T-violation in neutron scattering

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NOPTREX collaboration

NOPTREX

Neutron Optical Parity and Time-Reversal EXperiment

Laboratory for Particle Properties

Neutron Optics and Physics

Why is there far more matter than antimatter?

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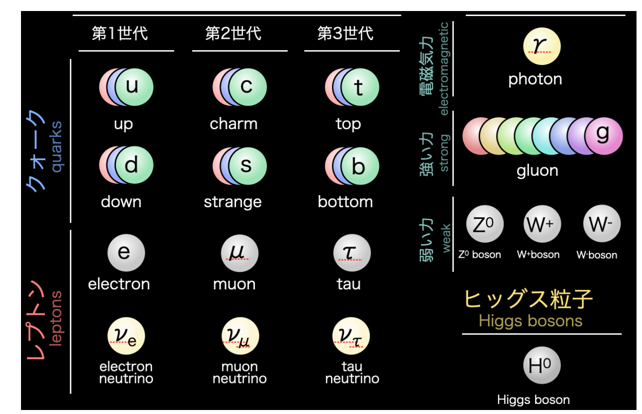
Sakharov conditions

- Baryon number violation
- Departure from thermal equilibrium
- C- and **CP-violation**

$n_b/n_\gamma = (0.61 \pm 0.02) \times \mathbf{10^{-9}}$

More CP-violation
(from unknown source) is required !

Standard Model



$n_b/n_\gamma = \mathbf{10^{-18}}$

Neutron Electric Dipole Moment

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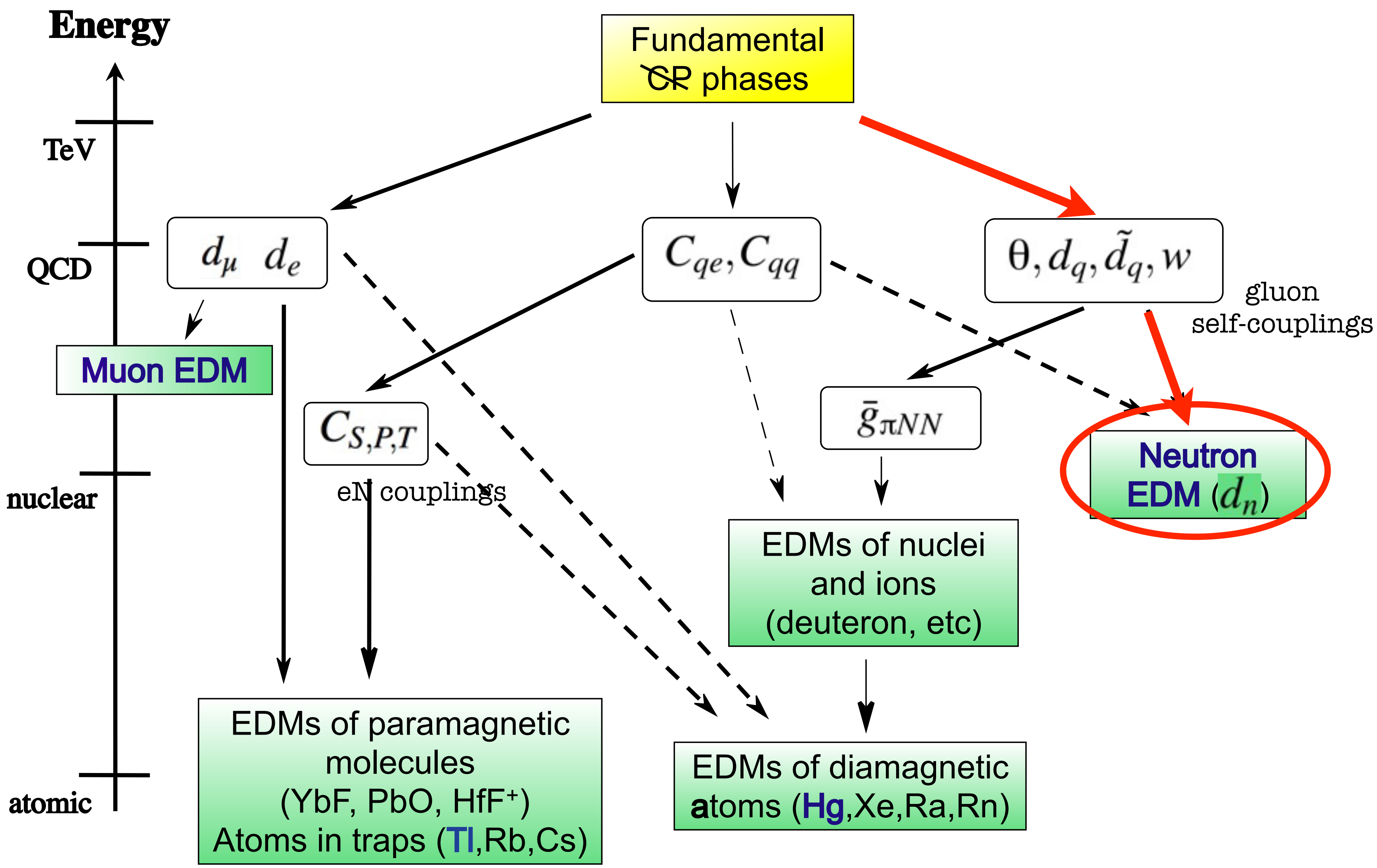
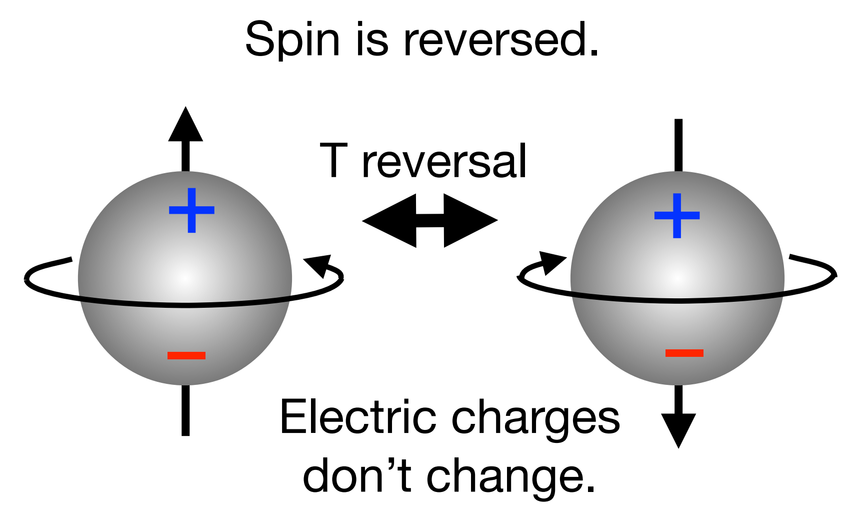
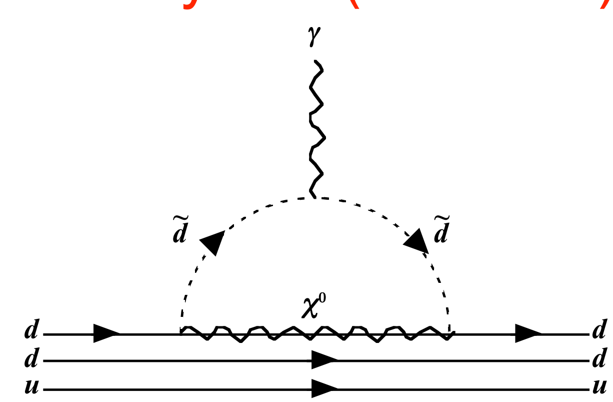


Pospelov Ritz, Ann Phys 318 (05) 119



New Physics (SUSY ...) :



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Combinations of coupling constants

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atomic

EDMs of paramagnetic molecules
(YbF, PbO, HfF⁺)
Atoms in traps (Tl,Rb,Cs)

EDMs of diamagnetic atoms (Hg,Xe,Ra,Rn)

nucleon EDMs | Nucleon-electron int.

$$d_{\rm dia} = \boxed{\alpha_{\rm Sch} S_{\rm Sch}} + \alpha_{d_{\rm p}} d_{\rm p} + \alpha_{d_{\rm n}} d_{\rm n} + \alpha_{C_{\rm T}^{(0)}} C_{\rm T}^{(0)} + \alpha_{C_{\rm T}^{(1)}} C_{\rm T}^{(1)}$$

$d_{\rm Hg}$: Vanishingly small contribution from $\bar{g}_{\pi NN}^{(1)}$

Coefficient values, from the compilation of:
[J. Engel *et al*., *Prog. Part. Nucl. Phys.* **71** (2013) 21]

$$d_{\rm Hg} = -\left(0.38^{+2.3}_{-0.19} \times 10^{-17}\right)\cdot \bar{g}_{\pi NN}^{(0)} + \left(0^{+1.6}_{-4.9} \times 10^{-17}\right)\cdot \bar{g}_{\pi NN}^{(1)} - \left(2.0^{+3.9}_{-0.0} \times 10^{-20}\right)\cdot C_{\rm T}$$

$$d_{\rm Xe} = -\left(0.29^{+2.3}_{-0.11} \times 10^{-18}\right)\cdot \bar{g}_{\pi NN}^{(0)} - \left(0.22^{+1.7}_{-0.11} \times 10^{-18}\right)\cdot \bar{g}_{\pi NN}^{(1)} + \left(4^{+2}_{-0} \times 10^{-21}\right)\cdot C_{\rm T}$$

$$d_{\rm n} = -\left(1.5 \times 10^{-14}\right)\cdot \bar{g}_{\pi NN}^{(0)} + \left(1.4 \times 10^{-16}\right)\cdot \bar{g}_{\pi NN}^{(1)}$$

$d_{\rm n}$: No contribution from $C_{\rm T}$

T-odd Correlation in Compound Nuclei

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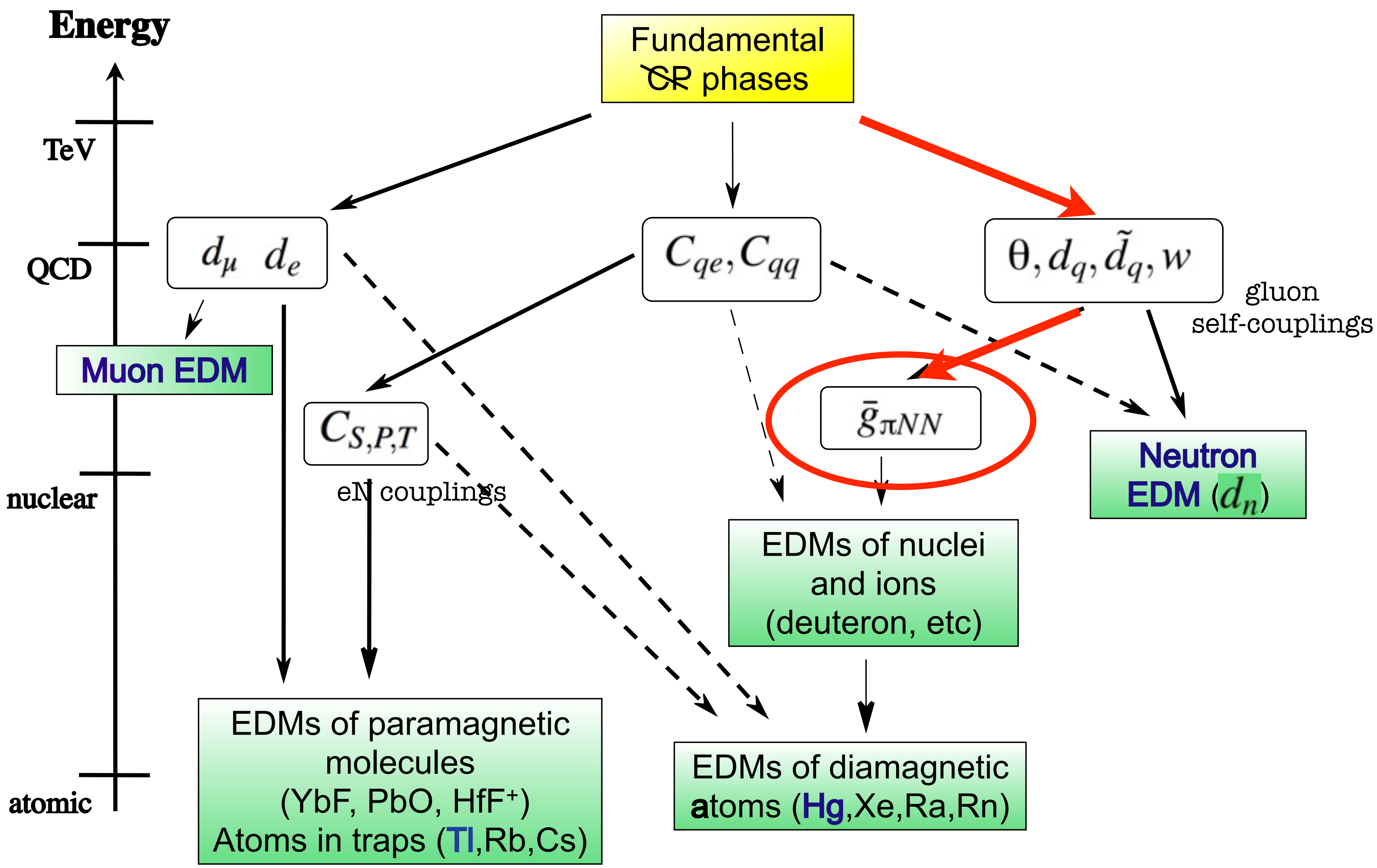
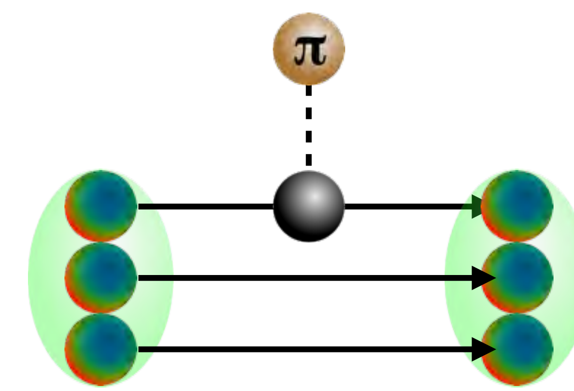
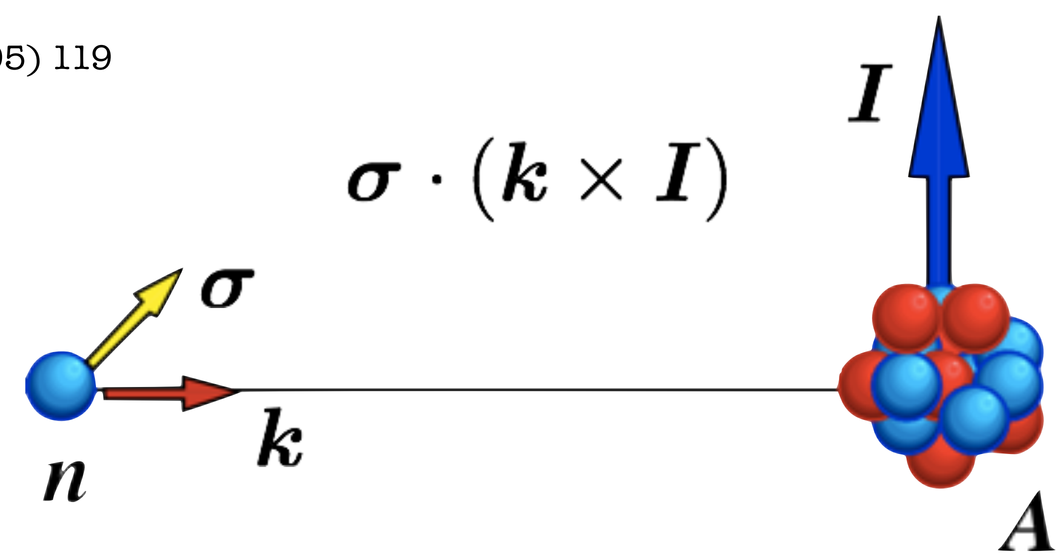


