Update to ESS Moderators, version 19/9/2016

To be lodged in CHESS as follows:
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An update has taken place to the ESS moderator-reflector baseline [1], resulting in a change in the source brightness and viewable width. The main change is a move from the "butterfly 2" to the "butterfly 1" geometry, as sketched in Fig. 1 below. The change is applied equally to the top and bottom moderator assemblies.

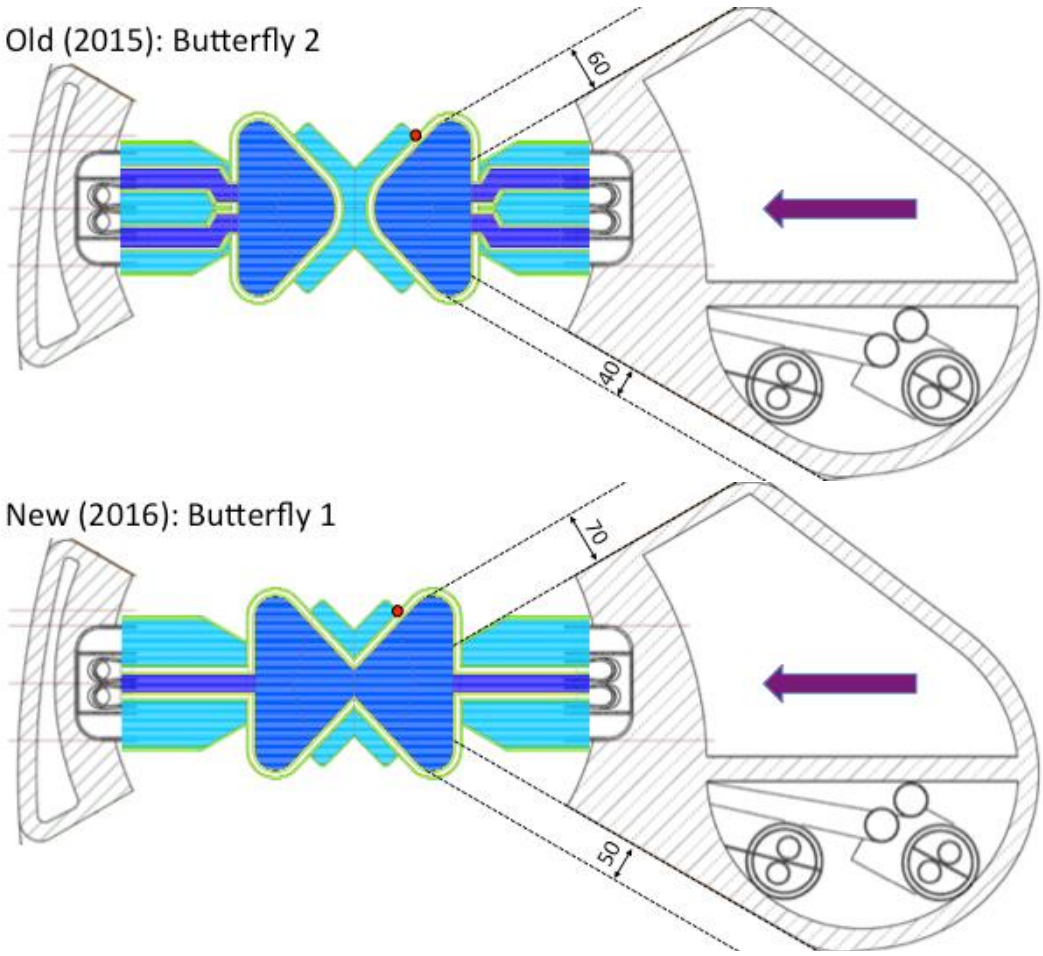

Fig. 1 Butterfly 2 (upper frame) and Butterfly 1 (lower frame) geometries. The direction of the proton beam is indicated by the purple arrow. The water volumes are shown in light blue and the para-H_2 volumes in dark blue. The green lines are the Al walls of the moderator structure. The grey and hatched areas indicate components in the outer reflector which define the viewable moderator width. The viewable projected width of the cold moderator is indicated for beamports N1 and E1. The focal point for the North sector is indicated by the red dot.

