The SNS Second Target Station and Instrument Optimization Across ORNL Neutron Sources

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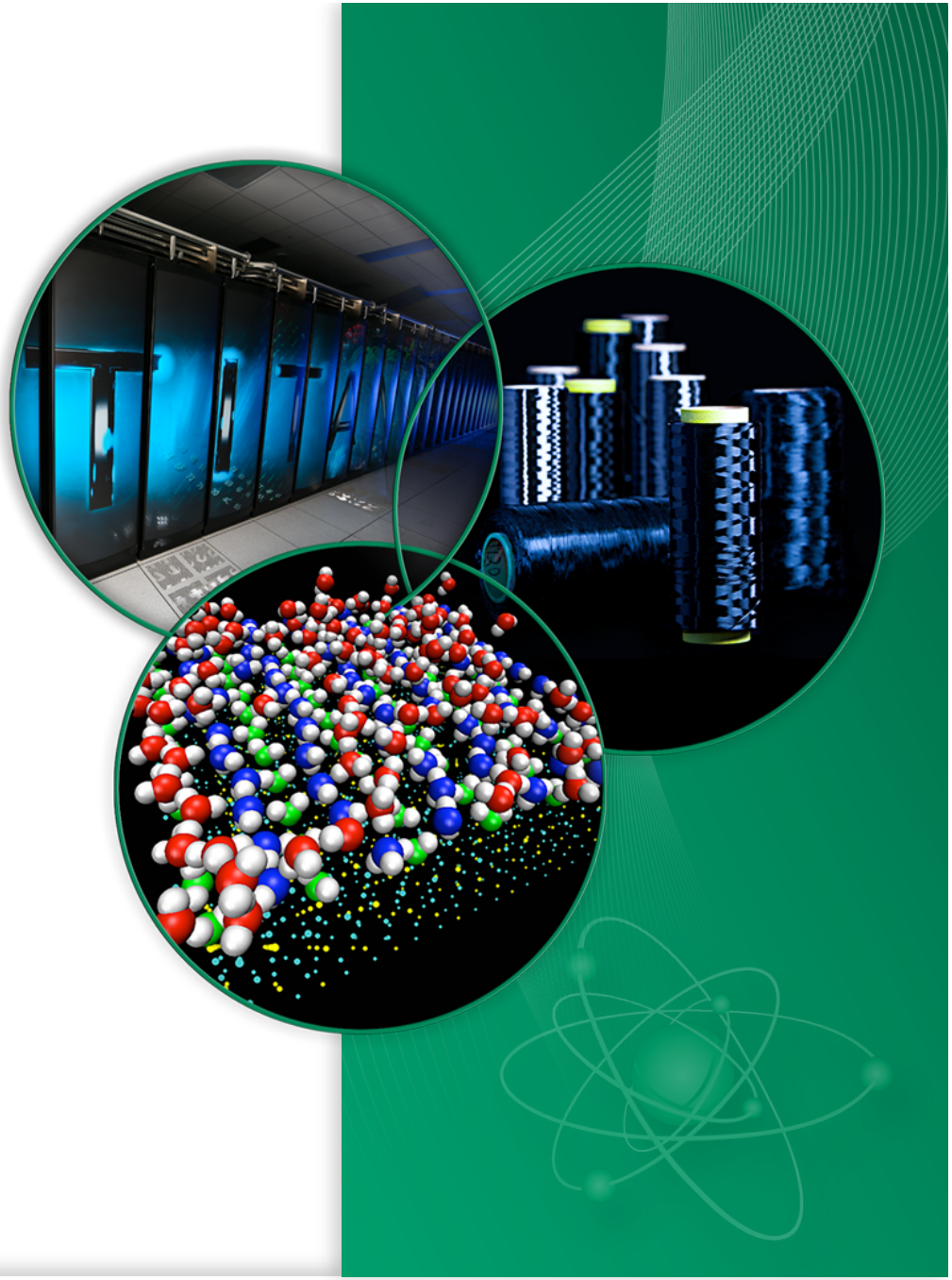
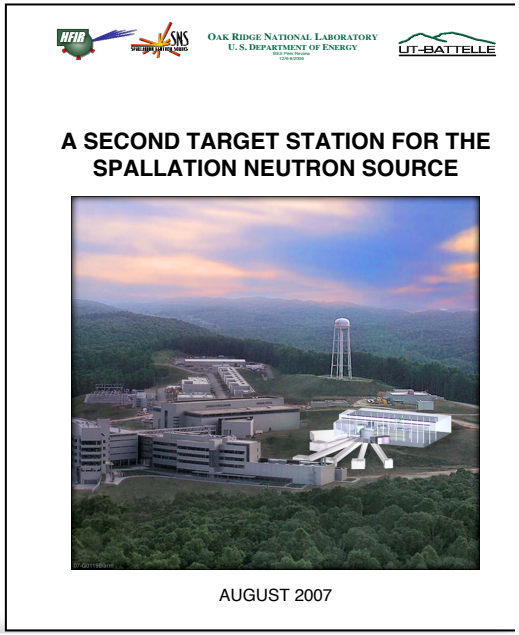


Background

- SNS First Target Station (FTS) is a 60 Hz, 1.4 MW short-pulsed neutron source (baseline design parameters)
- An SNS Second Target Station (STS) had been planned from the beginning
  - Lower repetition rate to complement FTS
- Two design studies
  - 2002 – Jack Carpenter – a short-pulse Long Wavelength Target Station
    - 2 MW SNS, 1/6 pulses diverted to STS (10 Hz)
  - 2007 – Kent Crawford – long-pulse STS
    - 2.33 MW SNS, 1/3 pulses diverted to STS (20 Hz)
    - Speculated that perhaps 50% per pulse gain could come from eliminating chopping (required for injection into the ring for short-pulse operation)
- Mission Need Statement for STS (CD0) approved in 2009
  - Double the accelerator baseline power
  - Long-wavelength, cold neutron emphasis (long length scales, slow dynamics)
- SNS is no longer a "greenfield" site
  - Site geometry restricts maximum instrument length to ≈120 m
  - SNS has an accumulator ring



