The International Seminar on Interaction of Neutrons with Nuclei “Fundamental Interactions & Neutrons, Nuclear Structure, Ultracold Neutrons, Related Topics” (ISINN-31)

MONTE CARLO SIMULATION OF FOCUSING UCN NEUTRON GUIDES

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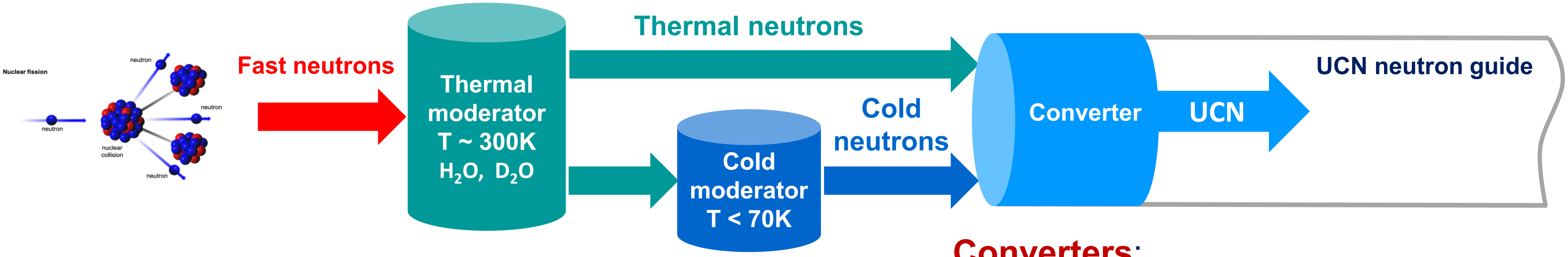
Ultracold neutron production



Converters:

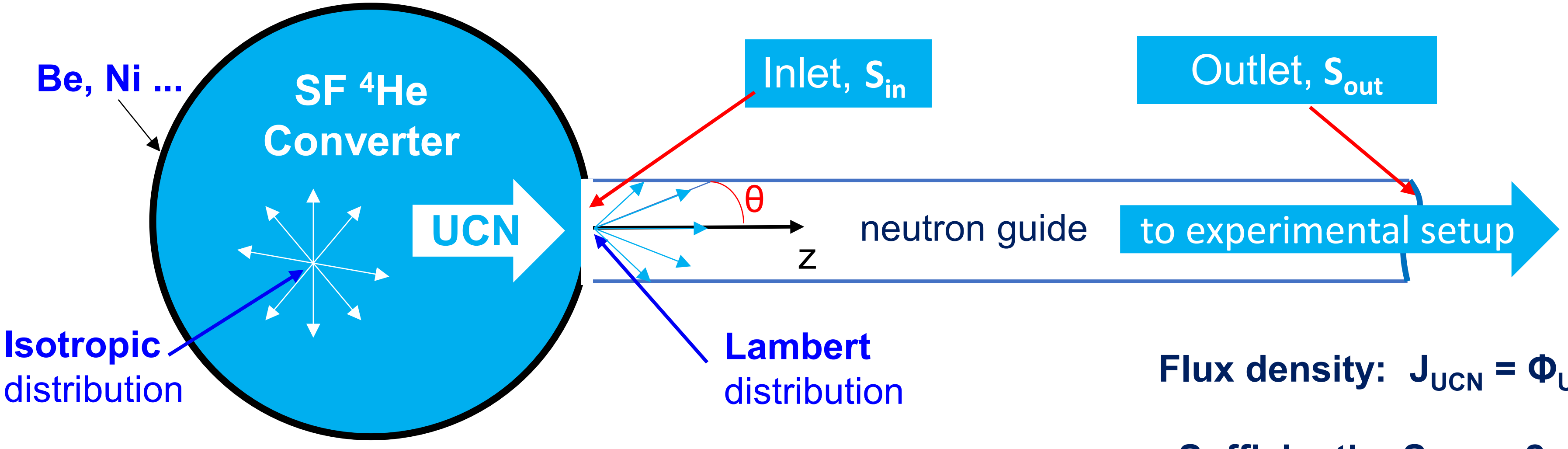
Liquid H_2	$\tau_{stor} < 0.2$ ms
Liquid D_2	$\tau_{stor} < 1$ ms
Solid D_2	$\tau_{stor} < 30$ ms
Superfluid ^4He	$\boldsymbol{\tau_{stor}}$ **= 610s** (at T = 0.8K)

- Moderators - Many collisions
- Converters - One collision

τ_{stor}: storage time

UCN production process

Purpose and tasks



Flux density: $J_{UCN} = \Phi_{UCN}/S_{out}$

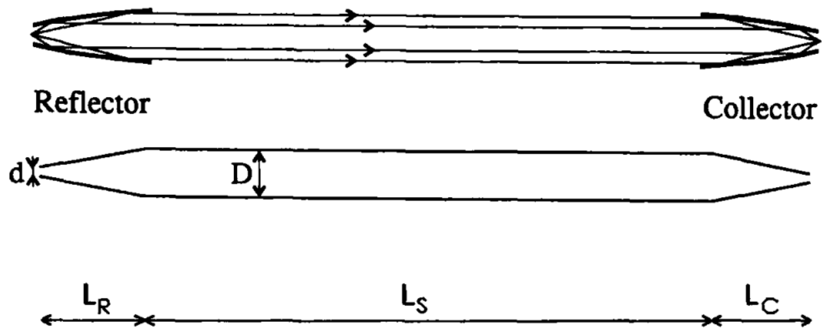
Sufficiently: S_{in} = ~ 2..3 cm^2

Length of UCN neutron guide: up to ~ 30 m

Angular distributions:

Isotropic: $f(\Omega)d\Omega = const(\Omega)d\Omega \sim \sin(\theta)d\theta$

Lambert: $f(\Omega)d\Omega \sim \cos(\theta)d\Omega \sim \cos(\theta)\sin(\theta)d\theta$



“Ballistic” neutron guide of Thermal Neutrons
Mezei, F. (1997). Journal of Neutron Research, 6(1), 3–32

Purpose and tasks

1. Purpose

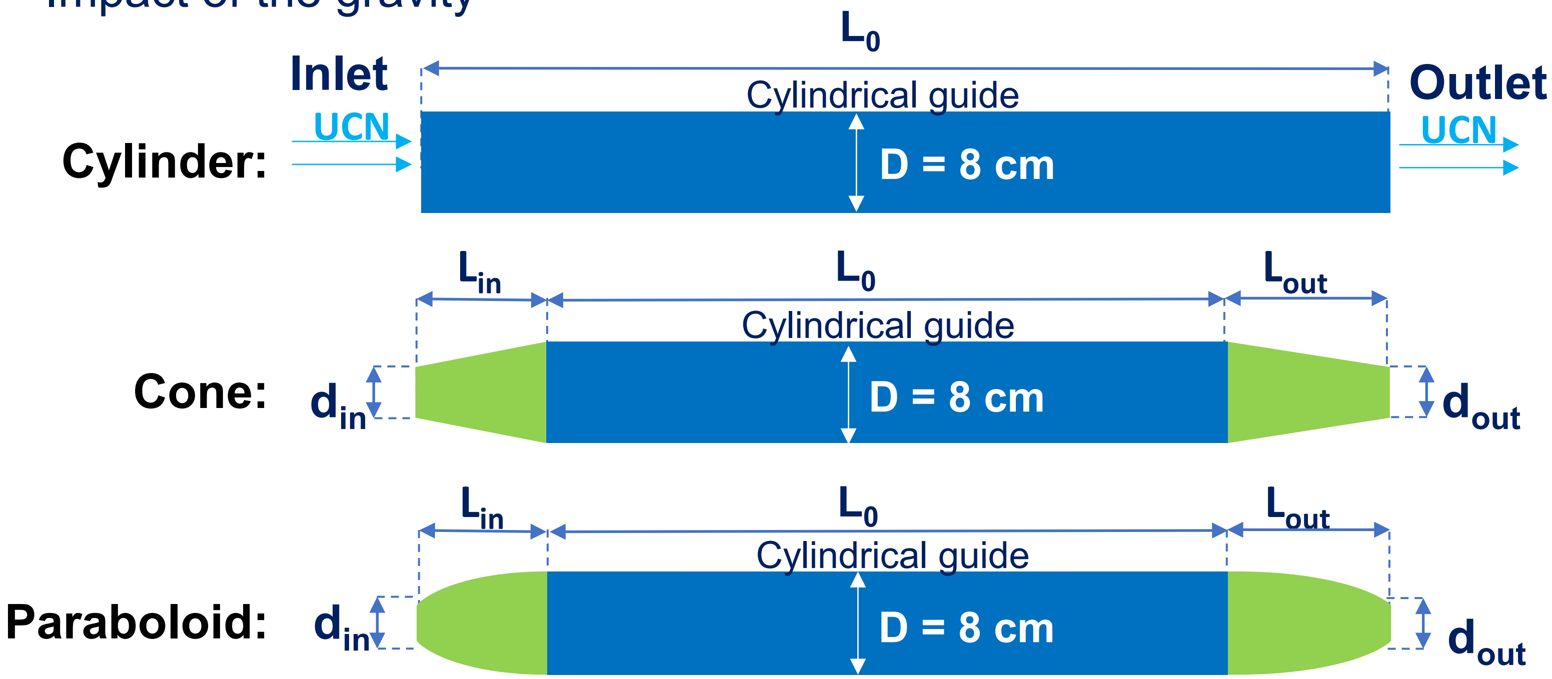
Simulation of a new type of a UCN neutron guide: focusing UCN neutron guides that greatly increases UCN transmittance and flux density.

2. Tasks

- Efficiency optimization
    + Determine the optimal neutron guide geometry to maximize the flux density;
    + Minimize the number of collisions of UCN with walls of neutron guide.
- Geometric design
- Neutron wavelength (energy) dependence
- Impact of the gravity

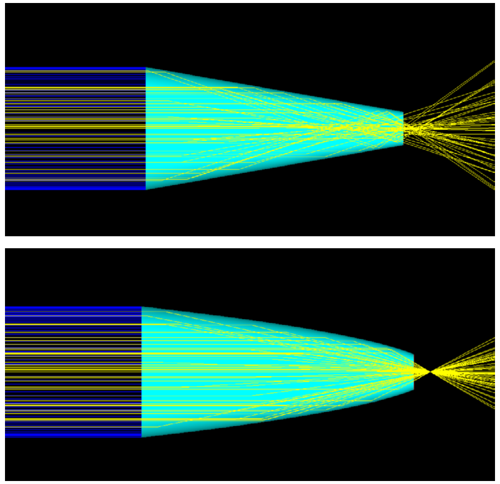
3. Conditions (as a rule)

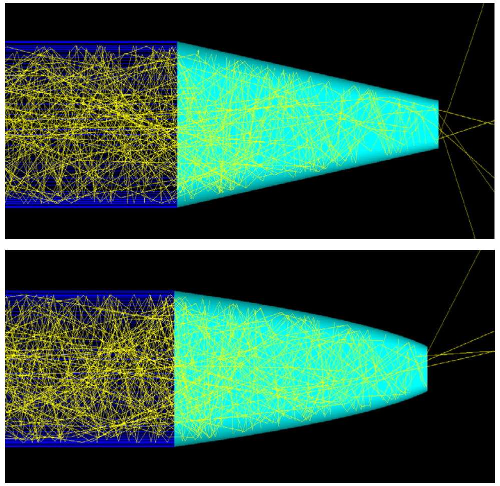
- No gravity
- No losses
- No roughness
- No accumulation
- $E_{UCN} < E_F$ of neutron guide



