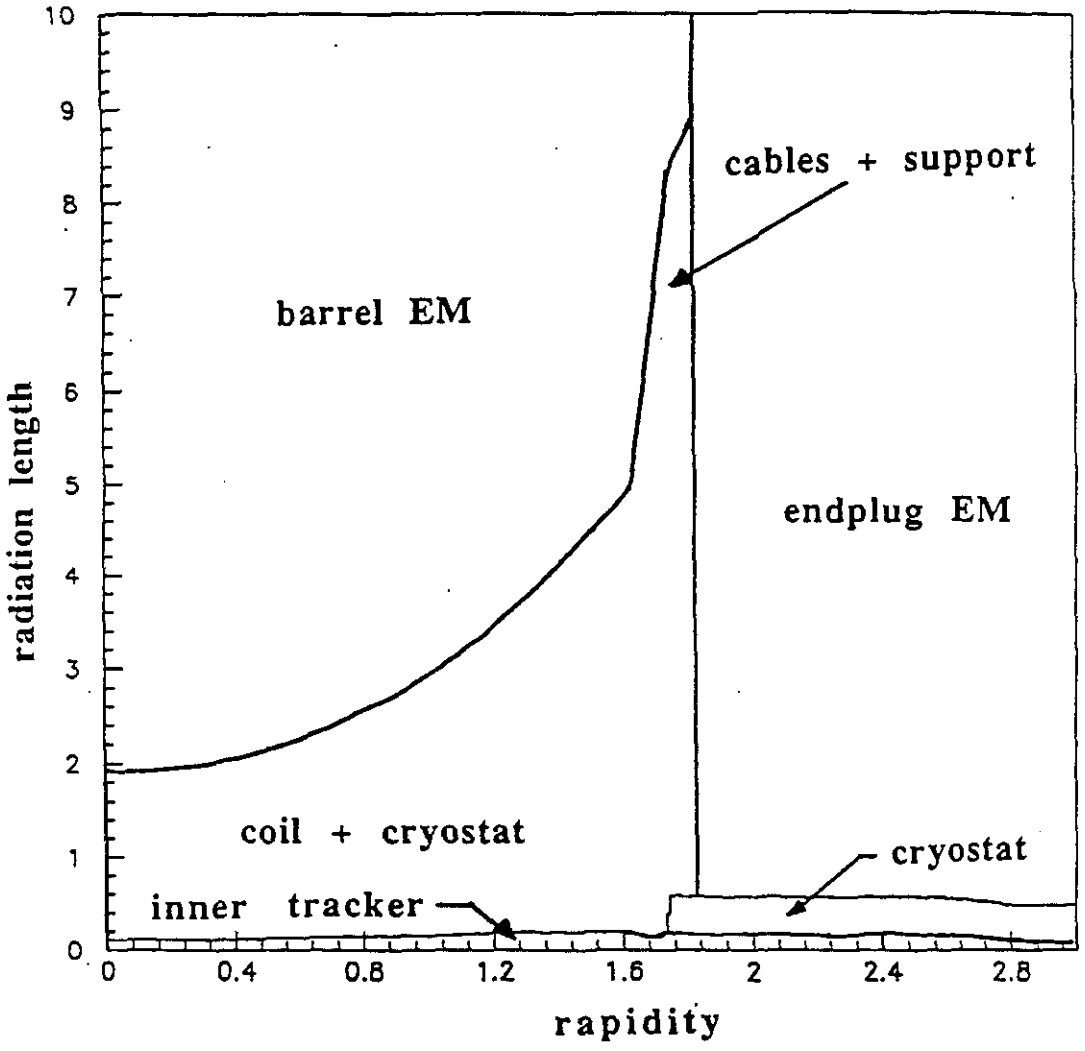

Fig.8 Rapidity dependence of radiation length for case-2 (long coil + liquid argon).

