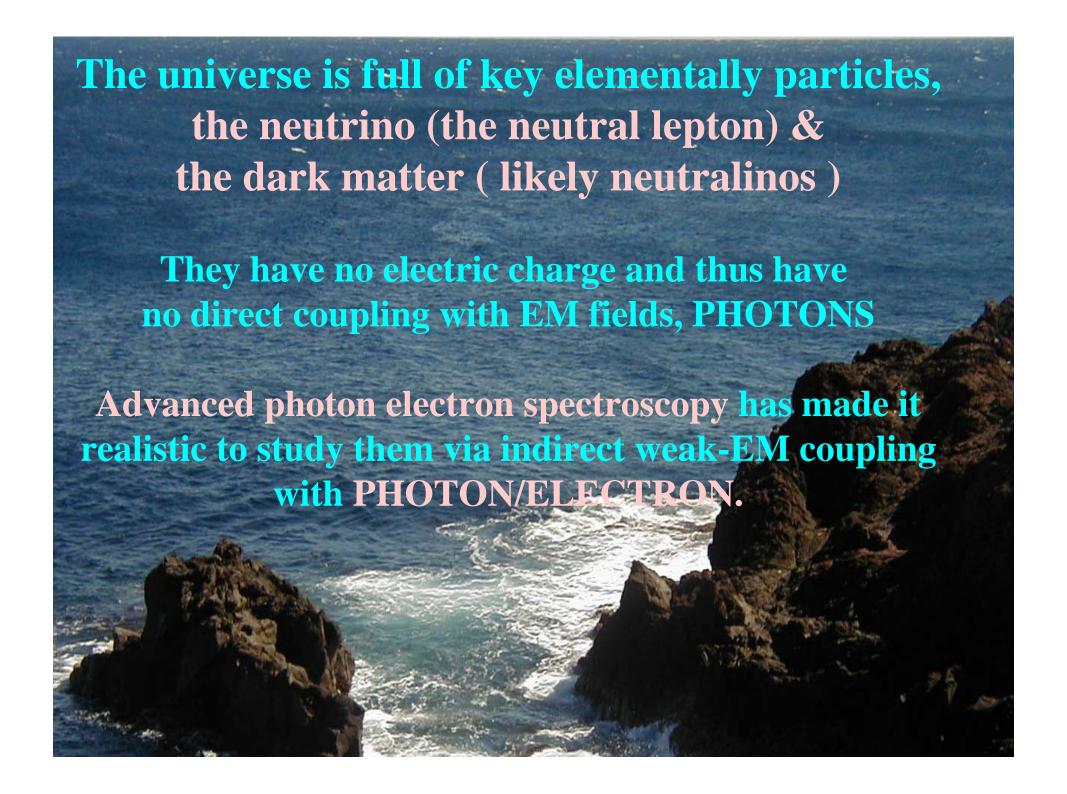
# Photon electron spectroscopy for neutrinos and dark matter

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RCNP Osaka and CTU Praha

**APSE2010 17-6** 

A view from the Ejiri's weekend house



### **Bohr and Mottelson (1975 Nobel prize)**

Nucleons and strong force play major roles in nuclei.  $\beta$ - $\gamma$  (photons -electrons) and EM force play crucial roles in nuclear studies.

I started nuclear particle physics by photon electron spectroscopy in 1958 in Univ. Tokyo, and then enjoyed them at many nice labs. in US, Europe, RCNP, KEK, recently, at Spring 8, and now studing  $\nu$  & DM by photons and electrons (present talk).

(3-terms RCNP director till 1999, now ~100% physics

In 2003, YS1 on Neutrinos and DM symposium, and in 2010, YS4 on photons symposium APSE2010.

- 1. Introduction: Photon and electron spectroscopy for neutrinos γ and DM neutralinos χ.
- 2. Photon electron spectroscopy for astro v's
- 3. Double beta/electron photon spectroscopy for y properties and y masses
- 4. Nuclear v process studies by photo-nuclear processes
- 5. Nuclear recoils ionization/scintillation and photon(X-γ ray) spectroscopy for dark matter χ
- 6. Concluding remarks and perspectives



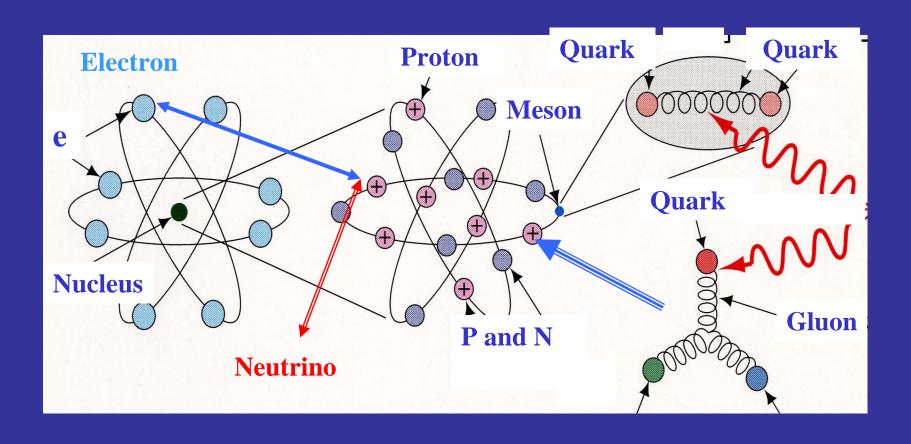
A view from the weekend house

### **Constituent elementary particles**

Atom 10<sup>-8</sup> cm

Nucleus 10<sup>-12</sup> cm

Nucleon and meson 10<sup>-13</sup> cm



## SM: Elementary particles & fundamental interactions



- 3 sets of quarks, ud, cs, tb
- 3 sets of leptons  $v_e$  e,  $v_\mu \mu$ ,  $v_\tau \tau$
- 3 fundamental interactions bosons of Higgs Boson. Strong (gluon), EM(photon), weak(W,Z boson), where EM and weak forces are unified in SU(2)U(1).

#### Fundamental questions on SM.

- 1. Neutrinos, which are electrons without EM charge, Neutrinos ≠ or = ? anti-neutrinos, masses?, mixing?.
- 2. Neutralinos, super symmetric partners of photon, Z, H, Exist?, masses?, dark matter?

### Neutrinos v and neutralinos x

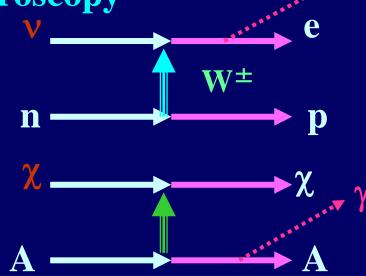
**KEY** particles for particle and cosmology beyond SM Neutral particles, NO EM photon coupling

They are weakly interacting particles flying through the earth and the universe, hardly caught (detected).

