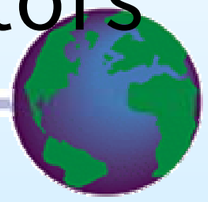
Dark Matter Search with Direction Sensitive Scintillators



The10th ICEPP Symposium

February 16, 2004, Hakuba

H. Sekiya

University of Tokyo

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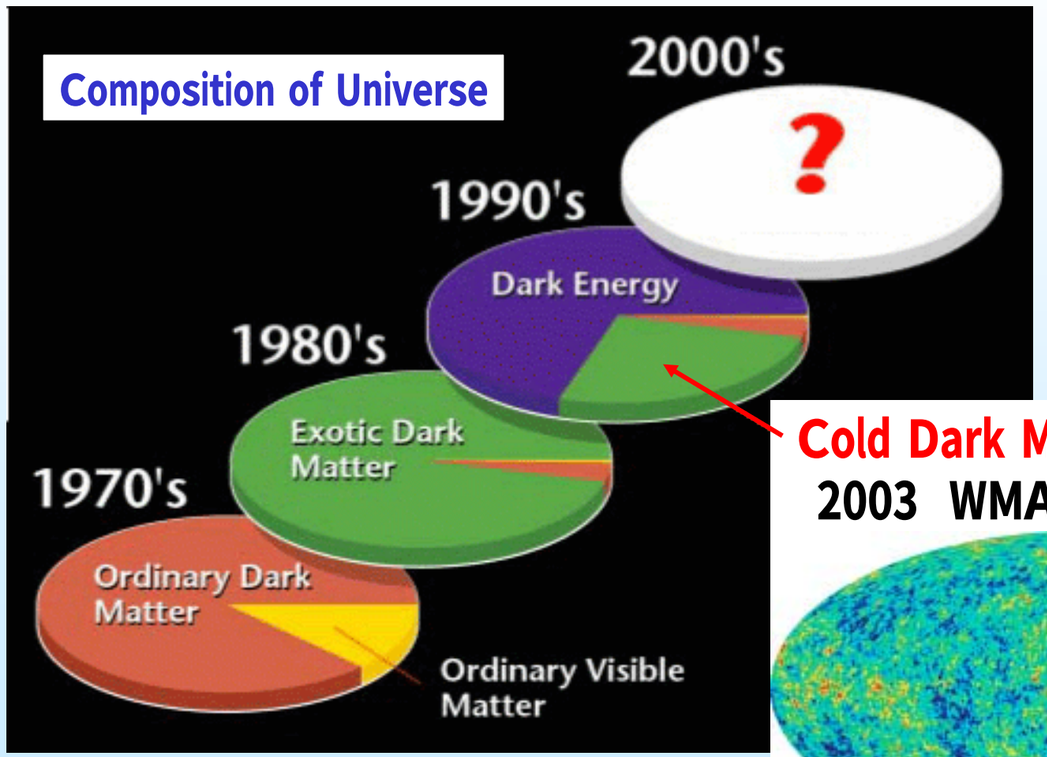
“ History ” of Dark Matter

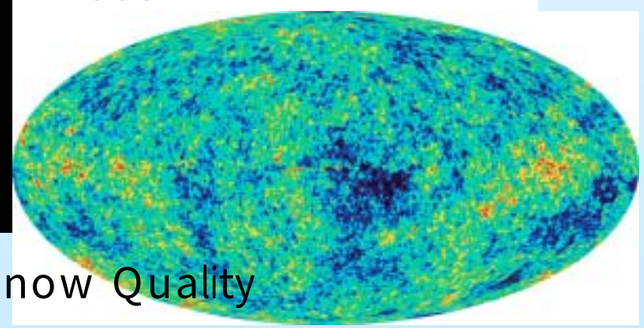
Dark Matter changes by decades.



NASA/WMAP Science Team

Cold Dark Matter 23%

2003 WMAP

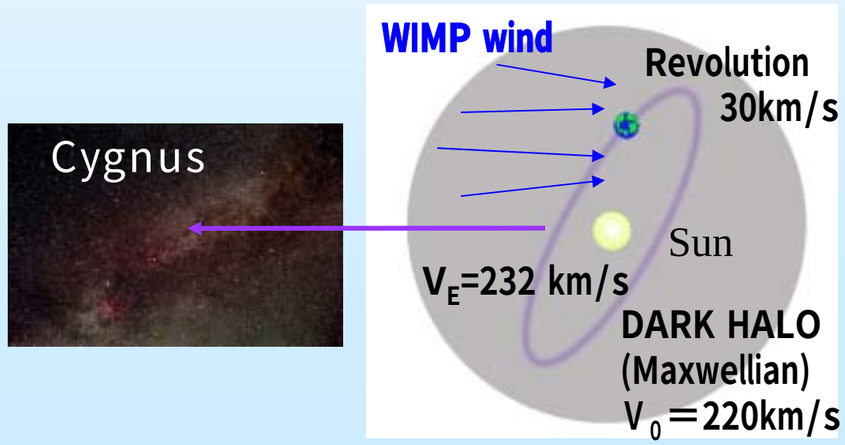


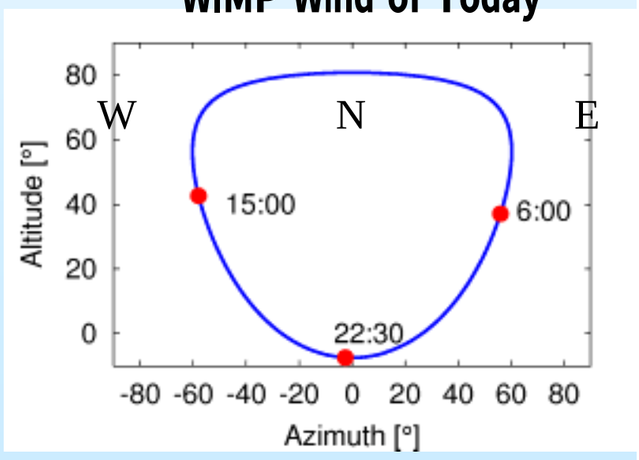
Quantity is determined, we want to know Quality

Motivation

How to distinguish WIMPs from BGs?