There are a number of motivations for this change:

- The balance of the viewed width of the thermal (up to 140 mm) and cold (60-80 mm) was skewed to the detriment of the cold moderators

- The 4 edge beamlines (at 30° and 120° to the proton beam) were limited by structures in the monolith that will not be changed during the lifetime of the facility
- The footprint of the moderator assembly was too large compared with the neutron production hotspot in the target
- Many thermal instruments had difficulty in viewing the central, most intense part of the thermal moderator, due to its large distance (73 mm along the proton beam) from the moderator focal points.
- Instruments near the edges of the sectors will benefit from an increase in cold brightness, due to the increased projected depth of para-H_2 at those angles.

The details of the geometry and neutronics calculations are given in [2]. In order to minimise the impact on the neutron optical design of the instruments, the change of moderator design is associated with a change of the beamline origins (the "focal points") of the instrument beamports. Each focal point has been translated by 21 mm along the direction of the proton beam, towards the target centre. The new focal points are thus at (54mm, 89mm) [3]. For most instruments, the change of moderator geometry thus has no impact on the beam optics.

The main impact on the instruments of the geometry change, and a key motivation in making the change, is in the projected widths of the cold and thermal sources, which are shown in Fig. 2 below, as a function of beamport angle.

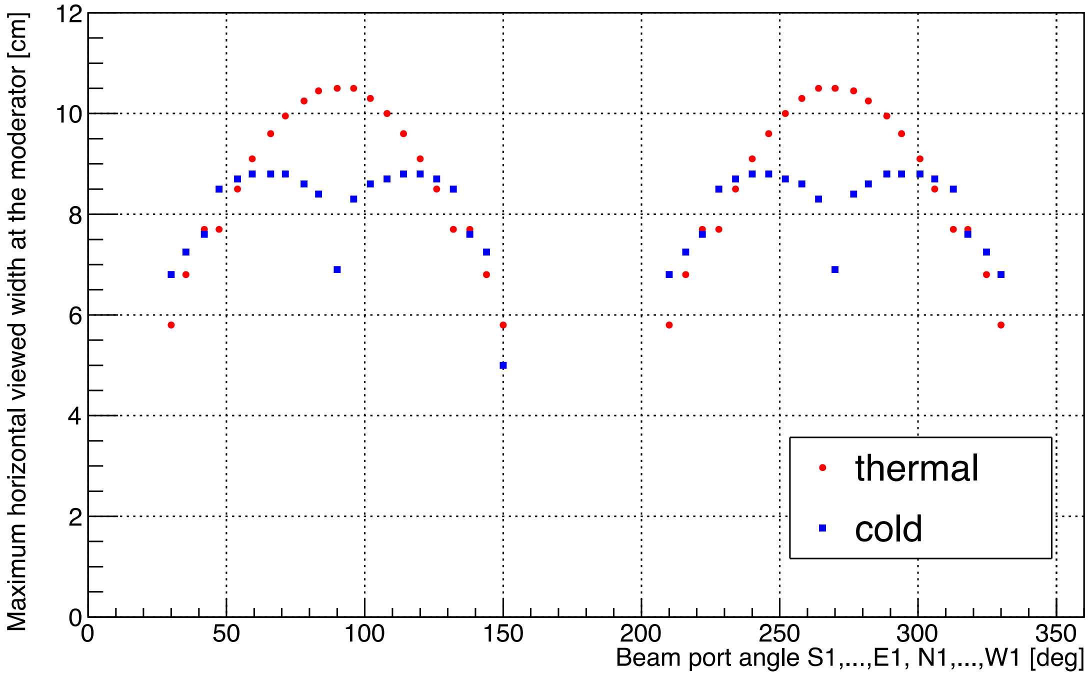

Fig. 2 Projected full width of moderators for all beamports from [2]. The angle runs in a counter-clockwise direction with zero pointing along the proton beam, such that the beamports are shown starting with S1 and ending with W1.