Study of v,  $\chi$  by photon spectroscopy

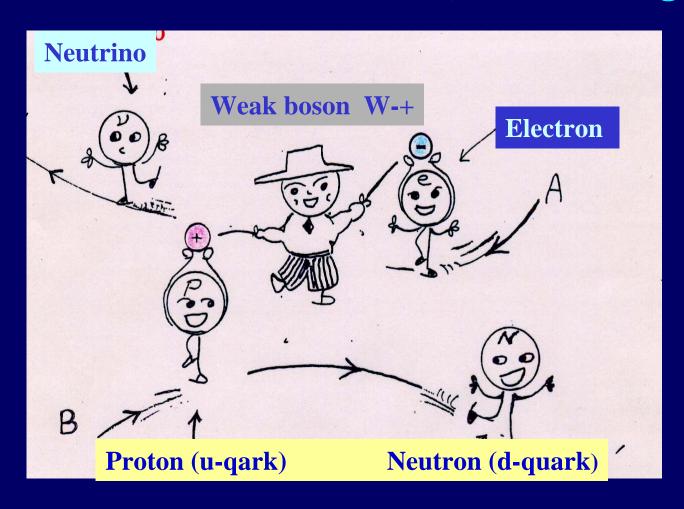
1. v—e conversion by charge exchange weak interaction

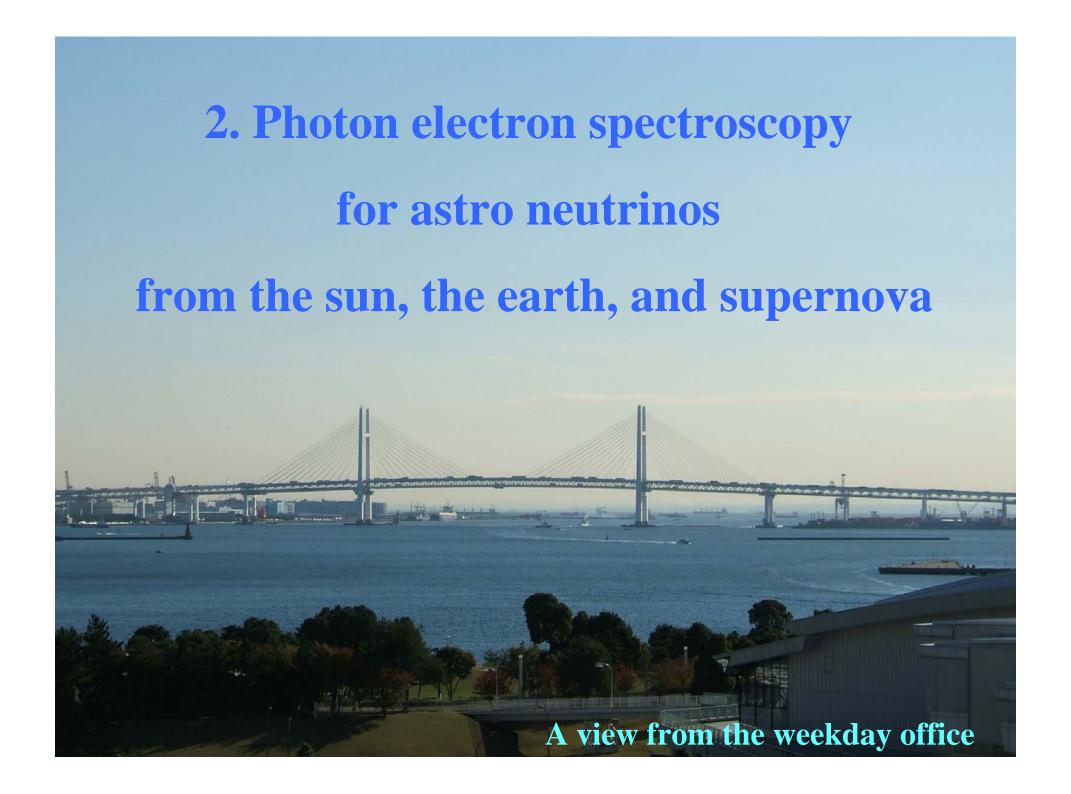
2. ν–e, χ-N(+) scattering by neutral "weak" interaction



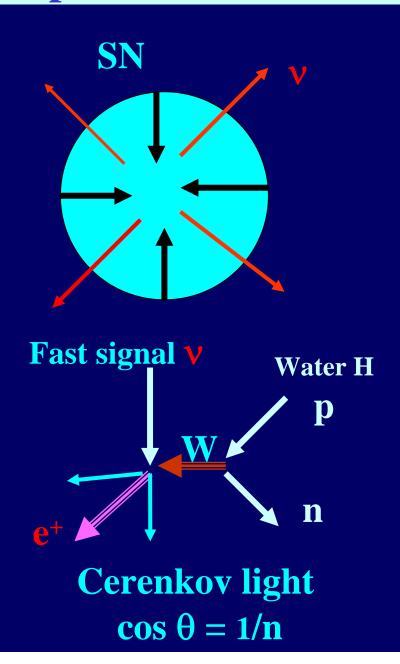
### Neutrinos and weak process via weak boson.

Weak boson mass ~ 100 proton mass ,  $\lambda_c/2\pi$  ~  $10^{-16}$ cm. Weak force ~  $10^{-3}$  of EM force,  $10^{-6}$  of strong force.





### Supernova neutrinos 1987 Koshiba, IMB, Baksan

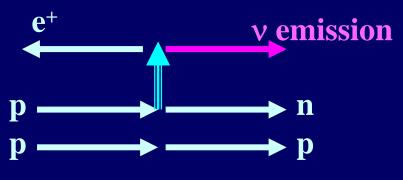


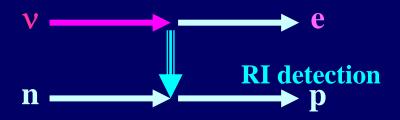


SK water Cerenkov detector 22K t

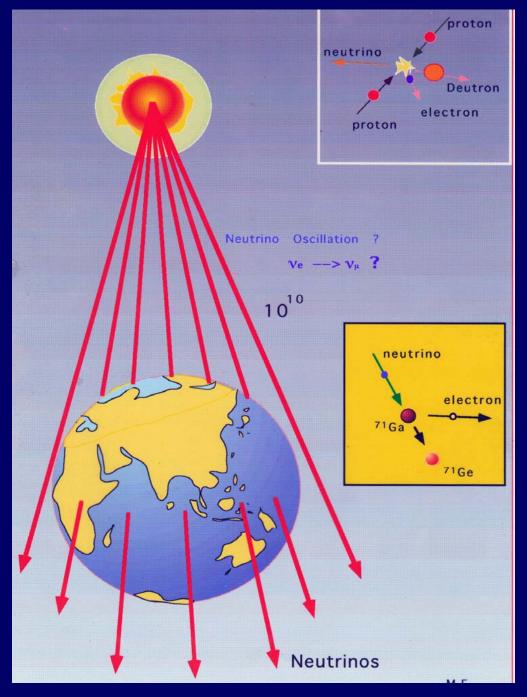
# **Solar neutrinos** 60 bilions /cm<sup>2</sup> s