- Realistic distinctive WIMP signals arise from the earth's motion in the galactic halo.
- The annual modulation of event rate is one of the possible WIMP signal caused by earth's revolution around the sun.
- The earth's rotation through the galaxy provides WIMP wind.
- Most convincing signature would be identified with recoil direction sensitive detector.



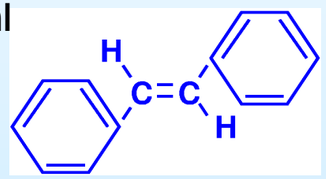


Organic single crystals

- Scintillation efficiency depends on direction of nuclear recoils with respect to crystallographic axes.
- We focus on the stilbene crystals.

Stilbene has an advantage in realizing large single crystal.

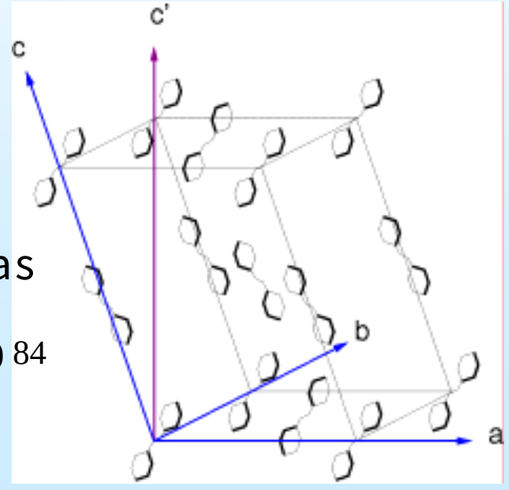
- **Light yield : 30% of NaI**
- **λ max : 410 nm**
- **Decay time : 5 ns**



- In high energy regions, the response was precisely measured.

P. Heckmann *et al.*, Z. Phys 162(1961) 84

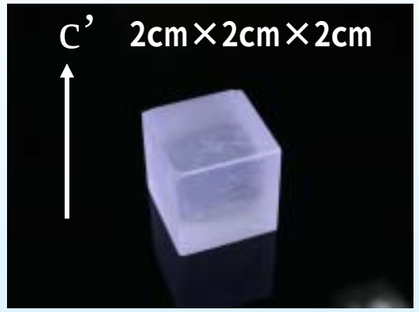
- Scintillation efficiency depends on only the angle with respect to c' axis.

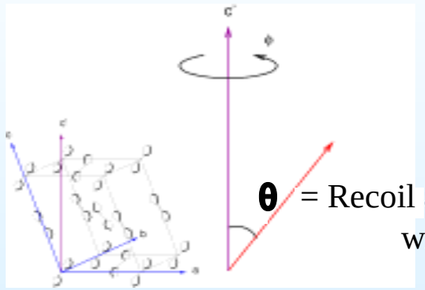


monoclinic system

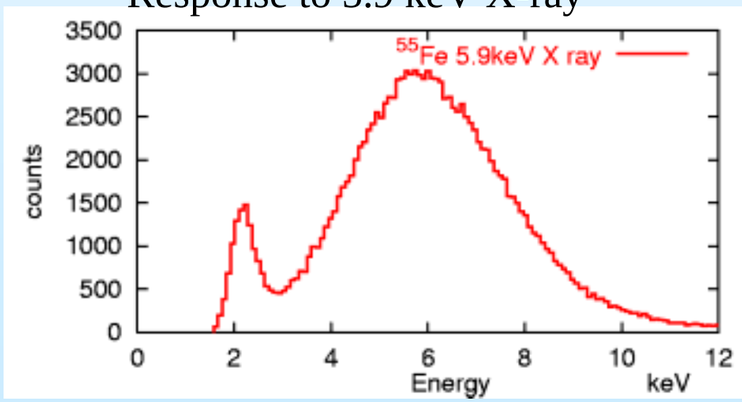
Anisotropy for Carbon Recoils

We measured the angle/energy dependence of the scintillation efficience of carbon recoils in a stilbene crystal using neutrons in energies of 30 keV to 1MeV. H. Sekiya *et al.*, PLB 571(2003) 132