Pospelov Ritz, Ann Phys 318 (05) 119

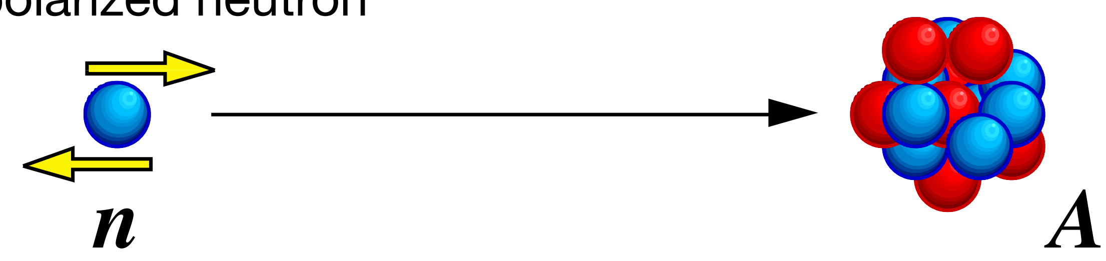


T-odd P-odd pion-nucleon coupling



P-odd and T-odd

P-odd



$\sigma \cdot k$

T-odd

$\boldsymbol{\sigma} \cdot (\boldsymbol{k} \times \boldsymbol{I})$

P-violation in Compound Nuclei

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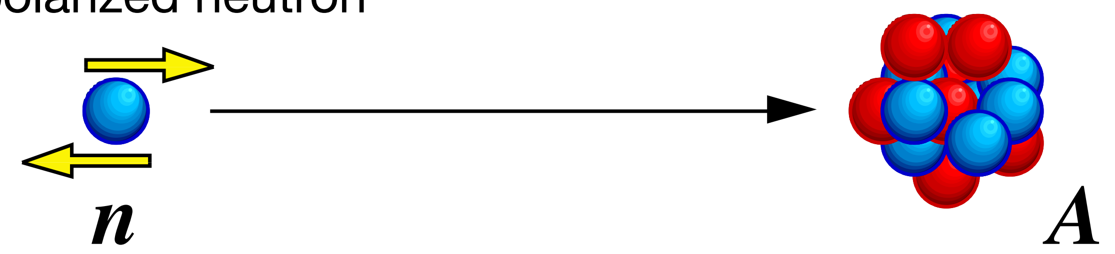
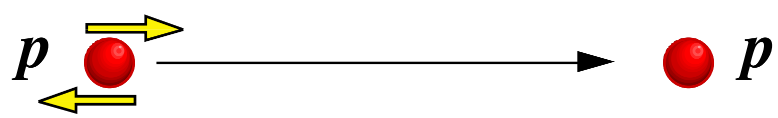
neutron capture
around p-wave resonance

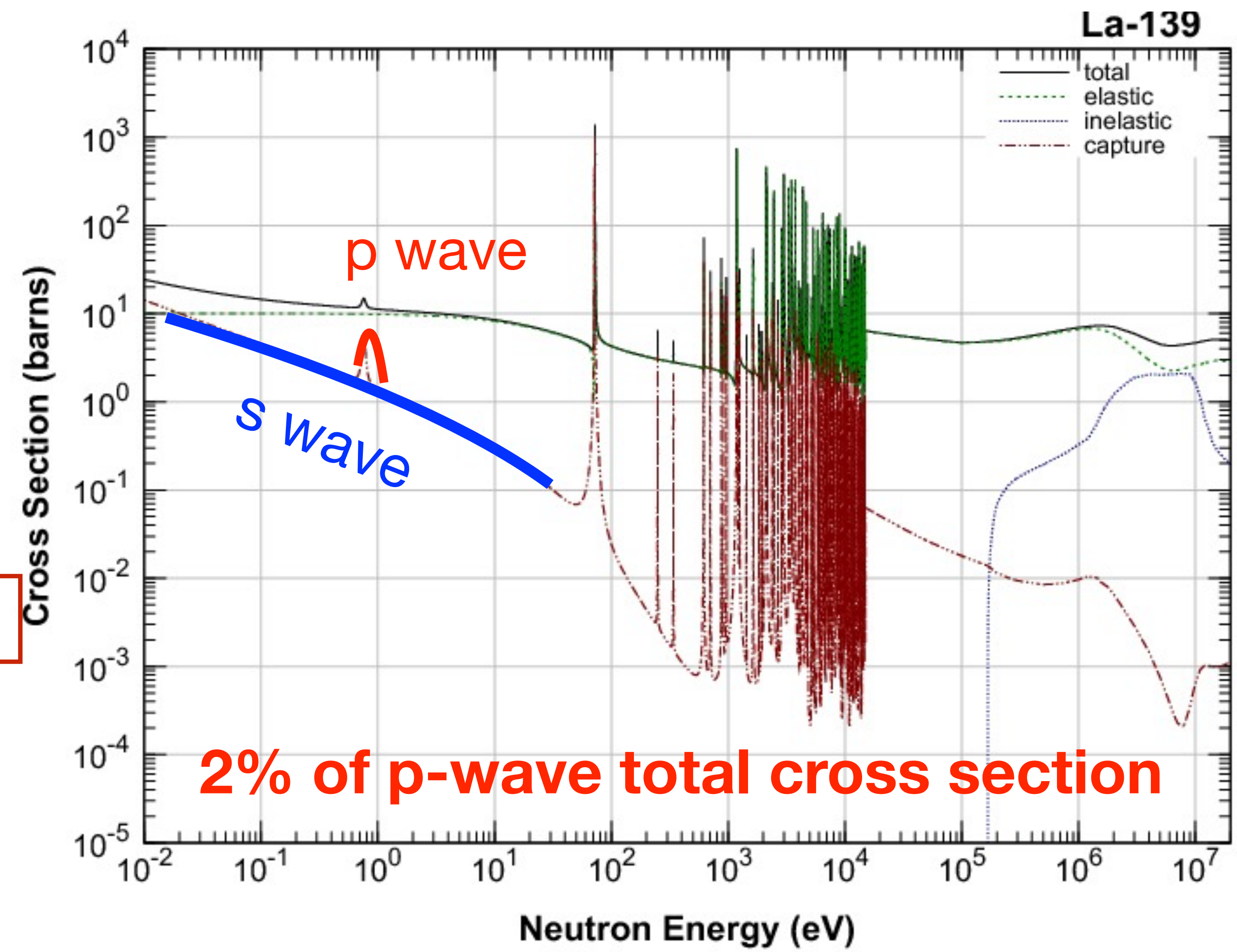
polarized neutron



^{139}La $E_n = 0.734$ eV 0.097±0.003

polarized proton 15MeV $-(1.7\pm0.8)\times10^{-7}$





P-violation is enhanced in
the interference between s-wave and p-wave
of compound nuclei.

P-violation in Compound Nuclei

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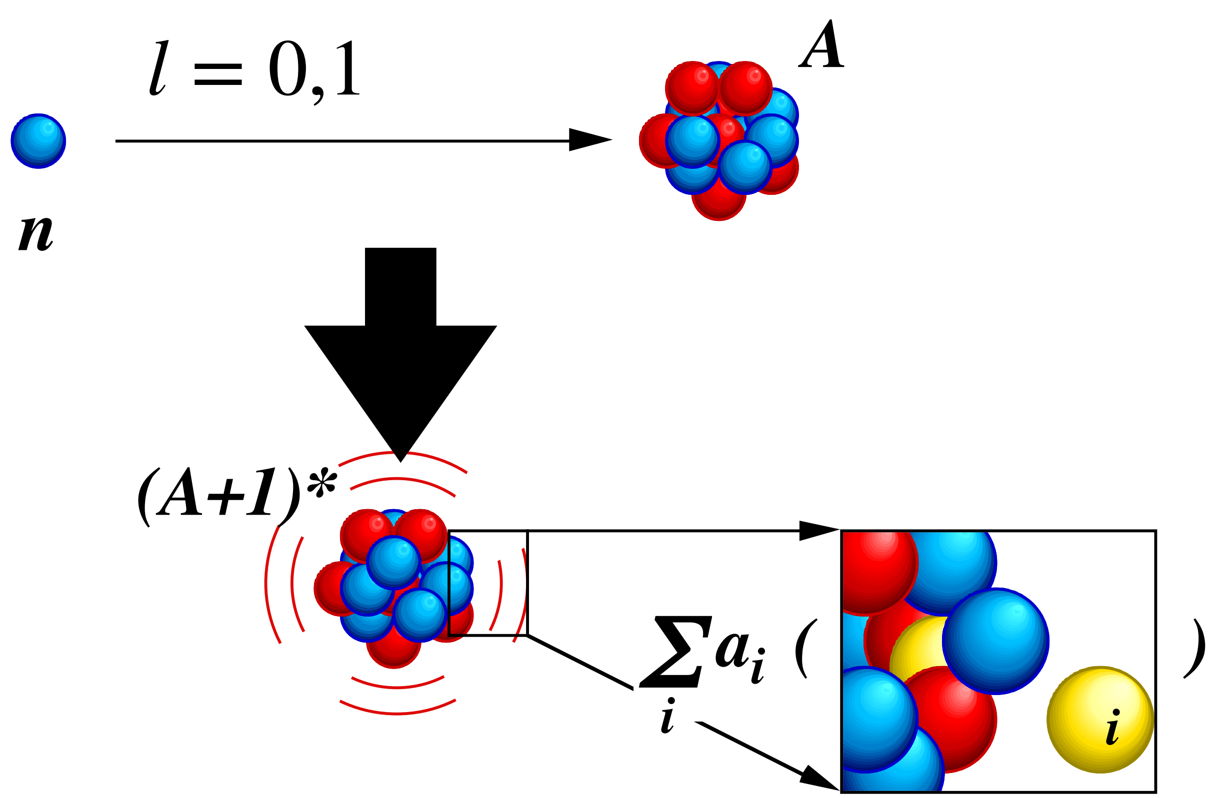
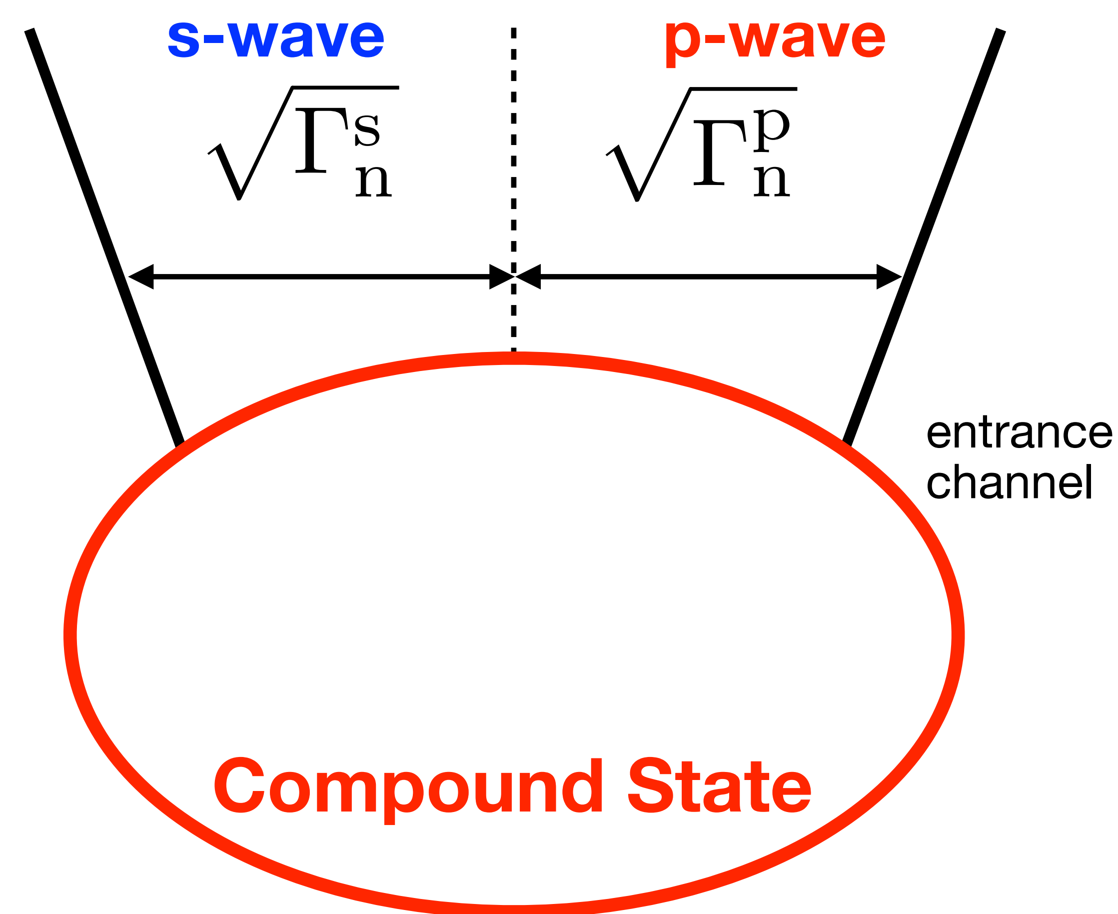
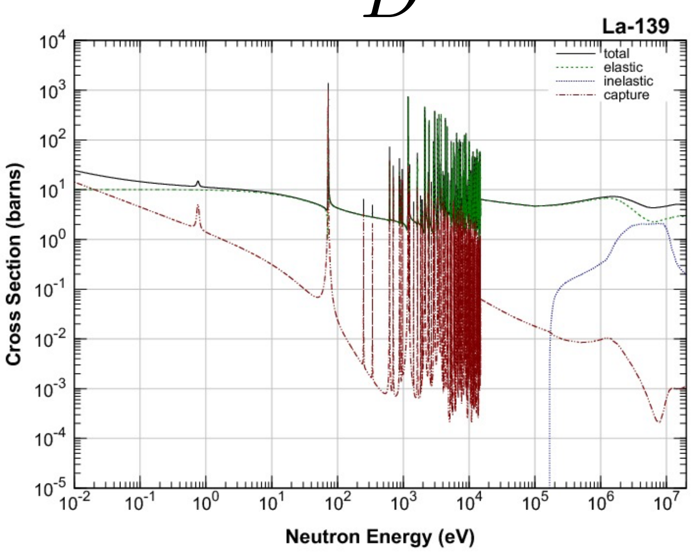


$$J = I + j \qquad j = l + s$$

Resonance spin — target spin — neutron total angular momentum



$$N \sim \frac{\Delta E}{D} \sim 10^5$$



$$|\mathrm{p}\rangle = \sum_{i=1}^{N} b_i \, |\psi_i\rangle$$

$$|\mathrm{s}\rangle = \sum_{i=1}^{N} a_i \, |\psi_i\rangle$$

$$\langle \mathrm{s}|W|\mathrm{p}\rangle = \sum_{i,j}^{N} a_i^* b_j \, \langle \psi_i|W|\psi_j\rangle \sim \frac{1}{\sqrt{N}} \frac{1}{\sqrt{N}} \langle W \rangle \sqrt{N}$$

