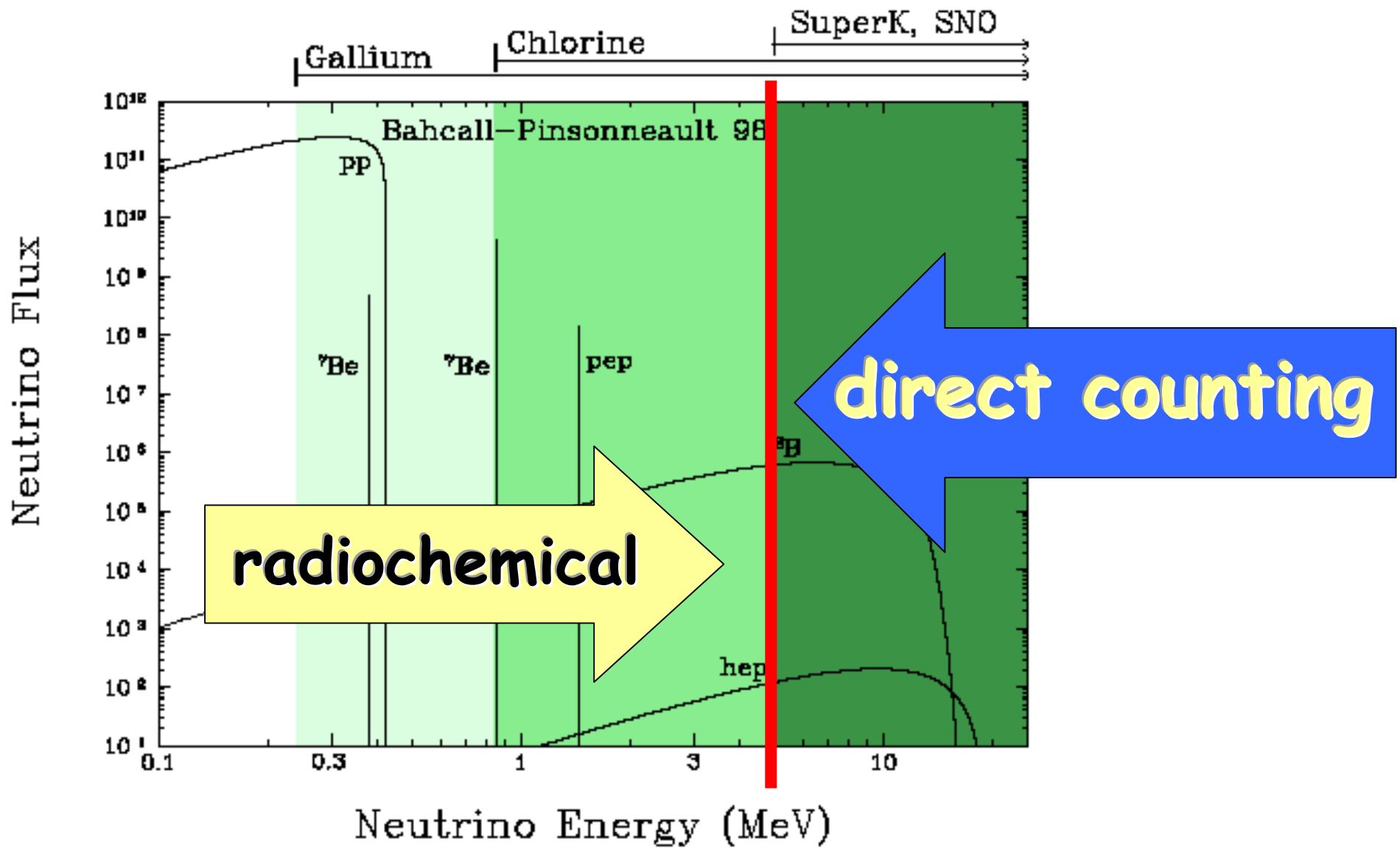


Low energy solar neutrinos detection with GSO crystal scintillators

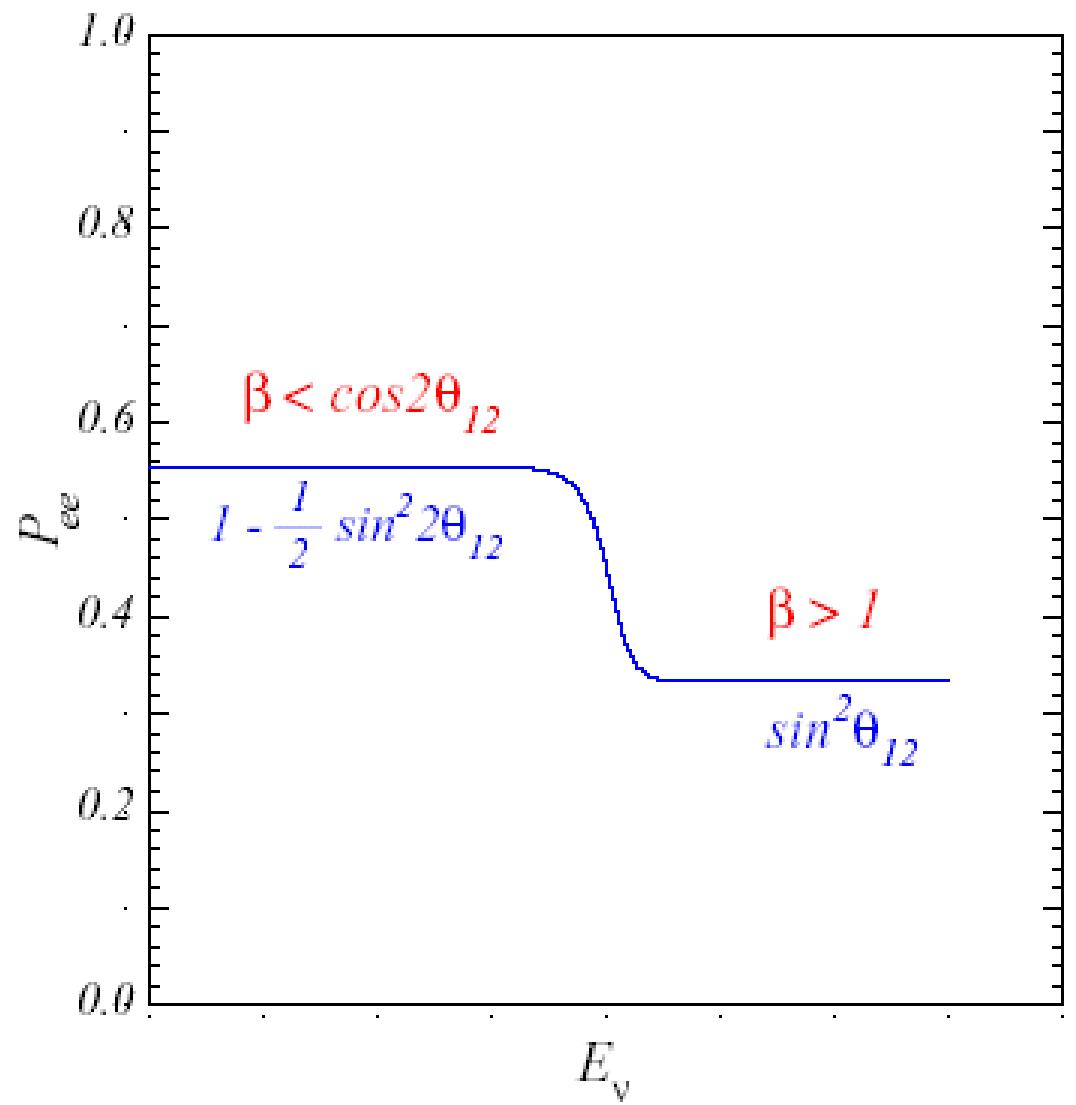
A.Sh.Georgadze, V.V.Kobychev, O.A.Ponkratenko

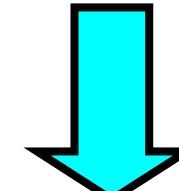
Kiev Institute for Nuclear Research
Ukraine

