Robustness of TOF-MIEZE

(+ Present status of VIN ROSE @ J-PARC)

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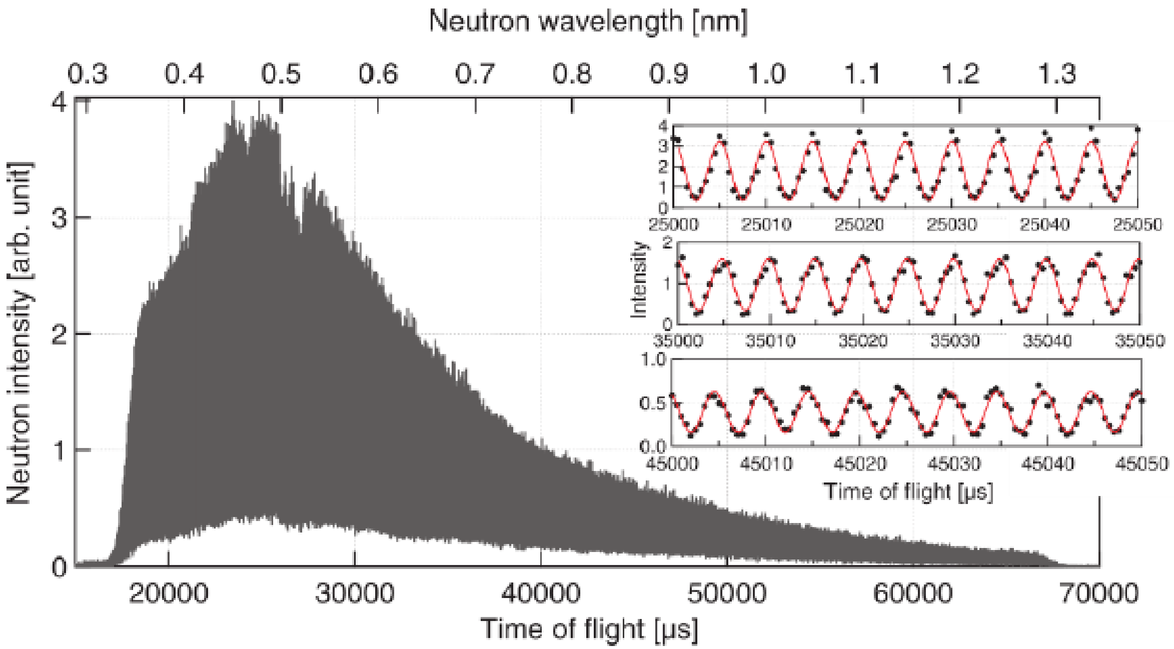
TOF-MIEZE

The echo signals are plotted as a function of <u>time (TOF)</u>



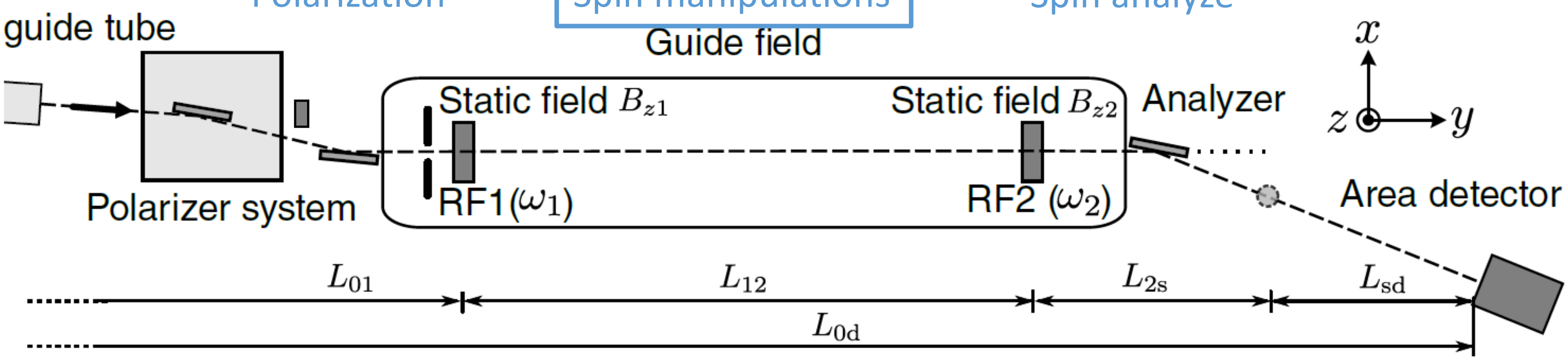
In TOF-MIEZE, the hypersensitivity of MIEZE signals is significantly alleviated with a short pulsed beam. This robustness is very useful to optimize experimental alignments and enables accurate measurements of QENS.

T. Oda, M. Hino, M. Kitaguchi, P. Geltenbort, and Y. Kawabata, Rev. Sci. Instr., **87** (2016), 105124.

TOF-MIEZE instrument

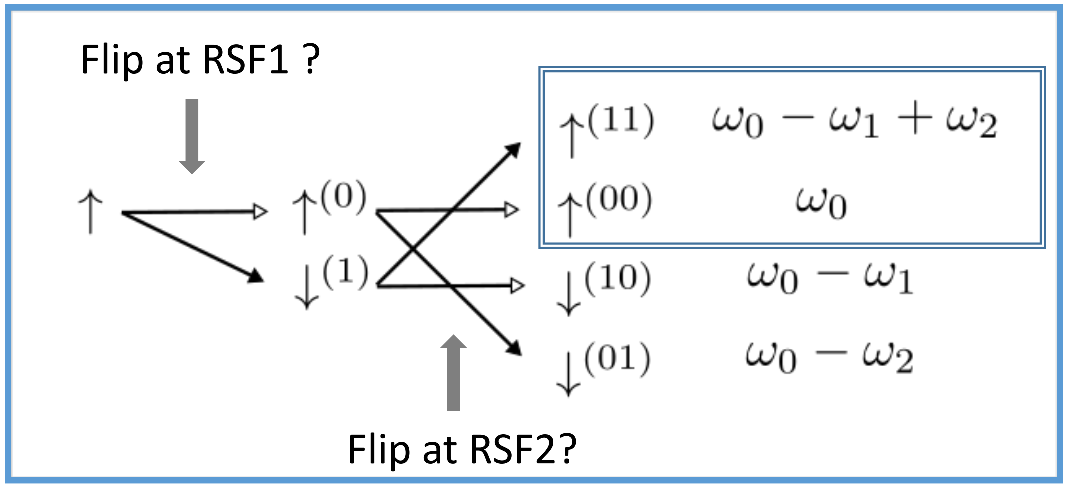
Two RSFs (π/2 – π/2)

