



# Target - Moderator- Reflector design for the ICONE HiCANS source





# The ICONE project



# A French HiCANS source

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- **In 2024 the French Ministry of Research requested the CEA and the CNRS to work on a French HiCANS dedicated to neutron scattering**
- **The Preliminary Design report has been elaborated in 2024 - 2025**
  - Some parts are « ready » to build
- **The Scientific Council of the ICONE project has identified 11 instruments which should be prioritize**
  - 9 scattering instruments
  - + 1 imaging + 1 PGAA



# ICONE Instrument suite

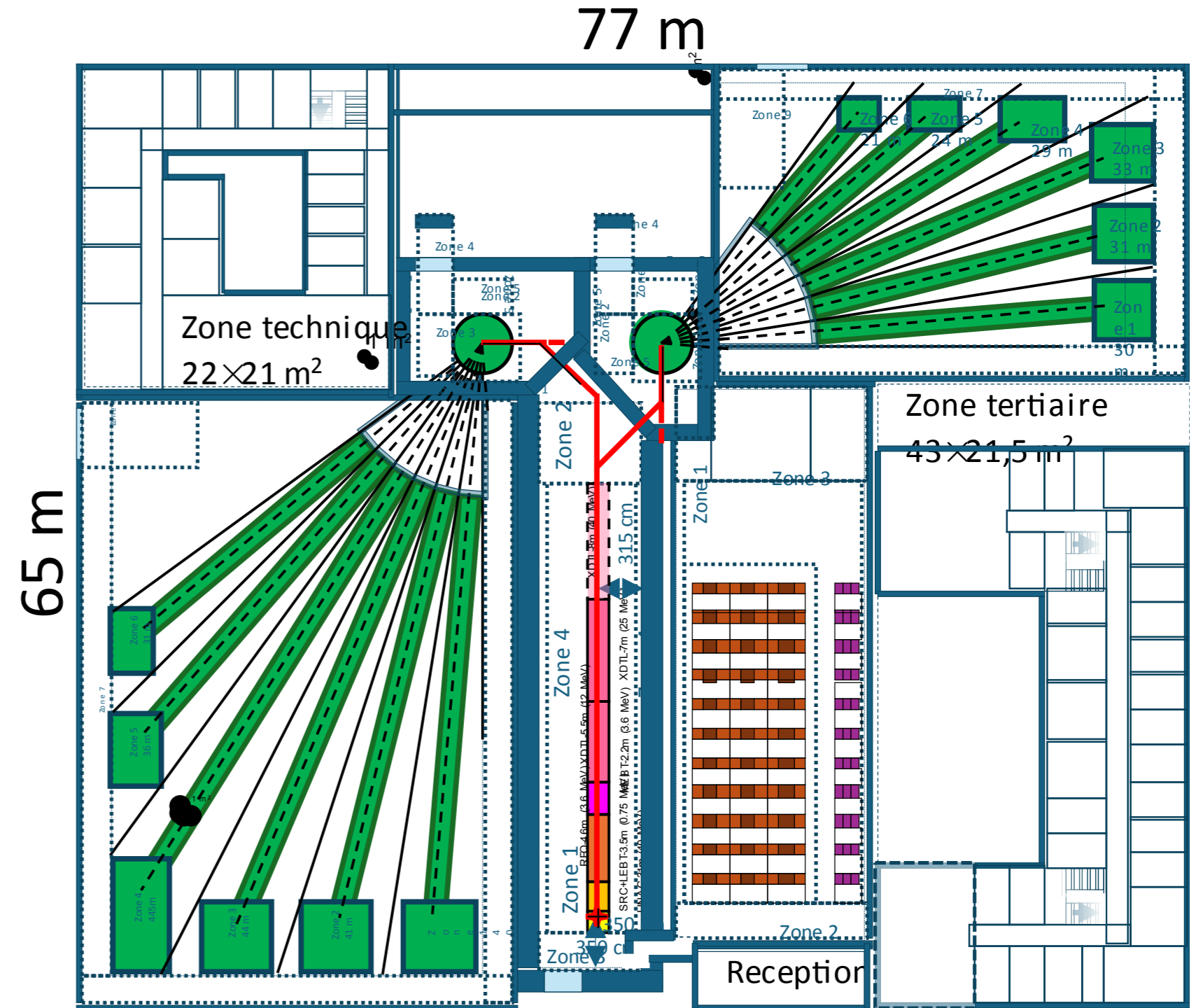
| Technique          | Instrument | $\lambda$ (Å) | C | T | TS | X [mm] | Y [mm] | Comment                    |
|--------------------|------------|---------------|---|---|----|--------|--------|----------------------------|
| <b>PHASE 1</b>     |            |               |   |   |    |        |        |                            |
| SANS               | LAMBDA     | 2 – 20        | ■ |   | ■  | 30     | 30     |                            |
| Reflectivity       | PREMS      | 2 – 16        | ■ |   | ■  | 40+    | 10     | No point going down to 1Å° |
| Imaging            | TULIP      | 1 – 16        | ■ | ■ | ■  | 30     | 30     |                            |
| Diffractometer     | PRESTO     | 0.5 – 6       | ■ | ■ | ■  | 30     | 30     |                            |
| Inelastic Indirect | FANTASTIC  | 1 – 5         | ■ | ■ | ■  | 40     | 40     |                            |
| Tests              | LiTe-HR    |               |   |   |    |        |        | Takes what is left         |
| <b>PHASE 2</b>     |            |               |   |   |    |        |        |                            |
| SANS               | NANOSANS   | 2 – 20        | ■ |   | ■  | 20     | 20     |                            |
| Diff. HR           | PRECIS     | 0.5 – 6       | ■ | ■ | ■  | 30     | 30     |                            |
| Inelastic Direct   | INEDIT     | 2 – 10        | ■ |   | ■  | 40     | 40     |                            |
| High Res. Spec.    | PULSE      | 2 – 16        | ■ |   | ■  | 40     | 40     | Spin-echo (?)              |
| PGAA               | GOLF       | 1 – 10        | ■ | ■ | ■  | 30+    | 30+    |                            |
| Engineering        | DISChO     | 1 – 5         | ■ | ■ | ■  |        |        | Texture - Strain           |

- All instruments are requesting cold neutrons
- A large fraction of the instruments are « bispectral »



# ICONE Reference Design

- **Accelerator :**
  - 25 MeV ;  $I_{\text{peak}} = 80 \text{ mA}$  ;  $I_{\text{av}} = 3.2 \text{ mA}$
- **2 target stations**
  - « Long pulse » : 2ms ; DC = 4% ; P = 80kW
  - « Short pulse » : 400  $\mu\text{s}$  ; DC = 4% ; P = 80kW
- **6 instruments per target**  
**12 instruments max in total**



5x5 m<sup>2</sup>  
1:500  
1 cm = 5 m



# The ICONE moderator

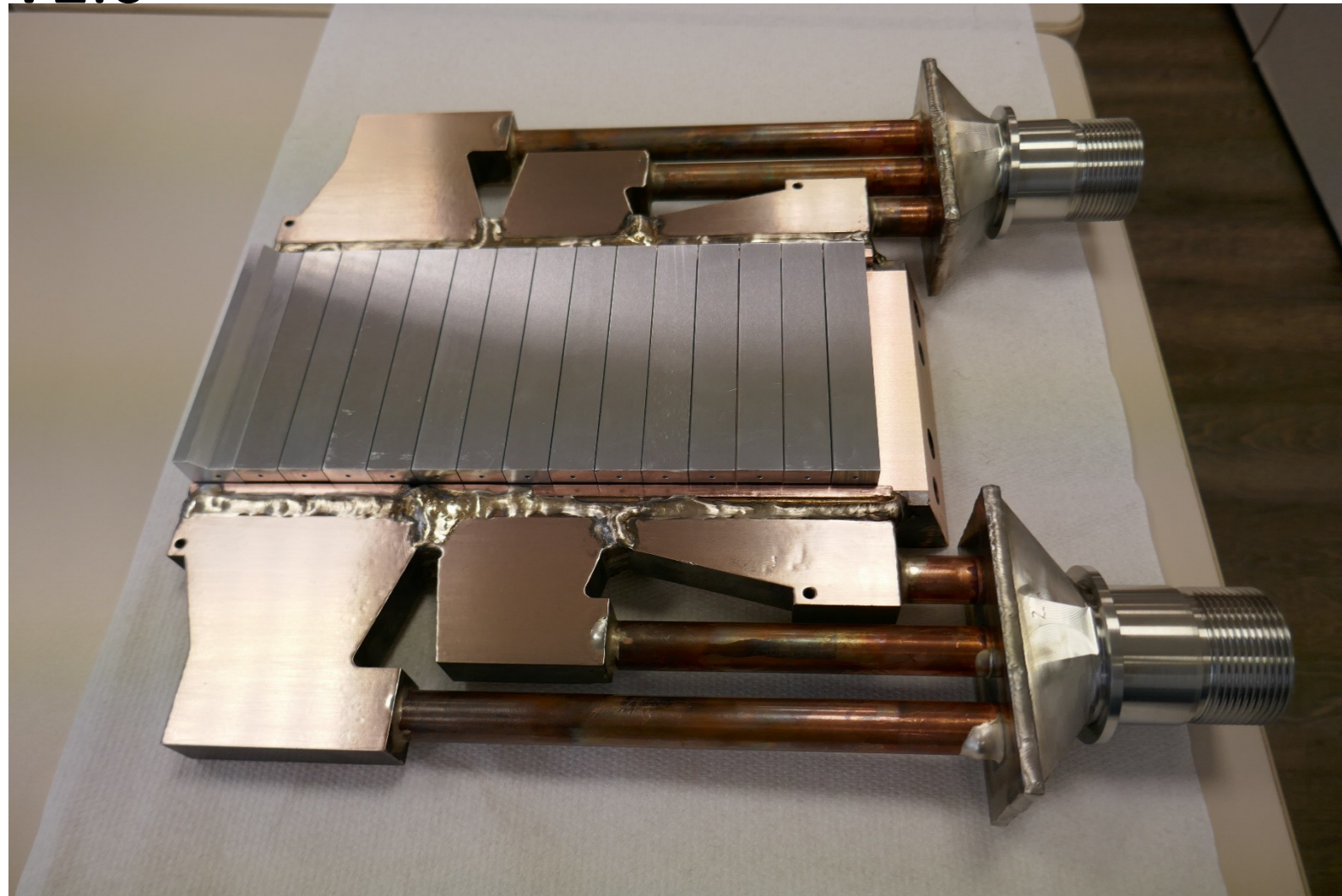
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**Strategy and performances**

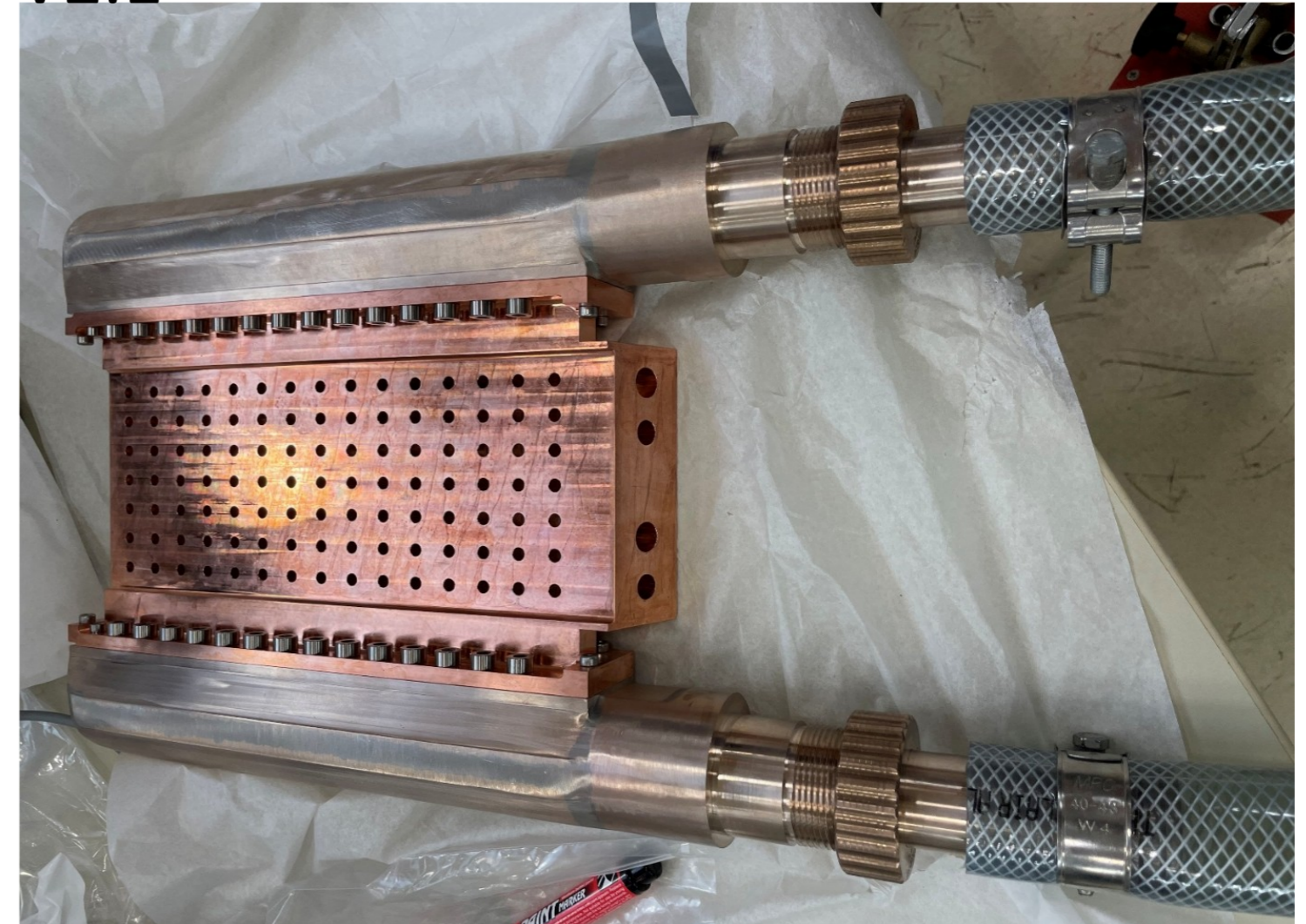


# Target design

V2.0



V2.1



Tested on *IPHI – Neutrons* 110 heures @ 30 kW  
(*éq.* ~300 h on *ICONE* in fluence terms)



