Conceptual Designs for
Thermal, Cold, and Very Cold Neutron
Moderator Systems for CANS

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Research article

Conceptual moderator designs for compact neutron sources

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Comisión Nacional de Energía Atómica

THE CHALLENGE (or part of it)

Spectrum of neutrons from the 100 K liquid methane moderator of IPNS.
(Carpenter & Loong, *Elements of Neutron Scattering,* Cambridge 2015)

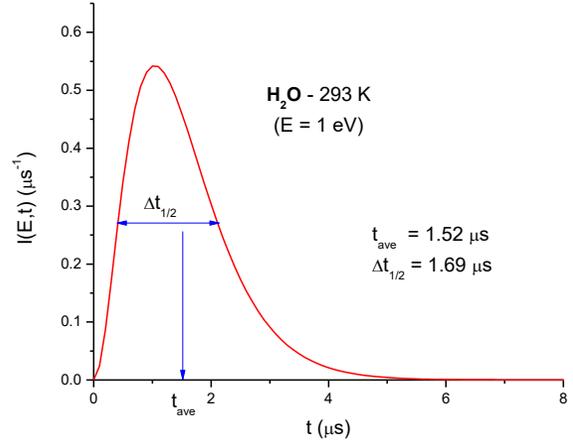# The slowing-down parameters for several typical protonated moderators.

Parameter	H_2O 293 K	$(CH_2)_n$ 293 K	C_2H_6 180 K	C_2H_6 100 K	CH_4 100 K	CH_4 20 K	C_9H_{12} 20 K	H_2 16K
σ_{free} (barn)	44.749	45.73	132.46	132.46	86.73	86.73	288.69	20.505
ρ (g/cm³)	1	0.94	0.550	0.641	0.4392	0.510	0.91	0.0751
N^{molec} (10^{24}/cm³)	0.0335	0.0404	0.0110	0.0129	0.0165	0.0192	0.0046	0.0226
N^H (10^{22}/cm³)	6.69	8.09	6.63	7.72	6.61	7.68	5.48	4.52
Σ_{free} (cm⁻¹)	1.5	1.849	1.463	1.705	1.431	1.665	1.318	0.927
ξ	0.926	0.913	0.940	0.940	0.954	0.954	0.876	1
γ	0.924	0.908	0.936	0.936	0.951	0.951	0.976	1
$v\,t_s$ (cm)	2.105	1.723	2.135	1.832	2.162	1.858	2.58	3.235
$v\,\Delta t_s$ (cm)	1.183	0.963	1.205	1.034	1.227	1.055	1.476	1.867
$v\,\Delta t_{1/2}$ (cm)	2.346	1.915	2.383	2.046	2.421	2.080	2.897	3.65

The time distribution of neutrons slowing-down past 1 eV in water (normalized).

H_2O - 293 K
(E = 1 eV)

t_{ave} = 1.52 μs
$\Delta t_{1/2}$ = 1.69 μs

Thermalization parameters for some hydrogenous moderators.

Parameter	H_2O 293 K	$(CH_2)_n$ 293 K	C_2H_6 180 K	C_2H_6 100 K	CH_4 100 K	CH_4 20 K
α_0 (s^{-1})	4898	5821	4860	5650	4868	5654
D_0 (cm^2 s^{-1})	38415	27130	19140	10794	17110	6011
C (cm^4 s^{-1})	2838	2422	590	184	650	80
λ_{tr} (cm)	0.47	0.26	0.30	0.23	0.36	0.28

Decay constant:
$$\alpha \approx \alpha_0 + D_0 B^2 - C B^4$$
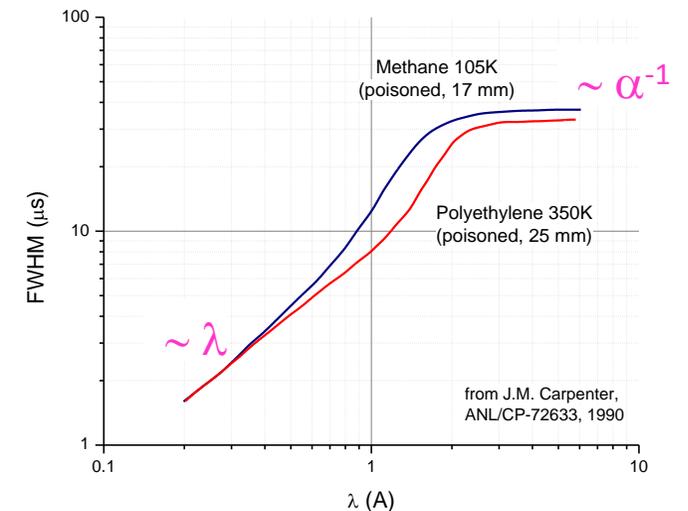
Geometrical Buckling: B^2, Diffusion Constant: D_0, Cooling Constant: C

Evaluation of thermalization parameters:

https://doi.org/10.1103/PhysRevA.36.5585

The FWHM of the neutron pulse as a function of wavelength.

Methane 105K (poisoned, 17 mm)

$\sim \alpha^{-1}$

Polyethylene 350K (poisoned, 25 mm)

$\sim \lambda$

FWHM (μS)

λ (A)

