Supported by Grant-in-Aid for Scientific Research (C) 24540295 and
Grant-in-Aid for Scientific Research on Innovative Areas 24104501 and 26105502

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事象の探索Ⅴ

日本物理学会　2014年秋季大会

2014年9月20日

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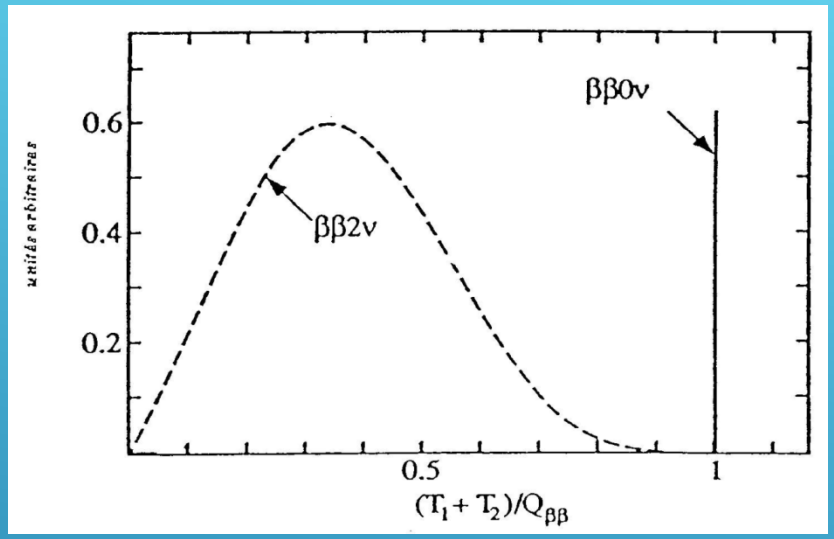
NEUTRINOLESS DOUBLE BETA DECAY

$\beta\beta$ 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



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

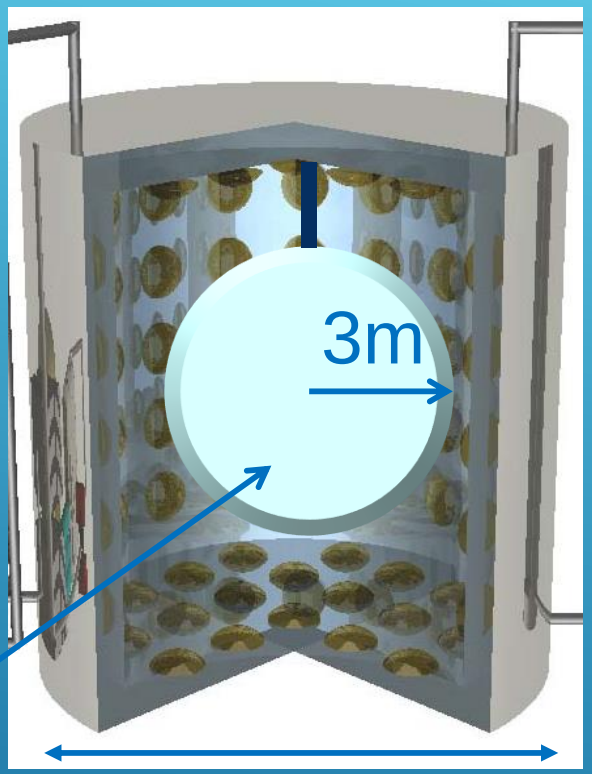
$T_{1/2} \sim a(Mt/\Delta EB)$ a: abundance M: target mass

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



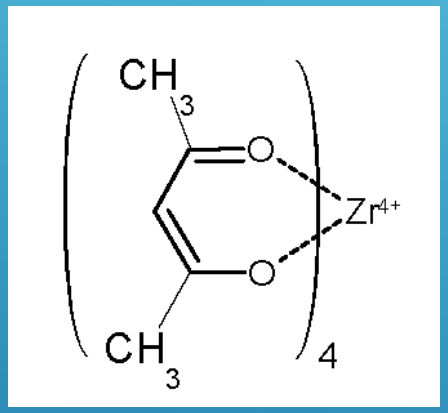
PMT with 40% photo coverage

Water shield surrounding inner balloon to veto γ's

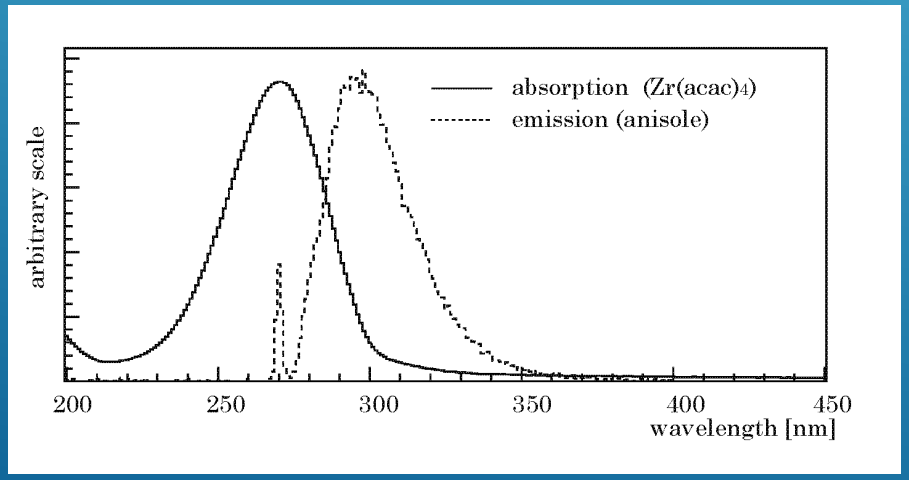
Zirconium loaded 100 tons LS
(300kg ^{96}Zr assuming10% enrich)

