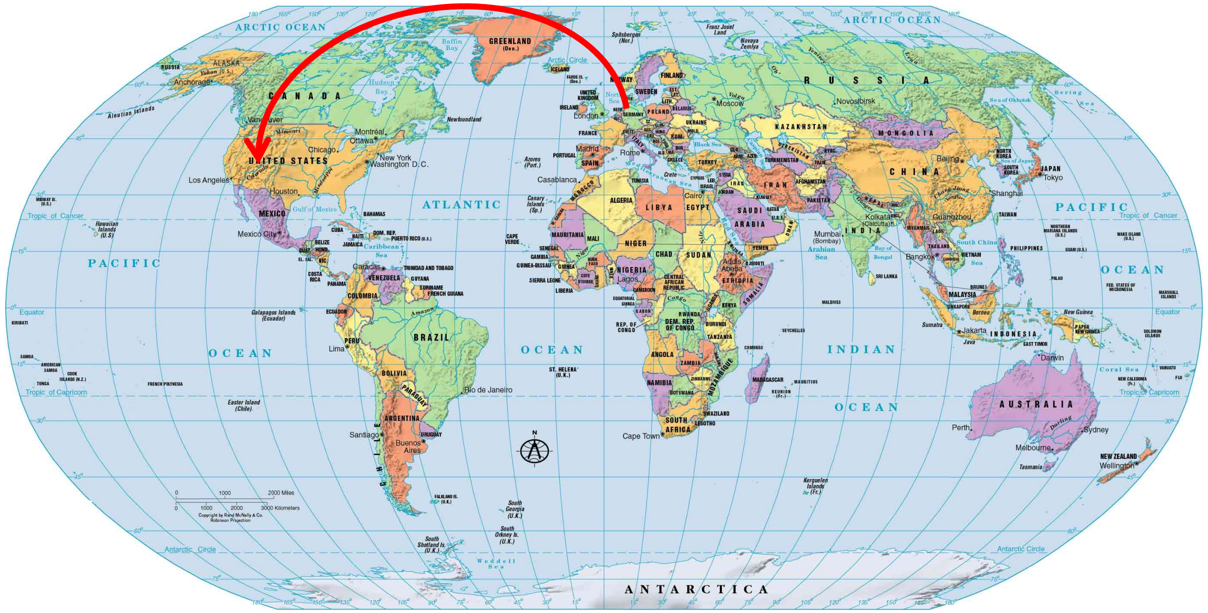
Neutron Generation and Detection/Neutron Optics and Instrumentation - Part 1

Thomas Huegle

Neutronics Scientist

August 2023

Neutron school 2007 (Los Alamos)!

