Implementing the ORNL 3-Source Strategy

Presented at

Neutron Day Seminar Series

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April 26, 2018

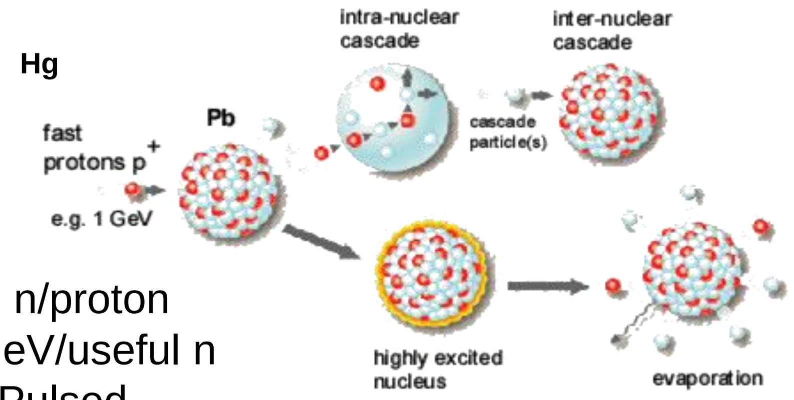
ORNL is managed by UT-Battelle
for the US Department of Energy

ORNL 3-source strategy – develop instruments and scattering techniques on the source that delivers optimal performance

- Exploit the strengths of the current HFIR and SNS-First Target Station (FTS)
  - Improve the science productivity of the current instruments with major upgrades (39 projects have been prioritized since 2015 start at a total cost of $43.6M)
  - Build new instruments at HFIR and SNS-FTS that take full advantage of source strengths and will remain relevant in an SNS-Second Target Station (STS) era
- Maximize the strengths of HFIR and SNS-FTS for neutron scattering
  - Explore opportunities to improve the HFIR cold source and guide configuration (x2 improvement)
  - Replace SNS-FTS H_2O reflector coolant with D_2O (20% – 26% gain on high resolution moderators)
  - Execute the Proton Power Upgrade Project (PPU): 2/1.4 = 43% gain across all FTS instruments
- Plan for a future STS that is optimized to produce high peak brightness beams of cold neutrons
  - Some current instrument capabilities will be better served at STS
  - Coupled moderator at FTS can be replaced with a high performing p-dc moderator

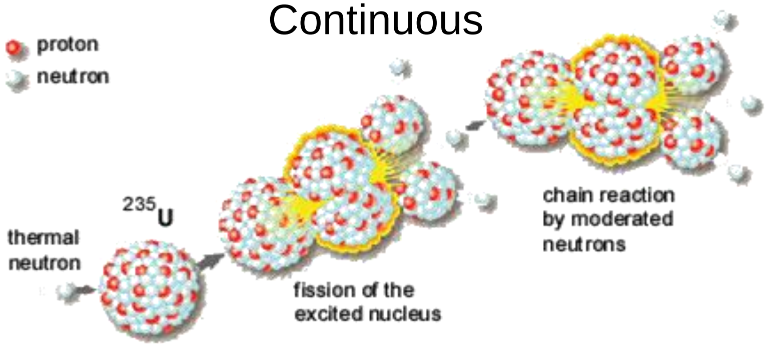
ORNL is home to two advanced neutron sources with different strengths

Spallation Neutron Source (1.4 MW)



26 n/proton
25 MeV/useful n
Pulsed

2.5 n/fission
190 MeV/useful n
Continuous



High Flux Isotope Reactor (85 MW)

Apples and Oranges – What about power?

- Reactor power (MW) is the thermal power released by fission reactions
  - Example, ORNL's HFIR is 85 MW reactor

$$\frac{\text{n}}{\text{sec}} = 85 \bullet 10^{6}\ \text{W}\ x\ \frac{\text{J}/\text{sec}}{\text{W}}\ x\ \frac{1\,\text{n}}{190 \bullet 10^{6}\,\text{eV}}\ x\ \frac{6.24 \bullet 10^{18}\,\text{eV}}{\text{J}}$$

$$= 2.79 \bullet 10^{18}\ \frac{\text{n}}{\text{sec}}$$

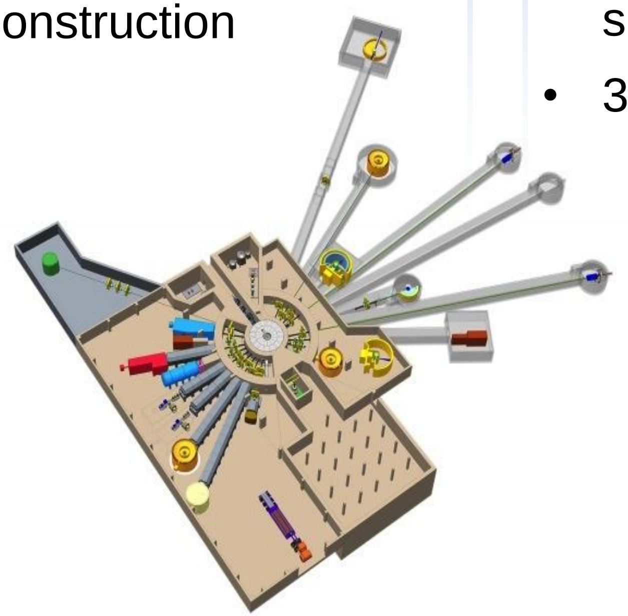
- Spallation source power is the power of the proton beam
  - Example, ORNL's Spallation Neutron Source at 1 MW proton beam (1 GeV protons @ 1 mA, ~$1.04 \bullet 10^{14}$ protons/pulse, 60 Hz)

$$\frac{\text{n}}{\text{sec}} = 26\ \frac{\text{n}}{\text{p}}\ x\ 6.24 \bullet 10^{15}\ \frac{\text{p}}{\text{sec}} = 1.62 \bullet 10^{17}\ \frac{\text{n}}{\text{sec}}$$

- On a time averaged basis HFIR makes ≈ 17 times more useful neutrons than 1 MW SNS

Upgrading SNS to a world-leading fourth-generation neutron source

SNS-PPU	SNS-STS
• Increases power capabilities of existing 60 Hz accelerator structure from 1.4 MW to 2.8 MW • Increases power delivered to first target station (FTS) to 2 MW • Increases neutron flux on available beam lines • Provides platform for construction of STS	• Initial suite of 8 beam lines, with capacity to accommodate 22 beam lines • 700 kW diverted to STS by additional accelerator systems • 15 Hz repetition rate, enabling broad dynamic range • World's highest brightness short-pulse source optimized for cold neutrons • 300,000 ft^2 of new infrastructure

