OAK RIDGE National Laboratory

Neutron Generation and Detection/Neutron Optics and Instrumentation

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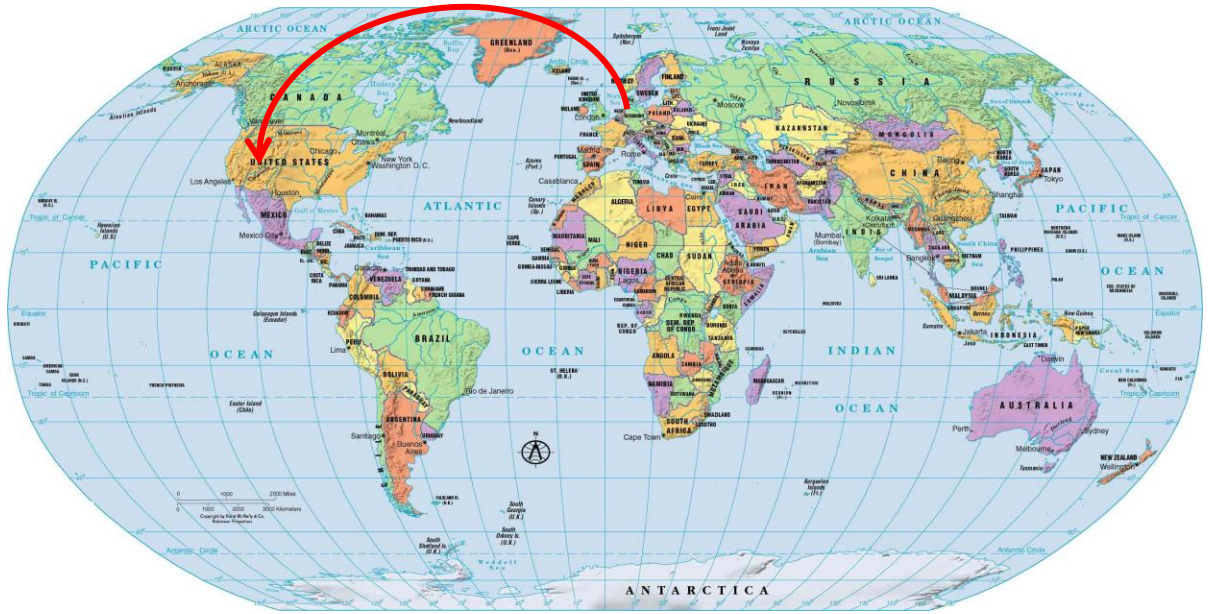
ORNL is managed by UT-Battelle, LLC for the US Department of Energy

U.S. DEPARTMENT OF ENERGY

Neutron school 2007 (Los Alamos)!

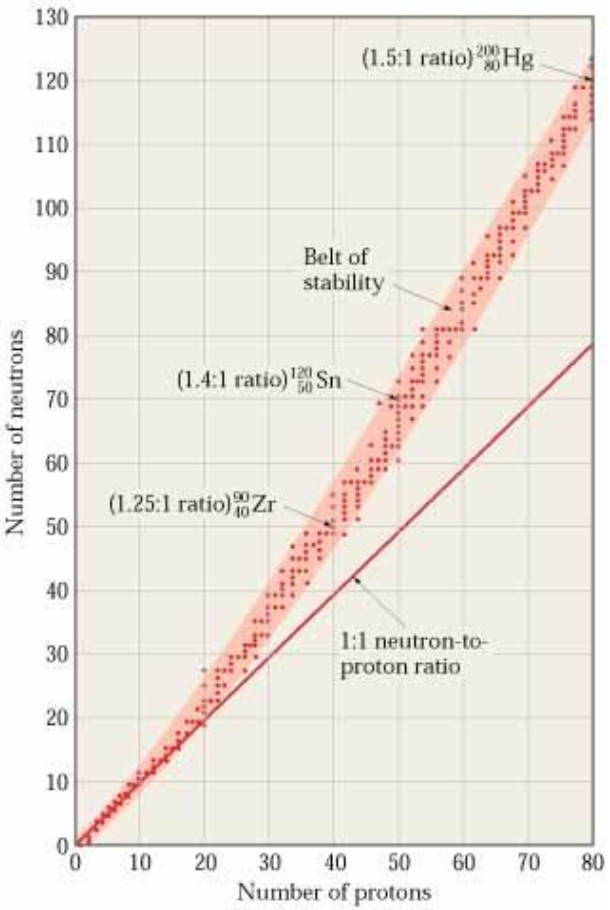


Neutron Generation and Detection/Neutron Optics and Instrumentation

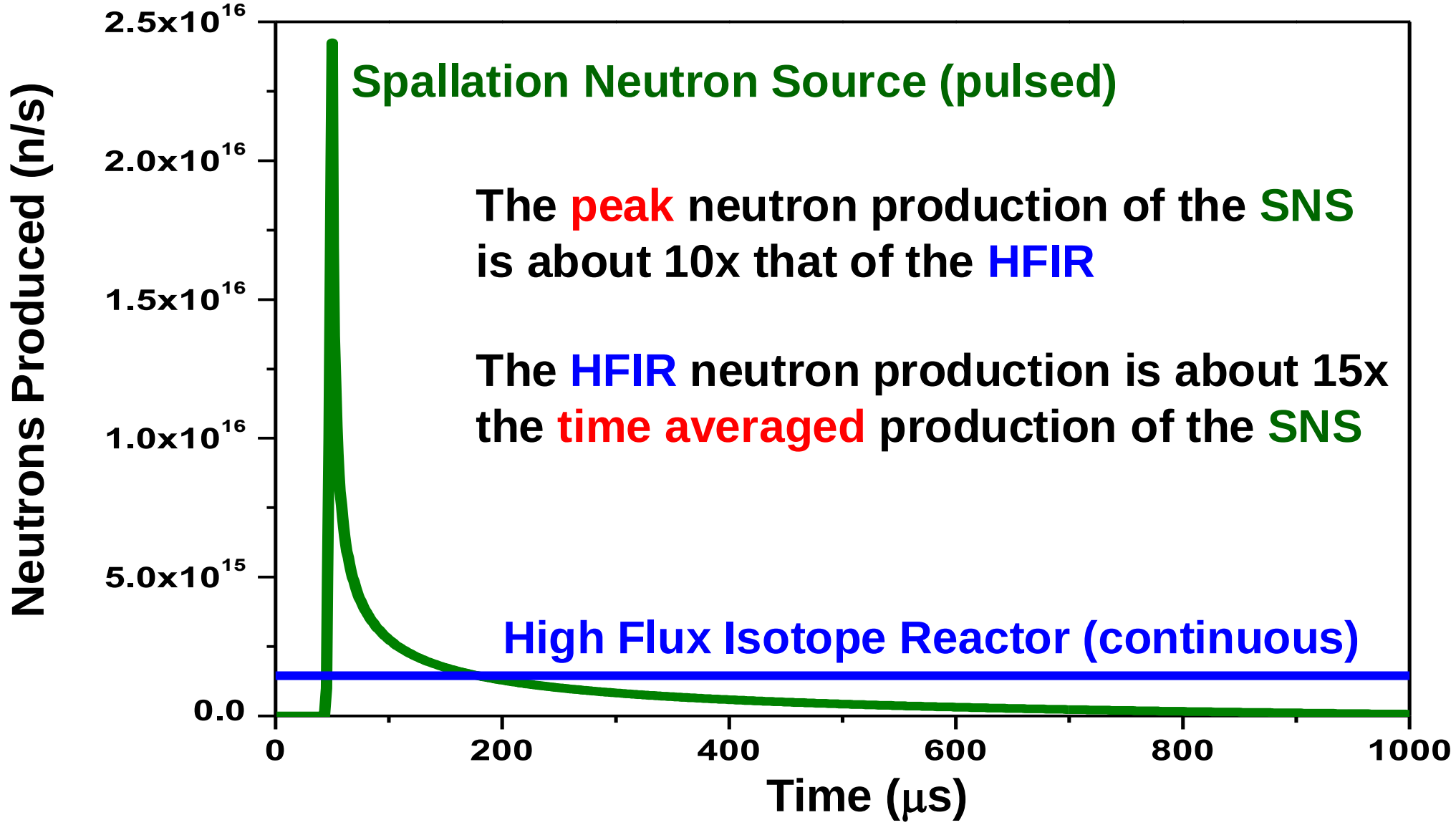
- How to build a neutron scattering instrument from scratch:
  - Make neutrons!
  - Transport neutrons!
  - Scatter neutrons! (other people will tell you about this)
  - Detect neutrons!

Make neutrons!

- We don't make neutrons, we "liberate" them
- …by breaking atoms!
- Heavy atoms have disproportionally more neutrons
  - Split them into smaller atoms, and you have a surplus of neutrons!
- At HFIR: nuclear chain reaction (Uranium)
- At SNS: high power accelerator (Protons -> Mercury)



Pulsed vs Continuous Neutron Sources



Slide courtesy of Lee Robertson

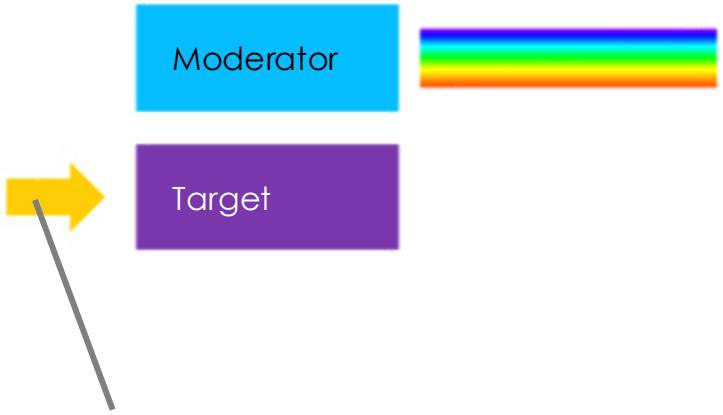
Make useful neutrons!

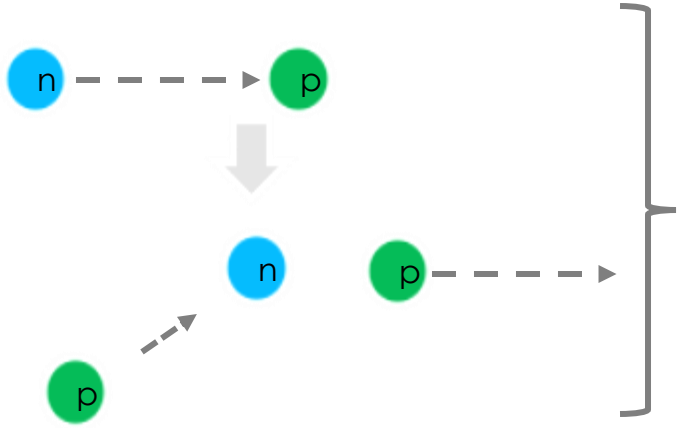
Energy (meV)	Velocity (m/s)	Temp (K)	Wavelength (Å)
0.1 – 5	100-1000	1 – 120 (“Cold”)	4 – 30
5 – 100	1000-4000	120 – 1000 (“Thermal”)	1 – 4
100 – 500	4000-40000	1000 – 6000 (“Hot”)	0.4 –1
.			
.			
.			
> MeV	~1E7	1E9	< mÅ

You are here!

