22 January 2026

Soft Matter II: Stroboscopic and Time-Resolved Rheo-Scattering

Synchronization, Data Acquisition, and Practical Execution

Presented by

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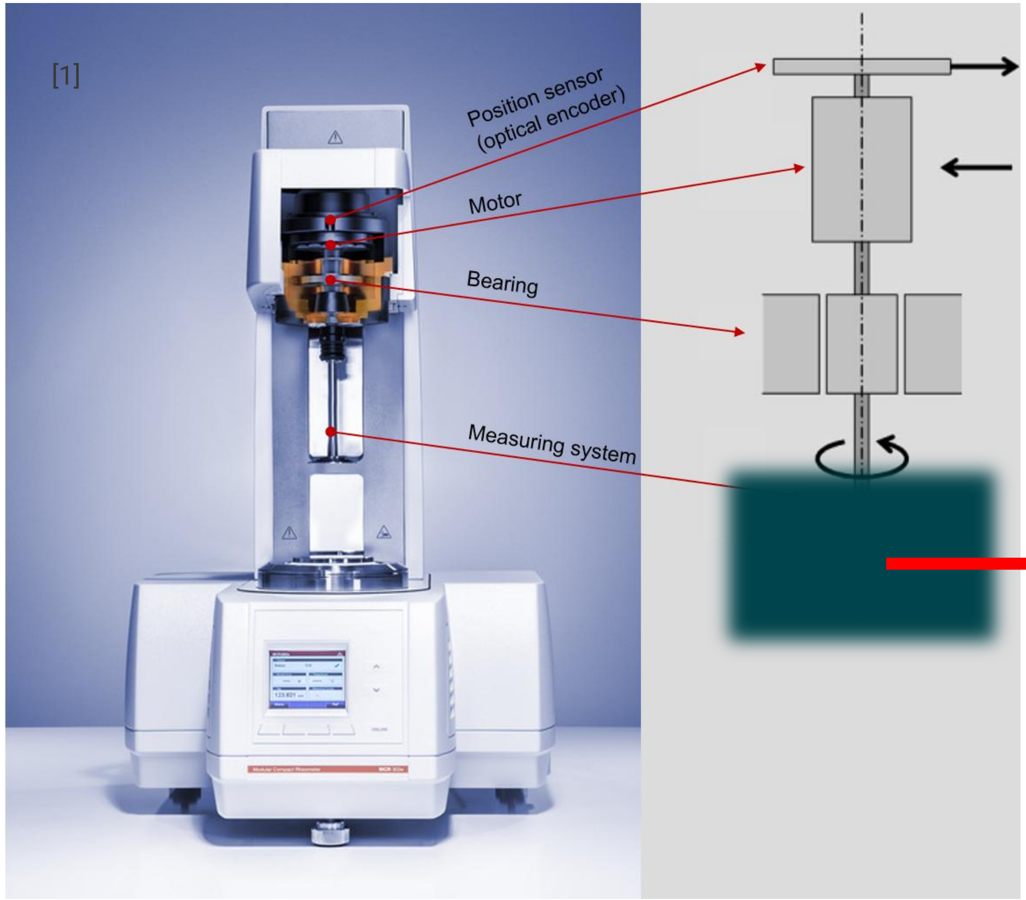
Neutron Scattering Division

Rheometer basics recap: Motion and Mechanics

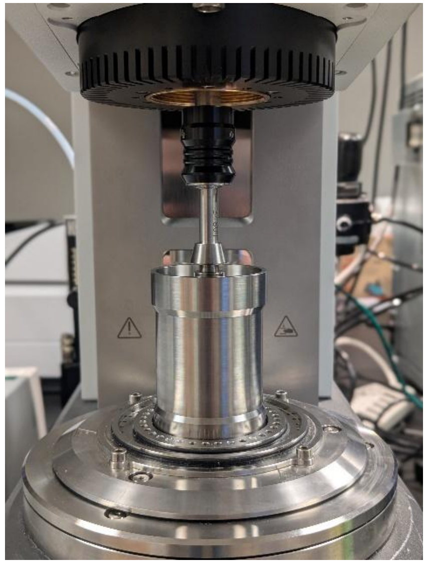
A rheometer is a precision rotary actuator sitting on top of very sensitive force sensors

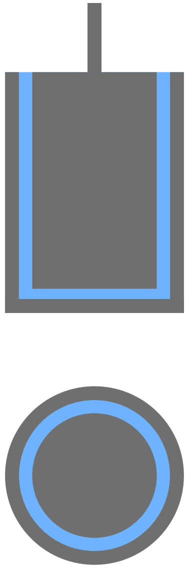


Measures **angle** (θ) and **normal force** (F_N)

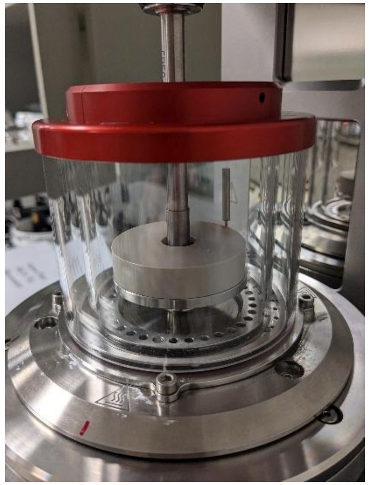
Applies **torque** (τ), controls rotation to the sample

Rheo-SANS cup-and-bob





Rheo-NR cone-and-plate



Rheology tells us how the sample flows.
SANS tells us why.

Rheo-SANS bridges nano → micro gap in soft matter characterization

Anton Paar

Oak Ridge National Laboratory

[1] Anton Paar

Why communication is the hard part

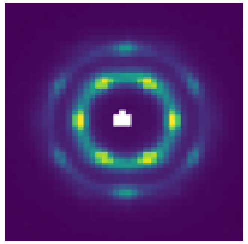
Rheo-Scattering couples two instruments with fundamentally different clocks, assumptions, and priorities.

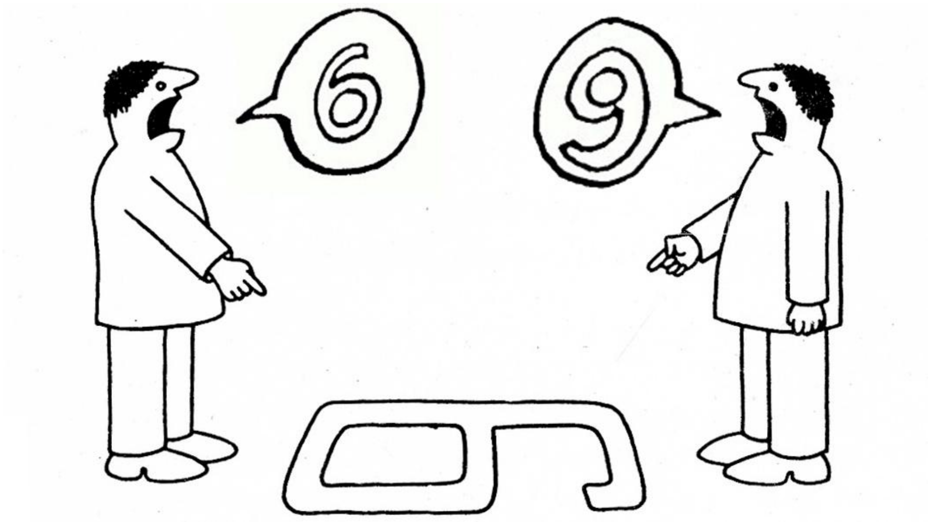
Rheometer

- Defines time relative to motion start
- Asks "*what is the sample doing?*"
- Wants **autonomy**

Scattering Instrument

- Defines time relative to absolute timestamps, run boundaries
- Asks "when did neutrons arrive?"
- Wants **determinism**

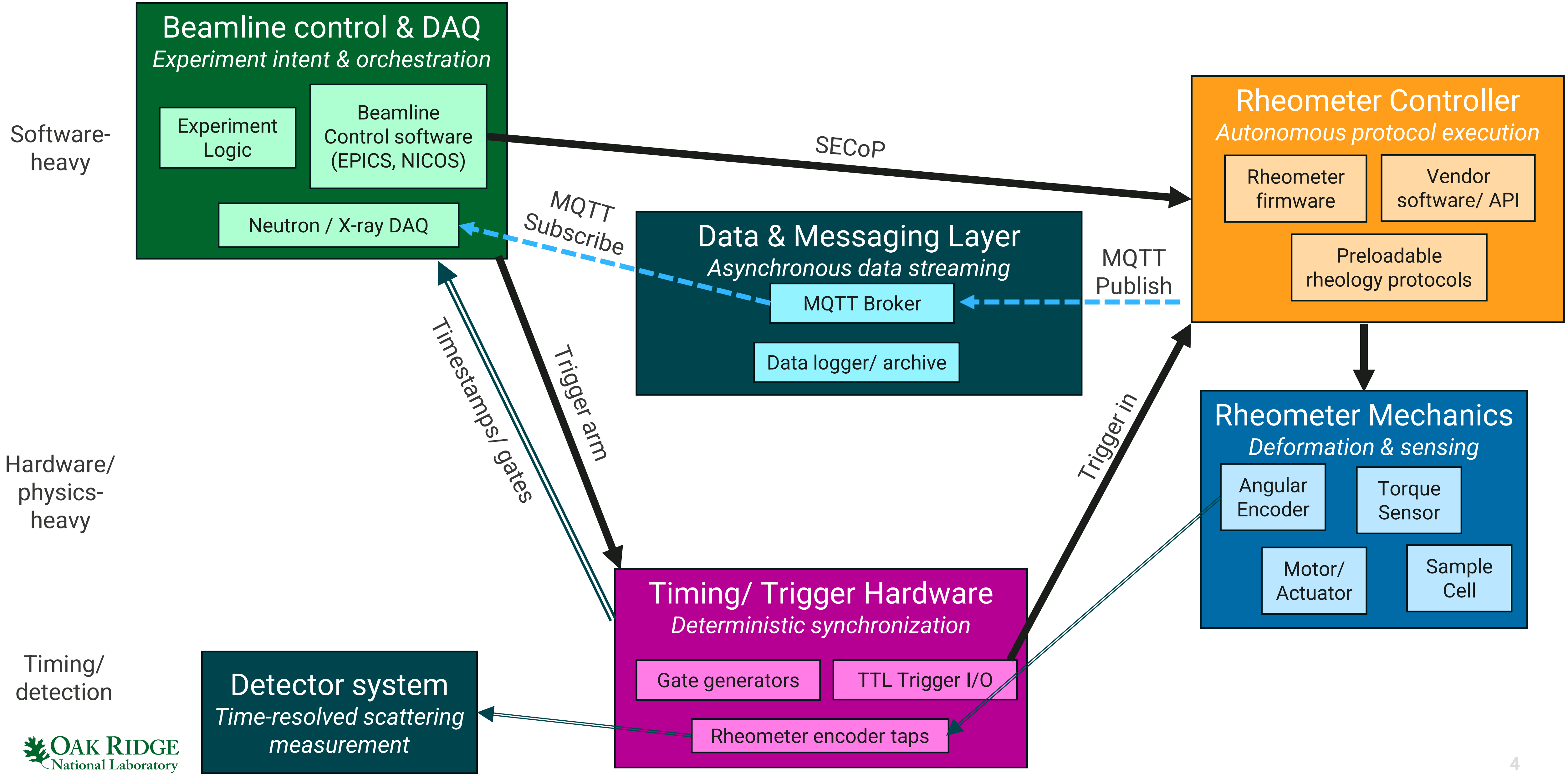




You don't have a rheometer experiment and a scattering experiment, you have one synchronized experiment with two beasts of instruments

How do we synchronize deformation, data acquisition, and scattering without breaking either system?

Relevant control domains - Rheo-Scattering experiments



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Controlling the Rheometers

How do we tell the rheometer what to do?

The naïve timing assumption

Why not set both rheometer and scattering instruments to run for ~20 minutes each and move on independently?

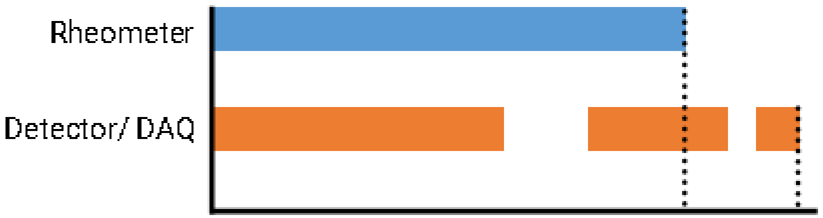
Both sides followed the plan, they just never checked in

What “building from each end” looks like in a Rheo-Scattering experiment

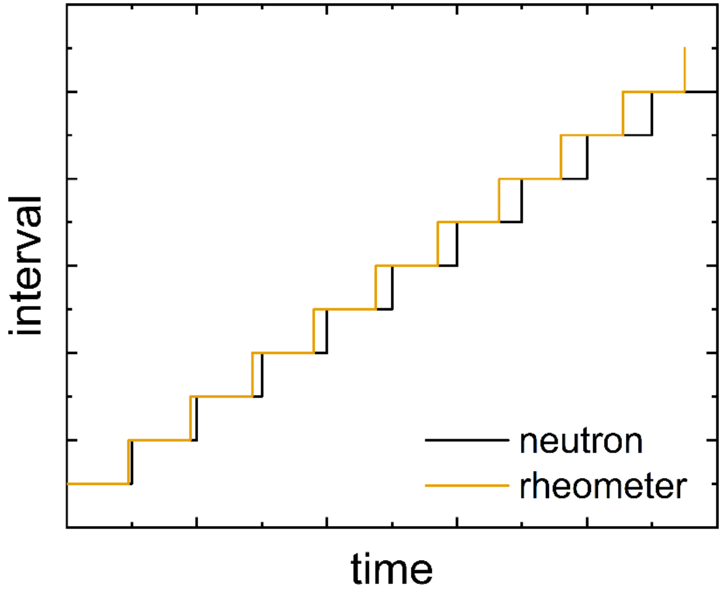
Synchrotrons, spallation sources often face unexpected short-term beam outages

Many beamline scientists prefer to run neutron measurements by neutron counts rather than time

Coordination ensures rheometer does not jump ahead of neutron measurements



Nothing crashed, nothing failed loudly.
But the data is still misaligned



Even if nothing ever pauses, clocks are never perfectly identical

Clock drift on long experiments can desynchronize instruments

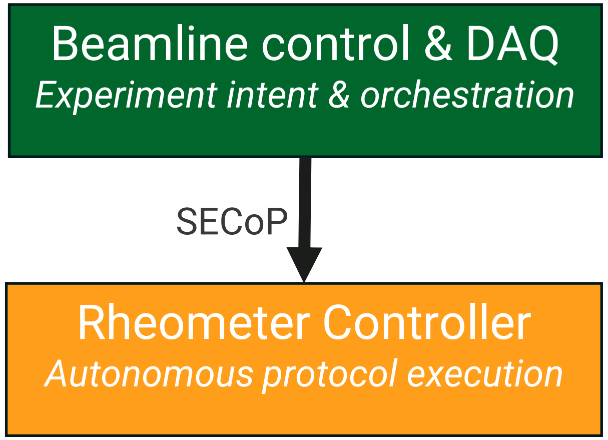
Even tiny alignment errors add up over long distances.

