Precision Frontiers with Optically Controlled Neutrons

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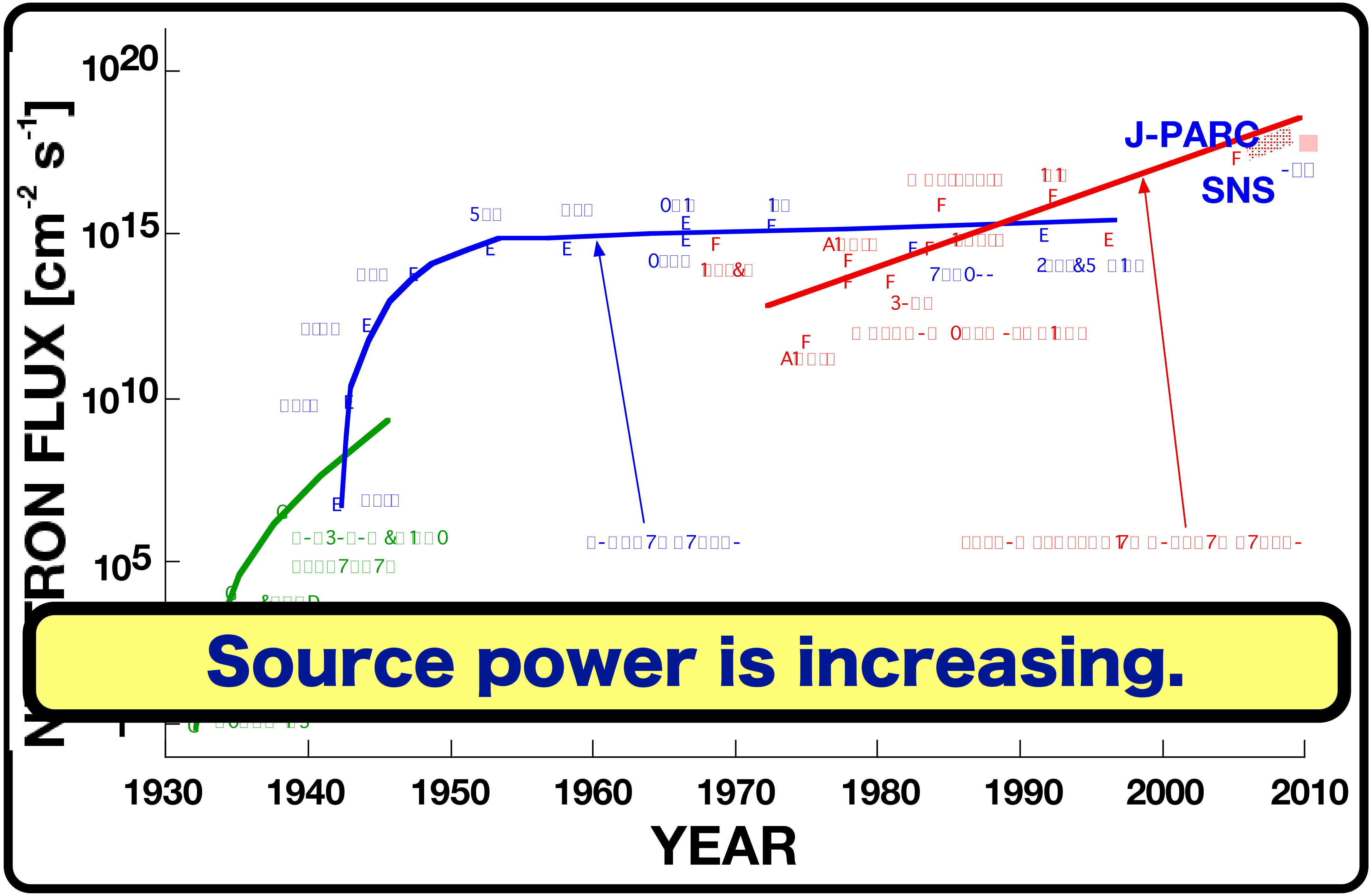
0. Introduction

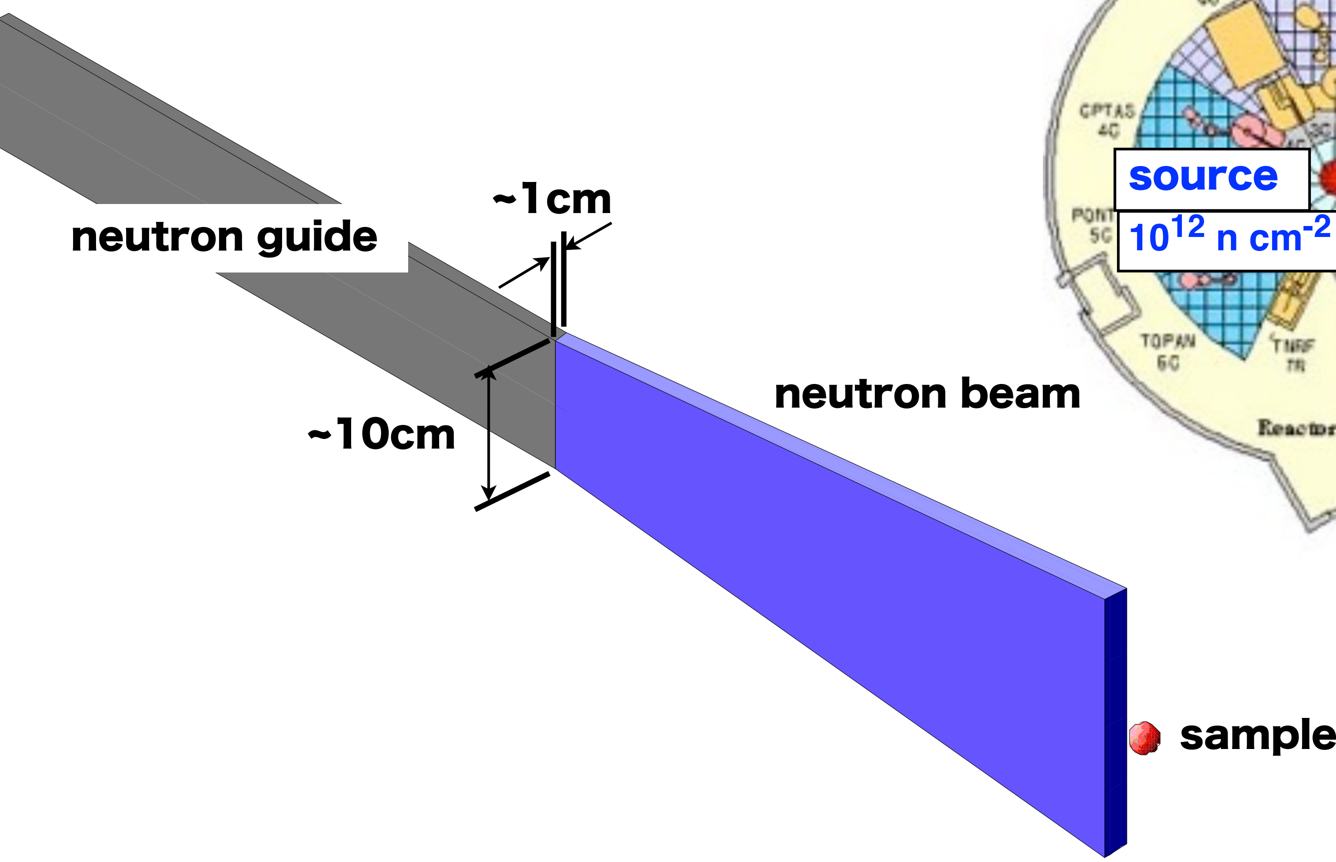
Neutron Sources

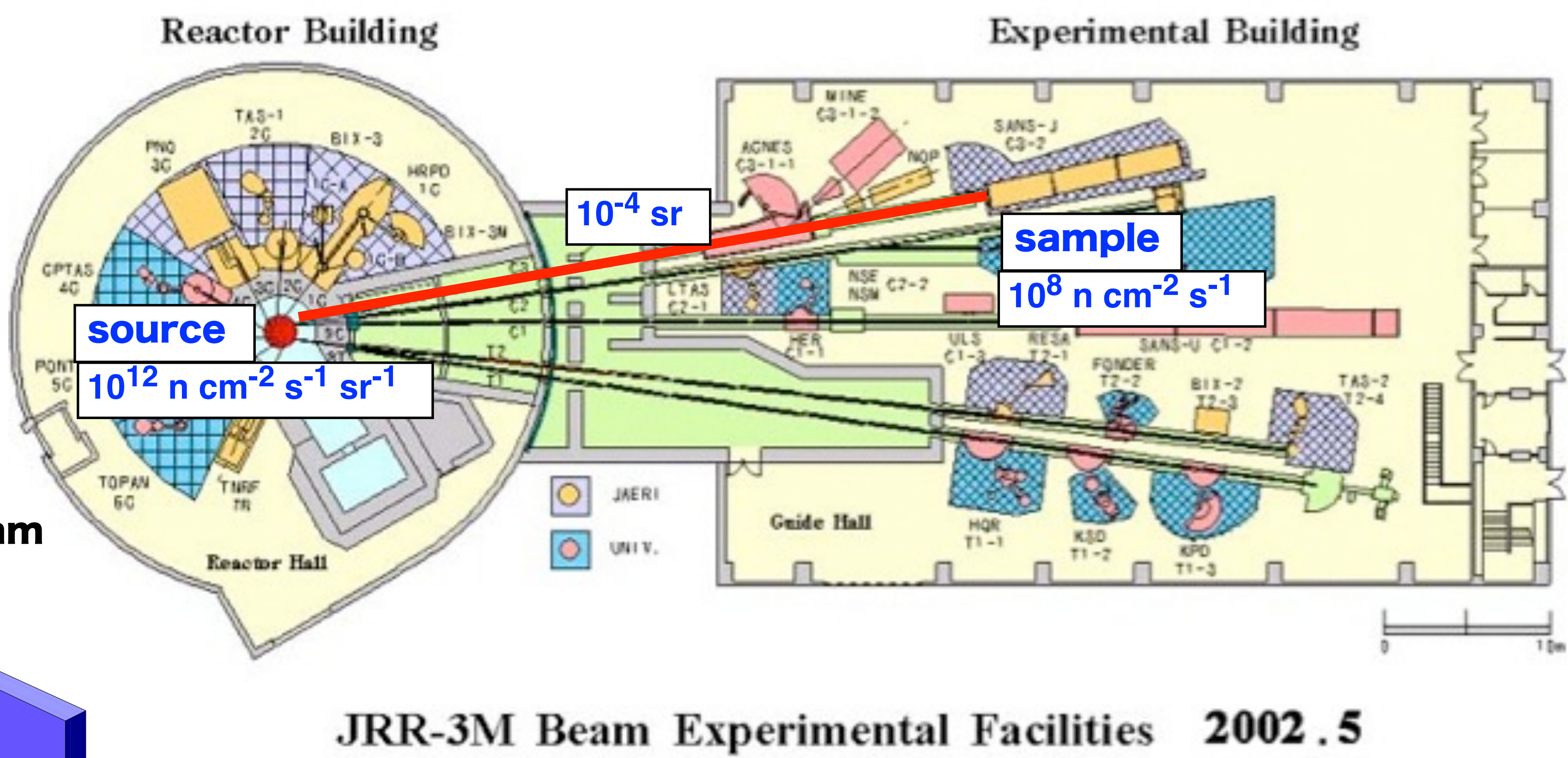
Slow neutron beam is attracting scientists' attention as its sensitivity to light elements, dynamics and magnetism. However, it is less commonly used than X-rays. One of the reasons is that its low luminosity.



(Analyzing Capability)=(Source Power)×('Efficacy')

deceleration, optics, detector, sample environment, signal processing, analysis algorithm, theoretical model, ... etc.





most neutrons are not contributing to physics data

innovations → improve 'efficacy'

Function of Neutron Optics

Beam Transport

Beam Delivery to Remote Place

Neutron Guide

Phase Volume Shaping

Beam Definition to Sample Position

Beam Collimation **Beam Focus**

Increase of 'Efficacy'

Neutron Science (Interdisciplinary Playground)

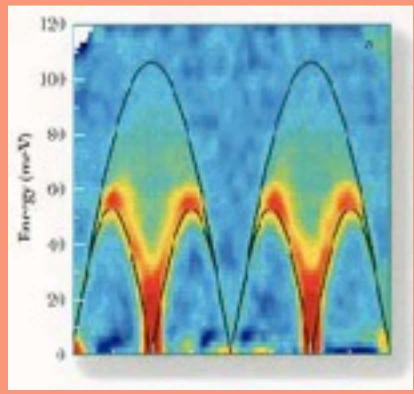
Material Science

Diffraction

λ=0.1-10nm

Spectroscopy

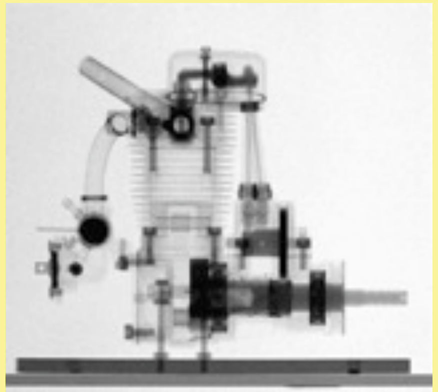
ΔE<100meV t>10^{-13}s



Industry

Radiography

Residual Stress



Neutron Optics

Optics

Detectors

Signal Processing

Neutron EDM

Decay

Gravity

motive force of innovation

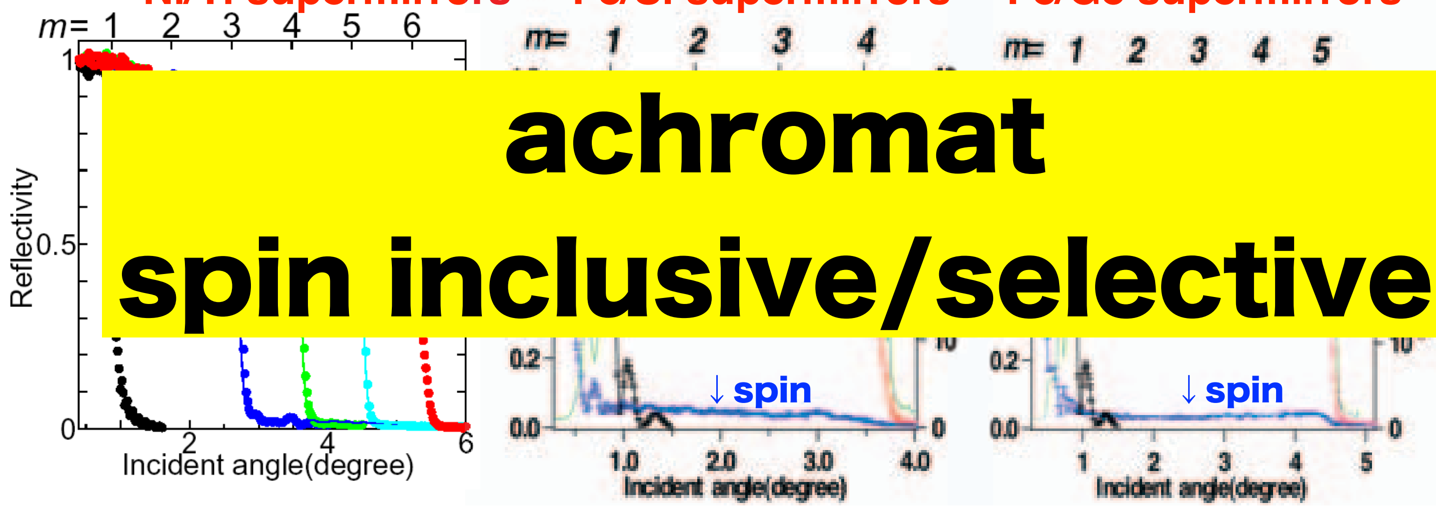
Fundamental Physics

Neutron Optics (device-level achievements)

Reflective Optics

M.Hino et al. (Kyoto Univ.)

Ni/Ti supermirrors Fe/Si supermirrors Fe/Ge supermirrors



achromat

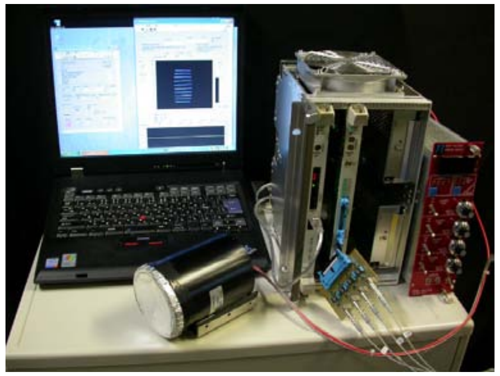
spin inclusive/selective

K.Ikeda et al. (RIKEN)

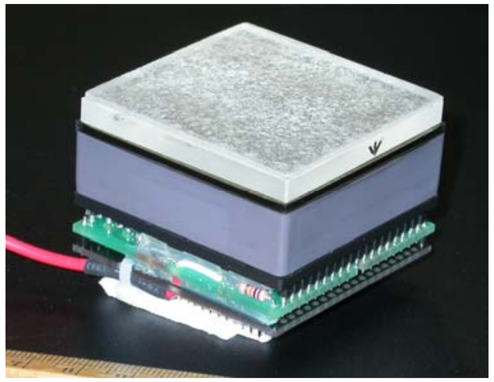
Imaging Detector

K.Hirota (RIKEN)
S.Sato (KEK) et al.

RPMT



FPPMT



Compound Refractive Optics

Biconcave Fresnel-shape Coaxial Double Biconcave Microprism

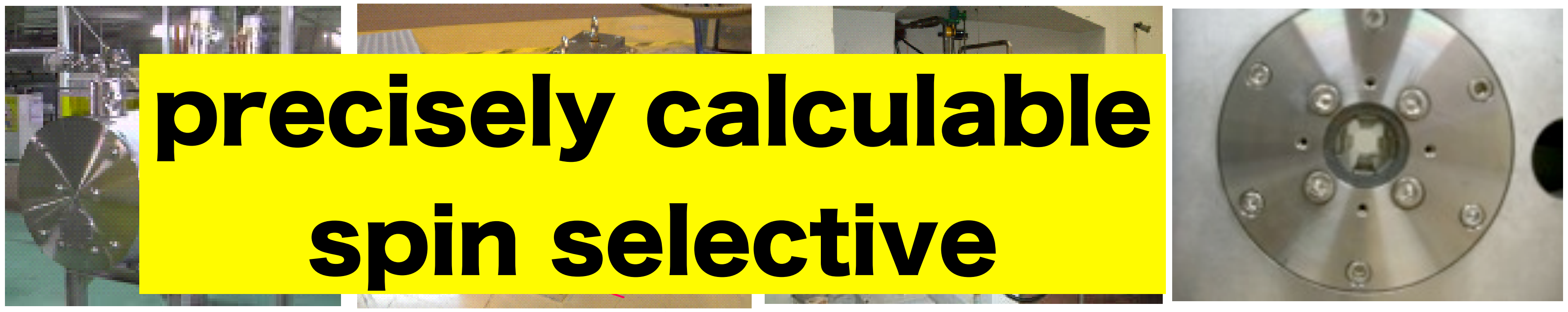
compact

strong bending power

T.Adachi et al. (RIKEN) T.Shinohara et al. (RIKEN)

Magnetic Optics

Superconducting Permanent Pulsed Variable Permanent

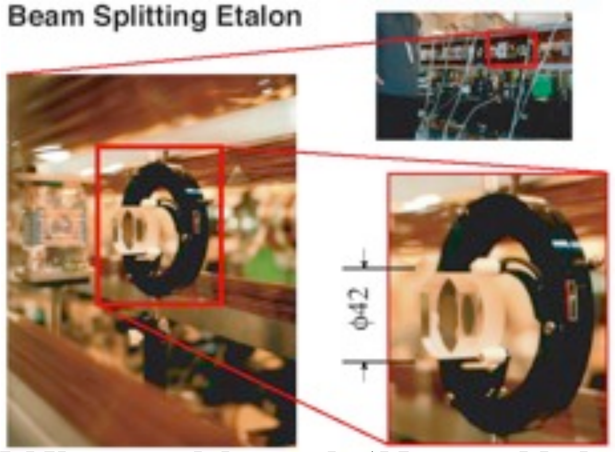


precisely calculable

spin selective

H.M.Shimizu (RIKEN), T.Oku, J.Suzuki (JAERI) Y.Iwashita et al. (Kyoto Univ.)

Interference Optics



M.Kitaguchi et al. (Kyoto Univ.)

1. Fundamental Physics

probing new physics
through quantum loops

Neutron

CKM matrix

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

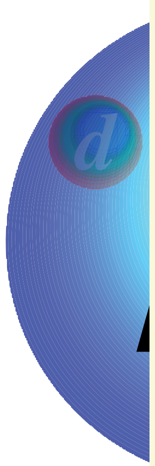
$I(J^P)=\frac{1}{2}(\frac{1}{2}^+)$ (ref. PDG2008)

mass
$m=939.565360\pm0.000081$ MeV

mean life
$\tau=885.7\pm0.8$ s

magnetic dipole moment
$\mu=(-1.91304273\pm0.00000045)\,\mu_N$

electric dipole moment



precision measurements

↓

probing high energy phenomena in quantum loops

in a

em

proton asymmetry parameter
$C=-0.2377\pm0.0010\pm0.0024$

e-$\overline{\nu}_e$ angular correlation coefficient
$a=-0.103\pm0.004$

phase of g_A relative to g_V

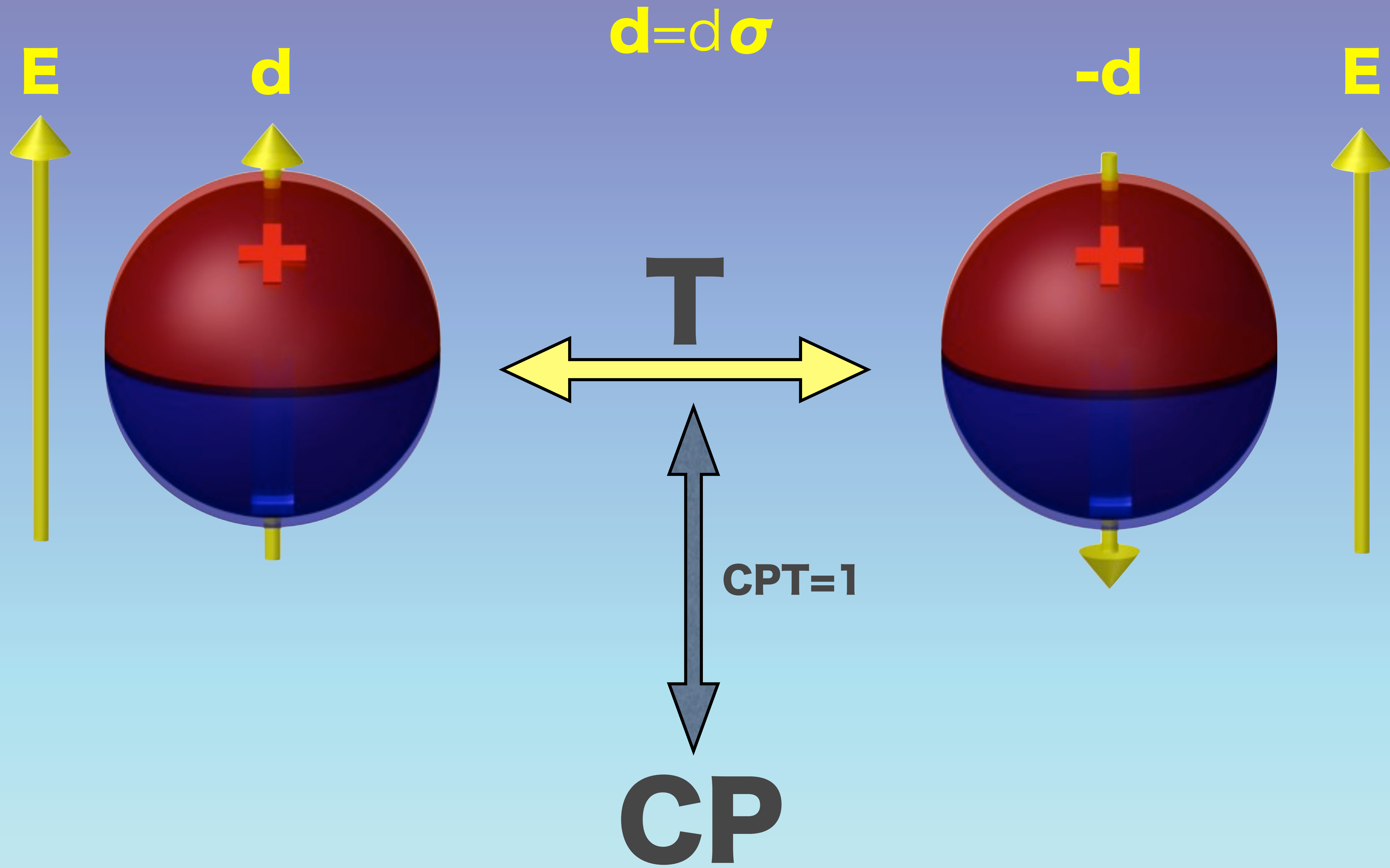
medium range

rch

ultimate efficacy is desired

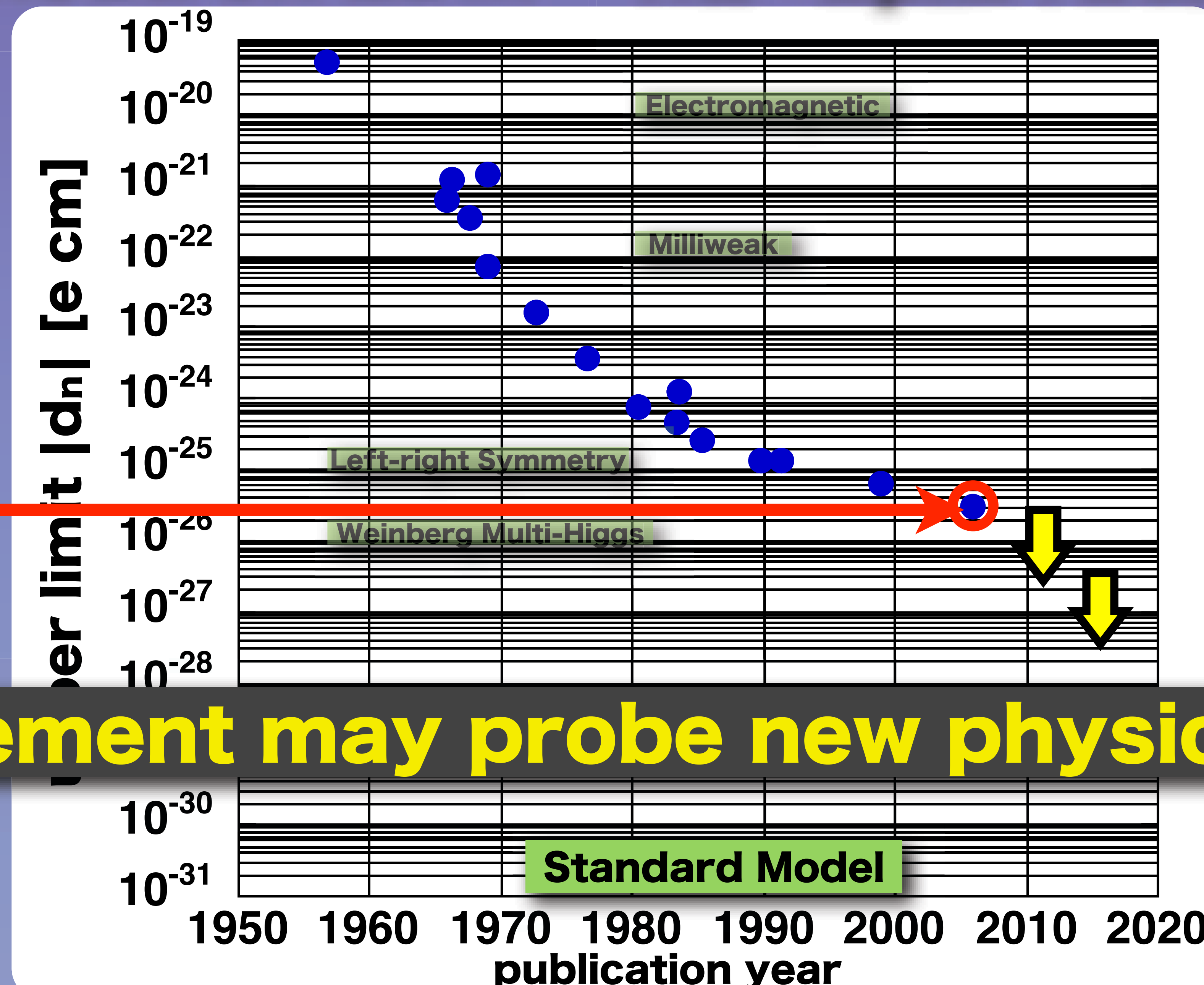
$n\rightarrow p\nu_e\overline{\nu}_e$ $< 8\times10^{-27}$ (68%CL)

Electric Dipole Moment



Electric Dipole Moment

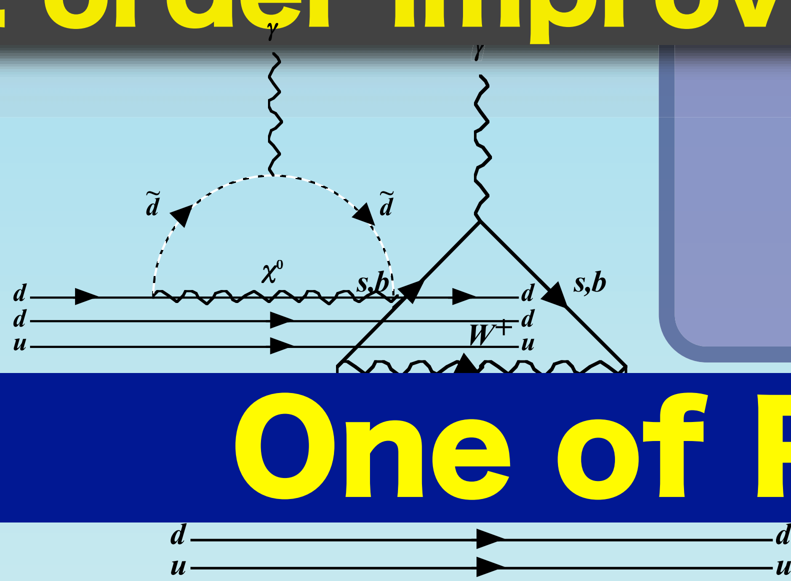
neutron EDM $\hbar\omega = 2\mu_n B + 2 d_n E$



$|d_n| < 2.9\times10^{-26}$ e cm
(90%C.L.)

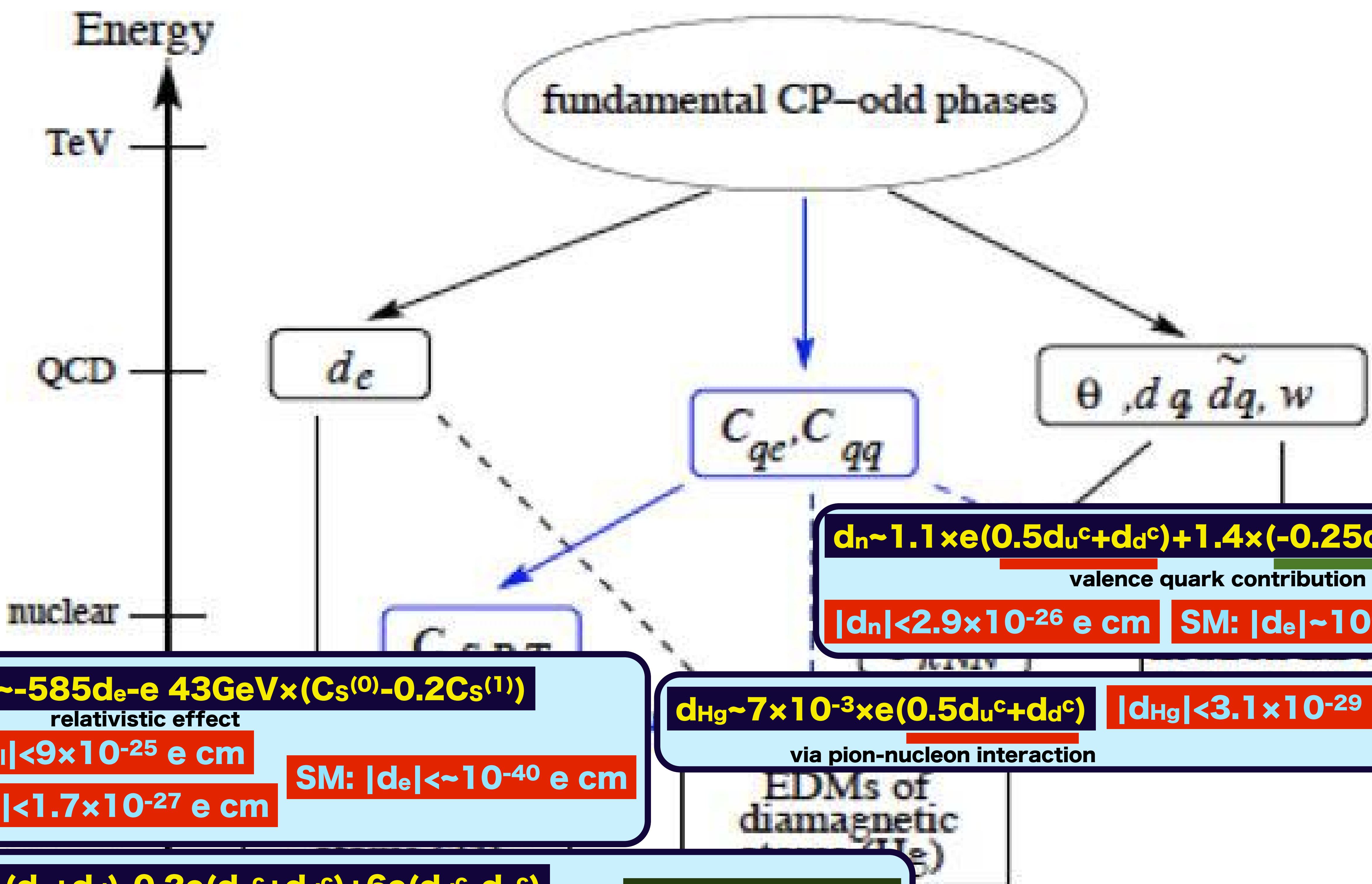
Baker et al., PRL97 (2006)131801

1-2 order improvement may probe new physics



One of Precision Frontiers

TeV→EDM



$d_n \sim 1.1 \times e(0.5 d_u^c + d_d^c) + 1.4 \times (-0.25 d_u + d_d)$

valence quark contribution

$|d_n| < 2.9 \times 10^{-26}$ e cm

SM: $|d_e| \sim 10^{-32}$ e cm

$d_{Tl} \sim -585 d_e - e\ 43\,\mathrm{GeV} \times (C_S^{(0)} - 0.2 C_S^{(1)})$

relativistic effect

$|d_{Tl}| < 9 \times 10^{-25}$ e cm

$|d_e| < 1.7 \times 10^{-27}$ e cm

SM: $|d_e| <\sim 10^{-40}$ e cm

$d_{Hg} \sim 7 \times 10^{-3} \times e(0.5 d_u^c + d_d^c)$

$|d_{Hg}| < 3.1 \times 10^{-29}$ e cm

via pion-nucleon interaction

$d_D \sim (d_u + d_d) - 0.2e(d_u^c + d_d^c) + 6e(d_d^c - d_u^c)$

constituent particle EDMs — pion exchange

$|d_D| \Rightarrow 10^{-29}$ e cm

Measurement Procedure

search for the phase change when the electric field is reversed

$$\frac{\omega_\pm}{2\pi} = 3\times10^{1}\frac{B}{1\mu T} \pm 5\times10^{-8}\frac{d_n}{10^{-26}\text{ e cm}}\frac{E}{10\text{kV/cm}}$$

magnetic electric

$\hbar\omega_+ = 2\mu_n B + 2d_n E$

$$\Delta\phi = \int(\omega_+ - \omega_-)dt = \frac{2d_n ET}{\hbar}$$

$$\Delta d_n = \frac{\hbar/2}{ET\, N^{1/2}}$$

$\hbar\omega_- = 2\mu_n B - 2d_n E$

$ET=10^6$ s kV/cm

$E=10^4$ V/cm, $T=100$s

Confined Ultracold Neutron Spin Precession Freq.

