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The magnetic field studies of the Tilecal PMTs

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Abstract

A set of measurements on the PMT shielding has been performed for several shielding configurations and PMTs, and every magnetic field orientation with respect to the PMT axis. For the best PMT choice, it is shown that using only an arrangement of two cylinders (made of 0.8 mm thick mumetal and 2.5 mm thick mild steel), a full effective shieding is achieved up to 170 mT in the transverse direction and 60 mT in the longitudinal direction. Full magnetic field simulations in Atlas show that the residual field at the PMT location does not exceed about 2 mT in the worst case. So the individual PMT shielding will never be a problem.

1 Introduction

It is well known that the presence of magnetic fields affects most PMTs. The gain variation due to magnetic fields deflecting electrons mainly during their path from the photocathode to the first dynode depends strongly on the photomultiplier tube [1]. In the ATLAS project the magnetic field will arise from both the toroid and the solenoid components. So the magnetic shielding of the PMTs becomes basically necessary. That important point has been widely debated peculiarly the involvement of the number of the toroid coils decreasing from 12 to 8 ultimately.

Earlier magnetic fields simulations guided our shielding goals, transverse fields around 120 mT and axial ones about 40 mT were expected, respectively the field component perpendicular and parallel to the revolution axis of the PMT. Our first shielding tests by the end of 1993 provided rather poor results [2]. It turned out that magnetic shielding is relatively easy in the transverse direction and very difficult at small angles versus the PMT axis. However the drawer system supporting the PMTs is designed in such a way to make up the shielding easier since the toroid and the solenoid fields are mainly transverse to the PMT axis [Fig.1].

The study we report in this note was based on a magnetic shielding efficiency up to 60 mT in any directions. We, now, know by new simulations [3] it was a very pessimistic assumption since the expected magnetic fields would be around 2 mT. On Fig-2 is shown just for illustration the effect of magnetic field on anode output for two possible dynode structures (without any magnetic shielding): a linear structure (Hamamatsu R647 or Philips XP1901) and the new special structure of the Hamamatsu R5600 PMT. The effect of the direction of the magnetic field appears clearly. In our studies, the comparison is done between the PMTs Philips XP1901 and Hamamatsu R5600 (called Philips and Hamamatsu in this note), but our previous studies showed that having also a linear structure the PMT R647 is equivalent to XP1901 [2].

2 The set-up

Our various shieldings have been chosen to protect in the same way PMTs having the following photocathode diameters: $\phi = 14$ mm for Philips, $\phi = 8$ mm for Hamamatsu.

The magnetic shield cases are schemed on Fig-3a and 3b. We can see the mild steel cylinders, the air gap necessary to disrupt the magnetic lines and the mu-metal cylinder for killing out the tiny remaining field. At the front of the shields the dashed part shows the possibility of adding a mild steel ring for a better sheltering against axial fields. In any cases a mild steel end-cap closes the other extremity.

Our experimental tests were carried out with the Venus magnet in the DELPHI test area at CERN in june 1994. Venus provides a magnetic field in the range 10 mT to 1000 mT.

A L.E.D. illuminated through 2 optic fibers a reference PMT located outside the magnetic field and the tested PMT situated in the air gap between the magnet poles. [Fig.4]. An aluminium removable structure held in position the PMT and allowed a ϕ rotation of the PMT around its axis and an α rotation versus the magnetic field.

The integrated charges Q and Q_0 respectively from the PMT inside the B field and outside the field permit the evaluation of the normalized PMT relative gain R versus the earth field B_0 measurements:

$R = (Q/Q_0)_B/(Q/Q_0)_{B_0}$ with $\Delta R/R$ around 1 percent

3 The measurements

It should be noticed that before checking out the various shieldings at CERN, we began our tests with a transverse magnetic field provided by an electromagnet with, unfortunately, a small air-gap aperture (50mm) at Clermont-Ferrand. In spite of the non uniformity of the fields surrounding the magnetic shield cases these tests were crucial to check out the correctness of our semi-theoretical calculations on the thickness of the shields, and fully confirmed later at CERN in the measurements explained below.

3.1 ϕ angle effect

The ϕ angle is defined by the rotation of the PMT versus its dynodes location. A glance at Figure 5 gives the physical meaning of the many ϕ values.

The Figures 6 to 13 show out clearly some important points for transverse magnetic fields. At first, the effect of a front ring improves significantly the shielding for any PMTs for the relatively high fields (B around .3T), but unfortunately with axial fields such an improvement does not appear. Second, for the Philips PMTs the $\phi = 270°$ is a privileged position for magnetic shielding up to 300 mT, whereas for other angles no plateau is present.

On the other hand, for the Hamamatsu PMTs (Fig.3b, case A) we get a plateau in all ϕ cases excepted when one single iron shield without mu-metal protects the PMT. The shielding is efficient from .3T to .17T for respectively 2 iron cylinders and 1 iron cylinder plus mu-metal for each.

Finally, the sensitivity to the distance between the edges of the mu-metal and of the iron cylinders sounds very small at least for the Hamamatsu PMTs [Fig.13].

3.2 α angle effect

Varying the angle α from 0° to 180° is equivalent to reversing the orientation of the magnetic field B.

We may notice, on the one hand, using Philips PMTs the low effect at small angles of adding a ring at the front of the PMT [Fig.14-15] and, on the other hand, similar results for small angles (0° to 30°). These PMTs always show a slope for low magnet field even with a double iron shield case. The field attenuation obtained by an iron cylinder plus mu-metal is very poor [Fig.16].

On the contrary, protecting the Hamamatsu PMTs turns out to be much easier [Fig.17-19]. For instance in the worst case, i.e. α near 0° we see on the curves [Fig.19] a magnet shielding about 60 mT can be reached out. Encouraged by these results we tried a single iron shield without mu-metal, but then the shielding is really very weak [Fig.20]. We also tested the sensitivity to the iron part projecting beyond the mu-metal (case A and case B on Fig.21 a and b). That effect is shown not very significant at α about 0°.

4 Conclusion and future prospects

To sum up, our study shows out clearly that only the Hamamatsu PMTs having the "metal channel dynode structure", do satisfy the requirements for the magnetic shieldings.

We have proved an efficient magnetic shielding for transverse fields till 170 mT and for axial fields about 60 mT could be easily reached with only an iron plus a mu-metal cylinder.

More, our tests with front ring having a small thickness do not act as foreseen. In the same way it seems useless to have an exceeding length of the cylinders in front of the photocathode (1 time the diameter seems enough).

We propose to hold back a similar set-up for the square PMT Hamamatsu R5900 (with a structure similar to the R5600 type) which would provide a very large safety factor against magnetic field and would be mechanically suitable.

Preliminary tests of these new shieldings have been done at Yerevan [4], using a magnetic probe instead of the the square PMT. The performances are close to those obtained with the previous shielding. Very interesting results are concerning the residual field at several PMT locations. It appears that the PMT front face could be located up to 20–30 mm from the iron shielding input. The role played by a thicker front ring appears also more clearly. So the next step will be to test again in the Venus magnet these new shieldings, but considering now the whole PMT block [5] in which are included the shieldings, the light mixer, the square PMT and its associated electronics. In addition to this circular shielding, a square shape design could be consider. New studies for magnetic fields below 10 mT may be carried out if we need reduced shield cases with Helmoltz coils in our lab.

In conclusion, a very large shielding safety factor above 60 mT, even in the worst conditions, is guaranteed when using PMT with this new dynode structure.

Acknowledgements

We would like to acknowledge the DELPHI collaboration for using the VENUS magnet in their test area.

References

[1] E. Durand, electrostatique, vol.3, Masson et Cie, 1966.

[2] Clermont-Ferrand measurements, Tilecal meeting (16-12-1993).

[3] S.B. Vorozhtsov, F. Bergsma, V.I. Klioukhine et al., ATLAS Internal Note Tilecal-no-7,12,18,22,26 (1994)

[4] Yerevan measurements, Tilecal meeting (13-09-1994).

[5] Z. Ajaltouni et al., ATLAS Internal note Tilecal-no-41 (1994)

Figures Captions

Fig-1. Main magnetic components from toroid (T) and from solenoid (S) acting perpendicularly on the PMTs located in the drawer design.

Fig-2. The Hamamatsu linear structure R647 and the special ones R5600 schemes and the effect of magnetic fields on anode output for illustration.

Fig-3a. Schematic view of the magnetic shielding cases with mild steel (E24) cylinders and the mu-metal surrounding the PMT.

Fig-3b. The sizes in mm for the various shield cases respectively for the Philips and the Hamamatsu PMTs. ϕ is the diameter and e the cylinder thickness, d1, d2, d3 are their overstepping from the photocathode.

Fig-4. Not scaled drawing of the CERN Venus magnet with one PMT inside, the position angles versus the field are shown on it.

Fig-5. Reference marks are given for the two PMTs.

Fig-6. Relative gain (in percent) versus magnetic field for the Philips PMT shielded with 2 mild steel cylinders plus 1 mu-metal cylinder for transverse field ($*$ and Δ respectively with and without a protecting front ring [$\alpha = 90°$, $\phi = 270°$]).

Fig-7. Philips PMT for transverse field, with 2 mild steel cylinders, 1 mu-metal cylinder and a front ring, in function of the ϕ angle ($\alpha = 90°$).

Fig-8. Philips PMT for transverse field, with 1 mild steel cylinder and 1 mu-metal cylinder, in function of the ϕ angle ($\alpha = 90°$).

Fig-9. Hamamatsu PMT for transverse field with 2 mild steel cylinders, 1 mu-metal cylinder and a front ring, in function of the ϕ angle ($\alpha = 90°$).

Fig-10. Hamamatsu PMT for transverse field with 2 mild steel cylinders, one mu-metal cylinder, in function of the ϕ angle ($\alpha = 90°$).

Fig-11. Hamamatsu PMT for transverse field with 1 mild steel cylinder and 1 mu-metal cylinder, in function fo the ϕ angle ($\alpha = 90°$).

Fig-12. Hamamatsu PMT for transverse field with only 1 mild steel, in function of the ϕ angle ($\alpha = 90°$).

Fig-13. Hamamatsu PMT for transverse field, with 1 mild steel cylinder and 1 mu-metal cylinder ($\alpha = 90°$, ($\phi = 90°$): Case A: $d_1 = 10$ mm, $d_2 = 20$ mm Case B: $d_1 = 10$ mm, $d_2 = 10$ mm.

Fig-14. Philips PMT with 2 mild steel cylinders, 1 mu-metal cylinder and a front ring, in function of the α angle ($\phi = 270°$).

Fig-15. Philips PMT with 2 mild steel cylinders and 1 mu-metal cylinder, in function of the α angle ($\phi = 270°$).

Fig-16. Philips PMT with 1 mild steel cylinder and 1 mu-metal cylinder, in function of the α angle ($\phi = 0°$).

Fig-17. Hamamatsu PMT with 2 mild steel cylinders, 1 mu-metal cylinder and a front ring, in function of the α angle ($\phi = 180°$).

Fig-18. Hamamatsu PMT with 2 mild steel cylinders and 1 mu-metal cylinder, in function of the α angle ($\phi = 90°$).

Fig-19. Hamamatsu PMT with 1 mild steel cylinder and 1 mu-metal cylinder, in function of the α angle ($\phi = 90°$).

Fig-20. Hamamatsu PMT with only a mild steel cylinder, in function of the α angle ($\phi = 90°$).

Fig-21. Hamamatsu PMT with 1 mild steel cylinder and 1 mu-metal cylinder for $\alpha = 0°$ and $90°$ ($\phi = 90°$): 21.a) Case A: $d_1 = 10$ mm, $d_2 = 20$ mm, 21.b) Case B: $d_1 = 10$ mm, $d_2 = 10$ mm.