P-violation in Compound Nuclei

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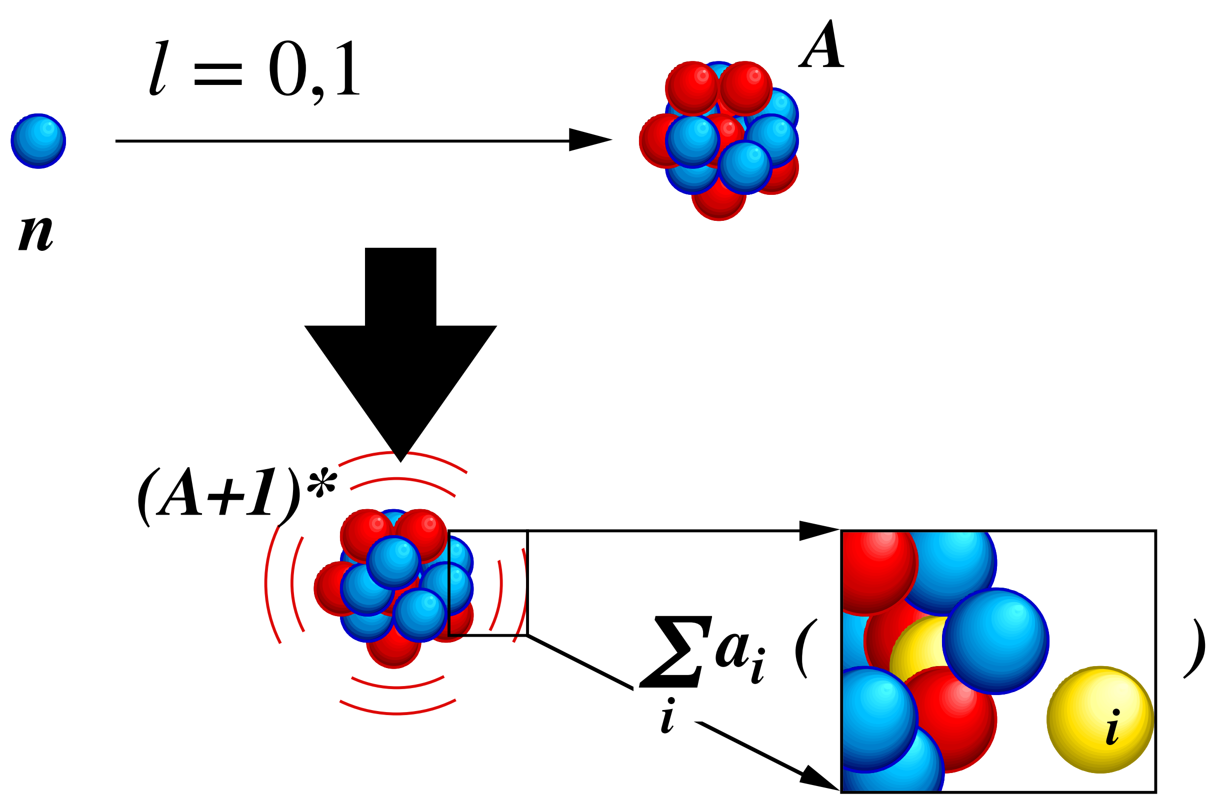
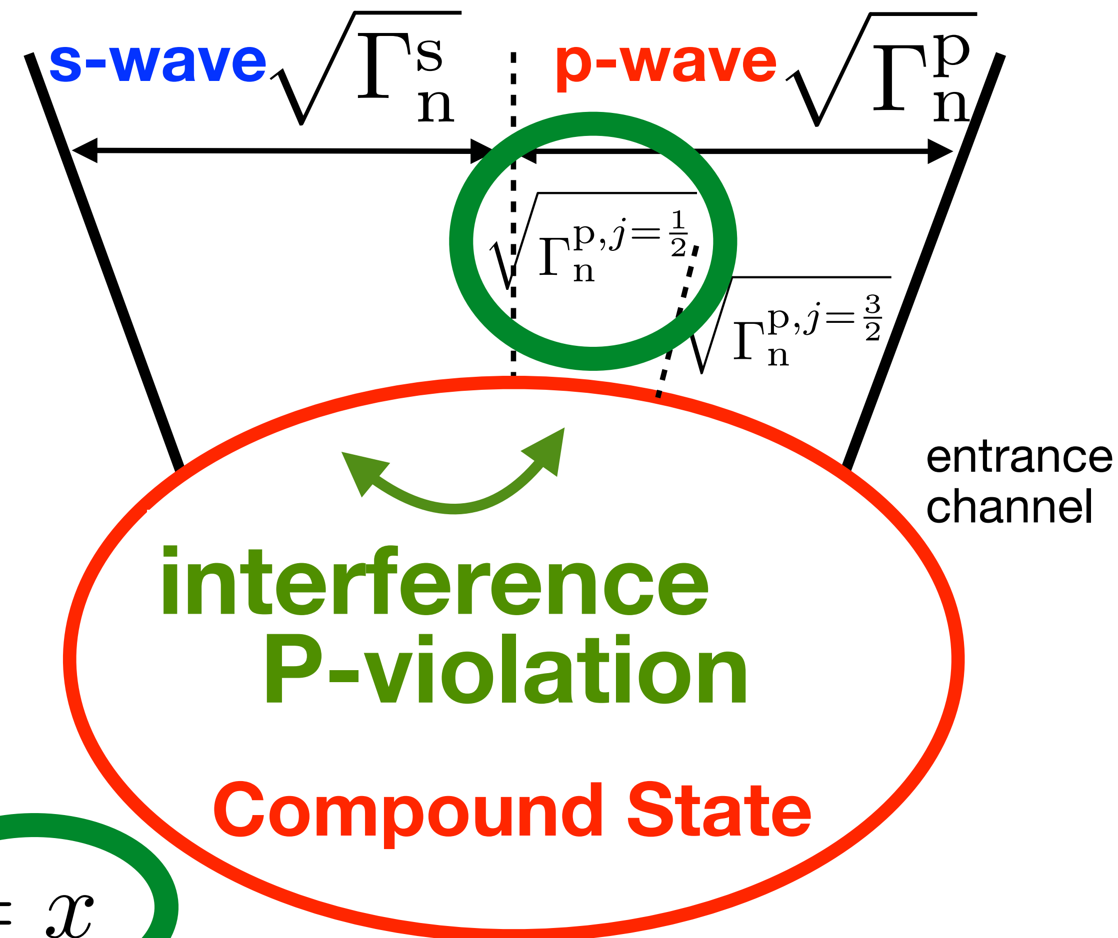


$$J = I + j$$

J: Resonance spin; I: target spin; j: neutron total angular momentum

$$j = l + s$$



$$A_L = -\frac{2W}{E_p - E_s}\sqrt{\frac{\Gamma_n^s}{\Gamma_n^p}}\sqrt{\frac{\Gamma_n^{p,j=\frac{1}{2}}}{\Gamma_n^p}}$$

$$= x$$

$$\left(x = \sqrt{\frac{\Gamma_n^{p,j=\frac{1}{2}}}{\Gamma_n^p}} \quad y = \sqrt{\frac{\Gamma_n^{p,j=\frac{3}{2}}}{\Gamma_n^p}} \quad x^2 + y^2 = 1 \quad \begin{matrix} x = \cos\phi \\ y = \sin\phi \end{matrix} \quad \text{Unknown parameter} \right)$$

T-violation in Compound Nuclei

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The interference between s-wave and p-wave results in the interference between partial waves with different channel spin.

Gudkov, Phys. Rep. 212 (1992) 77.

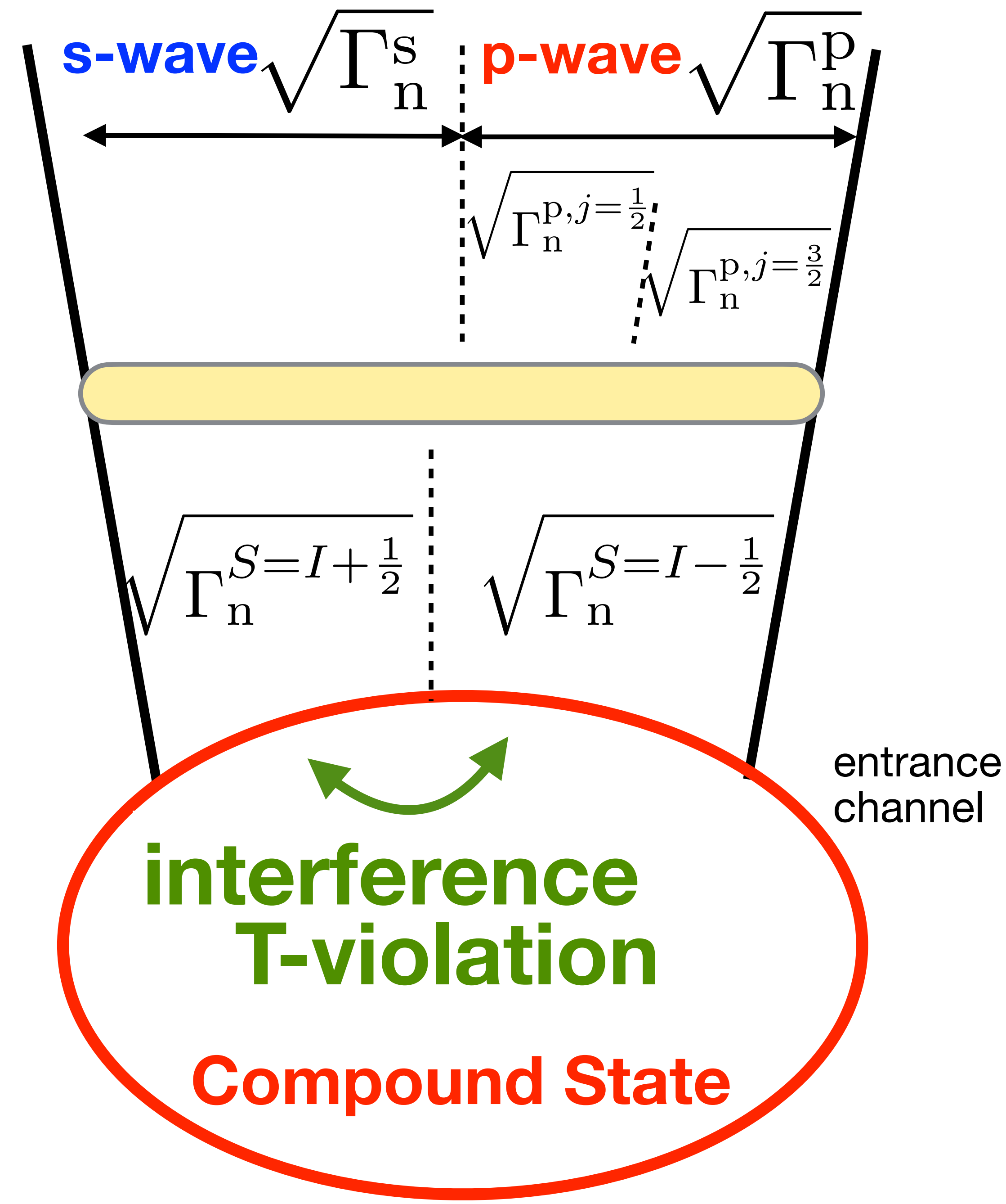
$$\boldsymbol{J} = \boldsymbol{l} + \boldsymbol{s} + \boldsymbol{I}$$

$$\boldsymbol{j} = \boldsymbol{l} + \boldsymbol{s}$$

$$\boldsymbol{S} = \boldsymbol{s} + \boldsymbol{I}$$

$$P : |lsI\rangle \to (-1)^l \, |lsI\rangle$$

$$T : |lsI\rangle \to (-1)^{i\pi S_y} K \, |lsI\rangle$$



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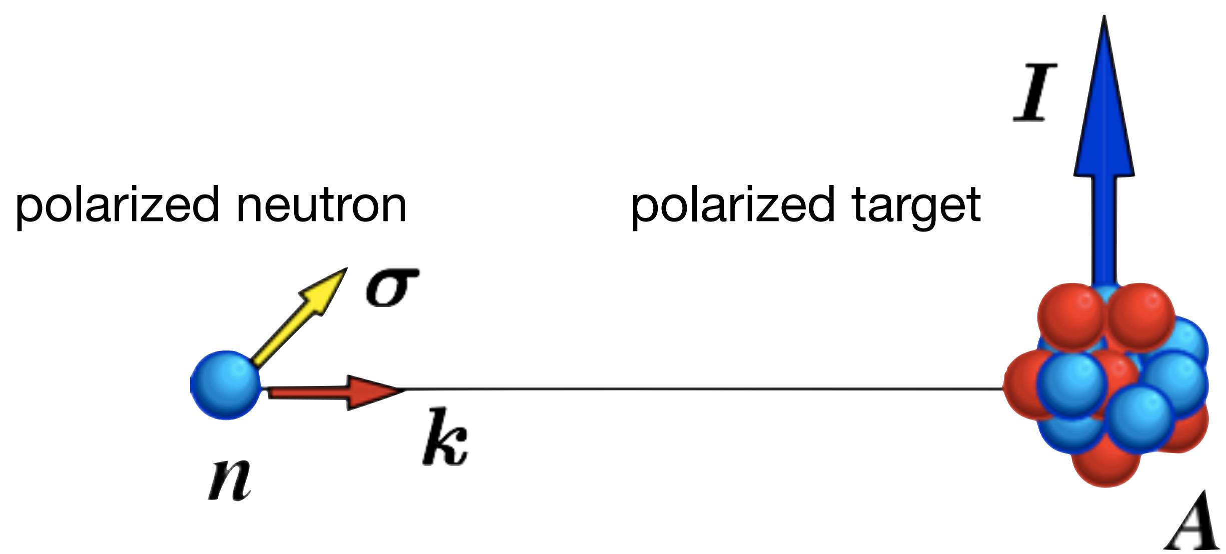
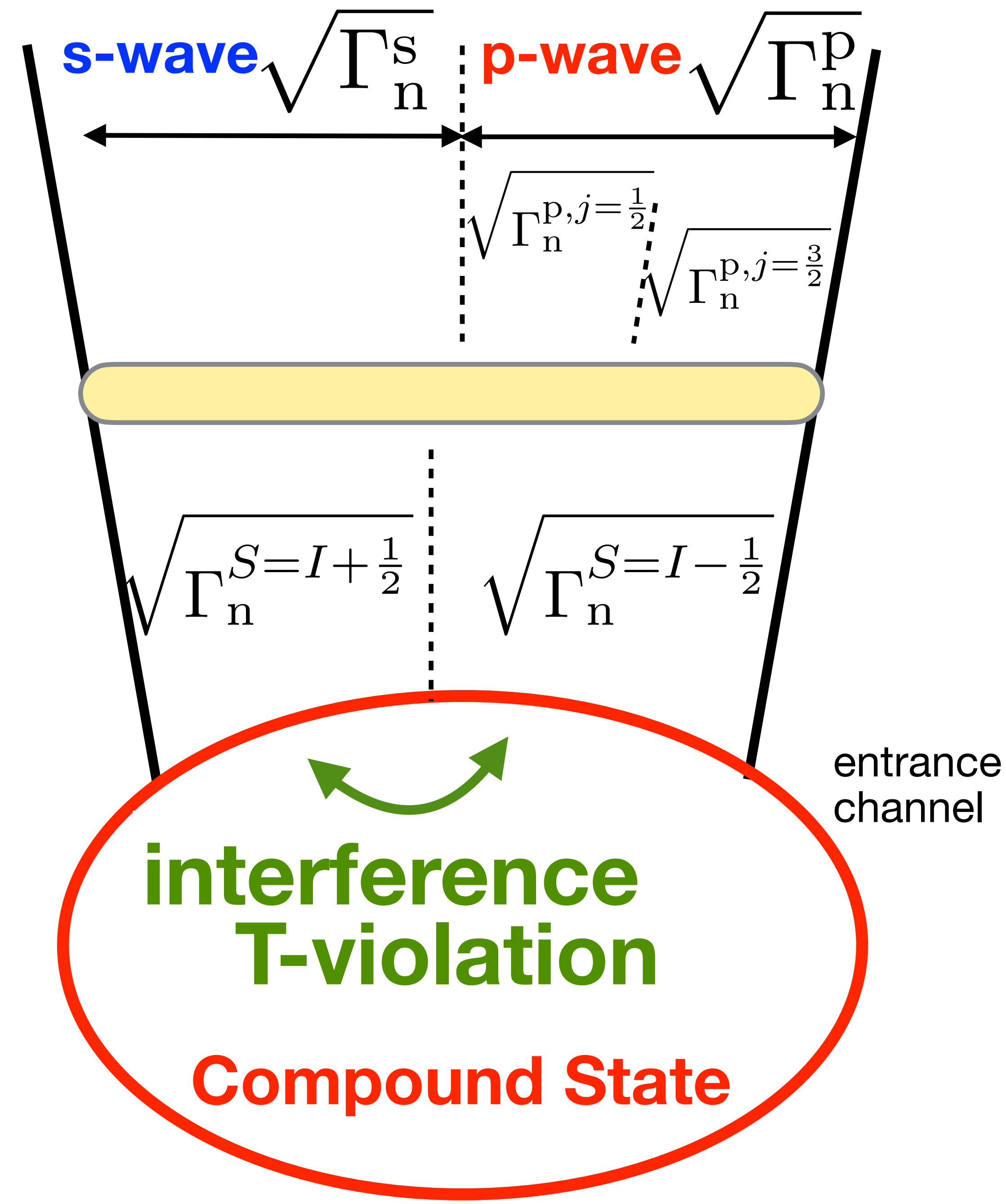


$$\boldsymbol{\sigma} \cdot (\boldsymbol{k} \times \boldsymbol{I})$$



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$$\Delta\sigma_{\mathrm{T}} = \kappa(J)\frac{W_{\mathrm{T}}}{W}\Delta\sigma_{\mathrm{P}}$$