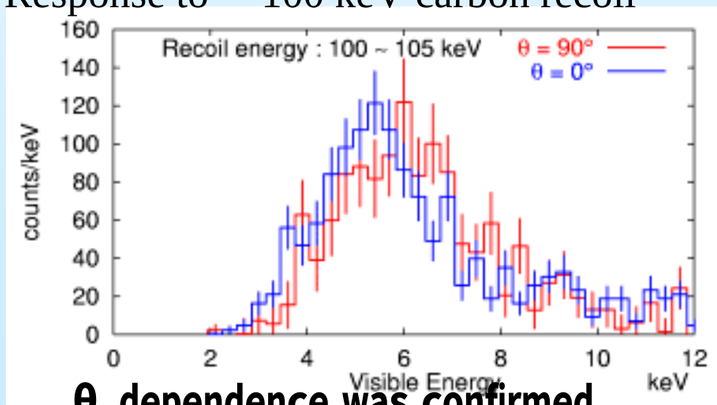




Response to 5.9 keV X-ray

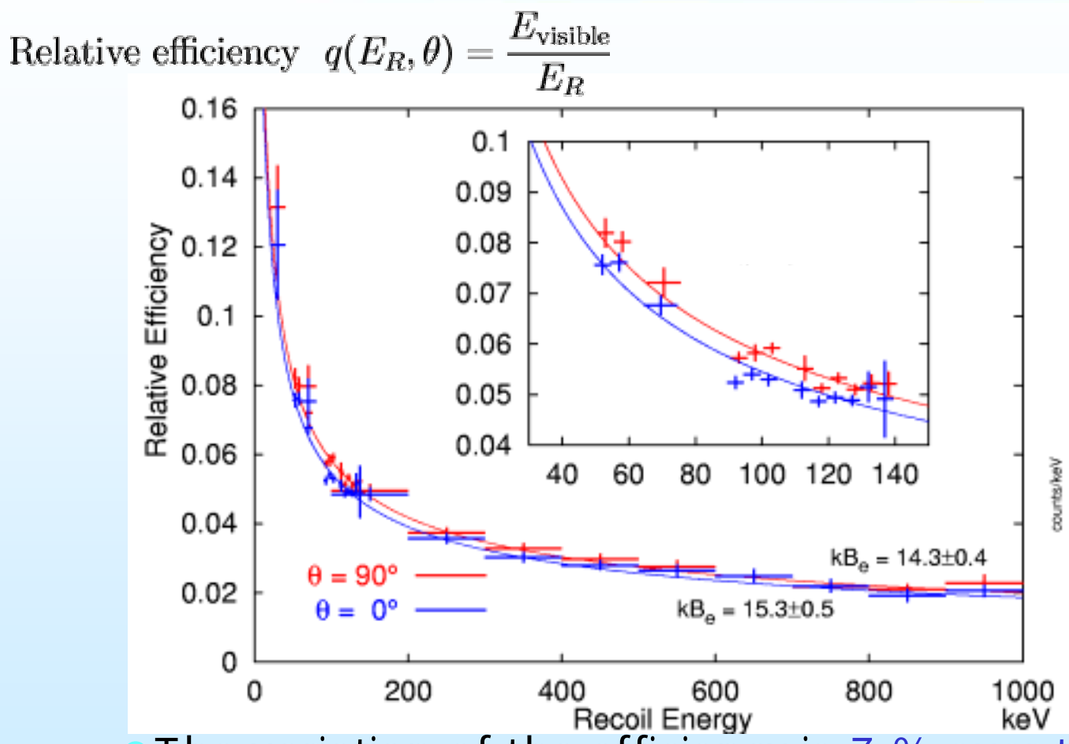


Response to ～100 keV carbon recoil

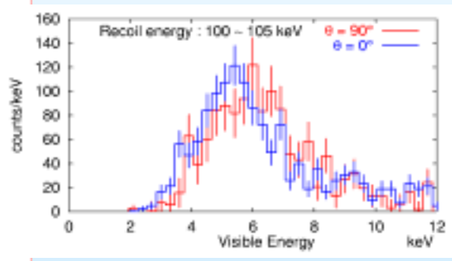


θ dependence was confirmed.

Anisotropy for Carbon Recoils



Relative efficiency $q(E_R, \theta) = \frac{E_{\text{visible}}}{E_R}$

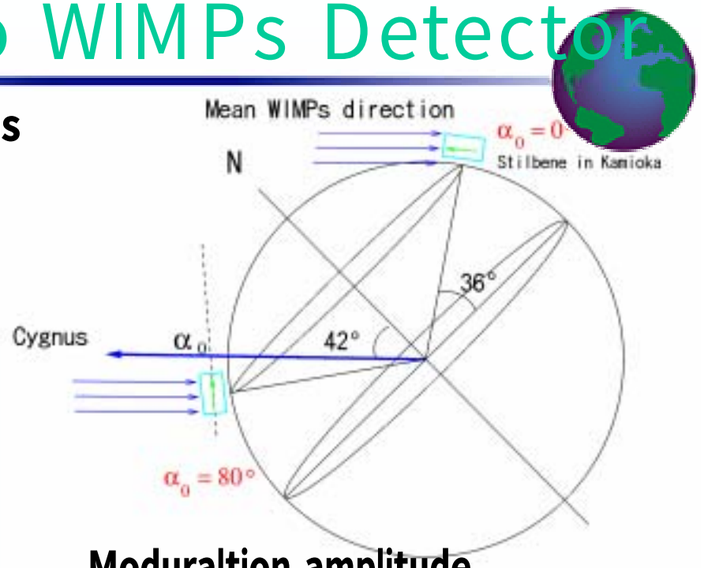


- The variation of the efficiency is 7 % over the measured energy region.
- Only 7%, however, the WIMP wind is strong enough!

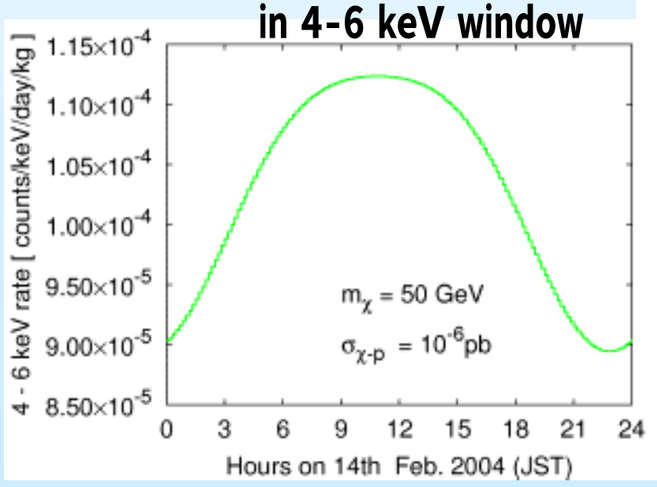
Application to WIMPs Detector

- **The earth moves toward Cygnus (42 ° to the earth's axis)**
- **Kamioka 36 ° N**

