EUROPEAN
SPALLATION
SOURCE

ESS

Flat moderators neutronics

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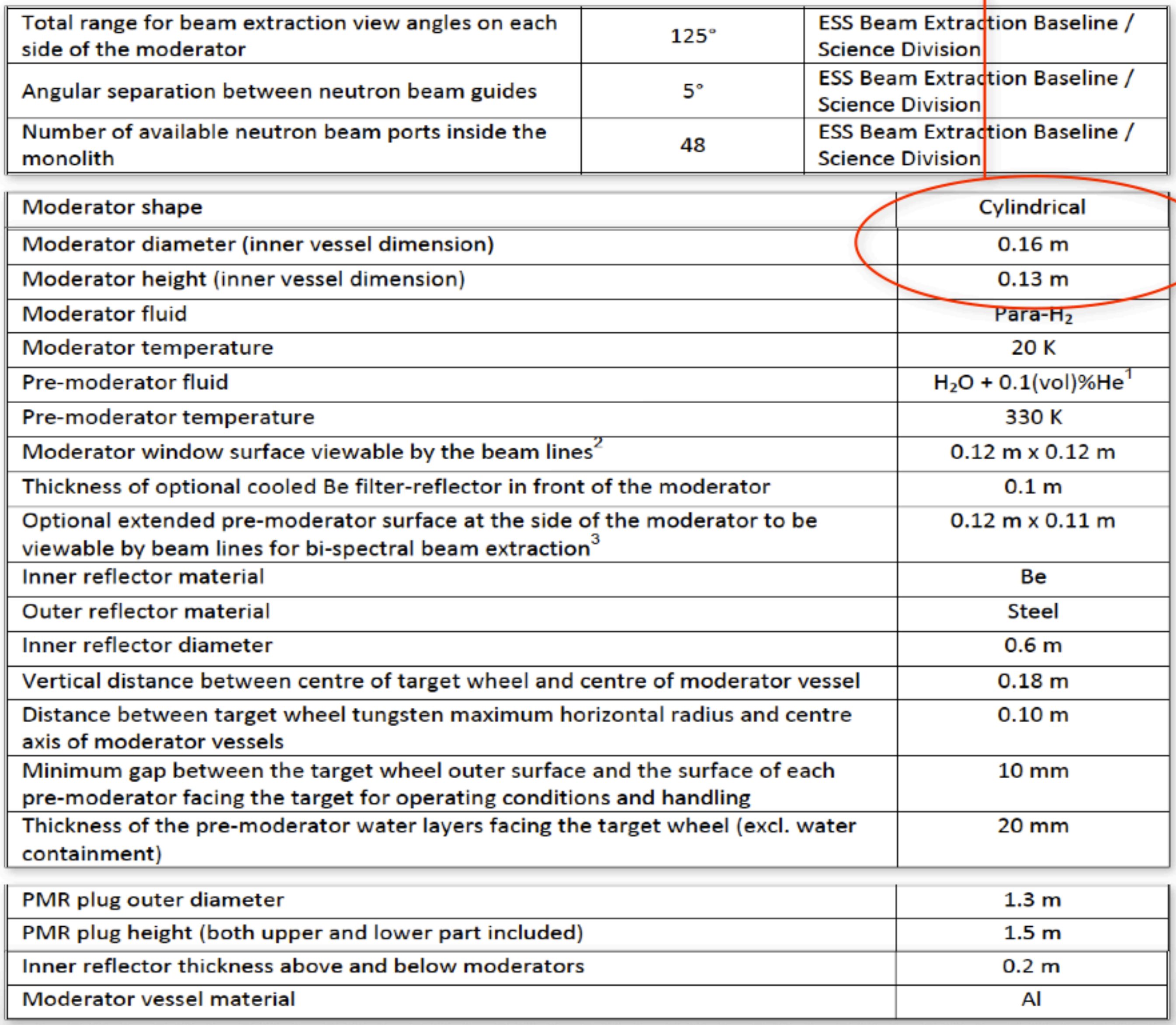
ESS 2014-1-24

The baseline



Conventional Moderator

Total range for beam extraction view angles on each side of the moderator	125°	ESS Beam Extraction Baseline / Science Division
Angular separation between neutron beam guides	5°	ESS Beam Extraction Baseline / Science Division
Number of available neutron beam ports inside the monolith	48	ESS Beam Extraction Baseline / Science Division

Moderator shape	Cylindrical
Moderator diameter (inner vessel dimension)	0.16 m
Moderator height (inner vessel dimension)	0.13 m
Moderator fluid	Para-H_2
Moderator temperature	20 K
Pre-moderator fluid	H_2O + 0.1(vol)%He[1]
Pre-moderator temperature	330 K
Moderator window surface viewable by the beam lines[2]	0.12 m x 0.12 m
Thickness of optional cooled Be filter-reflector in front of the moderator	0.1 m
Optional extended pre-moderator surface at the side of the moderator to be viewable by beam lines for bi-spectral beam extraction[3]	0.12 m x 0.11 m
Inner reflector material	Be
Outer reflector material	Steel
Inner reflector diameter	0.6 m
Vertical distance between centre of target wheel and centre of moderator vessel	0.18 m
Distance between target wheel tungsten maximum horizontal radius and centre axis of moderator vessels	0.10 m
Minimum gap between the target wheel outer surface and the surface of each pre-moderator facing the target for operating conditions and handling	10 mm
Thickness of the pre-moderator water layers facing the target wheel (excl. water containment)	20 mm

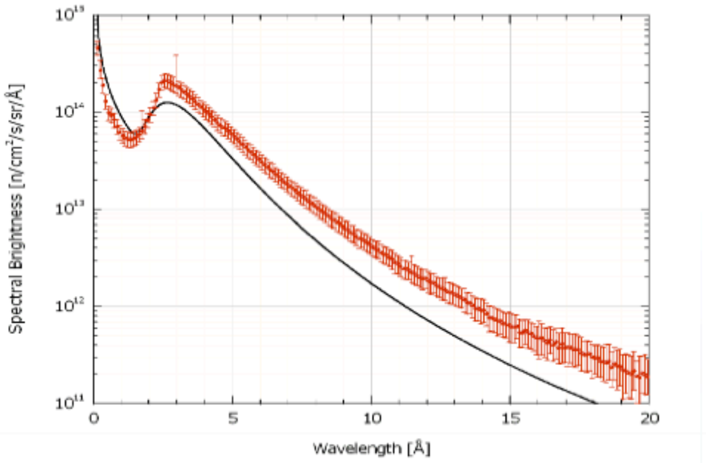
PMR plug outer diameter	1.3 m
PMR plug height (both upper and lower part included)	1.5 m
Inner reflector thickness above and below moderators	0.2 m
Moderator vessel material	Al

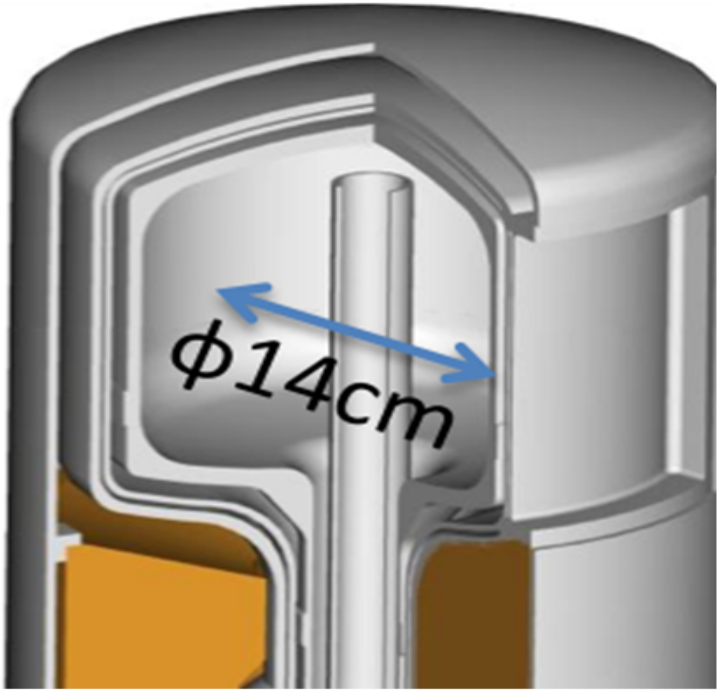
High performance cold moderator

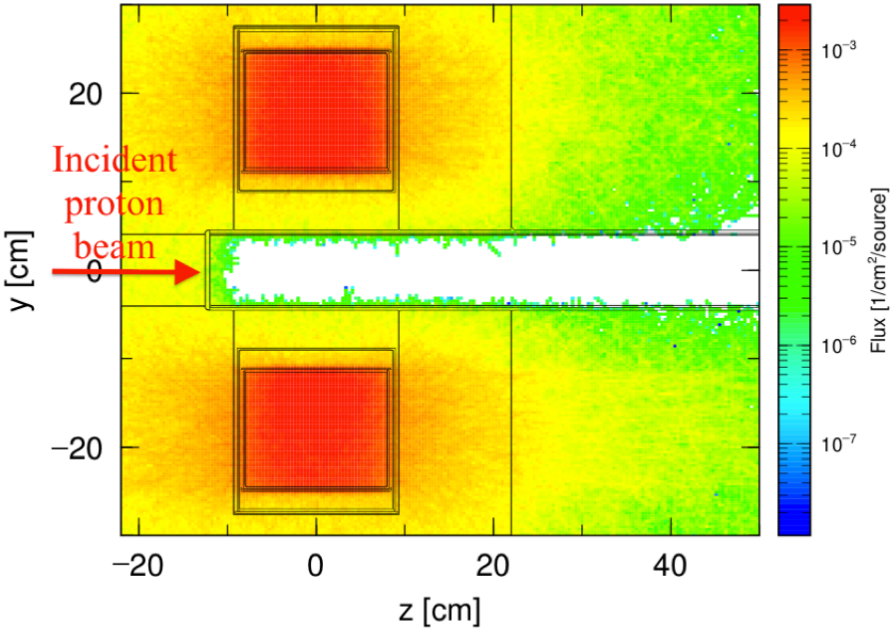
Volume moderator:

