Development of InP solid state detector and liquid scintillator containing indium complexes for measurement of pp/7Be solar neutrinos and Neutrinoless double beta decay

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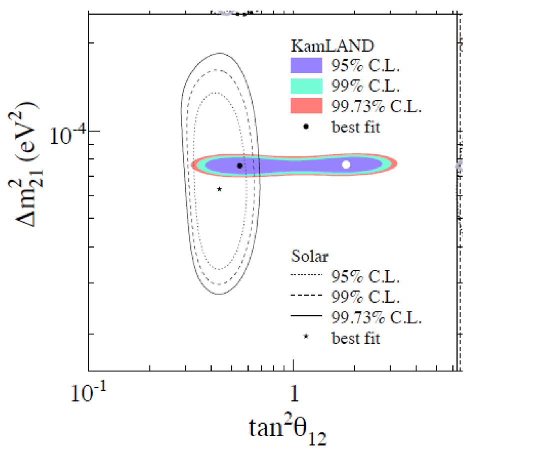
1. Introduction

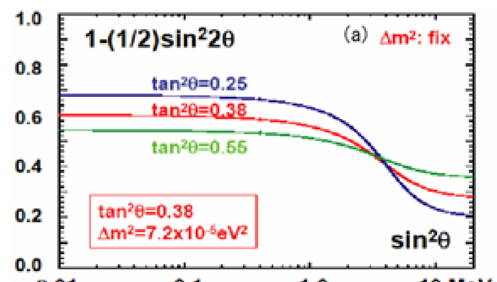
◆ Purpose : Measurement of precise mixing angle θ_{12}



- 96%C.L. allowed region obtained by global fit
  LMA solution (blue) : Cl + Ga + SK (D/N spectrum)
  KamLAND (green) → **confirm Δm_{12}^2.**

27° < θ_{12} <37°

- mixing angle θ_{12} is not fixed compared with θ_{23} (obtained by Atm. ν)
- survival probability would increase at 5MeV or less in case of LMA solution, and the shape depends on the value of θ_{12}.
  pp/^{7}Be solar neutrino spectrum could obtain precise θ_{12}



- **on-going solar 7Be experiment**
  - KamLAND (Liquid scintillator, electron elastic scattering [ES])
  - Borexino (Liquid scintillator, ES)
- **future solar pp/^{7}Be experiment**
  - XMASS (LXe, ES, DARK MATTER)
  - LENS (Liquid scintillator loaded In/Ye, charged current [CC])
  - others

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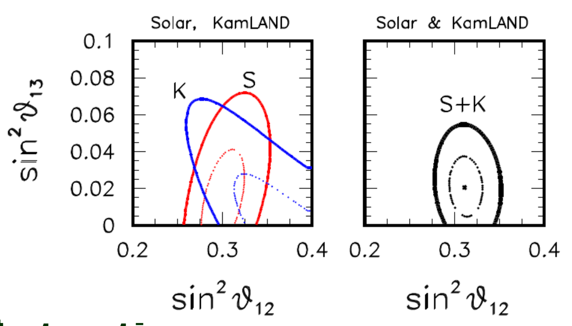
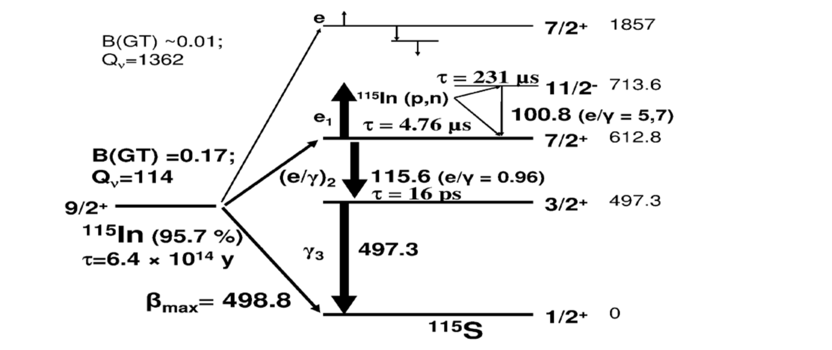
◆ Contribution to determination of θ_{13}



- Precise θ_{12} from solar neutrino experiment and KamLAND experiment will contribute to determination of θ_{13}
  (Phys.Rev.Lett. 110(2008)141801)