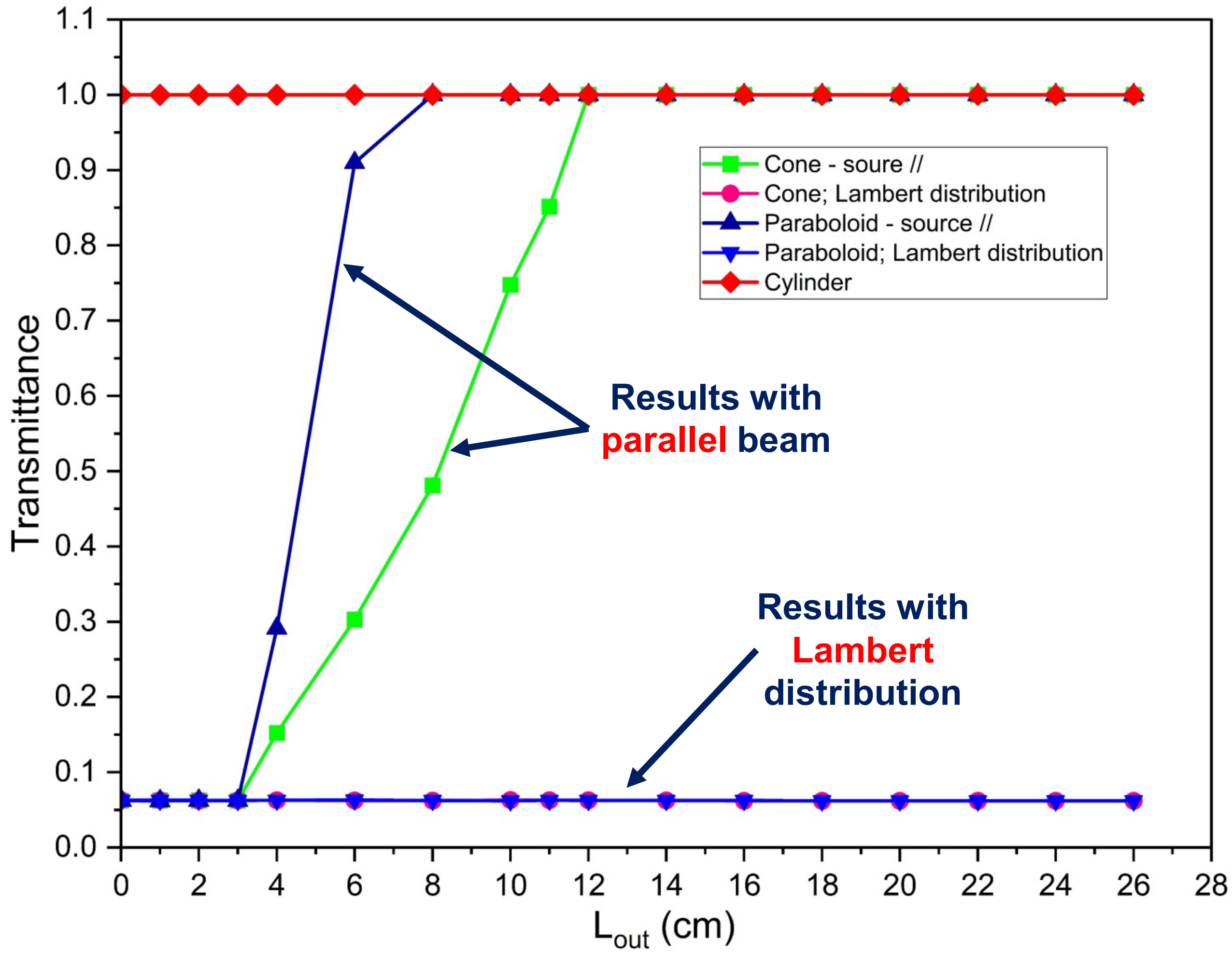
Simulation implementation and Results

Input UCN angular distribution:
Parallel beam and Lambert distribution





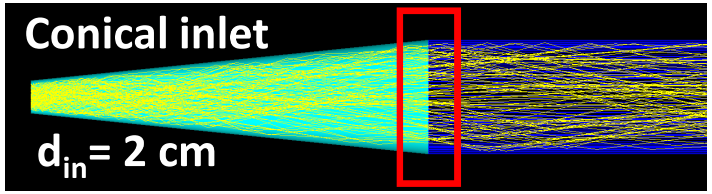
- ❖ Parallel angular distribution source
- ❖ Lambert angular distribution source

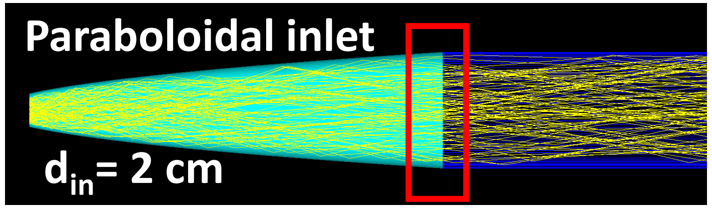


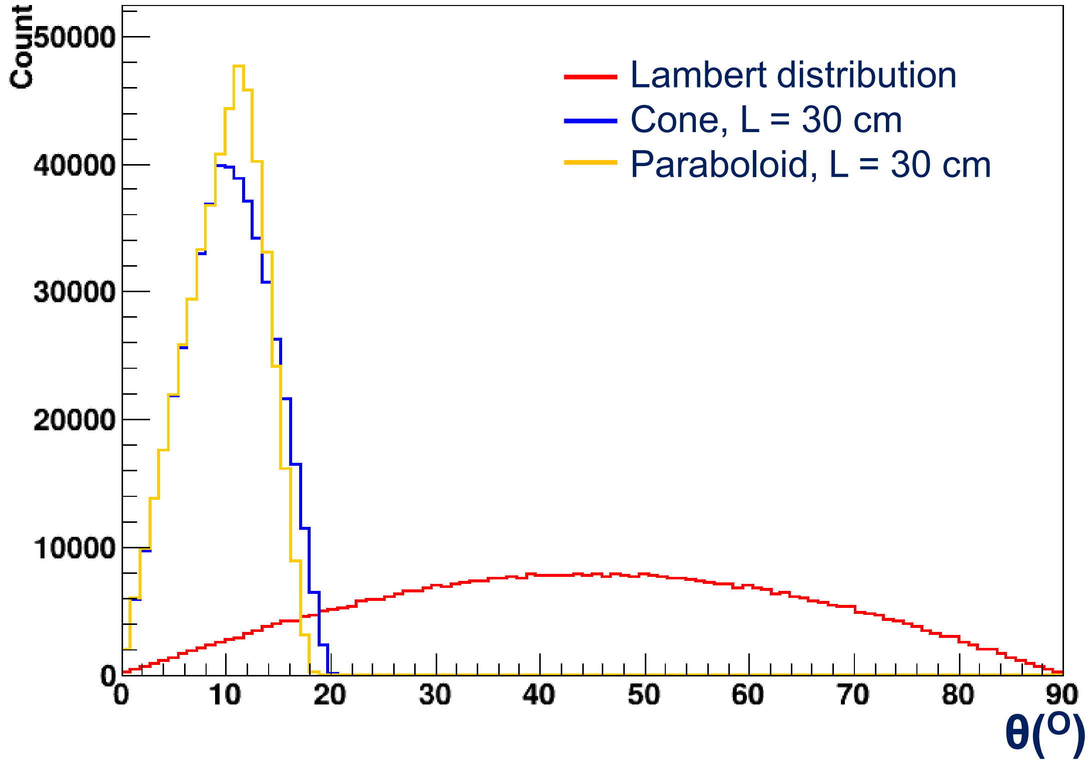
Dependence of the transmittance on the length of the outlets for parallel and Lambertian angular distribution sources

Simulation implementation and Results

Input UCN angular distribution - Lambert







Angular distribution at the end of conical and paraboloidal inlets, L_{in} = 30 cm, d_{in}= 2 cm

Lambert: <θ> = 45°, tg(<θ>) = 1

Conical inlet: <θ> = 10.166°, tg(<θ>) = 0.179

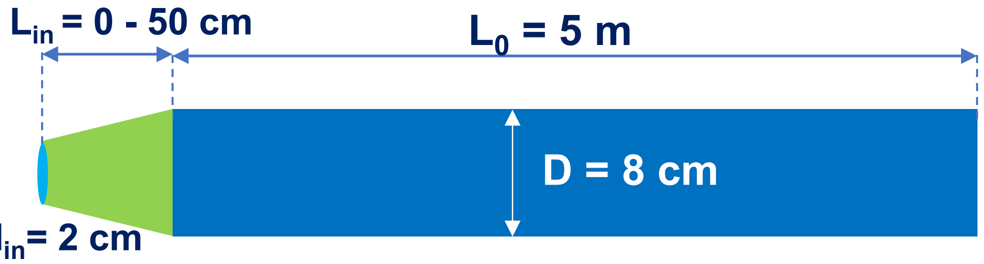
Paraboloidal inlet: <θ> = 9.812°, tg(<θ>) = 0.173

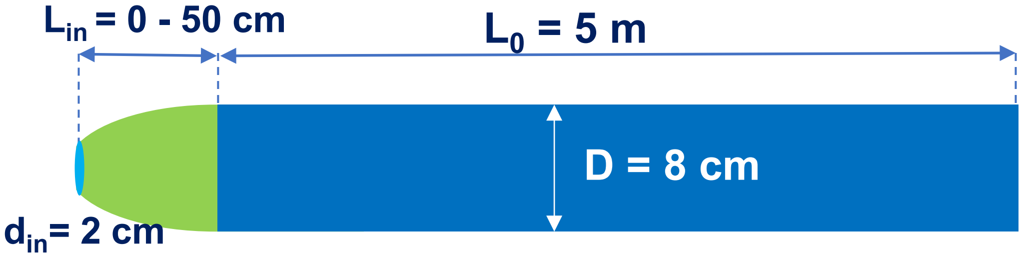
A good criterion for beam divergence: tg(<θ>)

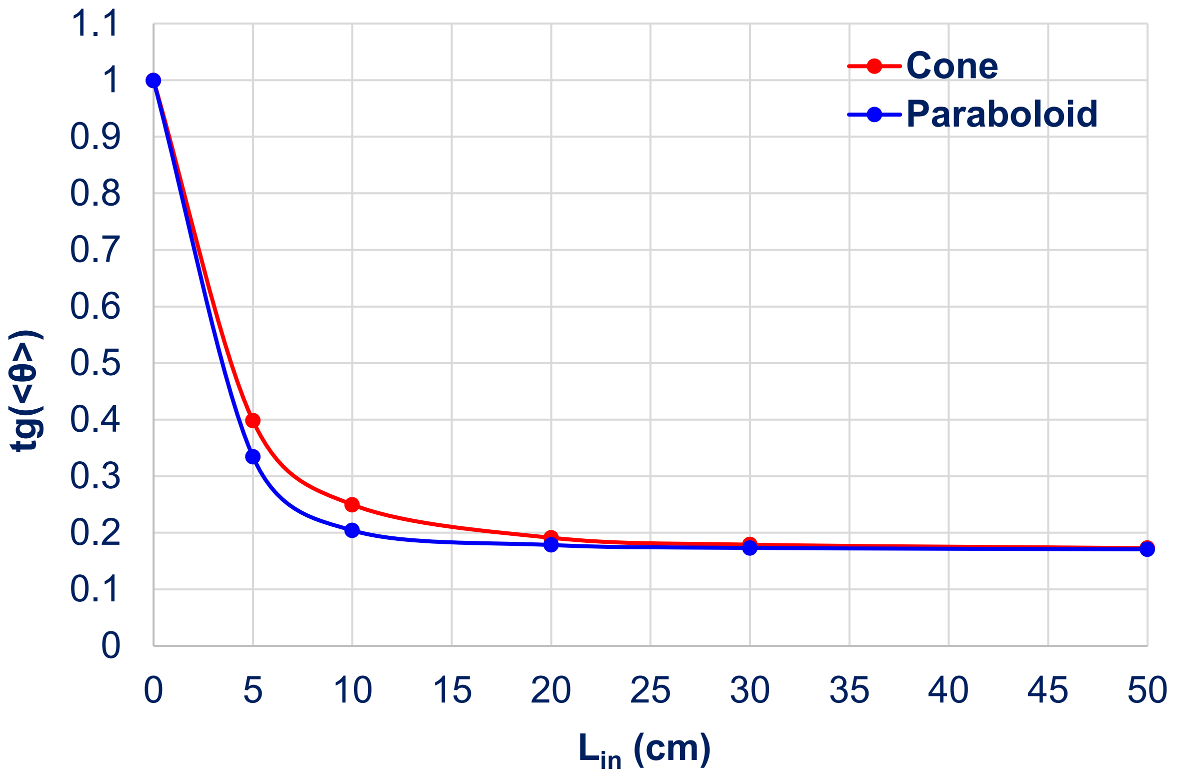
Note: The angle θ is calculated right after the conical and paraboloidal inlets.

