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

IPNOS for low energy solar neutrinos and ZICOS for neutrinoless double beta decay

Aspen Winter Workshop--New Directions in Neutrino Physics

February 4th ,2013

Yoshiyuki FUKUDA (Miyagi University of Education)
S.MORIYAMA , H.Sekiya(ICRR, Univ. of Tokyo) I. Ogawa (Fukui University), T.Namba(ICEPP, Univ. of Tokyo), and
M.Asakura ,T.Izawa(Hamamatsu Photonics KK)

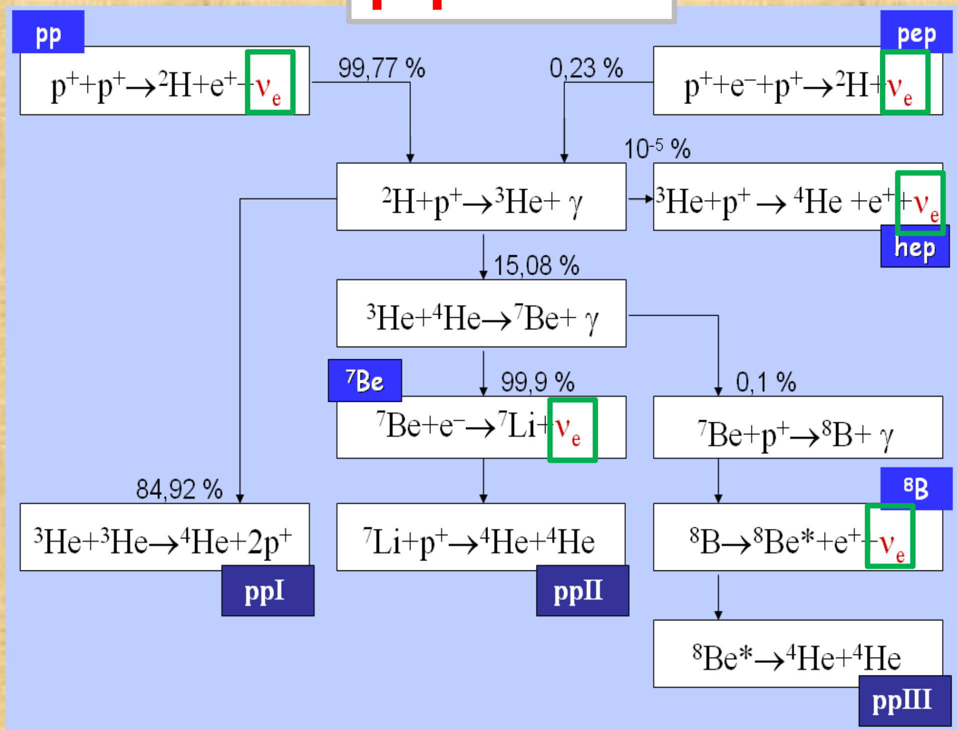
Indium Project on Neutrino Observation for Solar Interior (IPNOS) experiment for low energy solar neutrinos

Solar neutrino

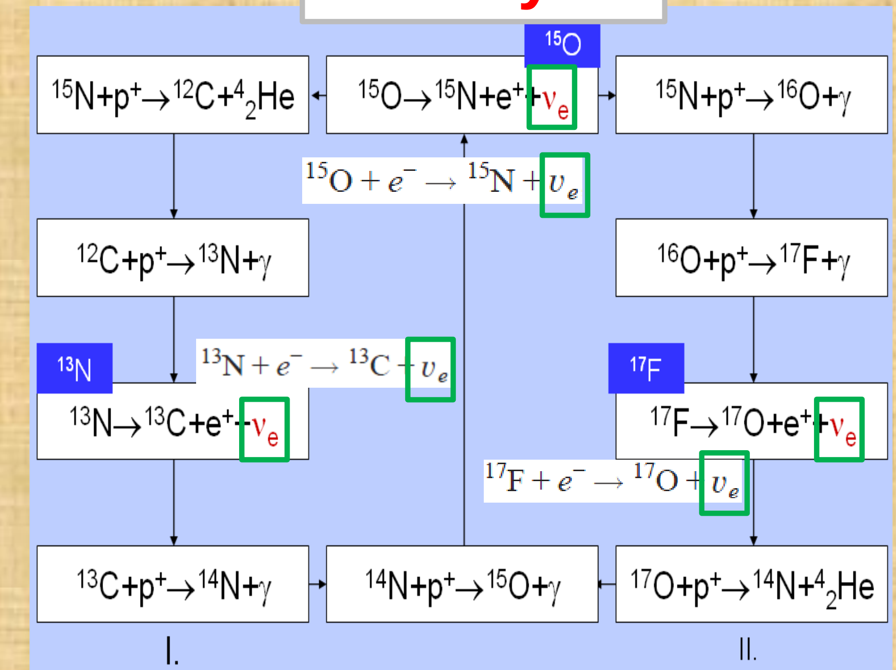
Takeuchi @ LowNu2011

Overall reaction: $4p \rightarrow {}^4He + 2e^+ + 2\nu_e + 25\mathrm{MeV}$

p-p chain



CNO cycle



- **Solar fusion cross sections are updated. (SF-II, Rev. of Mod. Phys. 83 (2011) 195)**
- **Solar abundances: GS98 (High metallicity), AGSS09 (Low metallicity)**

Experimental status

Takeuchi @ LowNu2011

long term stability of pp rate (cf. PRC 80, 015807 (2009))

- pp(0.6%): SAGE (all:5%,pp:14%), Gallex/GNO
- 7Be(7%): Homestake, Borexino (5%)
- pep(1.2%): Borexino (19%)
- 8B(14%): Kamiokande, Super-K, SNO (4%), Borexino, KamLAND

  high precision spec. & d/n
- hep(30%): (SK, SNO, upper limit only)

  SK: 40x10^3 /cm2/s (90%CL, w/o osc.) PRL 86, 5651 (2001)

  SNO: 23x10^3 /cm2/s (90%CL, w/ osc.) ApJ 653, 1545 (2006)
- CNO (14~17%): (Borexino, upper limit only)

  7.7x10^8 /cm2/s (95%CL, w/ osc.) arXiv:1110.3230

  purification efforts are now on-going

radiochemical experiments

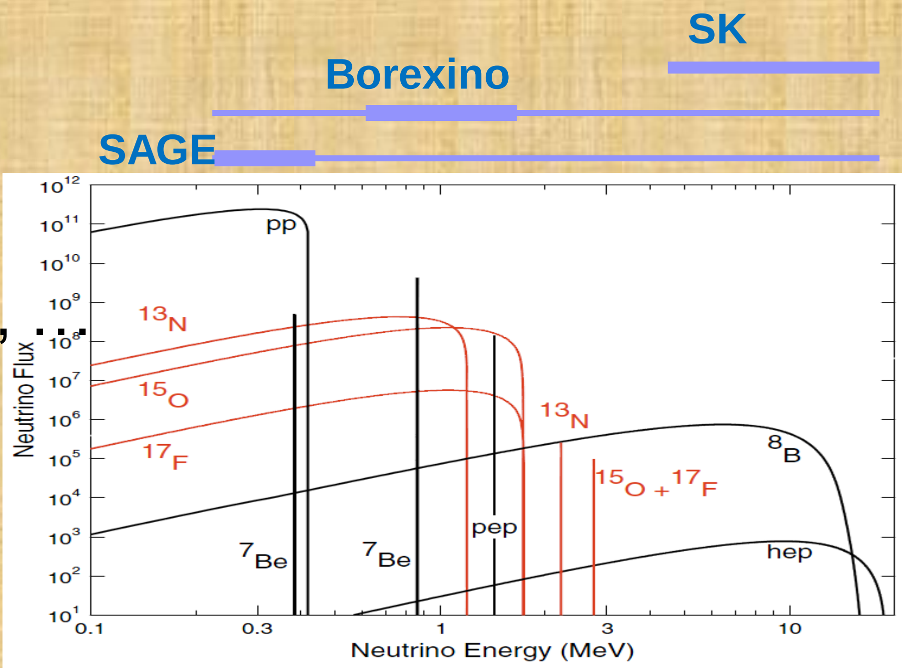
theoretical / experimental uncertainties **running**

