WIMPs search project with highly segmented NaI(Tl) scintillators

Ken-Ichi Fushimi

Faculty of Integrated Arts and Sciences

The University of Tokushima

CONTENTS

- Signal Selection by Spatial and Time Correlation
- Thin NaI(Tl) plate for WIMPs search
- Performance of thin NaI(Tl)
- Plan for Underground Experiment
- Summary

Collaboration

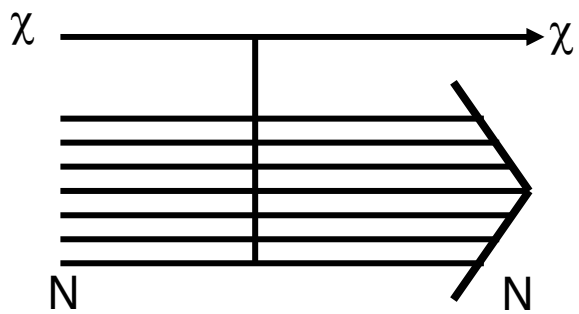
- The University of Tokushima
  - K.F, H.Kawasuso, M.Toi, K.Yasuda, E.Matsumoto, E.Aihara, R.Hayami, S.Nakayama, N.Koori
- Osaka University
  - K.Ichihara, S.Umehara, S.Yoshida, M.Nomachi, H.Nakamura, R.Hazama
- ICU
  - H.Ejiri

WIMPs search by scintillators

- Large Mass (~100kg)
- Good Target Nuclei
  - ^{23}Na for SD (NaI)
  - ^{127}I for SI,SD,EX (NaI, CsI)
  - ^{19}F for SD (CaF_2)
  - ^{129}Xe for SD,SI,EX (Xe)
- Low Cost

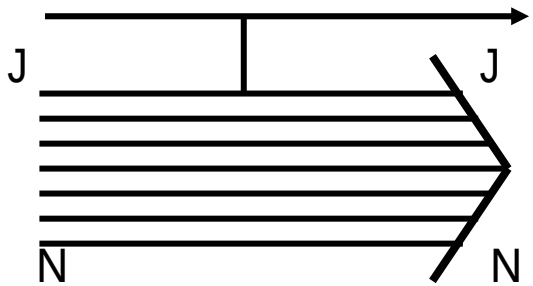
Sensitivity for WIMPs

SI



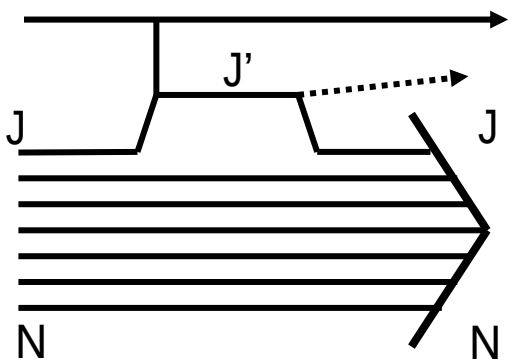
$$\sigma \propto A^2$$

SD



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

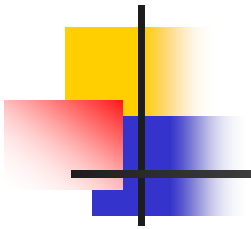
EX



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

Signal selection by Spatial and Timing Correlation

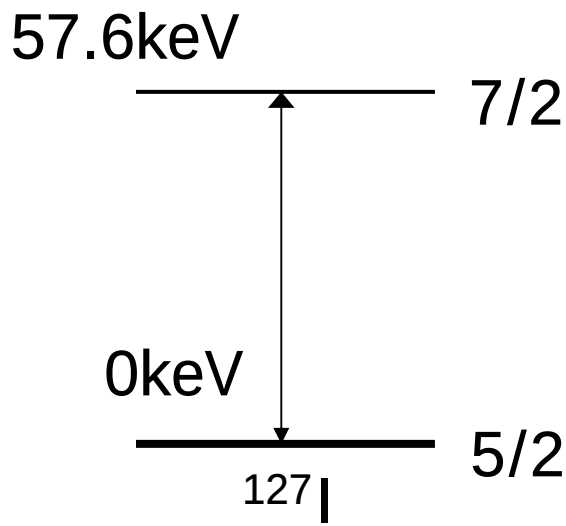
- SSSC analysis
- Signal Selection by Spatial Correlation
  - Signal → 57.6keV γ + Low energy recoil
  - Localized event
  - Background → High energy γ and β
  - Diffused event



- SSTC analysis
- Signal Selection by Time Correlation
  - Signal → Timely localized
  - $T_{1/2}$=0.9ns (57.6keV excited state)
  - Background → Timely correlated
    - $^{214}Bi \rightarrow {}^{214}Po$ ($T_{1/2}$=164μs)
    - $^{210}Pb \rightarrow {}^{210}Bi$($T_{1/2}$=5days)

Segmented NaI(Tl) plate for DM search

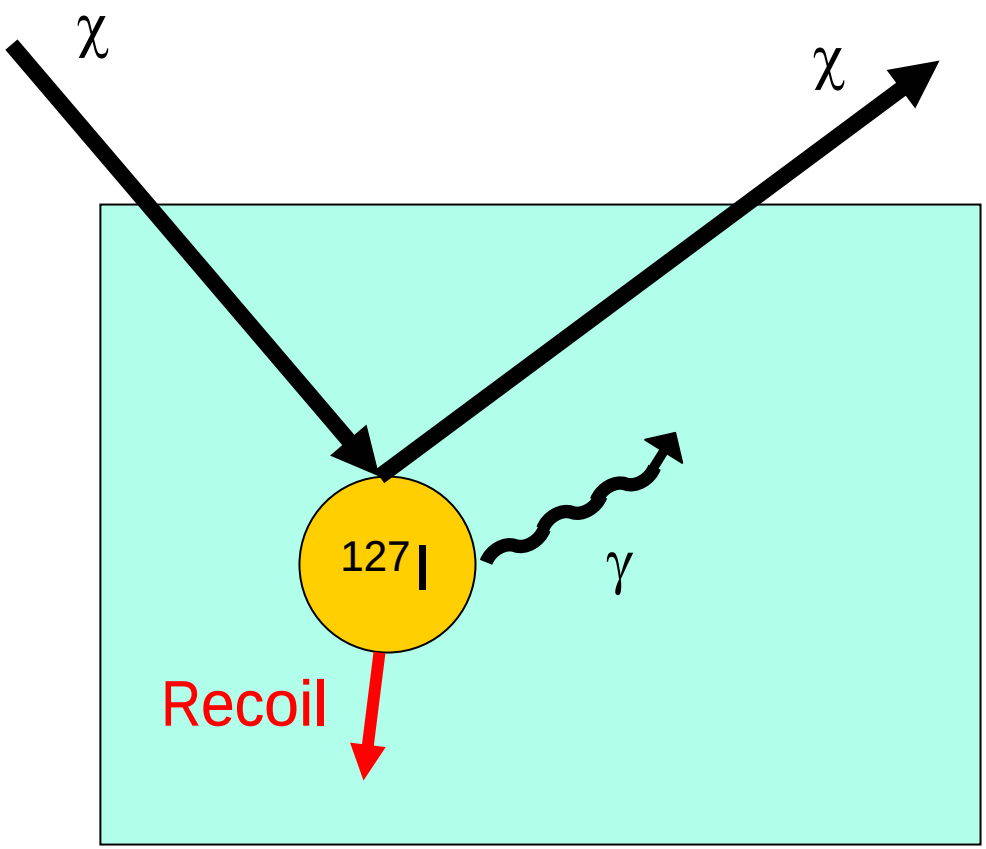
- ^{23}Na & ^{127}I
  - Sensitive to SD and SI
  - 100% natural abundance
- ^{127}I
  - Sensitive to EX
  - Low energy excited state
  - Expect: 3.60×10^{-3}/day/kg (Higgsino)
  - Limit: 4.98×10^{-2}/day/kg (ELE V NaI)