from J.M. Carpenter, ANL/CP-72633, 1990
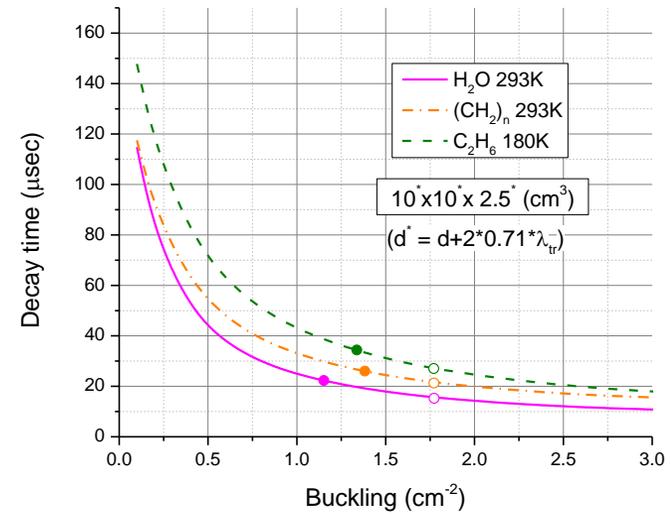
TN, CN, & VCN MODERATOR CONCEPTS
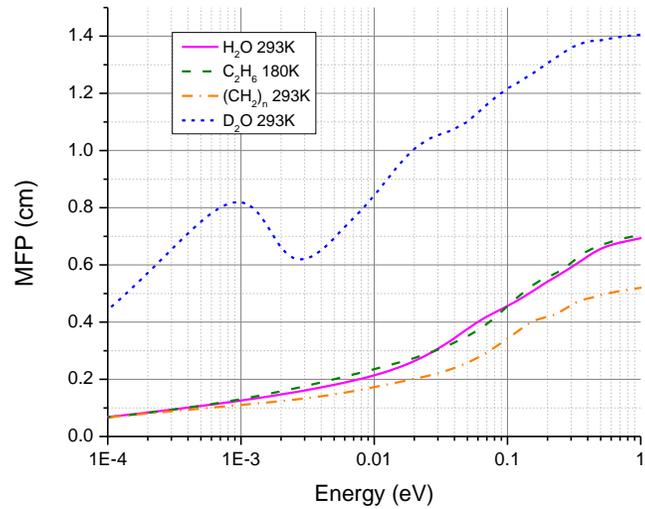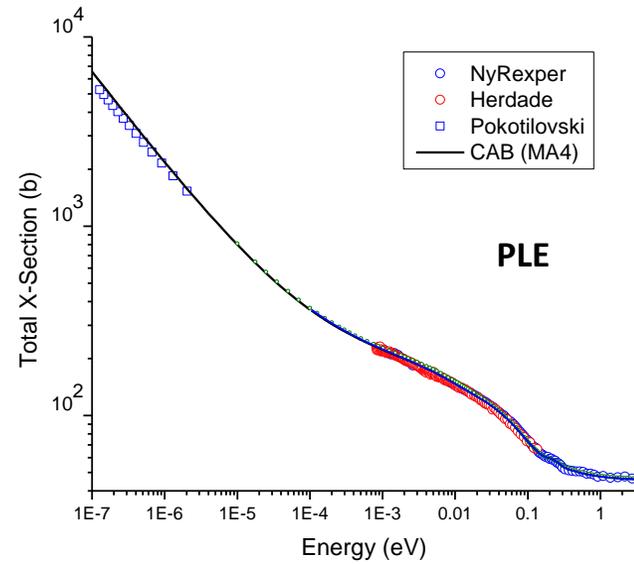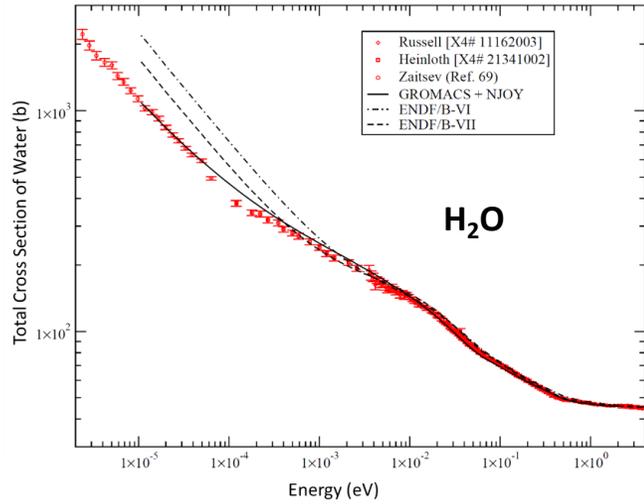# FOR HiCANS

Motivation:

To develop basic concepts for the moderator complex
of HiCANS, assuming that they may include thermal (TN),
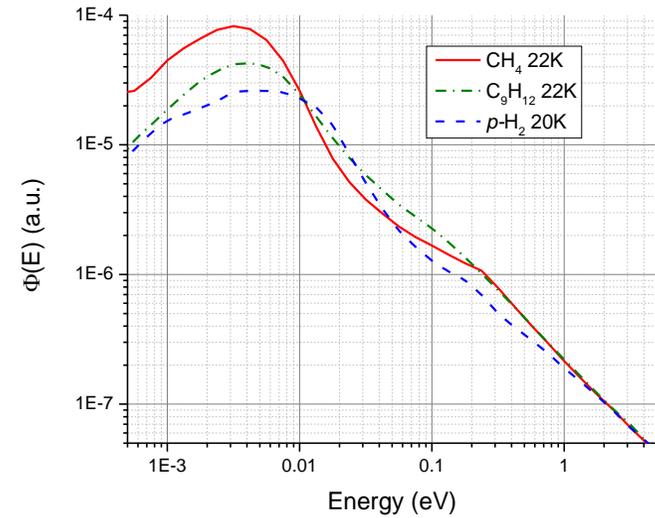cold (CN), and very cold (VCN) neutron sources.

Components and Materials

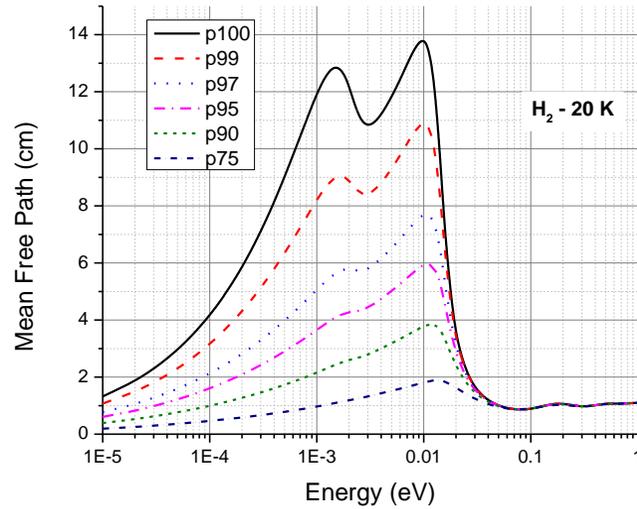- ✓ Target   Square (10x10 cm)
- ✓ TN moderator material: H_2O, PLE (RT) / C_2H_6 (100K - 180K)
- ✓ CN moderator material: Liquid *para*-H2 (20K)
- ✓ VCN moderator material: Solid (4K) CH_4 II
- ✓ Premoderator material: H_2O
- ✓ CN & VCN reflectors: MgH_2 / ND
- ✓ Fast neutron reflector: Be (long tail) or Pb (faster)

Thermal Moderators

Cold Moderators

Very Cold Moderators

METHANE
(low frequencies)

Solid methane in phase II at T = 7.0K

(w. JI Marquez Damián)

TN+CN concept

This concept corresponds to a moderator system able to produce 4 beams of TN and 4 beams of CN.

TN+CN+VCN concepts

A second concept also includes provision of a VCN beam. The latter is based on a Methane (II) moderator at 4K.

A third concept includes <u>high intensity</u> TN, CN, and VCN beams.

A fourth concept is a variant of concept 3, but includes only high intensity CN and VCN beams.