SNS Accelerator Complex

Front-End:
Produce a 1-msec long, chopped, H- beam

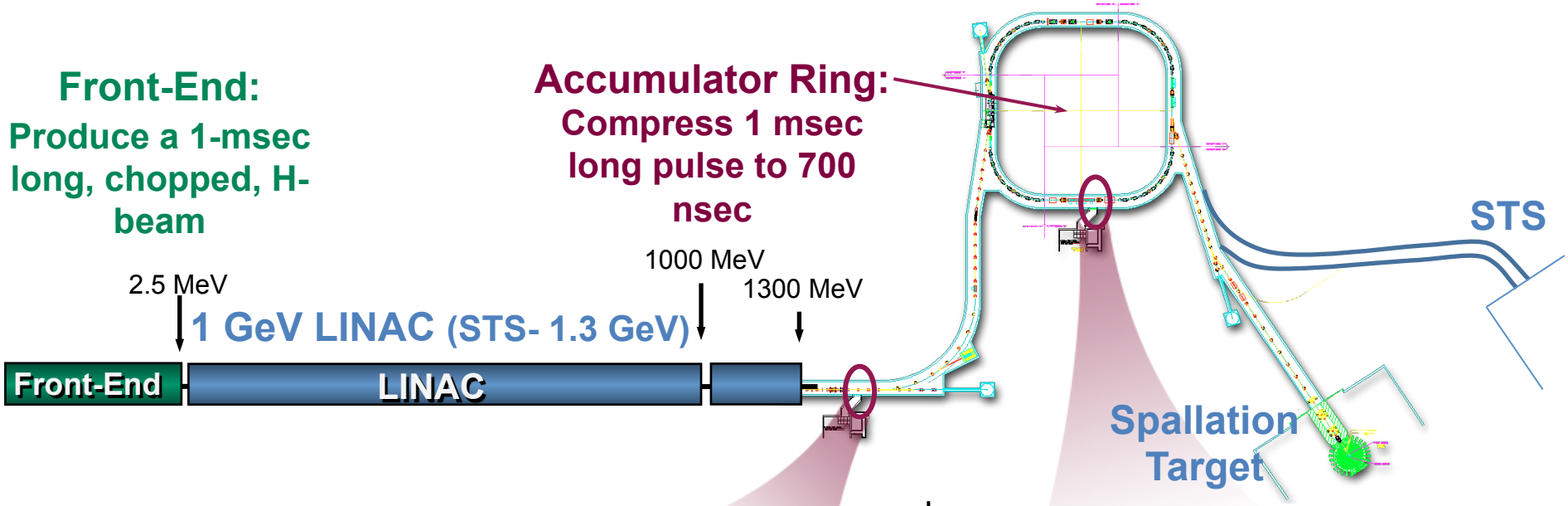
Accumulator Ring:
Compress 1 msec long pulse to 700 nsec

