Neutron Diffractometers: Overview

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- 2021.3　J-PARC Center, High Energy Accelerator Research Org., Japan

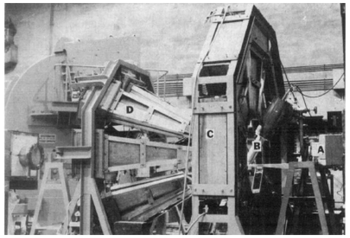
My past 40 years: Increase in Neutron Intensity by 10^4—10^5

(in Kamiyama's research life)

Electron accelerator

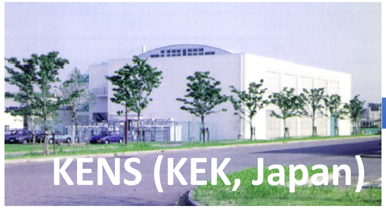
Tohoku Univ. (Japan)

First diffractometer

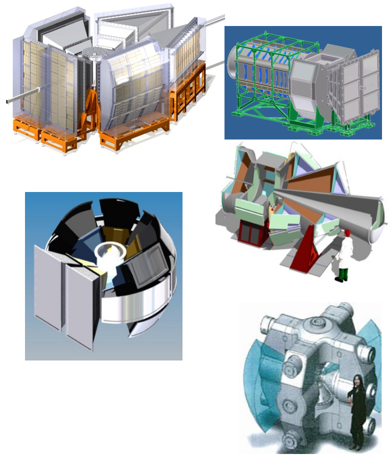


1

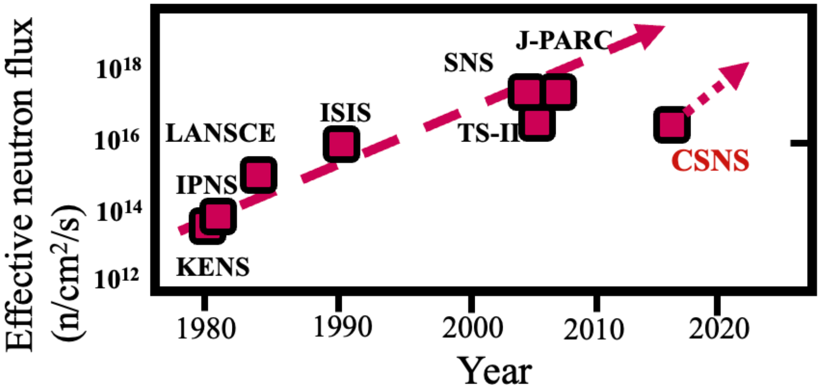
Proton accelerator: Spallation

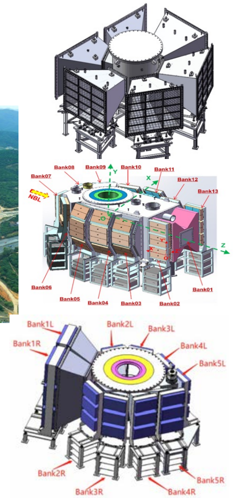


～50 ～150,000



Advanced neutron Instruments





Increasing Source Intensity and Advancing Instrumentation → → → **Opportunities are extending now**

Contents

1. ***Brief history of Neutron Diffraction and its Advantages***

2. ***Angle-Dispersive Diffraction (monochromatic neutron) and Time Of Flight Diffraction (white neutron)***

3. ***High Resolution and High Intensity Diffractometers***

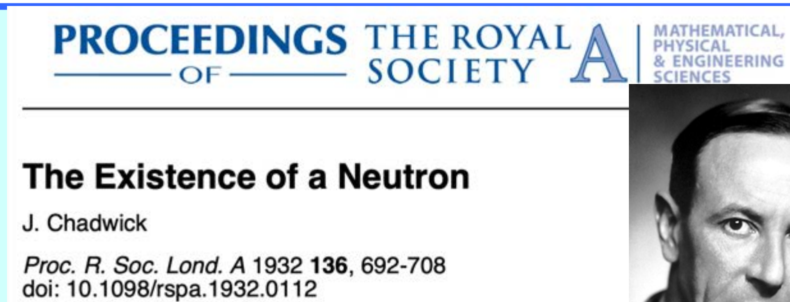
Discover Neutron and its Wave Nature

During the context of the Wave–Particle duality of Matter:

1895 Discovery X-ray by Röntgen
1912 Discovery of X-ray diffraction
1927 Discovery of Electron Diffraction : Wave Nature of Electron was confirmed

1932 Discover Neutron: J. Chadwick
Proc. Roy. Soc. A 136, 692 (1932)

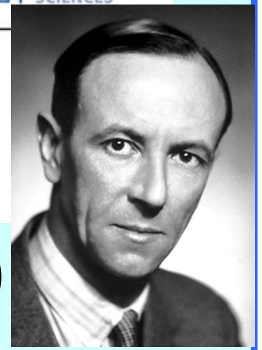
→ 1935 Nobel Prize in Physics


PROCEEDINGS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

The Existence of a Neutron

J. Chadwick

Proc. R. Soc. Lond. A 1932 **136**, 692-708
doi: 10.1098/rspa.1932.0112

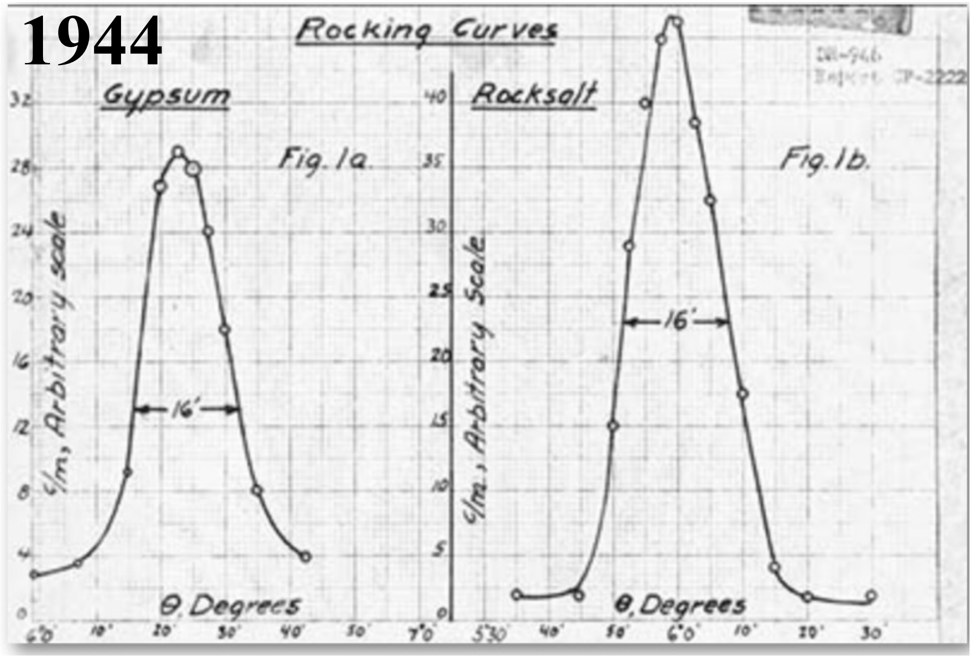


1936 Wave Nature of Neutron confirmed **(de Broglie wave)**

(prediction)
W. Elsasser, C. R. Acad. Sci. Paris 202 (1936)1029, Sur la Diffraction des Neutrons Lents par les Substances Cristallines
(experiments using radioactive sources)
H. Halban & P. Preiswerk, C. R. Acad. Sci. Paris 203 (1936) 73, Preuve Experimentale de la Diffraction des Neutrons,
D. P. Mitchell & P. N. Powers, Phys. Rev. 50 (1936) 486, Bragg Reflection of Slow Neutrons,

(magnetic scattering: prediction and experiments)

Neutron Diffraction at the Oak Ridge Reactor by *Ernest Wollan*



Ernest Wollan (left) and Clifford Shull
Diffraction Exp. at ORNL in 1949

Thom Mason et al.
Acta Crystallography A **69**(1), 37–44 (2013),

Because of high neutron intensities from a reactor, it was shown
wave nature of neutrons can be used to study materials structure

Discover Neutron and its Wave Nature

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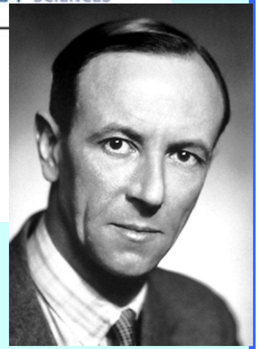

1936 Wave Nature of Neutron confirmed (de Broglie wave)
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(experiments using radioactive sources)
H. Halban & P. Preiswerk, C. R. Acad. Sci. Paris 203 (1936) 73, Preuve Experimentale de la Diffraction des Neutrons,
D. P. Mitchell & P. N. Powers, Phys. Rev. 50 (1936) 486, Bragg I

(magnetic scattering: prediction and experiments)
F. Bloch, Phys. Rev. 50 (1936) 259, On the Magnetic Scattering
C. G. Shull and J. S. Smart, Phys. Rev. 76 (1949)1256, Detection
Antiferromagnetism by Neutron Diffraction

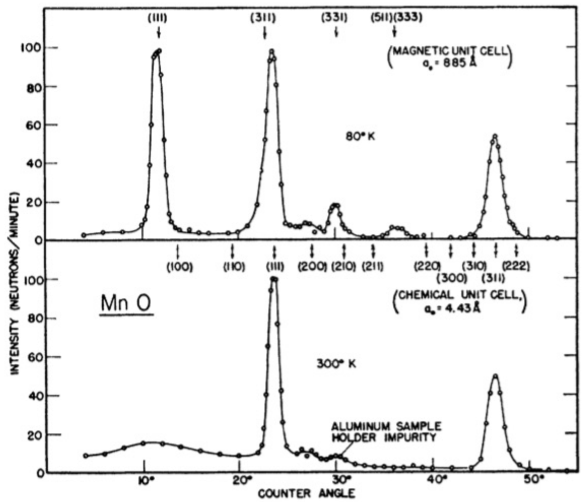
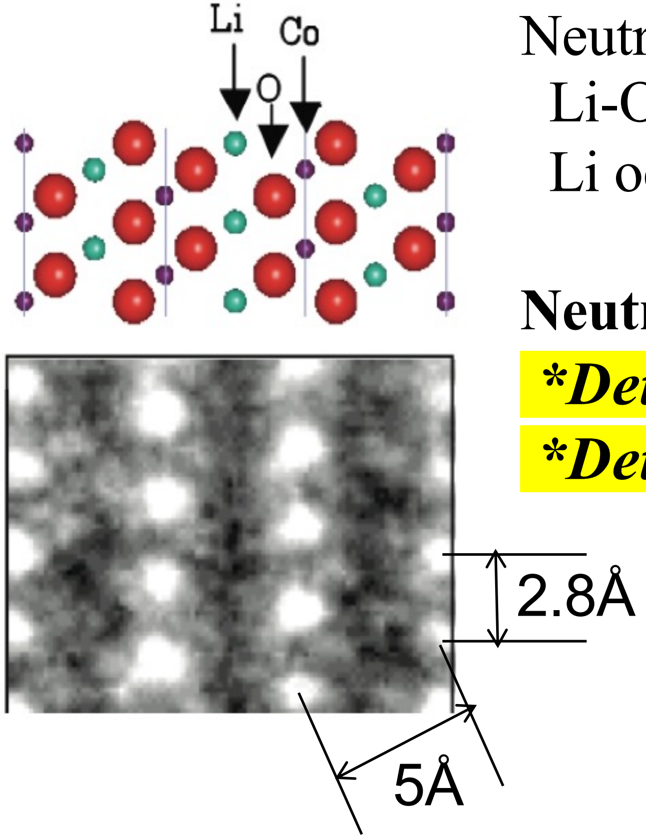


FIG. 1. Neutron diffraction patterns for MnO at room temperature and at 80°K.

Advantage of Neutron Diffraction

Compared with Transmission Electron Microscopy



Neutron Diffraction :

Li-O: 2.0903+-0.0002Å → XRD X

Li occupancy: 0.993+-0.008 → XRD X

Neutron Diffraction

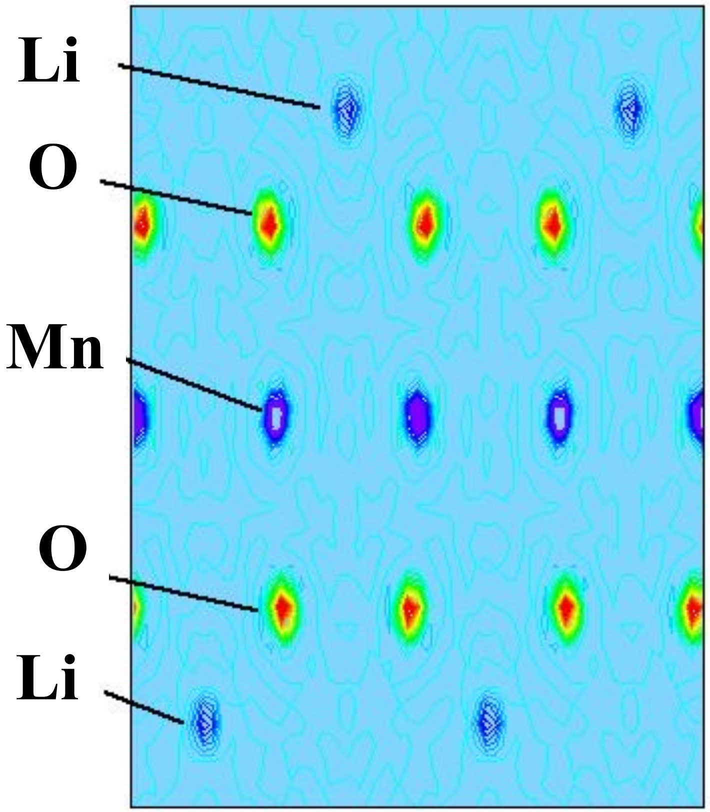
Determine atomic position precisely

Detect as small as 1 % lithium defect

Advantage of Neutron Diffraction

Compared with X-ray diffraction

Neutron (Scattering Amplitude)

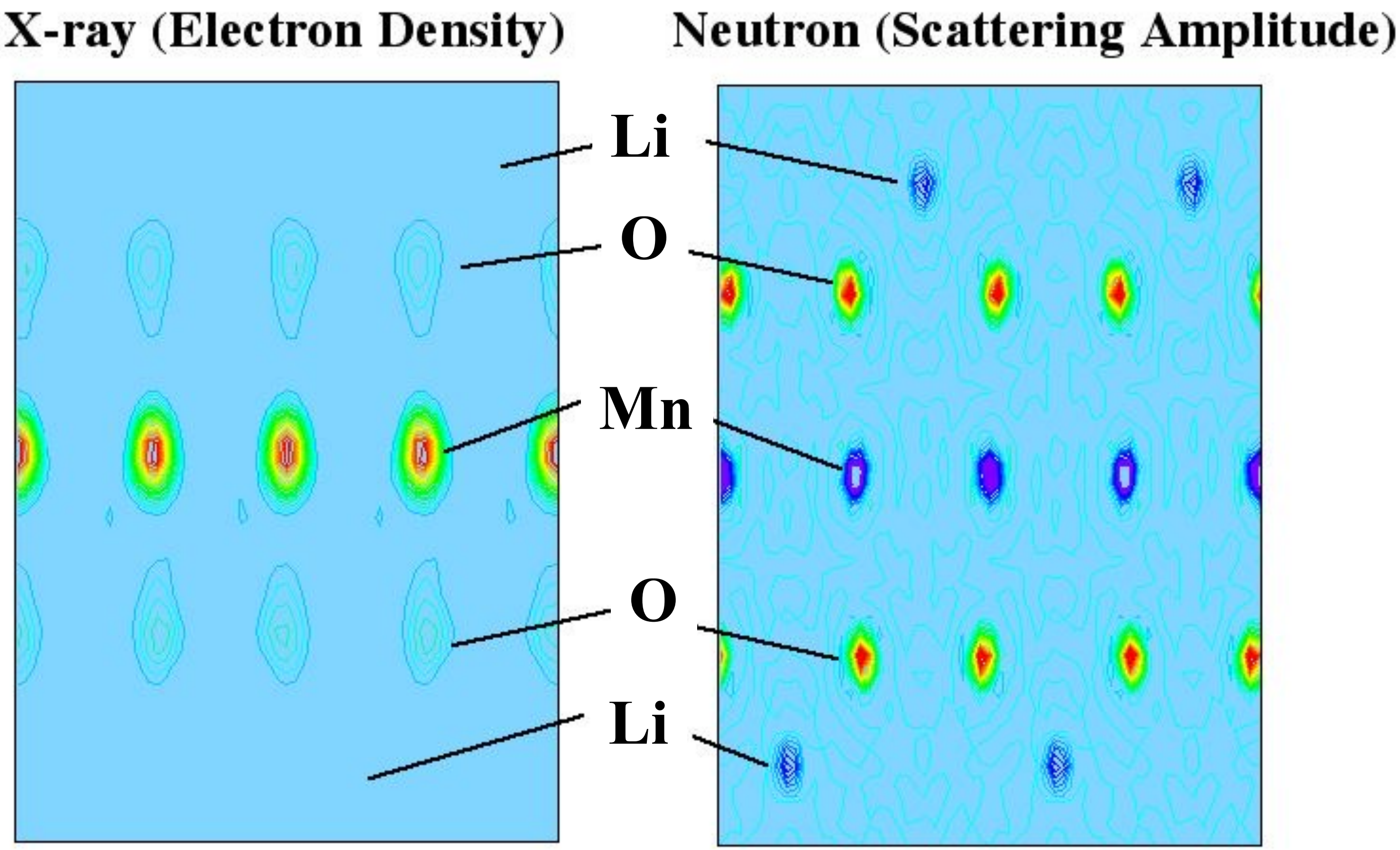


Cathode

$LiMn_2O_4$

Advantage of Neutron Diffraction

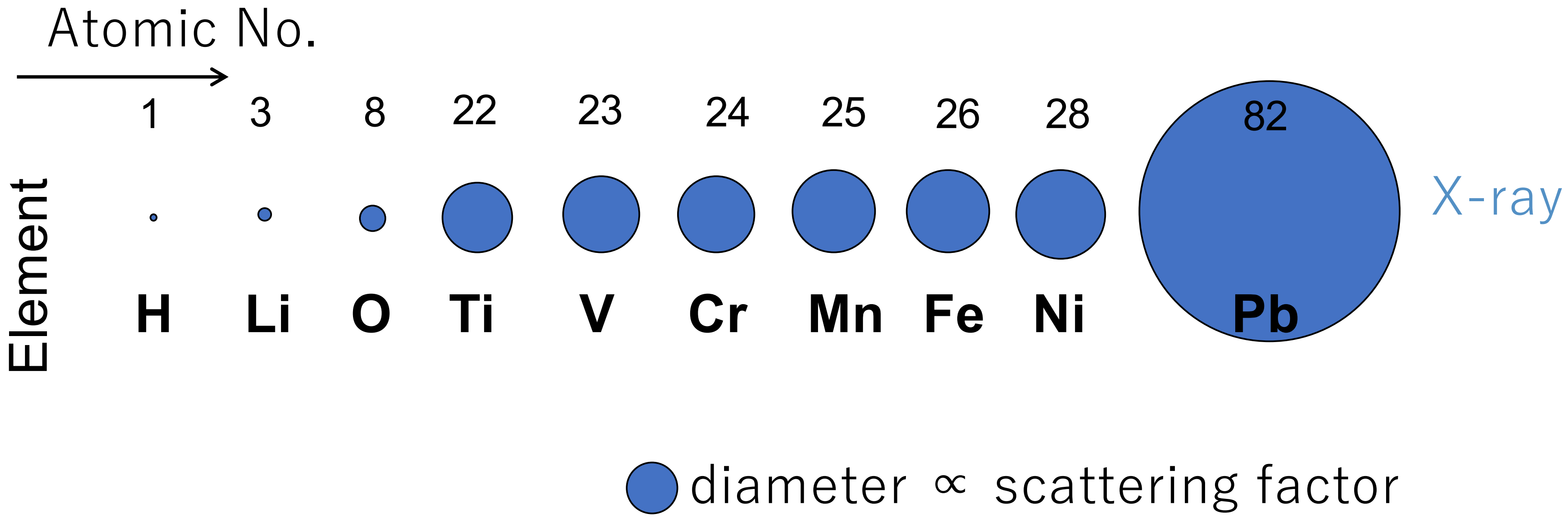
Compared with X-ray diffraction

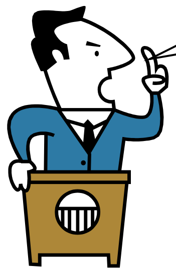


$LiMn_2O_4$ **Cathode**

Neutron is sensitive to light elements:
H, Li, F, O, *etc.*

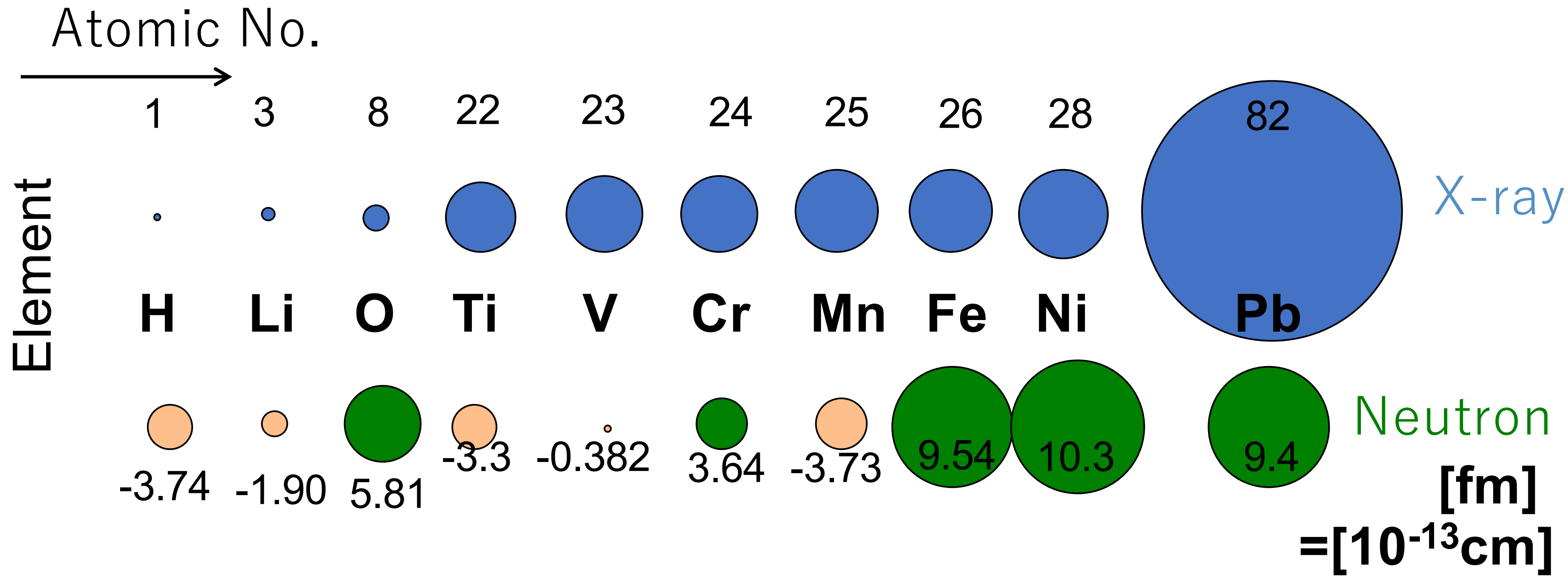
Scattering of X-ray



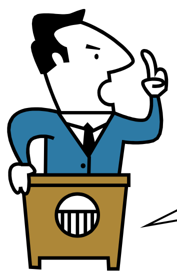


- **X -ray is not sensitive to light element**
- **X -ray is hard to distinguish transition metals**

