Prospects for Solar Neutrino Observation in KamLAND

Joint Meeting of Pacific Region Particle Physics Communities

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Solar Neutrinos : Prediction and Measurement

Prediction

SSM (Standard Solar Model)

high energy	^{8}B ν	0.01%
	CNO ν	1.6%
	pep ν	0.2%
	^{7}Be ν	7%
low energy	pp ν	91%

Measurement

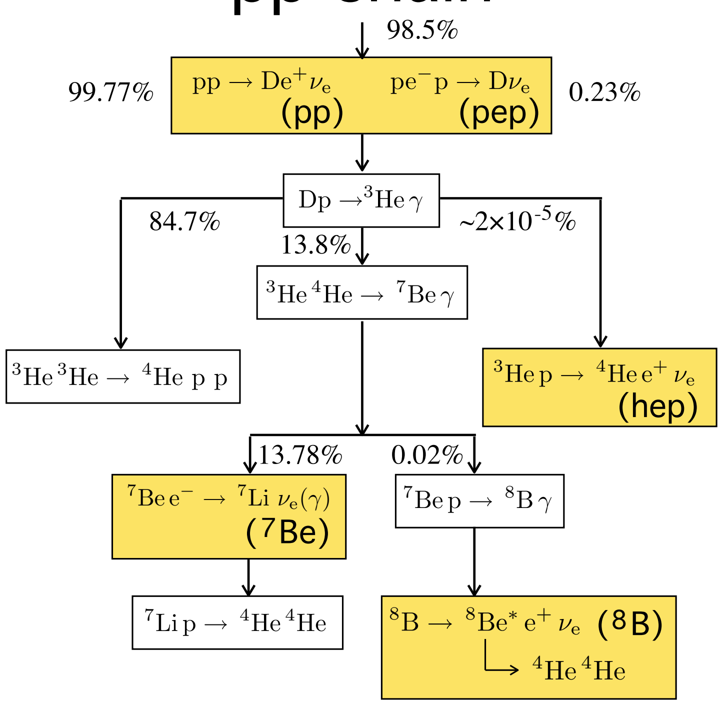
Super-Kamiokande, SNO

NC/CC discrimination

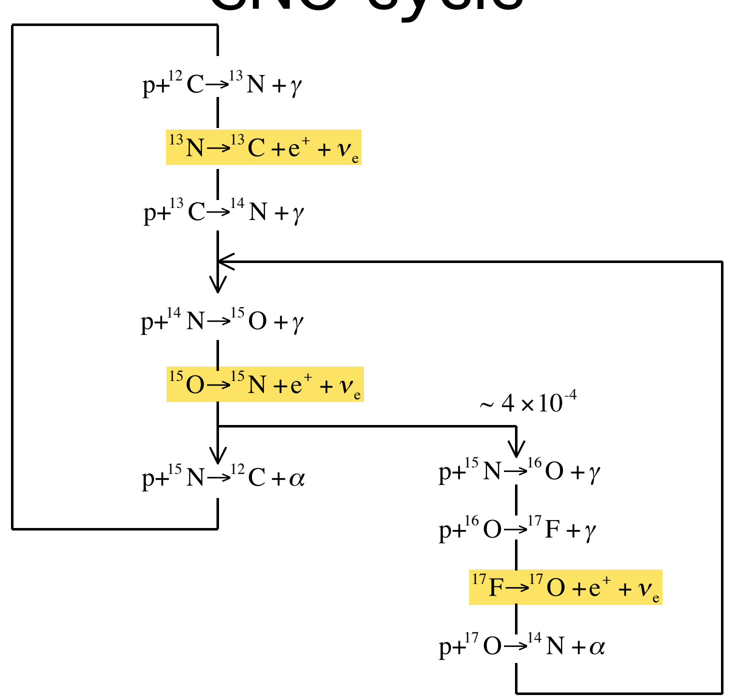
Cl (Homestake)

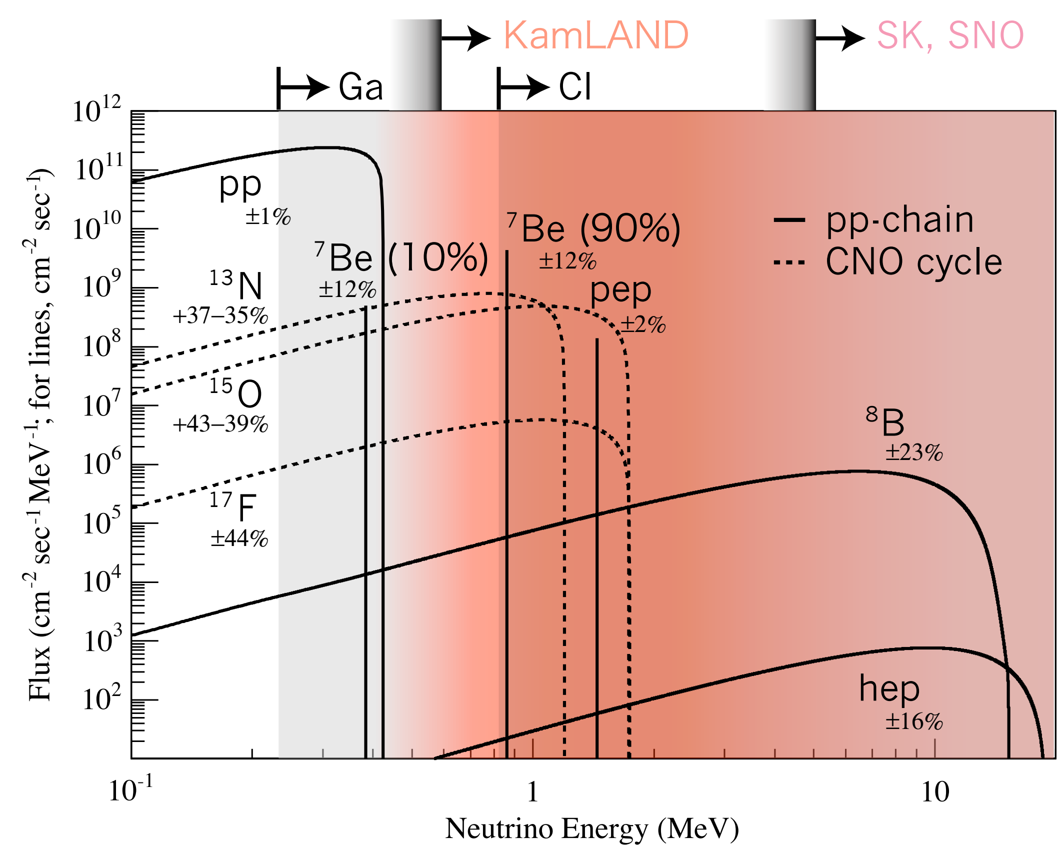
Ga (Gallex/GNO, SAGE)

pp chain

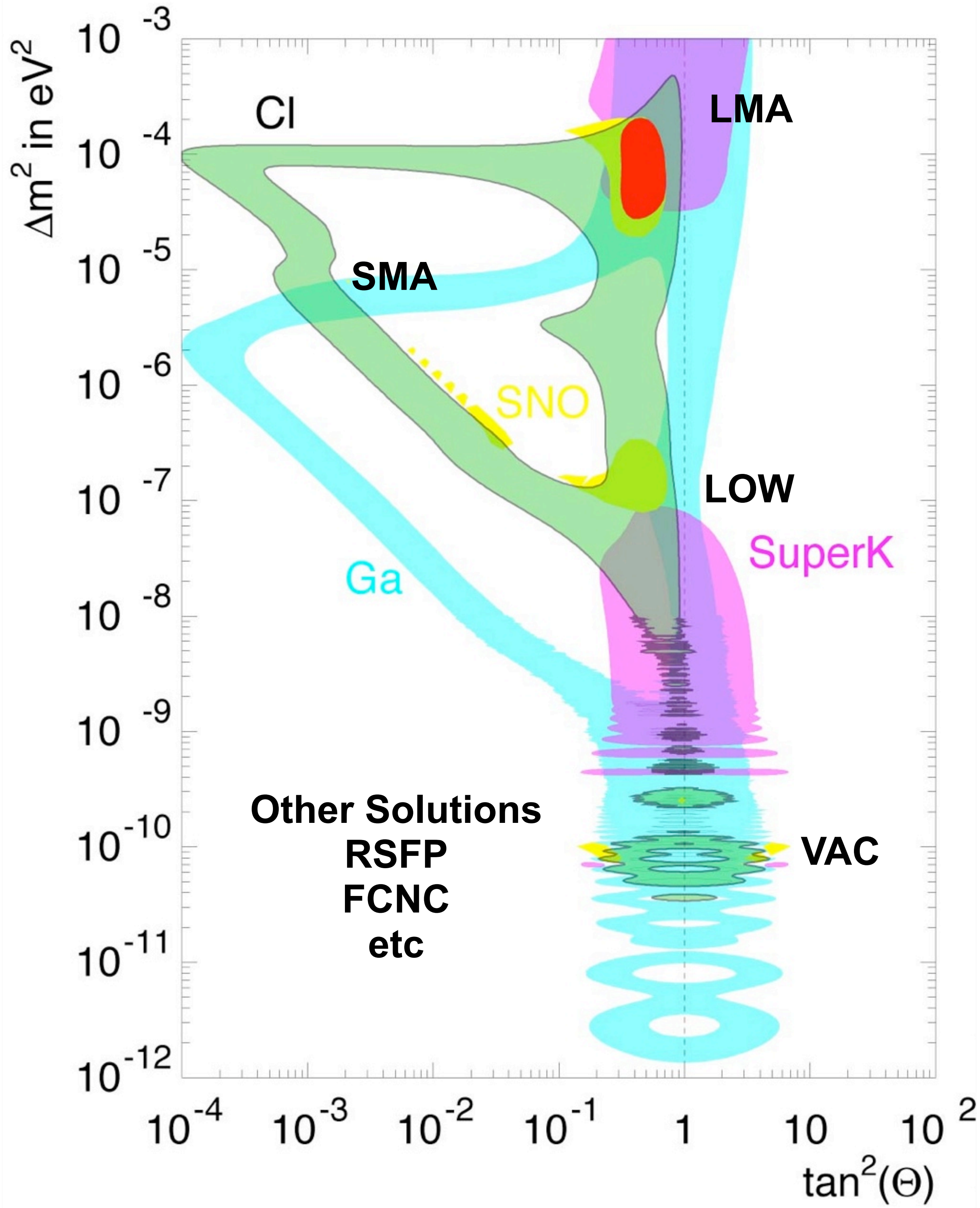


CNO cycle

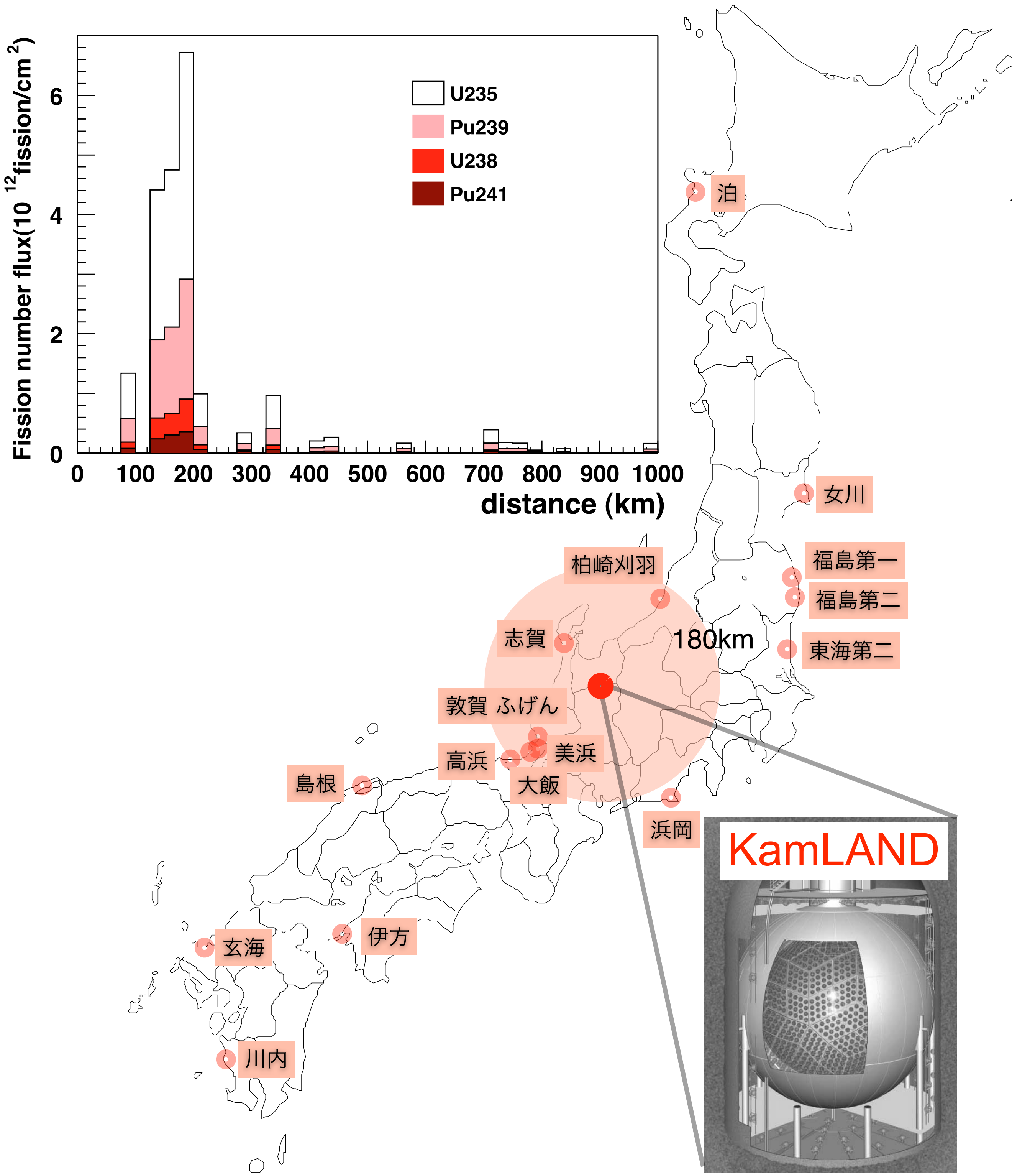




Neutrino Oscillation Parameter which Reconcile all Experiments



Reactor Neutrino Observation



2 flavor neutrino oscillation

$$P(\nu_e \rightarrow \nu_e) = 1 - \sin^2 2\theta \sin^2\left(\frac{1.27\Delta m^2[\mathrm{eV}^2]l[m]}{E[\mathrm{MeV}]}\right)$$

most sensitive region

$$\Delta m^2 = (1/1.27) \cdot (E[\mathrm{MeV}]/L[m]) \cdot (\pi/2)$$
$$\sim 3 \times 10^{-5}\mathrm{eV}^2$$

