Neutronics for Final Moderator Configuration

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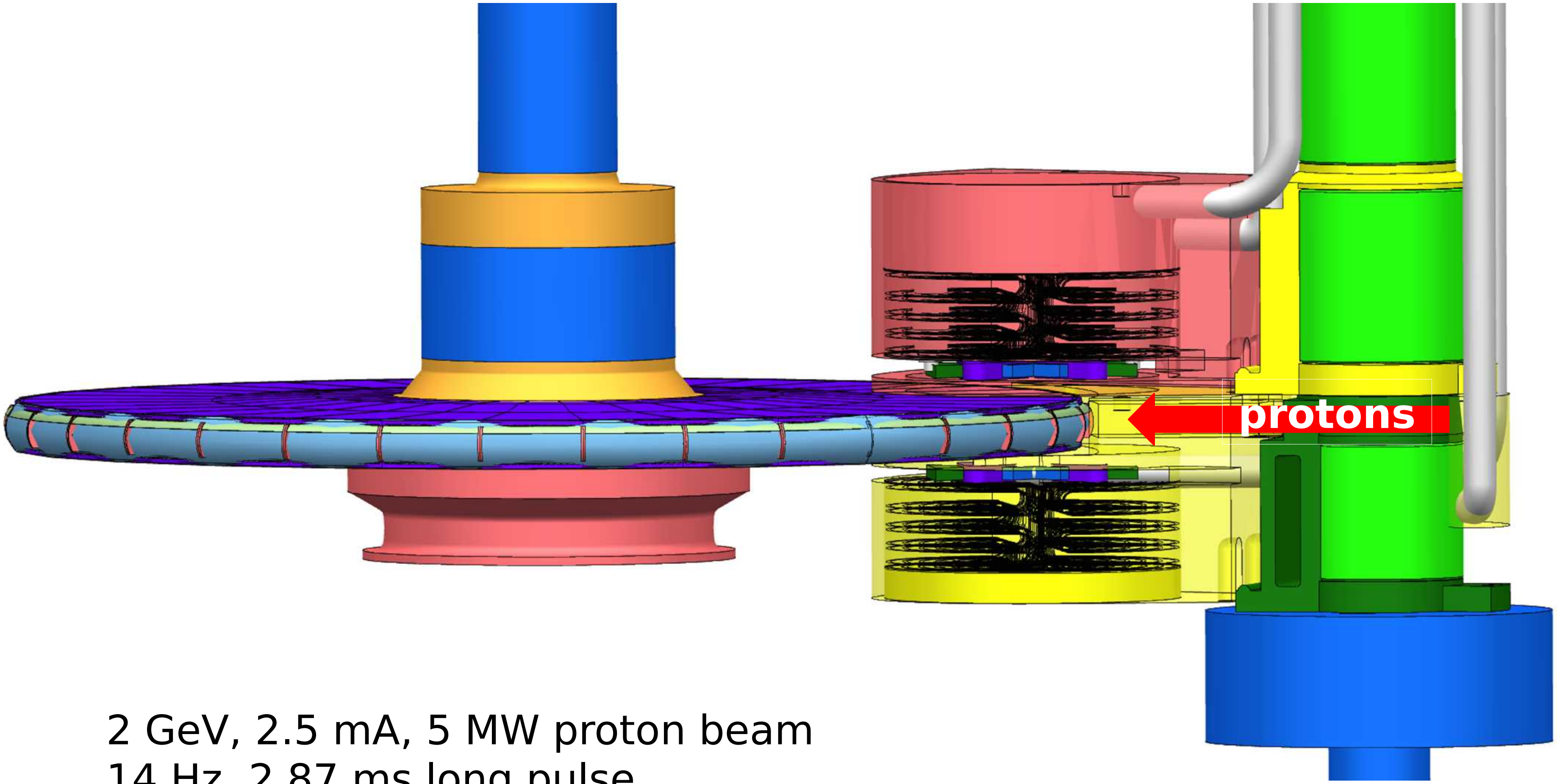
TAC 11, Lund, April 1st-2nd 2015

ESS Target-moderator-reflector assembly



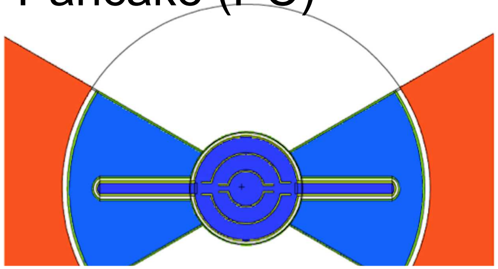
2 GeV, 2.5 mA, 5 MW proton beam
14 Hz, 2.87 ms long pulse

(Bengt Jönsson)

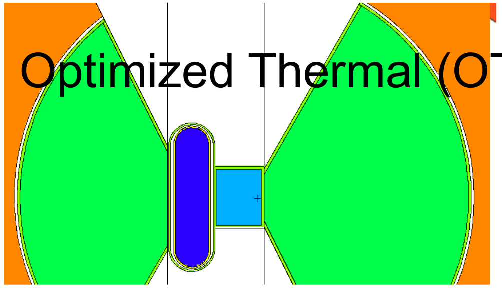
....since last TAC

- Several moderator concepts discussed & performance compared
  - Pancake
  - Optimized Thermal
  - Butterfly
- In the meantime studies have advanced on all aspects:
  - Neutronic performance
  - Moderator engineering
  - Beam extraction
  - Instrument performance
- Marts 6th : CCB accepted change request to two Butterflies (3cm & 6cm)
- During this talk I will try to explain the arguments behind this decision. Focus on neutronic aspects

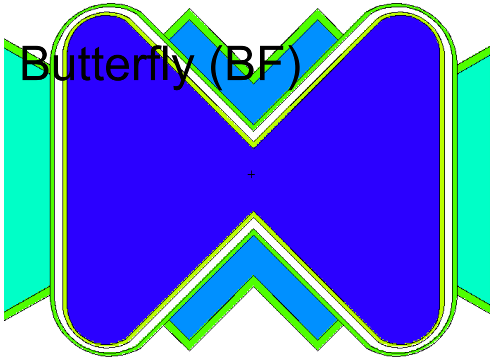
Pancake (PC)



Optimized Thermal (OT)



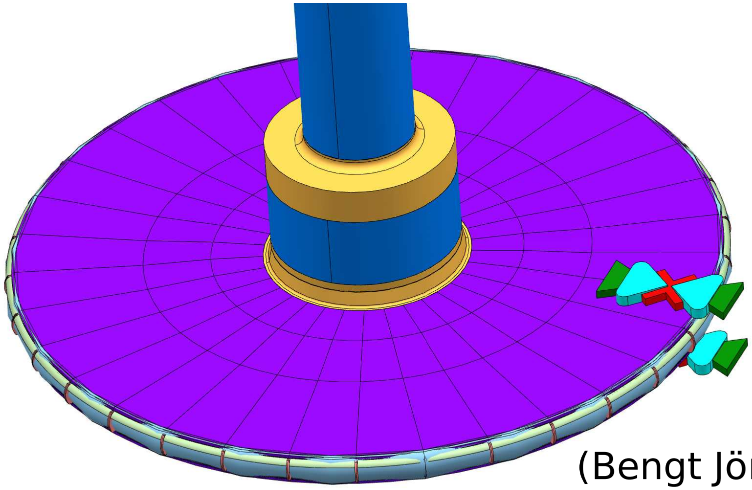
Butterfly (BF)



Moderator Design Principles

Summary / reminder

- ❑ Low-dimensional moderators
- ❑ Importance of positioning
- ❑ Importance of premoderator
- ❑ Grooving
- ❑ Reflector / Size of openings

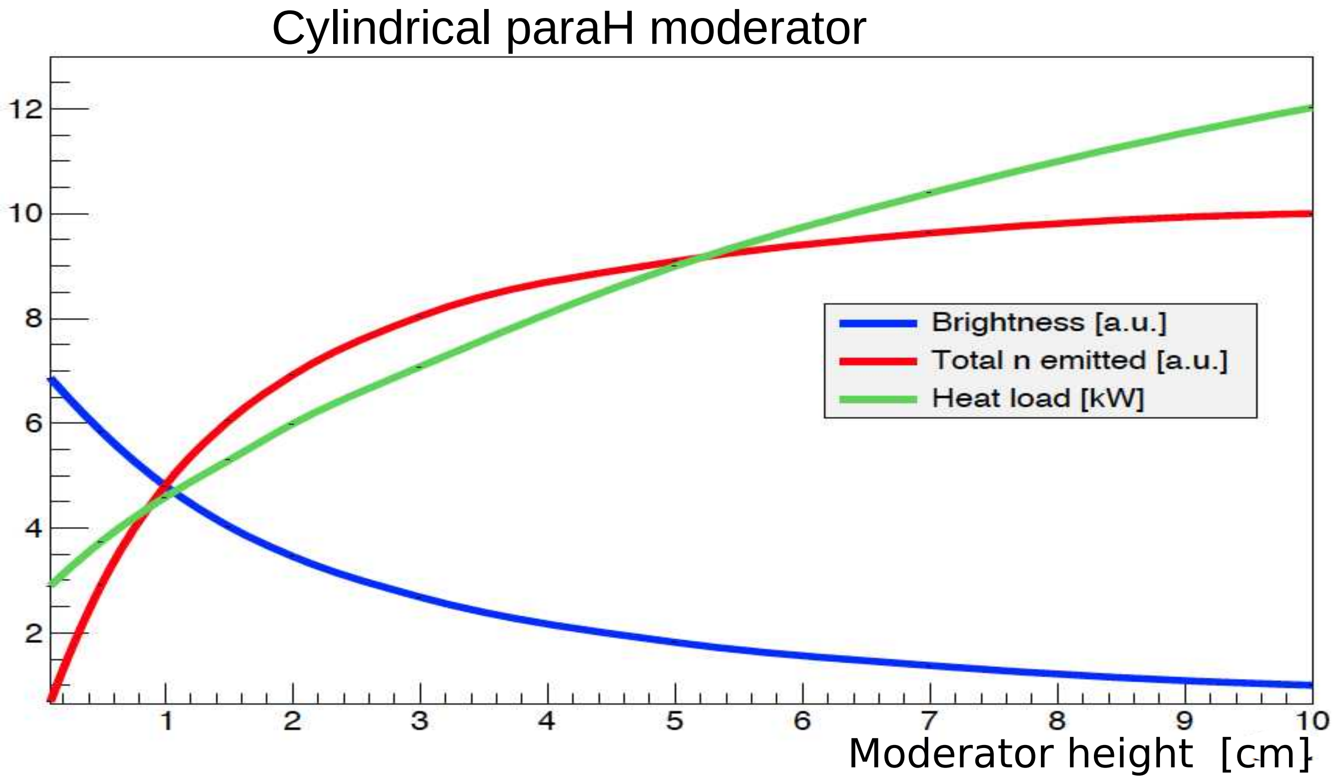


(Bengt Jönsson)