Simulation implementation and Results

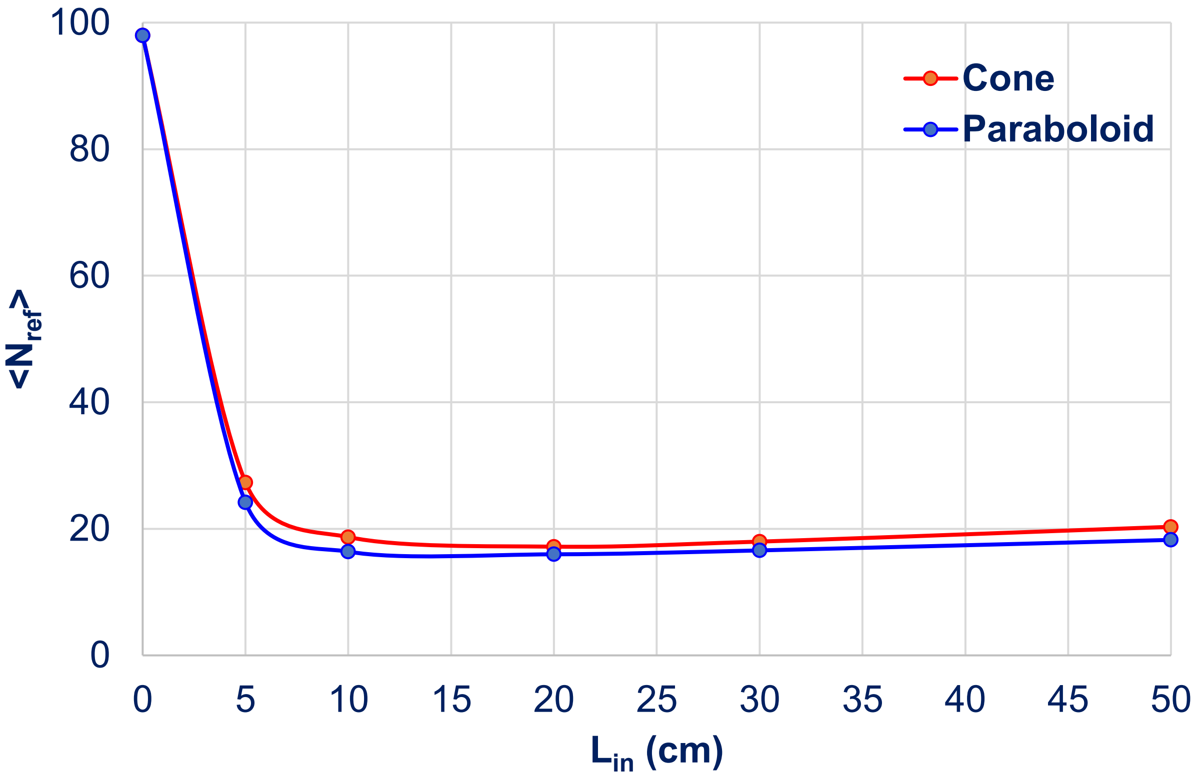
Input UCN angular distribution - Lambert





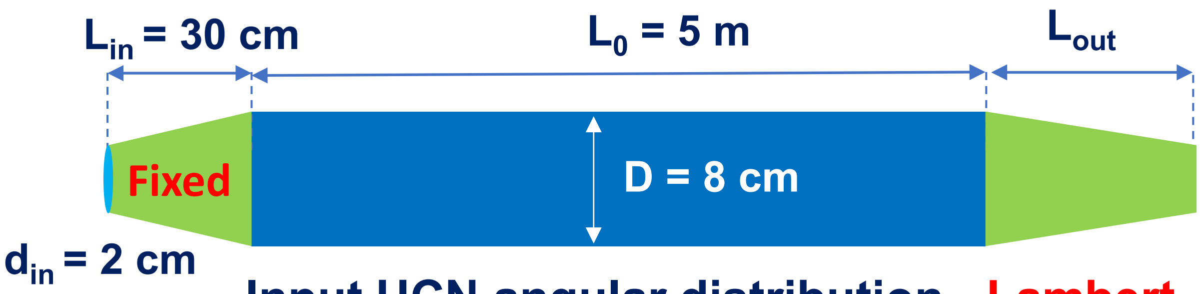


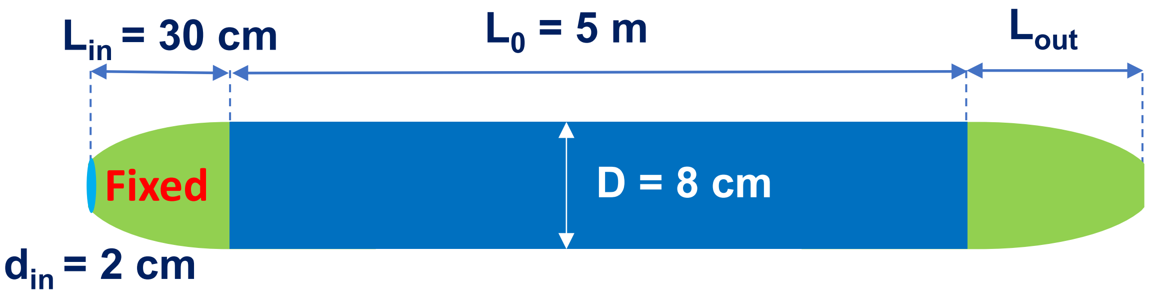
Dependence of **tg(<θ>)** on L_{in}



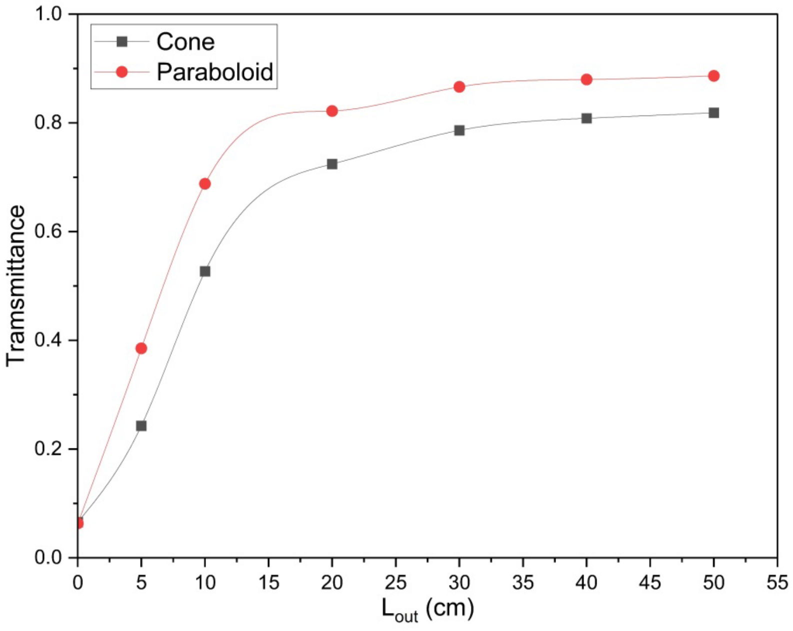
Average number of reflections **<N_{ref}>** on L_{in}

Simulation implementation and Results

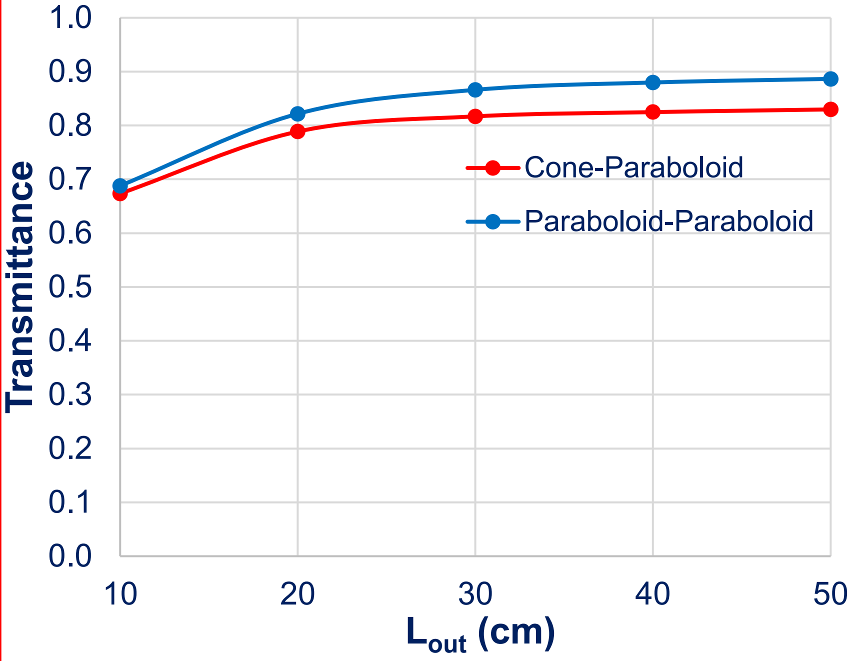




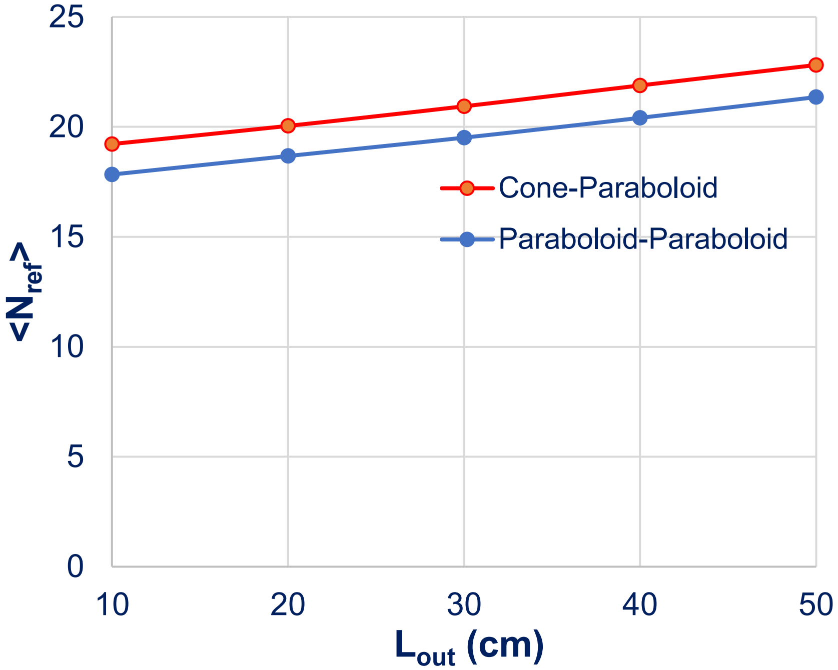
Input UCN angular distribution - Lambert



Dependence of the transmittance T on the length L_{out} of the outlets



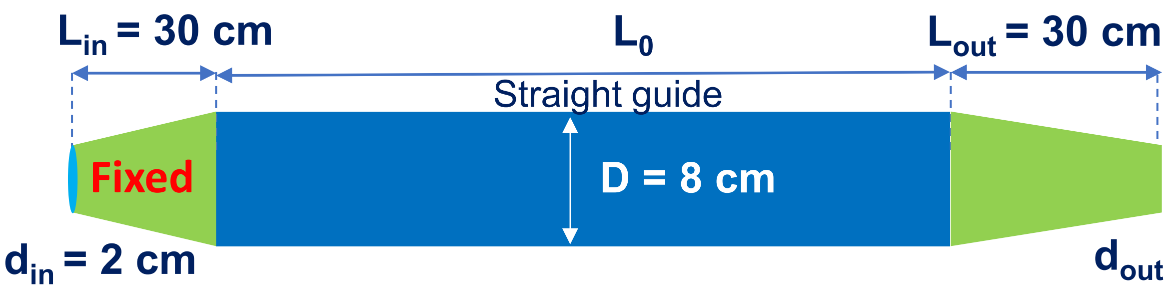
Dependence of the transmittance **T** on the length L_{out} of the outlets

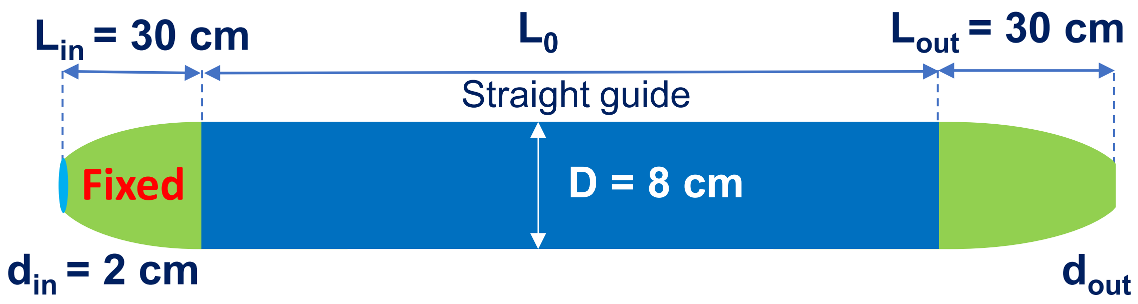


Dependence of the number of reflections N_{ref} on the length L_{out} of the outlets