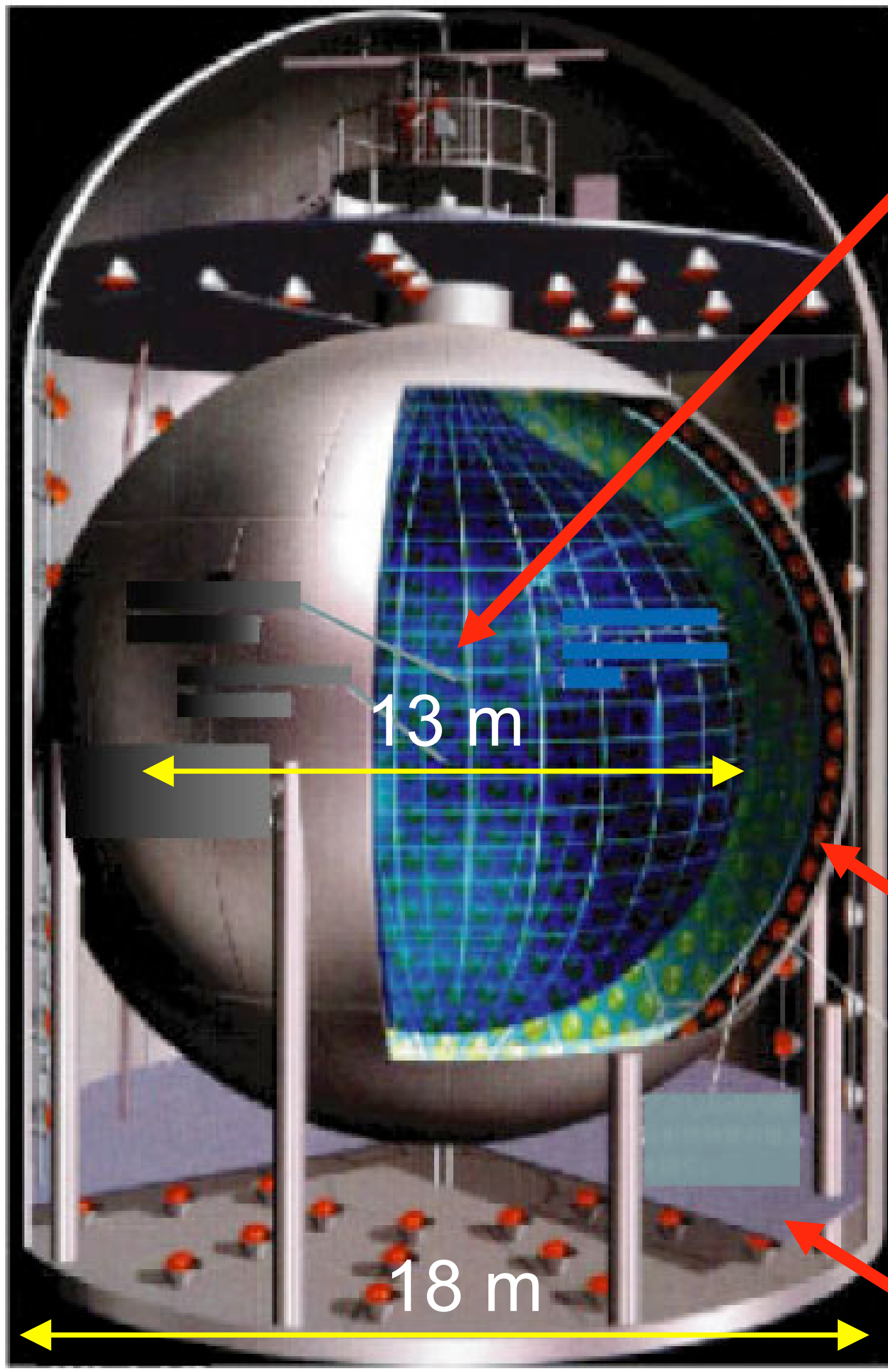
⟶ LMA solution

ΔL (distance spread from reactors)	
175 ± 35 km	~ 20%
ΔE (energy resolution)	
17 inch PMTs	$7.3\% / \sqrt{E(\mathrm{MeV})}$
17 inch + 20 inch	$6.2\% / \sqrt{E(\mathrm{MeV})}$

Good condition to confirm solar neutrino oscillation

KamLAND

Kamioka Liquid Scintillator Anti-Neutrino Detector

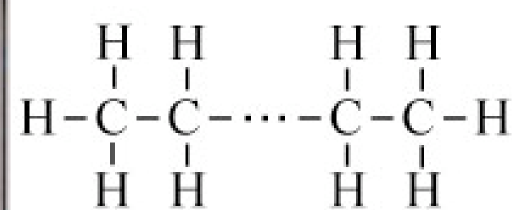


1,000 ton Liquid Scintillator

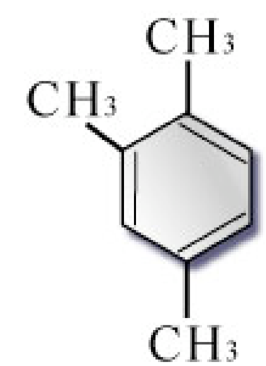
Dodecane (80%)

Pseudocumene (20%)

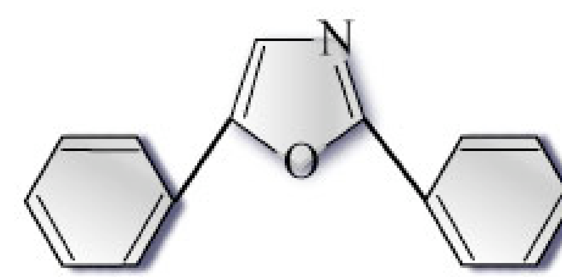
PPO (1.5 g/l)



Dodecane ($C_{12}H_{26}$) : 80%



Pseudocumene : 20%
(1,2,4-Trimethyl Benzene)



PPO : 1.5 g / l
(2,5-Diphenyloxazole)

