Development of Liquid Scintillator containing Zirconium Complex for Neutrinoless Double Beta Decay Experiment

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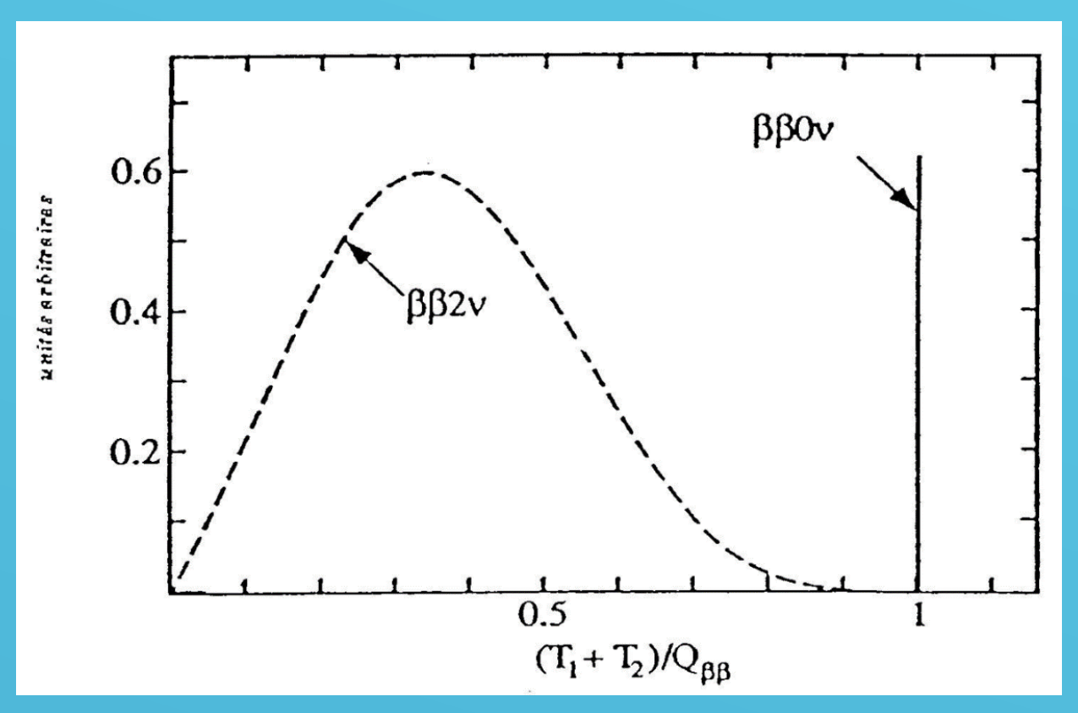
1. Neutrinoless Double Beta Decay

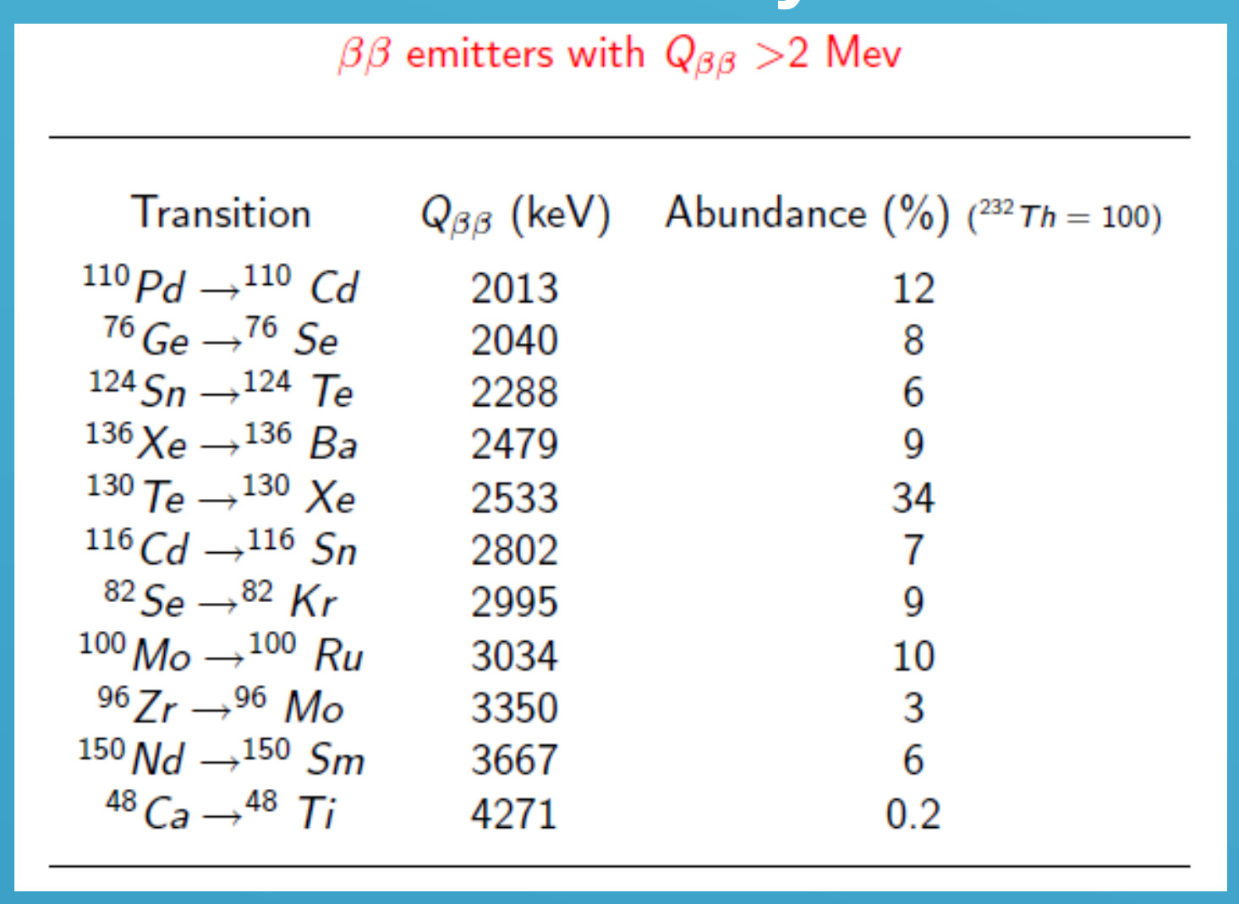
◆ Neutrinoless double beta decay

- Lifetime and neutrino mass
  $[T_{1/2}^{0\nu}(0^+ \rightarrow 0^+)]^{-1} = G_{0\nu}(E_0,Z)|M_{0\nu}|^2\langle m_\nu\rangle^2$
- Energy spectrum and lifetime measurement
  - monochromatic energy = Q-value
  - $T_{1/2} \sim a(Mt/\Delta EB)$ a: abundance M: mass t: meas.time ΔE: energy res. B: BG rate



