The Neutron Intensity Modulated Spectrometer (NIMS)

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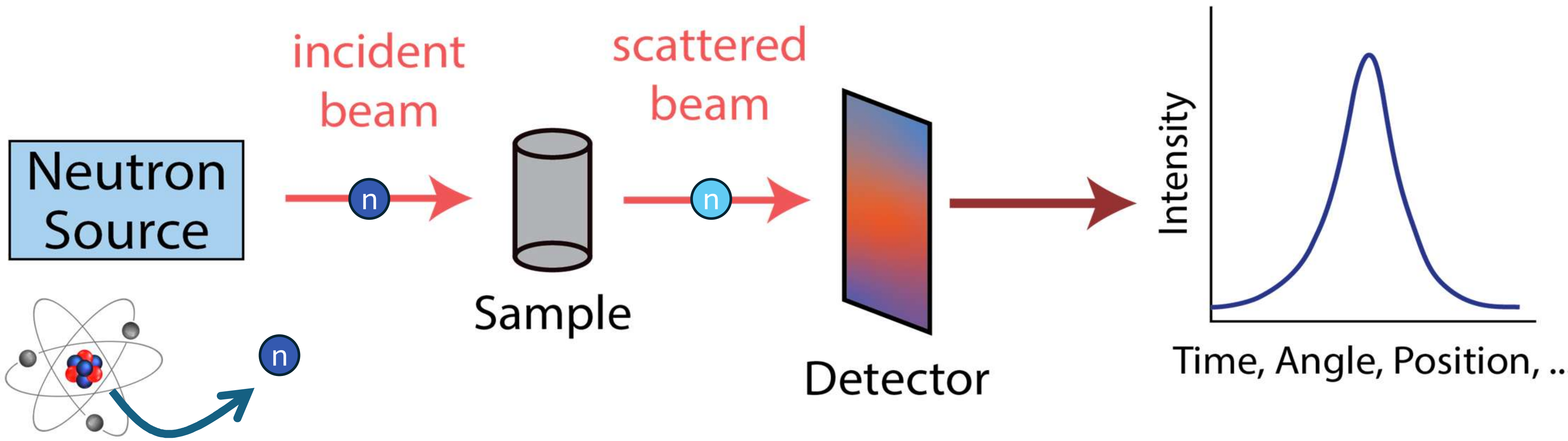
NIST CENTER FOR NEUTRON RESEARCH

NSF CHRNS CENTER FOR HIGH RESOLUTION NEUTRON SCATTERING NIST

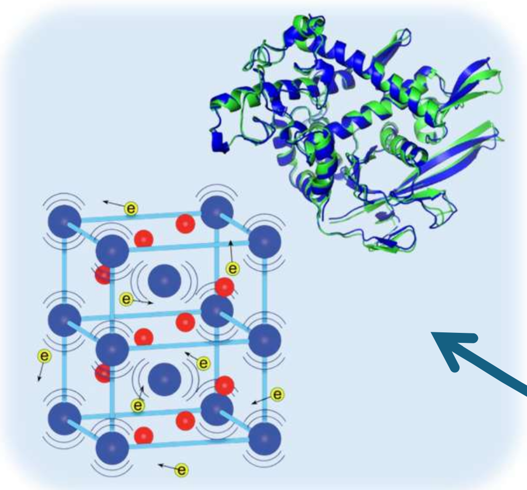
Neutron Scattering

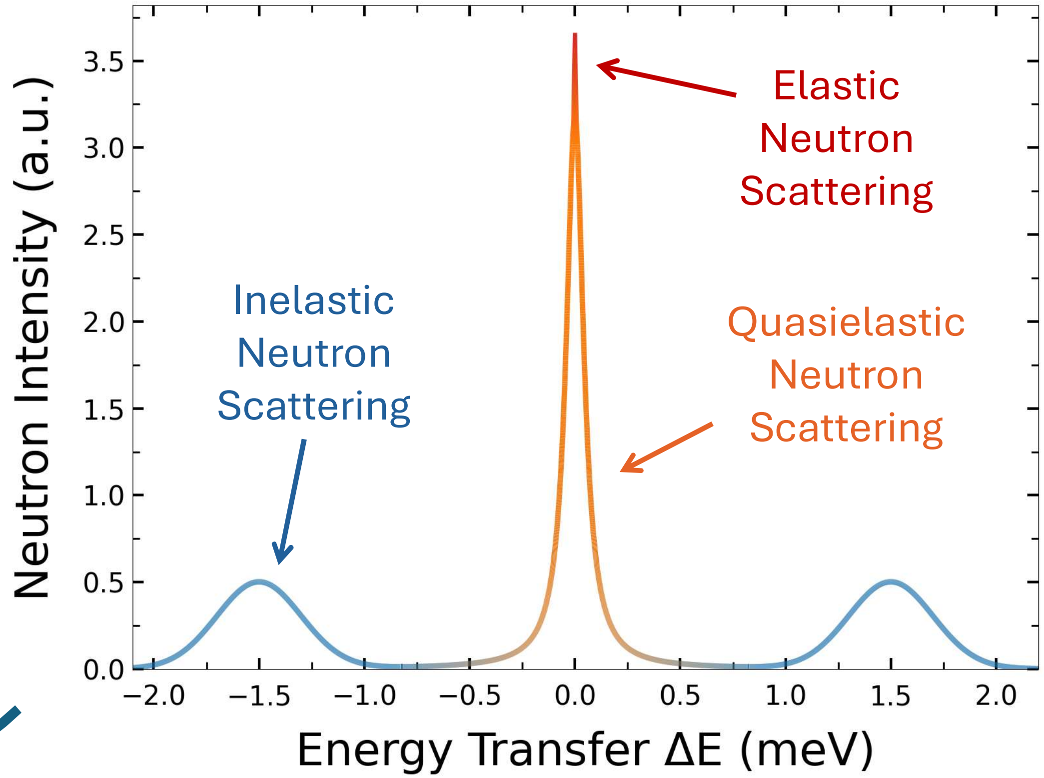


Tells us about the geometry and dynamics of the sample at the molecular and atomic levels.

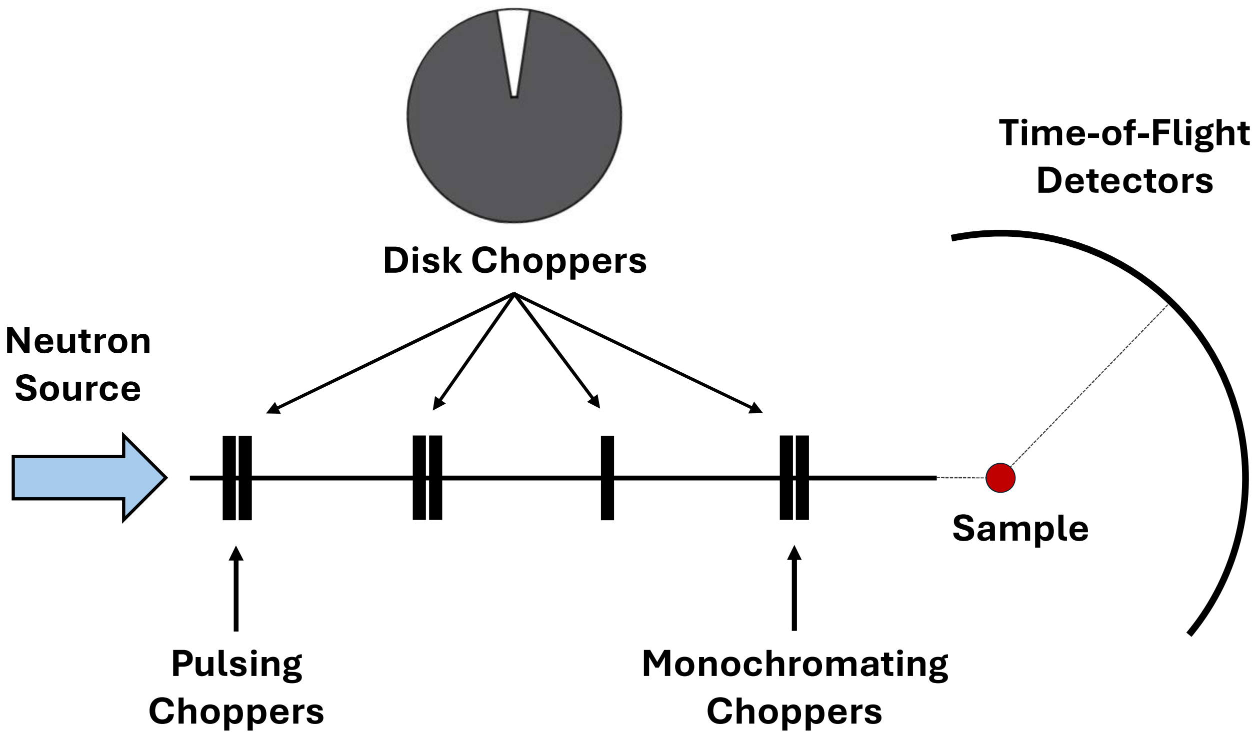
Quasielastic Neutron Scattering (QENS)

QENS → small exchange of energy between the neutron and the sample.