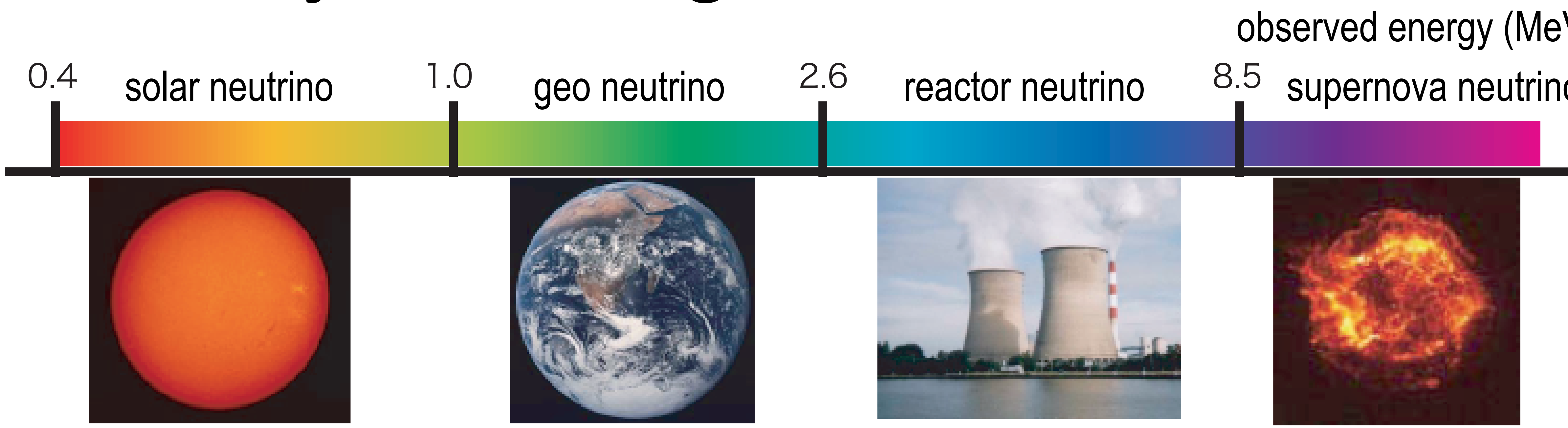
1,325 17 inch + 554 20 inch PMTs

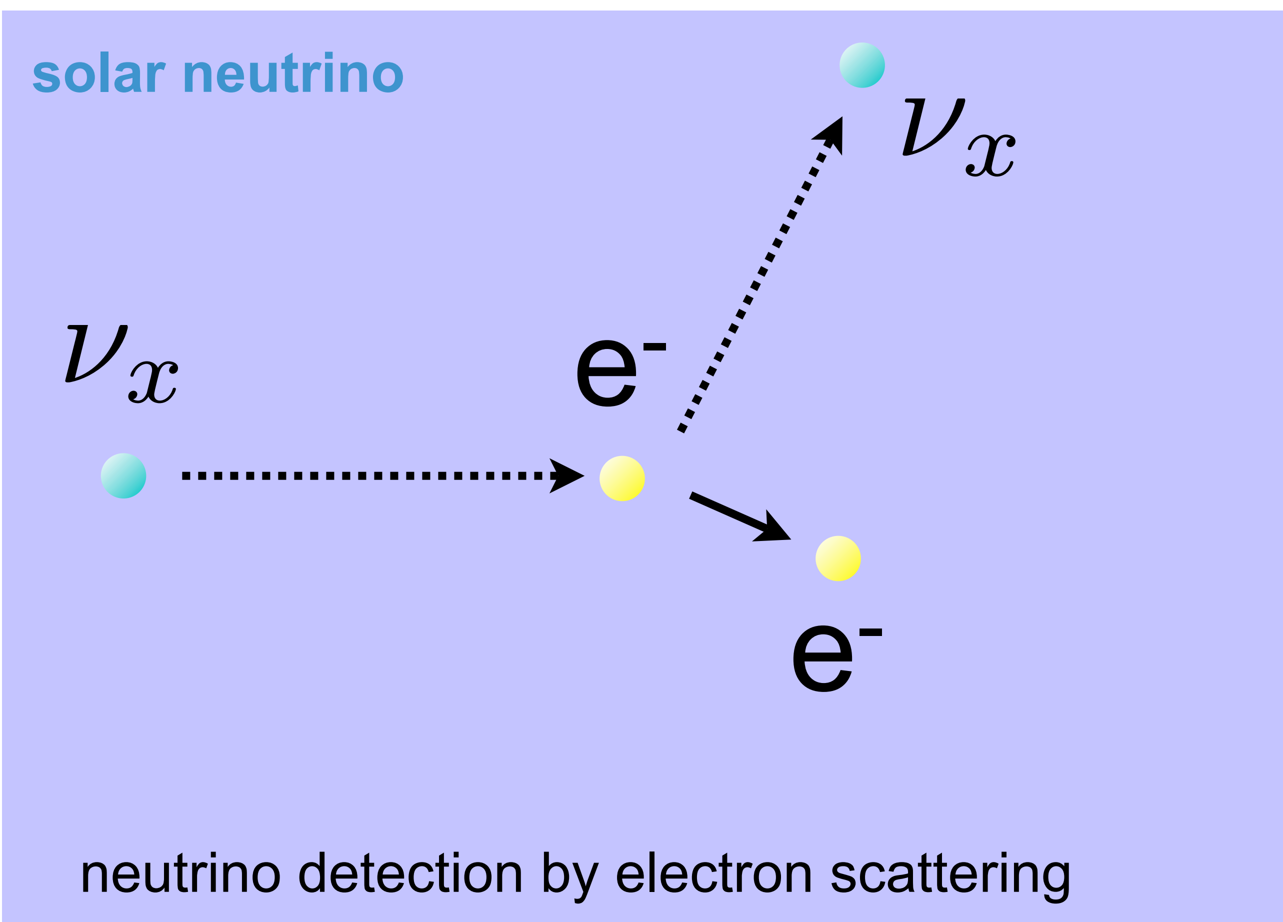
commissioned in February, 2003

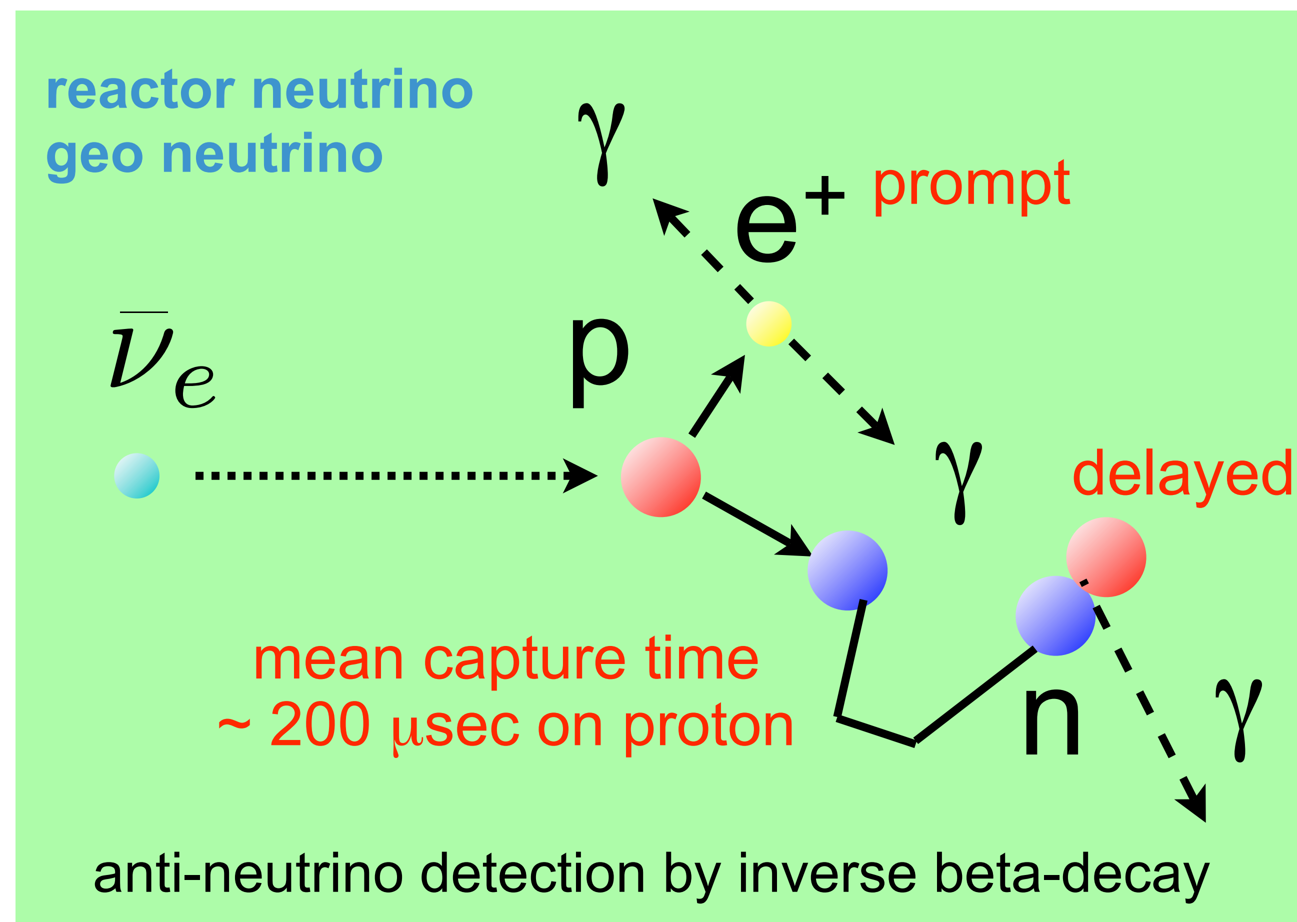
photocathode coverage : 22% → 34%

Water Cherenkov Outer Detector

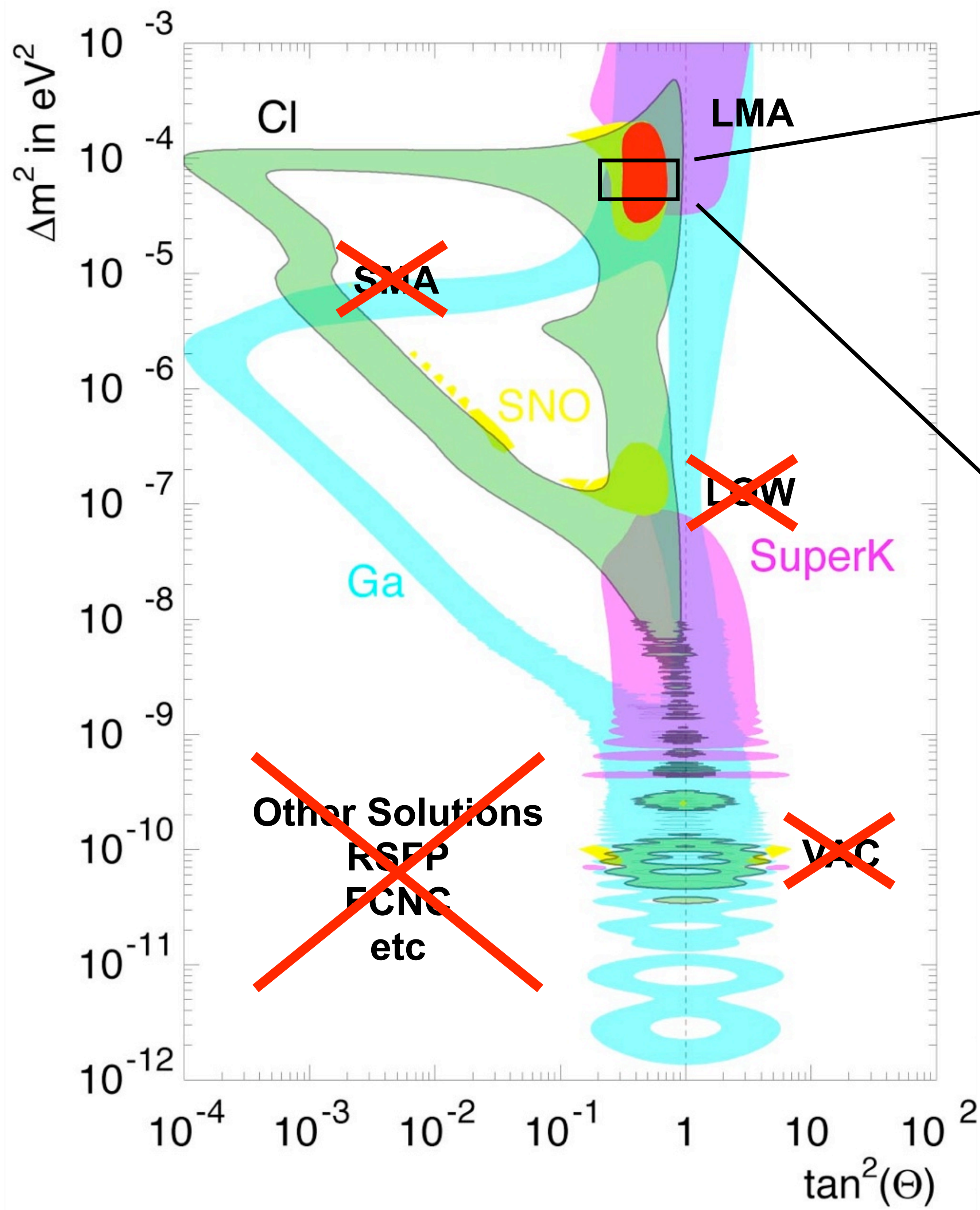
Physics Target in KamLAND

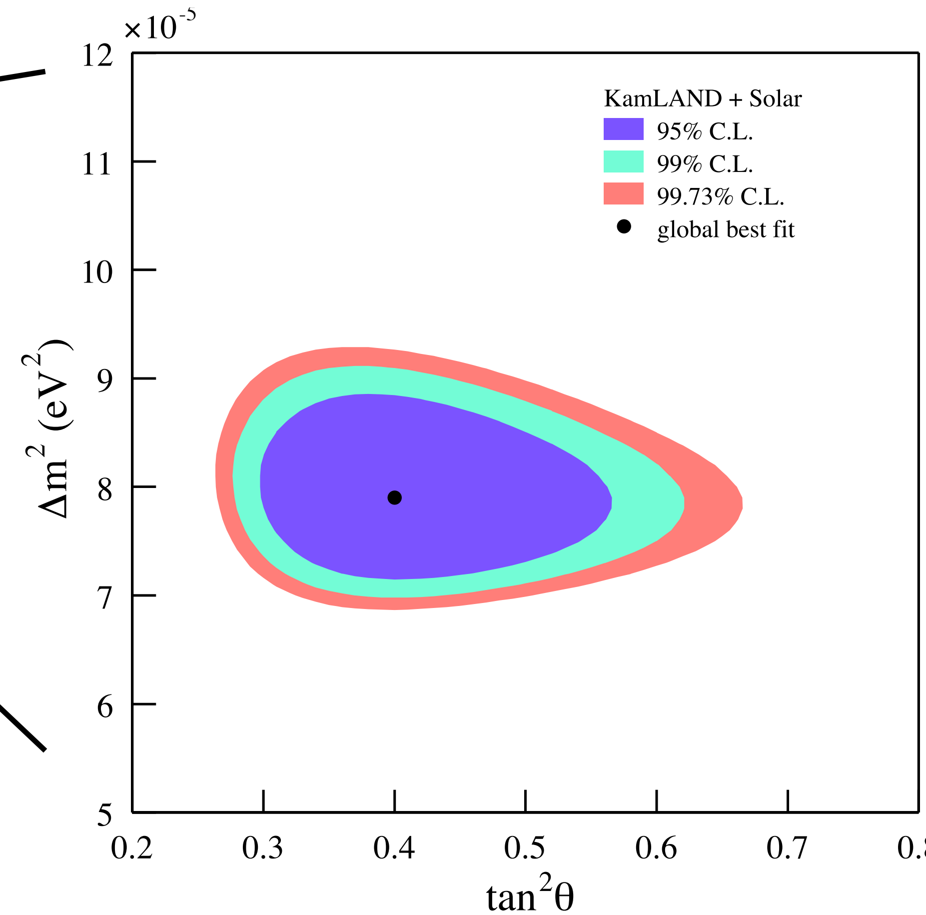






Precise Measurement of Oscillation Paramter





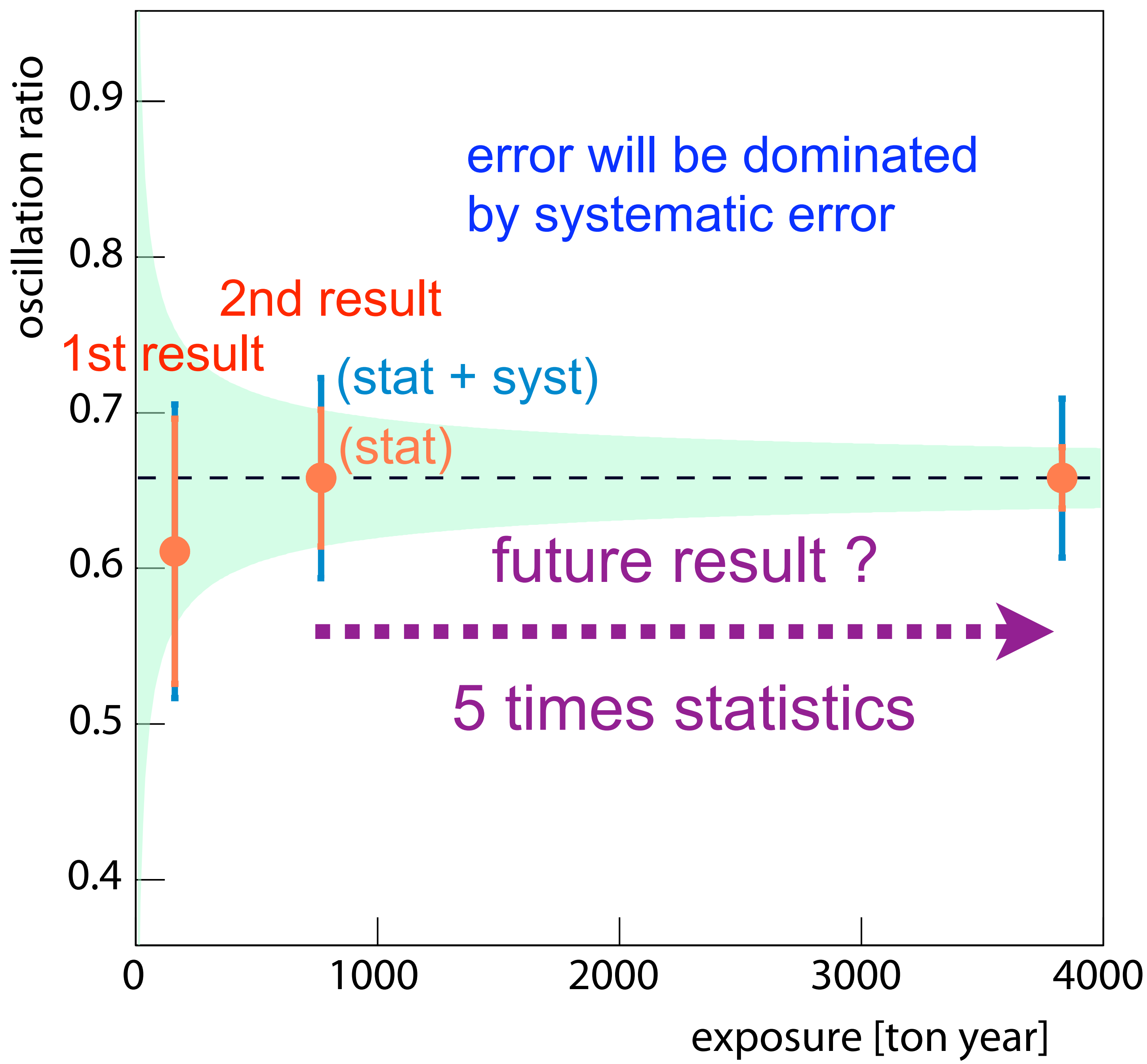
solar + KamLAND result

$$\tan^2\theta = 0.40^{+0.10}_{-0.07}$$

$$\Delta m^2 = 7.9^{+0.6}_{-0.5} \times 10^{-5}\ \mathrm{eV}^2$$

Reactor Future Prospect

oscillation ratio = $(N_{obs} - B.G.) / N_{exp}$



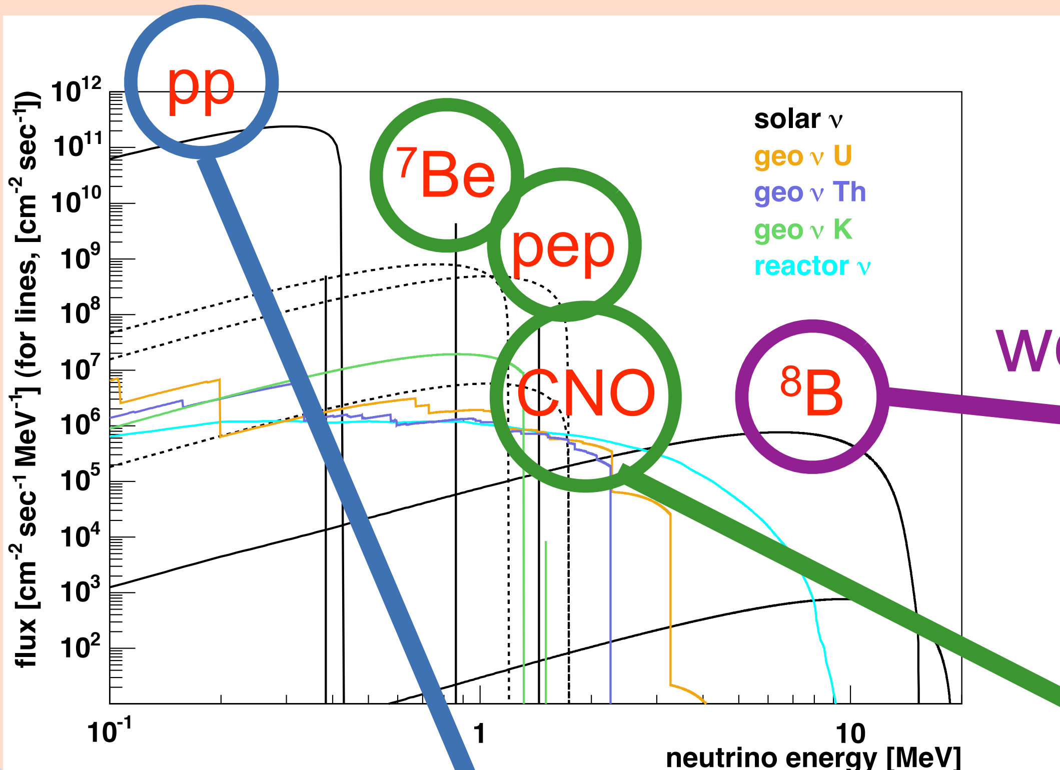
Systematic	%
Fiducial volume	4.7 dominant
Energy threshold	2.3
Efficiency of cuts	1.6
Livetime	0.06
Reactor power	2.1
Fuel composition	1.0
$\overline{\nu}_e$ spectra	2.5
Cross section	0.2
Total	6.5

Fiducial volume uncertainty will be reduced by full volume calibration (now planing)

full volume calibration ⟶ systematic uncertainty ~ 4%

Future Solar Neutrino Measurement

low energy solar neutrino observation



well understood

~ 0.01%

high energy

Super-Kamiokande
SNO

~ 9%

development stage ...