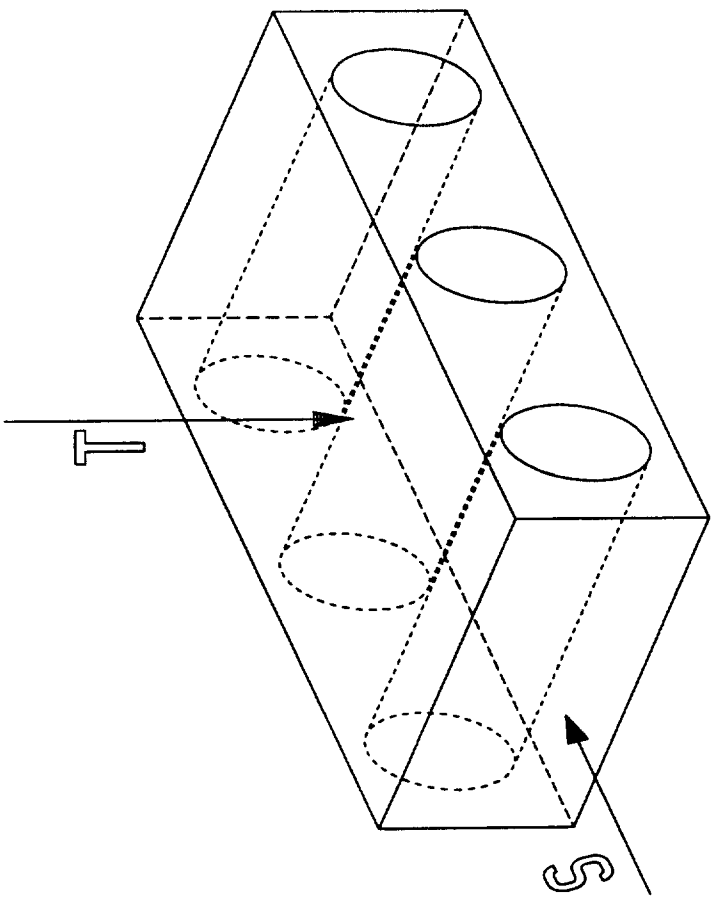
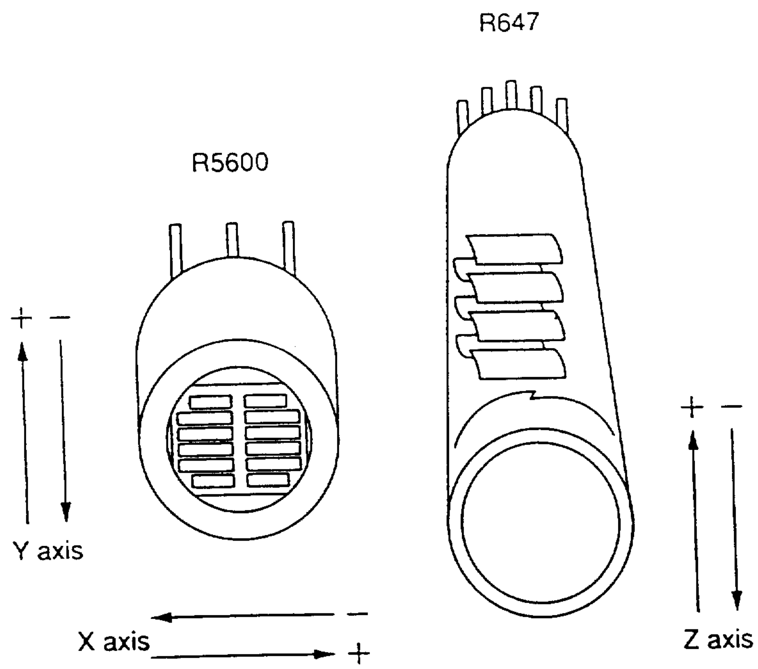
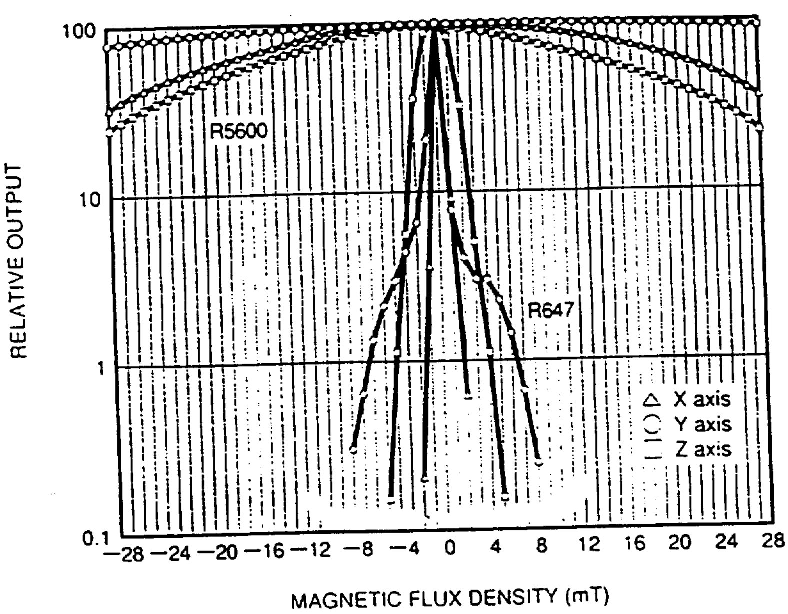


Fig.1



Direction of Magnetic Field



Effect of Magnetic Fields on Anode Output

FIG.2

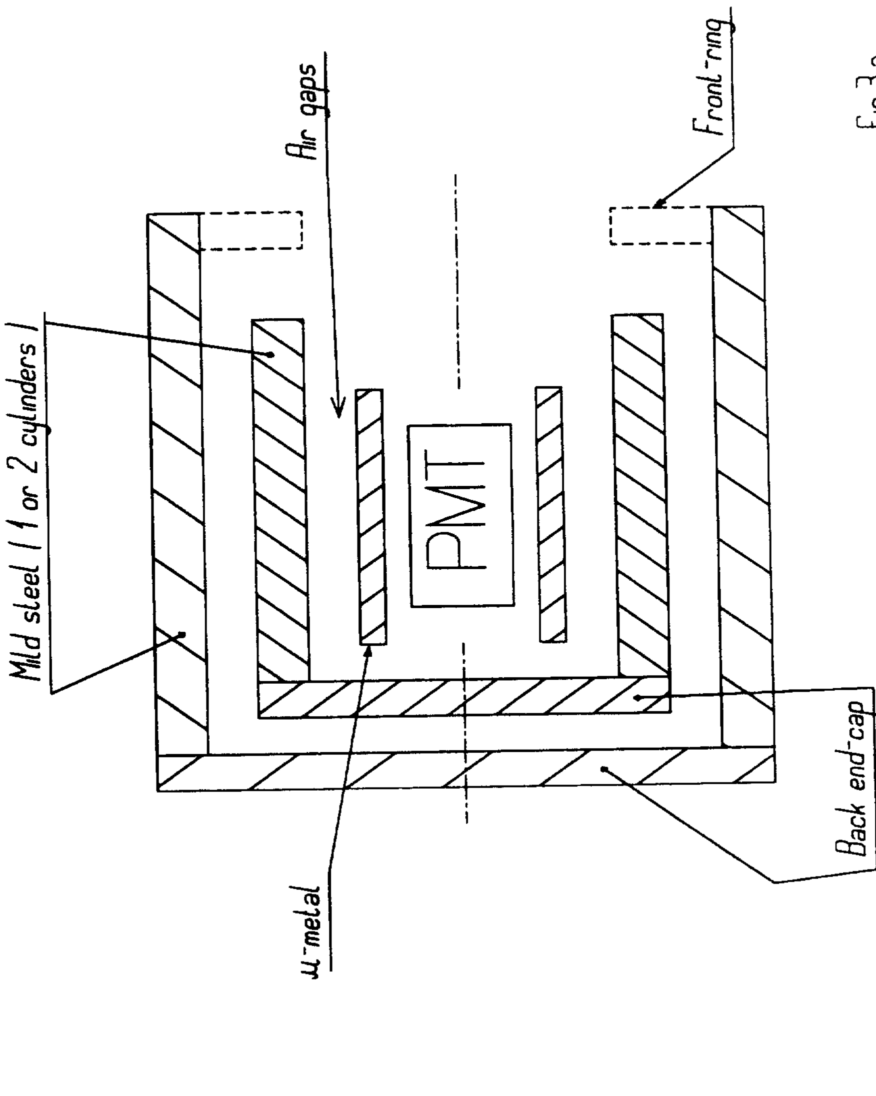
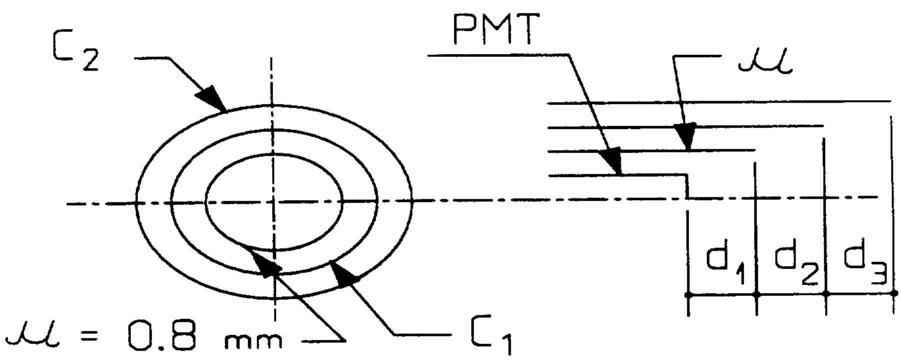

Mild steel (1 or 2 cylinders)
Air gaps
PMT
Front-ring
Back end-cap
μ-metal

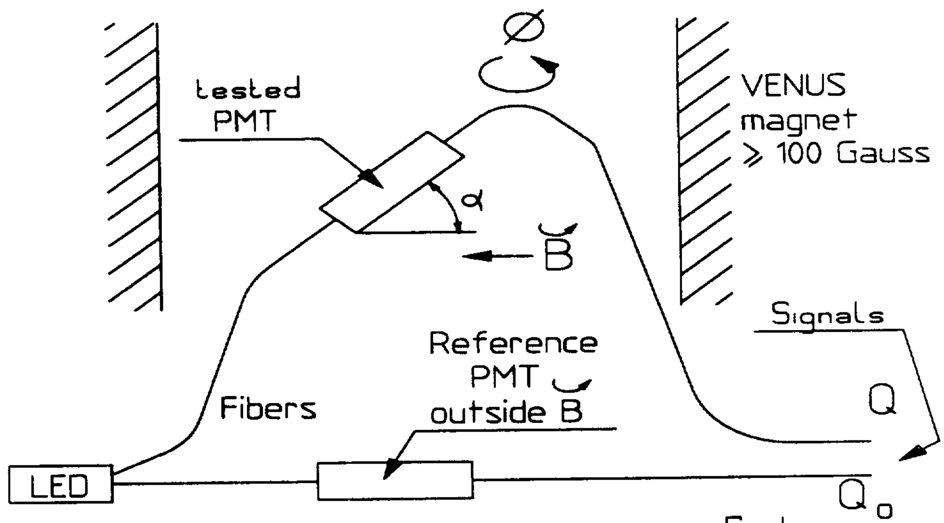
Fig.3.a



		Philips 3/4"	Hamamatsu 8mm
C_1	Ø	33.7	26.9
	e	3.25	2.65
C_2	Ø	60.3	48.3
	e	6.3	5.0
d_1		10	10 (A,B)
d_2		15	20 (A),10 (B)
d_3		25	30 (A),20 (B)

Sizes in mm

Fig.3b



∅
tested
PMT
VENUS
magnet
≥ 100 Gauss
α
B
Signals
Reference
PMT
outside B
Fibers
Q
LED
Q o