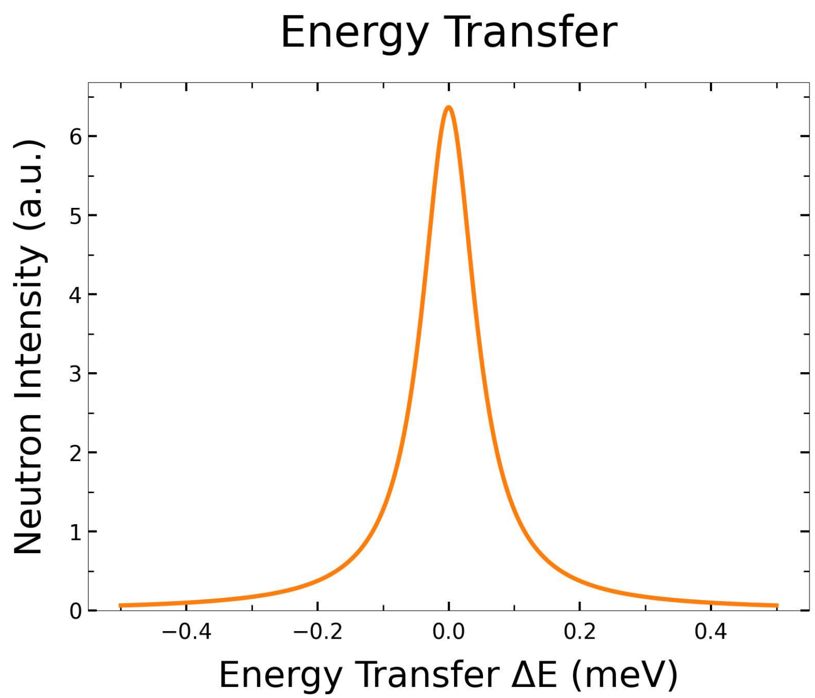


The Disk Chopper Spectrometer (DCS)



Current Instruments

Most current QENS instruments directly measure the energy transfer.



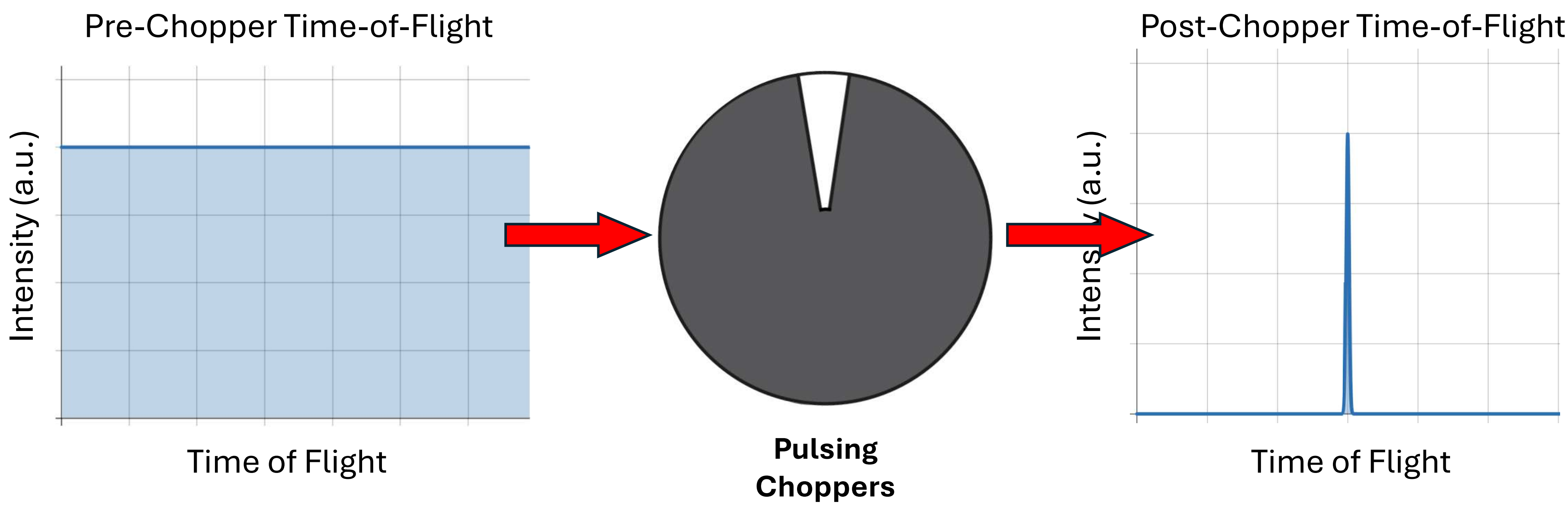
$$\Delta E = E_{final} - E_{initial}$$

Requires knowing:

- Initial energy of every neutron
- Final energy of every neutron

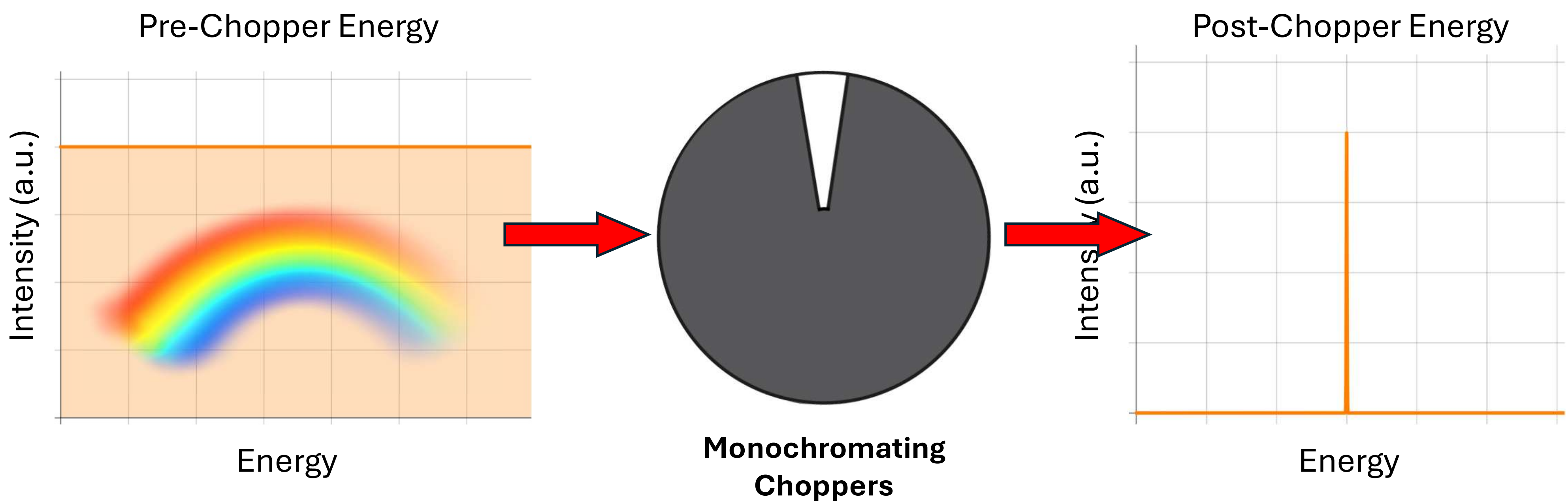
Hard!

