Measurement of angular correlations in the (n, γ) reaction for T-violation search

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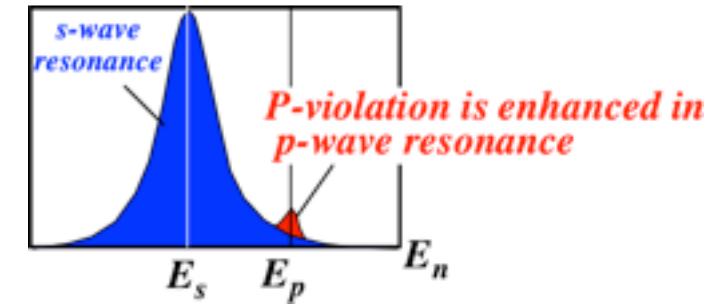
Determination of κ(J) of ^{139}La

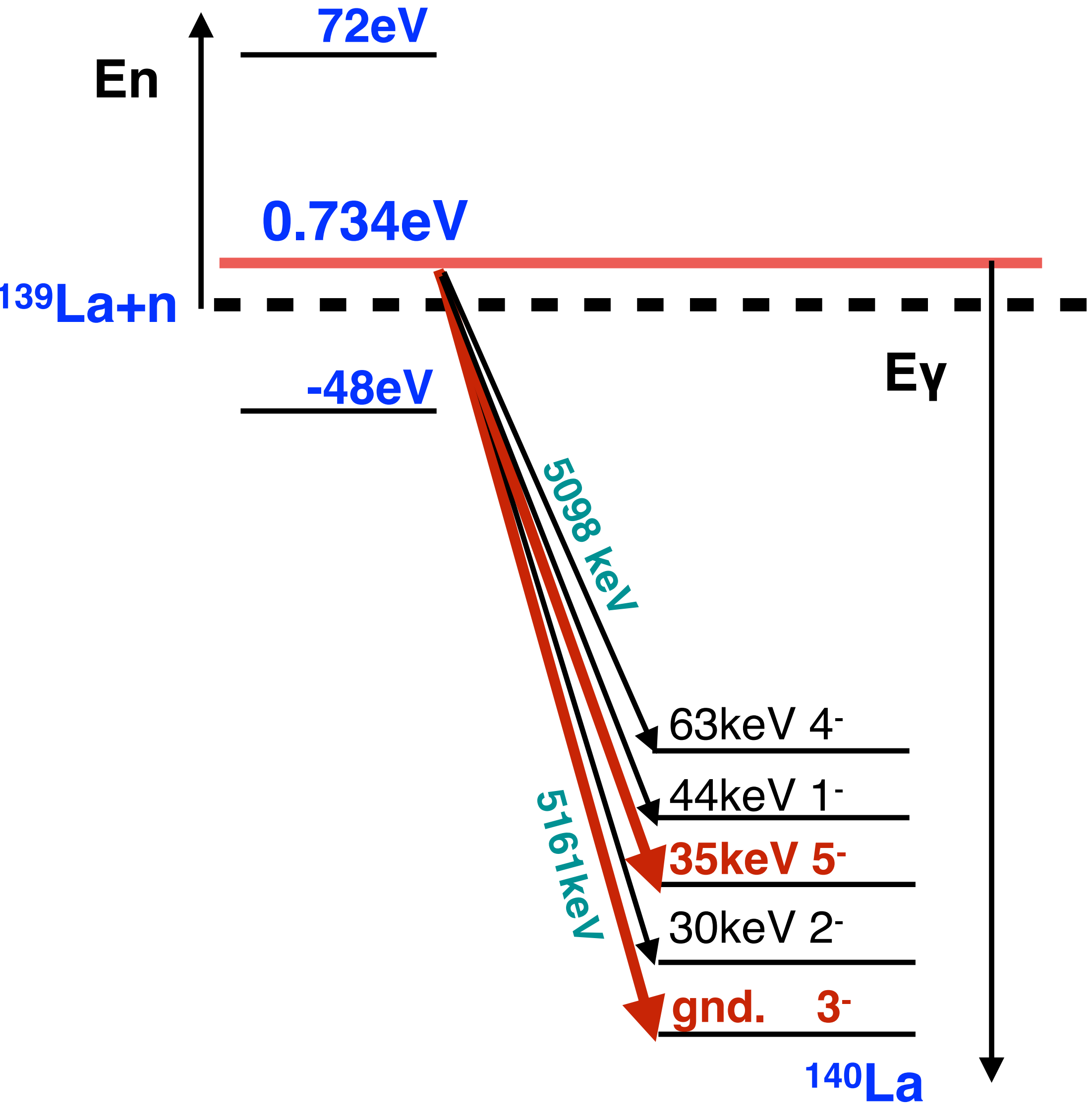
for checking the feasibility of T-violation search

Resonance s of ^{139}La



^{139}La(n,γ)

E[eV]	ℓ	J	gΓn [meV]	Γ_γ [meV]	A_L[%]	
-48.6	0	4	82	62.2		s
0.734 ± 0.1	1	4	3.65×10^{-5}	45	9.56±0.	p
72.3 ± 0.1	0	3	1.78	52.6		s



κ(J)→ϕ→angular correlation of (n,γ)

Angular correlation of 0.73eV p-wave resonance is measured

Because Flambaum's formalism depends on angular momentum of final state, we need to select γ ray

The enhancement of the CP violation

It is suggested that T violation also can be enhanced in compound nucleus reaction enhanced P violation

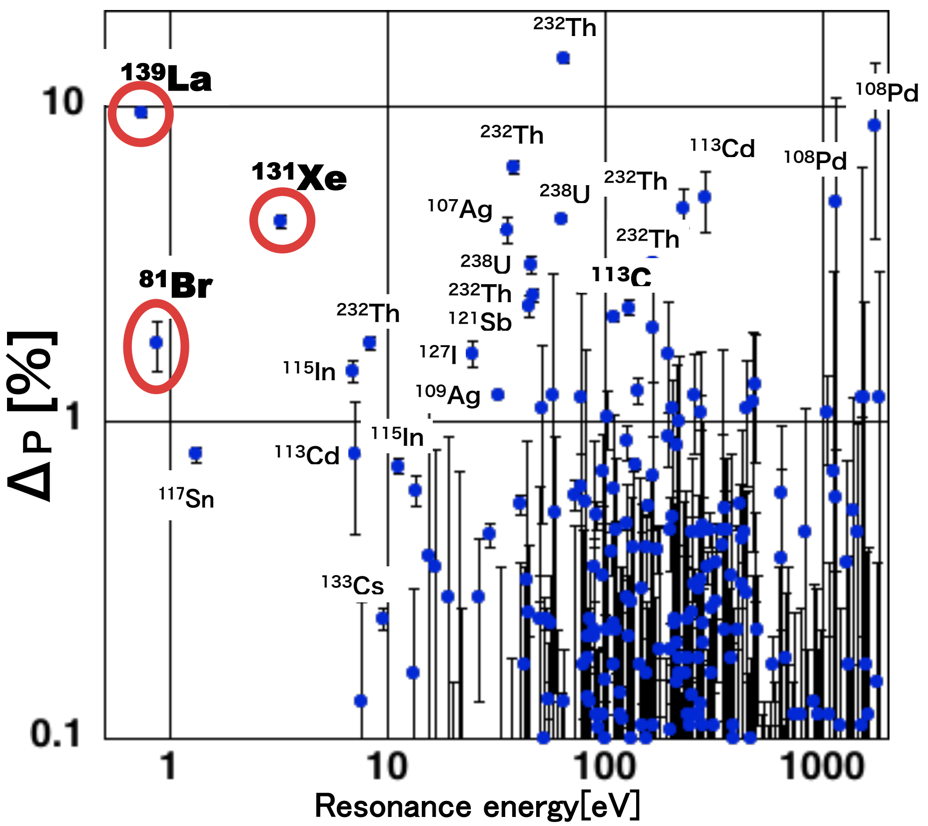
$$\Delta\sigma_{CP} = \kappa(J)\frac{W_T}{W}\Delta\sigma_P$$

$\kappa(J) > 0$ — <u>The unknown parameter</u>

$\frac{W_T}{W} \simeq 10^{-3}$ — The ratio between P violation and CP violation in nucleus

$\Delta\sigma_P = 10^{-1} \sim 10^{-2}$ — The P violation in compound nucleus

For sensitive CP violation search,
the nucleus that has large P violation and κ(J) are better.