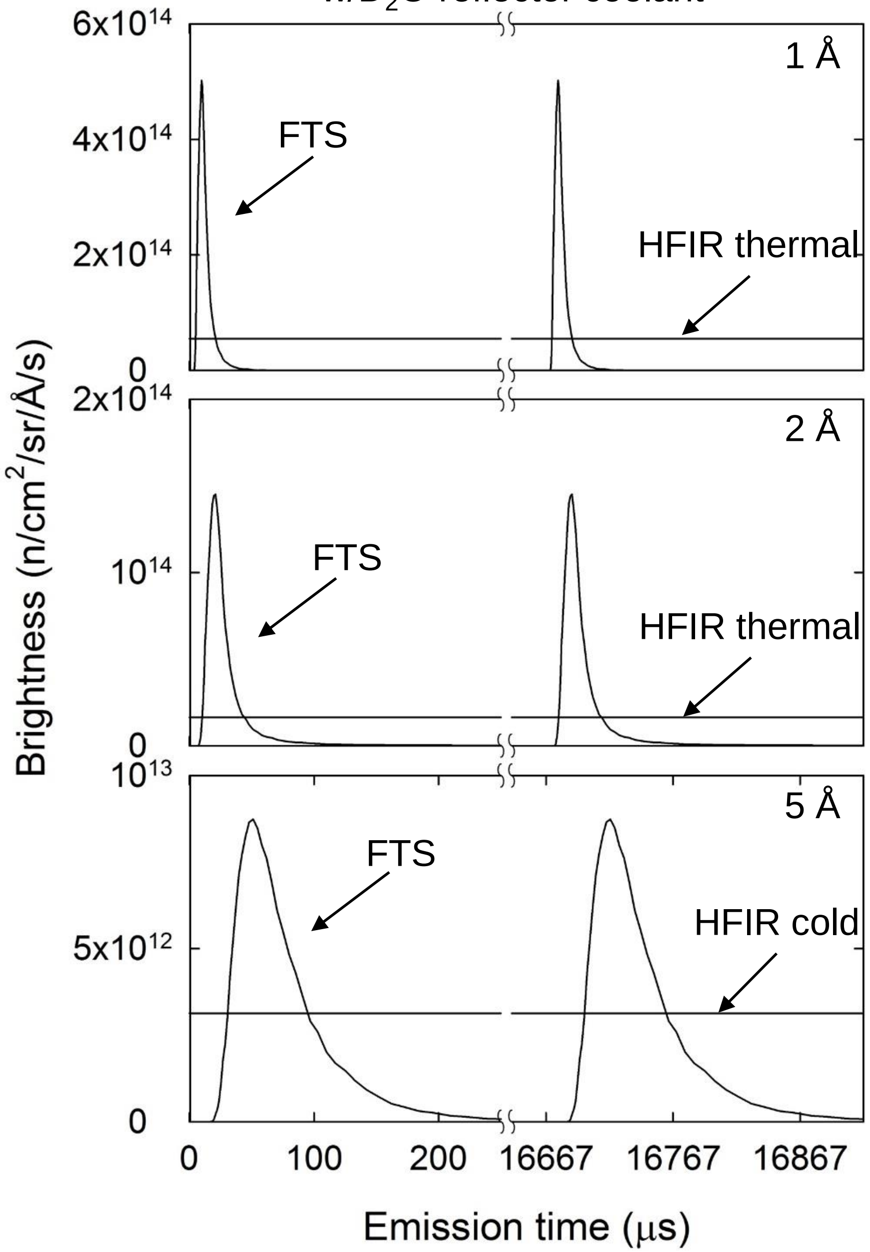


CD-1 Review: May 2017
CD-1 approved: April 2018

Integrated Systems Review: April 2017

Strengths of the ORNL neutron sources -

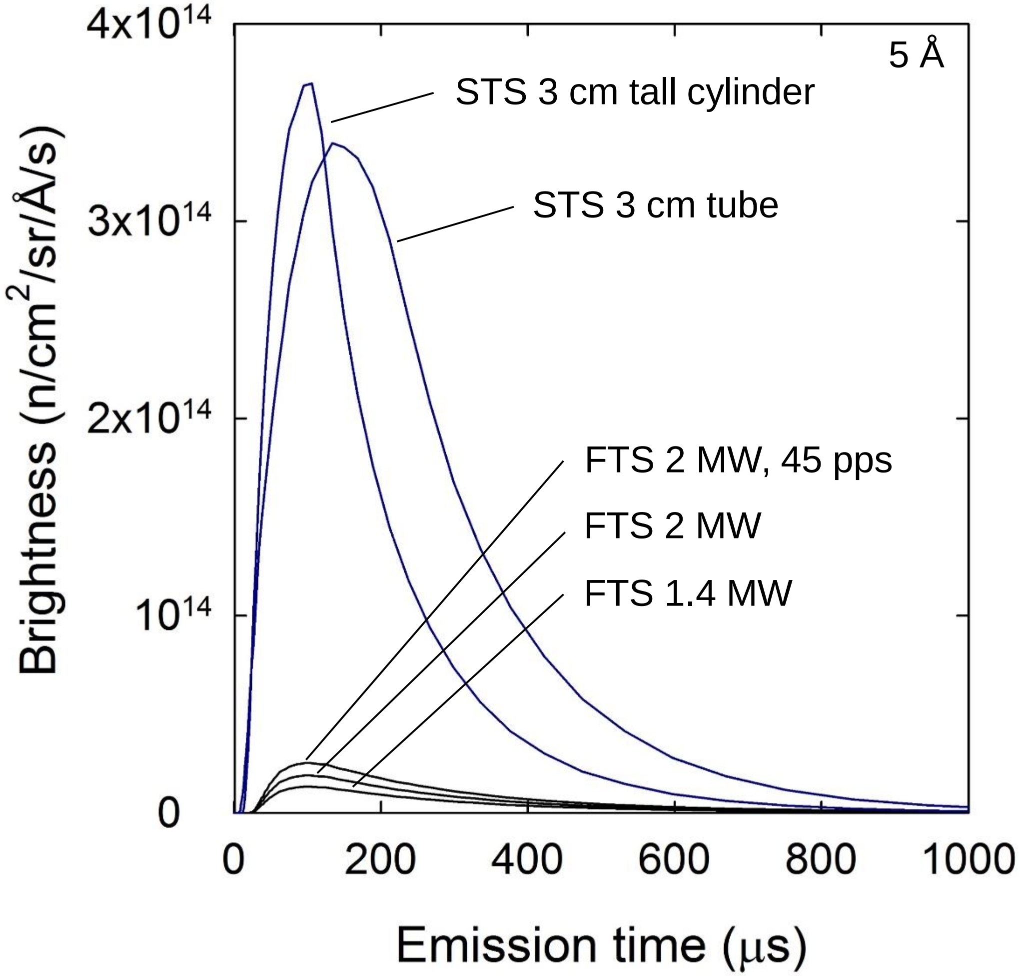
FTS p,dc p-H_2 @1.4 MW and 60 Hz w/D_2O reflector coolant



- **HFIR strength is time average cold and thermal brightness**
  - @1 Å, HFIR average brightness is ≈200x FTS (≈40x FTS p,dc H_2O)
  - @5Å,HFIR average brightness is ≈90x FTS (≈10x FTS coupled para-H_2)
- **FTS strength is high wavelength resolution and peak brightness**
  - @1 A, FTS peak brightness is ≈10x HFIR (≈20x for H_2O moderator)
  - @5Å, FTS peak brightness is ≈3x HFIR (≈5x for coupled p-H_2 moderator)