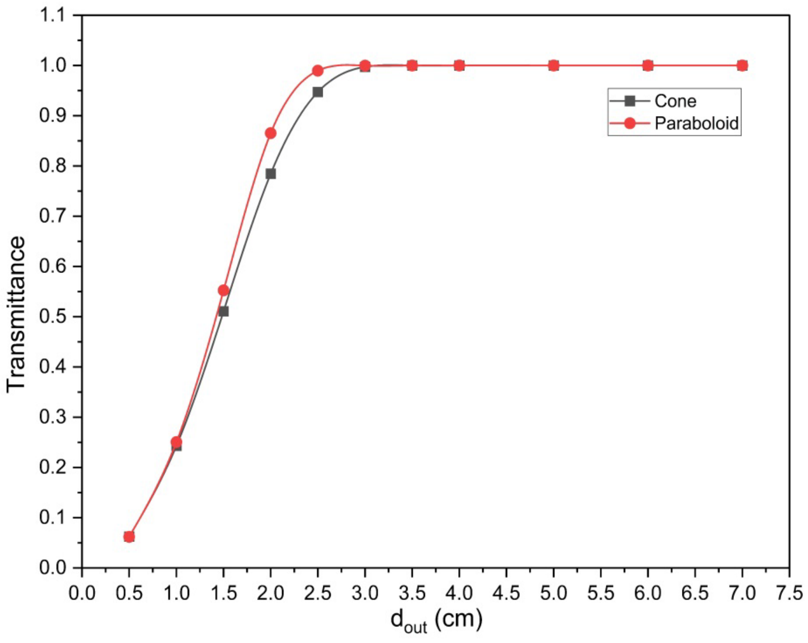
Note: The results in the red framework are calculated for the conical inlets.

Simulation implementation and Results

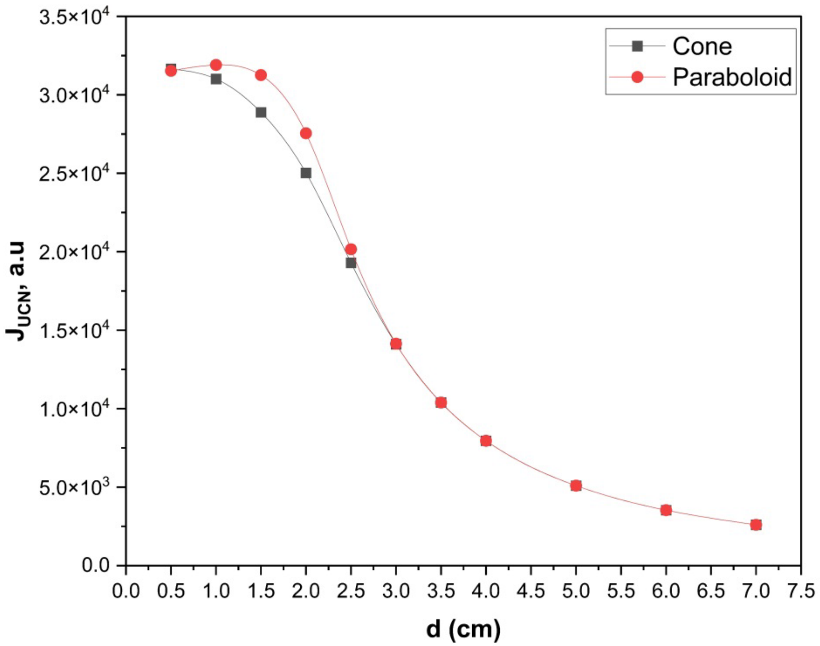




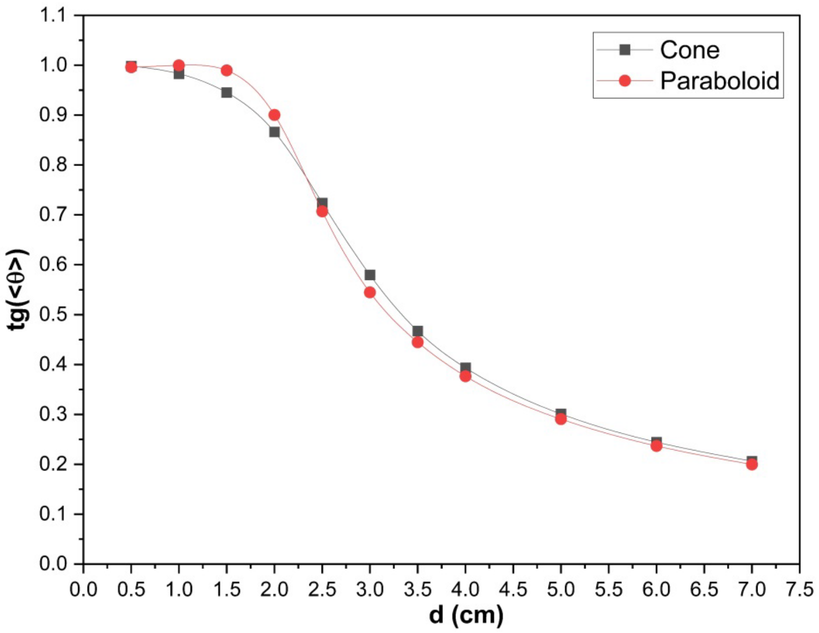
Input UCN angular distribution - Lambert



Dependence of the transmittance T on d_{out}



Outlets UCN flux density, J_{UCN} on d_{out}



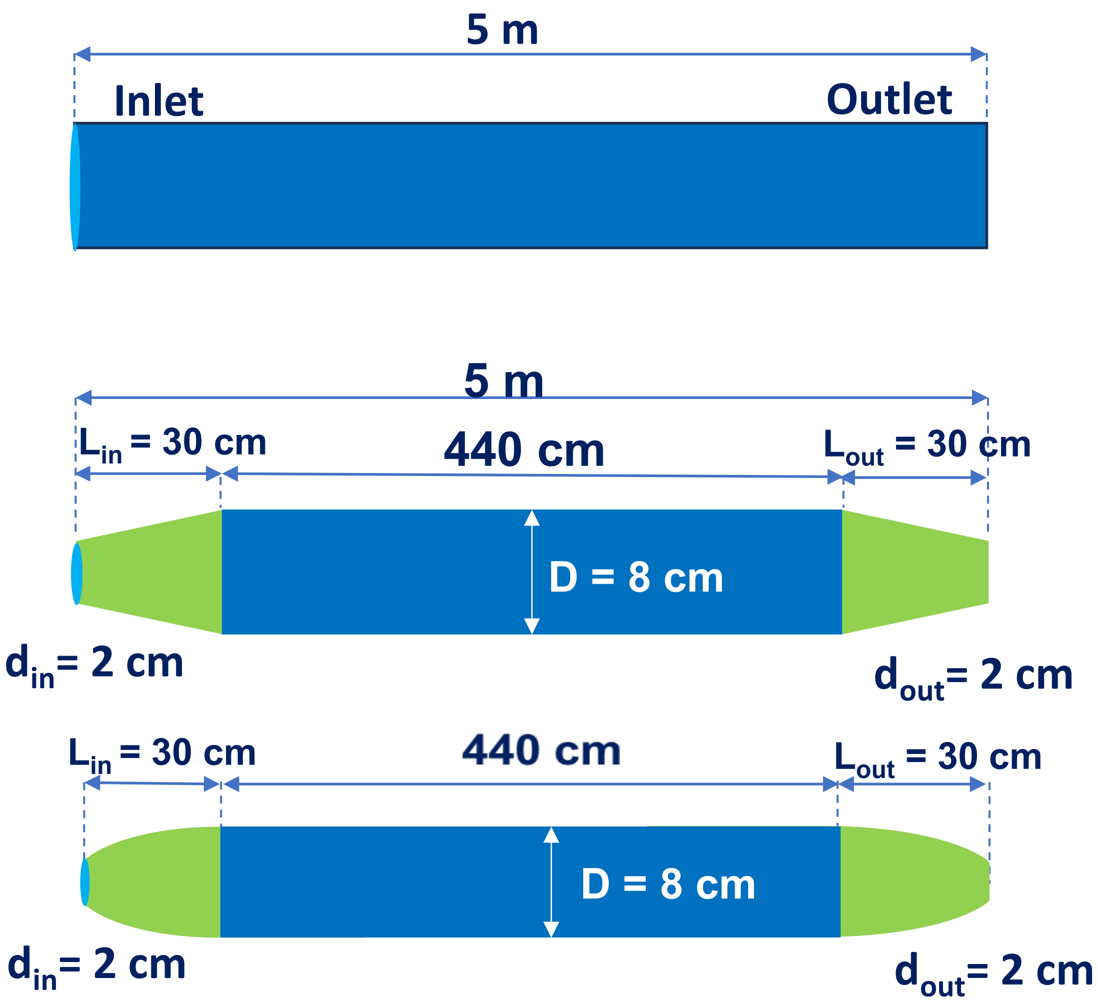
Dependence of tg(<θ>) on d_{out} for outlets UCN

Simulation implementation and Results

Dependence on loss probability

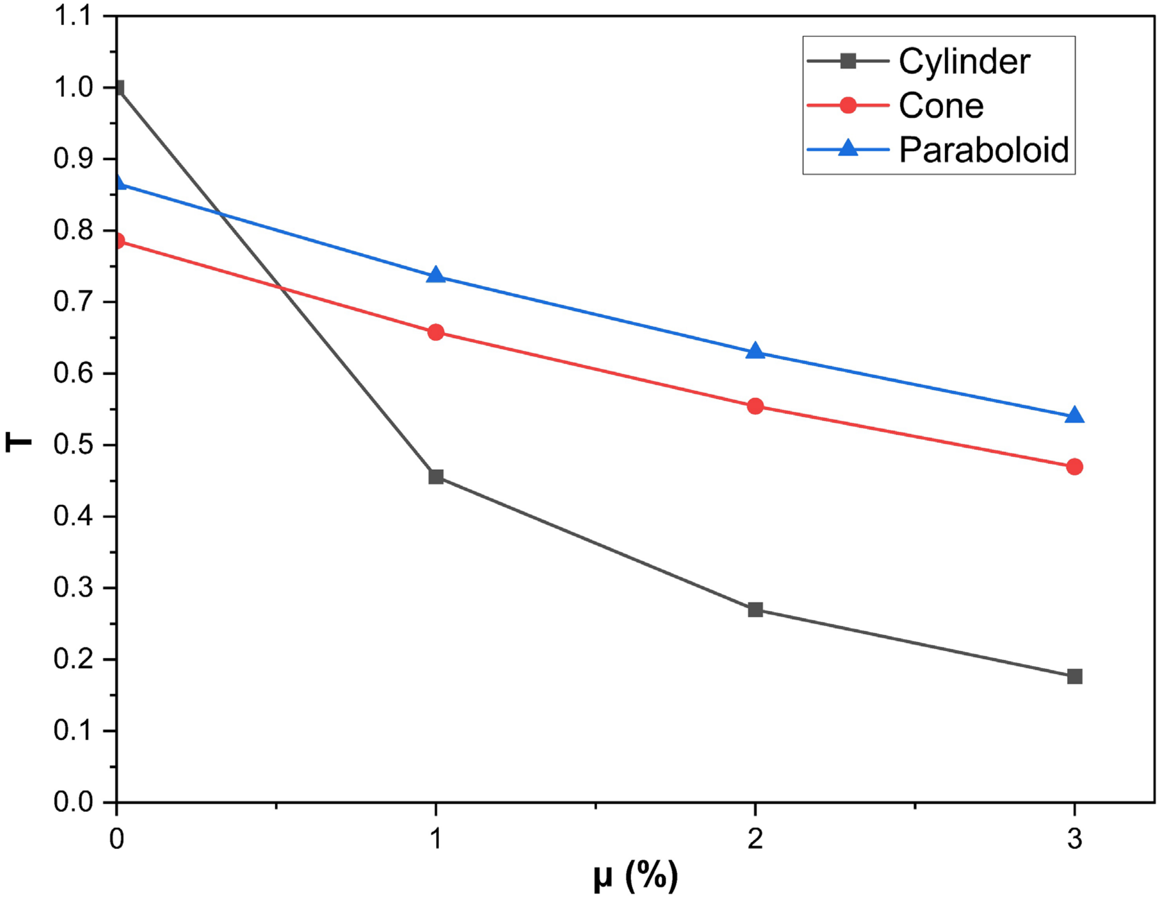
Input UCN angular distribution - Lambert

