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ジルコニウム９６を用いたニュートリノを放出しない二重ベータ崩壊の研究

新学術領域　「宇宙の歴史をひもとく地下素粒子原子核研究」
第一回　研究会

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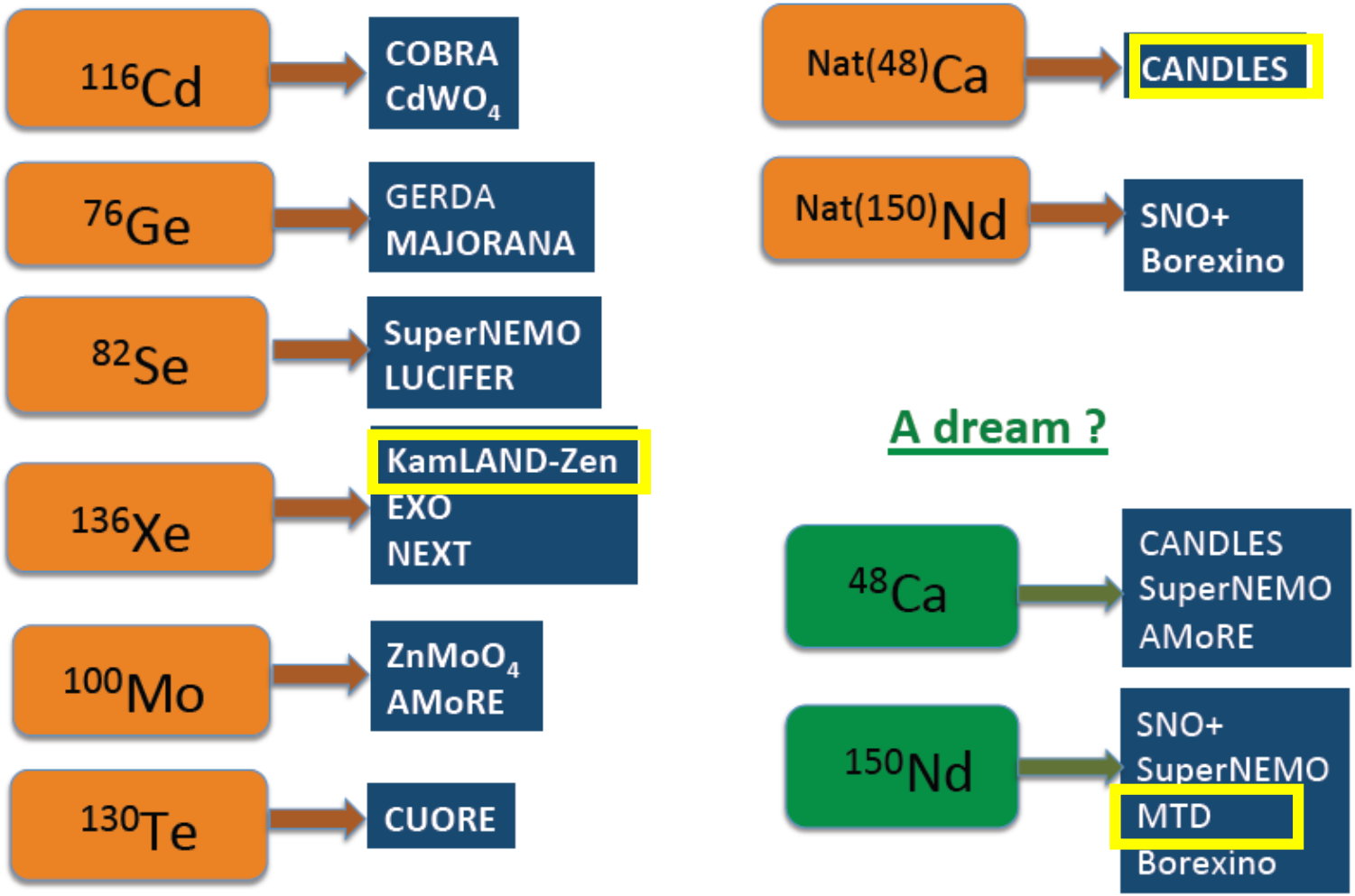
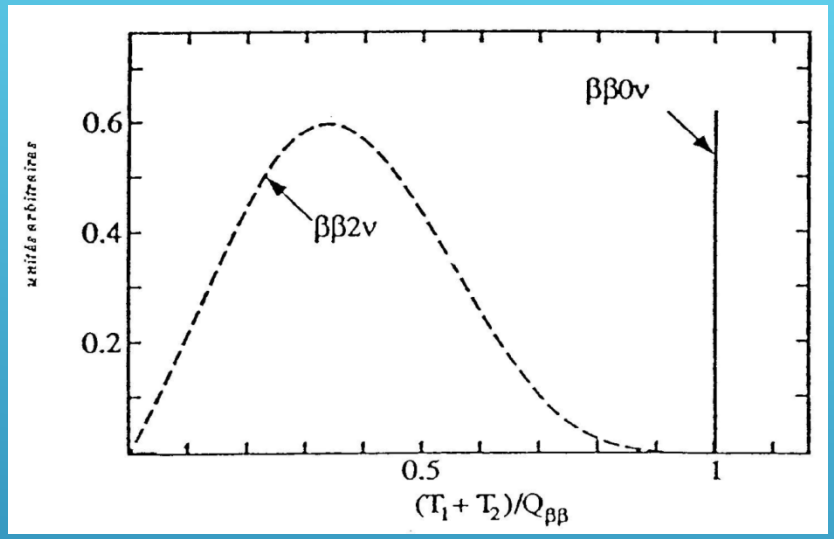
Studied isotopes



NEUTRINOLESS DOUBLE BETA DECAY

$\beta\beta$ 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



$$[T_{1/2}^{0\nu}(0^+ \rightarrow 0^+)]^{-1} = G_{0\nu}(E_0,Z) \mid M_{0\nu} \mid^2 \langle m_\nu \rangle^2$$

