EUROPEAN
SPALLATION
SOURCE

Full Brightness Phase-space

Using SSW and ROOT to study advanced brightness features for the ESS.

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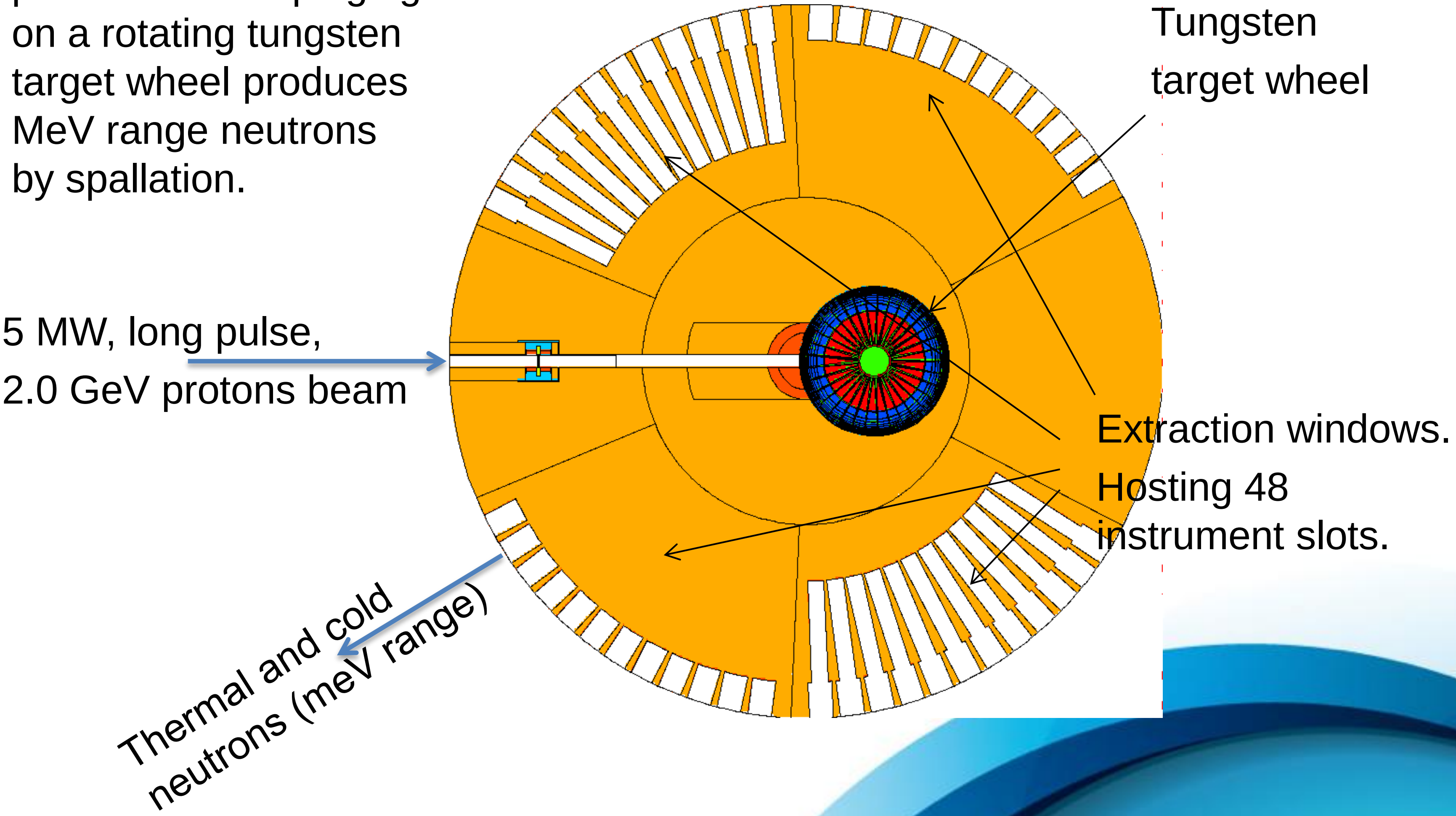
DTU Nutech
Center for Nuclear Technologies

ESS target station

ESS: A 5 MW, 2.0 GeV proton beam impinging on a rotating tungsten target wheel produces MeV range neutrons by spallation.