ZIRCONIUM BETA-DIKETON COMPLEX

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

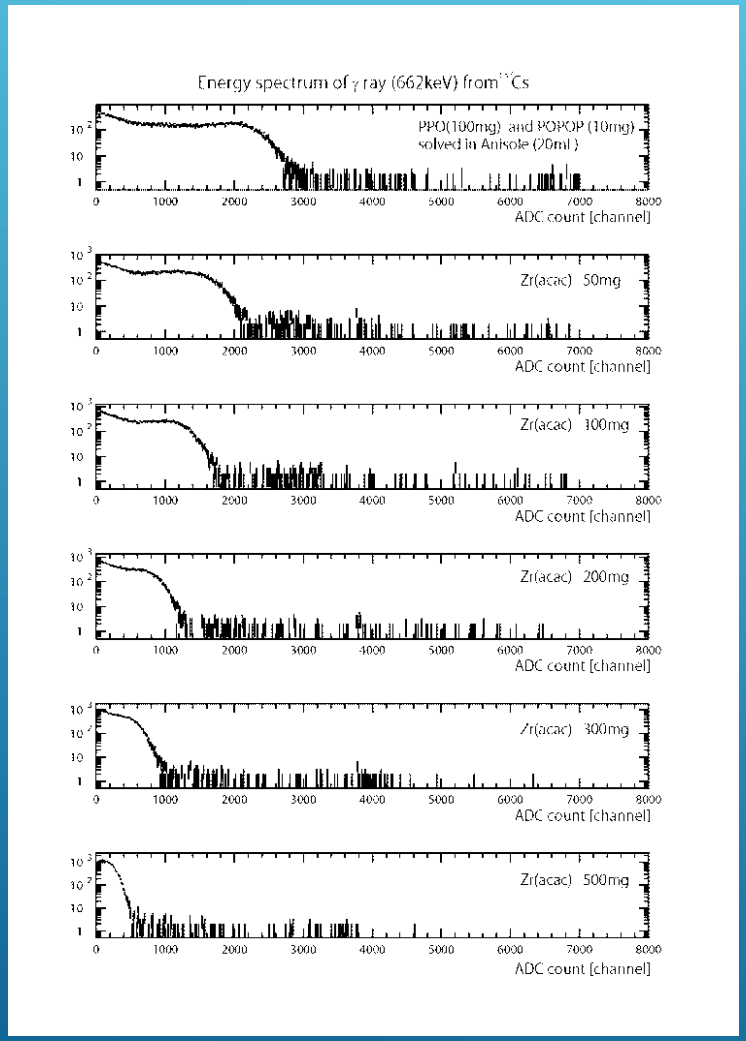


MW: 487.66



- 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.

