Powerful and Cost-Effective Elliptical Neutron Guide Designs for the ESS

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Introduction

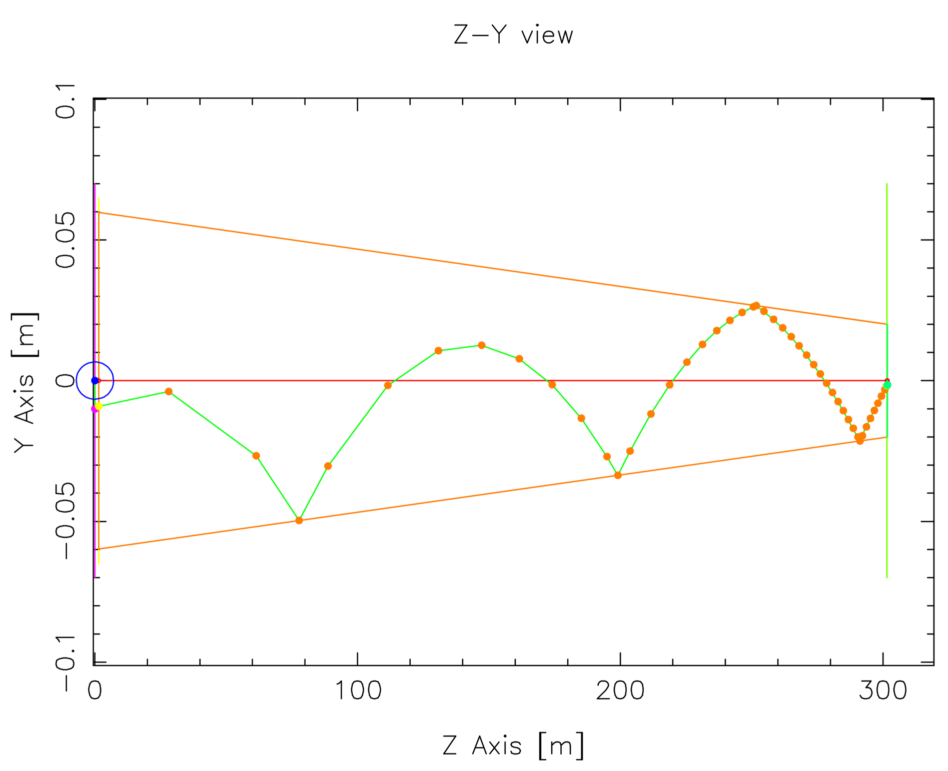
The relatively low intensities of neutron sources, in comparison with X-ray synchrotron sources, demands thorough design of neutron instruments, in order to maximize the use of the neutrons available.

The European Spallation Source (ESS) is expected to have a pulsed flux 10 times greater than the Spallation Neutron Source at Oak Ridge. The ESS will allow for novel instrumentation, which requires long neutron guides of up to 300 m.[1] With long guides especially, proper optimization of the guide geometry and coating can drastically reduce the loss of intensity otherwise experienced.

This has been done using the McStas Monte Carlo Neutron Ray Tracing Simulations Package[3, 4], and simulated using 5 Å and 6.7 Å neutrons.

Guide Geometry

3 basic guide shapes have been investigated: a straight 12x3 cm guide (to provide a benchmark performance), a linearly tapering guide and an elliptic guide.