implemented at J-PARC

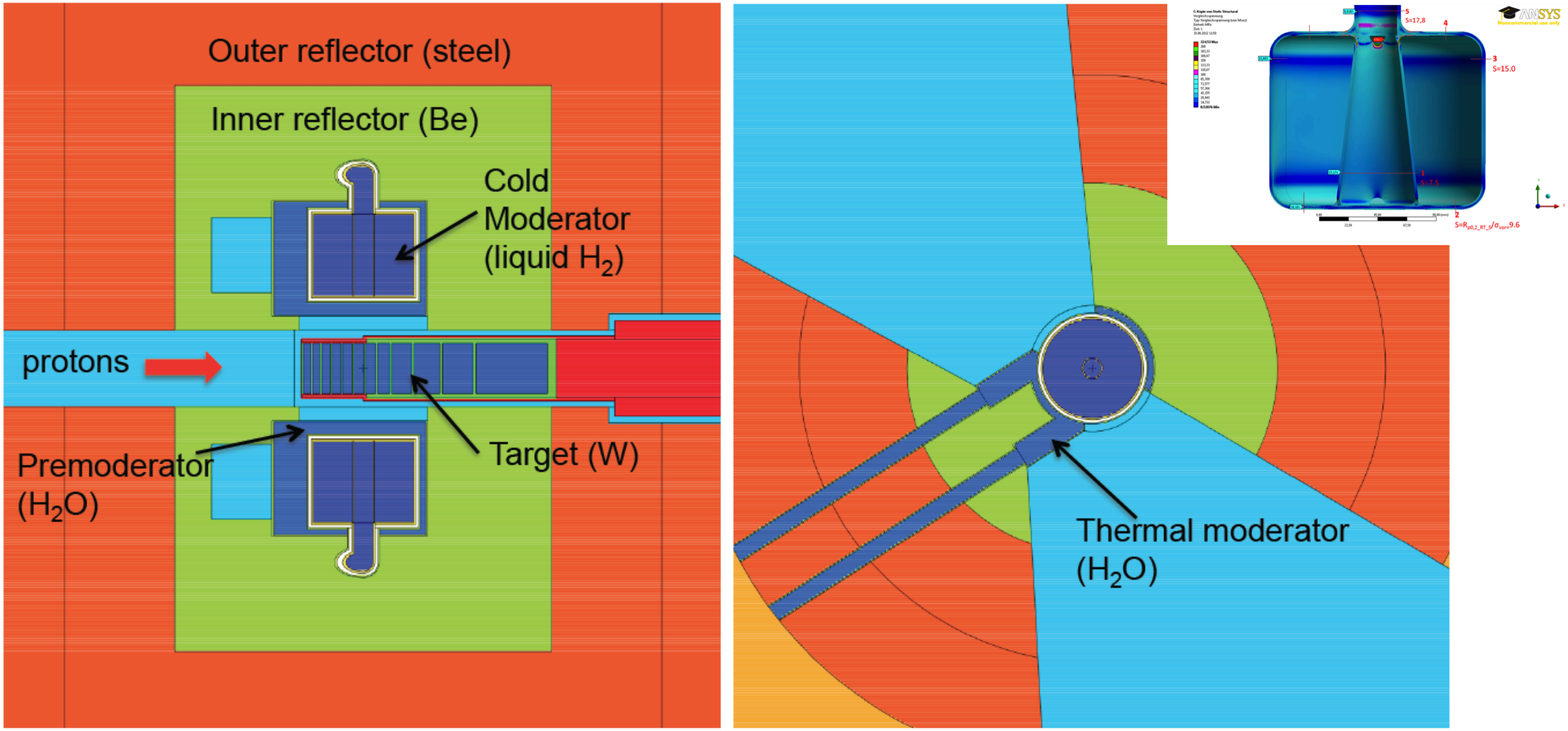
99 % para-H_2 tested





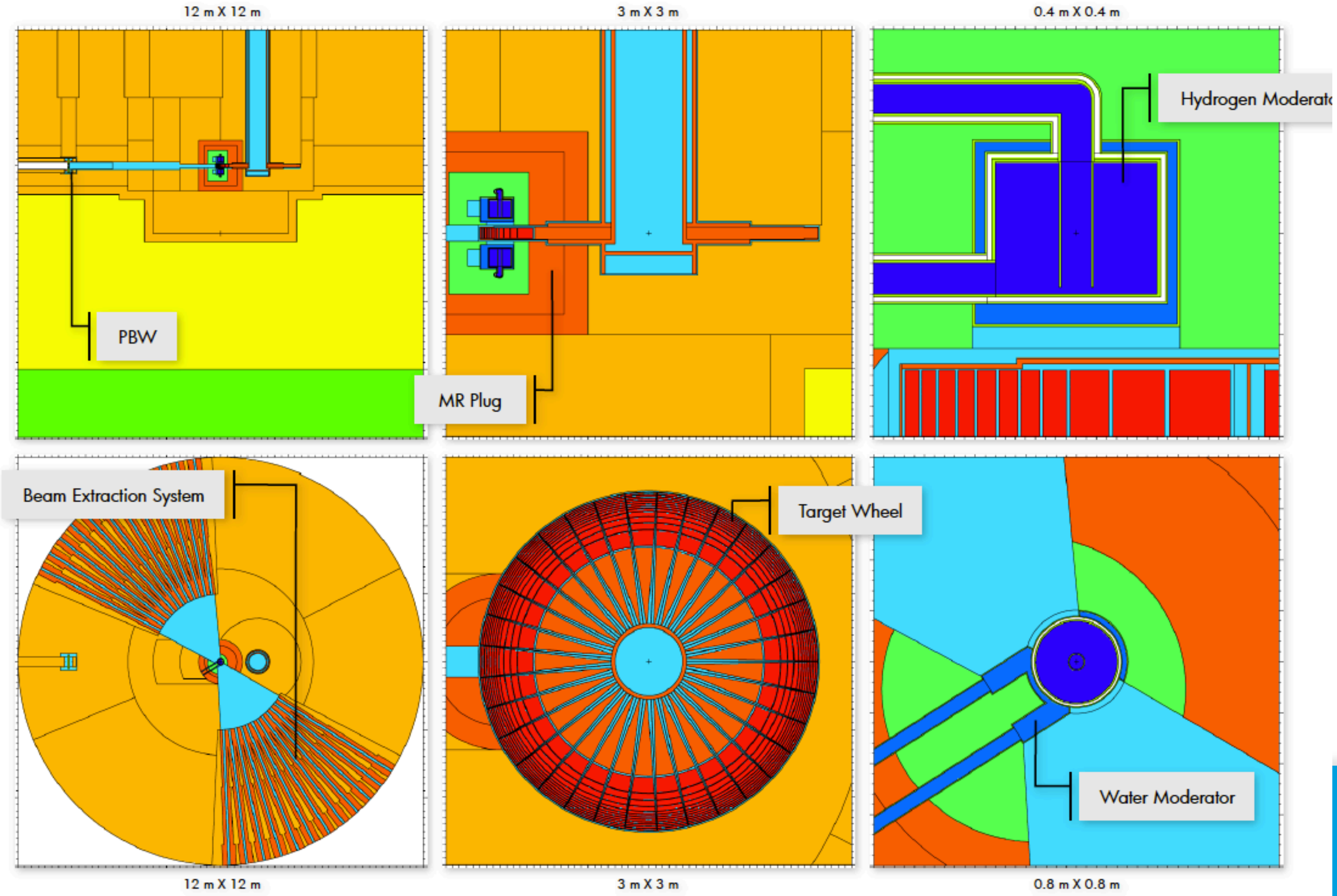


The TDR baseline design is a volume para-hydrogen moderator (13 cm high x 16 cm ø)

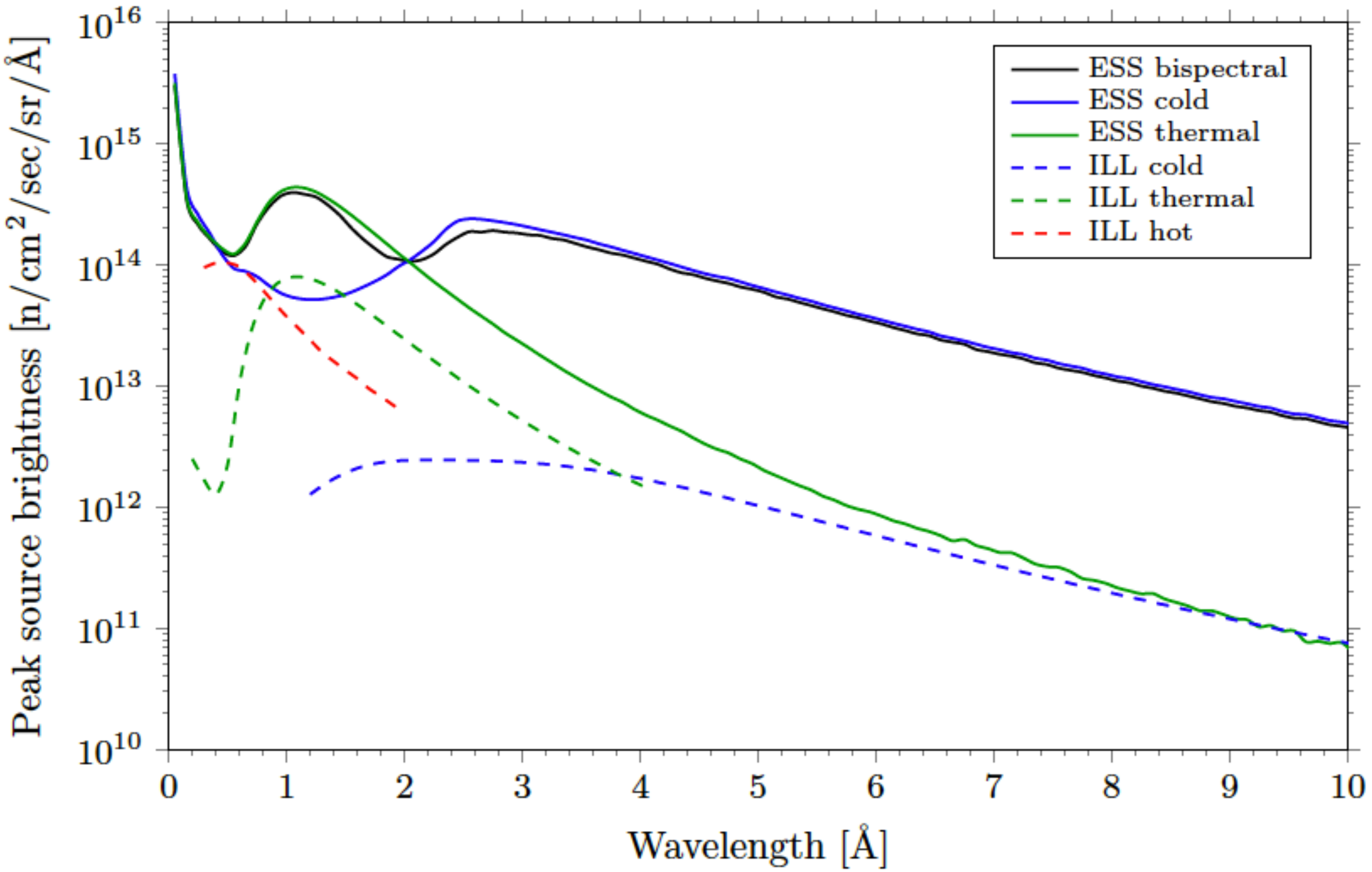


Thermal wings provide a bi-spectral source.

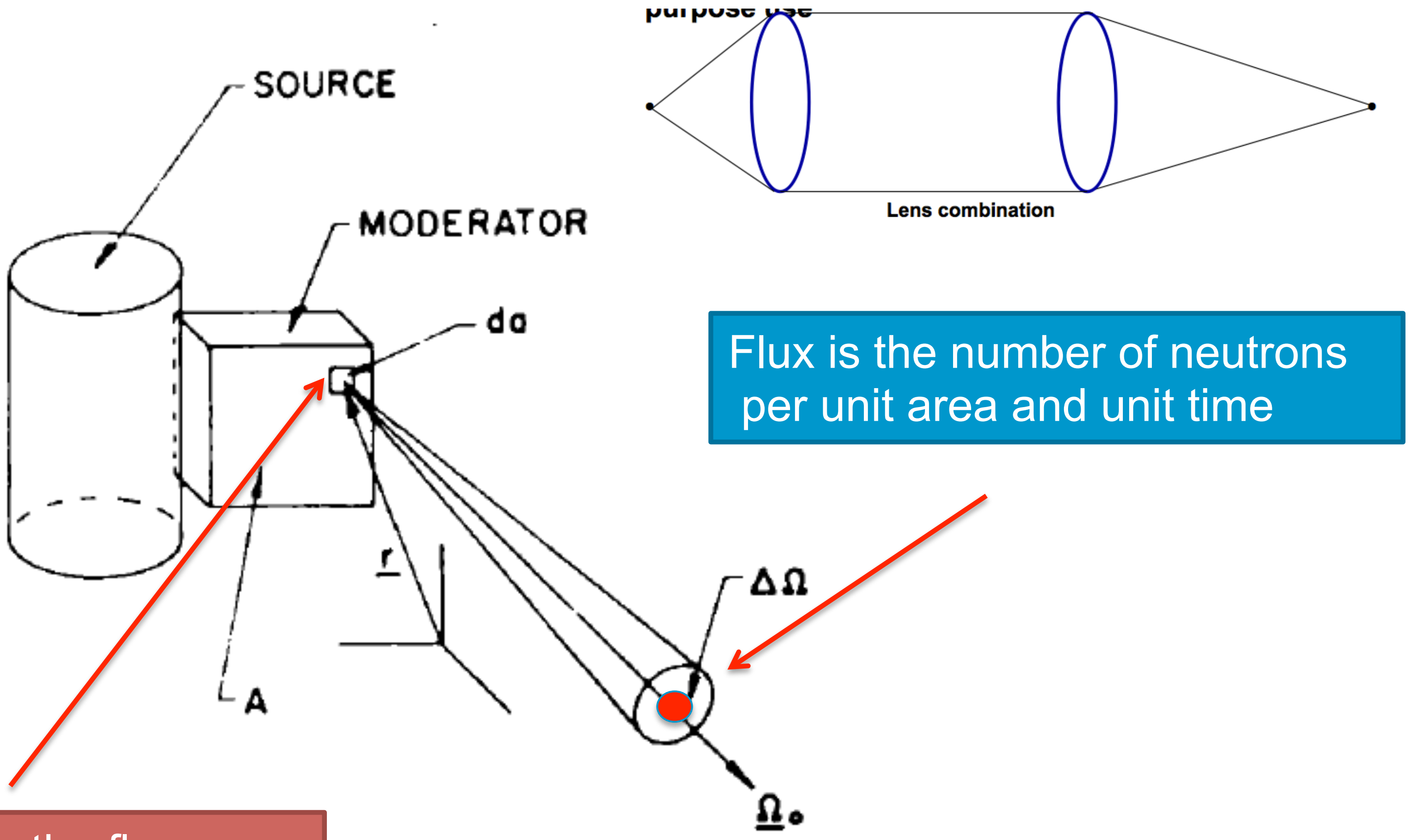
Target station monolith design (Alan Takibayev)



Unprecedented neutronic performance



Flux or Brightness ?