◆ Technique of low energy solar neutrino detection

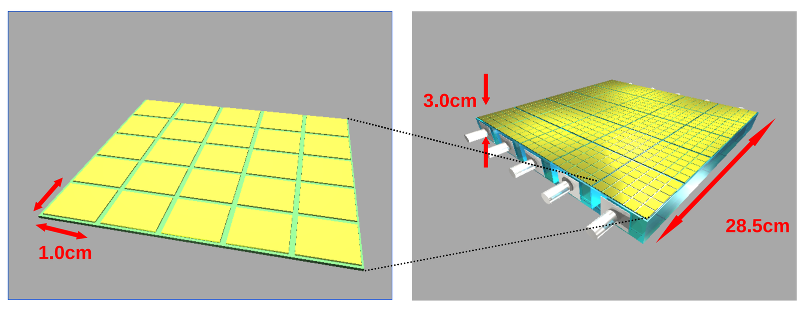
R.S.Raghavan Phys.Rev.Lett.37(1976)259



^{115}In + ν_e → ^{115}Sn* + e_1^-
^{115}Sn*(4.76μs) → ^{115}Sn + γ_2(115keV) + γ_3(497keV)

- **Advantage**
  - large cross section (~640SNU)
  - direct counting for solar neutrinos
  - sensitive to low energy region (E_ν ≧ 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 × 10^{14} yr , Ee≧498keV)
  - possible BG due to correlated accidental coincidence by radiative Bremsstrahlung

◆Indium Project on Neutrino Observation for Solar interior (IPNOS) experiment



- **Hybrid structure of InP and external scintillator**
  - InP multi-pixel detector (10mmX10mmX0.2mm cell)
  - external scintillator to detect γ_1 and γ_2
- **4tons of ^{115}In detector for solar ν experiment**
  - InP : 5.1tons (2.0X10^6 modules with **ΔE/E~10%**)
  - high Z material for external scintillator
  - total size ~5m X ~5m X ~5m (depends on structure)

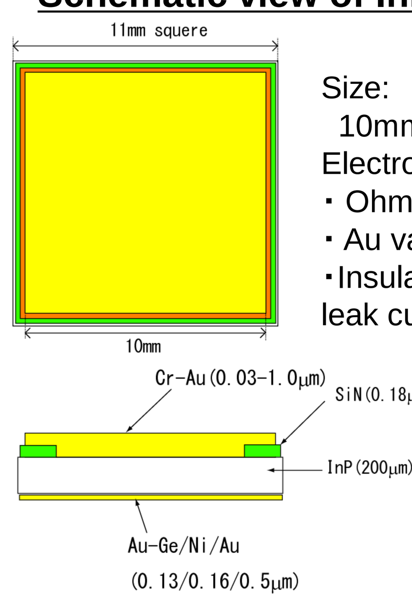
- Number of expected events assuming no ν oscillation → 1885
- Number of expected event assuming LMA solution with Ee≧100keV → 720