Fig.4

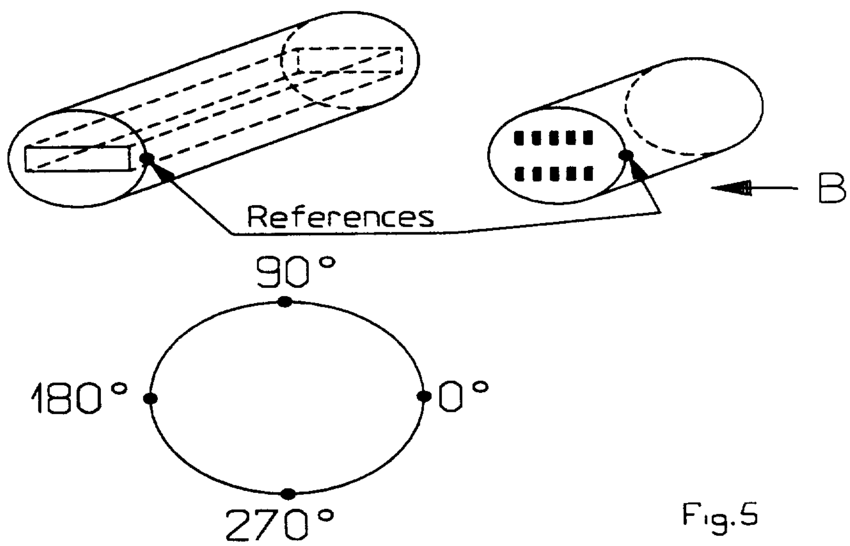
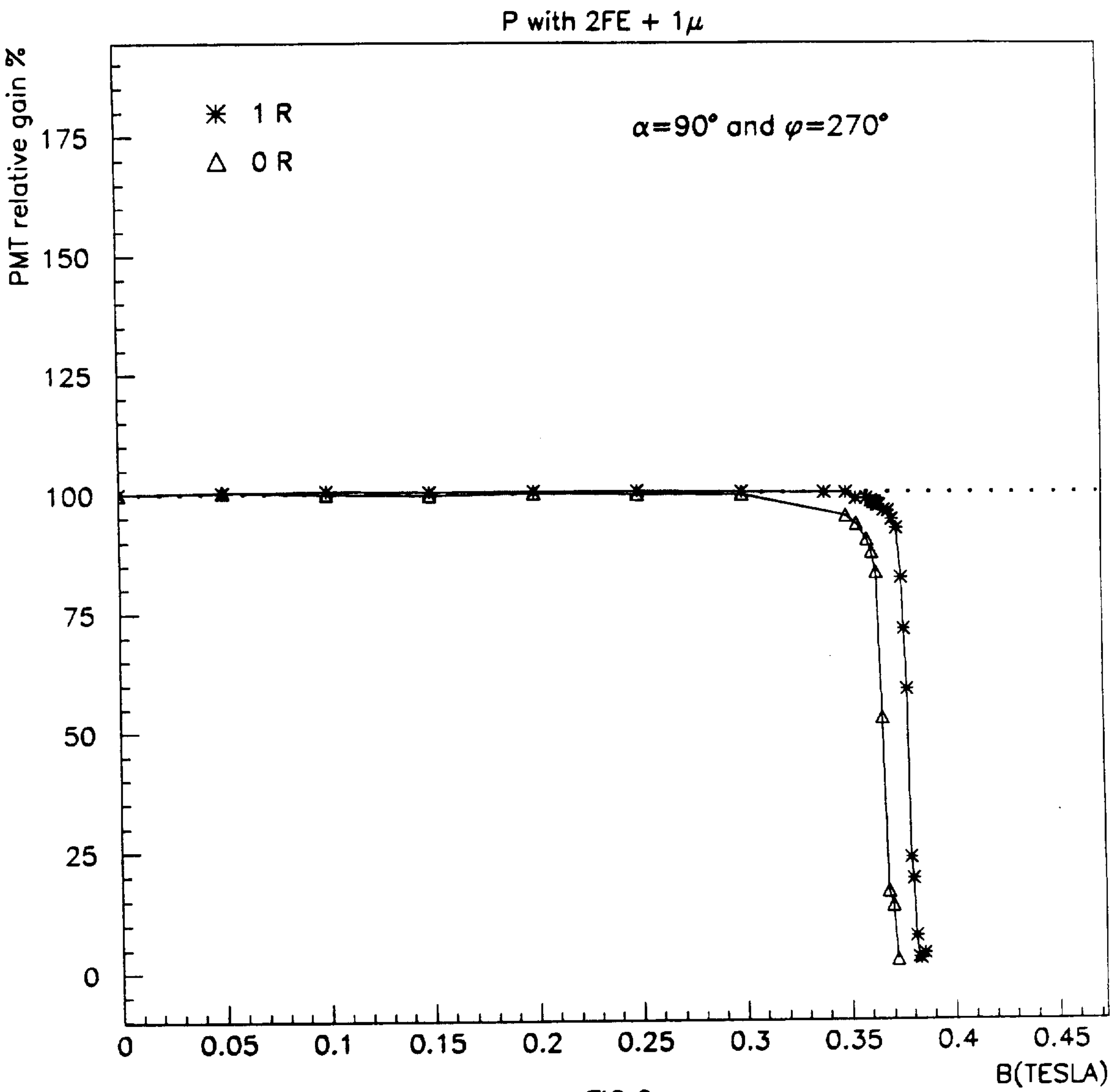


Fig.5



P with 2FE + 1μ
PMT relative gain %
1 R
0 R
α=90° and φ=270°
175
150
125
100
75
50
25
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
B(TESLA)

FIG.6

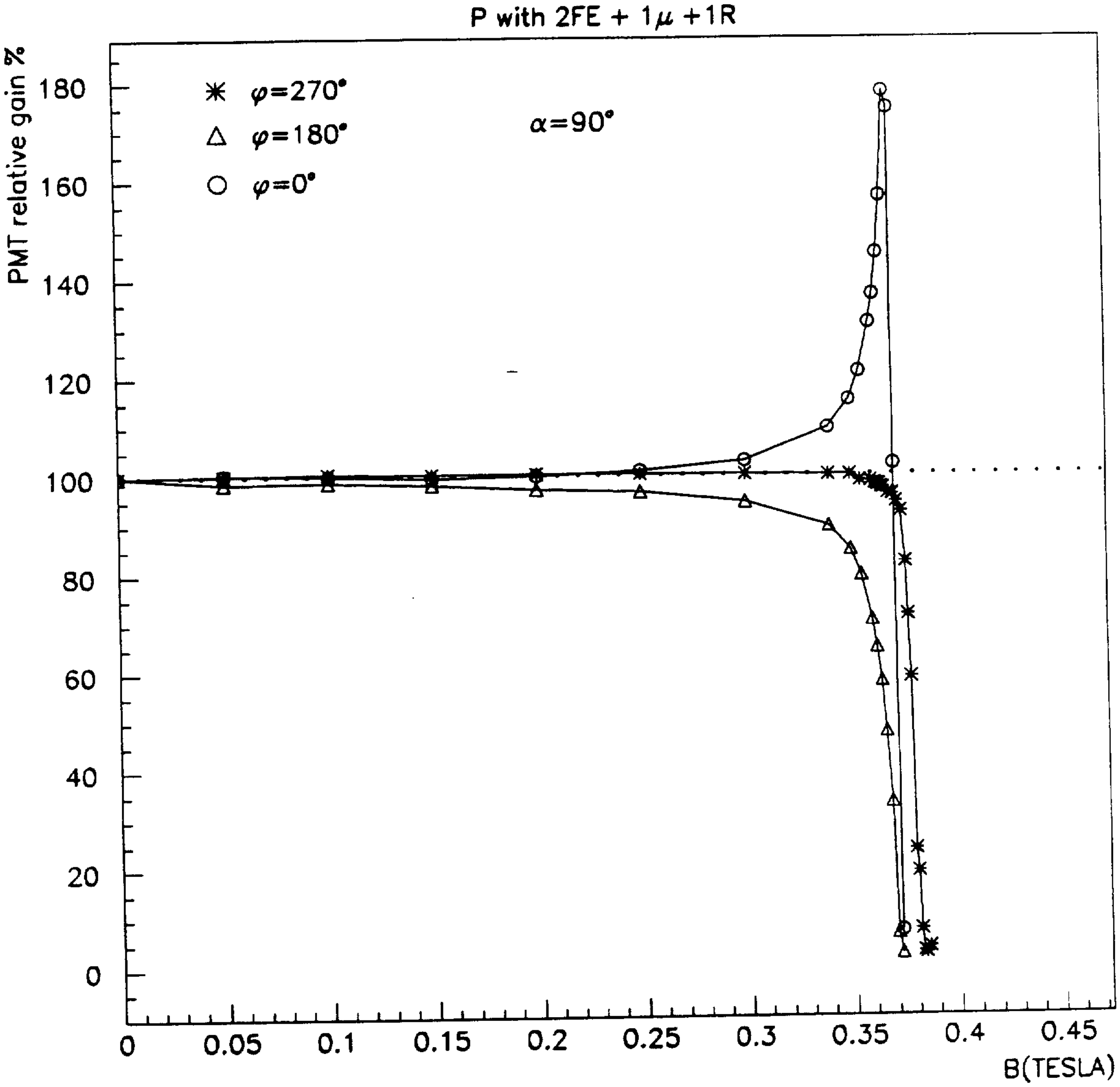

P with 2FE + 1μ +1R
PMT relative gain %
φ=270°
φ=180°
φ=0°
α=90°
180
160
140
120
100
80
60
40
20
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
B(TESLA)