Flux is the number of neutrons per unit area and unit time

Brightness is the flux, divided by unit solid angle

Brightness

- It refers to the source of the neutrons (the moderator)
- It does not depend on the distance from the source

- However, the story is more complex:
  - There are losses of neutrons in the guides (brilliance transfer)
  - Instruments want high-quality beams (low divergence)
  - Samples are of different sizes

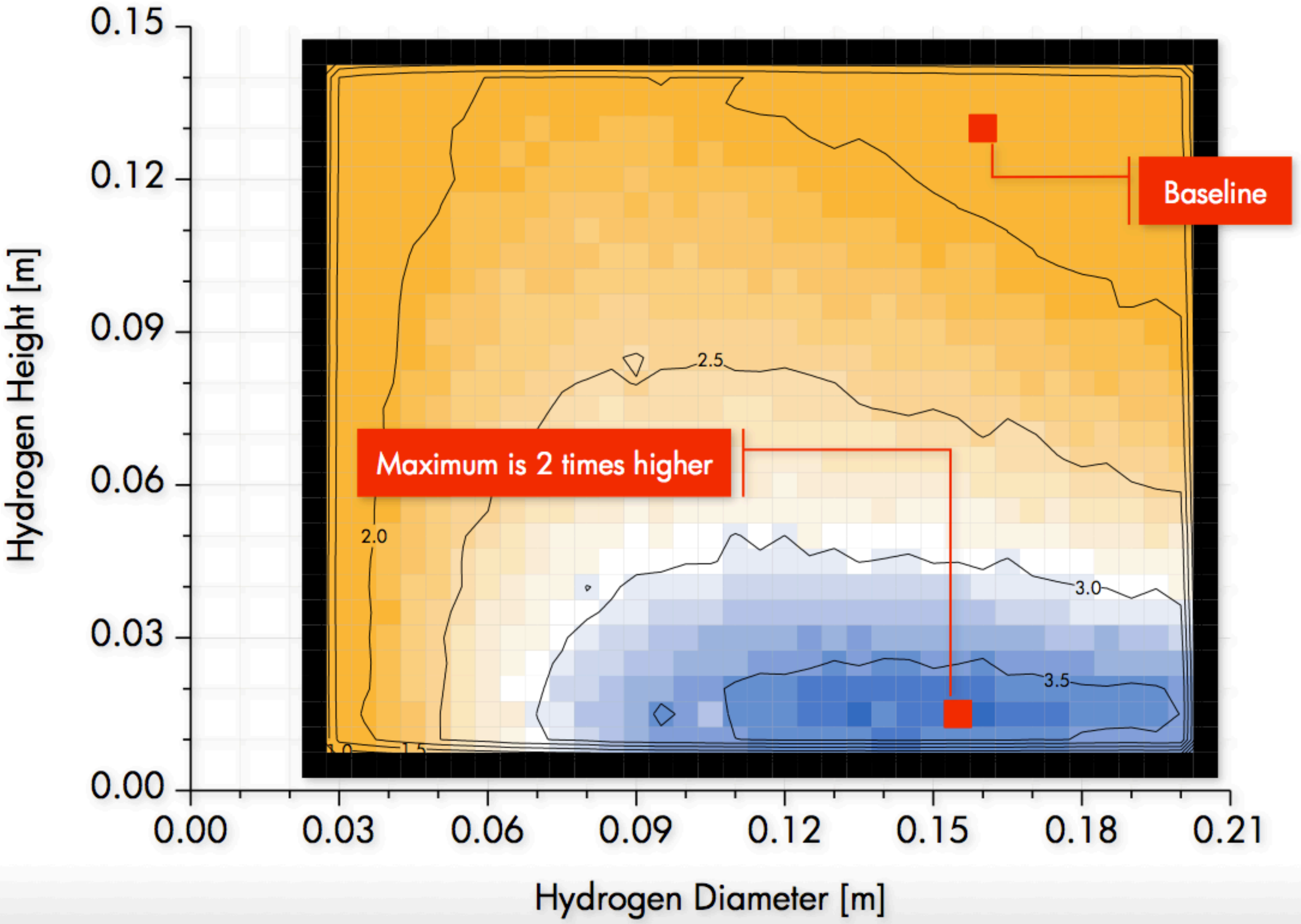
A global effort

- So the ultimate figure of merit, the number of ‘good’ neutrons at the sample, will depend on:
  - The moderator brightness
  - The brilliance transfer

  - It is a job that needs to be done together between moderator neutronics, neutron guide, and instrument users

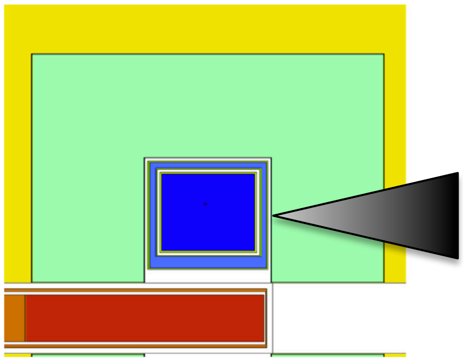
Moderator Brightness

We start from the *unperturbed* brightness


Map of cold brightness < 5 meV | Ref:. NIMA 729 (2013) 500-505

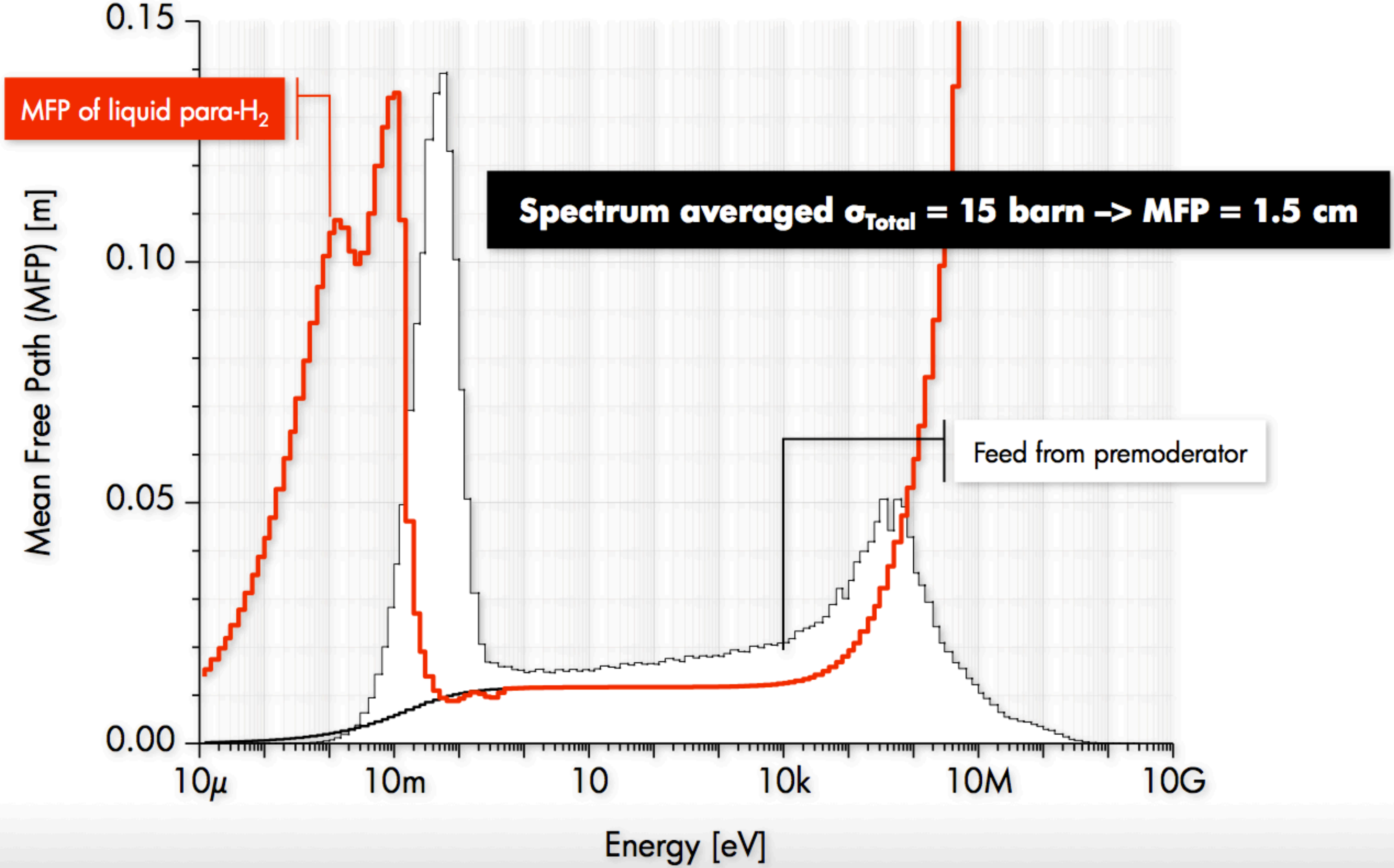
Baseline

Maximum is 2 times higher



Why flat moderators work

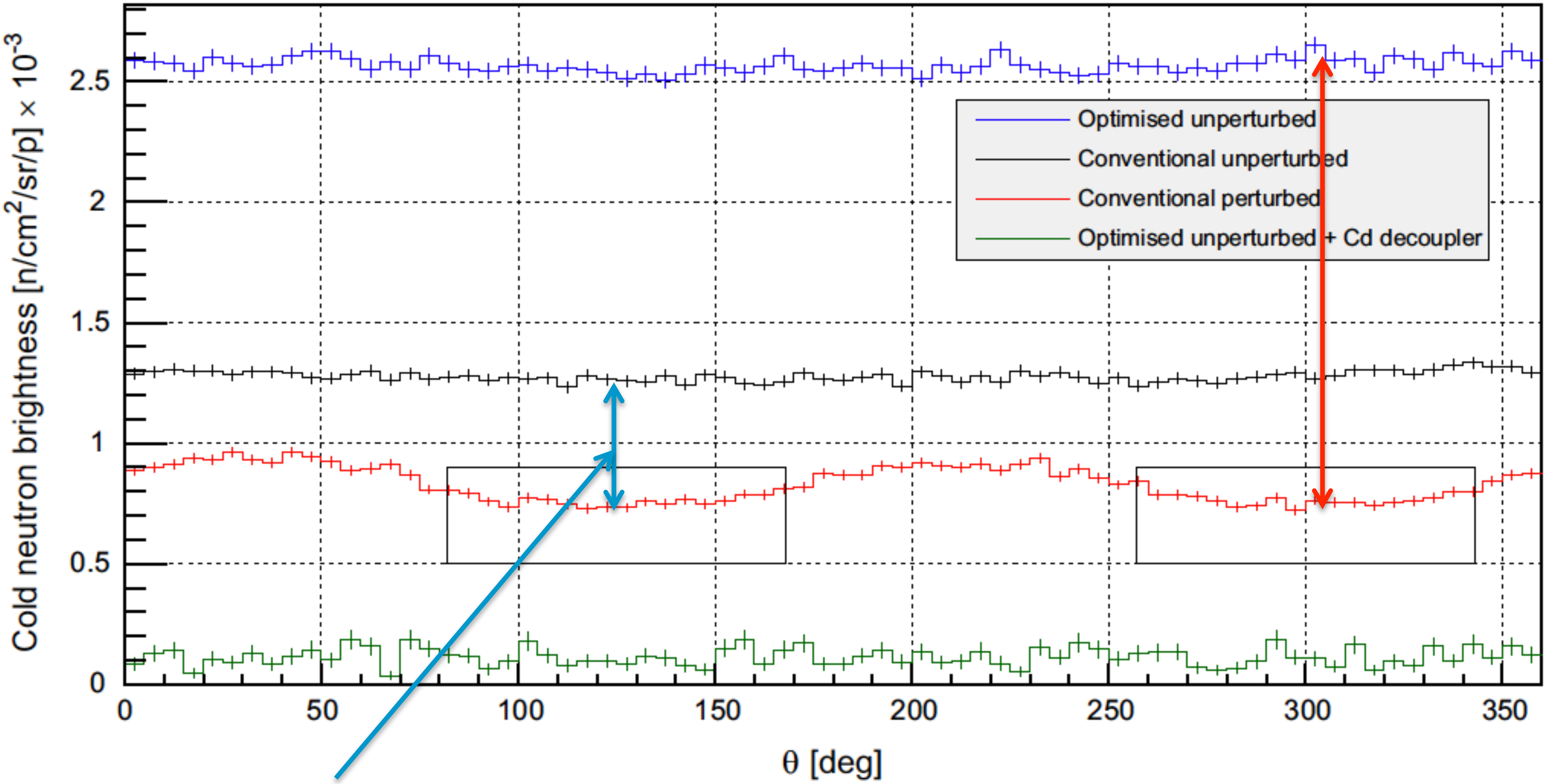
1.5 cm of liquid para-H_2 is enough to moderate neutrons



Spectrum averaged σ_{Total} = 15 barn –> MFP = 1.5 cm

Feed from premoderator

Effects of the beam extraction lines (perturbation)

