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Application of the MCNPX-McStas interface for shielding calculations at ESS

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Application of the MCNPX-McStas interface for shielding calculations at ESS

EUROPEAN SPALLATION SOURCE

DTU Nutech
Center for Nuclear Technologies

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ESS

The European Spallation Source (ESS), presently starting construction in Lund, Sweden, will be the most intense source of spallation neutrons ever built[1]. Protons from a 5MW, 2.5GeV linear accelerator will impact a rotating tungsten target in 14, 2.86ms long pulses every second. The spallation neutrons hereby created are thermalized in water and some of them are further cooled in liquid para-hydrogen before extracted through individual beam-lines serving 22 cold/thermal instruments.
To fully exploit the long pulse characteristics, many instruments benefit from being long – up to ~200m is foreseen.
→ Guide design challenging and important, since guides and in particular their shielding is a major cost driver for the ESS facility

McStas Scatter logger

Useful to have a tool that:

- Can monitor where in a guide neutrons are lost
- Allows to optimize reflectivity requirements along a guide
- Serves as an input for dose-rate calculations along guide (n,γ)
- Works within the work-flow accustomed to instrument designers (McStas)

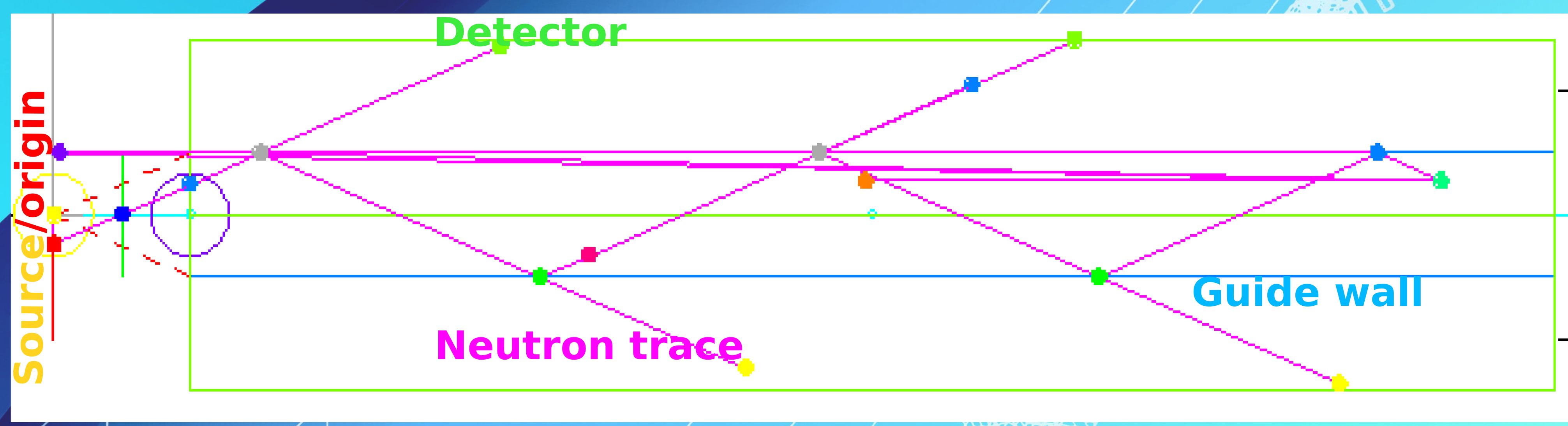
McStas Scatterlogger is the backbone that facilitates these calculations

At each scattering for any McStas component (e.g. a guide) the incoming a outgoing neutron state can be temporarely stored and analyzed

At each scattering:

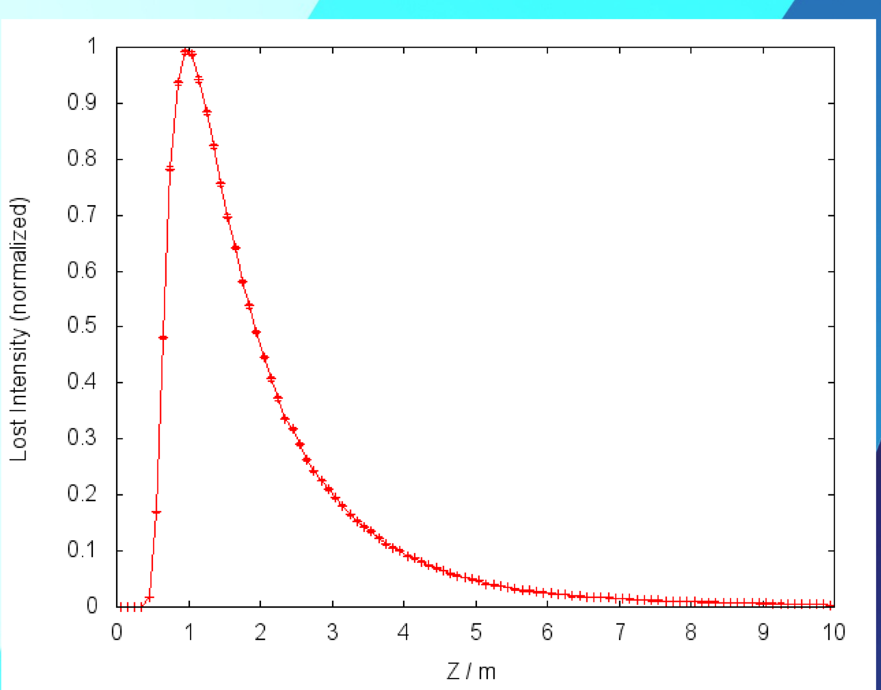
Incomming state: $n_{in} = (\mathbf{x}, \mathbf{v}_{in}, t, w_{in})$
Transmitted state: $n_{trans} = (\mathbf{x}, \mathbf{v}_{in}, t, w_{trans})$
Reflected state: $n_{refl} = (\mathbf{x}, \mathbf{v}_{out}, t, w_{in} - w_{itrans})$

All states available for post-processing



Visualization of a neutron trajectory in a guide. At each scattering both the reflected and transmitted neutron weight is available for post-processing

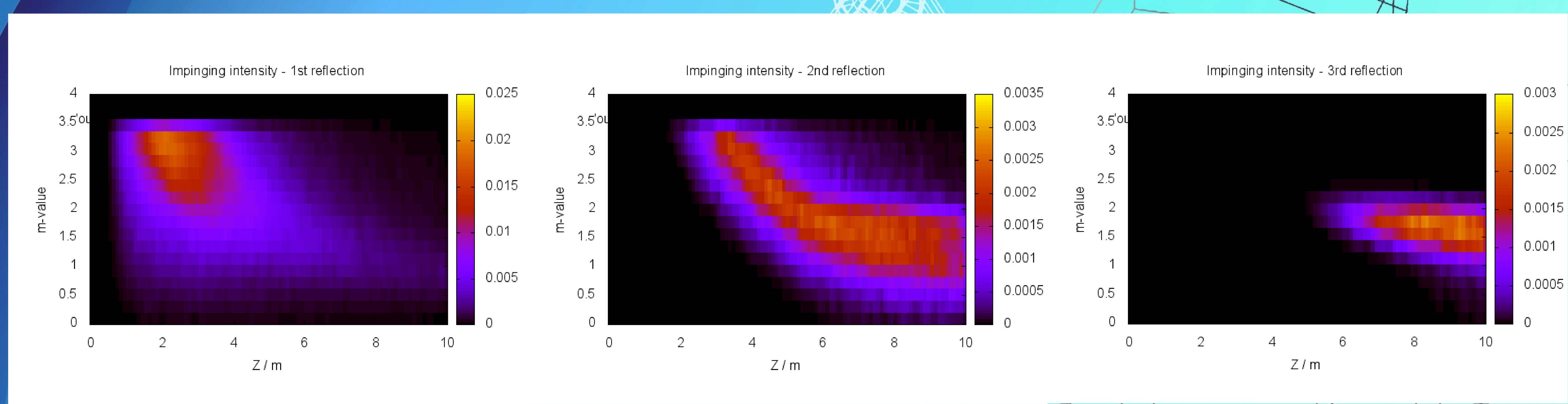
Use-case 1: Lost intensity



Lost intensity along a 10m straight guide

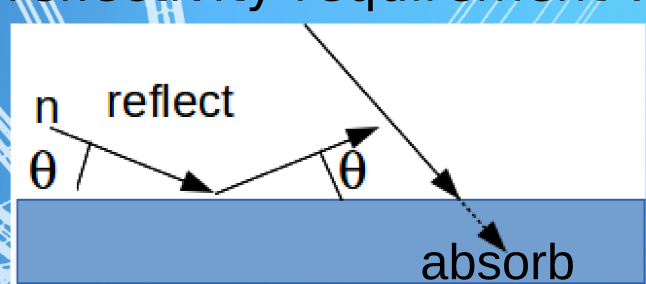
To which extent intensity is lost, depends strongly on specific guide design, and incoming neutrons (i.e. source) spectrum and divergence.