Time-of-flight gain for POWGEN is >1000

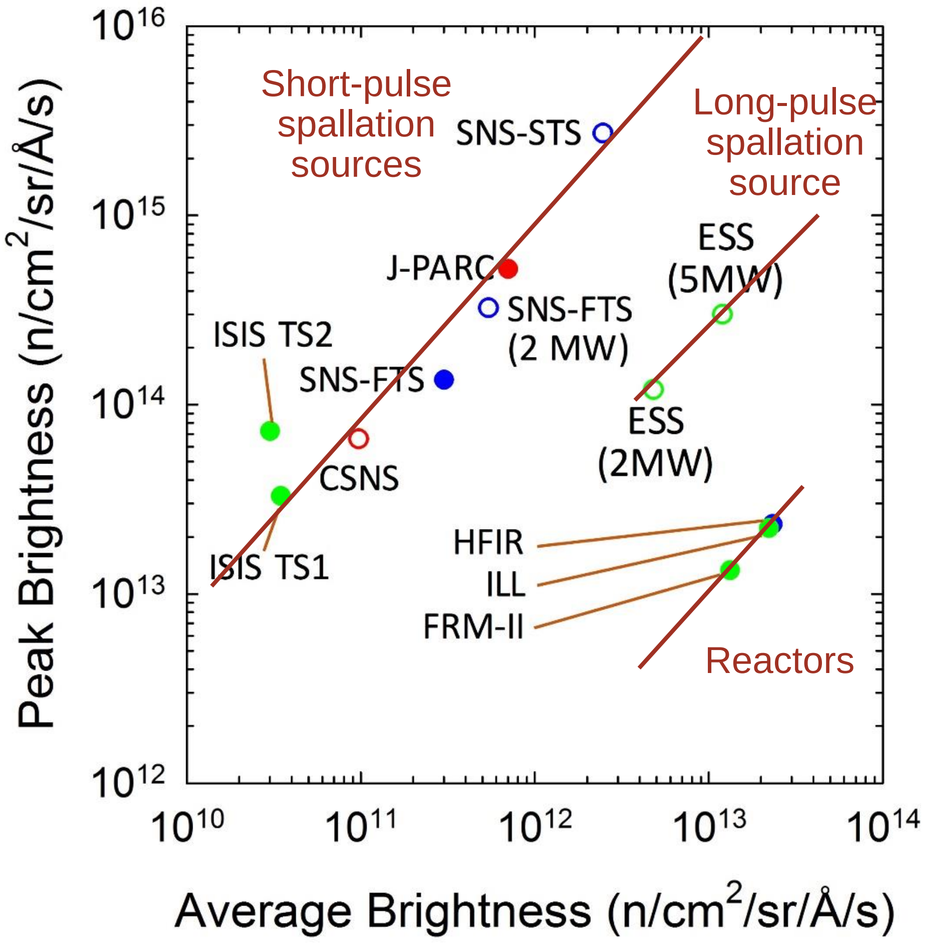
Evolution of coupled moderators at SNS



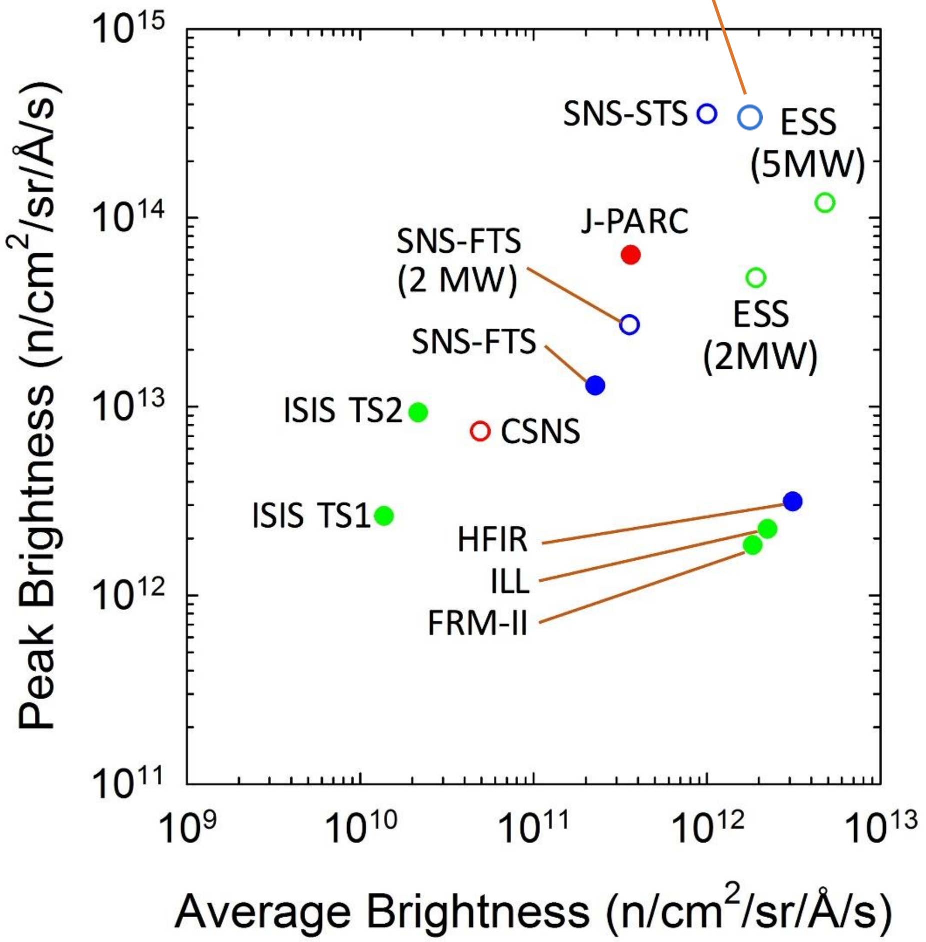
- **STS strength will be high peak brightness cold neutrons**

Strengths of the ORNL neutron sources

λ = 1.8 Å



λ = 5 Å



New high-brightness tube moderator

ORNL neutron sources – now

SNS-FTS (first target station) **60 Hz, 1.4 MW**	**HFIR** **85 MW**
Poisoned, De-coupled Moderators *(1 thermal, 1 cold)*	*Thermal Beam Room*

• Atomic scale structure and processes
• **Strengths:**
  • High wavelength resolution
  • Thermal to epithermal neutrons
  • Peak brightness
• 16 beam lines (4 are empty)
• 12 GUP instrument end stations
	• Atomic scale structure and processes
	• **Strengths:**
	  • Average brightness
	  • Thermal neutrons
	• 3 thermal beam tubes
	• 7 GUP instrument end stations (+1 other)

2 Coupled, Cold Moderators	*Cold Guide Hall*

• Nano-mesoscale structure and processes, low-energy excitations, fundamental physics (FNPB)
• **Strengths:**
  • Peak brightness
  • Cold neutrons
• 8 beam lines (1 is empty)
• 6 GUP instrument end stations + FNPB
	• Nano-mesoscale structure, low-energy excitations
	• **Strengths:**
	  • Average brightness
	  • Cold neutrons
	• 4 guides
	• 5 GUP instrument end stations (+3 other)

GUP is general user program

ORNL neutron sources – after HFIR beryllium outage and PPU

SNS-FTS **60 Hz, 2 MW**	**HFIR** **85 MW**

Poisoned, De-coupled Moderators
(1 thermal, 1 cold)
• Atomic scale structure and processes
• **Strengths:**
  • High wavelength resolution
  • Thermal neutrons
  • Peak brightness
• 16 beam lines (2 are empty)
• 14 GUP instrument end stations
	Thermal Beam Room
	• Atomic scale structure and processes
	• **Strengths:**
	  • Average brightness
	  • Thermal neutrons
	• 3 thermal beam tubes
	• 7 GUP instrument end stations

2 Coupled, Cold Moderators
• Nano-mesoscale structure and processes, low-energy excitations, fundamental physics (FNPB)
• **Strengths:**
  • Peak brightness
  • Cold neutrons
• 8 beam lines (1 is empty)
• 6 GUP instrument end stations + FNPB
	Cold Guide Hall
	• Nano-mesoscale structure, low-energy excitations
	• **Strengths:**
	  • Average brightness
	  • Cold neutrons
	• 6-7 guides and mirror optics systems
	• 5-6 GUP instrument end stations

GUP is general user program

ORNL neutron sources – after HFIR beryllium outage, PPU and STS

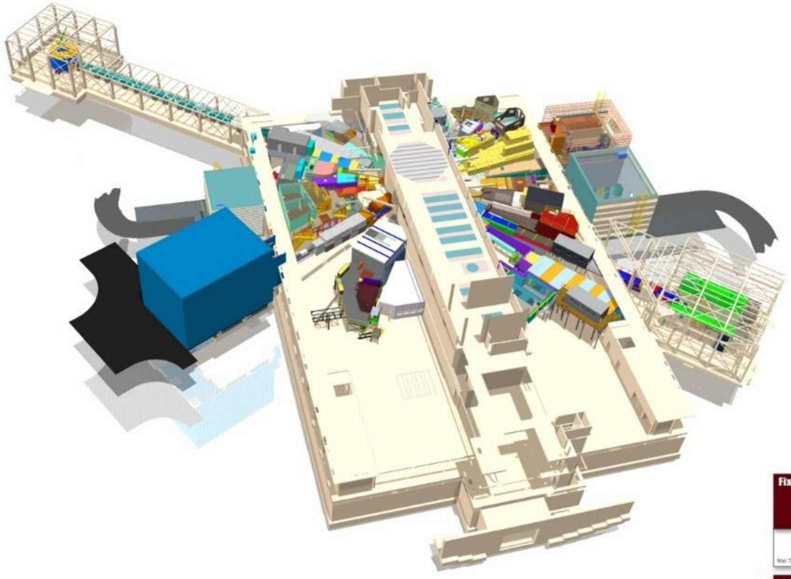
SNS-FTS **45 pulses/sec, 2MW**	**SNS-STS** **15 Hz, 700 kW**	**HFIR** **85 MW**
Poisoned, De-coupled Moderators (1 thermal, 1 cold)	*Geometrically Optimized, Coupled Cold Moderators*	*Thermal Beam Room*