T-violation

T-violating matrix element

P-violating matrix element

P-violation

Angular momentum factor

$$\kappa(J) = \begin{cases} (-1)^{2I}\left(1+\frac{1}{2}\sqrt{\frac{2I-1}{I+1}}\frac{y}{x}\right) & (J = I - \frac{1}{2}) \\ (-1)^{2I+1}\frac{I}{I+1}\left(1-\frac{1}{2}\sqrt{\frac{2I+3}{I}}\frac{y}{x}\right) & (J = I + \frac{1}{2}) \end{cases}$$

$$x = \sqrt{\frac{\Gamma_{\mathrm{n}}^{\mathrm{p},j=\frac{1}{2}}}{\Gamma_{\mathrm{n}}^{\mathrm{p}}}} \quad y = \sqrt{\frac{\Gamma_{\mathrm{n}}^{\mathrm{p},j=\frac{3}{2}}}{\Gamma_{\mathrm{n}}^{\mathrm{p}}}} \quad x^2 + y^2 = 1 \quad \begin{array}{l} x = \cos\phi \\ y = \sin\phi \end{array}$$

Unknown parameter

Feasibility of T-violation experiment

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T-violating pion exchange coupling

$$\frac{W_T}{W} = \frac{\Delta\sigma^{TP}}{\Delta\sigma^{P}} \simeq (-0.47)\left(\frac{\bar{g}_\pi^{(0)}}{h_\pi^1} + (0.26)\frac{\bar{g}_\pi^{(1)}}{h_\pi^1}\right)$$

P-violating pion exchange coupling

Y.-H.Song et al.,
Phys. Rev. C83 (2011) 065503,
Phys. Rev. C84 (2011) 025501

n+p→d+γ $h_\pi^1 = (3.04 \pm 1.23) \times 10^{-7}$

nEDM $\bar{g}_\pi^{(0)} < 2.5 \times 10^{-10}$

^{199}Hg EDM $\bar{g}_\pi^{(1)} < 0.5 \times 10^{-11}$

→ $\left|\frac{W_T}{W}\right| < 3.9 \times 10^{-4}$

$$\Delta\sigma_T = \kappa(J)\frac{W_T}{W}\Delta\sigma_P \xrightarrow{\kappa(J) \sim 1}$$

Discovery potential

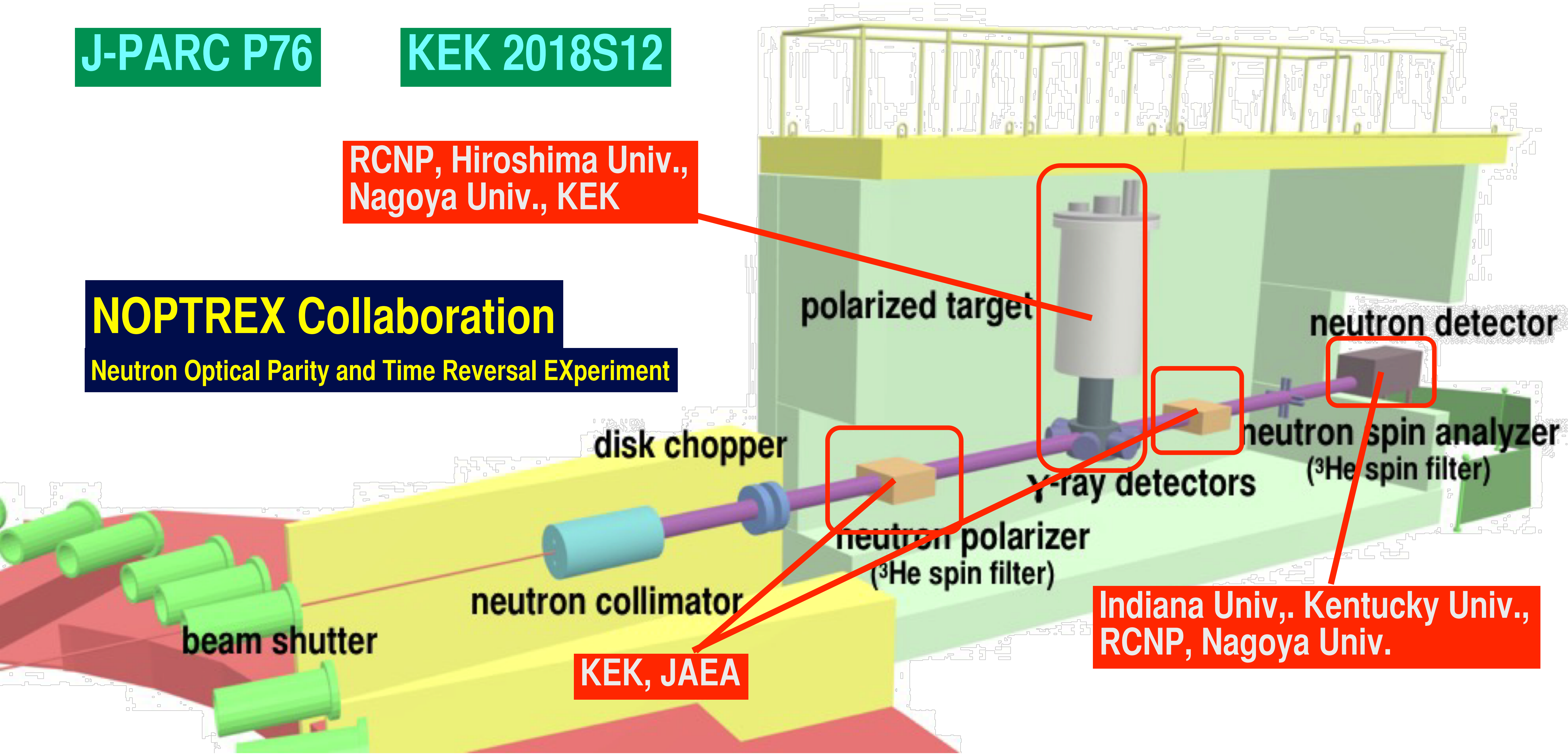
$$\left|\Delta\sigma_T\right| < 1.0 \times 10^{-4}\,\text{barn}$$

T-violation experiment at J-PARC

J-PARC P76

KEK 2018S12

NOPTREX Collaboration
Neutron Optical Parity and Time Reversal EXperiment

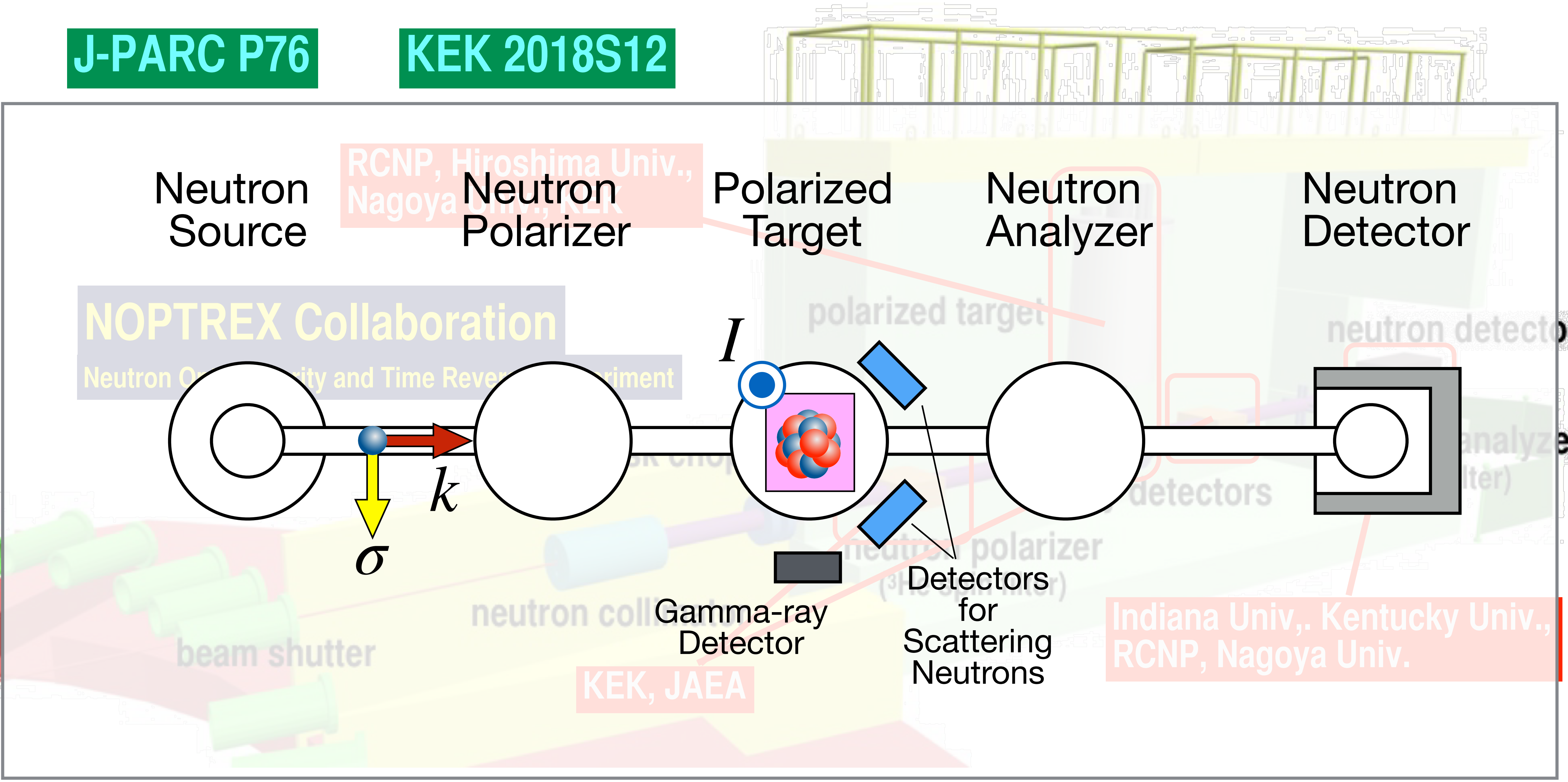


T-violation experiment at J-PARC

NOPTREX
Neutron Optical Parity and Time-Reversal EXperiment

J-PARC P76

KEK 2018S12



Feasibility of T-violation experiment

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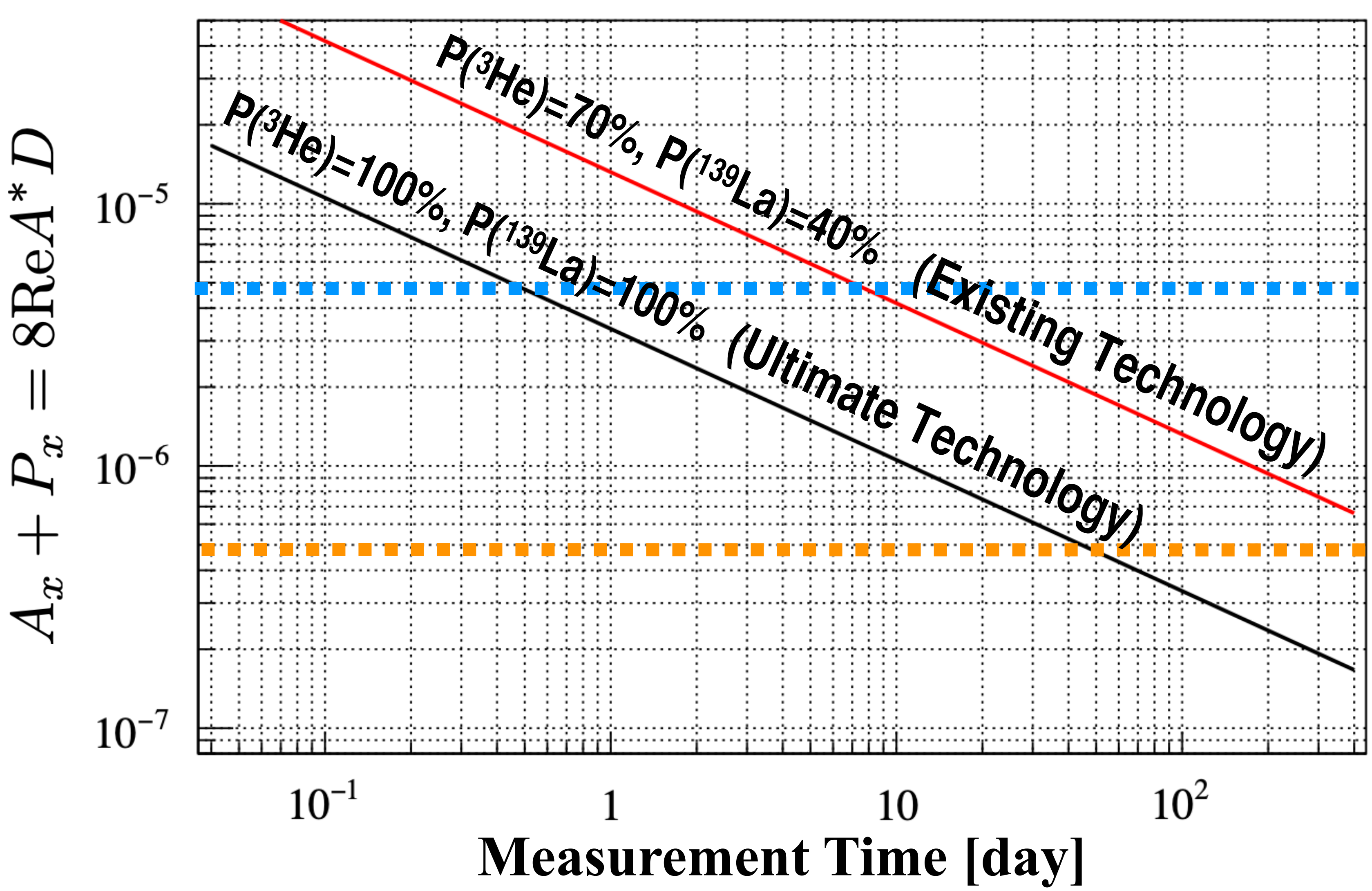
$\overrightarrow{^{139}\mathrm{La}}$ $\mathrm{LaAlO_3}$

$P(^{139}\mathrm{La}) \geq 0.4$, $V \geq 4\,\mathrm{cm} \times 4\,\mathrm{cm} \times 2.8\,\mathrm{cm}$
$B_0 \leq 0.1\,\mathrm{T}$

$$\left|\frac{\langle W_\mathrm{T}\rangle}{\langle W\rangle}\right| < 3.9 \times 10^{-4}$$

$$8\mathrm{Re}A^* D = 5.3 \times 10^{-5}$$



discovery potential corresponding to $d_n = 3.0 \times 10^{-26}$ e cm

discovery potential corresponding to $d_n = 3.0 \times 10^{-27}$ e cm

T-violation in Compound Nuclei

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$$\Delta\sigma_{\mathrm{T}} = \kappa(J)\frac{W_{\mathrm{T}}}{W}\Delta\sigma_{\mathrm{P}}$$