$T_{1/2} \sim a(Mt/\Delta EB)$ a: abundance M: target mass

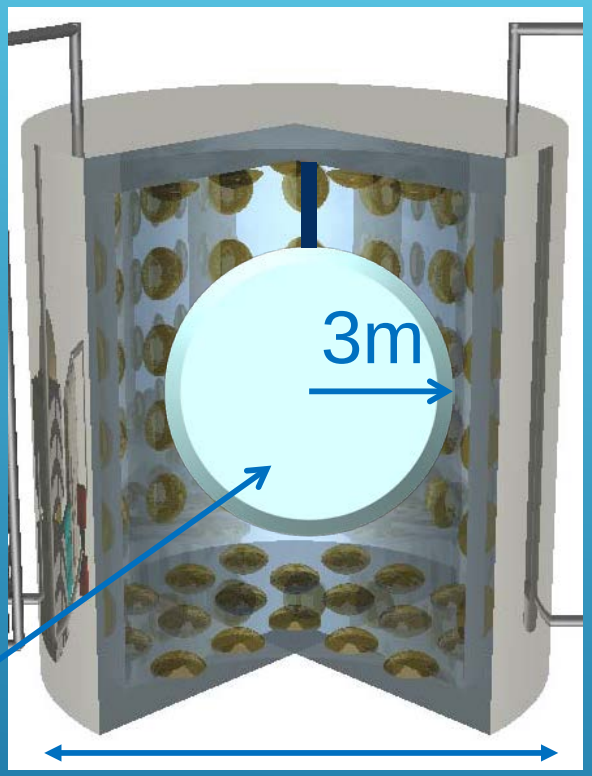
t: measurement time ΔE: energy resolution B: BG rate

Requirement : Low BG, Large target mass, High energy resolution

ZIRCONIUM COMPLEX IN ORGANIC LIQUID SCINTILLATOR FOR DOUBLE BETA DECAY EXPERIMENT (ZICOS EXPERIMENT)

Goals :
(1) Over 10w.t.% solubility
(2) 60% light yield to BC505
(3) 4% at 2.5MeV energy-resolution

Water shield surrounding inner balloon to veto γ's

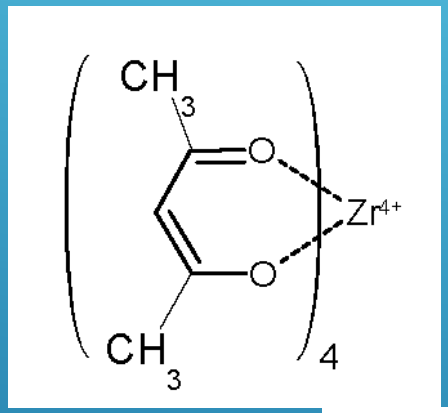


PMT with 40% photo coverage

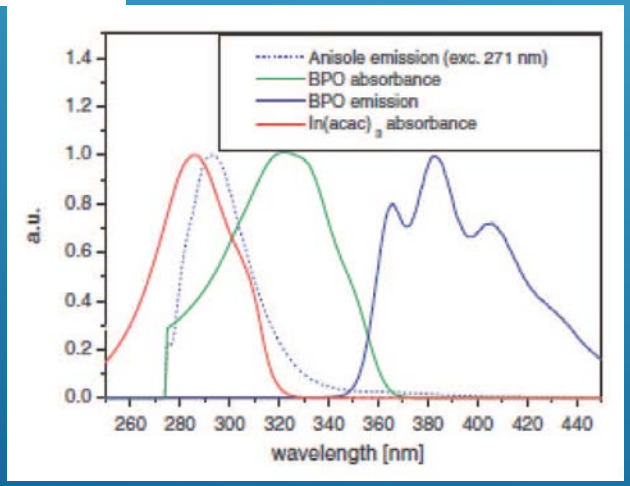
Zirconium loaded 100 tons LS
(300kg ^{96}Zr assuming10% enrich)

ZIRCONIUM BETA-DIKETON COMPLEX

- Zirconium(IV) acetylacetonate ($Zr(acac)_4$)

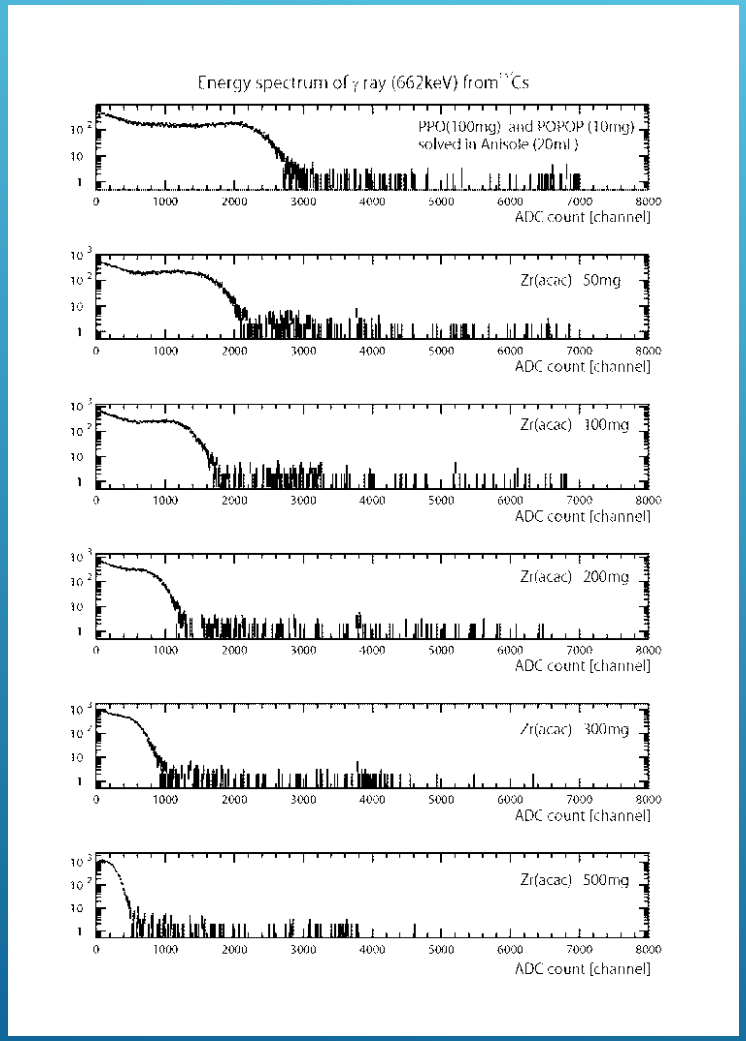


MW: 487.66



- Advantage
  - good solubility (over 10w.t.%) in Anisole (PhOMe)
  - Stable and cheep
  - Commercial product
- Disadvantage
  - Low scintillation light yield due to overlap the absorption of ligand and emission of anisole.