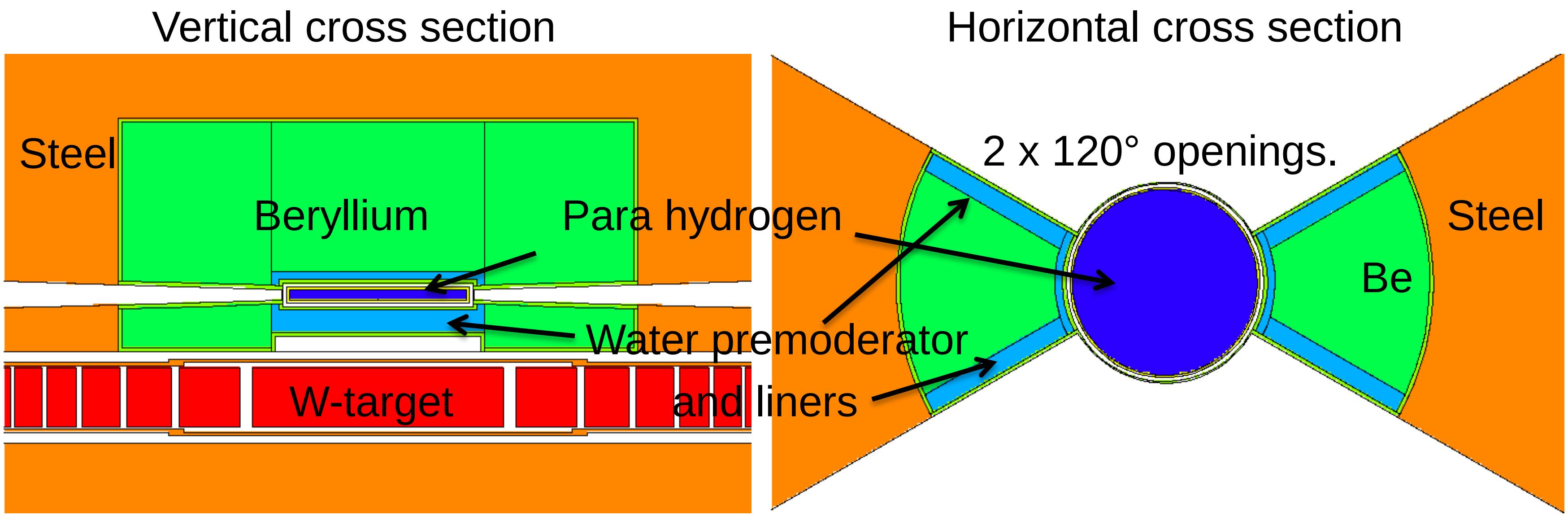
Tungsten
target wheel

5 MW, long pulse,
2.0 GeV protons beam

Extraction windows.
Hosting 48 instrument slots.

Thermal and cold
neutrons (meV range)

ESS moderator design


Vertical cross section

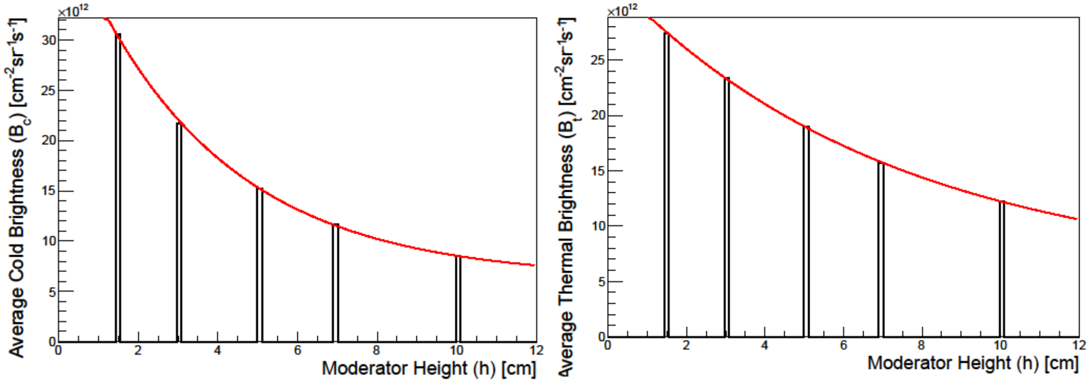
Horizontal cross section

ESS will have two moderator systems, one is yet undecided (see the talk of K. Batkov), the other will be:

- Cold: para hydrogen at 20 K.
- Flat: around 3 cm high.
- Bispectral: 2 thermal water liners (bispectral extraction)
- Serves all instruments: two openings of 120°

Flat moderator brightness ESS expectation

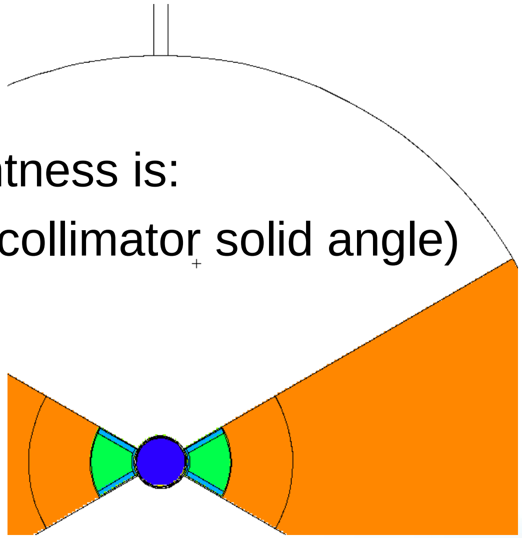
Especially for cold neutrons the flat moderator yields a huge brightness increase.



$$B_c(h) = 3.63926 \times 10^{13} e^{-.278203h} + 6.28705 \times 10^{12}$$

$$B_t(h) = 2.70429 \times 10^{13} e^{-.140318h} + 5.58627 \times 10^{12}$$

f5:n tally (flux)

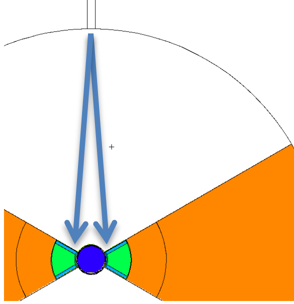


Collimator

Brightness is:

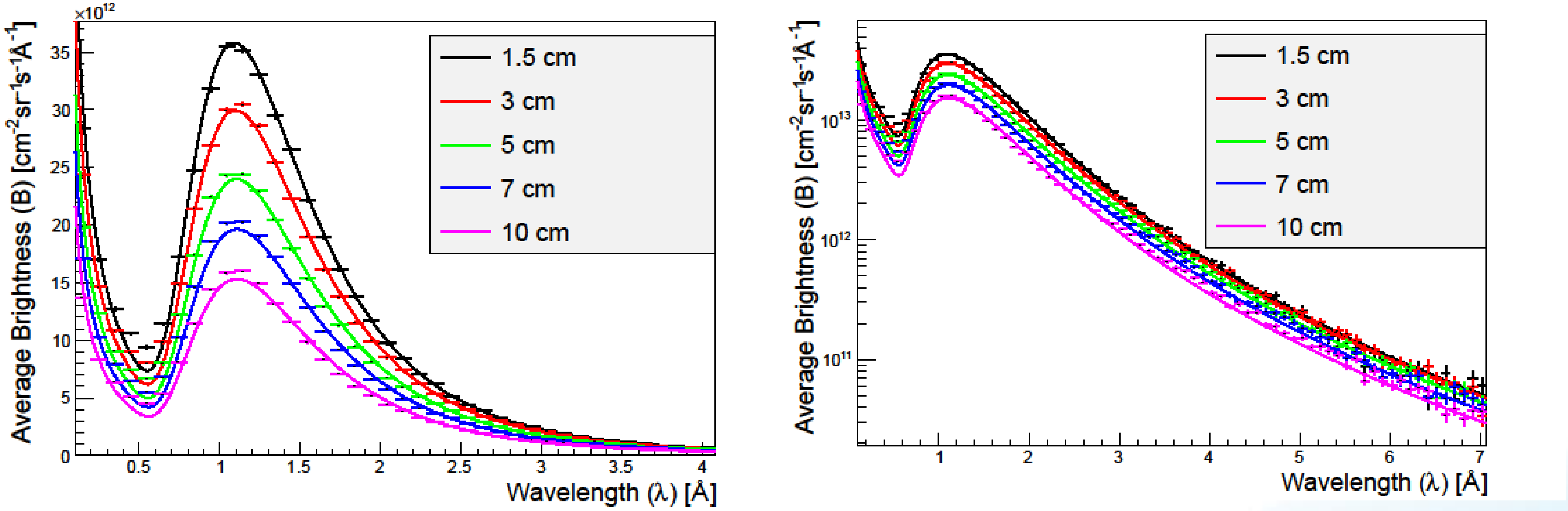
flux/(collimator solid angle)

Thermal spectrum

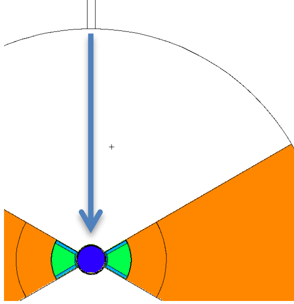


The brightness spectrum, with fits to a modified thermal Maxwellian:

$$B_t(\lambda) = I_t \frac{2k_{Th}^2}{T^2\lambda^5}\lambda^{\chi} e^{-\frac{k_{Th}}{T\lambda^2}} + I_{SD}\frac{1}{\lambda}\frac{1}{1+e^{\alpha(\lambda-\lambda_{SD})}}$$



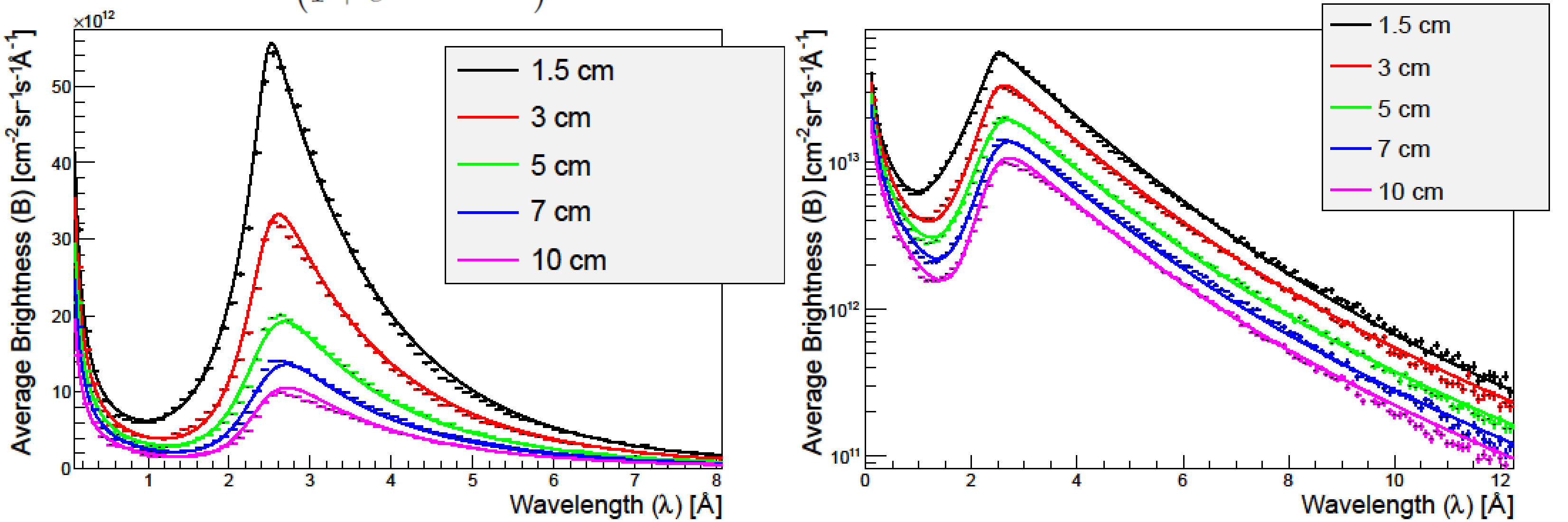
Cold spectrum



Para hydrogen is not a thermalizing medium, hence the spectrum cannot be described by a Maxwellian.

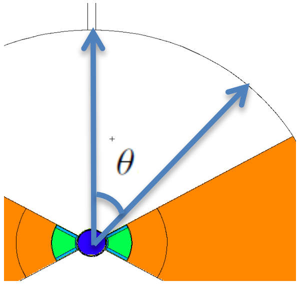
A good model for the para H_2 spectrum is:

$$B_c(\lambda) = \frac{1}{\left(1+e^{\alpha_{cf}(\lambda-\lambda_{cf})}\right)^{\frac{1}{\gamma}}} I_c\left(e^{-\alpha_1\lambda}+\kappa e^{-\alpha_2\lambda}\right) + I_{SD}\frac{1}{\lambda}\frac{1}{1+e^{\alpha_{SD}(\lambda-\lambda_{SD})}}$$



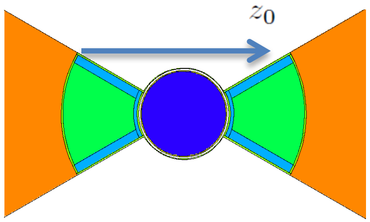
Note that this function also fits very well to the TDR model, which is quite different geometrical.