Moderators

usually: LH_2 or H_2O

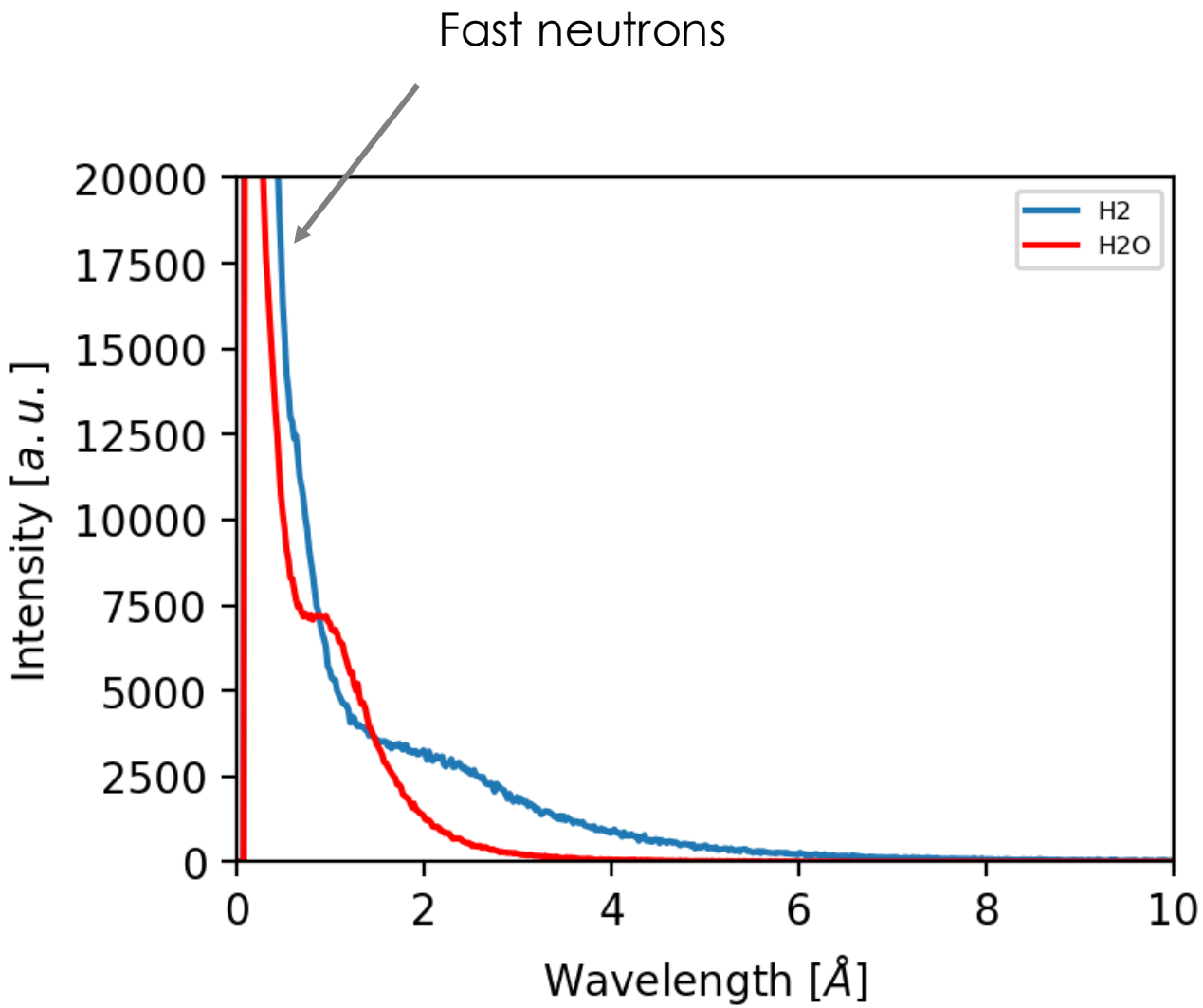




Within a few collisions, the energies will have equilibrated around the temperature of the moderator.

Energy (meV)	Velocity (m/s)	Temp (K)	Wavelength (Å)
0.1 – 5	100-1000	1 – 120 (“Cold”)	4 – 30
5 – 100	1000-4000	120 – 1000 (“Thermal”)	1 – 4
100 – 500	4000-40000	1000 – 6000 (“Hot”)	0.4 –1

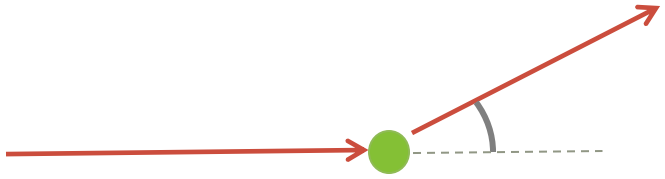
Spectra H2 vs H2O @ SNS



Two instrument concepts

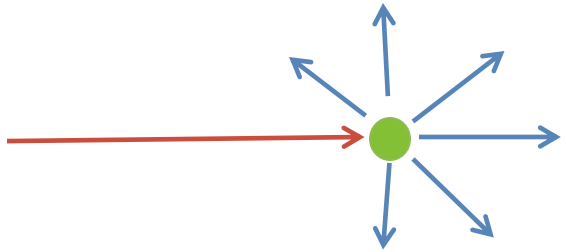
Diffractometer (elastic scattering)

- Characteristic changes in angle
- No change in wavelength

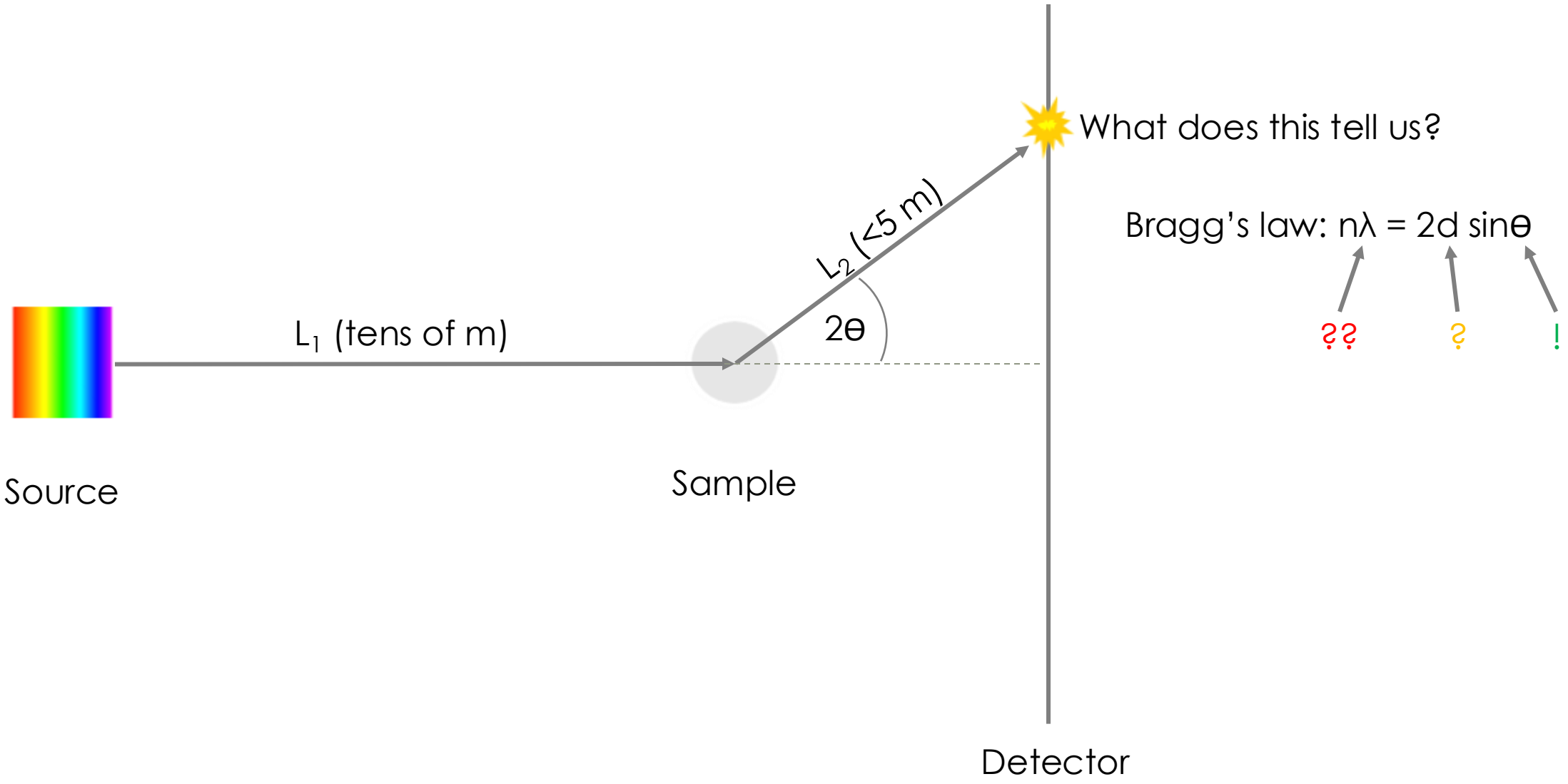


Spectrometer (inelastic scattering)

- Isotropic change in angle
- Characteristic change in wavelength

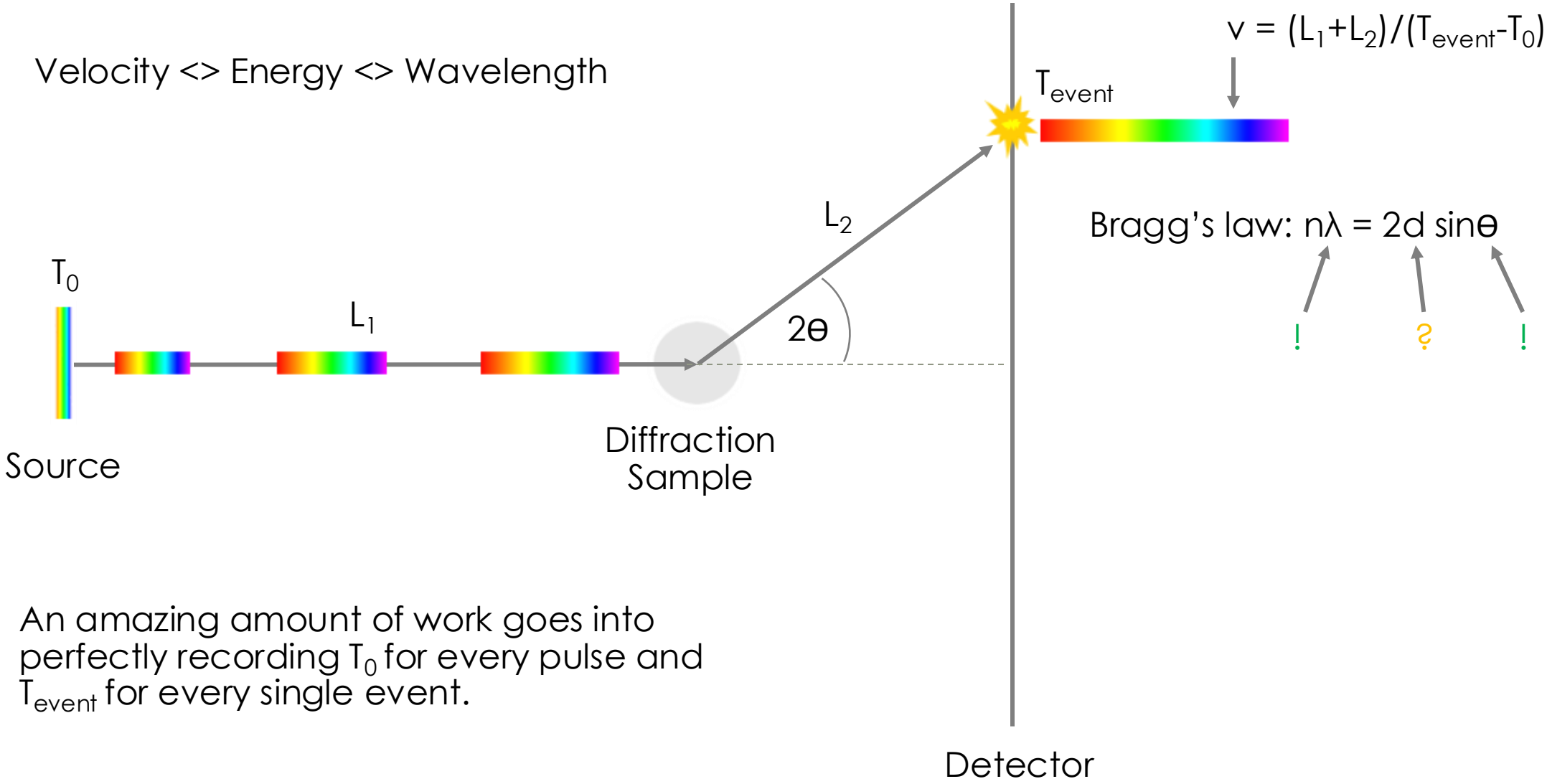


Let's build an instrument already!