Polarization → Spin manipulations → Spin analyze



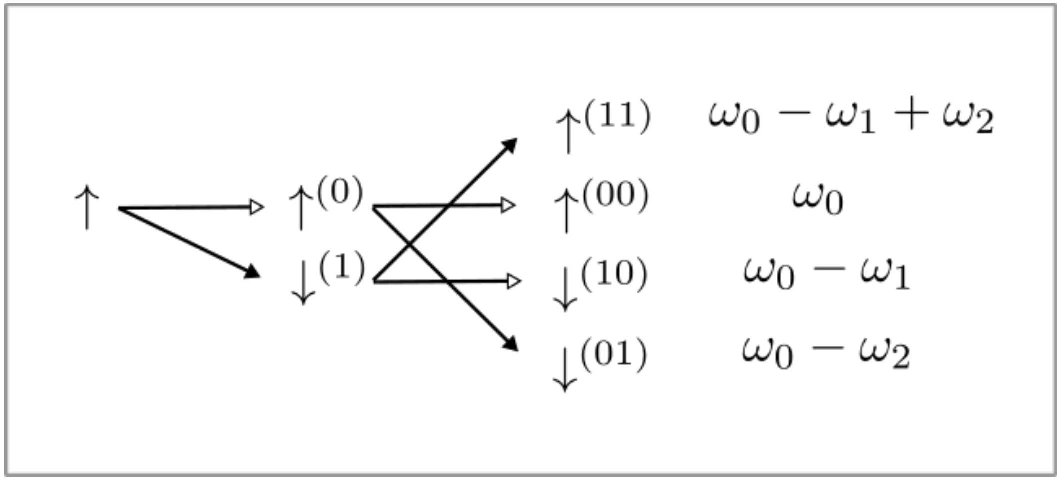
RSF1 and RSF2 were set as π/2 condition i.e. Flipping probabilities were 0.5

Possible states of neutron



Coherent state with different energy in the up spin eigen state

Wave function of MIEZE



After RSF1

$$\psi^{(0)} = \frac{1}{\sqrt{2}} \exp\left[\mathrm{i}(k_0 y - \omega_0 t)\right]$$

$$\psi^{(1)} = \frac{1}{\sqrt{2}} \exp\left[\mathrm{i}\left[\left(k_0 - \frac{\omega_1}{v}\right) y - (\omega_0 - \omega)t + \chi_1\right]\right]$$

After RSF2

$$\psi^{(00)} = \frac{1}{2} \exp\left[\mathrm{i}(k_0 y - \omega_0 t)\right]$$

$$\psi^{(11)} = \frac{1}{2} \exp\left[\mathrm{i}\left[\left(k_0 - \frac{\omega_1 - \omega_2}{v}\right) y - (\omega_0 - \omega_1 + \omega_2)t + \chi_1 - \chi_2\right]\right]$$

$$\psi^{(10)} = \frac{1}{2} \exp\left[\mathrm{i}\left[\left(k_0 - \frac{\omega_1}{v}\right) y - (\omega_0 - \omega_1)t + \chi_1\right]\right]$$

$$\psi^{(01)} = \frac{1}{2} \exp\left[\mathrm{i}\left[\left(k_0 - \frac{\omega_2}{v}\right) y - (\omega_0 - \omega_2)t + \chi_2\right]\right]$$

Formalism of the TOF-MIEZE

Neutron intensity is calculated to be a function of phase difference:

$$I \propto \left| \frac{1}{\sqrt{2}} \left(|\uparrow^{(00)}\rangle + |\uparrow^{(11)}\rangle \right) \right|^2 = \left| \frac{1}{\sqrt{2}} (1 + \mathrm{e}^{\mathrm{i}\phi}) \, |\uparrow\rangle \right|^2 = \frac{1 + \cos\phi}{2}$$

The Elastic case: The phase difference at time point t_d is given by

RSF1 —RSF2 RSF2 — Detector

$$\phi_{\mathrm{el}}(t_{\mathrm{d}}) = -(\omega_2 - \omega_1) t_{\mathrm{d}} - \frac{\omega_1}{v} L_{12} + \frac{(\omega_2 - \omega_1)}{v} L_{2\mathrm{d}}$$

Phase difference by total energy difference (depends on time)

Phase difference by kinetic energy difference ΔkL

To see a MIEZE oscillation, the term depending velocity should be canceled.

=> echo condition for MIEZE (MIEZE condition):

$$\omega_1 L_{12} = (\omega_2 - \omega_1) L_{2\mathrm{d}}$$

Formalism of the TOF-MIEZE

Definitions

MIEZE frequency:

$$\omega_{\mathrm{M}} = \omega_2 - \omega_1$$

Detuning frequency:

$$\Delta\omega = \frac{-\omega_1 L_{12} + (\omega_2 - \omega_1) L_{2\mathrm{d}}}{L_{0\mathrm{d}}}$$

Rewriting the phase difference φ with these parameters

$$\phi_{\mathrm{el}}(t_{\mathrm{d}}) = -(\omega_2 - \omega_1) t_{\mathrm{d}} - \frac{\omega_1}{v} L_{12} + \frac{(\omega_2 - \omega_1)}{v} L_{2\mathrm{d}} = -\omega_{\mathrm{M}} t + \Delta\omega \frac{L_{0\mathrm{d}}}{v}$$