Loss probability, μ = 0%			
	Cylinder	Cone	Paraboloid
T	1	0.786	0.866
$\langle N_{ref} \rangle$	124.1	18.28	16.76

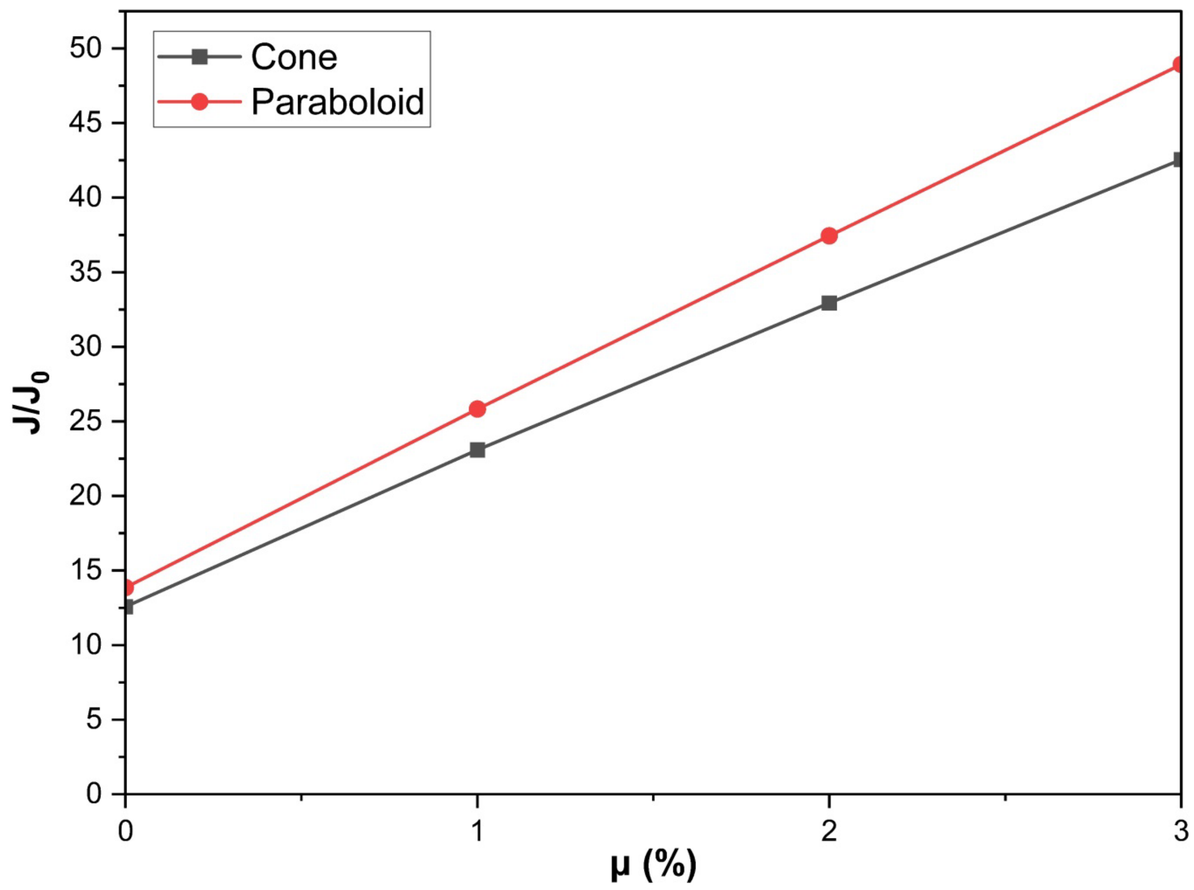


Simulation implementation and Results

Dependence on loss probability



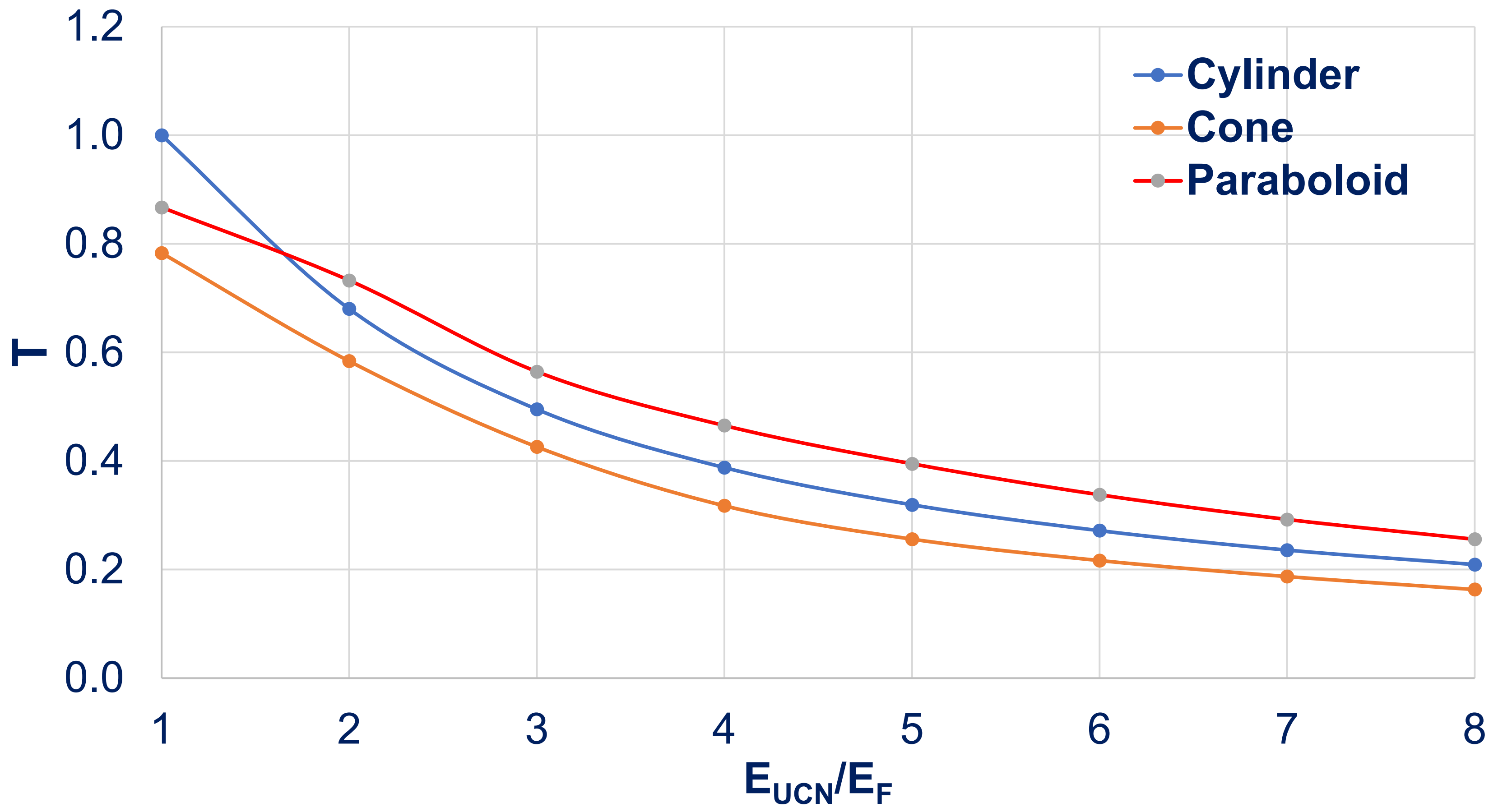
Dependence of the transmittance
T on loss probability μ



Ratio J/J_0 on loss probability μ
J - flux density of outlet UCN from a conical and paraboloidal neutron guides
J_0 - flux density from a cylindrical neutron guide

Simulation implementation and Results

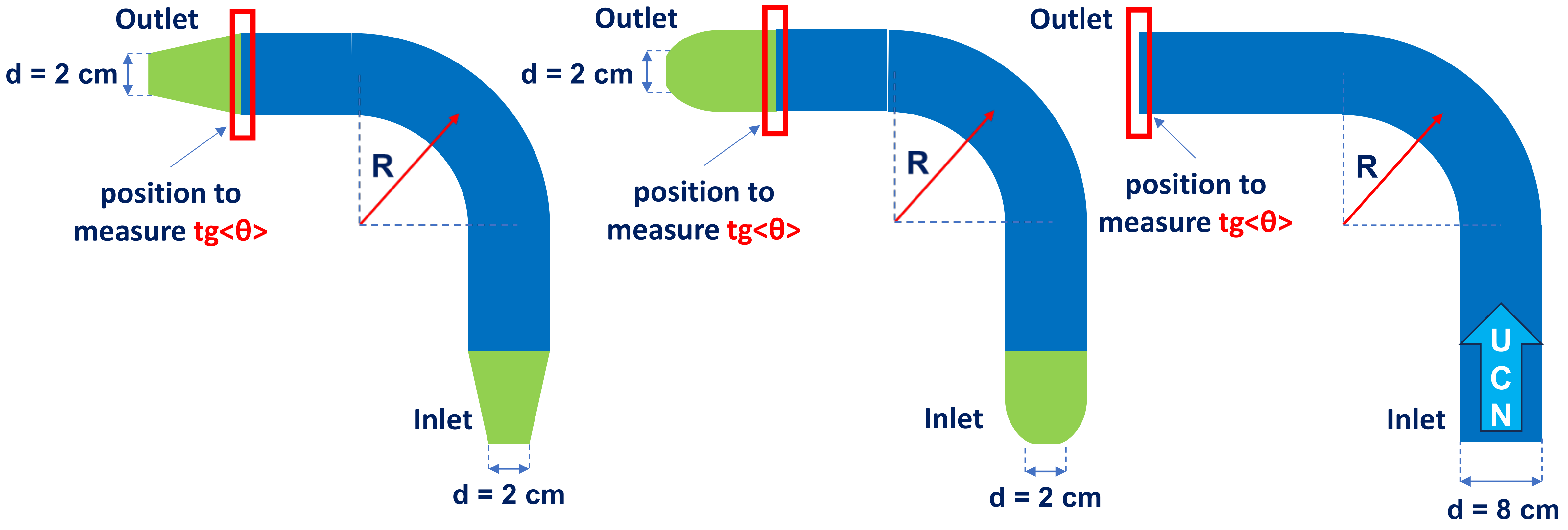
Dependence on UCN energy



Dependence of the **Transmittance T** on the UCN energy, $\mathbf{E_{UCN}}$, in units of Fermi potential, $\mathbf{E_F}$, of the neutron guide walls