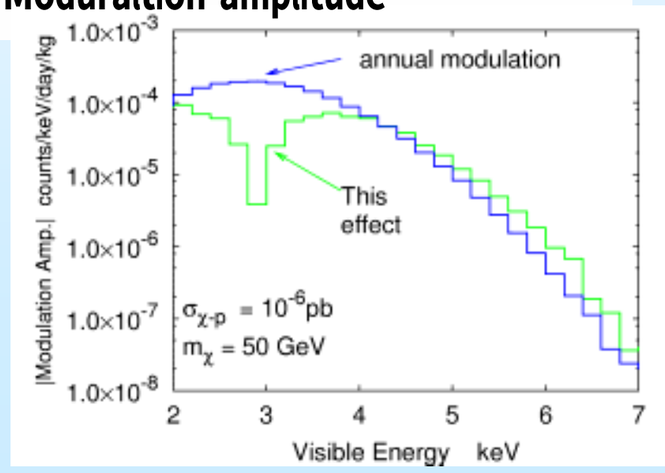
If we install the crystal with the c' axis towards the North, WIMP incident angle changes 80 ° over 12 sidereal hours



Expected moduraltion of today in 4-6 keV window

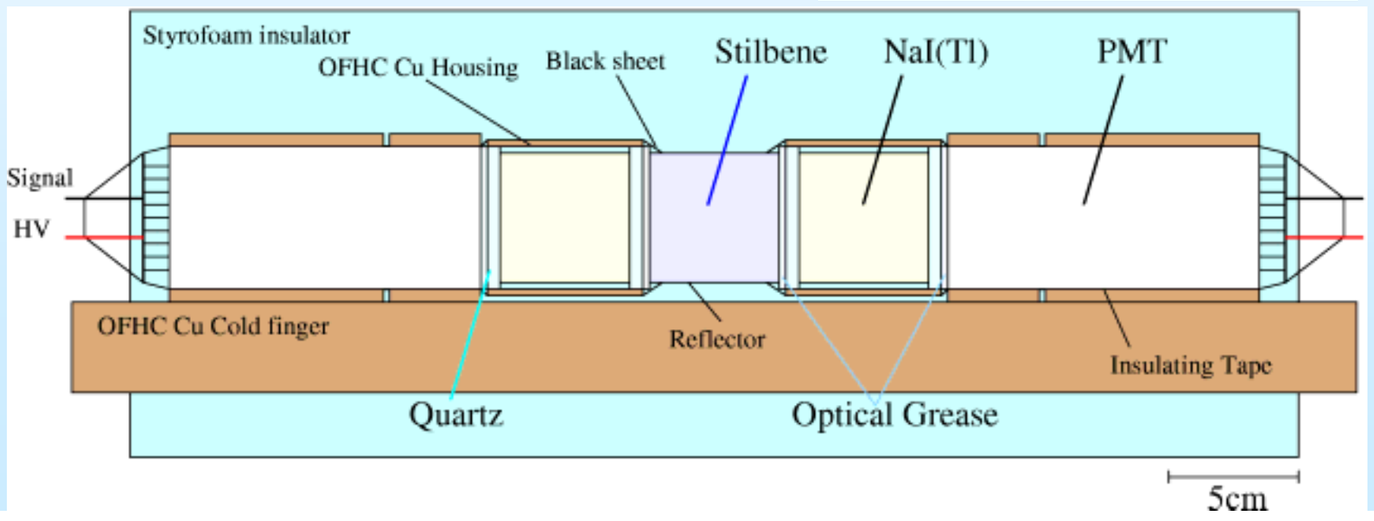


Moduraltion amplitude

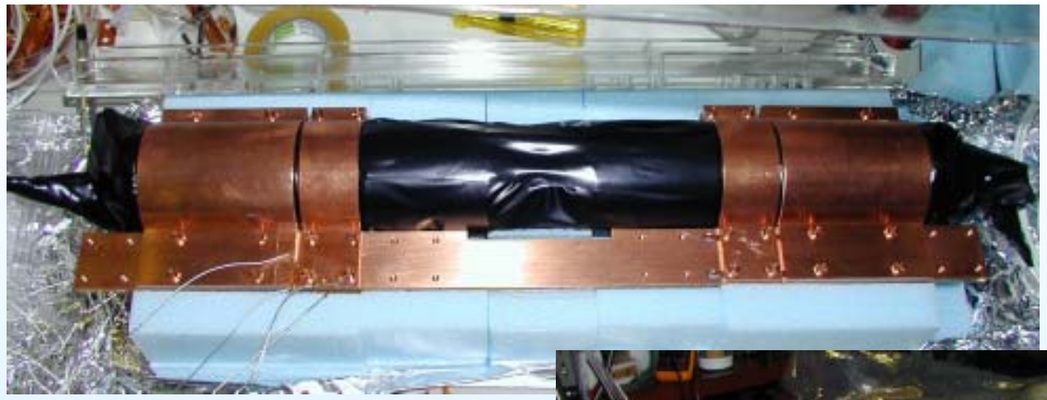


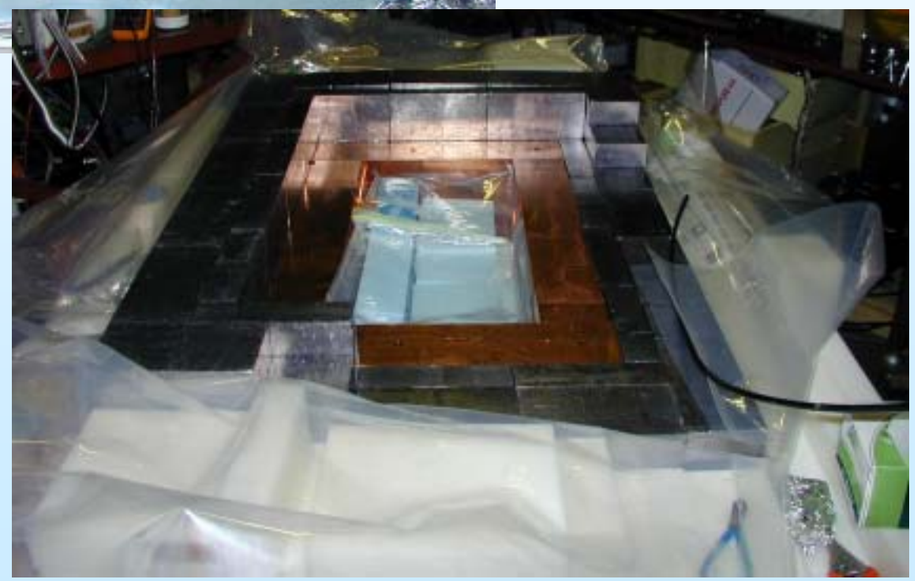
Pilot Measurement in Kamioka

- 116g stilbene crystal
- 2 low BG PMT read out
  (Hamamatsu R8778MOD)
- PMTs cool down -7℃
  by Peltier coolers
- 2 low BG NaI(Tl) active shields
  (Horiba, Ltd.)



