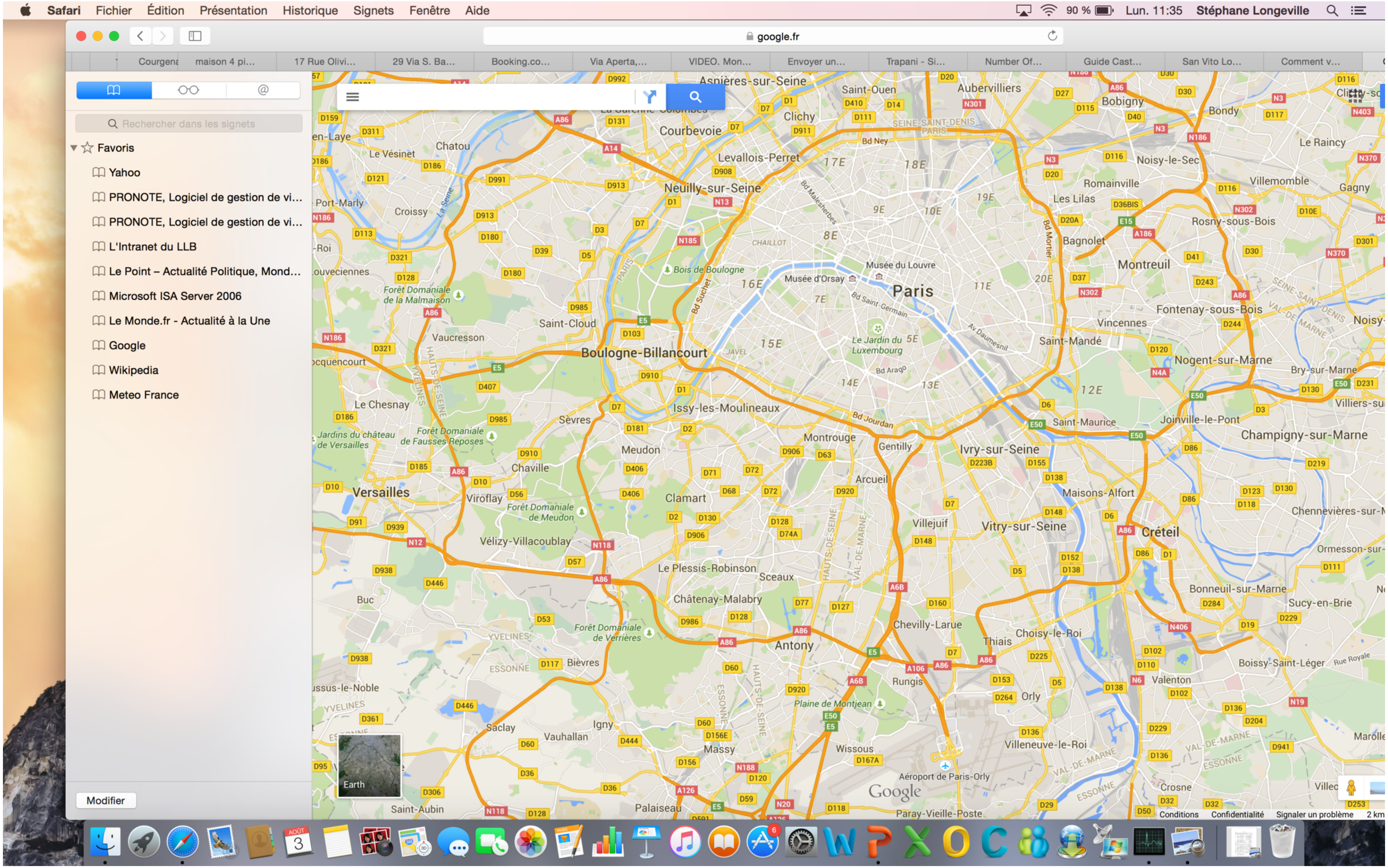
Time-of-flight and backscattering neutron spectrometers

S. Longeville,
Laboratoire Léon Brillouin (LLB), France



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Historique
Signets
Fenêtre
Aide
90 %
Lun. 11:35
Stéphane Longeville
google.fr
Courgena
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17 Rue Olivi...
29 Via S. Ba...
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Asnières-sur-Seine
Saint-Ouen
Aubervilliers
Bobigny
Bondy
Clichy
Courbevoie
Levallois-Perret
Neuilly-sur-Seine
Chatou
Le Vésinet
Croissy
Port-Marly
Louveciennes
Bois de Boulogne
Musée du Louvre
Musée d'Orsay
Le Jardin du Luxembourg
Saint-Cloud
Vaucresson
Montreuil
Bagnolet
Les Lilas
Romainville
Noisy-le-Sec
Rosny-sous-Bois
Villemomble
Gagny
Le Raincy
Fontenay-sous-Bois
Vincennes
Saint-Mandé
Nogent-sur-Marne
Bry-sur-Marne
Joinville-le-Pont
Champigny-sur-Marne
Saint-Maurice
Issy-les-Moulineaux
Sèvres
Meudon
Chaville
Le Chesnay
Versailles
Viroflay
Vélizy-Villacoublay
Clamart
Montrouge
Gentilly
Arcueil
Ivry-sur-Seine
Vitry-sur-Seine
Villejuif
Maisons-Alfort
Créteil
Chennevières-sur-M
Ormesson-sur-
Bonneuil-sur-Marne
Sucy-en-Brie
Boissy-Saint-Léger
Le Plessis-Robinson
Sceaux
Châtenay-Malabry
Antony
Chevilly-Larue
Thiais
Choisy-le-Roi
Rungis
Orly
Valenton
Villeneuve-le-Roi
Crosne
Buc
Bièvres
Saclay
Igny
Vauhallan
Massy
Wissous
Palaiseau
Saint-Aubin
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Forêt Domaniale de la Malmaison
Forêt Domaniale de Fausses Reposes
Forêt Domaniale de Meudon
Forêt Domaniale de Verrières
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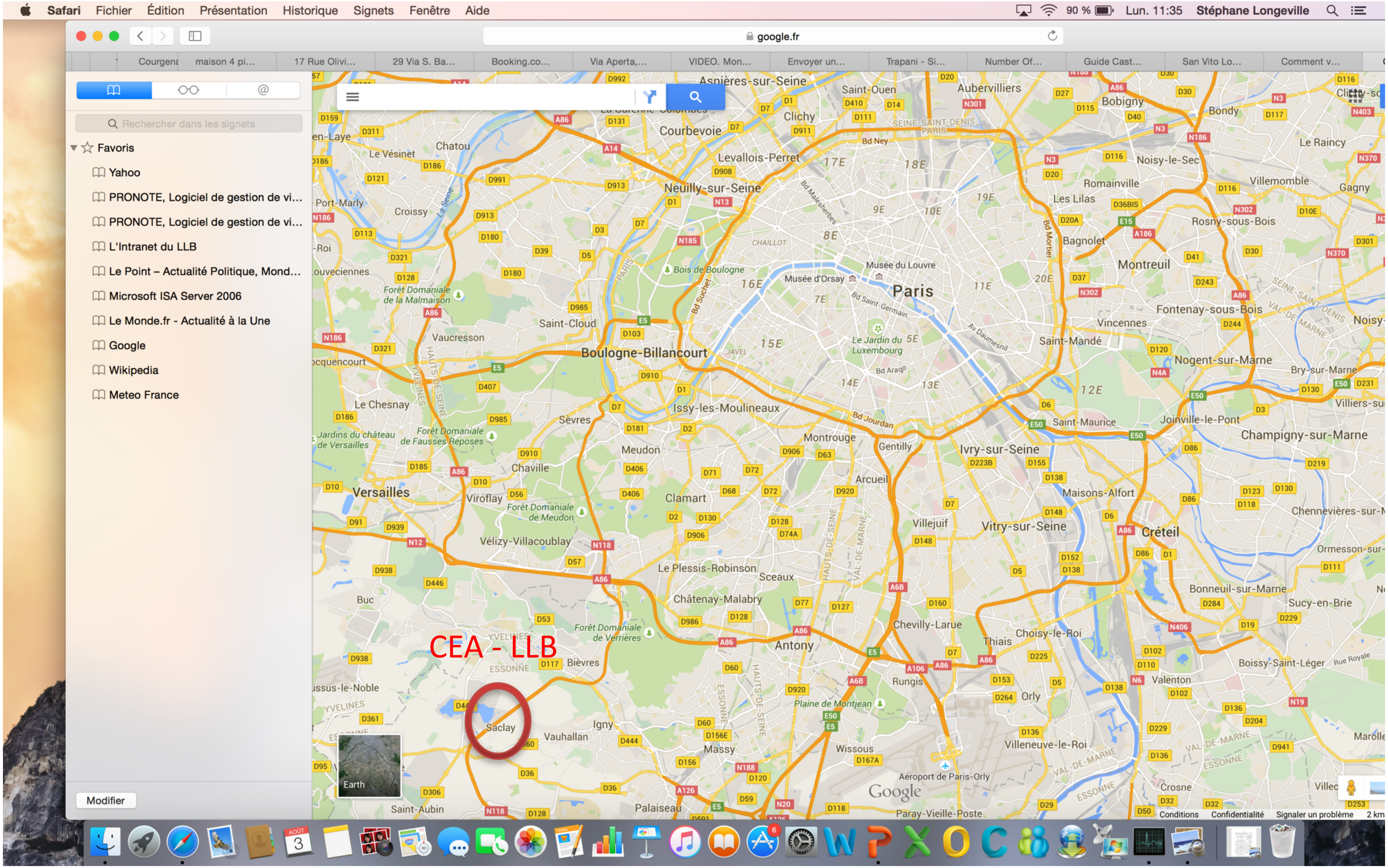
Confidentialité
Signaler un problème
2 km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Montreuil
Neuilly-sur-Seine
Issy-les-Moulineaux
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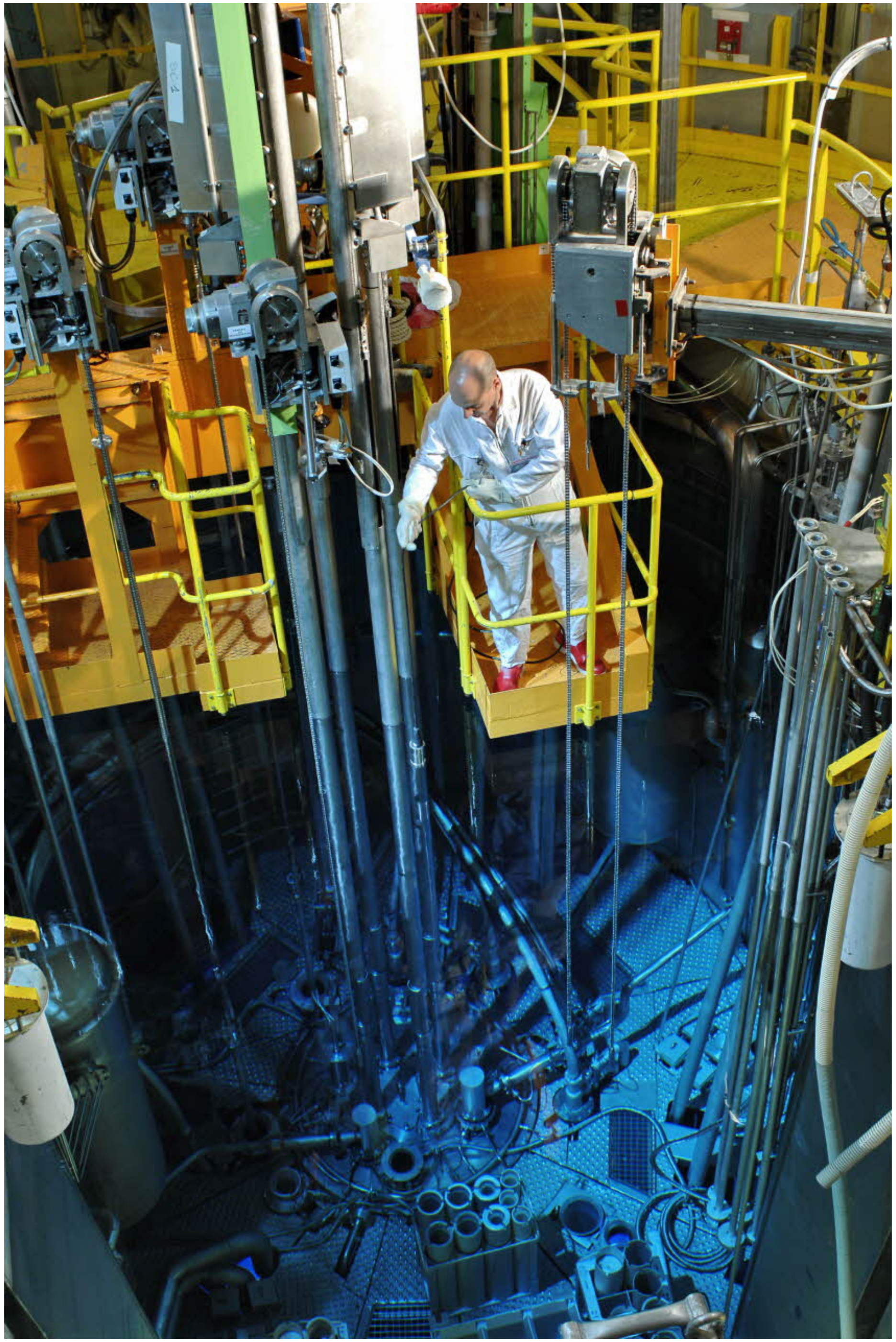
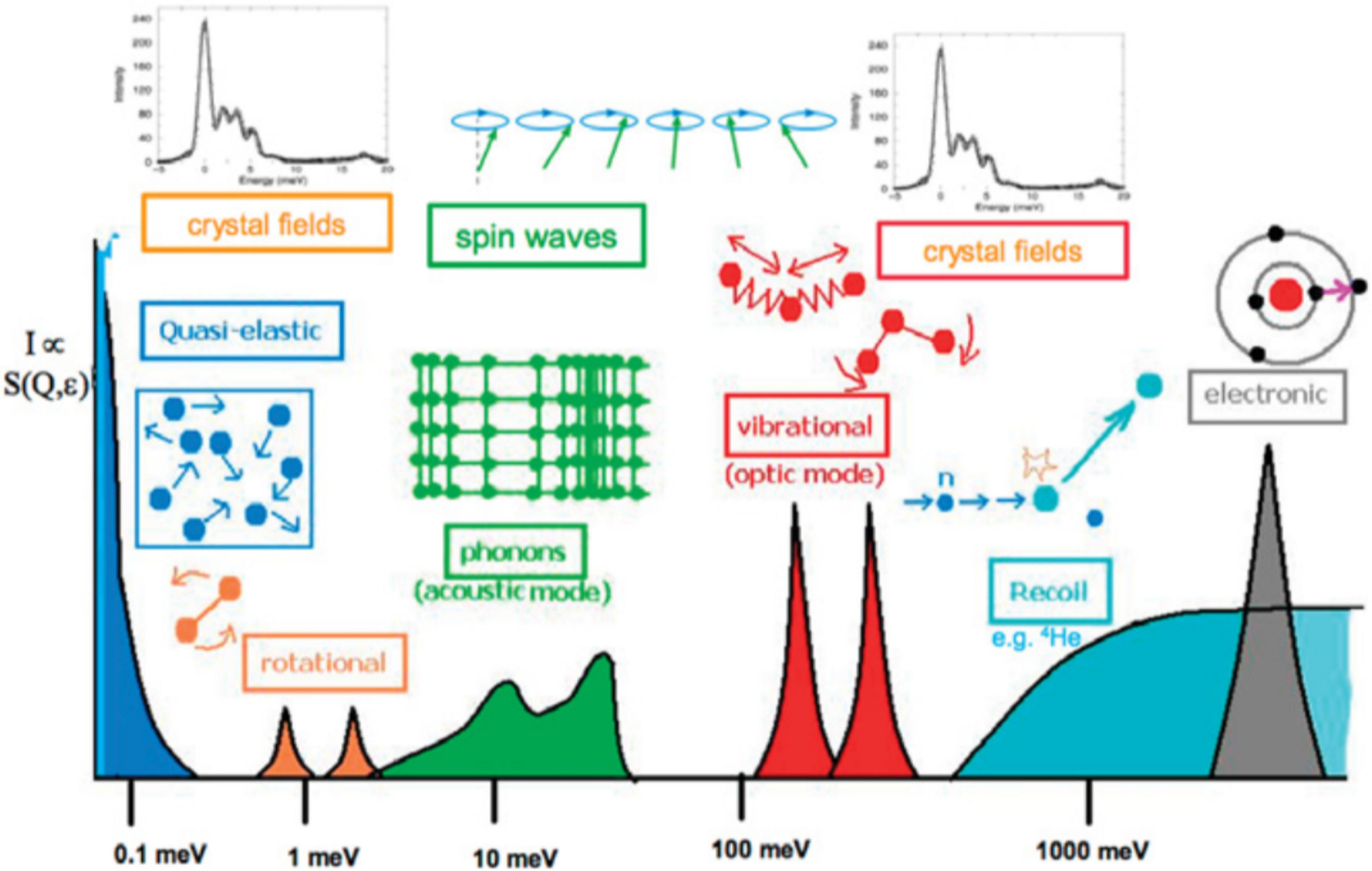
2 km

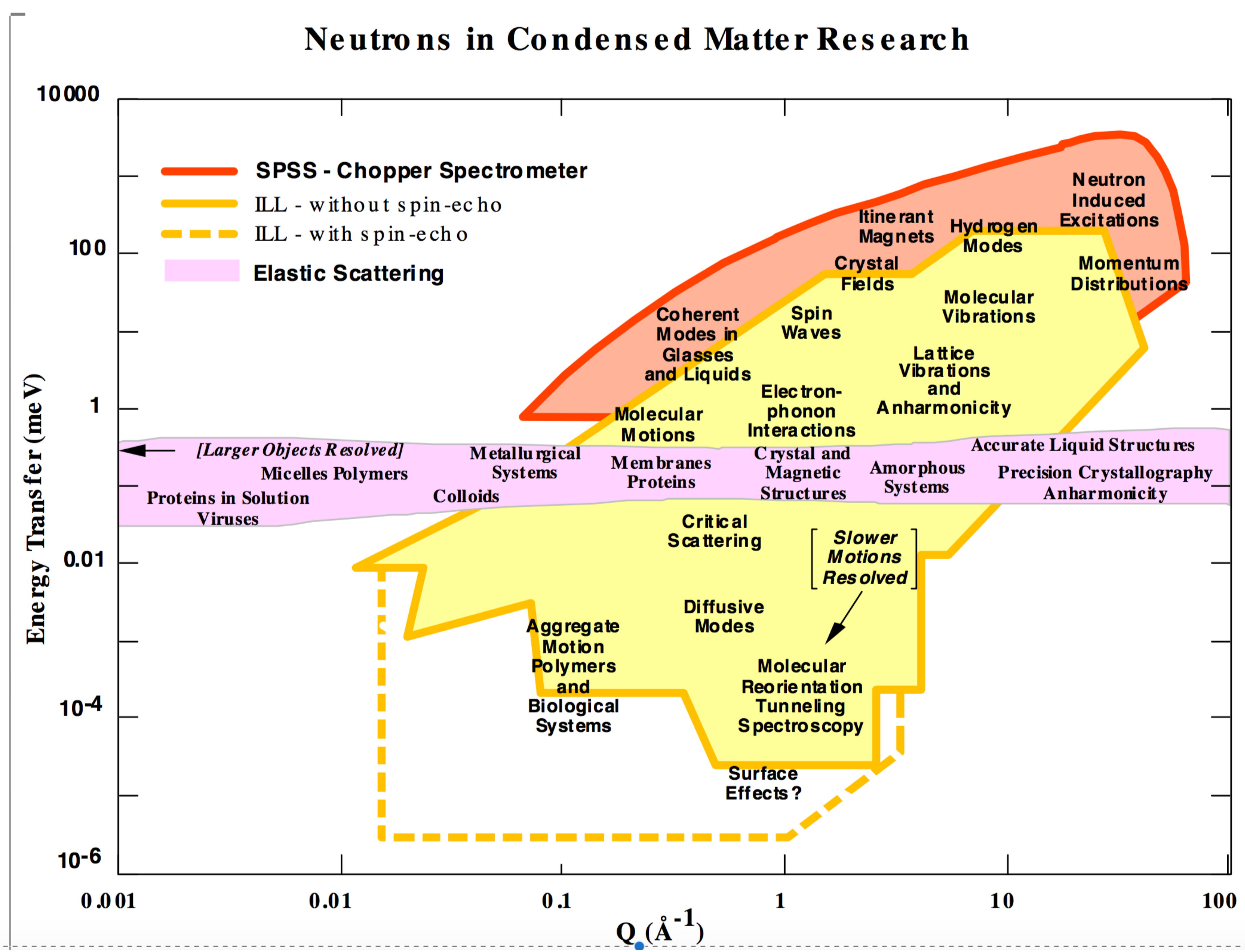
Orphée reactor : 14 MW D_20 moderated reactor





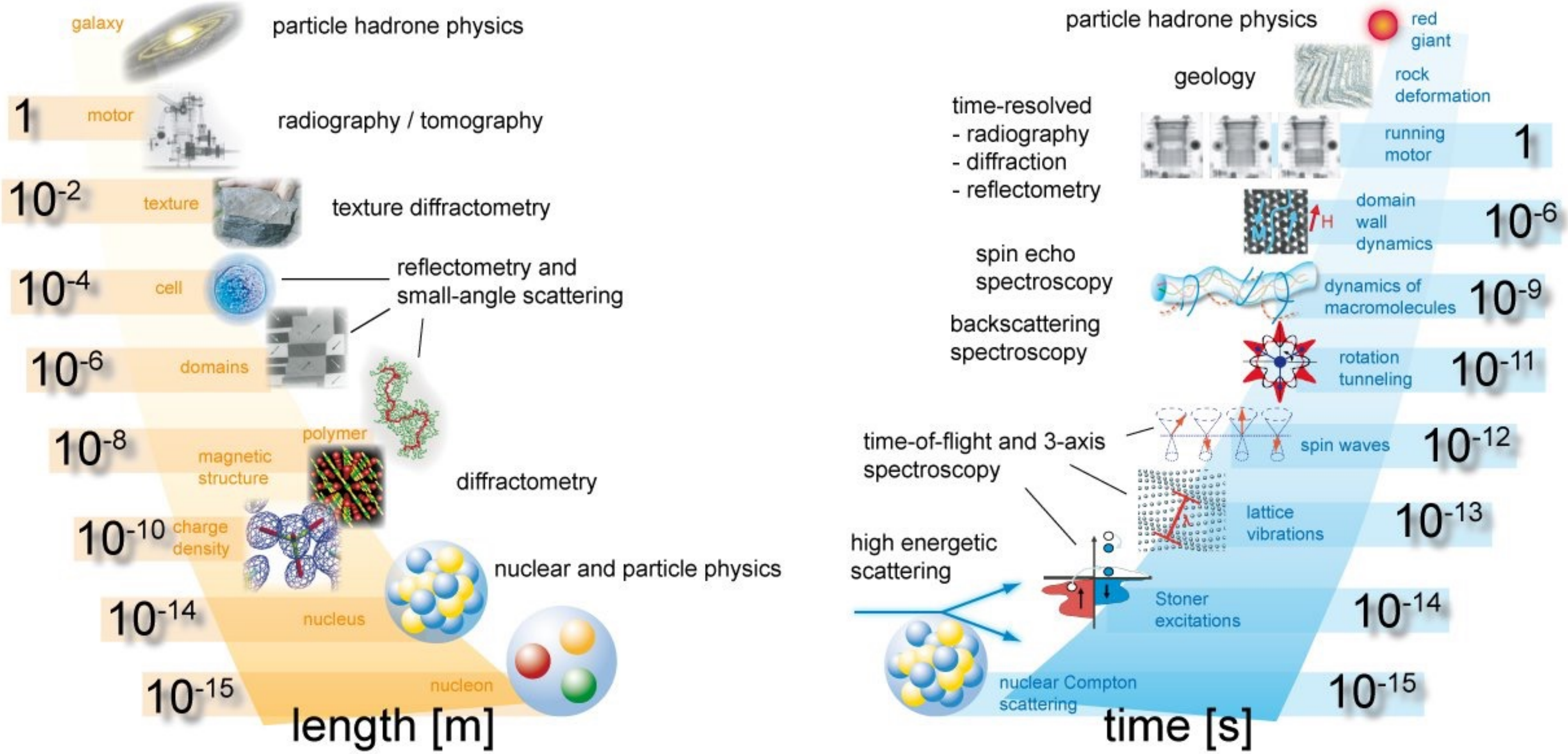
crystal fields
spin waves
crystal fields
Quasi-elastic
I ∝ S(Q,ε)
vibrational
(optic mode)
electronic
n
phonons
(acoustic mode)
Recoil
e.g. 4He
rotational
0.1 meV
1 meV
10 meV
100 meV
1000 meV

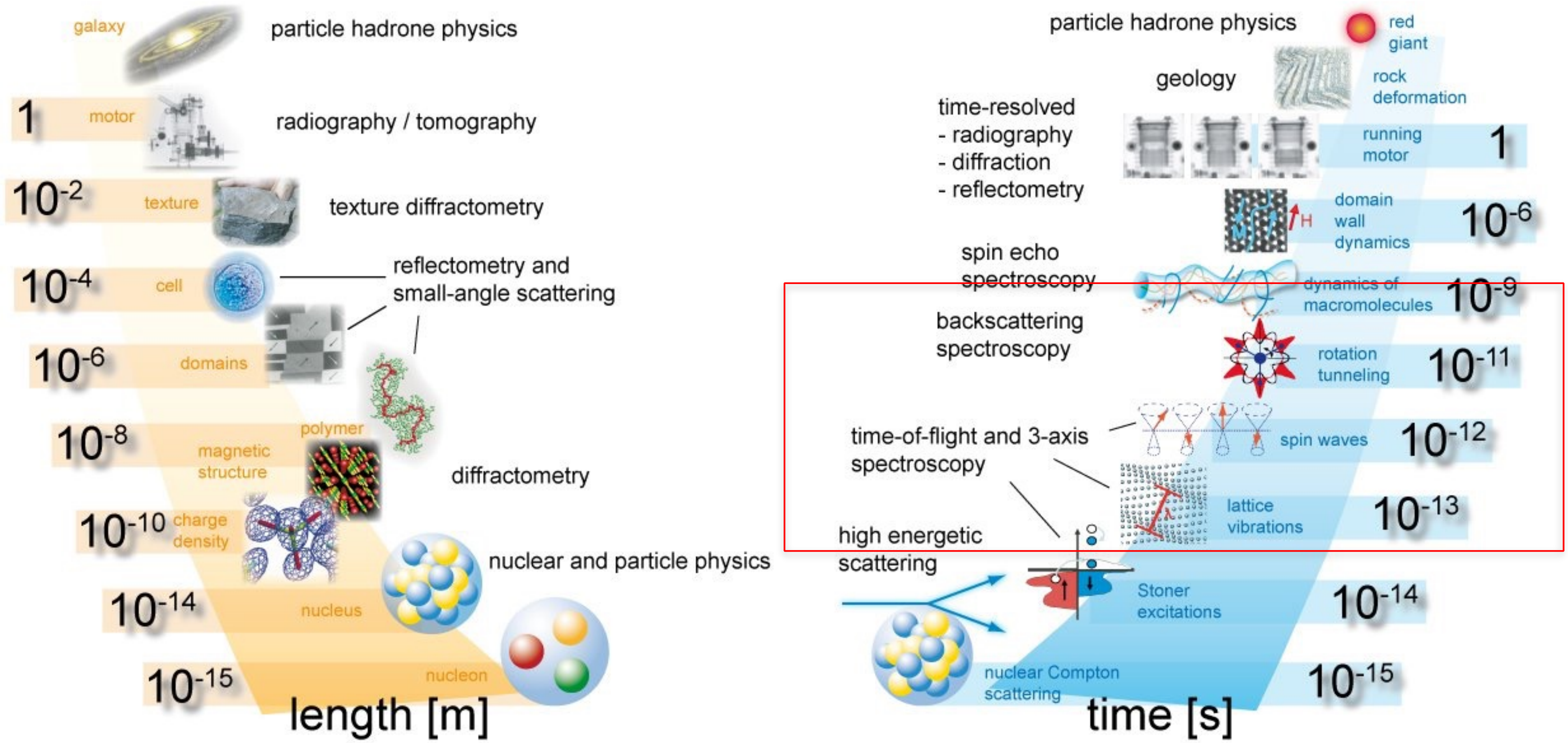
T. Perrin



Neutrons in Condensed Matter Research
SPSS - Chopper Spectrometer
ILL - without spin-echo
ILL - with spin-echo
Elastic Scattering
10000
100
1
0.01
10-4
10-6
Energy Transfer (meV)
0.001
0.01
0.1
1
10
100
Q (Å-1)
Neutron Induced Excitations
Momentum Distributions
Itinerant Magnets
Hydrogen Modes
Crystal Fields
Molecular Vibrations
Coherent Modes in Glasses and Liquids
Spin Waves
Lattice Vibrations and Anharmonicity
Electron-phonon Interactions
Molecular Motions
[Larger Objects Resolved]
Micelles Polymers
Proteins in Solution
Viruses
Metallurgical Systems
Colloids
Membranes Proteins
Crystal and Magnetic Structures
Amorphous Systems
Accurate Liquid Structures
Precision Crystallography
Anharmonicity
Critical Scattering
Slower Motions Resolved
Diffusive Modes
Aggregate Motion Polymers and Biological Systems
Molecular Reorientation Tunneling Spectroscopy
Surface Effects?