Simulation implementation and Results

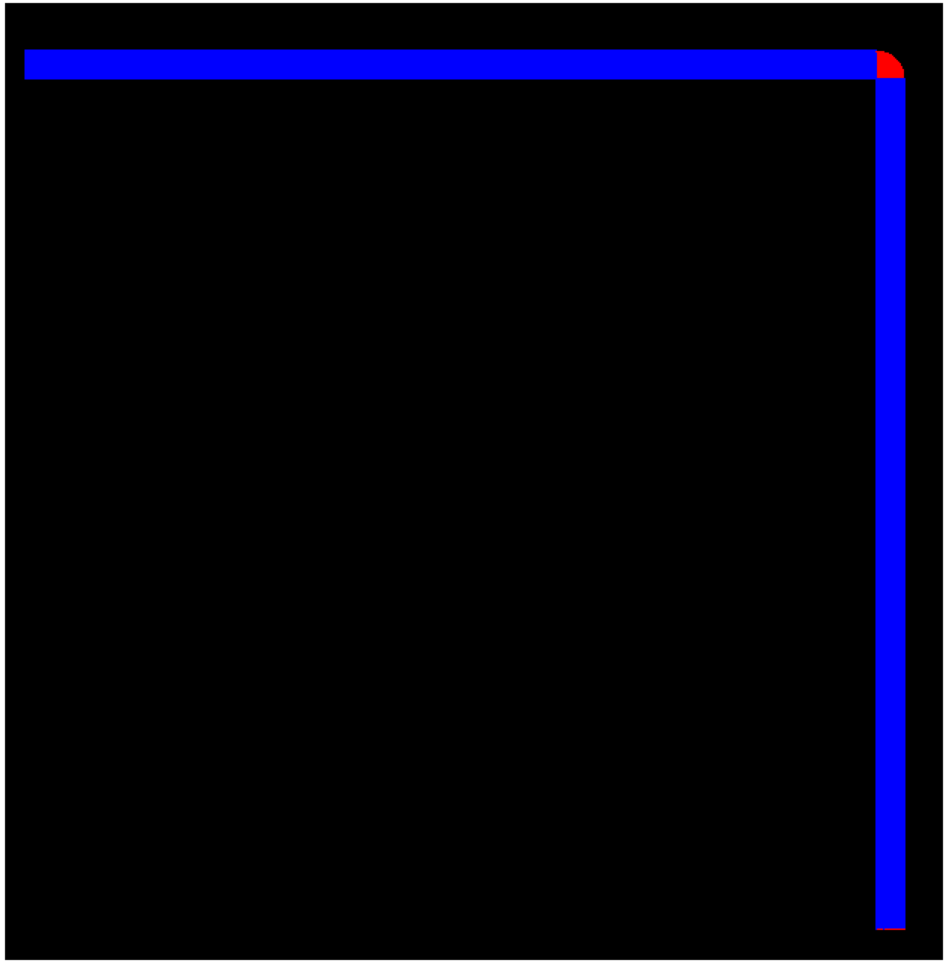
Curved (torus-shaped) neutron guides



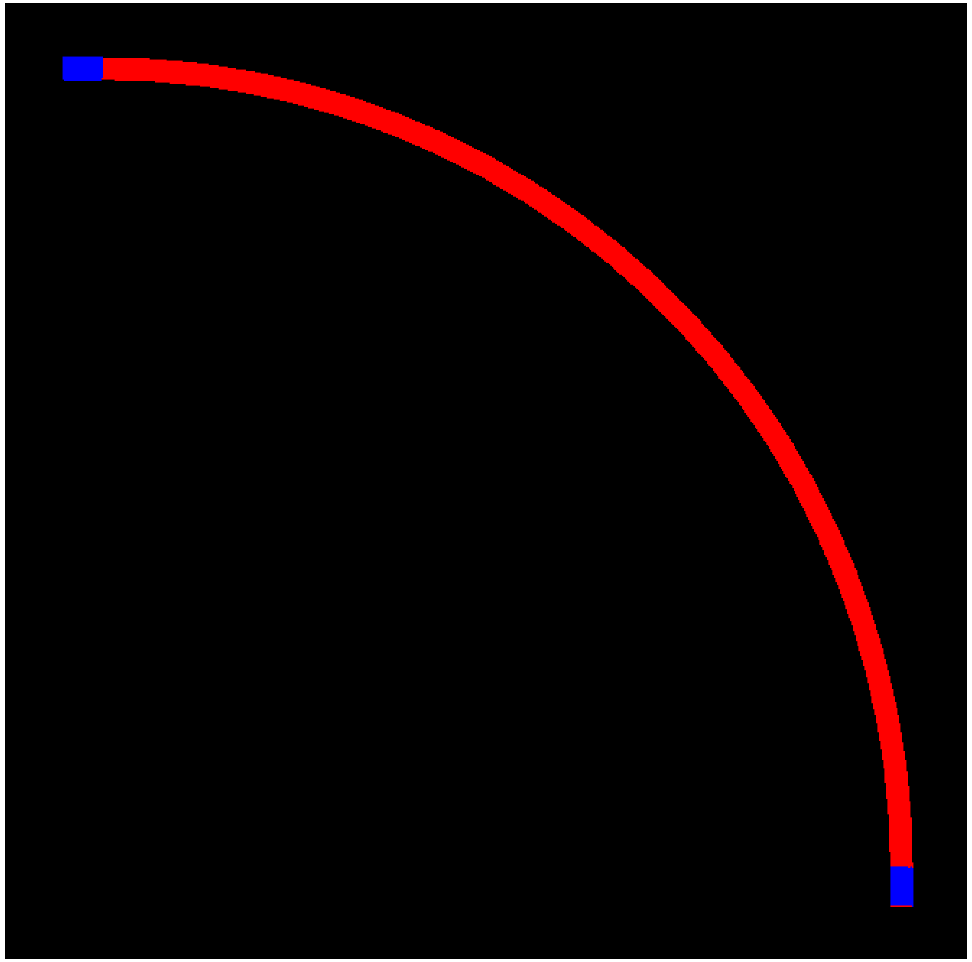
Total length for any configuration = 5 m

