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EUROPEAN SPALLATION SOURCE

Optimization of neutron beam extraction at ESS

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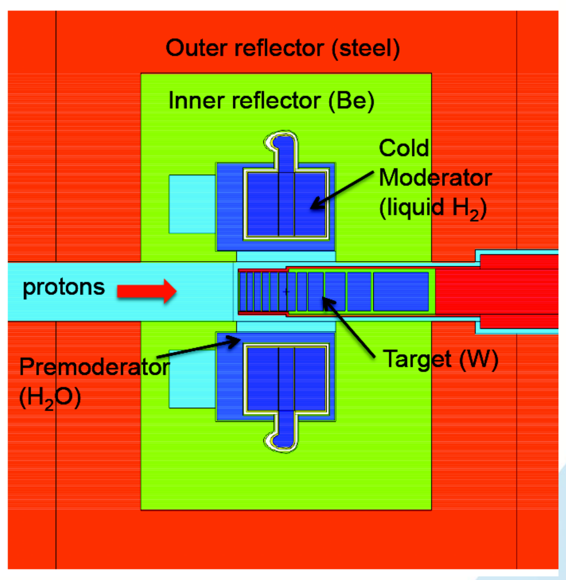
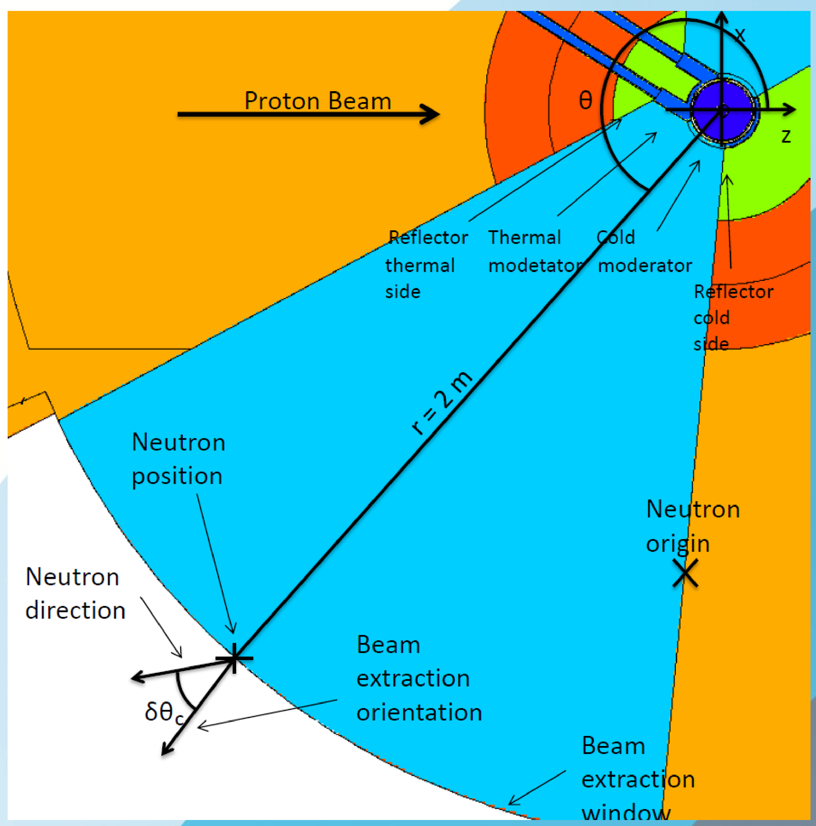
ESS

At the European Spallation Source (ESS) a 5 MW beam of 2.5 GeV protons impinging a tungsten target will produce neutrons by spallation.

A moderator-reflector system is situated above and below the W-target. Here neutrons will be cooled to meV range energies and emitted towards the experiments in four 60° windows. The advanced coupled moderators and the high power proton beam enables ESS to reach unprecedented cold and thermal neutron intensities.



Vertical [1] (above) and enlarged horizontal (right) cross section of ESS target-moderator-reflector system.

