HighNess

Towards an In-Beam UCN-Source at the ESS

Second Workshop on UCN and VCN Sources at ESS

Richard Wagner, ILL

09.05.2023, ESS, Lund

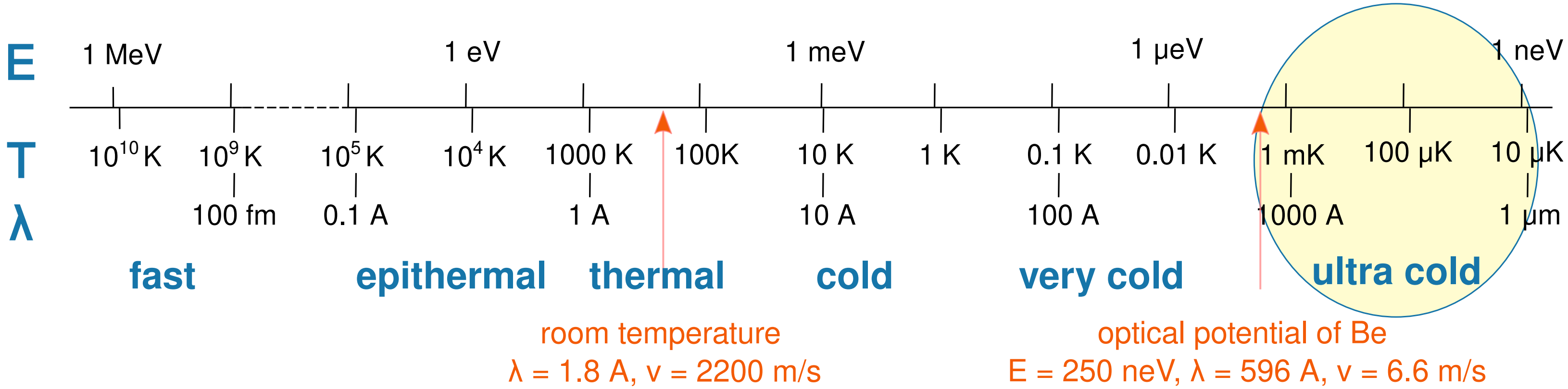
HighNESS is funded by the European Framework for Research and Innovation Horizon 2020, under grant agreement 951782

Ultra Cold Neutrons

- **General definition:**
  UCNs are neutrons whose energy is so low that they are reflected under any angle of incidence

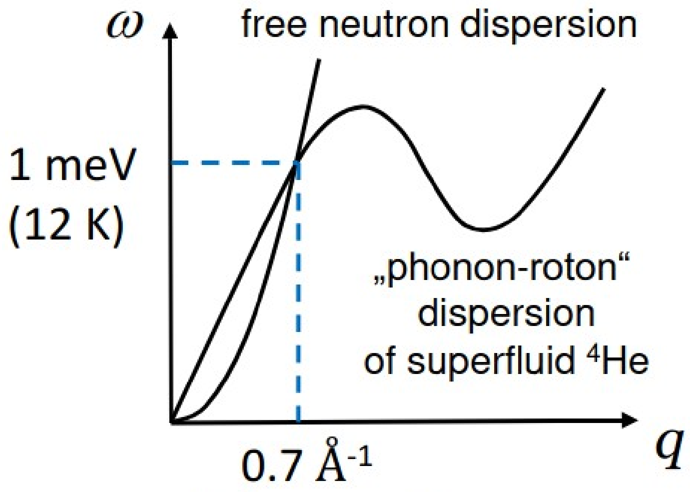
  ➔ can be contained in traps

- UCNs are important tools for fundamental physics experiments on:
  ➔ Neutron lifetime
  ➔ Neutron Dipole Moment
  ➔ Gravitational interactions
  ➔ n-$\bar{n}$ and n-n’ oscillations



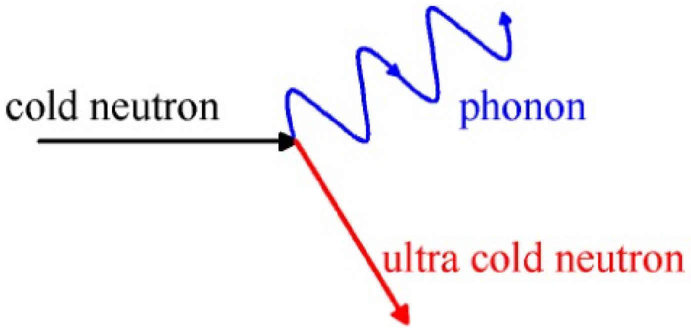
Ultra Cold Neutron Production

One possibility: Single Phonon Conversion in superfluid Helium



(8.9Å →UCN)

Golub & Pendlebury, PL **53A** (1975) 133



Spectrum of incident neutrons
evaluated at E* (= 8.9Å)

Production Rate:

$$P\left(E_{\mathrm{UCN}}\right) = \frac{d\phi(E^*)}{dE} \cdot 1.44 \times 10^{-7} \quad \mathrm{UCN/sec/cm^3}$$

8.9Å flux at source will convert to UCN flux

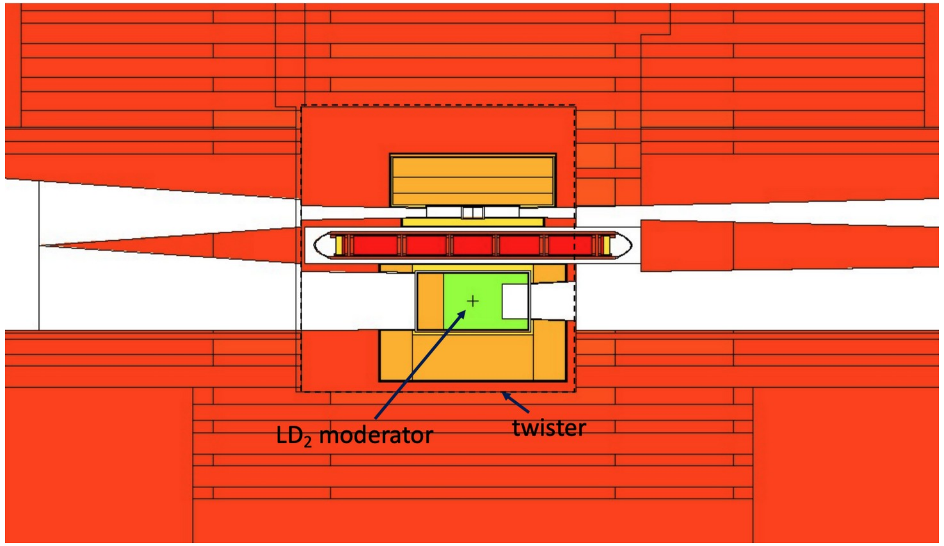
UCN Objectives in the HighNESS Project

Task 4.3. Neutronic study of in-beam UCN

- UCN converter placed after monolith exit

Task 4.4. Neutronic study of in-pile UCN

- study of scenarios for an UCN source placed inside the ESS monolith



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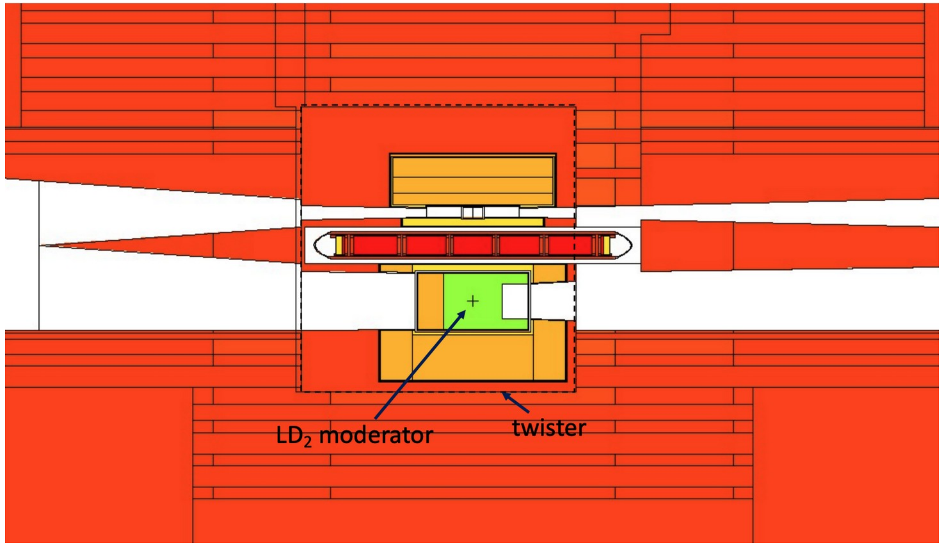

