EUROPEAN
SPALLATION
SOURCE

Design of neutron moderators for ESS

Konstantin Batkov
for the ESS neutronics team

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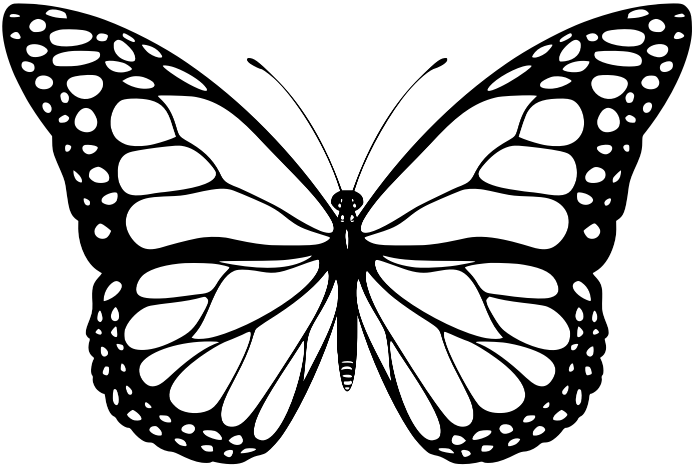
UCANS V
Padova • Italy • 2015

Our way to the butterfly



[animatedcliparts.net]

Outline

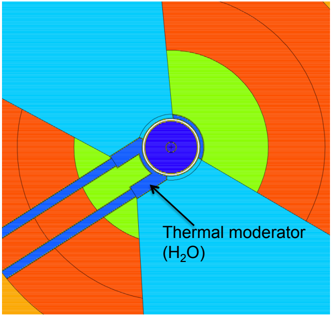
Nomenclature

Neutron energy range

Cold	Thermal
$< 5\,\mathrm{meV}$	$20 - 100\,\mathrm{meV}$
> 4 Å	$0.9 - 2$ Å

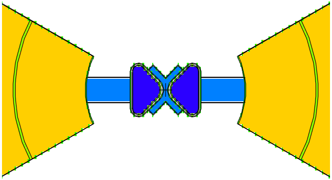
Nomenclature
Moderator names

Volume



$\sim 16 \times 16 \times 13\,\text{cm}^3$

Butterfly

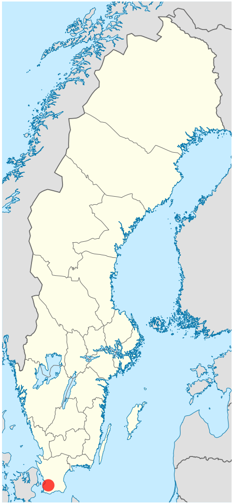


$\sim 20 \times 30 \times 3\,\text{cm}^3$

Outline

European Spallation Source (ESS)

- Lund, Sweden
- First neutrons by 2019

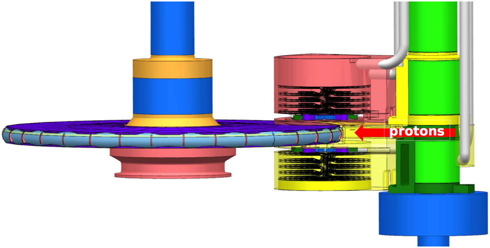


[Google maps]

http://europeanspallationsource.se

European Spallation Source (ESS)

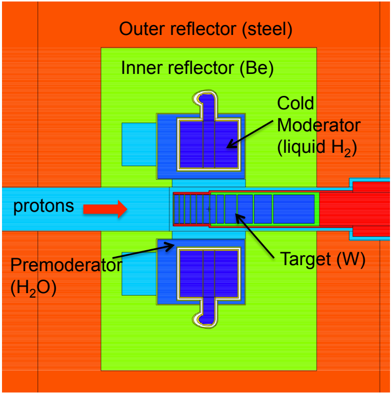
- Proton beam:
  - $2\,\text{GeV} \times 2.5\,\text{mA} = 5\,\text{MW}$
  - 14 Hz, 2.86 msec
- Tungsten rotating target
- Cold neutrons:
  - Para-H_2 at 20 K
- Thermal neutrons:
  - Water at 300 K

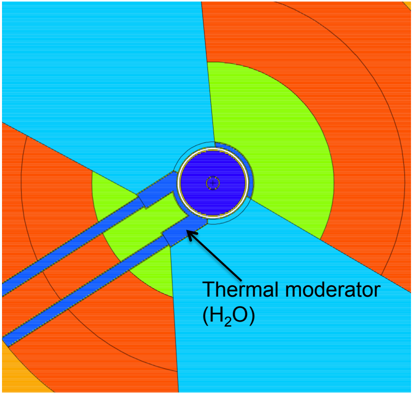


[Bengt Jönsson]

Outline

Starting point: baseline configuration
J-PARC style cold moderator

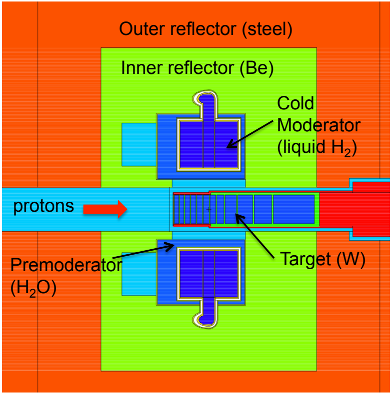


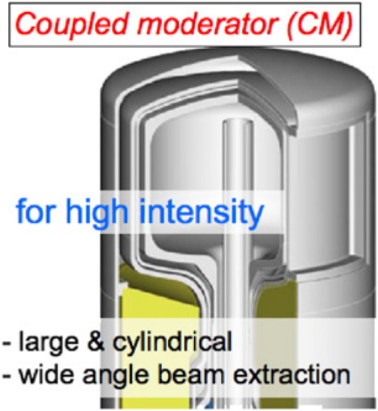


[ESS Technical design report, page 174]

- Para-H_2 volume moderator 13 cm high $\times$ 8 cm radius
- Thermal wings provide a bi-spectral source

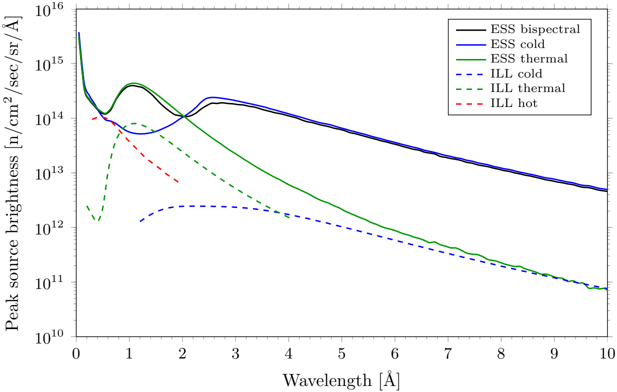
Starting point: baseline configuration
J-PARC style cold moderator





