Introduction to Pr:LuAG scintillator

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SuperBelle calorimeter meeting

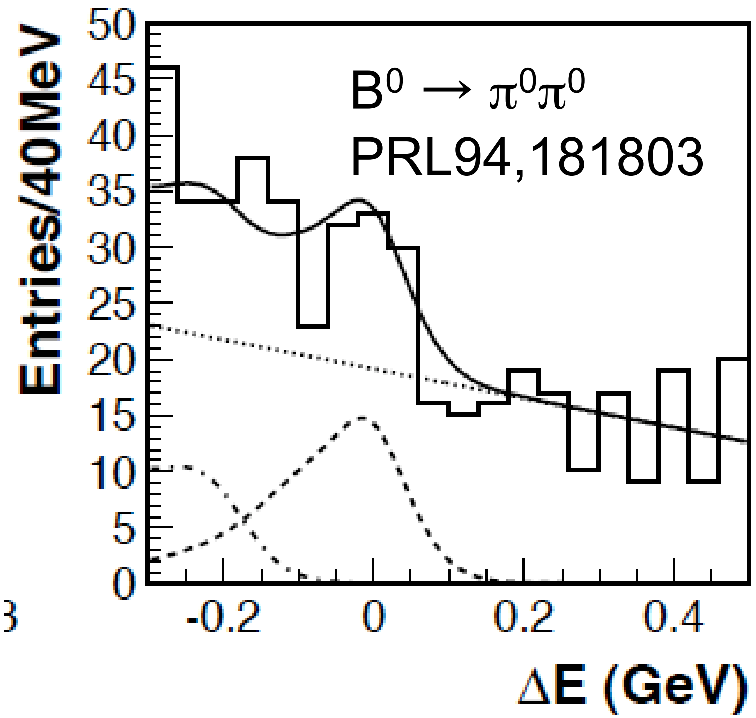
When we built the existent electromagnetic calorimeter,

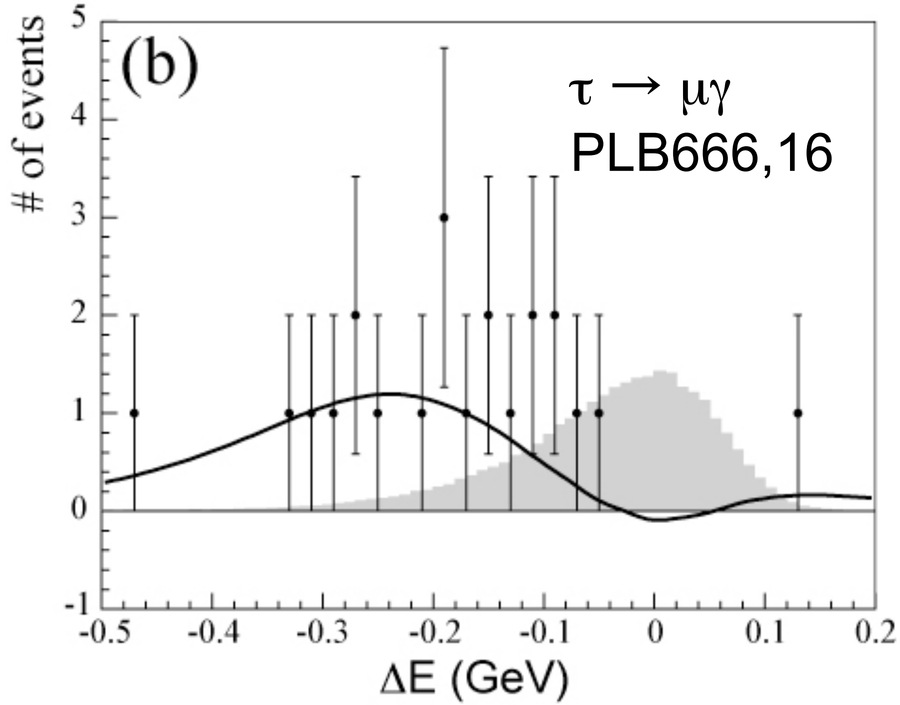
- We thought that it is ultimate performance crystal calorimeter for a B-factory.
- Compared to CLEO calorimeter, much more stable operation thanks to good hardware design R&D.
- Even compared to BaBar calorimeter, larger coverage(backward endcap), better energy resolution(thanks to lower noise level), etc.
- Crystal calorimeter is expensive, we have to keep as it is forever…

