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Performance test of $PbWO_4$ Cherenkov detector

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1) Active degrader in E787/E949

- ***) Role of active degrader,**
- ***) Necessity of heavy and radiation-hard Cherenkov radiators**

2) A promising candidate:

- ***) $PbWO_4$ heavily doped with 3+ RE ions (La^{3+}. Y^{3+}, Gd^{3+}, etc.)**

3) Performance with radioisotopes

4) Beam test on light yield

5) Summary

Active Degrader for E787/E949

(1) Degrade K^+ energy (as an absorber)

(2) **K/π separation** (as a threshold Ch. counter or any other detector)

(3) **γ-ray veto (as EM** calorimeter)

Material for active degrader

	SF5	**SF5:Ce**	SF6	PbF_2	**$PbWO_4:R^{3+}$**
X_0(cm)	2.55	2.55	1.69	0.93	0.89
n	1.67	1.67	1.81	1.82	2.2
Rad. Hardness (rad)	10^{3-4}	10^{4-5}	10^{2-3}	10^{4-5}	10^{7-8}
λ(cutoff) (nm)	340	360	360	245	(325→)350

Quality of ideal active degraders (Cherenkov radiators):

1) heavy (**for efficient** γ-veto)

2) **reasonably small** n <1.7-1.8 (for π/K separation)

3) radiation **resistant** up to $>10^7$ rad

However, **Usually** 1) and 2) don't match each other.---> compromise!

PWO28T.doc 00/05/24

Table 1 Characteristics of typical Cherenkov radiators. R^{3+} in PWO:R^{3+} denotes La^{3+}, Gd^{3+}, Y^{3+}, etc.

Quantity	PWO:R^{3+}	SF5 (PbO:50%) [3]	SF6 (PbO:75%) [3]	PbF_2 [6]	$BaYb_2F_8$ [7]	Cd_2F:Ce (Ce 0.5%) [8]	$NaBi(WO_4)_2$ [9]
Density (g/cm3)	8.28	4.07	5.19	7.77	7.0	6.38	7.57
Radiation length X_0 (cm)	0.89	2.55	1.69	0.93	1.28	1.73	0.98
Index of refraction	2.2	1.67	1.81	1.82	1.76	1.55	2.15
Cutoff in T(%) (nm)	320	340	360	245	230	320	360
Hygroscopicity	no	no	no	no	no	no	no
Melting point (°C)	1123	442	455	822		1090	950
Radiation-hardness(rad)	10^{7-8}	10^{3-4}	10^{2-3}	10^{4-5}	$<10^7$	10^7	10^6
2 1 Hardness (Mohs)	3			~3		3.5	6
Cleavage	(101)	none	none	(111)		none	
Available length* (X_0)	30	large	large	14	small	small	>10
Moliere radius(cm)	2.19			2.21	2.44	-	2.66

*) only approximate numbers.

○ 放射線に強く重いチェレンコフ radiator がないか？

Any heavy, radiation-hard Cherenkov radiators ?

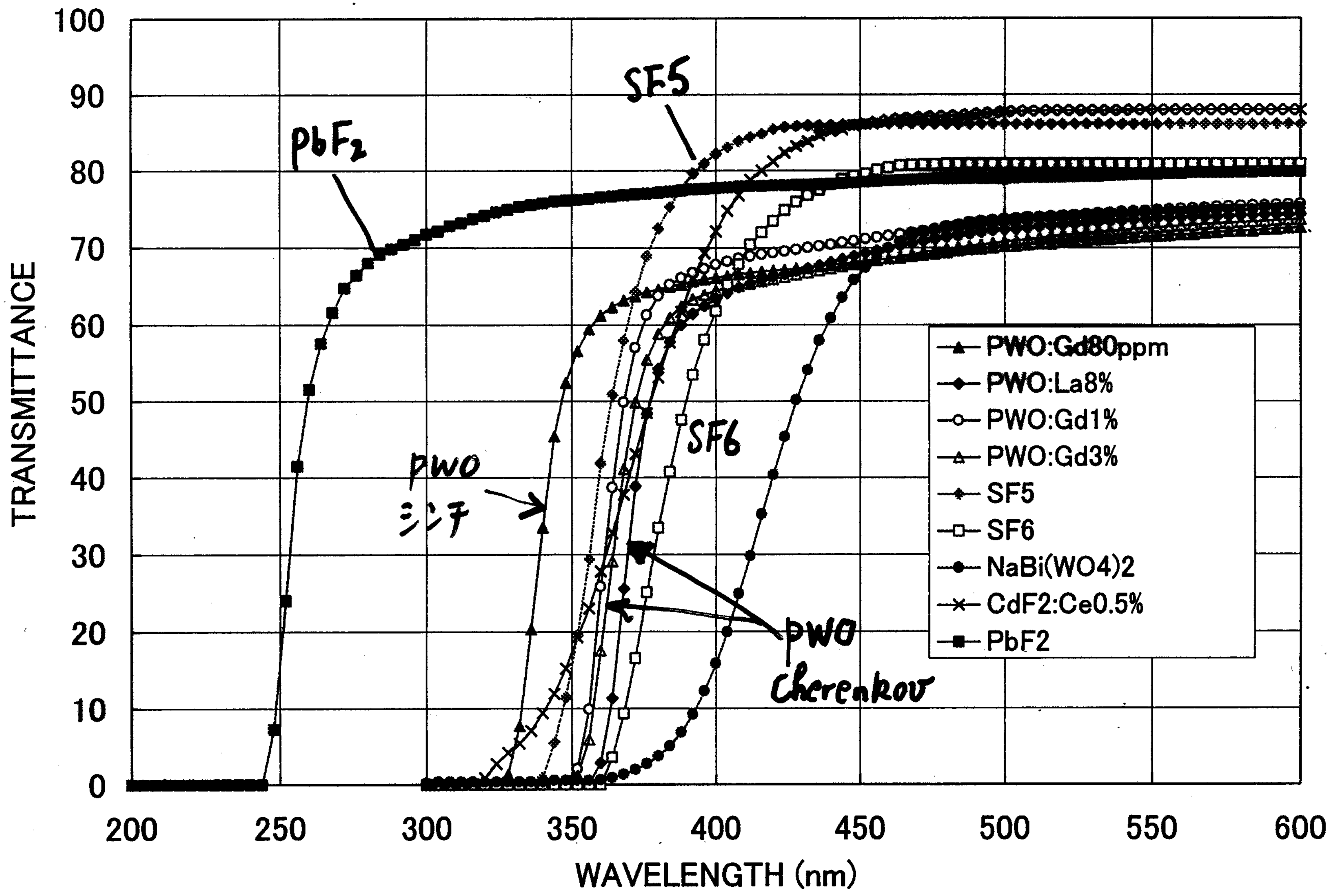
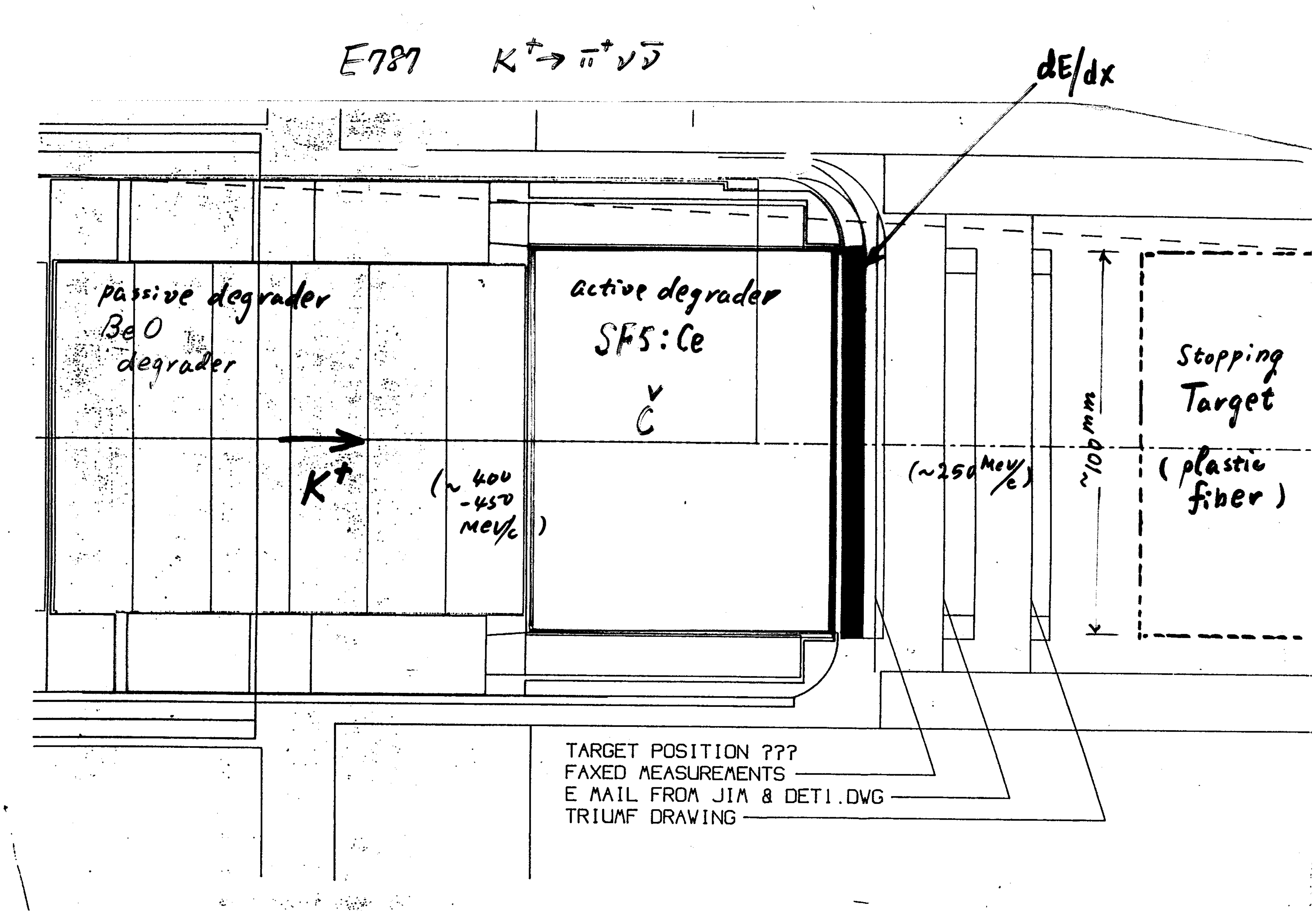