Thin platform (3 cm):   High brilliance
Thick platform (6 cm):   High intensity

Concept 1. TN + CN - High Brightness

♦ Low-dimensional **CN** moderators (3x3x14 cm) – *para* H2

    4 beams with best coupling to the thermal source

    Use of CN reflector (MgH2) to minimize leakage from CN to TN regions.

♦ Fast, intense **TN** moderator (Reentrant, 3x3x1.5 cm) – H2O

    4 beams using Reentrant holes to extract thermal neutrons from the highest

    thermal flux region.

    Thermal source optimally coupled to the fast and epitermal (from the premods)

    neutron sources

MERIT: High brightness CN beams; intense TN pulse

Reflector

1cm

Premods

H₂O   H₂

3 cm

2cm   H₂O

Reflector

Target

TN (Reentrant Hole: 3x3x1.5 cm)

CN Reflector (MgH₂)

Liquid H₂

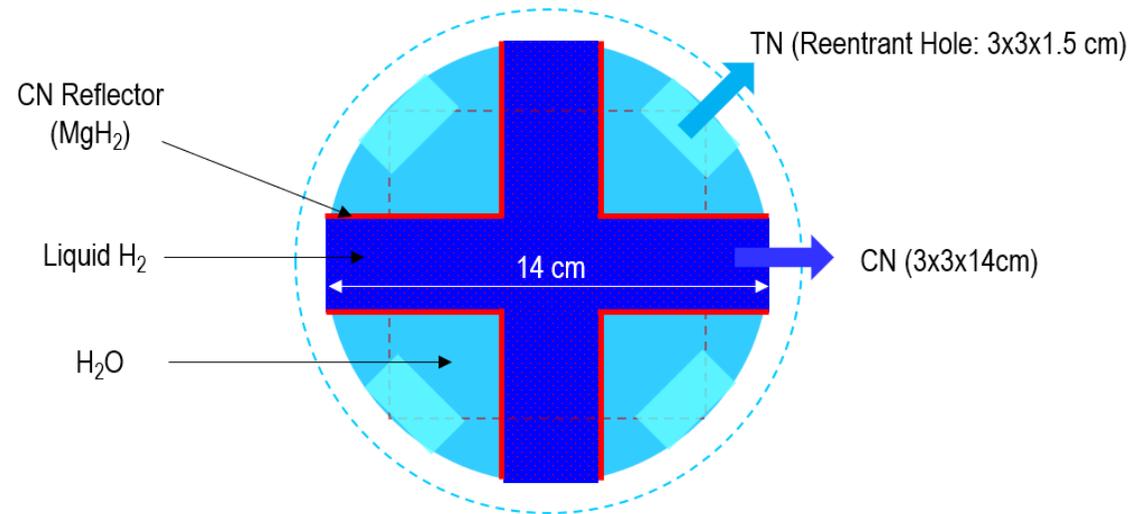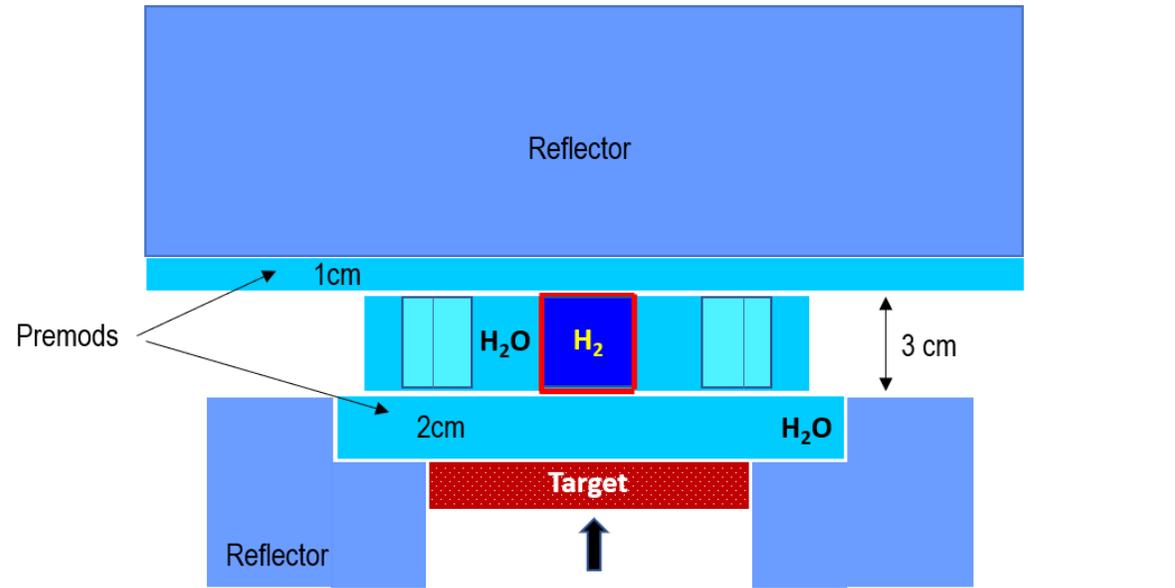14 cm

CN (3x3x14cm)

H₂O

4 TN
4 hb CN

Concept 2. TN + CN + VCN – High Brightness

♦ Low-dimensional **CN** moderators (3x3x14 cm) – *para* H2

    4 beams with best coupling to the thermal source

    Use of CN reflector (MgH2) to minimize leakage from CN to TN regions.

♦ Small (fast) **VCN** moderator (3x3x1.5 cm) – solid CH4 (II)

    2 beams with best coupling to the thermal source, achieved by placing

    the VCN moderator at the bottom of a reentrant hole of 2.7 cm in depth

♦ Fast, intense **TN** moderator (Reentrant, 3x3x1.5 cm) – H2O

    1 beam using Reentrant hole to extract thermal neutrons from the highest

    thermal flux region.

    1 beam from a very fast thermal moderator (decoupled).

MERIT: High brightness CN beams; fast TN pulse; fast VCN beam

Reflector

Premods

1cm

3 cm

H_2O H_2

2cm H_2O

Target

Reflector

H_2O

CN Reflector (MgH_2)

Liquid H_2

CH_4 (4K)

14 cm

TN (Reentrant Hole: 3x3x1.5 cm)

CN (3x3x14cm)

Cd

VCN (3x3x1.5 cm)

Very fast TN (3x3x2.5 cm, decoupled)

2 TN (1 very fast)
4 hb CN
2 VCN

Reflector

1cm

Premods

H₂O H₂

3 cm

2cm H₂O

Target

Reflector

TN (Reentrant Hole: 3x3x1.5 cm)

CN Reflector (MgH₂)

H₂O

Liquid H₂

VCN (3x3x1.5 cm)

Bispectral CN + VCN

Liquid H₂

Cd

CH₄ (4K)

VCN (reentrant 3x3x1.5 cm)

Very fast TN (3x3x2.5 cm, decoupled)

3 TN (1 very fast)
2 hb CN
2 VCN
1 CN+VCN

Concept 3. TN + CN + VCN – High Intensity

♦ Semi Low-dimensional **CN** moderators (3x6x14 cm) – *para* H2

    4 intense beams with best coupling to the thermal source

    Use of CN reflector (MgH2) to minimize leakage from CN to TN regions.