As can be seen in Fig. 2, the angular variation of the projected width of the moderators is now much better matched between the cold and thermal moderators; the cold widths have increased by about 1 cm, while the thermal widths have decreased by about 2.5 cm, resulting in cold and thermal widths which are much more similar than before. The increase in the width of the cold moderator is important, since cold instruments generally can use more phase space than thermal instruments, due to the greater angular acceptance of neutron guides for cold neutrons.

The angular dependence of the brightness of the top (3 cm) moderator is shown in Fig. 3 below

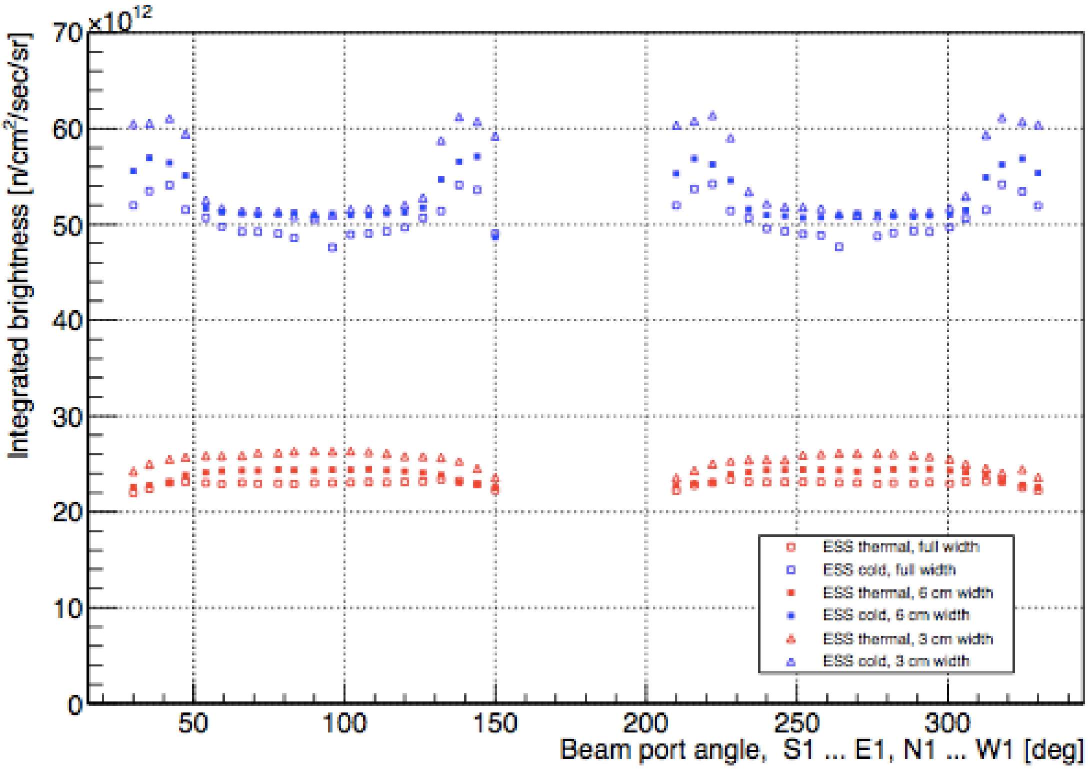

Fig. 3 Energy-integrated time-average moderator brightness from [2]. Cold spectra are integrated between 0 and 20 meV, thermal spectra between 20 meV and 100 meV. The x-axis is the same as in Fig. 2. Three brightness data sets are shown for both the cold and the thermal moderators: (1) averaged over the full projected width shown in Fig. 2 (2) averaged over a 6cm wide surface adjacent to the focal point, shifted to start within the moderating volume, as defined in [2], and (3) averaged over the most intense 3cm width.