Current targets

Takeuchi @ LowNu2011

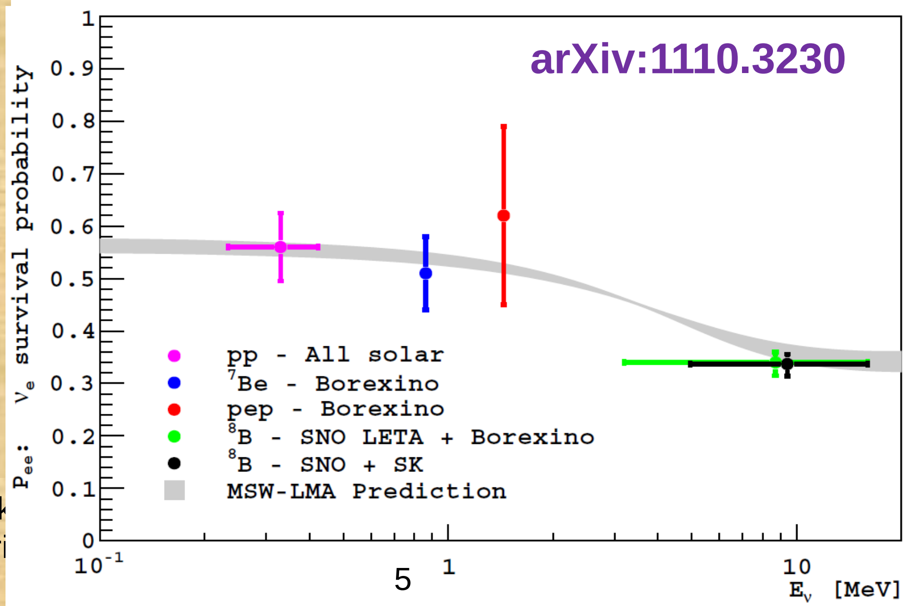
Neutrino physics

- Vacuum-MSW transition
  - pep flux(ES,CC), 8B spectrum, …
- Precise theta12
  - pp flux, 8B spectrum, …



Astrophysics

- Separate solar models
  - CNO fluxes
- Solar core
  - high stat. solar ν



Future solar neutrino projects

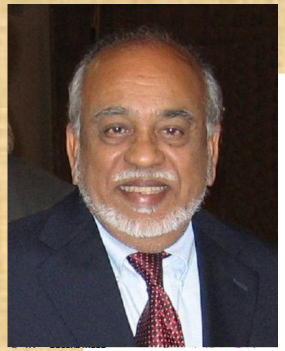
Takeuchi @ LowNu2011

project	target for solar ν	current status / recent information
pep/CNO (ES)		
SNO+	1kt LS	under construction
KamLAND2	1kt LS	will be after KamLAND-Zen
pp(ES)		
XMASS	10 ton(FV) Lq. Xe	commissioning of XMASS-I (total 1ton, ~0.1ton FV)
CLEAN	50 ton Lq. Ne	MiniCLEAN is under construction
HERON	10 ton Lq. He	will not built a full detector (Astropart. Phys. 30, 1 (2008))
pp/7Be(CC)		
LENS	10ton 115In	R&D (In loaded LS)
IPNOS	115In	R&D (InP cell + Lq. Xe detector)
MOON	1.5~3ton 100Mo	R&D (EC branch of 100Tc was measured)

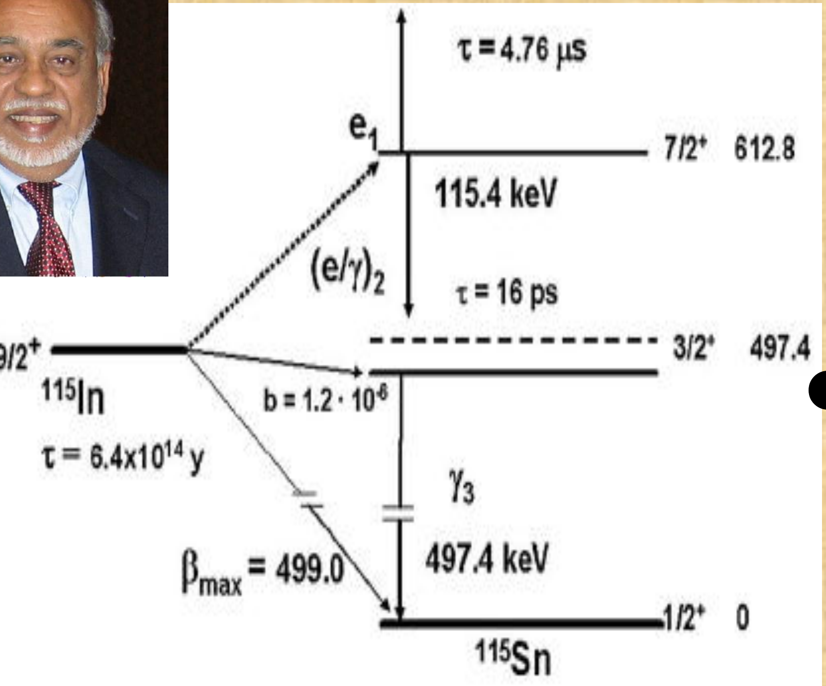
Next generation

Water Cherenkov	Megaton water	LOI from Hyper-K (arXiv:1109.3262)
Lq. Scintillator	~0.1Mton LS	white paper from LENA (arXiv:1104.5620)

Capture of low energy solar neutrinos by ^{115}In



R.S.Raghavan Phs.Rev.Lett37(1976)259



Nuclear Physics A 748 (2005) 333-347

$^{115}In + \nu_e \rightarrow {}^{115}Sn^* + e^-$

$^{115}Sn^*(4.76\mu s) \rightarrow {}^{115}Sn +$

$\gamma_1(115keV) + \gamma_2(497keV)$

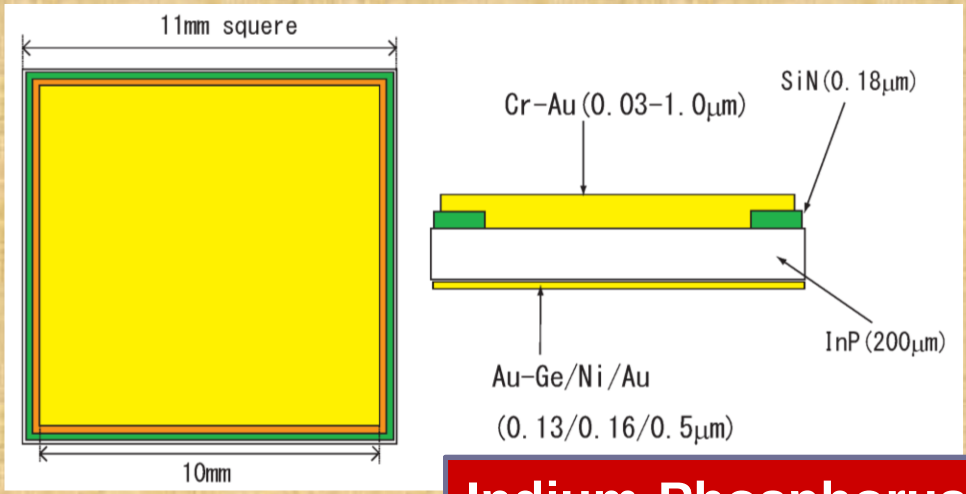
- **Advantage**
  - large cross section (~640SNU)
  - direct counting for solar neutrinos
  - sensitive to low energy region ($E_\nu \geqq 125keV$)
  - energy measurement ($E_e = E_\nu - 125keV$)
  - triple fold coincidence to extract neutrino signal from huge BG ($e_1 + \gamma_2 + \gamma_3$)
- **Disadvantage**
  - natural β-decay of ^{115}In ($\tau_{1/2} = 4.4 \times 10^{14}$ yr , $Ee \geqq 498keV$)
  - possible BG due to correlated coincidence by radiative Bremsstrahlung