R. Pynn


galaxy
particle hadrone physics
1
motor
radiography / tomography
10^{-2}
texture
texture diffractometry
10^{-4}
cell
reflectometry and
small-angle scattering
10^{-6}
domains
10^{-8}
polymer
magnetic
structure
diffractometry
10^{-10}
charge
density
nuclear and particle physics
10^{-14}
nucleus
10^{-15}
nucleon
length [m]
particle hadrone physics
red
giant
geology
rock
deformation
time-resolved
- radiography
- diffraction
- reflectometry
running
motor
1
domain
wall
dynamics
10^{-6}
spin echo
spectroscopy
dynamics of
macromolecules
10^{-9}
backscattering
spectroscopy
rotation
tunneling
10^{-11}
time-of-flight and 3-axis
spectroscopy
spin waves
10^{-12}
lattice
vibrations
10^{-13}
high energetic
scattering
Stoner
excitations
10^{-14}
nuclear Compton
scattering
10^{-15}
time [s]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particle hadrone physics
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10-2
texture
texture diffractometry
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cell
reflectometry and
small-angle scattering
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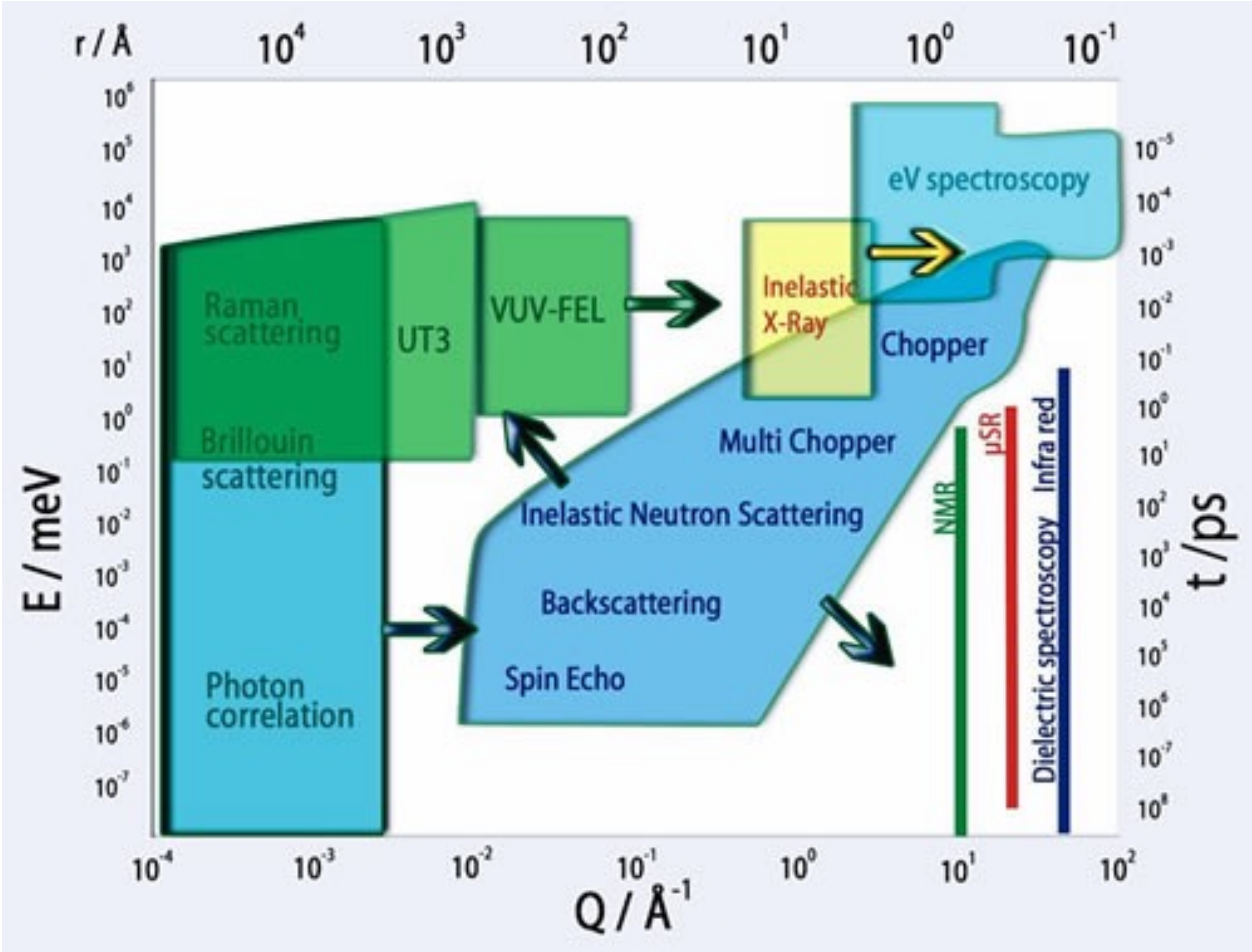
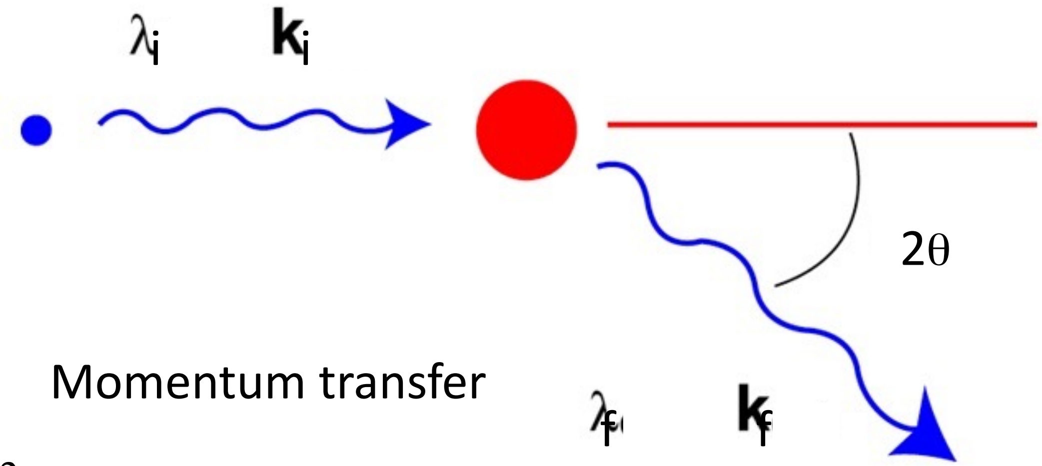
domains
10-8
polymer
magnetic
structure
diffractometry
10-10
charge
density
nuclear and particle physics
10-14
nucleus
10-15
nucleon
length [m]
particle hadrone physics
red
giant
geology
rock
deformation
time-resolved
- radiography
- diffraction
- reflectometry
running
motor
1
domain
wall
dynamics
10-6
spin echo
spectroscopy
dynamics of
macromolecules
10-9
backscattering
spectroscopy
rotation
tunneling
10-11
time-of-flight and 3-axis
spectroscopy
spin waves
10-12
lattice
vibrations
10-13
high energetic
scattering
Stoner
excitations
10-14
nuclear Compton
scattering
10-15
time [s]

TOF and BS


r / Å
10^4
10^3
10^2
10^1
10^0
10^-1
E / meV
t /ps
Q / Å^-1
Raman scattering
Brillouin scattering
Photon correlation
UT3
VUV-FEL
Inelastic X-Ray
eV spectroscopy
Chopper
Multi Chopper
Inelastic Neutron Scattering
Backscattering
Spin Echo
NMR
µSR
Dielectric spectroscopy
Infra red

Principle of inelastic neutron scattering



$$\hbar\vec{Q} = \hbar(\vec{k}_f - \vec{k}_i)$$ Momentum transfer

$$\hbar\omega = E_f - E_i = \frac{\hbar(k_f^2 - k_i^2)}{2m}$$ Energy exchange

information about microscopic motion

information about microscopic structure

Quasi-elastic or inelastic scattering experiment:

- Measure the number scattered of neutrons as a function of $\vec{Q}$ and ω ($\hbar\omega \approx 0.01$ to few meV, $Q \approx 0.05$ to few $Å^{-1}$)

- The aim is to extract from the measure the dynamical structure factor $S(Q,\omega)$ which depends on the properties of the sample *only* (microscopic structure and dynamics)

- Time-of-flight techniques : TOF-TOF, cristal-TOF (TOF-cristal) and backscattering spectrometers

Neutrons

Mass : m_N=1.675 10^{-27} kg

Charge=0; s=1/2;

γ=-2913 2π $(Gs)^{-1}$

$$E = \frac{\hbar k^2}{2m} = \frac{1}{2} m v^2$$

Neutrons

Mass : m_N=1.675 10^{-27} kg

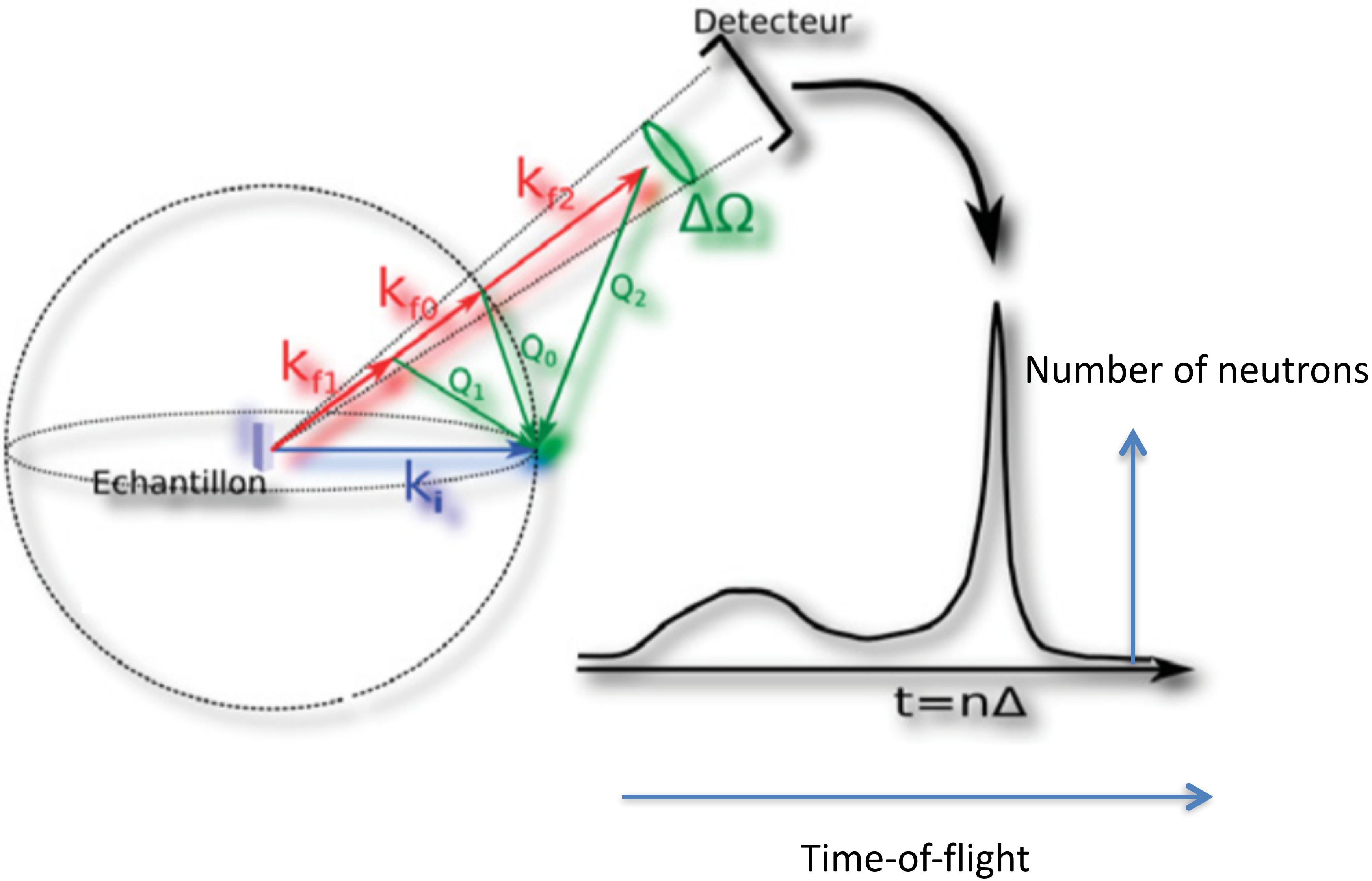
Charge=0; s=1/2;

γ=-2913 2π $(Gs)^{-1}$

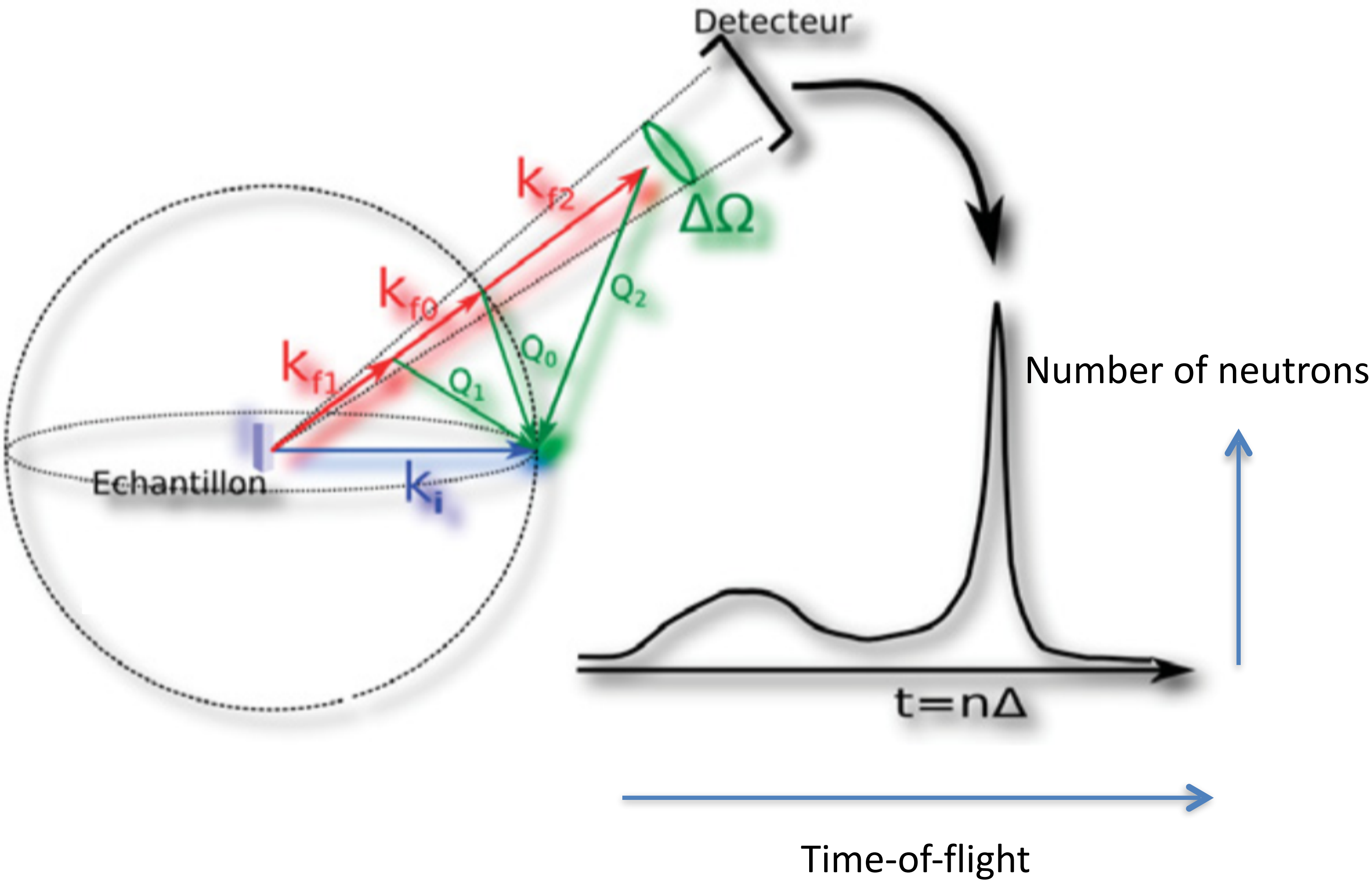
$$E = \frac{\hbar k^2}{2m} = \frac{1}{2}mv^2 \qquad v = \frac{d}{t} \approx \frac{3950}{\lambda(\text{Å})} m.s^{-1}$$

$$\lambda = 5\text{Å} \quad v \approx 800\ ms^{-1}$$

$$\lambda = 10\text{Å} \quad v \approx 400\ ms^{-1}$$

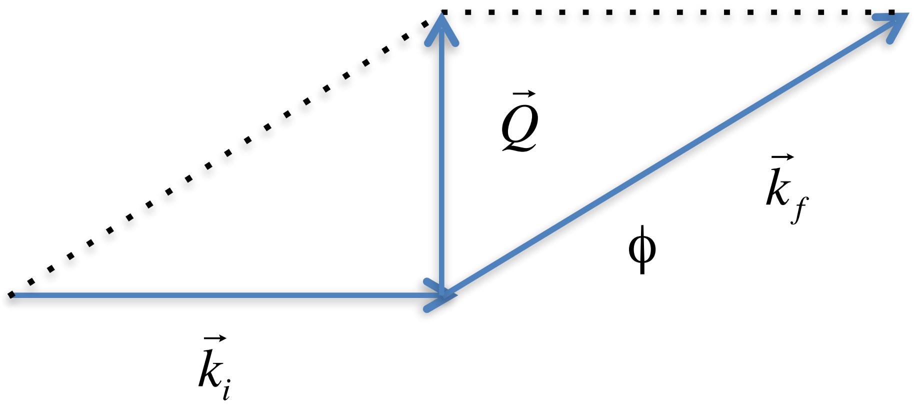


Detecteur
ΔΩ
Echantillon
Number of neutrons
t=nΔ
Time-of-flight



Same scattering angle : different wavevectors Q (and energy)

Energy – wavevector plot

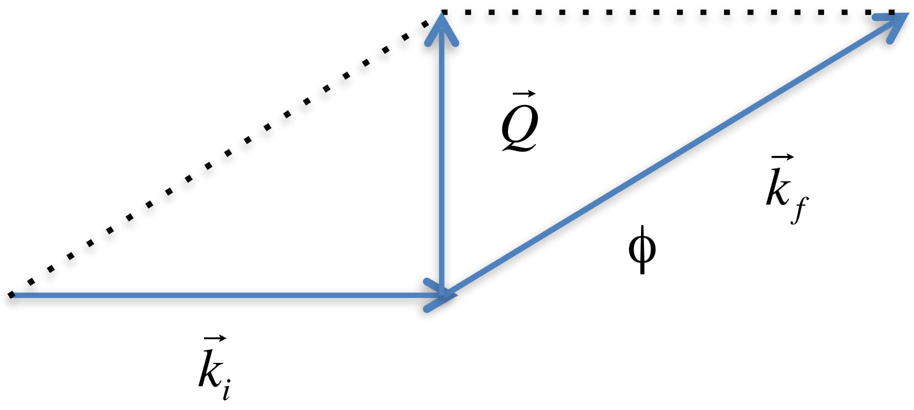


$$Q = \left|\vec{Q}\right|$$

$$Q^2 = k_i^2 + k_f^2 - 2\left|\vec{k}_i\right|\left|\vec{k}_f\right|\cos(\phi)$$

$$Q^2 = 2\left[\frac{2\pi}{\lambda_i}\right]^2\left(1 - \frac{\hbar\omega}{2E_i} - \sqrt{1 - \frac{\hbar\omega}{E_i}}\cos(\phi)\right)$$

Energy – wavevector plot



$$Q = \left|\vec{Q}\right|$$

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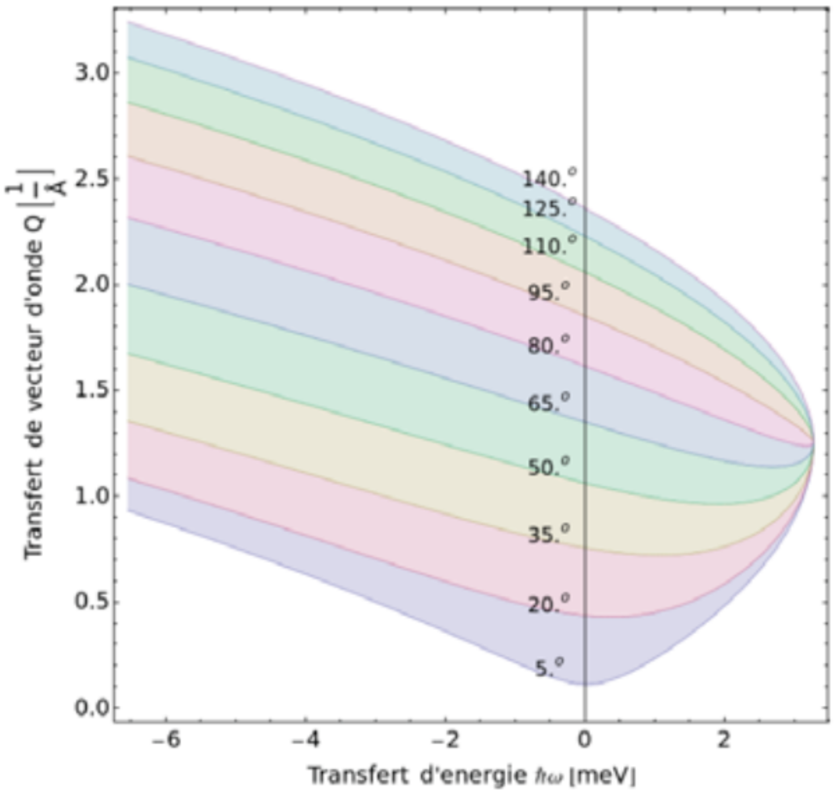
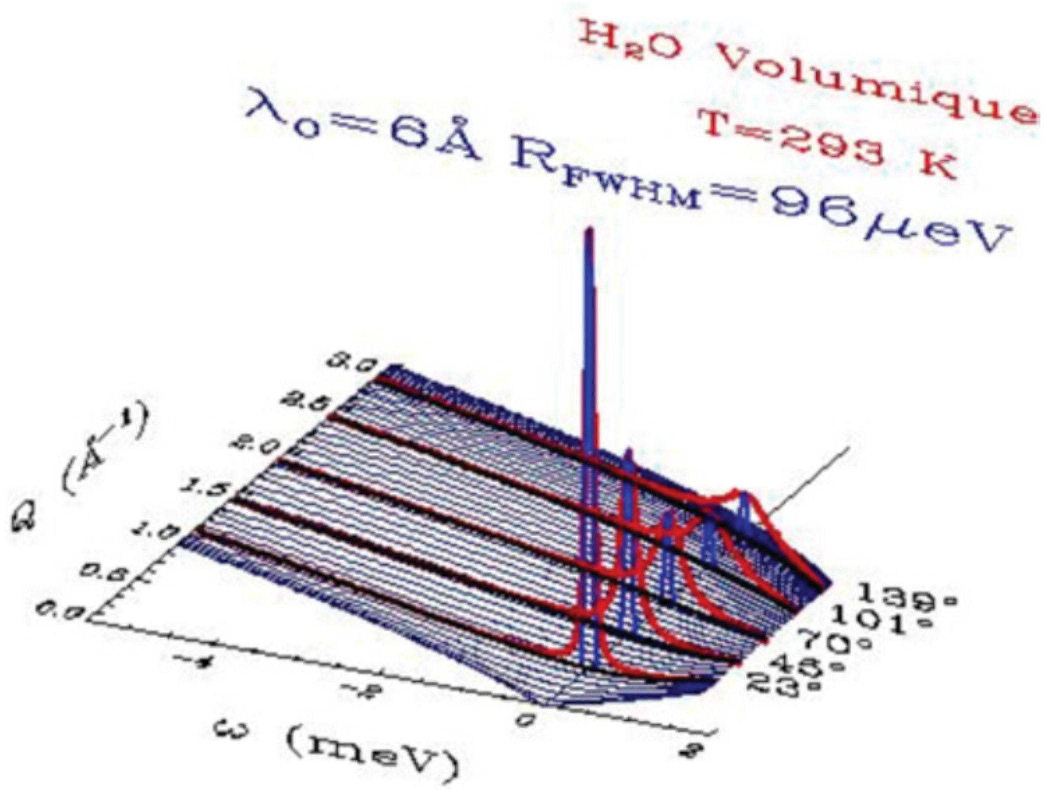
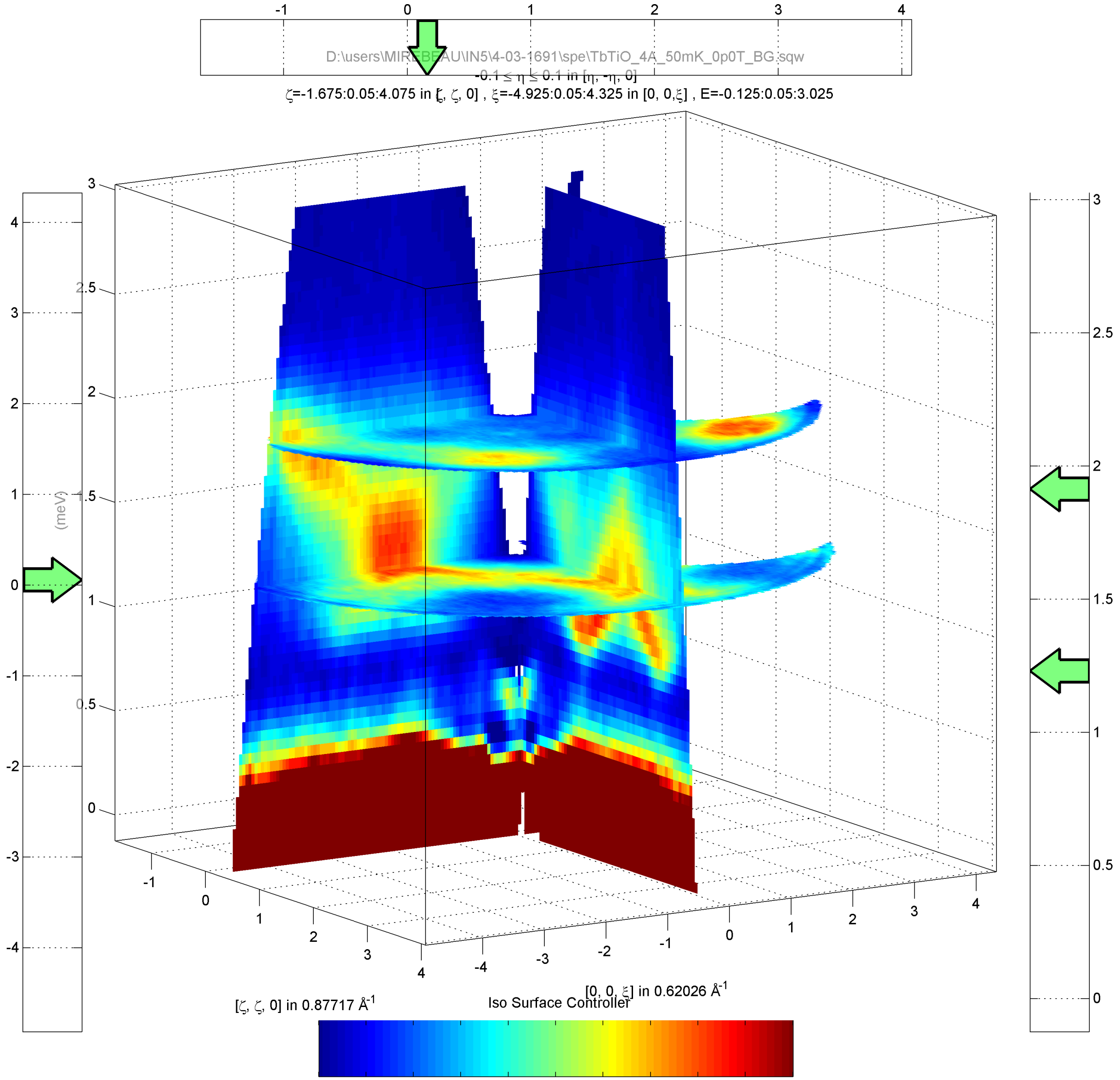