$ET=10^6$ s kV/cm

$E=10^9$ V/cm, $T=1$ms

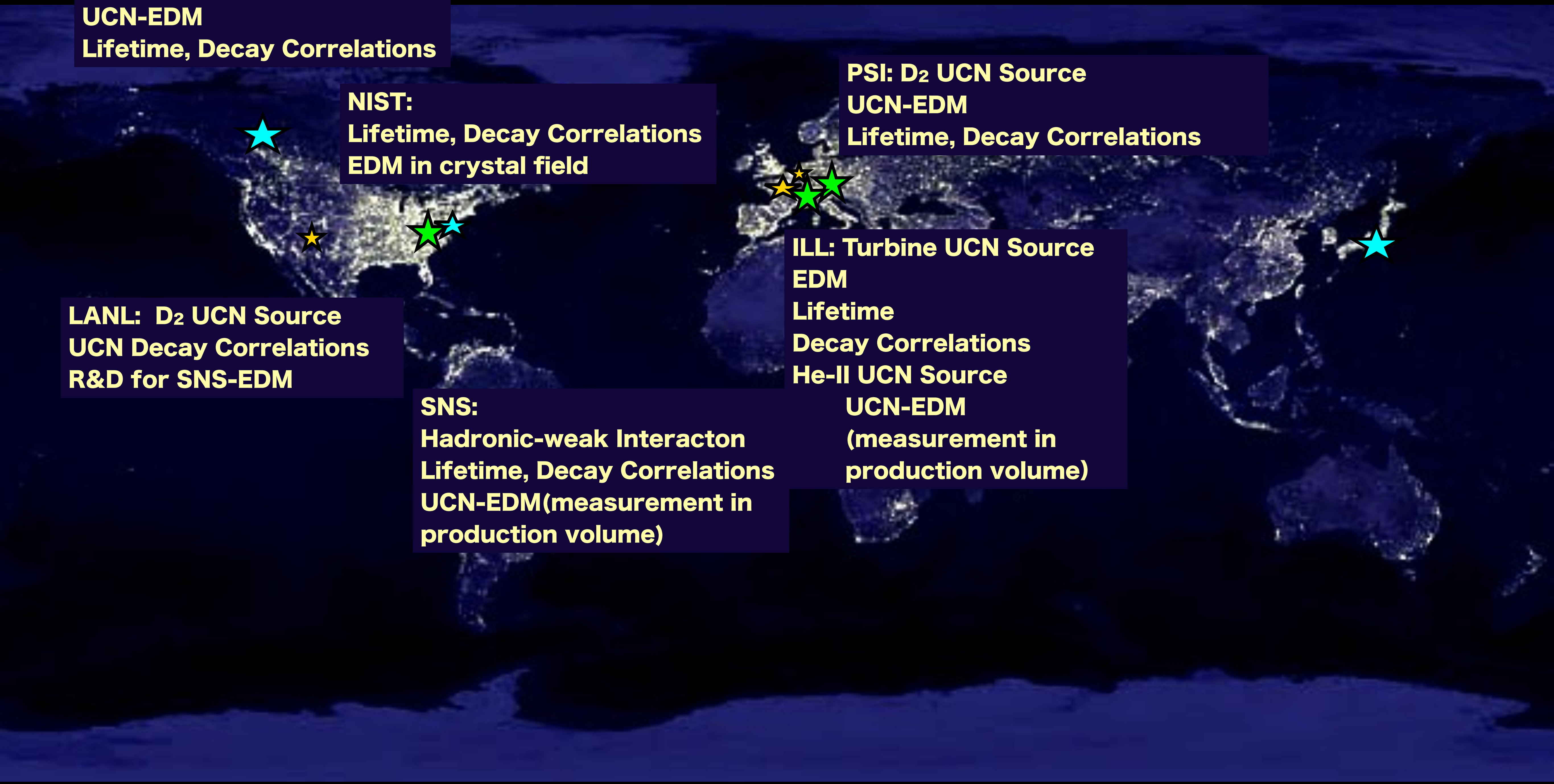
$|d_n| < 2.9\times10^{-26}$ e cm (90%CL)

Cold Neutron Diffraction in Single Crystal

$2d_n E = 6\times10^{-22}$ eV

Statistics	Systematics
larger storage volume	smaller storage volume
faster UCN	slower UCN
denser UCN	

Neutron Fundamental Physics

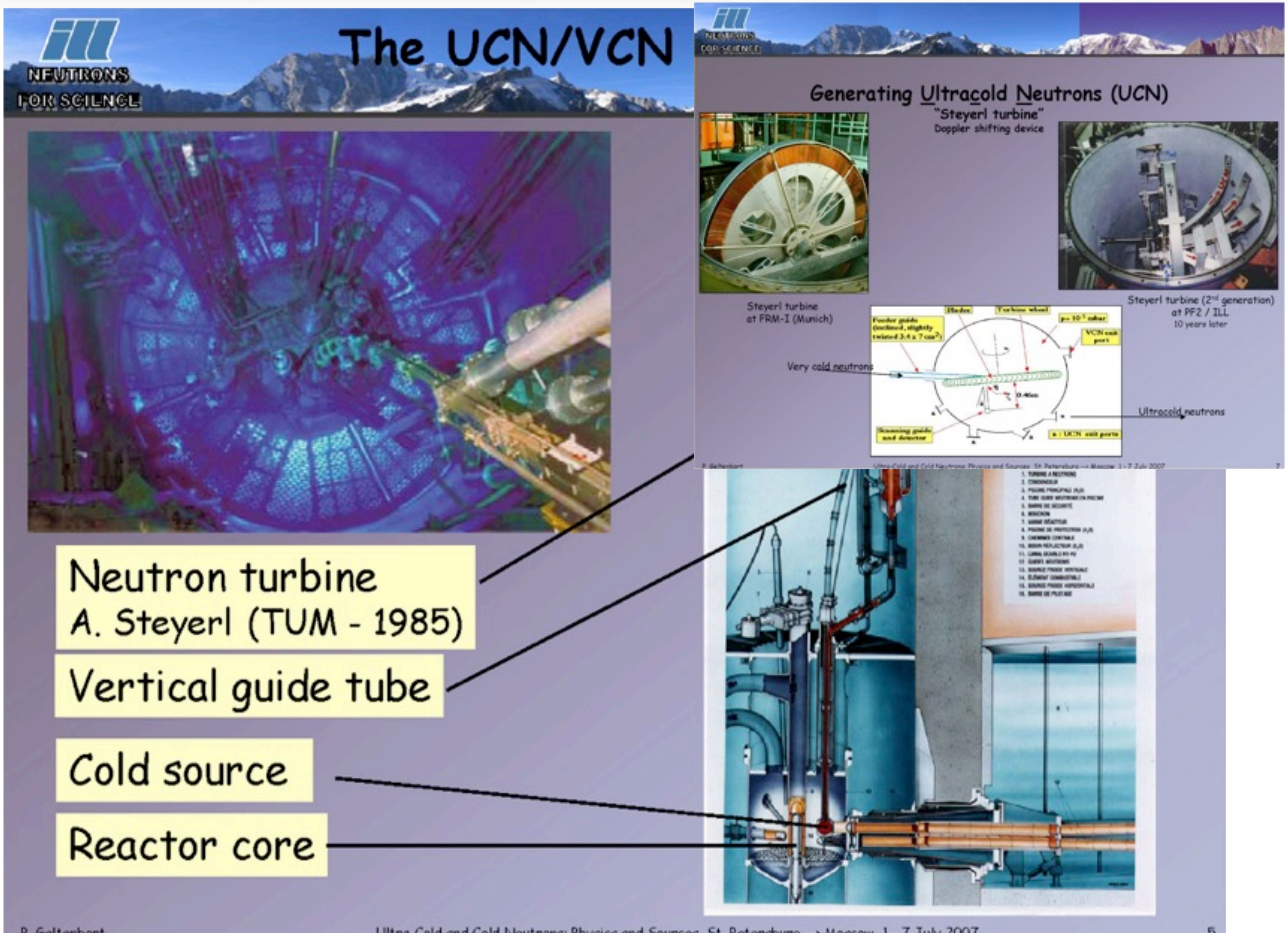


existing UCN facilities - ILL / LANL / Mainz $I \sim 10^1$

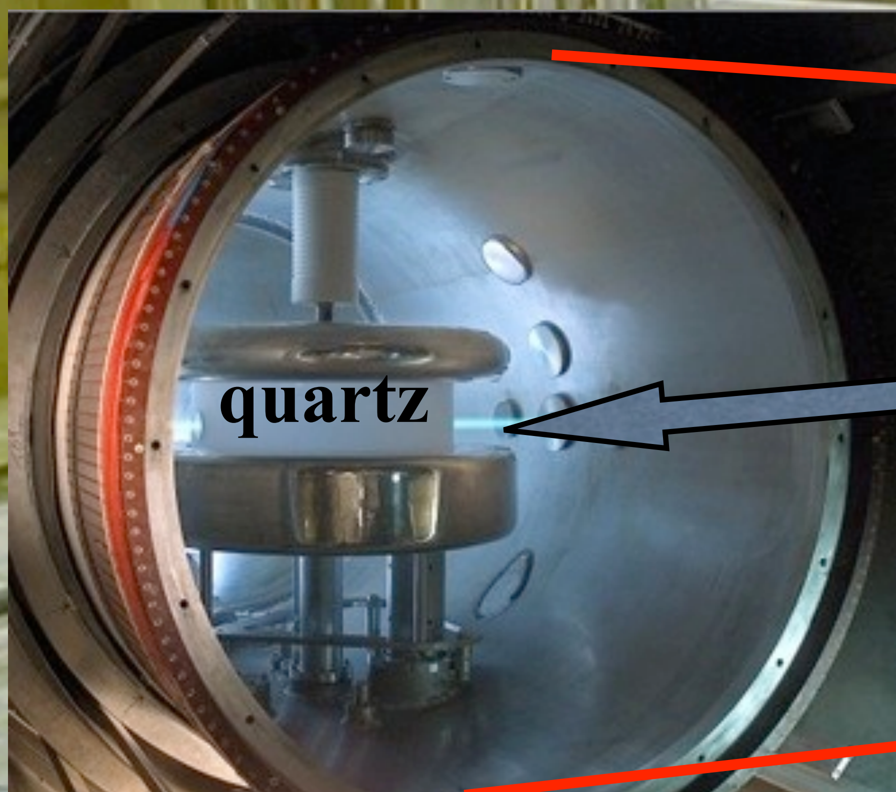
UCN facilities in construction - PSI / SNS / TUM $\sim >10^3$

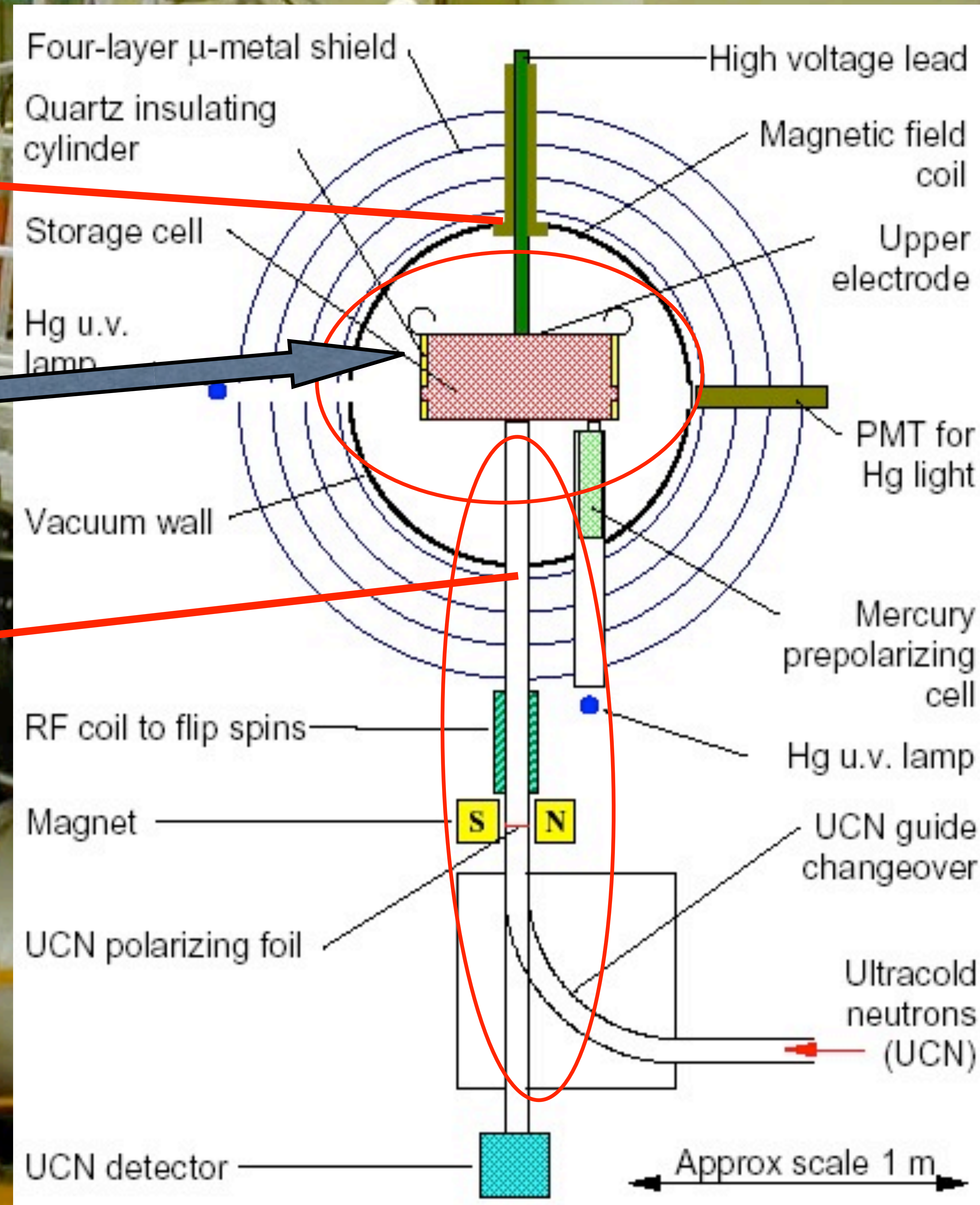
UCN facilities planned - J-PARC / TRIUMF / NCSU

ILL-UCN (~10UCN/cm³) gravity+mechanical turbine



ILL EDM Measurement





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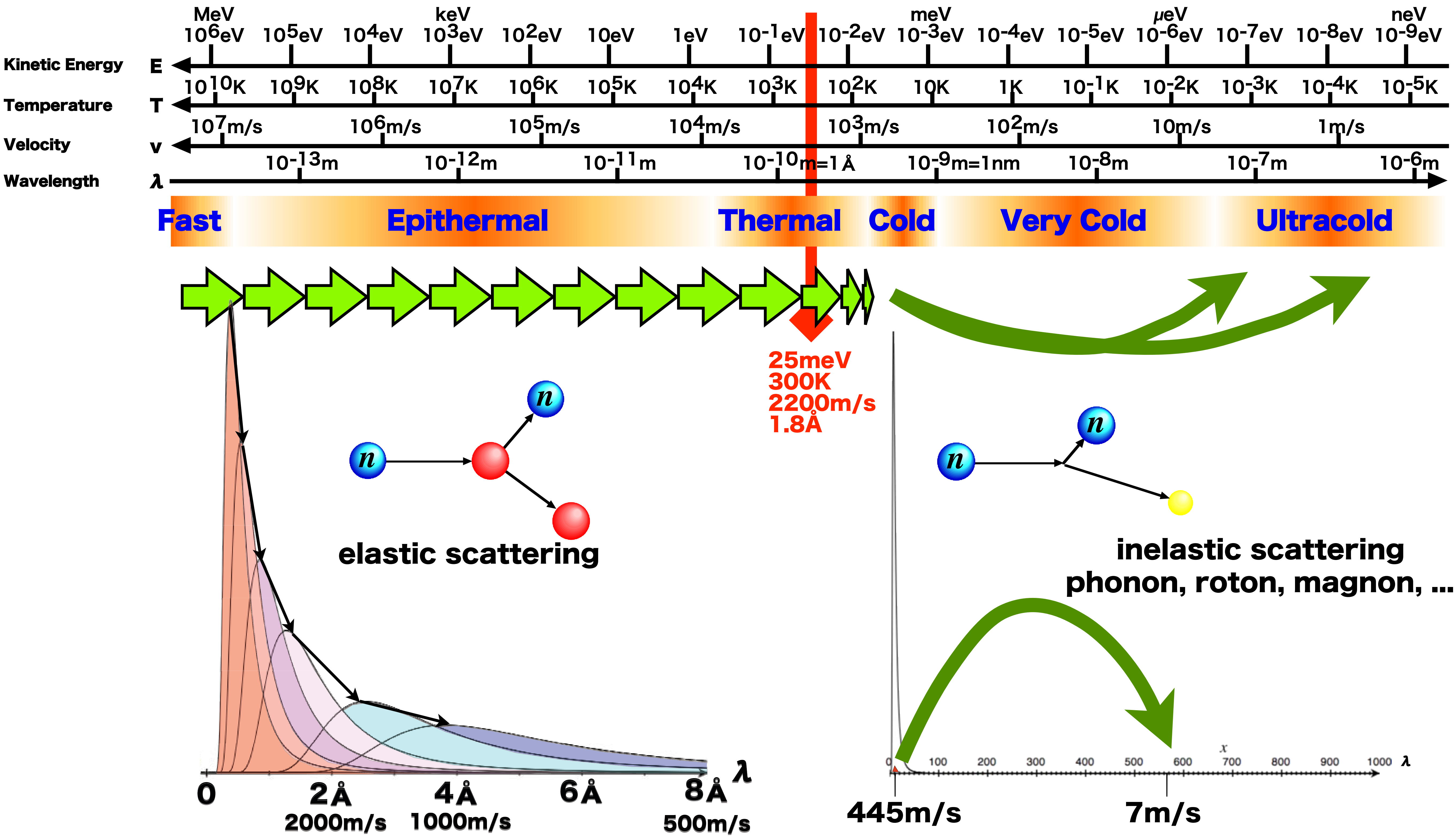
Superthermal UCN Production



Superthermal UCN Converters

C.-Y.Liu, Dissertation, Princeton Univ. (2002)

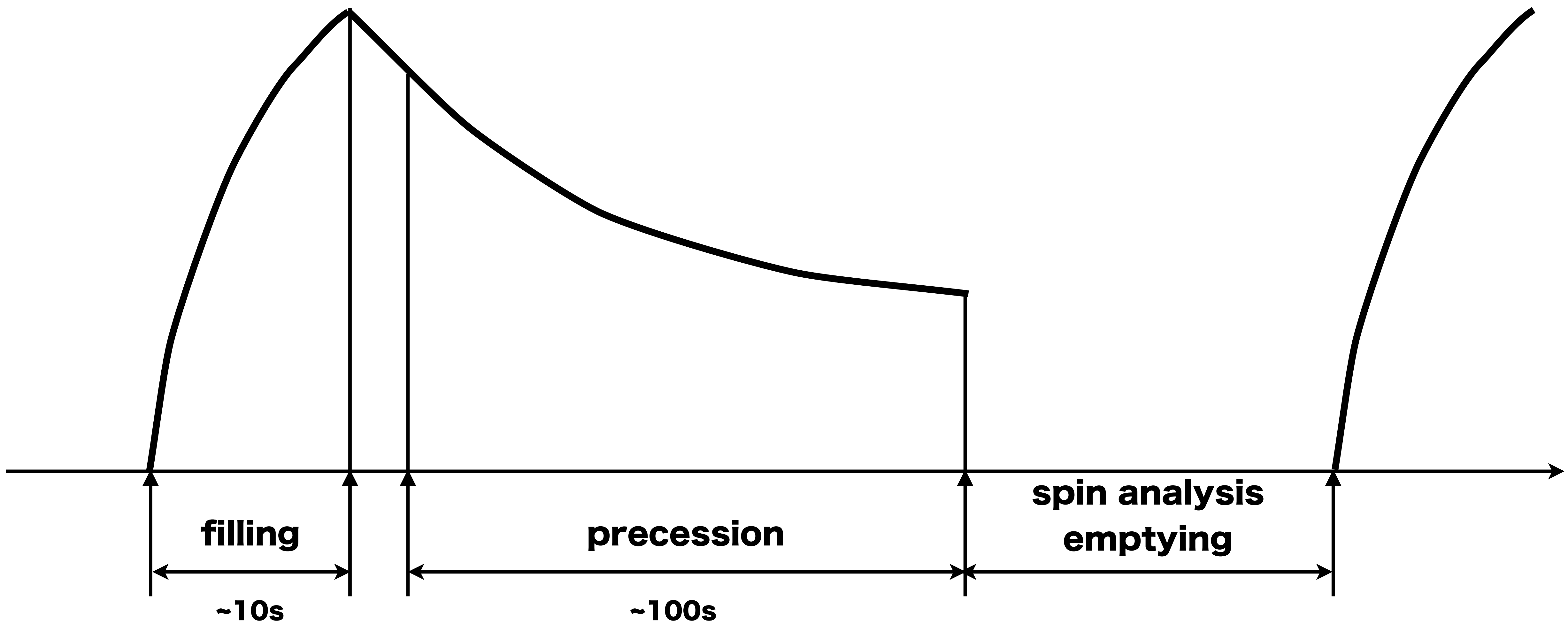
converter	He-II	Solid ortho-D_2	α-O_2
interaction	phonon	phonon	magnon?
converter temperature	0.7K	5K	2K
optimal neutron temperature	9K	29K	12K
production rate (30K neutrons)	$90\times10^{-11}\Phi_0$ cm^{-3} s^{-1}	$1300\times10^{-11}\Phi_0$ cm^{-3} s^{-1}	$\sim1000\times10^{-11}\Phi_0$ cm^{-3} s^{-1}
ideal lifetime (no wall loss, no upscattering)	886 s	146 ms	489 ms

low loss large production rate

$\rho_{UCN}=10^{-11}\Phi_0$

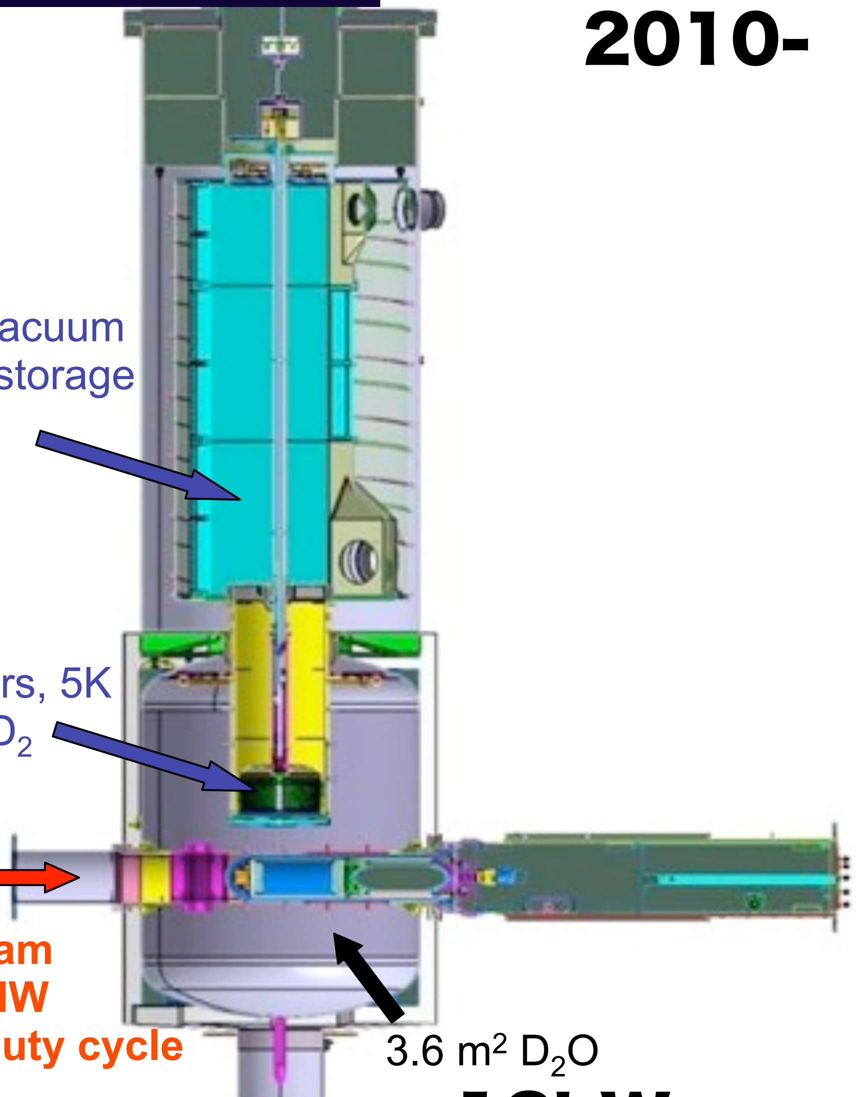
(thermal moderator)

Measurement Procedure



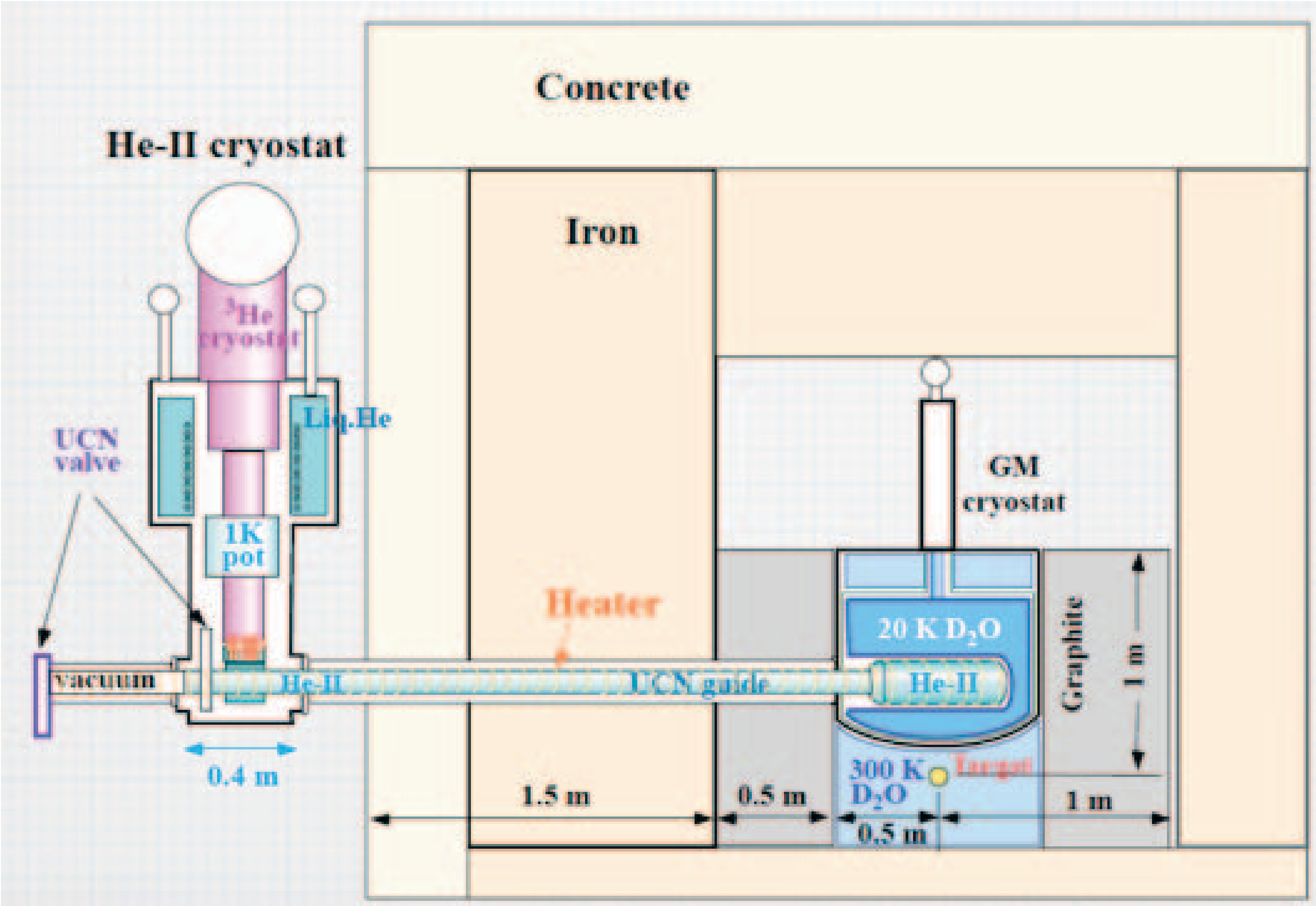
UCN Sources (Accelerator+Spallation)

PSI high power 2010-



average = 13kW
max. peak power = 1.3MW

TRIUMF low loss 2013-?

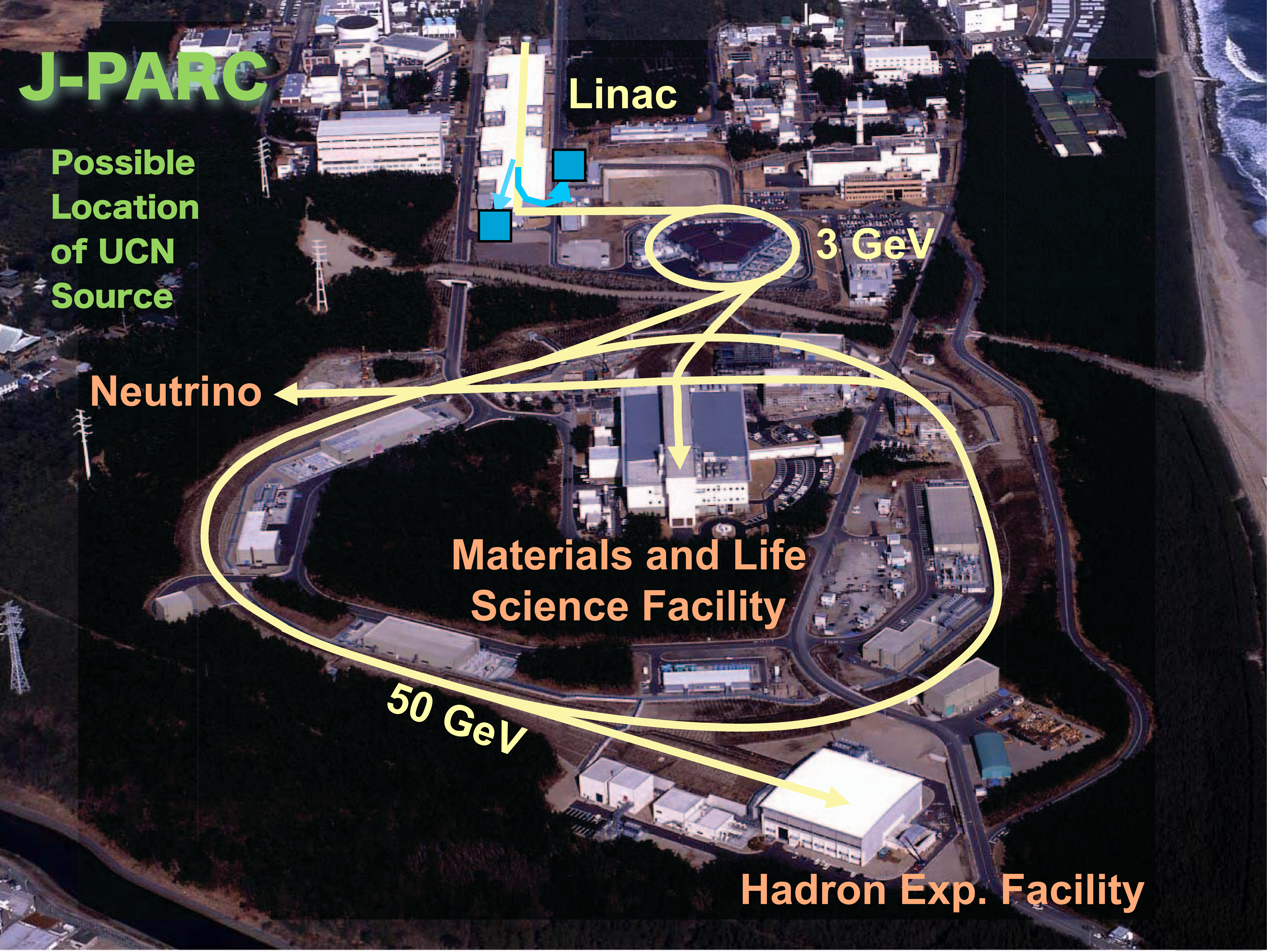


average=20kW
max. peak power = 200kW

J-PARC P33

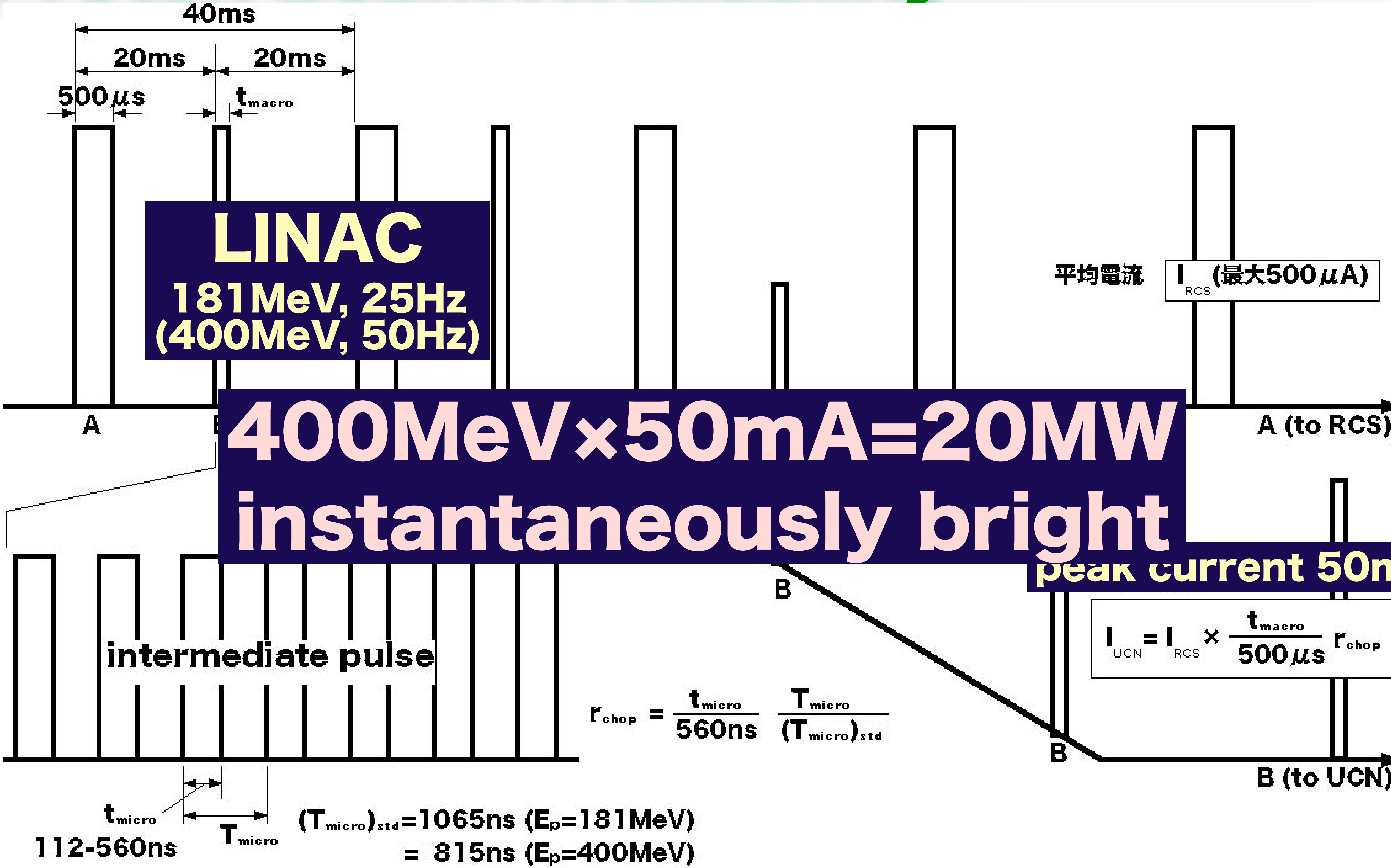
instantaneous power + transport optics

average = 2kW
max. peak power = 20MW


J-PARC
Linac
Possible Location of UCN Source
3 GeV
Neutrino
Materials and Life Science Facility
50 GeV
Hadron Exp. Facility

arXiv:0907.0515[physics.ins-det

Proton Beam Availability



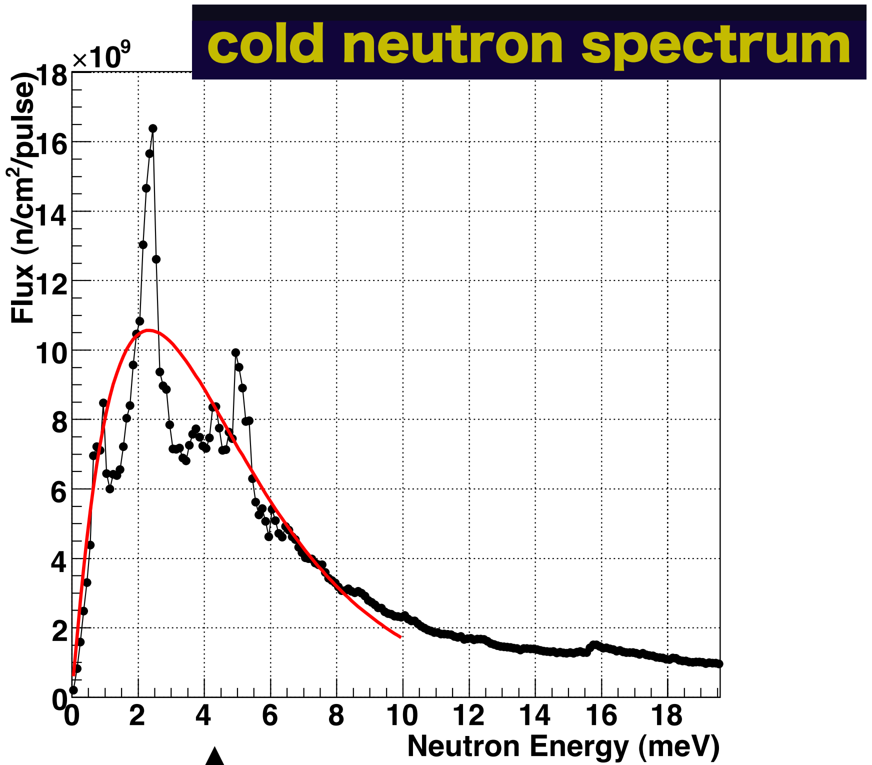
LINAC
181MeV, 25Hz
(400MeV, 50Hz)

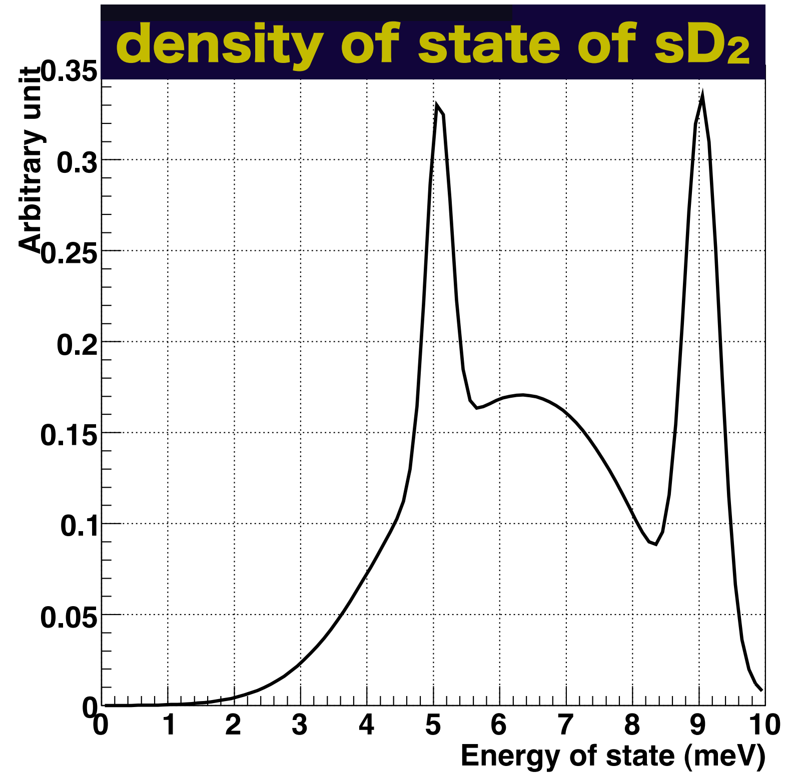
400MeV×50mA=20MW
instantaneously bright

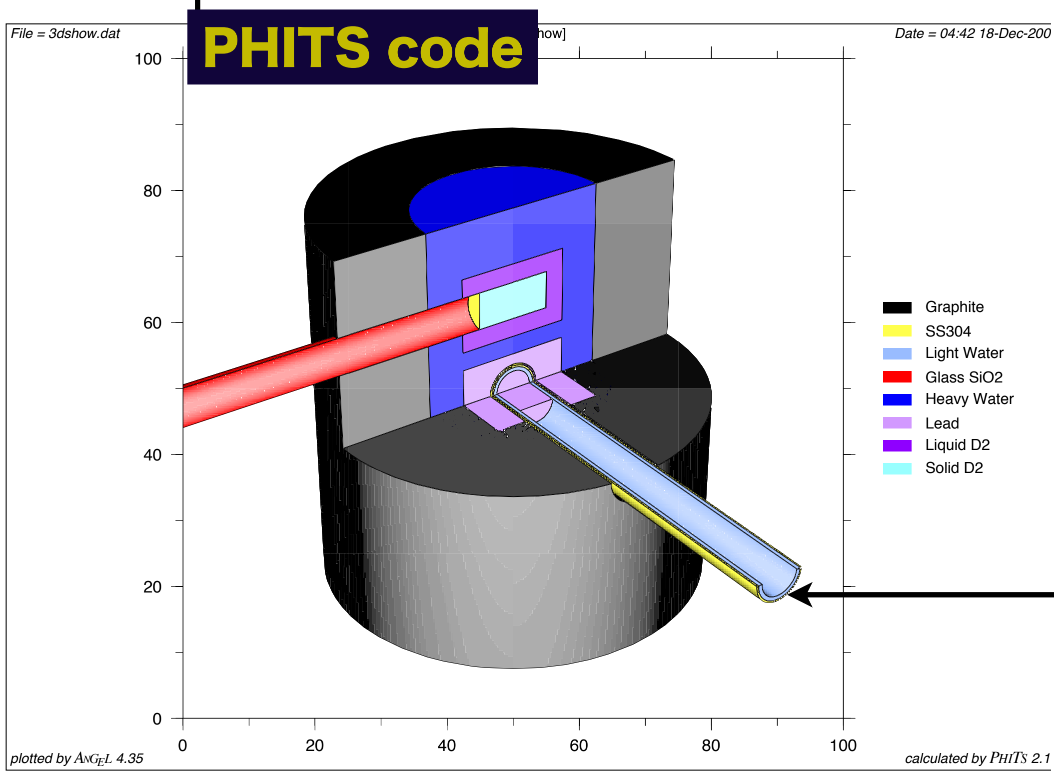
peak current 50mA

maximum 250kW (400MeV) is available
for 2nd Target Station, Nuclear Transmutation and UCN

