WIMPs search with multilayer scintillator modules

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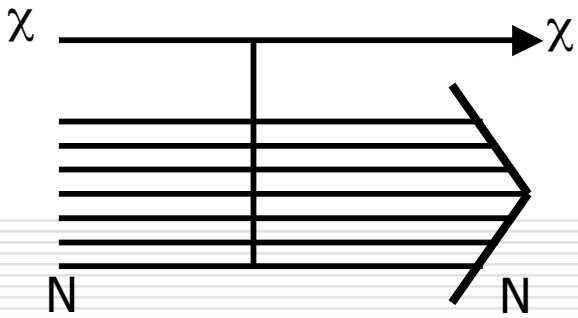
- Introduction
- Merit of segmentation of NaI(Tl)
- Performance of thin NaI(Tl)
- Purification check of NaI(Tl) powder
- Summary & Prospects

Interactions between WIMPs and nucleus

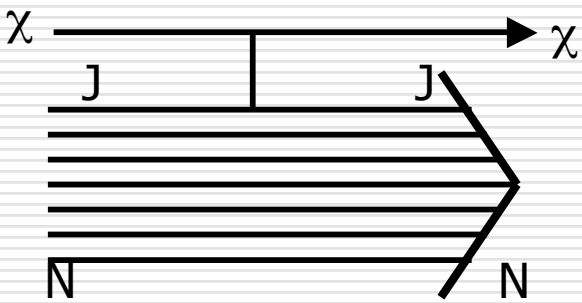
H.Ejiri K.Fushimi and H.Ohsumii,
Phys. Lett B317(1993)14

SI



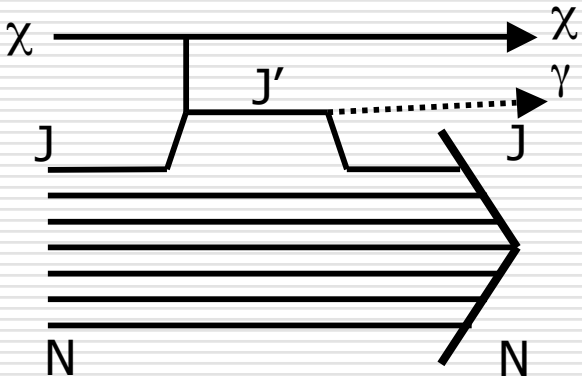
$$\sigma \propto A^2$$

SD



$$\sigma \propto C\lambda^2 J(J+1)$$

EX

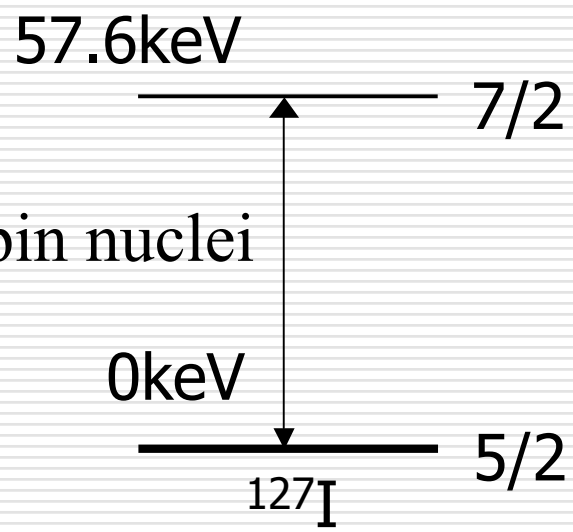


$$\sigma \propto \sqrt{\frac{2J'+1}{2J+1}} \frac{1}{g_M} \langle A | M1 | A^* \rangle$$

We planned to study all the types of interaction!!

Why NaI(Tl) ?

- ^{23}Na & ^{127}I
  - Sensitive to SD and SI
  - 100% natural abundance of finite spin nuclei
- ^{127}I
  - Sensitive to EX
  - Low energy excited state



Experimentally obtained

$$\left|M_{M1}\right|^2 = 0.1$$

- Expect: 3.60×10^{-3}/day/kg (Higgsino)
- Limit: 4.98×10^{-2}/day/kg (ELE V NaI)

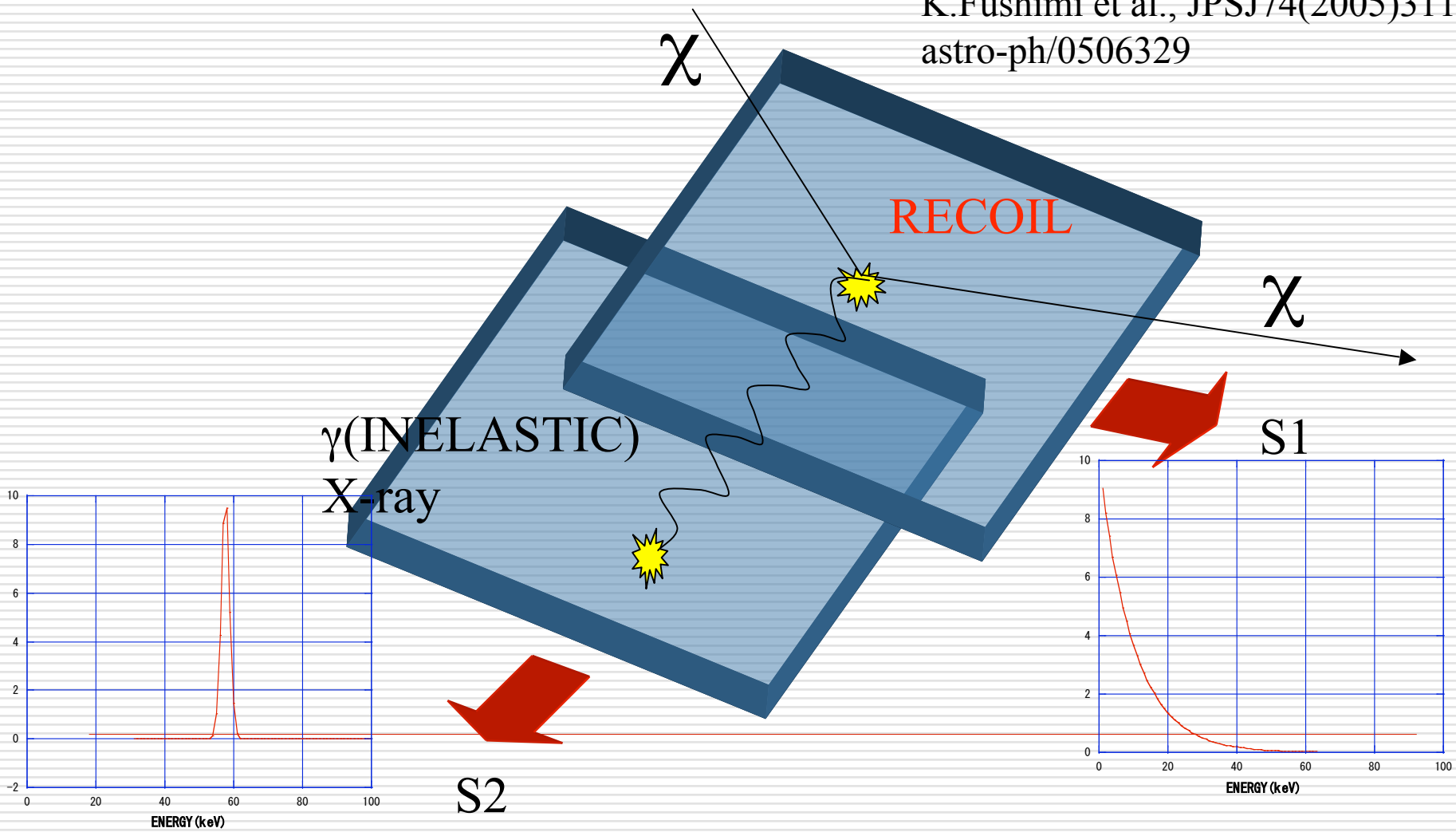
K.Fushimi et al., Nucl. Phys. B(Proc. Suppl.) 48 (1996) 70