FIG.7

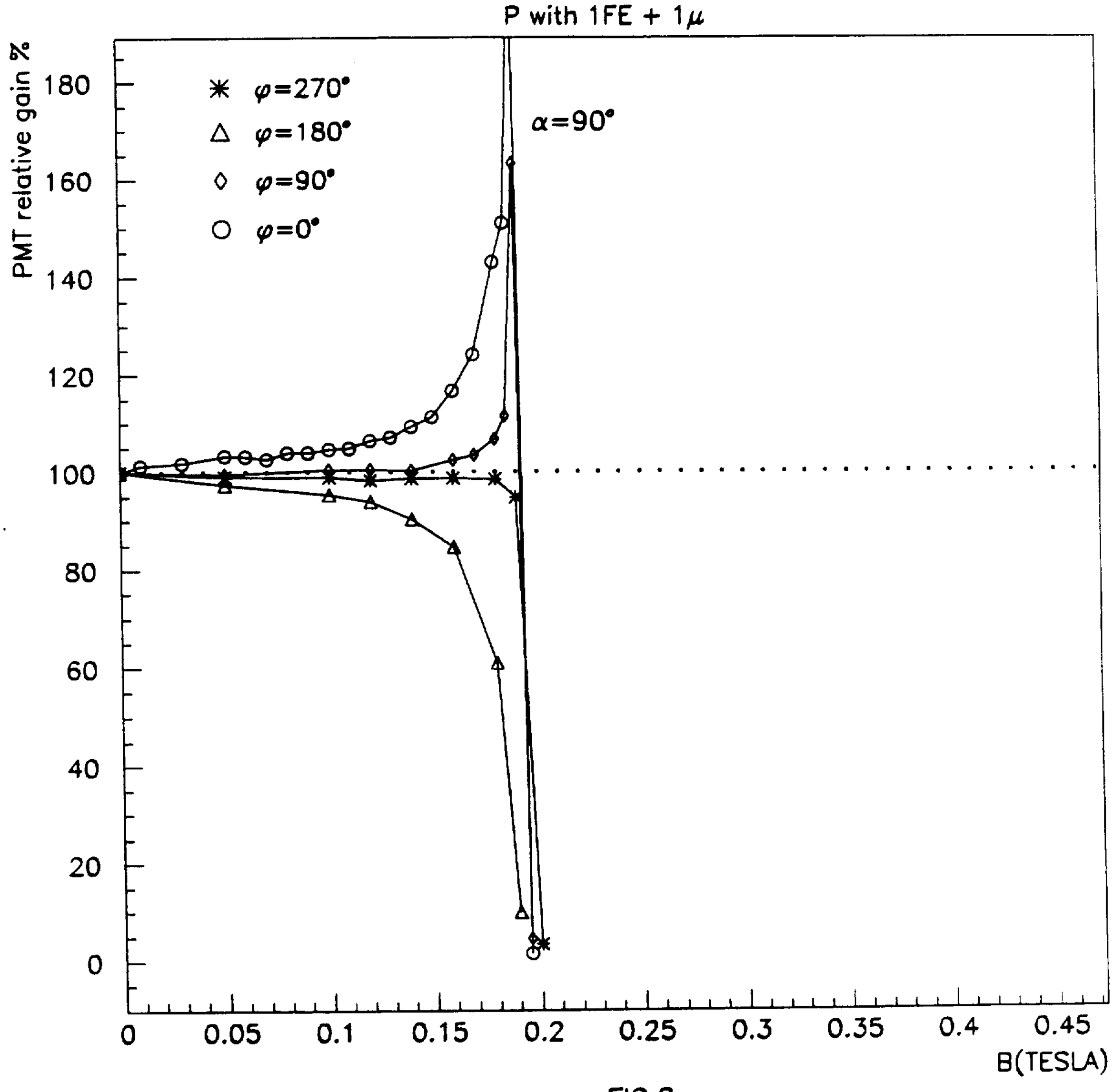
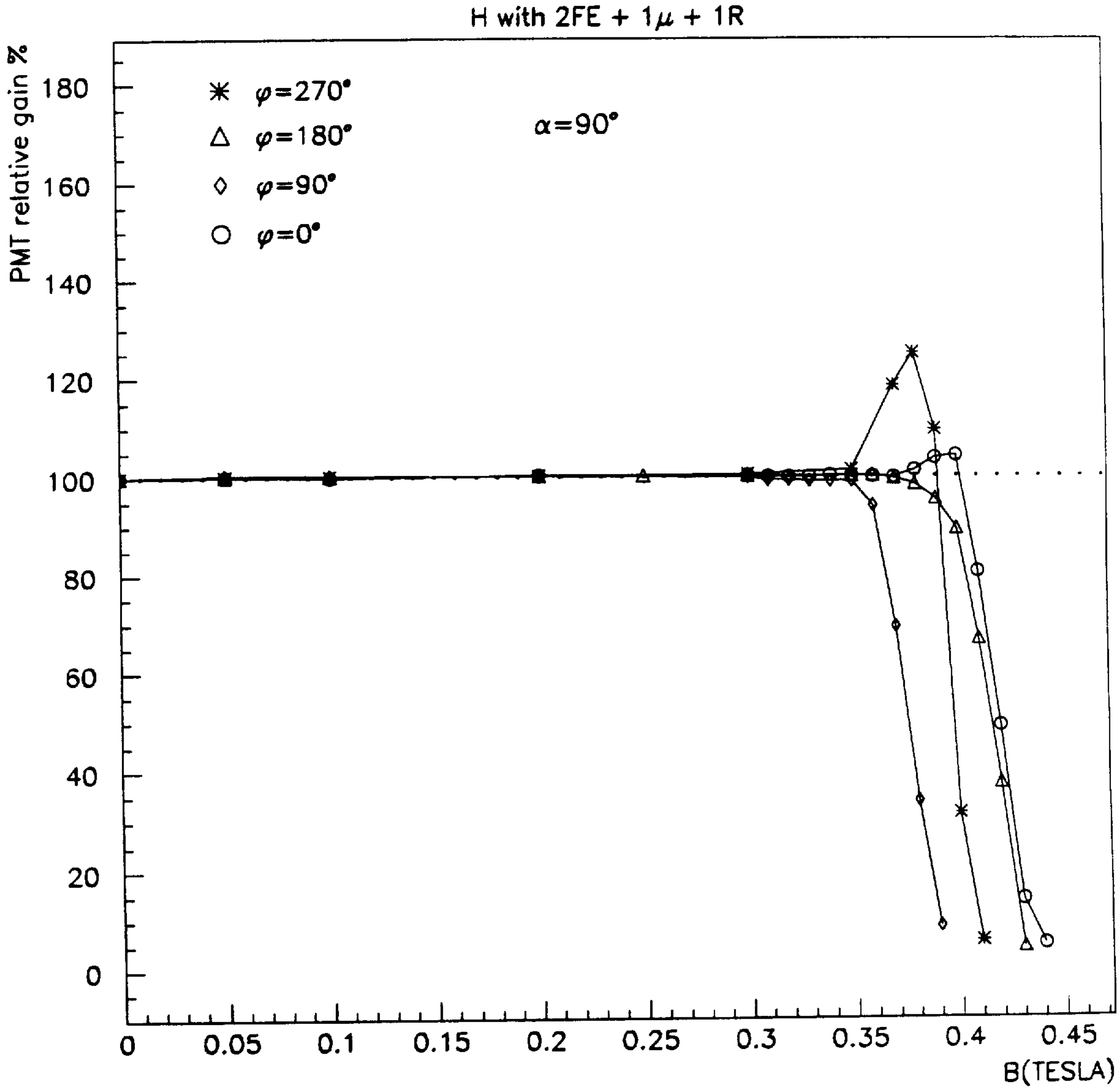

P with 1FE + 1μ
PMT relative gain %
180
160
140
120
100
80
60
40
20
0
φ=270°
φ=180°
φ=90°
φ=0°
α=90°
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
B(TESLA)

FIG.8



H with 2FE + 1μ + 1R
PMT relative gain %
φ=270°
φ=180°
φ=90°
φ=0°
α=90°
180
160
140
120
100
80
60
40
20
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
B(TESLA)

FIG.9

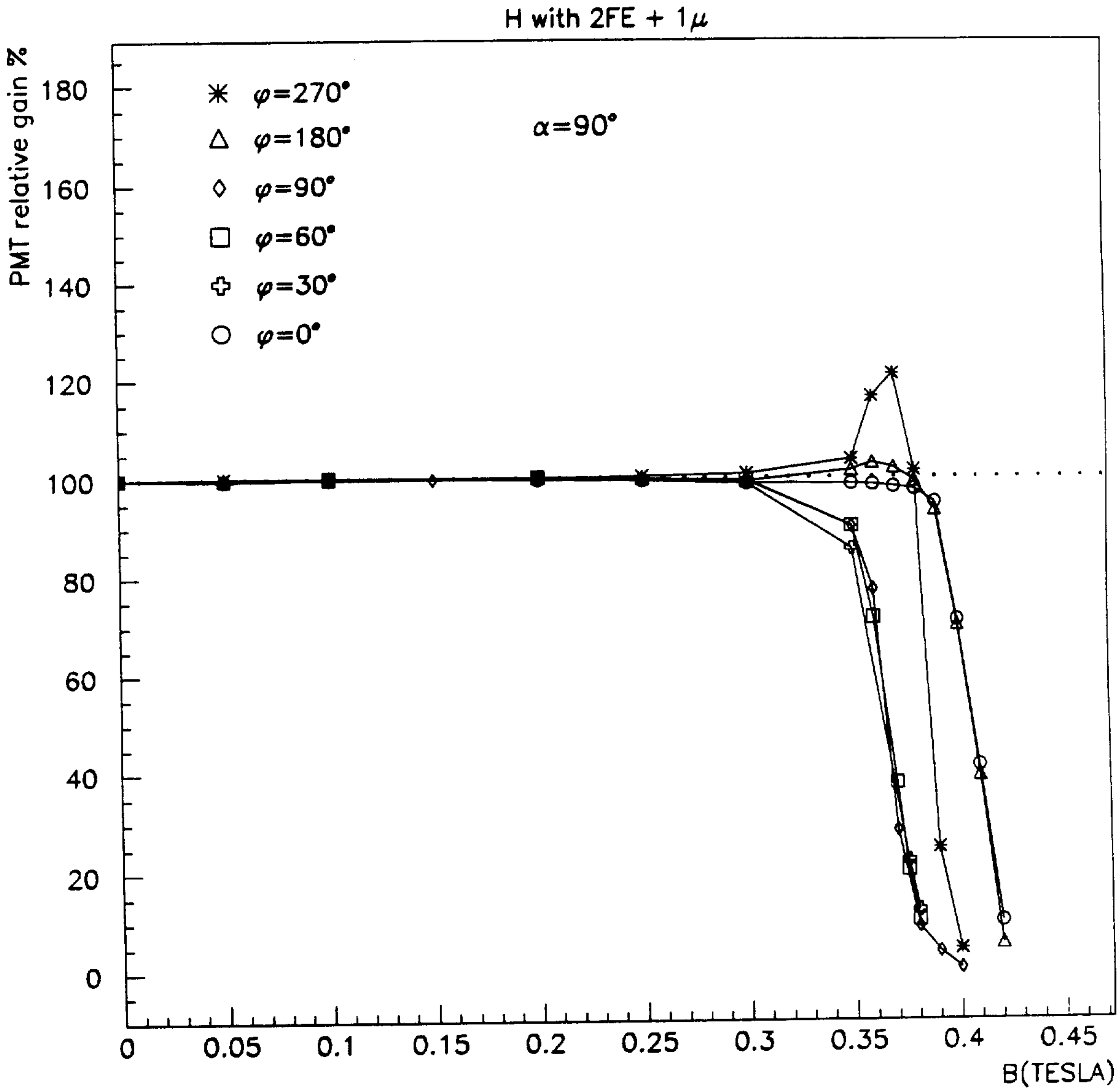

H with 2FE + 1μ
PMT relative gain %
φ=270°
φ=180°
φ=90°
φ=60°
φ=30°
φ=0°
α=90°
180
160
140
120
100
80
60
40
20
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
B(TESLA)

