Developments in Target

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for the neutronics team

EUROPEAN
SPALLATION
SOURCE

Optics TAP meeting
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Outline

1. UCN beam tube
2. Moderator optimisation
3. Conclusions

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1. UCN beam tube
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Esben Klinkby,
Konstantin Batkov, Luca Zanini, Ferenc Mezei
First investigations of possibilities for a through-going UCN tube at the ESS
AccApp 2013

Ultra-cold neutrons at ESS

- UCN experiments are typically of counting type:
  More neutrons $\Rightarrow$ better results

$\Rightarrow$ A large beam extraction tube is needed to achieve high UCN rate: a 25 cm $\times$ 25 cm tube is studied

Ultra-cold neutrons at ESS

The primary ESS mission is to deliver high brightness to the cold/thermal instruments.

$\Downarrow$

Constraint

The cold/thermal beam lines should not be significantly affected by introducing the trough-going UCN tube.

Ultra-cold neutrons at ESS

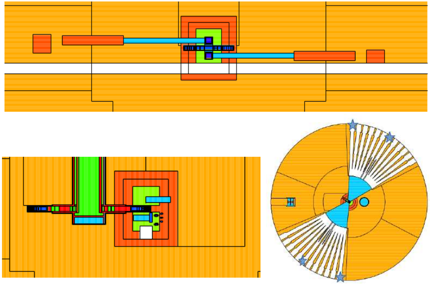
Method

Measure flux available for UCN moderation,
while monitoring the cold/thermal flux in the neutron scattering beam lines.

$$\lambda > 0.9\,\text{Å}$$

$$(E < 100\,\text{meV})$$

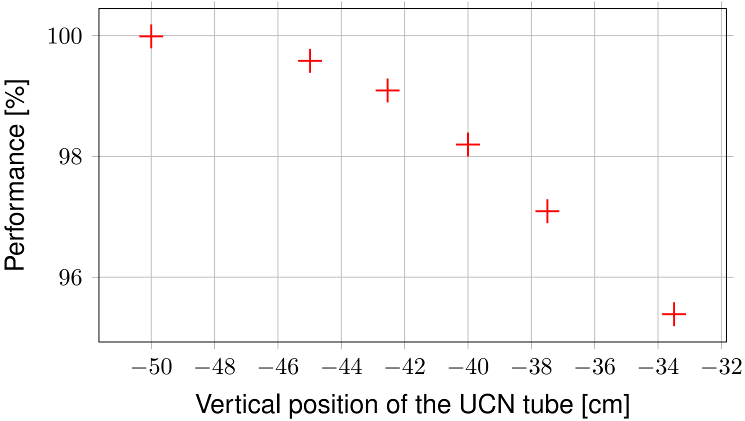
Geometry



- 25 cm $\times$ 25 cm.
- Perpendicular to the proton beam to reduce background.
- Vertical position of the tube is varied.

Impact on existing beam lines < 5 %

Flux relative to the Baseline — average over lower beam lines



Impact on existing beam lines < 5 %

- Flux penalty on lower instruments $< 5\,\%\,(\lambda < 0.9$ Å).
- No effect seen in the upper beam lines.
- Loss is $\approx$energy independent.

Neutron flux and UCN moderator heat load

UCN tube position	cm	-47.5	-55.0	-62.5
Flux in the tube	n/cm^2/sec	$2.4 \cdot 10^{13}$	$1.3 \cdot 10^{13}$	$0.29 \cdot 10^{13}$
Heat load density	W/cm^3	0.20	0.11	0.06

Similar to the heat load density of the FRM-II reactor in Münich.

Summary on UCN

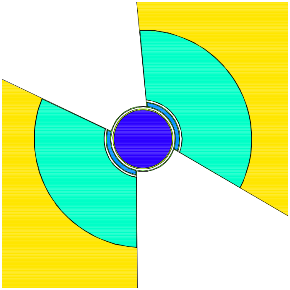
- It is feasible to include a large cross section (25 cm $\times$ 25 cm) through-going beam tube below the lower cold moderator in order to meet potential needs for fundamental neutron research.
- Such a beam line will have less than 5 % effect on the neutron flux in the beam lines for neutron scattering work.

