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Neutron Data Acquisition from SINQ to ESS

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Agenda

- Why Neutrons?
- Neutron Detection
  - Gas Detectors
  - Szintillators
- Time of Flight Data Acquisition
- The complete system at SINQ
- In what way is ESS different?
- Workshop aims

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Why Neutrons?

- Because anything with atoms was seen as the future and cool in the 1950-1970
- Why did it survive our age of optimization and cuts then?
- Boys like big machines….., politicians are mostly boys
- There is real scientific value

Scientific Value of Neutrons

- Compared to x-ray neutrons penetrate
  - Look at bulk properties of matter
  - Allows for extreme sample environment
- Neutron cross section varies wildly across periodic system
  - Can distinguish elements which cannot be resolved with x-rays
  - Can see H
  - Can be used for isotope labelling
- Neutrons have a magnetic moment
- Neutrons allow to study dynamic properties in materials

Neutron Sources

- Research Reactors: ILL, HMI, Munich, Saphir,…
- Continuous flux spallation sources: SINQ
- Pulsed spallation sources: ISIS, SNS, ESS, …

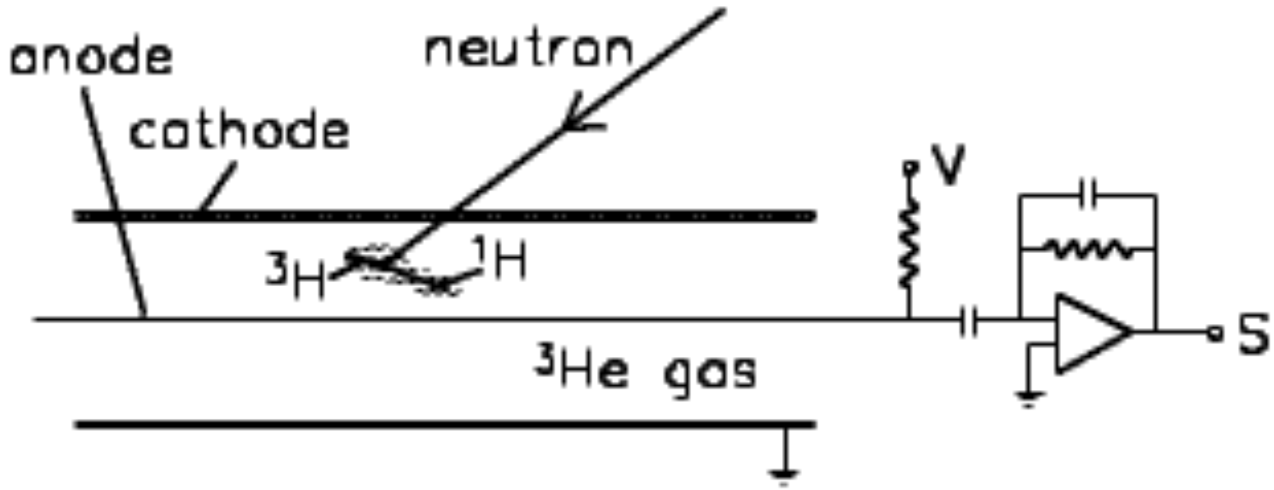
Neutron Instruments

- Transmission
- Elastic neutron scattering
  - Braggs law: n * lambda = 2 *d * sin(theta)
  - diffractometers, reflectometers, SANS
- Inelastic neutron scattering
  - monochromate, interact, analyse, detect
  - detects energy changes in the neutron beam
  - spectrometers

Neutron Reactions

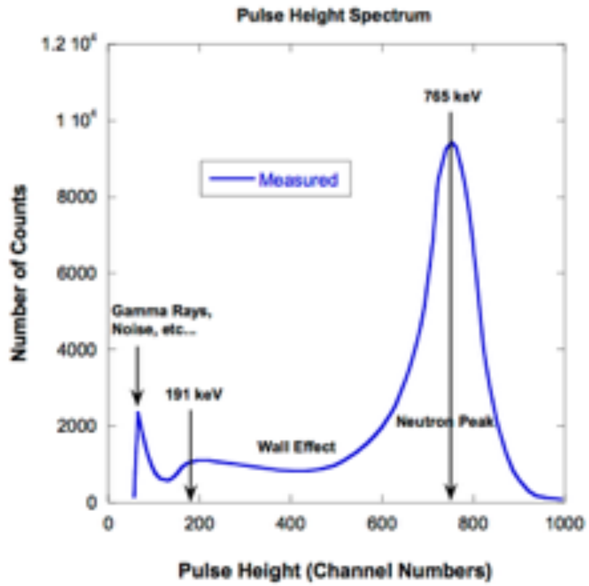
- $n + {}^{3}He \rightarrow {}^{3}H + {}^{1}H + 0.764$ MeV
- $n + {}^{6}Li \rightarrow {}^{4}He + {}^{3}H + 4.79$ MeV
- $n + {}^{10}B \rightarrow {}^{7}Li^{*} + {}^{4}He \rightarrow {}^{7}Li + {}^{4}He + 0.48$ MeV γ +2.3 MeV (93%)
  $\rightarrow {}^{7}Li + {}^{4}He$ +2.8 MeV (7%)
- $n + {}^{155}Gd \rightarrow Gd^{*} \rightarrow \gamma$-ray spectrum $\rightarrow$ conversion electron spectrum
- $n + {}^{157}Gd \rightarrow Gd^{*} \rightarrow \gamma$-ray spectrum $\rightarrow$ conversion electron spectrum
- $n + {}^{235}U \rightarrow$ fission fragments + ~160 MeV
- $n + {}^{239}Pu \rightarrow$ fission fragments + ~160 MeV

Gas Detectors



- Neutron reacts with gas, ionizes
- HV accelerates ions, more reactions, avalanche
- Signal on the cathode/anode

Discrimination and Deadtime

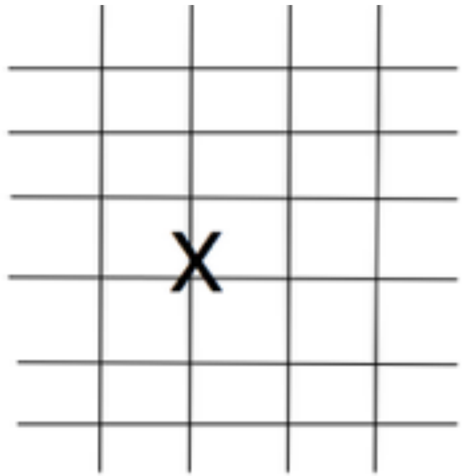


- There is background from gamma and electronics
- Pulse height discrimination for reduction
- Detector and electronics need time to recover from detecting a neutron
- This is called deadtime: between 2-6 micro seconds

Detection Gases

- He^3
  - 80-85% detection efficiency
  - Is a decay product of Tritium
  - Very expensive: 1750 US$/l, DMC: 250l, 437 KUS$
- BF3
  - 40-60% detection efficiency
  - enriched with B^{10}
  - cheap

Position Detection: Coincidence



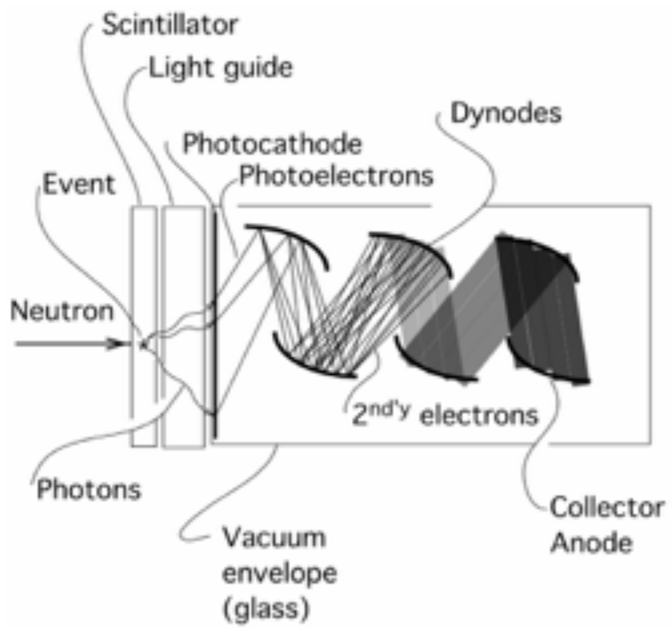
- Have a lattice of wires in X,Y
- When events are detected on X,Y wires within a coincidence time: that is your position!

