FUTURE 8 MEV UPGRADE FOR THE LVB COMPACT ACCELERATOR-DRIVEN NEUTRON SOURCE

Mina Akhyani, Ha Shuai, Ferenc Mezei

AGENDA

LvB project history and now

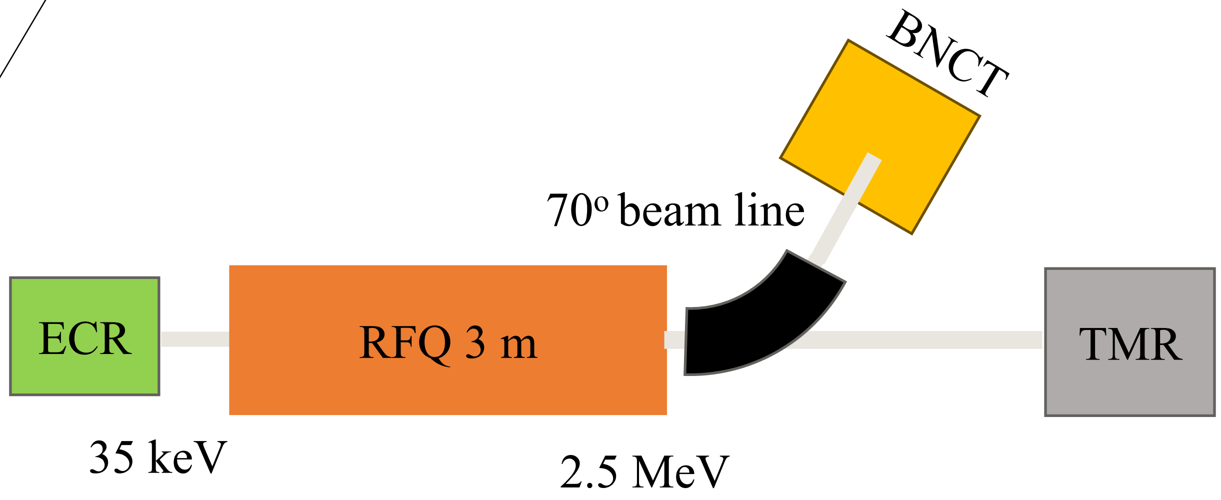
LvB upgrade plan

Performance estimate in the upgrade

Brightify implementation

Conclusions

LVB COMPACT SOURCE PROJECT

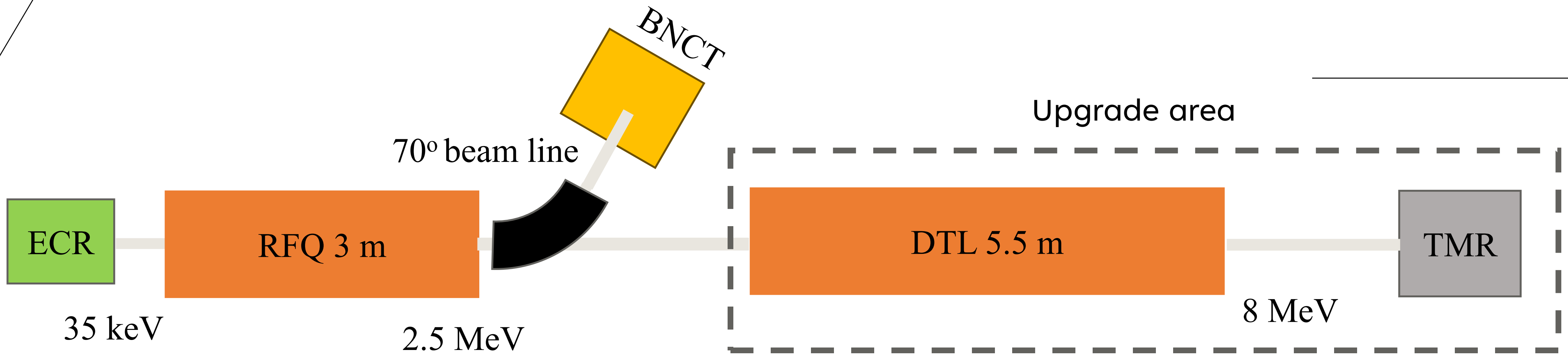


Started at 2018

Purpose of the LvB project

- Meet the neutron demand of Mirrotron Ltd for supermirror and other instrument testing
- Provide neutron beam time for other industrial companies

LVB COMPACT SOURCE PROJECT

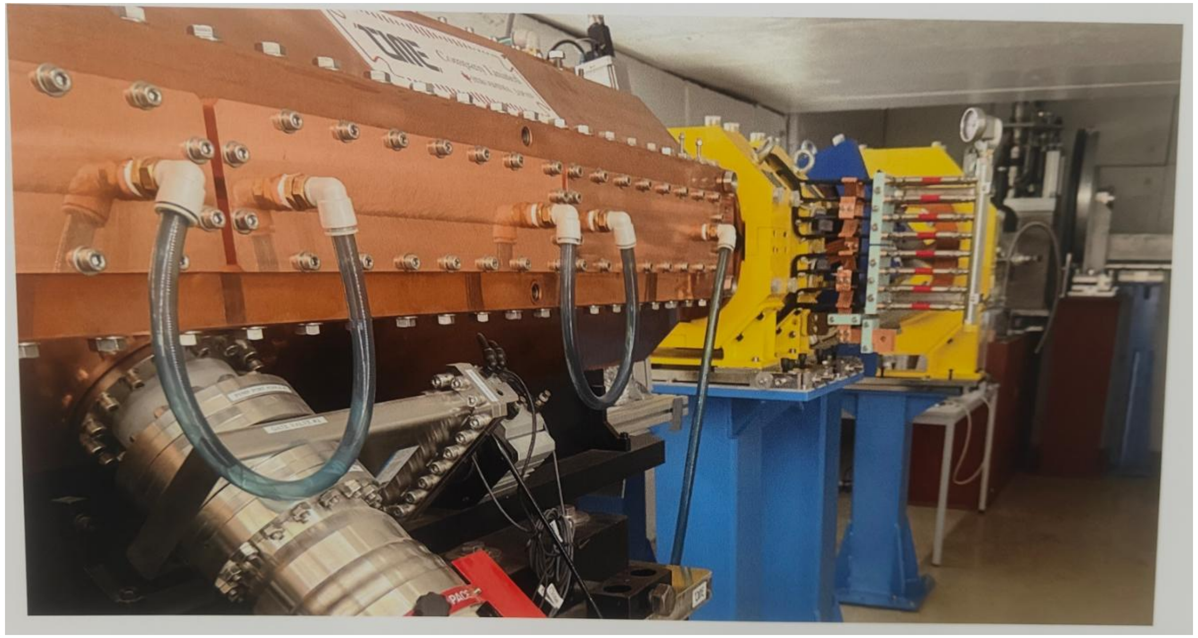


Started at 2018

Purpose of the LvB project

- Meet the neutron demand of Mirrotron Ltd for supermirror and other instrument testing
- Provide neutron beam time for other industrial companies

