# ESS

## Flat moderators neutronics

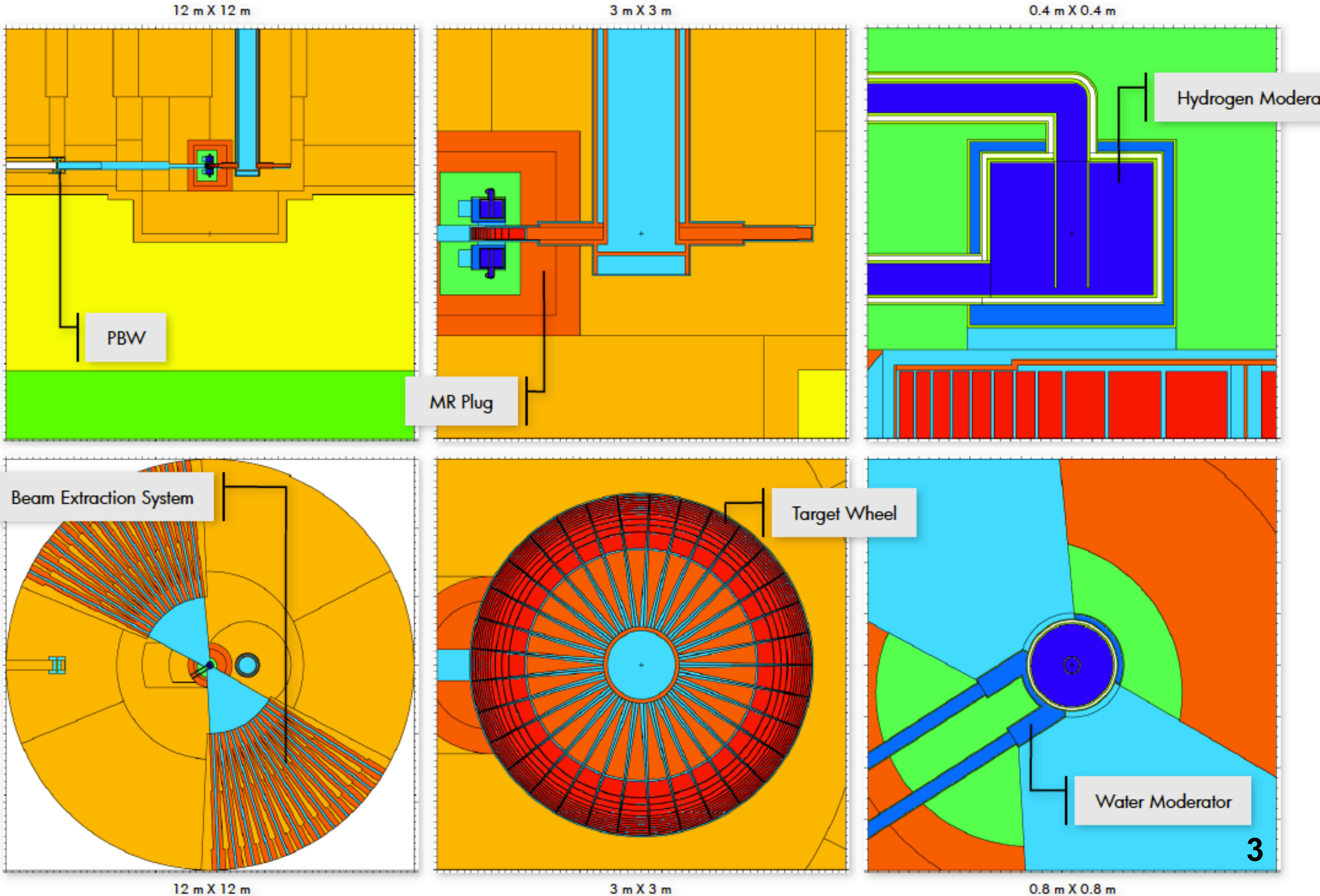
Lund, Sweden
Luca Zanini

ESS 2014-02-06

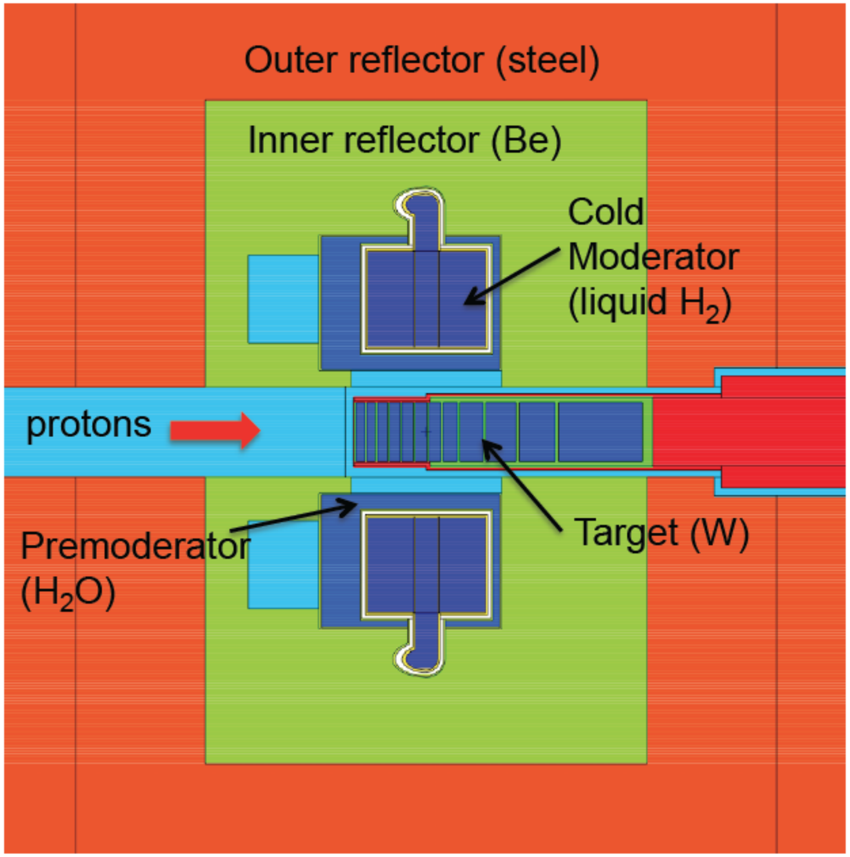
# Moderator team

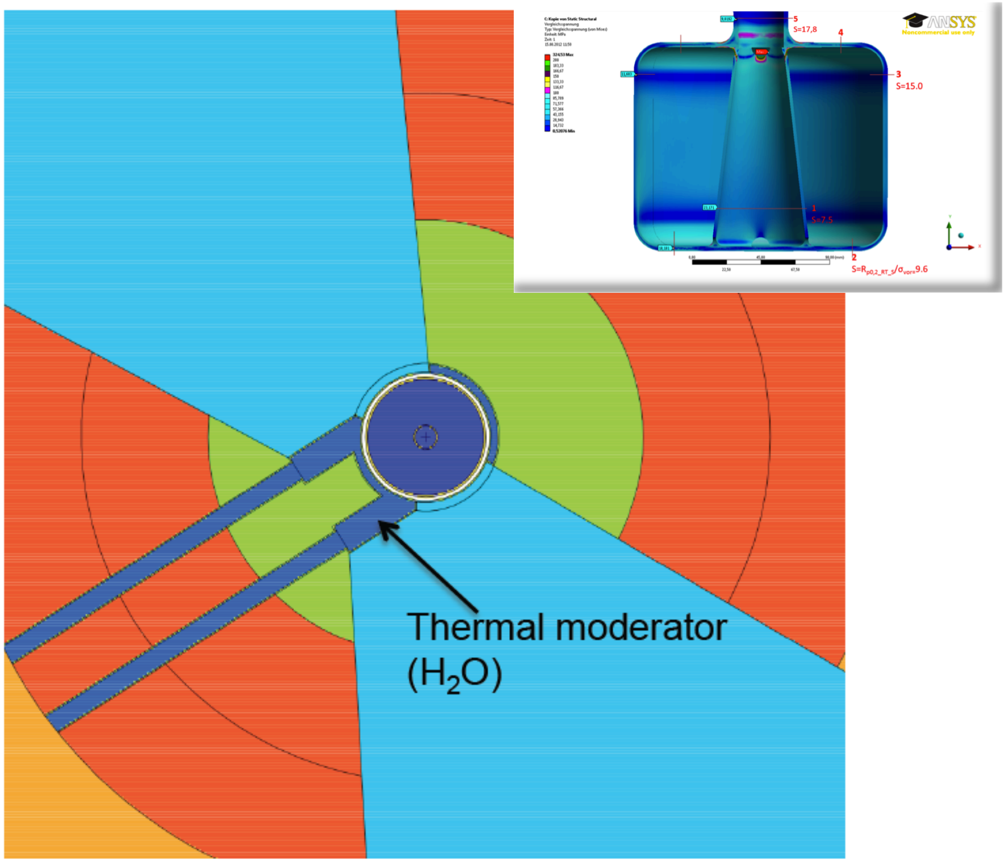
- Neutronics Group
  - K. Batkov, E. Klinkby, T. Schönfeldt, A. Takibayev, L. Zanini
- Plus
  - F. Mezei, G. Mührer, E. Pitcher