Requirements : Low background rate, Large target mass and High energy resolution

◆ Double beta decay candidates



$\beta\beta$ emitters with $Q_{\beta\beta}$ >2 Mev

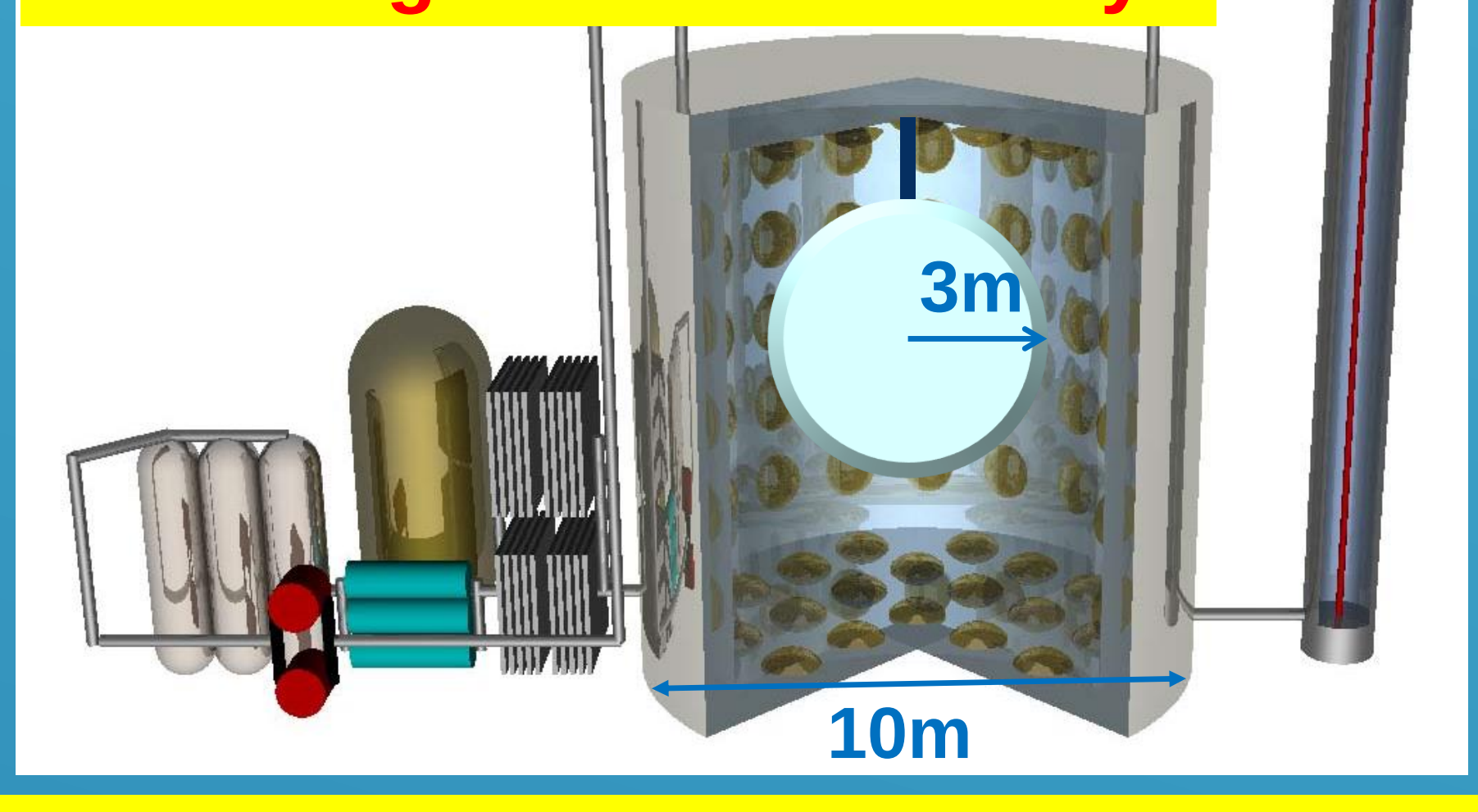
Transition	$Q_{\beta\beta}$ (keV)	Abundance (%) ($^{232}Th = 100$)
$^{110}Pd \rightarrow ^{110}Cd$	2013	12
$^{76}Ge \rightarrow ^{76}Se$	2040	8
$^{124}Sn \rightarrow ^{124}Te$	2288	6
$^{136}Xe \rightarrow ^{136}Ba$	2479	9
$^{130}Te \rightarrow ^{130}Xe$	2533	34
$^{116}Cd \rightarrow ^{116}Sn$	2802	7
$^{82}Se \rightarrow ^{82}Kr$	2995	9
$^{100}Mo \rightarrow ^{100}Ru$	3034	10
$^{96}Zr \rightarrow ^{96}Mo$	3350	3
$^{150}Nd \rightarrow ^{150}Sm$	3667	6
$^{48}Ca \rightarrow ^{48}Ti$	4271	0.2

- above ^{208}Tl γ line (2.614MeV) : ^{48}Ca, ^{150}Nd, ^{96}Zr, ^{100}Mo, ^{82}Se…
- large abundance : ^{100}Mo, ^{82}Se, ^{150}Nd, ^{96}Zr
- solved in liquid scintillator formed as metal complex

Zirconium (^{96}Zr) is possible candidate

◆ Detector design for Zr loaded liquid scintillator

Assuming 10w.t.% solubility



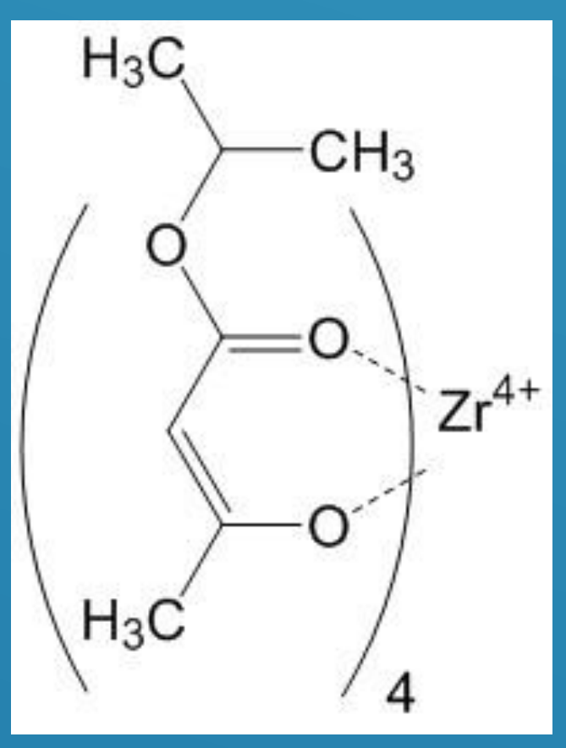
Goal: $\langle m_\nu\rangle \sim$10meV

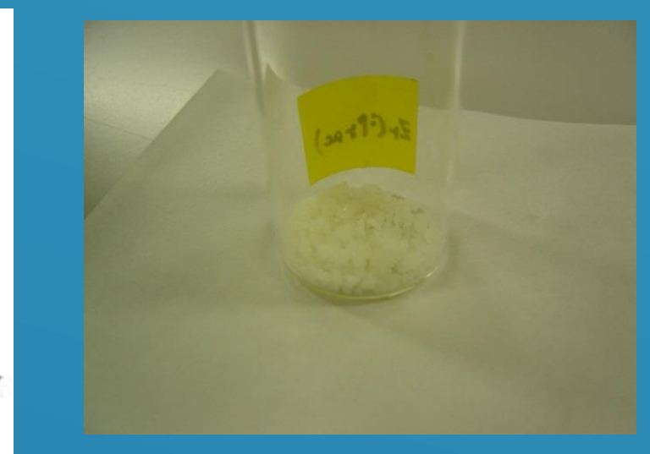
- light yield : **60% for BC505**
- high energy resolution : **4%@2.5MeV = 100keV**
- low background rate : **0.01count kg^{-1} y^{-1}**
- target volume : **~ton scale**

Zirconium Complex in Organic liquid Scintillator (ZICOS) experiment for neutrinoless double beta decay

