^{139}La polarized target study for NOPTREX

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Nagoya UnivA., Nagoya Univ. KMI[B], Hiroshima Univ. ADSM[C], Osaka Univ. RCNP[D], Yamagata Univ.[E], KEK[F], Tohoku Univ. IMR[G]

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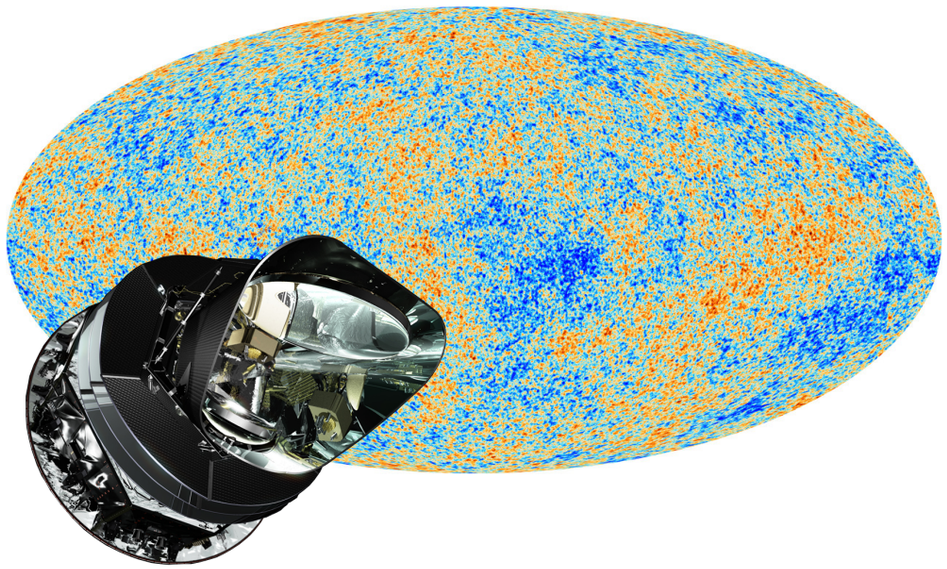
The asymmetry between particles and antiparticles



Observational cosmology

$$V_{\mathrm{CKM}} = \begin{pmatrix} V_{\mathrm{ud}} & V_{\mathrm{us}} & V_{\mathrm{ub}} \\ V_{\mathrm{cd}} & V_{\mathrm{cs}} & V_{\mathrm{cb}} \\ V_{\mathrm{td}} & V_{\mathrm{ts}} & V_{\mathrm{tb}} \end{pmatrix}$$

CP-violation in the weak interaction

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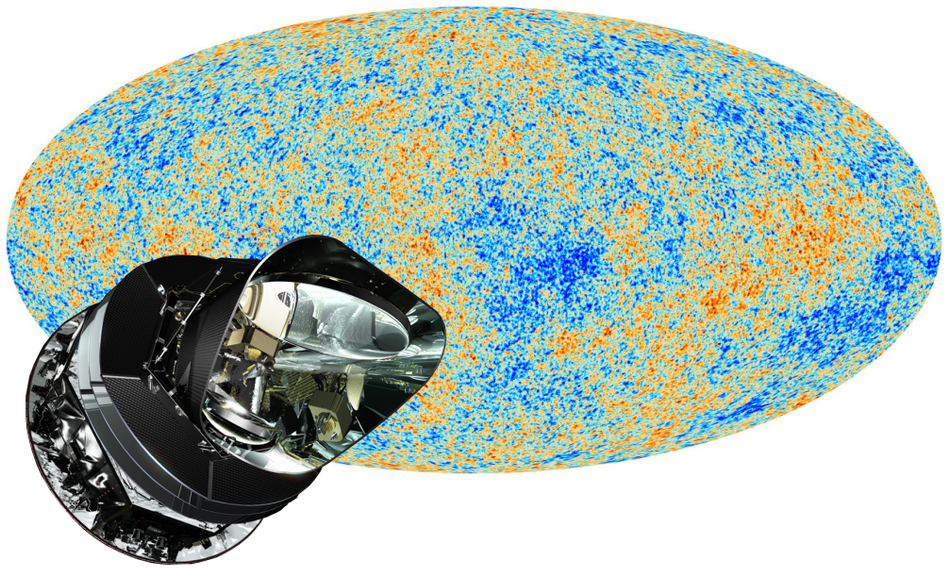

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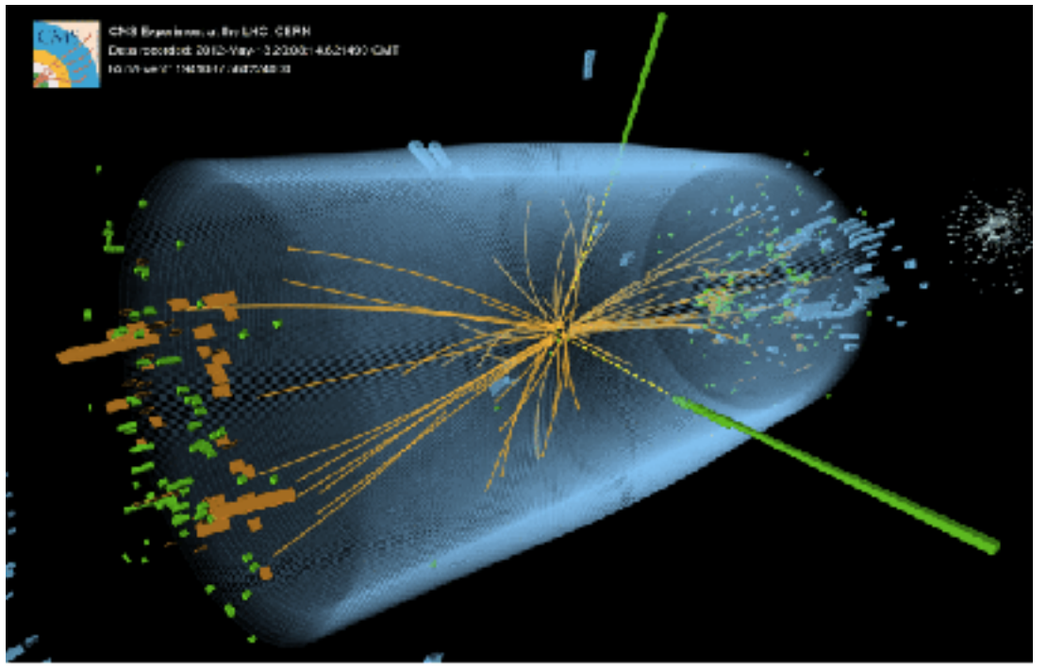
CP-violation in the weak interaction

These approaches have **the discrepancy of ~10^{-9}** in the asymmetry of the amount of baryon and antibaryon.

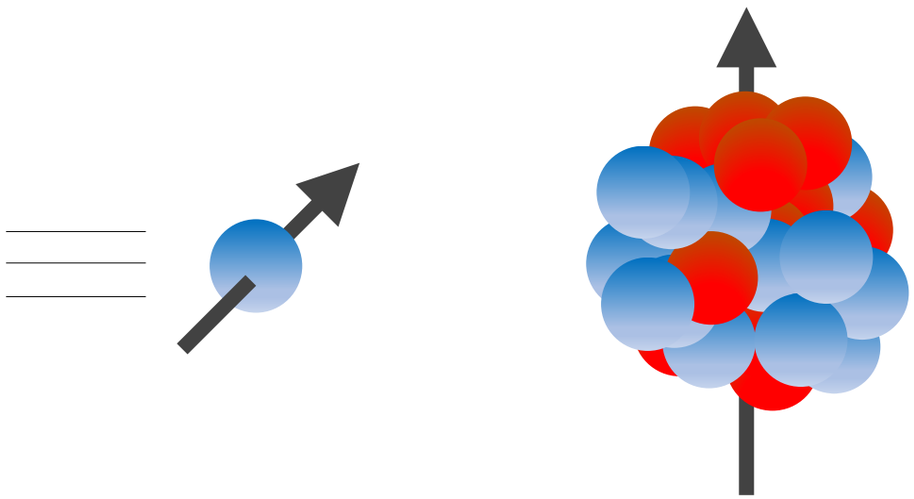
(M. Peskin, 2002, Nature, 419, and therein.)