The echo（MIEZE）condition: $\Delta\omega = 0 \iff \omega_1 L_{12} = (\omega_2 - \omega_1) L_{2\mathrm{d}}$

Using pulsed beam, we can obtain neutron velocity *v* by Time-of-flight, t_{0d}

$$v = \frac{y_{\mathrm{d}} - y_0}{t_{\mathrm{d}} - t_0} = \frac{L_{0\mathrm{d}}}{t_{0\mathrm{d}}}$$

⟶

$$\phi_{\mathrm{el}}(t_{\mathrm{d}}) = -(\omega_{\mathrm{M}} - \Delta\omega) t_{\mathrm{d}} - \Delta\omega t_0$$

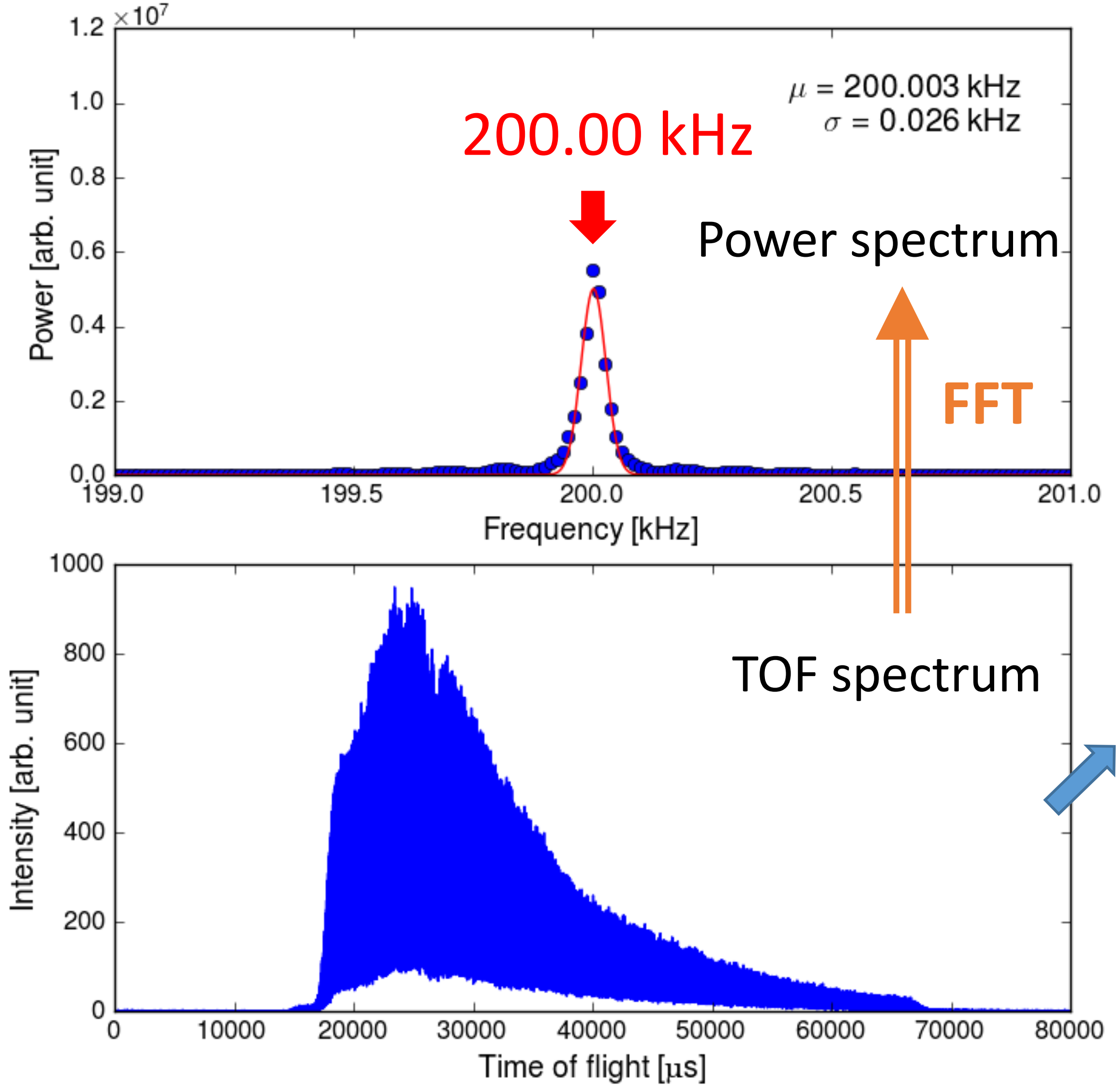
be constant for a precise pulse timing t_0