2. Zirconium β-keto ester complex

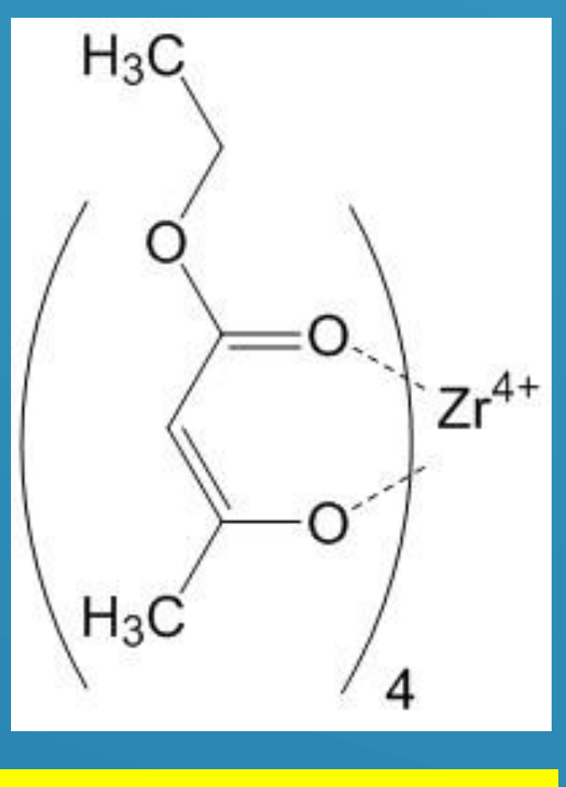
◆tetrakis (isopropyl acetoacetate) Zr

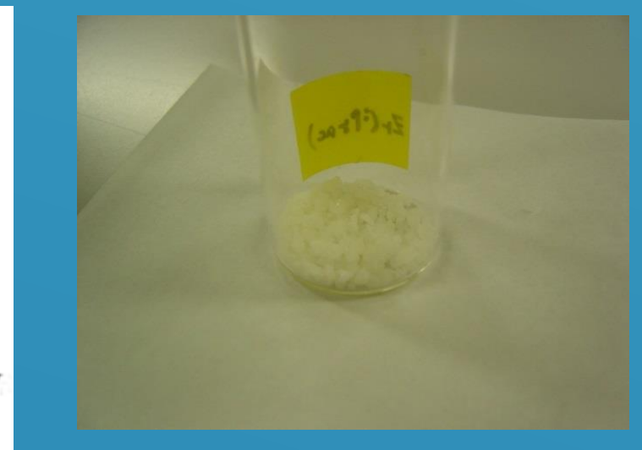




$Zr(CH_3COCHCOOCH(CH_3))_4$ = $Zr(iprac)_4$
M.W. : 663.87

◆ tetrakis (ethyl acetoacetate) Zr

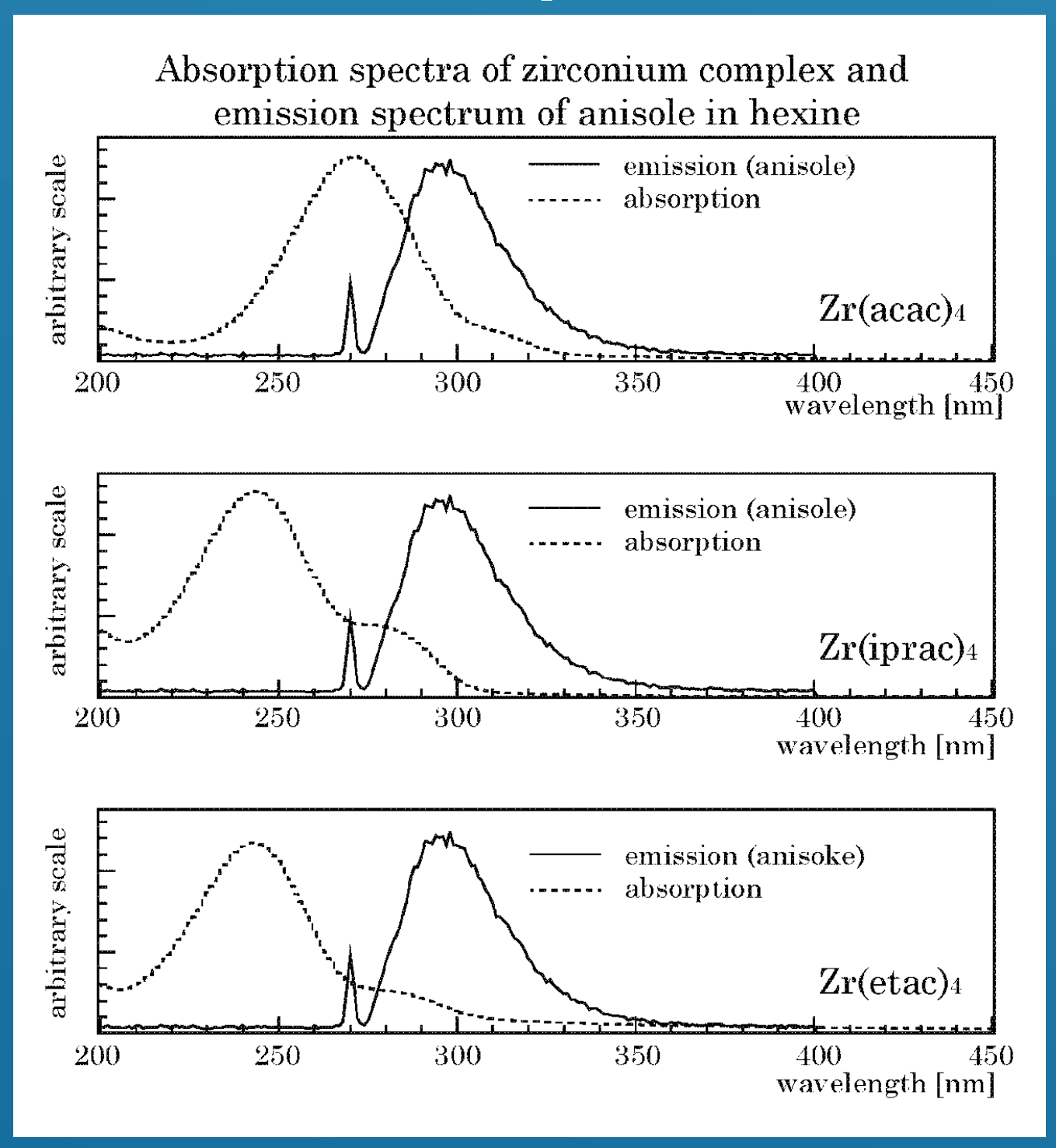




$Zr(CH_3COCHCOOH_2CH_3)_4$ = $Zr(etac)_4$
M.W. : 607.76

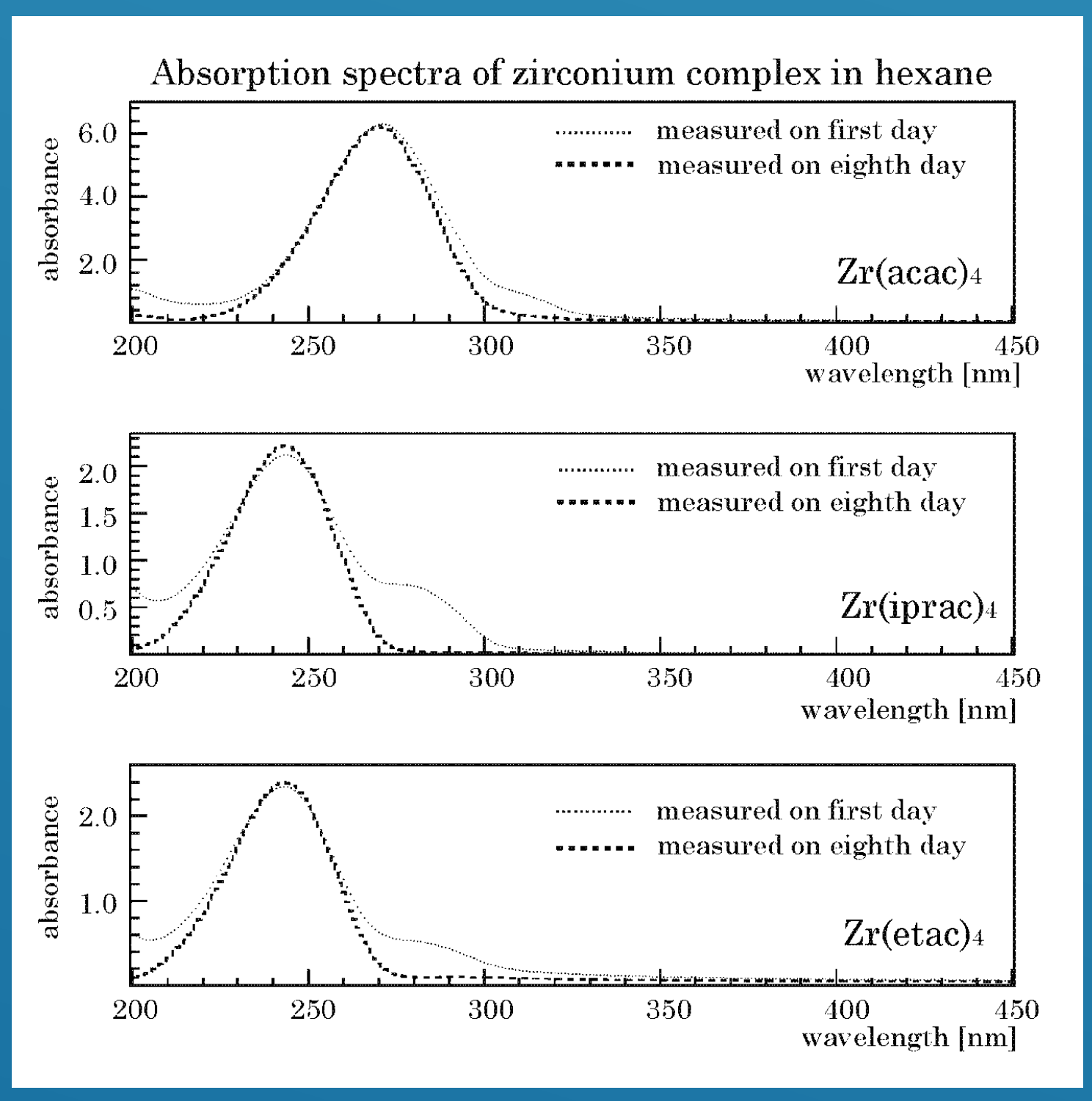