Need to pulse the beam to determine Time-of-Flight (ToF) → E_{final}



Neutron Flux ↓↓↓ ☹

Need to monochromate the neutron beam to determine $E_{initial}$

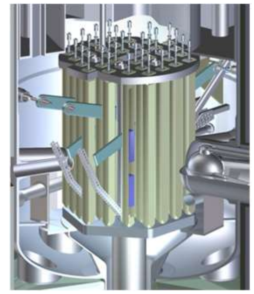


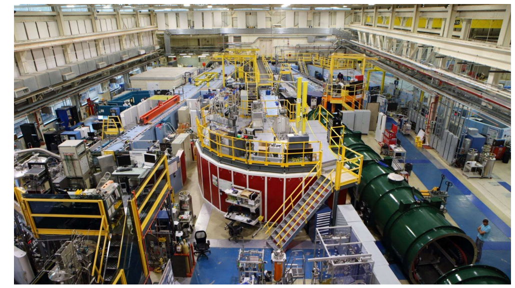
Neutron Flux ↓↓↓ ☹

Time Constraints…

- The average Disk Chopper Spectrometer experiment is **~5 days**
- Researchers request ~2.5 times more instrument time than is available (oversubscription)
- 60% of requested beam time is unavailable!

Another thing…





X-ray spectrometer

Electron spectrometer

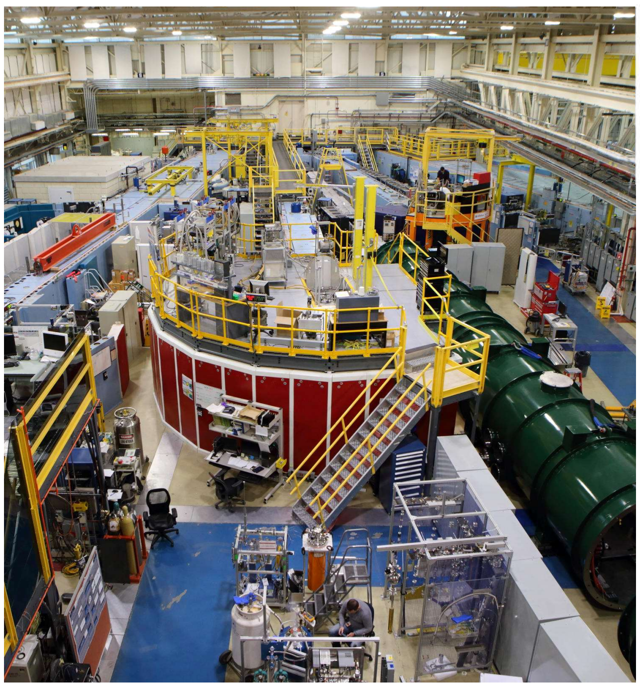
Neutron spectrometer

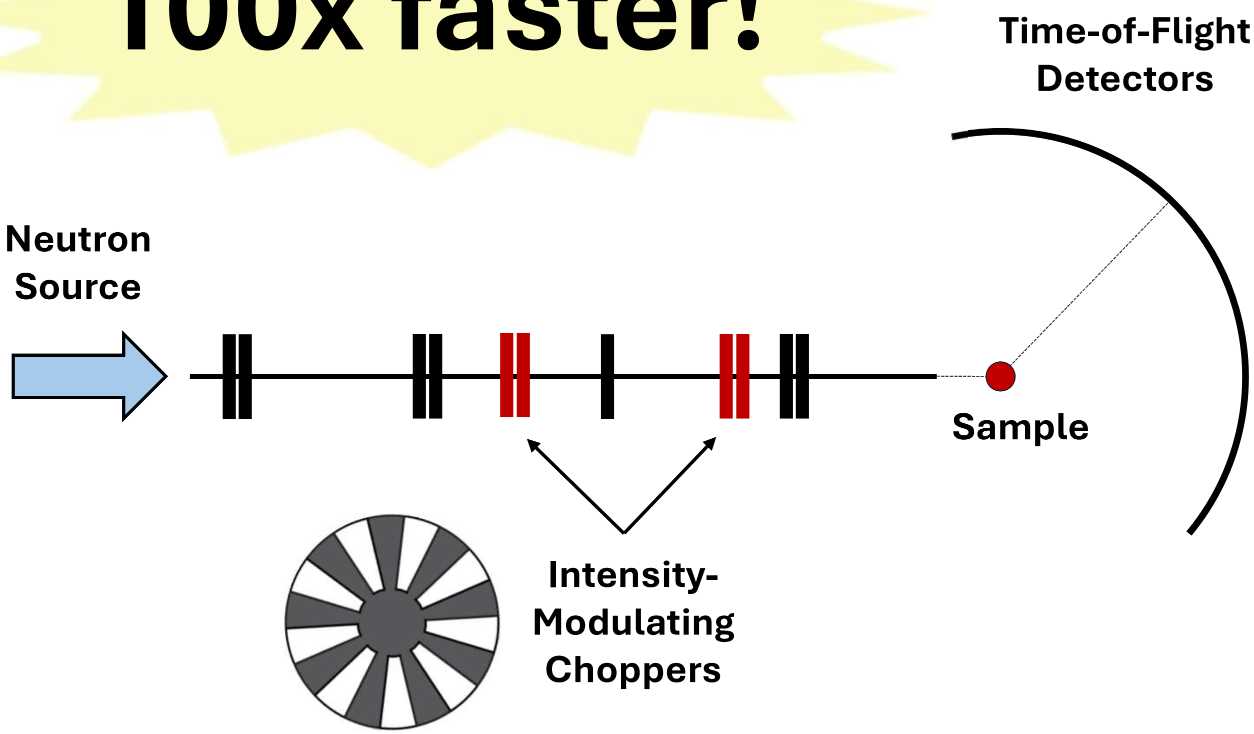
- Neutrons are **expensive!**
- **$5,000 per day → $25,000 per experiment!**

A Small Upgrade

Experiment time: 5 days → 1.5 hours

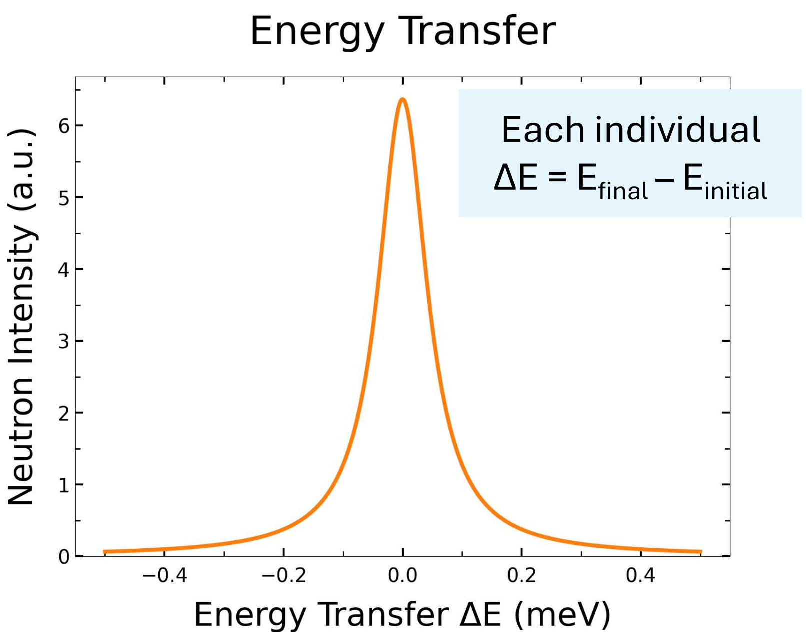
100x faster!



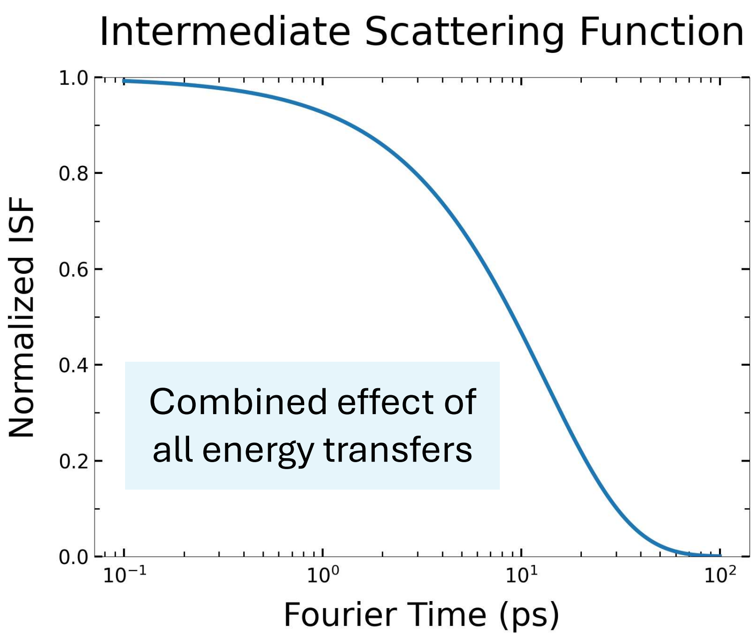


Intermediate Scattering Function

Instead, we can obtain the **exact same information** about the sample by measuring the Intermediate Scattering Function.