Signal selection by Spatial and Timing Correlation (SSSTC)

- Signal Selection by Spatial Correlation
  - Signal → 57.6keV γ + Low energy recoil
  - Localized event in space and time
  - Background → U,Th chain, ^{40}K etc.
  - Diffused event in space and time
- Signal Selection by Timing Correlation
  - Signal → No following events
  - Background → Time-correlated events by decay chain

Signal Identification by Segmentation

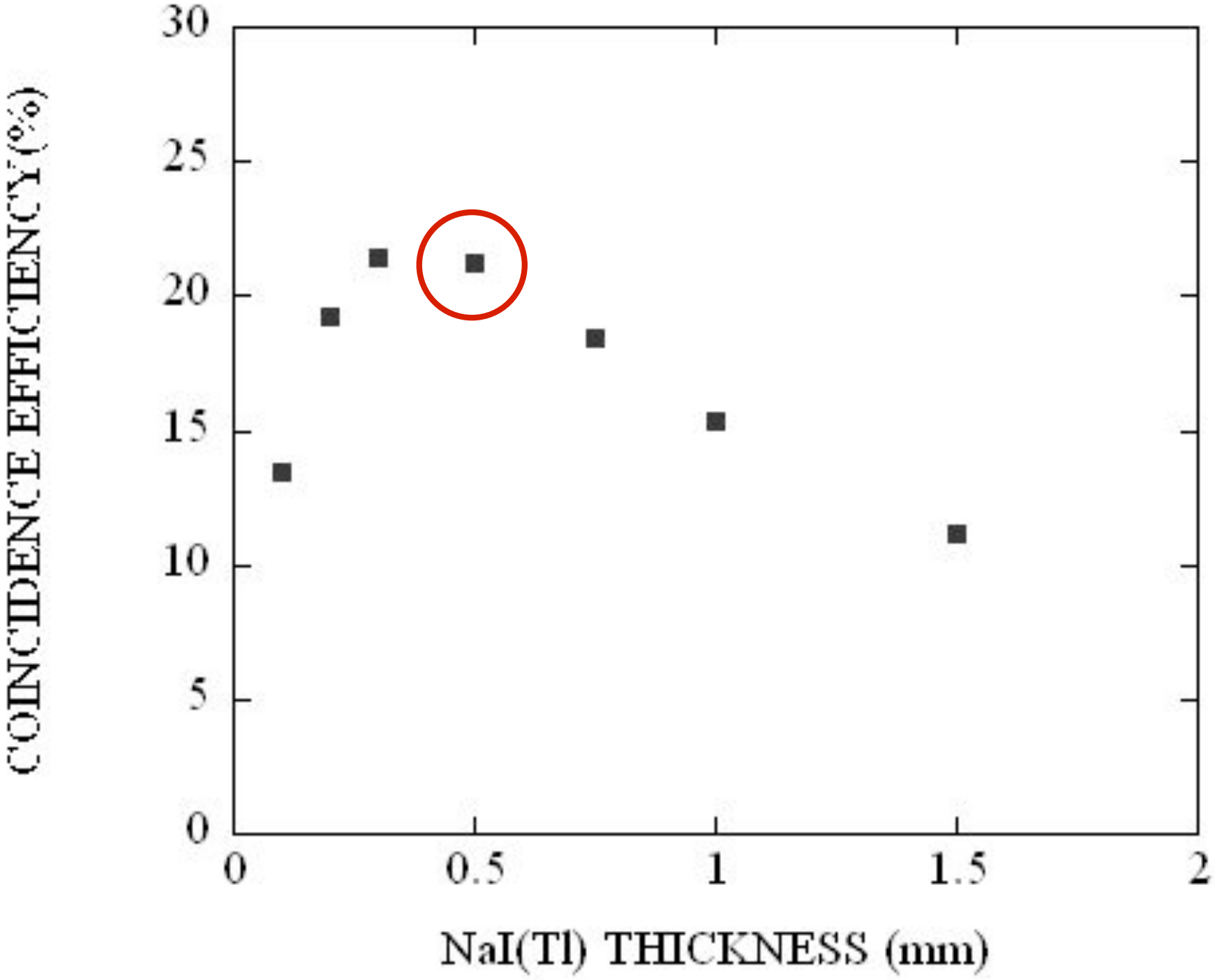
K.Fushimi et al., JPSJ74(2005)3117
astro-ph/0506329



Estimation of signal selectivity

- Monte Carlo simulation (GEANT4)
- 57.6keV γ ray ($^{127}I^* \rightarrow {}^{127}I$) from one module
- γ is detected the another module
- Next module to the emitter module

The fraction which is detected both sides of emitter


COINCIDENCE EFFICIENCY (%)
30
25
20
15
10
5
0
0
0.5
1
1.5
2
NaI(Tl) THICKNESS (mm)

Specification of thin NaI array

- 0.05cmX5cmX5cm NaI(Tl)
- 0.05cmX6cmX0.5cm Acrylic Light Guide
- ESR™ reflector
- 16plates (phase 1)
  - [Under construction]
- 256plates (phase 2)
- 1024, 2176 (phase 3,4)

Estimation of sensitivity

- Radioactive contamination
  - Uniformly contaminated in NaI(Tl) crystal
  - ^{210}Pb 0.1mBq/kg (1/100 of present value)
  - ^{214}Pb, ^{214}Bi 10μBq/kg (present value)
- Monte Carlo Simulation
  - GEANT4

Condition of Signal Selection by Space and Time Correlation (SSSTC)