100
90
80
70
60
50
40
30
20
10
0
TRANSMITTANCE
200
250
300
350
400
450
500
550
600
WAVELENGTH (nm)
PWO:Gd80ppm
PWO:La8%
PWO:Gd1%
PWO:Gd3%
SF5
SF6
NaBi(WO4)2
CdF2:Ce0.5%
PbF2
PbF2
SF5
SF6
PWO
シンチ
PWO
Cherenkov

Fig. 3c

Characteristics of typical scintillators.

Quantity	NaI:Tl	CsI:Tl	CWO	BGO	BSO	GSO:Ce	PWO:La
Density (g/cm^3)	3.67	4.53	7.90	7.13	6.80	6.71	8.2
Radiation length X_0 (cm)	2.59	1.86	1.06	1.12	1.15	1.38	0.92
Decay constant (ns)	230	1050	5000	300	100	30-60	<10/<40
Peak emission (nm)	415	550	470/540	480	480	440	420
Light yield (relative)	100	85	38	7-10	2	20	0.26/0.04
Radiation hardness (rad)	10^3	10^3	10^3	10^{4-5}	10^{5-7}	$>10^8$	10^{7-8}
XCT	◌	○	○	◌	—	○	—
PET	◌	—	—	○	—	○	◌
Nuclear, HE Experiments	○	○	—	○	○	○	○


E787 $K^+ \to \pi^+ \nu \bar{\nu}$
dE/dx
passive degrader
BeO
degrader
K^+
(~400 -450 MeV/c)
active degrader
SF5:Ce
Č
(~250 MeV/c)
~100 mm
Stopping
Target
(plastic fiber)
TARGET POSITION ???
FAXED MEASUREMENTS
E MAIL FROM JIM & DET1.DWG
TRIUMF DRAWING