# Target station monolith design (Alan Takibayev)



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



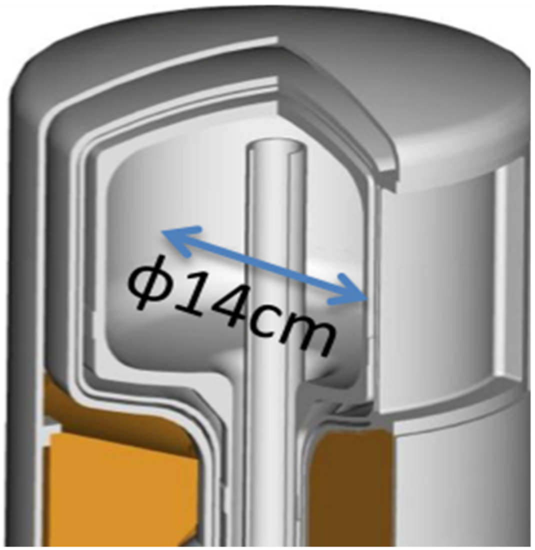

*Thermal wings provide a bi-spectral source.*

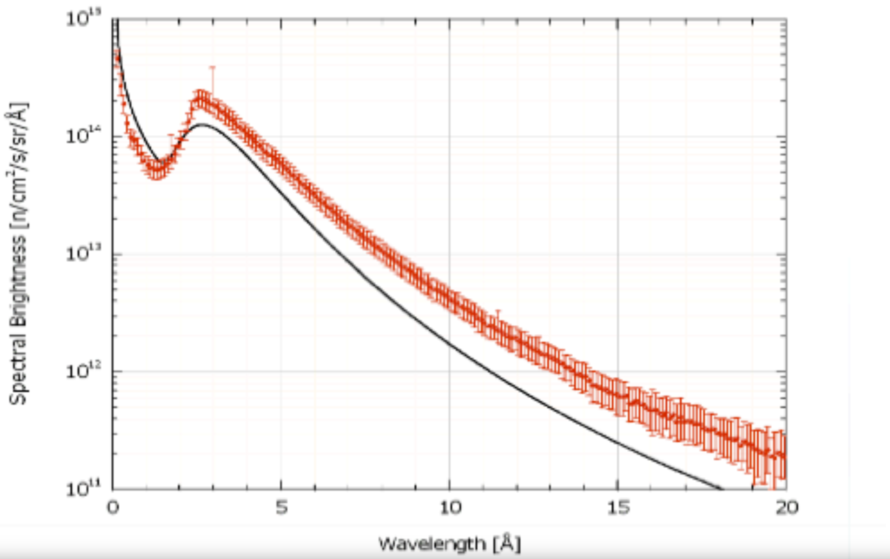
# TDR: High performance cold moderator

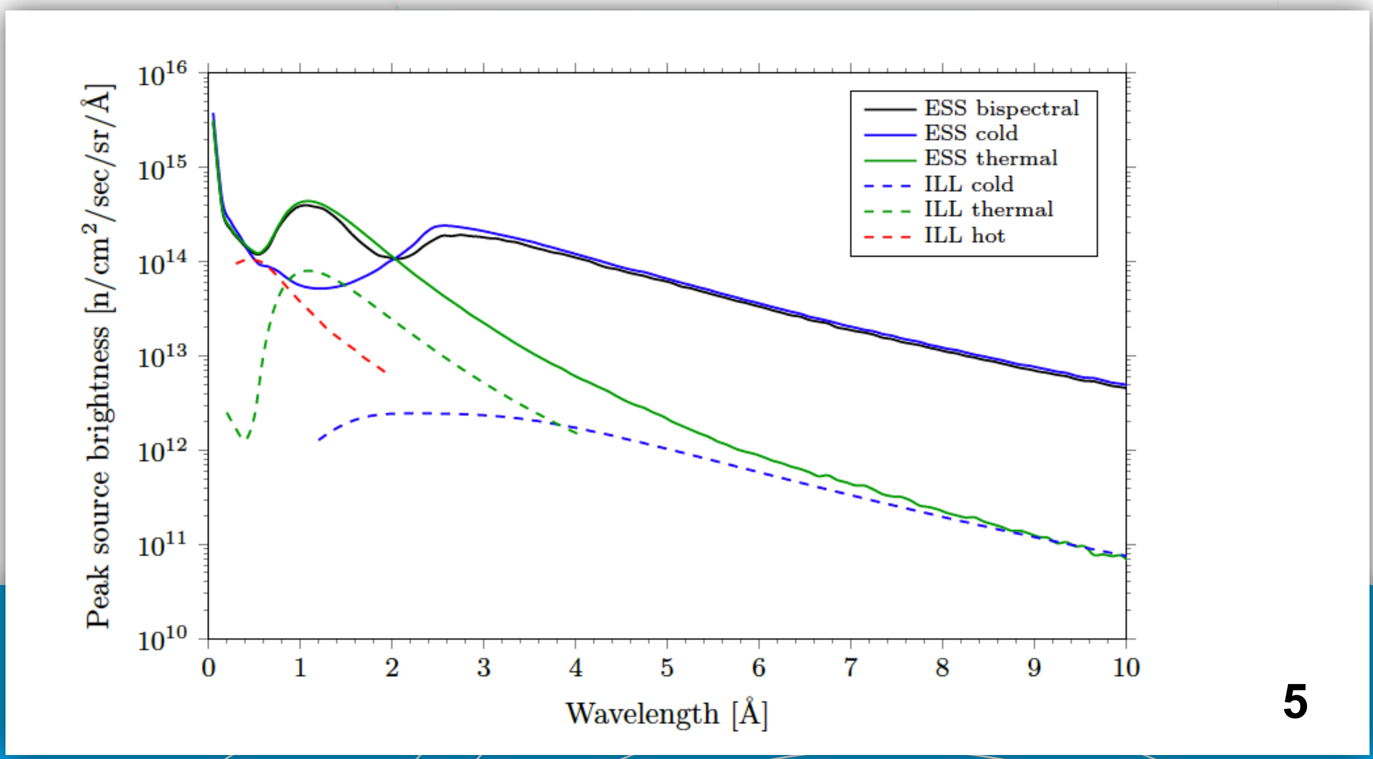
**Volume moderator:**

implemented at J-PARC

99 % para-$H_2$ tested



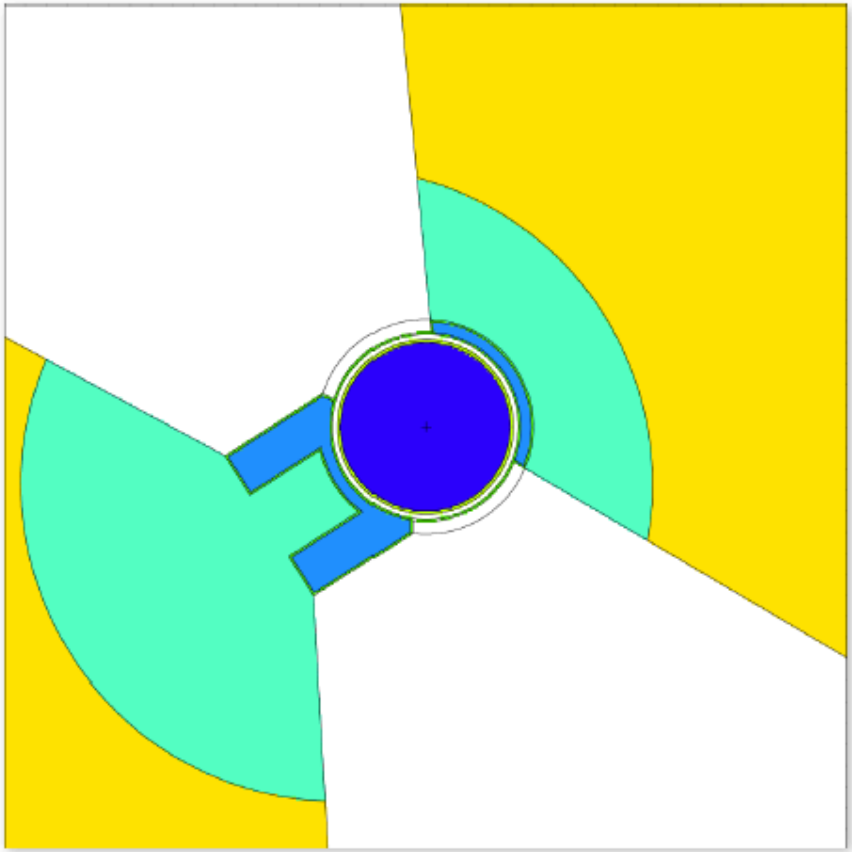




EUROPEAN SPALLATION SOURCE

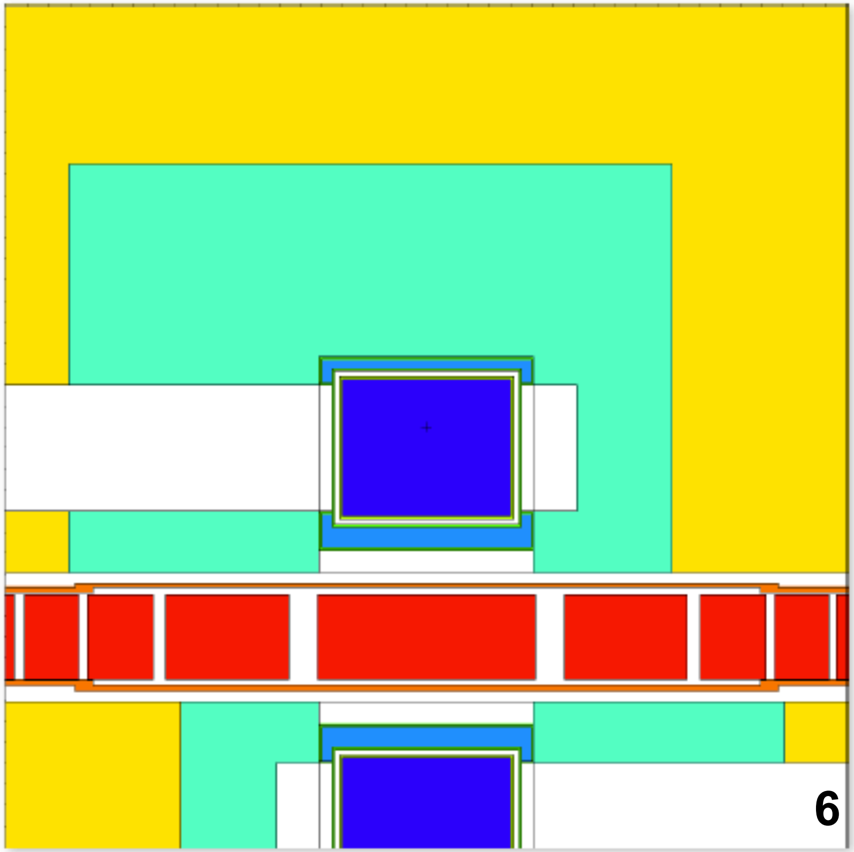
# TDR baseline moderator performance

Brightness:



**COLD (0-5 meV): 1.0**
**THERMAL (20-100 meV): 1.5**

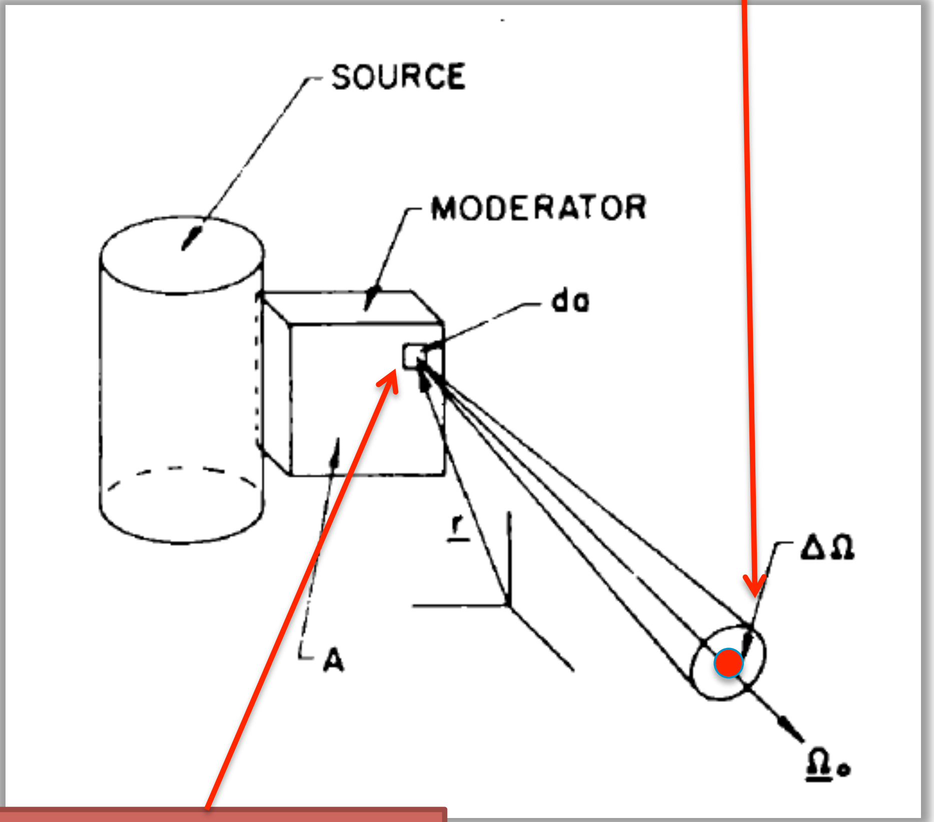
(numbers in absolute units of 5.6 $10^{-4}$ n/cm$^2$/sr/proton)



# Source brightness

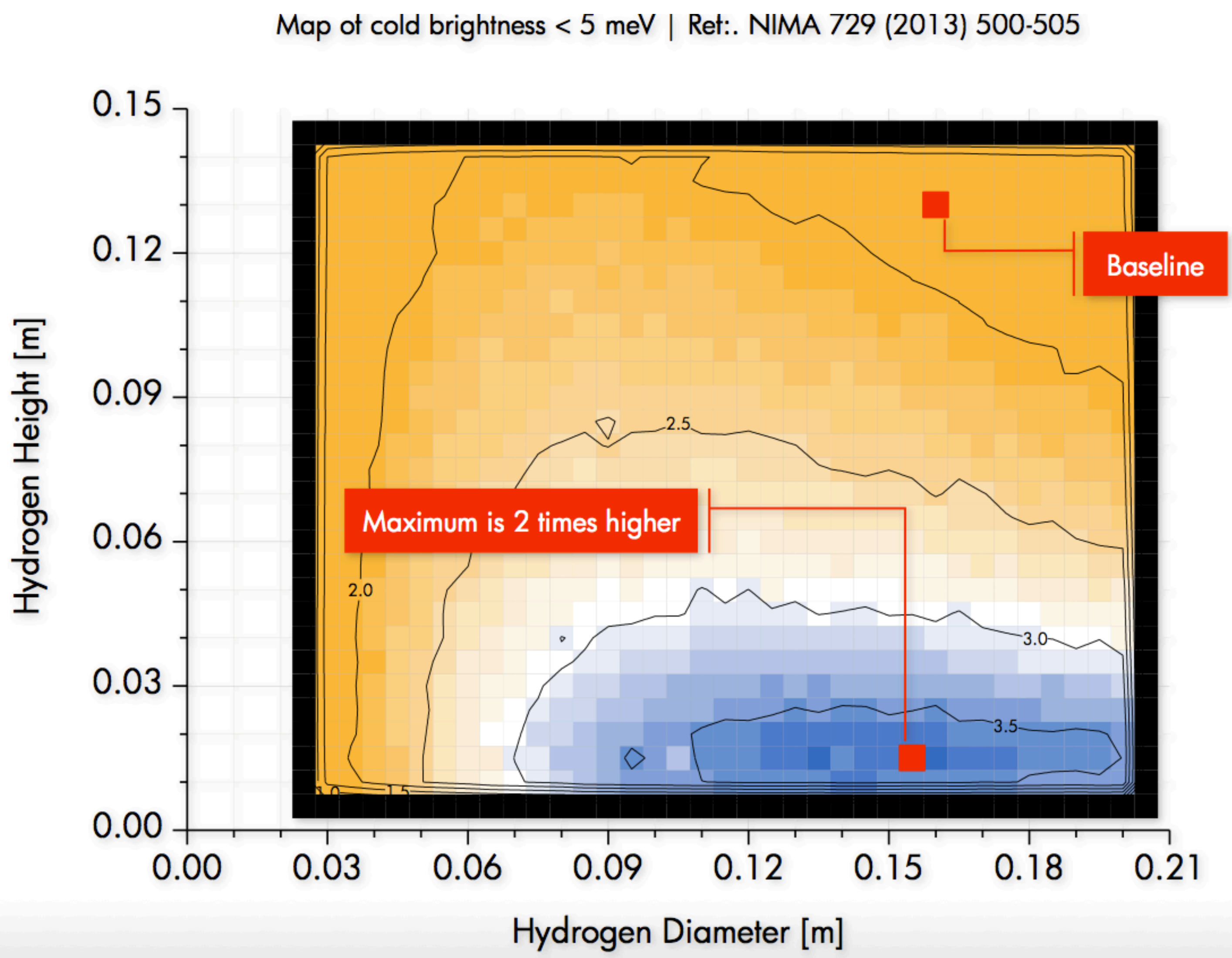
- It refers to the source of the neutrons (the moderator)
- It does not depend on the distance from the source, except for losses (Liouville theorem)
- The ultimate figure of merit, the number of 'good' neutrons at the sample, will depend on:
  - The moderator brightness
  - The brilliance transfer
- It is a job that needs to be done together between moderator neutronics, neutron guide, and instrument users
- Answer questions like:
  - Best moderator size and shape
  - Viewed surface

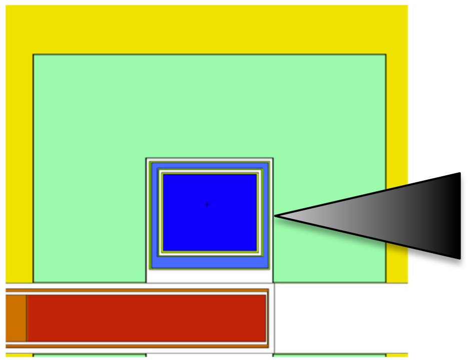
Flux is the number of neutrons per unit area and unit time