Approaches toward the new particle physics

Direct search



Precise measurement search



$$f = \underbrace{A}_{\text{P-even T-even}} + \underbrace{B\hat{\sigma}\cdot\hat{I}}_{\text{P-even T-even}} + \underbrace{C\hat{\sigma}\cdot\hat{k}}_{\text{P-odd T-even}} + \underbrace{D\hat{\sigma}\cdot(\hat{I}\times\hat{k})}_{\text{P-odd T-odd}}$$

Find new particles

ex:) High energy experiment

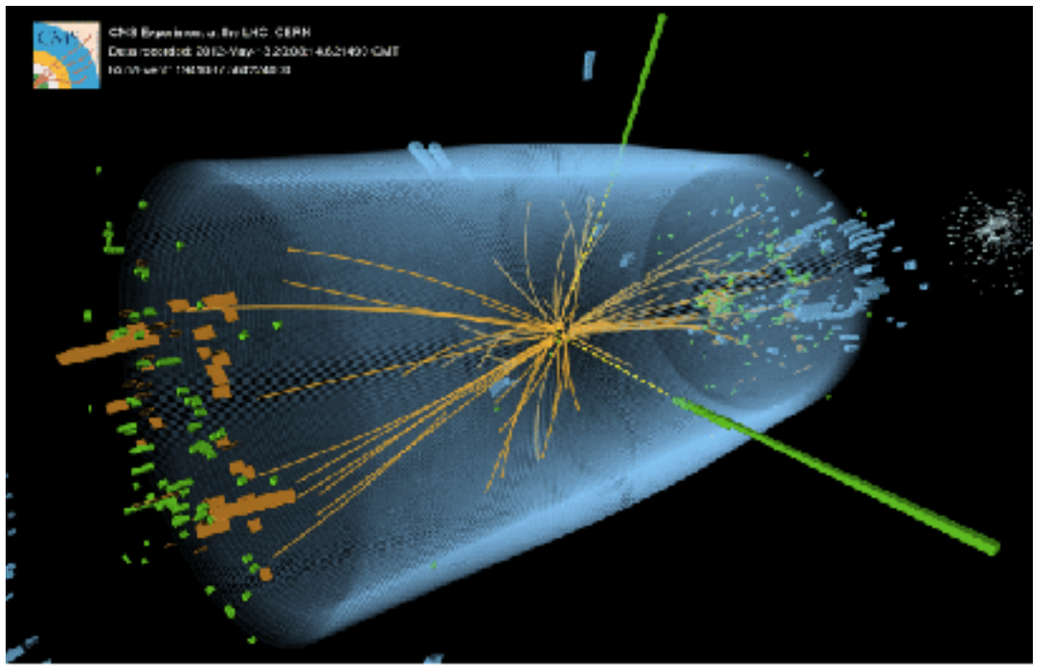
Parameters measurement

ex:) Low energy experiment

Approaches toward the new particle physics

THIS TALK

Direct search



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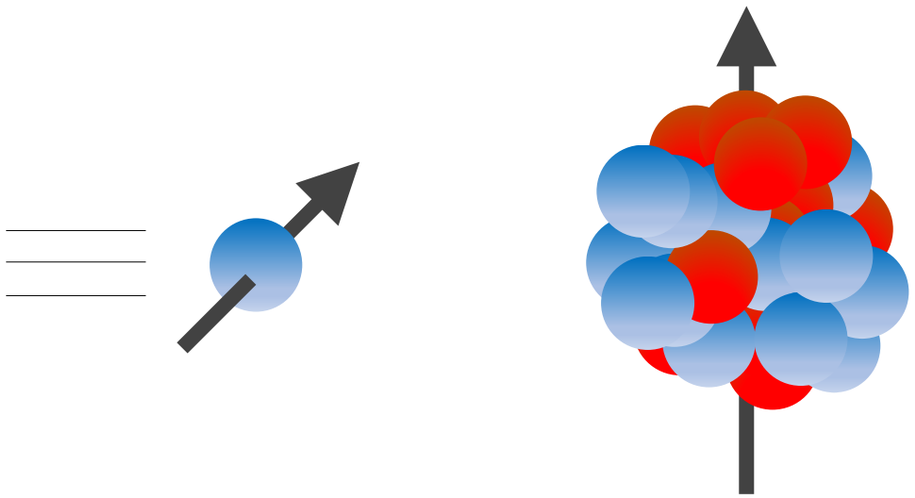

$$f = A + B\hat{\sigma}\cdot\hat{I} + C\hat{\sigma}\cdot\hat{k} + D\hat{\sigma}\cdot(\hat{I}\times\hat{k})$$

P-even T-even | P-odd T-even | P-odd T-odd

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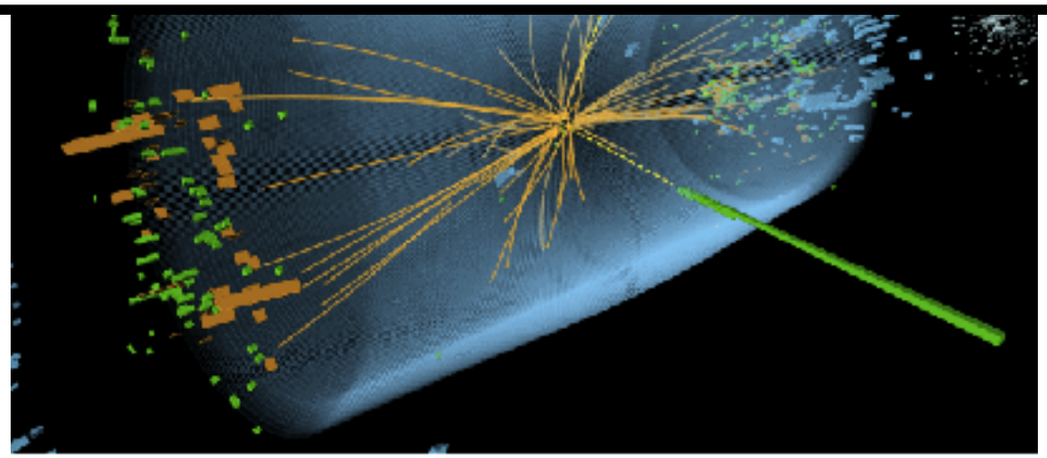
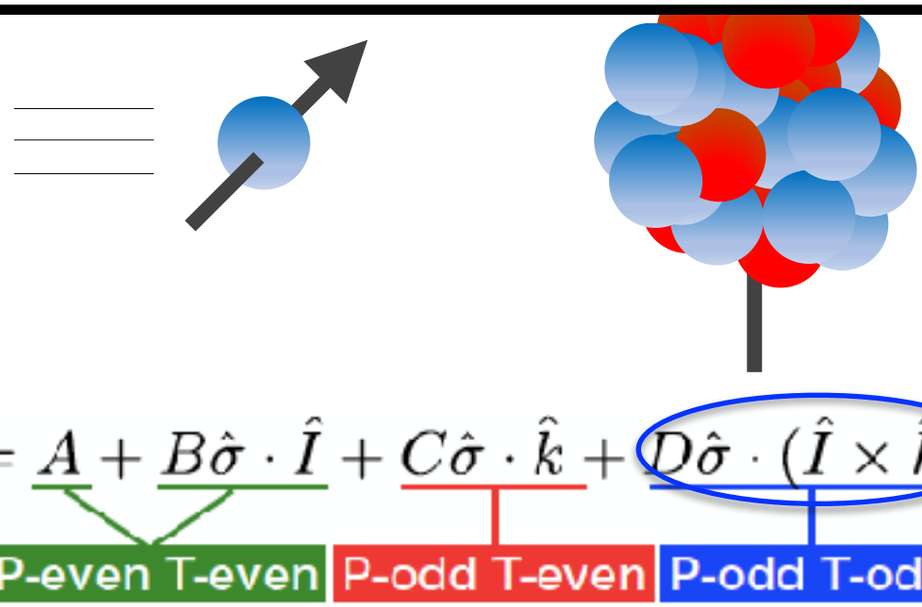
Approaches toward the new particle physics

THIS TALK

According to the relativistic quantum field theory, the CP-violative process is equivalent to the T-violative process. (**CPT theorem**)