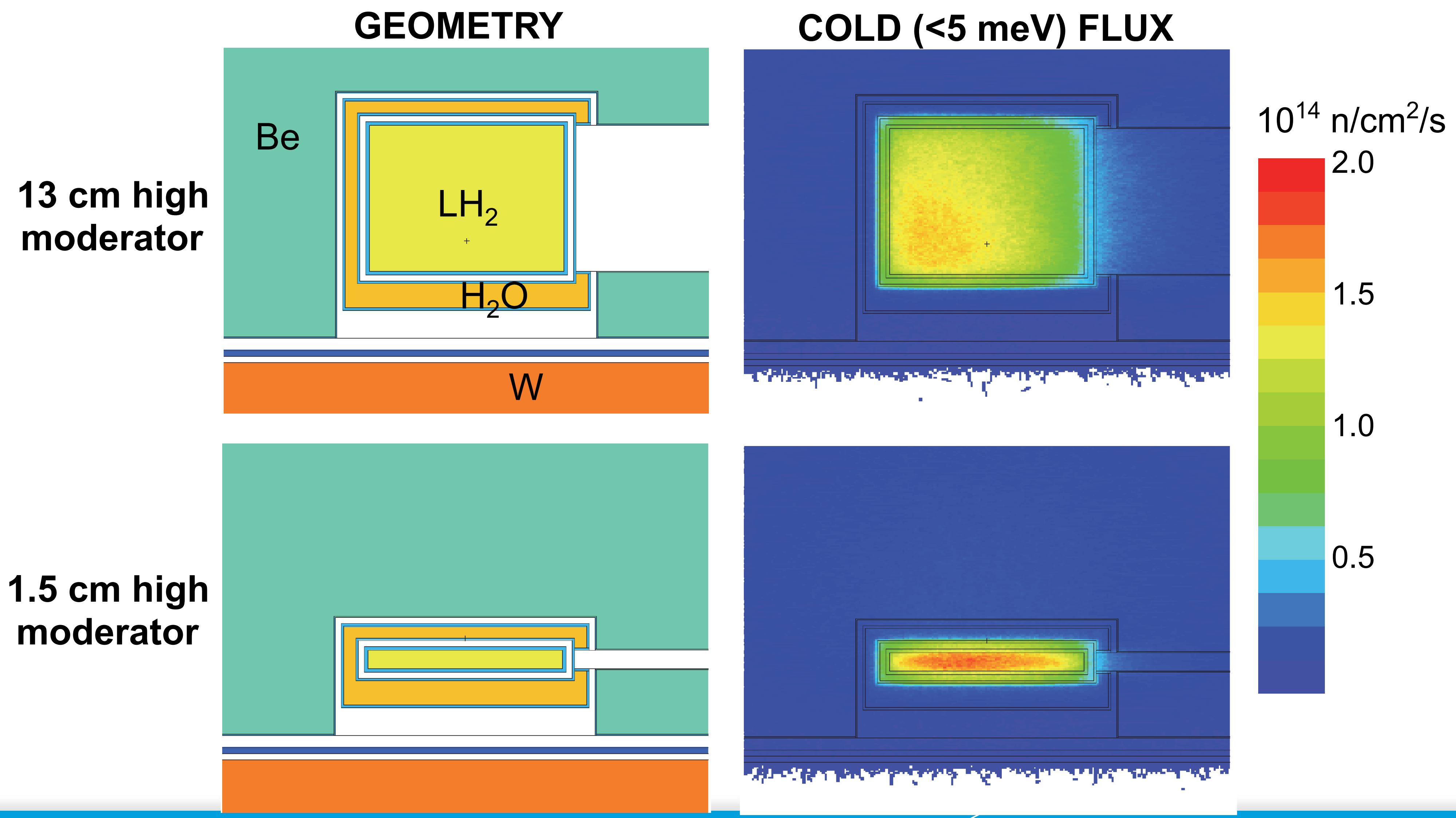


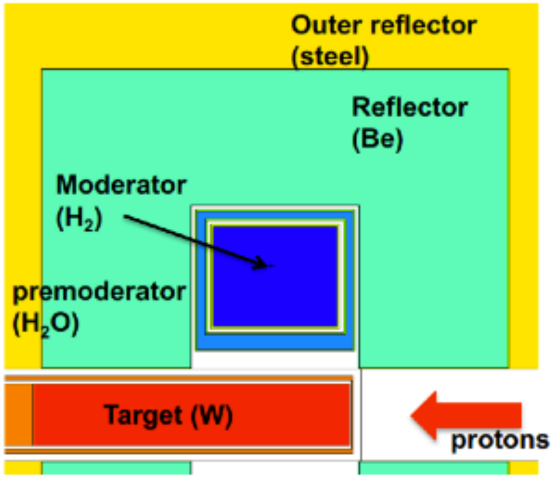
Perturbation of a flat moderator is expected to reduce only slightly the performance

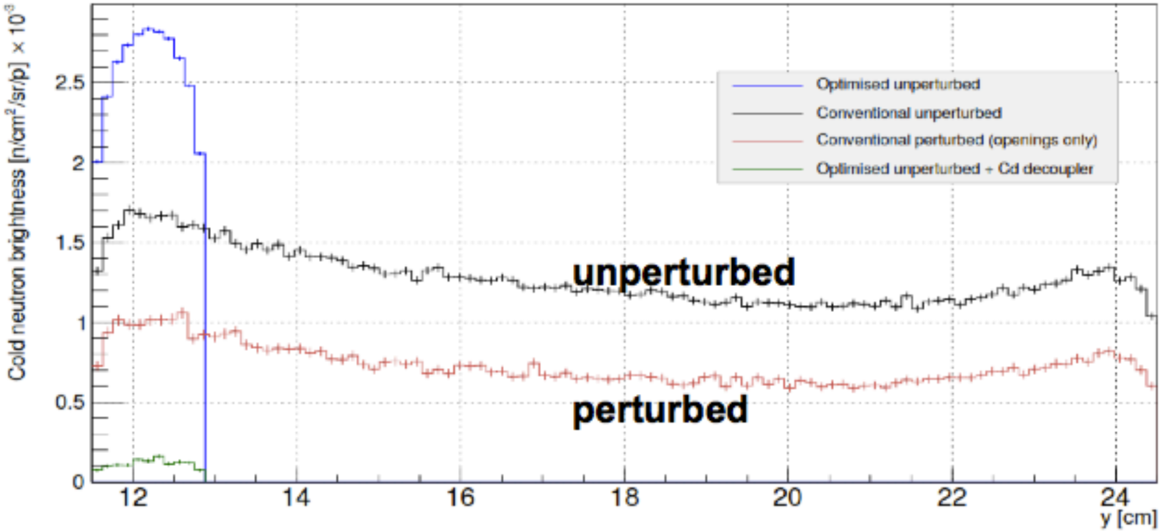
Perturbation of a conventional moderator means removing a lot of reflector

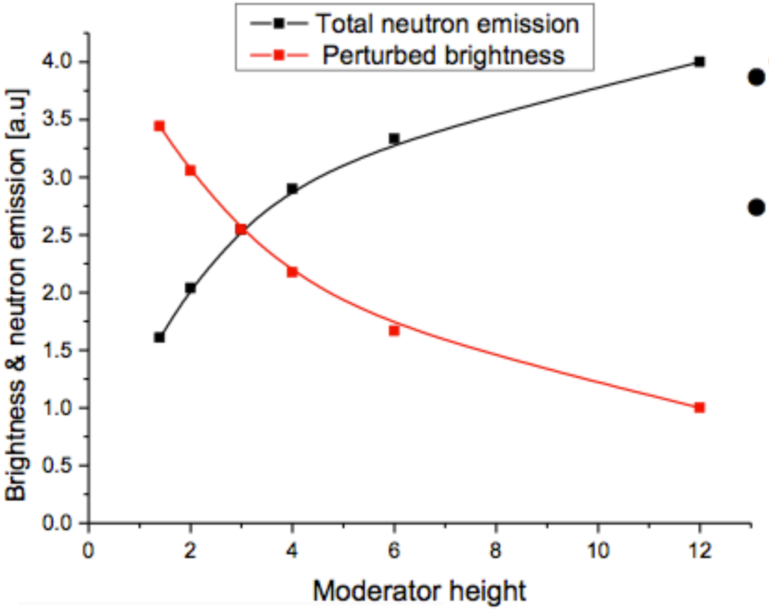
BIGGER GAINS (> 3) EXPECTED FOR THE PERTURBED (=REAL) CASE !

Neutron maps conventional vs flat



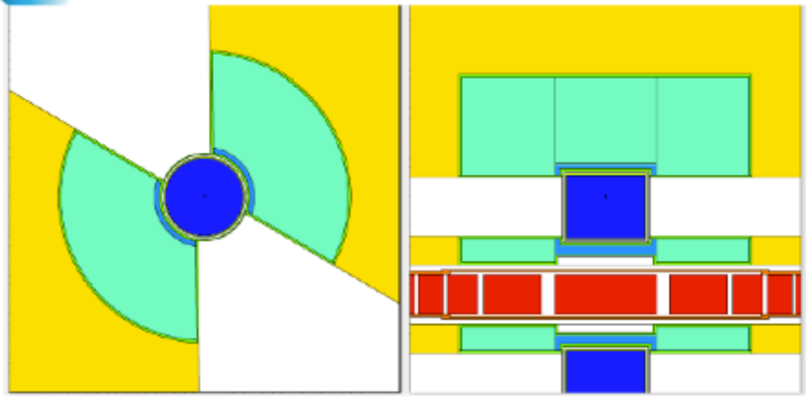


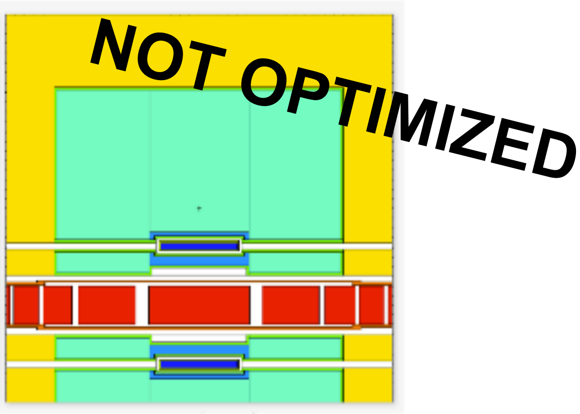




- Trend **even stronger for the perturbed flux**
- Also applies to the thermal flux from water moderator / Be reflector

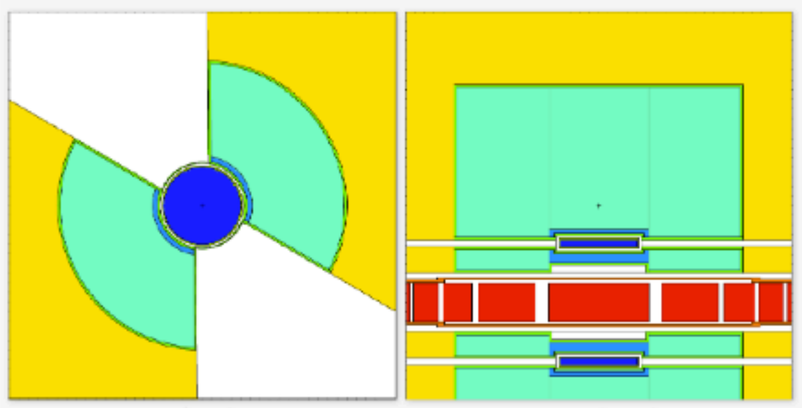
From volume to flat moderator

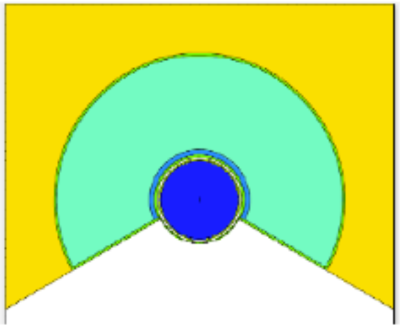




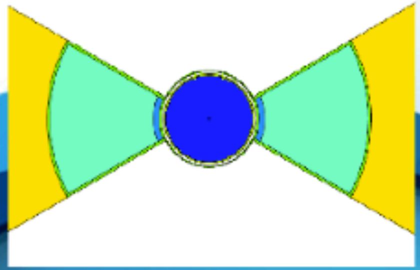
Gain 3.2
(13% perturbation loss)

Considering different opening options:





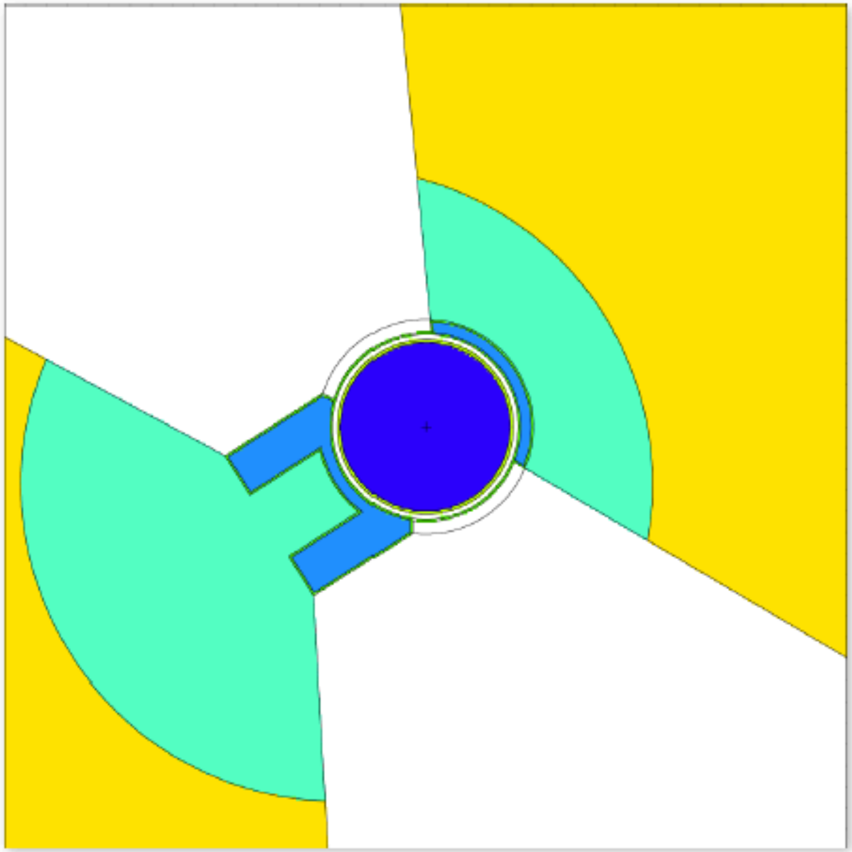
Gain 3.0



Gain 2.8

There is not a big loss due to perturbation, even for two 120 openings!