Goal

1. Good energy resolution : 10%(FWHM)
2. Fine segmentation (10^4-10^5)
3. High efficiency γ detection

Semi-insulating InP detector

mounted in vacuum dewar



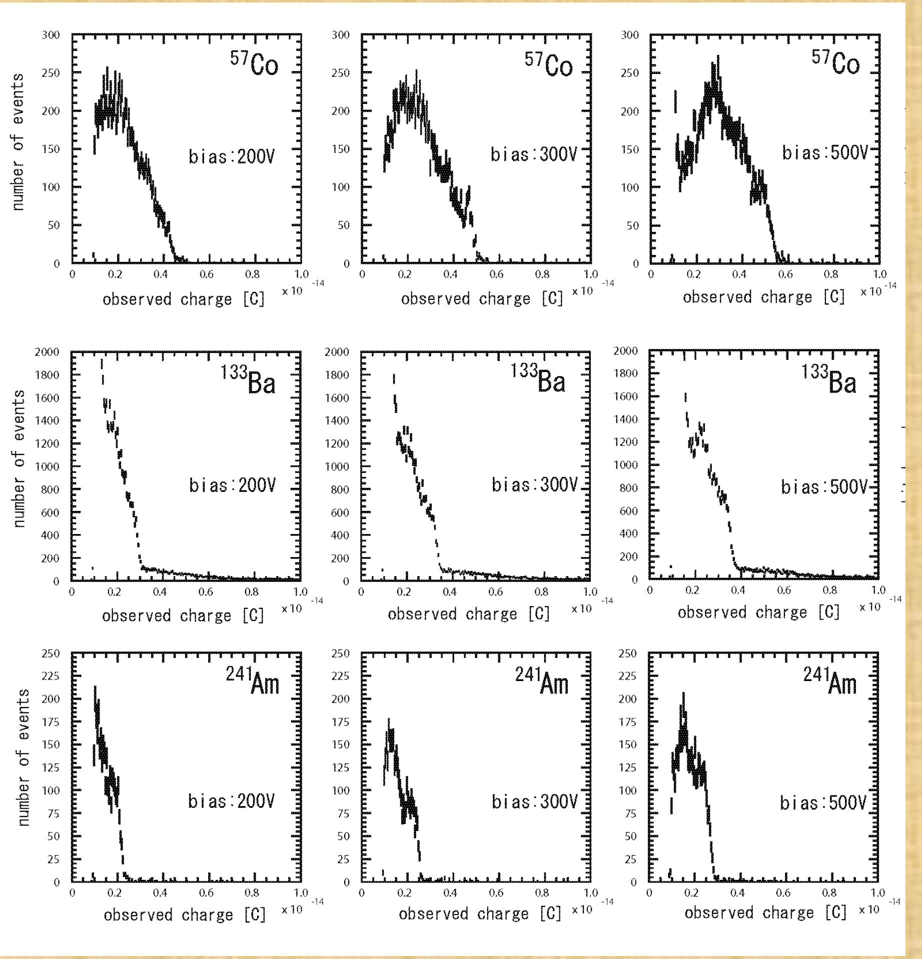
Indium-Phosphorus (200μm)

- Semi-insulating InP VCZ substrate by Sumitomo Electric Industrials
- Assembled by Hamamatsu Photonics
- Operation at -79degree

Surface size:
- ･10mm × 10mm × 0.2mm
- ･6mm × 6mm × 0.2/0.23/0.28/0.45mm

Electrode :
- ･ Ohmic contact
- ･ evaporated Au/Cr base metal
- ･ Insulator (SiN) to avoid leak current

Gamma ray spectrum observed by InP

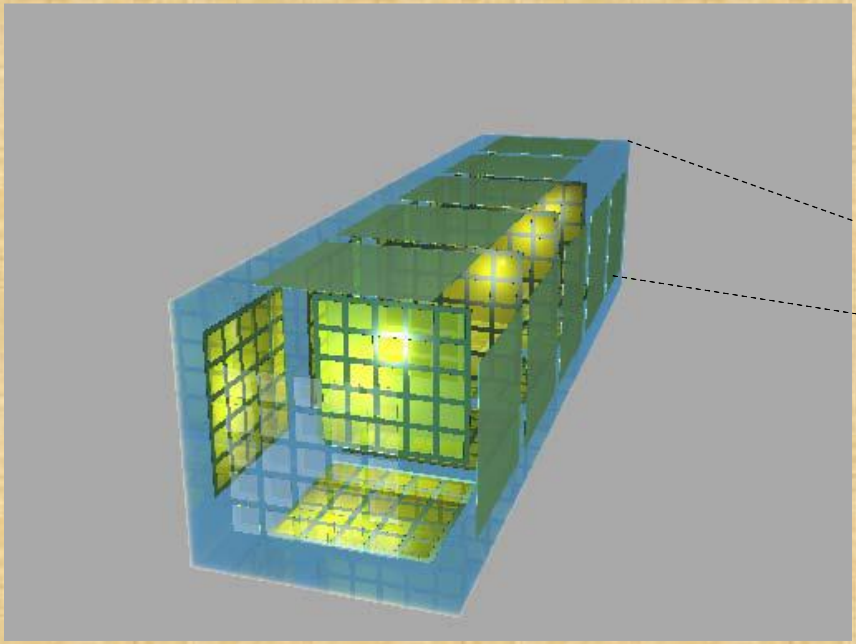


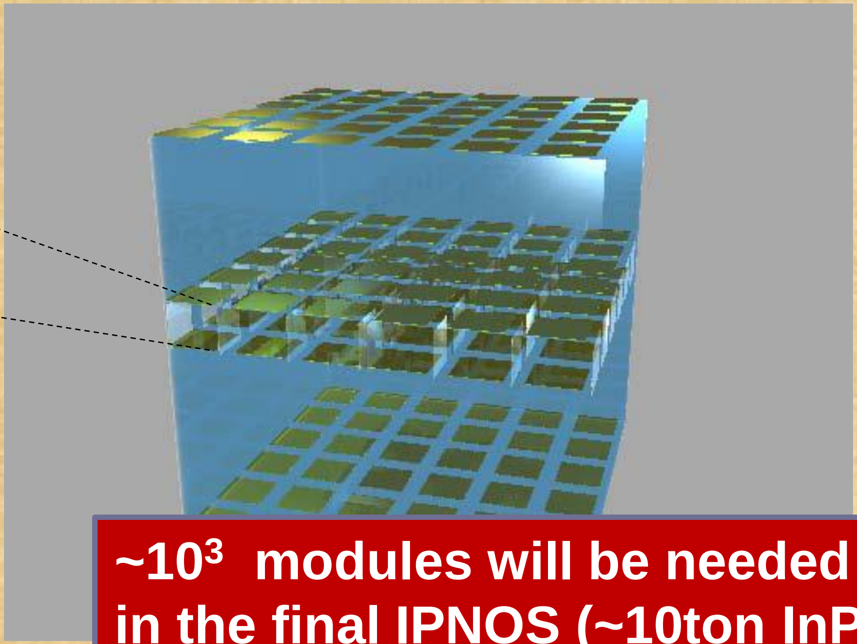
- Measured clear photo- peak
- induced charge collection (L_{ed}~200μm L_{he} ~ 30μm)
- Energy of electron-hole pair production :3.5eV
- Energy resolution : 25%@122keV

