Research Activities at the RCNP Cyclotron Facility

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International Symposium on Nuclear Physics in Asia
Convention Center of Beihang University (China)
October 14 –15, 2010

Outline

- Introduction
- Researches in nuclear physics

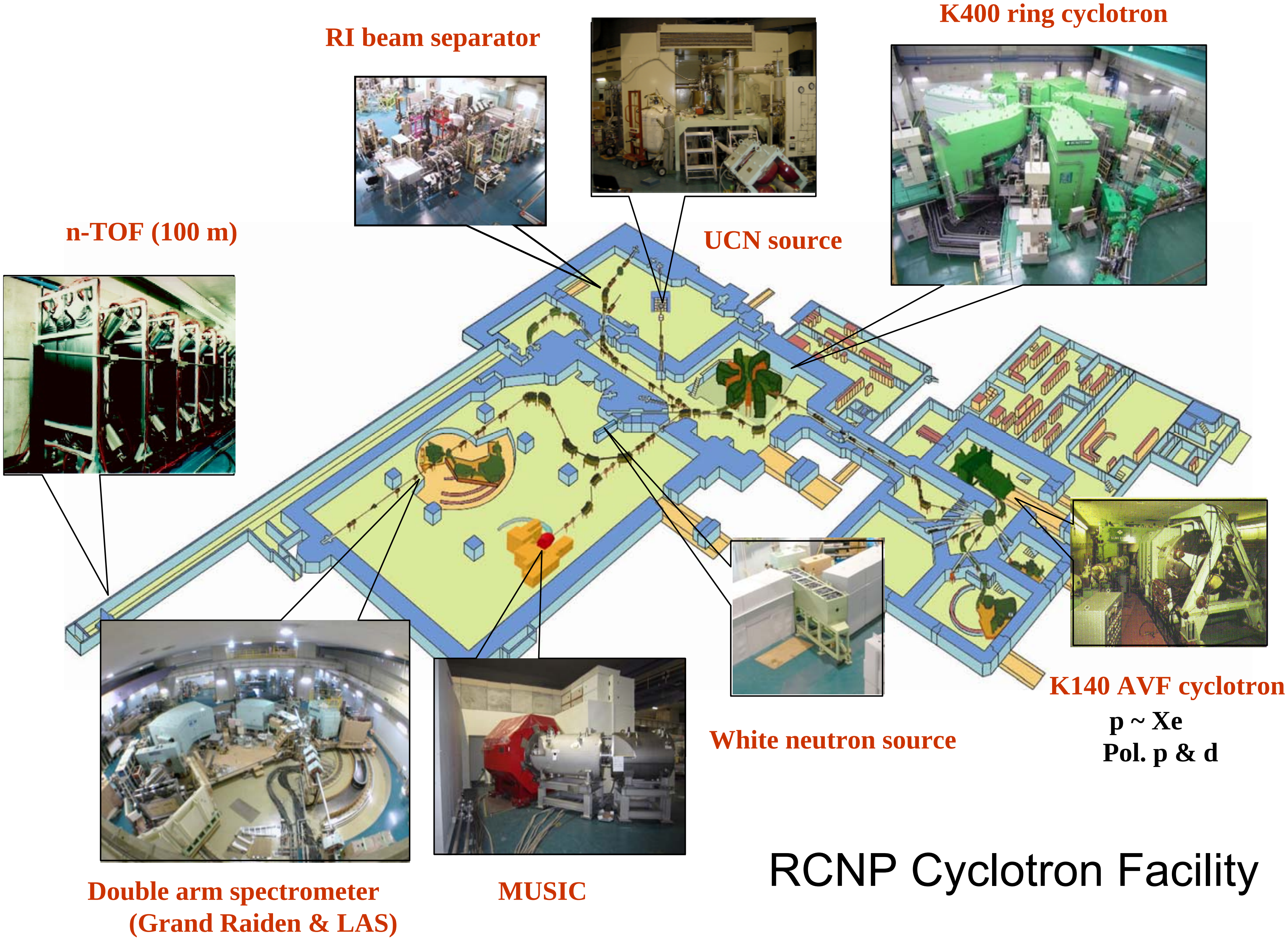
  - 3NF effects

  - E1 excitations in ^{208}Pb

  - 0^- states in nucleai
- Developments of a Superthermal UCN source
- Summary

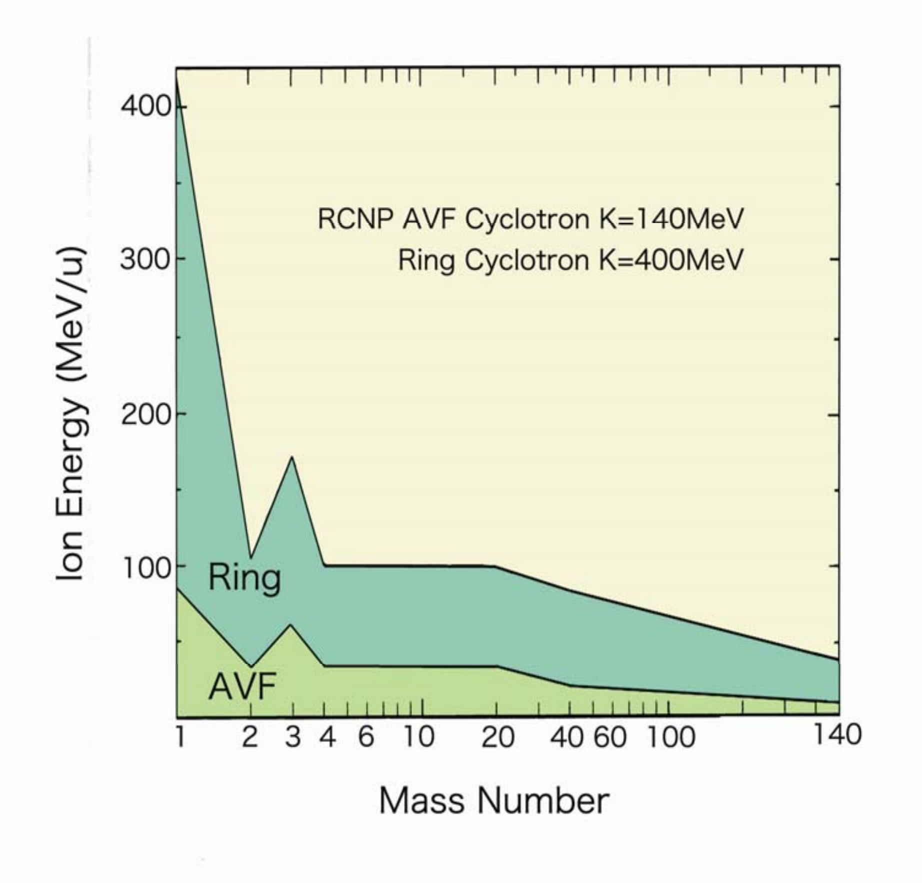
RCNP cyclotron facility

- Nuclear physics
  - Few-body problem
  - Reaction mechanism
  - Effective interactions
  - Nuclear structures of stable and unstable nuclei
- Fundamental physics
  - Neutron EDM measurements (by Y. Masuda, tomorrow)
- Applications
  - Radiochemistry
  - Medical science
  - Radiation effects on RAM, power devices, etc.
- Education of undergraduate students

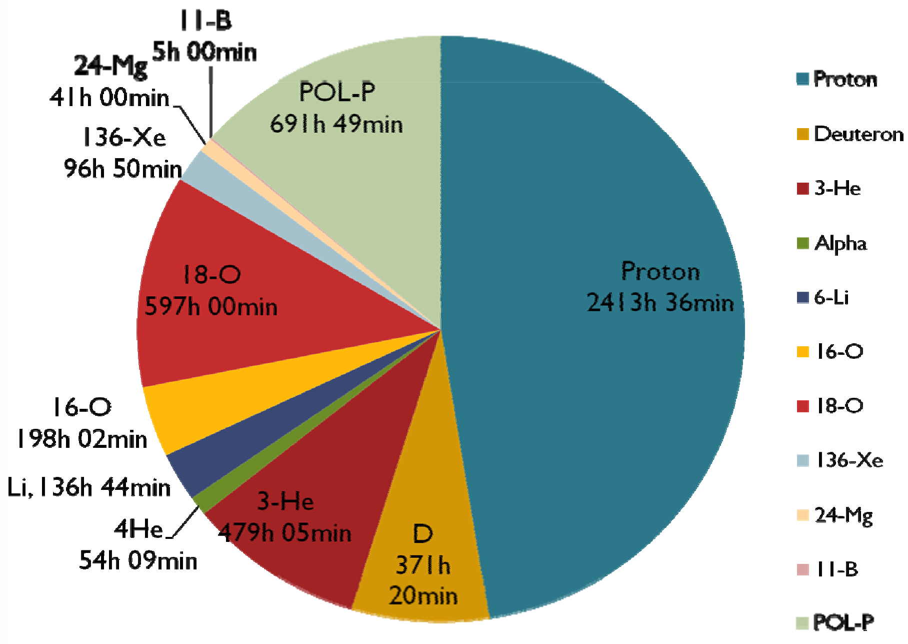


RCNP Cyclotron Facility

RCNP Cyclotrons



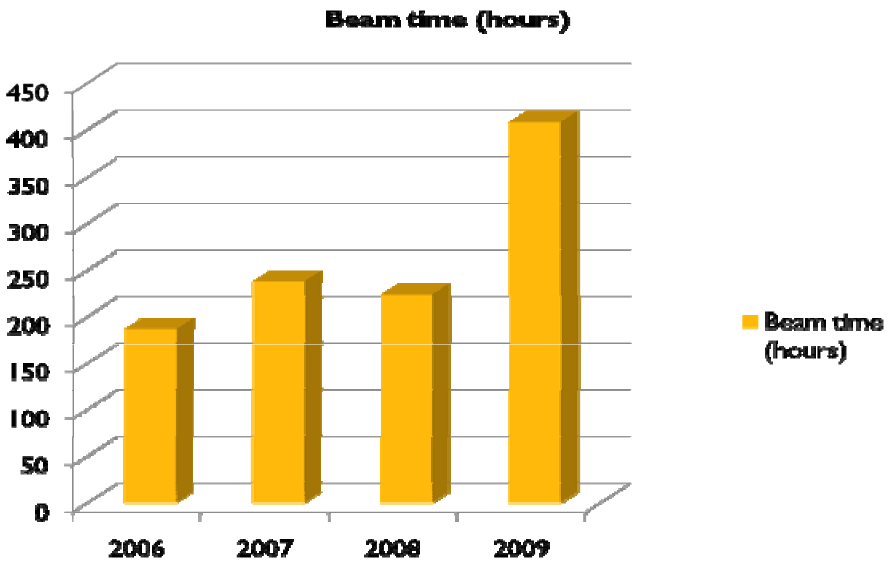
Energy of accelerated ions

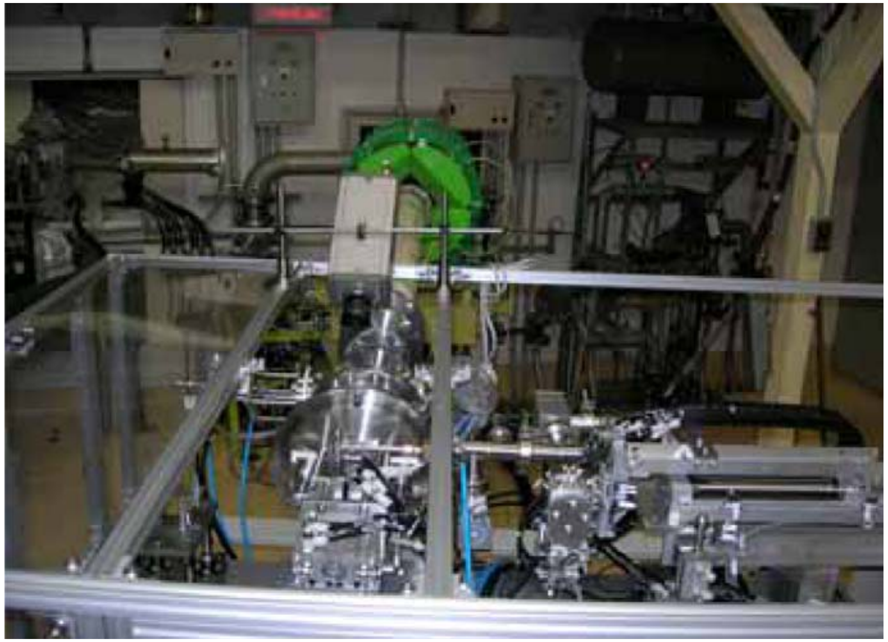


Statistics in 2009

RI production

- Radiochemistry
- Medical science
- Education of students





Beam line and the gas jet RI-transport system.