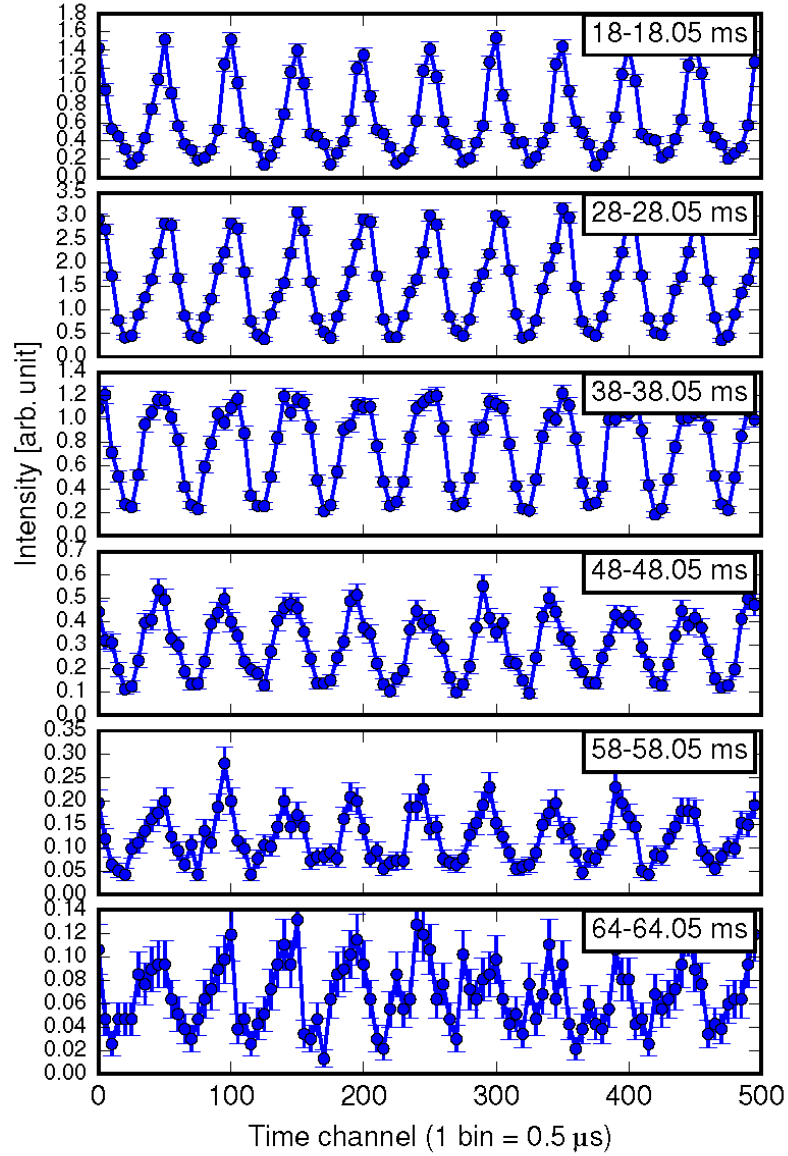
With sufficiently fixed pulse timing t_0, one obtains perfect sinusoidal oscillation even in an off-MIEZE condition ($\Delta\omega \neq 0$)
（but the effective frequency shifts by $\Delta\omega$）

$$I(t_{\mathrm{d}}) = \int \mathrm{d}v\, I_0(v) \frac{1 + \cos\left[(\omega_{\mathrm{M}} - \Delta\omega) t_{\mathrm{d}}\right]}{2}$$

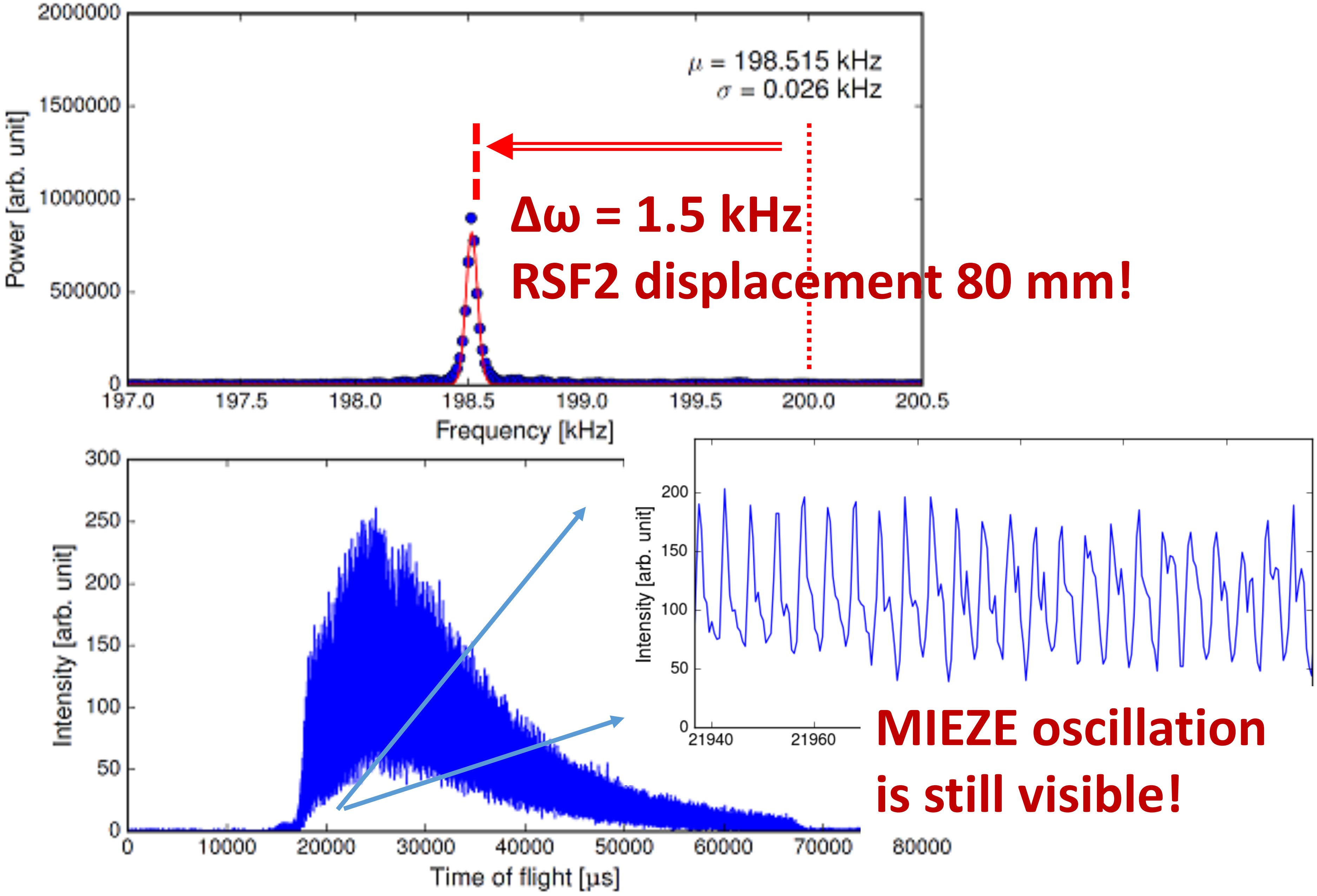
Observed TOF-MIEZE signal (200kHz)

Settings: $\omega_1/2\pi$ = 200 kHz, $\omega_2/2\pi$ = 400 kHz, MIEZE frequency $\omega_M/2\pi$ = 200 kHz