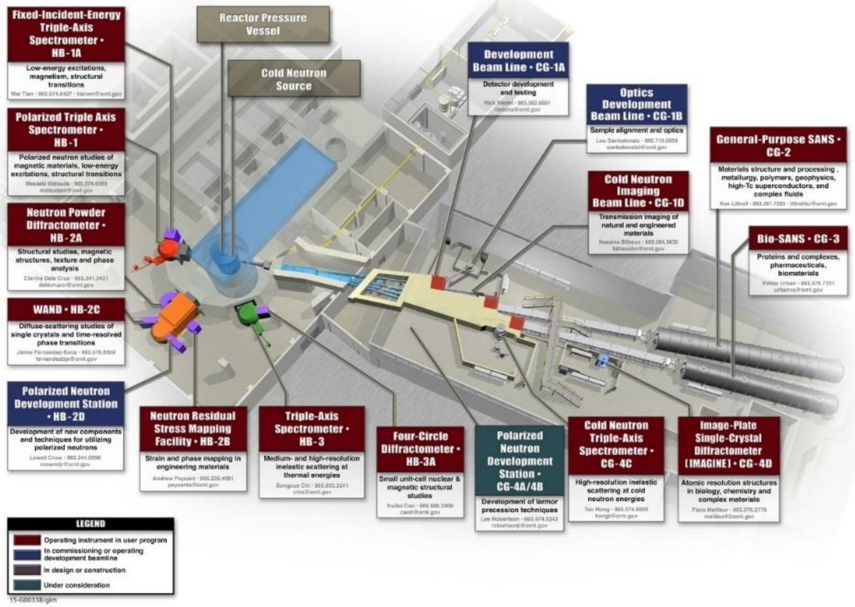
• Atomic scale structure and processes
• **Strengths:**
  • High wavelength resolution
  • Thermal neutrons
  • Peak brightness
• 16 beam lines (2 are empty)
• 14 GUP instrument end stations
	• Nano-mesoscale structure and processes, complex and hierarchical materials, low-energy excitations, kinetics
	• **Strengths:**
	  • Peak brightness (13× FTS (@2 MW, 45 pps) and 113× HFIR cold source @ λ=5 Å)
	  • Cold neutrons
	  • Low repetition rate
	  • Small beams
	• 22 beam lines
	• 8 initial GUP instrument end stations
		• Atomic scale structure and processes
		• **Strengths:**
		  • Average brightness
		  • Thermal neutrons
		• 3 thermal beam tubes
		• 7 GUP instrument end stations

2 Coupled, Cold Moderators *(possible replacement with p, dc)*		*Cold Guide Hall*

• Nano-mesoscale structure and processes, low-energy excitations, fundamental physics
• **Strengths:**
  • 45 pps
  • Cold neutrons
  • Large beams
• 8 beam lines (1 is empty)
• 6 GUP instrument end stations + FNPB
		• Nano-mesoscale structure, low-energy excitations
		• **Strengths:**
		  • Average brightness
		  • Cold neutrons
		• 6-7 guides and mirror optics systems
		• 5-6 GUP instrument end stations

Opportunities at SNS and HFIR for new instruments now

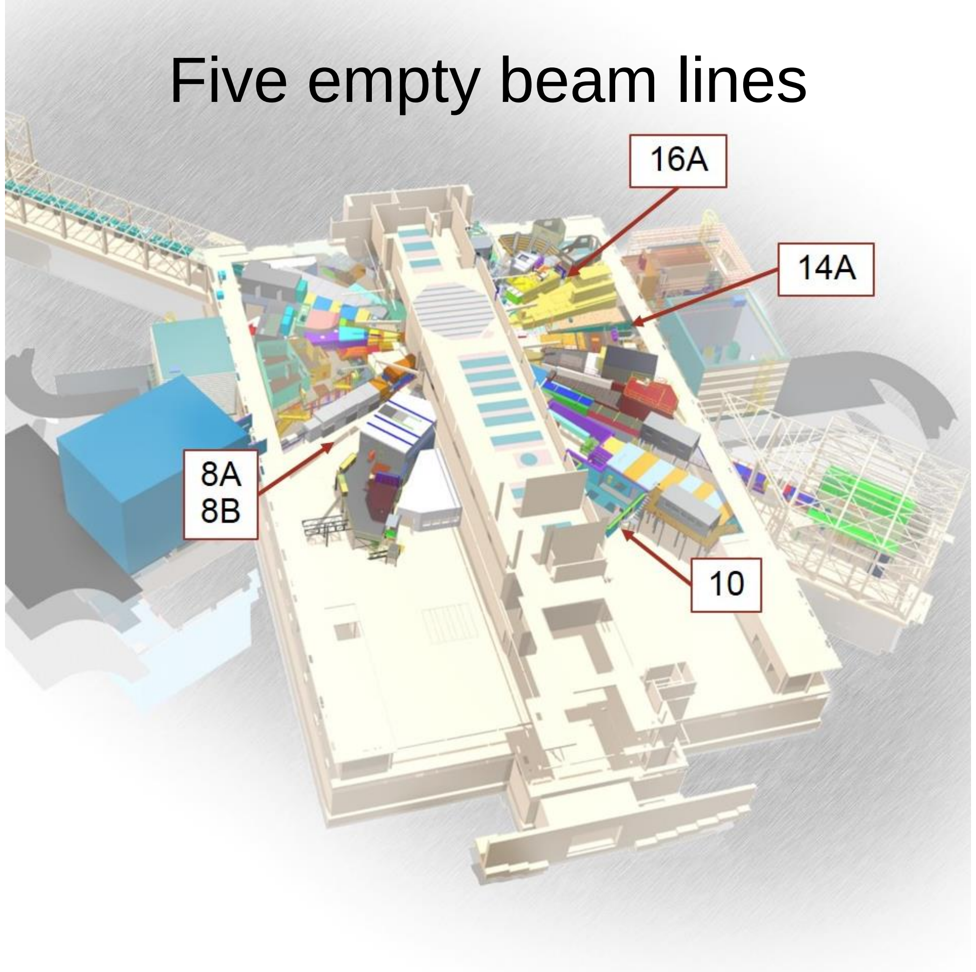




Guidelines for building new instruments

- Commit money and resources to build new instruments that have high science impact
  - fill gaps in capabilities (e.g. DISCOVER, MANTA)
  - address capacity and user access (e.g. high throughput SANS)
  - implement new methods to meet emerging needs (e.g. VENUS)
- Engage the user community to identify priorities
- New instruments should have a minimum 10 year operations horizon
- Exploit the complementarity that exists between the current and proposed ORNL neutron sources
  - Wavelength resolution, average and peak brightness, cold and thermal neutrons, repetition rate
  - Locate instruments at the neutron source where they will be most productive
- Create opportunities and an environment that encourage external partnerships

High priority instruments for FTS leverage its high wavelength resolution strength