Brightness is the flux in unit solid angle

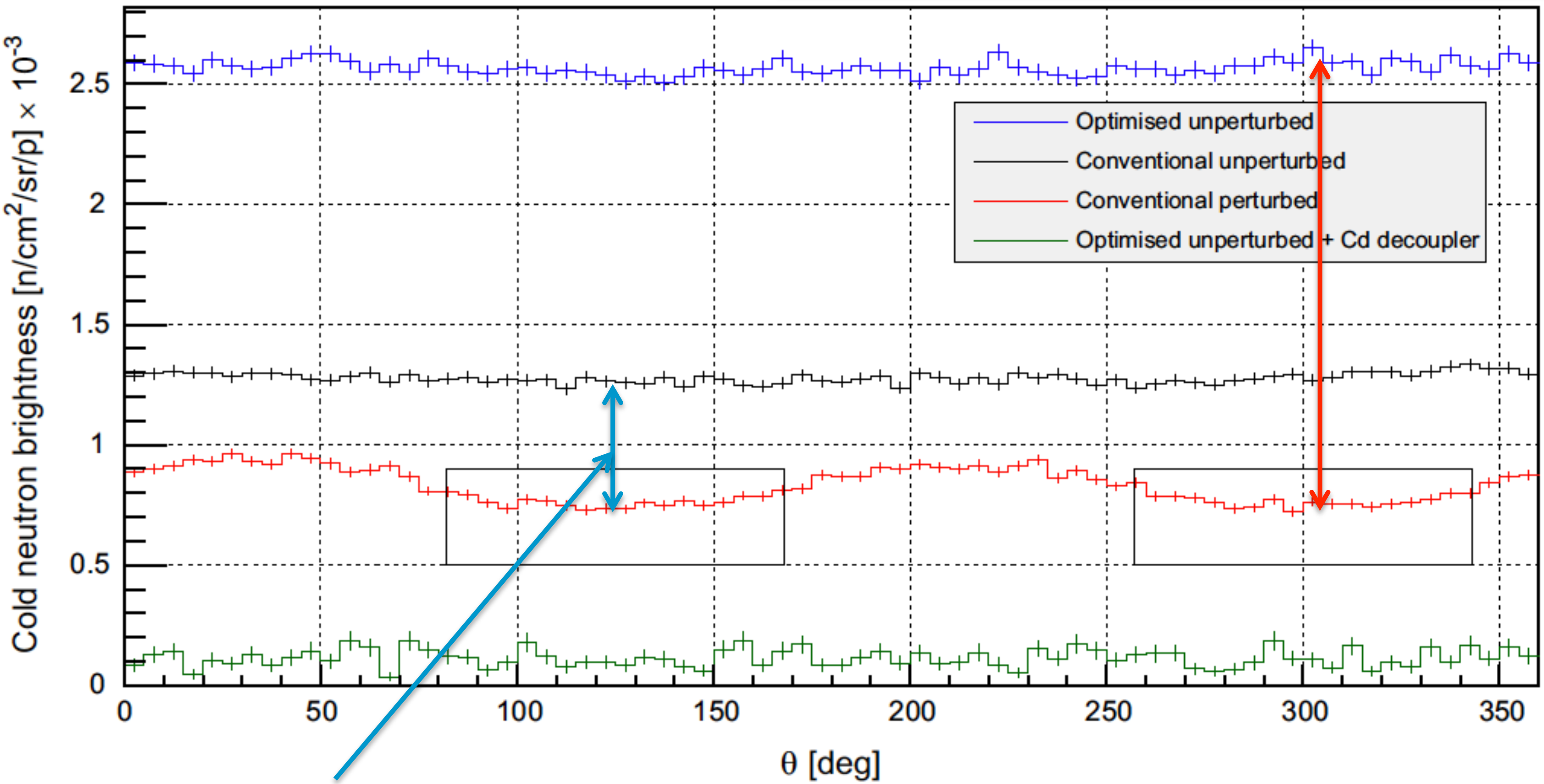
# *Unperturbed* moderator brightness



# Effects of the beam extraction lines (perturbation)

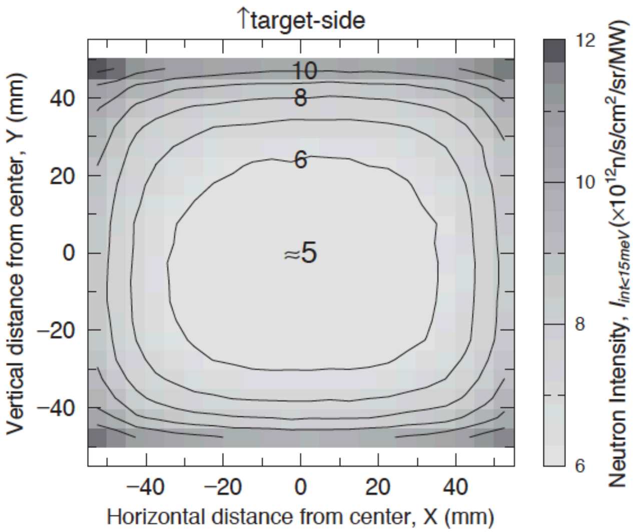
Perturbation of a flat moderator is expected to reduce only slightly the performance



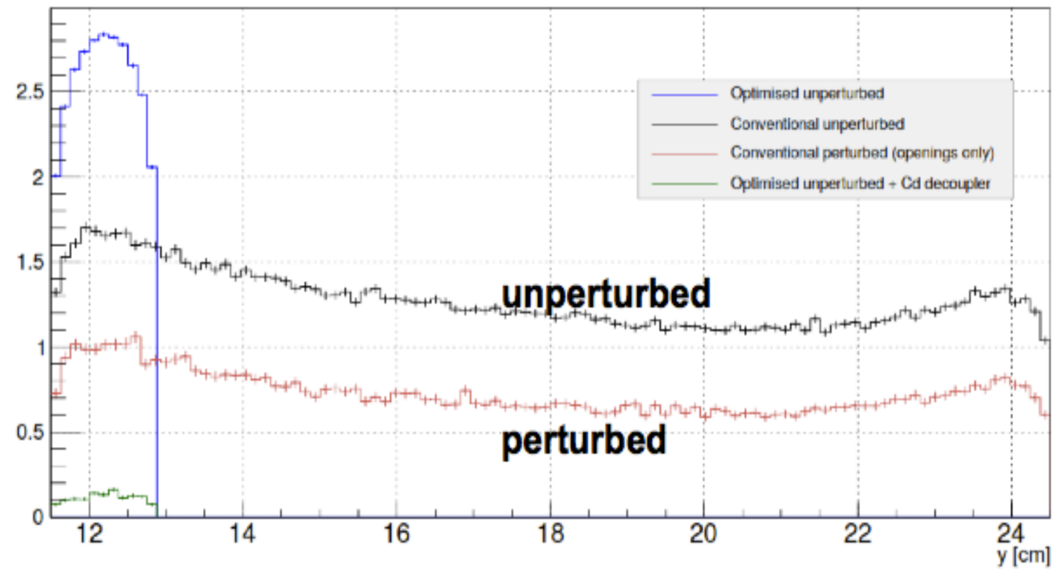

Perturbation of a conventional moderator means removing a lot of reflector

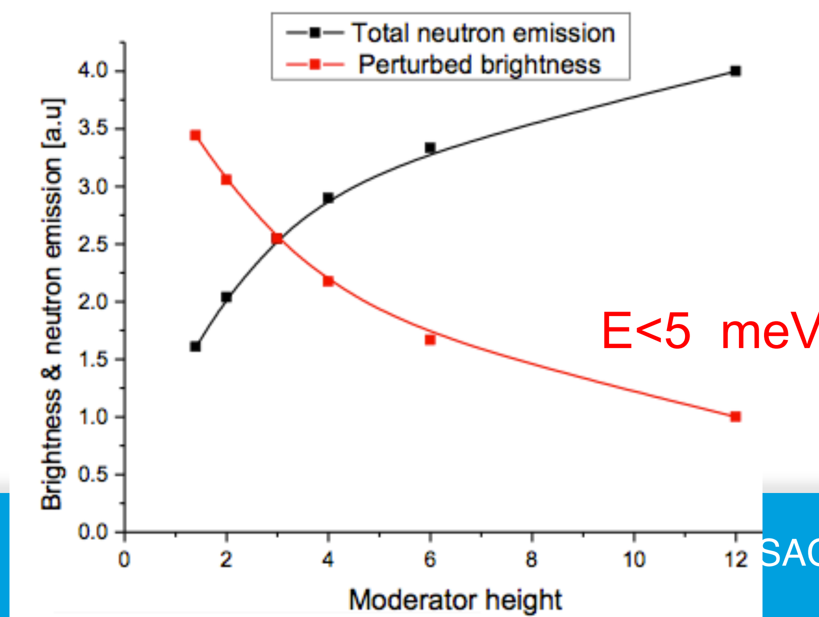
BIGGER GAINS (> 3) EXPECTED FOR THE PERTURBED (=REAL) CASE !

