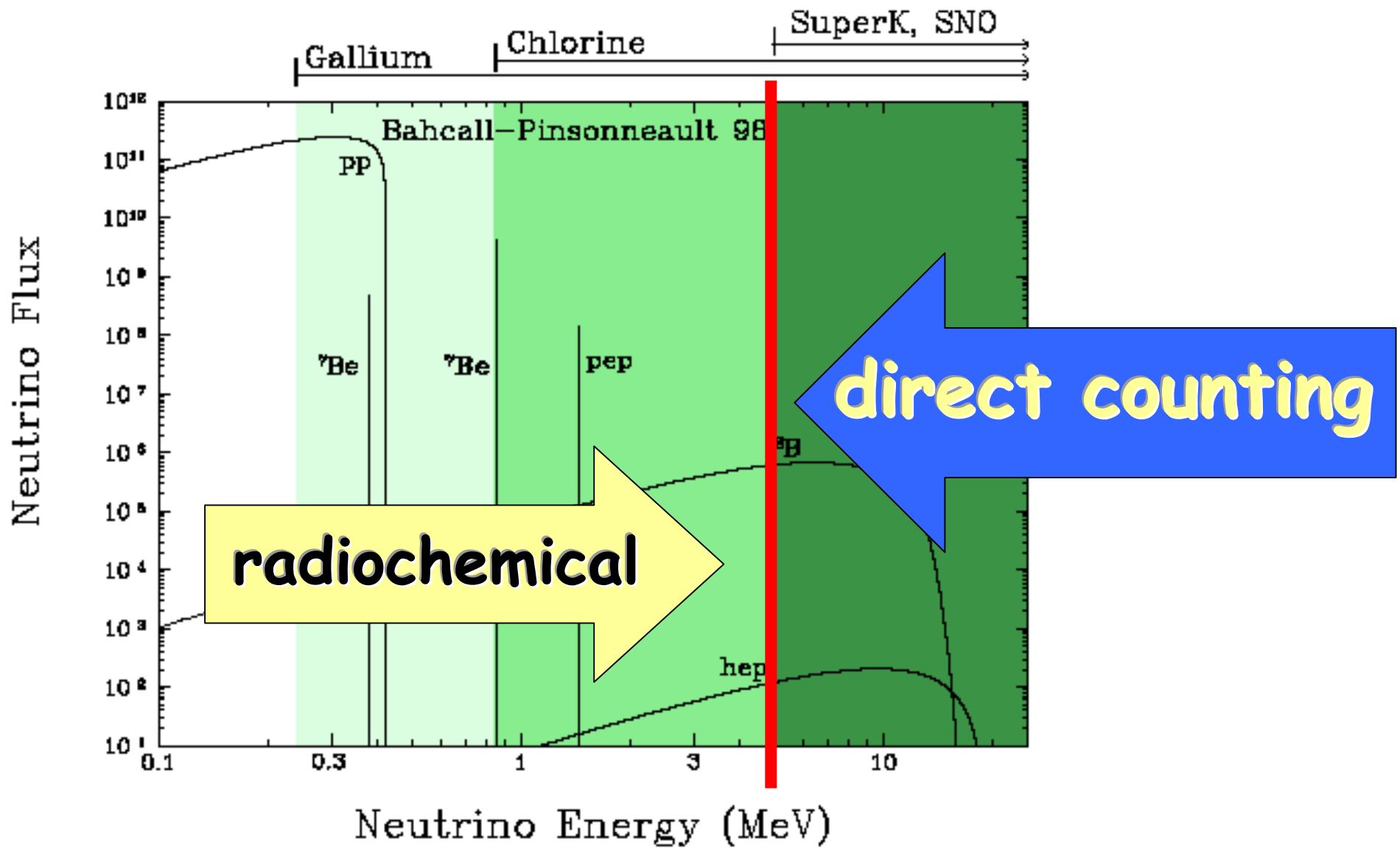


# **Low energy solar neutrinos detection with GSO crystal scintillators**

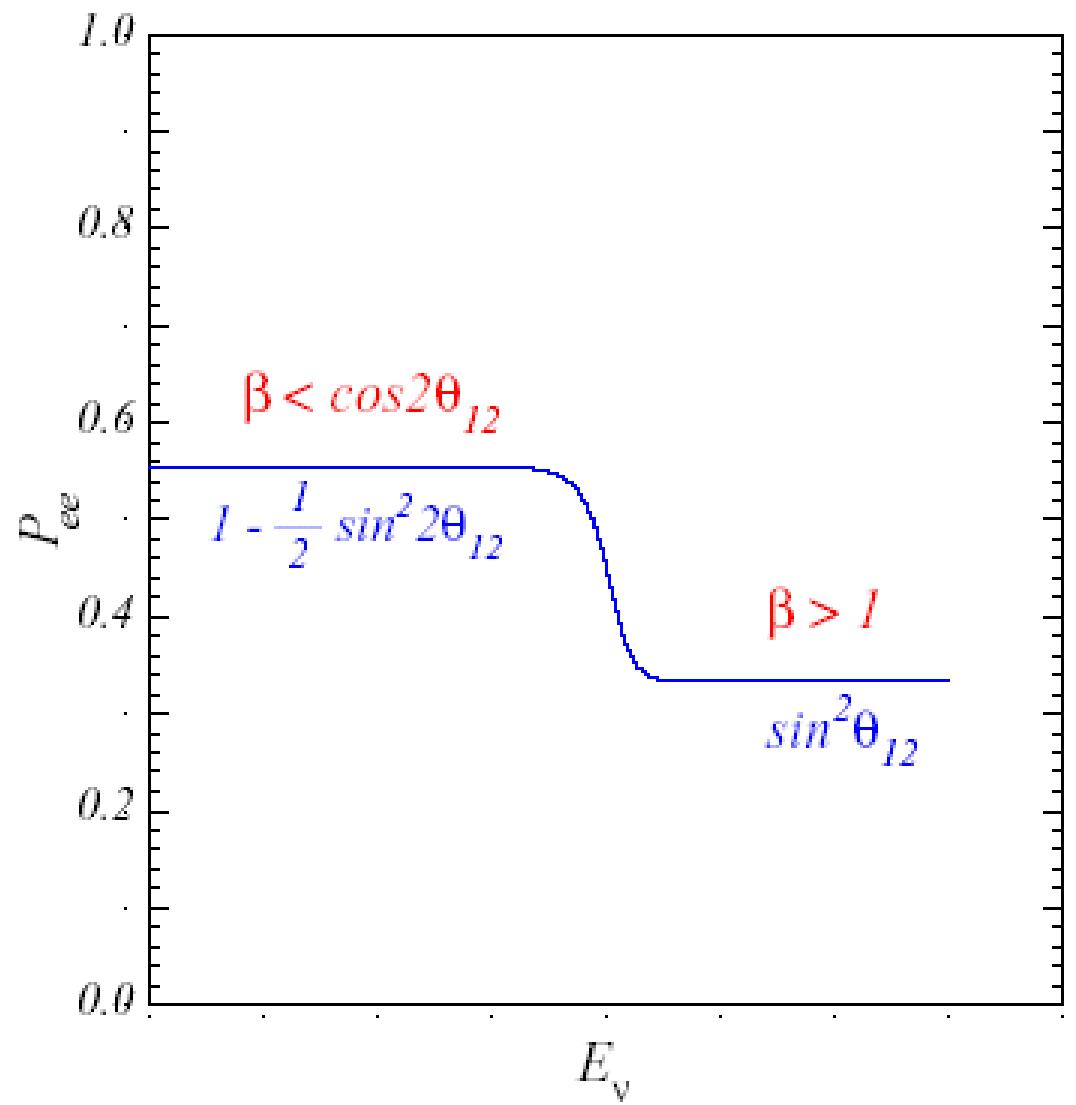
A.Sh.Georgadze, V.V.Kobychev, O.A.Ponkratenko