F. Maekawa et al
First neutron production utilizing J-PARC pulsed spallation neutron source JSNS and neutronic performance demonstrated (2010)

Excellent performance from the volume moderators



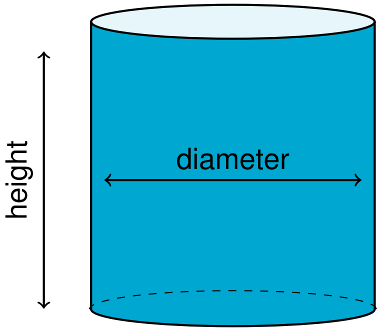
- Cold: $\times$60 ILL Yellow Book
- Thermal: $\times$7 ILL Yellow Book
- $\times$ 2 ESS 2003

[ESS Technical design report, page 178]

How to make it better?

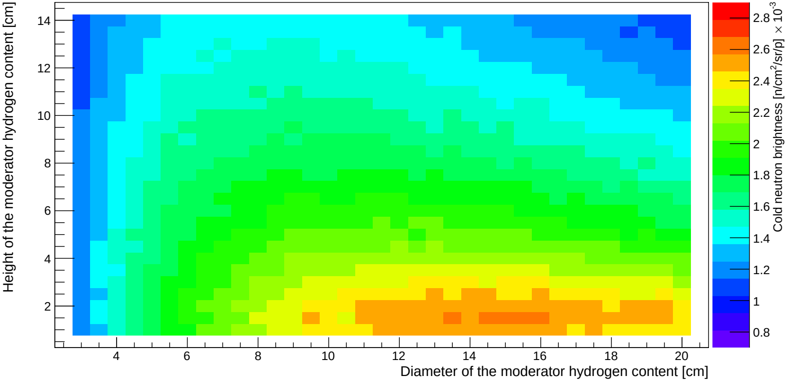
- Planned 1 year time to improve the moderator design

Optimisation
Cylindrical moderator dimensions



Unperturbed brightness

Cylindrical moderator performance as a function of its dimensions



Unperturbed brightness

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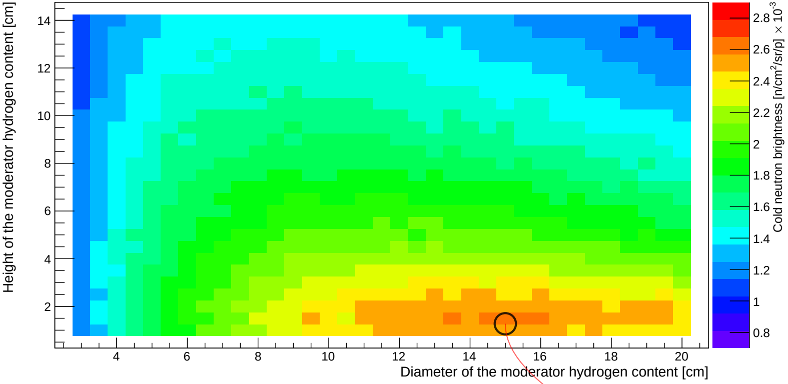


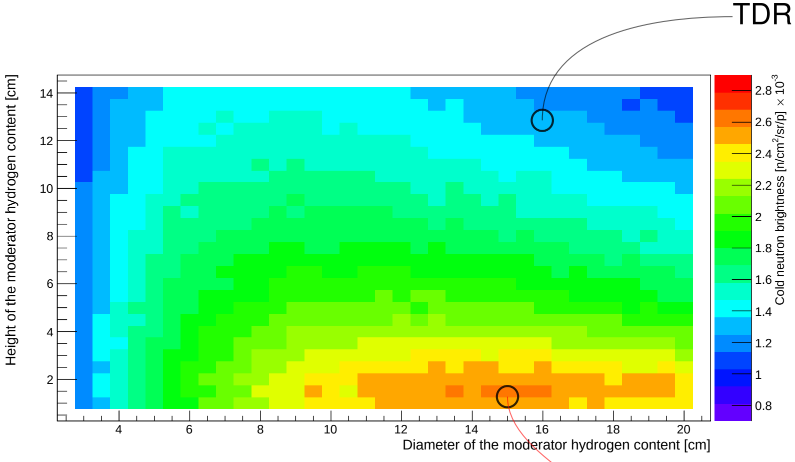
Moderator size for highest cold brightness:

ø = 15 cm   h = 1.4 cm ← Pancake

[K. Batkov et al, 2013]

Unperturbed brightness

Cylindrical moderator performance as a function of its dimensions



Moderator size for highest cold brightness:

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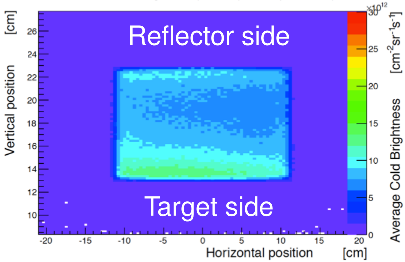
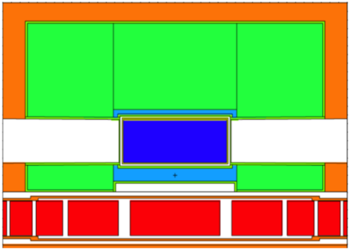
[K. Batkov et al, 2013]

Why flat moderators work
Cold neutron map in volume moderator

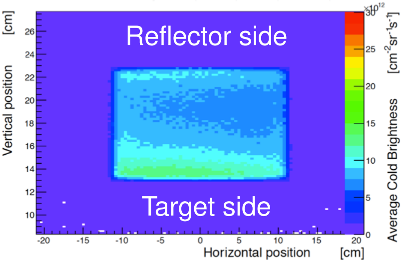


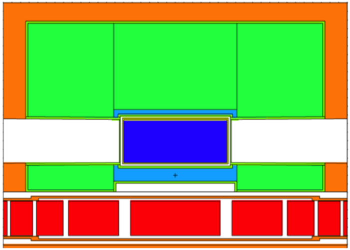


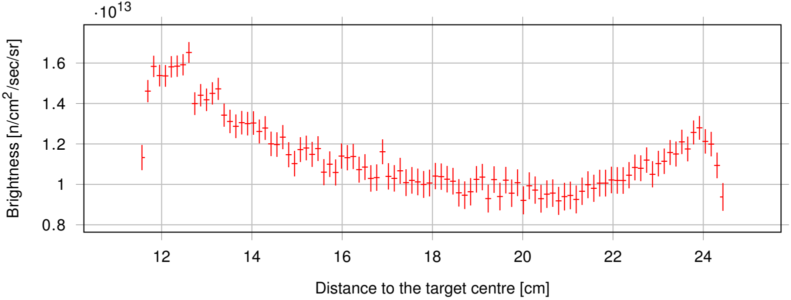
- Neutrons are effectively moderated within 1 – 2 cm of liquid hydrogen