At a pulsed source: Time Of Flight (TOF) - elastic

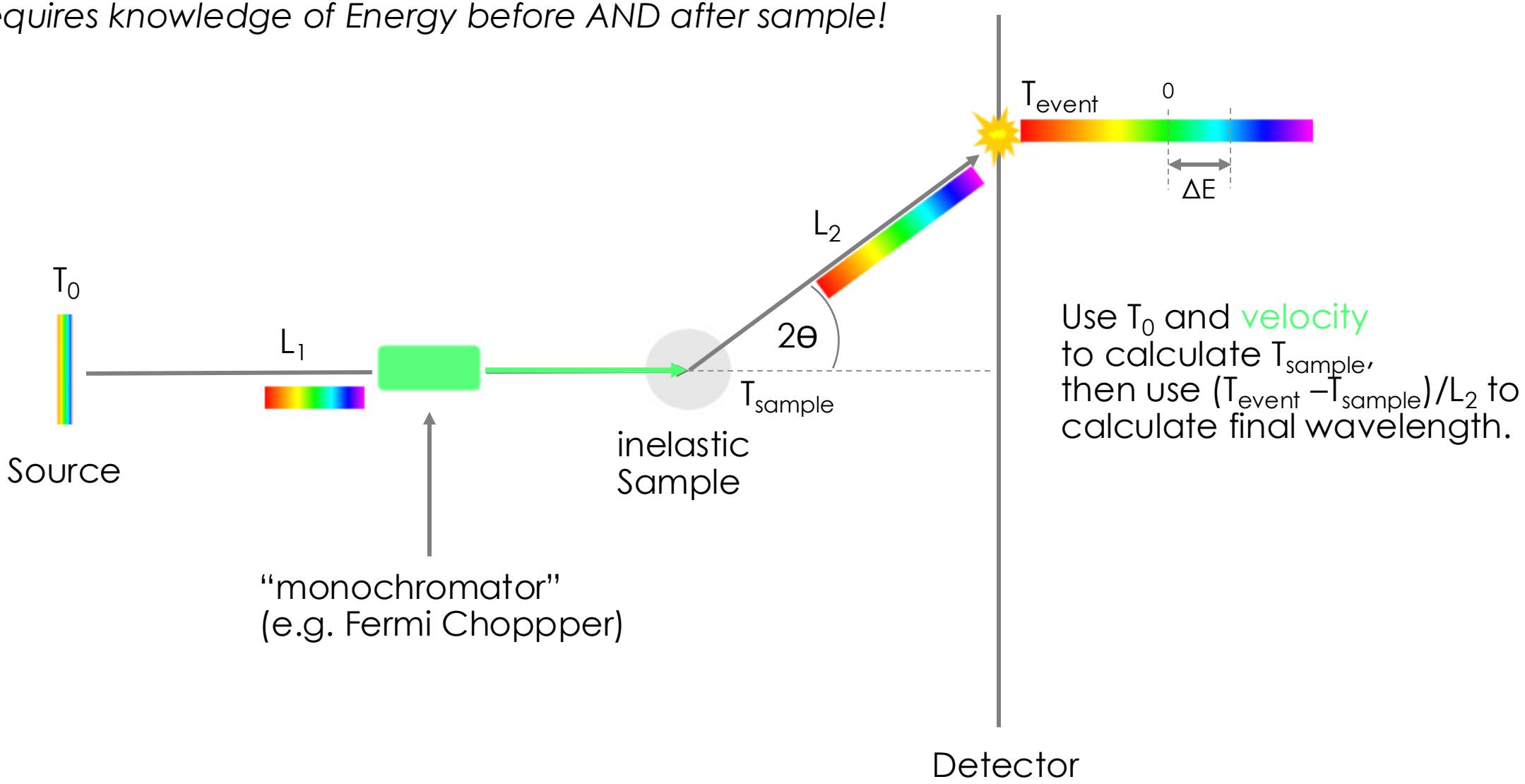
Velocity <> Energy <> Wavelength



An amazing amount of work goes into perfectly recording T_0 for every pulse and T_{event} for every single event.

At a pulsed source: Time Of Flight (TOF) - inelastic

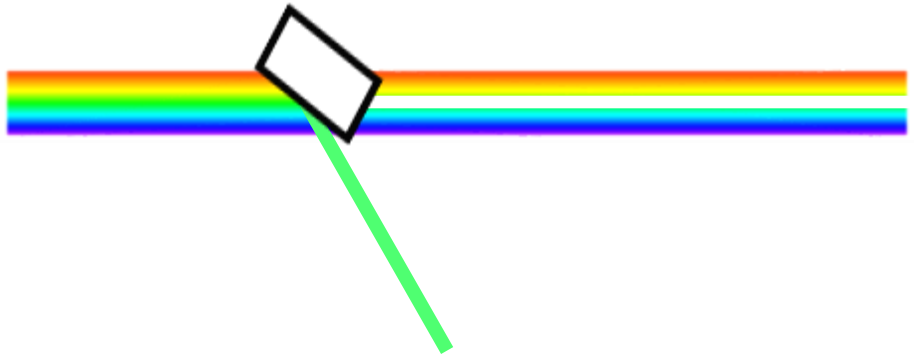
Requires knowledge of Energy before AND after sample!



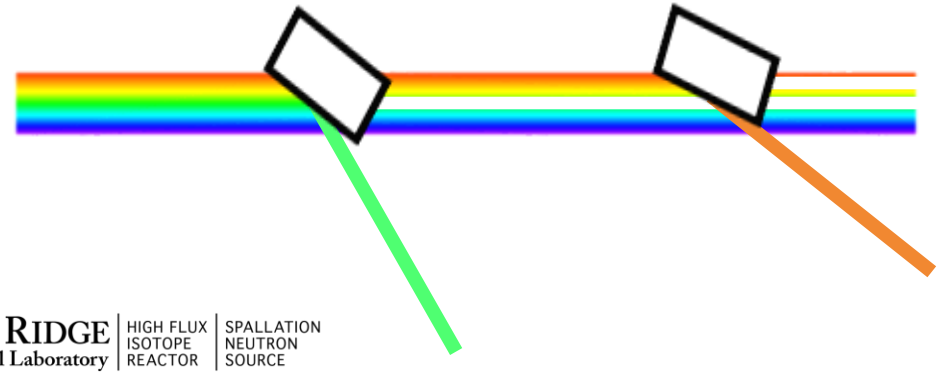
Use T_0 and velocity to calculate T_{sample}, then use $(T_{event} - T_{sample})/L_2$ to calculate final wavelength.

Detour: Crystal monochromators

- Bragg's law: $n\lambda = 2d \sin\theta$
  - Known d-spacing, can select λ by choosing θ

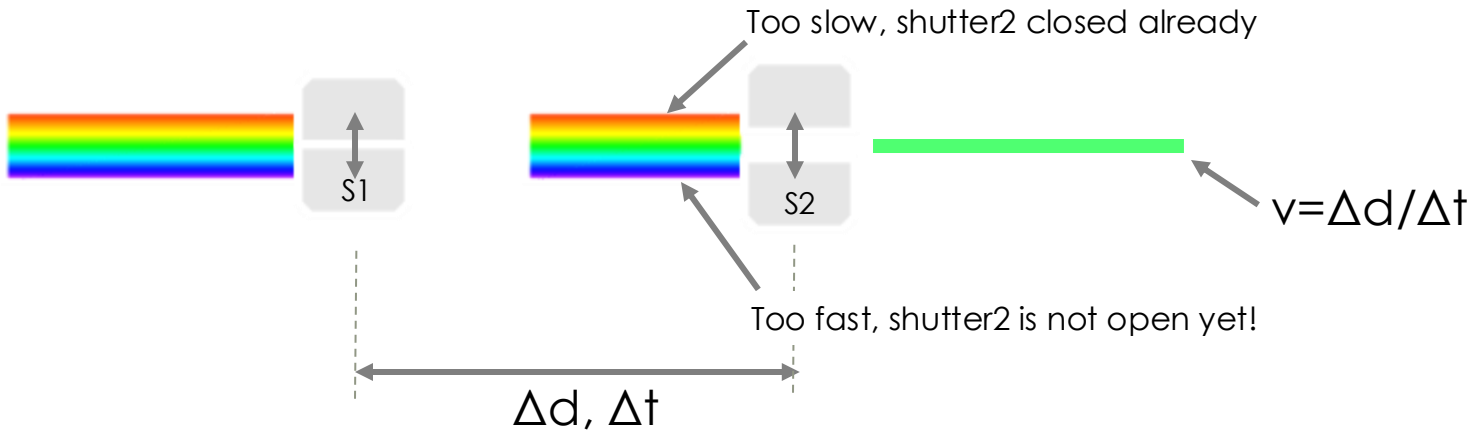


- Can re-use the transmitted beam for other wavelengths!

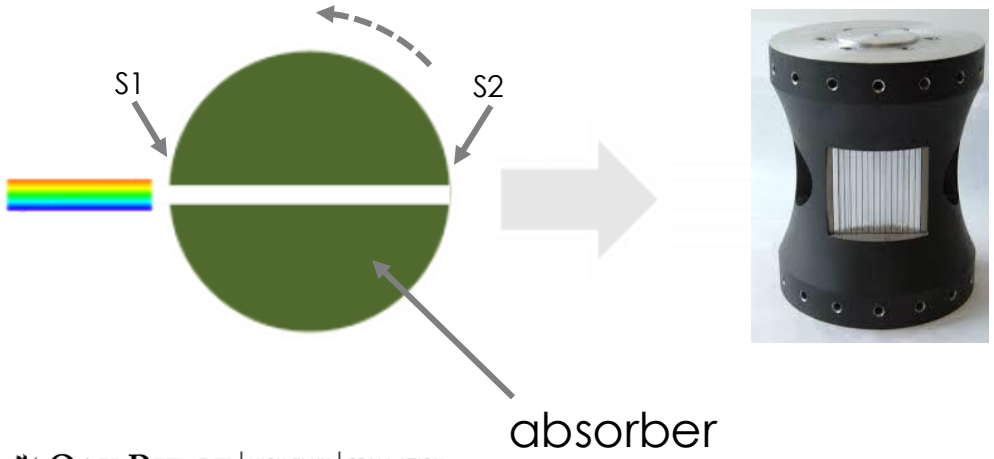


USANS @ SNS

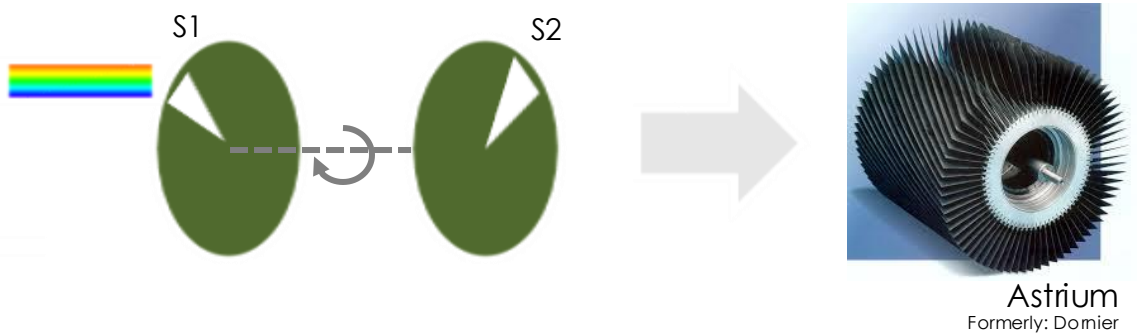
Detour: Fermi Choppers, velocity selectors