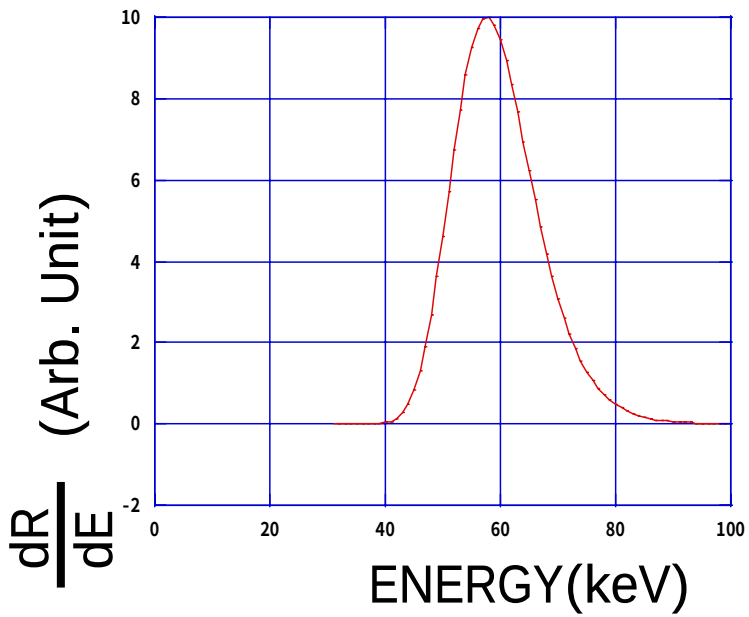


Experimentally obtained

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

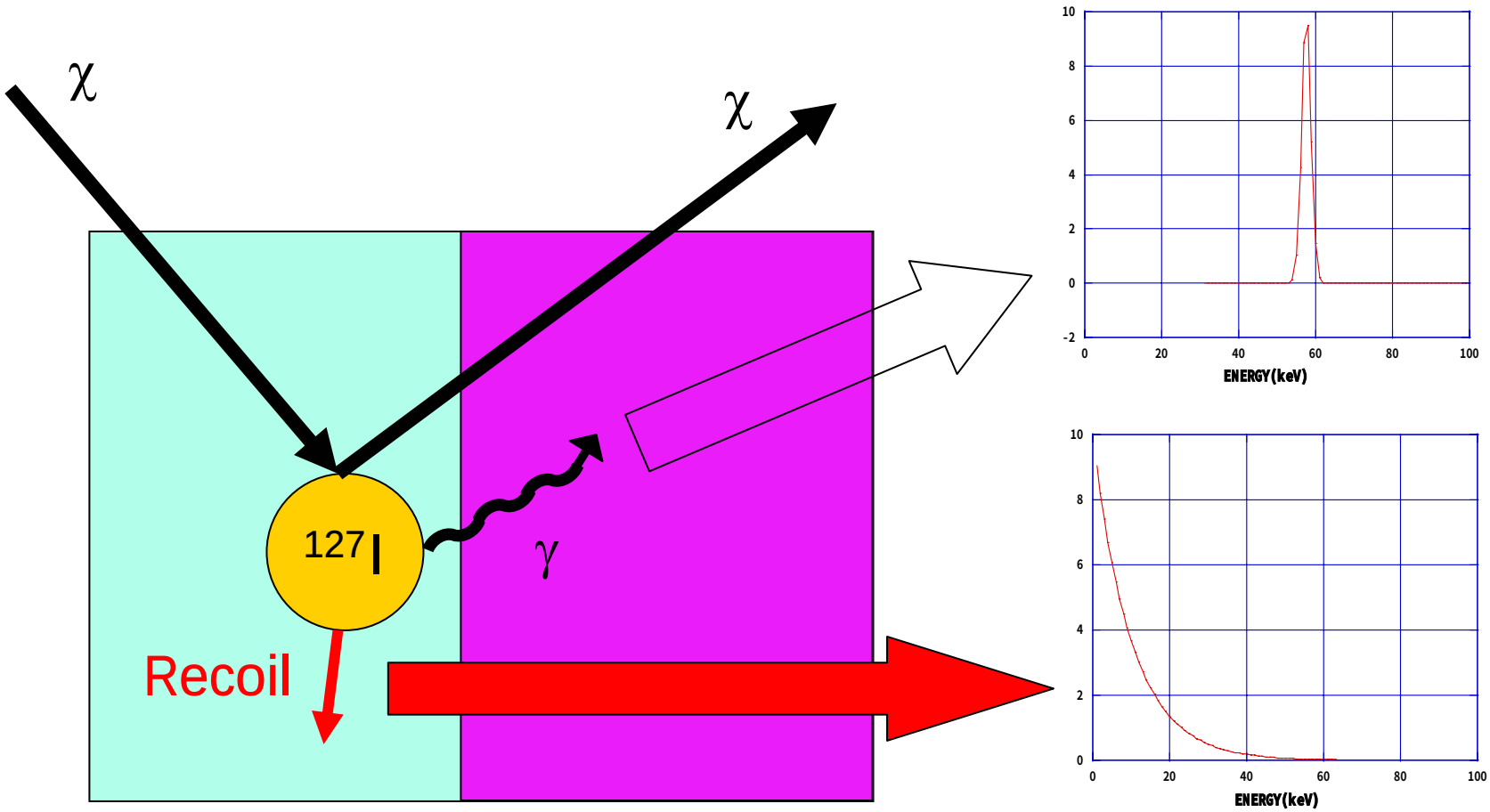
Previous technique





Difficult to identify BG and Signal.

Signal identification by segmentation



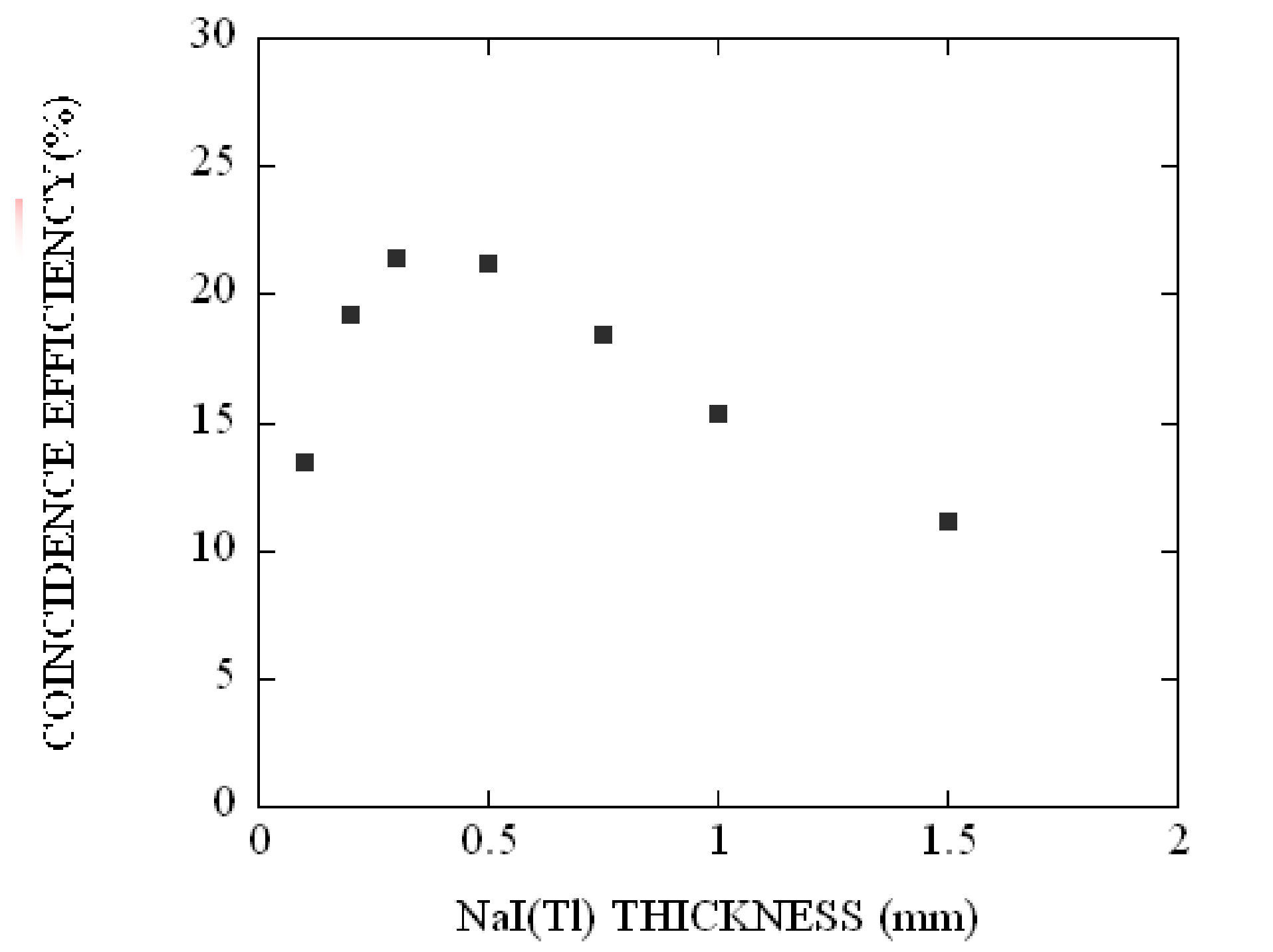
Estimation of signal selectivity

- Monte Carlo simulation (GEANT4)
- 57.6keV gamma ray from one module
- γ is detected the another module
- Next module to the emitter module

The fraction which is detected both sides of emitter

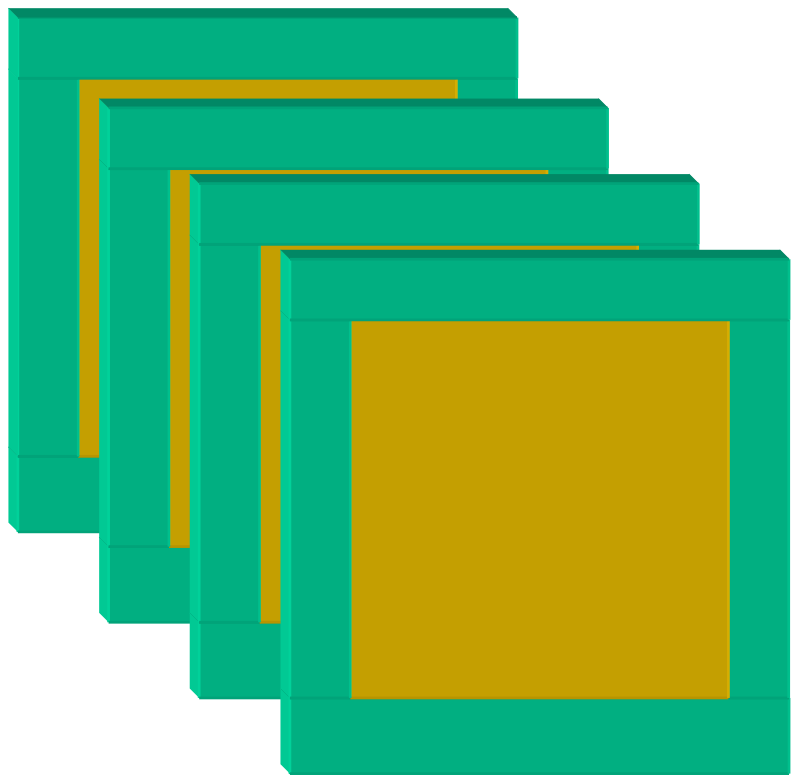
Fraction of detected g by neighboring modules

Thickness of NaI(Tl)	Coincidence probability
0.5mm	0.21
0.75mm	0.18
1.0mm	0.15
1.5mm	0.11


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
- 16modules (phase 1)
- 256modules (phase 2)
- 1024, 2176 (phase 3,4)