^{60}Co-γ rays

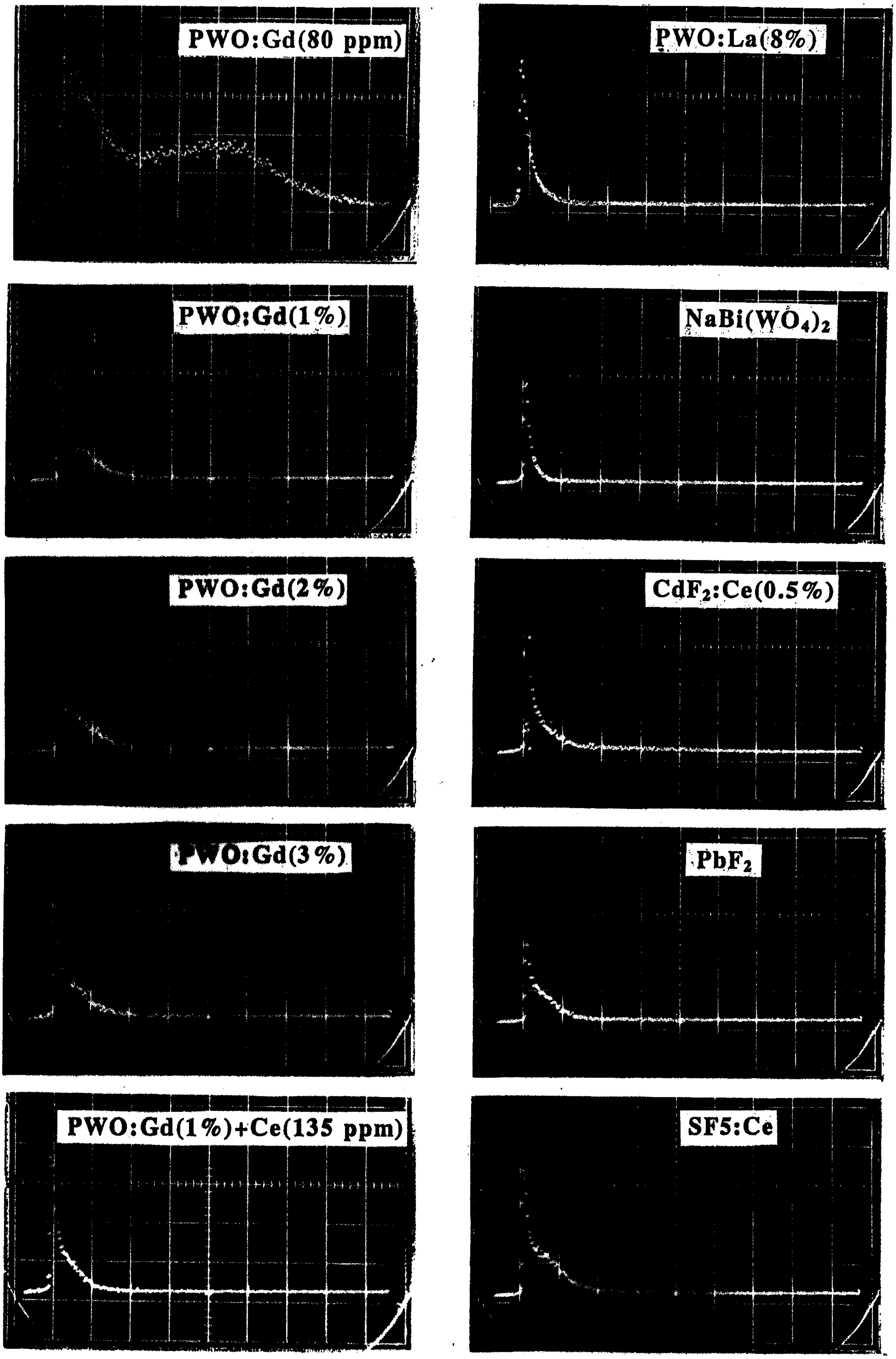
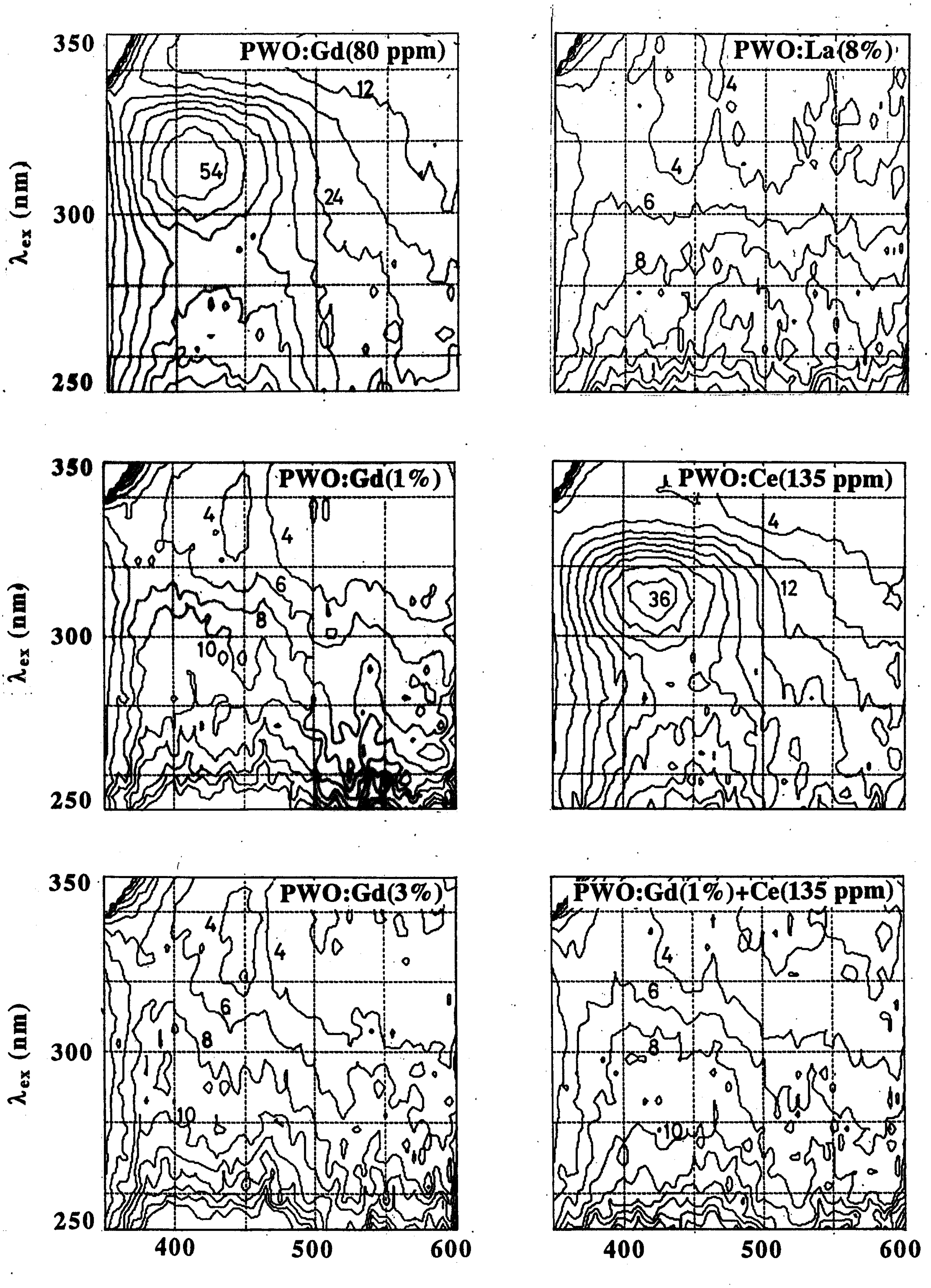
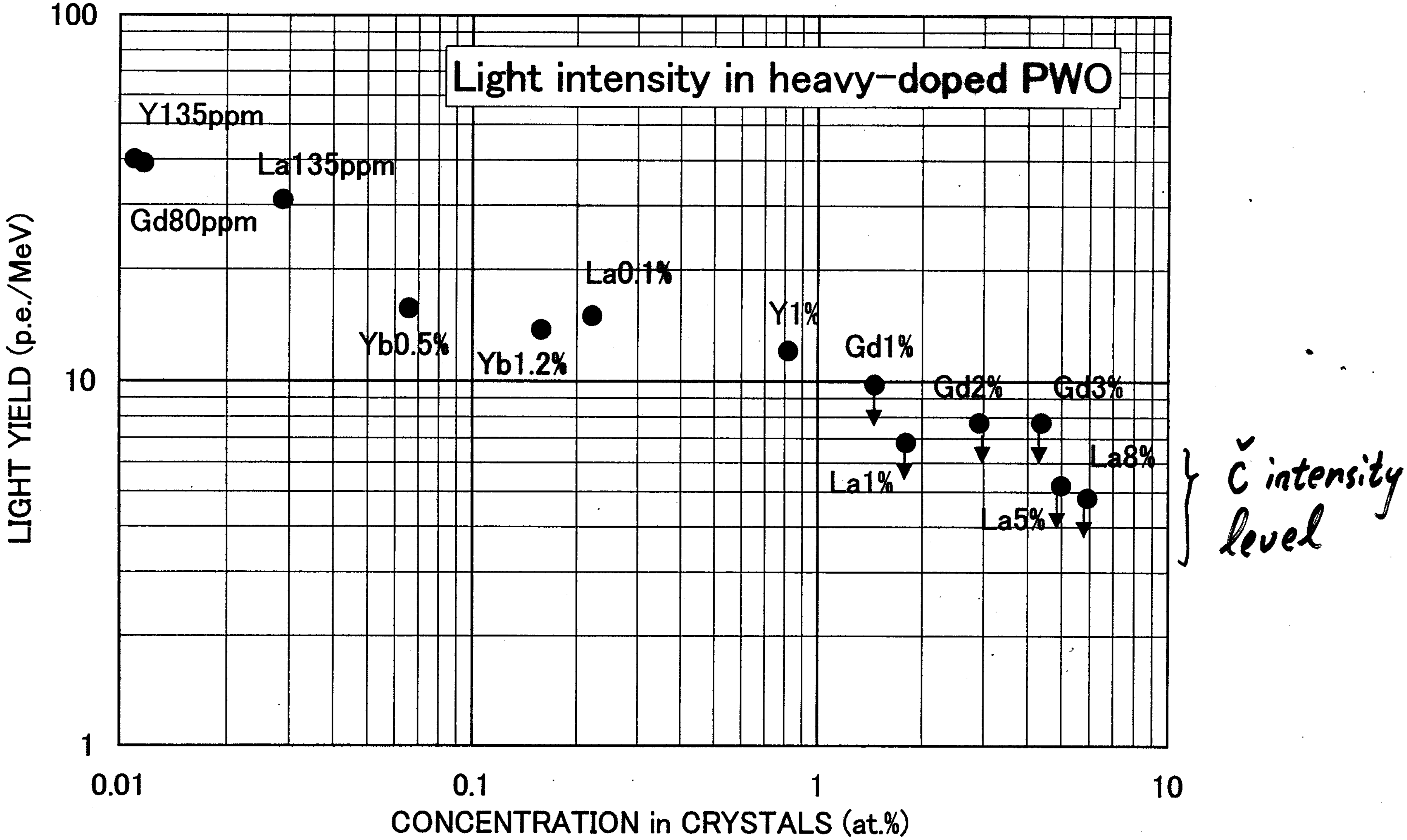