Butterfly

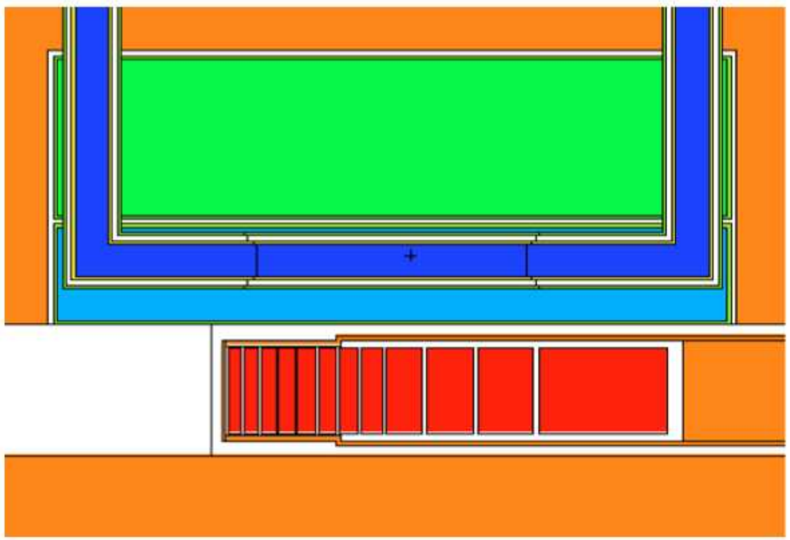
- ❑ Beam extraction
  - Viewed surface area
  - Distance between cold and thermal moderators
- ❑ Neutron emission uniformity
  - Flexibility for placing instruments (and for instruments to choose moderator)
- ❑ Neutronic performance
- ❑ Instrument performance

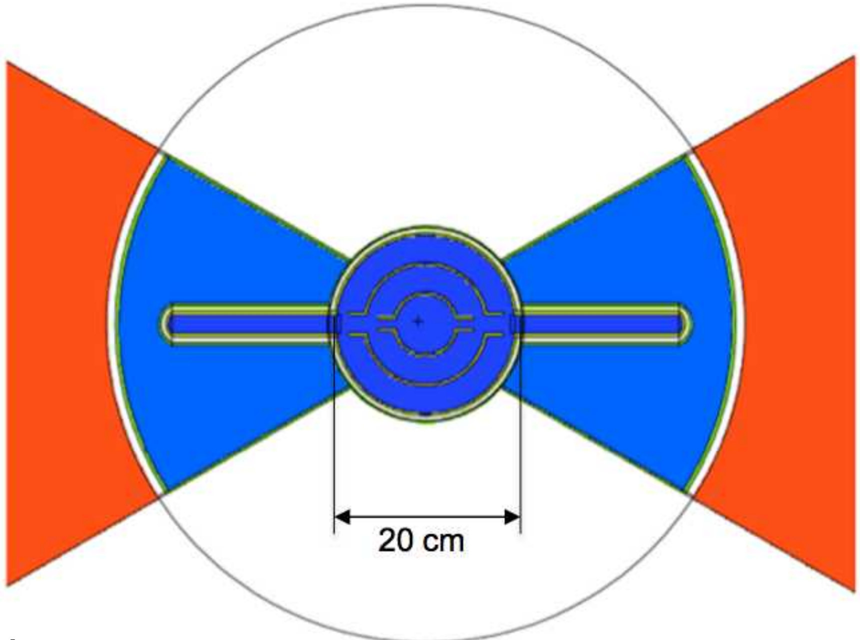
Low dimension moderators:
Higher brightness, lower heat load



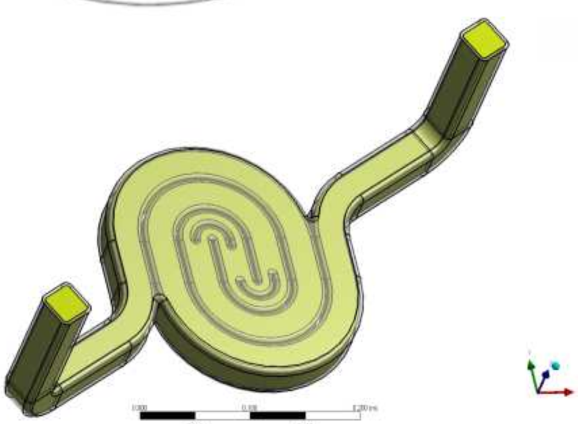
Lesson learned: Moderator should only be as tall as needed by instruments

Reminder: Flat moderator reference configuration - the “pancake”



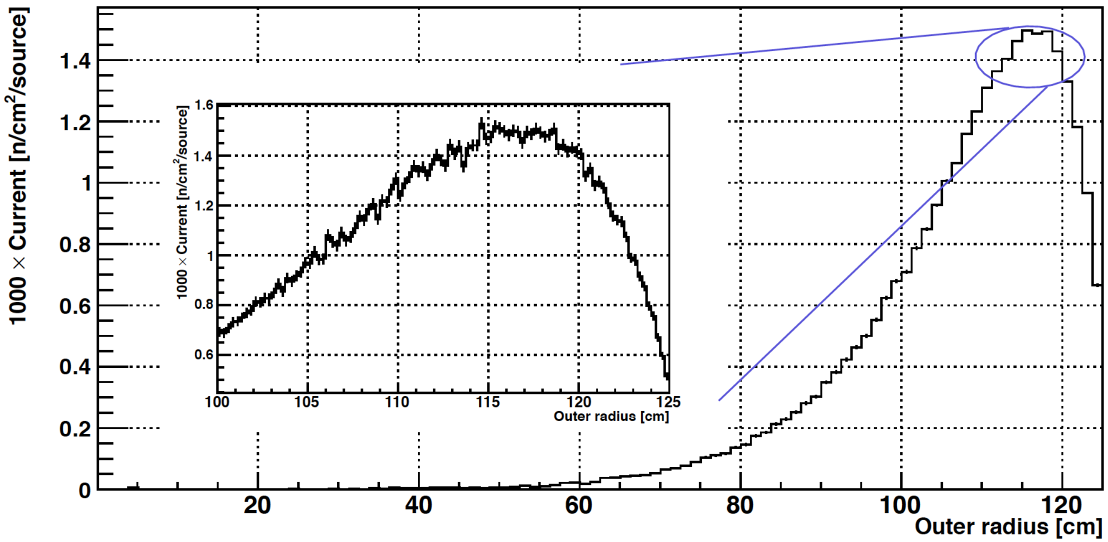


- Optimized for cold (2.5 × TDR)
- Thermal extraction from the wing => large angle between cold and thermal hot-spots (not so good)
- Non-uniform thermal performance



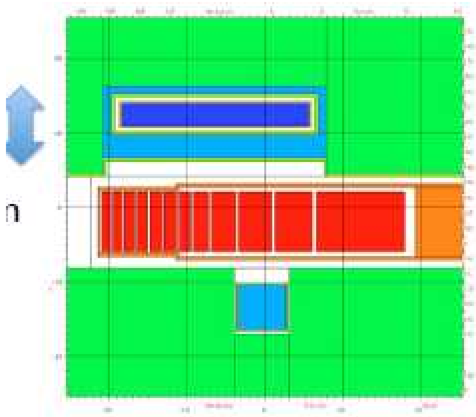
Sensitivity to **Positioning**

Correct positioning can improve brightness by 30-50%



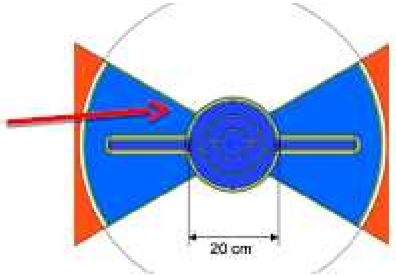
Neutron side leakage current as a function of the distance from the wheel centre. The peak defines the radial position of the moderator.

≈3%/cm (elevation with respect to target)