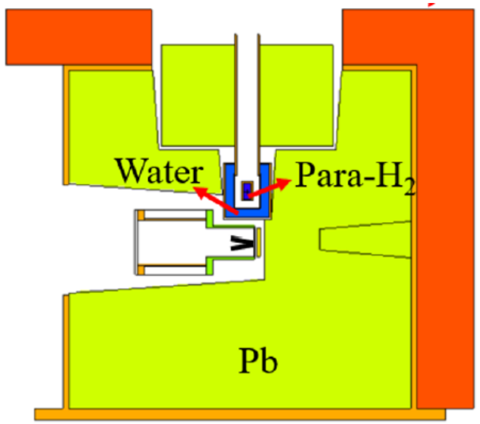
LVB ACCELERATOR

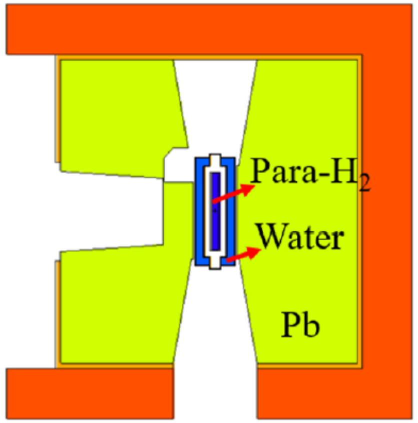


Accelerator Parameters		
Ion Source	Mode	Pulsed beam
	Pulse width	1.25 ms
	Output energy	35 keV
	Pulse frequency	40 Hz
	Peak current	20 mA
RFQ	Output energy	2.5 MeV
	RF frequency	200 MHz
	Duty factor	5%

LVB CURRENT TMR ASSEMBLY

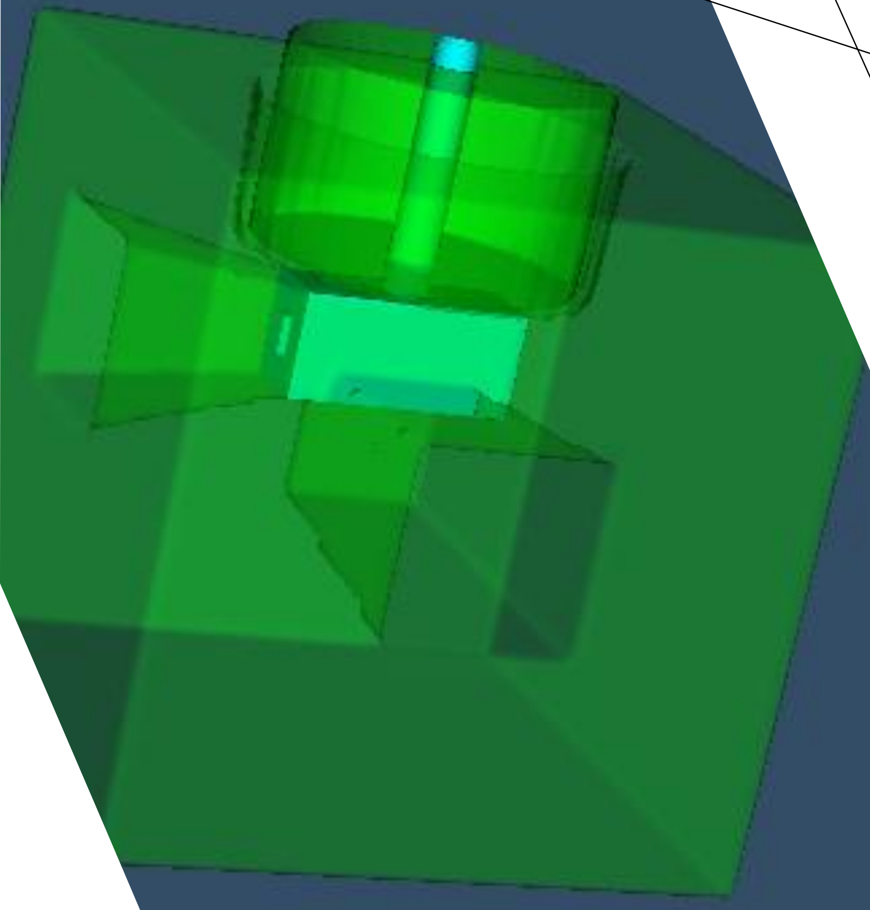
Side view





top view

TMR specifications		
Target	Material	Lithium
	Geometry	V-shaped 15 deg wrt beam
	Dimensions	3,5*3,5 cm2
	Thickness	50 μm
Pre- Moderator	Material	Water (300 K)
	Wall Thickness	1.5 cm
	Length	21 cm
	External Cross-section	8,2*9,9 cm2
Cold Moderator	Material	Para-H2 (20 K)
	Cross-section dimensions	1,5*3 cm2
	Length	15 cm
Reflector	Material	Lead
	External Dimensions	60*60*60 cm3



UPGRADE PLAN: WHICH PARTS OF TMR MUST/COULD BE MODIFIED?

Target (MUST)

- Replace existing solid Li target
- Goal: enable high neutron yield and long target lifetime at 8 MeV proton energy (blistering, heat load)

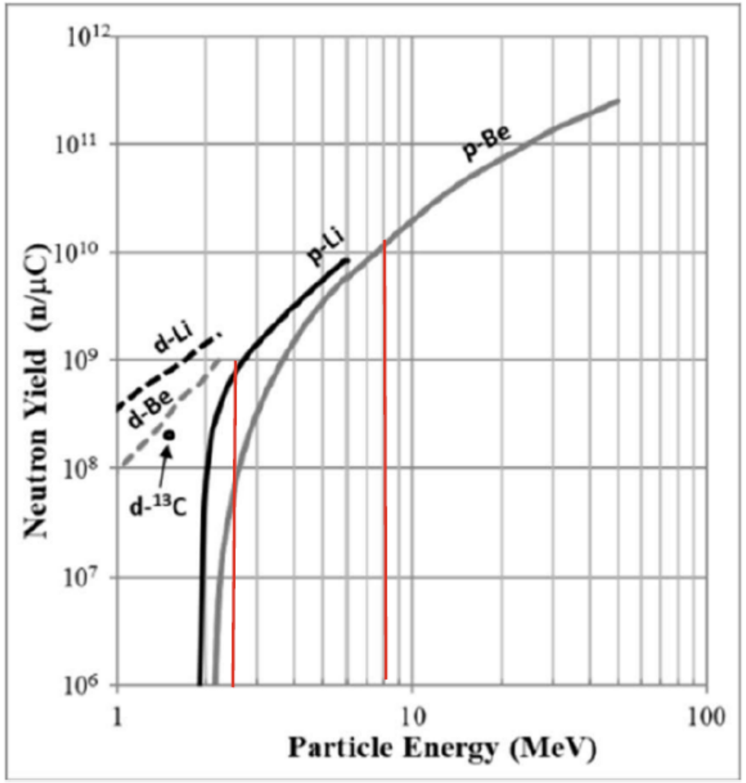
Moderator (COULD)