~ 91%

low energy

LENS (^{115}In)
MOON (^{100}Mo)
SIREN (^{160}Gd)

XMass
GENIUS
CLEAN
HERON

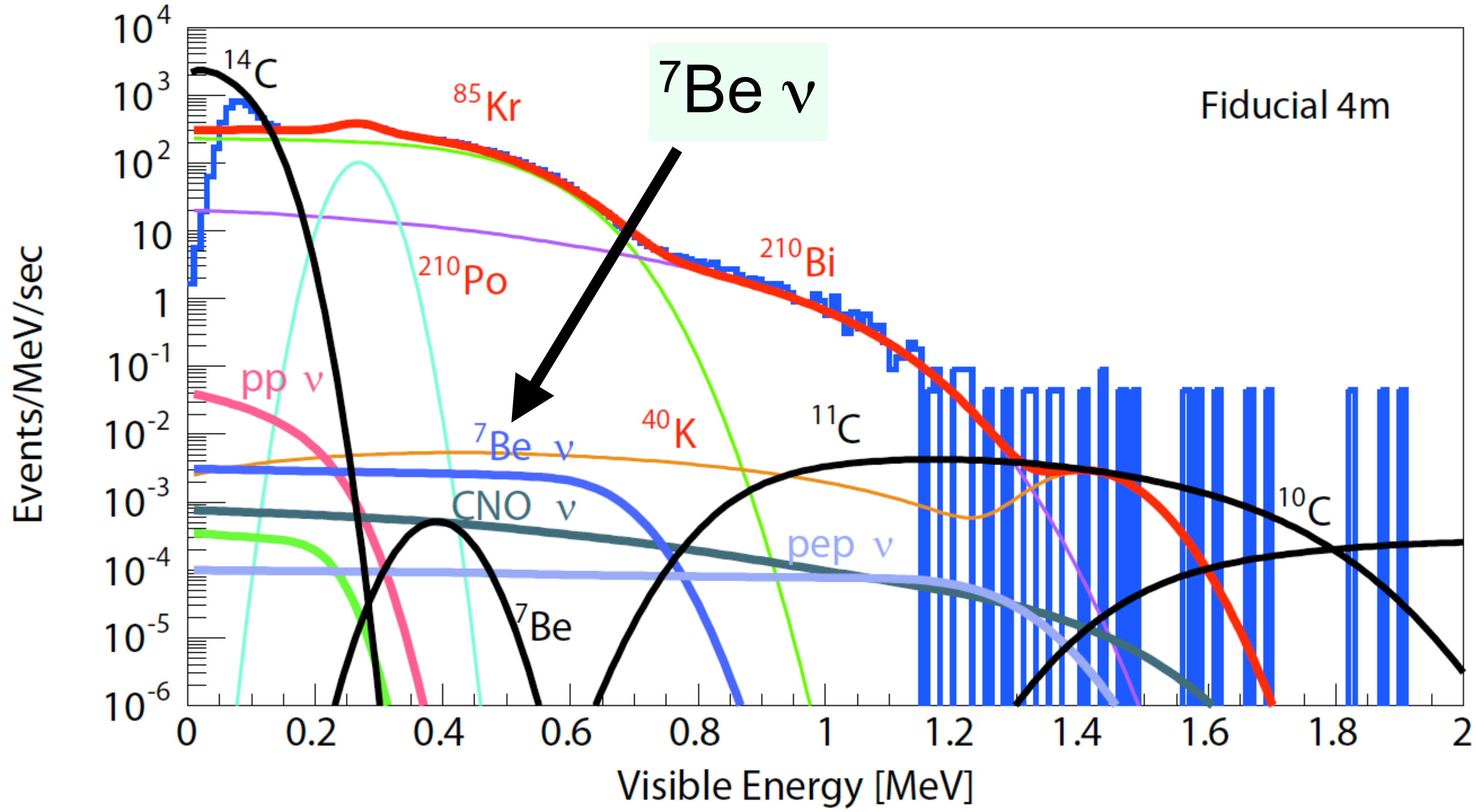
Borexino
KamLAND II
SNO+
LENA

$$\nu_e n \rightarrow e^- p$$

$$\nu_e e^- \rightarrow \nu_e e^-$$

KamLAND II (Solar Neutrino Phase)

KamLAND singles spectra

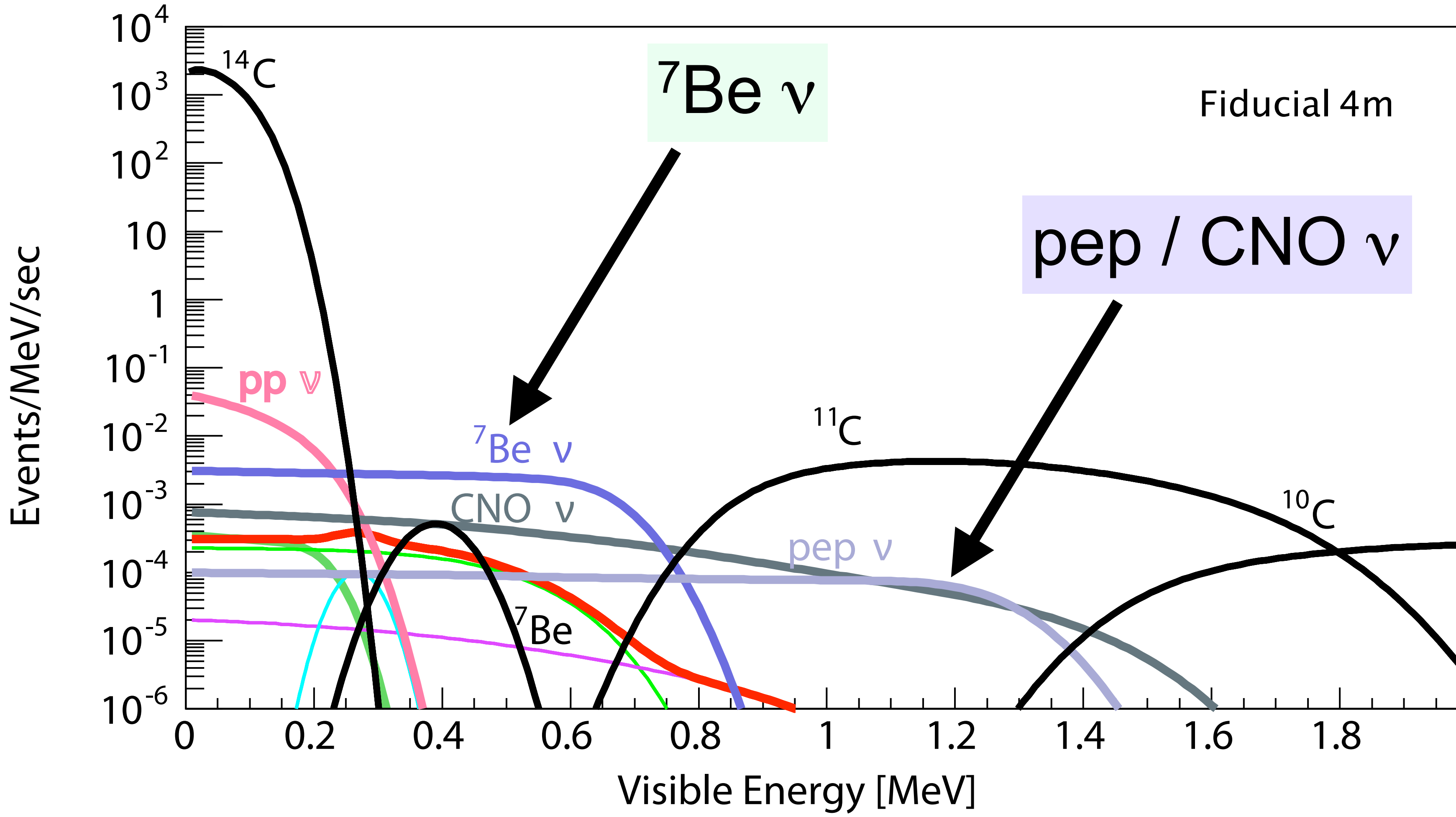


^{7}Be ν observation

B.G. reduction requirement ~ 1 μBq / m^3

Energy Spectra after Purification

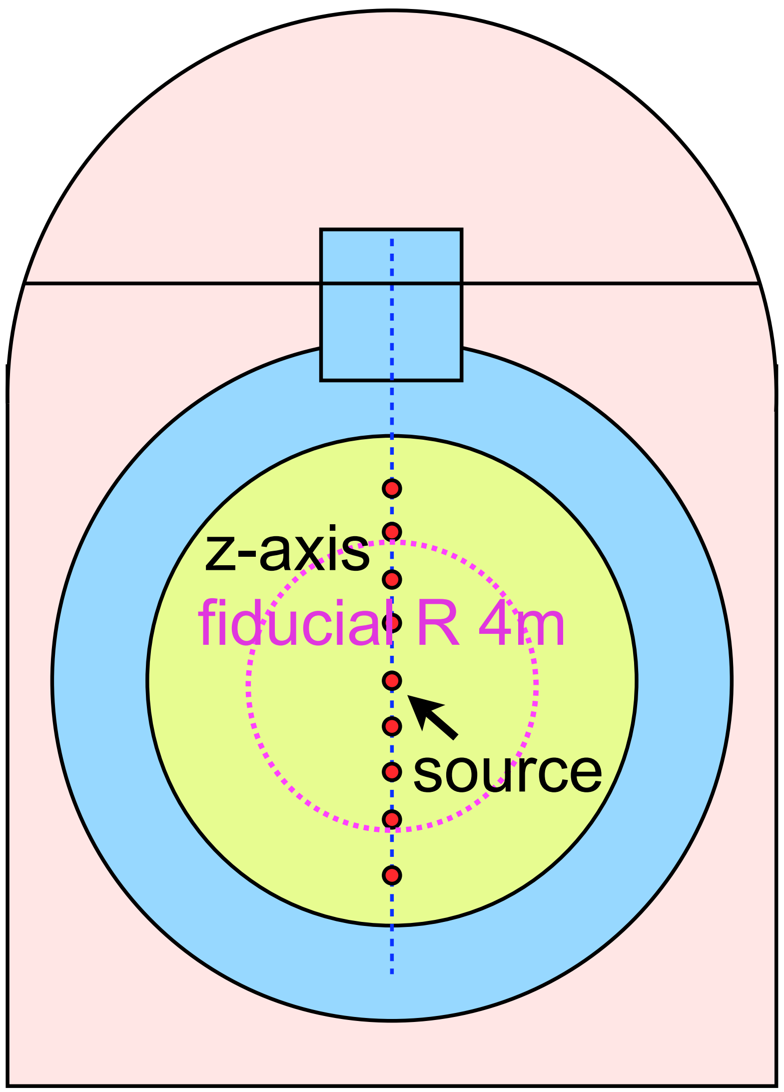
assuming 10^{-6} reduction of ^{210}Pb, ^{85}Kr and ^{40}K