Simulation implementation and Results

Curved (torus-shaped) neutron guides



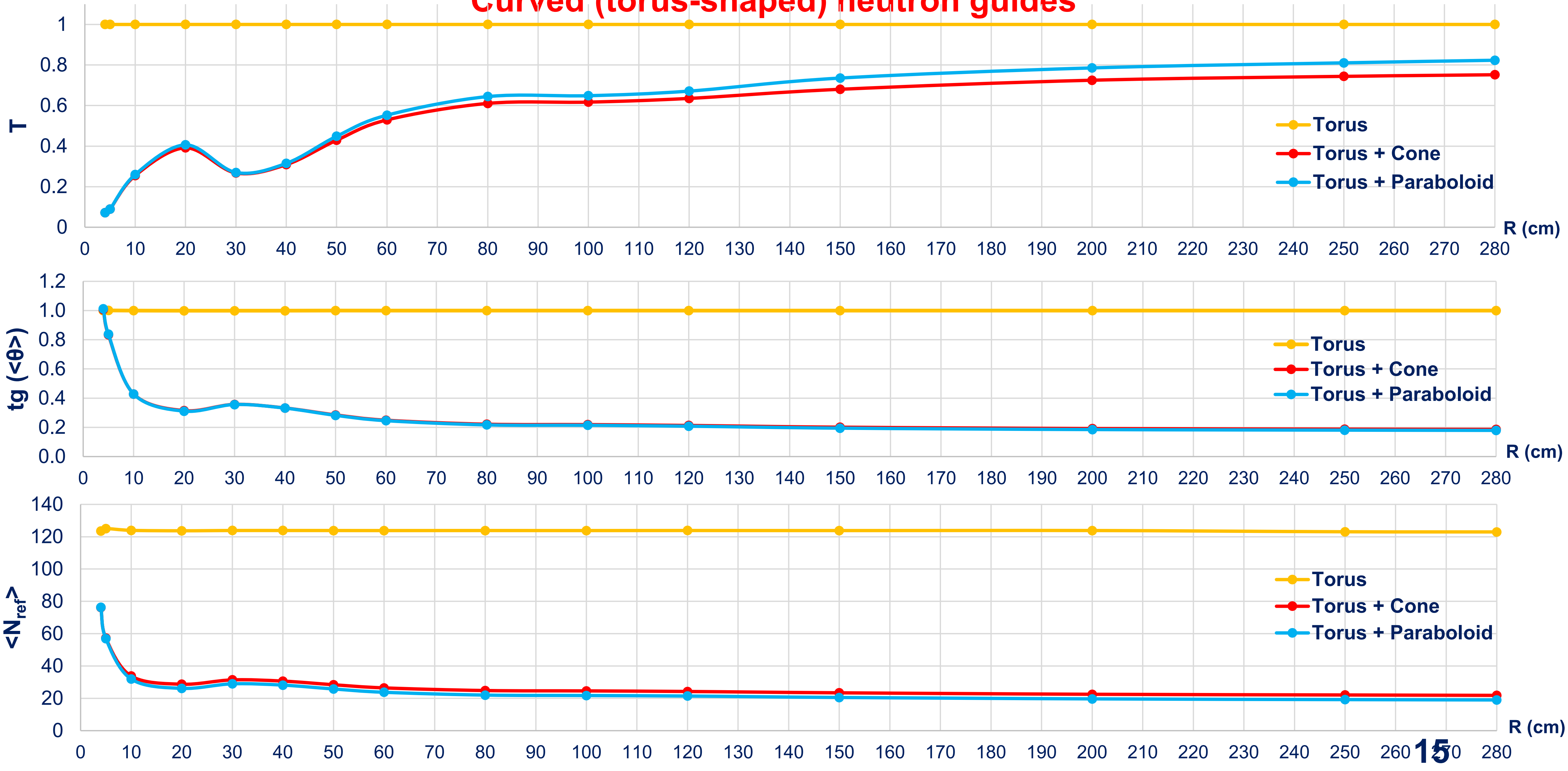
R = 4 cm



R = 300 cm

Simulation implementation and Results

Curved (torus-shaped) neutron guides



Simulation implementation and Results

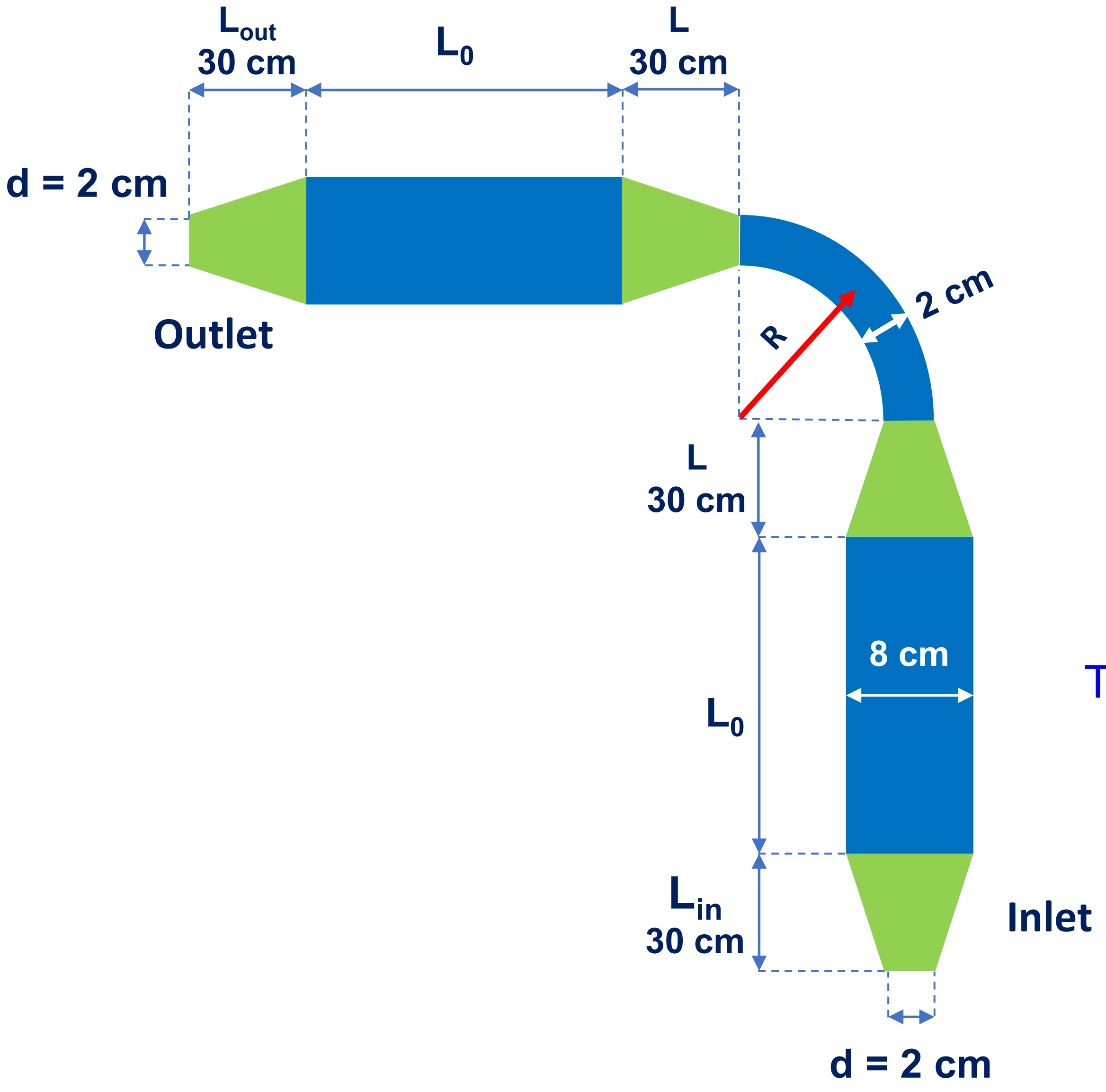
Curved (torus-shaped) neutron guides

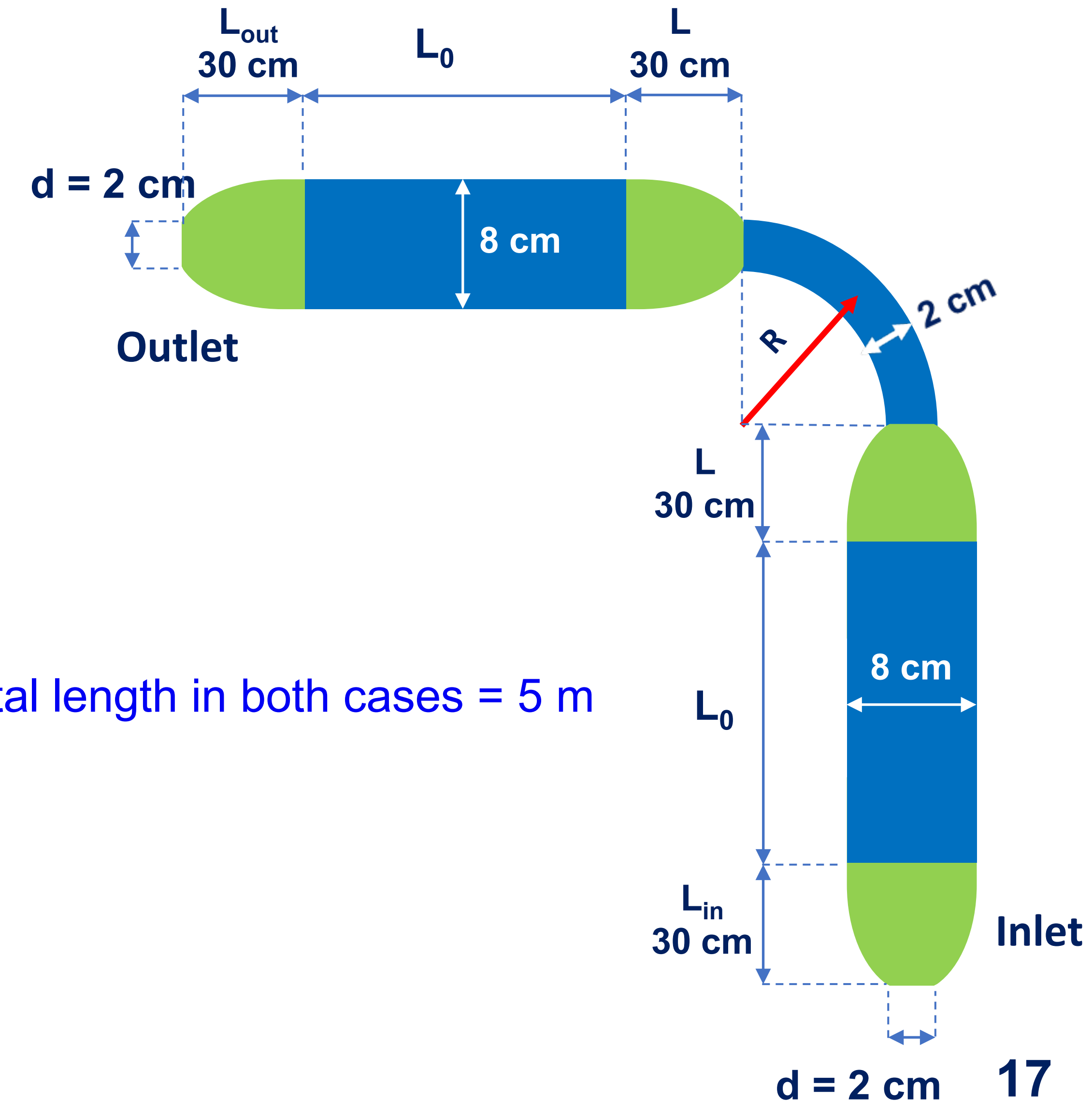
Conclusions for the curved (torus-shaped) neutron guides (in the absence of losses and roughness):

- At small turning radii of the focusing neutron guides, the angular divergence of the UCN beam increases significantly, which leads to a decrease in transmission and an increase in the number of reflections on the walls;
- At turning radii ≥ 3 m, the curved focusing neutron guides with a diameter of 8 cm do not differ from straight, cylindrical neutron guides;
- In parallel neutron guides, the transmission is **always 100%** at any turning radii and any angular distribution of UCN at the inlet;
- In parallel neutron guides, the angular distribution of UCN does not change, **at any turning radii**, if the UCN at the inlets have a Lambert distribution.