3NF effects in nuclei

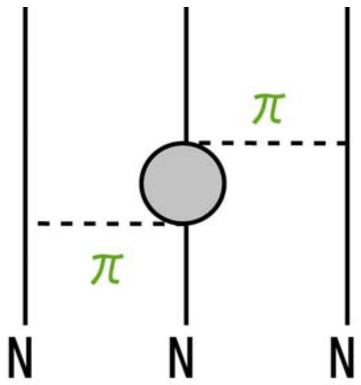
Experimental value of the B.E. of ^{3}H is 8.48 MeV.

Theoretical predictions by Faddeev calculations
Bochum-Cracow-KIT group.

NN pot.	NN only	NN+3NF(TM)	$\Lambda(m_\pi)$
CD Bonn	8.00	8.483	4.86
AV18	7.65	8.479	5.22
Nijm93	7.66	8.480	5.10
	7.64	8.459	5.31

- NN force only calc. is underboud by 0.5-1.0 MeV.
- 3NF fills this gap. (but with Λ)

→ put constraint on overall strength of 3NF.



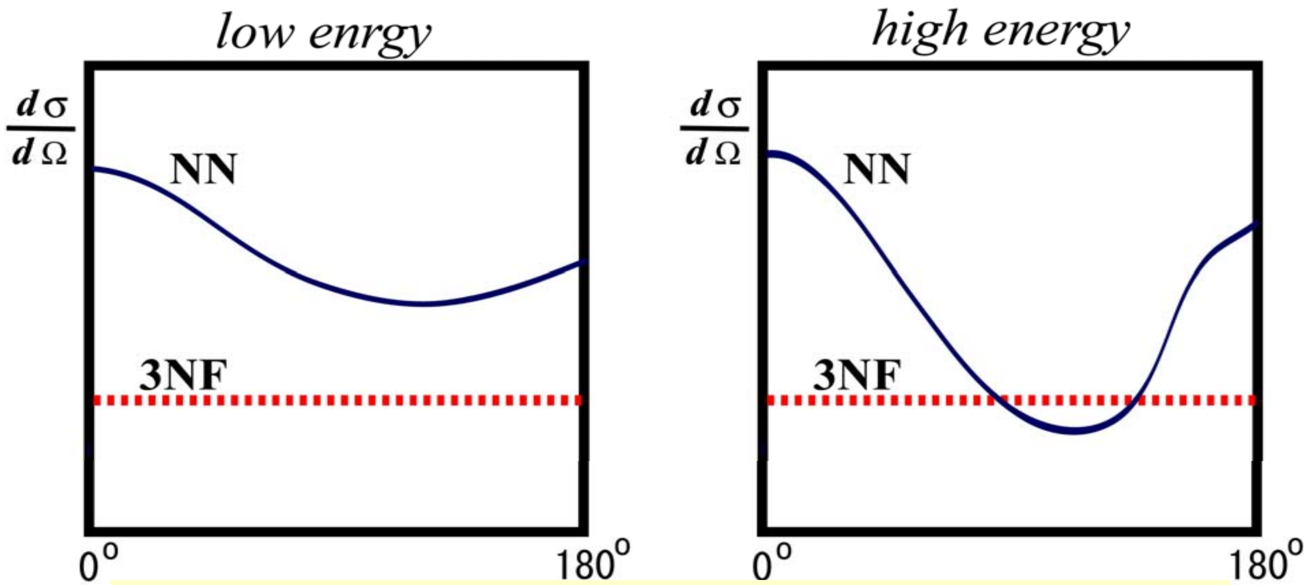
Fujita-Miyazawa 3NF model
Prog. Theor. Phys. 17 (1957) 360

Where can we study dynamical aspects of 3NF effects?

H.Witała proposed to study Nd scatterings at intermediate energy to investigate dynamical properties of 3NF.

(PRL 81('98) 1183.)

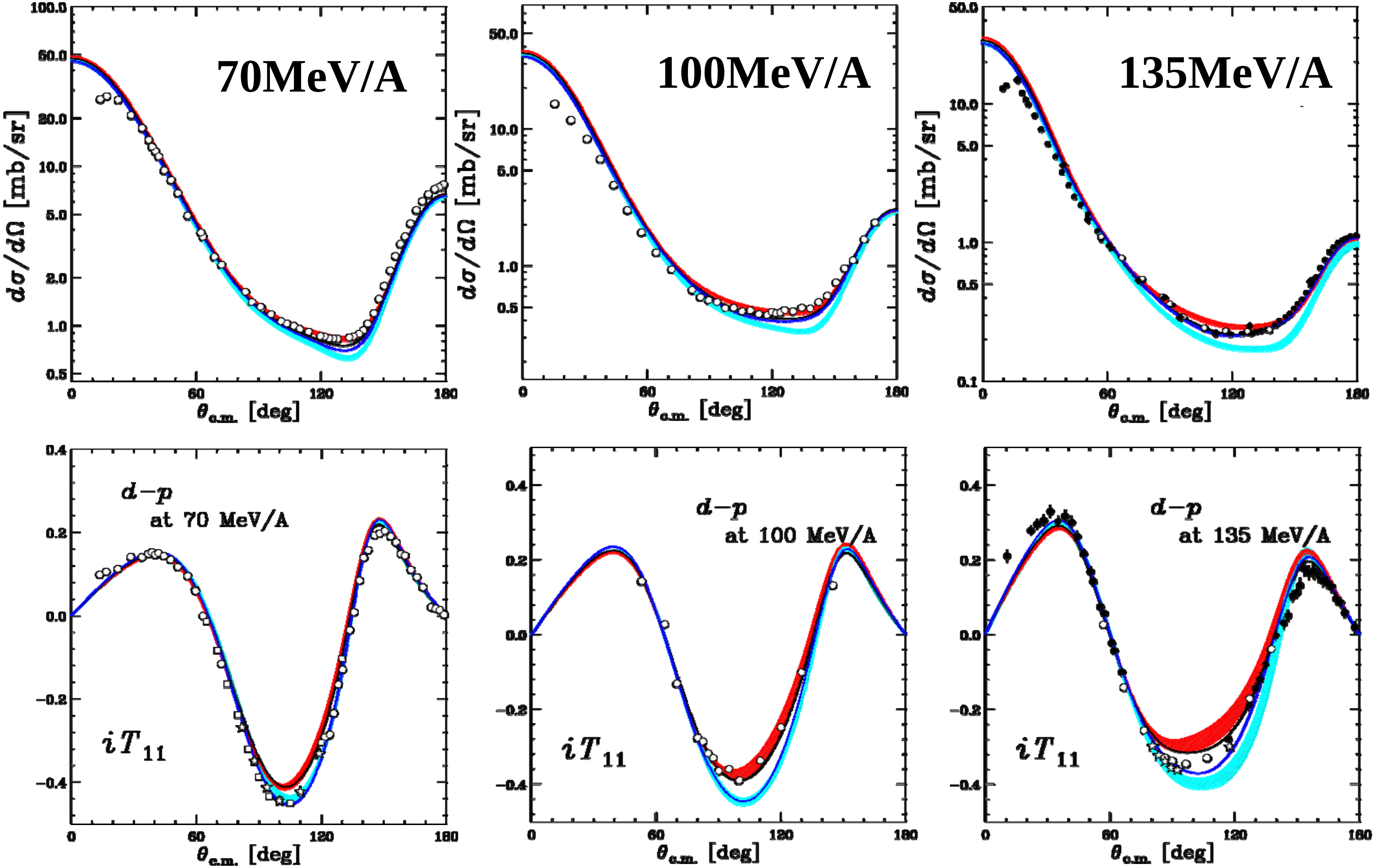
Cross section by NN force becomes smaller at higher energies, but the 3NF effect is almost energy independent. The relative 3NF effect becomes larger at higher energy.



Especially in *dσ/d Ω* minimum region.

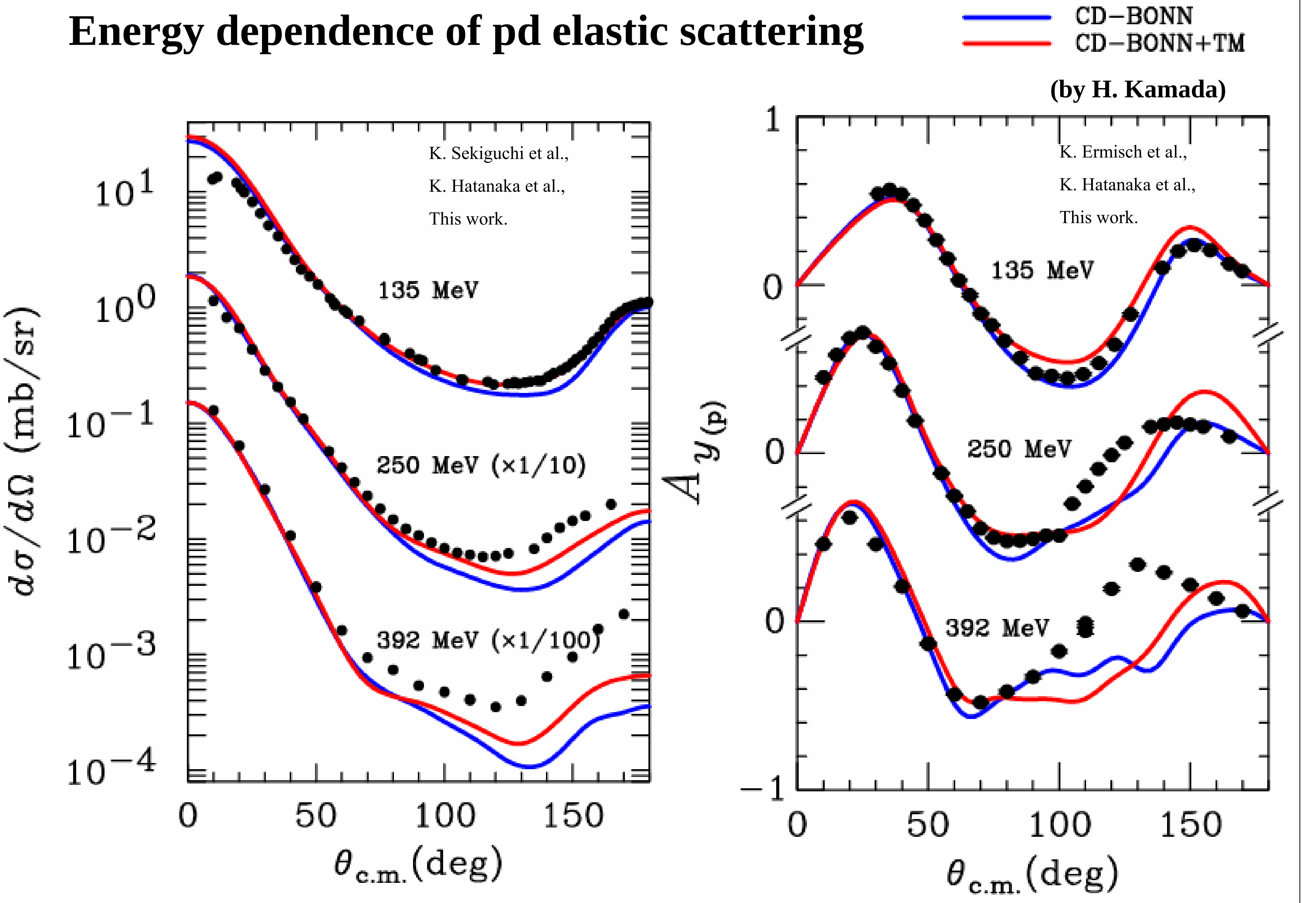
K. Sekiguchi et al. PRC 65, 034003(2002); PRC 70, 014001(2004)

dp elastic scattering data (RIKEN)



Energy dependence of pd elastic scattering

(by H. Kamada)



Nuclear structure studied by (p,p'), (p,n) & (n,p) at 300 MeV

Advantages

1. Effective interaction favors Spin-flip transitions over Non-Spin-flip ones ($t_{\sigma\tau} / t_{\tau}$)

⇒ GT transitions are most clearly seen.