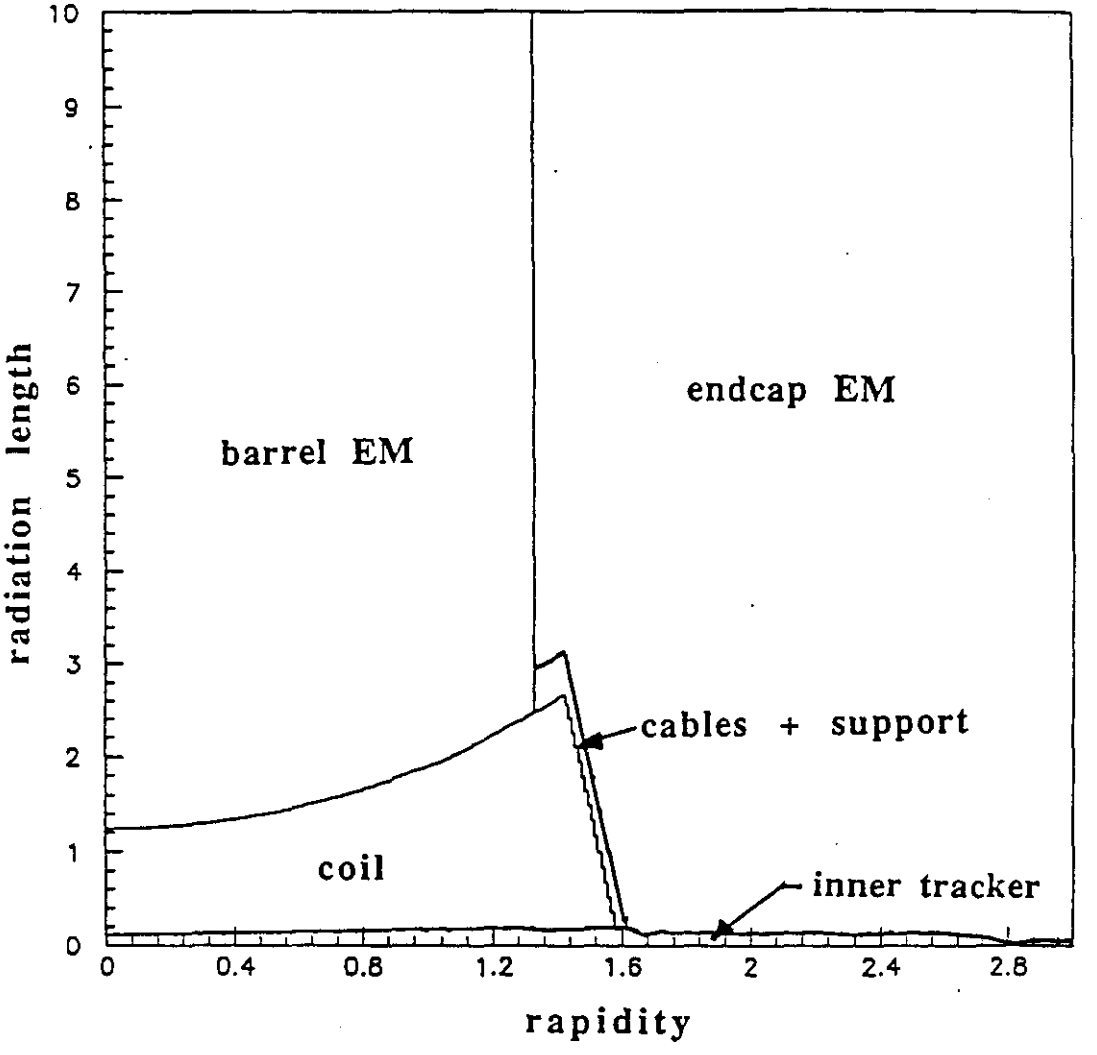

Fig.9 Rapidity dependence of radiation length for case-3 (short coil + non-liquid argon).