$Er_2Ti_2O_7$

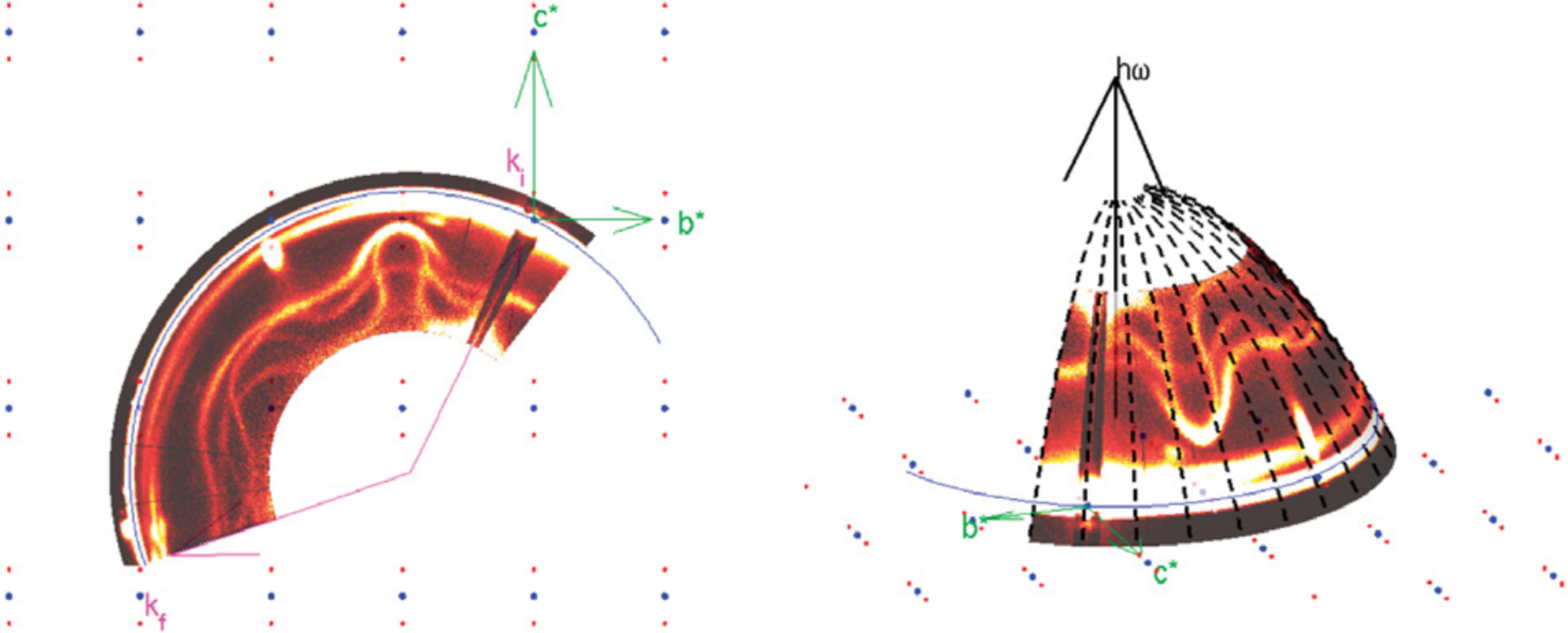


IN5 Xcrystal mode
Full S(Q,ω) in 2 days

« However »

One λ
One T
One H

S. Petit, et al



V. Simonet, R. Ballou, unpublished results obtained on IN5
on $Ba_3NbFe_3Si_2O_{14}$ (BNFS)

Measured quantity : double differential cross section

Number of neutrons per unit of time *dt* and solid angle $d\Omega$

$$\frac{\partial\sigma}{\partial\Omega\partial t}$$

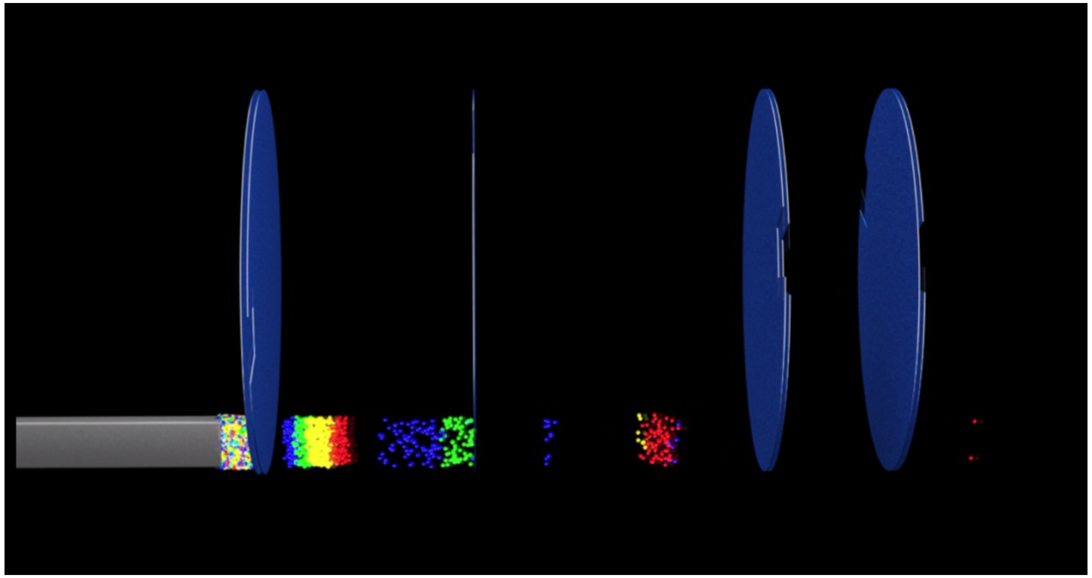
Measured quantity : double differential cross section

Number of neutrons per unit of time *dt* and solid angle $d\Omega$

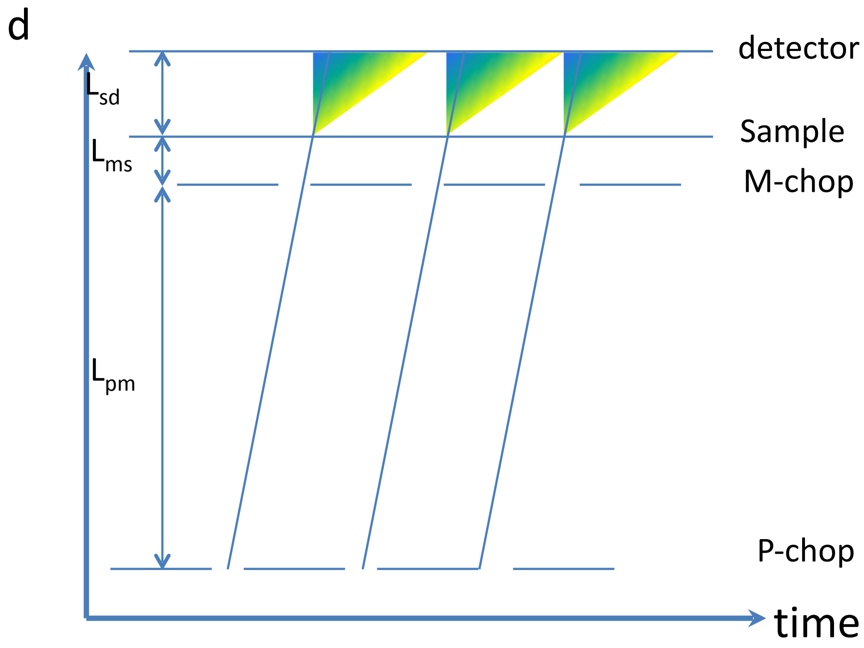
$$\frac{\partial^2\sigma}{\partial\Omega\partial t} \rightarrow \frac{\partial^2\sigma}{\partial\Omega\partial\omega} = N\frac{k_f}{k_i}\frac{\sigma}{4\pi}S(Q,\omega)$$

TOF → Energy

Direct chopper spectrometer: TOF-TOF (reactor based)



time - distance diagram

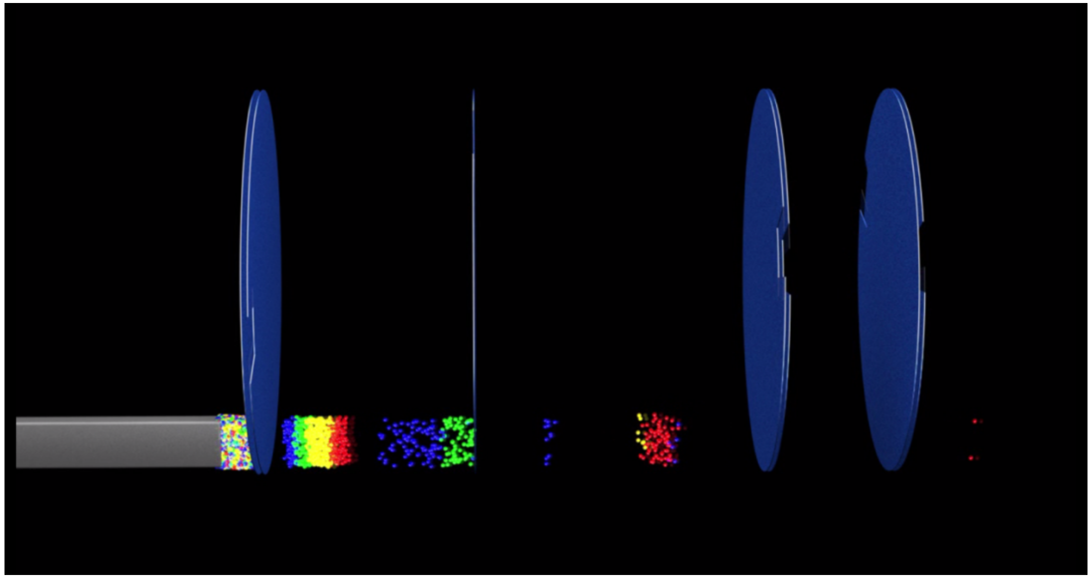


5 Å v≈800 m.s^{-1}
TOF of a few msec

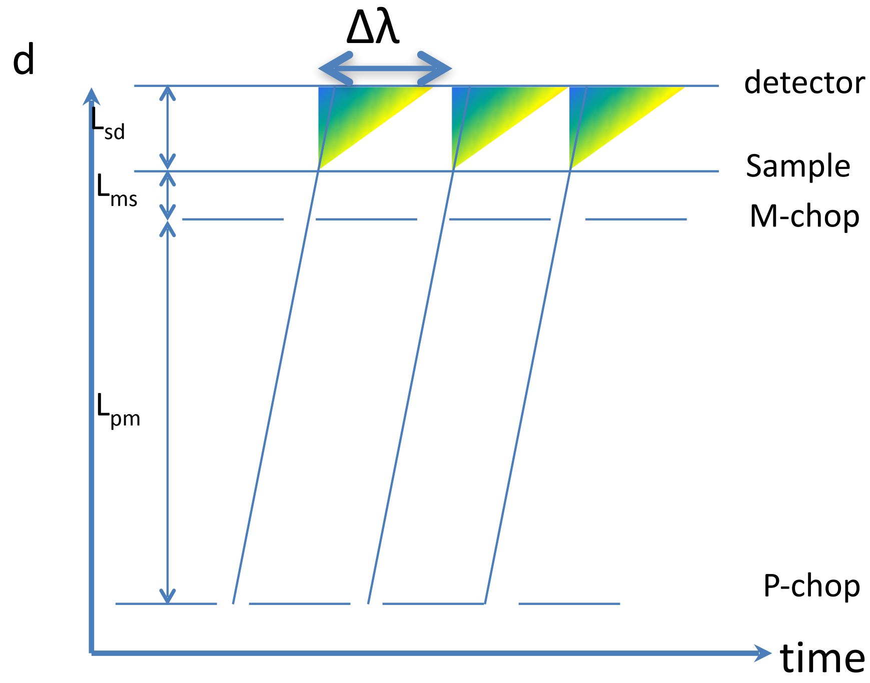
- repetition rates

50-150 Hz
Depending on λ and Δλ

Direct chopper spectrometer: TOF-TOF (reactor based)



time - distance diagram



Chopper system versus cristal monochromatisation

- No high order
- Clean and well-defined shape
- Tunable resolution
- 100% transmission at the centerline

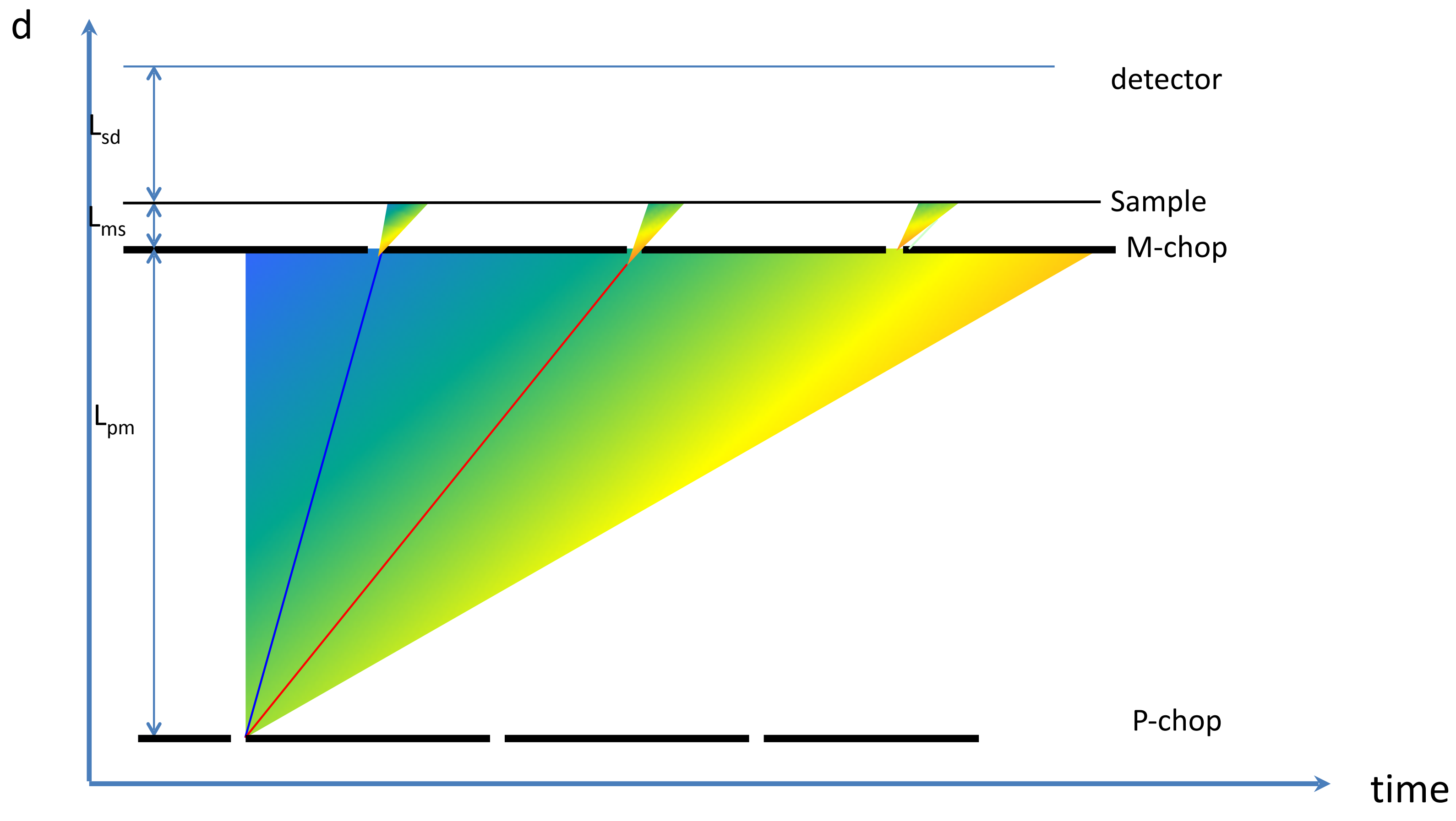
5 Å v≈800 m.s^{-1}
TOF of a few msec

- repetition rates

50-150 Hz
Depending on λ and Δλ

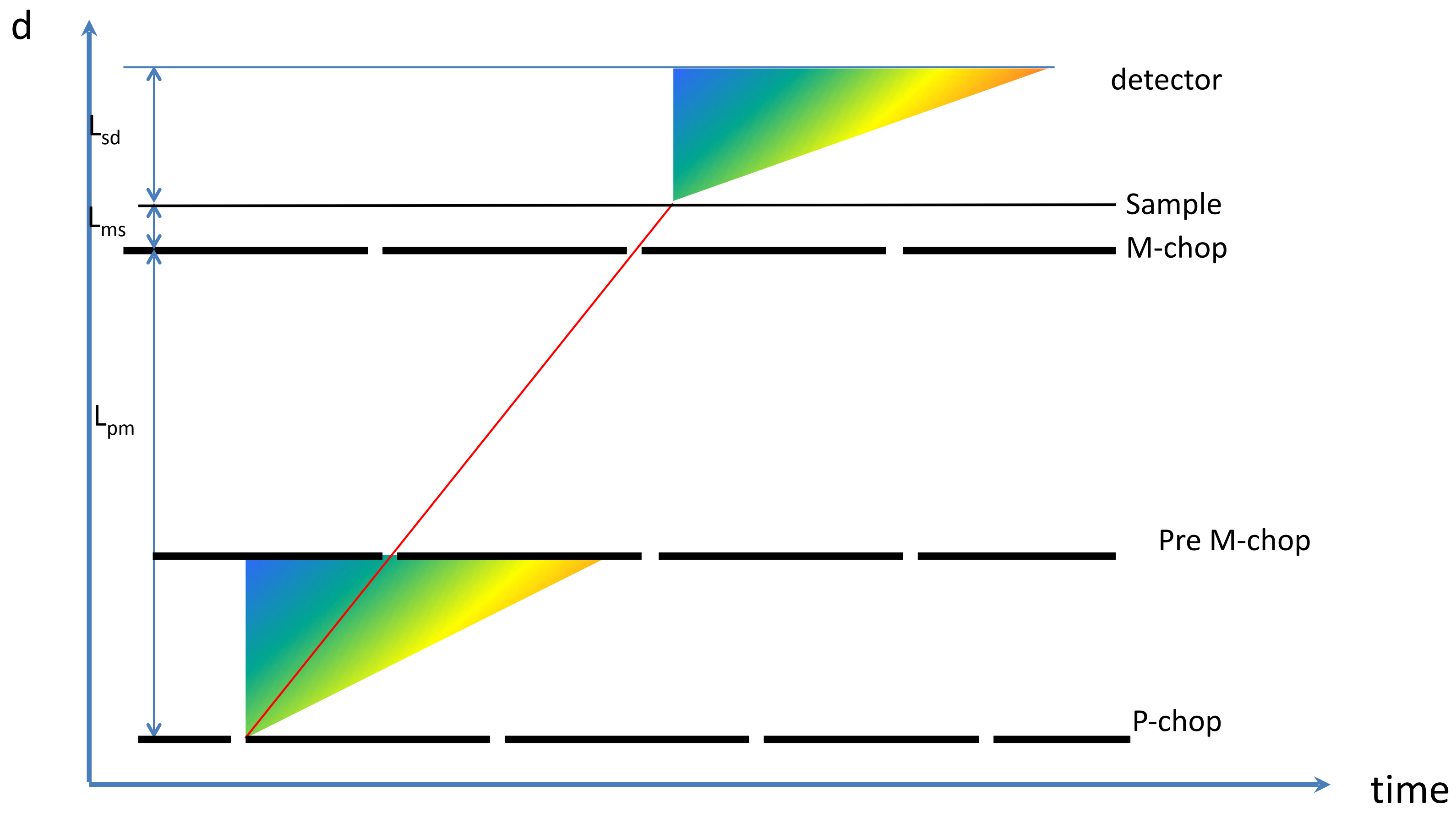
Direct chopper spectrometer: TOF-TOF (reactor based) - reality

time - distance diagram



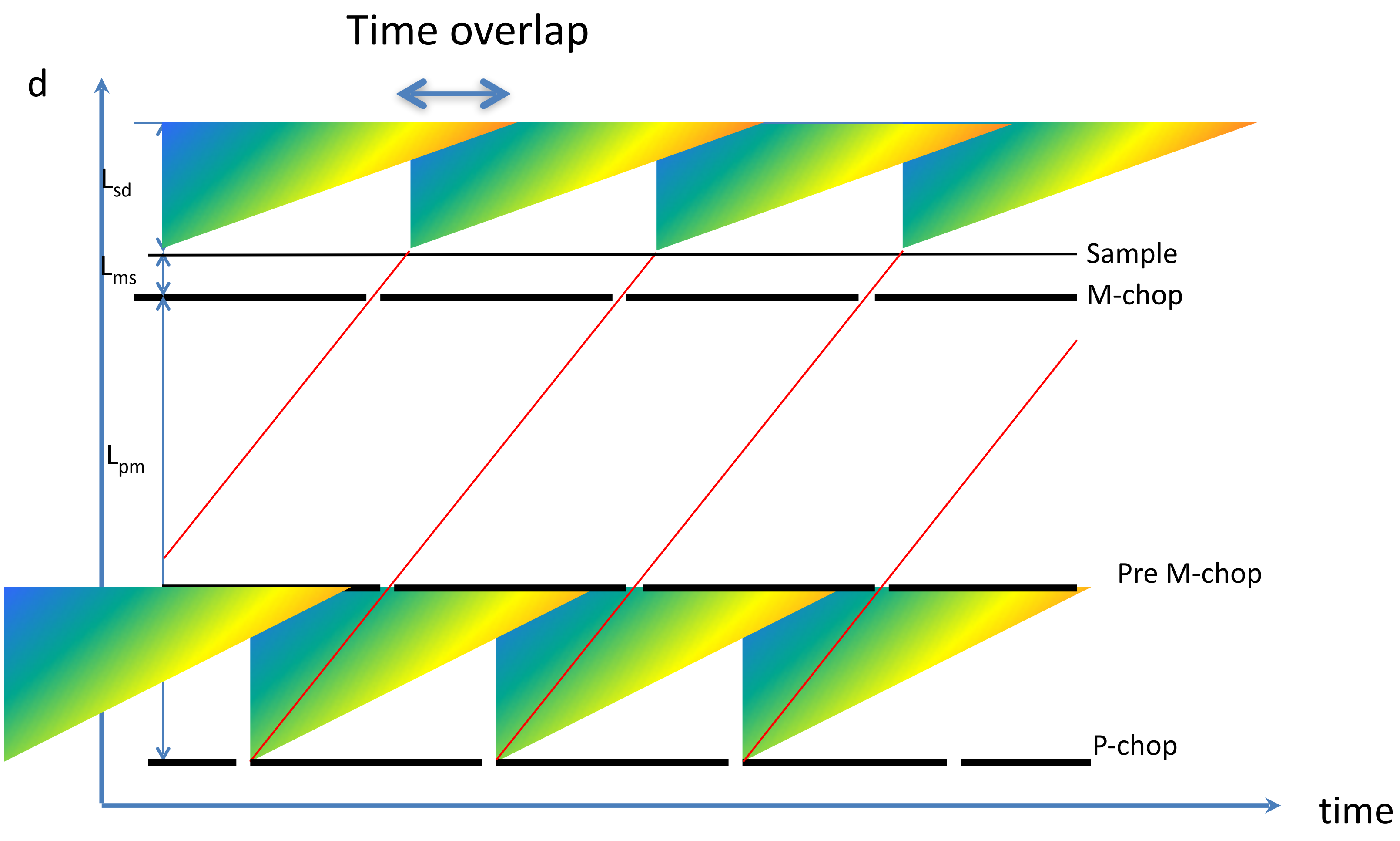
Direct chopper spectrometer: TOF-TOF (reactor based) - reality

time - distance diagram



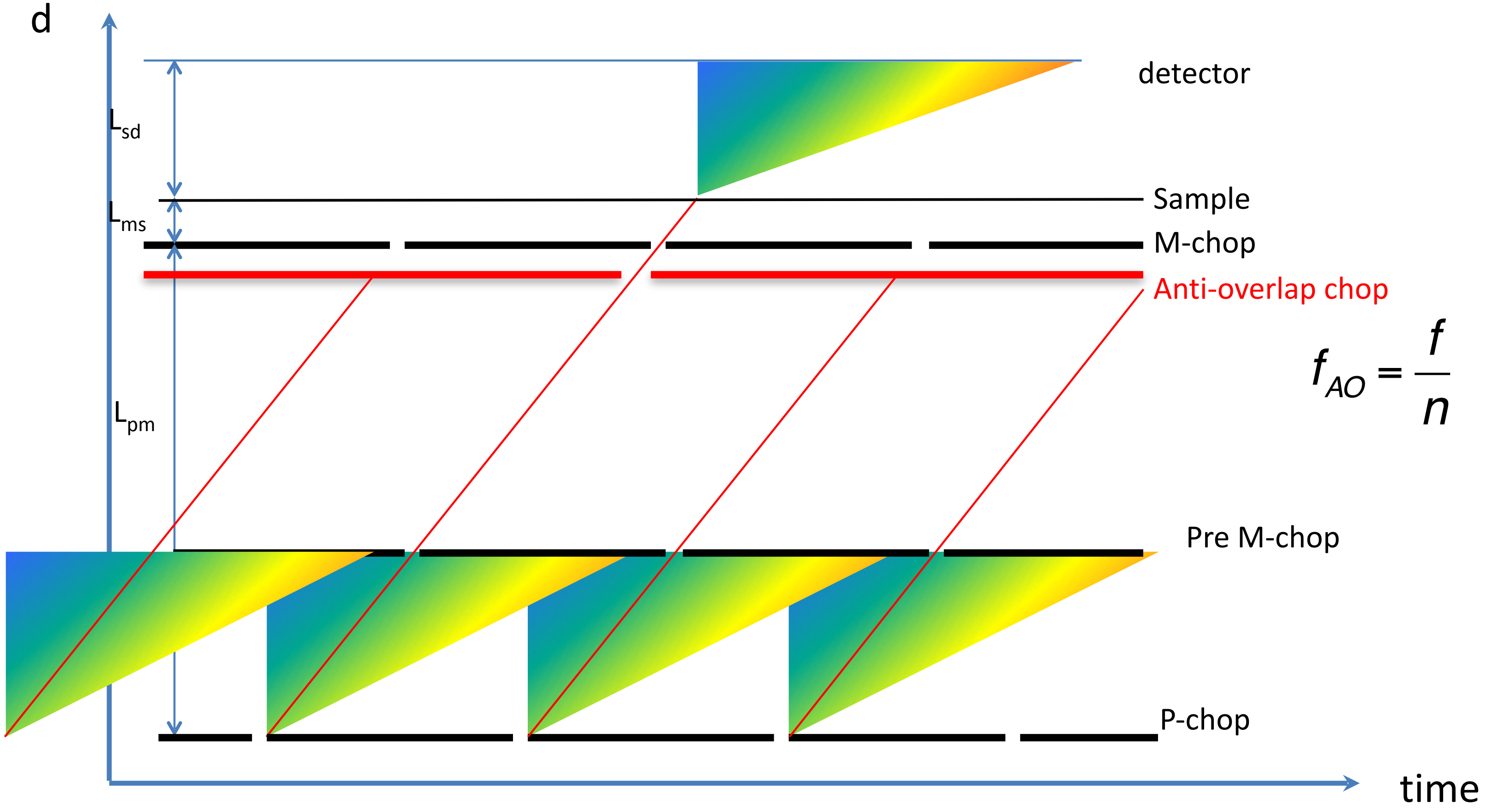
Direct chopper spectrometer: TOF-TOF (reactor based) - reality

time - distance diagram



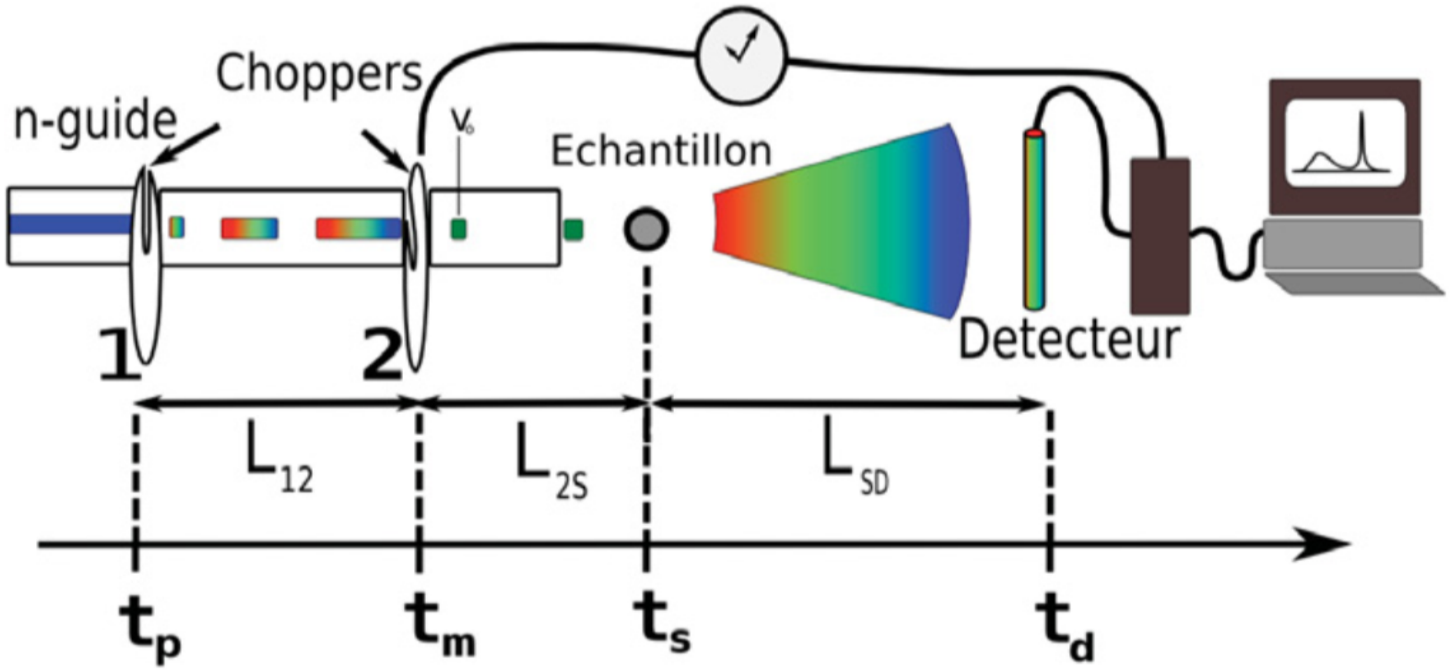
Direct chopper spectrometer: TOF-TOF (reactor based) - reality