Solid D_2 Converter







UCN density in the converter

6200 cm^{-3} $pulse^{-1}$

J-PARC LINAC

proton 400MeV

t_{pulse}=0.5ms I_{peak}=50mA

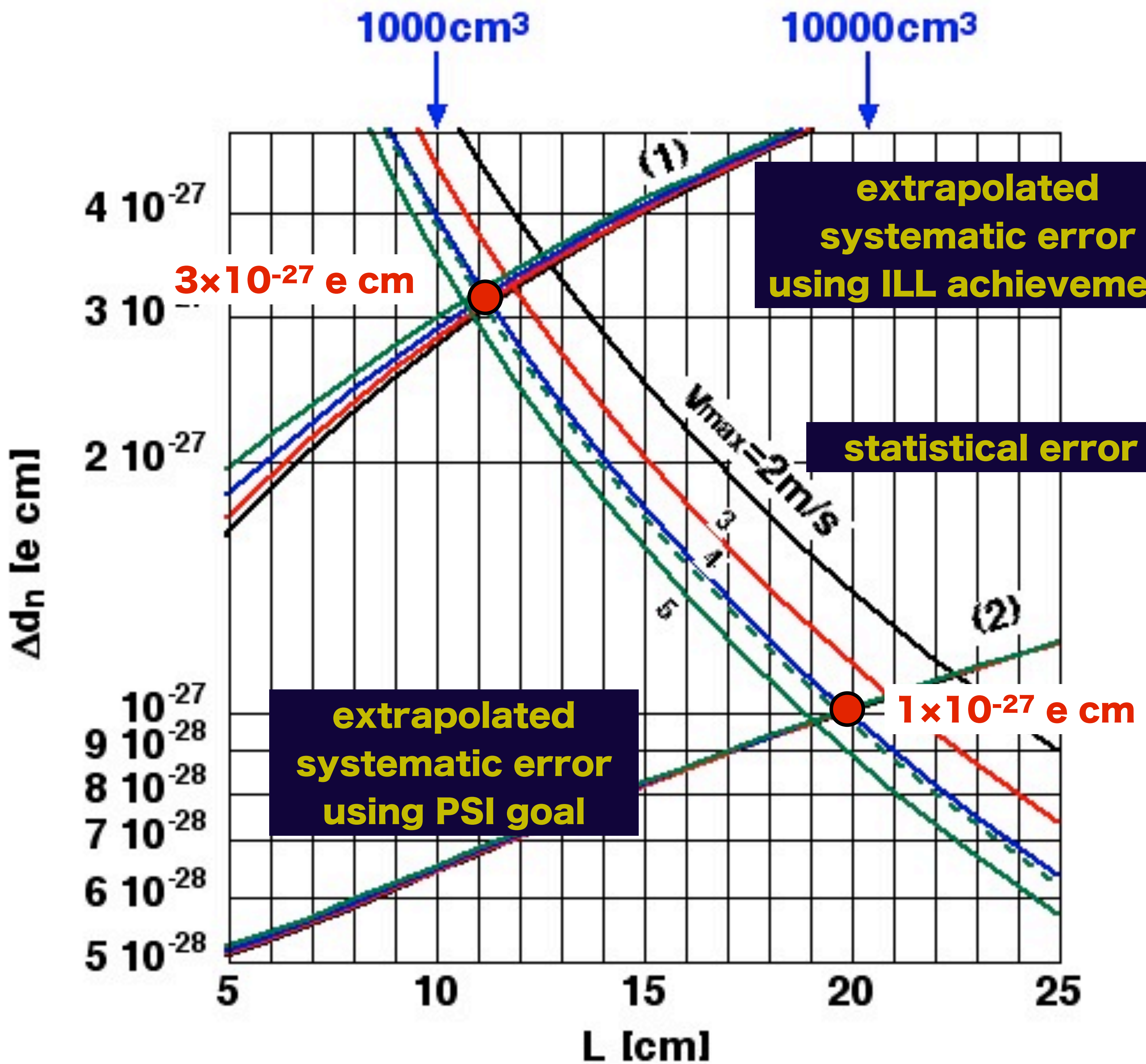
(10 kJ $pulse^{-1}$)

Experimental Errors

$\rho_0 = 6200\ cm^{-3}$

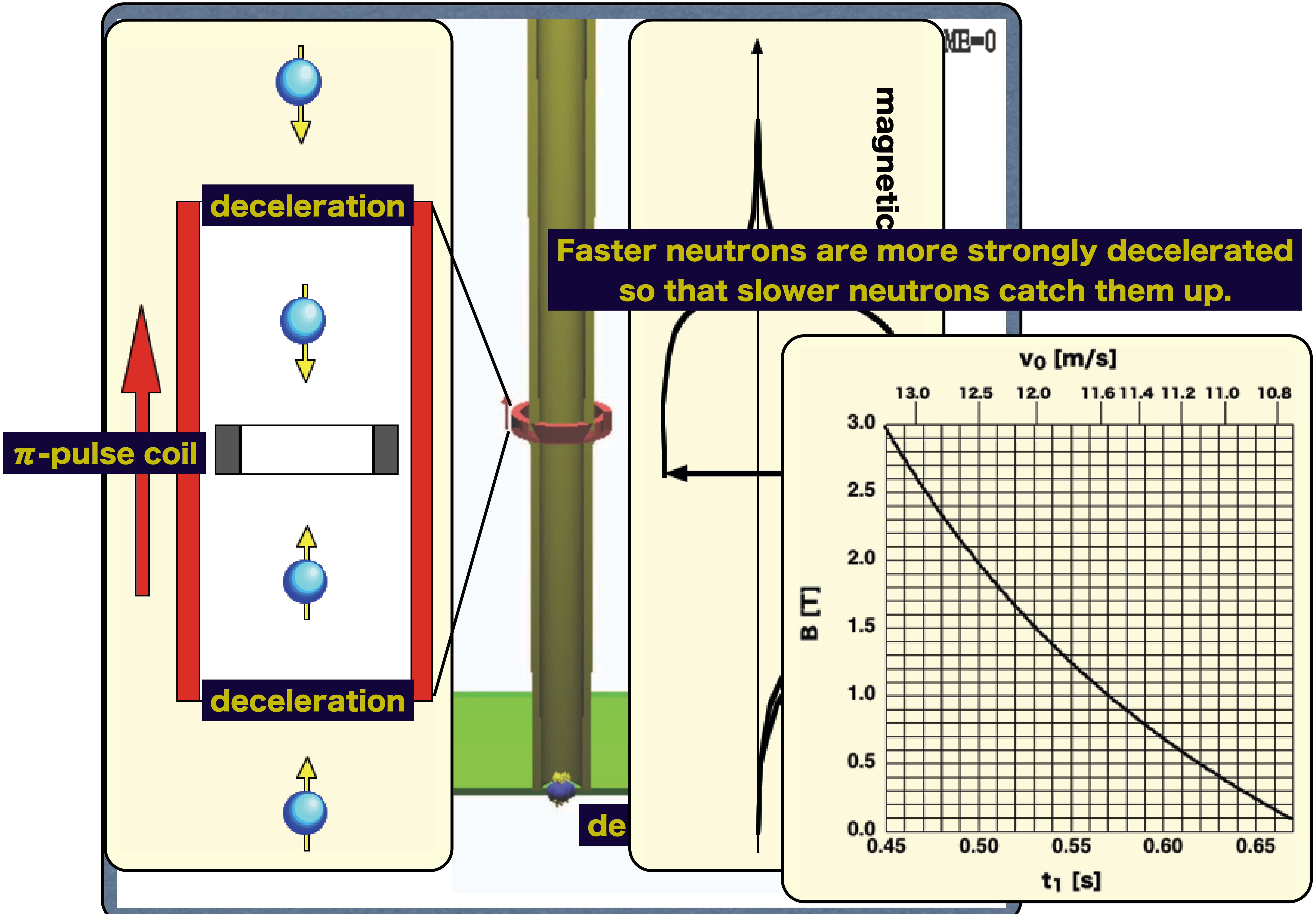
5000h

T=150s

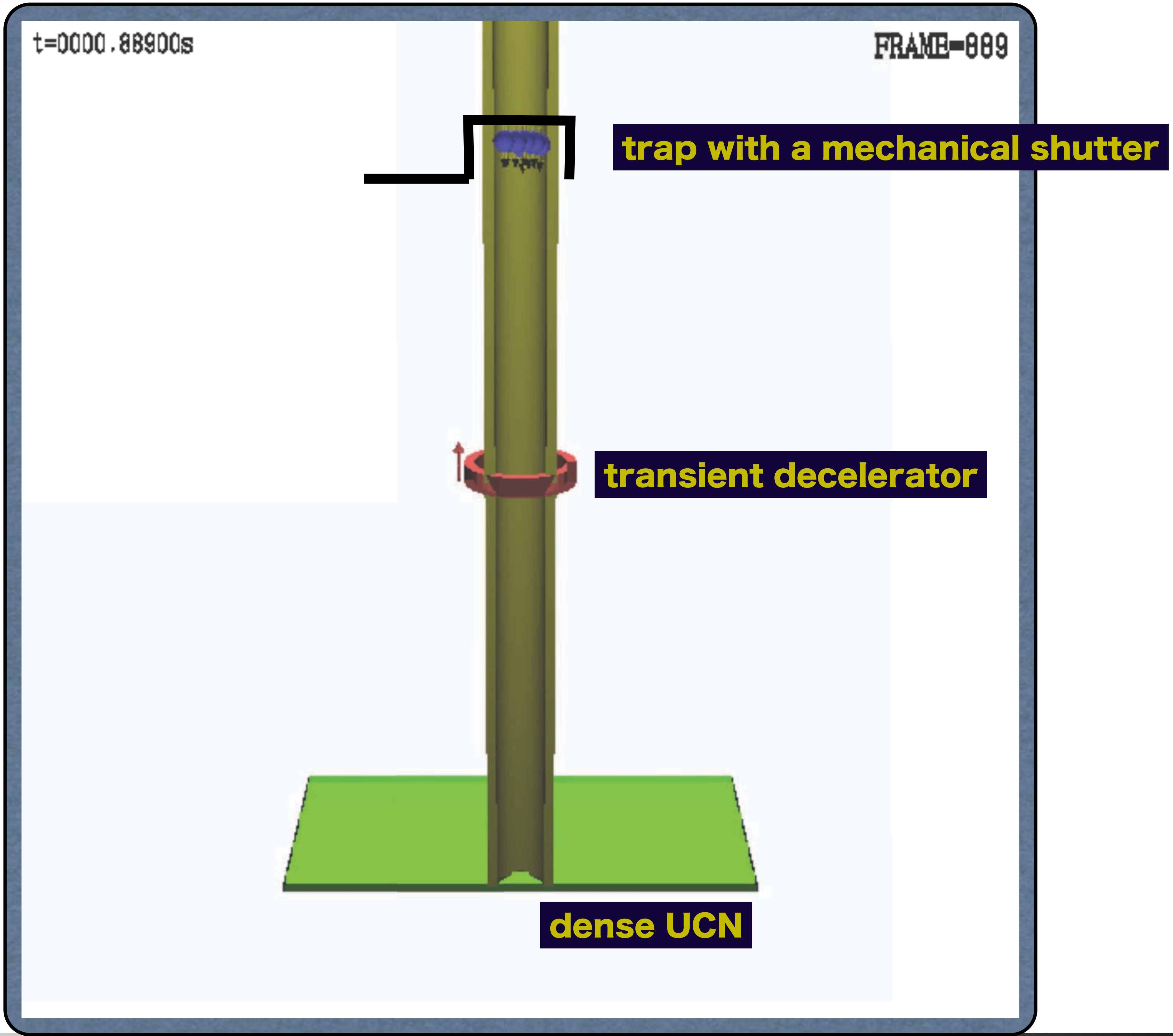


cell size

UCN Rebuncher



UCN Rebuncher



Experimental Errors

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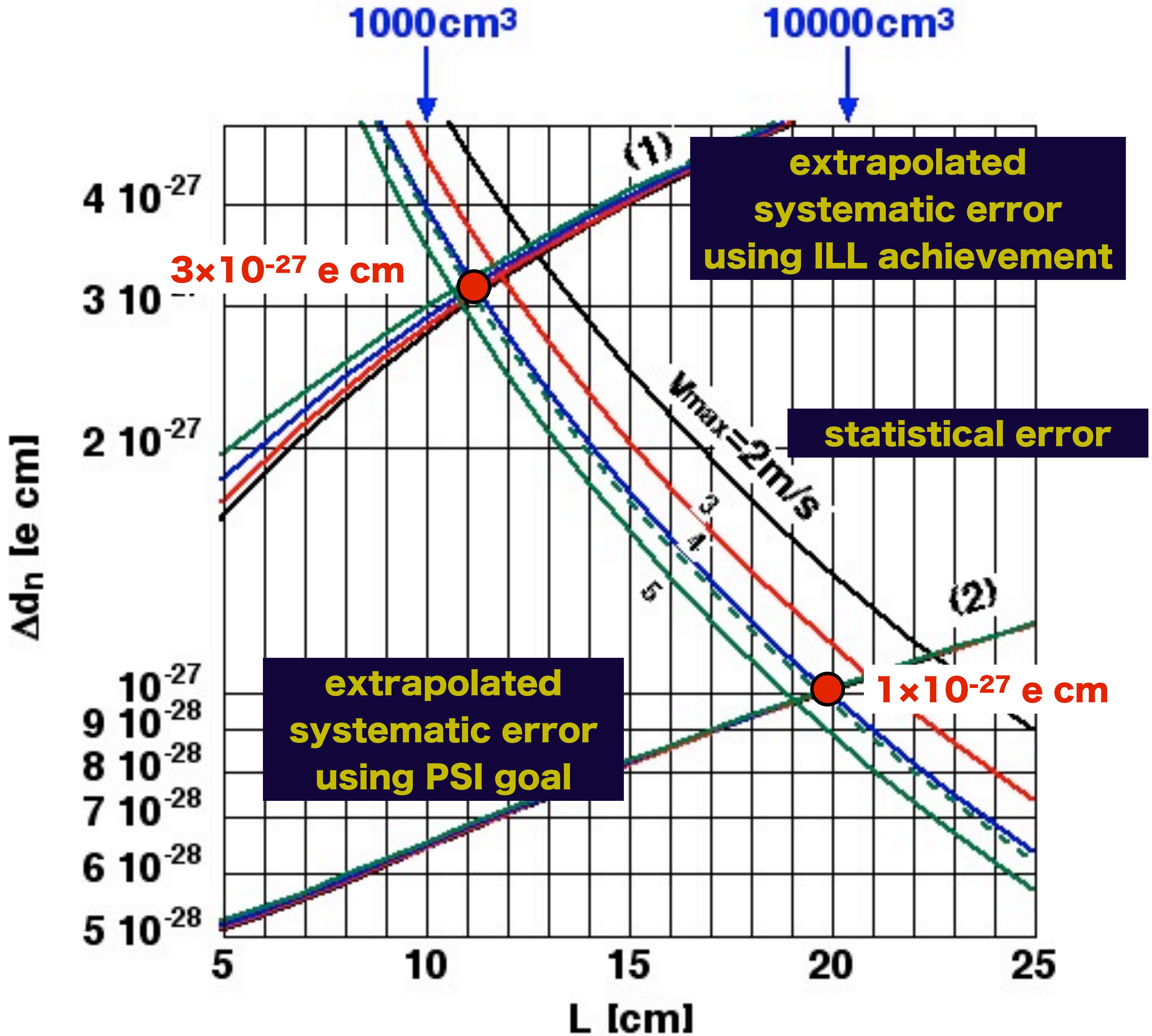
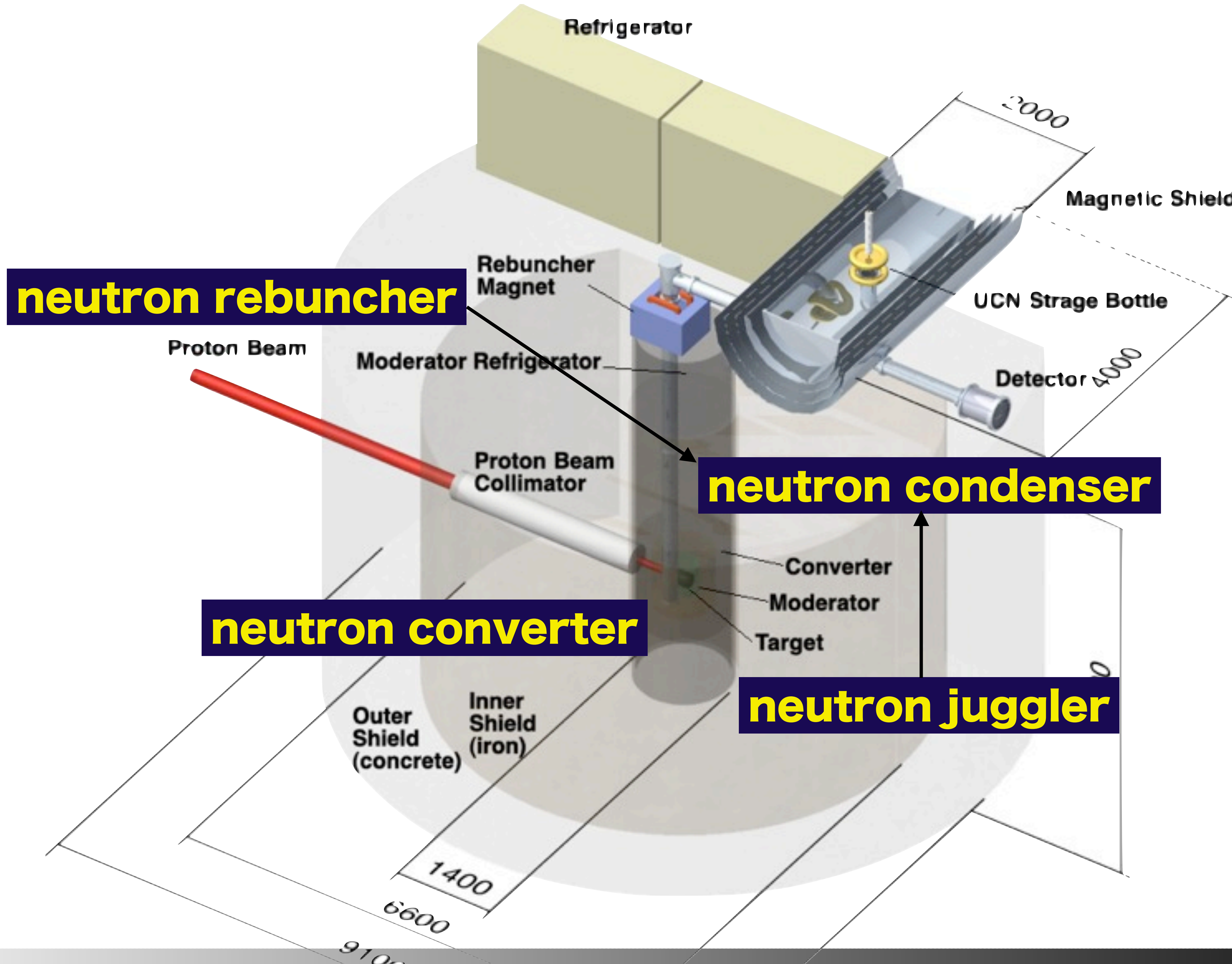


cell size

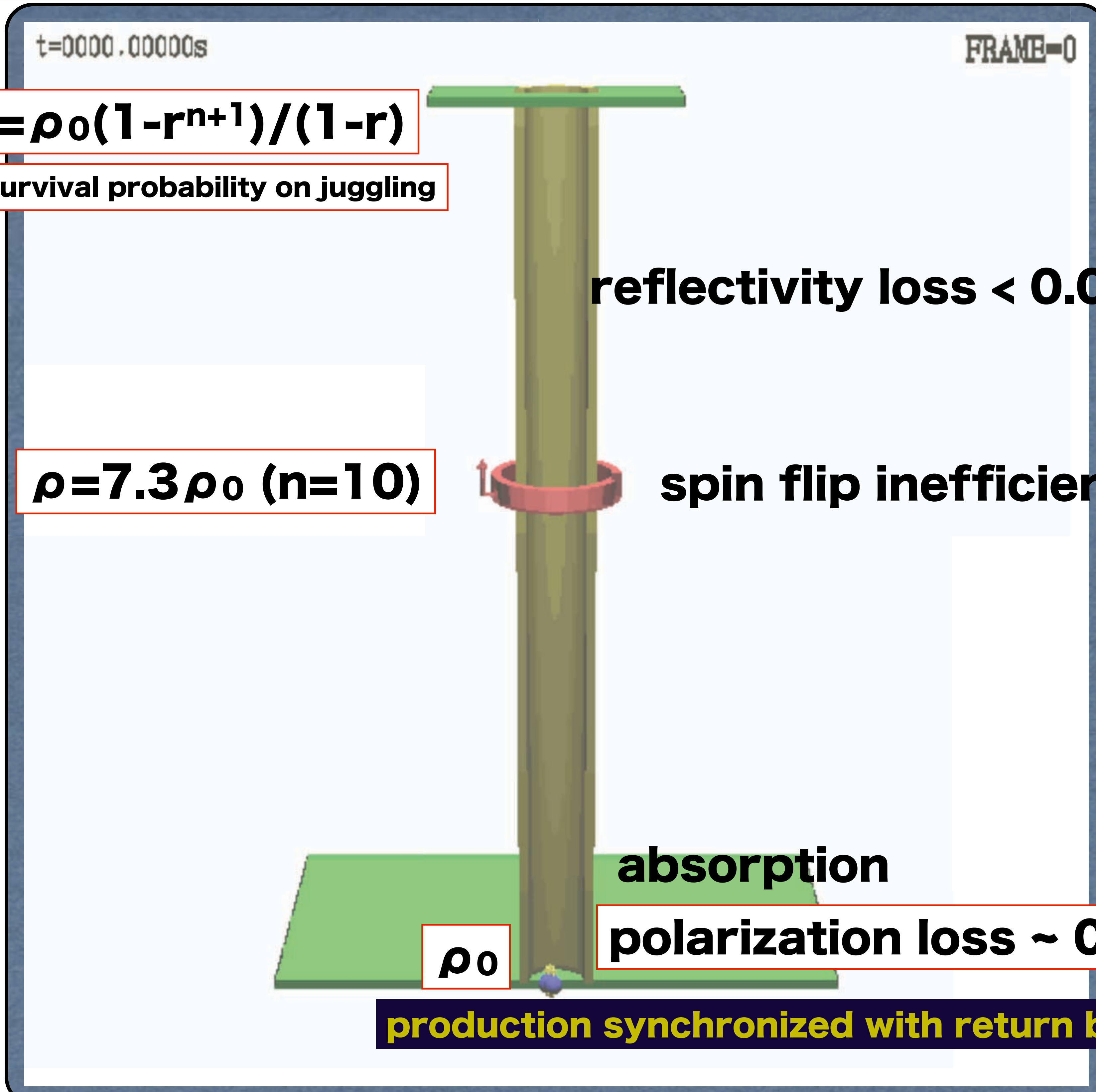
J-PARC P33: J-PARC UCN for $|d_n|<10^{-27}$ e cm

for the study of new physics with the improved experimental accuracy by the optically controlled transport of pulsed ultracold neutrons to the measurement cell.



UCN Condenser

Pulsed Source+Rebuncher+Juggler



$\rho=\rho_0(1-r^{n+1})/(1-r)$

r=survival probability on juggling

reflectivity loss < 0.01

$\rho=7.3\rho_0$ (n=10)

spin flip inefficiency < 0.01

absorption

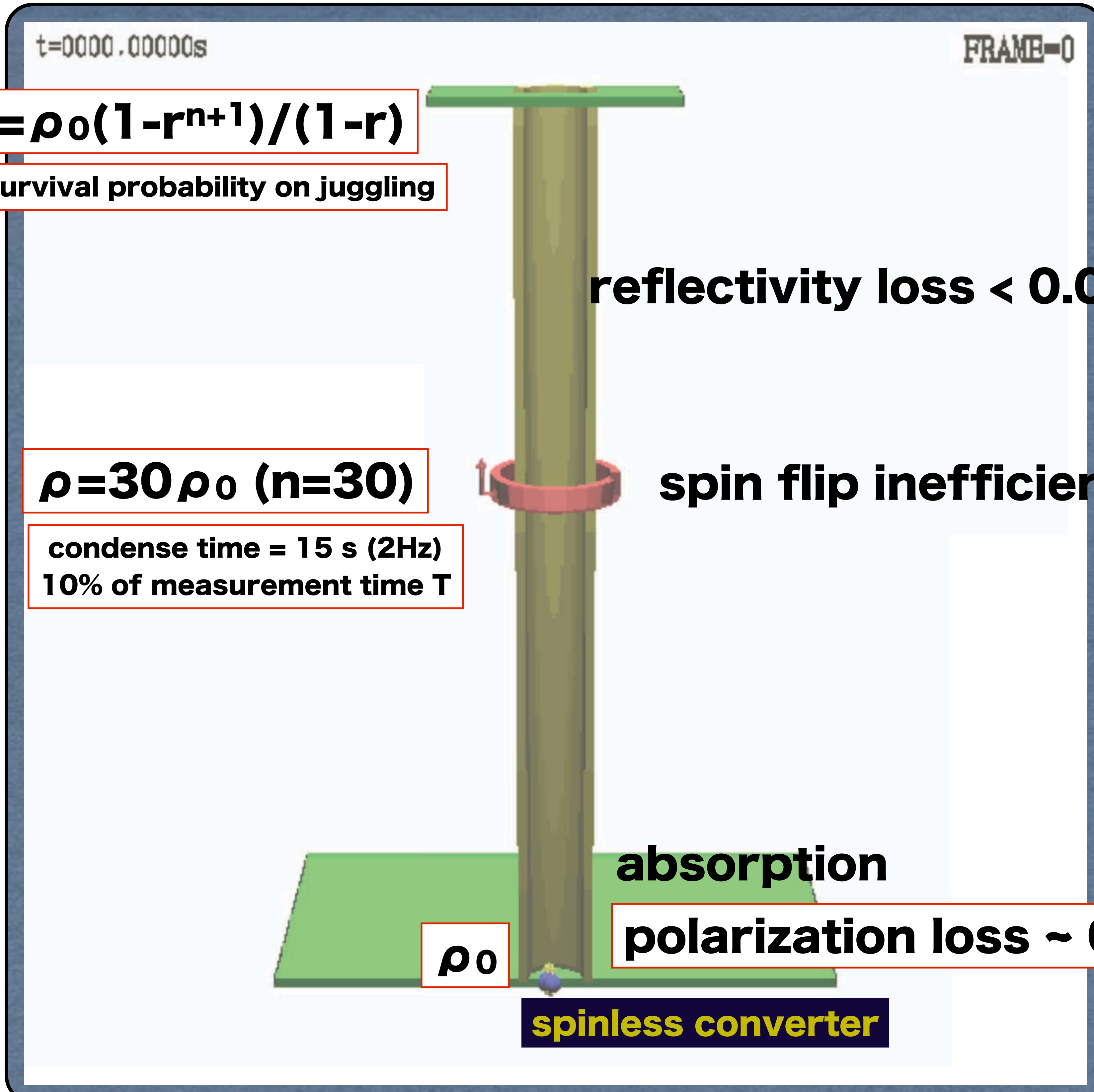
polarization loss ~ 0.13 (1cm D_2)

ρ_0

production synchronized with return back

UCN Condenser

Pulsed Source+Rebuncher+Juggler



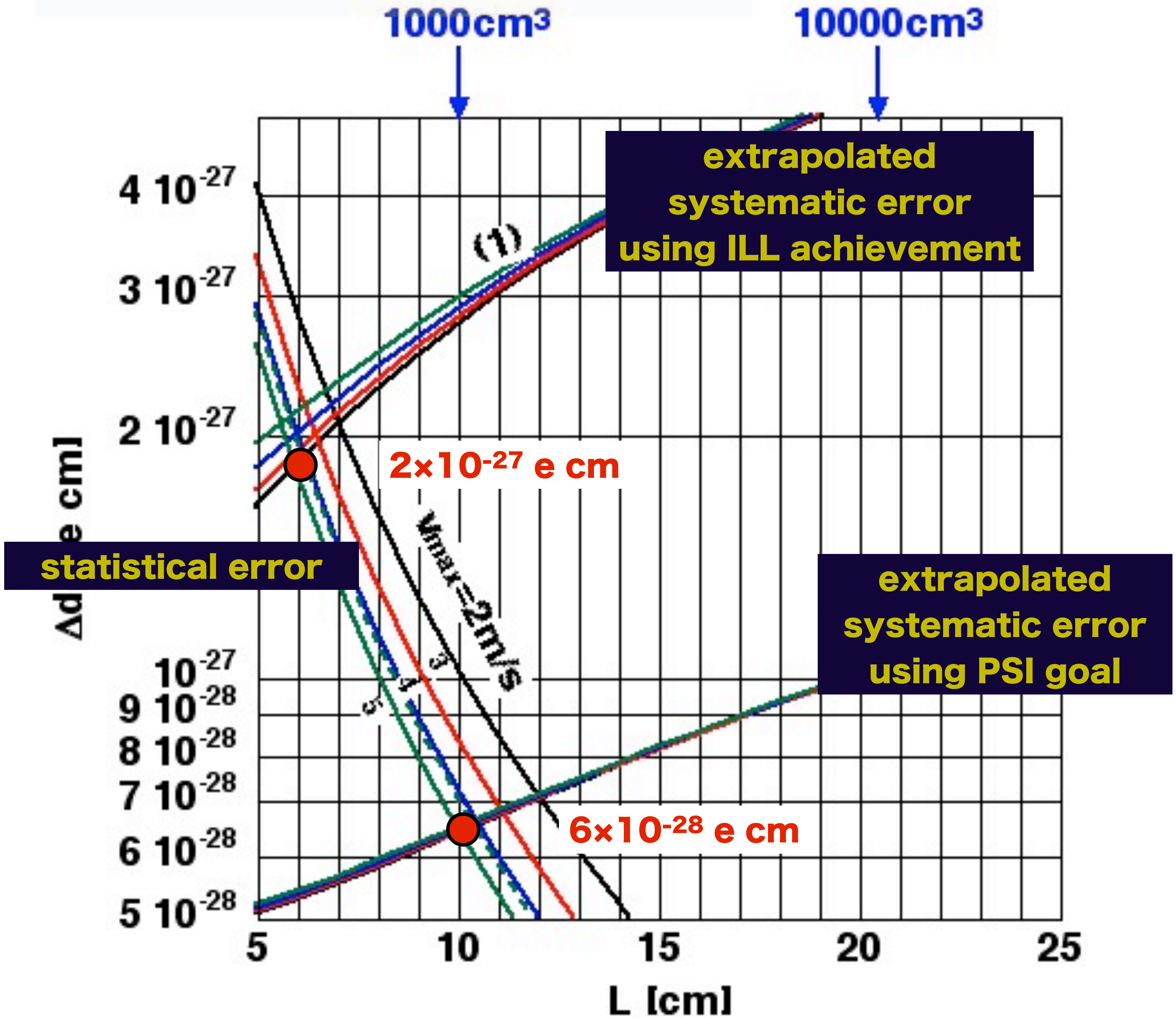
$$\rho = \rho_0 (1 - r^{n+1})/(1 - r)$$

Experimental Errors

$\rho_0 = 93000\ cm^{-3}$

5000h

T=150s



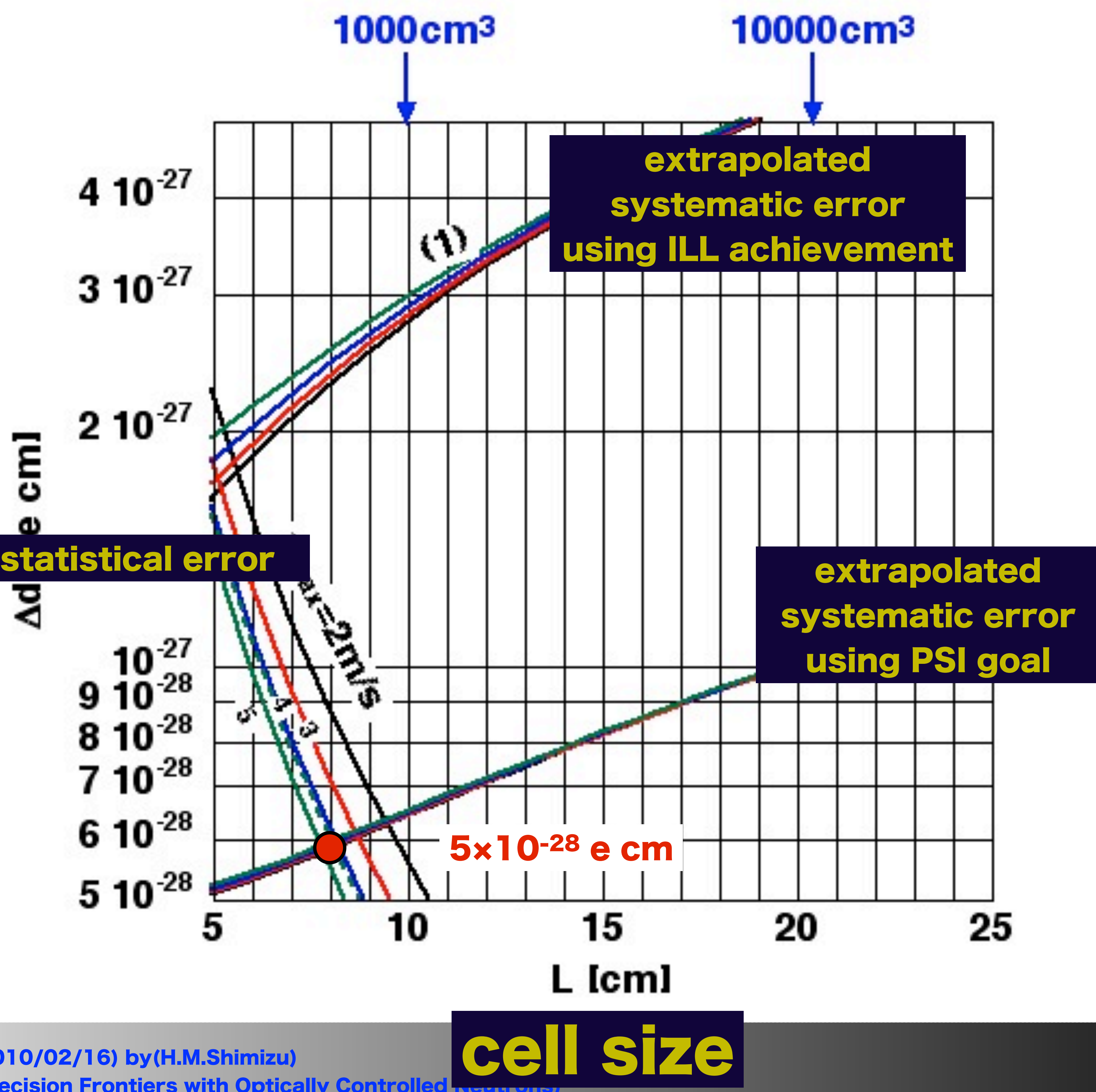
cell size

Experimental Errors

ρ_0 = 620000 cm^{-3}

5000h

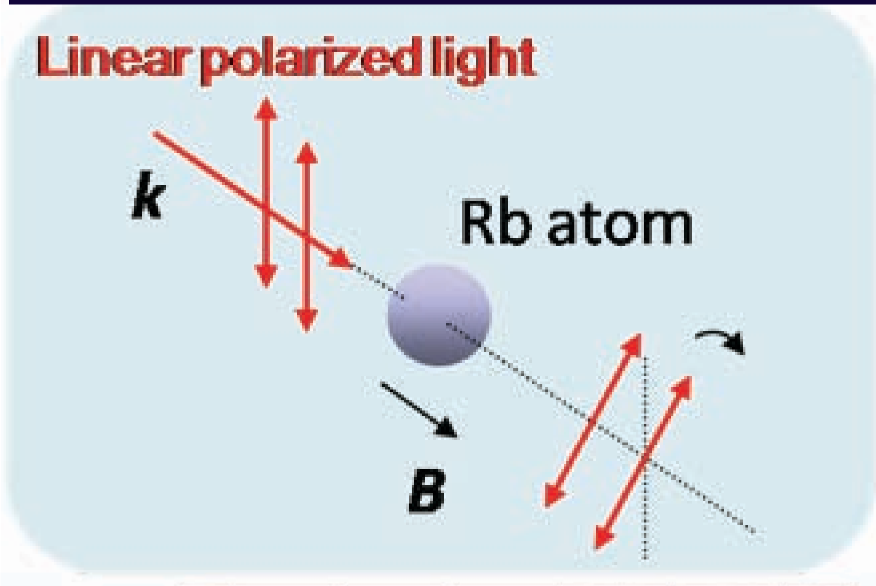
T=150s

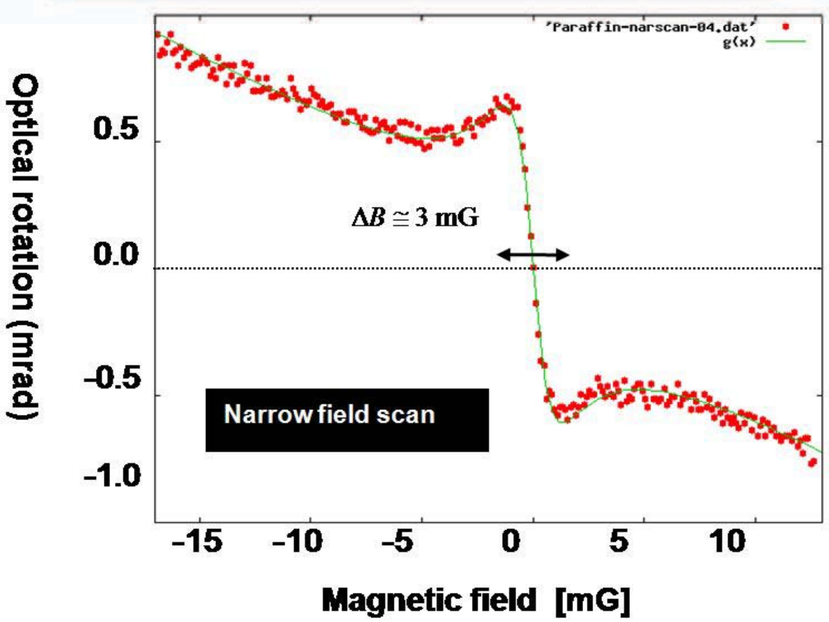


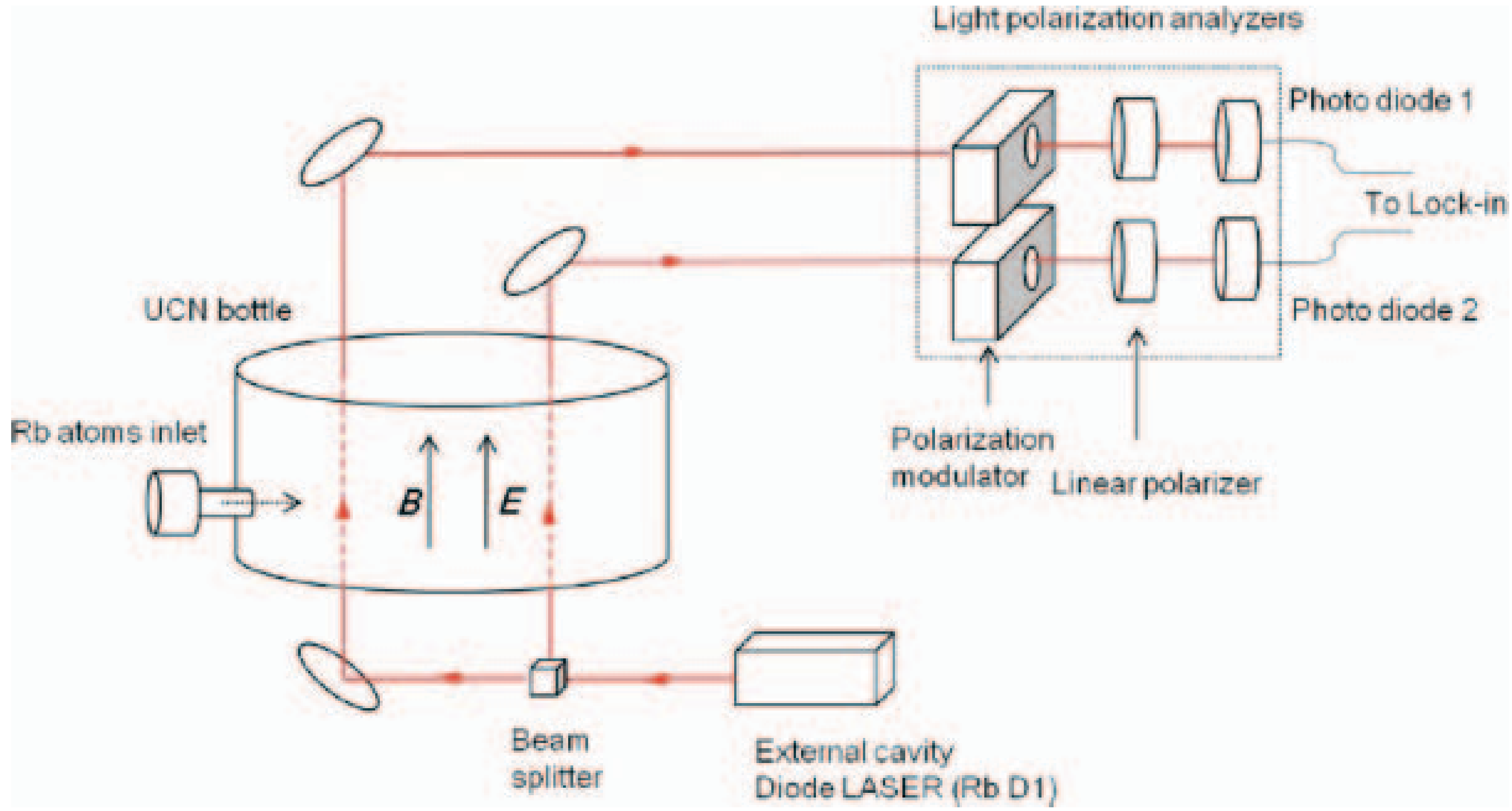
Magnetometry

Hg magnetometer	100fT
Cs magnetometer	3fT
^{3}He magnetometer	1fT
SQUID magnetometer	80aT/Hz$^{1/2}$ requires low temperature