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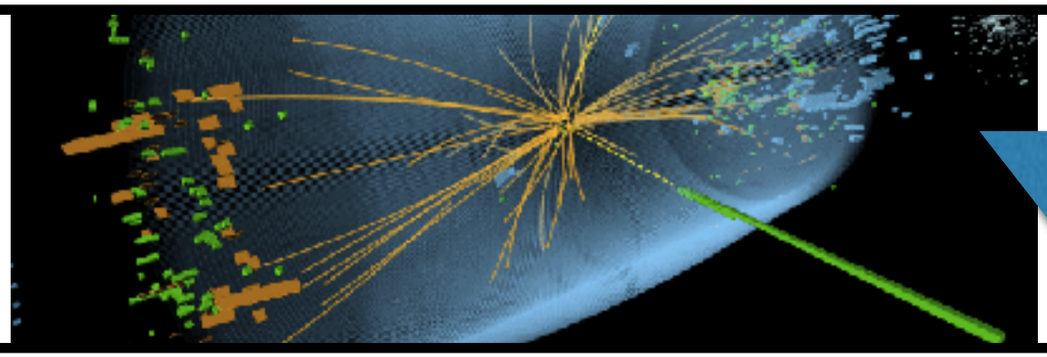
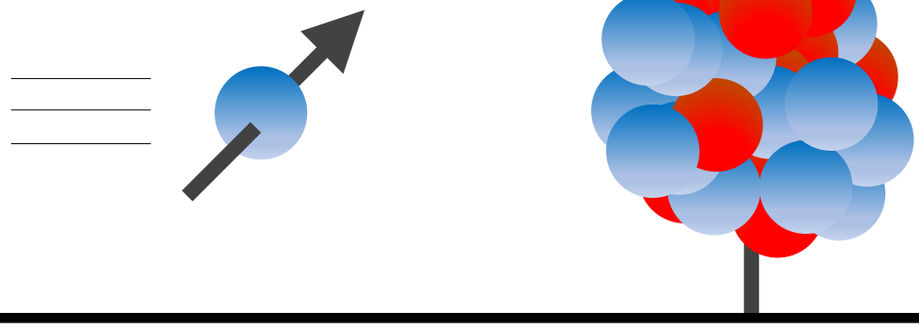


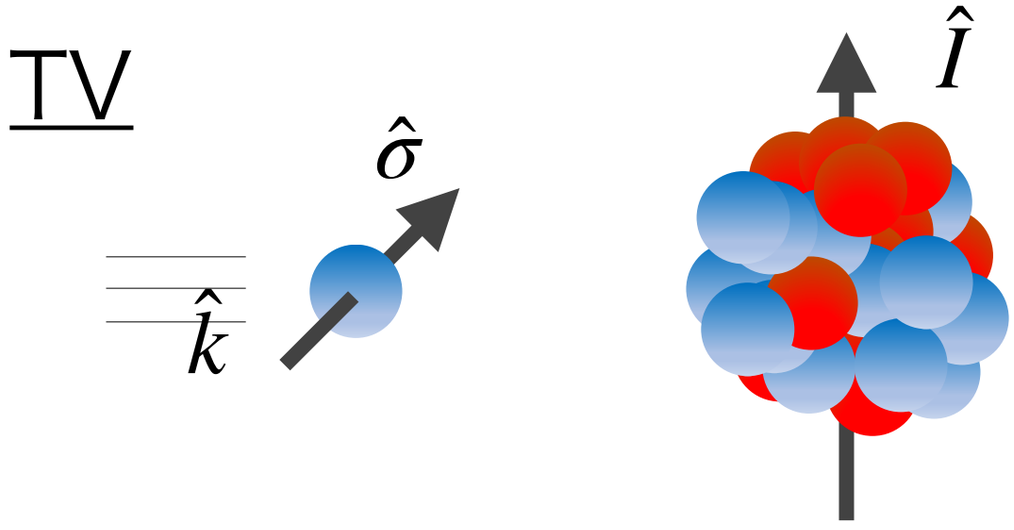


We can approach to a discovery of unknown CP-violation through a precise measurement of T-violating phenomena.

Find new particles — Parameters measurement

ex:) High energy experiment — ex:) Low energy experiment

The experiment project for the search of T-violation in the neutron capture by nucleus.



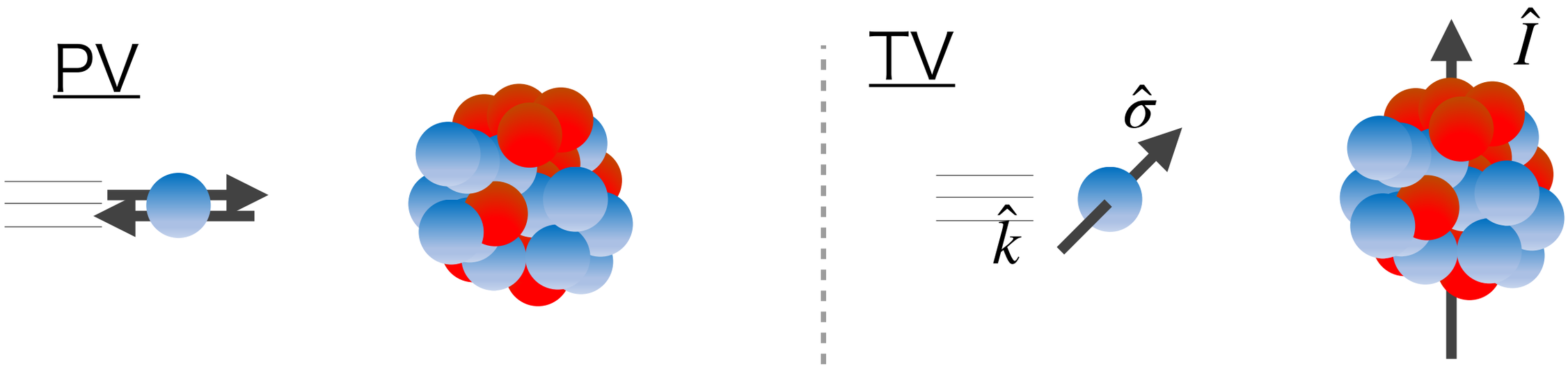
forward scattering amplitude： $f = A + B\hat{\sigma}\cdot\hat{I} + C\hat{\sigma}\cdot\hat{k} + D\hat{\sigma}\cdot(\hat{I}\times\hat{k})$

P-even T-even　P-odd T-even　P-odd T-odd

$$T:\boldsymbol{\sigma}\cdot(\hat{\boldsymbol{k}}\times\hat{\boldsymbol{I}}) \to (-\boldsymbol{\sigma})\cdot((-\hat{\boldsymbol{k}})\times(-\hat{\boldsymbol{I}}))$$

NOPTREX (Neutron Optics for Parity and Time Reversal EXperiment)

The experiment project for the search of T-violation in the neutron capture by nucleus.



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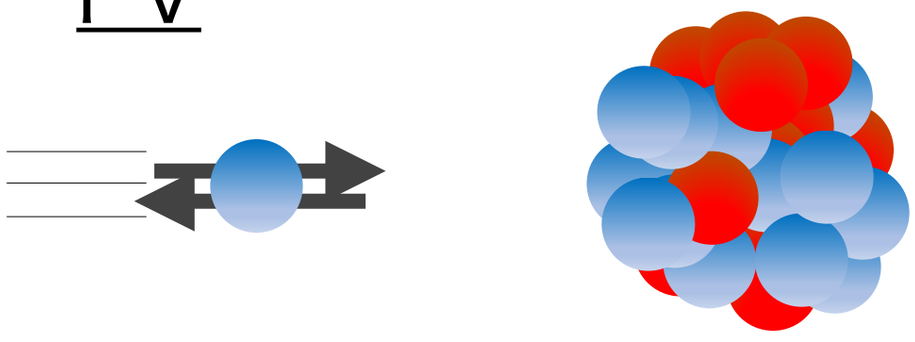
$\hat{\sigma}\cdot(\hat{k}\times\hat{I}) \to (-\sigma)\cdot((-\hat{k})\times(-\hat{I}))$

This P-violation asymmetry is about **10^6 times** as large as that of p-p scattering.

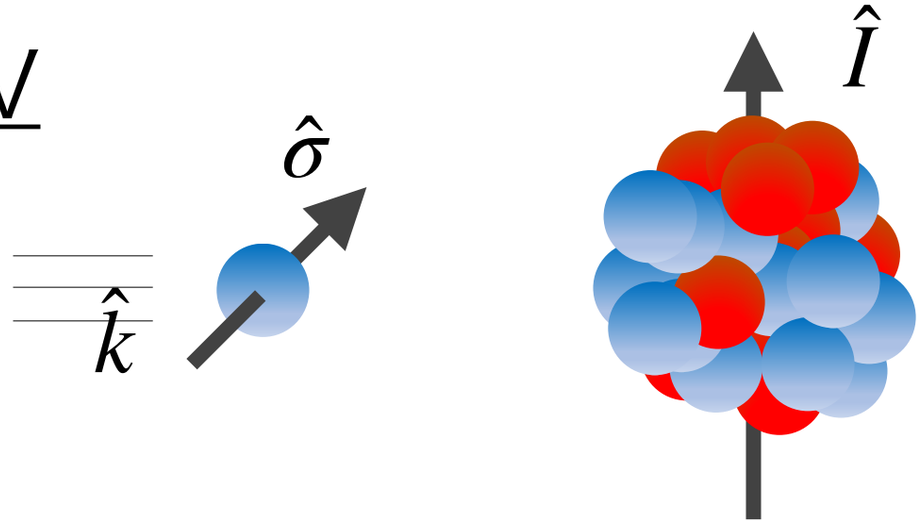
(V. P. Alfimenkov, 1982 etc…)

The experiment project for the search of T-violation in the neutron capture by nucleus.