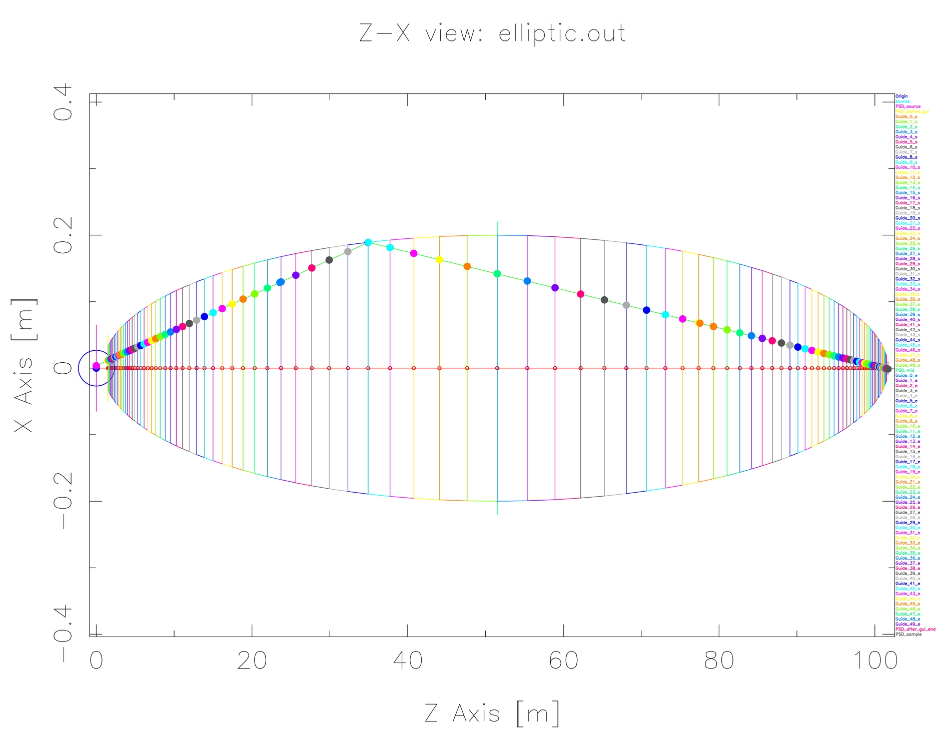


The tapering guide. Note the gravitational bending of the ray, which results in multiple reflections from the bottom.

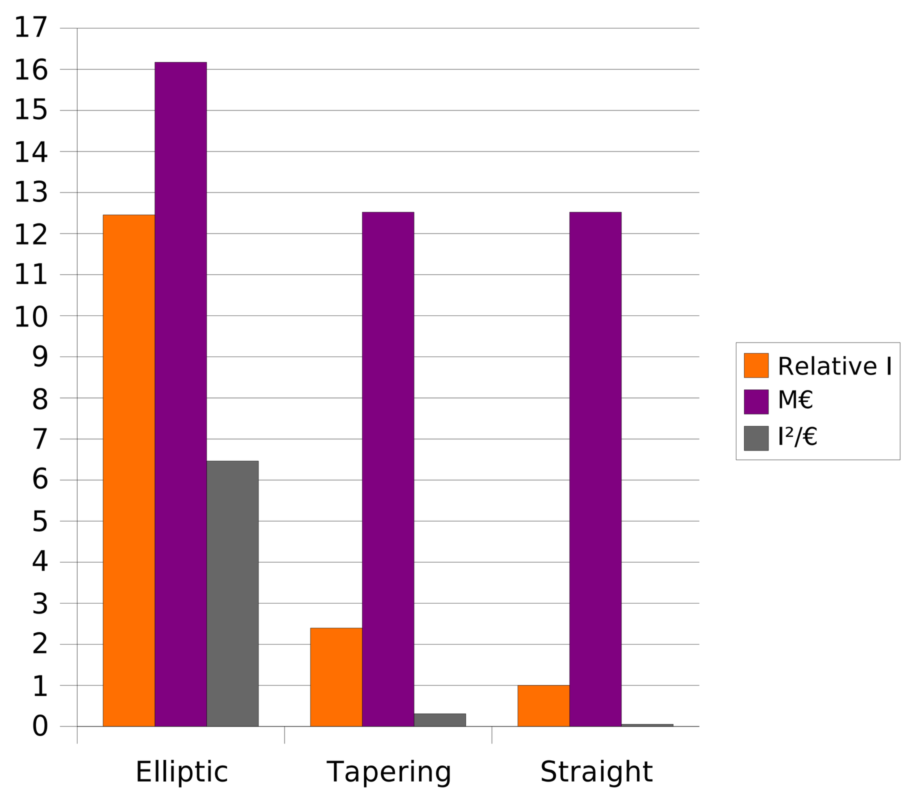
The straight guide is in common use today, and thus used as a performance baseline.

The linearly tapering guide uses the simple focusing principle of following a straight line from the edge of the source to the edge of the target.

The elliptic guide is composed of 50 straight guide sections, arranged to form an elliptic shape.