Toward Super B-factory, I'm afraid those might be old dogmas…

For some physics analysis

Needless to say, good electromagnetic calorimeter is essential.





Of course, software effort for existent calorimeter is important, but at the same time, we'd better to think about better hardware.

Table 28.4: Properties of several inorganic crystal scintillators. Most of the notation is defined in Sec. 6 of this *Review.*

Parameter:	ρ	MP	X_0^*	R_M^*	dE/dx	λ_I^*	τ_{decay}	λ_{max}	$n^\natural$	Relative output†	Hygro-scopic?	$d(LY)/dT$
Units:	g/cm^3	°C	cm	cm	MeV/cm	cm	ns	nm				%/°C‡
NaI(Tl)	3.67	651	2.59	4.13	4.8	42.9	230	410	1.85	100	yes	−0.2
BGO	7.13	1050	1.12	2.23	9.0	22.8	300	480	2.15	21	no	−0.9
BaF_2	4.89	1280	2.03	3.10	6.6	30.7	630^s	300^s	1.50	36^s	no	-1.3^s
							0.9^f	220^f		3.4^f		$\sim 0^f$
CsI(Tl)	4.51	621	1.86	3.57	5.6	39.3	1300	560	1.79	165	slight	0.3
CsI(pure)	4.51	621	1.86	3.57	5.6	39.3	35^s	420^s	1.95	3.6^s	slight	−1.3
							6^f	310^f		1.1^f		
$PbWO_4$	8.3	1123	0.89	2.00	10.2	20.7	30^s	425^s	2.20	0.083^s	no	−2.7
							10^f	420^f		0.29^f		
LSO(Ce)	7.40	2050	1.14	2.07	9.6	20.9	40	420	1.82	83	no	−0.2
GSO(Ce)	6.71	1950	1.38	2.23	8.9	22.2	600^s	430	1.85	3^s	no	−0.1
							56^f			30^f		

Currently our choice

* Numerical values calculated using formulae in this review.

$\natural$ Refractive index at the wavelength of the emission maximum.

† Relative light output measured for samples of 1.5 X_0 cube with a Tyvek paper wrapping and a full end face coupled to a photodetector. The quantum efficiencies of the photodetector is taken out.

‡ Variation of light yield with temperature evaluated at the room temperature.

f = fast component, s = slow component

Is there better material?

Pr:LuAG scintillator

- Pr^{3+} 5d-4f transition scintillating
- Pr^{3+} scintillation decay time, wavelength change by host material.
- LuAG:$Lu_3Al_5O_{12}$:host material
- Yoshikawa group in Tohoku developed.
- Original motivation is next generation PET.
- Furukawa Co. has been doing R&D of crystal growth.

Crystal with Pr doping in 0.25 atomic%.
2in. diameter ingot

$Lu_3Al_5O_{12}$:X_0

- Dahl approximation

$$X_0 = \frac{716.4 \text{ g cm}^{-2} A}{Z(Z+1)\ln(287/\sqrt{Z})}$$

  - Lu: Z=71, A=175 → X_0=6.951 g･cm^{-2}
  - Al: Z=13, A=27 → X_0=24.28 g･cm^{-2}
  - O: Z=8, A=16 → X_0=34.46 g･cm^{-2}