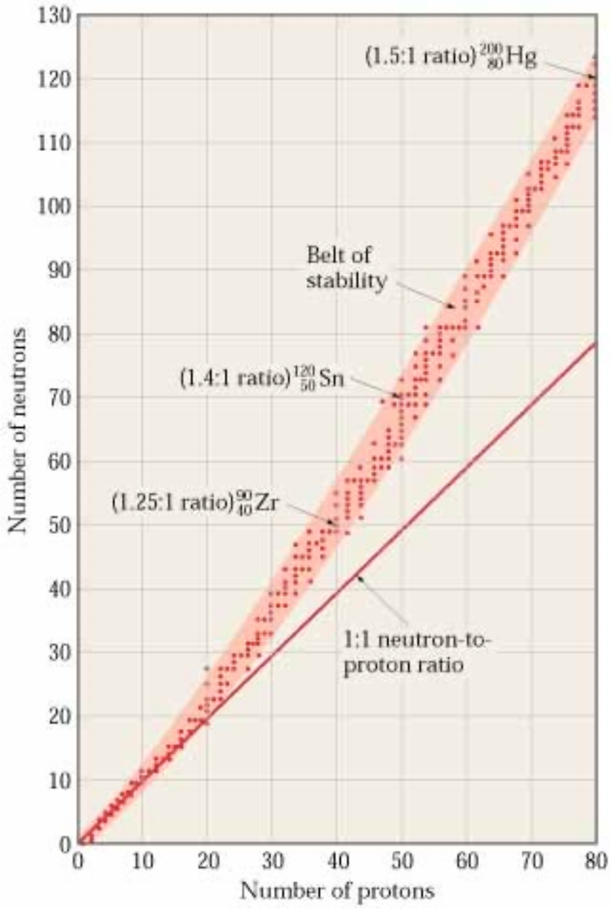


Neutron Generation and Detection/Neutron Optics and Instrumentation

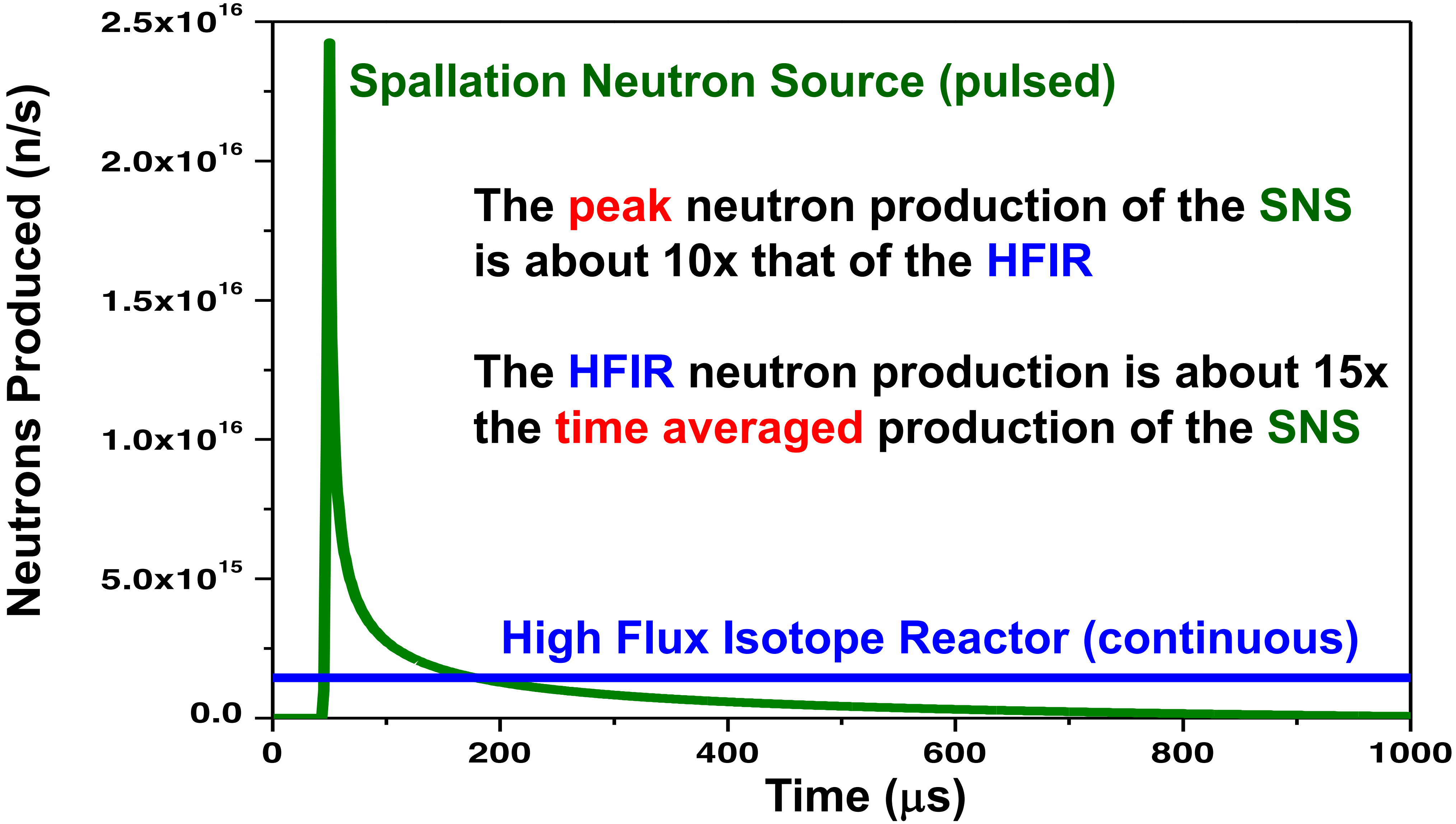
- How to build a neutron scattering instrument from scratch:
  - Make neutrons!
  - Transport neutrons!
  - Scatter neutrons! (other people will tell you about this)
  - Detect neutrons!

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

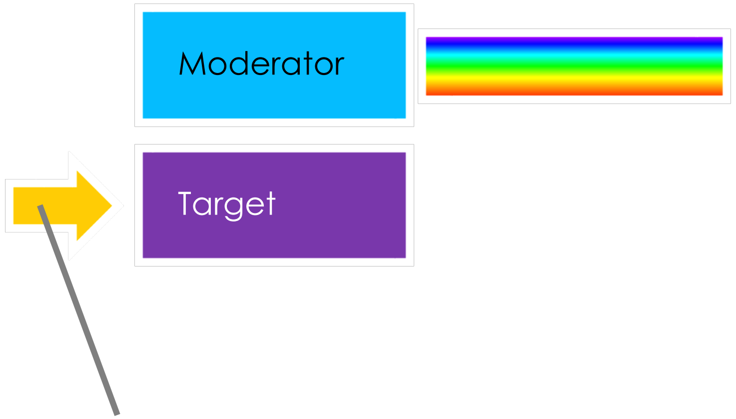
Make <u>useful</u> neutrons!

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

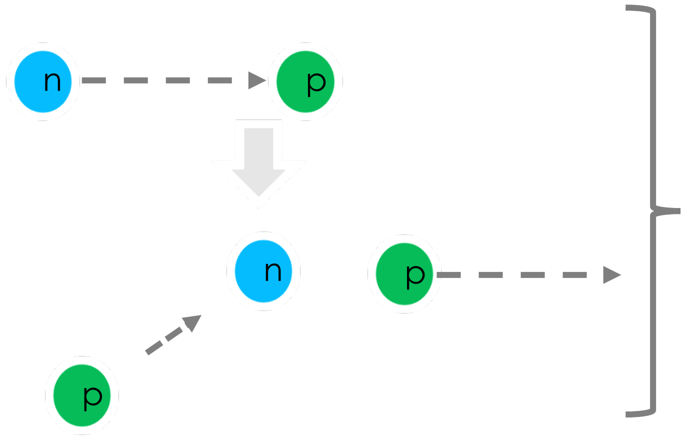
You are here!