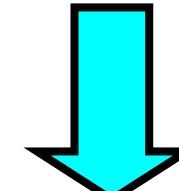
Kiev Institute for Nuclear Research  
Ukraine

<http://lpd.kinr.kiev.ua>



J. N. Bahcall. *Astrophys. J.*, 467, 1996. **ctrp?**



Best fit from all experiments  
 $\sim 0 \div 1 \text{ MeV}$   
 Vacuum oscillations  
  
**MSW**  
 $> 1 \text{ MeV}$

J. N. Bahcall and C. Pena-Garay, JHEP 0311, 004  
 (2003)

# How to study low energy solar neutrinos?

$^{100}\text{Mo}$

$^{115}\text{In}$

$^{160}\text{Gd}$

KamLAND

BOREXINO

HERON

HELLAZ

XMASS

CLEAN

Charged  
current  
reactions

Elastic  
scattering

Possible answers:  
Neutrino  
oscillations  
parameters at low  
energies

Solar models  
parameters

# Is it possible to measure low energy solar neutrinos in ton scale direct counting experiments?

- Careful selection of detector materials.
- Good spatial resolution - high segmentation of detector.

# Spatial resolution for some detectors

Detector	Spatial resolution at 1 MeV
BOREXINO	~10 cm
KamLAND	~10 cm
SNO+	~10 cm
XMASS	~3 mm
MOON	~2 mm
LENS InLS	~7 cm
Crystal scintillators*	~2÷3 mm

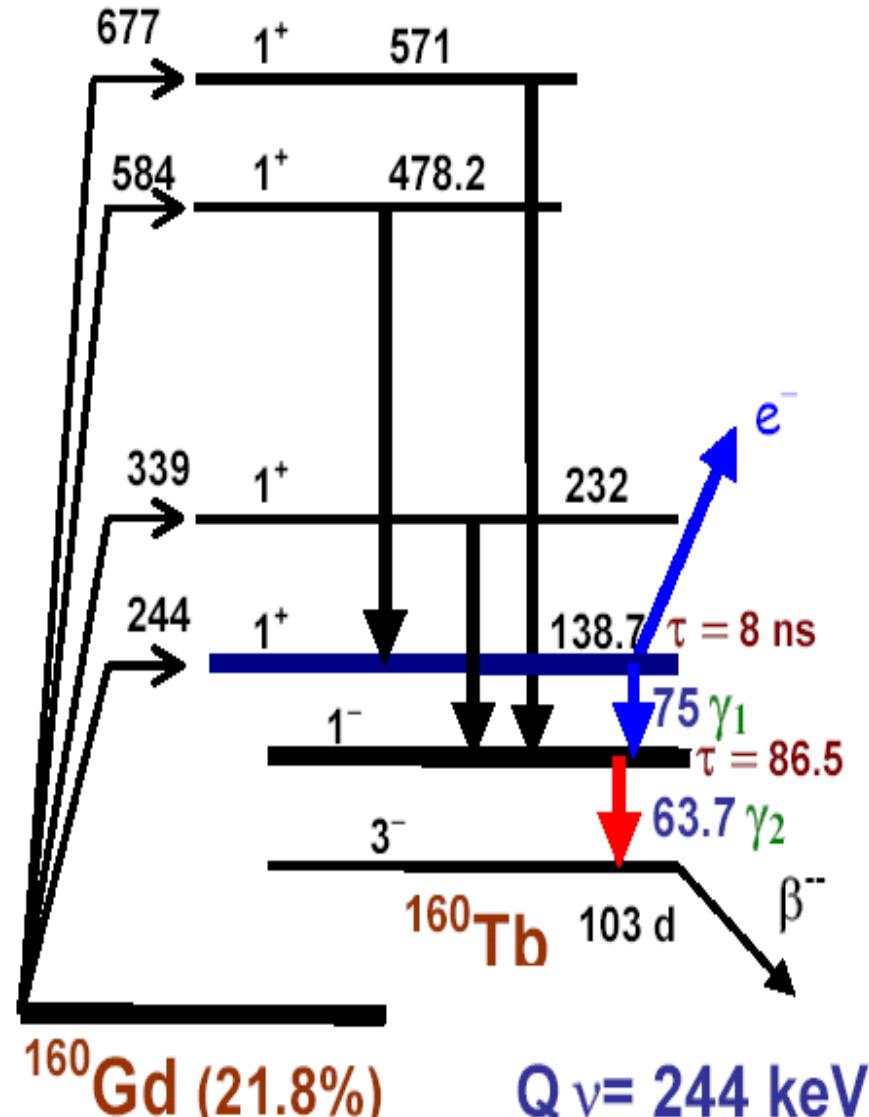
\*in suggested multiple PMT detector

Crystal scintillator	$Gd_2SiO_5$	$CdWO_4$	$CaMoO_4$
Neutrino capture threshold in keV	244	470	168