The brightness numbers have overall decreased by about 30% for the thermal moderators and 20% for the cold moderators, compared to ref. [1]. This is due to the transition from a physics model to an engineering model used in the calculations, performed in parallel to the evolving engineering design of the target station. A detailed modelling of the target-moderator-reflector assembly according to the engineering design of the moderators and reflectors was performed. Design changes in the target, which impacted on the brightness, were also incorporated, such as the reduction of the effective density of tungsten in the target, in order to ensure good flow of the helium gas coolant, and the increased distance between the target wheel and pre-moderators, for safe operation of the target. A full description of the MCNP model can be found in Ref. [2].

Another effect to take into account, is that the brightness numbers for the thermal source shown in Fig. 3 are now defined for a more realistic source width than before. The previous brightness numbers tended to overstate the thermal brightness by including the central, most intense part of the thermal, which is often not accessible, due to its distance from the beamport focal point.

The spectral brightness, averaged over all beamports is shown in Fig. 4 below.

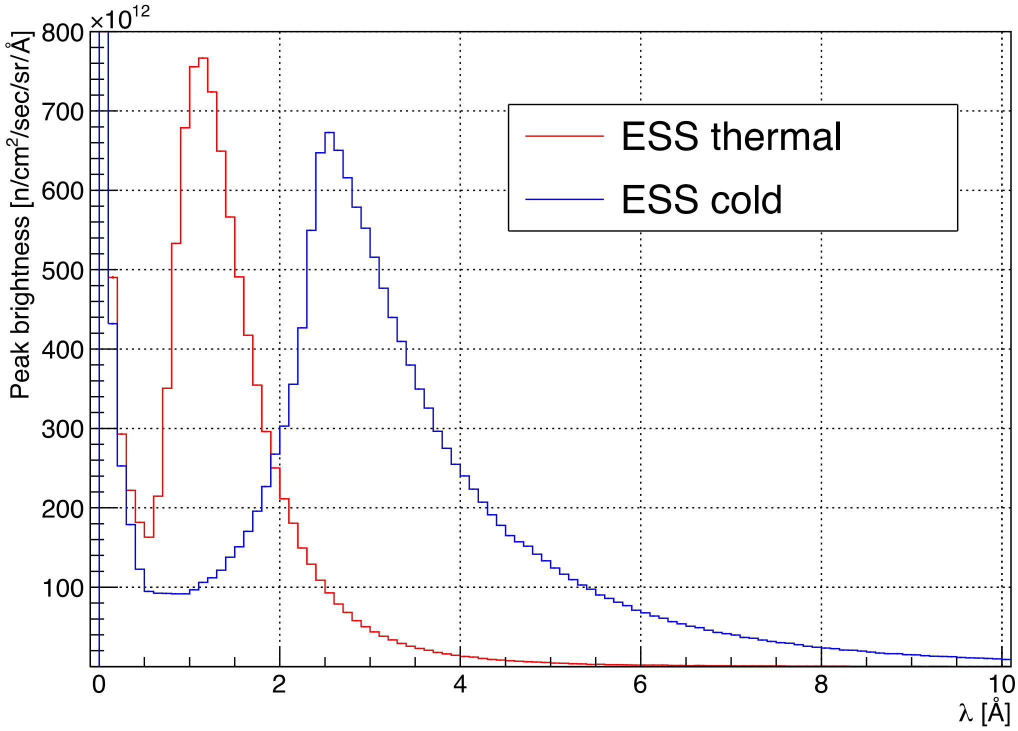

Fig. 4 Peak spectral brightness for the updated thermal and cold moderators from [2], averaged over all beamports and over a 6cm width, as defined in [2]. We recall that the peak brightness is 25 times higher than the time-average brightness [1].

Engineering details of the new moderator geometry are extrapolated from the butterfly 2 moderator, currently being built. It is to be expected that the spectral brightness curves will change by of the order of 10% when new calculations are performed. This is within the absolute uncertainties of the brightness curves of about 15%, which includes uncertainties related to models and libraries used in the calculations [2].