- $^{214}Pb, ^{214}Bi$
  - SSSTC analysis
  - Delayed Coincidence $\Delta T<1ms$
  - Reduction factor=0.03
  - SSSTC $1s<\Delta T<60min$ ($3T_{1/2}$)
  - Reduction factor=0.003
- $^{210}Pb, ^{210}Bi$
  - SSSTC analysis
  - Successive β ray in 12.5 days ($2.5T_{1/2}$)
  - Reduction factor=0.177

Expected BG

K.Fushimi et al., JPSJ74(2005)3117
astro-ph/0506329

← SINGLES

← SSSTC

Energy window of analysis

Coincidence
event rate

Upper limit on BG rate

Calculation of Exclusion plot

- Upper limit on R_{lim} (Experimental result)
- Upper limit on Cross section σ_{lim}
- Local halo density ρ_0=0.3GeV/cm^3
- Mean velocity $<v>$=230km/sec
- Target number density N_T=4.013X10^{24}/kg

Exclusion plot for σ_{EX}

Calculation of limit on $\sigma_{p\text{-}\chi}$

Using the relation,

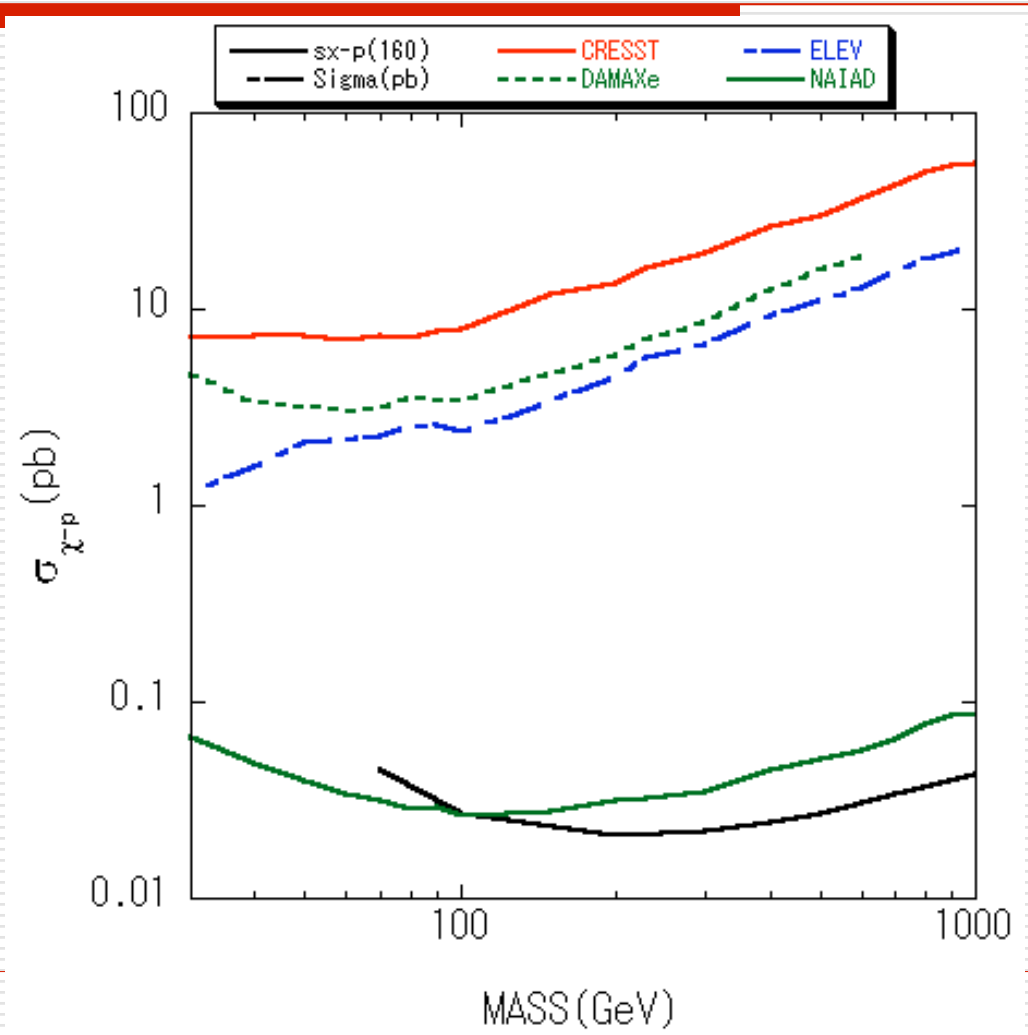
The Upper limit on proton-WIMPs cross section