PV



TV



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The T-violation can be also enhanced!!

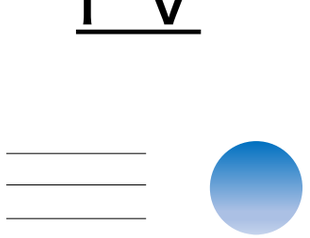
(T. Okudaira, et. al., 2018)

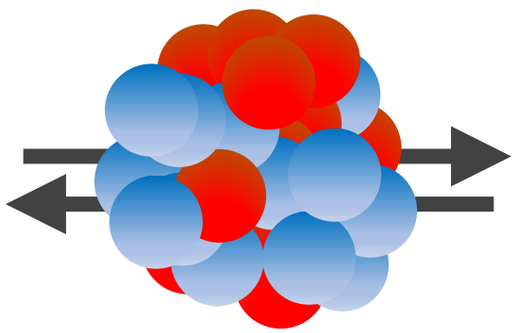
Polarized targets in the T-violation search

The polarized ^{139}La target was used for P-violation experiment.

(V. P. Alfimenkov, et. al., Physics of Atomic Nuclei, vol. 59, 1996)

PV





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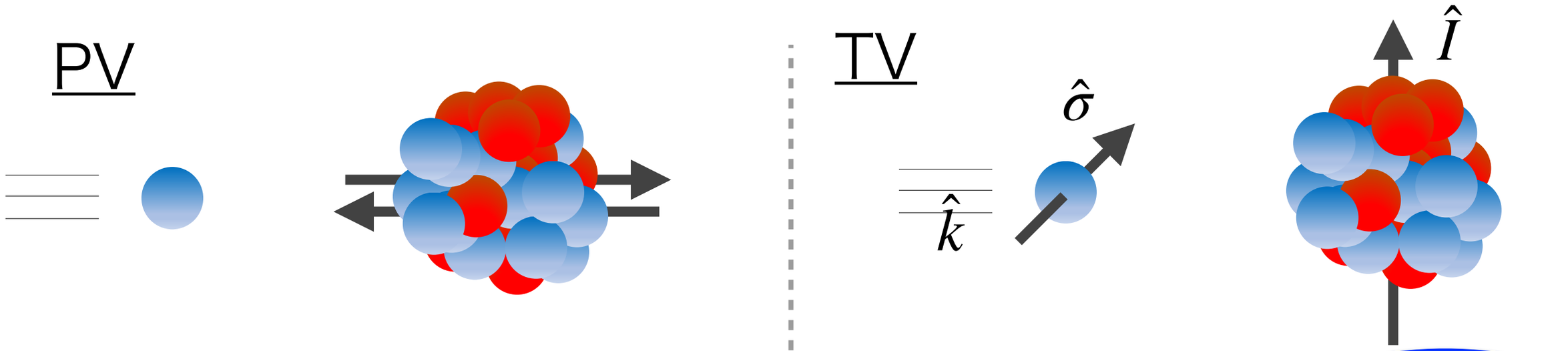

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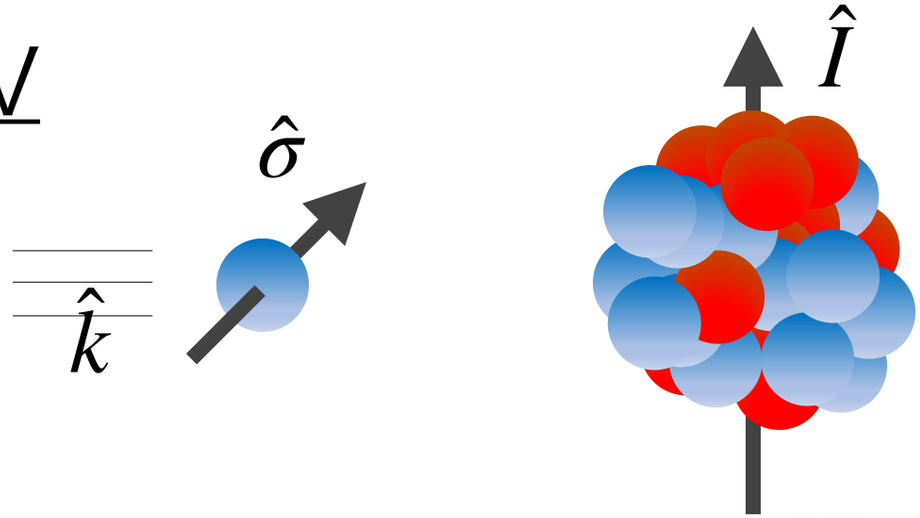
However, strong magnetic field makes incident polarized neutron spin to rotate, and we cannot measure the coefficient D.

PV

TV



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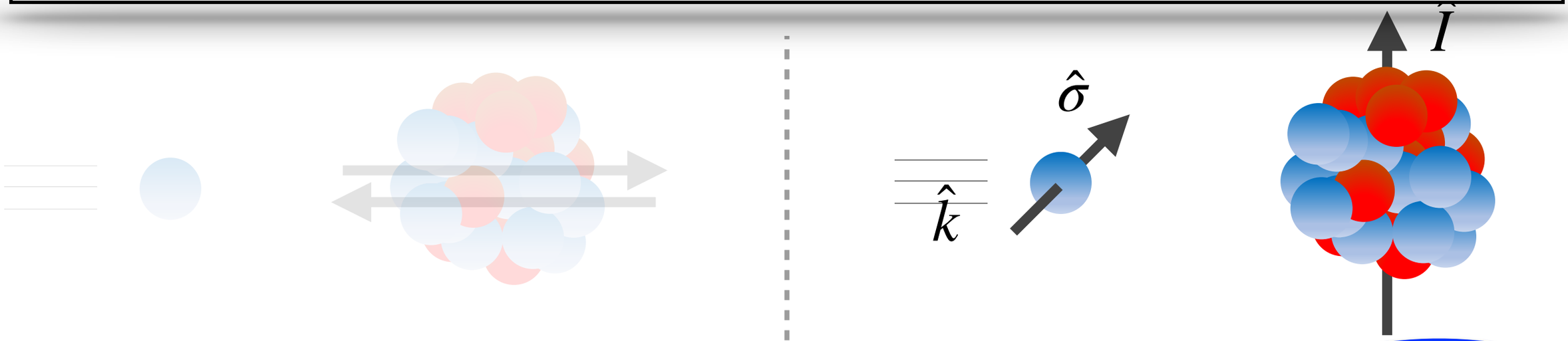
Solid polarized target in the T-violation search

Strong magnetic field cannot be applied during the measurement

We can only apply about 100 G for reducing the pseudo-magnetic rotation.



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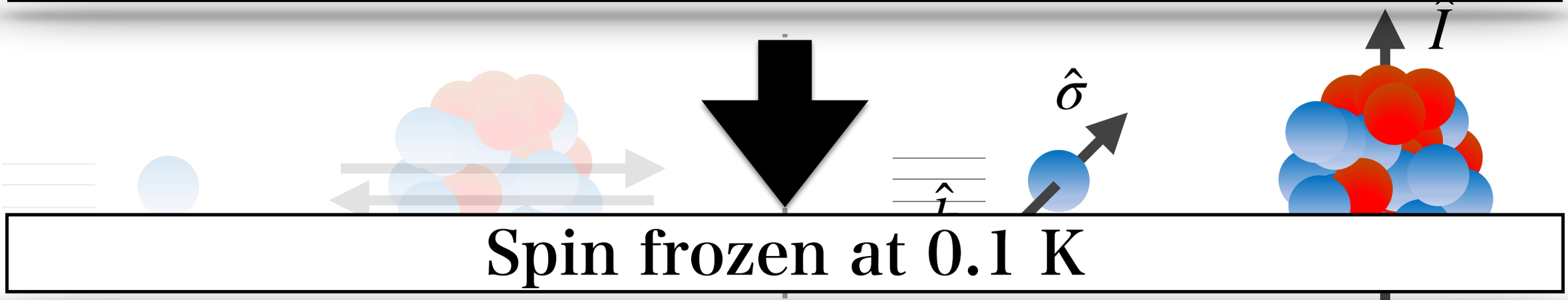

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^{139}La polarization method

Brute-Force

B~17 Tesla, T~10 mK, long T_1.