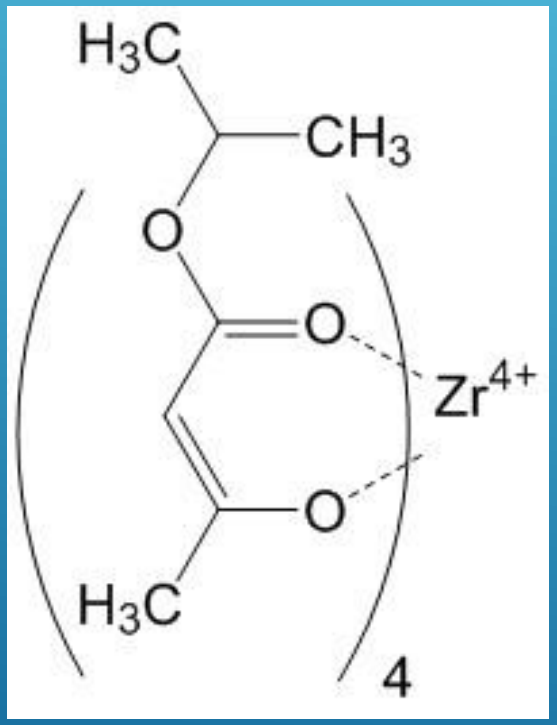
LIGHT YIELD AS A CONCENTRATION OF ZIRCONIUM ACETYLACETONATE



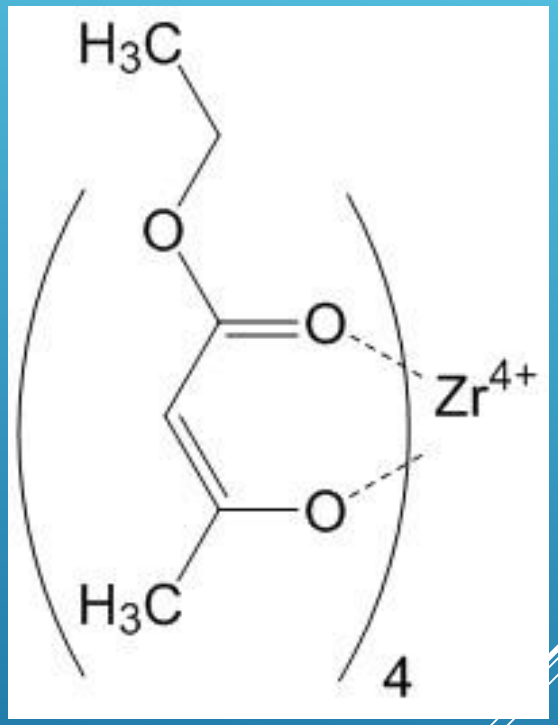
concentration of $Zr(acac)_4$	Observed channel	Expected channel
0 mg	2450	2450
50mg	1800	1997
100mg	1400	1687
200mg	950	1284
300mg	650	1038
500mg	300	750