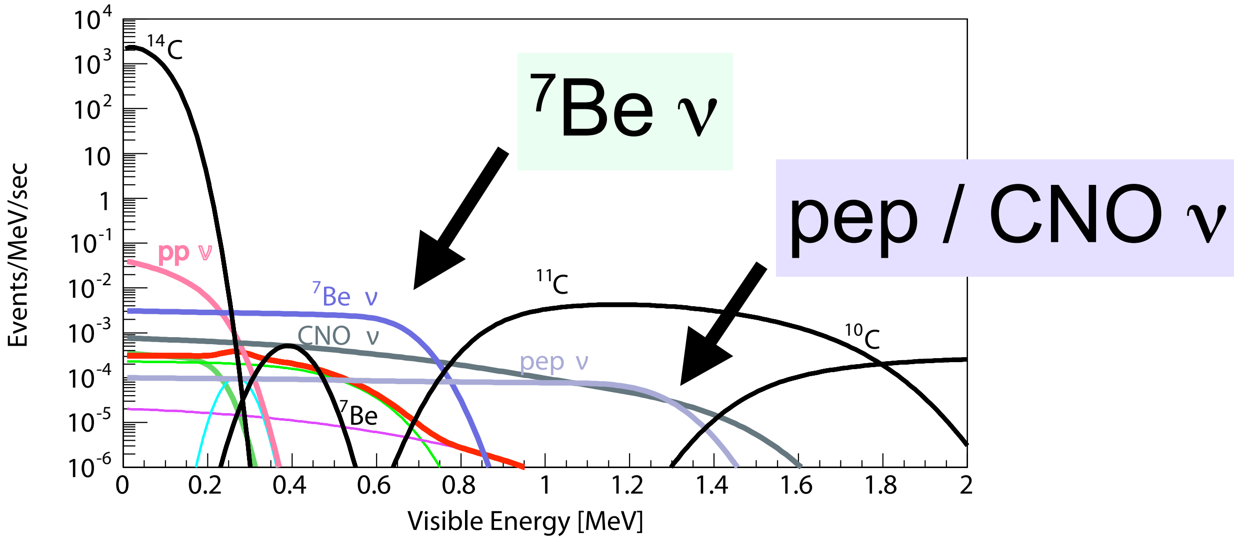


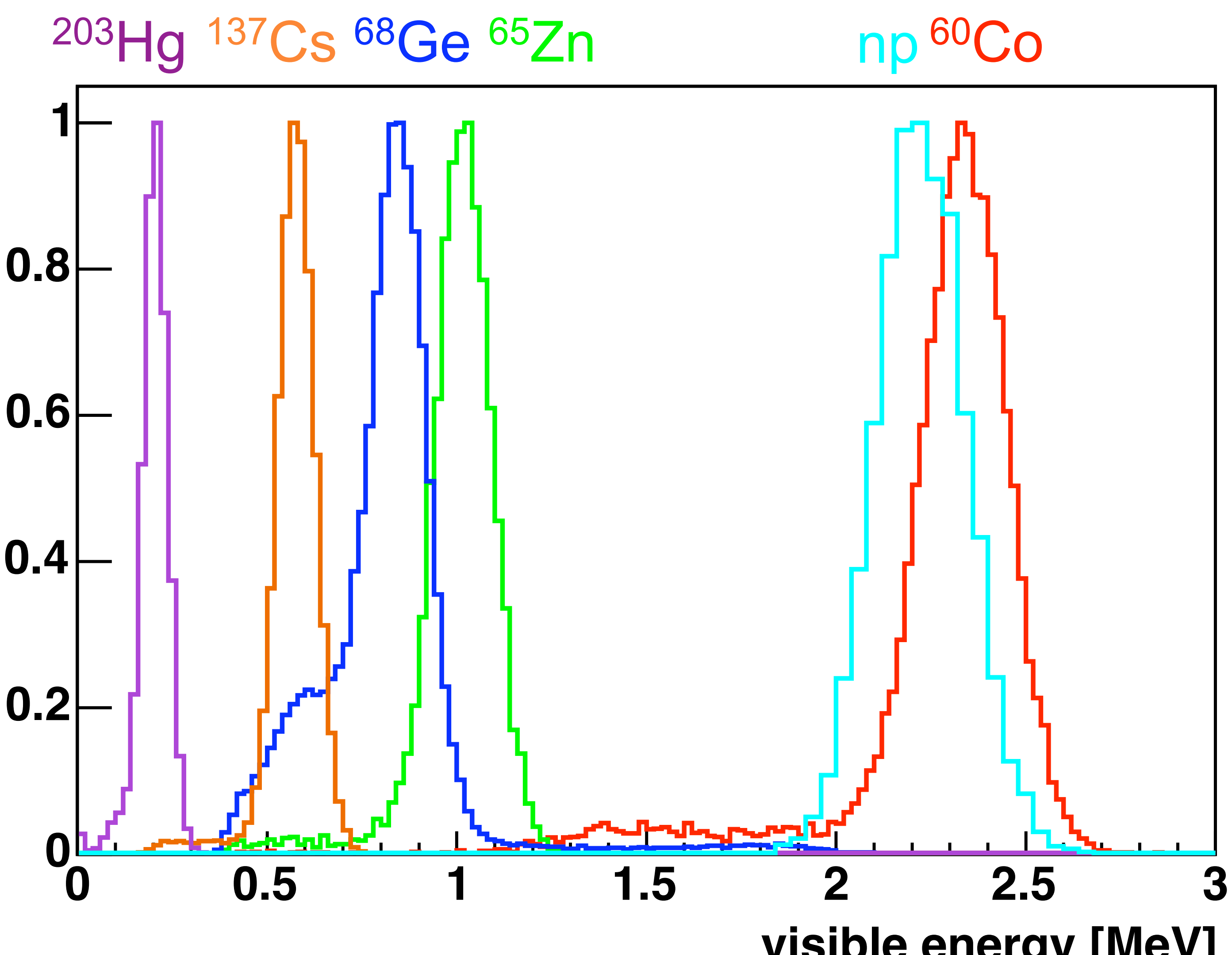
expected event rate (no oscillation) 0.3 < E < 0.8 MeV

