Second Target Station Design and Technical Parameters

Presented to
Neutron Advisory Board

Presented by
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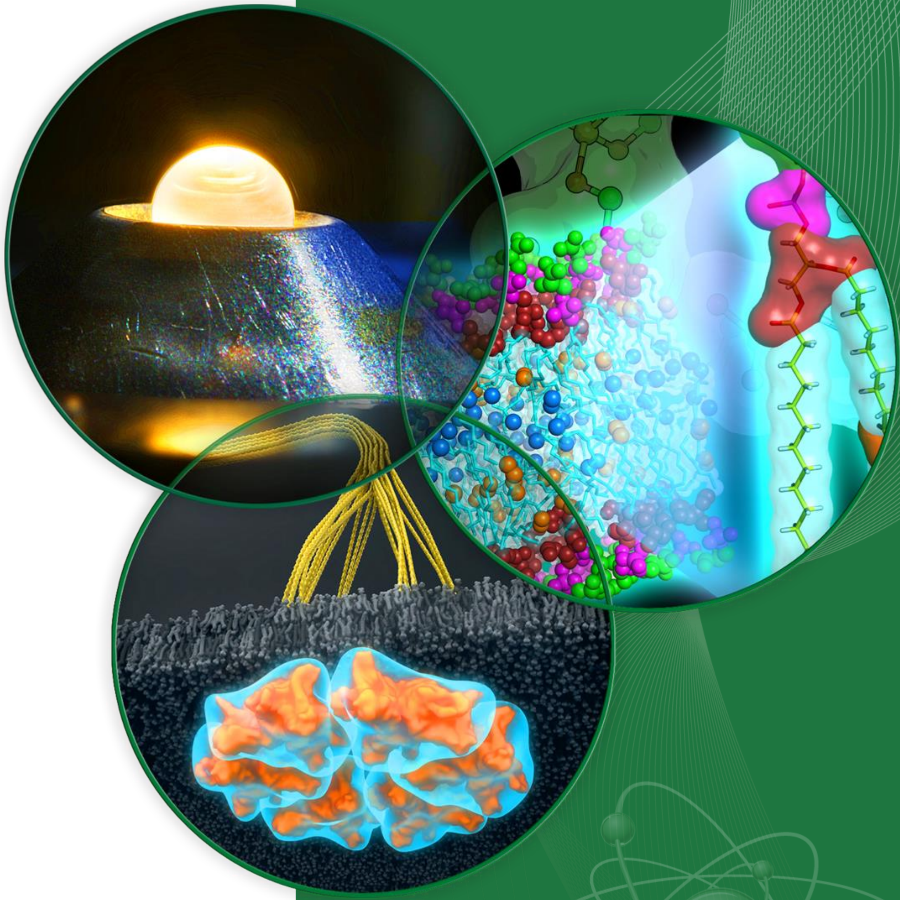
June 30, 2016
Clinch River Cabin
Oak Ridge, Tennessee



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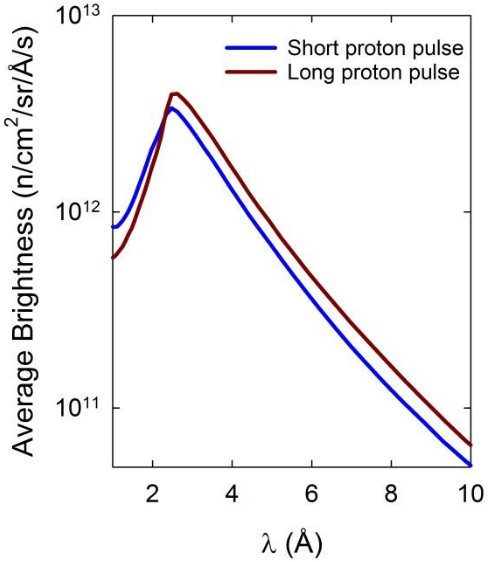
Preparing for the Technical Review Panel – neutron scattering instruments

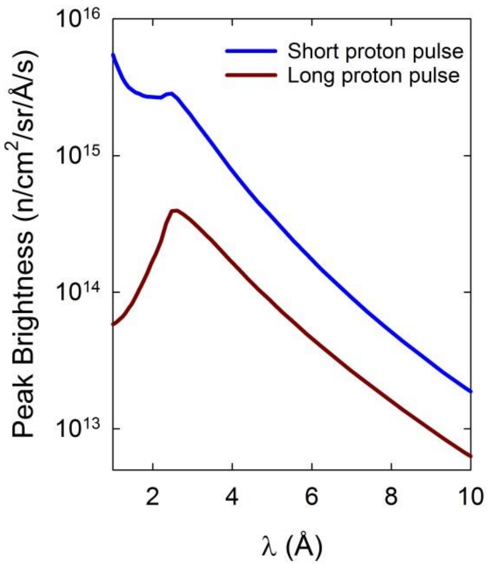
- Pulse Length question
  - Develop a source figure-of-merit (FOM) appropriate for instrument types (SANS, diffraction, reflectometry, spectroscopy…)
  - Analyze the planning suite of instruments
- Repetition rate 10 – 20 Hz
  - Analyze the science needs of the planning suite of instruments and trade-offs between instrument lengths, bandwidth ($\Delta\lambda$), and resolution ($\delta\lambda/\lambda$)
  - Evaluate the relative gain/loss against cost, complexity, source considerations
- Evaluate impact of maintaining a power upgrade path for STS

2013 NAB report recommended a short proton pulse Second Target Station

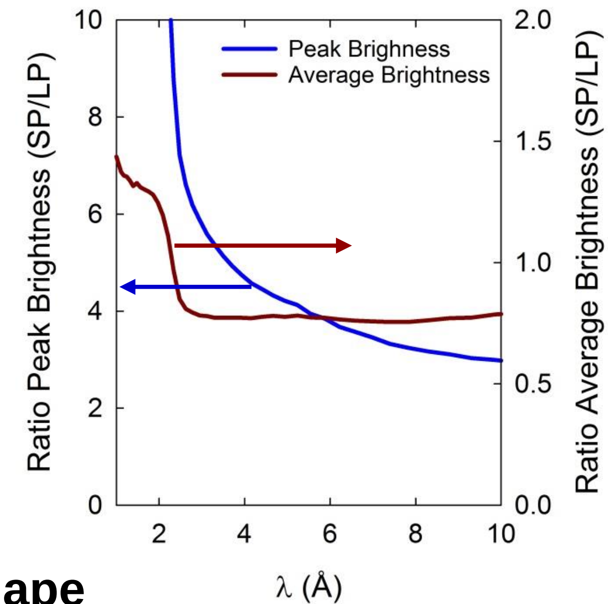
- "From all standpoints – scientific case, site geometry, and engineering practicality, NAB is in favor of using the short pulse option for reference purposes during the upcoming scoping and design phases for upgrading the SNS."
  - Instrument performance scales somewhere between average neutron flux and peak neutron flux.
  - "Instruments designed to take advantage of short proton pulses are expected to fit better within the available SNS footprint…" Instruments have to be less than 100 m long.
  - SNS already has an accumulator/compressor ring able to provide short pulses.
  - SNS experience in designing short pulse source instruments and user community familiarity makes early scientific impact more likely.