IPNOS phase-I experiment for low energy solar ν experiment

InP multi-pixel detector inside of Liquid Xenon (LXe) with PMTs

30cm cubic chamber (like XMASS 100kg prototype) includes ~10kg InP detector



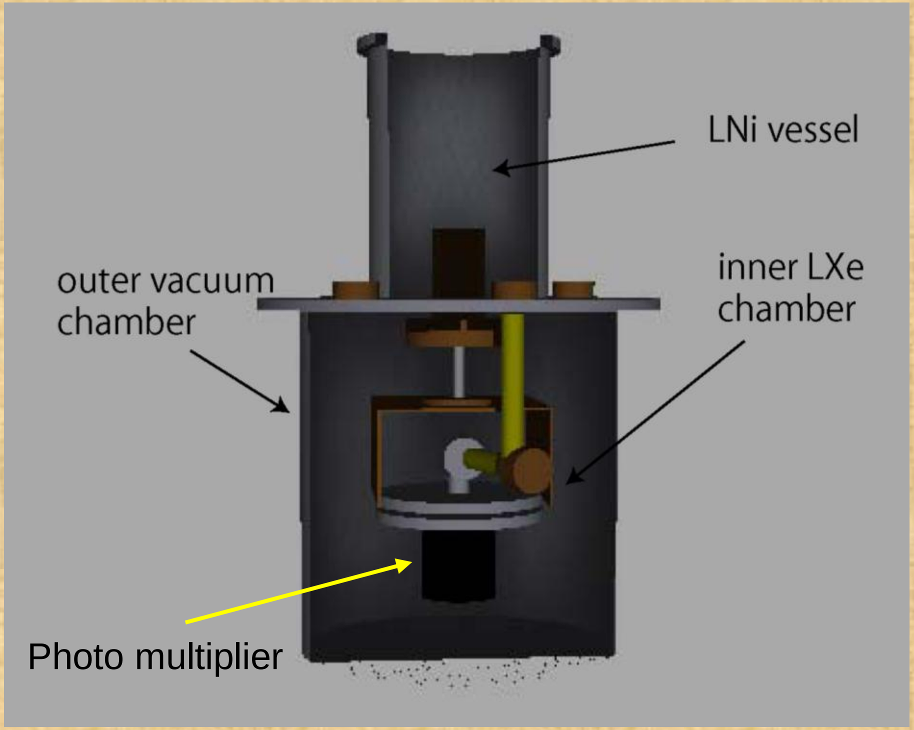


~10^3 modules will be needed in the final IPNOS (~10ton InP)

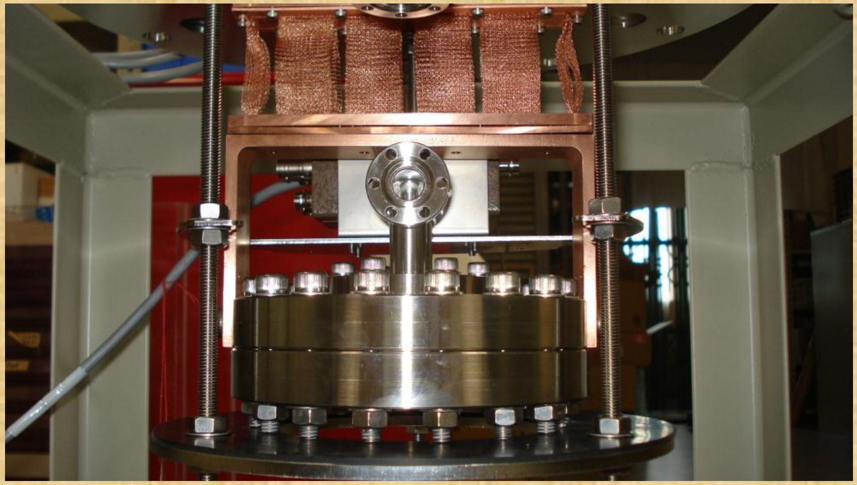
Need larger area InP detector

Development of LXe chamber for IPNOS phase-I proto-type

- 24cc Liquid Xenon (LXe) in inner chamber
- 4 InP detectors mounted inside of LXe
- PMT (used for XMASS) detects sci. light from gammas



Cooling test of Liquid Xenon chamber



New InP crystal (low etch pit density)

ACROTEC
SEMICONDUCTOR MATERIALS

DF 2inch Fe doped InP 69 point EPD map

JX

		2158	1826	124	664	373		
	456	581	166	83	0	41	0	
373	290	332	124	0	0	0	0	871
290	498	747	166	0	41	0	83	83
456	498	166	41	249	249	207	249	124
332	249	207	249	539	332	166	0	0
456	581	913	1826	1826	1328	166	0	0
	498	1328	1784	996	539	124	0	
		4647	788	373	581	41		

黄色セル<500cm-2

DF area:72%

DF サンプル品EPDマップ

		16763	6307	3693	2905	3071		
	10124	15270	4938	1618	1203	830	2116	
5477	3071	11950	11950	5477	913	2614	2946	5643
1784	1120	4813	9129	7635	13278	1743	2365	5477
539	1328	4896	4979	4896	6307	15104	2656	6805
830	2365	3651	2324	2822	2116	4813	20913	4149
6805	3983	4979	4481	1992	830	1452	9627	5975
	2407	954	1203	581	705	1369	7801	
		3071	3320	2490	2780	1245		

DF area:0%

通常品EPDマップ

JX Nippon Mining & Metals Corporation

1

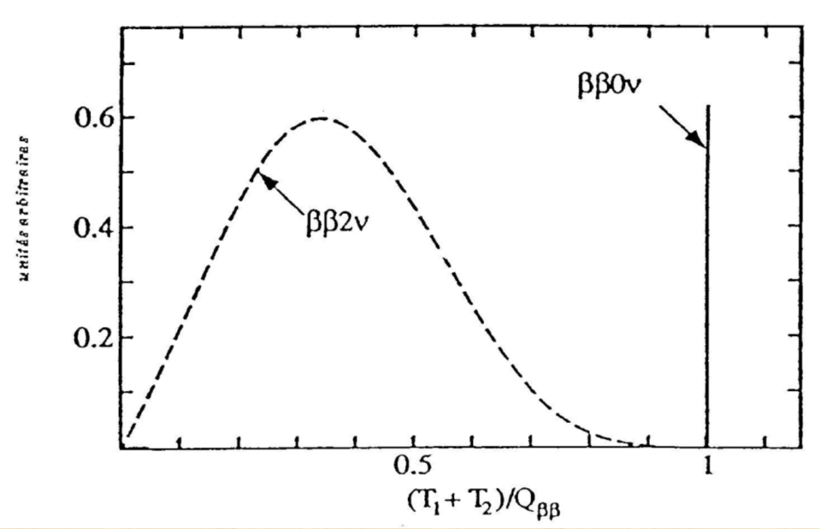
EPD related to Lattice Defect which generates significant dark current