Moderators

usually: LH_2 or H_2O



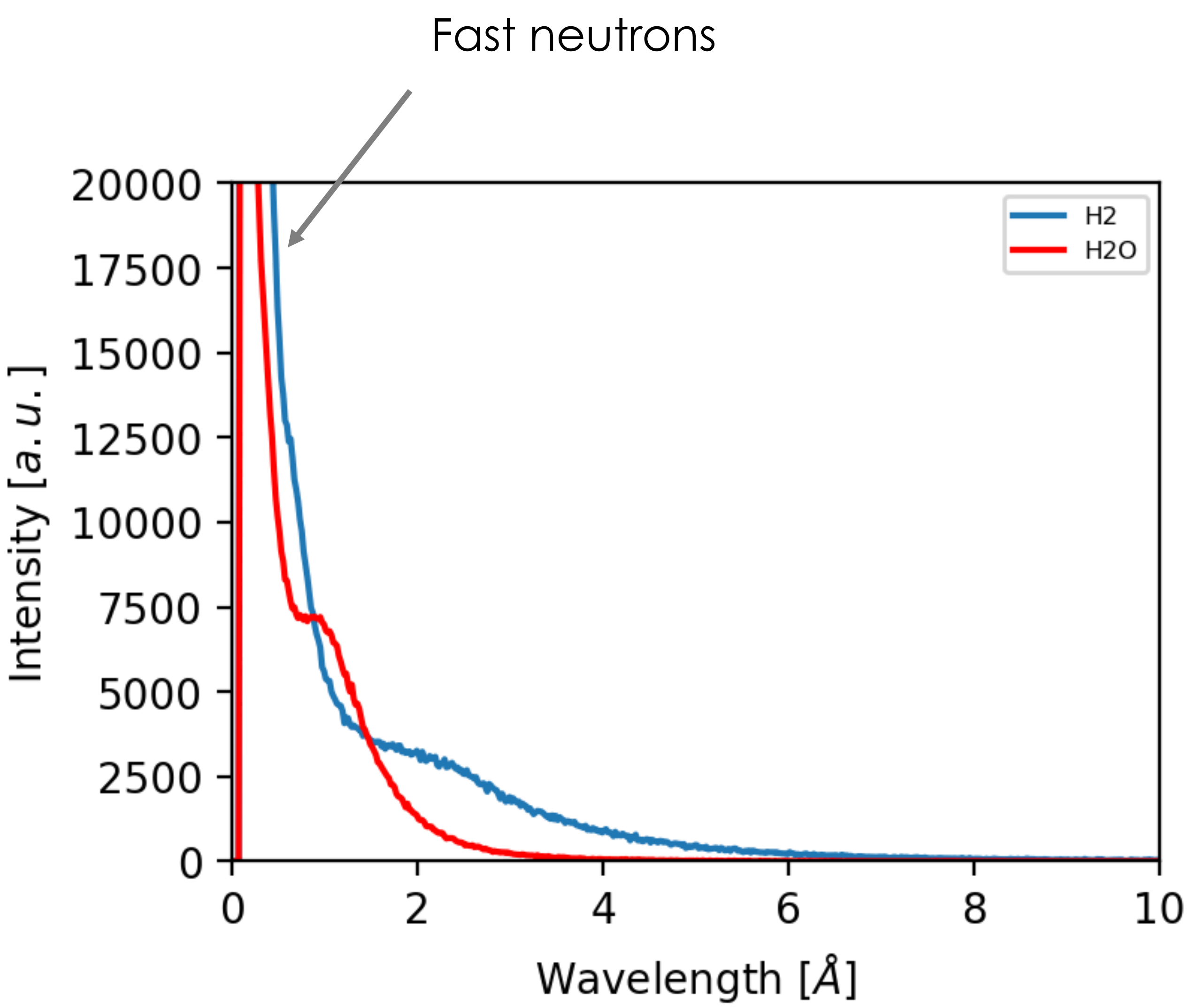
Proton beam



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

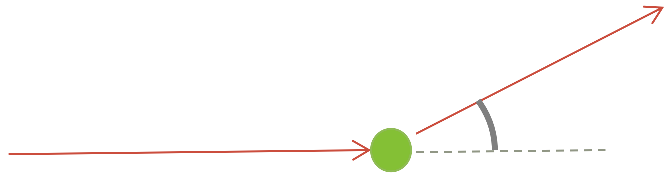
Spectra H2 vs H2O @ SNS



Two instrument concepts

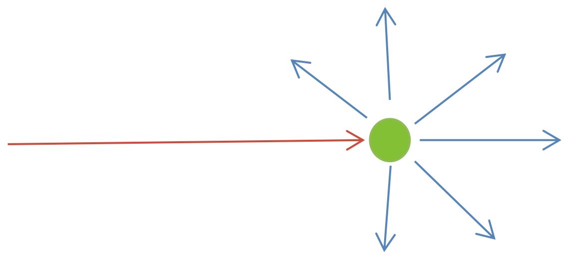
Diffractometer (elastic scattering)