Why flat moderators work

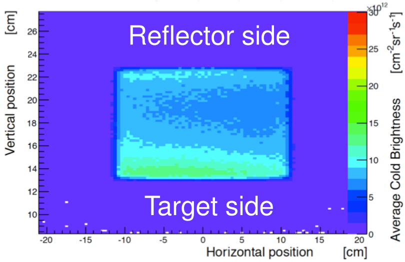
Cold neutron map in volume moderator

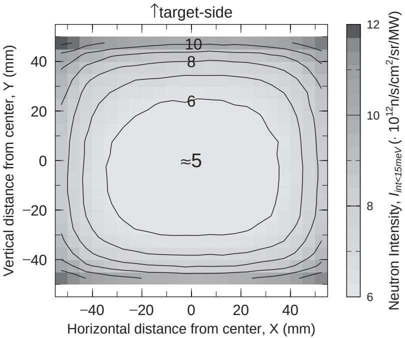






Why flat moderators work
Cold neutron map in volume moderator



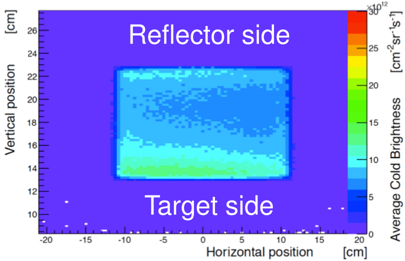


- Behaviour used and measured at J-PARC

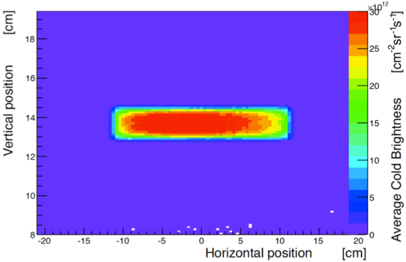
T. Kai, M. Harada, M. Teshigawara, N. Watanabe, Y. Ikeda
Coupled hydrogen moderator optimization with ortho/para hydrogen ratio
2004

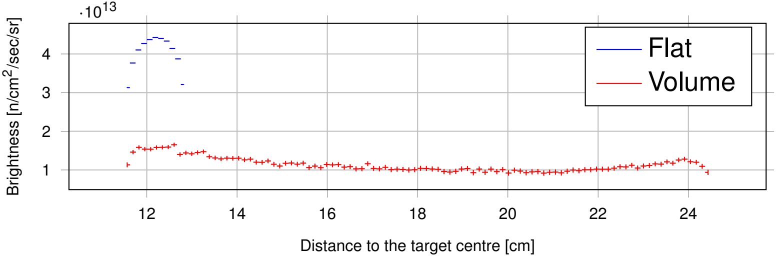
Why flat moderators work
Cold neutron maps in volume and flat moderators

Volume moderator

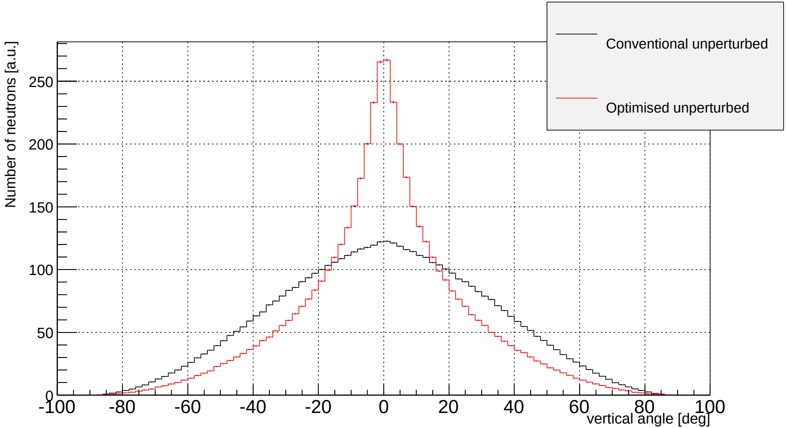


Flat moderator





Why flat moderators work
Angular distribution

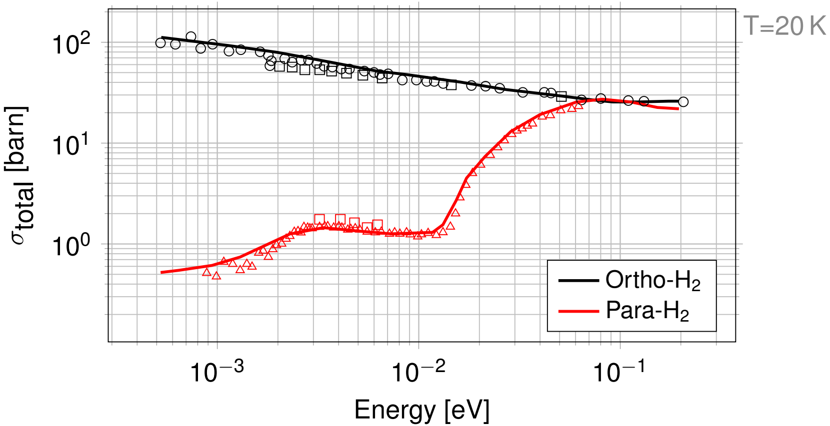


Flat moderator shows a strong effect at small vertical emission angles

[K. Batkov et al, 2013]

Properties of para-H_2

Scattering cross-section

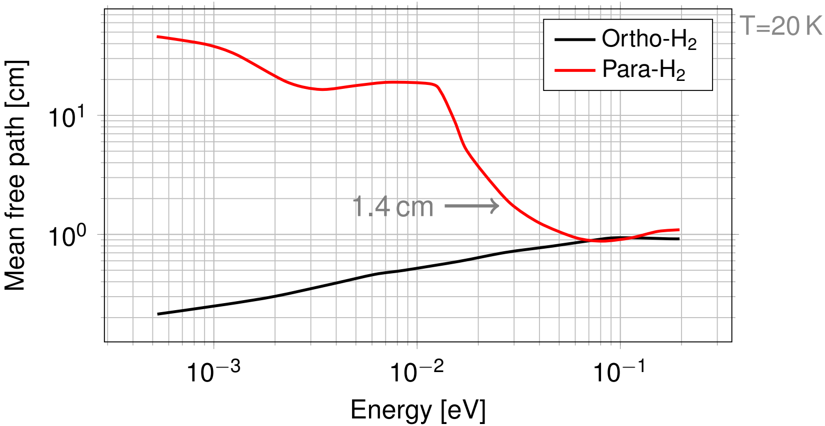


[N. Watanabe, Neutronics of pulsed spallation sources, 2003]

New para-H_2 data

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

Properties of para-H_2
Mean free path

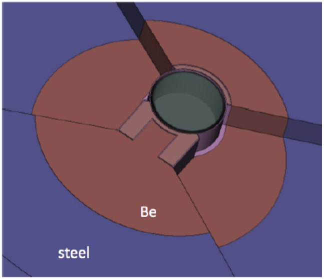


Mean free path below 50 meV becomes comparable to the height of the small optimised moderator, making the whole volume to be the source of neutrons.