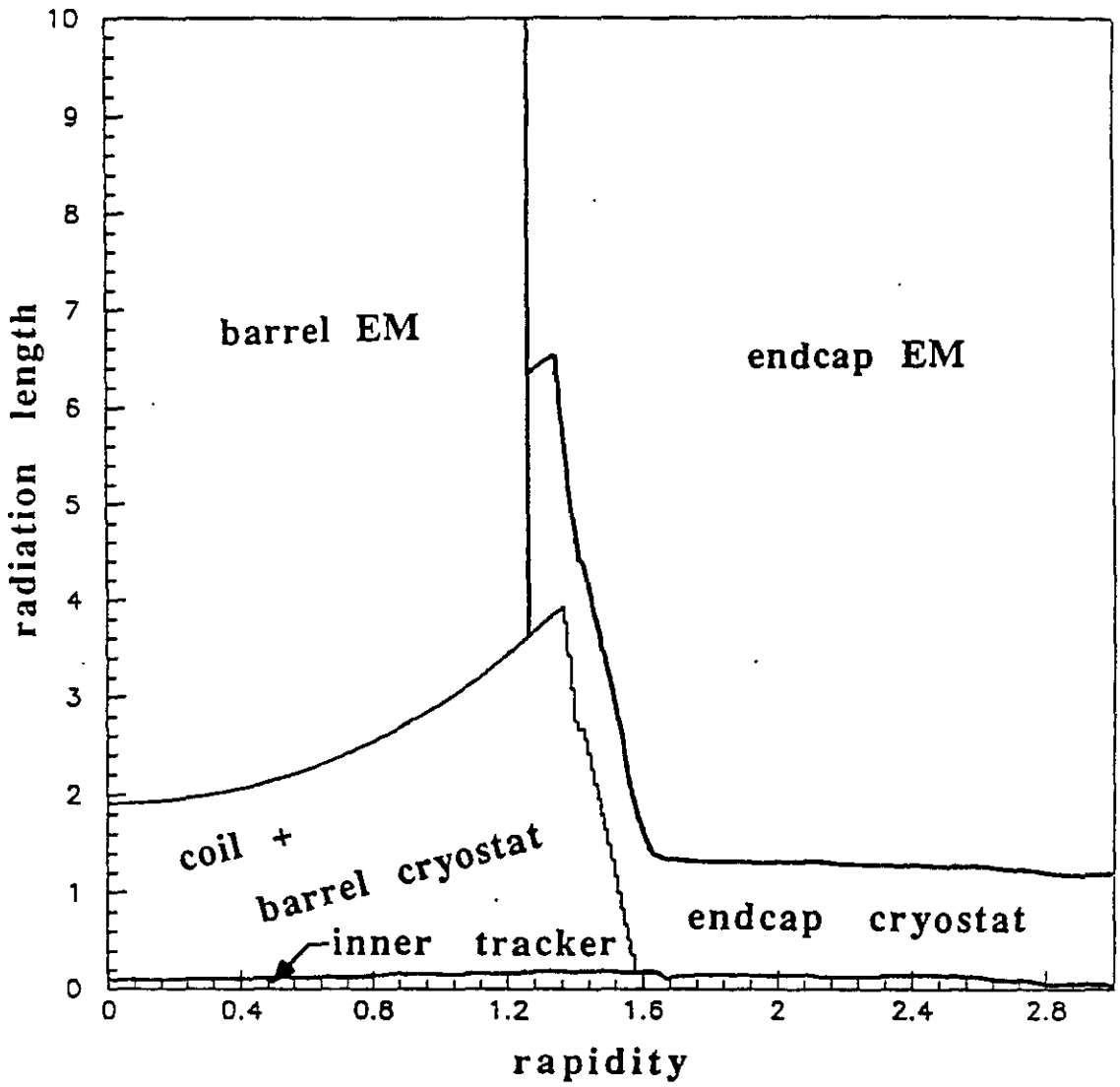

Fig.10 Rapidity dependence of radiation length for case-4 (short coil + liquid argon).