<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}Mo

^{115}In

^{160}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

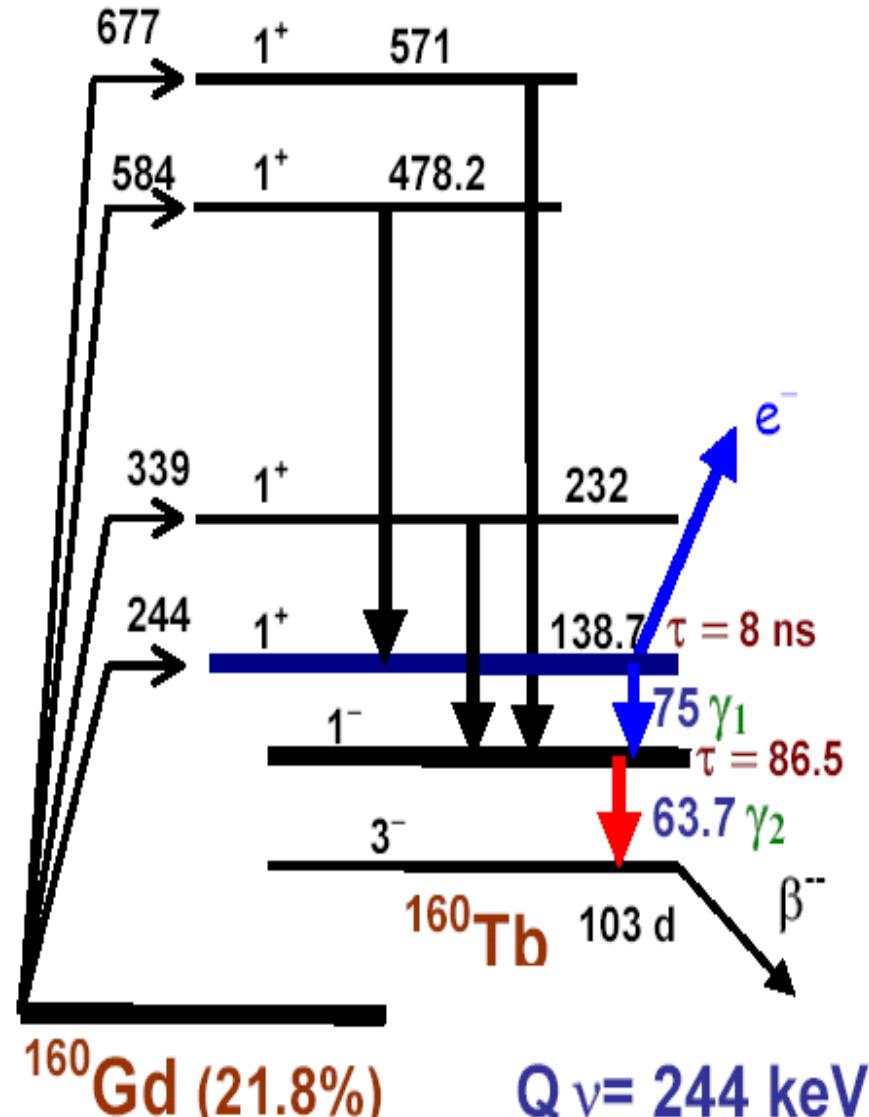
*in suggested multiple PMT detector