Position Detection 2

- Read out at both ends
- Delay line readout: compare the times at which the event arrives at both ends: deduce position
- Resistive readout: wire has resistivity: compare peak heights at both ends

Many more position readout systems

Scintillators



$$n + {}^{6}Li \rightarrow {}^{4}He + {}^{3}H + 4.79\,MeV$$

- Converter Material converts ^{4}He, ^{3}H to light
- Detection efficiency close to 40%
- Gamma sensitive

Scintillation Materials

- Li^6F, ZnS
- GS-20, a glass with Ce^{3+} and Li^20 in melt
- $Li_6Gd(BO_3)_3$ (Ce^{3+})

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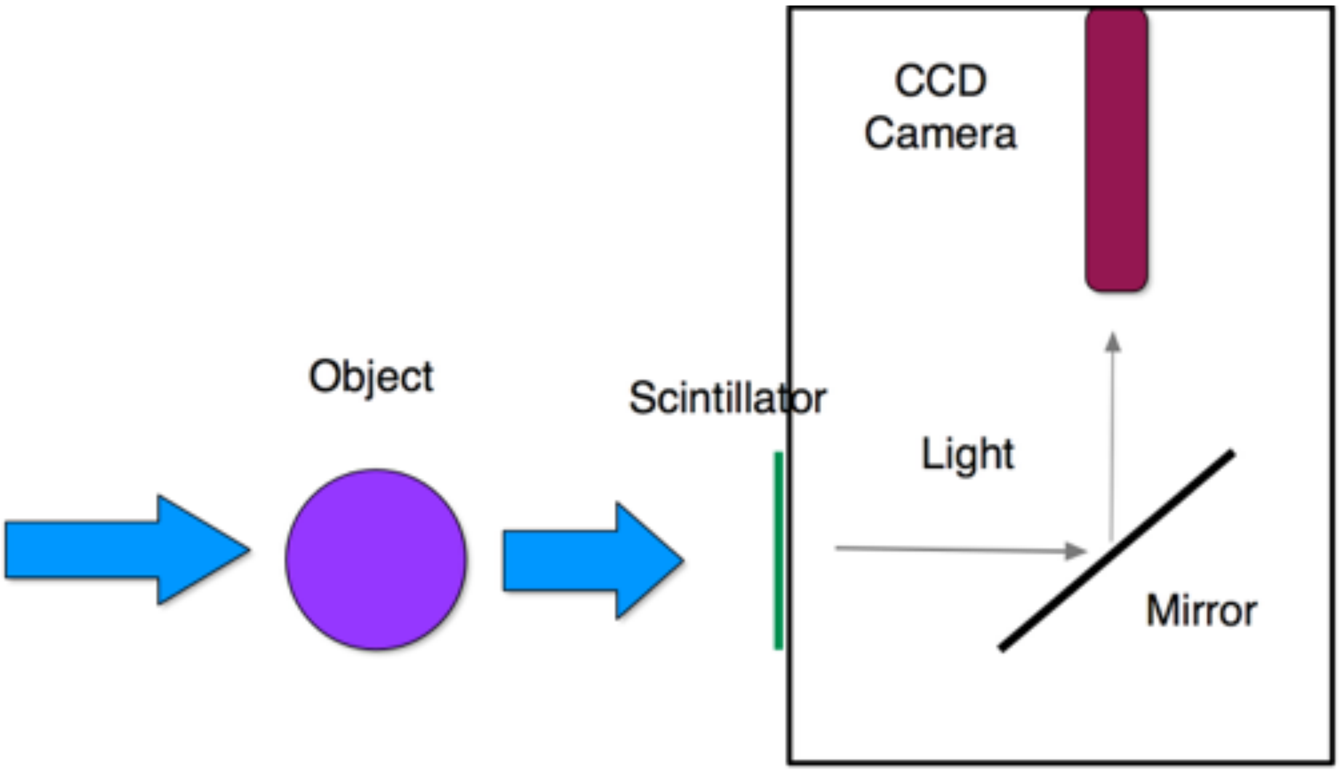
Scintillation Detector Example