Fig 4



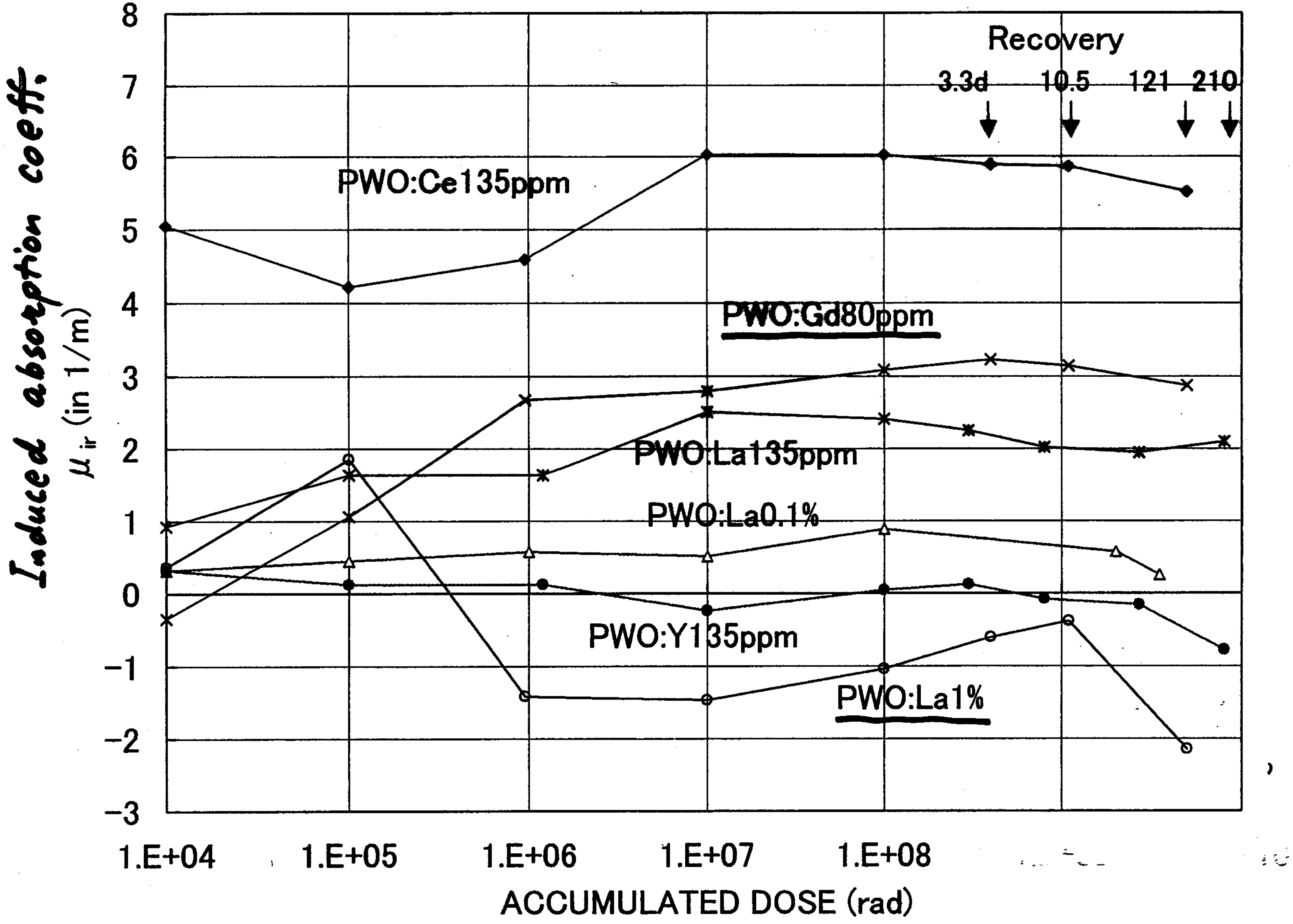
PWO:Gd(80 ppm)
PWO:La(8%)
PWO:Gd(1%)
PWO:Ce(135 ppm)
PWO:Gd(3%)
PWO:Gd(1%)+Ce(135 ppm)
λex (nm)
λem (nm)
350
300
250
400
500
600

7.1



Light intensity in heavy-doped PWO
LIGHT YIELD (p.e./MeV)
100
10
1
0.01
0.1
1
10
CONCENTRATION in CRYSTALS (at.%)
Y135ppm
La135ppm
Gd80ppm
Yb0.5%
Yb1.2%
La0.1%
Y1%
Gd1%
La1%
Gd2%
Gd3%
La5%
La8%
Č intensity level

Fig. 5



$T = T_0 e^{-\mu_{ir} d}$

T = 透過率

d = 結晶厚さ(長さ)