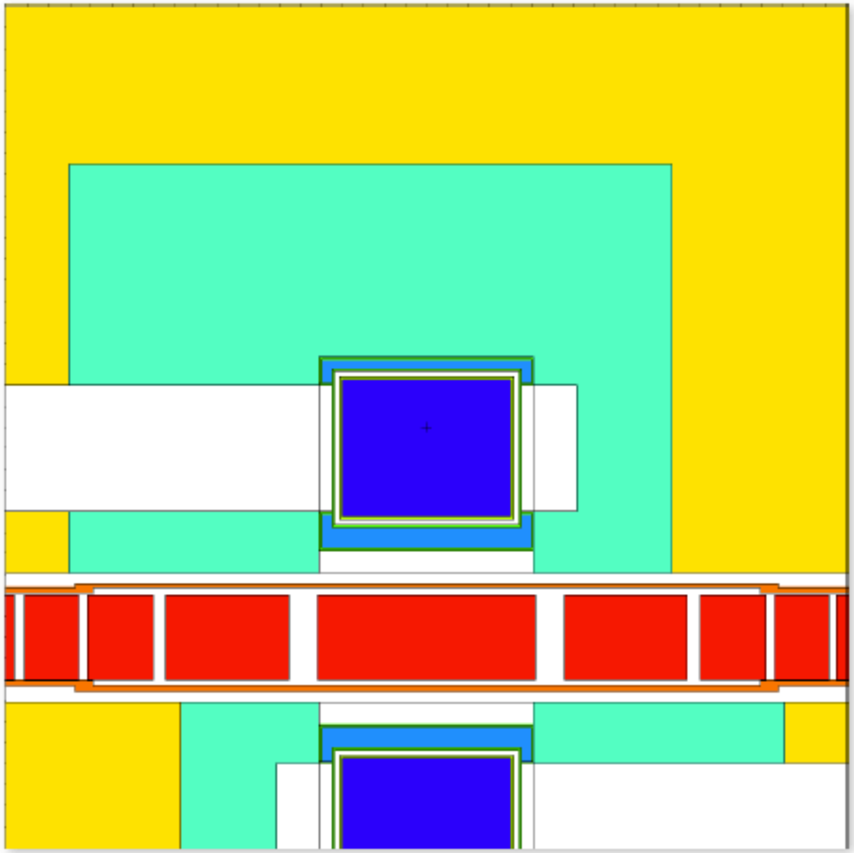
TDR baseline moderator



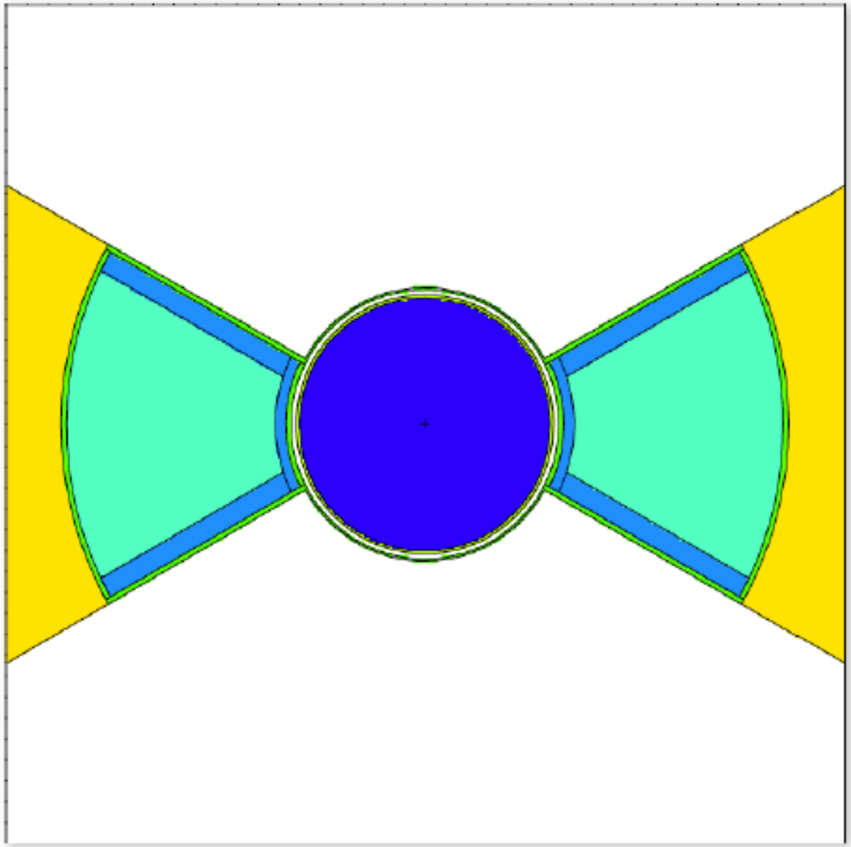
Brightness:

Cold (0-5 meV): 1.0
Thermal (20-100 meV): 1.5

In some particular absolute units.

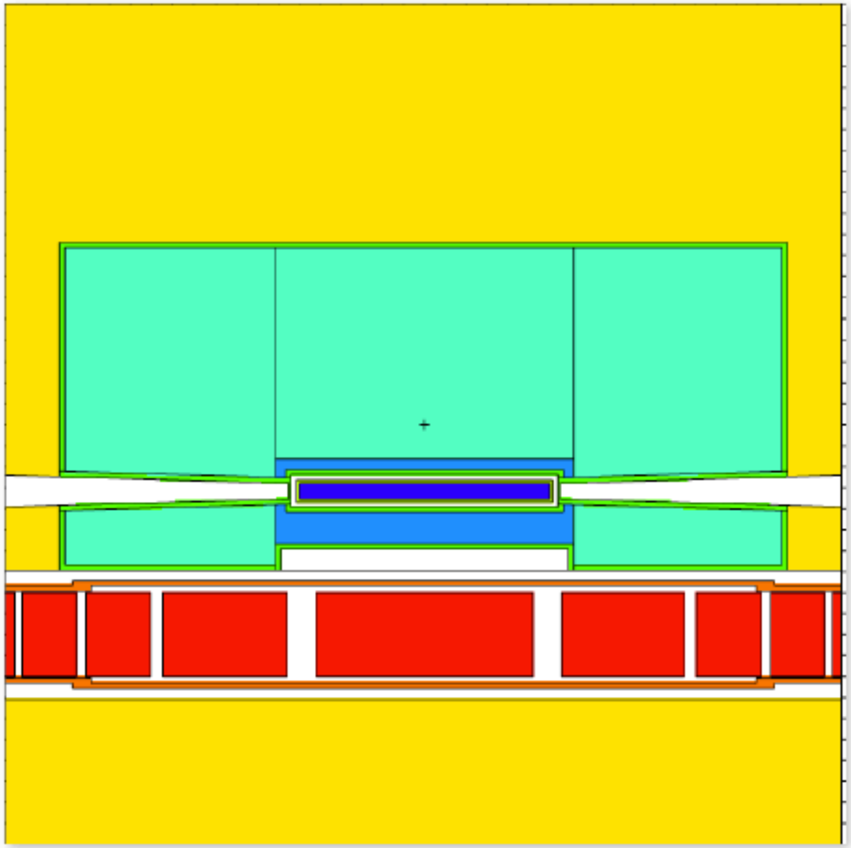


FLAT moderator



Change in brightness TDR -> Flat:

Cold: 1.0 -> 3.4 (+240%)
Thermal: 1.5 -> 2.5 (+70%)

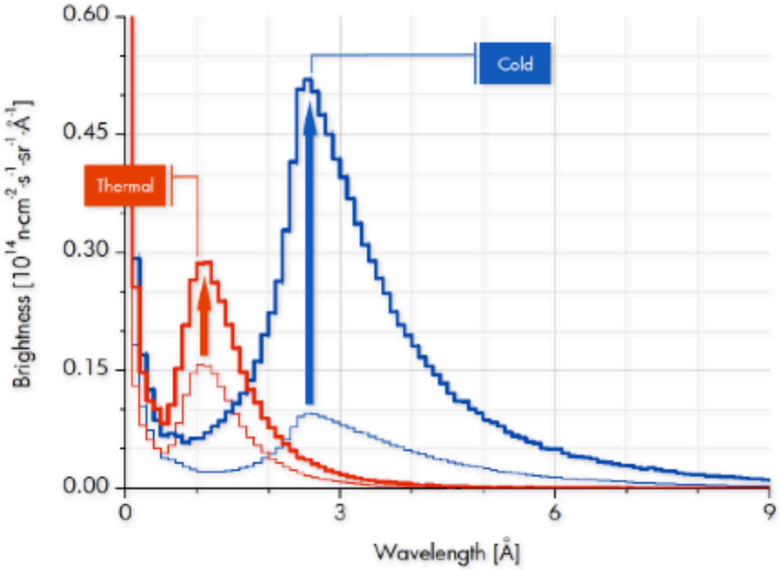


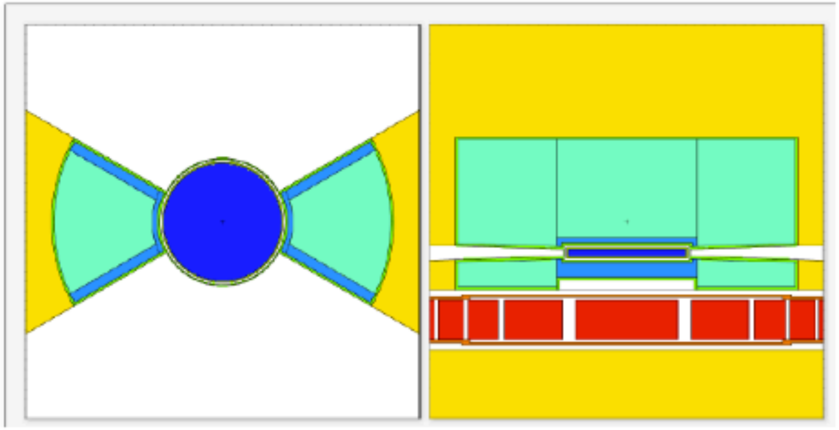
Gain in brightness

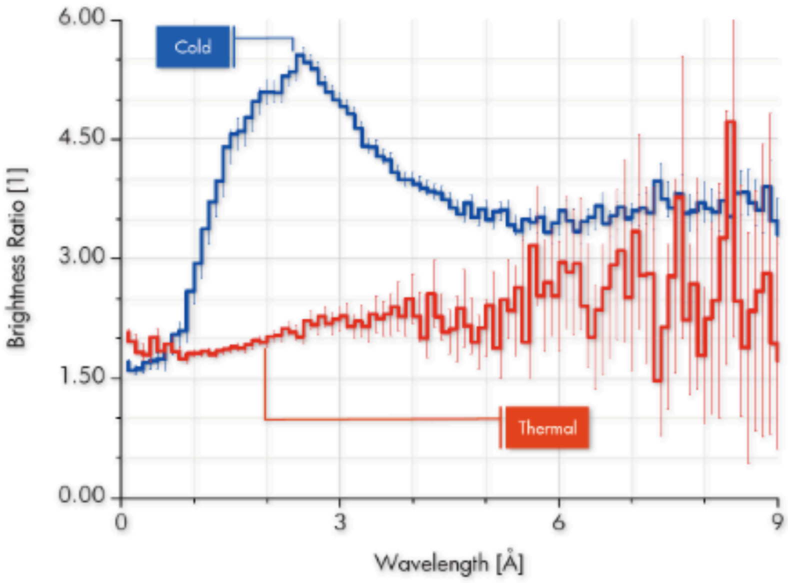
- There is an increase for thermal and cold brightness.

- Thermal flux increase by about factor of 2.

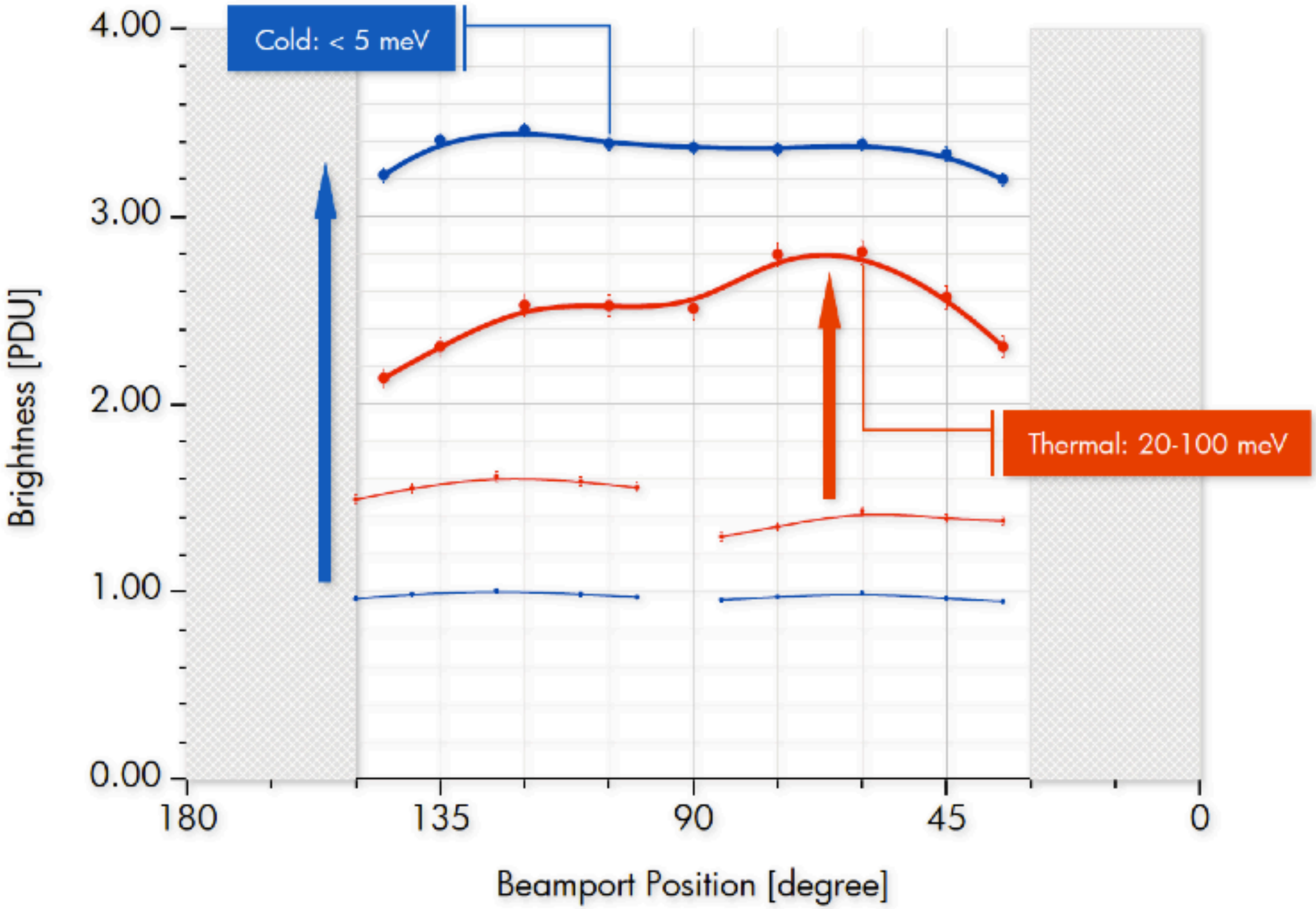
- Cold flux increase by a factor of 5 (from 2 to 3 Angstrom) and factor 3.5 (above 4 Angstrom)







Angular distribution



From flat to tube?