^7Be ν	79.9 event / day
pep ν	3.8 event / day
CNO ν	16.3 event / day

Source Calibration below 1 MeV







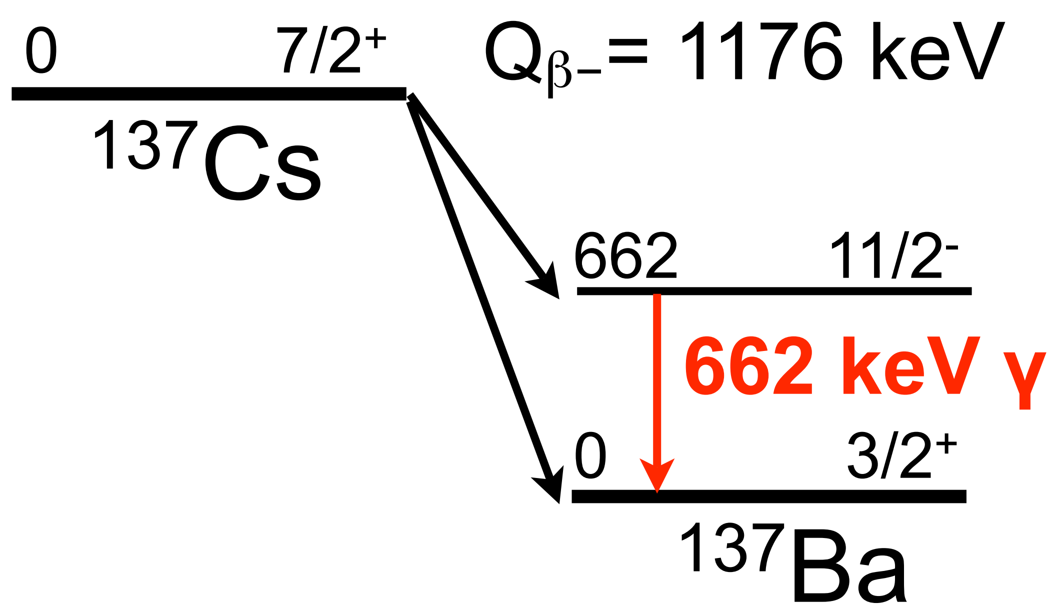
calibration below 1 MeV

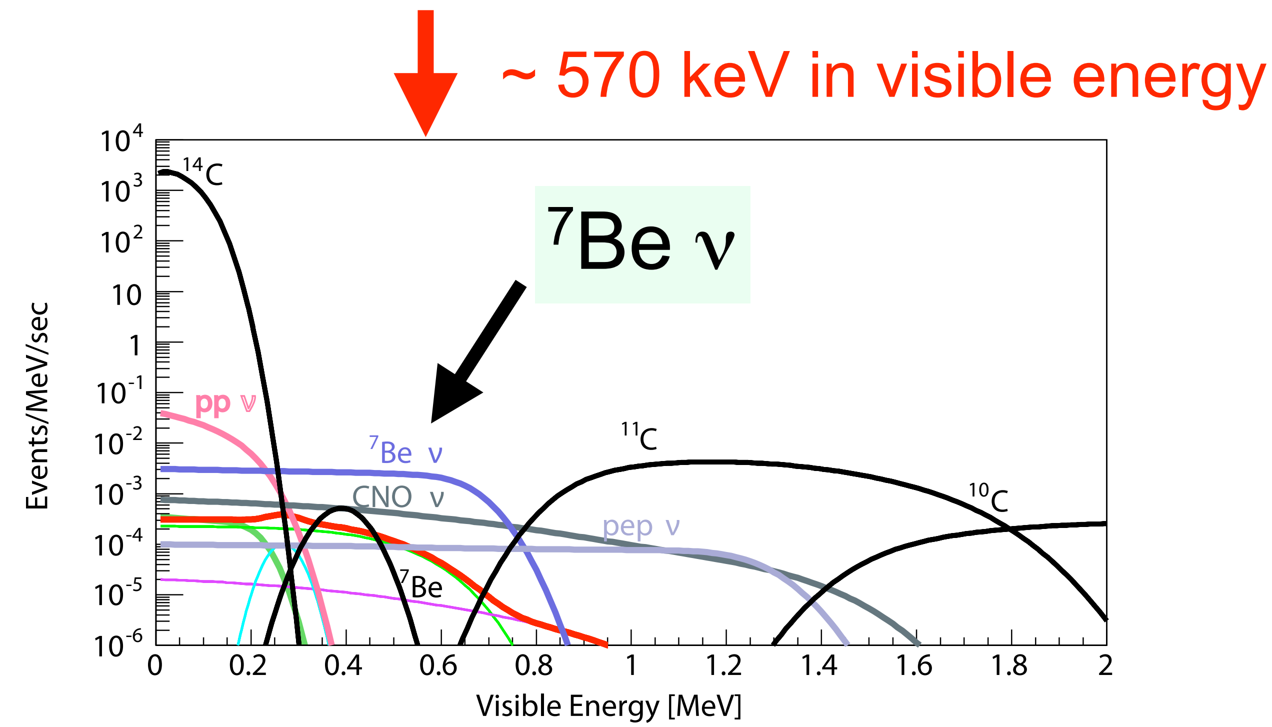
↓

^{68}Ge, ^{137}Cs, ^{203}Hg

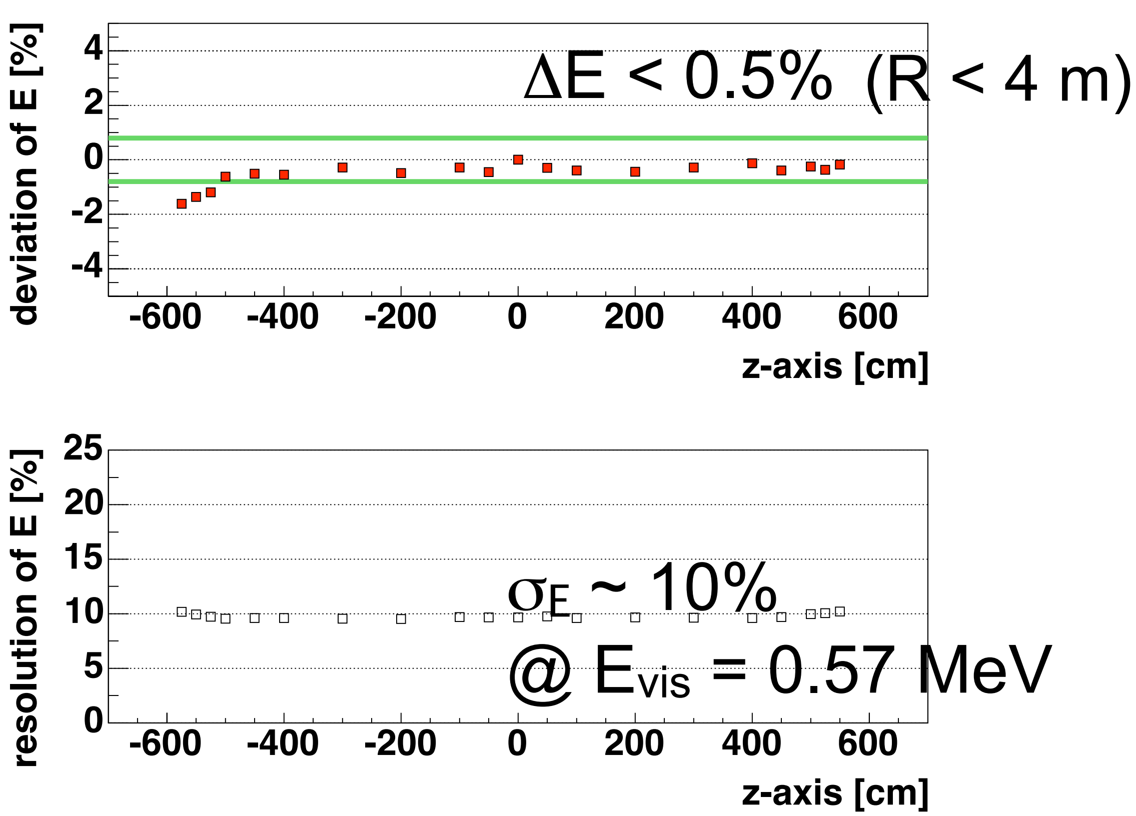
Event Reconstruction in Low Energy

^{137}Cs source calibration

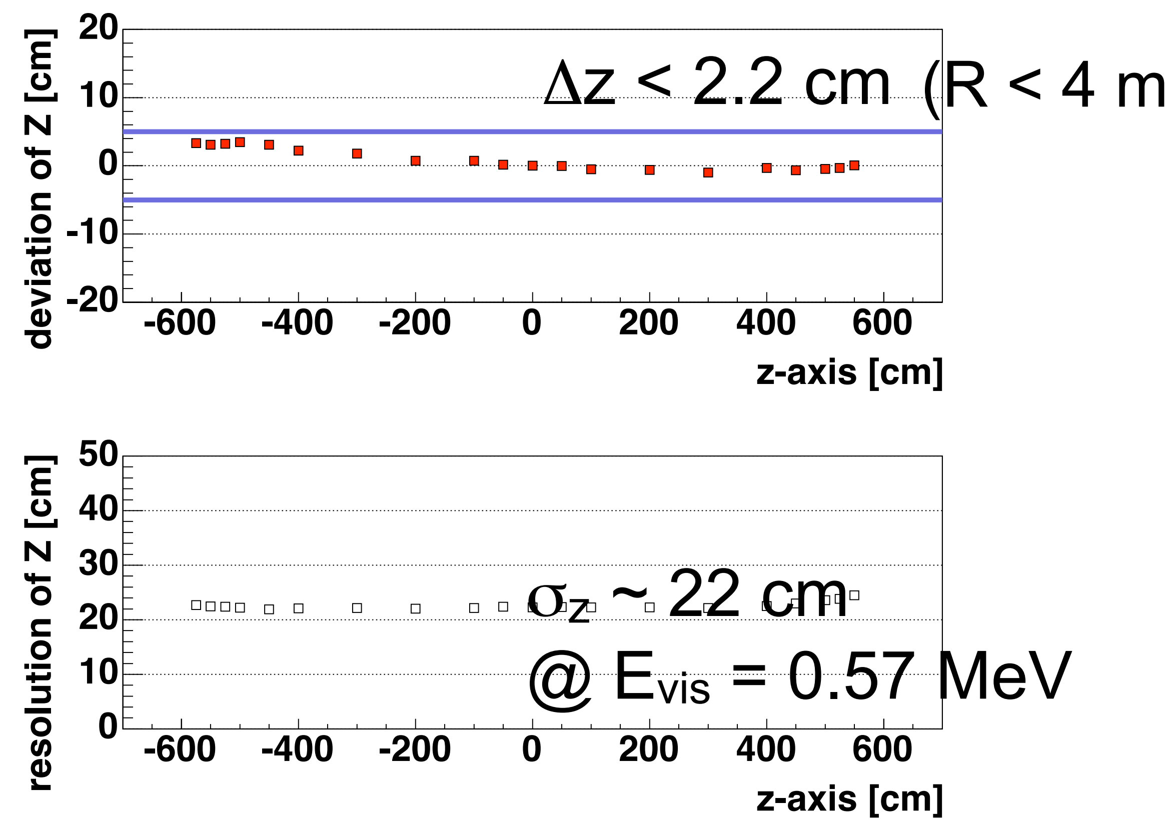




energy

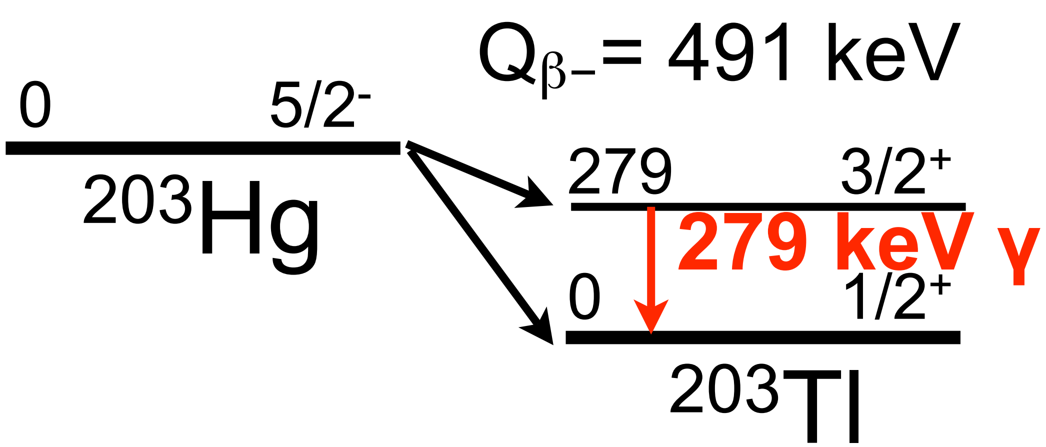


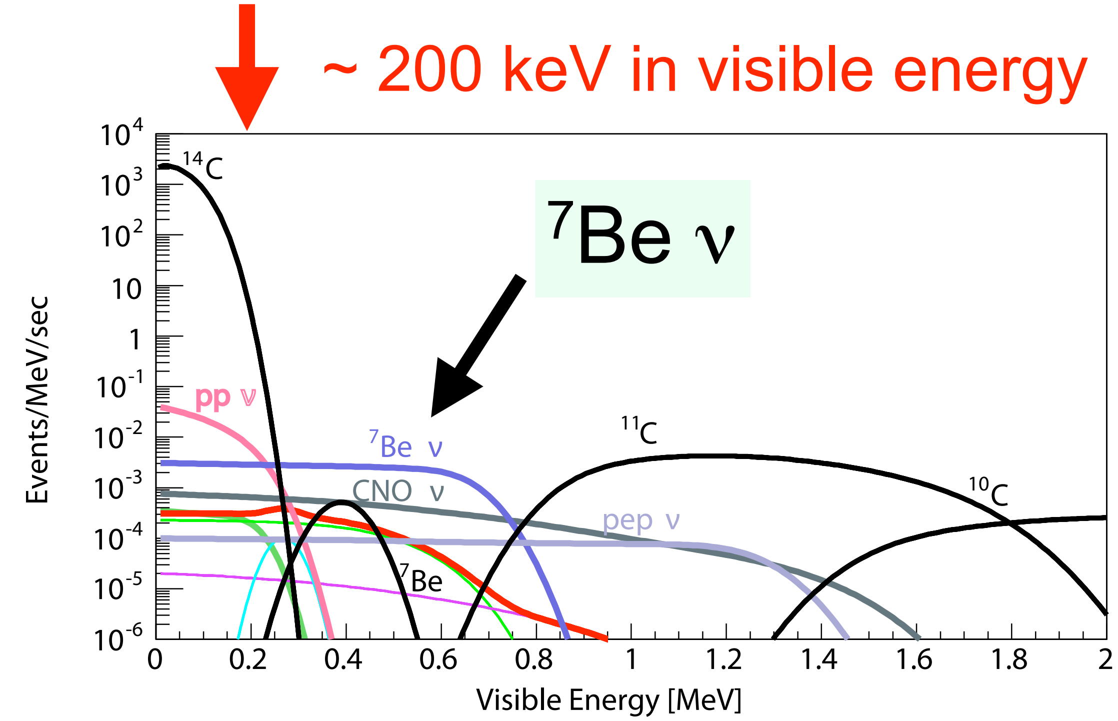
vertex



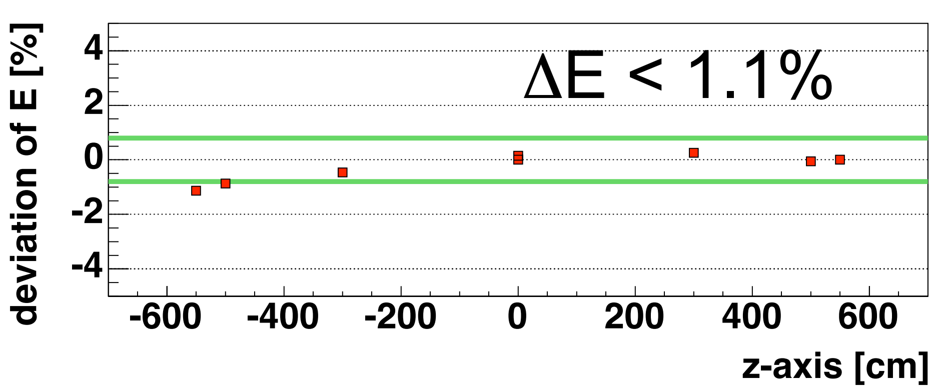
Event Reconstruction in Low Energy

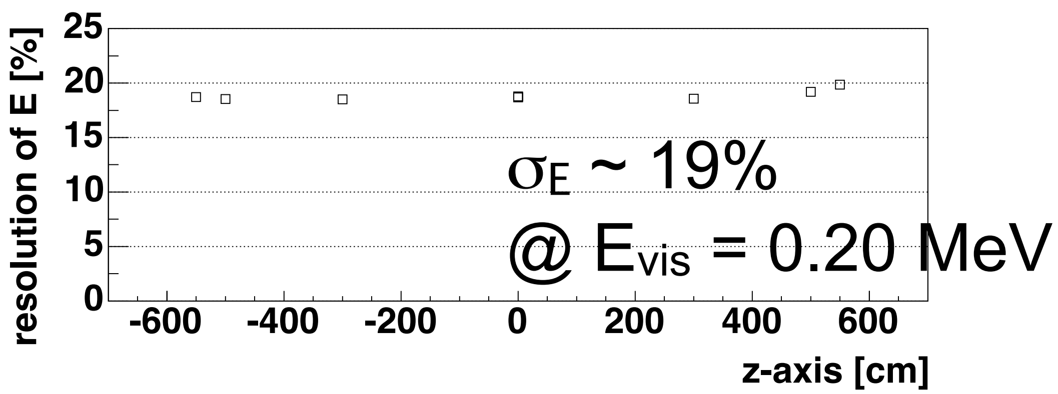
^{203}Hg source calibration



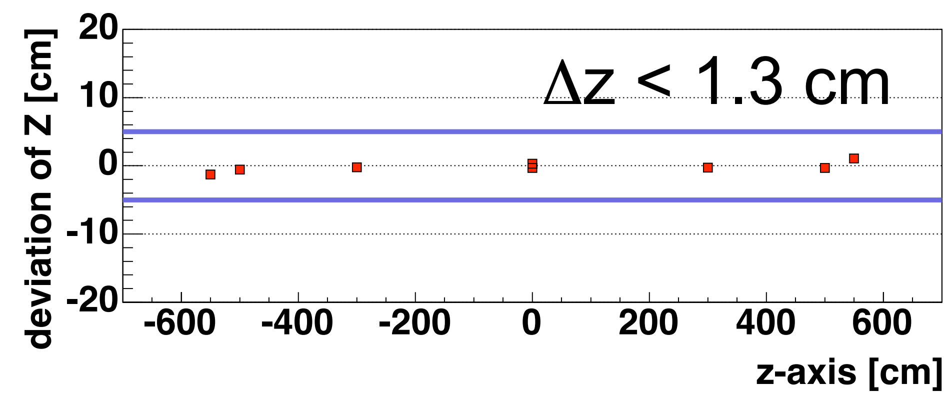


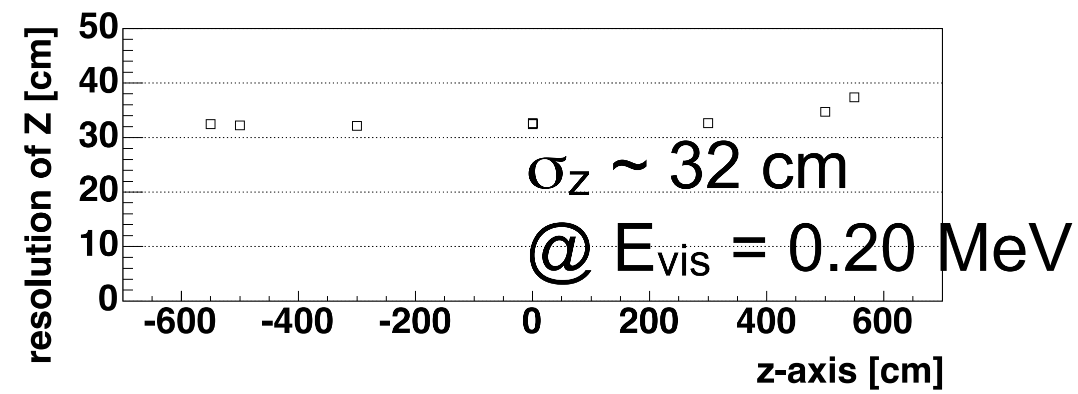
energy



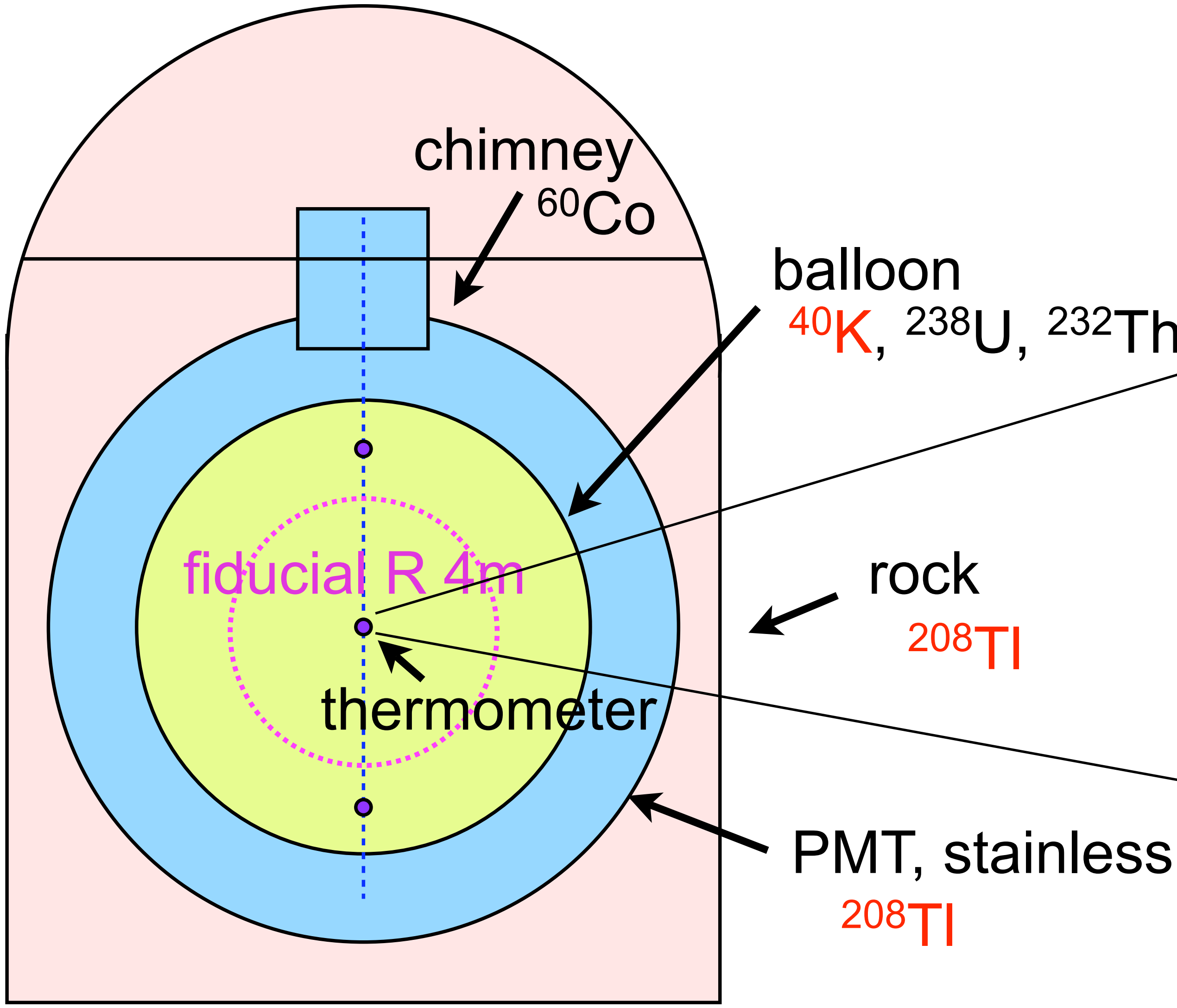


vertex

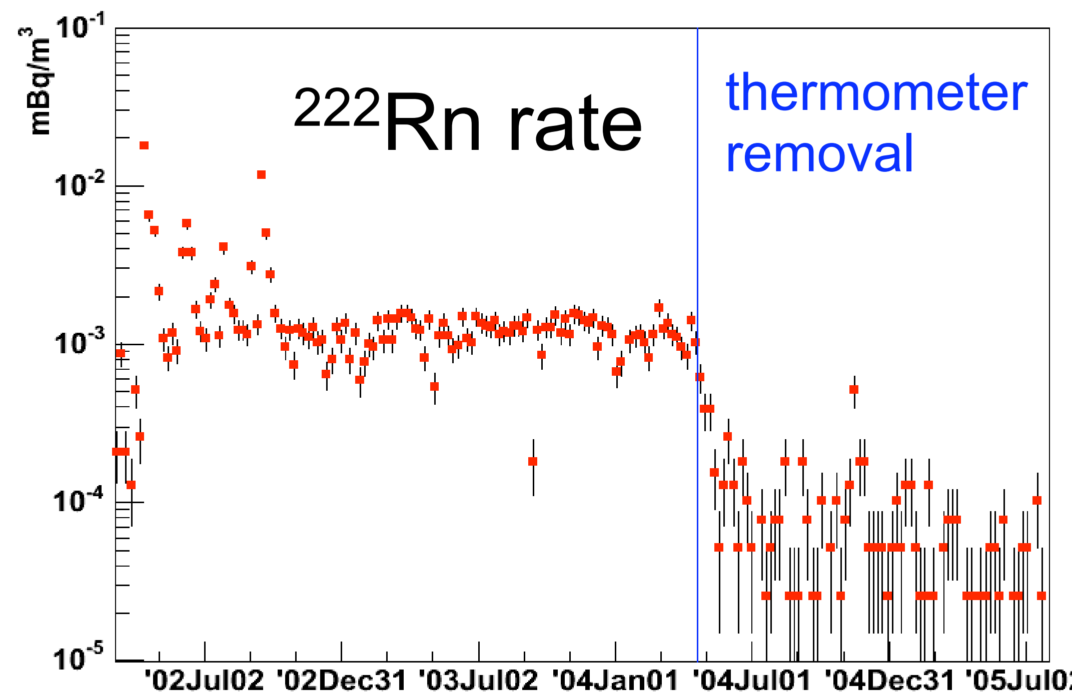




External Background



thermometer removal (Apr. 19, 2004)



thermometer removal

↓

^{222}Rn rate around z-axis (ρ < 2 m)