- Characteristic changes in angle
- No change in wavelength

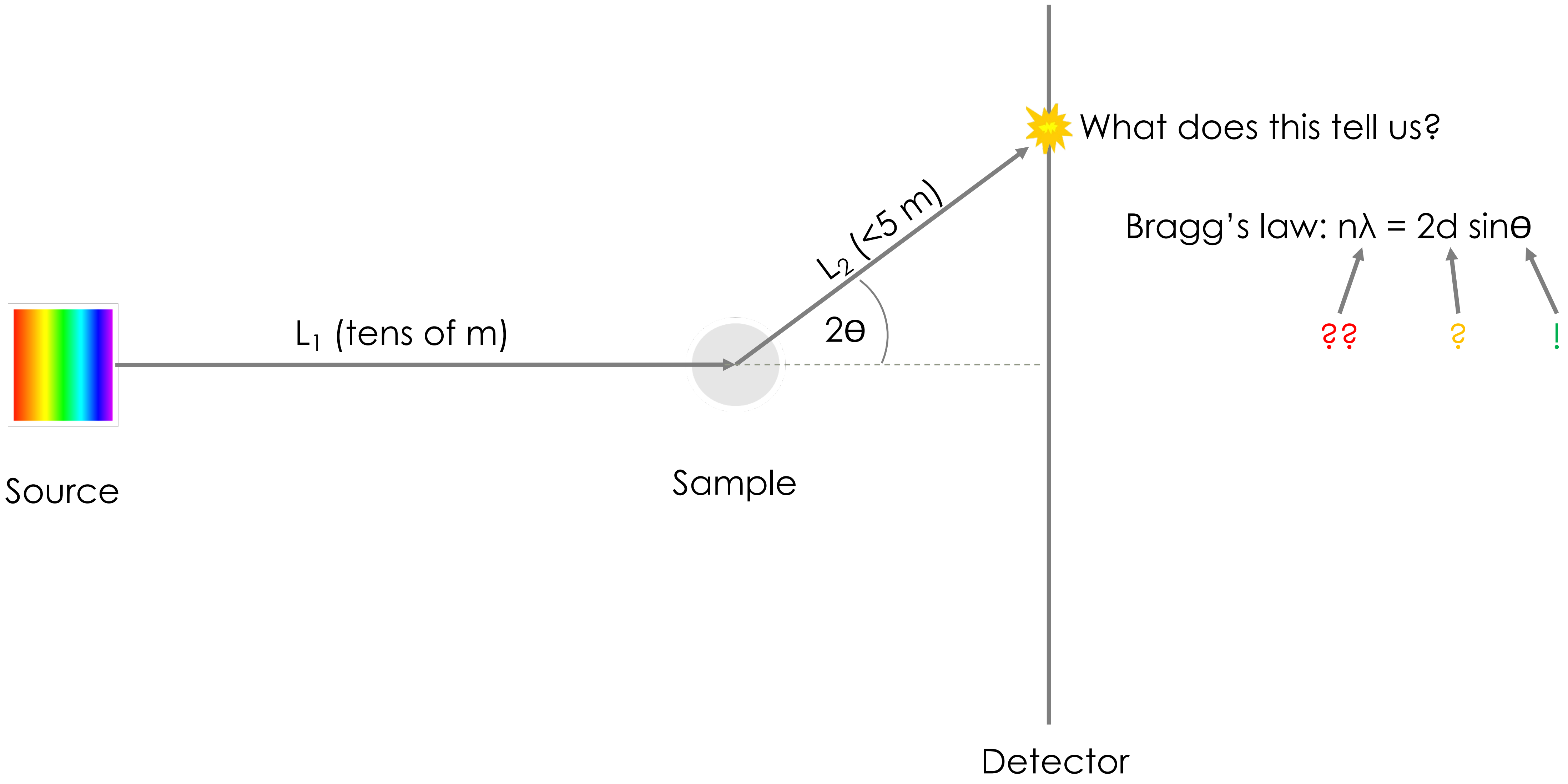


Spectrometer (inelastic scattering)

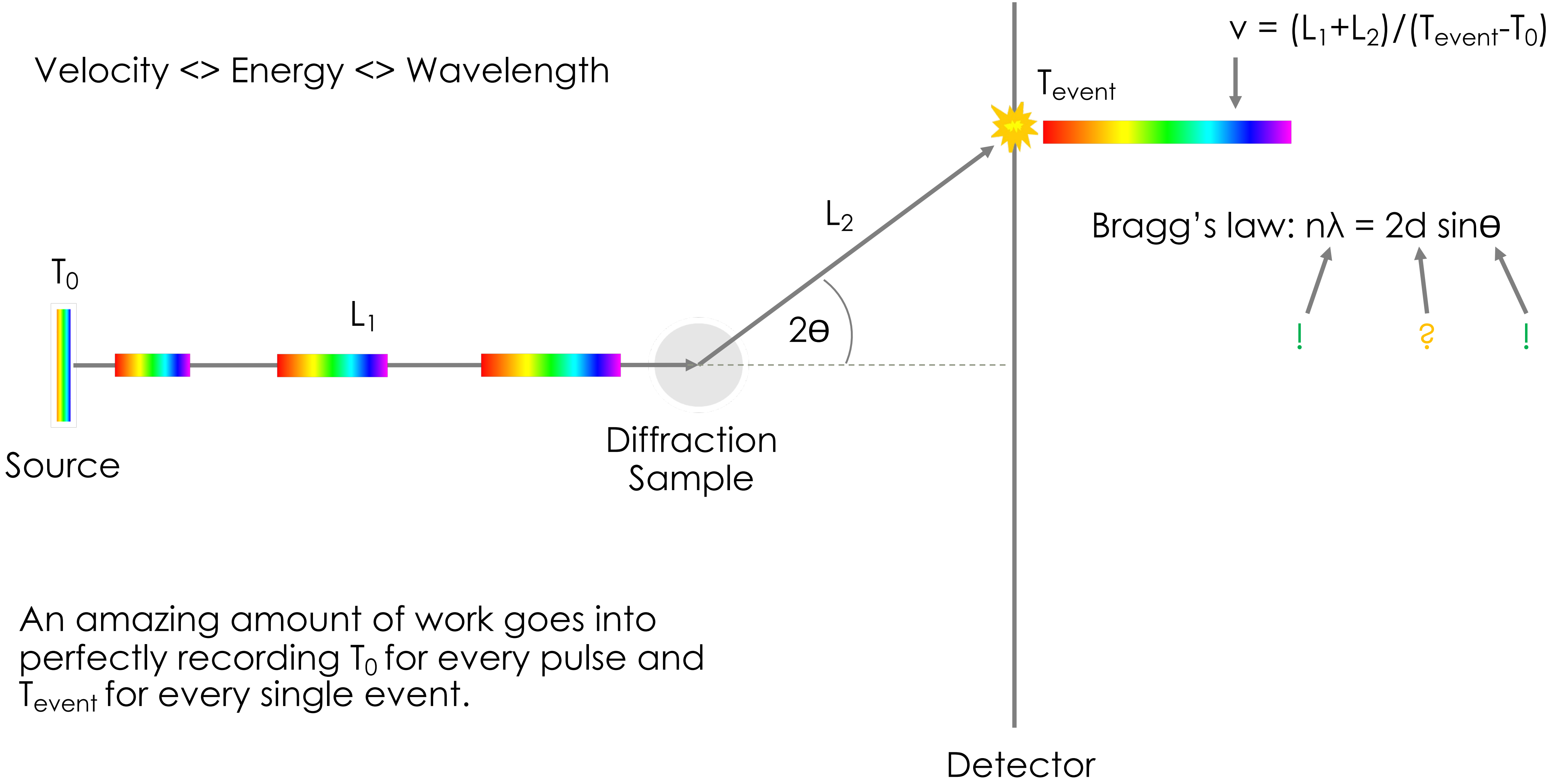
- Isotropic change in angle
- Characteristic change in wavelength



Let's build an instrument already!