♦ Large **VCN** moderator (1.5 cm thick, Φ = 6 cm) – solid CH4 (II)

    1 beam with best coupling to the thermal source, achieved by placing

    the VCN moderator at the bottom of a reentrant hole of 3 cm in depth

♦ Large **TN** moderator (Reentrant hole, 3 cm depth, Φ = 6 cm) – H2O

    1 beam using Reentrant hole to extract thermal neutrons from the highest

    thermal flux region.

    Thermal source optimally coupled to the fast and epitermal (from the premods)
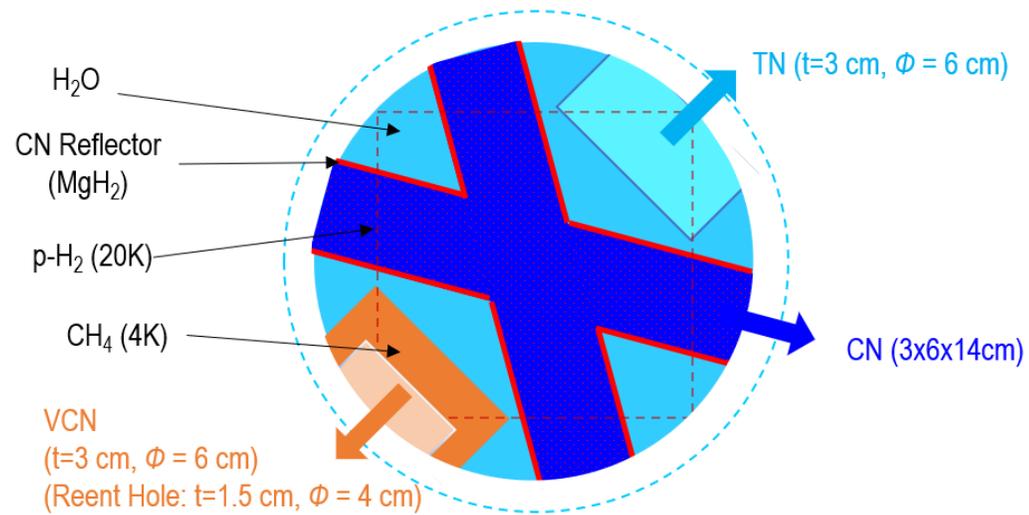
    neutron sources.

MERIT: Intense CN beams; Very intense TN beam; Intense VCN beam

Reflector

1cm

Premods

CH$_4$

H$_2$

H$_2$O

6 cm

2cm

H$_2$O

Target

Reflector (Be)

H$_2$O

CN Reflector (MgH$_2$)

p-H$_2$ (20K)

CH$_4$ (4K)

TN (t=3 cm, Φ = 6 cm)

CN (3x6x14cm)

VCN
(t=3 cm, Φ = 6 cm)
(Reent Hole: t=1.5 cm, Φ = 4 cm)

1 TN (very int.)
4 hi CN
1 VCN (very int.)

Reflector

1cm

CH_4

H_2O

H_2

$D_2O/$ H_2O

6 cm

Premods (H_2O)

2cm

H_2O

Target

Reflector

CN (3 x 6 x 12 cm)

D_2O/H_2O

TN (t=3 cm, Φ = 6 cm)

CN Reflector (MgH_2)

H_2O

p-H_2 (20K)

CH_4 (4K)

CN (3 x 6 x 14 cm)

VCN (t =3 cm, Φ = 6 cm) (Reent Hole: t =1.5 cm, Φ = 4 cm)

Bispectral CN + TN

THERMAL POOL: H2O (1:1) D2O

1 TN (very int.) 3 hi CN 1 VCN (very int.) 1 TN+CN

Reflector

1cm

Premods (H₂O)

CH_4

H_2O

H_2

D_2O/H_2O

6 cm

2cm

H_2O

Target

Reflector

THERMAL POOL: H2O (1:1) D2O

CN (3 x 6 x 12 cm)

D_2O/H_2O

TN (t=3 cm, Φ = 6 cm)

VCN (3 cm x 6 cm)

H_2O

CH_4 (4K)

Bispectral VCN + CN (3x6)