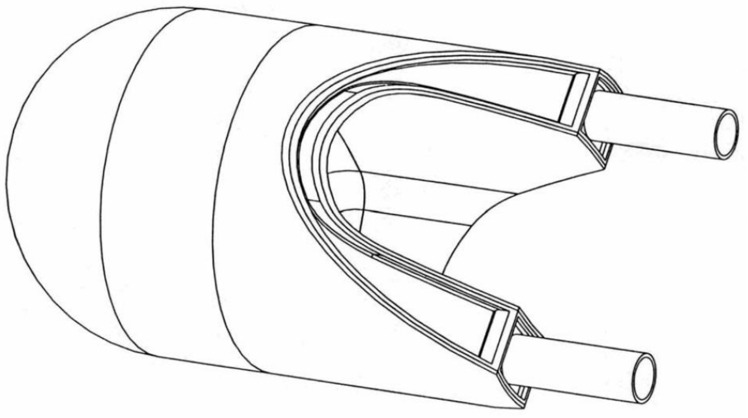

Five empty beam lines

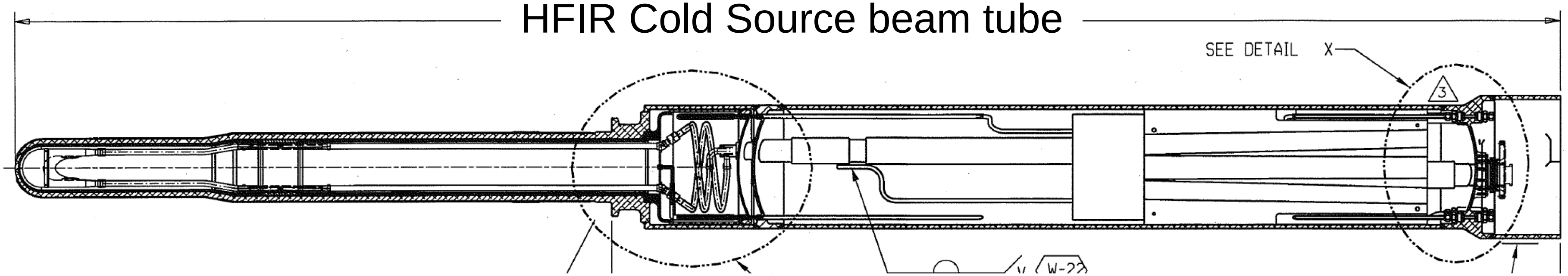
HIGGS	Inverse geometry spectrometer	BL-8A dc-p H_2O
Micro	Compact, texture, special purpose diffractometer	
DISCOVER	Medium resolution/flux diffractometer	BL-8B dc-p H_2O
VENUS	Time-of-flight neutron imaging station	BL-10 dc-p para-H_2
INVENT	Concept development station	BL-14A c para-H_2
SANS/GI-SANS	SANS and/or GI-SANS	
BeFAST	Beryllium filter spectrometer	BL-16A dc-p H_2O
HRPD	High Resolution Powder Diffractometer	Needs dc-p para-H_2 100 m flight path

dc-p: decoupled, poisoned
c: coupled
H_2O: thermal
para-H_2: cold

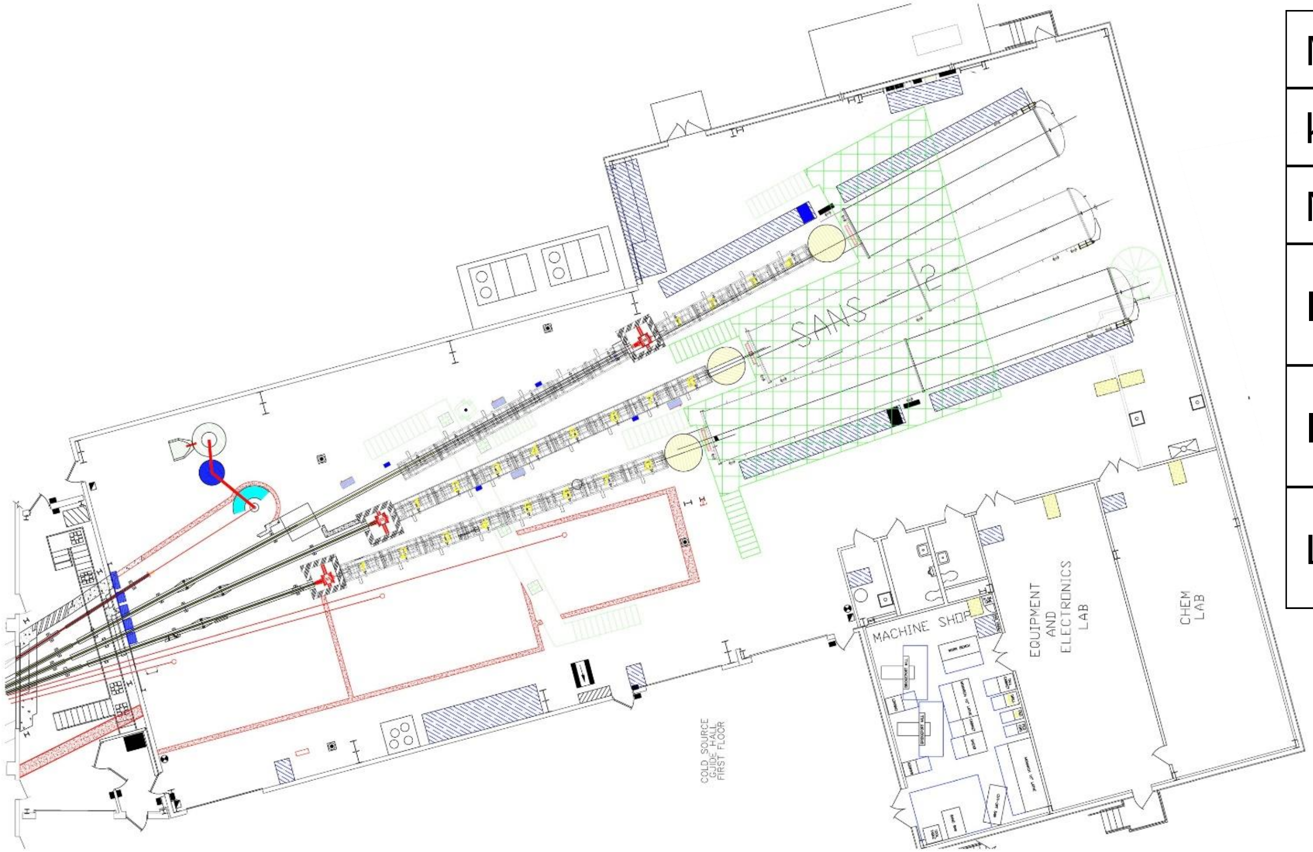
Re-optimization of the HFIR guide hall will support additional instrument end stations

- HFIR cold source is compact (69 cm^2 area) H_2
- Adding a para-H_2 convertor could increase brightness by 30%
- Moving guide entrance from 5 m to 4 m from cold source will improve illumination by H25/16 (56%)
  - Guides are under-illuminated at long wavelengths
  - Best optimized to instrument end stations that have small samples and/or require limited beam divergence
- The opportunity is to gain a factor of x2 in ability to illuminate the guide system and support a more capable instrument suite




HFIR Cold Source beam tube

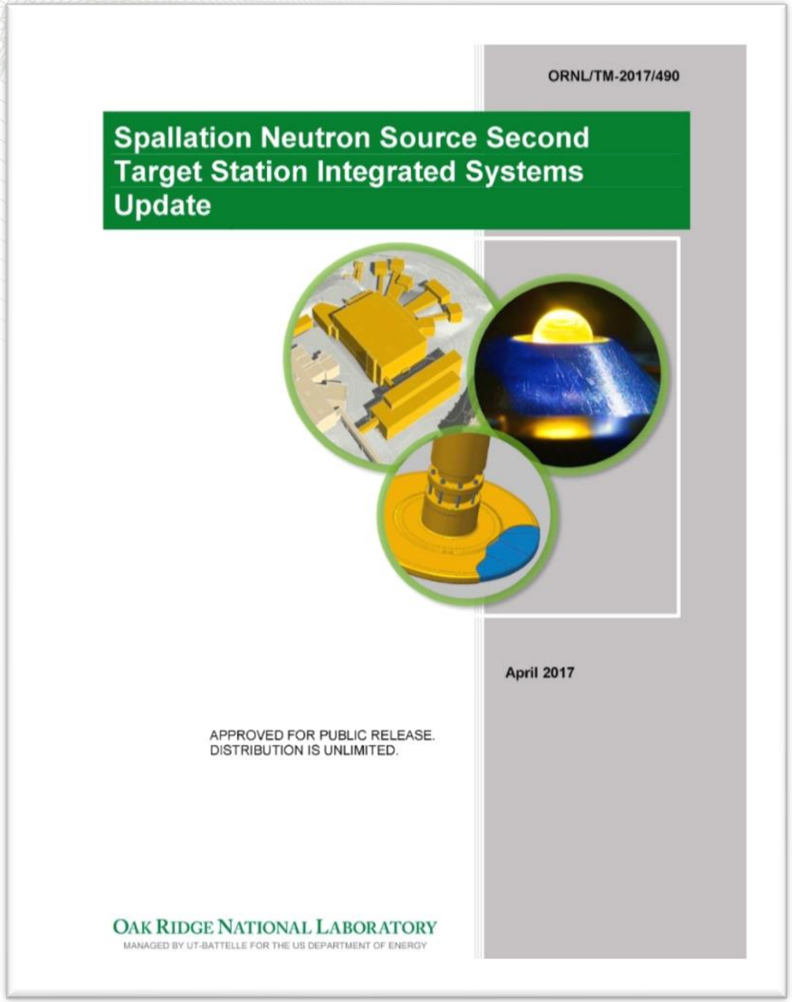
Instruments proposed for the HFIR guide hall are optimized to its high time-average cold neutron brightness