Brightness definition



Brightness is nothing but a coordinate transformation of the common phase space coordinates: $q_x, q_y, q_z, p_x, p_y, p_z$

And: $\frac{d\rho}{dt} = 0$ (this is the single most important equation for large scale neutron facilities)

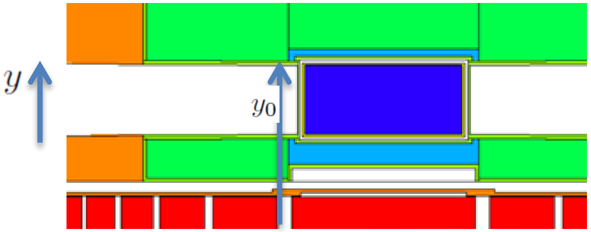


In the F5 case, the maximal extension to brightness (without doing something insanely complex) is a in the space:

$$B(\theta, \lambda, t)$$

This is clearly some dimensions short, so something have been integrated out…A minimal full model could read:

$$B(\theta, y, z_0, y_0, \lambda, t)$$



By assuming some independence, we can rewrite:

$$B_c(\theta, y, z_0, y_0, \lambda, t) = \frac{B_c(y_0)}{B_c}\frac{B_c(z_0)}{B_c}\frac{B_c(y)}{B_c}\frac{B_c(\theta)}{B_c}\frac{B_c(t,\lambda)}{B_c(\lambda)}B_c(\lambda)$$

$$B_t(\theta, y, z_0, y_0, \lambda, t) = \frac{B_t(y_0)}{B_t}\frac{B_t(z_0)}{B_t}\frac{B_t(y)}{B_t}\frac{B_t(\theta)}{B_t}\frac{B_t(t,\lambda)}{B_t(\lambda)}B_t(\lambda)$$

Where for example:

$$B(y_0) = \left(\int_{5d} B(\theta, y, z_0, y_0, \lambda, t)\, d\lambda\, dt\, dz_0\, dy\, d\theta\right)\left(\int_{4d} dt\, dz_0\, dy\, d\theta\right)^{-1}$$

Method

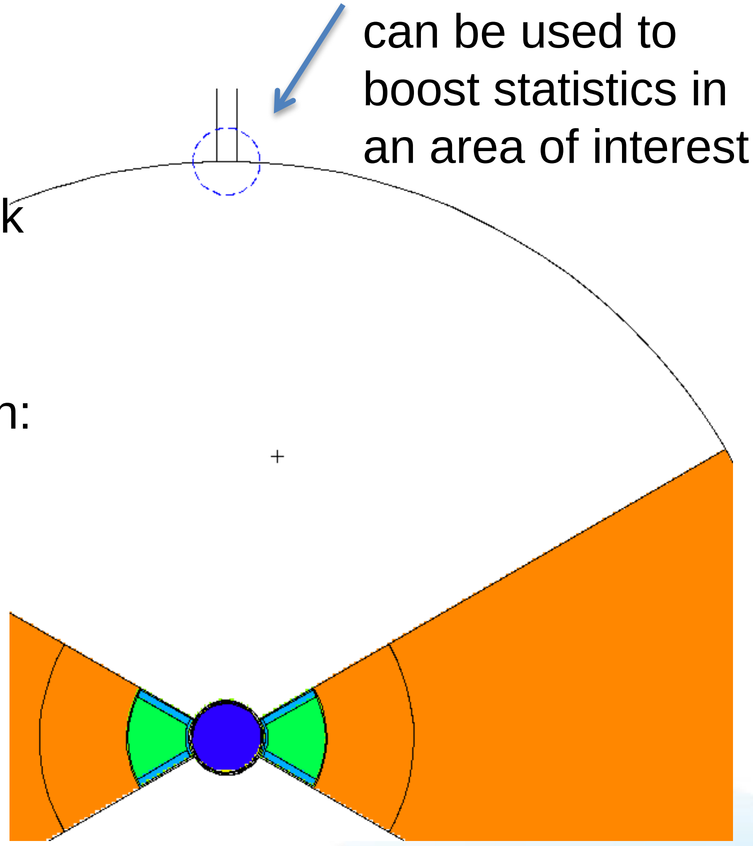
Extracting the full phase space information is impossible in MCNPX using F5 detectors.

But, with present computer power and hard disk availability other methods becomes available.

SSW files contains full phase space information:

x,y,z,dx,dy,E,t for each neutron crossing a specific surface. In root it is trivial use this to extract: $B(\theta, y, z_0, y_0, \lambda, t)$

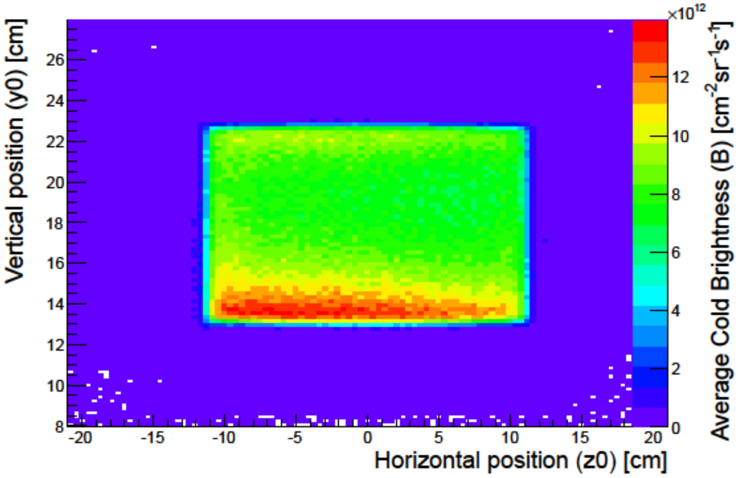
There exists a tool (by K. Batkov – available online) for converting SSW files into easily readable ROOT files.