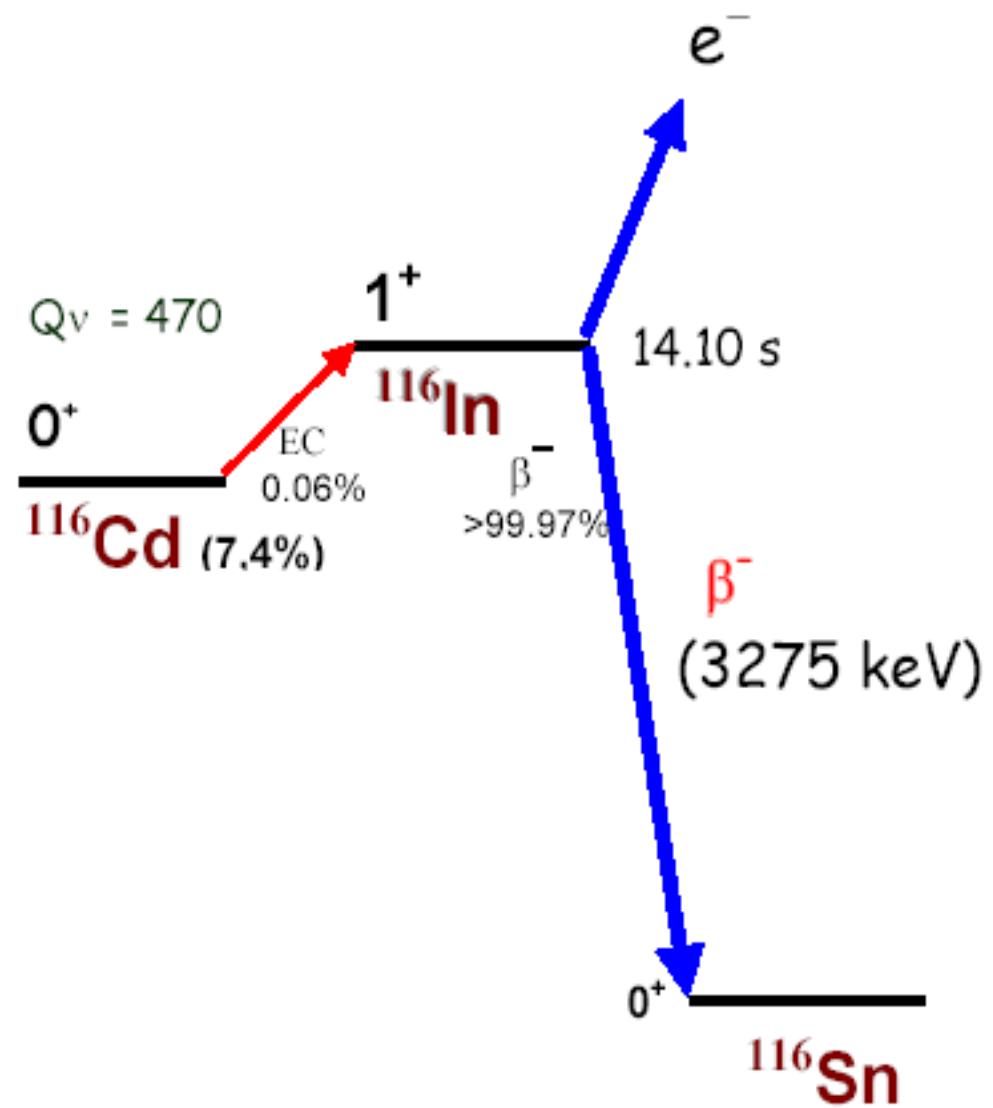
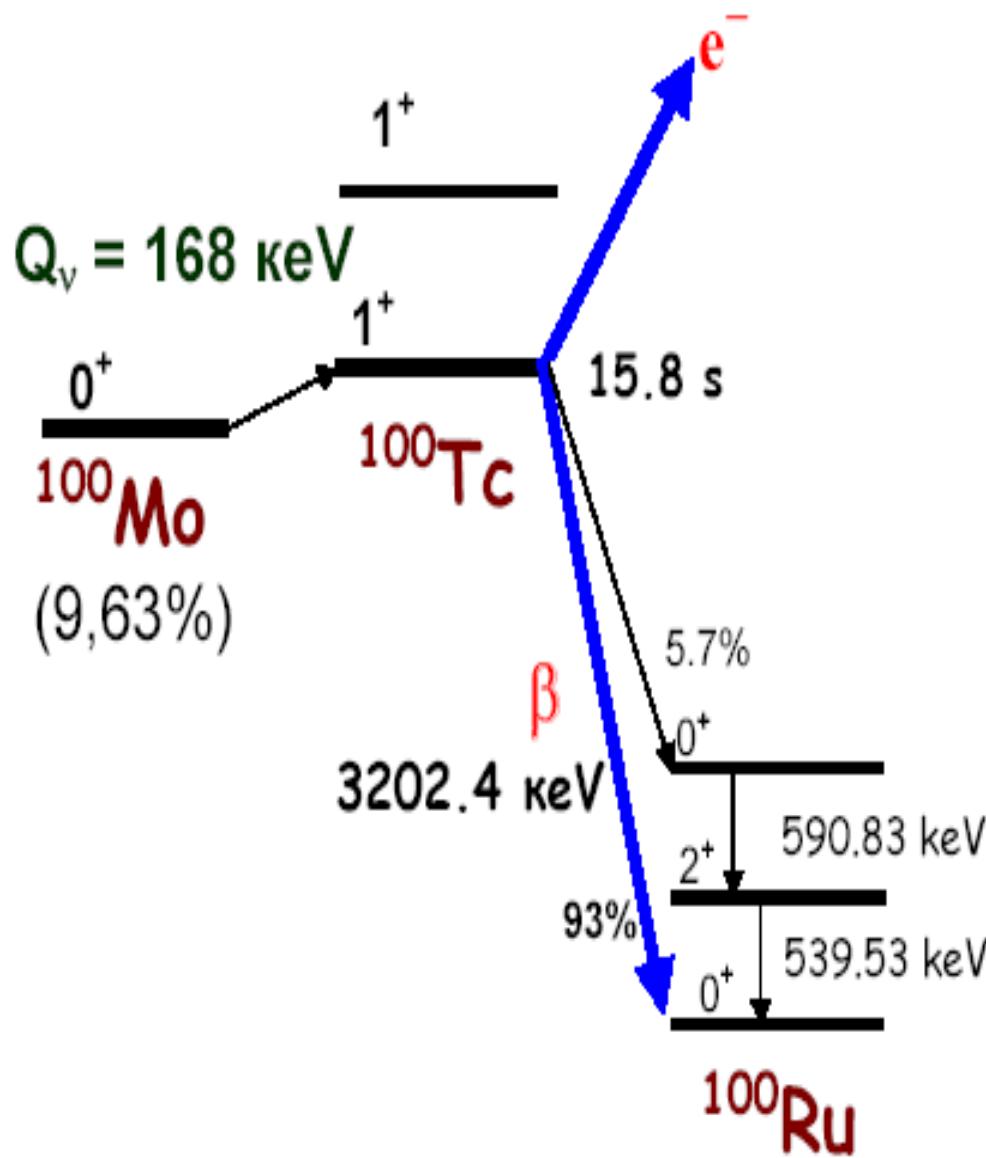
### Solar-neutrino capture rates in SNU