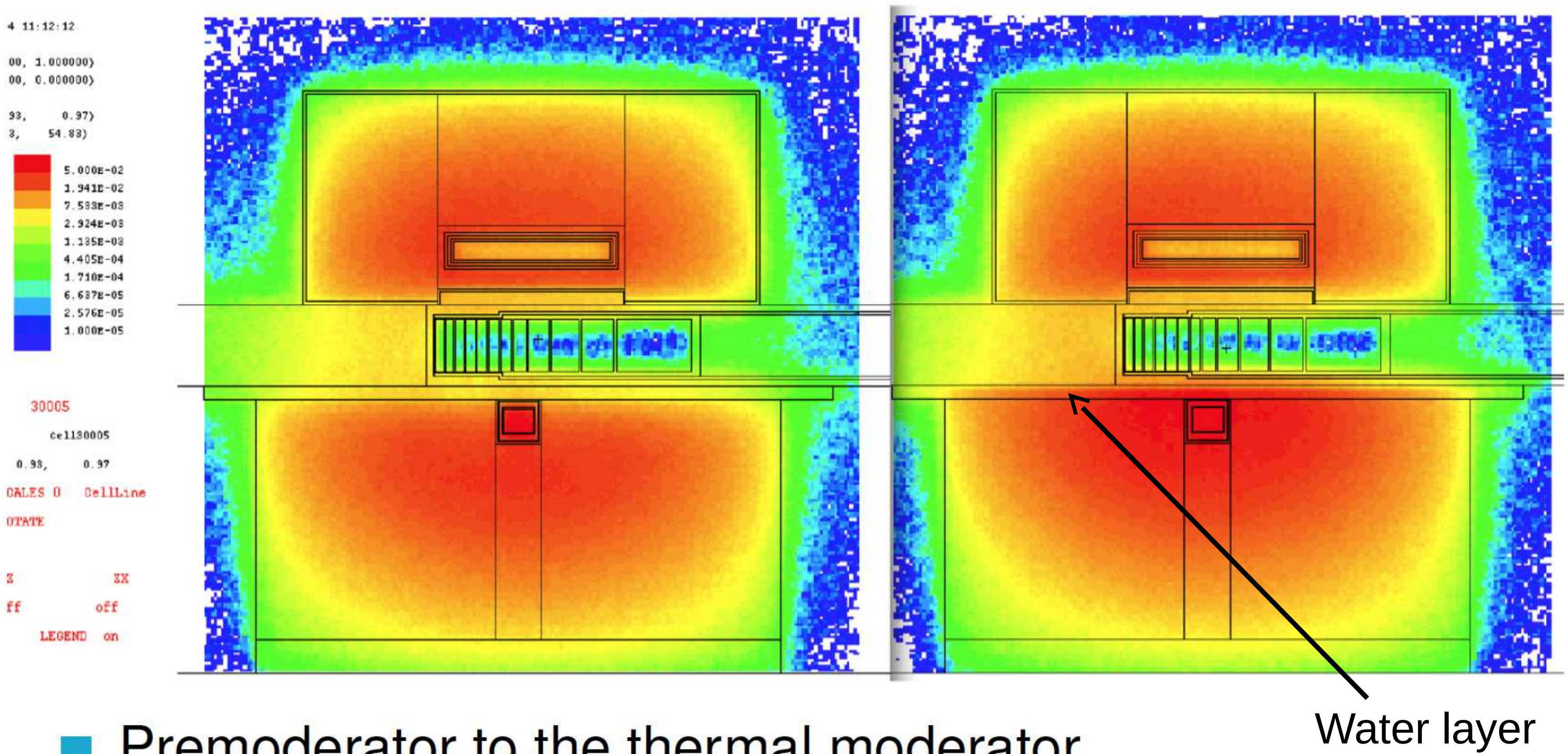


≈2%/cm (offset with respect to target)

Thermal source some 15 cm from hot spot

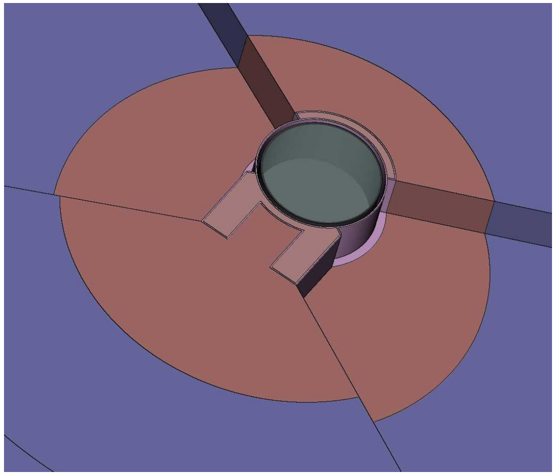


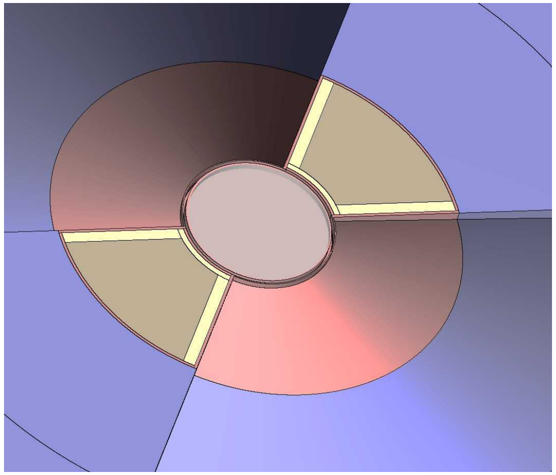
Importance of **Premoderator**, also for water moderator



- Premoderator to the thermal moderator
- Neutrons are thermalised by this layer $\Rightarrow$ moderator is mainly a scatterer

Importance of **Reflector**





- 2 × 60° was mandatory for the TDR
- 2 ×120° is possible for flat moderator

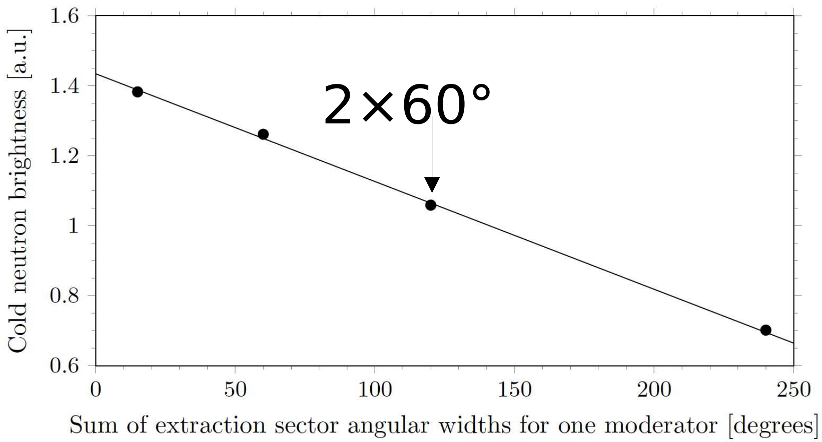
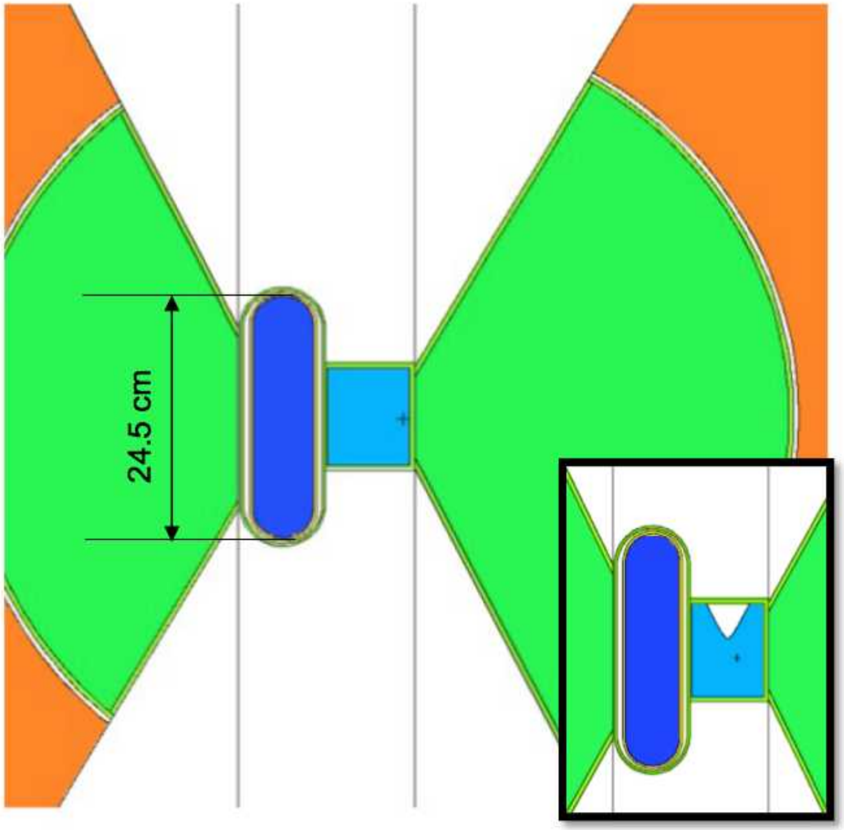


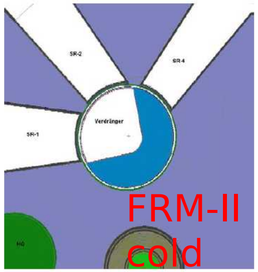
Figure 3.19: Calculated dependence of cold neutron brightness on total opening angle around a cold moderator.

Reminder: Optimized Thermal (with optional grooving)

- Optimized for thermal
- Higher brightness than pancake on a double emission surface
- Cold extraction from “tube” moderator
- Serving 2 × 60-70° maximum



- Grooving or reentrant holes look at maximum and more thermalized flux
- Does not work on pure para-H_2.