Scattering X-ray vs. Neutron

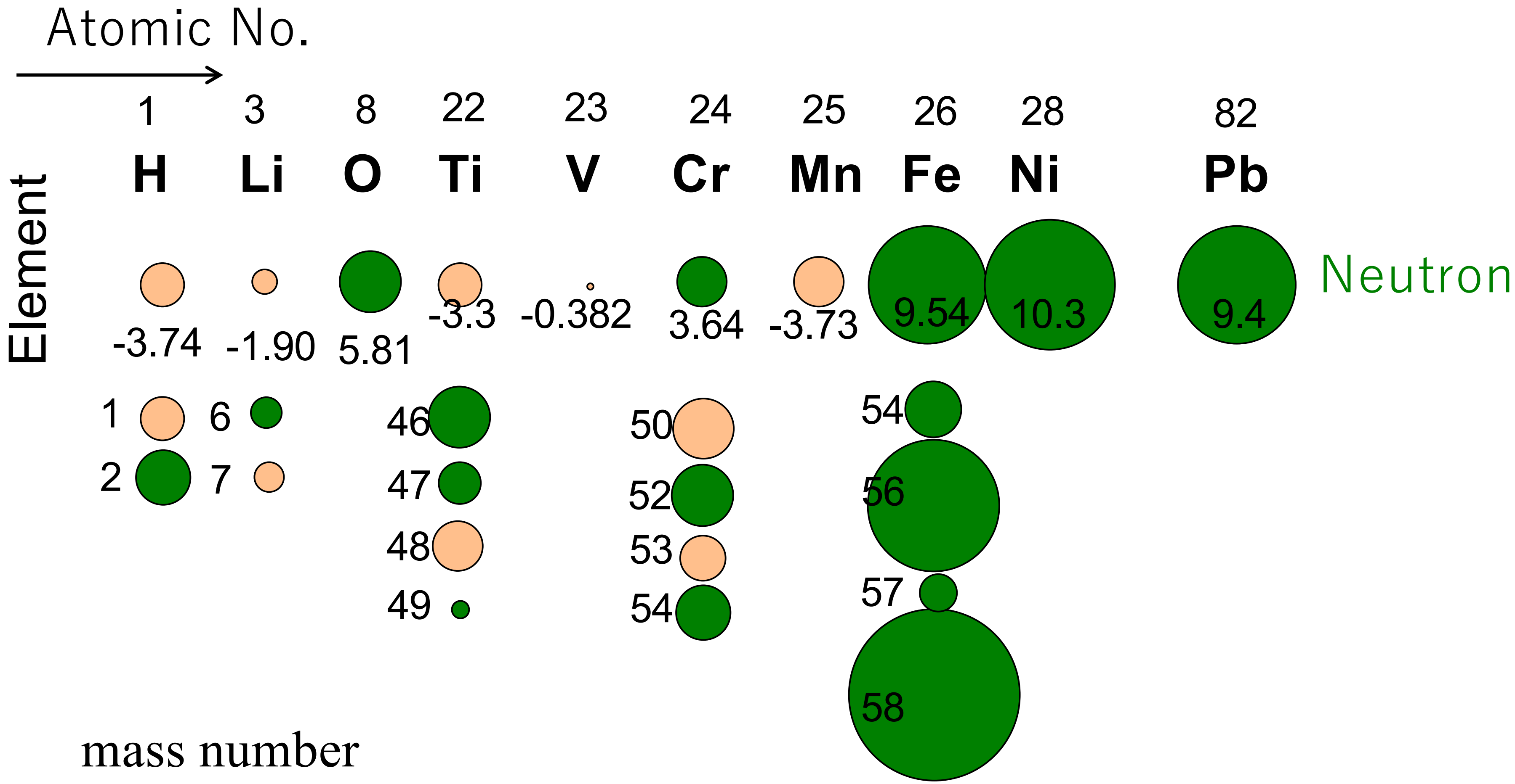


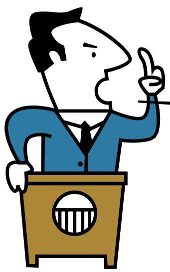
- diameter ∝ neutron scattering amplitude
- minus values mean turning over phase during scattering



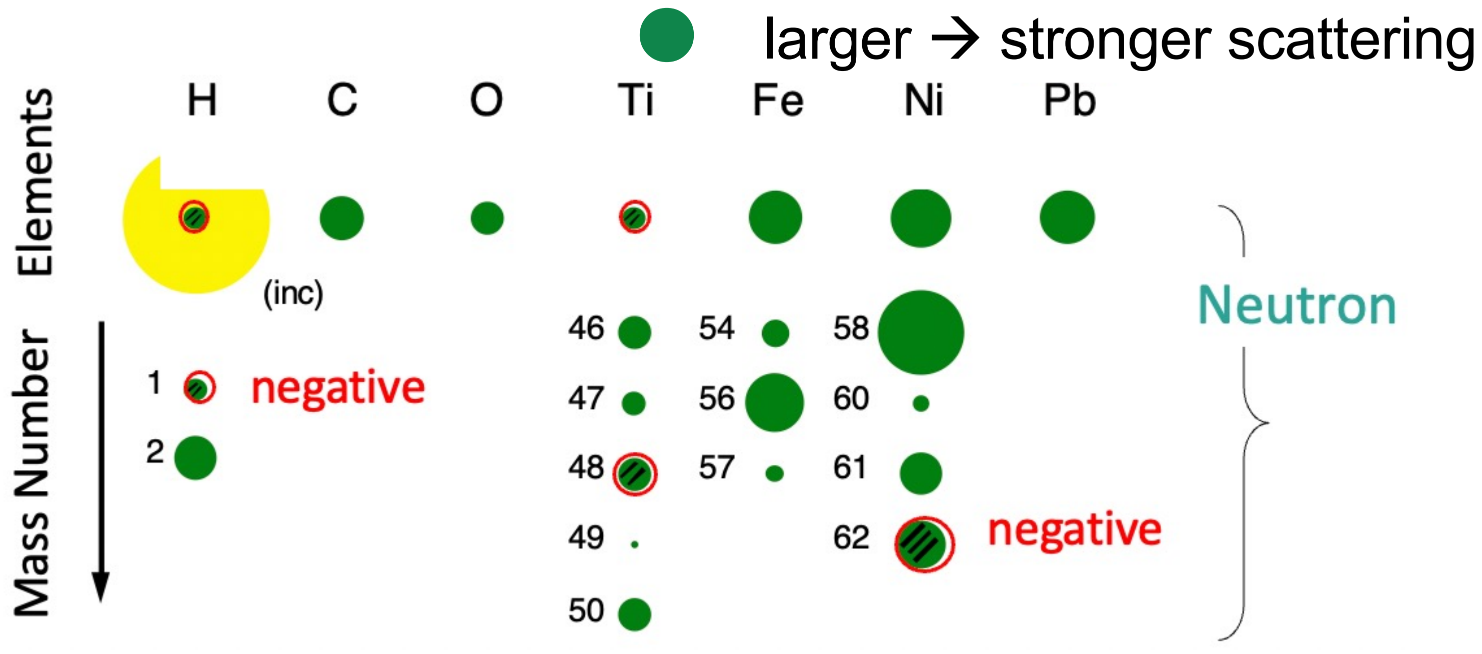
- **Neutron is more sensitive to light element**
- **Neutron can distinguish transition metals**

Neutron can distinguish Isotopes





- **Neutron can distinguish isotopes**



	Z	A	$I(\pi)$	c	b_c	b_i	σ_c	σ_i	σ_s	σ_a
H	1				−3.7390(11)		1.7568(10)	80.26(6)	82.02(6)	0.3326(7)
		1	1/2(+)	99.985	−3.7406(11)	25.274(9)	1.7583(10)	80.27(6)	82.03(6)	0.3326(7)
		2	1(+)	0.015	6.671(4)	4.04(3)	5.592(7)	2.05(3)	7.64(3)	0.000519(7)
		3	1/2(+)	(12.32 a)	4.792(27)	−1.04(17)	2.89(3)	0.14(4)	3.03(5)	0
Li	3				−1.90(2)		0.454(10)	0.92(3)	1.37(3)	70.5(3)
		6	1(+)	7.5	2.00(11)	−1.89(10)	0.51(5)	0.46(5)	0.97(7)	940.(4.)
					−0.261(1)*i*	+0.26(1)*i*				
		7	3/2(−)	92.5	−2.22(2)	−2.49(5)	0.619(11)	0.78(3)	1.40(3)	0.0454(3)
Ni	28				10.3(1)		13.3(3)	5.2(4)	18.5(3)	4.49(16)
		58	0(+)	68.27	14.4(1)	0	26.1(4)	0	26.1(4)	4.6(3)
		60	0(+)	26.10	2.8(1)	0	0.99(7)	0	0.99(7)	2.9(2)
		61	3/2(−)	1.13	7.60(6)	±3.9(3)	7.26(11)	1.9(3)	9.2(3)	2.5(8)
		62	0(+)	3.59	−8.7(2)	0	9.5(4)	0	9.5(4)	14.5(3)
		64	0(+)	0.91	−0.37(7)	0	0.017(7)	0	0.017(7)	1.52(3)

$LiCoO_2$

Li	3				−1.90(2)		0.454(10)	0.92(3)	1.37(3)	70.5(3)
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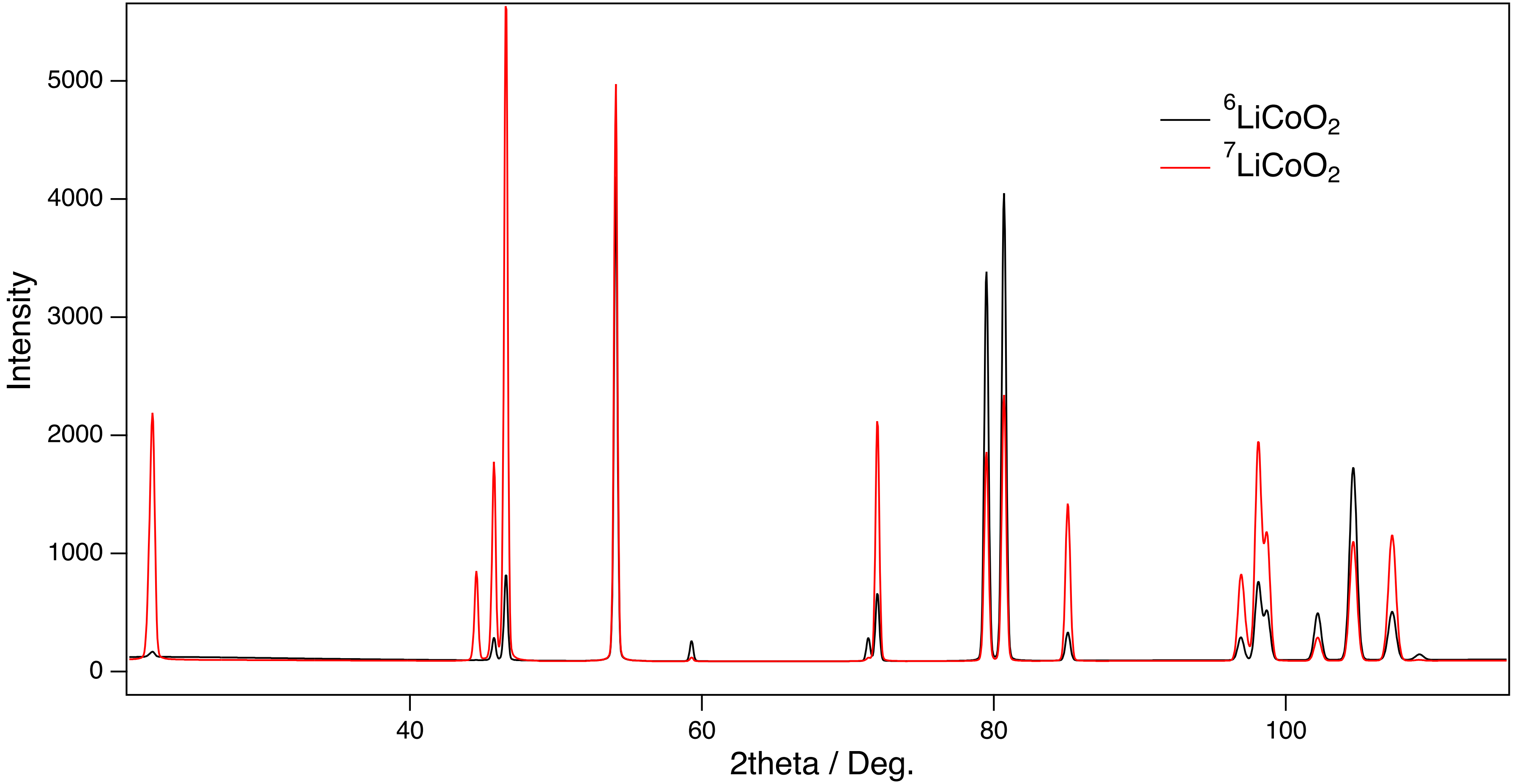
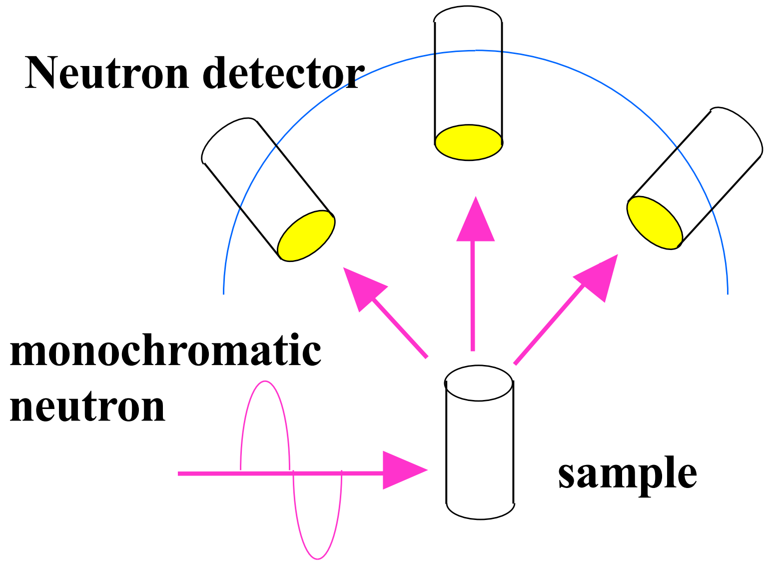


Structure factor F_{hkl} depends on *hkl*. We observe $|F_{hkl}|^2$, not F_{hkl} .

Bragg scattering condition: $\lambda = 2d \sin\theta$

Angle-dispersive method
(constant wavelength λ)

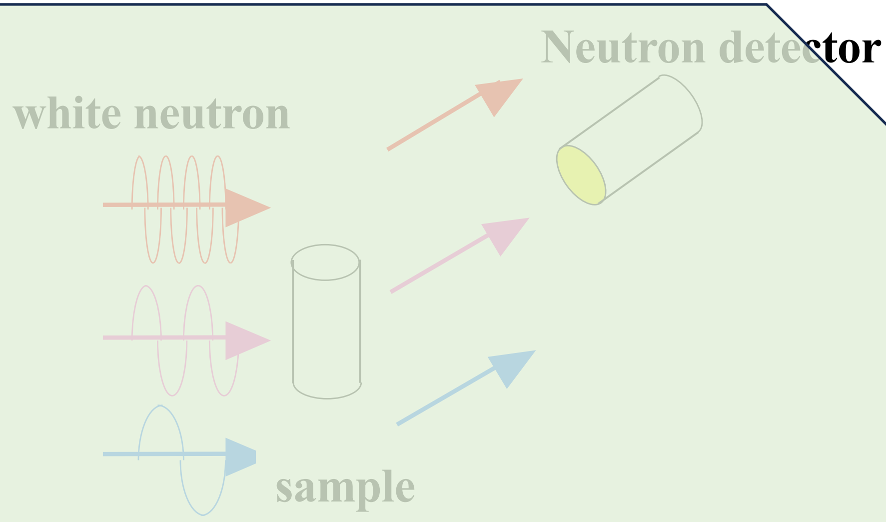


(Purpose) Obtain lattice spacing d

→ Move a detector to obtain the angle to satisfy $\lambda = 2d \sin\theta$

<u>often used in reactor facilities</u>

Energy-dispersive method
(variable wavelength λ)



(Purpose) obtain lattice spacing d

→ Obtain λ to satisfy $\lambda = 2d \sin\theta$

→ $\lambda \propto 1/$*neutron velocity*

$\propto$ *time-of-flight of neutron*

→ time-of-flight method

<u>often used in accelerator facilities</u>

Neutron Beam From
Some Research Reactors in the World

China Advanced Research Reactor

China Mianyang Research Reactor

OPAL (ANSTO, Australia)

JRR-3 (JAEA, Japan)

HANARO (KAERI, Korea)

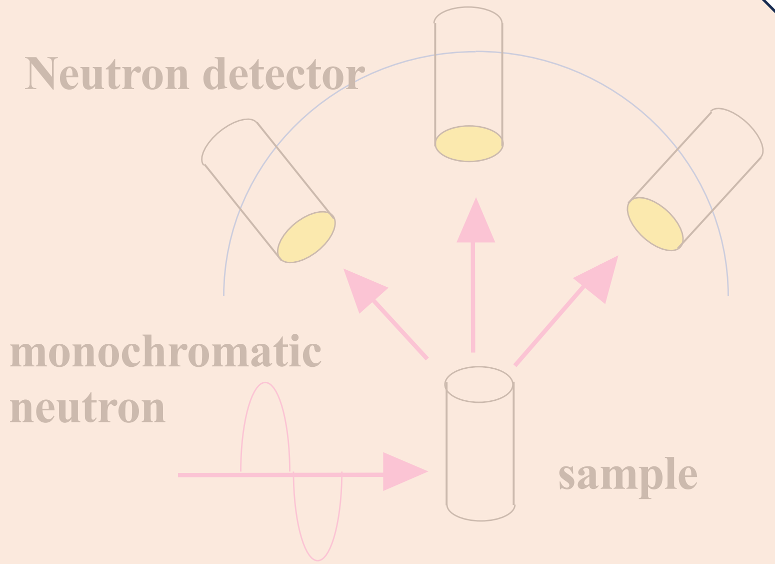
Institut Laue- Langevin (ILL, France)

Forschungsreaktor München II (FRM II, Germany)

High Flux Isotope Reactor (ORNL, USA)

Bragg scattering condition: $\lambda = 2d \sin\theta$

Angle-dispersive method
(constant wavelength λ)



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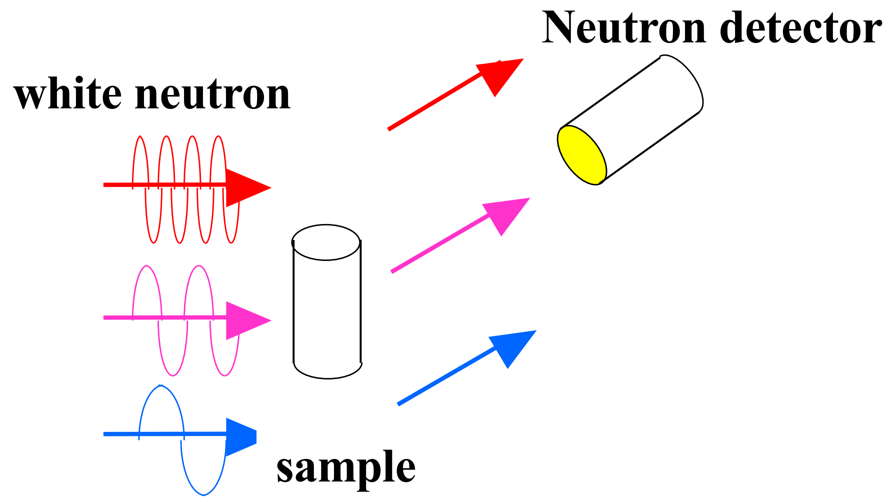

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→ $\lambda \propto 1/\textit{neutron velocity}$

$\propto \textit{time-of-flight of neutron}$

→ time-of-flight method

<u>often used in accelerator facilities</u>

Birth of Time-flight (TOF) diffraction: Idea

TOF neutron diffraction was (probably) first proposed by **P A Egelstaff** in 1953, 1954 (IUCr) and 1961 (the Saclay symp. on Neutron Time-of-Flight Methods)

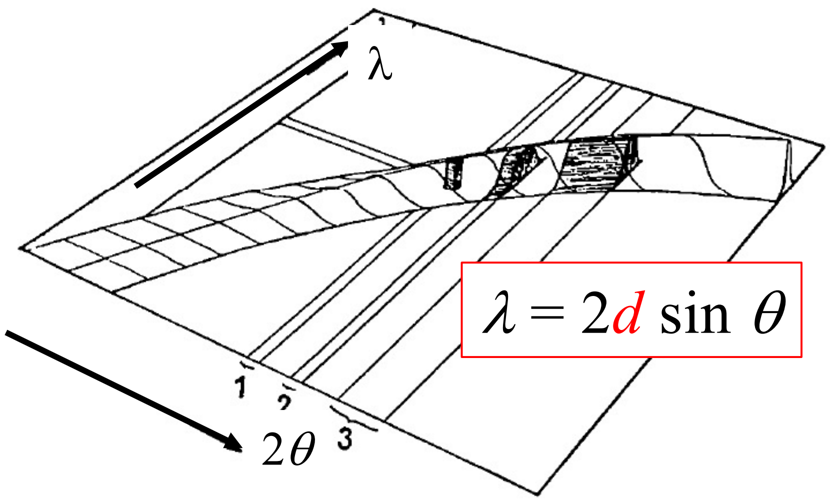
In 1956, **Lowde** theoretically discussed the **intensity gain of the TOF method** over the constant wavelength method.

Acta Cryst. (1956). **9**, 151

A New Rationale of Structure-Factor Measurement in Neutron-Diffraction Analysis

By R. D. Lowde

Atomic Energy Research Establishment, Harwell, Berkshire, England



TOF method utilizes

a wide range of energy spectra

Angle-dispersive method utilizes

a small part of energy spectra using a monochromator

Birth of TOF diffraction: real experiments:
Pulsed Neutron by Mechanical Chopper at Reactors

1963年～

Buras ***et al.***

The time-of-flight method in investigations of crystal structure by neutron diffraction

Back | View Full Text Options

Buras, B.; Leciejewski, J.

Nukleonika (1963), 8(1), 75-7 CODEN: NUKLAS; ISSN: 0029-5922. English.

nethod for
n

Buras, B.

Nukleonika (1963), 8(4), 259-60 CODEN: NUKLAS; ISSN: 0029-5922. English.

structure
tion with

Buras, B.; Leciejewicz, J.; Nitc, W.; Sosnowska, I.; Sosnowski, J.; Shapiro, F.

Nukleonika (1964), 9(7-8), 523-37 CODEN: NUKLAS; ISSN: 0029-5922. English.