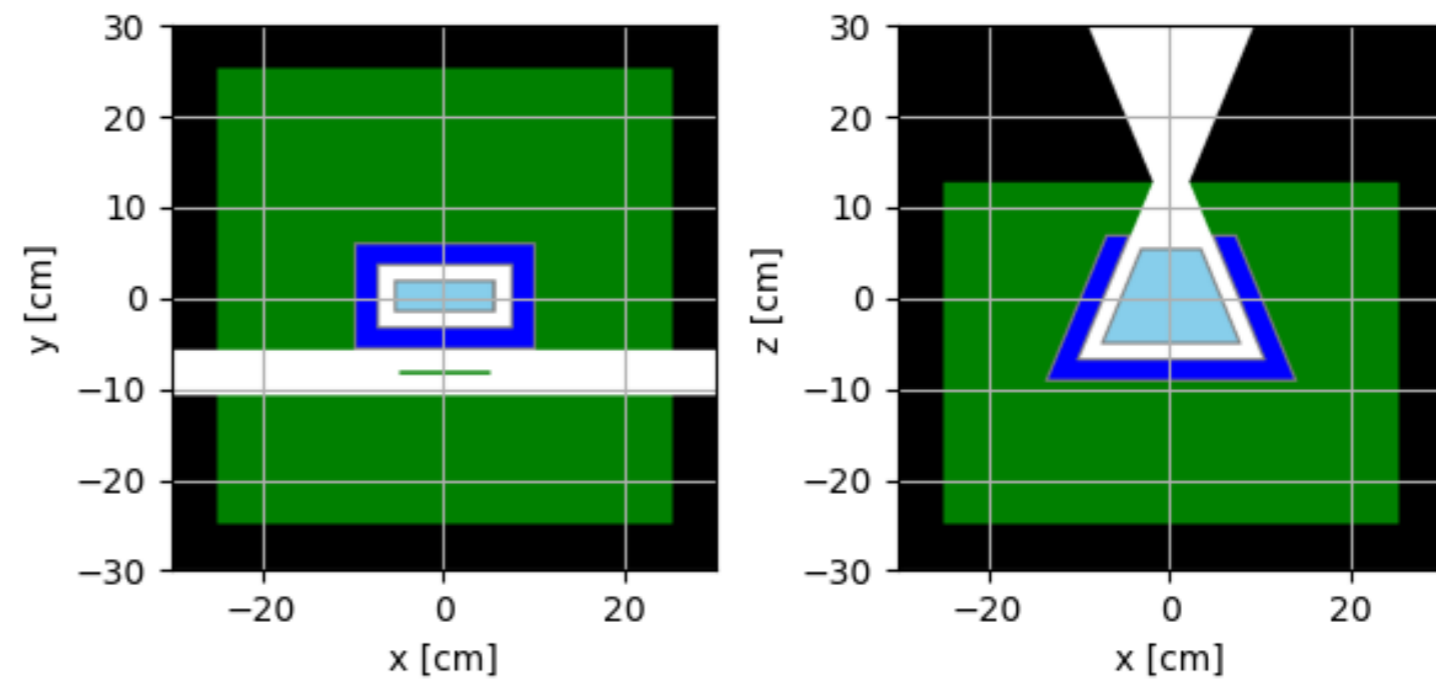
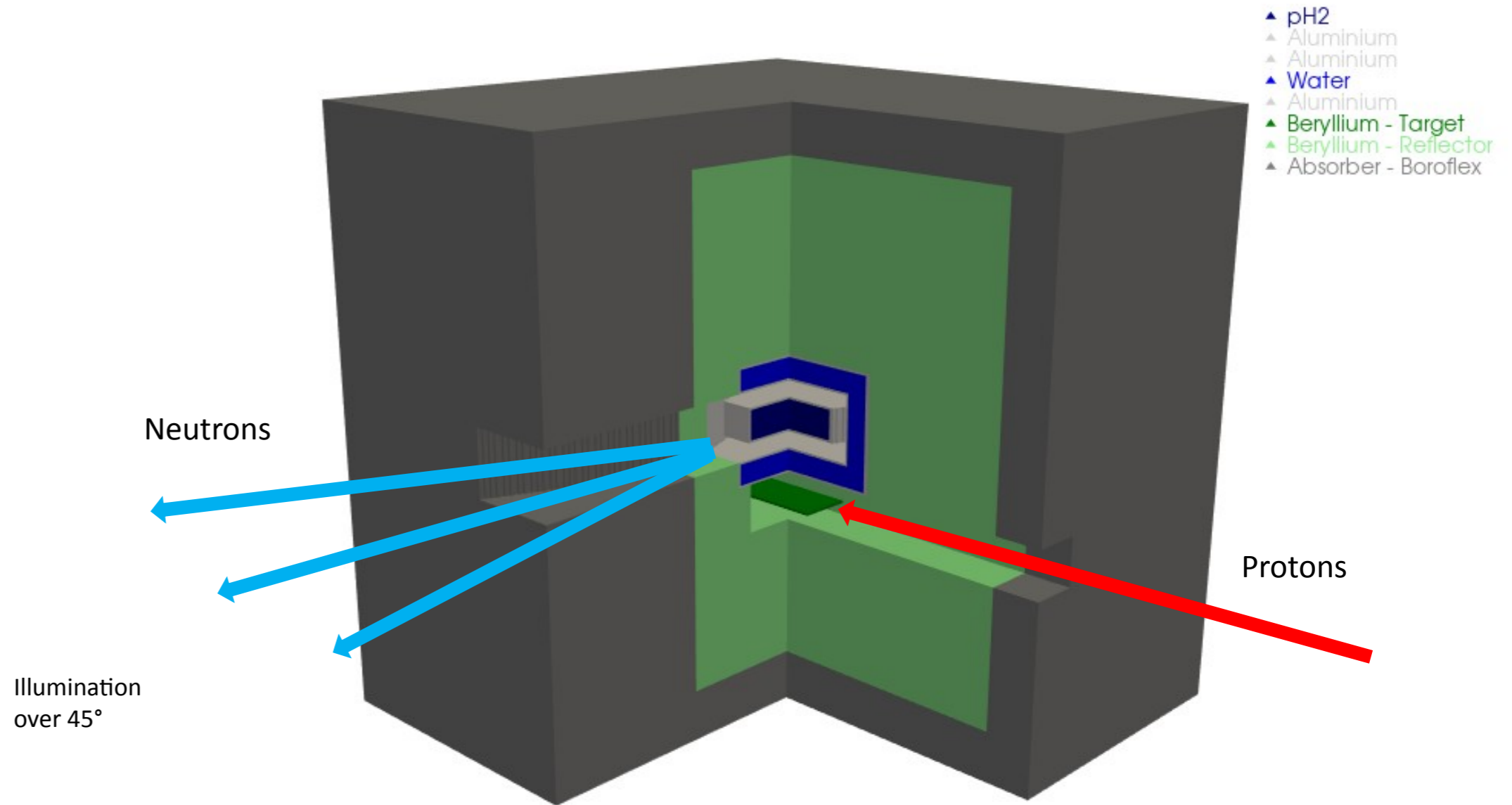
# TMR design