Calculation of limit on $\sigma_{p-\chi}$

Important parameters

K.Fushimi et al., JPSJ74 (2005) 3117.
astro-ph/0506329

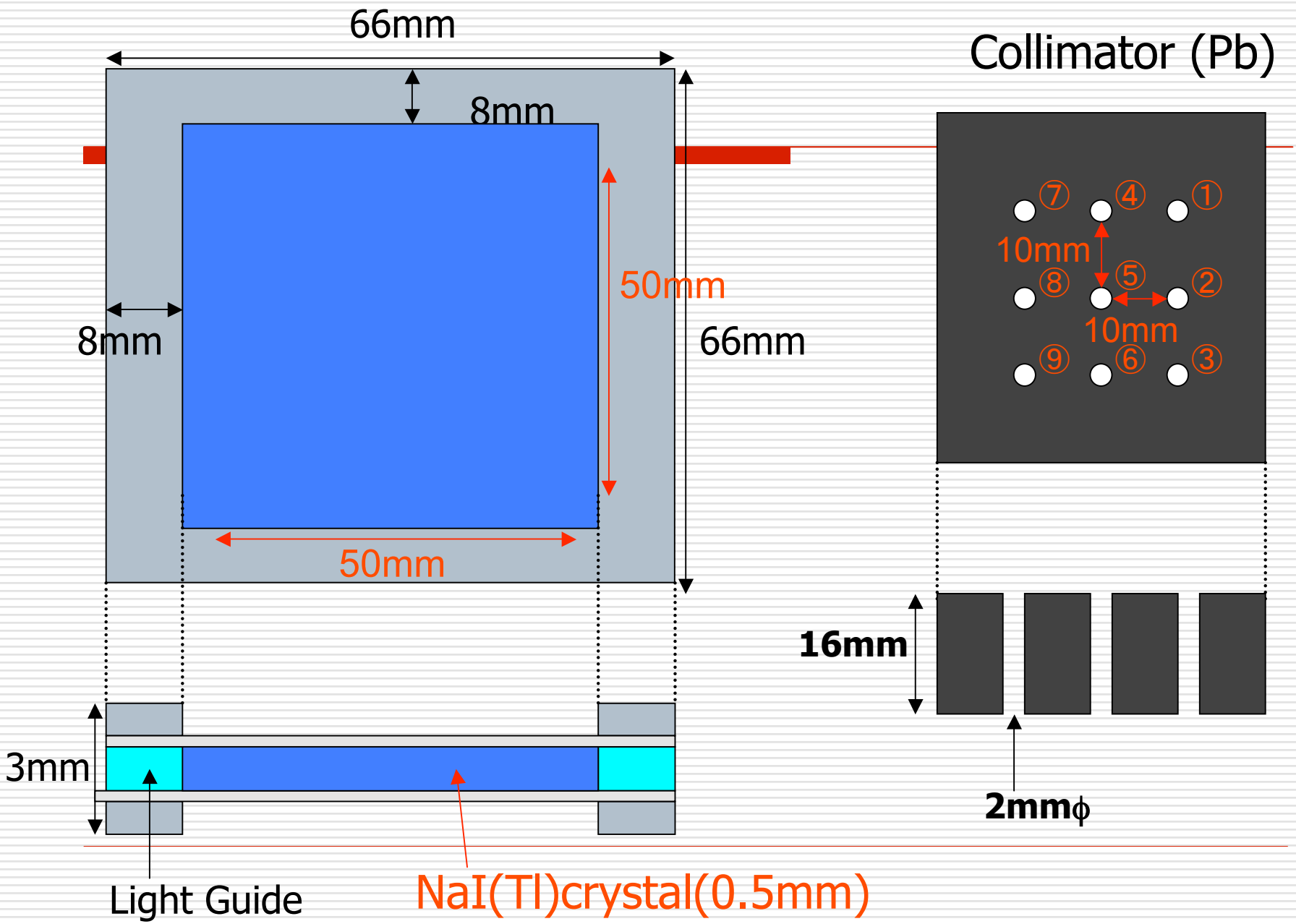
Expected sensitivity for WIMPs



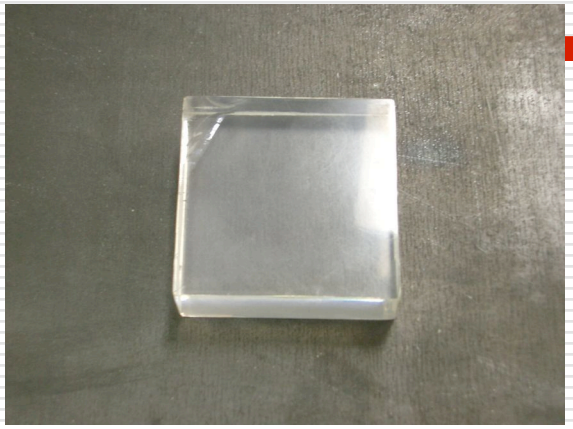
Stringent limit will be obtained by 1year measurement

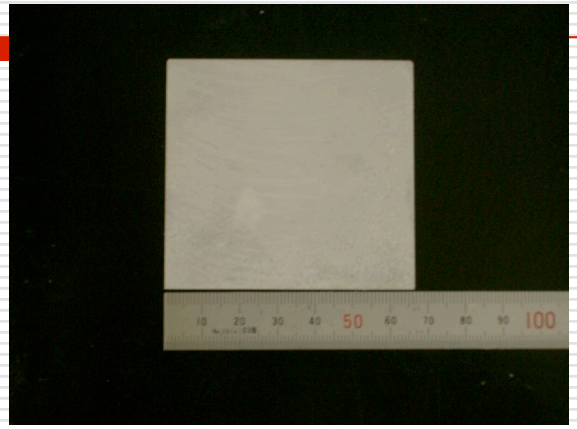
Development of thin NaI(Tl)

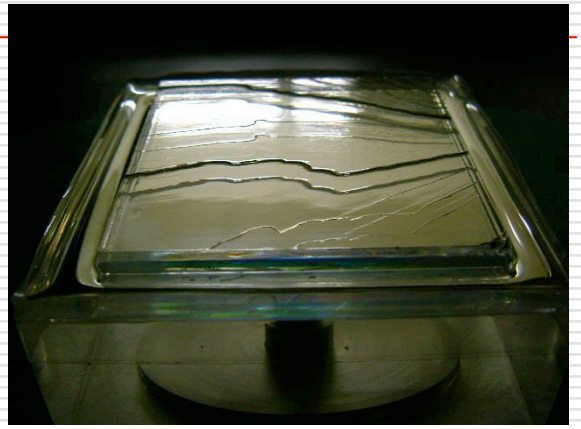
- Collaboration with Horiba Ltd.
  - Production of thin NaI plate
  - Selection of reflector ESR™ by 3M
- ~2004/Feb.
  - Design and production method were discussed
- 2004/Apr.
  - First single plate was completed!!
- 2004/May~
  - Performance, stability test.
- 2005/June~
  - 16plates detector and 3plates detector was completed.

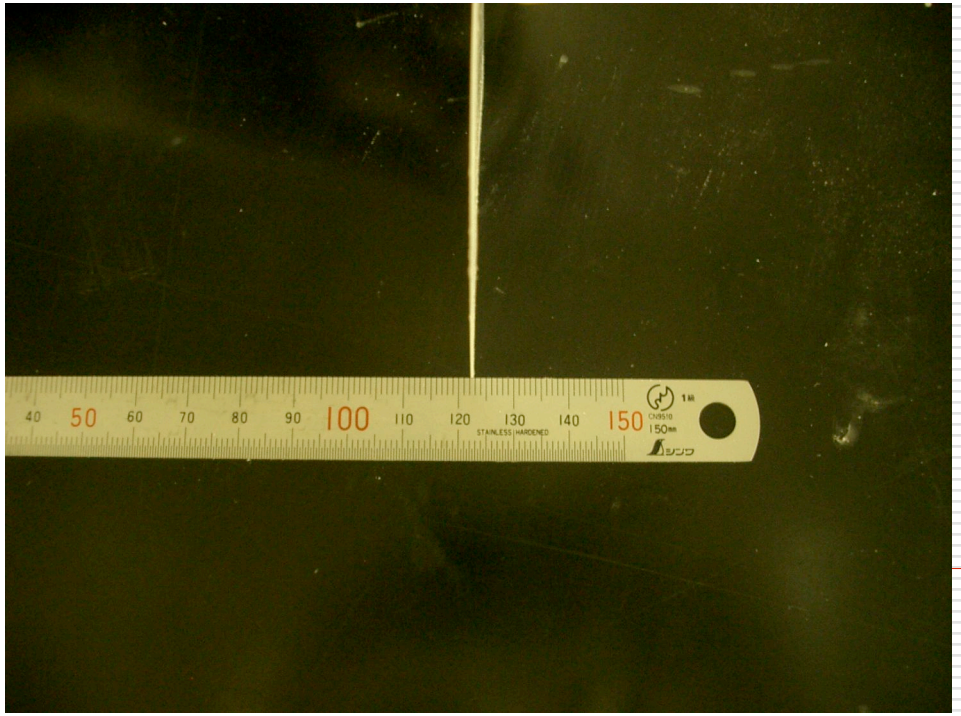

66mm
8mm
50mm
8mm
66mm
50mm
3mm
Light Guide
NaI(Tl)crystal(0.5mm)
Collimator (Pb)
⑦
④
①
10mm
⑧
⑤
②
10mm
⑨
⑥
③
16mm
2mmϕ