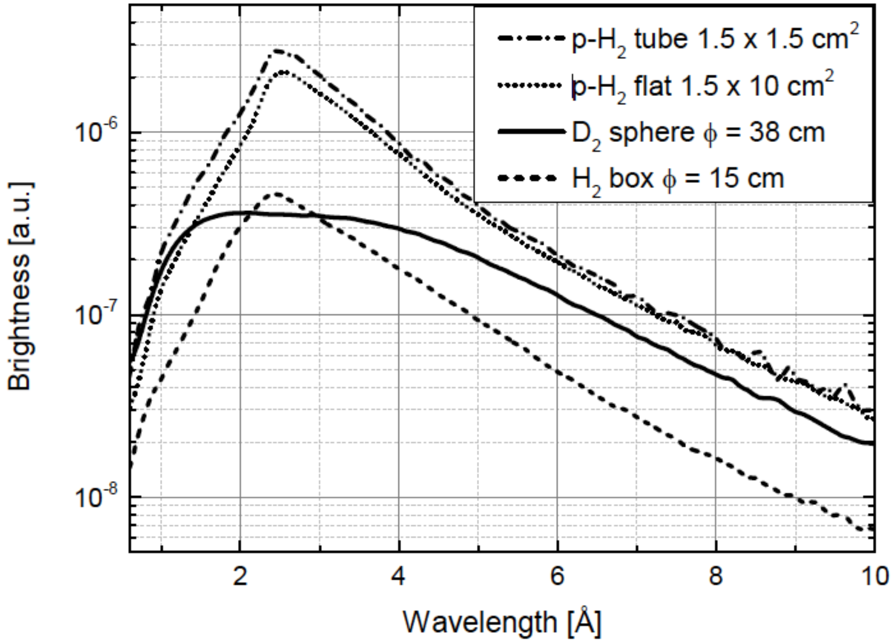
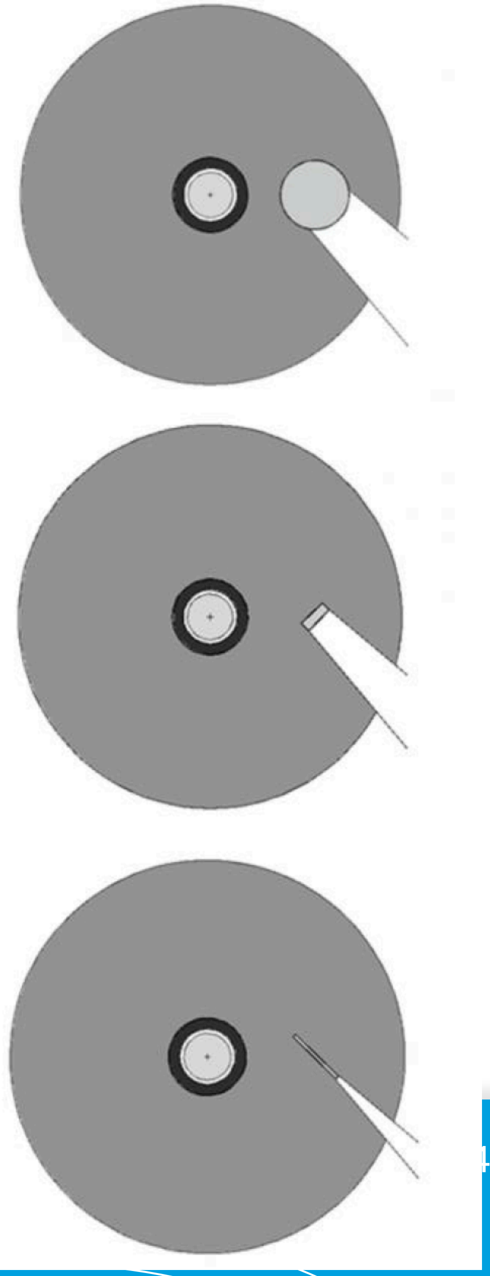


Fig. 2. MCNPX simulation results for the relative perturbed neutron brightness of a variety of cold neutron moderators at an ILL type fission reactor with heavy water reflector. The dimensions in the figure define the viewed moderator surface. The depth of the rectangular flat and tube moderators is 25 cm. The H$_2$ moderator contains 25 % ortho and 75 % para, and it is 5 cm thick. More details on the geometry are given in the text.



Low dimensional neutron moderators for enhanced source brightness, Ferenc Mezei et al, in press, Jour. Neutron Research.

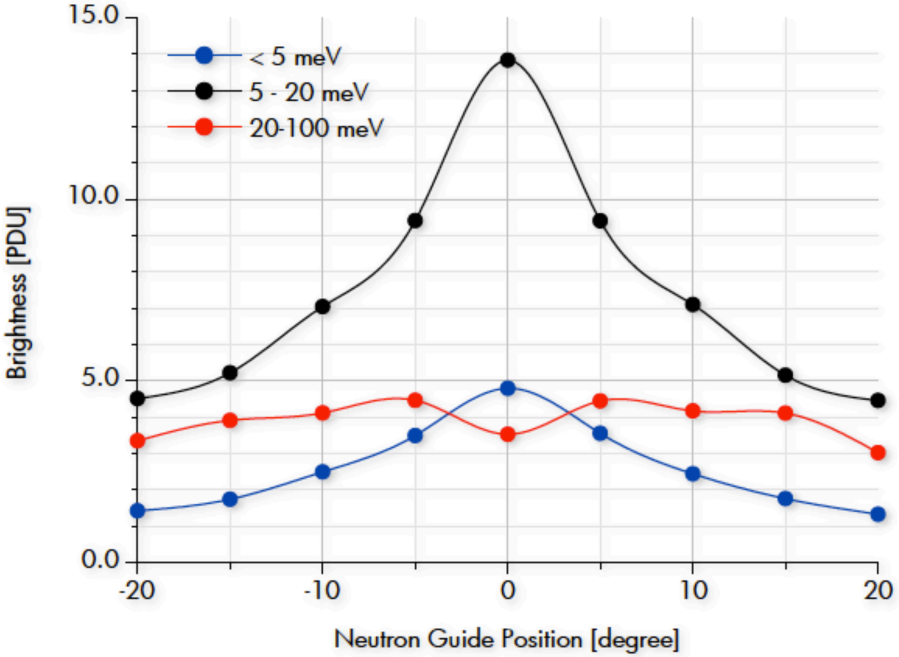
arXiv:1311.2474

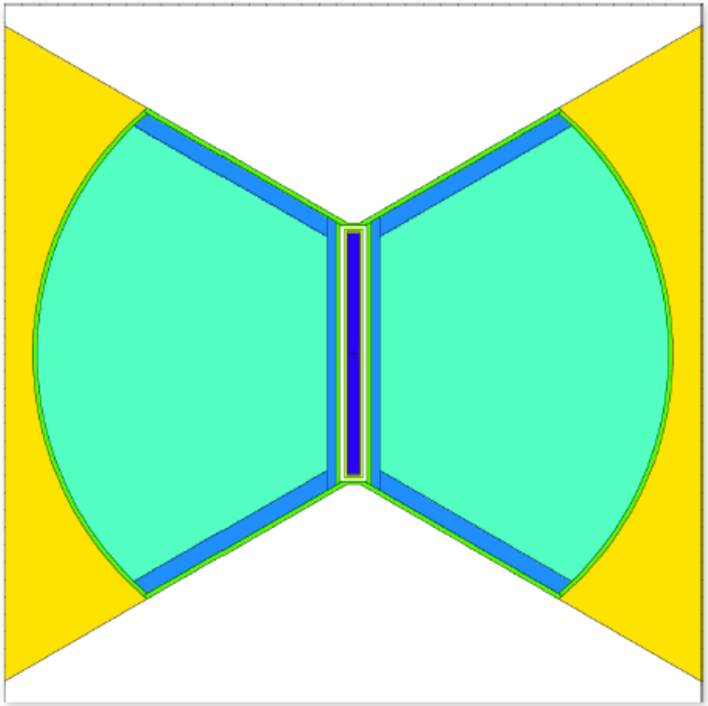
Tube moderator

Change in brightness Flat -> Tube:

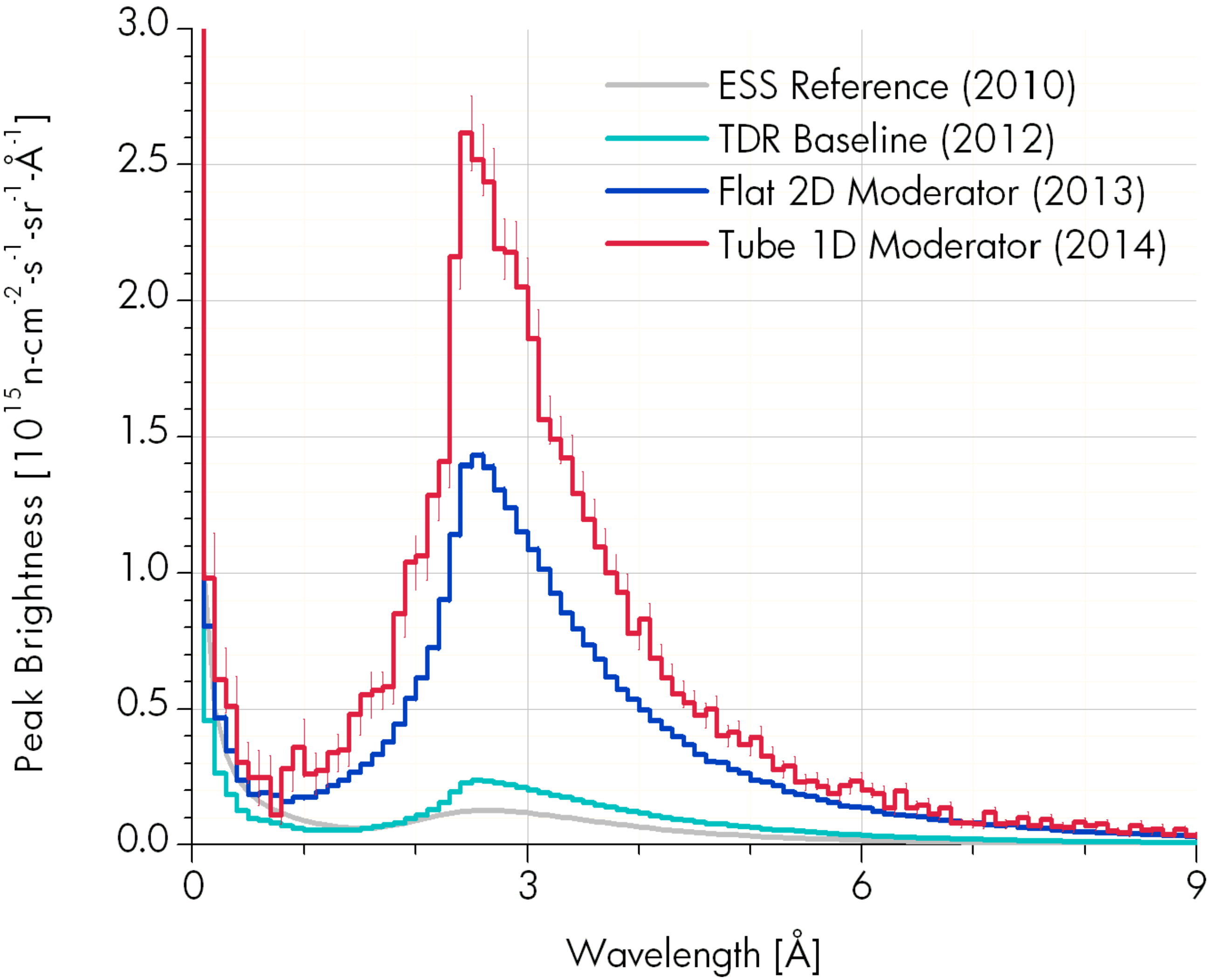
Cold: 3.4 -> 4.8 (+40%)

However, tube is highly directional! Can serve 3-4 beamlines only.