Fourier Transform



Neutron Spin Echo

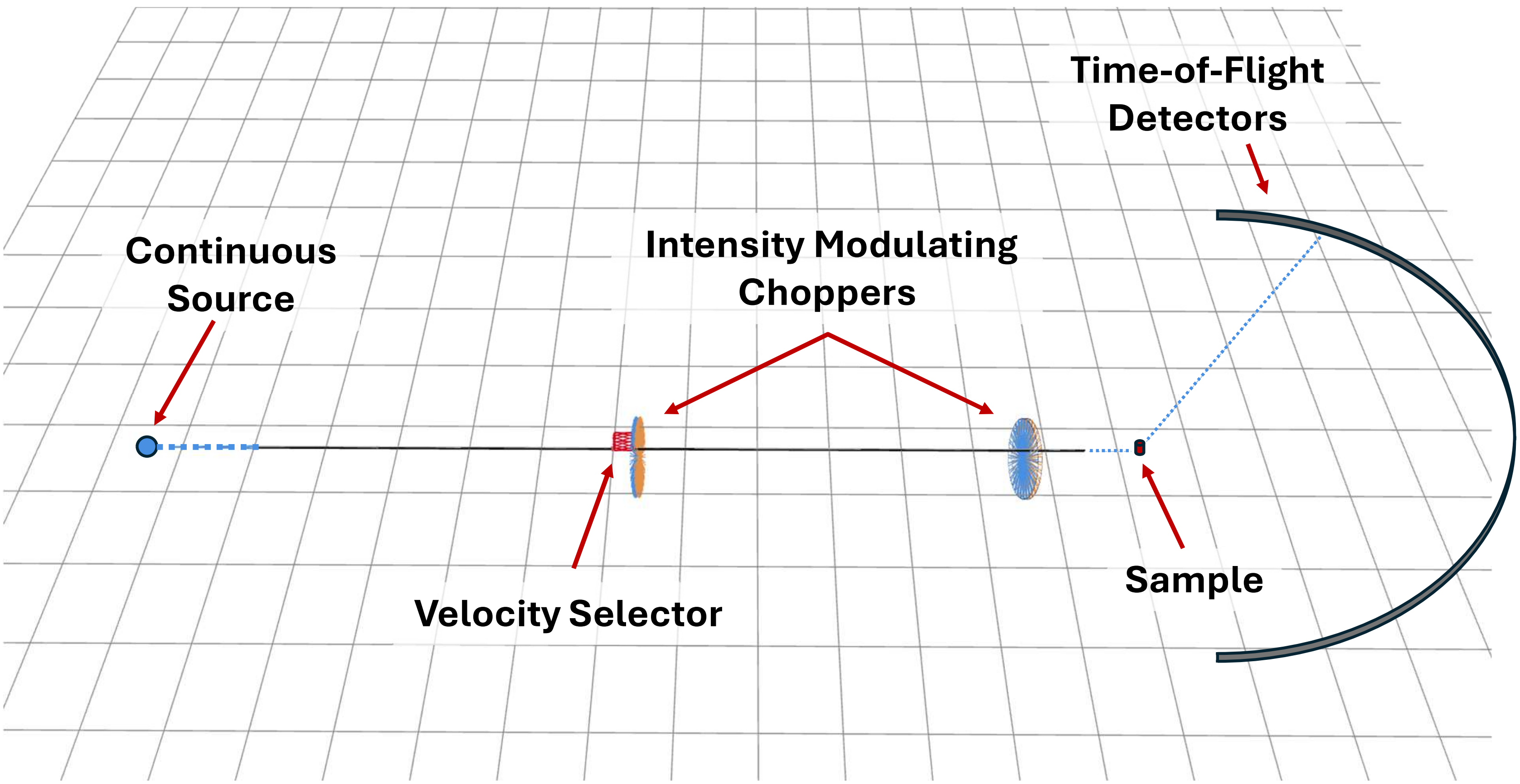
Pros:

- Doesn't pulse the beam (neutron flux ↑↑↑ ☺)
- Doesn't monochromate beam (neutron flux ↑↑↑ ☺)
- High measurement resolution ☺

Cons:

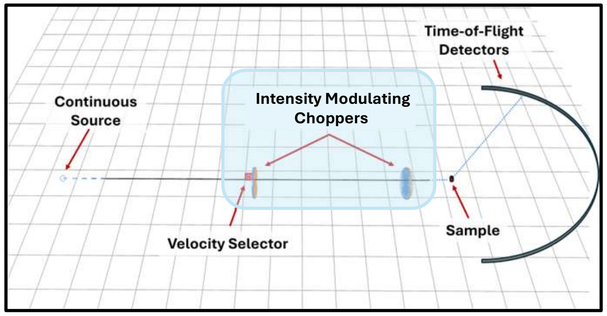
- Small detector area (neutron flux ↓↓↓ ☹)
- Requires beam polarization (neutron flux ↓↓↓ ☹)

Neutron Intensity Modulated Spectrometer (NIMS)

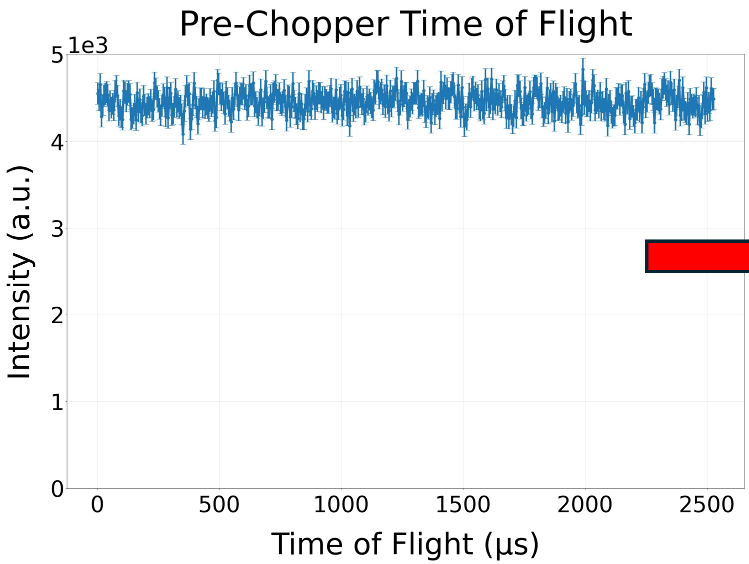


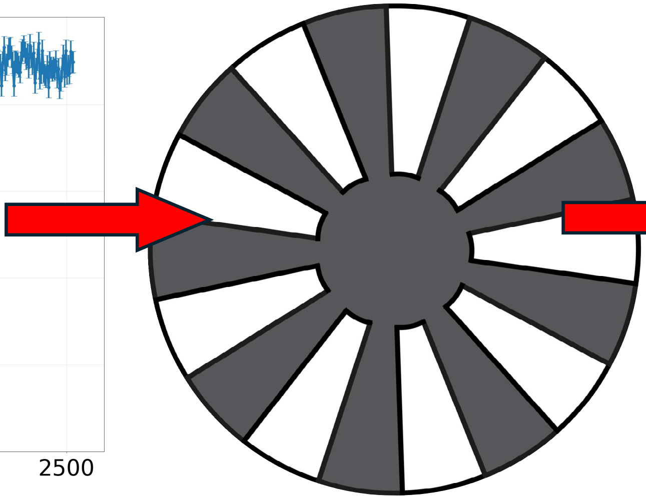
Intensity-Modulating Chopper

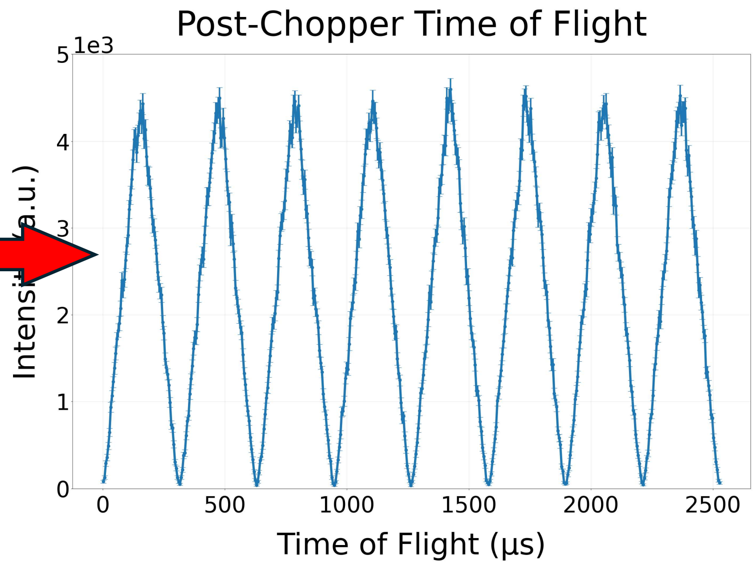
Instead of pulsing, the NIMS chopper creates a triangle-wave profile.