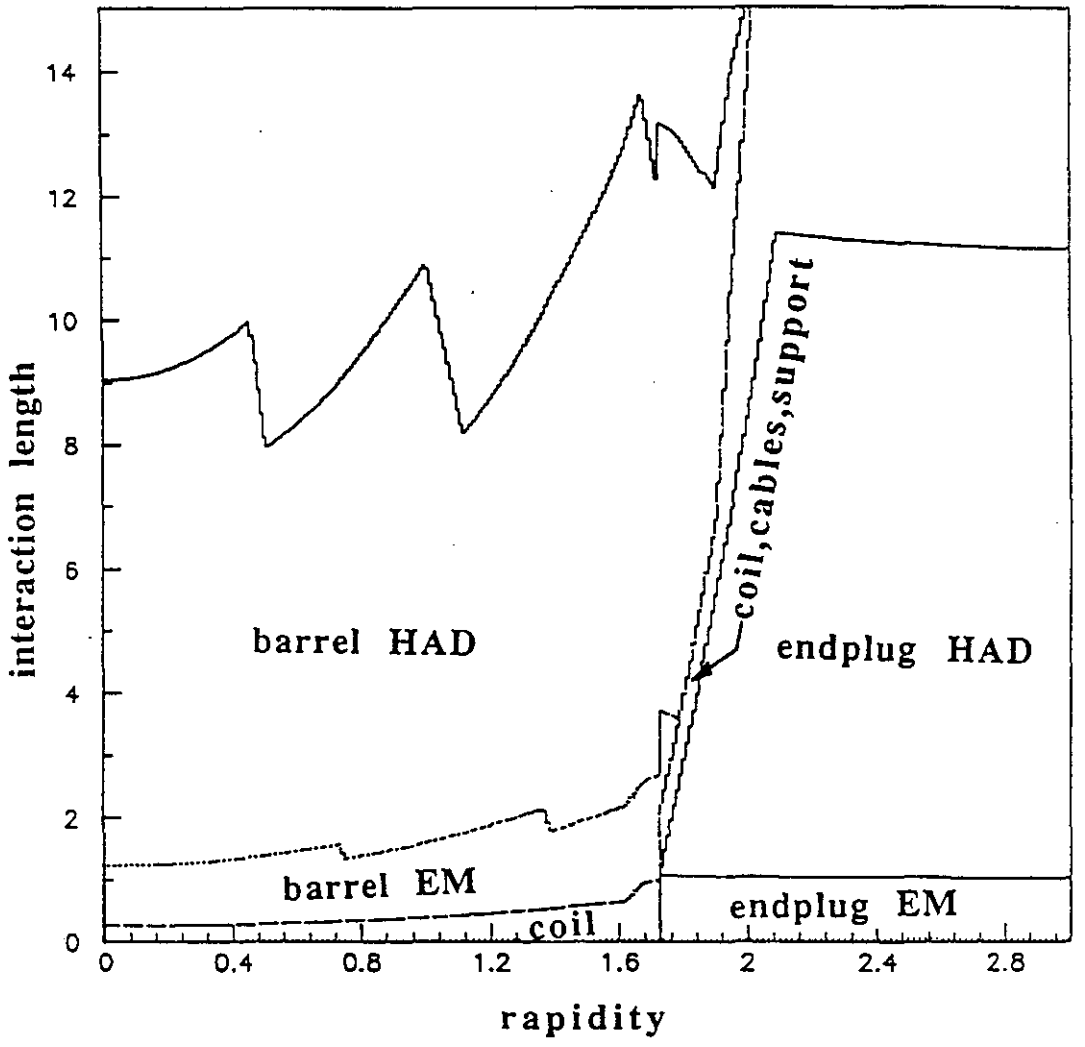

Fig.11 Rapidity dependence of interaction length for case-1 (long coil + non-liquid argon).