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

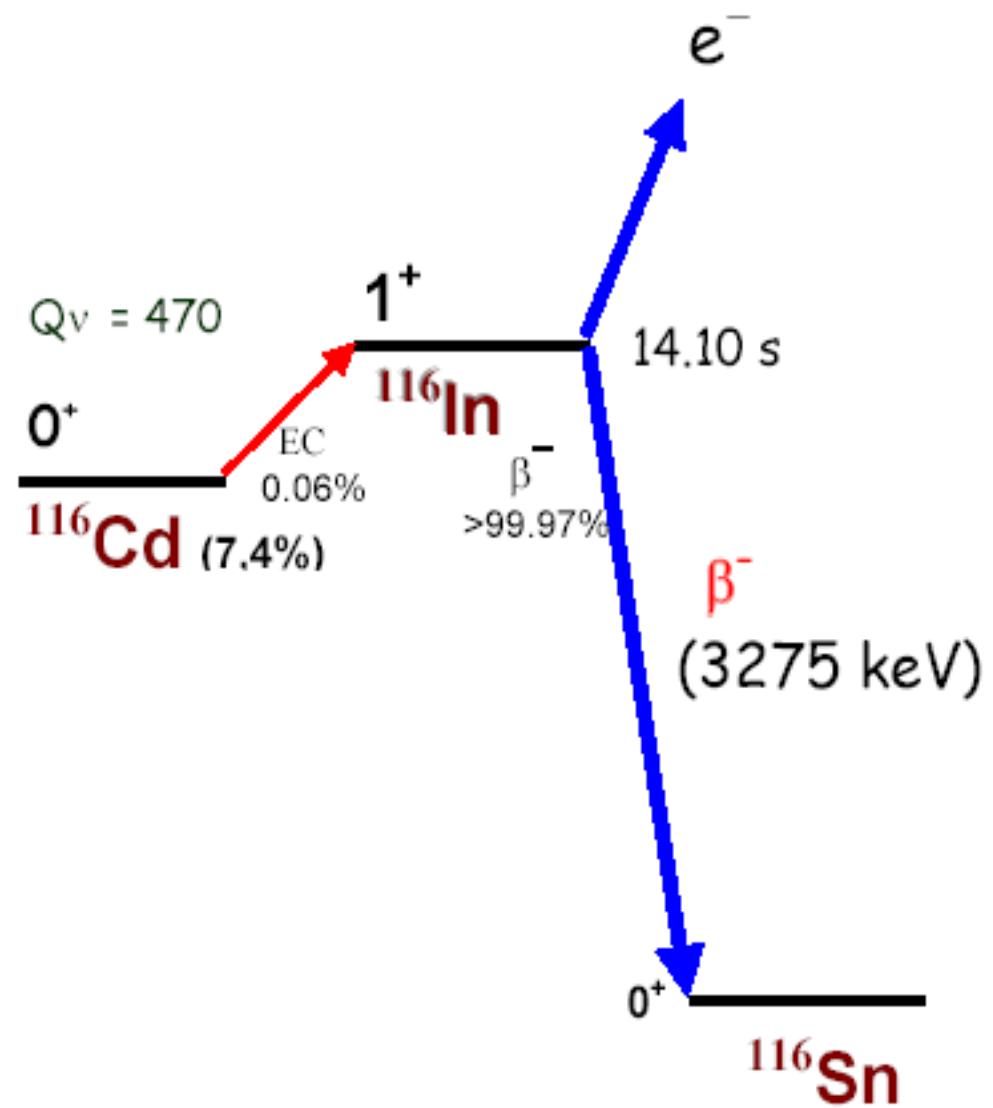
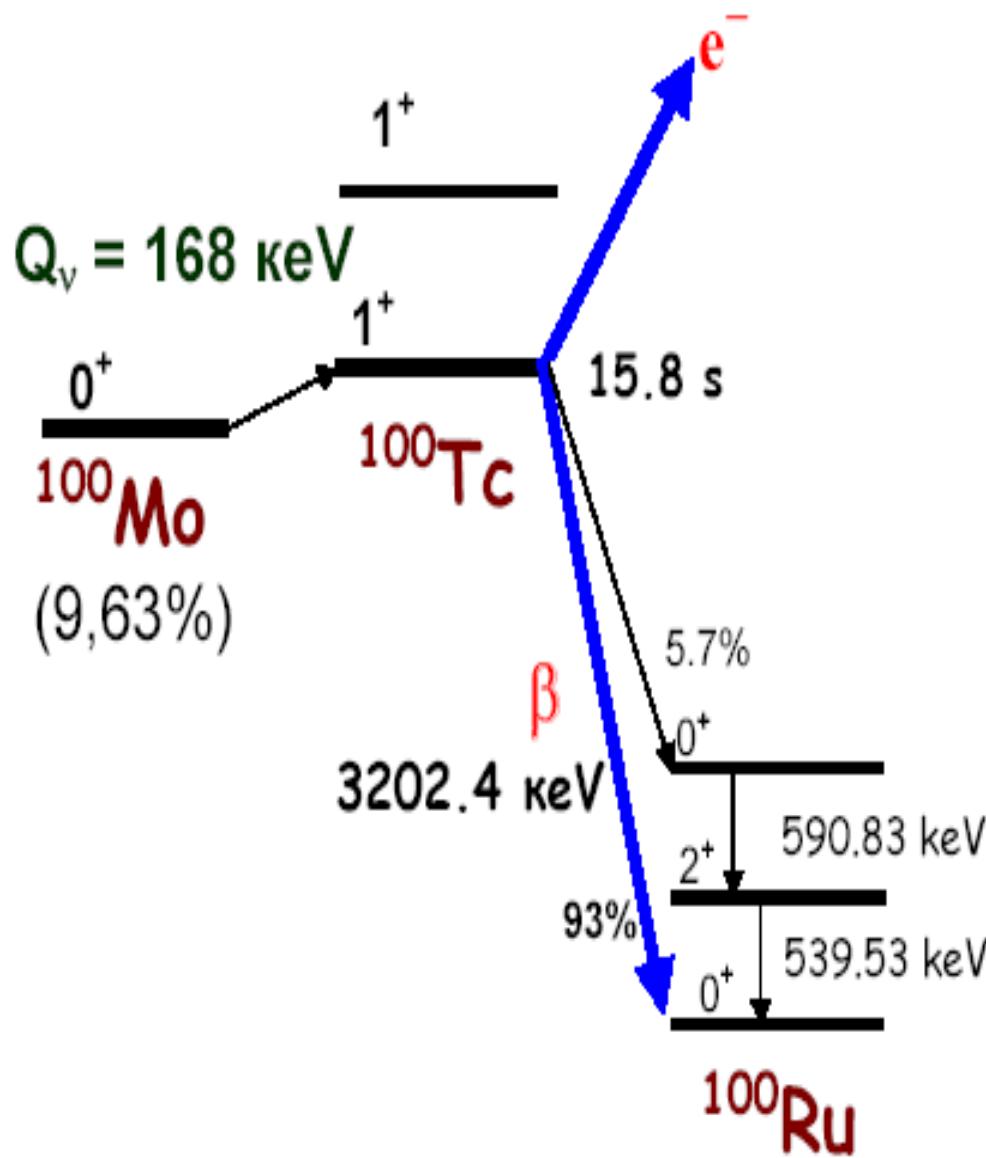
Solar-neutrino capture rates in SNU