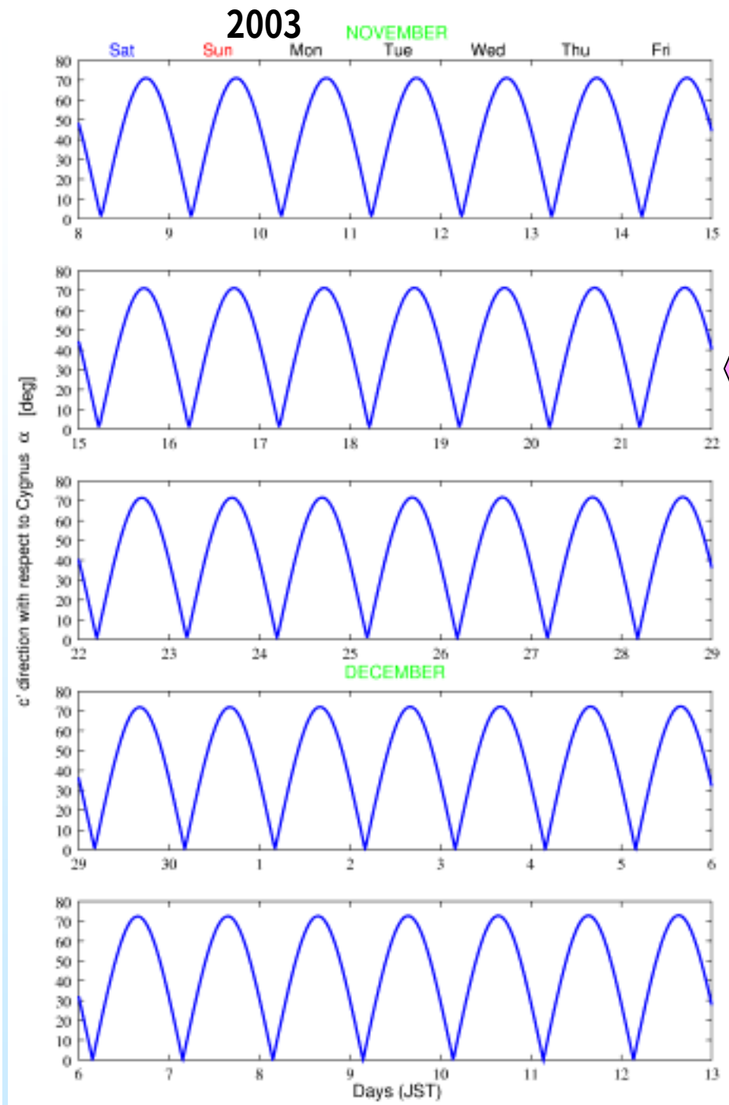
Pilot Measurement at Kamioka





OFHC Copper 10cm
Lead 15cm
Polyethylene 20cm

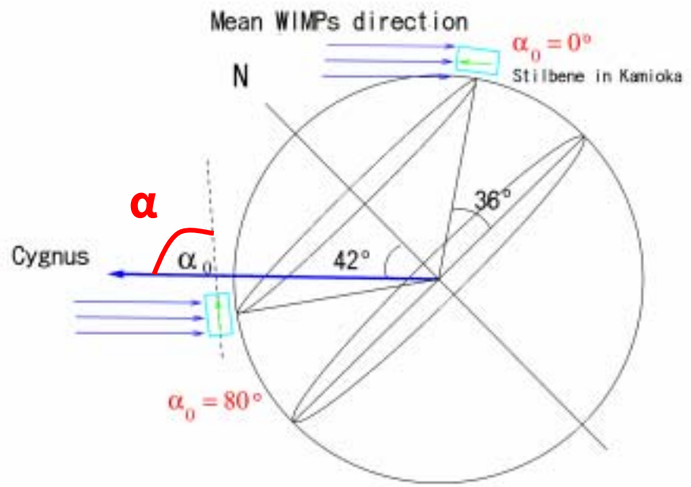
N_2 gas for Rn purge

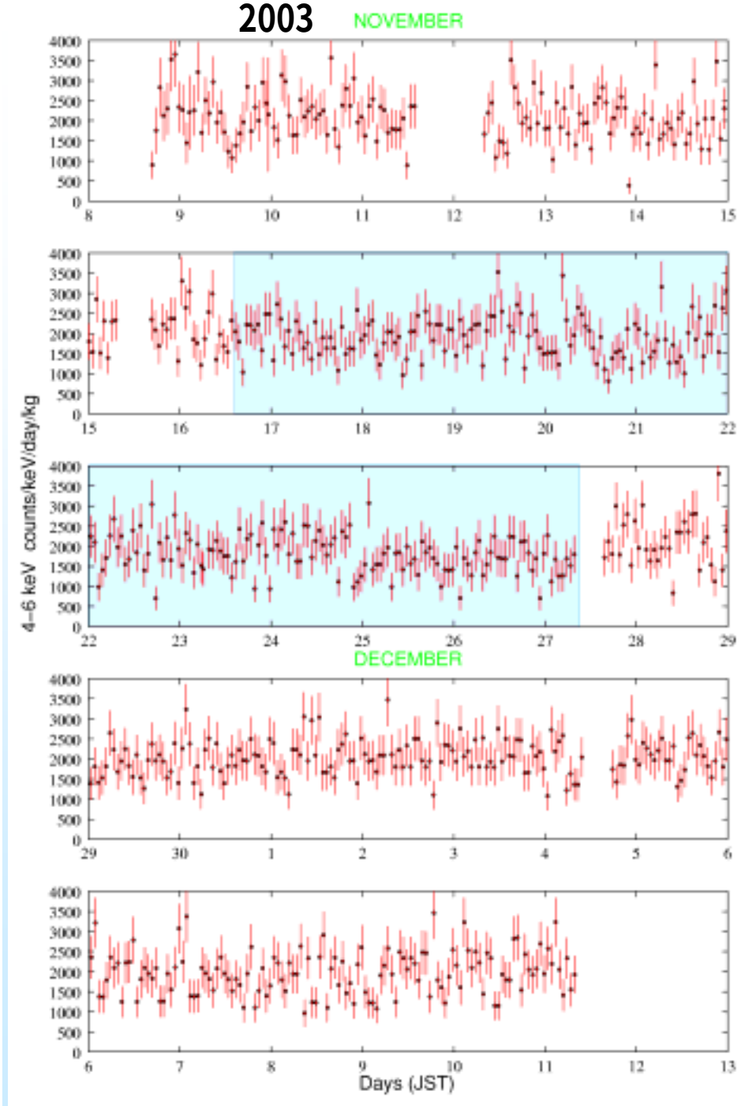


Direction of the Wind

- **November 8 2003 to December 11 2003**

Variation of the angle between the direction of c' axis and the direction of the earth's motion



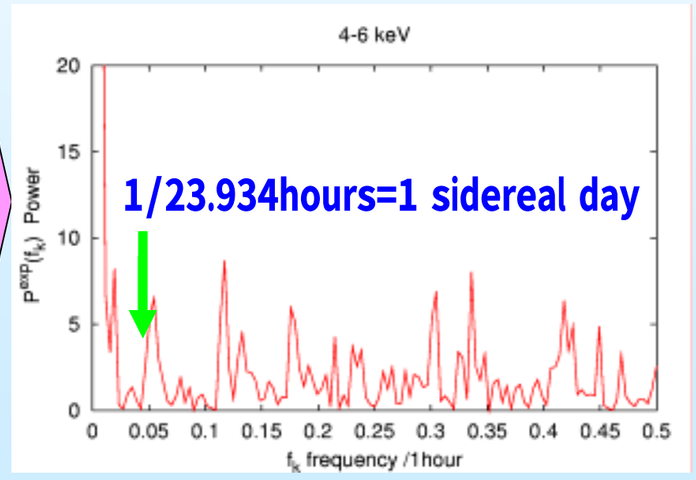


Measured Count Rates

The count rate for 4-6 keV
of every one hour.

2000 counts/keV/day/kg
in 4-6 keV energy window

Fourier transformation



→ white background noise

Current Issues

1. Rather high background events

- Radio isotopes in PMT

Ge spectrometry

U-chain	Th-chain	^{40}K	^{60}Co
1.8×10^{-2}Bq	6.9×10^{-3}Bq	1.4×10^{-1}Bq	5.5×10^{-3}Bq

- Although NaI(Tl) worked effectively, highly radio-pure device is needed in principle.
  (Special material-selected PMT or avalanche photo diode...)

2. Stilbene itself.

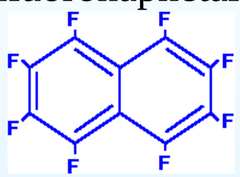
$$\sigma^{SI}_{\chi-p} \propto A^2$$

- Organic material contains only proton or ^{12}C.
- Anisotropy is limited to 7%.

Future Prospects

- Spin dependently interacting WIMPs serch with fluorine loaded organic crystals.