Task 4.4. Neutronic study of in-pile UCN

- study of scenarios for an UCN source placed inside the ESS monolith

See talks by: Nicola, Blahoslav, Mathias and Mina

UCN Objectives in the HighNESS Project

This talk

Task 4.3. Neutronic study of in-beam UCN

- UCN converter placed after monolith exit

Task 4.4. Neutronic study of in-pile UCN

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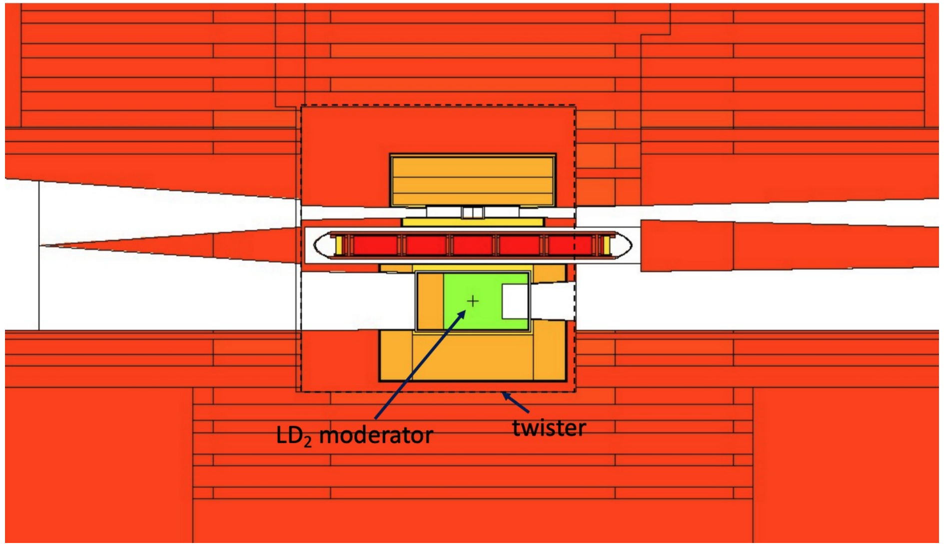
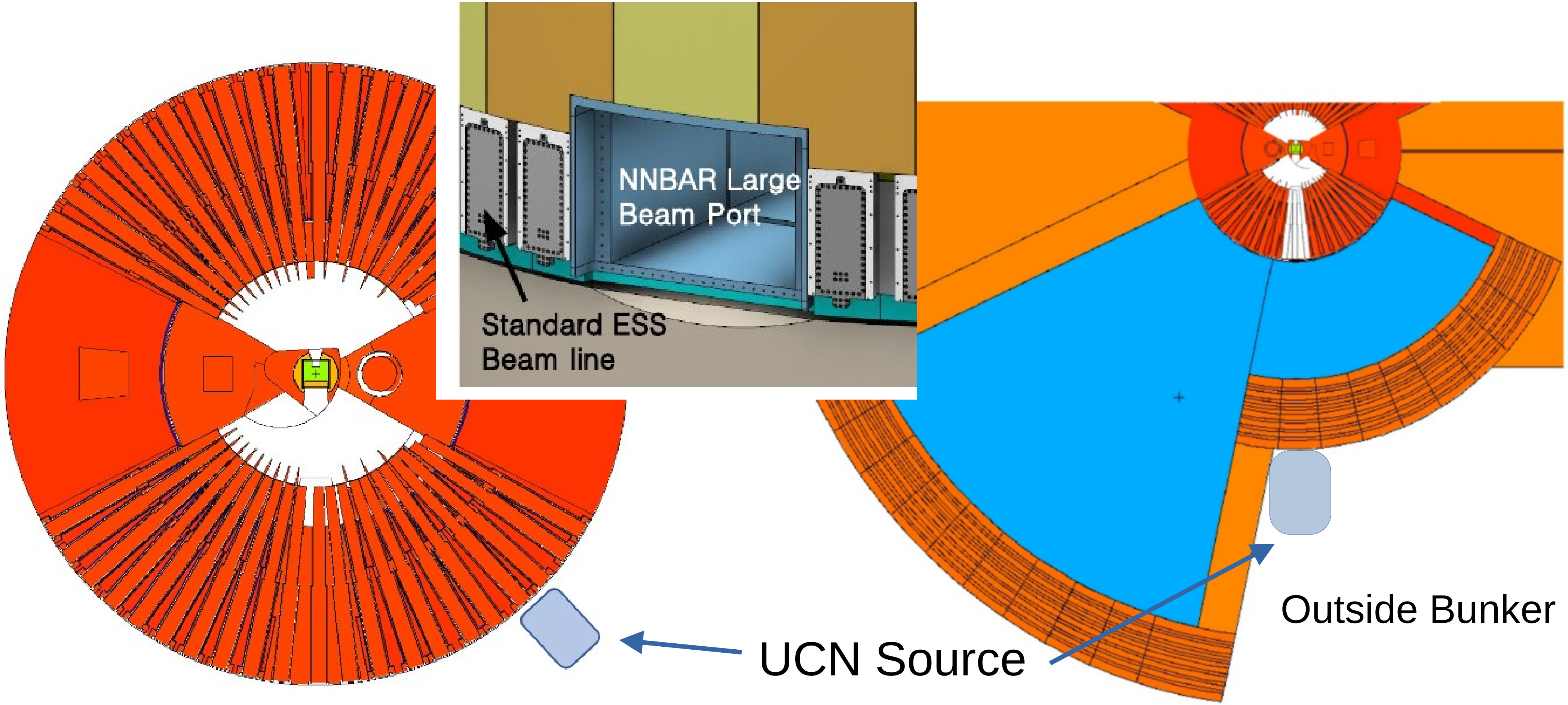


UCN Source In-Beam Option



Outside Bunker (>15m)

UCN Source

Inside Bunker (6m)

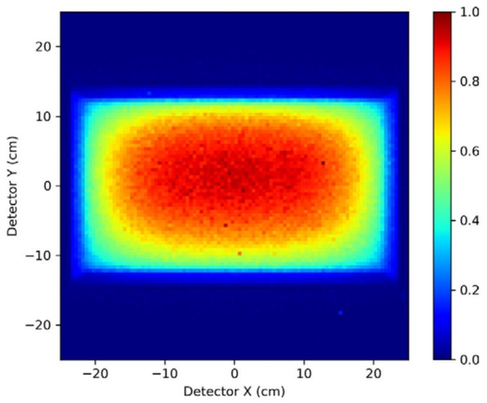
In-Beam UCN Source ESS

- Need a neutron delivery system with high brilliance transfer from moderator to UCN source, with largest technically possible solid angle
- Neutron imaging from the moderator to the UCN source via Nested Mirror Optics (NMO) has been identified as feasable solution

In-beam superfluid-helium ultracold neutron source for the ESS

Oliver Zimmer [a,*], Thierry Bigault [a], Skyler Degenkolb [b], Christoph Herb [c], Thomas Neulinger [a], Nicola Rizzi [d], Valentina Santoro [d], Alan Takibayev [d], Richard Wagner [a] and Luca Zanini [d]

Journal of Neutron Research 24 (2022) 95–110 95
DOI 10.3233/JNR-220045



Intensity map (simulated) at the ESS LD2 moderator surface of neutrons with WL near 8.9 Å

$$b_{LD2} = 3.4 \times 10^{11}\, s^{-1}\, cm^{-2}\, sr^{-1}\, Å^{-1}\, at\, 5\, MW$$