Fig. 7

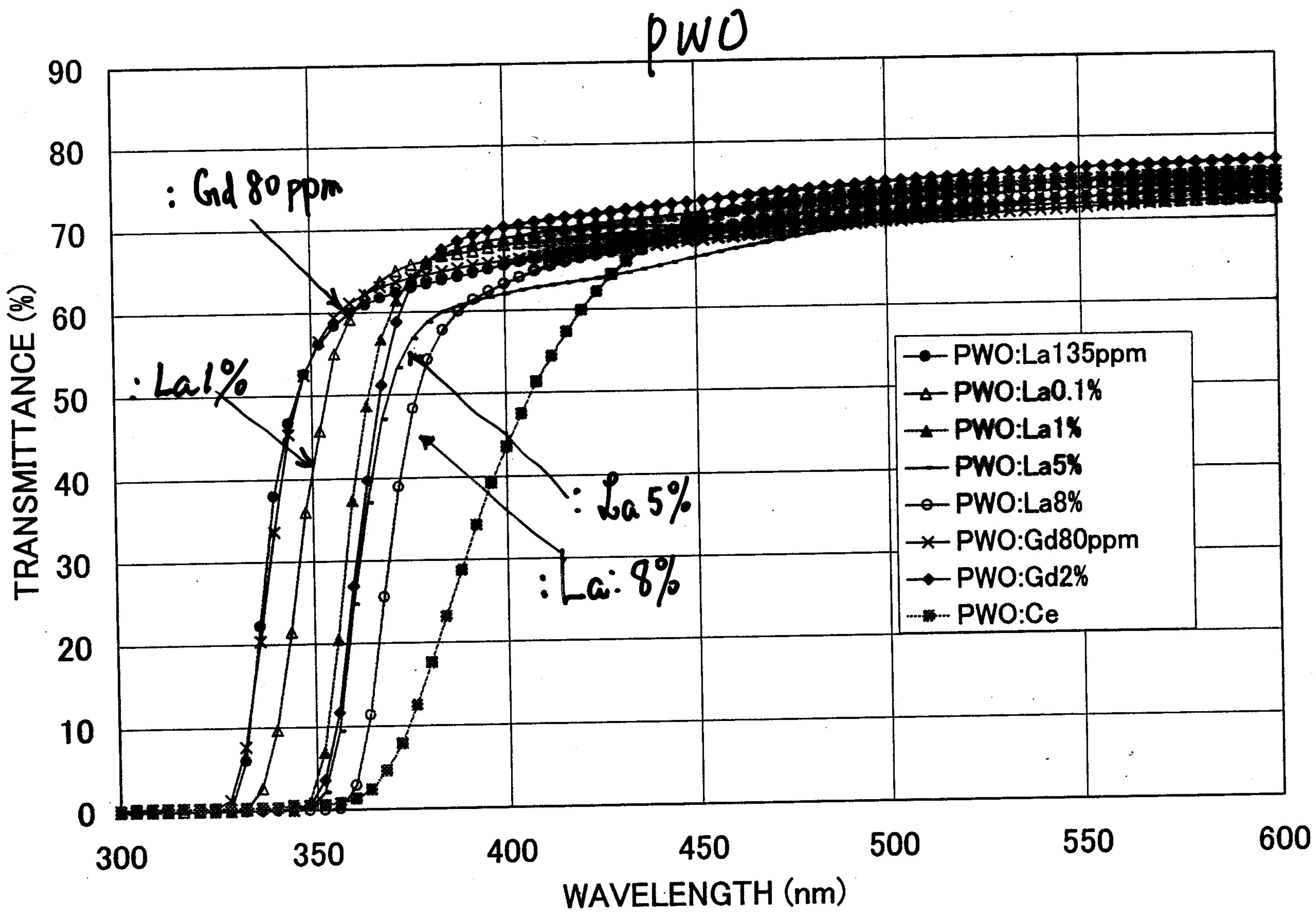

PWO
TRANSMITTANCE (%)
WAVELENGTH (nm)
90
80
70
60
50
40
30
20
10
0
300
350
400
450
500
550
600
: Gd 80 ppm
: La1%
: La 5%
: La: 8%
PWO:La135ppm
PWO:La0.1%
PWO:La1%
PWO:La5%
PWO:La8%
PWO:Gd80ppm
PWO:Gd2%
PWO:Ce

Fig. 3b

Test of $PbWO^4$:R^{3+} (R=La or Gd or Y) without beam

*) Excellent scintillator for dopant concentration ~ 100 ppm level

*) Small shift of λ(cutoff) even for heavy doping.

*) Can be converted to Cherenkov radiator by 1-10% doping

-- scintillation light yield is reduced below Cherenkov level

*) No significant degradation in radiation hardness,.

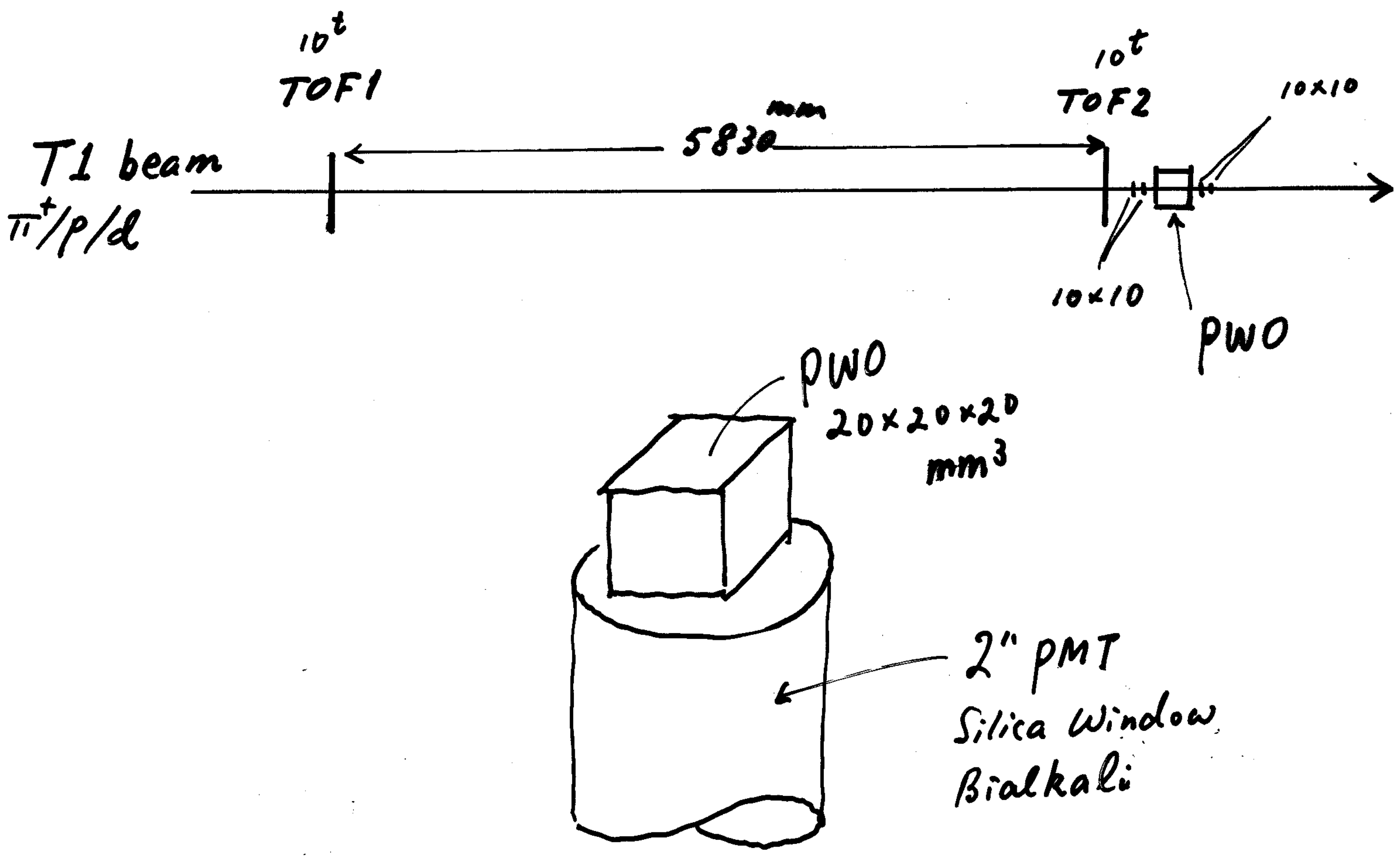
Carried out a beam test for more precise conclusion.