FIG.10

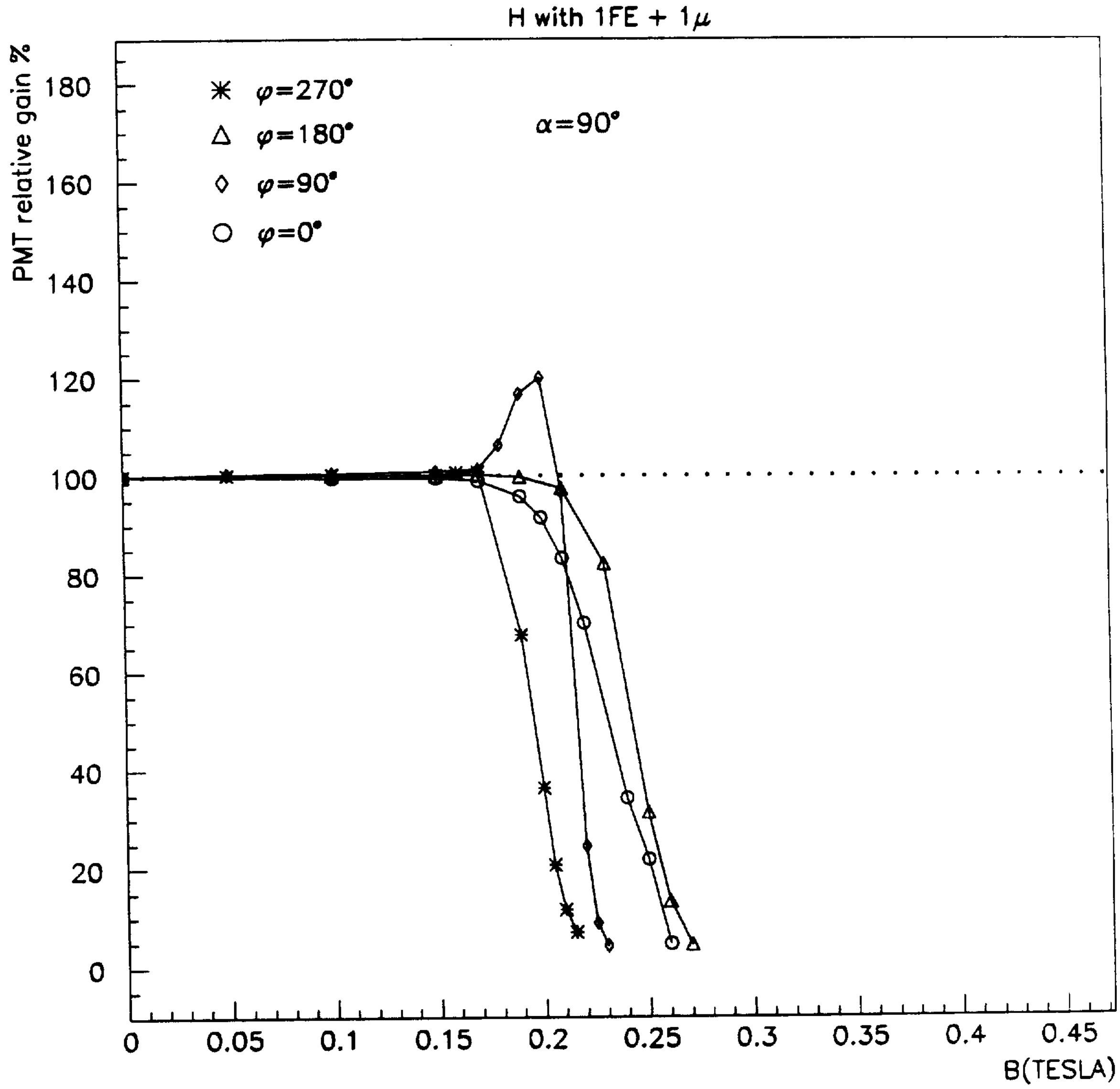

H with 1FE + 1μ
PMT relative gain %
φ=270°
φ=180°
φ=90°
φ=0°
α=90°
180
160
140
120
100
80
60
40
20
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
B(TESLA)

FIG.11

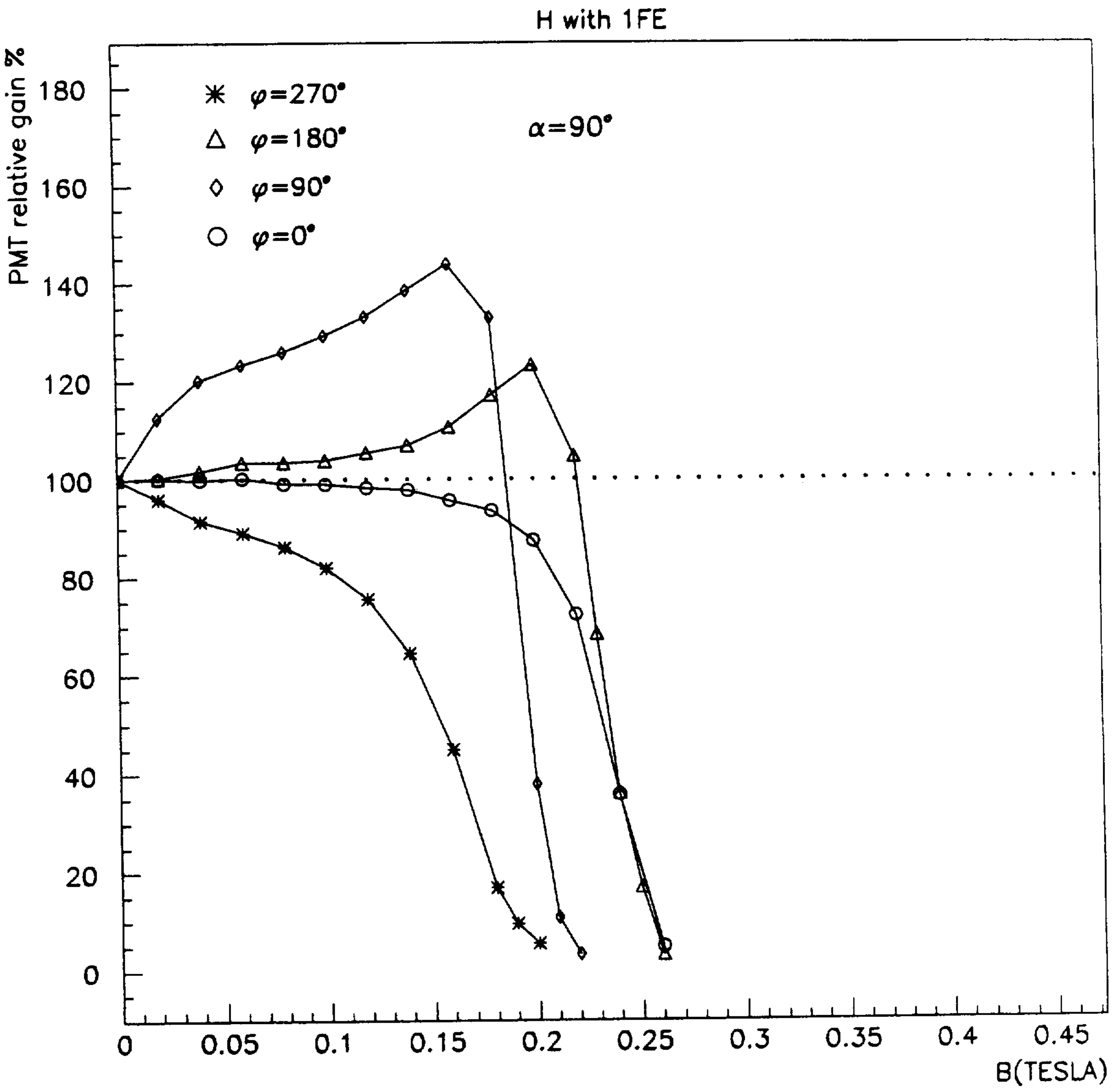
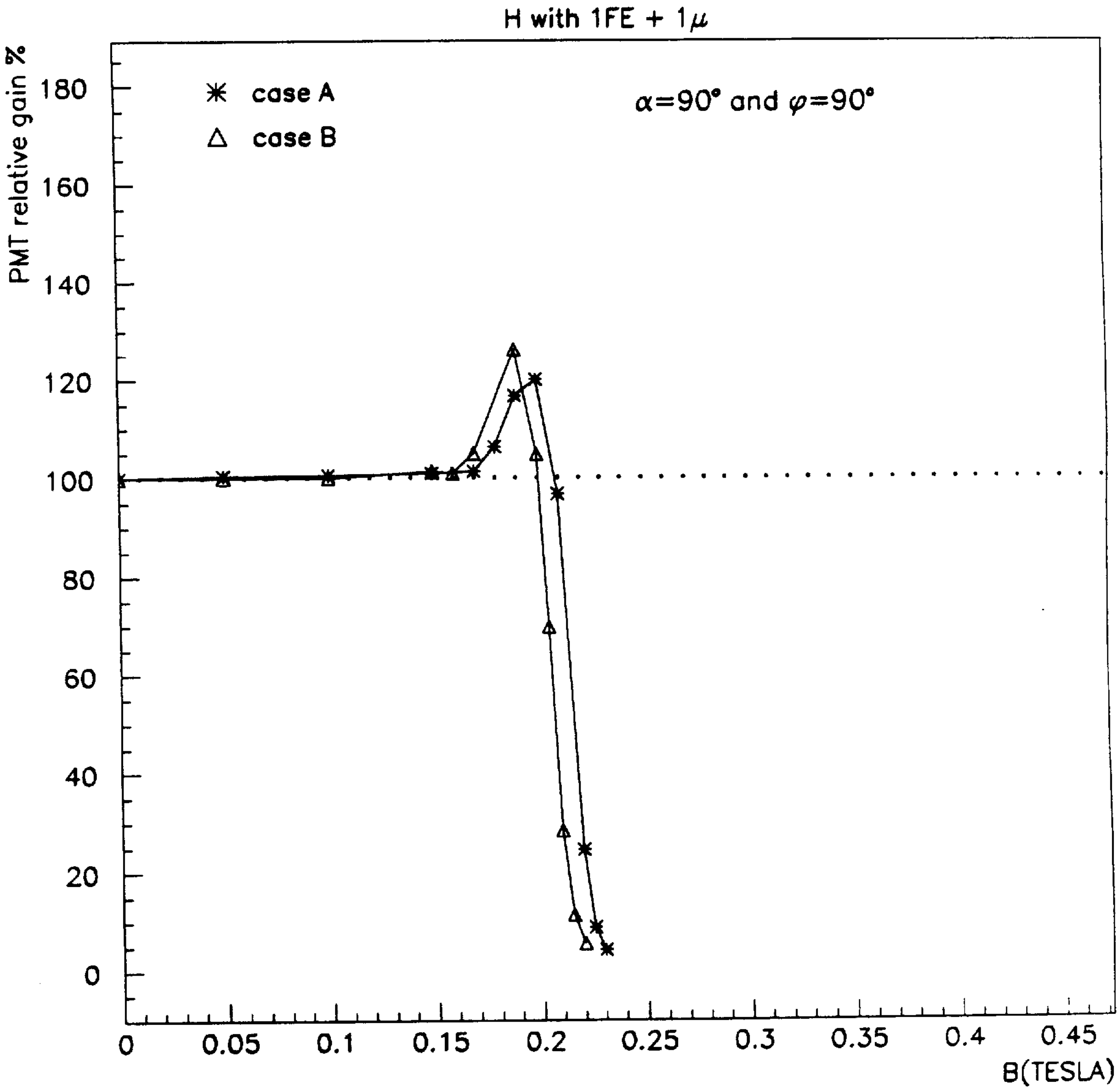
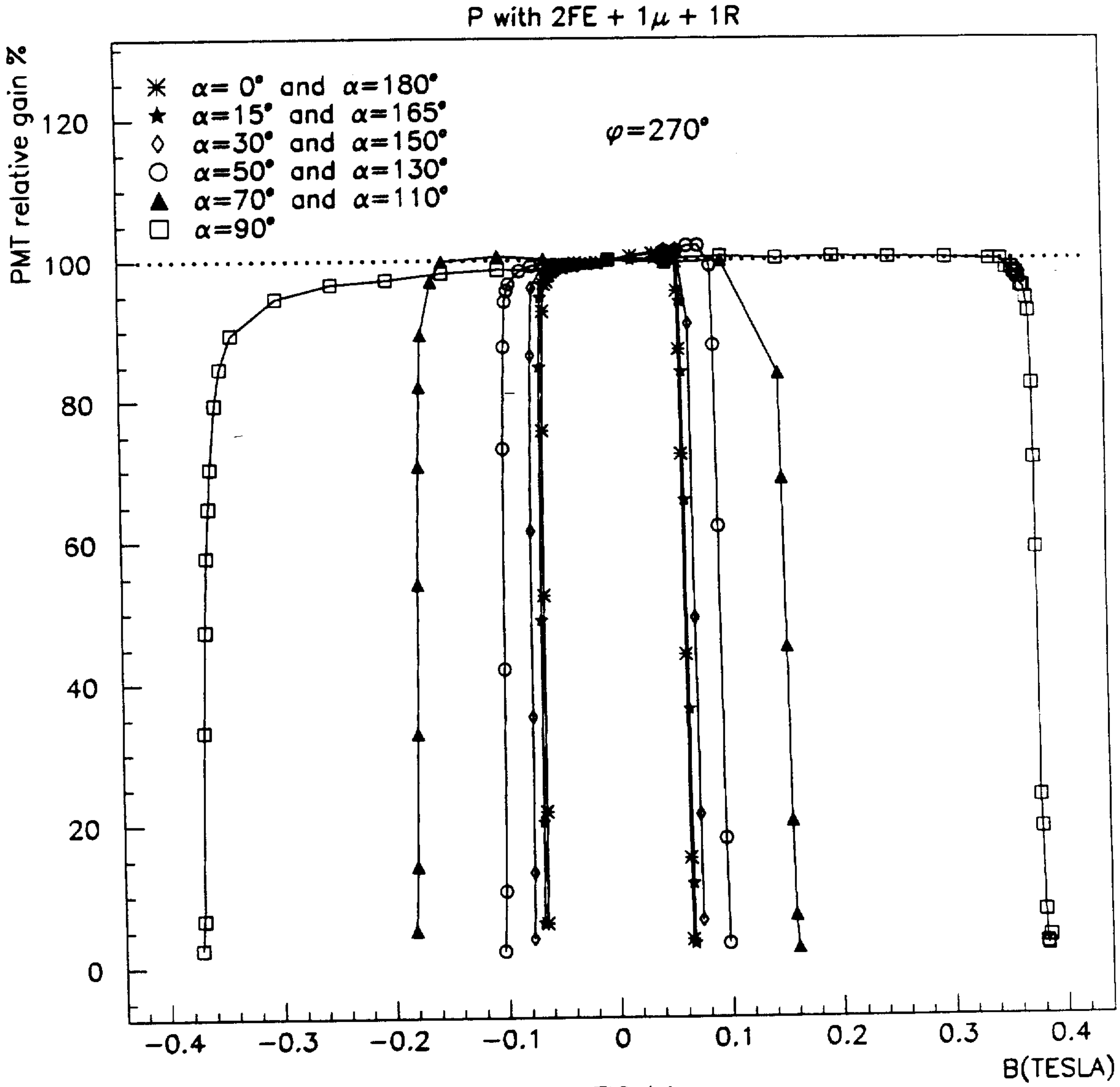