Nukleonika

Initially using Fermi chopper at a Poland 2MW reactor, and then using pulsed reactor at Dubna (1kW)

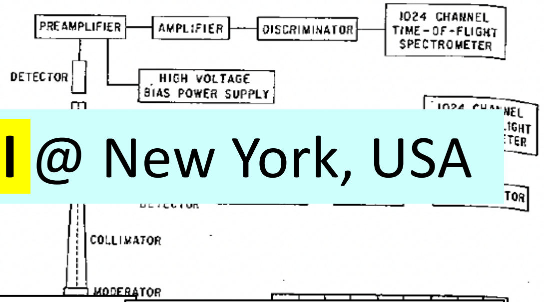
Birth of TOF diffraction:
Pulsed Neutron by Electron Accelerators

1968年

NATURE, VOL. 219, AUGUST 24, 1968

Neutron

We have successfully tested a new method of obtaining neutron diffraction patterns from polycrystalline specimens using a pulsed linear accelerator (LINAC) as a neutron

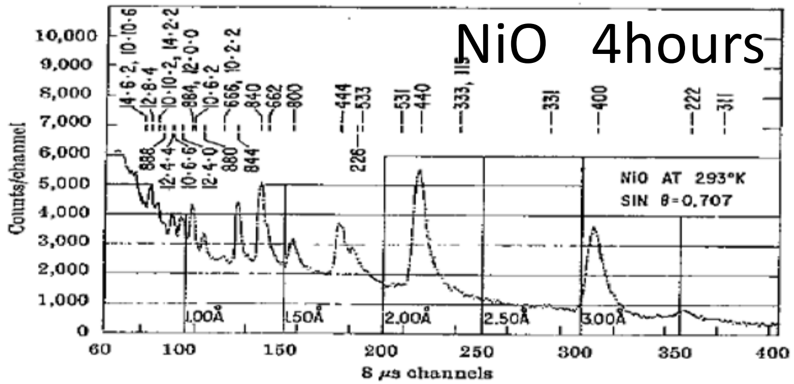


Moore, Kasper, Menzel @ New York, USA

Brugger *et al.*[5,6]. All the previous applications of the TOF technique to neutron diffraction have used a reactor as a neutron source, and generally the pulsing of neutrons has been achieved by means of a fast chopper. In our application, however, the normal pulsed operation of the

They did not continue the neutron research

Rensselaer Univ. LINAC



NUCLEAR INSTRUMENTS AND METHODS 71 (1969) 102–110; © NORTH-HOLLAND PUBLISHING CO.

M. Kimura, S. Tomiyoshi, N. Watanabe *et al.* @ Tohoku, Japan

1968年

M. KIMURA, M. SUGAWARA, M. OYAMADA, Y. YAMADA

Laboratory of Nuclear Science, Tohoku University, Tomizawa, Sendai, Japan

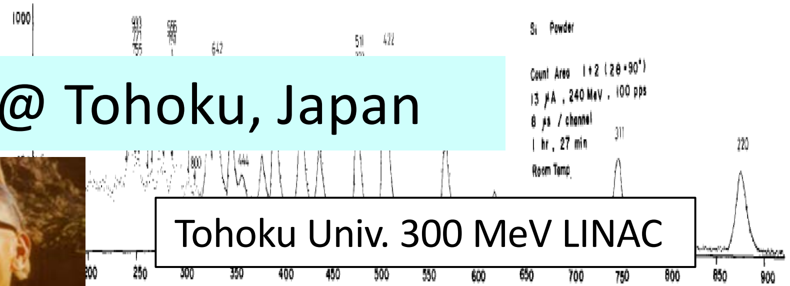
S. TOMIYOSHI, T. SUZUKI

...iversity, Katahiracho, Sendai, Japan

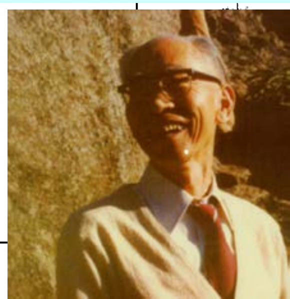
N. WATANABE, S. TAKEDA

Faculty of Engineering, Tohoku University, Aramaki, Sendai, Japan

They continued the neutron research



Tohoku Univ. 300 MeV LINAC



M. Kimura

Neutronics improved, and instruments were used for materials science

NUCLEAR INSTRUMENTS AND METHODS 72 (1969) 237–253; © NORTH-HOLLAND PUBLISHING C...

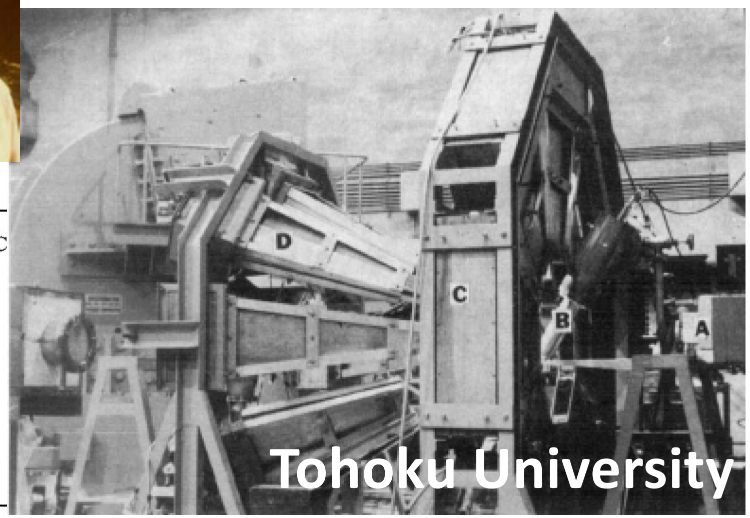
1969年

Day and Sinclair @ Harwell, UK

...ON MODERATOR ASSEMBLIES FOR PULSED THERMAL NEUTRON TIME-OF-FLIGHT EXPERIMENTS

D. H. DAY and R. N. SINCLAIR

A.E.R.E., Harwell, Didcot, Berks., U.K.



In 1975, A. Hewat seriously compared TOF powder diffractometers with angle dispersive ones in viewpoints of intensity gain, resolution, achievable small *d* spacings, *etc.*, which are said to be advantages of TOF methods.

NUCLEAR INSTRUMENTS AND METHODS 127 (1975) 361–370; © NORTH-HOLLAND PUBLISHING

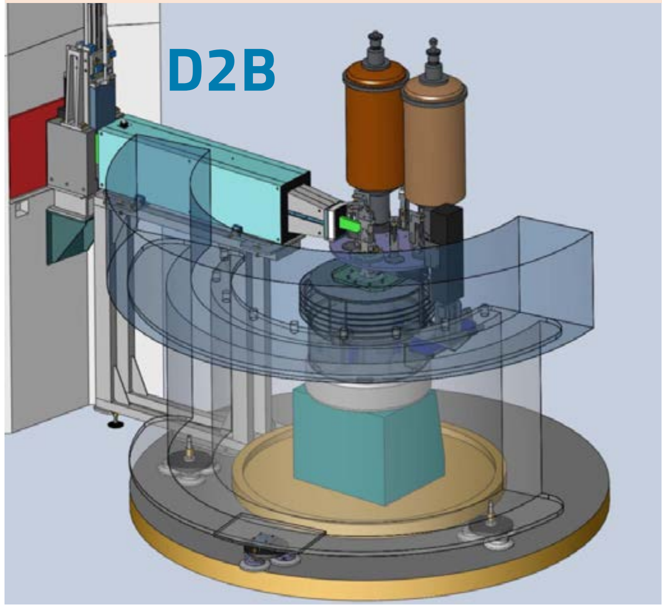
DESIGN FOR A CONVENTIONAL HIGH-RESOLUTION NEUTRON POWDER DIFFRACTOMETER

A. W. Hewat

Institut Laue–Langevin, B.P. Nº 156, 38042-Grenoble Cédex, France

Progress of Angle-Dispersive Neutron Diffractometry

Hewat developed powder diffractometers with multi-detectors with soller slits, which became the world standard powder diffractometers.



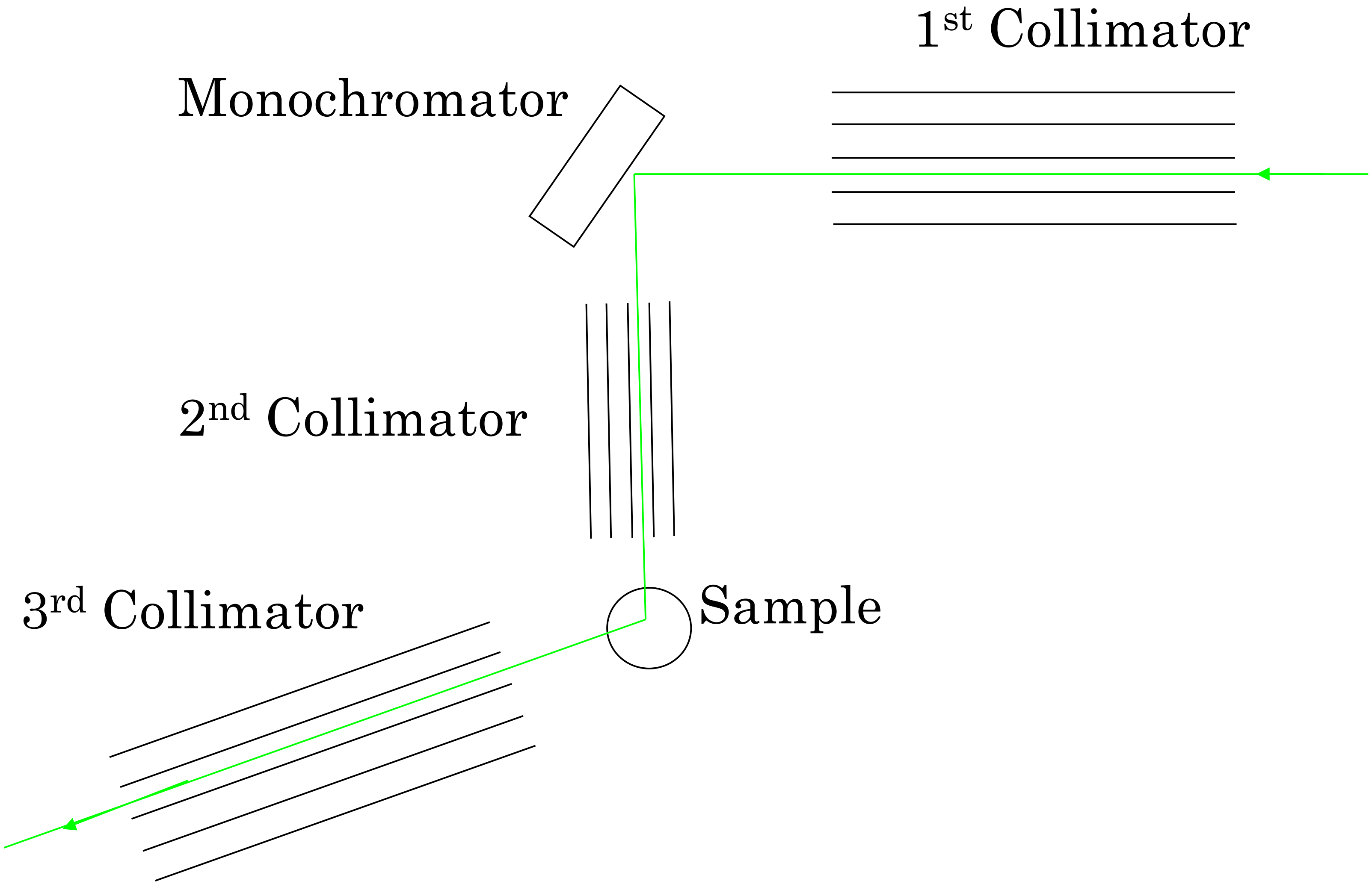
--- 1975 ---

The TOF technique may actually be better suited to low- and medium-resolution instruments if high intensity is required, since then short path lengths and large incident solid angles can be used.

neutron transpotation problem

→ *very advancing later*

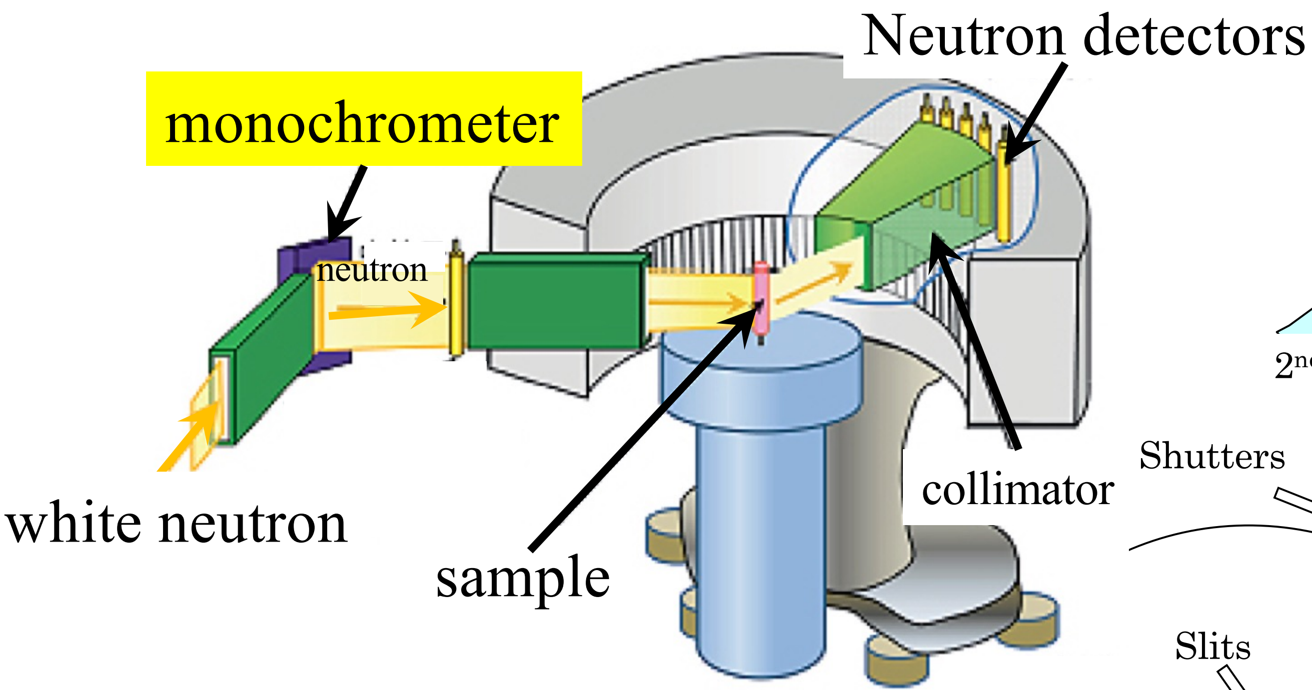
→ ***now, high resolution diffractometry is very suited***

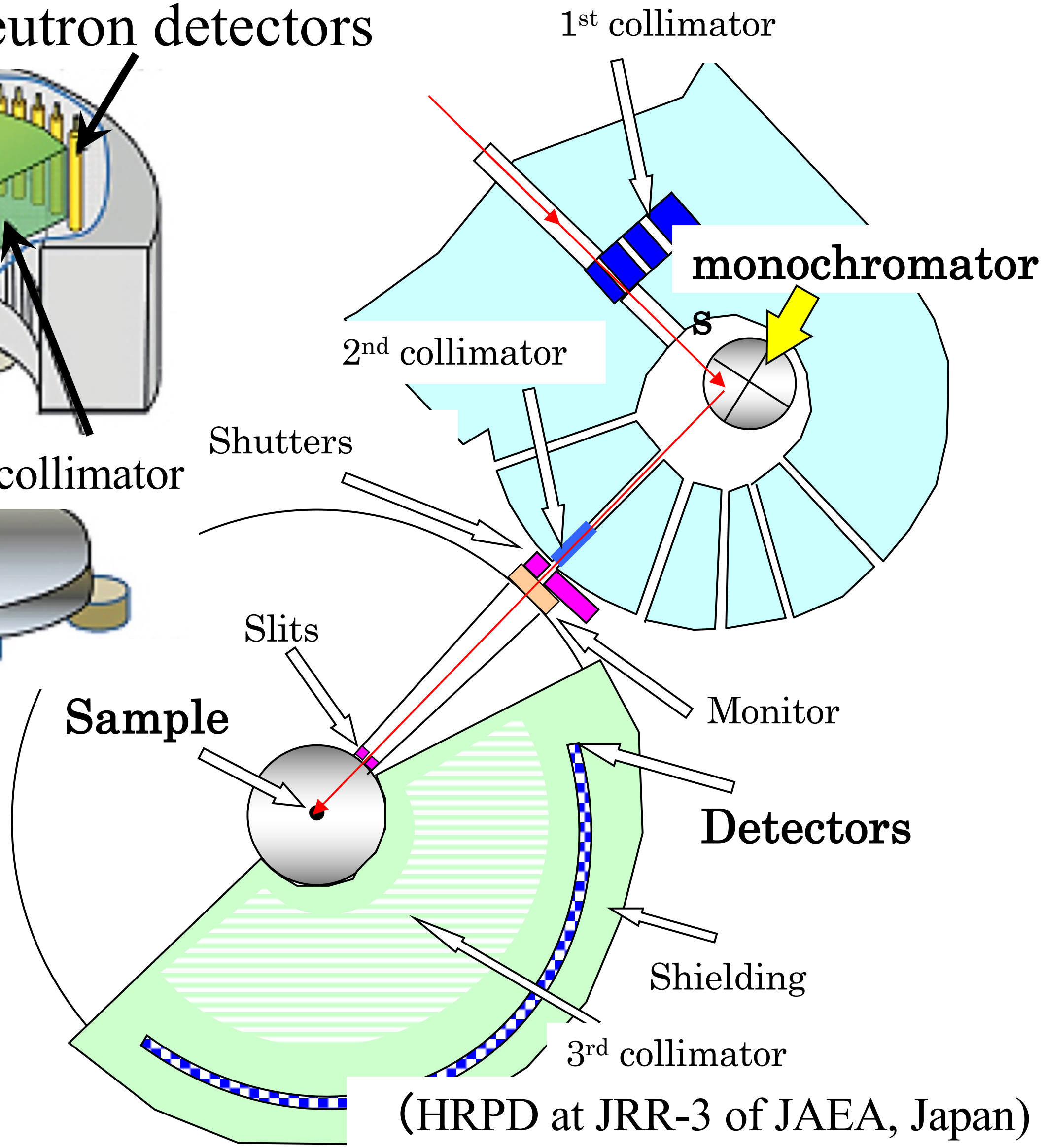

1st Collimator
Monochromator
2nd Collimator
3rd Collimator
Sample

原子炉：角度分散型回折装置

Research Reactor : Angle-dispersive Diffractometer

原子反应堆：角度色散衍射仪





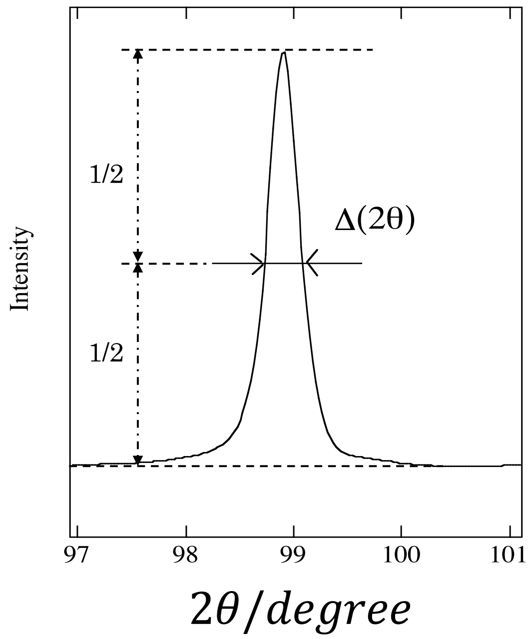
(HRPD at JRR-3 of JAEA, Japan)

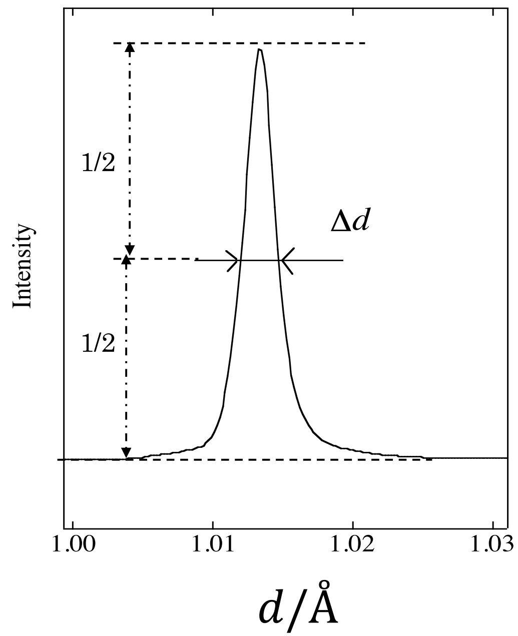
Angle-dispersive diffractometry (constant wavelength) utilizes only several % of neutron by using a monochromator

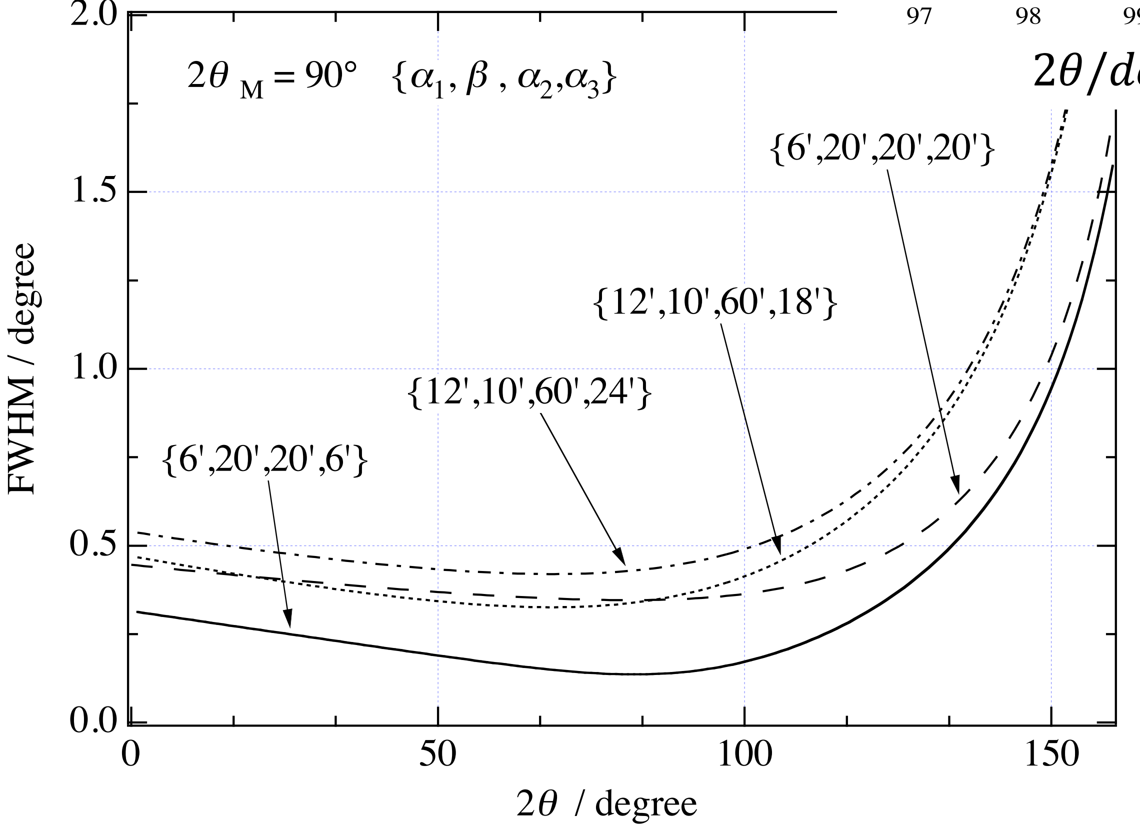
Bragg equation

$$\lambda = 2d \sin \theta$$

FHHM of the diffraction pattern in angle-dispersive diffractometry (constant wavelength method)







$$H = (U \tan^2 \theta + V \tan \theta + W)^{1/2}$$

$$U = \frac{4(\alpha_1^2\alpha_2^2 + \alpha_1^2\beta^2 + \alpha_2^2\beta^2)}{\tan^2 \theta_M(\alpha_1^2 + \alpha_2^2 + 4\beta^2)}$$