Isotope	p-p	pep	$^7Be$	$^8B$	CNO	Total
$^{100}Mo$	652	14	197	8	54	925
$^{115}In$	468	8.1	116	14	31	639
$^{116}Cd$	-	17	203	10	53	292
$^{160}Gd$	226	19	207	9	53	514

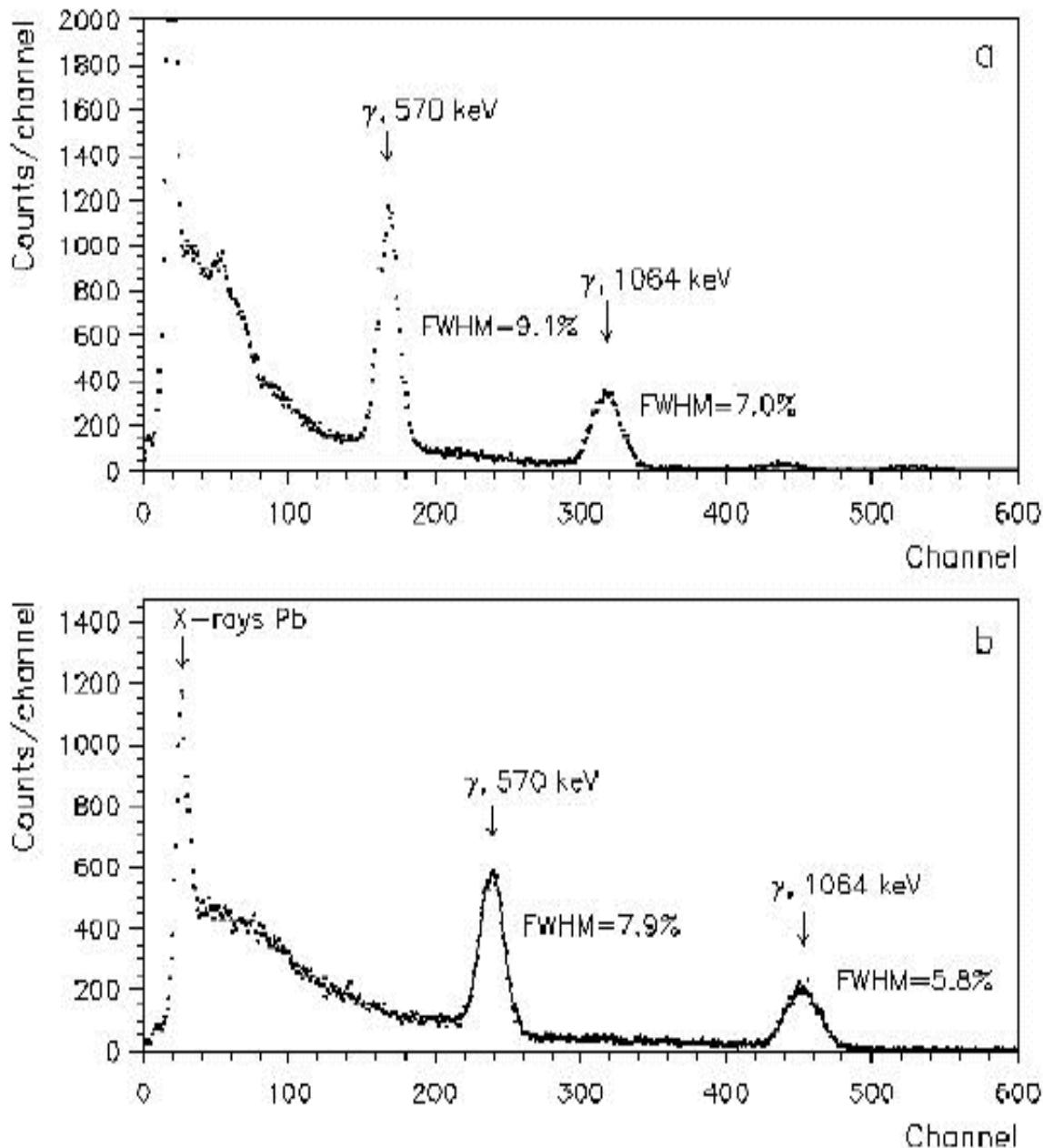
main properties	GSO	CdWO <sub>4</sub>	CaMoO <sub>4</sub>
light yield/NaI	20%	30%	1-3%
Density (g/cm <sup>3</sup> )	6.71	7.8	4.34
Gd,Cd,Mo content (mass)	74%	30%	49%
<sup>160</sup> Gd, <sup>116</sup> Cd, <sup>100</sup> Mo content (mass)	16%	2.25%	4.72%
decay time	30-60 ns	15 μs	10 μs
light emission (ph/MeV)	8×10 <sup>3</sup>	12×10 <sup>3</sup>	400÷1000
peak emission (nm)	430	490	~500
refractive index at peak	1.85	2.3	2.0