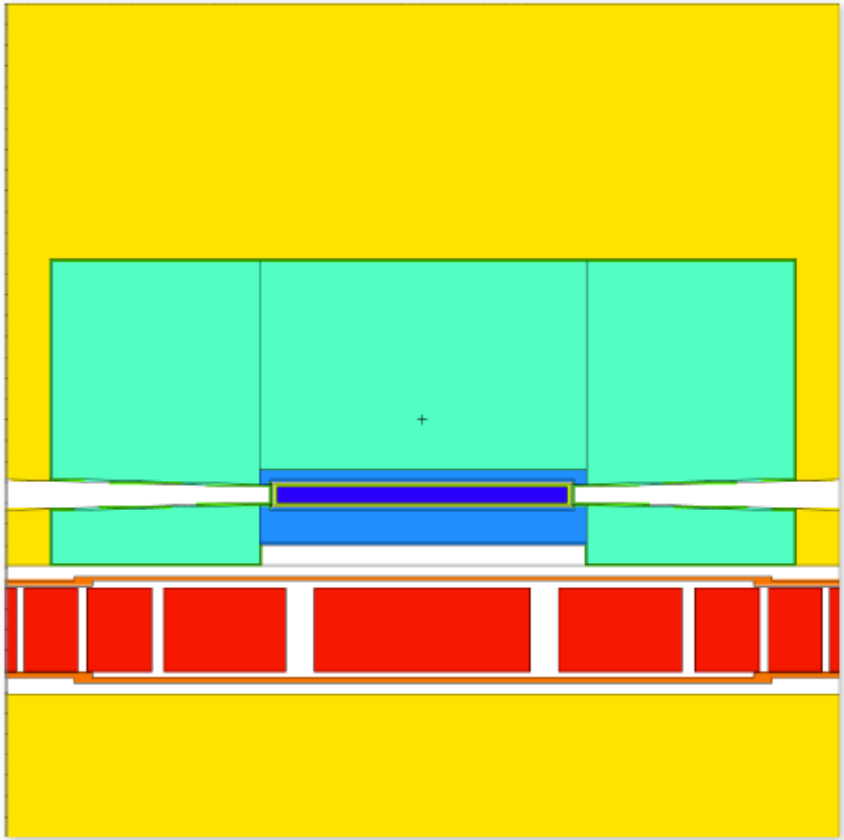
Brightness increase

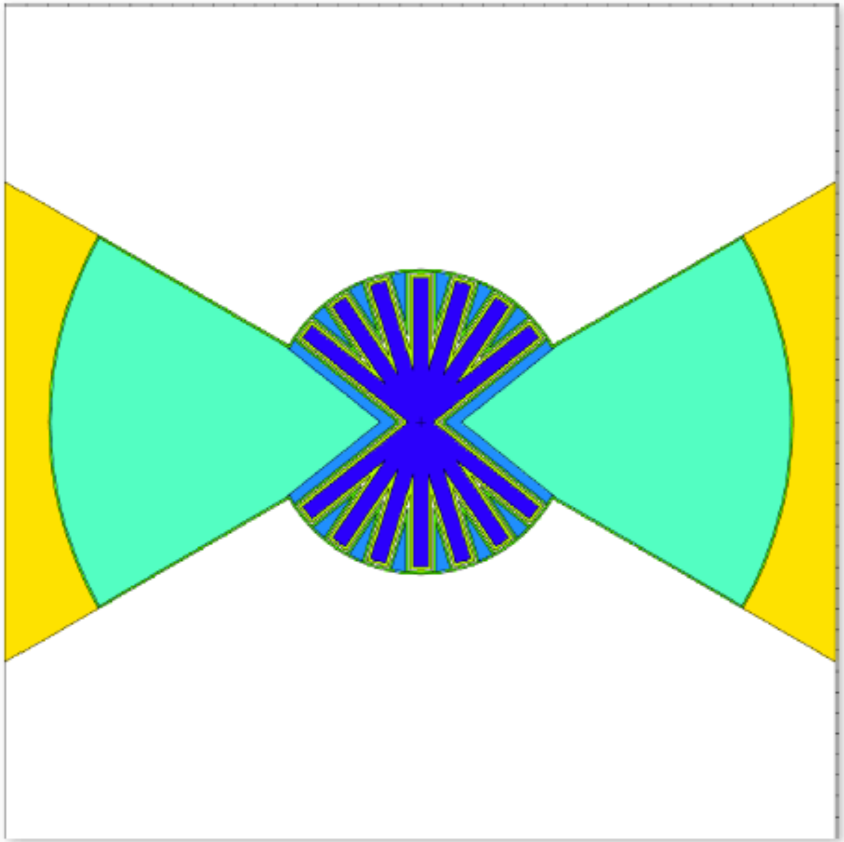


Starfish moderator

Change in brightness Flat -> Starfish:

Cold: 3.4 -> 4.3 (+30%)
Thermal: 2.5 -> 3.2 (+30%)





Parameters:

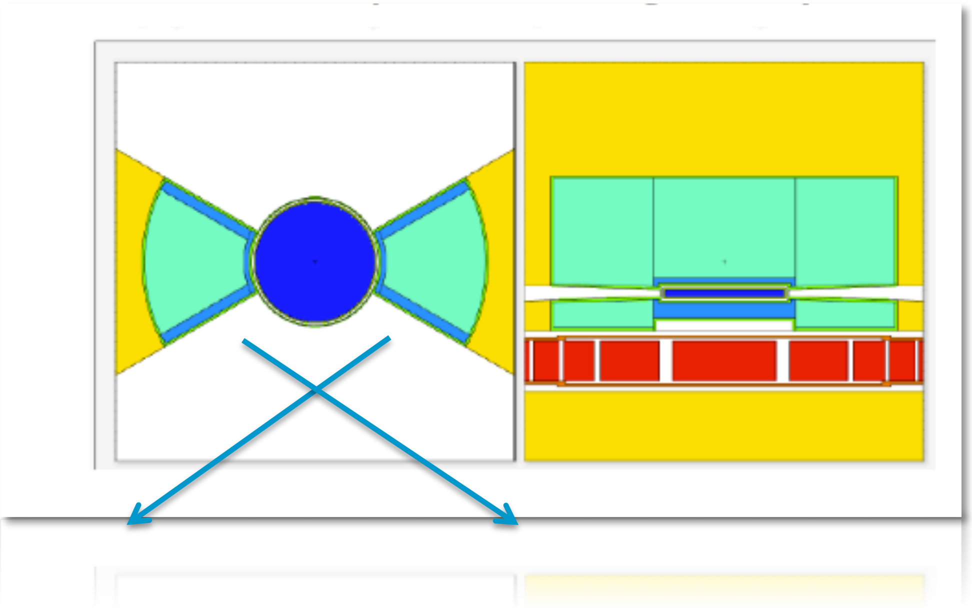
Tube cross-section: 1.5 cm X 1.5 cm (cylindrical or rectangular)
Tube length: 25-30 cm
Cryo-Al thickness: 3 mm
Vacuum gap: 2 mm, up to 5 mm is ok
Pre/Ref-Al thickness: as small as possible, 2 mm so far
Cryo-moderator heatload: 4.5 kW total

Options for bispectral extraction (1)

- From the sides
- From the top
- From the center

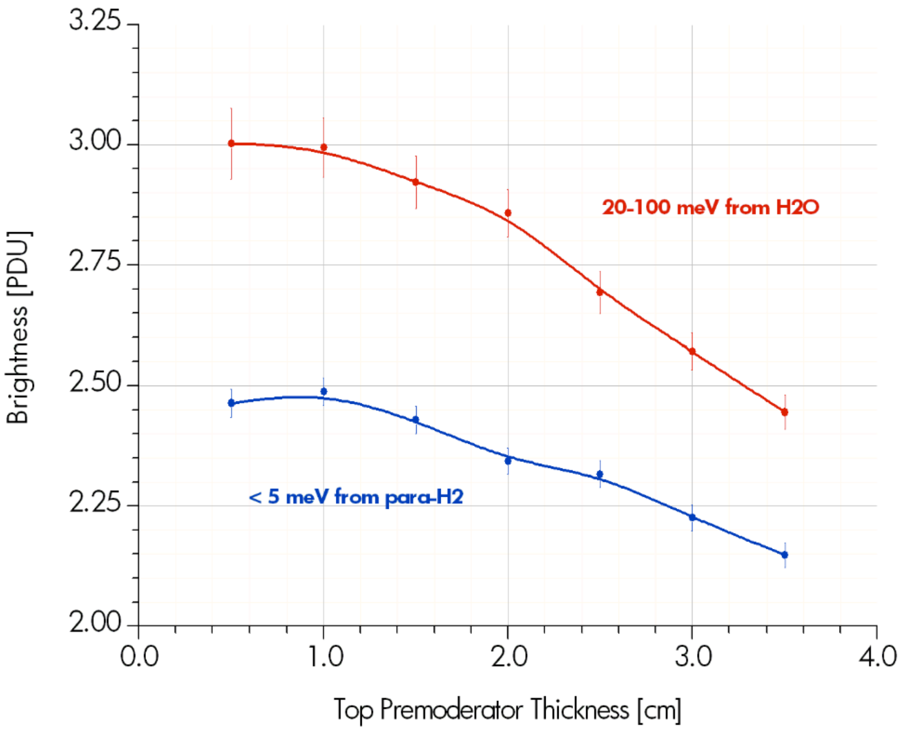
Options for bispectral extraction (2)

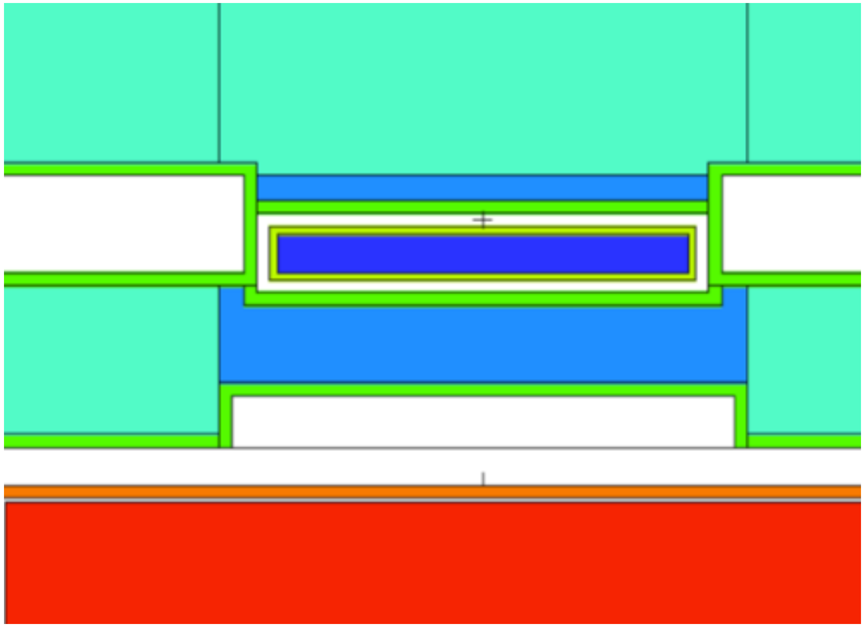
- From the sides
- Distance between cold and thermal hot spots similar to TDR (about 12 cm)

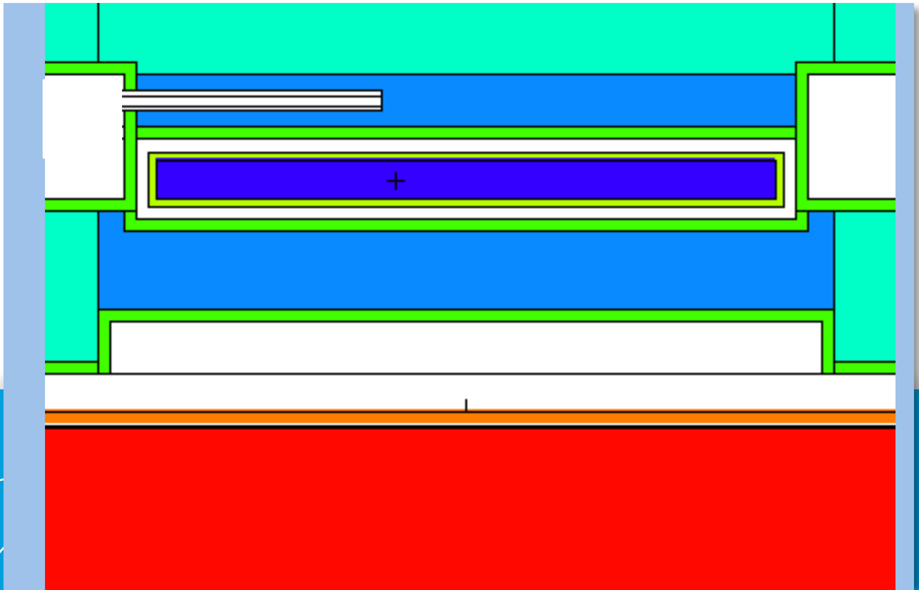


Options for bispectral extraction (3)

- From the top
  - Penalty in cold 15-20%
- Possible grooving
  - Thermal increase 60%
  - Partial gain in cold