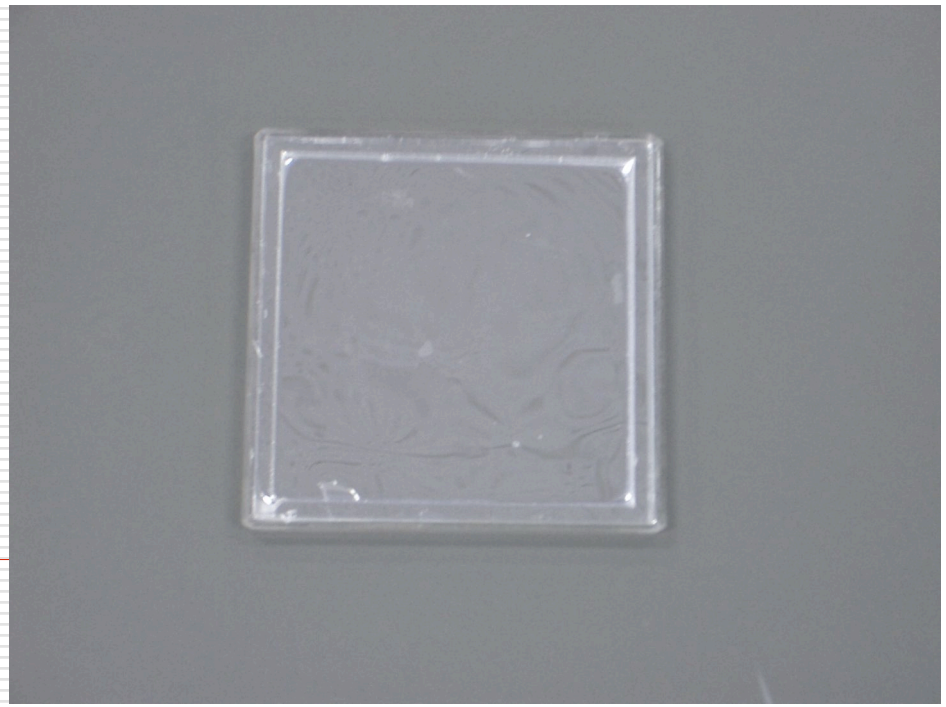
Production of thin NaI(Tl) by Horiba Ltd.