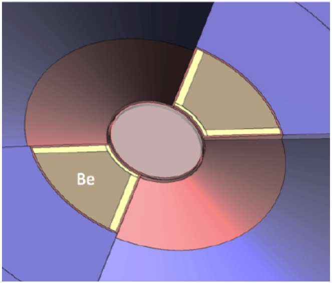
Why flat moderators work

Perturbation effect

Volume



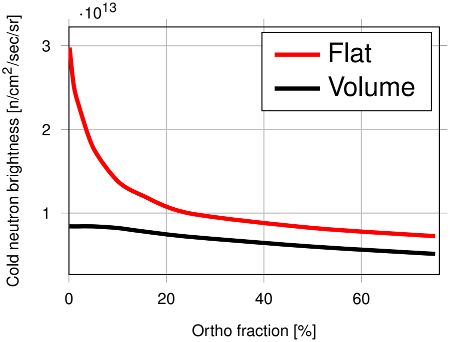
Flat



- Less reflector material is removed in the case of flat moderator $\Rightarrow$
- No difference between openings $2 \times 60^\circ$ and $2 \times 120^\circ$ $\Rightarrow$
- Possible to serve more instruments

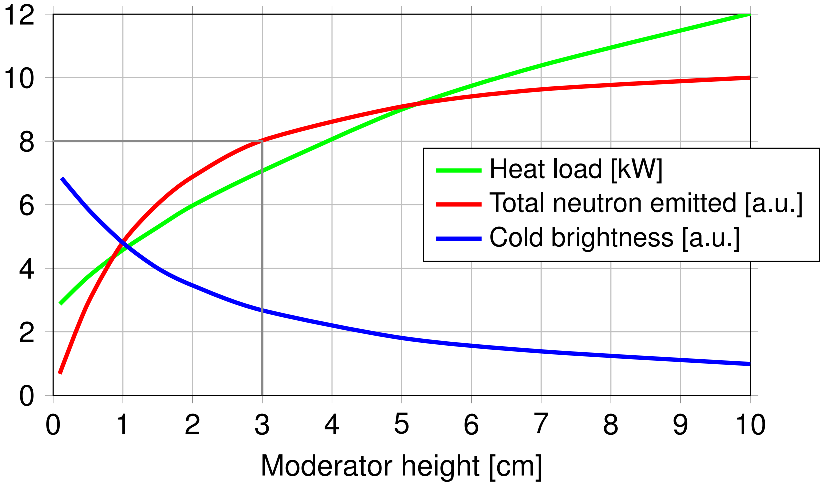
Importance of pure para-H_2

- Extreme dependency of the brightness on the purity of para-H_2
- Importance of the catalyst
- More than 99 % para measured at J-PARC



- Experimental measurements at high power required

Moderator should be as tall as needed by instruments



- At 3 cm 80 % of total neutrons emitted compared to maximum

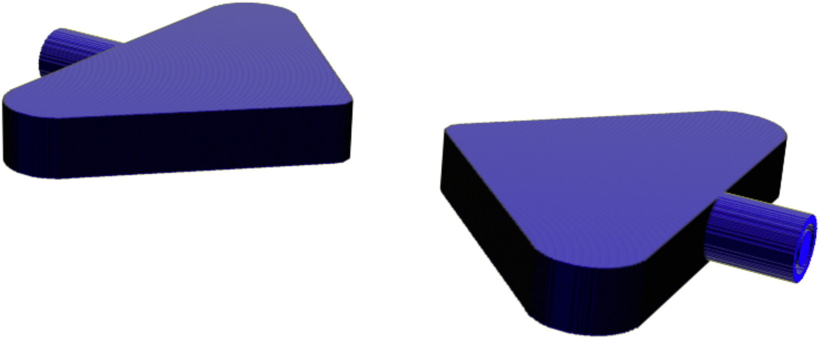
Why flat moderators work
Physics summary

- Neutrons are **effectively moderated within 1-2 cm** of para Hydrogen
- Para-hydrogen transparency window allows to **collect neutrons from depth**
- With respect to volume moderators:
  - **Less parasitic absorption** due to smaller amount of Hydrogen (with respect to volume moderators)
  - **Less perturbation** due to smaller amount of reflector removed
- However: very sensitive to **para-H_2 purity**