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Dynamic Nuclear Polarization (DNP)

B~a few Tesla, T~0.5 K, relatively short T_1.

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Dynamic Nuclear Polarization (DNP)

B~a few Tesla, T~0.5 K, relatively short T_1.

NOPTREX is studying both method.
However, I'm concentrating on the topic on the DNP.

Depolarization by quadrupole interaction

Nuclear quadruple interaction ($I \geq 1$)

$$H_Q = \frac{e^2qQ}{4I(2I-1)}[(3I_z^2 - I^2) + \frac{\eta}{2}(I_+^2 - I_-^2)],$$

$$\eta = \left(\left.\frac{\partial^2 V}{\partial x^2}\right|_{\boldsymbol{x}=\boldsymbol{0}} - \left.\frac{\partial^2 V}{\partial y^2}\right|_{\boldsymbol{x}=\boldsymbol{0}} \right) \Big/ \left.\frac{\partial^2 V}{\partial z^2}\right|_{\boldsymbol{x}=\boldsymbol{0}}$$

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We cannot ignore this depolarization effect.

$$(Q_{^{139}\mathrm{La}}/Q_{\mathrm{D}} \sim 70)$$

This depolarization is a serious problem for NOPTREX.

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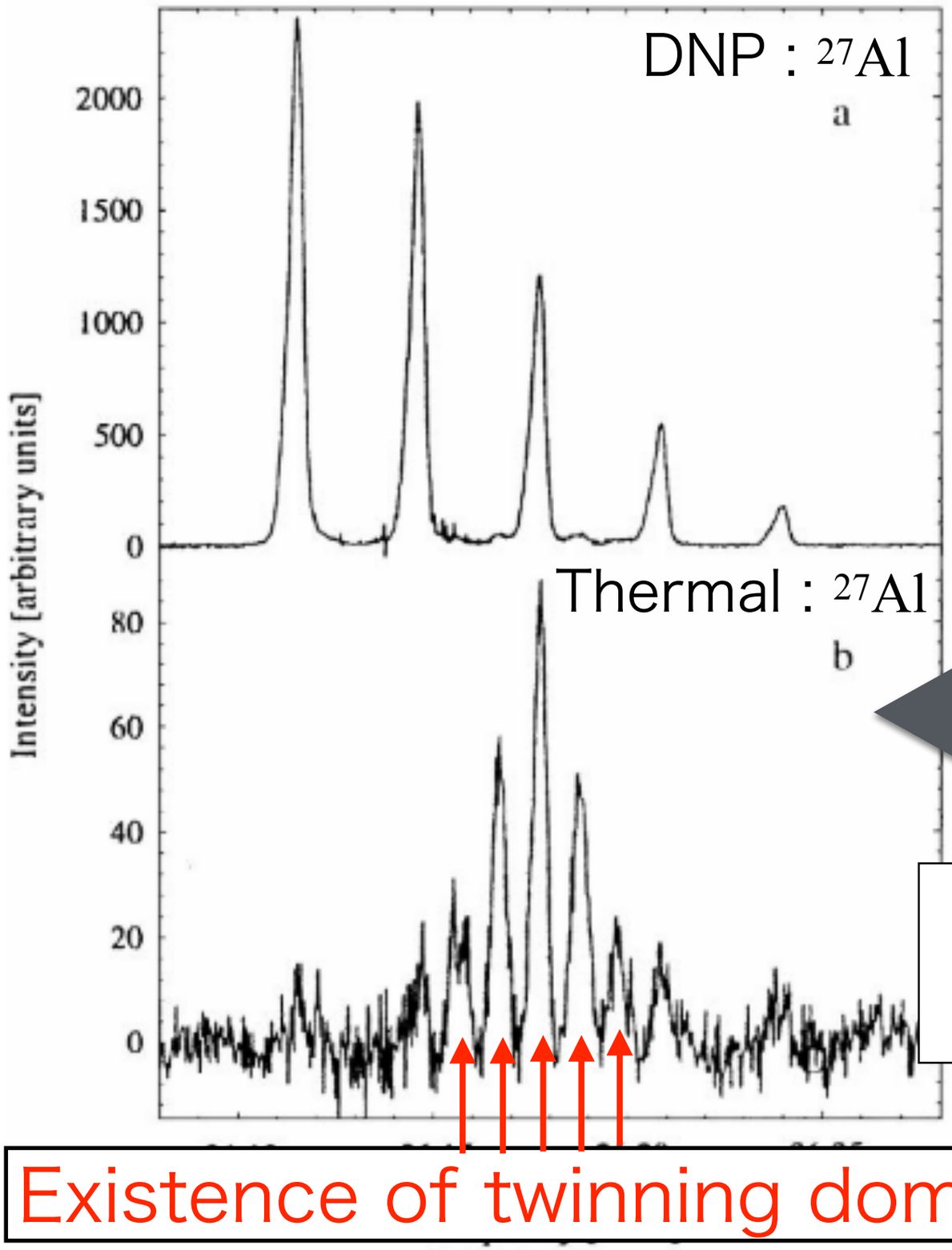
The LaAlO3 crystal has $\eta = 0$!!

Previous study of $LaAlO_3$ crystal DNP experiment at PSI

(P. Hautle, M. Iinuma, 2000)



This NMR spectrum indicates the existence of twinning.

Existence of twinning domain

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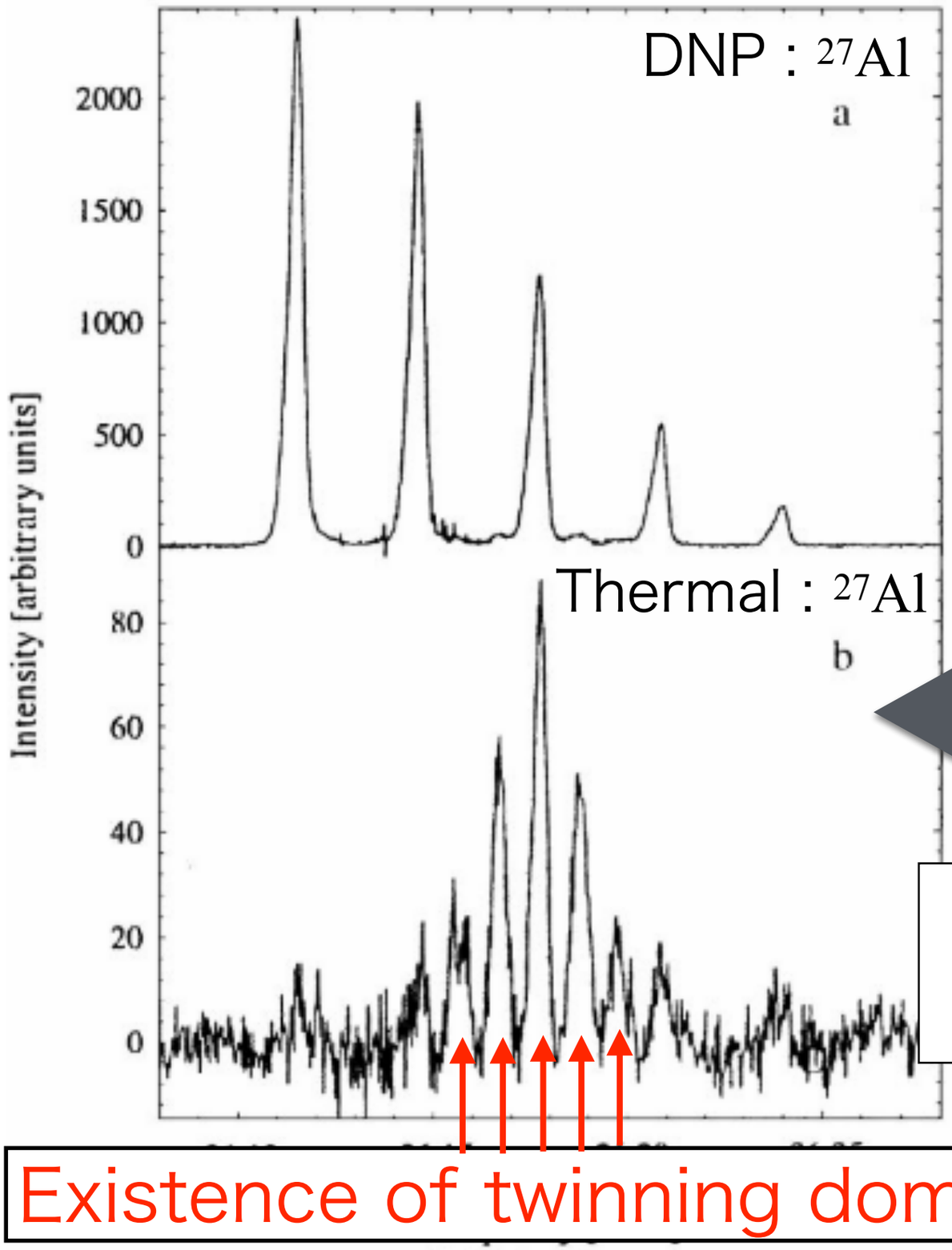