Control vs. coordination

"Control" and "coordination" are different engineering problems

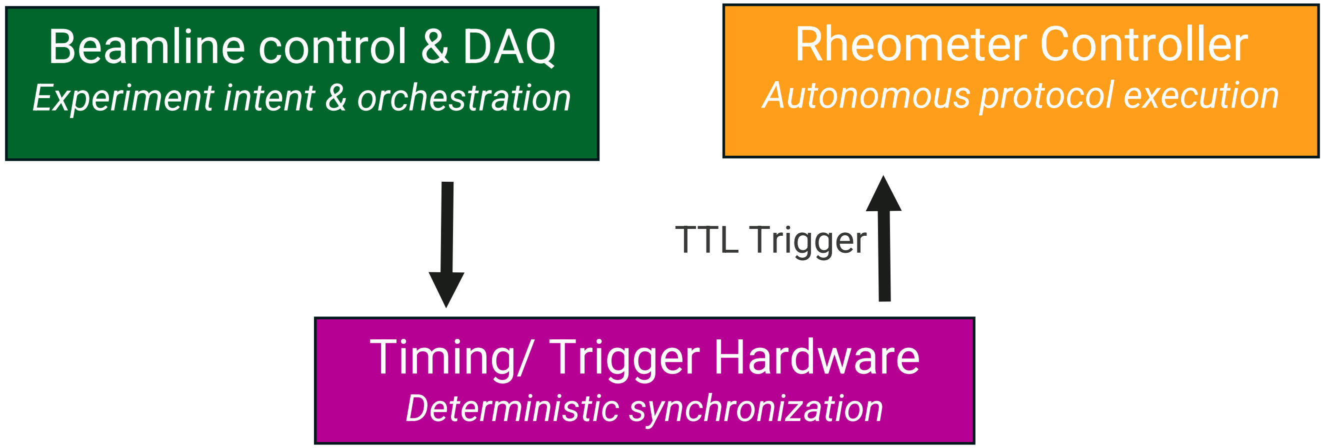
Direct control

- Full parameter access
- Software-driven sequencing
- Flexible, scriptable
- Timing depends on software stack



Coordination

- Rheometer executes autonomously
- Deterministic timing
- Minimal software coupling
- Limited mid-run flexibility



Direct control of rheometer through SeCOP

Beamline control & DAQ
Experiment intent & orchestration

SECoP ↓

Rheometer Controller
Autonomous protocol execution

- **S**ample **E**nvironment **Co**mmunication **P**rotocol (developed by ISSE)
- Speaking to the rheometer in short, explicit commands directly and timestampably
- Easier for beamline staff, not necessarily for those who work in RheoCompass regularly

Unified instrument control

Fully scriptable

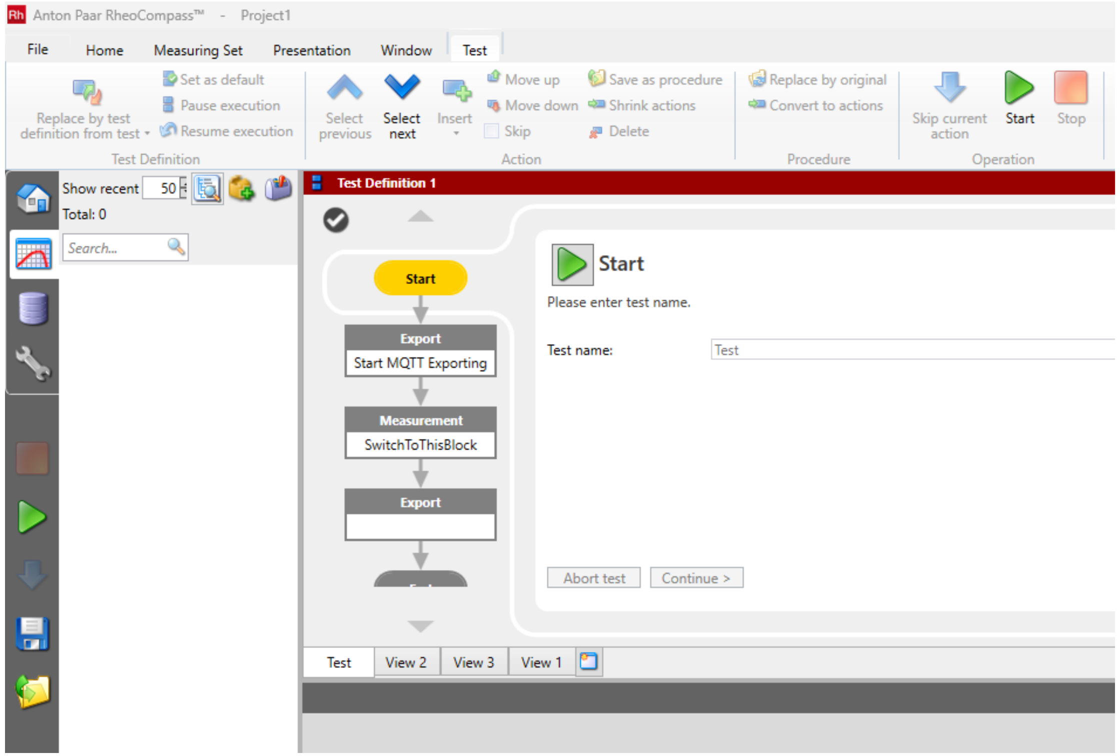
No direct support from Anton Paar

Complex rheometer experiments may be impractical

Rheometer firmware updates may be unpredictable

SeCOP gives you clean timing — but you're responsible for development and correctness

Trigger-based control using RheoCompass



Proprietary software developed, sold by Anton Paar

Translates high-level experiments into low-level commands

Easy to set up multi-step experiments

- Temperature ramps
- Shear ramps
- Overnight runs

Control through RheoCompass suffers from latency, timing

Familiar for many academic users

RheoCompass is excellent for experiments — not for clocks

Can we utilize the advantages of RheoCompass and minimize the latency issues to work for us?

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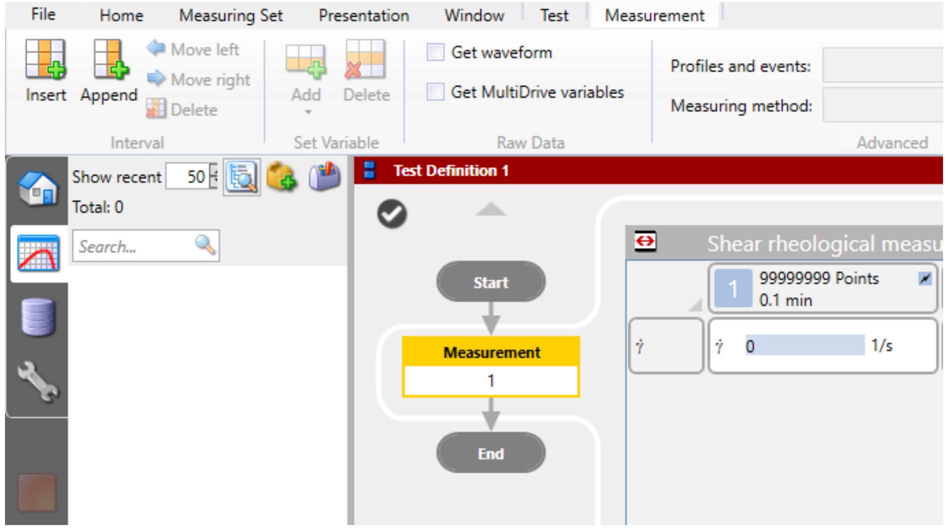
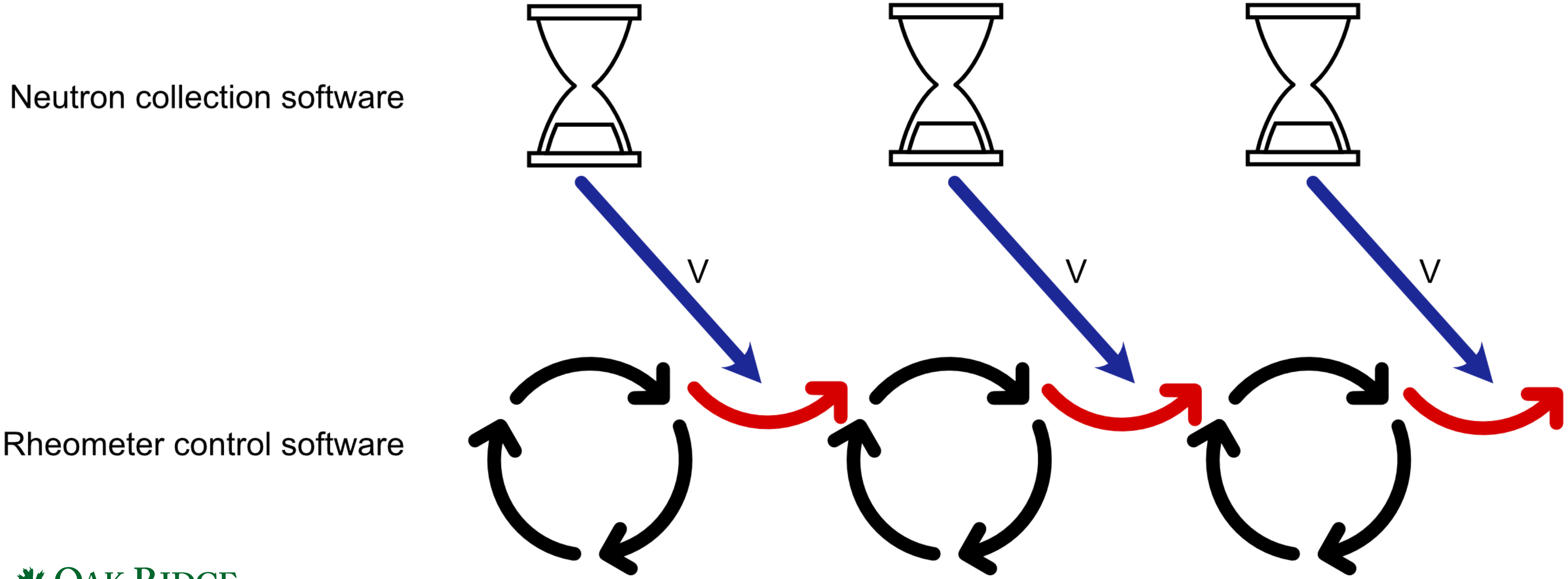
Basic triggering – switching rheometer intervals



Set up rheometer intervals to run for ~infinite time

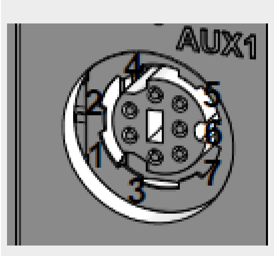
Rheology intervals run as long as neutron collection requires

I/O device sends voltage signal to rheometer → move forward interval



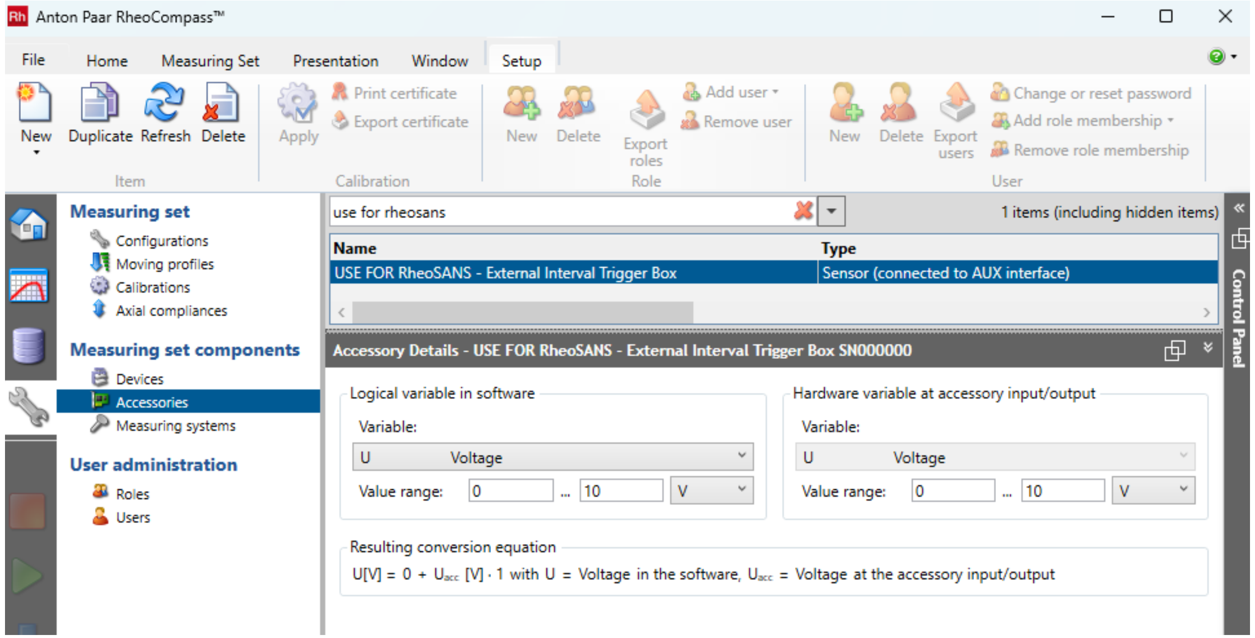
How do we set up the rheometer to listen for I/O signals?

MCR rheometers have built-in I/O electronic accessory ports



Pin	Name	Description
1	RGND	Remote GND
2	RSW2	Relay switch 1
3	R+	Remote +
4	RSW1	Relay switch 2
5	AIN-	Analog IN-
6	AIN+	Analog IN+
7	N.C.	not connected

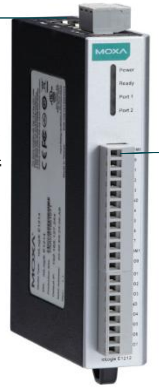
+/- 10 VDC, 0.305 mV resolution, max 300 mA



Connector:
Mini Din 7 position; cable needs male pins
Option: Kycon KMDLAX-7P
Available at Digikey, Mouser (~$6 USD/ea.)