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

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



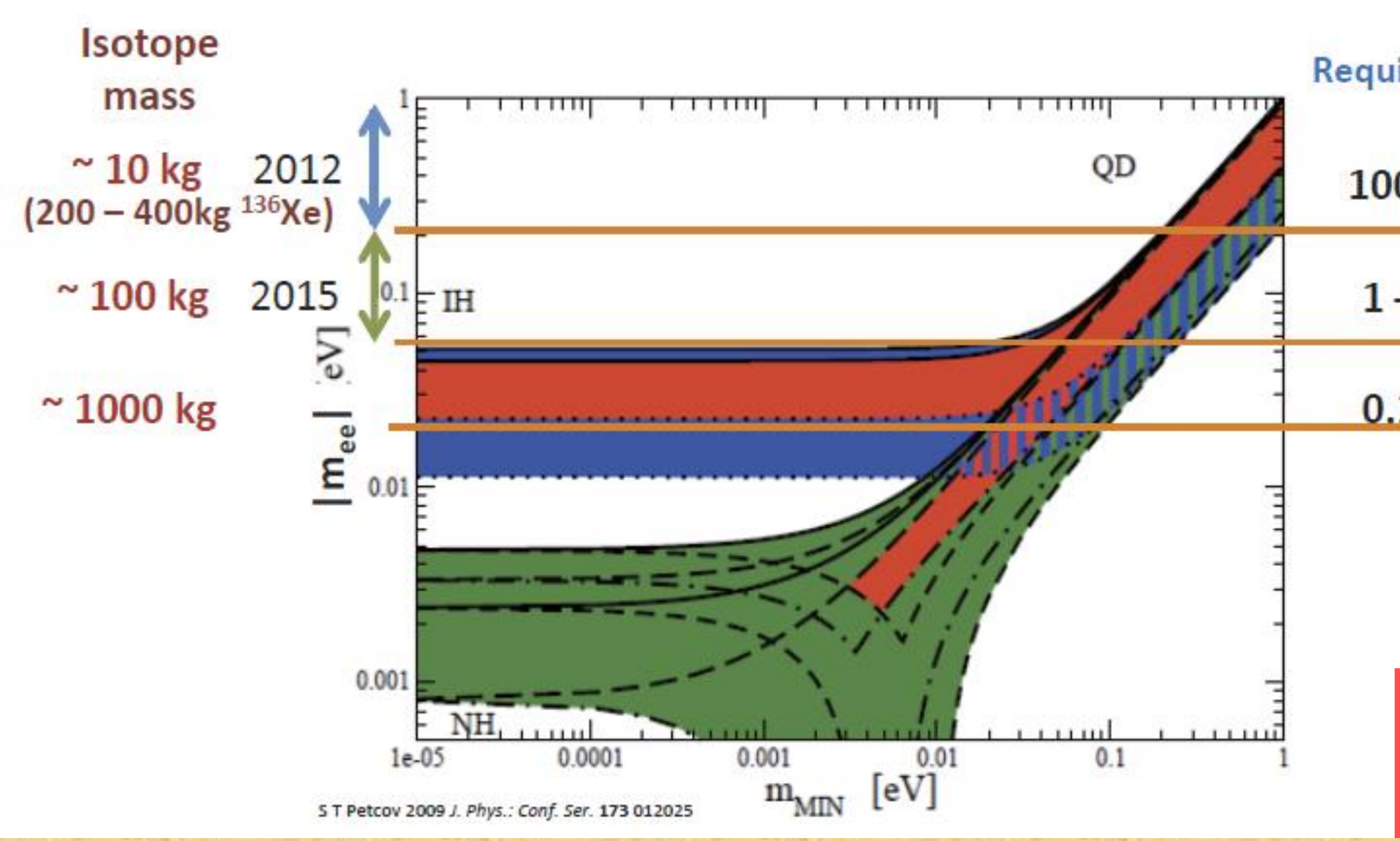
$$[T_{1/2}^{0\nu}(0^+ \rightarrow 0^+)]^{-1} = G_{0\nu}(E_0,Z)|M_{0\nu}|^2 \langle m_\nu \rangle^2$$

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

t: meas.time ΔE: energy res. B: BG rate

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

For future experiments



F.Piquemal @ν2012

http://kds.kek.jp/getFile.py/access?contribId=37&sessionId=16&resId=2&materialId=slides&confId=9151

~tons of target will be needed for next generation detector

Studied isotopes

Piquemal@ν2012

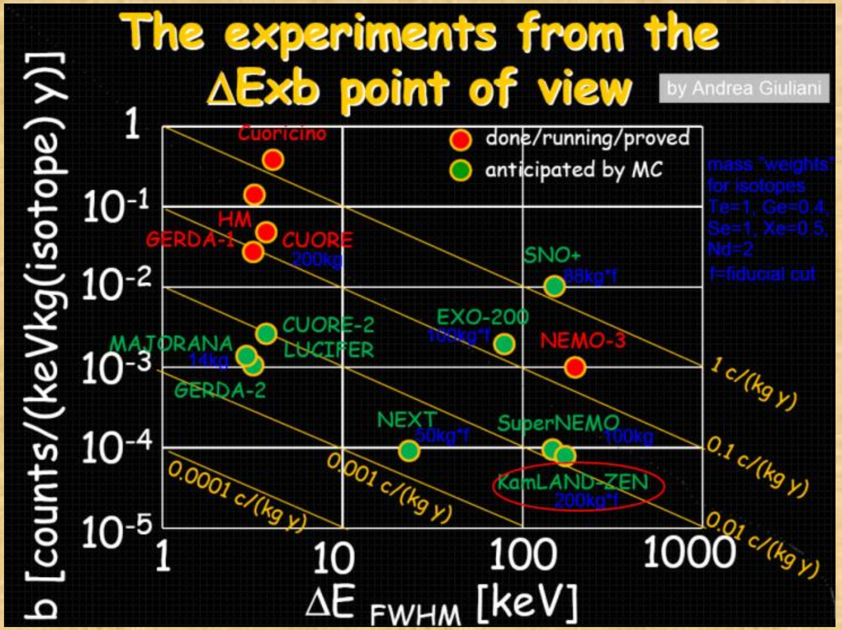
^{116}Cd	COBRA, $CdWO_4$
^{76}Ge	GERDA, MAJORANA
^{82}Se	SuperNEMO, LUCIFER
^{136}Xe	KamLAND-Zen, EXO, NEXT
^{100}Mo	$ZnMoO_4$, AMoRE
^{130}Te	CUORE
$^{Nat(48)}Ca$	CANDLES
$^{Nat(150)}Nd$	SNO+, Borexino

A dream ?