Neutrino capture tag on  $^{160}\text{Gd}$

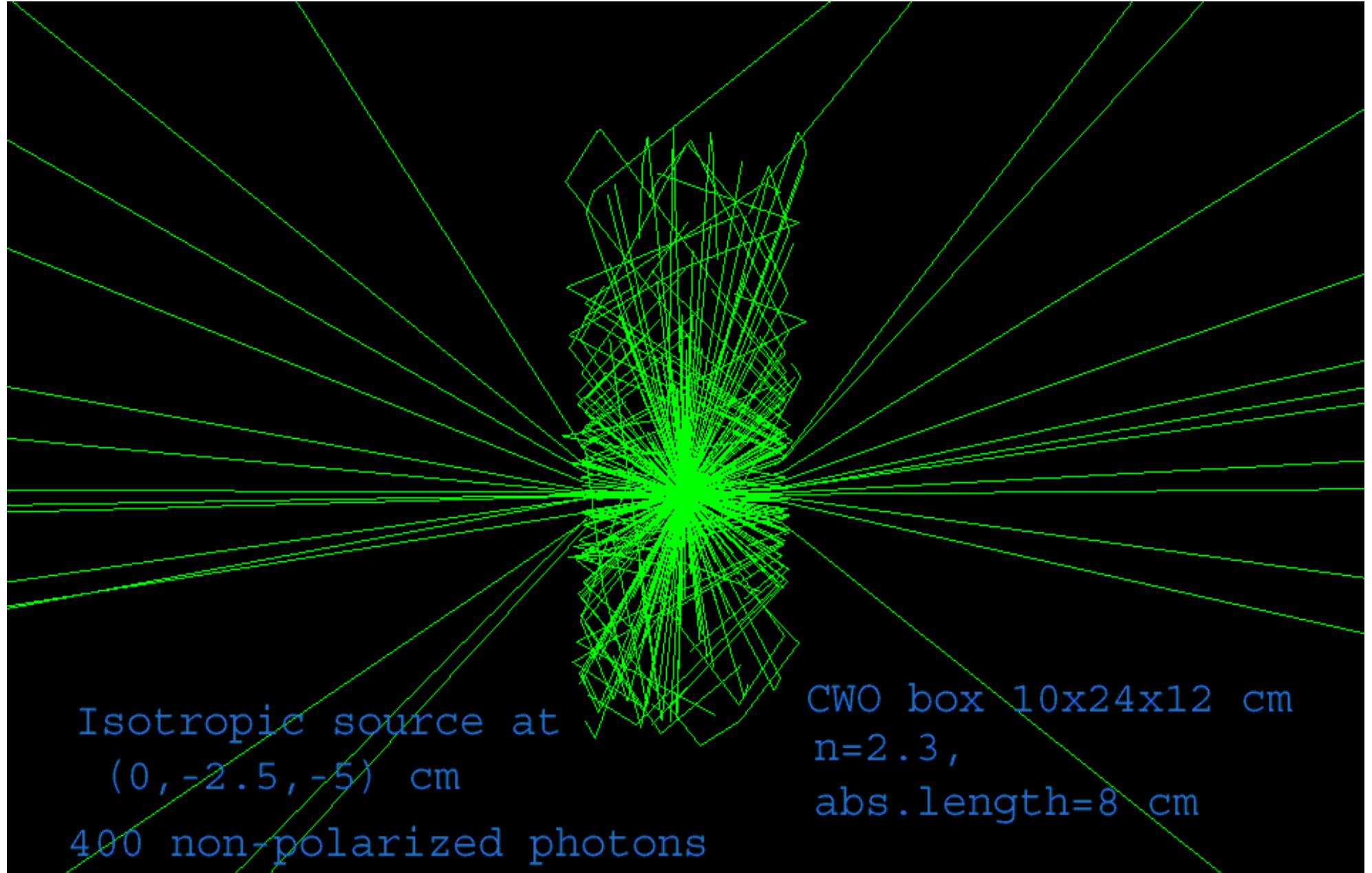


Neutrino capture tag on  $^{100}\text{Mo}$  and  $^{116}\text{Cd}$



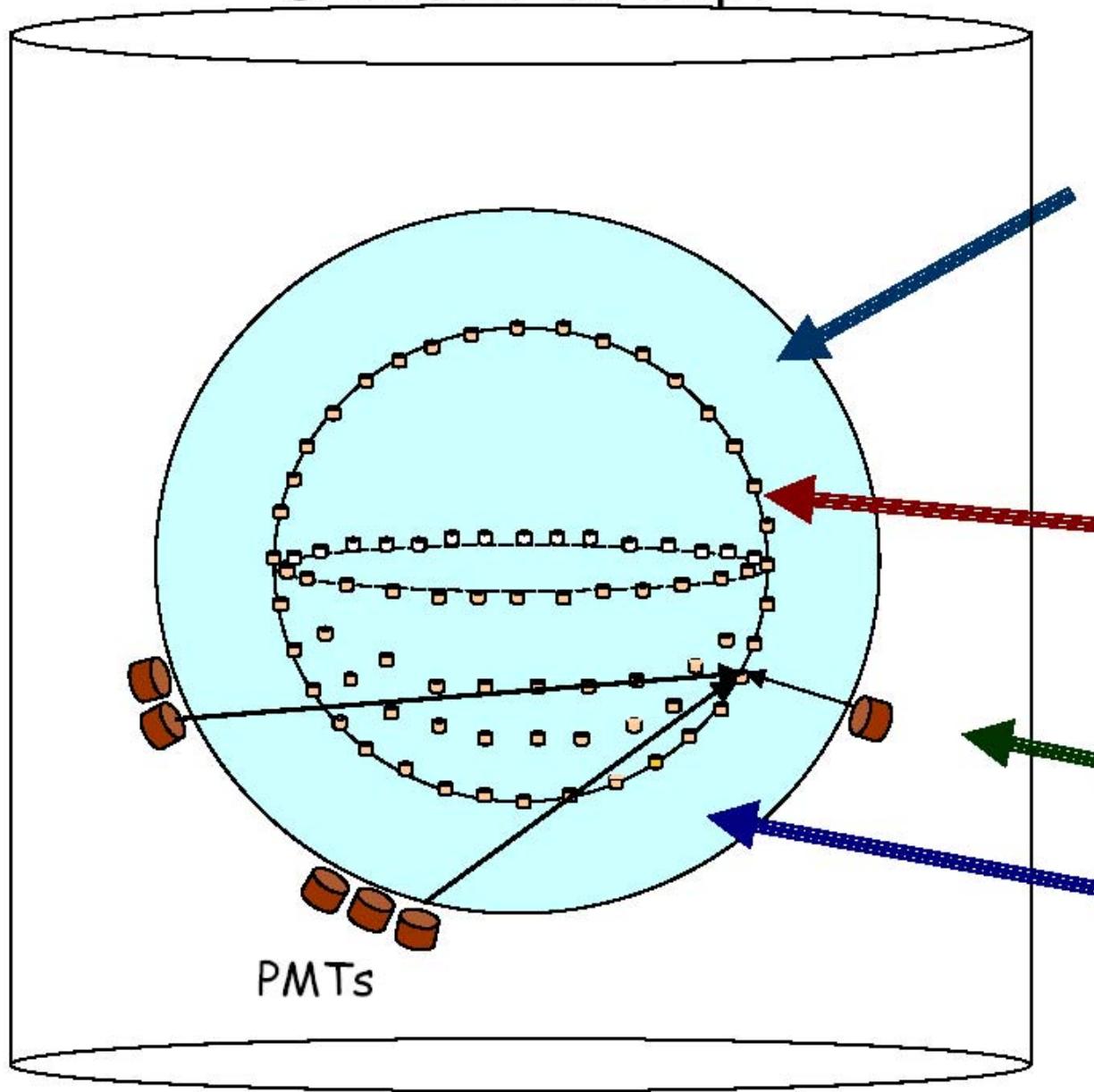
# Why in liquid?