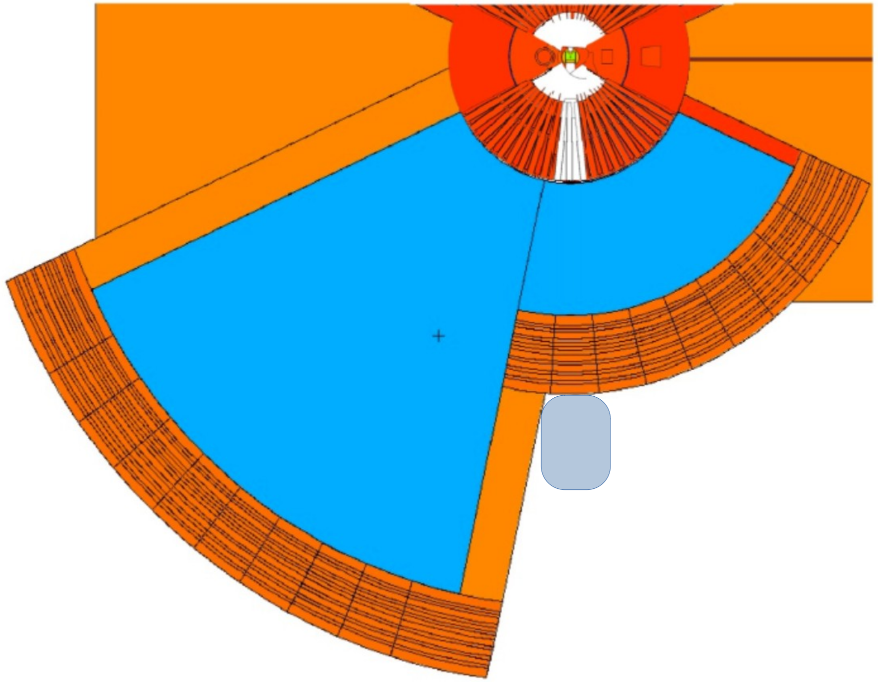
UCN Source In-Beam Option

- Concentrate on outside of Bunker scenario

  → NDS and UCN converter are placed outside the bunker

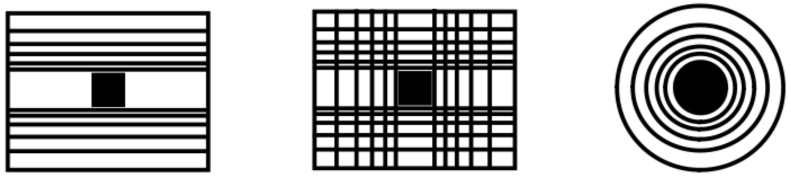
Practical advantages

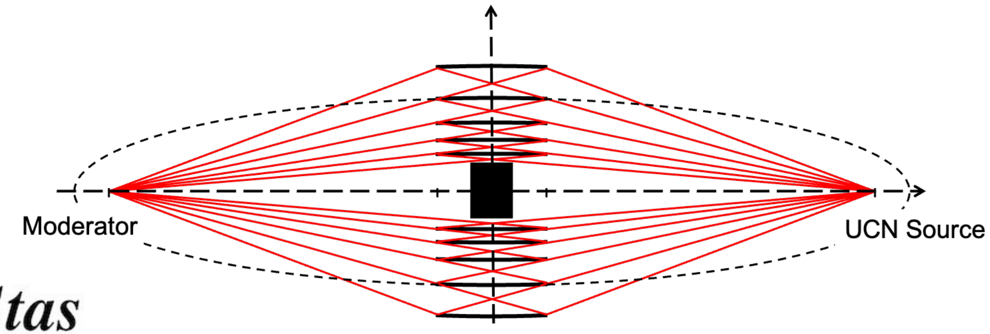
- No strong radiation fields
- Required cooling power greatly reduced
- UCN source accessible to troubleshooting
- UCN need to be transported only very short distances to experimental area
- Simpler nuclear licensing procedures



Nested Mirror Optics (NMO) for Neutron Delivery

- Elliptical guide: possible architecture to transport neutrons diverging from a source to a detector (sample)
- Elliptical shaped mirror - has the property to reflect a beam that emanates from one of its focal points directly to the other one
- The layers of several guides can be nested to build up a spatial tight optical component
  → Focusing reflector in (compact) nested arrangement
- Elliptical mirrors in planar or cylindrical arrangement possible
- Verify & quantify performance of these optical systems in McStas Simulations





O.Zimmer, arXiv:1611.07353
Journal of Neutron Research 20 (2018) 91-98

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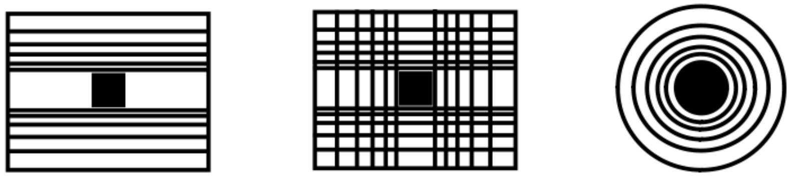
NMO - component creation library

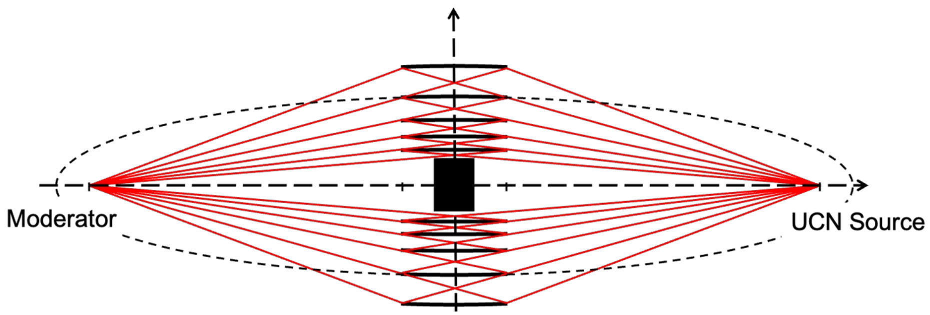
- **Collection of Python functions to build Nested Mirror Optics to be used in McStas with Guidy_anyshape.comp**

- Example

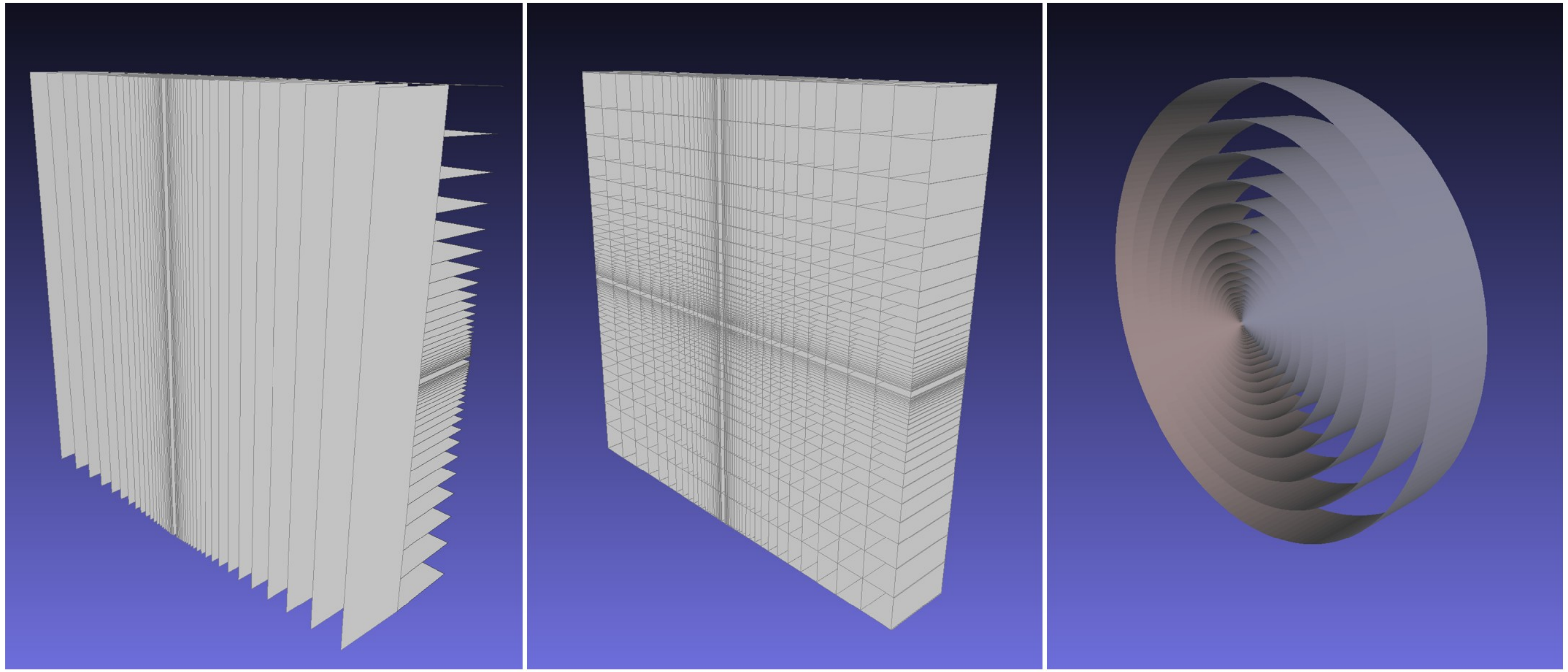
Table 5: Input parameters for the `createToroidalNestedOFFwArray()` function