- **Strategy : simplicity of conception / flexibility**

- We accept compromise on the performances
- We consider a « generic » design

- **A parametric model was created**

- Possibility to explore a wide range of configurations

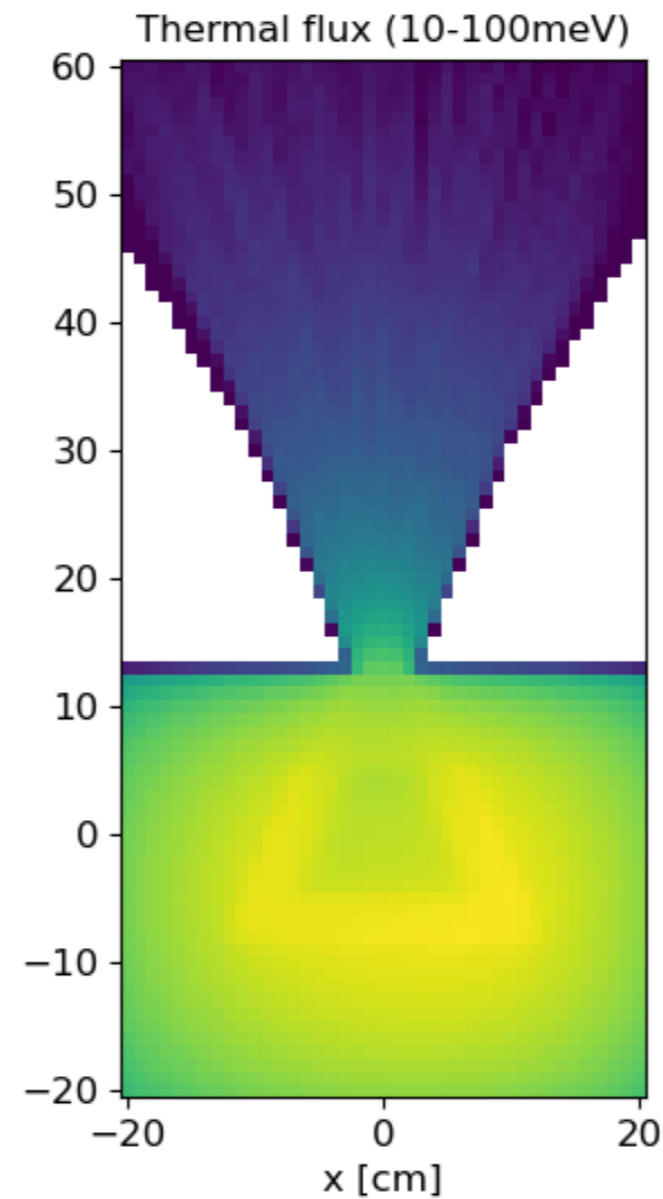
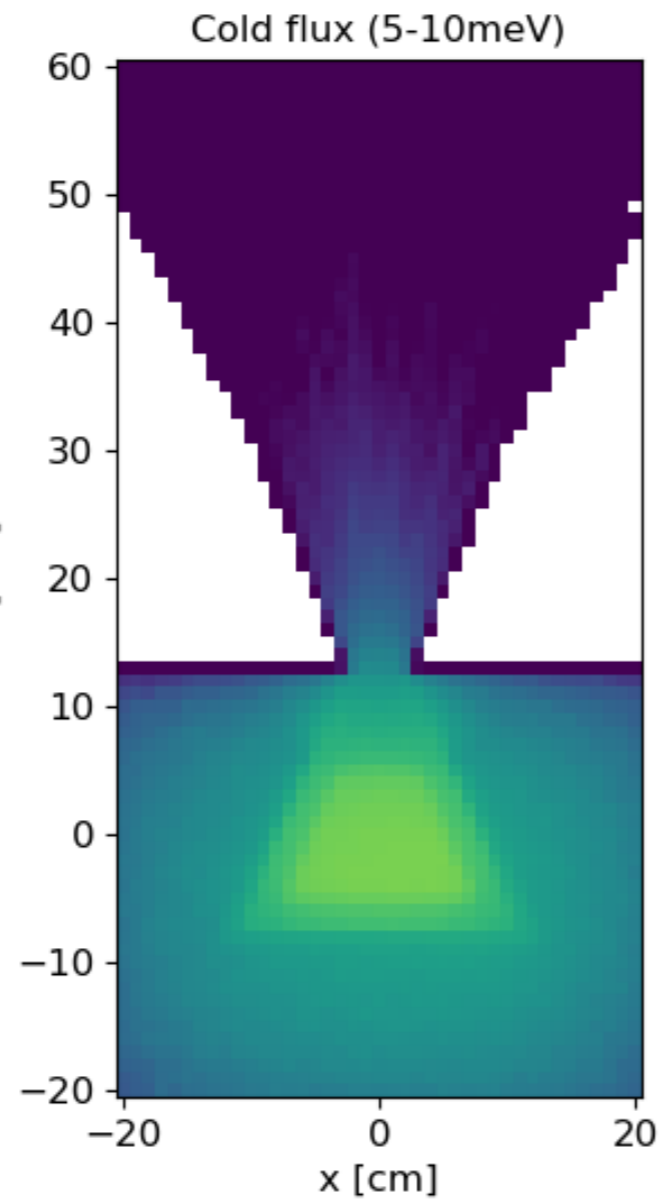
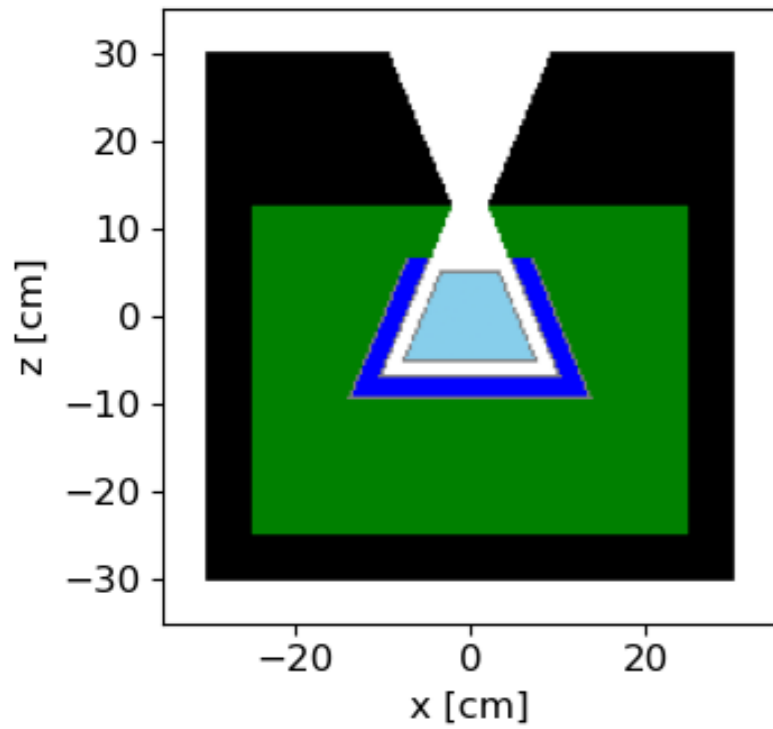
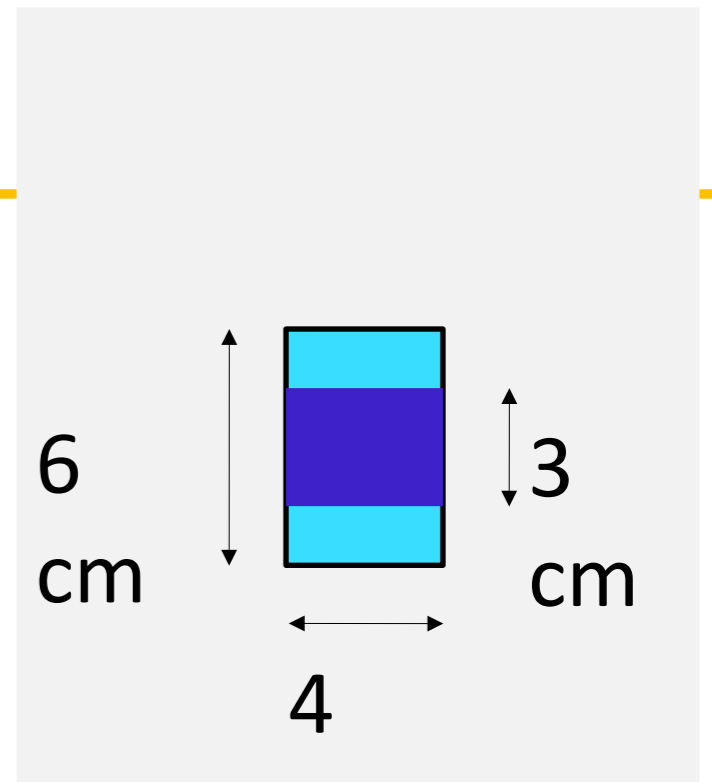