Fermi Chopper

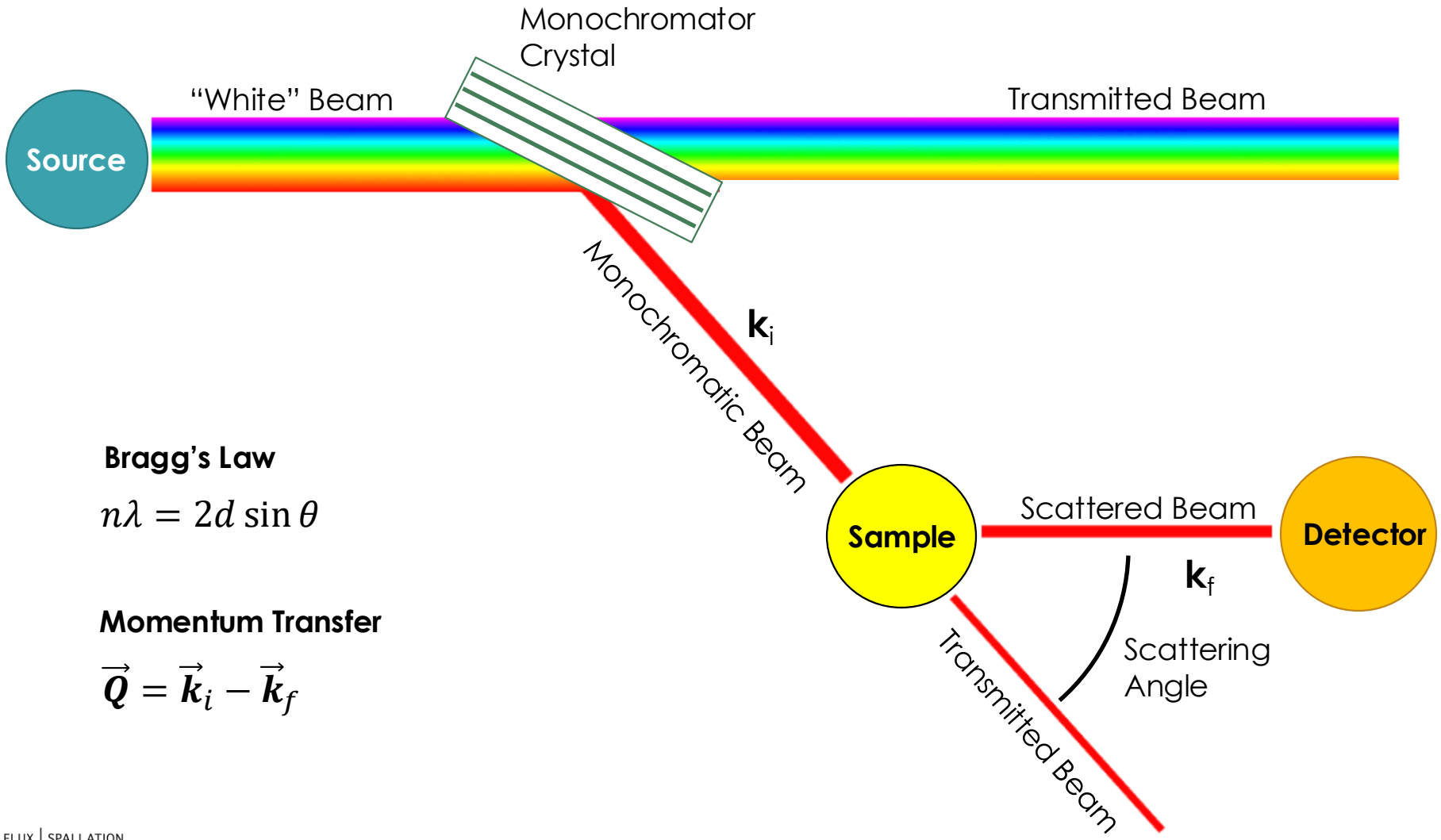


Velocity selector



Astrium
Formerly: Domier

Reactor instruments - elastic



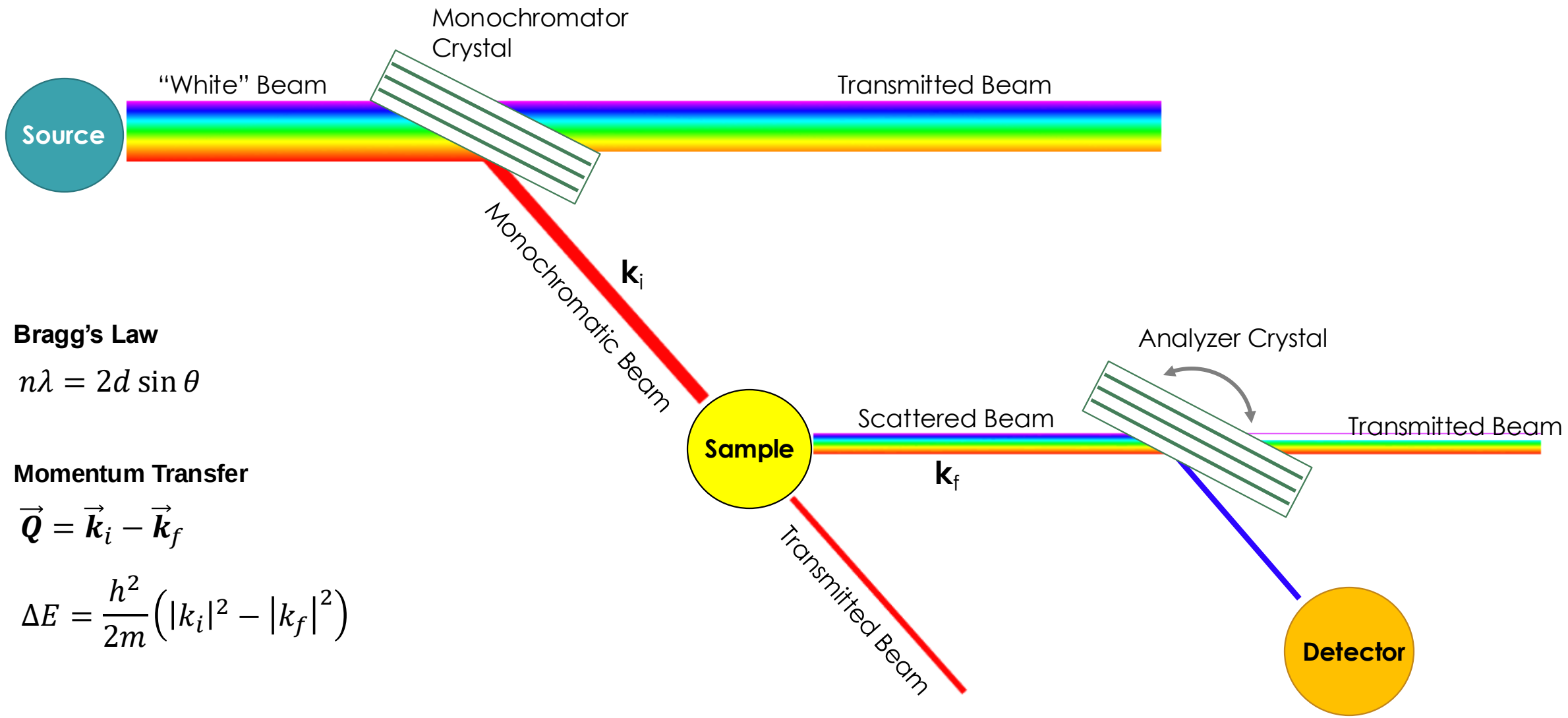
Bragg's Law

$$n\lambda = 2d \sin\theta$$

Momentum Transfer

$$\vec{\boldsymbol{Q}} = \vec{\boldsymbol{k}}_i - \vec{\boldsymbol{k}}_f$$

Reactor instruments - inelastic



Bragg's Law

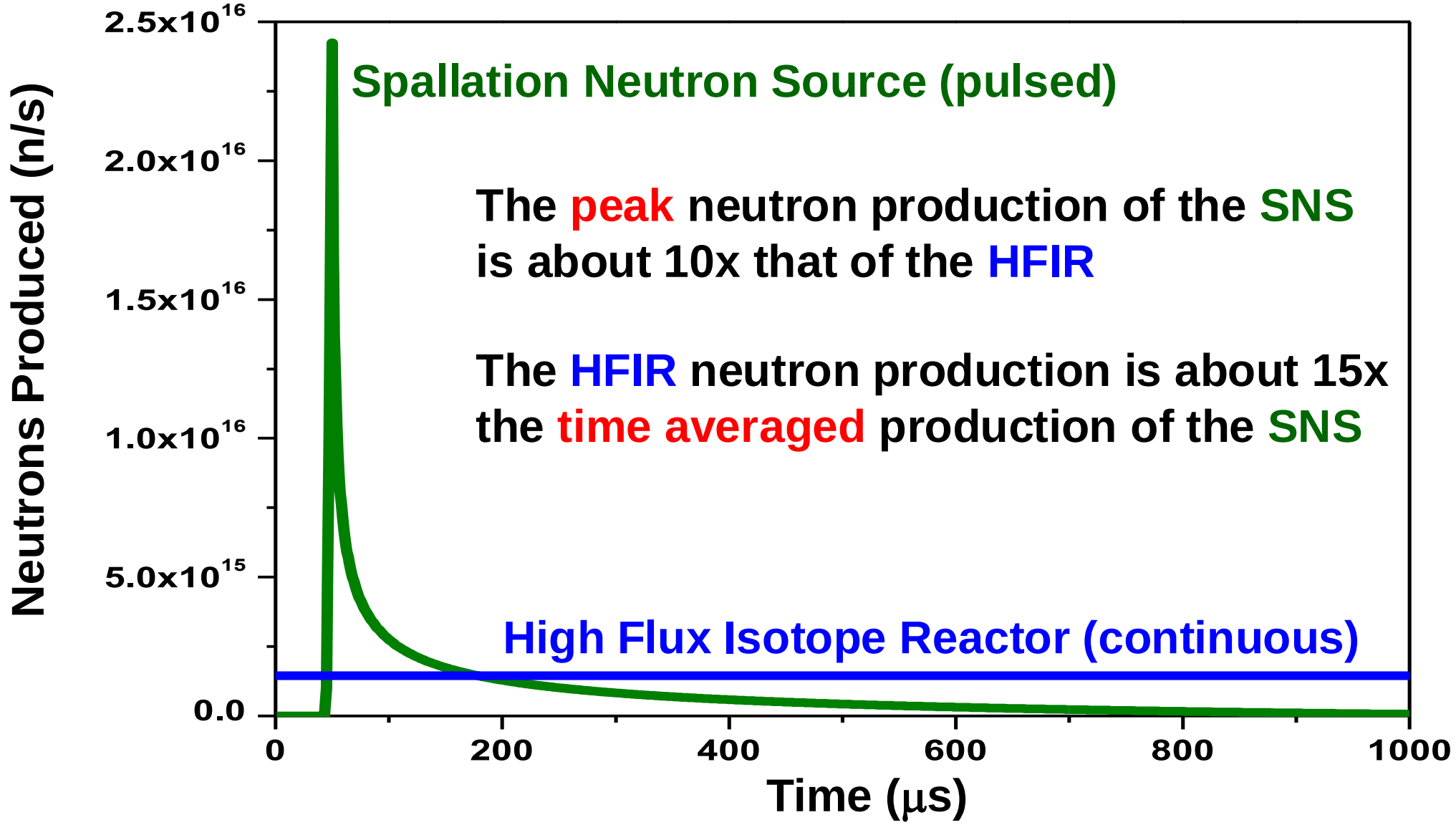
$$n\lambda = 2d \sin\theta$$

Momentum Transfer

$$\vec{\boldsymbol{Q}} = \vec{\boldsymbol{k}}_i - \vec{\boldsymbol{k}}_f$$

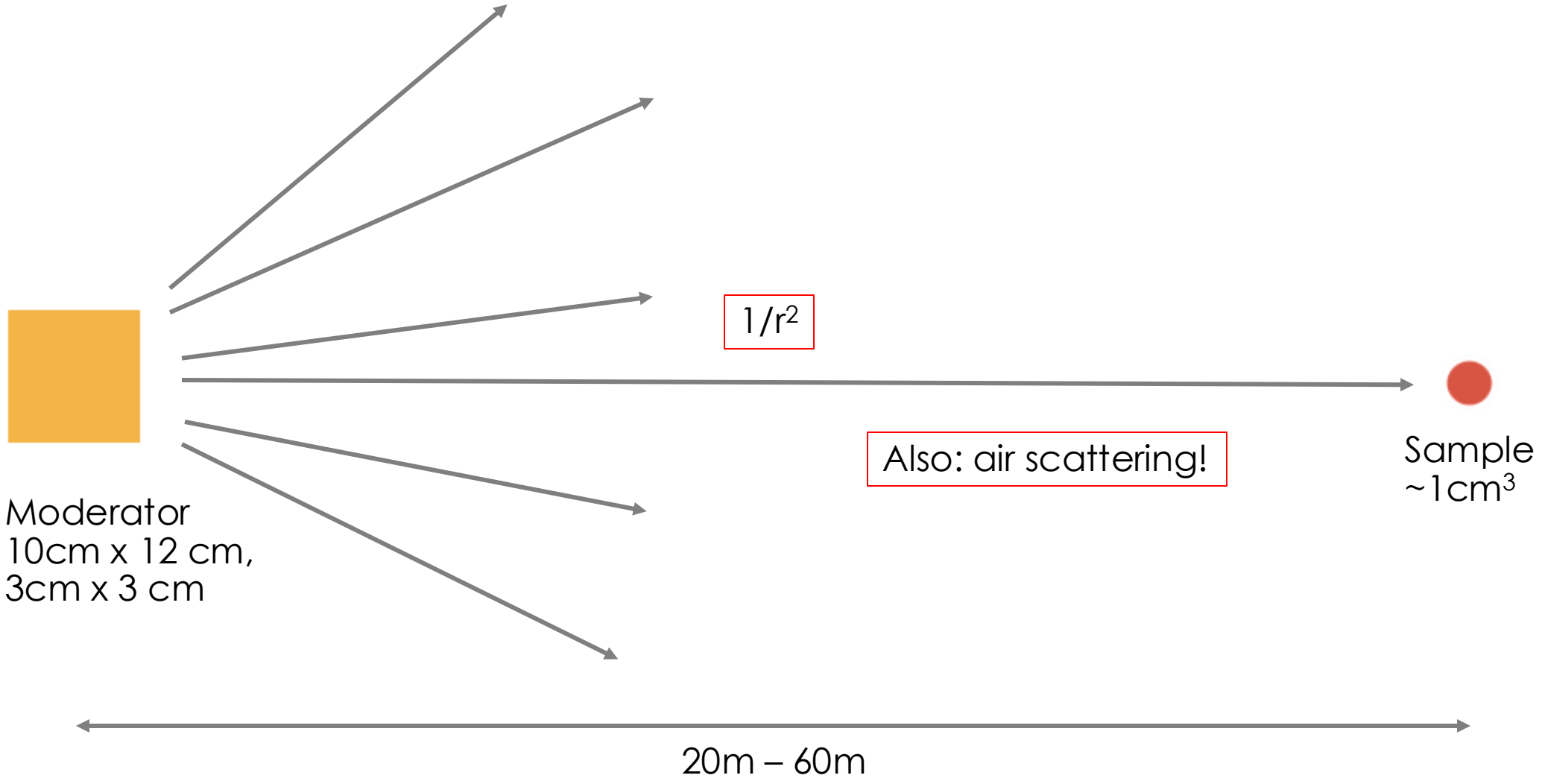
$$\Delta E = \frac{h^2}{2m}\left(|k_i|^2 - |k_f|^2\right)$$