In the sun

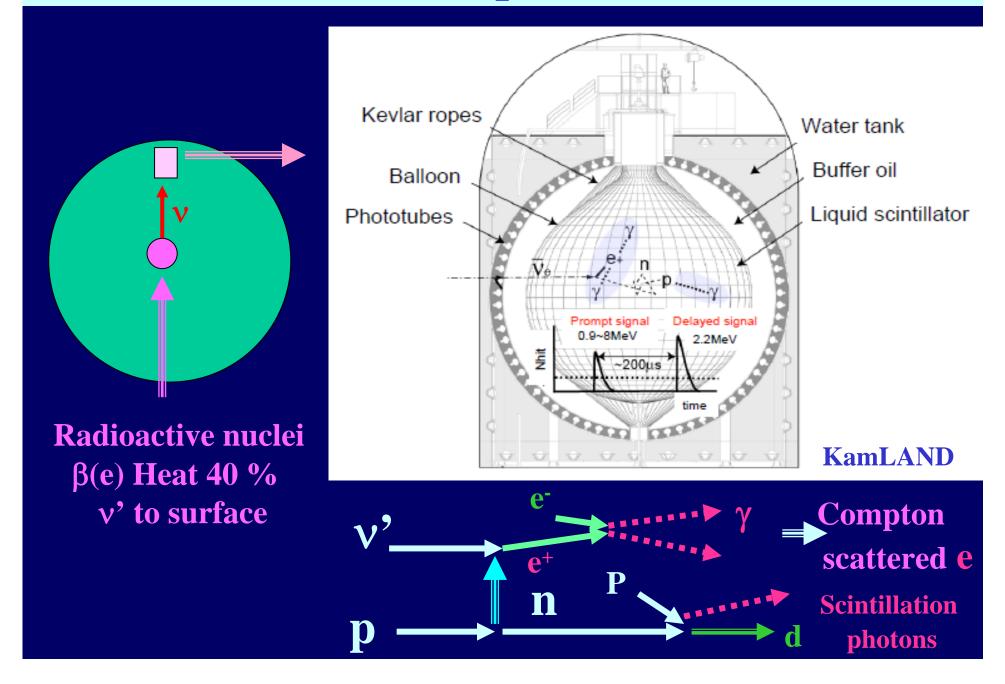




On the earth
v: the fast signal from the core
Homestake, SK, Gran Sasso

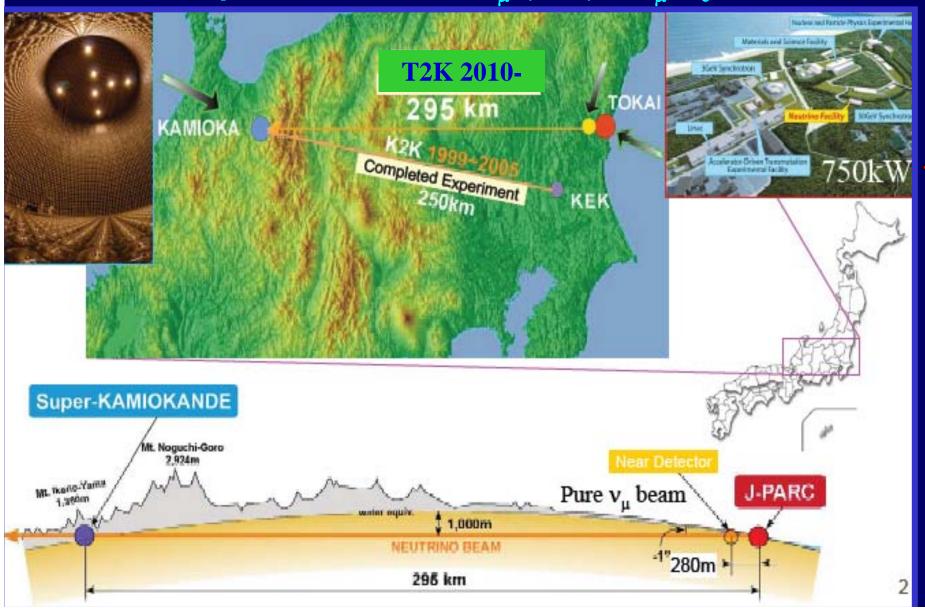


### 3. Geo-neutrinos to explore the earth interior.



#### 4. Accelerator neutrinos for v-oscillation

$$\label{eq:power_problem} p \,+\, X \,=\, n \,\,\pi \quad \pi \,=\! \nu_{\mu} \!\!+\! \mu \qquad \mu = \nu_{\mu} \!\!+\! \nu_{e} \,+\! e$$



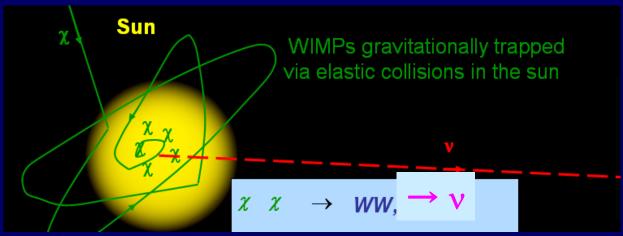
### **Neutrino Telescope**

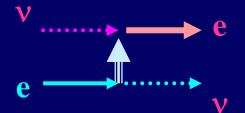
Mediterranean deep sea ANTARES, NEMO, NESTOR Hawaii DUMAND Lake Baikal South pole AMANDA IceCub