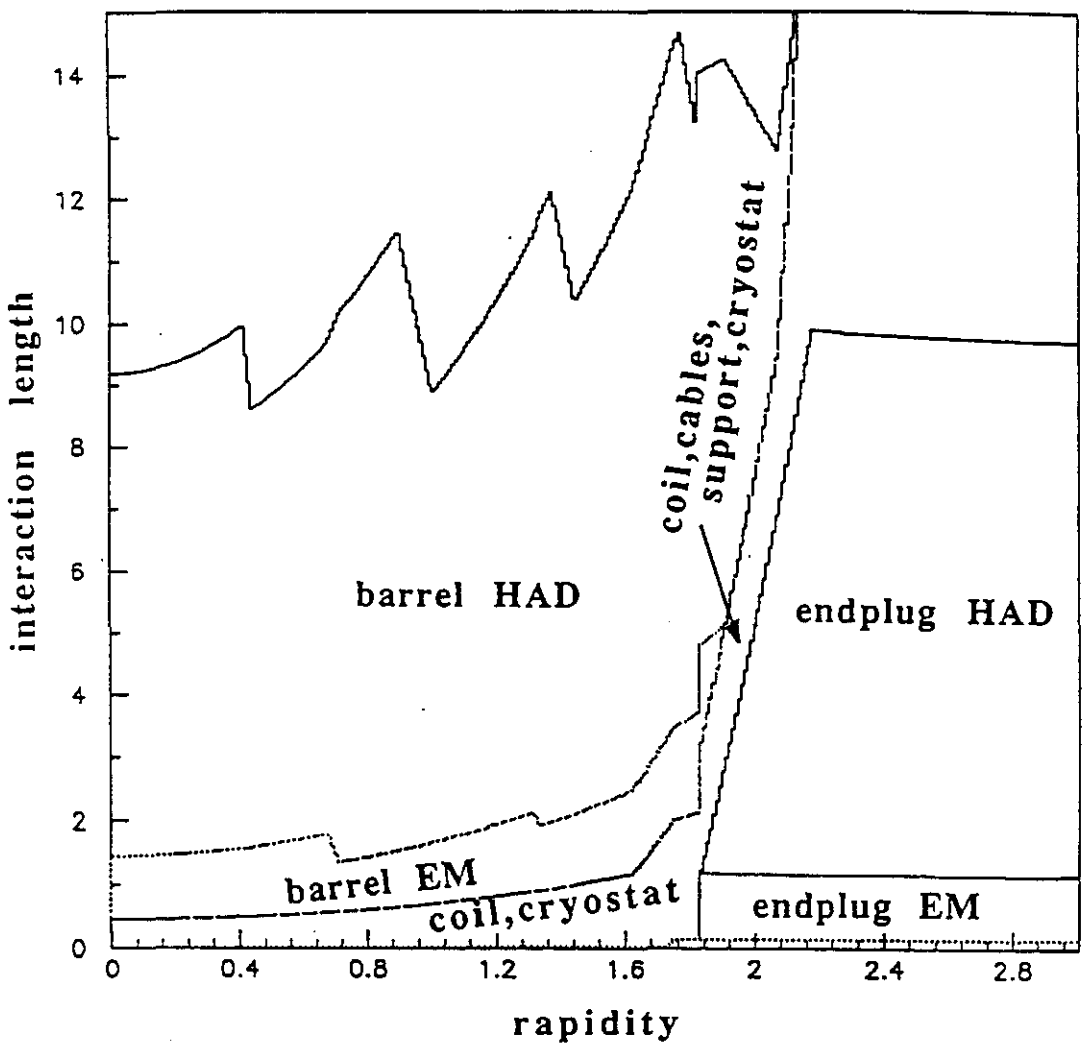

Fig.12 Rapidity dependence of interaction length for case-2 (long coil +liquid argon).

