Search for sterile neutrinos at reactors

Osamu Yasuda
Tokyo Metropolitan University

27 September 2011@SNAC11

Based on OY, arXiv:1107.4766 [hep-ph]

● New prediction of the reactor ν flux

→ (3+1)-scheme may fit to the data (LSND+MB+other short baseline expts.) better with new flux than before (with old flux).

→ It is important to confirm sterile ν oscillations

- A ten kilocurie scale anti-ν source (^{144}Ce, ^{106}Ru) $\bar{\nu}_e \to \bar{\nu}_e$
  M. Cribier et al., arXiv:1107.2335
- A proposal for a β-beam $\nu_e \to \nu_e$

  Agarwalla-Huber-Link, JHEP 1001:071,2010
- ν oscillation experiments at a reactor with a small core → Present work arXiv:1107.4766 [hep-ph] $\bar{\nu}_e \to \bar{\nu}_e$

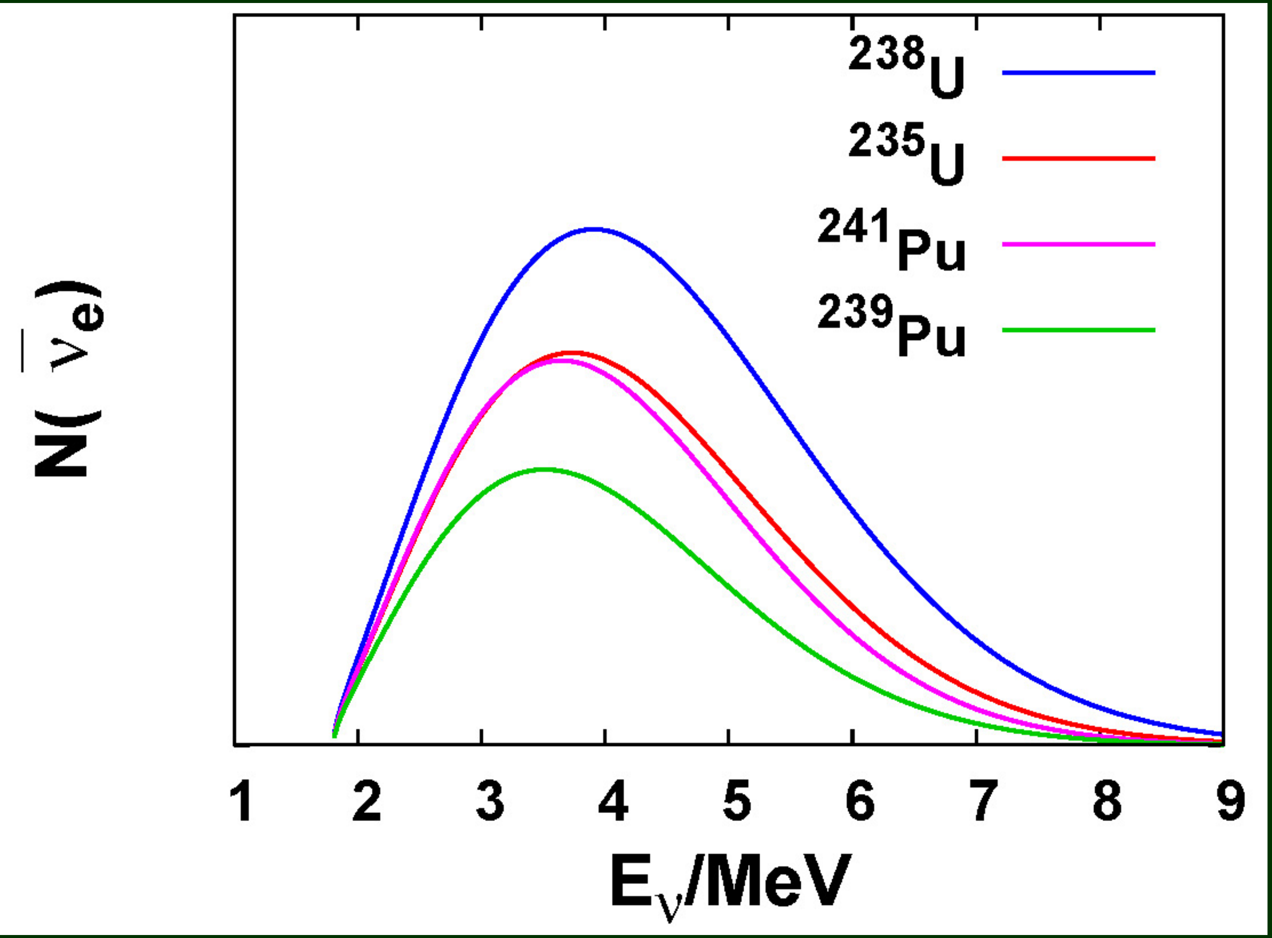
Thermal (Neutron) Reactors vs Fast (Neutron) Reactors

Fuels must be distant ⇨ the volume must be larger

	Kinetic energy of neutron	Moderator	Coolant	Power density
Thermal Neutron Reactor (w/ H_2O)	~0.02eV	H_2O	H_2O	~O(10MW/m^3)
Fast Neutron Reactor	~2MeV	None	Na	~O(100MW/m^3)