STS-SP performance is superior to STS-LP

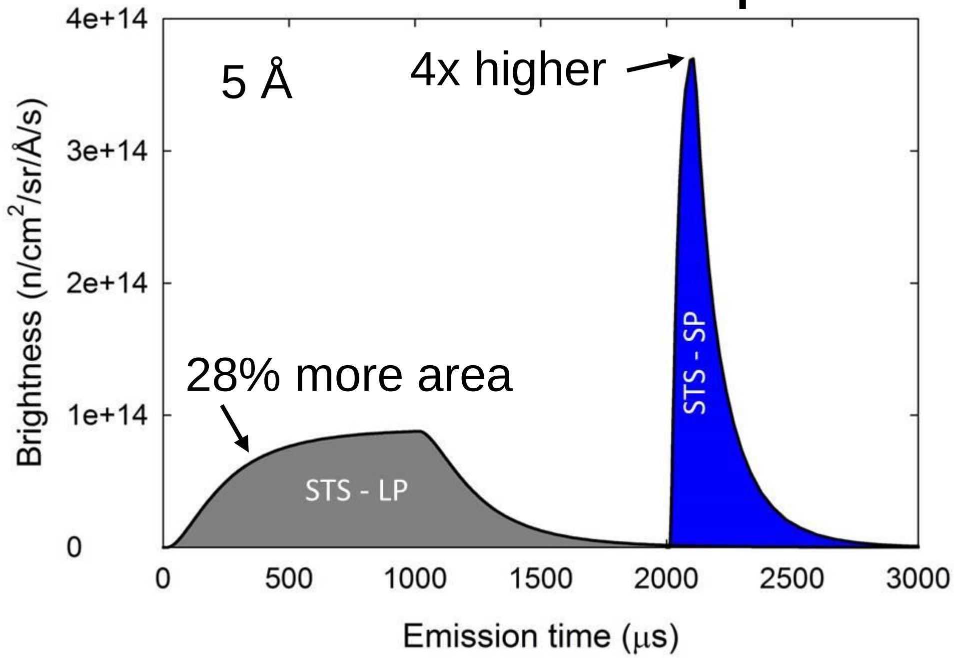




- Average instrument performance scales somewhere between average brightness and peak brightness
- Instruments whose performance scales as peak brightness gain about a factor of 4 with SP concept versus LP concept
- Instruments whose performance scales as average brightness lose about 20% with SP concept versus LP concept



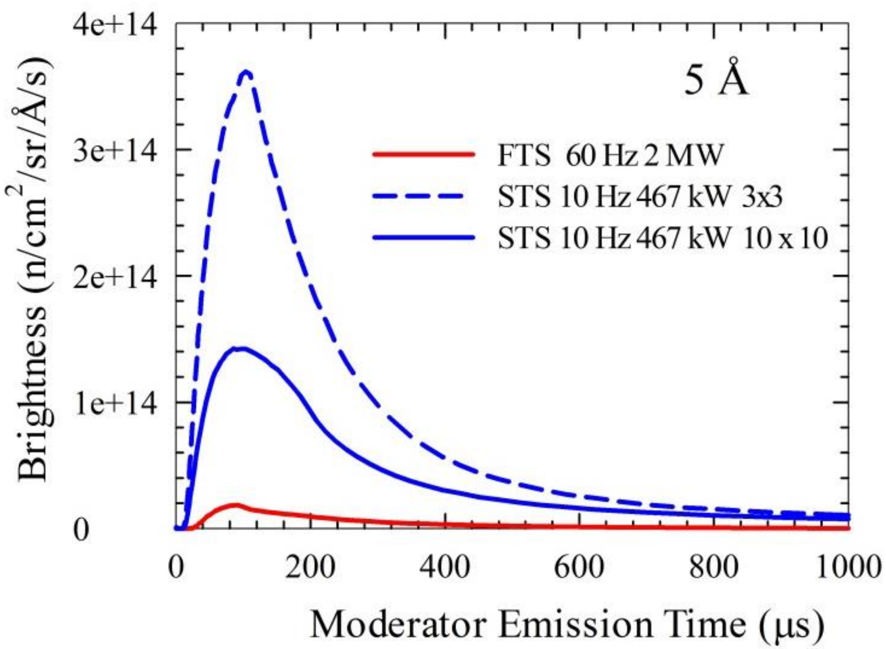
Moderator Pulse Shape



Area is average brightness

Amplitude is peak brightness

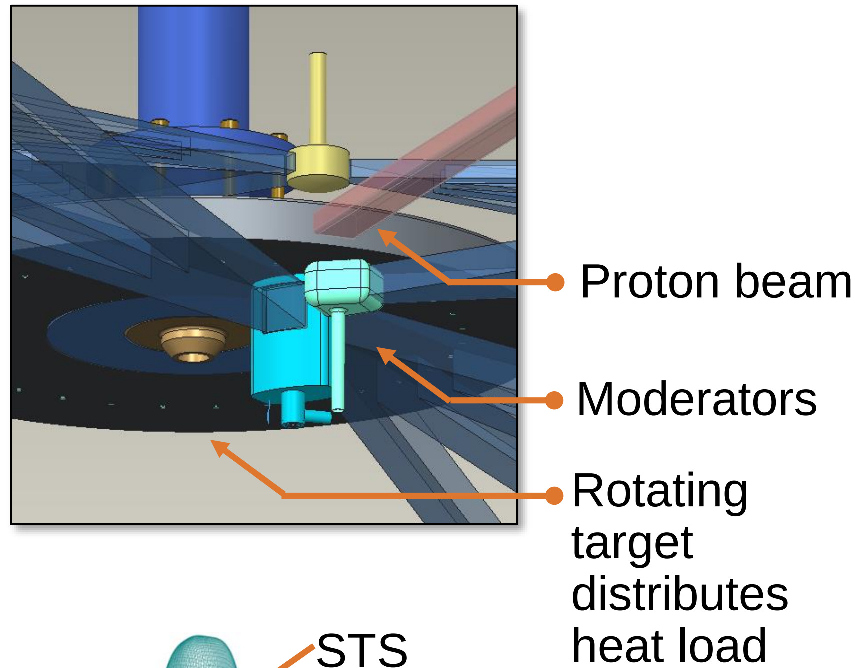
STS is optimized for highest neutron peak brightness at long wavelengths