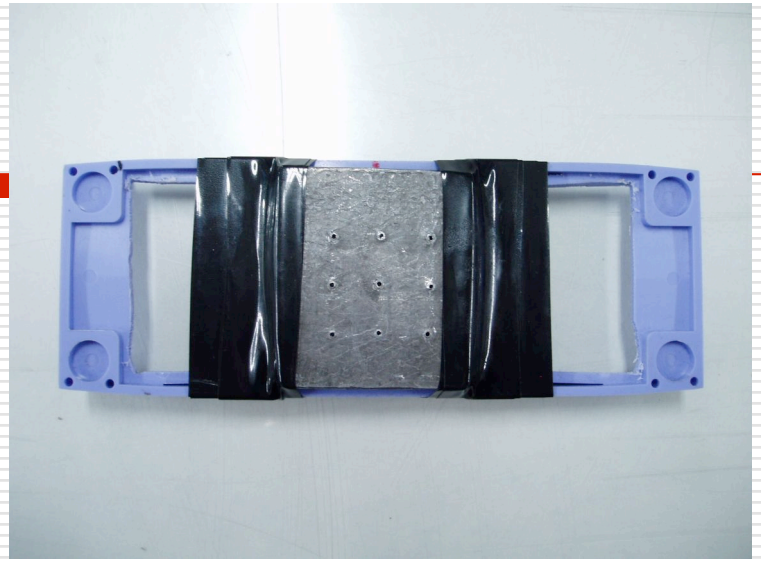


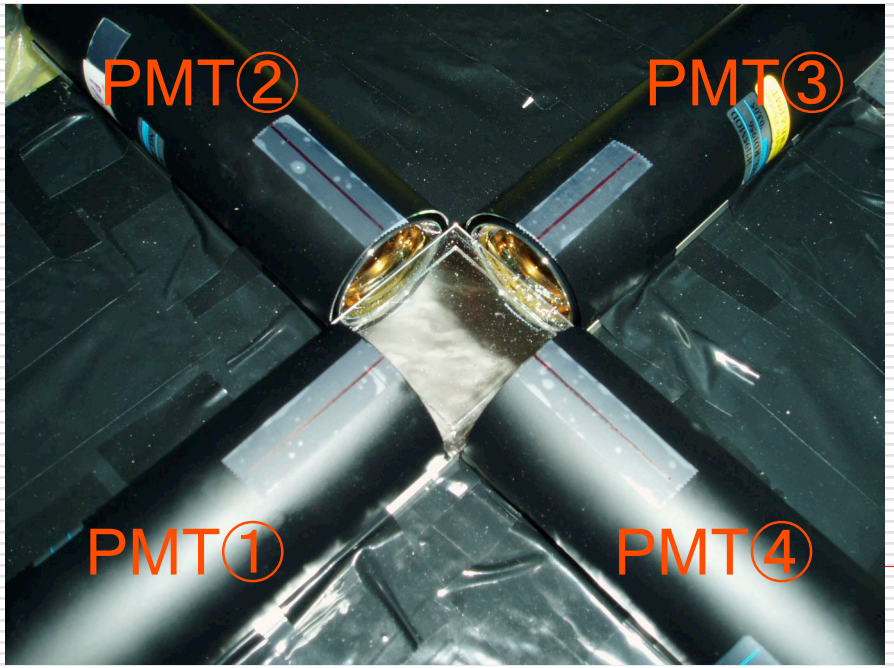
Performance of thin NaI(Tl) plate

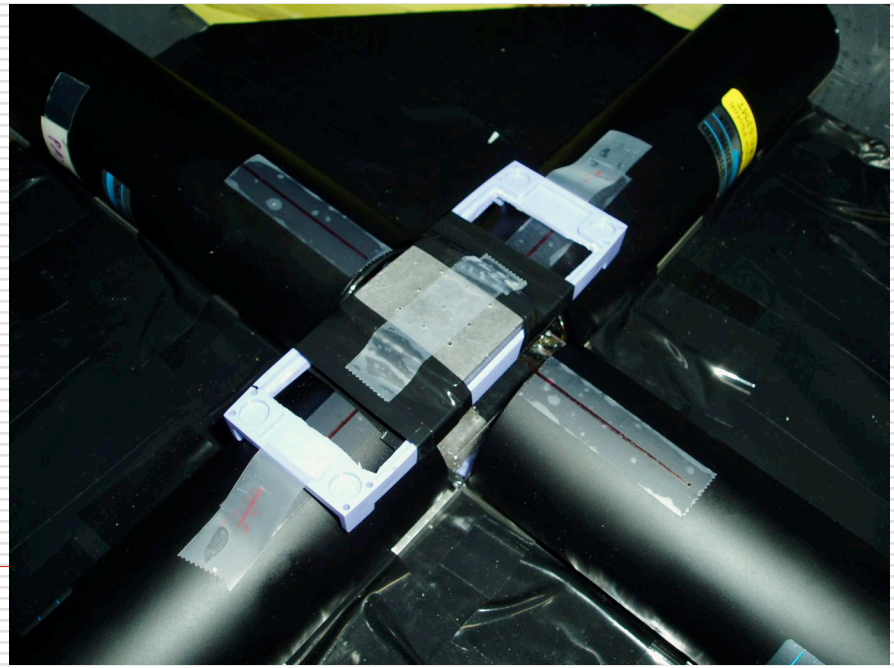
- Dimension of NaI(Tl)
  - 0.05cmX5cmX5cm
- Energy resolution
- Energy threshold
- Photon number/keV
- Position selectivity
- PMT : Hamamatsu R329P

Thin NaI(Tl) scintillator

Collimator

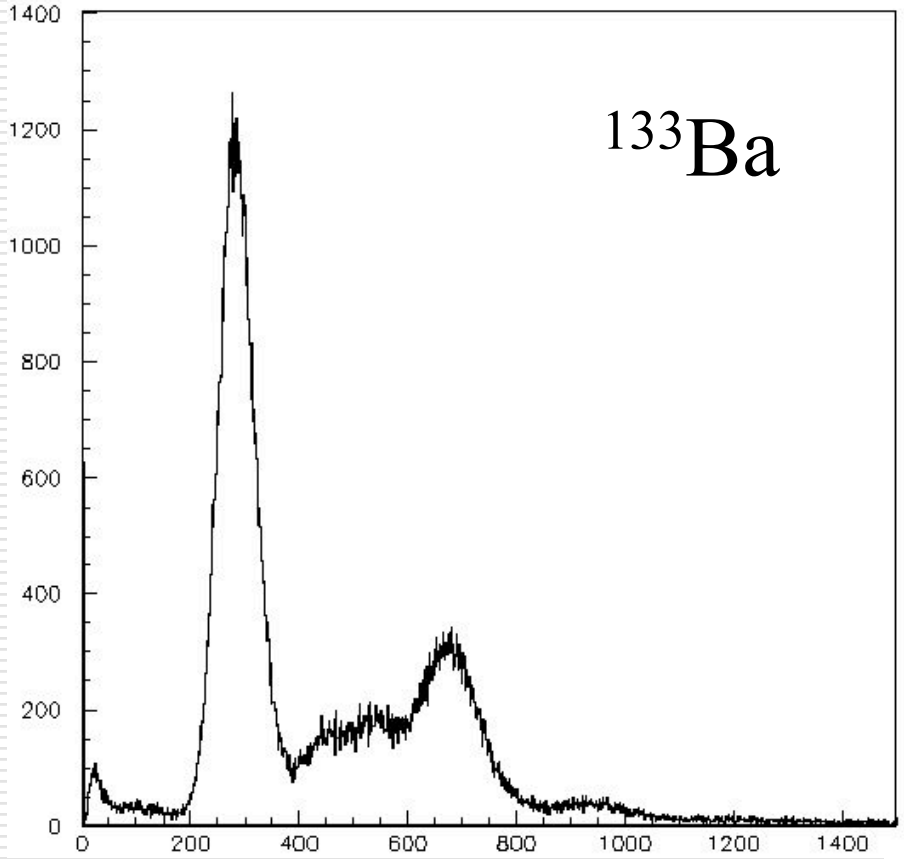


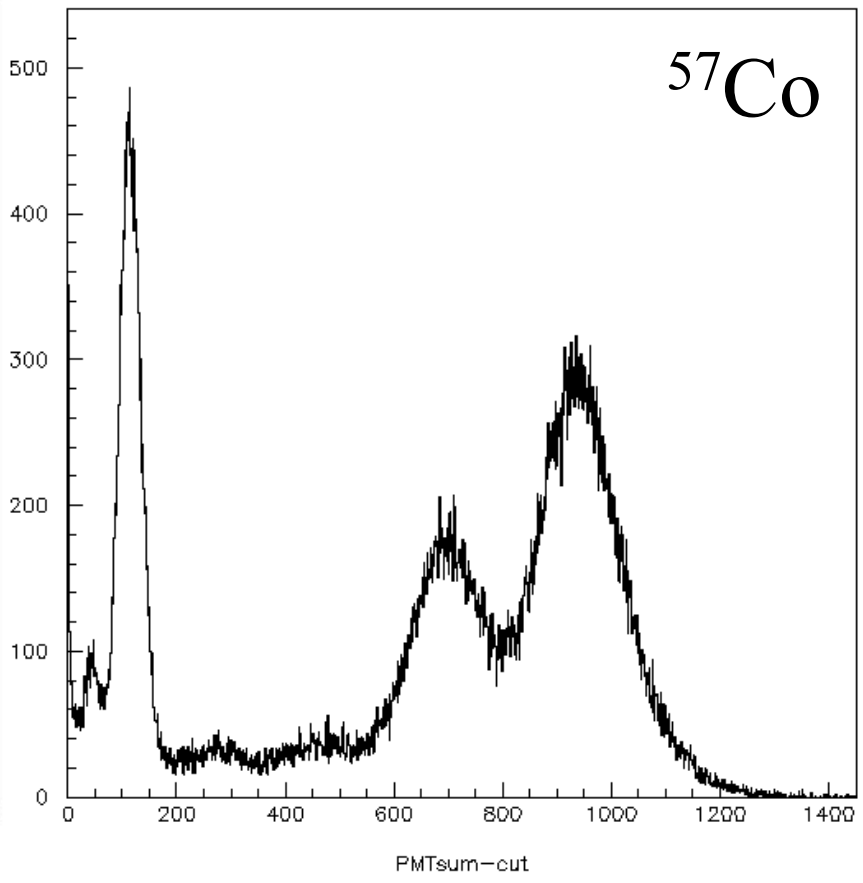




K.Fushimi et al., JPSJ 75 (2006) 064201

Result (Preliminary)