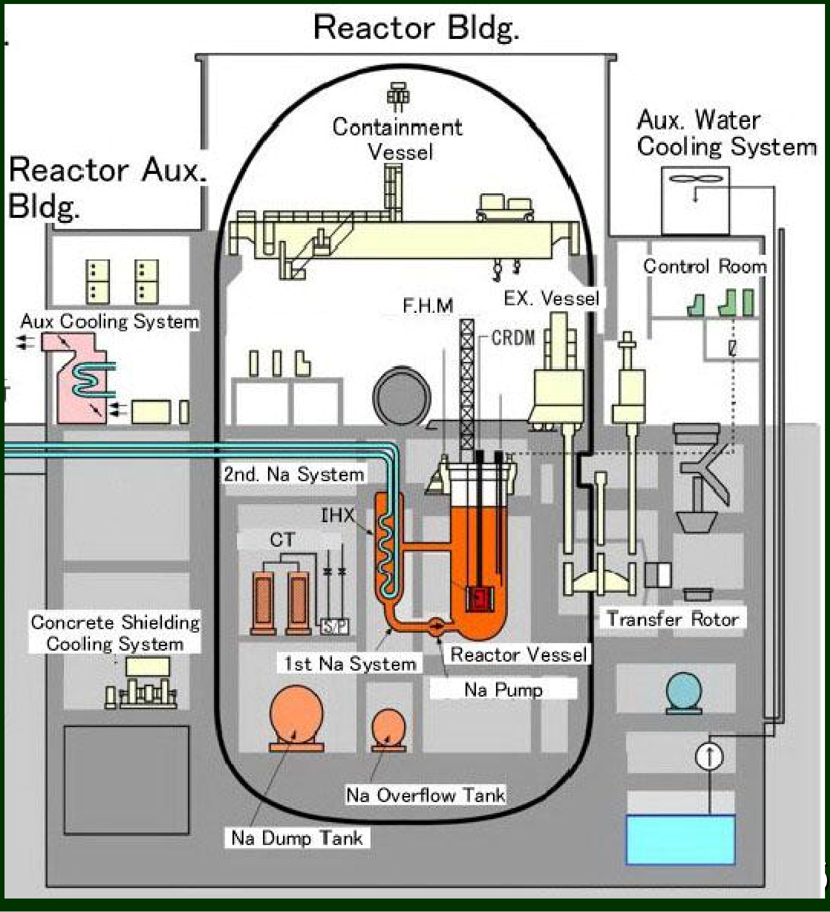
Fuels can be closer ⇨ the volume can be smaller

Composition of Thermal Reactor & Fast Reactor



	^{235}U	^{239}Pu	^{238}U	^{241}Pu
Thermal Neutron Reactor (w/ H_2O)	53.8%	32.8%	7.8%	5.6%
Fast Neutron Reactor	37.1%	51.3%	7.3%	4.3%

Joyo Fast Research Reactor



Operated by JAEA
P_{th}=140MW
Frequent On/Off

●Analysis of a reactor neutrino oscillation experiment with one reactor & two detectors

$$\chi^2 = \min_{\alpha's}\left\{ \sum_{A=N,F}\sum_{i=1}^{n}\frac{1}{(t_i^A\sigma_i^A)^2}\left[m_i^A - t_i^A(1+\alpha+\alpha^A+\alpha_i) - \alpha_{\rm cal}^A t_i^A v_i^A\right]^2 \right.$$
$$\left. + \sum_{A=N,F}\left[\left(\frac{\alpha^A}{\sigma_{\rm dB}}\right)^2 + \left(\frac{\alpha_{\rm cal}^A}{\sigma_{\rm cal}}\right)^2\right] + \sum_{i=1}^{n}\left(\frac{\alpha_i}{\sigma_{\rm Db}}\right)^2 + \left(\frac{\alpha}{\sigma_{\rm DB}}\right)^2 \right\}.$$

n=#(bin)=32

OY, arXiv: 1107.4766 [hep-ph]

m^A_i : Measured numbers of events

t^A_i : Theoretical prediction

v^A_i : Variation due to energy calibration error

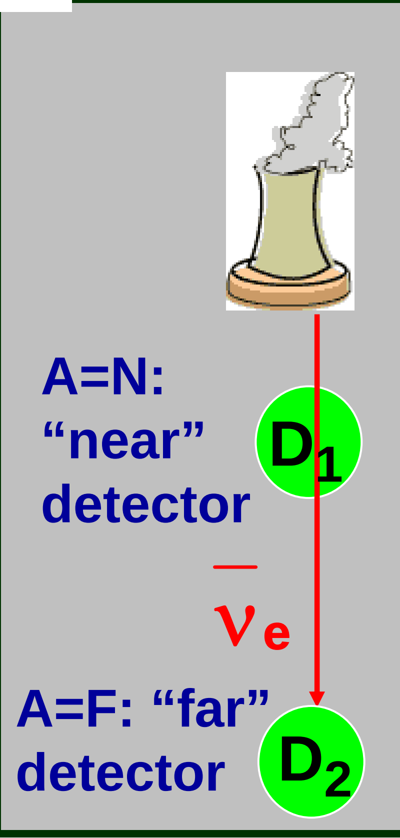
$$(t_i^A\sigma_i^A)^2 = t_i^A + \left(t_i^A\sigma_{\rm db}^A\right)^2$$