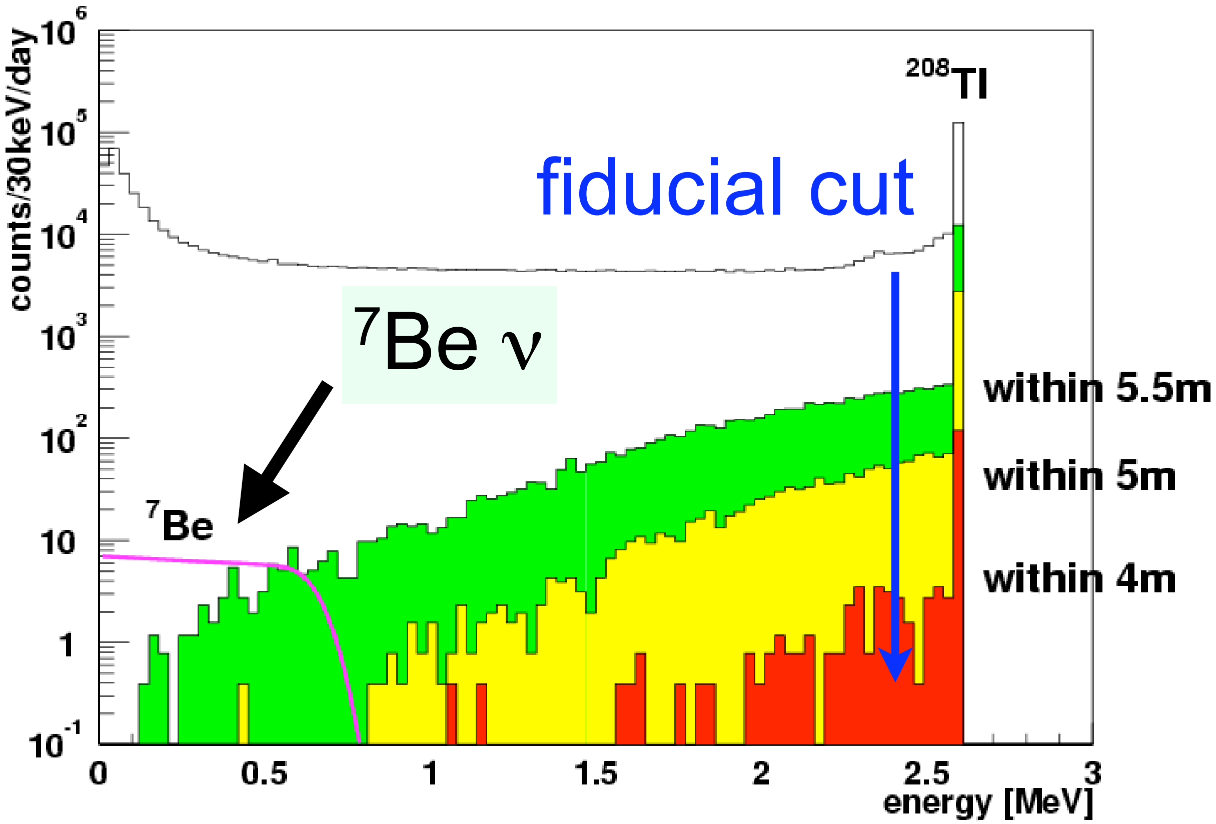
1 μBq/m^3 → < 0.1 μBq/m^3

(^{7}Be rate ~ 3 μHz/m^3)

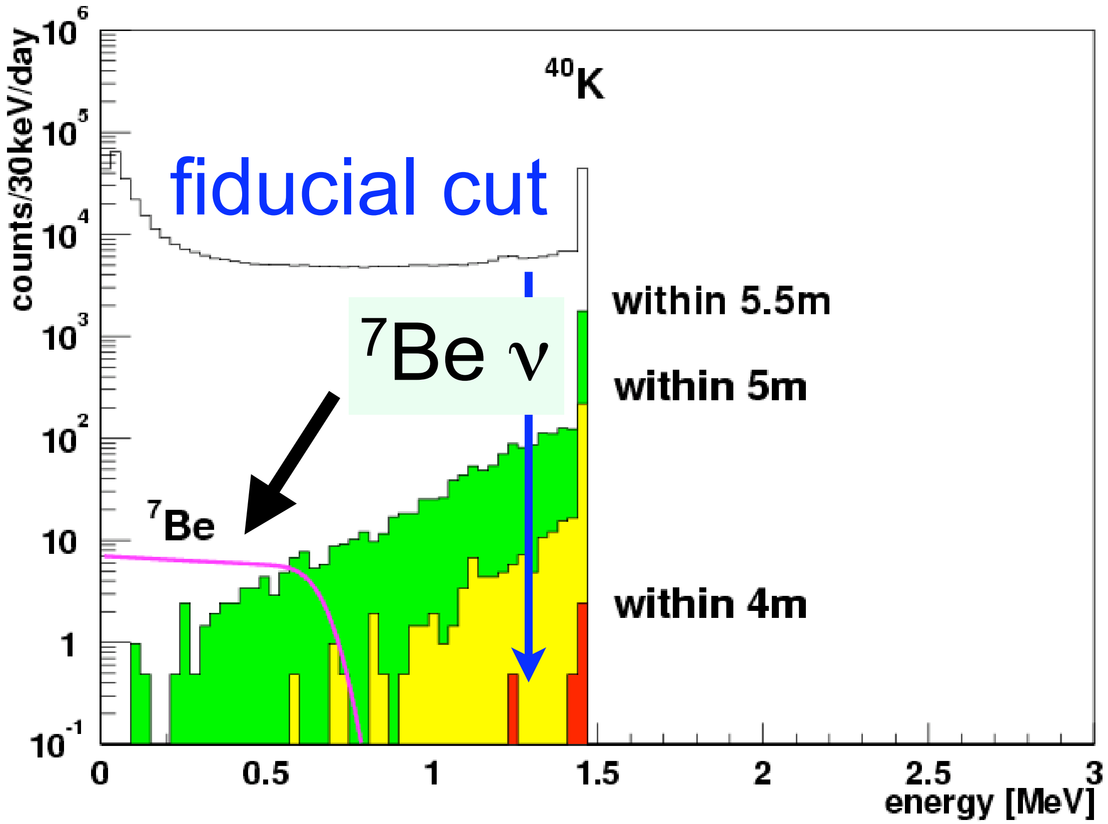
External Gamma-ray Background

External gamma-ray B.G. is studied by MC

^{208}Tl (2.62 MeV γ)
Rock, PMT, stainless, ...

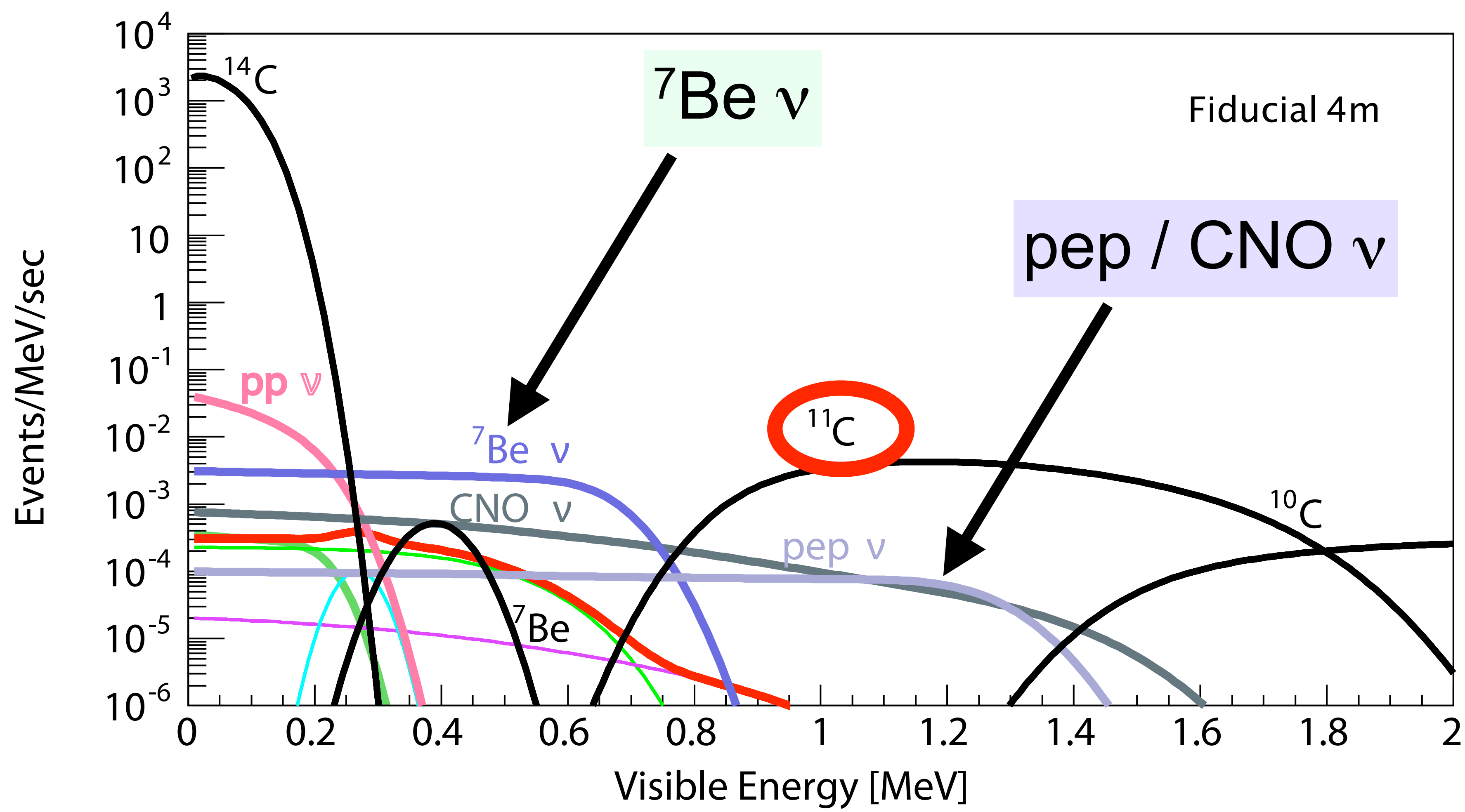


^{40}K (1.46 MeV γ)
EVOH film, Kevlar rope, ...



fiducial R 4 m cut is enough

Muon Spallation Background

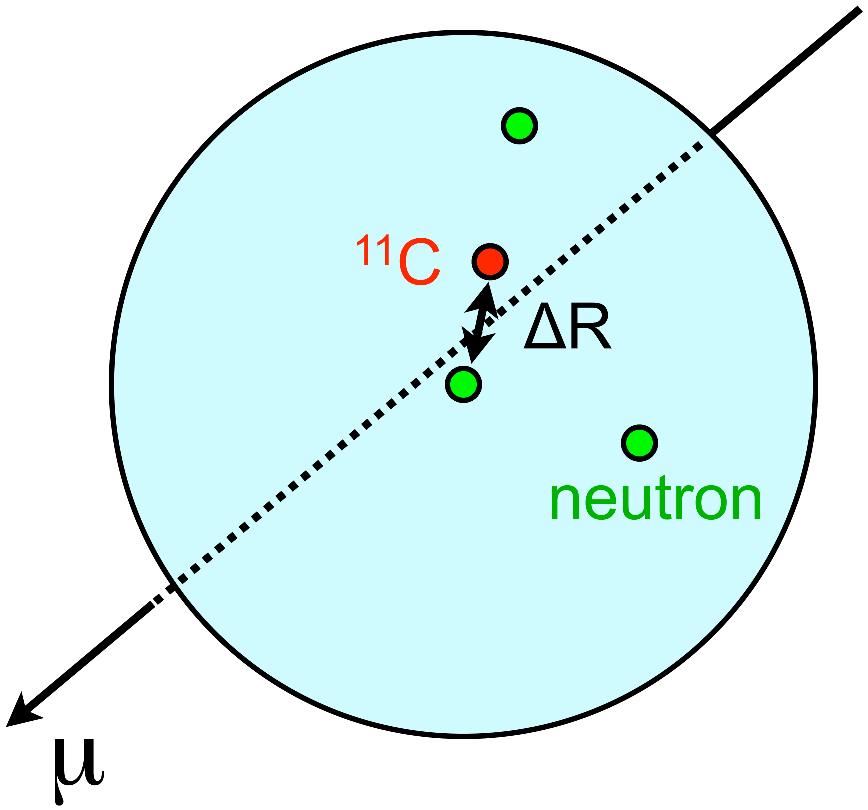


	Life time	Q value	Hagner et al. (ev/d/kton)
^{10}C	27.8 sec	3.65 MeV (β^{+})	139
^{11}C	29.4 min	1.98 MeV (β^{+})	1039
^{7}Be	76.9 day	0.478 MeV (EC)	231

serious B.G. for pep / CNO ν

^{11}C Rejection by Neutron Events

nuclear spallation reaction by cosmic-ray muons



^{11}C rejection by triple coincidence

(1) cosmic-ray muon

(2) neutron (mean capture time ~ 210 μsec)

(3) ^{11}C (lifetime = 29.4 min)