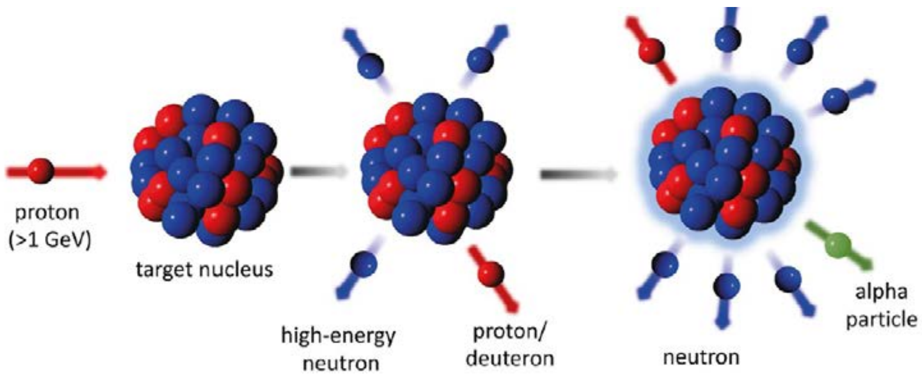
$$V = \frac{-4\alpha_2^2(\alpha_1^2 + 2\beta^2)}{\tan \theta_M(\alpha_1^2 + \alpha_2^2 + 4\beta^2)}$$

$$W = \frac{\alpha_1^2\alpha_2^2 + \alpha_1^2\alpha_3^2 + \alpha_2^2\alpha_3^2 + 4\beta^2(\alpha_2^2 + \alpha_3^2)}{(\alpha_1^2 + \alpha_2^2 + 4\beta^2)}$$

$$L = \frac{\alpha_1\alpha_2\alpha_3\beta}{(\alpha_1^2 + \alpha_2^2 + 4\beta^2)^{1/2}}$$

Towards Higher Flux by Pulsed Proton Accelerators

Spallation (散裂)：Protons with energy around 1 GeV bombard heavy metal targets.
10 to 30 neutrons per proton are released in the entire process



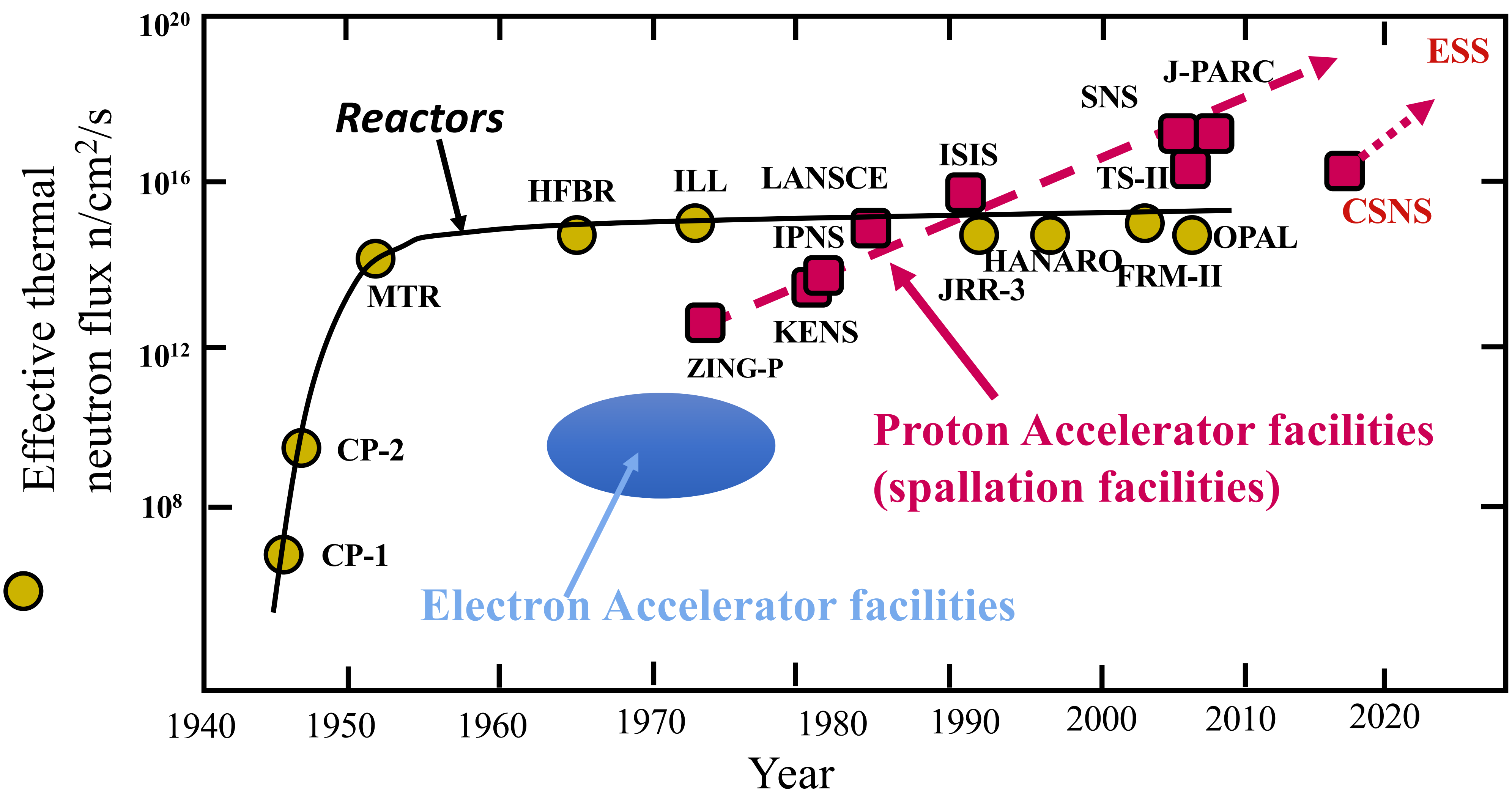
1980' -

KENS (KEK, Japan)	1980
IPNS (ANL, USA)	1981
LANSCE (Los Alamos, USA)	1986
ISIS (RAL, UK)	1986

→ ***Present Facilities***

Toward Higher Neutron Flux by Spallation

散裂sàn liè

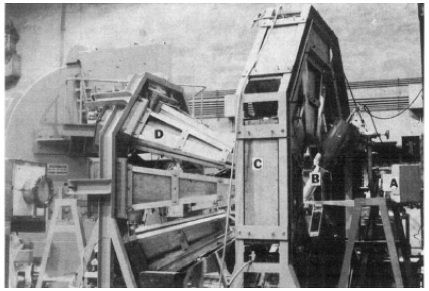


Advances in Pulsed Neutron facilities: Electron Accelerator to Proton Accelerator

Electron accelerators

1967-

Rensselaer Univ. (USA)
Tohoku Univ. (Japan)
Harwell (UK)



Spallation

ZING-P (1974) → IPNS (1981) J. Carpenter (ANL, US)
KENS (1980) N. Watanabe (KEK, Japan)
ISIS (1985) A. Taylor (RAL, UK)
LANSCE (1986) R. Pynn (Los Alamos, US)
SNS (2006)
J-PARC
CSNS (2017) H.Chen (IHEP, China)
ESS

Proton accelerators: Spallation

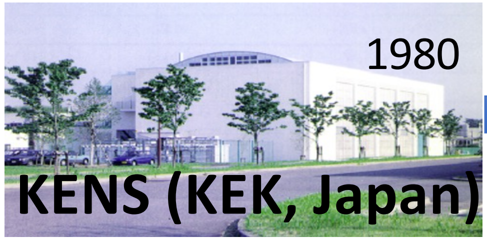
散裂sàn liè

1980' -

IPNS (ANL, USA) 1981

→ **2nd Target station**

LANSCE (Los Alamos, USA) 1986 →



→

→ **2nd Target station?**

→ **ISIS - II**

→

→ **CSNS – II (2029)**

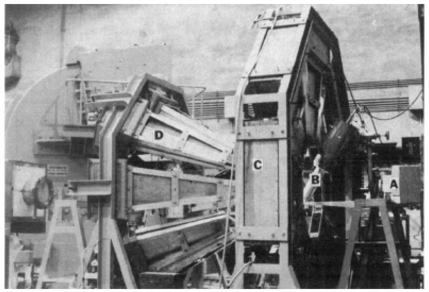
Advances in Pulsed Neutron facilities: Electron Accelerator to Proton Accelerator

Electron accelerators 1967-

Proton accelerators: Spallation 1980’ -

散裂sàn liè

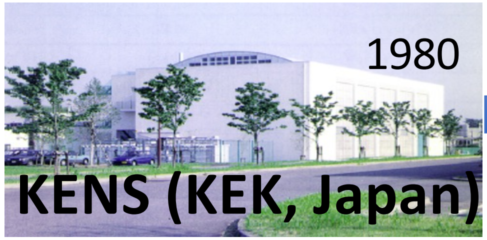
Rensselaer Univ. (USA)
Tohoku Univ. (Japan)
Harwell (UK)



IPNS (ANL, USA) 1981

2nd Target station

LANSCE (Los Alamos, USA) 1986



2nd Target station?

ISIS - II

CSNS – II (2029)

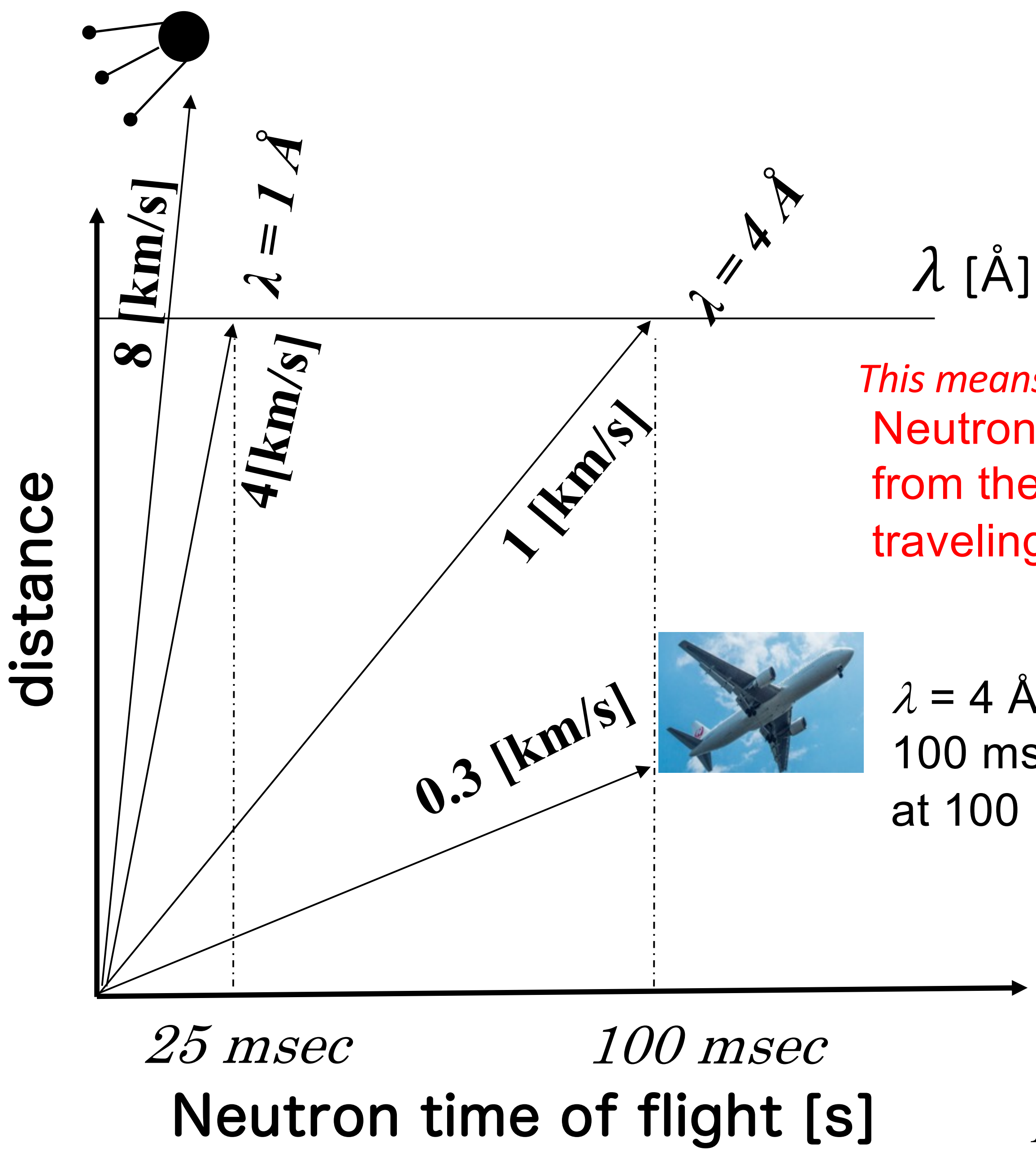
Spallation

ZING-P (1974) → IPNS (1981) J. Carpenter (ANL, US)
KENS (1980) N. Watanabe (KEK, Japan)
ISIS (1985) A. Taylor (RAL, UK)
LANSCE (1986) R. Pynn (Los Alamos, US)
SNS (2006)
J-PARC
CSNS (2017) H.Chen (IHEP, China)
ESS

Time-of-Flight Method

Time-Of-Flight method is the method to obtain ***velocity (of neutron)*** *by measuring the time of flight* ***(of neutron)*** *in a certain distance.*

Distance-Time Diagram



de Broglie relationship

Neutron wavelength

$$\lambda = \frac{h}{mv}$$

$$\lambda\ [\text{Å}] = \frac{3.96\ [\text{Åkm/s}]}{\text{distance [km] /time[s]}}$$

This means

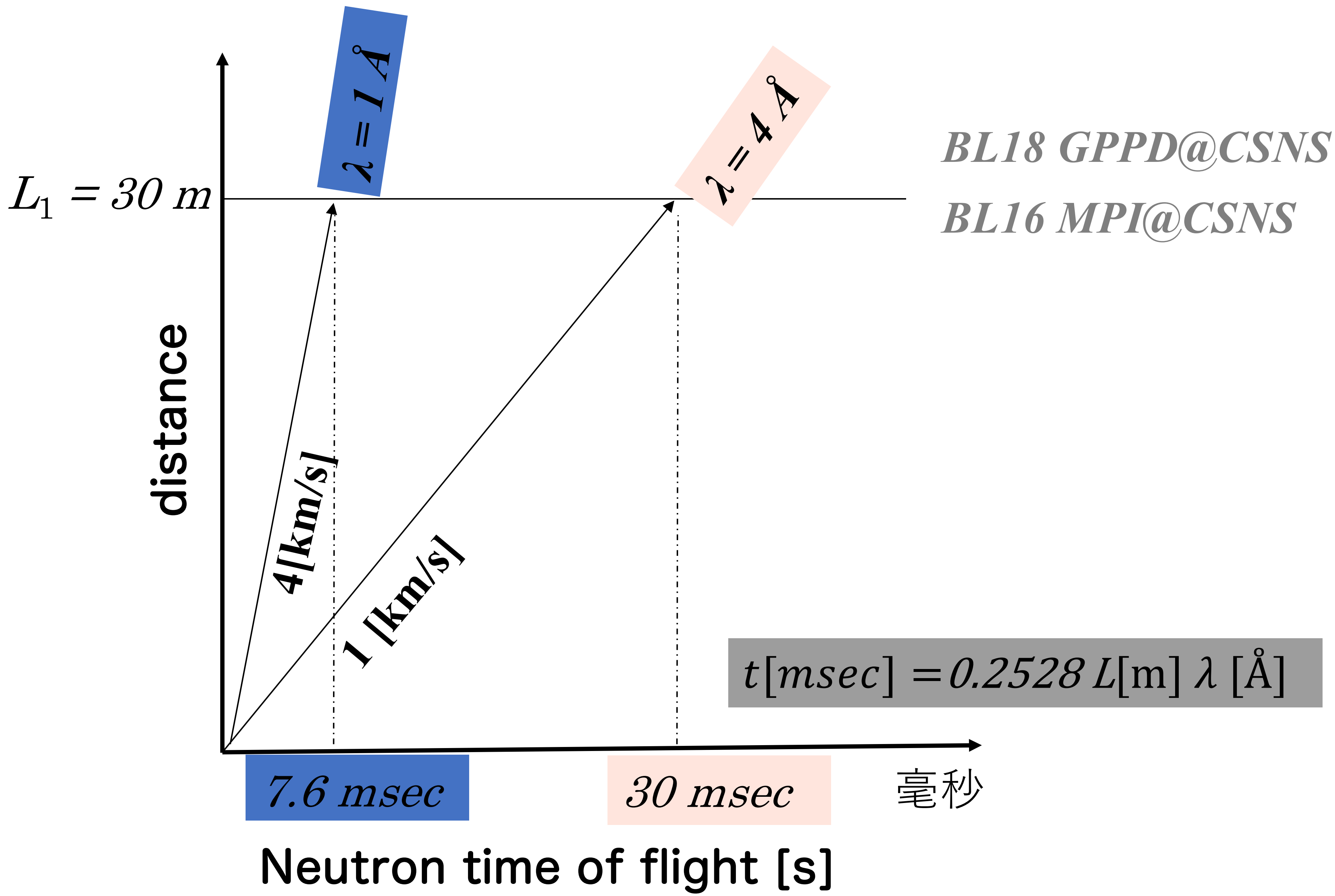
Neutron Wavelength can be calculated from the Time-Of-Flight of Neutron traveling in a certain distance

→ **TOF method**

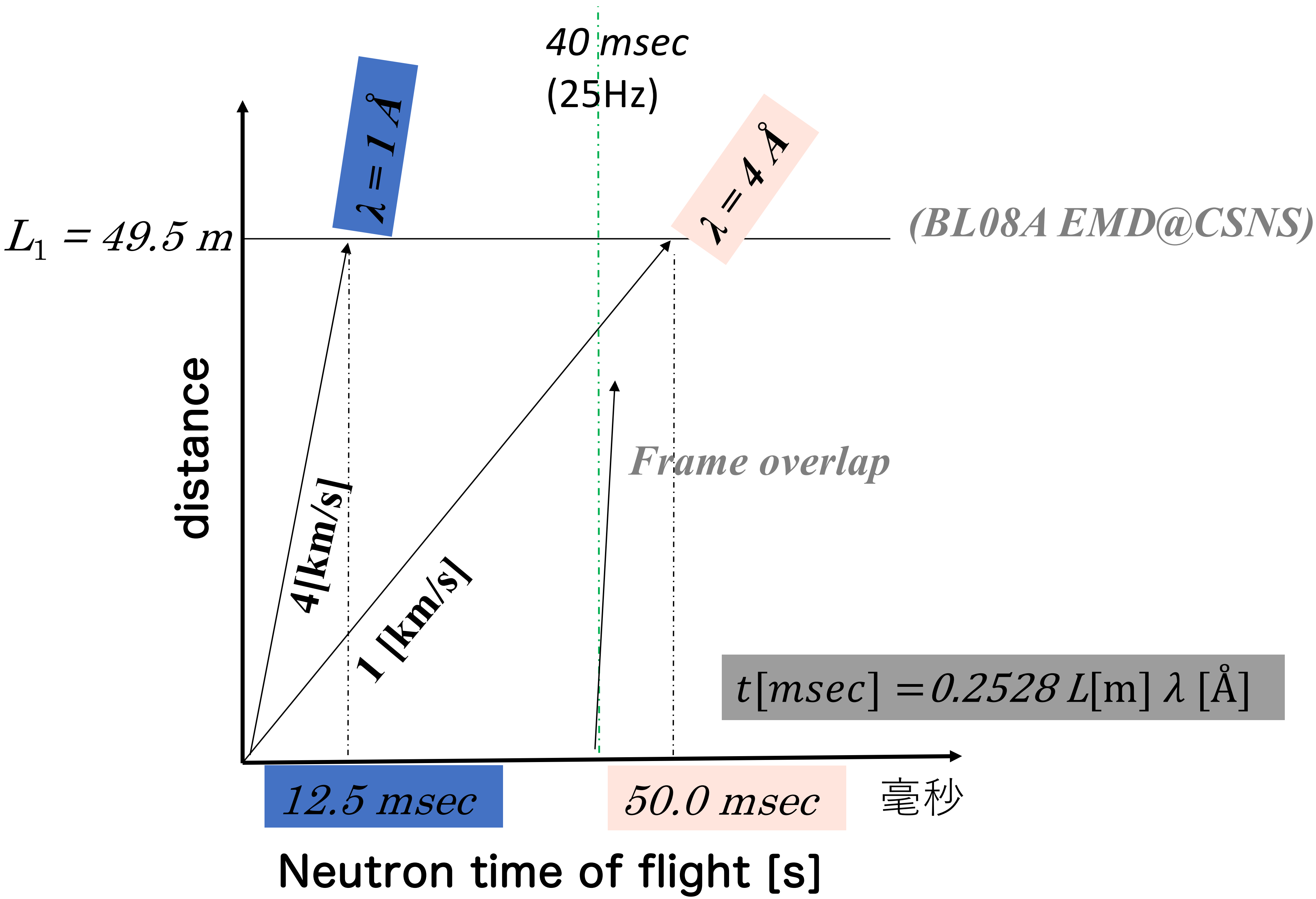
λ = 4 Å neutron arrives at 100 m after 100 msec. Then, if Δ(TOF) < 10 μsec at 100 msec, $\Delta(\lambda) / \lambda = 0.0001$

With TOF method, λ can be determined precisely.