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

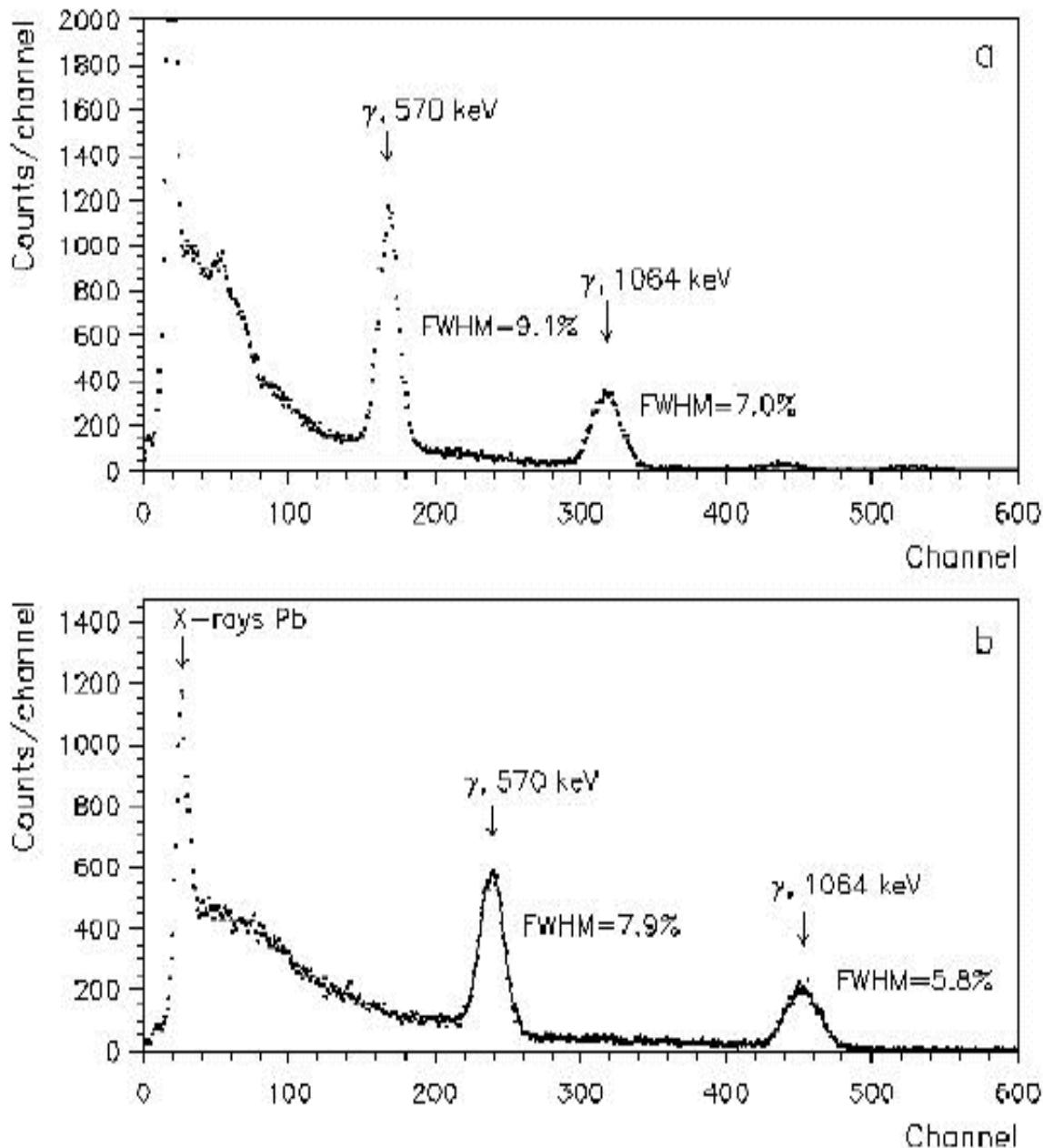
main properties	GSO	CdWO ₄	CaMoO ₄
light yield/NaI	20%	30%	1-3%
Density (g/cm ³)	6.71	7.8	4.34
Gd,Cd,Mo content (mass)	74%	30%	49%
¹⁶⁰ Gd, ¹¹⁶ Cd, ¹⁰⁰ Mo content (mass)	16%	2.25%	4.72%
decay time	30-60 ns	15 μs	10 μs
light emission (ph/MeV)	8×10 ³	12×10 ³	400÷1000
peak emission (nm)	430	490	~500
refractive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