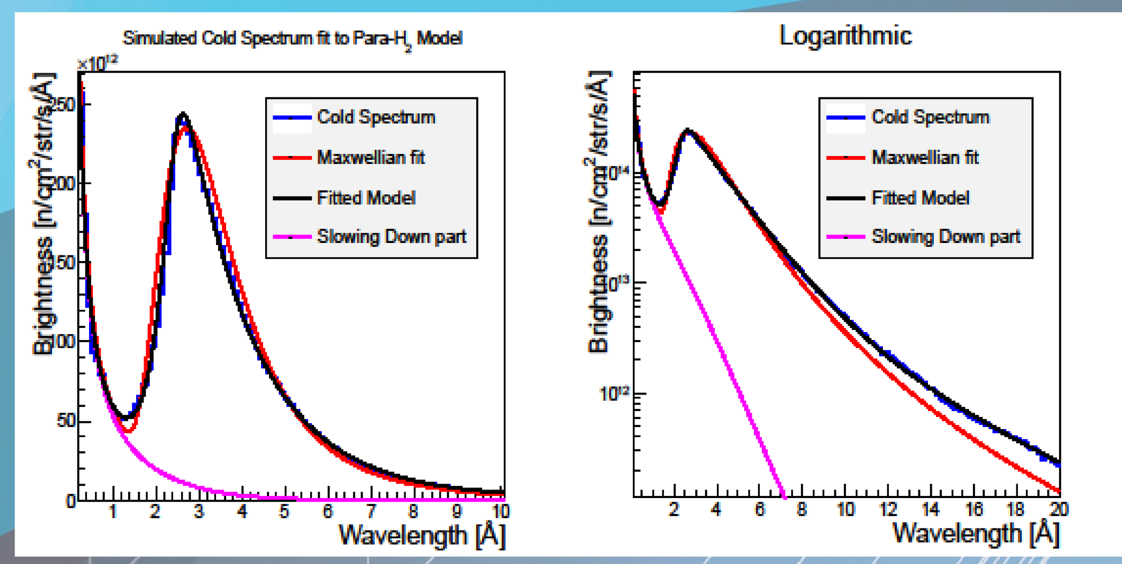


The moderator-reflector system consists of a thermal light water moderator (an extended premoderator) and a cold para-hydrogen moderator surrounded by an inner reflector made from beryllium and an outer reflector made from steel.

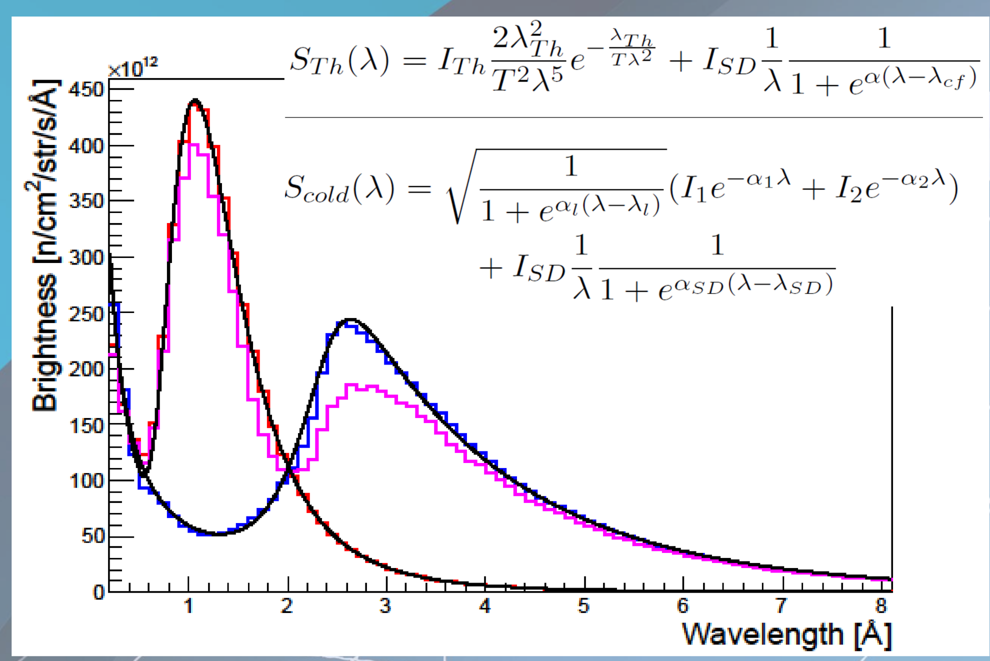
Thermal and para-H_2 spectra

As neutrons slow down some are emitted from the moderator-reflector system, before they thermalize, these are known as the slowing down neutrons. The slowing down spectra falls off as 1/λ with a cutoff near the thermal region (around λ>0.5 Å for thermal moderator and around λ>2 Å for the cold moderator).

For ordinary moderators the thermalized neutrons follow a Maxwellian distribution. Therefore the thermal spectra can be described by the sum of a Maxwellian and the slowing down function: STh(λ).