Rb NMOR magnetometer (Nonlinear Magneto-Optical Rotation)







300aT/Hz$^{1/2}$

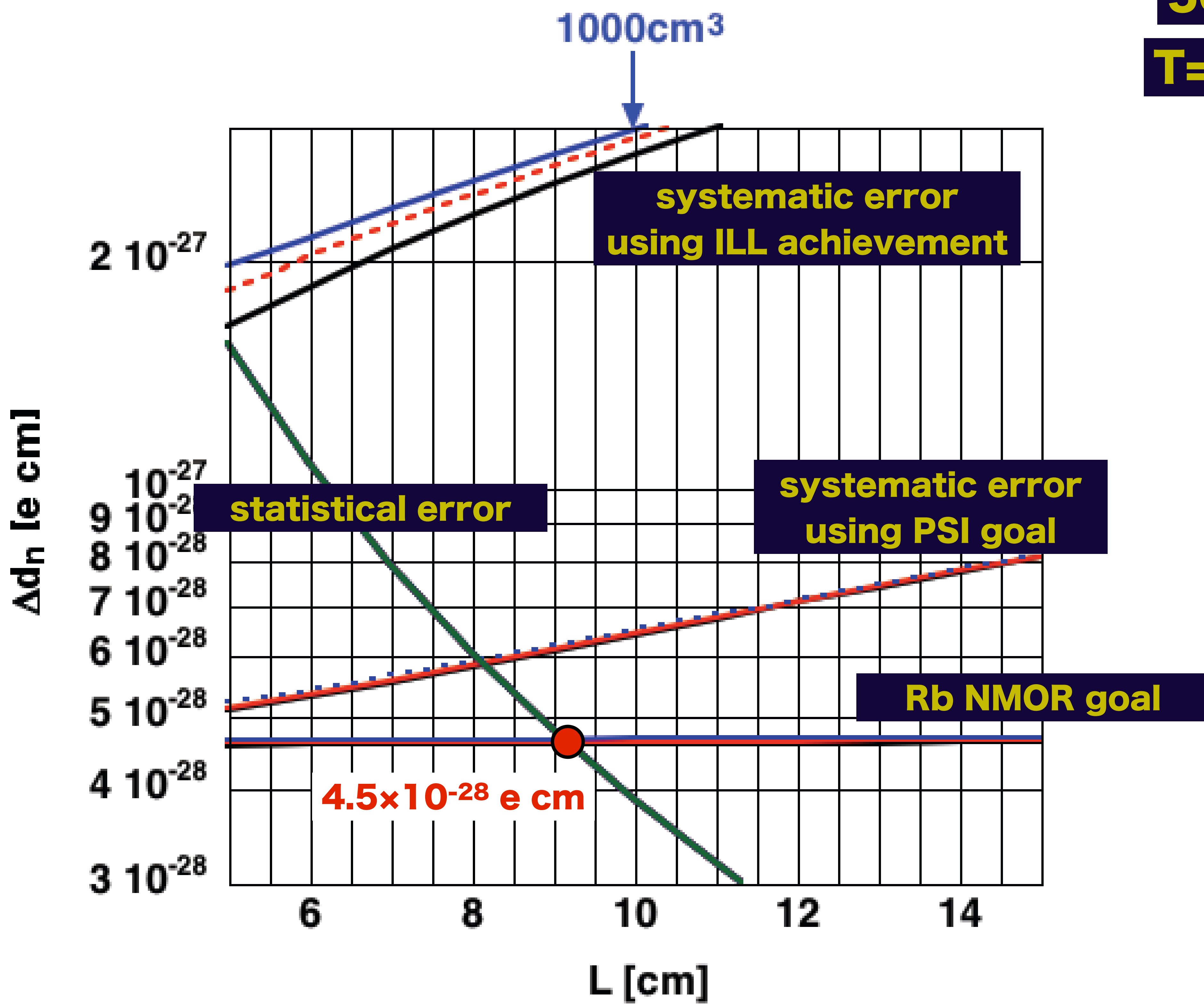
100aT @ 0.1-0.01Hz

Experimental Error

$\rho_0 = 620000\ cm^{-3}$

5000h

T=150s

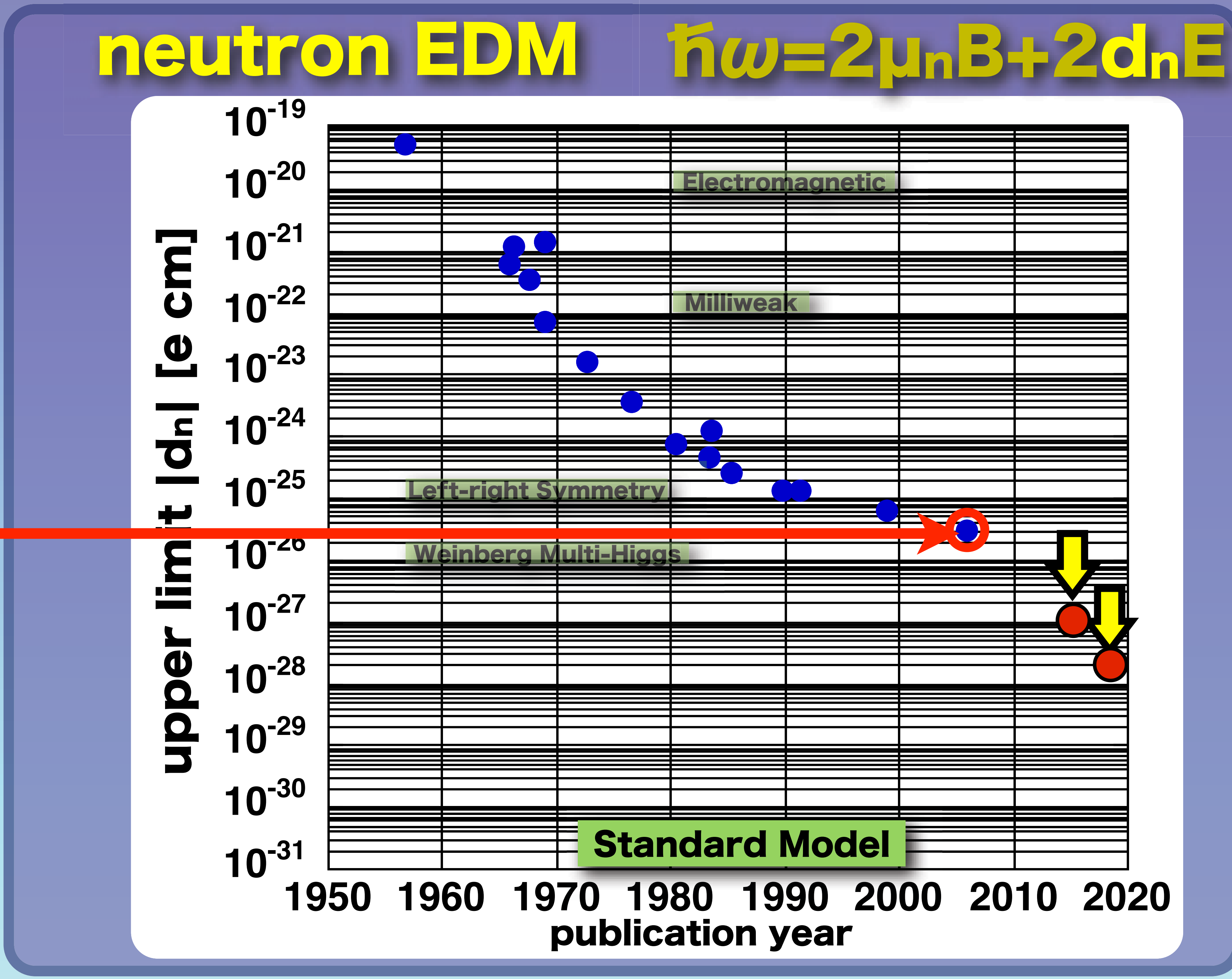


cell size

Electric Dipole Moment

$|d_n| < 2.9 \times 10^{-26}$ e cm
(90%C.L.)

Baker et al., PRL97 (2006)131801



Neutron Fundamental Physics

lifetime

medium range force search

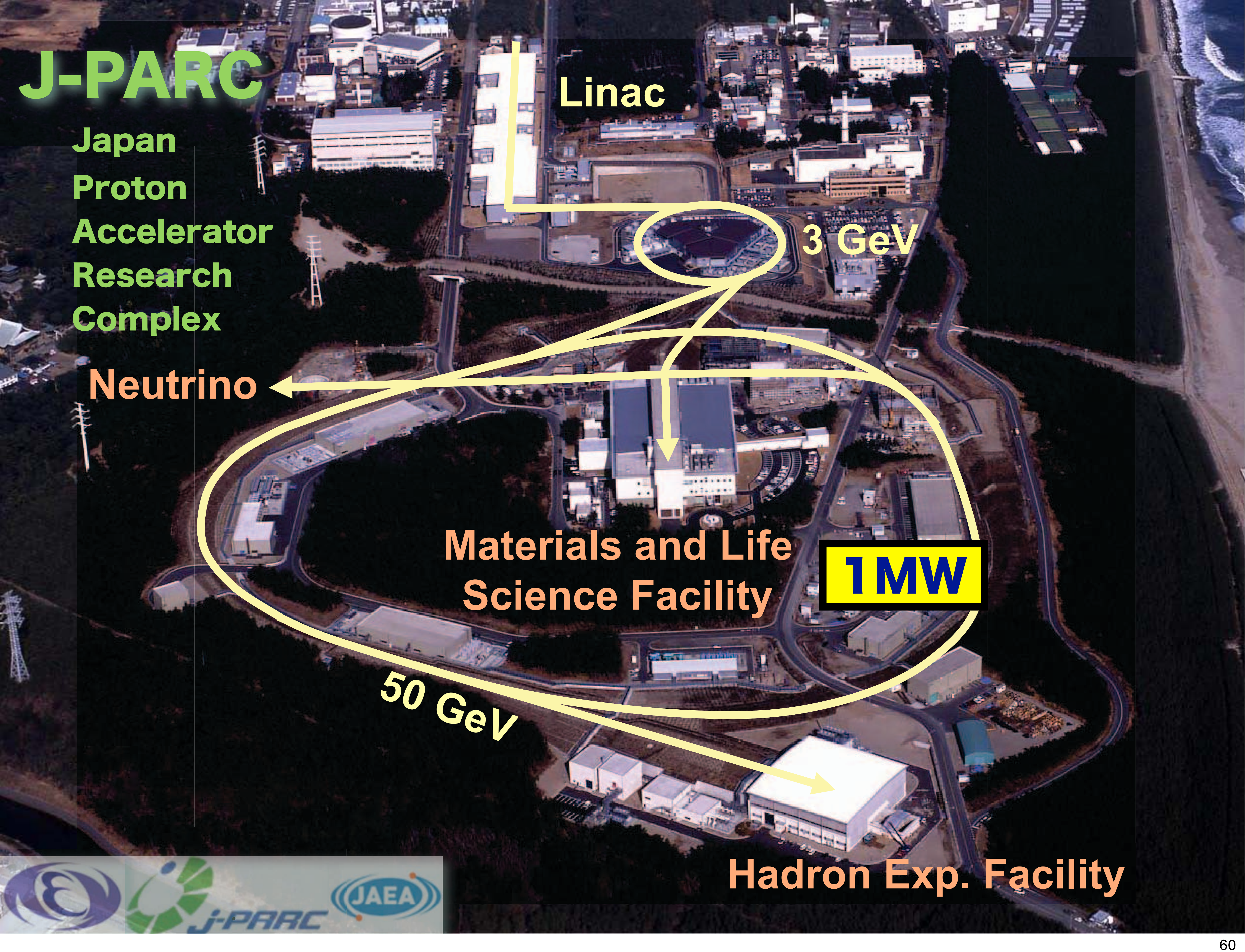
interference

neutron charge

spinor

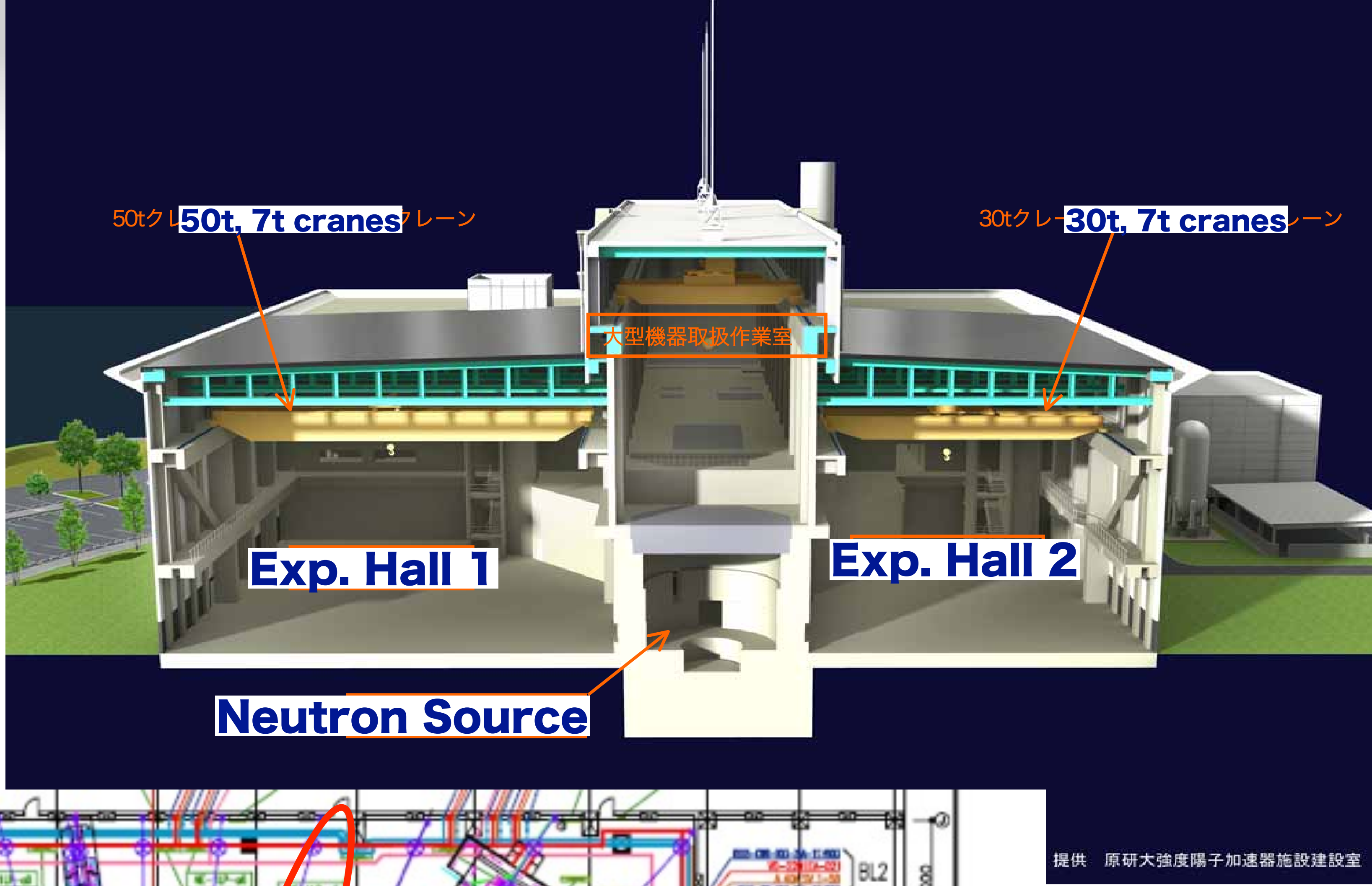
subatomic equivalence principle

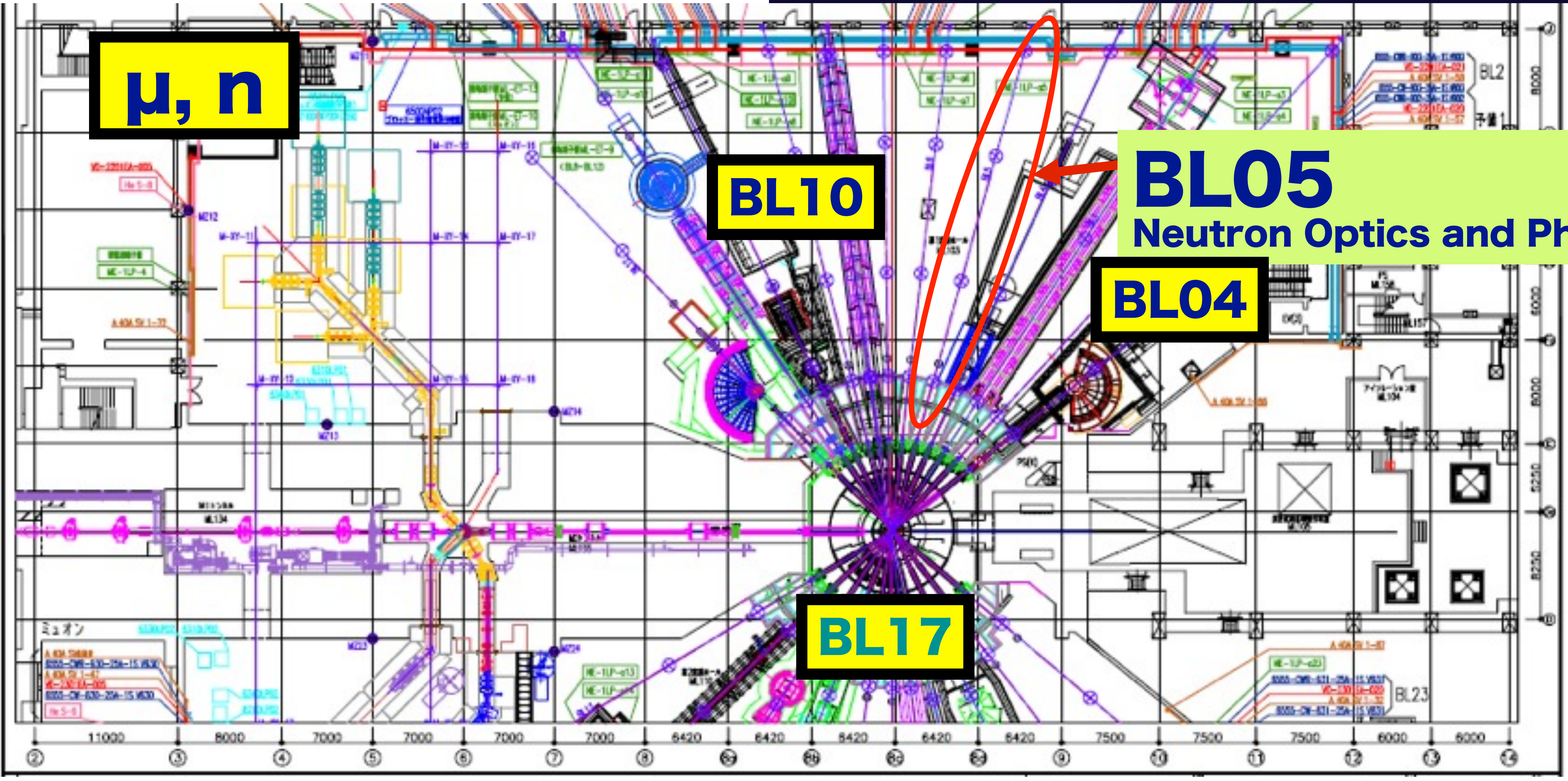
n-nbar oscillation


J-PARC
Japan
Proton
Accelerator
Research
Complex
Linac
3 GeV
Neutrino
Materials and Life
Science Facility
1MW
50 GeV
Hadron Exp. Facility
JAEA
J-PARC

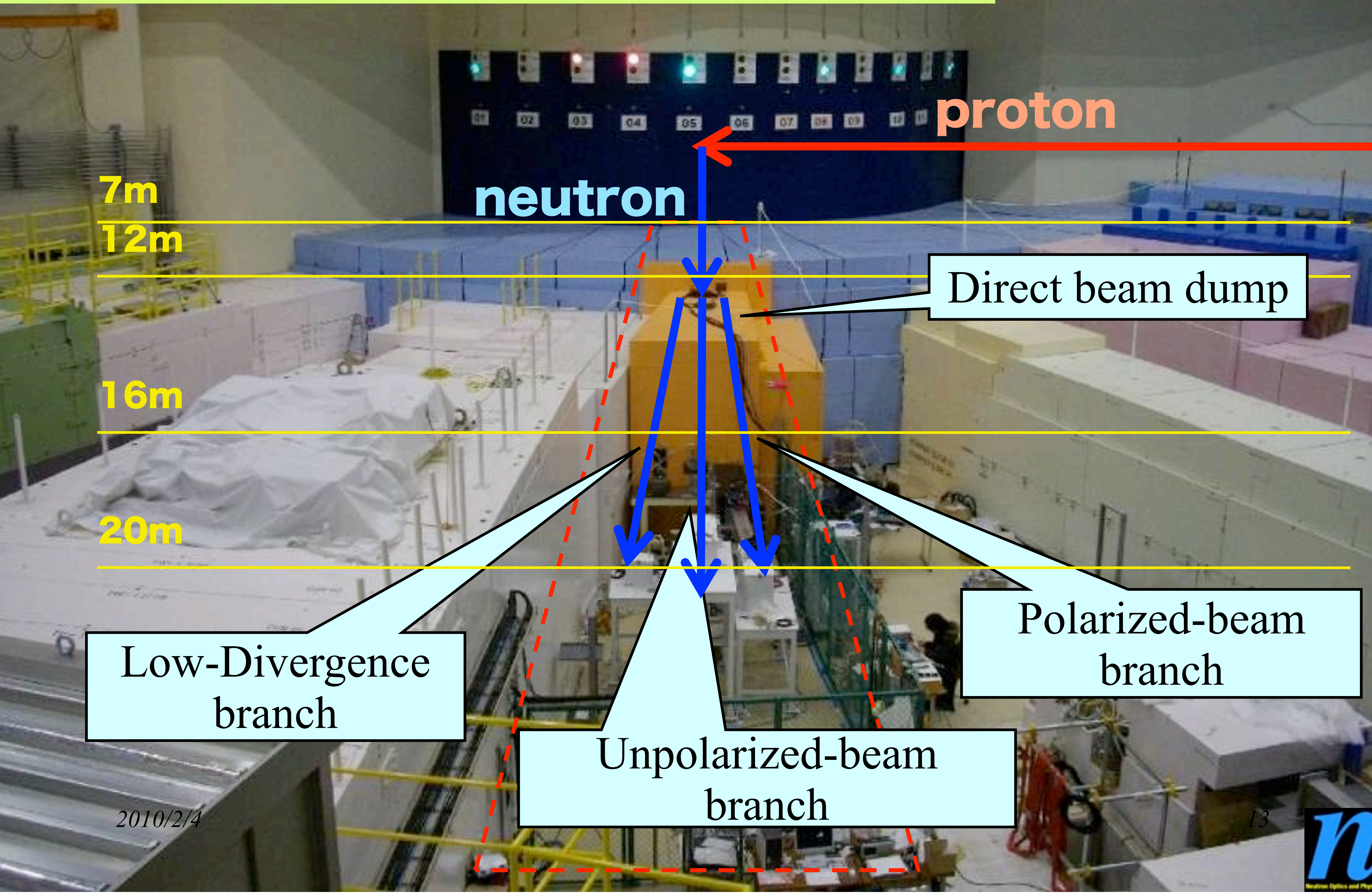
J-PARC MLF

Material and Life-science Facility



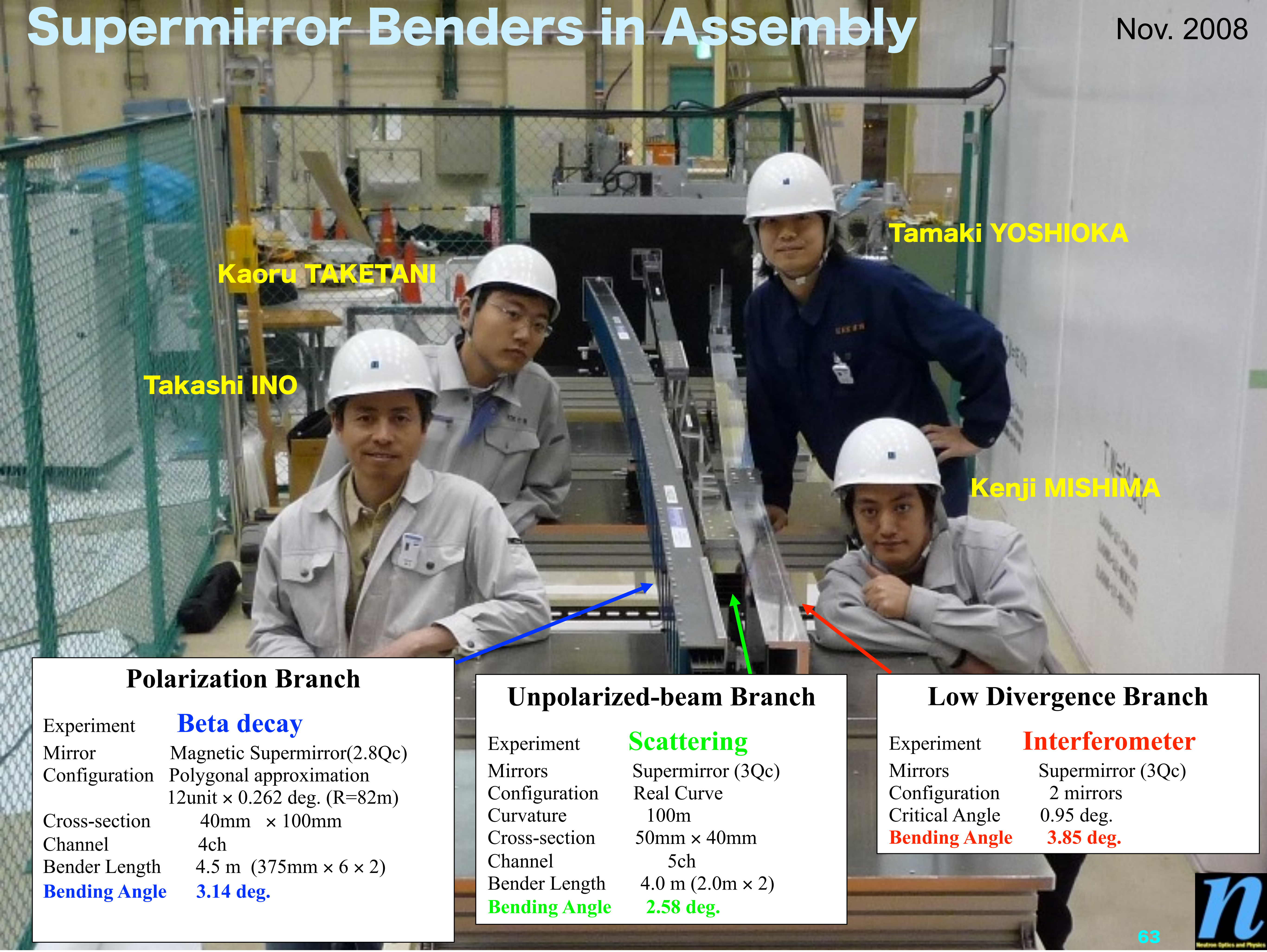


J-PARC BL05
Neutron Optics and Physics (NOP)



Supermirror Benders in Assembly

Nov. 2008



Polarization Branch

Experiment	**Beta decay**
Mirror	Magnetic Supermirror(2.8Qc)
Configuration	Polygonal approximation 12unit × 0.262 deg. (R=82m)
Cross-section	40mm × 100mm
Channel	4ch
Bender Length	4.5 m (375mm × 6 × 2)
Bending Angle	**3.14 deg.**

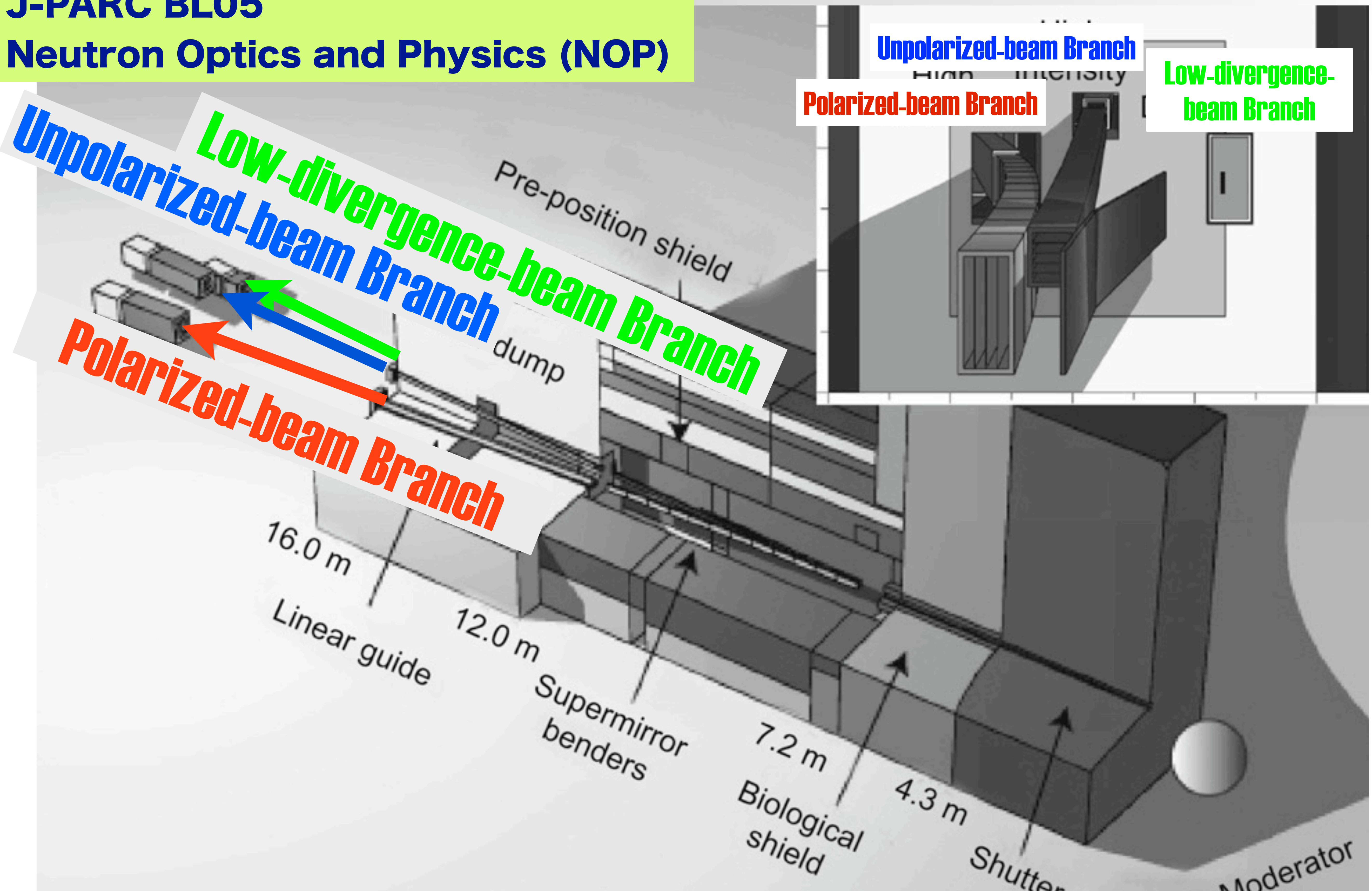
Unpolarized-beam Branch

Experiment	**Scattering**
Mirrors	Supermirror (3Qc)
Configuration	Real Curve
Curvature	100m
Cross-section	50mm × 40mm
Channel	5ch
Bender Length	4.0 m (2.0m × 2)
Bending Angle	**2.58 deg.**

Low Divergence Branch

Experiment	**Interferometer**
Mirrors	Supermirror (3Qc)
Configuration	2 mirrors
Critical Angle	0.95 deg.
Bending Angle	**3.85 deg.**

J-PARC BL05
Neutron Optics and Physics (NOP)



K.Mishima et al., NIM A600 (2009) 423.

Instantaneously Luminous

background separated in time
wide wavelength range

Polarized-beam Branch

4.0×10^{8} cm^{-2} s^{-1} MW^{-1}
10cm×4cm P=0.998

Unpolarized-beam Branch

1.2×10^{9} cm^{-2} s^{-1} MW^{-1}
5cm×4cm

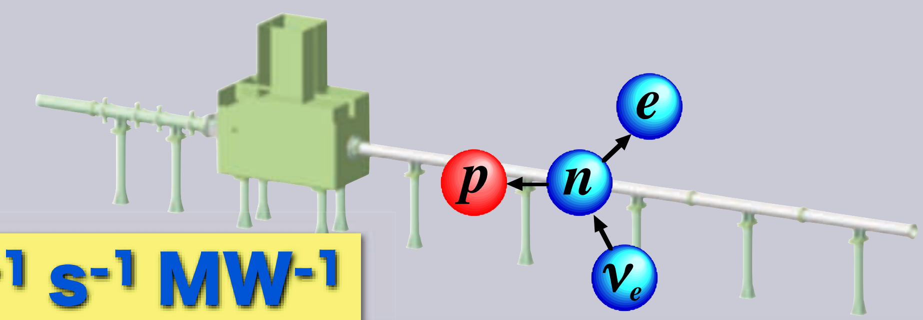
Low-divergence-beam Branch

9.2×10^{5} cm^{-2} μsr^{-1} s^{-1} MW^{-1}

"Decay"

- decay parameters
- unitarity of CKM matrix
- T-violation

10^{4} decay m^{-1} s^{-1} MW^{-1}

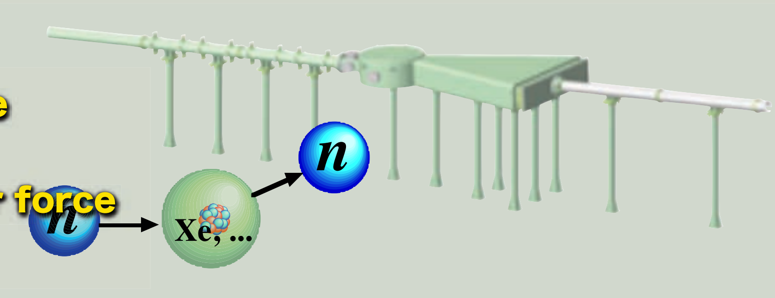


instantaneous decay rate ~ 10^{5} decay m^{-1} s^{-1} MW^{-1}

"Scattering"

- unknow medium range force
- large extra-dimension
- charge symmetry of nuclear force

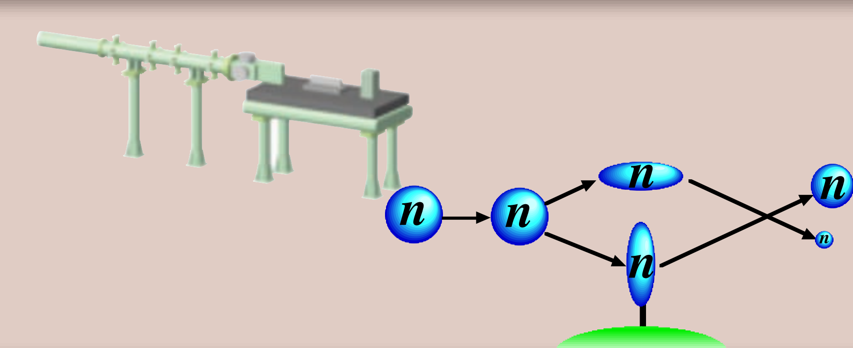
etc.



"Interference"

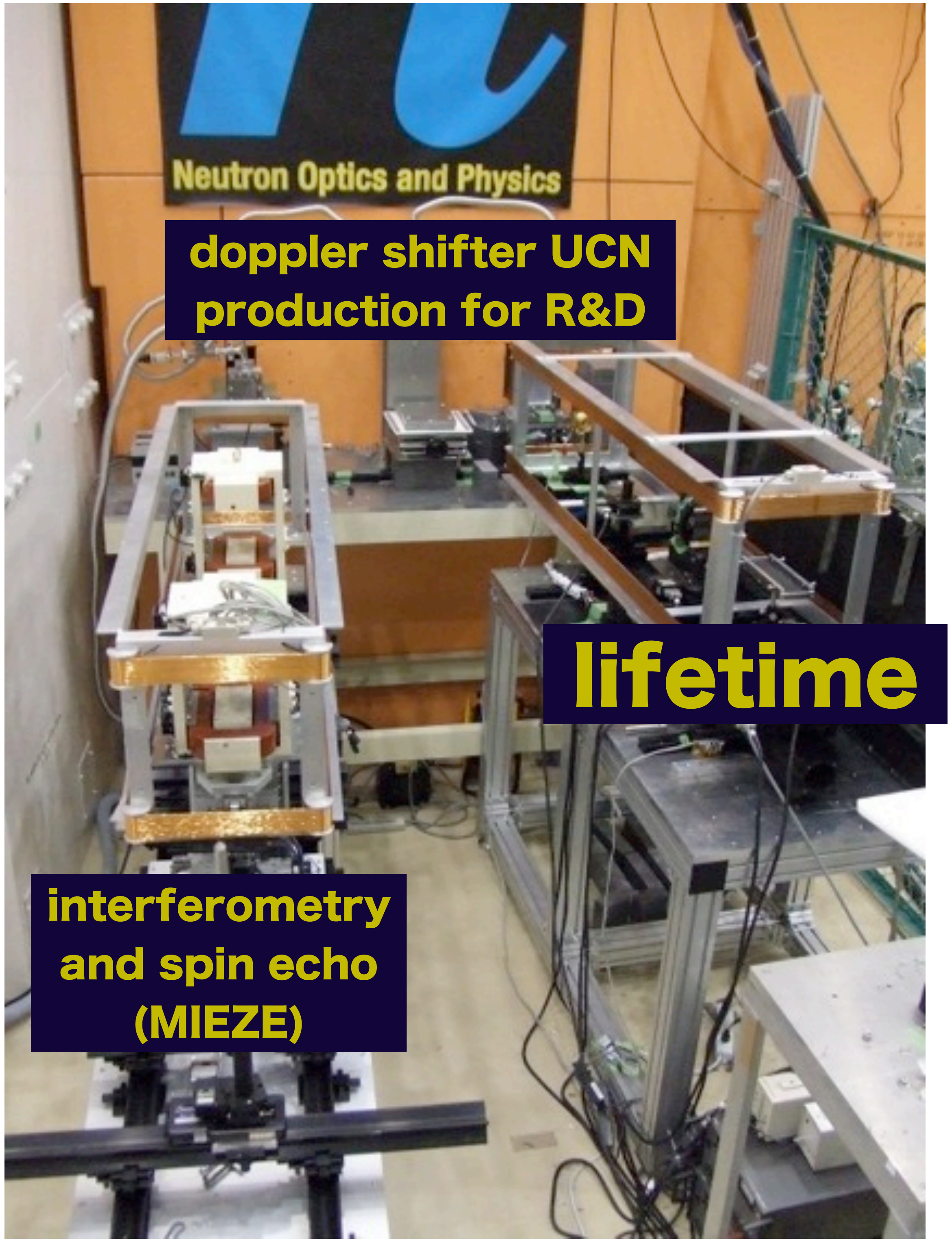
- gravitational phase shift
- Ahoronov-Casher effect

etc.