Re-optimized HFIR cold guide hall

MANTA	Multi-analyzer cold TAS	CG-1
kSANS	High throughput SANS	CG-X
NSE	Neutron Spin Echo	
IMAGING	Cold neutron imaging	Moves to CG-X Improved optics
IMAGINE	Laue Diffractometer	Moves to CG-X Improved optics
LARMOR	Spin-precession techniques	Moves to CG-X Improved optics

Instruments at the STS



ORNL/TM-2017/490

Spallation Neutron Source Second Target Station Integrated Systems Update

April 2017

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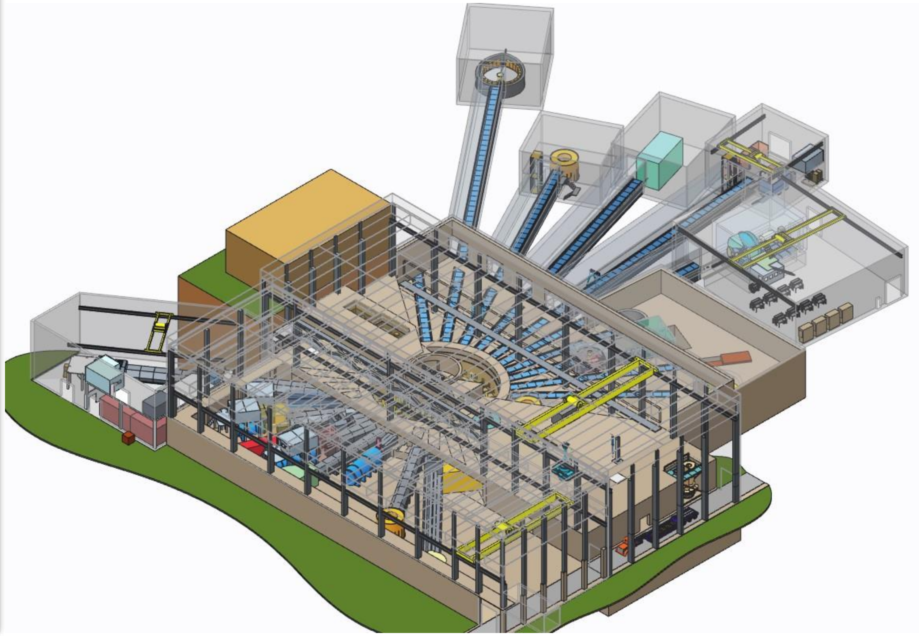
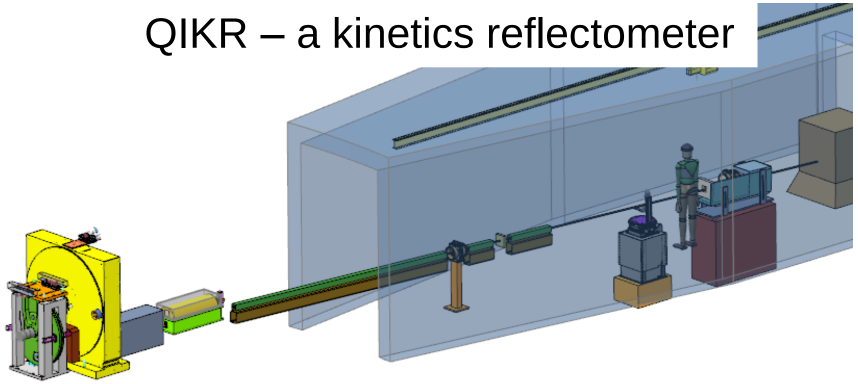
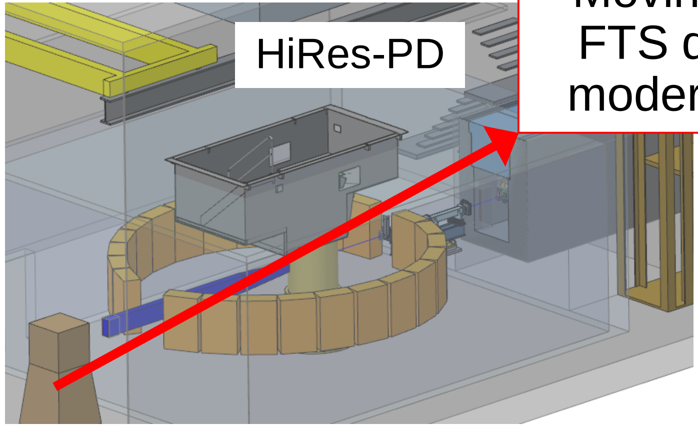


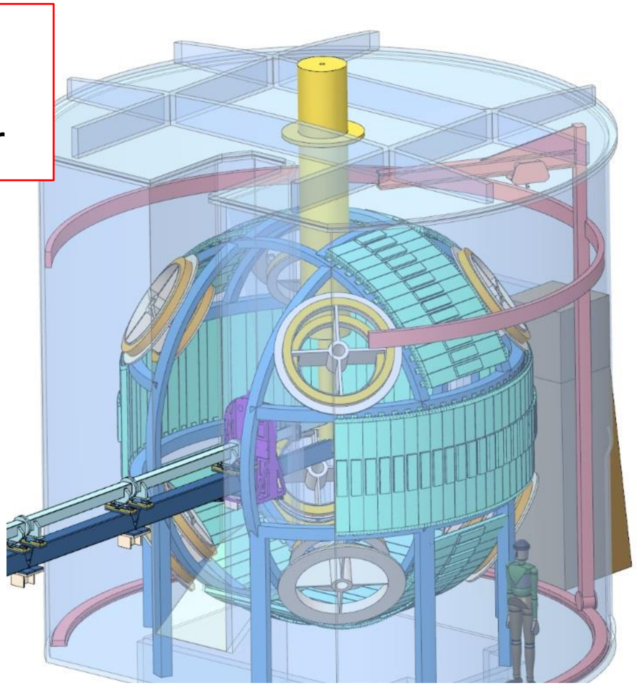
https://info.ornl.gov/sites/publications/Files/Pub103496.pdf

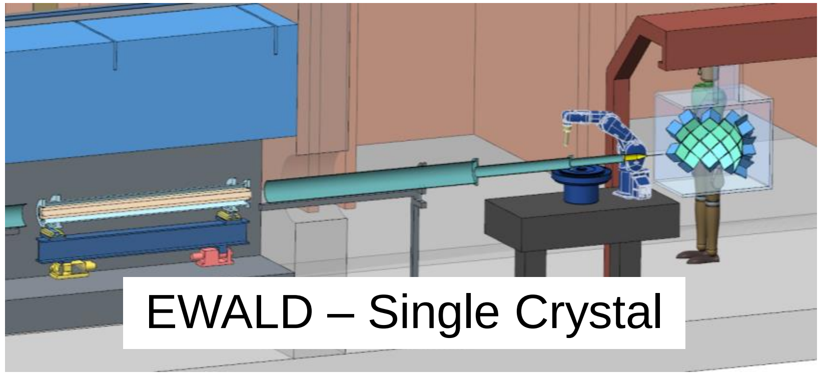
8 high priority STS instrument concepts were developed for April 2017 review