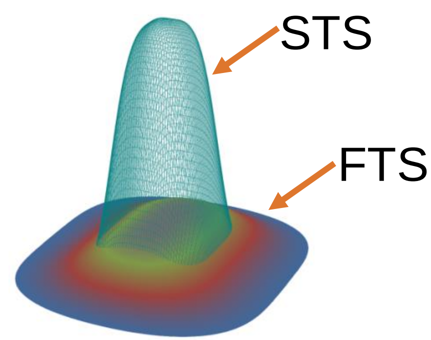


STS: 20× FTS

- Optimal moderator placement: 2×
- Compact neutron production zone: 4×
- Moderator geometry: 2.5×

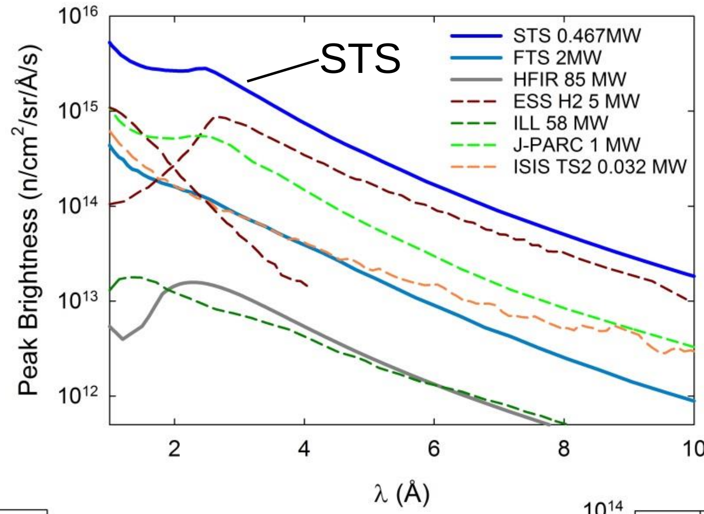
2016 – adopted rotating target option for higher power



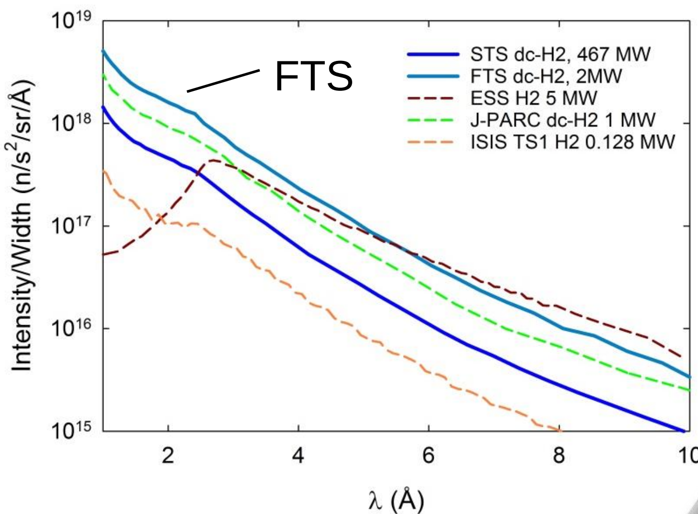


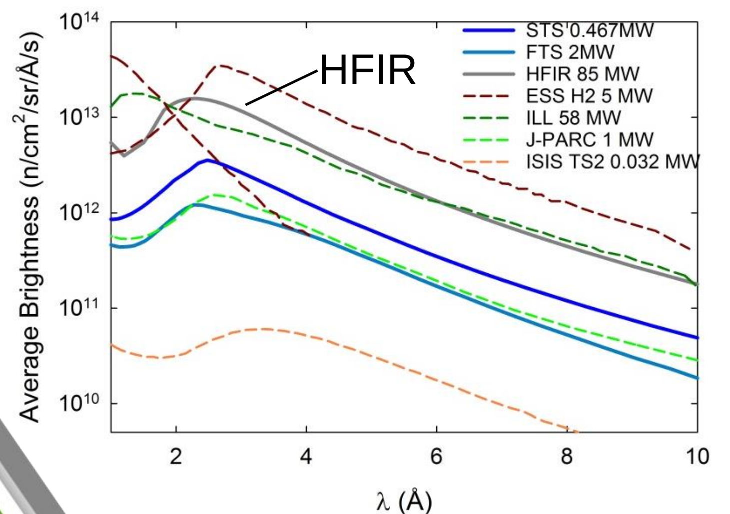
Proton beam footprint

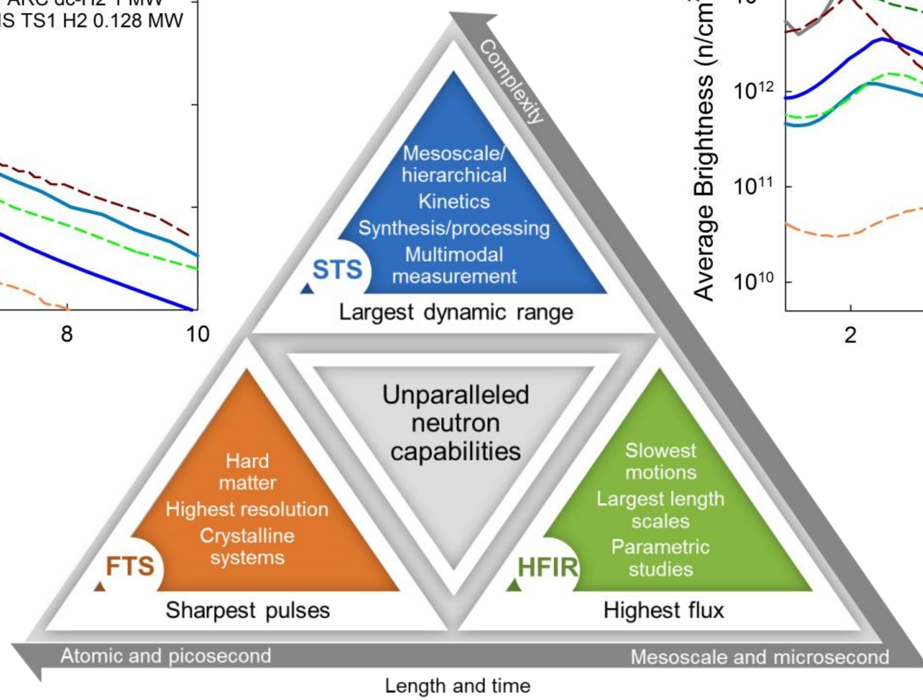
Three source strategy ensures US leadership in neutron sciences