Solubility > 10w.t.% for anisole

◆ Absorbance spectra for complex and emission spectra for anisole



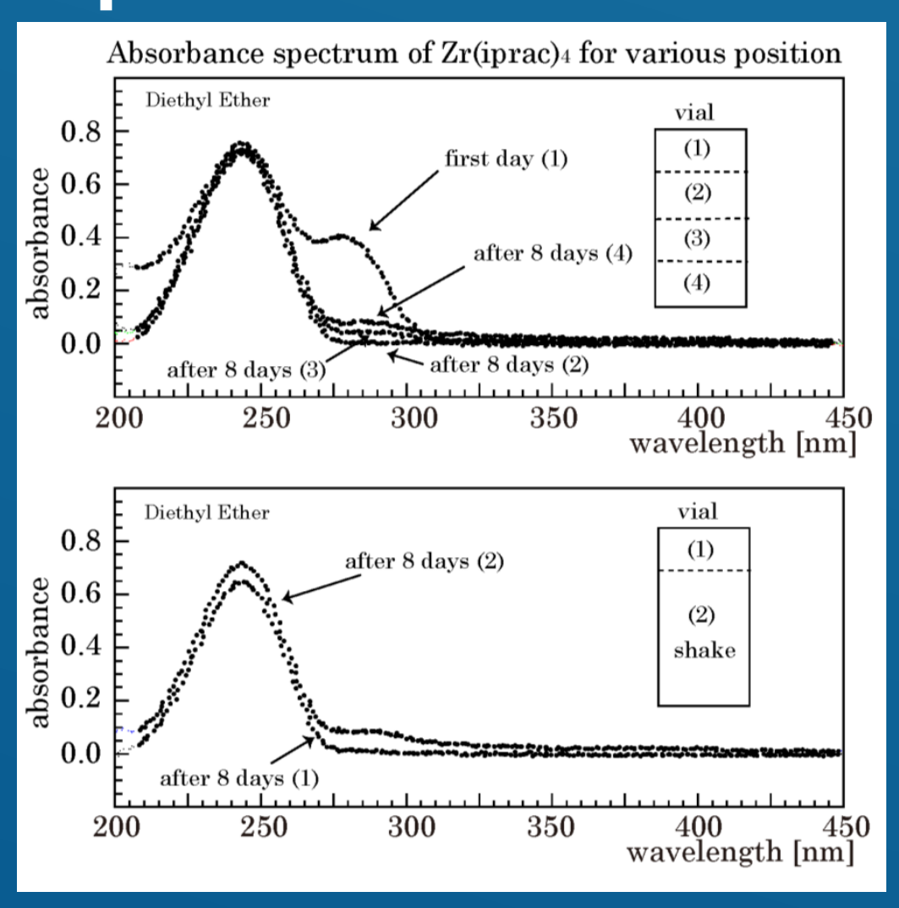
- Absorption peaks of Zirconium β-keto ester complex : 245nm
- Small bump : ~280nm

◆ Absorbance spectra for complex after 1 week

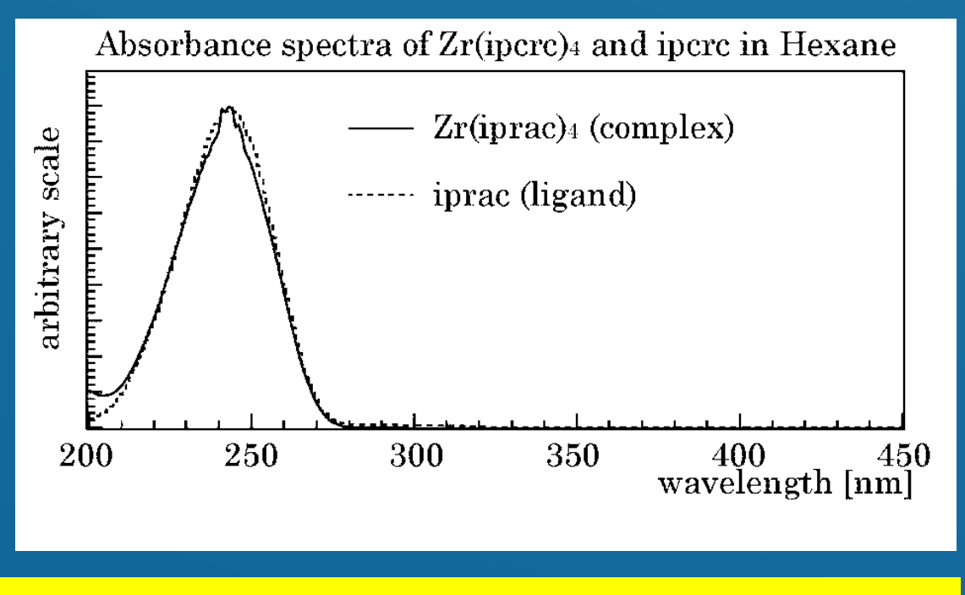


- Small bump was disappeared after ~ 1 week.
- Impurities contained in the complex could be precipitated.