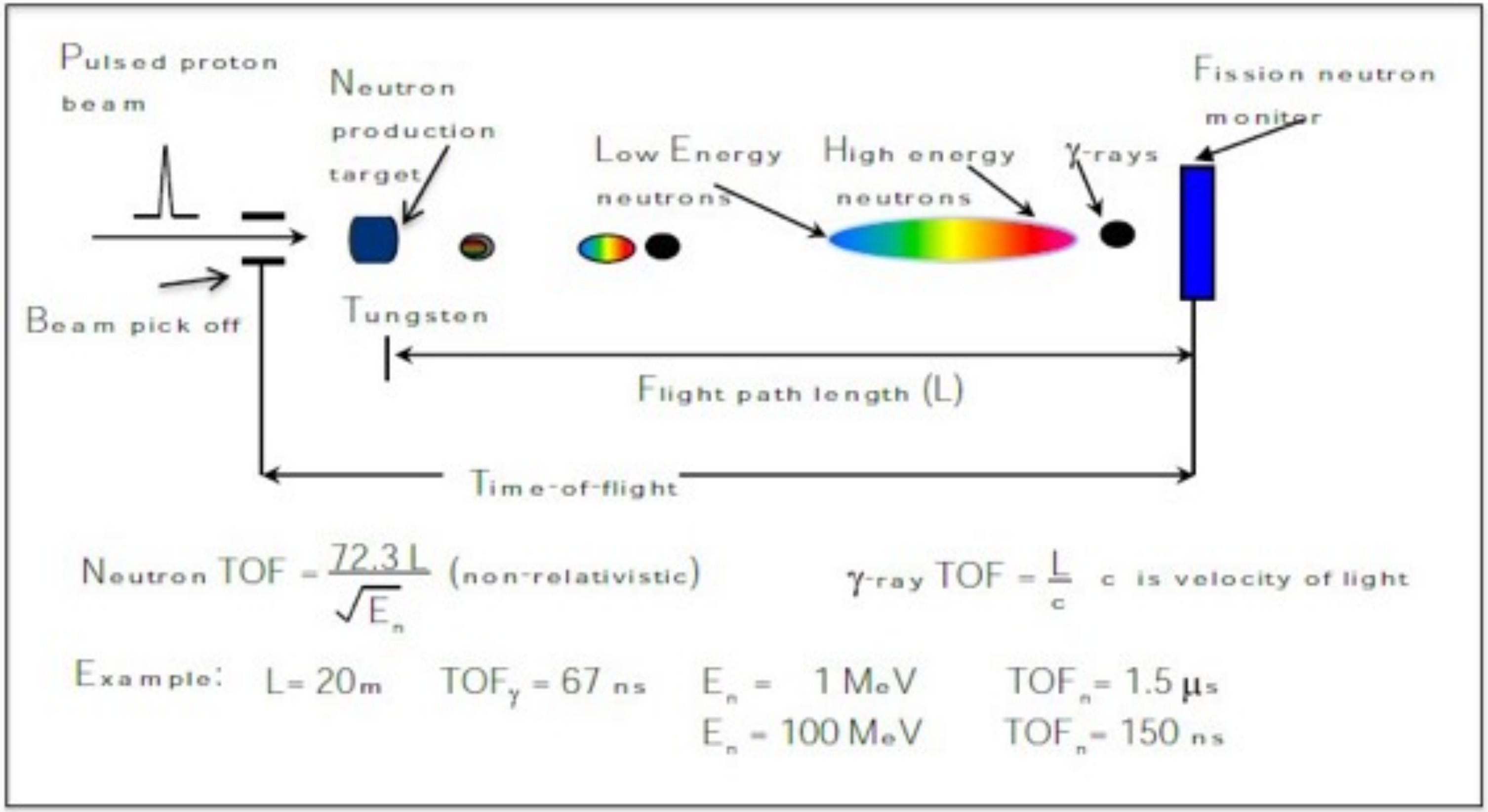
Neutron Imaging



Monitors

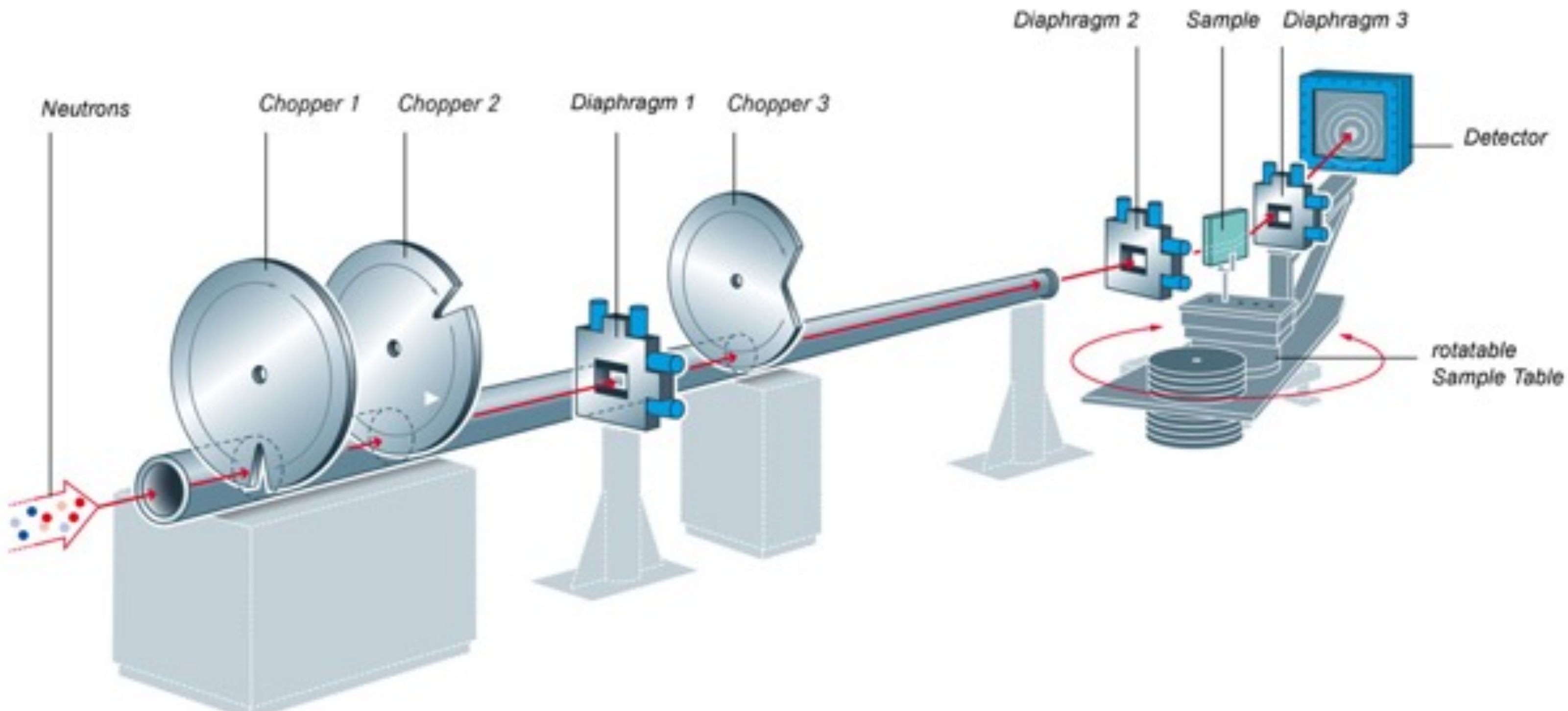
- Fission chambers
  - n + $^{235}U \rightarrow$ fission fragments + ~160 MeV
  - Thin layer of U-235 in detector
  - Low detection efficiency ~10^{-4}
  - Used as Monitors
- In order to compare experiment data and scale experiment data against each other, we need to know how may neutrons hit the sample

Time-of-Flight Technique



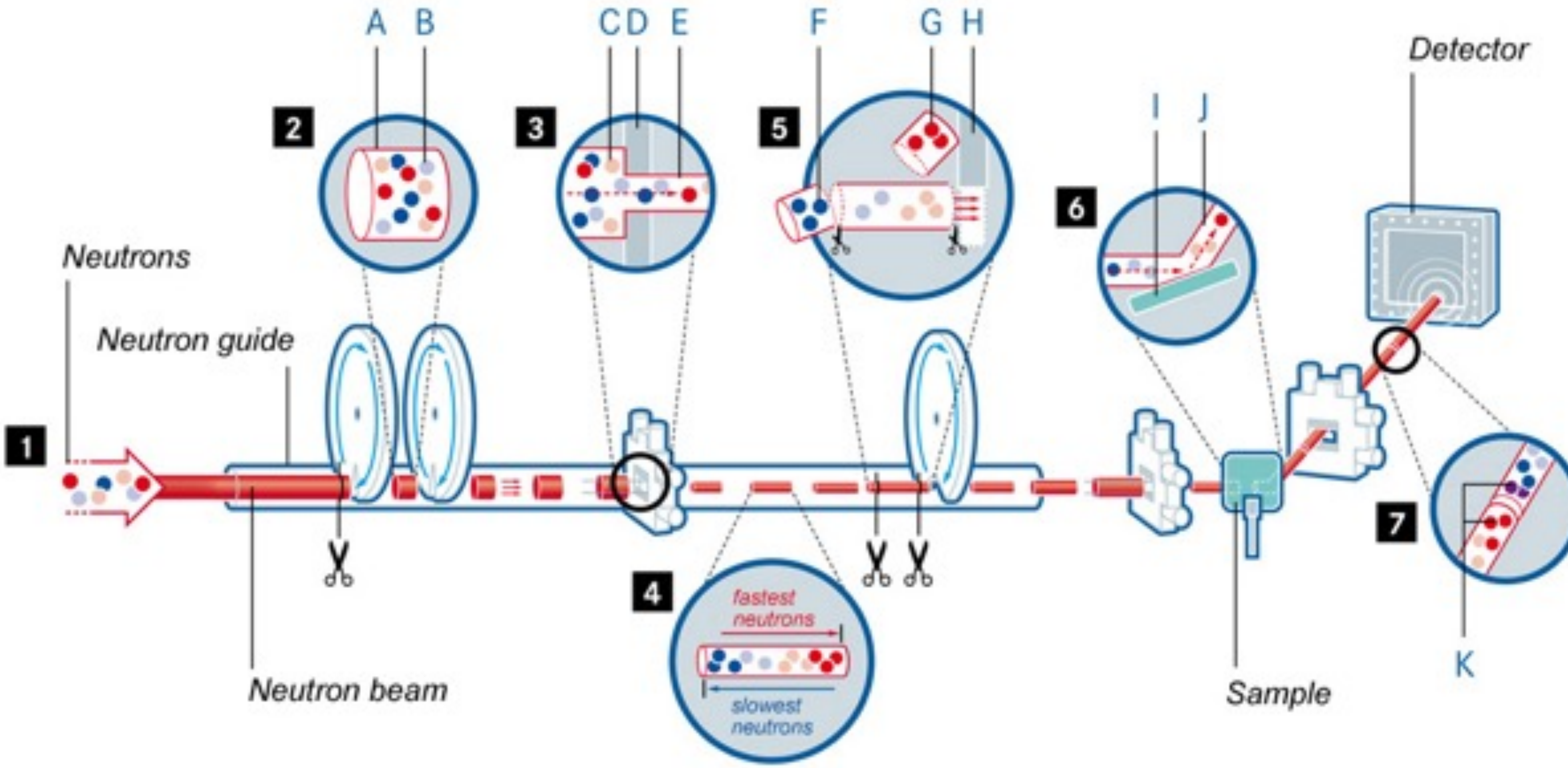
- Thermal neutrons: 1.8 A = ~2200m/sec = ~26meV = ~9 milliseconds/20m