- In case of composite material
  - j-th material's X_0:X_j
  - Ratio in weight:W_j
  - Lu:0.616, Al:0.158, O:0.226
  - →X_0=9.83 g･cm^{-2} 、density 6.7g/cm^3 → 1.47cm

$$1/X_0 = \sum w_j/X_j$$

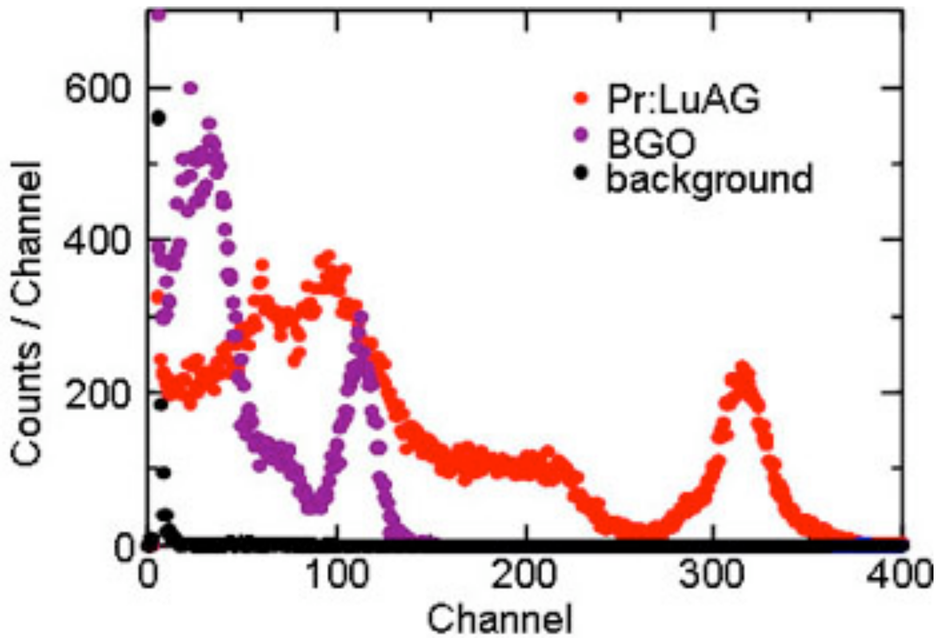
$Lu_3Al_5O_{12}$:R_M

- j-th material's critical energy E_{cj}, X_0:X_j, ratio in weight : W_j
- E_s=21.21MeV
- Ec=610/(Z+1.24) MeV
- →R_M=14.5 g・cm^{-2}、6.7 g/cm^3 → 2.16cm。