Parameter	Description
L	distance between focal points of the ellipses
b_array	array containing the minor axes of the nested ellipses
z_start	starting point of the optic, relative to the focal point
l	length of the optic
nb_segments	number of segments by which the ellipses are approximated
nb_segments_T	number of segments the circumferences of
	the toroidal sections are approximated with
filename	name of the generated OFF-file
opticHalfWidth	limit for extent of the optic.
	The area the optic can occupy is between $\pm$ `opticHalfWidth`
bBoundingBox	outer level is surrounded by a bounding box (true/false)





Examples of NMO Types



a) two separated planar mirror assemblies

b) two intersecting planar assemblies (double-planar)

c) toroidal assembly

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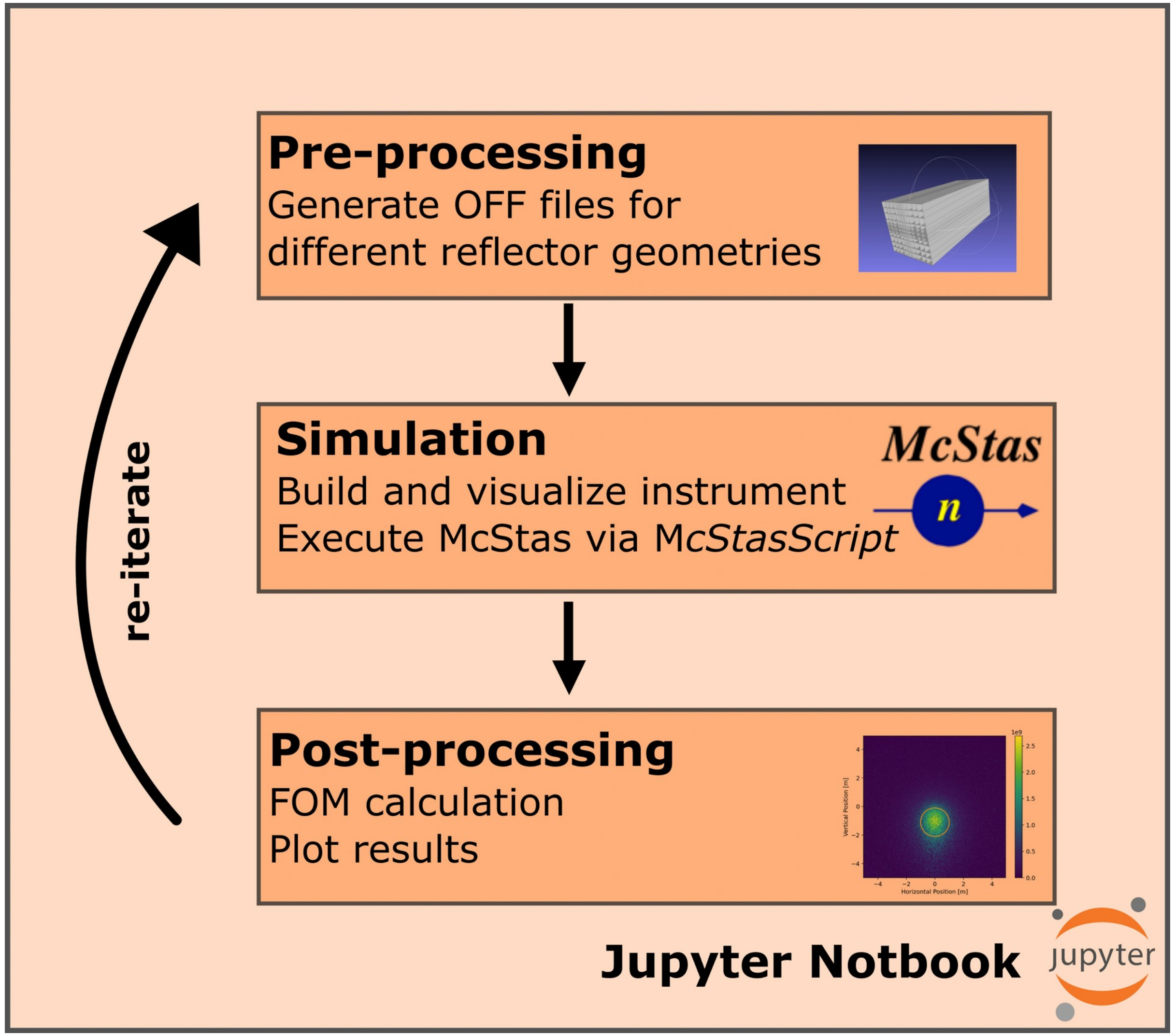
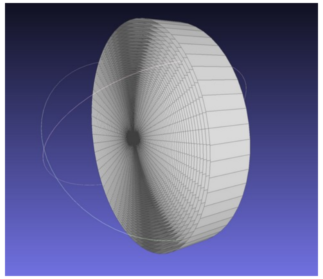
Simulation process

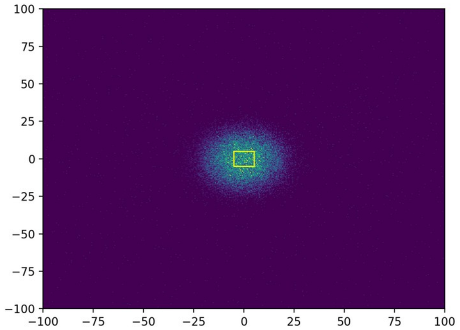


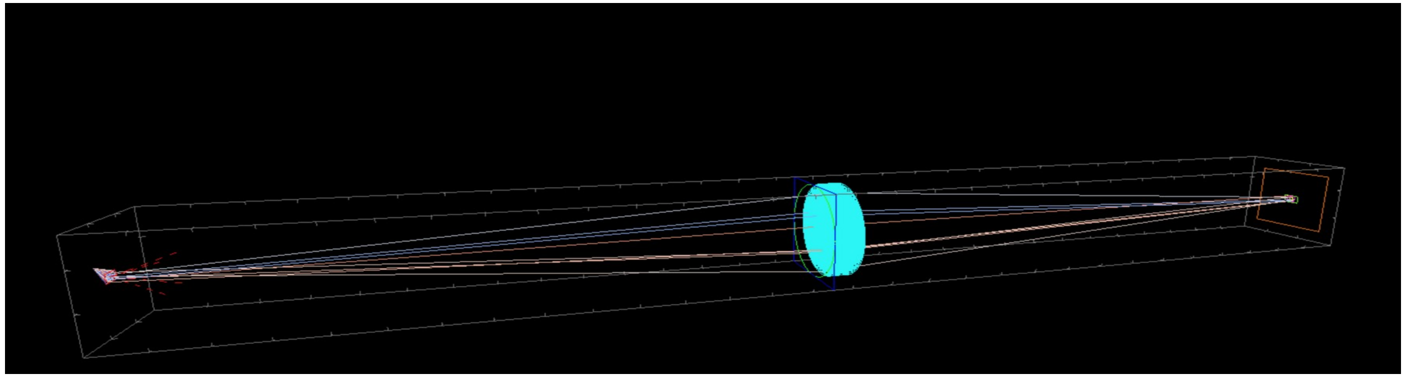
A First In-Beam UCN Source
McStas Simulation