Outline

1. UCN beam tube
2. Moderator optimisation
3. Conclusions

Konstantin Batkov, Alan Takibayev,
Luca Zanini, Ferenc Mezei
Unperturbed moderator brightness in pulsed neutron sources
NIMA (2013), volume 729, pages 500–505
http://dx.doi.org/10.1016/j.nima.2013.07.031

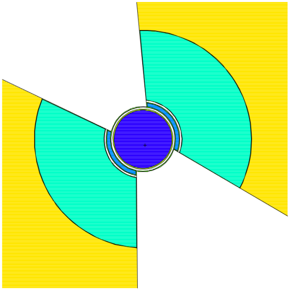
Perturbed configuration



- Brightness depends on beam extraction

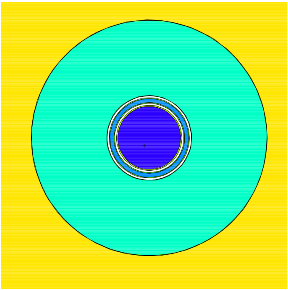
- Openings are needed to extract neutrons
- Openings reduce moderator performance
- Optimisation is done towards brightness viewed through openings

Perturbed configuration



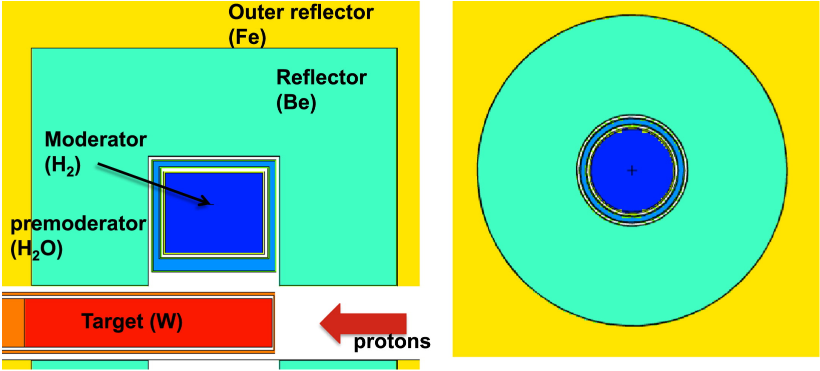
- Brightness depends on beam extraction

Unperturbed configuration



- Brightness = source performance
- Fundamental quantity
- Research reactors

Geometry



The moderator position and dimensions were optimised for a fixed target and reflector geometry.

Parameter space

	unit	min	max
Moderator height	cm	1	14
Moderator diameter	cm	3	20
Target offset	cm	5	15

Figure of merit ≡ cold neutron brightness

$$\text{FoM} = \frac{1}{\Omega \cdot A} \int_S dS \int_0^{\varphi_{max}} d\varphi \int_0^{\infty} dt \int_0^{5\,\text{meV}} dE \;\; \Phi(t, \varphi, E)$$

[n/cm^2/sr/proton]

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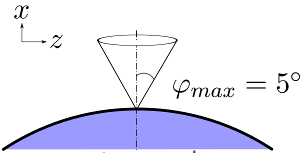

sector angle

only neutrons which will potentially arrive to the neutron guide

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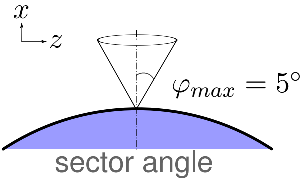


only neutrons which will potentially arrive to the neutron guide

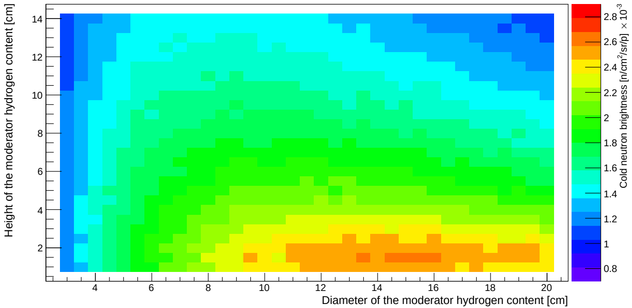
Solid angle:

$$\Omega = 2\pi \cdot (1 - \cos \varphi_{max})$$

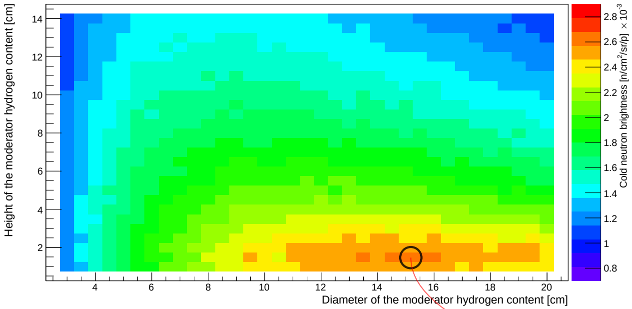
Moderator side surface area:

$$A = 2\pi \cdot r \cdot h = \int_S dS$$

Map of unperturbed moderator performance



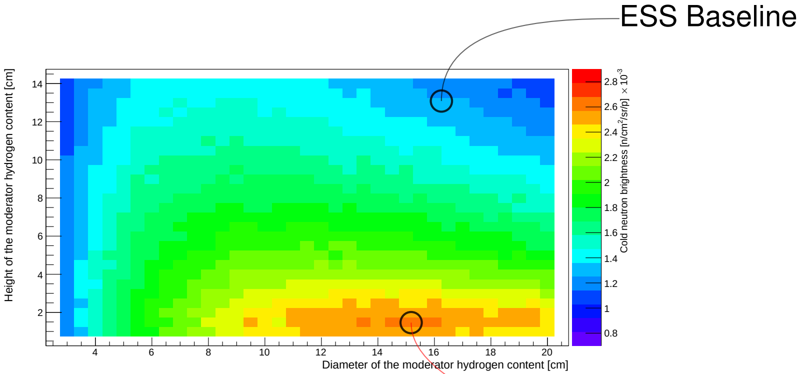
Map of unperturbed moderator performance



Moderator size for highest unperturbed brightness:

ø = 15 cm h = 1.4 cm

Map of unperturbed moderator performance



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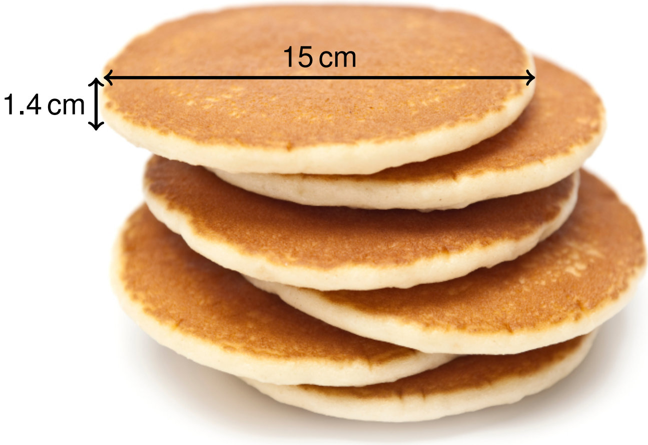
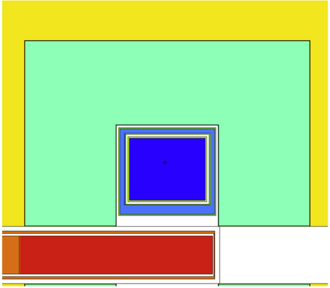


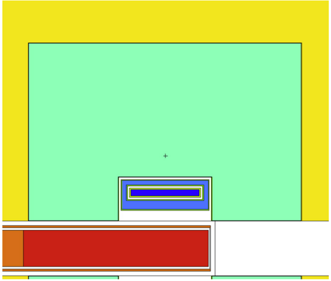
[news.slnutrition.com]

Optimised geometry

Conventional moderator (ESS Baseline)



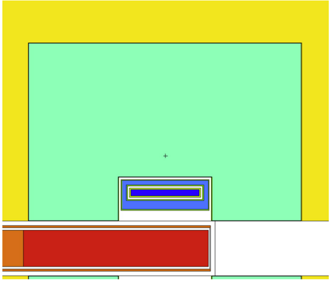
Optimised for unperturbed brightness



Optimised geometry

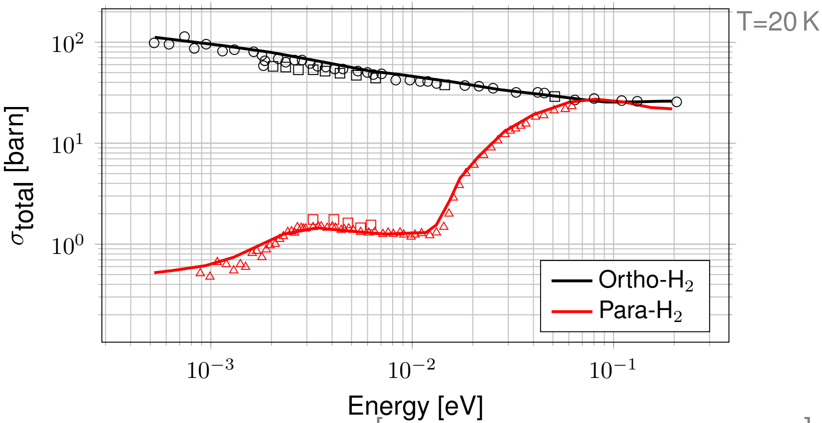
Optimised for unperturbed brightness

- Properties of para-H_2
- Added reflector
- Directionality effect



- Small height $\longleftrightarrow$ para-H_2 cross-section properties
- Large radius $\longleftrightarrow$ neutron production region in tungsten