Intensity-Modulating Chopper (IMC)

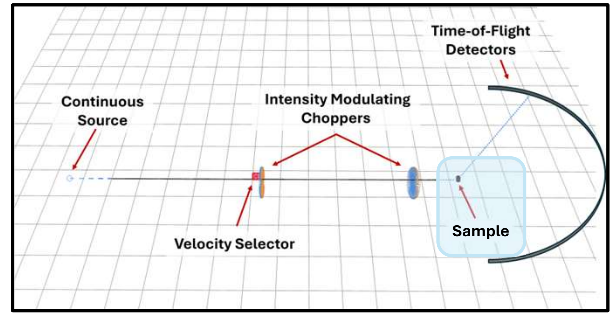


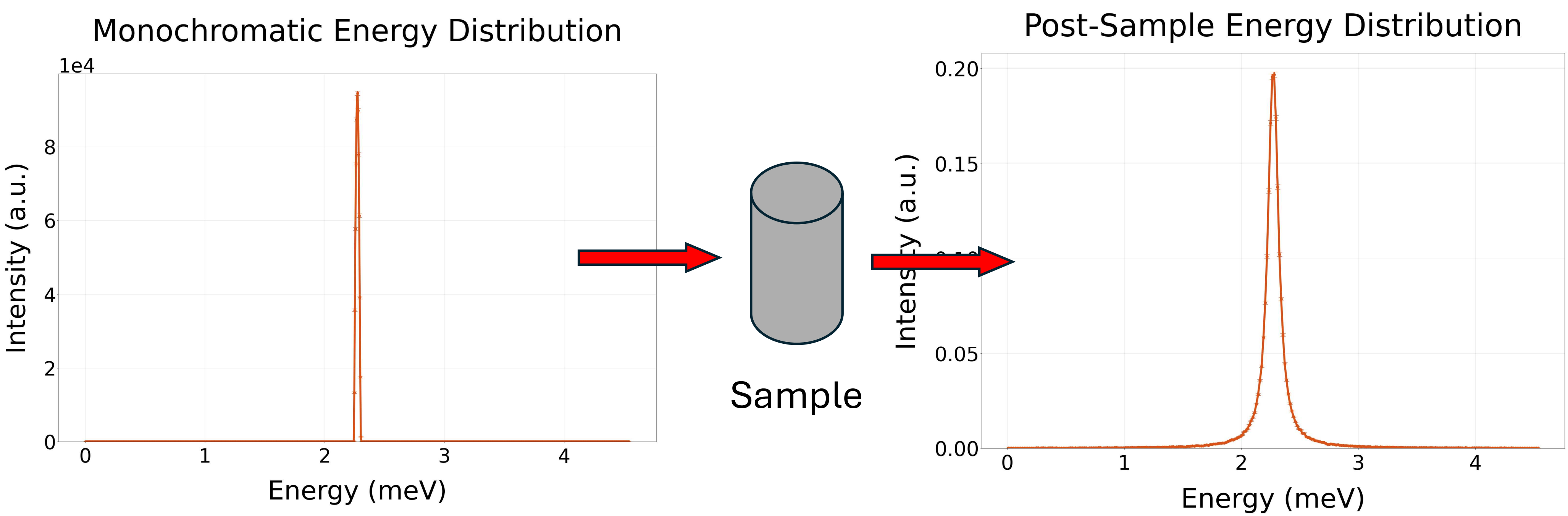




Scattering Sample

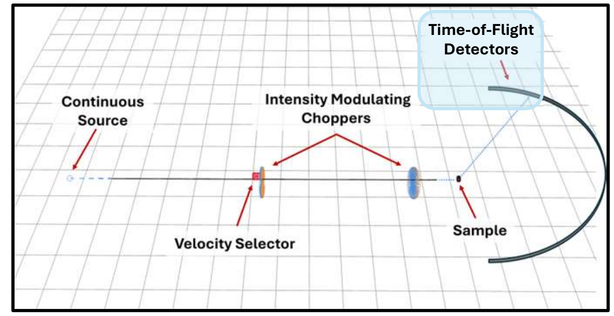
Quasielastic scattering causes the neutrons' energies (velocities) to spread out.

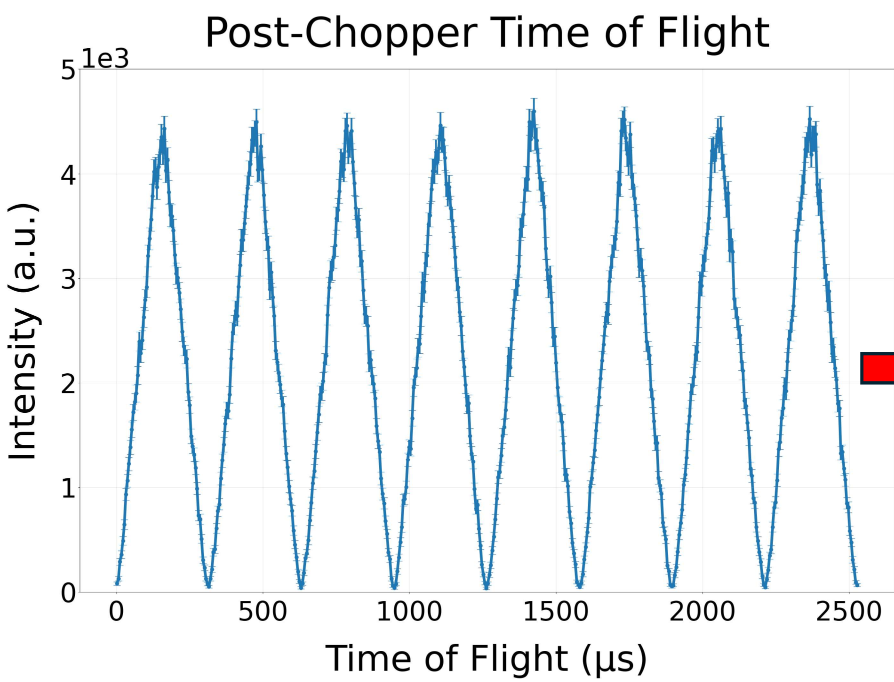




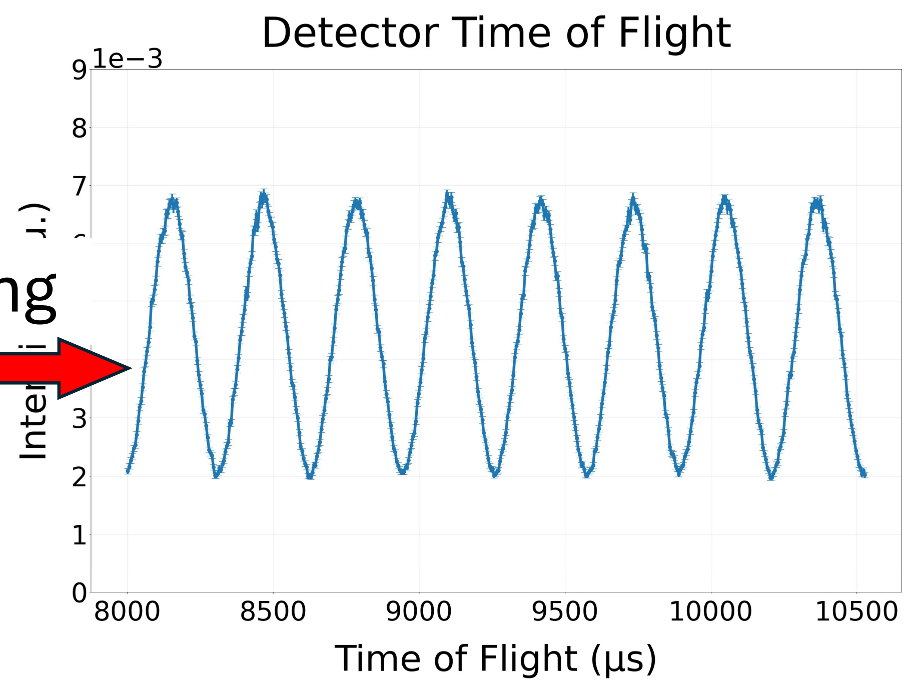
Final Detector

Differences in neutron velocities will smear the triangle wave shape over time.