TOF at a reactor source



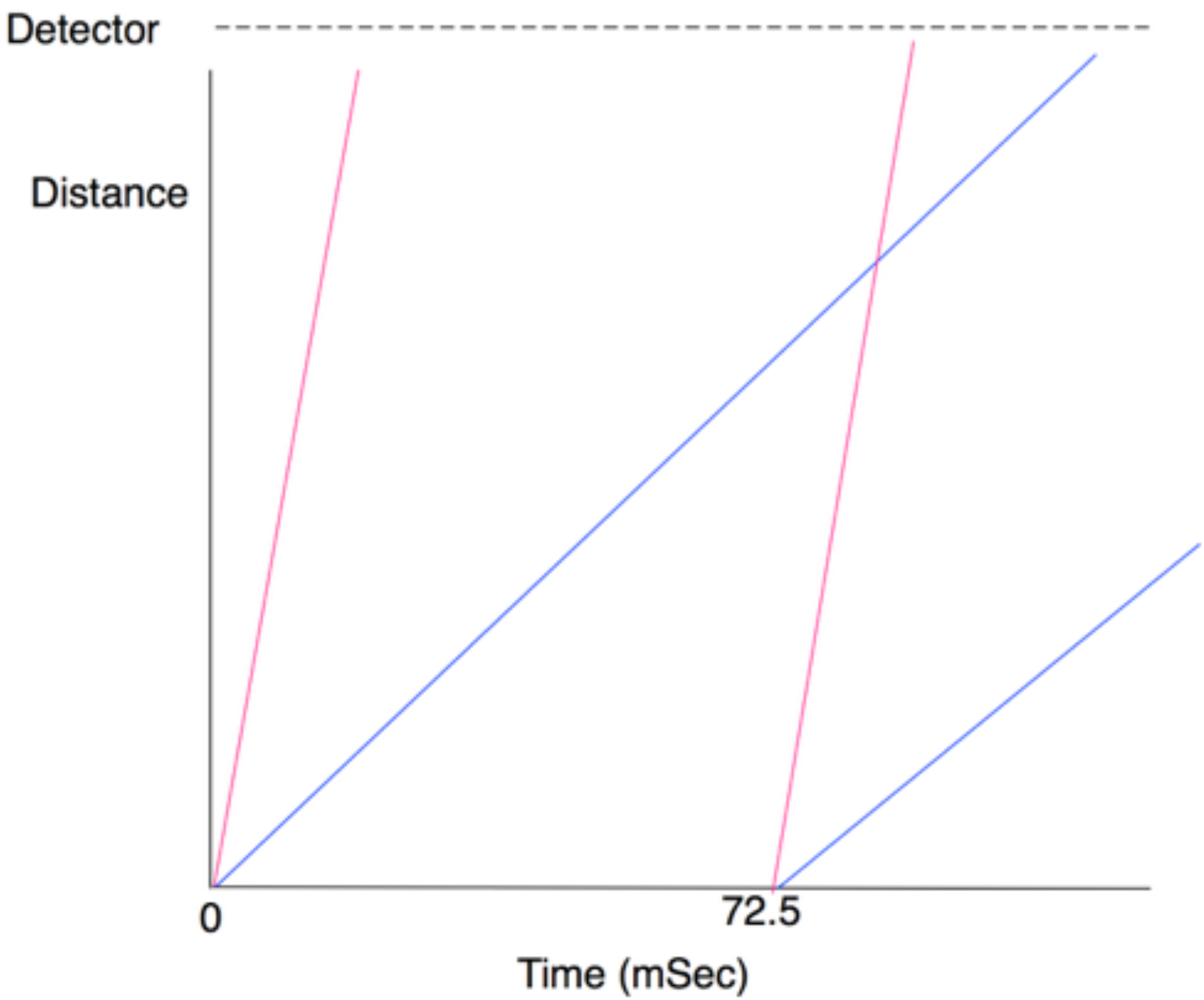
- Choppers instead of a pulsed source
- Chopper phases
- Chopper pickup