↓

point-like rejection (not track-like) using neutron vertex information

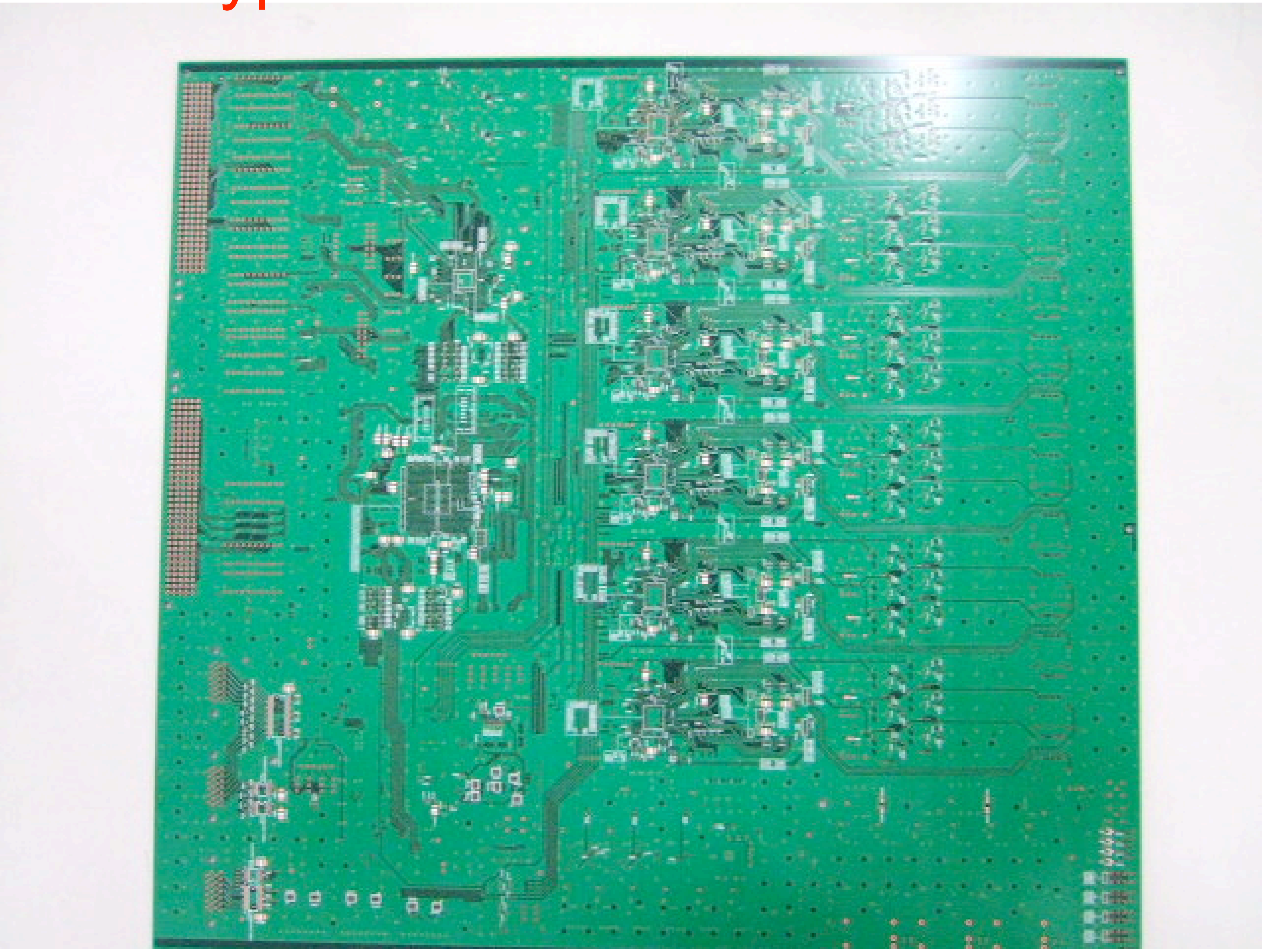
$$^{12}\mathrm{C} + \mathrm{X} \rightarrow {}^{11}\mathrm{C} + n + \mathrm{Y} + \cdots$$

$$\mathrm{X} = \gamma, n, p, \pi^-, \pi^+, e, \mu$$

n production rate ~ 95% (Galbiati et al., hep-ph/0411002)

Electronics for ^{11}C Tagging

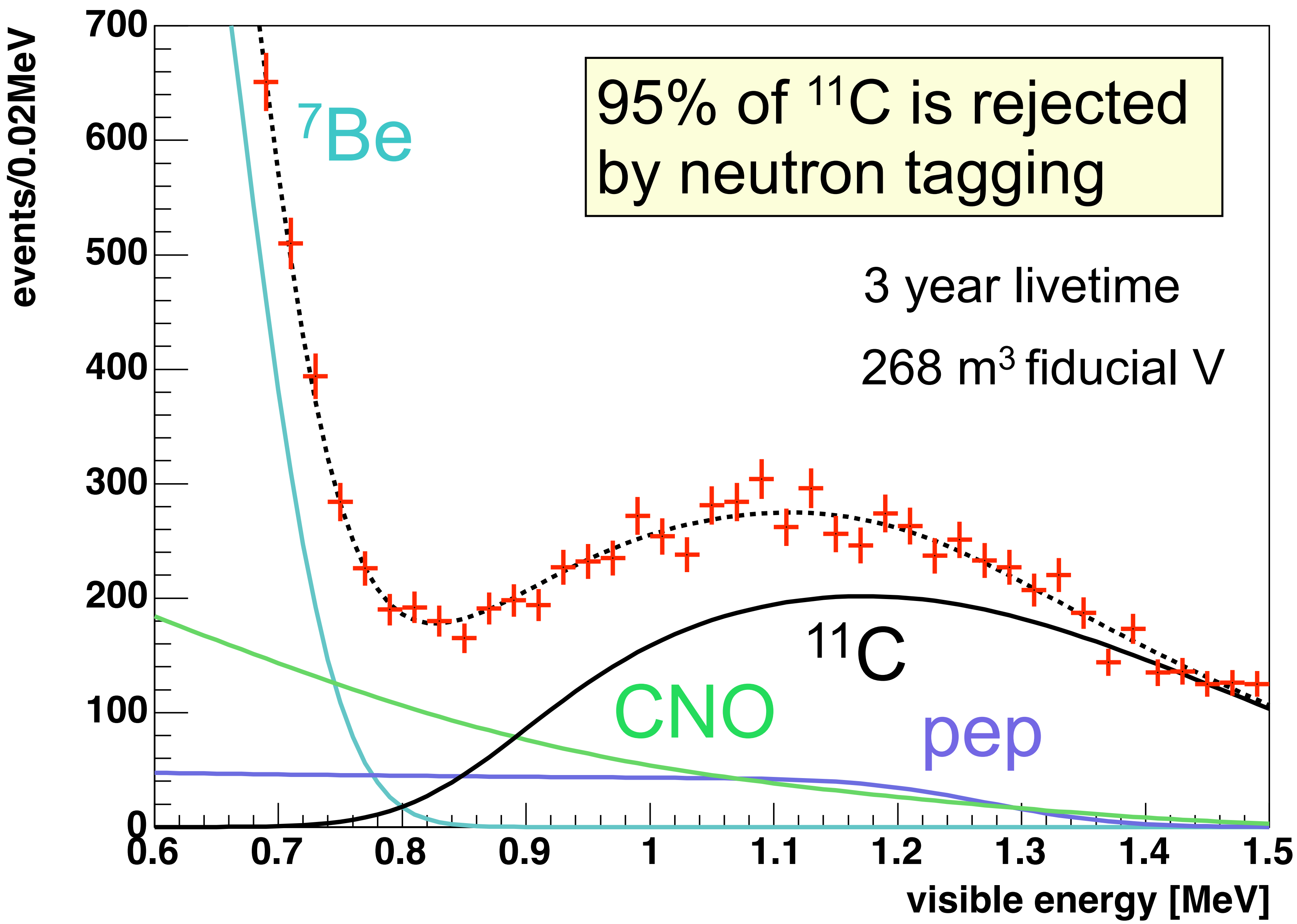
Prototype



no dead time for high multiplicity events (spallation neutrons) after muons

Energy Spectra after ^{11}C Rejection

pep and CNO ν (0.8 < E < 1.4 MeV)



^{11}C rejection simulation

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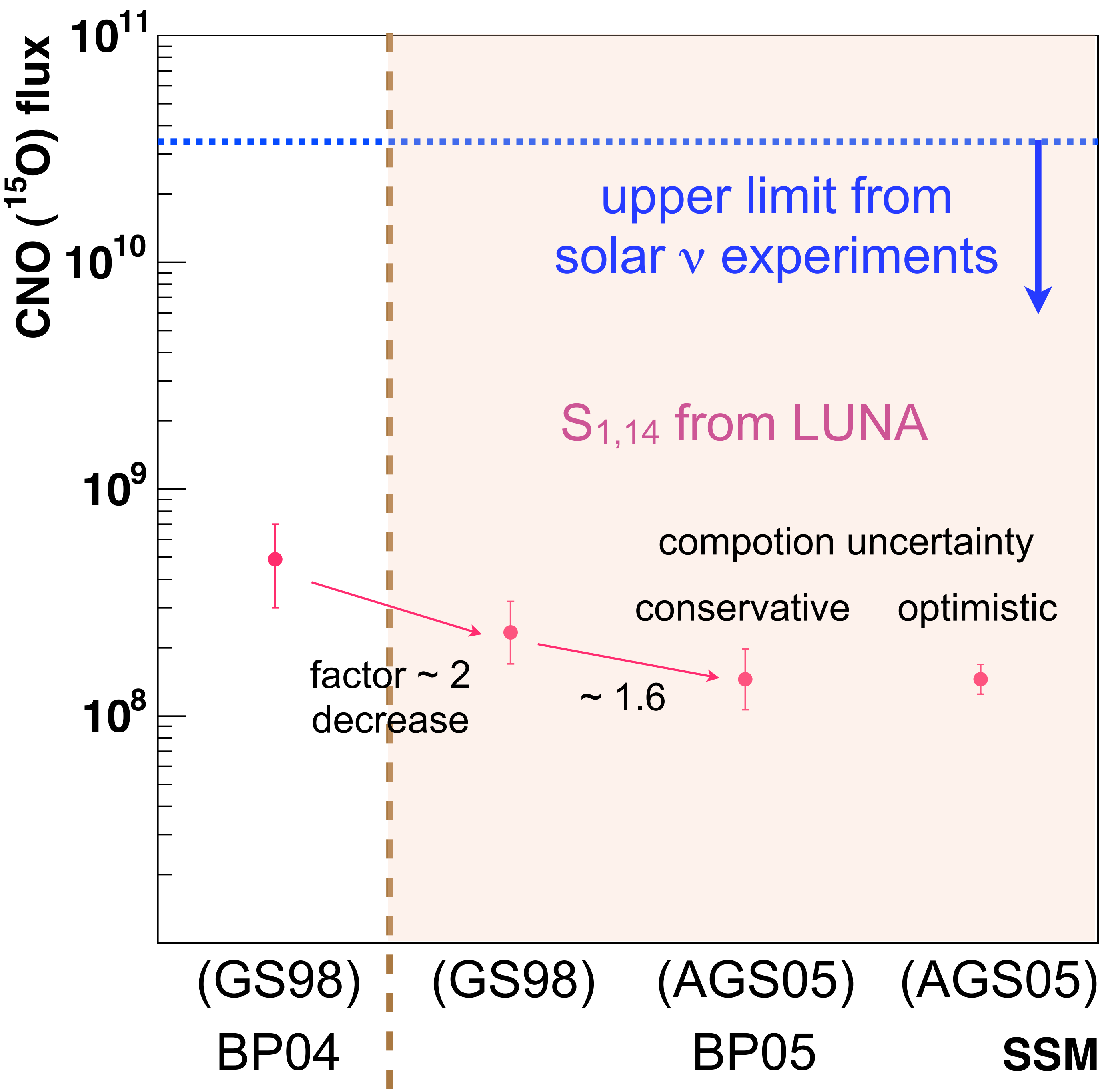
pep + CNO flux error ~ 6% (statistical error)

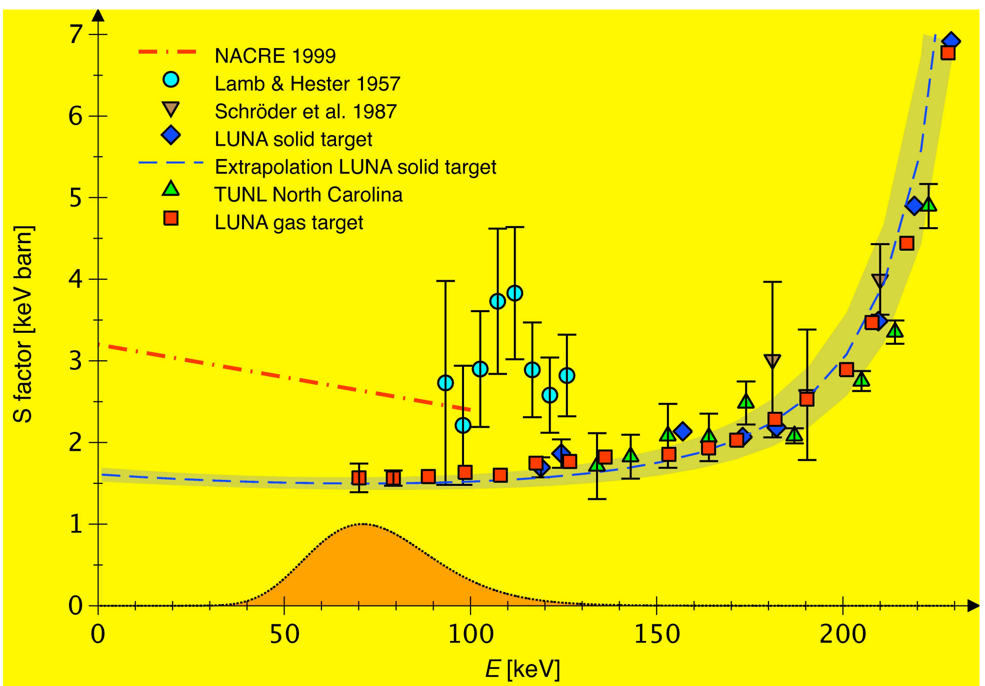
CNO Neutrino Flux

CNO neutrino flux has large uncertainty from $^{14}N(p, \gamma)^{15}O$ cross section and heavy element abundance in the sun



LUNA result

(Carlo Broggini et al., NOW2006)



$S(0) = 1.7 \pm 0.2$ keV b

- $S_{1,14}$ decrease from LUNA
- heavy element abundance decrease

↓

KamLAND observation will test

Summary

- Reactor neutrino experiment contributed to solutions in solar neutrino problem.

KamLAND experiment

↓

- oscillatory shape of reactor anti-neutrinos
- precise measurement of oscillation parameter

- We will observe ^{7}Be, pep and CNO solar neutrino in KamLAND II.
- In the near future, observation of low energy solar neutrino will provide a greater understanding of the sun.