Ethernet

Moxa IoLogik e1200 series



DO

Raspberry Pi

PSI

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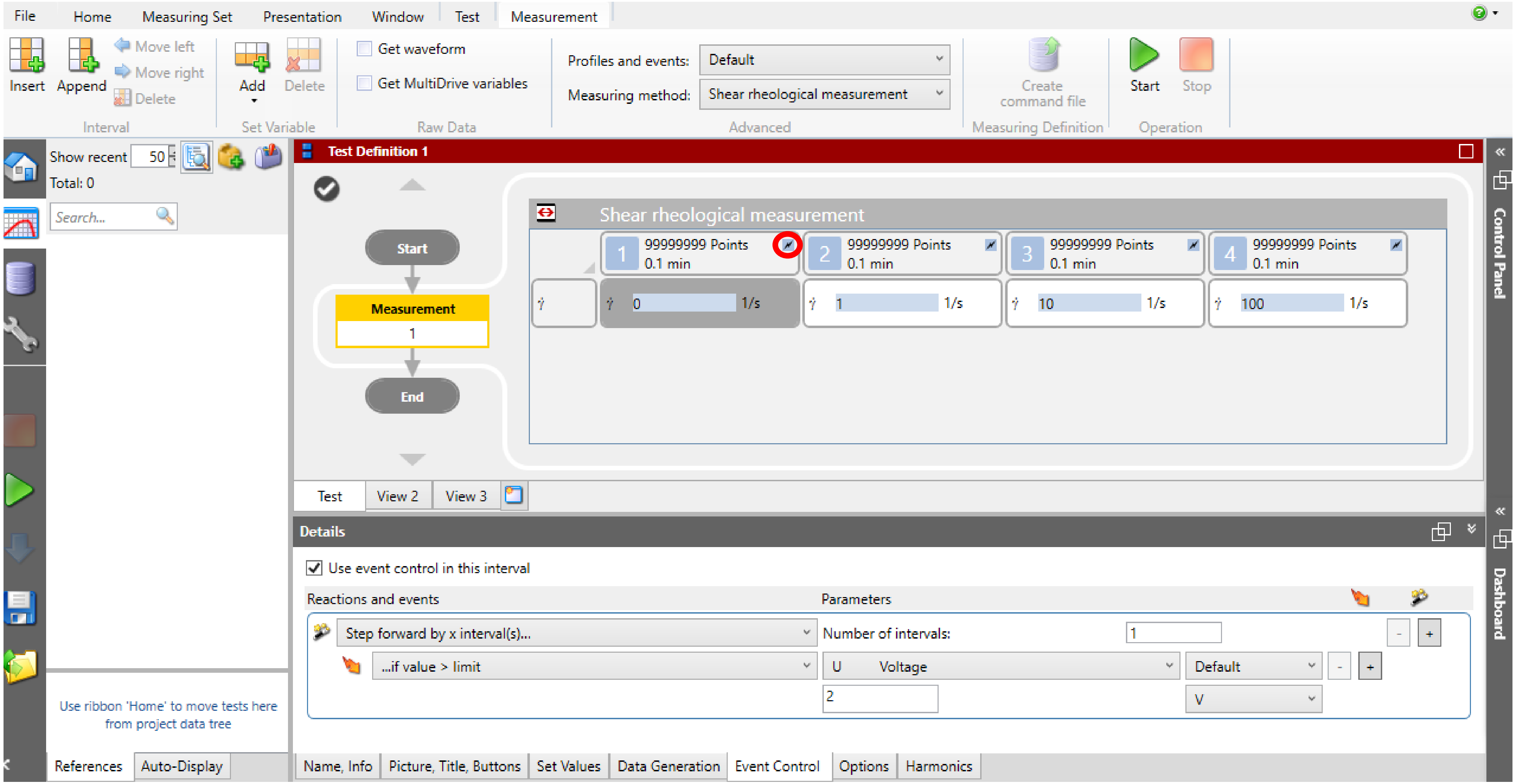
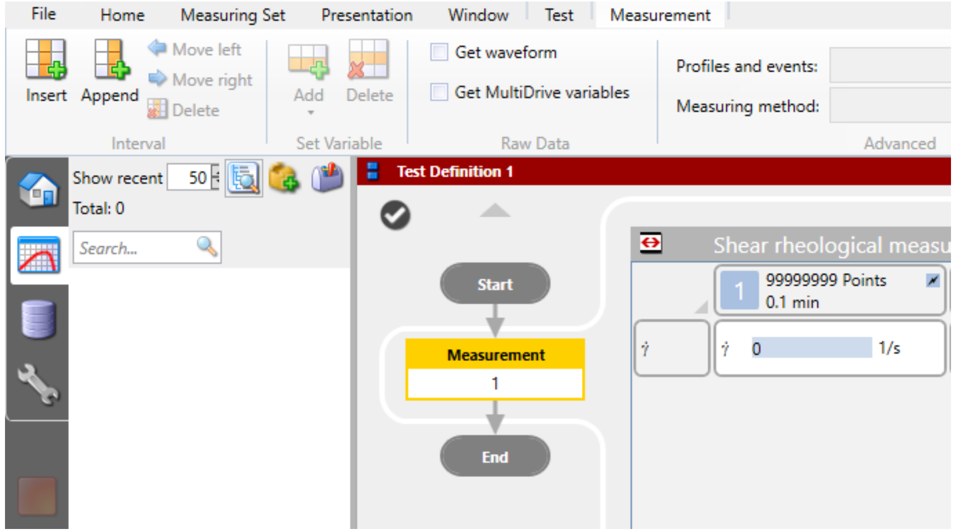
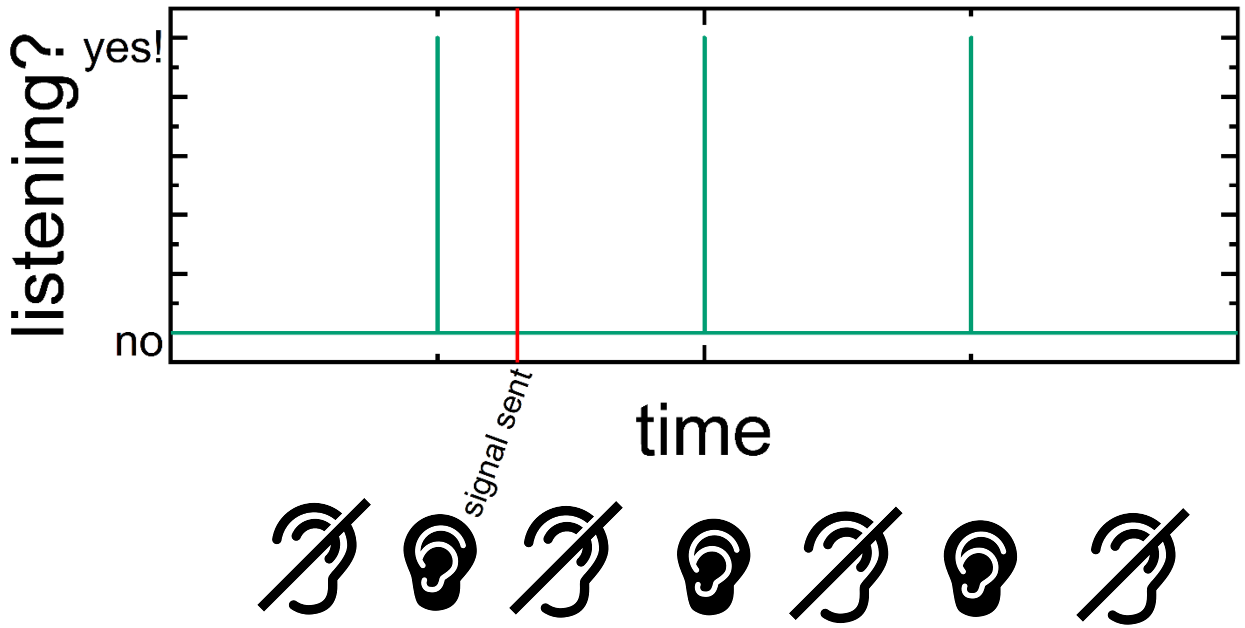
Configuring rheometer to expect signal device



Complexity: rheometer is not constantly listening for signals





Rheometer only listens for pulse when data point generated (every 0.1 min) in example below

Pulse HAS to line up with when rheometer makes data point

Time mismatch? Missed pulse, de-sync'ed rheometer and neutrons, experiment ruined

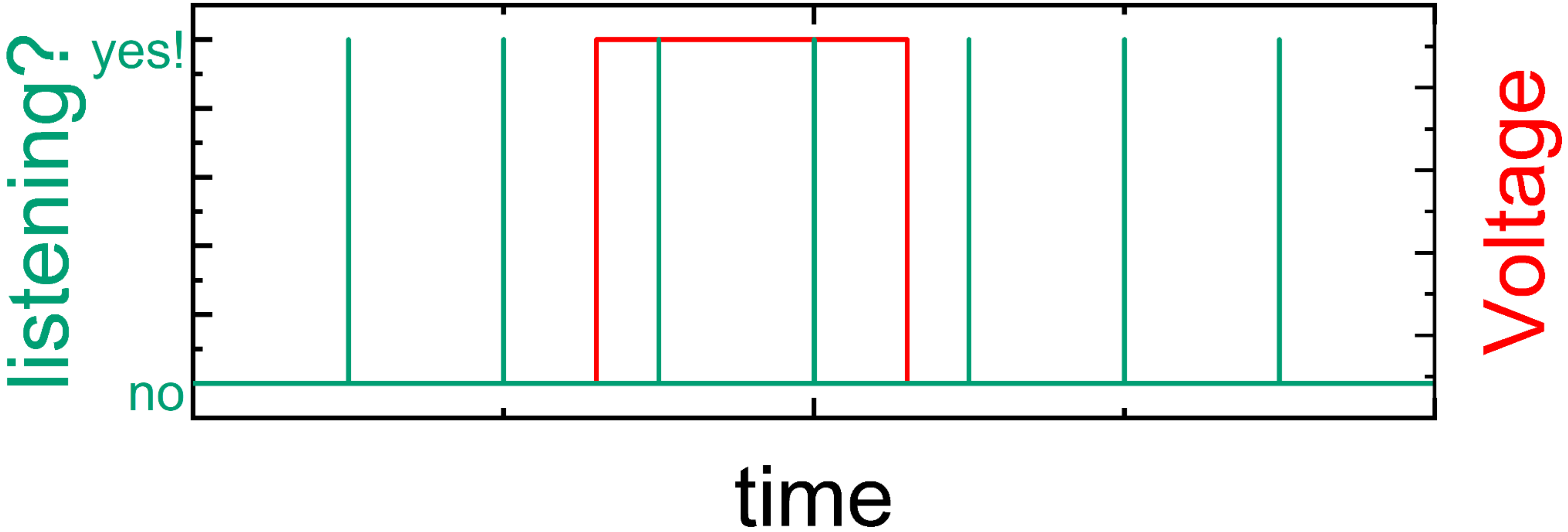
Solution 1: just make the pulse really long!

Instead of quick pulse, have a multiple second ‘pulse’

What if time per data point needs to change?

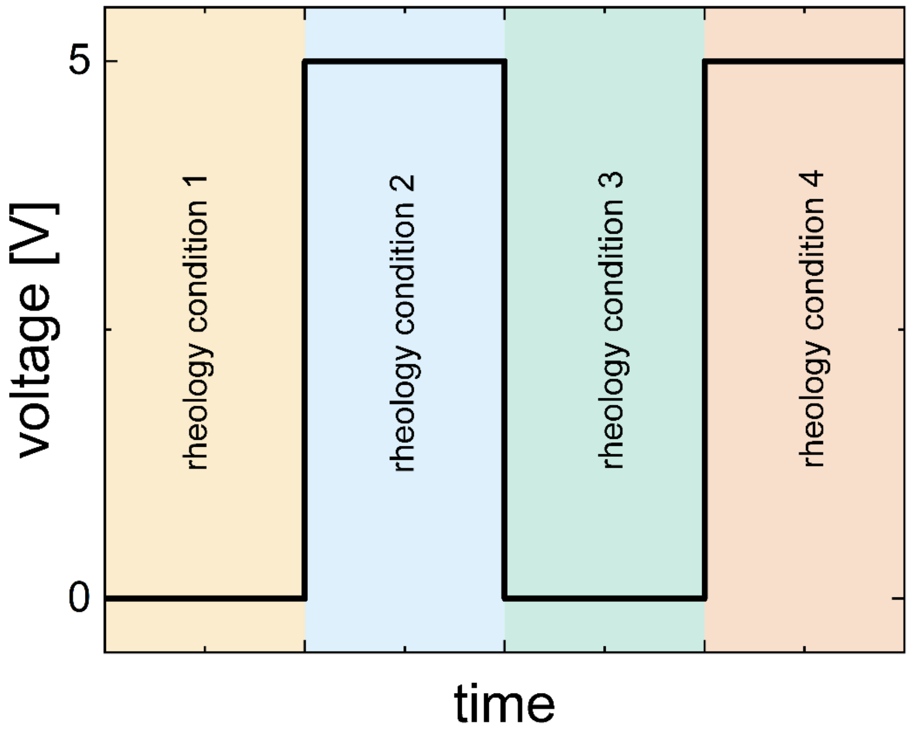
Could double trigger

Constant cat-and-mouse of chasing the right pulse length for every interval

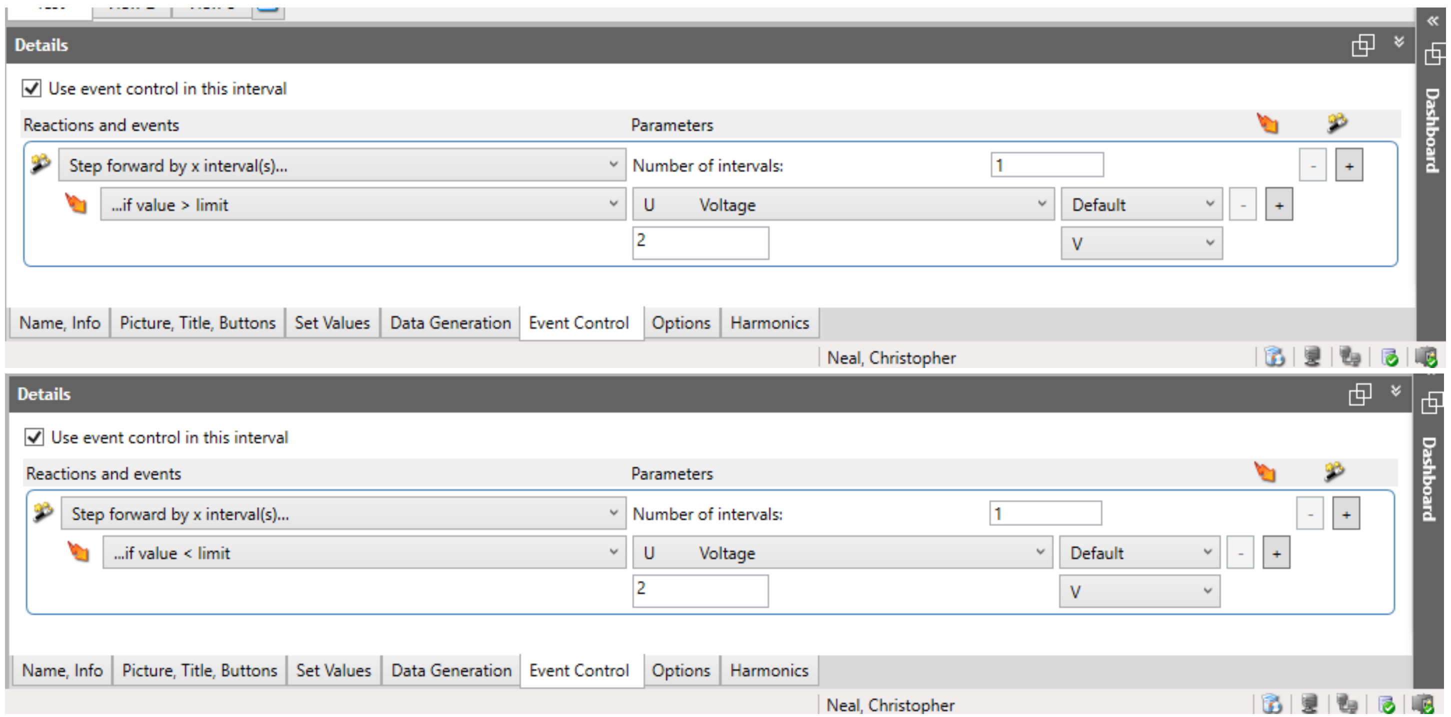


Solution 2: Toggle voltage

- Leave voltage high the entire second interval, rheometer waits for low voltage
- No double-triggering, no skipped triggers



- Now, rheometer configuration switches every interval
- All odd intervals (1,3,5…) have one configuration, even intervals have another



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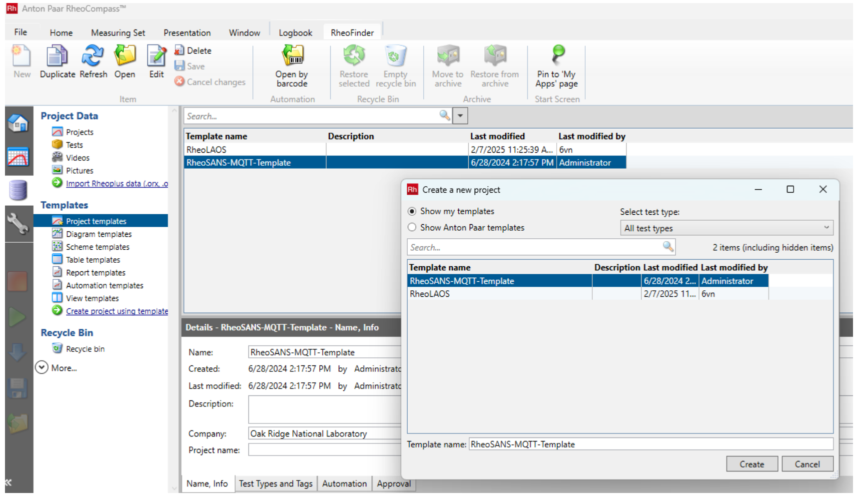
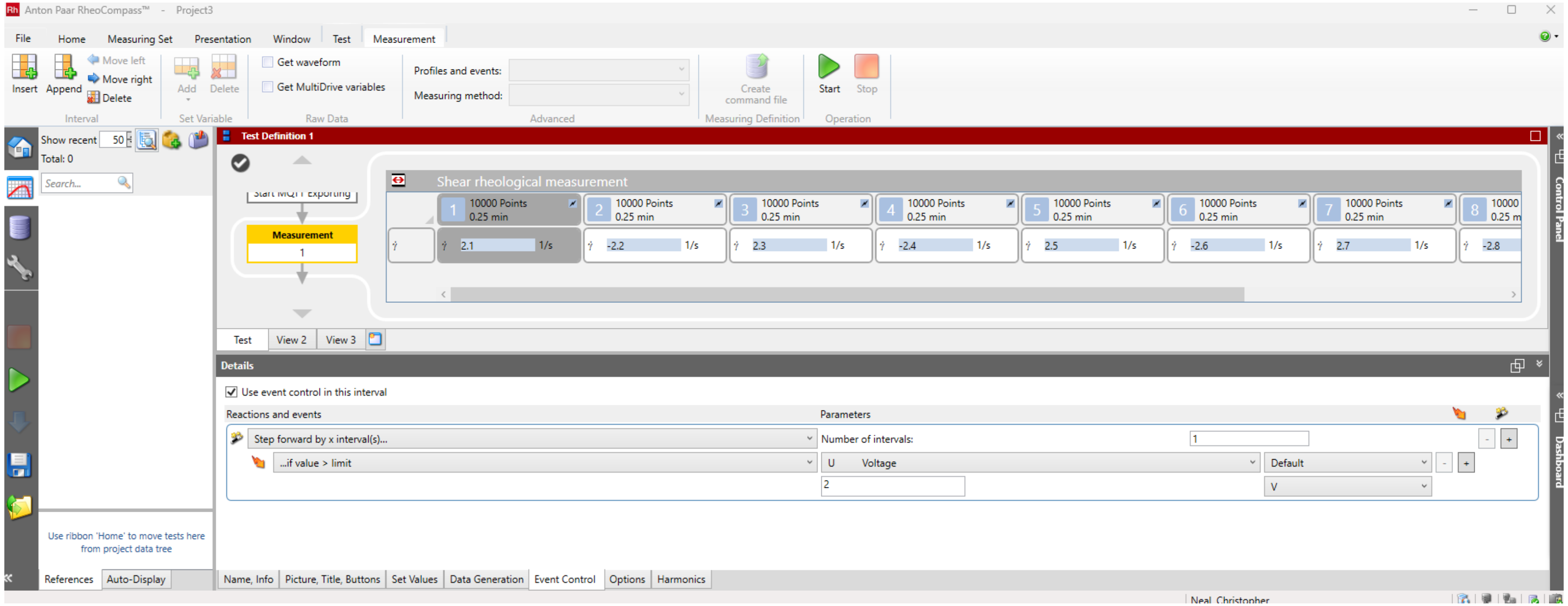
Set up Rheo-Scattering Template for easier user setup



Project template already has switching event control
User just has to edit shear rates
Saved a LOT of time, headache
Happy to provide if requested!