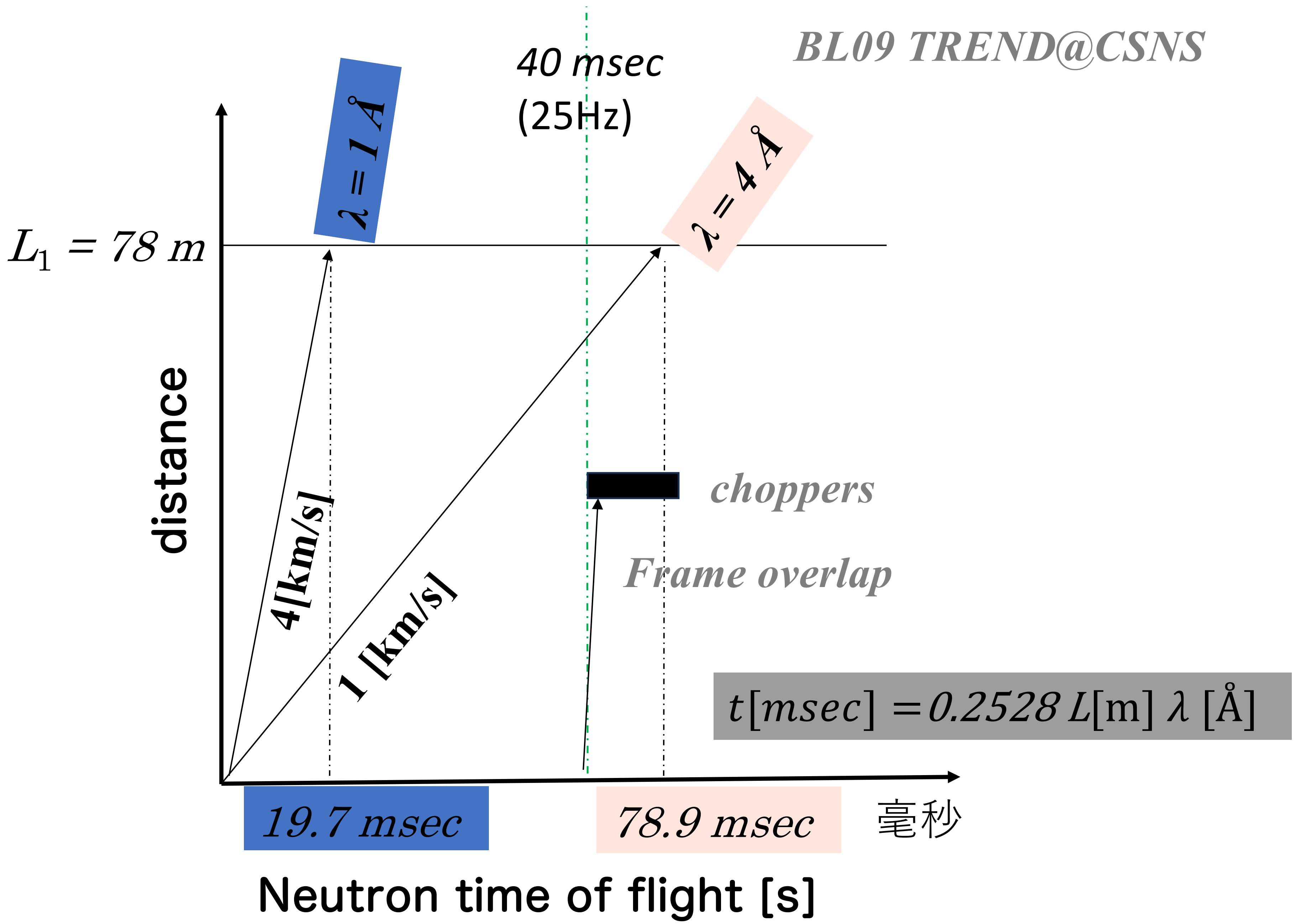
High resolution diffraction



λ = 1 Å
λ = 4 Å
BL18 GPPD@CSNS
BL16 MPI@CSNS
L_1 = 30 m
distance
4[km/s]
1 [km/s]
t[msec] = 0.2528 L[m] λ [Å]
7.6 msec
30 msec
毫秒
Neutron time of flight [s]



40 msec
(25Hz)
λ = 1 Å
λ = 4 Å
L1 = 49.5 m
(BL08A EMD@CSNS)
distance
4[km/s]
1 [km/s]
Frame overlap
t[msec] =0.2528 L[m] λ [Å]
12.5 msec
50.0 msec
毫秒
Neutron time of flight [s]



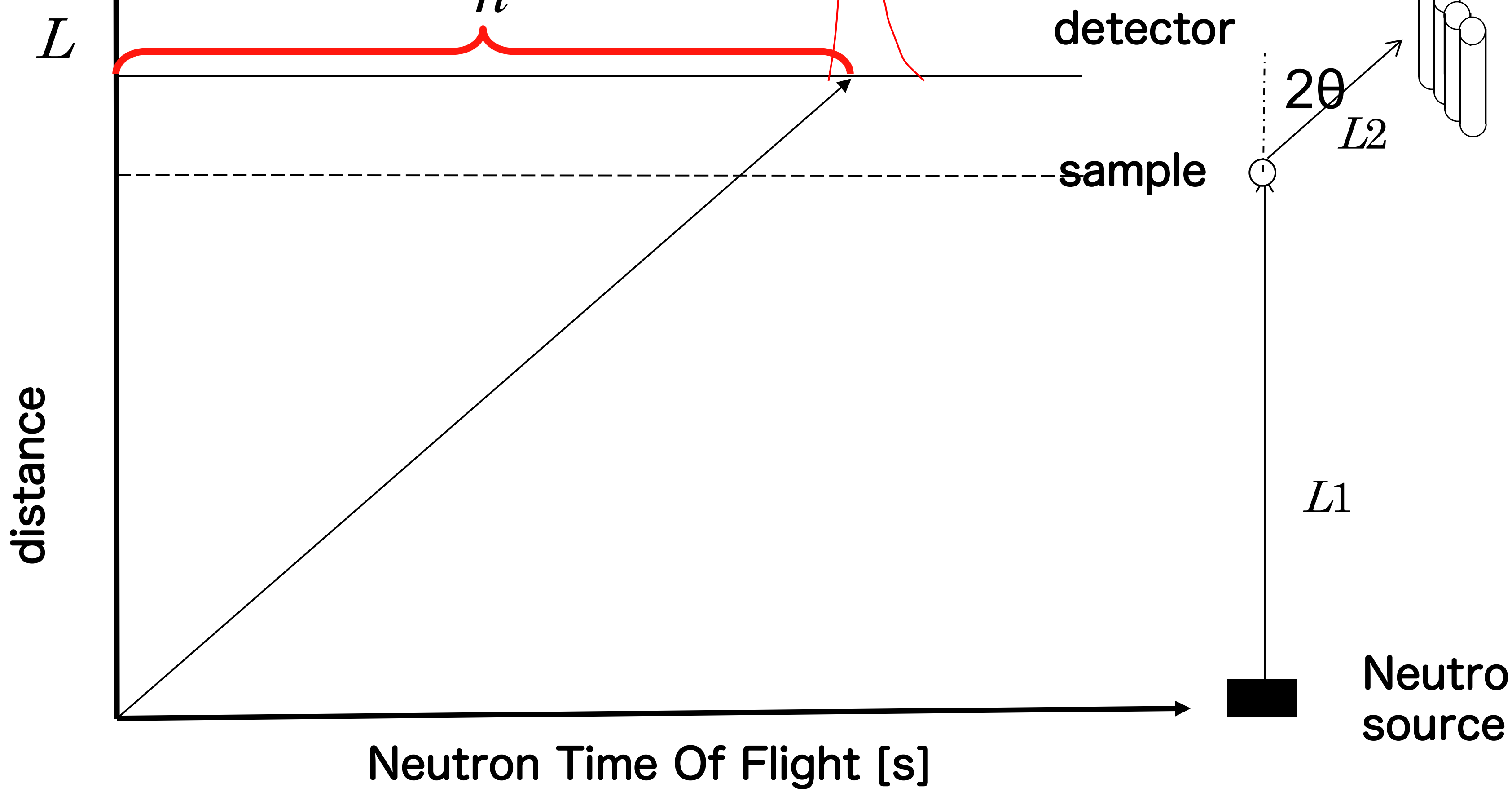
BL09 TREND@CSNS
40 msec
(25Hz)
λ = 1 Å
λ = 4 Å
L1 = 78 m
distance
4[km/s]
1 [km/s]
choppers
Frame overlap
t[msec] = 0.2528 L[m] λ [Å]
19.7 msec
78.9 msec
毫秒
Neutron time of flight [s]

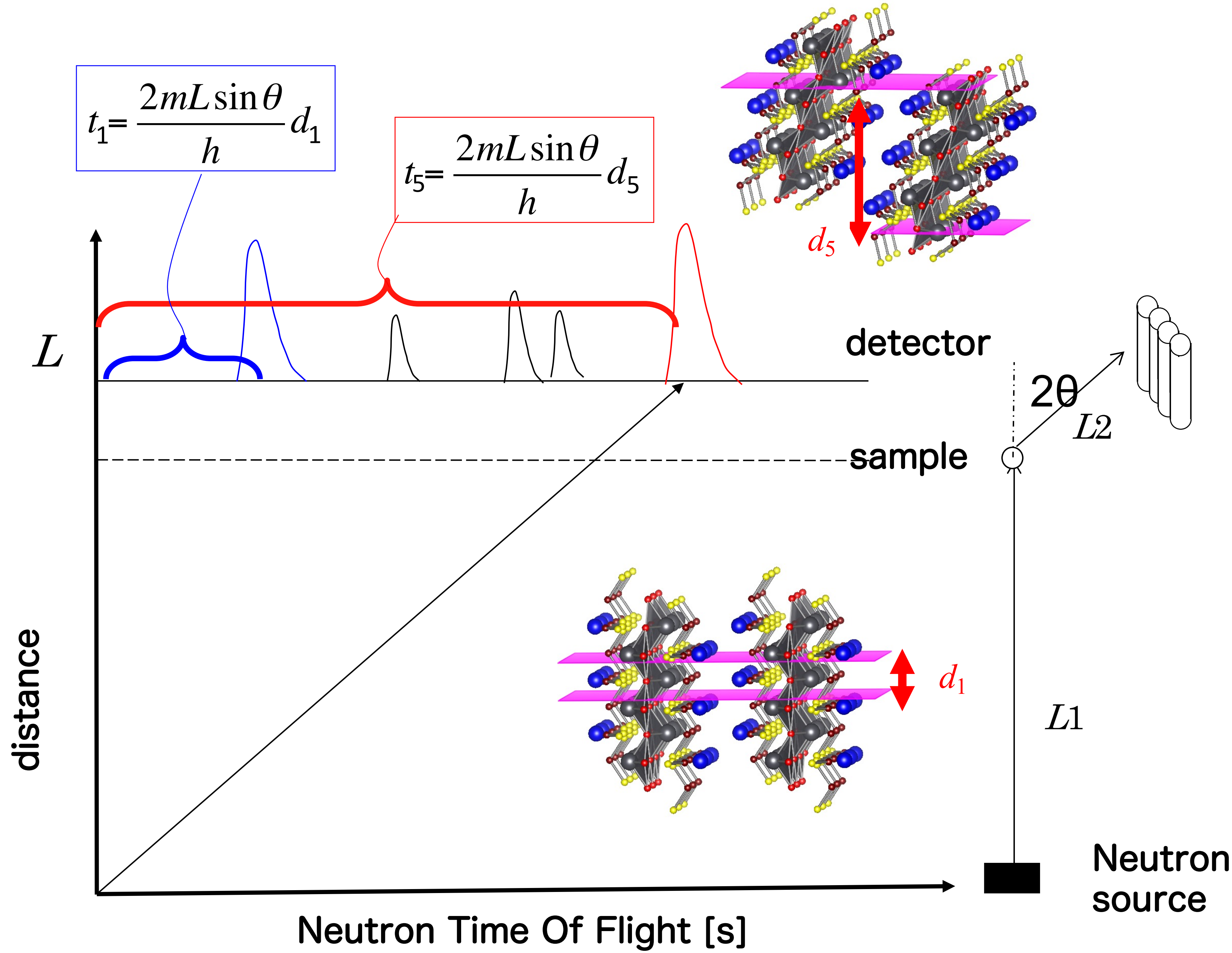
Bragg scattering + *de Broglie* relationship

$$\lambda = 2d \sin\theta$$

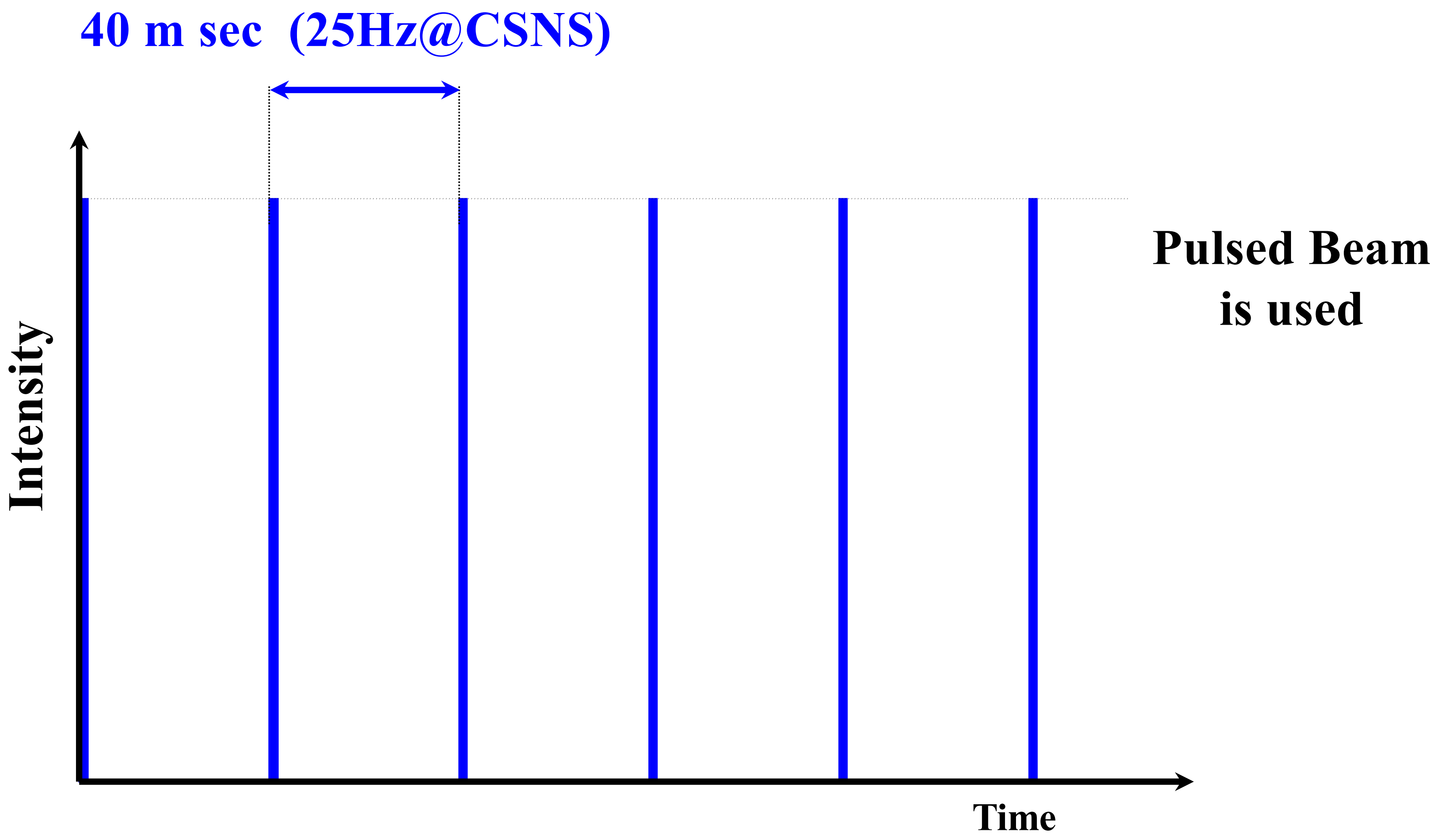
$$\lambda = \frac{h}{m \times v} = \frac{h}{m \times L/t}$$

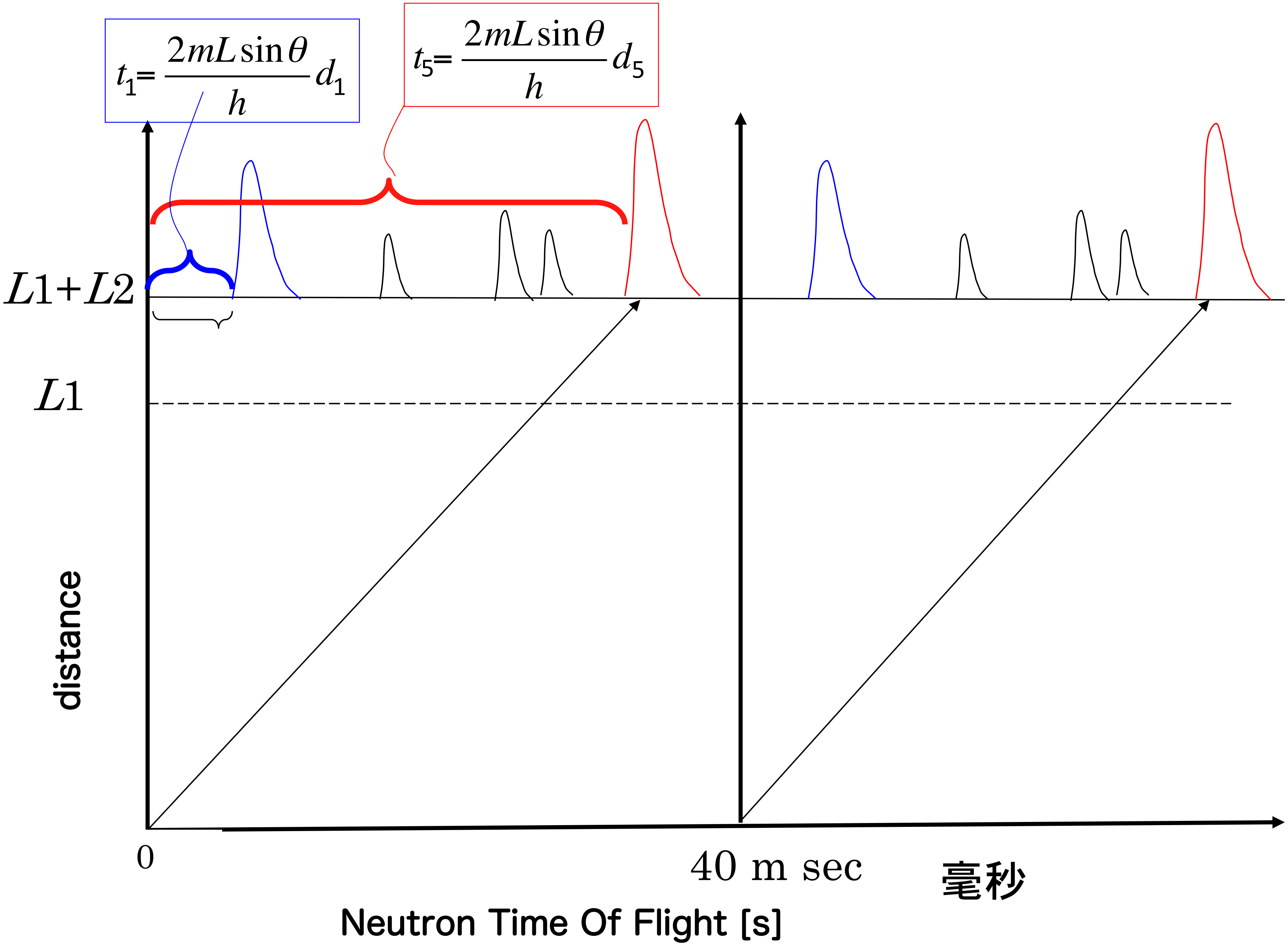
$$t = \frac{2mL\sin\theta}{h} d$$



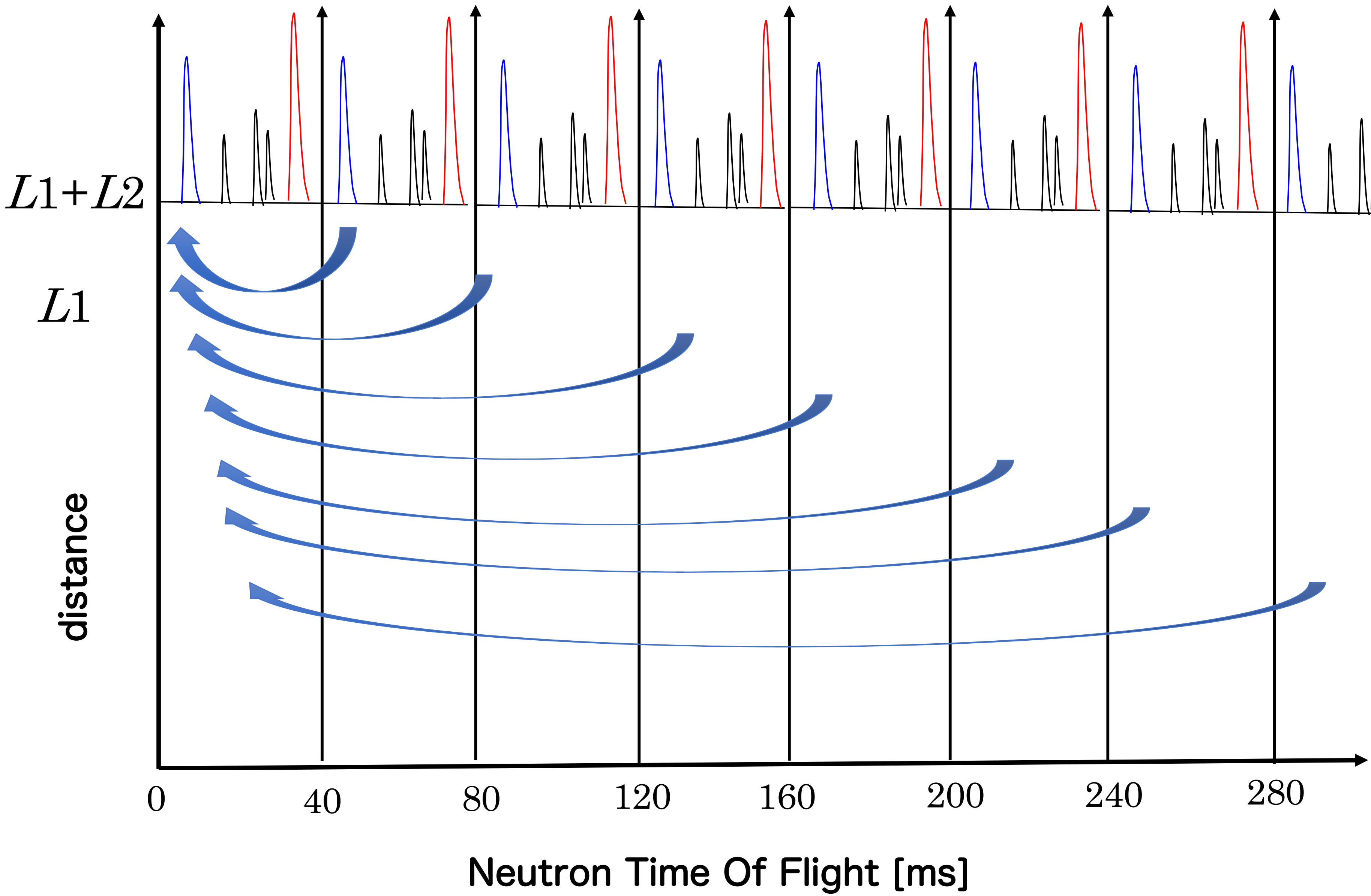


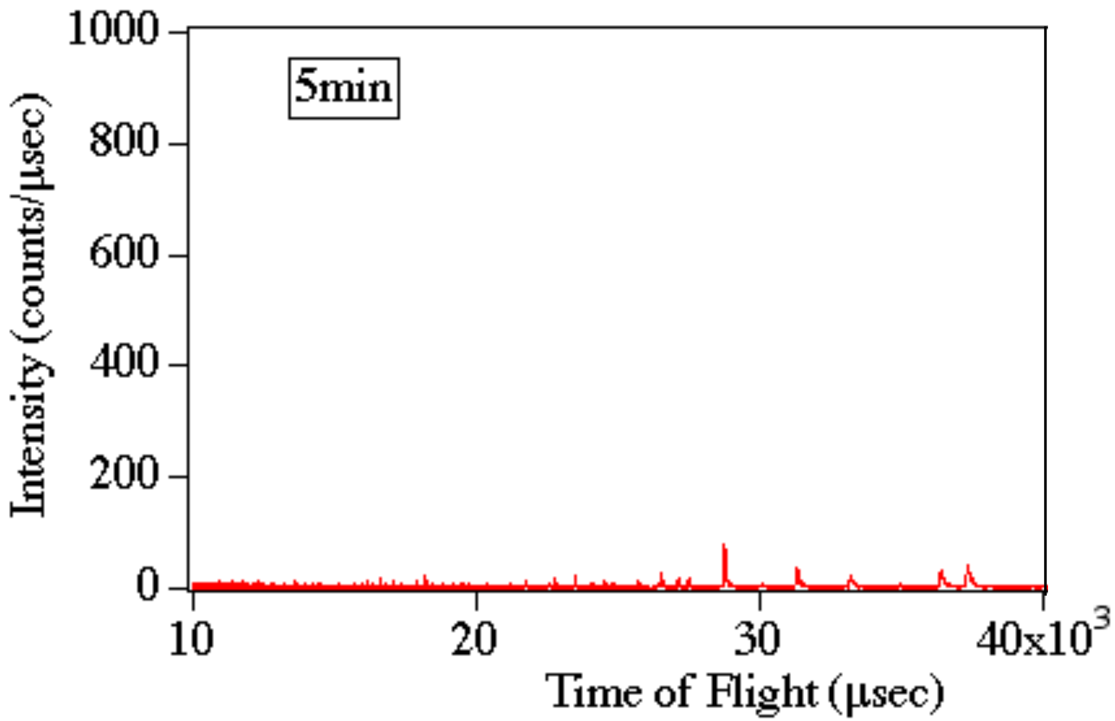
$t_1 = \frac{2mL\sin\theta}{h} d_1$
$t_5 = \frac{2mL\sin\theta}{h} d_5$
d_5
L
detector
2θ
$L2$
sample
d_1
distance
$L1$
Neutron source
Neutron Time Of Flight [s]