"Together these facilities can and will support the most potent and complete range of neutron beam facilities available anywhere in the world, now and in the foreseeable future." – NAB 2013

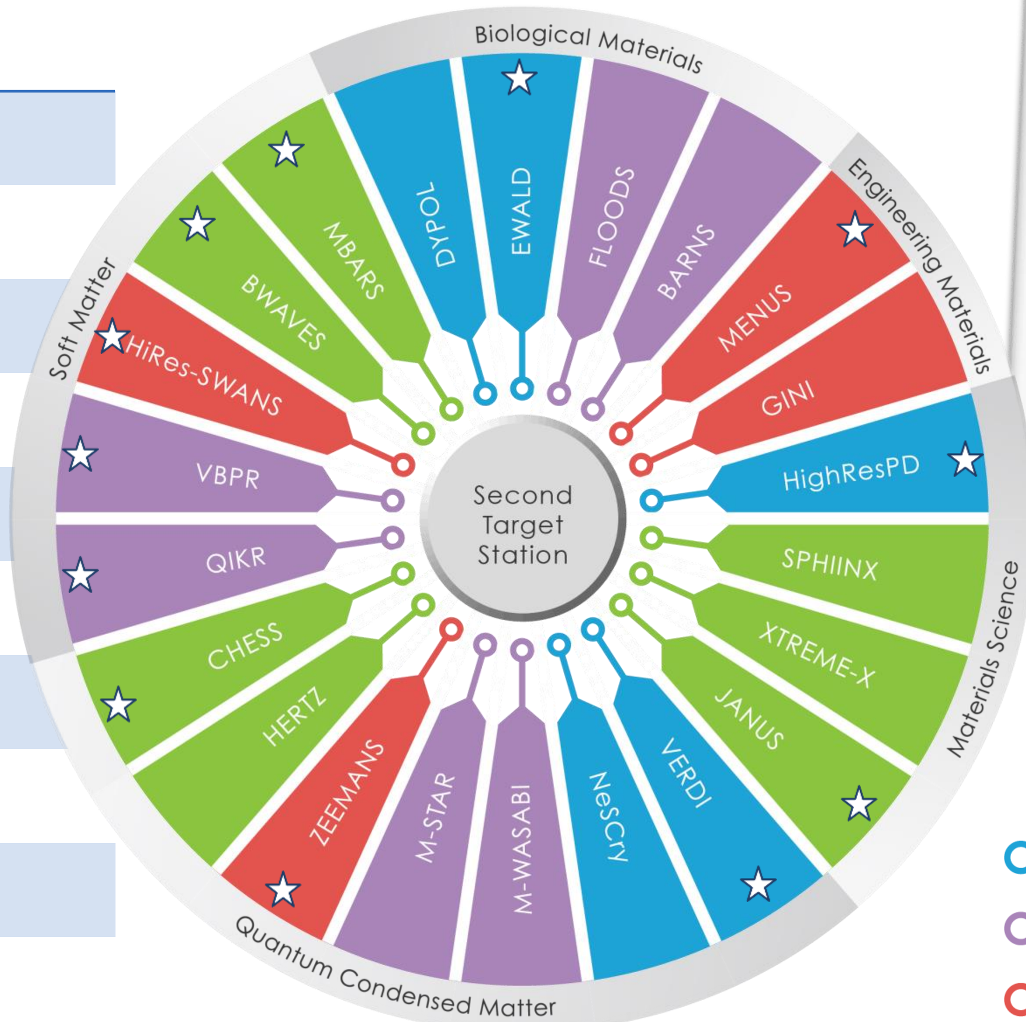


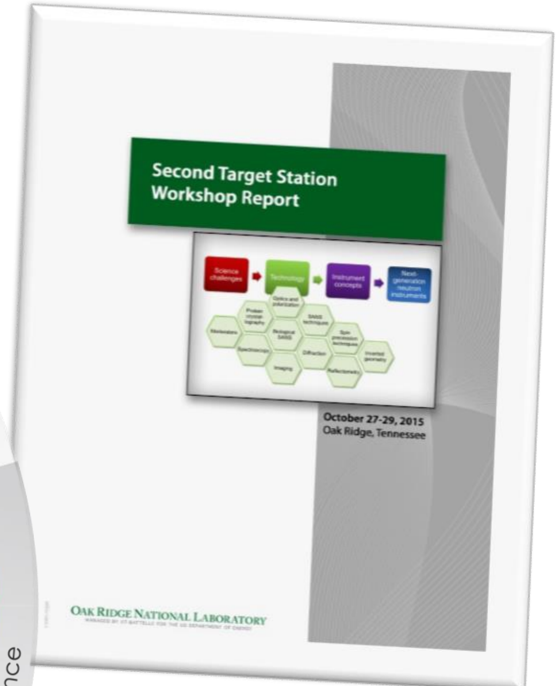




User community identified 12 high-priority instruments – October 2015

- MBARS
- BWAVES
- JANUS
- CHESS
- ZEEMANS
- MENUS
- EWALD
- VERDI
- HighResPD
- HiRes-SWANS
- QIKR
- VBPR



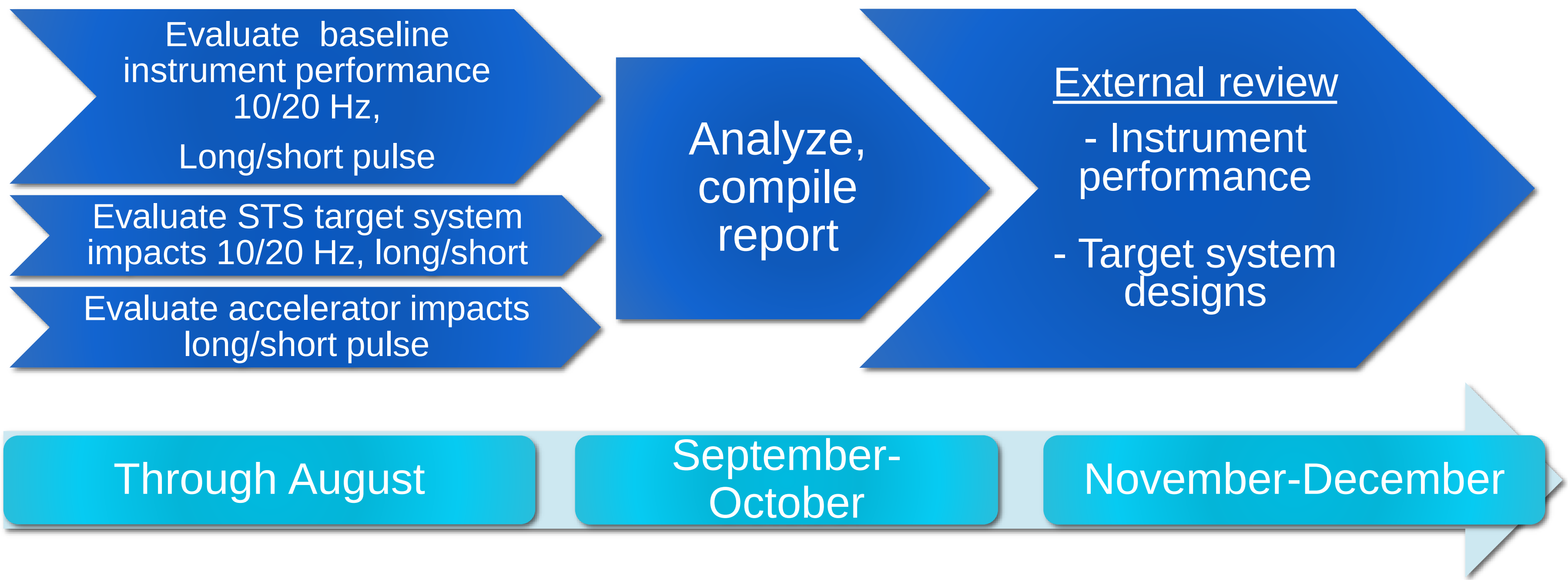


STS Instruments FY16-FY17

- Concept development – initial neutron optics designs – Monte Carlo models
  - QIKR – John Ankner and Tim Charlton
  - HiRes-PD – Uli Wildgruber
  - EWALD (DyPol) – Leighton Coates
  - CHESS – Georg Ehlers
  - ZEEMANS – Barry Winn (magnet technology)
  - FY17 – initiate 5 more from top 12 list
- Simulate early science experiments at STS
- Moderator Optimization
  - Develop new figures-of-merit for top 12 instruments
  - Re-optimize moderator suite
  - Explore production of 10-30 Å neutrons
- Integration with target monolith and conventional facilities
  - Long beam lines
  - Precision optics
  - Neutron Choppers
- Detector needs evaluation (white paper)
- High Magnetic Fields based on high-T_c workshop – August, 2016
  - Proposal to develop high-T_c technology for high-field applications on beam lines
- Zeemans instrument advisory team meeting – August 2016
  - Define magnet and sample environment requirements
- <u>Analyze instruments performance as a function of source frequency and pulse shape (duration)</u>

STS: Process towards detailed design evaluation

- June 2016: BESAC prioritization sub-committee recommendation
  - *Furthermore, BESAC strongly encourages ORNL to establish a review panel to make a detailed evaluation and recommendations on the proposed designs. Such a panel should be charged with detailed analysis of the technical issues such as those related to the STS **repetition rate and pulse length**.*
  - 10-20 Hz , short- or long-proton pulse



Methodology for Source Metrics – define a figure-of-merit (FOM)

- Comparing long and short-proton pulse sources
- F. Mezei, *New perspectives from new generations of neutron sources*, C. R. Physique **8**, 909-920 (2007).

$$F(\lambda) = \Phi(\lambda) \cdot \eta(\lambda) \cdot \min\left[1, (\delta\lambda/\lambda)_{delivered}/(\delta\lambda/\lambda)_{required}\right] \cdot P(\lambda)$$