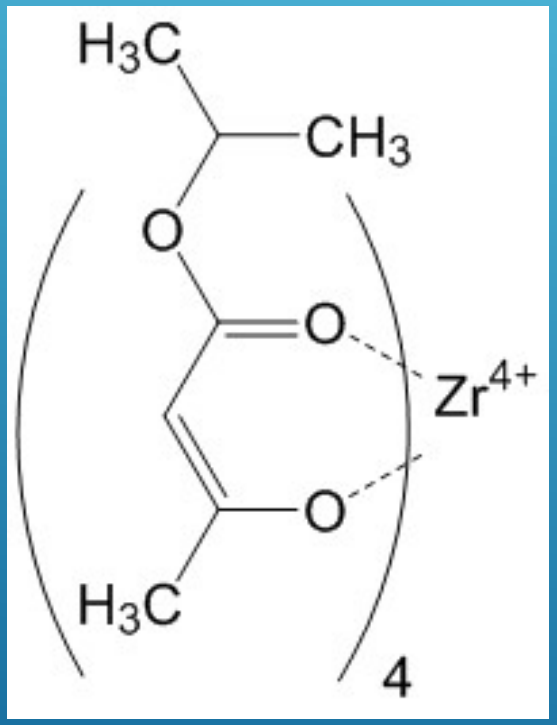
LIGHT YIELD AS A CONCENTRATION OF ZIRCONIUM ACETYLACETONATE



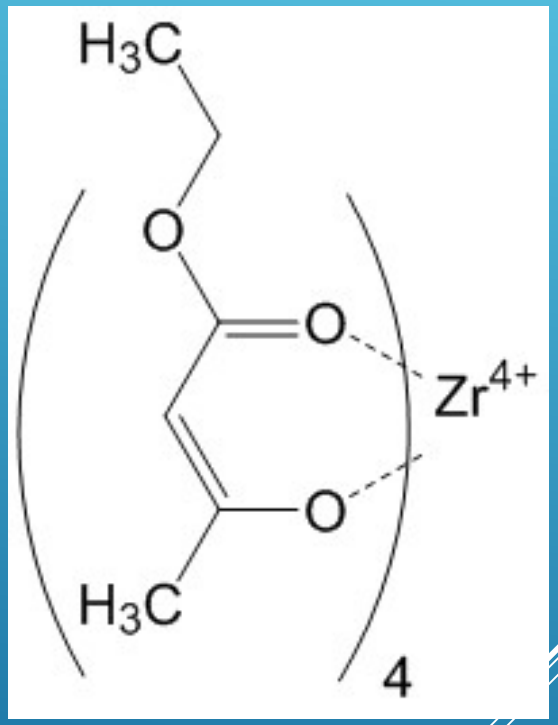
concentration of $Zr(acac)_4$	Observed channel	Expected channel
0 mg	2450	2450
50mg	1800	1997
100mg	1400	1687
200mg	950	1284
300mg	650	1038
500mg	300	750