◆ Explanation of small bump



Small bump was disappeared for top region, but still remained for bottom region of the vial. These could be explained by the precipitation.

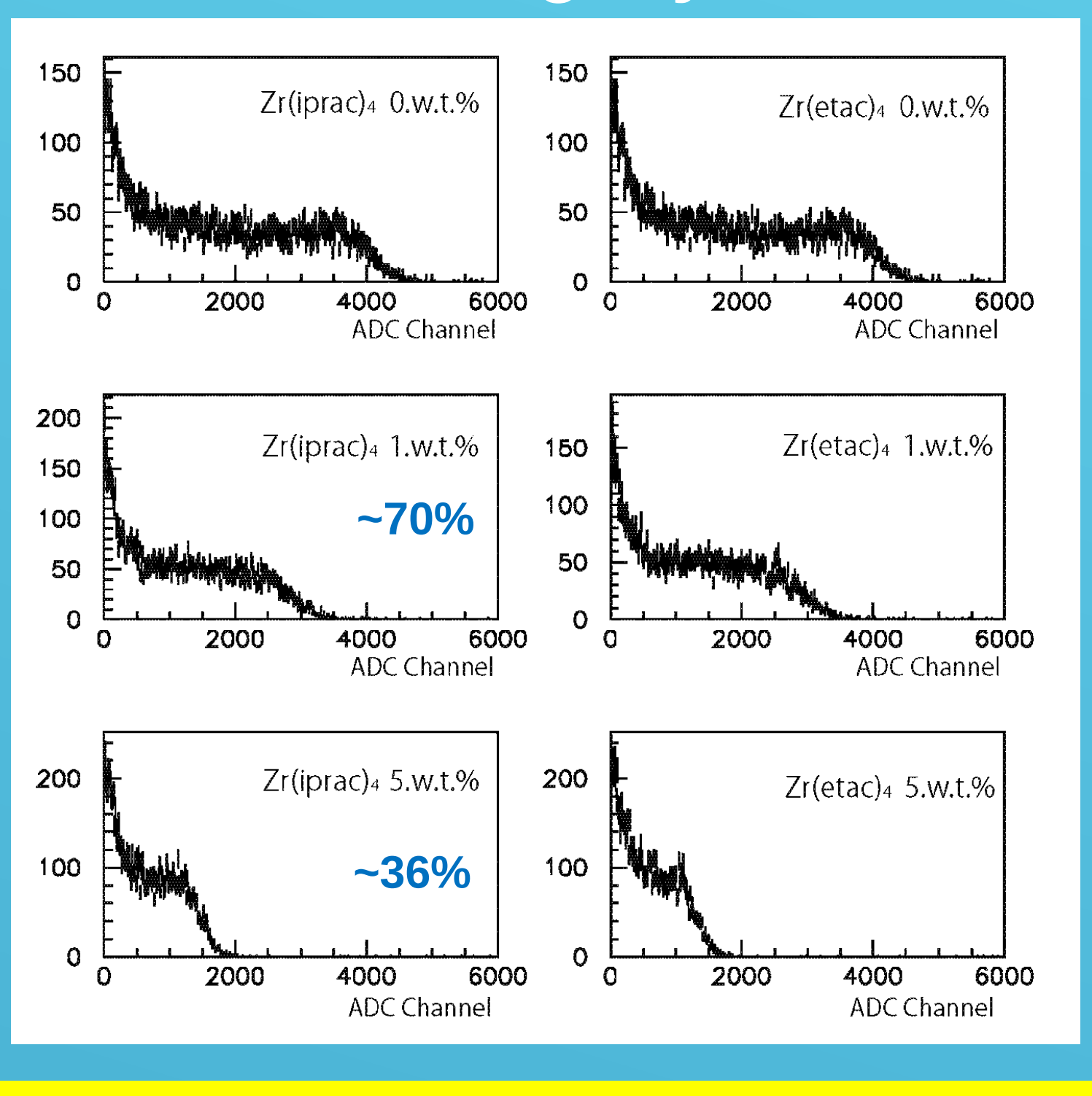


Absorption shapes are completely same between complex and ligand.

3. Scintillation yield with β-keto ester

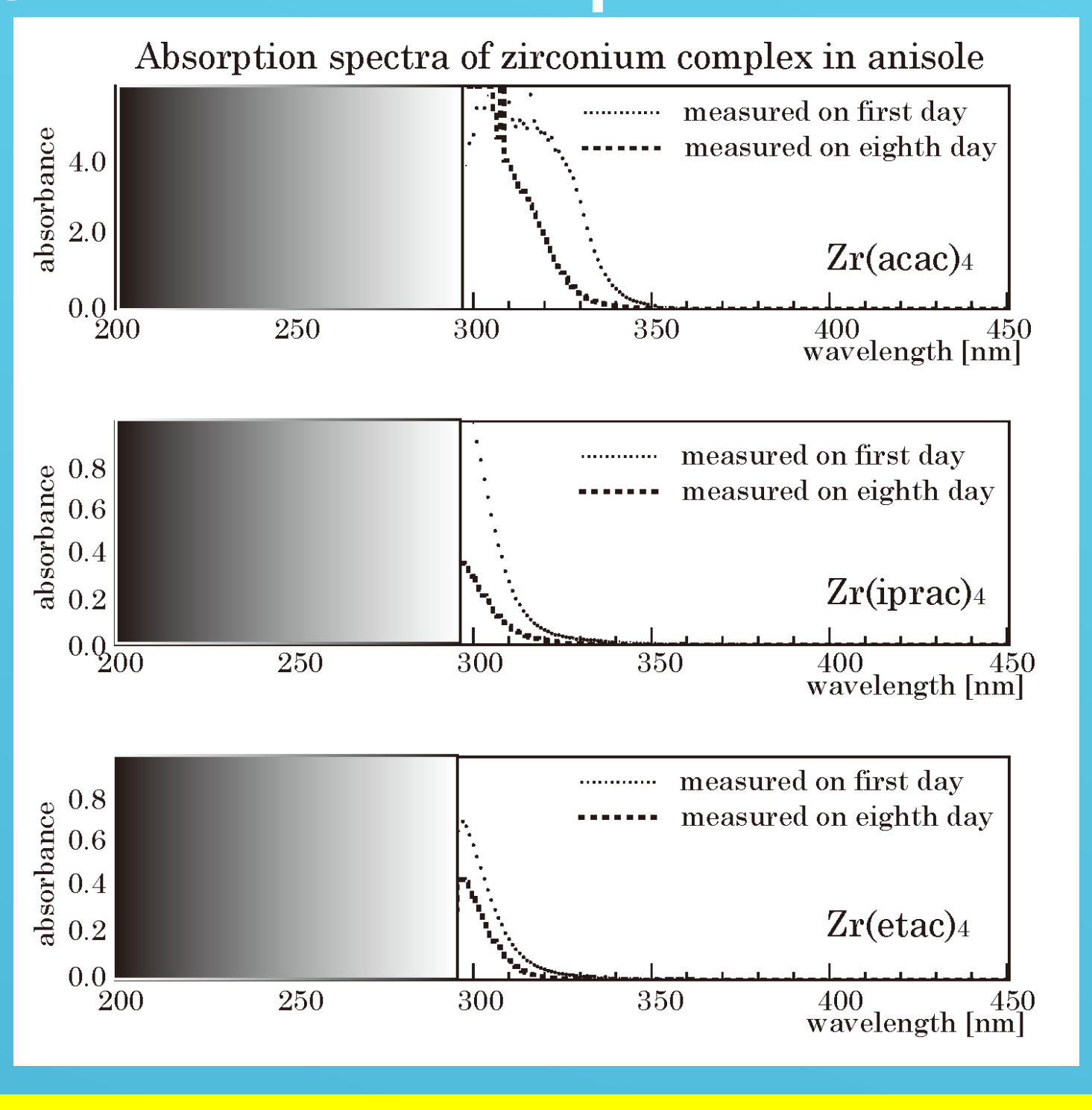
◆ Liquid scintillator containing Zr β-keto-ester complex