where

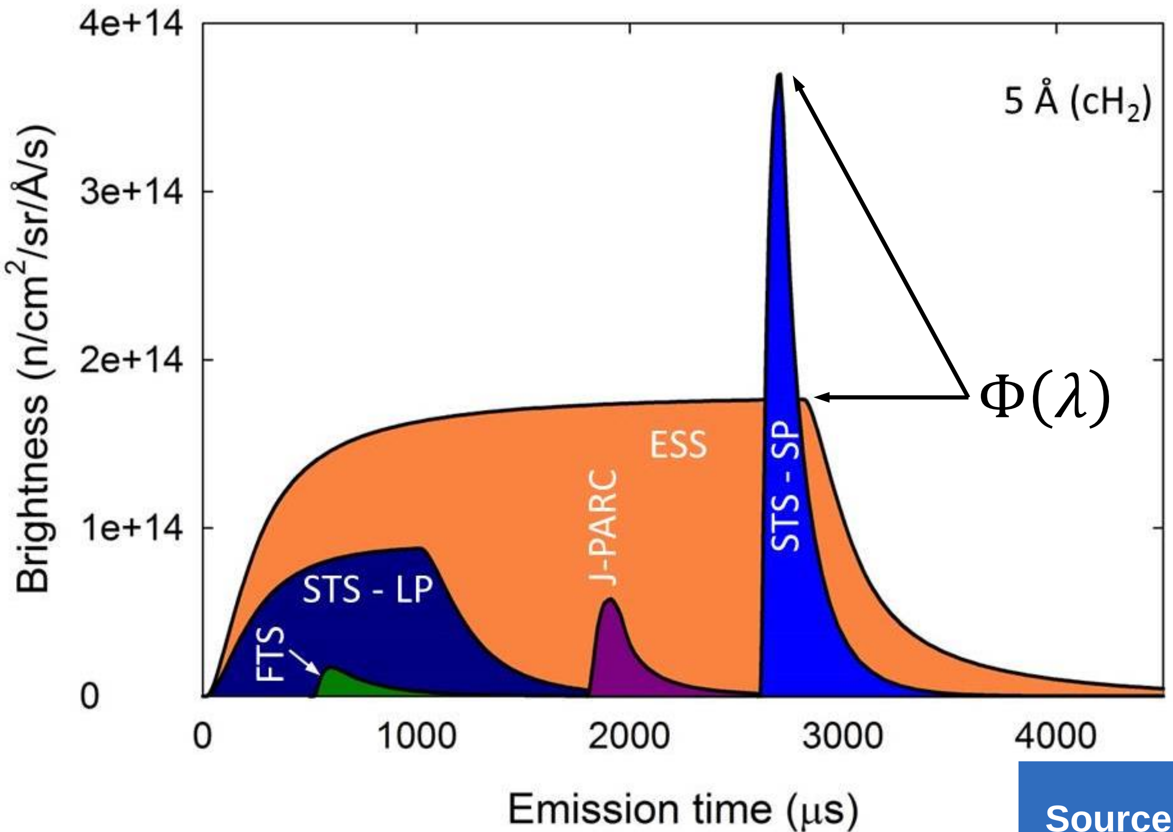
$$F(\lambda) = \text{FOM}$$

$$\Phi(\lambda) = \text{instantaneous source brightness at the peak of the moderator pulse}$$

$$\eta(\lambda) = \text{beam delivery efficiency (brightness transfer)} \approx 0.7$$

$$P(\lambda) = \text{"pulse shape factor" designed to characterize the information content}$$

Source characteristics



Source	Power (MW)	Proton Pulse (μsec)	Frequency (Hz)
ESS	5	2,800	14
SNS-SP	0.467	0.7	10
SNS-LP	0.467	1,000	10
FTS-SP	2	0.7	60
J-PARC	1	<1	25

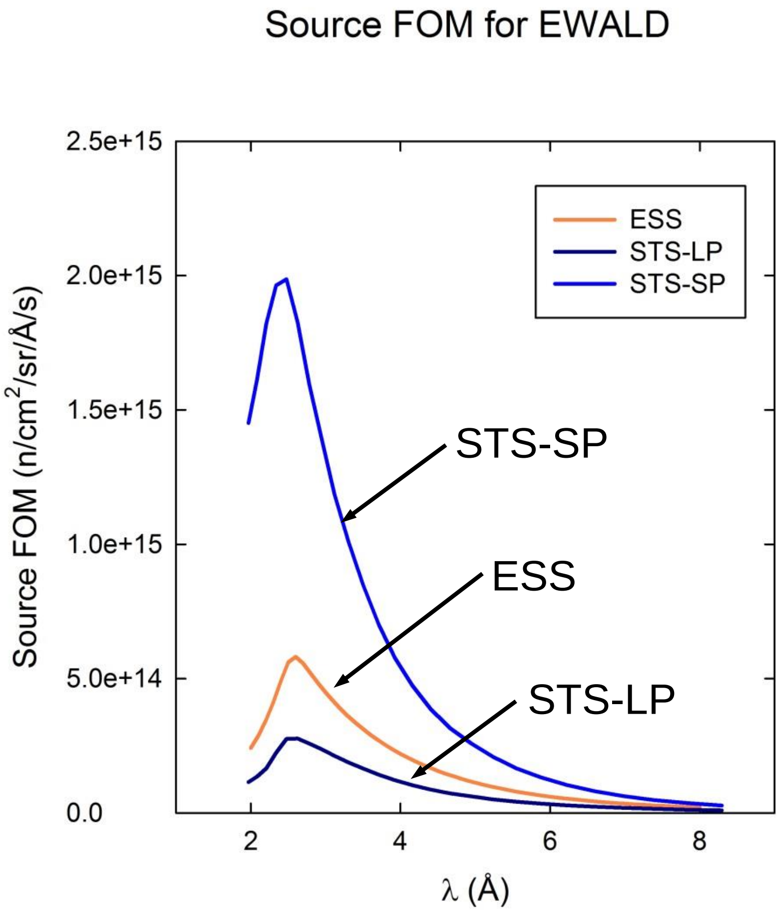
Case Study: EWALD – macromolecular single crystal diffractometer

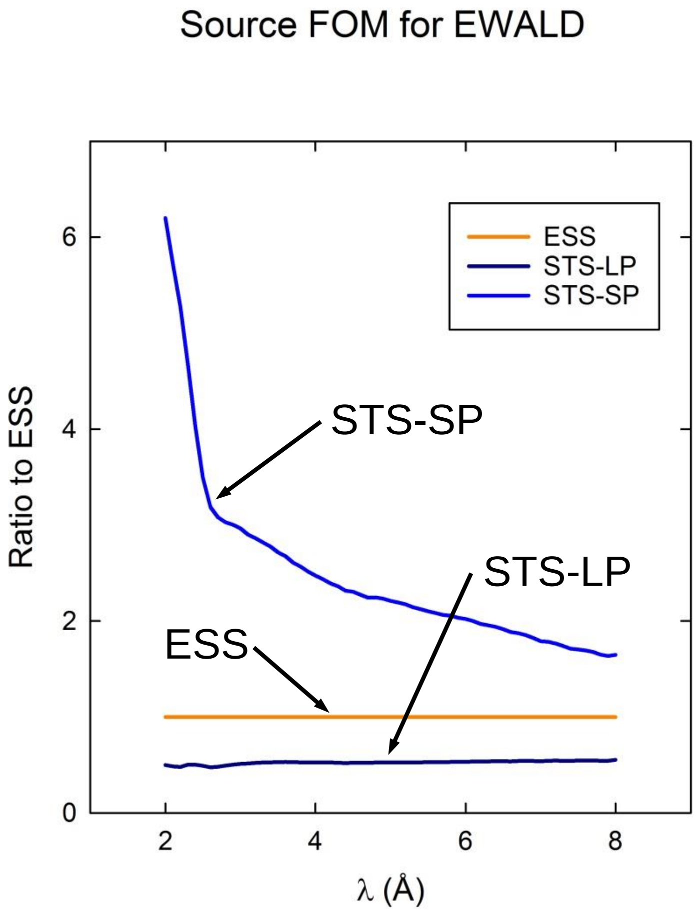
- Desired resolution is $\delta d/d = 0.0015$; desired wavelength resolution is $\delta\lambda/\lambda = 0.0011$

$$\frac{\delta d}{d} = \sqrt{\left(\frac{\delta\lambda}{\lambda}\right)^2 + (\text{geometric})^2} \qquad \frac{\delta\lambda}{\lambda} = \text{geometric} \qquad \frac{\delta d}{d} = \sqrt{2}\,\frac{\delta\lambda}{\lambda}$$