Statistical and theoretical error in total → **~3.5 %** ⇨ **θ_{12} = 30° - 34°**

2. SI InP cell detector

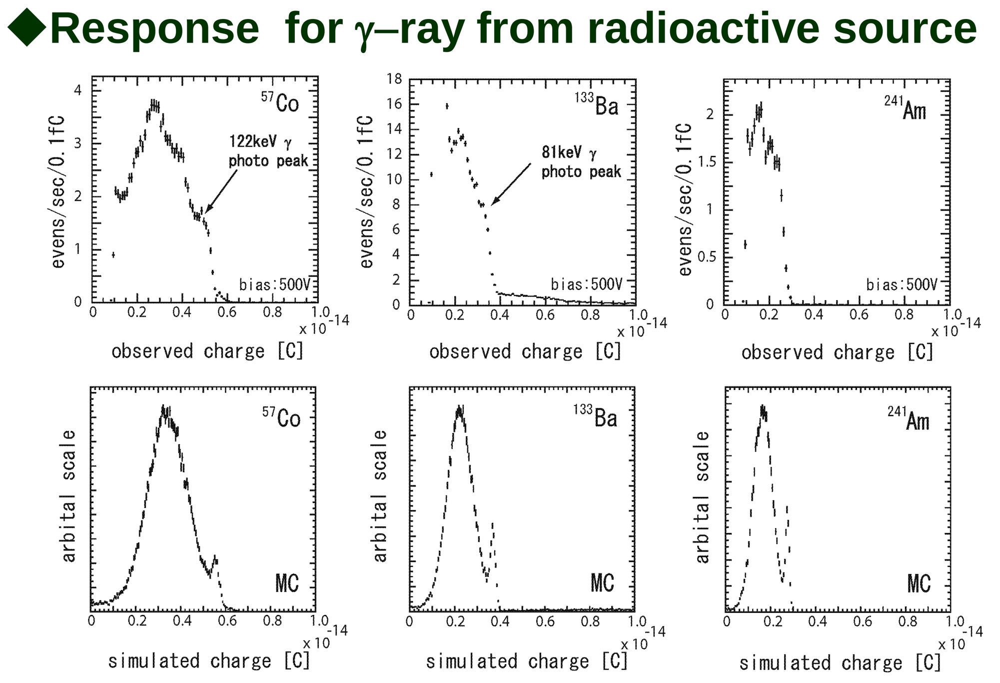
◆InP detector in vacuum dewar

Schematic view of InP detector



Size:
10mm×10mm×0.2mm
Electrode :
- Ohmic contact
- Au vacuum evaporation
- Insulator (SiN) to avoid leak current

◆Response for γ–ray from radioactive source



Setup Clearpulse 5102 preamplifier
Clearpulse 4417 shaping amplifier
CAEN V419 peak sensing VME ADC

- Measured clear photo- peak , but two peak structure
- Lower peak: induced charge (L_{ed}~200μm L_{he} ~ 30μm)
  Higher peak: e⁻ full collection
- Energy of electron-hole pair production :3.5eV
- Energy resolution : 25%@122keV

3. IPNOS phase-I experiment

◆ Detector

- 30cm cubic chamber (like XMASS 100kg prototype detector)
- InP multi-pixel detector inside of Liquid Xenon
- Chamber includes ~10kg InP detector

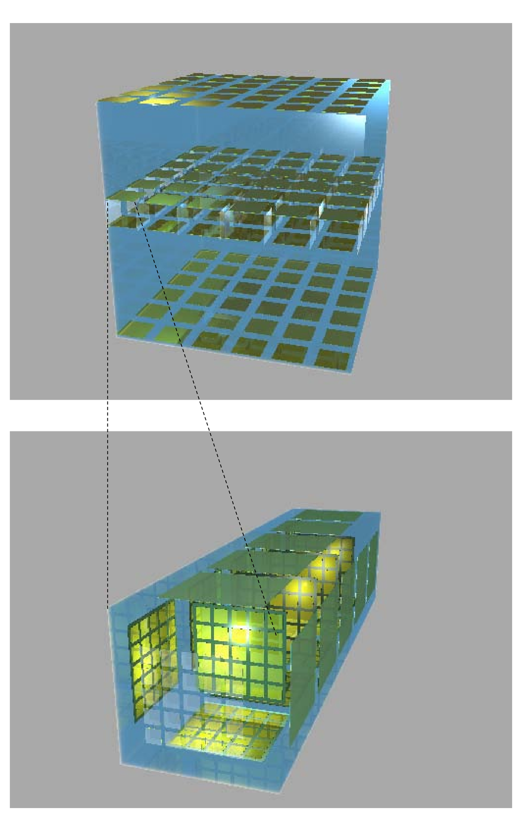
◆ Purpose

- demonstrate LowBG environment
- long stable operation (1 ppν event will be expected for half year)

◆ Requirements to detect γ_3 (498keV)

- assuming surface coverage : 0.8
- modify shape of electrode such as mesh structure
- assuming 50% for naked area

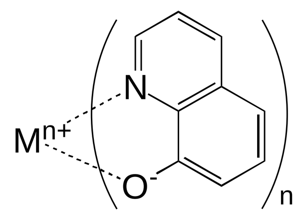
Expected number of photon for γ_3 is 8400, which corresponds to 30keV electron equivalent



4. Liquid scintillator containing metal complexes

◆ Development of liquid scintillator using metal complexes

- **goal : solubility : 5 wt%, light yield : 60% of BC505, attenuation length : 2~3m**
- **8-quinolinolate metal complex (InQ_3 ZrQ_4)**
  - AlQ_3 has been established as **organic Electro Luminescence** material (maximum luminescence @ 530nm)
  - InQ_3 (for solar ν) and ZrQ_4 (for ββ-decay) should have same luminescence