Shown in blue MCNPX simulations (peak brightness [2]), and comparison between to $S_{cold}(\lambda)$ (black) and a Maxwellian (red) fit, both with same slowing down function (purple).

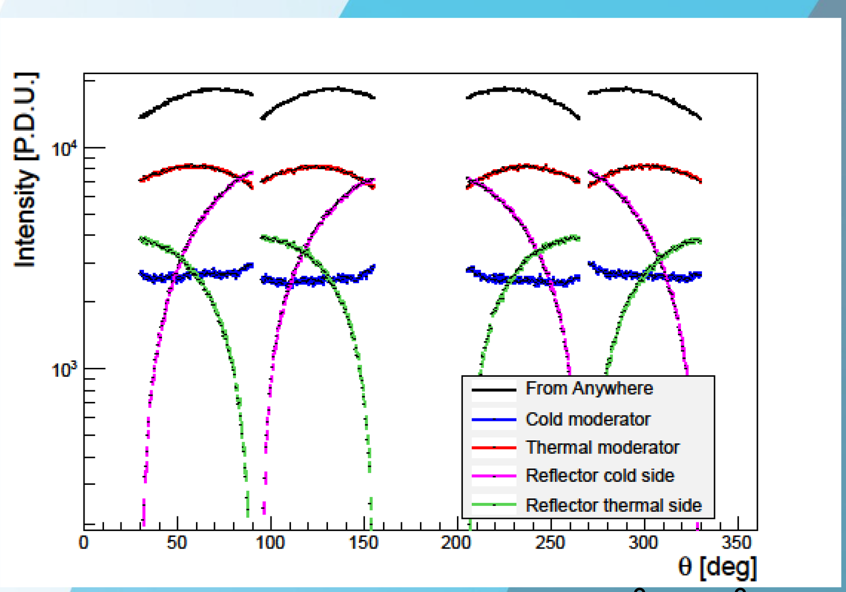


Expected peak brightness at ESS [2]. Red and blue histograms shows the MCNPX simulations for thermal and cold moderator respectively. Fit to the two shown functions is shown in black. The purple histogram is an example of bispectral extraction [3].

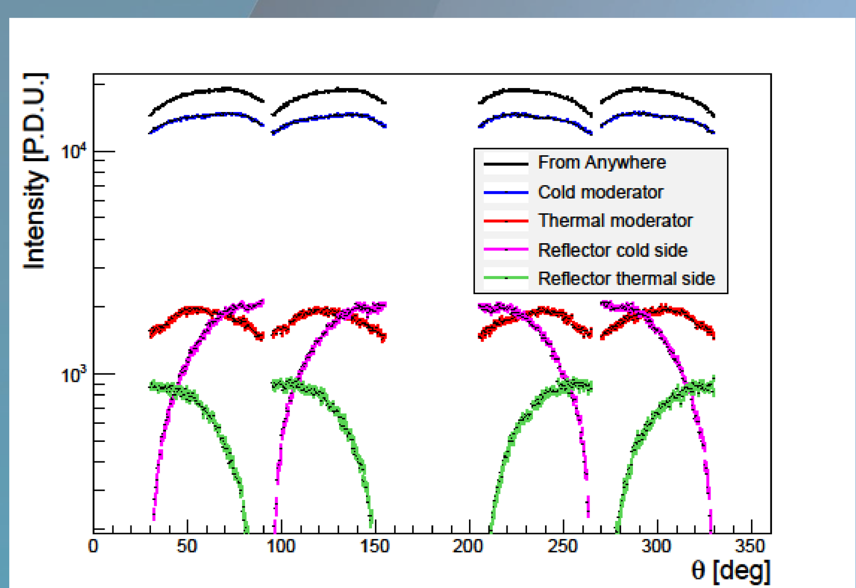
Due to the energy of the para-hydrogen spin singlet state (15.2 meV), scattering becomes inaccessible for neutrons with wavelengths above ~2.3 Å, which results in the moderator becoming transparent before the thermal equilibrium (20° K) is reached – therefore the spectrum is not a Maxwellian.

In this study an analytical description of the para-hydrogen spectra has been developed. The analytical formula Scold(λ) (seen on the left) describes the leaking of cooling down neutrons from a cold para-hydrogen moderator.
(fit parameters can be obtained from the author on request).