- Bandwidth required for a complete data set is $\Delta\lambda = 4$ Å, ability to use λ between 2 Å and 8 Å
- TDR: EWALD at 90 m from high brightness coupled moderator
- At 14 Hz ESS, EWALD would be at 64 m (90 x 10/14)
  - Narrower pulse shape implies less neutrons/pulse, but you get 14/10 more pulses – flux on sample evens out
- STS-LP effective pulse width (80% of max) = 710 usec, at 5.5 m chopper able to pulse shape $\Delta\lambda = 0.5$ Å/chopper pulse so need chopper system able to deliver x8 wavelength multiplication to deliver $\Delta\lambda = 4$ Å, and fill counting frame

EWALD performs best at a short proton pulse STS





- Similar calculations (with modified FOM) will be done for other instruments

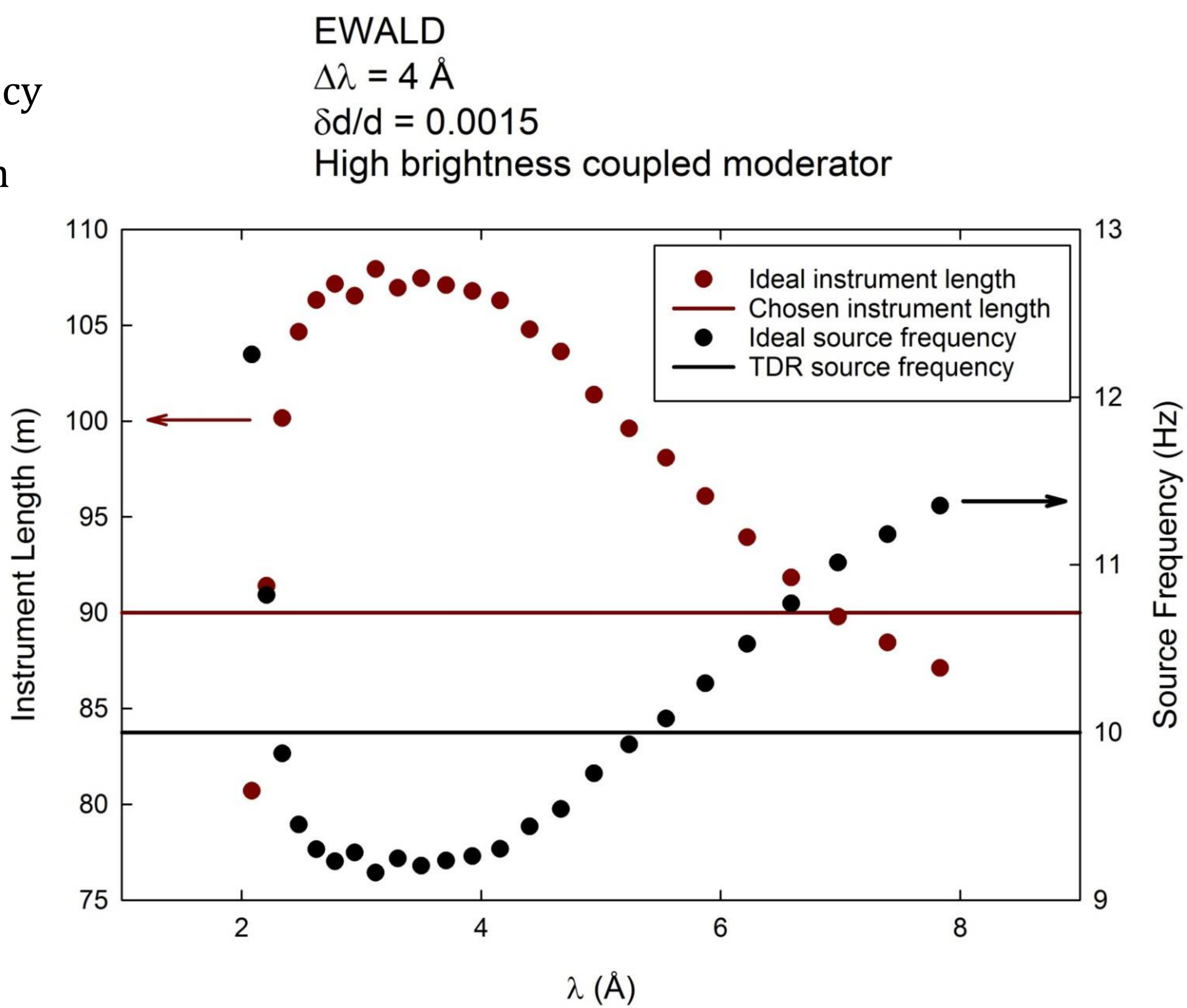
EWALD meets its science mission at 10 Hz

Bandwidth: $\Delta\lambda = \dfrac{3956}{\nu \cdot L}$

where ν = source frequency

and L = instrument length

Resolution: $\dfrac{\delta\lambda}{\lambda} = \dfrac{3956}{L}\dfrac{\delta t}{t}$



Summary

- NAB 2013 recommended a short-pulse STS for reasons that are still valid
- Development of a 20 instrument planning suite allows for deeper analysis of source pulse length optimization
  - Instrument-class specific figures-of-merit and relative value of pulse shapes needs evaluation
  - How to assign relative merits of instrument types? e.g. Is SANS a higher emphasis than cold neutron spectroscopy?
- With some caveats, instruments that best perform at 20 Hz can also operate on 10 Hz source (pulse suppression, split $\Delta\lambda$ across two source frames)
  - Backgrounds, signal-to-noise, kinetics, additional neutron choppers
- STS repetition rate will affect the operational parameters of the first target station within an acceptable range
  - 2 MW FTS at 50 pulses/sec receives 40 kJ per pulse
  - At full energy (47 kJ after PPU) per pulse, FTS at 40 pulses/sec is 1.88 MW

Questions?