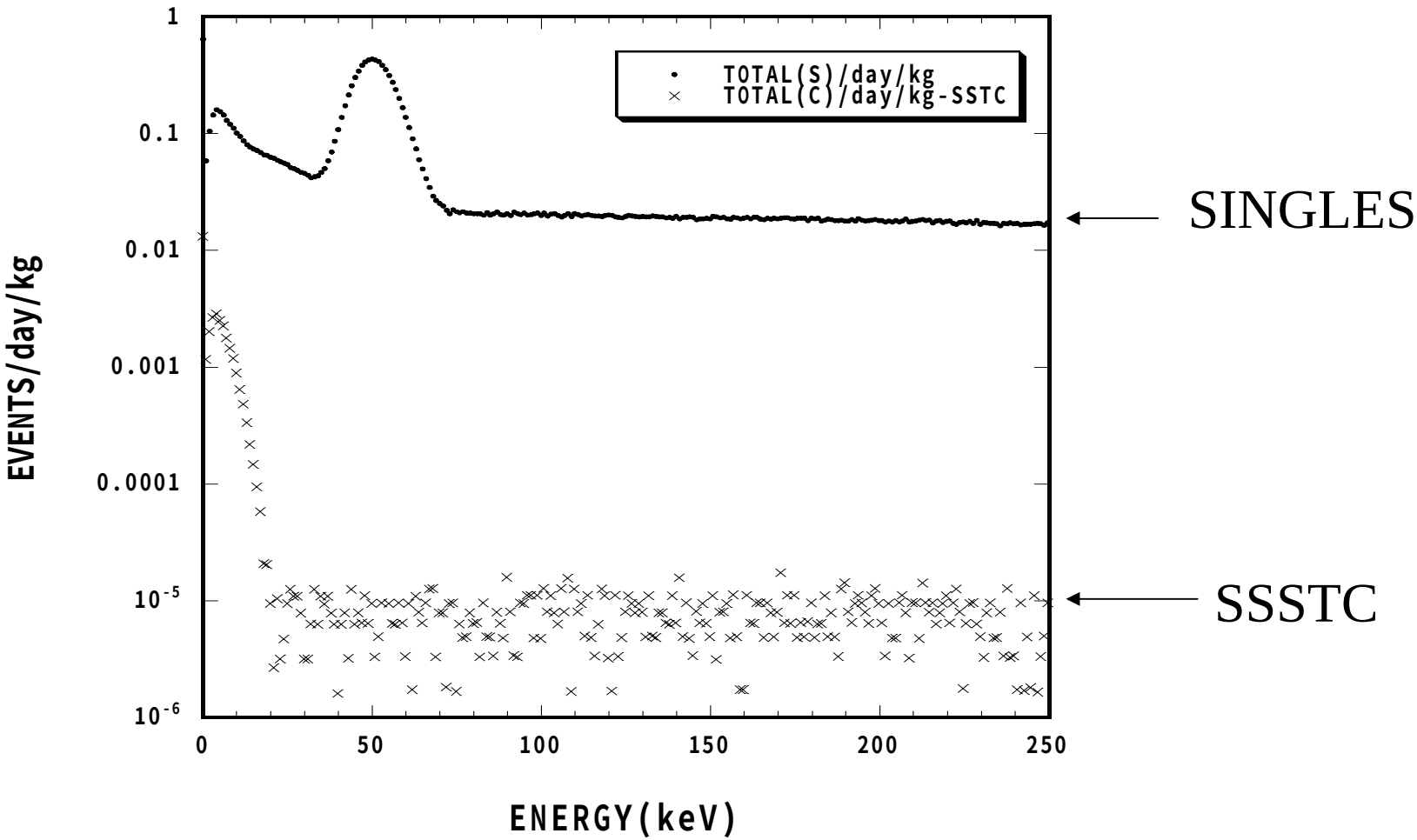
MC simulation for BG

- 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)

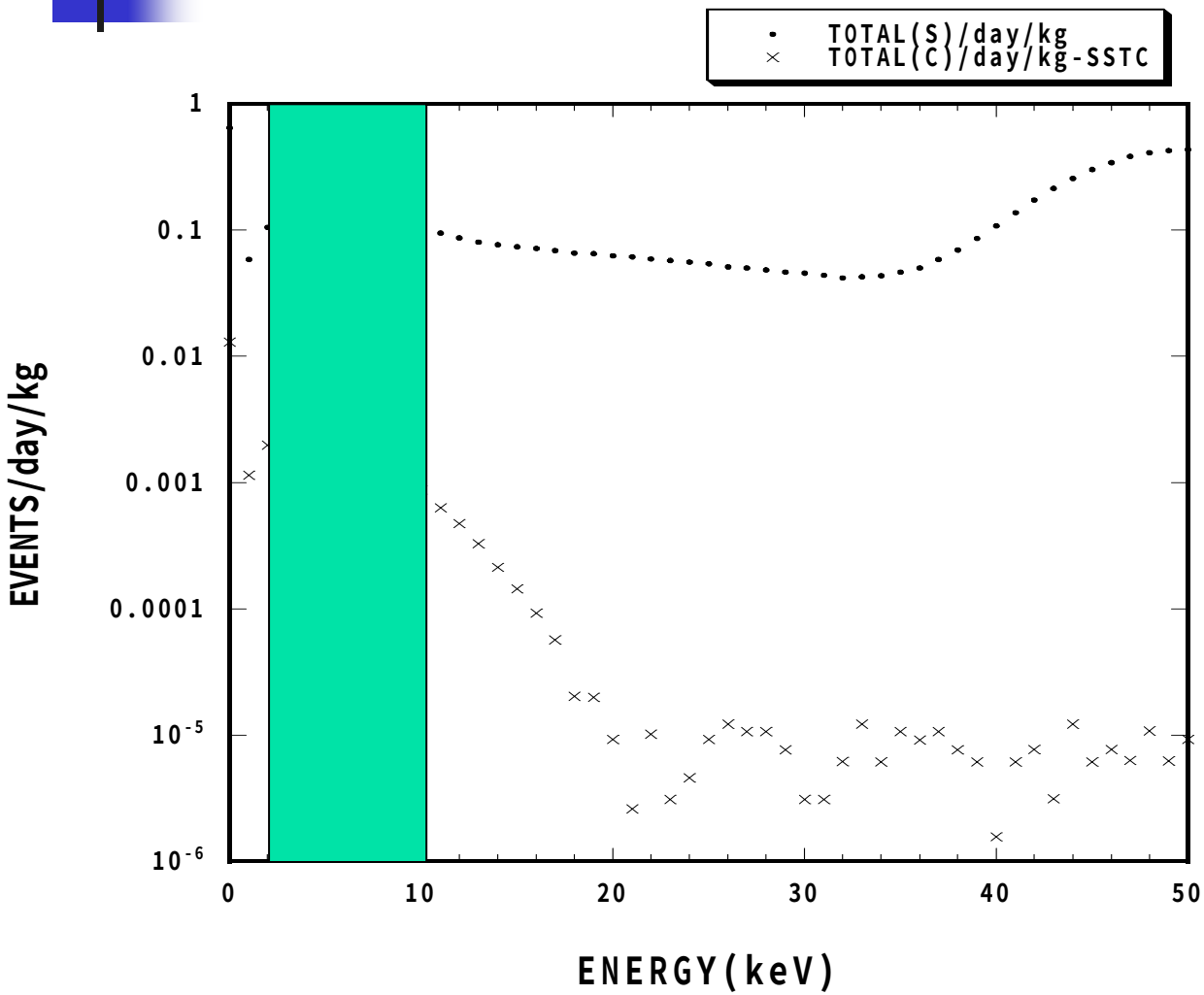
Condition of SSSTC

- ^{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

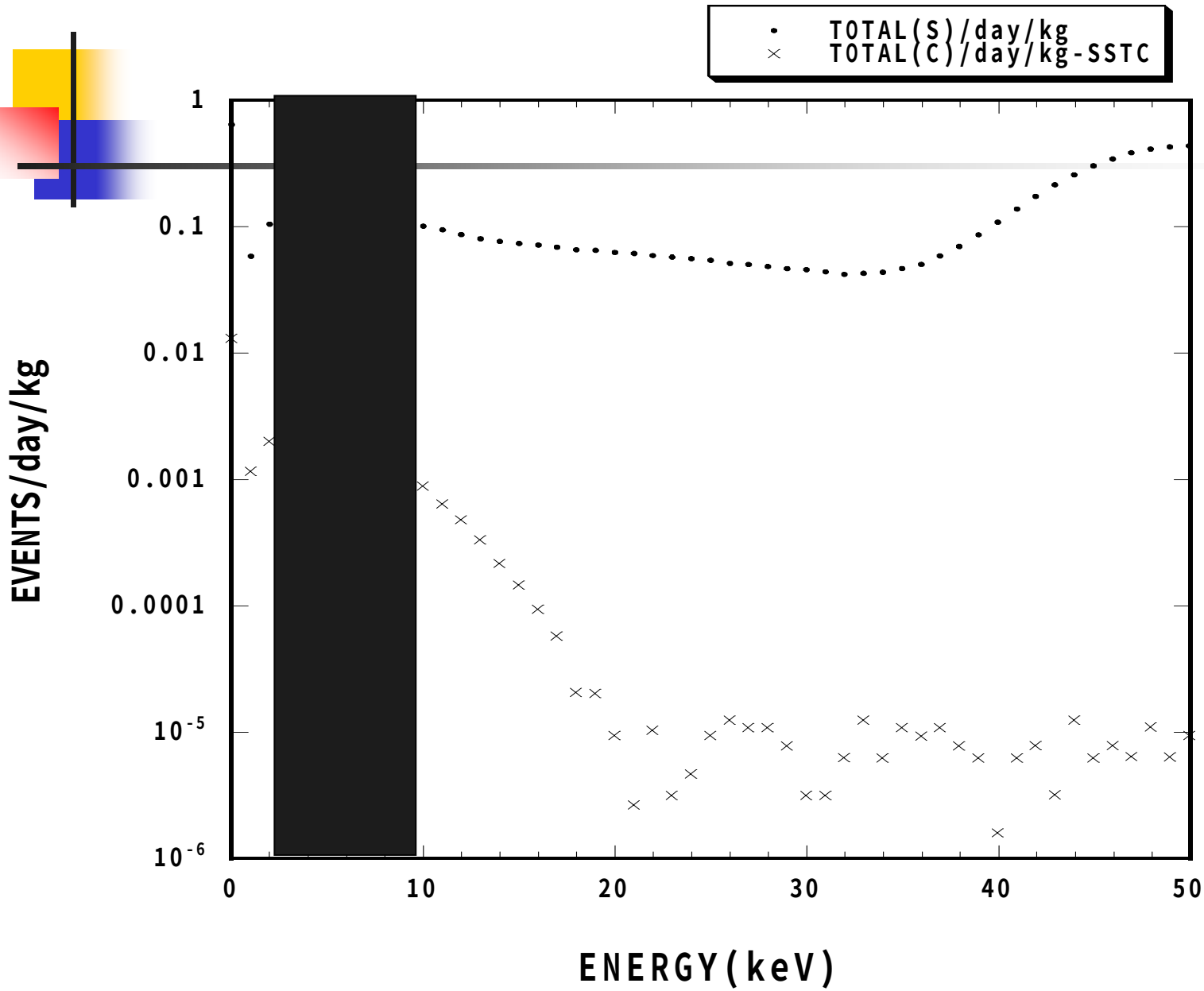

TOTAL(S)/day/kg
TOTAL(C)/day/kg-SSTC
EVENTS/day/kg
ENERGY(keV)
1
0.1
0.01
0.001
0.0001
10-5
10-6
0
50
100
150
200
250
SINGLES
SSSTC

Energy window of analysis



Coincidence event rate

$2\text{keV} \leq E_{ee} \leq 10\text{keV}$


TOTAL(S)/day/kg
TOTAL(C)/day/kg-SSTC
EVENTS/day/kg
1
0.1
0.01
0.001
0.0001
10-5
10-6
0
10
20
30
40
50
ENERGY(keV)