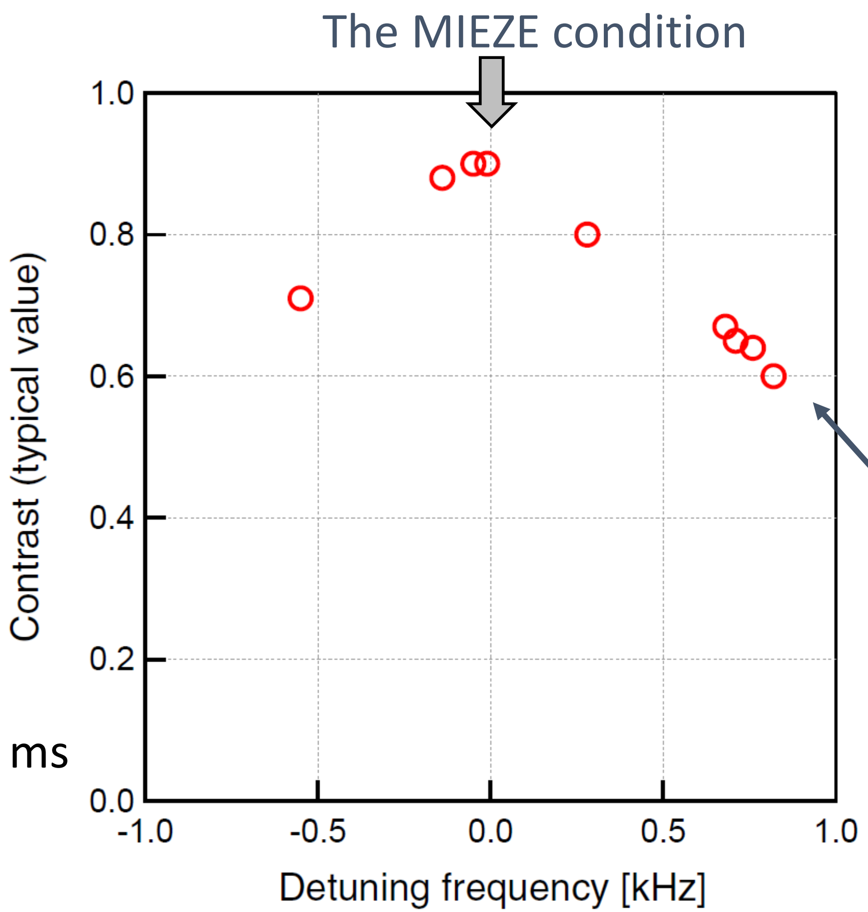


Example of "detuned" TOF-MIEZE signal



Signal contrast vs. "detuning freq."

Typical contrast values at off-MIEZE conditions (the case of $\omega_M/2\pi$ = 20 kHz)



@
TOF: 30 ms
(λ = 6Å)

$$\phi_{\rm el}(t_{\rm d}) = -\left(\omega_{\rm M} - \Delta\omega\right) t_{\rm d} - \Delta\omega t_0$$

Requirement to maintain the contrast:

$$\Delta\omega\Delta t_0 \ll 2\pi \iff \Delta t_0 \ll \frac{2\pi}{\Delta\omega}$$

The RSF2 displacement of this point was 300 mm!

It is a catastrophic misalignment in a MIEZE with continuous beam (Δλ/λ = 10 %)

The spatial period of MIEZE is calculated to be 35 mm for λ = 6 Å.

TOF-MIEZE signal is still visible with a misalignment 8.5 times larger than one spatial period of the MIEZE frequency.

The effect of a misalignment

Points to be tested:

1. **TOF-MIEZE signal can be visible even at an off-MIEZE condition with short pulsed beam.**
2. **Frequency shift of TOF-MIEZE signal at a off-MIEZE condition, and the shift amount varies in accordance with our formalization.**

$$\Delta\omega = 0 \iff \omega_1 L_{12} = (\omega_2 - \omega_1) L_{2\mathrm{d}}$$

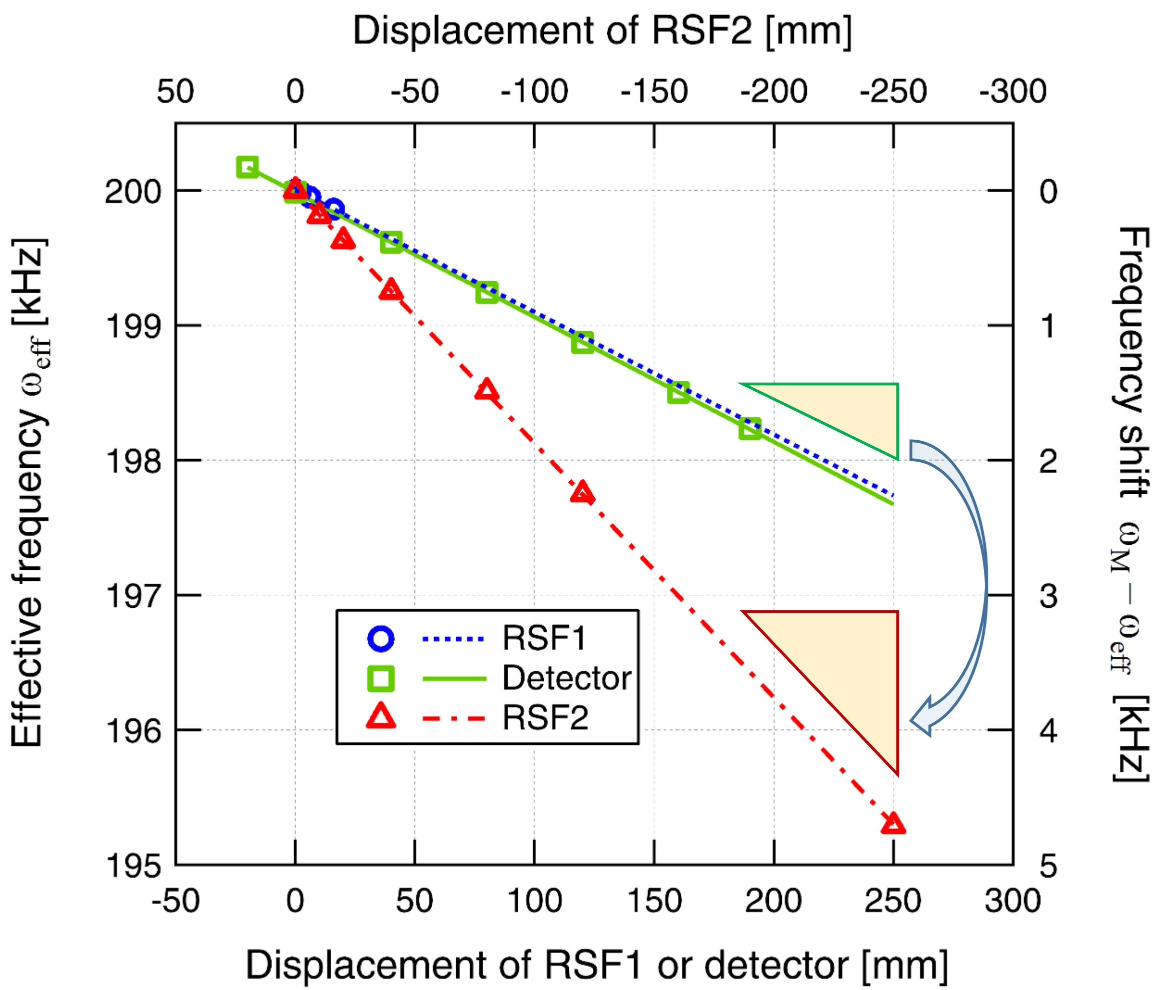
For example, the detuning frequency parameter changes with displacement of RSF2 Δy_2 as follows:

$$\begin{aligned}
\Delta\omega' &= \frac{-(\omega_1 - \tilde{\omega})(L_{12} + \Delta y_2) + (\omega_2 - \omega_1)(L_{2\mathrm{d}} - \Delta y_2)}{L_{0\mathrm{d}}} \\
&= \frac{-(\omega_1 - \tilde{\omega})L_{12} - \omega_1 \Delta y_2 + \tilde{\omega}\Delta y_2 + (\omega_2 - \omega_1)L_{2\mathrm{d}} - \omega_2 \Delta y_2 + \omega_1 \Delta y_2}{L_{0\mathrm{d}}} \\
&= \frac{-(\omega_1 - \tilde{\omega})L_{12} + (\omega_2 - \omega_1)L_{2\mathrm{d}} + \tilde{\omega}\Delta y_2 - \omega_2 \Delta y_2}{L_{0\mathrm{d}}} \\
&= \Delta\omega - (\omega_2 - \tilde{\omega})\frac{\Delta y_2}{L_{0\mathrm{d}}}
\end{aligned}$$

Note: $\tilde{\omega} \ll \omega_2$ is an angular frequency corresponding to magnitude of the field in RSF1- RSF2.

The effective frequency shift

Variations of $\Delta\omega$ vs. displacements of RSF1, RSF2 and the detector Δy_i



Current setup: $\omega_1/2\pi = 200$ kHz
$\omega_2/2\pi = 400$ kHz
$\omega_M/2\pi = 200$ kHz

- RSF1: $$\frac{\Delta\omega}{\Delta y_1} = \frac{(\omega_1 - \tilde{\omega})}{L_{0\rm d}}$$

  Fit result 9.01(20) Hz/mm

- Detector: $$\frac{\Delta\omega}{\Delta y_{\rm d}} = \frac{\omega_{\rm M}}{L_{0\rm d}}$$

  Fit result 9.26(2) kHz/mm

- displacement of RSF2 $$\frac{\Delta\omega}{\Delta y_2} = -\frac{(\omega_2 - \tilde{\omega})}{L_{0\rm d}}$$

  Fit result -18.84(4) kHz/mm

By the formula, the ratio of variations $\Delta\omega/\Delta y_i$ is expected to be ω_2/ω_M = **2**.
The experimental result, 18.84/9.26 = **2.03** shows good agreement with the calculation.

Characteristic features of TOF-MIEZE

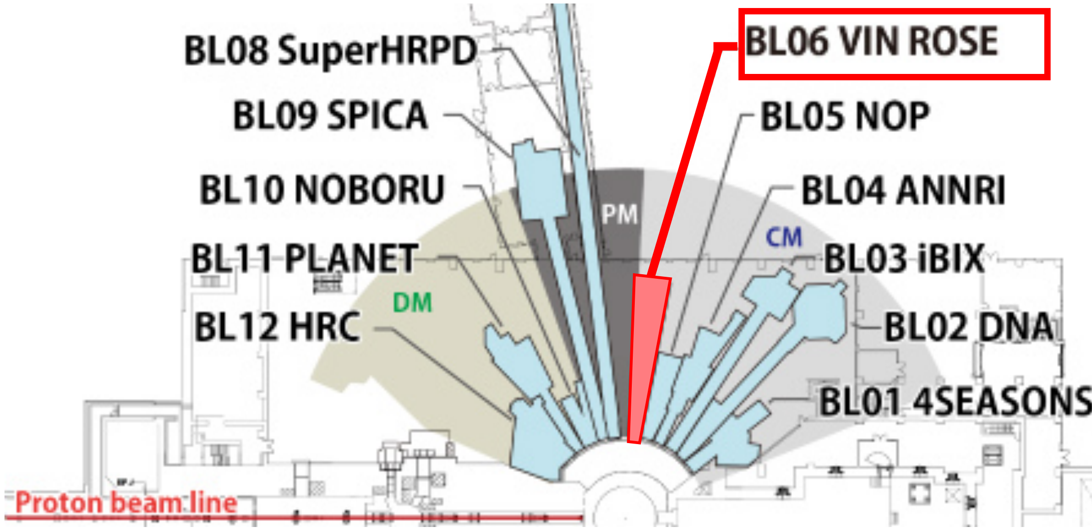
1. TOF-MIEZE signals are "robust" against misalignments of the setup (against detuning of MIEZE condition)

With $\Delta\omega << 2\pi/\Delta t_0$, a contrast decrease caused by a misalignment is very small : the short pulse beam of MLF can offer a robust TOF-MIEZE signal.
→ Overcoming disturbance environments, especially in long measurements?