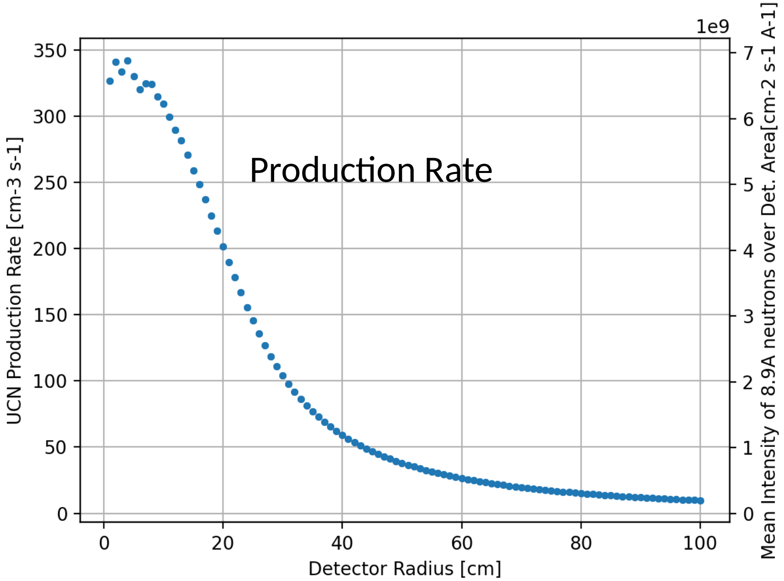
NMO at 15m:
length 0.5m, 119 levels

Distance Source-Detector
30m

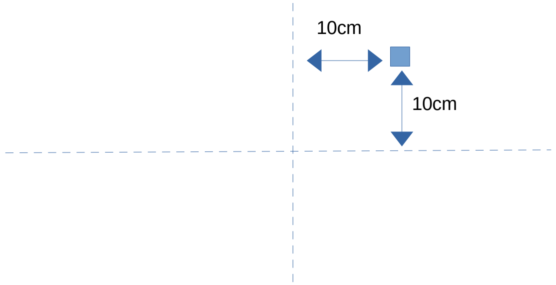






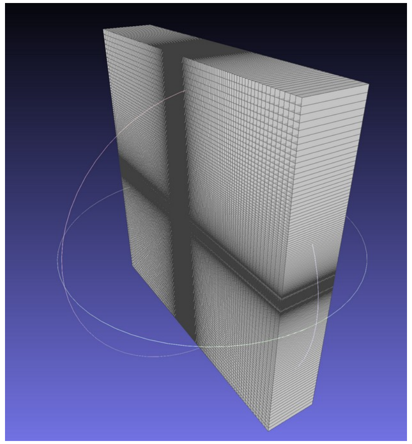


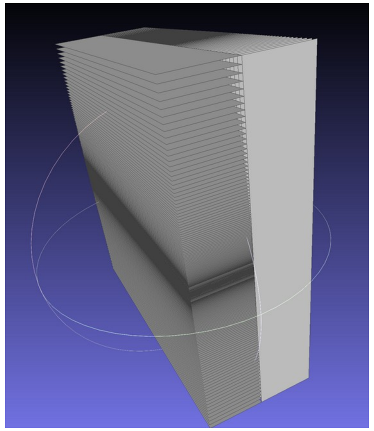
Imaging (Abberation) Considerations



off-axis “point” source

1 Double- or
2 Monoplanar
elliptical NMOs
at 15m
focal length 15m





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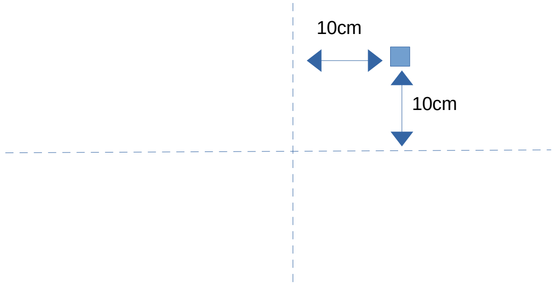

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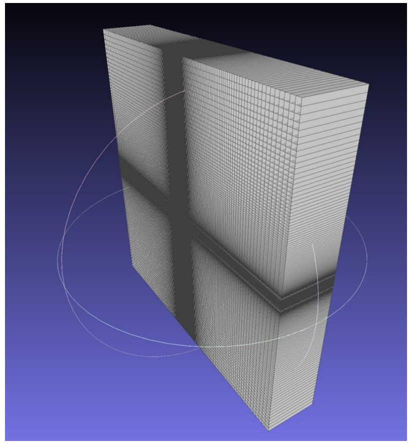
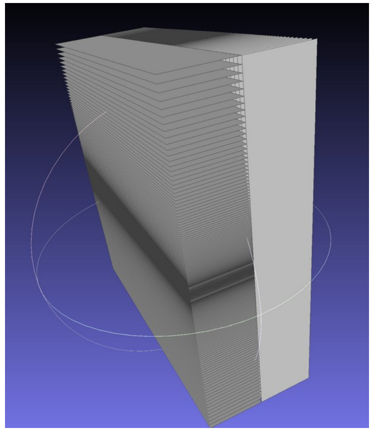
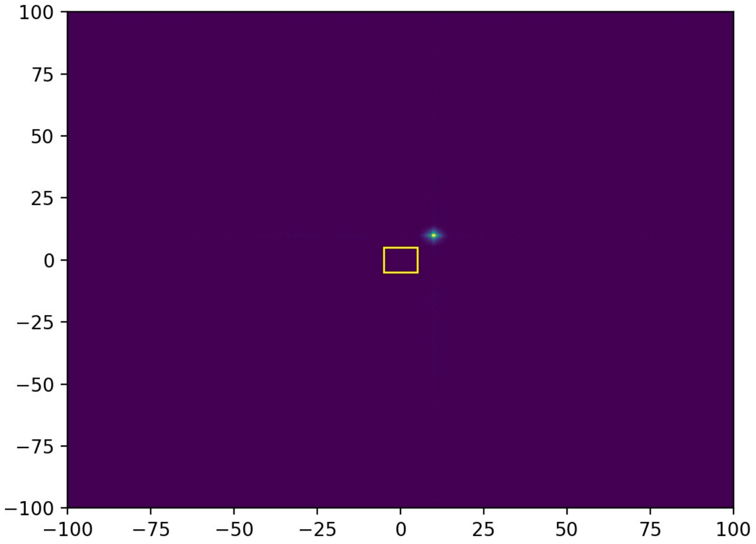




Detector at 30m



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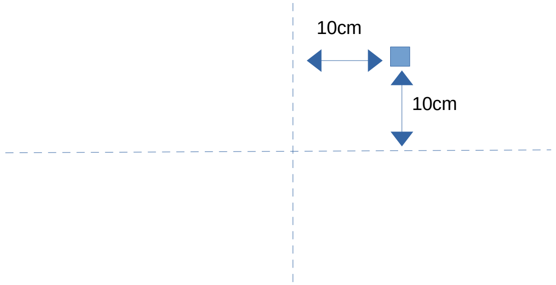
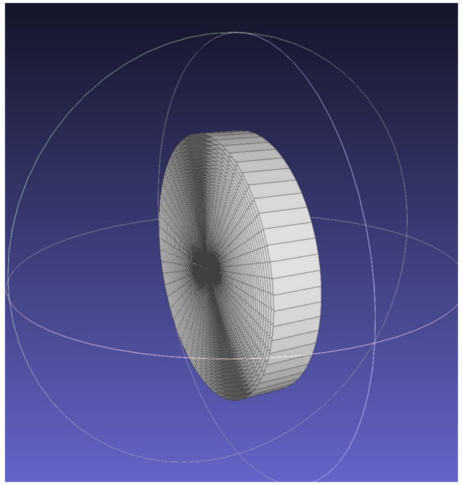