ZIRCONIUM BETA-KETO ESTER COMPLEX

$Zr(CH_3COCHCOOCH(CH_3)_2)_4$
= $Zr(iprac)_4$
mw : 663.87



$Zr(CH_3COCHCOOCH_2CH_3)_4$
= $Zr(etac)_4$
mw : 607.76

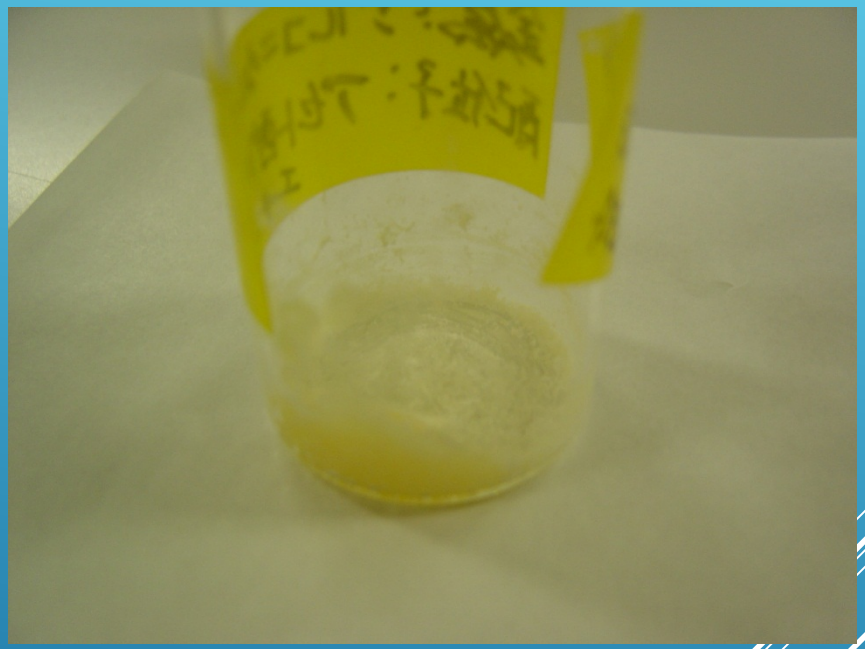


Expected shorter absorption wavelength

SYNTHESIZE OF ZIRCONIUM BETA-KETO ESTER COMPLEX

$Zr(iprac)_4$
state: powder

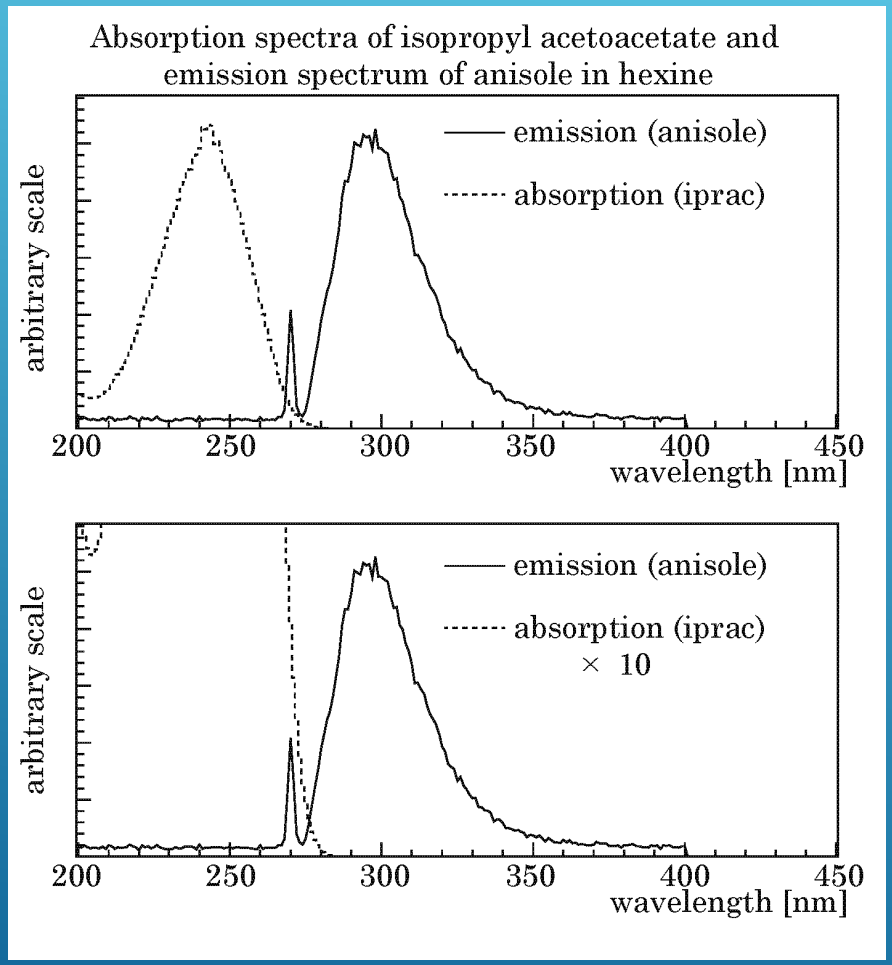
$Zr(etac)_4$
state : dry solid



Synthesized by Prof. Takahiro Gunji (Tokyo University of Science)