40 m sec (25Hz@CSNS)
Intensity
Time
Pulsed Beam
is used

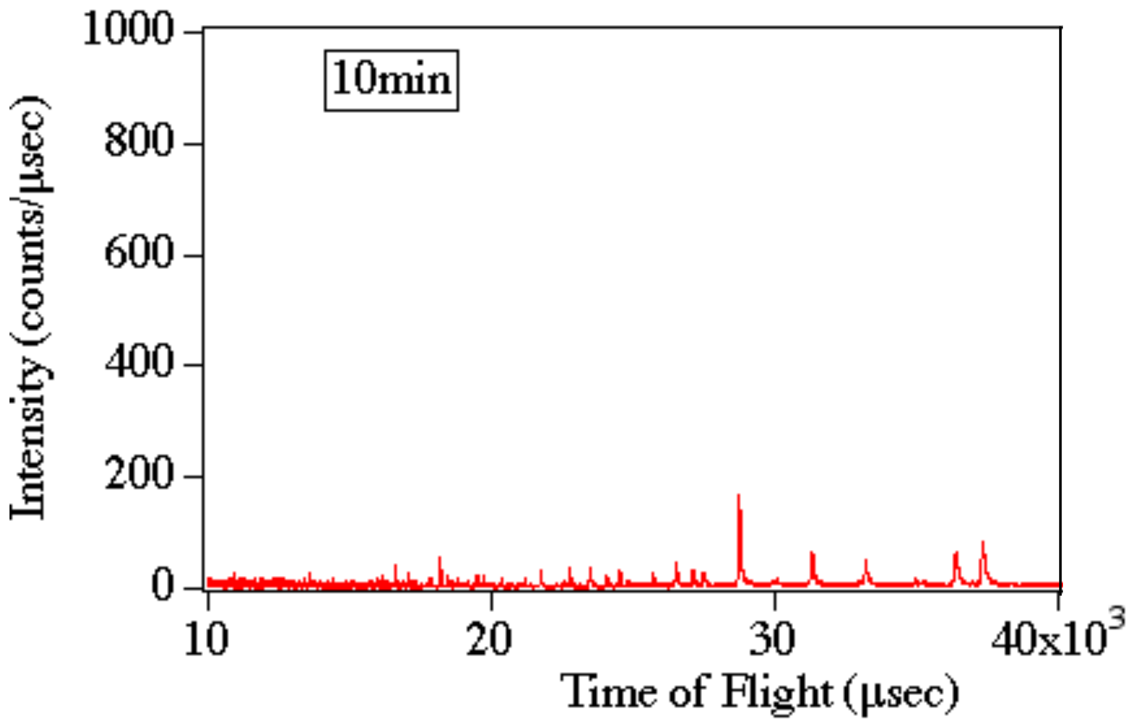


$t_1 = \frac{2mL\sin\theta}{h} d_1$
$t_5 = \frac{2mL\sin\theta}{h} d_5$
$L1+L2$
$L1$
distance
0
40 m sec
毫秒
Neutron Time Of Flight [s]

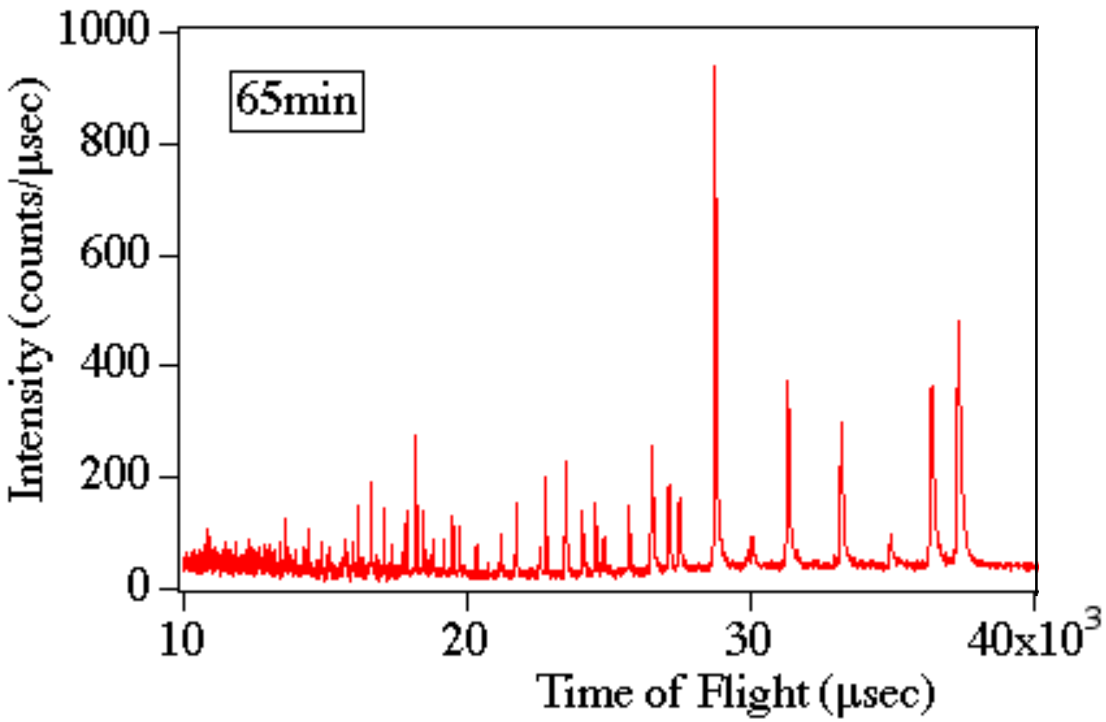

L1+L2
L1
distance
0
40
80
120
160
200
240
280
Neutron Time Of Flight [ms]


5min
1000
800
600
400
200
0
Intensity (counts/µsec)
10
20
30
40x10^3
Time of Flight (µsec)

微秒



10min
Intensity (counts/µsec)
1000
800
600
400
200
0
10
20
30
40x10³
Time of Flight (µsec)

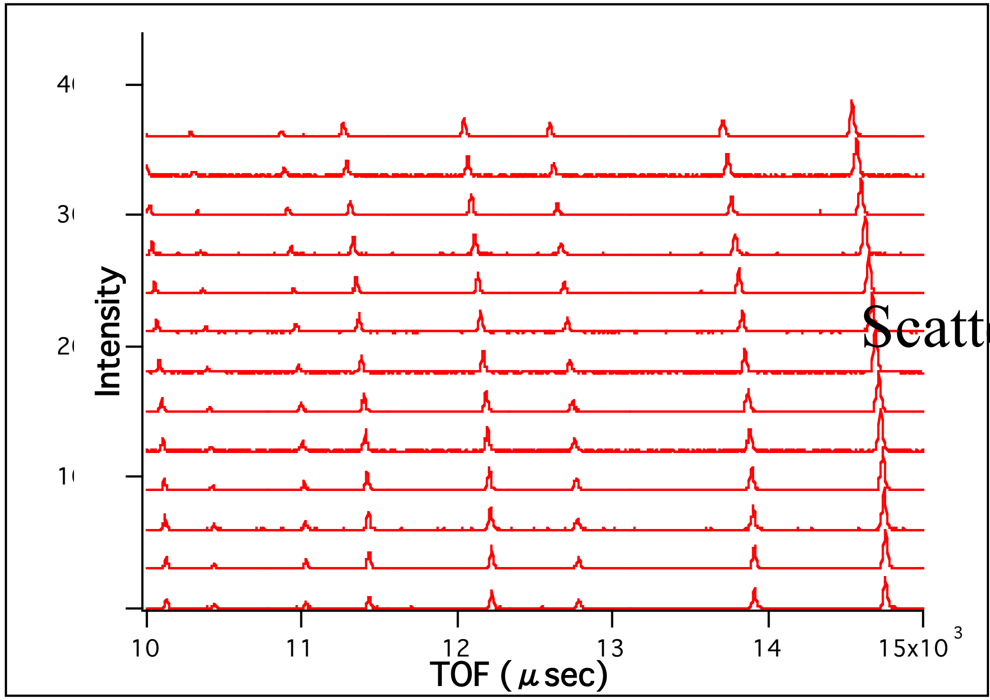


65min
Intensity (counts/µsec)
1000
800
600
400
200
0
10
20
30
40x10^3
Time of Flight (µsec)

Bragg scattering + *de Broglie* relationship

$$t = \frac{2mL\sin\theta}{h}d$$

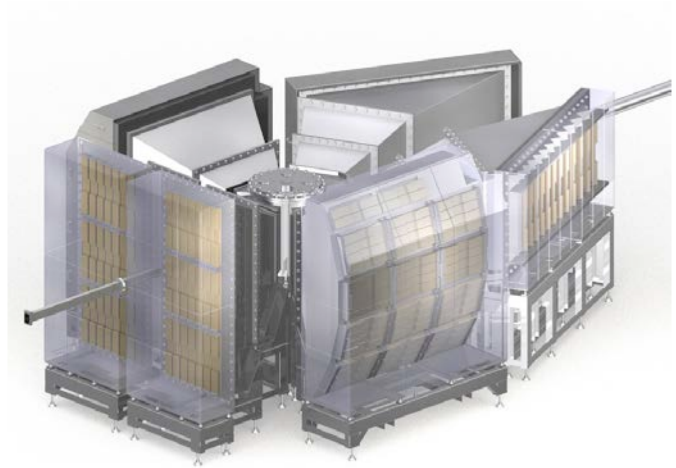
The same Bragg scattering *d* arrives at different time depending on *L*sin*θ*



Small

Scattering angle 2θ

Large



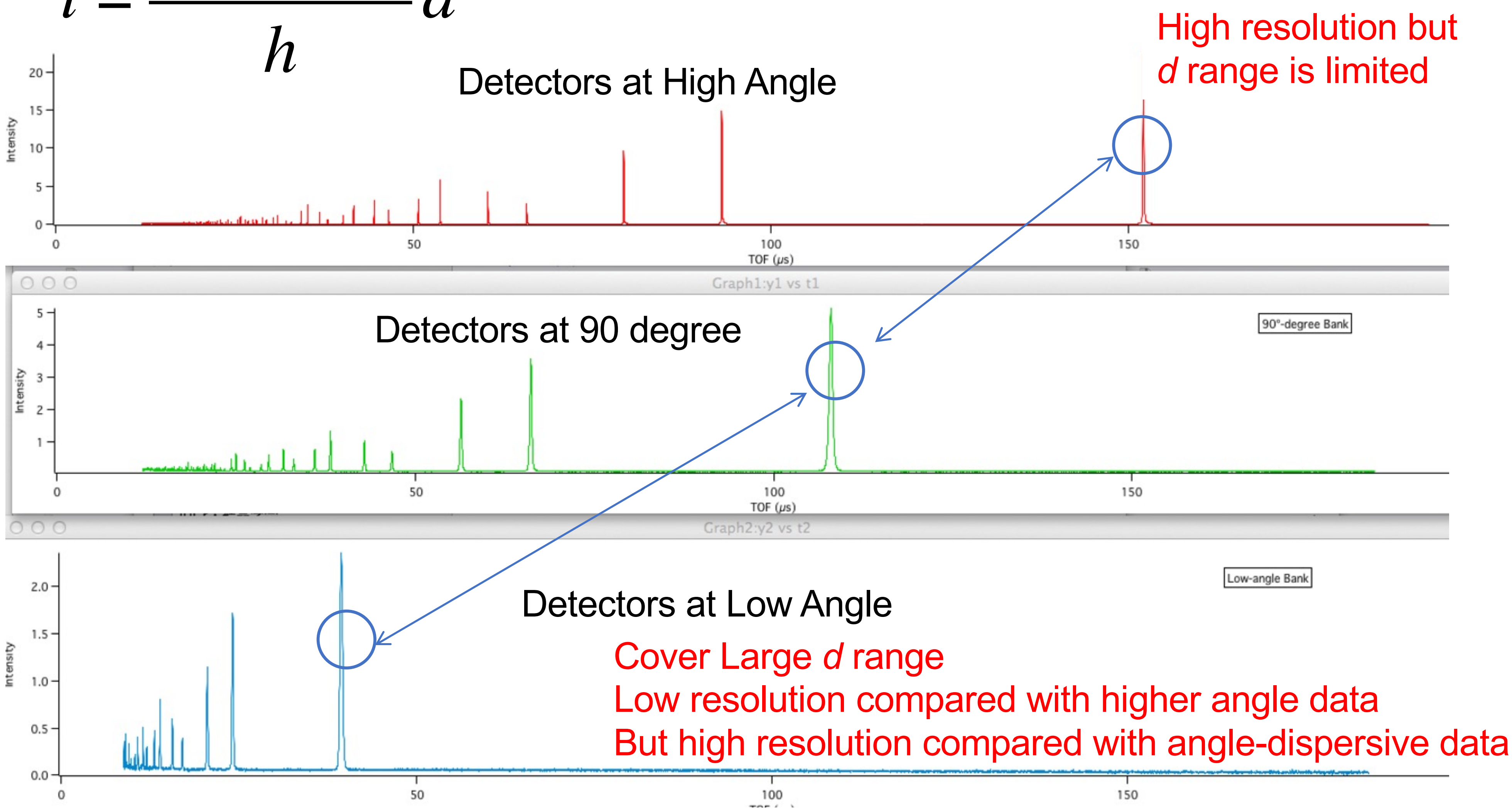
SuperHRPD

Time focusing 法 : Sum up data from different detectors

Time-of-flight diffractometers can have large detector banks without scarifying resolution → **intensity gain**

$$t = \frac{2mL\sin\theta}{h} d$$

NIST Silicon

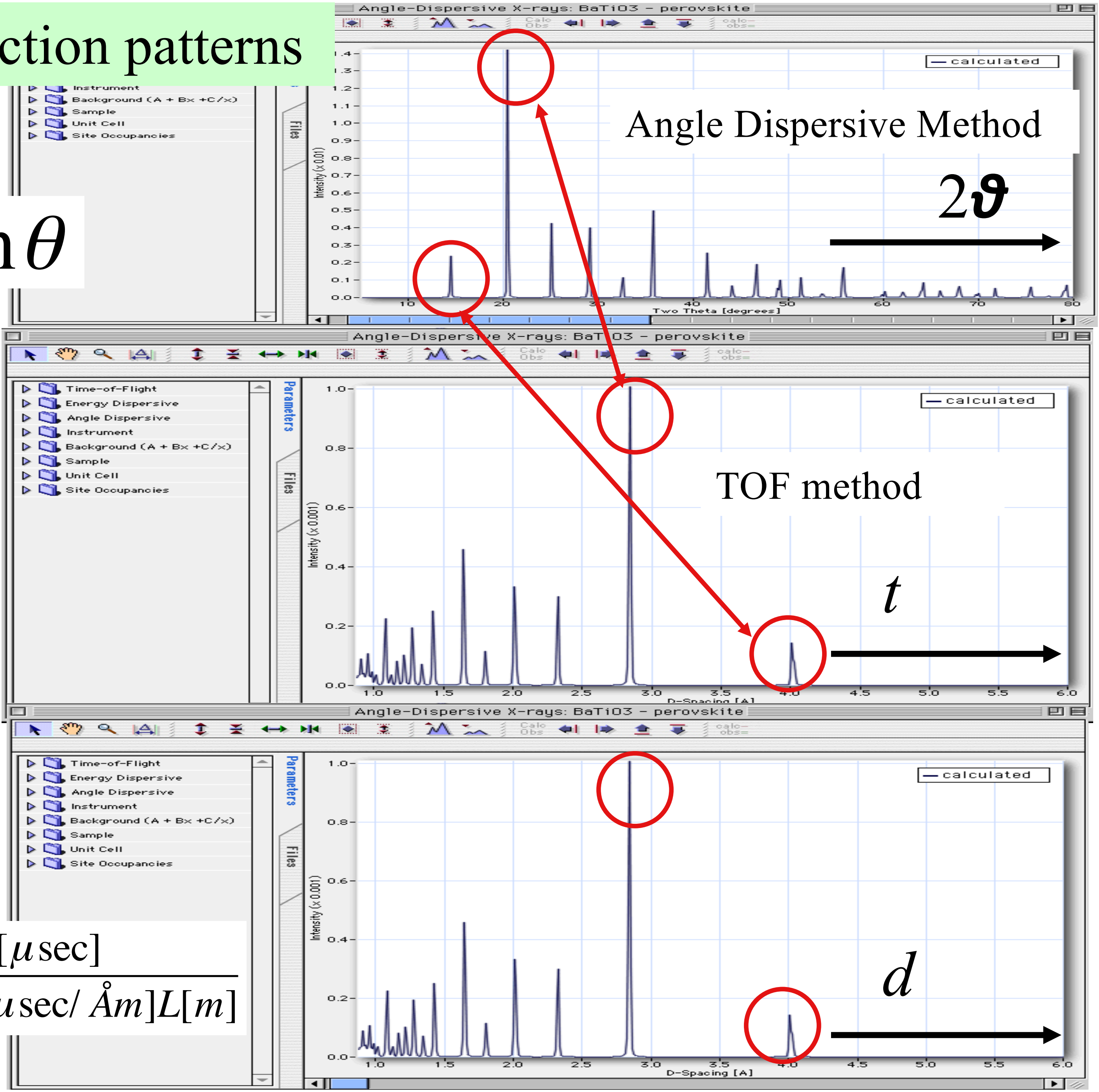


Compare diffraction patterns

$$\lambda = 2d\sin\theta$$

CrystallDiffract

$$d[\text{Å}]\sin\theta = \frac{t[\mu\sec]}{505.555[\mu\sec/\text{Å}m]L[m]}$$

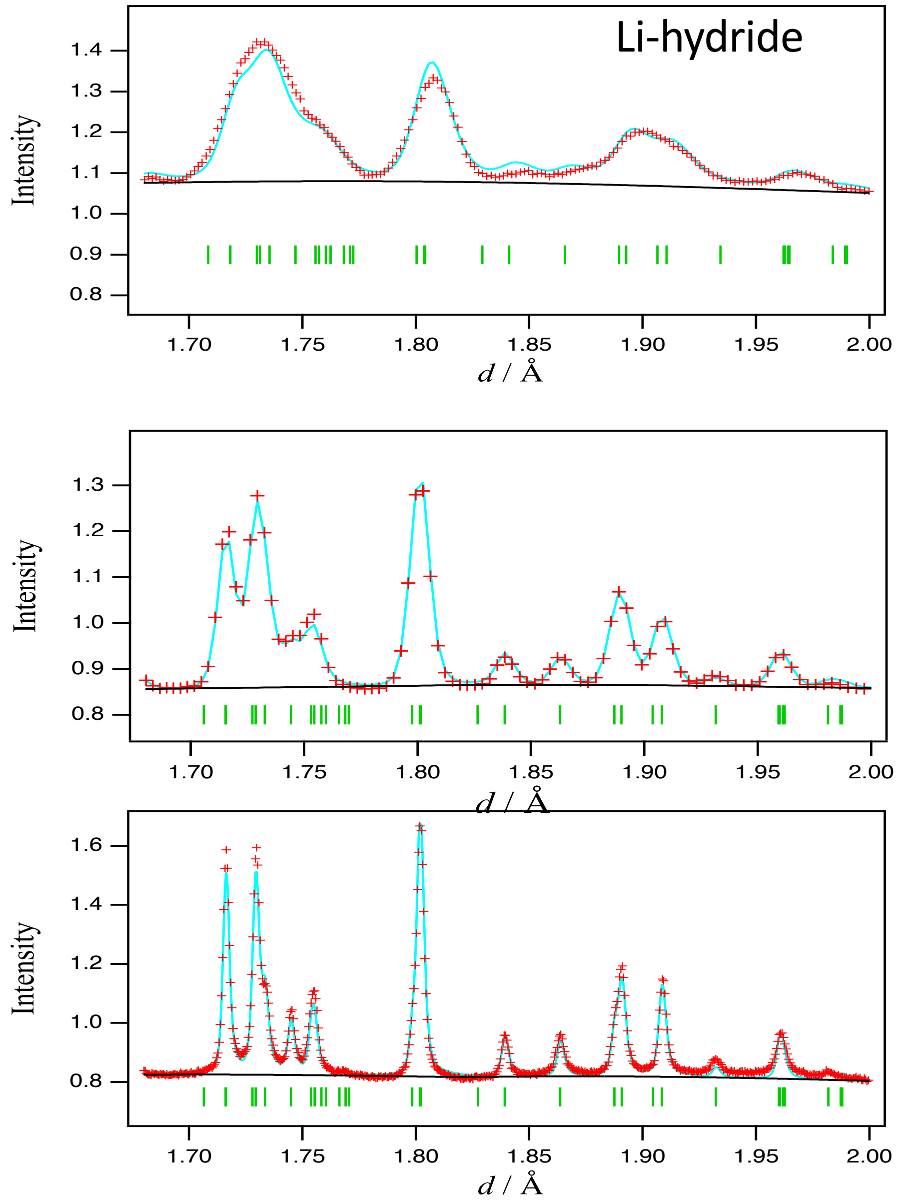


Higher Resolution

$$\frac{\Delta d}{d} = |\frac{\Delta t}{t}| + \sqrt{(\frac{\Delta L}{L})^2 + cot^2\theta\Delta\theta^2}$$

Moderator development
Long Flight Path
2θ → larger

Why Higher Resolution?