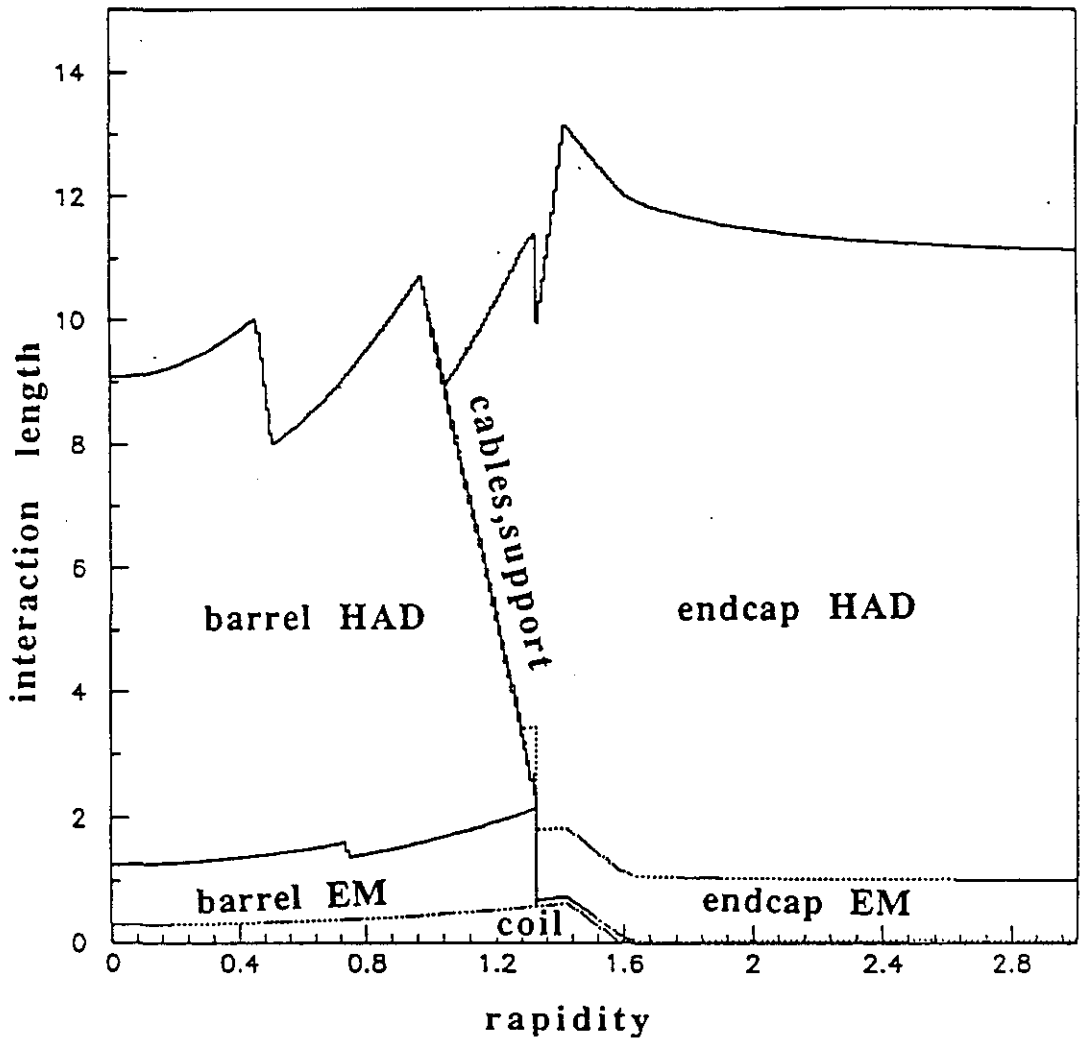

Fig.13 Rapidity dependence of interaction length for case-3 (short coil + non-liquid argon).