- Adjust dimensions
- ~~Optimize location~~

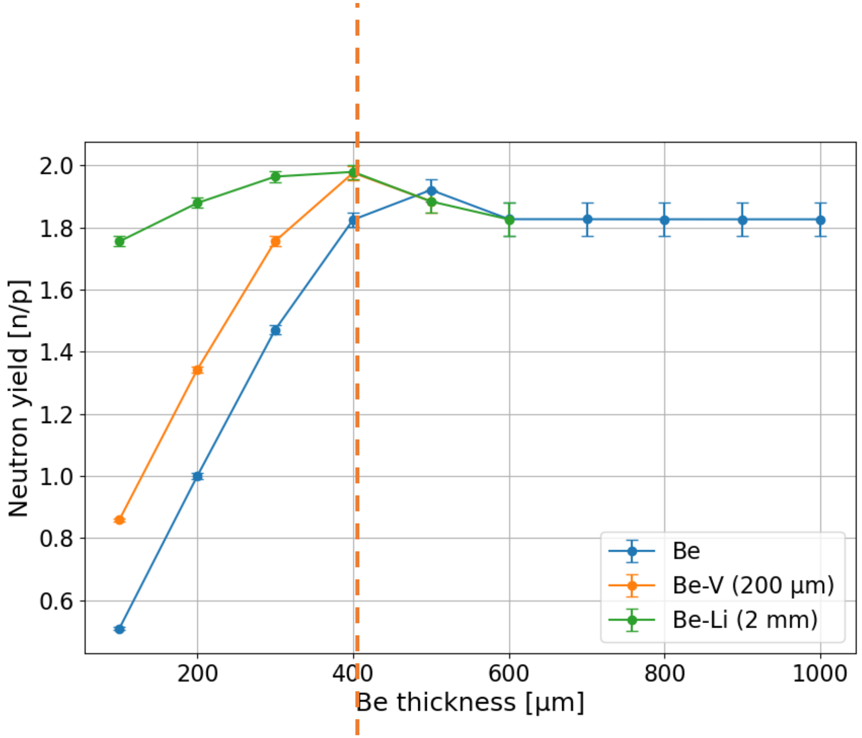
Reflector (COULD)

- Adjust dimensions

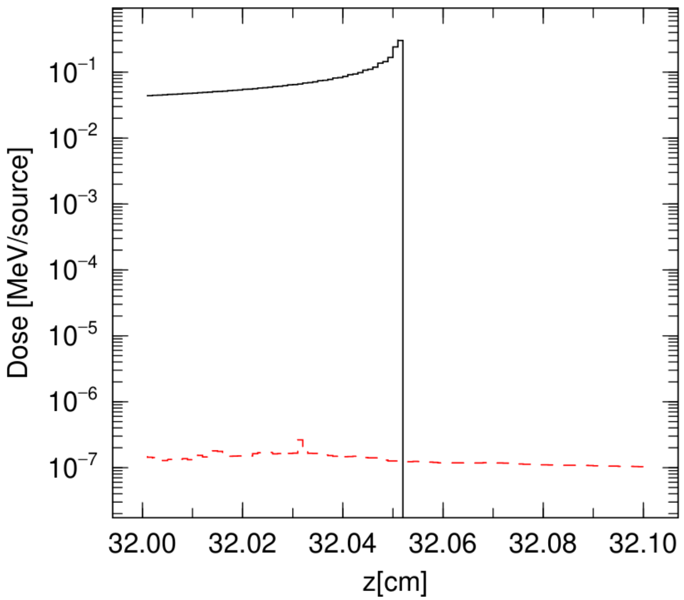
TARGET OPTIMIZATION



*IAEA, 2023. Advances in boron neutron capture therapy. IAEAL 23-01601.

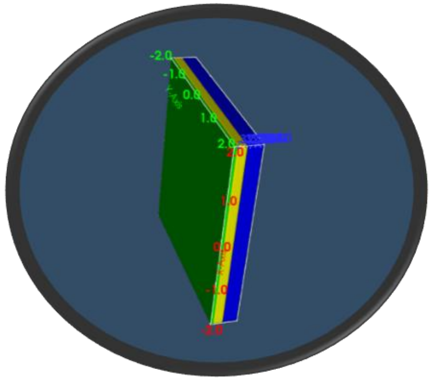


~530 μm



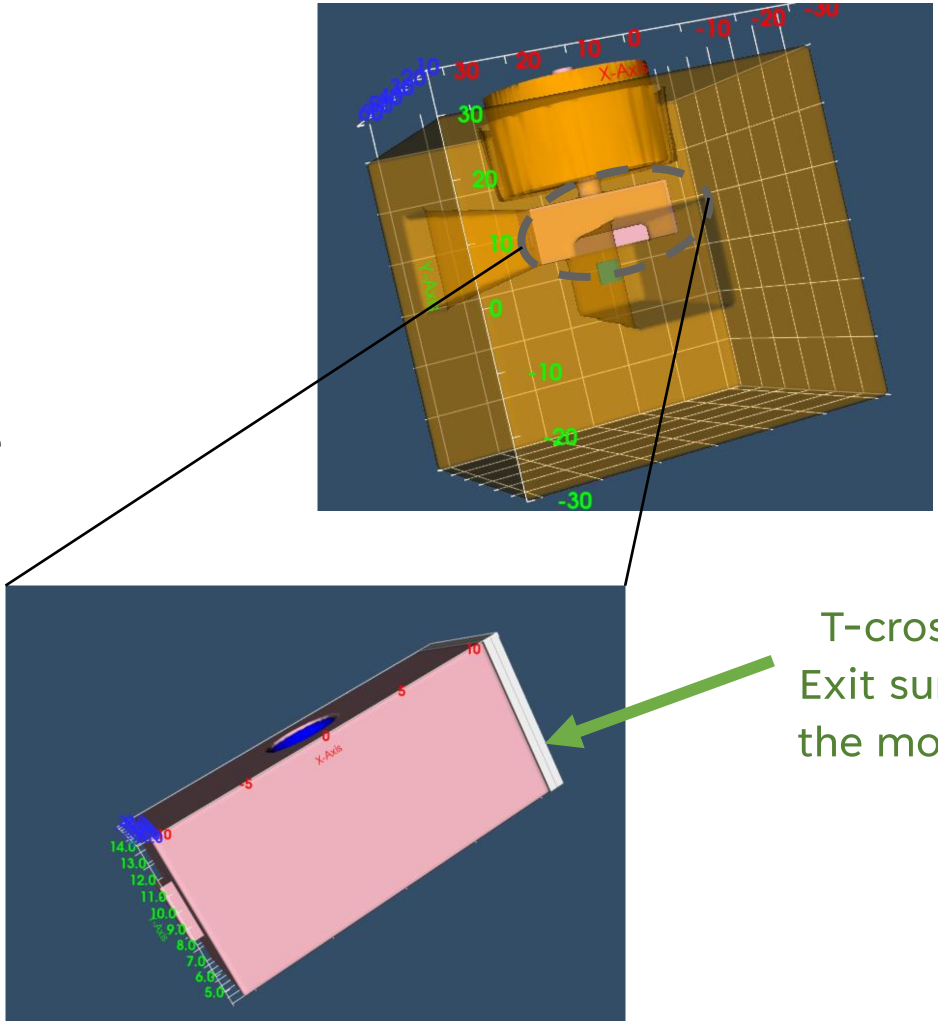
Heat load requirement:

~500 W/cm² -> Cross-section: 4 × 4 cm²



TMR PERFORMANCE

- Brightness: Figure-of-Merit
  - Phase-space density
- Brightness is calculated by T-cross, using angular current within 2 degrees.
- Void cell is added to the exit surface of the moderator (9.9 cm * 8.2 cm)
- Energy range : 2-80 meV (1-6 Å)