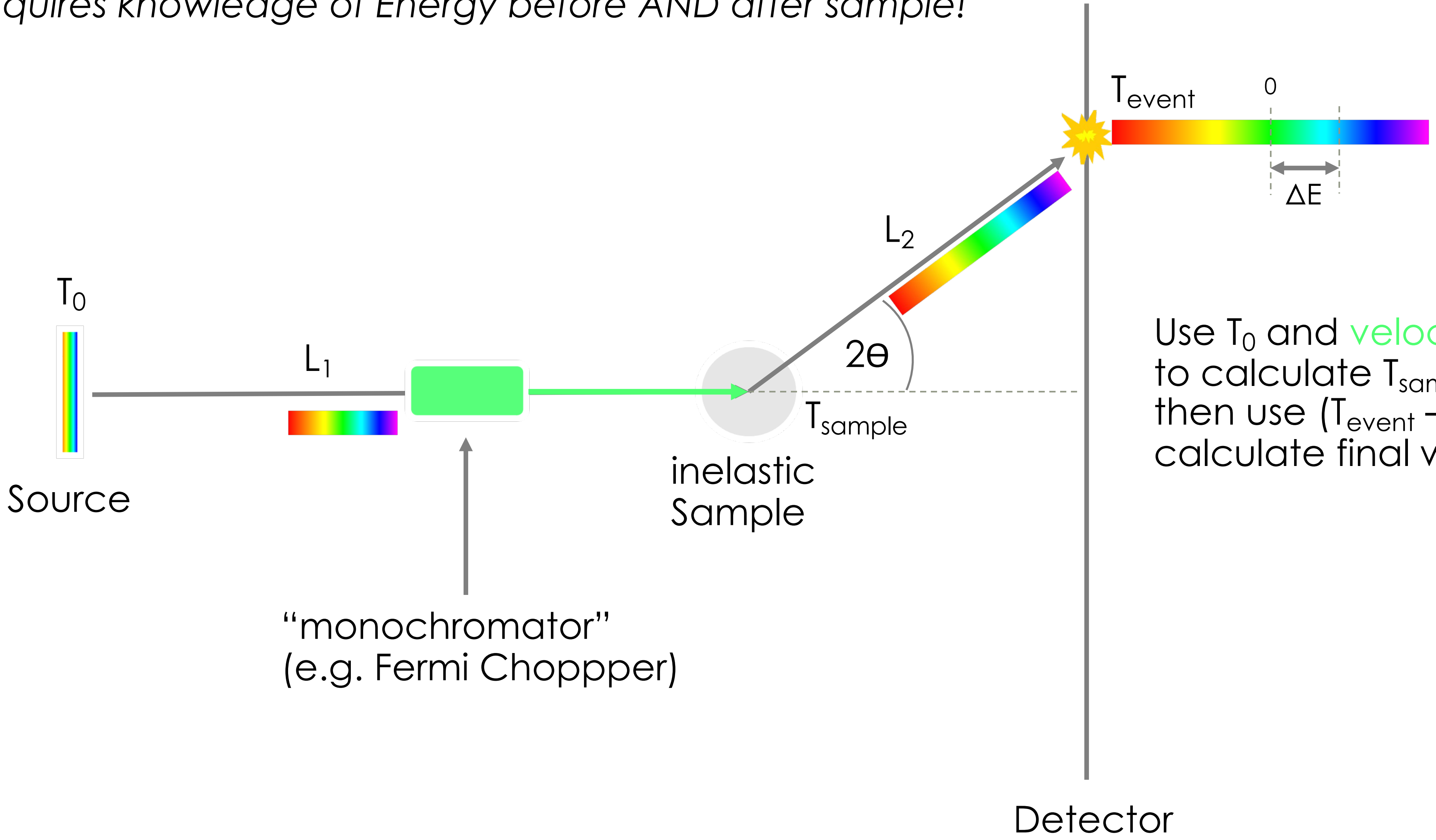
At a pulsed source: Time Of Flight (TOF) - elastic



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

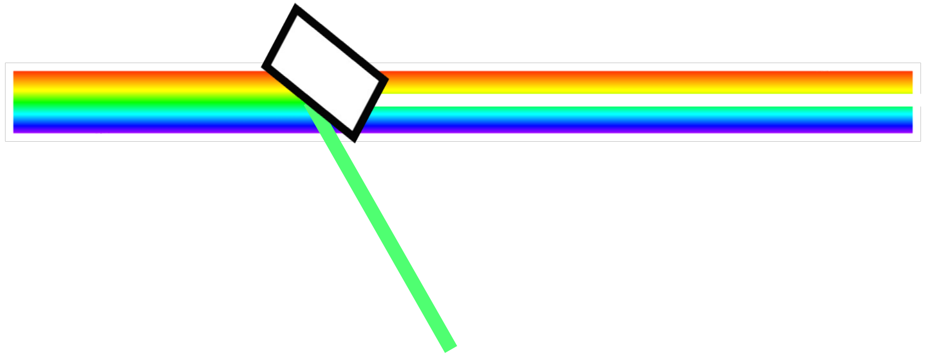
Requires knowledge of Energy before AND after sample!