2. Distortion effects are smallest (t_0).

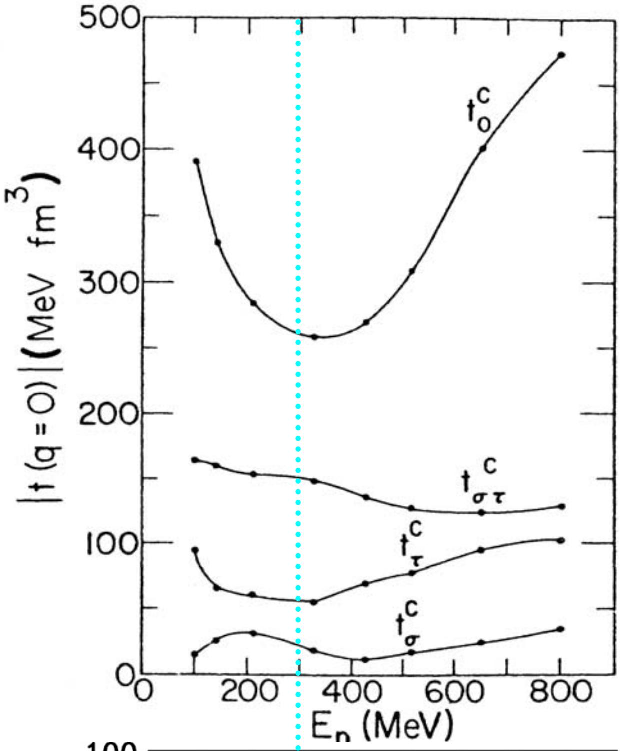
⇒ analysis with DWIA is reliable.

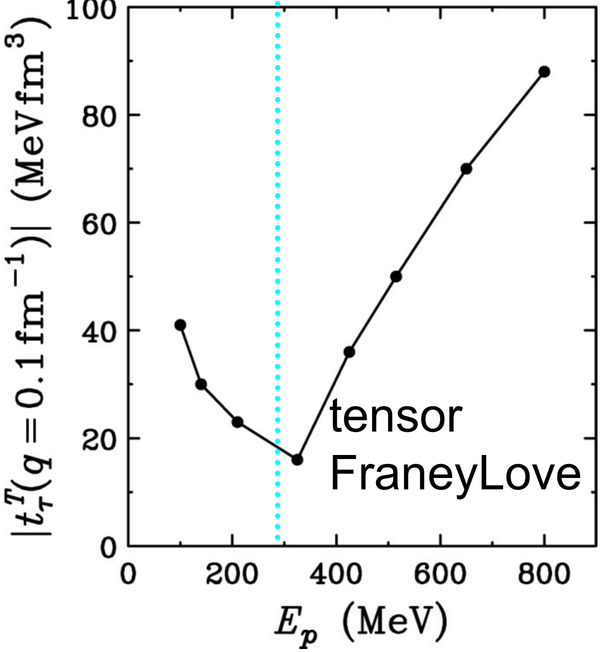
3. Tensor interaction is smallest (t_{τ}^{T}).

⇒ Proportionality relation is reliable.

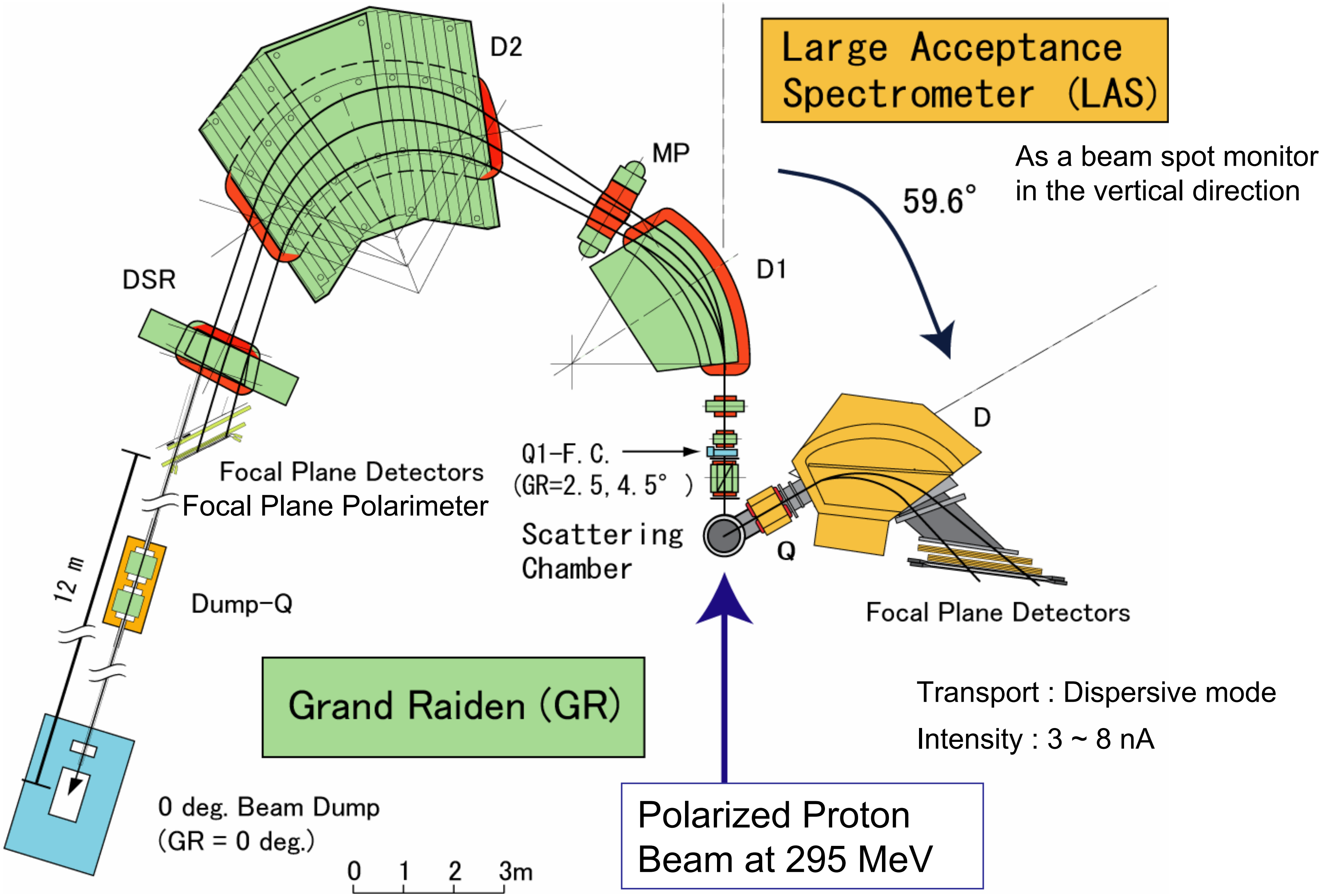
cross section ⟺ strength

Multipole decomposition analysis works best at this energy.





E1 strength distribution measured by (p,p') scattering at forward angles including 0-deg.



E1/M1 Decomposition by Spin Observables

- Polarization observables at 0° ➡ spinflip / non-spinflip separation*

  (model-independent)

$$D_{SS}+D_{NN}+D_{LL}=\begin{cases} -1 \text{ for } \Delta S = 1\text{, M1 excitations} \\ 3 \text{ for } \Delta S = 0\text{, E1 excitations} \end{cases}$$

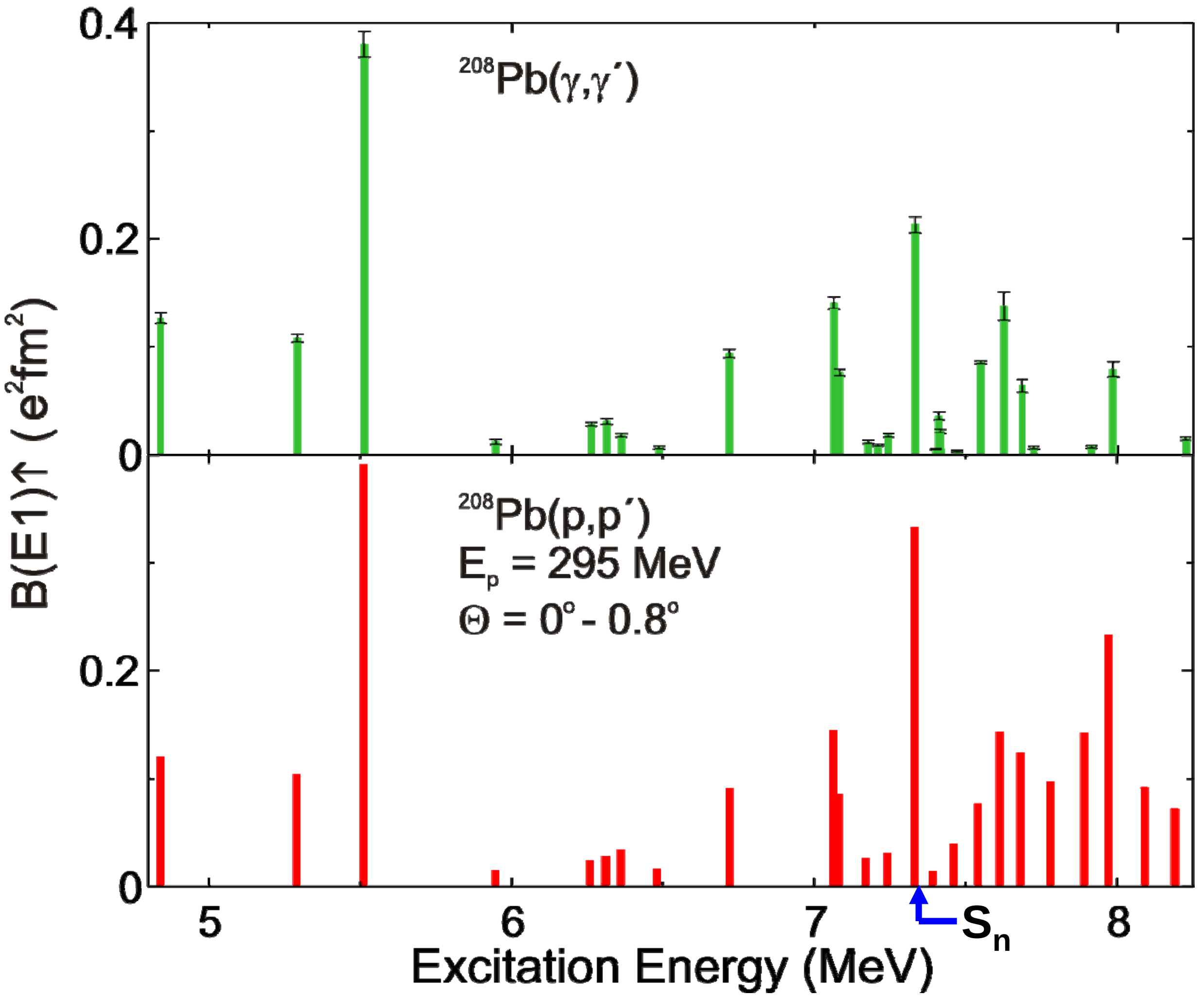
➡ E1 and M1 cross sections can be decomposed