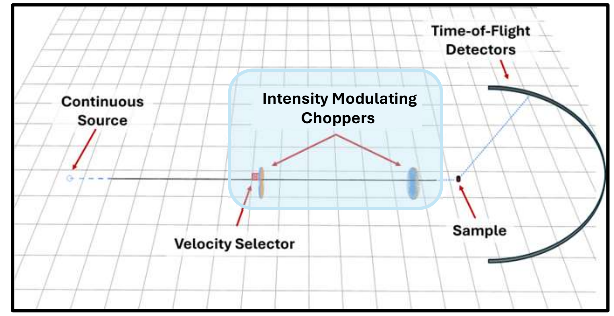


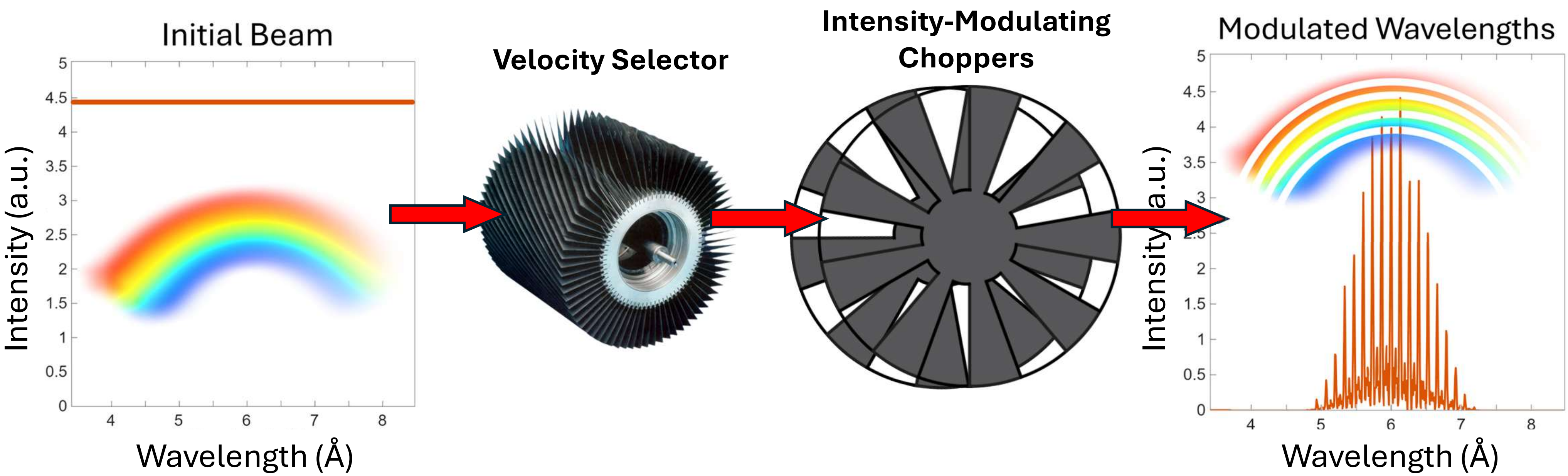
Smearing



Wavelength Modulation

Instead of monochromating the beam, the NIMS choppers modulate the wavelengths.

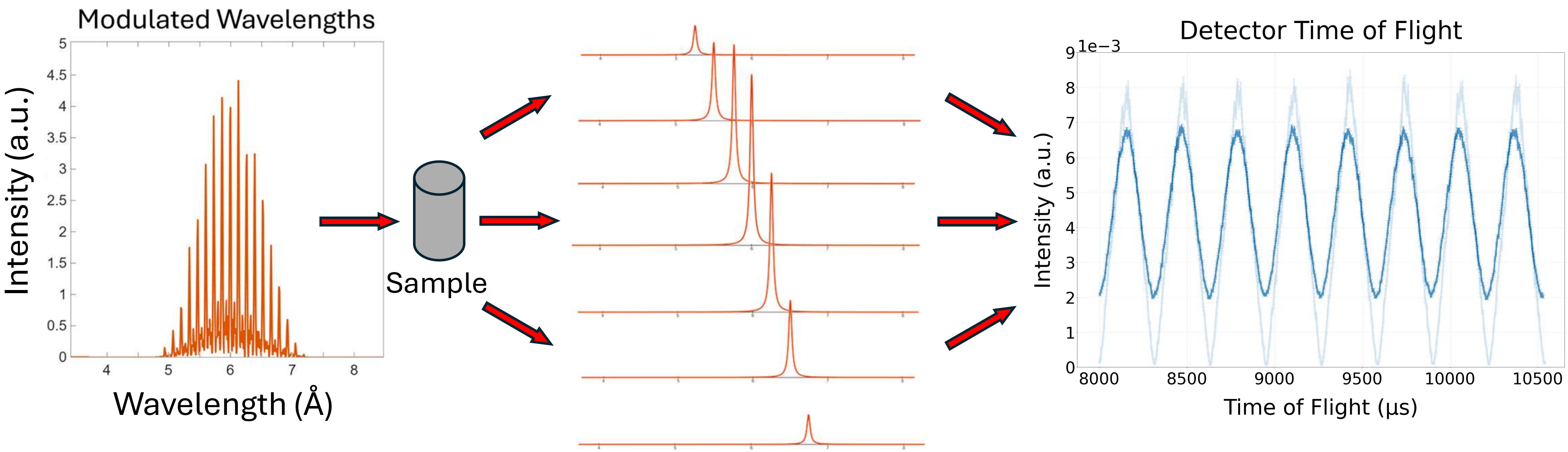




Wavelength Modulation

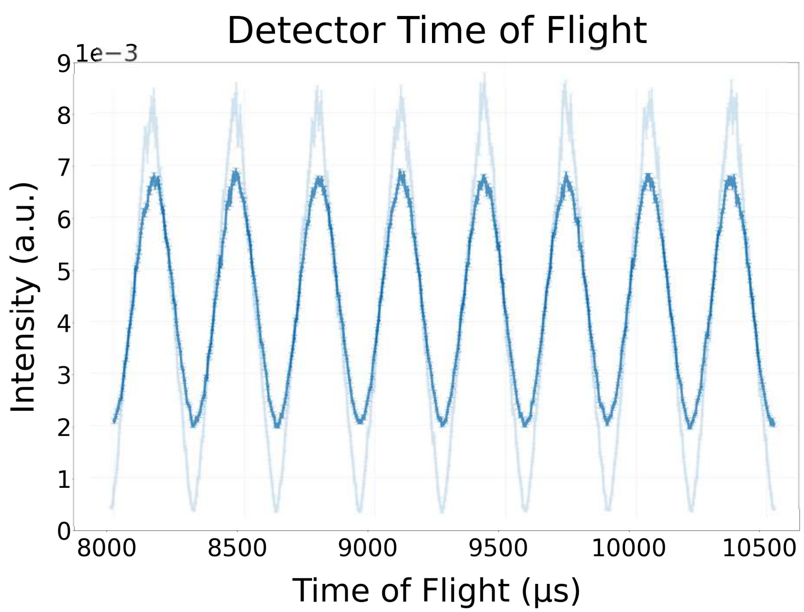
Each wavelength peak is broadened in the same way by the sample.