The geometry and brightness data presented here have been implemented in the most recent version of the McStas ESS source component ESS_butterfly.comp, released as an updated component library for McStas 2.3. The following features are worth highlighting:

- The brightness data are still based on last year's MCNP calculations, based on the Butterfly 2 geometry. As a result, the spatial variation of the brightness across the moderator face should be considered to have an uncertainty of the order of 10%. Detailed information on the horizontal spatial brightness variation can be found in [2]. The spectral shape [4] has been checked and has not changed significantly.
- A scaling factor has been introduced to in order to account for the decrease in brightness since 2015. To accommodate the influence of the changed geometry, this scaling factor has been applied independently for the cold and thermal contributions and is beamline dependent. It is adjusted to agree with the spectrally-integrated 6cm width data shown in Figure 3.

- To allow future user adjustments of source brightnes, the scalar parameters c_performance and t_performance have been implemented. For now, we recommend to keep these at their default value of 1.0.
- The geometry has been updated to correspond within about 2 mm to the geometry described here. This has been done by ensuring that the position and apparent width of the moderators correspond to Figure 2, which has been derived from current MCNP butterfly 1 model.
- The beamport is now defined directly by its sector and number (e.g. "W" and "5"), rather than giving the angle, as before. Figure 5 below shows the geometry of the moderator2, beamport insert and beamline axis for beamline W5. Since the underlying data is still from last year's MCNP run, when the brightness was calculated at 10° intervals, this means that the spectral curve for the nearest beamport on the grid 5°,15°,25°,35°,45°,55° is used. The use of this grid has no effect on the accuracy of the geometry or brightness because of the above-mentioned beamline-dependent adjustments to the brightness and geometry. See [5] for details.
- As before, the beamports all originate at the focal point of the sector (see Fig. 1). The beamline will in almost all cases be horizontally tilted in order to view the cold or thermal moderator, which should be done using an "arm" in McStas.

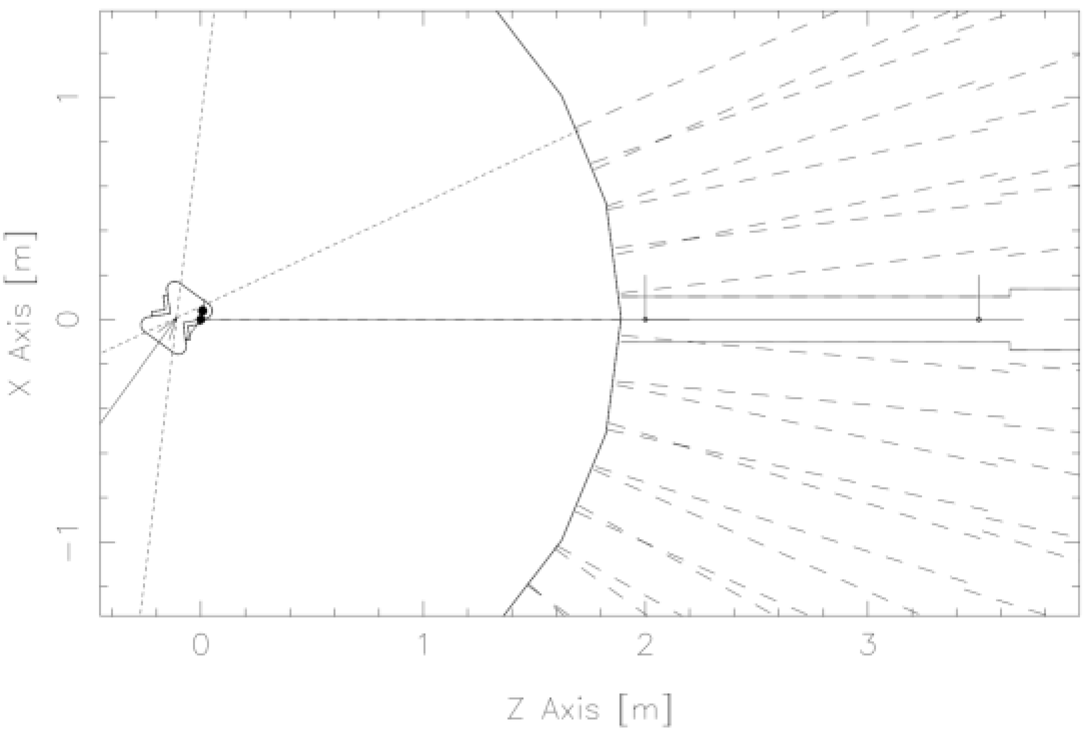

Figure 5: McStas illustration of monolith, moderators and beamline with choice of sector=W beamline=5. See [5] for other examples.