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Rheometer TTL triggering still suffers some latency

On MCR rheometers, external trigger advances the protocol at the next data point

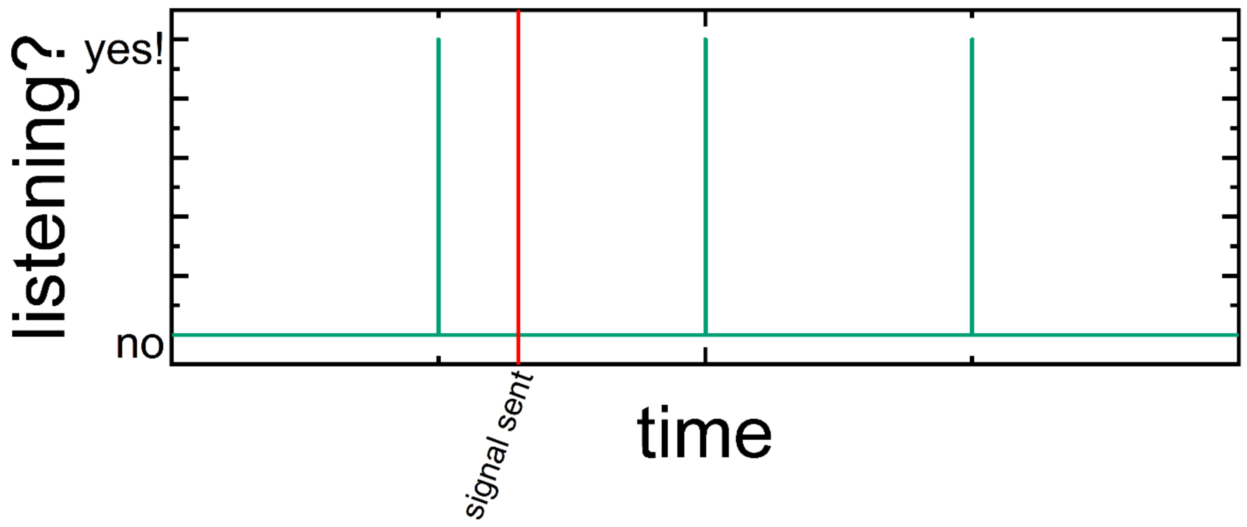
Deterministic, not real time

Triggering = **protocol coordination**, not **control**

SECoP may be more attractive when you want dynamic protocol changes

Does that make triggering useless?
No, triggering still gives immunity to network hiccups and a clean handshake between DAQ and the rheometer.

In either case, something else is required for sub-second resolution



	SECoP	MCR TTL trigger
Where is the logic defined?	Beamline	RheoCompass
When is the next step taken?	Software	Next data point
Timing granularity	Network + software	1-10 s
Determinism	Moderate	High (but coarse)
Phase awareness	None	None

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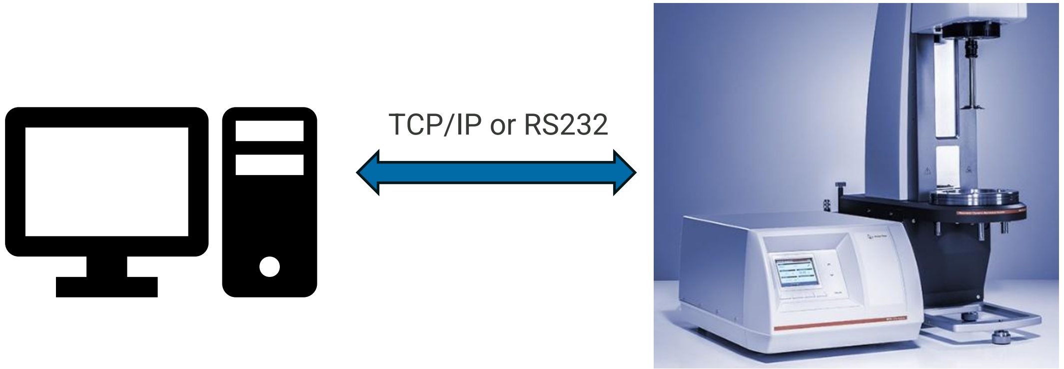
Listening TO the rheometers

Can we also receive data from the rheometer?

Rheometer triggering is one-way communication

Goal: tag at least some critical metadata into neutron files - Helps users troubleshoot if something looks off

Direct control has 2-way communications

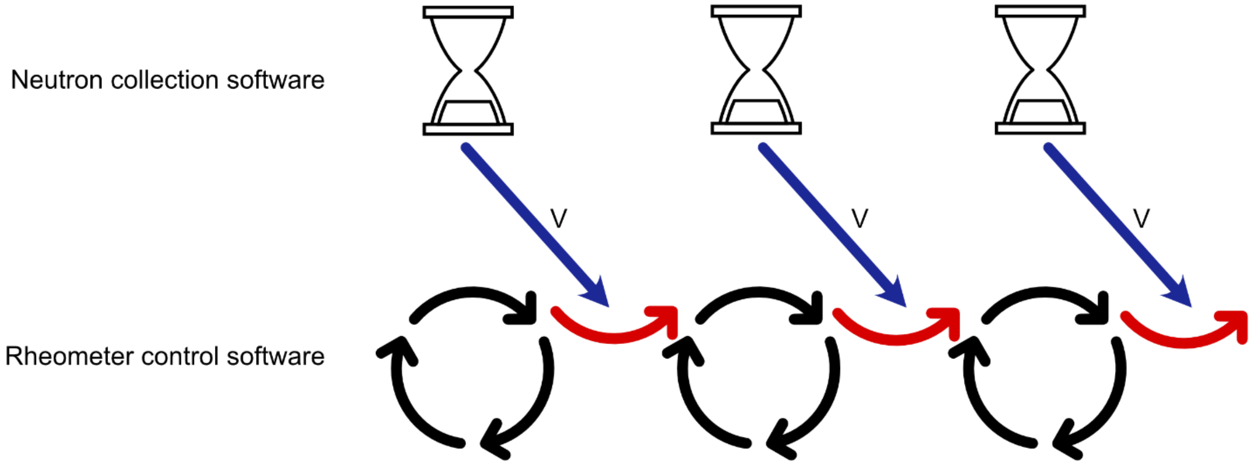


Data can be extracted directly

Anton Paar does not provide API

Extensive work required for integration

Triggering has 1-way communication



Two different data sets; one for neutrons, one for rheology.

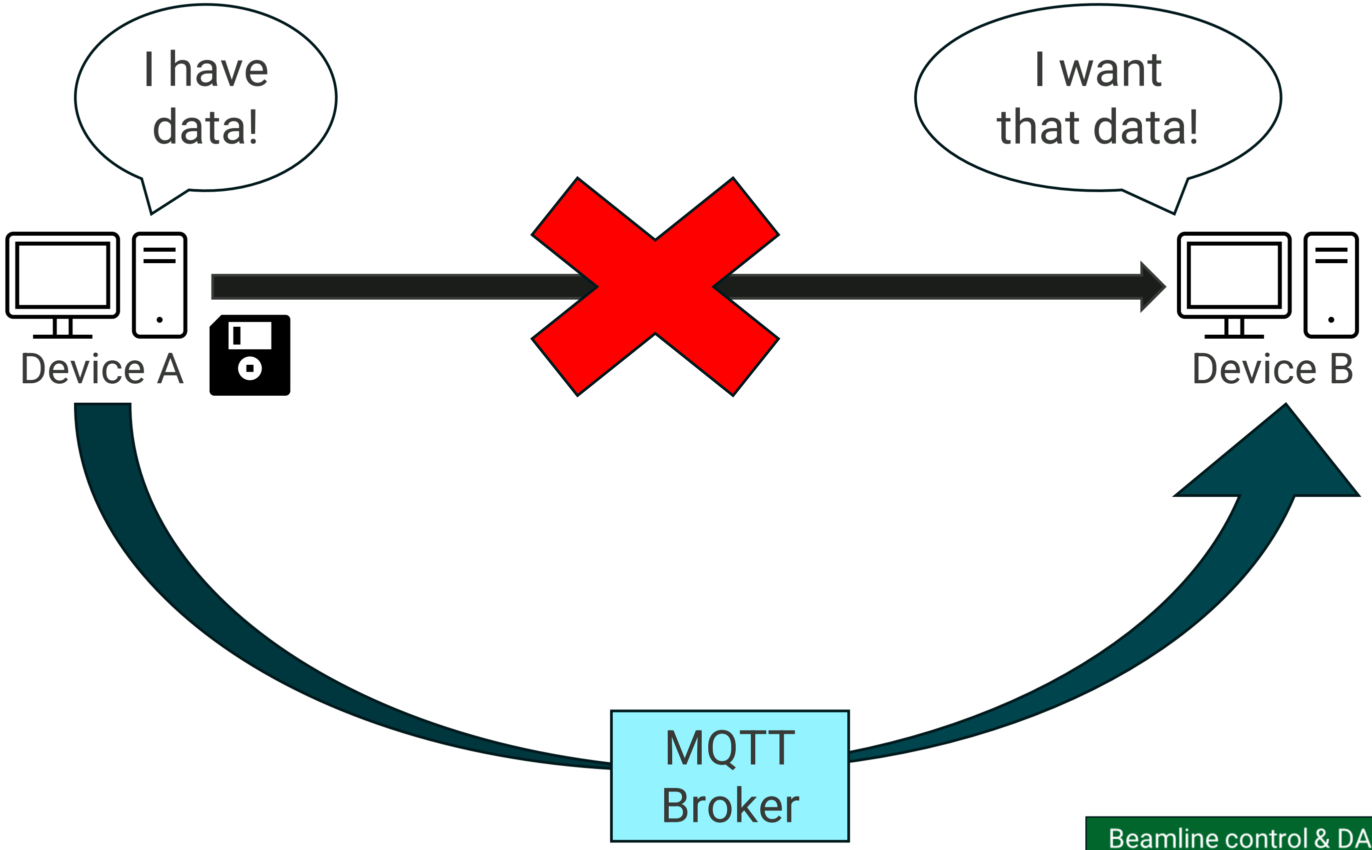
Latency, immediate data transfer (nearly) impossible

Can we pull data from the rheometer when triggering?

Anton Paar's solution: allowing communication through MQTT

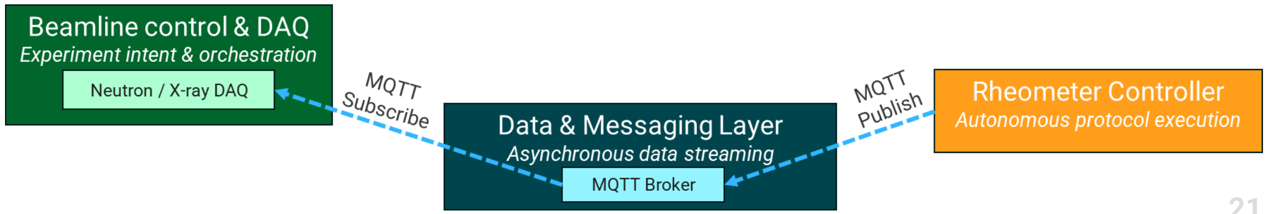
'Message Queue Telemetry Transport' – publish-subscribe messaging protocol

Typically, we work with client-server protocols, where device A talks directly to device B…. Not here



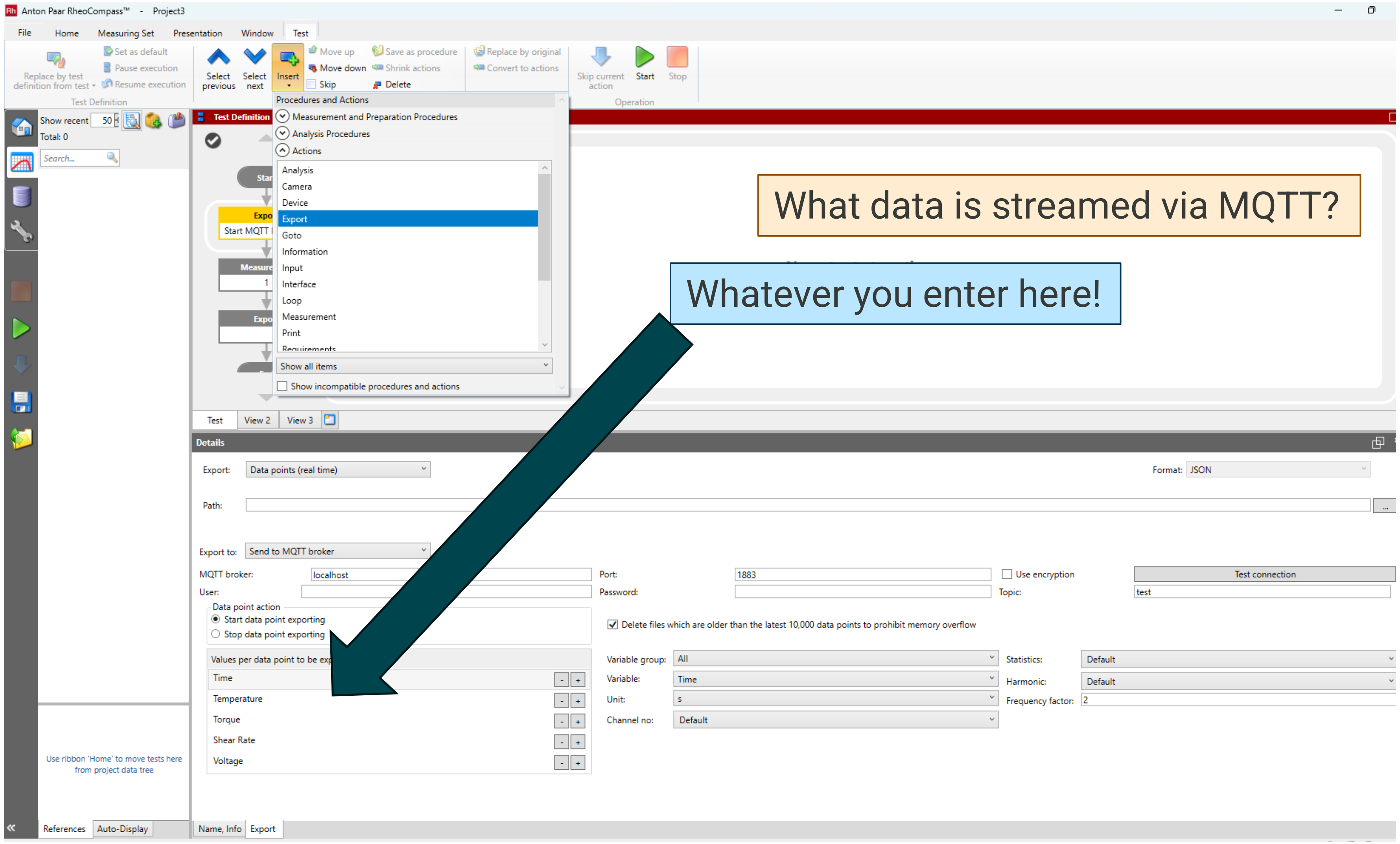
Why do we want to use MQTT?