Neutrino capture tag on ^{160}Gd

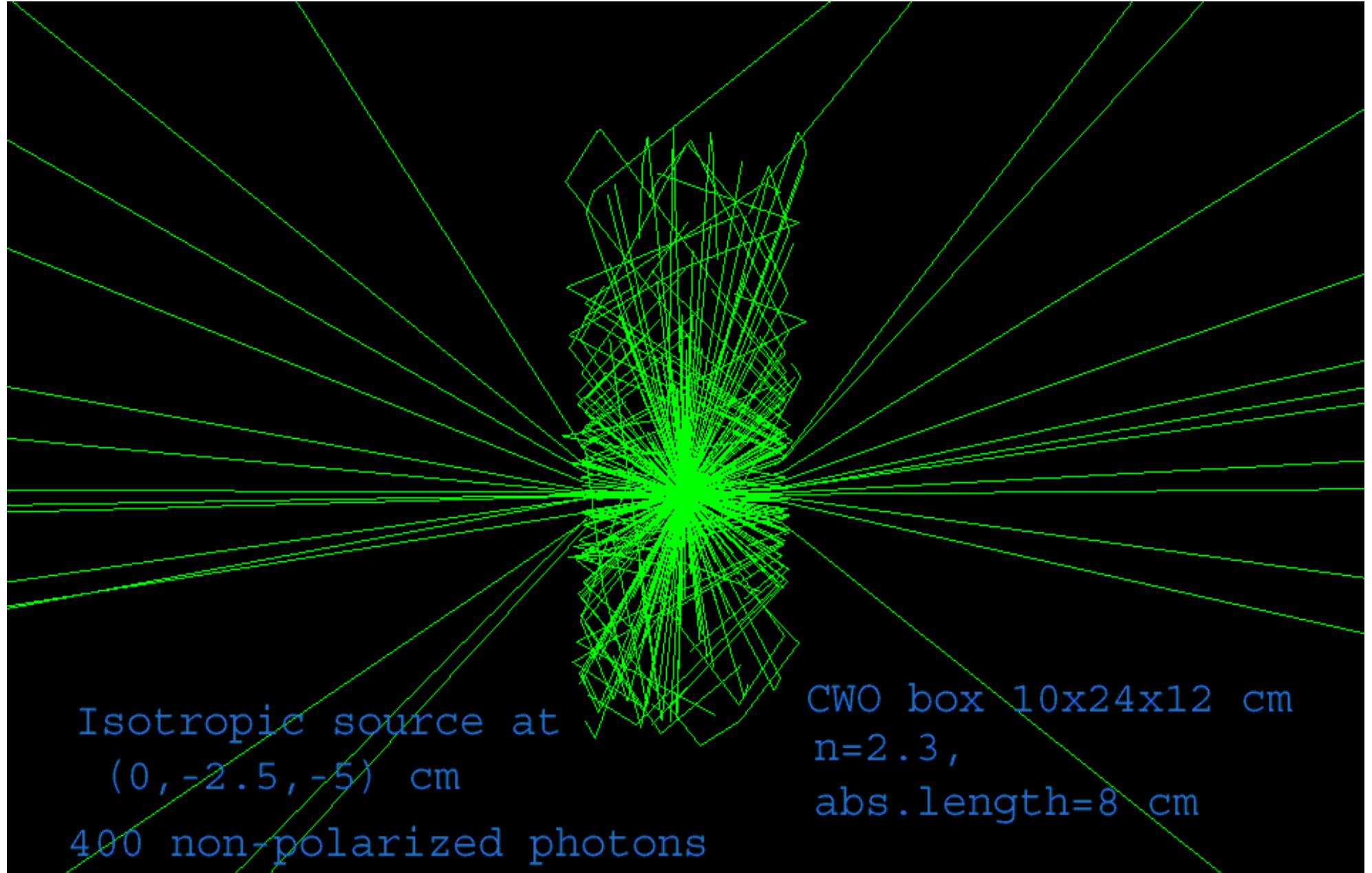


Neutrino capture tag on ^{100}Mo and ^{116}Cd



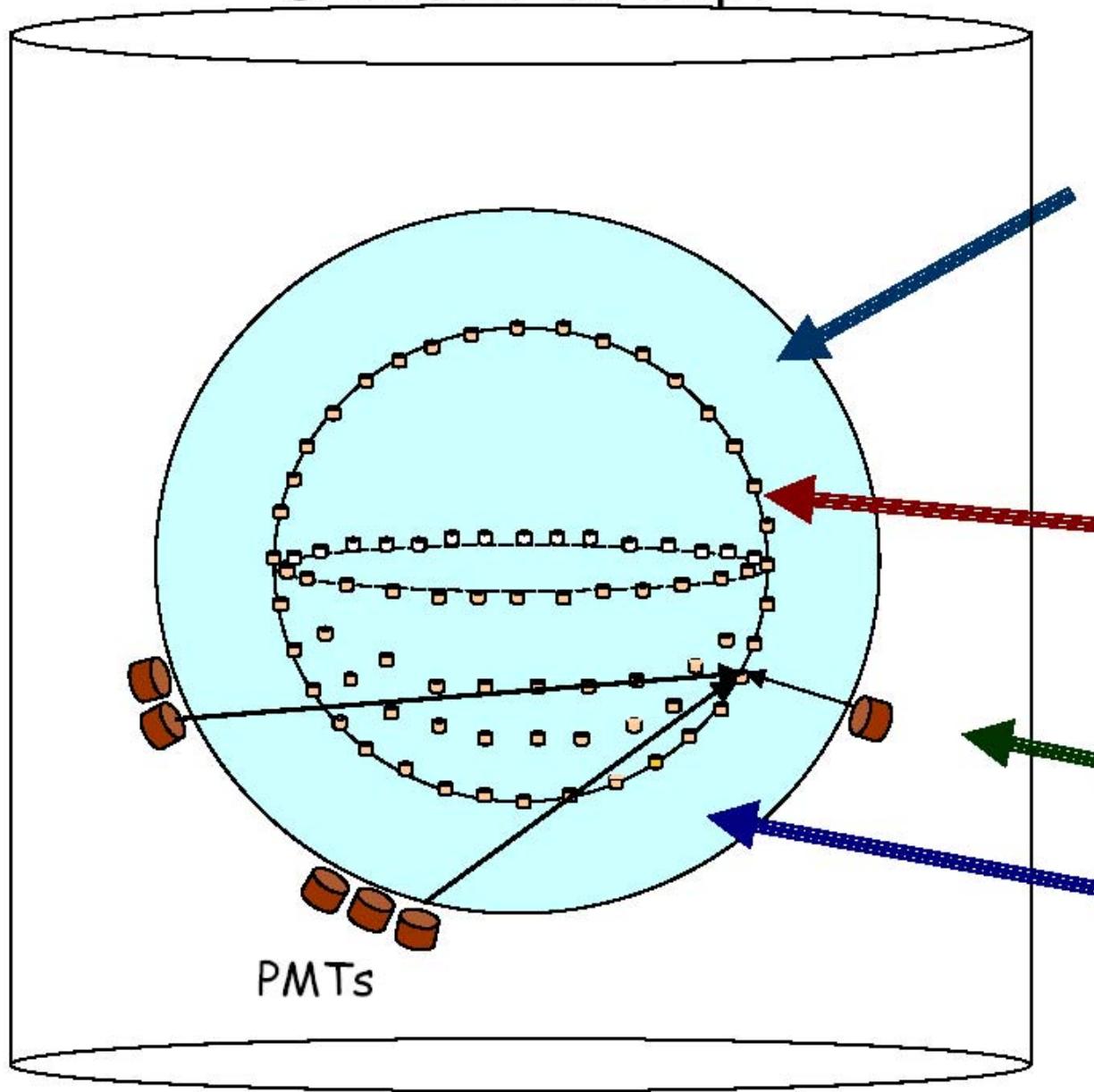
Why in liquid?

In liquid
light output
of 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

CdWO₄

¹¹⁶Cd

enrichment signal smearing due to
PMT noise

CaMoO₄

¹⁰⁰Mo

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.