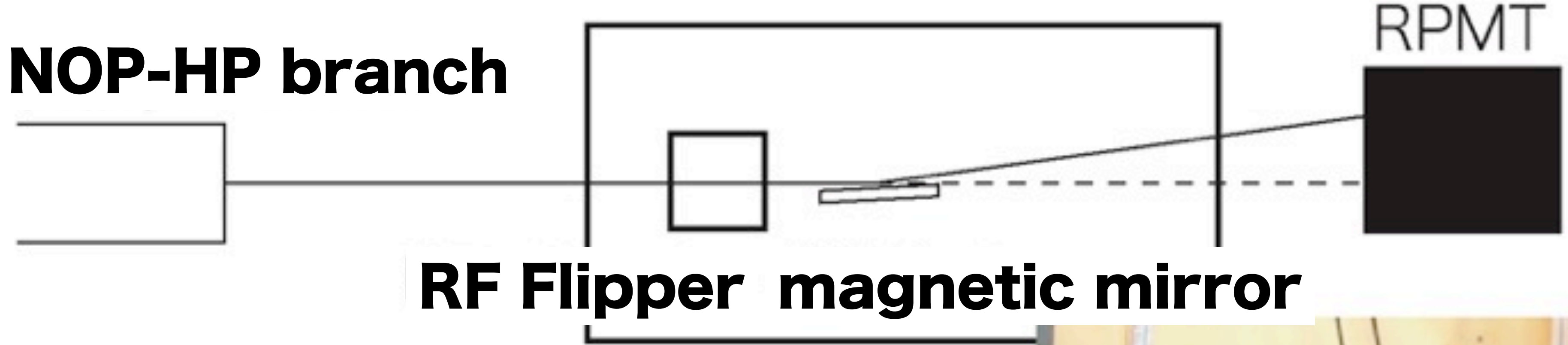


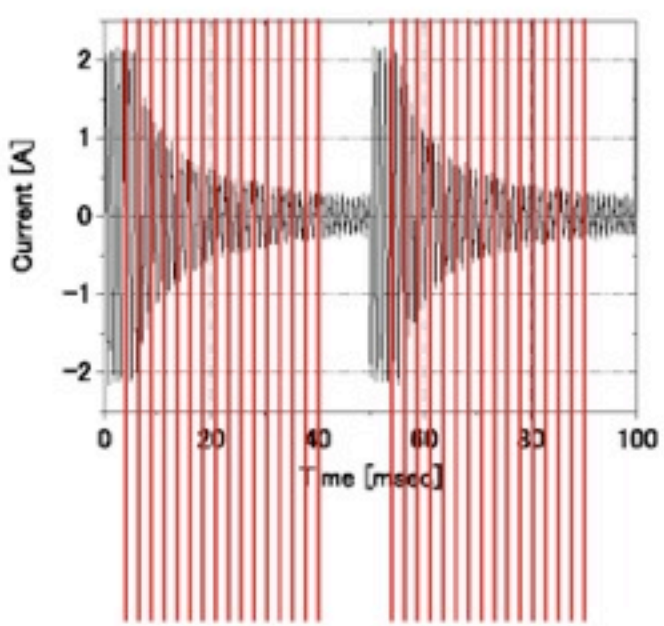
K.Mishima et al., NIM A600 (2009) 423.

On-going Researches at BL05

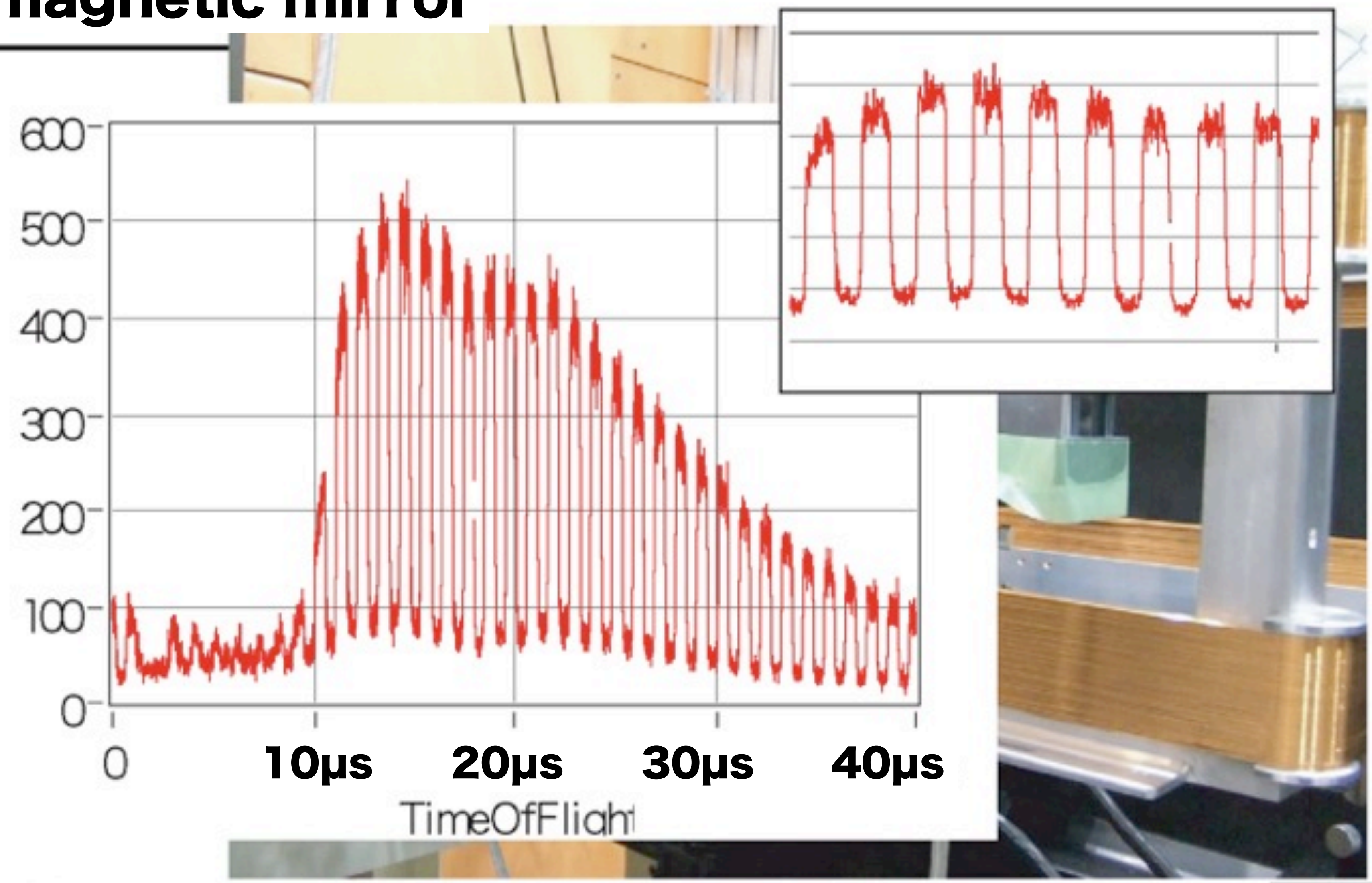


Demonstration

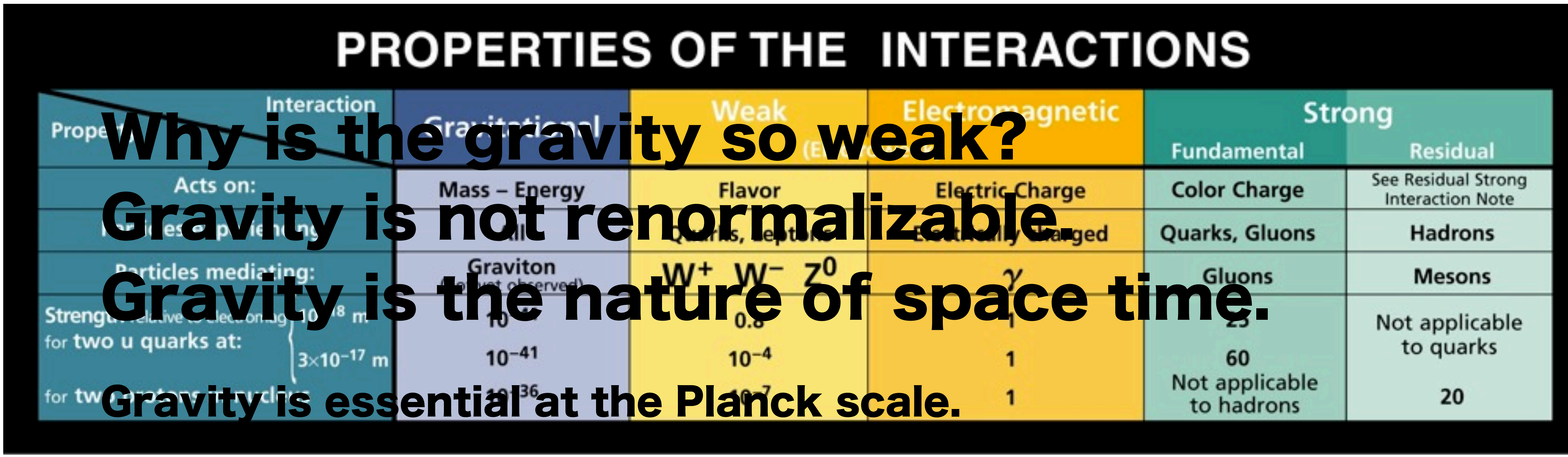




RF ON



Gravity



PROPERTIES OF THE INTERACTIONS

Property / Interaction	Gravitational	Weak (Electroweak)	Electromagnetic	Strong: Fundamental	Strong: Residual
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge	See Residual Strong Interaction Note
Particles experiencing:	All	Quarks, Leptons	Electrically charged	Quarks, Gluons	Hadrons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons	Mesons
Strength relative to electromag for two u quarks at: 10^{-18} m	[illegible]	0.8	1	25	Not applicable to quarks
3×10^{-17} m	10^{-41}	10^{-4}	1	60	
for two protons in nucleus	10^{-36}	10^{-7}	1	Not applicable to hadrons	20

Why is the gravity so weak?

Gravity is not renormalizable.

Gravity is the nature of space time.

Gravity is essential at the Planck scale.

"hierarchy problem": $M_{GUT}\sim10^{24}$eV ⇔ $M_{SU(2)\times U(1)}\sim10^{11}$eV

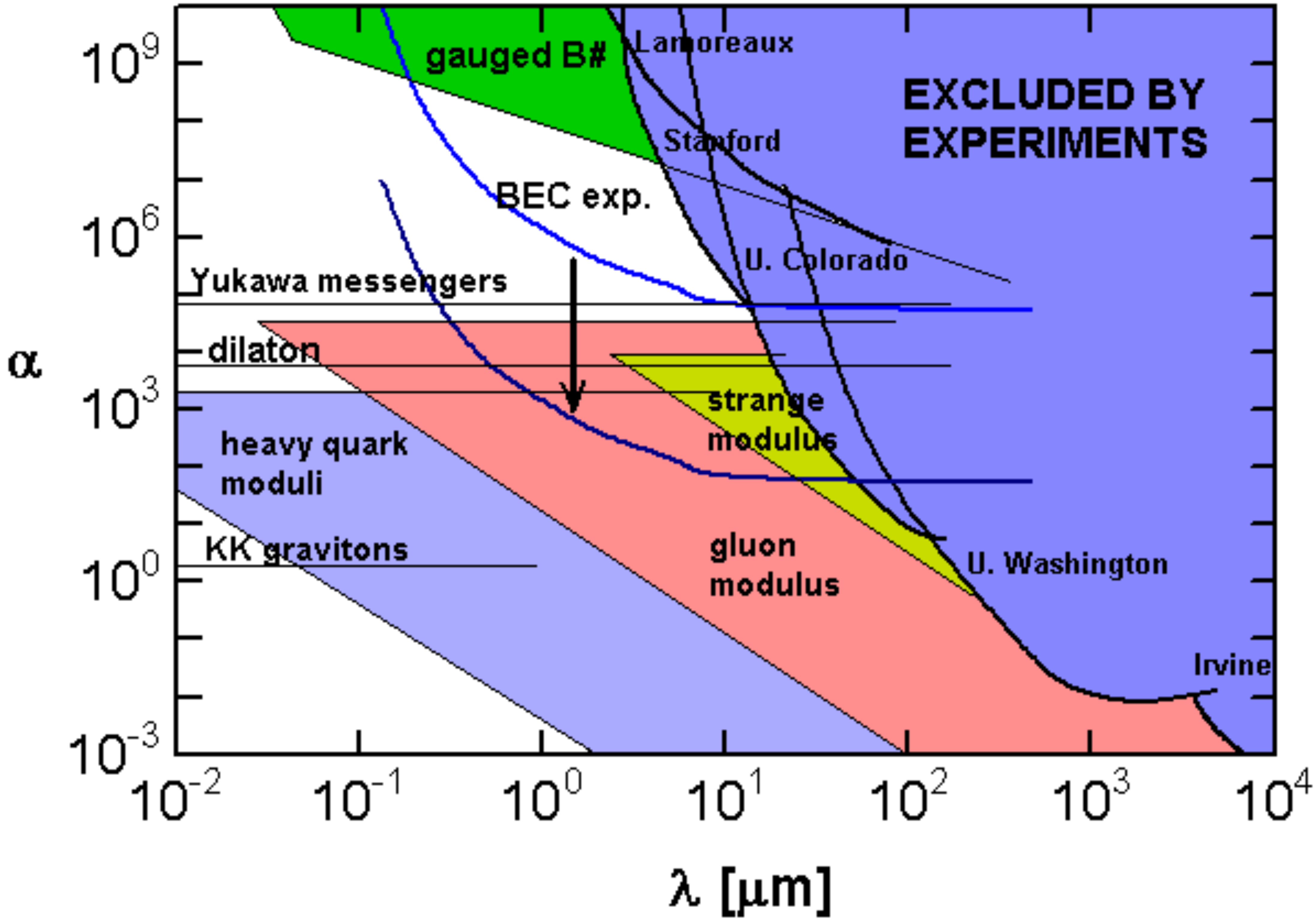
Phenomena out of the standard model is existing.

Neutrino Oscillation, Dark Energy, Dark Matter

Super-K, SNO, KamLAND WMAP

Gravity medium-range force search

$V(r)=-(GM/r)(1+\alpha e^{-r/\lambda})$



Gravity

3-dim. Gravity

$$F_3(r) = G_3 \frac{m_1 m_2}{r^2}$$

N-dim. Gravity

$$F_N(r) = G_N \frac{m_1 m_2}{r^{N-1}}$$

continuity at r=R*

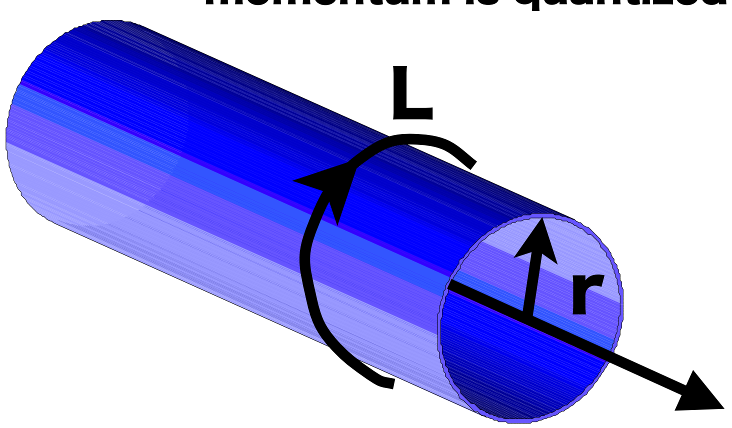
$$\frac{G_3}{R^{*2}} = \frac{G_N}{R^{*N-1}} \Rightarrow G_3 = \frac{G_N}{R^{*N-3}}$$

If R* is longer than the Planck's length, G_3 becomes smaller.

Parametrization: $V(r)=-(GM/r)(1+\alpha e^{-r/\lambda})$

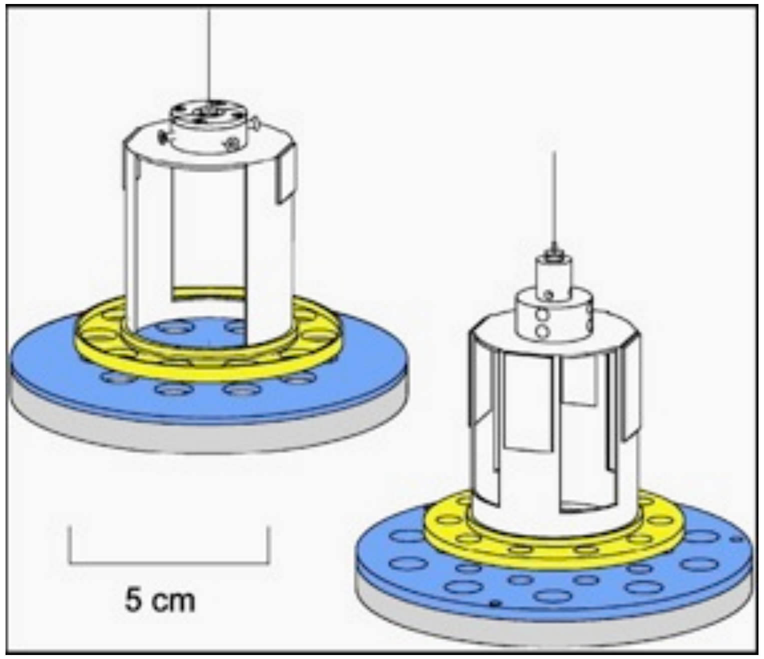
KK-graviton, which is emitted off our brane with the momentum (q_1, q_2, ...,q_n) along the extradimension, looks having the mass |q|.

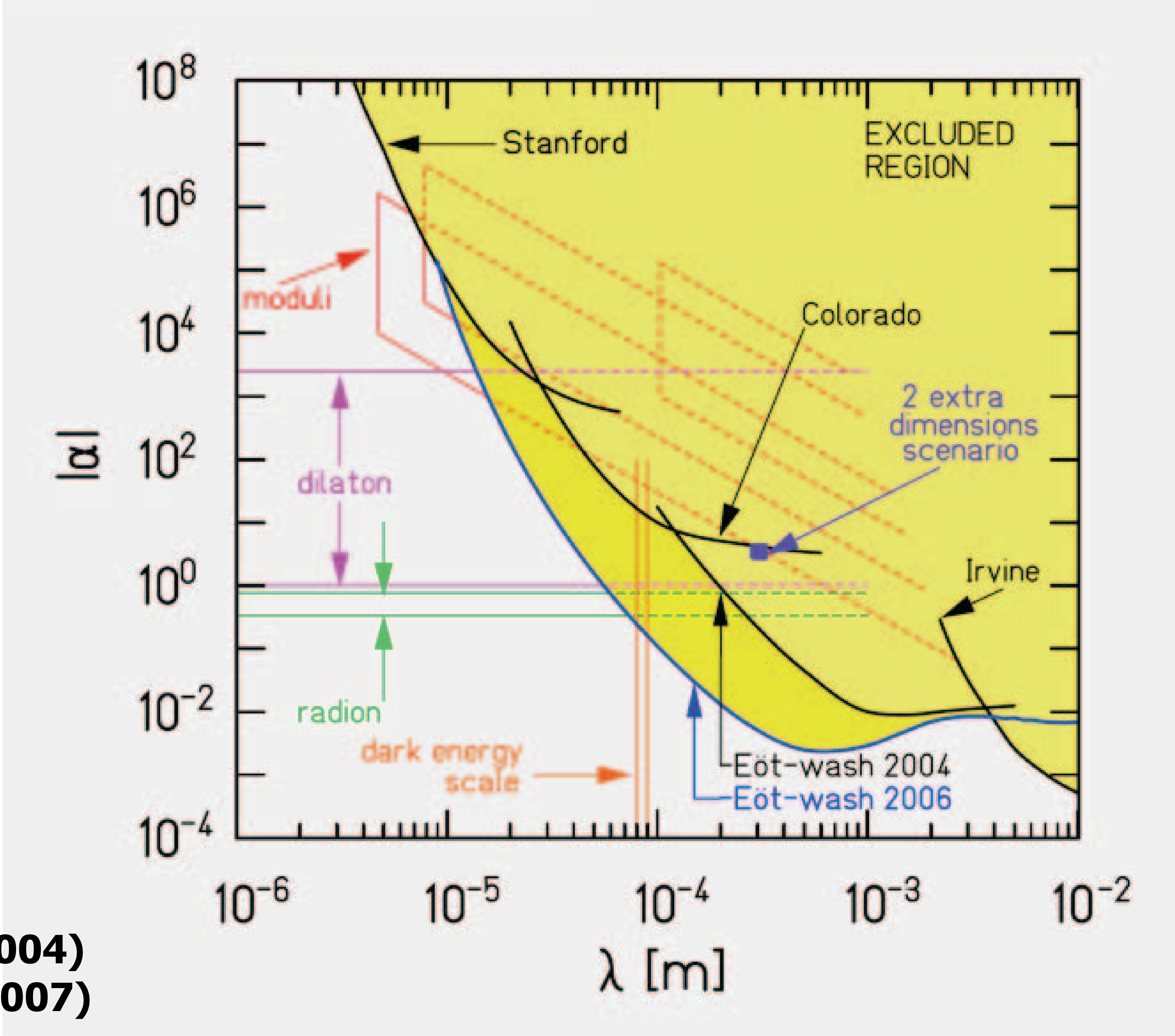
momentum is quantized in the unit of 2π/L in the extra-dimension



$$\frac{V(r)}{m_1 m_2} = G_3 \sum_{(k_1,\ldots k_n)} \frac{e^{-(2\pi|k|/L)r}}{r} \xrightarrow[r<<L]{} G_3 \frac{1}{r}\left(\frac{L}{2\pi r}\right)^n \int d^n u e^{-|u|}$$

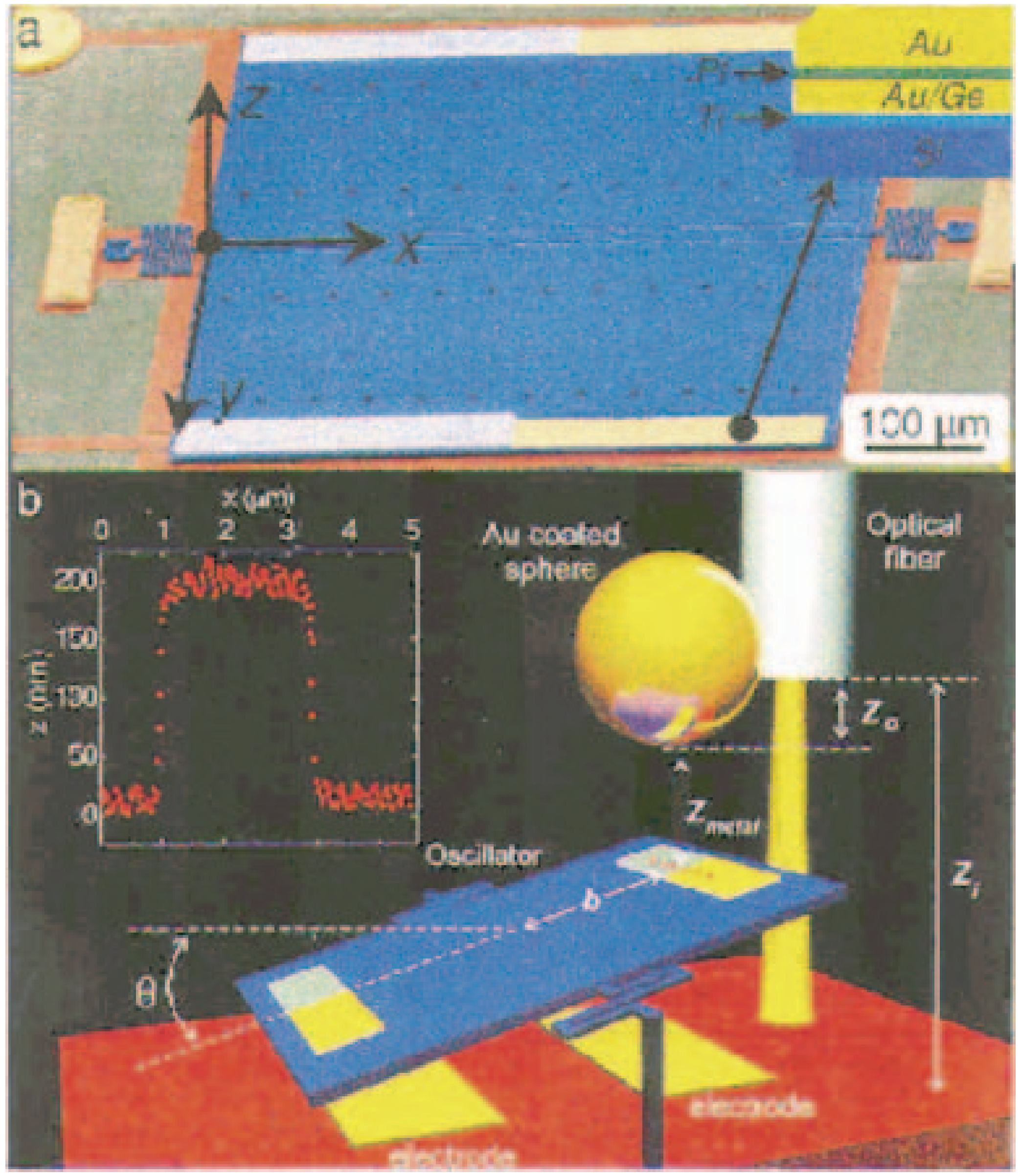
Torsion Balance

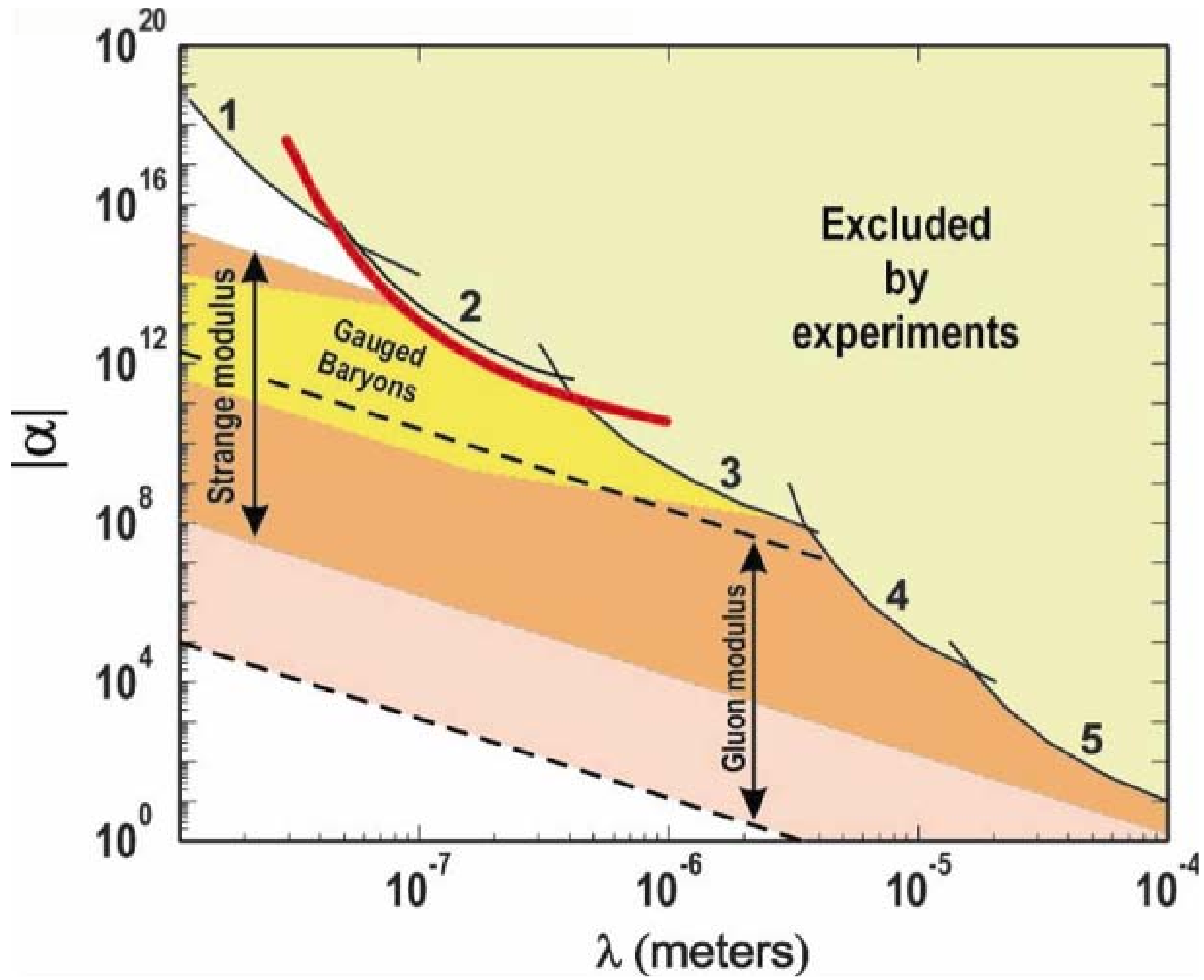




Hoyle et al. PRD70, 042004 (2004)
Karper et al. PRL98, 021101 (2007)

Atomic Force Microscope





R.S.Decca et al., Phys. Rev. Lett. 94 (2005) 240401

Gravity

Van der Waals force is dominant closer than 10μm

electric polarizability

$$U = -\frac{3\hbar c}{8\pi}\frac{\alpha}{r^4}$$

atoms $\alpha \sim 10^{15}\ \mathrm{fm}^3$

neutrons $\alpha \sim 10^{-3}\ \mathrm{fm}^3$

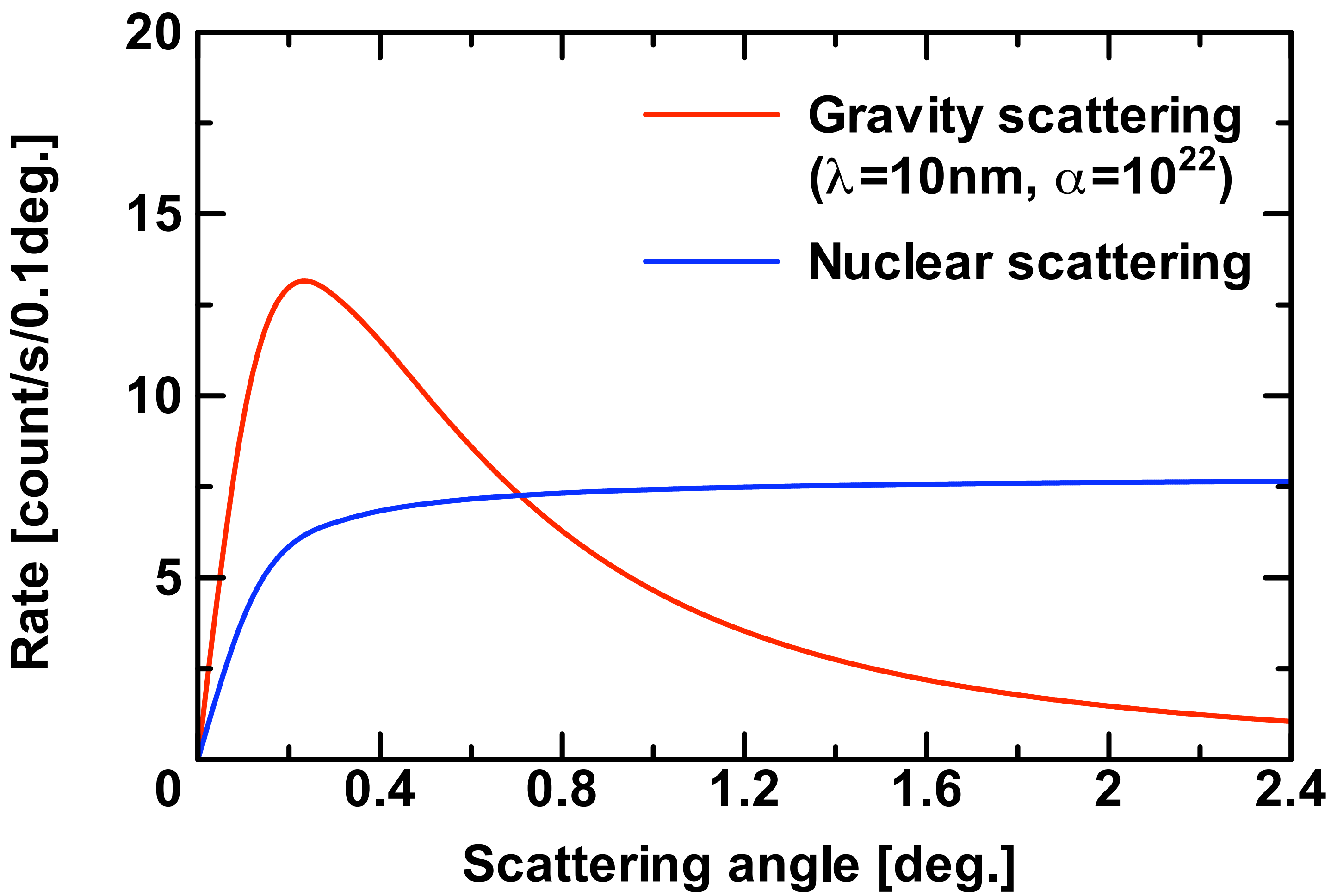
$I(J^P)=\frac{1}{2}\left(\frac{1}{2}^+\right)$ (ref. PDG2008)

mass
  $m=939.565360\pm0.000081$ MeV
mean life
  $\tau=885.7\pm0.8$ s
magnetic dipole moment
  $\mu=(-1.91304273\pm0.00000045)\mu_N$
electric dipole moment
  $|d|<2.9\times10^{-26}$ e cm (90%CL)
mean square charge radius
  $\langle r_n^2\rangle=-0.1161\pm0.0022\ \mathrm{fm}^2$
electric polarizability
  $\alpha=(11.6\pm1.5)\times10^{-4}\ \mathrm{fm}^3$
magnetic polarizability
  $\beta=(3.7\pm2.0)\times10^{-4}\ \mathrm{fm}^3$
charge
  $q=(-0.4\pm1.1)\times10^{-21}$ e
mean time for $n\bar{n}$ transition
  $\tau_{n\bar{n}}$[free]$>8.6\times10^7$ s (90%CL)
  $\tau_{n\bar{n}}$[bound]$>1.3\times10^8$ s (90%CL)
mean time for nn' oscillation
  $\tau_{nn'}>103$ s (95%CL)
decay modes
  $n\to pe^-\bar{\nu}_e$ 100%
    $\lambda=g_A/g_V=-1.2695\pm0.0029$
    e^- asymmetry parameter
      $A=-0.1173\pm0.0013$
    $\bar{\nu}_e$ asymmetry parameter
      $B=0.9807\pm0.0030$
    proton asymmetry parameter
      $C=-0.2377\pm0.0010\pm0.0024$
    e-$\bar{\nu}_e$ angular correlation coefficient
      $a=-0.103\pm0.004$
    phase of g_A relative to g_V
      $\phi_{AV}=(180.06\pm0.07)^\circ$
    triple correlation coefficient
      $D=(-4\pm6)\times10^{-4}$
  $n\to pe^-\bar{\nu}_e\gamma$ $(3.13\pm0.35)\times10^{-3}$ (35-100keV)
  $n\to p\nu_e\bar{\nu}_e$ $<8\times10^{-27}$ (68%CL)

$$\frac{d\sigma_G}{d\Omega} = \alpha^2\left(\frac{Gm_nM}{4}\right)^2\left[\frac{1}{\frac{1}{m_nc^2}+8E_n\sin^2\frac{\theta}{2}}\right]$$

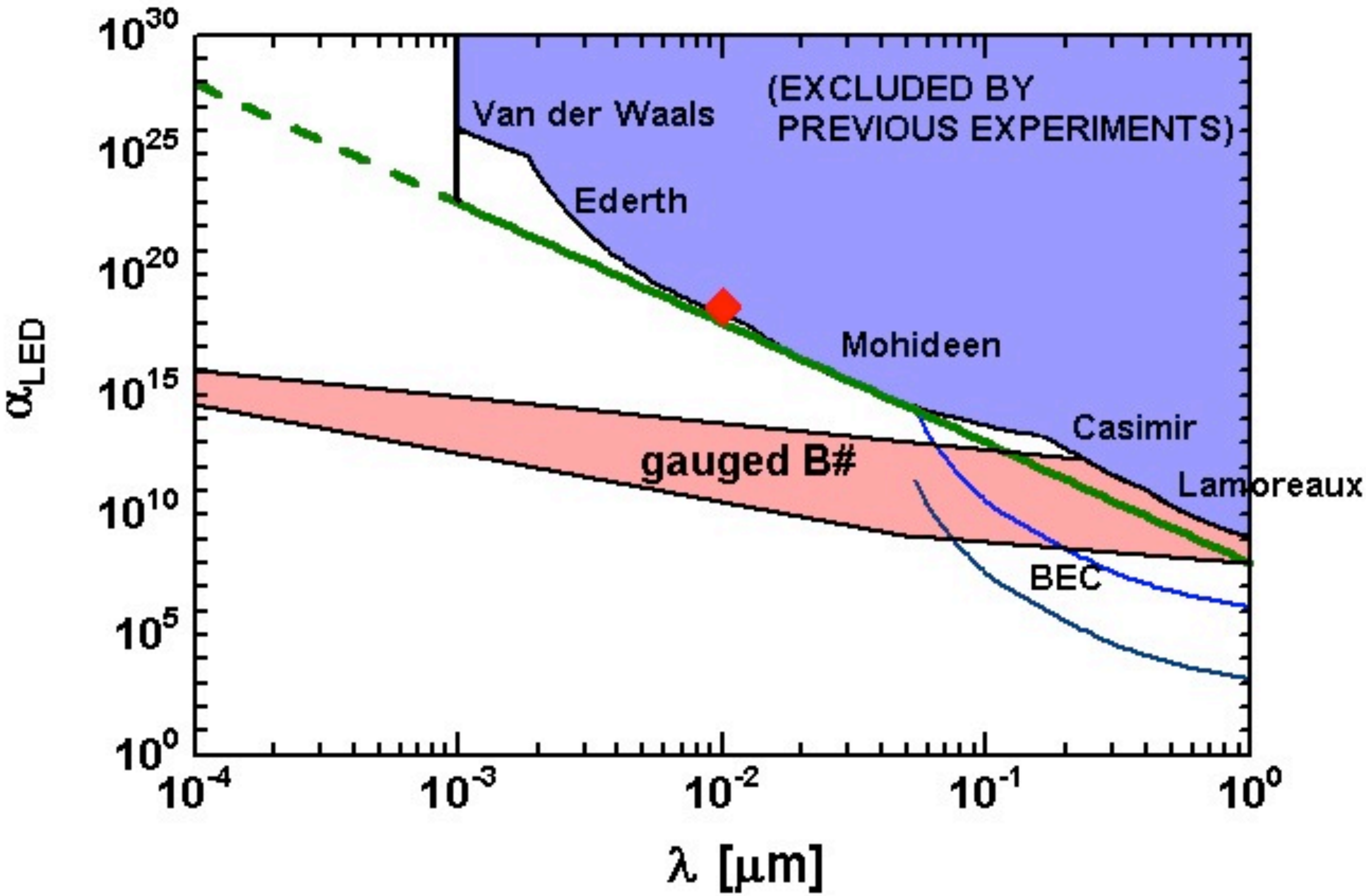
$\sigma_N(^{40}Ar)=0.421$ b
$\sigma_N(^{36}Ar)=77.9$ b