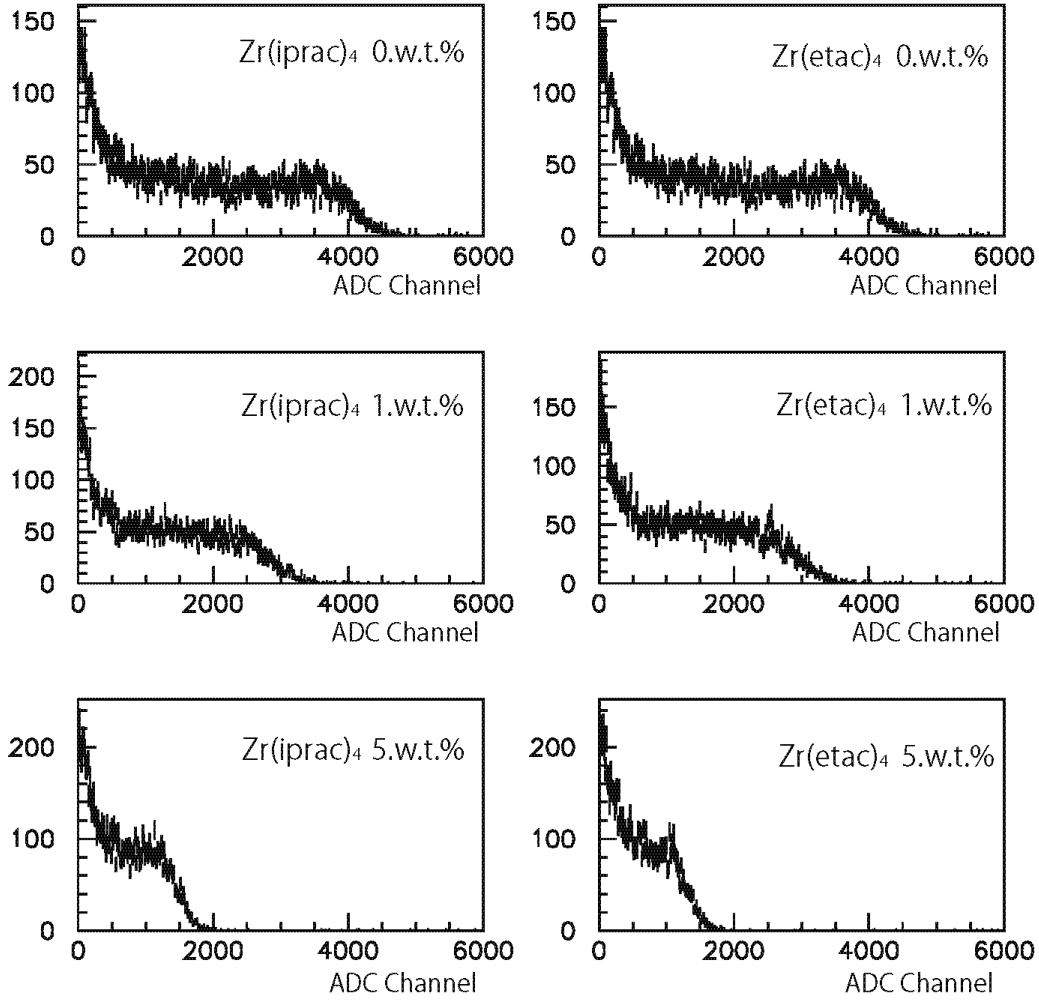
Solubility > 10 w.t.% for anisole

ABSORBANCE SPECTRA FOR ZIRCONIUM BETA-KETO ESTER COMPLEX



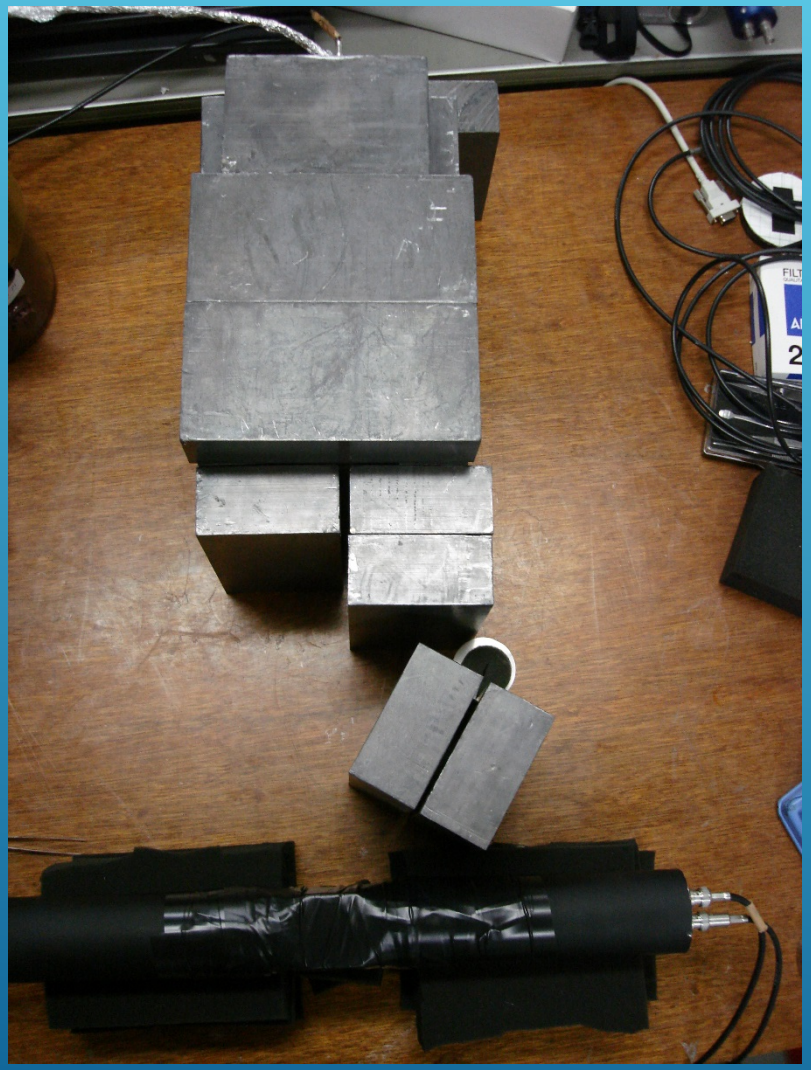
Absorption tail of β-keto ester ligands slightly overlapped with the region of the emission of anisole.

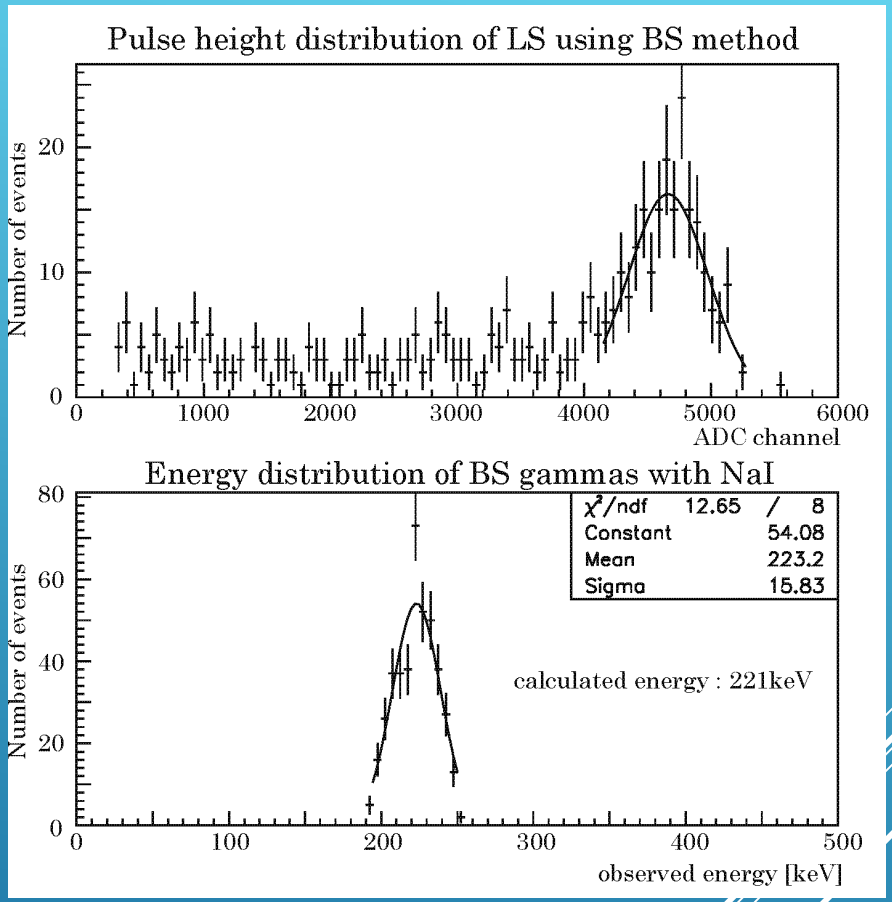
LIGHT YIELD OF LS CONTAINING ZIRCONIUM BETA-KETO ESTER COMPLEX



Light yield decreased as increasing the concentration of the complex even though small overlapping between the absorption of ligand and the emission of anisole .