time - distance diagram

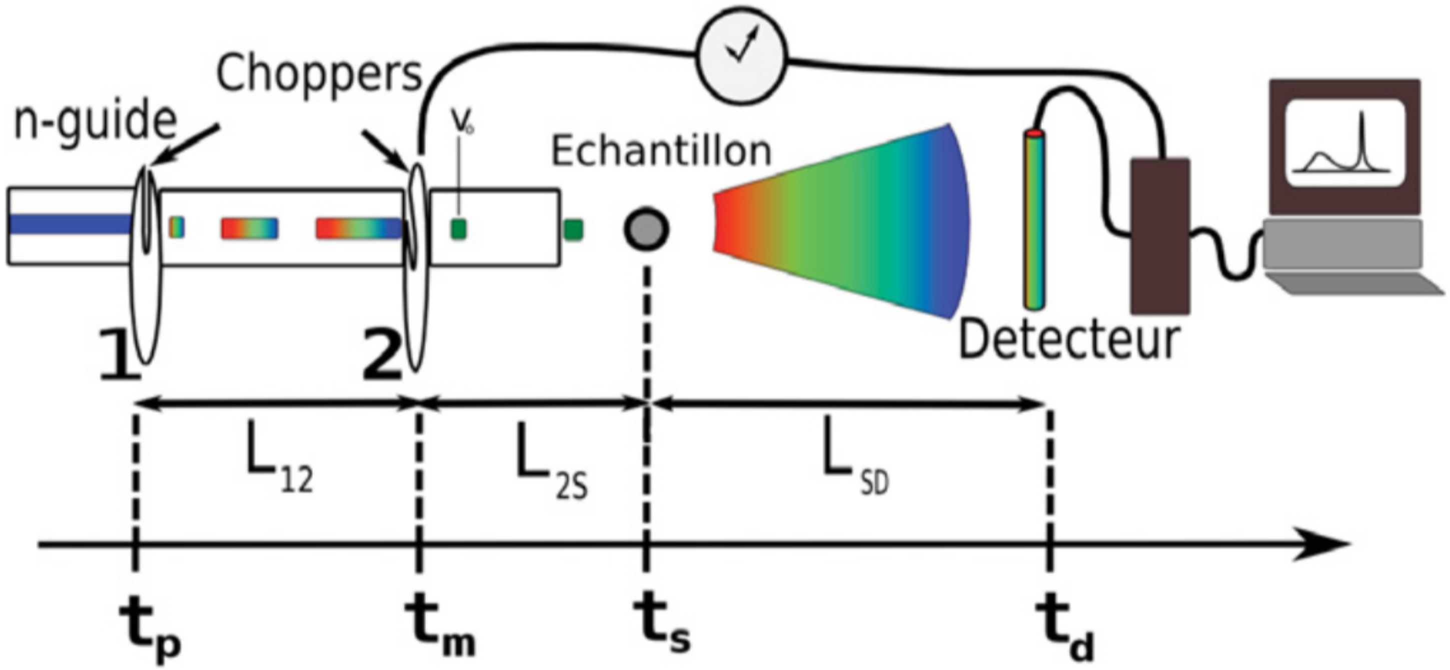


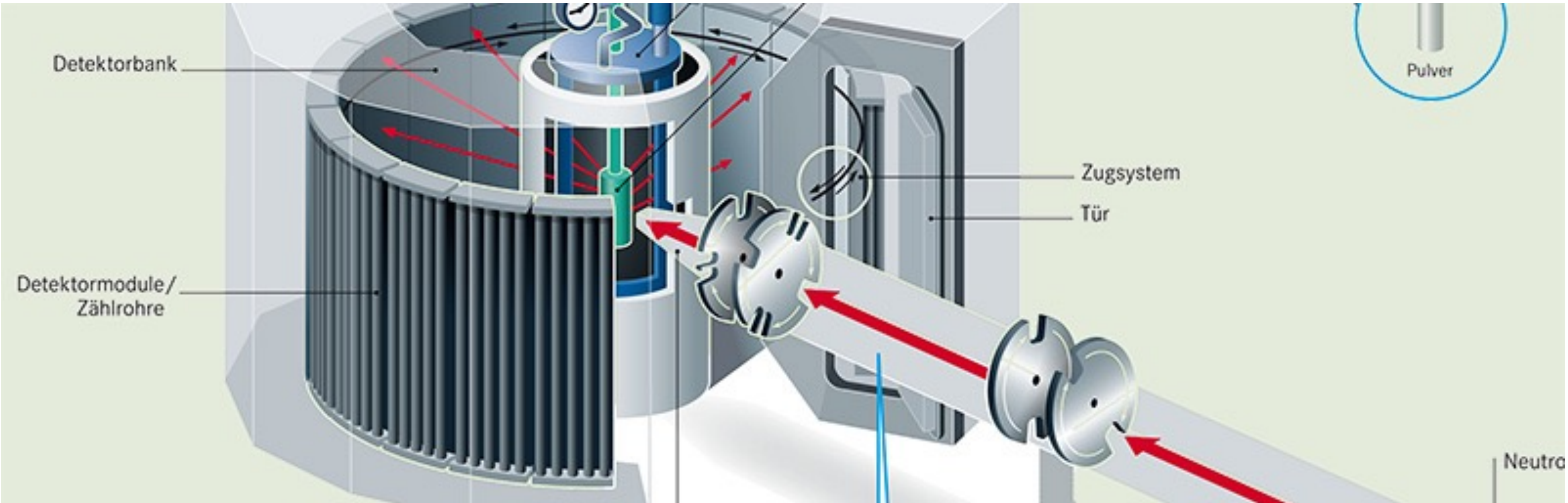
$$f_{AO} = \frac{f}{n} \quad n = 1, 2, 3 \ldots$$

Direct chopper spectrometer: TOF-TOF



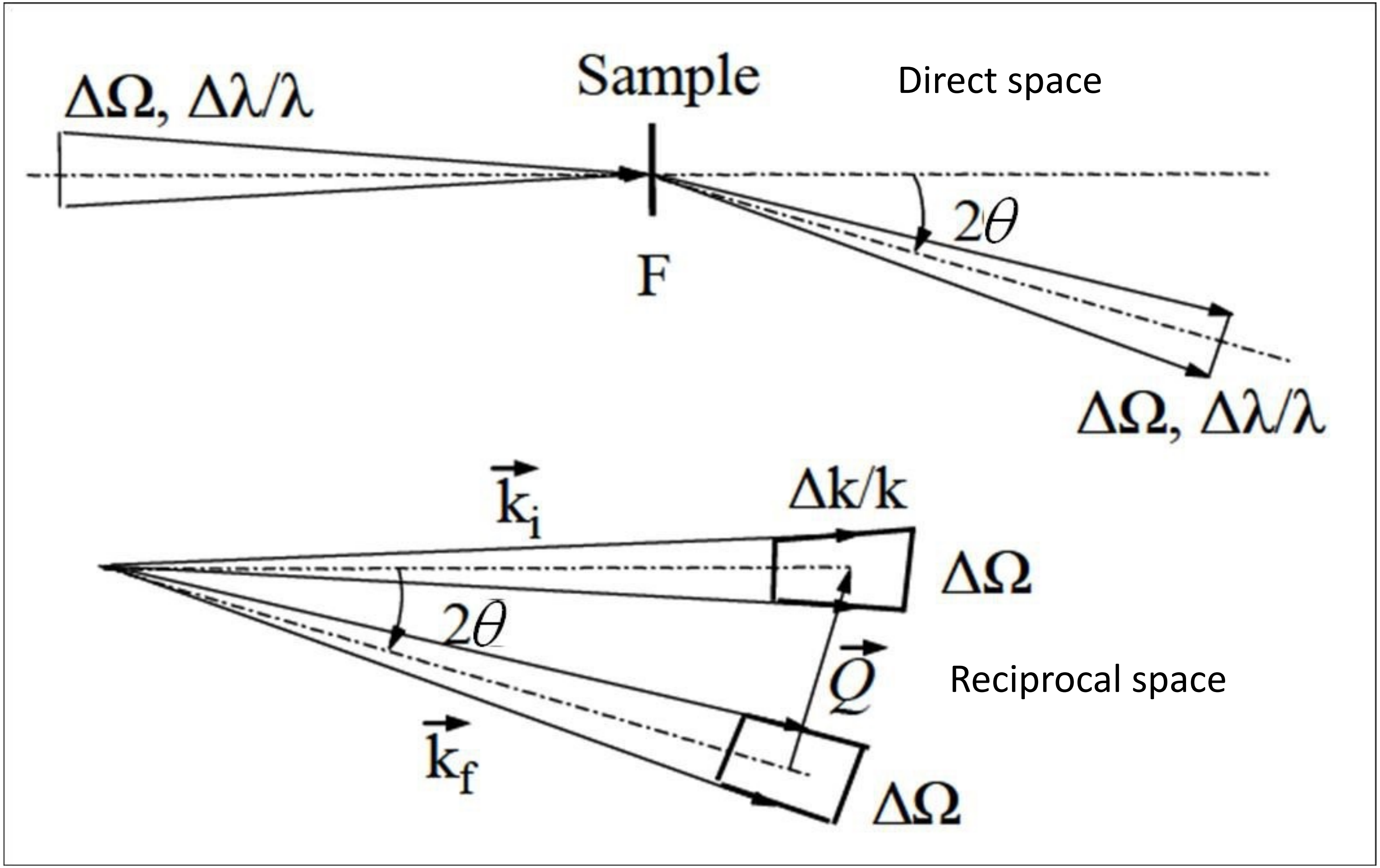
Direct chopper spectrometer: TOF-TOF



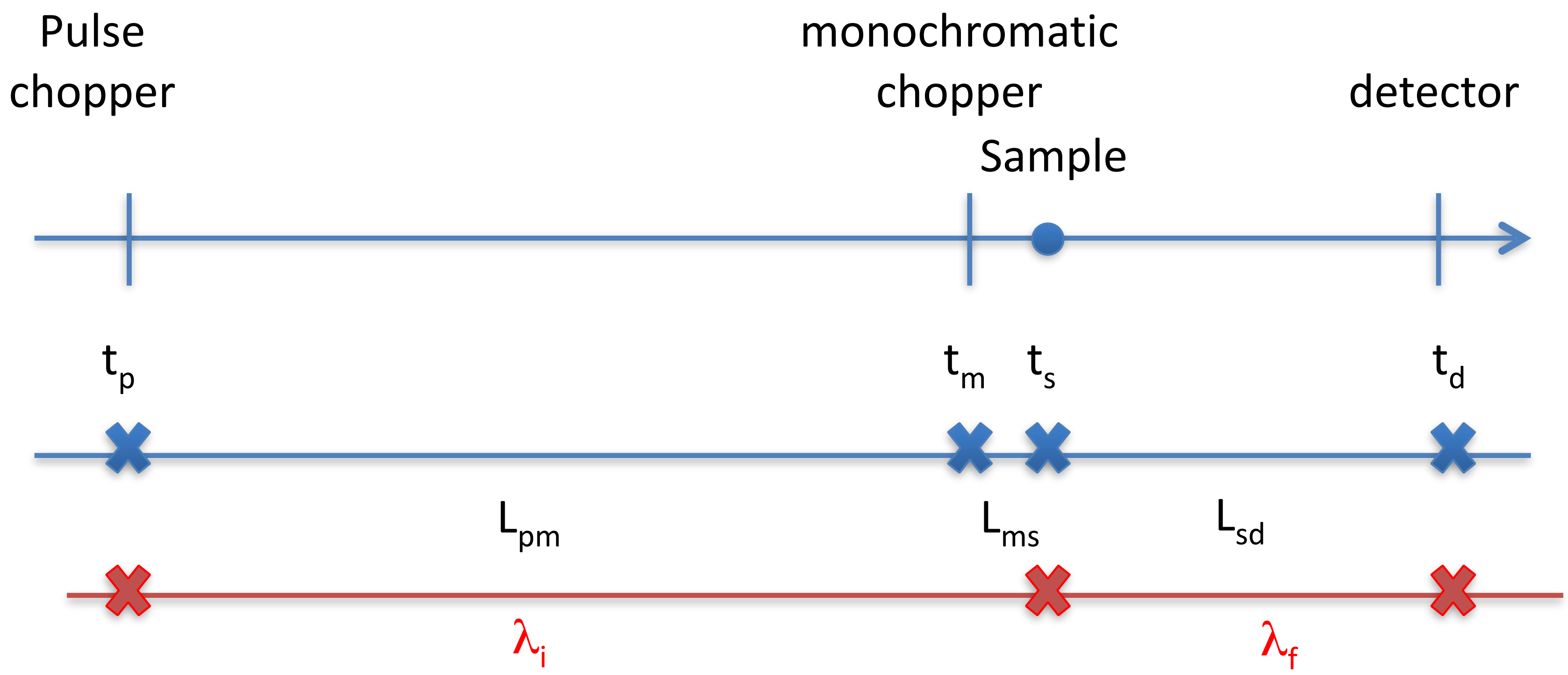


Direct chopper spectrometer: TOF-TOF

Energy Resolution (R.E. Lechner)



Direct chopper spectrometer: TOF-TOF



$$v_i = \frac{L_{pm}}{(t_m - t_p)} = \frac{L_{ms}}{(t_s - t_m)} \qquad v_f = \frac{L_{sd}}{(t_d - t_s)}$$

$$t_s = t_p + \frac{L_{pm} + L_{ms}}{v_i}$$

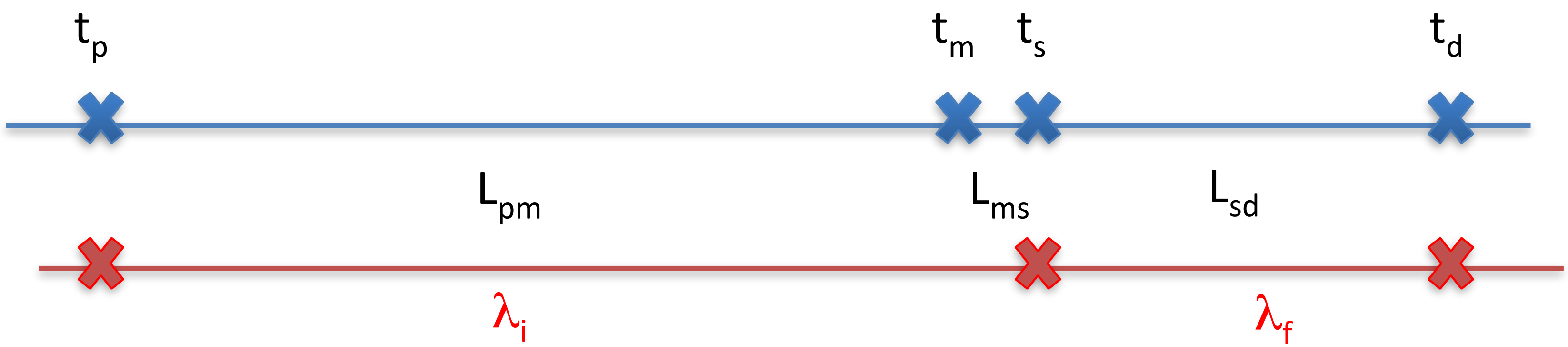
$$\hbar\omega = \frac{1}{2}m(v_i^2 - v_f^2) = \frac{1}{2}m\left[\frac{L_{pm}^2}{(t_m - t_p)^2} - \frac{L_{sd}^2}{\left(t_d - (1 + \frac{L_{ms}}{L_{pm}})t_m + \frac{L_{ms}}{L_{pm}})t_p\right)^2}\right]$$

Direct chopper spectrometer: TOF-TOF

Hypothesis of non correlated variables : $\delta\hbar\omega = \left[\sum_i \left(\frac{\partial \hbar\omega}{\partial t_i} \right)^2 \delta t_i^2 \right]^{\frac{1}{2}}$

$$t_{(TOF)} = \frac{L}{v} = \frac{Lm\lambda}{h} = \alpha L \lambda$$

$\alpha = m_n/h = 252.8\ \mu s.m^{-1}.Å^{-1}$



$$t_m - t_p = \alpha L_{pm} \lambda_i$$

$$t_d - t_m = \alpha (L_{ms} \lambda_i + L_{sd} \lambda_f)$$

$$t_d - t_s = \alpha L_{sd} \lambda_f$$

Direct chopper spectrometer: TOF-TOF

Hypothesis of non correlated variables : $\delta\hbar\omega = \left[\sum_i \left(\frac{\partial\hbar\omega}{\partial t_i}\right)^2 \delta t_i^2\right]^{\frac{1}{2}}$

$$t_m - t_p = \alpha L_{pm}\lambda_i$$
$$t_d - t_m = \alpha(L_{ms}\lambda_i + L_{sd}\lambda_f)$$
$$t_d - t_s = \alpha L_{sd}\lambda_f$$

$$\delta\hbar\omega = \frac{m}{\alpha^3 L_{pm} L_{sd} \lambda_f^3}\left[\begin{array}{c} \left[L_{ms} + L_{sd}\left(\frac{\lambda_f}{\lambda_i}\right)^3\right]^2 \tau_p^2 + \\ \left[L_{pm} + L_{ms} + L_{sd}\left(\frac{\lambda_f}{\lambda_i}\right)^3\right]\tau_m^2 + \\ L_{pm}^2 \delta t_d^2 \end{array}\right]^{\frac{1}{2}}$$

Direct chopper spectrometer: TOF-TOF

Hypothesis of non correlated variables : $\delta\hbar\omega = \left[\sum_i \left(\frac{\partial\hbar\omega}{\partial t_i}\right)^2 \delta t_i^2\right]^{\frac{1}{2}}$

$$t_m - t_p = \alpha L_{pm}\lambda_i$$
$$t_d - t_m = \alpha(L_{ms}\lambda_i + L_{sd}\lambda_f)$$
$$t_d - t_s = \alpha L_{sd}\lambda_f$$

Time opening of the pulsing chopper

$$\delta\hbar\omega = \frac{m}{\alpha^3 L_{pm} L_{sd} \lambda_f^3}\left[\left[L_{pm} + L_{sd}\left(\frac{\lambda_f}{\lambda_i}\right)^3\right]^2 \tau_p^2 + \left[L_{pm} + L_{ms} + L_{sd}\left(\frac{\lambda_f}{\lambda_i}\right)^3\right]\tau_m^2 + L_{pm}^2 \delta t_d^2\right]^{\frac{1}{2}}$$

Direct chopper spectrometer: TOF-TOF

Hypothesis of non correlated variables : $$\delta\hbar\omega = \left[\sum_i \left(\frac{\partial\hbar\omega}{\partial t_i}\right)^2 \delta t_i^2\right]^{\frac{1}{2}}$$

$$t_m - t_p = \alpha L_{pm}\lambda_i$$
$$t_d - t_m = \alpha(L_{ms}\lambda_i + L_{sd}\lambda_f)$$
$$t_d - t_s = \alpha L_{sd}\lambda_f$$

Time opening of the monochromating chopper

$$\delta\hbar\omega = \frac{m}{\alpha^3 L_{pm} L_{sd} \lambda_f^3}\left[\begin{array}{c} \left[L_{ms} + L_{sd}\left(\frac{\lambda_f}{\lambda_i}\right)^3\right]^2 \tau_p^2 + \\ \left[L_{pm} + L_{ms} + L_{sd}\left(\frac{\lambda_f}{\lambda_i}\right)^3\right]^2 \tau_m^2 + \\ L_{pm}^2 \delta t_d^2 \end{array}\right]^{\frac{1}{2}}$$

Direct chopper spectrometer: TOF-TOF

Hypothesis of non correlated variables : $$\delta\hbar\omega = \left[\sum_i \left(\frac{\partial\hbar\omega}{\partial t_i}\right)^2 \delta t_i^2\right]^{\frac{1}{2}}$$

$$t_m - t_p = \alpha L_{pm}\lambda_i$$

$$t_d - t_m = \alpha(L_{ms}\lambda_i + L_{sd}\lambda_f)$$

$$t_d - t_s = \alpha L_{sd}\lambda_f$$

$$\delta\hbar\omega = \frac{m}{\alpha^3 L_{pm} L_{sd} \lambda_f^3}\left[\left[L_{ms} + L_{sd}\left(\frac{\lambda_f}{\lambda_i}\right)^3\right]^2 \tau_p^2 + \left[L_{pm} + L_{ms} + L_{sd}\left(\frac{\lambda_f}{\lambda_i}\right)^3\right]\tau_m^2 + L_{pm}^2 \delta t_d^2\right]^{\frac{1}{2}}$$

Time spread due to secondary spectrometer uncertainty

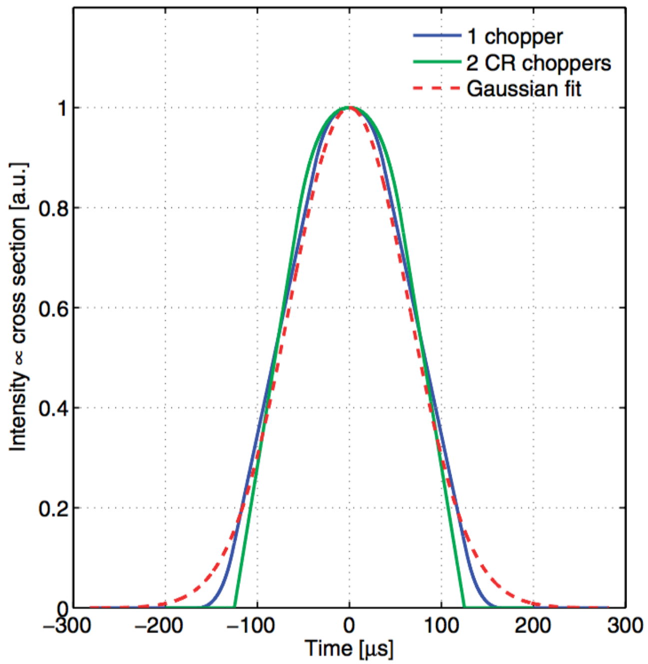
Direct chopper spectrometer: TOF-TOF

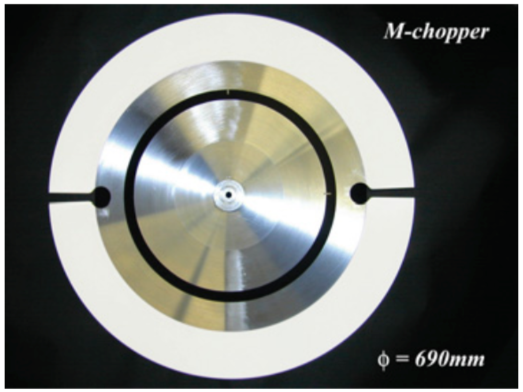
Resolution : convolution of 3 uncertainties

$$R(Q,\omega) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{1}{2}[(\hbar\omega - \hbar\omega_0)/\sigma]^2}$$

$$\delta\hbar\omega = 2\sqrt{2\ln 2}\sigma$$

$$\left(\frac{\partial^2\sigma}{\partial\Omega\partial\omega}\right)_{\exp} = N\frac{k_f}{k_i}\frac{\sigma}{4\pi} S(Q,\omega) \otimes R(Q,\omega)$$





IN5

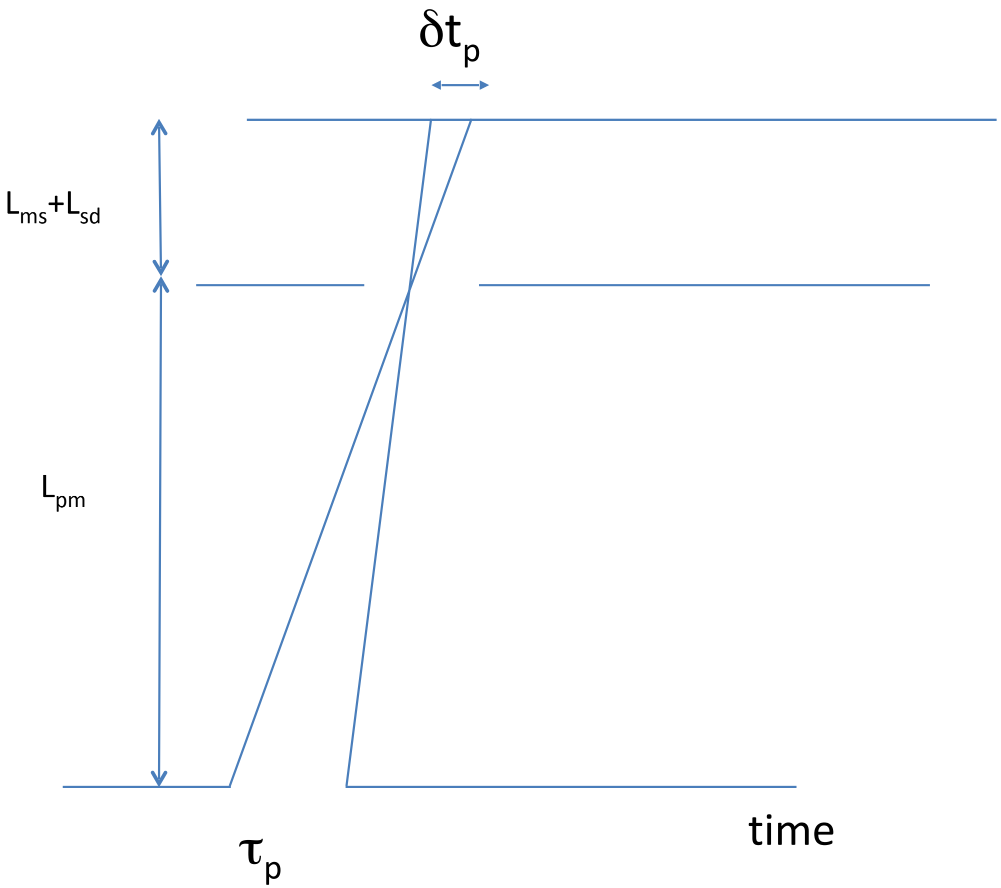
Direct chopper spectrometer: TOF-TOF

$$\delta\hbar\omega = \frac{m}{\alpha^3 L_{sd} \lambda_f^3} \begin{bmatrix} \delta t_p^2 + \\ \delta t_m^2 + \\ \delta t_d^2 \end{bmatrix}^{\frac{1}{2}}$$

Direct chopper spectrometer: TOF-TOF

Resolution : convolution of 3 uncertainties

- The spraid δt_p at the detector due to the pulsing chopper (τ_p)

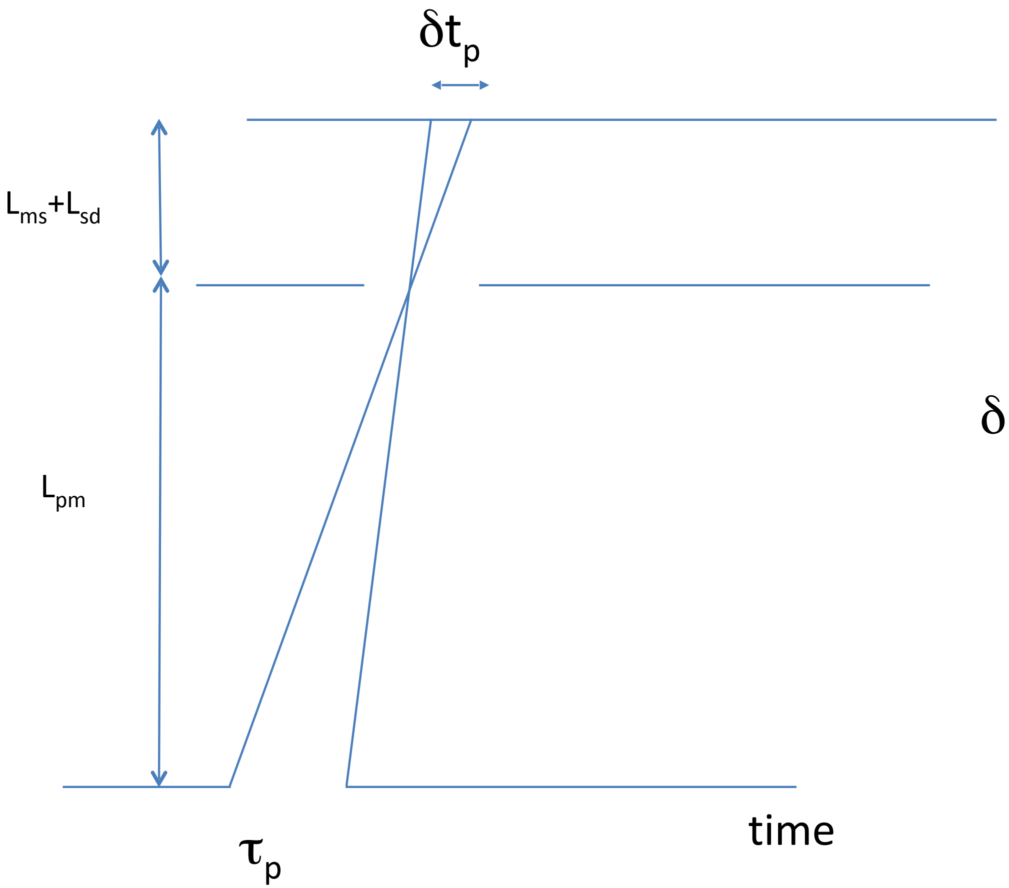


$$\frac{\delta t_p}{L_{ms} + L_{sd}} = \frac{\tau_p}{L_{pm}}$$

Direct chopper spectrometer: TOF-TOF

Resolution : convolution of 3 uncertainties

- The spraid δt_p at the detector due to the pulsing chopper (τ_p)