Upper limit on BG rate

NaI(Tl) thickness=0.05		Upper 4lines Eth=2keV, Lower 4lines Eth=4keV					
BG rate /kg/day	1モジュールの質量 (kg)	# of modules	Tolal mass(kg)	EVENTS/ year	ERROR/y ear	BG Upper limit/year (90%C.L.)	Upper limit(/kg/d ay)
1.72E-02	0.004588	16	0.0734	4.51E-01	0.671556	1.4175	0.052873
1.72E-02	0.004588	256	1.1744	7.22E+00	2.686224	3.465229	0.008078
1.72E-02	0.004588	1024	4.6976	2.89E+01	5.372448	6.930458	0.004039
1.72E-02	0.004588	2176	9.9824	6.13E+01	7.831622	10.10279	0.002771
1.27E-02	0.004588	16	0.0734	3.31E-01	0.575341	0.74219	0.027684
1.27E-02	0.004588	256	1.1744	5.30E+00	2.301363	2.968758	0.006921
1.27E-02	0.004588	1024	4.6976	2.12E+01	4.602726	5.937517	0.00346
1.27E-02	0.004588	2176	9.9824	4.50E+01	6.709569	8.655344	0.002374
NaI(Tl)の厚さ0.1cm							
BG計数率	1モジュールの質量 (kg)	モジュール数	全モジュールの質量 (kg)	1年間の計数値	1年間の計数誤差	BG上限値 (90%C.L.)	計数値上限値 (/kg/day)
2.74E-02	0.009175	16	0.1468	1.44E+00	1.197933	3.06	0.05707
2.74E-02	0.009175	256	2.3488	2.30E+01	4.791732	2.91E+01	0.033969
2.01E-02	0.009175	16	0.1468	1.05E+00	1.024964	2.457	0.045824
2.01E-02	0.009175	256	2.3488	1.68E+01	4.099858	2.21E+01	0.025758

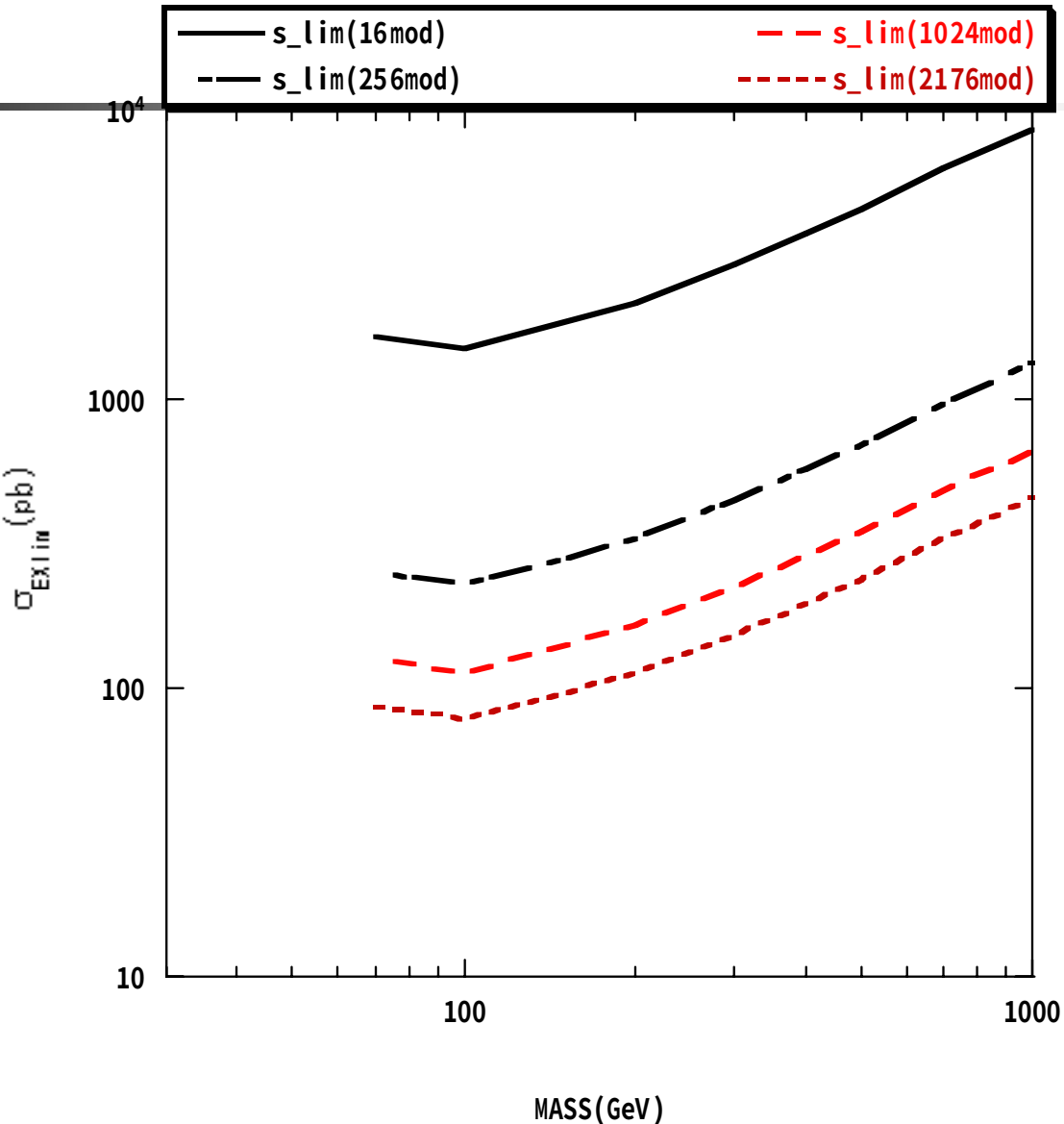
Calculation of Exclusion plot

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

$$\sigma_{\lim,EX} = \frac{m_\chi}{N_T \rho_0 \langle v \rangle f \left| F(q_{Th}) \right|^2 \varepsilon_{Coinc}} R_{\lim}$$

$$f = \frac{p_f}{p_i}$$

Exclusion plot for σ_{EX}



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

Using the relation,

$$\sigma_{EX} \propto \left(\frac{m_T m_\chi}{m_T + m_\chi} \right)^2 \frac{2J^* + 1}{2J + 1} \left| \frac{M_{M1}}{\mu_p} \right|^2 \left| \sum_q T_q^3 \Delta q \right|^2 \frac{p_f}{p_i}$$

$$\sigma_{SD} \propto \left(\frac{m_T m_\chi}{m_T + m_\chi} \right)^2 \lambda^2 J(J+1) \left| \sum_q T_q^3 \Delta q \right|^2$$

The Upper limit on proton-WIMPs cross section

$$\sigma_{\lim,\chi-p} = \lambda^2 J(J+1) \frac{m_p^2}{m_T^2} \left(\frac{m_p + m_\chi}{m_T + m_\chi} \right)^2 \frac{2J^* + 1}{2J + 1} \sigma_{\lim,EX}$$