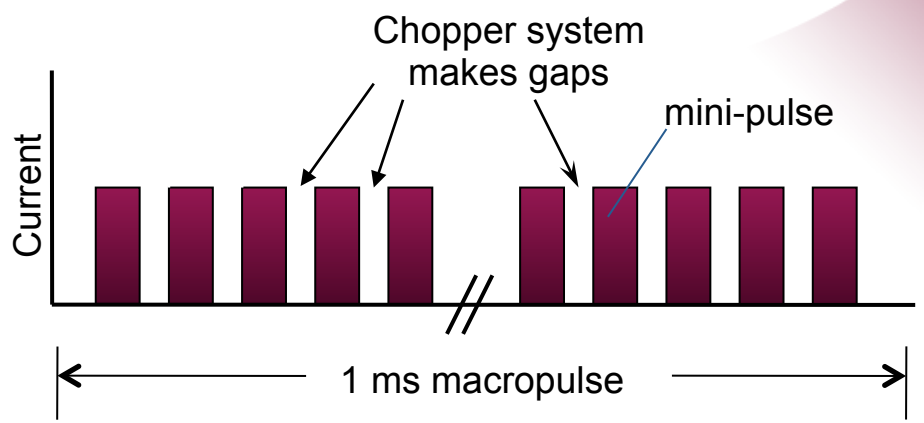
2.5 MeV

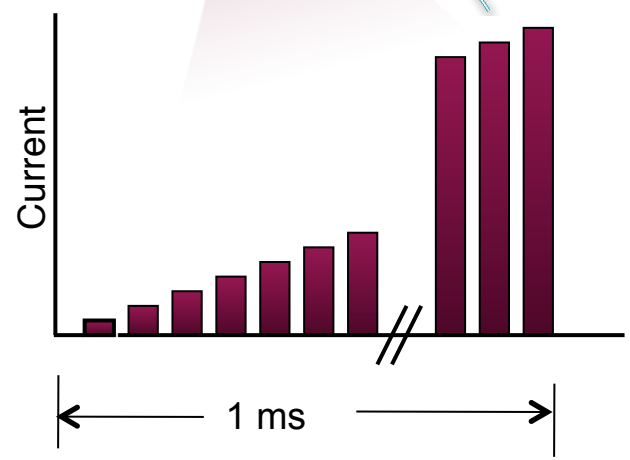
1000 MeV

1300 MeV

1 GeV LINAC (STS- 1.3 GeV)

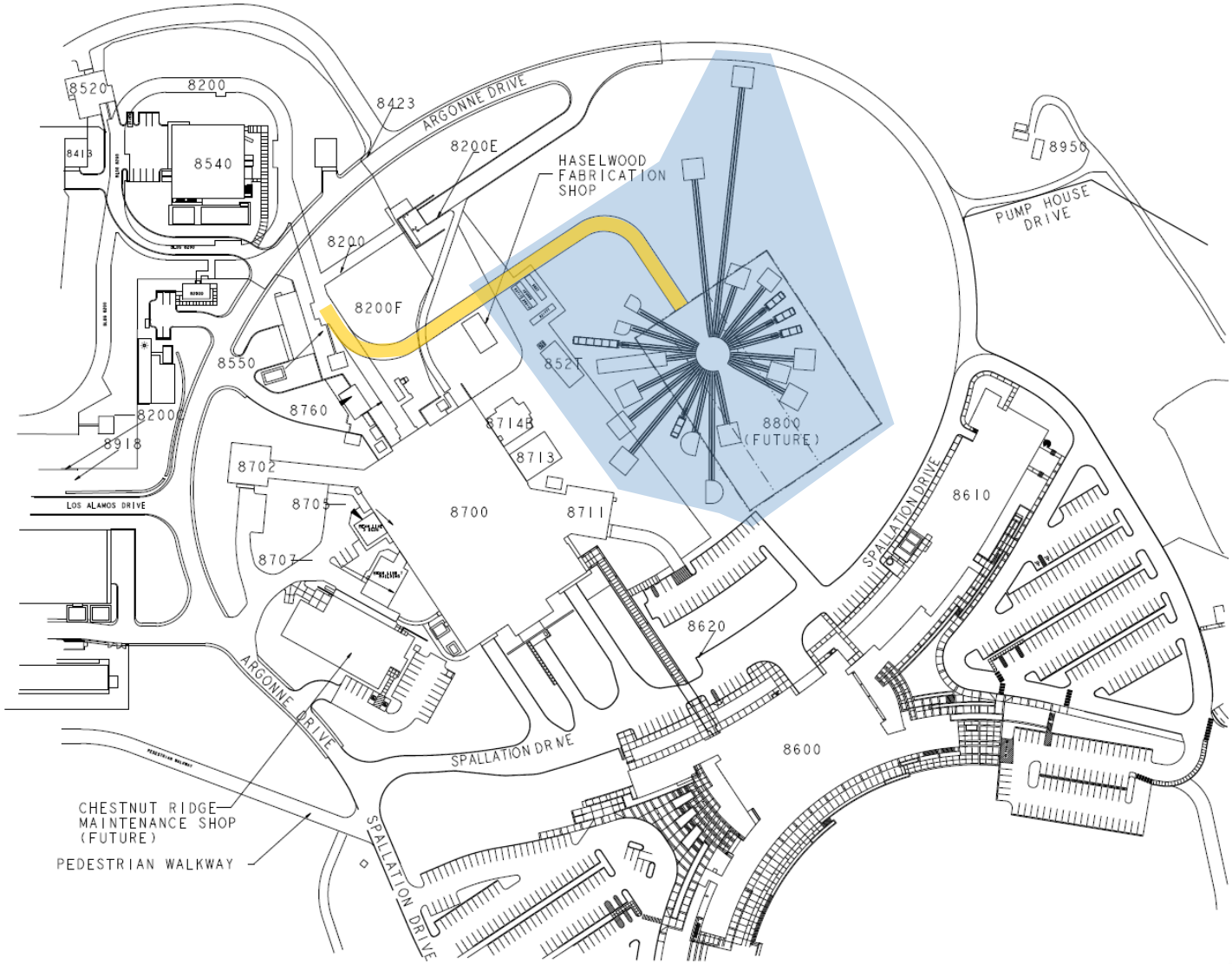






Site Geometry

STS and Site Geometry



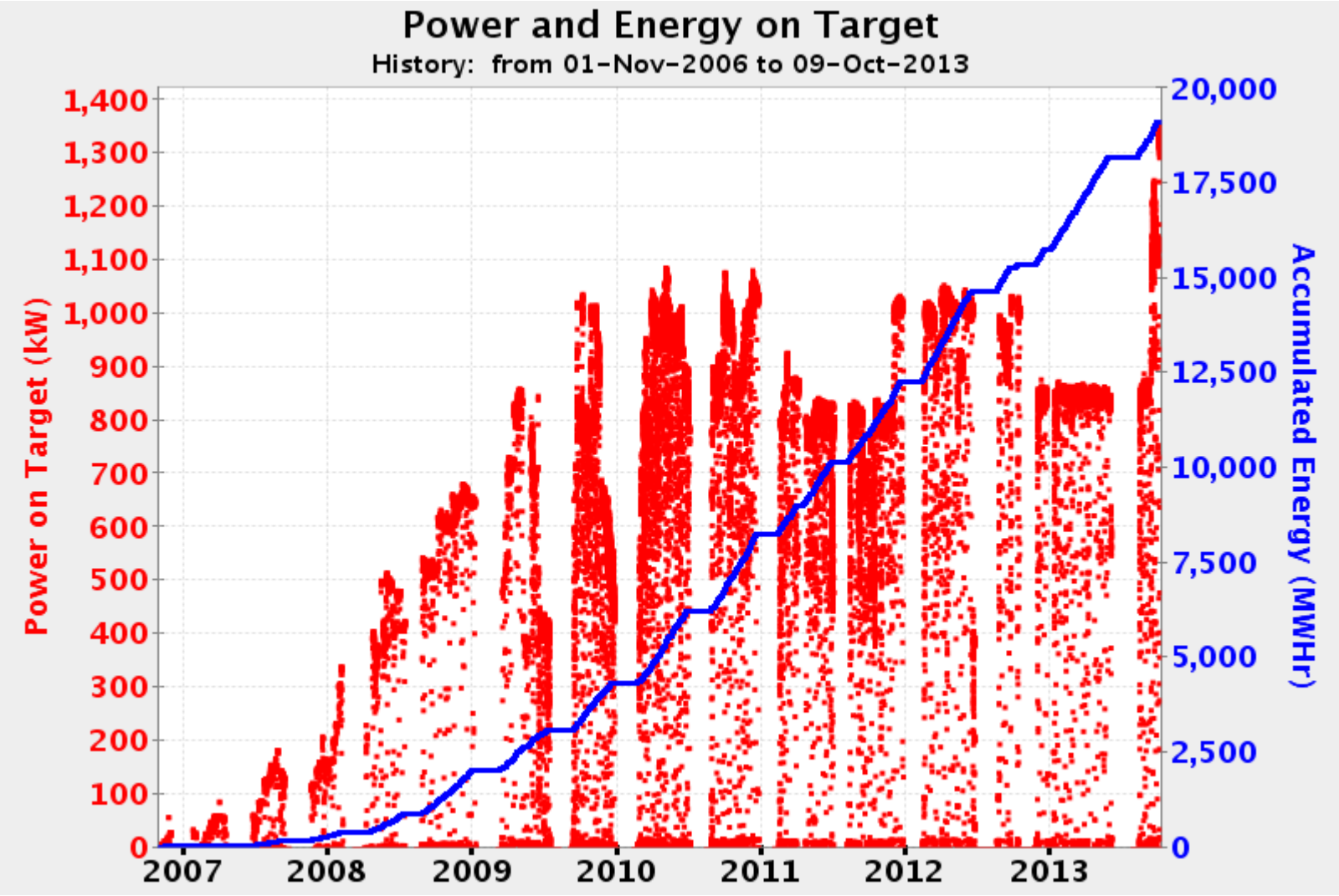
Neutron scattering facilities at Oak Ridge National Laboratory

High Flux Isotope Reactor:
Intense steady-state neutron flux
and a high-brightness cold neutron source

Spallation Neutron Source:
World's most powerful
accelerator-based neutron source

U.S. Department of Energy investments have provided forefront capabilities

SNS – Reaches 1.417 MW – September 29, 2013

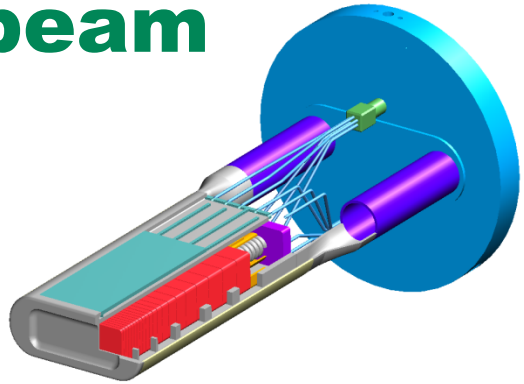


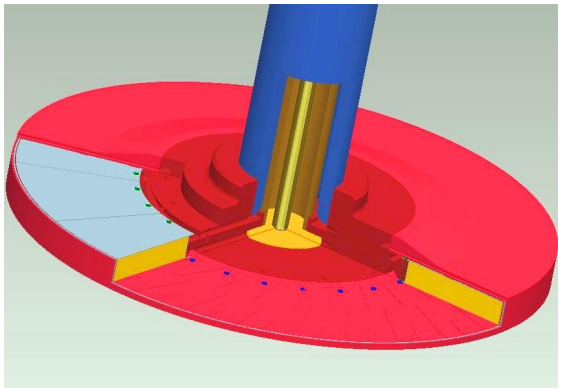
Approach to STS

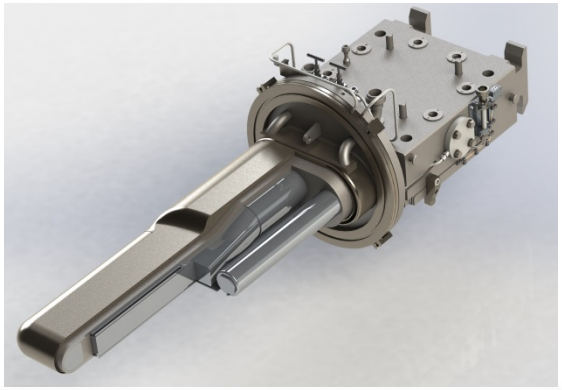
- Explore concepts for a short-pulse STS
  - Proton Beam Profile
  - Target
  - Moderator
  - **Highest Brightness**
- Compare instrument performance between SP-STS and LP-STS