T-violation — $\Delta\sigma_{\mathrm{T}}$

P-violation — $\Delta\sigma_{\mathrm{P}}$

T-violating matrix element — W_{T}

P-violating matrix element — W

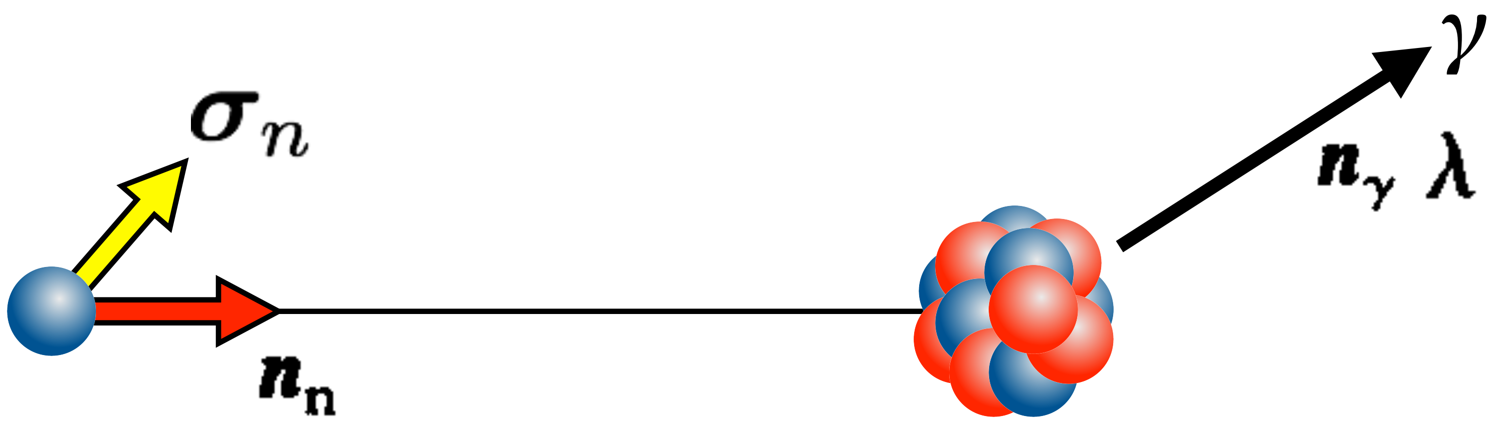
Angular momentum factor

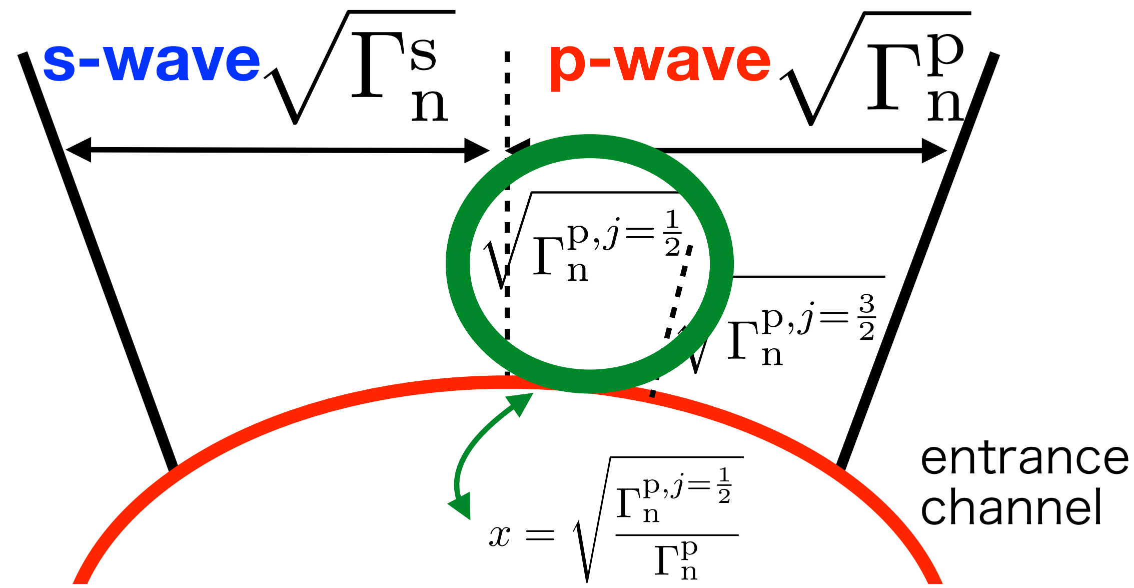
$$\kappa(J) = \begin{cases} (-1)^{2I}\left(1+\frac{1}{2}\sqrt{\frac{2I-1}{I+1}}\frac{y}{x}\right) & (J=I-\frac{1}{2}) \\ (-1)^{2I+1}\frac{I}{I+1}\left(1-\frac{1}{2}\sqrt{\frac{2I+3}{I}}\frac{y}{x}\right) & (J=I+\frac{1}{2}) \end{cases}$$

$$x = \sqrt{\frac{\Gamma_{\mathrm{n}}^{\mathrm{p},j=\frac{1}{2}}}{\Gamma_{\mathrm{n}}^{\mathrm{p}}}} \qquad y = \sqrt{\frac{\Gamma_{\mathrm{n}}^{\mathrm{p},j=\frac{3}{2}}}{\Gamma_{\mathrm{n}}^{\mathrm{p}}}} \qquad x^2+y^2=1 \qquad \begin{aligned} x &= \cos\phi \\ y &= \sin\phi \end{aligned}$$

Unknown parameter

(n, γ) measurement for κ





$$
\begin{aligned}
\frac{\mathrm{d}\sigma(\boldsymbol{n}_\gamma, \lambda)}{\mathrm{d}\Omega} = \tfrac{1}{2}\{ & a_0 + a_1(\boldsymbol{n}_\mathrm{n}\cdot\boldsymbol{n}_\gamma) + \tilde{a}_2\boldsymbol{\sigma}\cdot[\boldsymbol{n}_\mathrm{n}\times\boldsymbol{n}_\gamma] + a_3[(\boldsymbol{n}_\mathrm{n}\cdot\boldsymbol{n}_\gamma)^2 - \tfrac{1}{3}] \\
& + \tilde{a}_4(\boldsymbol{n}_\mathrm{n}\cdot\boldsymbol{n}_\gamma)\boldsymbol{\sigma}\cdot[\boldsymbol{n}_\mathrm{n}\times\boldsymbol{n}_\gamma] + a_5\lambda(\boldsymbol{\sigma}\cdot\boldsymbol{n}_\gamma) + a_6\lambda(\boldsymbol{\sigma}\cdot\boldsymbol{n}_\mathrm{n}) + a_7\lambda \\
& \times[(\boldsymbol{\sigma}\cdot\boldsymbol{n}_\gamma)(\boldsymbol{n}_\gamma\cdot\boldsymbol{n}_\mathrm{n}) - \tfrac{1}{3}(\boldsymbol{\sigma}\cdot\boldsymbol{n}_\mathrm{n})] + a_8\lambda[(\boldsymbol{\sigma}\cdot\boldsymbol{n}_\mathrm{n})(\boldsymbol{n}_\mathrm{n}\cdot\boldsymbol{n}_\gamma) - \tfrac{1}{3}(\boldsymbol{\sigma}\cdot\boldsymbol{n}_\gamma)] \\
& + a_9(\boldsymbol{\sigma}\cdot\boldsymbol{n}_\gamma) + a_{10}(\boldsymbol{\sigma}\cdot\boldsymbol{n}_\mathrm{n}) + a_{11}[(\boldsymbol{\sigma}\cdot\boldsymbol{n}_\gamma)(\boldsymbol{n}_\gamma\cdot\boldsymbol{n}_\mathrm{n}) - \tfrac{1}{3}(\boldsymbol{\sigma}\cdot\boldsymbol{n}_\mathrm{n})] \\
& + a_{12}[(\boldsymbol{\sigma}\cdot\boldsymbol{n}_\mathrm{n})(\boldsymbol{n}_\mathrm{n}\cdot\boldsymbol{n}_\gamma) - \tfrac{1}{3}(\boldsymbol{\sigma}\cdot\boldsymbol{n}_\gamma)] + a_{13}\lambda + a_{14}\lambda(\boldsymbol{n}_\mathrm{n}\cdot\boldsymbol{n}_\gamma) \\
& + \tilde{a}_{15}\lambda\boldsymbol{\sigma}\cdot[\boldsymbol{n}_\mathrm{n}\times\boldsymbol{n}_\gamma] + a_{16}\lambda[(\boldsymbol{n}_\mathrm{n}\cdot\boldsymbol{n}_\gamma)^2 - \tfrac{1}{3}] \\
& + \tilde{a}_{17}\lambda(\boldsymbol{n}_\mathrm{n}\cdot\boldsymbol{n}_\gamma)\boldsymbol{\sigma}\cdot[\boldsymbol{n}_\mathrm{n}\times\boldsymbol{n}_\gamma]\} \,.
\end{aligned}
$$

(n, γ) measurement for κ

for unpolarized case

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

Flambaum, Nucl. Phys. A435 (1985) 352

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

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

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

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

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

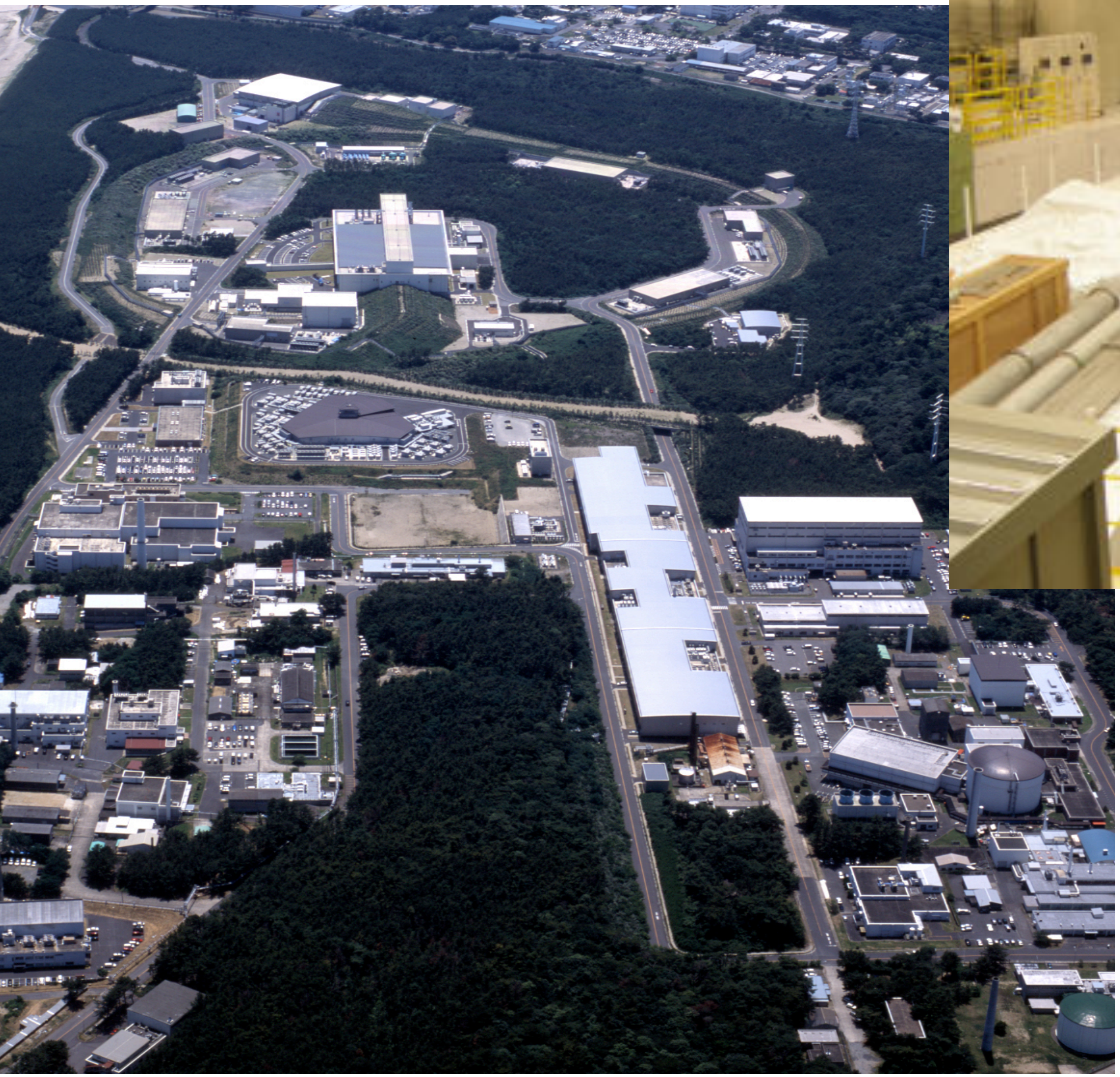
$$P(JJ'jj'kIF) = (-1)^{J+J'+j'+I+F} \frac{3}{2}\sqrt{(2J+1)(2J'+1)(2j+1)(2j'+1)} \begin{Bmatrix} j & j & j' \\ I & J' & J \end{Bmatrix} \begin{Bmatrix} k & 1 & 1 \\ F & J & J' \end{Bmatrix}$$

$$x = \sqrt{\frac{\Gamma_n^{p,j=\frac{1}{2}}}{\Gamma_n^p}} = \cos\phi$$

$V_2(j=1/2) = xV_2 = V_2 \cos\phi$

$V_2(j=3/2) = yV_2 = V_2 \sin\phi$

J-PARC MLF



^{139}La (n, γ) measurement

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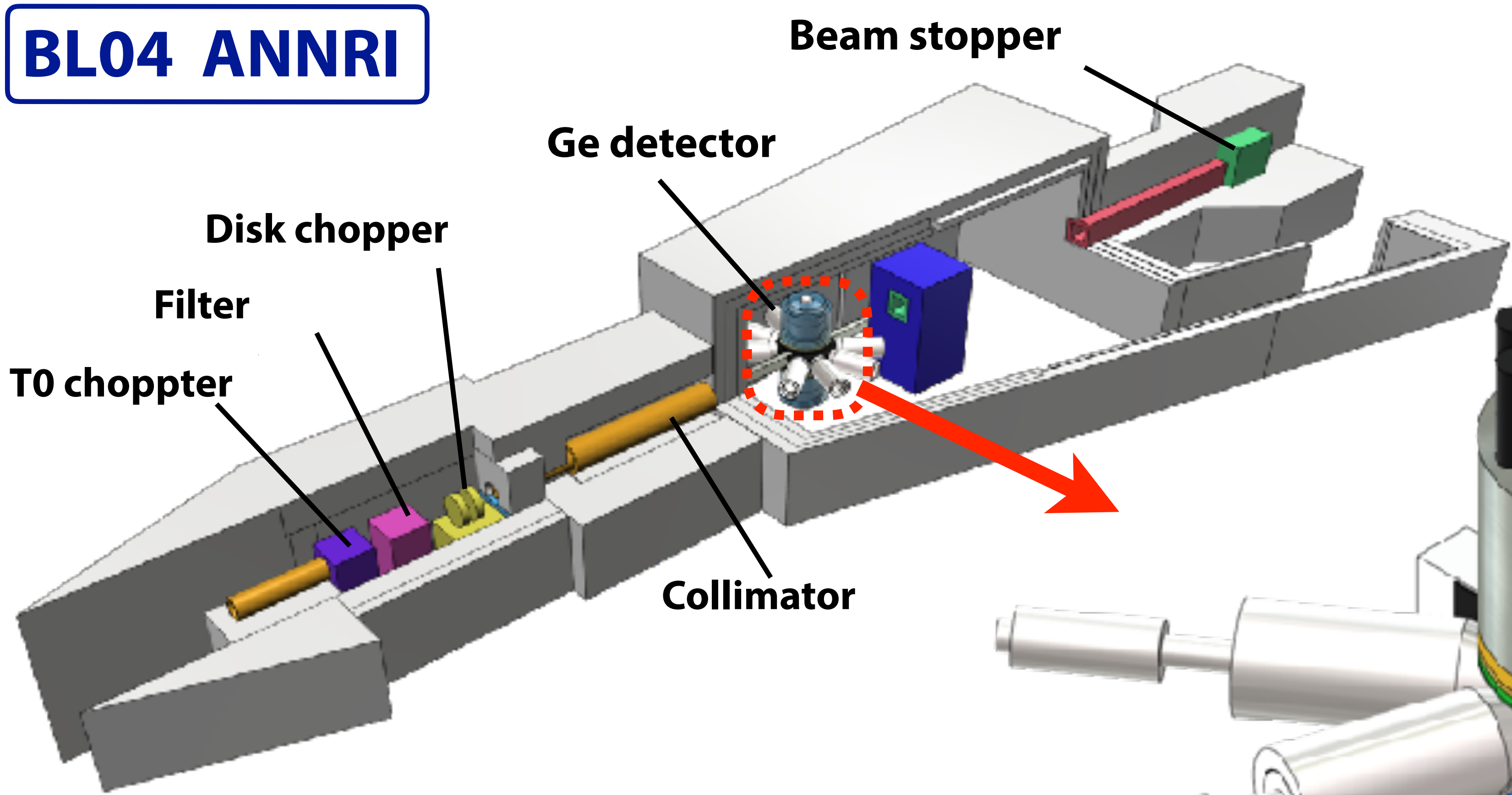
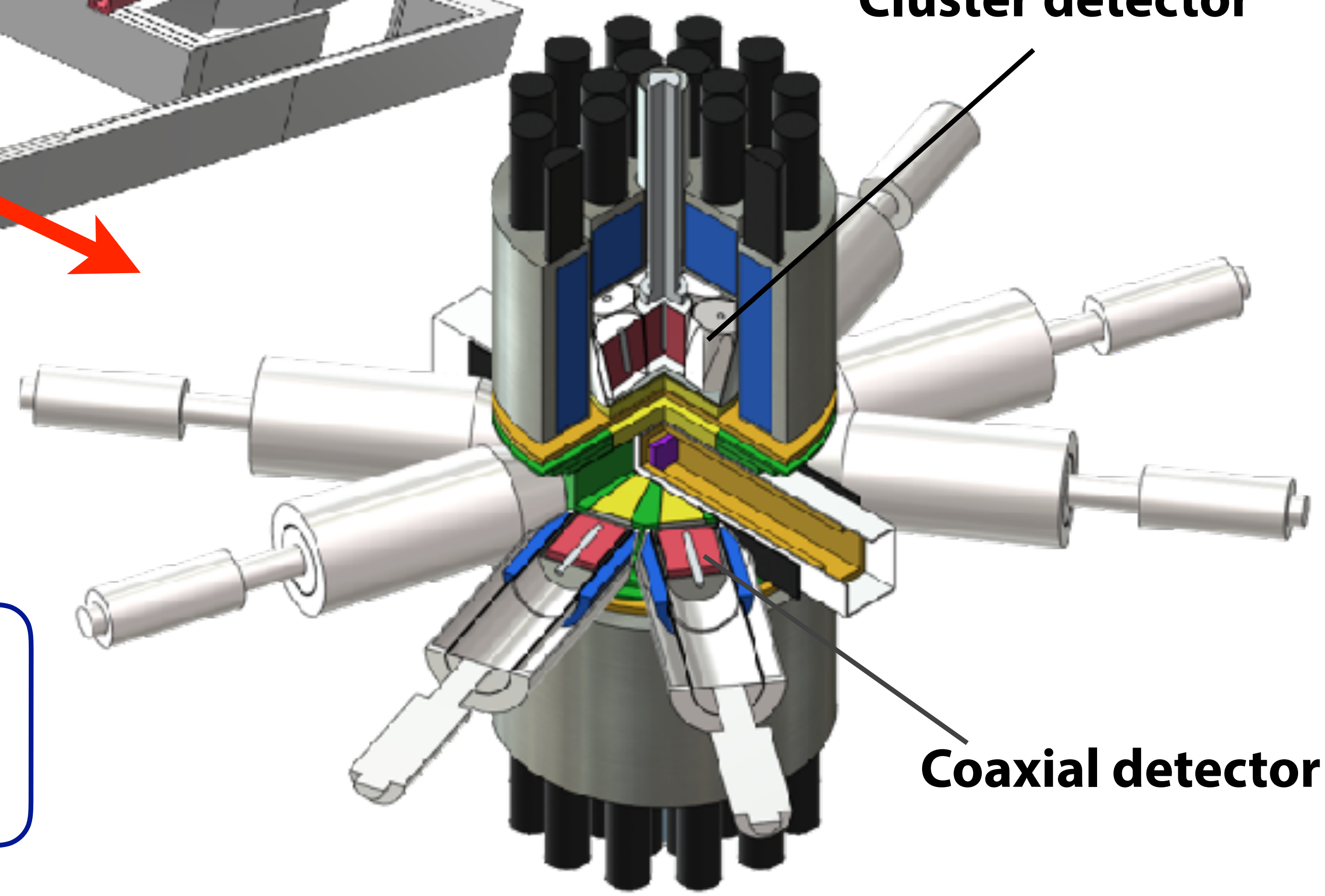
BL04 ANNRI