Neutron extraction geometry



Origin of thermal neutrons ([0.5 Å;2.0 Å])

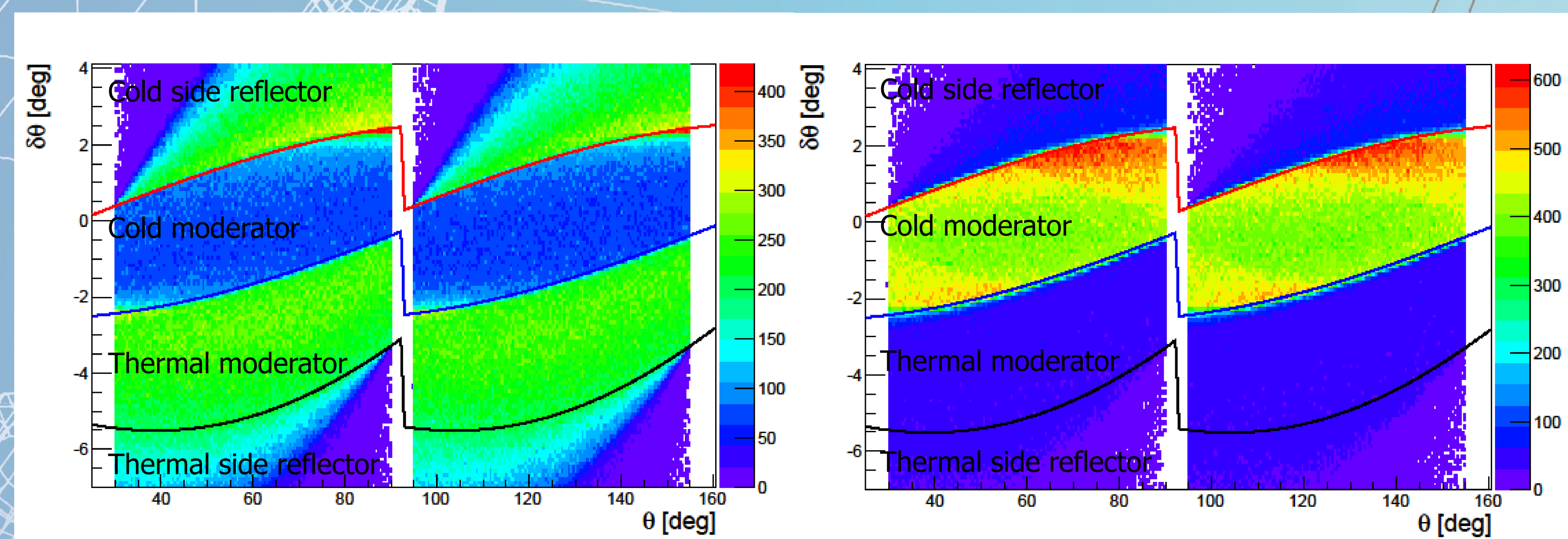


Origin of cold neutrons (λ>2.0 Å)

Shown above are the intensities of cold and thermal neutrons from different regions of the moderator-reflector system and from all four 60° (in θ) extraction windows. 70% of cold neutrons originate from the cold moderator. Thermal neutrons originate mainly from the thermal moderator and the reflector at the cold moderator side of the moderator-reflector system (more details in the 3 boxes below), some instruments at certain positions will have more thermal neutrons from the reflector than form the moderator.

At ESS the neutron spectra as well as both position and intensity of hot spots strongly depend on the position of an instrument in the 60° beam extraction window. Depending on their requirements instruments should chose their position carefully and heavily consider which direction to align their guide. Understanding the details of the extraction geometry, might win an experiment as much as a factor two in intensity at the sample in certain cases.

Each extraction instrument at ESS will be given a slot spanning 5° in θ (horizontal) and 12 cm in y (vertical) in one of the four 60° windows situated 2 m from the center of the moderator reflector system. The scope of this study aims at analyzing the details of neutrons which arrive on this 2 m extraction surface.



Direction of flight (δθ) of thermal (left) and cold (right) neutrons viewed from different angles (θ) in the extraction window.

The neutrons can be imaged through a pinhole at different angles of extraction (θ) revealing their direction of flight with respect to the direction of the guide instrument: δθ (known to instrument people as beam divergence).