off-axis “point” source

Toroidal (cylindrical)
elliptical NMO
at 15m
focal length 15m



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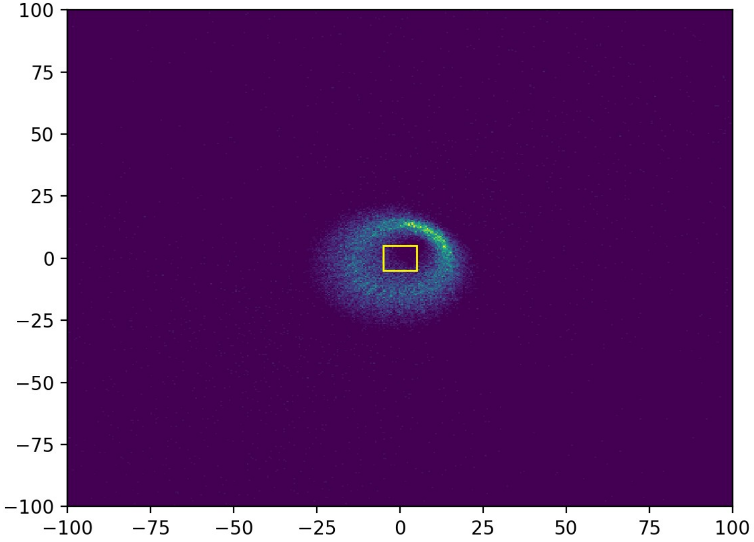
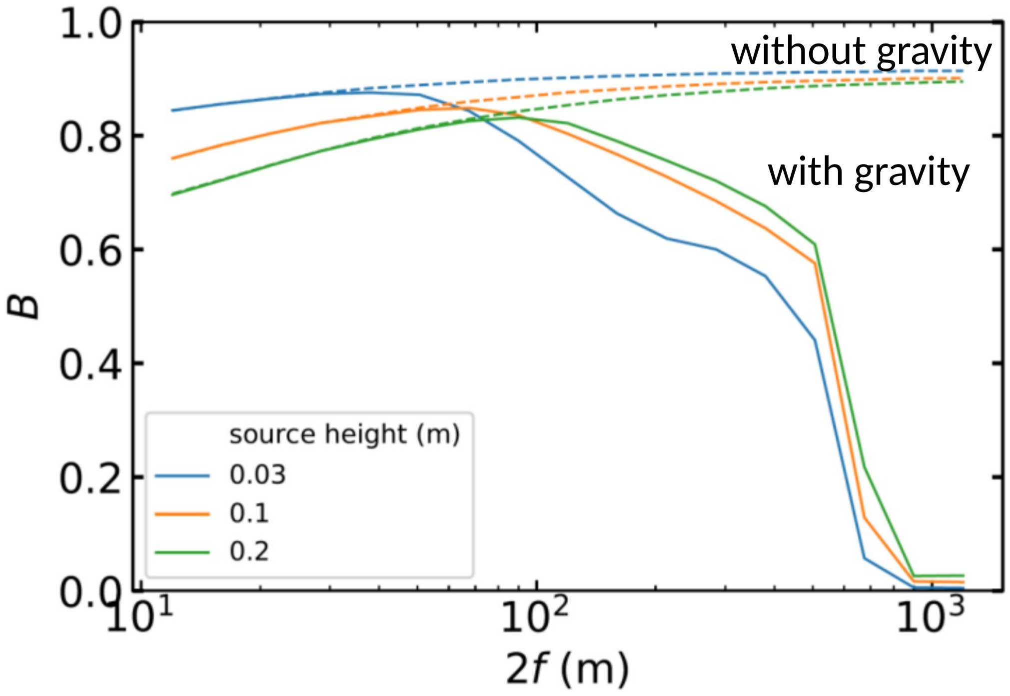


Impact of Gravity?

Integrated brilliance transfer (BT) by single planar elliptic NMO

$$BT = \frac{B_{conv}}{B_{mod}}$$

- m=6 supermirrors with 72 % edge reflectivity
- NMO scaled to full m=6 acceptance for each distance 2f



McStas simulation by **Christoph Herb**

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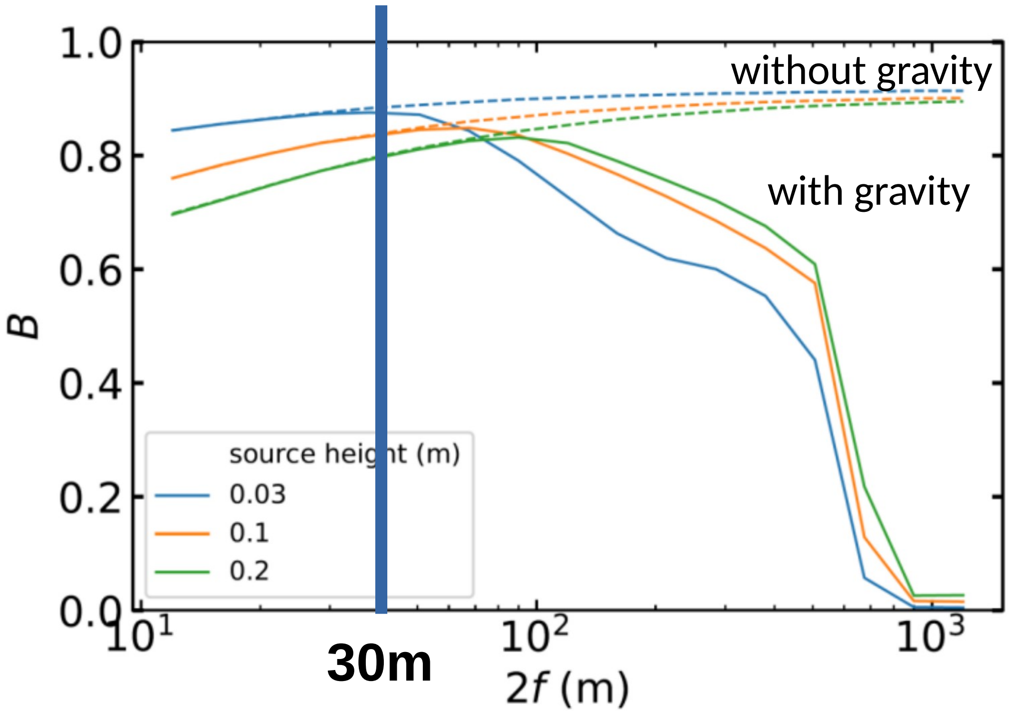
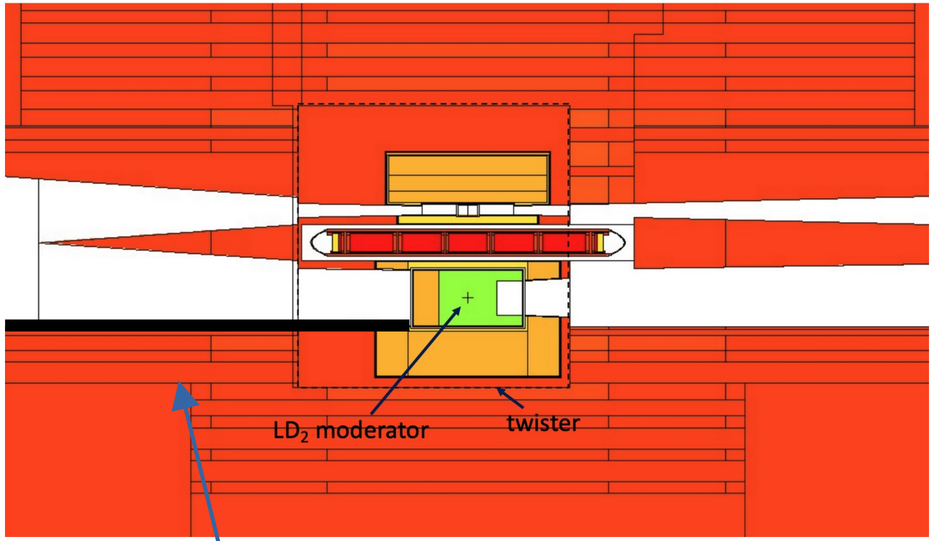
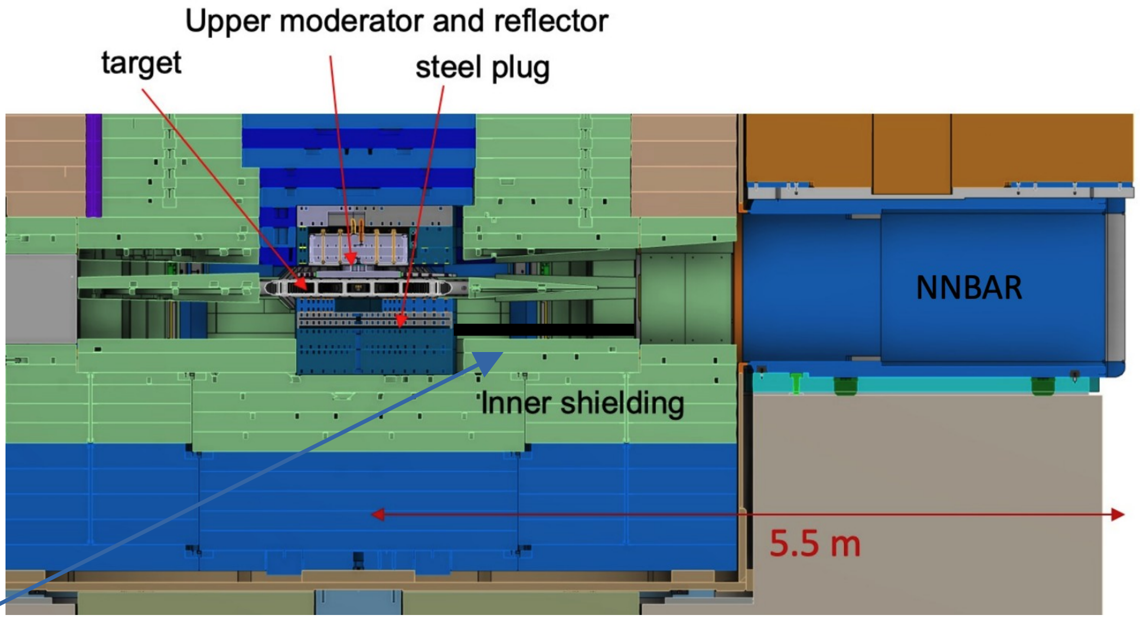