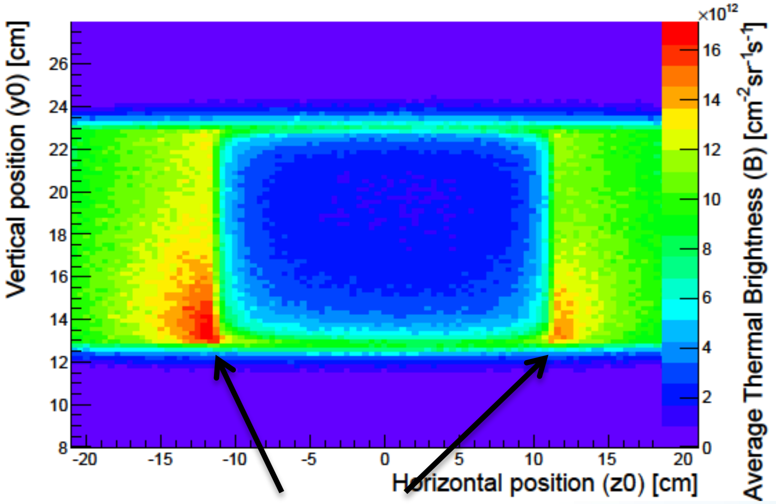
DXTRAN spheres can be used to boost statistics in an area of interest.

Moderator surface pictures

One thing which is immediately possible by this method, is producing a picture of the surface.



Cold moderator



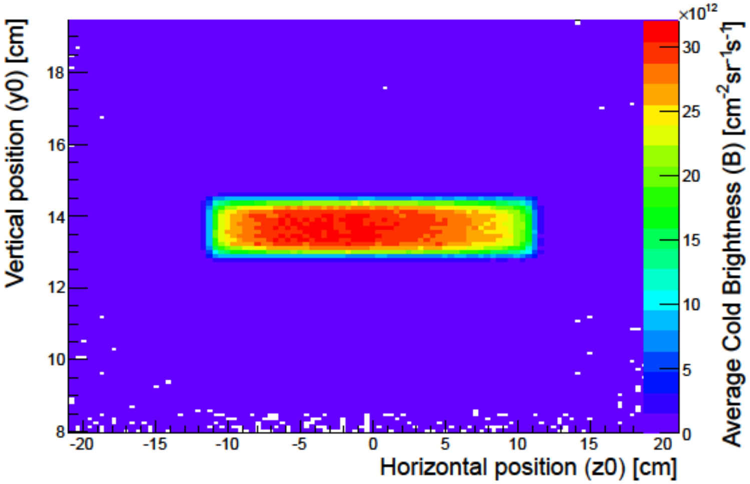
Thermal liners

This plot two lines in MCNPX and a few thousand CPU hours (~1 hour on a cluster) to produce the SSW files.

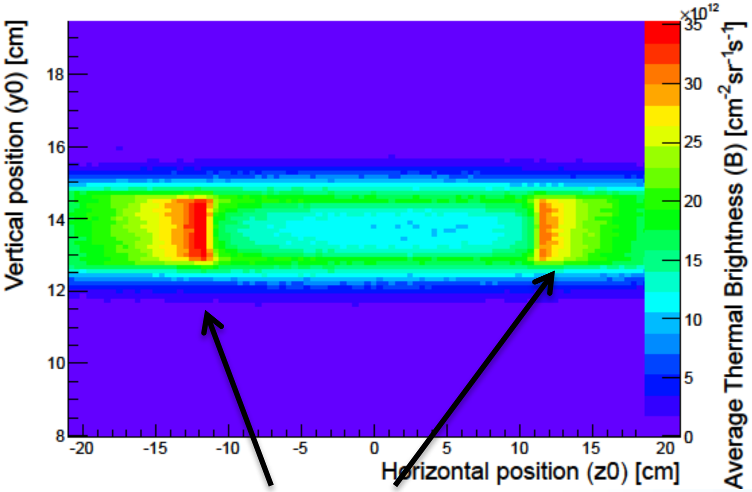
Followed by a one-liner in ROOT.