Three credible target concepts for STS for 300 – 500 kW 10 Hz SP beam

- Stationary tungsten plate target
  - Water-cooled
  - Good radiation lifetime
- Rotating tungsten target
  - Water-cooled, minimal in spallation zone gives brightness advantage
  - 20+ year radiation lifetime
  - Waste shipping and handling tbd.
- Mercury target
  - Established technology
  - Good radiation lifetime
  - Pulse issues (cavitation)

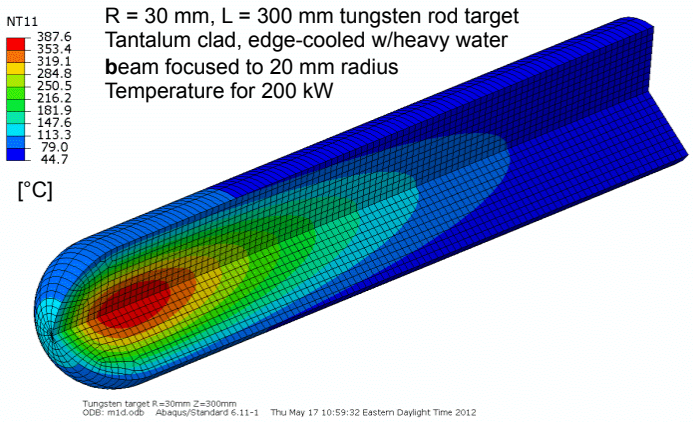




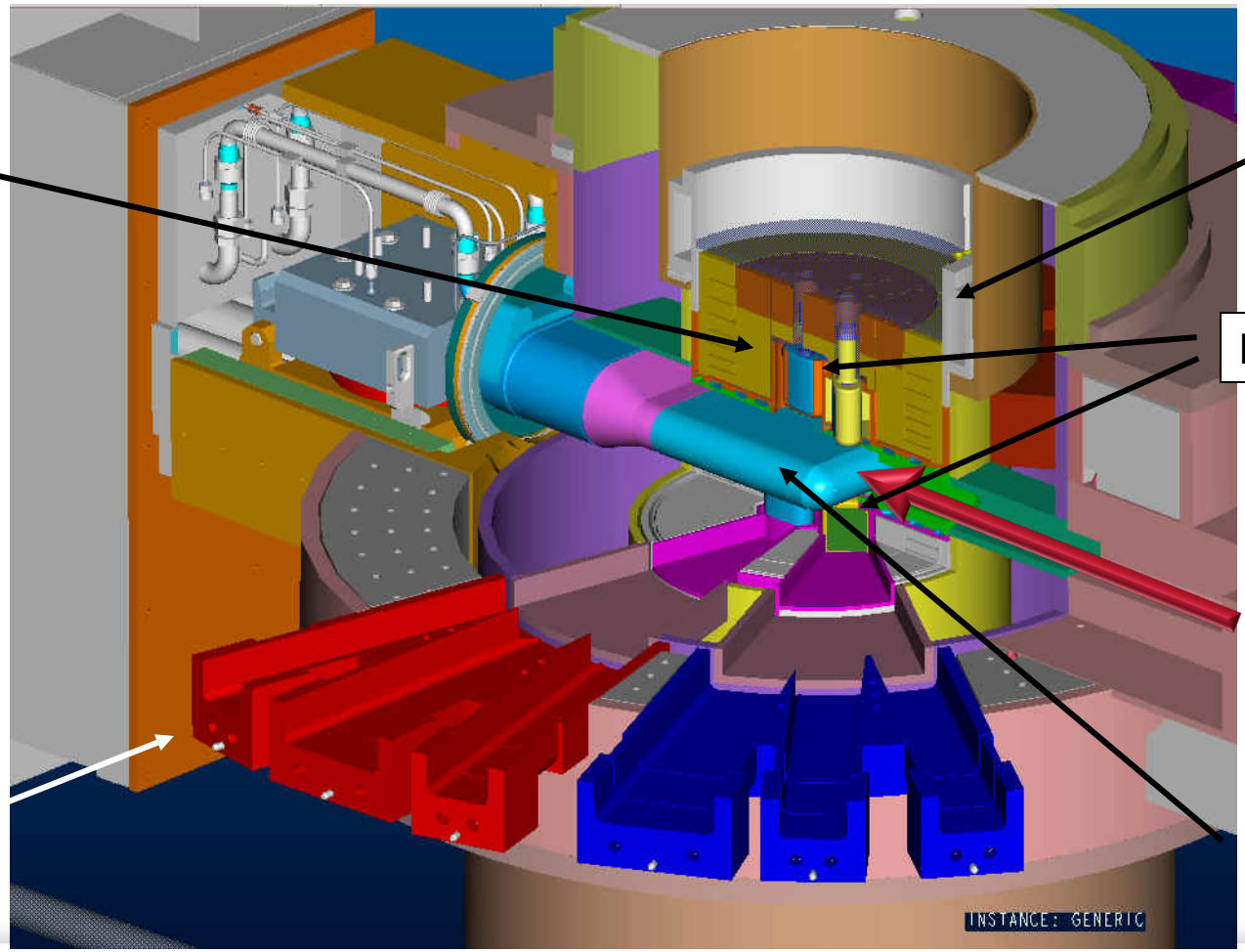


Edge-cooled, solid tungsten rod (Ta clad) concept was studied for SP STS

- Maximum tolerable power for a compact, edge-cooled cylindrical target, based on ISIS-TS2 design (32 kW)
  - Couples well to compact moderators
    - *optimized for peak brightness*
  - Steady state power limit is *no more than* 150 kW based on temperature and thermal stress
    - Would require water to be pressurized 3+ bar
  - Pulse / thermal shock effects may be more limiting
    - This was not investigated



The nature of the problem: Find a configuration of target, moderator and reflector to give prime neutron performance