Use-case 2: Reflectivity

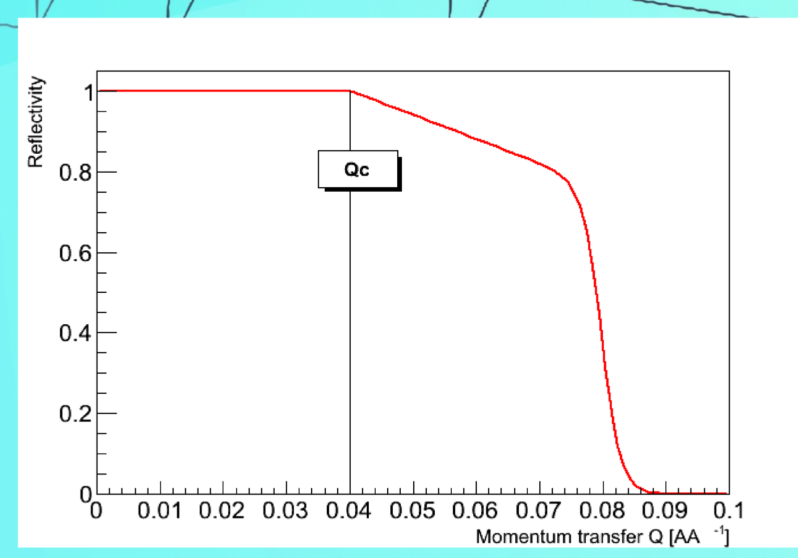


Minimum m-value required for neutrons to reflect along a 10 m guide, and corresponding intensity (color coded). Note that the guide has m=2, which explains the loss of intensity between the first, second and third scattering

- Neutrons are reflected if the energy/incident angle is low enough.
- Given a neutron state and a guide geometry, m_{min} can be calculated at a scattering: The minimum mirror reflectivity requirement which would reflect the neutron.



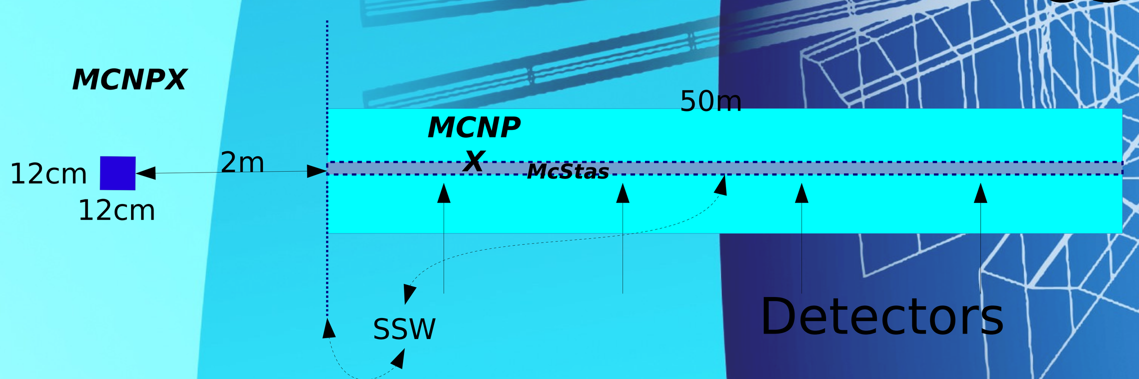
$\cos 2\theta = (\vec{v}_{in} \cdot \vec{v}_{out}) / |\mathbf{v}_{in}|$
$k = |\mathbf{v}_{in}| \cdot m_n / \hbar$
$m_{min} = 2 \cdot k \cdot \sin(\theta) / 0.0219$



Reflectivity as a function of momentum transfer.

- Result depends on guide design, and incoming neutrons divergence and energy (i.e. depends on the source)