At 0° $D_{SS} = D_{NN}$

Total Spin Transfer: $\Sigma \equiv \frac{3-(2D_{SS}+D_{LL})}{4} = \begin{cases} 1 \text{ for } \Delta S = 1 \\ 0 \text{ for } \Delta S = 0 \end{cases}$

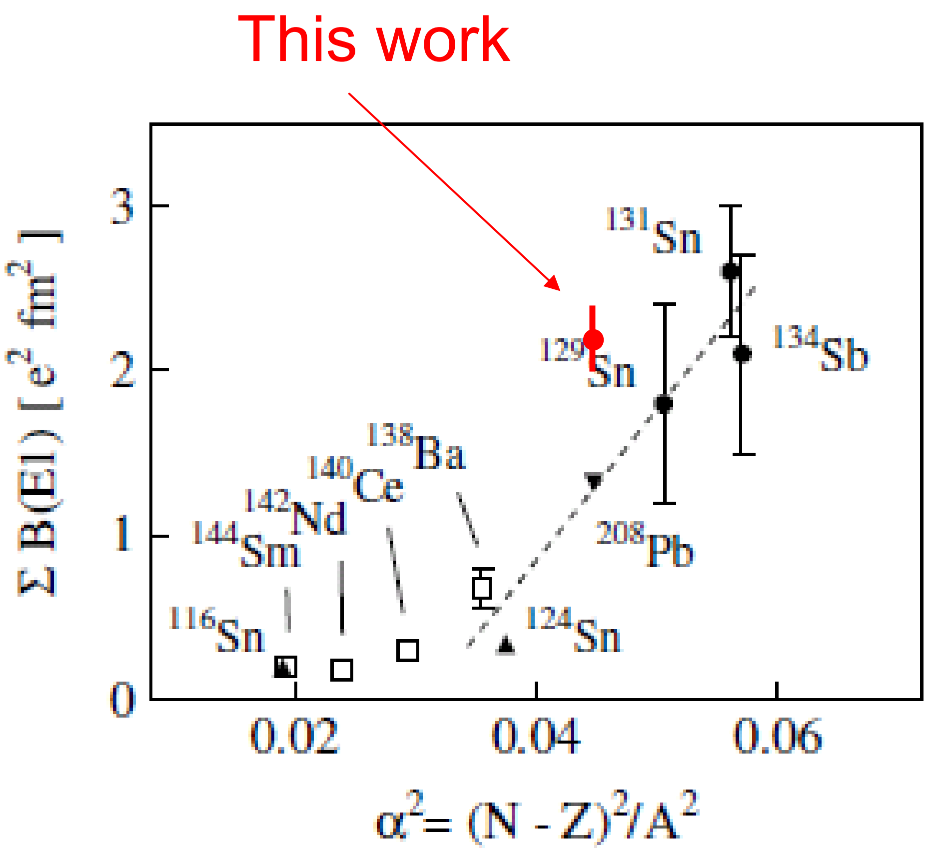
T. Suzuki, PTP 103 (2000) 859

B(E1) Strength: Low-Energy Region

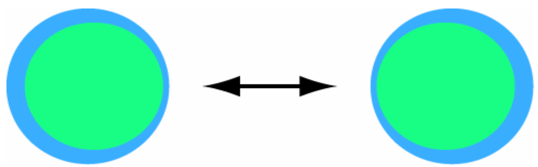


- Extracted assuming semiclassical Coulomb excitation

Pigmy Dipole Resonance



Dipole oscillation between an isospin-saturated core and a neutron (proton) skin?

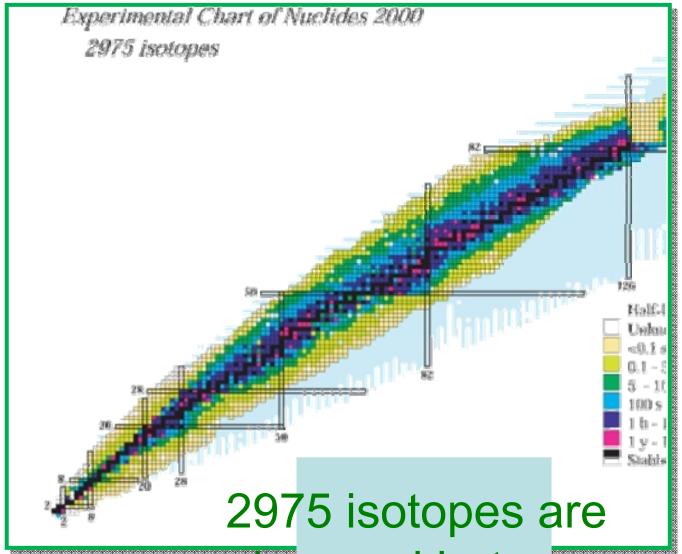


T. Aumann et al., NPA805, 198c(2008).

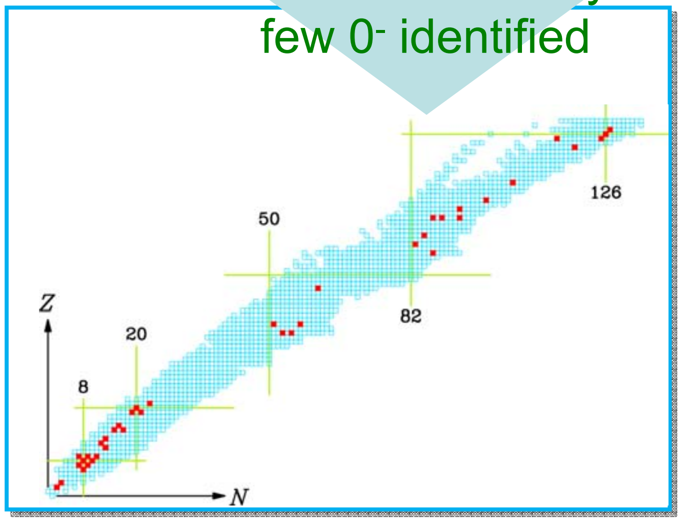
Missing 0^- Strength Search by (p,n) reaction

- Missing 0^- strength
  - Observed 0^- states are limited in a few nuclei
  - Crucial problem in nuclear physics
    - Model independent sum-rule for 0^-
- 0^- strength is expected to be small
  - Sum-rule
    - $S(0^-)$: $S(1^-)$: $S(2^-)$ = 1 : 3 : 5

<u>Highly-sensitive experimental tool for 0^- excitation is required</u>



2975 isotopes are observed but very few 0^- identified



Power of Polarization Observables

- $^{12}C(p, n)^{12}N$ at 296 MeV and 0°

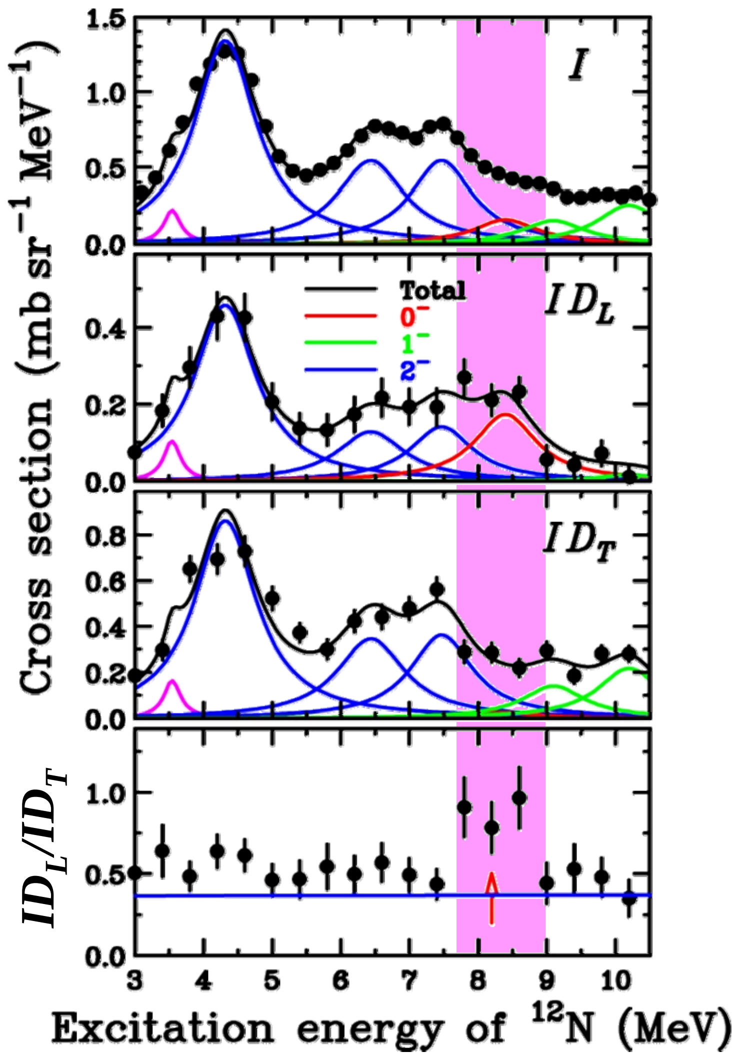
M. Dozono, JPSJ 77,014201(2008)

SDS	ID_L	ID_T	ID_L/ID_T
0^-	I	0	∞
1^-	0	I	0
2^-	$0.4\,I$	$0.6\,I$	0.66...