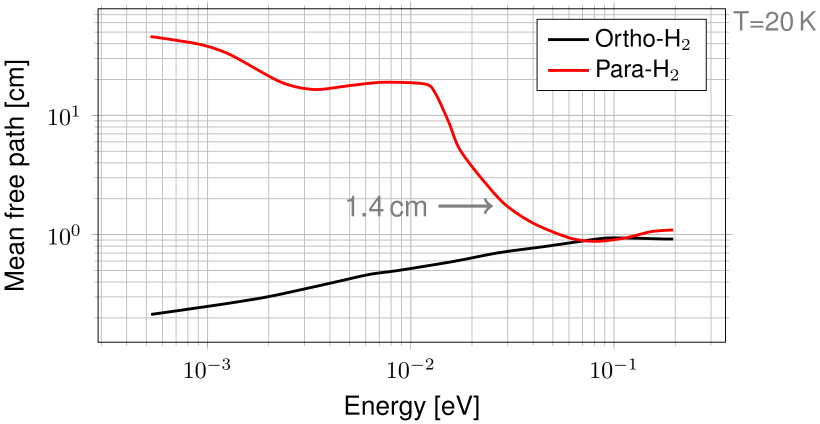
Properties of para-H_2: scattering cross-section



[N. Watanabe, Neutronics of pulsed spallation sources, 2003]

- Significant drop of σ below 50 meV $\Rightarrow$
- Medium is almost transparent for cold neutrons

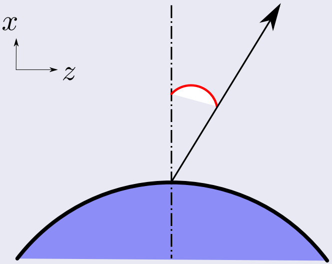
Properties of para-H_2: mean free path



Mean free path below 50 meV becomes comparable to the height of the small optimised moderator, making the whole volume to be the source of neutrons. ⇒ Directional emission?

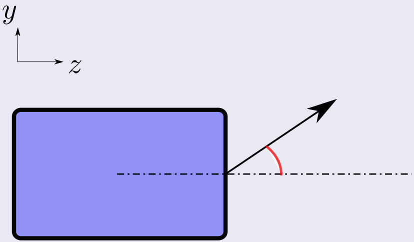
Directionality: emission from the moderator surface

Horizontal angle



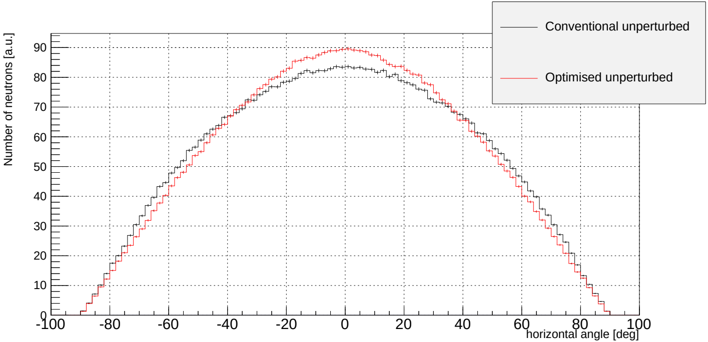
The angle between the direction of the emitted neutron and the vertical plane normal to the moderator surface.

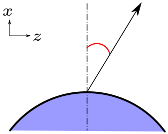
Vertical angle



The angle between the direction of the emitted neutron and the horizontal plane (i.e., the plane perpendicular to the moderator axis).

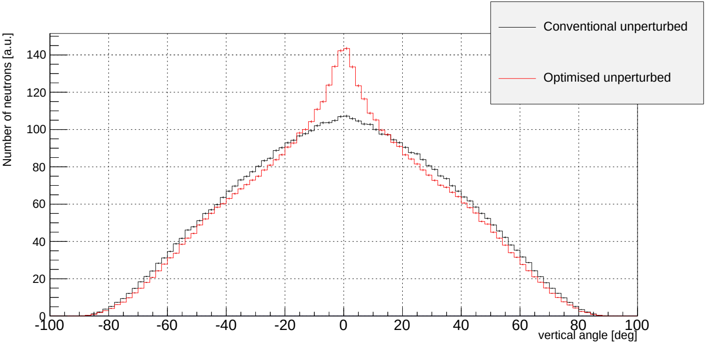
Directionality: horizontal emission angle

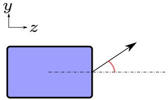




Small difference in horizontal emission.