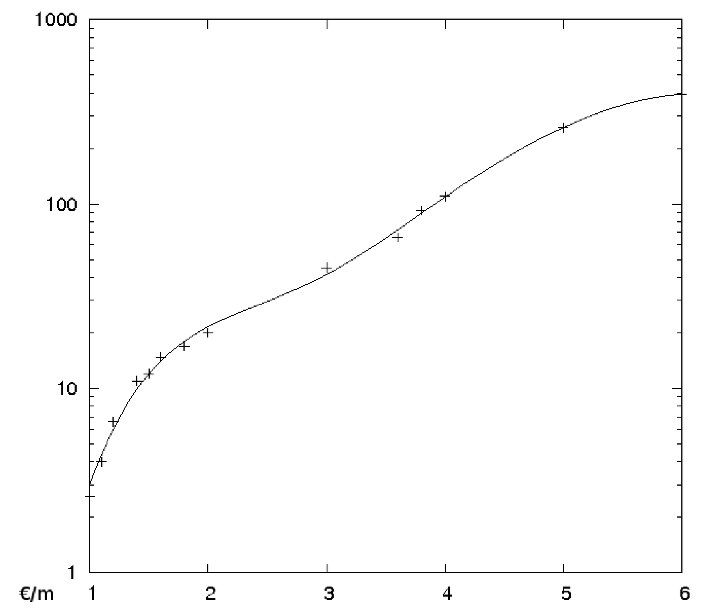
Top down view of the elliptic guide. Note the perfect, single reflection of the ray from source to target. The colours denotes different guide sections.



Comparison of intensity on sample, total cost and cost efficiency for guide shapes with m = 2 coating. As can be seen, the tapering shape is better than the straight shape, but the elliptic shape leads by about an order of magnitude in delivering neutrons to the sample.

Guide Coating and Price

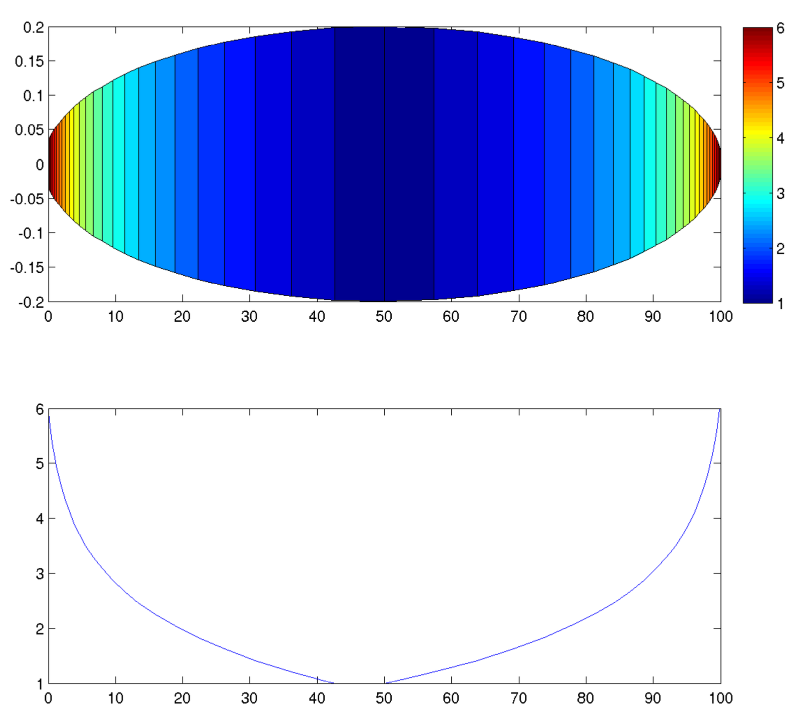
Supermirror coating can now reach m-values of up to 6, but at significant cost compared to lower m-values, as can be seen below.[2]



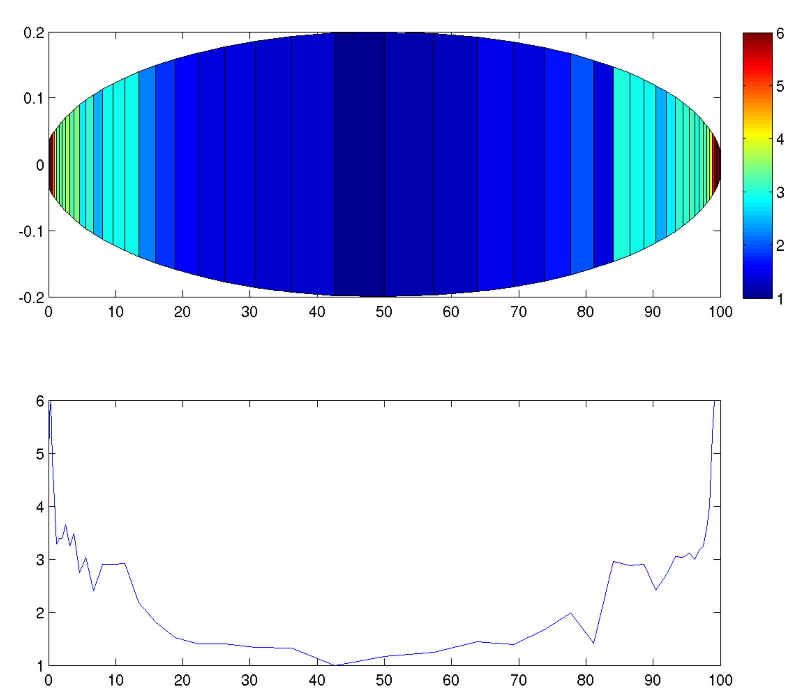
Good guide coating is expensive! Price as a function of the 'm-value' of the coating, in arbitary units.