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

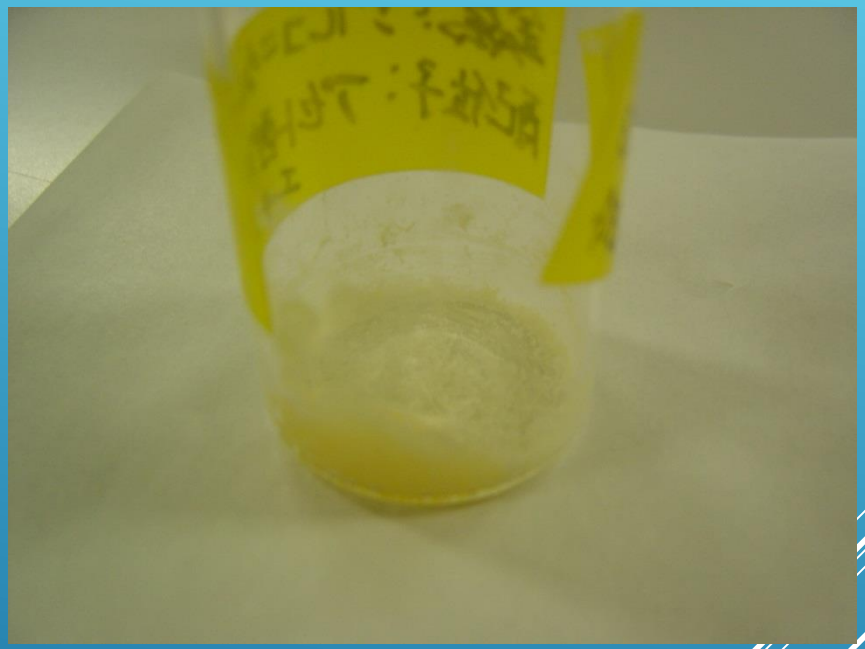


Expected shorter absorption wavelength

SYNTHESIZE OF ZIRCONIUM BETA-KETO ESTER COMPLEX

$Zr(iprac)_4$
state: powder

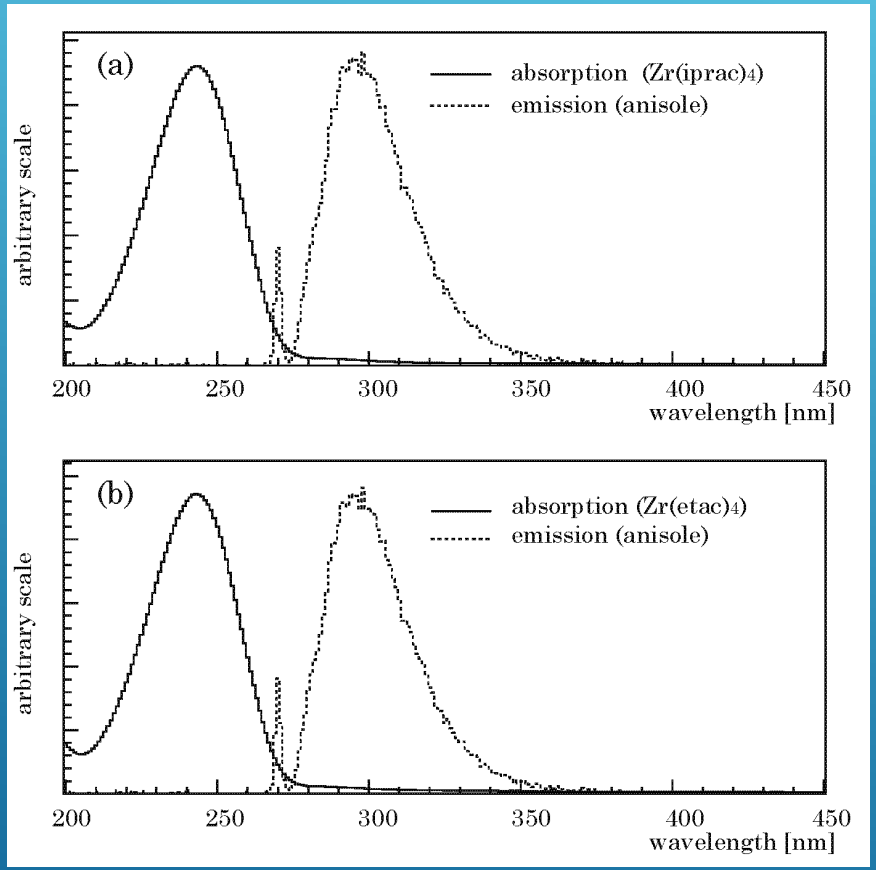
$Zr(etac)_4$
state : solid or powder



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

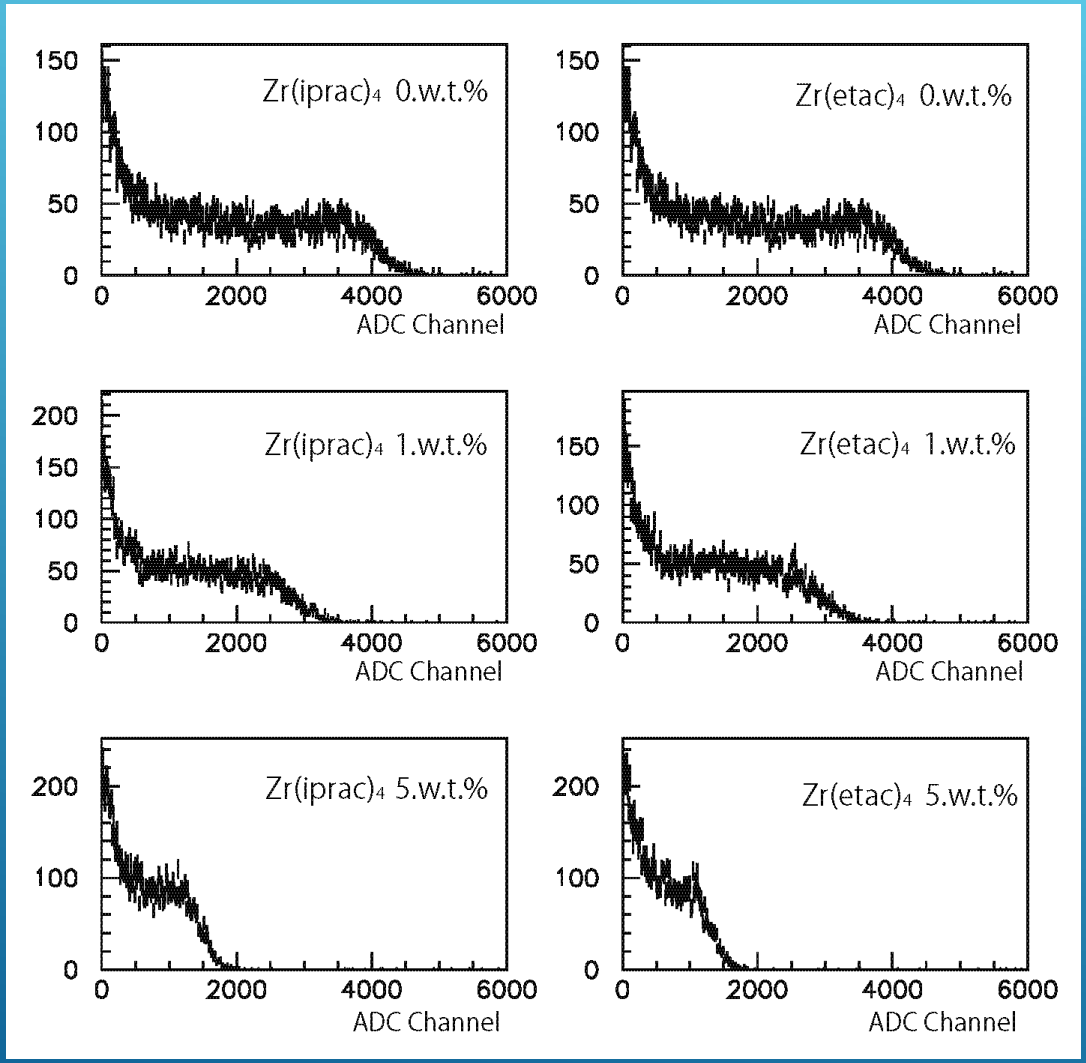
Solubility > 10 w.t.% for anisole

ABSORBANCE SPECTRA FOR ZIRCONIUM BETA-KETO ESTER COMPLEX



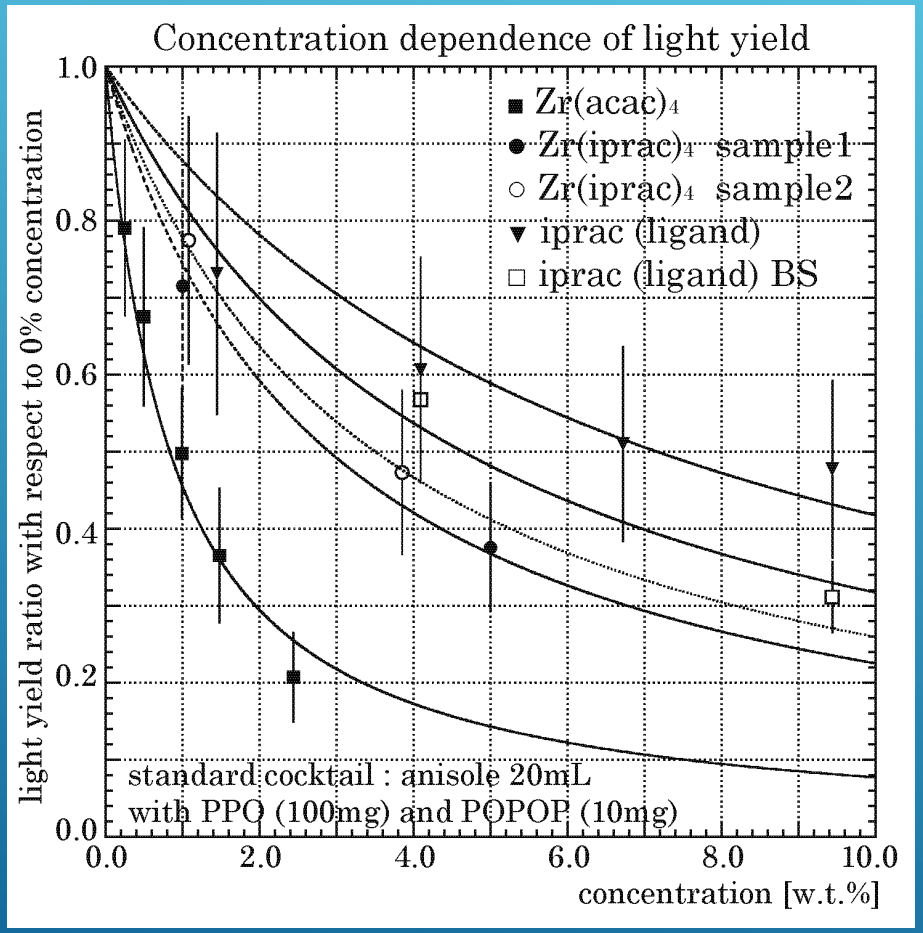