statistical errors

systematic errors

In the present case $\sigma_{stat} > \sigma_{sys}$:

statistical errors are more important



Assumed systematic errors

σ_{DB}: correlated wrt detectors, correlated wrt bins = **3%**

σ_{Db} :correlated wrt detectors, uncorrelated wrt bins = **2%**

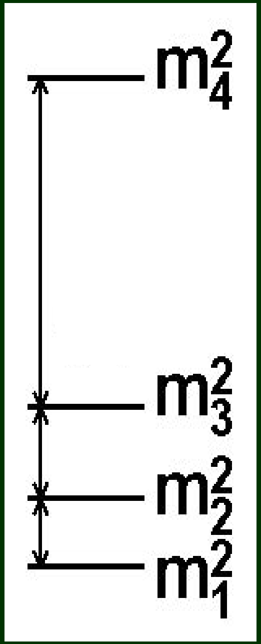
σ_{dB} :uncorrelated wrt detectors, correlated wrt bins = **0.5%**

σ_{db} :uncorrelated wrt detectors, uncorrelated wrt bins = **0.5%**

σ_{cal} :energy calibration error for each bin = **0.6%**

Formula for oscillation probability for (3+1)-scheme

$$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) = 1 - \sin^2 2\theta_{14} \, \sin^2\left(\frac{\Delta m^2_{41} L}{4E}\right)$$

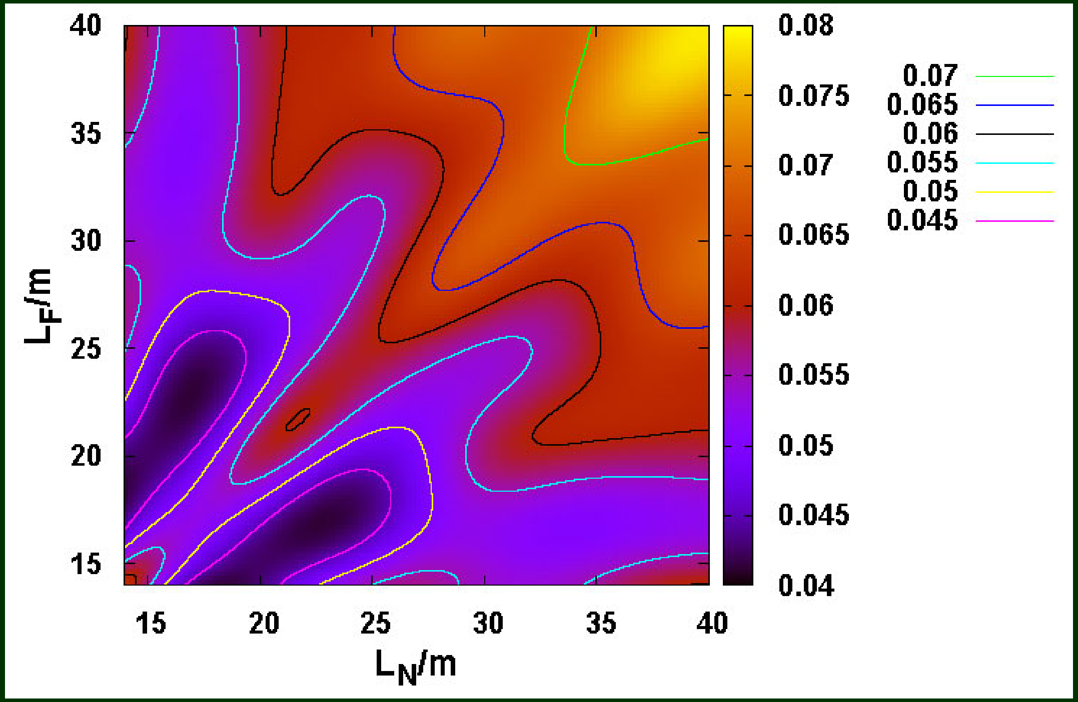


(1) A conventional reactor (thermal reactors)

Assumed parameters (a la Bugey)