– E_x = 6.5, 7.4 MeV
  - ID_L & ID_T ⟶ $J^p = 2^-$

– E_x = 8.4 MeV
  - ID_L only (Enhancement in ID_L/ID_T)
  ⟶ $J^p = 0^-$ (First observation)

– E_x = 9.1 and 10.2 MeV
  - ID_T only ⟶ $J^p = 1^-$



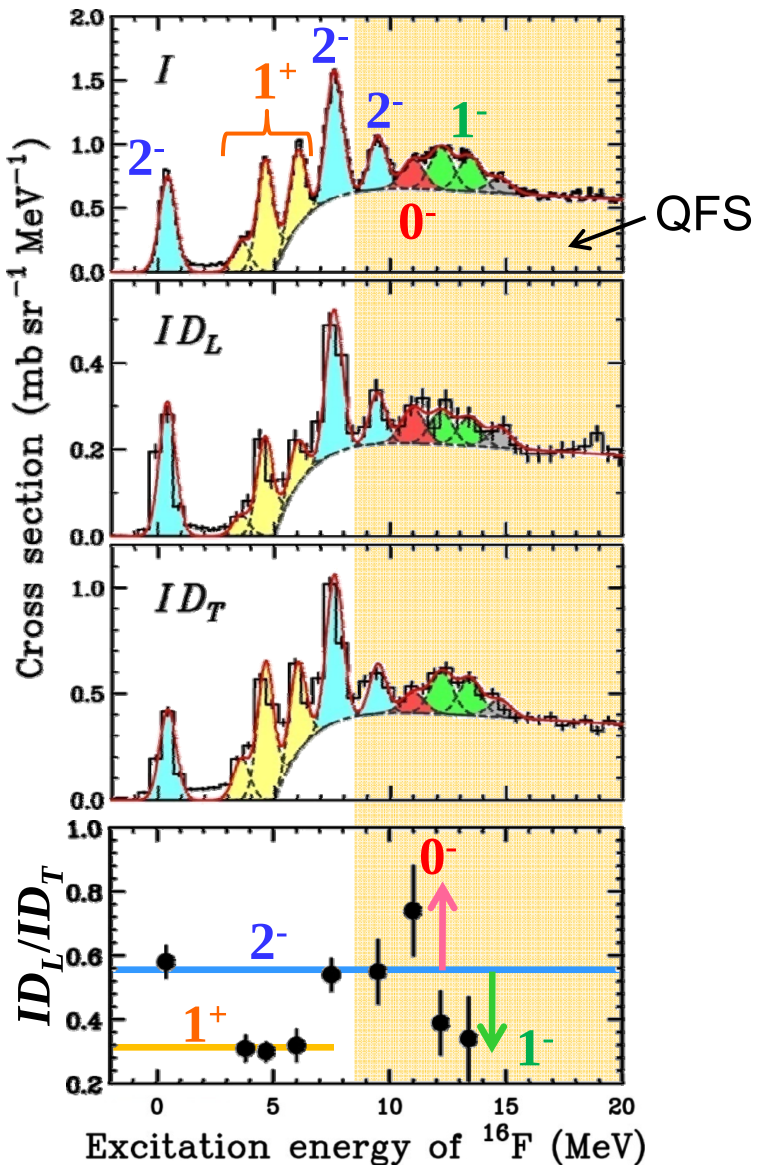
Complete PT measurement is very powerful for SDS study

$^{16}O(p,n)^{16}F$ ~ Spin-vector cross sections ID_L, ID_T ~

- E_x = 0.4, 3.8, 4.7 6.0, 7.5 MeV
  - J^p are known from early studies
  - Consistent with predictions
- E_x = 9.5 MeV
  - consistent with known 2^- case
  - 2^- (dominant)
- E_x = 11.0 MeV
  - Enhancement in ID_L/ID_T
  - 0^- (dominant)
- E_x = 12.2, 13.4 MeV
  - Reduction in ID_L/ID_T
  - 1^- (dominant)

$E_x(2^-) < E_x(0^-) < E_x(1^-)$ ➡
Importance of tensor correlations

Assigned in this work

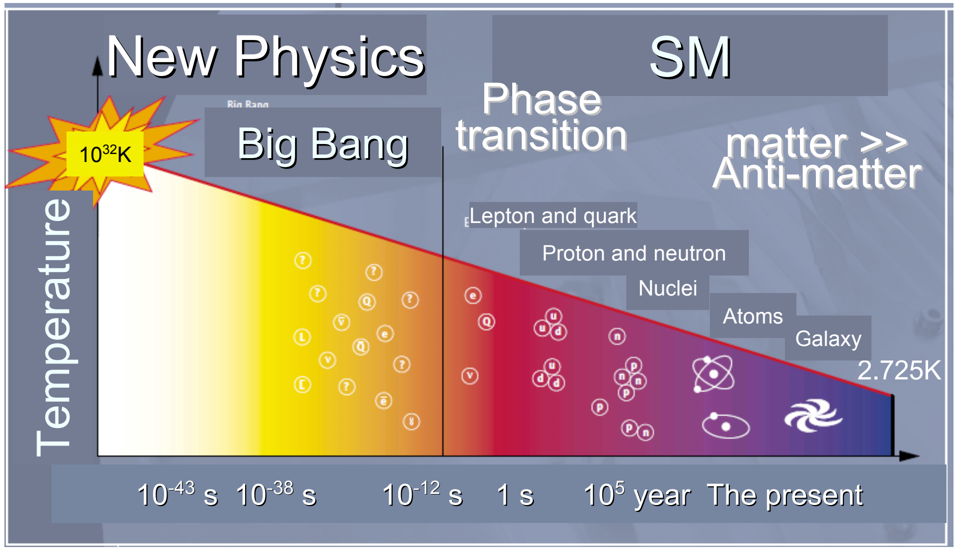


Developments of Super-thermal
UCN source

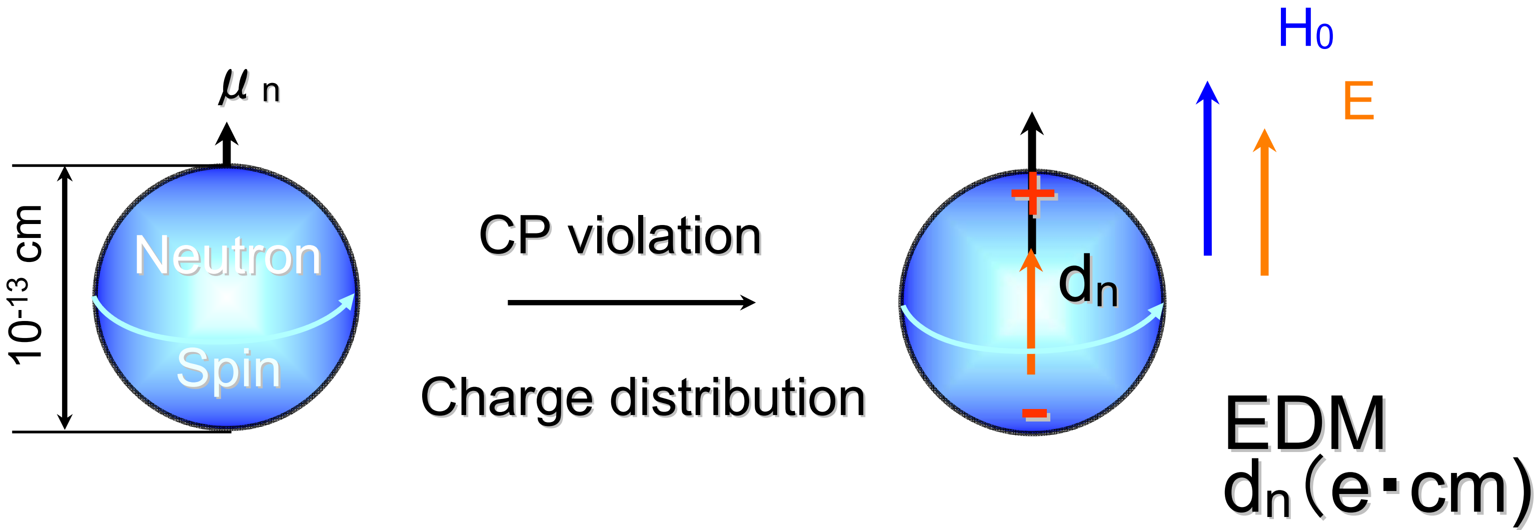
and

Preparation of nEDM
measurement

Big Bang



Existence of the Electric Dipole Moment of a particle violates P invariance as well as T and so CP invariance.