The full set of component parameters is listed in Table 1 below, extracted from the component online documentation.

Input parameters

Parameters in **boldface** are required; the others are optional.

Name	Unit	Description	Default
sector	str	Defines the 'sector' of your instrument position. Valid values are "N","S","E" and "W"	"N"
beamline	1	Defines the 'beamline number' of your instrument position. Valid values are 1..10 or 1..11 depending on sector	1
yheight	m	Defines the moderator height. Valid values are 0.03 m and 0.06 m	0.03
cold_frac	1	Defines the statistical fraction of events emitted from the cold part of the moderator	0.5
target_index	1	Relative index of component to focus at, e.g. next is +1 this is used to compute 'dist' automatically.	0
dist	m	Distance from origin to focusing rectangle; at (0,0,dist) - alternatively use target_index	0
focus_xw	m	Width of focusing rectangle	0
focus_yh	m	Height of focusing rectangle	0
c_performance	1	Cold brilliance scalar performance multiplicator c_performance > 0	1
t_performance	1	Thermal brilliance scalar performance multiplicator t_performance > 0	1
Lmin	AA	Minimum wavelength simulated	
Lmax	AA	Maximum wavelength simulated	
tmax_multiplier	1	Defined maximum emission time at moderator, tmax= tmax_multiplier * ESS_PULSE_DURATION.	3
n_pulses	1	Number of pulses simulated. 0 and 1 creates one pulse.	1
acc_power	MW	Accelerator power in MW	5

Table 1: Screenshot of parameter table from McStas online docs for the new component ESS_butterfly.comp.

It should be noted that, due to the model fitting used to create smooth brightness curves from the inherently noisy MCNP data, the active height of the moderators is effectively truncated to their design height of 30 mm and 60 mm. This is a good approximation for the cold moderators, but understates the height of the thermal source which contains significant brightness extending to about 5 mm both above and below the moderator face itself.

This truncation, as well as the uncertainties relating to the spatial variation of the source brightness, will be addressed in the next release of the McStas source component foreseen in early November 2016. This will allow more accurate, but slower calculations. It is expected that the current source component will be sufficient to allow fine-tuning of guide geometry to within less than 10% of the performance optimum. Until the update of the McStas source component, fine-tuning of the beam extraction can be double-checked with MCNP calculations from the Neutronics groups, if needed.

As an approximate solution, the ESS source component in Vitess, describing the butterfly moderator, has adjusted its spectral brightness by a factor of 0.75 to account for the reduction in brightness compared to [1].

As a final point, it should be noted, that since the engineering design of the moderator-reflector assembly has already been completed in order to allow timely installation, the moderators which will be installed for first neutrons in 2019 will follow the 2015 (Butterfly 2) geometry. The monolith and beamport inserts, however, will be designed for the focal points corresponding to the new (Butterfly 1) geometry. As a consequence, during the first few years of operation, the spectra delivered to the cold instruments will include a small thermal component. A future moderator-reflector assembly will be based on the new (Butterfly 1) geometry, so that the beam available for user operations is fully optimal.

References

1. New ESS Moderator Baseline, Ken Andersen, ESS-0068290
2. Description and performance of the new baseline ESS moderators, Luca Zanini, ESS-0068256
3. Interface Control Document Moderator-NSS, ESS-0032315.3
4. Functional description of the thermal and cold brightness distribution at ESS, T. Schönfeldt, K. Batkov, E.B. Klinkby, B. Lauritzen, G. Muhrer, A. Takibayev, P.K. Willendrup, L. Zanini, submitted to Nucl. Instr. Meth. A (2016)
5. See benchmarking figures at http://ess_butterfly.mcstas.org