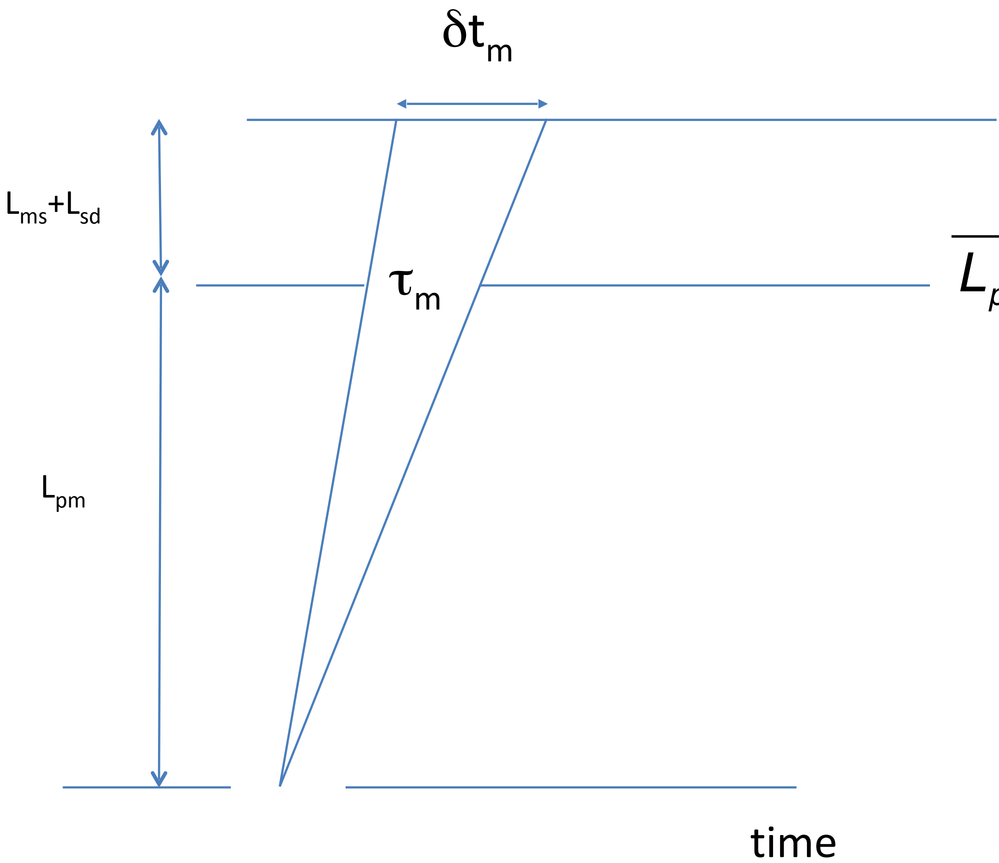
$$\frac{\delta t_p}{L_{ms} + L_{sd}} = \frac{\tau_p}{L_{pm}}$$

$$\delta t_p = \tau_p \frac{L_{ms} + L_{sd}}{L_{pm}}$$

Direct chopper spectrometer: TOF-TOF

Resolution : convolution of 3 uncertainties

- The spraid δt_p at the detector due to the pulsing chopper (τ_p)
- The spraid δt_m at the detector due to the monochromating chopper (τ_m)

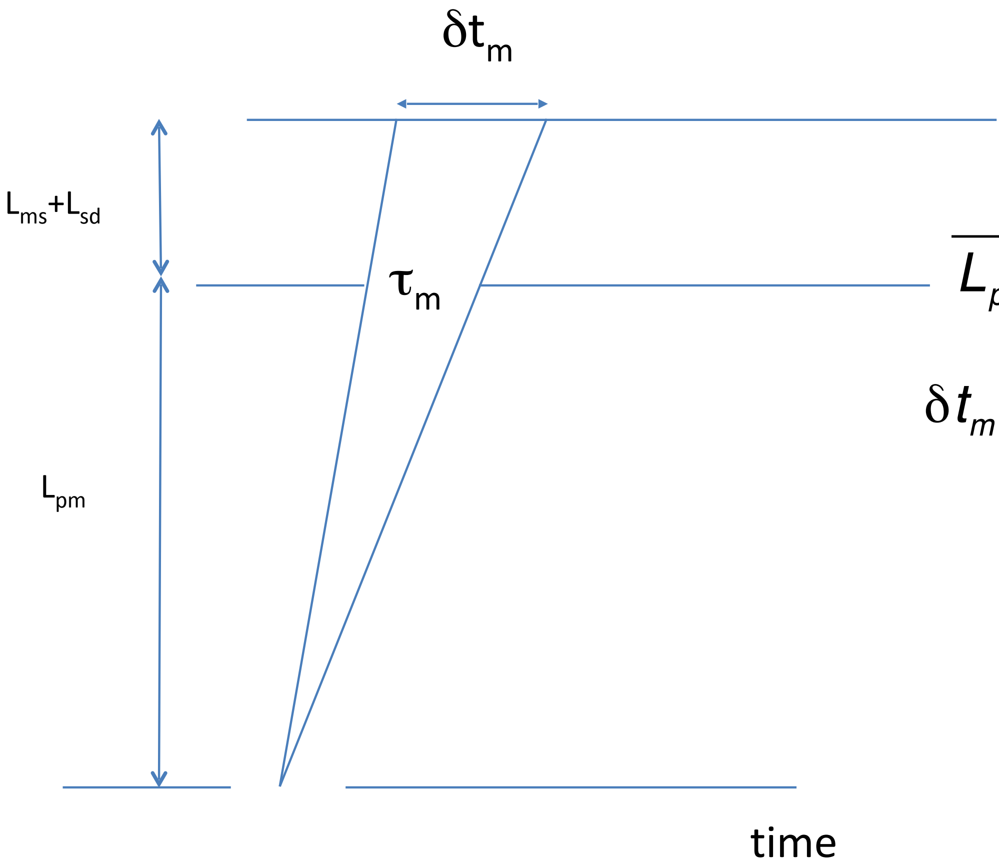


$$\frac{\delta t_m}{L_{pm} + L_{ms} + L_{sd}} = \frac{\tau_m}{L_{pm}}$$

Direct chopper spectrometer: TOF-TOF

Resolution : convolution of 3 uncertainties

- The spraid δt_p at the detector due to the pulsing chopper (τ_p)
- The spraid δt_m at the detector due to the monochromating chopper (τ_m)



$$\frac{\delta t_m}{L_{pm} + L_{ms} + L_{sd}} = \frac{\tau_m}{L_{pm}}$$

$$\delta t_m = \tau_m \frac{L_{pm} + L_{ms} + L_{sd}}{L_{pm}}$$

Direct chopper spectrometer: TOF-TOF

Resolution : convolution of 3 uncertainties

- The spraid δt_p at the detector due to the pulsing chopper (τ_p)
- The spraid δt_m at the detector due to the monochromating chopper (τ_m)
- TOF uncertainty in the secondary spectrometer δt_L (Detector+sample thickness)

Direct chopper spectrometer: TOF-TOF

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- The spraid δt_p at the detector due to the pulsing chopper (τ_p)
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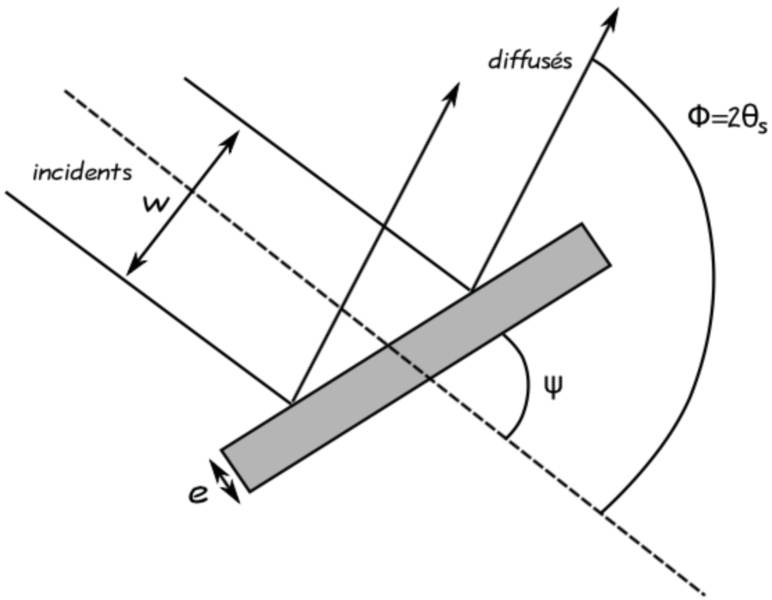

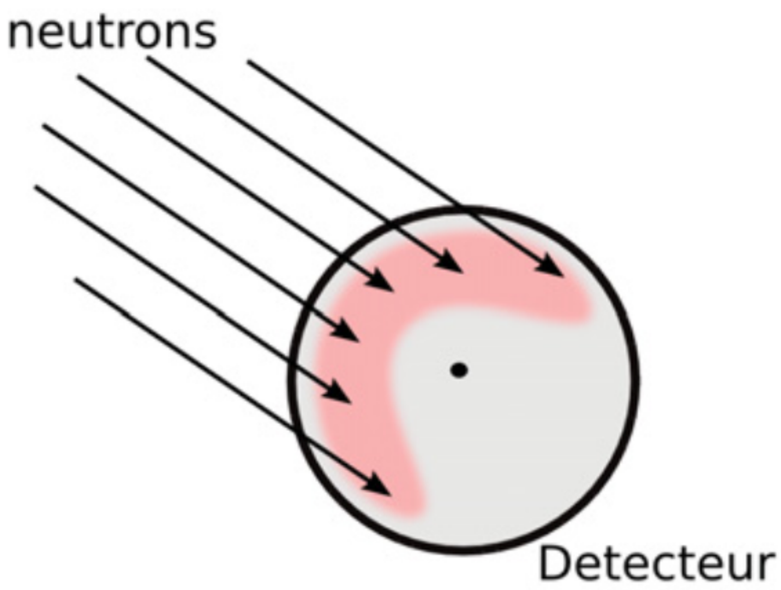

δL_s

δL_d

Direct chopper spectrometer: TOF-TOF

Resolution : convolution of 3 uncertainties

- The spraid δt_p at the detector due to the pulsing chopper (τ_p)
- The spraid δt_m at the detector due to the monochromating chopper (τ_m)
- TOF uncertainty in the secondary spectrometer δt_L (Detector+sample thickness)

$$\delta t_L = \alpha\lambda\delta L_{sd}$$

Direct chopper spectrometer: TOF-TOF

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$$\delta t_L = \alpha \lambda \delta L_{sd}$$

$$\delta L_{sd} \approx \delta L_s + \delta L_d$$

2 cm 2 cm

Direct chopper spectrometer: TOF-TOF

Resolution : convolution of 3 uncertainties

- The spraid δt_p at the detector due to the pulsing chopper (τ_p)
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2 cm 2 cm

For λ=5Å one gets $\delta t_L \approx 50 \mu s$

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The wavelength uncertainty arising from δt_L

$$\frac{\delta\lambda}{\lambda} = \frac{\delta t_L}{t_L} = \frac{\delta t_L}{\alpha\lambda L_{sd}} = \frac{\delta L_{sd}}{L_{sd}}$$

Direct chopper spectrometer: TOF-TOF

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$$\delta t_L = \alpha\lambda\delta L_{sd}$$

$$\delta L_{sd} \approx \delta L_s + \delta L_d$$

2 cm 2 cm

$\Delta\hbar\omega \approx 100\mu ev$ @ λ=5Å

$$\frac{\delta\lambda}{\lambda} \approx 1.5 - 2\%$$

For λ=5Å one gets $\delta t_L \approx 50\mu s$

The wavelength uncertainty arising from δt_L

$$\frac{\delta\lambda}{\lambda} = \frac{\delta t_L}{t_L} = \frac{\delta t_L}{\alpha\lambda L_{sd}} = \frac{\delta L_{sd}}{L_{sd}}$$

Direct chopper spectrometer: TOF-TOF

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2 cm   2 cm

$\Delta\hbar\omega \approx 100 \mu ev$ @ λ=5Å

$$\frac{\delta\lambda}{\lambda} \approx 1.5 - 2\%$$

Keep the possibility to have $\frac{\delta\lambda}{\lambda} \approx 1\%$

For λ=5Å one gets $\delta t_L \approx 50 \mu s$

The wavelength uncertainty arising from δt_L

$$\frac{\delta\lambda}{\lambda} = \frac{\delta t_L}{t_L} = \frac{\delta t_L}{\alpha \lambda L_{sd}} = \frac{\delta L_{sd}}{L_{sd}}$$

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$$\frac{\delta L_{sd}}{L_{sd}} \approx 1\%$$

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$$\frac{\delta\lambda}{\lambda} \approx 1.5 - 2\%$$

Keep the possibility to have $\frac{\delta\lambda}{\lambda} \approx 1\%$

$$\frac{\delta L_{sd}}{L_{sd}} \approx 1\%$$

$L_{sd} \approx 4$m

Direct chopper spectrometer: TOF-TOF

Resolution : convolution of 3 uncertainties

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Optimized spectrometer $\delta t_d \approx \delta t_p \approx \delta t_m$

(R.E. Lechner)

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$$\delta t_p = \tau_p \frac{L_{ms} + L_{sd}}{L_{pm}} \qquad \delta t_m = \tau_m \frac{L_{pm} + L_{ms} + L_{sd}}{L_{pm}}$$

τ_p

Direct chopper spectrometer: TOF-TOF

Resolution : convolution of 3 uncertainties

- The spraid δt_p at the detector due to the pulsing chopper (τ_p)
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$$\tau_p \frac{L_{ms} + L_{sd}}{L_{pm}} = \tau_m \frac{L_{pm} + L_{ms} + L_{sd}}{L_{pm}}$$

$$\frac{\tau_p}{\tau_m} = \frac{L_{pm} + L_{ms} + L_{sd}}{L_{ms} + L_{sd}}$$

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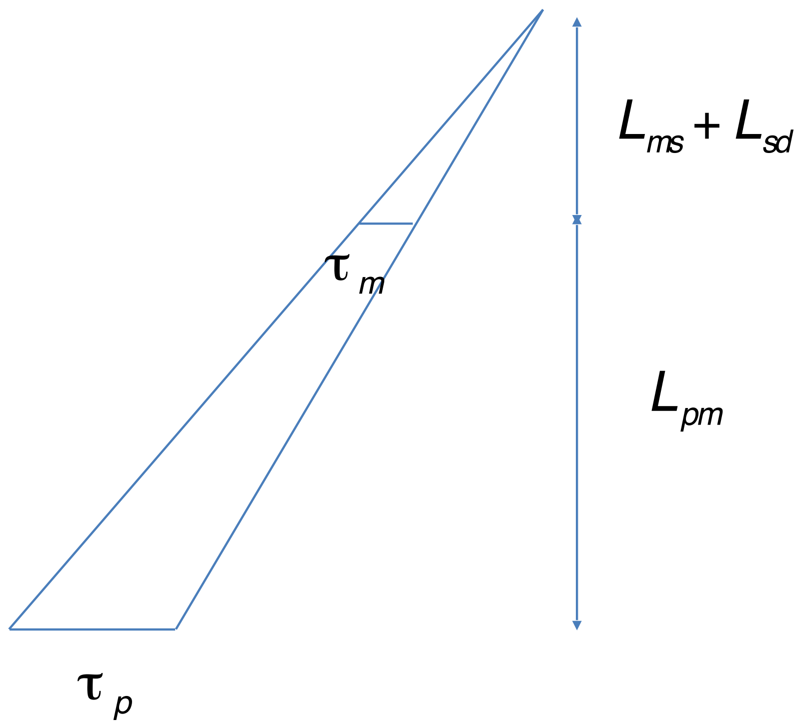

$$\tau_p \frac{L_{ms} + L_{sd}}{L_{pm}} = \tau_m \frac{L_{pm} + L_{ms} + L_{sd}}{L_{pm}}$$

$$\frac{\tau_p}{\tau_m} = \frac{L_{pm} + L_{ms} + L_{sd}}{L_{ms} + L_{sd}}$$

Direct chopper spectrometer: TOF-TOF

Resolution : convolution of 3 uncertainties

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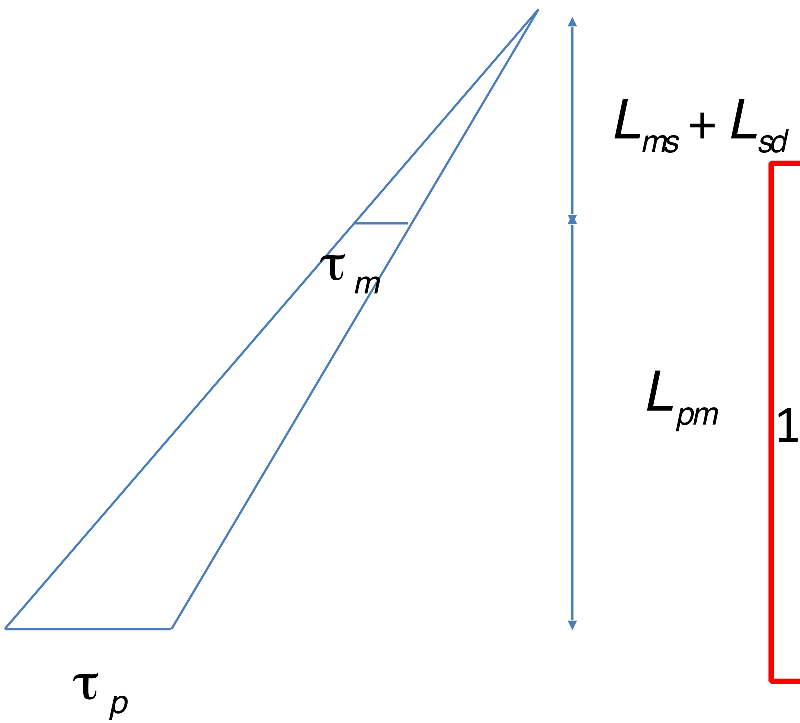
$$\frac{\tau_p}{\tau_m} = \frac{L_{pm} + L_{ms} + L_{sd}}{L_{ms} + L_{sd}}$$



IN5

100 μev @ 5Å

L_{pm}=8m

L_{ms}=1.2m

L_{sd}=4m

τ_p=88.6 μs

τ_m=32.01 μs

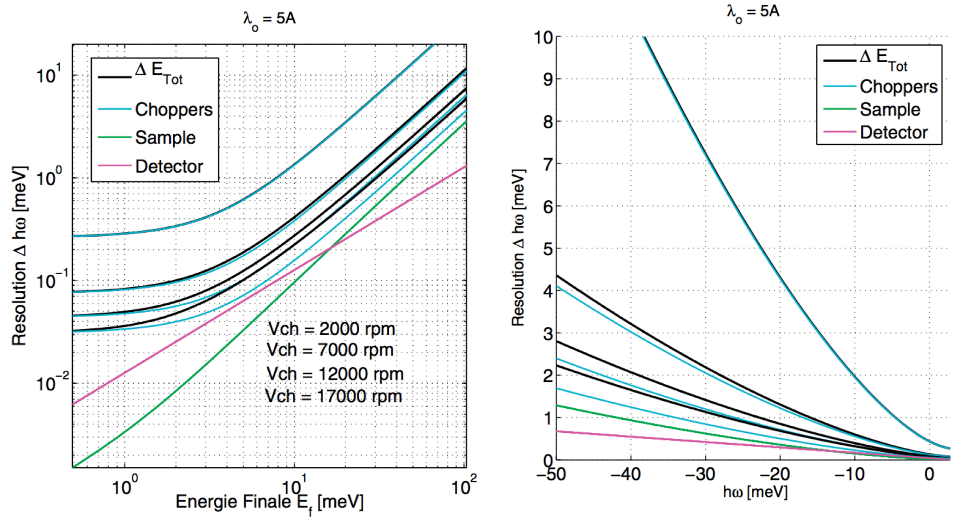
δt_p=57.6 μs

δt_m=52.8 μs

δt_L=50 μs

Direct chopper spectrometer: TOF-TOF Energy dependence of the resolution

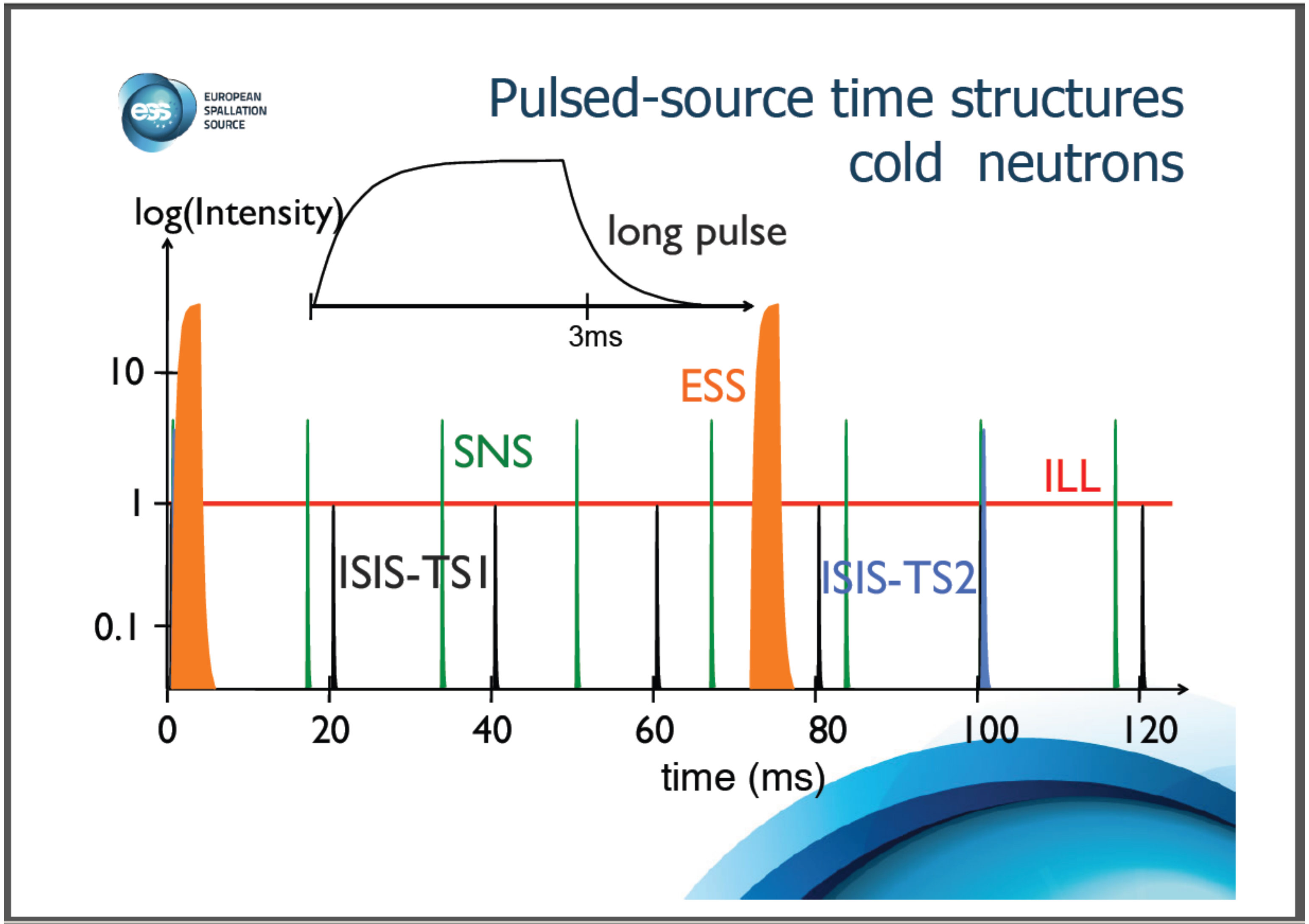
$$\delta\hbar\omega = \frac{m}{\alpha^3 L_{pm} L_{sd} \lambda_f^3} \left[\begin{array}{c} \left[L_{ms} + L_{sd}\left(\frac{\lambda_f}{\lambda_i}\right)^3 \right]^2 \tau_p^2 + \\ \left[L_{pm} + L_{ms} + L_{sd}\left(\frac{\lambda_f}{\lambda_i}\right)^3 \right] \tau_m^2 + \\ L_{pm}^2 \delta t_d^2 \end{array} \right]^{\frac{1}{2}}$$



J. Ollivier and J.-M. Zanotti

Direct chopper spectrometer at LPSS

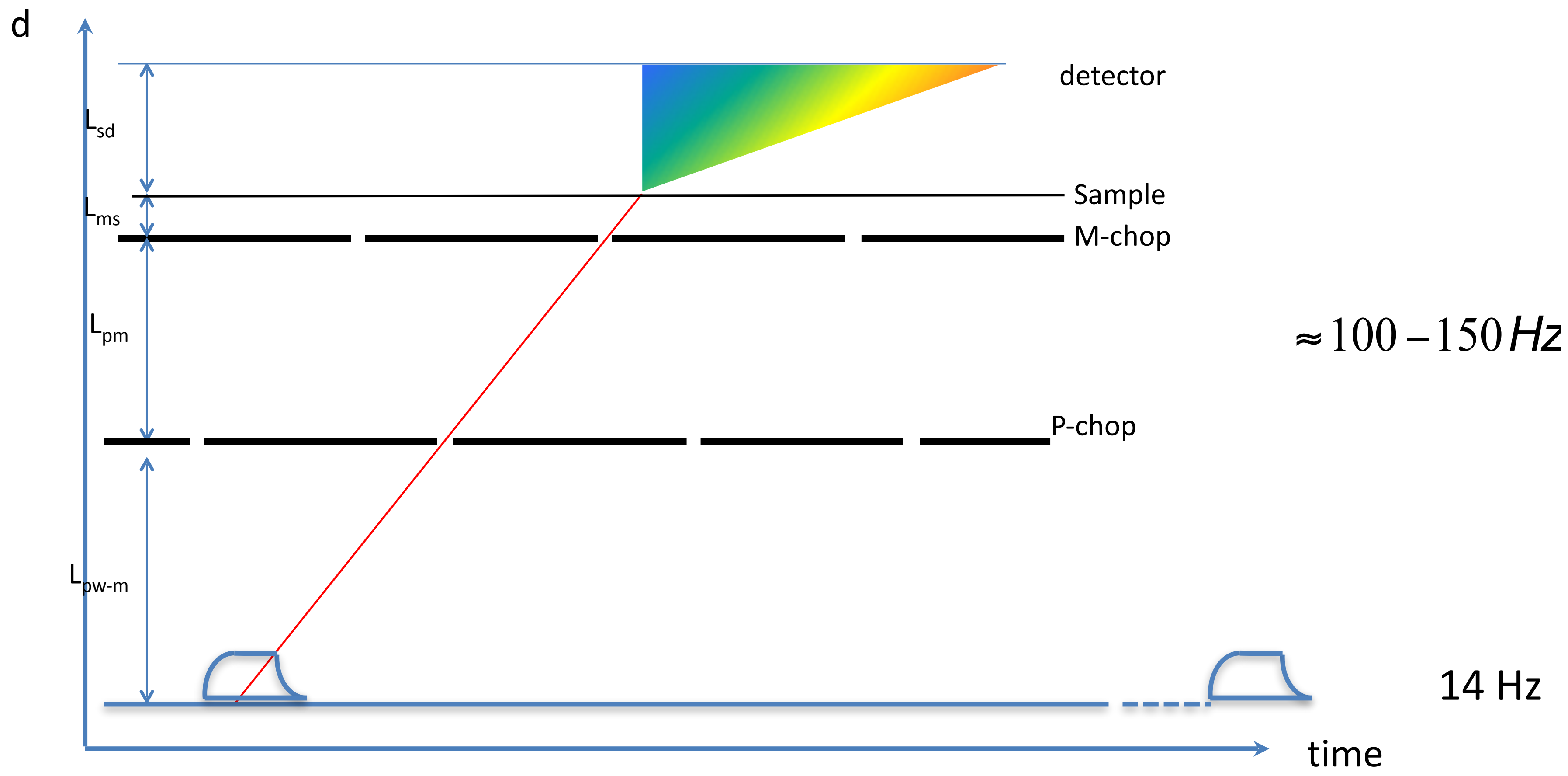
ESS a 5MW spallation source with 14 Hz and a PW=2.86 ms