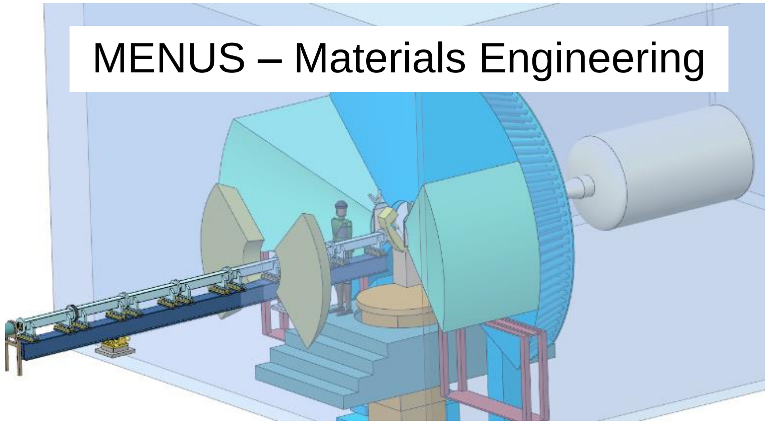

QIKR – a kinetics reflectometer

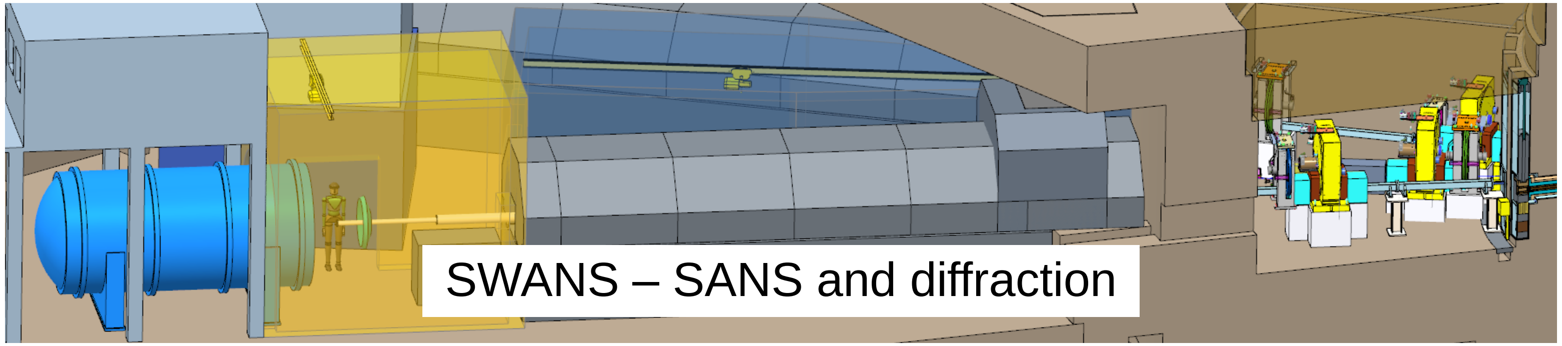

HiRes-PD

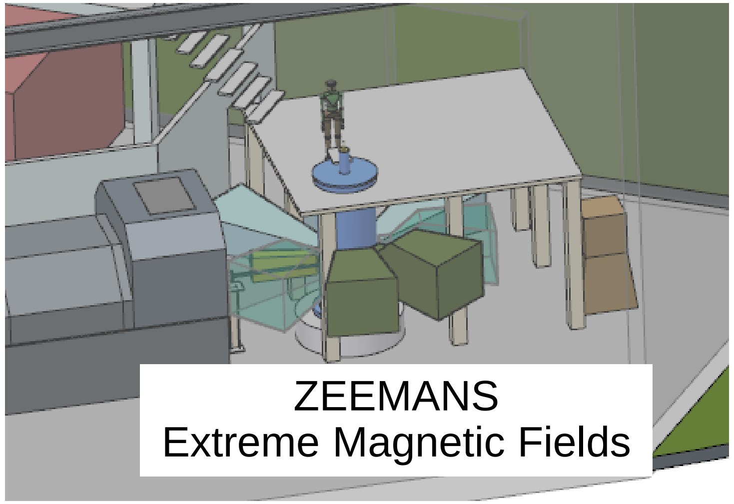
Moving to FTS dc-p moderator


CHESS – small sample cold chopper spectrometer


EWALD – Single Crystal

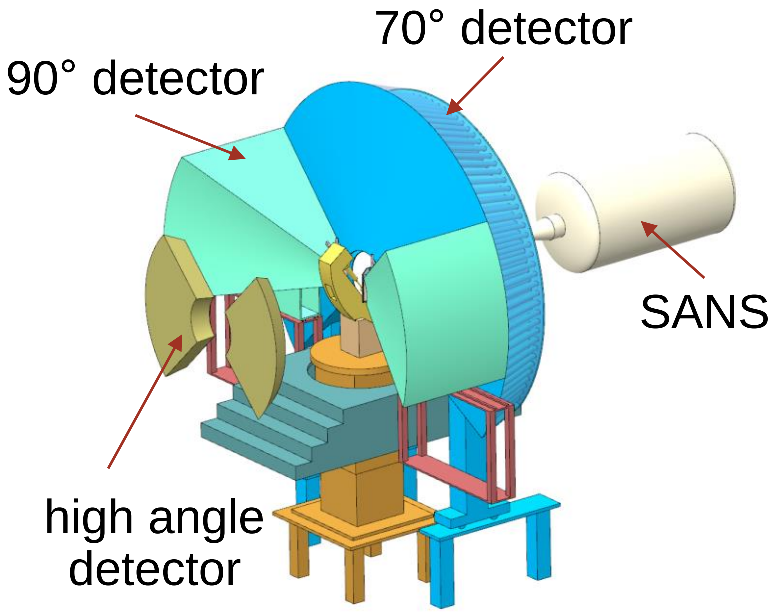

MENUS – Materials Engineering

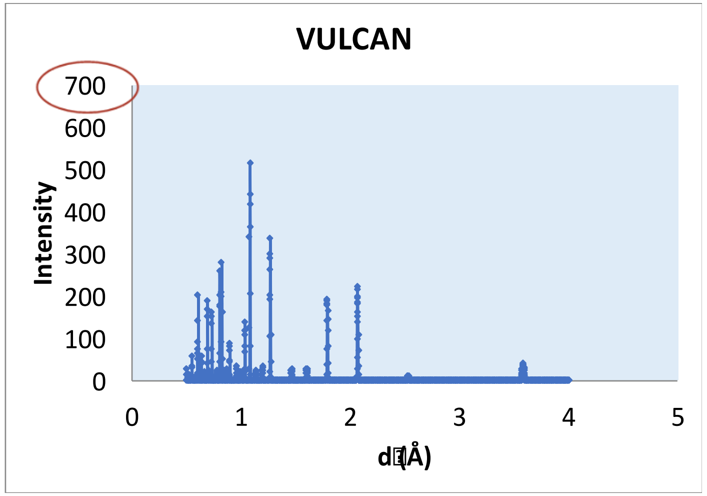

SWANS – SANS and diffraction

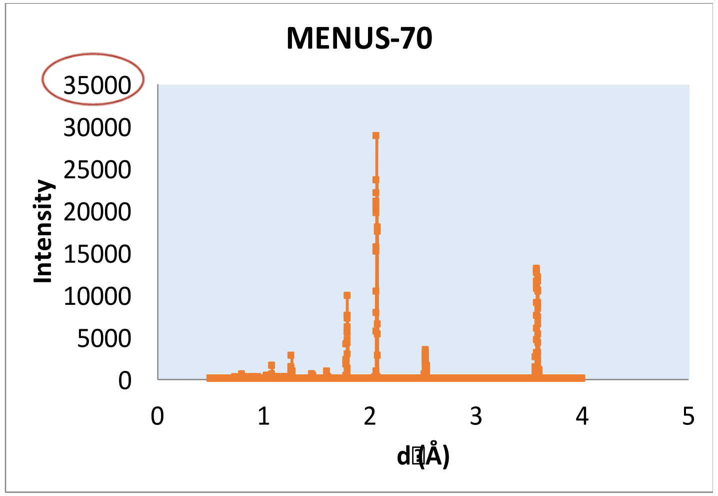

ZEEMANS
Extreme Magnetic Fields

MENUS – Materials Engineering by NeUtron Scattering

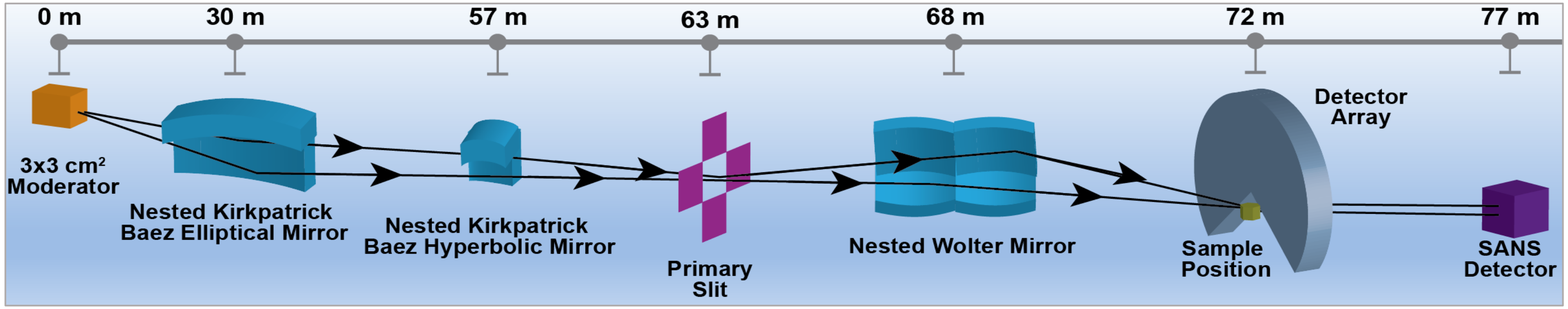
- Anisotropy in low symmetry materials
- Superlattice structures and stress partitioning
- In operando and extreme fields
- Kinetic phase transitions
- High spatial resolution strain scanning