**Galactic neutrinos** 

Neutralino (DM) annihilation







 $E > TeV \ 10^{12} \ eV,$   $\theta < 0.5 \ deg.$  to identify  $\nu$  direction

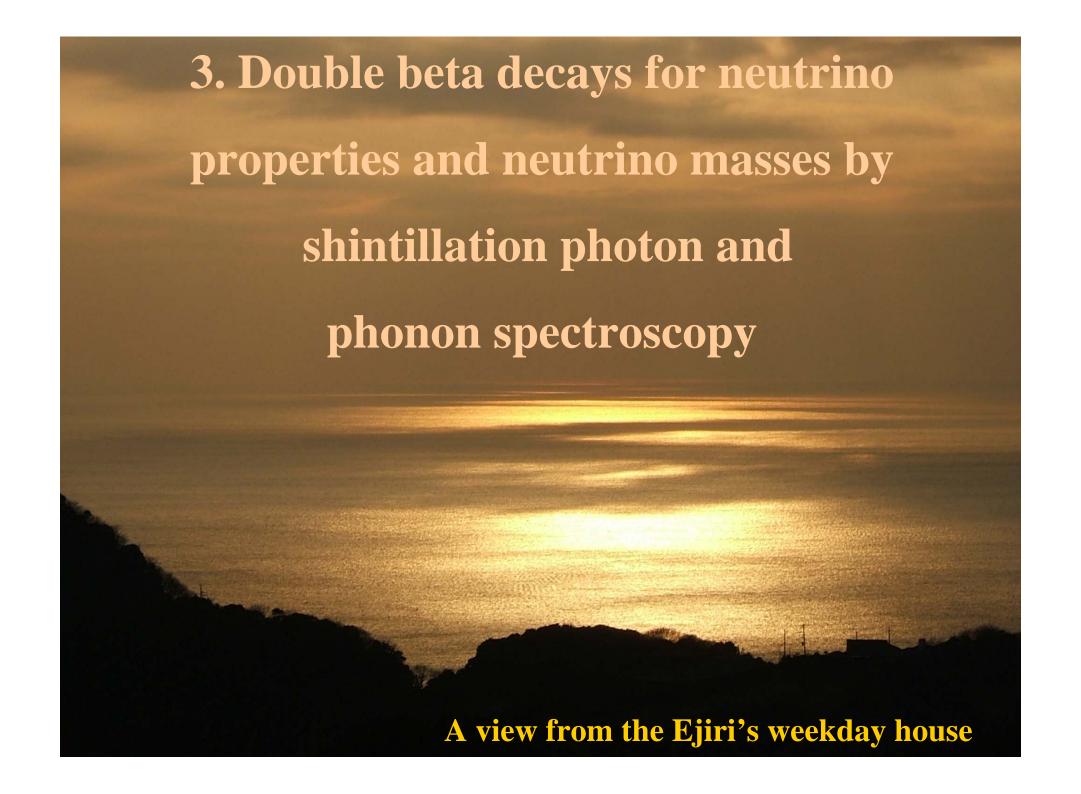




String-based PMT sat downward 45° at 2500 m deep



12 strings,  $0.35 \times 0.3 \times 0.3 \times 0.3 \times 0.3 \times 0.3$  Antarese Web, Site



### Fundamental questions on neutrinos

### **Neutrinos: leptons with no EM charge**

1. Neutrinos ≠ or = anti-neutrinos Dieac or Majorana particle.



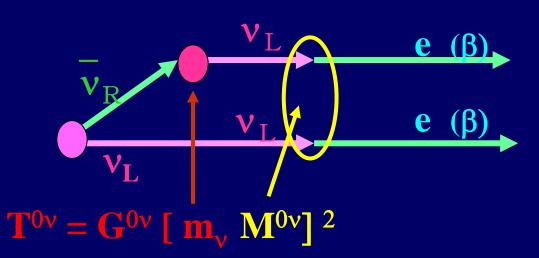


2. Absolute mass scale,  $m < 2 \text{ eV} = 4 \text{ m}_e/10^6$ 

$$\mathbf{O}\mathbf{V}\mathbf{\beta}\mathbf{\beta}$$
  $\mathbf{A} = \mathbf{B} + \mathbf{\beta} + \mathbf{\beta}$ 

Double weak (v-e) Extremely rare

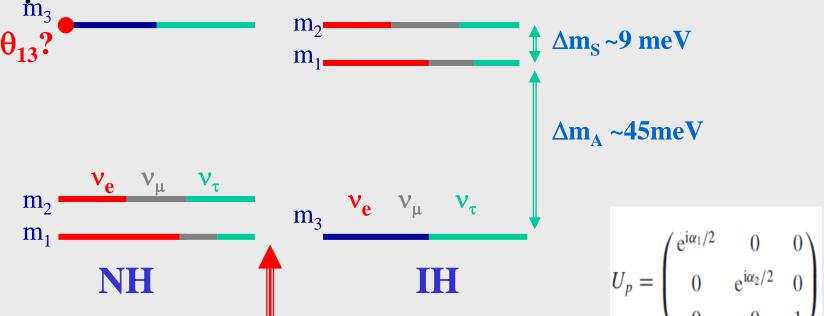
$$T < 10^{-25}/y$$



#### v matrix and masses

$$\begin{pmatrix} \nu_{e} \\ \nu_{\mu} \\ \nu_{\tau} \end{pmatrix} = \begin{pmatrix} C_{12}C_{13} & C_{13}S_{12} & S_{13}e^{-i\delta} \\ -S_{12}C_{23} - C_{12}S_{23}S_{13}e^{i\delta} & C_{12}C_{23} - S_{12}S_{23}S_{13}e^{i\delta} & S_{23}C_{13} \\ S_{12}S_{23} - C_{12}C_{23}S_{13}e^{i\delta} & -C_{12}S_{23} - S_{12}C_{23}S_{13}e^{i\delta} & C_{23}C_{13} \end{pmatrix} U_{p} \begin{pmatrix} \nu_{1} \\ \nu_{2} \\ \nu_{3} \end{pmatrix}$$

$$\dot{\mathbf{m}}_{3}$$

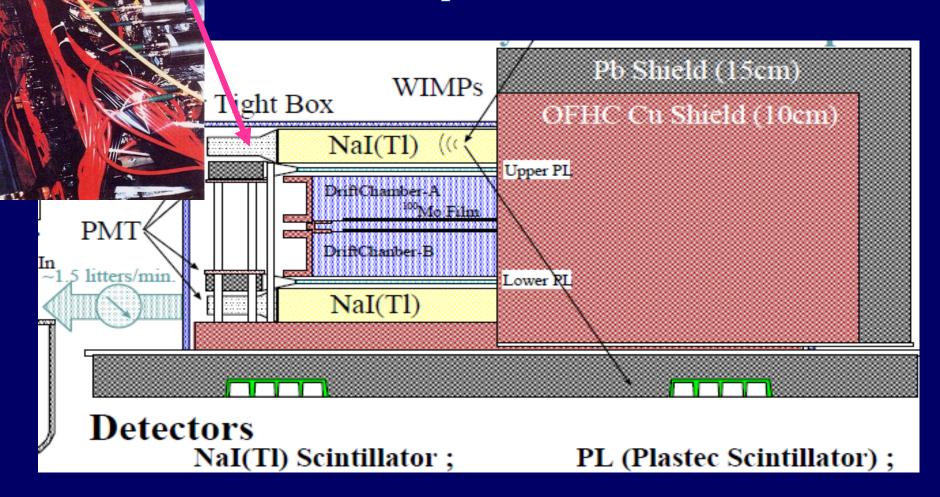


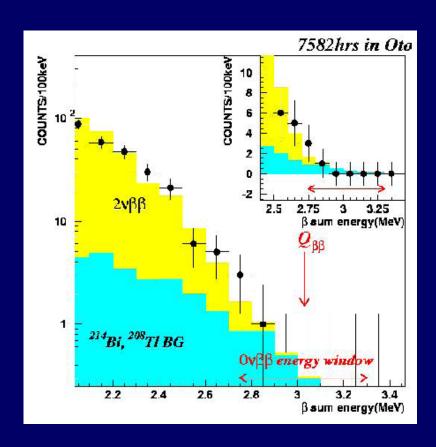
**Absolute mass scale** 

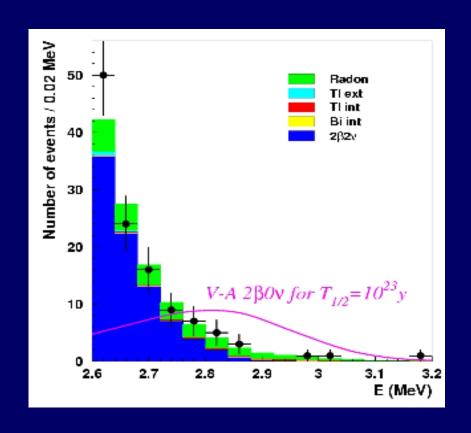
 $< m_{\nu}> = |\Sigma U_i|^2 \exp(i \phi_i) m_i|$   $\phi_i = \alpha_2 - \alpha_1$ ,  $\phi_i = \alpha_2 - 2\delta$  is given by using  $U_i \Delta m_S$ ,  $\Delta m_A$  given by  $\nu$  oscillations