H with 1FE
PMT relative gain %
φ=270°
φ=180°
φ=90°
φ=0°
α=90°
180
160
140
120
100
80
60
40
20
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
B(TESLA)

FIG.12



H with 1FE + 1μ
PMT relative gain %
case A
case B
α=90° and φ=90°
180
160
140
120
100
80
60
40
20
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
B(TESLA)

FIG.13



P with 2FE + 1μ + 1R
PMT relative gain %
α= 0° and α=180°
α=15° and α=165°
α=30° and α=150°
α=50° and α=130°
α=70° and α=110°
α=90°
φ=270°
120
100
80
60
40
20
0
−0.4
−0.3
−0.2
−0.1
0
0.1
0.2
0.3
0.4
B(TESLA)

FIG.14

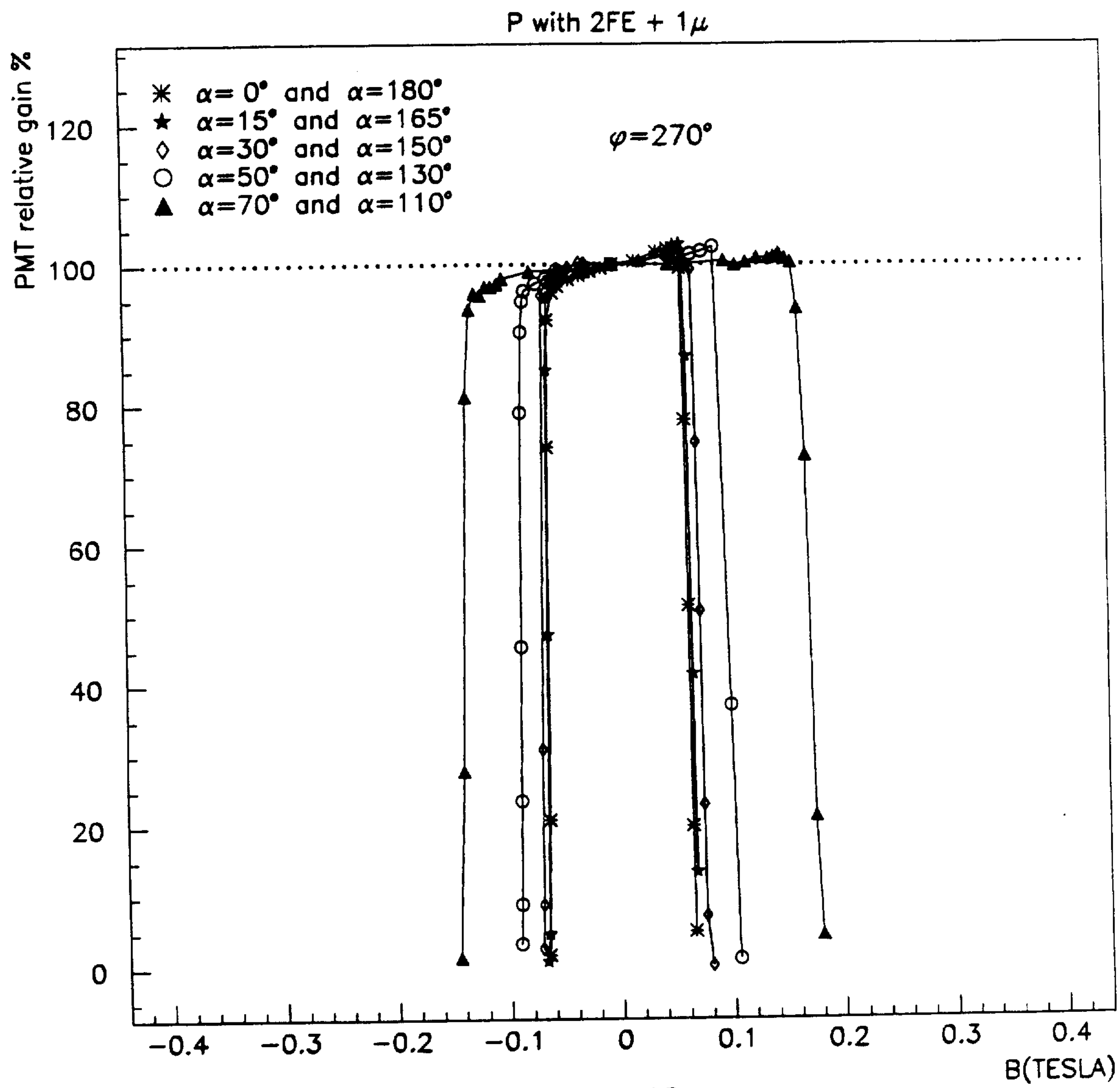

P with 2FE + 1μ
PMT relative gain %
α= 0° and α=180°
α=15° and α=165°
α=30° and α=150°
α=50° and α=130°
α=70° and α=110°
φ=270°
120
100
80
60
40
20
0
−0.4
−0.3
−0.2
−0.1
0
0.1
0.2
0.3
0.4
B(TESLA)

FIG.15

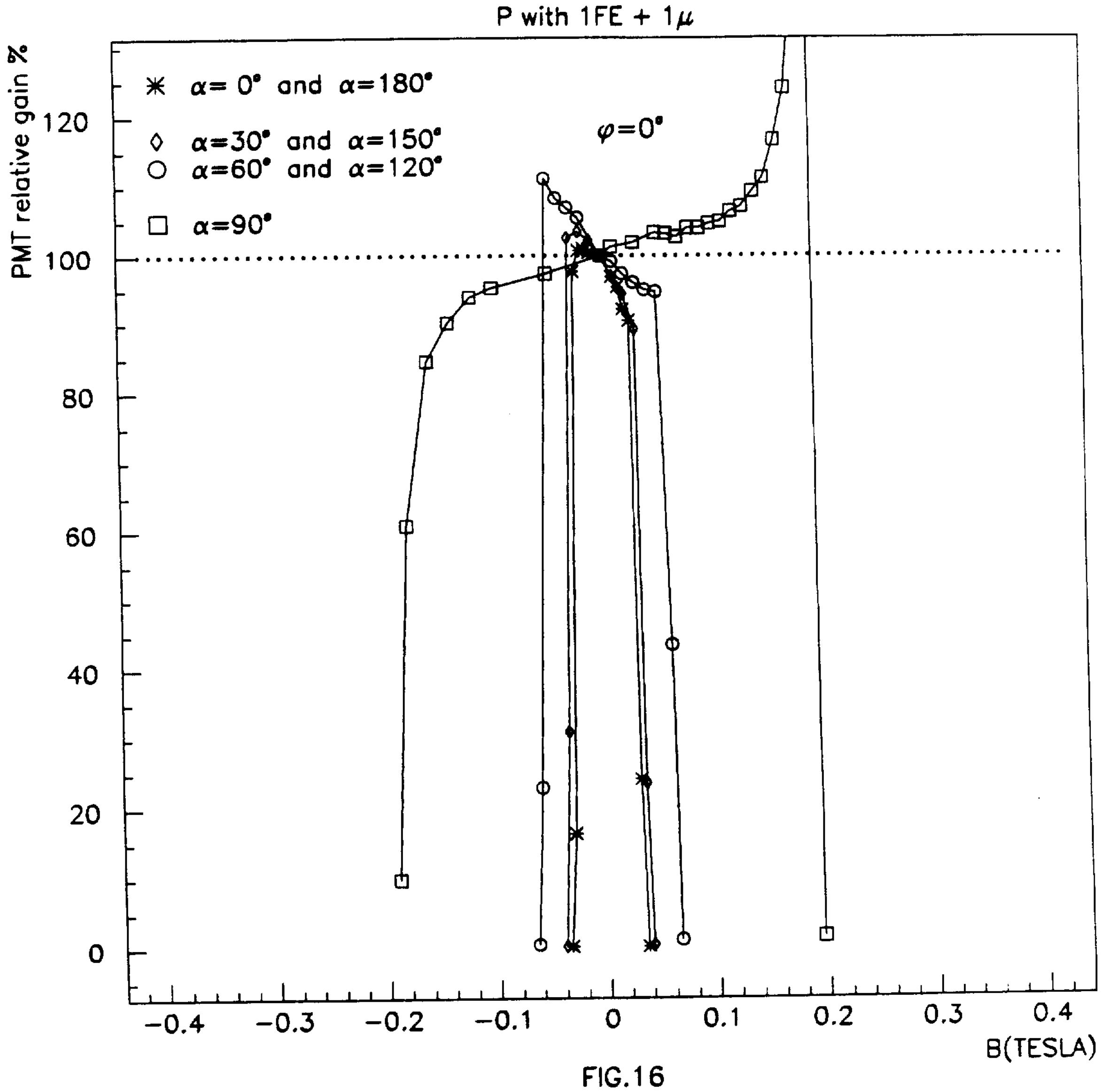
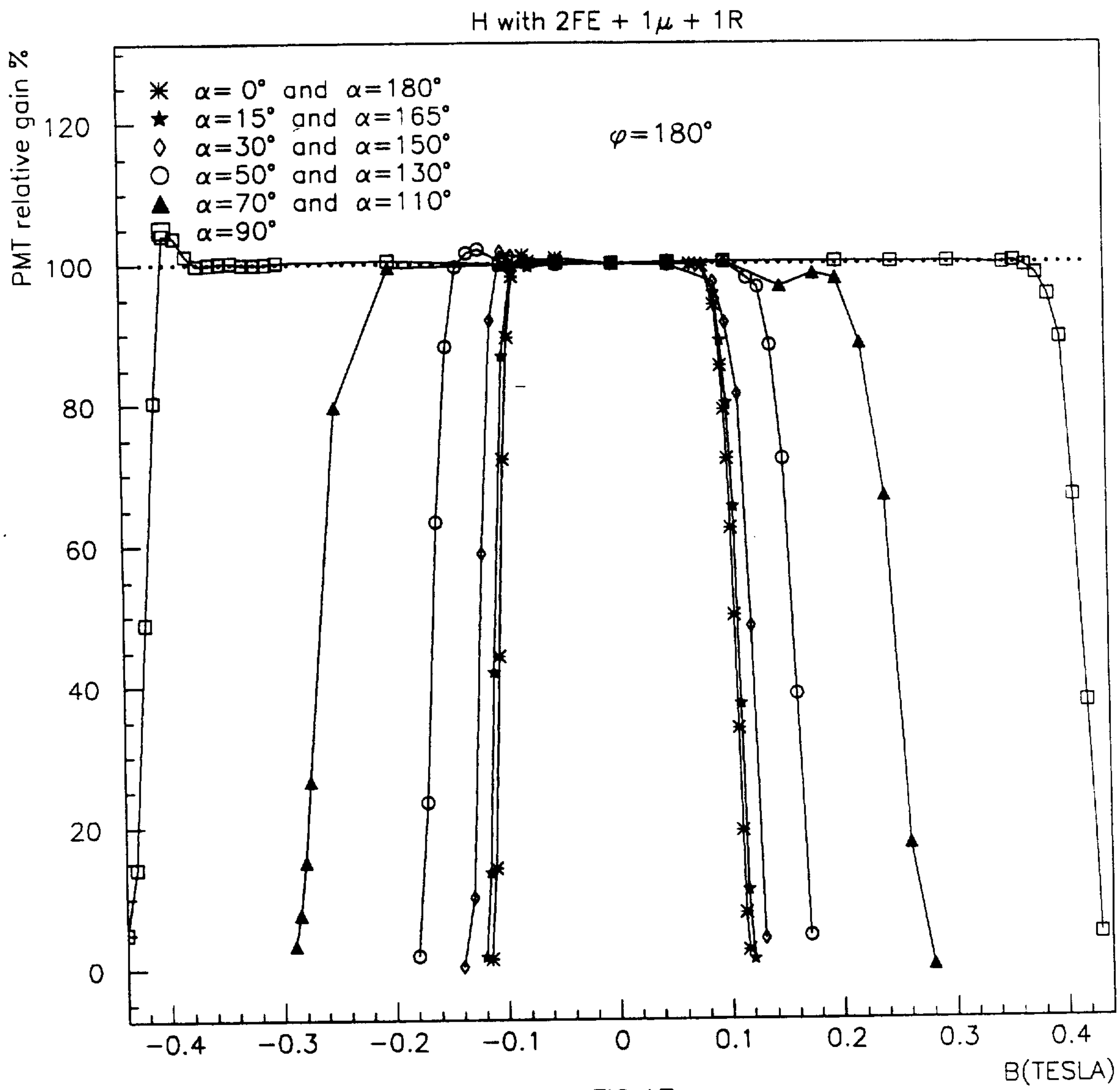