Pulsed vs Continuous Neutron Sources



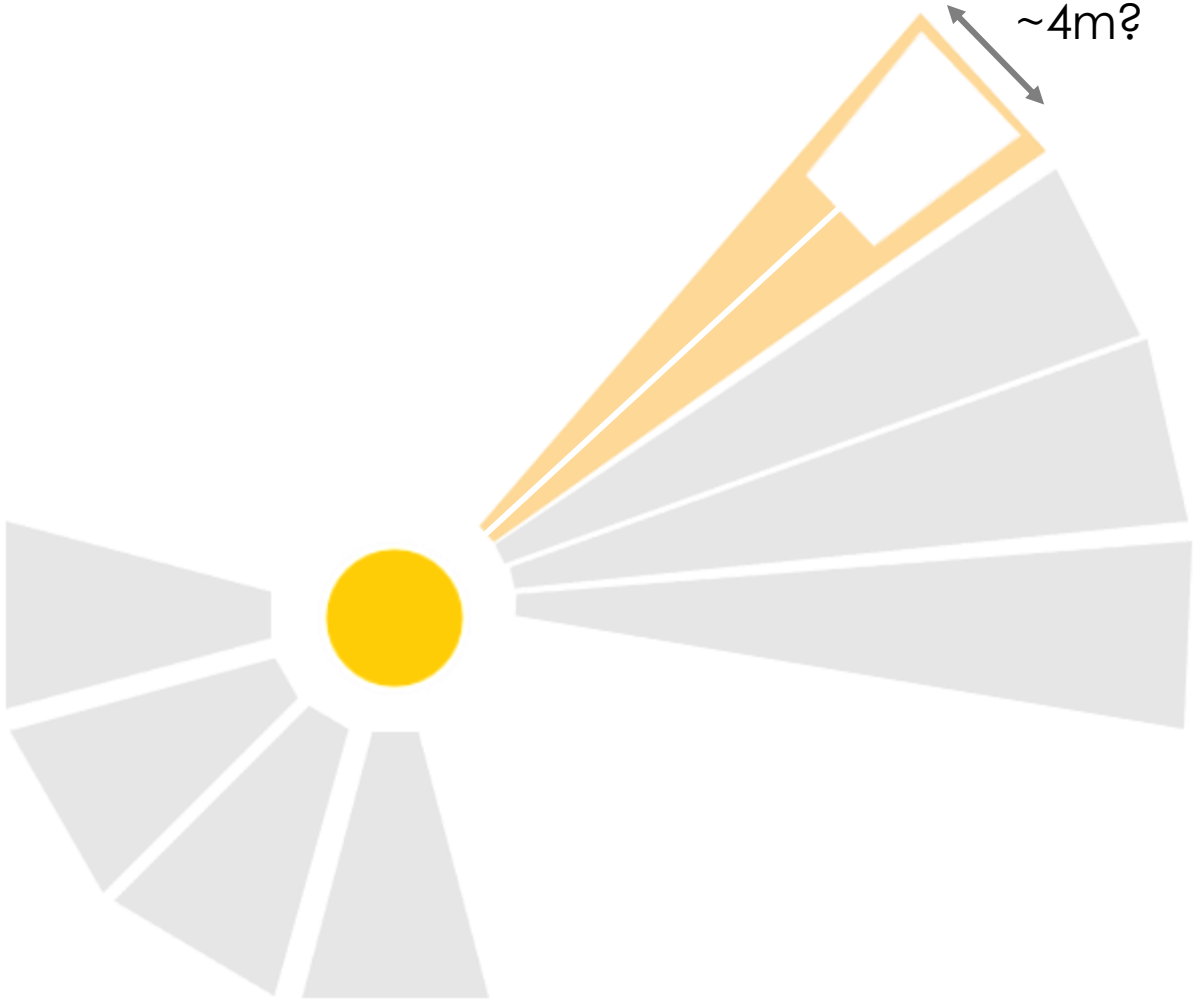
Slide courtesy of Lee Robertson

Transport neutrons!



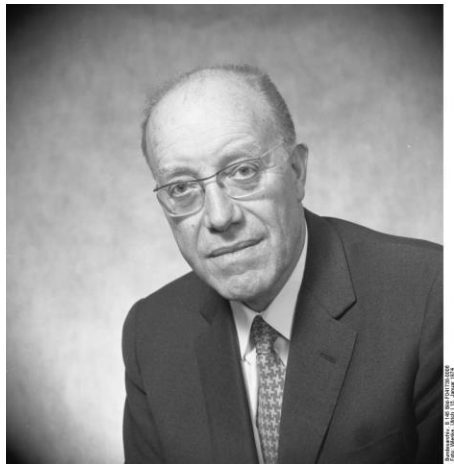
Why not build closer to the source?

- Real estate
- Background
- TOF Resolution:

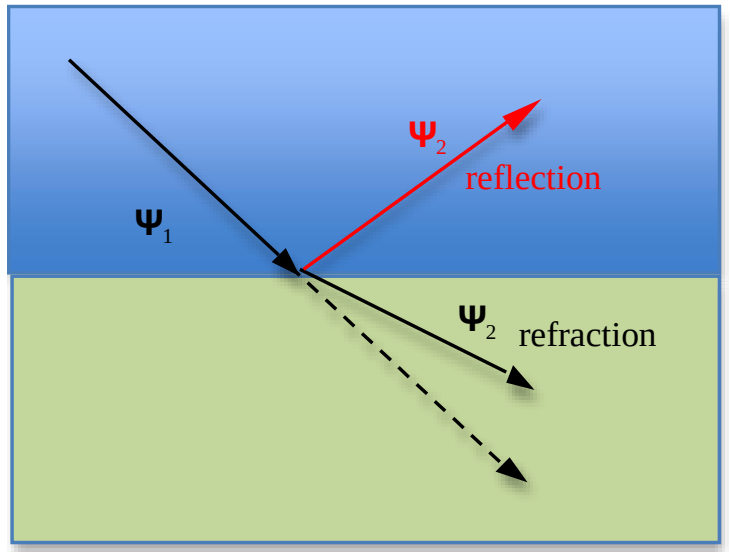


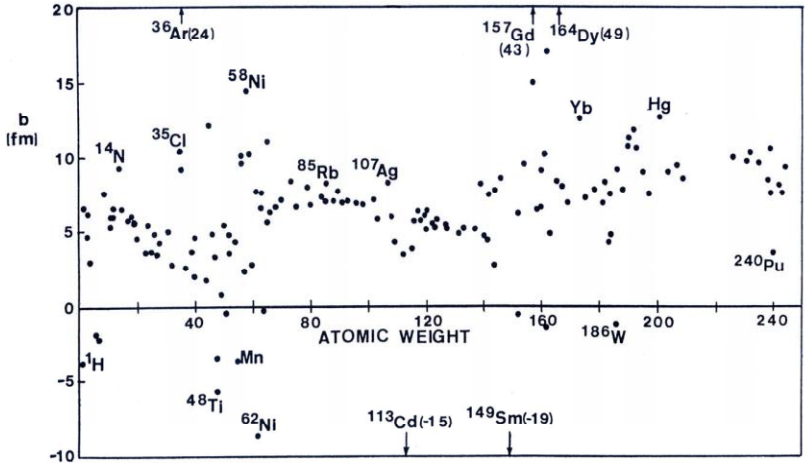
Neutron guides

- Like any wave, neutrons can reflect off a surface under certain conditions (see reflectometry lecture!)
  - Low angles, long wavelengths
  - Ni-58 layers deposited on glass
- Invented by Heinz Maier-Leibnitz at FRM reactor