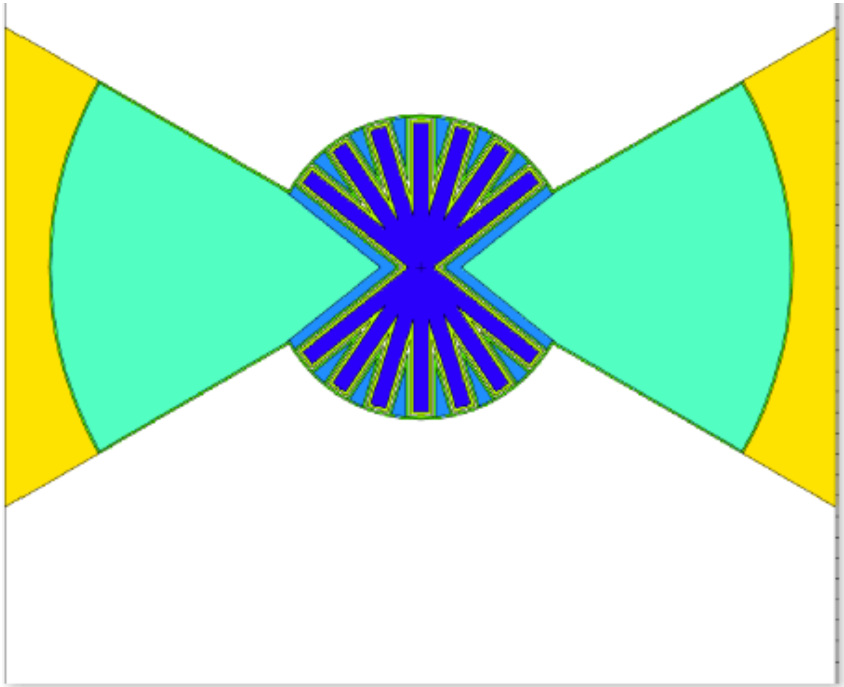


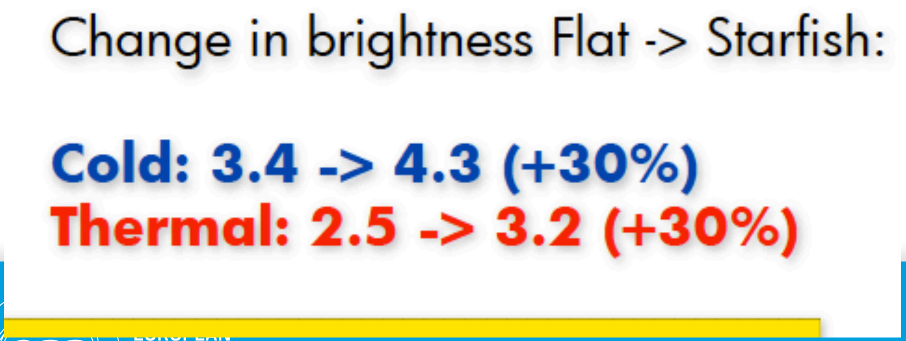




Options for bispectral extraction (4)

- From the center
- Distance between cold and thermal hot spots similar less than TDR (about 3 cm)
- Wedges can be of Pb instead of water





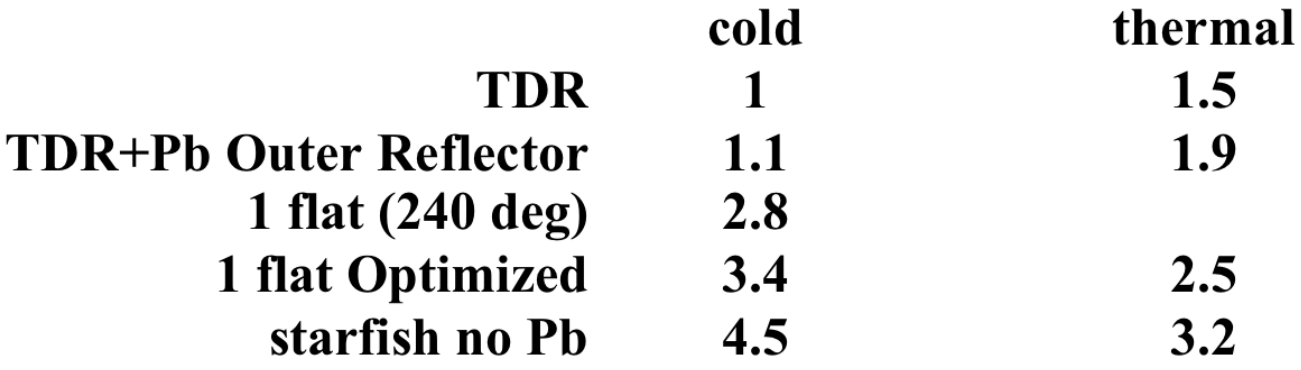
Change in brightness Flat -> Starfish:

Cold: 3.4 -> 4.3 (+30%)
Thermal: 2.5 -> 3.2 (+30%)

Work in progress on moderator

- Best design
- Best option for thermal extraction (side, top)
- Best option to accommodate different needs for instruments
  - Two moderators (big and small)
  - One moderator with openings of different heights
- Engineering design

E< 5 meV



	cold	thermal
TDR	1	1.5
TDR+Pb Outer Reflector	1.1	1.9
1 flat (240 deg)	2.8	
1 flat Optimized	3.4	2.5
starfish no Pb	4.5	3.2

REFERENCES

K. Batkov et al, Unperturbed moderator brightness in pulsed neutron sources, Nuclear Instruments and Methods in Physics Research A729 (2013) 500–505

F. Mezei et al, Low dimensional neutron moderators for enhanced source brightness, In press, Journal Nucl. Materials

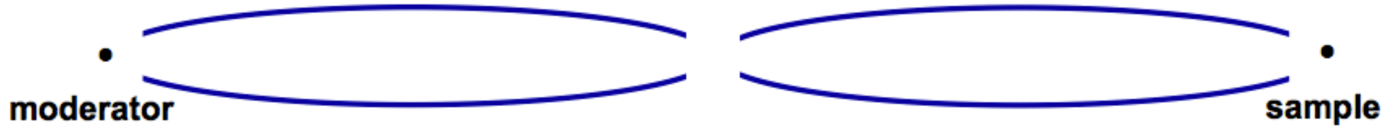
Brilliance transfer

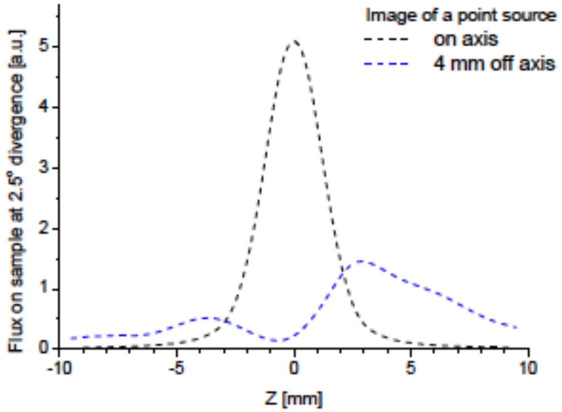
Optics aspects

- The feasibility of the use of reduced height moderators depends on the conception of neutron optical beam transport systems that are capable to deliver with moderate losses the enhanced source brightness to the samples.
- This requires the redefinition of the current beam extraction paradigm, which essentially assumed that the moderators must have larger size than the entrance of the guide.
- Neutron optical systems based on existing supermirror guide technology are capable of delivering most of the 3 fold gain in moderator brightness for small samples (2 – 4 mm high) both for thermal and cold neutrons to all neutron scattering instruments and for all sample sizes in high angular resolution work (such as reflectometry, small angle scattering, neutron imaging).
- For large samples (2 – 4 cm) the flux gains on the instruments still range between 10 – 100 %, thus the novel “flat” moderators perform better than the conventional ones in all neutron scattering applications.

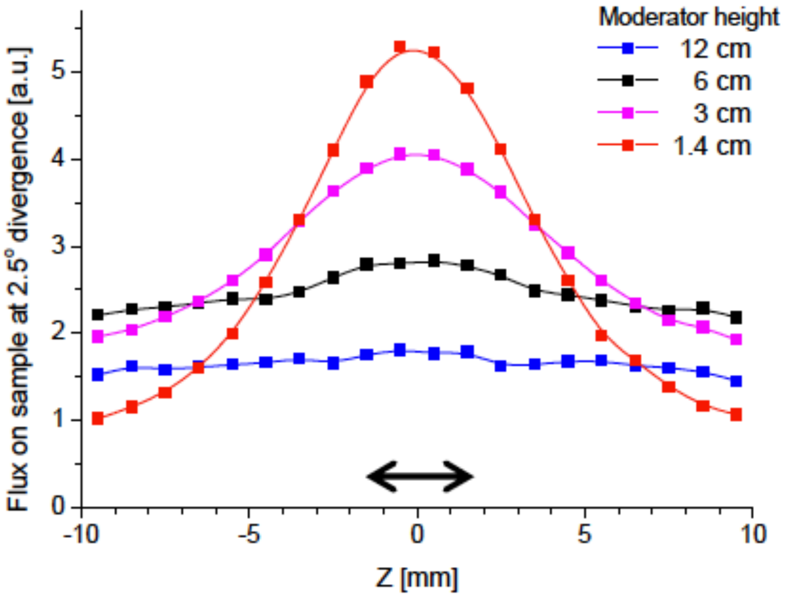
Example

- **Using best proposed / tested supermirror optics (cf. Stahn)**





Poor imaging quality outside axis!!
Example: double ellipse for 80 m,
25 cm flat guide pieces



Flux on sample as a function of moderator size
Gain factor for 3 mm sample: 2.95
for 40 mm sample: 1.8
(L=80 m, 2.5° divergence, λ=4 Å)

Next steps

- Task force between Machine and Science (F. Mezei – K. Andersen)
- Goal: find the best configuration (moderator size) for each instrument
- Next meeting
- 12 February
- Deadline:
  April 2014

Instrument	L(m-s)	Max HxV A	Max HxV Div	Size	Contact
Imaging	50m	3x3cm^2	±0.7°x0.7°	Medium	Markus Strobl
Polarized SANS	30m			Small	
Broadband SANS	20m			Small	
Surface scattering	30m			Small	
Horizontal reflectometer	27m			Small	
Vertical reflectometer	52m			Small	
Thermal powder diffractometer	150m	1x2cm^2		Small	
Bispectral powder diffractometer	75m	1x1cm^2		Small	Werner Schweika
Pulsed monochr diffractometer	46m			Medium	Paul Henry
Engineering diffractometer	150m	1x2cm^2		Small	Markus Strobl
High-pressure diffractometer	150m	1x1cm^2		Small	
Single-crystal mag diffractometer	150m	5x5mm^2		Small	Werner Schweika
Macromolecular diffractometer	150m	3x3mm^2	±0.1°x0.1°	Small	
Cold chopper spectrometer	150m	2x4cm^2		Large	Pascale Deen
Bispectral chopper spectrometer	25m	1x1cm^2		Medium	Pascale Deen
Thermal chopper spectrometer	150m	2x2cm^2		Large	Pascale Deen
Crystal-analyser spectrometer	150m		±1.5°x2°	Medium	??
Vibrational spectroscopy	60m	2x2cm^2	±2.5°x2.5°	Large	
Backscattering spectrometer	150m	3x3cm^2	±3°x3°	Large	Niko Tsapatsaris
High-resolution spin-echo	30m	3x3cm^2	±0.5°x0.5°	Medium	
Wide-angle spin-echo	50m	3x3cm^2	±0.5°x1°	Medium	
Fundamental physics	70m	10x12cm^2	±2°x2°	Large	

THANK YOU ;-) !

BACKUP

MR plug

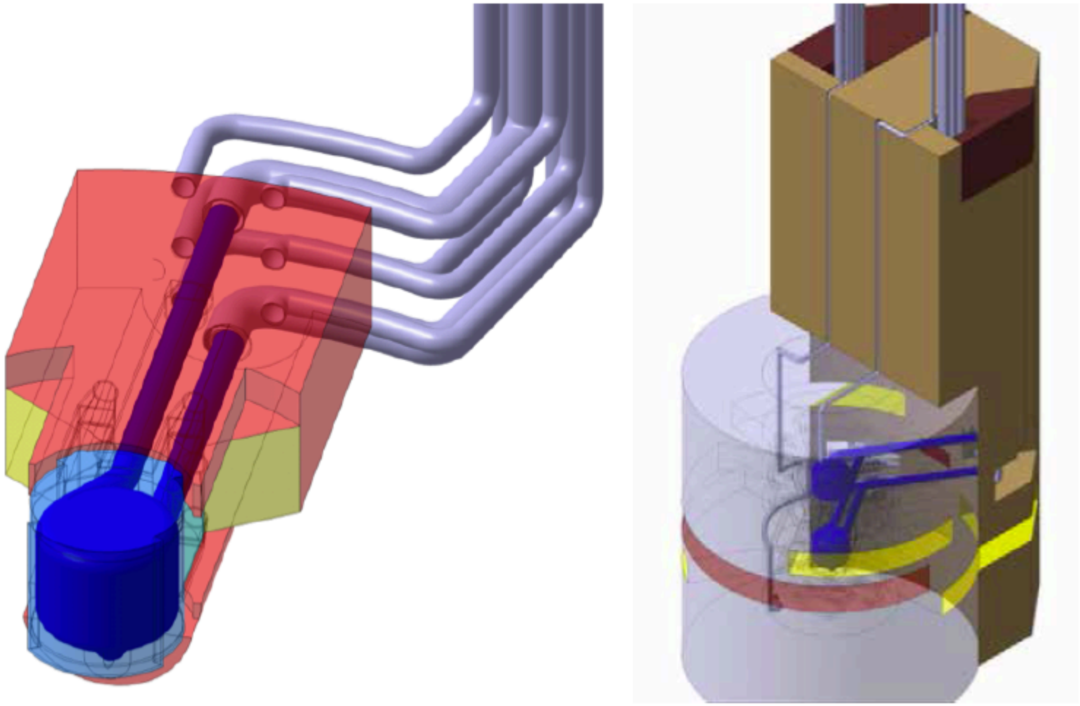


Figure 3.55: Left: The moderator plug. Right: The moderator-reflector plug, including the inner and outer reflectors. Also shown is the backpack block that handles and routes piping, with steps to avoid radiation streaming.