- Publish/Subscribe does not wait for receipt confirmation
- Experiment can continue even if one data point not received.



How do we set up MQTT Communication? RheoCompass side

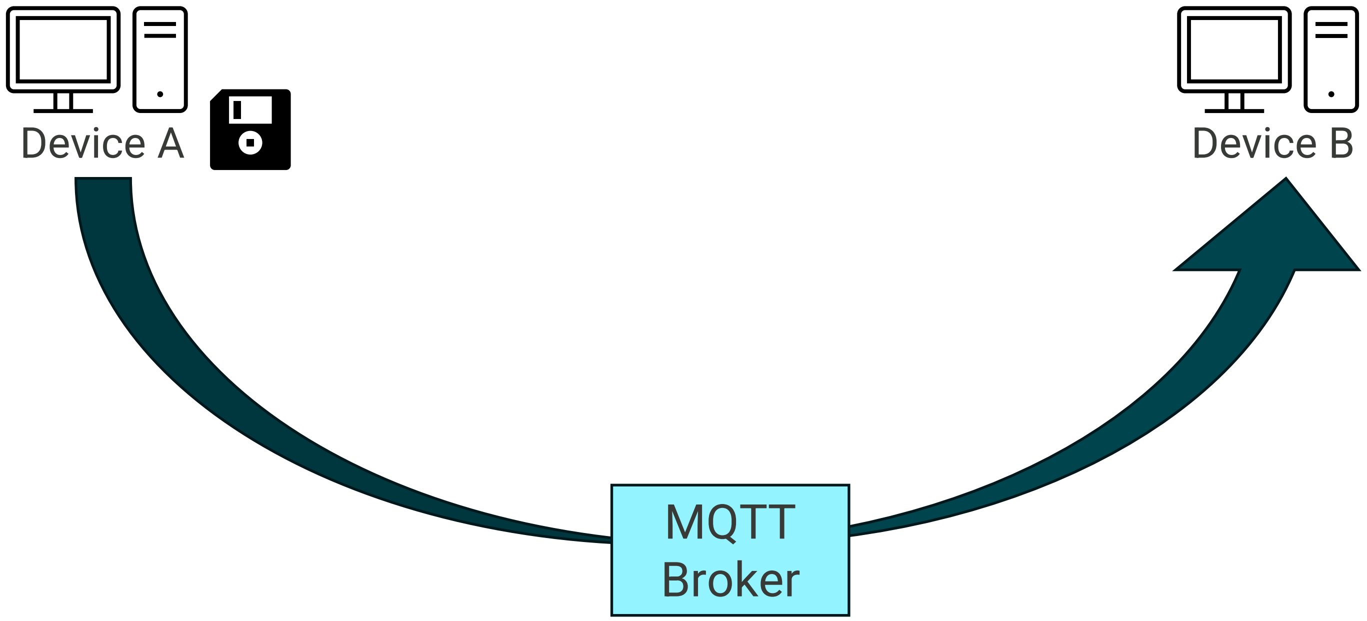
- Add ‘Export’ block before measurement starts
- Have RheoCompass Export ‘Data points (real time)’….’Send to MQTT broker.’
- Broker name: Windows account name running RheoCompass
- Select a port, topic that broker will be listening to.
    - Remember these!
- Select variables, units to export.
- All saved in Project Template (users do not touch).



How do we set up our MQTT broker?

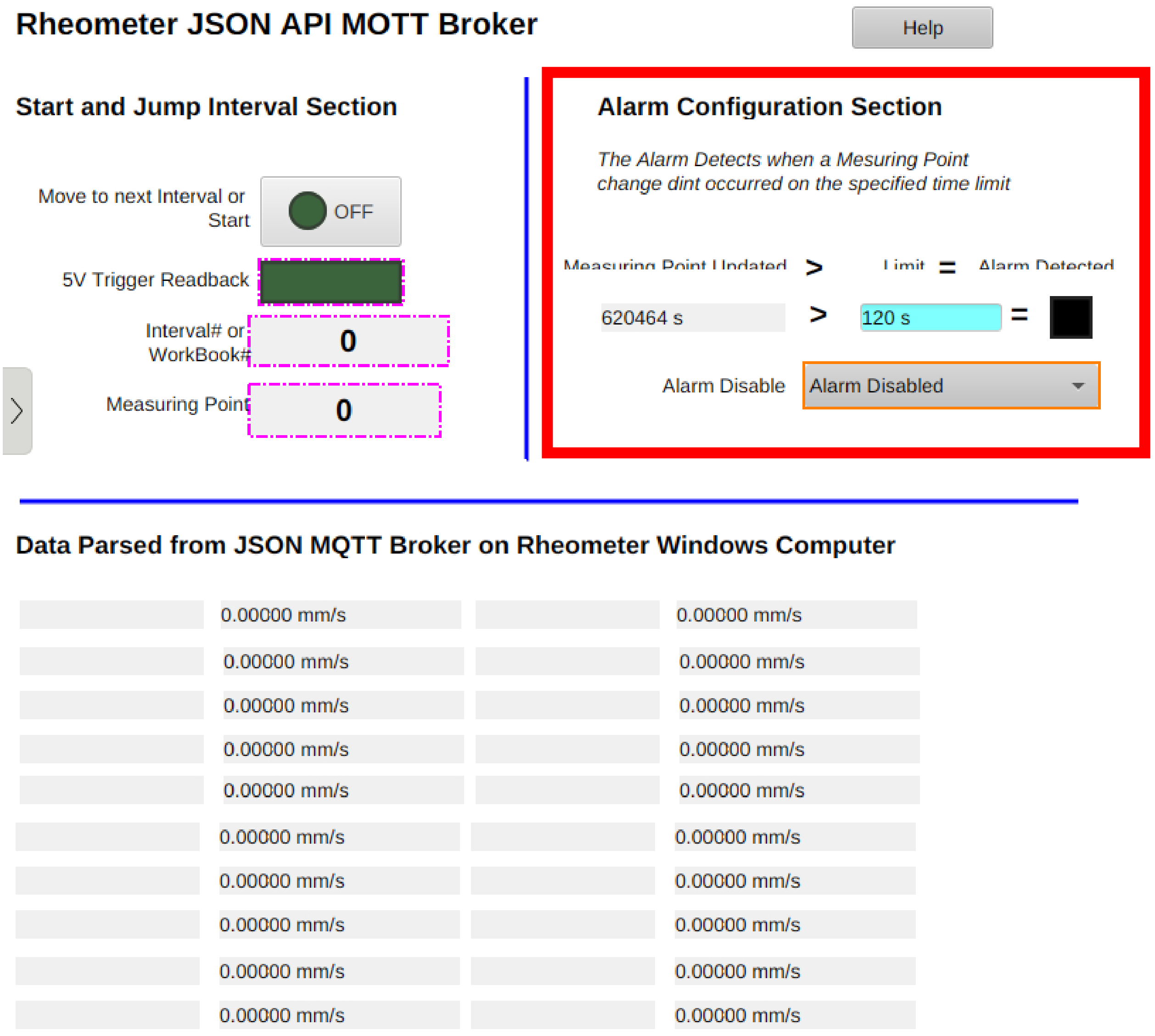
On the Windows machine running RheoCompass:

- Install Python, Eclipse Mosquitto, Python packages [numpy, paho_mqtt, pyparsing, setuptools, pyepics (last)
- Run python script in background:
    - Creates and connects to MQTT broker with known port, topic
    - Check for new messages every second
    - Parse message; send values, names, units to EPICS as desired PV’s



How does EPICS respond to MQTT data?

- RheoCompass generates interval + measuring point for every data packet
    - Also sent by MQTT broker, shown in EPICS
- Data table shown at bottom of IOC
    - Updates ~1/sec if data packet sent
    - Keep track of shear rates, temperatures, etc.
- Alarm handling if communication drops:
    - Alarms if packet not received after ~120s
    - MQTT broker breaking
    - rheometer failing.



High-resolution time synchronization

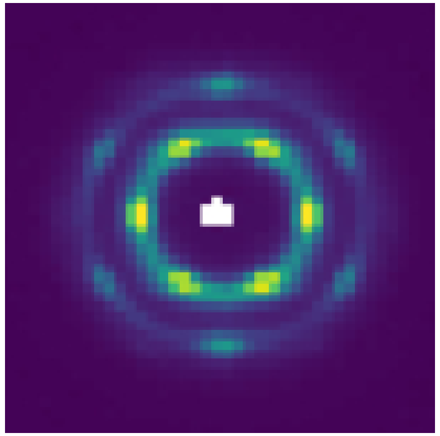
Can we achieve ms-level time-resolution?

1. control shear

2. log data output

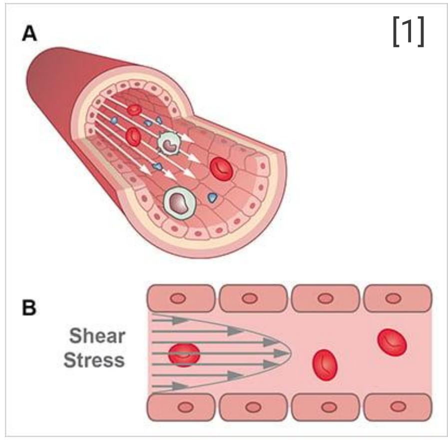
3. time resolution

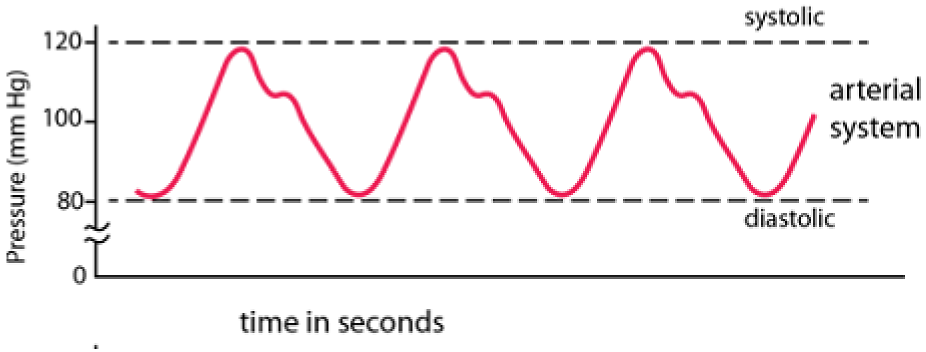
Detector



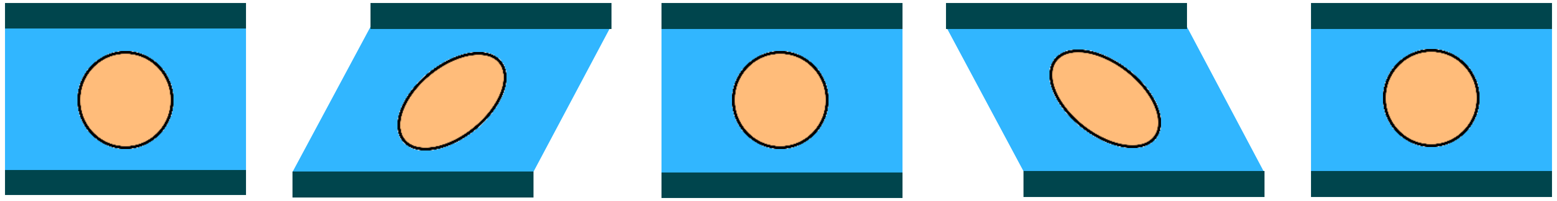
Why stroboscopic Rheo-Scattering?

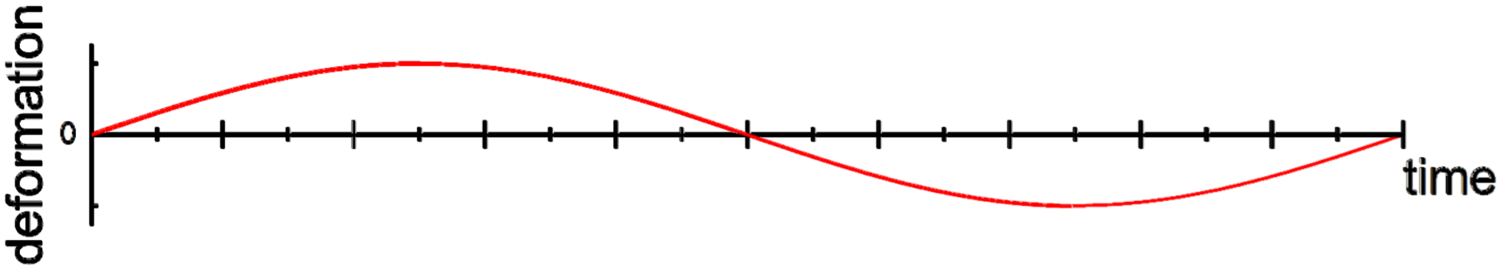
Periodic deformation exists in nature



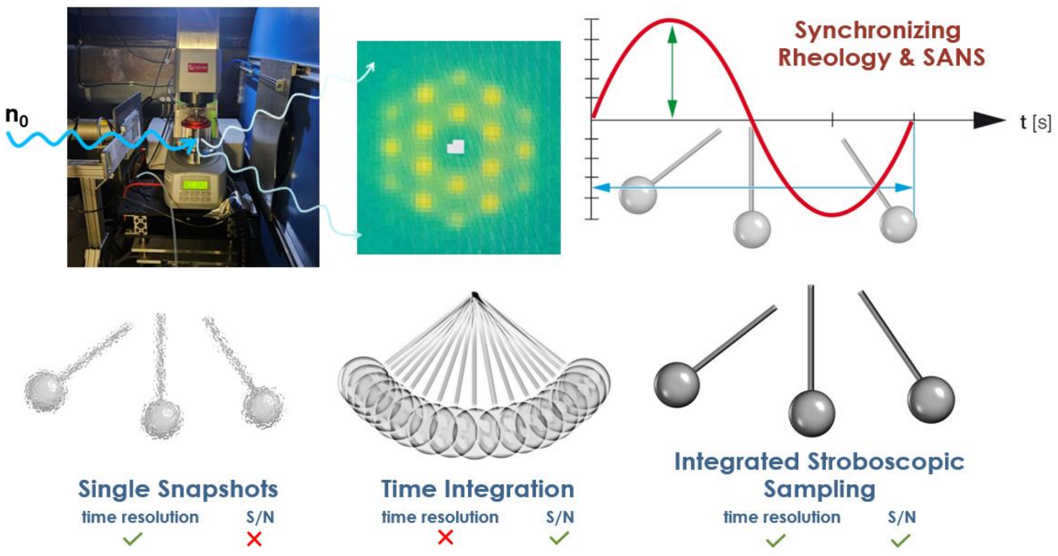


Large-amplitude oscillatory shear





Stroboscopic Rheo-SANS



Need: synchronize neutron scattering with oscillatory deformation

Result: bridge macroscopic mechanical properties with microstructural evolution

[1] ibidi.com [2] TA Instruments Inc.