## ELEGANT Ejiri 1986-2001 ELEctron Gamma-ray Neutrino Telescope

Signal/BG  $\sim 10^8 - 1$  by measuring v-electrons and photons associated with electrons





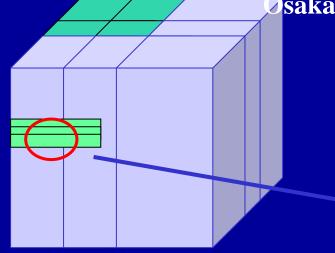


 $T^{0\nu} > 1.0 \ 10^{23} y \; ,$   $< 2 \ eV \ 4 \ m_e / 10^6 \ 1995-2001, \ H.Ejiri, \ et \ al.,$ 

 $T > 5.8 \times 10^{23} \text{ y}$ <  $(0.8 - 1.3) \text{ eV } 2 \text{ m}_e/10^6$ 2009 NEMO

### MOON (Majorana/Mo Observatory Of Neutrinos)

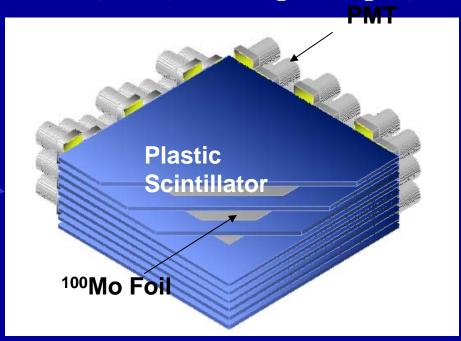
saka, JINR(Titov), LNR, NC. Prague(Finger), UW

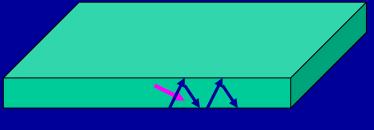


Challenge to  $m_e/10^7$ Ton's sample, S/N ~  $1/10^{10}$ 

H. Ejiri, et al., PRL, 85, 2000. H. Ejiri EPJ 162 2008,

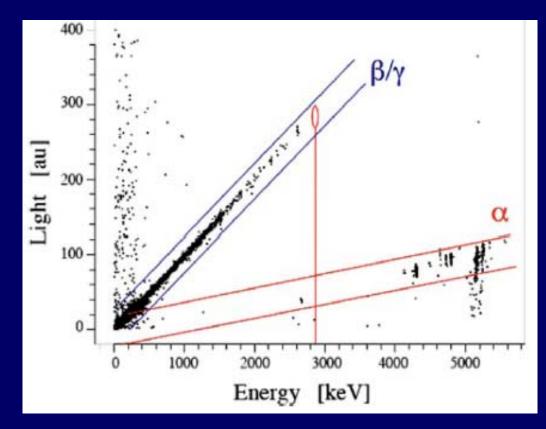
**PPNP 64 2010** 





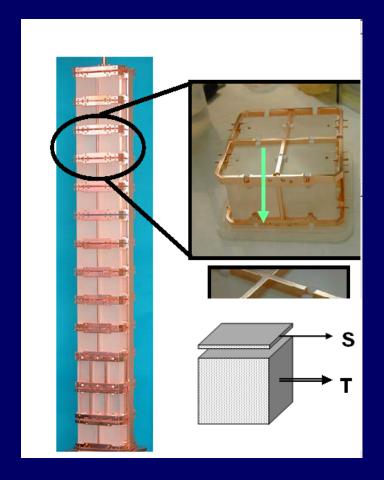
75% transmission, 25% photo-electron conversion, and 5500 photo-electrons  $\sigma \sim 2.2\%$  E resolution study

### Cryogenic scintillation-bolometer Fiorini Ejiri 2009



Gorla et al., Low Temp.Phys. 151 '08

Measure  $\beta\beta$  energy E by  $\Delta T$ : thermo sensor with  $\Delta E \sim 5$  keV Select  $\beta\beta$  signal against BG  $\alpha$  by scintillation photon signal

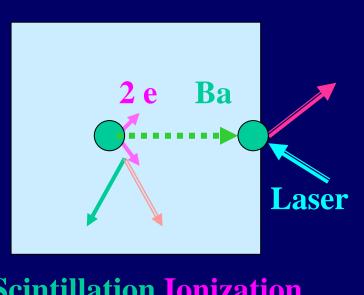


 $\Delta T = kE/C = kE/T^3$ 

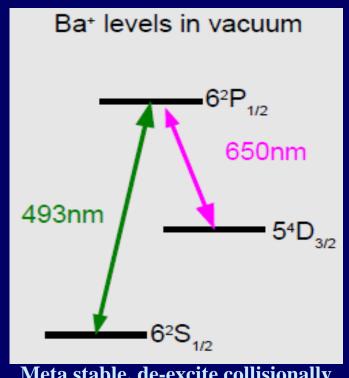
### EXO Enriched Xenon Observatory Moe PR C 44 '91 EXO2008

$$^{136}$$
Xe +(2v)  $\rightarrow ^{136}$ Ba + 2e

Among 2t 10<sup>28</sup> 136Xe atoms, 1 136Ba atom per month Signals; a few per year: 2e and <sup>136</sup>Ba atomic photons BG's  $10^8 \sim 10^9$  per year : 2 e from  $10^8 \beta$ ,  $\gamma$  BG's