Absorption tail of (pure) zirconium β-keto ester complex slightly overlapped with the region of the emission of anisole. (No bump around 270nm was seen. See next talk)

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 .

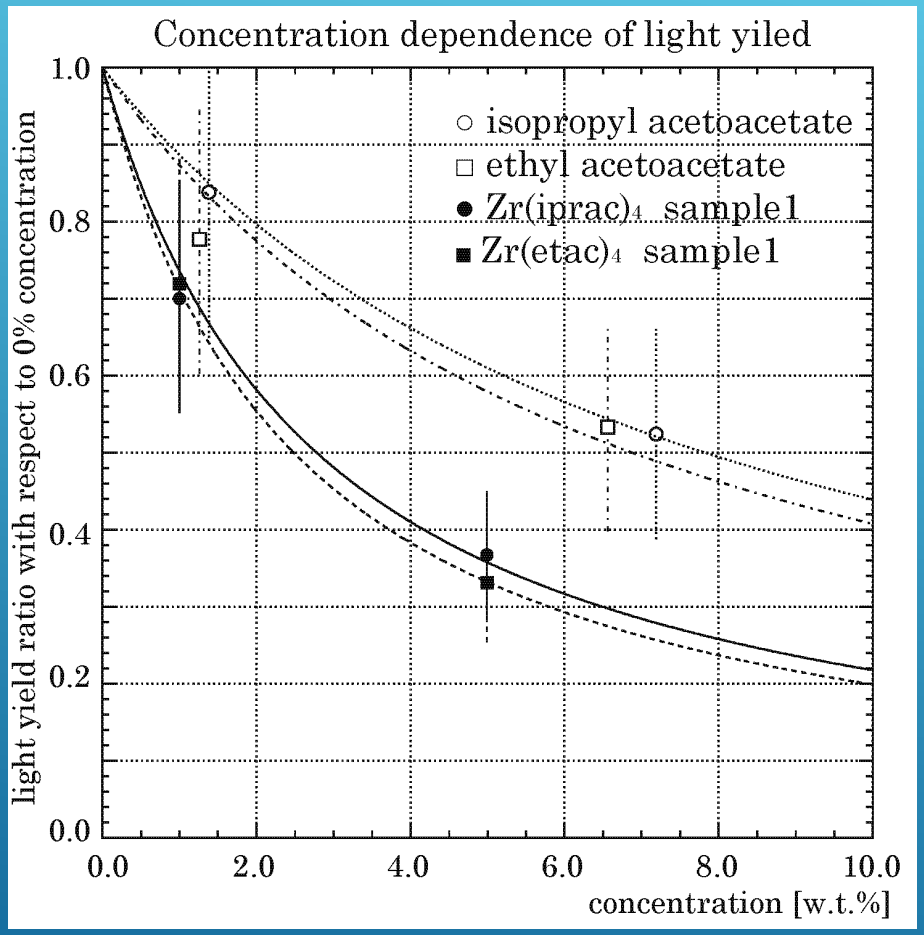
LIGHT YIELD OF LS CONTAINING ZIRCONIUM COMPLEX AS A FUNCTION OF CONCENTRATION



Light yield of $Zr(iprac)_4$ 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...

LIGHT YIELD OF LS CONTAINING COMPLEX AND LIGAND AS A FUNCTION OF CONCENTRATION



Both light yields of $Zr(iprac)_4$ and $Zr(etac)_4$ are almost same. They are also about half yield for those ligand.