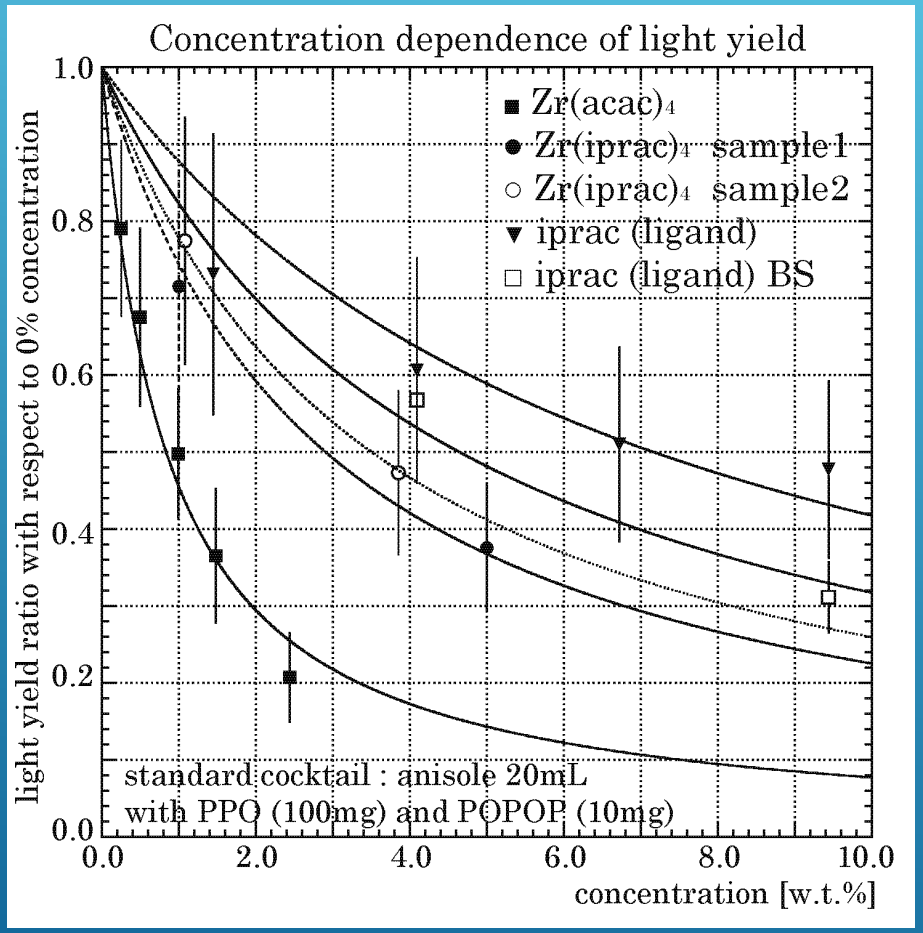
BACK SCATTERING METHOD





Single peak could be used even in liquid scintillator.

LIGHT YIELD OF LS CONTAINING ZIRCONIUM COMPLEX AS A FUNCTION OF CONCENTRATION



Light yield of $Zr(iprac)_4$ even with small bump recovered about double compared with $Zr(acac)_4$.

Light yield at 10w.t.% concentration was almost 40% to BC505 (≒ standard cocktail) . It is slightly smaller value than our goal...

ENERGY RESOLUTION OF LS CONTAINING ZIRCONIUM COMPLEX AS A FUNCTION OF CONCENTRATION

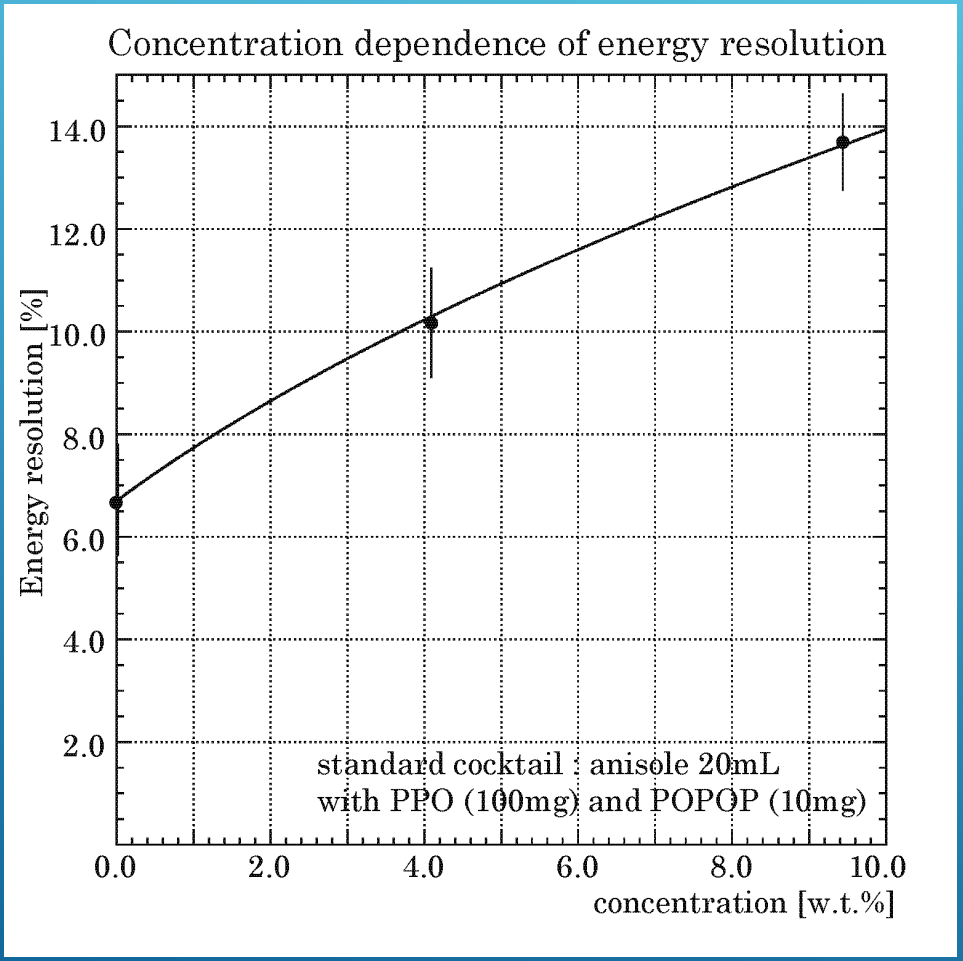
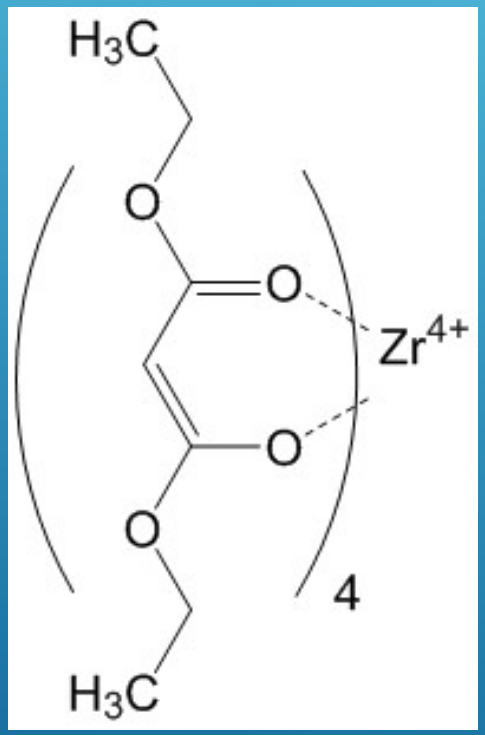