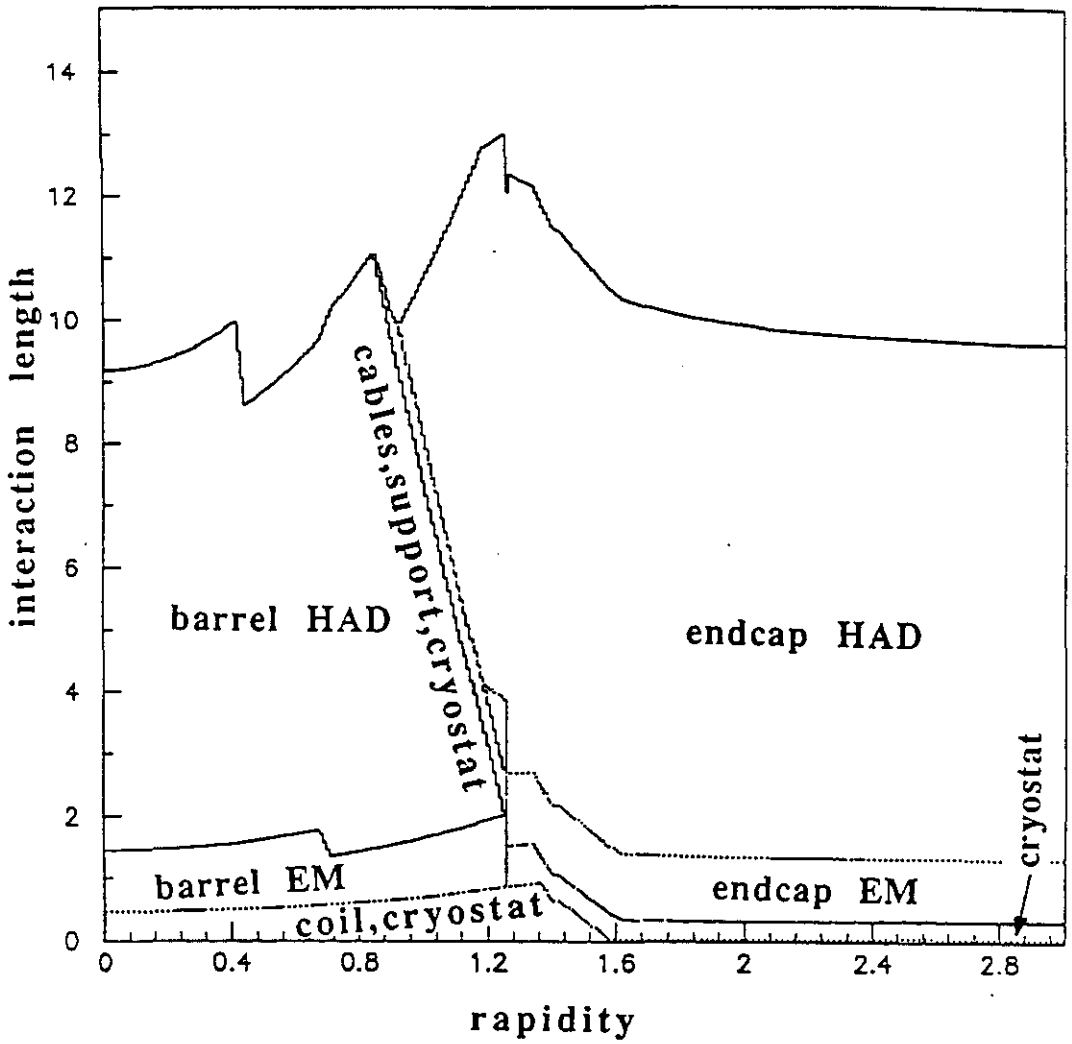

Fig.14 Rapidity dependence of interaction length for case-4 (short coil + liquid argon).