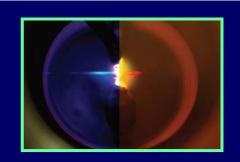


**Scintillation Ionization** 

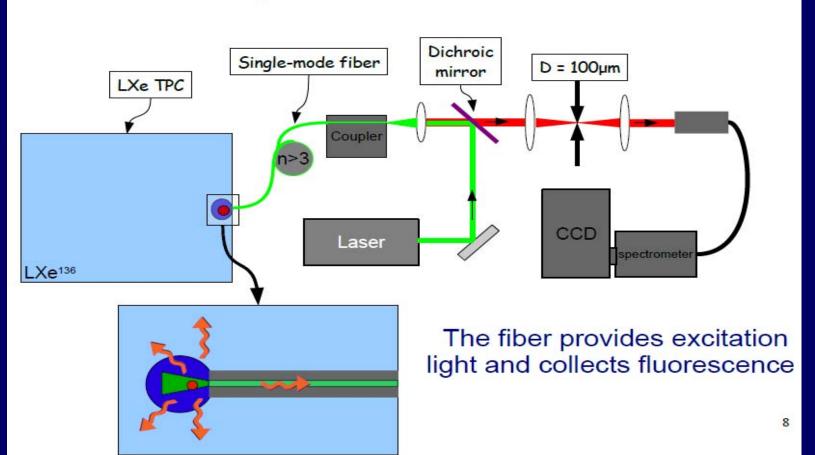


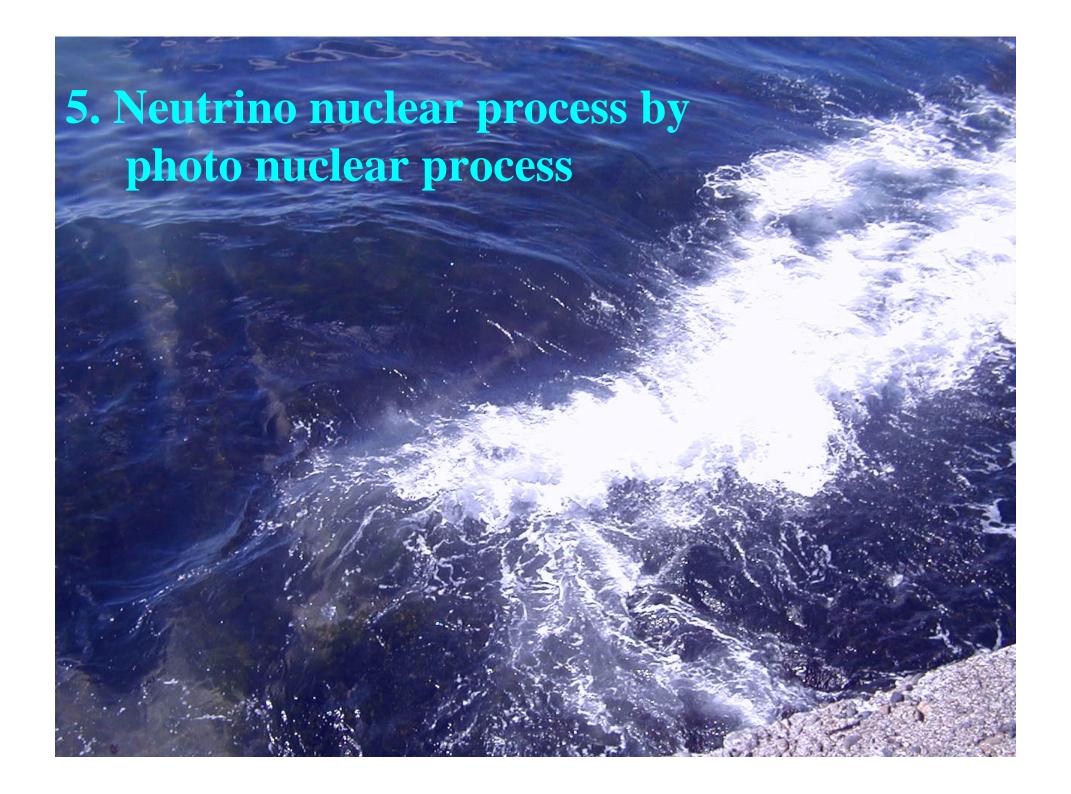
Meta stable, de-excite collisionally

# Single atom identification Excite with blue photons Look for red photons EXO 2008



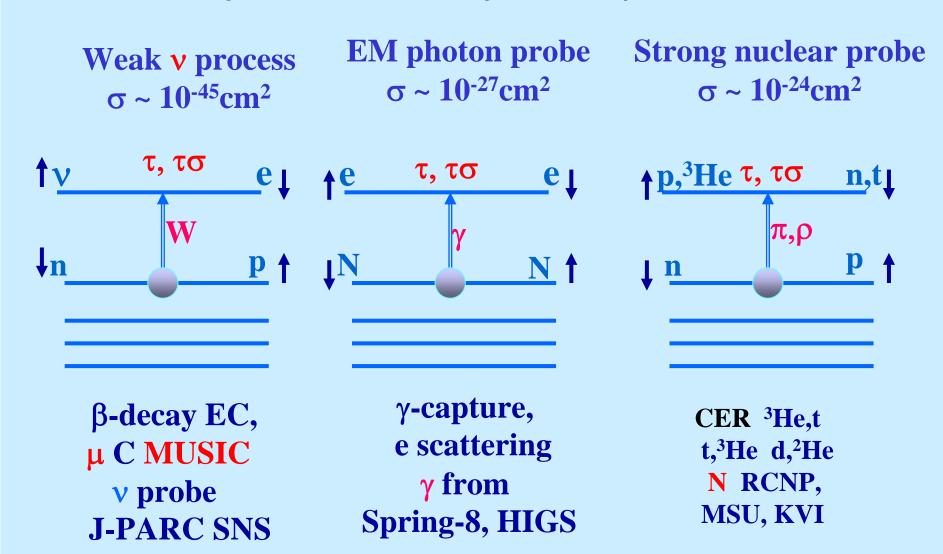




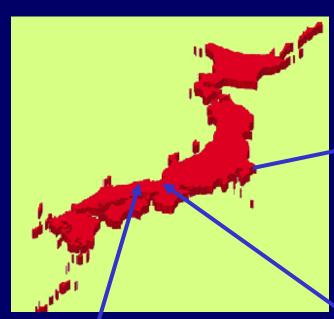


### Neutrino weak nuclear processes, which are extremely rare, are studied by EM photo-nuclear process

H. Ejiri, JPSJ 78 2009 H. Ejiri Euro Phys. J. 162 2008



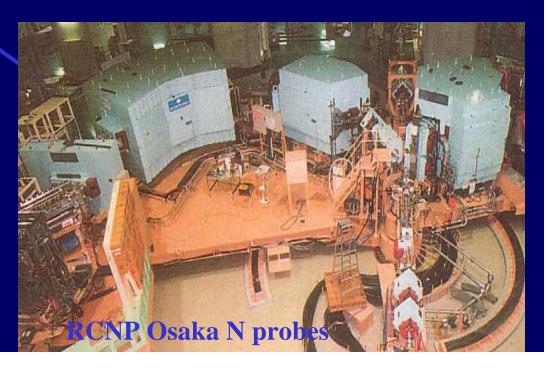
### Nuclear γ ν-μ probes for ν-responses