Option 1: Sync signal sent at beginning of each oscillation

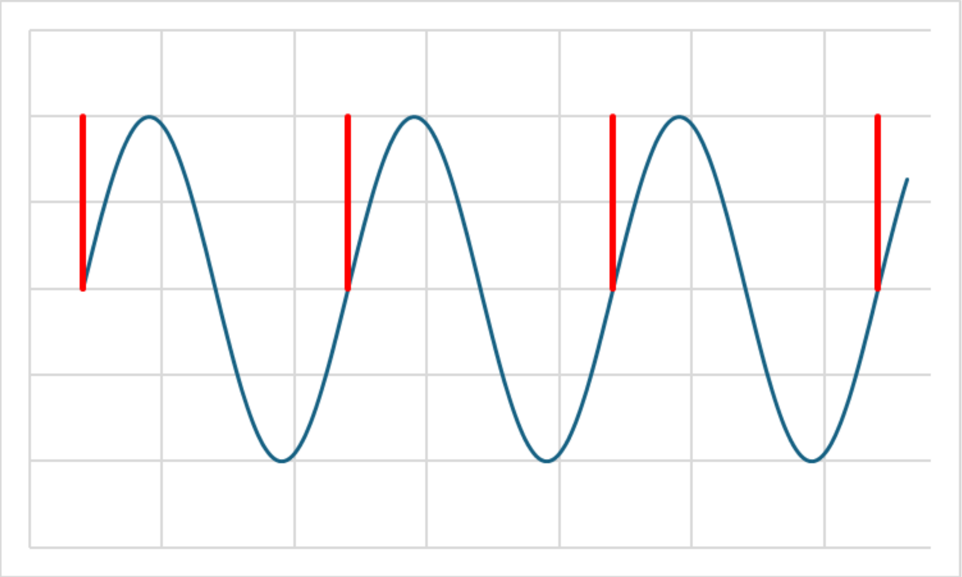
Rheometer Mechanics
Deformation & sensing

TTL →

Timing/ Trigger Hardware
Deterministic synchronization

→

Detector system
Time-resolved scattering measurement



One pulse per oscillation

Defines cycle boundaries

Phase inferred, not measured

Detector integrates relative to pulse

Gives repeatability at the cycle level, but not within the cycle itself

Simple

Minimal wiring

Stable over long runs

Assume waveform stability

Cannot correct distortions

Limited to simple oscillations

You KNOW which cycle you’re in, but have to assume where you are IN that cycle

Option 2: analog deformation signal spying

Rheometer Mechanics
Deformation & sensing
Angular Encoder

→ Analog Phase →

Timing/ Trigger Hardware
Deterministic synchronization
Rheometer encoder taps

→

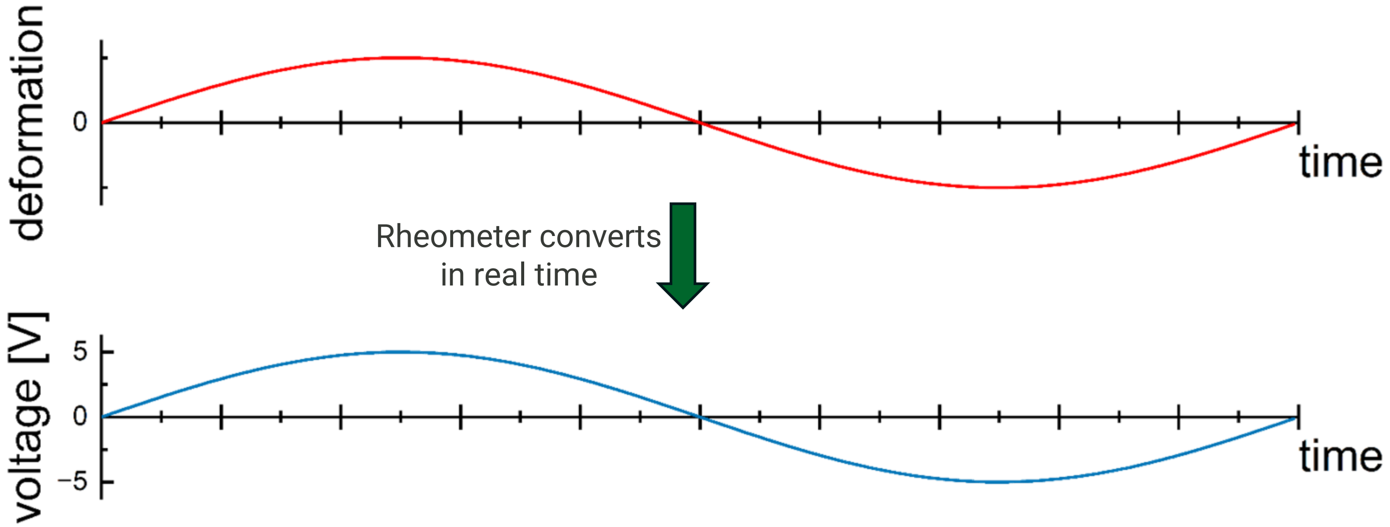
Detector system
Time-resolved scattering measurement

Continuous angle signal

True phase information (including glitches!)

Independent of rheometer timing

Enables stroboscopic gating



Instead of assuming phase from timing, we measure it

True phase

Immune to frequency drift

Works with non-sinusoidal waveforms

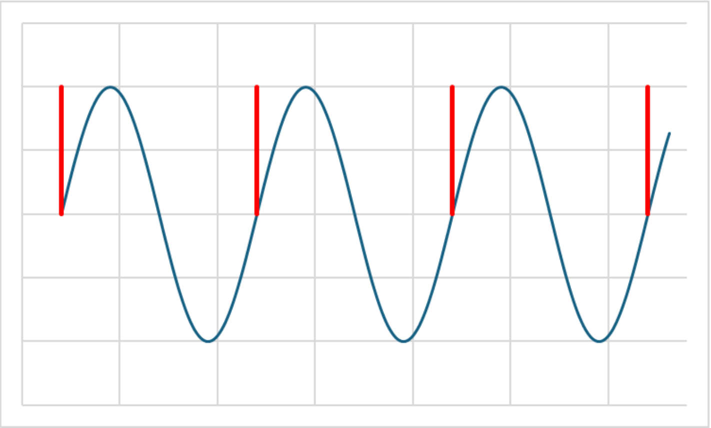
More complex hardware

Requires signal conditioning

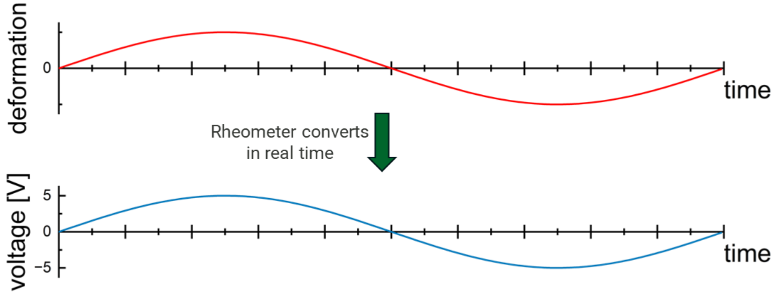
Data analysis can be tricky

Treats the rheometer as a signal source, not a clock

Sync pulse vs. Signal Spying



	TTL Sync Pulse	Analog Signal Spying
Time reference	Cycle Start	Instantaneous Phase
Phase resolution	Infered	Measured
Drift tolerance	Low	High
Hardware complexity	Low	Moderate*
Waveform assumptions	Sinusoidal	None
Stroboscopic fidelity	Moderate	High



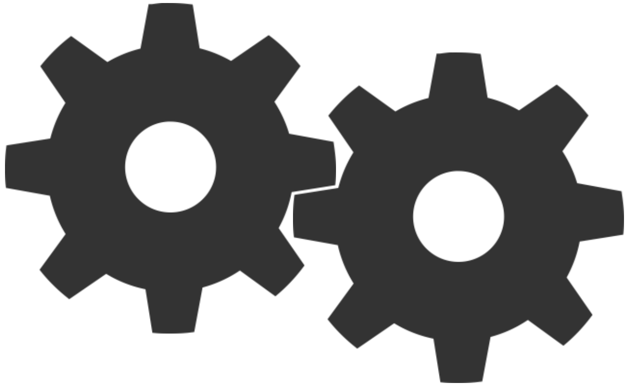
It doesn't HAVE to be either/or. It can be both!

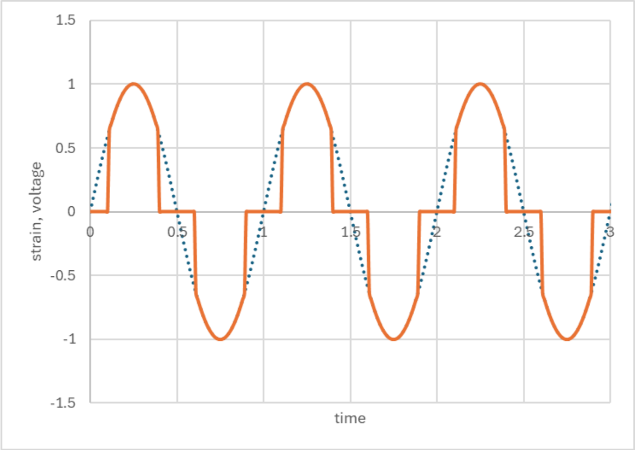
Sync pulse = absolute reference

Analog signal = local truth

REDUNDANCY

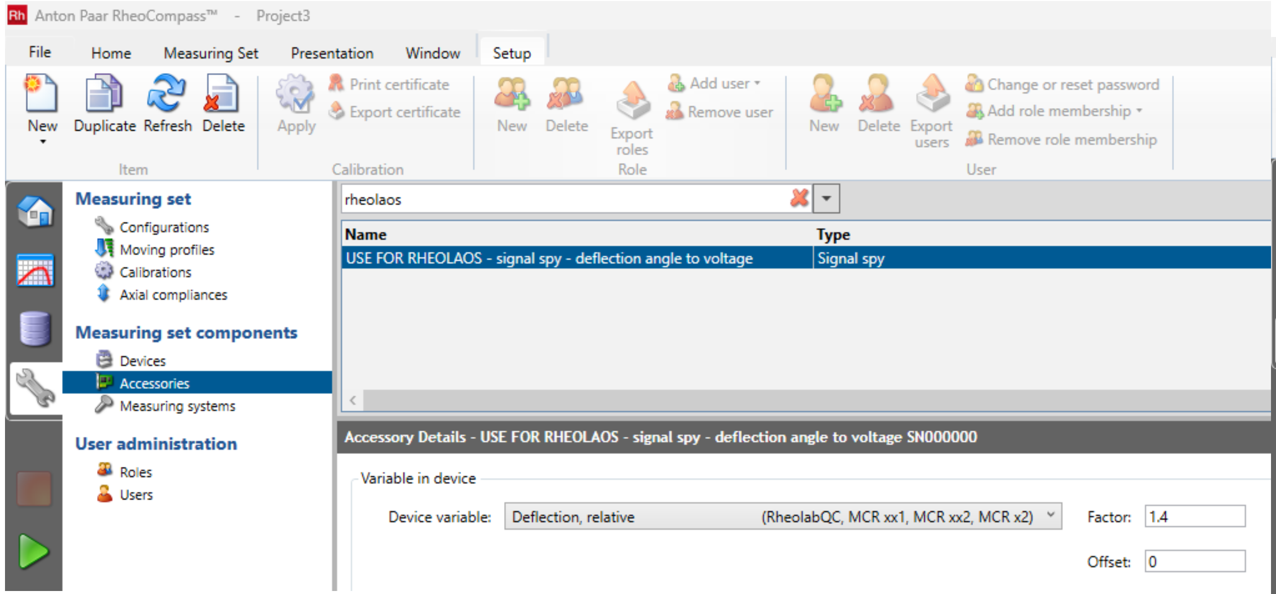
Recent rheo-experiment with bevel-gear system

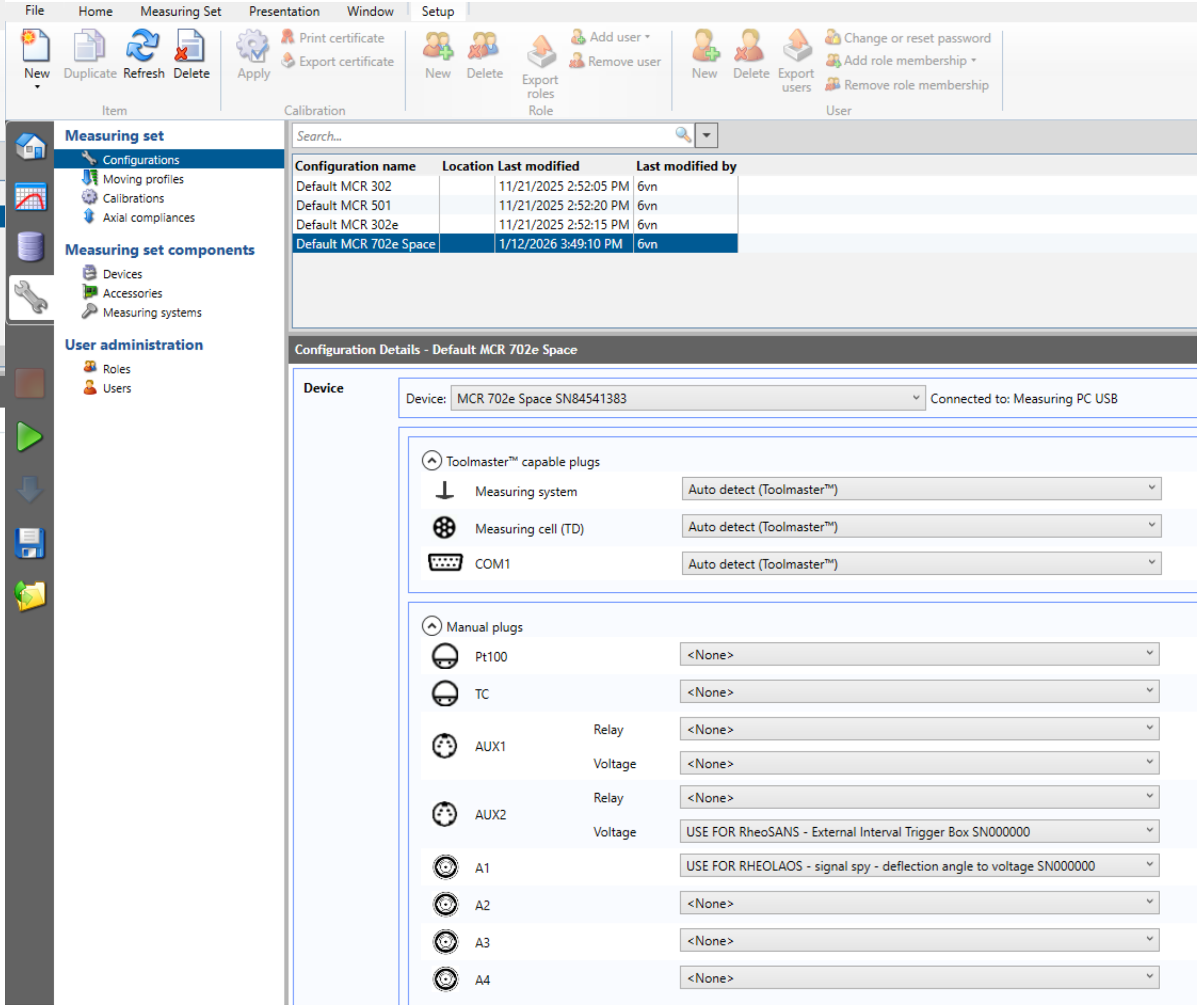




Gear backlash = non-sinusoidal response
Only visible via signal spying

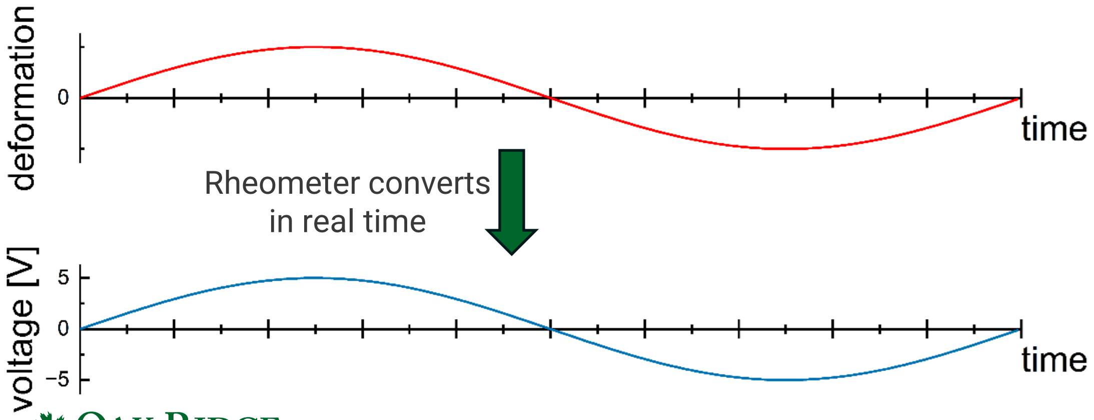
How to convince RheoCompass to give us the right signal?