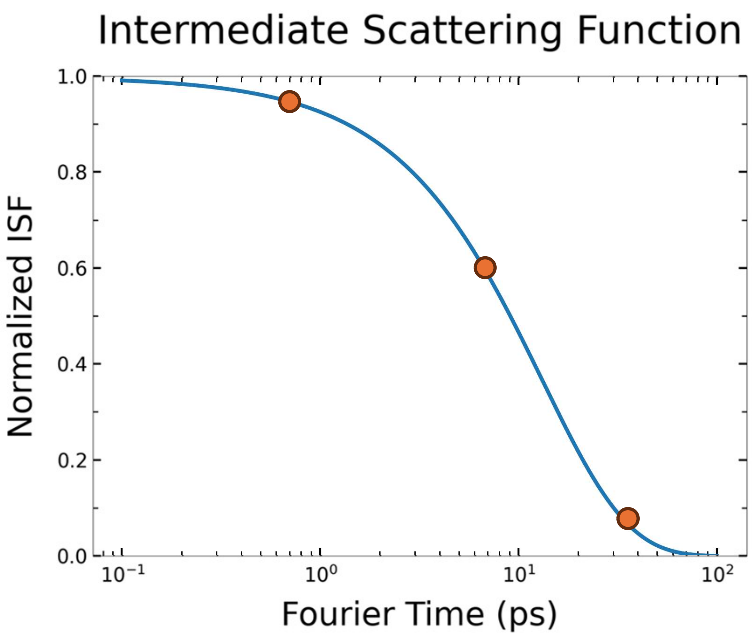
→ Each peak causes the same time-of-flight smearing.



Data Analysis

We can measure how much the Time-of-Flight profile smears at different chopper speeds → Intermediate Scattering Function.



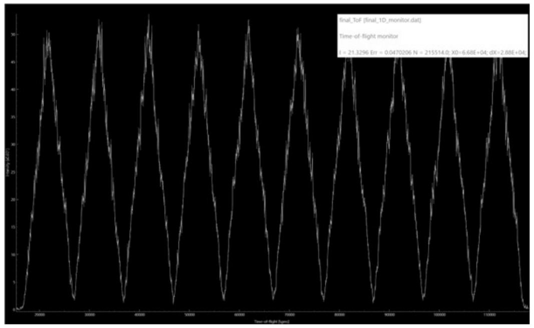


McStas

```
DEFINE INSTRUMENT Example(Param1=1, string Param2="two", ...)

COMPONENT A = Source(Parameters...)
AT (0, 0, 0) ABSOLUTE

COMPONENT B = Guide(Parameters...)
AT (0, 0, 1) RELATIVE A

COMPONENT C = DiskChopper(Parameters...)
AT (0, 0, 1) RELATIVE B

COMPONENT D = TOF_monitor(Parameters, filename="Tof.dat")
AT (0, 0, Param1) RELATIVE PREVIOUS
```

Code

Simulated Detector Data



```
File   Edit   View

# Format: McCode with text headers
# URL: http://www.mccode.org
# Creator: McStas 3.5.1 - Sep. 16, 2024
# Instrument: IMS_old.instr
# Ncount: 1000000
# Trace: no
# Gravitation: no
# Seed: 330562425
# Directory: C:\Users\nos\Downloads\1C_old\IMS_old_20250730_112119
# Param: detector_angle=45
# Param: chopper_period=100
# Param: sample_gamma=0
# Param: num_peirods=10
# Param: source_divergence=1e-007
# Param: source_lambda_d=1e-007
# Date: Wed Jul 30 11:21:21 2025 (1753888881)
# type: array_1d(1000)
# Source: IMS (IMS_old.instr)
# component: final_1D_monitor
# position: 1.0253 0 4.5253
# title: Time-of-flight monitor
# Ncount: 1000000
# filename: final_1D_monitor.dat
# statistics: X0=8001.74; dX=287.477;
# signal: Min=0; Max=3.79078e-031; Mean=1.44767e-031;
# values: 1.44767e-028 2.78499e-031 280587
# xvar: t
# yvar: (I,I_err)
# xlabel: Time-of-flight [\gms]
# ylabel: Intensity
# xlimits: 7483.35 8683.35
# variables: t I I_err N
7517.551408 2.749725063e-033 1.052309863e-033 7
7518.751408 1.551167098e-032 2.567503772e-033 41
7519.951408 3.05305467e-032 3.61357006e-033 78
7521.151408 5.809486828e-032 5.206276898e-033 137
7522.351408 8.235832239e-032 6.230491493e-033 190
7523.551408 1.181900492e-031 7.79414698e-033 246
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7525.951408 1.735281828e-031 9.549325632e-033 348
```
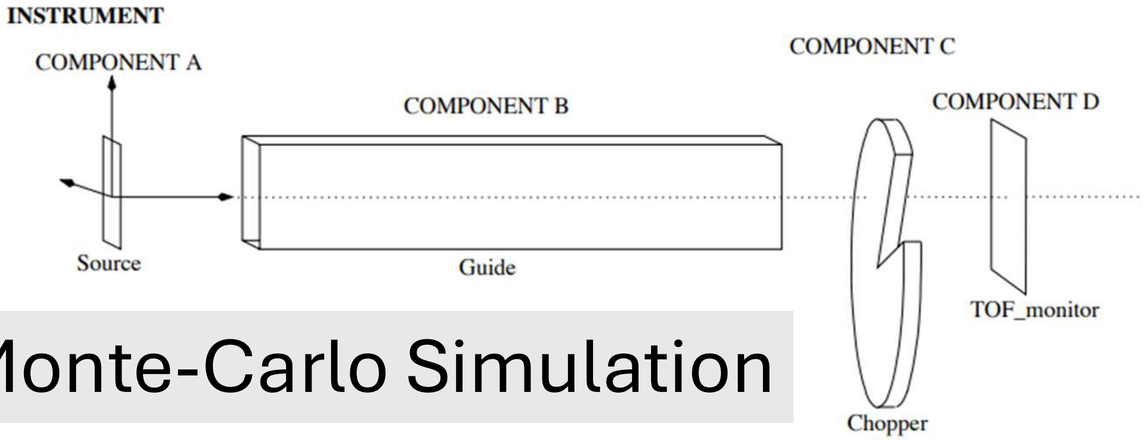
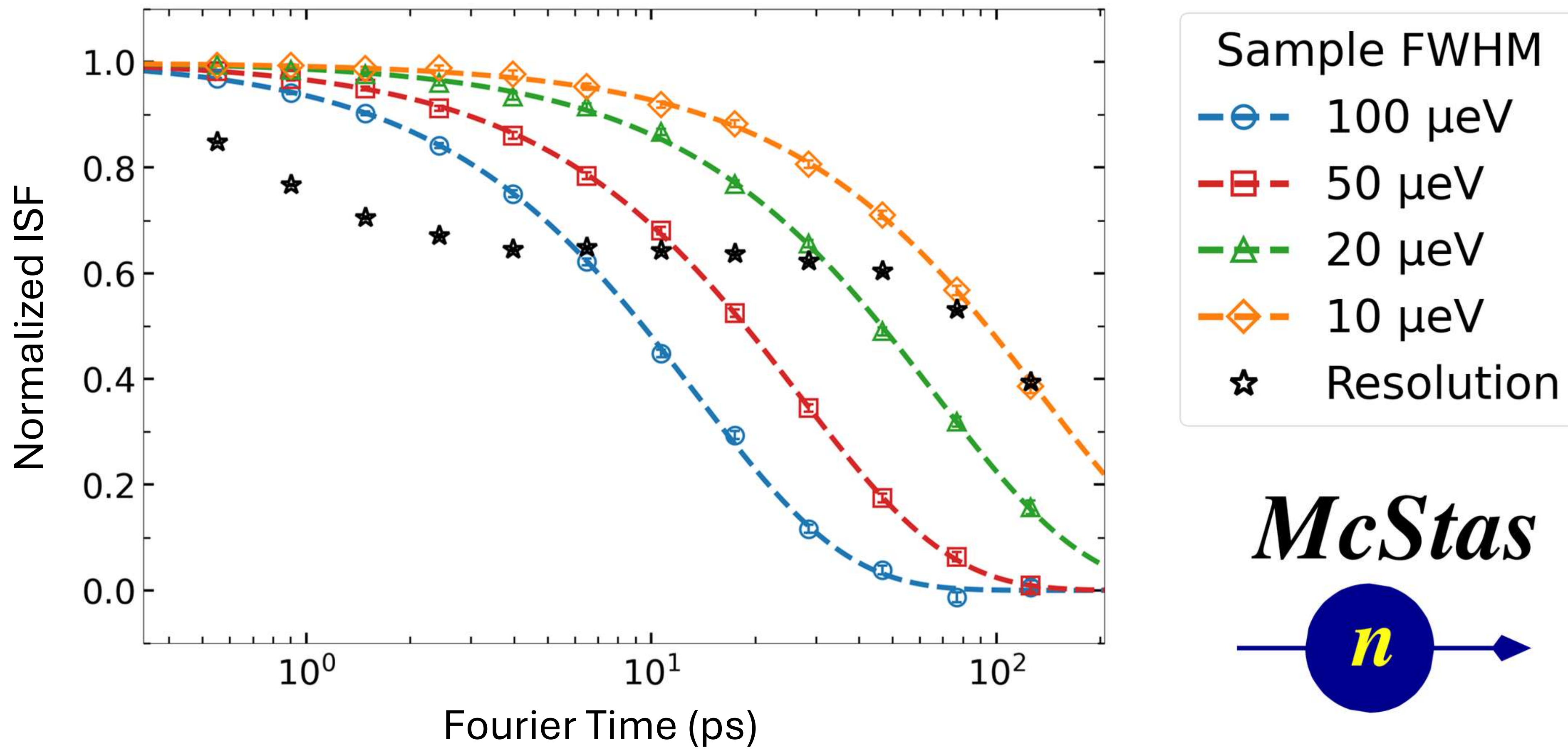