VCN (t =3 cm, Φ = 6 cm) (Reent Hole: t =1.5 cm, Φ = 4 cm)
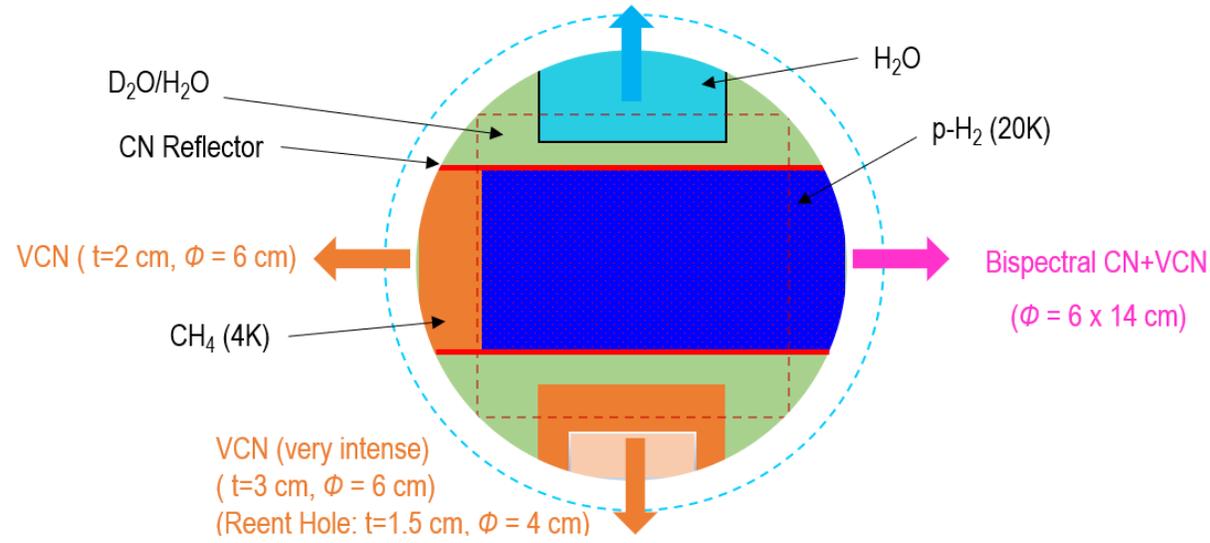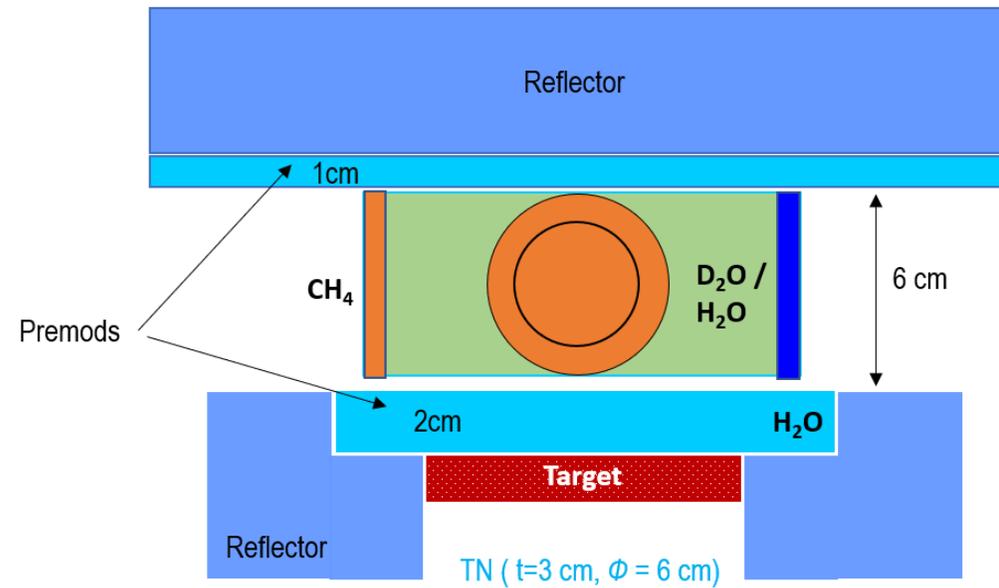
Bispectral CN (3x3) + TN (3x3)

1 TN (very int.)
1 CN
2 VCN (very int.)
1 TN+CN
1 CN+VCN

CNEA

OTHER COMBINATIONS...

Reflector

1cm

CH$_4$

D$_2$O / H$_2$O

Premods

6 cm

2cm

H$_2$O

Target

Reflector

TN (t=3 cm, Φ = 6 cm)

H$_2$O

D$_2$O/H$_2$O

CN Reflector

p-H$_2$ (20K)

CN (Φ = 6 x 14 cm)
(Very Intense)

VCN (very intense)
(t=3 cm, Φ = 6 cm)
(Reent Hole: t=1.5 cm, Φ = 4 cm)

1 TN (very int.)
2 hi CN
1 VCN (very int.)

Reflector

1cm

CH$_4$

D$_2$O / H$_2$O

6 cm

Premods

2cm

H$_2$O

Target

Reflector

TN (t=3 cm, Φ = 6 cm)

D$_2$O/H$_2$O

H$_2$O

CN Reflector

p-H$_2$ (20K)

VCN (t=2 cm, Φ = 6 cm)

Bispectral CN+VCN

(Φ = 6 x 14 cm)

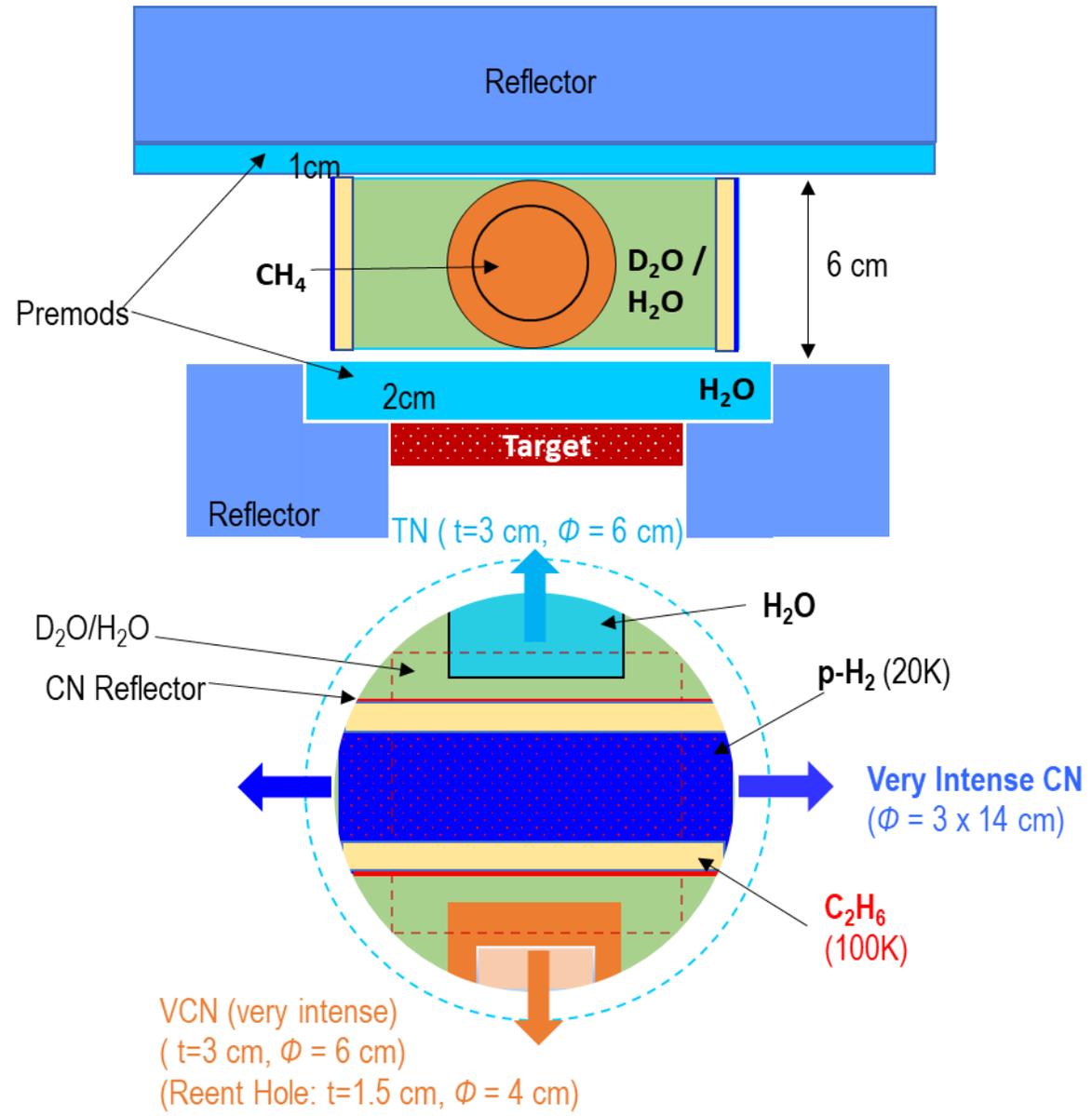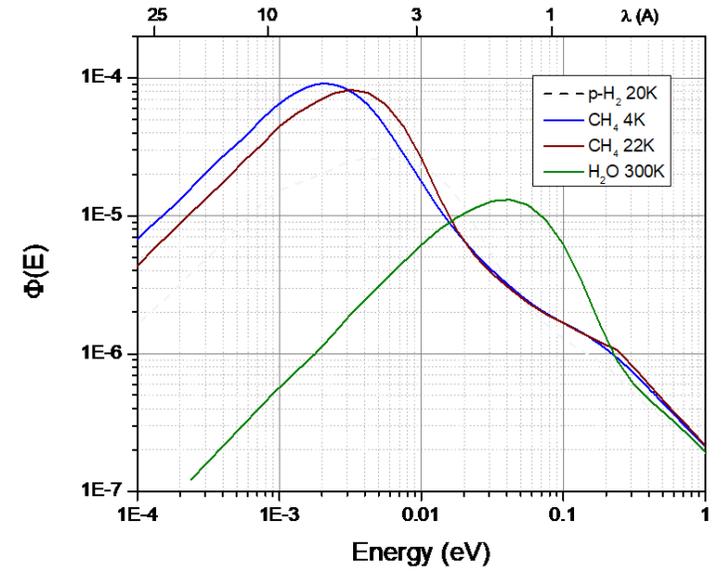CH$_4$ (4K)