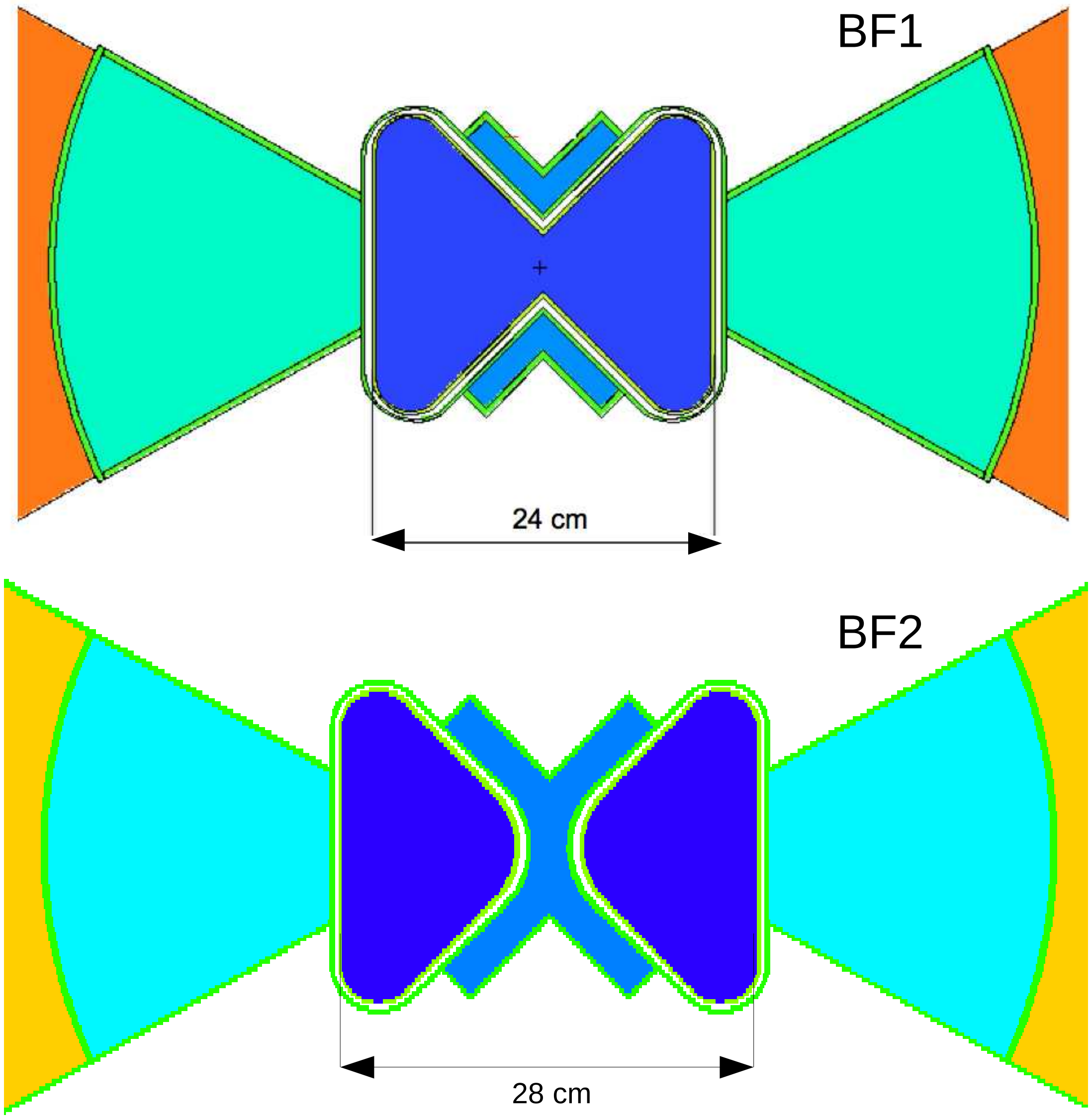
Final recipe

- ❑ Mean free path considerations √
- ❑ Premoderator √
- ❑ Moderator position √
- ❑ Reflector / openings √
- ❑ Grooving √

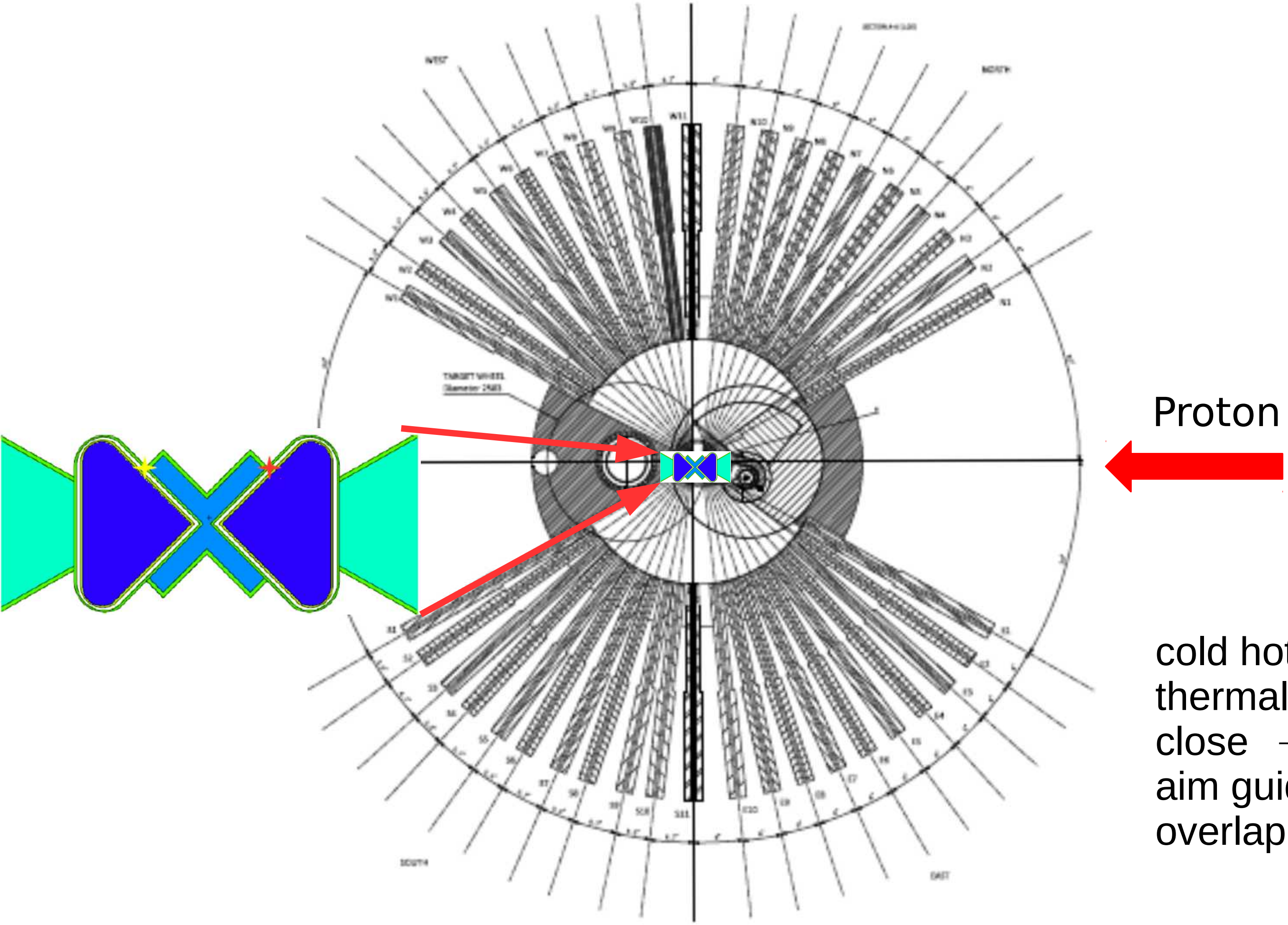
- ❑ Beam extraction considerations
- ❑ Flexibility (for placing instruments)
- ❑ Uniformity of neutron emission (across the surface and across beam-ports)

Combining all the design principles

- Optimized for thermal and cold
- Exploits all design principles
  - Low-D
  - Positioning
  - Premoderator
  - Beam extraction
  - Re-entry
  - Uniform emission
- Serving the full 2 × 120°

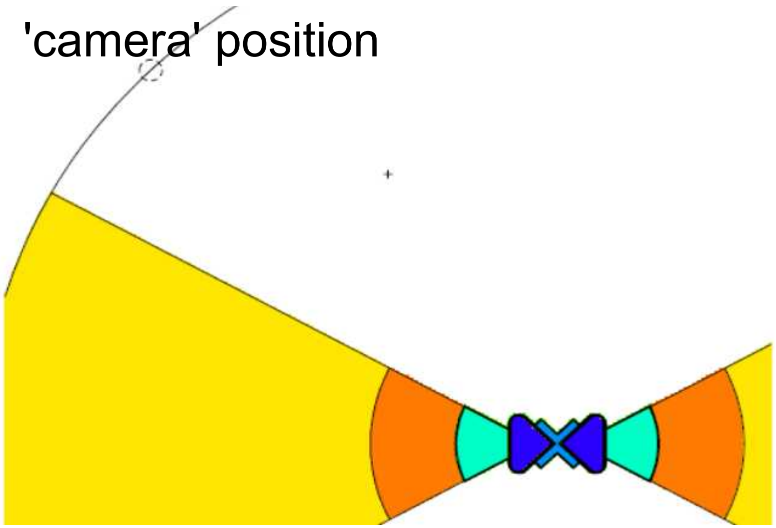


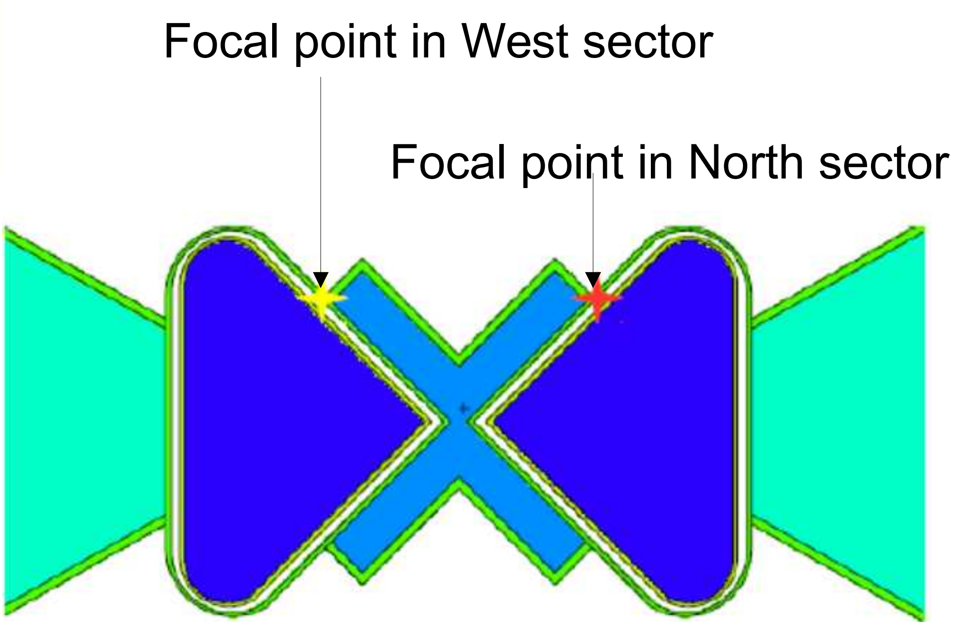
Beam extraction



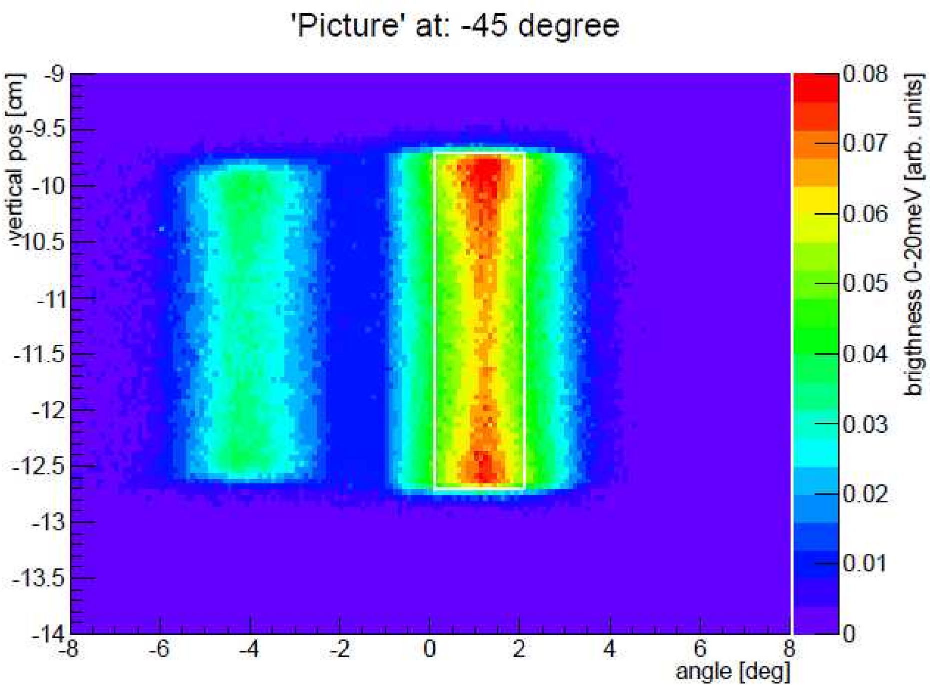
cold hot spot and thermal hot spot are close → easier to aim guides, without overlap