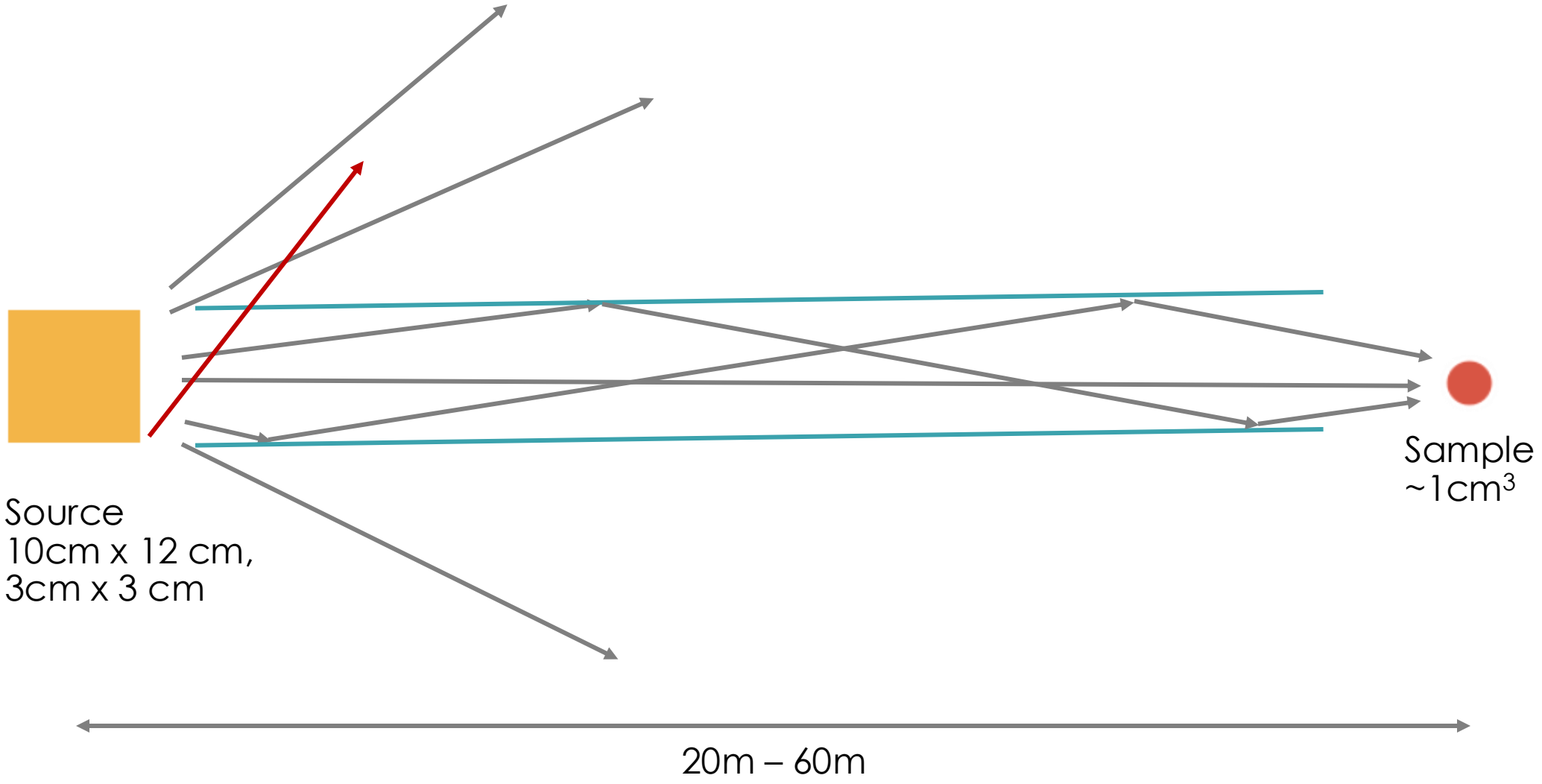
H. Maier-Leibnitz and T. Springer, React. Sci. Technol. 17, 217 (1963)



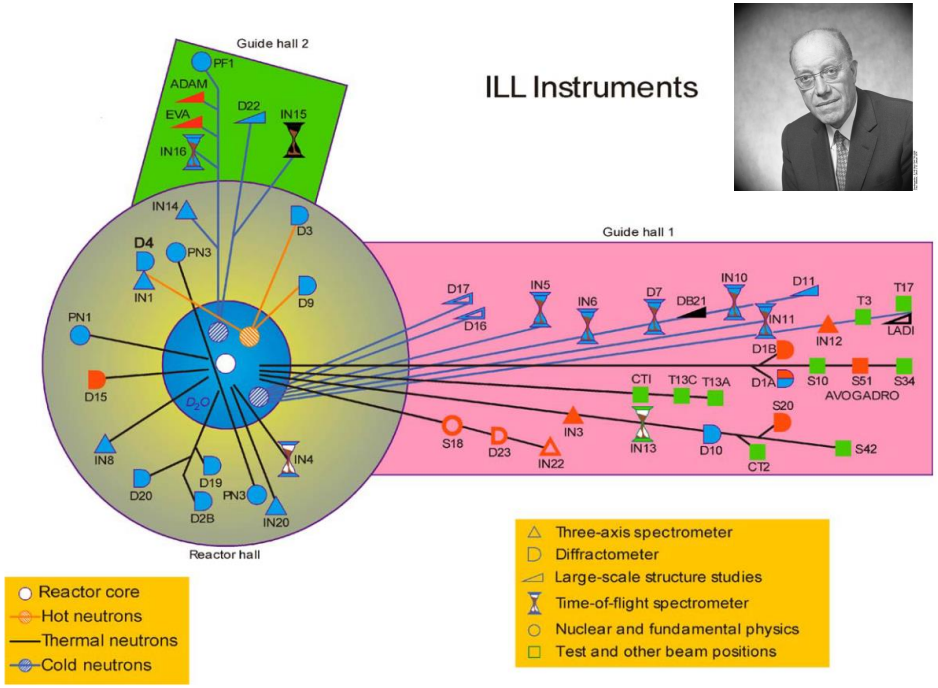


Bound coherent scattering length

Transport neutrons – with guides!