Sample size: 2x2x2 cm3

Samples:
- PWO:La(8at.%) as a Cherenkov radiator
- PWO:La(5at.%) as a " "
- PWO:Gd(3at.%) as a " "
- PWO:Gd(80at.ppm) as atypical scintillator

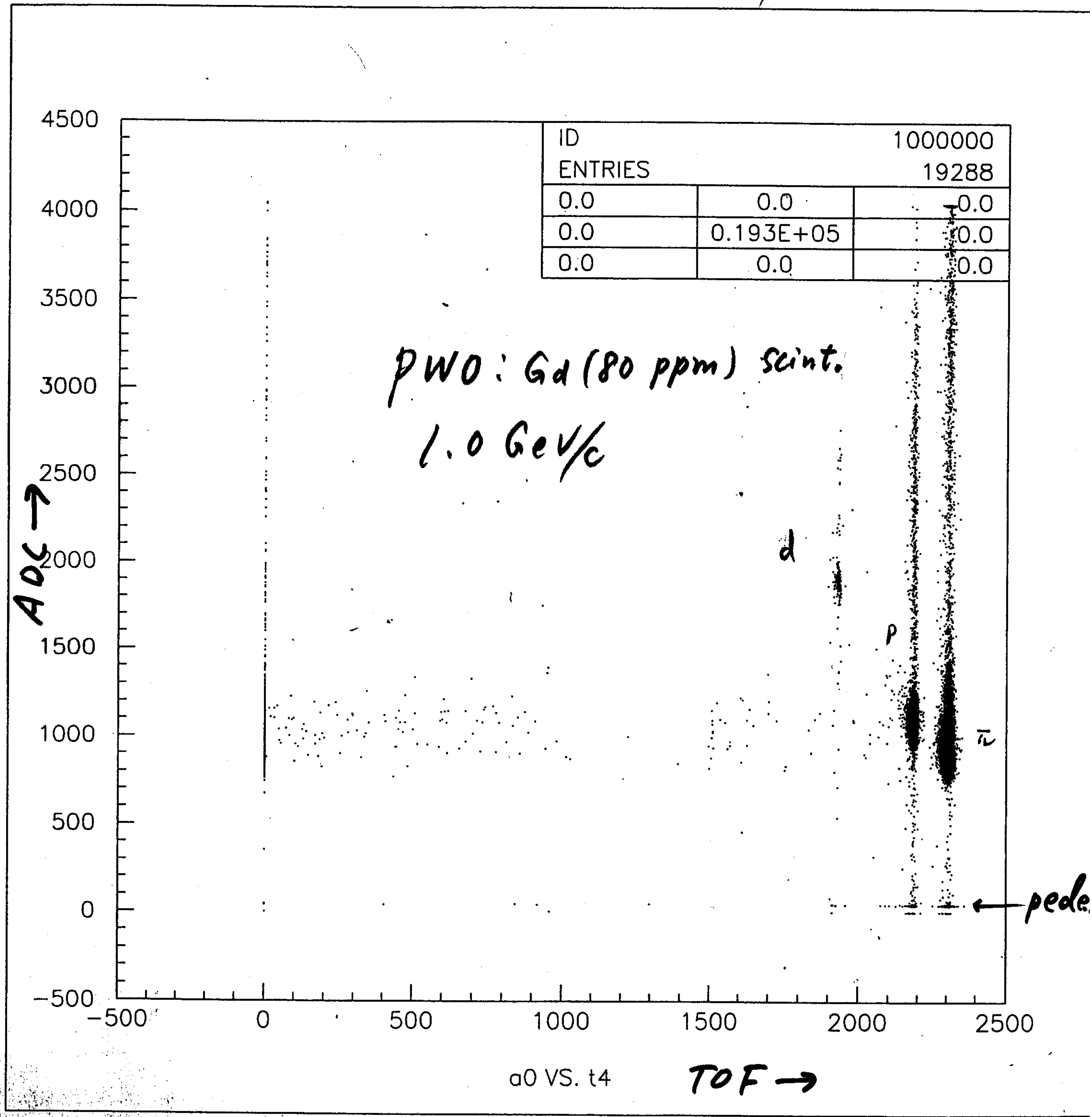
Beam: T1 **beam at KEK-PS**

0.5-1 GeV/c π^+, p, d beam.



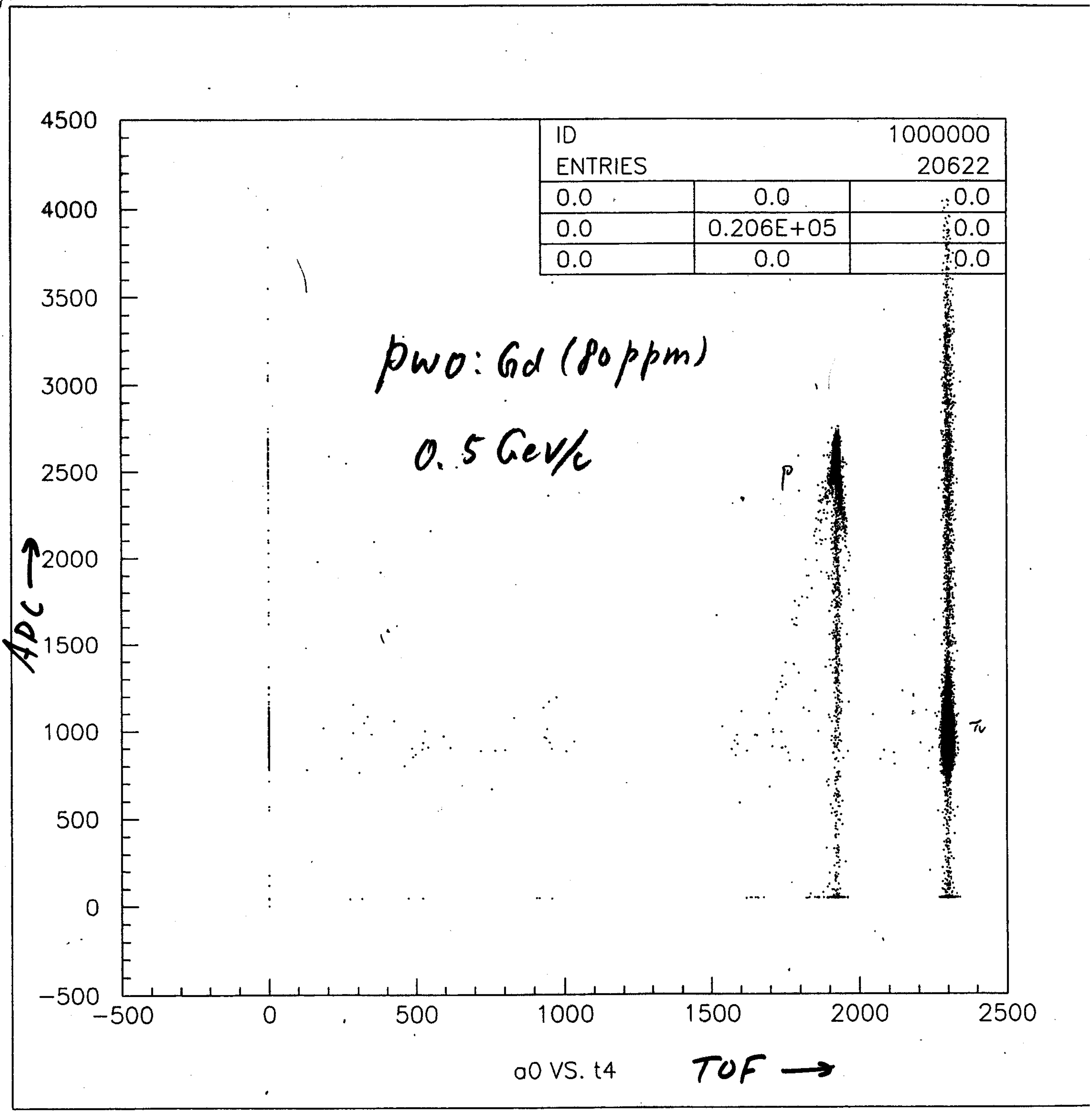
T1 beam
π+/p/d
10t
TOF1
5830mm
10t
TOF2
10×10
10×10
PWO
PWO
20×20×20
mm3
2" PMT
Silica Window
Bialkali