BL04 Ge Detector



2 Cluster Ge Detector 7ch ×2 : 14ch
8 Coaxial Ge Detector 8ch
22ch → 7 angles

Targets : ^{nat}La 40mm x 40mm x 1mm

T. Okudaira et. al. , Phys. Rev. C97 (2018) 034622.

^{139}La (n, γ) measurement

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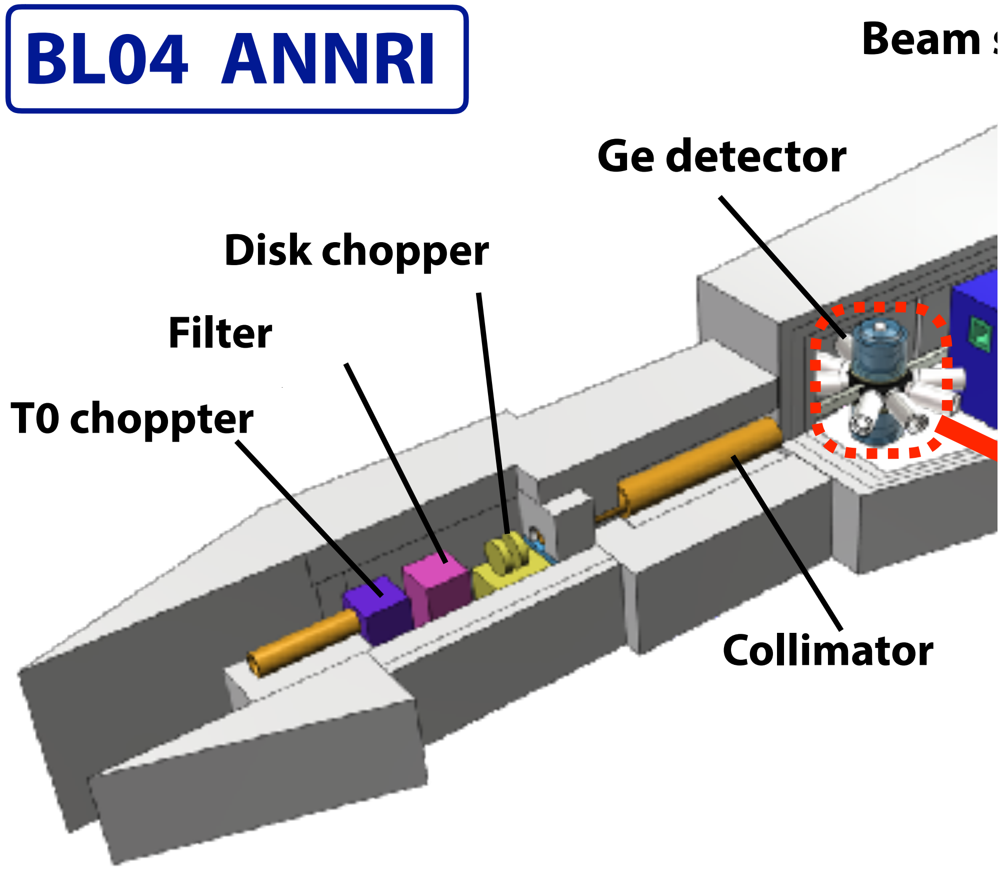

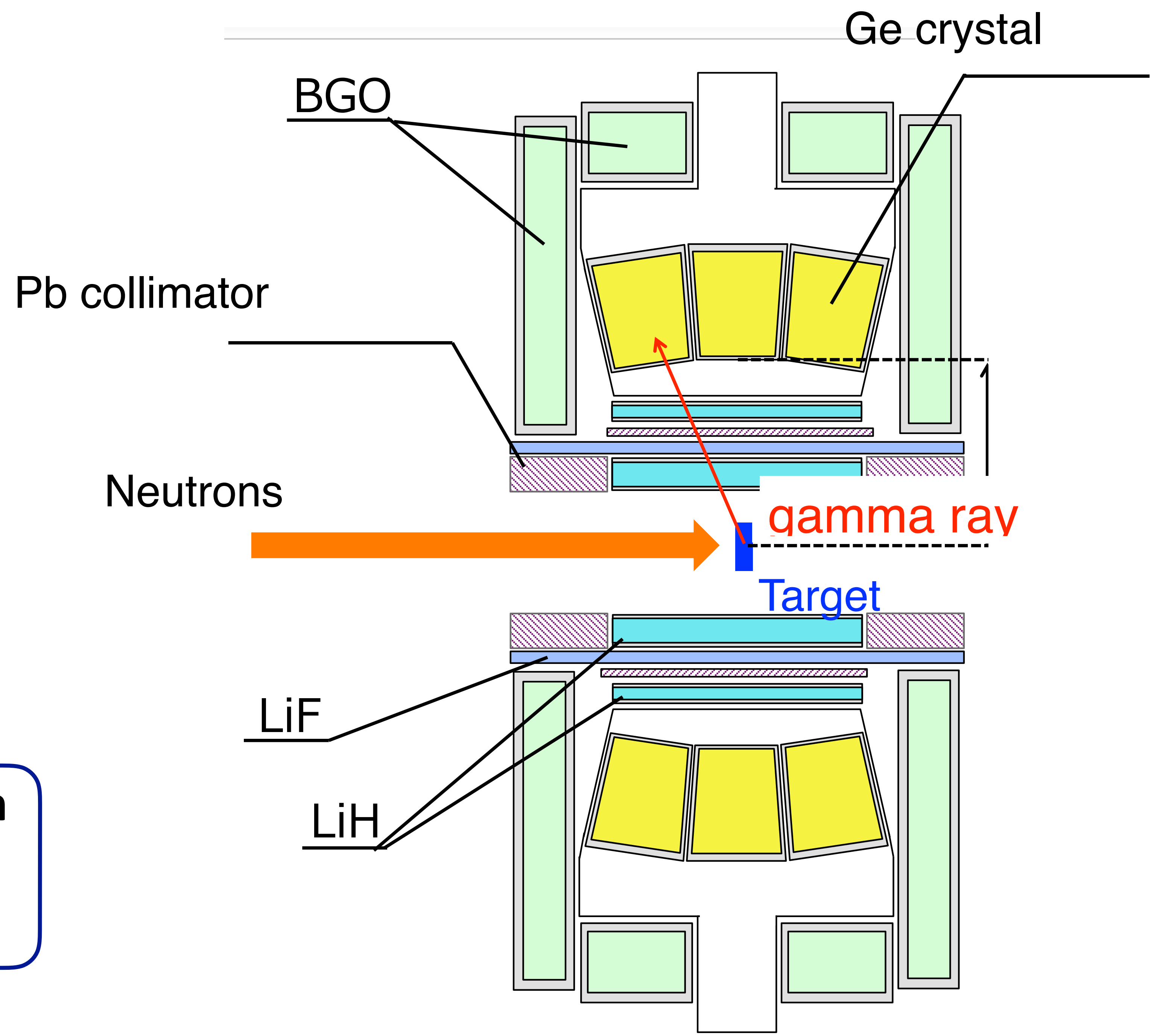

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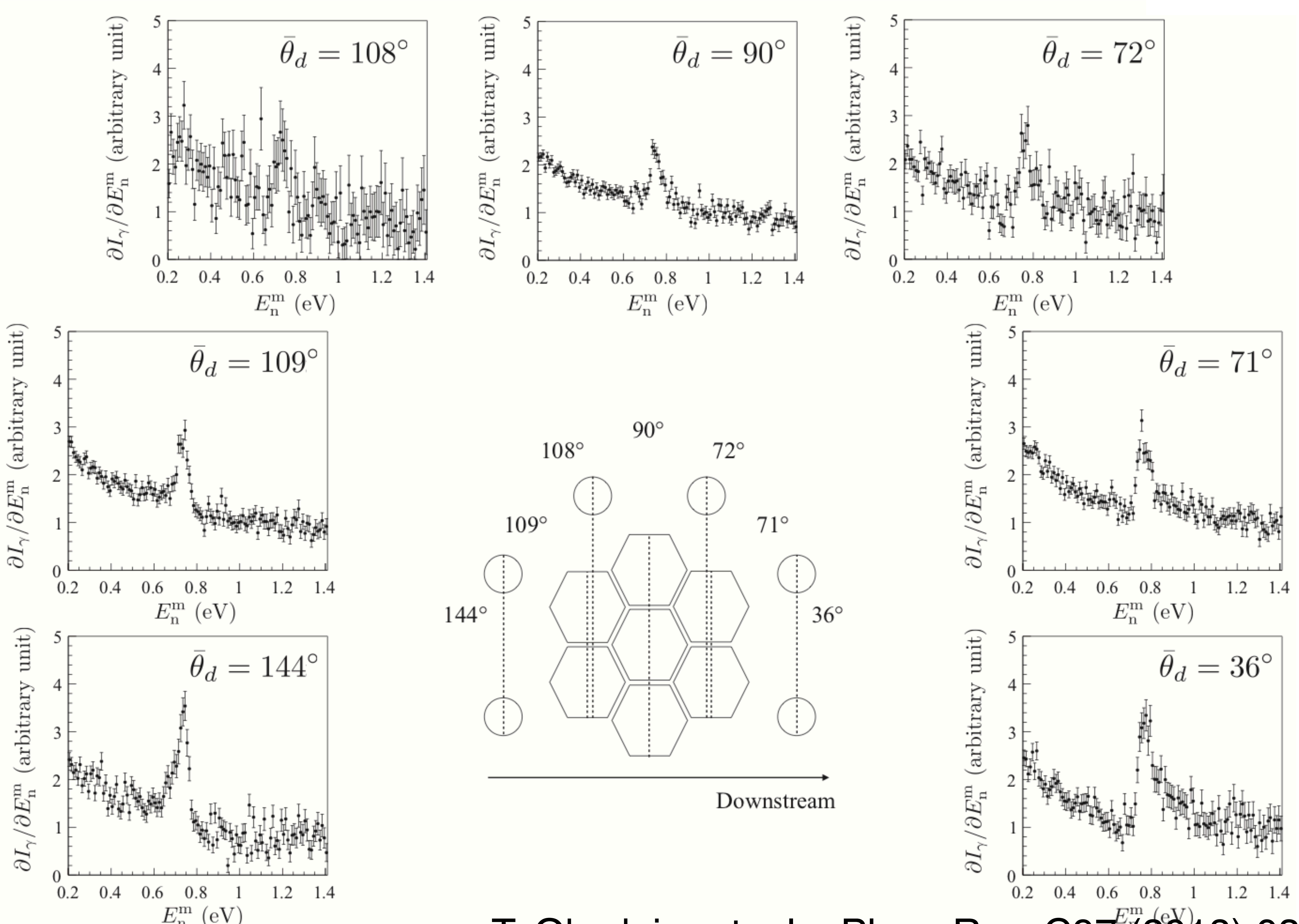

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^{139}La (n, γ) measurement

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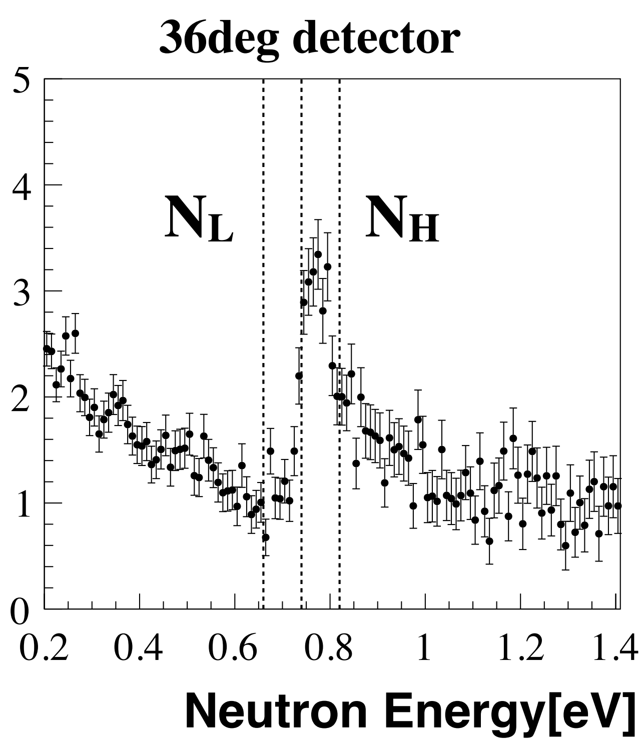
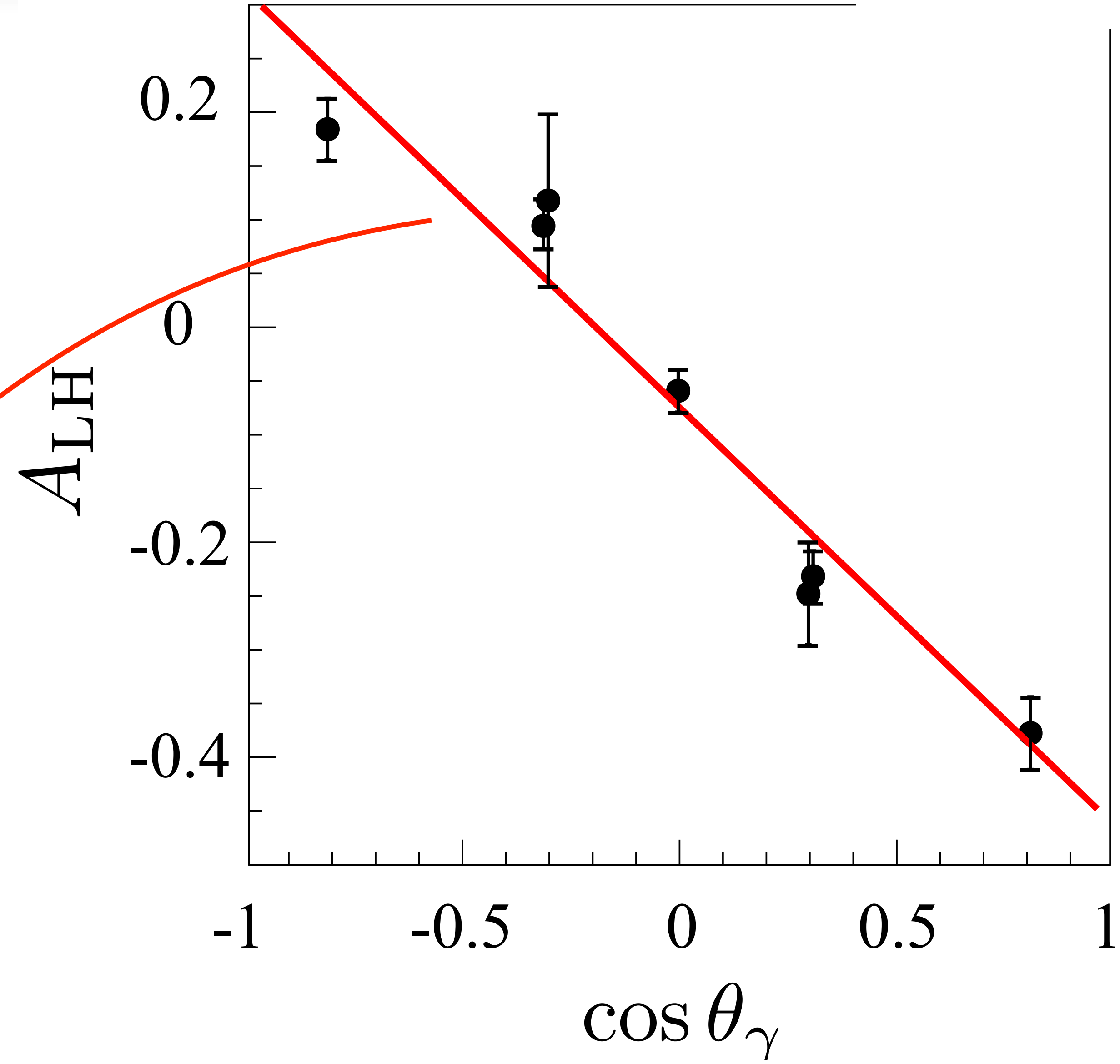
Neutron Optical Parity and Time-Reversal EXperiment