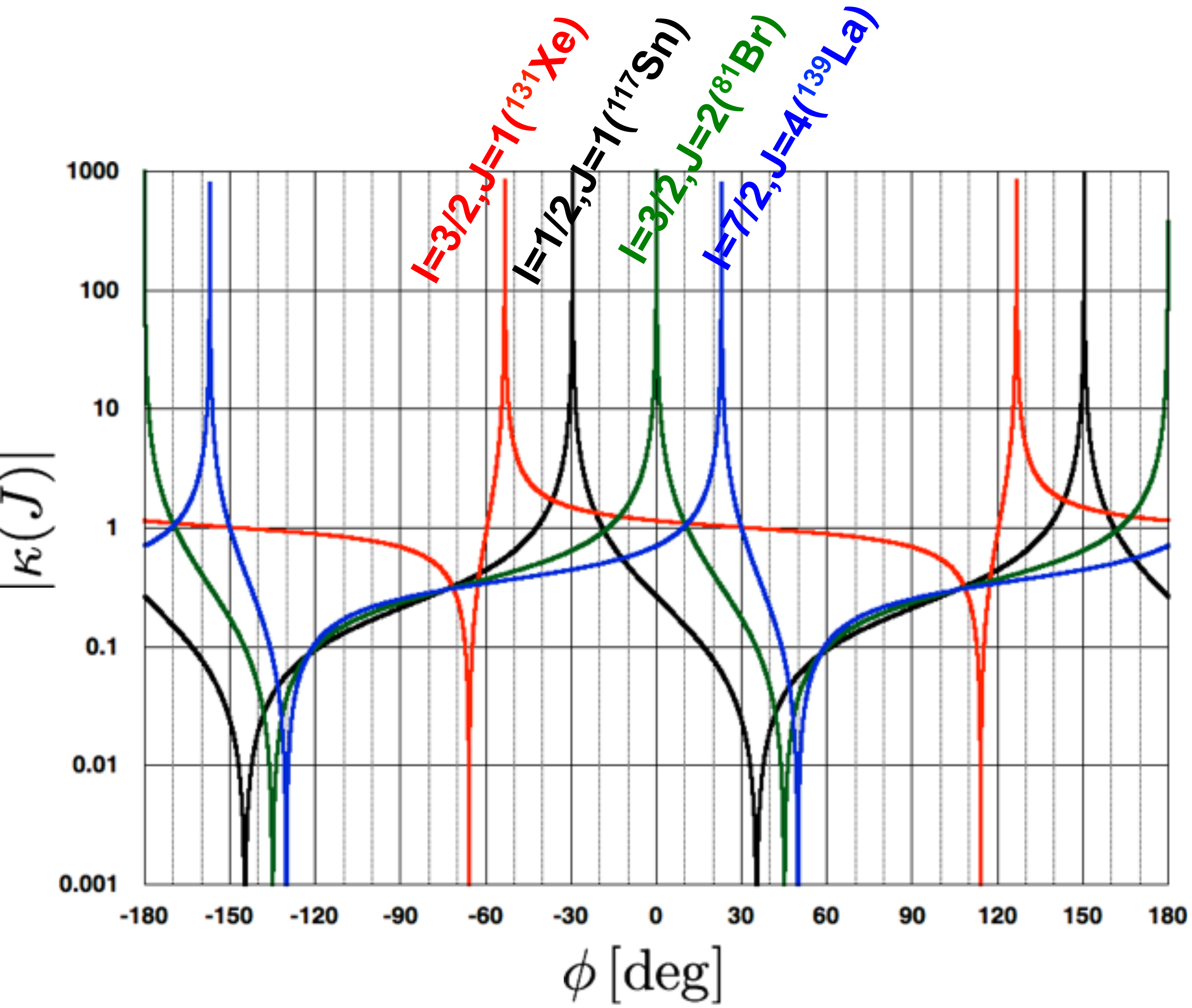
We need nucleus that has

- Large κ(J)
- Large $\Delta\sigma_P$
- Large natural abundance
- Low resonance energy

κ(J) has not been determined yet!

Determination of κ (J)

κ (J) is depend on angular momentum of nucleus and partial width of p wave resonance (ϕ parameter)



ϕ :partial width of p wave resonance

$$\kappa(J=I+\frac{1}{2}) = \frac{3}{2\sqrt{2}}\left(\frac{2I+1}{2I+3}\right)\frac{\sqrt{2I+1}(2\sqrt{I}x-\sqrt{2I+3}y)}{(2I-3)\sqrt{2I+3}x-(2I+9)\sqrt{I}y}$$

$$\kappa(J=I-\frac{1}{2}) = -\frac{3}{2\sqrt{2}}\left(\frac{(2I+1)\sqrt{I}}{\sqrt{(I+1)(2I-1)}}\right)\frac{2\sqrt{I+1}x+\sqrt{2I-1}y}{(I+3)\sqrt{2I-1}x+(4I-3)\sqrt{I+1}y}$$

$$x^2 = \frac{\Gamma^n_{p,1/2}}{\Gamma^n_p} \qquad y^2 = \frac{\Gamma^n_{p,3/2}}{\Gamma^n_p}$$

$$x^2 + y^2 = 1$$

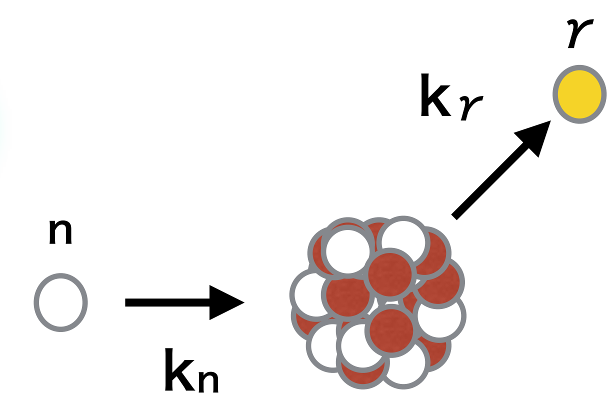
$$x = \cos\phi \qquad y = \sin\phi$$

To determine κ (J), ϕ is need to be measured.

Measurement of ϕ

ϕ can be determined by measuring angular correlation of (n,γ) reaction

(n,γ) Cross section (non-polarized neutron)



$$\frac{d\sigma}{d\Omega} = \frac{1}{2}\left(a_0 + a_1 \boldsymbol{k}_n \cdot \boldsymbol{k}_\gamma + a_3\left((\boldsymbol{k}_n \cdot \boldsymbol{k}_\gamma)^2 - \frac{1}{3}\right)\right)$$

$$a_0 = \sum_{J_s} |V_1(J_s)|^2 + \sum_{J_s,j} |V_2(J_p j)|^2$$

$$a_1 = 2\mathrm{Re}\sum_{J_s,J_p,j} V_1(J_s)V_2^*(J_p j)P(J_s J_p \tfrac{1}{2} j 1 I F)$$

$$a_3 = \mathrm{Re}\sum_{J_s,j,J'_p,j'} V_2(J_p j)V_2^*(J'_p j')P(J_p J'_p j j' 2 I F) 3\sqrt{10}\begin{Bmatrix} 2 & 1 & 1 \\ 0 & \frac{1}{2} & \frac{1}{2} \\ 2 & j & j' \end{Bmatrix}$$

$$V_1 = \frac{1}{2k_s}\sqrt{\frac{E_s}{E}}\frac{\sqrt{g\Gamma_s^n\Gamma_\gamma}}{E - E_s + i\Gamma_s/2}$$

$$V_2(j) = \frac{1}{2k_p}\sqrt{\frac{E_p}{E}}\sqrt{\frac{\Gamma_{pj}^n}{\Gamma_p^n}}\frac{\sqrt{g\Gamma_p^n\Gamma_\gamma}}{E - E_p + i\Gamma_p/2}$$

partial width of p wave resonance

$$x^2 = \frac{\Gamma_{p,1/2}^n}{\Gamma_p^n} \qquad y^2 = \frac{\Gamma_{p,3/2}^n}{\Gamma_p^n}$$