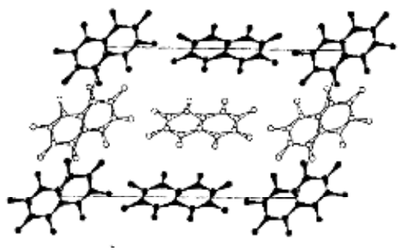
Octafluoronaphetalene



$C_{10}F_8$

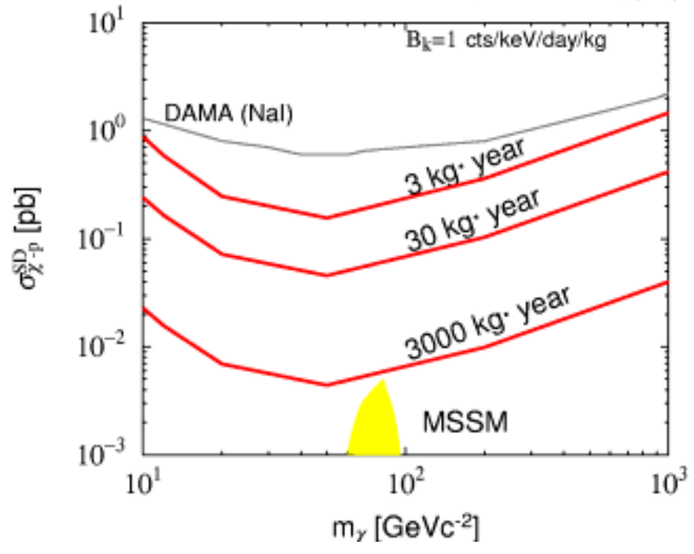
$$\sigma^{SD}_{\chi-p} \propto \lambda J(J+1)$$

- M.P. = 87 ℃
- λ max= 350 nm



Expected Sensitivity with $C_{10}F_8$

crystalline powder



Summary

- We focused on anisotropic scintillation detector with organic single crystals for dark matter search.

- The response of carbon recoils in a stilbene crystal in interested energy region was measured and the sensitivity to WIMPs was investigated.

- We have performed pilot measurements in Kamioka Underground laboratory, which presents a new method of dark matter search and the start point of the developments.

- We proposed new target (octafluoronaphetalene) for SD interacting dark matter.

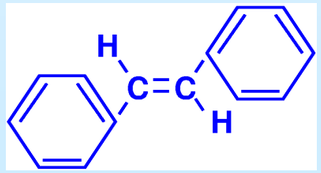
Organic single crystals

- Scintillation efficiency depends on direction of nuclear recoils with respect to crystallographic axes.
- The possibility of anthracene crystals as a WIMP detector was investigated by DAMA.

P. Belli *et.al.* Nuovo Ciment C 15(1992)475

- We focus on the stilbene crystals.
  - 70% light outputs of anthracene.
  - Self-absorption in stilbene is less than that in anthracene
  - Good transparent crystals can be grown because of its melting point (124°C).

→ Stilbene has an advantage in realizing large single crystal



trans-stilbene

- Light yield : 30% of NaI
- λmax : 410 nm
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Stilbene Scintillator

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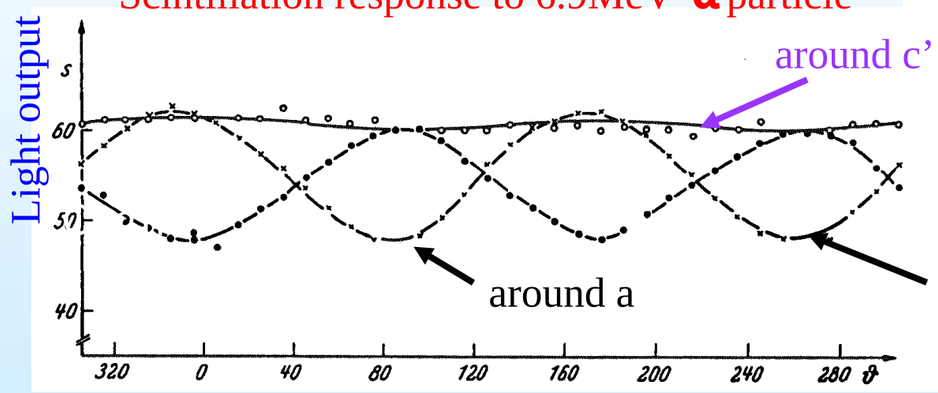
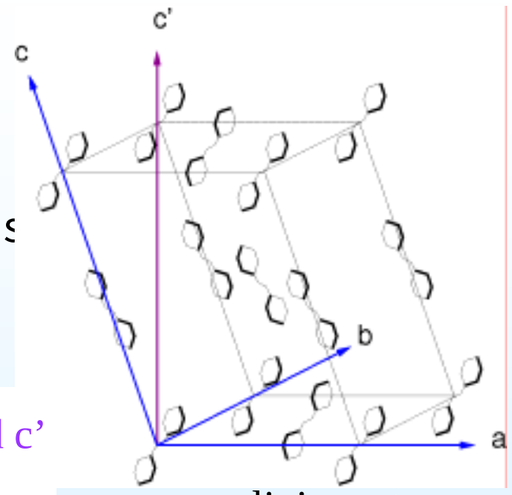
- In high energy regions, the response was precisely measured.

P. Heckmann *et al.*, Z. Phys 162(1961) 84

Scintillation response to 6.9MeV α particle





monoclinic system

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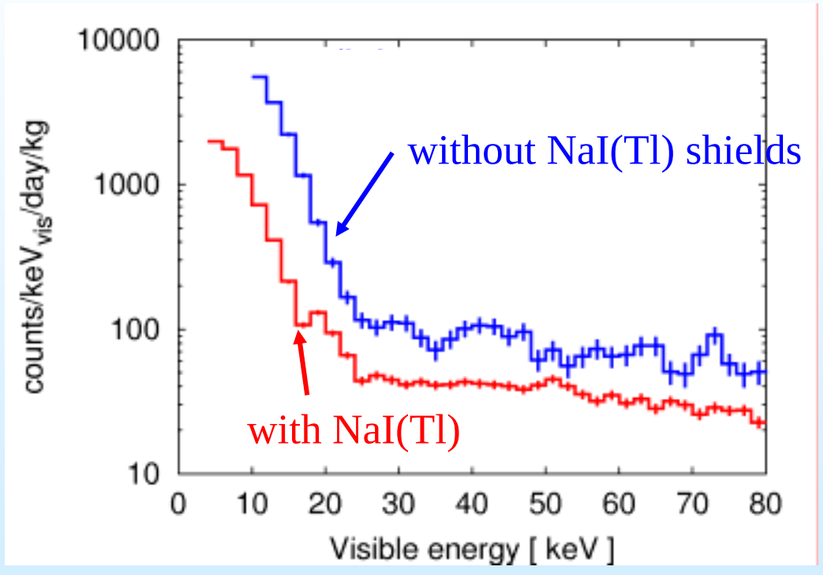
Obtained Visible Energy Spectra