It is due to small bump around 270nm (see next talk).

ENERGY RESOLUTION OF LS CONTAINING LIGAND AS A FUNCTION OF CONCENTRATION

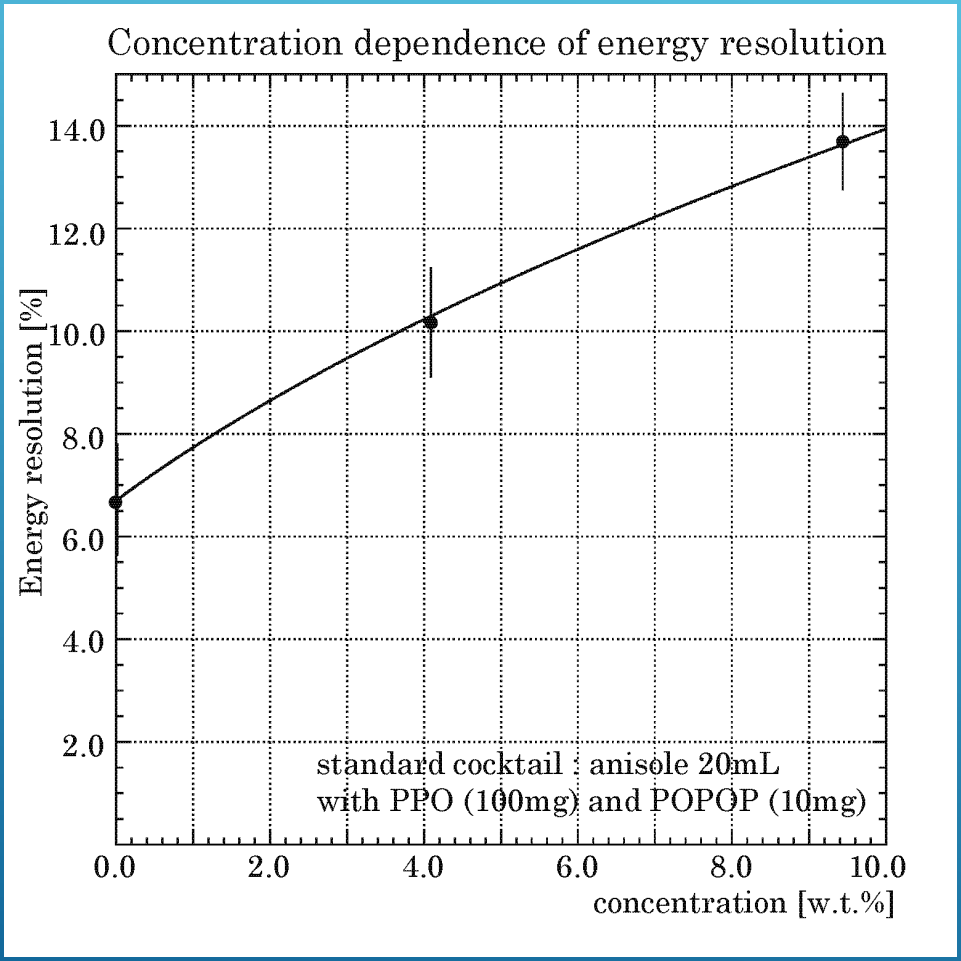
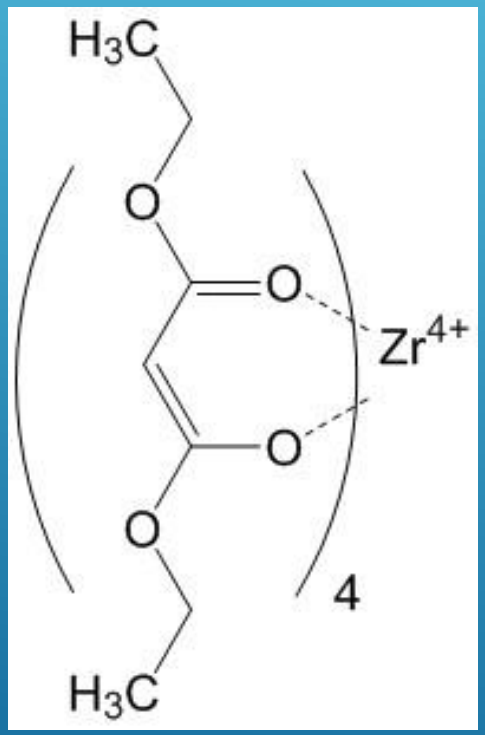