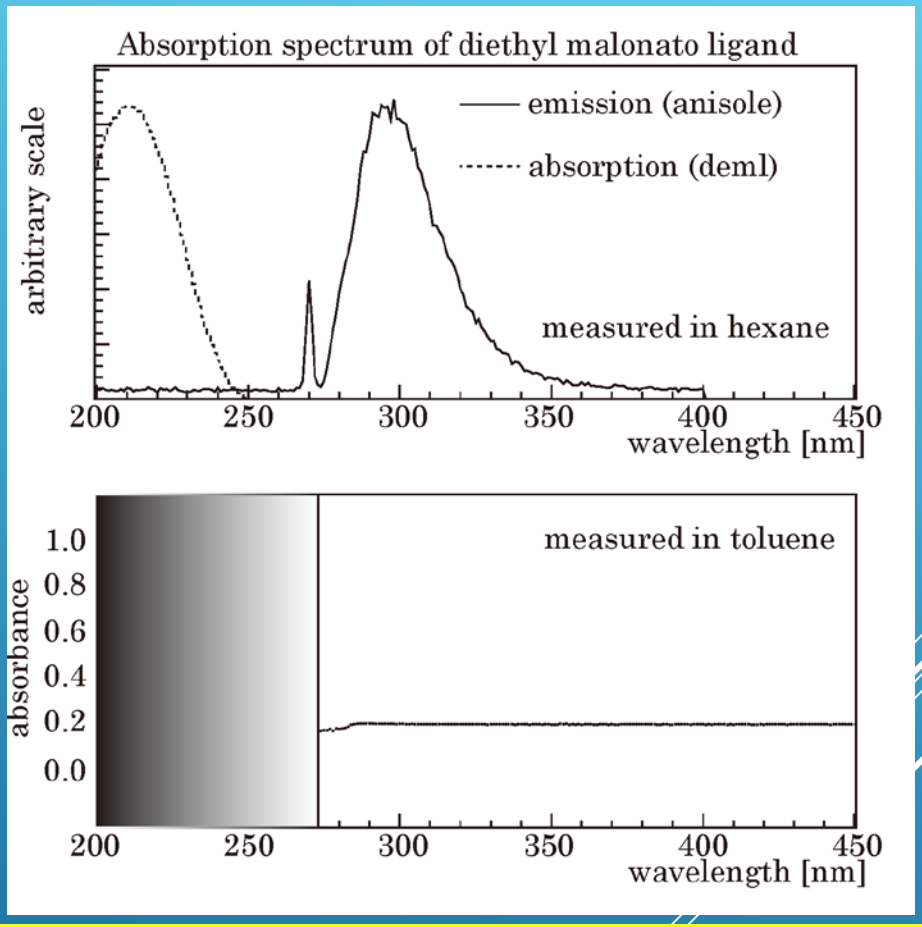
Photo coverage : ~8.5% (see explanation slide) Assuming 40% of photo coverage, the energy resolution will recover 6.5% @ 1MeV = 4.1% @ 2.5MeV for 10 w.t.% concentration.

They almost achieved to our initial goal!.