Monte-Carlo Simulation

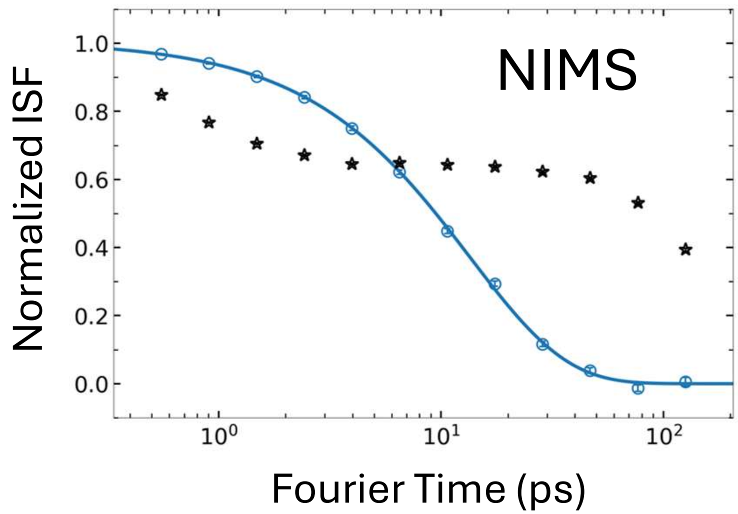
Monte-Carlo Simulation of NIMS



McStas

NIMS vs DCS

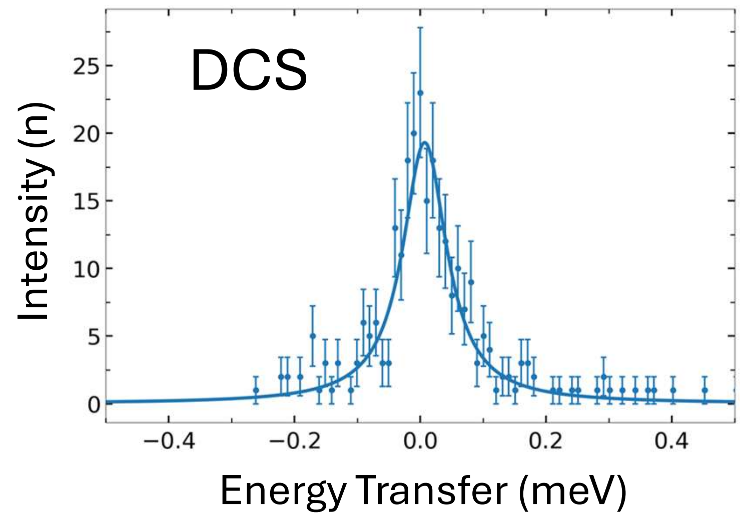
Same sample (**100 μeV**), same experiment duration (**1 hr**), same neutron source, same instrument geometry, same detector.



Compare Uncertainties:

$$\left(\frac{0.11}{0.011}\right)^2$$

≈ 100x faster!



FWHM Fit: 97 ± 1.1 μeV

Relative Uncertainty: 0.011

Resolution: 100 ps ≈ 10 ueV

Uncertainty ∝ 1/√measurement

10x lower uncertainty → 100x better measurement

FWHM Fit: 86 ± 9 μeV

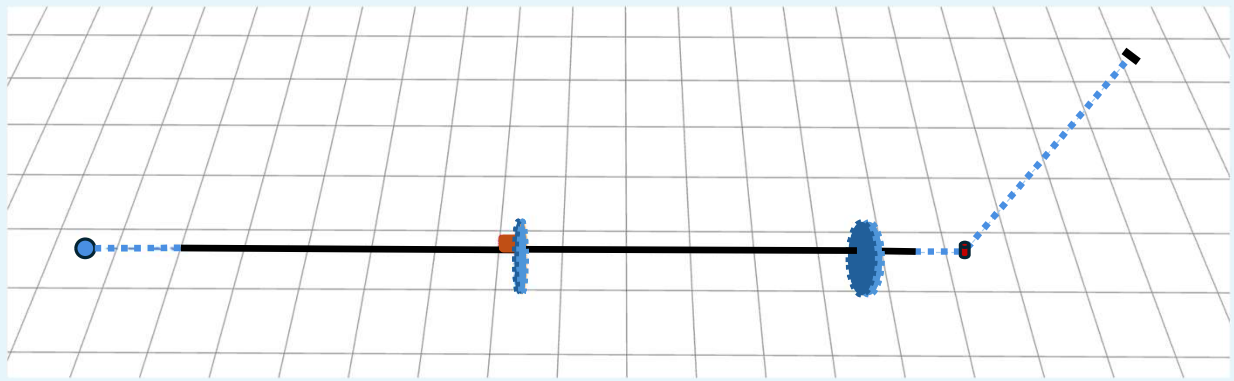
Relative Uncertainty: 0.11

Resolution: 24 ueV

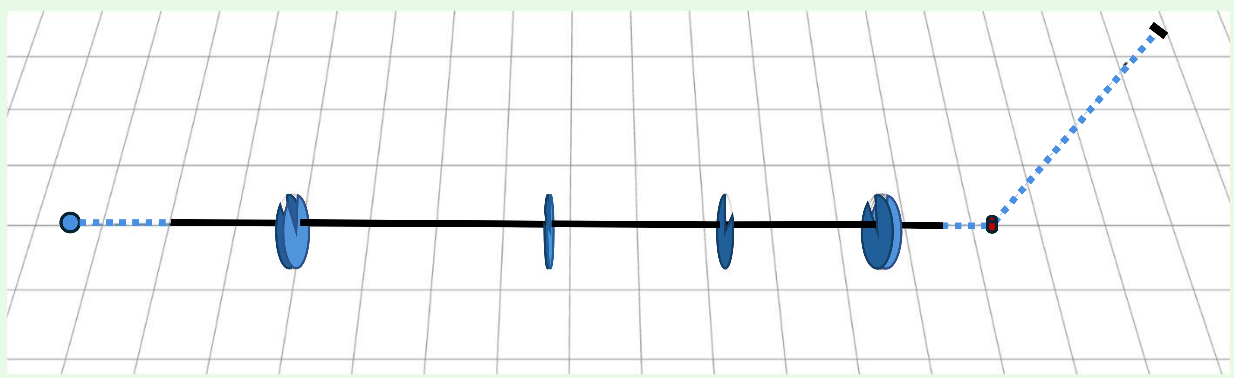
NIMS Overview

- ***~100x faster than DCS!***
- No polarization or magnets needed
- Wide detector range
- Can easily switch between DCS / NIMS
- Easy to add to existing DCS instrument

NIMS



DCS



Special Thanks!

Mentors: **Antonio Faraone & Leland Harriger**

CHRNS & CORE: **Julie Borchers & Leland Harriger**

CHRNS CENTER FOR HIGH RESOLUTION NEUTRON SCATTERING NSF NIST

CORE CHRNS OUTREACH AND RESEARCH EXPERIENCE

Image References

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