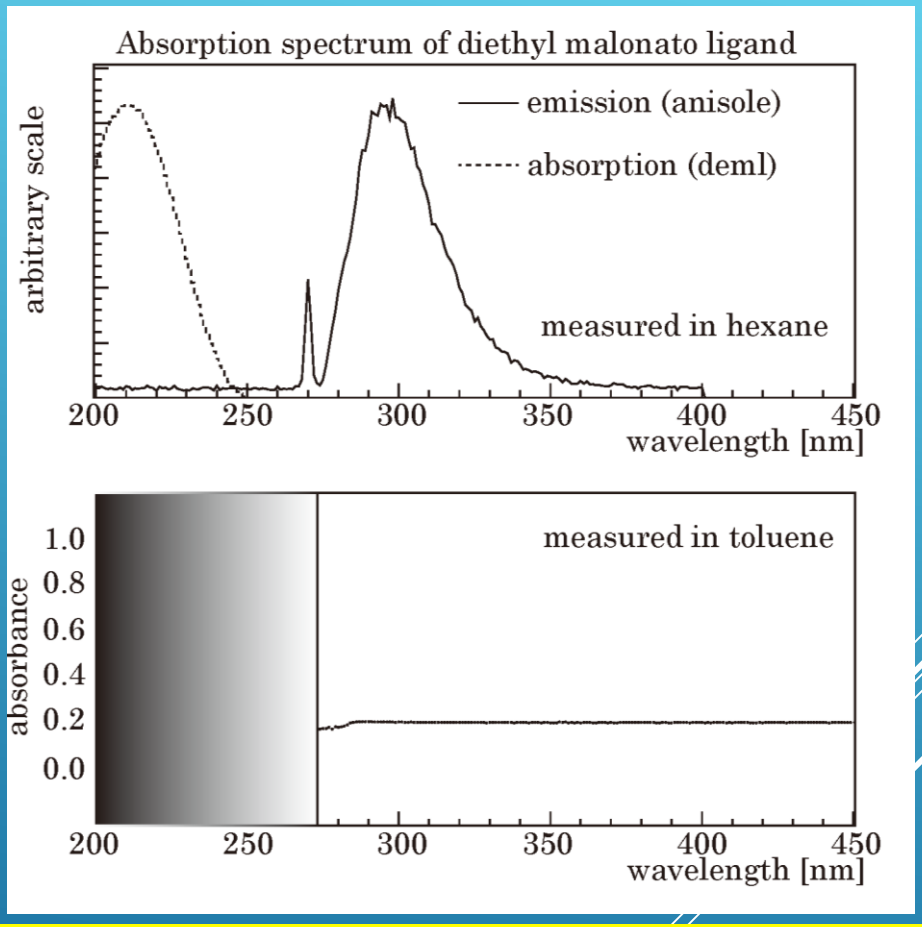
Photo coverage : ~8.5% (see explanation slide) Assuming 40% of photo coverage, the energy resolution will recover 6.5% @ 1MeV = 4.1% @ 2.5MeV for 10 w.t.% concentration.

They almost achieved to our initial goal!.

TETRAKIS (DIETHYL MALONATO) ZIRCONIUM AND ABSORBANCE SPECTRUM OF LIGAND

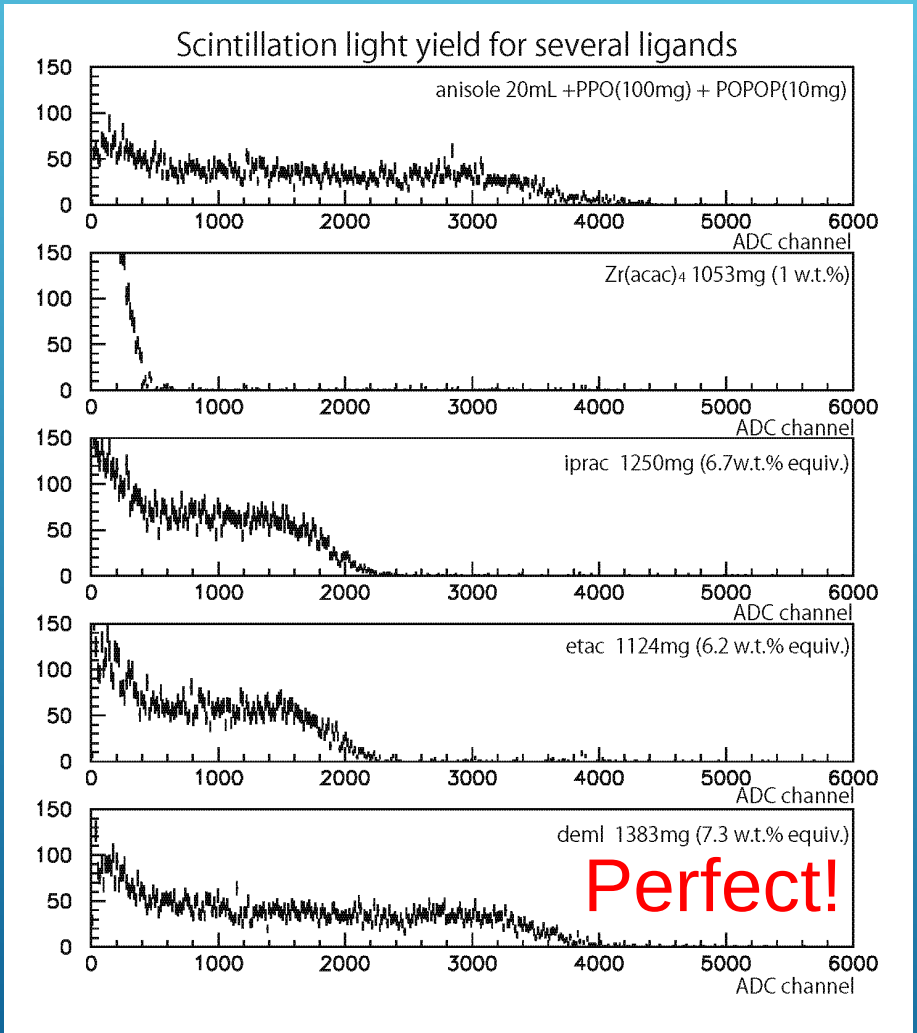
$Zr(CH_3CH_2OCOCHCOOCH_2CH_3)_4$
$= Zr(deml)_4$ mw : 727.87





shorter wavelength (~210nm)