$$\frac{1}{R_M} = \frac{1}{E_s} \sum \frac{w_j E_{cj}}{X_j}$$

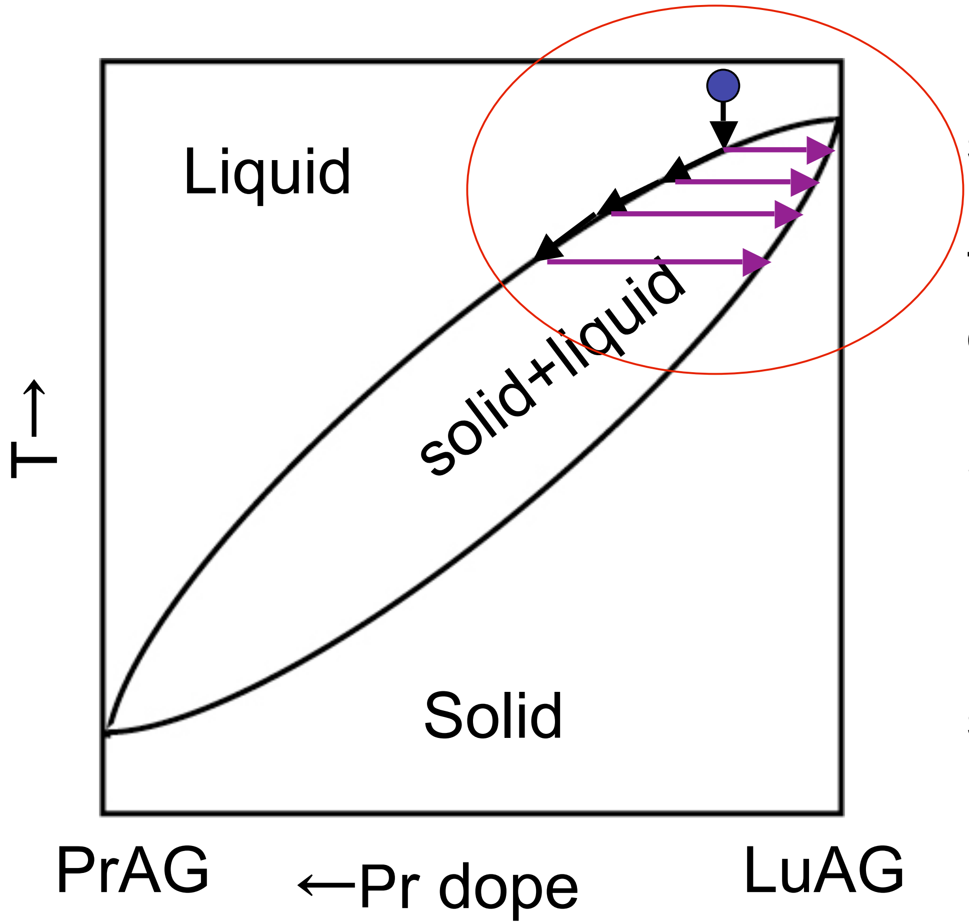
Pr:LuAG crystal growth

- Density=6.7g/cm^3
  （CsI:4.5g/cm^3）
- X_0(LuAG)=1.47cm
  （CsI:1.86cm）
- R_M(LuAG)=2.16cm
  （CsI:3.57cm）
- Wavelength=310nm
  （not different from pure CsI）
- L.O.=BGOx3
  （pureCsIx12?）
- Decay time<22ns
- Raw material=11,000yen/300g



Response for ^{137}Cs(662keV γ)
From Yoshikawa group's HP
Photon sensor(APD)'s QE corrected.

Intrinsic problem in crystal growth



Because of composite material, solid+liquid co-existent region is there.

↓

Transition temperature changes by Pr dope amount.

↓

Solid appeared earlier has less Pr, later has more Pr.

↓

It does not become serious problem for small size block for example, PET, etc. But…

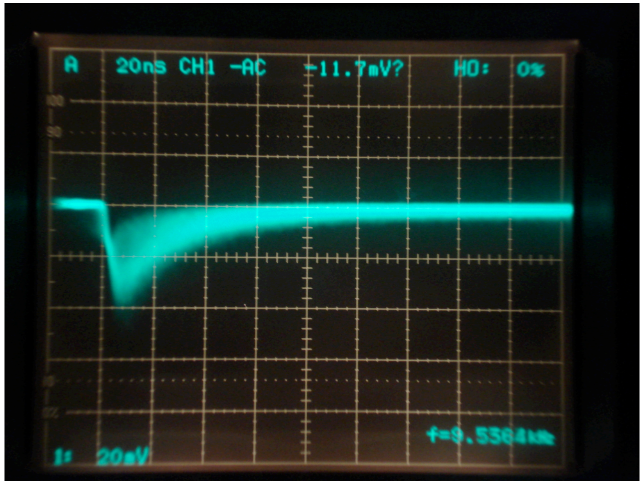
Pr dope amount can not be uniform for large block for particle physics experiments…