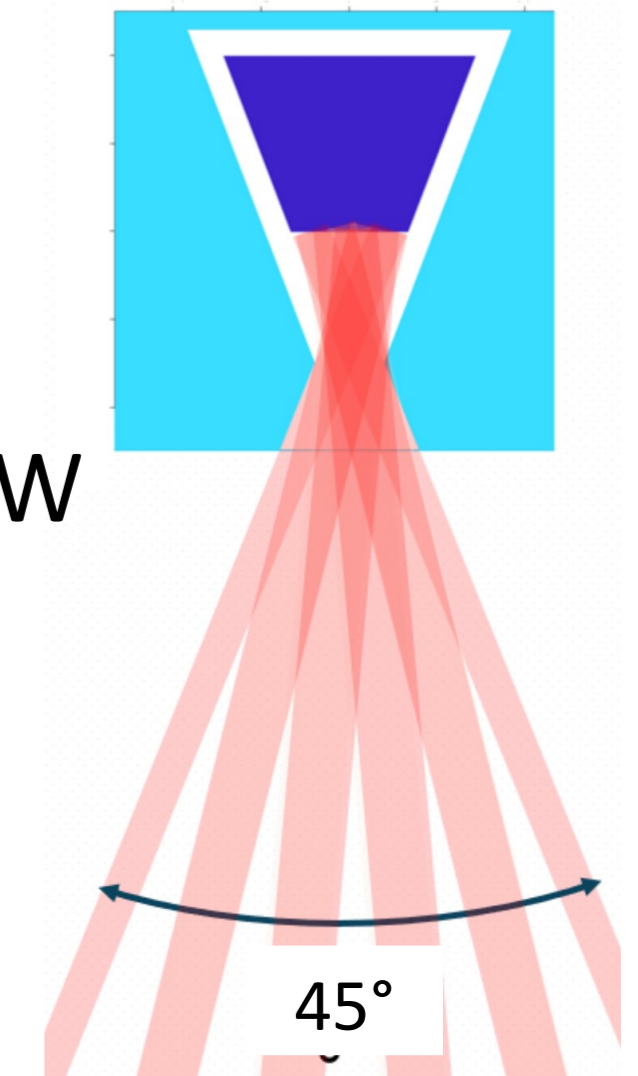
# Moderator emission surface

FRONT VIEW

Actual emission  
surface



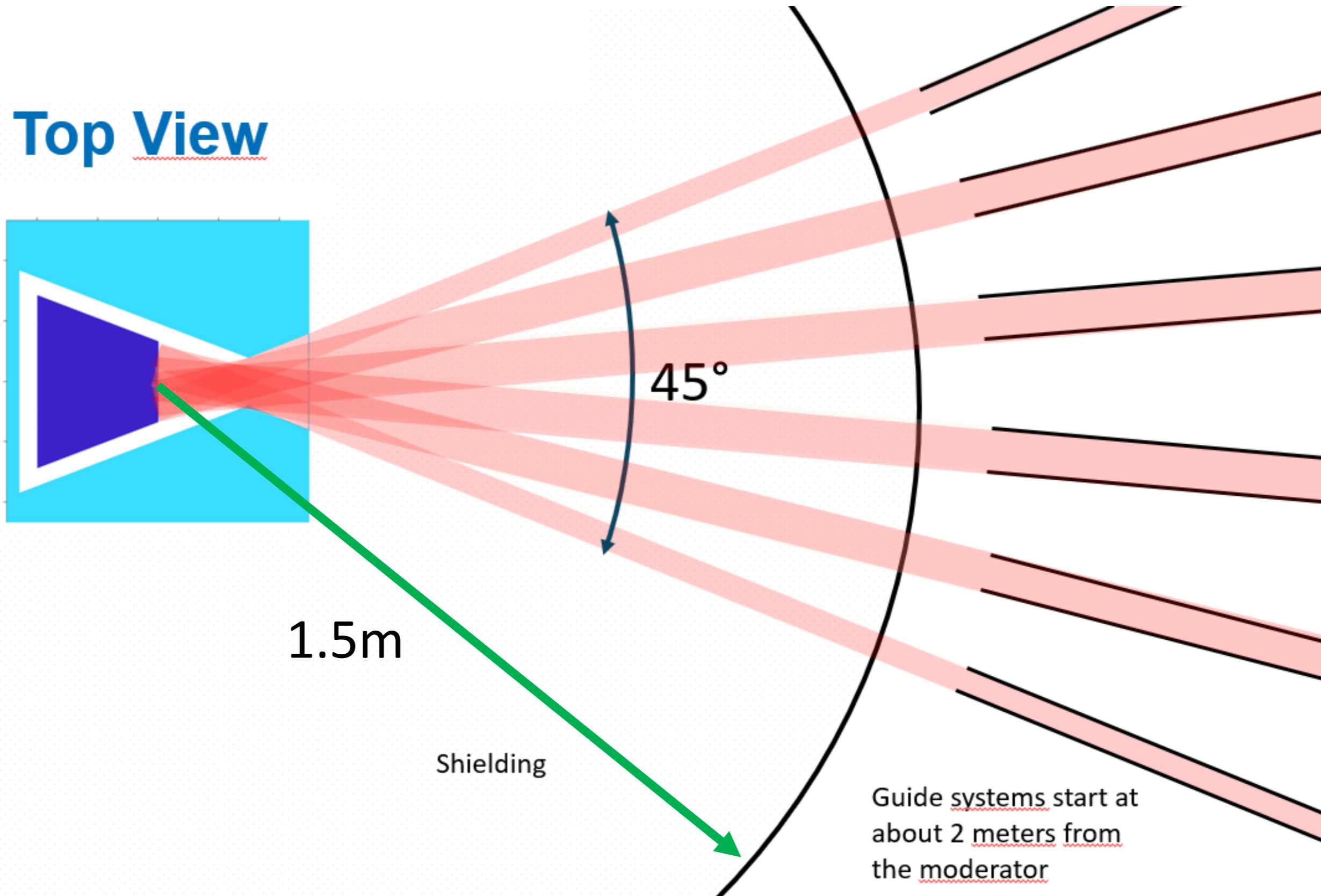
TOP VIEW





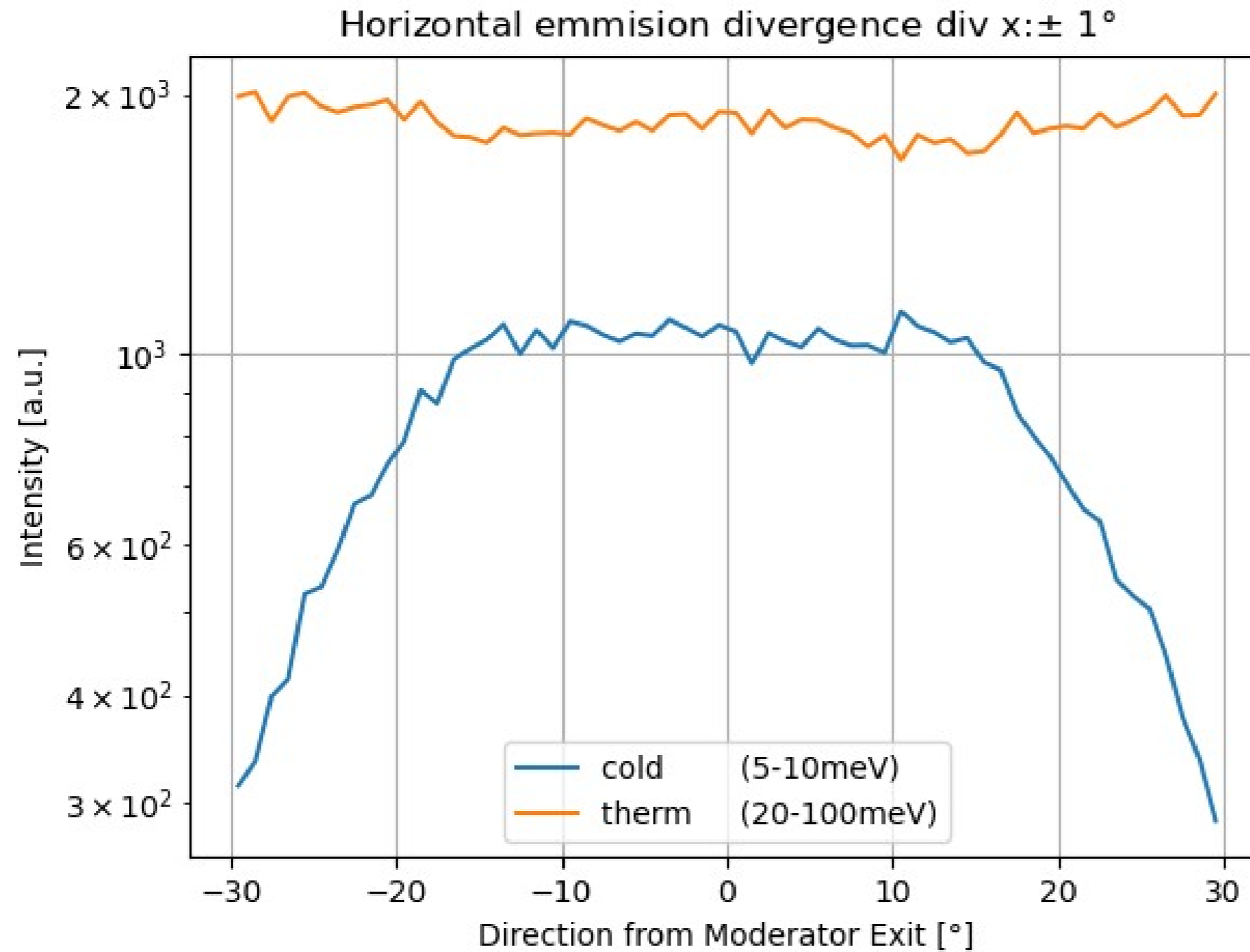
# Neutron extraction

**Top View**





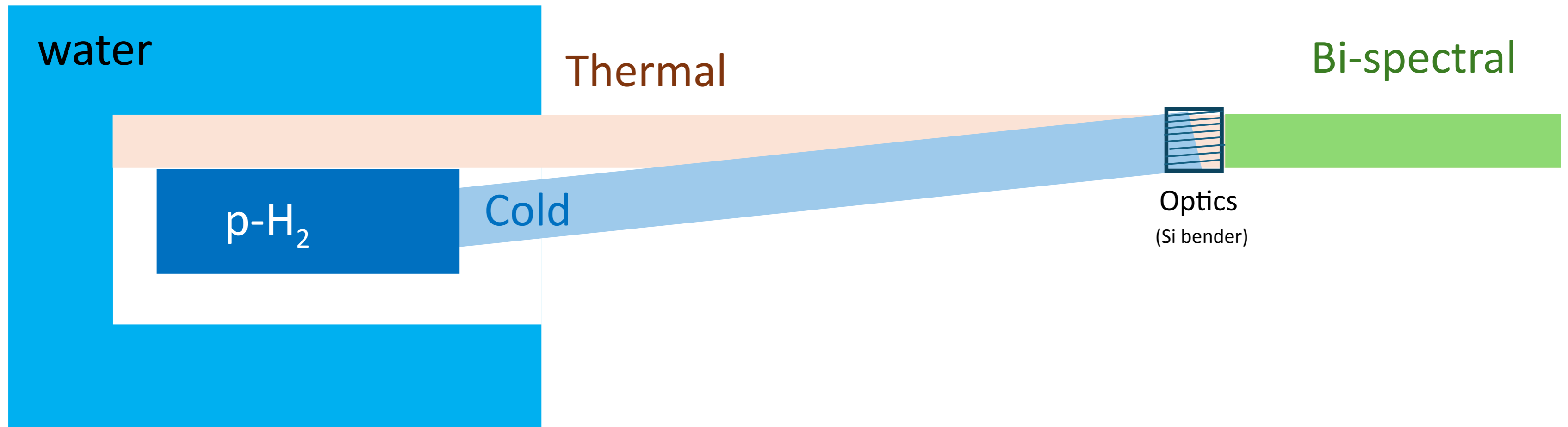
# Horizontal divergence



**Good and homogeneous  
illumination  
of the instrument ports**

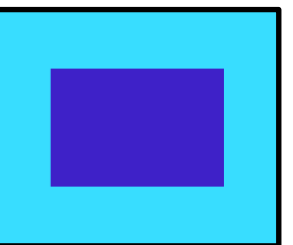
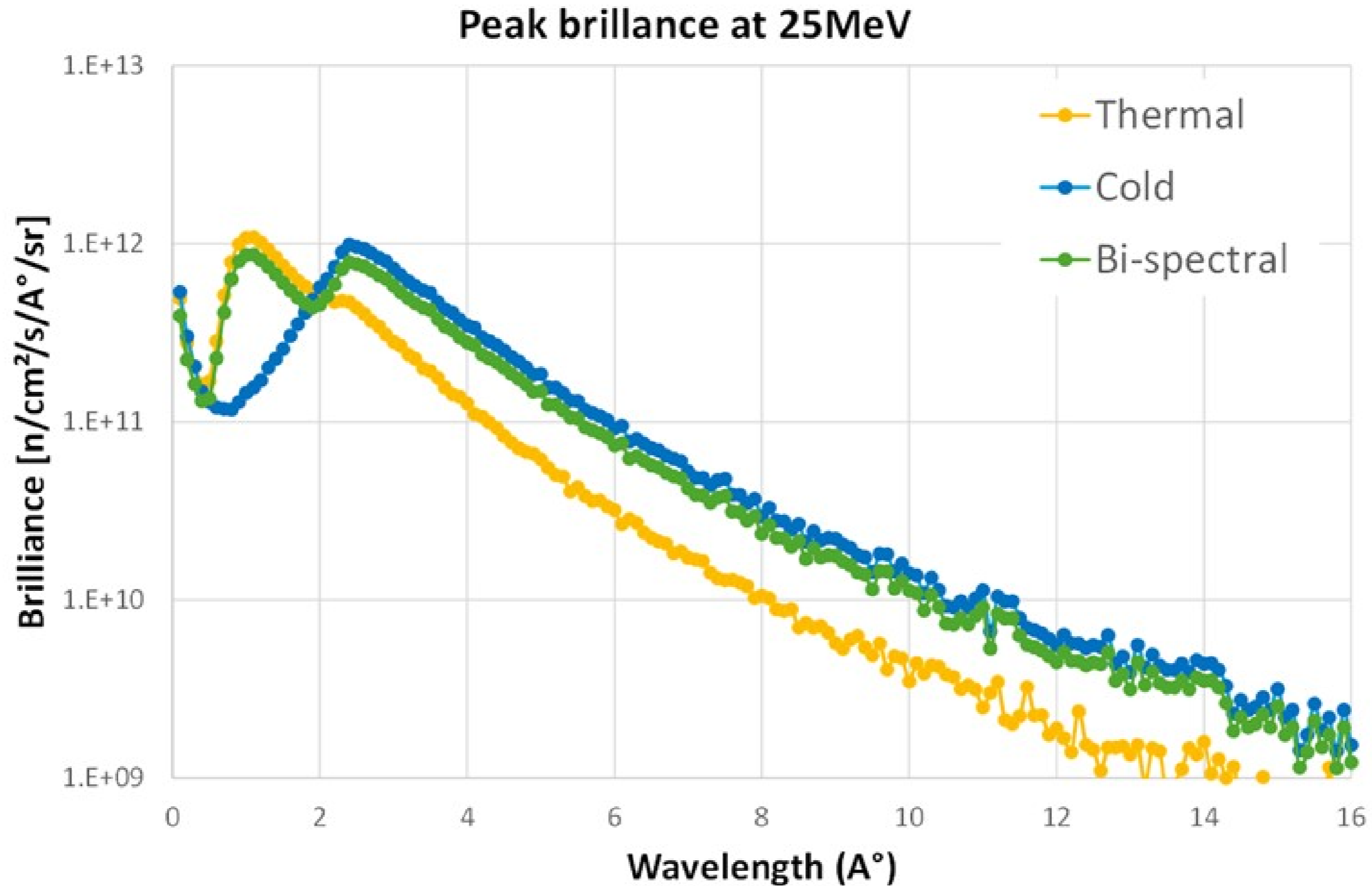