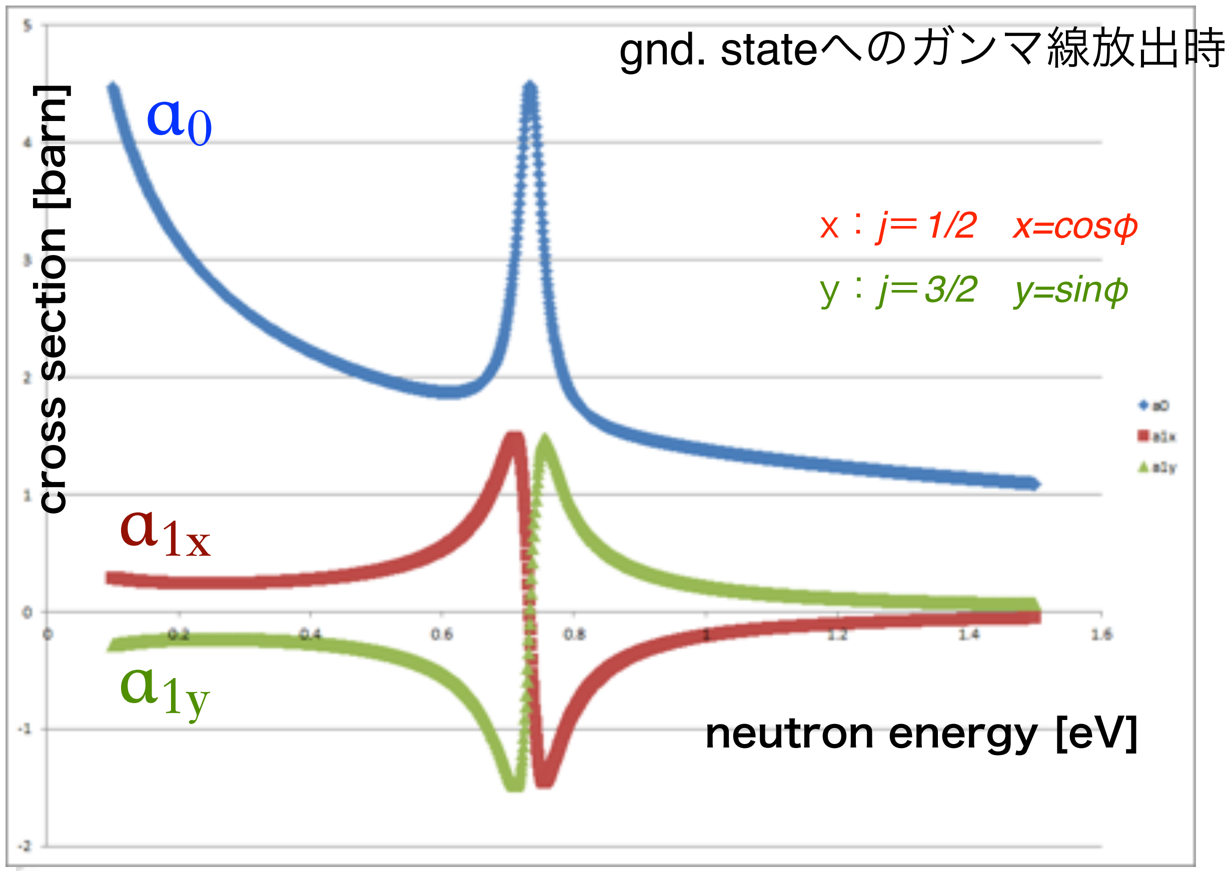
$$x^2 + y^2 = 1$$

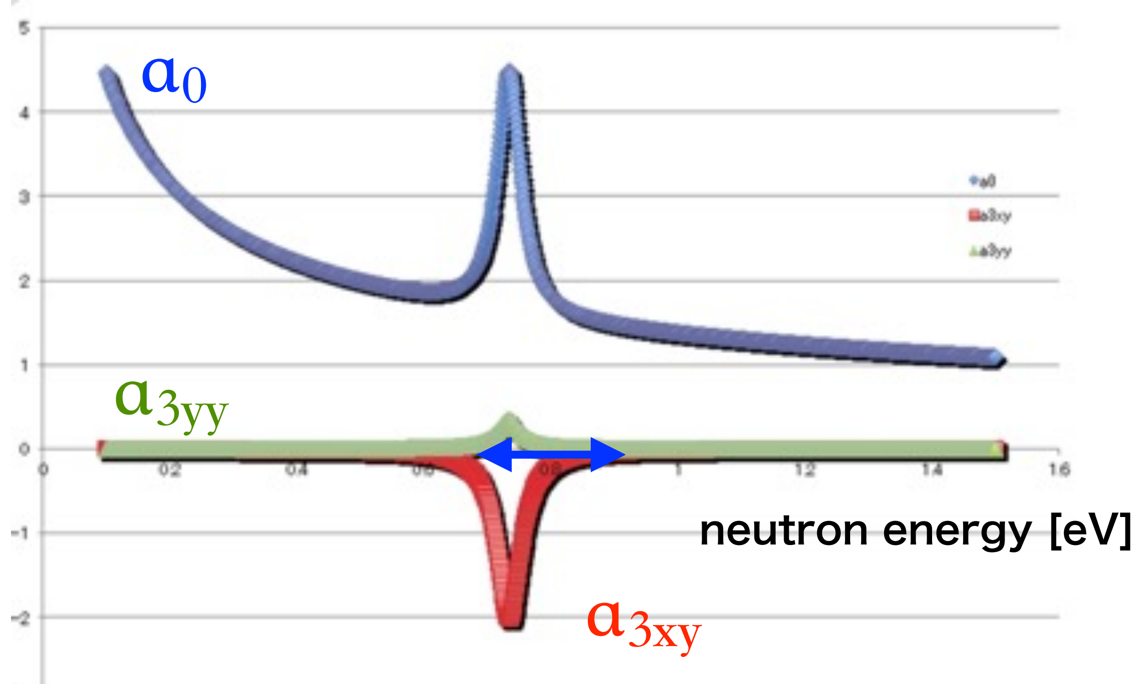
$$x = \cos\phi \qquad y = \sin\phi$$

$$P(JJ'jj'kIF) = (-1)^{J+J'+j'+I+F}\frac{3}{2}\sqrt{(2J+1)(2J'+1)(2j+1)(2j'+1))}\begin{Bmatrix} k & j & j' \\ I & J' & J \end{Bmatrix}\begin{Bmatrix} k & 1 & 1 \\ F & J & J' \end{Bmatrix} \left.\begin{matrix} 1 \\ J' \end{matrix}\right\}$$

Measurement of ϕ

^{139}La(n,γ) P-wave resonance 0.73 eV





(n,γ) Cross section (as a function of ϕ)

$$\frac{d\sigma}{d\Omega} = \frac{1}{2}(a_0 + a_1 k_n \cdot k_\gamma + a_3((k_n \cdot k_\gamma)^2 - \frac{1}{3}))$$
$$= \frac{a_0}{2}(1 + A_1 \cos\theta + A_3(\cos^2\theta - \frac{1}{3}))$$