Monte Carlo simulations has been used to investigate the optimal distribution of m-values in the guide, to get the optimal neutron flux, while keeping the cost down. The chosen optimization criterion is the square of the integrated intensity on the sample, divided by the estimated cost of the guide, coating and the remainder of the instrument. The latter has been fixed at 10 million Euro.

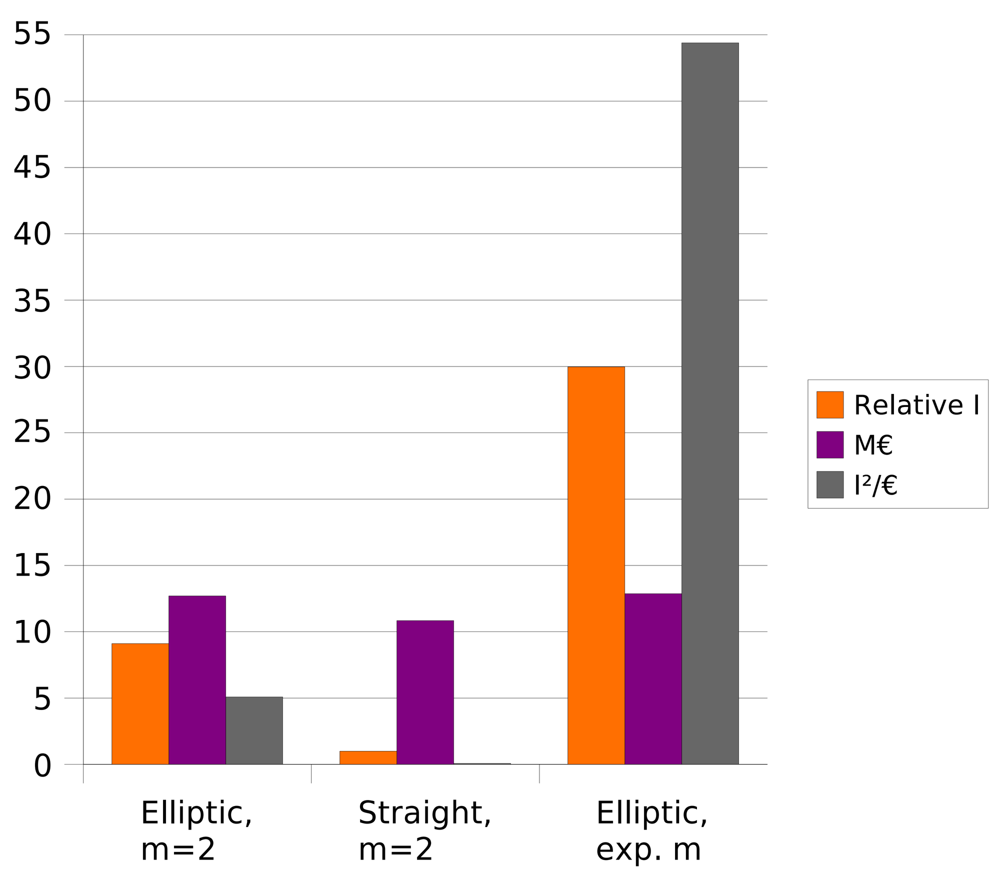
The best analytical coating distribution we have found, is one which starts out with m = 6 at the ends of the guide, which then decreases exponentially to m = 1 in the center of the guide.



Exponential coating distribution through the guide.



Result of algorithmic optimization of cost efficiency of the coating distribution. When smoothed out, this gives the same transmission as the analytical distribution, but with a price point 200 K Euros lower.