M = In, n = 3; M = Zr, n = 4

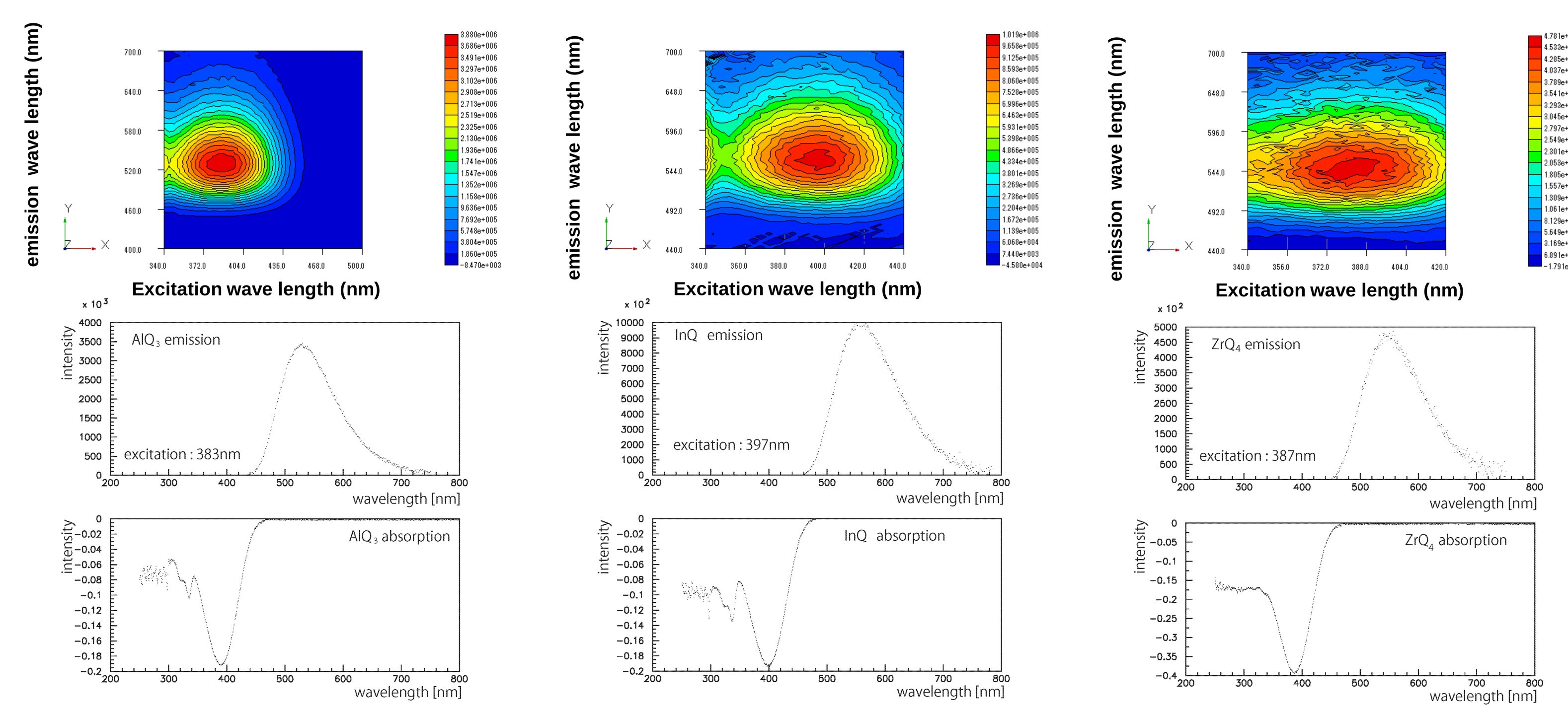
- **Synthesis efficiency**

InQ_3
primary yield 100%
sublimation 77%
ZrQ_4
primary yield 96%
sublimation 70%

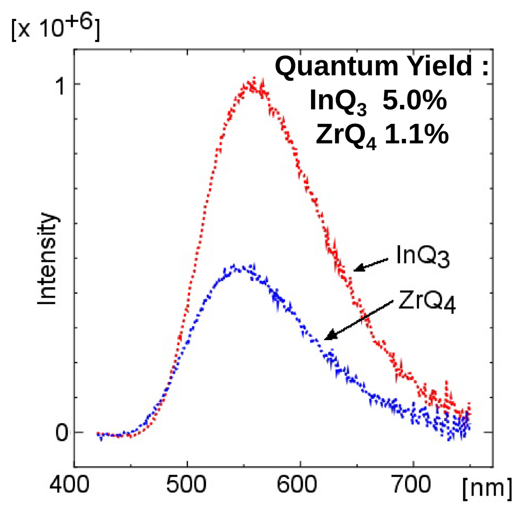
- **Solution of organic solvent**

Solvent : **Benzonitrile** (PhCN: C_6H_5CN)
density : 1.0g/mL flash point : 75°C
Photon emission : 291nm@maximum
Solubility of InQ_3 complex: **2wt%**
Attenuation length : 66cm (@0.5wt%)

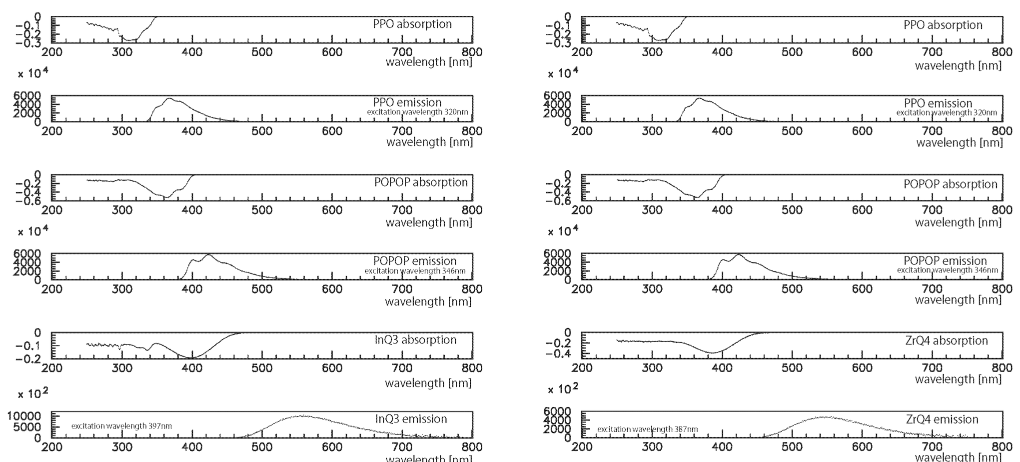