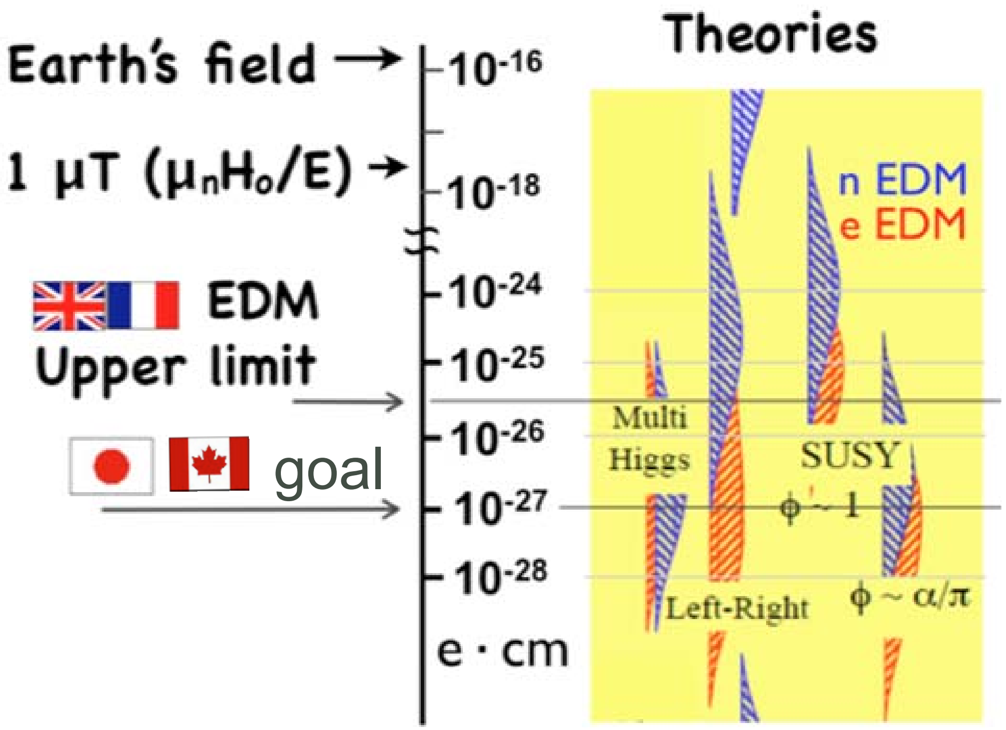


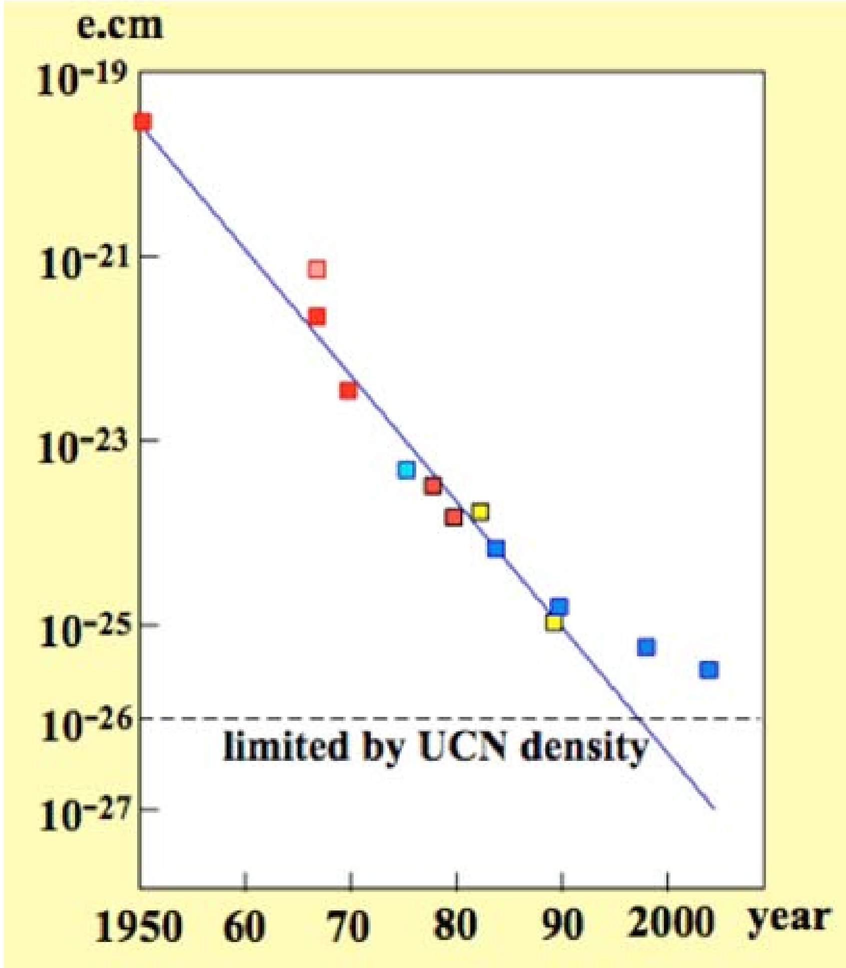
Measurement of $\mu_n H_0 \pm d_n E$

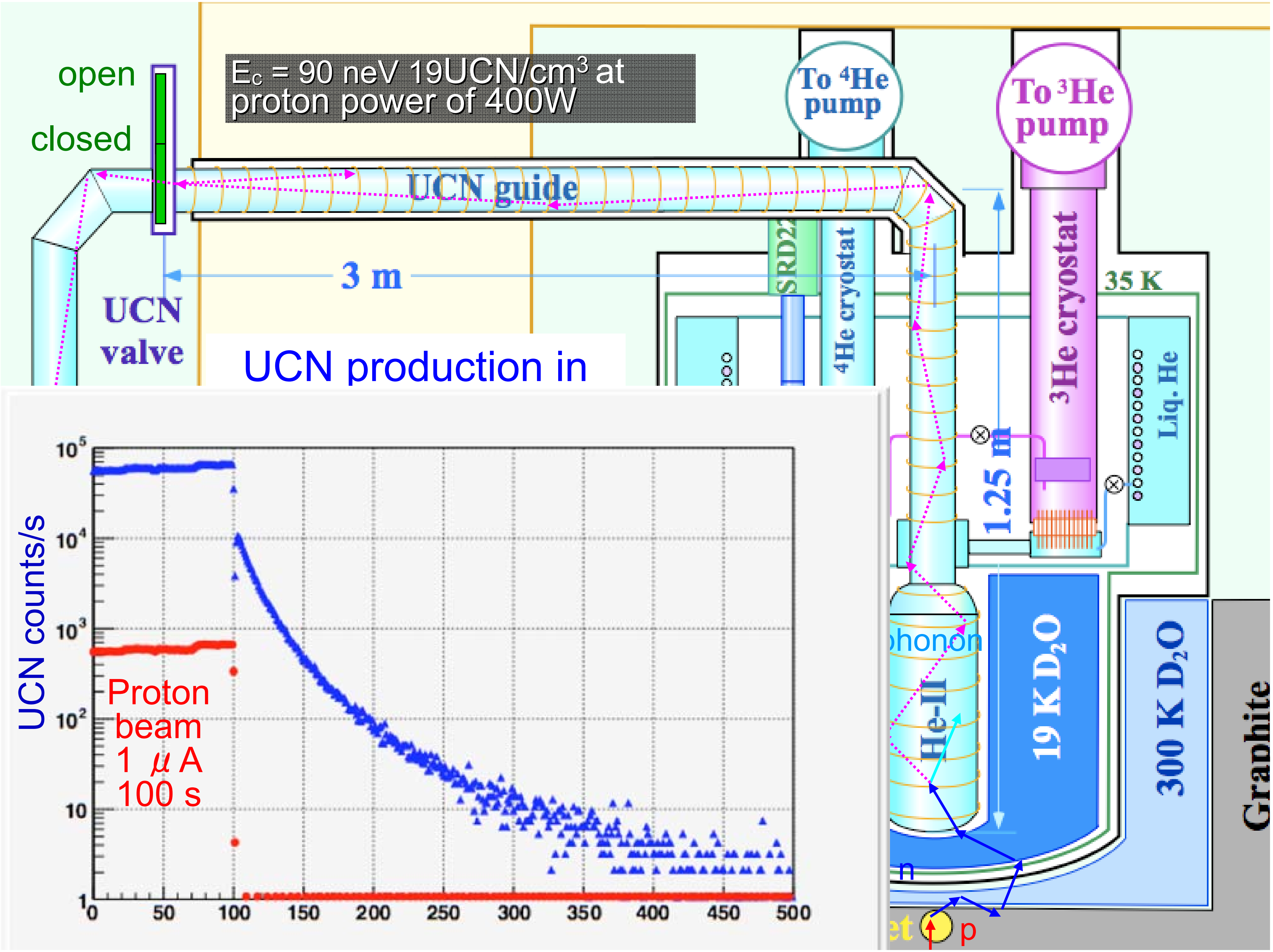
neutron EDM

- In the Standard Model (SM) all observations of CP and T violation in the K and B decays can be explained perfectly well. The SM prediction for the neutron EDM is at the level, less than 10^{-31} e•cm, which is below of the current experimental limit by five orders of magnitude.
- However the SM cannot explain the baryon asymmetry of the Universe. It appears at the level 10^{-25} in SM, while observations give the level 10^{-10}.
- Only theories beyond the SM suggesting new channels for CP violation as well as violation of the baryon number (A.D. Sakharov) necessary to explain the baryon asymmetry in the Universe.
- In such theories (unification, supersymmetry) the predicted value of the neutron EDM is raised by up to seven orders of magnitude.
- Hence, measurements of the neutron EDM could provide a significant argument for these extensions to the SM.