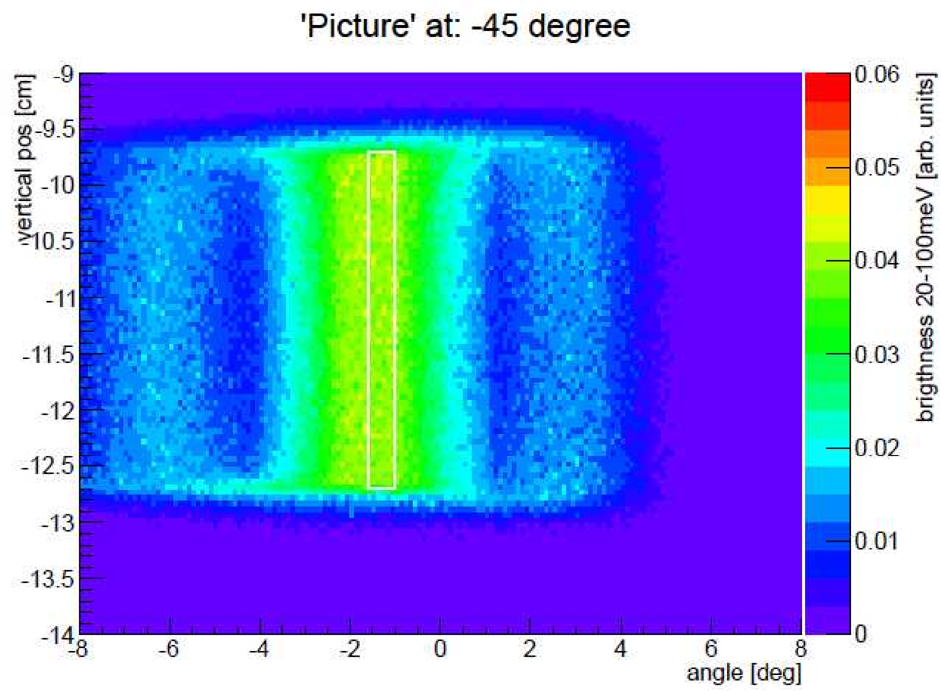
Beam extraction: Neutron emission images





Beam extraction: Neutron emission images





Box illustrates typical instrument acceptance:

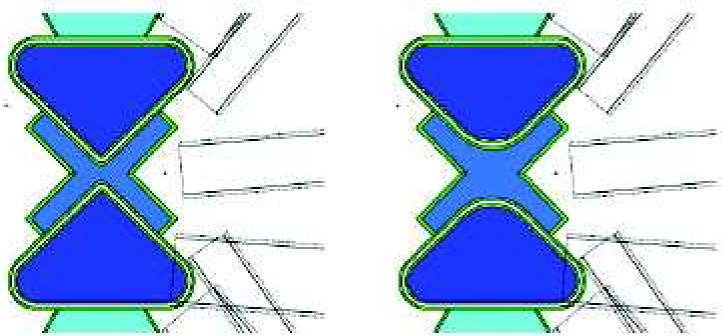
- 2.0 degree horizontal cold acceptance (~6.5cm)
- 0.6 degree horizontal thermal acceptance (~2.0cm)

Cold and thermal hotspots closer than for pancake: favorable beam extraction

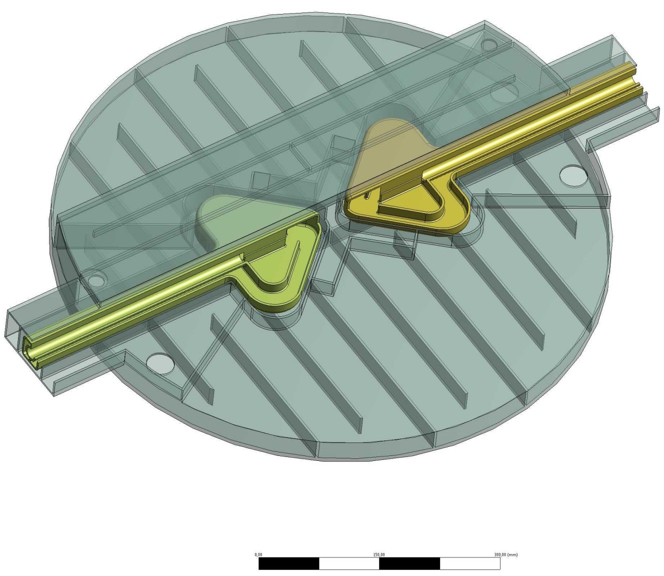
Nice and uniform : ease placing instruments