Low *Resolution*, but High *Intensity*

→if the model is OK, the result of fitting is acceptable

→ But you may not discover anything

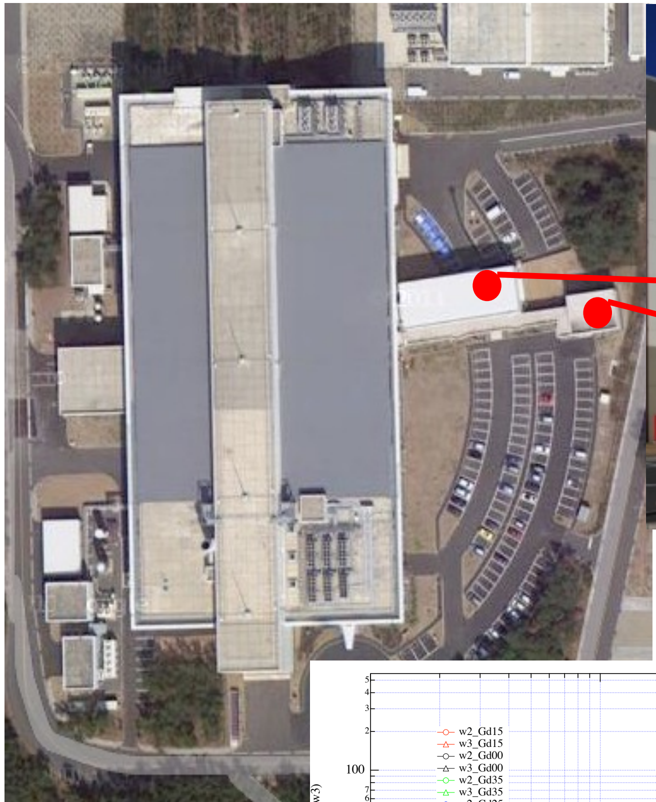
High *Resolution*

→ Can extract reliable |F|^2

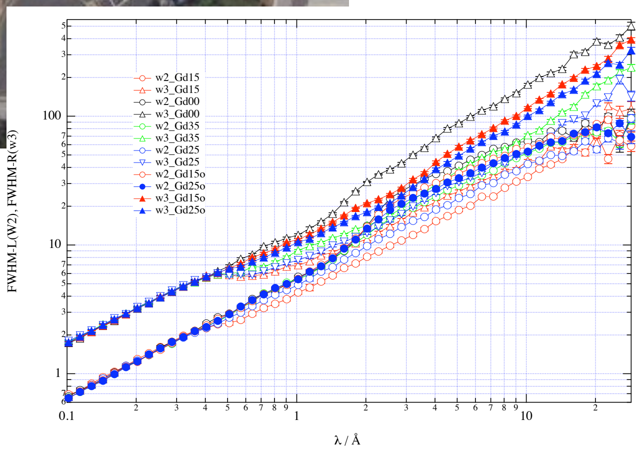
→ You may discover something

J-PARC
MLF building

SuperHRPD: World Highest-Resolution Diffractometer



SuperHRPD

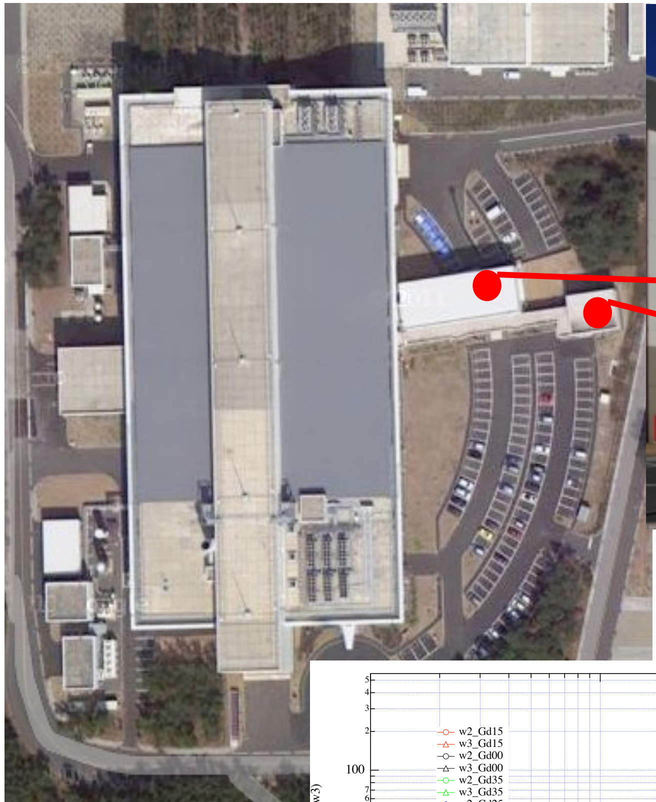


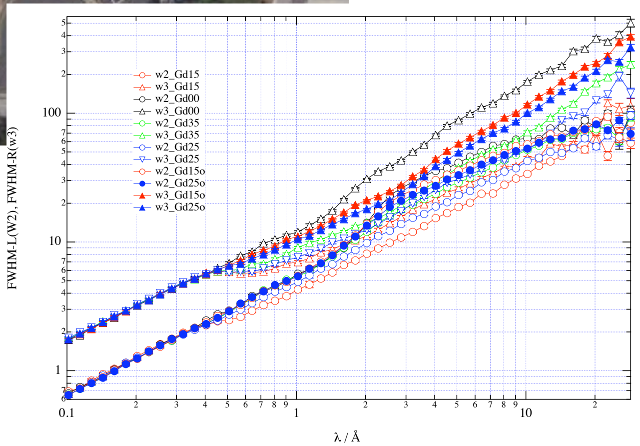
Moderator development
Long Flight Path with Guide Tubes
2θ → 大

Moderator development

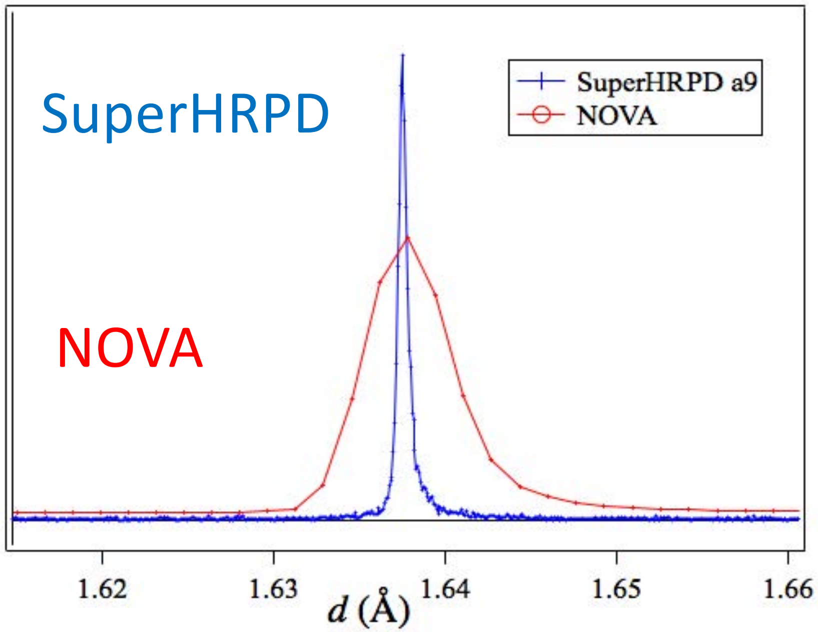
J-PARC
MLF building

SuperHRPD: World Highest-Resolution Diffractometer

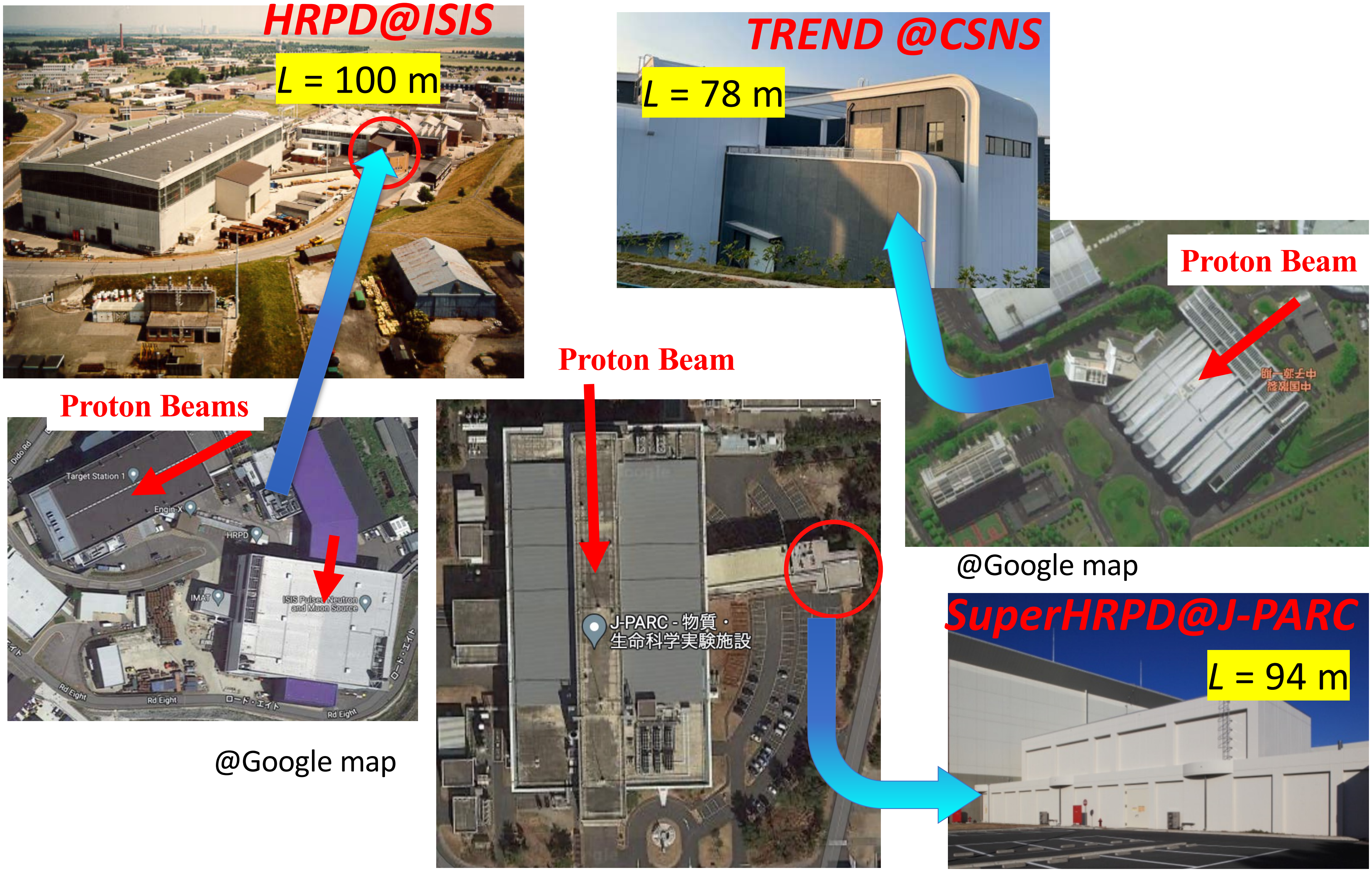




Moderator development

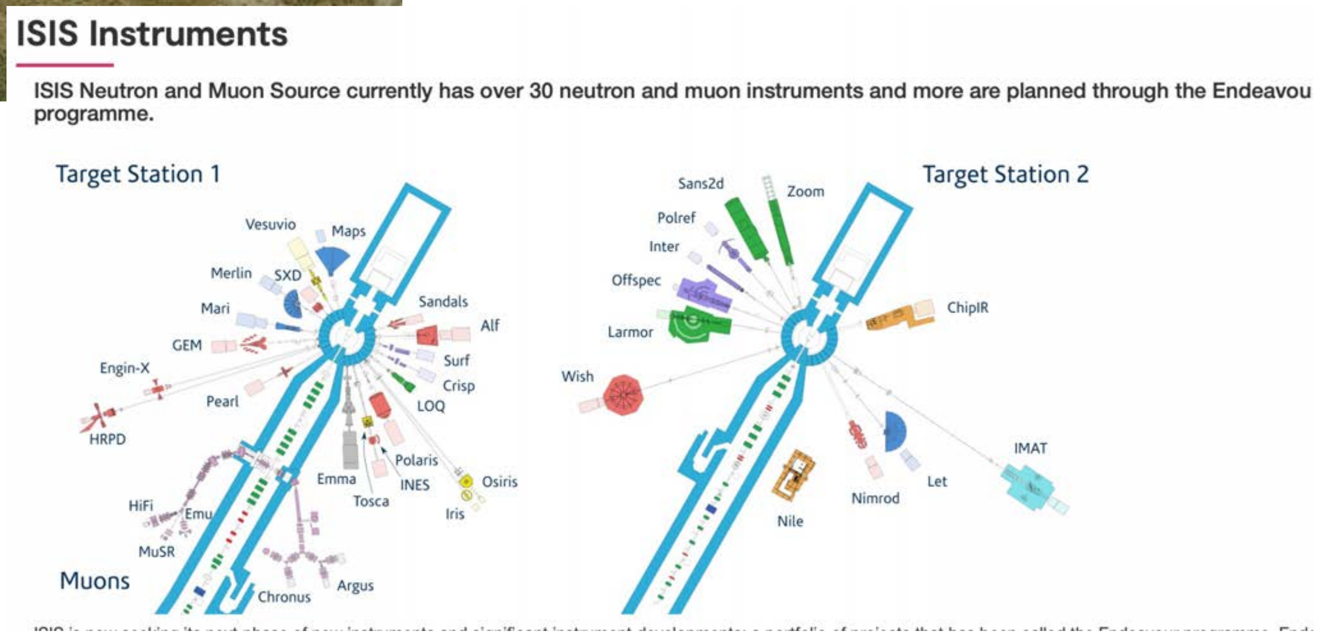


Towards Higher Resolution: Pulsed Proton Accelerators



RAL ISIS (UK)

1st TS since 1984
2nd TS since 2008



search by isis neutron

ORNL SNS (USA)

Since April, 2006

OAK RIDGE National Laboratory

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Home » Spallation Neutron Source

Spallation Neutron Source

SNS produces neutrons with an accelerator-based system that delivers short (microsecond) proton pulses to a steel target filled with liquid mercury through a process called spallation. Those neutrons are then directed toward state-of-the-art instruments that provide a variety of capabilities to researchers across a broad range of disciplines, such as physics, chemistry, biology, and materials science.

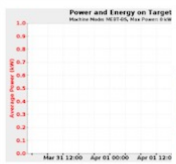
SNS is available to researchers around the world with varying degrees of experience. Submitted research proposals are reviewed by independent scientists from within the neutron scattering community to ensure the most promising ones are chosen.

OPERATING STATUS

Verizon cell phone servic[e] experiencing issues. Rep[a] underway. Service issues expected for several hour[s]

Sign up for Operating Sta[tus]

OPERATING GRAPH



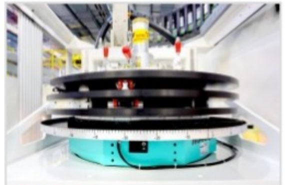
search by **sns neutron**

– Instruments

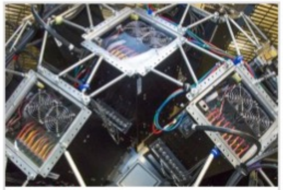
SINGLE CRYSTAL DIFFRACTION SUITE

CORELLI
Detailed studies of disorder in crystalline materials

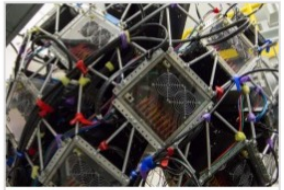
DEMAND
Small unit-cell nuclear & magnetic structural studies



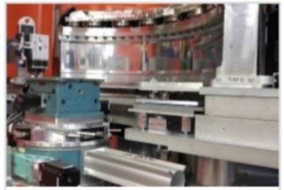
IMAGINE
Atomic resolution structures in biology, chemistry and



MANDI
Atomic level structures of proteins, macromolecules and

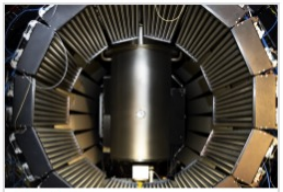


TOPAZ
Atomic-level structures in chemistry, biology, earth

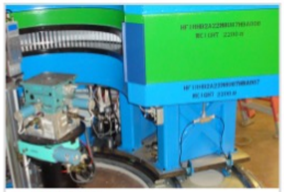


WAND²
Diffuse-scattering studies of single crystals and time-

POWDER DIFFRACTION SUITE



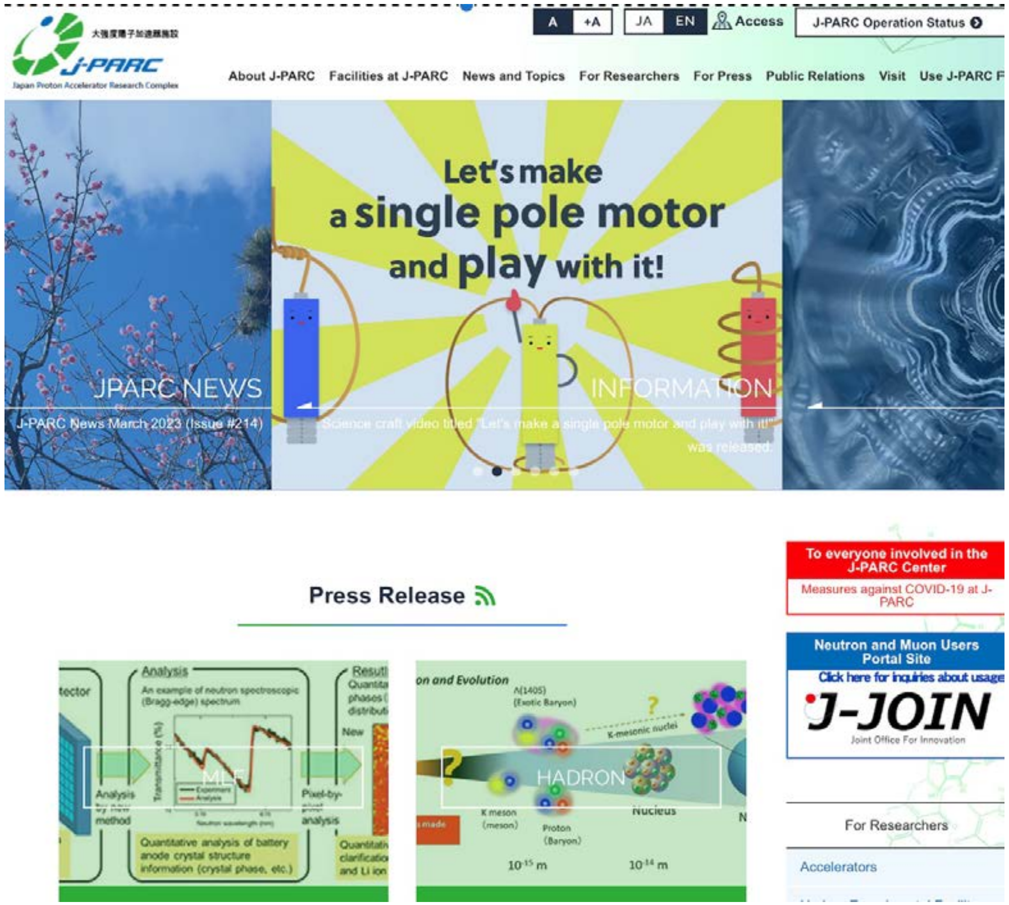
NOMAD
Liquids, solutions, glasses, polymers, nanocrystalline and



POWDER
Magnetic and crystal structure studies and phase analysis

POWGEN
Atomic-level structures in chemistry, materials science,

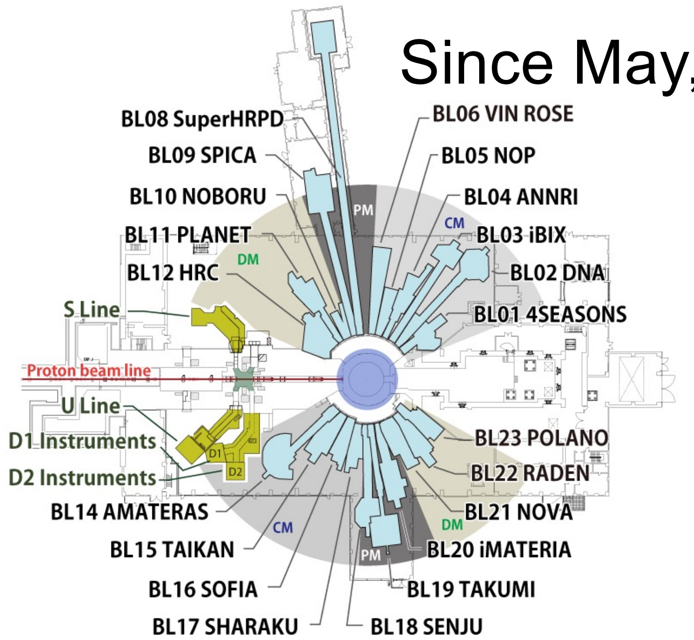
J-PARC MLF (Japan)



search by meet@mlf

Layout of Instruments & Features

Since May, 2008



Inelastic Neutron Scattering
- BL01 4SEASONS 4D-Space Access Neutron Spectrometer
- BL02 DNA Biomolecular Dynamics Spectrometer
- BL06 VIN ROSE Village of Neutron Resonance Spin Echo Spectrometers (VIN ROSE)
- BL12 HRC High Resolution Chopper Spectrometer
- BL14 AMATERAS Cold-Neutron Disk-Chopper Spectrometer
- BL23 POLANO Polarized Neutron Spectrometer

Neutron Diffraction
- BL03 iBIX IBARAKI Biological Crystal Diffractometer
- BL08 SuperHRPD Super High Resolution Powder Diffractometer
- BL09 SPICA Special Environment Powder Diffractometer
- BL11 PLANET High-Pressure Neutron Diffractometer
- BL18 SENJU Extreme Environment Single Crystal Neutron Diffractometer
- BL19 TAKUMI Engineering Materials Diffractometer
- BL20 iMATERIA IBARAKI Materials Design Diffractometer
- BL21 NOVA High Intensity Total Diffractometer

SANS & Neutron Reflectometry
- BL15 TAIKAN Small and Wide Angle Neutron Scattering Instrument
- BL16 SOFIA Soft Interface Analyzer
- BL17 SHARAKU Polarized Neutron Reflectometer

Neutron Imaging
- BL22 RADEN Energy Resolved Neutron Imaging System

Neutron-Nuclear Reaction, Prompt Gamma-Ray Analysis
- BL04 ANNRI Accurate Neutron-Nucleus Reaction Measurement Instrument

Neutron Fundamental Physics, Neutron Device Development
- BL05 NOP Neutron Optics and Fundamental Physics (NOP)
- BL10 NOBORU NeutrOn Beam-line for Observation and Research Use

Instruments for Muon Experiments
- Muon D1 Muon Apparatus for Materials and Life Science Experiments
- Muon D2 Muon Apparatus for Basic Science Experiments
- Muon U1 Ultra Slow Muon Microscope Apparatus
- Muon S1 ARTEMIS General purpose μSR spectrometer

Since 2017

中国散裂中子源工程
China Spallation Neutron Source
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谱仪规划
科学研究
运行实时状态
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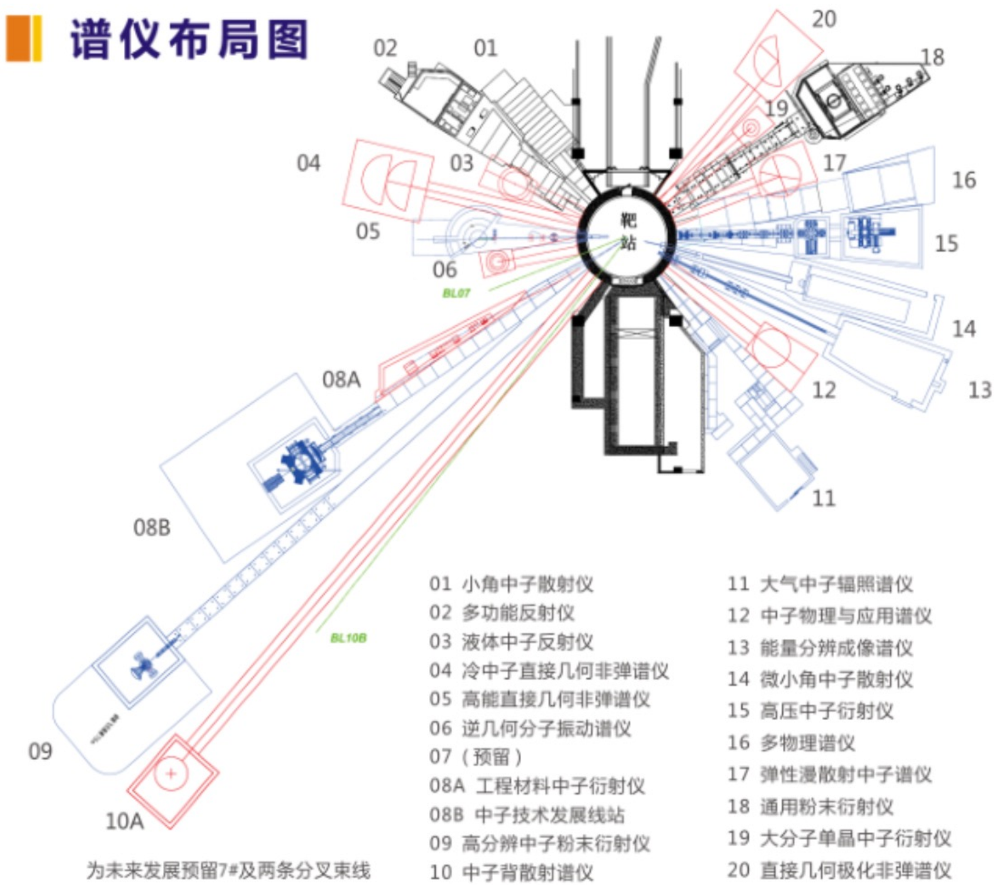
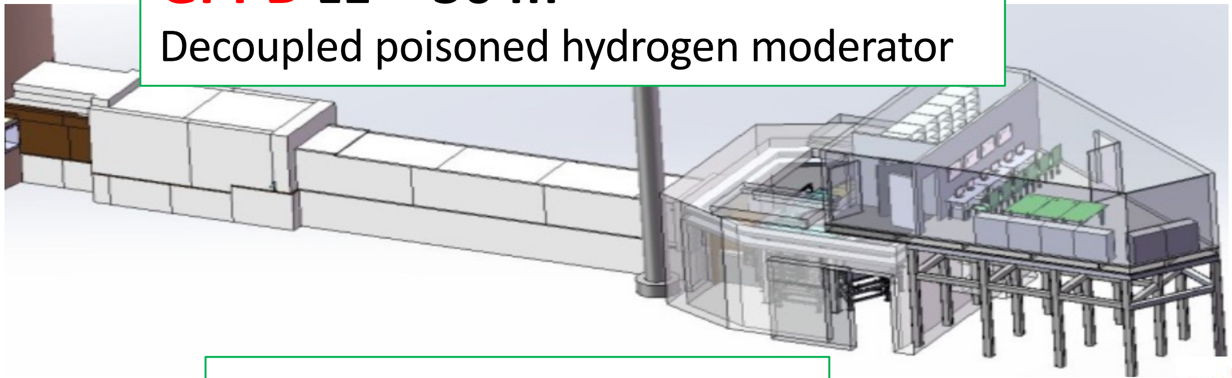
硼药及BNCT研讨会在东莞顺利召开
2023年3月19-21日，由中国科学院高能物理研究所东莞研究部主办、国科中子医疗科技有限公司协办的"硼药及BNCT研讨会"在东莞散裂中子源园区顺利召开。中国散裂中子源工程总指挥陈和生院士担任大会主席，中科院高能所郝权研究员、邢更妹研究员联合召集，南方科技大学谢作伟院士、国家纳米中心赵宇亮院士等来自国内30多所高校、研究所、医院、药企的100多名专家代表参加了会议。【详细内容】
科普园地
中国散裂中子源谱仪规划
散裂中子源科普小动画
要闻动态
硼药及BNCT研讨会在东莞顺利召开 2023-03-24
中国散裂中子源博士后成果研讨会召开 2023-03-24