History of nEDM measurements

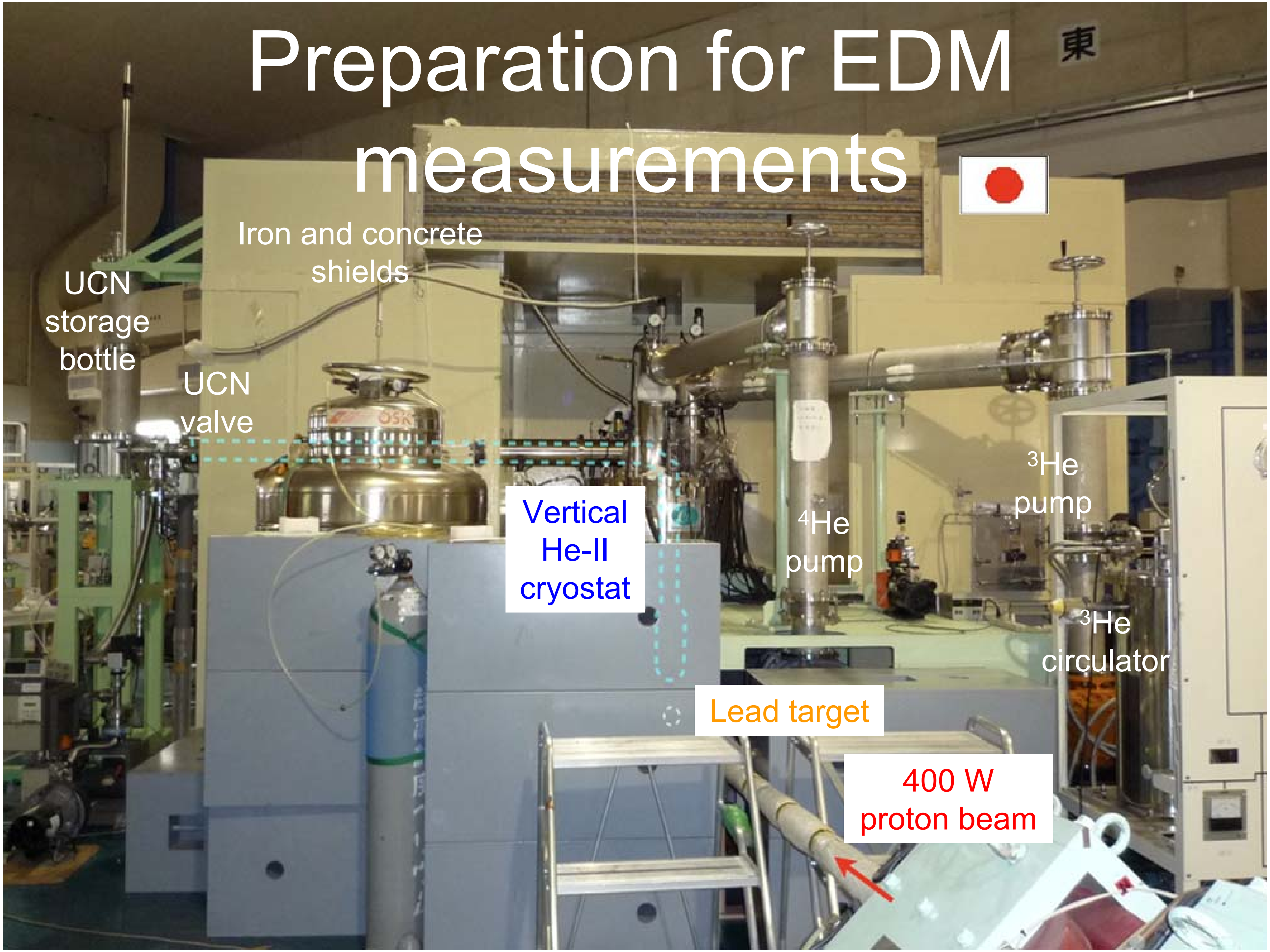




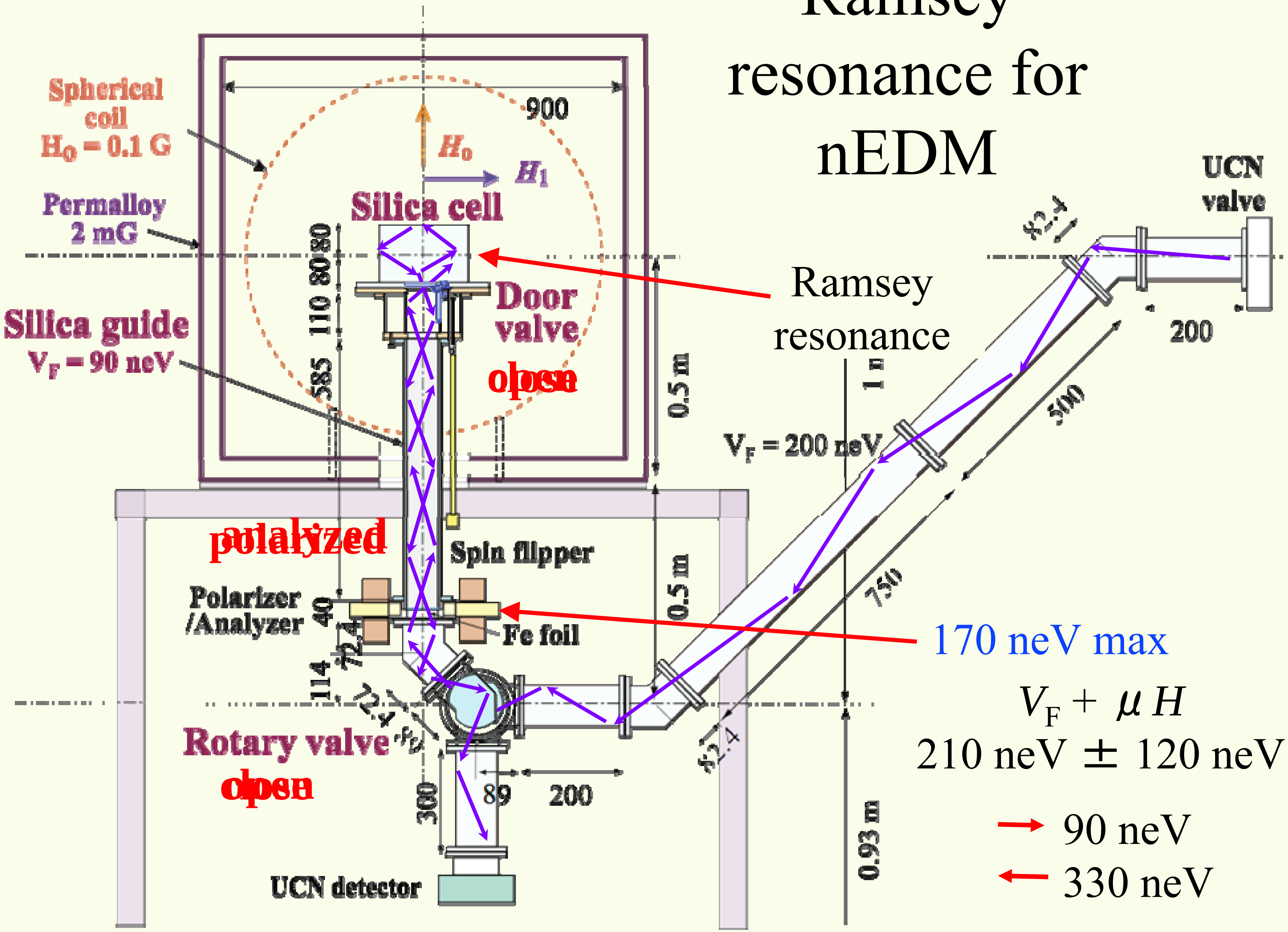


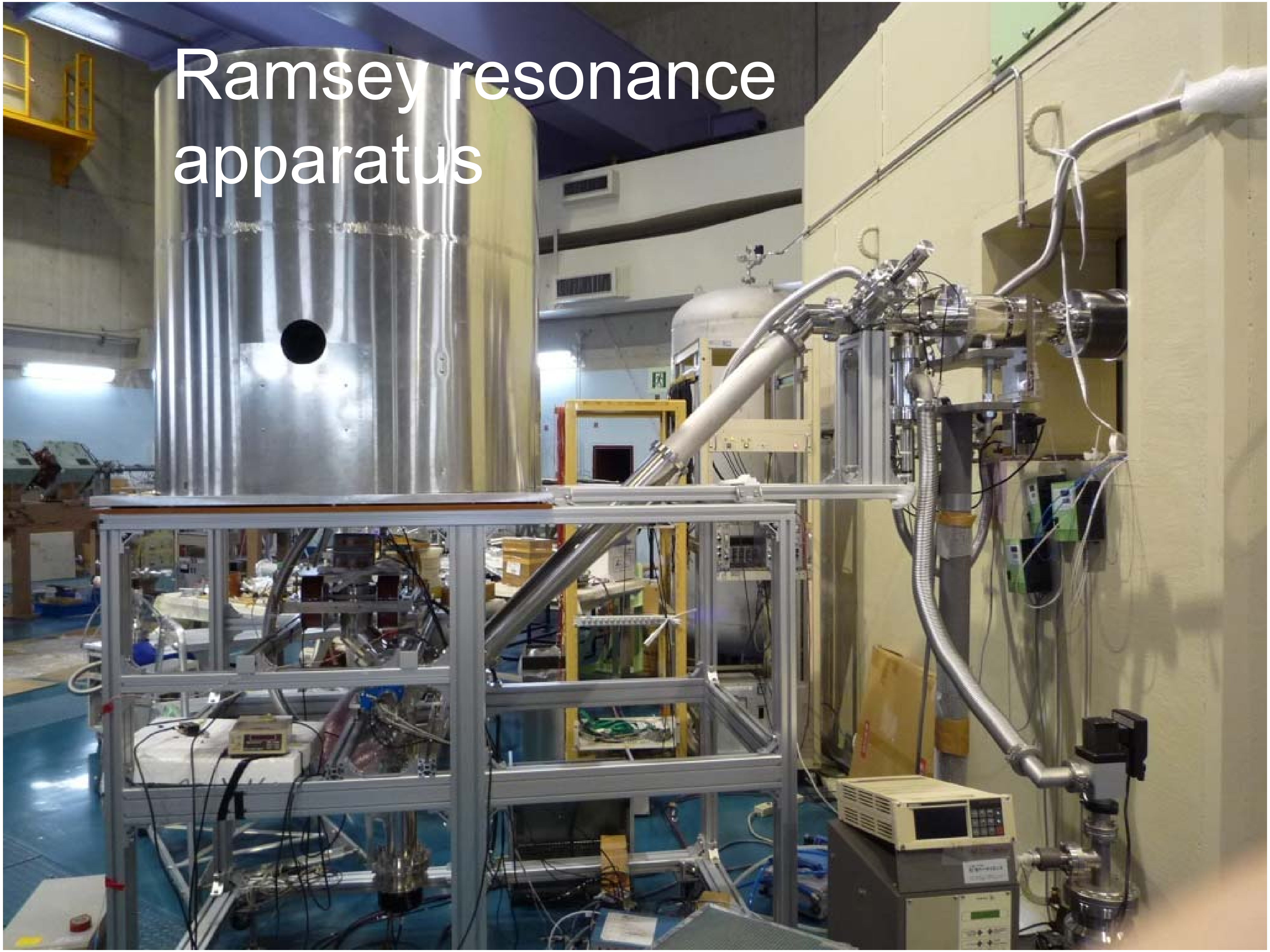
open
closed
E_c = 90 neV 19UCN/cm^3 at proton power of 400W
To ^{4}He pump
To ^{3}He pump
UCN guide
SRD2
^{4}He cryostat
3He cryostat
35 K
3 m
UCN valve
UCN production in
1.25 m
Liq. He
phonon
He-II
19 K D_2O
300 K D_2O
Graphite
n
p
UCN counts/s
Proton beam 1 μA 100 s