# n distribution much better in flat moderator



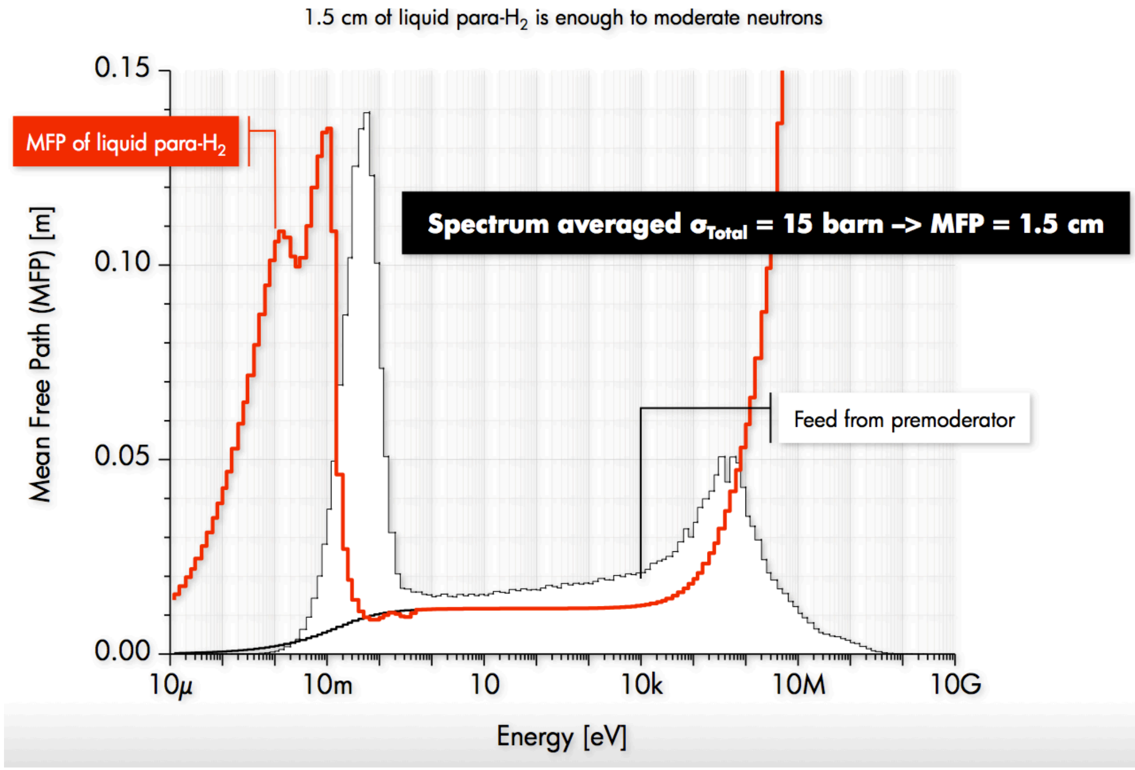

(Kai, 2004)

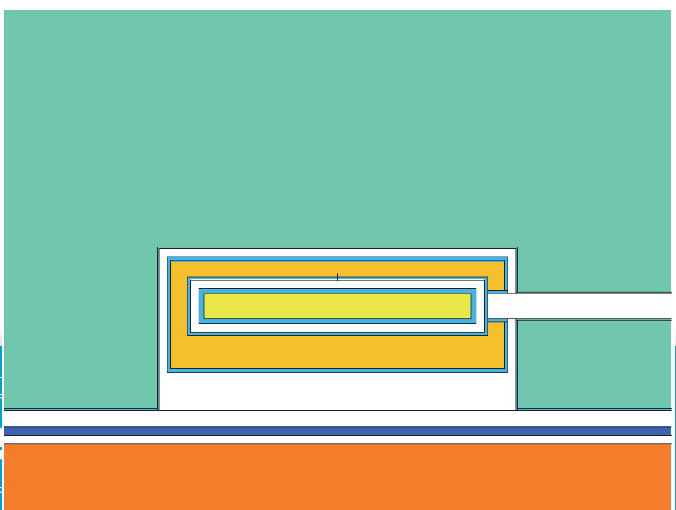


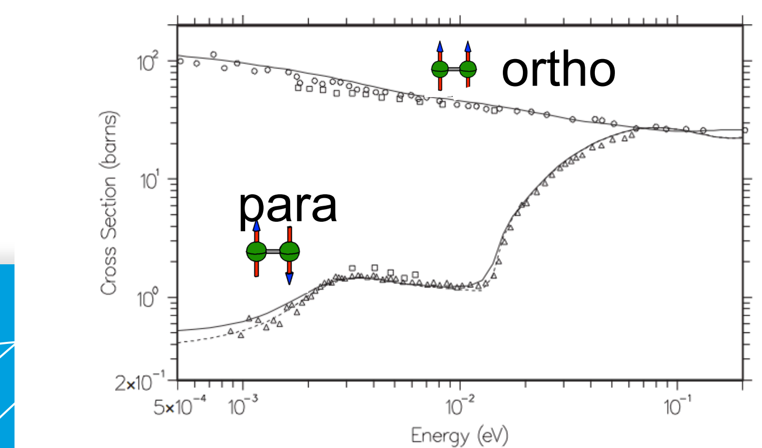



# Why flat moderators work

- ❑ MFP of (thermal) neutrons in para-$H_2$ is 1.5 cm, much shorter than cold n
- ❑ Works only for pure para-$H_2$
- ❑ Importance of premoderator and reflector



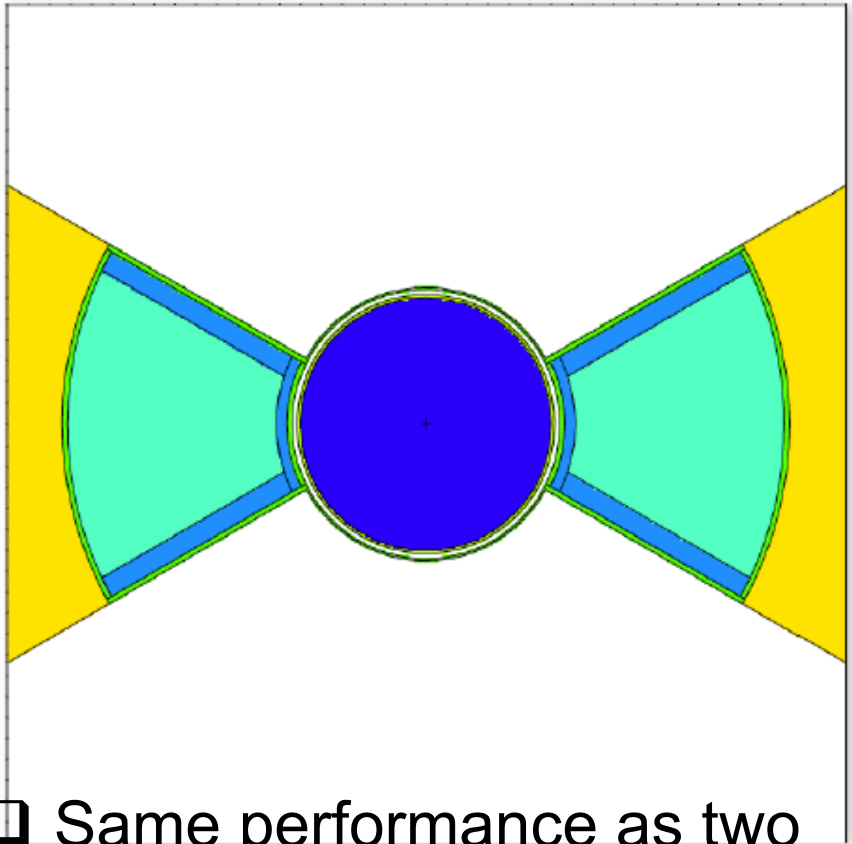


# Timeline and milestones for moderator optimization

- October 2, 2013: kick-off meeting Target-Instruments on flat moderators

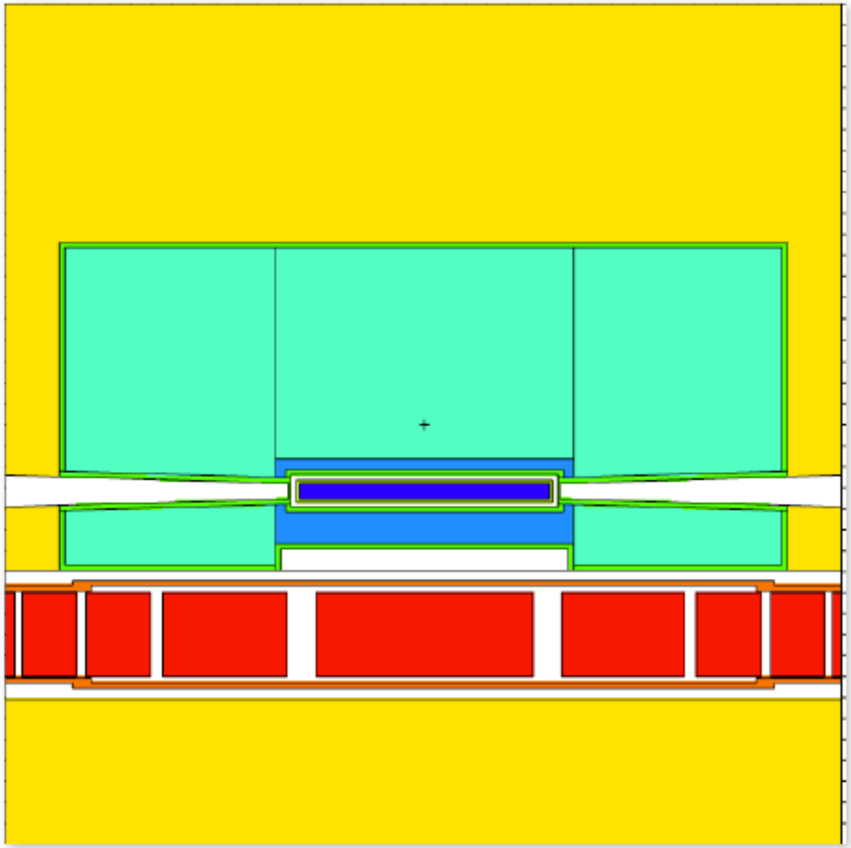
- Feb. 5-6: Discussion at SAC
- Feb. 12: 1st moderator workshop, refine parameter space for further optimisation
- March, second half: 2nd moderator workshop
- Apr. 2-3: Discussion at TAC
- April 30: New moderator configuration submitted to CCB