T-cross tally
Exit surface of
the moderator

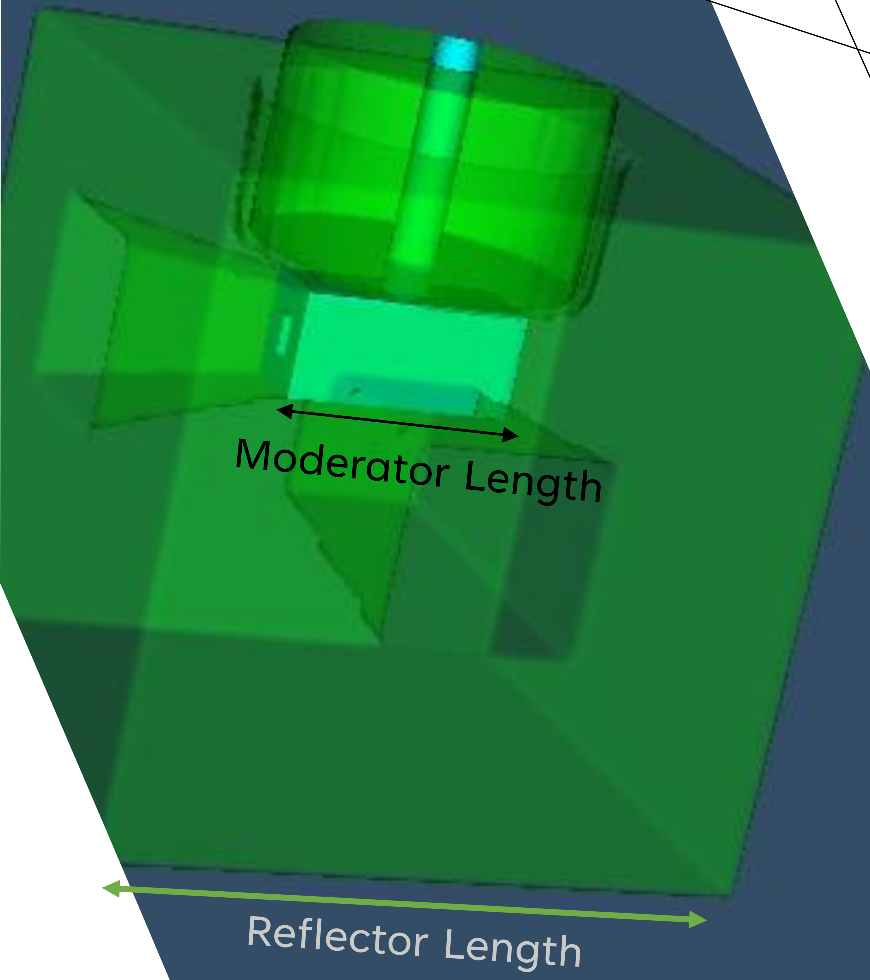
PHITS

TMR PERFORMANCE

Target	Proton energy [MeV]	Be layer thickness [μm]	Moderator length [cm]	Reflector length [cm]	Brightness*1e-8 [1/cm2/sr/source]	Relative error
Li	2.5	-	15	60	0.4	0.04
Be-Li	8	400	15	60	3.8	0.03

- Proton energy: 2.5 → 8 MeV
- Li target → Be-Li target

⇨ 9X better brightness



UPGRADE PLAN: WHICH PARTS OF TMR MUST/COULD BE MODIFIED?

✓ **Target (MUST)**

Moderator (COULD)

- Adjust dimensions

Reflector (COULD)

- Adjust dimensions

REFLECTOR OPTIMIZATION

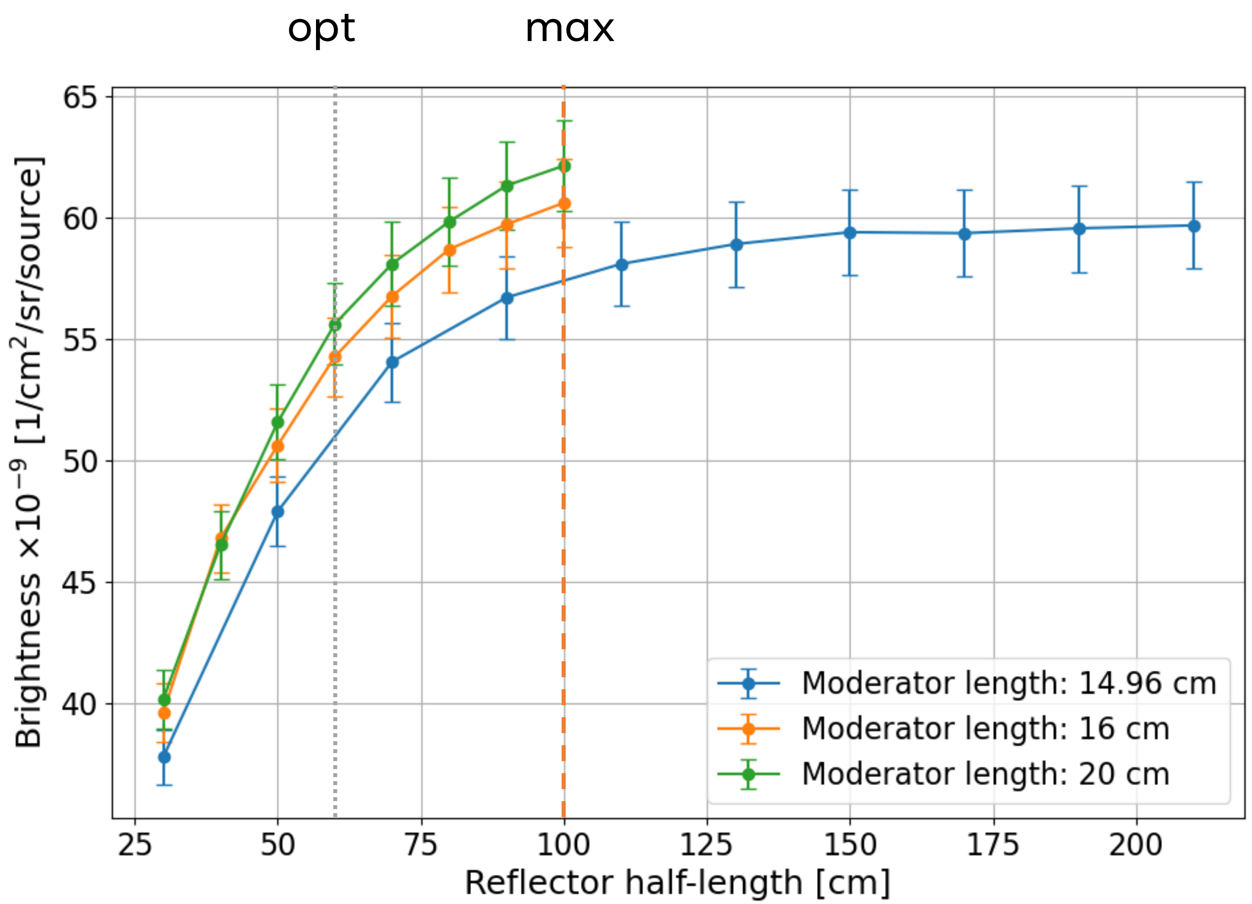
Highest brightness: 2*2*2 m3 lead

BUT:

- Weight: 100t → Too heavy for CANS

Optimal economical choice:

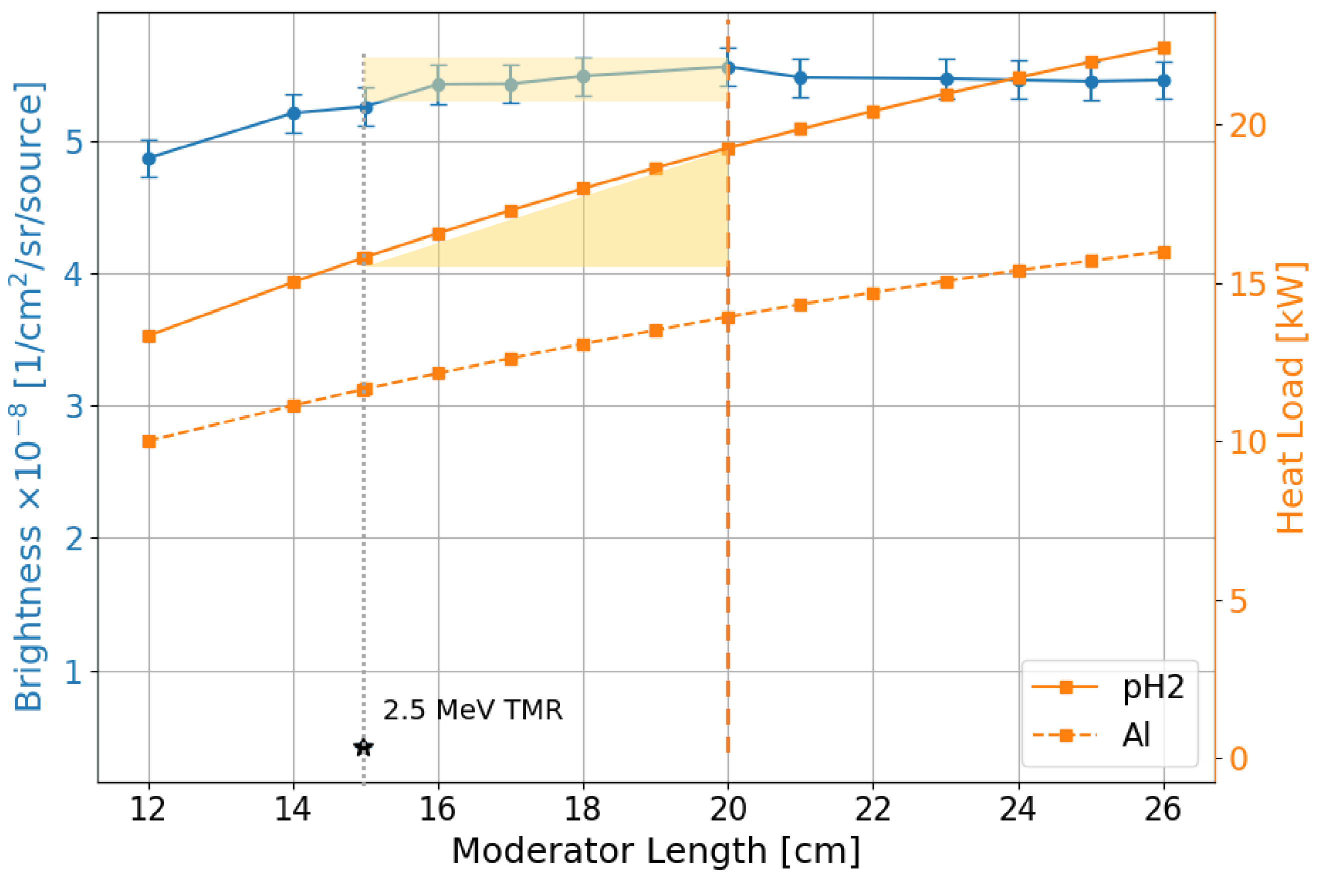
- 1,2*1,2*1,2 m3



MODERATOR OPTIMIZATION

- Due to cryogenic costs, smaller moderator would be a better choice.
- 3X more cryostat power is required compared to the current TMR.
- Optimal moderator length choice:

  15-16 cm

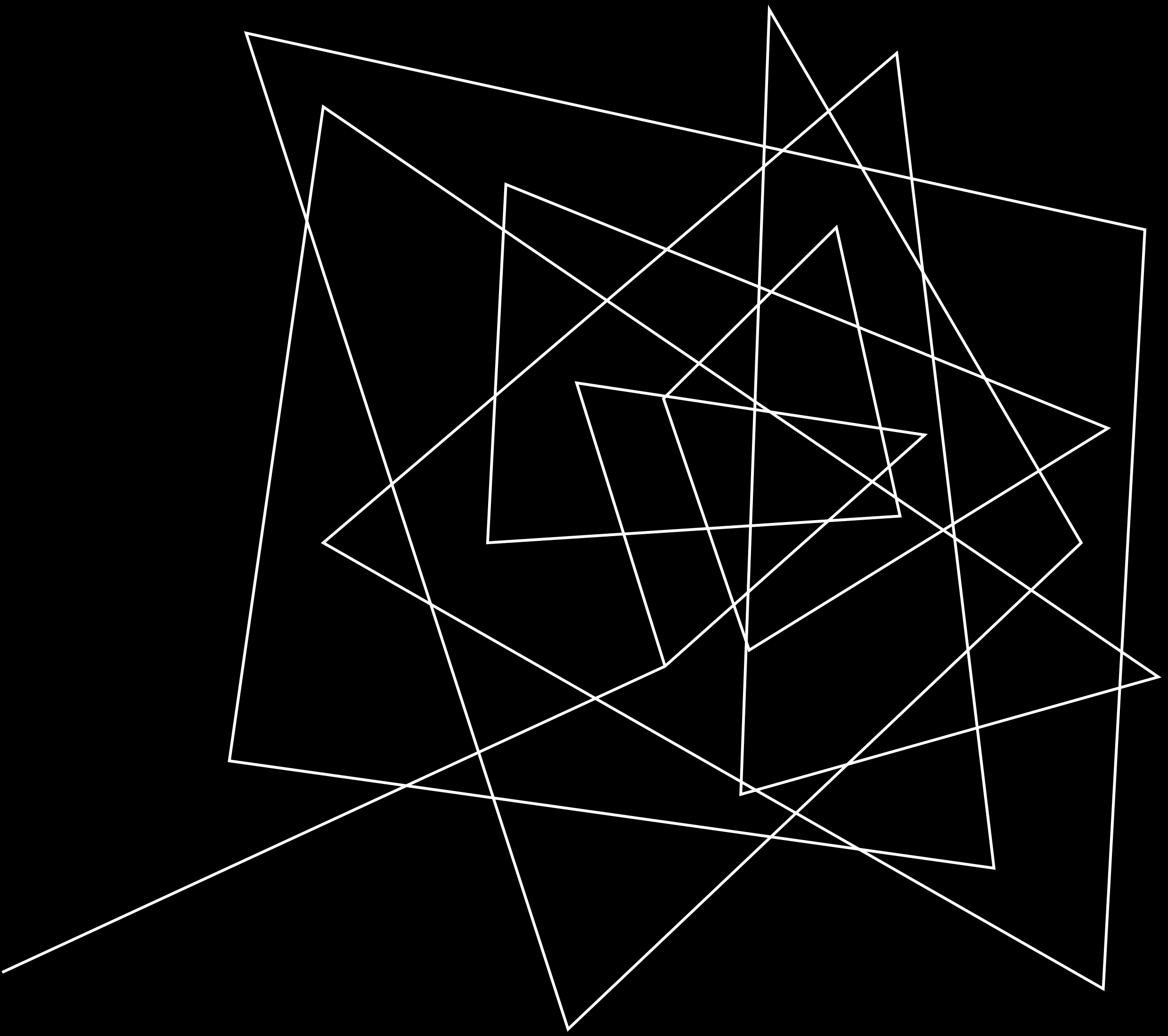


TMR PERFORMANCE

Target	Proton energy [MeV]	Be layer thickness [μm]	Moderator length [cm]	Reflector length [cm]	Brightness*1e-8 [1/cm2/sr/source]	Relative error
Li	2.5	-	15	60	0.4	0.04
Be-Li	8	400	15	60	3.8	0.03
Be-Li	8	400	15	120	5.2	0.03

- Proton energy: 2.5 → 8 MeV
- Li target → Be-Li target
- Reflector size increased by 8X

→ 13X better brightness

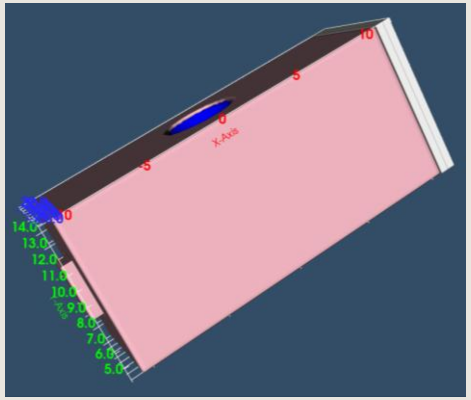


IS BRIGHTNESS CALCULATION ACCURATE?