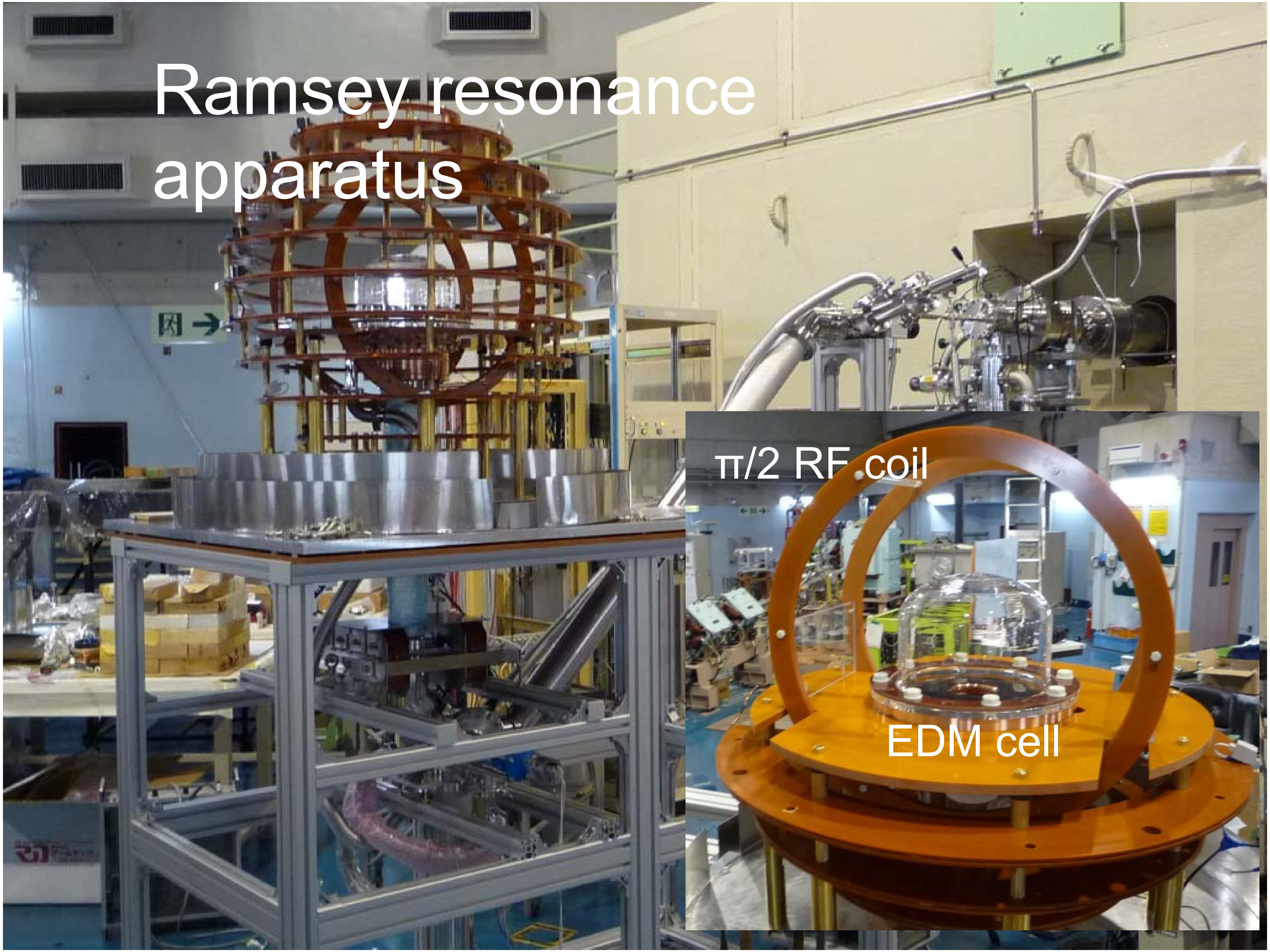
Preparation for EDM measurements



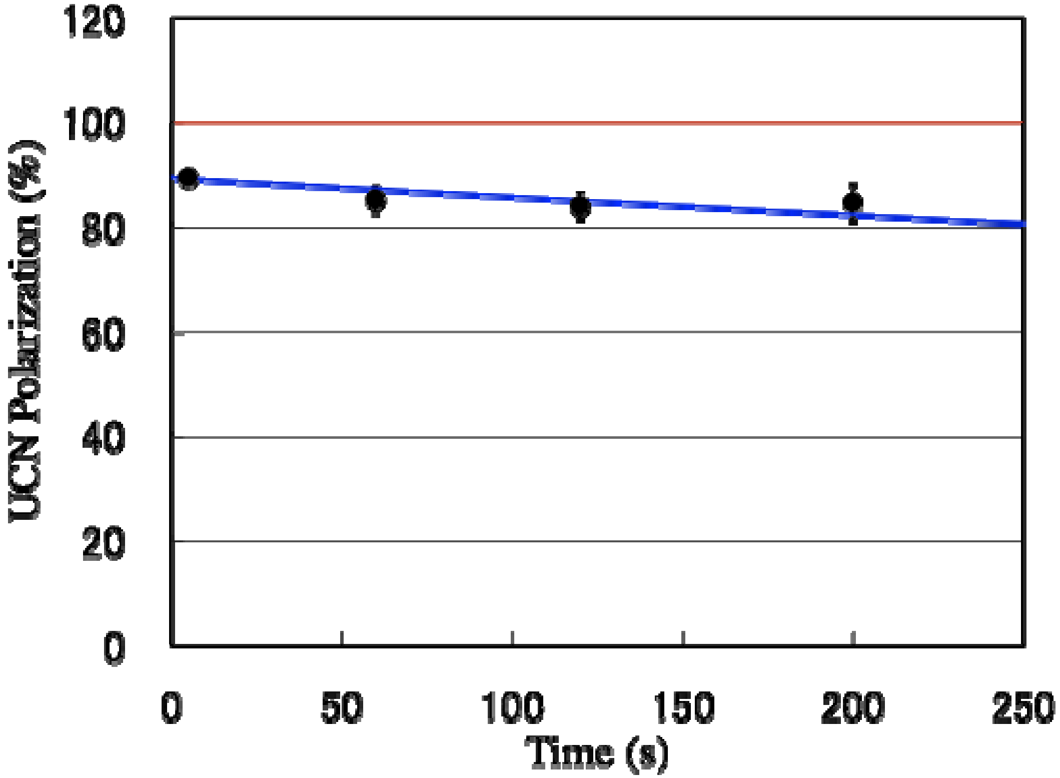
Ramsey resonance for nEDM




Ramsey resonance
apparatus


Ramsey resonance apparatus
π/2 RF coil
EDM cell

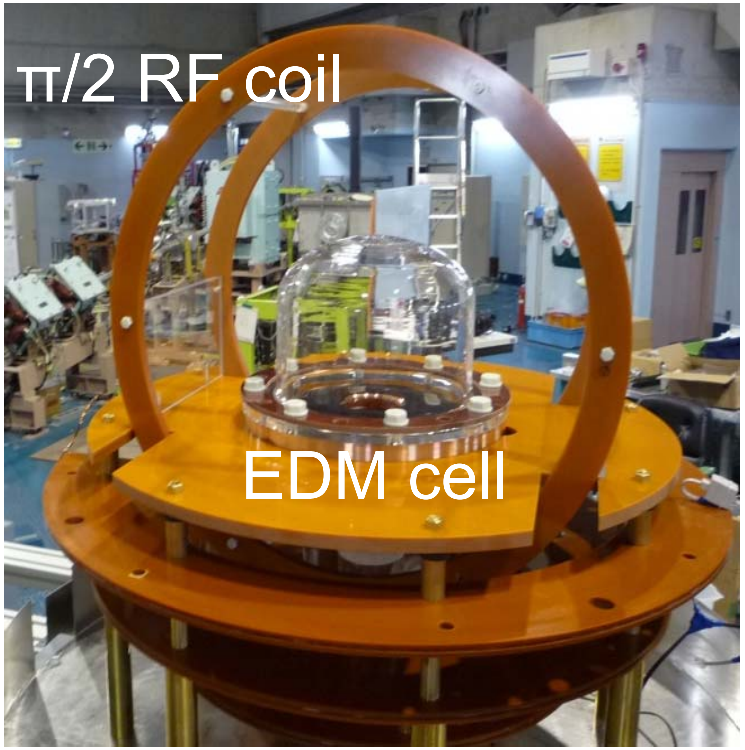
Relaxation of UCN Polarization in the Ramsey Cell



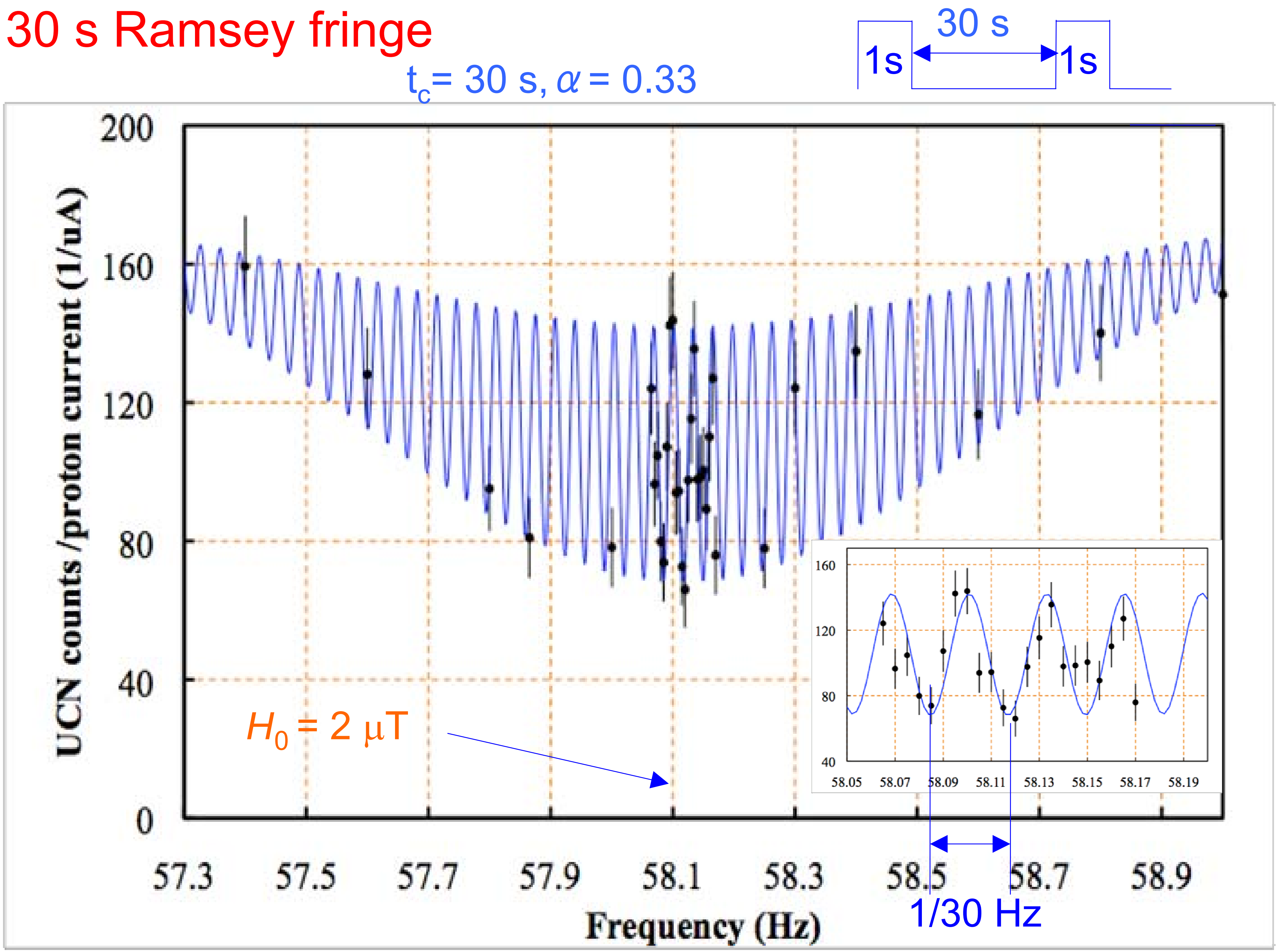
Silica + DLC

P_0 = 89.1(1.2) %

$T_1 = 2400^{+1300}_{-700}$ s



30 s Ramsey fringe

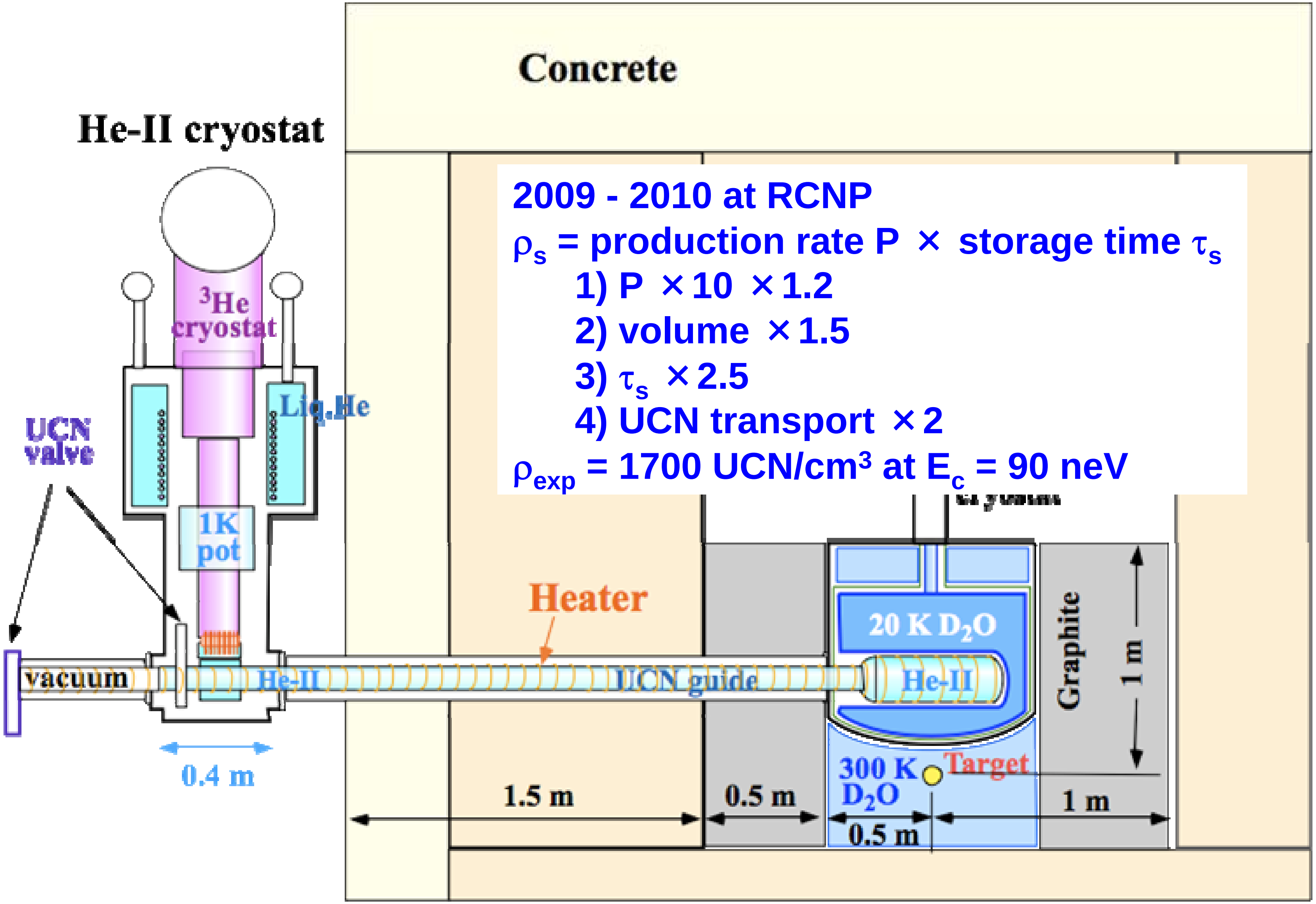


2009 - 2010 at RCNP

ρ_s = production rate P × storage time τ_s

1) P ×10 ×1.2
2) volume ×1.5
3) τ_s ×2.5
4) UCN transport ×2

ρ_{exp} = 1700 UCN/cm^3 at E_c = 90 neV



Present to near future of RCNP

- Research center for subatomic science (present)
  - Cyclotron facility
    - Nuclear Physics, Fundamental physics
    - Applications: Radiochemistry, Medical science, Solid state physics
    - Education of students (in Asia)

      Asian Accelerator Science School?
  - LEPS2: Hadron physics (GeV photon)
  - CANDLES: Double beta decay (Lepton number violation)
  - MUSIC: Lepton Flavor mixing (DC muons)
- Higher intensity for cyclotron facility (near future)
  - Neutron EDM, DC Muons

Thank you for your attention