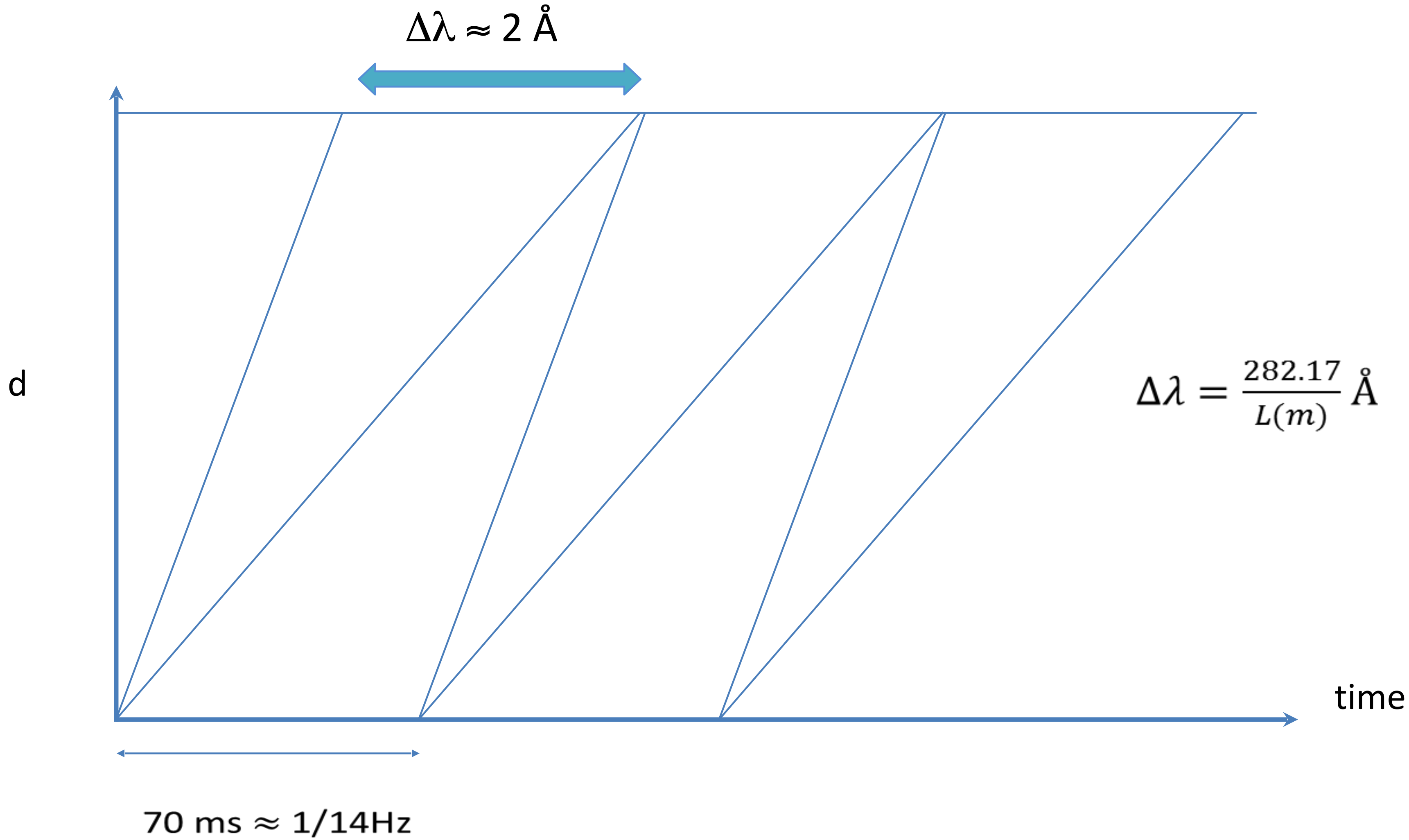
K. Anderson (2011), ESS

Direct chopper spectrometer at LPSS

ESS a 5MW spallation source with 14 Hz and a PW=2.86 ms



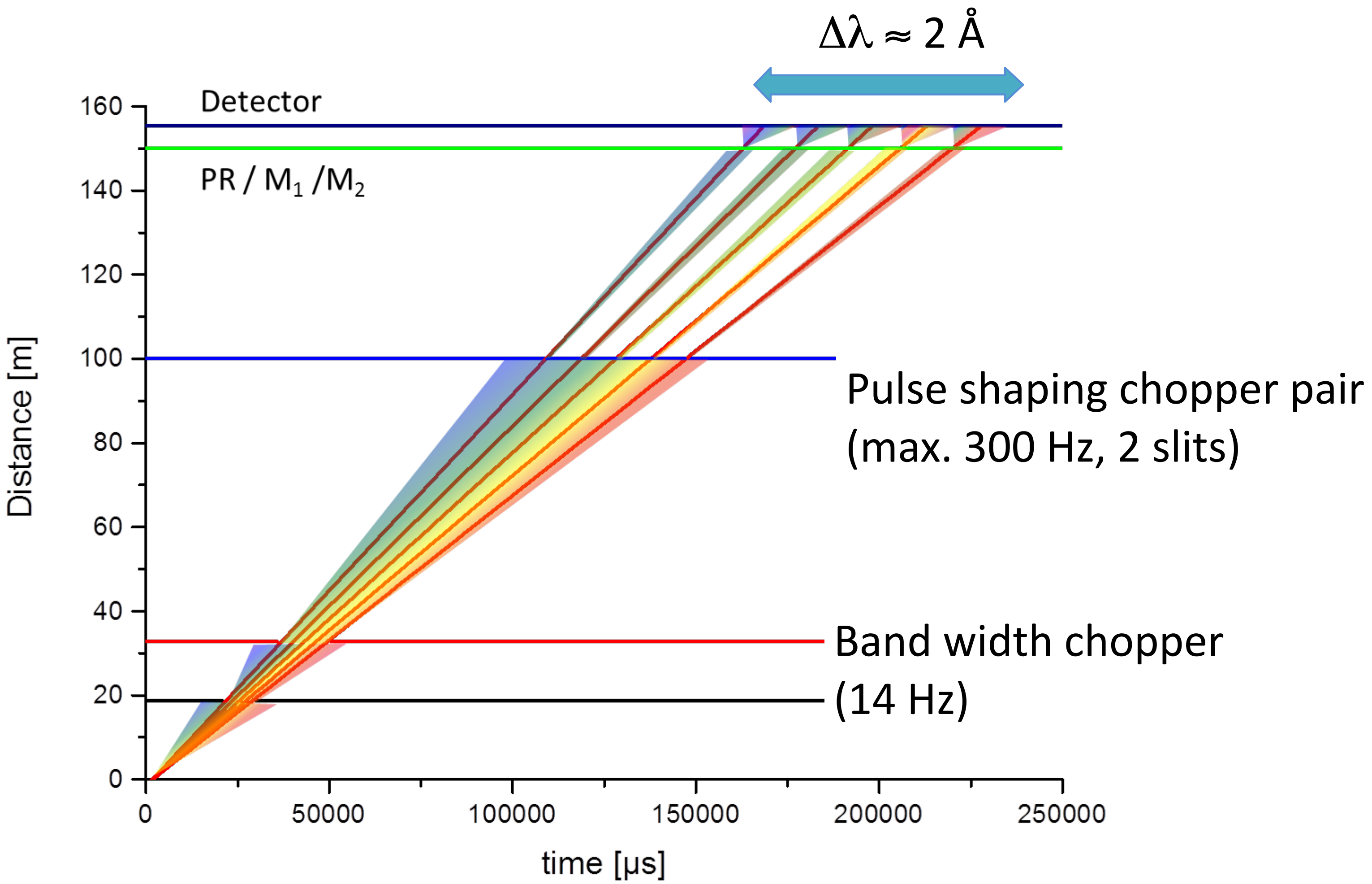
Direct chopper spectrometer at LPSS



Direct chopper spectrometer at LPSS

14 Hz (source) versus 50-150 Hz (TOF spectroscopy)

Repetition Rate Multiplication (RRM) = Multi wavelength mode



Direct chopper spectrometer at LPSS

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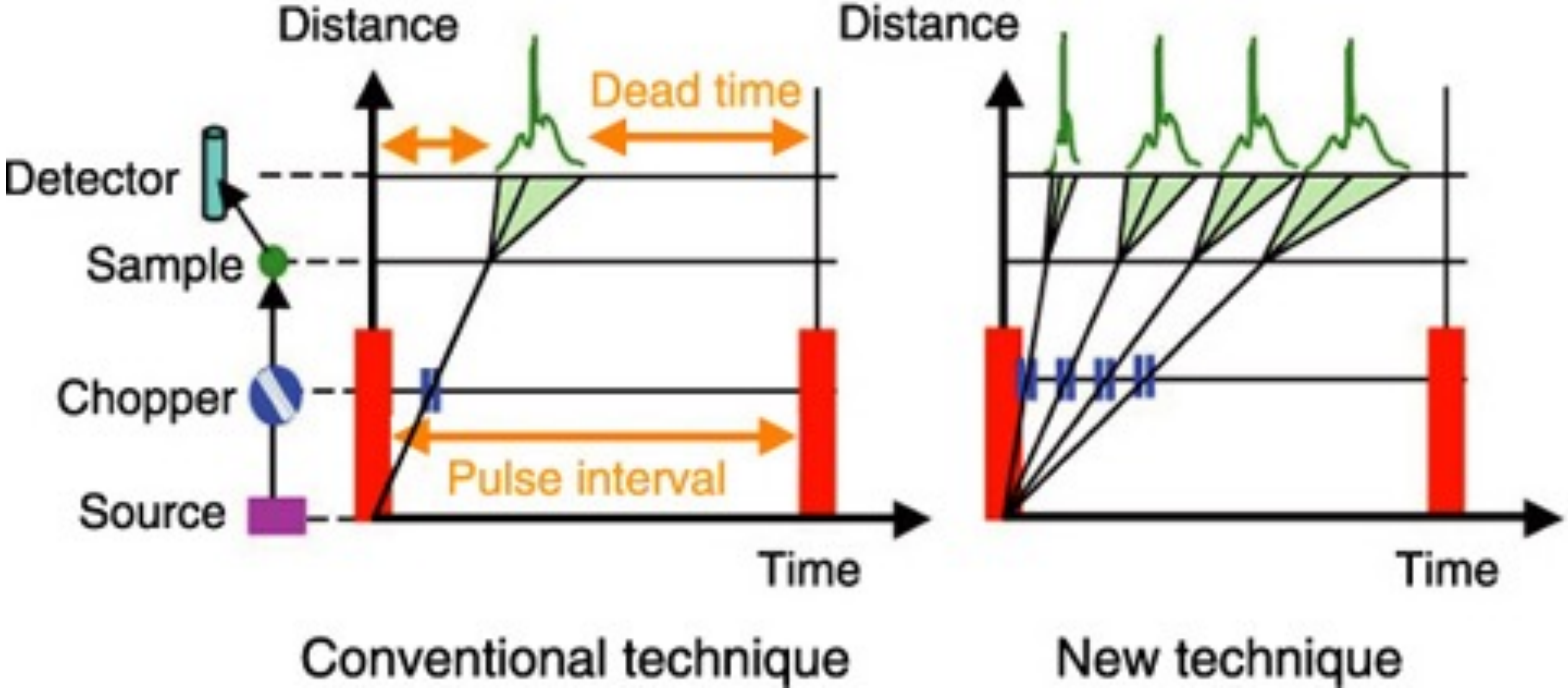
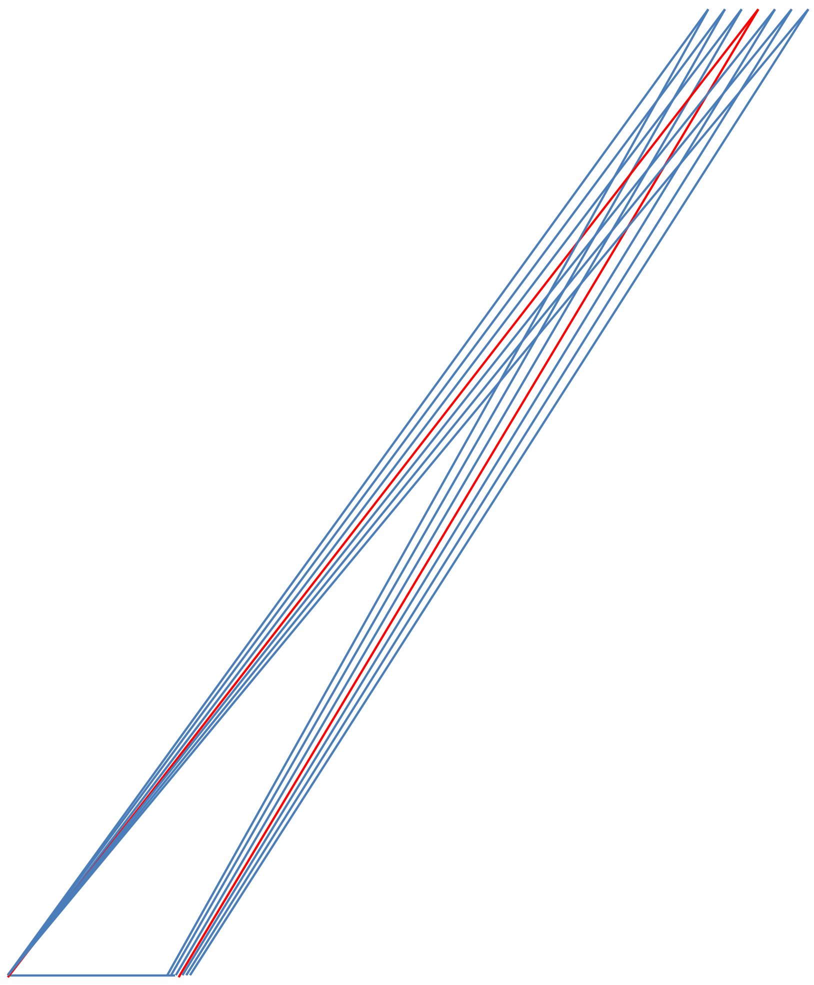


Direct chopper spectrometer at LPSS

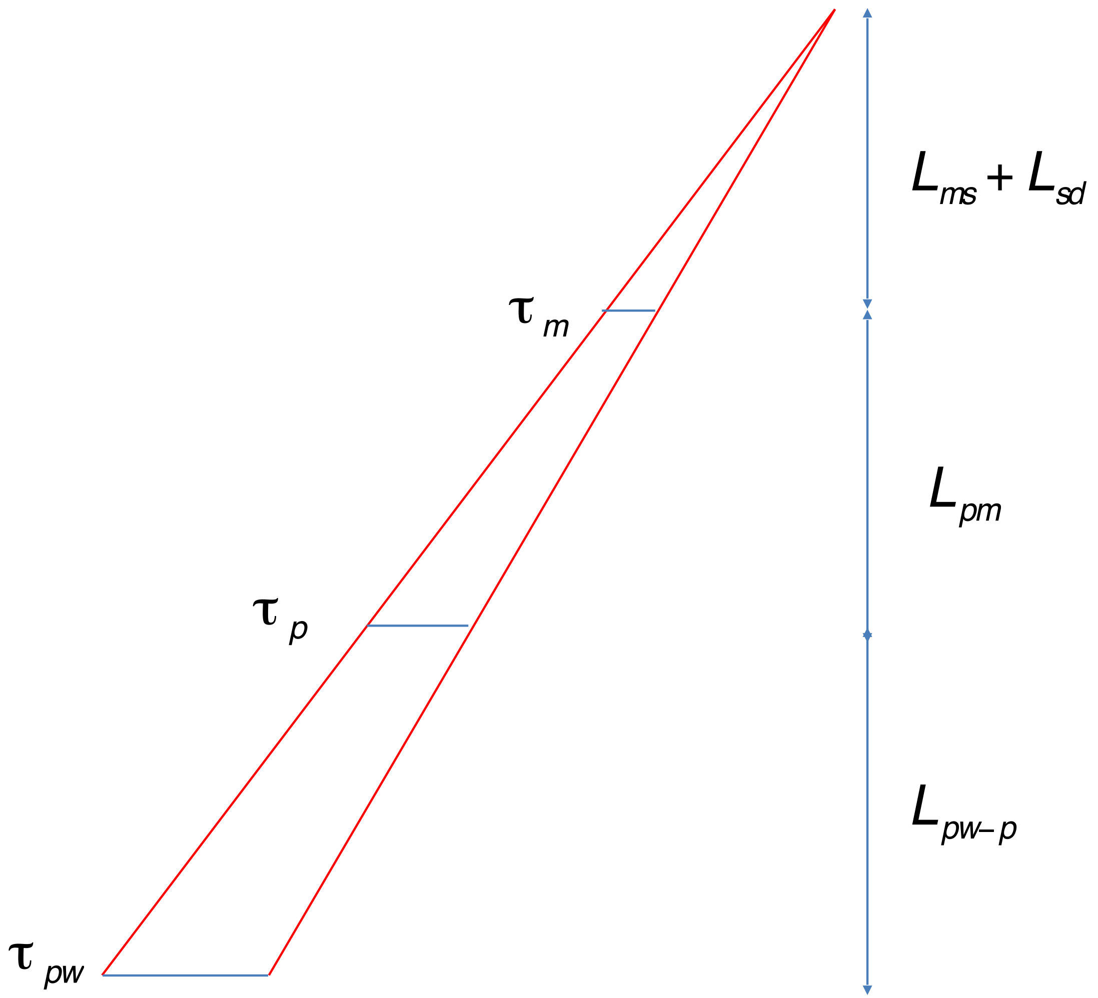
Optimized spectrometer @LPSS (ESS)



Direct chopper spectrometer at LPSS

Optimized spectrometer @LPSS (ESS) $\delta t_m \approx \delta t_p \approx \delta t_{pw} \approx \delta t_L$

$$\delta t_p = \tau_p \frac{L_{ms} + L_{sd}}{L_{pm}} \qquad \delta t_m = \tau_m \frac{L_{pm} + L_{ms} + L_{sd}}{L_{pm}}$$



Direct chopper spectrometer at LPSS

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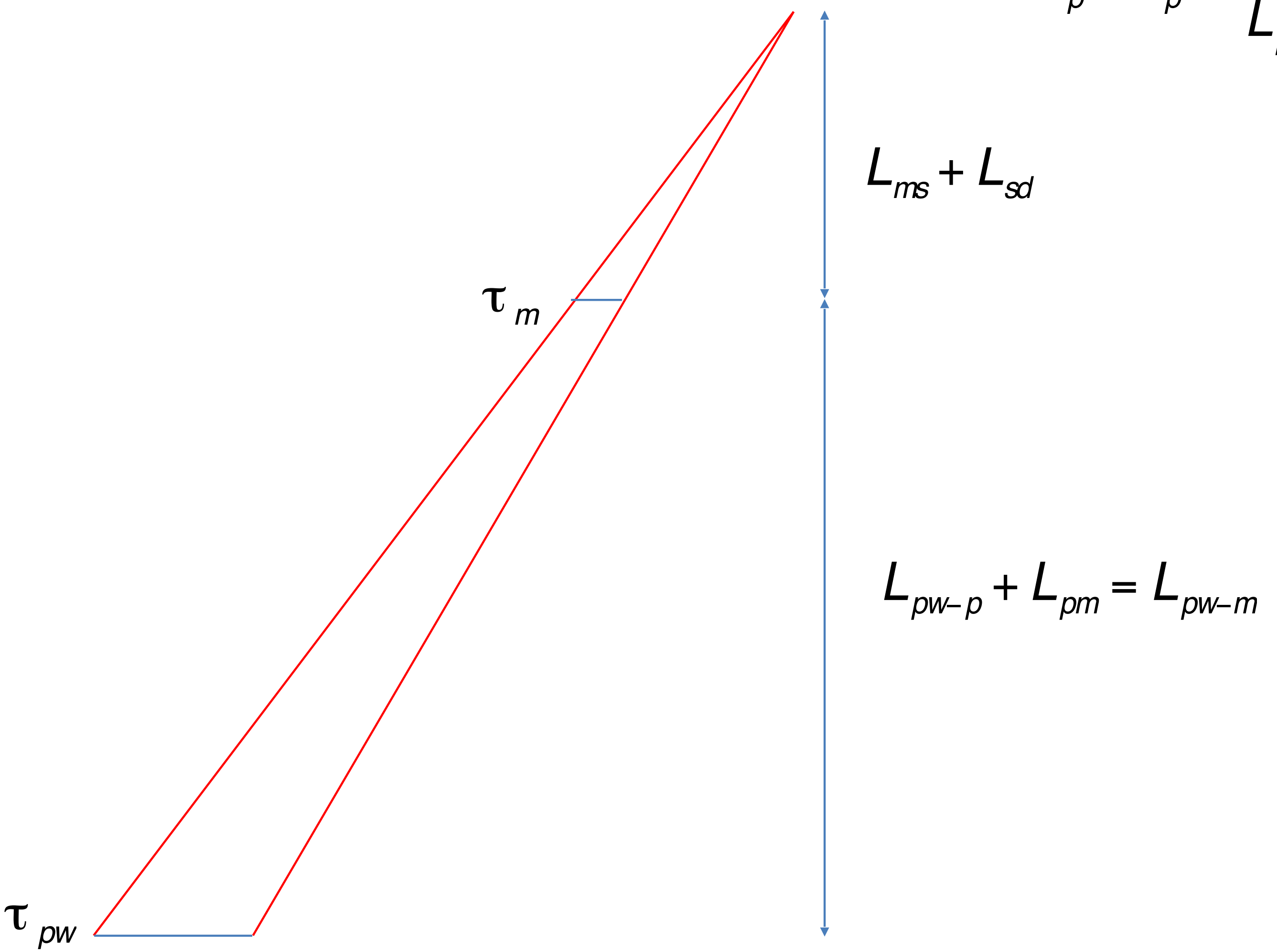

Direct chopper spectrometer at LPSS

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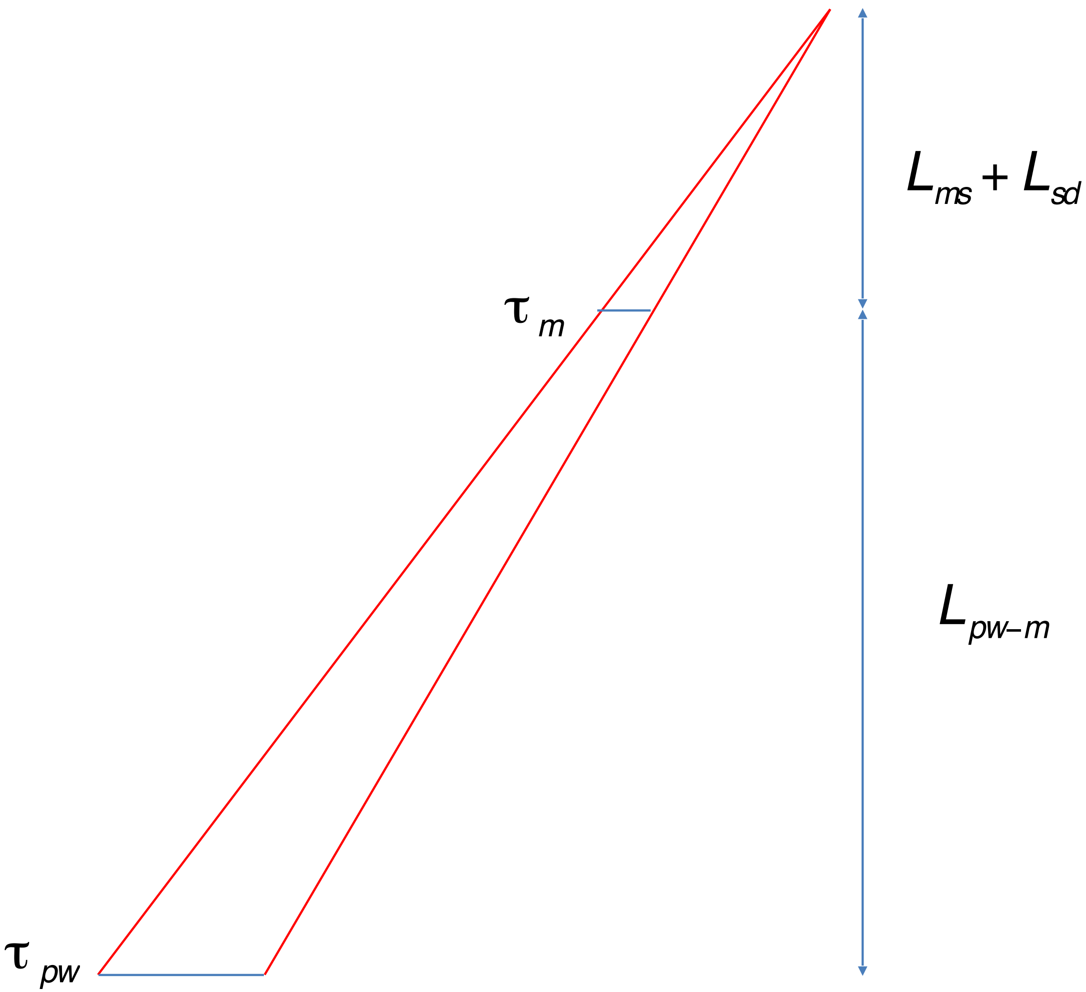
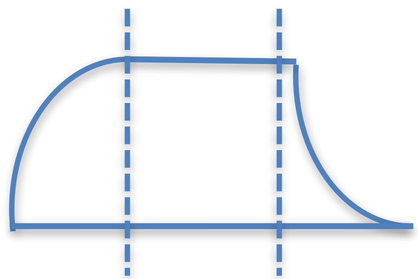


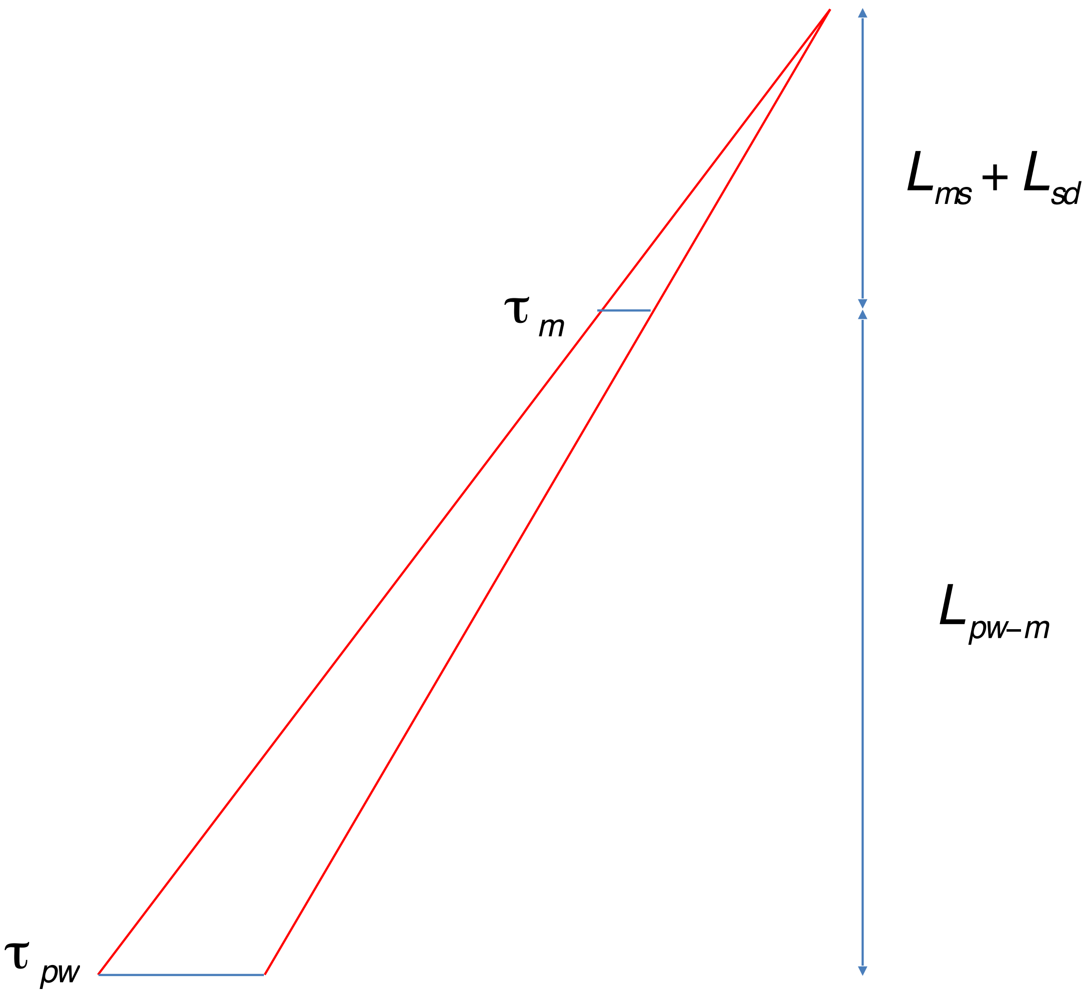
$$\delta t_{pw} = \tau_{pw} \frac{L_{pw-m} + L_{ms} + L_{sd}}{L_{pw-m}}$$