Chopper System



- Pulse shaping

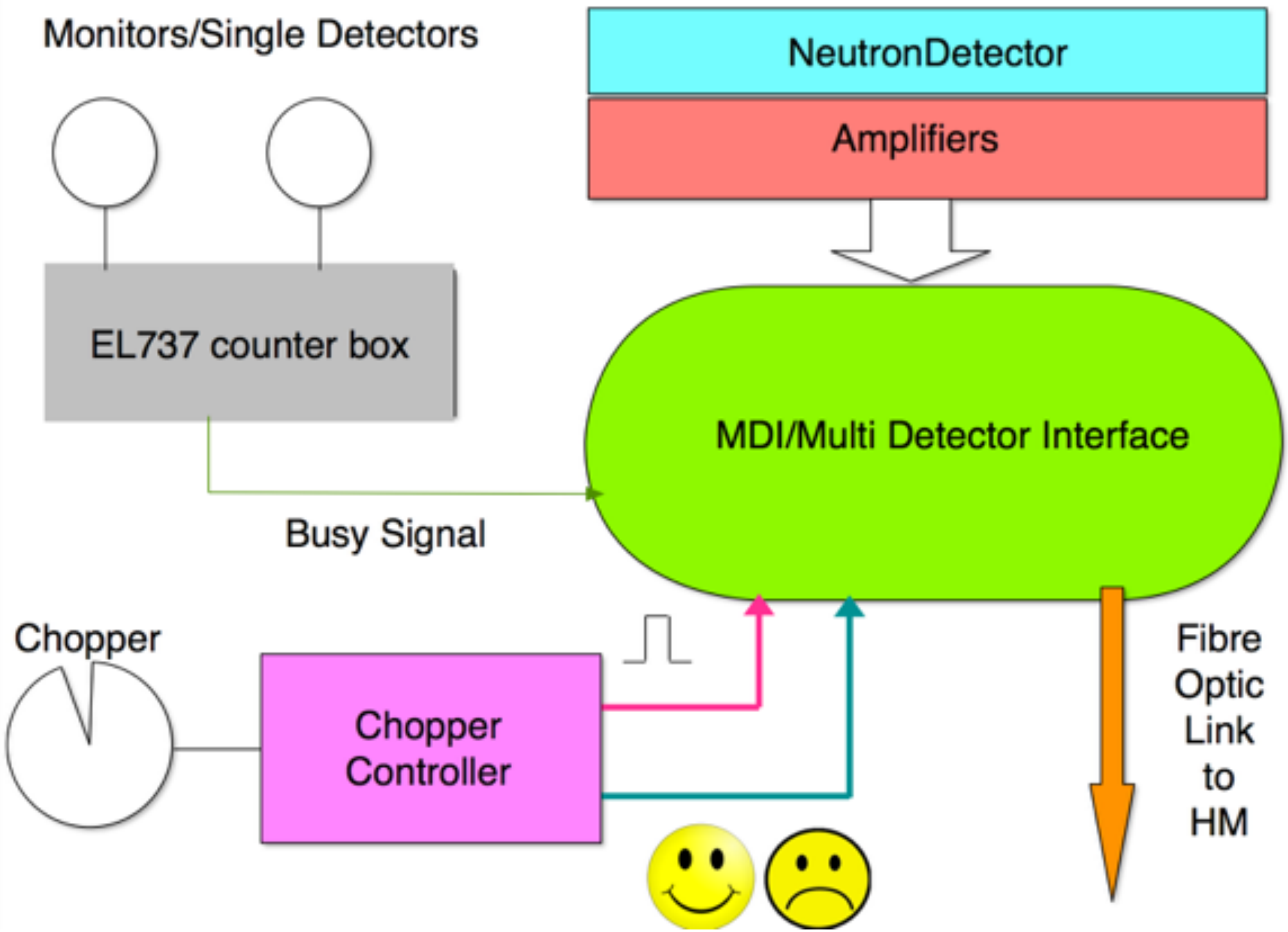
Frame Overlap



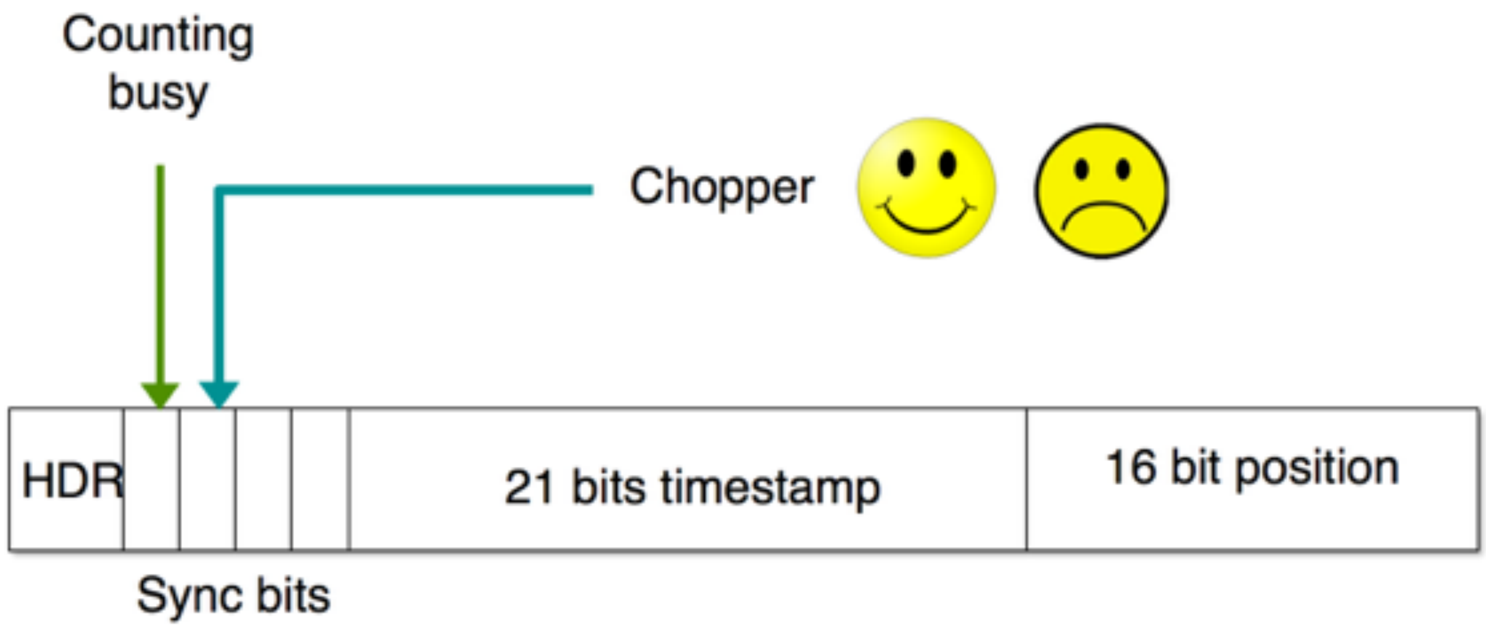
SINQ TOF Neutron Detection

- Frame Overlap is usually avoided
- We are interested in time relative to the pulse
- Chopper system emits pulse signal
- Detector electronics resets internal clock to 0 on reception of the chopper pulse signal
- T_{abs}(n-event) = T(pulse) + T(rel)