# Bi-spectral extraction





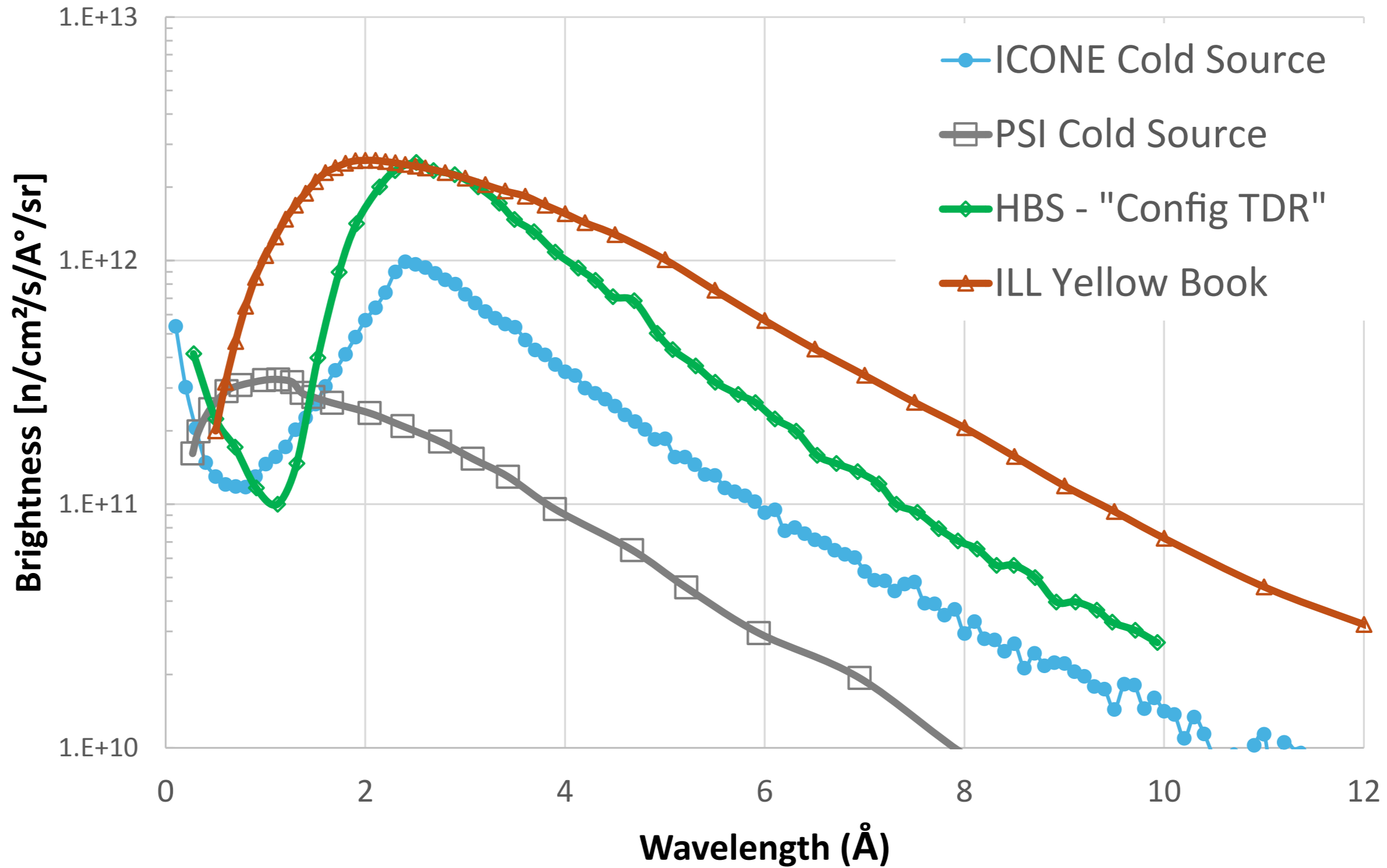
# Moderator Brilliance





# Peak brilliance comparisons

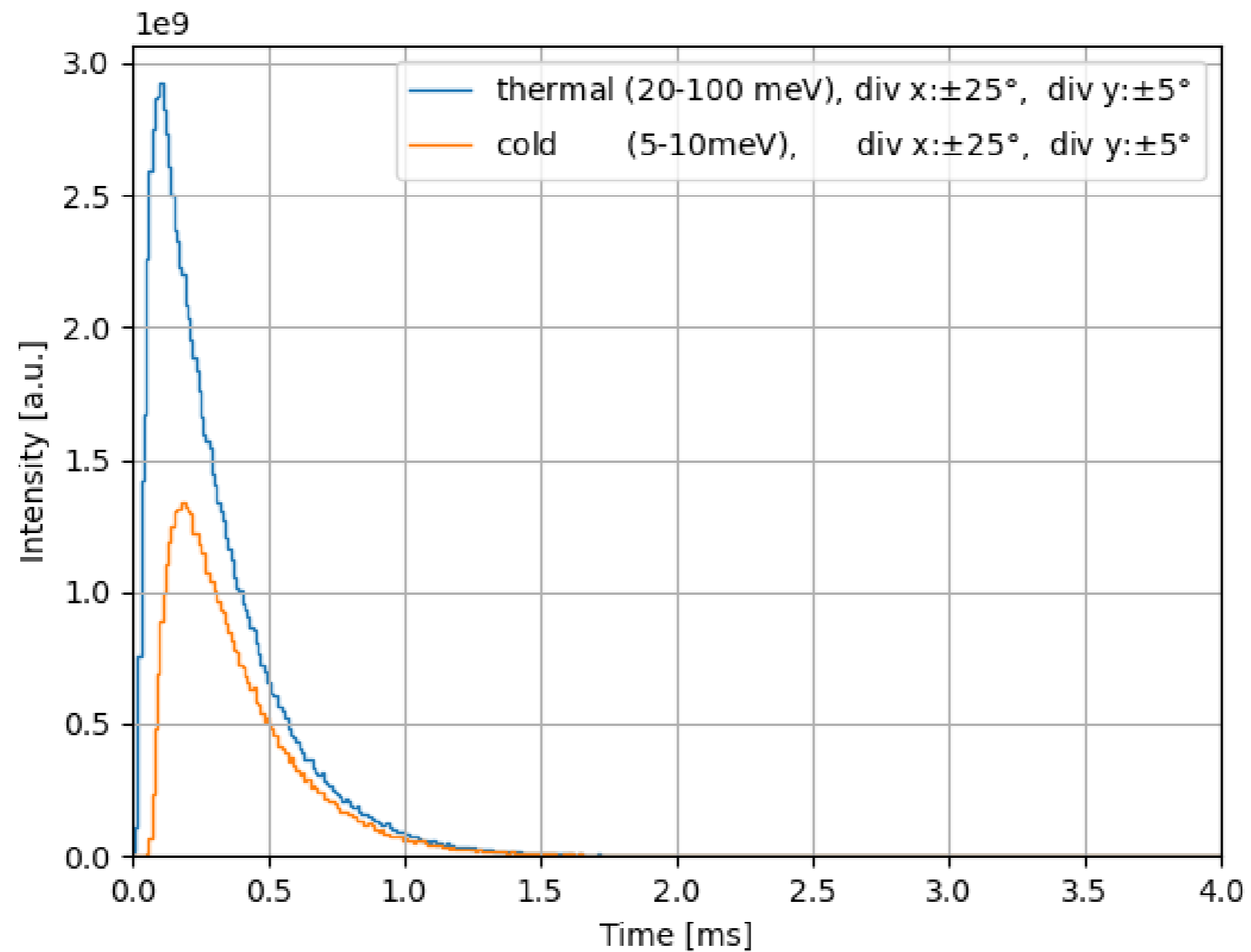
Peak brightness of different cold sources





# Time response of the moderator

## Pulse response







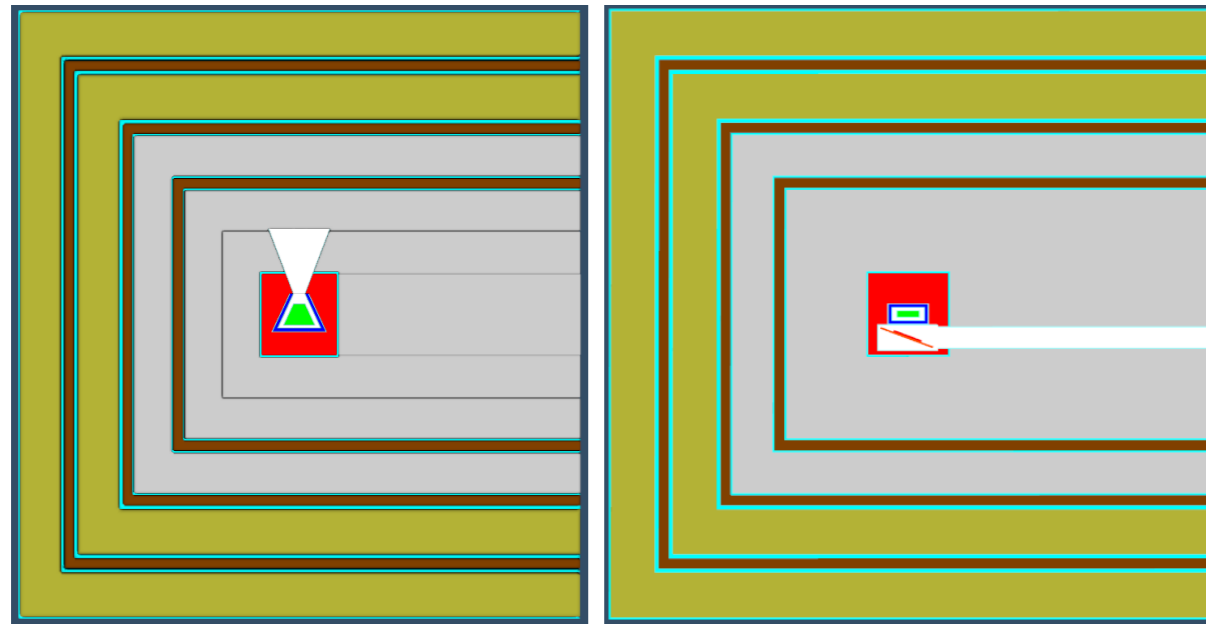
# PRACTICALITIES

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**Heat deposition - Shielding**



# Radiative heat load



- Cold cell (pH<sub>2</sub> + shell) : 2.2 W
- Water moderator : 20 W
- Reflector : 100 W
- Shielding : 230 W

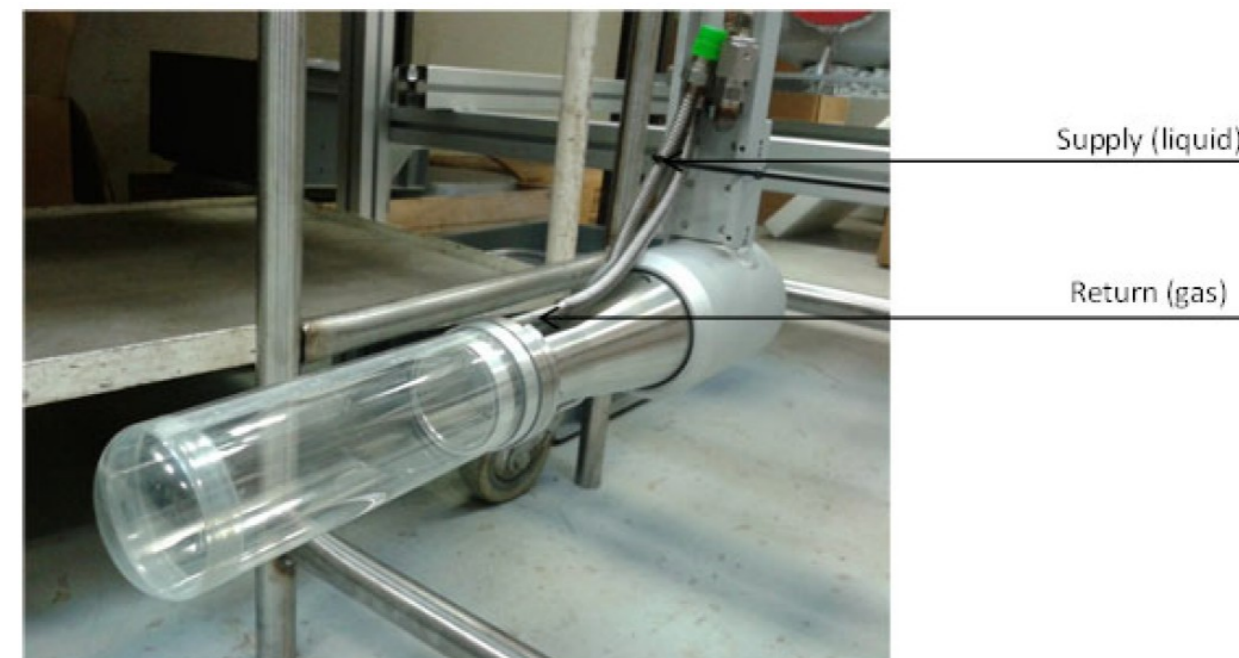
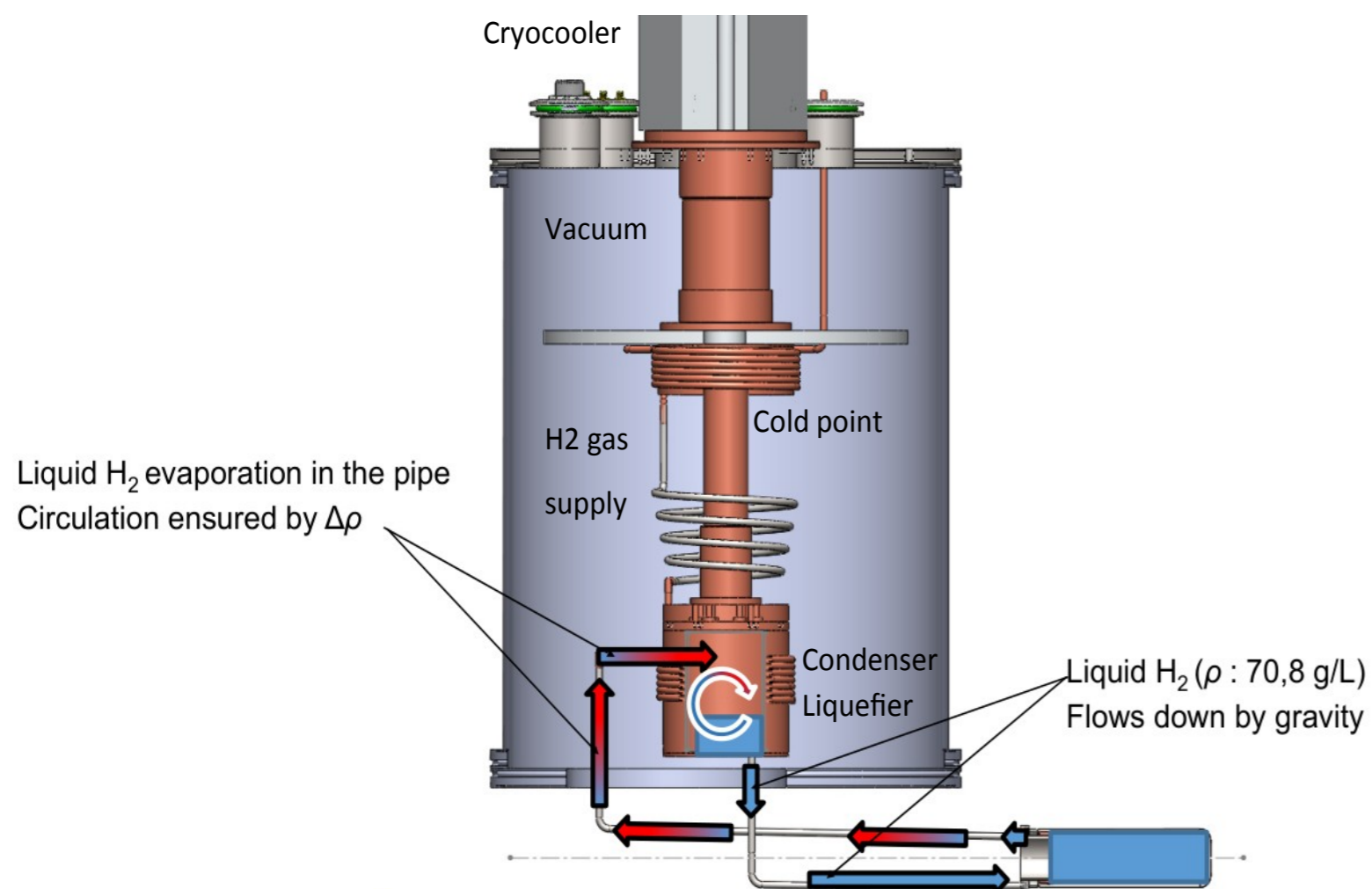
| Materials               |
|-------------------------|
| Beryllium (1.848 g/cc)  |
| Water (1 g/cc)          |
| Lead (11.35 g/cc)       |
| Colemanite (2.336 g/cc) |
| Mild steel (7.7g/cc)    |
| BPE (10%B) (1g/cc)      |
| BP (1.2 g/cc)           |
| Borflex (1.55 g/cc)     |
| Air (1.205e-3 g/cc)     |
| Para-H <sub>2</sub>     |

- PHITS calculation
- + MCNP cross check (30% variations, source term origin)
- + reproducing (Lavelle, 2008) calculations for LENS
- © B. Hjira



# Prototyping cold moderator

- The CEA has an long expertise in building liquid H<sub>2</sub> target for nuclear physics
- Example : MINOS experiment at RIKEN / thermo-siphon ; P < 1.5 bar / Volume H<sub>2</sub> ~ 300 cm<sup>3</sup>