Inner Reflector Plug

Outer Reflector Plug

Moderators

Protons

Target

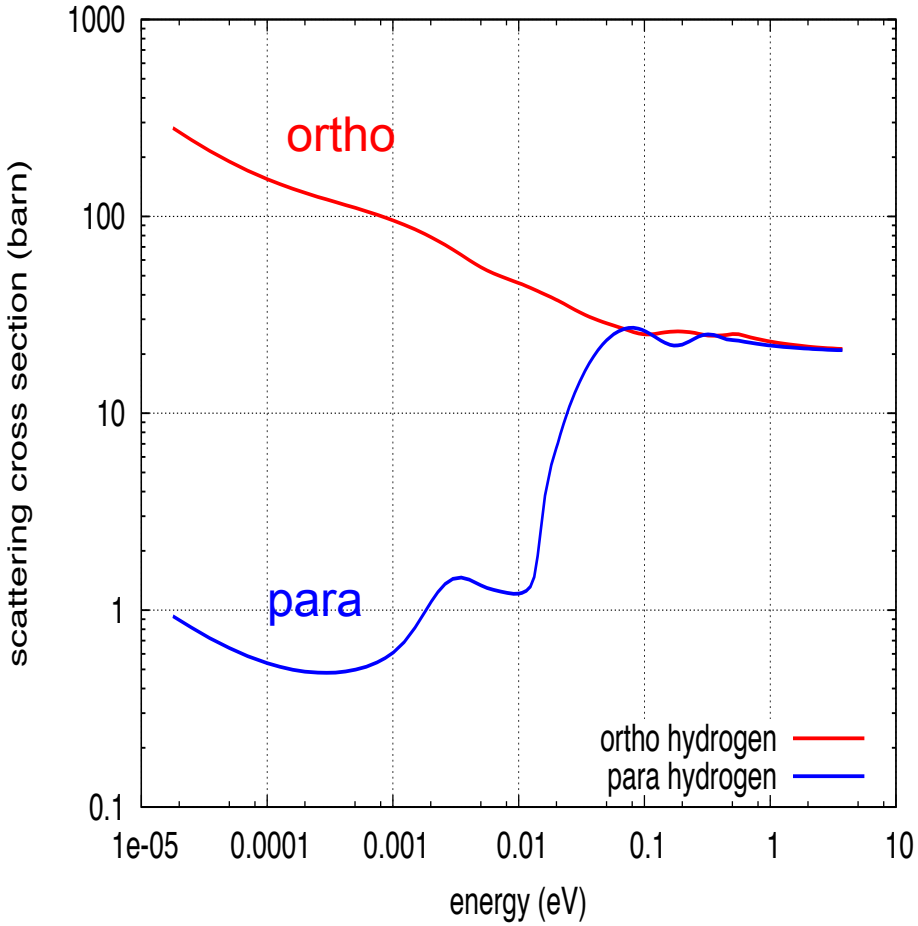
Neutron Flight Channels

Physics Driver

- Make the neutron production zone as small as reasonably possible
  - High target material density
  - Small proton beam footprint
- Position moderator as close as possible at the peak neutron production zone
- Have moderators with high slowing-down power
  - Hydrogen H with mass A=1 is performing best because it is very close in mass to the neutron's (billiard ball effect)
  - Material with high hydrogen density: CH_4 , H_2O, H_2 , NH_3 ...
  - Material very radiation resistant due to proximity to target
  - Material that can transfer deposited nuclear heating
  - Low neutron absorption
- Have a good neutron reflector around moderator

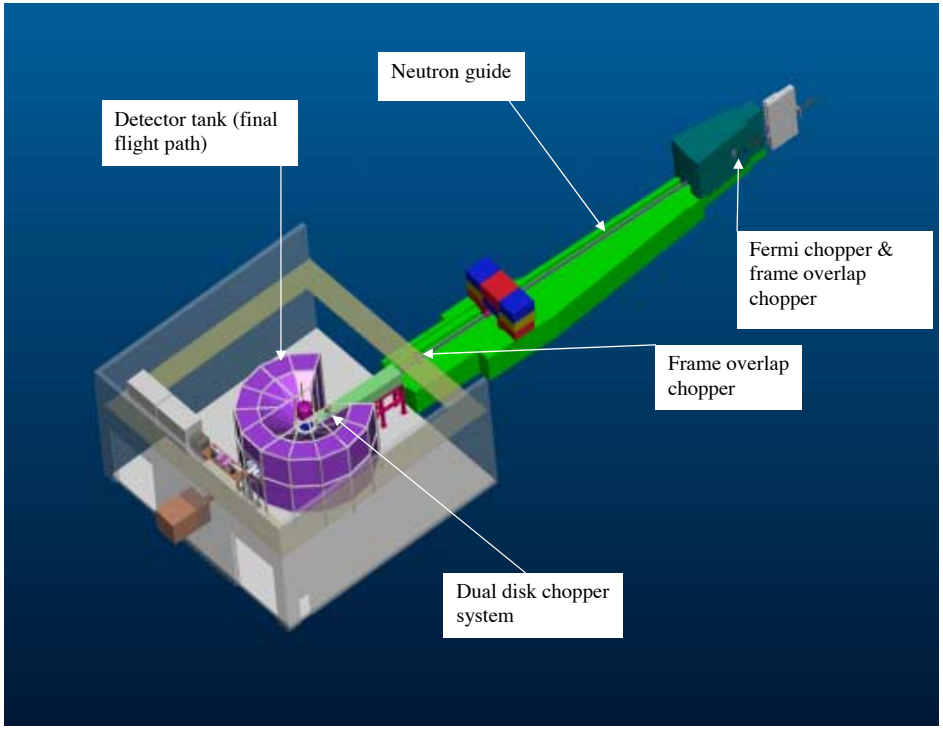
Our Choices

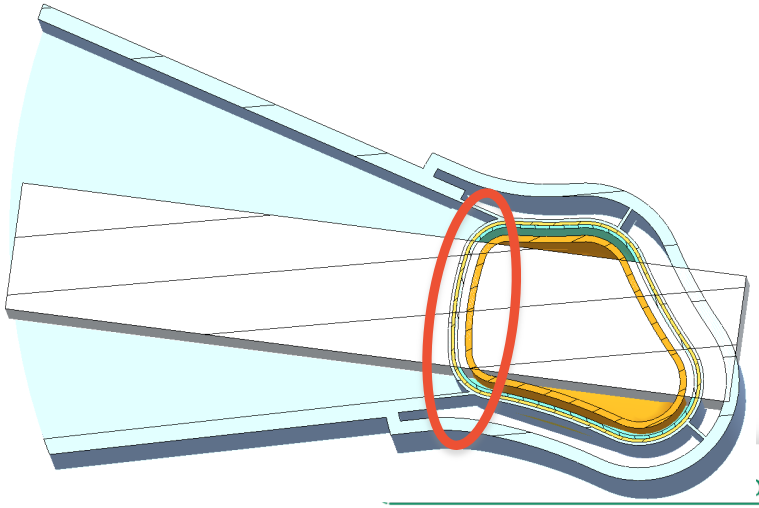
- Proton beam 1.3 GeV with 30 cm^2 cross sectional area
- Stationary tungsten target ~40 cm^2 cross sectional area (density 19.3 g/cc)
- Para-hydrogen moderator T=20 K
- Ambient water pre-moderator (for coupled moderators only?)
- Beryllium metal reflector



What is prime neutron performance?