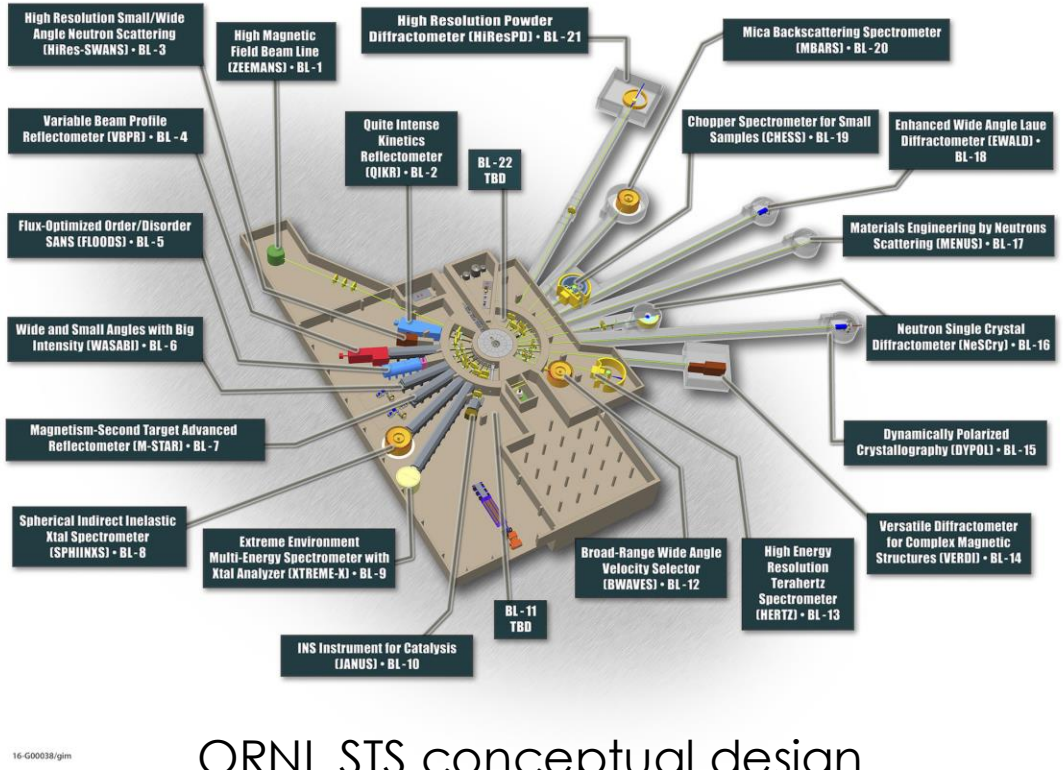


Neutron Guides allow unparalleled Utilization of Neutron Beams



ILL Instruments

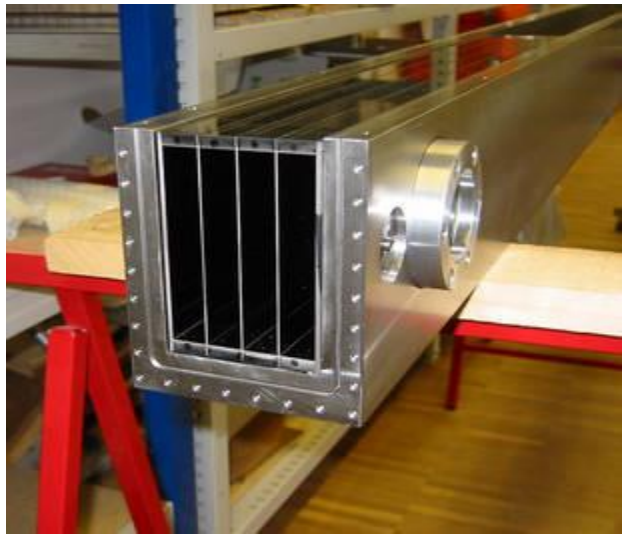
https://www.ill.eu/



ORNL STS conceptual design

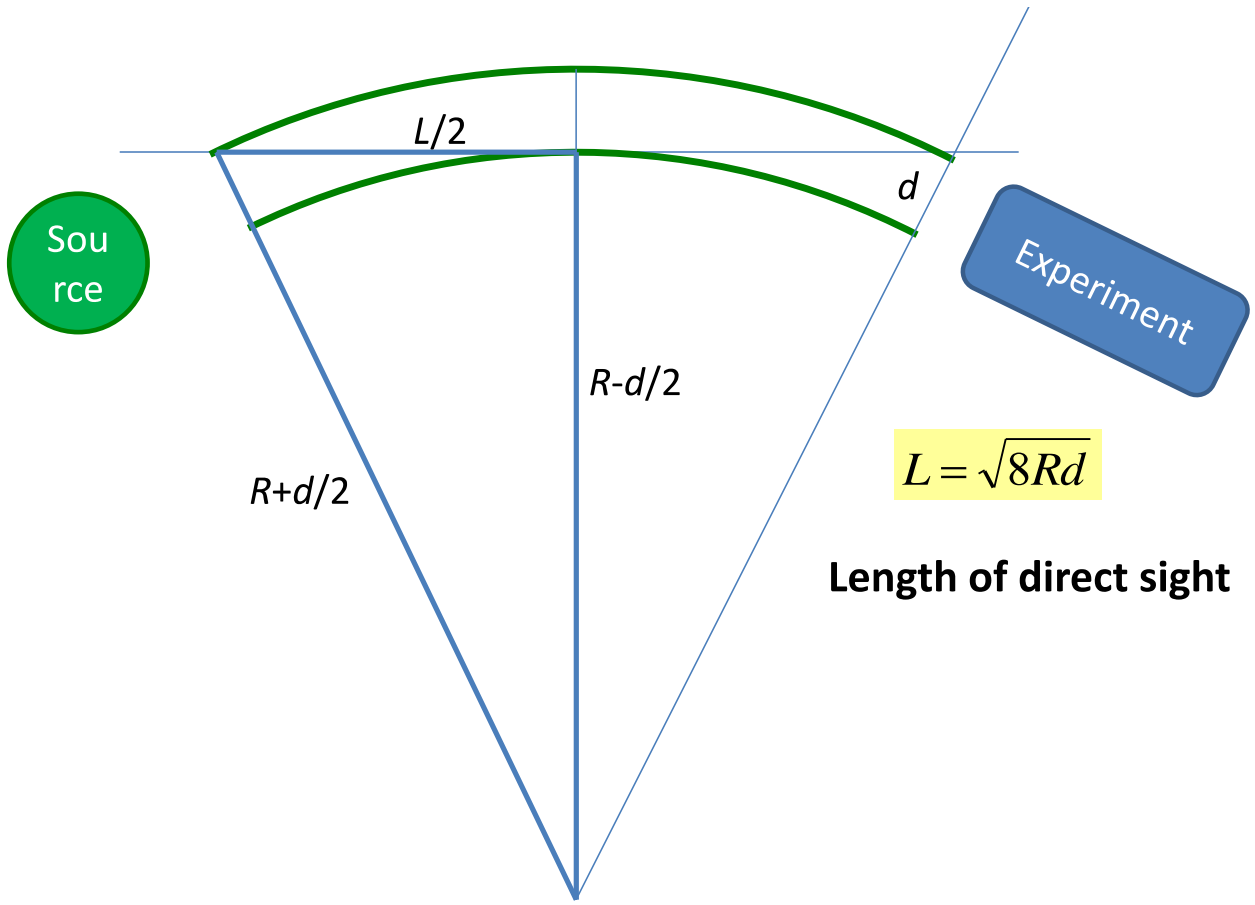
Pictures!

80m Guide for HRPD at J-PARC
Fabricated by Swiss Neutronics



Multichannel Curved Guide
Fabricated by Swiss Neutronics

Not just straight!



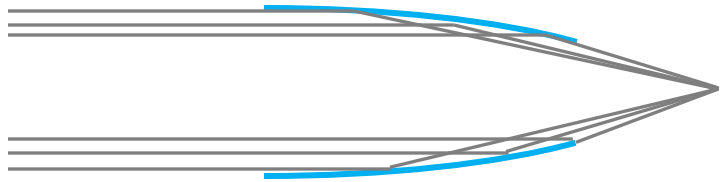
$$L = \sqrt{8Rd}$$

Length of direct sight

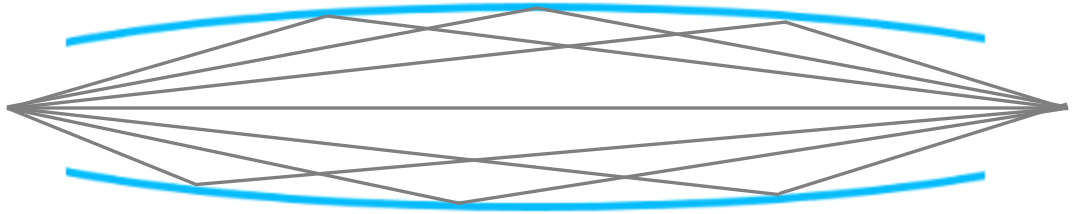
Getting out of direct line of sight reduces background from source

Advanced neutron optics

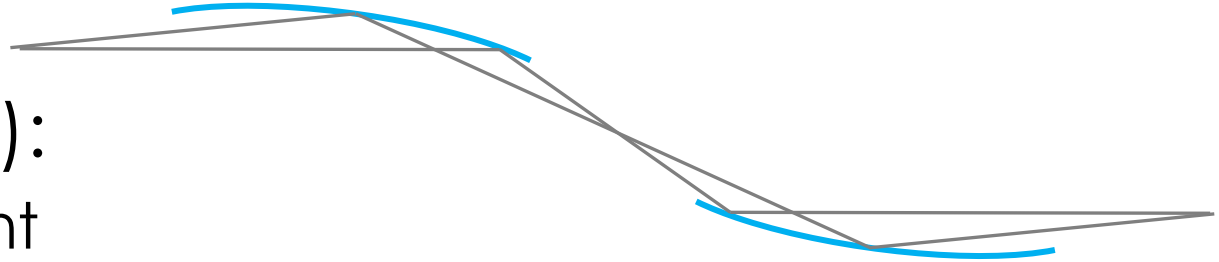
- Parabola: focusing



- Elliptic: imaging



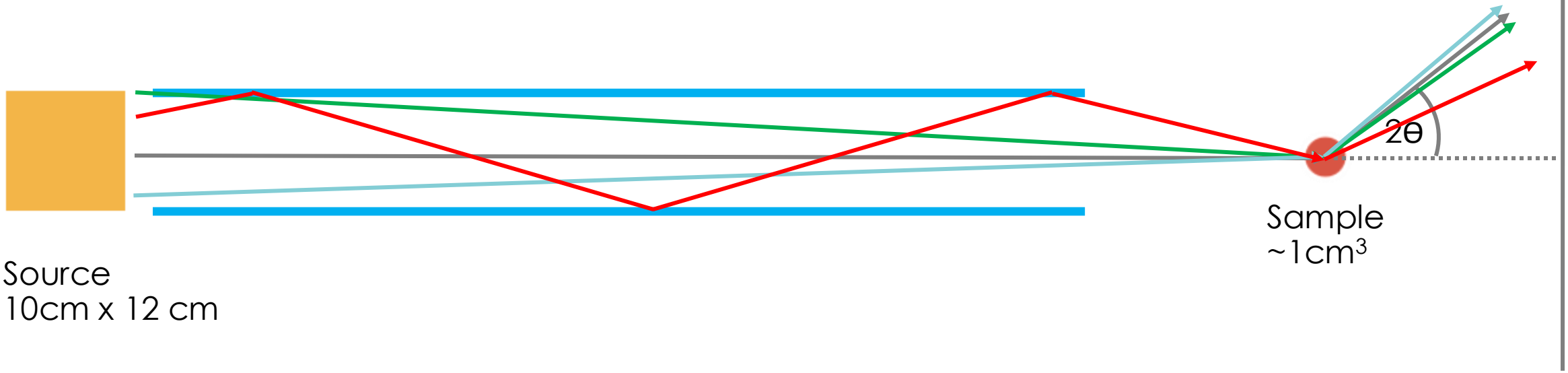
- Zig-Zag (half ellipses):
  - Imaging + line of sight



BUT!

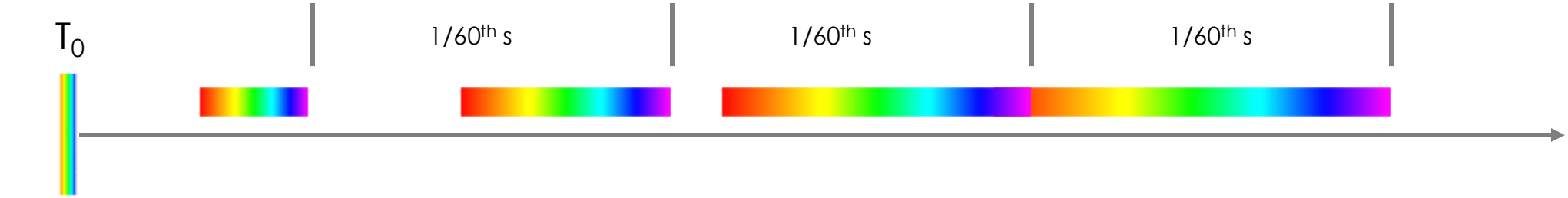
Joseph Liouville

- Angle/wavelength limited
- Liouville is watching you!
  - No free lunches.
  - Increase in neutron flux comes with decreased resolution
  - Finding the balance is a large part of instrument design

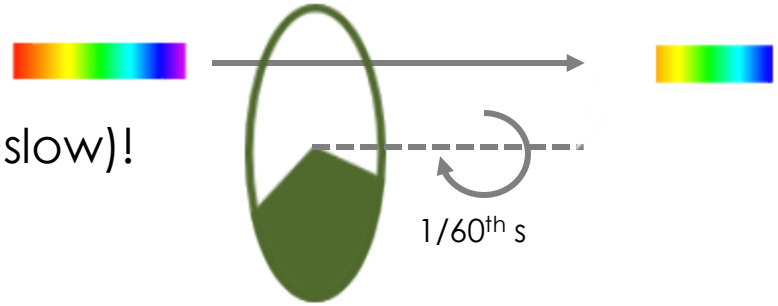


Other problems: Frame overlap

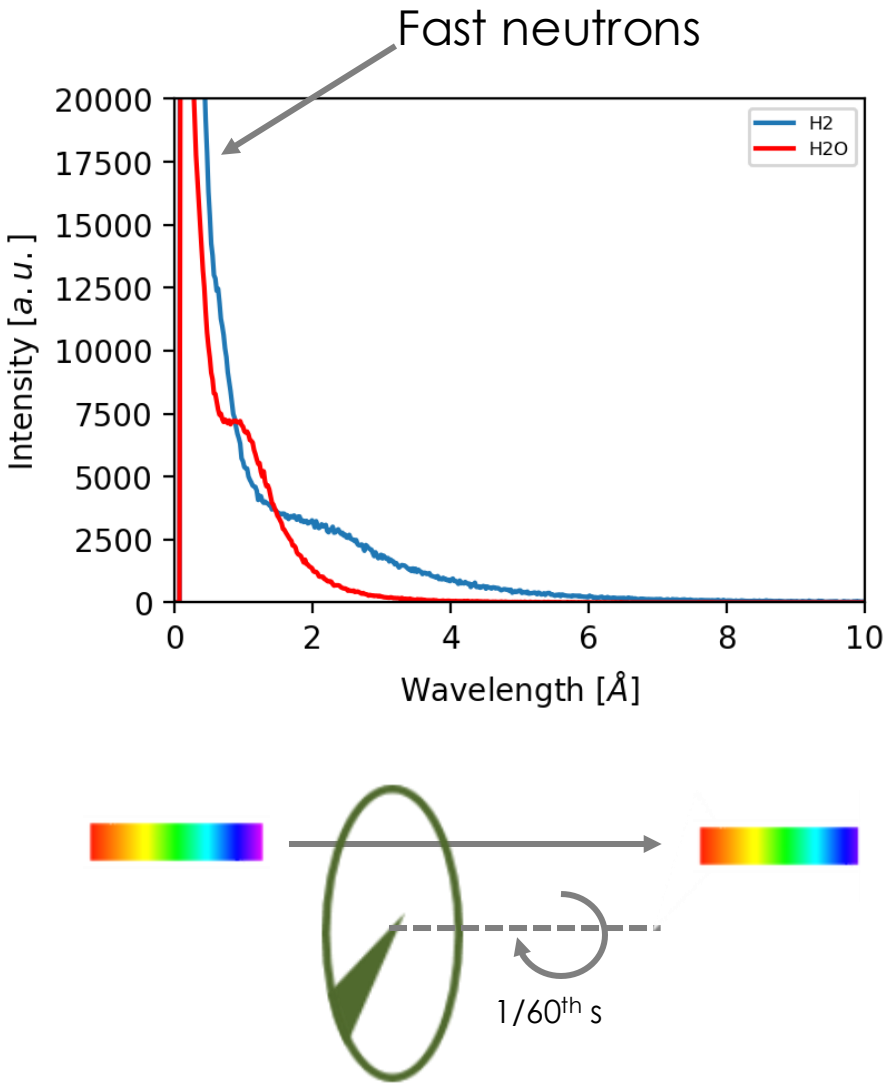
- There is usually more than one pulse in a beam line
- It is important (and difficult) to keep track of which pulse started when for TOF analysis
- Fast neutrons from one pulse can overtake the slow ones from the previous pulse "Frame overlap"
- TOF analysis becomes impossible
- The longer the beam line and the higher pulse frequency the worse