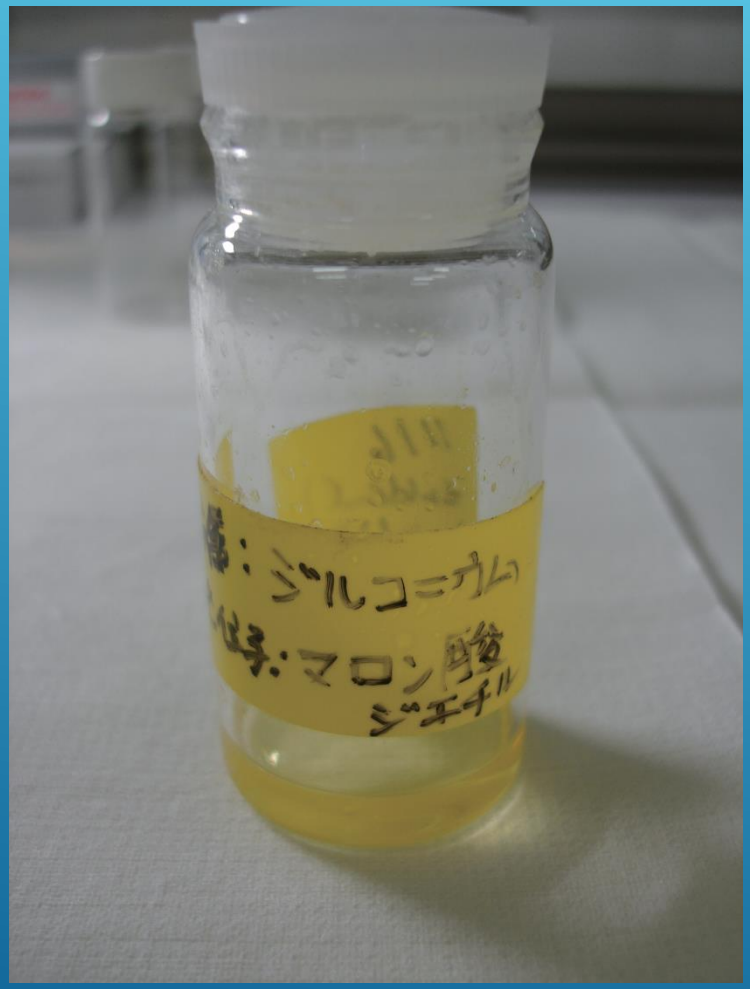
LIGHT YIELD OF LS CONTAINING DIETHYL MALONATO LIGAND

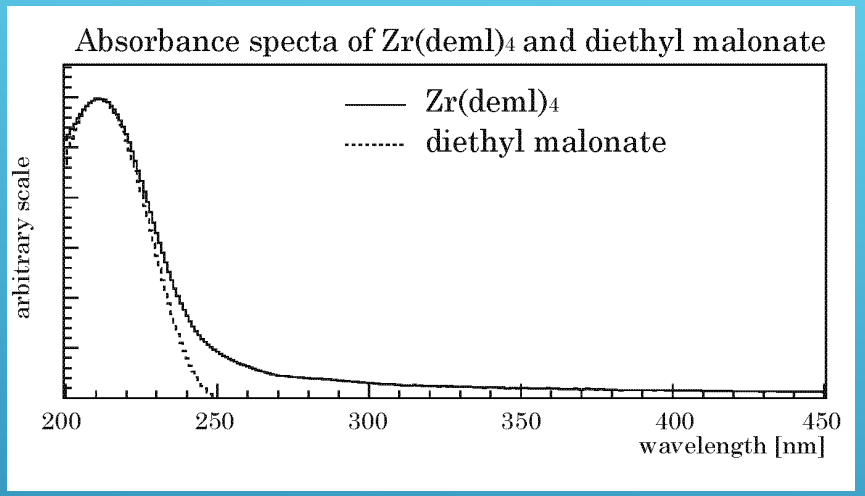


No quenching due to overlap between the absorption of ligand and the emission of anisole should be occurred.

$Zr(deml)_4$ will have an energy resolution of 2.9% @ 2.5MeV for 10w.t.% concentration.

SYNTHESIS OF TETRAKIS (DIETHYL MALONATO) ZIRCONIUM





Absorbance spectra of $Zr(deml)_4$ and diethyl malonate are almost same.

SUMMARY

- ZICOS uses liquid scintillator containing zirconium complex for neutrinoless double beta decay search.
- Confirmed that the absorption peak was moved to shorter wavelength (275nm → 245nm) by introducing β-keto ester substituent groups.
- Possible to anisole based liquid scintillator be 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 will be almost achieved our initial goal !**
- To improve both light yield and also energy resolution , we shall move the absorption peak around 210nm using $Zr(deml)_4$ and will get **2.9% @ 2.5MeV**!