# FLAT moderator performance



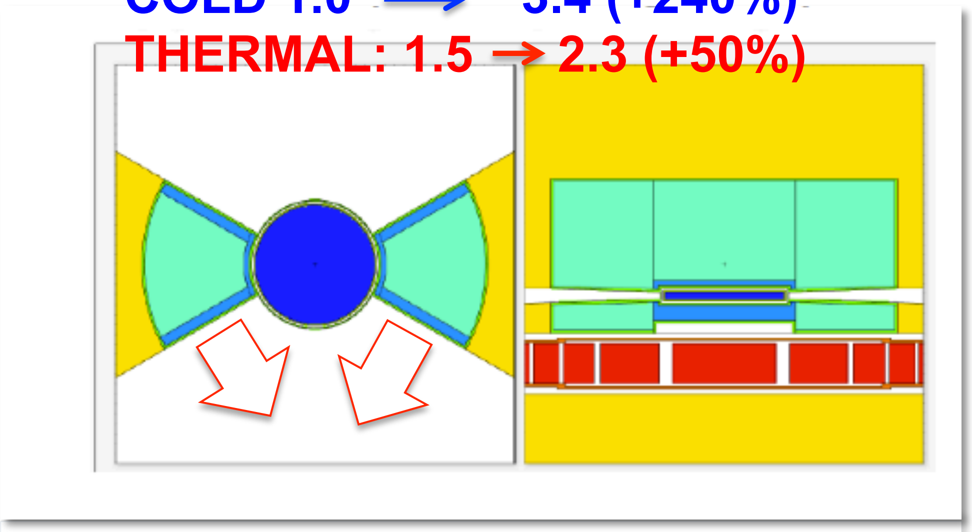
Change in brightness TDR -> Flat:

**COLD 1.0 ⟶ 3.4 (+240%)**
**THERMAL: 1.5 → 2.3 (+50%)**

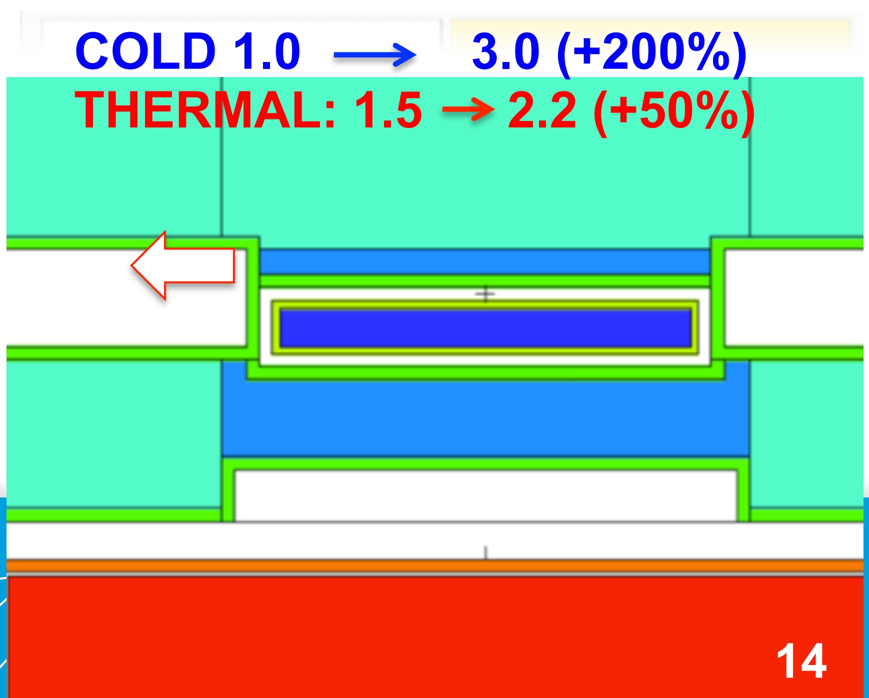


- ❑ Same performance as two flat moderators with 60° openings
- ❑ **No need for two flat moderators**

# Options for bispectral extraction



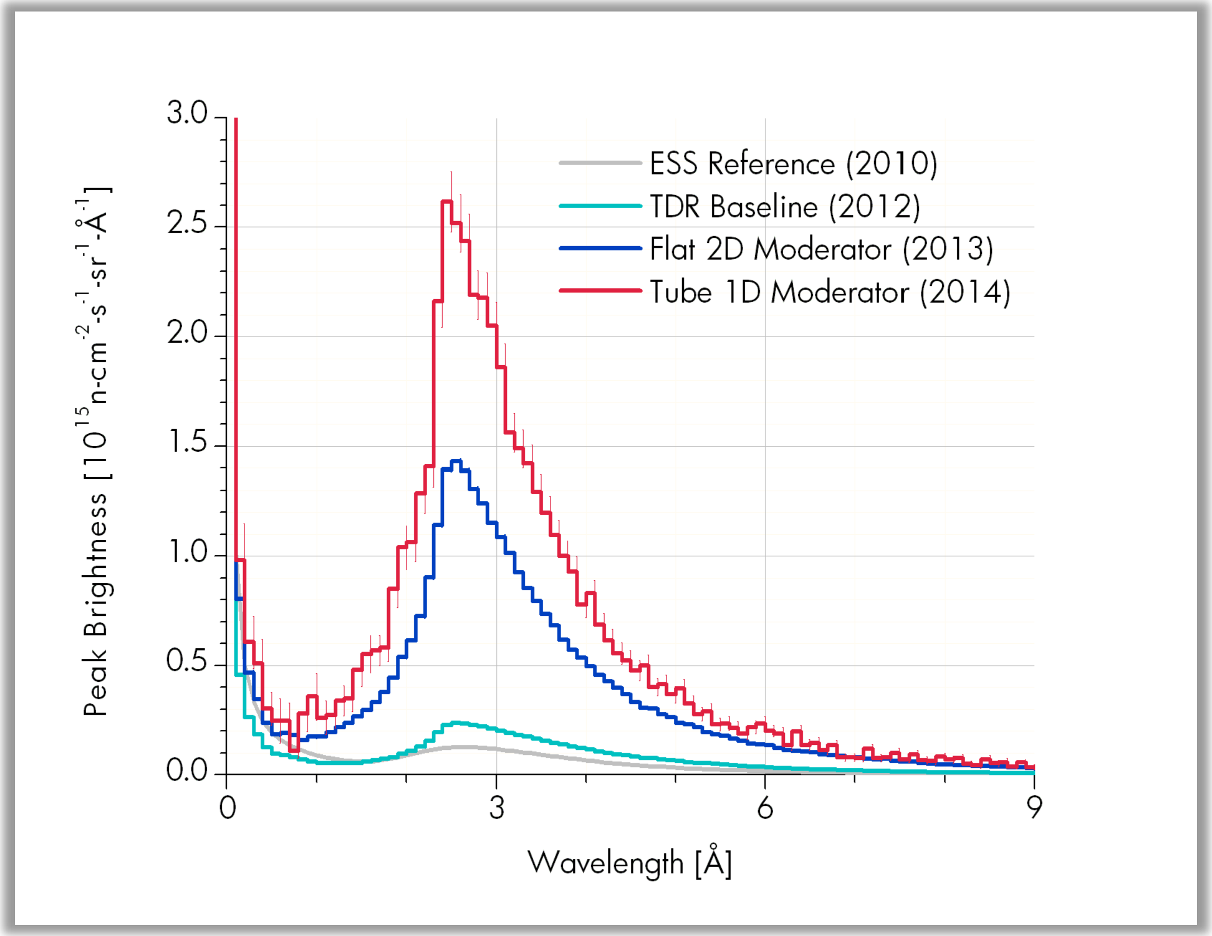

- ❑ **From the sides**
- ❑ Distance between cold and thermal hot spots similar to TDR (about 12 cm)

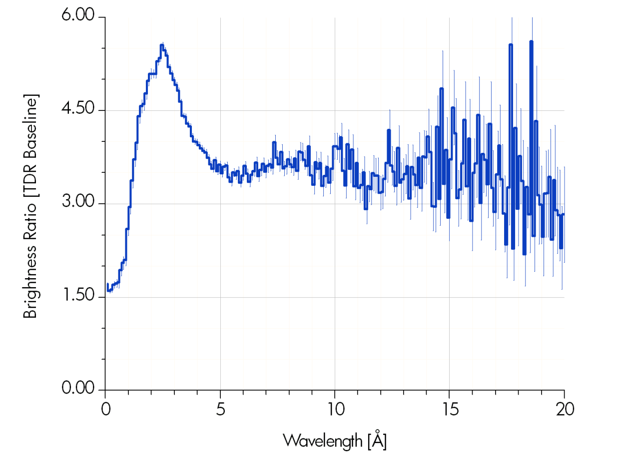



- ❑ **From the top**
  - ❑ Penalty in cold 10-15%
- ❑ Possible grooving
  - ❑ Thermal increase 60%