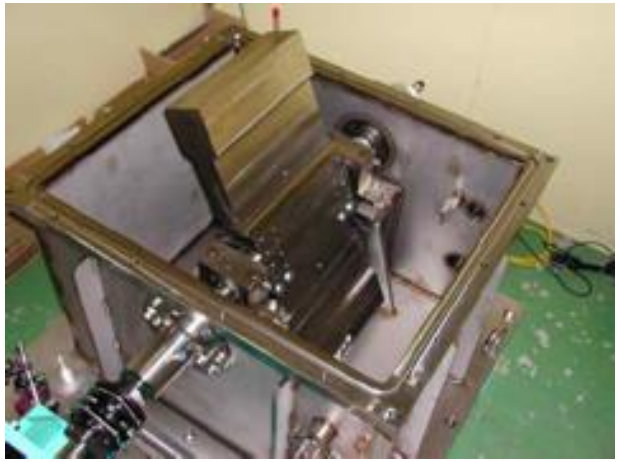
- Solution: Get rid of those neutrons (fast/slow/fast+slow)!
- Use a chopper in phase with the pulsed source
- Select time offset to chose spectrum
- Might need to measure twice for full spectrum



T0 choppers



- Fast neutrons and gammas arrive first after proton pulse delivery
- 20-50 cm thick steel blade attenuates these
- Requires well-balanced flywheel for good lifetime and prevention of vibrations



Unit running at JPARC

Detectors…

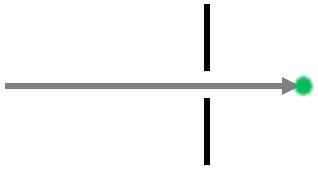
- Several types of detectors
- Idea: trigger a nuclear reaction that releases an energetic charged particle that can then be detected (e.g. through an ionization event)
- Requirements:
  - Position resolution
  - Timing resolution
  - Not sensitive to background
  - Cheap

… and where to put them

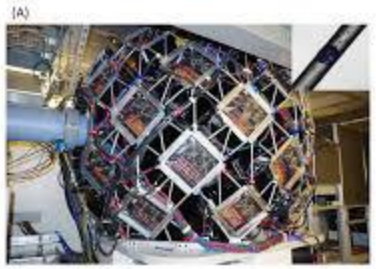
SANS:

Wide Q range:

High resolution powder diffraction:

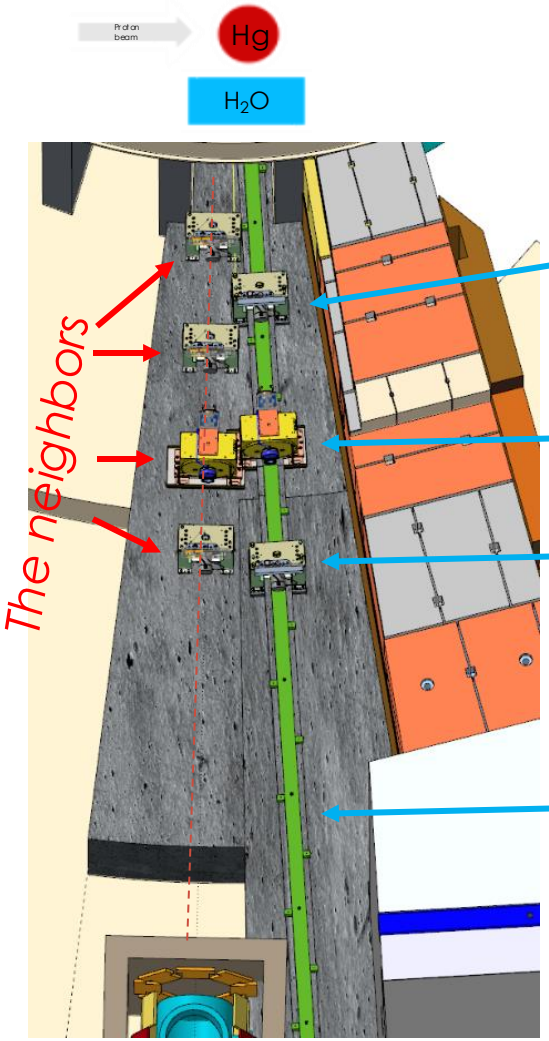


Single Crystal Diffractometer:



TOPAZ @ SNS

DISCOVER (planned @ SNS)

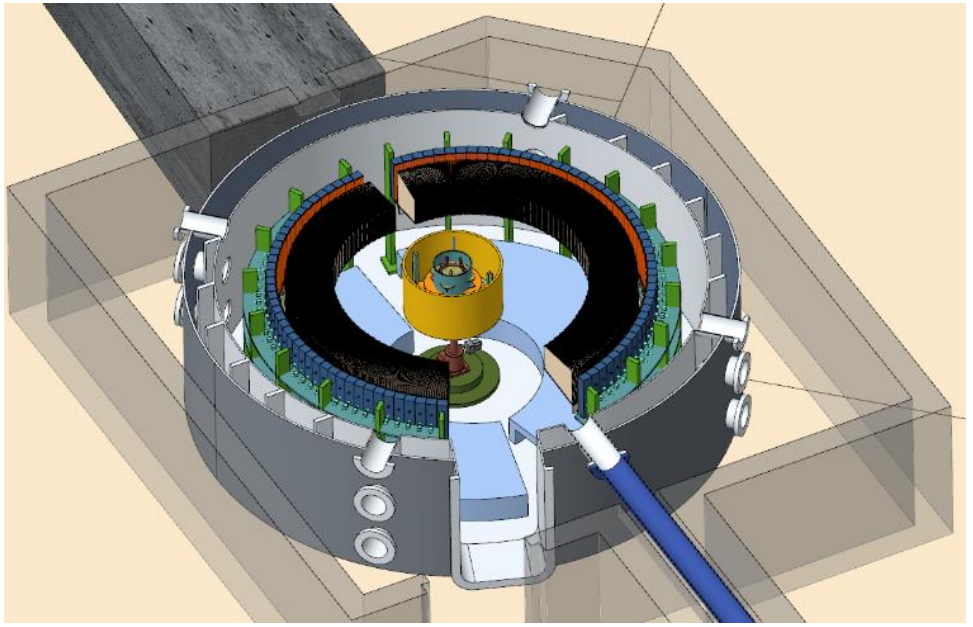


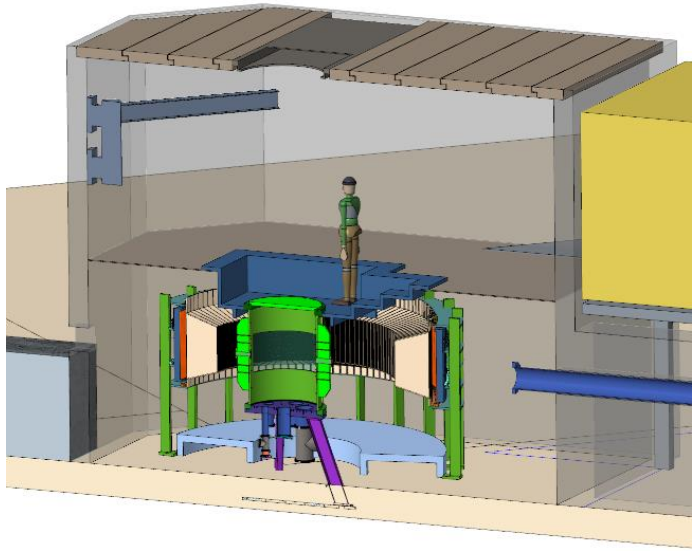
Frame overlap chopper 1

T0 chopper

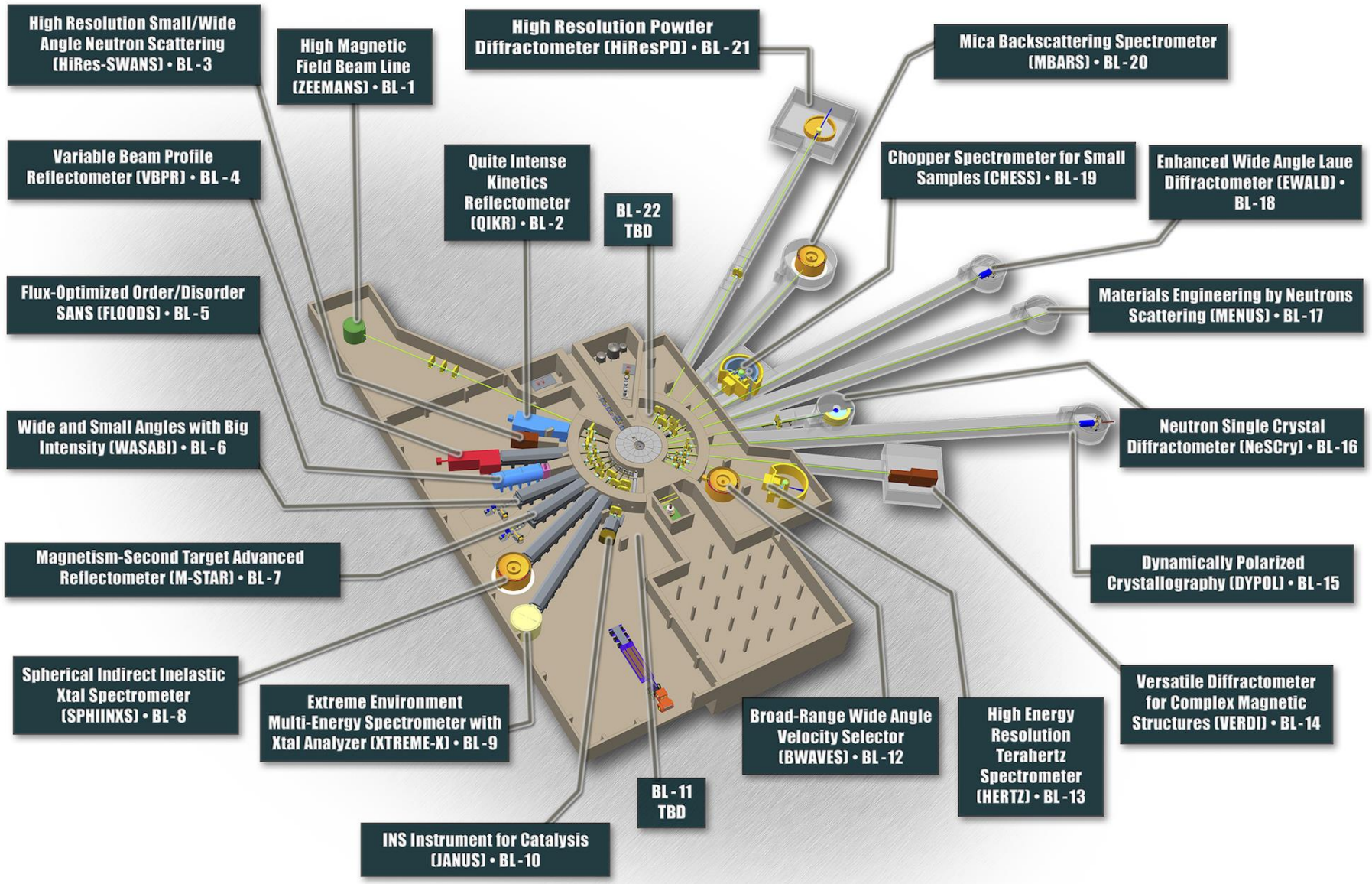
Frame overlap chopper 2

Guide





Second Target Station



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