● Scintillation light yield



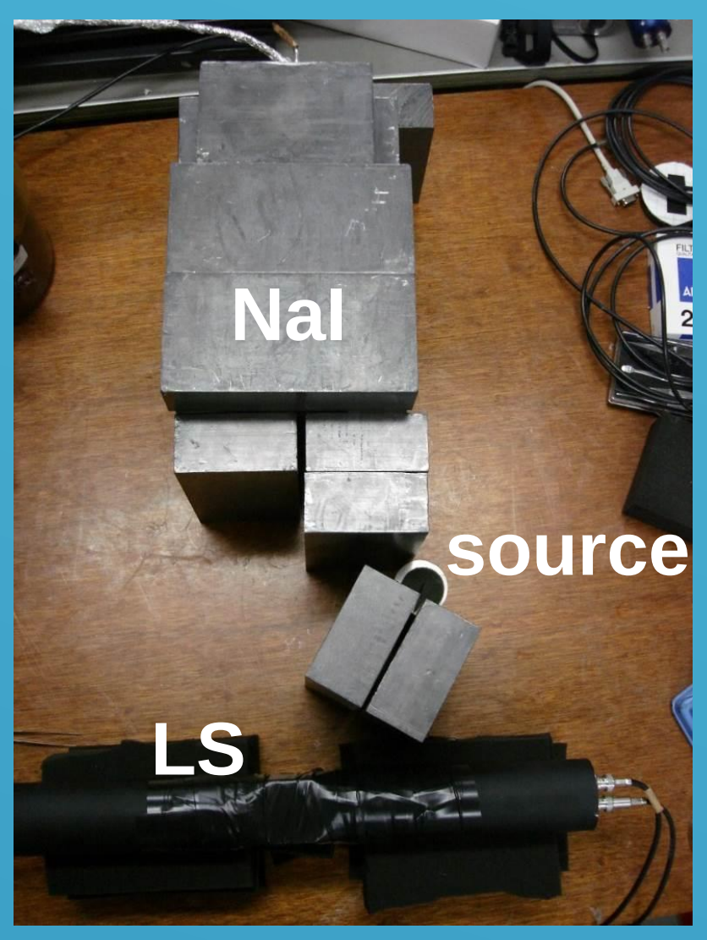
Observed scintillation light yield decreased (but improved). Still exist absorption peak around 280nm in anisole ?

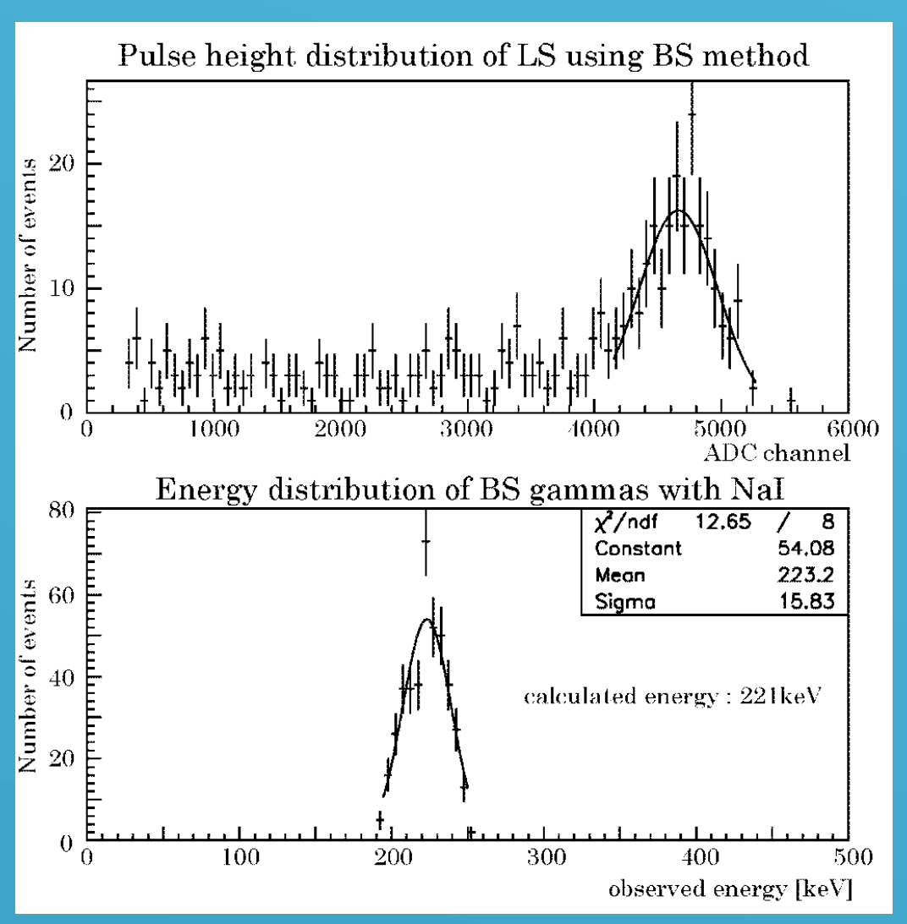
● Absorbance spectra in Anisole



Small bump around 280nm was found even after ~ 1 week. Impurities might be dissolved in Anisole, so we have to purify complex by using sublimation.