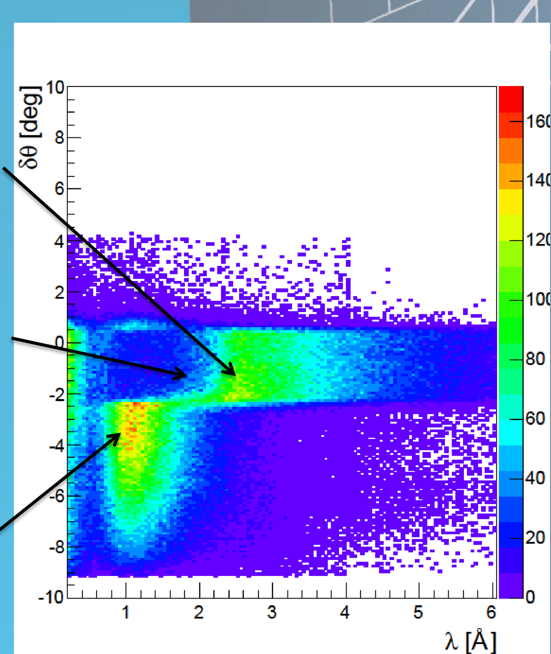
Note (in the figures above) the clear structure in the cold neutron distribution, this is an artifact of the advanced properties of para-hydrogen: the cold neutrons are leaked freely.

Cold side extraction slot

Most cold neutrons near the thermal moderator side of the cold moderator.

There is a narrow hotspot of semi-cold neutrons.

Largest range of origin of thermal neutrons.

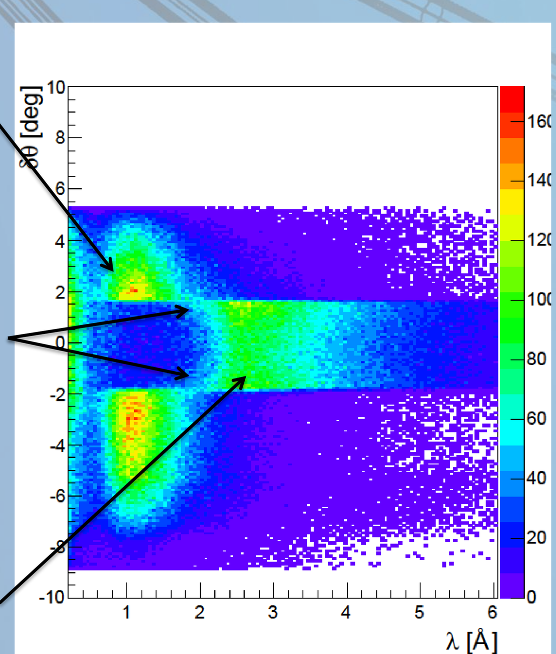


Central extraction slot

Some thermal neutrons form cold side reflector, (still more from the thermal moderator).

Almost no semi-cold neutrons ([1.8 Å;2.2 Å] is empty).

Cold neutron origin distribution is most "flat".

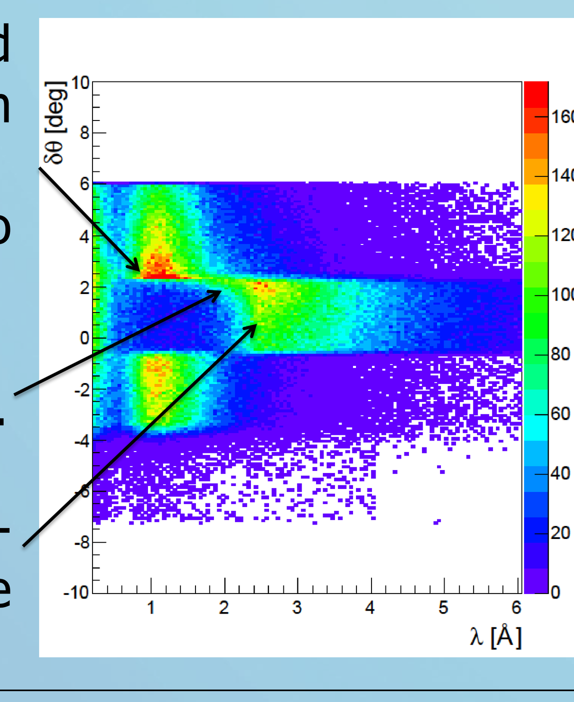


Thermal side extraction slot

More neutrons from cold side reflector than from thermal moderator.
Mainly from very close to the cold moderator.

Most semi-cold neutrons.

Clear cold neutron hot-spot at the reflector side of the cold moderator.



[1] S. Peggs, editor. ESS Technical Design Report. April 2013. [2] L. Zanini. Source Brightness Baseline Change, May preliminary, 2013. [3] F. Mezei. Private communications, 2013.

ICNS, Edinburg, July 2013 - presented by F. Mezei