IS BRIGHTNESS CALCULATION ACCURATE?

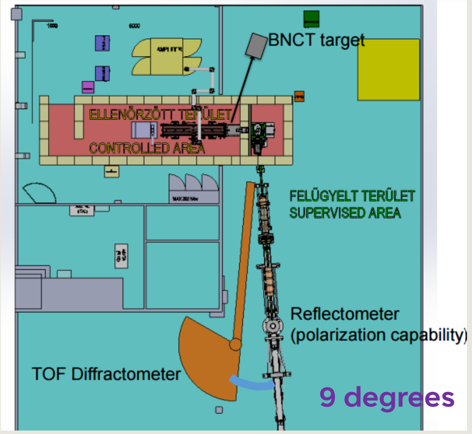
Current Method

- Integrates over the entire moderator exit surface
- Uses same phase-space volume for both instruments
- Assumes normal direction for brightness calculation

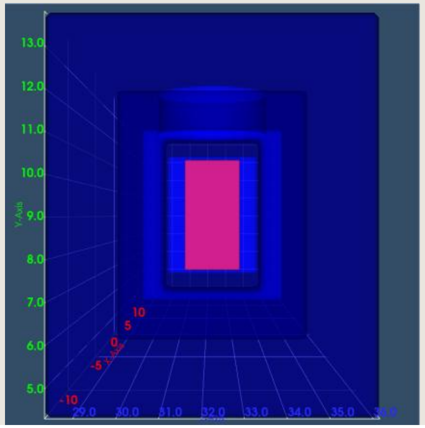


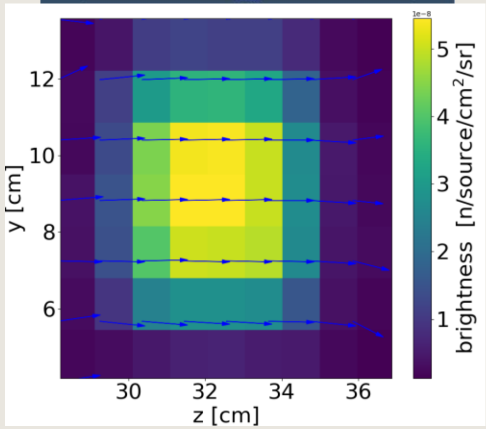
Caveat

- Guides accept only part of the moderator exit surface
- Each instrument has its own requirements
- Both instruments cannot simultaneously access the normal direction



IMPROVING THE BRIGHTNESS CALCULATION: *BRIGHTIFY**

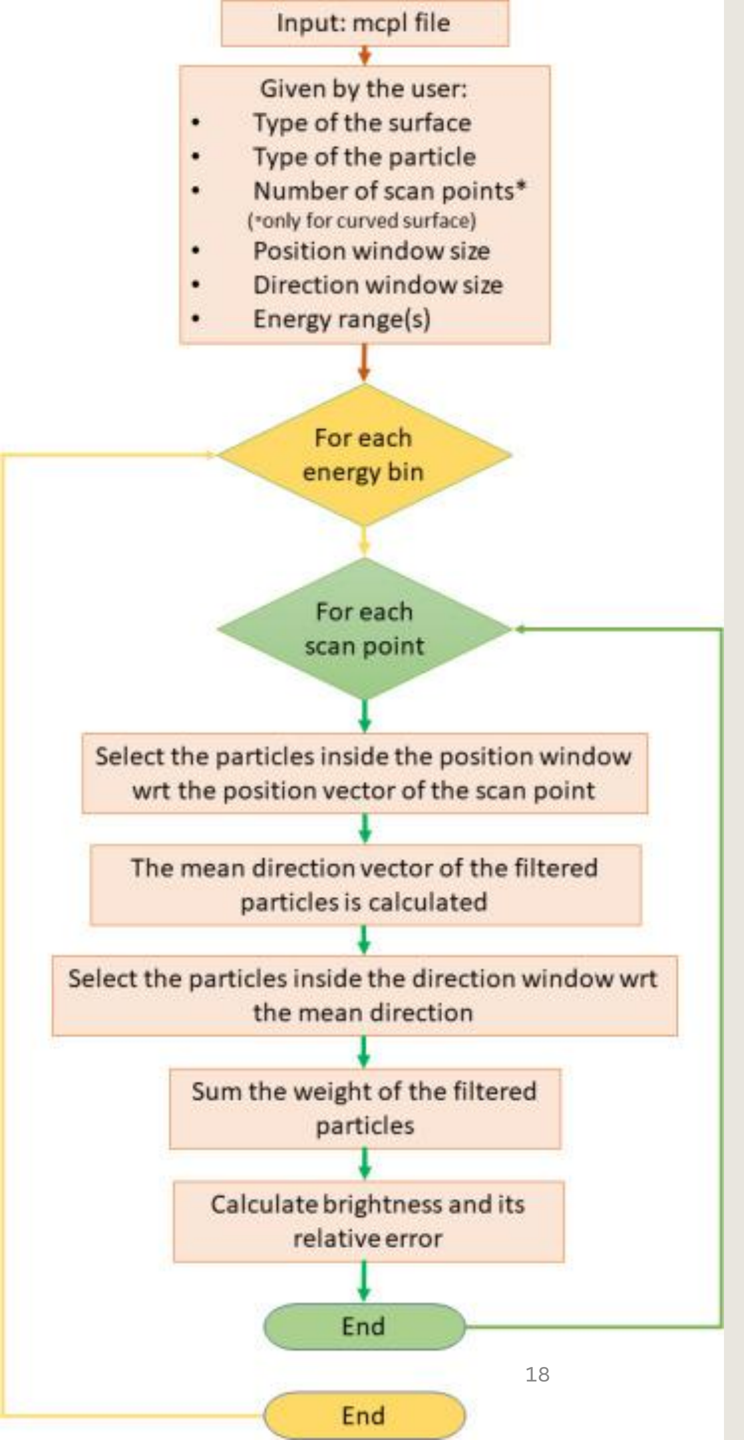




- Enables flexible selection of phase space volume
- Allows brightness evaluation for arbitrary emission directions, not limited to the surface normal
- Introduces an additional dimension –direction- into the brightness map.