Parameters

$$\left[\lambda^2 J(J+1)\right]_p = 0.75$$

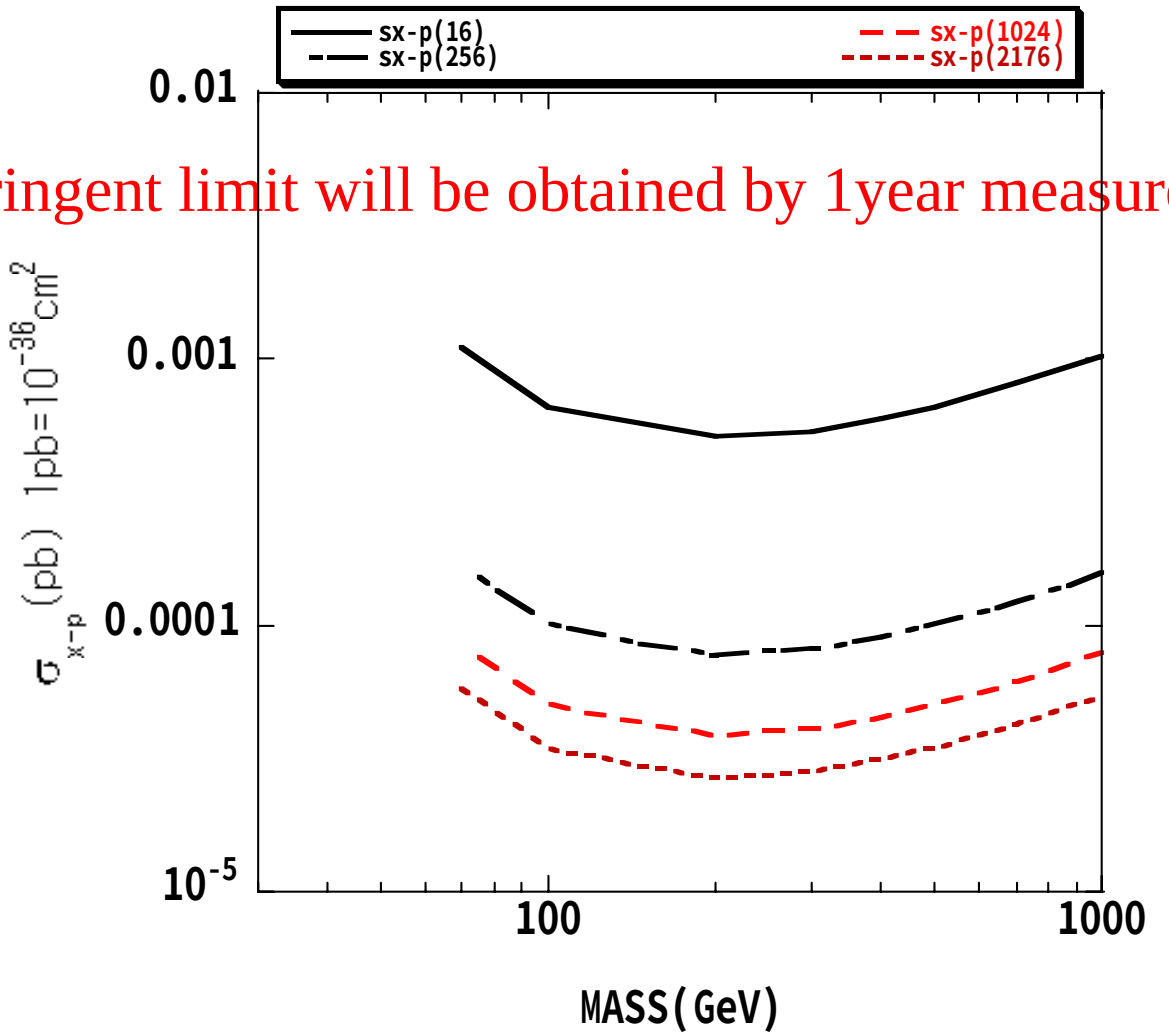
$$J = \frac{5}{2}, J^* = \frac{7}{2}$$

$$m_p = 0.938\text{GeV}$$

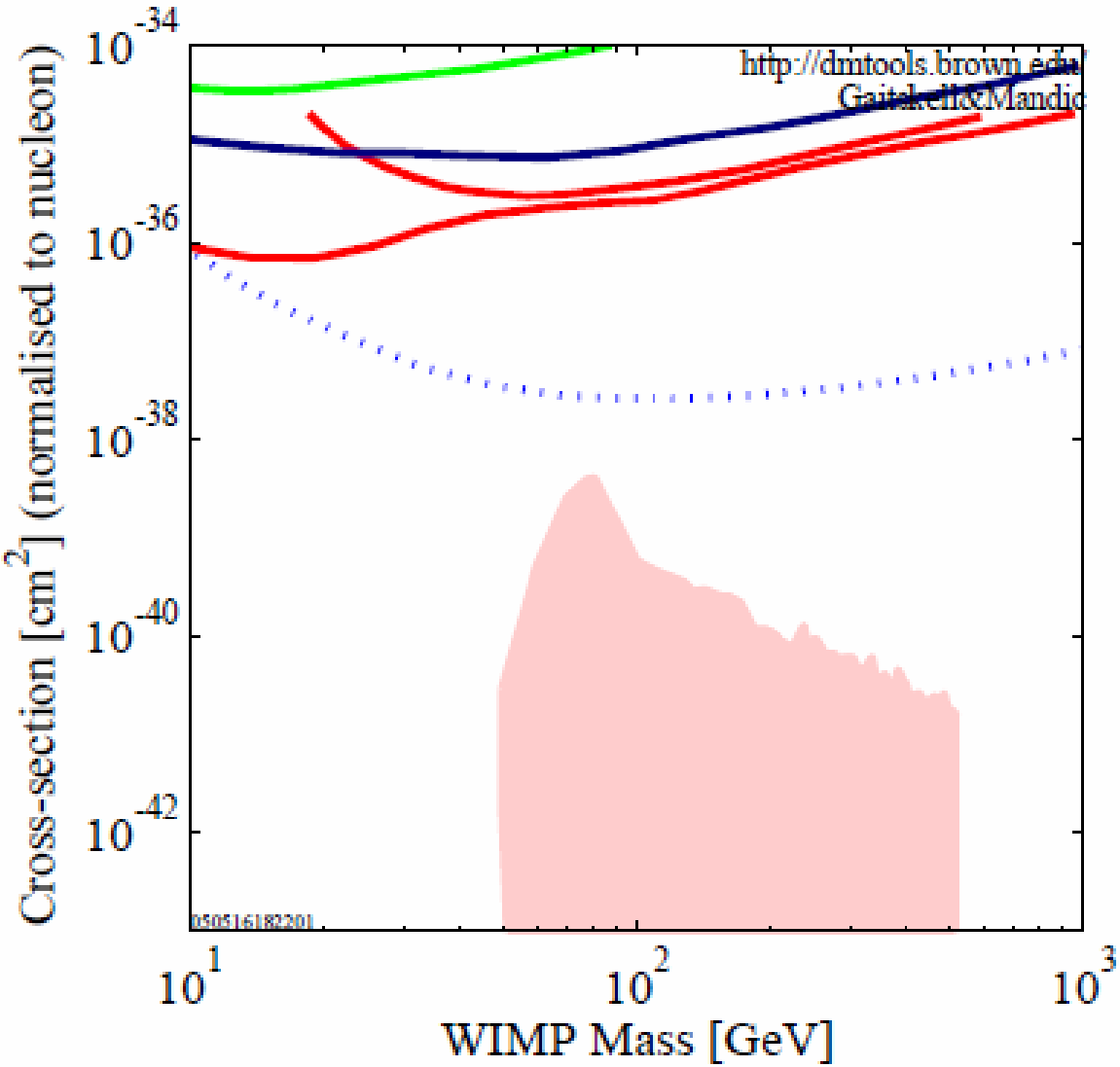
$$m_{^{127}\text{I}} = 118.18\text{GeV}$$

Expected sensitivity for WIMPs

Stringent limit will be obtained by 1year measurement



SD Exclusion plot

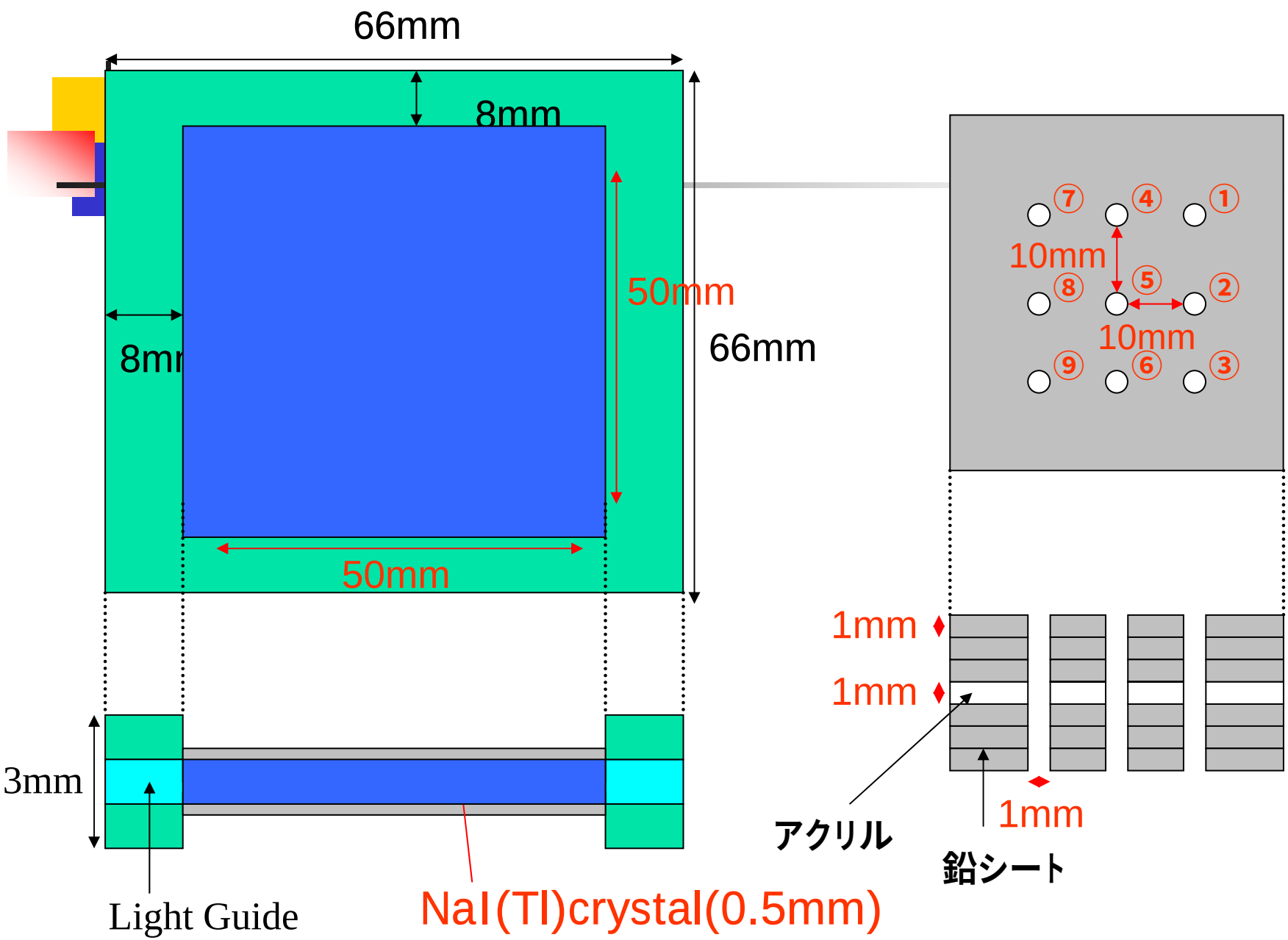


Performance of thin NaI(Tl)

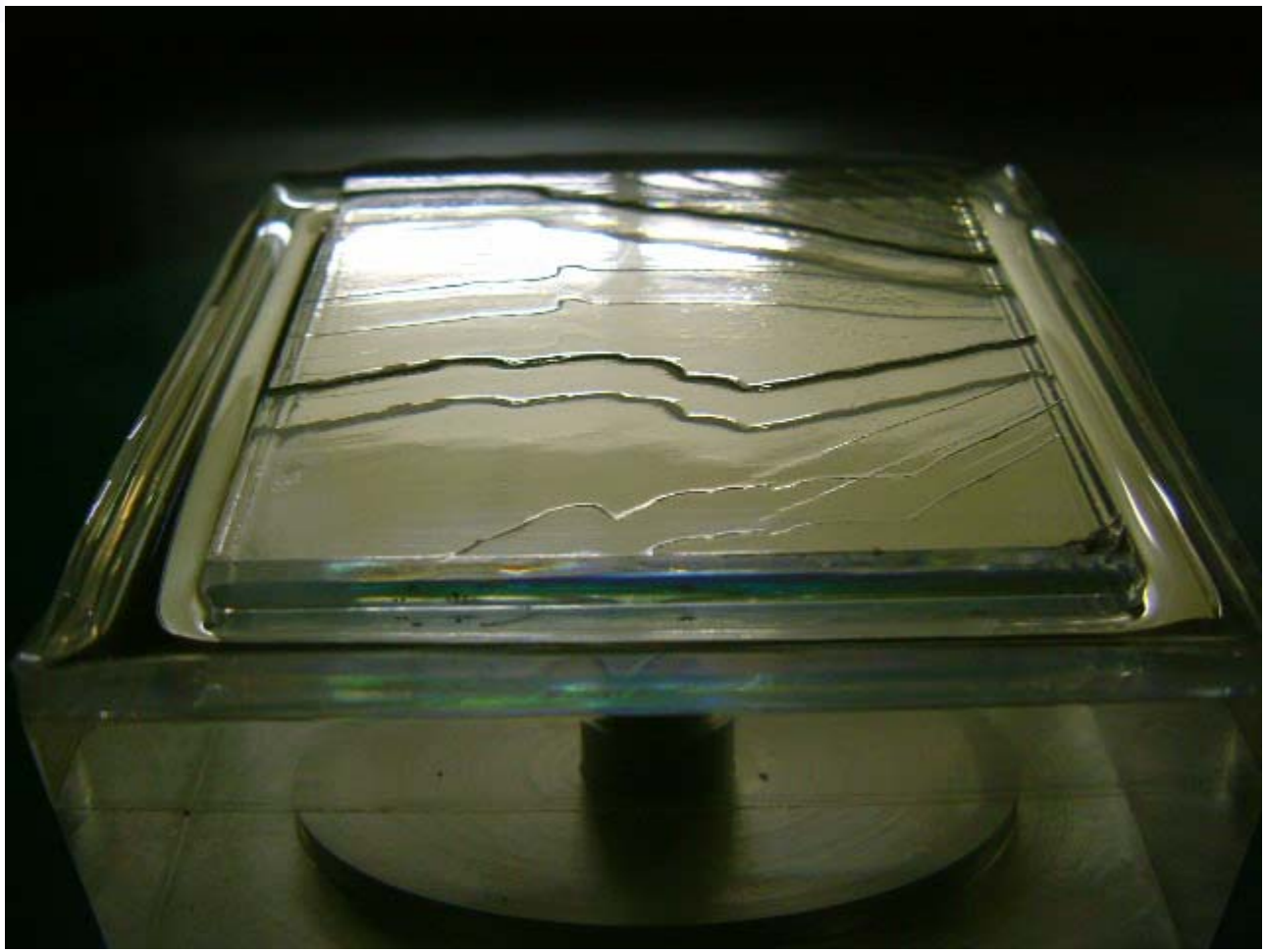
- Thickness of NaI(Tl)
  - 0.05cm
- Energy resolution
- Energy threshold
- Photon number/keV
- Position selectivity
- PMT : Hamamatsu R329P