McStas simulation by **Christoph Herb**

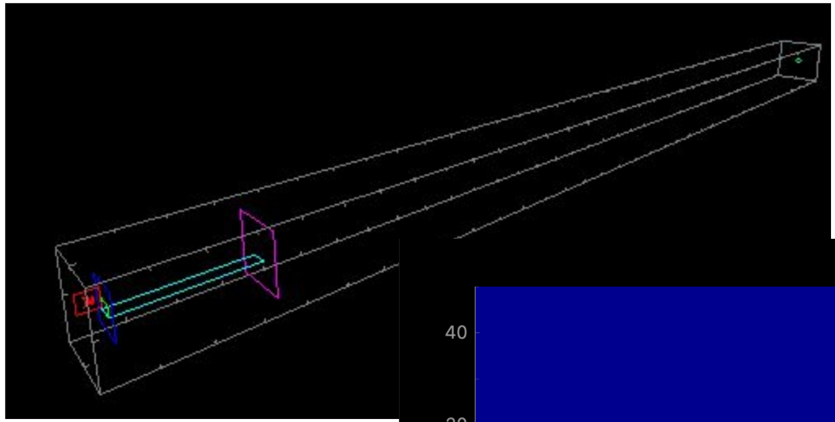
A Closer Look at the Moderator Exit



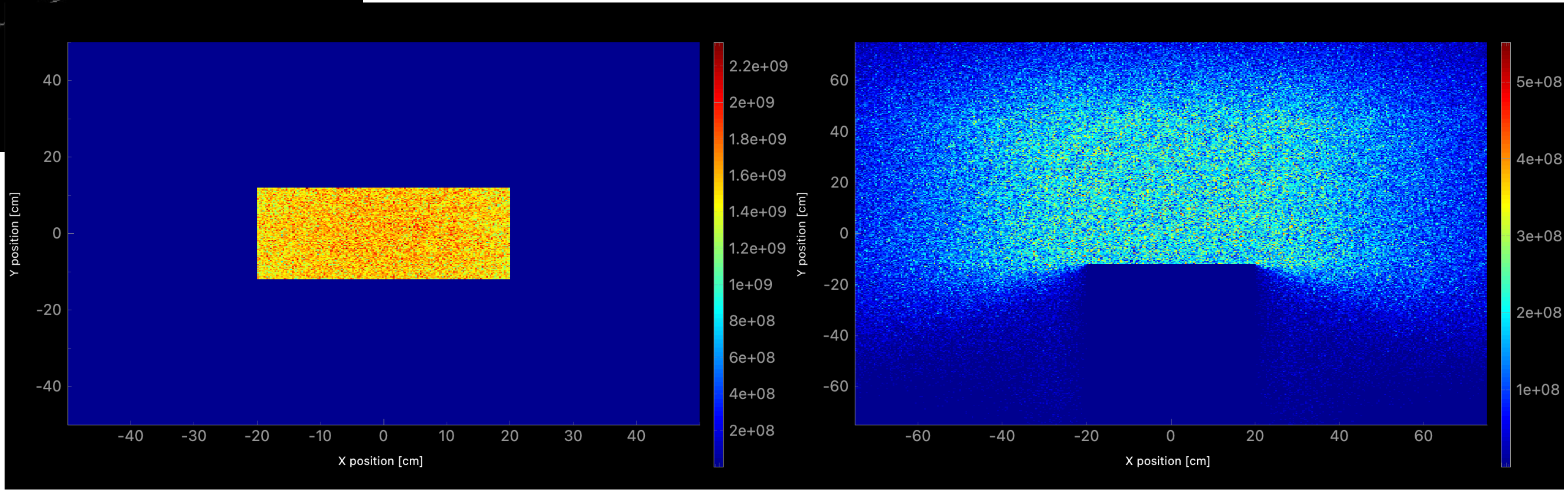


2 m long horizontal steel plate

McStas Simulation



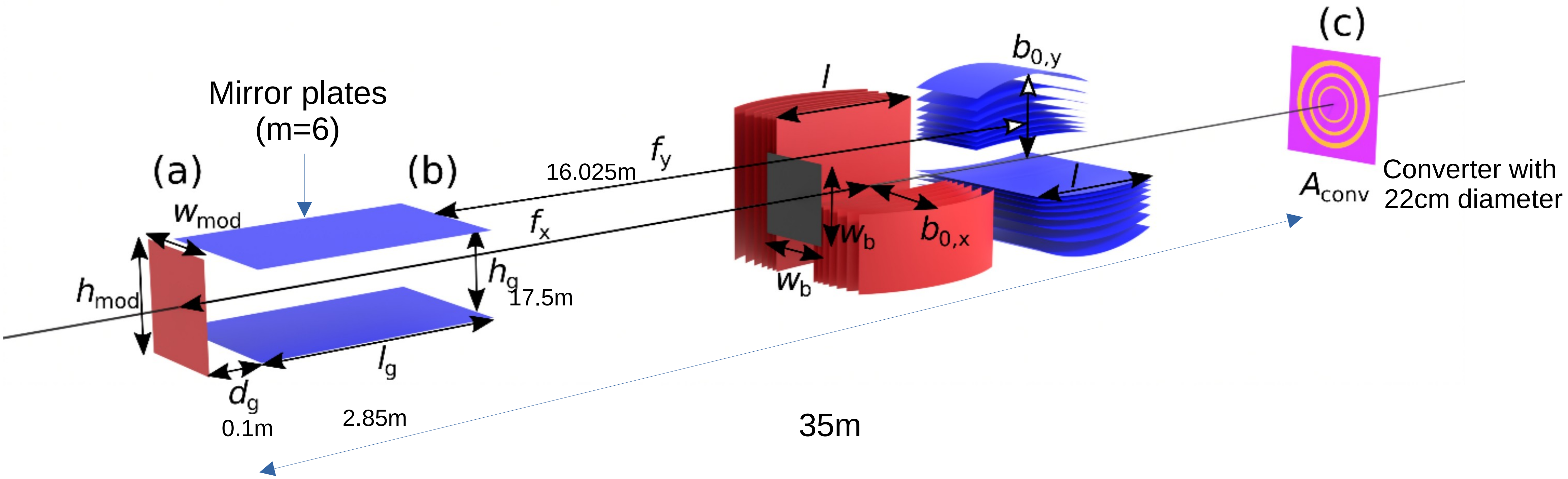
Steel plate cuts into neutrons field of view