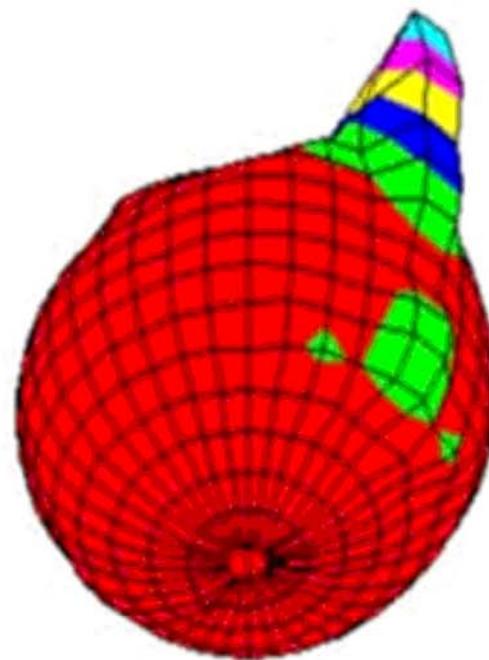
MC simulation of scintillation light collection in **GSO** crystal scintillator produce following main features for 1 MeV electrons.

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

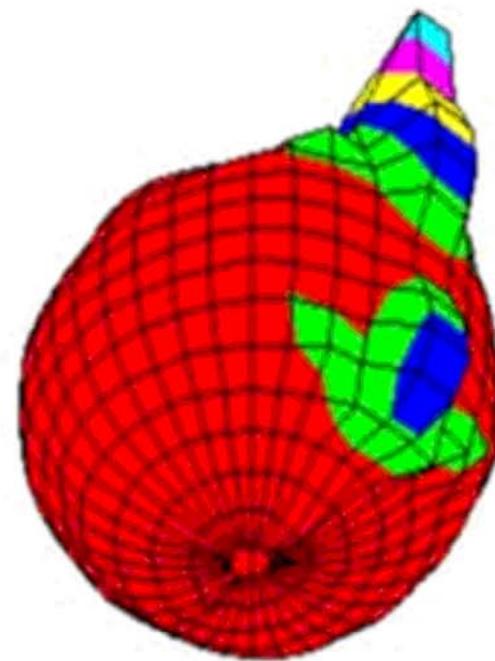
MC simulation of light collection in SNO detector for 100 p.e. vent.