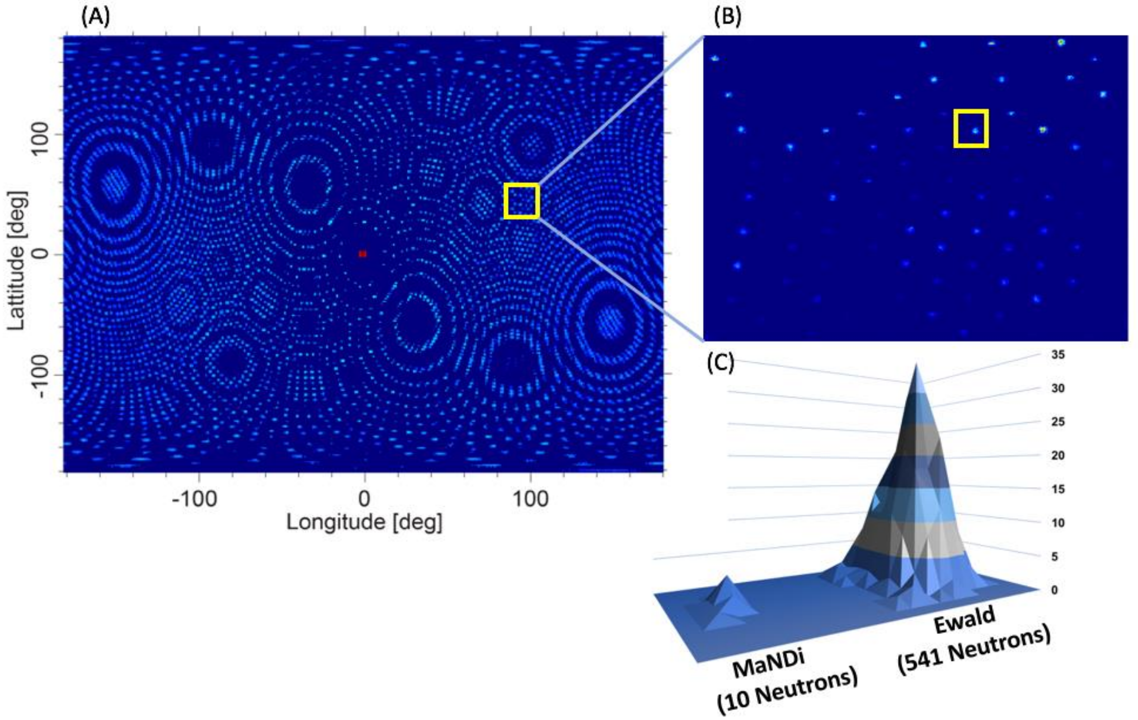


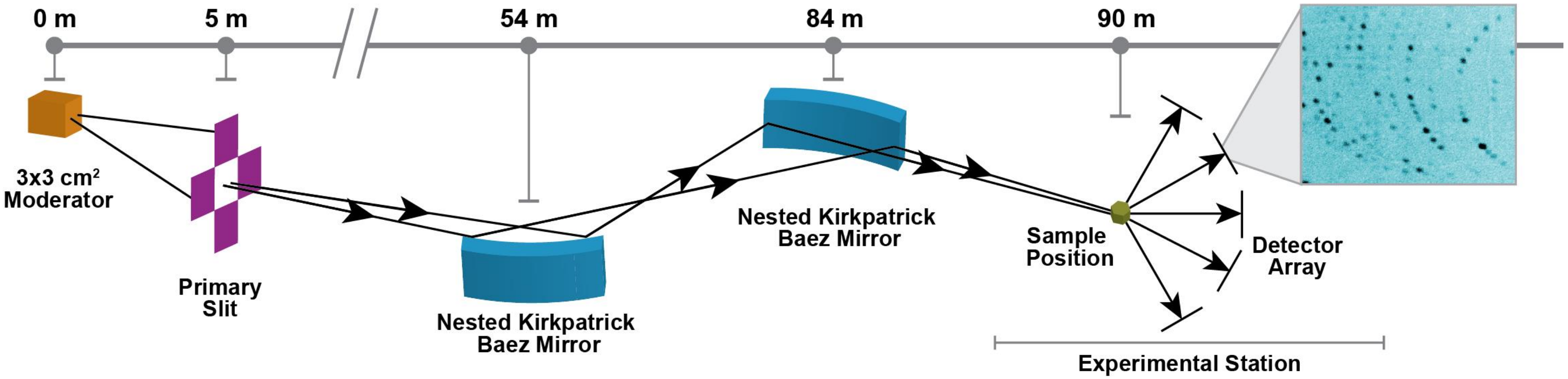
Simulated diffraction of Ni3Al with super lattice structure at (100) 3.58 Å

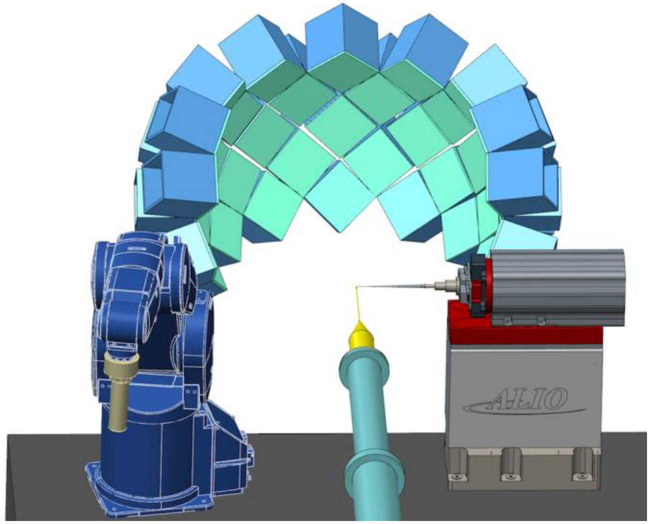


EWALD: Extended Wide Angle Laue Diffractometer

- Macromolecular neutron crystallography
- Minimum crystal size needed on MaNDi is 0.1 mm^3 (2016)
- ~60×flux of MaNDi at FTS







Neutron optics and polarization development

Recent and Next Steps

- Instrument Advisory Board – January 24-25, 2018
  - Incorporate board input on balance and composition into our planning for new instruments
- HFIR Cold Source Review – February 16, 2018
  - Following up on recommendation to validate ortho-para hydrogen ratio in cold source
- ORNL Neutron Users New Instrument Workshop – June 24, 2018 (satellite of ACNS)
  - https://conference.sns.gov/event/102/
  - SNS-HFIR User Group Executive Committee is organizing
  - Seeking guidance from the research community on priorities for building new instruments.
- Seek proposals for instrument end stations
  - Continue instrument pre-concept development
  - Assemble Instrument Advisory Teams that includes two co-PIs (one internal, one external to NScD) responsible to author the proposal
  - Proposal includes science case, concept, proposed funding model, anticipated user demand, and evaluation of performance (Monte Carlo model) and technical feasibility
- Complete optics design of HFIR guides (FY18) - Order new guides early in FY19
- Initiate new instrument projects at SNS in FY19
- Seek external partnerships for instrument end stations