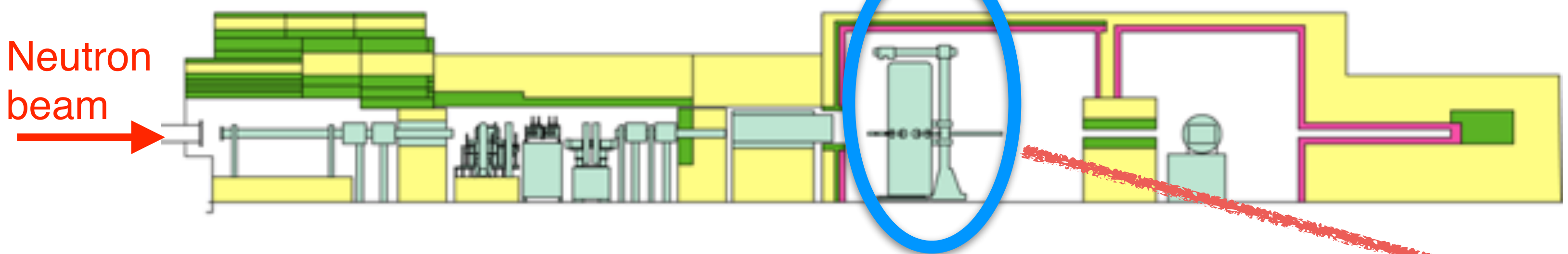
$$a_1 = a_{1x}\cos\phi + a_{1y}\sin\phi$$
$$a_3 = a_{3xy}\cos\phi\sin\phi + a_{3yy}\sin^2\phi$$

In Flambaum's formalism,a_1 term has
asymmetry that depends on ϕ
But these terms have not been measured

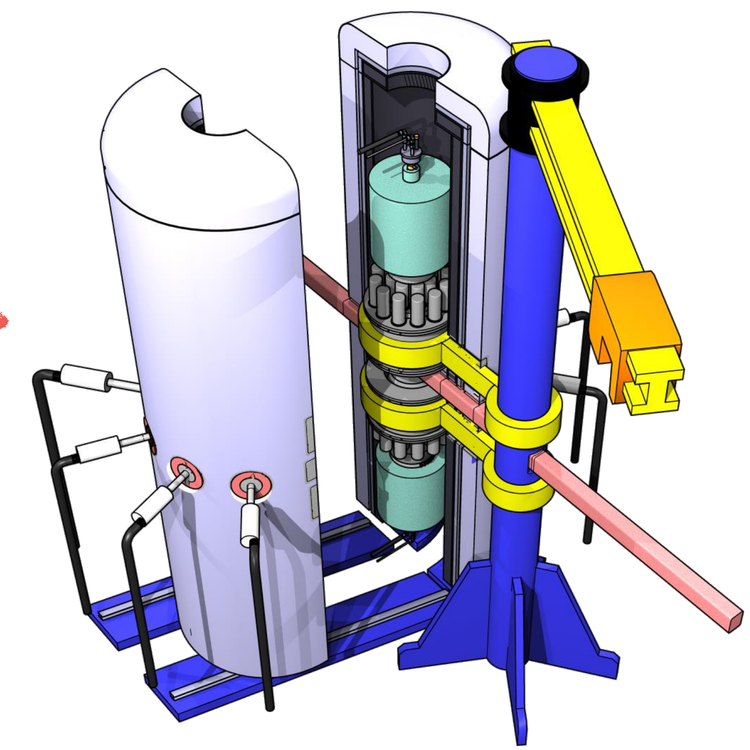
Purposes of my research
- **Verification of Flambaum's formalism by measuring (n,γ) angular correlation**
- **Determination of ϕ**

Measurement of (n,γ) reaction

We measured (n,γ) reaction of several nucleus at J-PARC BL04



Ge γ ray detector（21.5m）



Intensity :　~ 3 x 10^5 n/cm^2/s　: 0.9 eV < En < 1.1eV @300kW

We need to select γ ray.

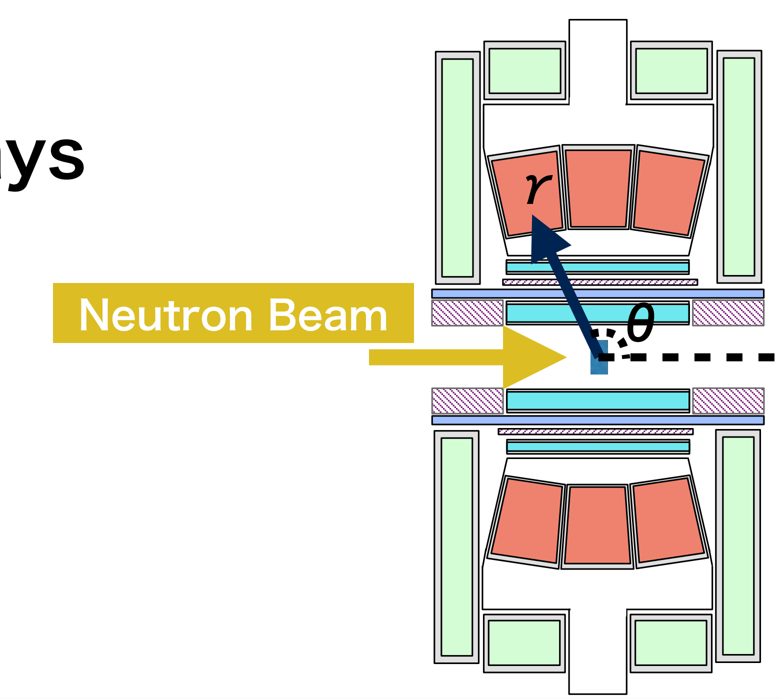
→　**High resolution detecter is necessary**