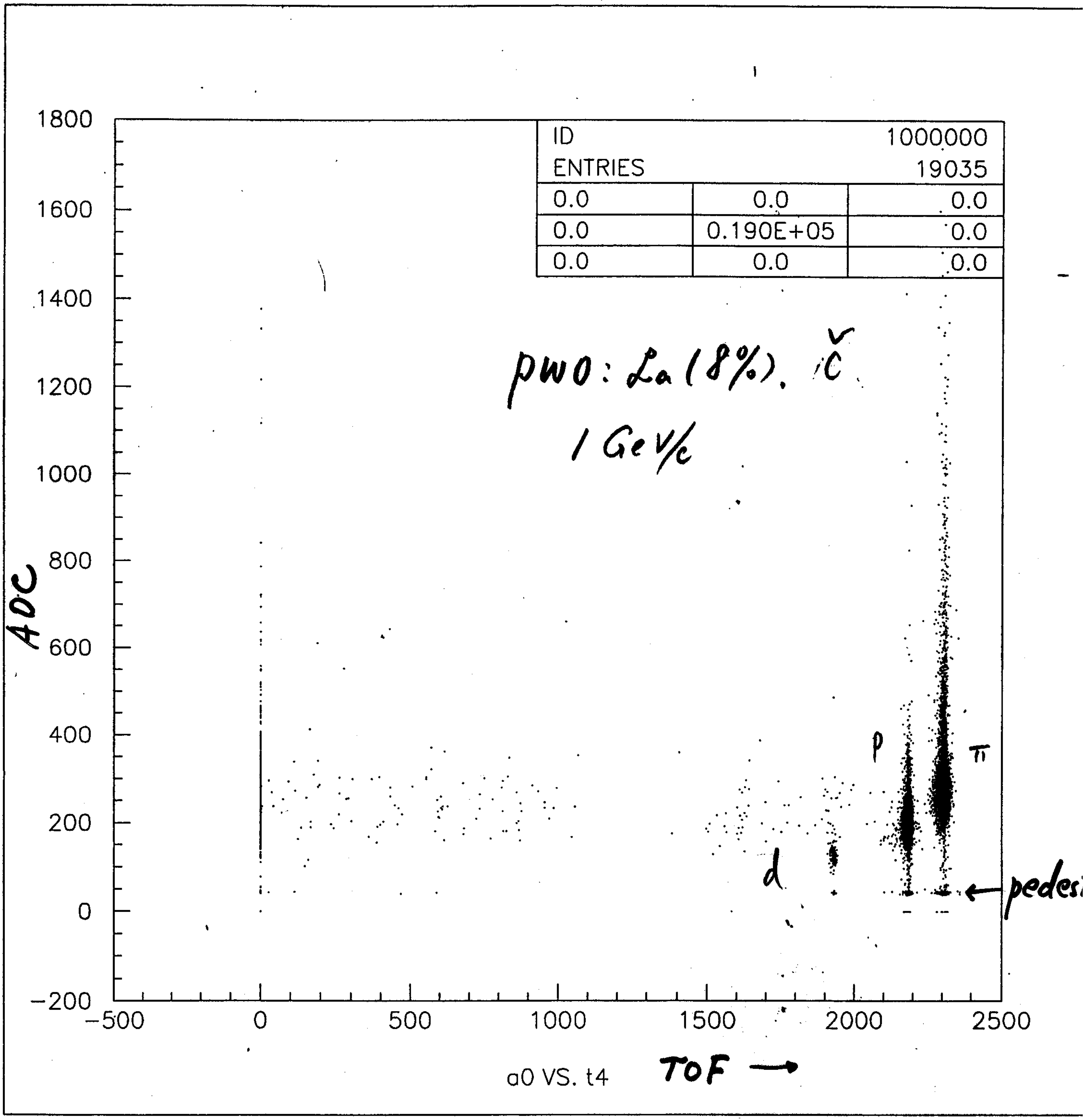
PWO
$2\times2\times2\ cm^3$
1 GeV/c



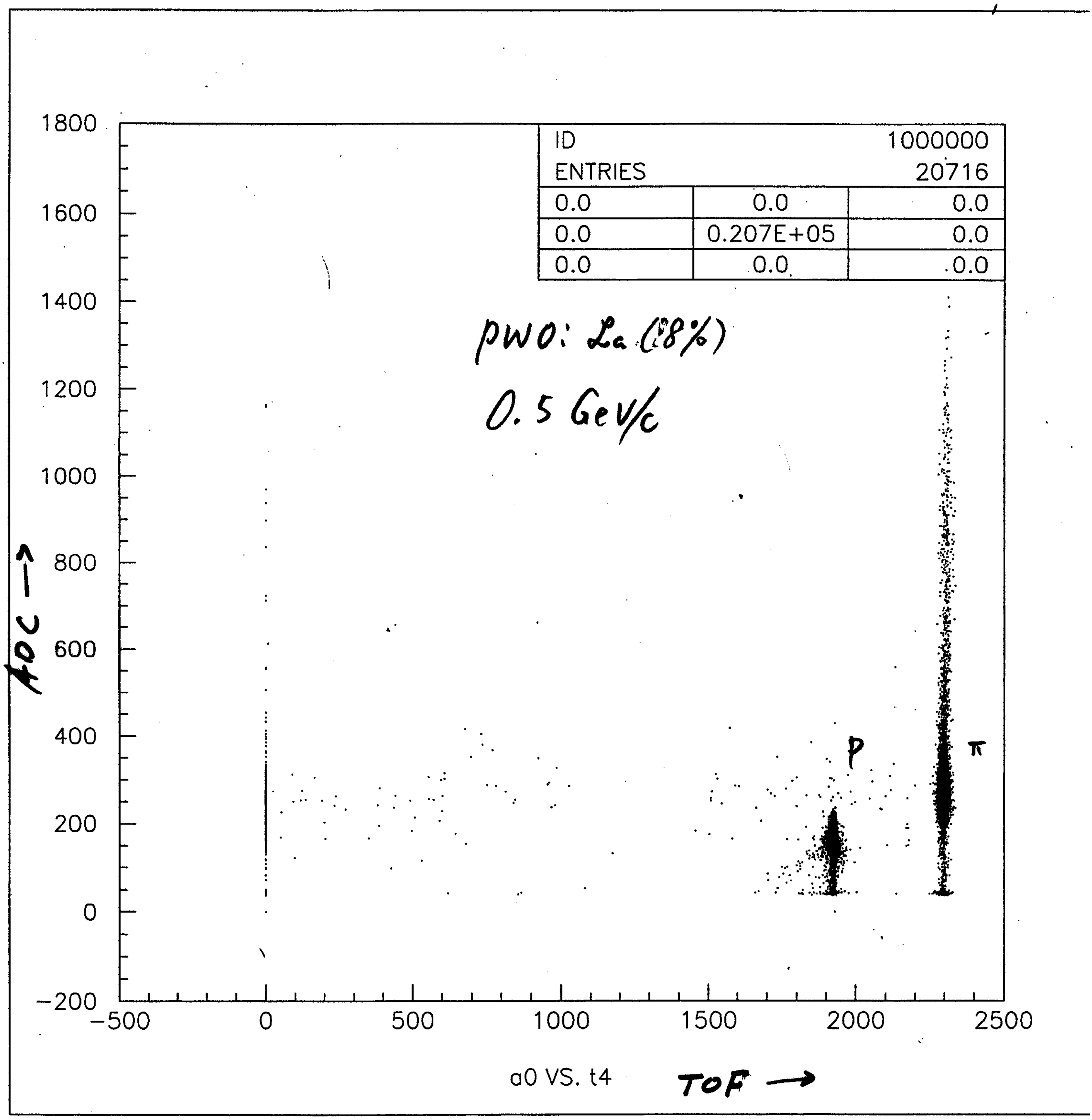
0.5 GeV/c 00/11/27

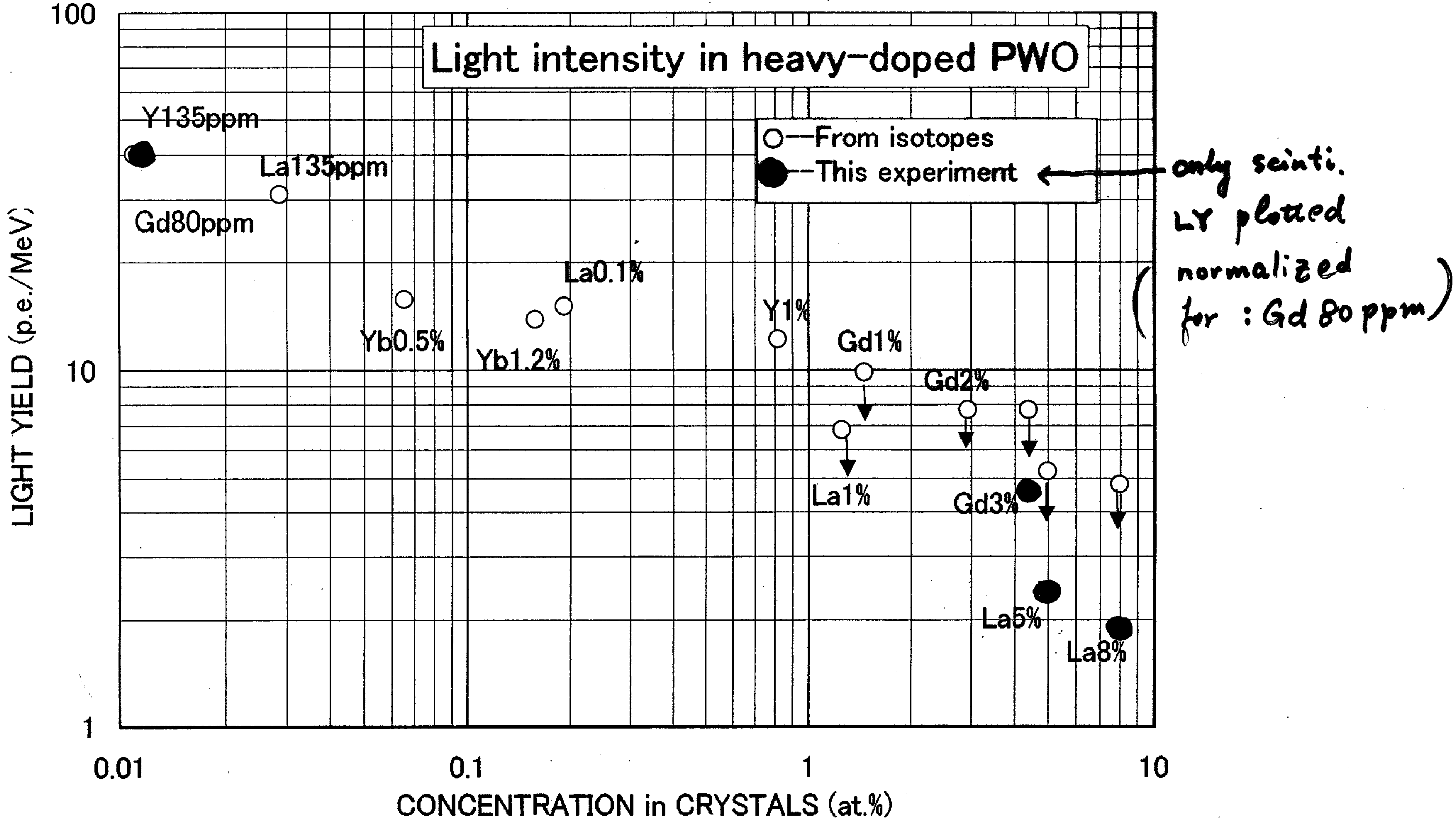
raw374.txt





ID 1000000
ENTRIES 19035
0.0 0.0 0.0
0.0 0.190E+05 0.0
0.0 0.0 0.0
PWO: La (8%). Č
1 GeV/c
ADC
TOF →
a0 VS. t4
p
π
d
← pedes
1800
1600
1400
1200
1000
800
600
400
200
0
−200
−500
0
500
1000
1500
2000
2500


ID 1000000
ENTRIES 20716
0.0 0.0 0.0
0.0 0.207E+05 0.0
0.0 0.0 0.0
PWO: La
0.5 GeV/c
ADC →
p
π
a0 VS. t4
TOF →
1800
1600
1400
1200
1000
800
600
400
200
0
−200
−500
0
500
1000
1500
2000
2500


Light intensity in heavy-doped PWO
From isotopes
This experiment
only scinti. LY plotted
(normalized for : Gd 80 ppm)
Y135ppm
La135ppm
Gd80ppm
Yb0.5%
Yb1.2%
La0.1%
Y1%
Gd1%
La1%
Gd2%
Gd3%
La5%
La8%
100
10
1
0.01
0.1
1
10
LIGHT YIELD (p.e./MeV)
CONCENTRATION in CRYSTALS (at.%)

Summary

$PbWO^4$:R^{3+} (R=La or Gd or Y)

1) Excellent scintillator for dopant concentration ~ 100 ppm level.

2) Can be converted to Cherenkov radiator by 5-8% doping

In the present test, we confirmed for La^{3+} doping by 8at.%

*) Remaining scintillation light is as weak as or weaker than 20% of Cherenkov for minimum ionizing particles,

*) Scintillation LY is reduced by 1/20.

3) No significant degradation in radiation hardness,

However confirmation is necessary for heavy doping up to 8%

Additional Comments:

(1) Doping usually degrades crystal. Inverse situation for 3+ ions in PWO.

(2) Crystal growth is now established up to 65mm (dia) x 300 mm(l)

(3) Scintillation/Cherenkov LY ratio could be stably controlled between 0.2 ~ 10 by adjusting dopant concentration.

A comment on the application of PWO-Ch. in E949

(1) Large n(=2.2) results in an incomplete threshold device for π/K separation. The capability of PWO-Ch. could be best utilized if the π/K separation could be achieved by the combination of

* PWO-Ch. from pulse height difference,
* dE/dx --> hopefully Si strip detectors (fast and real-time readout),
* upstream (separate) pure Cherenkov detector.

(2) If π/K separation could be achieved without the active degrader, PWO scintillator , instead of PWO-Ch. could be one of the best materials for the active degrader.