- **Power: 2.8 GW**
- **Size of the core: Diameter=4m, Height=4m**

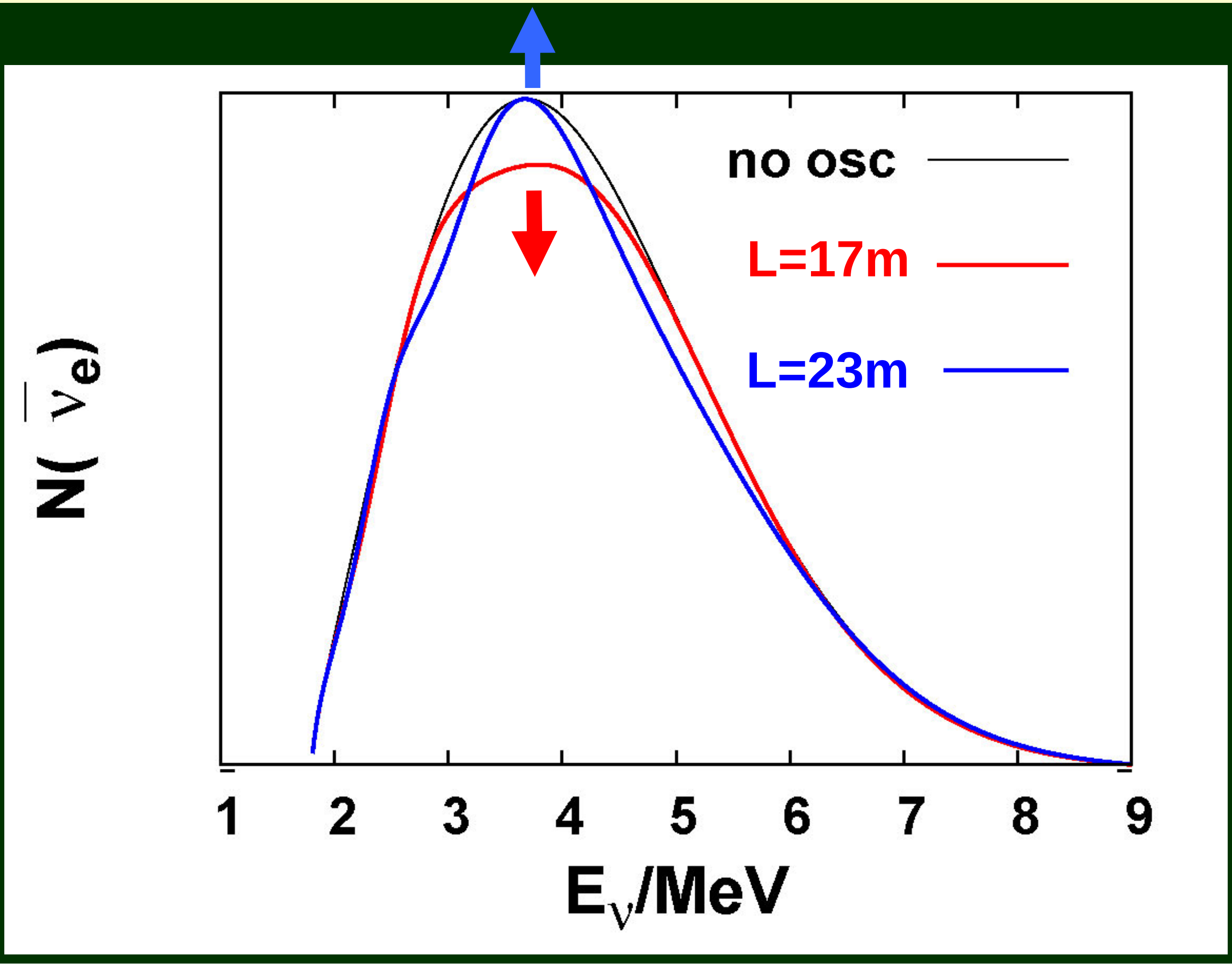
Optimization w.r.t. baseline lengths L_N, L_F for Δm^2=1eV^2



Optimized baseline lengths: L_N=17m, L_F=23m

The role of a "near" detecor in the energy spectrum analysis for $\Delta m^2=1eV^2$

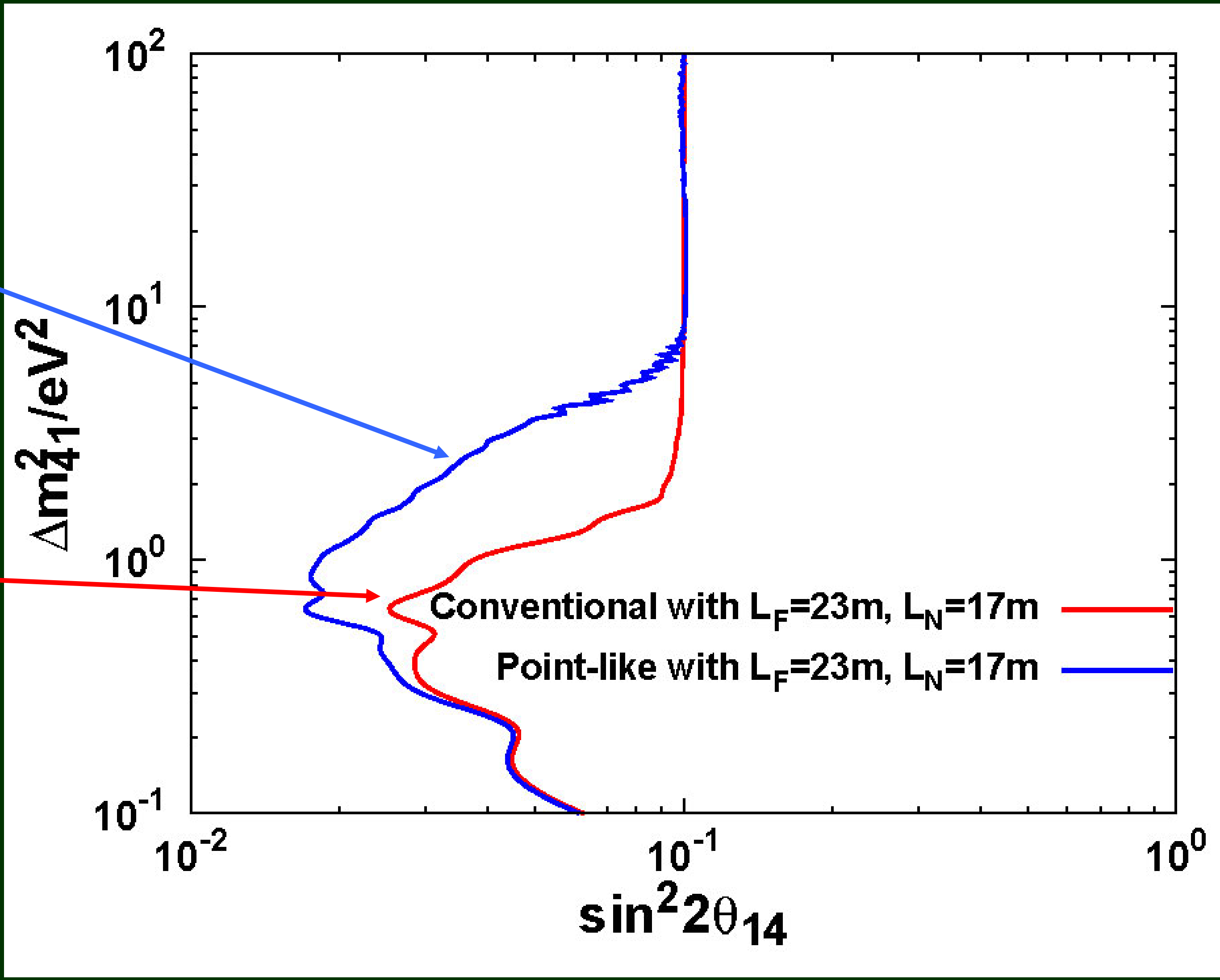
The difference at <E> ~ 4MeV is most significant for $L_N=17m$ $L_F=23m$