Impact:

Supports optimized guide design and placement



* https://doi.org/10.1016/j.nima.2025.171037

BRIGHTIFY IMPLEMENTATION: STEP-BY-STEP

1. Phase space definition

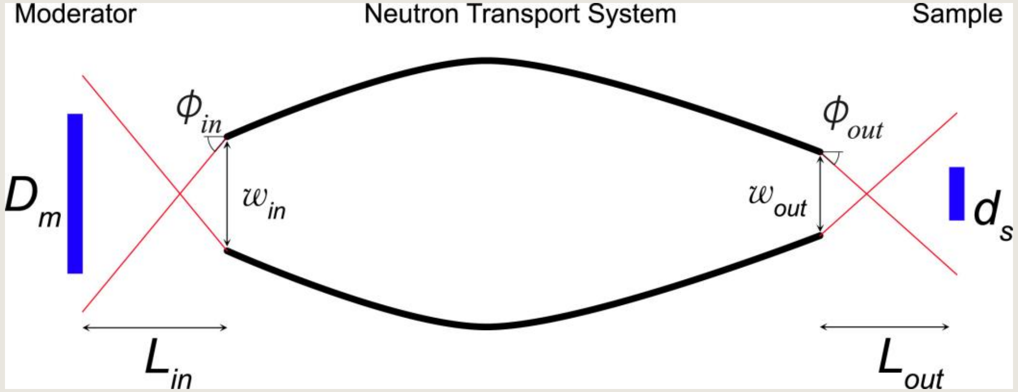
- Calculate the phase space volume on the moderator surface analytically (using COFSI*)
- This defines the resolution of the brightness map

2. Directional optimization

- Use *brightify* to identify optimal emission direction for cold brightness (highly directional)

3. Consistent direction application

- Apply the same optimized direction to: Thermal and bi-spectral brightness maps



COFSIs for four extreme cases of NTS.

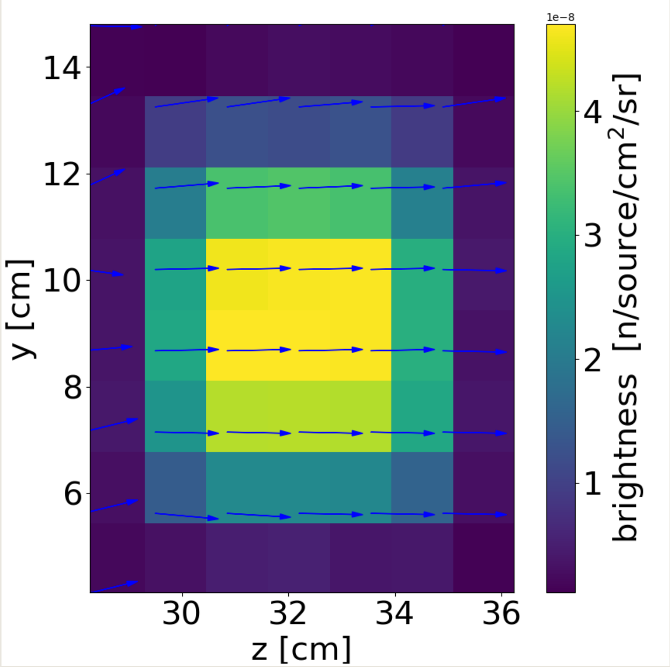
$D_{opt} =$		NTS entrance	
		F	NF
NTS exit	F	$\frac{2d_s\alpha_s L_{in}}{w_{in}}$	$\frac{2d_s\alpha_s L_{in}}{w_{in}} + w_{in}$
	NF double-slit	$\frac{2d_s\alpha_s L_{in}}{w_{in}} \cdot \frac{n}{n-1}$	$\frac{2d_s\alpha_s L_{in}}{w_{in}} \cdot \frac{n}{n-1} + w_{in}$
	NF Soller or natural	$\frac{2d_s\alpha_s L_{in}}{w_{in}} + \frac{4\alpha_s^2 L_{in} L_{out}}{w_{in}}$	$\frac{2d_s\alpha_s L_{in}}{w_{in}} + \frac{4\alpha_s^2 L_{in} L_{out}}{w_{in}} + w_{in}$

*https://doi.org/10.1016/j.nima.2023.168643

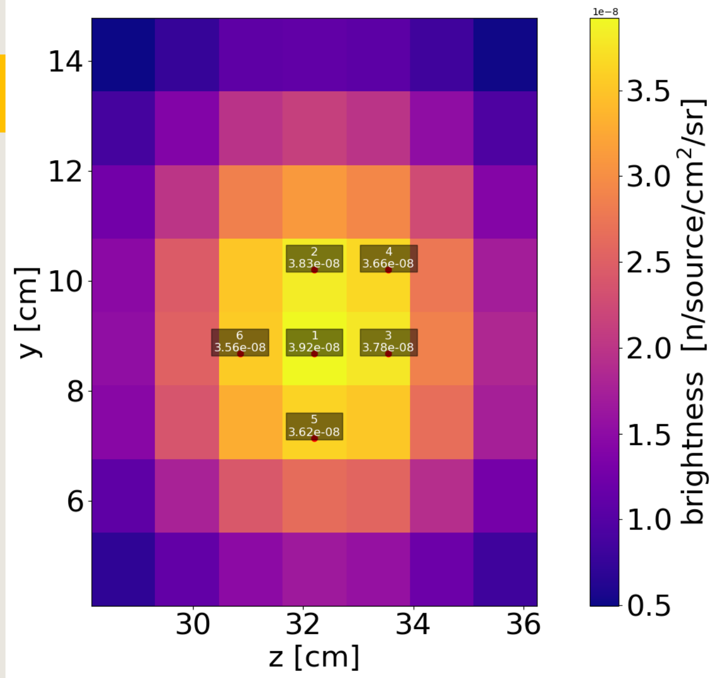
INSTRUMENT-SPECIFIC BRIGHTNESS

Instrument	Phase-space volume	(1) Cold Brightness 2-20 meV [n/cm2/source/sr] *1e-8	(2) Thermal 20-80 meV [n/cm2/source/sr] *1e-8	(3) Bispectral 2-80 meV [n/cm2/source/sr] *1e-8
Reflectometer	5.4*6.1 cm2 2 degrees	4.7	3.9	8.5
Diffractometer	4.4*6.3 cm2 2 degrees	5.45	4.0	9.5