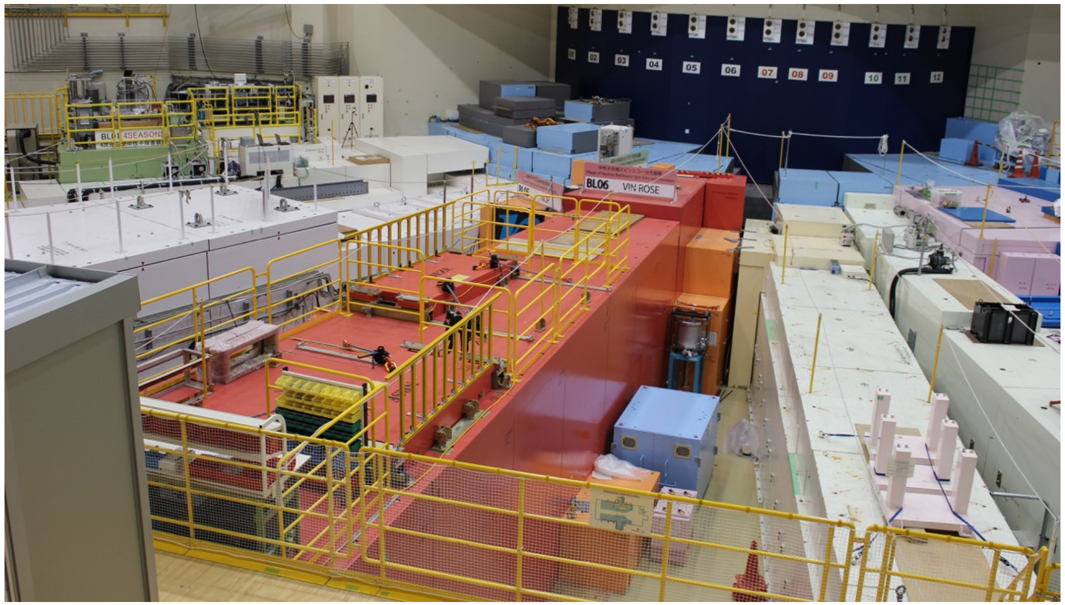
2. Shift amount in the effective frequency corresponds to "How far" the setup is from the MIEZE condition.

Frequency shift is equal to the detune parameter $\Delta\omega = (-\omega_1 L_{12} + \omega_M L_{2d})/L_{0d}$
→ Detuning of MIEZE condition is quantitatively detectable. The optimized position can be calculated from one trial measurement. This is quite useful in the alignment of experimental setup.

VIN ROSE



http://j-parc.jp/researcher/MatLife/ja/instrumentation/ns.html



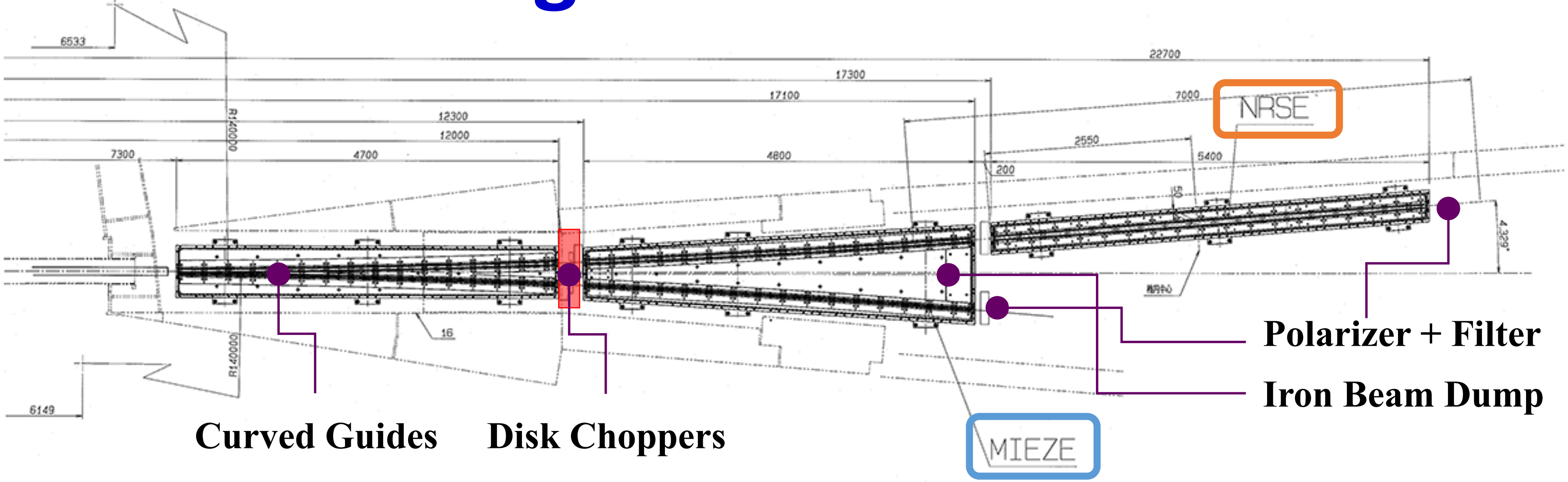
Village of neutron resonance spin echo spectrometers

VIN ROSE stays at a special position

	Continuous source	Pulsed source
Conventional NSE	IN11 (ILL) IN15 (ILL) J-NSE (FRM II, JCNS) NGA-NSE (NCNR, NIST) iNSE (JRR-3, JAEA)	SNS-NSE (SNS, ORNL)
Resonance-type NSE	RESEDA (FRM II, TUM) MIRA (FRM II, TUM)	VIN ROSE (J-PARC MLF)

BL06 a J-PARC MLF is the first beam line dedicated for the NRSE spectrometers at a pulsed source.