Moderator surface pictures

The same pictures for the flat moderator



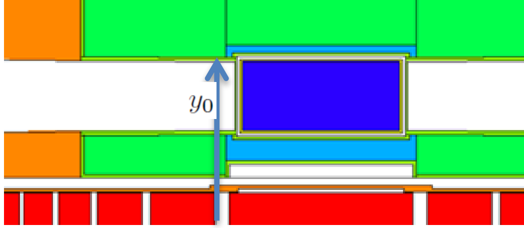
Cold moderator

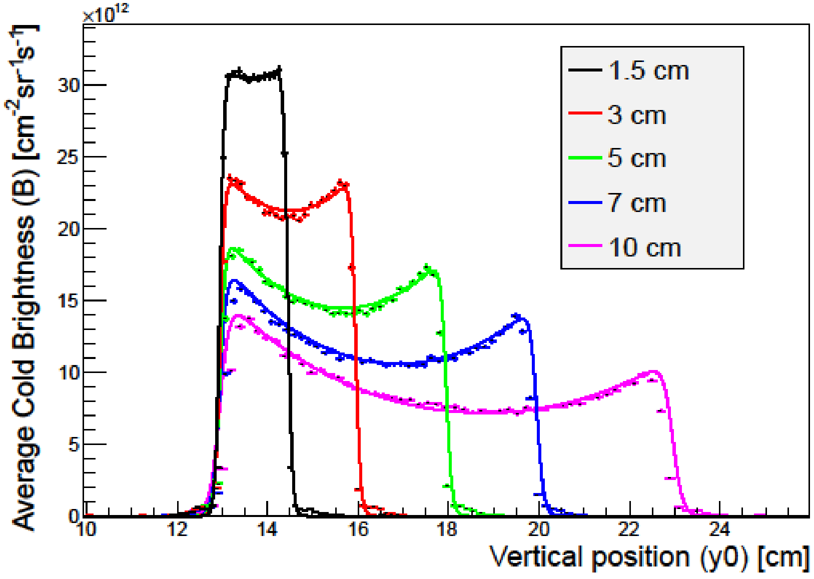


Thermal liners

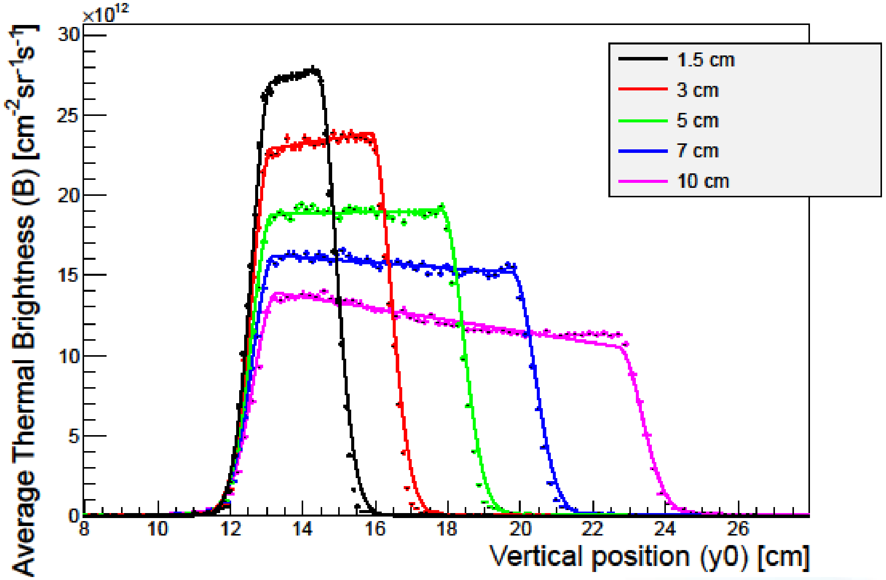
Results

Para-H_2 transparency



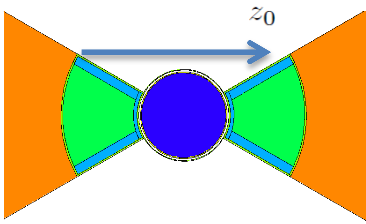


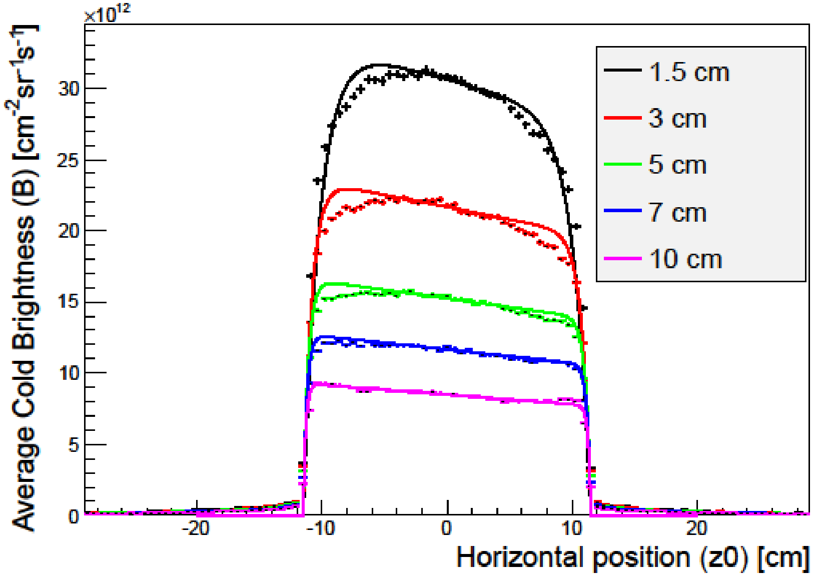
Cold moderator



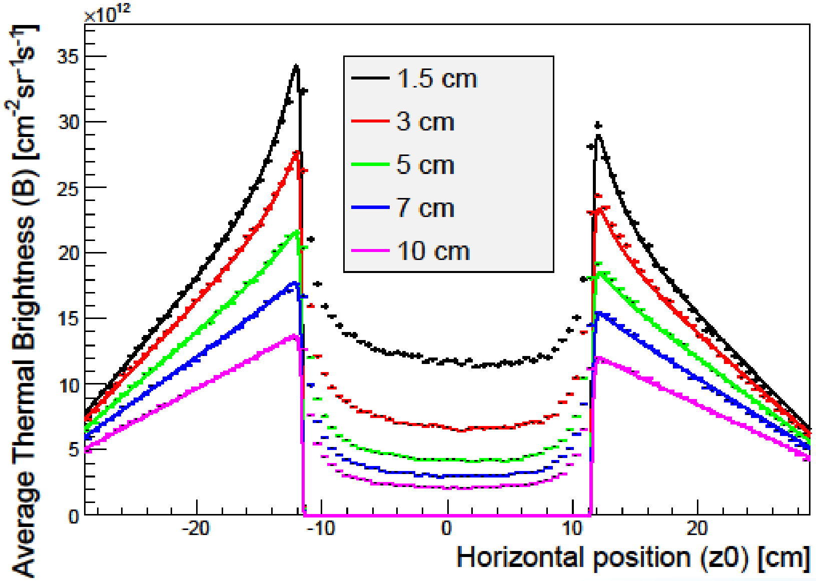
Thermal liners

Results
The not quite flat one…



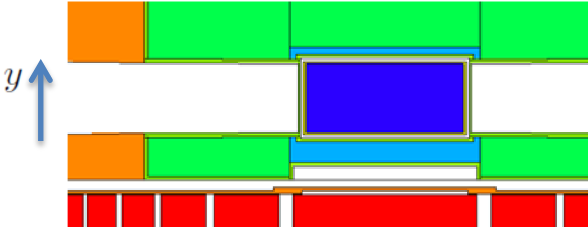


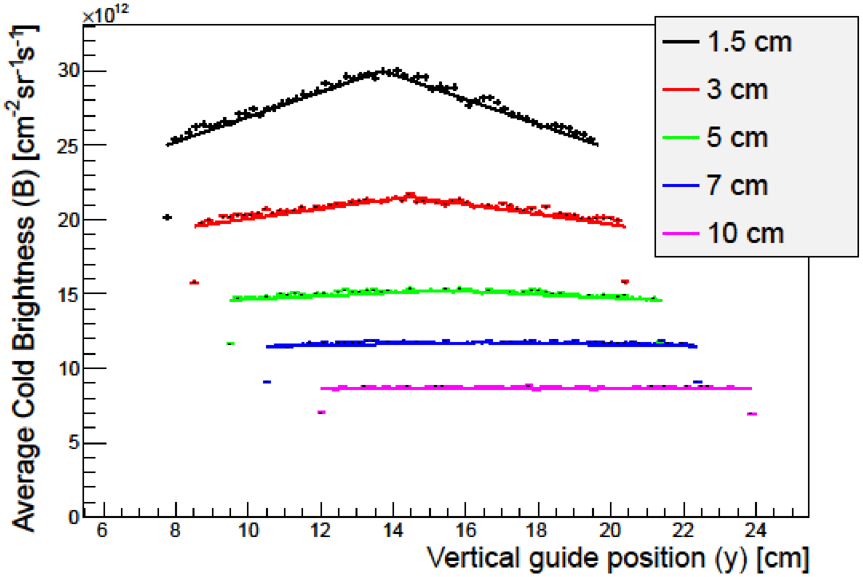
Cold moderator



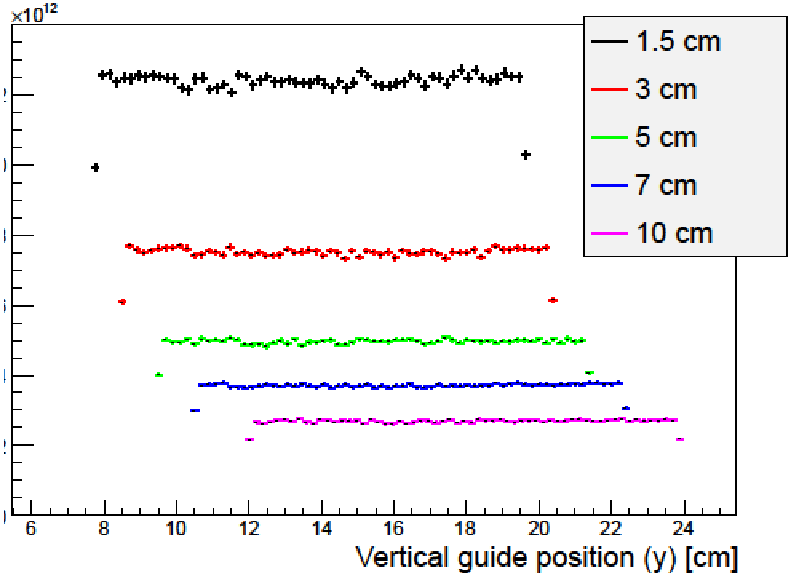
Thermal liners

Results
Directional moderator



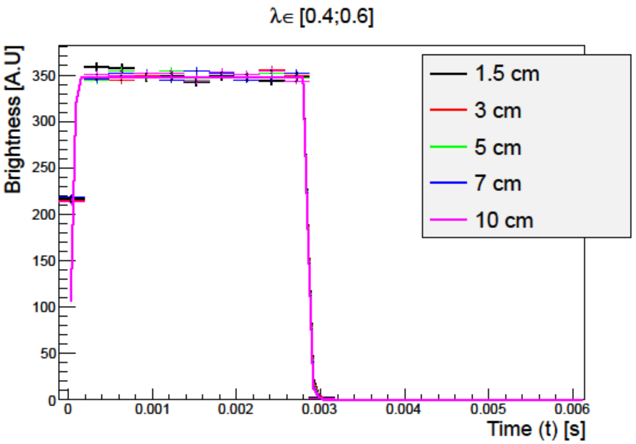


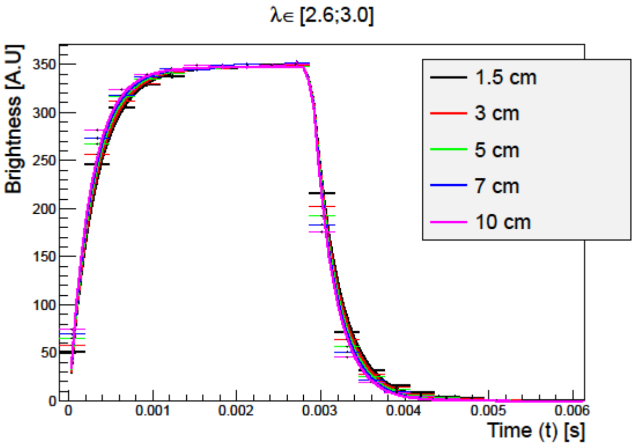