$$A_{\mathrm{LH}} = \frac{N_{\mathrm{L}} - N_{\mathrm{H}}}{N_{\mathrm{L}} + N_{\mathrm{H}}}$$





measured slope

$$-0.388 \pm 0.024 = 0.295\cos\phi - 0.345\sin\phi$$

calculated with Flambaum s-p mixing model

$$\phi = (99.2^{+6.3}_{-5.3})^{\circ}, \quad (161.9^{+5.3}_{-6.3})^{\circ}$$

$$x = \cos\phi$$

T. Okudaira et. al. , Phys. Rev. C97 (2018) 034622.

Estimation of Enhancement Factor

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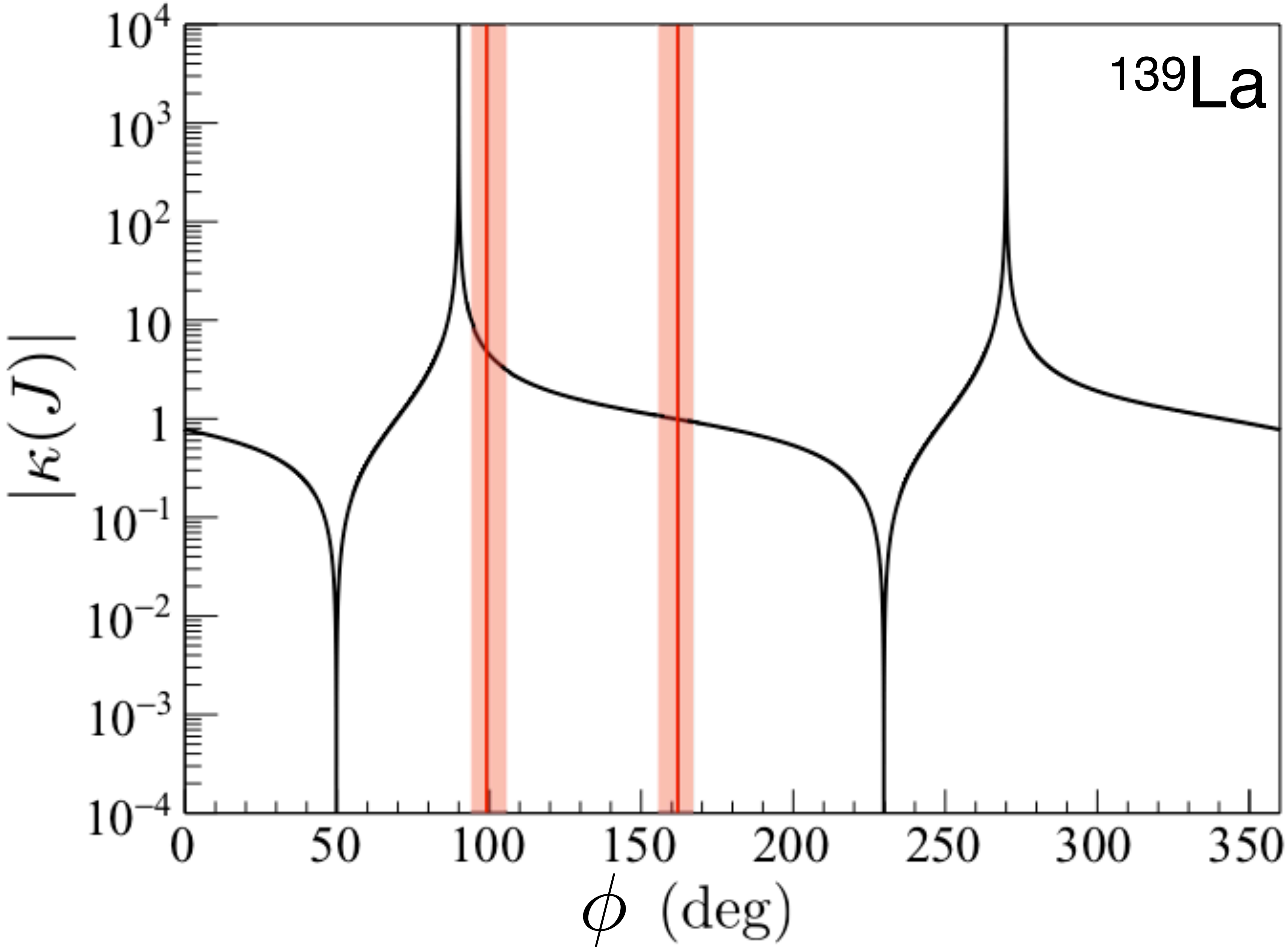
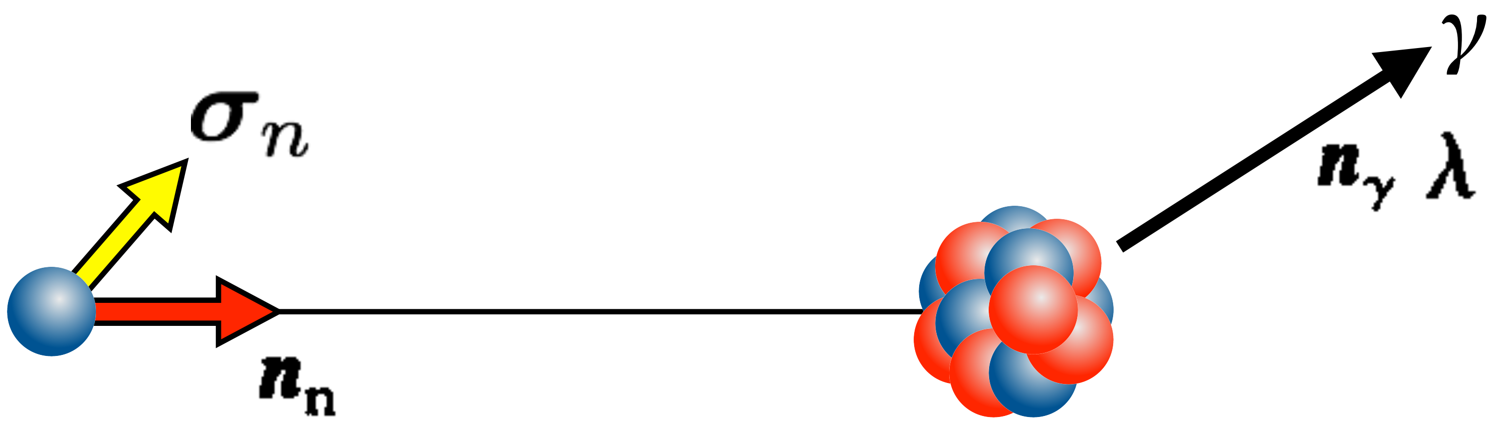
Neutron Optical Parity and Time-Reversal EXperiment

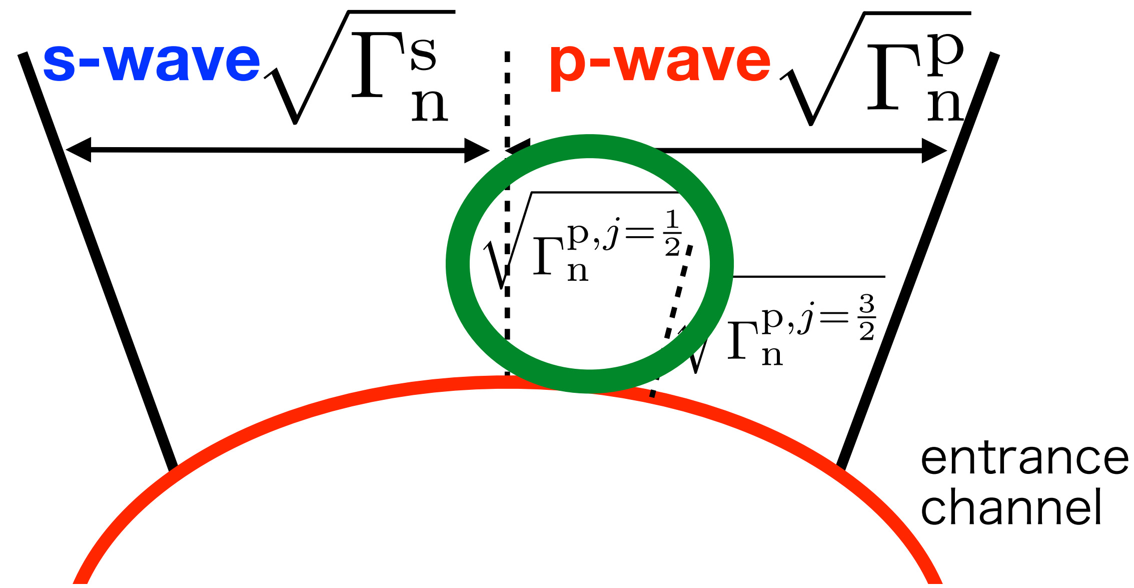
$$\kappa(J) = 0.99^{+0.88}_{-0.07}, 4.84^{+5.58}_{1.69}$$



T. Okudaira et. al. , Phys. Rev. C97 (2018) 034622.

(n, γ) measurement for κ





$$\begin{aligned}\frac{d\sigma(\boldsymbol{n}_\gamma,\lambda)}{d\Omega} = \frac{1}{2}\{ & \boxed{a_0} + \boxed{a_1}(\boldsymbol{n}_n\cdot\boldsymbol{n}_\gamma) + \boxed{\tilde{a}_2}\boldsymbol{\sigma}\cdot[\boldsymbol{n}_n\times\boldsymbol{n}_\gamma] + \boxed{a_3}[(\boldsymbol{n}_n\cdot\boldsymbol{n}_\gamma)^2-\tfrac{1}{3}] \\ & + \tilde{a}_4(\boldsymbol{n}_n\cdot\boldsymbol{n}_\gamma)\boldsymbol{\sigma}\cdot[\boldsymbol{n}_n\times\boldsymbol{n}_\gamma] + a_5\lambda(\boldsymbol{\sigma}\cdot\boldsymbol{n}_\gamma) + \boxed{a_6}\lambda(\boldsymbol{\sigma}\cdot\boldsymbol{n}_n) + a_7\lambda \\ & \times[(\boldsymbol{\sigma}\cdot\boldsymbol{n}_\gamma)(\boldsymbol{n}_\gamma\cdot\boldsymbol{n}_n)-\tfrac{1}{3}(\boldsymbol{\sigma}\cdot\boldsymbol{n}_n)] + a_8\lambda[(\boldsymbol{\sigma}\cdot\boldsymbol{n}_n)(\boldsymbol{n}_n\cdot\boldsymbol{n}_\gamma)-\tfrac{1}{3}(\boldsymbol{\sigma}\cdot\boldsymbol{n}_\gamma)] \\ & + \boxed{a_9}(\boldsymbol{\sigma}\cdot\boldsymbol{n}_\gamma) + \boxed{a_{10}}(\boldsymbol{\sigma}\cdot\boldsymbol{n}_n) + a_{11}[(\boldsymbol{\sigma}\cdot\boldsymbol{n}_\gamma)(\boldsymbol{n}_\gamma\cdot\boldsymbol{n}_n)-\tfrac{1}{3}(\boldsymbol{\sigma}\cdot\boldsymbol{n}_n)] \\ & + a_{12}[(\boldsymbol{\sigma}\cdot\boldsymbol{n}_n)(\boldsymbol{n}_n\cdot\boldsymbol{n}_\gamma)-\tfrac{1}{3}(\boldsymbol{\sigma}\cdot\boldsymbol{n}_\gamma)] + \boxed{a_{13}}\lambda + a_{14}\lambda(\boldsymbol{n}_n\cdot\boldsymbol{n}_\gamma) \\ & + \tilde{a}_{15}\lambda\boldsymbol{\sigma}\cdot[\boldsymbol{n}_n\times\boldsymbol{n}_\gamma] + a_{16}\lambda[(\boldsymbol{n}_n\cdot\boldsymbol{n}_\gamma)^2-\tfrac{1}{3}] \\ & + \tilde{a}_{17}\lambda(\boldsymbol{n}_n\cdot\boldsymbol{n}_\gamma)\boldsymbol{\sigma}\cdot[\boldsymbol{n}_n\times\boldsymbol{n}_\gamma]\}\,.\end{aligned}$$