"Clean pulse" 2.87 msec➔1.5msec



Direct chopper spectrometer at LPSS

Optimized spectrometer @LPSS (ESS) $\delta t_m \approx \delta t_p \approx \delta t_{pw} \approx \delta t_L$



$$\delta t_p = \tau_p \frac{L_{ms} + L_{sd}}{L_{pm}} \qquad \delta t_m = \tau_m \frac{L_{pm} + L_{ms} + L_{sd}}{L_{pm}}$$

$$\delta t_{pw} = \tau_{pw} \frac{L_{ms} + L_{sd}}{L_{pw-m}}$$

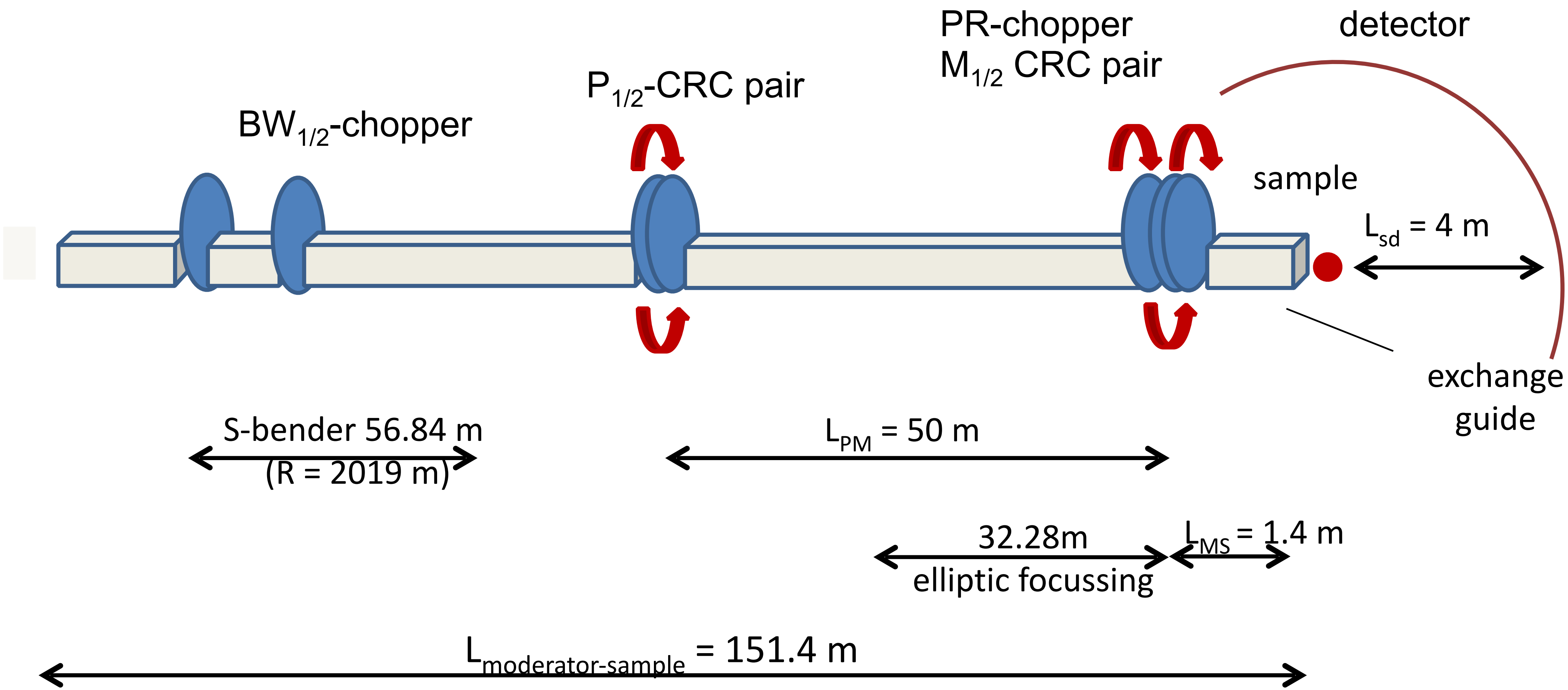
$$\delta t_{pw} = 1.5 \frac{5.5}{L_{pw-m}} \quad msec$$

$$\delta t_L \approx 50 \mu \sec$$

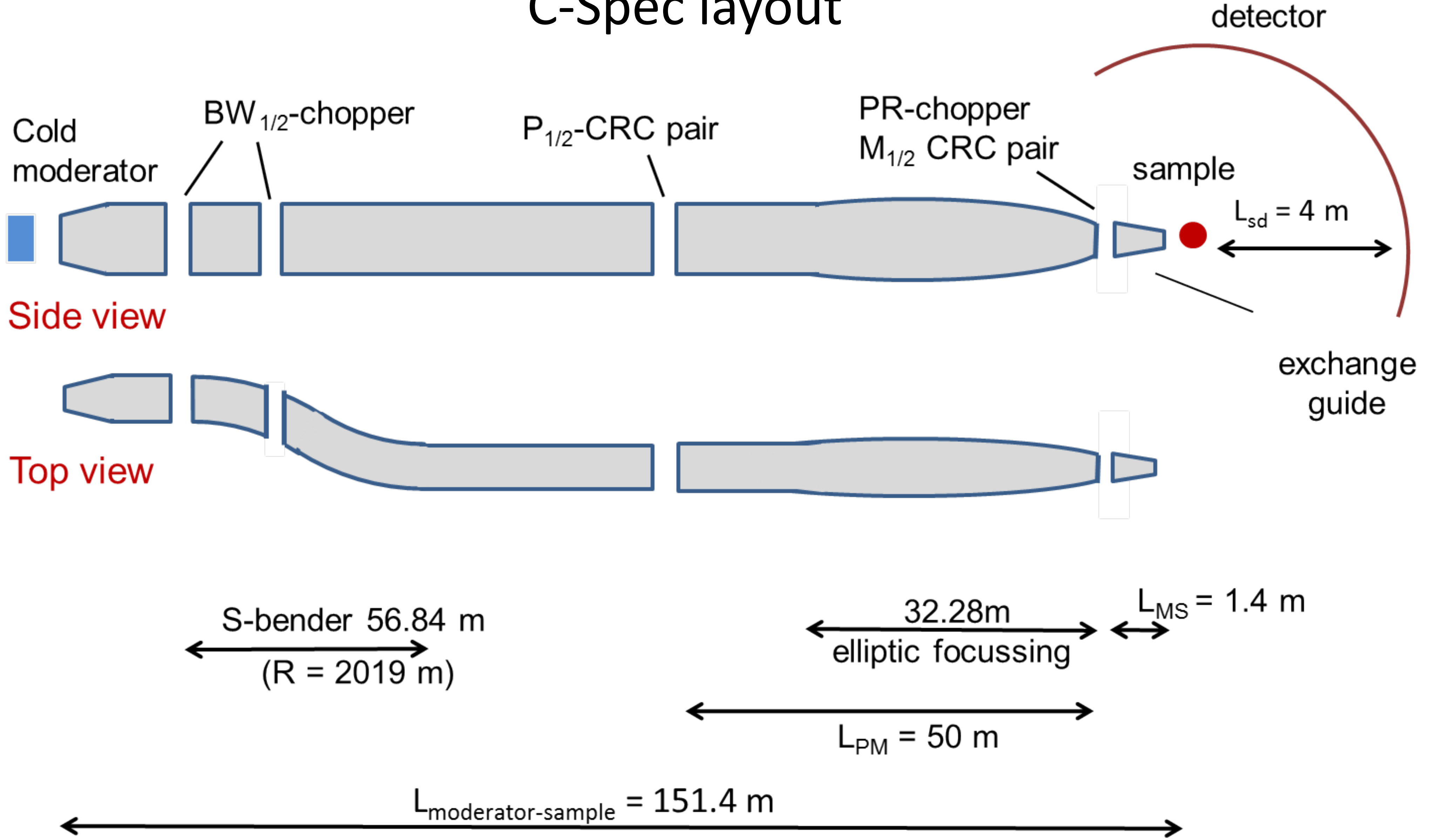
$$50.10^{-3} \approx 1.5 \frac{5.5}{L_{pw-m}}$$

$$\boxed{L_{pw-m} \approx 150 m}$$

C-Spec layout



C-Spec layout



Instrument performance

- Estimation of Flux values from McStas (single energy mode)

Chopper and guide settings		Flux (λ_0 = 4 Å) [n /(s cm^2)]	Flux (λ_0 = 5 Å) [n /(s cm^2)]	Flux (λ_0 = 9 Å) [n /(s cm^2)]	to compare with: [n /(s cm^2)]
N_1 = 7.5, N_2= 10	standard	$7.09\cdot10^6$	$5.7\cdot10^6$	$1.49\cdot10^6$	IN5: $6.38\cdot10^5$ (at 5 Å)
	focus	$1.68\cdot10^7$	$9.4\cdot10^6$	$1.30\cdot10^6$	TOFTOF: 1.14 10^5 (at 5 Å)
N_1 = 13.5, N_2 = 24	standard	$2.58\cdot10^6$	$1.75\cdot10^6$	$4.97\cdot10^5$	LET:5.6 10^4 (at 4 Å)
	focus	$5.24\cdot10^6$	$2.98\cdot10^6$	$4.17\cdot10^5$	IN5: 7 10^4 (at 4 Å)

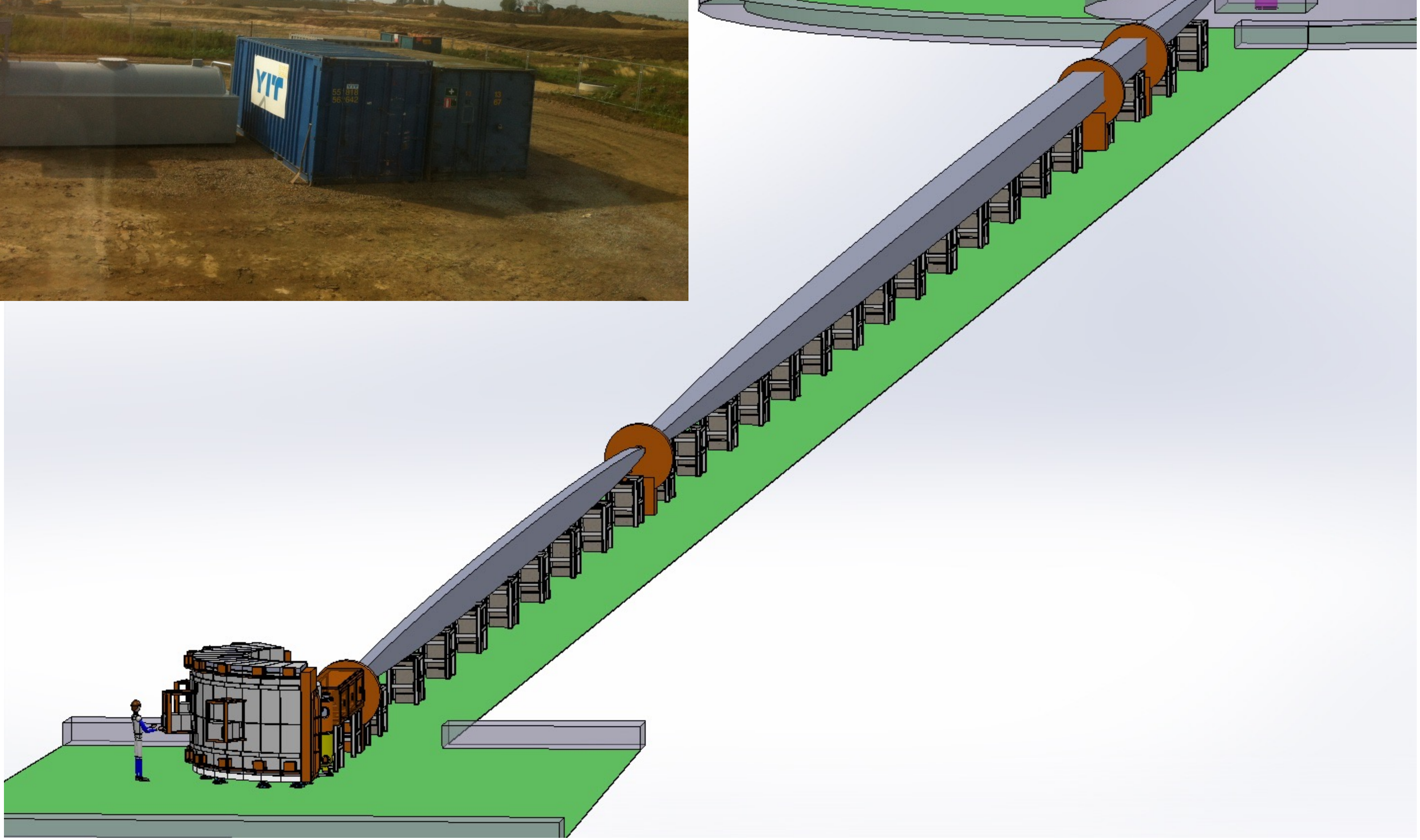
↓ **gain factor ~10**

↓ **gain factor ~75**

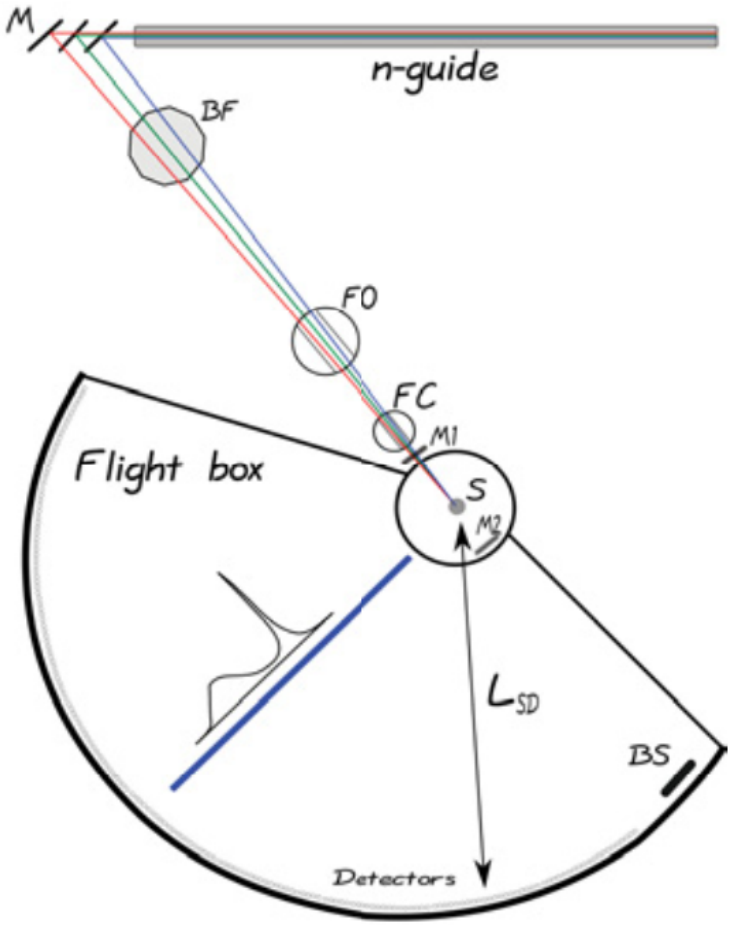
Summary C-Spec

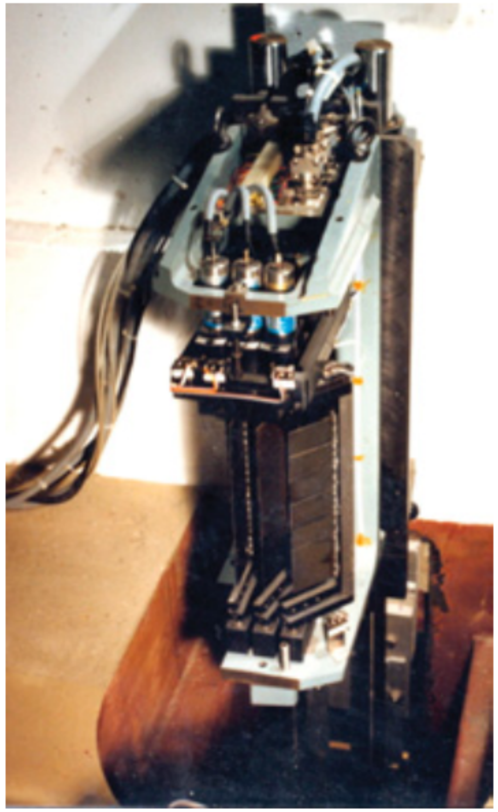
Moderator:		cold source
Moderator – sample distance:		151.4 m
wavelength band:		≤ 2 Å
Wavelength range:		1.5 – 15 Å
Energy Resolutions:	40 μeV – 170 μeV @ 5Å	
		2 – 7 μeV @ 15 Å
Q-range /Resolution:	@ 2 Å: 0.32 – 5.90 $Å^{-1}$	
		@ 5 Å: 0.13 – 2.36 $Å^{-1}$
		@ 10 Å: 0.066 – 1.18 $Å^{-1}$
		@ 15 Å: 0.044 – 0.78 $Å^{-1}$
Flux at sample($\Delta E/E$=3 %	5 Å:	5.7 $\cdot 10^6$ neutrons /(s cm^2), standard
		5 Å: 9.4 $\cdot 10^6$ neutrons /(s cm^2), focus
Beam size at sample:	standard: 40 x 20 mm^2	
		focus: 10 x 10 mm^2
Divergence (standard):		+/- 1 deg
Sample – detector distance:		4 m
Detector technology:	^{10}B converter layers or Helium	
Detector coverage:		-30 to 140 deg

2014



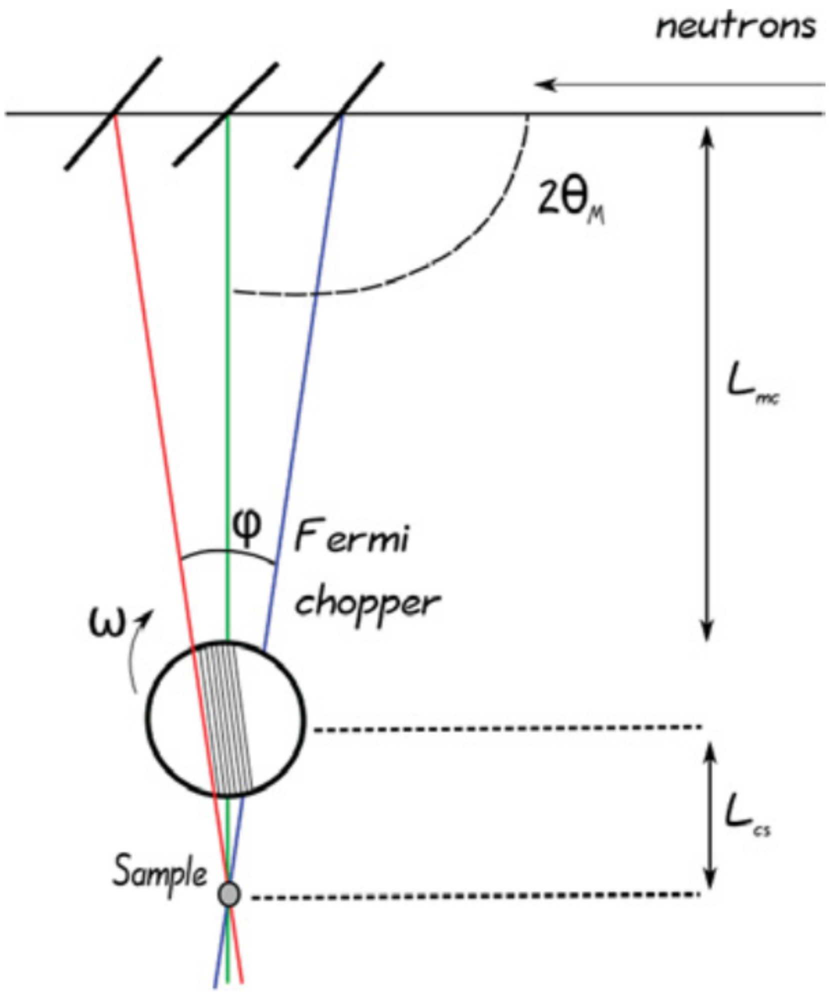
Cristal-chopper spectrometers: reactor based

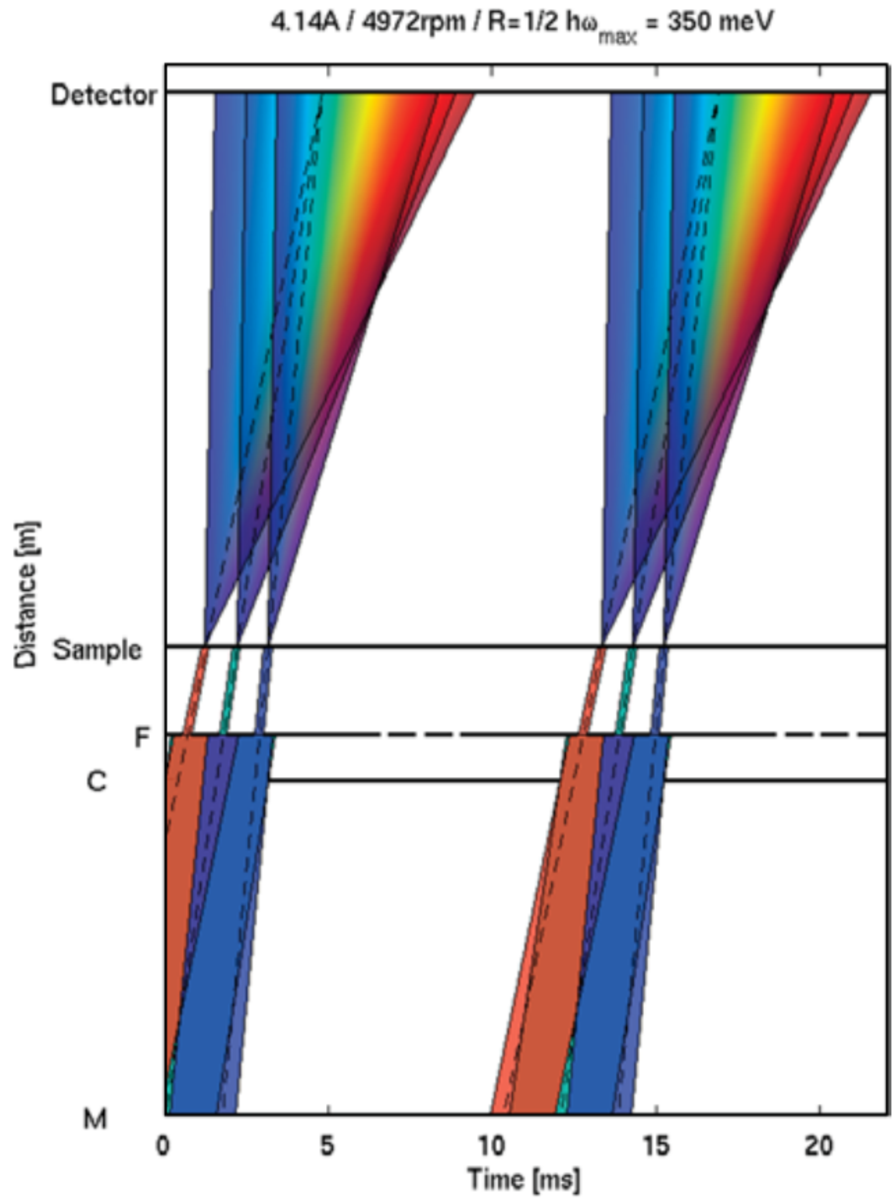




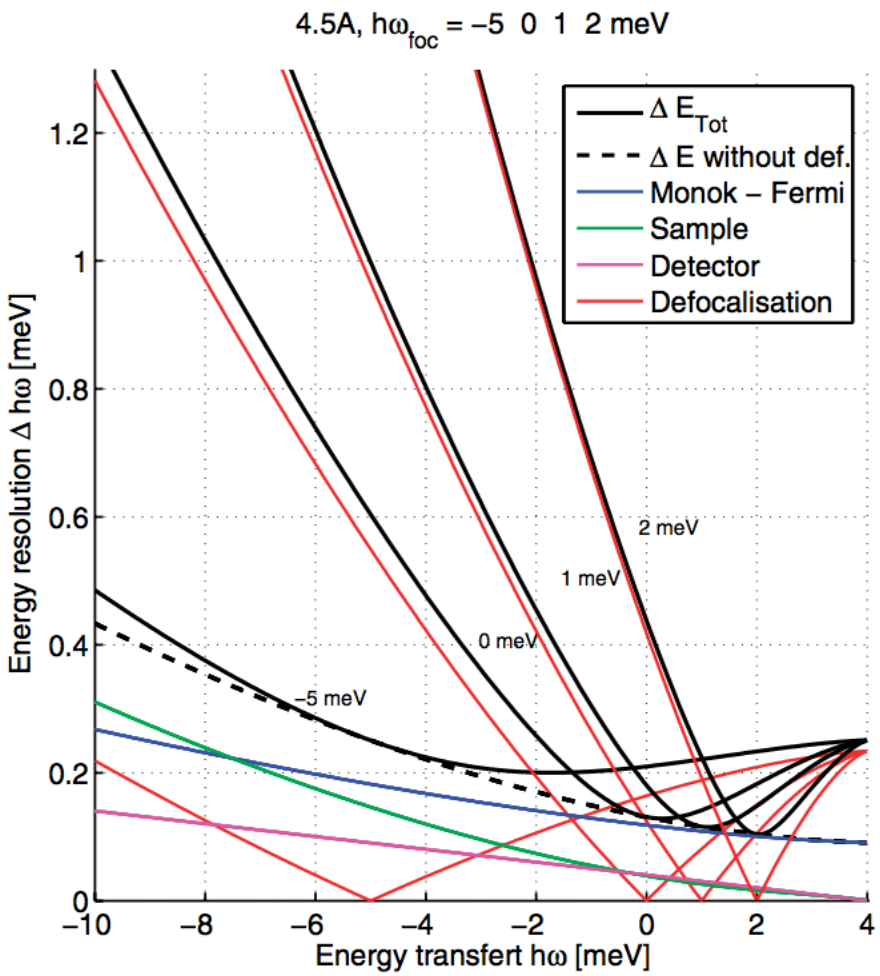
IN6 type : 3 single cristals, time focusing
(different wavelength arrive together at the detector)

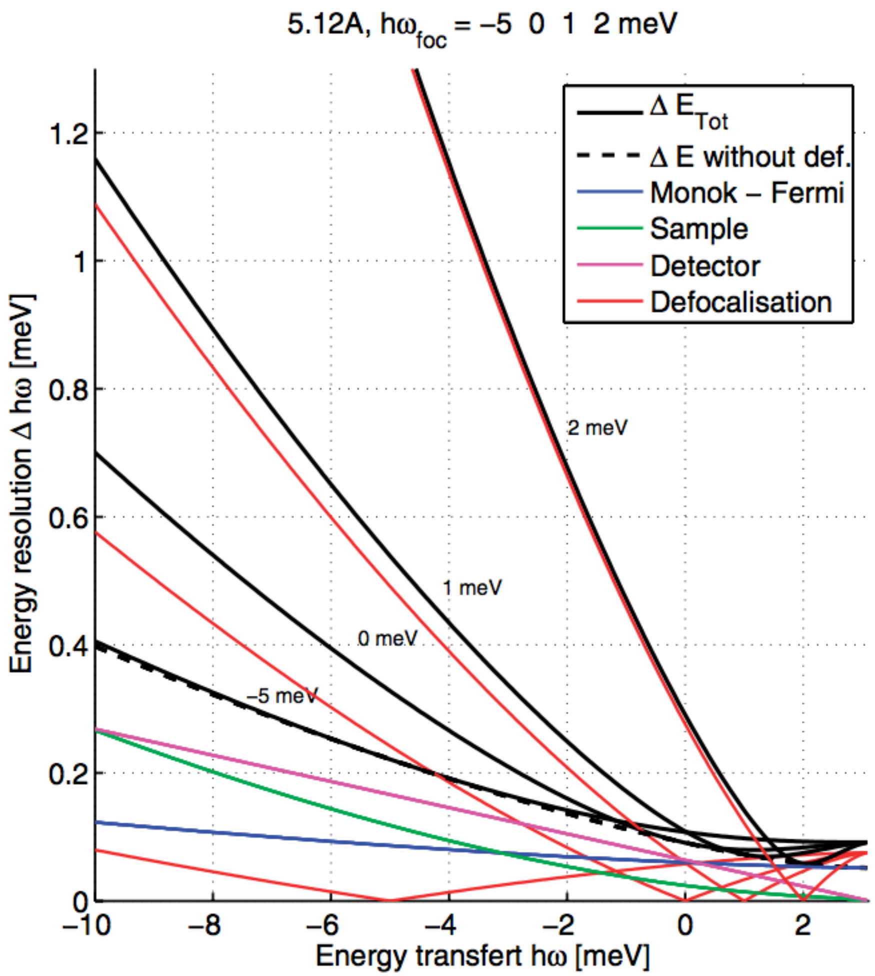
Cristal-chopper spectrometers: reactor based





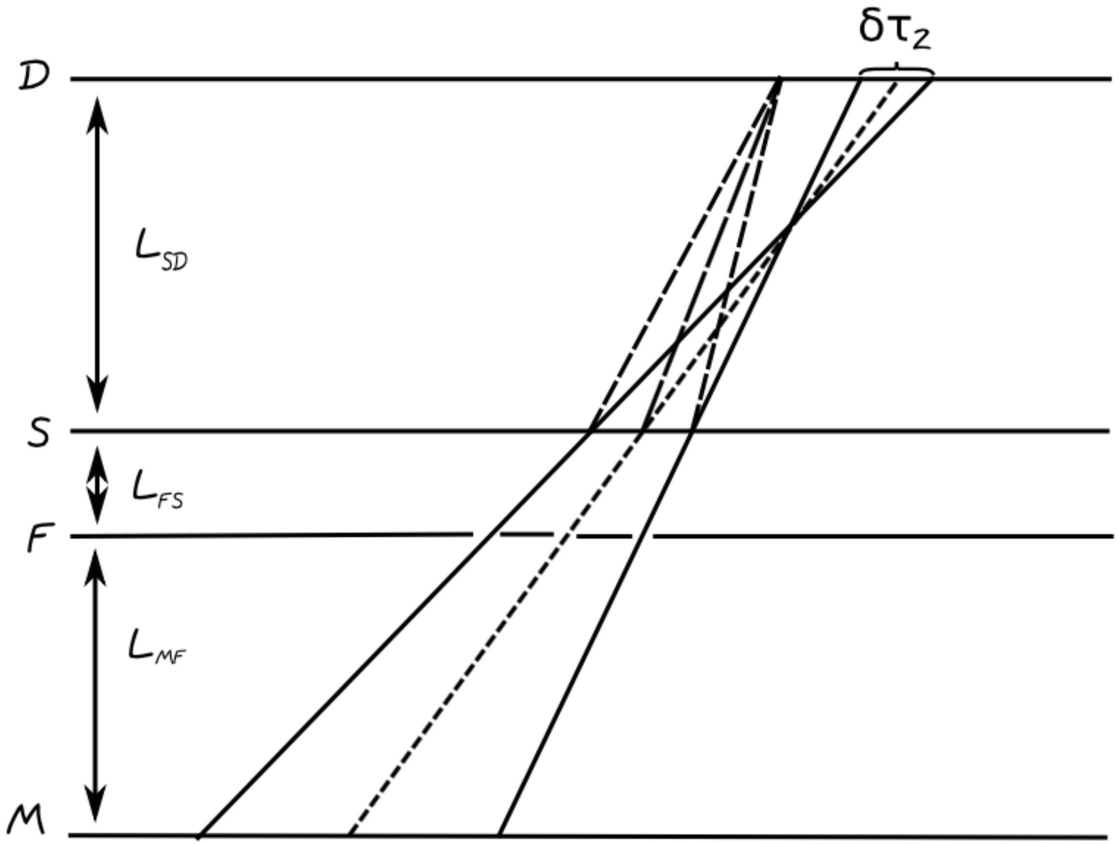
Cristal-chopper spectrometers: reactor based