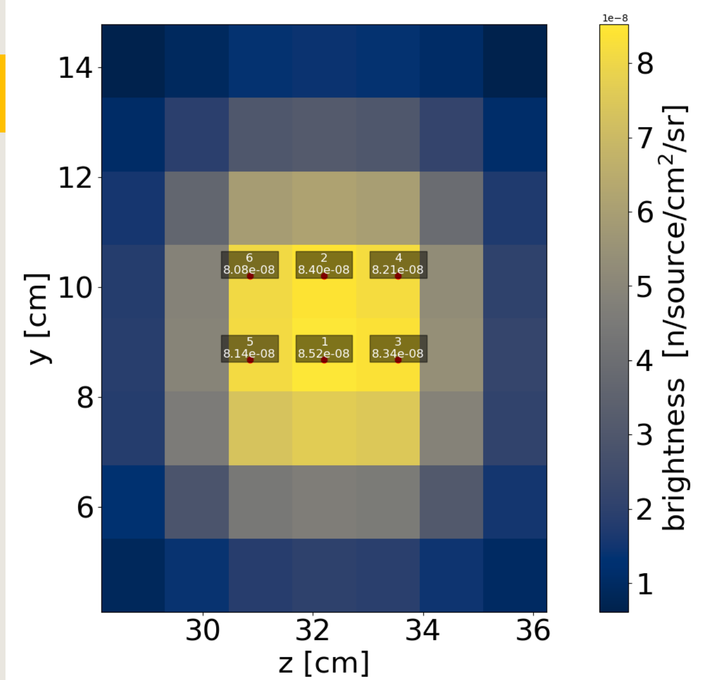
1



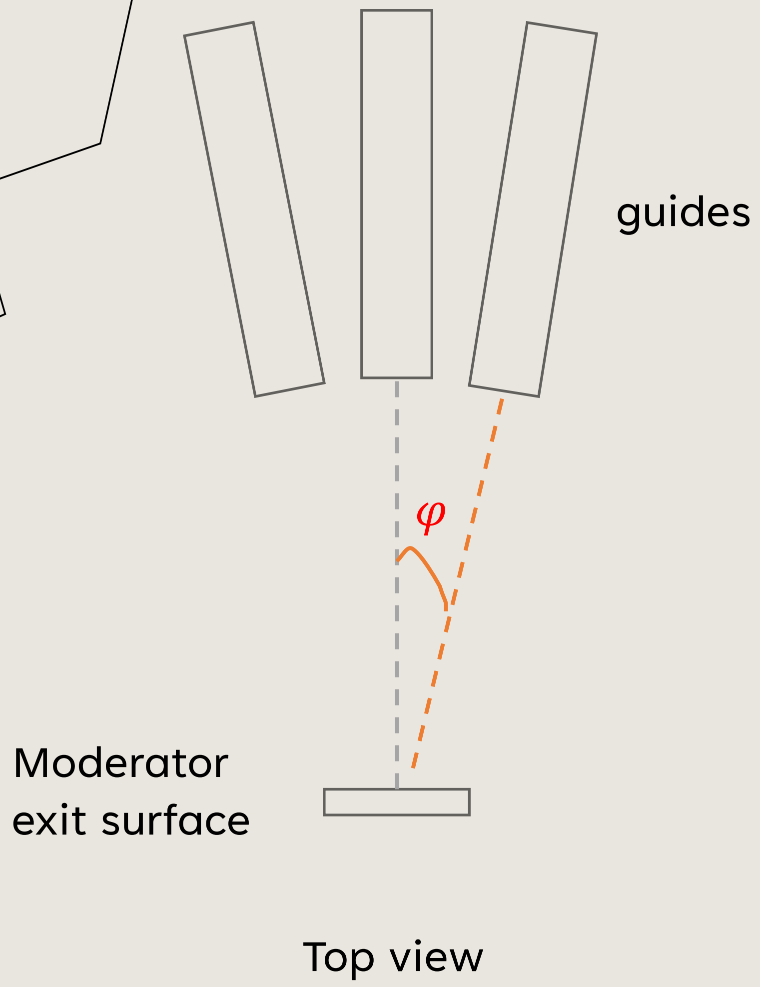
2

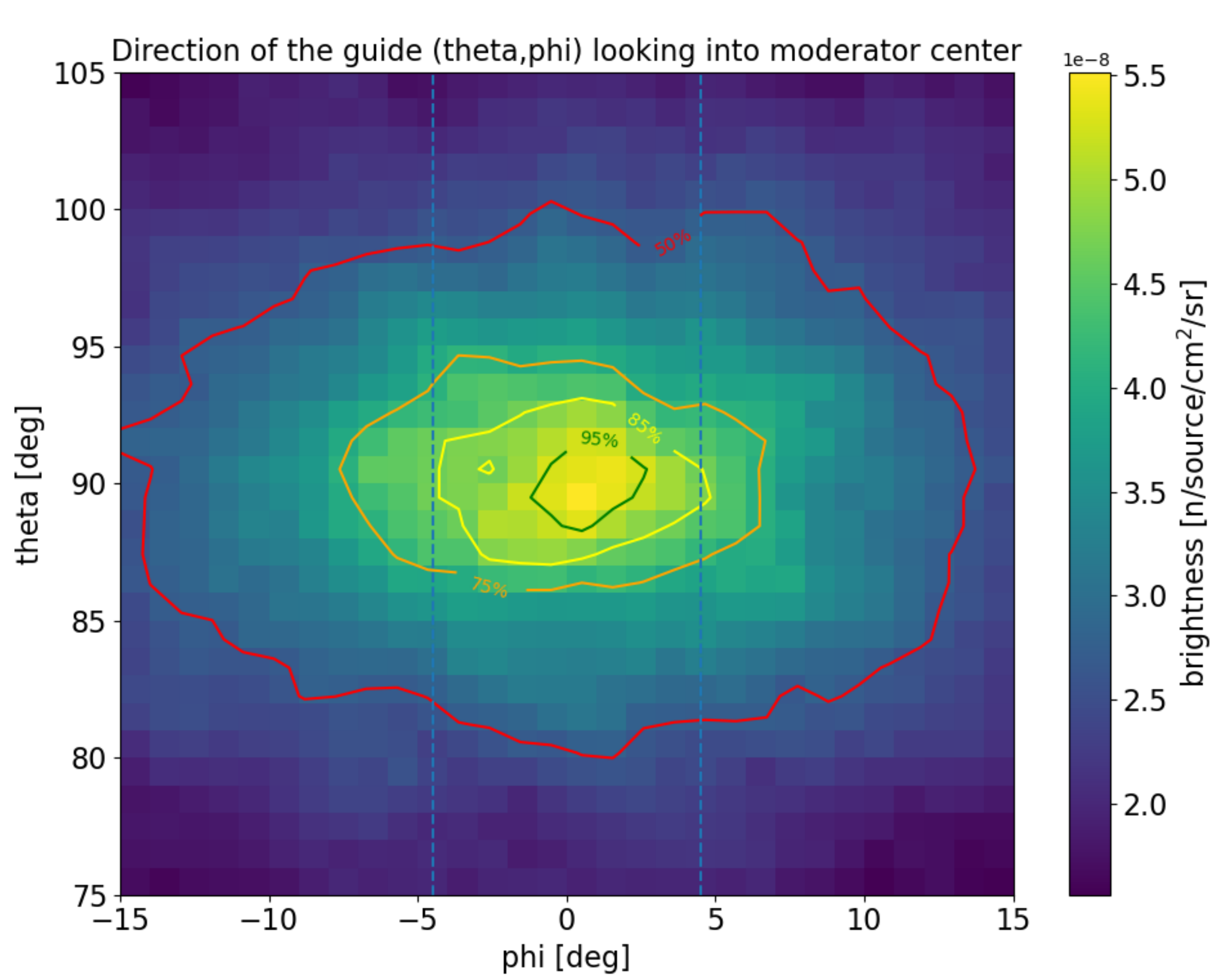


3



WHAT IF THE INSTRUMENT IS NOT IN THE NORMAL DIRECTION TO THE MODERATOR SURFACE?





FINAL TIPS & TAKEAWAYS

LvB upgrade

- **~13X** performance gain by:
  - Proton energy increased:
    2.5 MeV → 8 MeV
  - Target design improved:
    Li → Li-Be
  - Reflector volume increased by a factor of **8**

Improved brightness evaluation

- *Brightify* implemented for more realistic, instrument-relevant brightness estimation.
- Deviation from optimal direction results in:
  - **~15% loss at 4.5°**
  - **Up to 50% loss at 15°**

How can we better arrange the guides around a single moderator to without sacrificing this hard-won brightness?

THANK YOU

Mina Akhyani

m.Akhyani@fz-Juelich.de

https://github.com/BrightnessTools/Brightify