In liquid  
light output  
of  $\text{CdWO}_4$  is  
40 % higher.



Simulation of light in CWO box  $10 \times 24 \times 12$  cm

## Detector concept



### Support frame

$\varnothing$  18m with 9500  
20" PMT  
55% optical coverage

$\varnothing$  12 m  
25t  $\rightarrow$  7000 GSO  
3.5 kg each  
19t Gd  
Pure Water  
High purity water

**GSO**

No  
enrichment

No detector cooling

**CdWO<sub>4</sub>**

<sup>116</sup>Cd

enrichment signal smearing due to  
PMT noise

**CaMoO<sub>4</sub>**

<sup>100</sup>Mo

enrichment signal smearing due to  
PMT noise

The simplest detector concept is with  
**GSO** crystal scintillators → consider  
more close this case.

Input data for **MC simulation**:

GSO light output = 10000 ph/MeV,  
absorption length - 50 cm in crystal

Optical coverage - 55%

PMT quantum efficiency - 25%,

Decay time 30 ns.

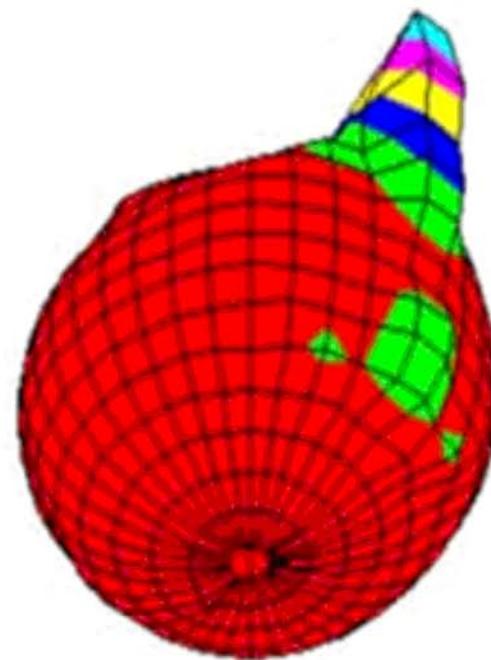
MC simulation of scintillation light collection in **GSO** crystal scintillator produce following main features for 1 MeV electrons.

Spatial resolution	3÷4 mm
Granularity	$10^4$
Energy resolution	6 %
Number of photoelectrons	2300
Energy threshold	10 keV

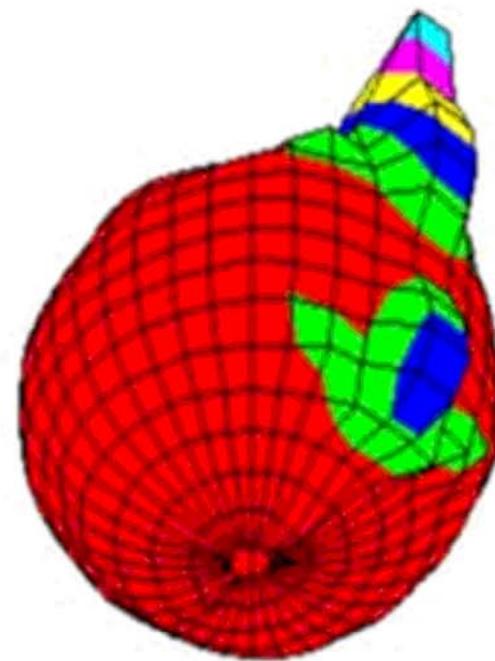
# MC simulation of light collection in SNO detector for 100 p.e. vent.

Color correspond to number of photoelectrons

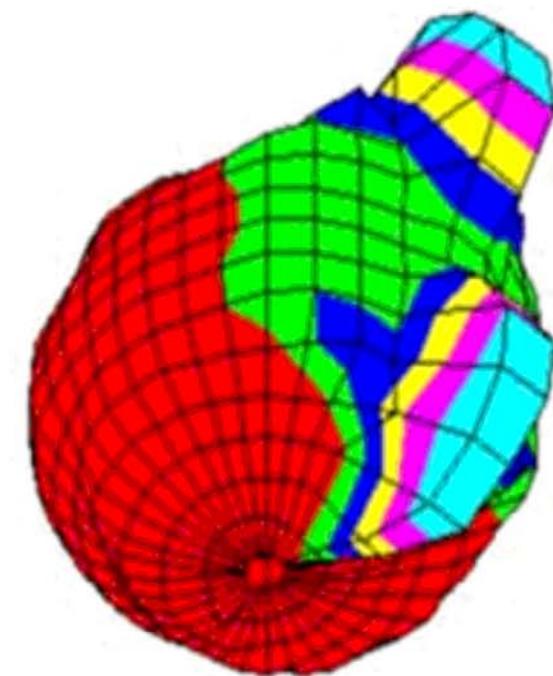
■ 0 p.e. ■ 1 p.e. ■ 2 p.e. ■ 3 p.e. ■ 4 p.e. ■ 5 p.e.