30keV R(FWHM)=0.25

122keV R(FWHM)=0.14

81keV R(FWHM)=0.13

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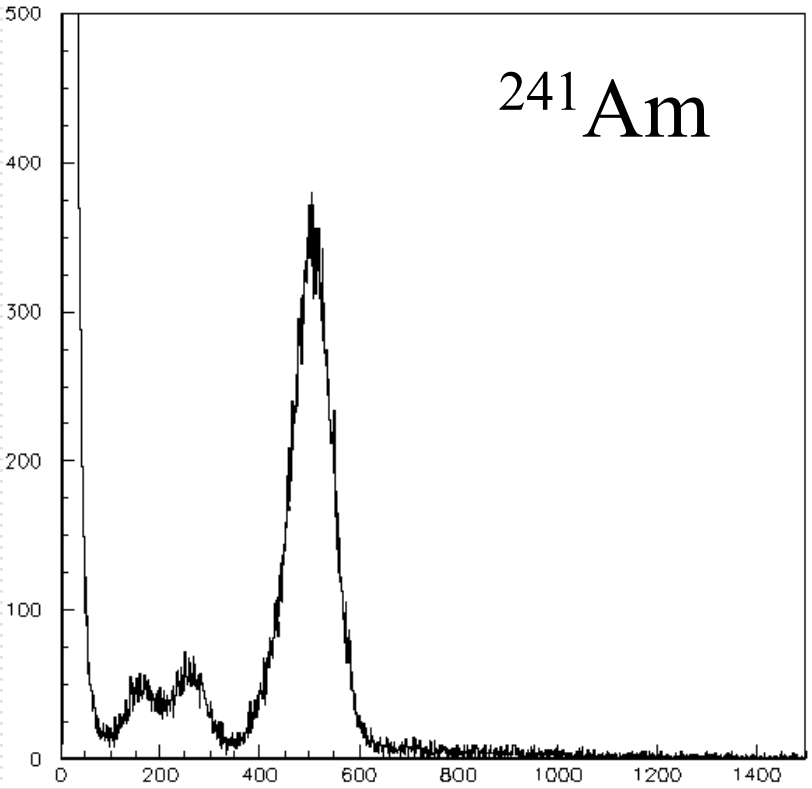
Energy spectrum of low energy γ rays



60keV ΔE/E(FWHM)=0.18

Source	Energy	FWHM
^{133}Ba	30keV	0.25
^{241}Am	60keV	0.18
^{133}Ba	81keV	0.13
^{57}Co	122keV	0.14

Single P.E. energy = 0.35keV

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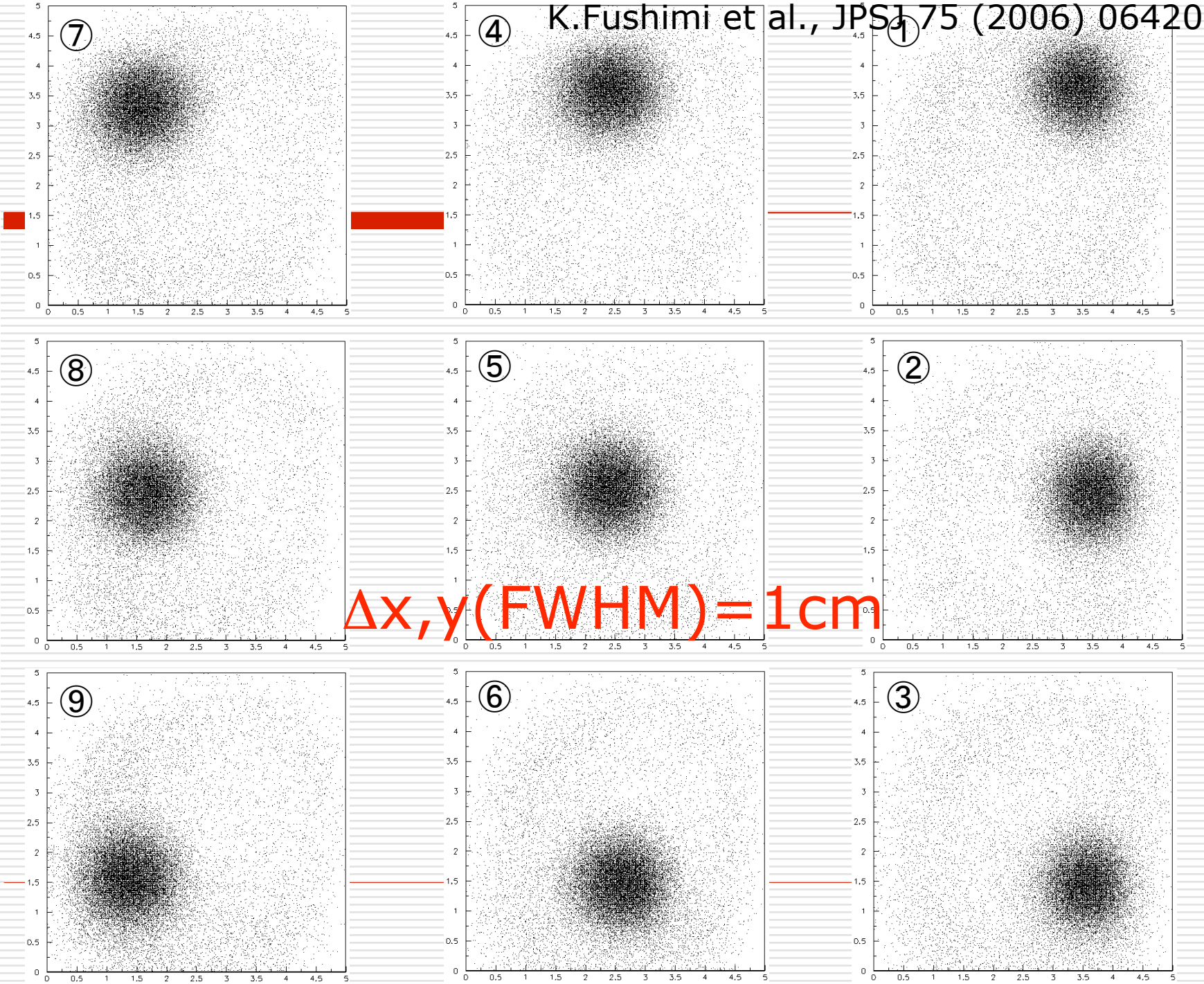
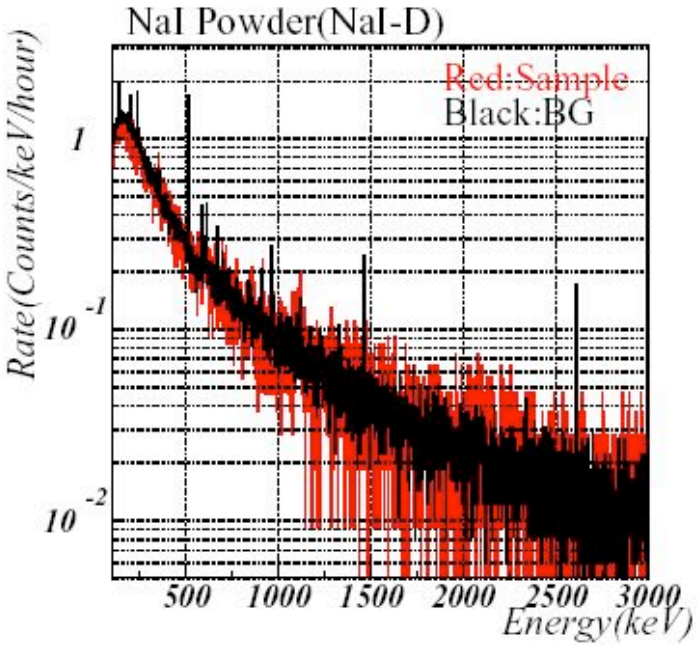
NaI(Tl) Real Position