# Cold moderator : ICONE vs ESS



| ICONE   | ESS   |
|---|---|
| Radiative heat load ( $\gamma - n$ )<br><b>&lt;0.004 kW</b>   | Radiative heat load ( $\gamma - n$ )<br><b>~4kW</b> |
| Cooling Cryocooler<br>Sumitomo: RDK-500B2 : <b>45W@20K</b><br>(1 <sup>er</sup> modèle, 25kg)  | Réfrigérateur : <b>30,3 kW</b> à 15 K               |
| Radiation damage is negligible  | Al6061 : <b>20 dpa/an</b><br>Lifetime ~1 an @ 5MW*  |
| <ul style="list-style-type: none"><li>• H<sub>2</sub> liquid cell : « thermo-siphon »<br/>No pump / P<sub>operation</sub> &lt; 1.5 bars</li><li>• Negligible heat load on moderator water (&lt;20W)</li></ul> |   |

\*Y. Lee, JPS 28 (2020)



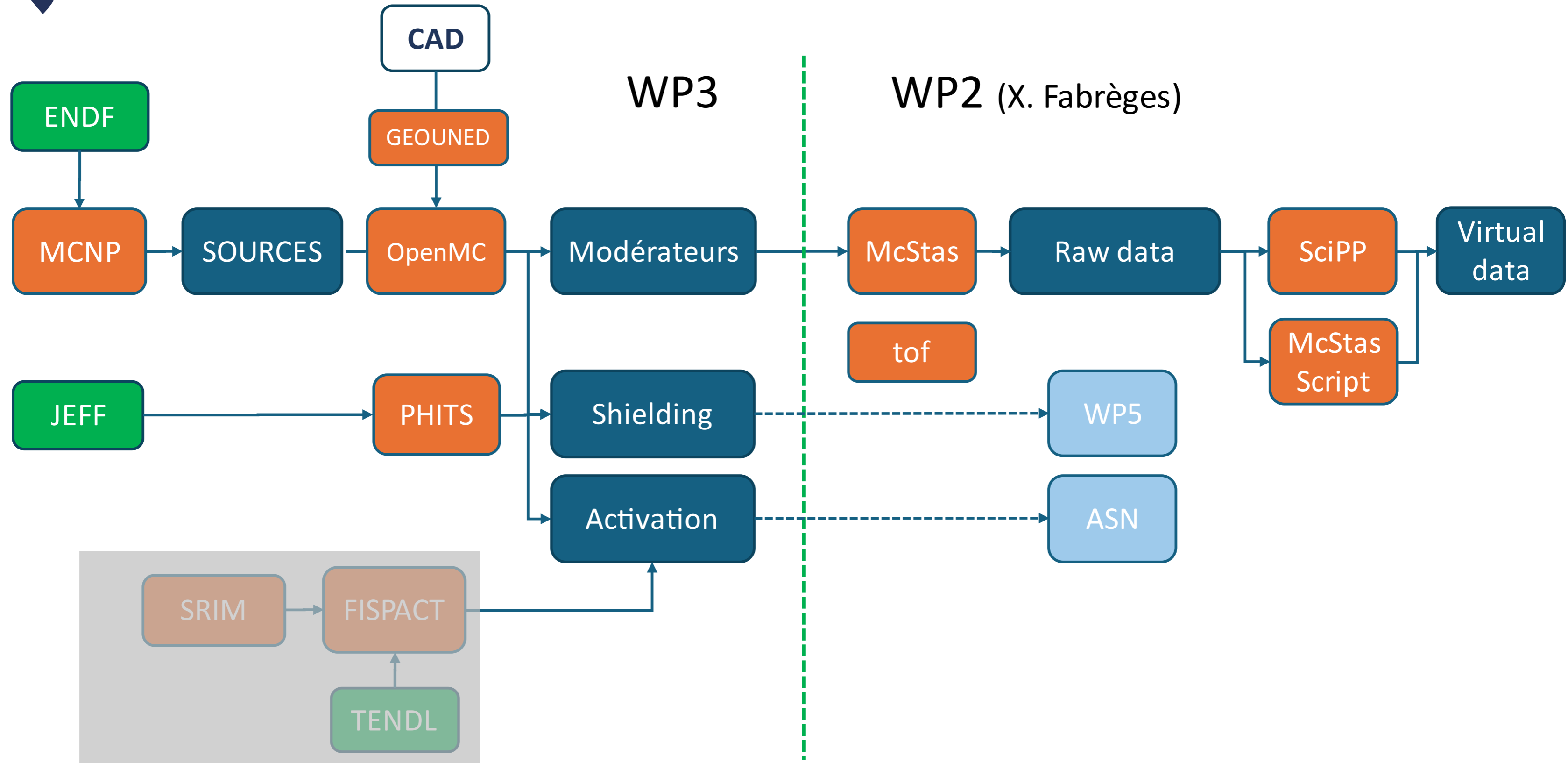
# Methodology

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**Simulation tools**



# Tools • « Simulation pipeline »





# Conclusions and Outlook

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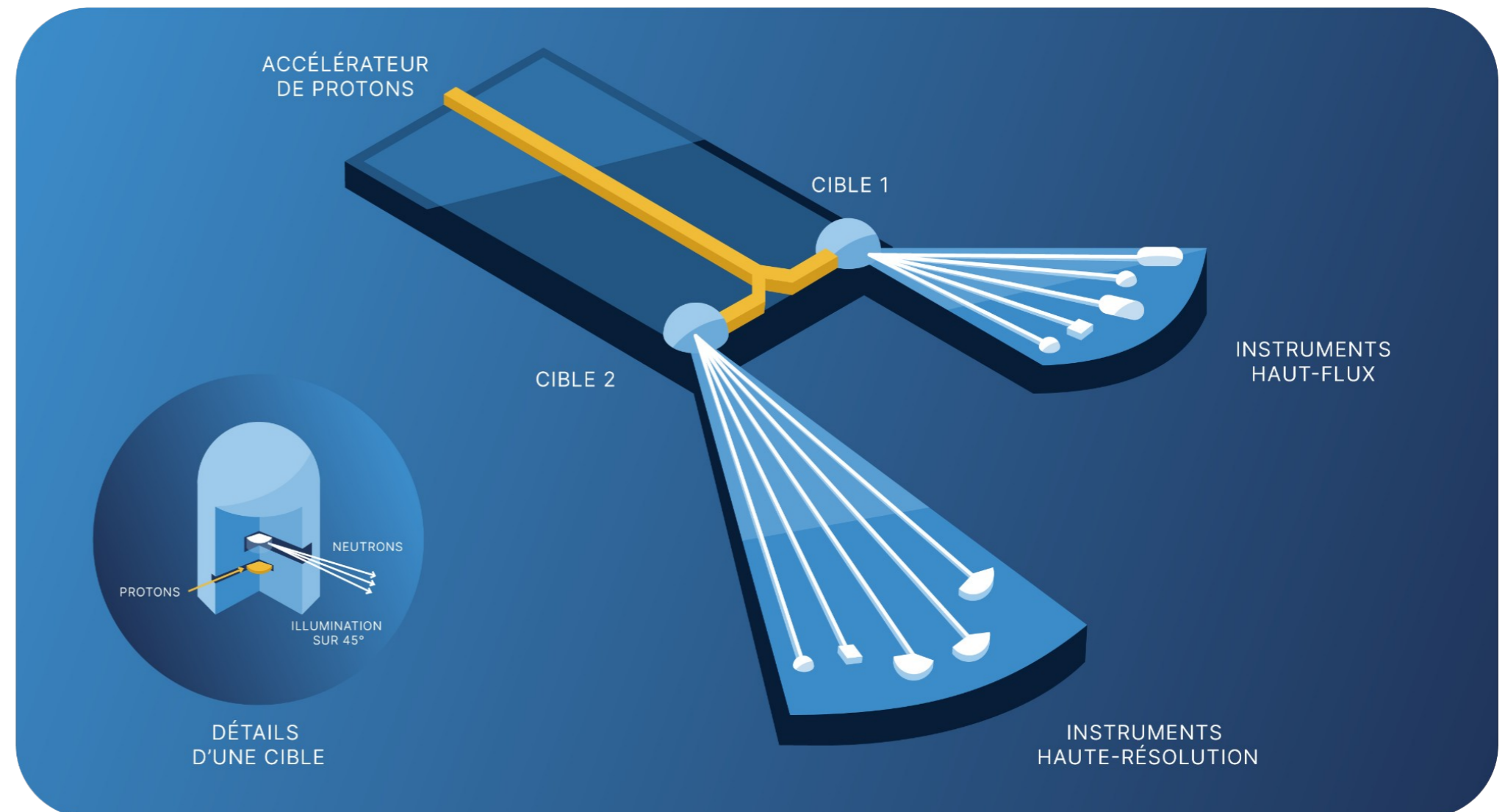
- **Compact Moderators on HiCANS sources can provide a peak brilliance comparable to medium power research reactors or spallation sources**
- **A practical TMR design is proposed for the ICONE project**
- **Construction and operation is simplified on HiCANS**
  - « small » shielding
  - « reduced » radiation levels



# Acknowledgments

- Richard Wagner
- Benjamin Canovas
- Jacques Darpentigny
- Brahim Hjira
- Frédéric Ott

[www.icone-neutron.fr](http://www.icone-neutron.fr)