TETRAKIS (DIETHYL MALONATO) ZIRCONIUM AND ABSORBANCE SPECTRUM OF LIGAND

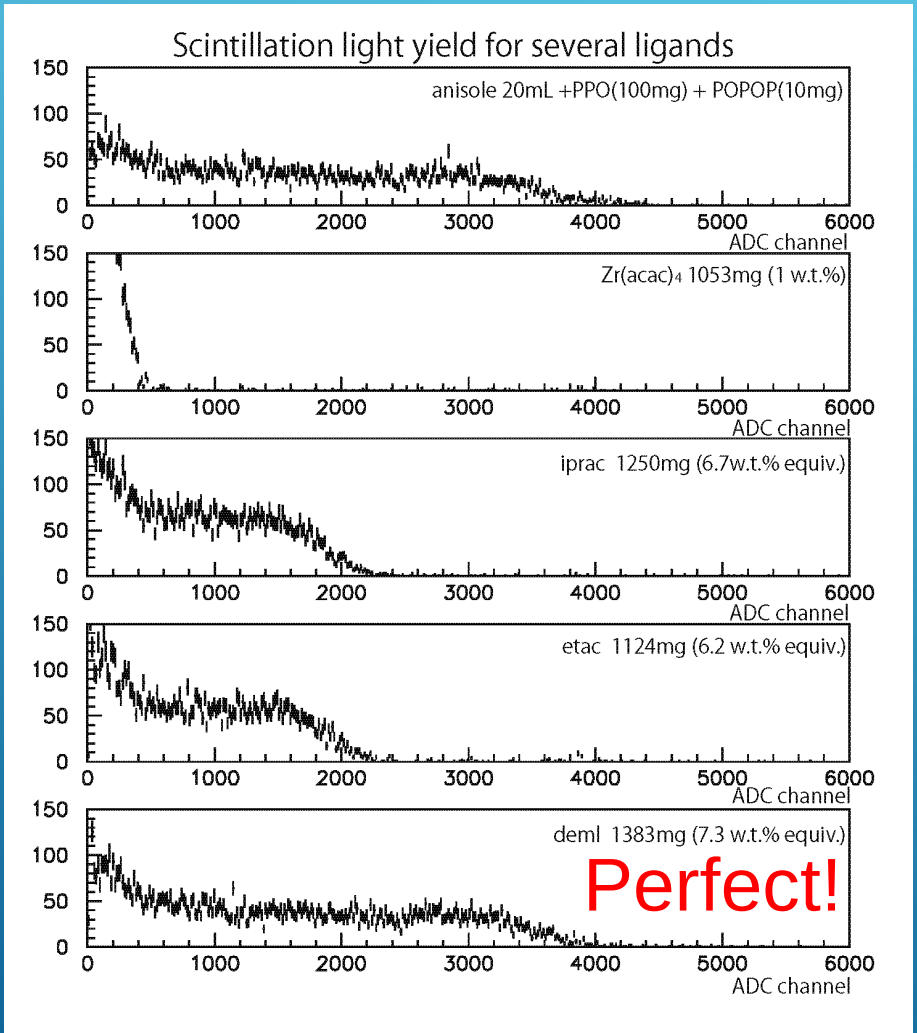
$Zr(CH_3CH_2OCOCHCOOCH_2CH_3)_4$
$= Zr(deml)_4$ mw : 727.87





shorter wavelength (~210nm)

LIGHT YIELD OF LS CONTAINING DIETHYL MALONATO LIGAND



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

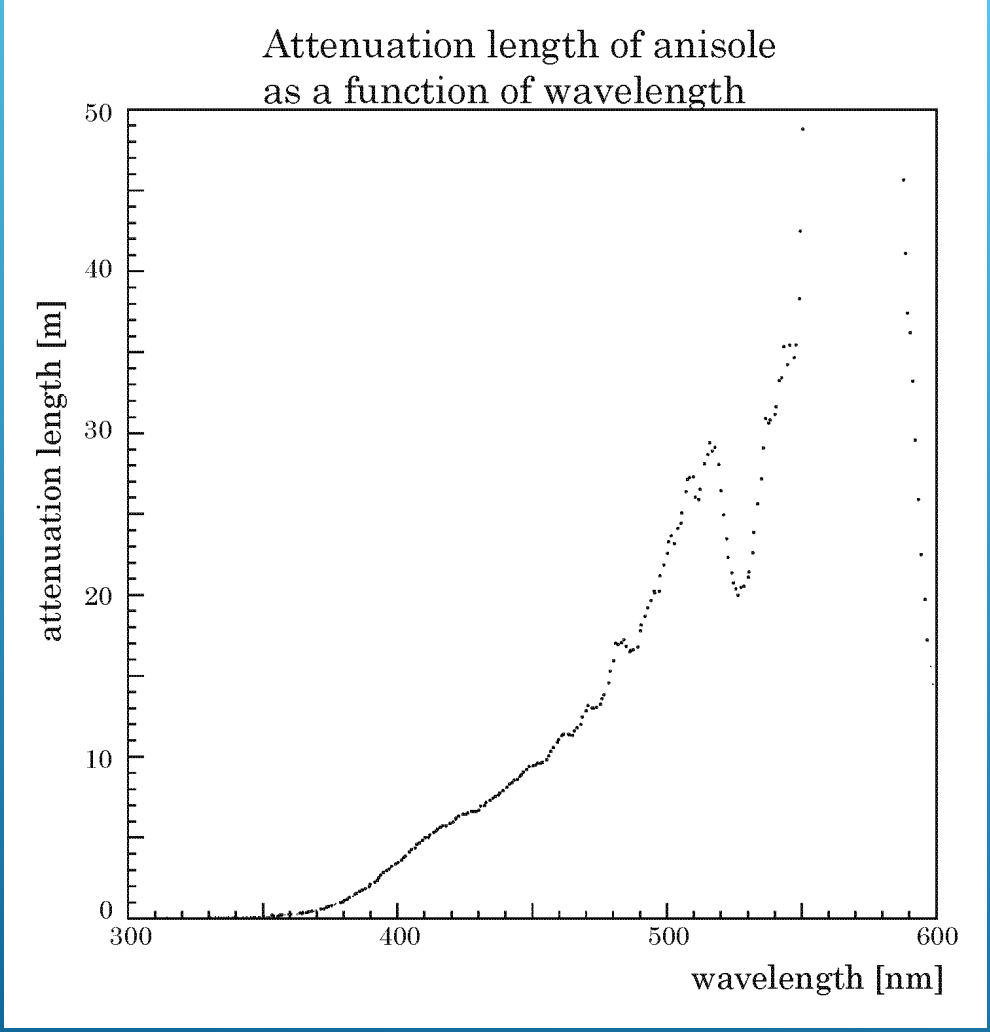
$Zr(deml)_4$ will be an ultimate complex if the solubility could be over 10w.t.% for anisole.

SUMMARY

- ZICOS uses liquid scintillator containing zirconium complex for neutrinoless double beta decay search
- Confirmed that the absorption peak moved shorter wavelength (275nm → 245nm) by introducing β-keto ester substituent groups.
- Succeeded anisole based liquid scintillator with **10 w.t.%** concentration of **$Zr(iprac)_4$** which has both **40% for light yield to BC505** and **4.1%@2.5MeV** (assuming 40% photo coverage) **for energy resolution**, so that **they almost achieved our initial goal !**
- To improve light yield (and also energy resolution), we shall move the absorption peak around 210nm using $Zr(deml)_4$ "tetrakis (diethyl malonato) zirconium".

BACKUP

ATTENUATION LENGTH OF ANISOLE



Attenuation length of light from POPOP was obtained as ~6m. It is almost equivalent with the detector size.