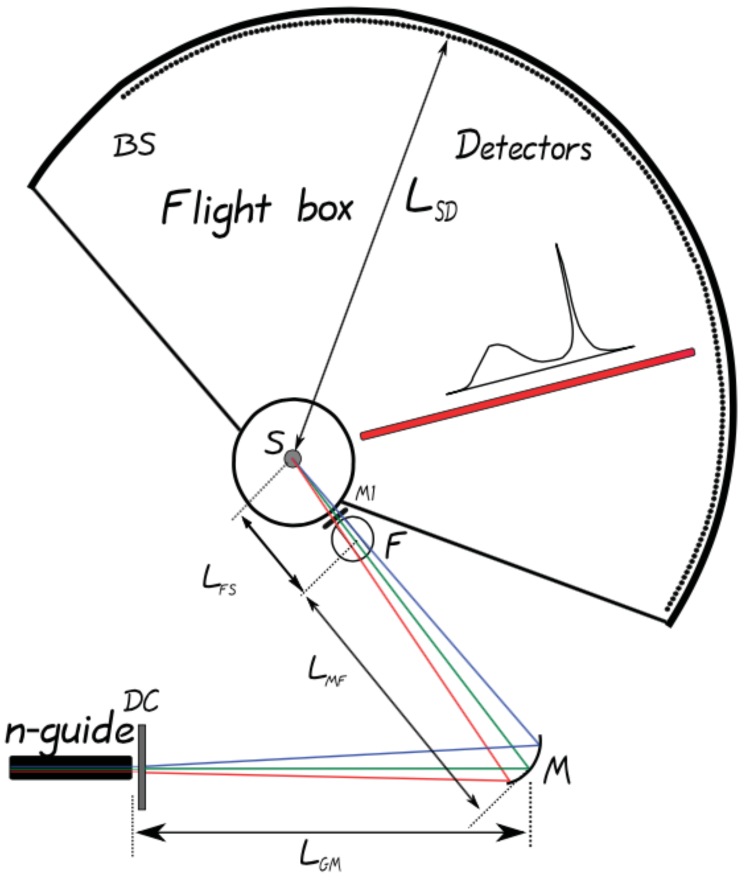
IN6 type : time focusing @ ħω≠0

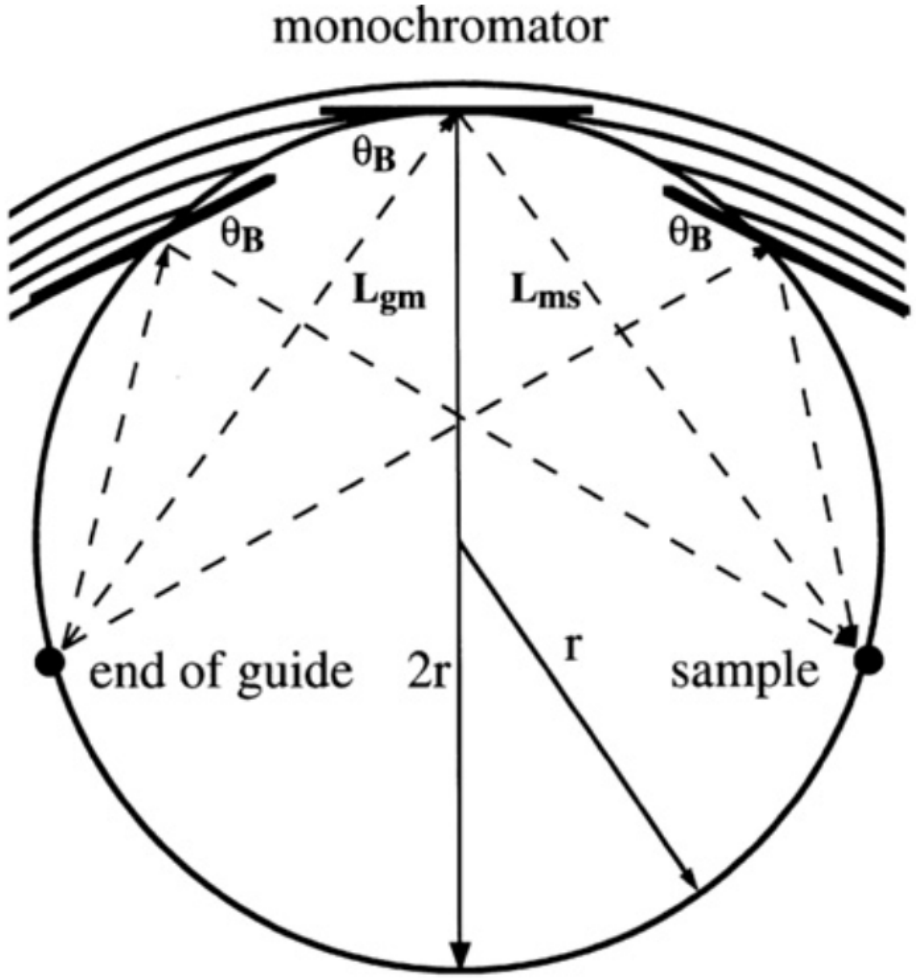
Cristal-chopper spectrometers: reactor based



IN6 type : time focusing @ ħω≠0

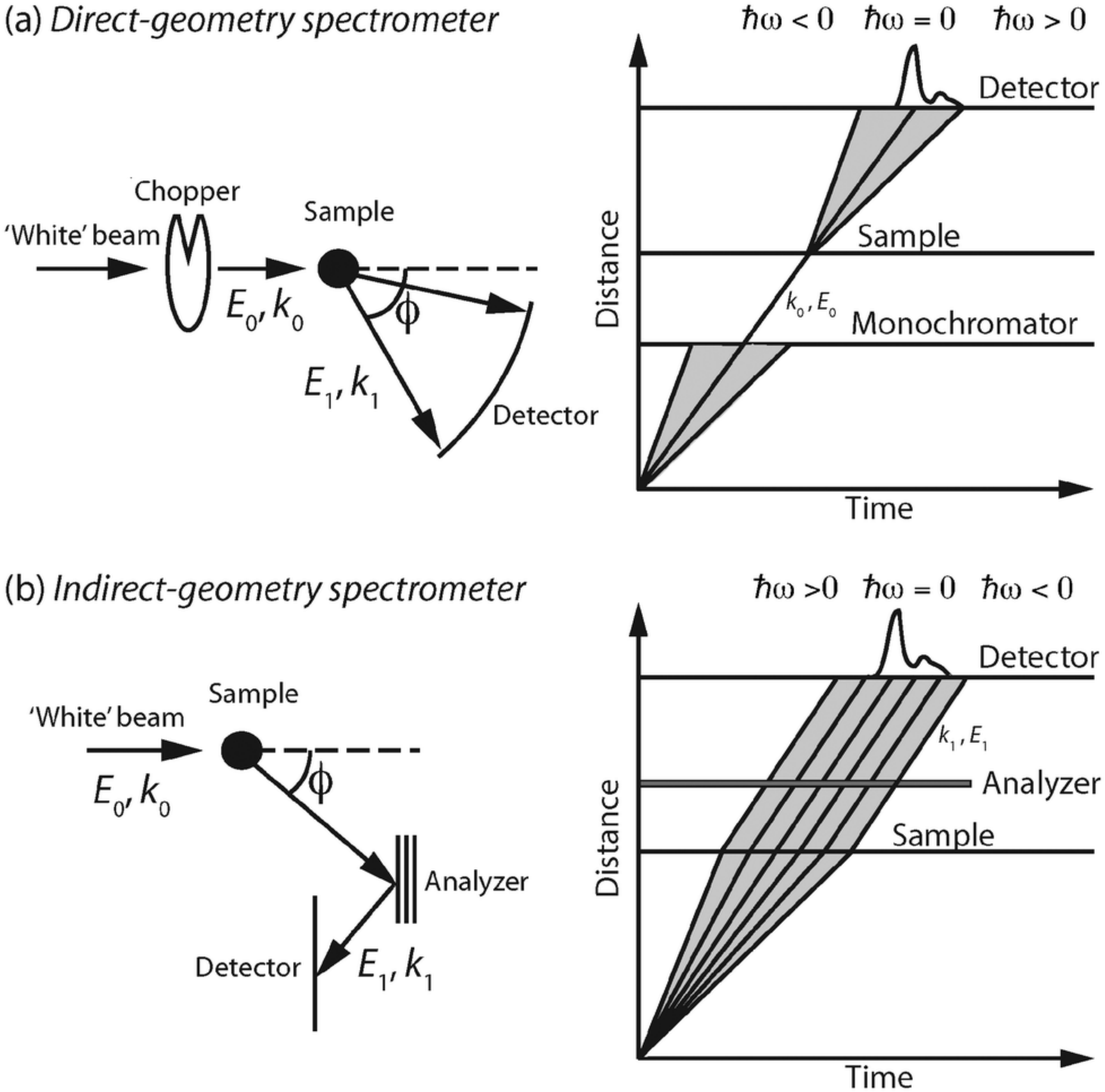
Cristal-chopper spectrometers: reactor based





Focus type (PSI-SINQ)

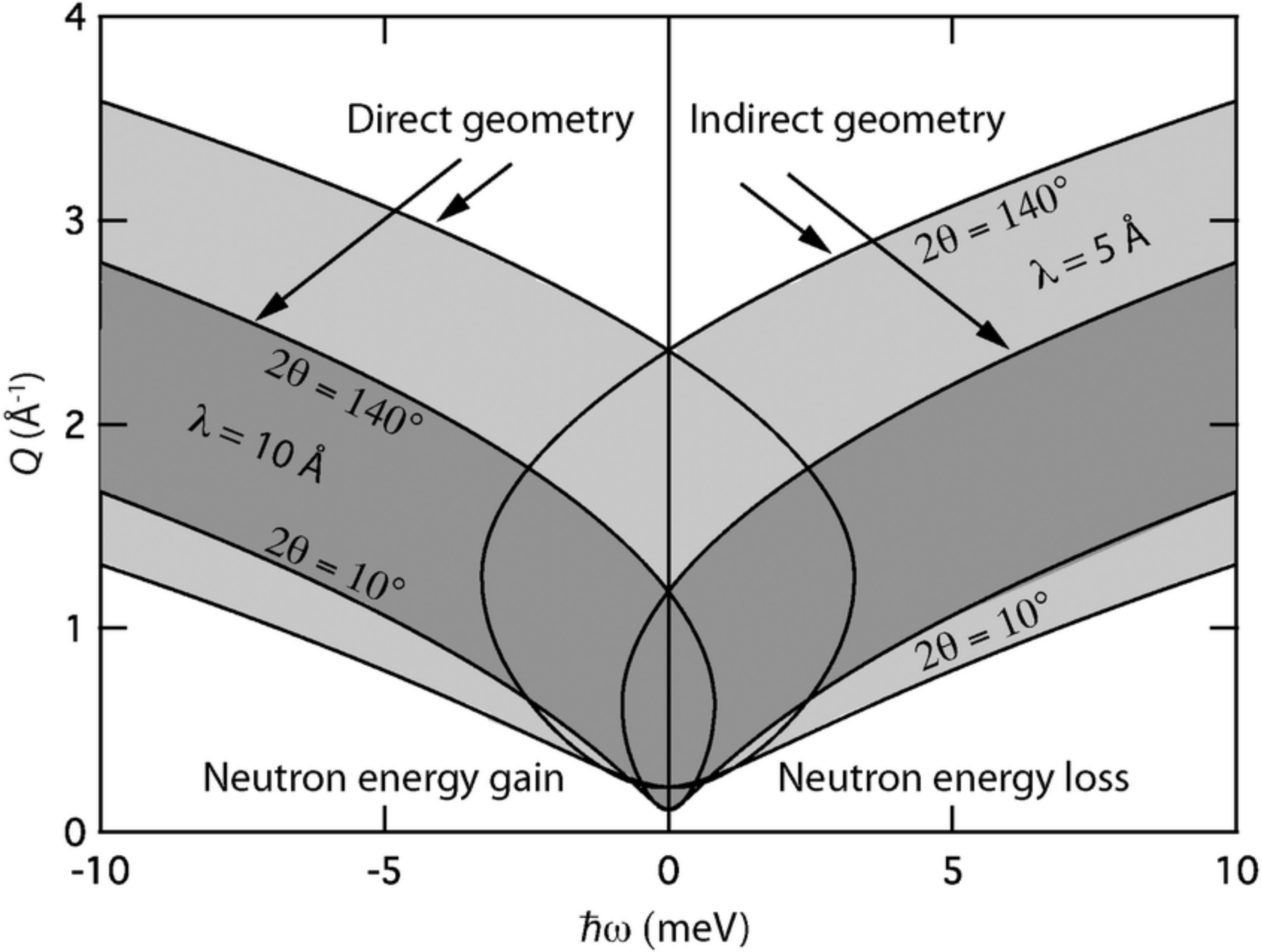
Chopper-cristal spectrometers: pulsed sources



(IRIS and Osiris @ ISIS)

M. Karlsson

Chopper-cristal spectrometers: pulsed sources



M. Karlsson

Backscattering spectrometer

(*H. Maier Leibnitz, A. Heidemman*)

$$\frac{\Delta k_{div}}{k} = \cot(\theta)\Delta\theta$$

For $\theta \to \frac{\pi}{2}$ $\quad \frac{\Delta k_{div}}{k} \approx \frac{(\Delta\theta)^2}{8}$

Backscattering spectrometer

(*H. Maier Leibnitz, A. Heidemman*)

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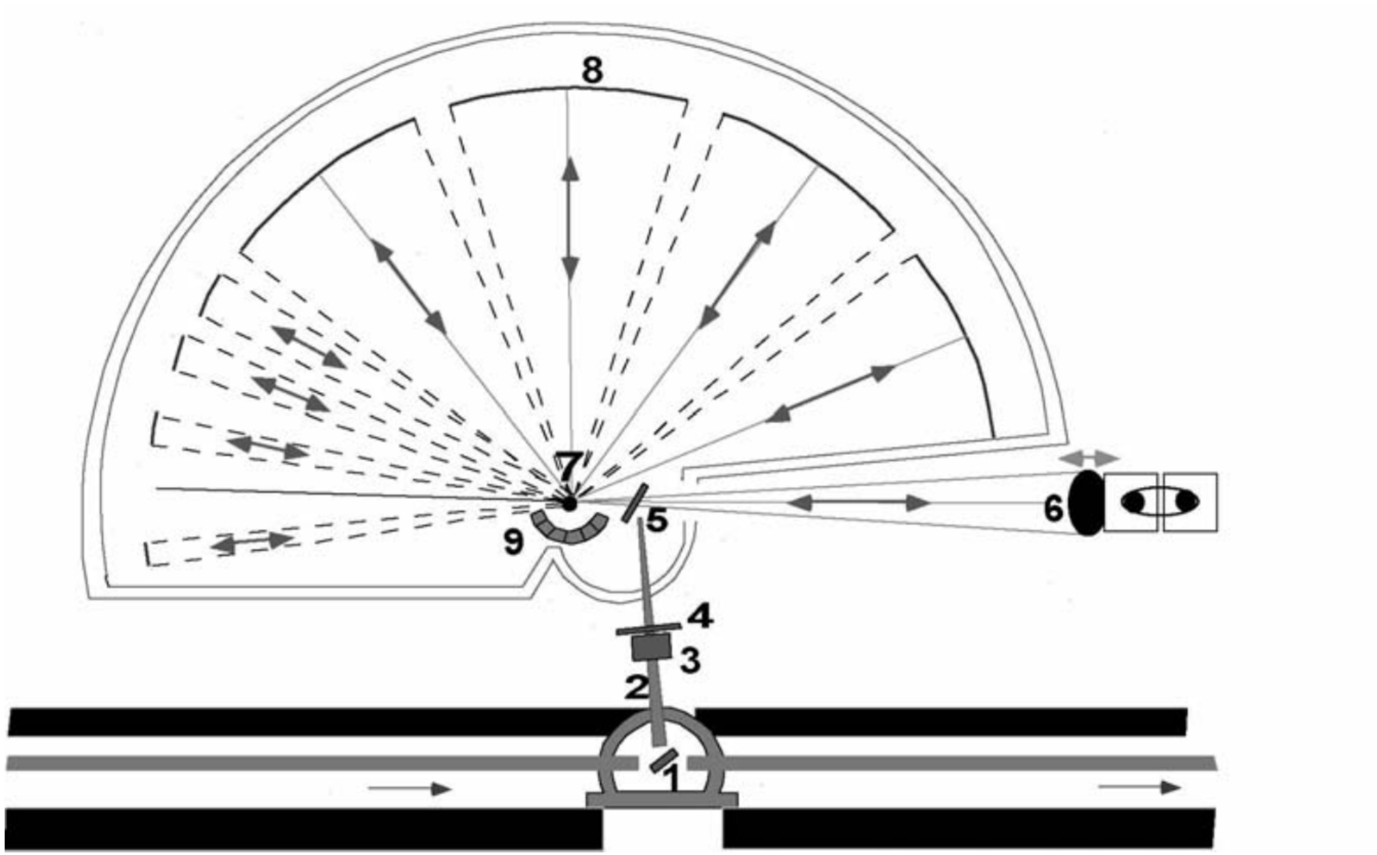
For $\theta \to \frac{\pi}{2} \quad \frac{\Delta k_{div}}{k} \approx \frac{(\Delta\theta)^2}{8}$



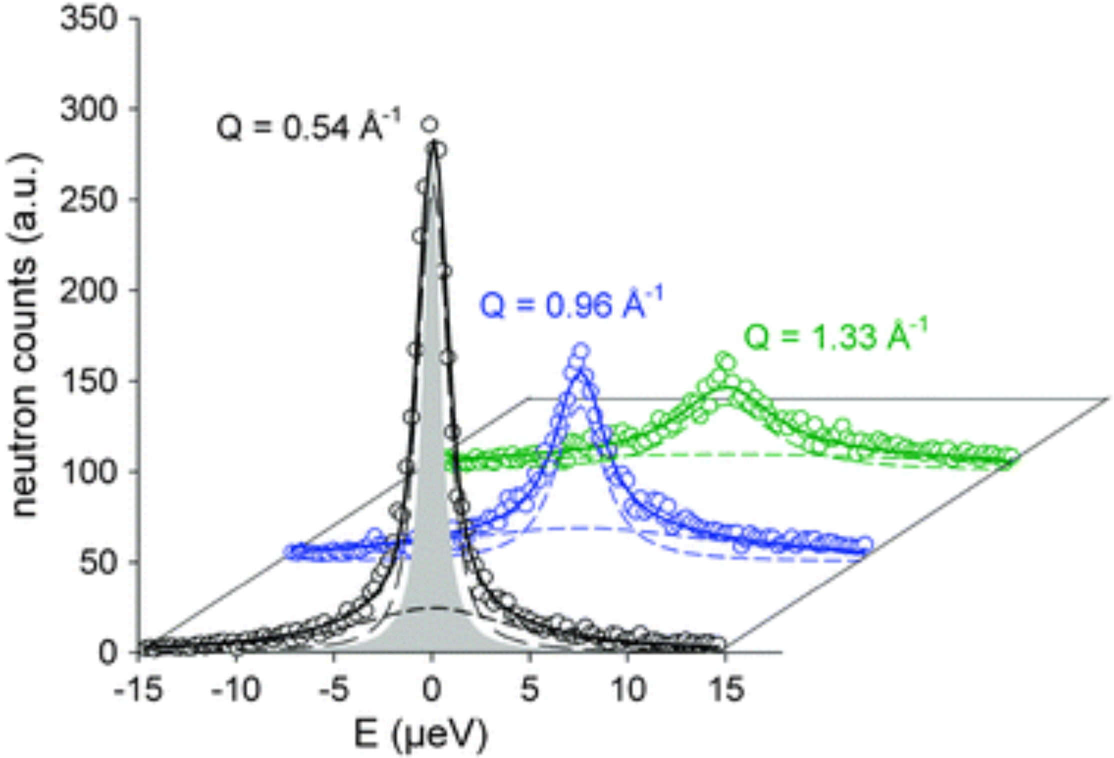
IN16 (ILL)

Backscattering spectrometer

(*H. Maier Leibnitz, A. Heidemman*)

$$\frac{\Delta k_{div}}{k} = \cot(\theta)\Delta\theta$$

For $\theta \to \frac{\pi}{2}$ $\quad \frac{\Delta k_{div}}{k} \approx \frac{(\Delta\theta)^2}{8}$



R. Lefort et al

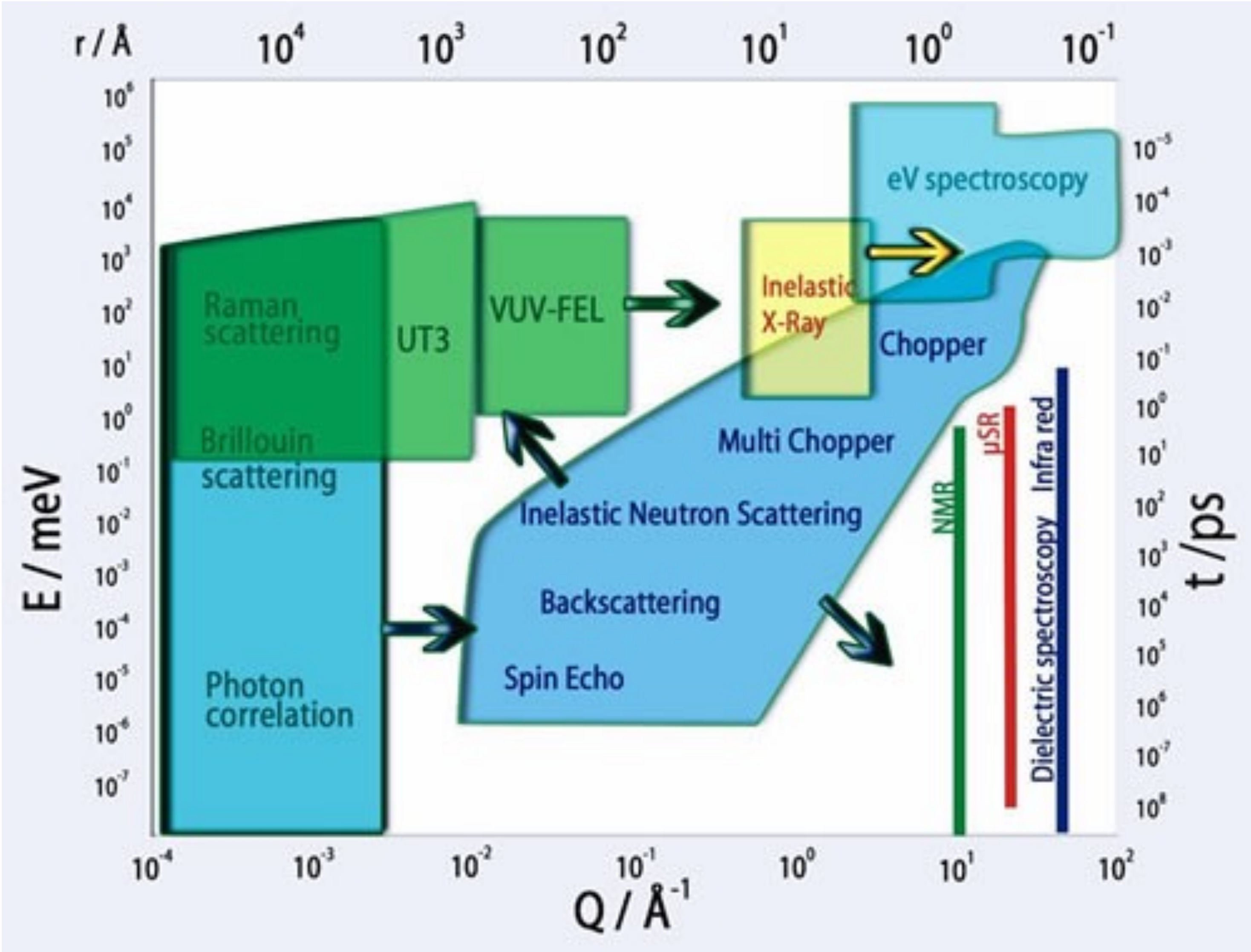
Institution	Instrument	Énergie incidente	Géométrie	Source	Gamme d'énergie	Gamme de résolution
	HET	15meV – 2000meV	Directe		$-\infty > E_f < 0.8E_i$ meV	$\Delta E/E_i = 1$-2%(4m) 2-3%(2.5m)
	MAPS	15meV - 2000meV	Directe		$-\infty < E_f < 0.8E_i$ meV	$\Delta E/E_i = 2$-5%
ISIS/RAL	MARI	10meV - 1000meV	Directe	Spallation	$-\infty < E_f < 0.8E_i$ meV	$\Delta E/E_i = 1$-2%
	PRISMA		Inverse		3 meV $< E_f <$ 20 meV	$\Delta E/E_i = 1$-2%
	MERLIN	10meV - 1000meV	Directe		$-\infty < E_f < 0.8E_i$ meV	$\Delta E/E_i = 2$-5%
	LET	1meV - 80meV	Directe		$-\infty < E_f < 0.6E_i$ meV $-\infty < E_f < 0.6E_i$ meV	5μeV at $E_i = 1$ meV 260μeV at $E_i = 20$ meV
	IRIS	0.25meV - 20meV	Inverse		$-0.8 < E_f < 2.2$ meV	1, 4.5, 11, 17.5, 54.5 μeV
	OSIRIS	0.25meV - 20meV	Inverse		$-0.5 < E_f < 0.5$ meV $-3.5 < E_f < 4.0$ meV	25 μeV 90 μeV
	ARCS	30 meV - 2000meV	Directe			$\Delta E/E_i = 2$-5%
SNS	SEQUOIA	30 meV - 2000meV	Directe	Spallation		$\Delta E/E_i = 1$-5%
	CNCS	0.8 meV - 20meV	Directe			10 - 500 μeV
	HYSPEC	5 meV - 50meV	Directe			$\Delta E/E_i = 2$-15%
PSI-SINQ	FOCUS	3meV - 30meV	Directe	Spallation continue	$-\infty < E_f < 0.6E_i$ meV	7μeV$< \Delta E <$5meV
	MARS	3meV - 30meV	Inverse			1μeV$< \Delta E <$170μeV
LLB (CEA-CNRS)	MIBEMOL	0.8meV - 20meV	Directe	Réacteur	$-\infty < E_f < 0.6E_i$ meV	$\Delta E/E_i = 1$-8%
HMI-BENSC	NEAT	0.25meV - 25meV	Directe	Réacteur	$-\infty < E_f < 0.6E_i$ meV	6μeV$< \Delta E <$5.4meV
	IN4	15meV - 80meV	Directe		$-\infty < E_f < 0.8E_i$ meV	$\Delta E/E_i = 3$-6%
ILL	IN5	0.2meV - 20meV	Directe	Réacteur	$-\infty < E_f < 0.6E_i$ meV	$\Delta E/E_i = 1$-3%
	IN6	2.35meV - 4.8meV	Directe		$-\infty < E_f < 0.6E_i$ meV	50, 80, 120, 170 μeV
FRM-II	TOFTOF	0.3meV - 20meV	Directe	Réacteur	$-\infty < E_f < 0.6E_i$ meV	$\Delta E/E_i = 1$-3%
	TOPAS	20meV -160meV	Directe	Réacteur		$\Delta E/E_i = 5$%
	HRMECS	3meV - 1000meV	Directe		0 - 800meV	$\Delta E/E_i = 2$-4%
IPNS, ANL	LRMECS	6meV - 600meV	Directe	Spallation	0 - 500meV	$\Delta E/E_i = 6$-8%
	QENS	?	Inverse		-2.5 $< E_f <$ 200 meV	90 μeV
NIST, NCNR	FCS	2.2meV - 15meV	Directe	Réacteur	$-\infty < E_f < 0.6E_i$ meV	60 to 1000 μeV
	DCS	0.4meV - 13meV	Directe		$-\infty < E_f < 0.6E_i$ meV	$\Delta E/E_i = 1$-3%
J-PARC	CNDCS	1meV - 80meV	Directe			$\Delta E/E_i \simeq 1$% ($E_i = 20$ meV)
KENS/MLF	LAM-D	1meV - 60meV	Inverse		-2$< E_f <$ 60meV	350 μeV
KEK	LAM-40	1meV - 60meV	Inverse	Spallation	-2$< E_f <$ 10meV	200 μeV
KENS	LAM-80	1meV - 60meV	Inverse		-30$< E_f <$ 30μeV	1.5 μeV
					-400$< E_f <$ 500μeV	6.5 μeV
Tsukuba					-1$< E_f <$ 1.5meV	17 μeV
	AMATERA	1meV - 80meV	Directe	Spallation		$\Delta E/E_i$ = 1-7%/ 0.3-1.5%
	4SEASONS	5meV - 300meV	Directe			$\Delta E/E_i = 6$%
	DNA	1meV - 60meV	Inverse			ΔE = 1μeV/10μeV
	HRC	1meV - 2000meV	Directe			$\Delta E/E_i = 1$%

Conclusion

Time-of-flight neutron spectrometers :

- Direct geometry
  - TOF-TOF (reactor and spallation sources, continuous and pulsed)
  - Cristal-TOF (reactor or continuous sources)
- Indirect geometry
  - TOF-Cristal (spallation or pulsed sources)
- Backscattering spectrometers (reactor and spallation)

Conclusion



r / Å
E / meV
t /ps
Q / Å⁻¹
eV spectroscopy
Raman scattering
UT3
VUV-FEL
Inelastic X-Ray
Chopper
Brillouin scattering
Multi Chopper
Inelastic Neutron Scattering
Backscattering
Spin Echo
Photon correlation
NMR
µSR
Infra red
Dielectric spectroscopy

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J.Ollivier and J.-M. Zanotti, *Collection SFN* **10** (2010) 379-423