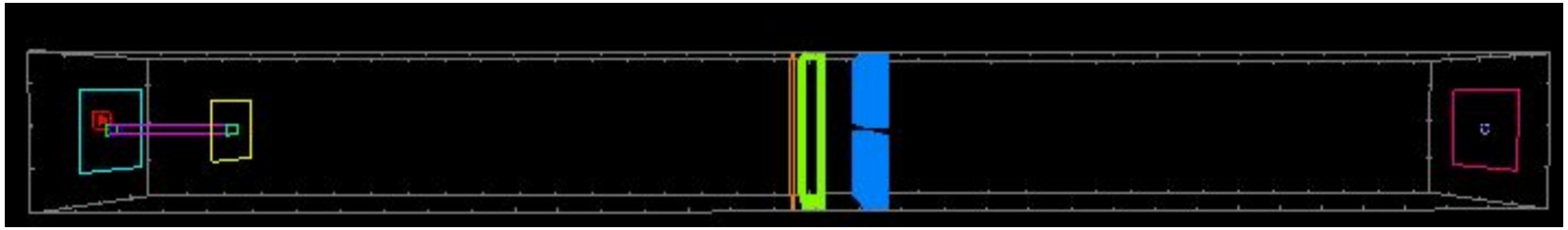
At Moderator Surface

After Plate

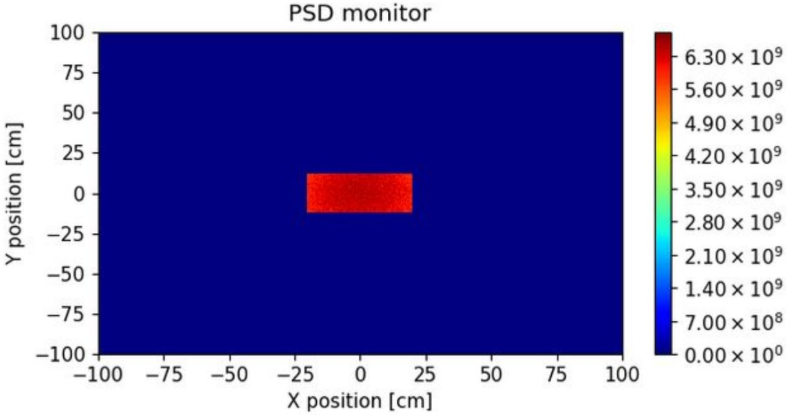
Proposed setup at ESS Large Beam Port

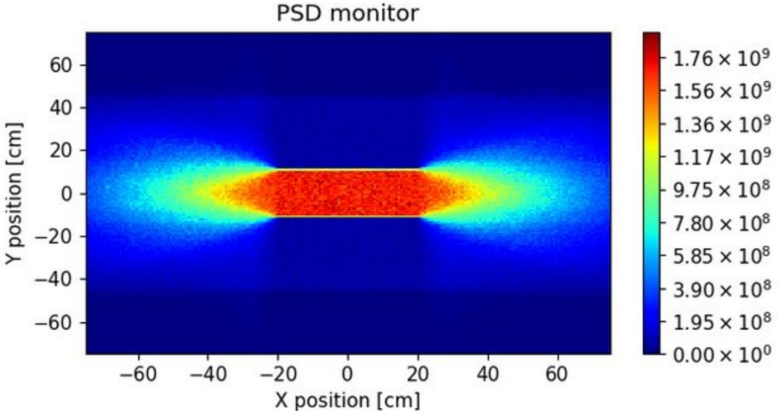


Results - McStas Simulation

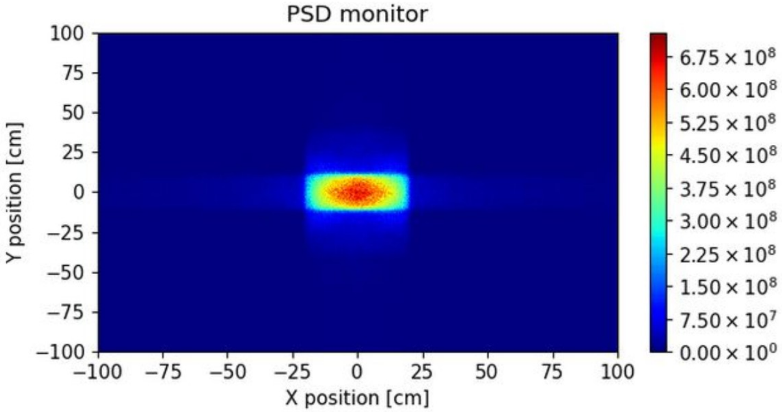


At Moderator Surface





At UCN Converter



Estimate Production Rate and Saturated UCN Density I

“single-phonon” process (p_I)

Mean 8.9 Å flux at converter area
assuming 20% additional losses due to imperfections

$$p_{\mathrm{I}} \approx 5.0 \times 10^{-16} \times \left(\frac{\mathrm{d}\Phi}{\mathrm{d}\lambda}\right)^{*}$$

$$p_{\mathrm{I}} = 260\ \mathrm{s}^{-1}\mathrm{cm}^{-3}$$

For details see:

In-beam superfluid-helium ultracold neutron source for the ESS

Oliver Zimmer [a,*], Thierry Bigault [a], Skyler Degenkolb [b], Christoph Herb [c], Thomas Neulinger [a], Nicola Rizzi [d], Valentina Santoro [d], Alan Takibayev [d], Richard Wagner [a] and Luca Zanini [d]

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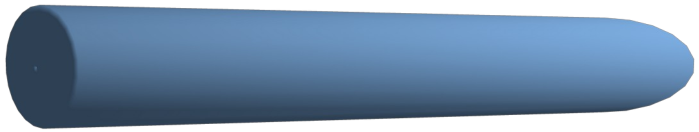
Saturated density $\rho_{sat} = p_I\,\tau$
With a τ UCN storage time constant of the converter of 300 s

$$\rho_{\mathrm{sat}} = 7.8 \times 10^{4}\ \mathrm{cm}^{-3}$$

Estimate Production Rate and Saturated UCN Density II

Converter with diameter 22 cm and length 3m:



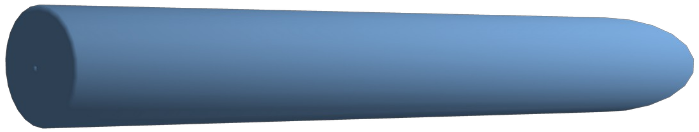
$$P_{\mathrm{I}} = 1.7 \times 10^{7}\ \mathrm{s}^{-1}$$

And total saturated UCN number N_{sat} :

$$N_{\mathrm{sat}} = 5.1 \times 10^{9}.$$

Estimate Production Rate and Saturated UCN Density II

Converter with diameter 22 cm and length 3m:



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> *"...at the top of the range of other current projects."*
> Zimmer et al., JNR 2022

Outlook

- Continue systematic and more detailed study of NMO (and alternative) geometries
- Improve on source term for simulations
  - Currently *Source_gen* component with mean Brilliance
  - Goal is to use MCPL file (still lacks statistics at the moment)
- Include multi-phonon conversion in UCN production rates
- Build and simulate realistic physical modell
  to get a more accurate account for losses :
  - Thickness of mirrors
  - Waviness, roughness of mirrors
  - Off-specular reflection

Thank you for our attention!

Credits: Aylen Cordoba, Jonathan Collin, Christoph Herb, Alexandra Karabasova, Nicola Rizzi, Luca Zanini, Oliver Zimmer

NEUTRONS
FOR SOCIETY

INSTITUT LAUE LANGEVIN