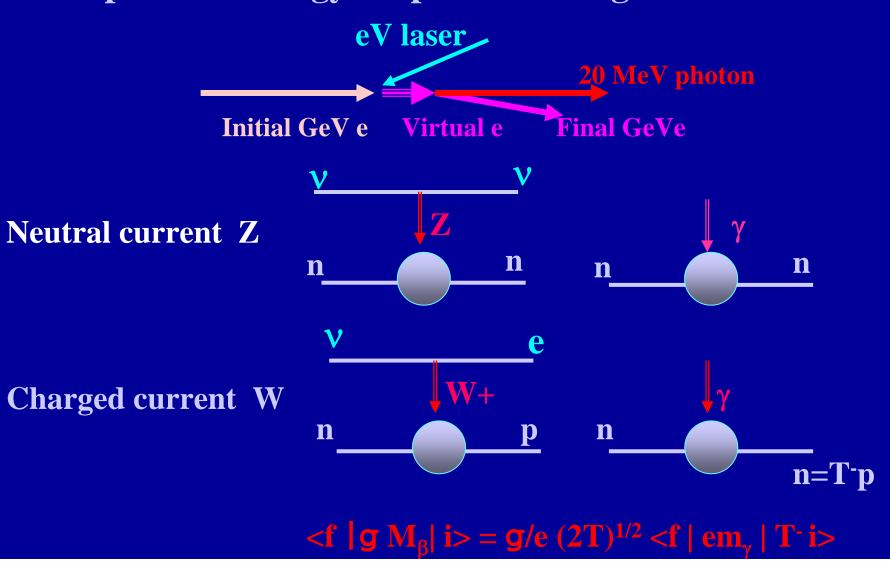


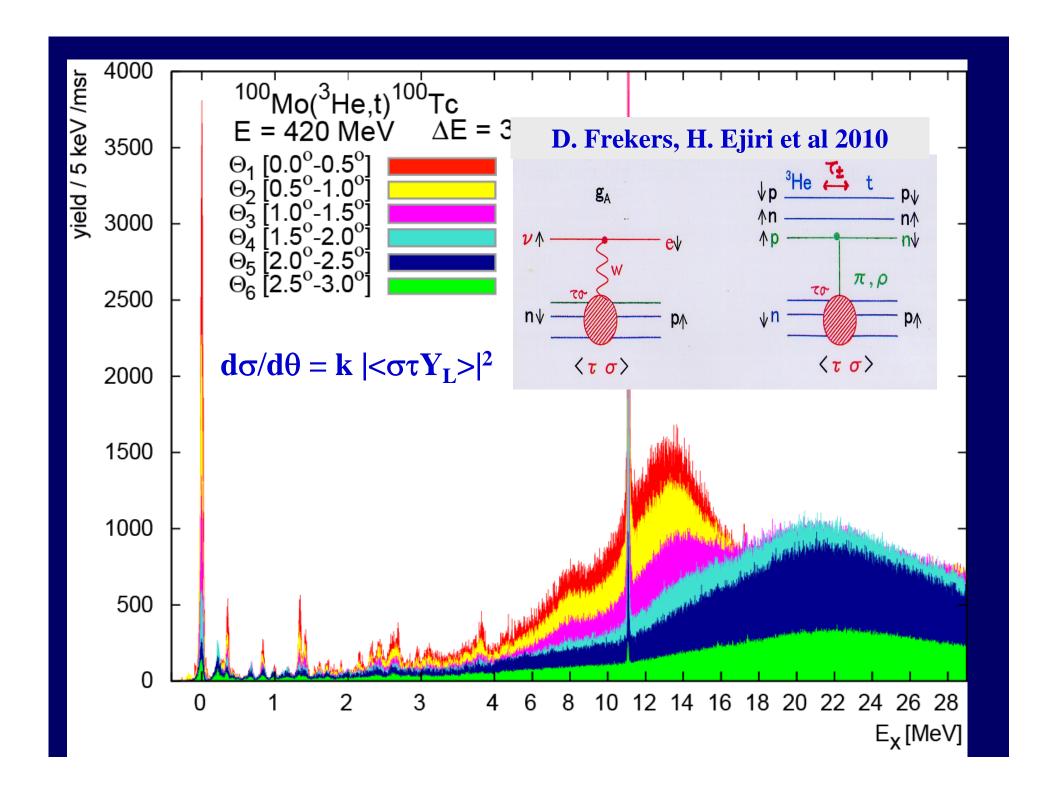
Spring-8 New SUBARU LEPS
Photon probes

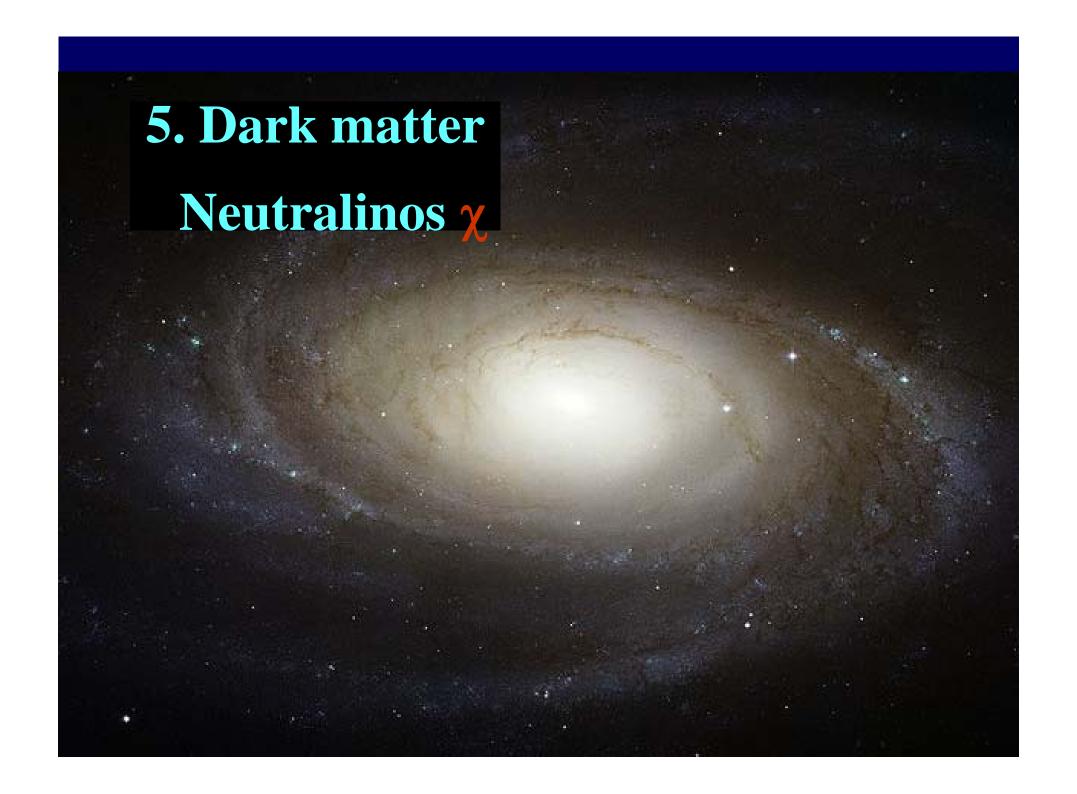


### Simulation of v-N process by photo nuclear process

Laser photons energy-amplified through GeV electron

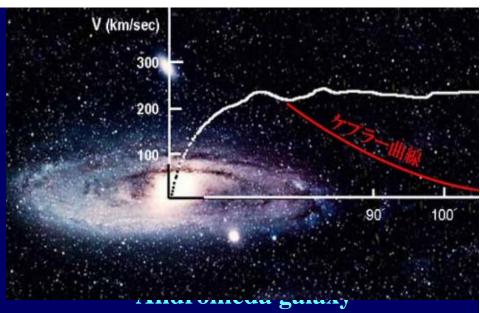






## Dark matter Universe Observation

Dark energy 70 % Photon 2.7 deg. Black Body 2-3 mm 1 meV 400/cc



velocity  $v \sim (M/r)^{1/2} = constant$ 

Proton/Barion/nuclei/star 5 %

Around us 0.3 GeV/cc

#### Dark matter

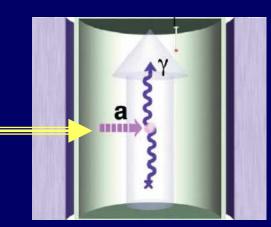
Invisible without EM charge to couple with photon Hot (fast) v's 300/cc: Too light to contribute to >1 %

Dark matter: Cold slow particle 24 %
Neutral, weakly interacting particles. Not found yet

### DM with no EM via indirect photon couplings

### **Axion**

m ~ 10<sup>-5</sup> eV, 1.5 GHz 20 cm EM photons =



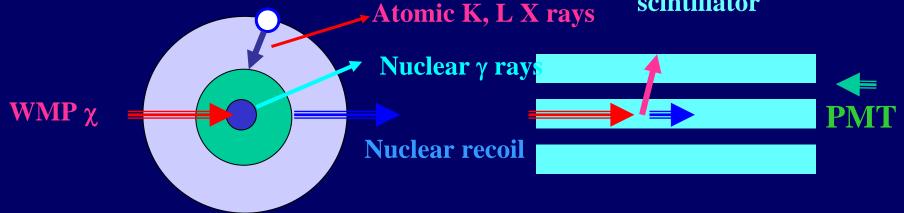
#### Neutralino

Super-symmetric SUSY particle Fermion with  $\frac{1}{2}$ , SUSY of photon, Z boson, Higgs

- $\chi$  in the universe : Annihilation in the sun,  $\gamma\gamma$ , ZZ, WW ... Study  $\nu$ ,  $\gamma$
- χ hits a nucleus with EM charge, ionization, and emitting photon X-γ rays, phonons, and ions.