Engineering model and neutronic optimization

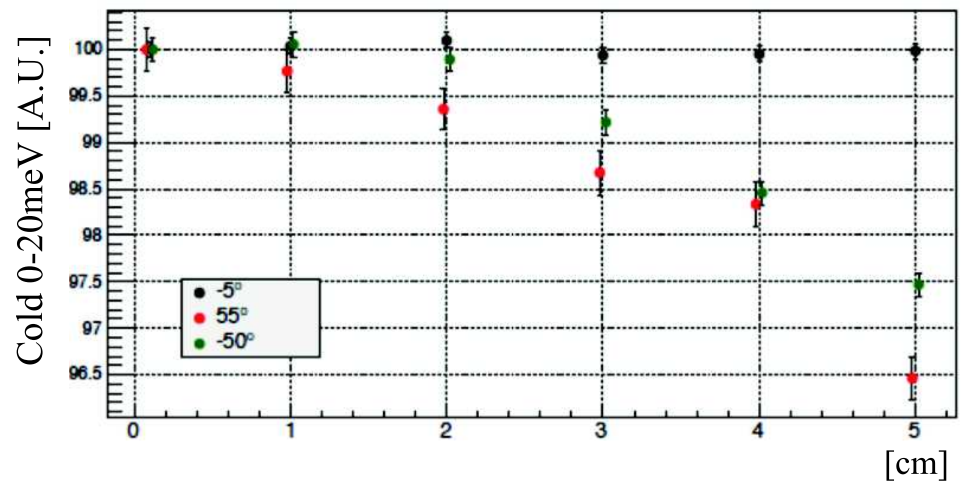
EUROPEAN SPALLATION SOURCE

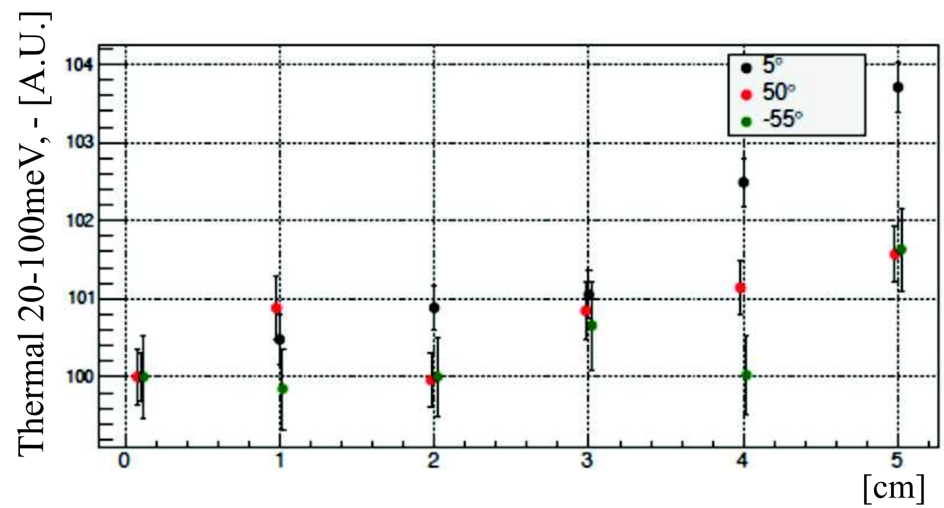


Curvature: 0.1cm 5cm

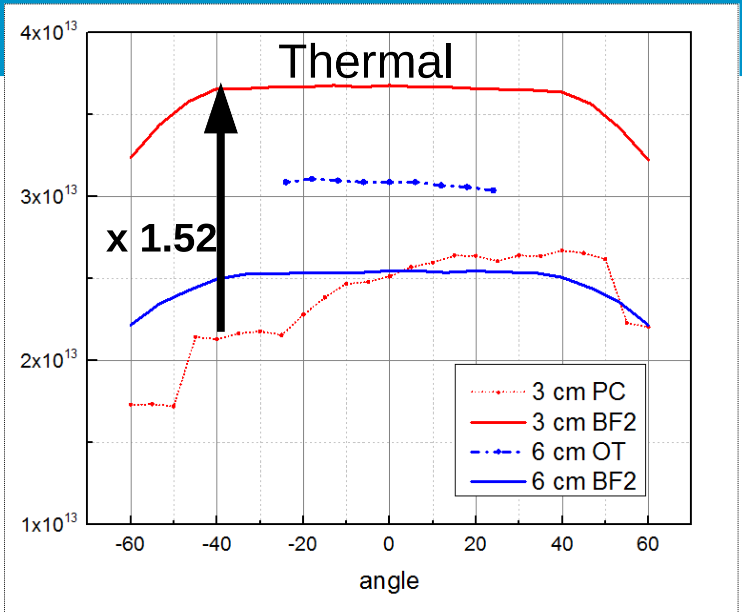


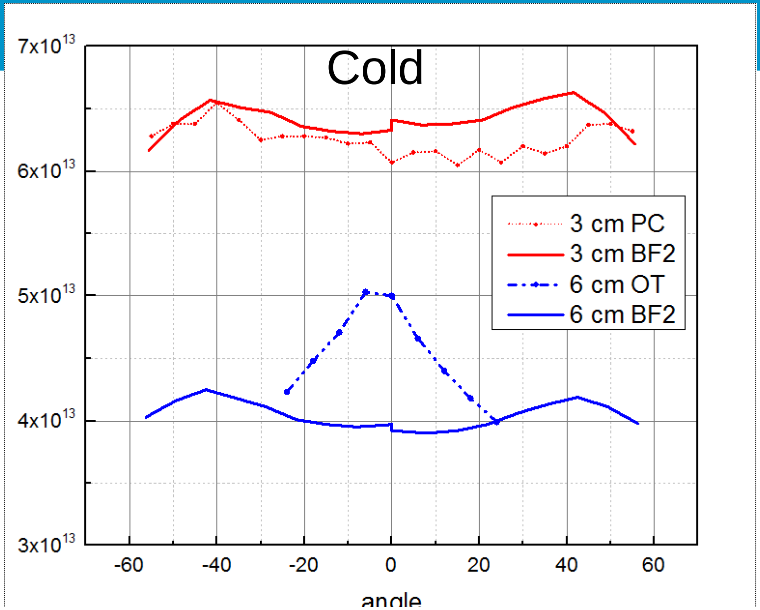
Brightness vs curvature radius





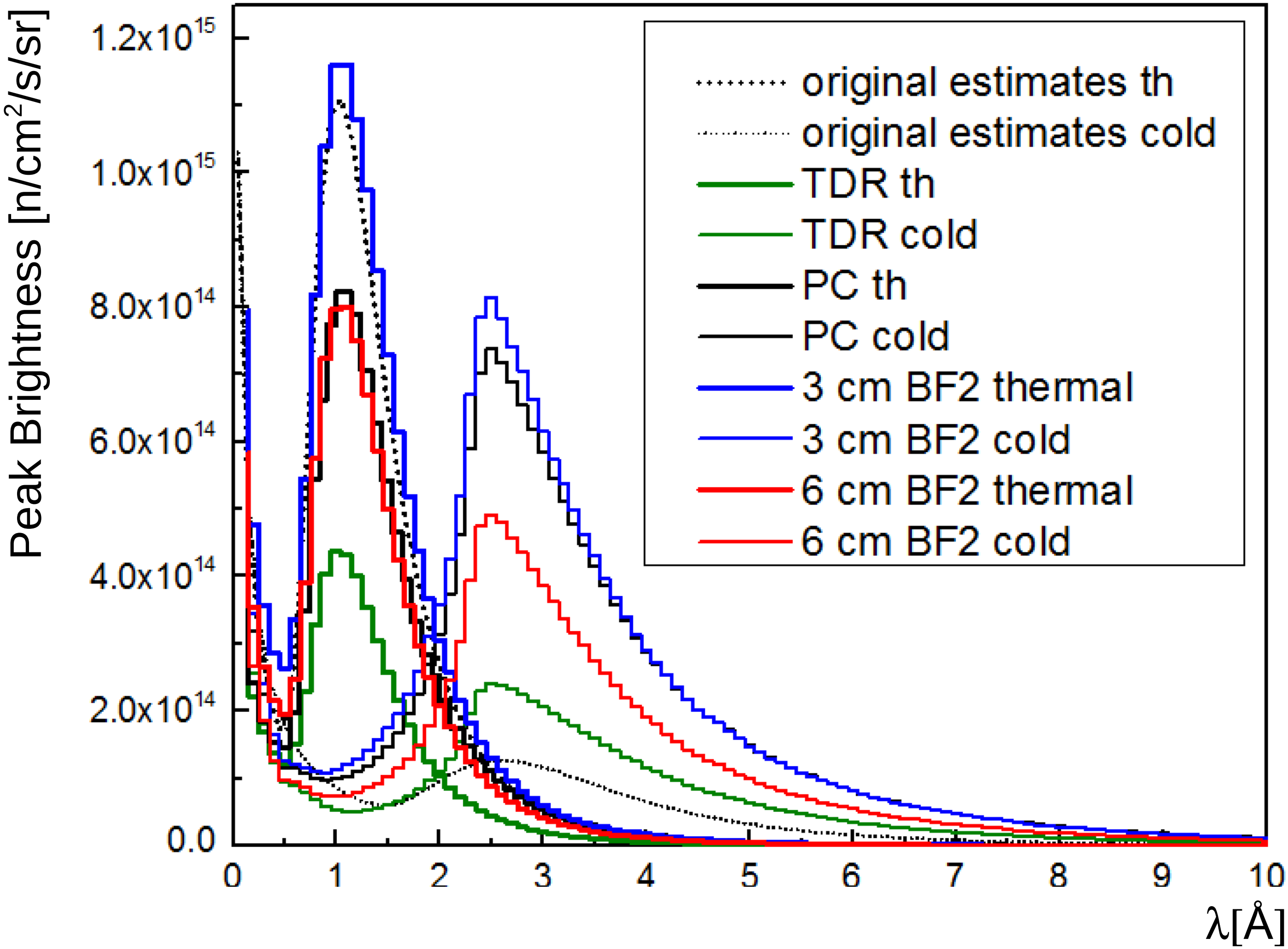
Neutronic performance: integrated





	Openings	Cold E < 5 meV [n/cm²/s/sr]	Cold E< 20 meV [n/cm²/s/sr]	Thermal 20 meV< E < 100 meV [n/cm²/s/sr]	Heat load [kW]
Pancake	2× 120°	2.02×10^{13}	6.25×10^{13}	2.35×10^{13}	8.2
BF2-3cm	2× 120°	1.97×10^{13}	6.41×10^{13}	3.58×10^{13}	9.0
OT-6cm	2× 60°	1.42×10^{13}	4.52×10^{13}	3.08×10^{13}	6.3
BF2-6cm	2× 120°	1.31×10^{13}	4.04×10^{13}	2.47×10^{13}	11.4
Ratio to pancake					
BF2-3cm		0.98	1.03	1.52	
OT-6cm		0.70	0.72	1.31	
BF2-6cm		0.65	0.65	1.05	

Neutronic performance: spectra



Instrument performance

Ken Andersen

	3cmPC 6cmCH	3cmPC 6cmBF2	3cmBF1 6cmOT	3cmBF1 6cmCH	3cmBF1 6cmBF2	3cmBF2 6cmOT	3cmBF2 6cmCH	3cmBF2 6cmBF2
ODIN	0.96 b	0.88 b	1.00 b	0.96 b	0.88 b	1.00 b	0.96 b	0.88 b
SKADI	1.00 t	1.00 t	1.12 t	1.12 t	1.12 t	0.97 t	0.97 t	0.97 t
LOKI	1.00 t	1.00 t	1.13 t	1.13 t	1.13 t	0.98 t	0.98 t	0.98 t
SLEIPNIR	1.00 t	1.00 t	1.02 t	1.02 t	1.02 t	0.92 t	0.92 t	0.92 t
FREIA	1.00 t	1.00 t	0.91 t	0.91 t	0.91 t	0.85 t	0.85 t	0.85 t
HERITAGE	1.00 t	1.00 t	1.02 t	1.02 t	1.02 t	0.92 t	0.92 t	0.92 t
ESTIA	1.00 t	1.00 t	1.13 t	1.13 t	1.13 t	0.98 t	0.98 t	0.98 t
HOD	0.92 b	1.04 b	1.00 b	0.92 b	1.04 b	1.00 b	0.96 t	1.04 b
DREAM	1.00 t	1.00 t	**1.25** t	**1.25** t	**1.25** t	**1.36** t	**1.36** t	**1.36** t
HEIMDAL	1.09 d	1.06 d	**1.25** d	1.15 d	1.12 d	**1.18** d	1.08 t	1.08 d
BEER	1.02 t	1.02 t	**1.18** t	**1.18** t	**1.18** t	**1.20** t	**1.20** t	**1.20** t
MAGIC	0.97 t	0.97 t	**1.19** t	**1.19** t	**1.19** t	**1.24** t	**1.24** t	**1.24** t
NMX	1.00 t	1.00 t	1.13 t	1.13 t	1.13 t	0.98 t	0.98 t	0.98 t
C-SPEC	1.00 t	1.00 t	1.09 t	1.09 t	1.09 t	0.97 t	0.97 t	0.97 t
VOR	1.00 t	1.00 t	1.02 t	1.02 t	1.02 t	0.93 t	0.93 t	0.93 t
T-REX	1.14 b	0.96 t	1.13 t	1.14 b	1.13 t	1.11 t	1.14 b	1.11 t
ThChSpec	0.88 b	0.85 b	1.00 b	0.88 b	0.85 b	1.02 t	1.02 t	1.02 t
CAMEA	1.00 t	1.00 t	1.05 t	1.05 t	1.05 t	0.96 t	0.96 t	0.96 t
MIRACLES	1.00 t	1.00 t	0.89 t	0.99 b	0.89 t	0.85 b	0.99 b	0.87 b
ESSENSE	1.00 t	1.00 t	1.06 t	1.06 t	1.06 t	0.95 t	0.95 t	0.95 t
WA-NSE	1.00 t	1.00 t	1.12 t	1.12 t	1.12 t	0.98 t	0.98 t	0.98 t
FPBL	1.00 t	1.00 t	1.07 t	1.07 t	1.07 t	0.96 b	1.00 b	0.95 t
n-nbar	1.00 t	**1.36** b	1.10 t	1.10 t	**1.36** b	1.09 t	1.09 t	**1.36** b
Average	1.00	1.01	1.08	1.07	1.08	1.02	1.02	1.02
top+bot	19+5	19+5	20+4	18+6	19+5	19+5	19+4	19+5

EUROPEAN SPALLATION SOURCE

Instrument performance

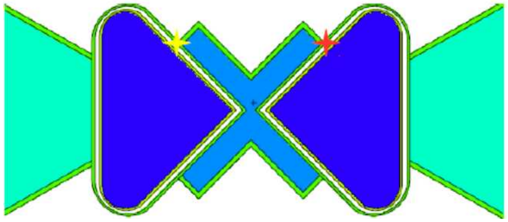
- ❑ <u> 3 cm pancake → 3 cm butterfly: </u>
  - Negligible impact on the cold-neutron instruments
  - Substantially improving the performance of the bispectral instruments.