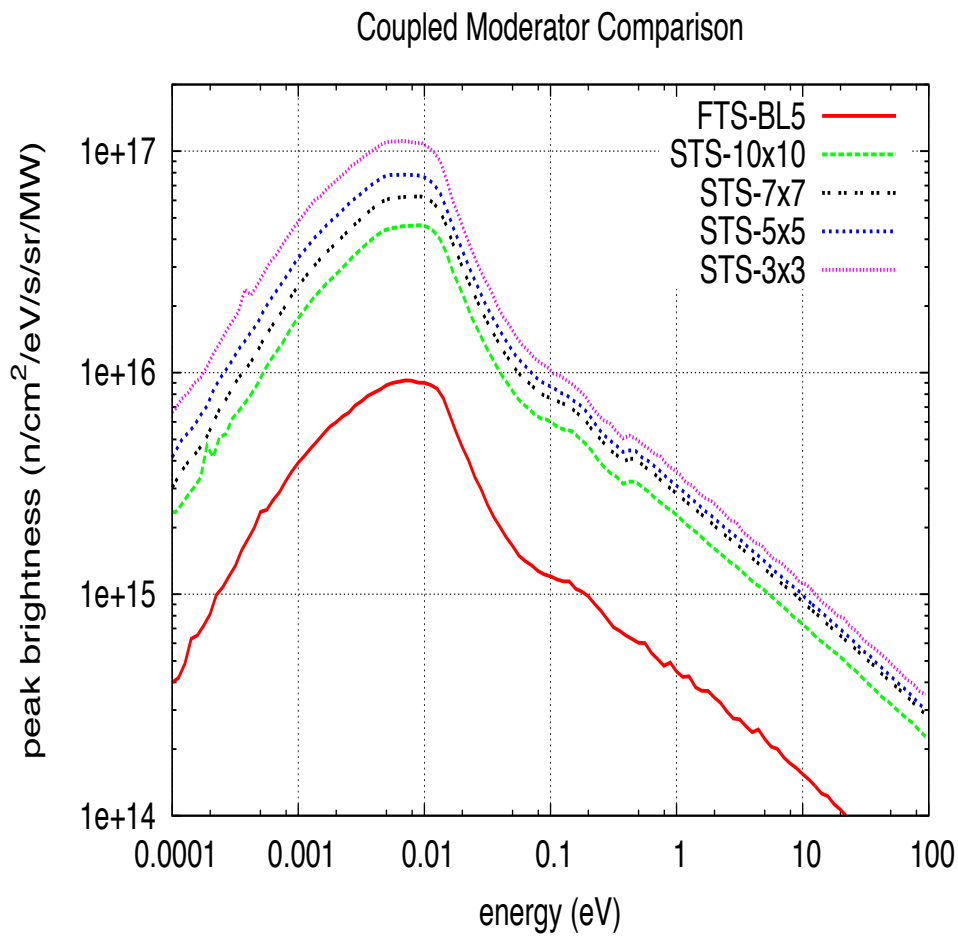
- Ideally: number of useful neutrons on sample at a particular instrument
- Reality: we only have a very rough idea about instruments to be built at STS
- Fall back metric:
  - neutron emission from moderator viewed area
  - peak intensity
  - long-wavelength
  - Brightness (n/cm^2/s/eV/sr)





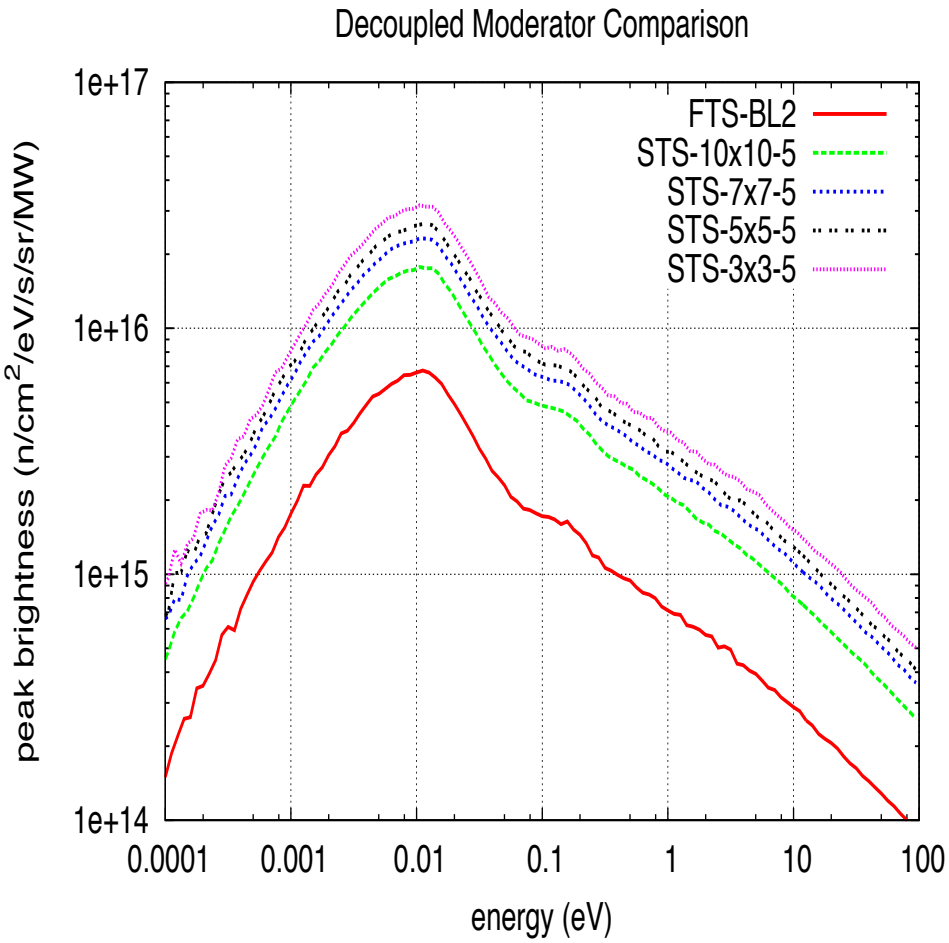
Coupled Moderator Performance

- Gains in time-integrated and peak brightness of a factor of 5 are possible for SP-STS compared to FTS on a per unit power basis for moderators with 10x10cm viewed area
- Another factor of 2.4 can be gained in brightness by reducing the viewed area to 3x3cm.



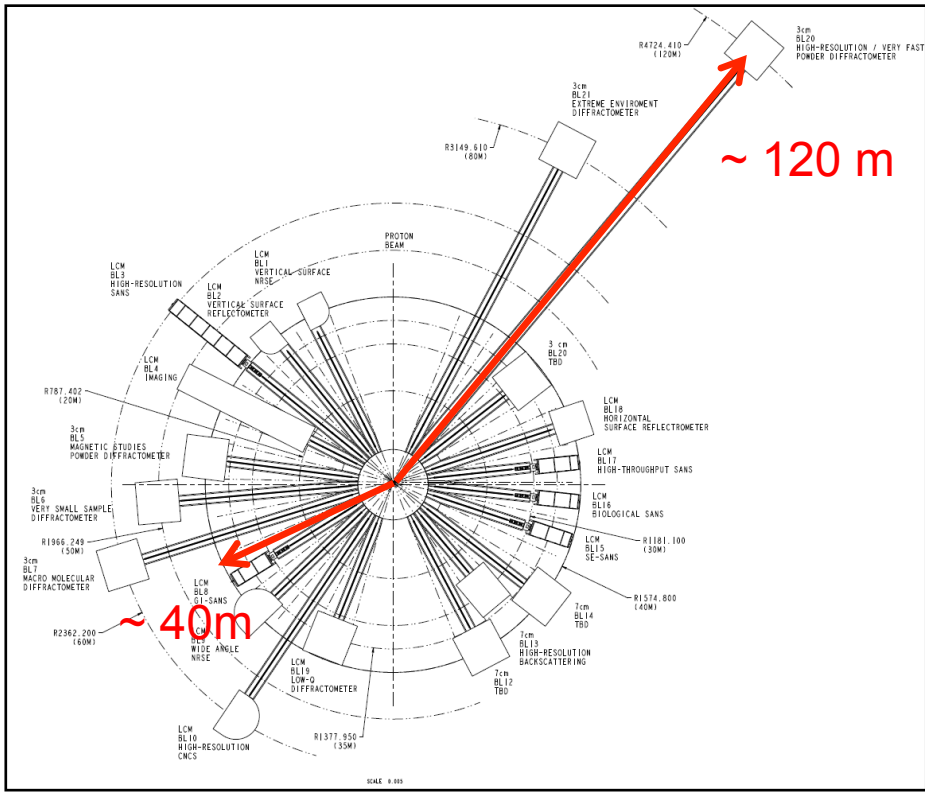
Decoupled moderator performance

- A factor of 2.5 can be gained in peak brightness on a per unit power basis over FTS by improved coupling of target and moderator
- by downsizing the viewed area from 10x10cm to 3x3 cm, another factor of 2 can be gained