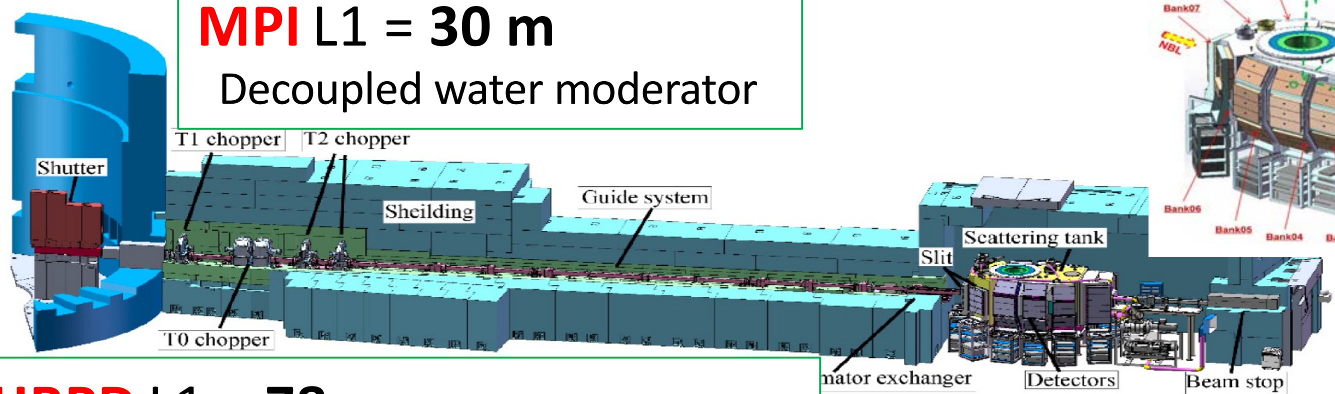
谱仪布局图
靶站
01 小角中子散射仪
02 多功能反射仪
03 液体中子反射仪
04 冷中子直接几何非弹谱仪
05 高能直接几何非弹谱仪
06 逆几何分子振动谱仪
07（预留）
08A 工程材料中子衍射仪
08B 中子技术发展线站
09 高分辨中子粉末衍射仪
10 中子背散射谱仪
11 大气中子辐照谱仪
12 中子物理与应用谱仪
13 能量分辨成像谱仪
14 微小角中子散射仪
15 高压中子衍射仪
16 多物理谱仪
17 弹性漫散射中子谱仪
18 通用粉末衍射仪
19 大分子单晶中子衍射仪
20 直接几何极化非弹谱仪
为未来发展预留7#及两条分叉束线

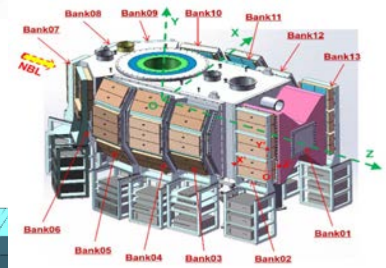
High Resolution TOF Diffractometers @ CSNS, Dongguan

GPPD L1 = **30 m**
Decoupled poisoned hydrogen moderator

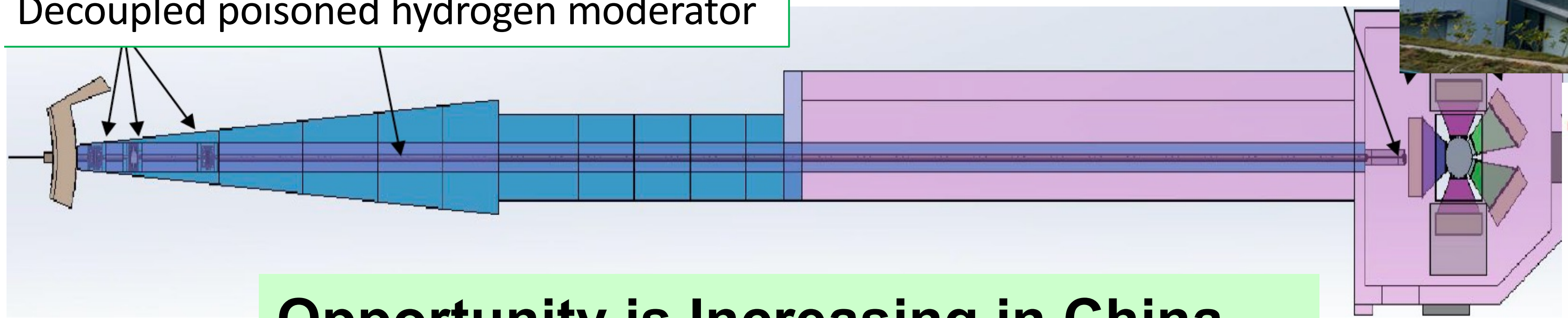


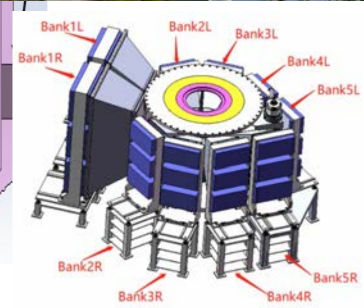
MPI L1 = **30 m**
Decoupled water moderator





HRPD L1 = **78 m**
Decoupled poisoned hydrogen moderator





Opportunity is Increasing in China

Selected list of constant wavelength neutron powder diffractometers

Facility	CW NPD instrument	
	High resolution	High intensity
Institut Laue-Langevin (France)	D2B	D20
Forschungsreaktor München II (Germany)	SPODI	ErwiN (under const)
aul Scherrer Institute (Switzerland)	HRPT	DMC (cold neutrons)
Delft University of Technology (Netherlands)		PEARL
High Flux Isotope Reactor (US)	POWDER, HB-2A	WAND^2, HB-2C
National Institute of Standards and Technology (US)	BT-1	
Australian Nuclear Science and Technology Organisation (Australia)	Echidna	Wombat
Japan Atomic Energy Agency JRR-3 reactor (Japan)	HRPD	HERMES
China Advanced Research Reactor (China)	HRPD	HIPD
China Mianyang Research Reactor (China)	Xuanwu	Fenghuang
Korea Atomic Energy Research Institute (Korea)	HRPD	HIPD
Bhabha Atomic Research Centre (India)	PD-2, PD-3	PD-1

Neutron diffraction: a primer in https://degruyter.com/document/doi/10.1515/zkri-2024-0001/html

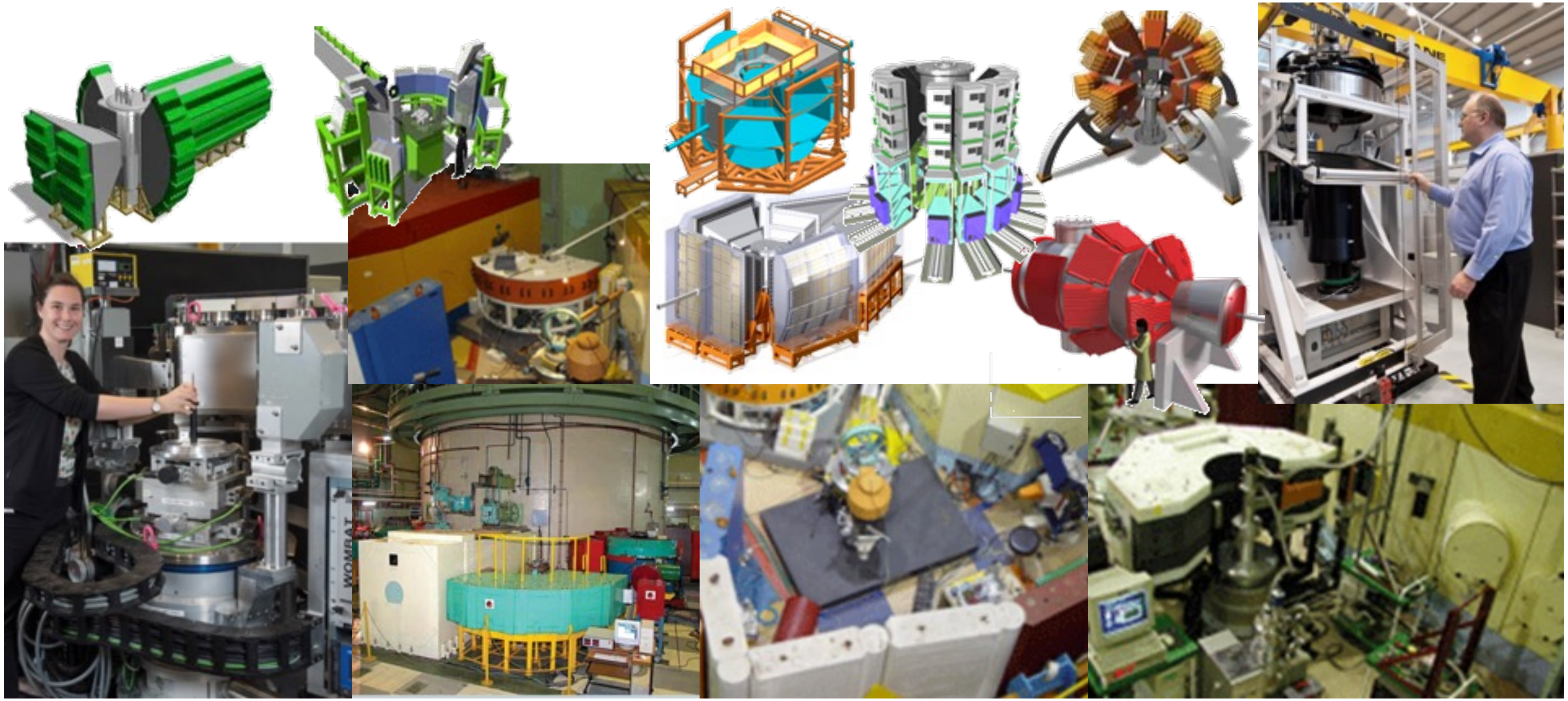
Selected list of time-of-flight neutron powder diffractometers

Facility	TOF Neutron Powder Diffractometers		
	High-Resolution	High-Intensity	Special Diffractometers
ISIS (UK)	HRPD WISH	GEM Polaris	PEARL: High Pressure ENGIN-X: Engineering Diff.
SNS (US)	POWGEN	NOMAD	SNAP: High Pressure VULCAN: Engineering Diff.
LANSCE (US)			SMARTS: High Pressure & Pref. Orien. HIPPO: Engineering Diff.
J-PARC (Japan)	SuperHRPD iMATERIA SPICA	NOVA	PLANET: High Pressure TAKUMI: Engineering Diff.
CSNS (China)	TREND GPPD	MPI	High Pressure Diffractometer EMD: Engineering Diff.

Neutron diffraction: a primer in https://degruyter.com/document/doi/10.1515/zkri-2024-0001/html

Neutron Diffractometers in Asia and Oceania

OPAL	3NPD	1SXD	Echidna, Wombat, KOWARI, KOALA
J-PARC	6NPD	2SXD	S-HRPD, iMATERIA, NOVA, TAKUMI, PLANET, SPICA, iBIX, SENJU
HANARO	3NPD	2SXD	HRPD, HIPD, residual stress, four circle, area-detector
BARC	4NPD	1SXD	3 powder, 1high-Q (2.5%reso, -15Å^{-1}), 1 single
CARR	4NPD	1SXD	HRPD, HIPD, residual stress, texture diffractometer, four circle,
BATAN	2NPD	1SXD	HRPD, residual stress, four circle/texture diffractometer
CSNS	from 2018		



Summary

1. *Brief history of Neutron Diffraction and its Advantages*

2. *Angle-Dispersive Diffraction (monochromatic neutron) and Time Of Flight Diffraction (white neutron)*

3. *Time Of Flight Diffractometers*

- *Opportunities have been increasing in China and is going to take a role in the Worldwide Infrastructure*

Thank you very much for attention!

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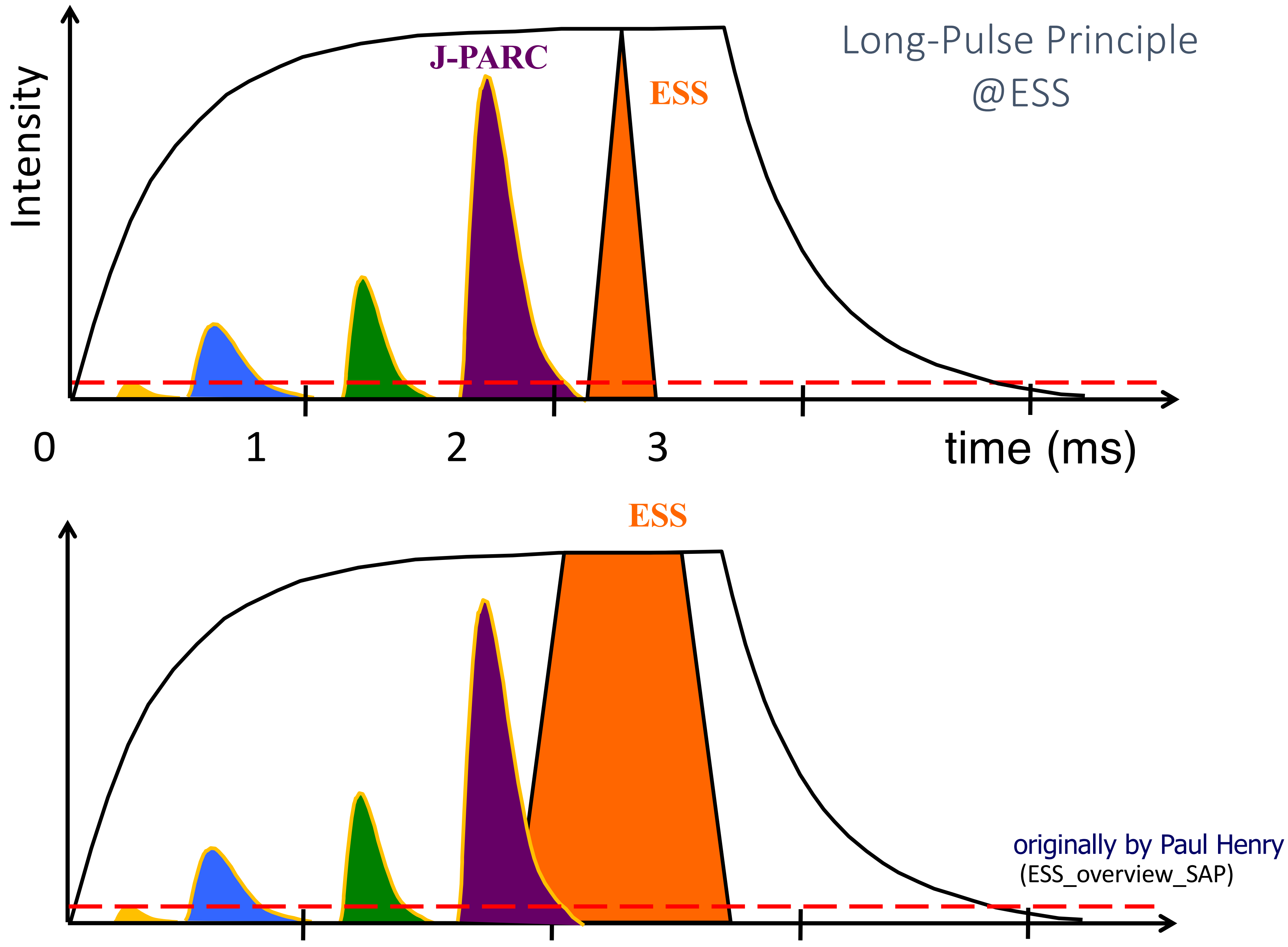
kamiyama@ihep.ac.jp

reference

Neutron diffraction: a primer in Zeitschrift für Kristallographie - Crystalline Materials
April 29, 2024

Richard Dronskowski EMAIL logo , Thomas Brückel , Holger Kohlmann , Maxim Avdeev , Andreas Houben , Martin Meven , Michael Hofmann , Takashi Kamiyama , Mirijam Zobel , Werner Schweika , Raphaël P. Hermann and Asami Sano-Furukawa

https://degruyter.com/document/doi/10.1515/zkri-2024-0001/html



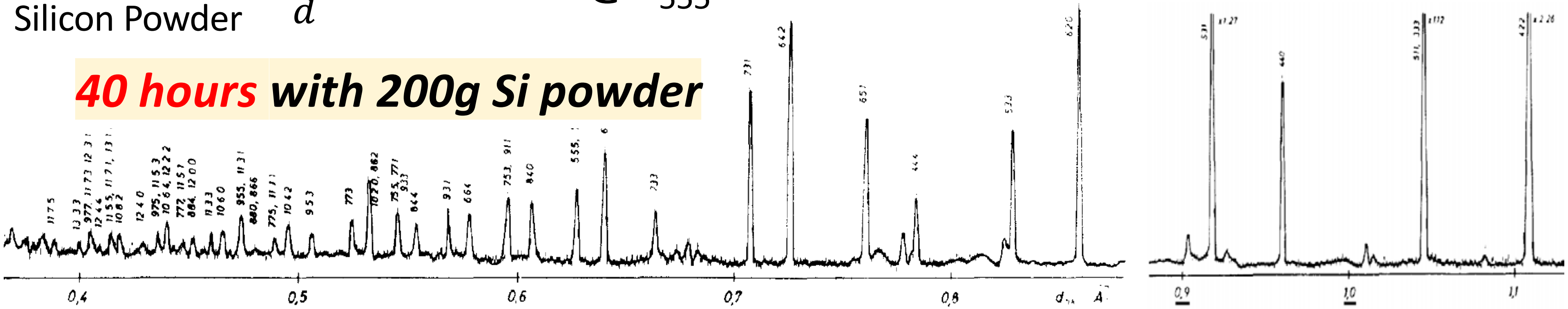
Long-Pulse Principle
@ESS
Intensity
J-PARC
ESS
0
1
2
3
time (ms)
ESS
originally by Paul Henry
(ESS_overview_SAP)

Towards Higher resolution: Compare the diffractometers

Munich diffractometer E. Steichele and P. Arnold, Physics letters 44A, 165(1973)

Silicon Powder $\frac{\Delta d}{d} = \mathbf{2 \times 10^{-3}}$ $@d_{555} = 0.63$ Å $L \approx 150\ m$

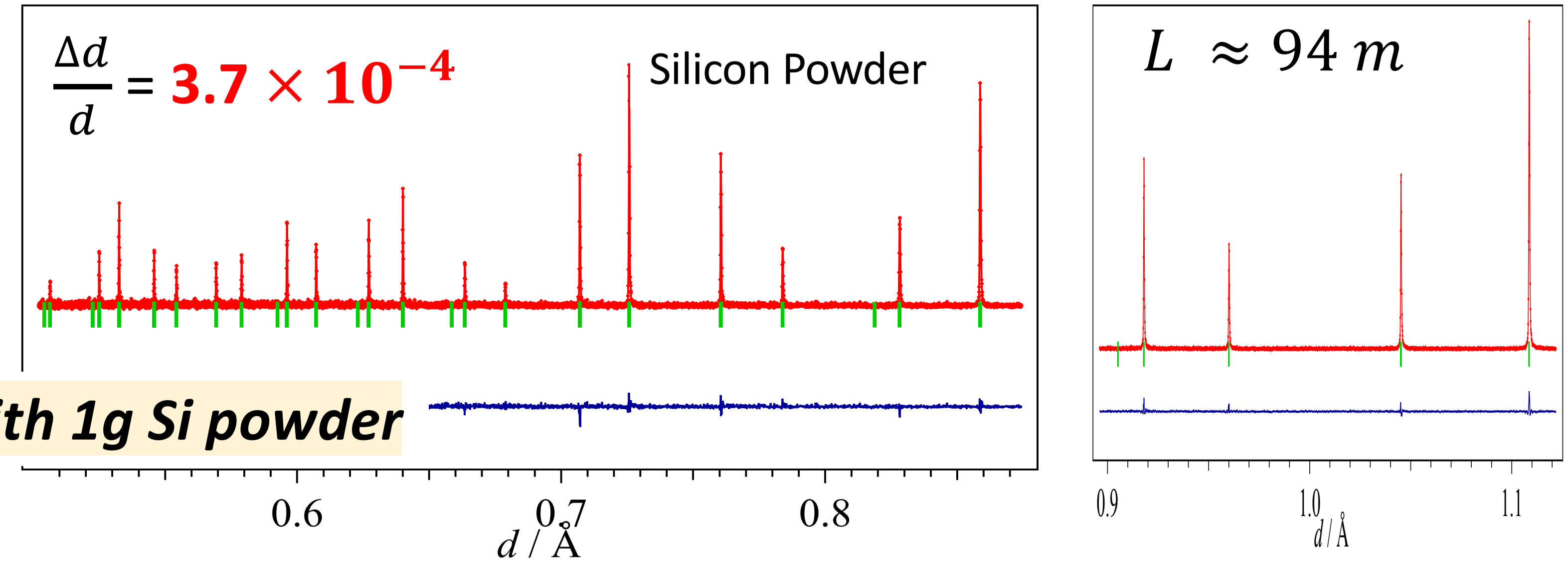
***40 hours* with 200g Si powder**



SuperHRPD @J-PARC

$\frac{\Delta d}{d} = \mathbf{3.7 \times 10^{-4}}$ Silicon Powder $L \approx 94\ m$

***~1 hours* with 1g Si powder**



TREND @CSNS L = 78 m, HRPD@ISIS L = 100 m has similar performance