- ❑ <u> 6 cm Optimized Thermal → 6 cm butterfly: </u>
  - Little effect on the performance of the individual instruments
  - Dramatically increase the flexibility of the instrument layout, allowing all instruments to freely choose the optimum moderator for their needs.

Conclusions

- Two butterfly moderators each serving 2 x 120° sector
  - Top: 3cm tall
  - Bottom: 6cm tall
- Exploits all neutronics design criteria developed
- Optimal beam extraction, double decker configuration
  - Flexible to place instruments
  - Flexible for instruments to choose moderator
- Engineering feasible
- Instrument performance gain

- Accepted by Change Control Board (CCB)



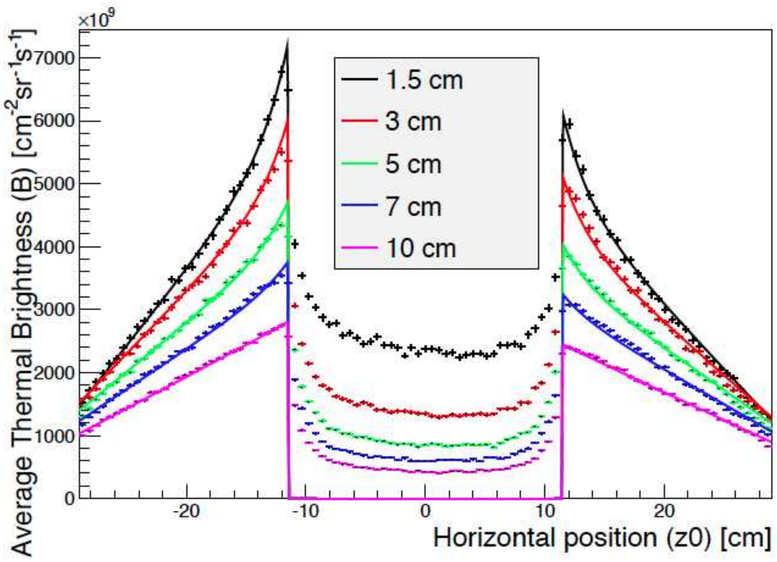
Next steps

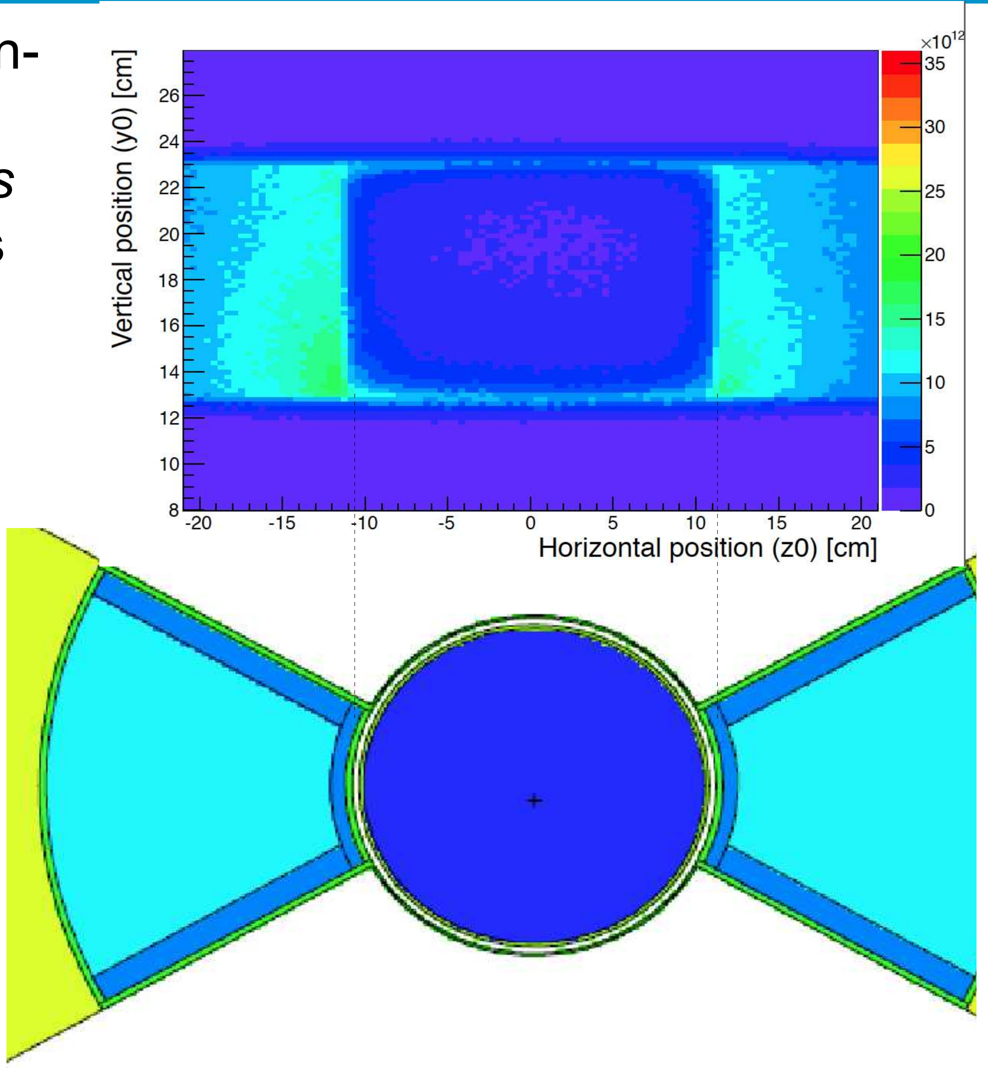
- Finalize butterfly design (round corners etc)
- Flat moderator verification experiment: J-PARC, April 2015

Back-up slides

Instrument optimizations :: thermal source

- Important to take into account non-uniformities.
- Source is parametrized in *McStas* using below (*MCNP*) distributions