### Neutralino-nuclear $\gamma$ X Ionization scintillation

Thin(~300mm) scintillator



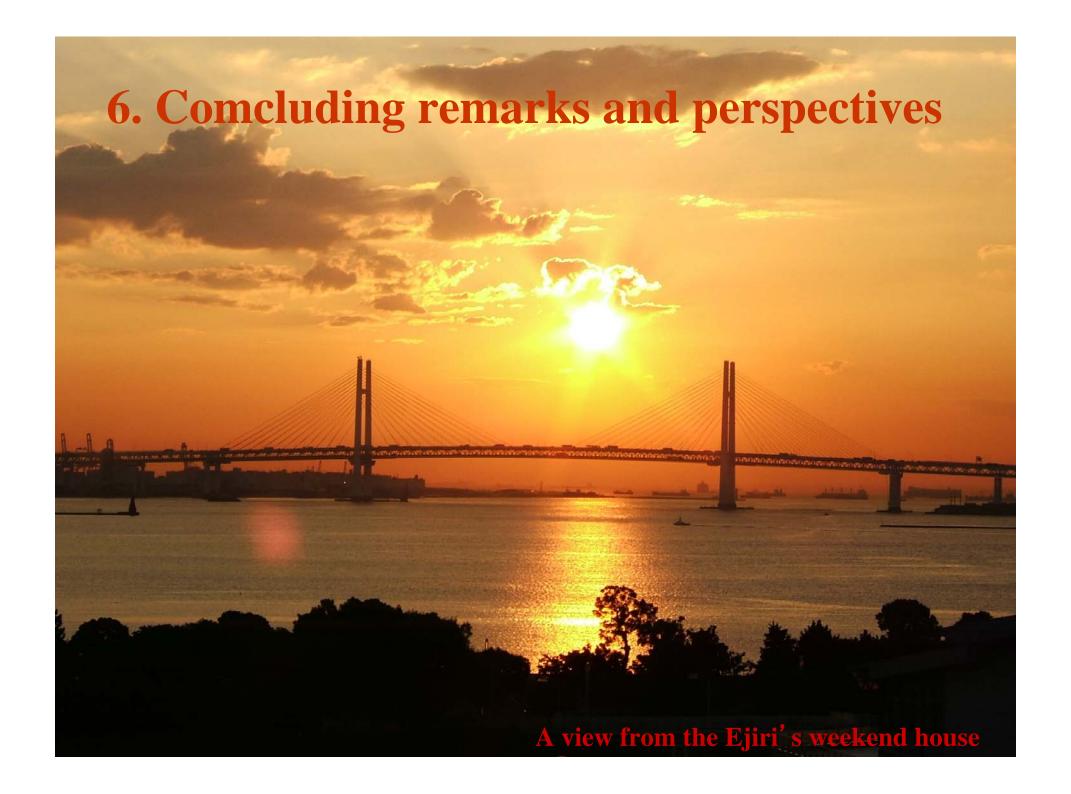
**Recoil nucleus** 

5 keV 20 shintillation photons

X ray 30 keV 600 scintillation photons

K X-ray	$E_K(K_{ij})$ keV	$\left[\frac{\sigma_K(K_{ij})}{\sigma_r}\right]_M$	$\left[\frac{\sigma_K(K_{ij})}{\sigma_r}\right]_H$
$K_{\alpha 2}$	29.5	0.0560	0.0645
$K_{\alpha 1}$	29.8	0.1036	0.1196
$K_{\beta 1}$	33.6	0.0303	0.0350
$K_{\beta 2}$	34.4	0.0067	0.0077

H. Ejiri, et al, Phys Lett. B. 639 (06), B317 (93)



- 1. Neutrinos and neutralinos are key elementary particles for the standard model (SM) and beyond SM.
- 2. They are neutral (NO EM charges) and no direct EMphoton coupling, so that they are transformed to EM charged particles (electrons, nuclei) via weak interaction to be studied by EM photon spectroscopy.
- 3. The weak interactions are so weak( $\sigma \sim 10^{-43} \text{cm}^2$ ) that the signal rates are so rare (a few /year /ton, S/N  $\sim 10^{-9}$ ).
- 4. Advanced photon spectroscopy of single atom/nucleus/photon counting and multi-type photon detections (scintillation photons, atomic photons (X-rays), nuclear photons ( $\gamma$ -rays), and others) have made  $\nu$  and  $\chi$  studies realistic by using ton's of samples at low-BG underground laboratories.