- Total exposure 0.29 kg days without NaI(Tl) shields
  2.58 kg days with NaI(Tl) shields



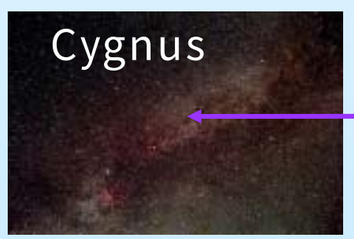
2000 counts/keV/day/kg
in 4-6 keV energy window

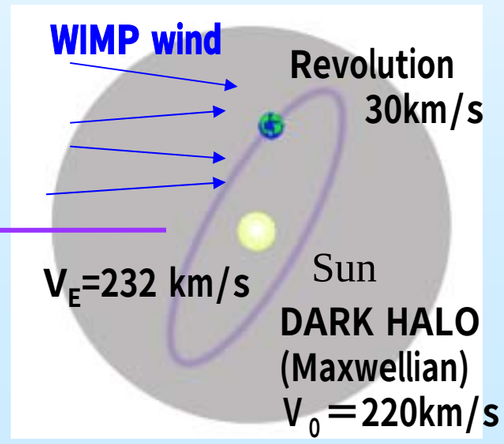
- It is clear that the backgrounds originate from the PMTs are dominat.

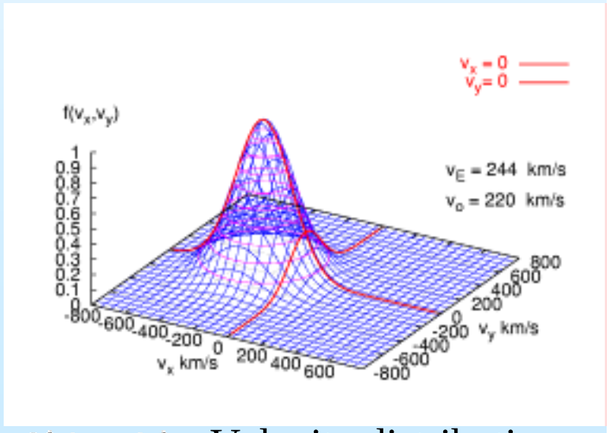
Motivation

How to distinguish WIMPs from BGs?

- Realistic distinctive WIMP signals arise from the earth's motion in the galactic halo.
- The annual modulation of event rate is one of the possible WIMP signal caused by earth's revolution around the sun.
- The earth's rotation through the galaxy provides WIMP wind.
- Most convincing signature would be identified with recoil direction sensitive detector.

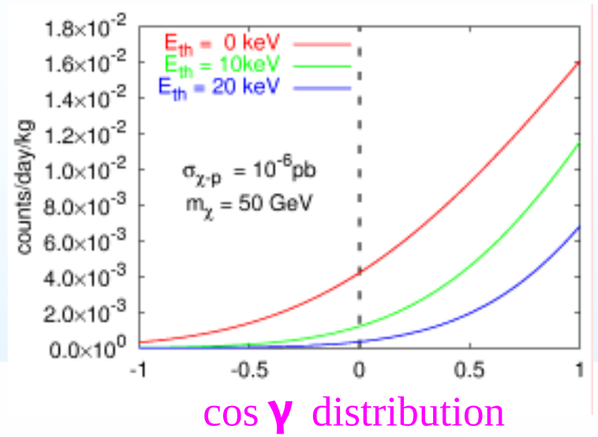




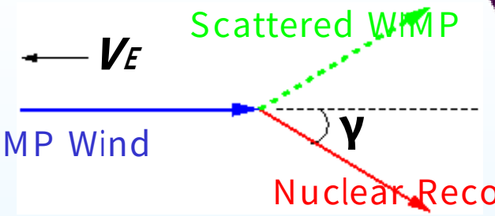


$f(\vec{v}+\vec{v}_{\mathrm{E}})$ Velocity distribution

Application to WIMPs Detector

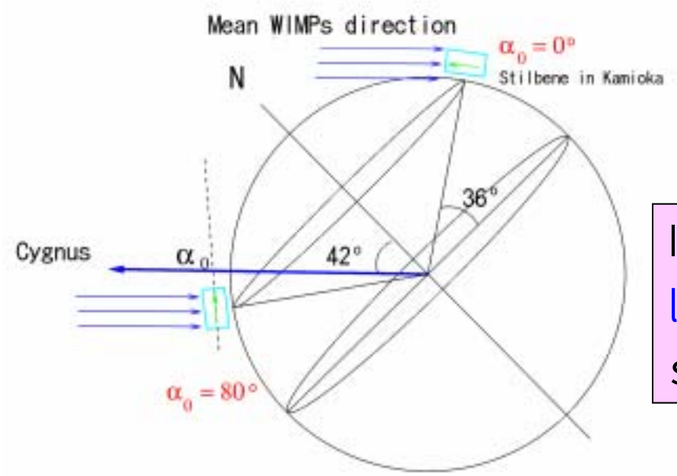


cos γ distribution



Light output should be

- **minumum at** c' // V_E
- **maximum at** c' ⊥ V_E



If the crystal is fixed to the earth, light outputs spectra would modulate synchronized to the earth's rotation