◆ Luminescence of 8-quinolinolate metal complex



- **Quantum yield**



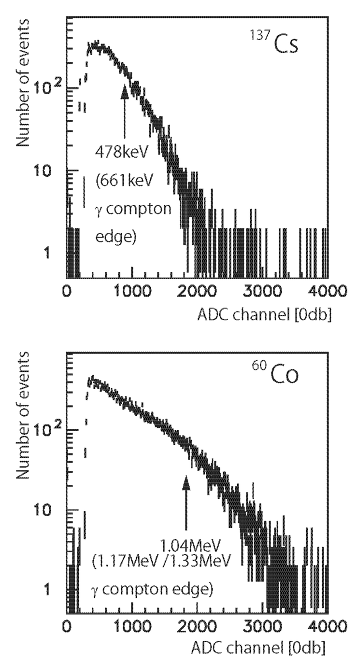
- **Light (energy) transfer to InQ_3 / ZrQ_4**



◆ Performance of liquid scintillator

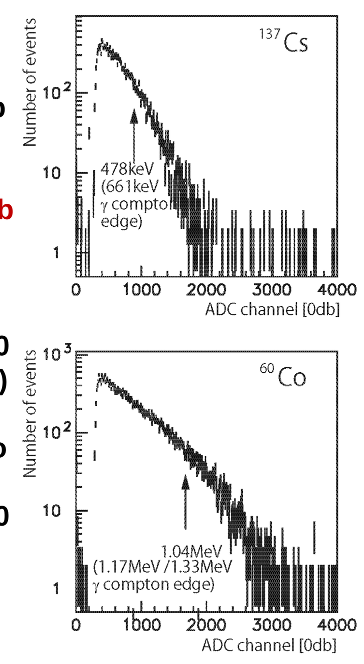
- **Setup**
  - Hamamatsu H6410 2inch photomultiplier
  - Fisherbrand 20mL Borosilicate Glass Scintilation Vials
  - Acrylic light guide
  - LeCroy 1182 charge sensitive VME ADC
  - coincidence method was used for eliminating BG
  - Solution : PhCN with PPO 100mg and POPOP 10mg