◆ Backscattering method for measurement of light yield and energy resolution



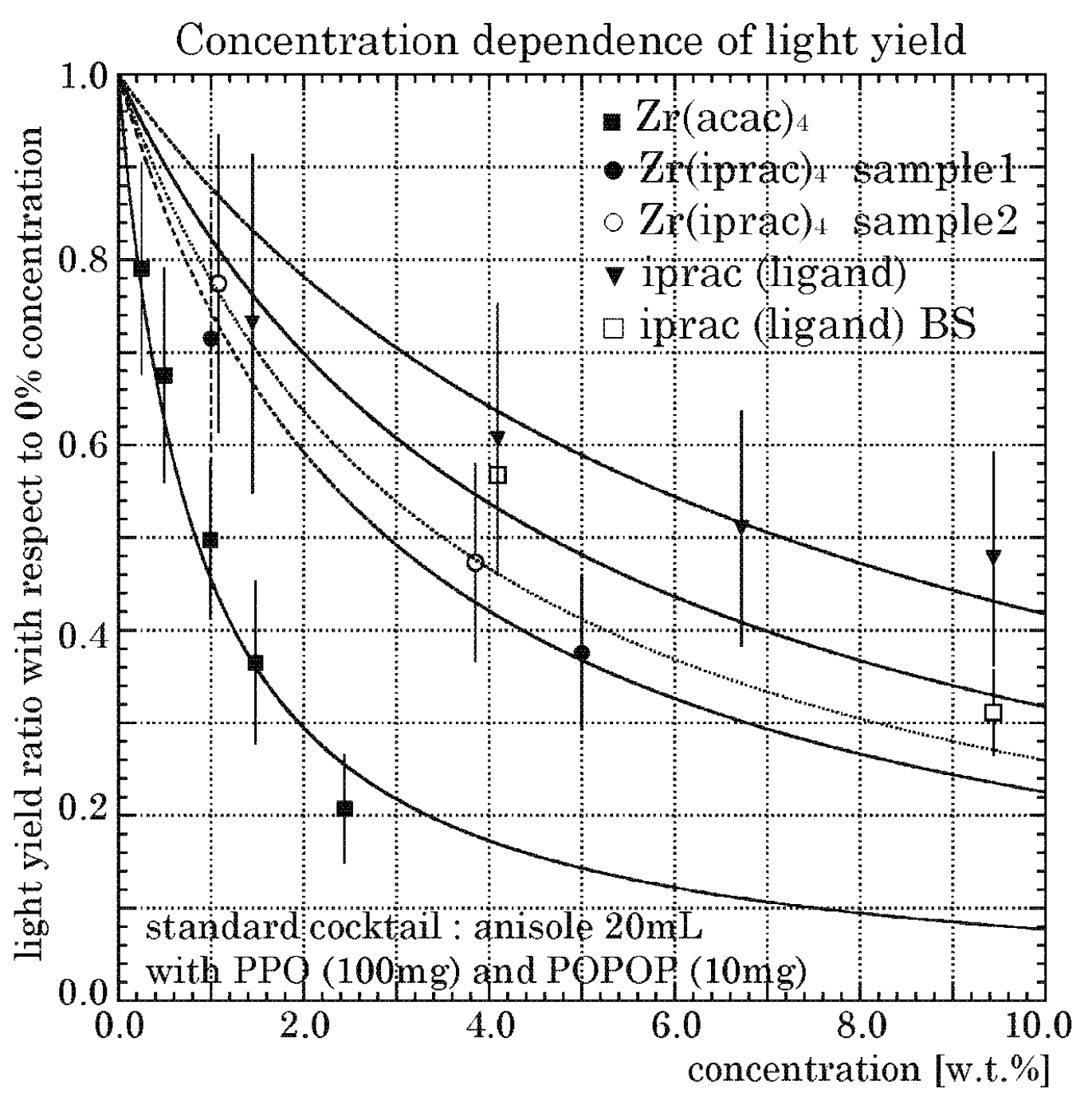


Monochromatic energy electrons were selected by tagging back scattered gammas with NaI scintillator.

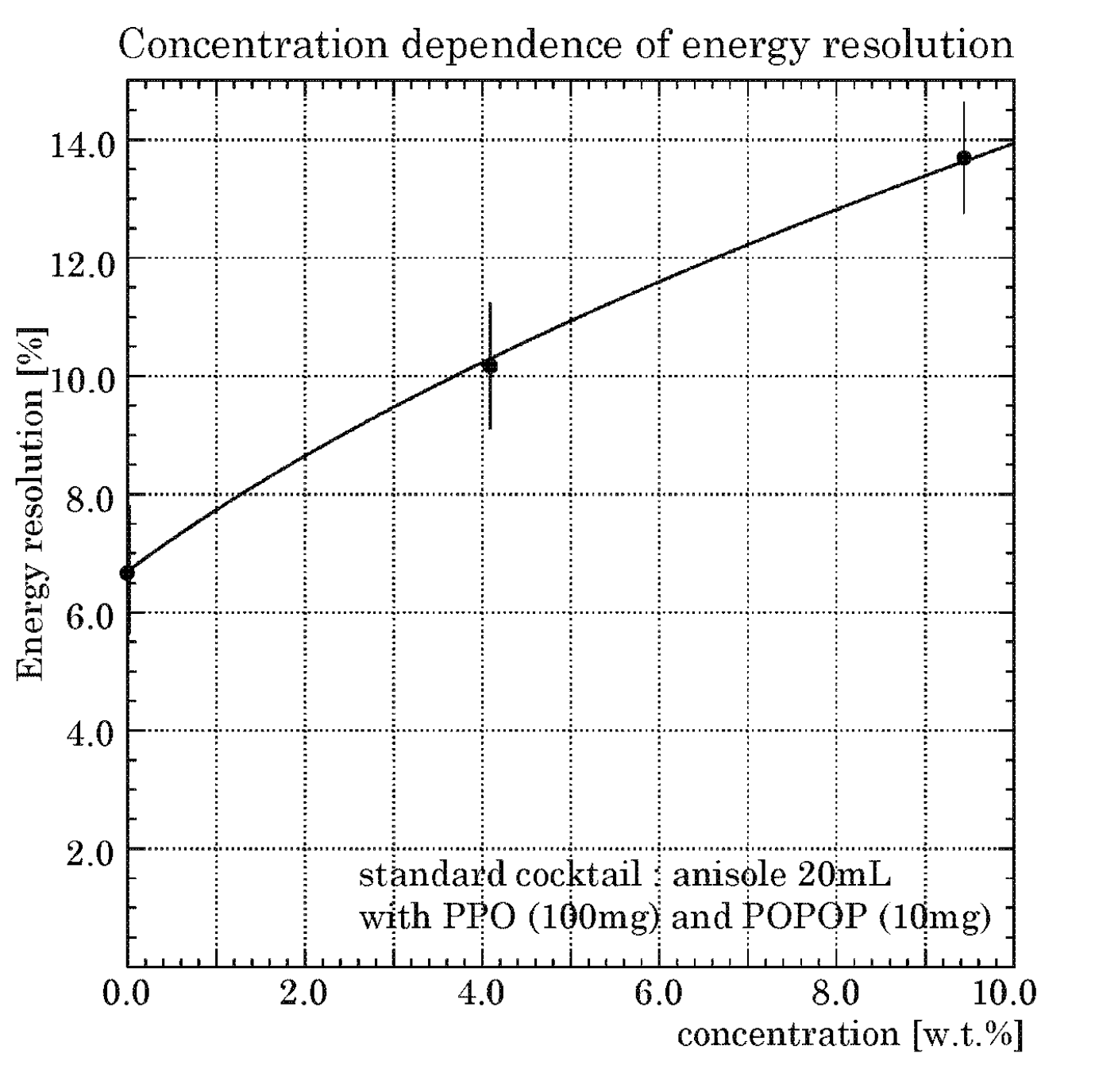
Single peak could be used even though liquid scintillator in small vial.

◆ Performance of liquid scintillator (assuming purified)

● Light yield vs concentration



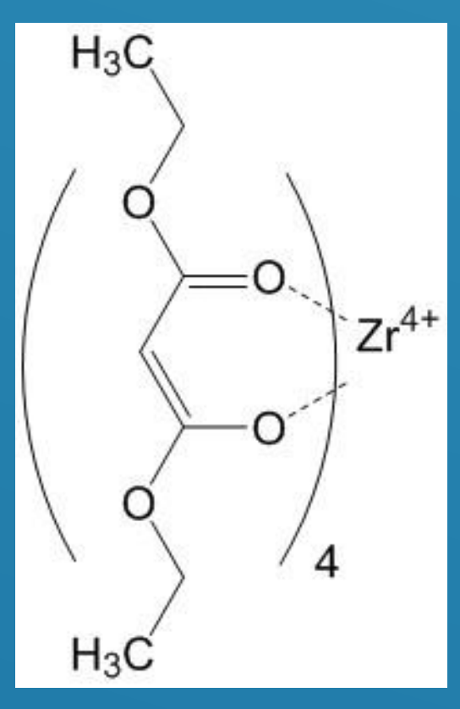
● Resolution vs concentration

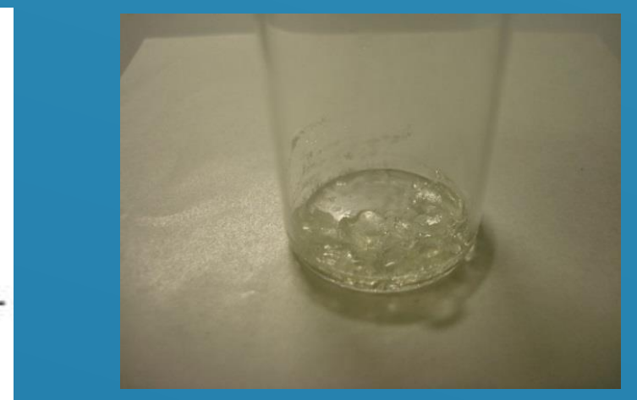


Light yield was ~40% to that of BC505 (almost same as our cocktail) , and energy resolution was 4.1% @2.5MeV for 10 w.t.% concentration assuming 40% photo coverage. They almost achieved to our goal!.