Instruments Performance on Short- or Long-Pulse STS

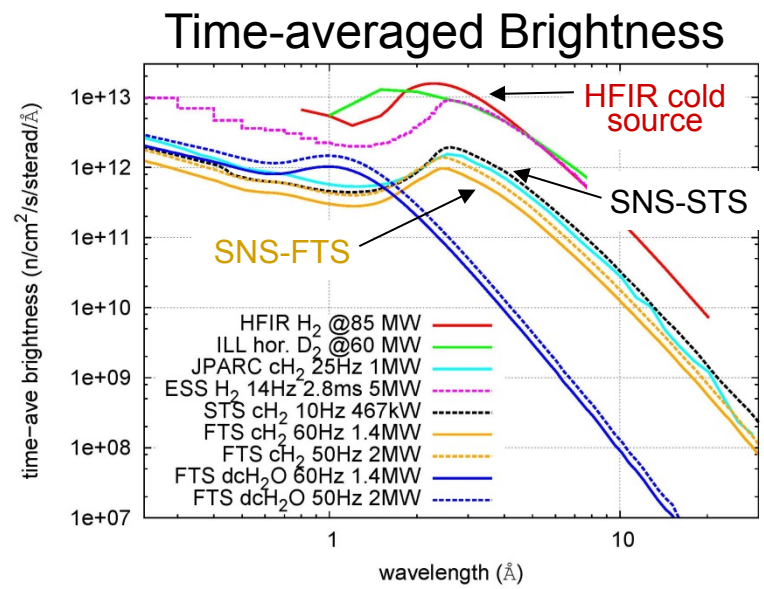
- Four instrument classes were considered
  - Broadband, low wavelength resolution instruments (SANS)
  - High wavelength resolution, broadband instruments (high-resolution powder diffactometer
  - Narrowband, peak-flux driven instruments (cold neutron chopper spectrometer)
  - Small sample instruments (single crystal, high pressure diffractometers)
- The short-pulse option for STS offers significantly better performance for most instruments
- *Instrument performance on the short and long pulse second SNS target station*, J. K. Zhao, et al., Rev. Sci. Instrum. **84**, art. 105104 (2013).

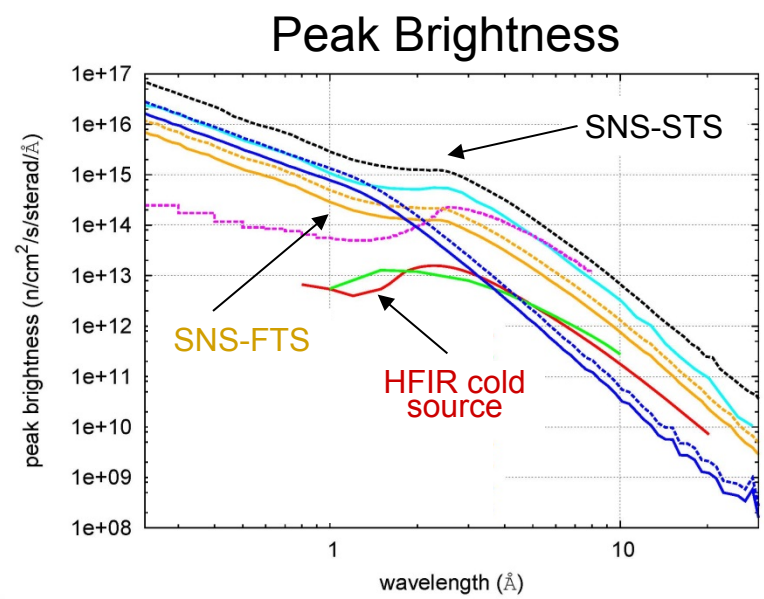


Representative instrument suite for STS.

ORNL Source Strengths

- HFIR
  - Highest time-averaged thermal flux – about 40 x that of SNS-first target station (SNS-FTS)
  - Highest time-averaged cold brightness – about 10 x that of SNS-FTS or SNS-second target station (SNS-STS)
- SNS-FTS (optimized for de-coupled moderators)
  - High peak-brightness @60 Hz
  - De-coupled moderators – sharp time pulses across broad wavelength band
- SNS-STS (optimized for cold neutrons and coupled moderators)
  - Highest cold-neutron peak brightness
  - 10 Hz – very broad wavelength band





Qualitative Analysis

- Instrument Case 1 – Performance depends on time-averaged source brightness integrated over wavelength band of interest
  - High integrated flux of cold neutrons (SANS) or limited wavelength band (TAS)

HFIR strength

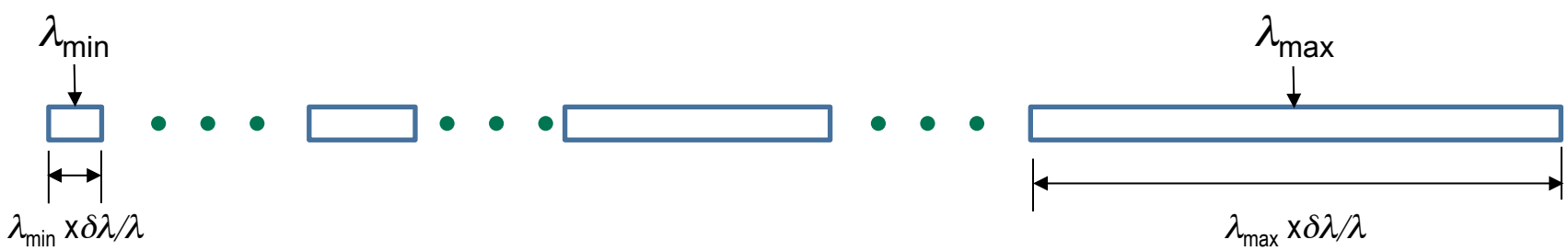
- Instrument Case 2 – Performance depends on peak source brightness
  - Good-excellent wavelength resolution and can effectively use a broad incident wavelength band (Powder and single-crystal diffraction)
  - Uses a broad scattered-wavelength band (chopper spectrometers)