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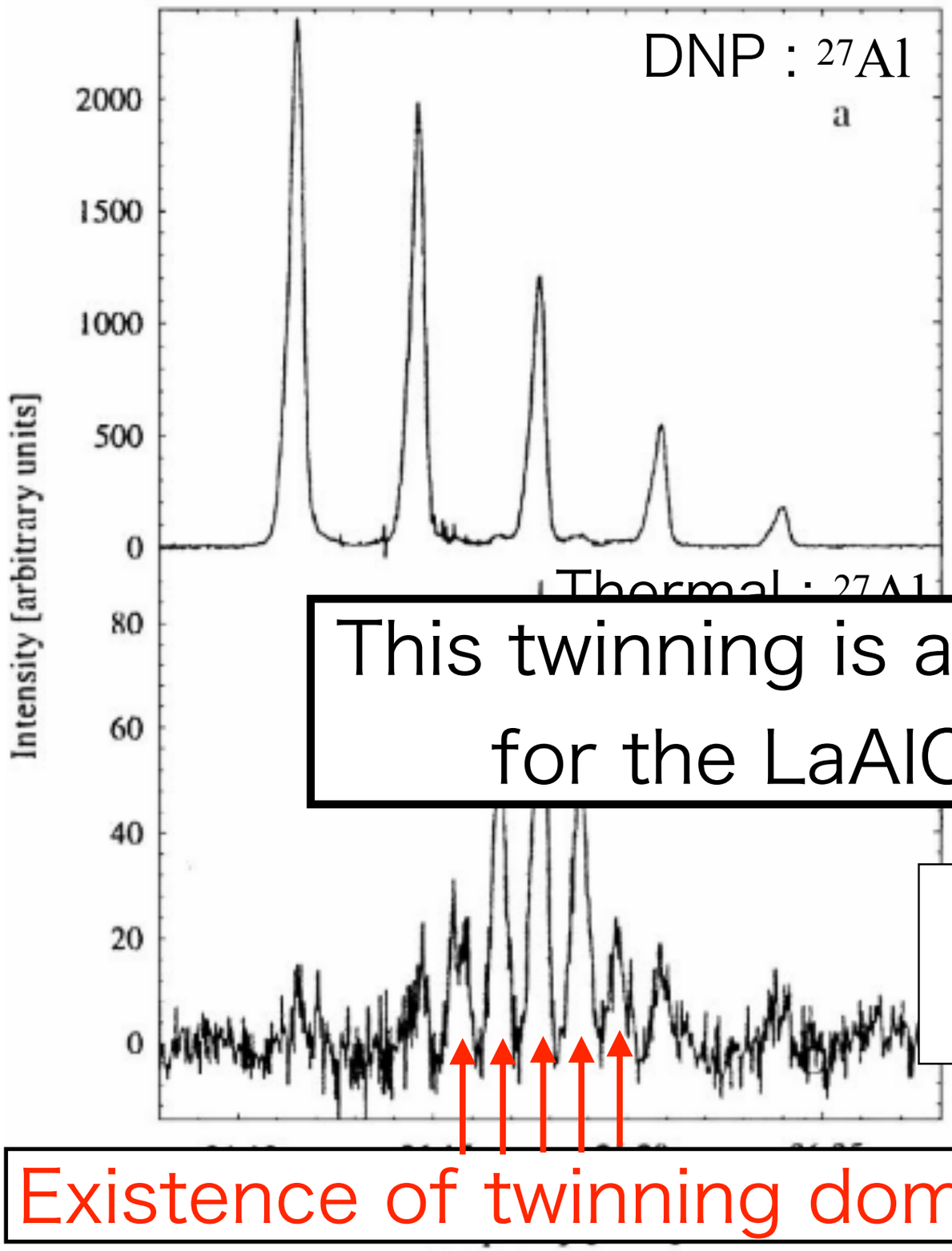

DNP enhancement doesn't simultaneously occurr in both twinning domain.

This twinning is a **serious problem** for the $LaAlO_3$ DNP target.

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Existence of twinning domain

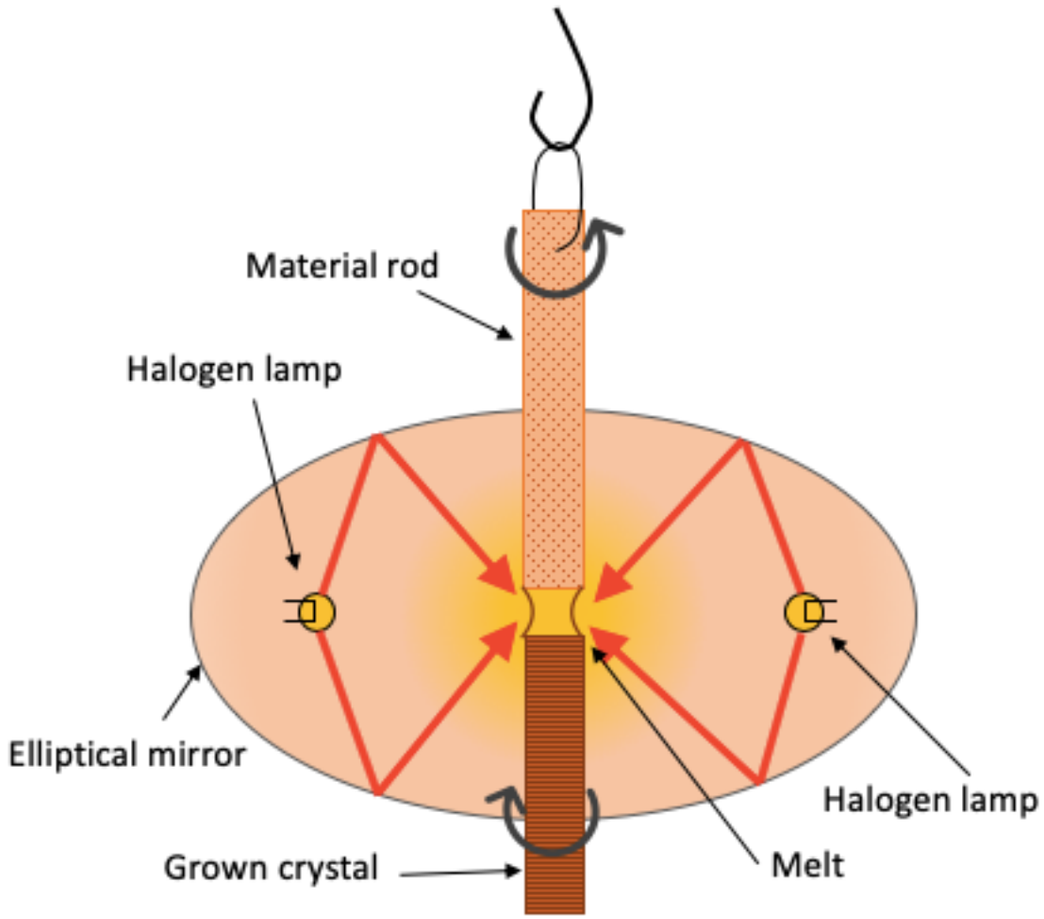
Crystal growth

We have studied $LaAlO_3$ crystal since 2018.