Outline

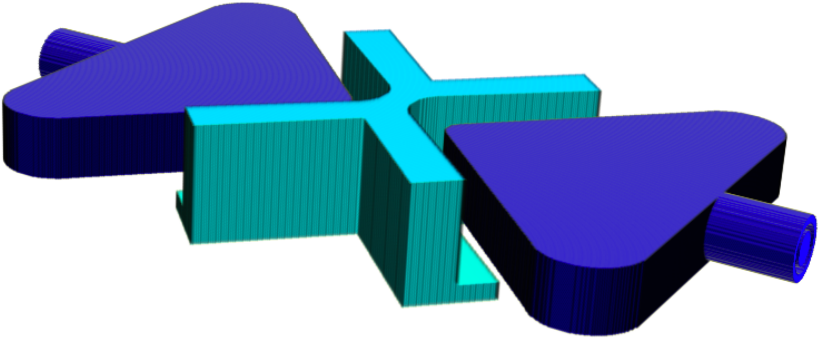
Butterfly moderator

Para-H_2



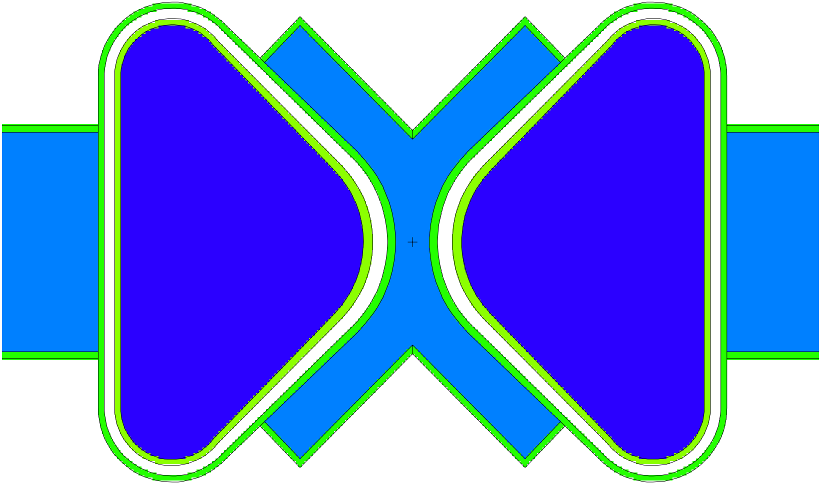
Butterfly moderator

Para-H_2 and water



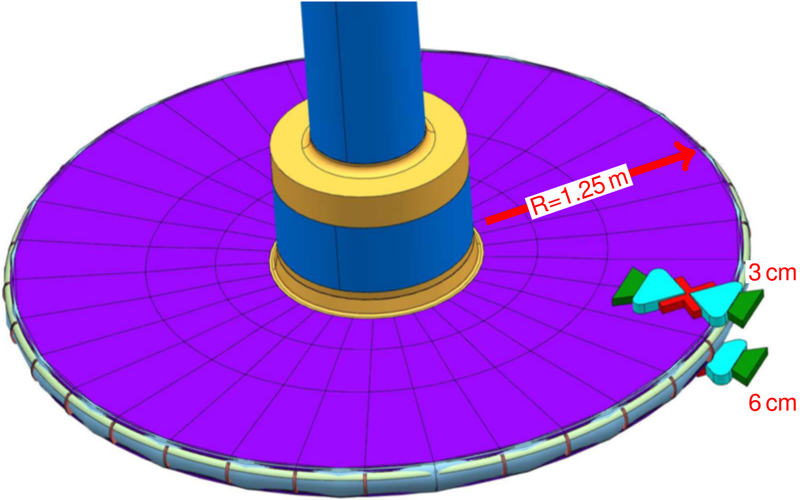
Butterfly moderator

Horizontal cut



Butterfly moderator

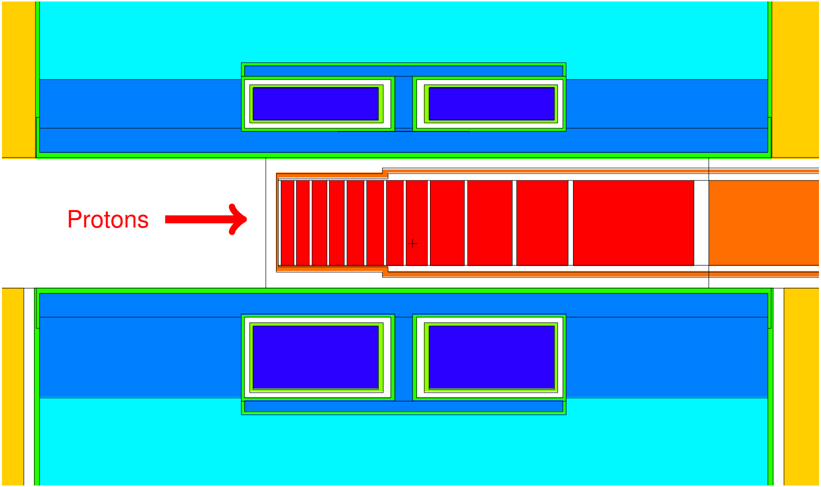
Target wheel and Moderators



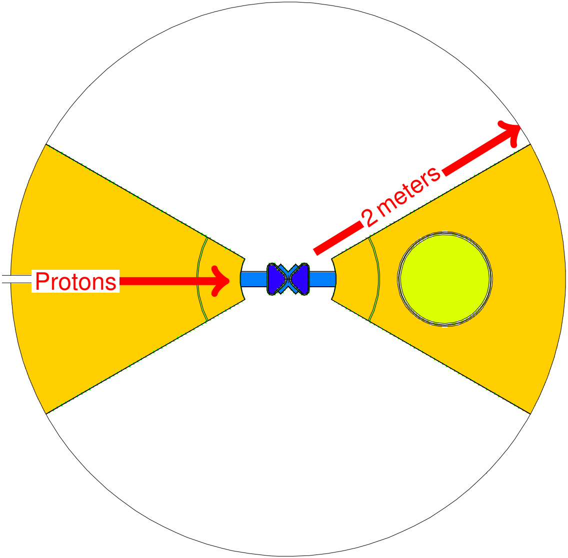
[Bengt Jönsson]