P with 1FE + 1μ
PMT relative gain %
α= 0° and α=180°
α=30° and α=150°
α=60° and α=120°
α=90°
φ=0°
120
100
80
60
40
20
0
−0.4
−0.3
−0.2
−0.1
0
0.1
0.2
0.3
0.4
B(TESLA)

FIG.16



H with 2FE + 1μ + 1R
PMT relative gain %
α= 0° and α=180°
α=15° and α=165°
α=30° and α=150°
α=50° and α=130°
α=70° and α=110°
α=90°
φ=180°
120
100
80
60
40
20
0
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
B(TESLA)

FIG.17

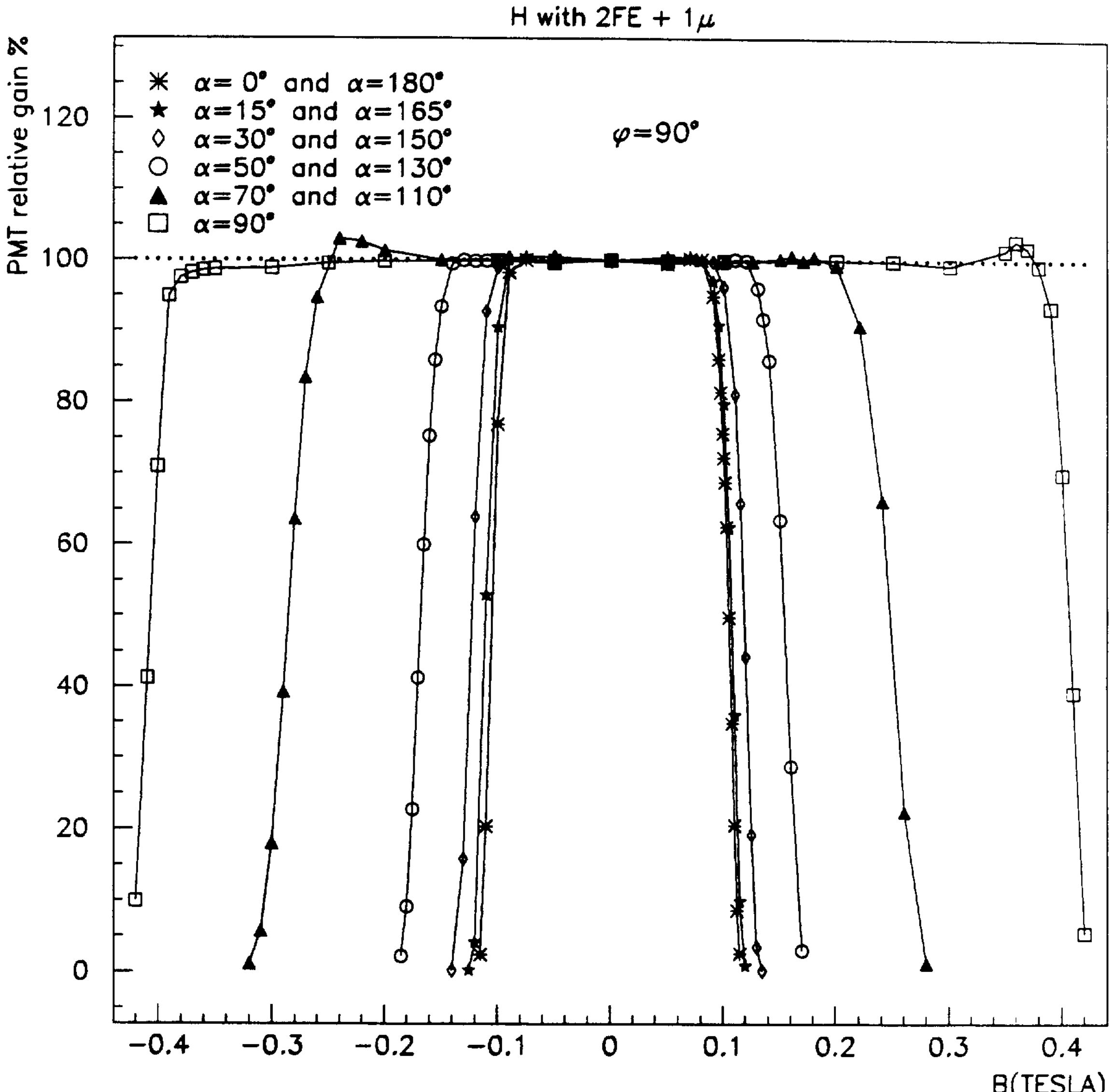

H with 2FE + 1μ
PMT relative gain %
α= 0° and α=180°
α=15° and α=165°
α=30° and α=150°
α=50° and α=130°
α=70° and α=110°
α=90°
φ=90°
120
100
80
60
40
20
0
−0.4
−0.3
−0.2
−0.1
0
0.1
0.2
0.3
0.4
B(TESLA)

FIG.18

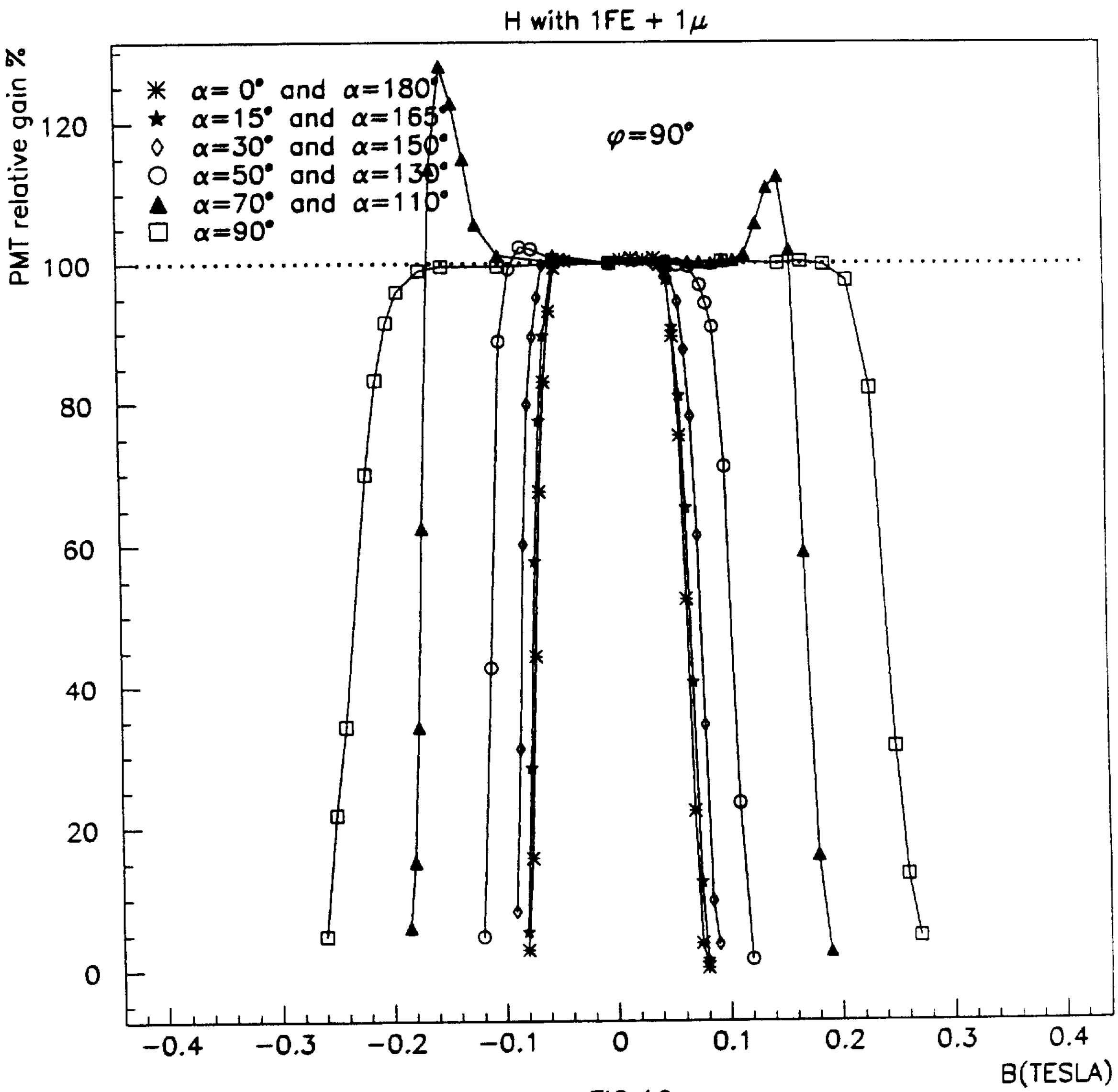

H with 1FE + 1μ
PMT relative gain %
α= 0° and α=180°
α=15° and α=165°
α=30° and α=150°
α=50° and α=130°
α=70° and α=110°
α=90°
φ=90°
120
100
80
60
40
20
0
−0.4
−0.3
−0.2
−0.1
0
0.1
0.2
0.3
0.4
B(TESLA)