X=0, Y=20, Z=0 mm

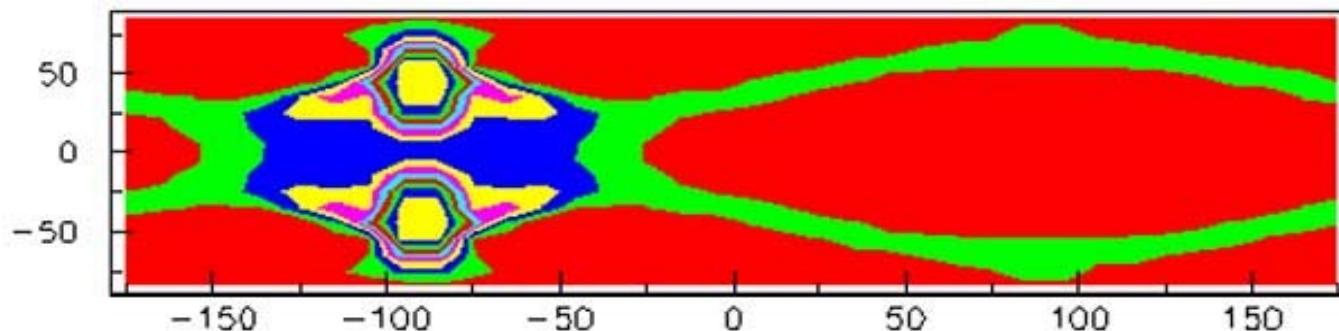


Z=5 mm

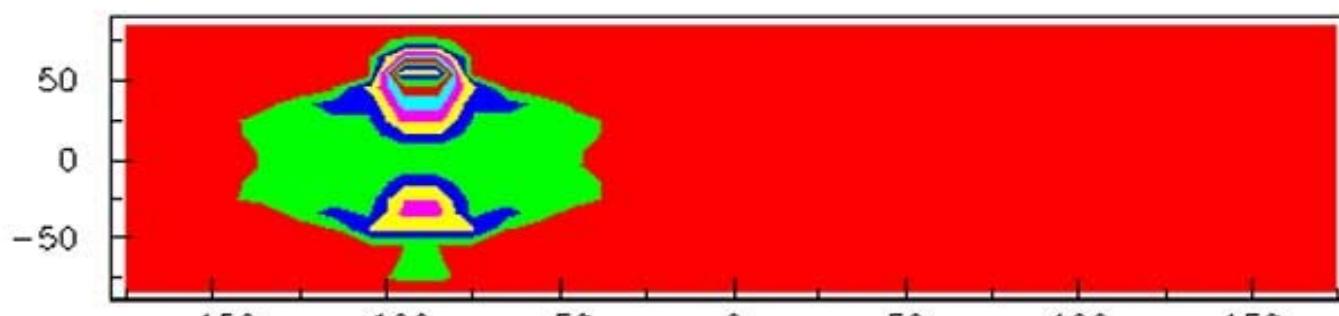


Z=10 mm

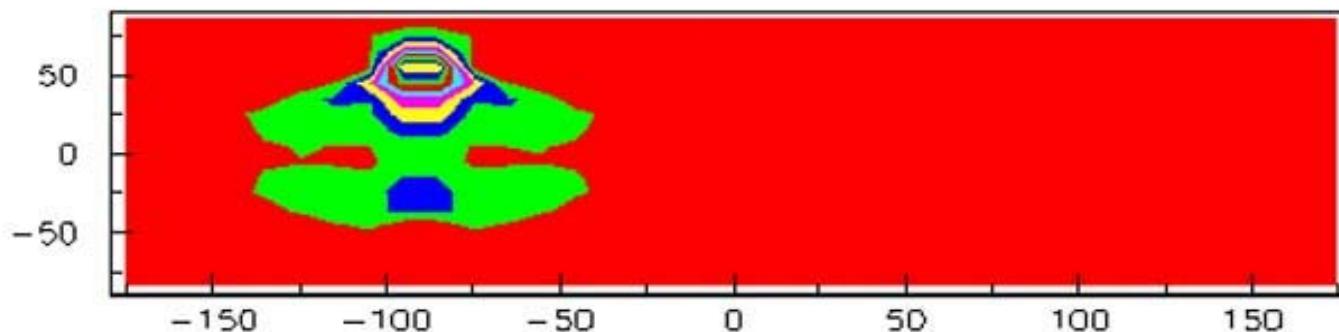
# The same in plane view



$X=0$   
 $y=20$   
 $Z=0$



$Z=5 \text{ mm}$



$Z=10 \text{ mm}$

$x=0, y=20, z=5$

$x=0, y=20, z=10$

Electron energy	0.05 MeV	1 MeV	3 MeV
Spatial resolution	1 cm	3÷5 mm	1÷2 mm
Granularity	$10^3$	$10^4$	$10^6$
Energy resolution	20 %	6 %	4 %

# Detection efficiency of neutrino reactions

$$\varepsilon = \varepsilon_t \cdot \varepsilon_{E1E2} \cdot \varepsilon_z \cdot \varepsilon_{2\text{pulses}} ,$$