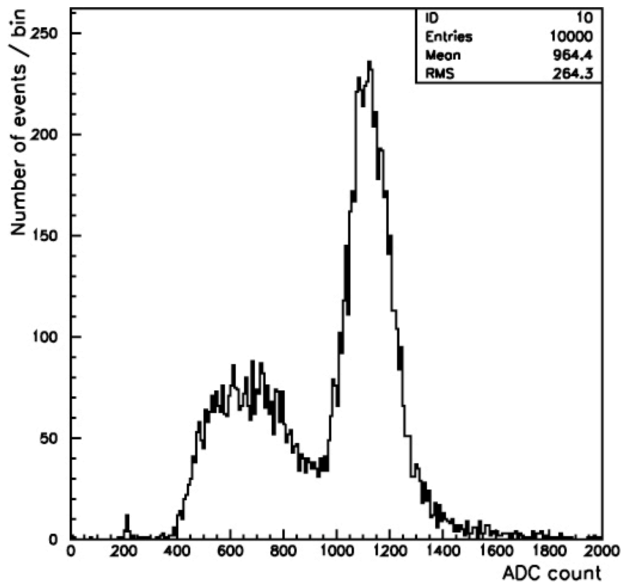
Ceramic block R&D going on

- No transition from liquid to solid; Pr dope could be uniform.
- Less defects of unit cell is expected.
- Now optimum Pr dope amount investigation is being done by Yoshikawa group and the company.

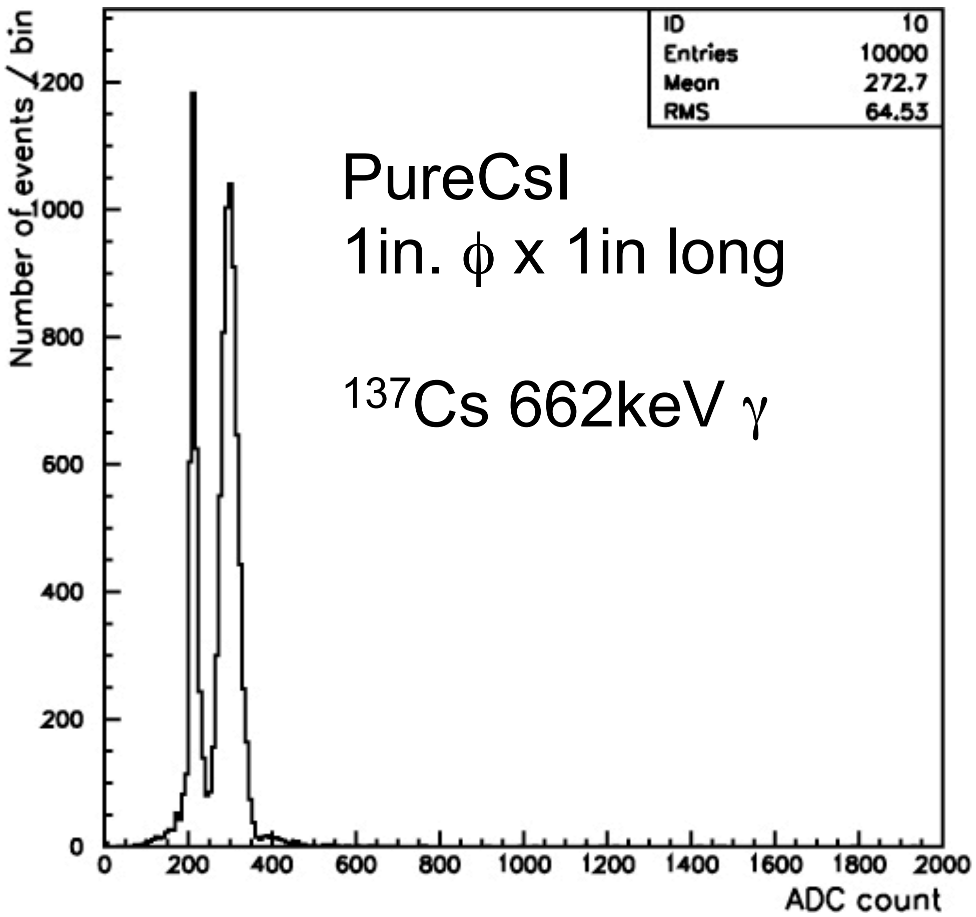
Crystal growth sample test started.