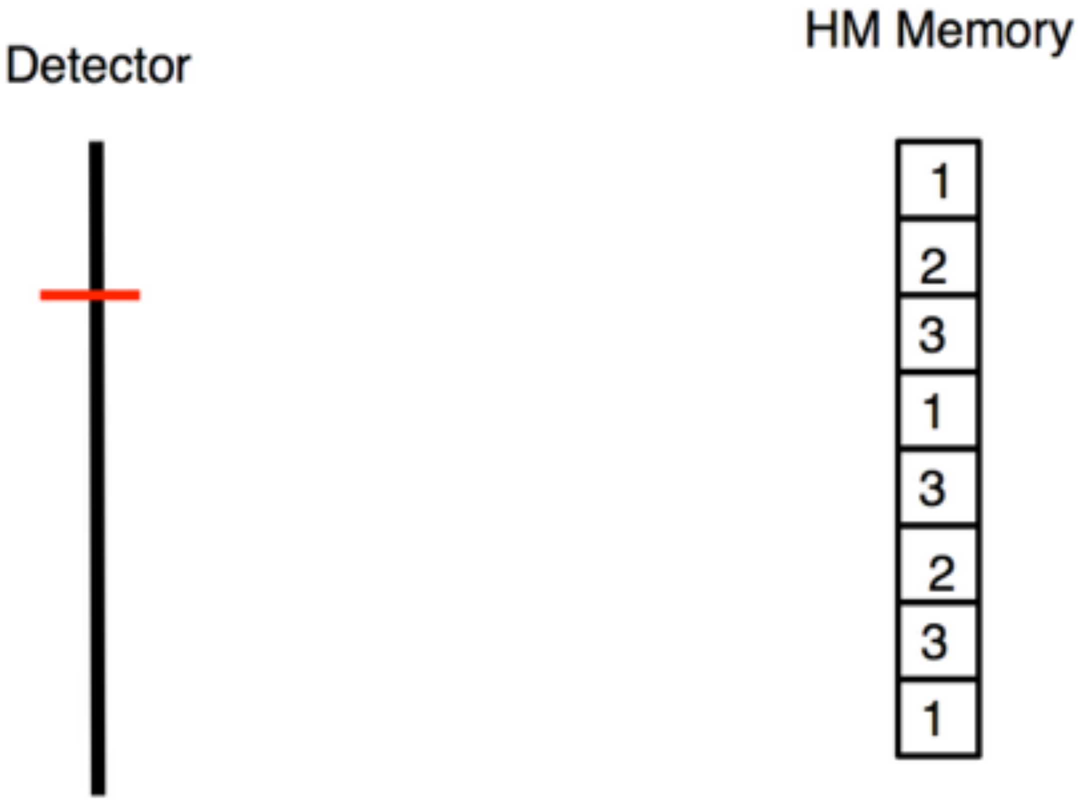
SINQ Detector Hardware



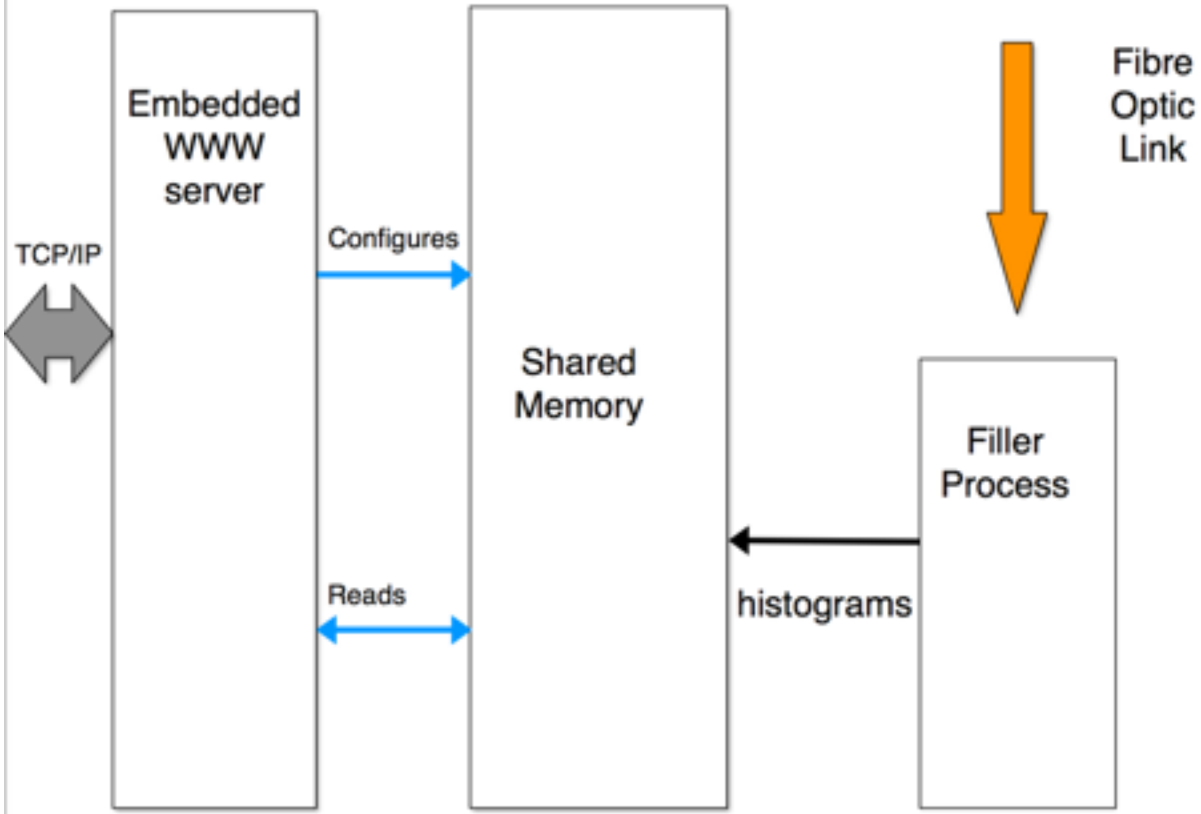
Fibre Optic Link Packet



Histogramming

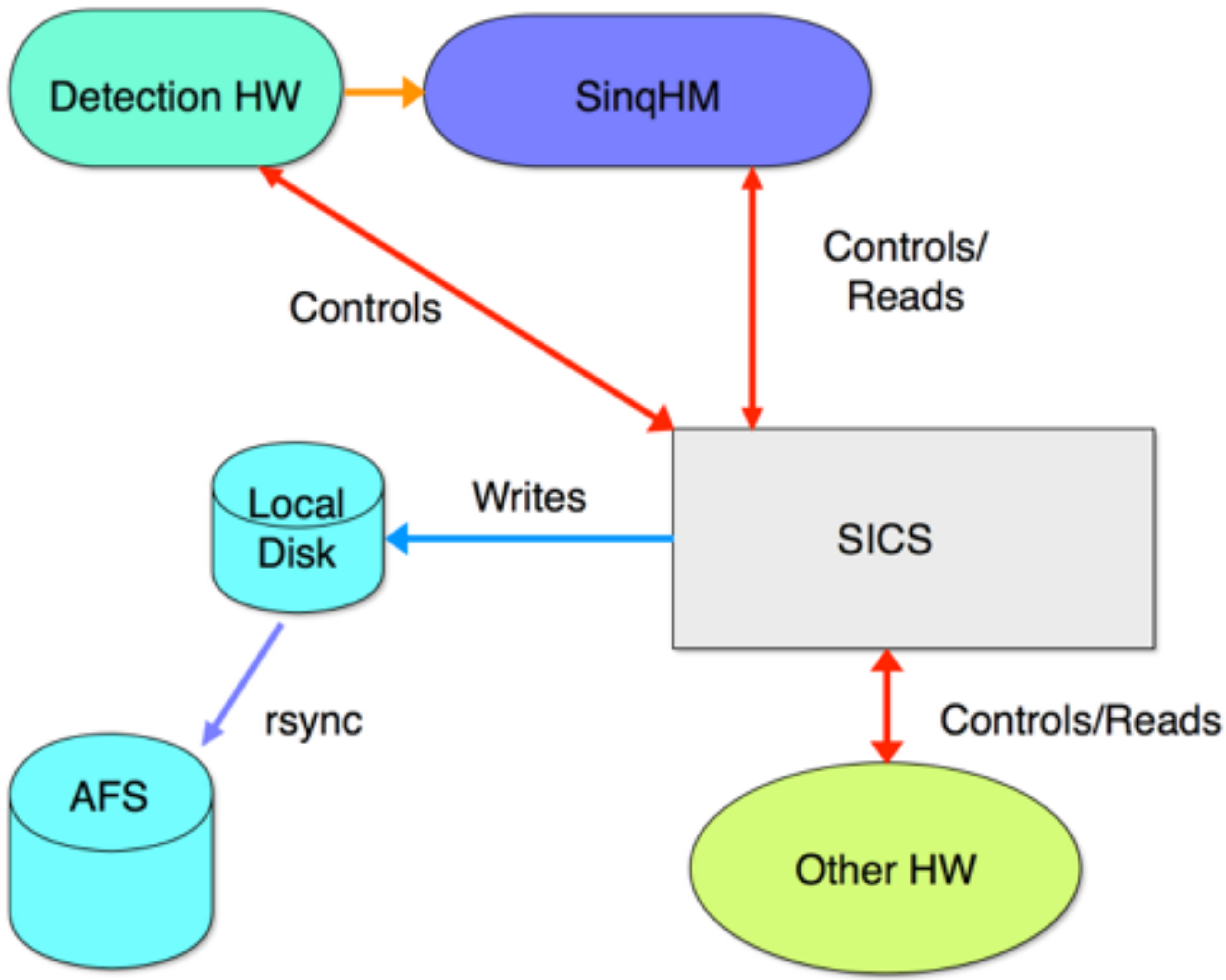


SinQ Histogram Memory



- Men A-12 VME on board computer
- Realtime Linux

SINQ Software



How is ESS Different?

- The source
  - SINQ is a continuous source with 1 MW power
  - ESS will be pulsed at 14 hz with 5 MW power
  - ESS is a long pulse source: 2-2.8 micro seconds
- Timing system
- Detectors
  - SINQ has mainly He^3 detectors
  - For ESS there will be novel detector concepts
    - Scintillators, 3D detector concepts
- Detector electronics
  - SINQ: Hardware
  - ESS:
    - Discrimination, position finding etc in software
    - Output: detectorID, timeStamp stream

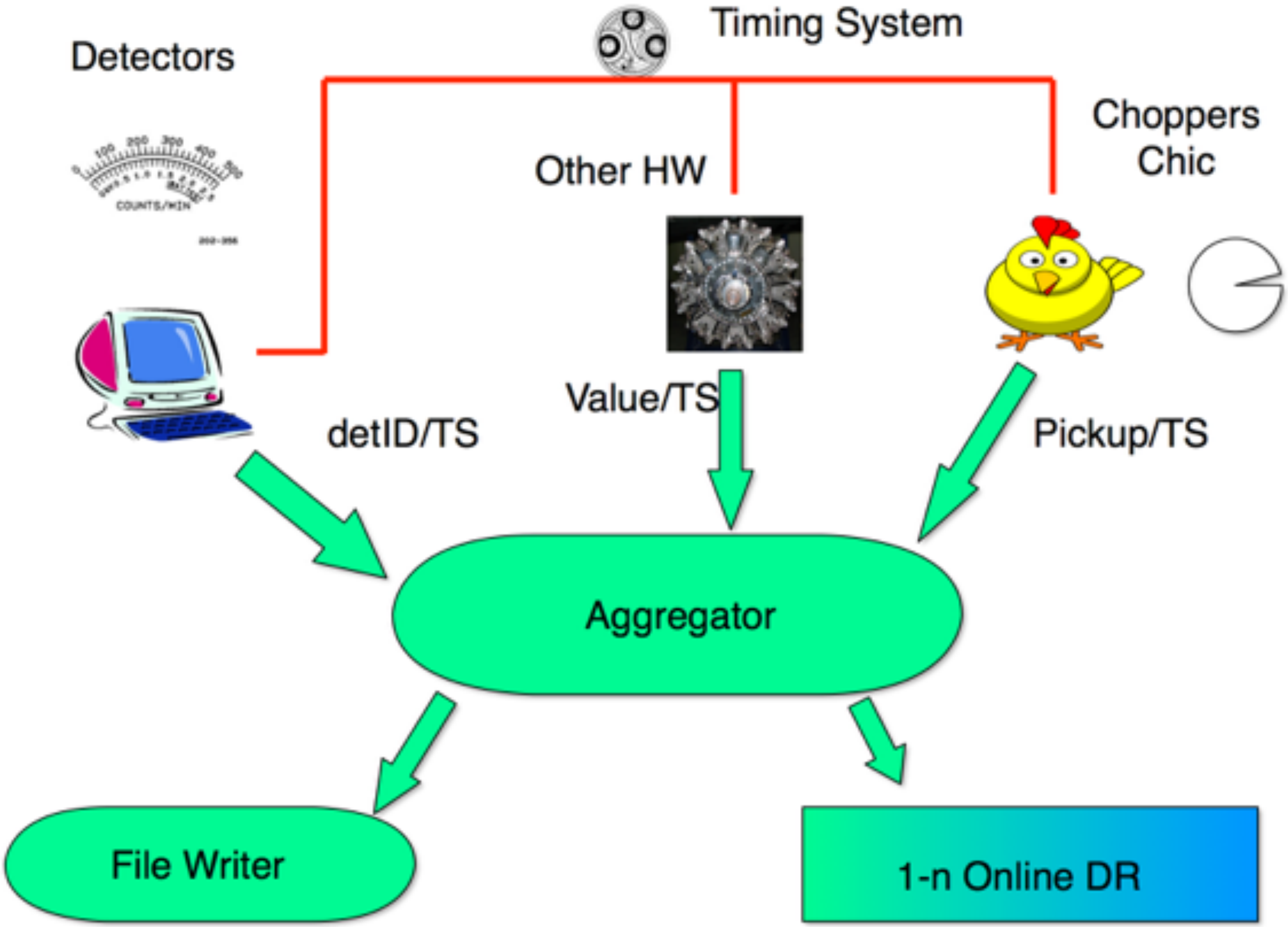
More ESS Differences

- Neutron event processing
  - SINQ: histogramming
  - ESS:
    - streaming to network
    - store the n-event data stream
    - Online experiment status directly calculated from event stream
    - Automated online data reduction
- Chopper systems
  - SINQ: electronics
  - ESS: Chick
    - Streaming of chopper happiness and pick up times
    - Novel chopper usage concepts