Sensitivity of Conventional reactors to $\sin^2 2\theta_{14}$ at L_N=17m L_F=23m

The case of a hypothetical reactor with a point-like core → better sensitivity

Finite size effect of a core → poor sensitivity for Δm^2~2eV^2

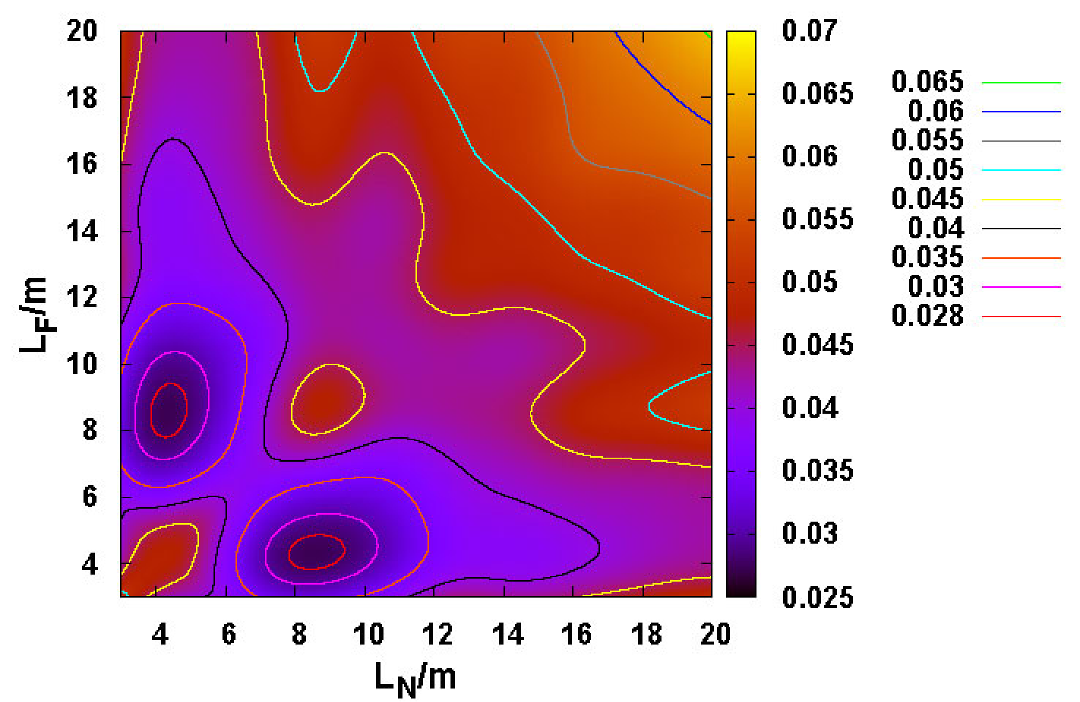


(2) A fast neutron reactor

Assumed parameters (a la Joyo)