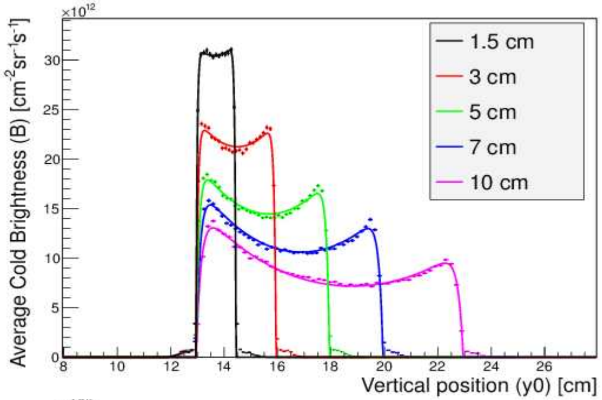


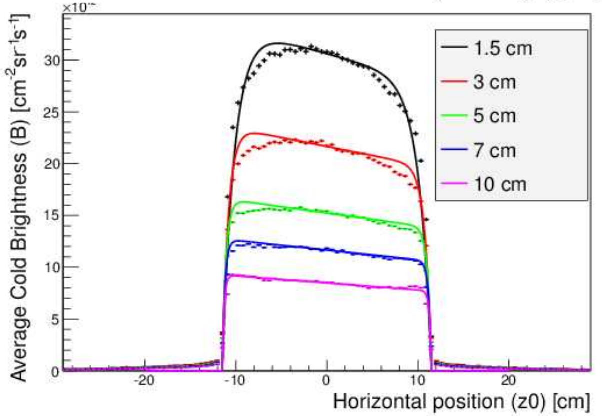


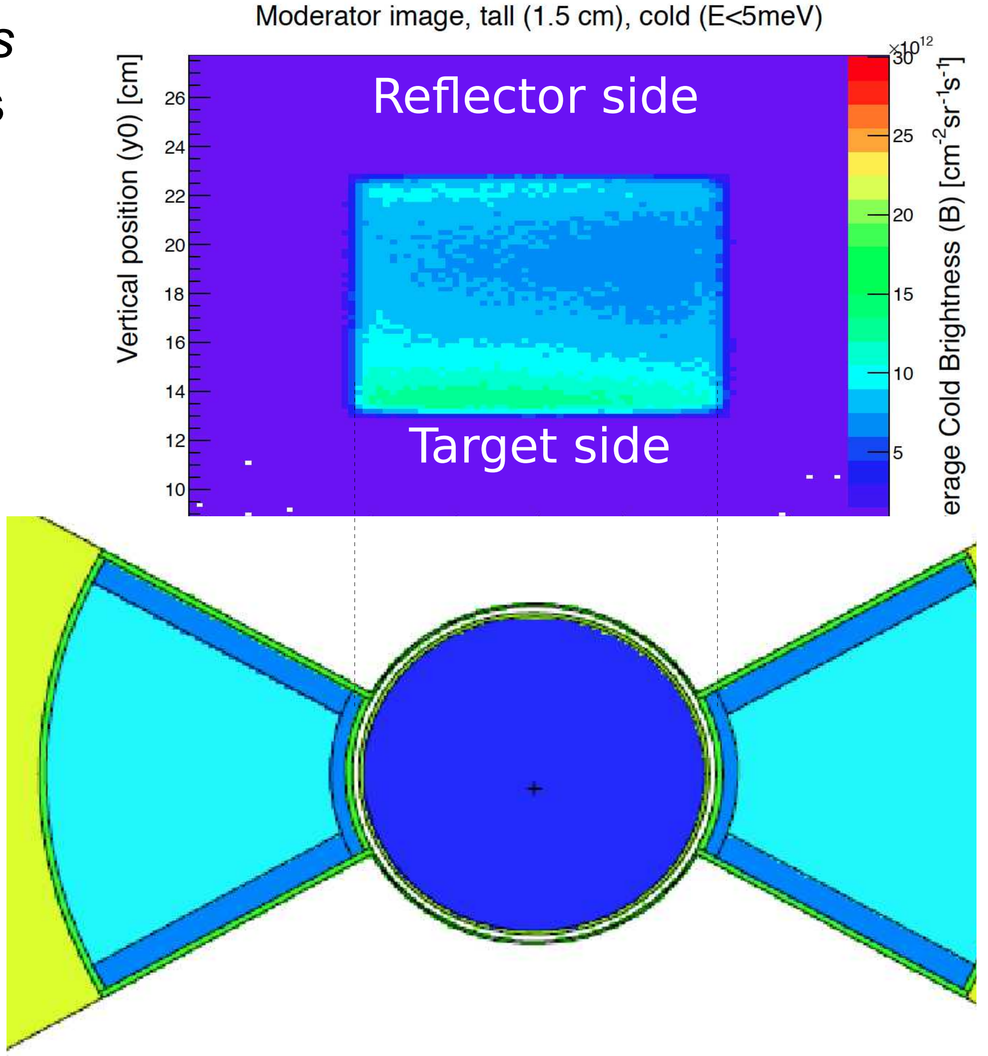
Instrument optimizations :: cold source

EUROPEAN SPALLATION SOURCE

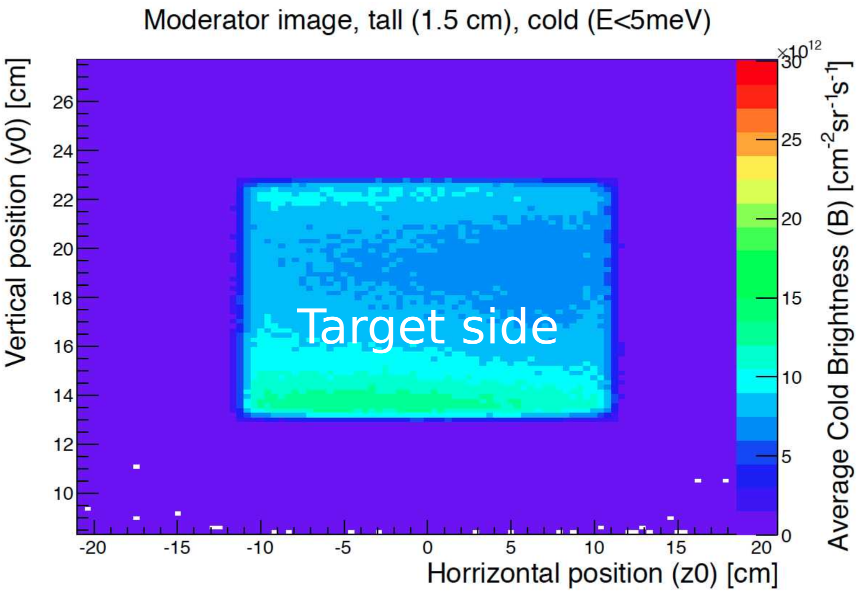
- Source is parametrized in *McStas* using below (*MCNP*) distributions
- Revisited as soon as moderator decision is final

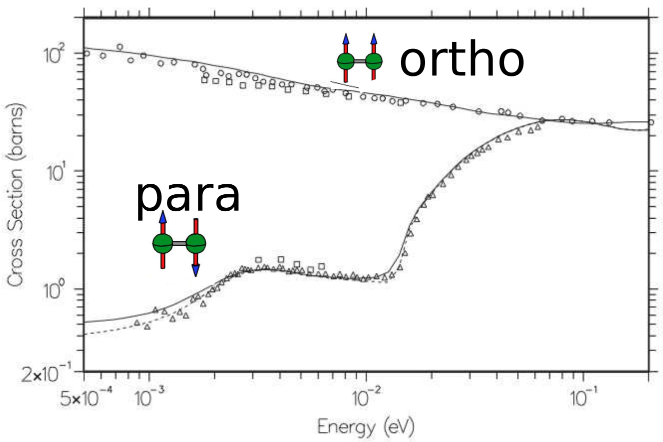






Why flat moderators work - the physics

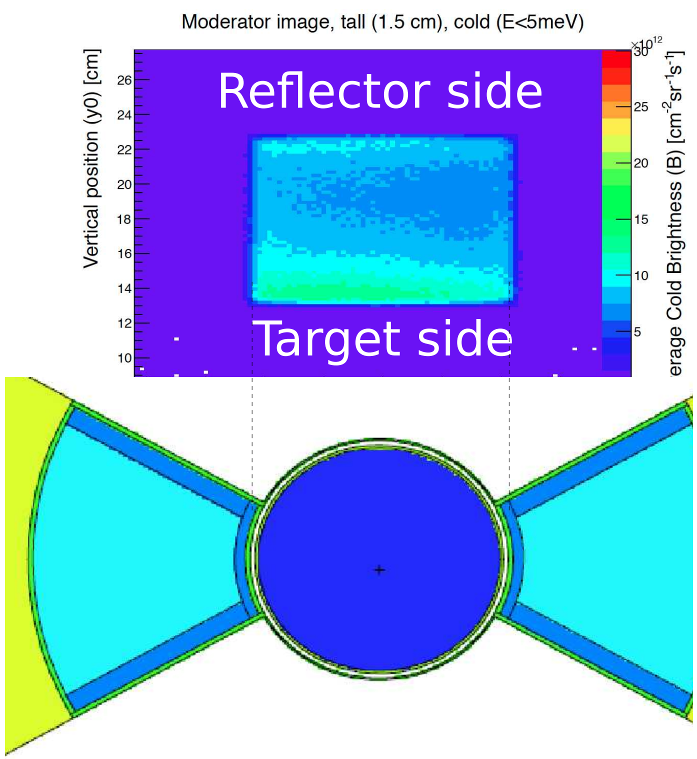


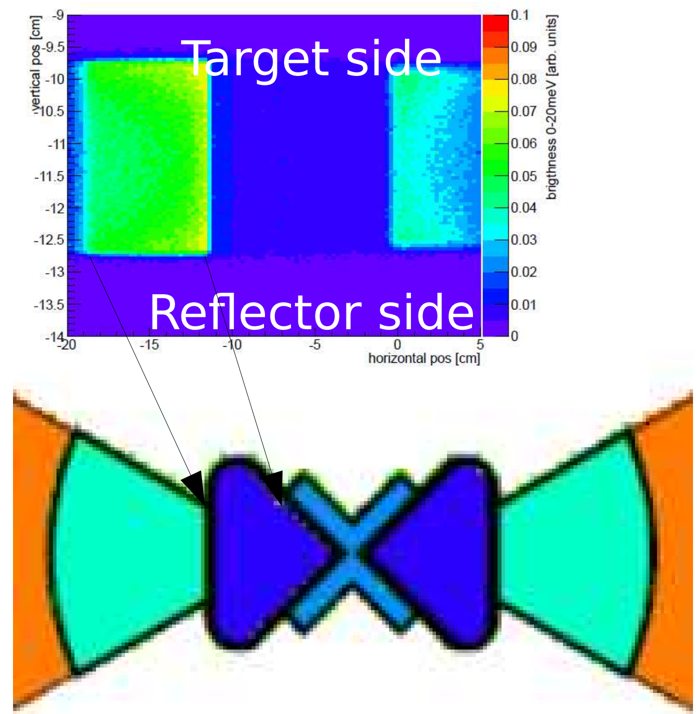


- thermal neutrons arriving from the surroundings are transformed into cold ones within about 1 cm of the walls of the moderator vessel

MCNPX→McStas,ROOT,GEANT4

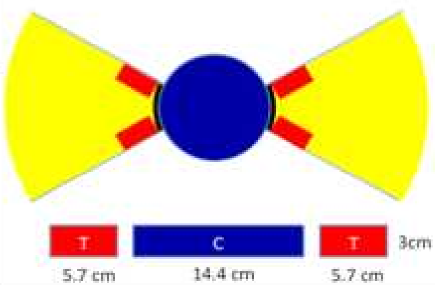
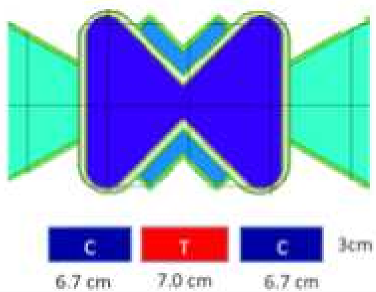
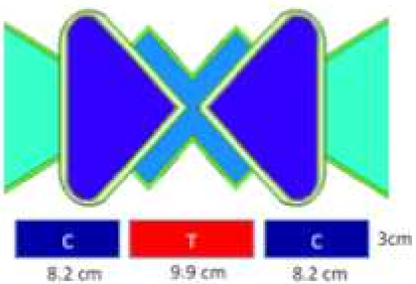
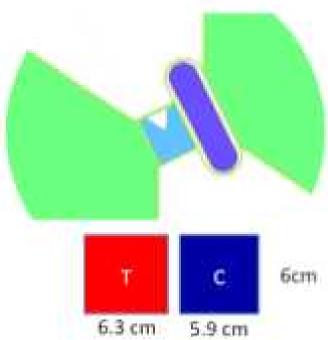
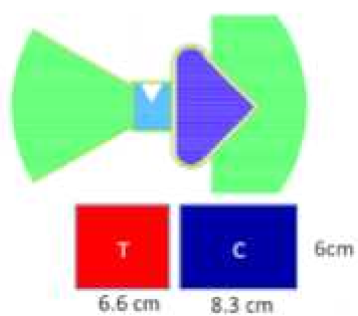
- Correlations and non-uniformity is handled by transferring individual events from one code to the next, or by carefully fitting the full parameter space, taking into account significant correlations.





- Software written to transfer events to ROOT, McStas. GEANT4 is upcoming

Moderators – from an instrument perspective (K. Andersen)

3 cm tall Top Moderator	**Baseline Pancake (PC)** 20 cm diameter para-H2 disc with 4 water wings, each 6 cm wide. Viewable in two 120° sectors.  	**Butterfly 1 (BF1)** Pinched para-H_2 disc with V-shaped water wings at the pinch point. Viewable in two 120° sectors.  	**Butterfly 2 (BF2)** Deeply pinched para-H_2 disc with crossing V-shaped water wings at the pinch point. Viewable in two 120° sectors. 
6 cm tall Bottom Moderator	**Baseline Optimised Thermal (OT)** Side-by-side water and para-H_2 volumes with. The water moderator has re-entrant cavities in both viewable faces. Viewable in two 60° sectors.  	**Cold Heart (CH)** Variant of OT allowing views in sectors oriented at 120 ° to each other. The water moderator has re-entrant cavities in both viewable faces. Viewable in two 60° sectors.  	**Butterfly 2 (BF2)** Deeply pinched para-H_2 disc with crossing V-shaped water wings at the pinch point. Viewable in two 120° sectors.