Color correspond to number of photoelectrons

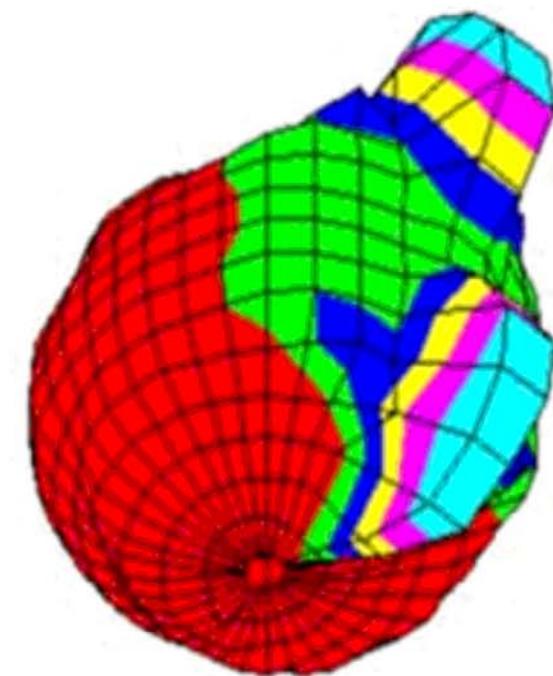
■ 0 p.e. ■ 1 p.e. ■ 2 p.e. ■ 3 p.e. ■ 4 p.e. ■ 5 p.e.