Detectors for angular distribution of γ rays

2 Cluster Ge Detector　7ch ×2 : 14ch

8 Coaxial Ge Detector　 8ch

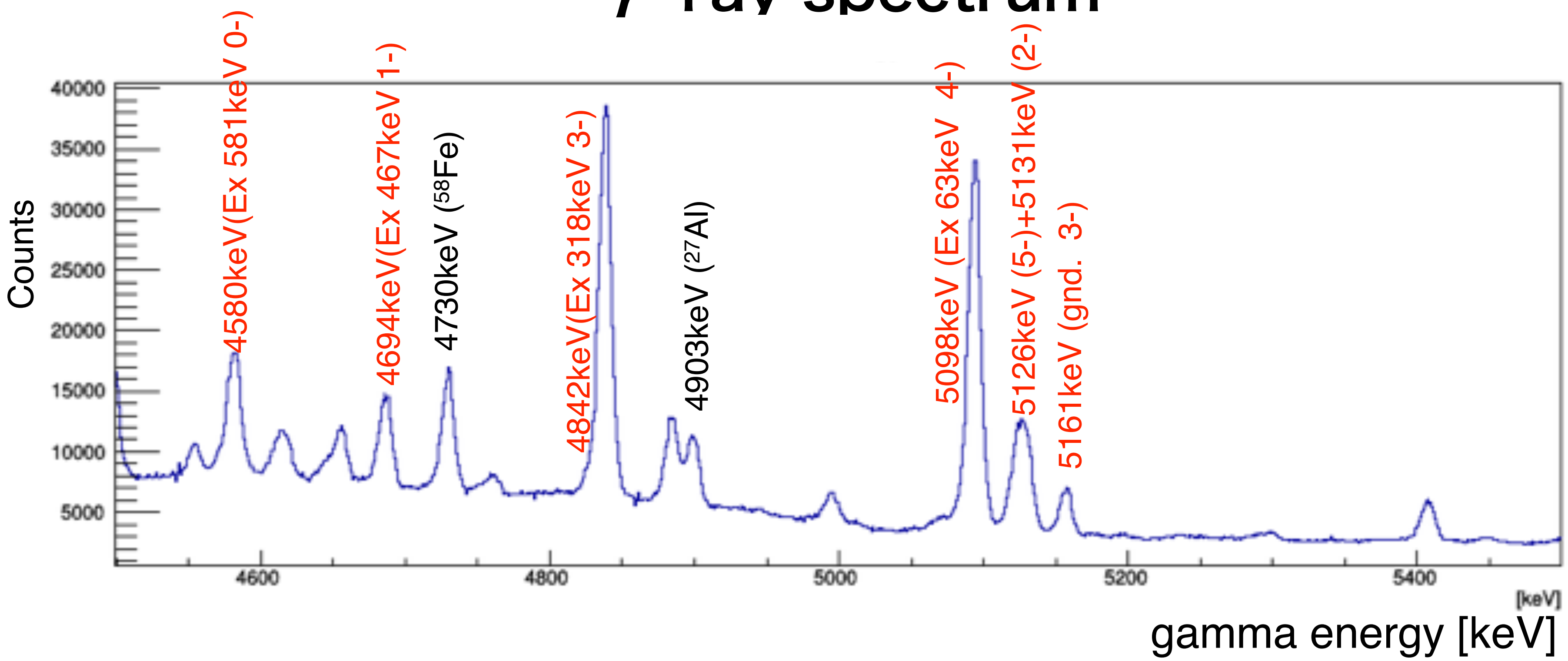
計 22ch → 7 angles

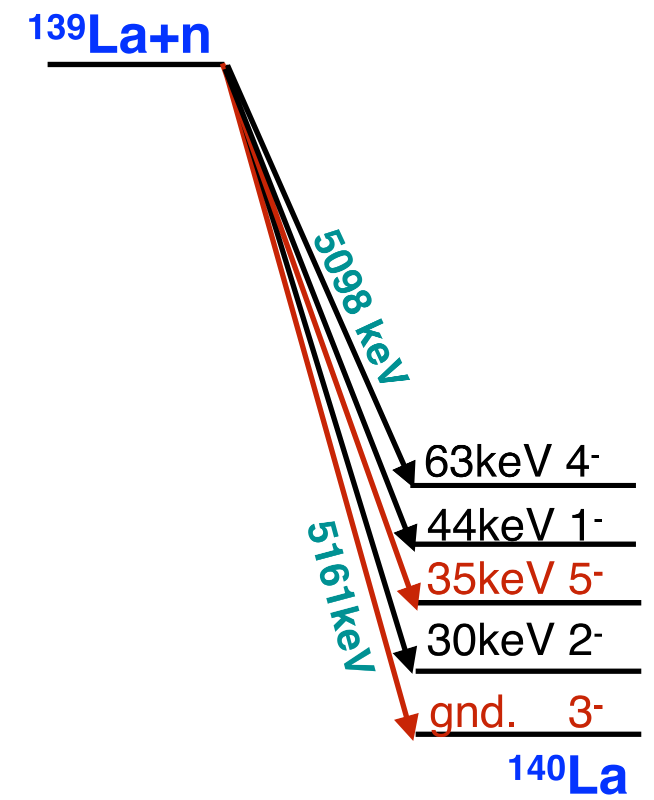


Targets nucleus : ^{nat}La, ^{nat}Xe, ^{nat}In

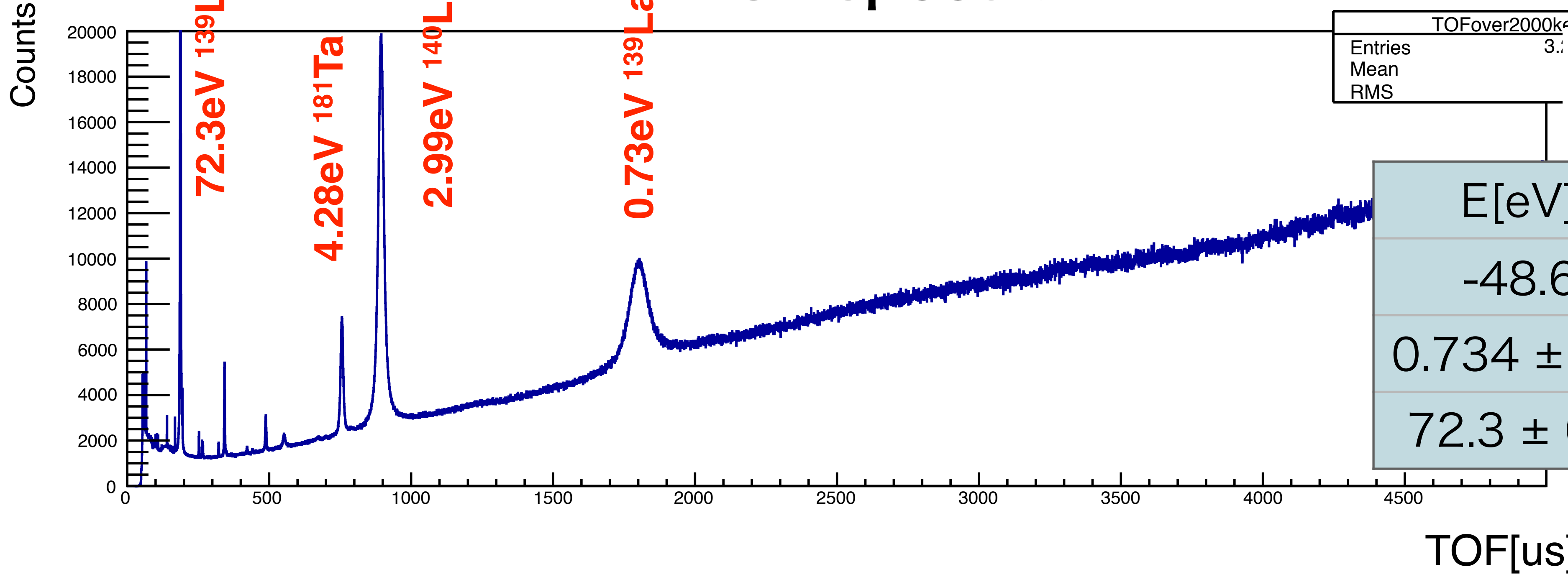
γ ray spectrum and Neutron Spectrum of La

γ ray spectrum





TOF spectrum



^{139}La(n,γ)

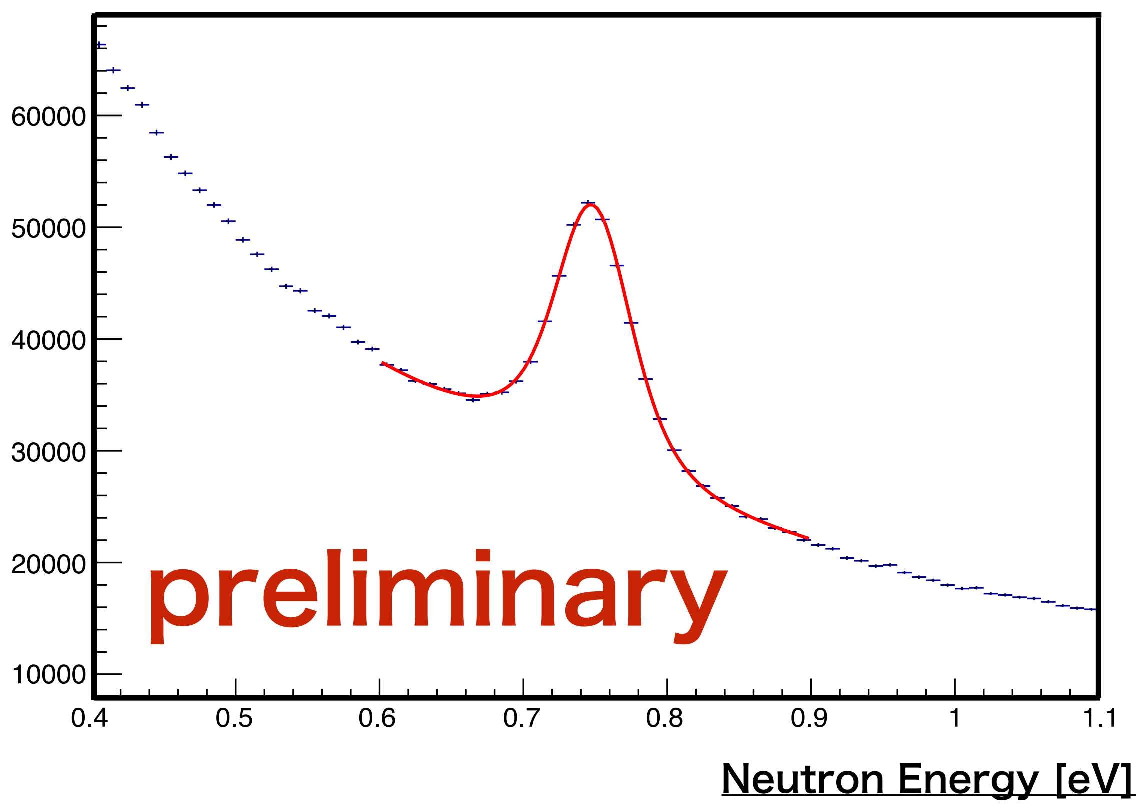
E[eV]	ℓ	gΓn [meV]
-48.6	0	82
0.734 ± 0.1	1	3.65×10^{-5}
72.3 ± 0.1	0	1.78