(n, γ) measurement with polarized neutrons

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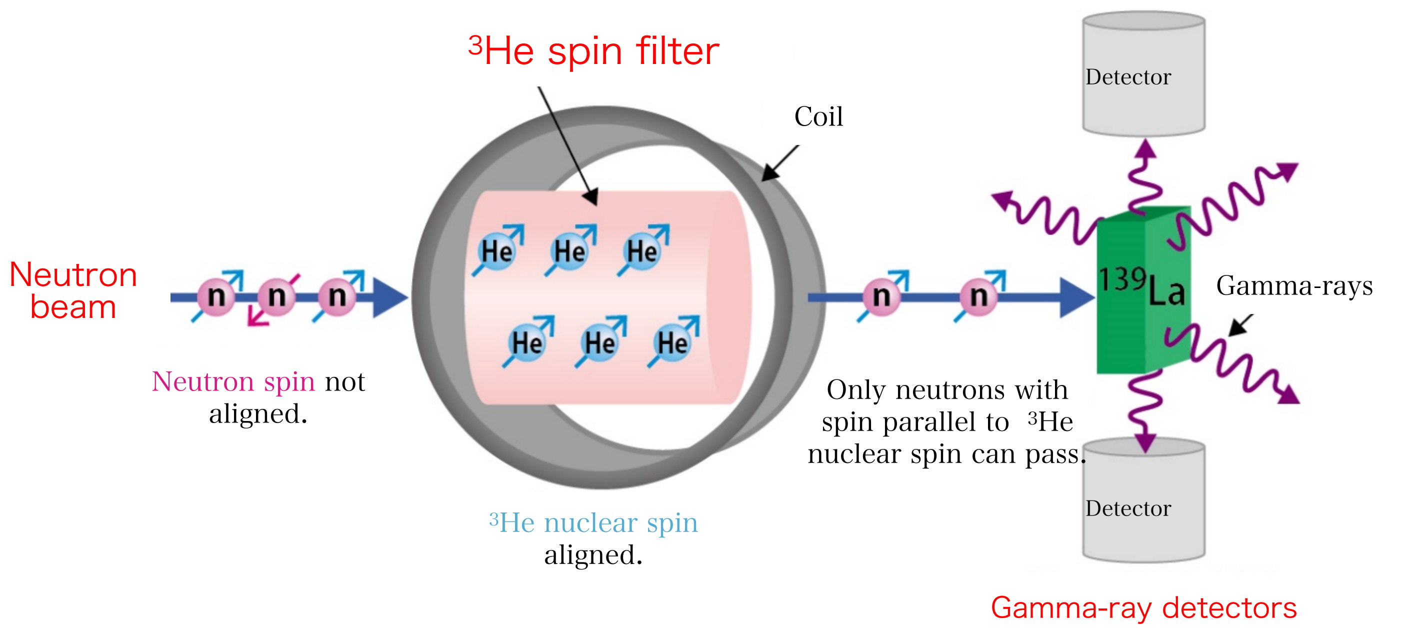
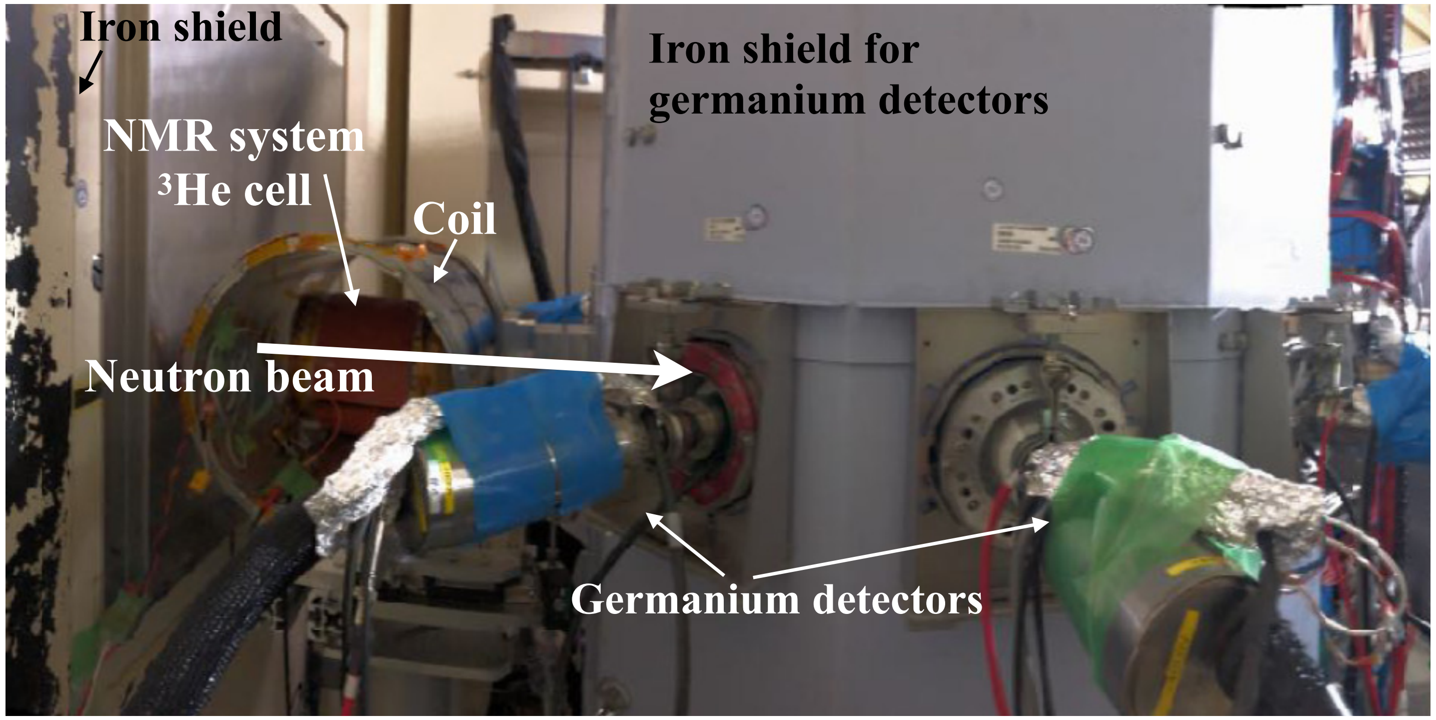


³He Cell ³He Polarization > 0.8
Relaxation time > 100 hours

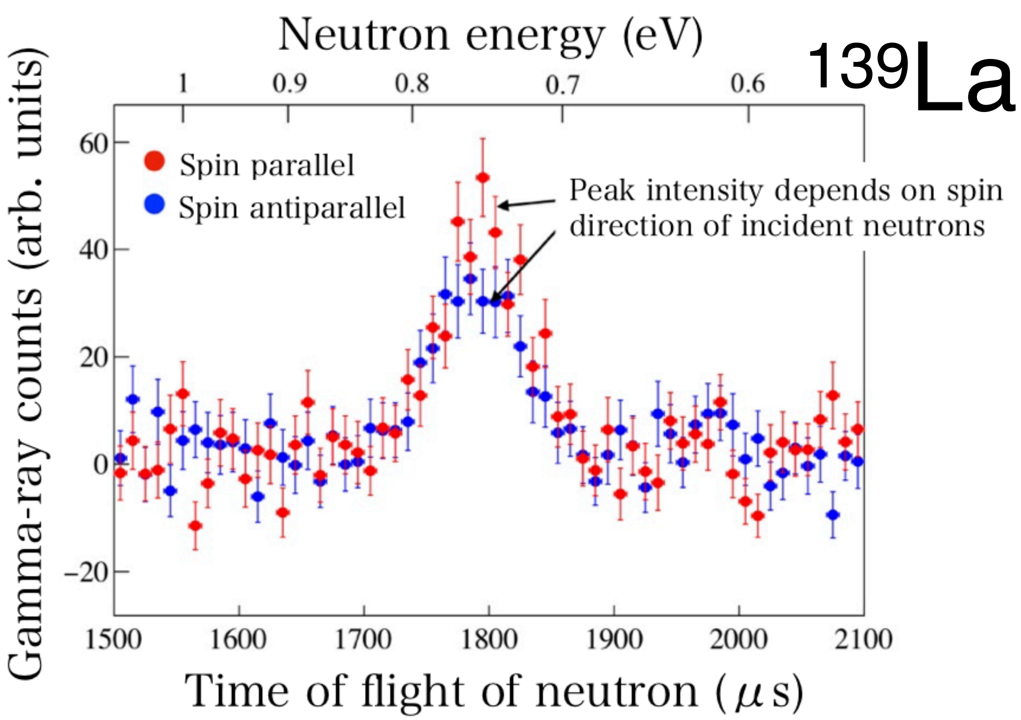
T. Okudaira et. al., Nucl. Instr. Meth. A977 (2020) 164301

Polarized neutron Unpolarized target

Pol. neutron experiments at BL04 ANNRI in J-PARC



T. Yamamoto et. al., Phys. Rev. C101, 064624 (2020)



Candidates for T-violation search

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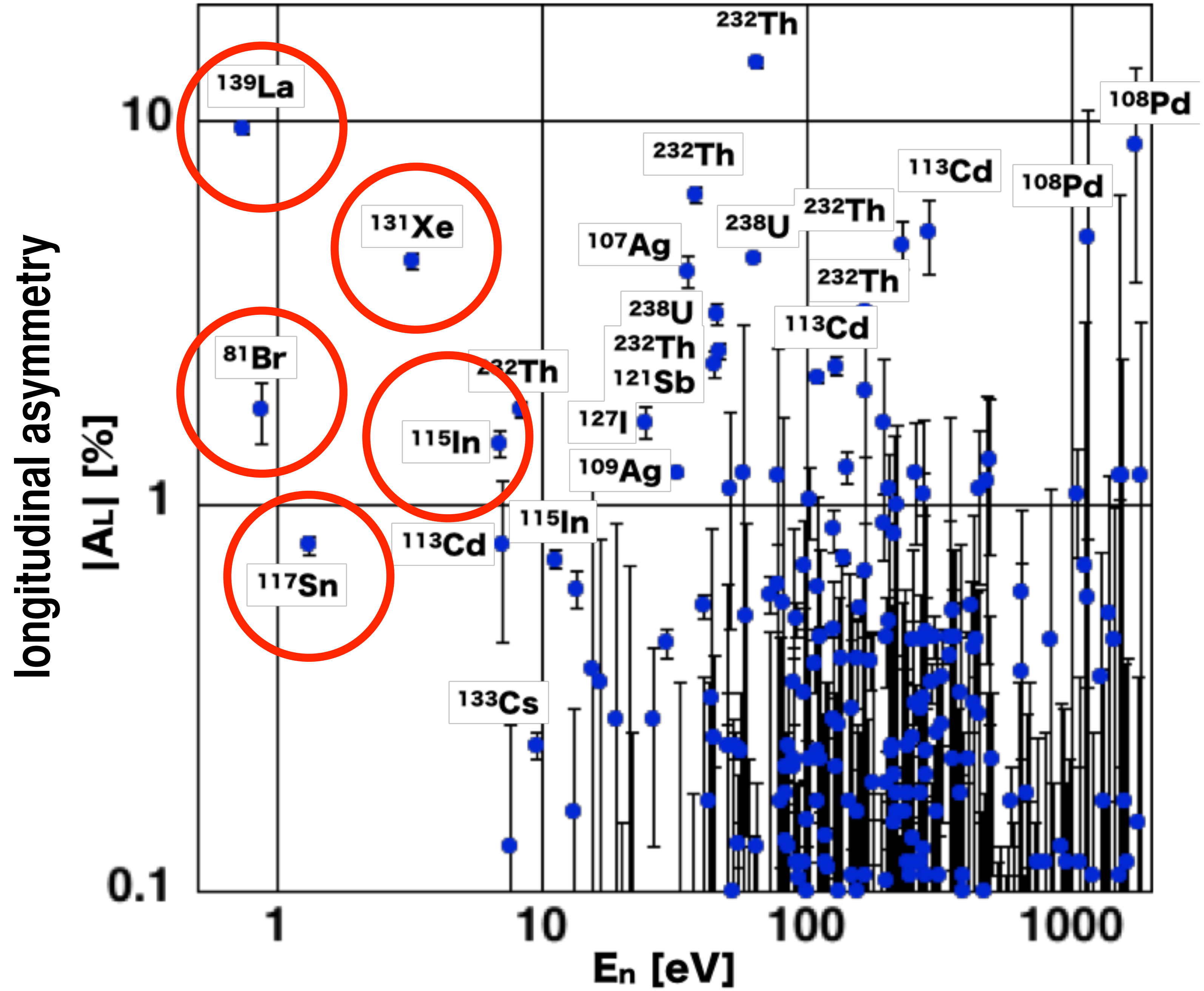
Neutron Optical Parity and Time-Reversal EXperiment



Mitchell, Phys. Rep. 354 (2001) 157

	large $\Delta\sigma_P$	low E_p	small spin
^{139}La	😍	😍	🙂
^{81}Br	😍	😍	🙂
^{117}Sn	🙂	🙂	😍
^{131}Xe	😍	🙂	🙂

Polarized target R&D

→ Masataka Iinuma's talk
12:55 22 Oct.

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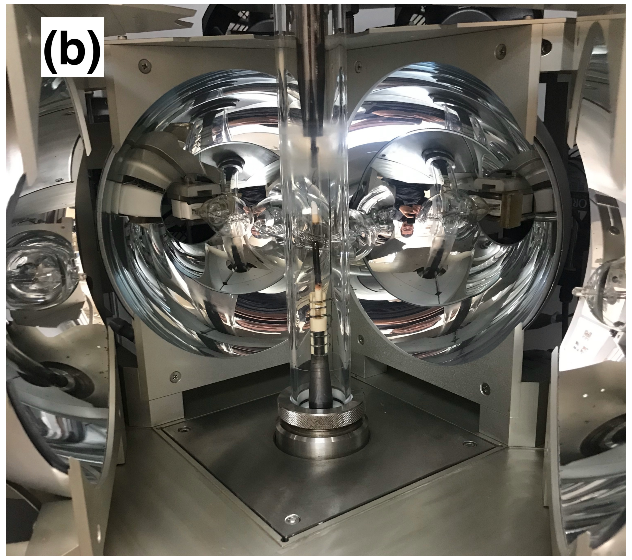
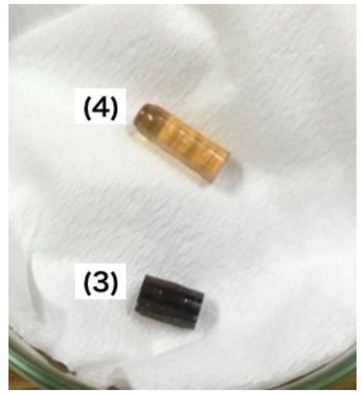
Neutron Optical Parity and Time-Reversal EXperiment

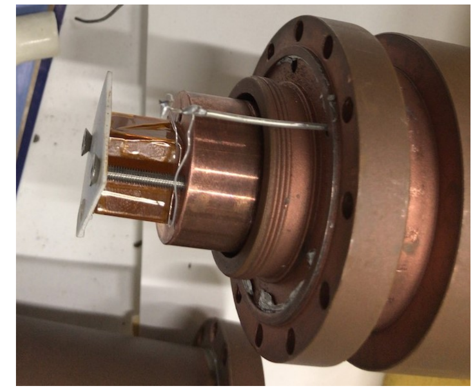
Crystal Growth at Tohoku Univ.





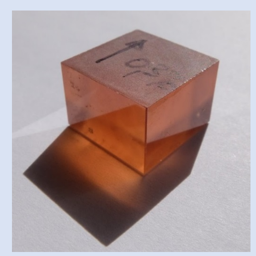
Tohoku Univ.,
Hiroshima Univ.
Nagoya Univ.

Target Polarization at RCNP, Osaka Univ.



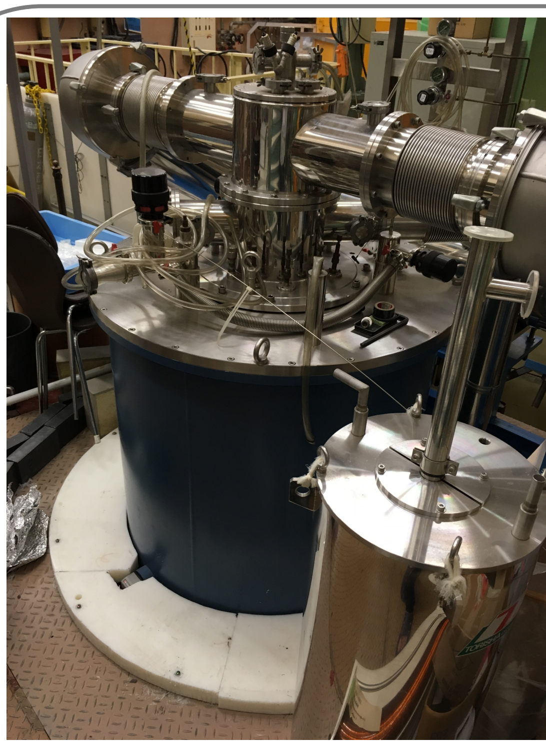
RCNP, Osaka Univ.
Hiroshima Univ., Nagoya Univ. ,Yamagata Univ.

Polarized La Target



$LaAlO_3$ (Nd^+) single crystal

Cryogenics



Nagoya Univ.,
RIKEN,
Japan Women's Univ.
Ashikaga Univ.
Hiroshima Univ.

Relaxation Time Control

Hiroshima Univ.
Nagoya Univ.

Relaxation time control with aromatic molecule

NOPTREX collaboration

NOPTREX
Neutron Optical Parity and Time-Reversal EXperiment

NOP-T

KEK 2018S12

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E. Babcock

Nottingham
M. Barlow

Depauw
A. Komives

Summary

NOPTREX
Neutron Optical Parity and Time-Reversal EXperiment

Discrete symmetry violation is enhanced in Compound States induced by Epithermal Neutron.

Statistical nature of compound states

T-violation in compound nuclei has a discovery potential of new physics beyond the standard model.

Feasibility study and R&D starts.

(n, γ) for enhancement factor

Target polarization

Intense neutron source

Epithermal neutron polarizer

Triplet-DNP

We start US-China-Japan collaboration NOPTREX.