4. Zirconium (diethyl malonato) complex

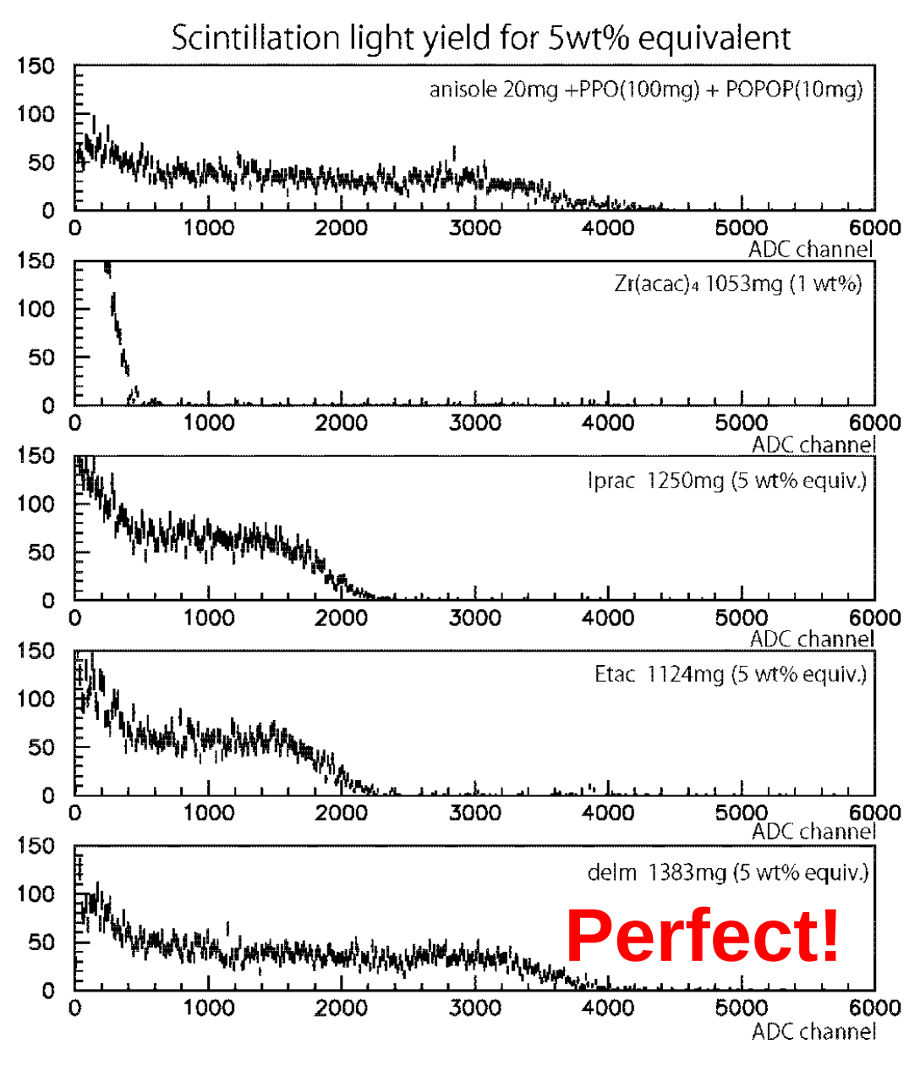
◆ Tetrakis (diethyl malonato) Zr



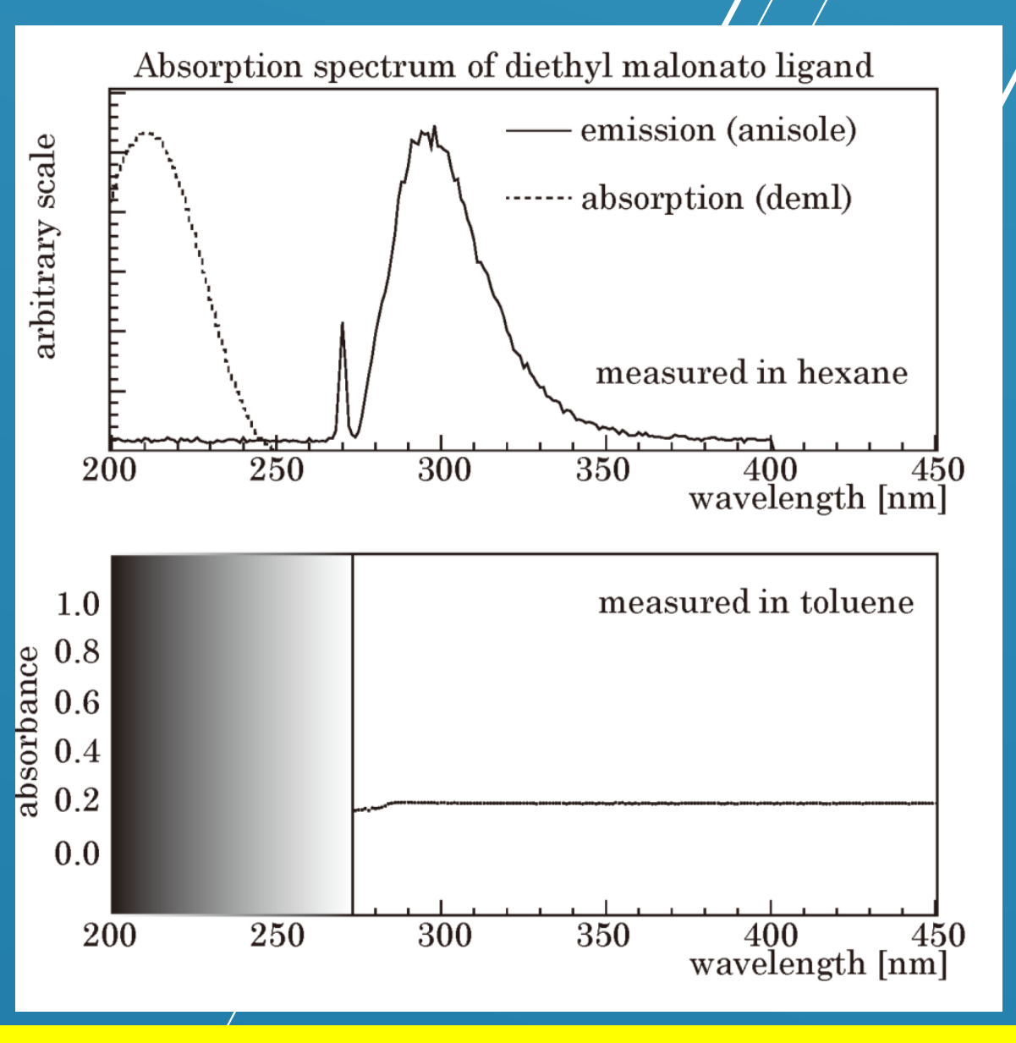


$Zr(CH_3CH_2OCOCHCOOCH_2CH_3)_4$ = $Zr(deml)_4$
M.W. : 727.86

◆ Scintillation light yield



◆ Absorbance of ligand



shorter wavelength (~210nm)

No quenching due to overlap between the absorption of ligand and the emission of anisole should be occurred even though high concentration.

Light yield will be almost same as that of BC505 and energy resolution will be ~2%@2.5MeV for 10w.t.% concentration.

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