Butterfly moderator

Target wheel and Moderators: vertical cut

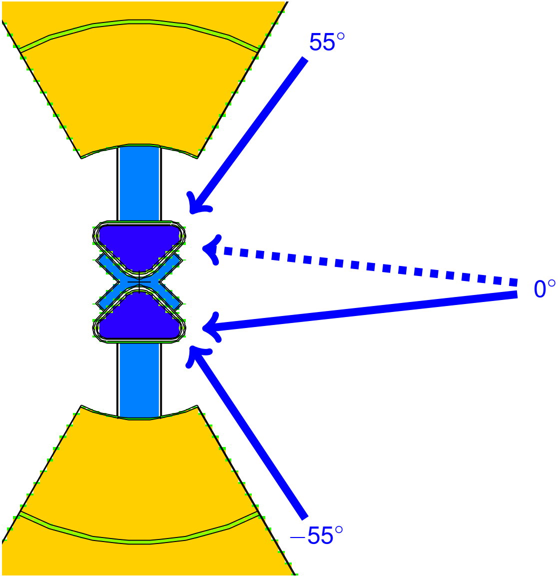


Butterfly moderator
Horizontal view



Butterfly moderator

Cold neutron extraction



Butterfly moderator

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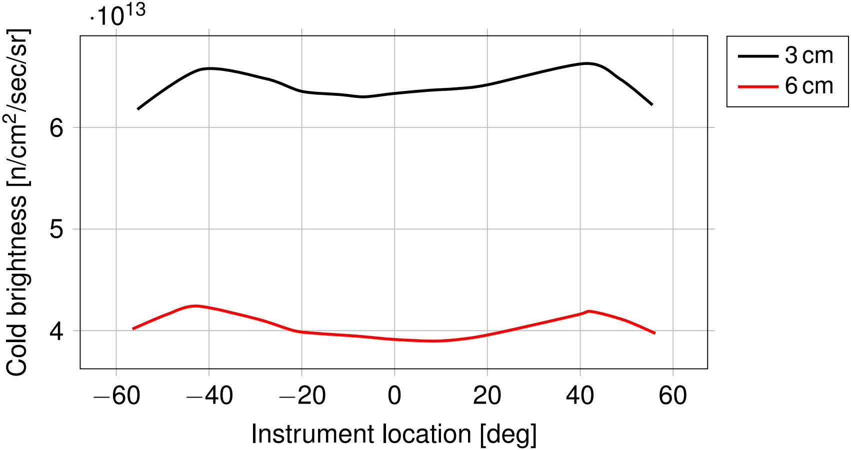
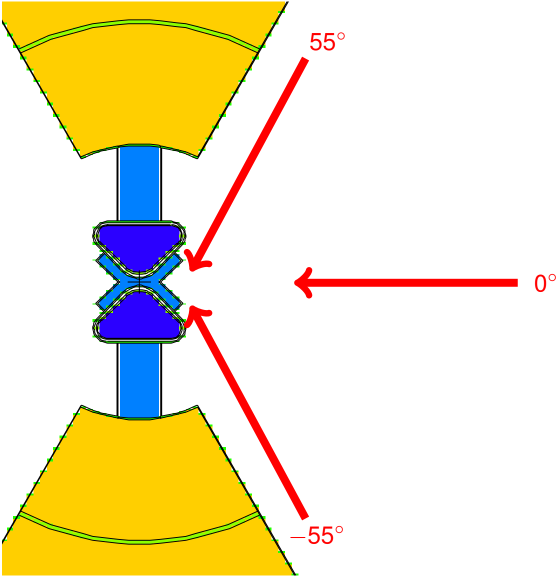


[Esben Klinkby, TAC11, page 17]

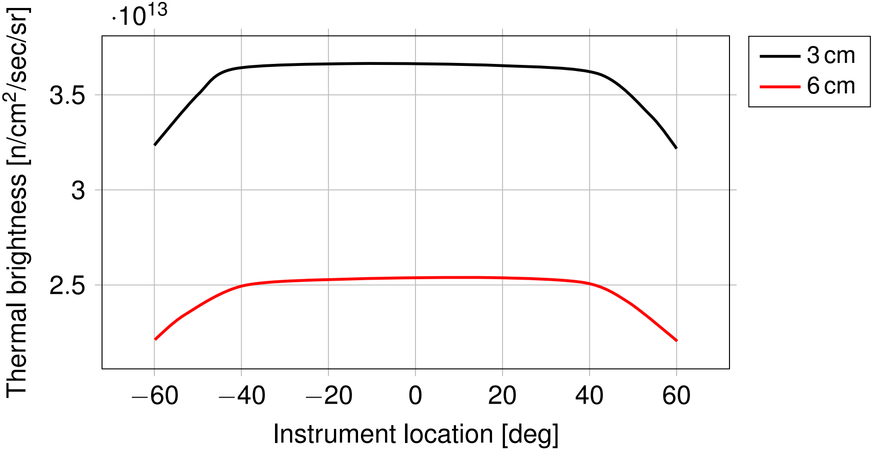
Statistical errors ∼ 1 %

Butterfly moderator

Thermal neutron extraction



Butterfly moderator
Thermal neutron extraction

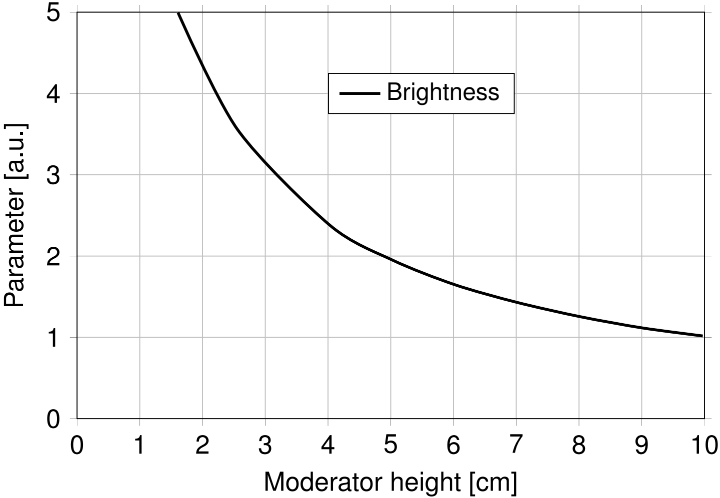


[Esben Klinkby, TAC11, page 17]

Statistical errors $\sim 1\,\%$

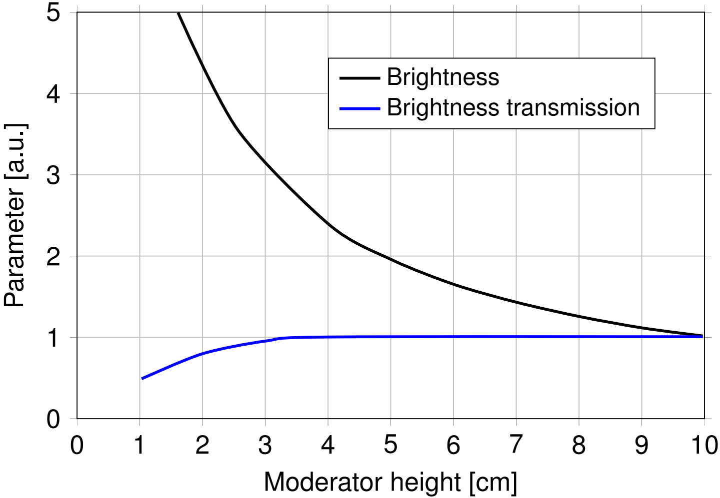
Outline

Optimisation of Instrument Suite
Example 1: NMX — macromolecular diffractometer



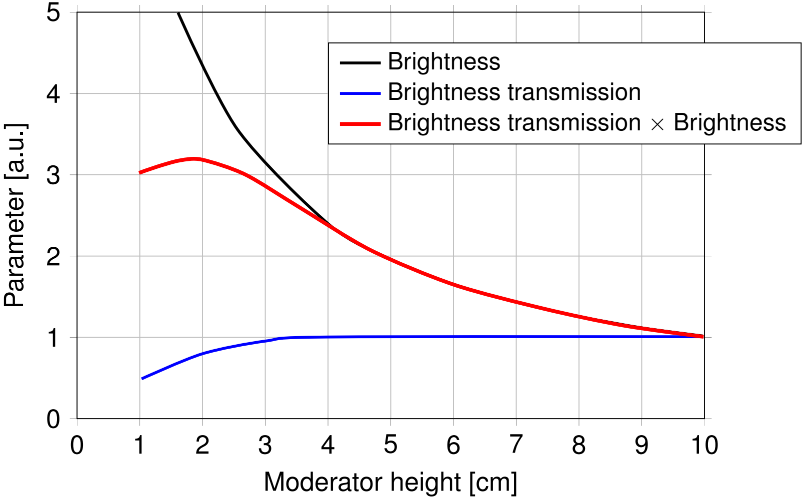
[Data provided by Ken Andersen, ESS]