The resonance parameters of ^{139}La p-wave

We measured the resonance parameters of ^{139}La p-wave

The resonance parameters are obtained by fitting with neutron pulse broadening and doppler broadening correction

^{139}La p-wave resonance



The result of fitting

E_0=0.7404 ± 0.002eV

Γ=40.41± 0.76meV

x^2/ndf~1.0

T=300K(fixed)

The resonance parameters Ref.1

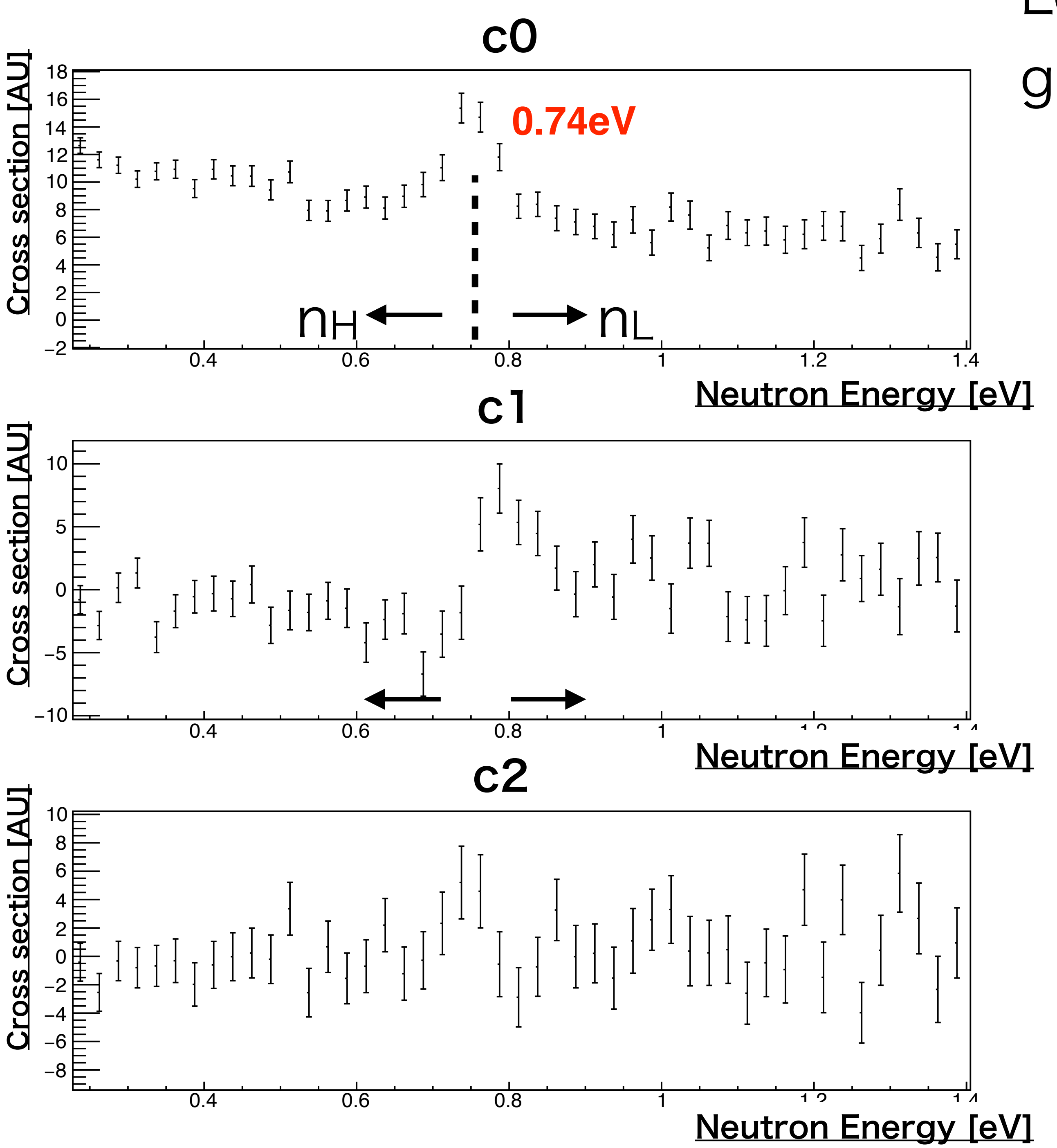
E_0=0.734 ± 0.100eV

Γ=45 ±5meV

Ref.1 : “Atlas of Neutron Resonances” by S.F.Mughabghab

→ **More precise than the Ref.1**

Angular correlation of ^{139}La (n,γ)



Preliminary

Legendre expansion of neutron spectrum gated by gamma ray to F=3 final state

$$\frac{d\sigma}{d\Omega} = c_0(E) + c_1(E)x + c_2(E)\frac{1}{2}(3x^2 - 1)$$

$$x = \cos\theta$$

c_1 term has asymmetry!

The asymmetry are

-0.69±0.13

$$n(E_{\mathrm{Lab}}, \theta_{\mathrm{Lab}}) = \sum_{i=0}^{\infty} c_i P_i(\cos\theta)$$

$$= c_0 \left\{1 + \sum_{i=1}^{\infty} C_i P_i(\cos\theta)\right\}$$

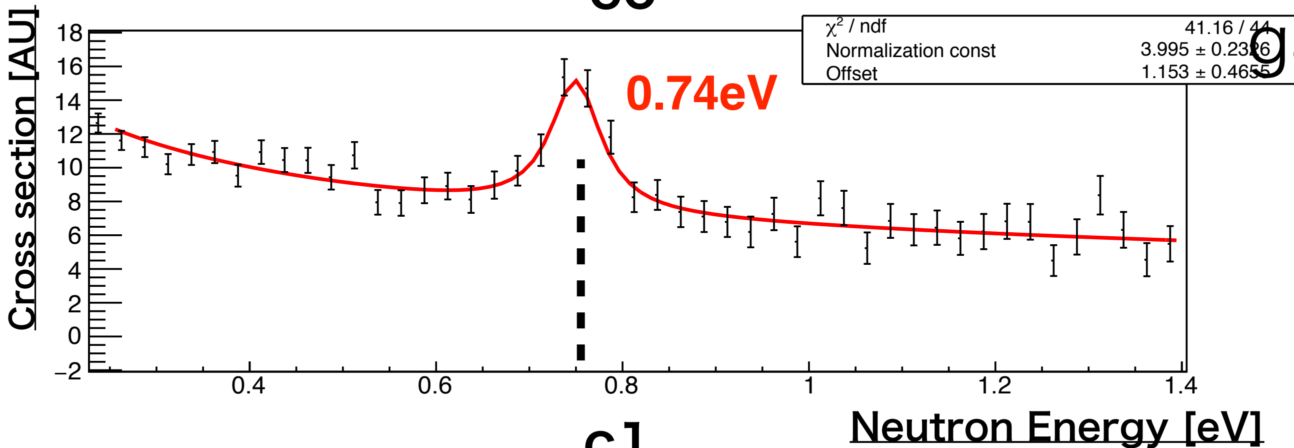
$$A_{\mathrm{HL}} = \frac{n_{\mathrm{H}} - n_{\mathrm{L}}}{n_{\mathrm{H}} + n_{\mathrm{H}}}$$