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

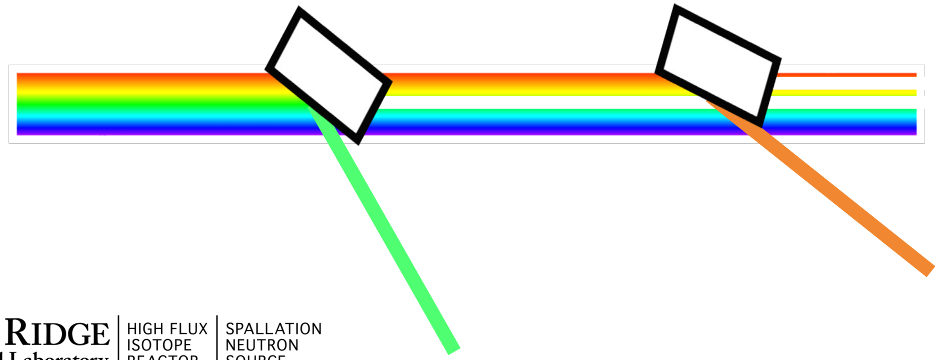
Detour: Crystal monochromators

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

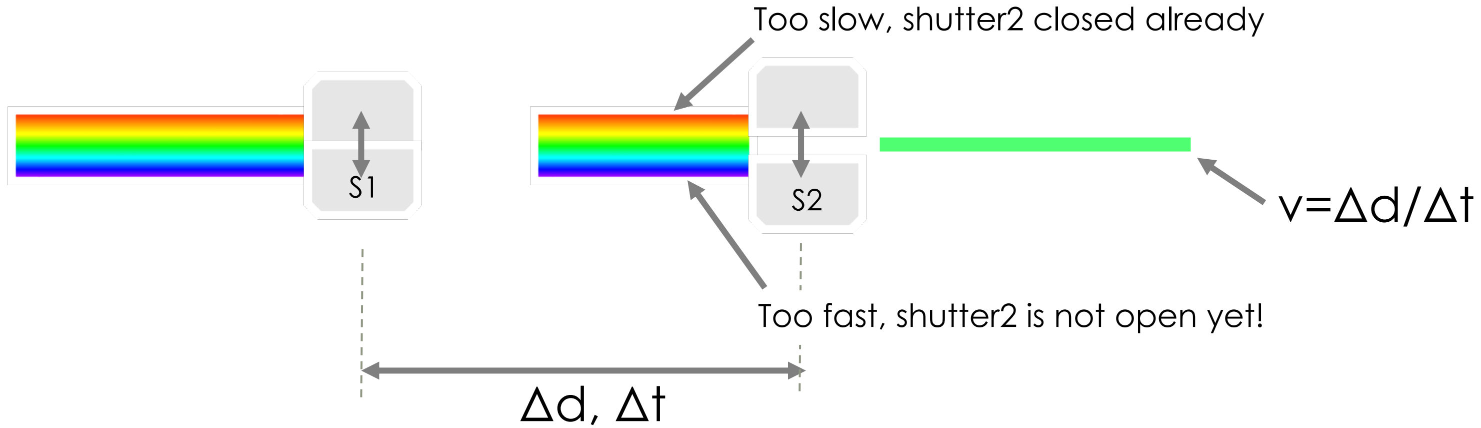


- Can re-use the transmitted beam for other wavelengths!

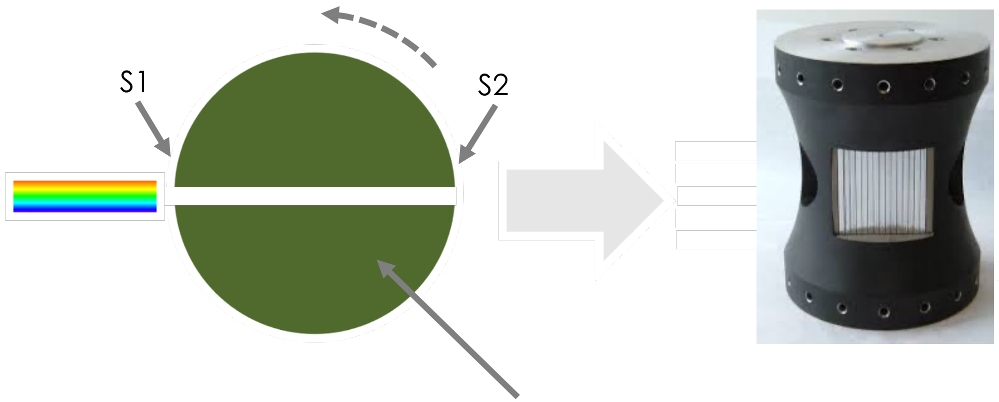
USANS @ SNS



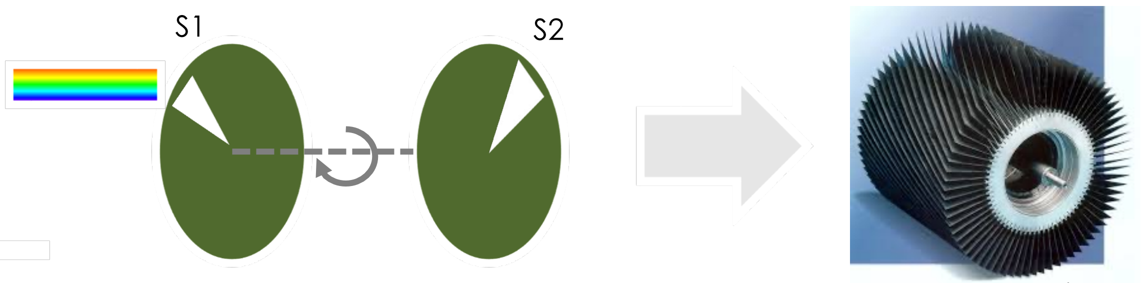
Detour: Fermi Choppers, velocity selectors