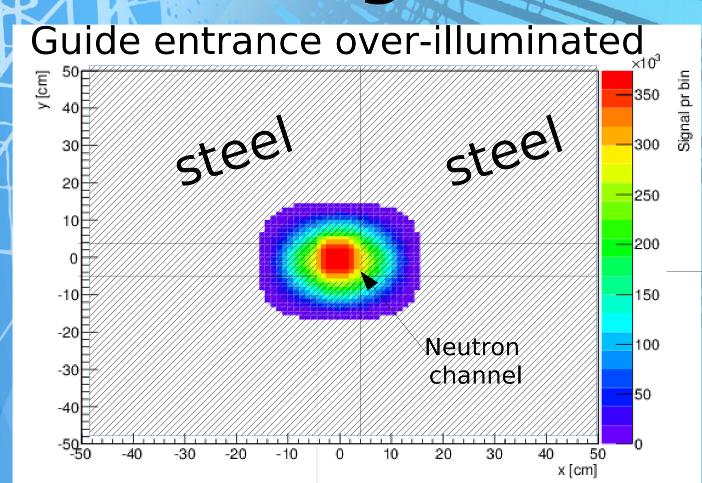
Use-case 3: Background along guides



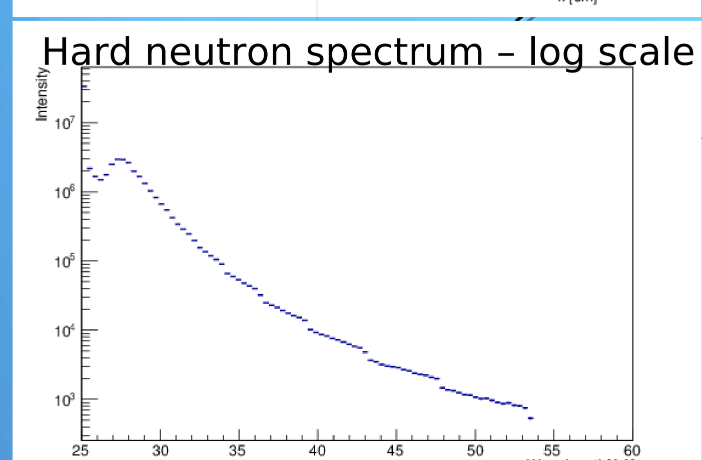
Geometry setup. 50m curved guide (r=1500m) in a steel housing. Beam divergence: 5%, preliminary ESS source spectrum. Detectors are placed 5cm into the steel.

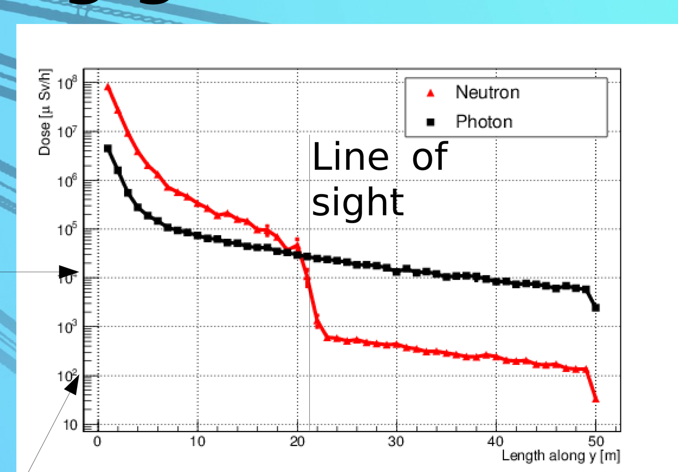
Neutrons generated with MCNPX
Handed to McStas through SSW interface [2]
Unreflected neutrons returned to MCNPX for dose-rate calculation, using the same interface

Guide entrance over-illuminated



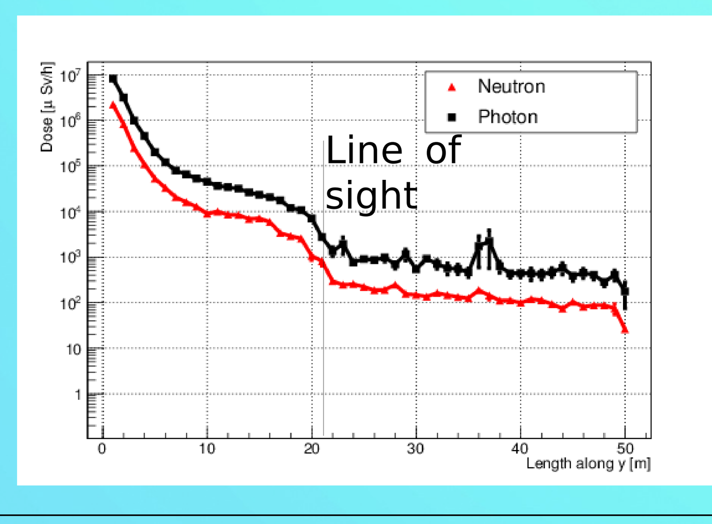
Hard neutron spectrum – log scale





Up: Dose-rate from neutrons and photons seperately. The curve corresponding to neutrons drops when line-of-sight is reached. Due to over-illumination of the guide entrance by energetic neutrons, no similar drop is seen in photon induced dose-rate.
Right: Limiting to 0.5-1.0Å neutrons, the drop is also observed for photons

Logging mechanism useful for guide design:
→Monitor lost intensity
→Optimize use of high/low reflectivity mirrors
→Shielding along guide
→Works from within common tool: McStas



[1] S. Peggs, editor. ESS Technical Design Report. April 2013.
[2] E. Klinkby et al. 'Interfacing MCNPX and McStas for simulation of neutron transport.' Nucl. Instr & Meth A , 700:106