$$n_{\mathrm{H}}(\Gamma, \theta) = \int_{E_{\mathrm{Lab0}}}^{E_{\mathrm{Lab0}}+\tilde{\Gamma}} n(E_{\mathrm{Lab}}, \theta_{\mathrm{Lab}}) dE$$

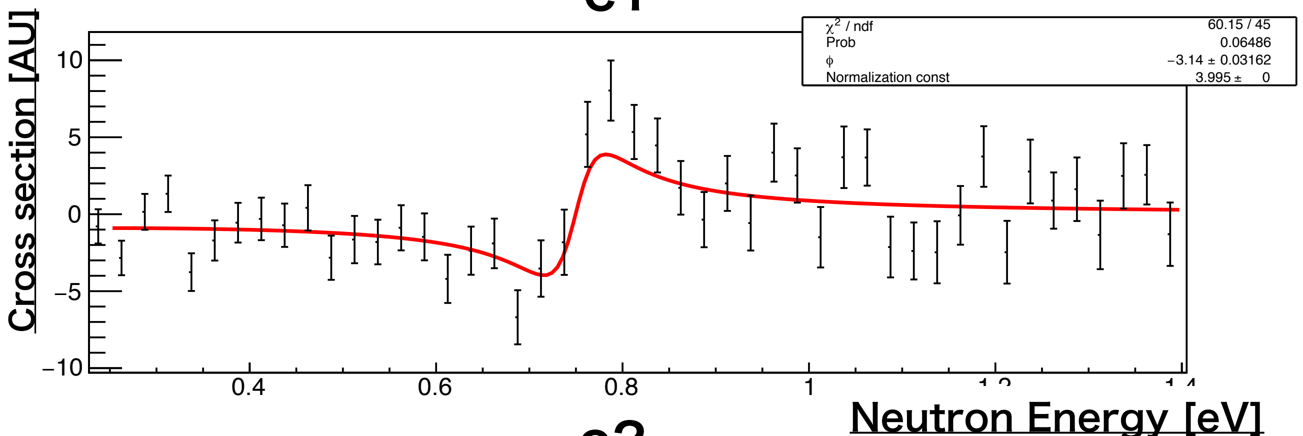
$$n_{\mathrm{L}}(\Gamma, \theta) = \int_{E_{\mathrm{Lab0}}-\tilde{\Gamma}}^{E_{\mathrm{Lab0}}} n(E_{\mathrm{Lab}}, \theta_{\mathrm{Lab}}) dE$$

Analysis with Flambaum's formalism

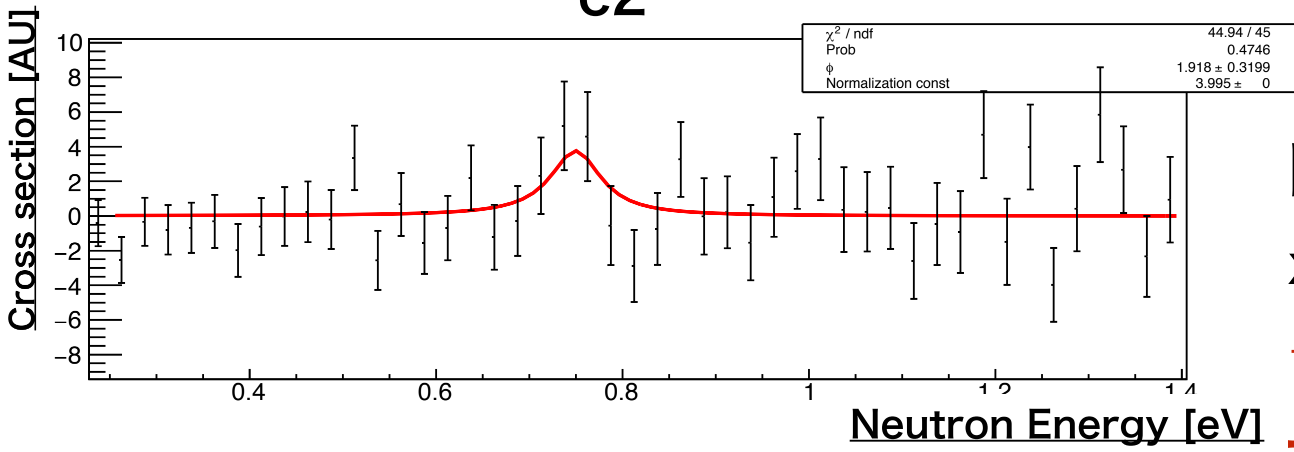
c0



c1



c2



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$$x = \cos\theta$$

c_1 term has asymmetry!