E_n=2meV
Beam size: 4cm×4cm Collimation: 1.7mrad×1.7mrad
Target: ^{40}Ar 0.1atm, 10cm Detector efficiency: 0.4



$$\sigma_G/\sigma_N \cong 0.1\% \Rightarrow \alpha = 5\times10^{18}$$

Gravity

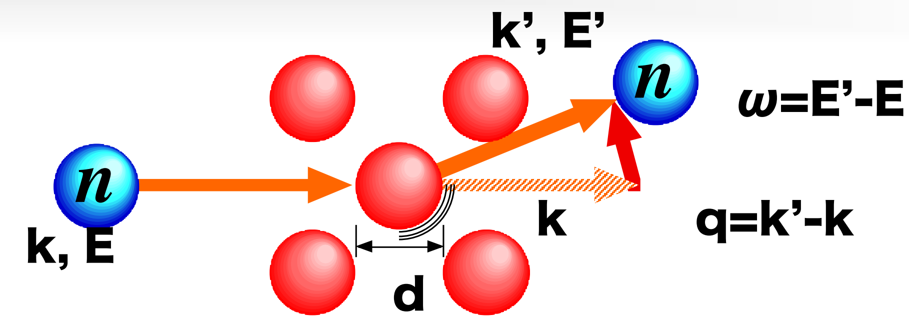


(EXCLUDED BY PREVIOUS EXPERIMENTS)
Van der Waals
Ederth
Mohideen
Casimir
Lamoreaux
gauged B#
BEC
10^{30}
10^{25}
10^{20}
10^{15}
10^{10}
10^{5}
10^{0}
α_{LED}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
λ [μm]

2. applications to material researches

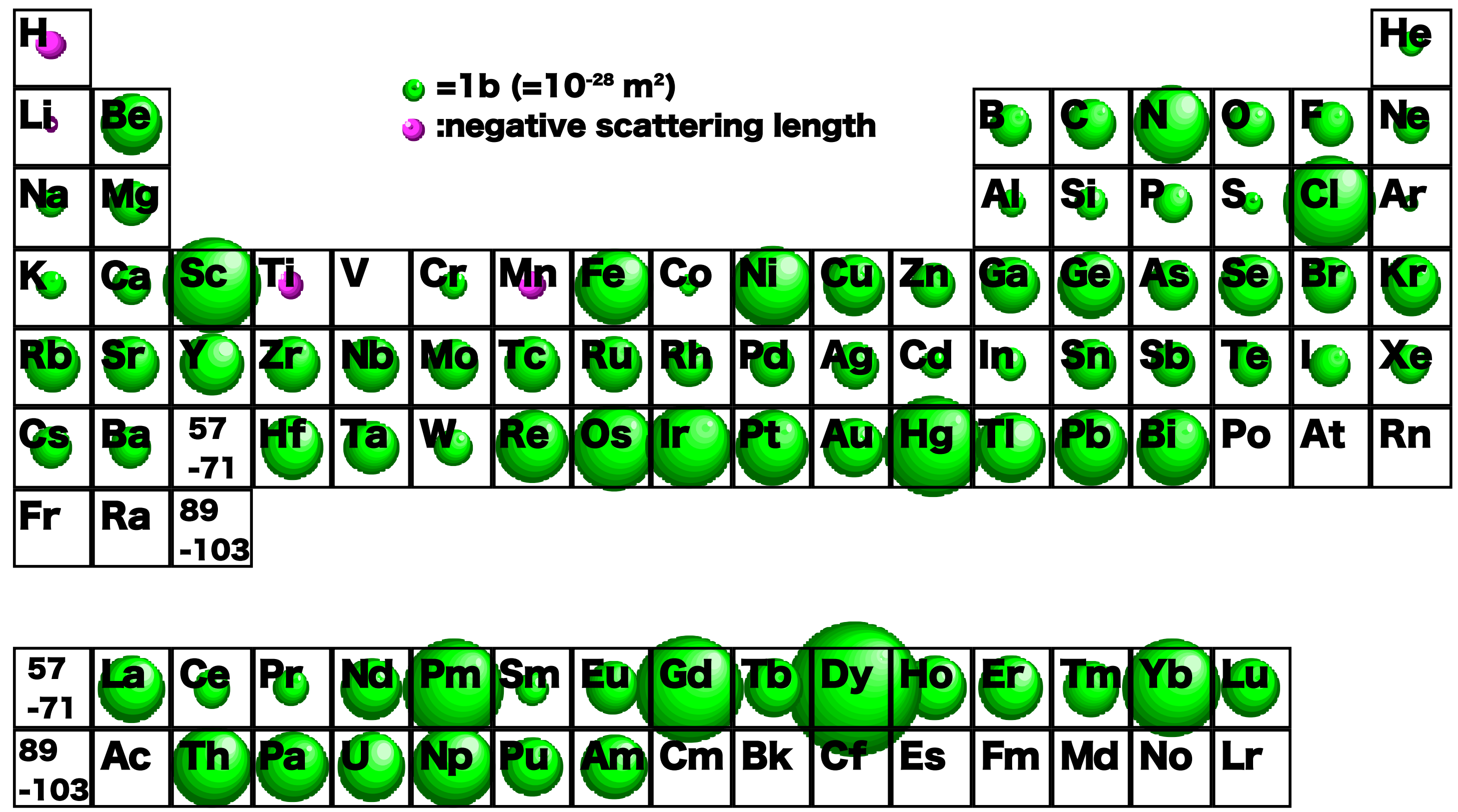
Neutron

is good at studying



the nm-scale structure and slow dynamics

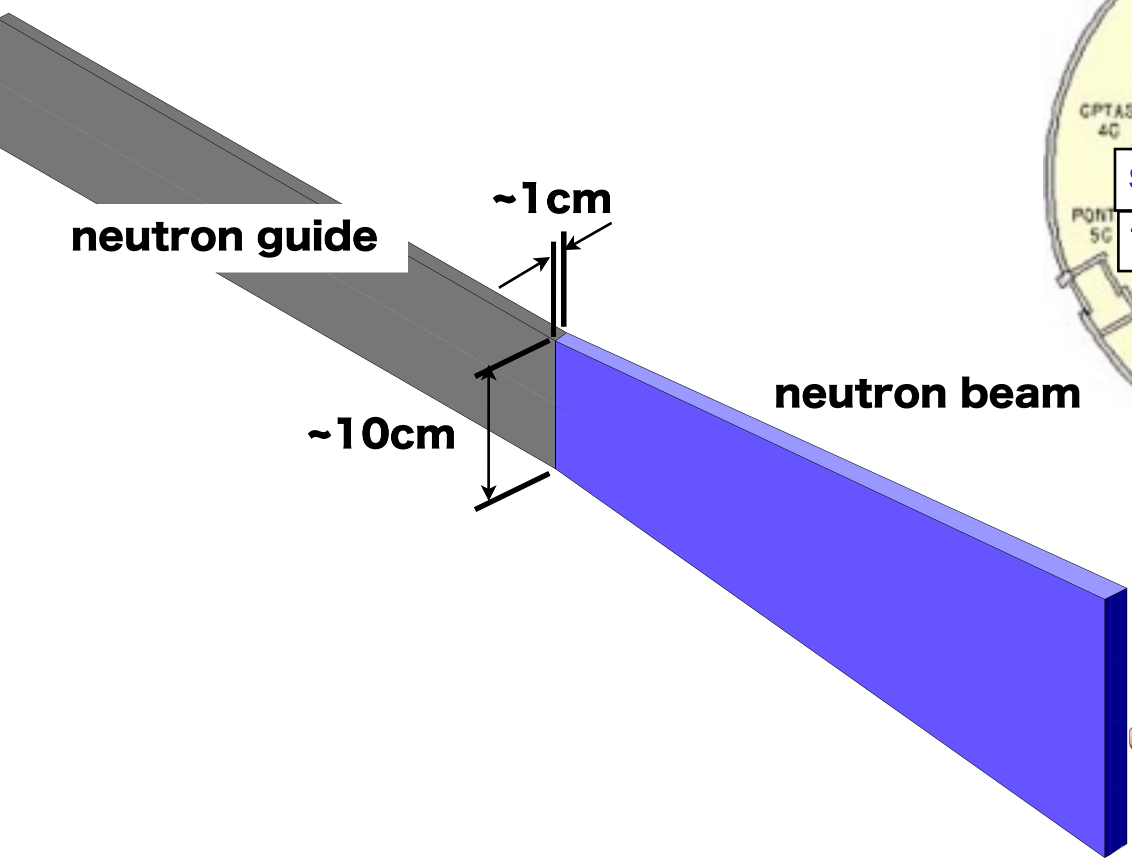
of light elements

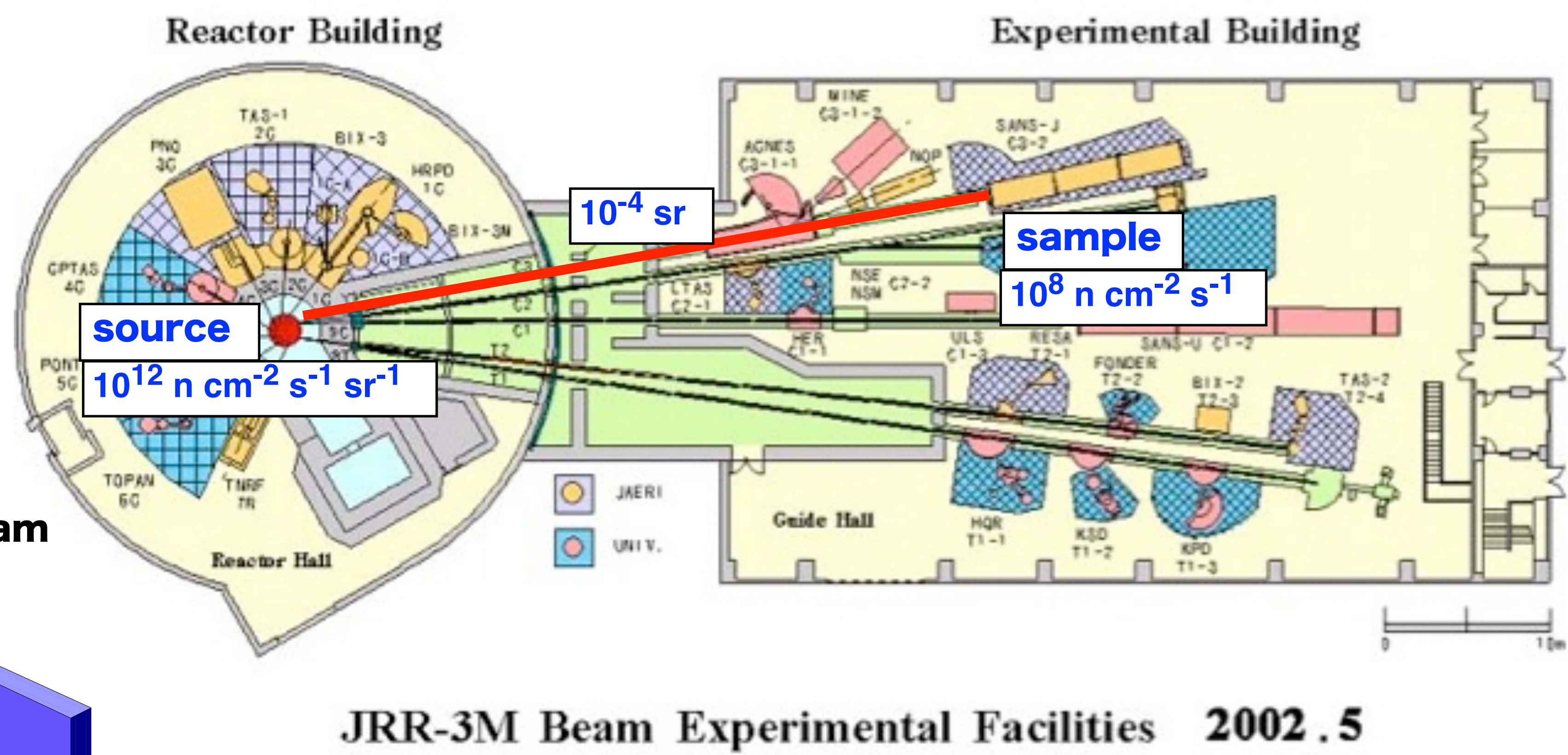


with small chemical change.

(Analyzing Capability)=(Source Power)×('Efficacy')

deceleration, optics, detector, sample environment, signal processing, analysis algorithm, theoretical model, ... etc.





most neutrons are not contributing to physics data

innovations → improve 'efficacy'

Focusing ⇔ 'Efficacy'

Concentrating Neutron

increase spatial density
accepting large beam divergence

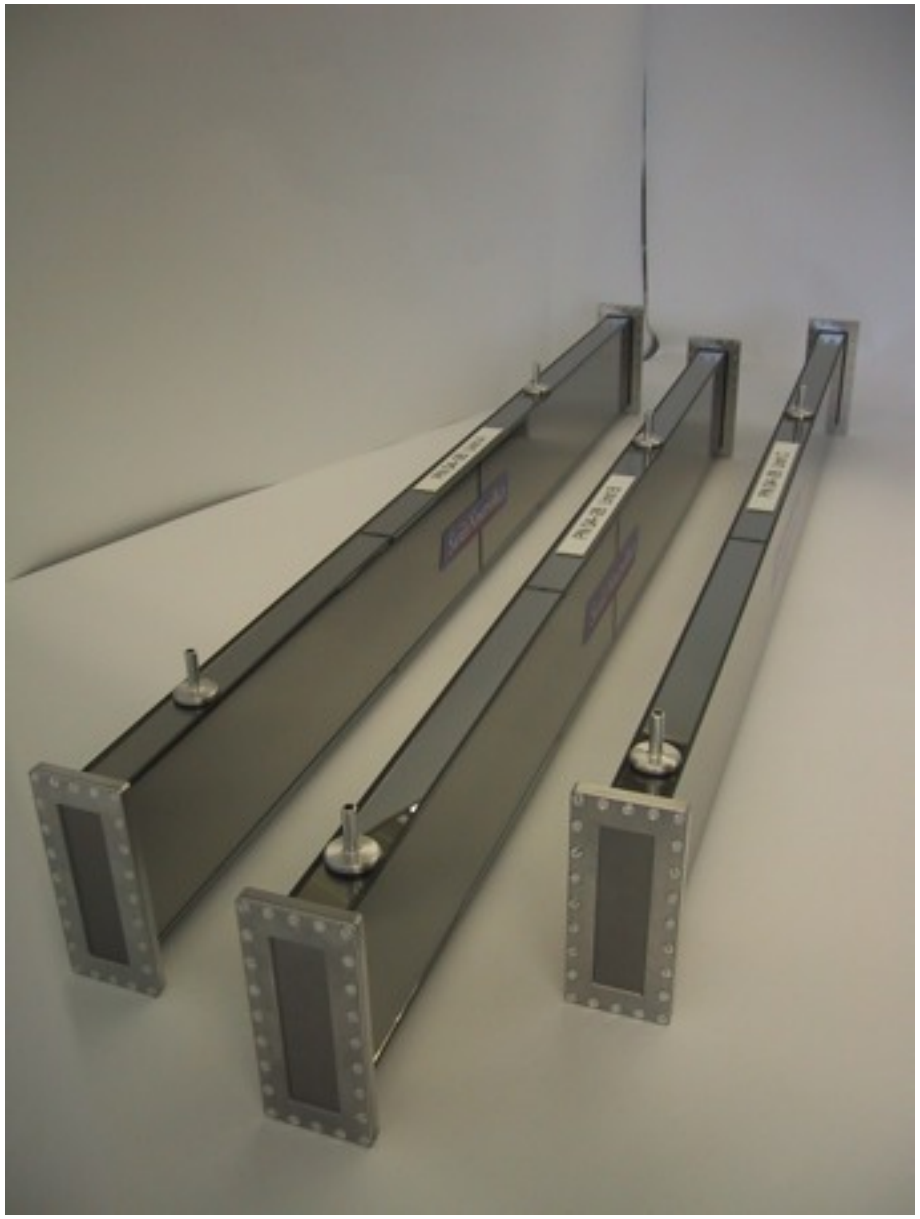
- Kumakov Lens
- Converging Guide
- Mosaic Mirror
- Mosaic Crystal

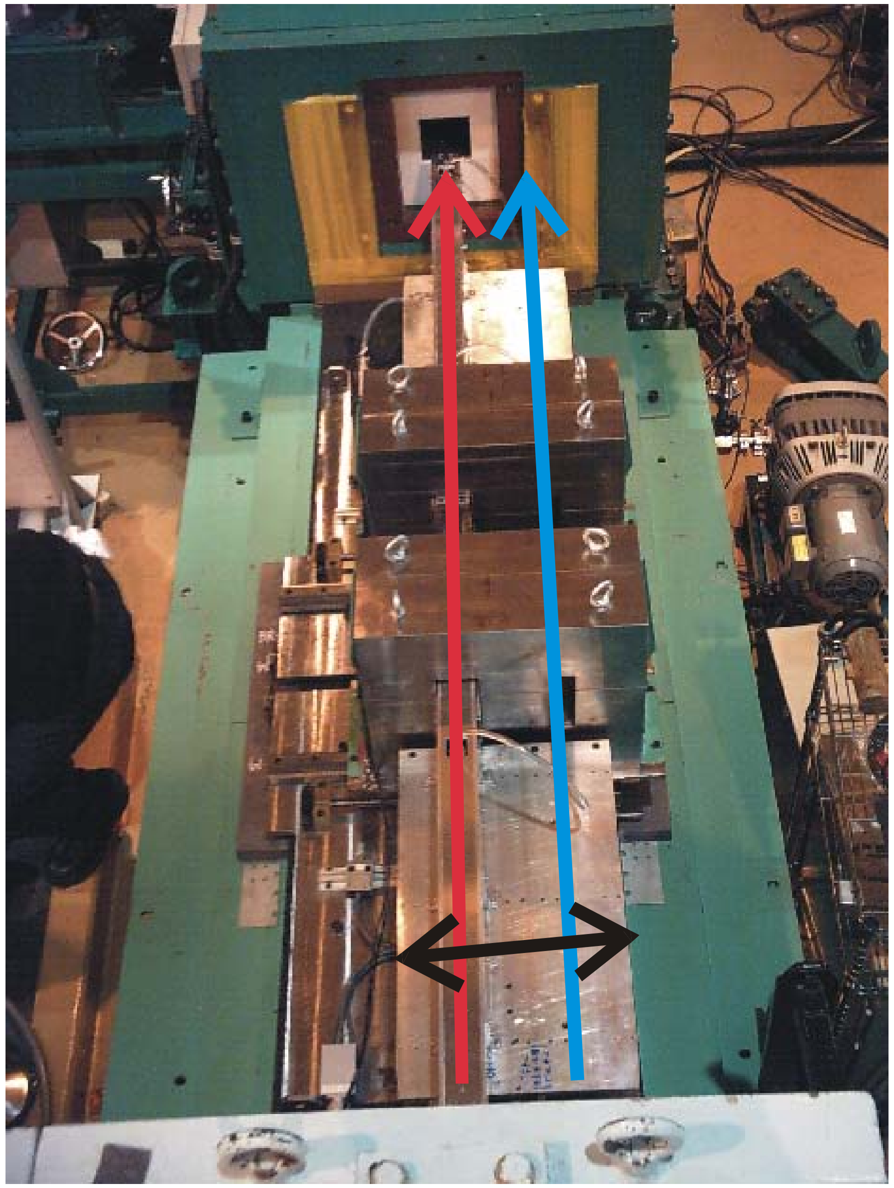
Fine Focus

- Curved Mirror
- Refractive Lens

Prompt γ-ray Analysis

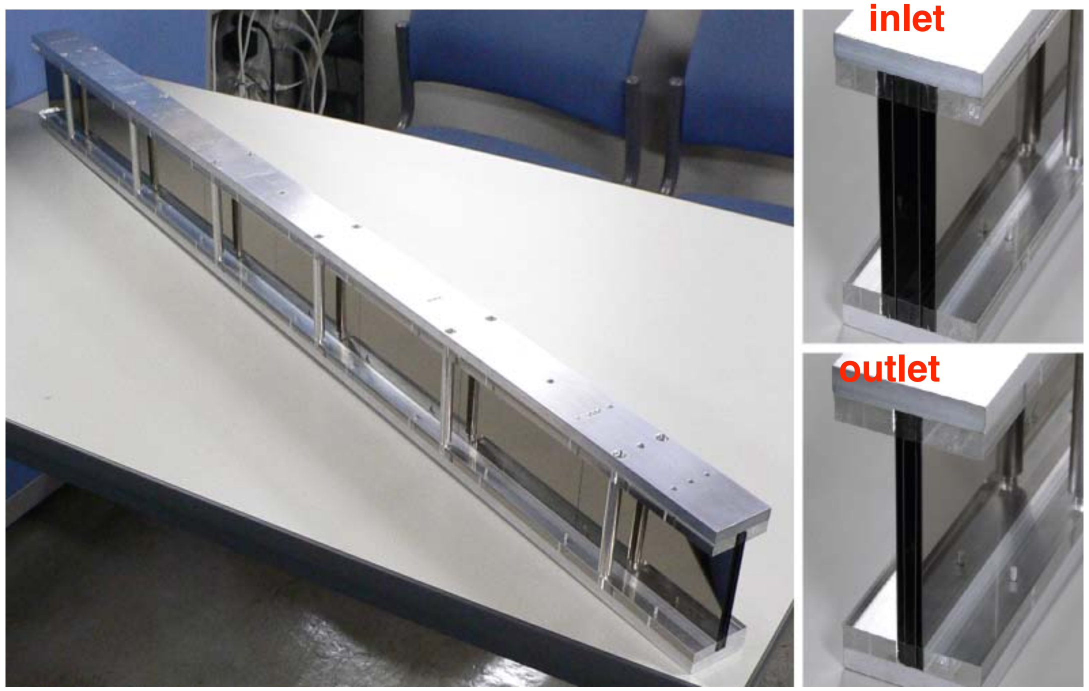
element/isotope analysis

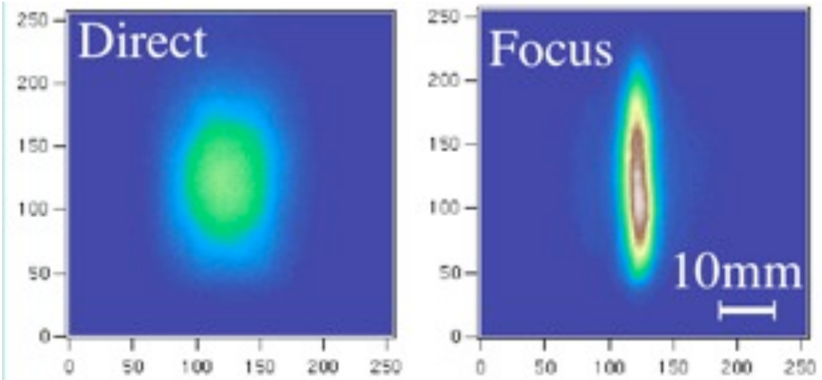




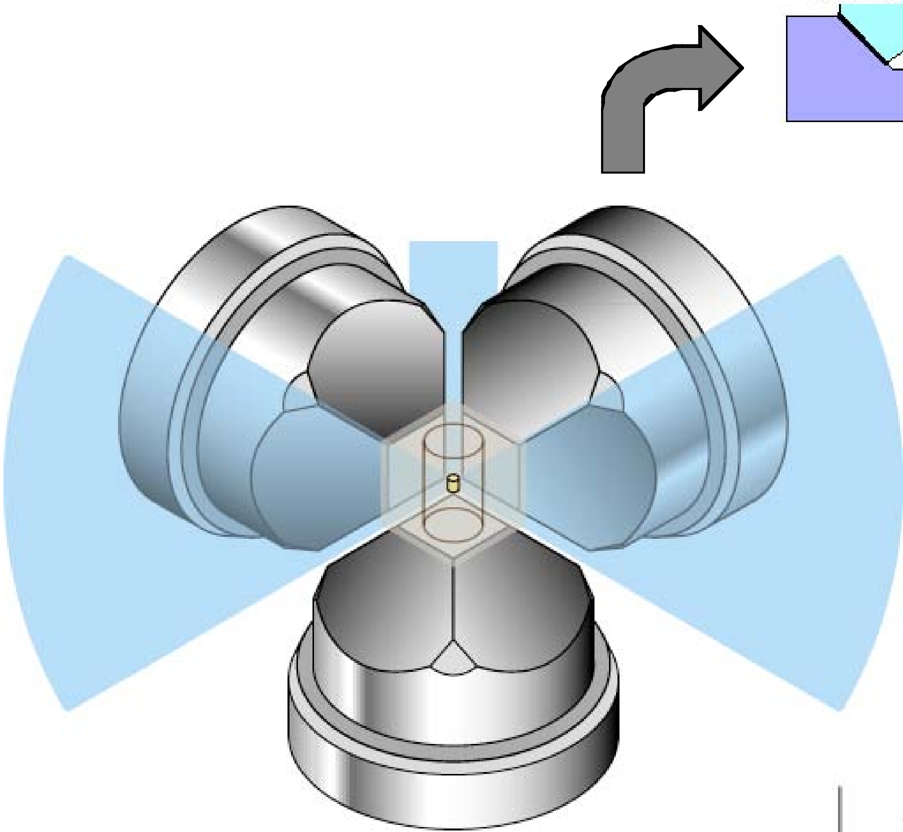
Powder Diffraction

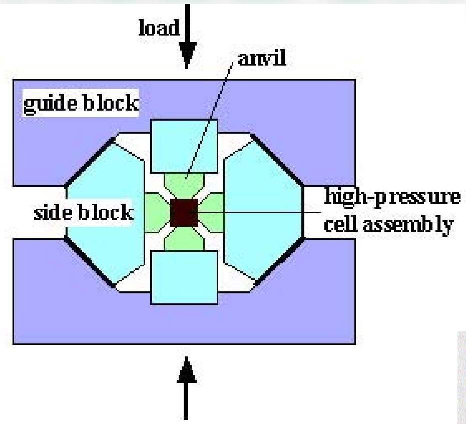
sacrificing q-resolution

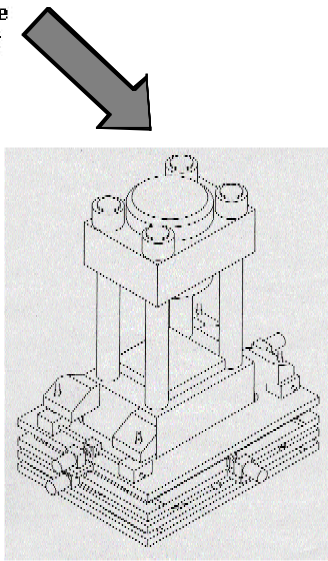




High Pressure Neutron Diffractometry

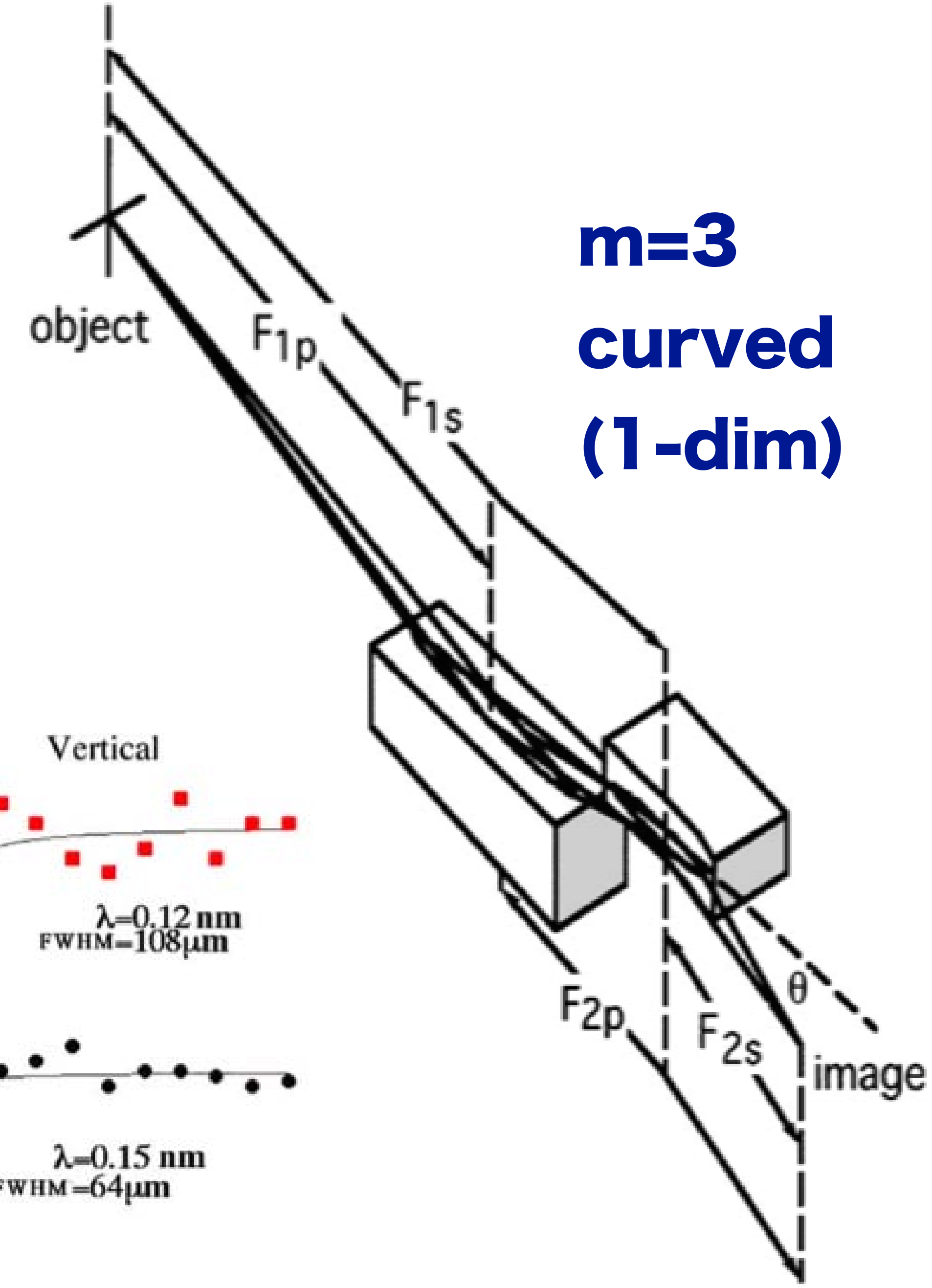




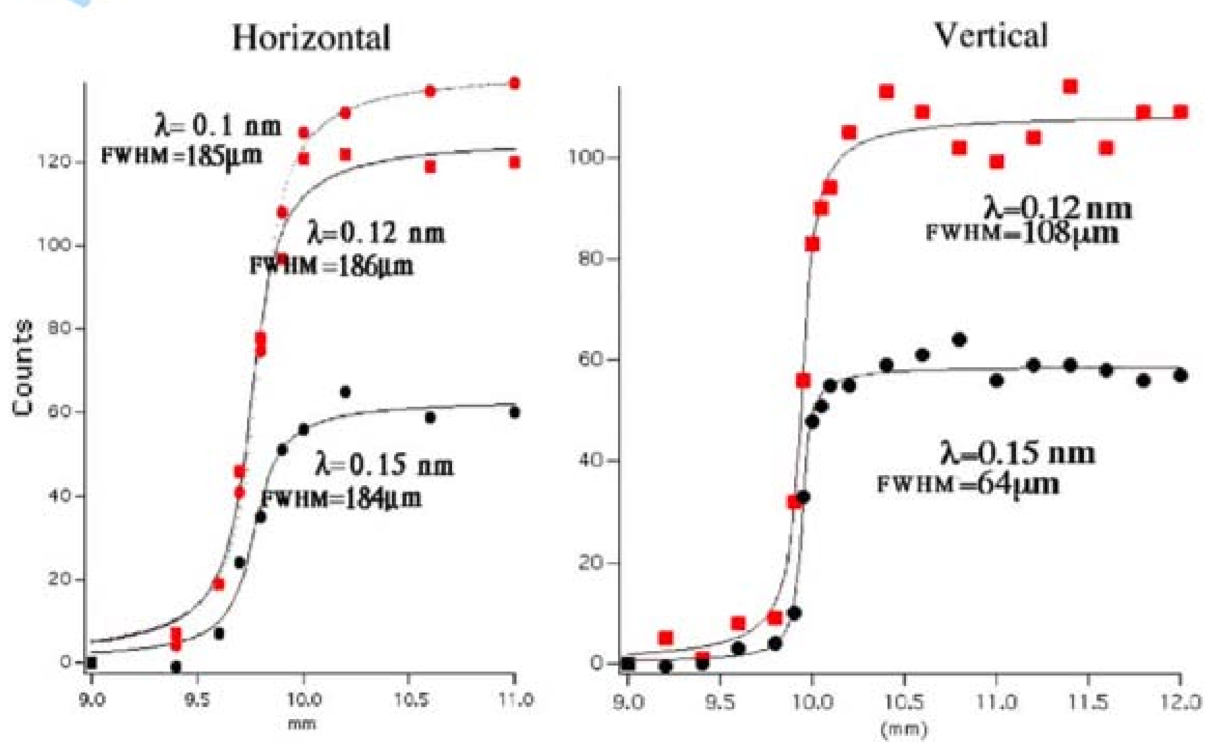


Kirkpatrick-Baez Optics

G.Ice et al., Nucl. Instrum. Methods A539 (2005) 312

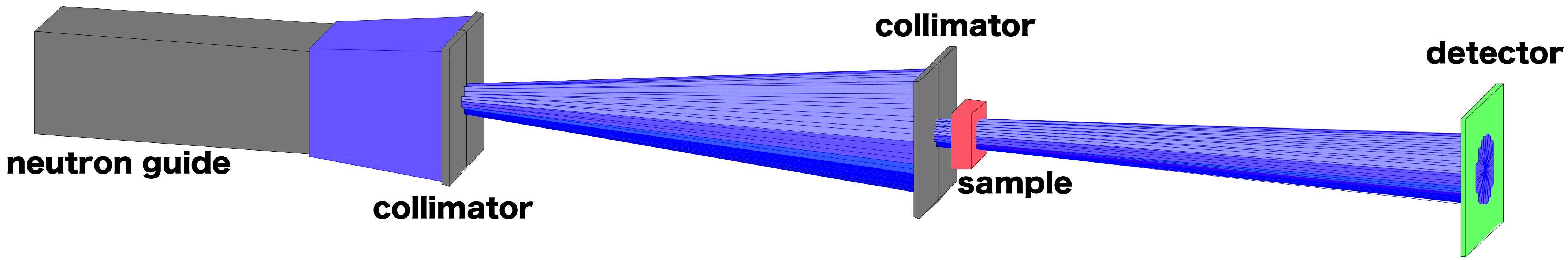


m=3
curved
(1-dim)

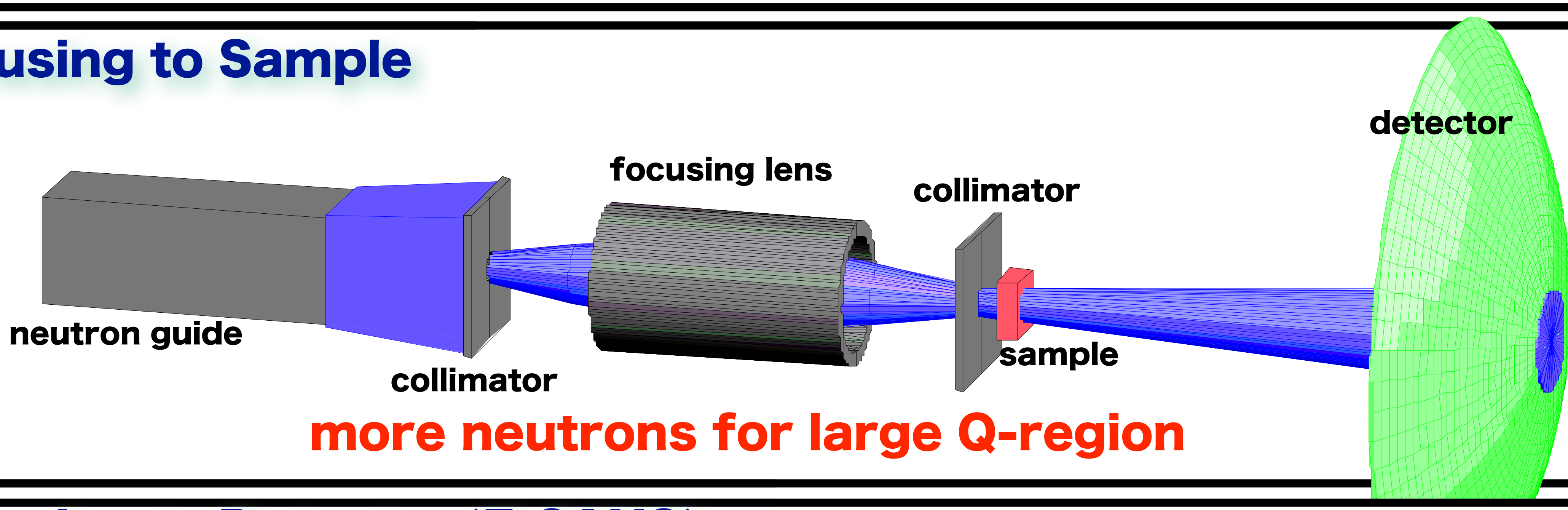


Example: Small Angle Neutron Scattering

Pin-hole Geometry (P-SANS)

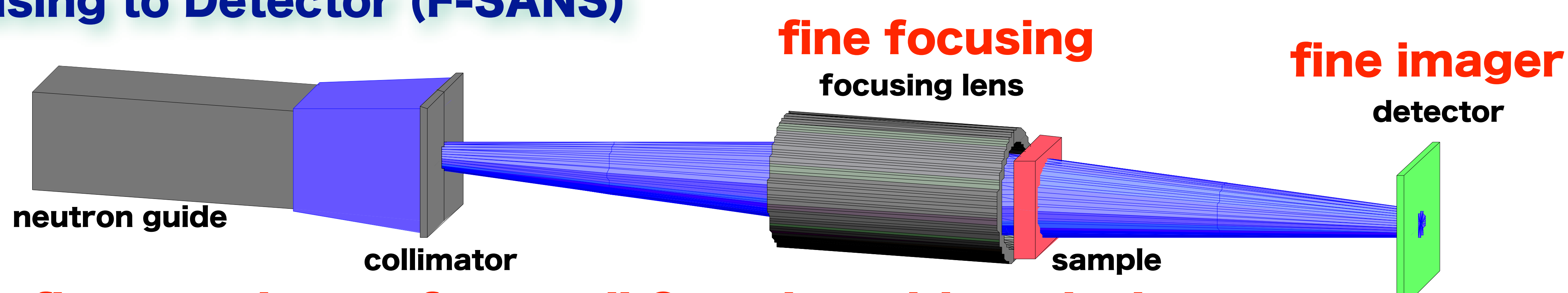


Focusing to Sample



more neutrons for large Q-region

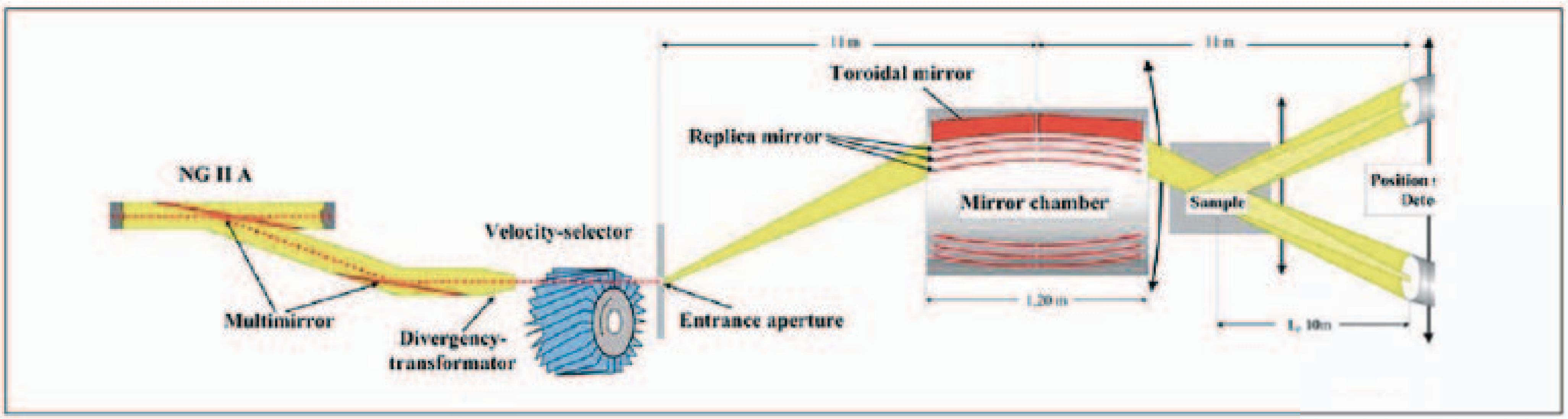
Focusing to Detector (F-SANS)