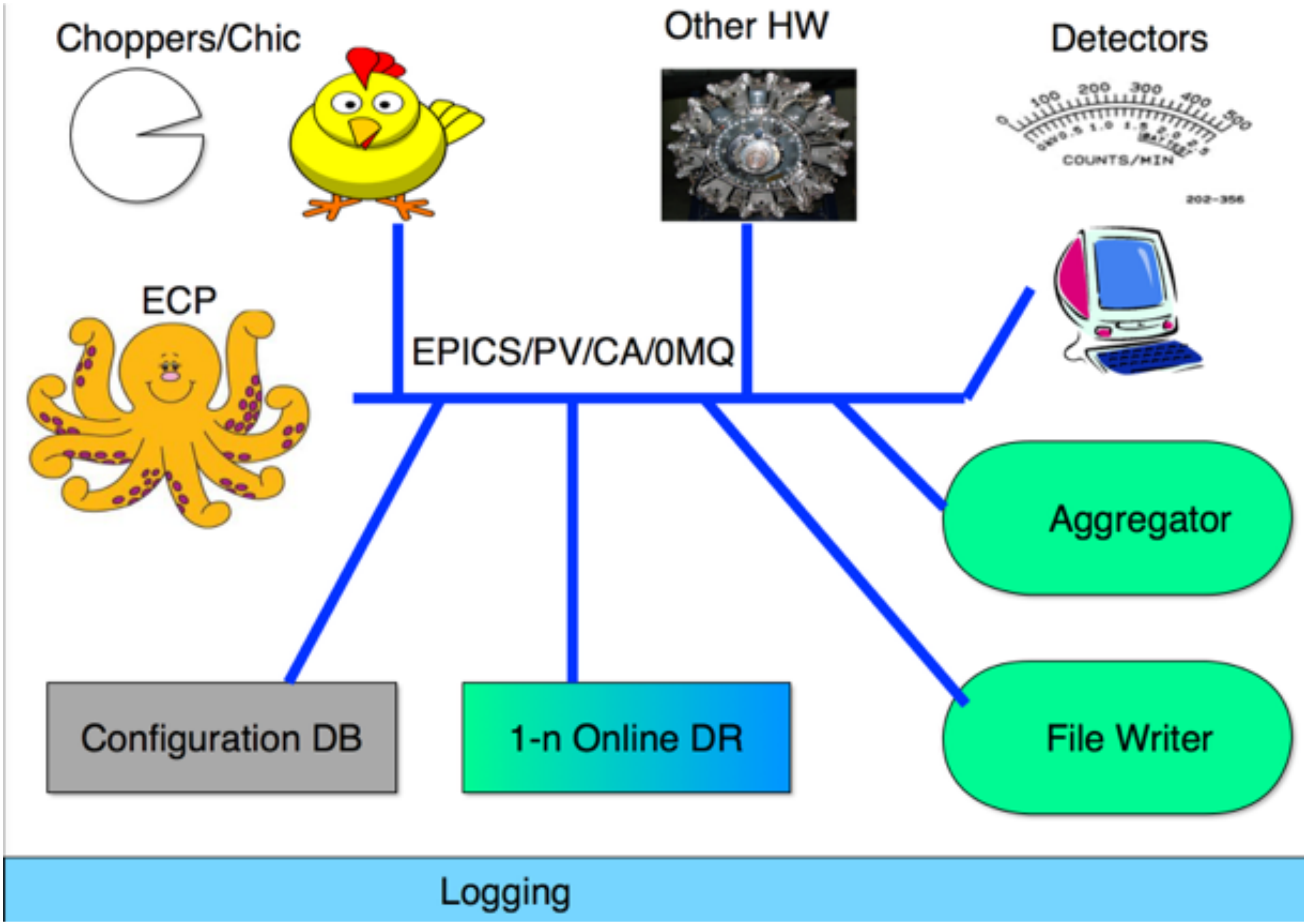
Even more ESS Differences

- Other hardware
  - SINQ: controlled by SICS
  - ESS:
    - EPICS
      - Experimental Physics and Industry Control System
      - Distributed
      - Network protocol: CA, PV
      - Infrastructure: IOC, Records, Online DB
    - controlled by ECP via EPICS
    - Streaming of hardware values
      - Motor positions
      - Fast sample environment
      - …….