Simulation implementation and Results

Curved (torus-shaped) neutron guides

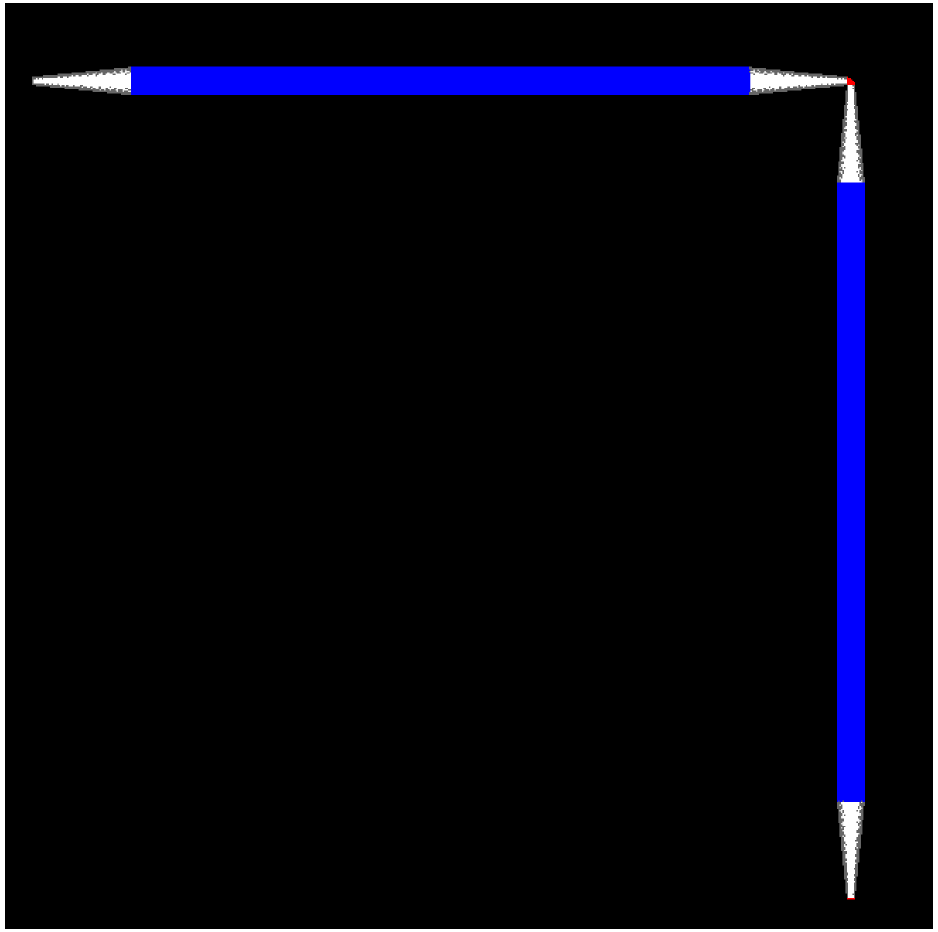




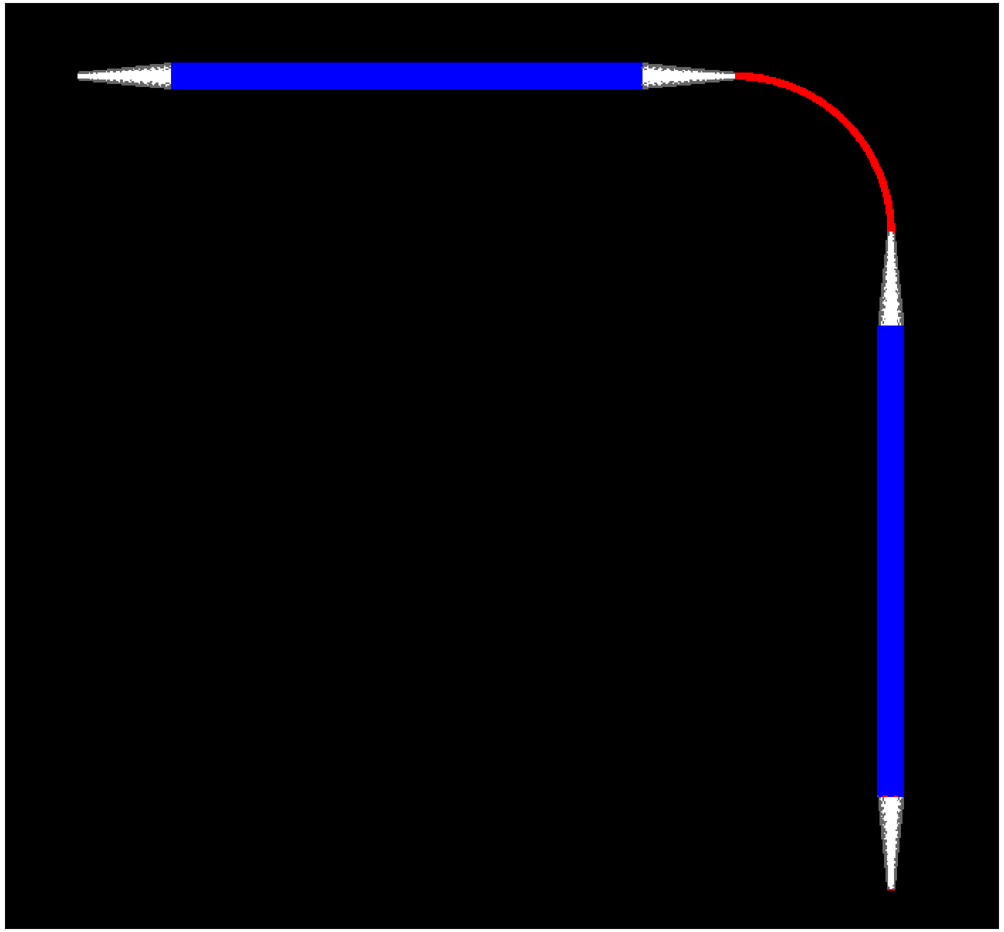
Total length in both cases = 5 m

Simulation implementation and Results

Curved (torus-shaped) neutron guides



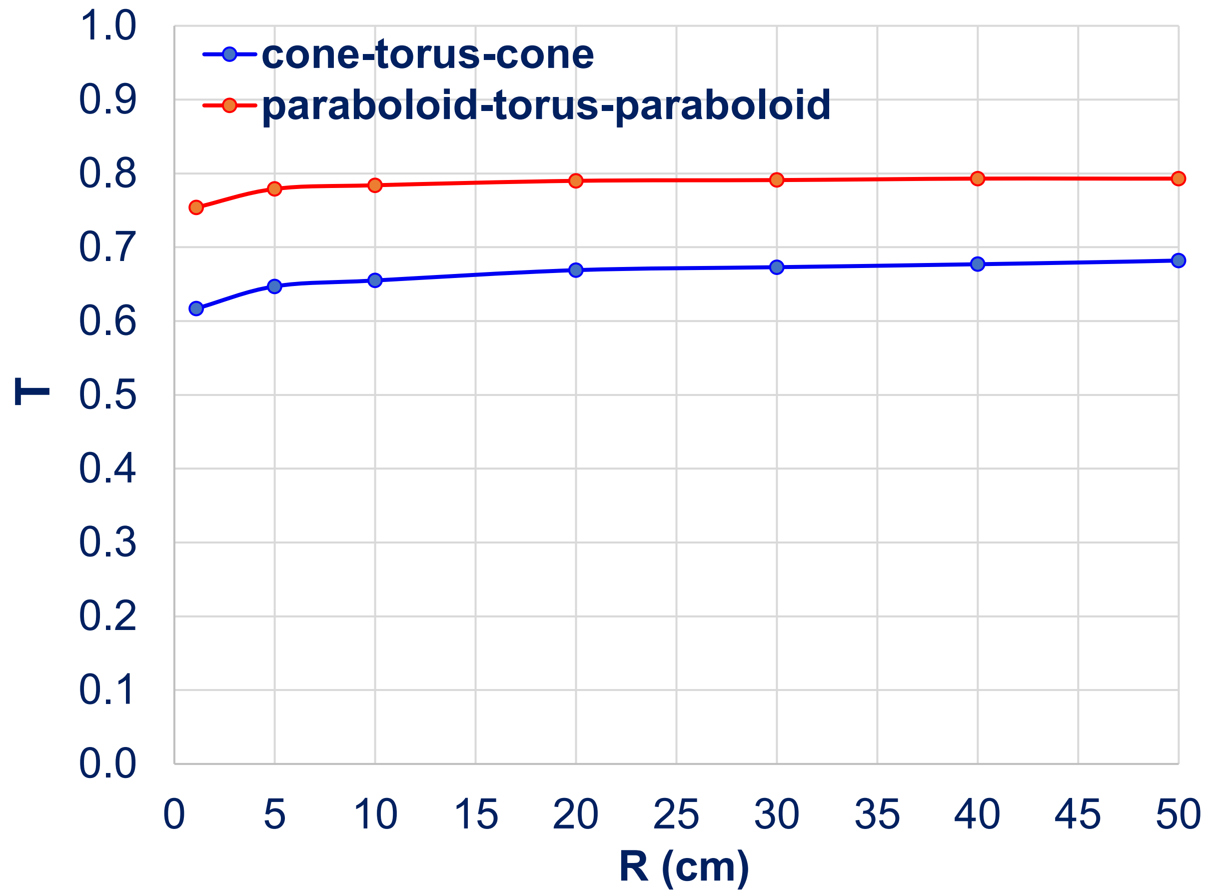
R = 1.1 cm



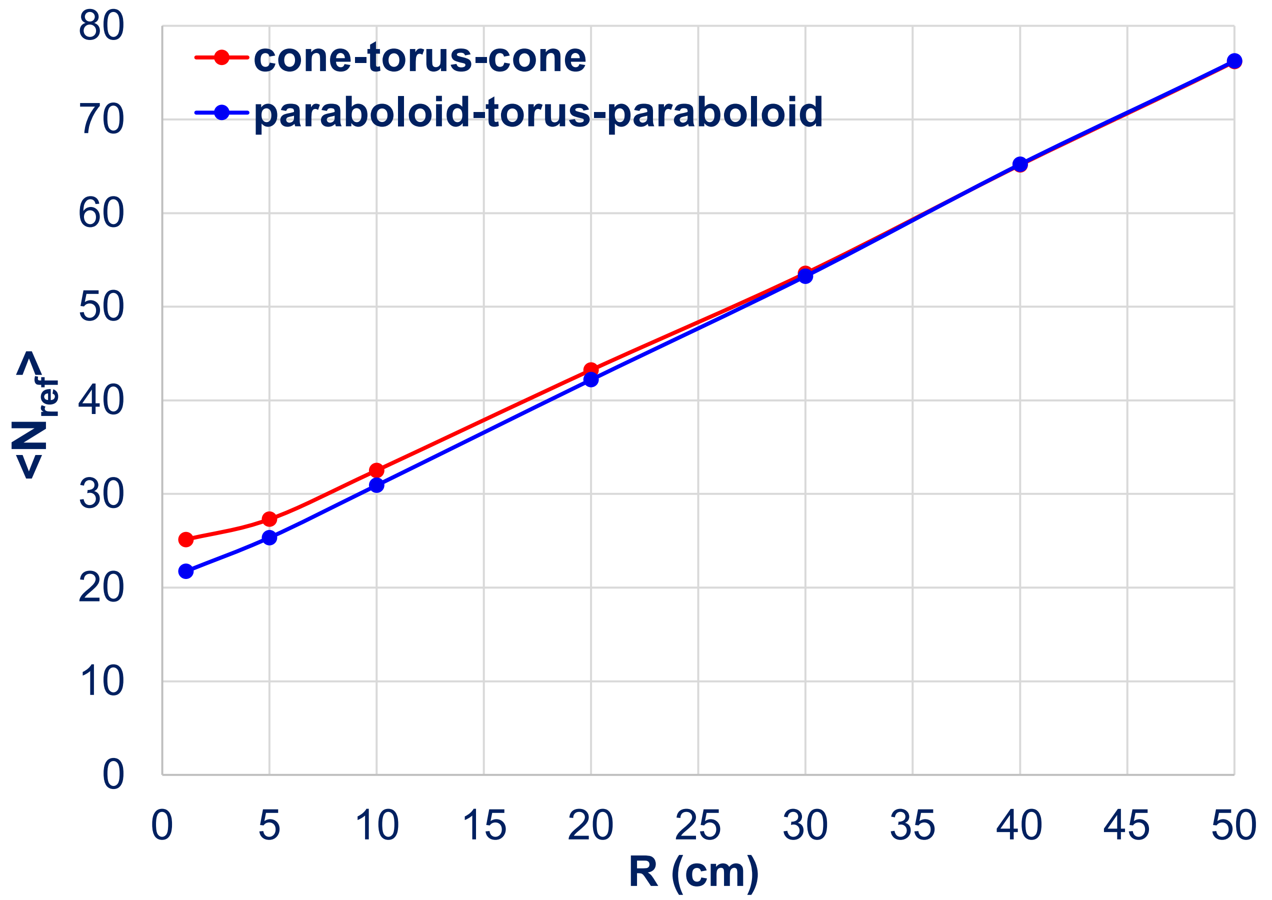
R = 50 cm

Simulation implementation and Results

Curved (torus-shaped) neutron guides

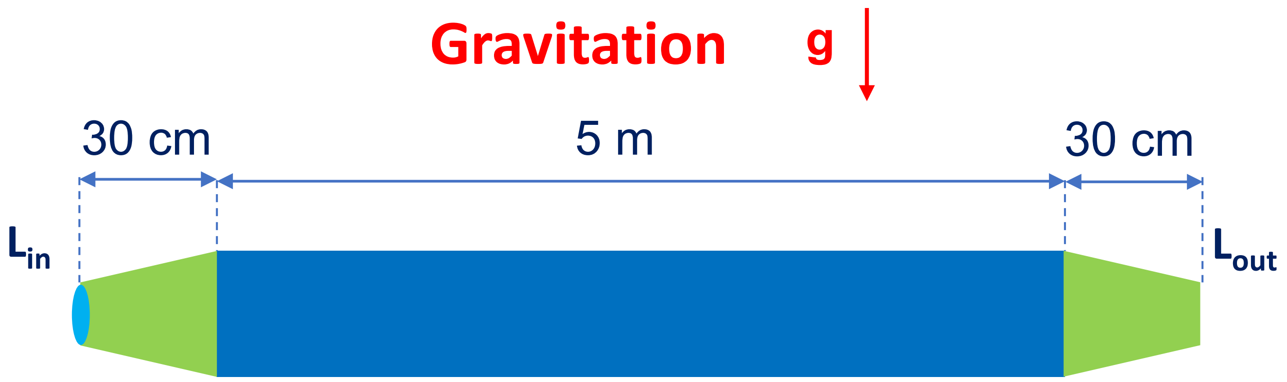


Transmittance **T** on **R** of the torus

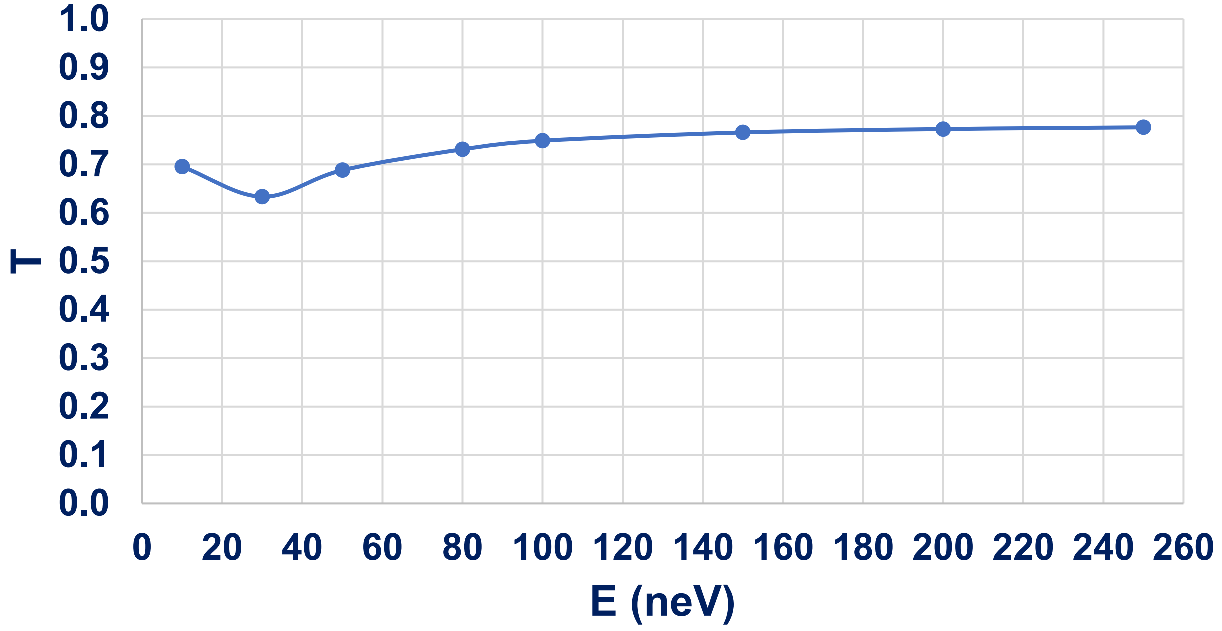


Average number of reflections $\langle N_{ref} \rangle$ on **R** of the torus

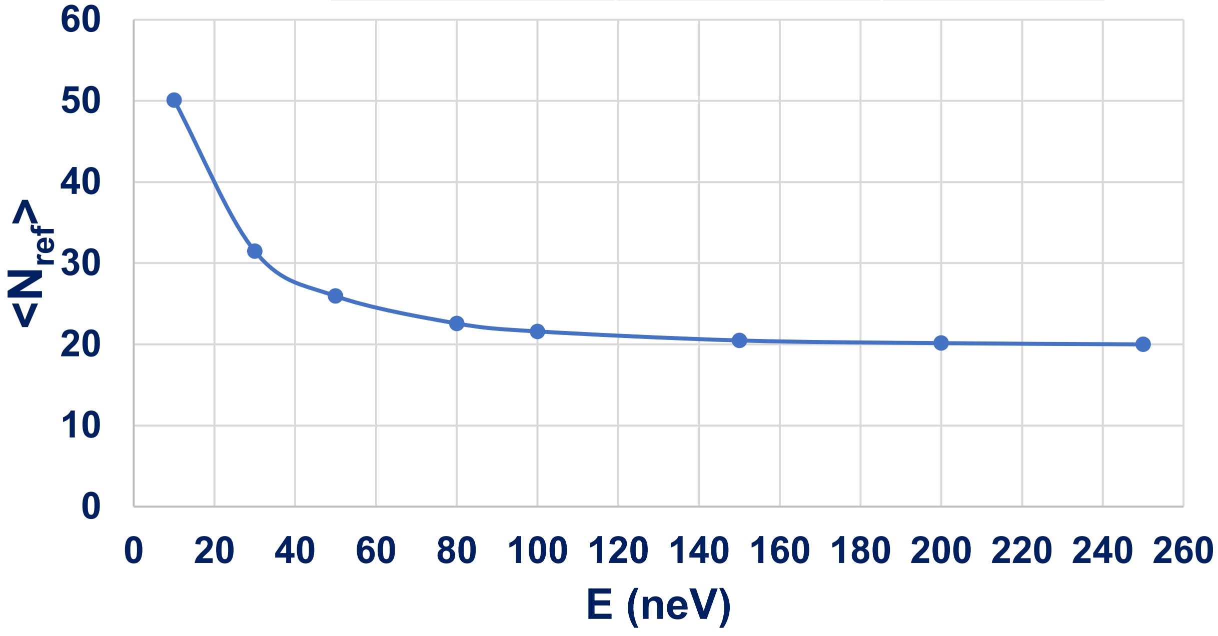
Simulation implementation and Results



Energy (neV)	Transmittance	<N_{ref}>
10	0.695	50.088
30	0.633	31.471
50	0.688	25.944
80	0.731	22.575
100	0.749	21.591
150	0.766	20.477
200	0.773	20.148
250	0.777	19.994



Dependence of transmittance **T** on UCN energy



Average number of reflections **<N_{ref}>** on UCN energy

Conclusion

- The first simulations of focusing neutron guides of UCN of different geometry for a UCN source based on a superfluid helium converter were performed.
- The research has shown that the new kind of neutron guide reduce UCN losses during the transmission several times and increase the UCN density at the outlets by several tens of times, compared to standard parallel neutron guides.
- Neutron guides with the parabolic inlet and outlet parts showed the best results in all the cases considered.

Further plan

- Assess the impact of diffuse reflection on the efficiency of neutron transmission;
- Investigate several different geometric configurations of curved neutron guides.


Thank you!