VCN (very intense)

(t=3 cm, Φ = 6 cm)

(Reent Hole: t=1.5 cm, Φ = 4 cm)

1 TN (very int.)

1 CN+VCN

2 VCN (very int.)

CNEA

Reflector

1cm

CH$_4$

D$_2$O / H$_2$O

Premods

6 cm

2cm

H$_2$O

Target

Reflector

TN (t=3 cm, Φ = 6 cm)

H$_2$O

D$_2$O/H$_2$O

CN Reflector

p-H$_2$ (20K)

Very Intense CN
(Φ = 3 x 14 cm)

C$_2$H$_6$
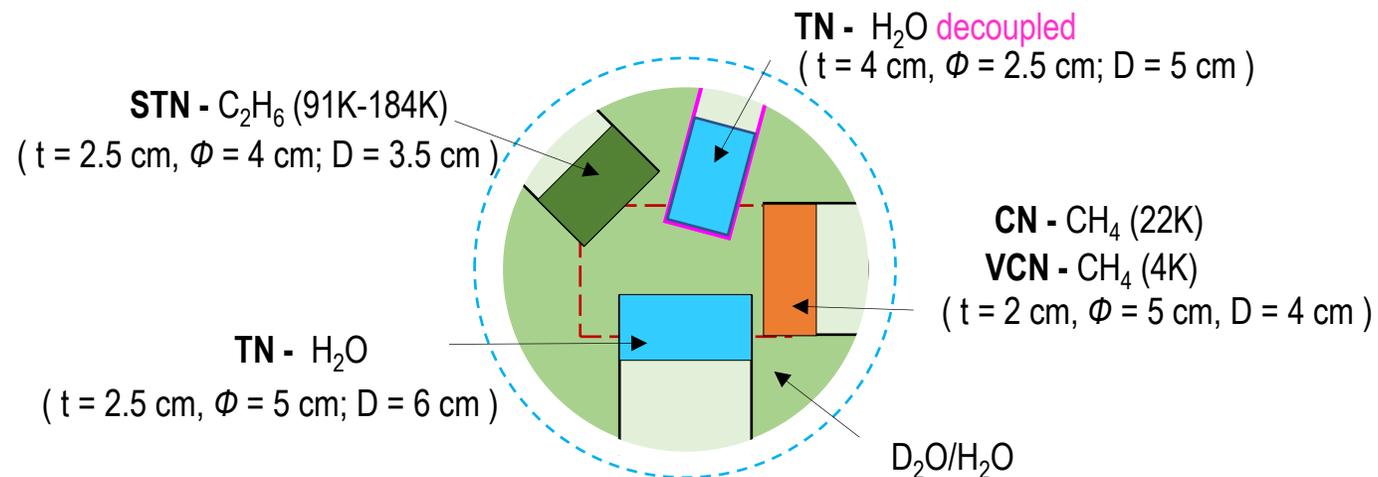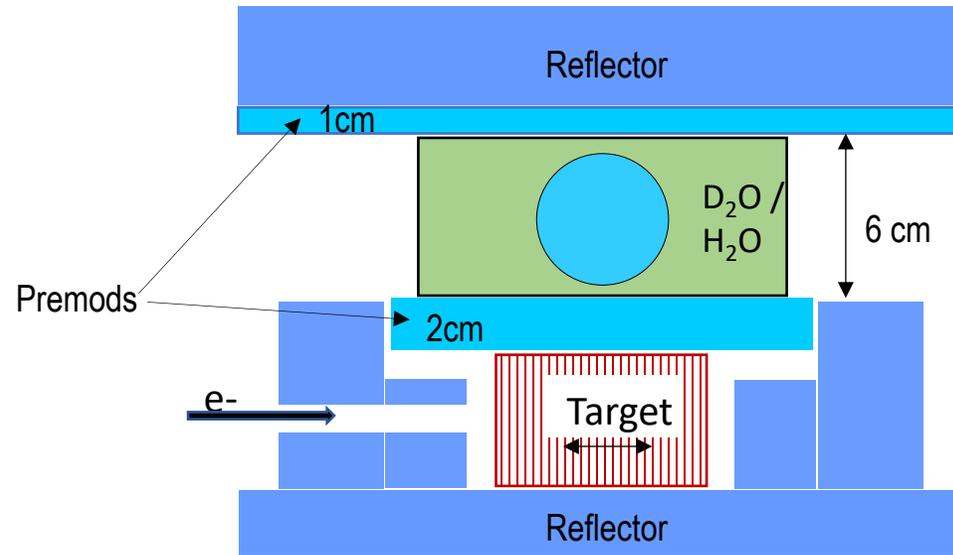(100K)