- **Power: 0.14 GW**
- **Size of the core: Diameter=0.8m, Height=0.5m**

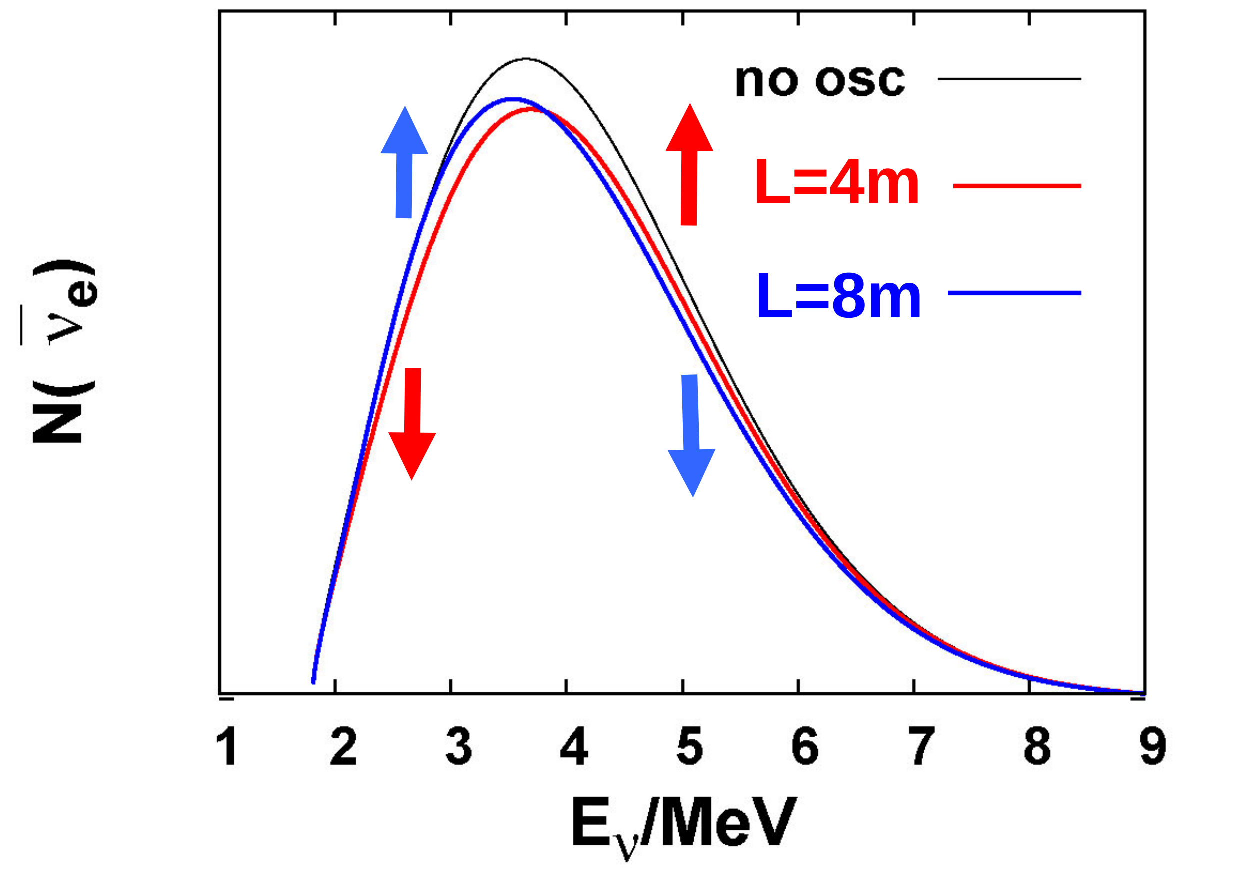
Optimization w.r.t. baseline lengths L_N, L_F for Δm^2=1eV^2



Optimized baseline lengths:
L_N=4m
L_F=8m

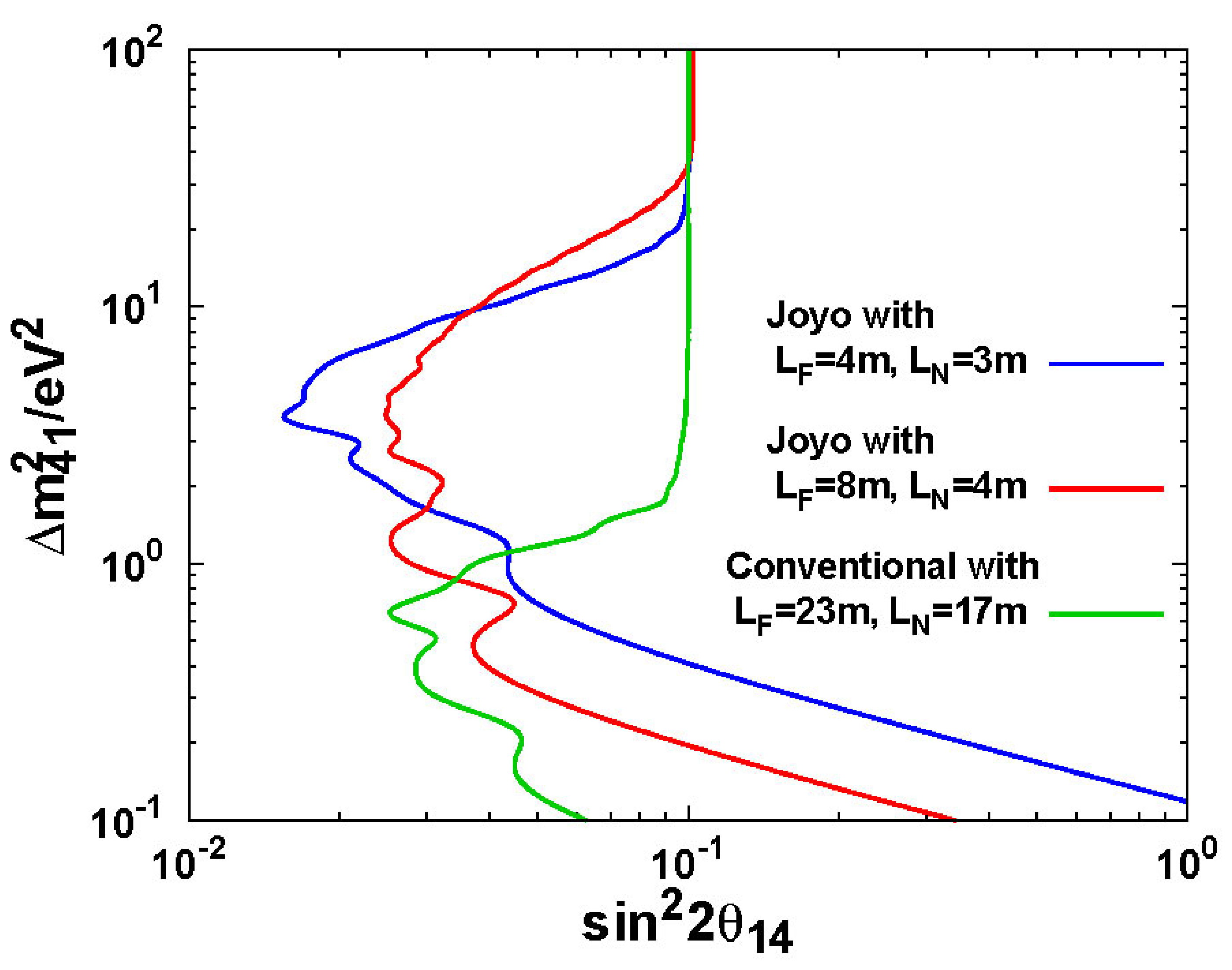
The role of a "near" detecor in the energy spectrum analysis for Δm^2=1eV^2