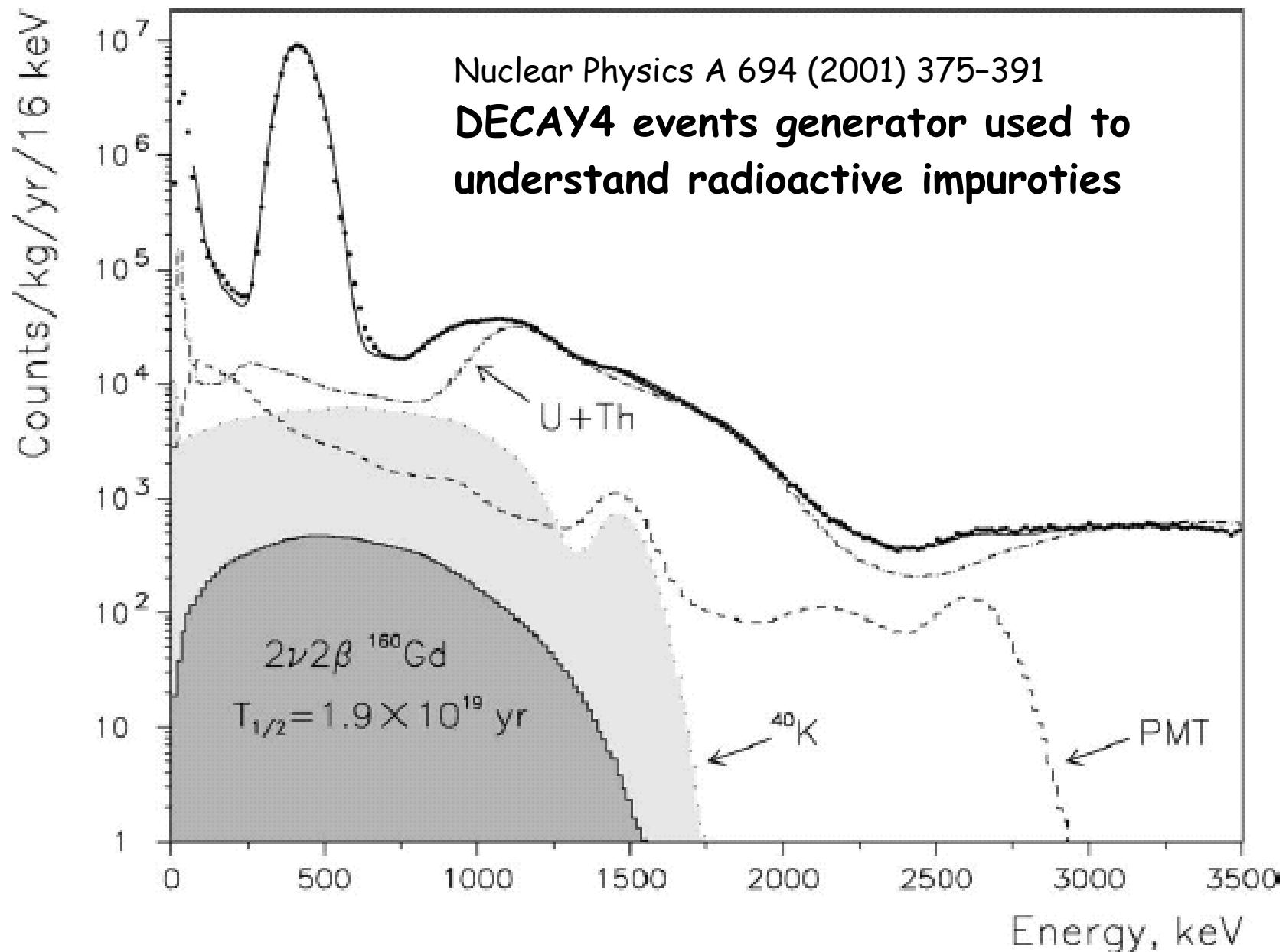
- a)  $\varepsilon_t$  time window (250 ns) efficiency = 0.96
- b)  $\varepsilon_{E1E2}$  energy (two) window efficiency =  $0.9 \times 0.9 = 0.81$
- c)  $\varepsilon_z$  granularity (volume) = 0.9
- d)  $\varepsilon_{2\text{pulses}}$  efficiency of separation of double pulse (electron from neutrino capture 75 keV and 64 keV) from single background pulse =  $0.6 \div 0.7$

$$\varepsilon \sim 40\div 50\%$$

# Counting rates for 25 tons of GSO crystals (19 tons Gd)

Signal window (keV)	75-250	693	1273	0-1700	0-16000
$\nu$ source	pp	$^7\text{Be}$	pep	CNO	$^8\text{B}$
Events/year	77	86	6	18	3

# GSO background spectrum measured in Solotvina underground laboratory of Kiev Institute for Nuclear Reaserch



The following activities found in GSO scintillator:

$^{40}\text{K} \leq 14 \text{ mBq/kg}$

$^{138}\text{La} \leq 55 \text{ mBq/kg}$

$^{228}\text{Th} = 2.287(13) \text{ mBq/kg}$

$^{232}\text{Th} \leq 6.5 \text{ mBq/kg}$

$^{226}\text{Ra} = 0.271(4) \text{ mBq/kg}$

$^{227}\text{Ac} = 0.948(9) \text{ mBq/kg}$

$^{228}\text{Ra} \leq 9 \text{ mBq/kg}$

$^{231}\text{Pa} \leq 0.08 \text{ mBq/kg}$

$^{230}\text{Th} \leq 9 \text{ mBq/kg}$

$^{210}\text{Pb} \leq 0.8 \text{ mBq/kg}$

$^{238}\text{U} \leq 2 \text{ mBq/kg}$

# Main backgrounds

- Random coincidence of backgrounds
  - $^{152}\text{Gd}$  background
    - Natural abundance : 0.2% (2.14 MeV  $\alpha$  decay,  
 $T_{1/2} = 1.1 \times 10^{14}$  years) Visible energy  $\sim 400$  keV  
(just between pp and  $^7\text{Be}$ )
  - Single pulse background
  - Time-correlated background
- $^{235}\text{U} \Rightarrow ^{231}\text{Th}$   $\beta_{\max}$  (305 keV) +  $\gamma$  (84 keV),  
 $\tau=65$  ns
- Cosmic ray induced background

Cosmogenic nuclides calculated by code COSMO for  
 1 month exposition on Earth surface and after 1  
 year underground

Nuclid <i>e</i>	$T_{1/2}$	Mode	Q keV	A $\mu\text{Bq/kg}$	Delay ns	$E_\gamma$ keV
$^{160}\text{Tb}$	72 d	$\beta^-$	1833	0.3	2.0	87
$^{155}\text{Eu}$	4.9 y	$\beta^-$	246	5	6.4	86

## Background contributions in events/year

	pp	$^7\text{Be}$
Neutrino source	77	86
Random coincidence*	4	4
$\text{I}^{152}\text{Gd}$ background	4	4
Single pulse background	1	-
Correlated background* $^{235}\text{U}$ ( $^{238}\text{U}/^{235}\text{U}=20/1$ )	400	-
Cosmic ray induced backgrounds	$^{155}\text{Eu}$	$\sim 1000$

\* $^{238}\text{U}$  activity 100  $\mu\text{Bq}/\text{kg}$

# **GSO U/Th measurements by M.Nakahata**

(Kamioka observatory, ICRR, Univ. of Tokyo) at LowNu: Solar Neutrino Experiments  
below 1 MeV, June 15, 2000, Sudbury, Ontario

## **Radioactive impurities in raw materials and GSO**

$\text{Gd}_2\text{O}_3$        $< 5 \times 10^{-10} \text{ g(U,Th)/g}$

$\text{SiO}_2$        $< 5 \times 10^{-11} \text{ gU,Th/g}$

$\text{CeO}_2$        $< 5 \times 10^{-10} \text{ gU,Th/g}$

$\text{GSO}$        $(5\text{-}9) \times 10^{-8} \text{ gU/g}$

# Conclusions

1. Good spatial and energy resolutions help to overcome random coincidence and  $^{152}\text{Gd}$  backgrounds.
2. But correlated and cosmic ray backgrounds still a problem - purification required.

## The possible solutions:

- Need R&D to grow GSO in clean conditions
- Need to grow GSO underground