^{48}Ca	CANDLES, SuperNEMO, AMoRE
^{150}Nd	SNO+, SuperNEMO, MTD, Borexino

Neutrinoless double beta decay using liquid scintillator

- Experimental limits for neutrino mass



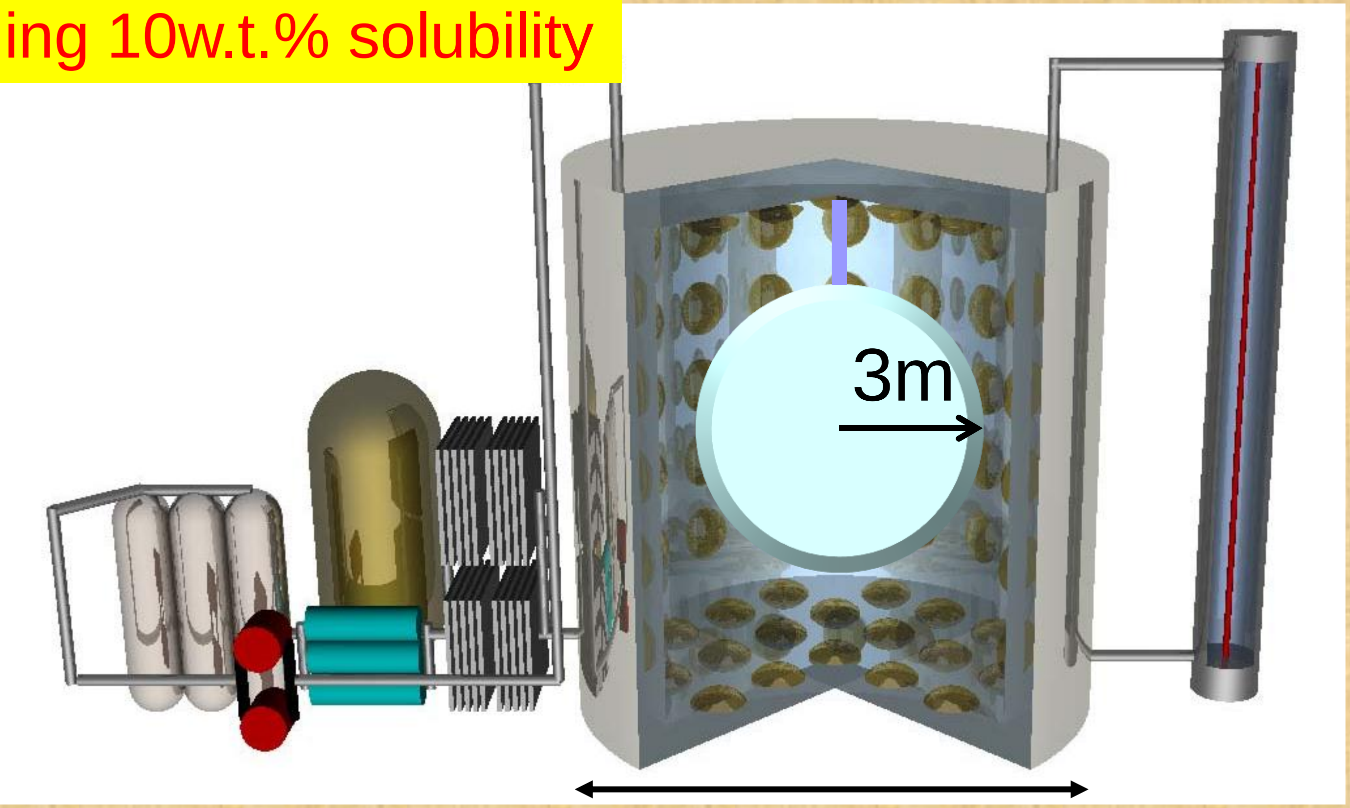
- Requirement for $<m_{\nu}>$:50~100meV
  - high energy resolution 4%@2.5MeV
  - low background rate 0.01count kg^{-1} y^{-1}
  - ton scale of target

Liq. Scintillator is easy to scale up target mass

Detector concept design

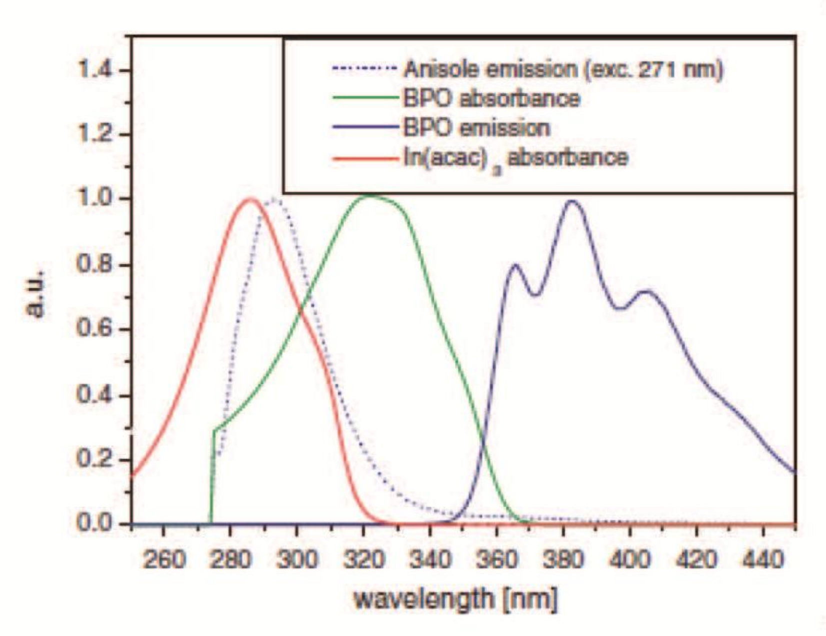
- Spherical structure (Zr loaded 100ton LS)

Assuming 10w.t.% solubility



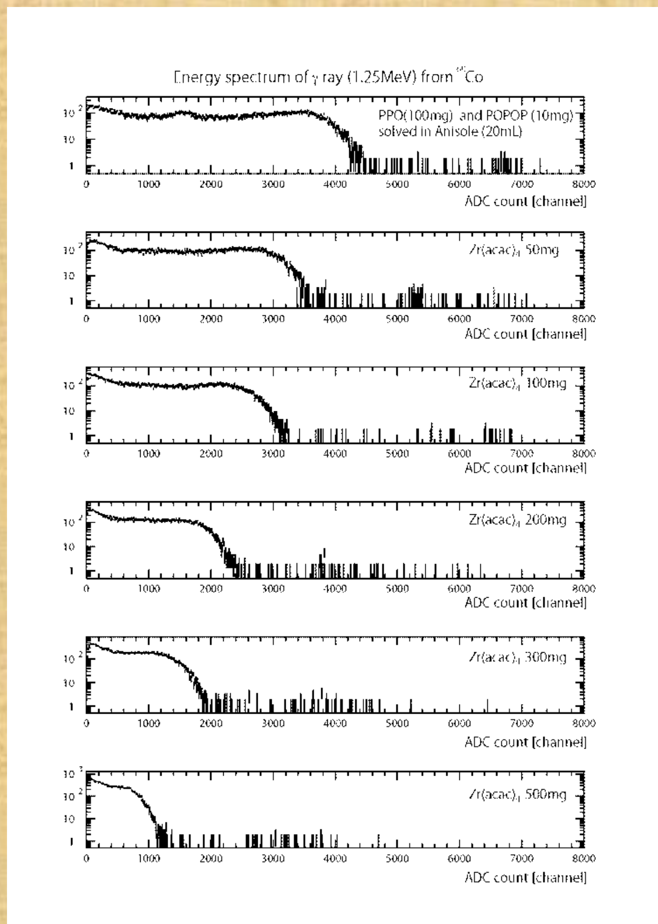
What's problem

- Absorption spectra of $In(acac)_3$ (indium acetyl acetone) was overlapped with the emission spectra from Anisole（Chem. Phys. Lett., 435(2007), 252)



Same overlap of the emission and the absorption spectrum would be occurred even if different metal (Zr) was used.