Optimisation of Instrument Suite
Example 1: NMX — macromolecular diffractometer



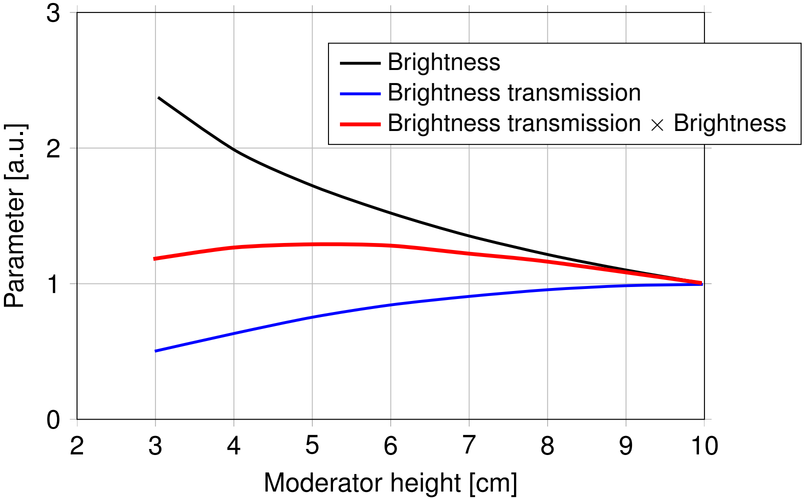
[Data provided by Ken Andersen, ESS]

Optimisation of Instrument Suite
Example 1: NMX — macromolecular diffractometer



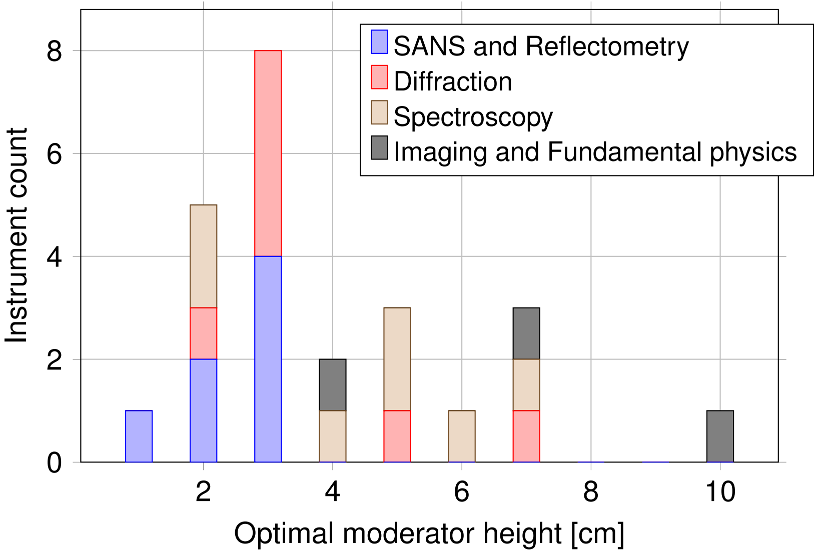
[Data provided by Ken Andersen, ESS]

Optimisation of Instrument Suite
Example 2: ESSENSE — spin echo spectroscopy



[Data provided by Ken Andersen, ESS]

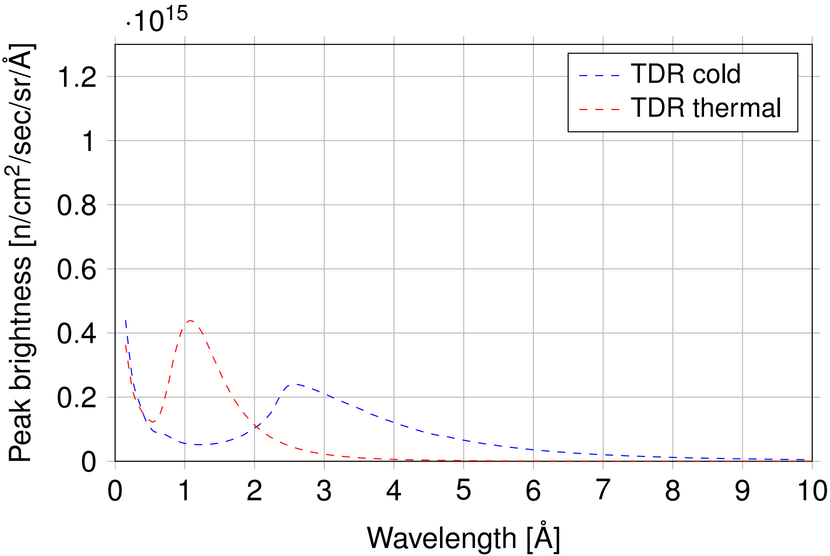
Optimisation of Instrument Suite
Optimal moderator height



[Ken Andersen, Moderator/Instruments Meeting, 6 June 2014]