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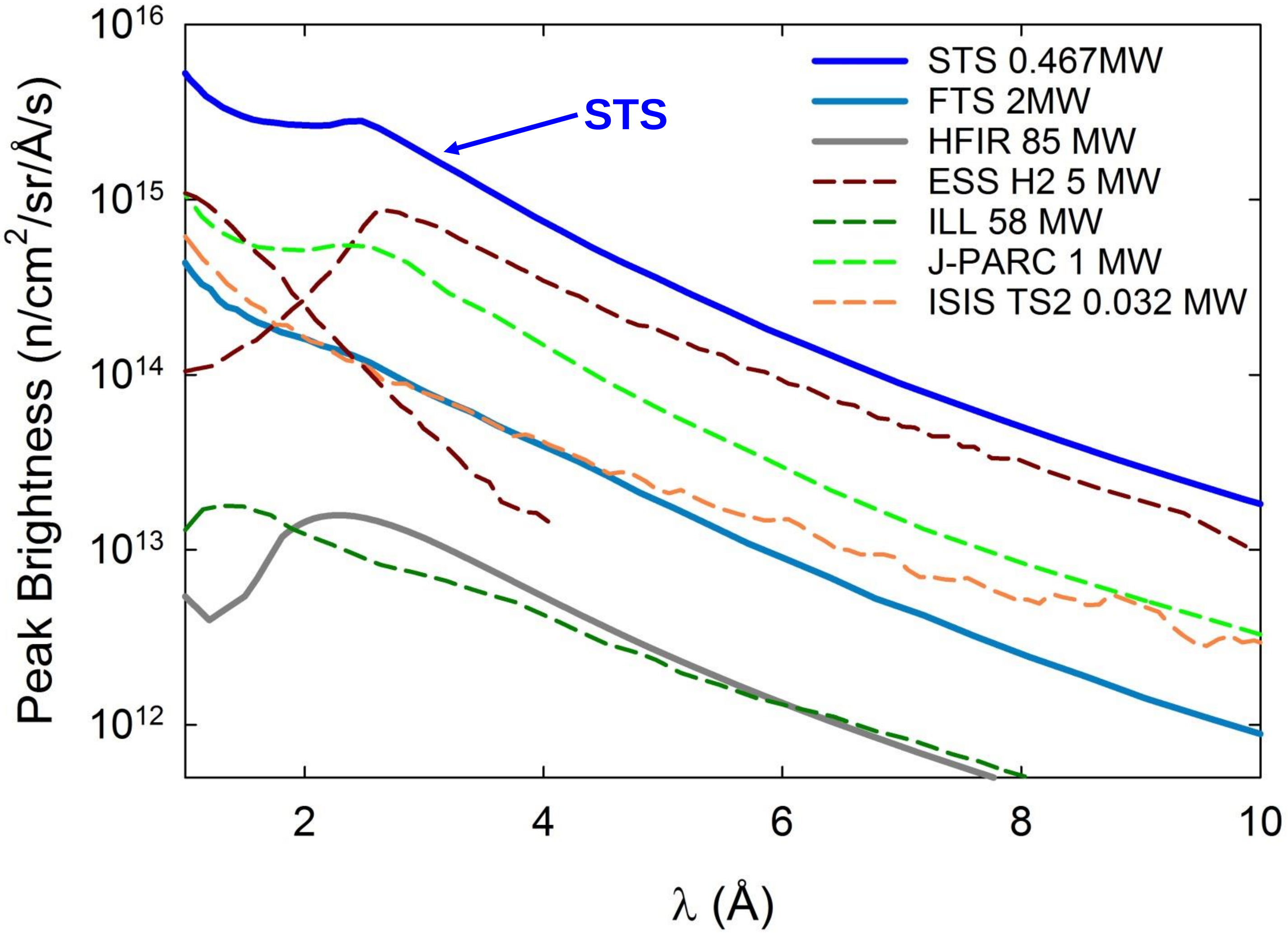
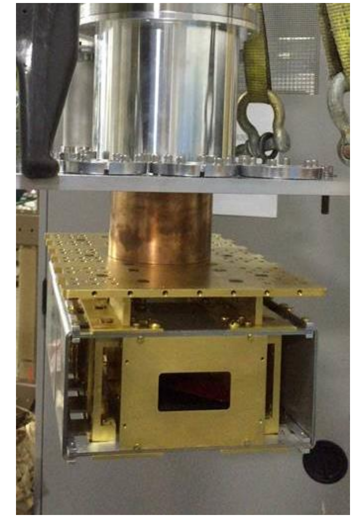
Backup Material

STS is a 4th generation source that will provide world's highest peak brightness neutron beams

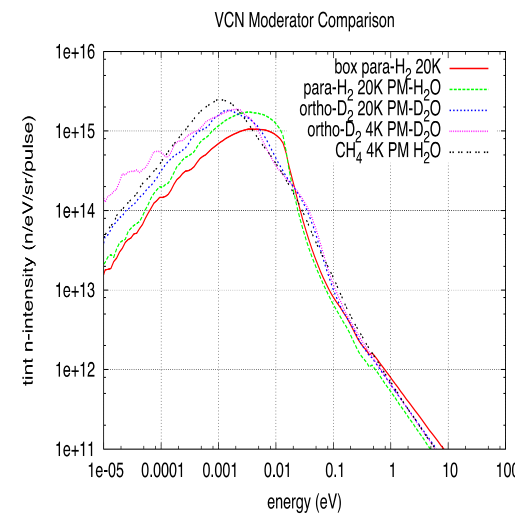


Two recent workshops explored opportunities for novel concepts and very cold neutrons at STS

- Novel Concepts for STS – April 25-26, 2016
  - ≈25 participants organized around 5 transformative opportunities for discovery science identified in November 2015 BESAC report.
  - Neutron imaging has made dramatic progress with advances of new methods such as grating-based phase-contrast radiography.
  - Energy dispersive reflectometry might significantly reduce substrate background.
  - Automated data analysis and the application of data analytics and machine learning will be needed.
  - Continue to explore advanced moderator concepts (e.g. beryllium filter/reflector) to boost cold neutron production.
- Opportunities for Very Cold Neutrons at STS – April 27-28, 2016 (report is released)
  - ≈30 participants explored methods and motivation to significantly boost the production of 10 to 40 Å neutrons
  - Feri Mezei – “The science case for very cold neutrons is beyond compelling.” (nuclear physics, cold imaging (sub-micron), Larmor spin precession)
  - Optimize a conventional p-H_2 moderator for intensity in this λ-range
  - Explore new materials that take more advantage of lowered moderator temperature.



New devices for implementing Larmor techniques – Wollaston prism tested at HFIR F. Li, et al.)



VCN performance - F. Gallmeier