@Tohoku Univ. IMR (Institute of Materials Research)

(IMR cooperative program, proposal No. 18G0034, 19K0081, and 19G0037)

Floating Zone method



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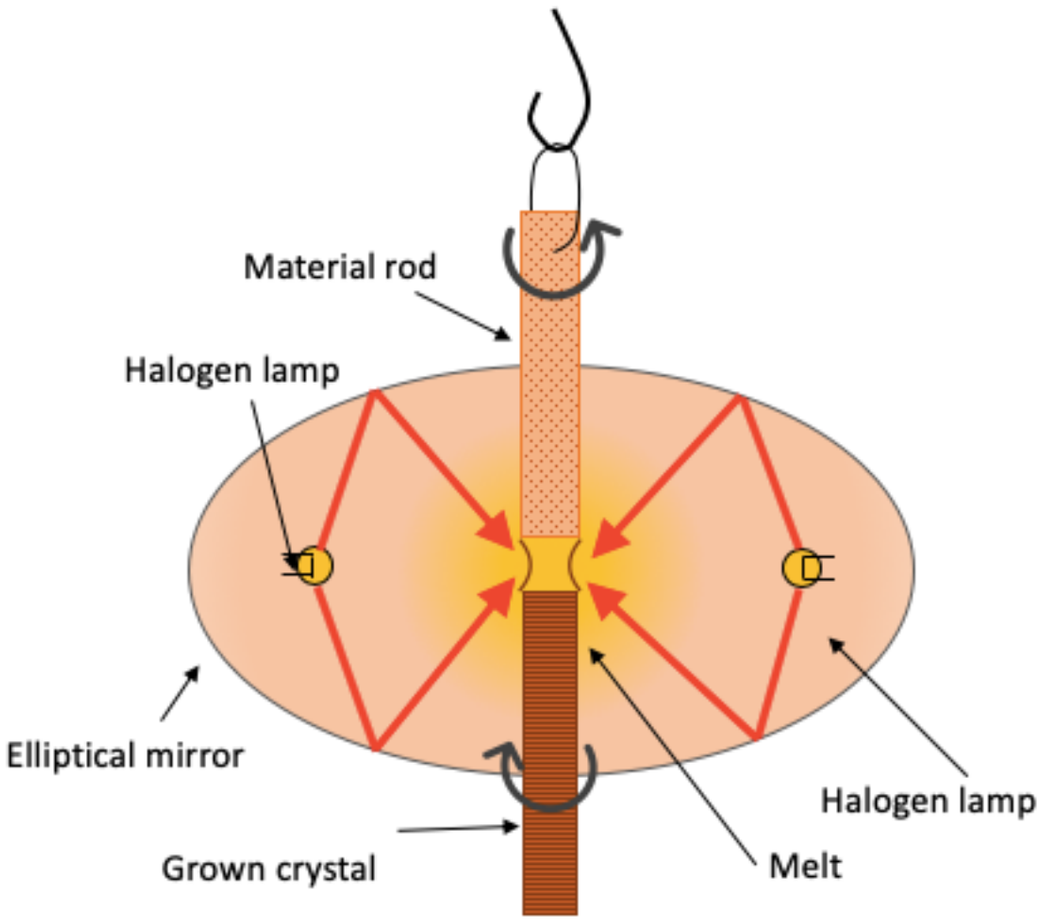

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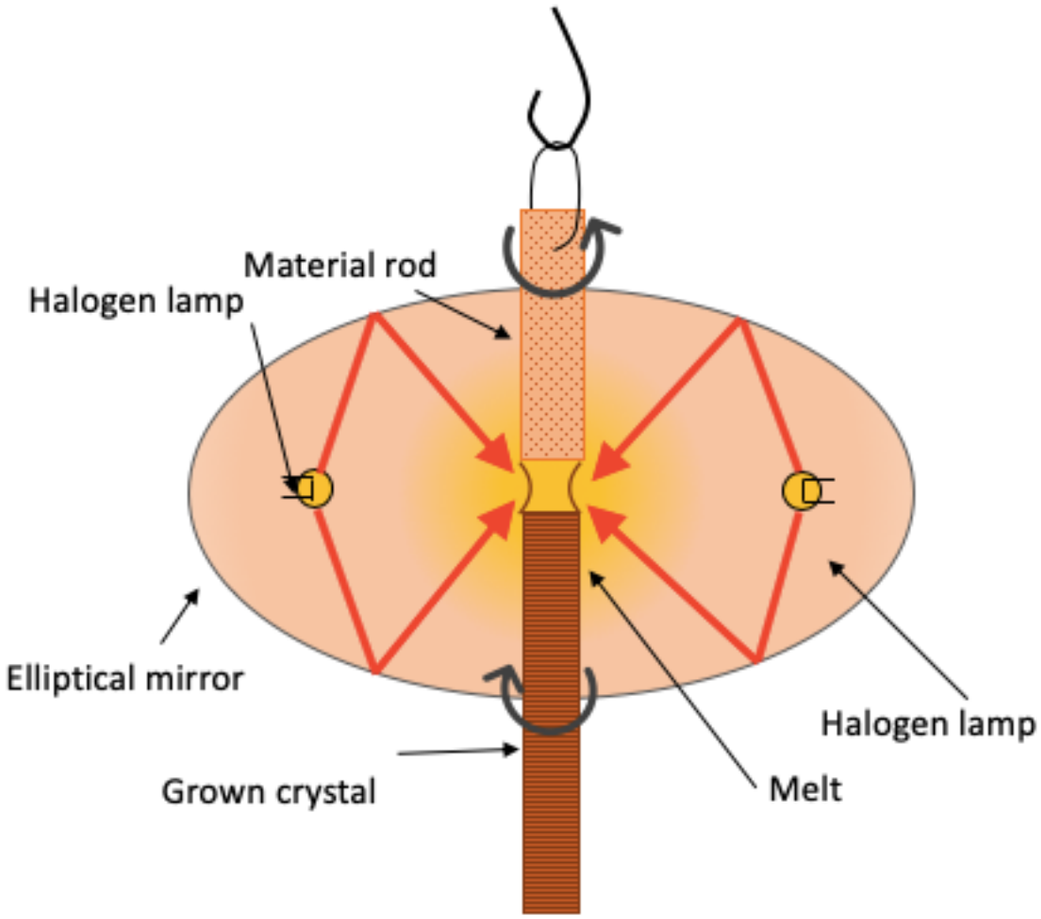

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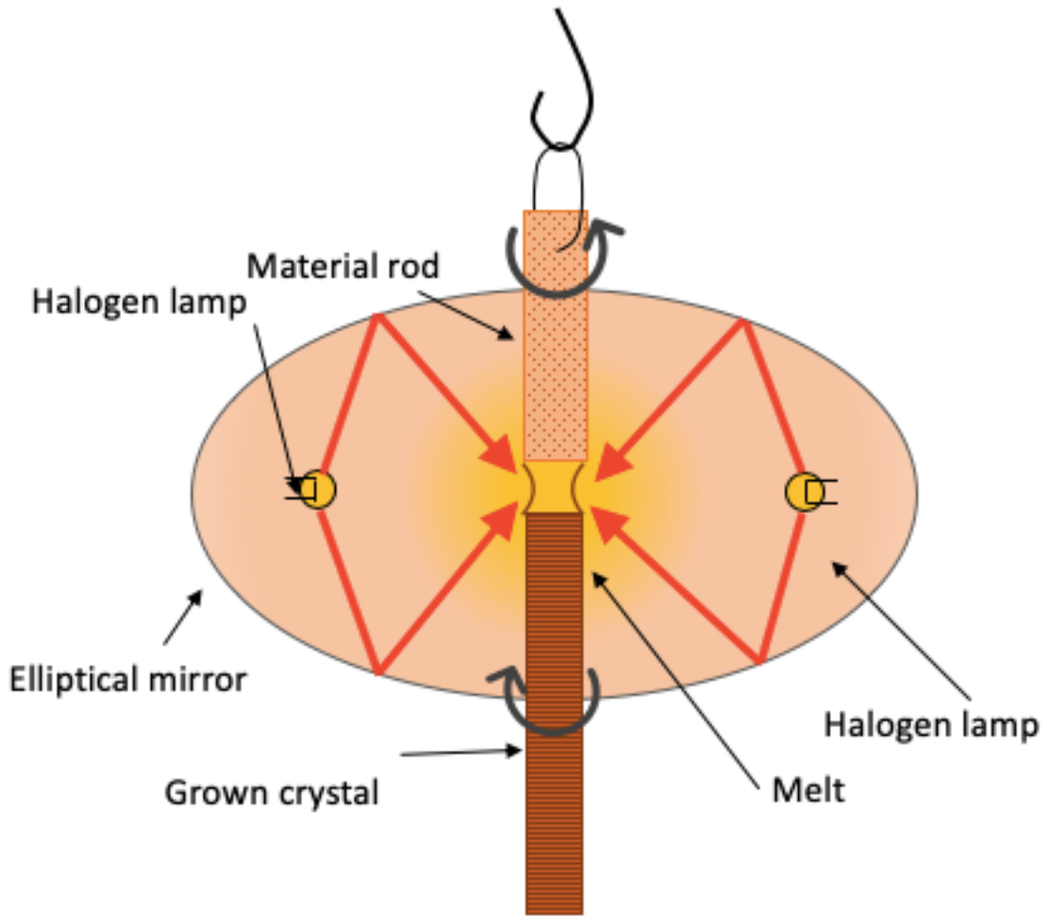
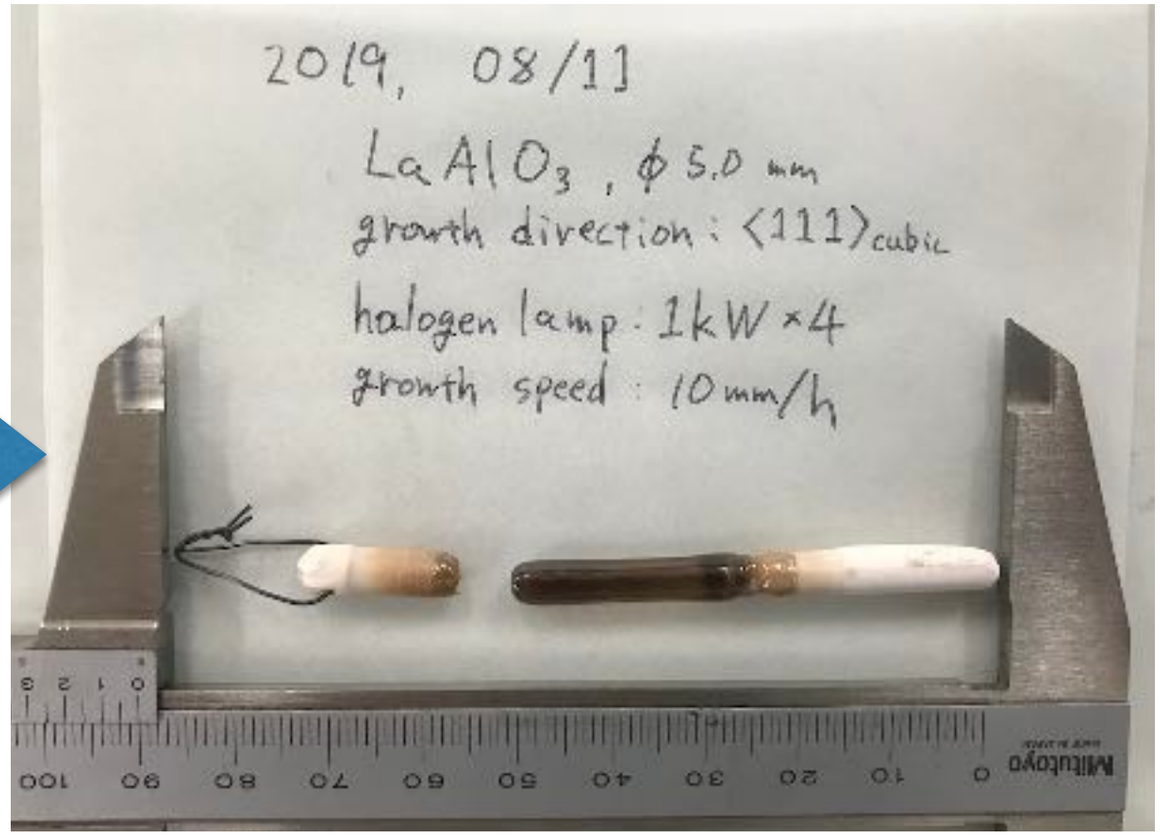