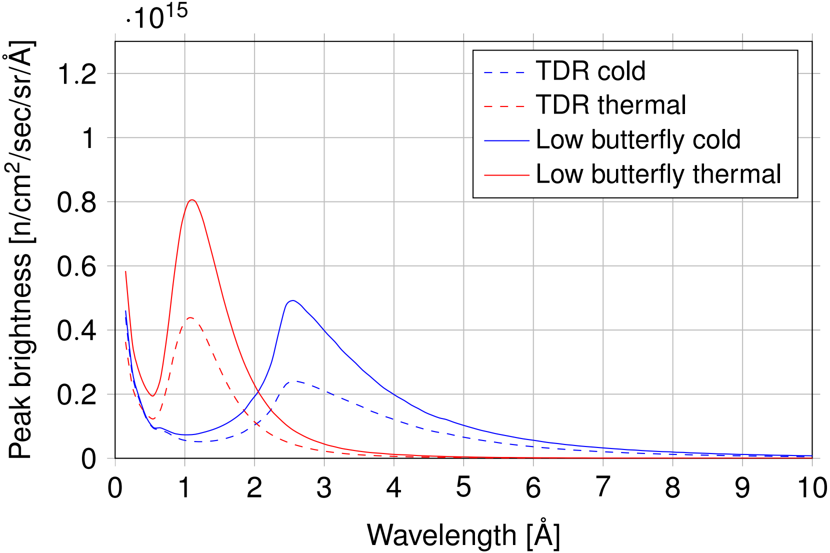
Outline

Wavelength spectra



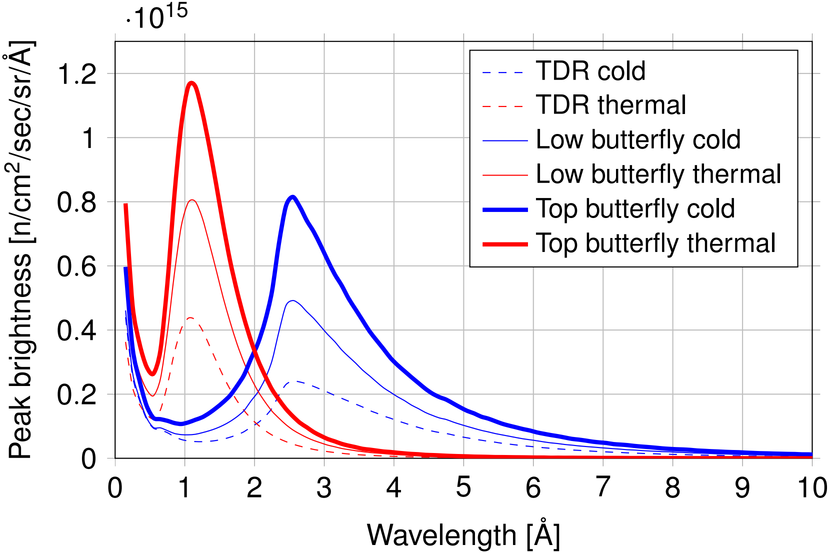
Statistical errors $< 5\,\%$

Wavelength spectra



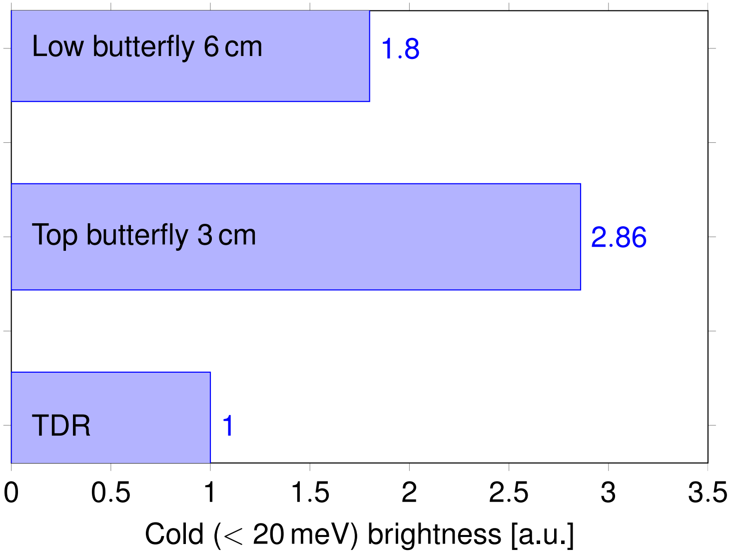
Statistical errors $< 5\,\%$

Wavelength spectra

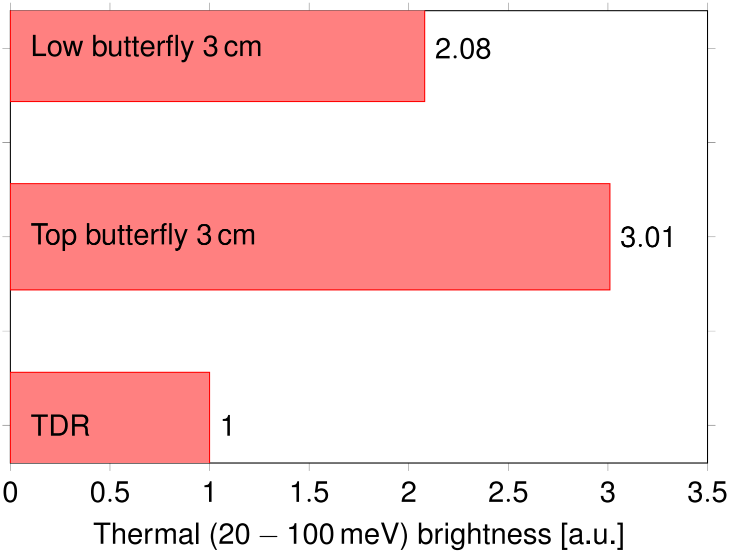


Statistical errors $< 5\,\%$

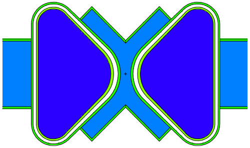
Integrated brightness



Integrated brightness



Conclusions



- Two butterfly moderators, each serving 2 × 120° sector
  - Upper: 3 cm tall
  - Lower: 6 cm tall
- Exploits all neutronic design criteria developed
- Optimal beam extraction
  - Flexible to place instruments
  - Flexible for instruments to choose moderator
  - Optimal for bispectral instruments
- Feasible engineering

References

- F. Mezei, L. Zanini, A. Takibayev, K. Batkov, E. Klinkby, E. Pitcher, T. Schönfeldt,
  Low dimensional neutron moderators for enhanced source brightness
  arXiv:1311.2474
  2013

- K. Batkov, A. Takibayev, L. Zanini, F. Mezei
  Unperturbed moderator brightness in pulsed neutron sources
  Nuclear Instruments & Methods in Physics Research A
  http://dx.doi.org/10.1016/j.nima.2013.07.031
  2013

Thank you for your attention

New para-H cross-section
by K. B. Grammer *et al*, 2015

PHYSICAL REVIEW B **91**, 180301(R) (2015)

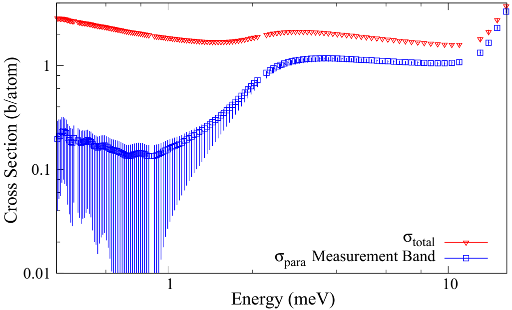


FIG. 6. (Color online) Total cross section from this work in b/atom (triangles); parahydrogen scattering cross section (squares). The upper error bar on the parahydrogen cross section comes from Table I and the lower error bar is given by the upper limit on the orthohydrogen contamination.

Back