VCN (very intense)
(t=3 cm, Φ = 6 cm)
(Reent Hole: t=1.5 cm, Φ = 4 cm)

1 TN (very int.)
2 hi-hb CN
1 VCN (very int.)

A CONFIGURATION FOR MiCANS

Reflector

1cm

Premods

2cm

D$_2$O / H$_2$O

6 cm

e-

Target

Reflector

TN - H$_2$O decoupled
(t = 4 cm, Φ = 2.5 cm; D = 5 cm)

STN - C$_2$H$_6$ (91K-184K)
(t = 2.5 cm, Φ = 4 cm; D = 3.5 cm)

CN - CH$_4$ (22K)
VCN - CH$_4$ (4K)
(t = 2 cm, Φ = 5 cm, D = 4 cm)
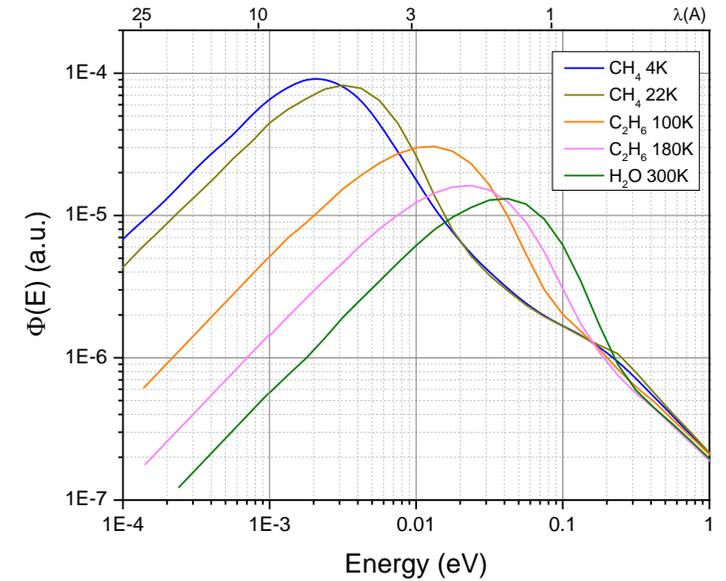
TN - H$_2$O
(t = 2.5 cm, Φ = 5 cm; D = 6 cm)

D$_2$O/H$_2$O

A CONFIGURATION FOR MiCANS

STN - C$_2$H$_6$ (91K-184K)
(t = 2.5 cm, Φ = 4 cm; D = 3.5 cm)

TN - H$_2$O decoupled
(t = 4 cm, Φ = 2.5 cm; D = 5 cm)

CN - CH$_4$ (22K)
VCN - CH$_4$ (4K)
(t = 2 cm, Φ = 5 cm, D = 4 cm)

TN - H$_2$O
(t = 2.5 cm, Φ = 5 cm; D = 6 cm)

D$_2$O/H$_2$O

A CONFIGURATION FOR MiCANS

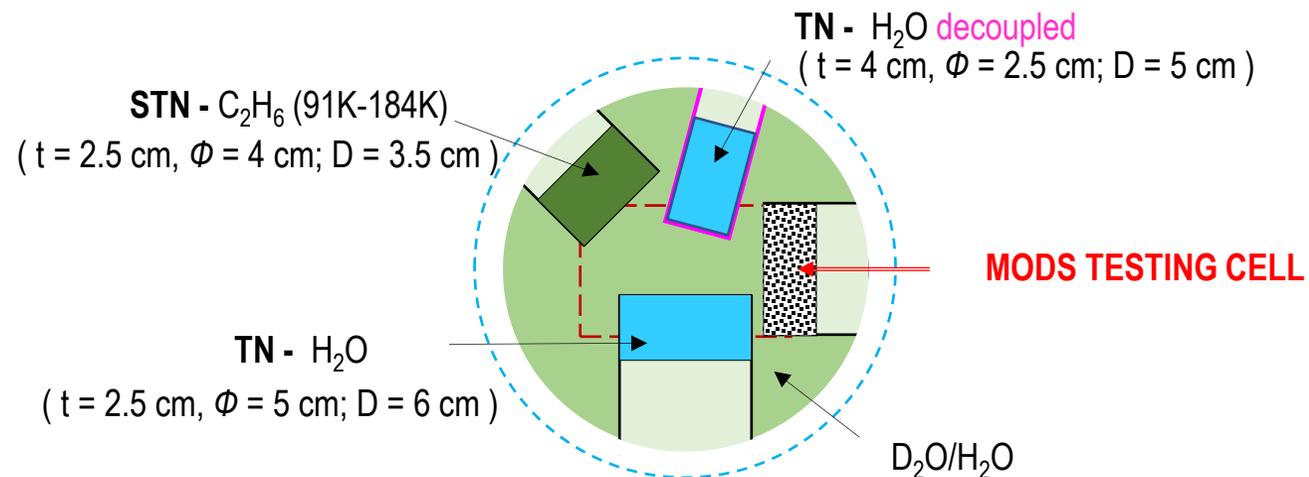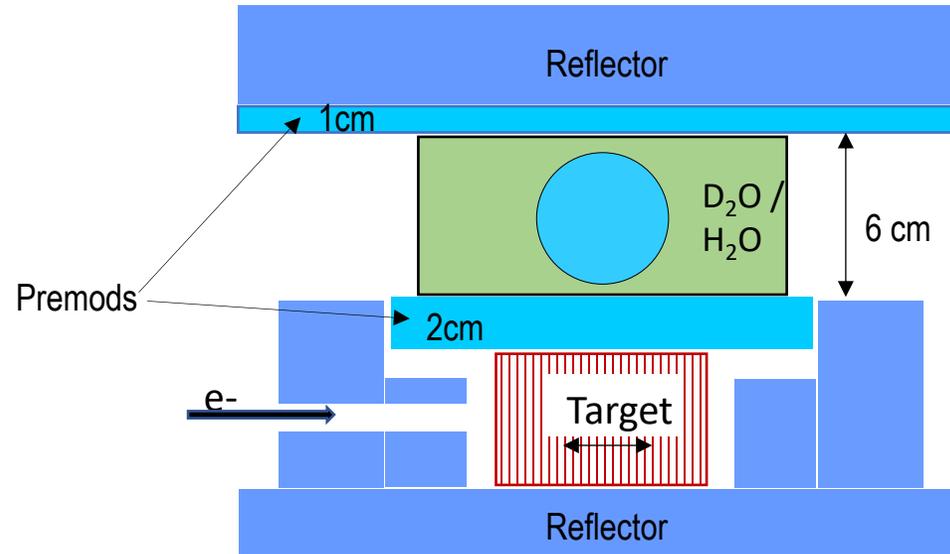# A CONFIGURATION FOR MiCANS