Beamline design



Incident … elength

neutron…

	Wavelength	Q range	Fourier time
MIEZE	3 - 13 Å	0.2 - 3.5 $Å^{-1}$	1 ps - 2 ns
NRSE	5 - 20 Å	0.02 - 0.65 $Å^{-1}$	0.1 ns - 0.1 μs

NiC/Ti S… E & 5.2 Å

for NRSE…

Beam focusing guide for NRSE

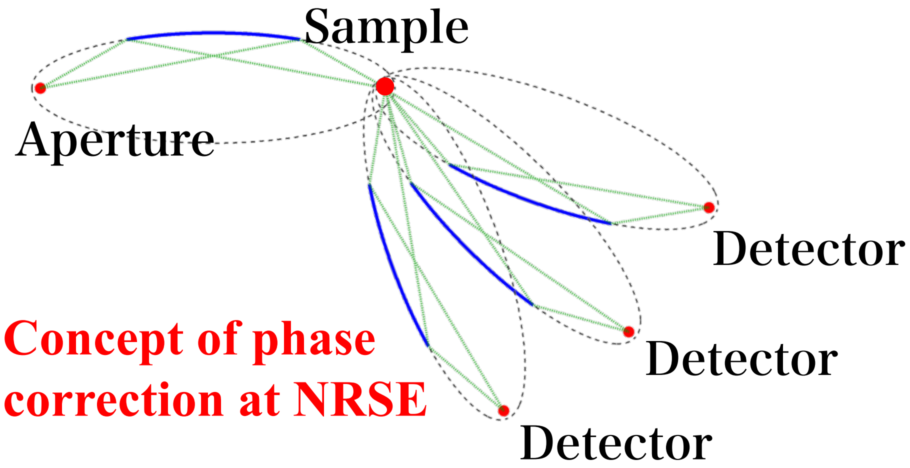
Cross section at the guide ends: 30(w) × 50(h) mm for NRSE, 14(w) × 50(h) mm for MIEZE

Neutron Intensity: ~2×10^8n/cm^2/s/Å @guide-end for characteristic wavelength with 1MW operation

One disk chopper for each (for first– third flame)

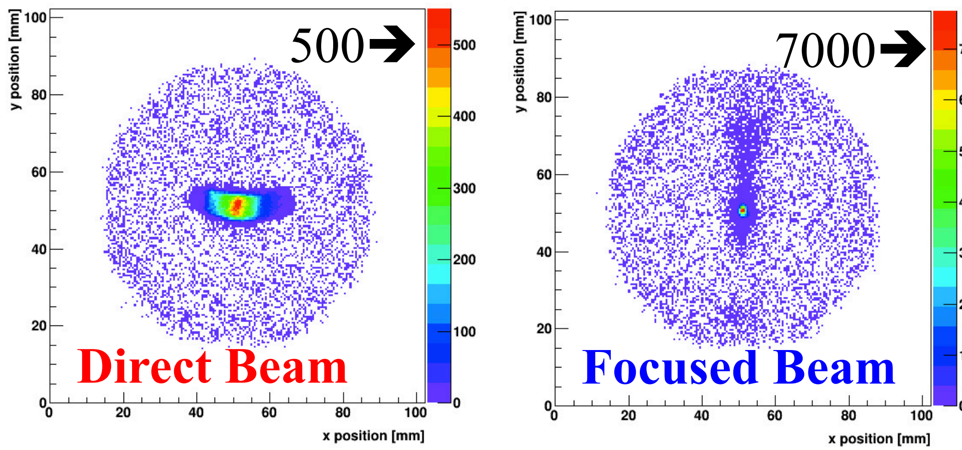
2D elliptical super mirrors

2-D elliptical super mirrors for phase (optical path) correction are key devices for NRSE spectrometers with high energy resolution.

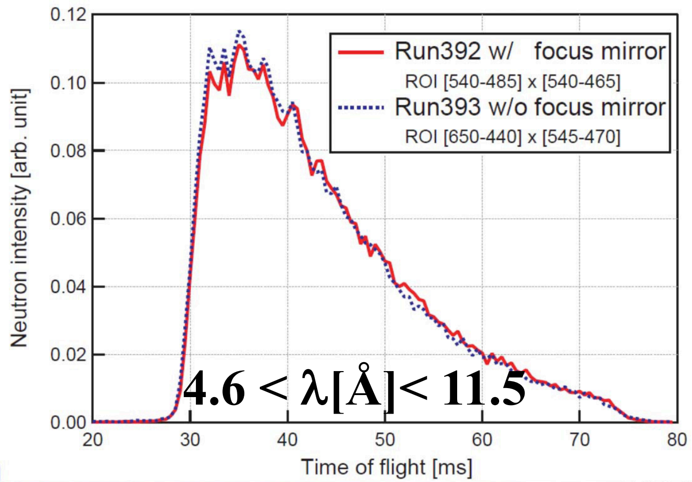


Concept of phase correction at NRSE

2D Beam Profiles



Developed a 2-D elliptical super mirror (**3*Q*$_m$**) with **300mm** length (a = 1250mm, b = c = 20mm).



TOF beam profiles for direct beam (blue) and mirror-focused beam (red)

Present Status

- The commissioning has been done from the acceptance of the first beam on April 22, 2014. The MIEZE instrument is almost ready for user program, and the call for proposals is started from 2017B (Nov. 2017-).

- The commissioning of NRSE, especially the development of elliptical mirrors is underway. We expect to start the user program from 2018B (Nov. 2018-).

Summary

- VIN ROSE in J-PARC dedicated for NRSE spectrometers is almost ready for users (in part).
- TOF-MIEZE signals with practical frequencies (e.g. 200 kHz) were obtained with a good contrast.
- Methodological test measurements were done and the properties of TOF-MIEZE signal were quantitatively examined.
- The “detuning parameter” clearly explains the relation between the signal contrast and misalignments for a pulsed beam.