Polarization experiments @RCNP

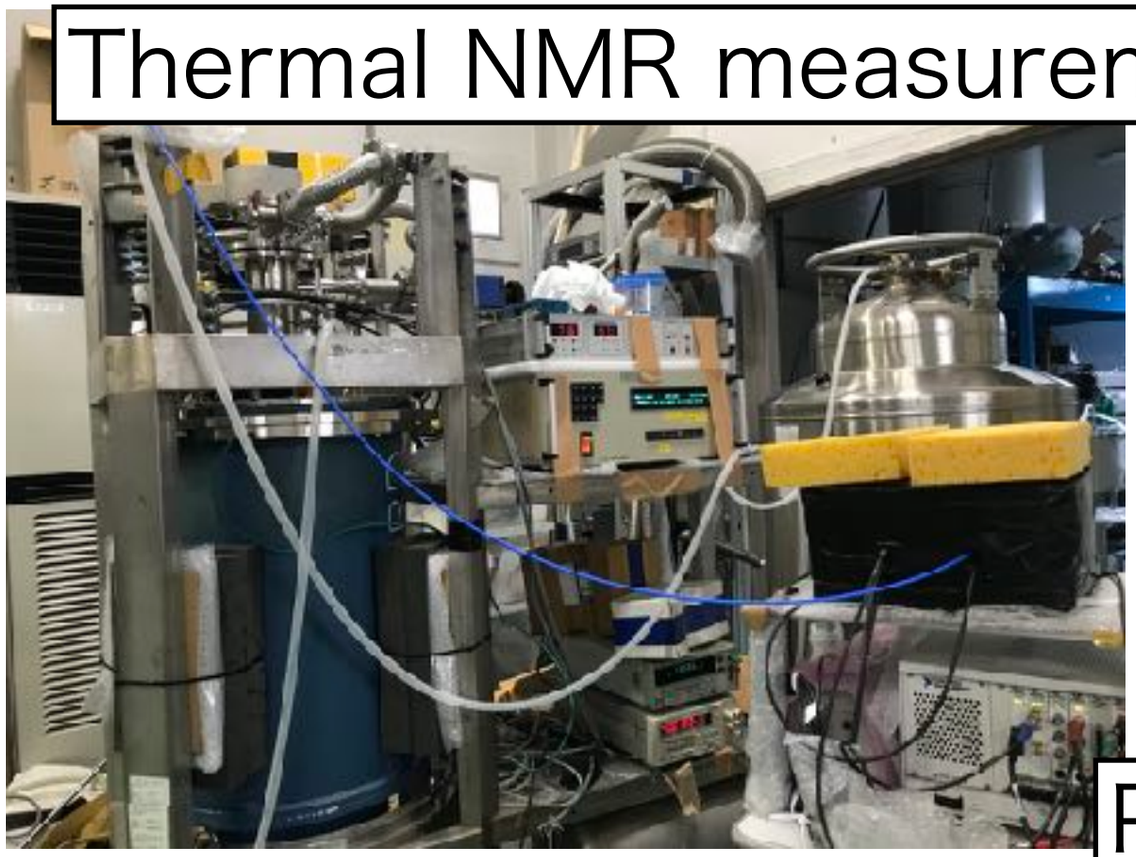
Preparing for the DNP cryostat and T1 measurement has been started.

@Osaka Univ. RCNP (Research Center for Nuclear Physics)

RCNP project

(Development of polarized target for new physics search via T-violation)

Thermal NMR measurement



Preparing the Cryostat for DNP

KEK 2018S12

NOPTREX Collaboration

Neutron Optical Parity and Time Reversal EXperiment

Nagoya University

H.M.Shimizu, M.Kitaguchi, K.Hirota, T.Yamamoto, K.Ishizaki, S.Endoh, Y.Niinomi, I.Ide, H.Tada, T.Morishima, Y.Kiyanagi, J.Hisano, N,Wada, T.Matsushita

Kyushu University

T.Yoshioka, S.Takada, J.Koga, S.Makise

JAEA

T.Okudaira, K.Sakai, A.Kimura, H.Harada

KEK

T.Ino, S.Ishimoto, K.Taketani, K.Mishima, G.Ichikawa

Hiroshima Univ.

M.Iinuma

Tokyo Inst. Tech.

H.Fujioka, Y.Tani

Univ. British Columbia

T.Momose

Osaka Univ.

K.Ogata, H.Kohri, M.Yosoi, T.Shima, H.Yoshikawa

Tohoku Univ.

M.Fujita

RIKEN

Y.Yamagata, T.Uesaka, K.Tateishi, H.Ikegami

Yamagata Univ.

T.Iwata, Y.Miyachi

Ashikaga Univ.

D.Takahashi

Japan Women's Univ.

R.Ishiguro

Kyoto Univ.

Y.I.Takahashi, M.Hino

Kyungpook Univ.

G.N.Kim, S.W.Lee

Indiana University

W.M.Snow, J.Curole, J.Carini

Univ. South Carolina

V.Gudkov

Oak Ridge National Lab.

J.D.Bowman, S.Penttila, X.Tong, P.Jiang

Kentucky Univ.

B.Plaster, D.Schaper, C.Crawford

NIST

C.C.Haddock

Paul Scherrer Institut

P.Hautle

Southern Illinois University

B.M.Goodson

Univ. California Berkeley

A.S.Tremsin

Berea College

M.Veillette

Summary

* The T-violation search in the neutron capture by ^{139}La is a good probe for the unknown CP-violation.
* LaAlO3 crystal is a candidate for ^{139}La DNP target.
* Some project have been started recently to develop the polarized ^{139}La target for T-violation search.

Acknowledgement

Our research is performed under the following program.

* Tohoku University IMR cooperative program, proposal No. 18G0034, 19K0081, and 19G0037.
* Osaka University RCNP project “Development of polarized target for new physics search via T-violation”