Set up accessory that ‘spies’ on deflection angle, φ

$$V = (\text{factor}) * \varphi + (\text{offset})$$

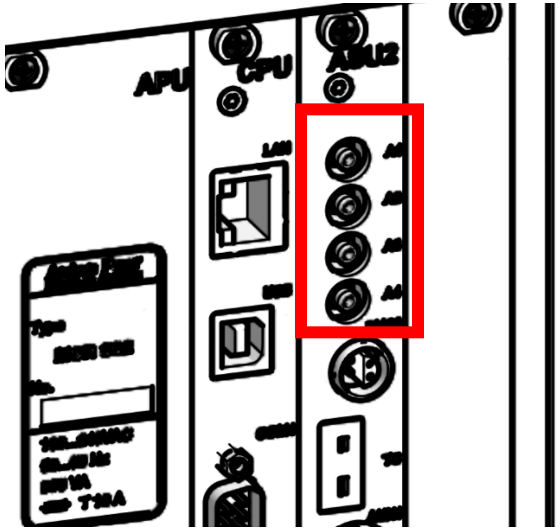


Where to plug the signal cable into the rheometer?

<u>MCR xx2 series</u>
SMB-to-BNC
095-850-236-006
Available on Digikey, Mouser
~$20 USD/cable

Table 12: Analog outputs A1 to A4

	Pin	Name	Description
 A1	inner	analog signal	Analog representation of a value as voltage between -10 V and +10 V.
	outer	GND	Signal ground



Up to 4 outputs!

<u>MCR xx1 series</u>
BNC
115101-19-06.00
Available on Digikey, Mouser,
(pretty much anywhere)
~$10 USD/cable

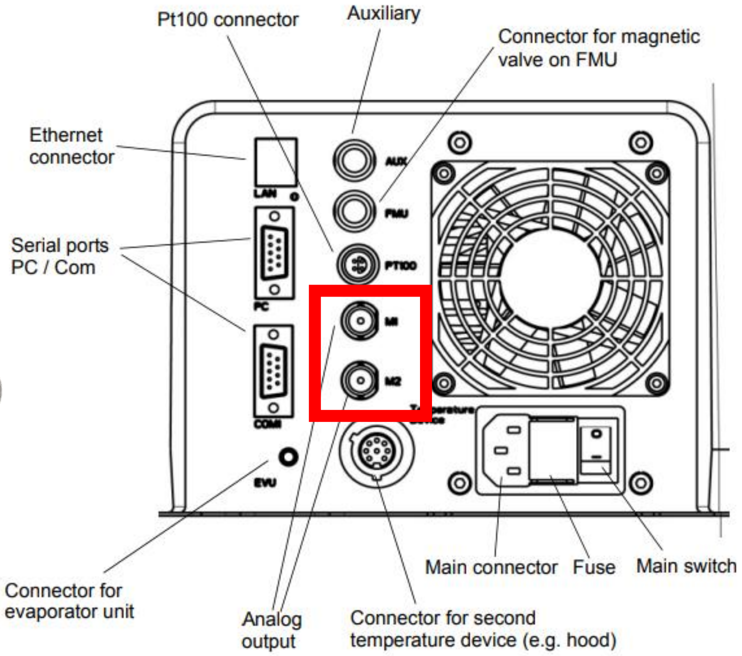
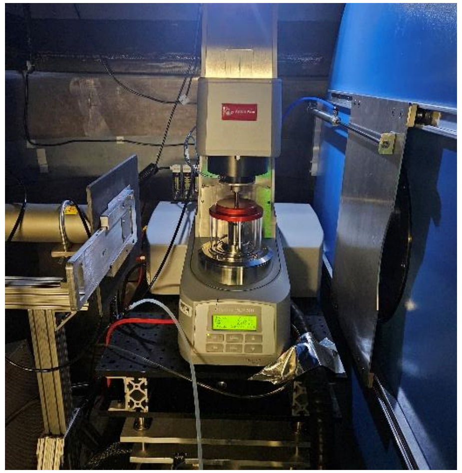


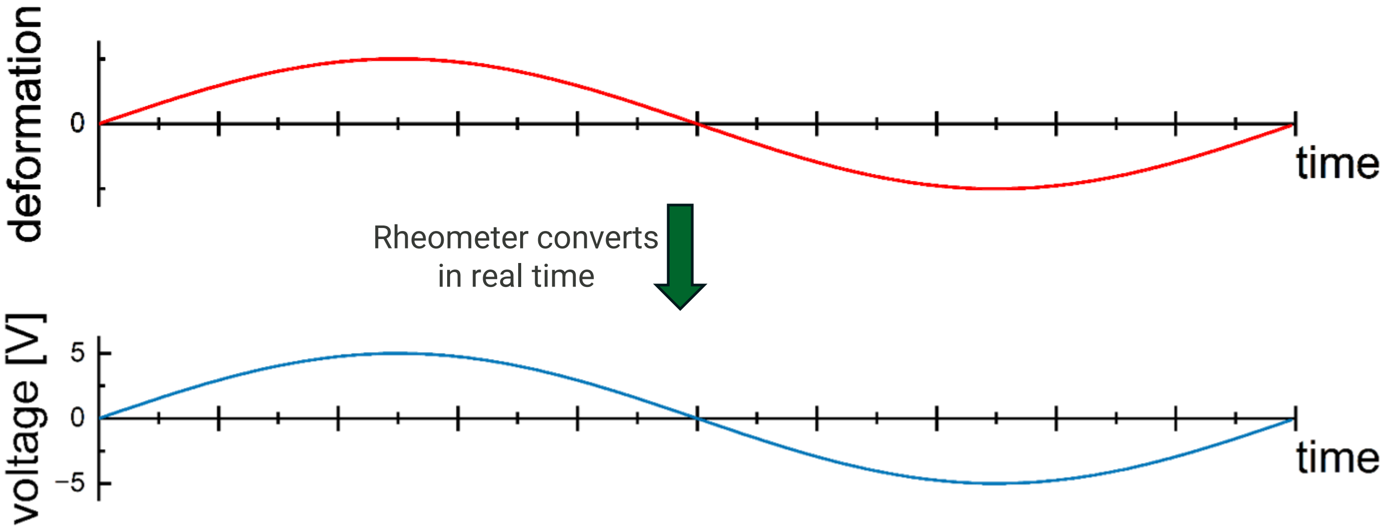
Fig. 6 - 2 Side panel - Physica MCR xx1

Up to 2 outputs

Communications pathways for time-resolved Rheo-SANS



Anton Paar MCR 501



data

Analog-to-Digital Converter ReadOut Card 'ADC ROC'

Analog-to-Digital Converter 'ADC' → data → Time-stamping → timestamped data → Beamline control system

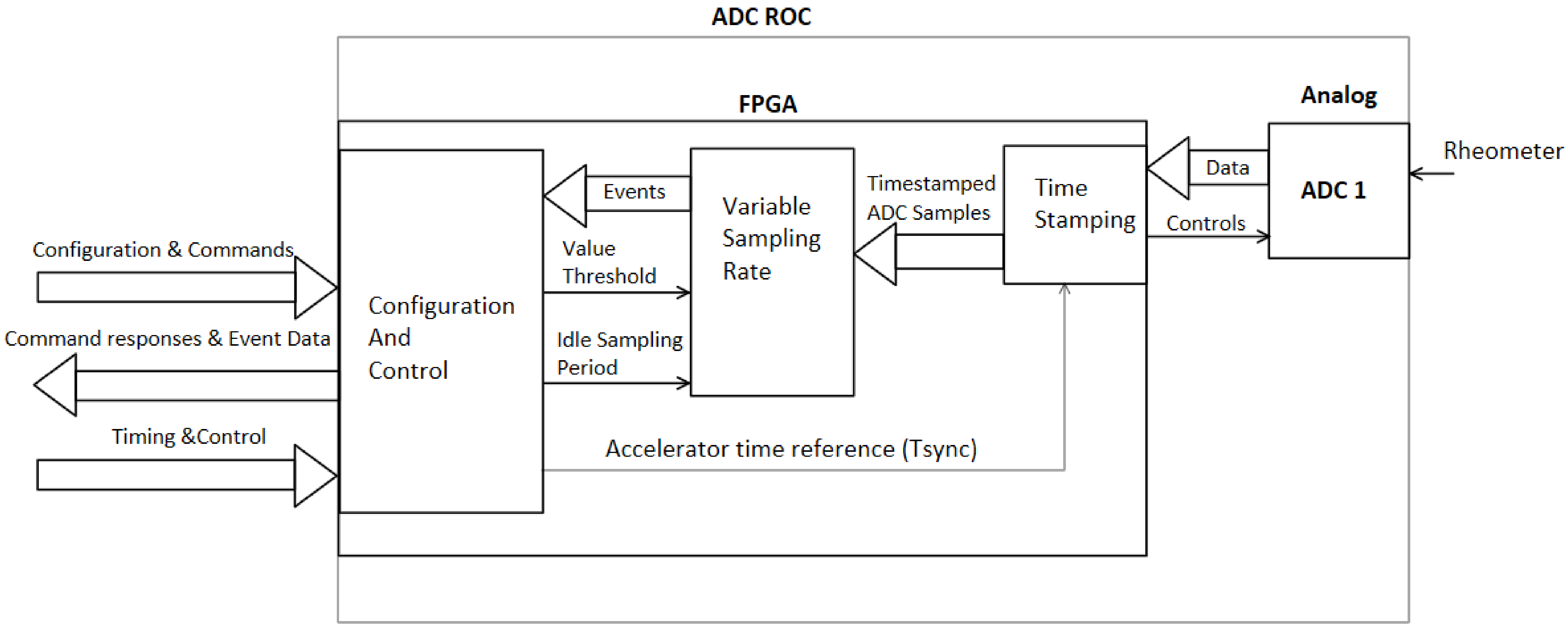
Accelerator Reference time

Accelerator reference timestamped neutron events

Synchronized Nexus files!

Expanded view of timestamping system – ADC ROC

FPGA = Field-programmable Gated Array (or, “Fast, precise gated acquisition!”)
Ns-resolution stopwatch to timestamp analog signal

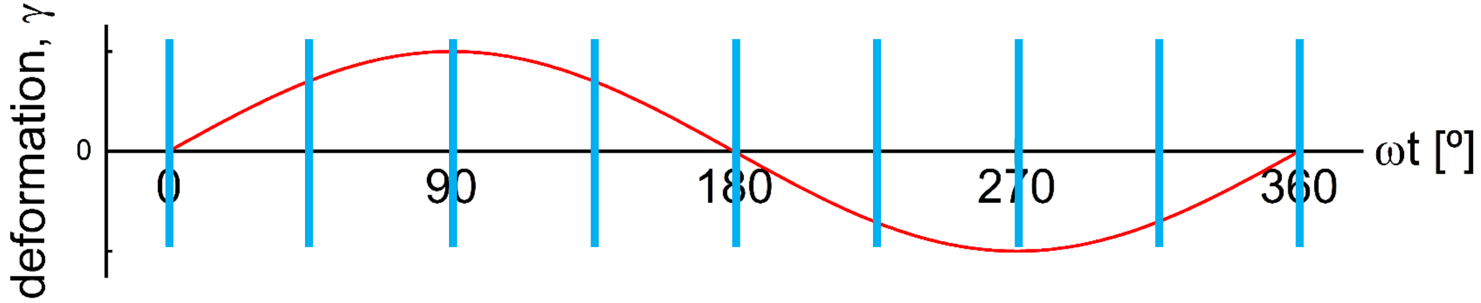


Relies on accelerator time reference
ORNL’s HFIR has ‘pseudo-accelerator time reference system’

Andrew Nelson from ANSTO has clever method of doing this with a raspberry pi!

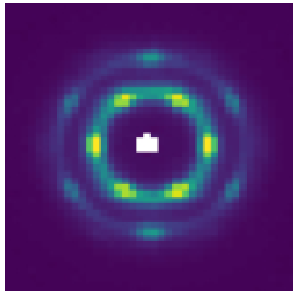
OAK RIDGE National Laboratory

How do we time slice the data to extract meaningful results?

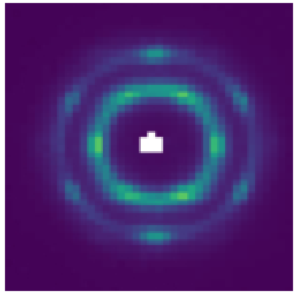


ω = 10.01 Hz
γ_{max} = 100%

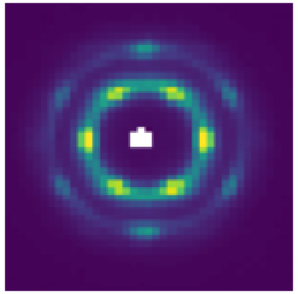
ωt = 0º

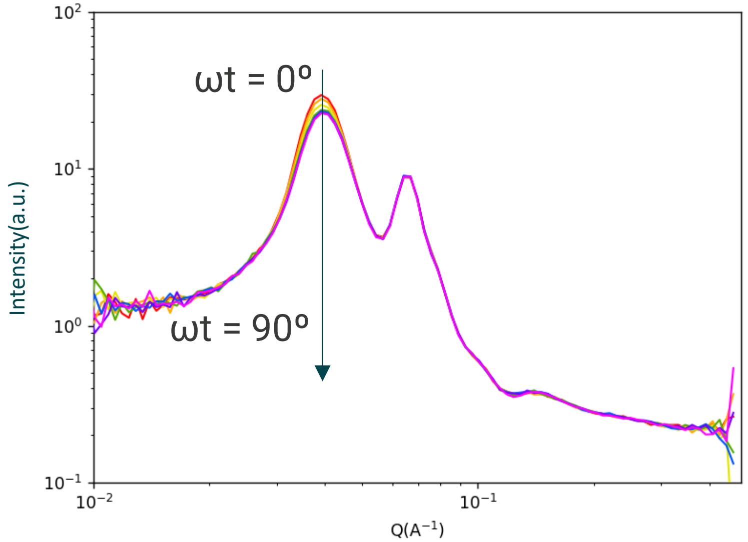


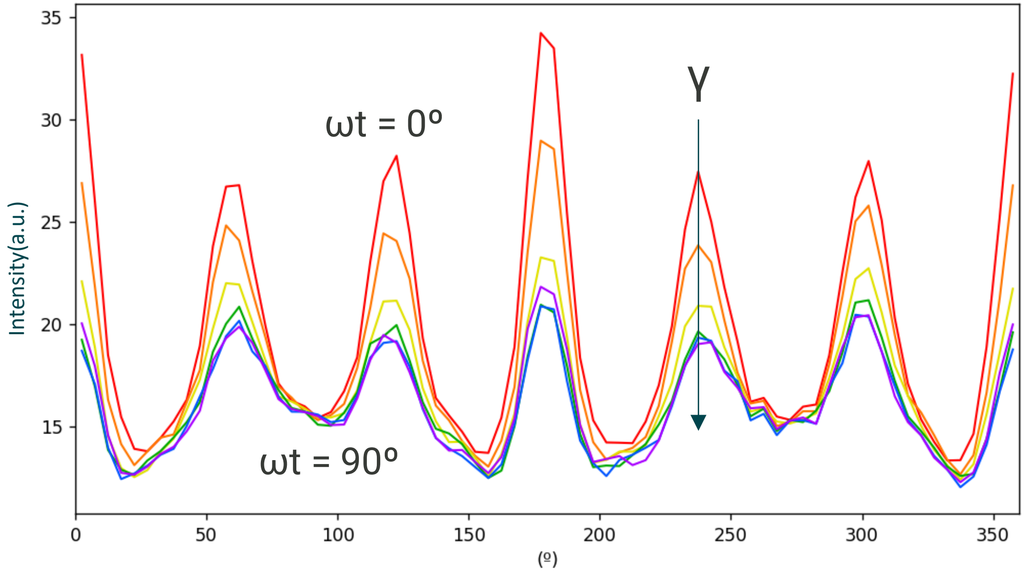
ωt = 90º



ωt = 180º





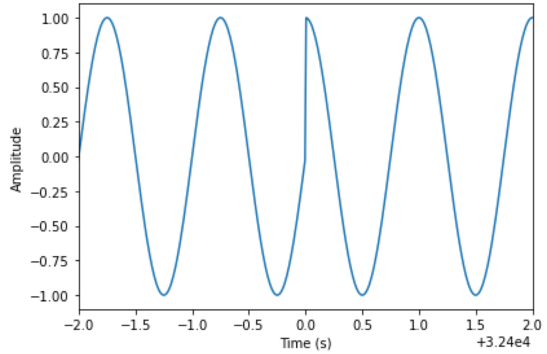


Clear changes in low-q scattering intensity within oscillating shear

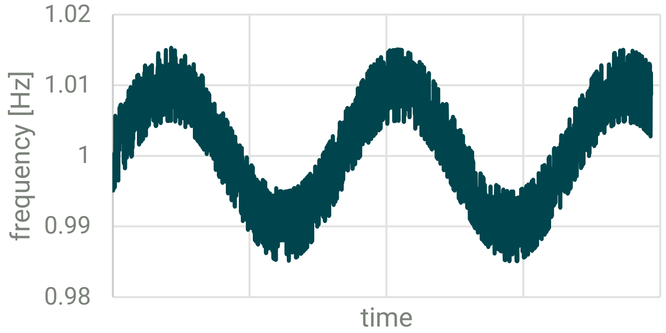
Frequency shifts and drifts: making data analysis hard