Pulsed-Source strength

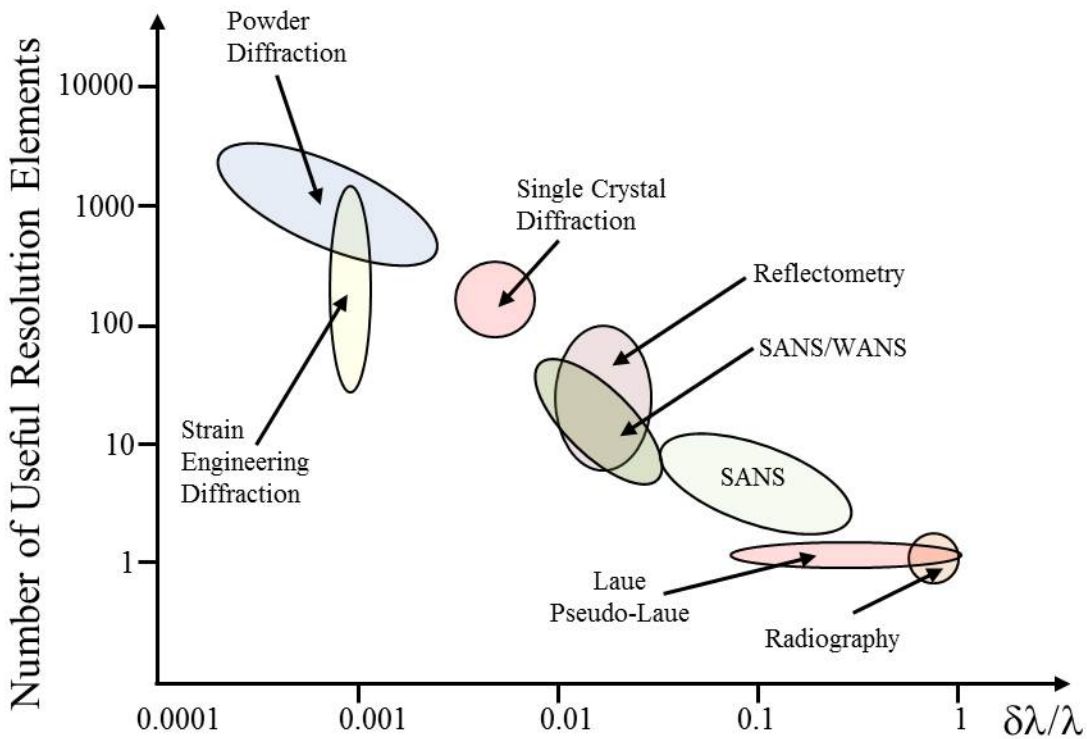
- Instrument Case 3 – Performance depends on details of the science being addressed
- Note : Instruments of all types have been built on both continuous and pulsed sources
- Our Opportunity – Design and Position instruments at the optimum source to deliver the highest impact science
- Neutron Advisory Board – *"Together, these three facilities can and will support the most potent and complete range of neutron beam facilities available in the world, now and in the foreseeable future."*

Semi-Quantitative Analysis – Elastic Instrument Optimization at ORNL Sources

- Performance depends on range of accessed momentum transfers, *Q*-resolution, and effective count rate.
  - *Q*-resolution is typically proportional to wavelength resolution as instrument geometry is matched to wavelength term.
  - Wavelength resolution -- $\delta\lambda/\lambda$ – x-axis scaling of elastic instrument performance
  - Number of useful/needed resolution elements, $\delta\lambda/\lambda$, will be the y-axis of our map
    - Allows us to identify where time-of-flight gains are practical and useful
    - Example 1 – SANS
      - Typically required wavelength resolution – $0.03 \leq \delta\lambda/\lambda \leq 0.20$
      - Data set can be obtained with 1 to a few wavelength resolution elements
    - Example 2 – Powder diffraction
      - Medium to high resolution instruments - $0.003 \geq \delta\lambda/\lambda \geq 0.0003$
      - Data set can usefully employ 100's to 10000's of resolution elements



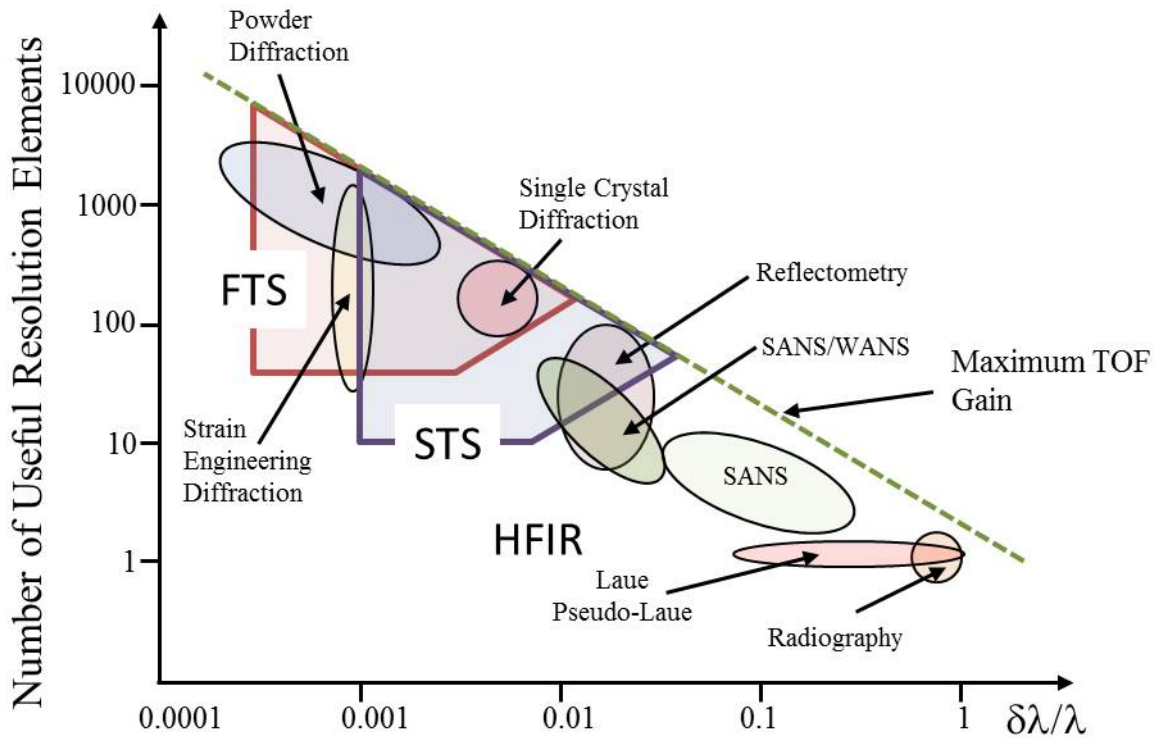
Instrument Performance Map



Time-of-flight gains and source comparison

- Time-of-flight gain is the number of resolution elements that can be collected in a single pulse of the source.
  - The break even point is when the time-of-flight gain times the time averaged flux of the pulsed source = time averaged flux of a continuous source
- Maximum possible time-of-flight gain is proportional to $(\delta\lambda/\lambda)^{-1}$
  - Requires that an instrument can be built at a length such that the required wavelength band can be obtained in a single pulse of the source (if multiple frames are required than tof-gain is reduced by that factor)
  - That this length corresponds to the required wavelength resolution, $\delta\lambda/\lambda$

Elastic Instrument/Source Performance Map



Inelastic Instruments