# Wavelength spectra

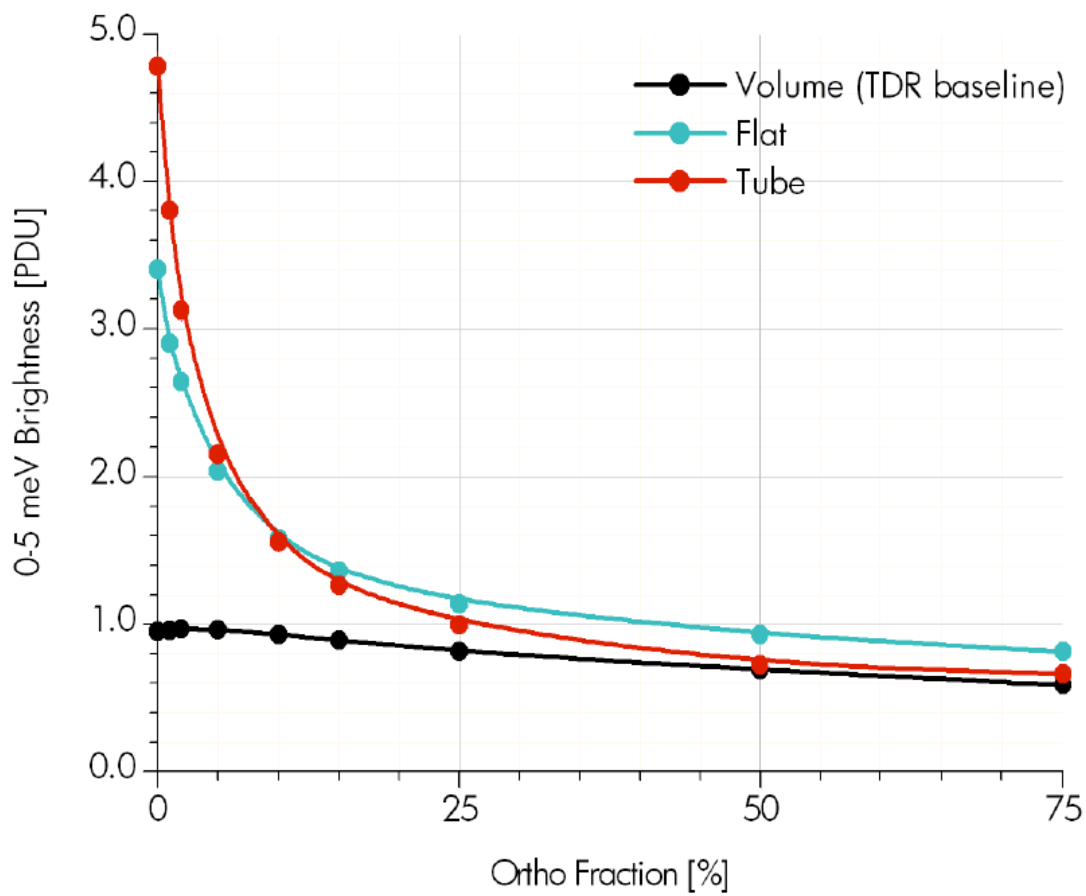
- ❑ Increase for cold and thermal brightness
  - ❑ Thermal increase by about a factor of 2
  - ❑ Cold flux increase by higher factor, also dependent of wavelength.



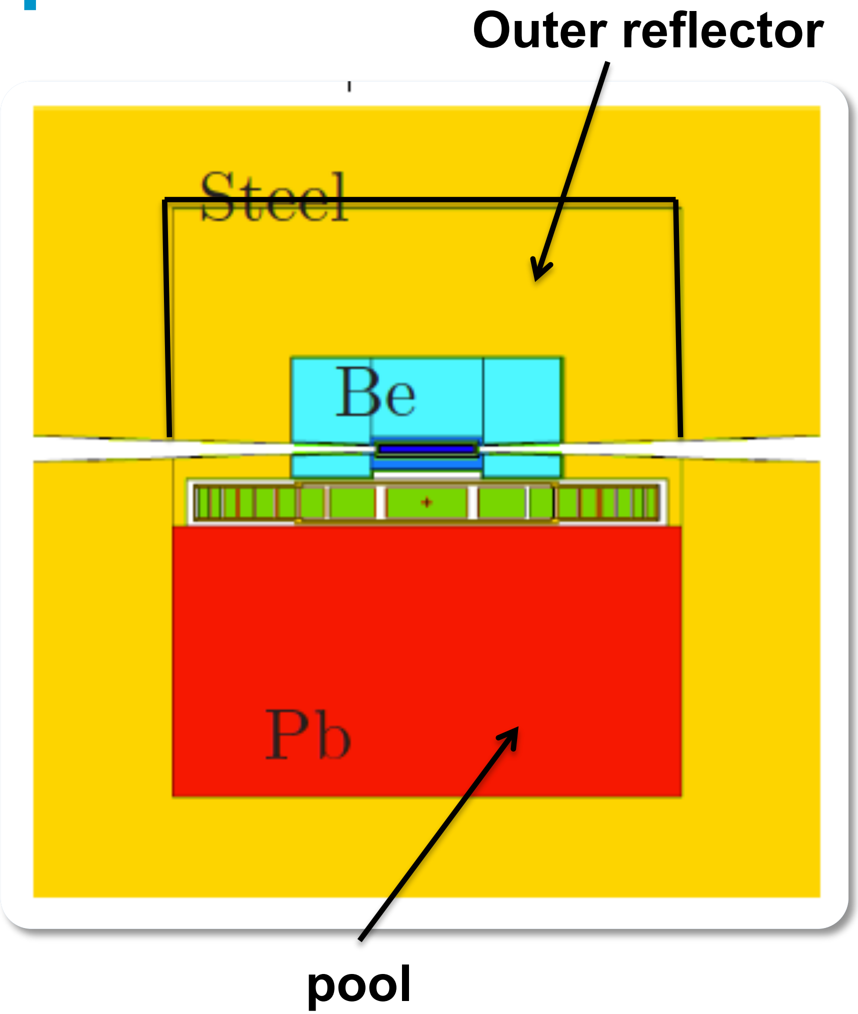
# Importance of pure para-$H_2$

- Extreme dependency of the brightness on the purity of para-$H_2$
- Importance of catalyst
- Theoretical estimates indicate negligible conversion (0.003% for flat) within one macropulse.
- More than 99% measured at J-PARC



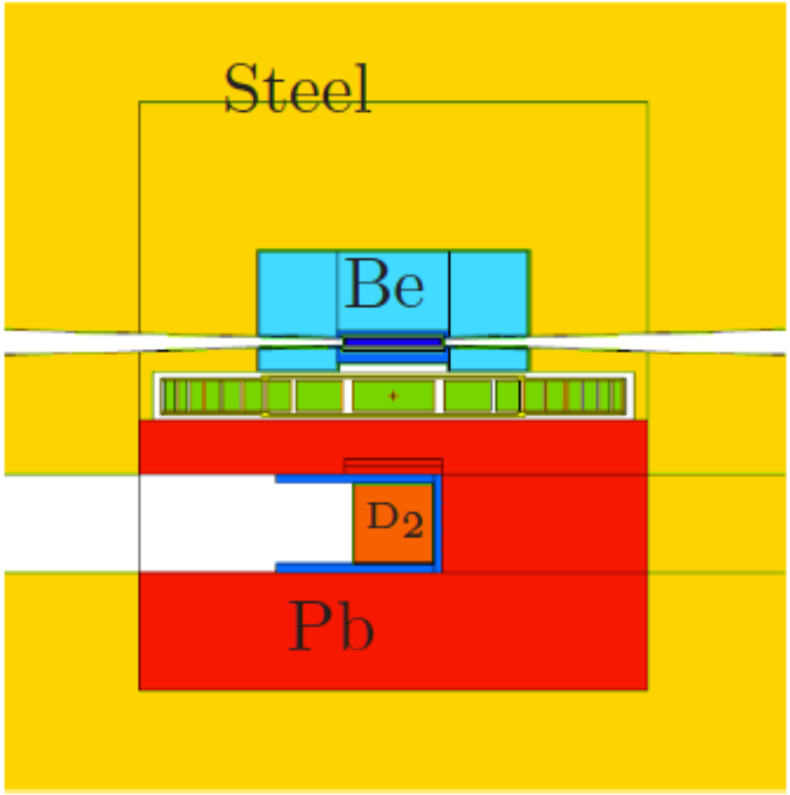
# Increase of neutrons to top half using Pb reflector ‘pool’

- Use of lead as outer reflector has the following advantages
  - Reflect fast neutrons without slowing down
    - No absoprtion in tungsten target
  - Increase cross talk between above and below the target (like having an effective bigger reflector)
- **Calculated 10% effect**
- Use of Pb outer reflector above raises gain to 15% (a bit more for thermal)