Asymmetry at <E> ~ (4$\mp$1)MeV is most significant for L_N=4m L_F=8m



Sensitivity of Joyo to $\sin^2 2\theta_{14}$ at L_N=4m, L_F=8m

- Less power is compensated by closer distance
- A reactor with a small core prevents smearing effect



A Study of Reactor ν Monitoring at Experimental Fast Reactor JOYO

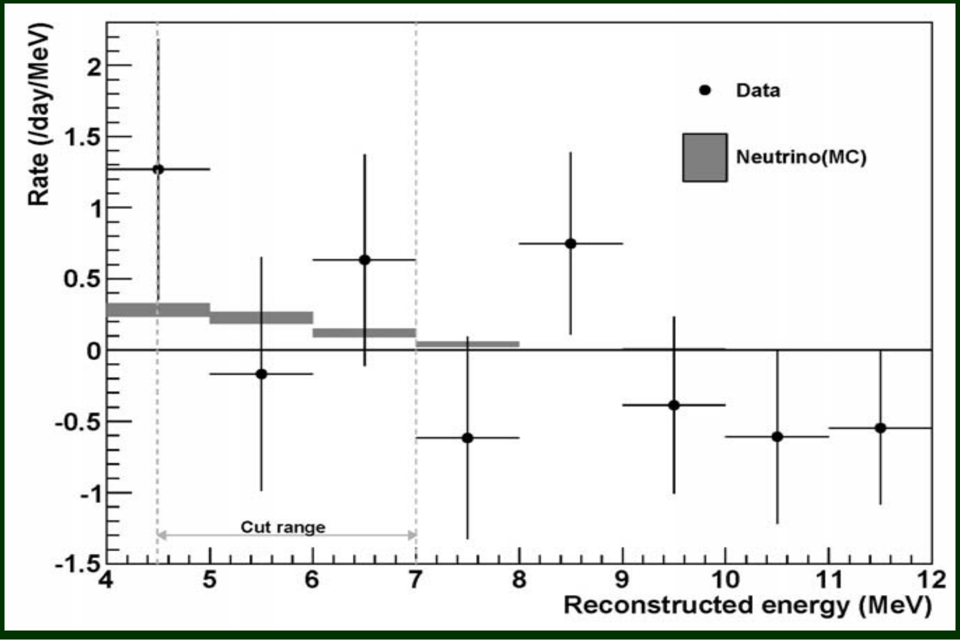
H.Furuta et al., arXiv:1108.2910v1 [hep-ex]

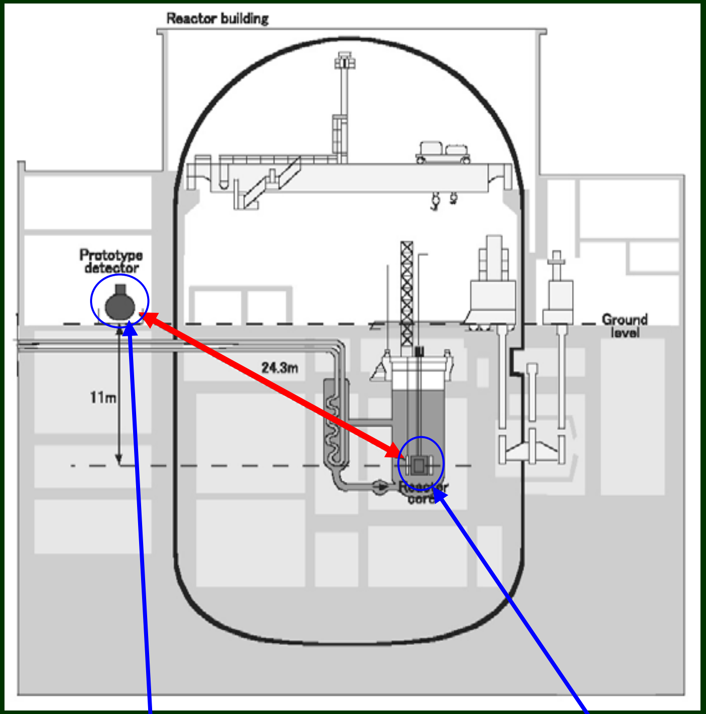
L=24.3m; about 150 νp → e⁺n reactions/day

The measured ν event rate from reactor on-off comparison was 1.11±1.24(stat.)±0.46(syst.) events/day.