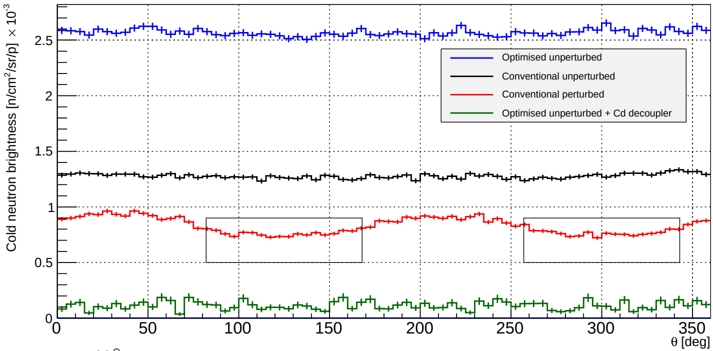
Directionality: vertical emission angle





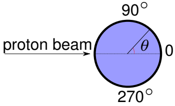
Optimised moderator shows a strong effect at small vertical emission angles: **anisotropic emission**

Moderator performance *vs* horizontal coordinate

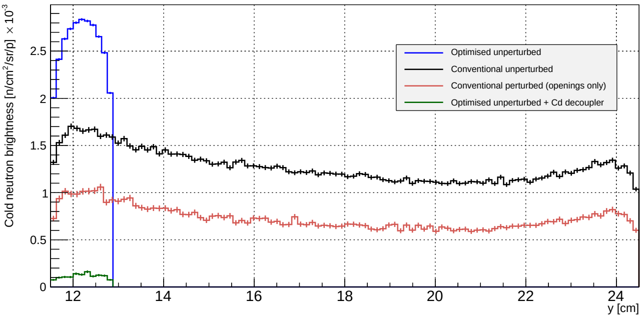


$\times 2$

$\times 1.8 - 1.9$

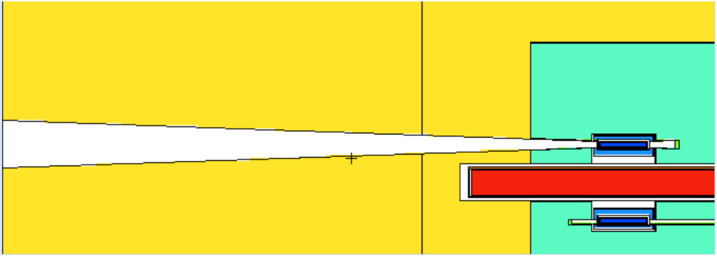


Moderator performance *vs* vertical coordinate



- Conventional moderator peaks near edges.
- Small moderator peaks in the centre: it's an optimised moderator for cold neutron emission from the side surface.

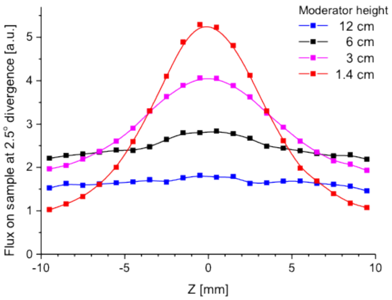
Perturbation



- Since the moderator is thin, only small amount of reflector is removed.

⇒ Perturbation brings <10 % penalty in brightness.

Flux on sample as a function of moderator size



- Gain for 3 mm sample: 2.95
- Gain for 40 mm sample: 1.8

L=80 m, 2.5° divergence, $\lambda = 4\,\text{Å}$

Summary on moderator optimisation

- Unperturbed brightness — fundamental source parameter. Upper limit for the perturbed brightness.
- Unperturbed moderator can achieve $\lesssim 4$ times the perturbed moderator brightness in the common moderator – beam extraction configurations.
- Optimal unperturbed moderator dimensions: height = 1.4 cm, diameter = 15 cm

Outline

Conclusions

- It is feasible to include a through-going UCN beam tube below the lower cold moderator in order to meet potential needs for fundamental neutron research.
- Flat moderator approach offers a significant gain for small beam divergence and for small samples for most instruments.

Thank you for your attention