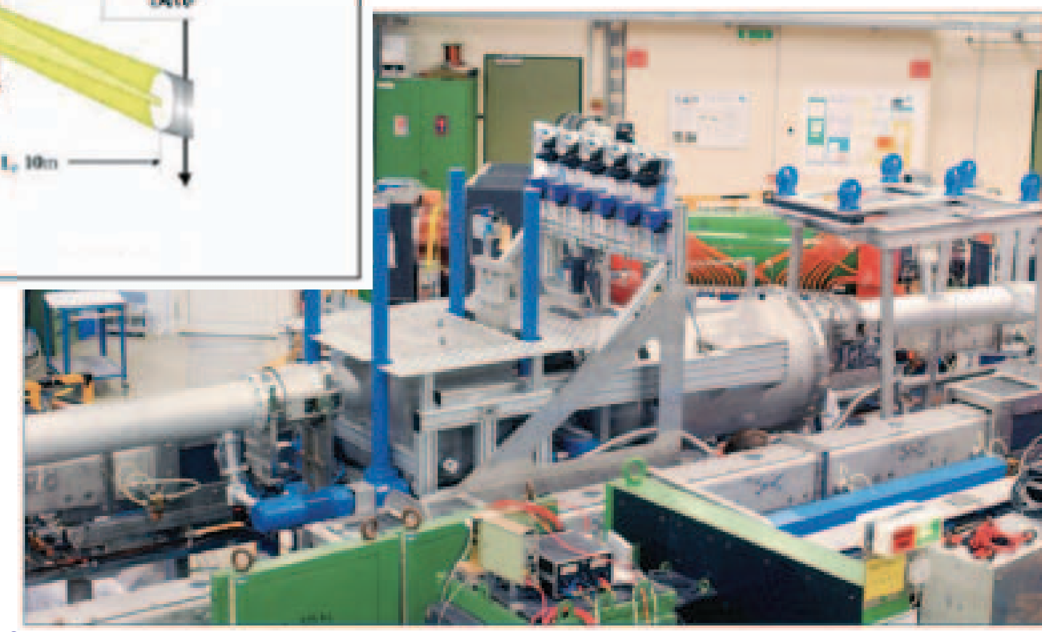


fine spot image for small Q-region without losing neutrons

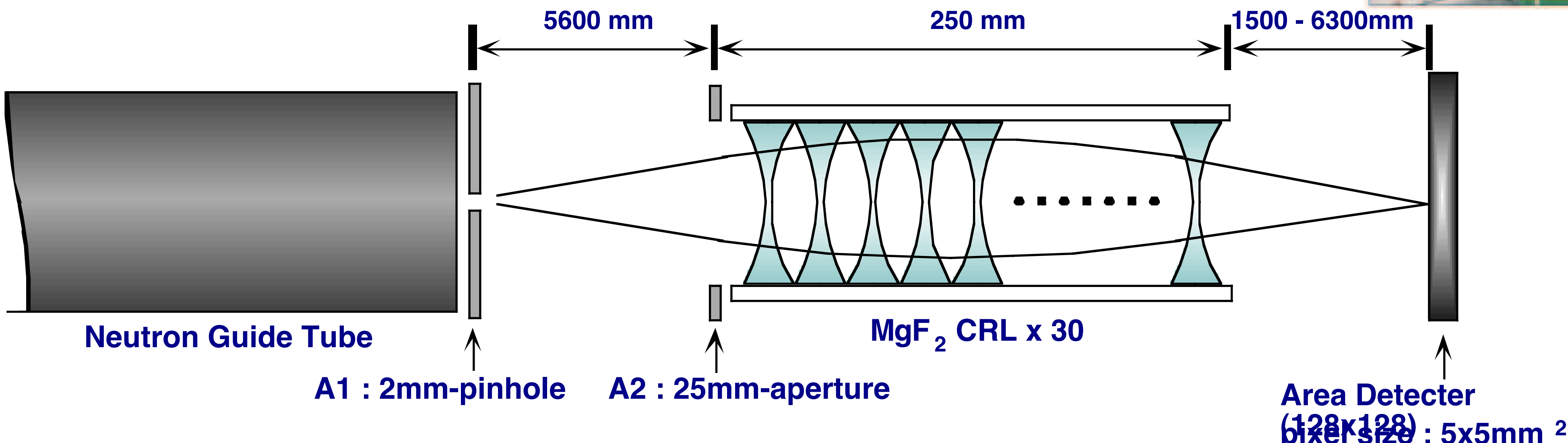
Focusing SANS

Focusing-Mirror High-Resolution SANS and Reflectometer (KWS-3)



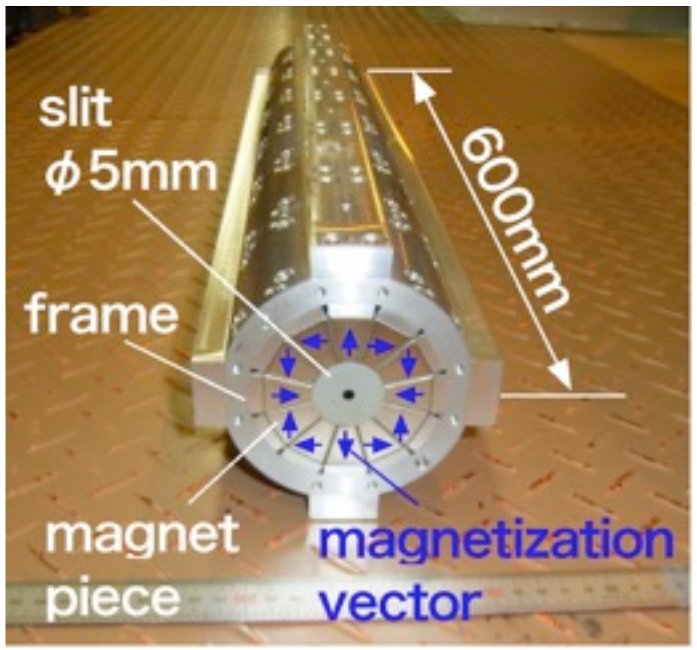


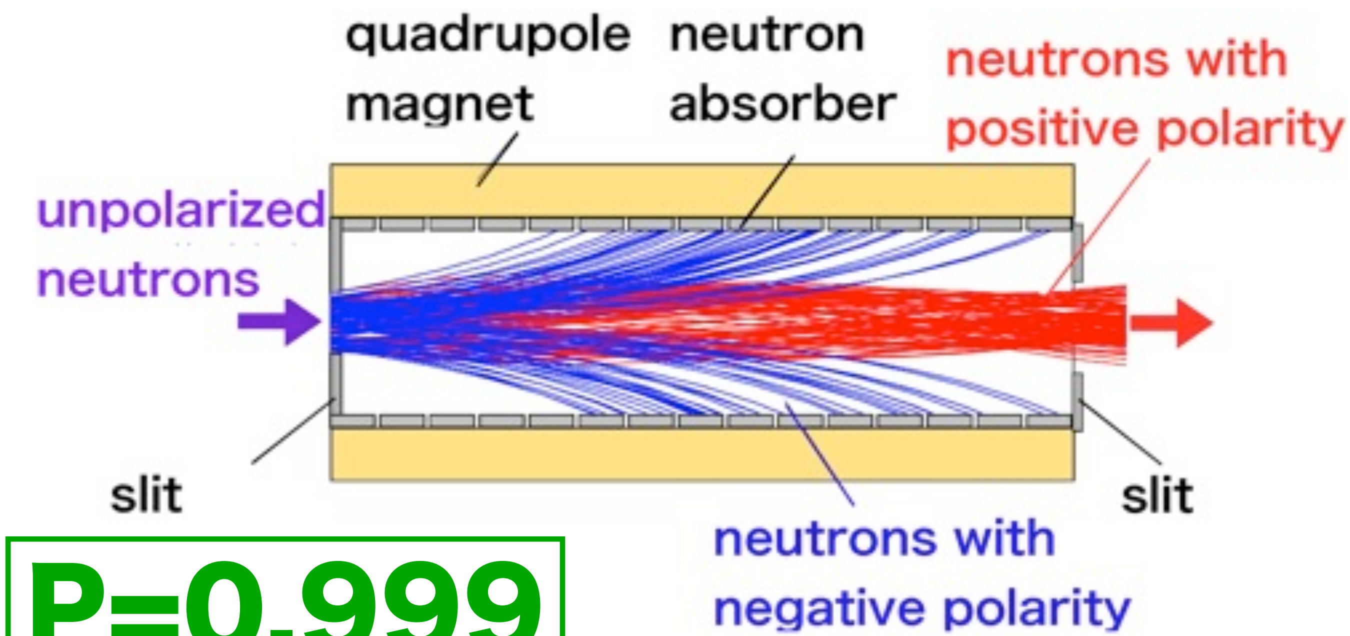
Focusing-Lens SANS (NIST)



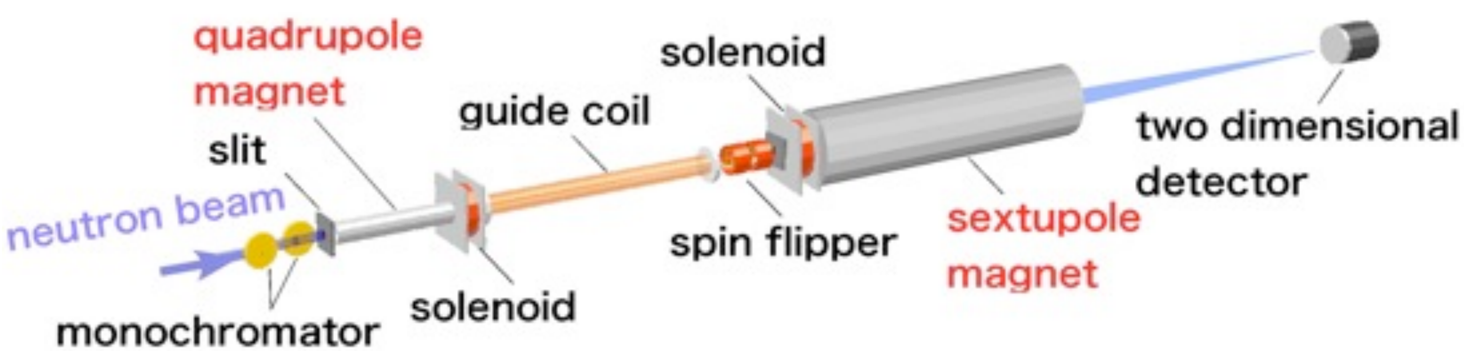
Biconcave MgF_2 lens x 30

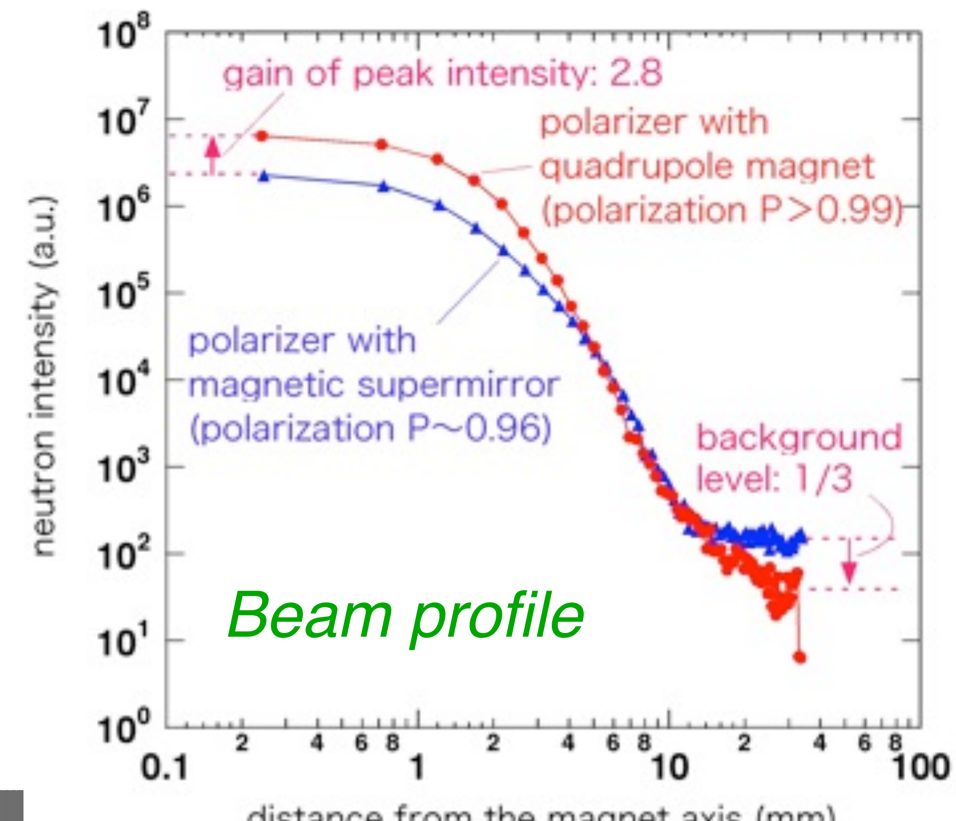
Focusing SANS with Quadrupole and Sextupole Magnetic Lens





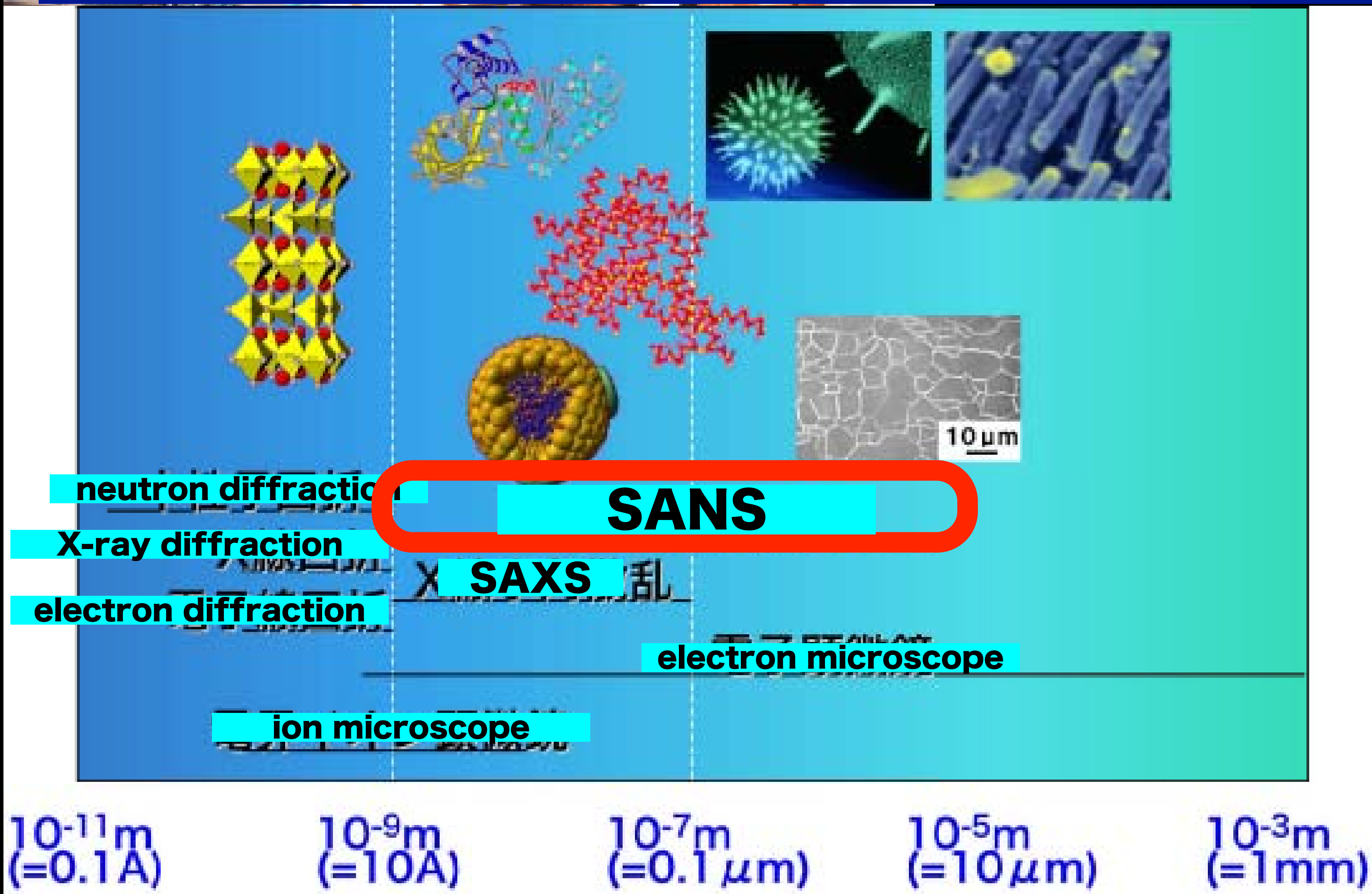
P=0.999

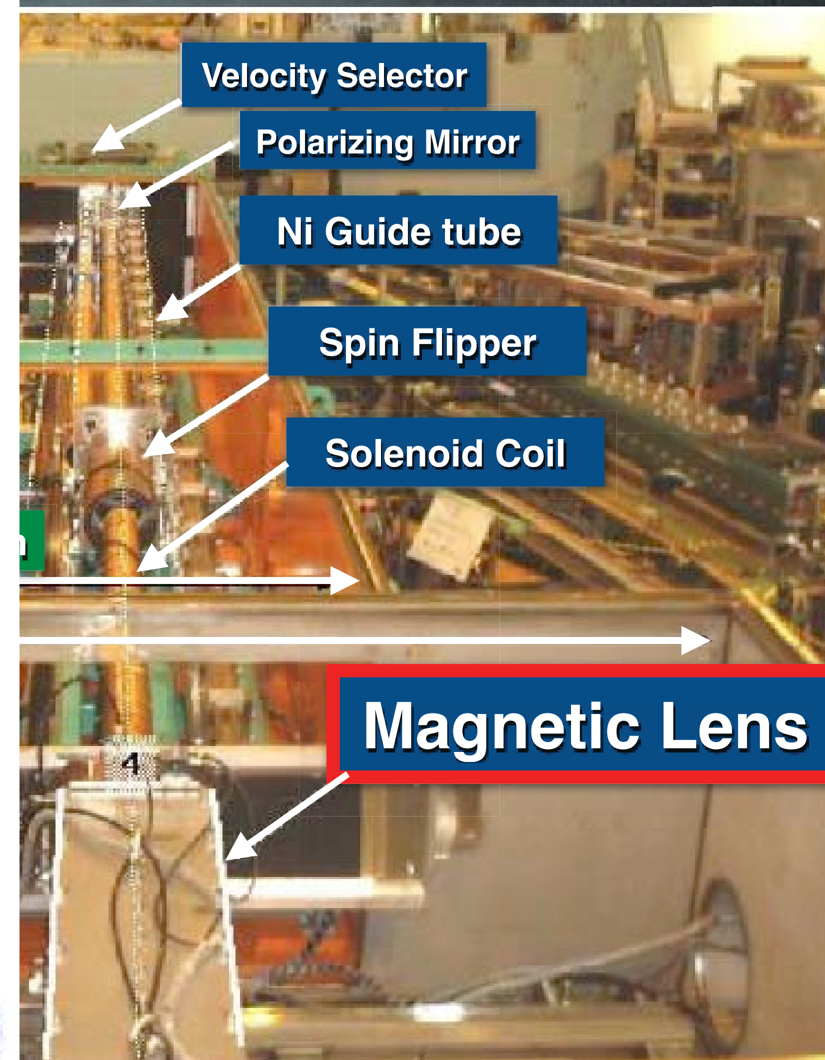




Focusing options implemented at
JRR-3)

accesible range expanded up to micrometers





Focusing SANS

beam efficacy enhancement more than 100 times

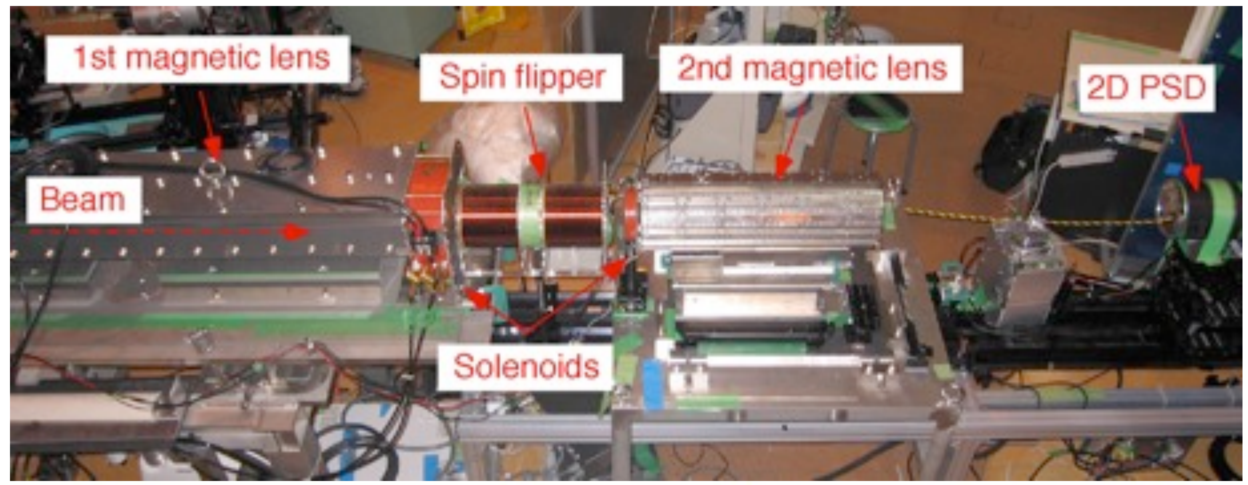
collimator section of SANS-J-II

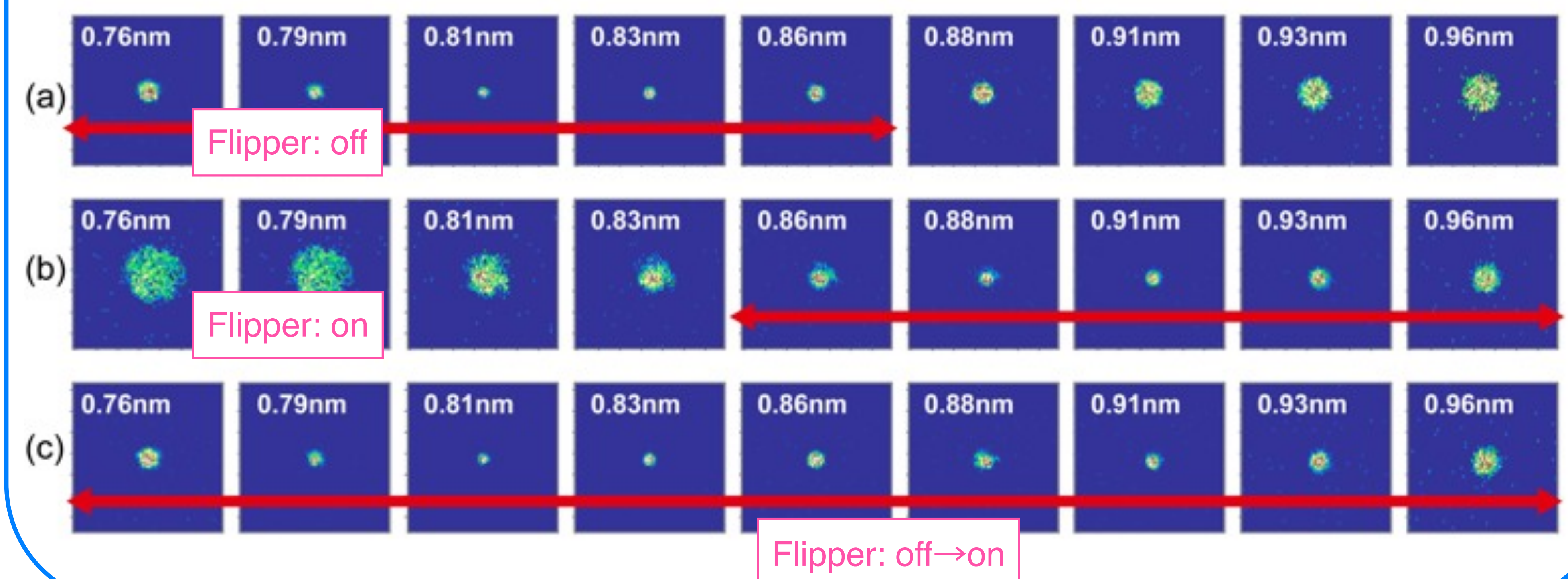
Extended Application to Pulsed Sources

Multiplet with Spin-flippers

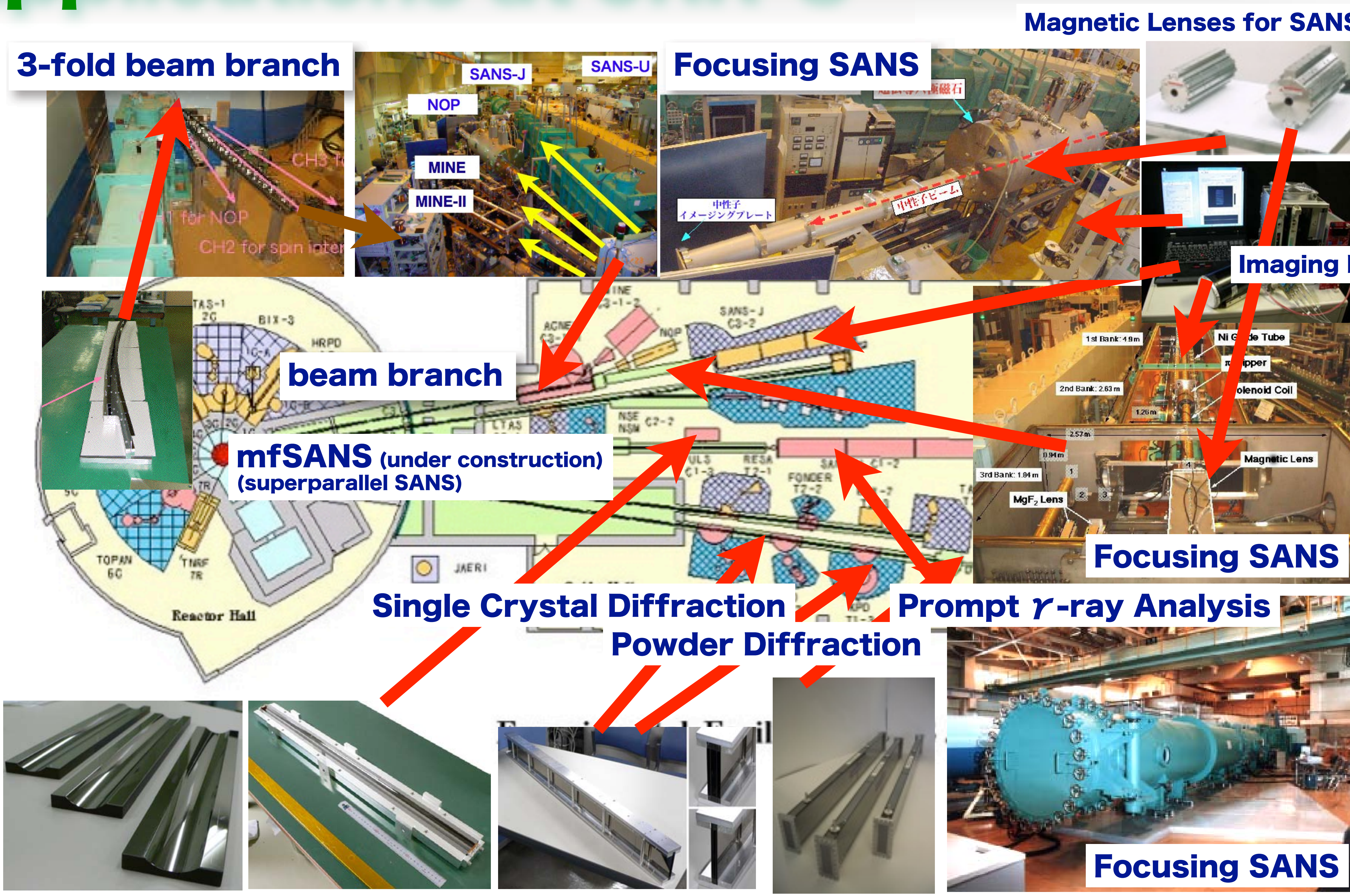
Focusing for wide-λ

JRR-3





Applications at JRR-3



Ellipsoidal Supermirrors for mfSANS

Multichannel Focusing Guides

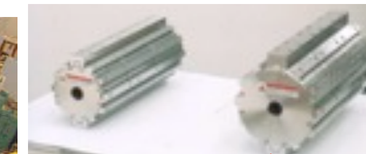
M.Furusaka, Hokkaido Univ.

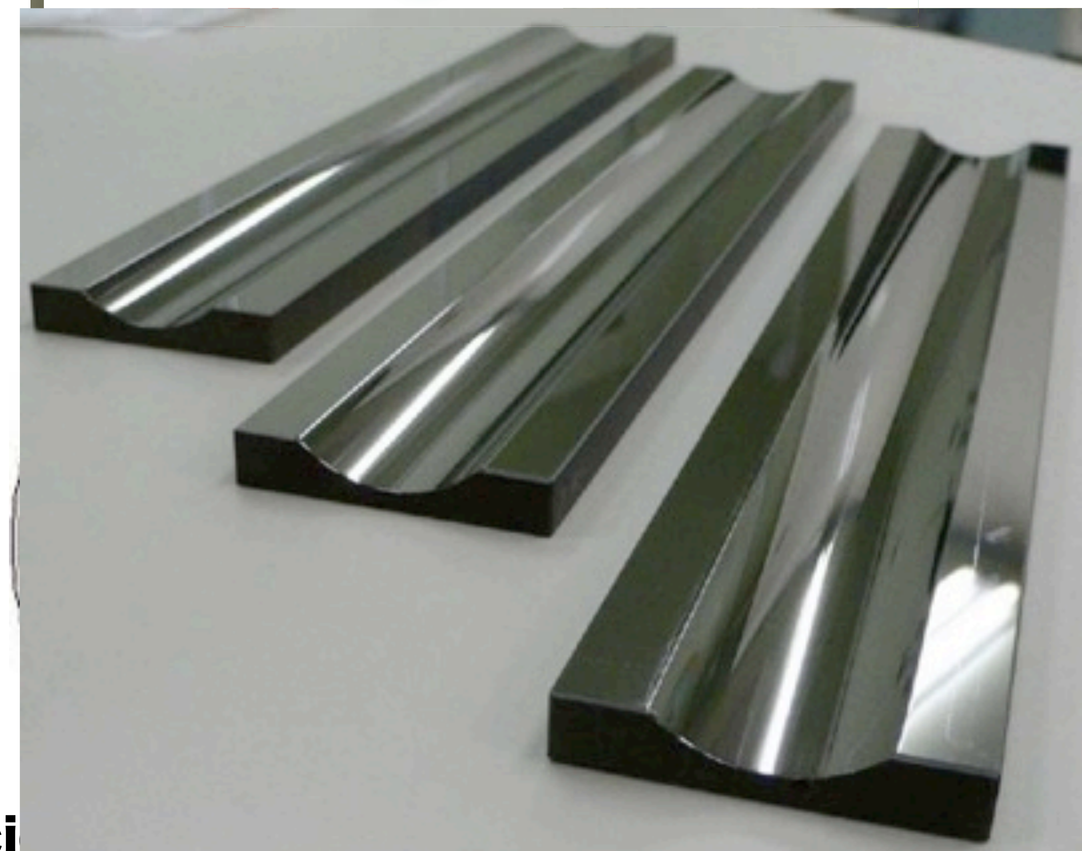
Applications at JRR-3

Ellipsoidal Mirror
for Micro-Focusing SANS

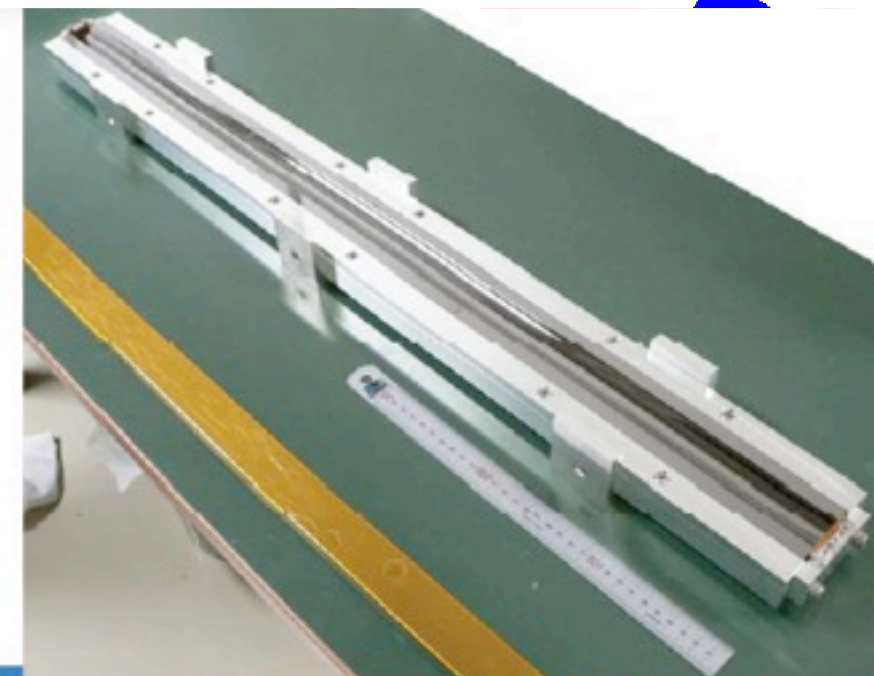
Pa... use of many mfSANS's
more branches...
individual mfSANS unit

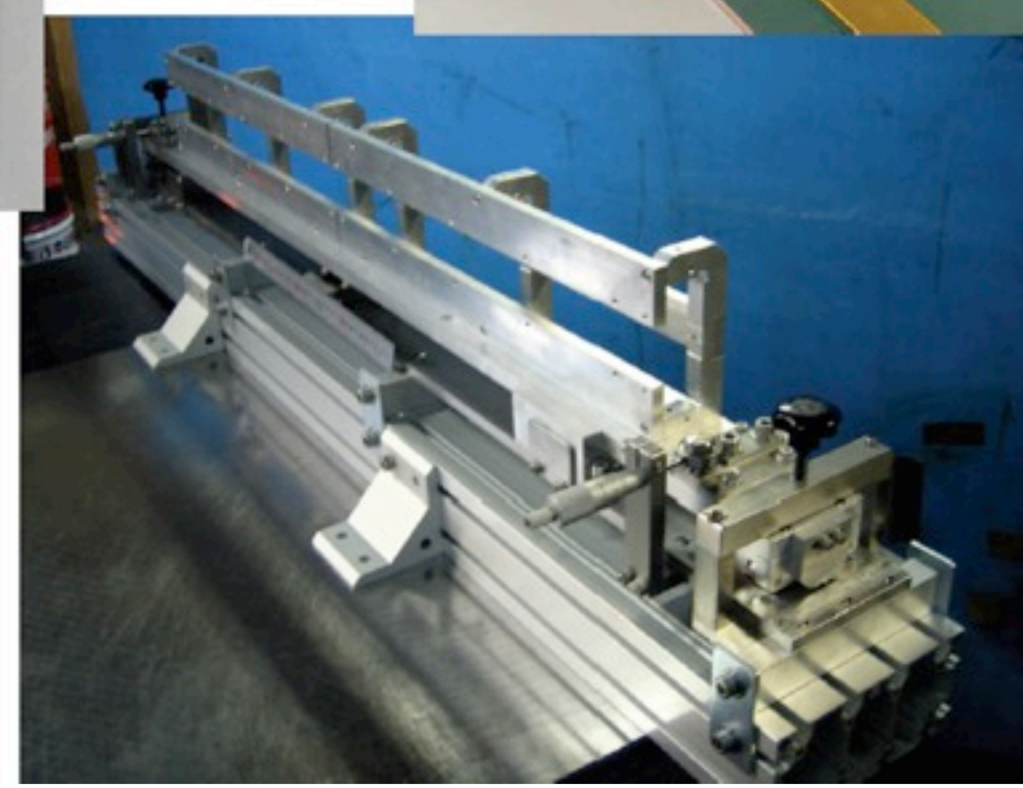
Magnetic Lenses for SANS



Made by JNOP





ectors

time
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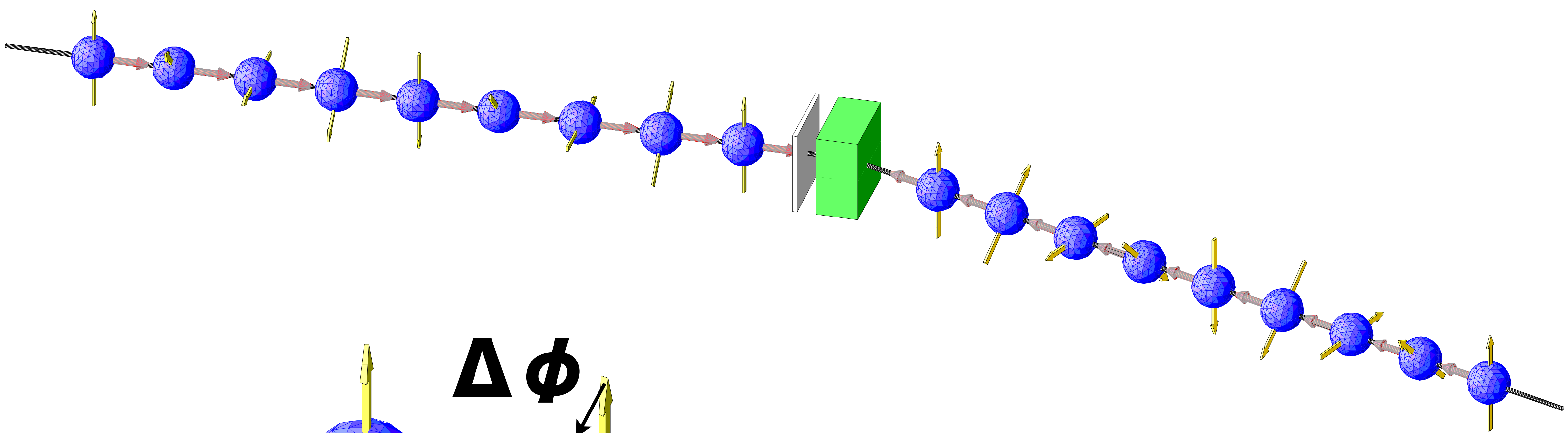
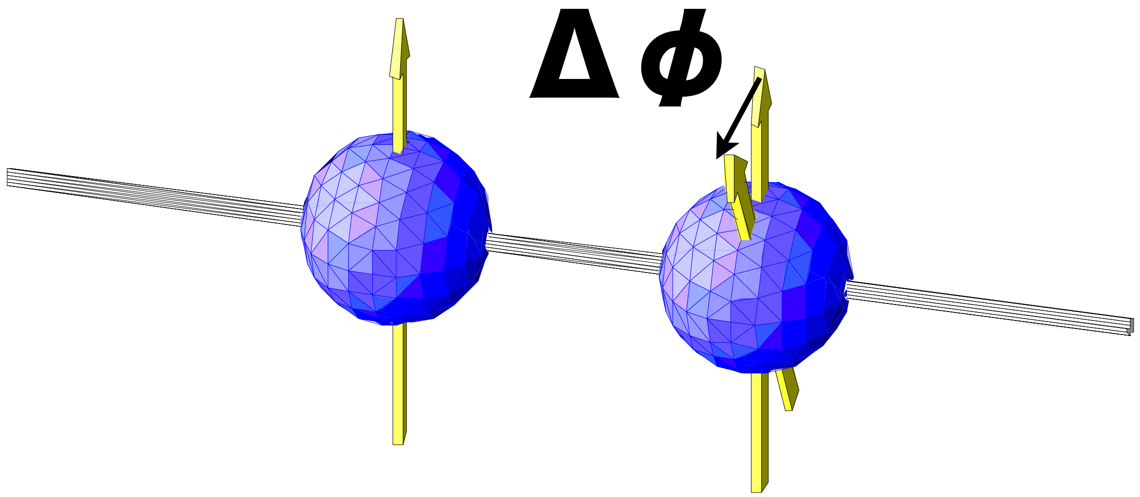
Elli