# Integration / Handling

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**Strategy**

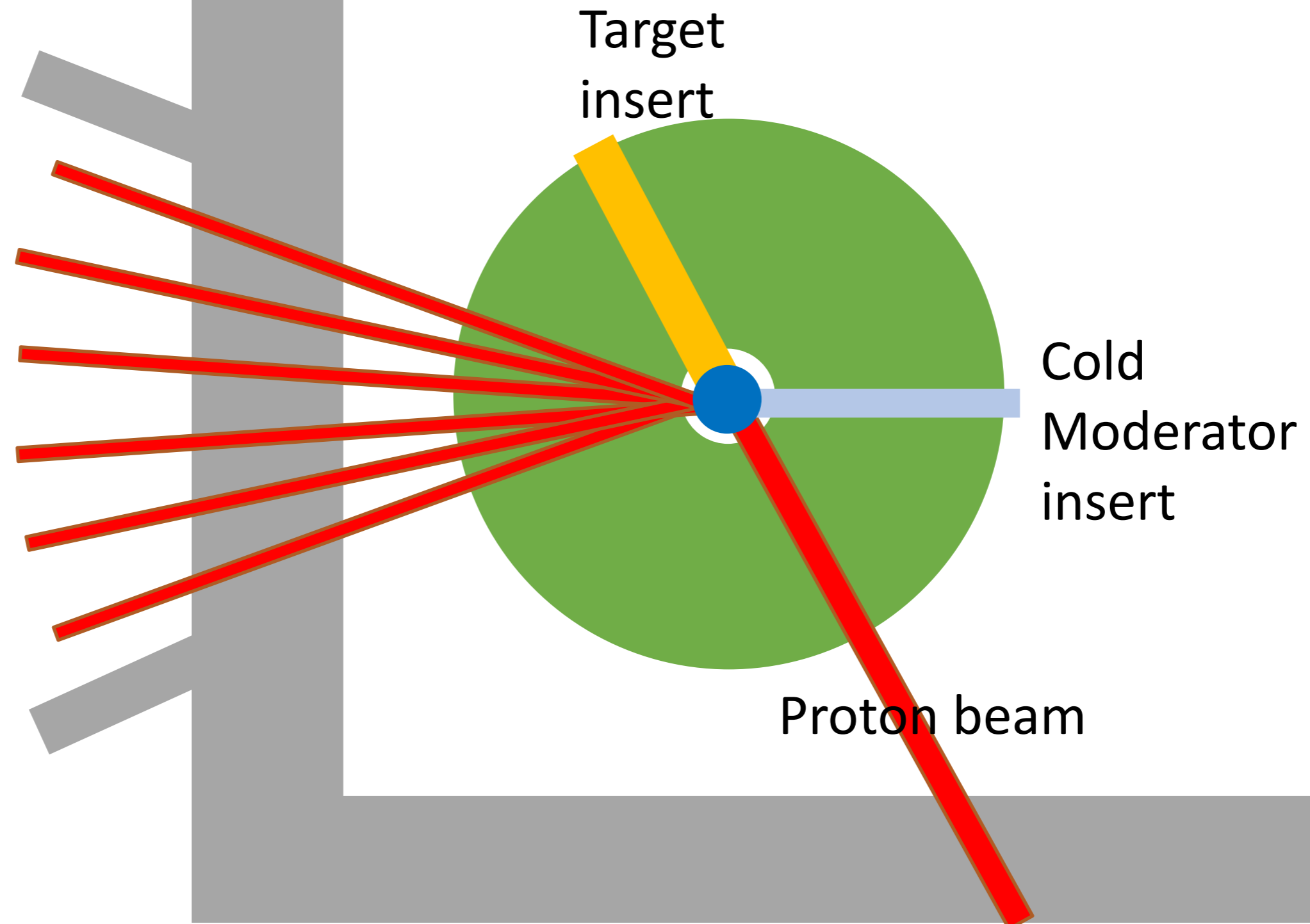
# Maintenance



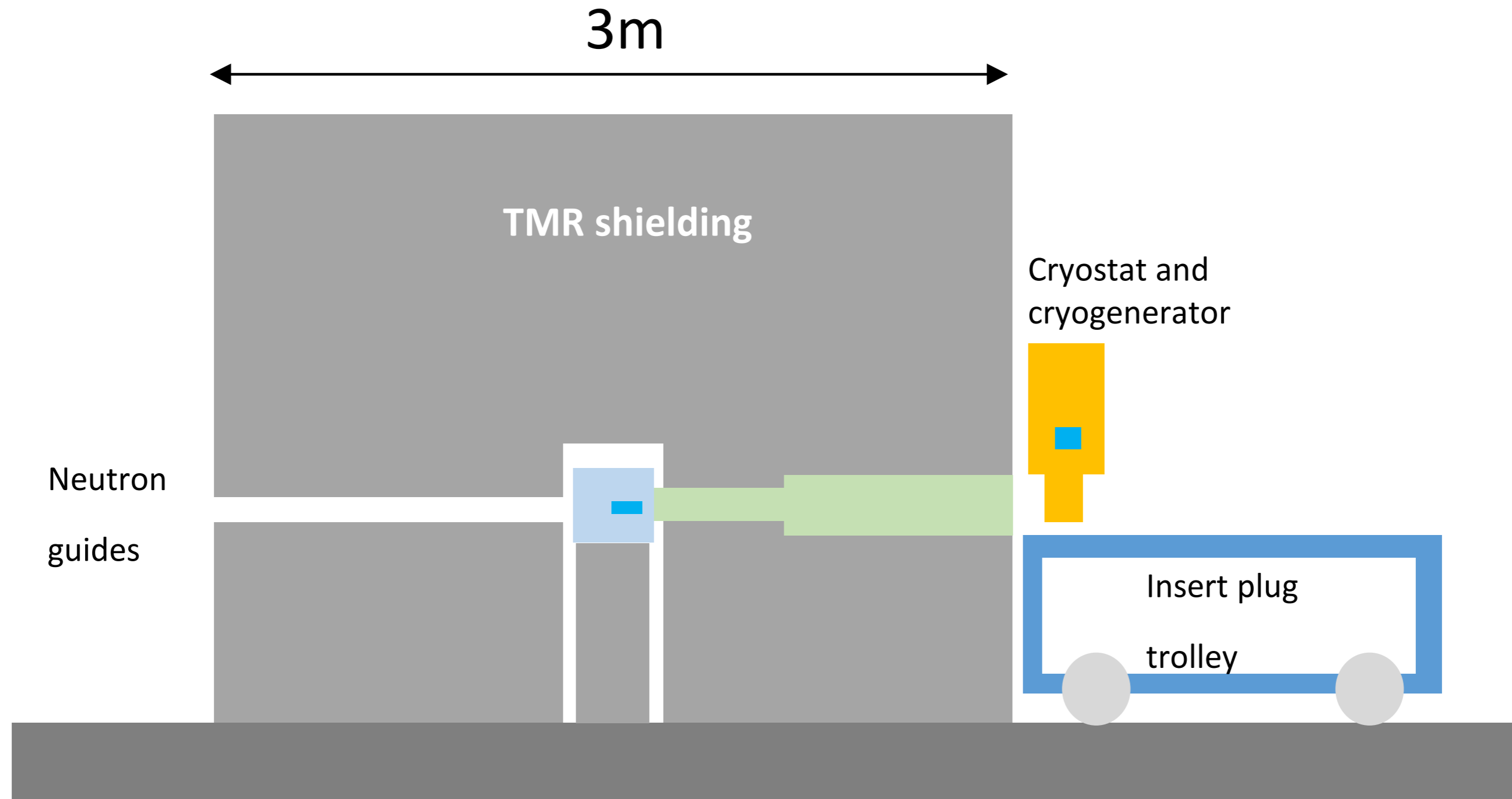
## Proposed layout

- Maintenance mainly at the ground level
- No need to open the TMR

Neutrons  
to guide hall



# Moderator insertion

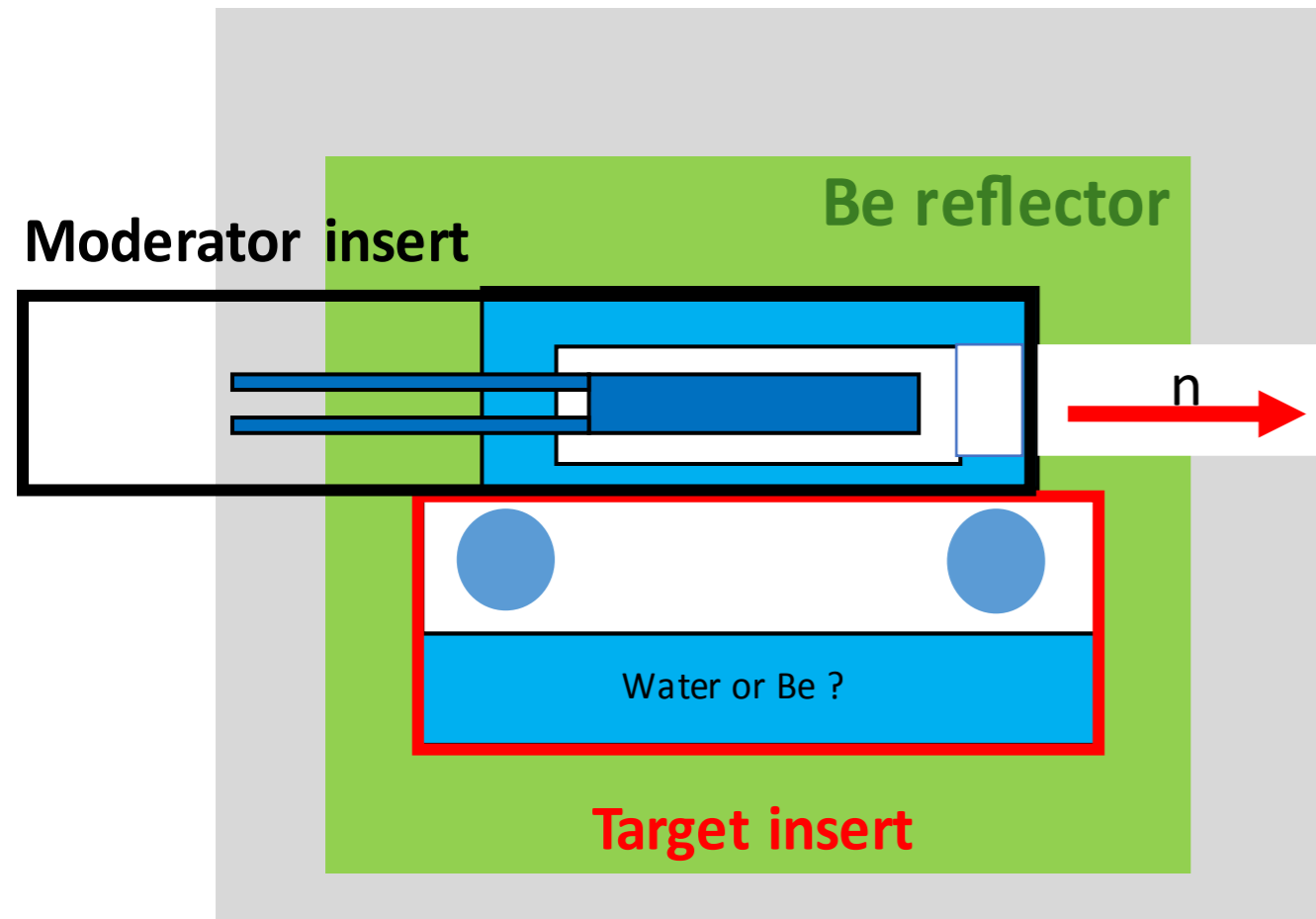




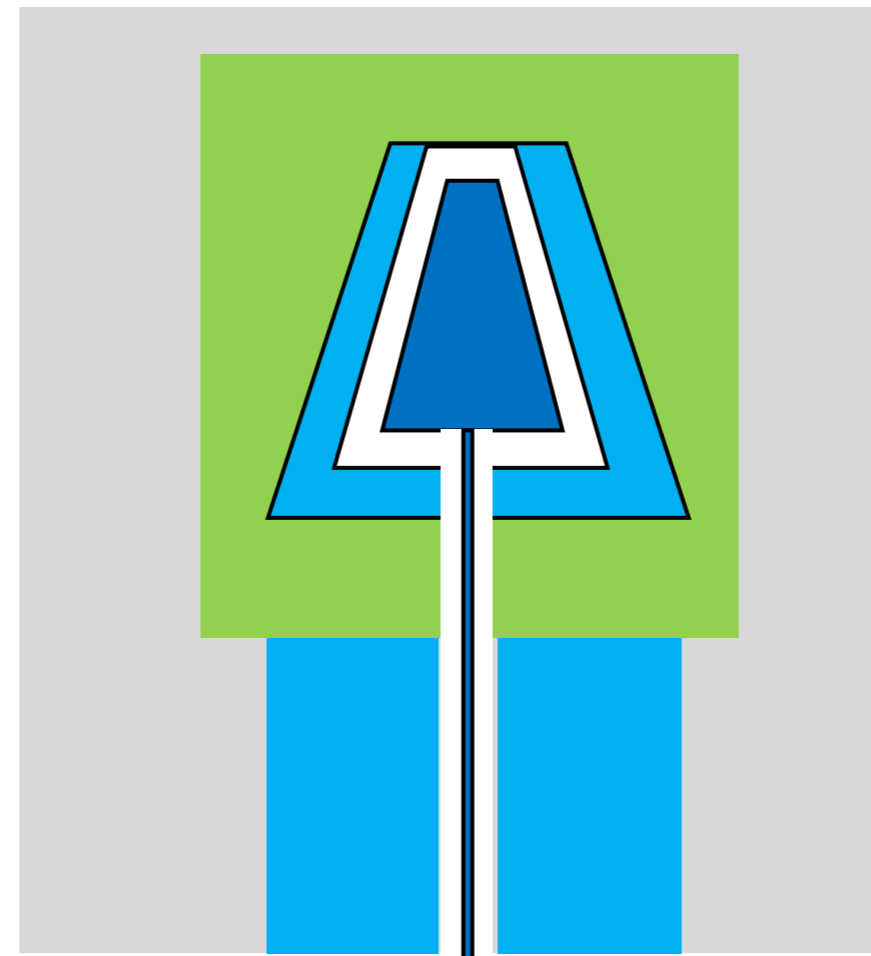
# Moderator insert

Side view

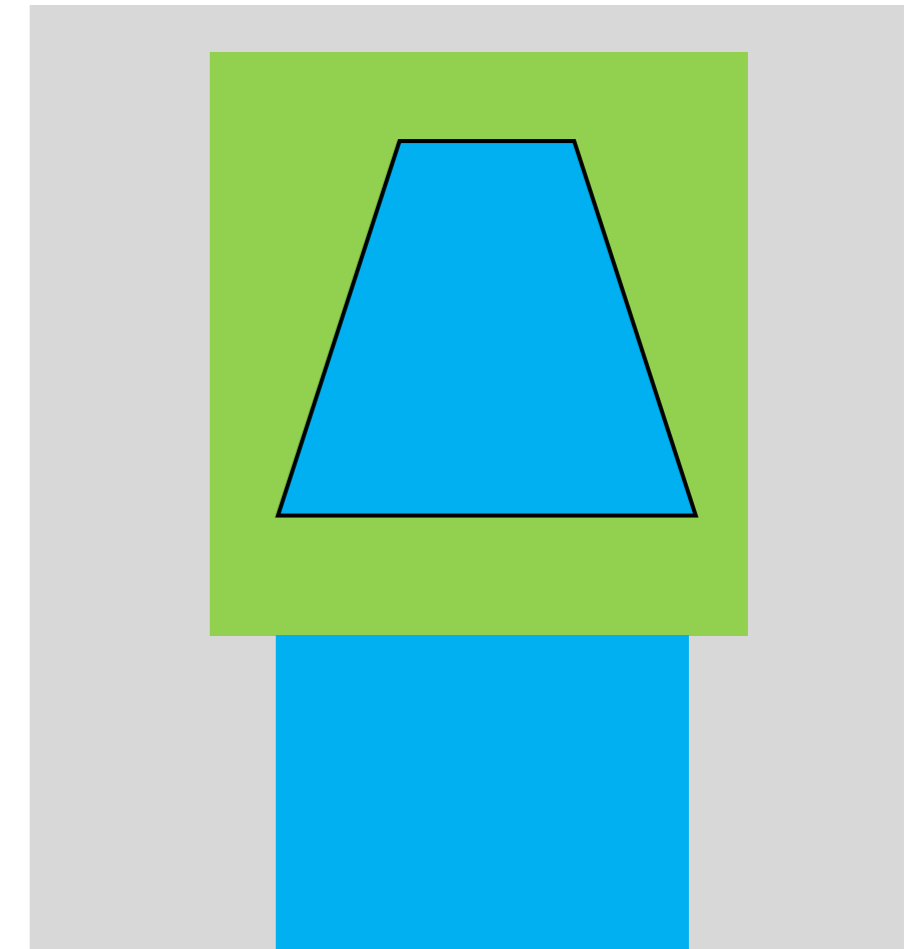
The moderator cell "sits"  
on the target tube