The statistical significance of the measurement was not enough.

Their motivation: to detect ν from a fast reactor (not motivated by ν_s)





Prototype detector

Reactor core

Summary (1)

- Because of the recent re-evaluation of the reactor ν flux, scenarios of sterile ν oscillations with $\Delta m^2 \sim O(1 eV^2)$ are reviving.

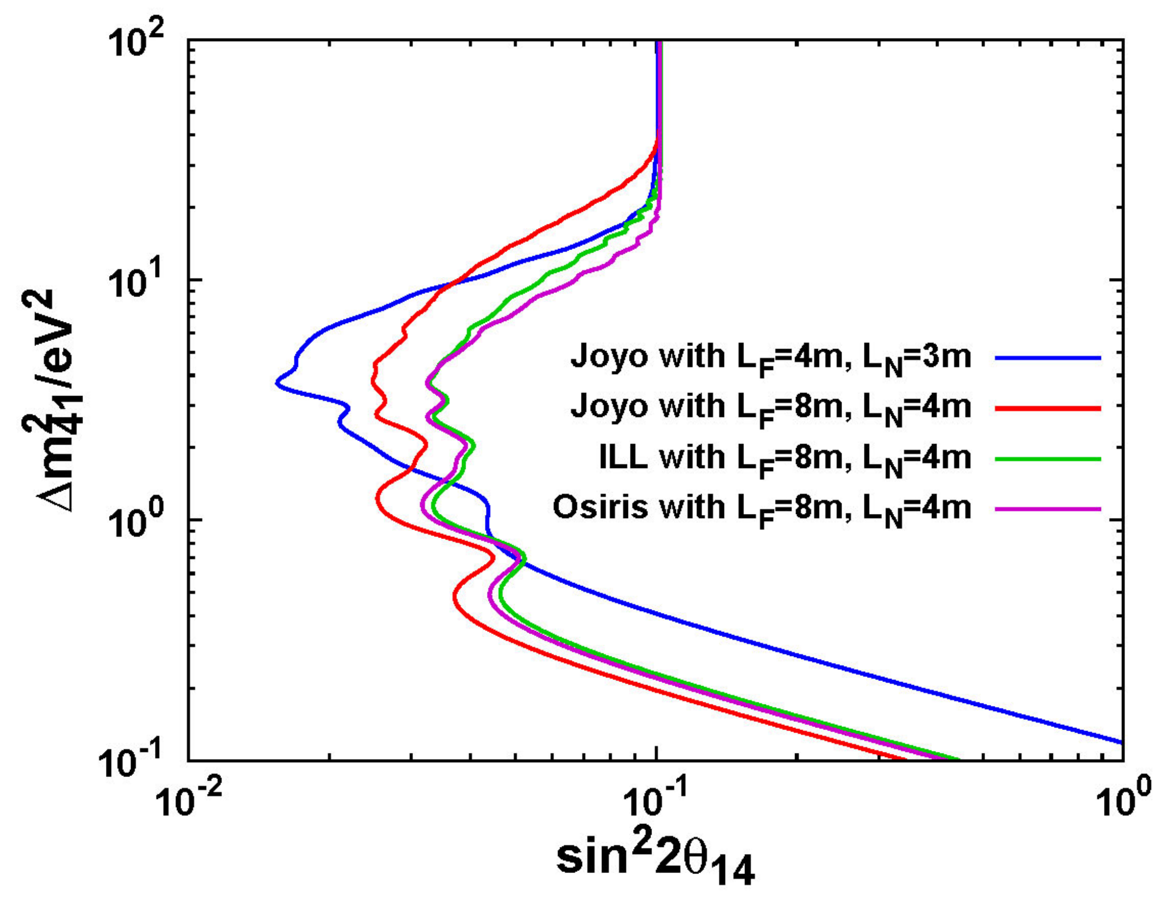
- To get a useful information from the spectrum analysis of reactor ν for $\Delta m^2 > 1 eV^2$, a reactor with a small core is necessary to avoid the smearing effect.

- Fast neutron reactors have a small core in general, and measurements of ν from a fast neutron reactor Joyo may be able to offer a test of LSND/MiniBooNE.

- A preliminary experiment to measure ν from Joyo has been performed, but not sufficient significance of the signals was obtained. → More developments are needed.

●Summary (2)

- There exist in France a couple of experimental thermal neutron reactors with a small core. → **Nucifer project**



ILL (Institut Laue-Langevin near Grenoble) research reactor
Power=58 MW,
Diameter=40cm,
Height=80cm

Osiris (in the French Atomic Energy Commission (CEA) centre at Saclay)
Power=70 MW,
Size=57cmx57cmx60cm

Great if the detectors are placed very closed to a reactor!