Scontillation Light yield (^{60}Co) with respect to concentration of $Zr(acac)_4$

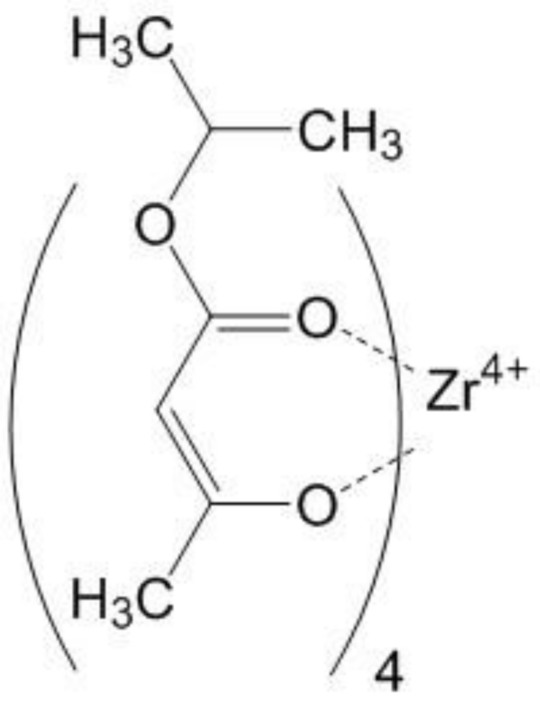


concentration of $Zr(acac)_4$	Observed channel	Expected channel
0 mg	3850	3850
50mg ($1.03X10^{-4}$)	3175	3138
100mg ($2.05X10^{-4}$)	2800	2651
200mg ($4.10X10^{-4}$)	2000	2018
300mg ($6.15X10^{-4}$)	1600	1613
500mg ($1.03X10^{-3}$)	900	1178

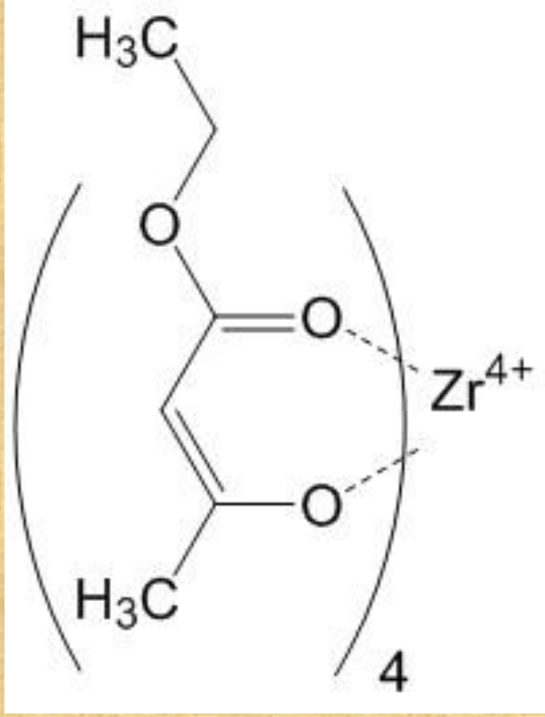
PPO 100mg : $4.52X10^{-4}$ mol

Zr β-diketon complex introducing substituent groups (β-keto ester complex)

Zr(CH3COCHCOOCH(CH3))$_4$ = Zr(iprac)$_4$
mw : 711.92



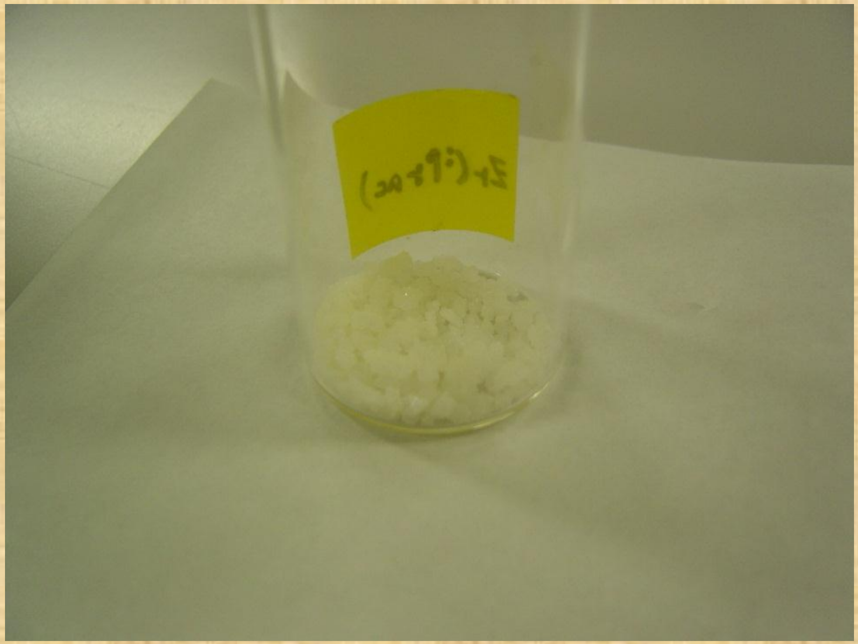
Zr(CH3CCOCHCOOCH3)$_4$ = Zr(etac)$_4$
mw : 665.81



Zr β-keto ester complex

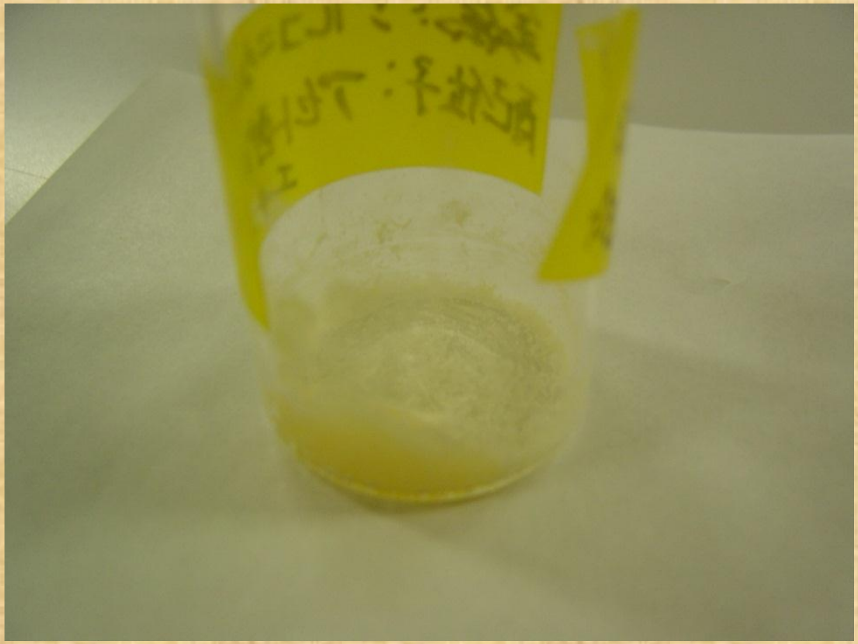
$Zr(iprac)_4$+$(iprac)_{1.5}$

state: powder



$Zr(etac)_4$

state : dry solid

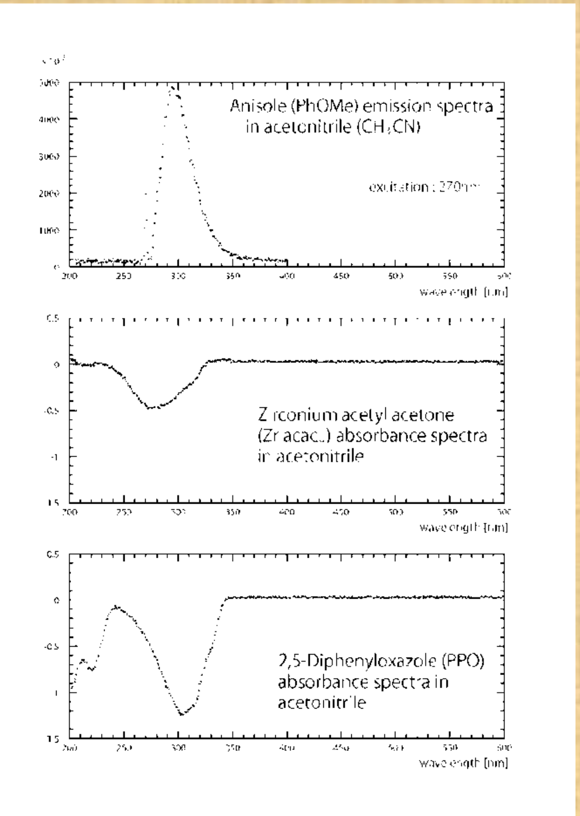


Synthesized by Prof. Takahiro Gunji (Tokyo University of Science)