Neutron Spin Echo

measures momentum transfer and energy transfer for observation of slow dynamics



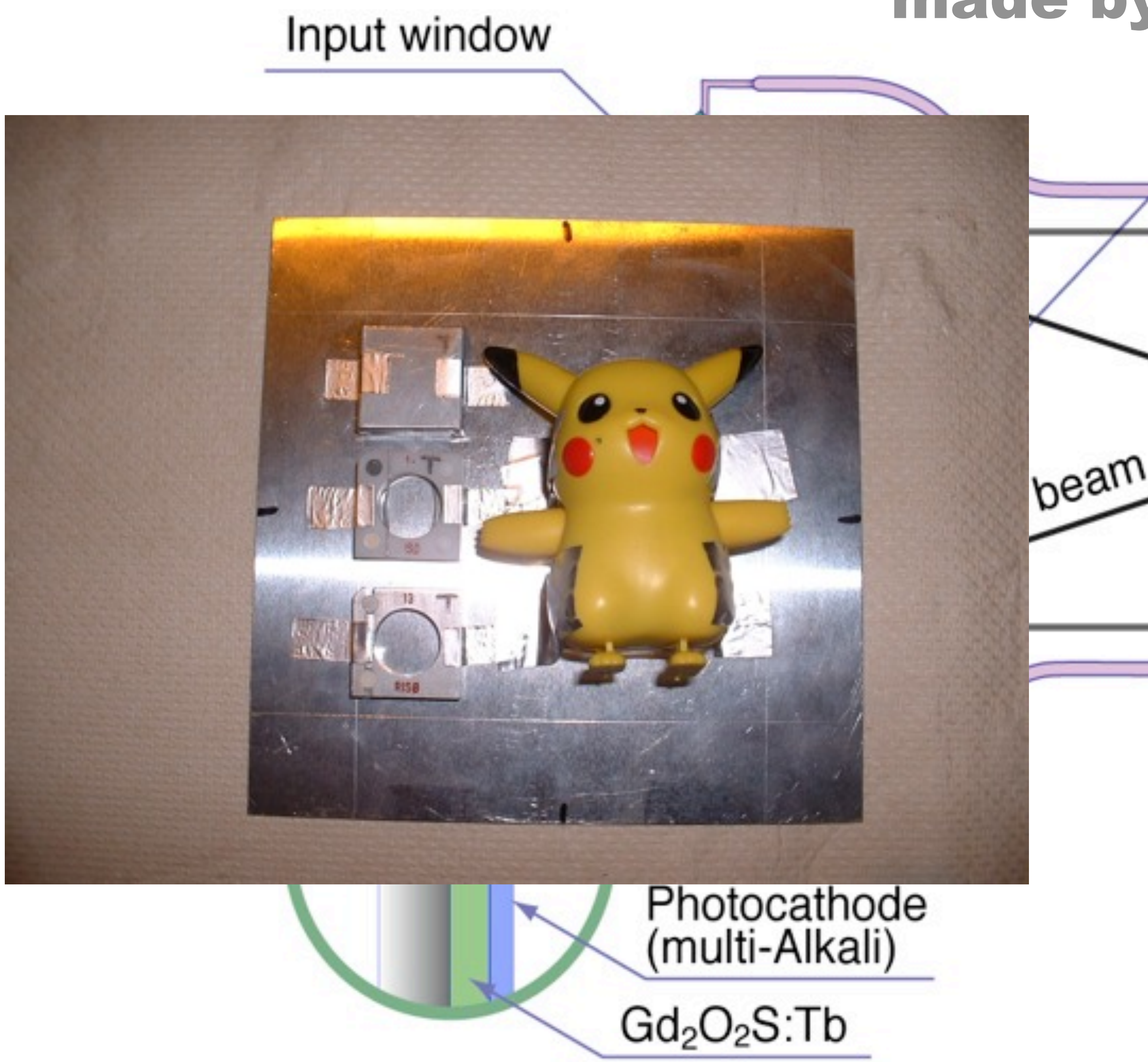


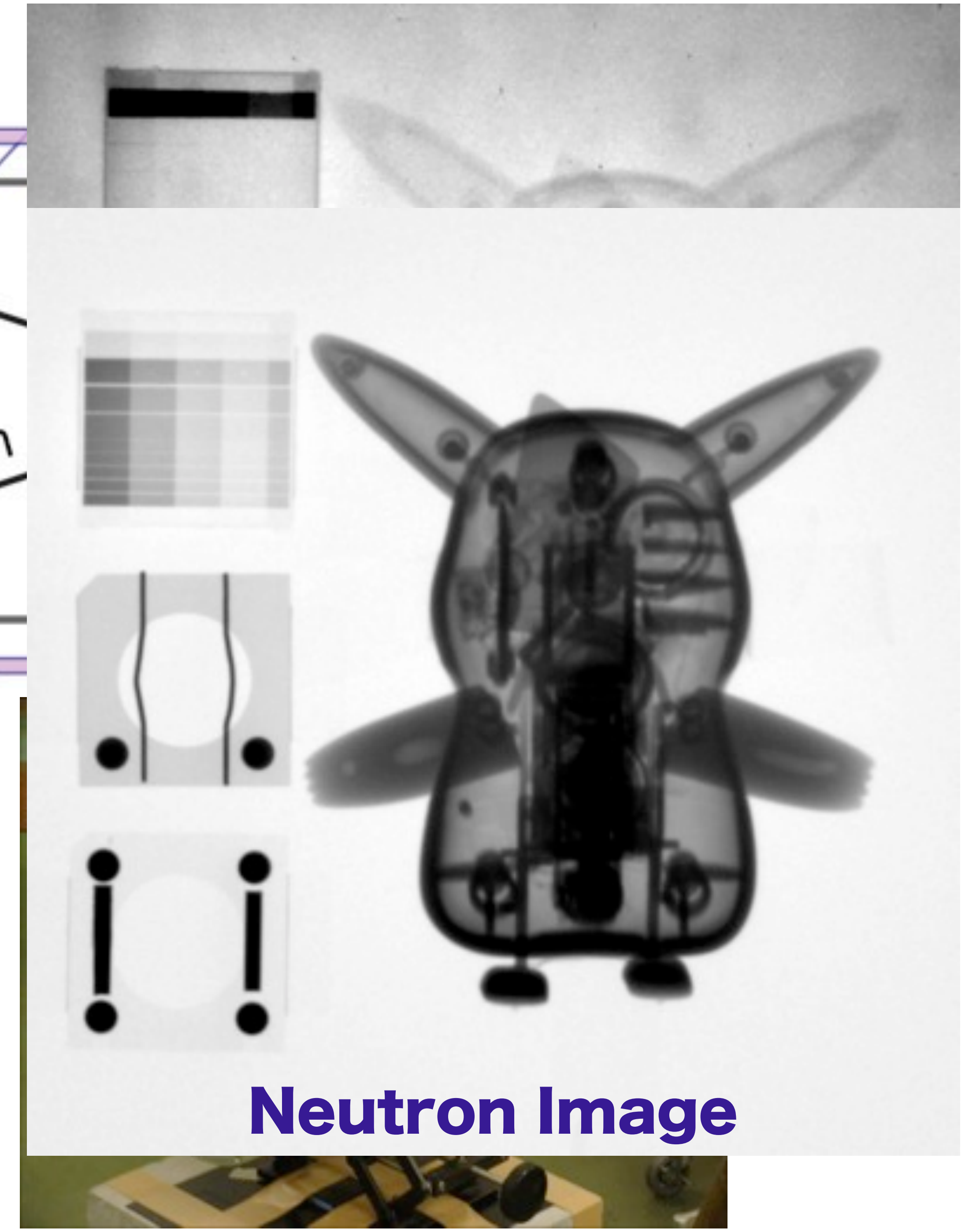
$\Delta\phi = 0$ if $\Delta E = 0$

Imager

Neutron Image Intensifier

made by Toshiba Corporation



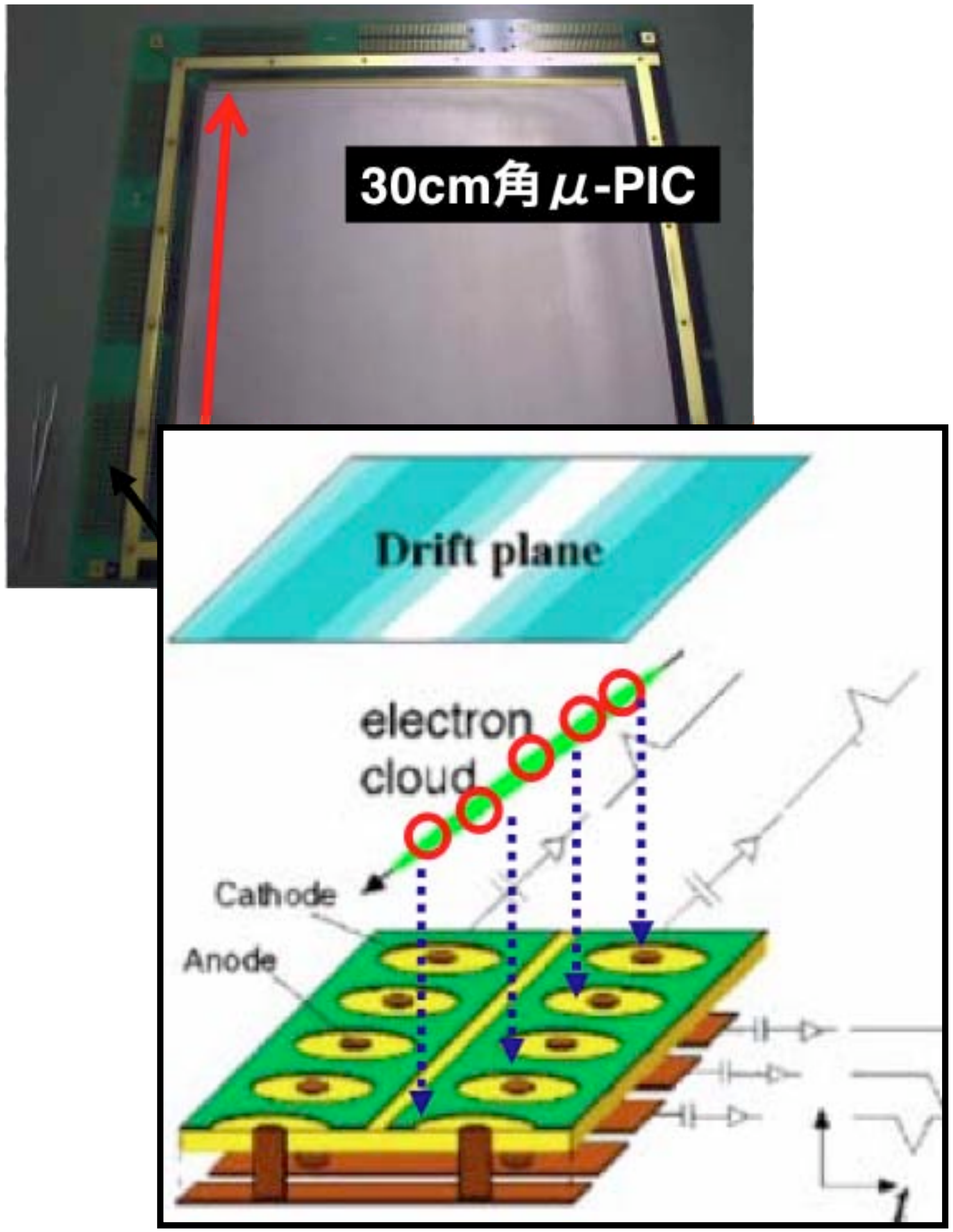


□9, 6, and 4.5 inch

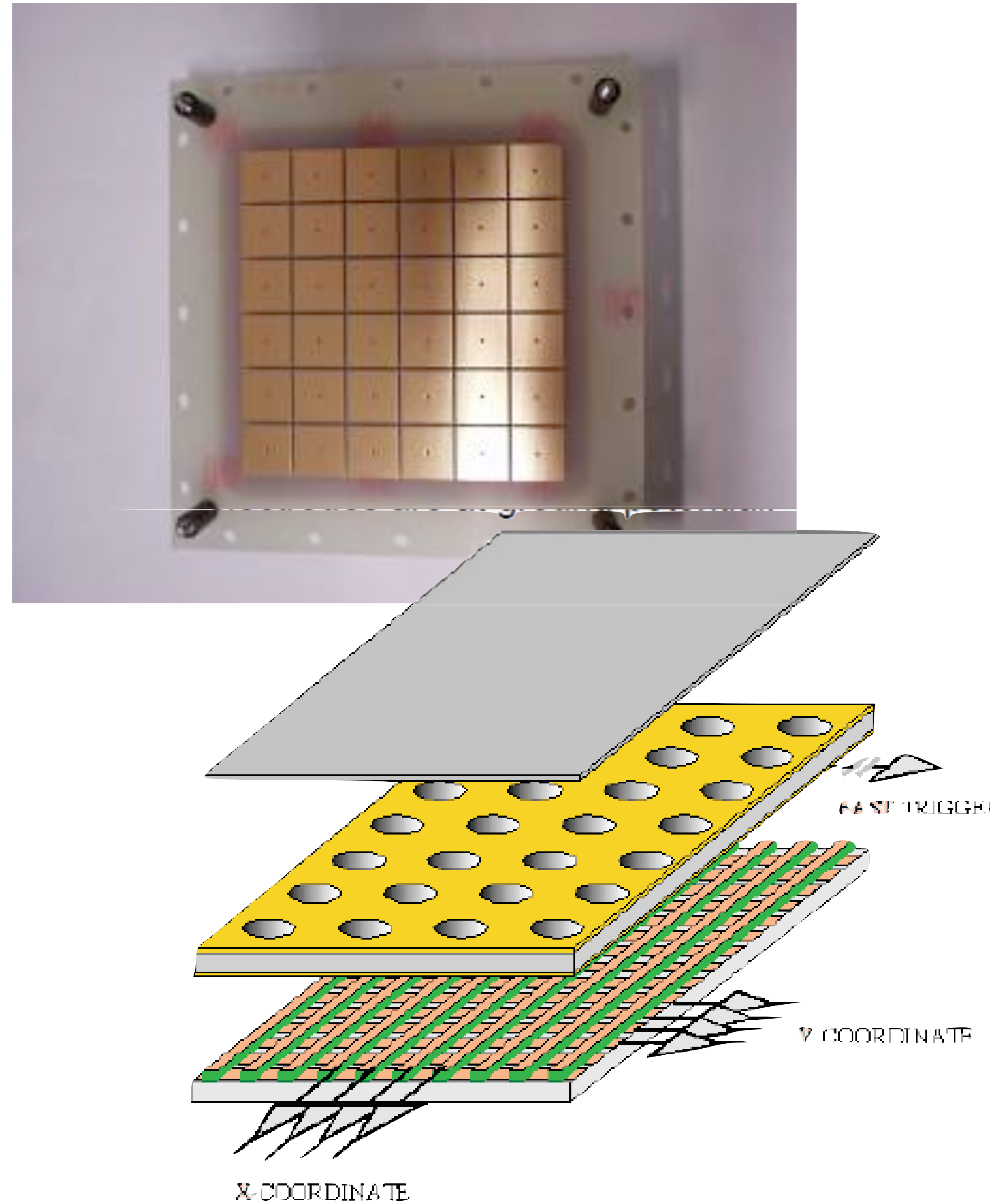
Imager

MPGD (Micro Patterned Gaseous Detector)

μ-PIC (Kyoto Univ.)

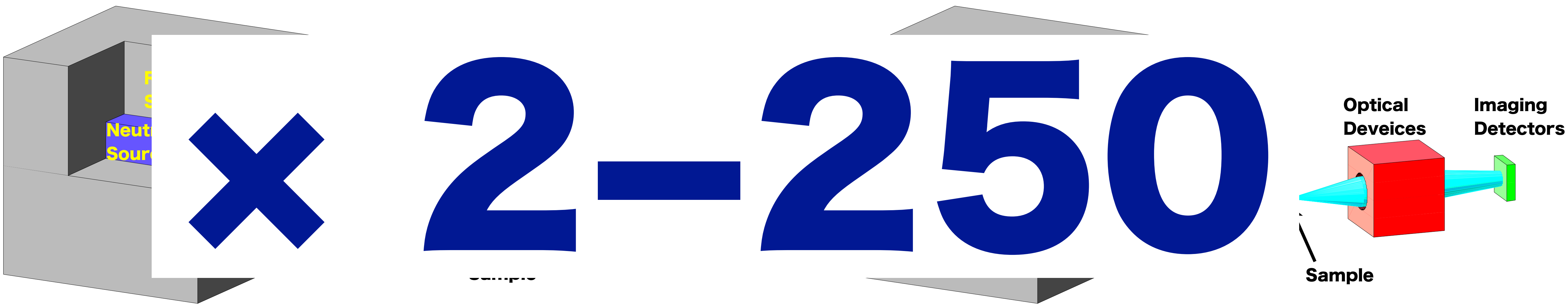


GEM (KEK)



Neutron Optics

Advances in neutron optics enhance the capability of neutron beam.



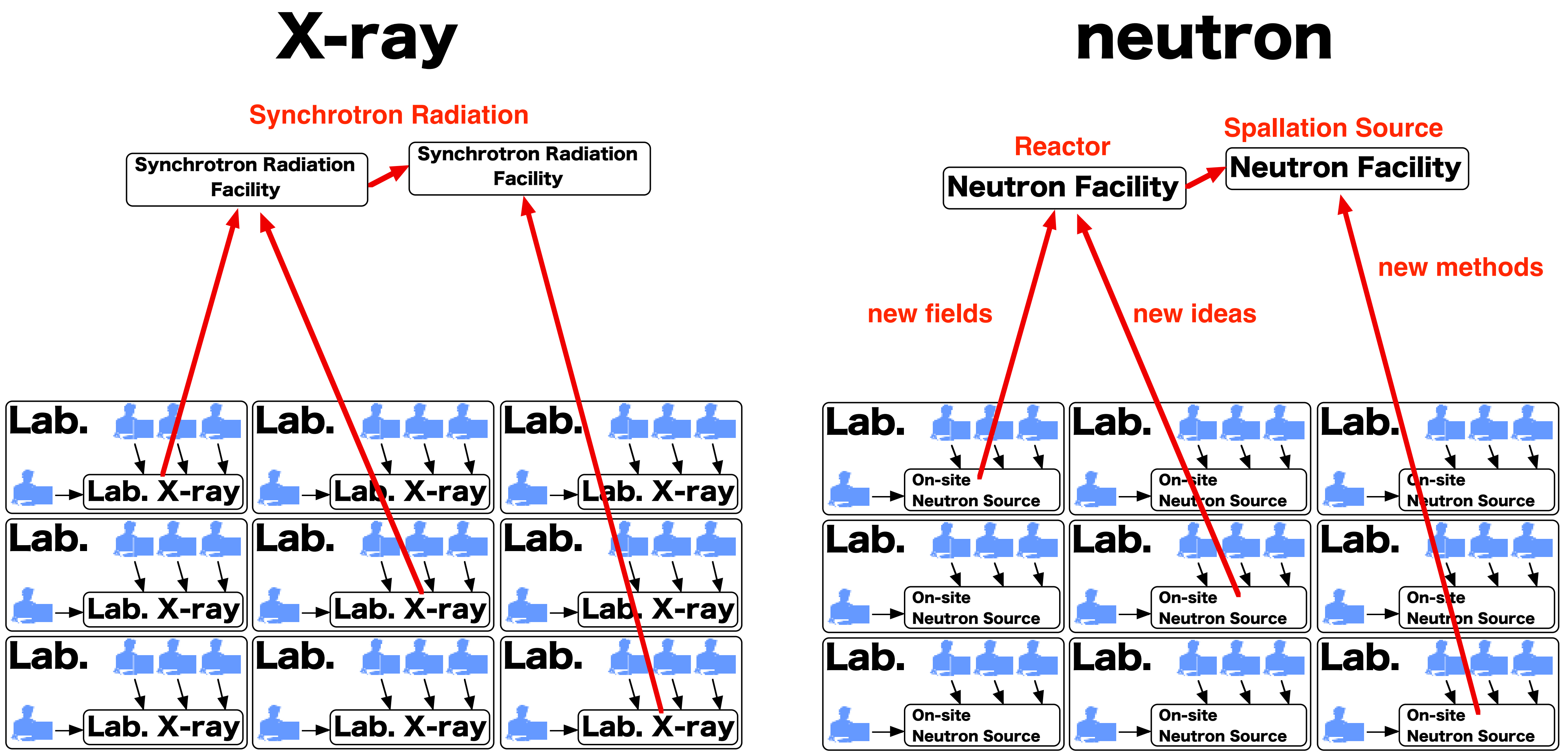
× 2–250

	conventional		advanced neutron optics
Efficacy of Neutron Beam Utilization			
Large-scale Neutron Facility			
Small- and Medium-scale Neutron Sources			

← **Existing Window**

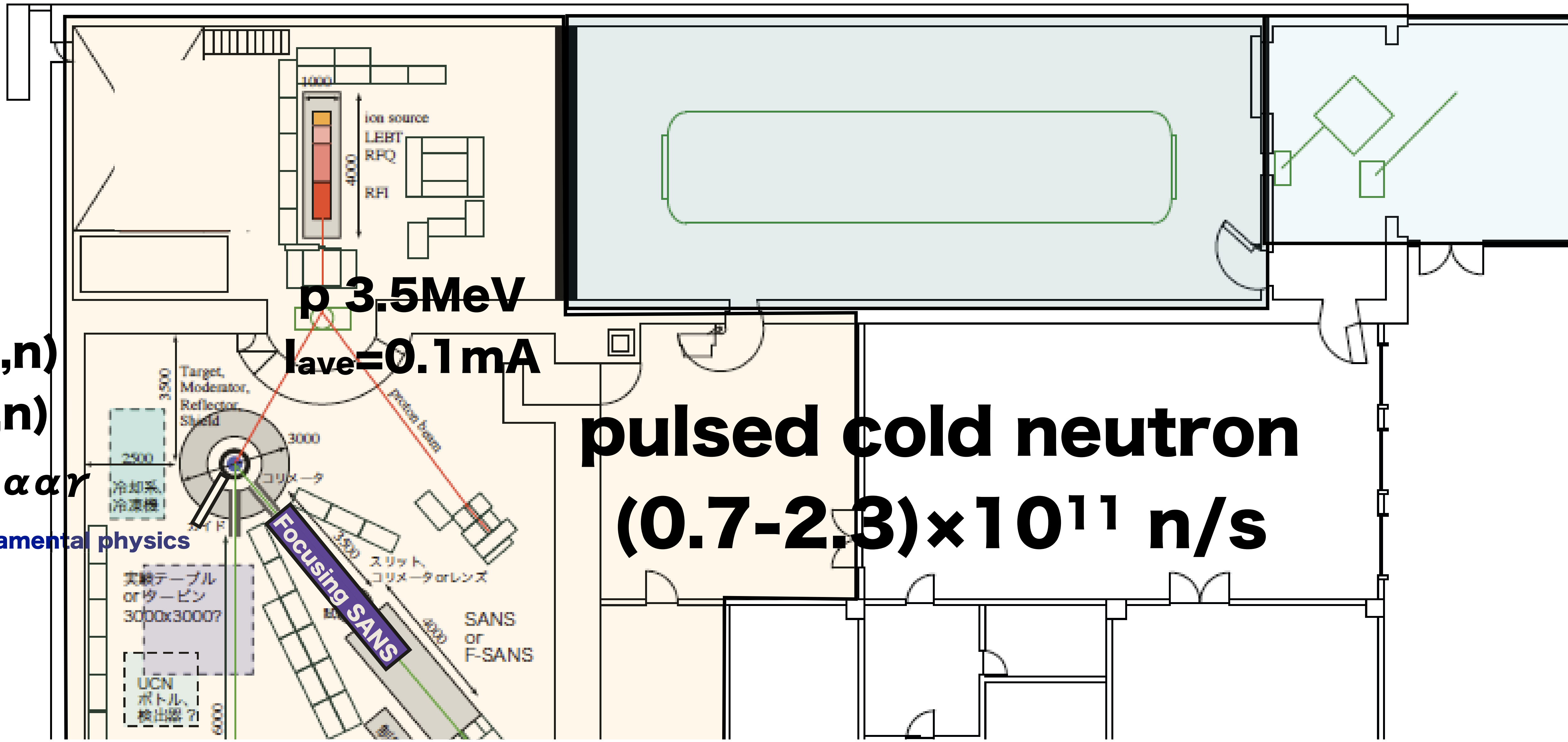
↑ **Newly Activated Window**

Compact Neutron Source



more opportunities to incubate new ideas, pioneering works and epoch-making break-throughs for both of fundamental and material researchs

Compact Source at Kyoto



$^{9}Be(p,n)$

$^{7}Li(p,n)$

$^{7}Li(p,n)\alpha\alpha\gamma$

fundamental physics

p 3.5MeV

I_{ave}=0.1mA

pulsed cold neutron

(0.7-2.3)×10^{11} n/s

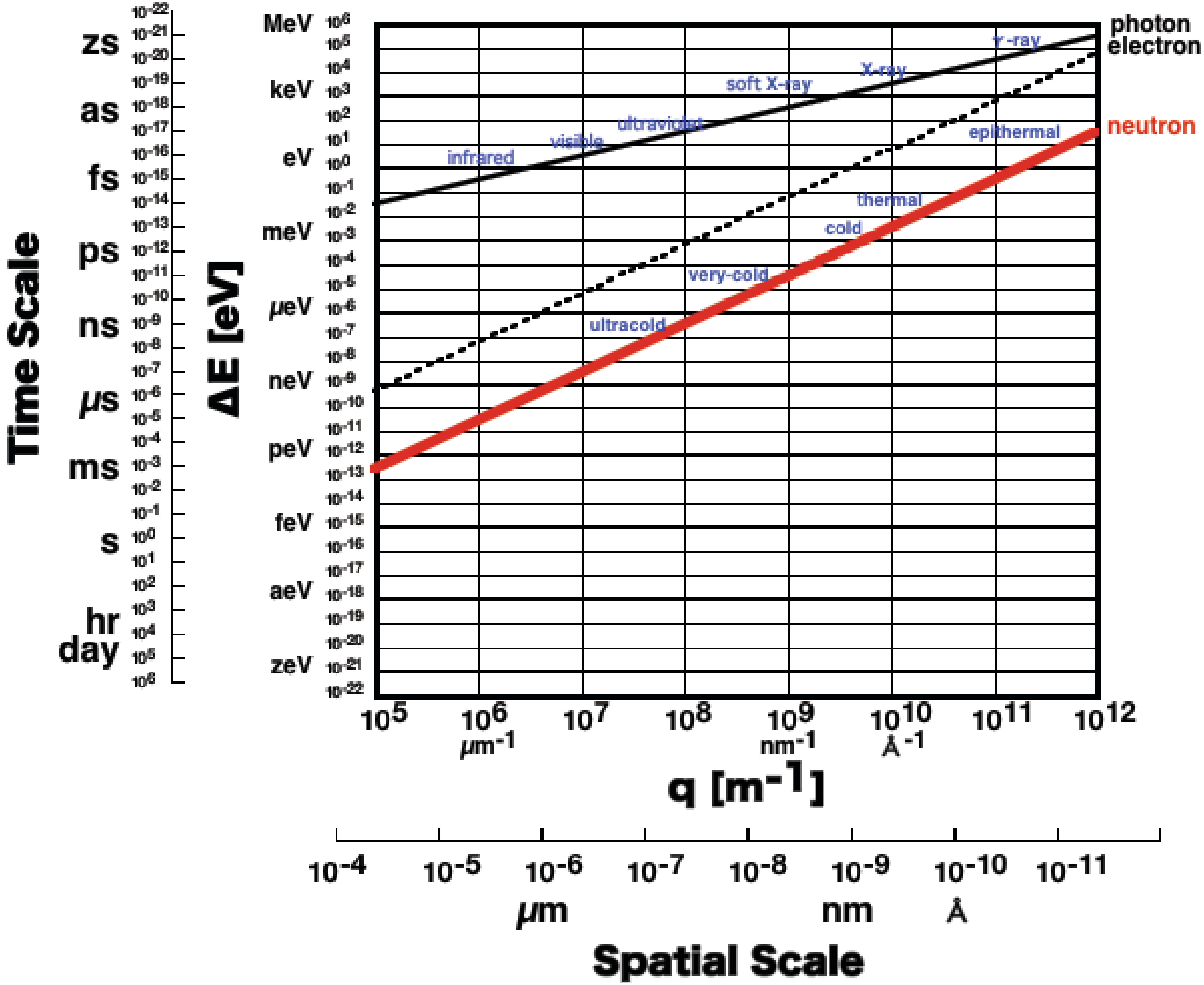
to be discussed on Feb. 19

Feb.19, 13:00-17:30

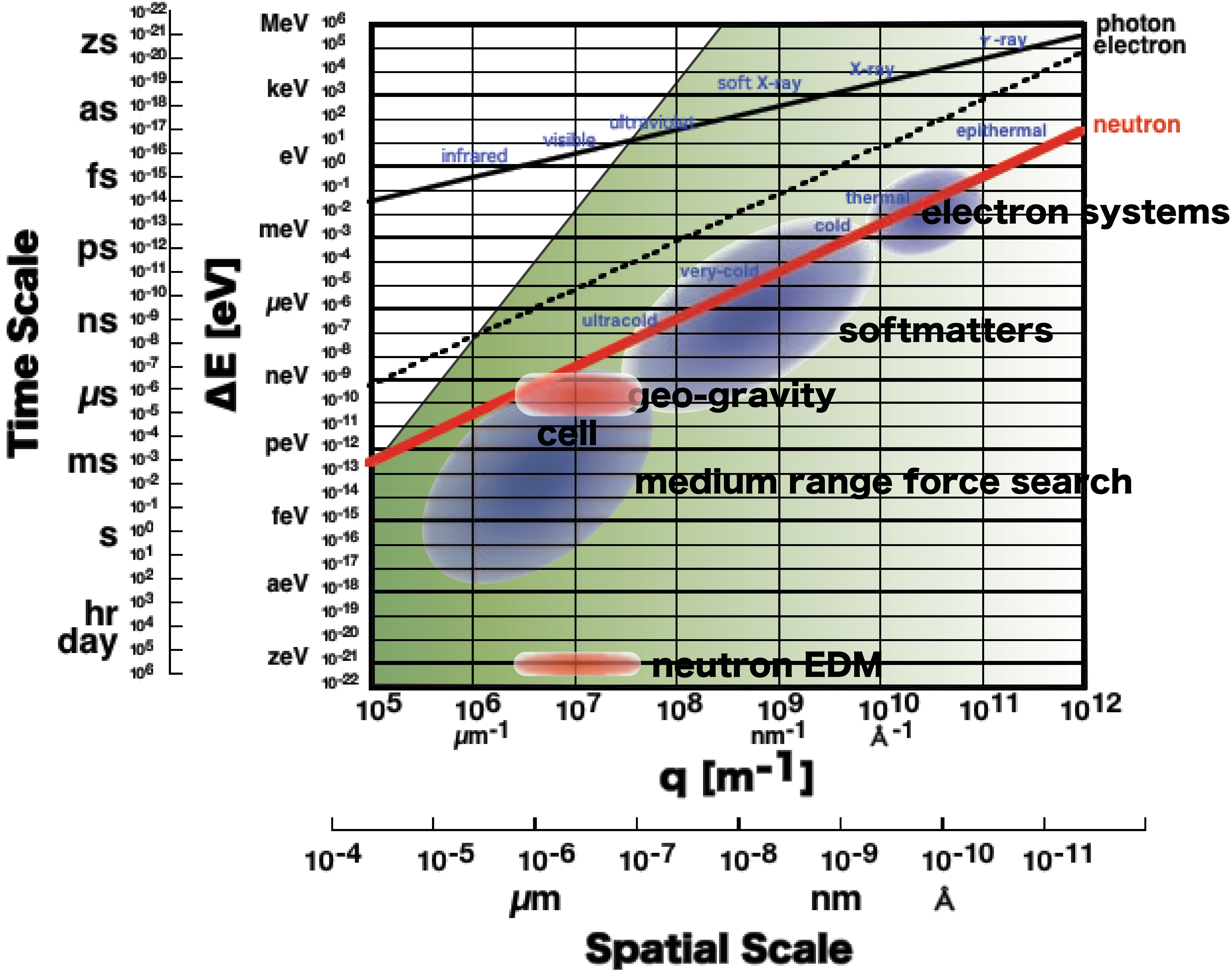
Room#525 Building #5 Faculty of Science, Kyoto Univ.

http://www-nh.scphys.kyoto-u.ac.jp/QuantumBeam/

3. summary



Time Scale
zs
as
fs
ps
ns
μs
ms
s
hr
day
ΔE [eV]
MeV
keV
eV
meV
μeV
neV
peV
feV
aeV
zeV
photon
electron
neutron
γ-ray
X-ray
soft X-ray
ultraviolet
visible
infrared
epithermal
thermal
cold
very-cold
ultracold
μm-1
nm-1
Å-1
q [m-1]
μm
nm
Å
Spatial Scale


Time Scale
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ΔE [eV]
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neutron
γ-ray
X-ray
soft X-ray
ultraviolet
visible
infrared
epithermal
thermal
cold
very-cold
ultracold
electron systems
softmatters
geo-gravity
cell
medium range force search
neutron EDM
q [m-1]
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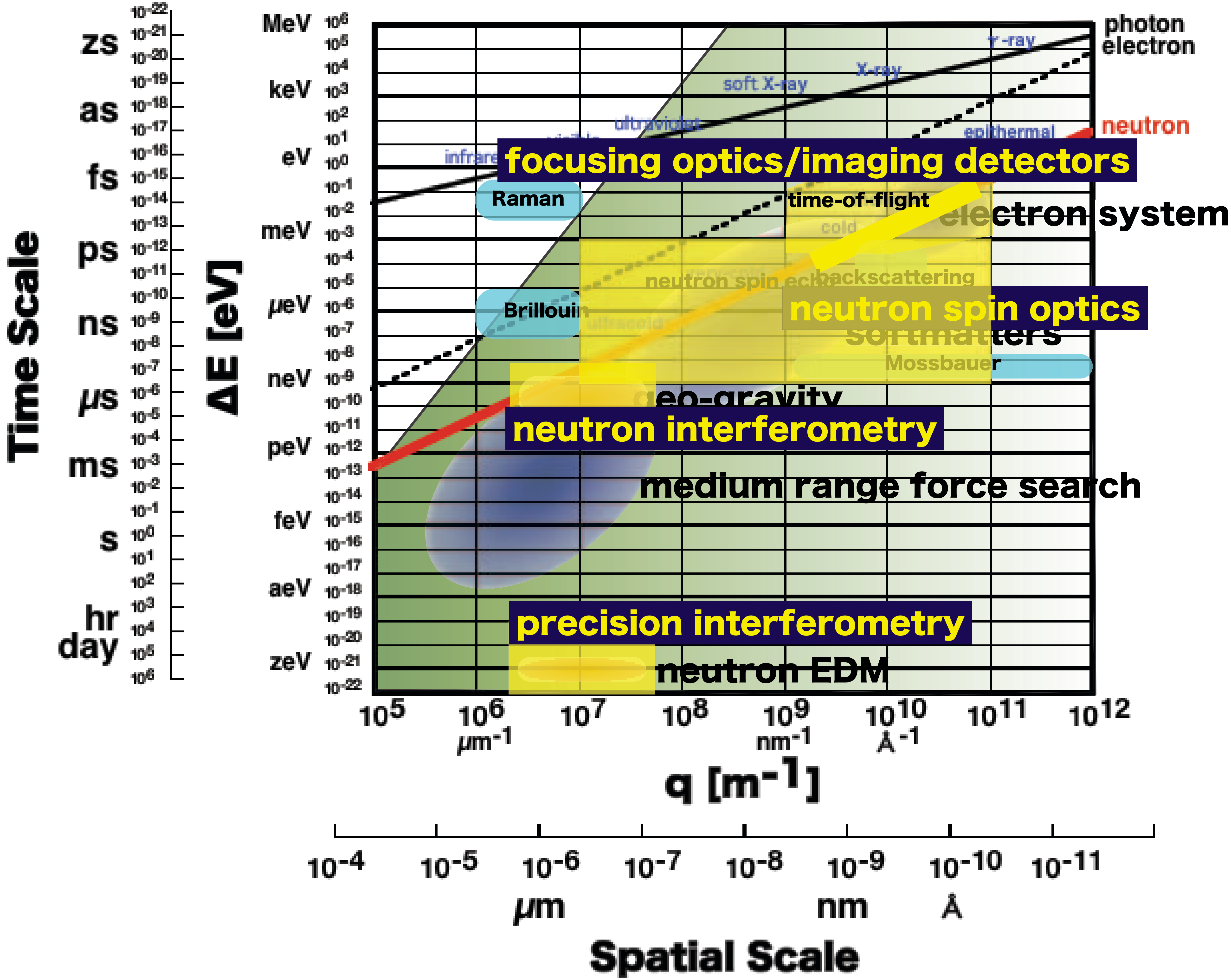
nm-1
Å-1
μm
nm
Å
Spatial Scale


Time Scale
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ΔE [eV]
MeV
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neV
peV
feV
aeV
zeV
photon
electron
neutron
γ-ray
X-ray
soft X-ray
ultraviolet
epithermal
focusing optics/imaging detectors
Raman
time-of-flight
electron system
cold
neutron spin echo
backscattering
neutron spin optics
Brillouin
softmatters
Mossbauer
geo-gravity
neutron interferometry
medium range force search
precision interferometry
neutron EDM
q [m-1]
μm-1
nm-1
Å-1
μm
nm
Å
Spatial Scale

Neutron Science (Interdisciplinary Playground)

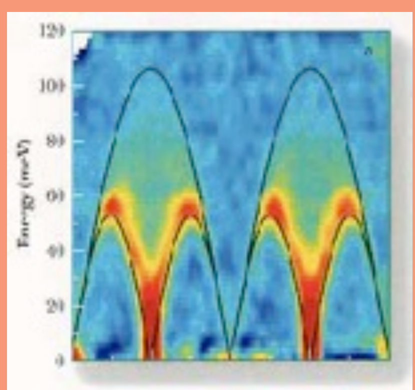
Material Science

Diffraction

λ=0.1-10nm


Spectroscopy

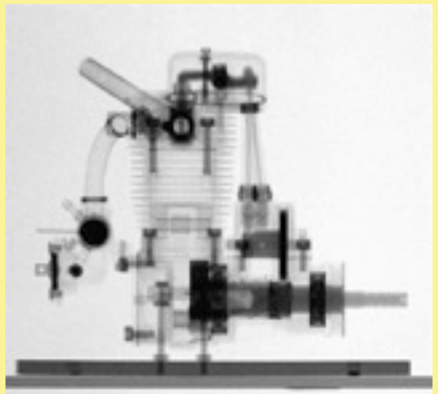
ΔE<100meV t>10^{-13}s



Industry

Radiography

Residual Stress



Neutron Optics

Optics

Detectors

Signal Processing

Neutron EDM

Decay

Gravity

Fundamental Physics

motive force of innovation