Development of thin NaI(Tl)

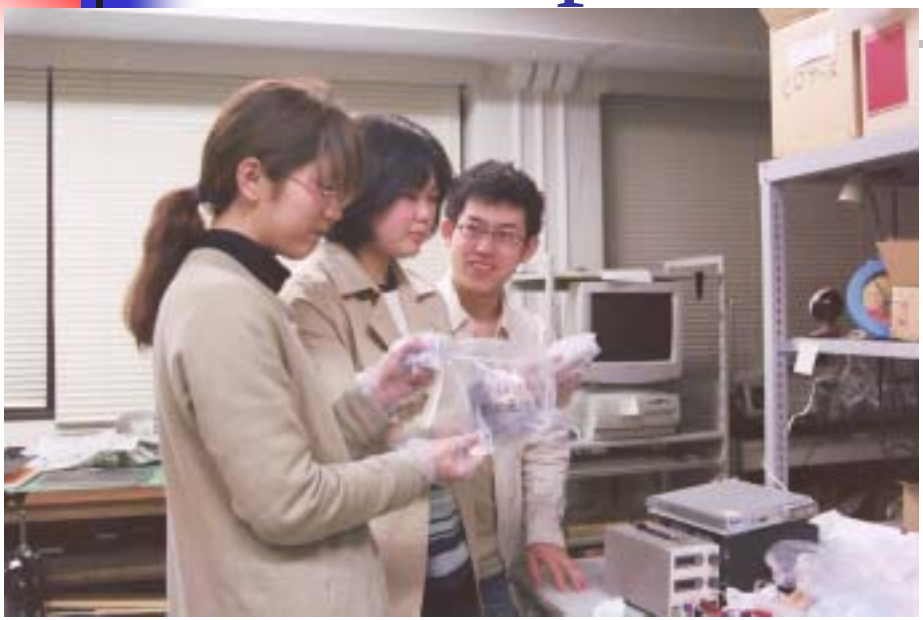
- Collaboration with Horiba Ltd.
  - Production of thin NaI plate
  - Selection of reflector
- ~2004/Feb.
  - Design and production method
- 2004/Apr.
  - First module was completed!!
- 2004/May~
  - Performance, stability test.


66mm
8mm
8mm
50mm
66mm
50mm
7
4
1
10mm
8
5
2
10mm
9
6
3
1mm
1mm
1mm
3mm
アクリル
鉛シート
Light Guide
NaI(Tl)crystal(0.5mm)

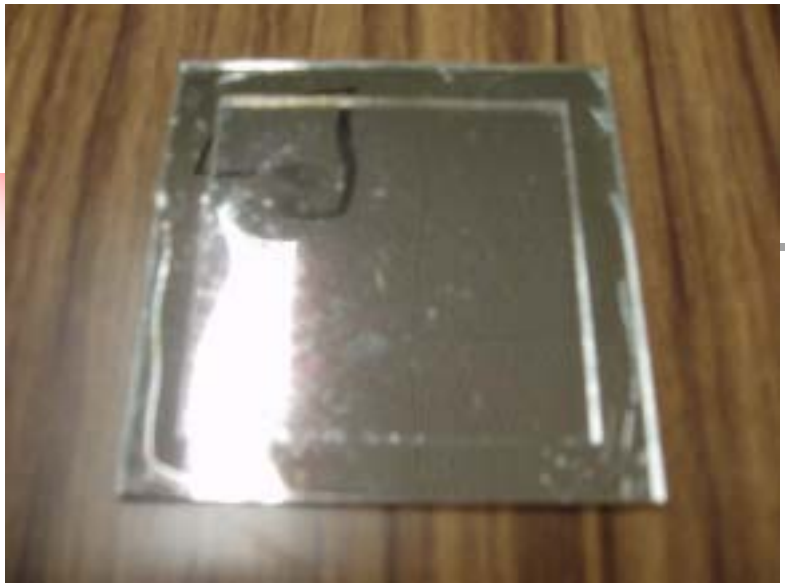
Production of thin NaI(Tl) by Horiba Ltd.