Fermi Chopper

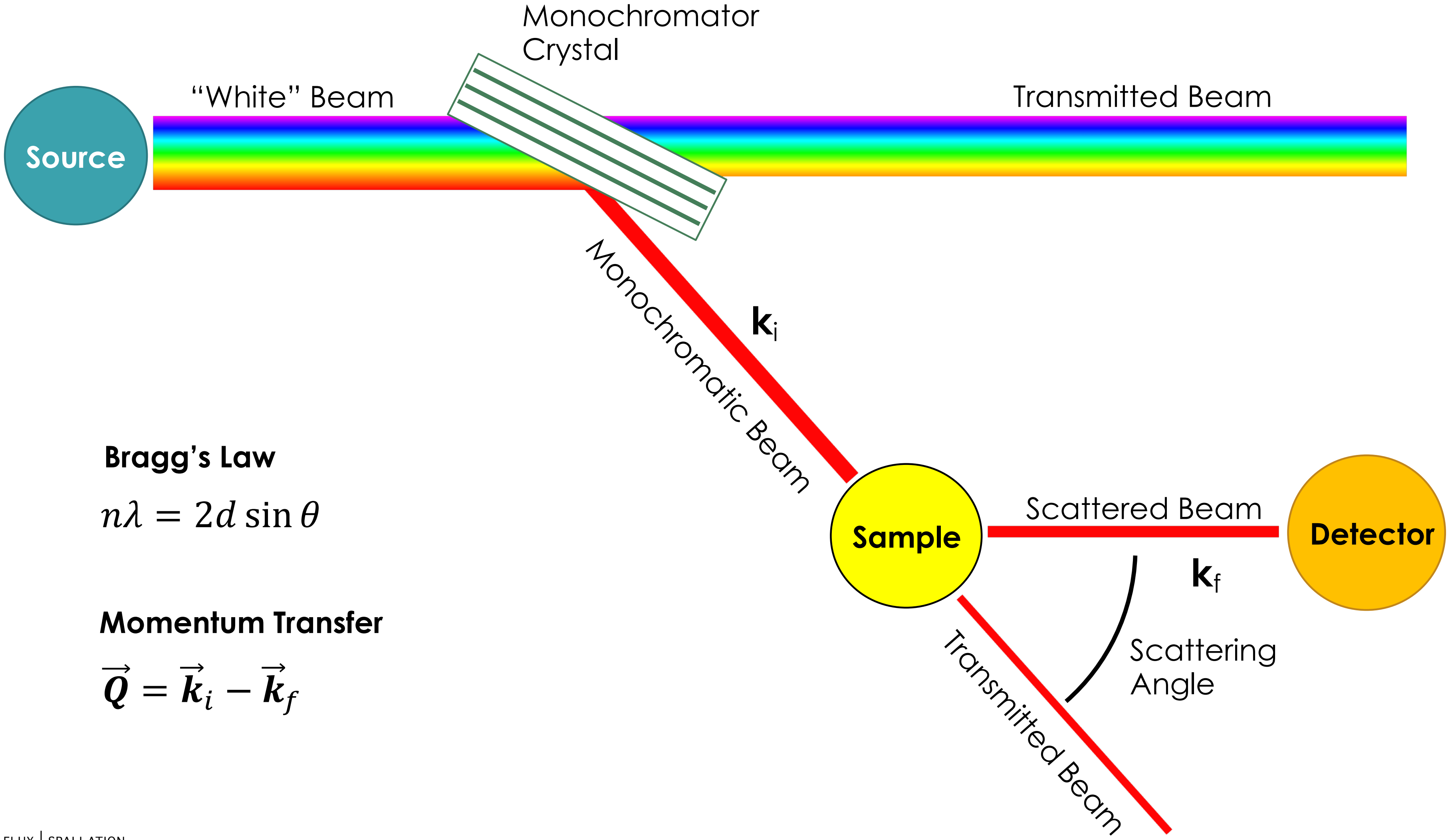


Velocity selector



Astrium
Formerly: Dornier

Reactor instruments - elastic



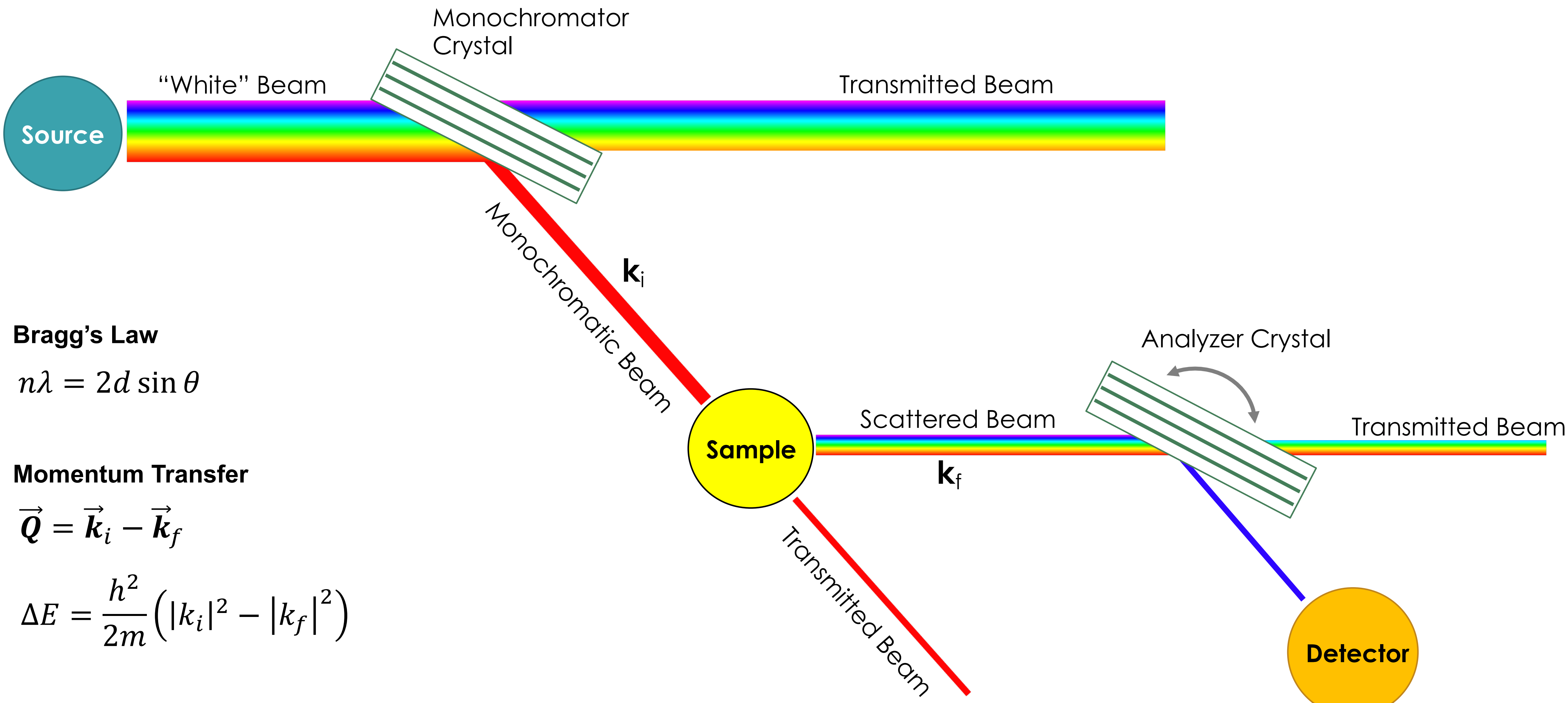
Bragg's Law

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

Momentum Transfer

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

Reactor instruments - inelastic



Bragg's Law

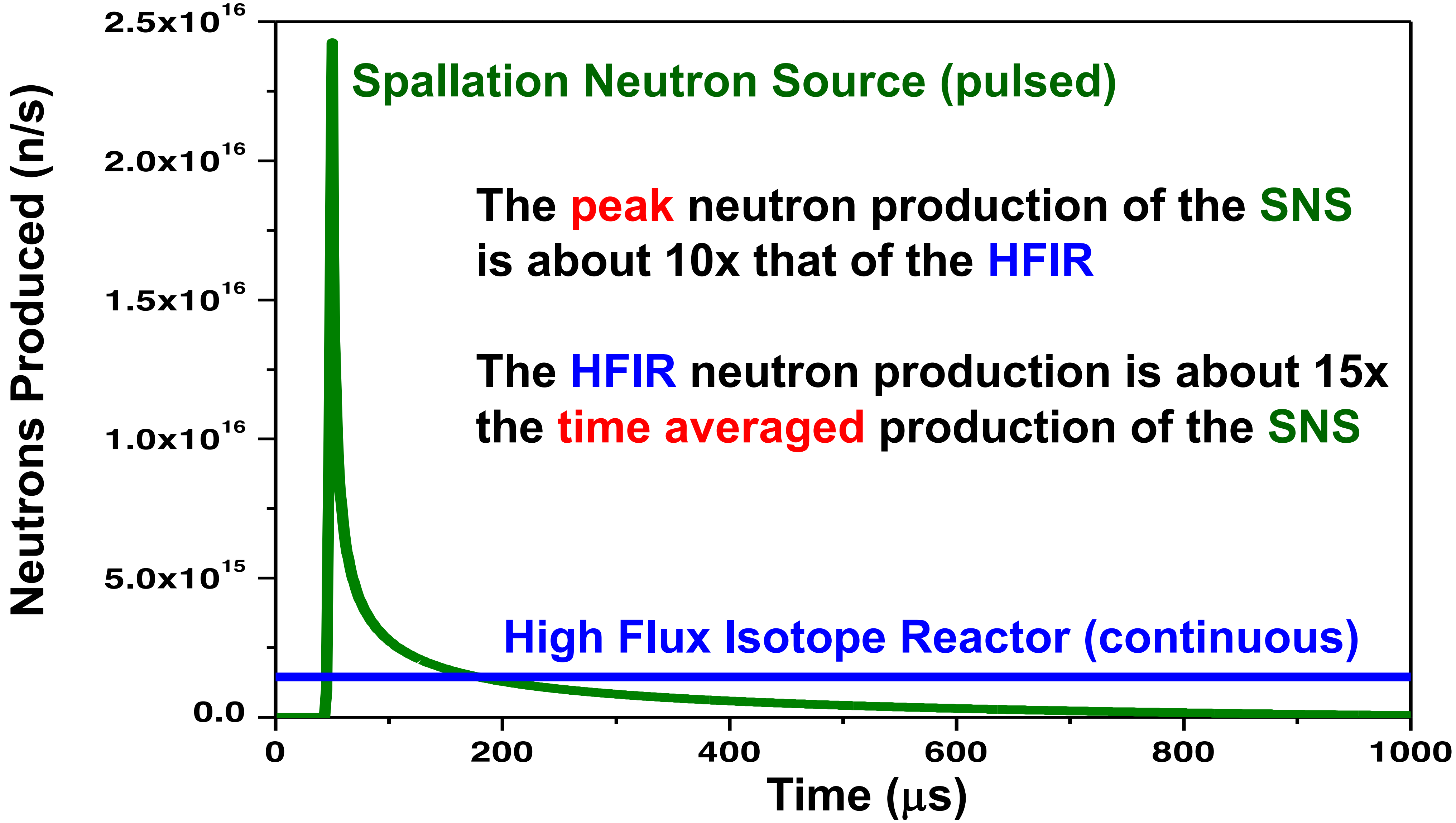
$$n\lambda = 2d \sin\theta$$

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

End of part one

- So far:
  - How to make neutrons
  - Difference between Reactor and Pulsed Source
  - How to make useful neutrons
  - How to determine and/or select neutron wavelength:
    - Time-of-flight
    - Crystal monochromators, Fermi Choppers, Velocity Selectors
  - Two essential instrument concepts:
    - Diffractometer (elastic scattering)
    - Spectrometer (inelastic scattering)
- Please post questions into the slack channel!