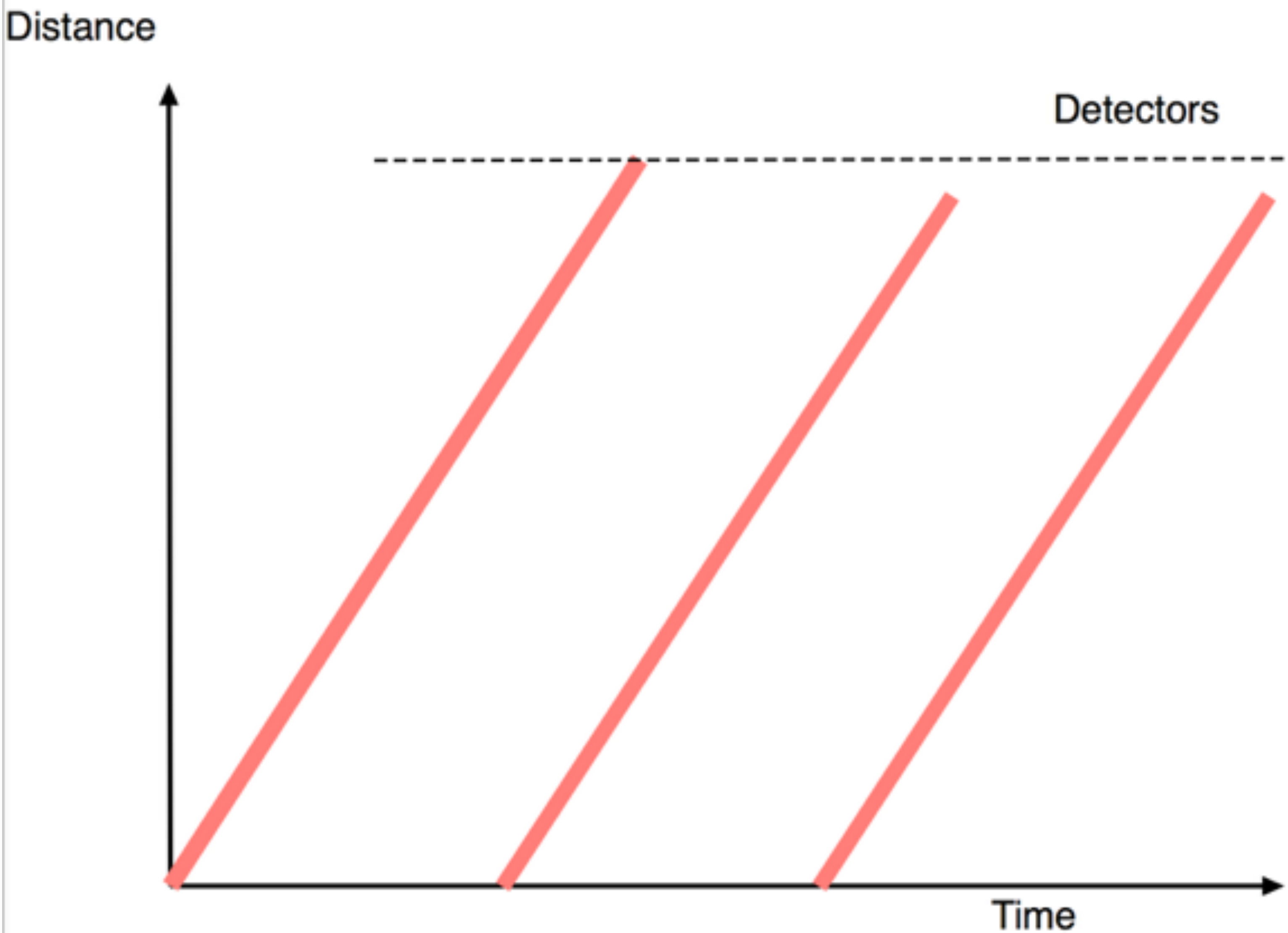
ESS Data Acquisition



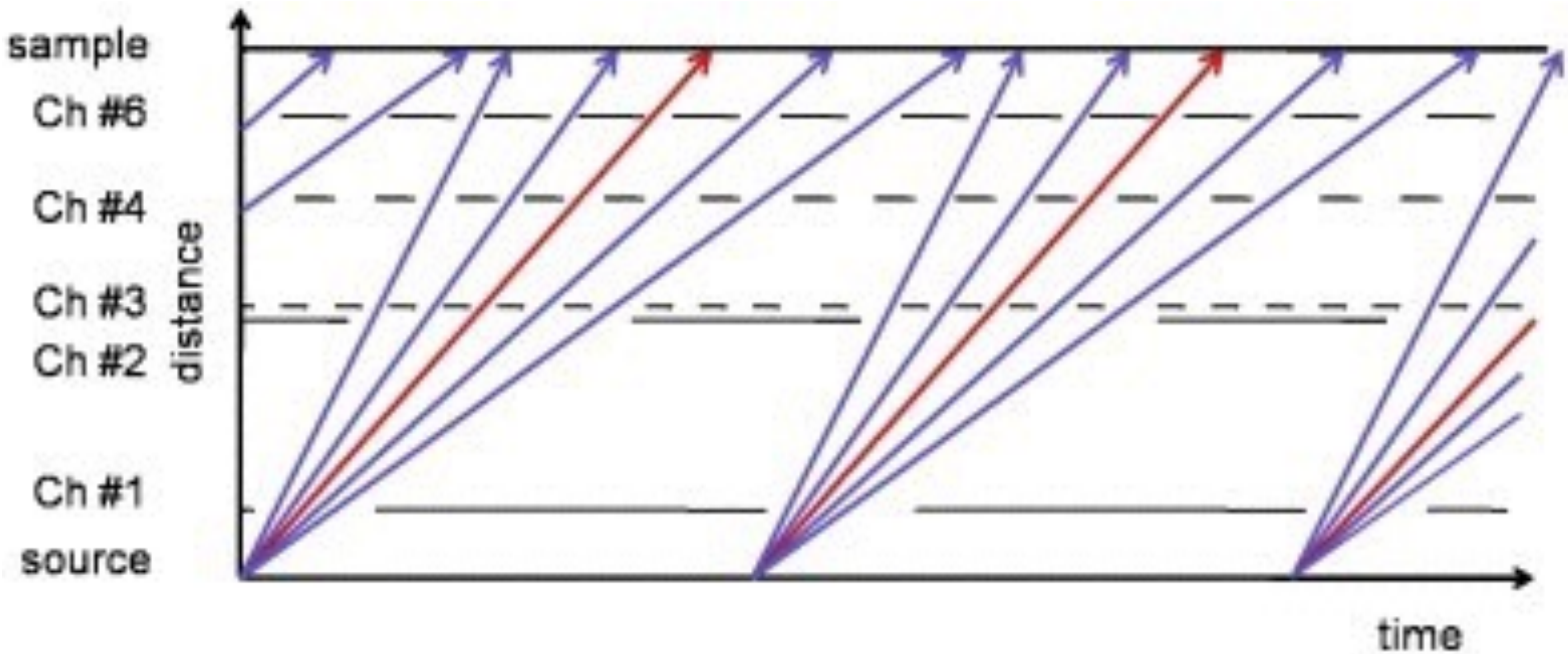
ESS Controls



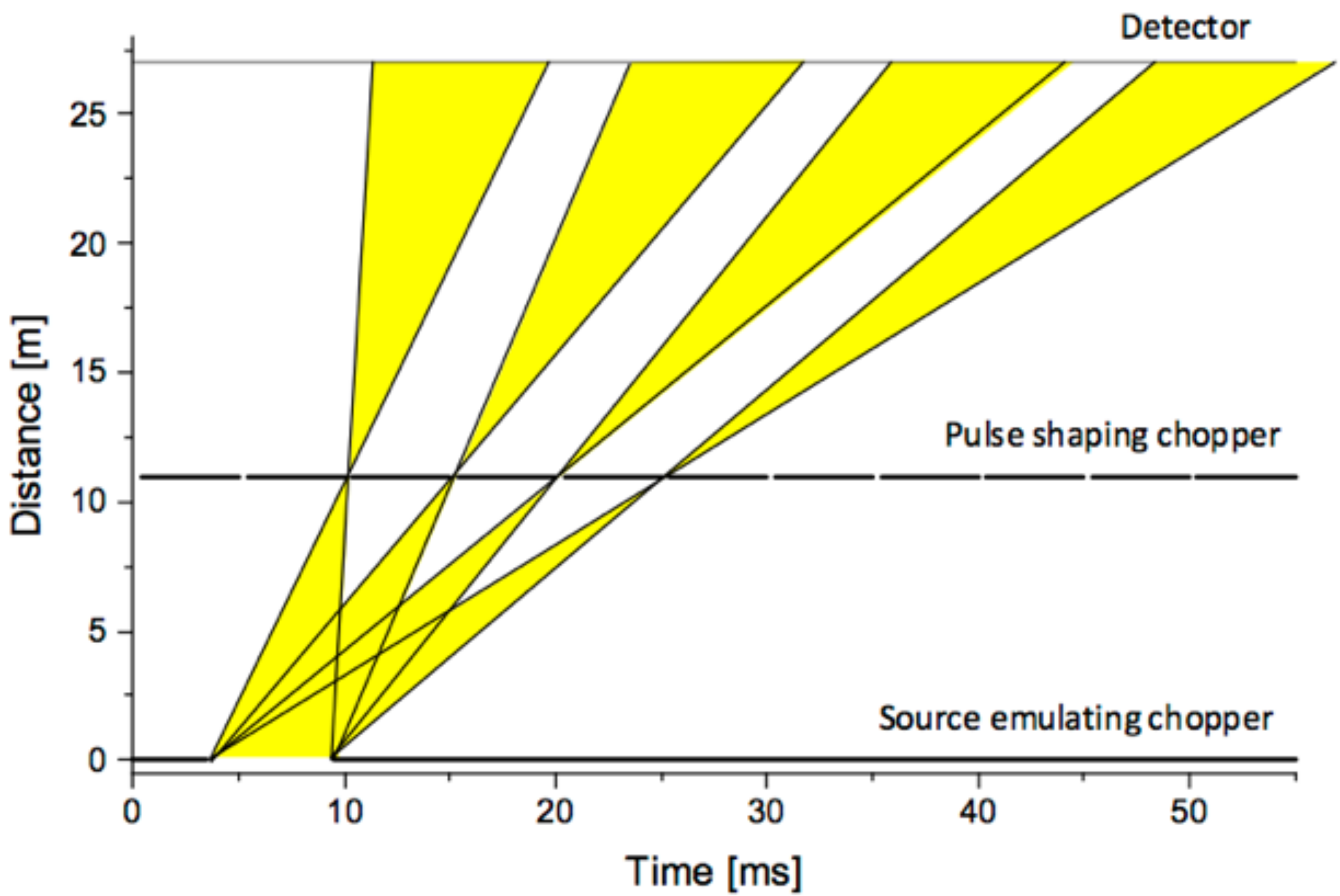
ESS Choppers: Repetition Rate



ESS Choppers: Repetition Rate Multiplication



ESS Choppers 2: Wavelength Frame Multiplication



ESS DAQ Sub Projects

- Hardware interface: EPICS (4), run by ESS group ICS, Timo Korhonen
- Neutron frontend event processing (ESS, U Copenhagen)
- Neutron event streaming, correlation etc: BrightnESS, ESS, PSI
- Experiment Control Program: ESS, ISIS and PSI, Swiss In Kind
    - Jonathan Taylor, Freddy Akeroyd, Mark Könnecke
- Online data reduction: ESS, ISIS
    - Jonathan Taylor, Thomas Rod, Owen Arnold
- All this needs to work together

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BrightnESS: Why Event Streaming?

- Can redo histogramming with other parameters any time
- Saves disk space for sparse detectors
- Correlate with whatever we want to correlate with
- Enables dynamic experiments
- Better data recovery when something goes sour in the course of the experiment

Event Streaming Challenges

- 24/7 Operation for extended periods of time
- Runtime Reconfiguration
- Project Management
- Provision for up to 1.5 GB/sec on events
  - Parallel Processing
  - Parallel File Writing
- Take heart!
  - ESS will ramp up slowly
  - 2gen source: high resolution —> low counts in detector
  - 2gen source: small samples —> low counts in detector
  - Only when medium resolution, high throughput we get high count rates

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Workshop Aims

- Get to know each other
- Get a better understanding of what we need to accomplish
- Develop ideas how we want to solve the problem
- Define a project structure
- Get a handle on interfaces
  - To electronics
  - To data reduction
  - To ECP
  - EPICS
  - ….