We're relying on the rheometer outputting constant, steady oscillations over long times (hrs)

<u>Frequency Shift</u>
Sudden change in phase

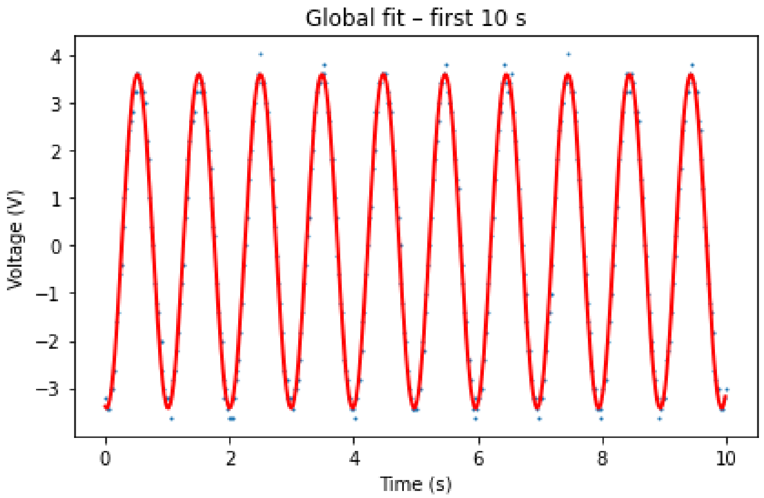


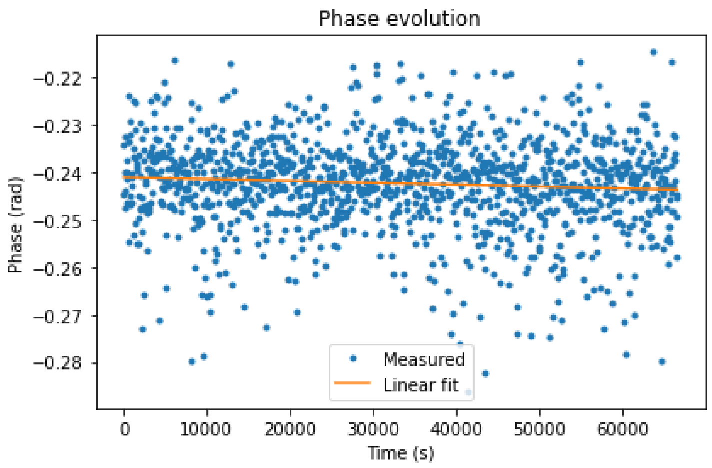
<u>Frequency Drift</u>
Varying frequency over time

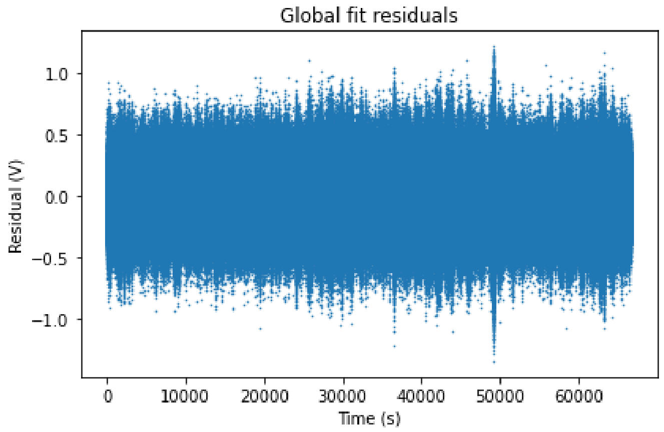


Can we be confident in analog signal spy?

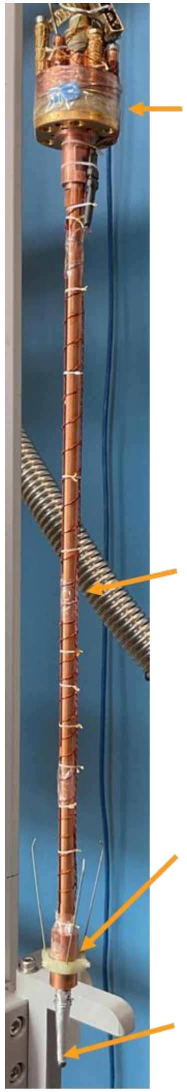
We're researchers, lets put it to the test!
Ran 1 Hz oscillation to oscilloscope for 22 hours, zero shifts or drifts







Developing stroboscopic techniques isn't just for Rheo-scattering



Thermal Link

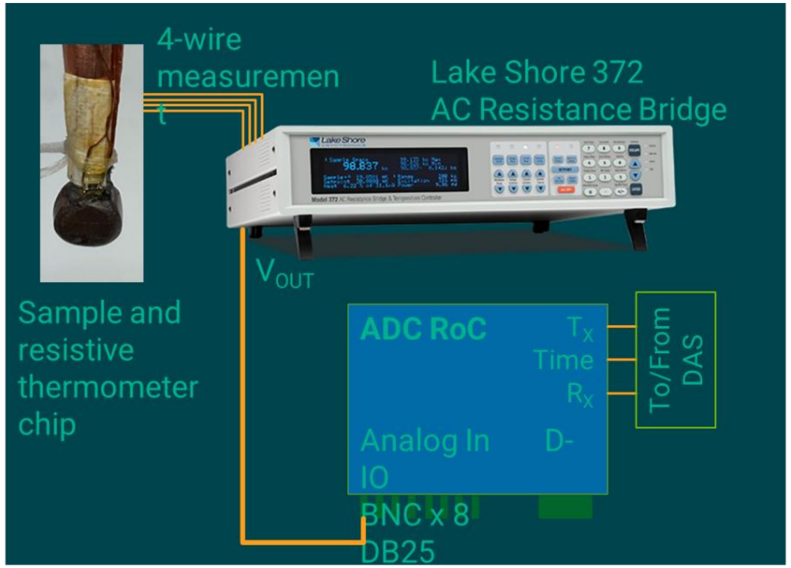
RuO_2 Thermometer on Thermal Link

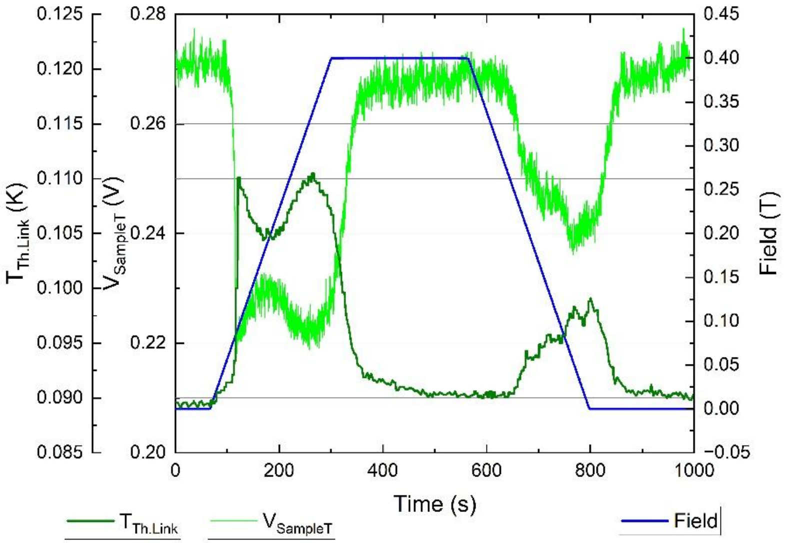
Sample and RuO_2 Thermometer Chip

5 T Vertical Field Split Pair Magnet

Magnetocaloric effect – measuring heat generation/consumption from magnetically-induced phase transitions

Sweep magnetic field, measure voltage from temperature sensor





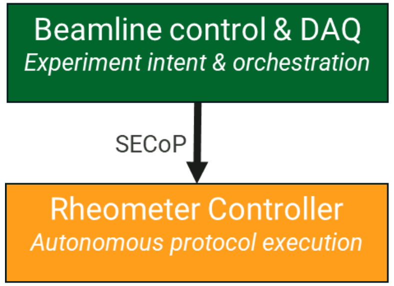
Contact Todd Sherline for more information:
Sherlinete (at) ornl.gov

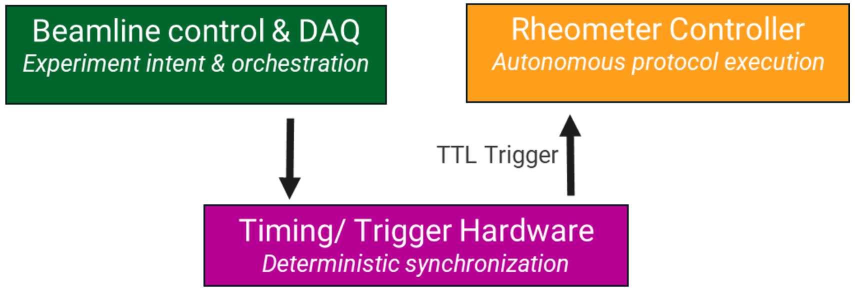
Summary: Rheo-Scattering works when communications intentional

Rheometers and scattering instruments speak different languages, want different things

Control: who is driving?

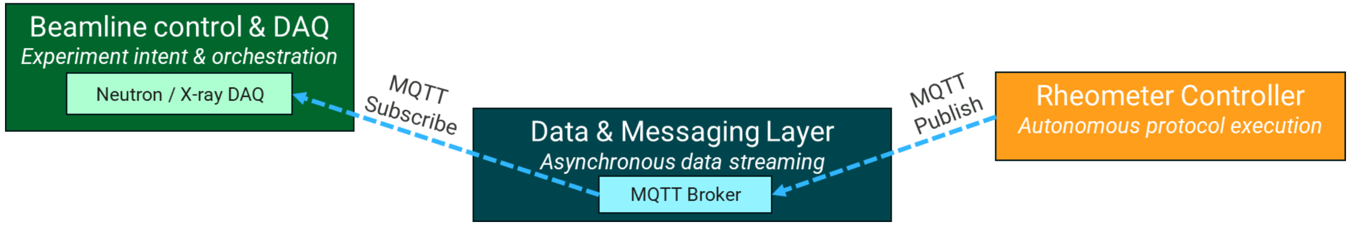
SECoP direct control vs. indirect TTL triggering





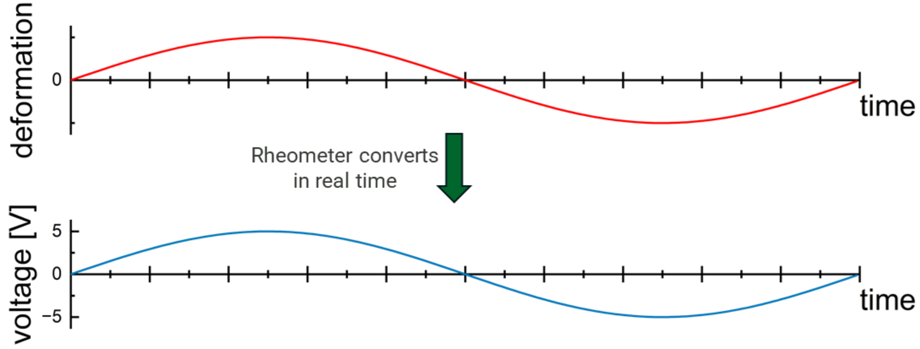
Communication: listen to the rheometer

Publish/Subscribe for uninterrupted data transfer



Timing: listen to the hardware

Analog signal spying gives full phase information



Rheo-Scattering succeeds when:
Control is intentional
State is communicated
Physics directly observed

Acknowledgements

Oak Ridge National Laboratory


Luke Heroux

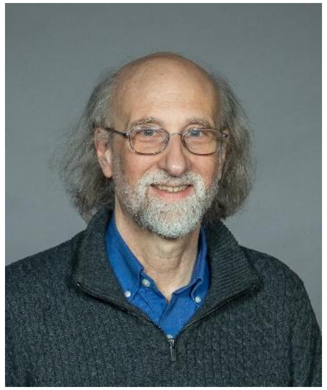

Gernot Rother


Wei-Ren Chen


Changwoo Do

NIST Center for High-Resolution Neutron Scattering


Katie Weigandt


Paul Butler


Ryan Murphy

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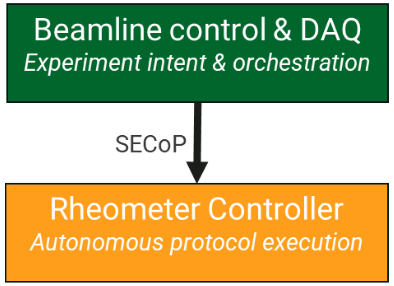

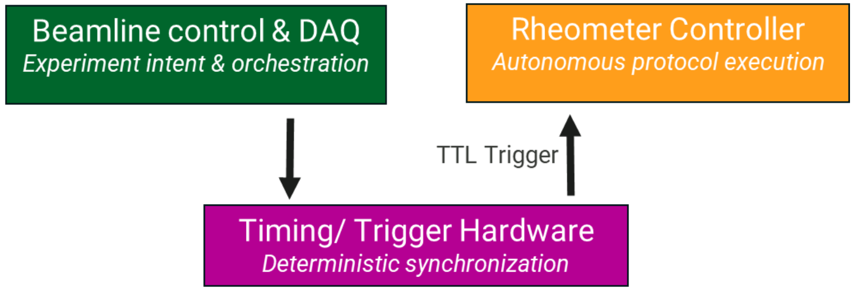

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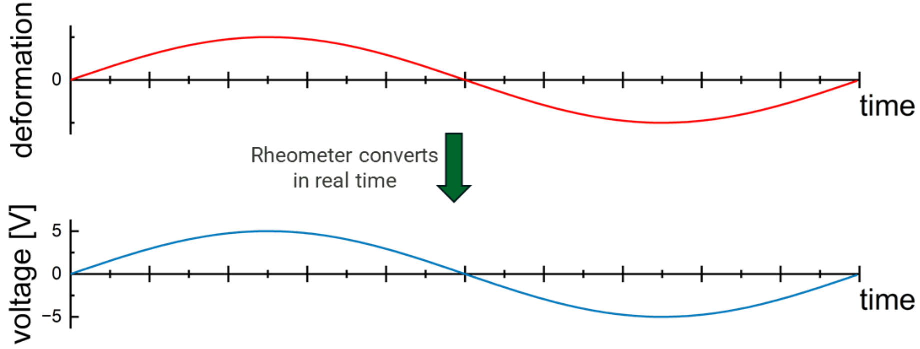

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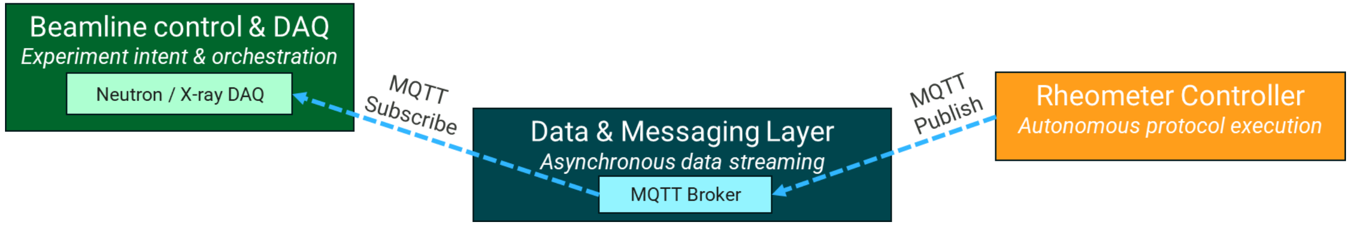

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