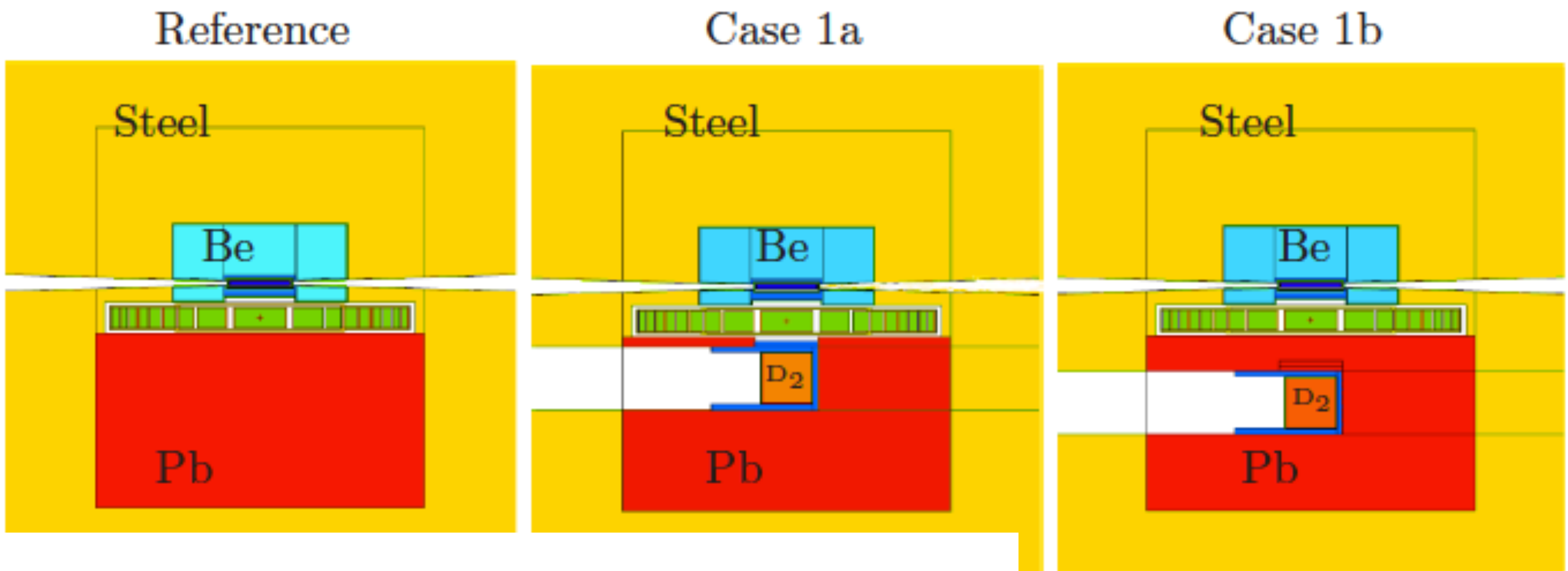


# A possible scenario for maximum moderators performance

- One (flat) moderator on the top
- Pb reflector at the bottom
- Use of Pb compensates for the loss from having a 240° openings, but with the added value of easier extraction of MR plug and less Be.
- A large through going tube at the bottom where a large $D_2$ moderator can be arranged for high-intensity flux for fundamental physics studies.



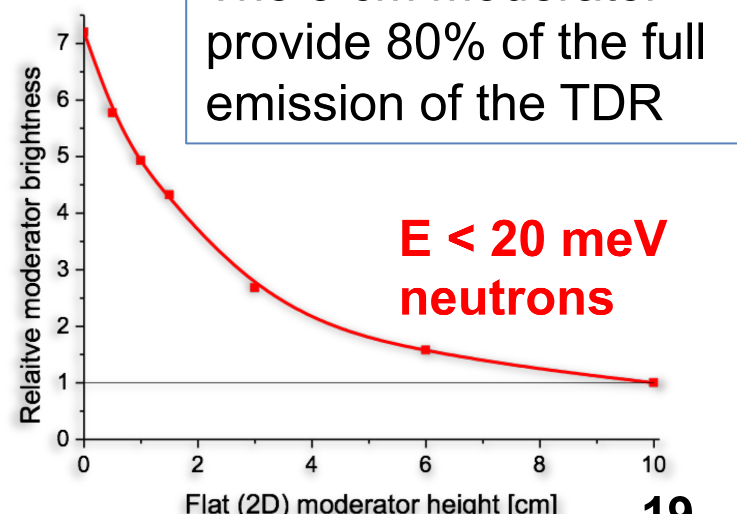
# Through-going tube




| Case | $A \times B$ [n/sr/s] |
|---|---|
| TDR $H_2$ - 12 $cm$ × 12 $cm$ | $1.17 \times 10^{15}$ |
| 1a $D_2$ - 25 $cm$ × 20.6 $cm$ | $4.27 \times 10^{15}$ |
| 1b $D_2$ - 25 $cm$ × 20.6 $cm$ | $2.85 \times 10^{15}$ |

- ❑The real high intensity moderator is the big moderator at the bottom:
- ❑never achieved at any pulsed spallation sources, because $D_2$ was never considered

The 3 cm moderator provide 80% of the full emission of the TDR



# Summary

- Summary table:

| | Cold (E<5 meV) | Thermal 20 meV < E < 100 meV) |
|---|---|---|
| TDR baseline | 1 | 1.5 |
| 2 flat (two 60 openings each) | 3.4 | N/A |
| 1 flat (two 120 openings) | 3.4 | 2.3 |
| 1 flat (two 120 openings) + Pb outer reflector + pool | 3.9 | 2.7 |

(numbers in absolute units of 5.6 $10^{-4}$ $n/cm^2/sr/proton$)

- Through-going beam line, at least 3 times gain compared to TDR baseline for n-nbar experiment.
- As a last option, preserve the possibility to opening the vertical beam line
  - can be readily achieved essentially at no cost by the shielding design above the moderator plug.

# Outlook

- Looking for best option for thermal extraction (side, top)
- Best option to accommodate different needs for instruments
  - Two moderators (big and small)
  - One moderator (different heights in a single moderator under study)
- Harmonisation with Instrument Suite:
  - Complex optimisation is in progress over the instrument suite and sample sizes
  - Collaboration between Instruments and Target division and many Instrument Consortia partners
- Deadline April 30

# Thank you ! ;-)

## 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 Neutr. Research, 2014

E. Klinkby et al., *Voluminous D2 source for intense cold neutron beam production at the ESS*, 23 Jan 2014, arXiv:1401.6003

# Backup slides

# Low-dimensional moderators work also for reactors

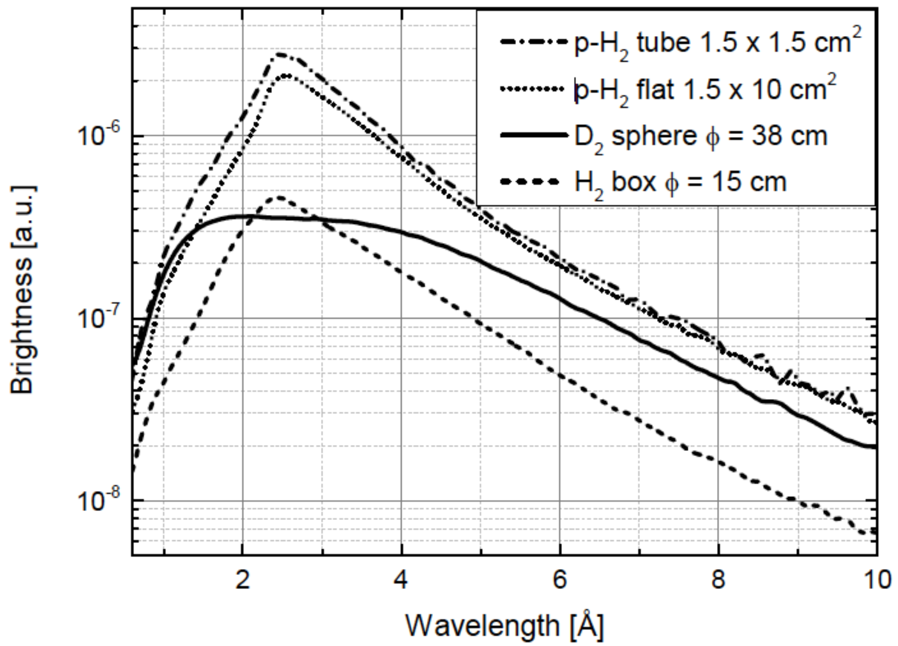
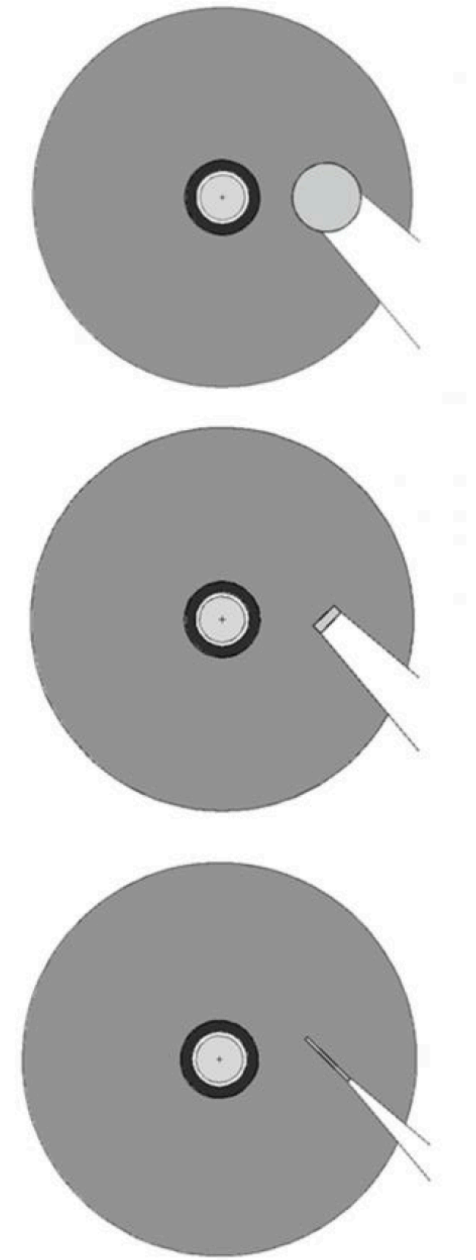



Fig. 2. MCNPX simulation results for the relative perturbed neutron brightness of a variety of cold neutron moderators at an ILL type fission reactor with heavy water reflector. The dimensions in the figure define the viewed moderator surface. The depth of the rectangular flat and tube moderators is 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.