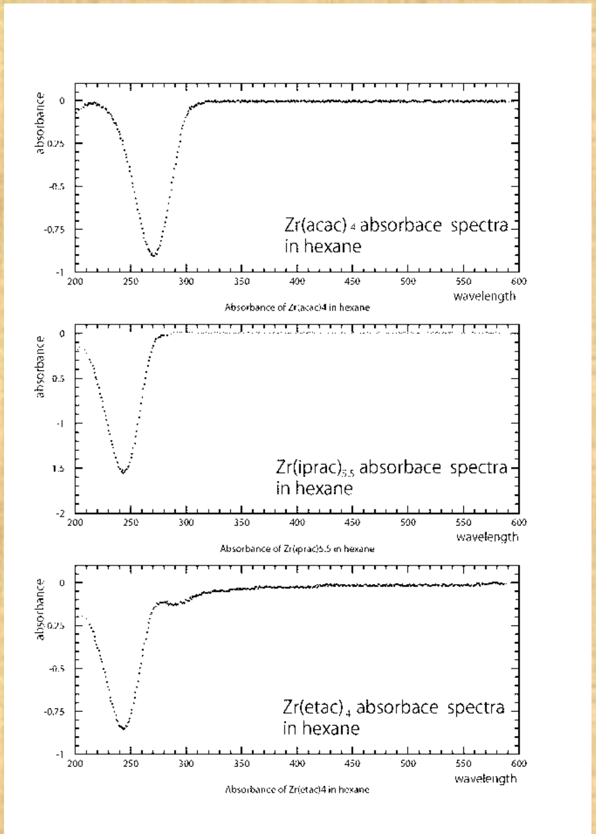
Solubility > 10 w.t.% for anisole

Absorption spectra

Overlap with emission peak



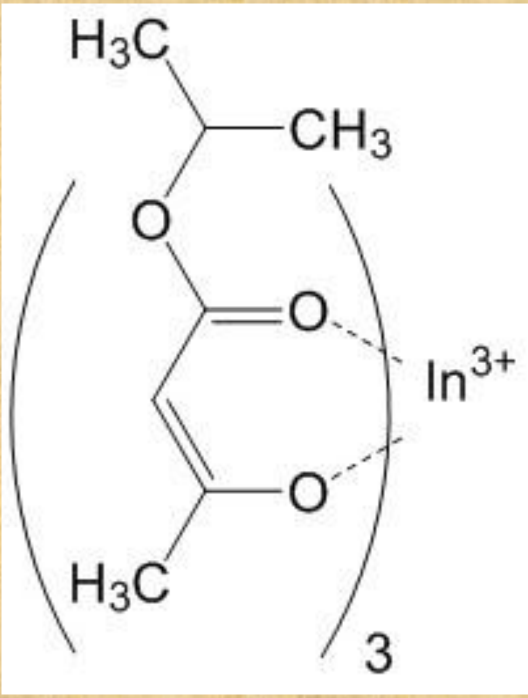
Absorption peak of keto-ester complex



No overlap between emission and absorption

Development for new LS for IPNOS phase-II

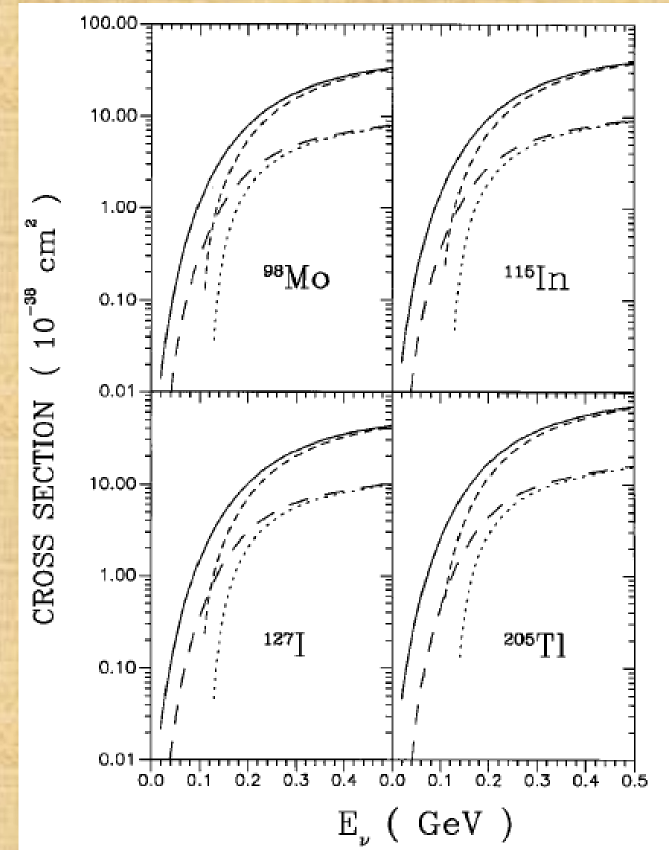
- Liquid Scintillator containing indium β-keto ester complex



- Advantages
  - Easy to scale up for 10ton In in 100ton LS
  - Possible same design as ZICOS
- Low energy solar ν
  - pp/^{7}Be and CNO ν
  - Modulation using ^{7}Be ν
- Supernova ν burst
  - ν_e burst form Neutralization

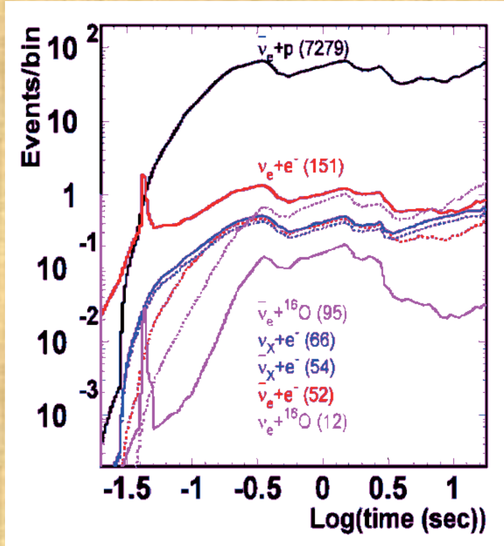
ν_e from Neutralization burst

- ν-nucleus σ



Rhy.Rev.C53(1996)1409

- ^{115}In has ~10^{-39} cm^2 for 20-100MeV compared with $\sigma_{\nu ee}$~10^{-43} cm^2
- Sensitive to neutralization burst



100ton of In detects 20-100 ev

- Nuclear synthesis (r-process)
- ν mass hierarchy

Summary

- InP detector for IPNOS phase-I needs more larger area to reduce the number of channel.

  → new substrate will solve them.

- High solubility of Zr β-keto ester in Anisole (>~10w.t.%) for ZICOS detector was achieved.
- Confirmed absorption peak of beta-keto ester complex moves to shorter wavelength (275nm → 245nm). → no overlap with emission spectra from anisole.
- Indium β-keto ester complex will be developed for IPNOS phase-II to measure both low energy solar neutrinos and supernova neutralization burst.