Cold moderator

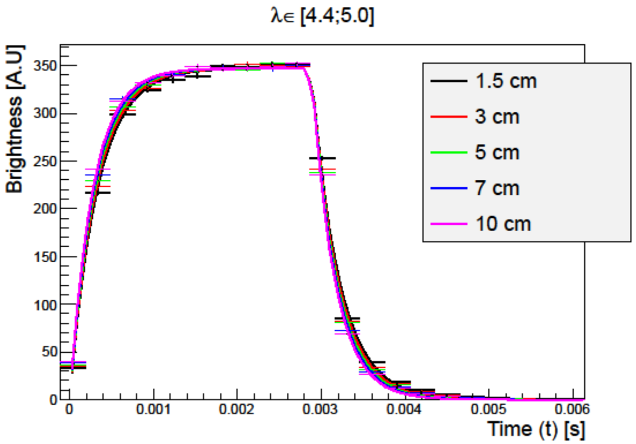


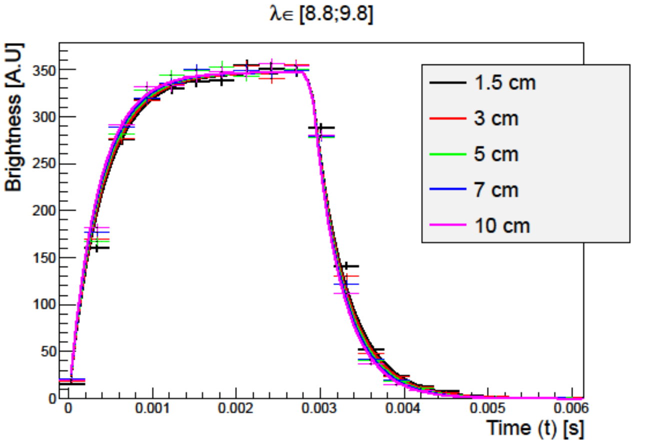
Thermal liners

Results
Time





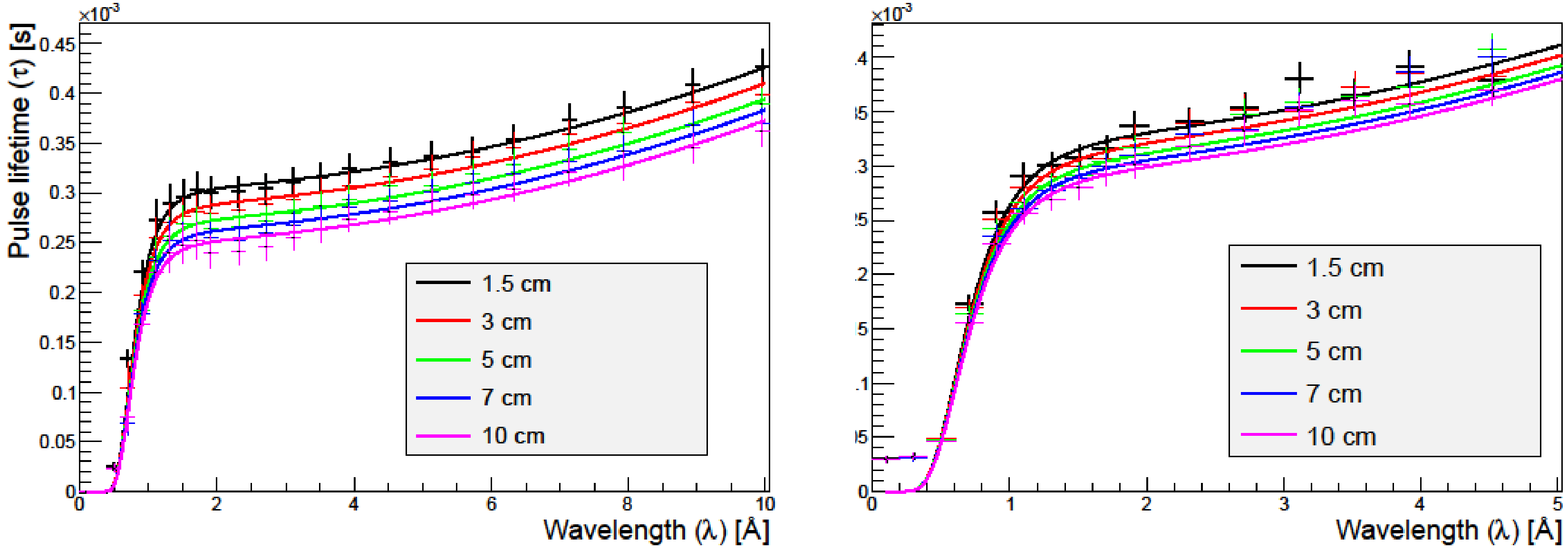




These fits are from the cold moderator

Results

Time constant, τ



$$B(t,\lambda) = B(\lambda) \times \frac{1}{t_{max} f} \begin{cases} \left(1 - e^{-\frac{t}{\tau(\lambda)}}\right) & \text{for } t < t_{max} \\ \left(1 - e^{-\frac{t_{max}}{\tau(\lambda)}}\right) e^{-\frac{t - t_{max}}{\tau(\lambda)}} & \text{otherwise} \end{cases}$$

$$\tau(\lambda) = 3 \times 10^{-4} \times (a_\tau \lambda^2 + b_\tau) \times \begin{cases} e^{\alpha_\tau (\lambda - S)^\gamma} & \text{for } \lambda - S > 10^{-13} \text{ Å} \\ e^{\alpha_\tau 10^{-13\gamma}} & \text{otherwise} \end{cases}$$

In summary

Though very powerful, the commonly used method for measuring brightness is insufficient, as it misses hot-spots and other geometrical effects.

The method developed in this study can be used to map the entire brightness phase-space.

This method not only reveals the missed information which would have been missed using the f5 method, it also reveals hints about where to optimize and what is the driving physics in the moderator-reflector system.

The functions have been implemented into McStas and will be available through the ESS source module in the next McStas release.

A publication is underway, which includes all the function and fits.