FIG.19

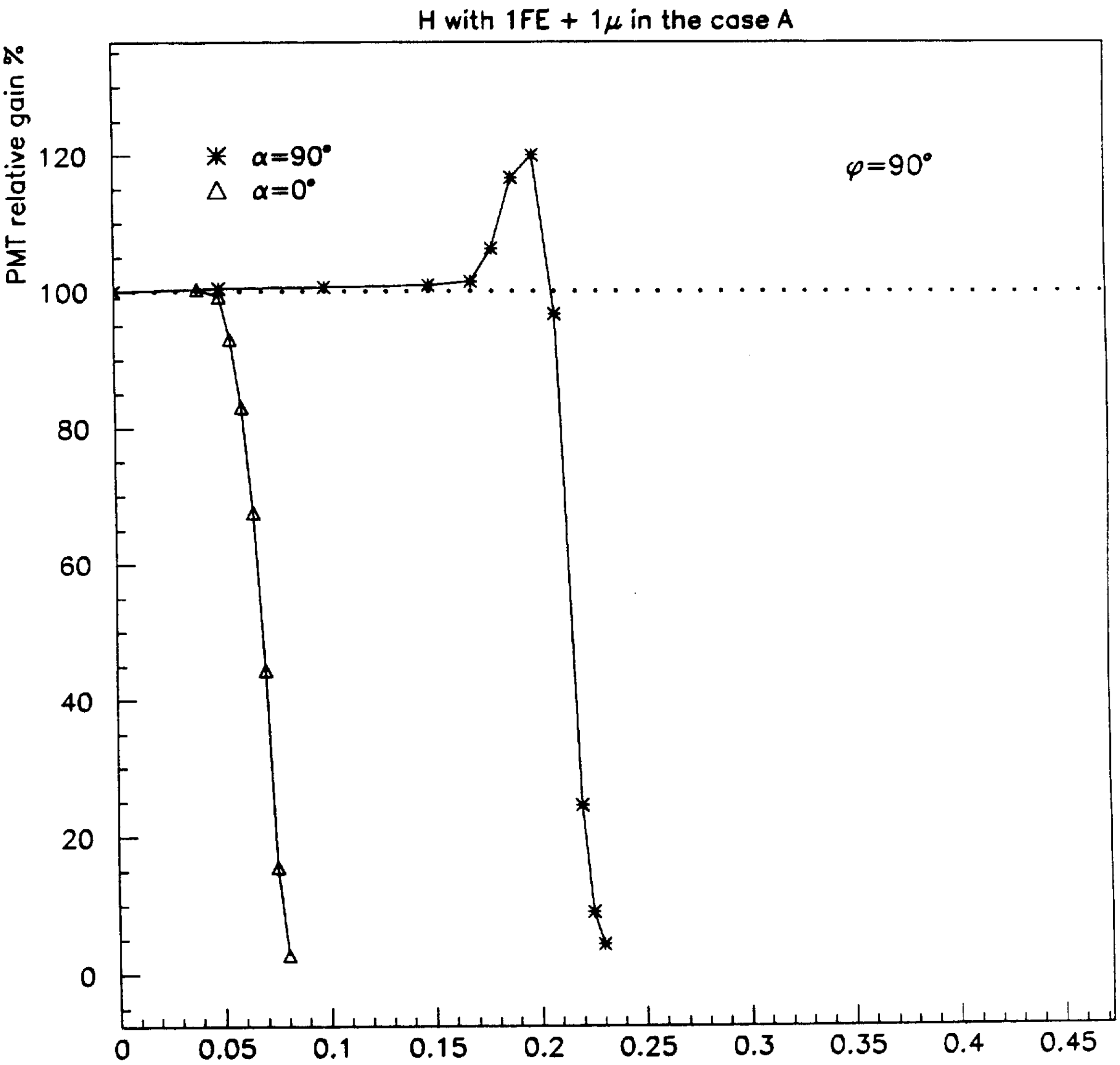

H with 1FE + 1μ in the case A
PMT relative gain %
α=90°
α=0°
φ=90°
0
20
40
60
80
100
120
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
B(TESLA)

FIG.21A

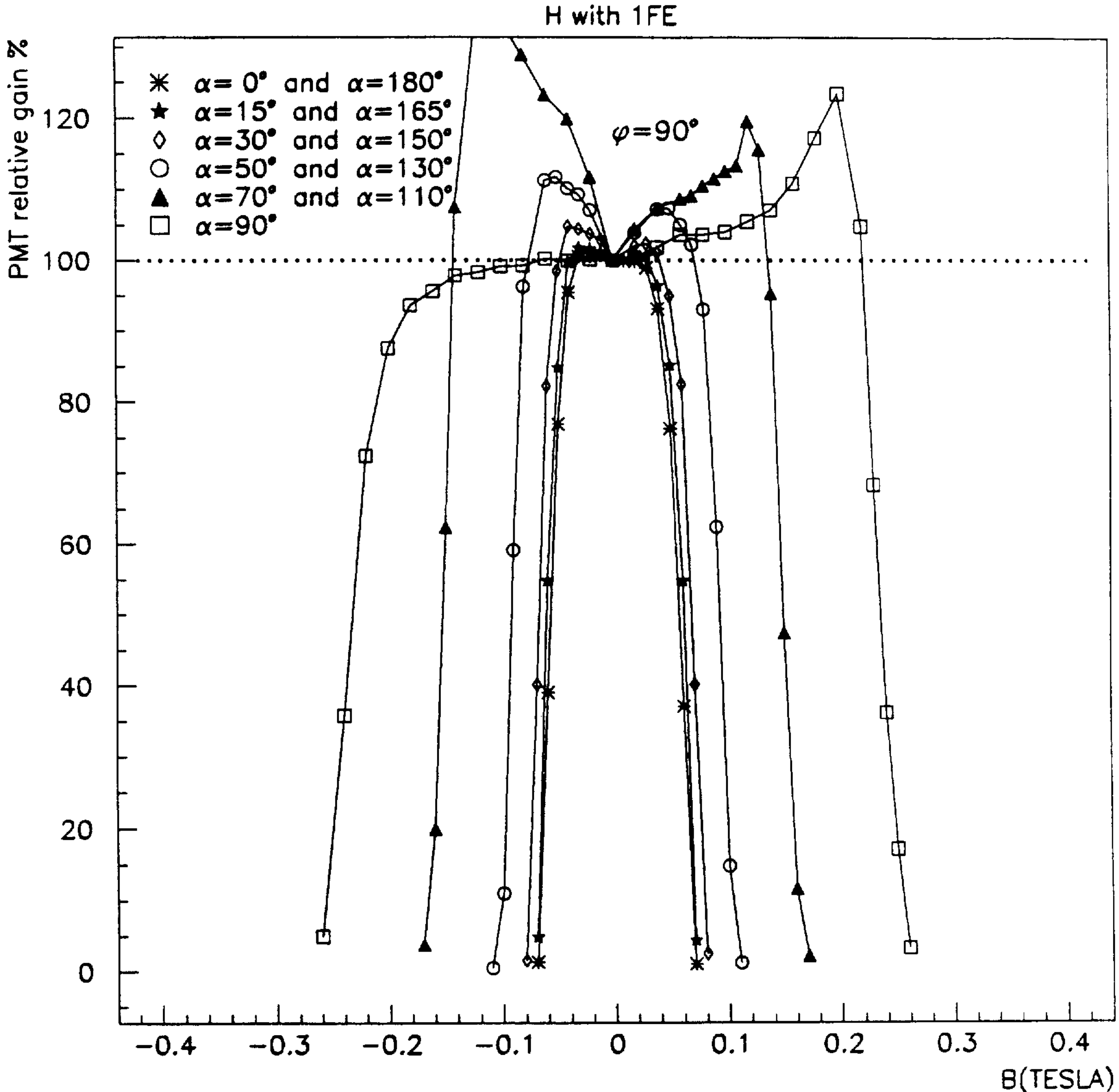

H with 1FE
PMT relative gain %
B(TESLA)
α= 0° and α=180°
α=15° and α=165°
α=30° and α=150°
α=50° and α=130°
α=70° and α=110°
α=90°
φ=90°
0
20
40
60
80
100
120
−0.4
−0.3
−0.2
−0.1
0
0.1
0.2
0.3
0.4

FIG.20

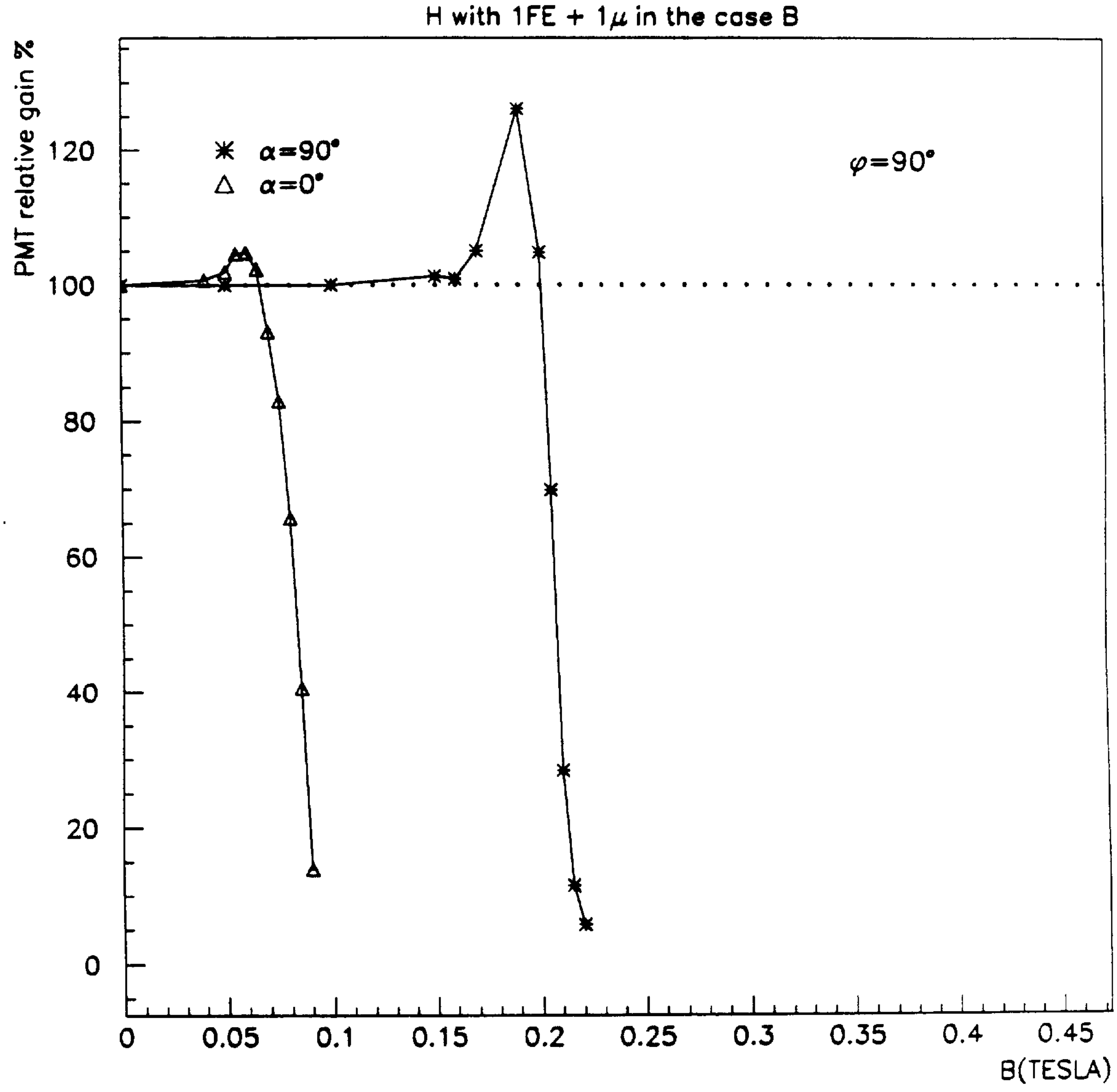

H with 1FE + 1μ in the case B
PMT relative gain %
α=90°
α=0°
φ=90°
120
100
80
60
40
20
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
B(TESLA)

FIG.21B