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

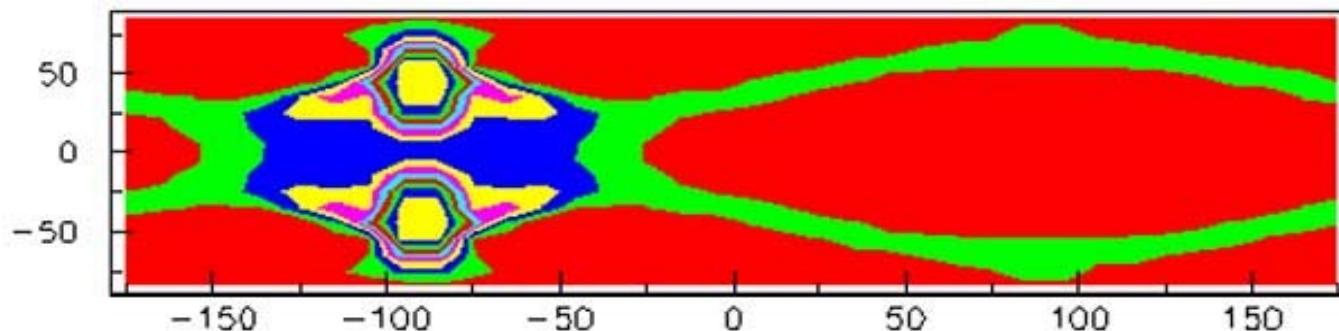


Z=5 mm

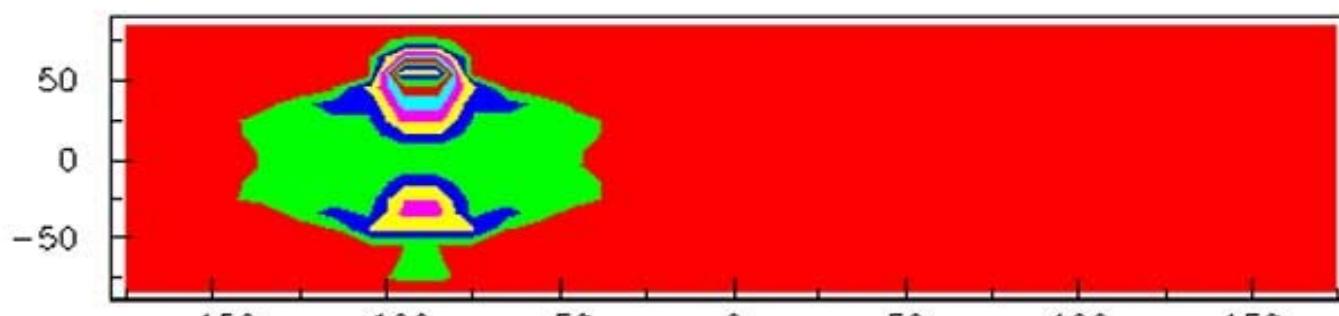


Z=10 mm

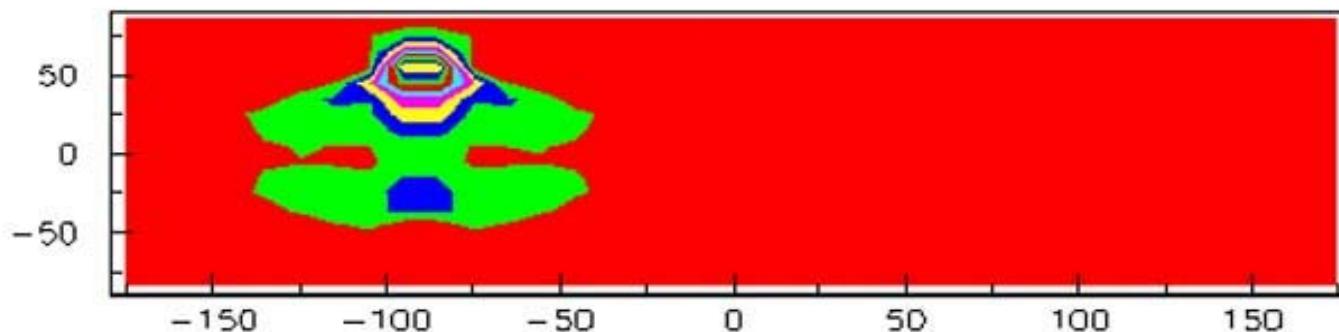
The same in plane view



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



$Z=5 \text{ mm}$



$Z=10 \text{ mm}$

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

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

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

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

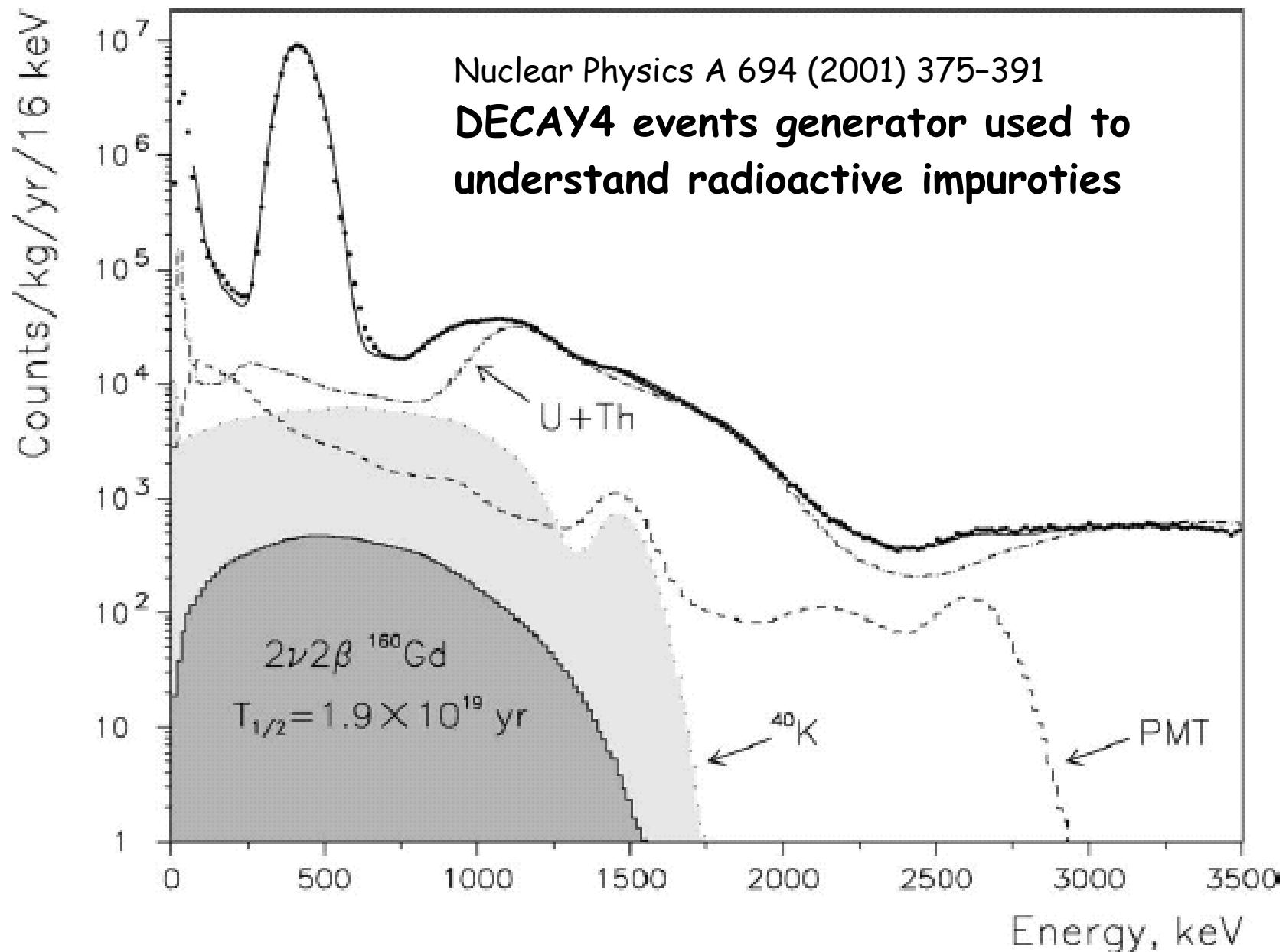
- a) ε_t time window (250 ns) efficiency = 0.96
- b) ε_{E1E2} energy (two) window efficiency = $0.9 \times 0.9 = 0.81$
- c) ε_z granularity (volume) = 0.9
- d) $\varepsilon_{2\text{pulses}}$ efficiency of separation of double pulse (electron from neutrino capture 75 keV and 64 keV) from single background 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
ν source	pp	^7Be	pep	CNO	^8B
Events/year	77	86	6	18	3

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



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}Gd background
 - Natural abundance : 0.2% (2.14 MeV α decay,
 $T_{1/2} = 1.1 \times 10^{14}$ years) Visible energy ~ 400 keV
(just between pp and ^7Be)
 - Single pulse background
 - Time-correlated background
- $^{235}\text{U} \Rightarrow ^{231}\text{Th}$ β_{\max} (305 keV) + γ (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_γ keV
^{160}Tb	72 d	β^-	1833	0.3	2.0	87
^{155}Eu	4.9 y	β^-	246	5	6.4	86

Background contributions in events/year

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

* ^{238}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

Gd_2O_3 $< 5 \times 10^{-10} \text{ g(U,Th)/g}$

SiO_2 $< 5 \times 10^{-11} \text{ gU,Th/g}$

CeO_2 $< 5 \times 10^{-10} \text{ gU,Th/g}$

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

Conclusions

1. Good spatial and energy resolutions help to overcome random coincidence and ^{152}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