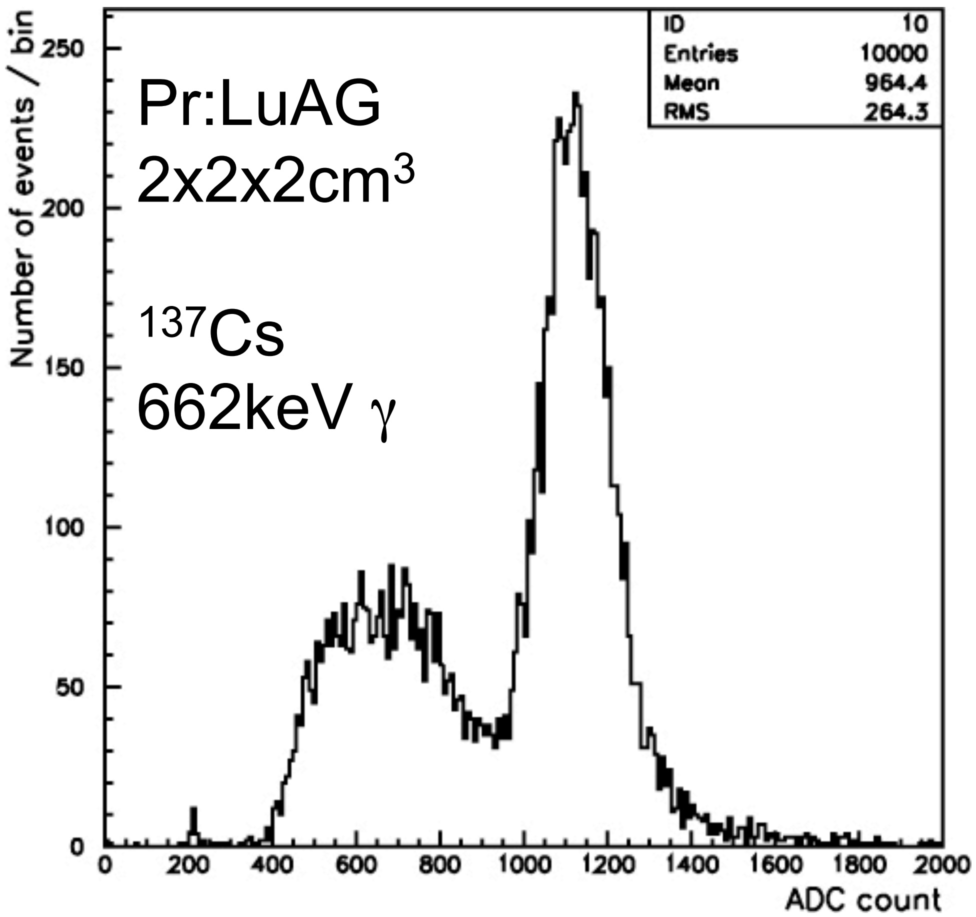
- $2x2x2cm^3$ blocks cut from crystal growth ingot delivered.
- Read out by usual PMT.
- Clear full-energy peak seen for 662keV γ from ^{137}Cs by charge-sensitive ADC readout.
- Temperature dependence relatively small; 0.4%/^oC including PMT gain change.





Much more L.O. than pureCsI





Details(difference in PMT's QE for different wavelength, etc.)
are to be concerned/revisited.

Plan and summary

- Pr:LuAG has nice characteristics
  - Shorter X_0 : 1.47cm
  - Shorter R_M : 2.16cm
  - Rich L.O. (3xBGO)
  - Fast decay time (a few x 10 ns)
  - Readout developed for pureCsI can be used.
- Ceramic sample R&D going on.
- Radiation hardness test is planned.
- Performance improvement estimation has to be done with GEANT simulation (even simple geometry/model).