The asymmetry are

-0.69±0.13

Fitting with Flambaum's formalism

x^2/ndf~1.2

→Consistent with Flambaum's formalism

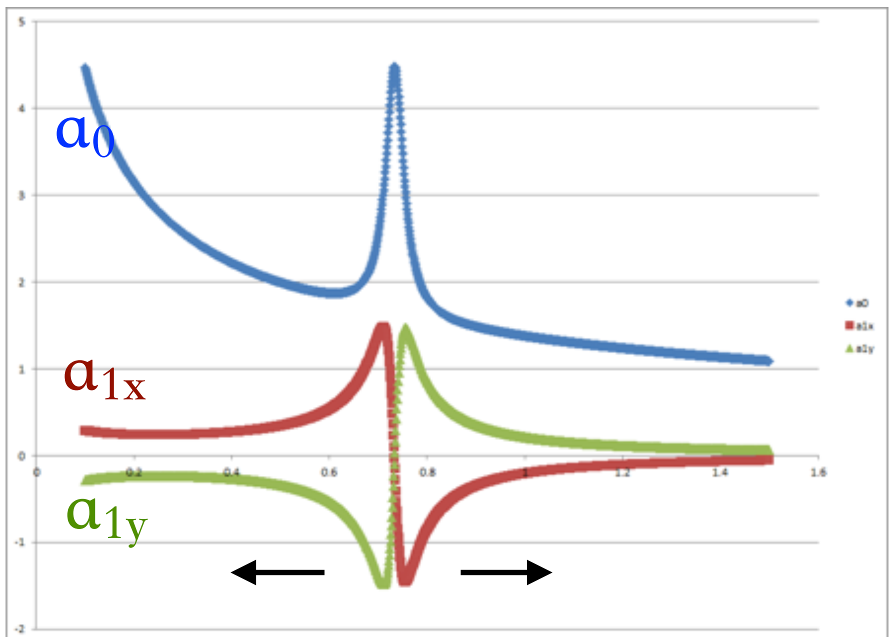
Preliminary

Analysis with Flambaum's formalism

Asymmetry of ^{139}La p-wave resonance is -0.691±0.127

→ ϕ is determined by comparing with a_1 term of Flambaum's formalism

theoretical calculation of P-wave resonance



$$a_1 = a_{1x}\cos\phi + a_{1y}\sin\phi$$

The asymmetry of a_{1x} = 0.543

The asymmetry of a_{1y} = -0.545

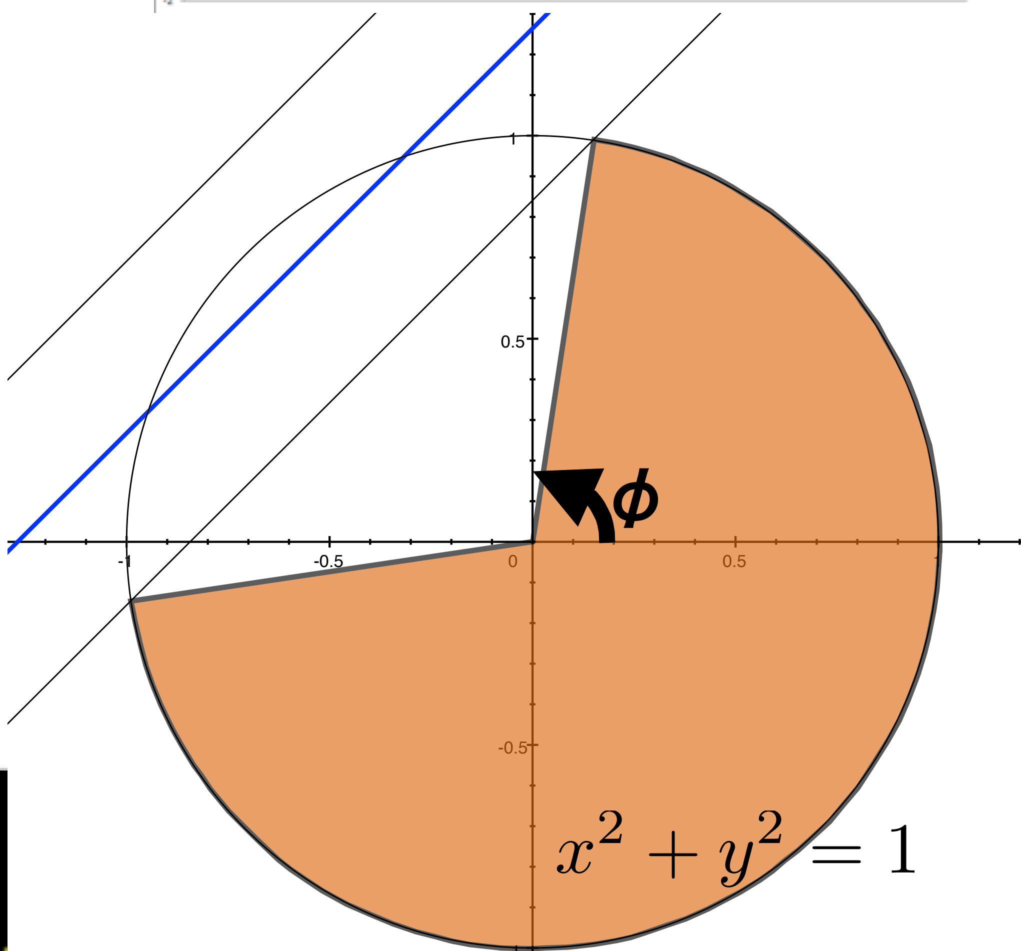
Compare with theoretical calculation and experimental result

$$\underline{-0.69 \pm 0.13} = \underline{0.54}\cos\phi + \underline{0.55}\sin\phi$$

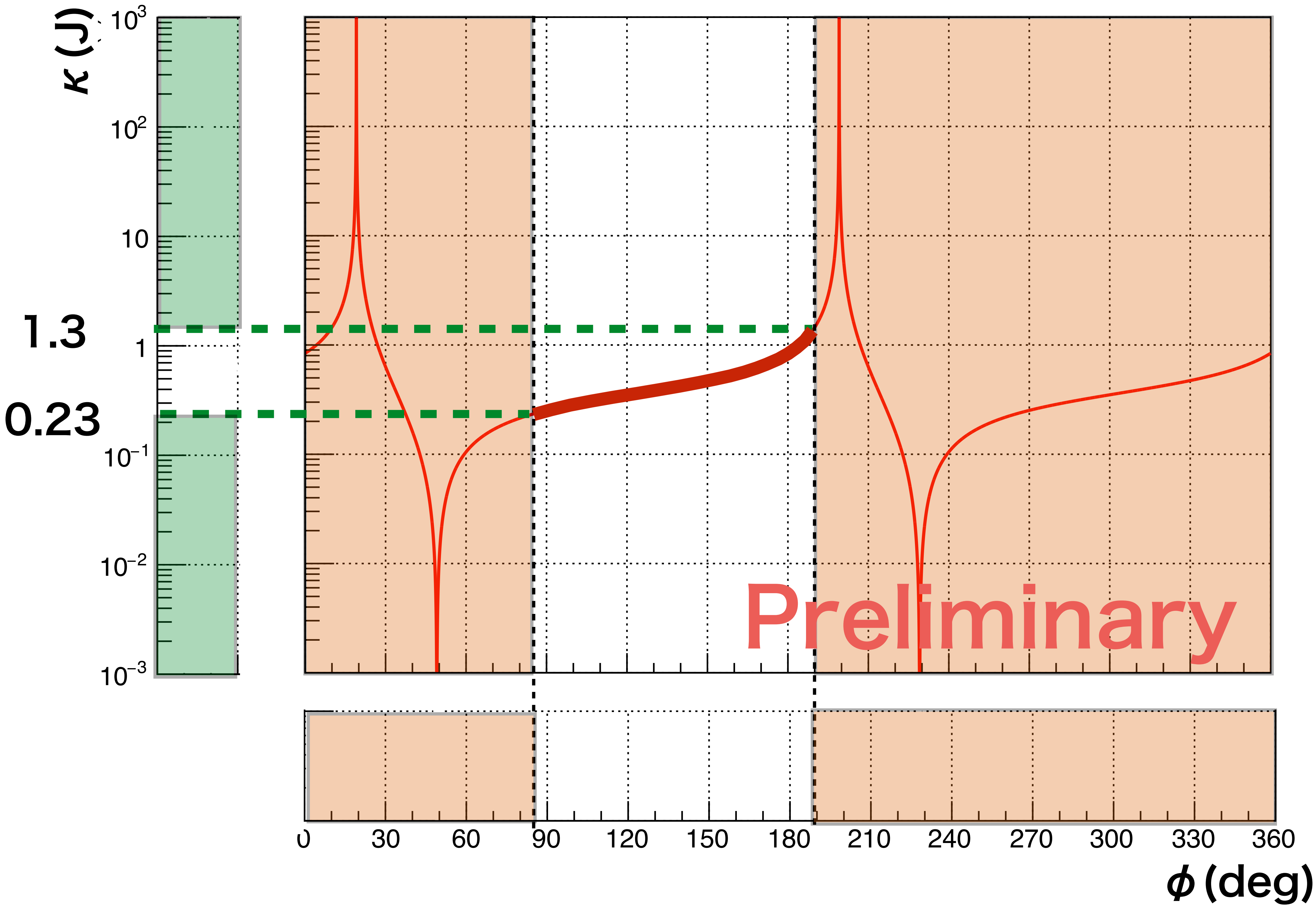
experimental result theoretical calculation

$$84.1\mathrm{deg} < \phi < 188.4\mathrm{deg} \quad (99\%\mathrm{CL})$$

Preliminary



Analysis with Flambaum's formalism



$$0.23 < \kappa(J) < 1.3 \quad (99\%\mathrm{CL})$$

Summary

Our goal is search for T violation in compound nucleus
→We need to find out compound nucleus that has large κ (J)

We measured ^{139}La (n,γ) reaction at J-PARC BL04
→The angular correlation is obtained and this is consistent with Flambaum's formalism

We limited ϕ and κ (J) of ^{139}La (n,γ) reaction to F=3 final state.
→Other transmission is need to analysis.