Reflector

6 cm

Premods

e-

Target

Reflector

TN - H$_2$O decoupled
(t = 4 cm, Φ = 2.5 cm; D = 5 cm)

STN - C$_2$H$_6$ (91K-184K)
(t = 3 cm, Φ = 4 cm; D = 3.5 cm)
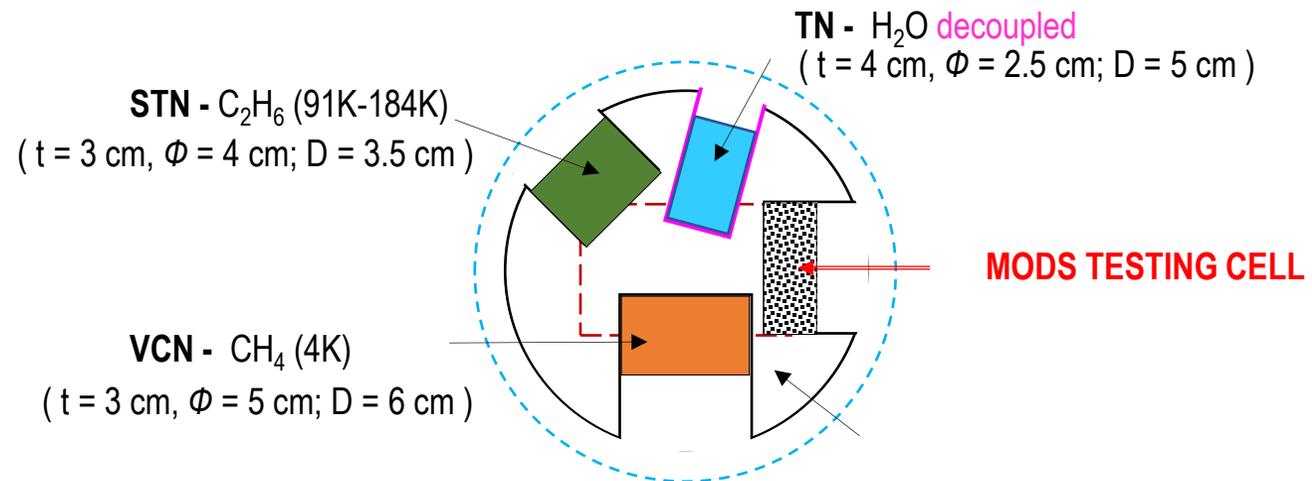
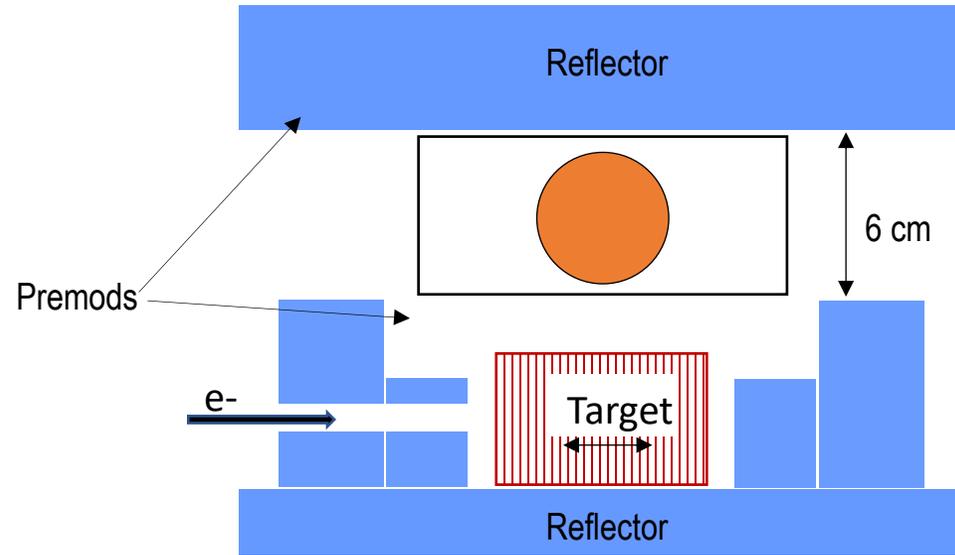**MODS TESTING CELL**

VCN - CH$_4$ (4K)
(t = 3 cm, Φ = 5 cm; D = 6 cm)

A CONFIGURATION FOR MiCANS

Reflector

6 cm

Target

e-

Reflector

STN - C_2H_6 (91K-184K)
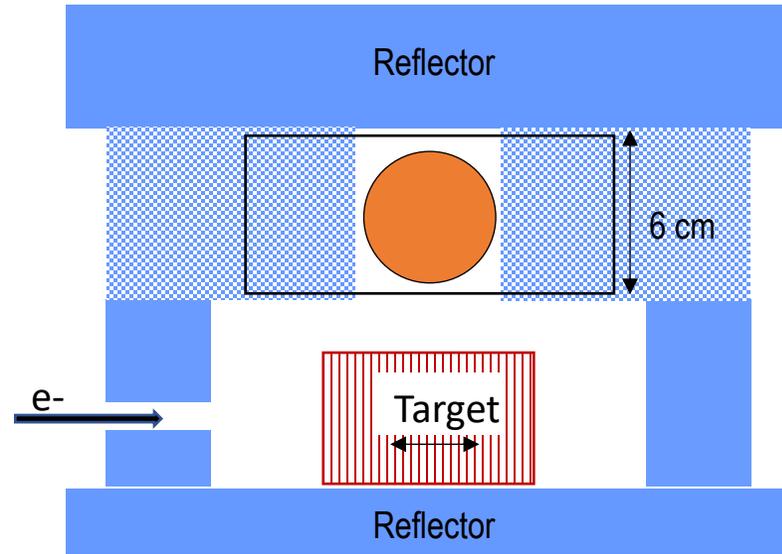(t = 3 cm, Φ = 4 cm; D = 3.5 cm)

TN - H_2O decoupled
(t = 4 cm, Φ = 2.5 cm; D = 5 cm)

MODS TESTING CELL

VCN - CH_4 (4K)
(t = 3 cm, Φ = 5 cm; D = 6 cm)

CONCLUSIONS

Compact moderators, and in particular low-dimensional moderators are very well suited for CANS.

Conceptual geometries were presented to motivate simulations aimed at the optimization of different spectral beam characteristics. The dimensions proposed are compatible with the HBS target.

These concepts are oriented to the production of thermal, cold, and very cold neutron beams, either of high brilliance or high intensity types.

The concepts presented here are only indicative of the different combination of thermalized sources that can be arranged for each target station.

THANKS FOR YOUR ATTENTION!