- **Response for γ–ray from radioactive source**



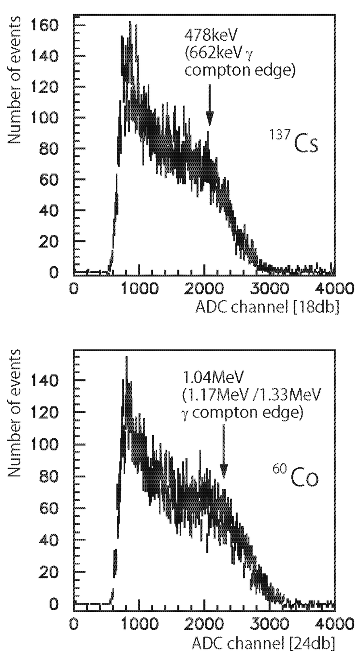
1040keV : 1925ch@0db (QE : 0.093)
20699ch@0db
Quantum Yield : 20699/132800 =15.6%(5.0%)
Light Yield to BC505: 20699/208640 =9.9%

InQ_3 50mg



1040keV : 1525ch@0db (QE : 0.10)
15250ch@0db
Quantum Yield : 15250/132800 =11.5%(1.1%)
Light Yield to BC505: 15250/208640 =7.3%

ZrQ_4 50mg



1040keV : 2075ch@24db
33200ch@0db (QE : 0.25)
132800ch@0db
Light Yield toBC505: 63%
478keV: 1875ch@18db expected : 1907ch

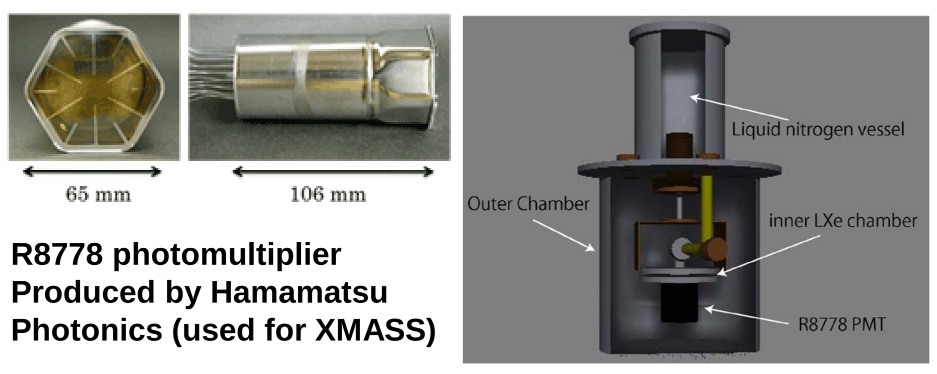
PhCN coktail

Photo luminescence caused by γ-ray was confirmed

5. Next step

◆ For IPNOS phase-I

- Measurement of scintillation light from LXe



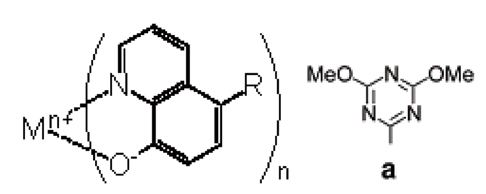
R8778 photomultiplier Produced by Hamamatsu Photonics (used for XMASS)

- direct measurement of LXe scintillation light
- construct small LXe chamber (volume : 0.15L)
- use R8778 PMT for coincidence method
- **finalize shape of electrode for InP detector**

supported by **Grant-in-Aid for Scientific Research on Priority Areas 22011001**

◆ For liquid scintillator containing metal complex

- modify 8-quinolinolate ligand to add substituent



- beta diketon complex
  - good solubility (over 10wt.%) has been reported
  - For ββ decay experiment, **4%@3MeV of energy resolution should be required.**

supported by **Grant-in-Aid for Scientific Research (C) 22540303**