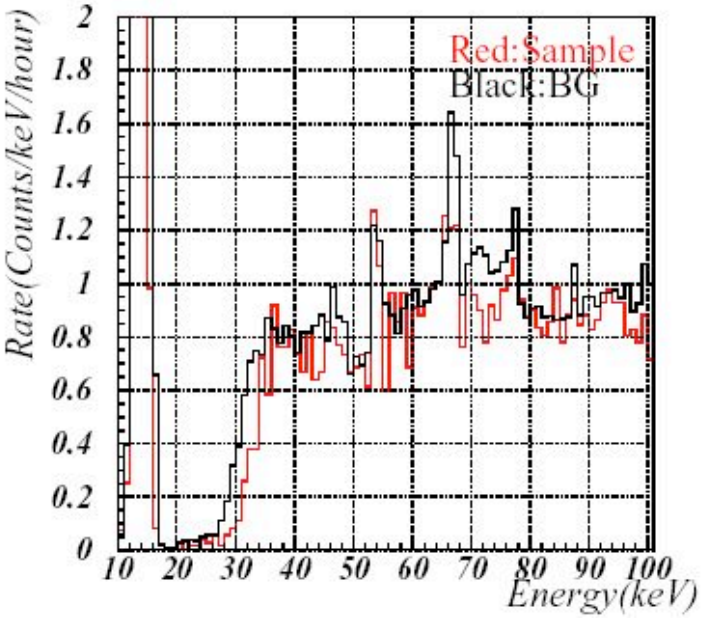


Δx,y(FWHM)=1cm

Test of NaI(Tl) purity

- Five samples of NaI powder
- Measured by Ge detector in OTO
- Small contamination of ^{210}Pb, ^{40}K,Th, U
- <10μBq/kg(Upper limit)

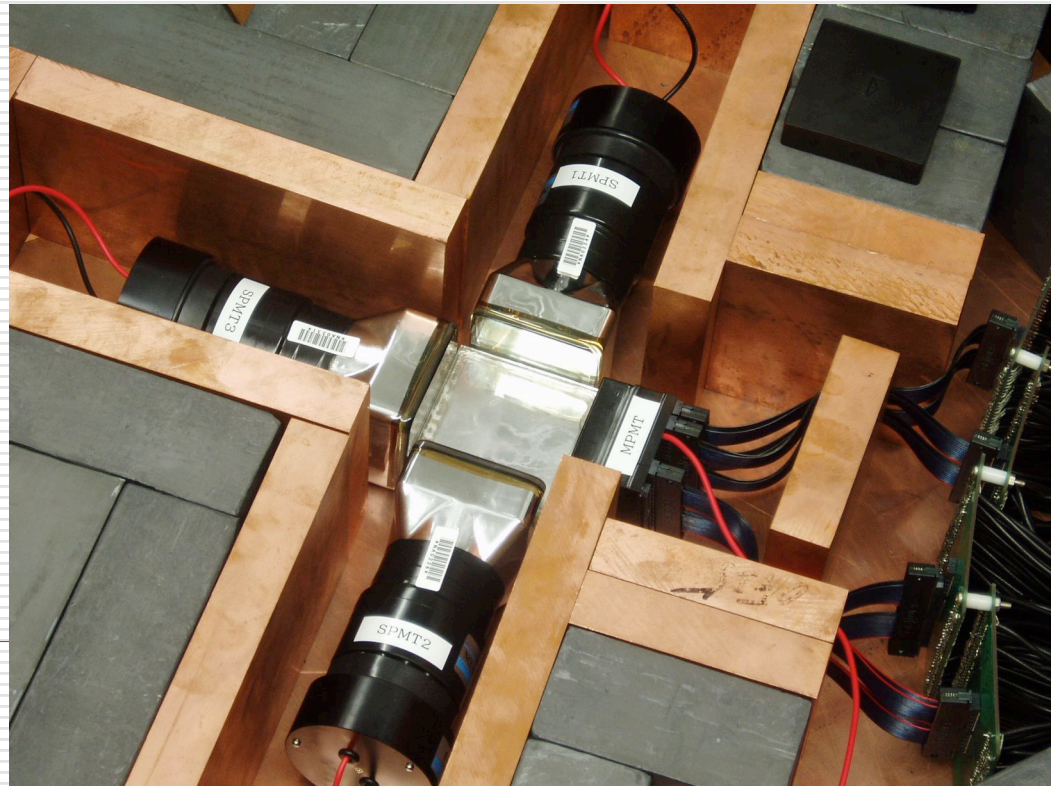




Test experiment in Tokushima

- 3-layers NaI(Tl) detector
- One MAPMT
- Three SQPMT
- Test started

  Just Now !



Summary

- Segmentation of NaI(Tl) enhances the sensitivity
  - High selectivity of signal and BG by segmentation
  - 0.05cmX5cmX5cm NaI(Tl) plates was successfully made.
- Good performance was obtained
  - 18% FWHM at 60keV
  - E_{th}~2-3keV(S.P.E~0.35keV)
- Prospect
  - 16 modules stacked detector and 3 modules detector
  - Test experiment is now running.
  - Low BG measurement in OTO in this winter.

Collaboration

- The University of Tokushima
  - K.F, H.Kawasuso, M.Toi, K.Yasuda, E.Matsumoto, E.Aihara, R.Hayami, S.Nakayama, N.Koori
- Horiba Ltd.
  - K. Imagawa, H. Ito
- Osaka University
  - K.Ichihara, S.Umehara, S.Yoshida, M.Nomachi, H.Nakamura, R.Hazama
- ICU, Spring-8
  - H.Ejiri