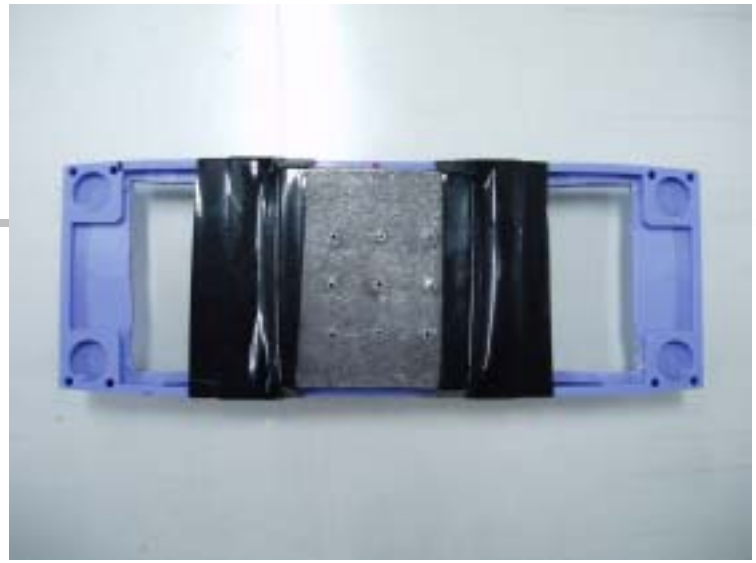
Test of performance

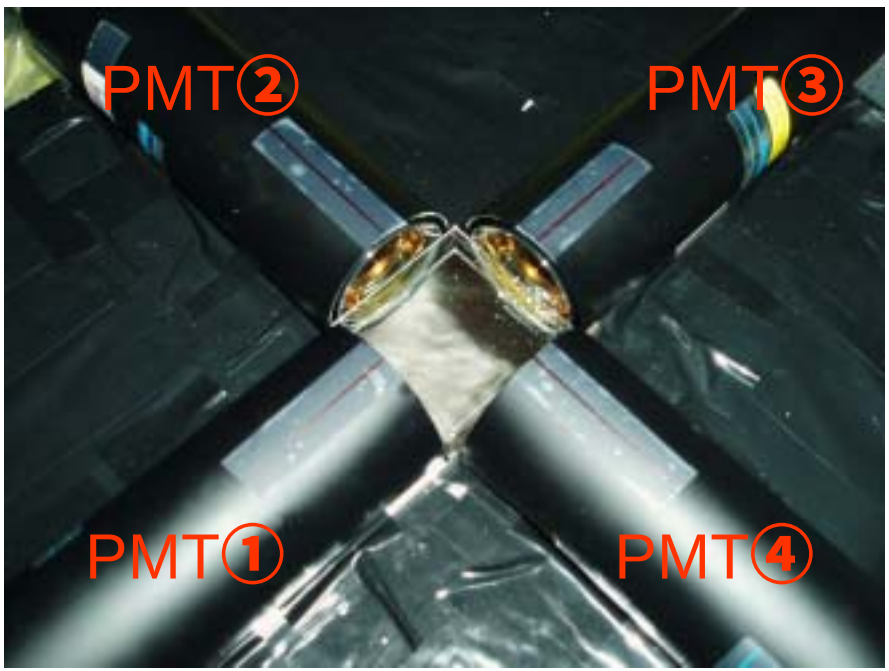


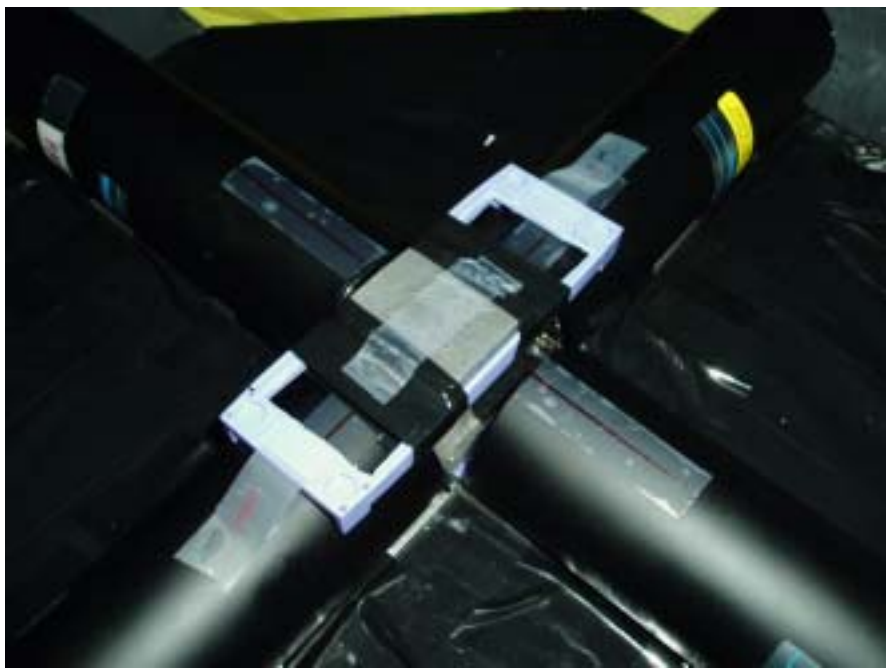
Thin NaI(Tl) scintillator



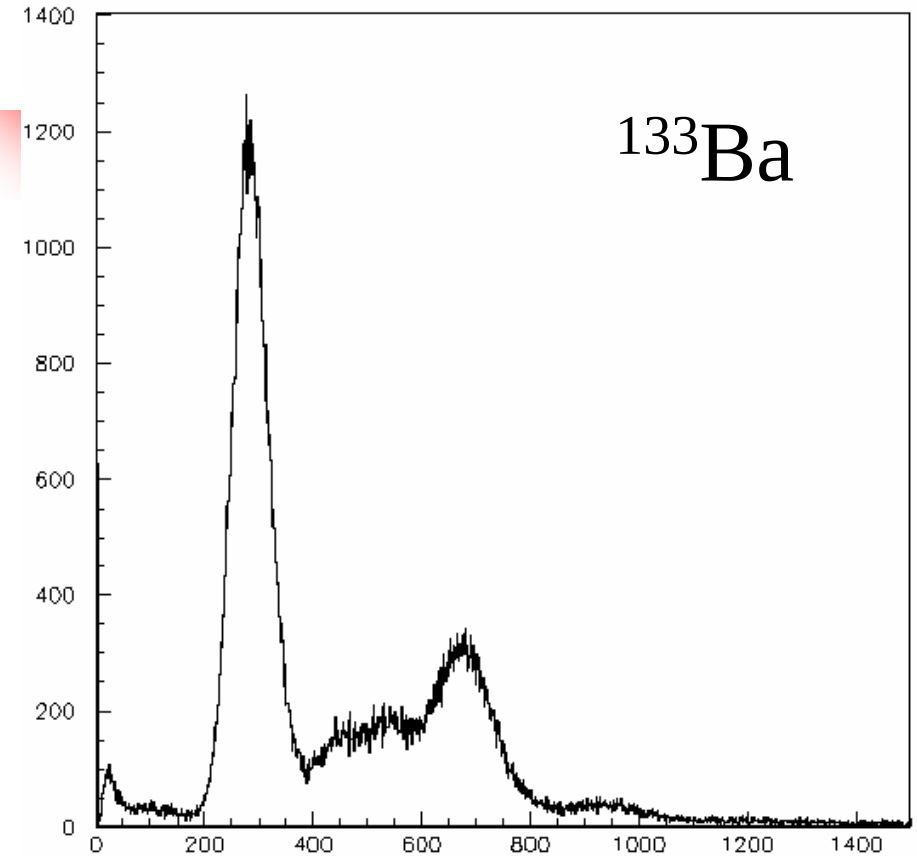
Collimator

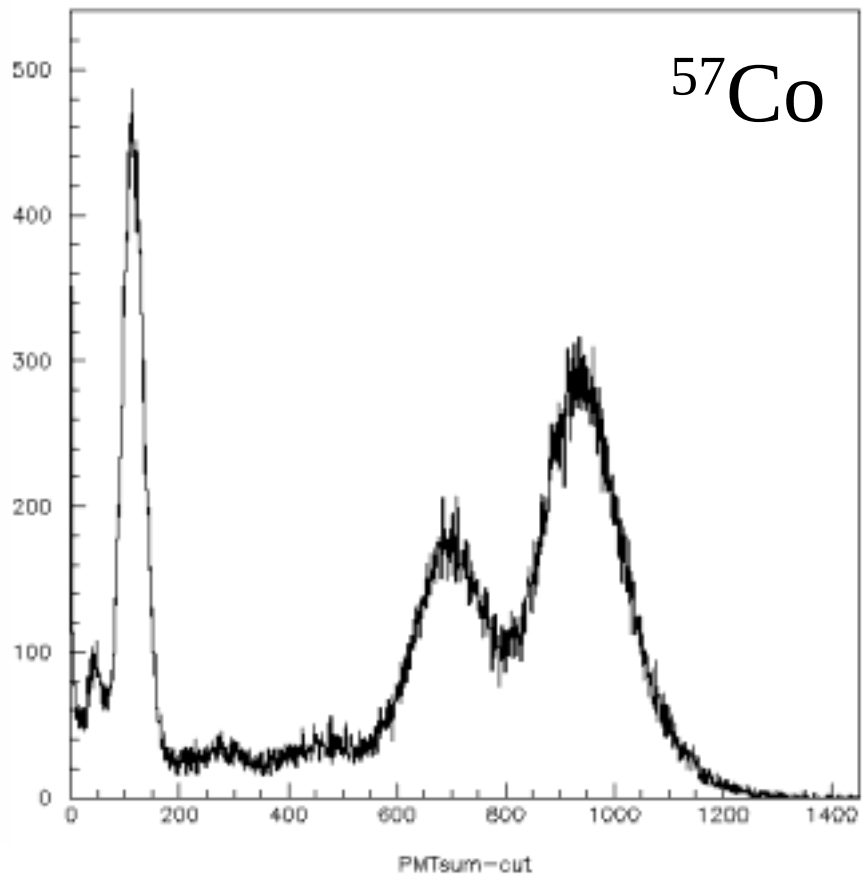






Result (Preliminary)

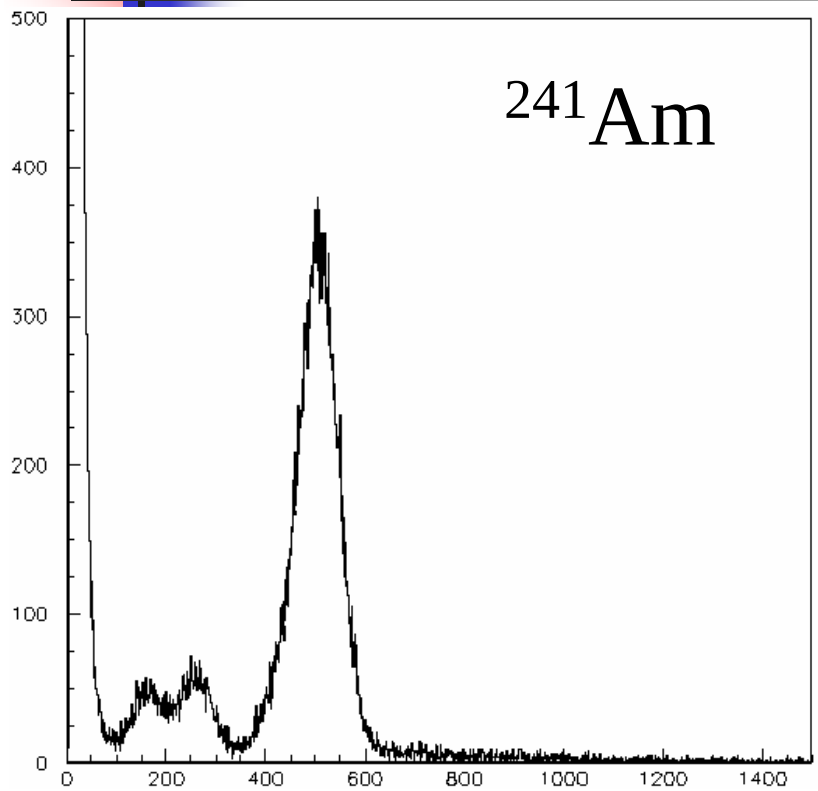




30keV R(FWHM)=0.25

122keV R(FWHM)=0.14

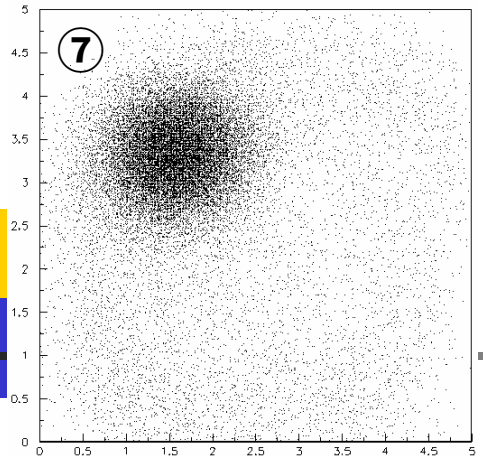
81keV R(FWHM)=0.13

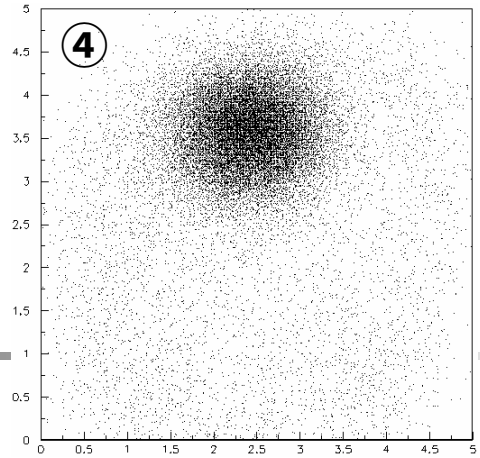


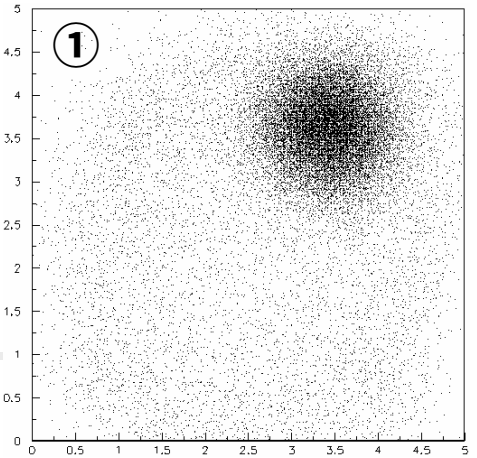
60keV R(FWHM)=0.18

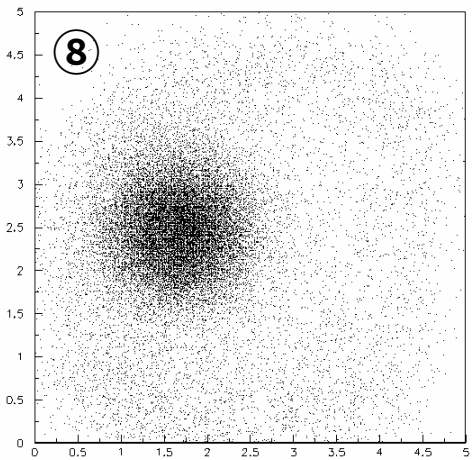
Source	Energy	FWHM
^{133}Ba	30keV	0.25
^{241}Am	60keV	0.18
^{133}Ba	81keV	0.13
^{57}Co	122keV	0.14