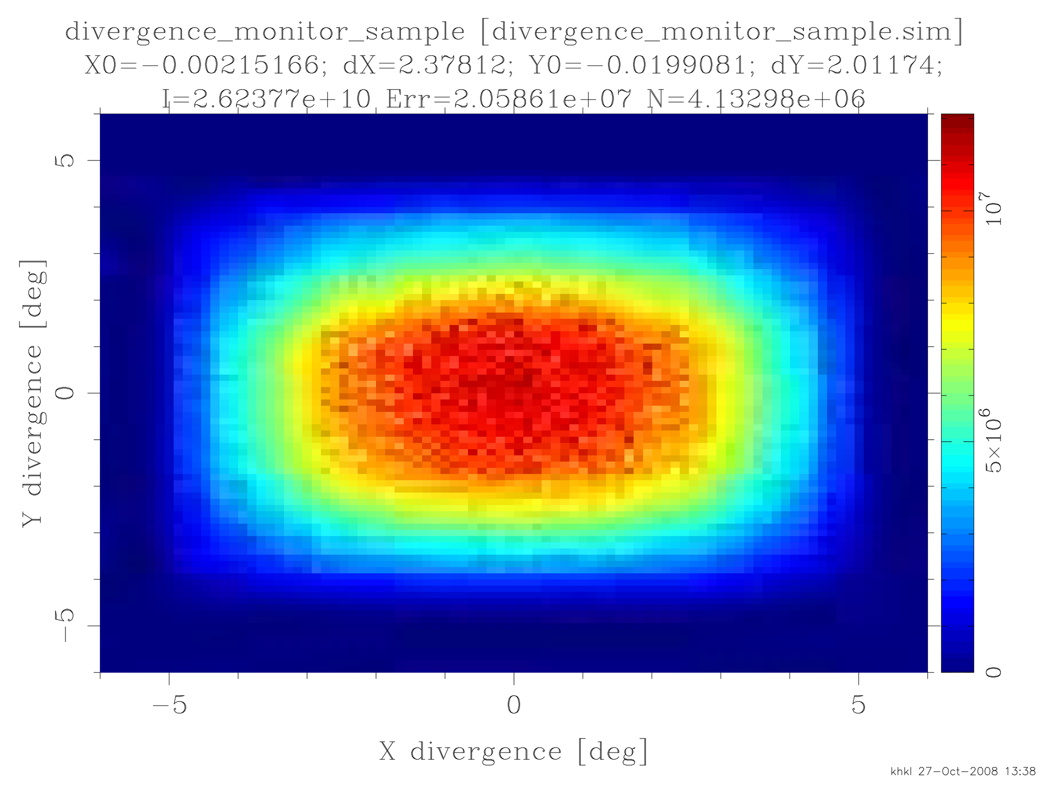


The drastic effect of distributing coating exponentially. m = 2 guides are shown for comparison. Price is guide + remainder of instrument (10 MEuro).

By using this exponential distribution, we have a high value coating in the ends of the guide and a low value coating in the middle of the guide. This gives a another significant gain over guides which have uniform coating, while at the same time keeping the cost down.

Drawbacks of the elliptic shape

While the elliptic shape and an exponential coating distribution leads to great increases in the intensity transmitted to the target, Liouville's theorem dictates that any gains in intensity on target must be offset by an increase in divergence. Thus for instruments which are very sensitive for divergence in both the vertical and horizontal directions, an elliptical guide geometry will likely be useless. A good guide coating will still improve intensity though, by decreasing the absorption rate in the guide.



The divergence profile of the beam at the sample position, from an elliptical guide. The improved transmission of elliptical guides will ineviably increase the beam divergence.

Conclusion

A drastic factor 30 in improved transmission to sample can be achieved over the baseline m = 2 straight guide, by using an elliptically shaped guide with exponentially distributed coating value, for a price increase of only 19 % (2 M Euro), for a 100 m long guide. Compared to an elliptic guide with uniform coating, we gain a factor 3 in intensity, for 0.5 MEuro *less*.

While elliptic guides are not suitable for all instruments, many of the instruments planned for the European Spallation Source could be made significantly more powerful, for a modest price increase.

References

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[3] K. Lefmann and K. Nielsen, *McStas, a General Software Package for Neutron Ray-tracing Simulations*, Neutron News 10, 20, (1999).

[4] McStas project website at http://www.mcstas.org