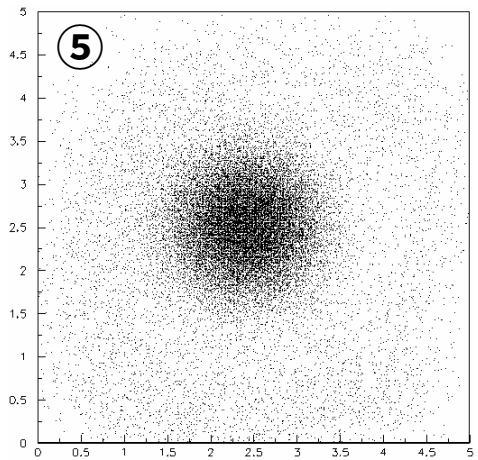
NaI(Tl) Real Position

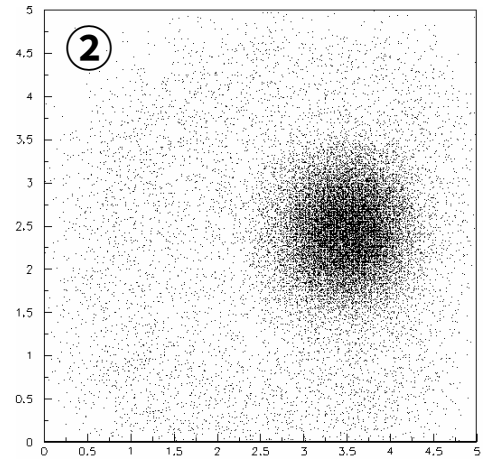


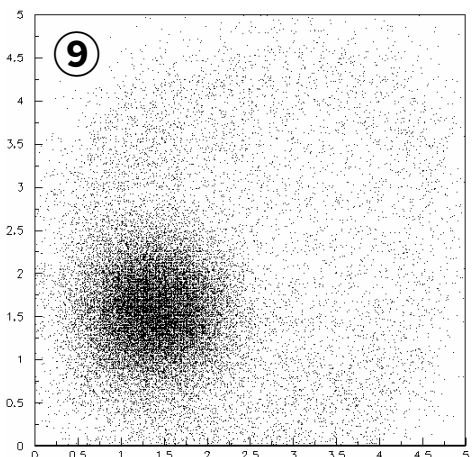


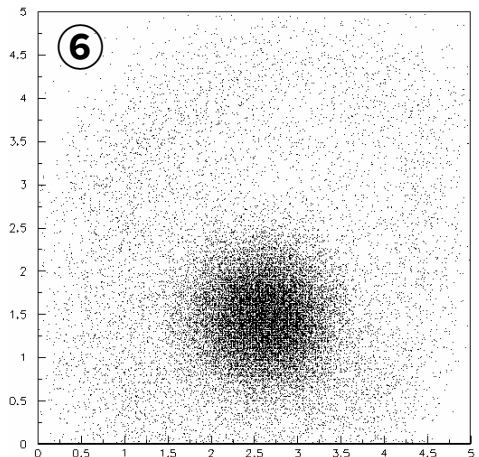


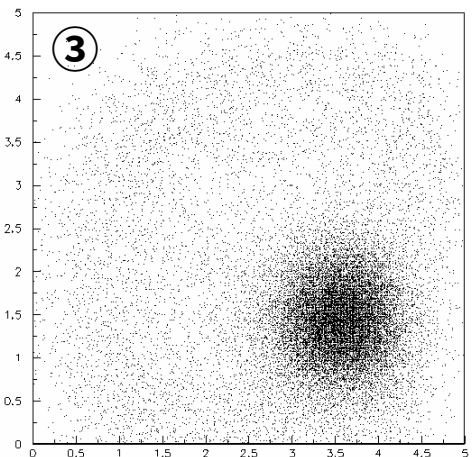












Future Prospect

- 2005~2006
  - Underground experiment with 16 modules
  - Laboratory: Oto Cosmo Observatory

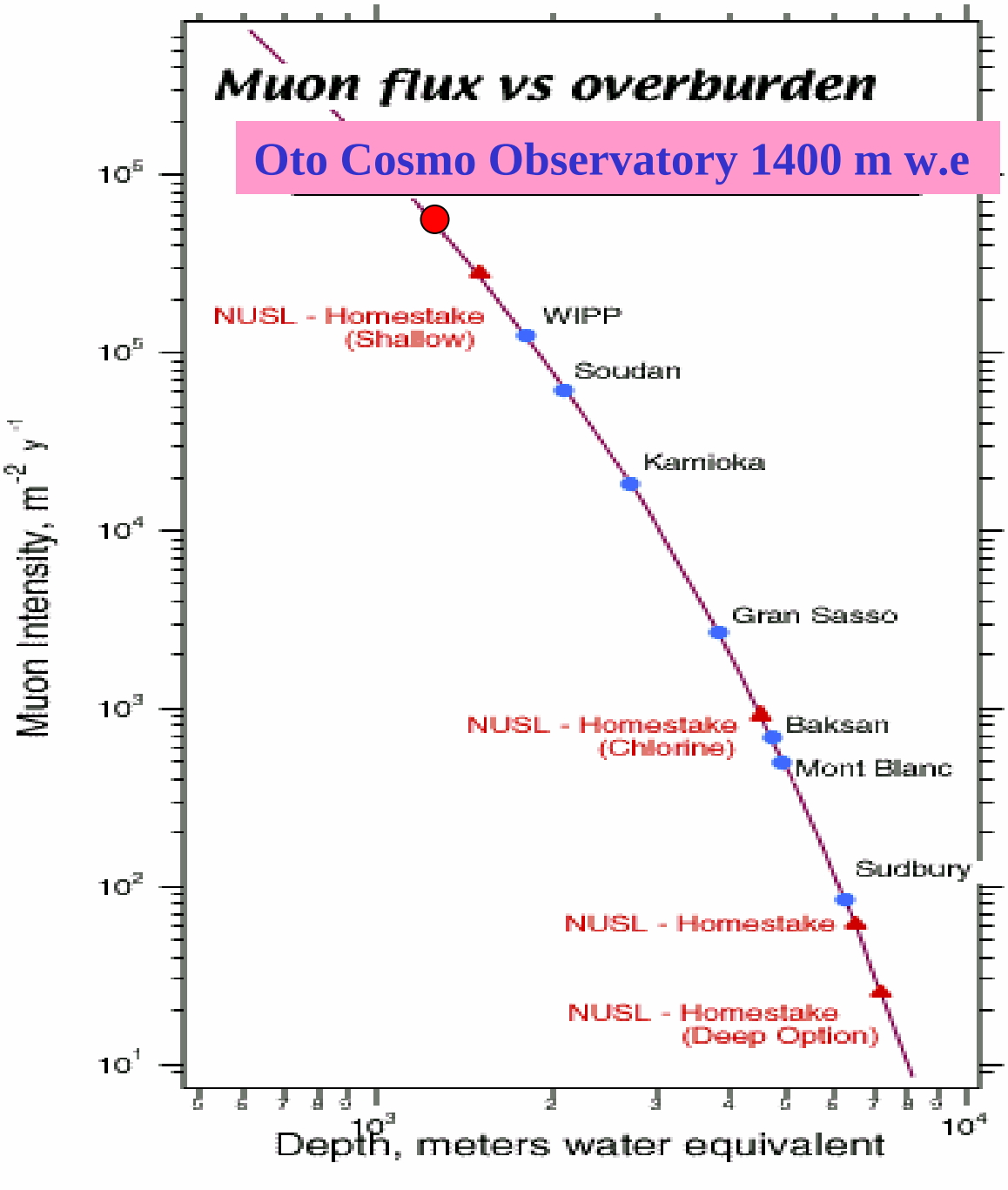

Oto Cosmo Observatory
ELEGANT Group
RCNP/Osaka/Tokushima

BG's in OTO

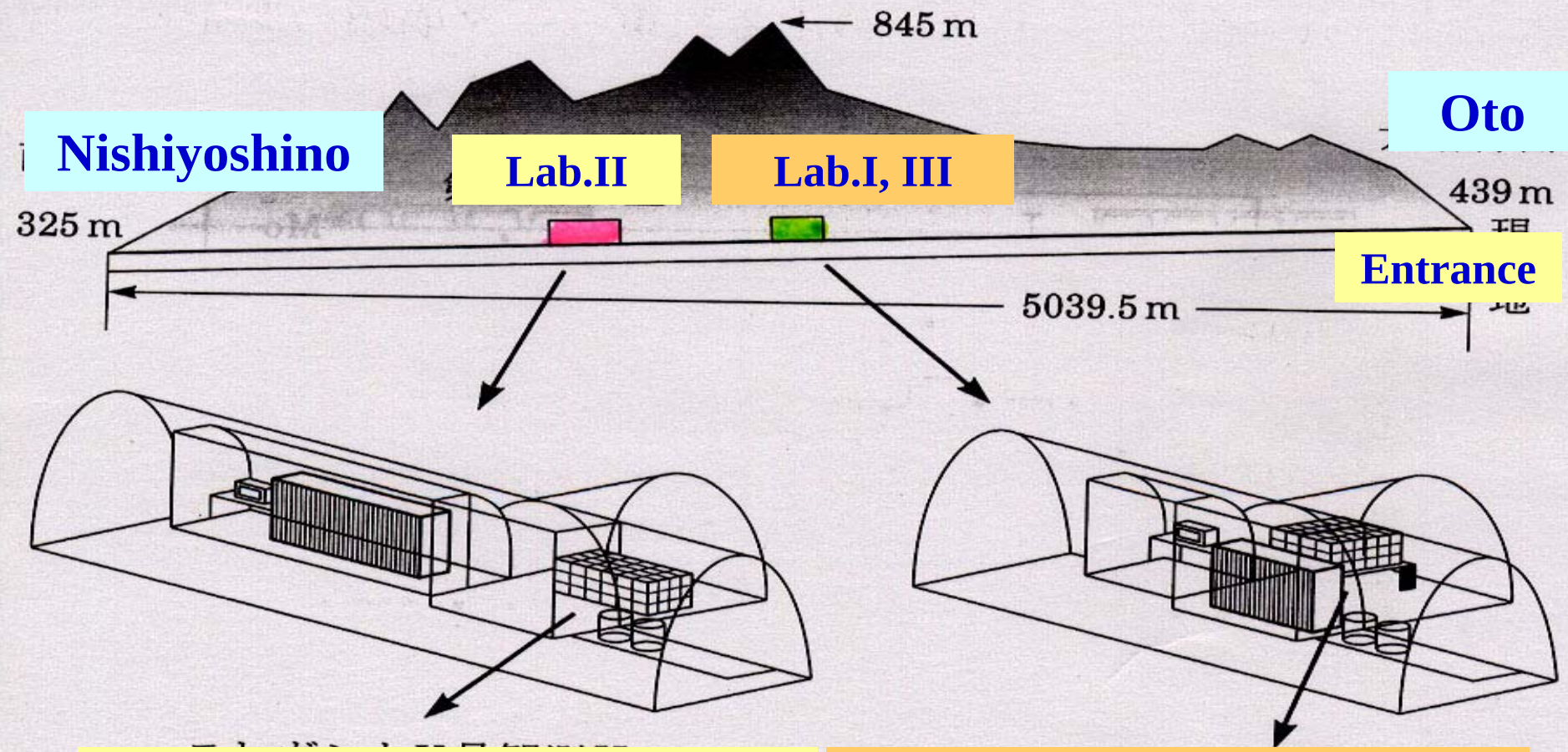
Cosmic μ
$4x10^{-3}$ /m^2/s

Neutron
$4x10^{-1}$/m^2/s

Rn 10 Bq/m^3



60 km south of Osaka, 150km east of Tokushima



Lab. II. 45 m^2
MOON-I, ββ of ^{100}Mo and DM with NaI

Lab.I. 33 m^2
ELEGANT VI
ββ of ^{48}Ca and DM with CaF_2

Plan

- Preparation of multi layer NaI(Tl)
  - ~This Summer
- Installation into OTO Cosmo Obs.
  - ~This winter
- Times π or 4π

Summary(1)

- Signal Selection by

  Spatial and Timing Correlation
  - Reduces the background events
  - High sensitivity with a moderately pure detectors
- Position resolution
  - Segmentation is most efficient way

Summary(2)

- Development of thin NaI(Tl) array
- 5cmx5cmx0.05cm NaI(Tl)
- Successfully developed
- Purity of radioactivity
  - 12μBq/kg for U
  - 10mBq/kg for ^{210}Pb
- Good perfomance
  - 18% FWHM at 60keV
  - E_{th}~2-3keV