Cut at the cold cell height



Cut above the cold cell height





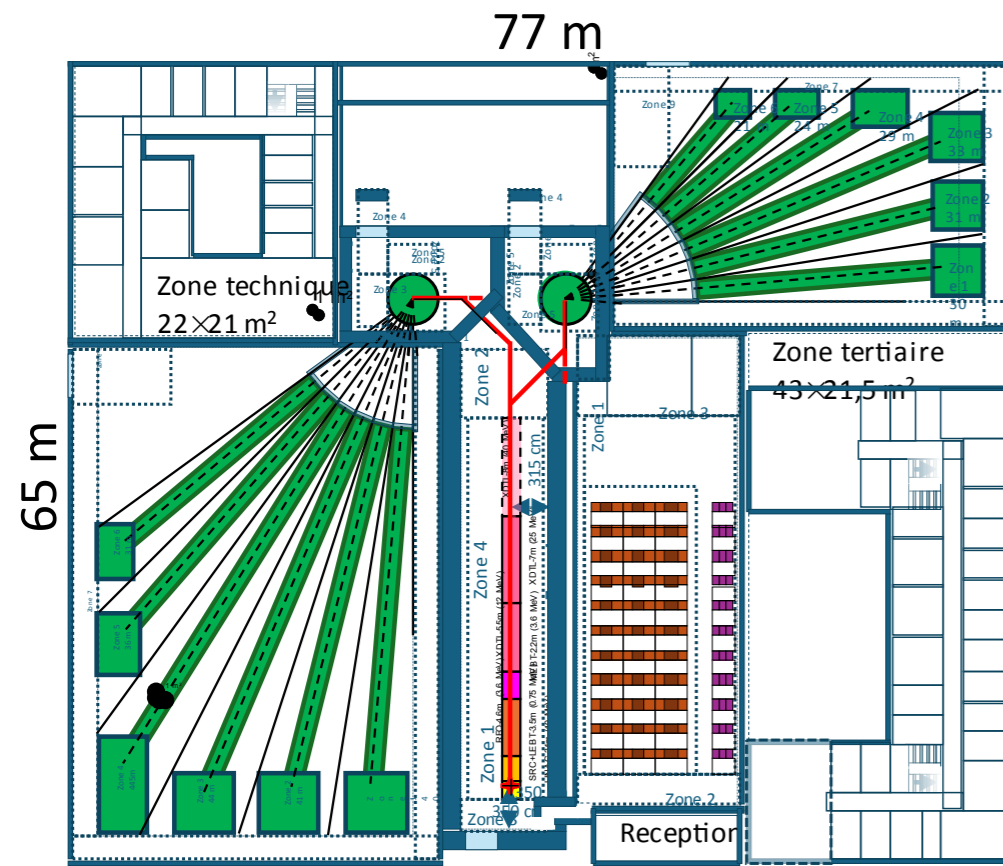
# EN STOCK

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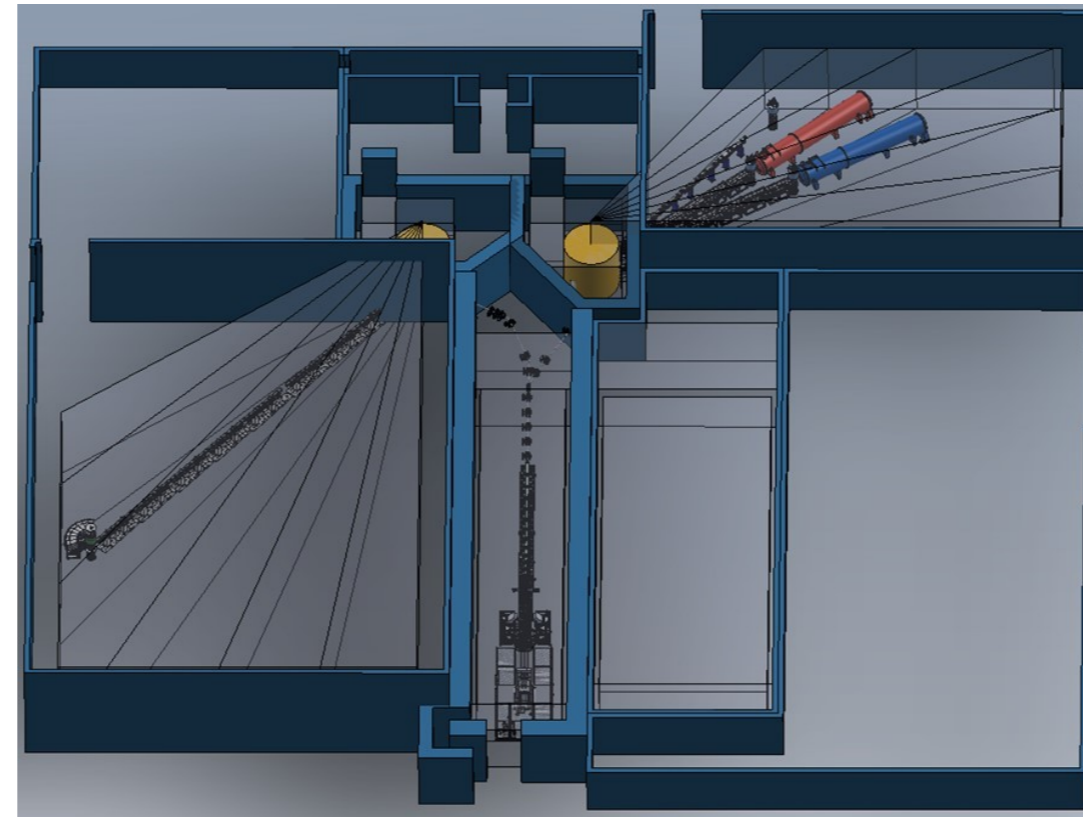
**Stratégie**



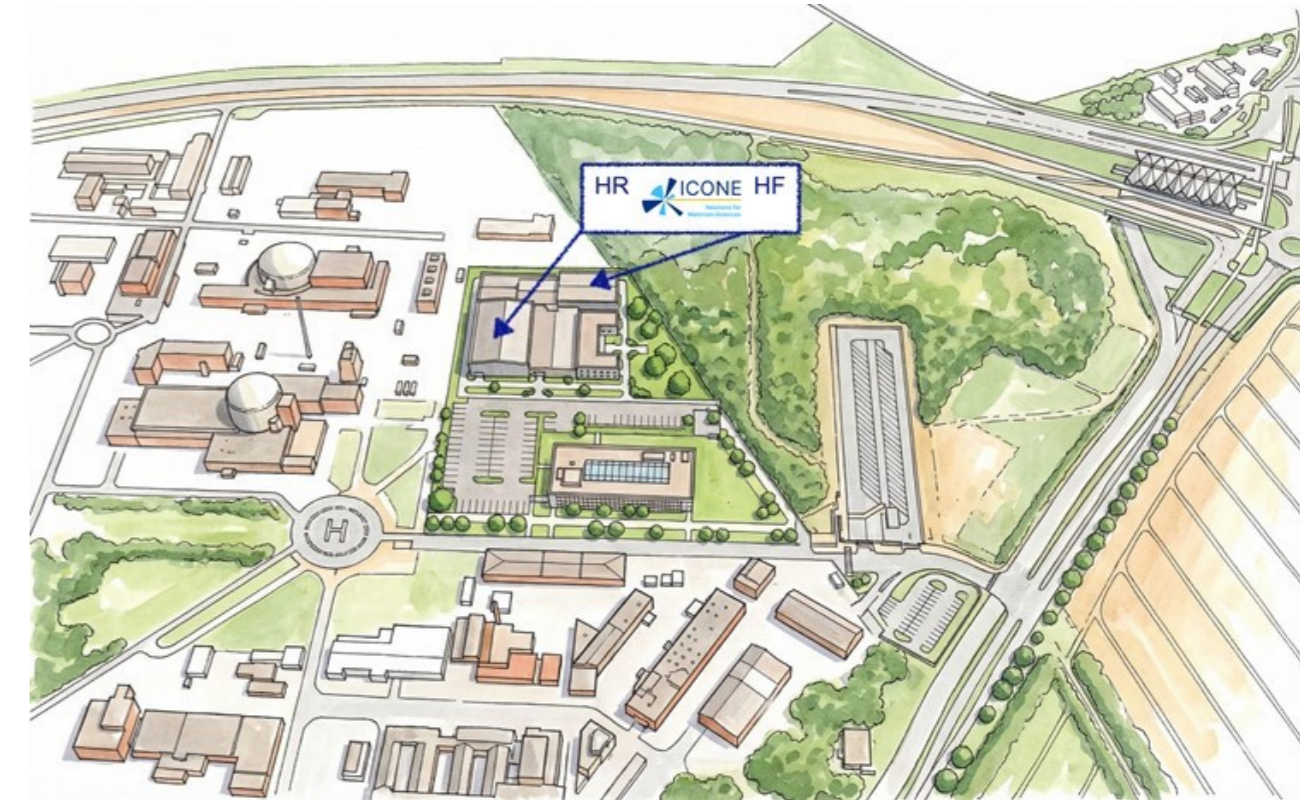
# Le projet ICONE



Esquisses « fonctionnelle »



Maquette 3D



Implantation

$$E_p = 25 \text{ MeV}, I_{av} = 3.2 \text{ mA}, I_{peak} = 80 \text{ mA}, \text{Power} = 80 \text{ kW}, \text{D.C.} = 4\%$$

5x5 m²  
1:500  
1 cm = 5 m



# Moving from « reactor » to « pulsed source »

## ■ ESS instrument suite

- The LLB is involved in the design and construction of 5 ESS instruments ☾ significant REX

|          |            |                                   |
|----------|------------|-----------------------------------|
| LOKI     | 2 – 22     | Cold                              |
| SKADI    | 3 – 21     | Cold                              |
| ESTIA    | 3.75 - 28  | Cold                              |
| FREIA    | 2 – 10     | Cold                              |
| NMX      | 1.8 – 10   | Cold                              |
| BEER     | 0.8 – 6    | BiSpectral                        |
| ODIN     | 1 - 10     | BiSpectral                        |
| DREAM    | 0.5 - 4.1  | BiSpectral                        |
| HEIMDAL  | 0.5 – 4    | « Thermal (Bispectral and Cold) » |
| MAGIC    | 0.6 – 6    | BiSpectral                        |
| CSPEC    | 2 - 20     | Cold                              |
| T-REX    | 0.7 - 6.5  | BiSpectral                        |
| BIFROST  | 1.5 – 6 A° | Cold                              |
| MIRACLES | 2 – 20 A°  | Cold                              |
| VESPA    | 0.4 – 4.7  | Thermal                           |

- All instruments are requiring cold neutrons
- A large fraction of the instruments are « bispectral »
- Only one purely thermal instrument



# A CONSIDERER

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- Dessin du modérateur froid de Brahim
- Est-ce que je parle de la source de neutrons rapides ?
- Impact de l'énergie primaire des neutrons rapide
- Impact du réflecteur (brillance – temps)
- Faire un dessin avec une cible mieux intégrée
- GEOUNED
- Continuer à compiler le fichier avec les sources des figures ☾  
//ICONE

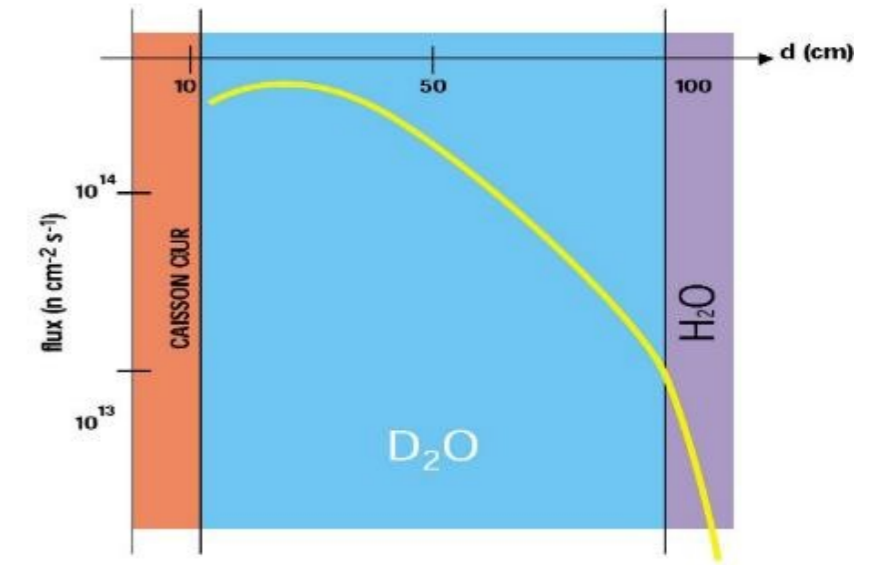
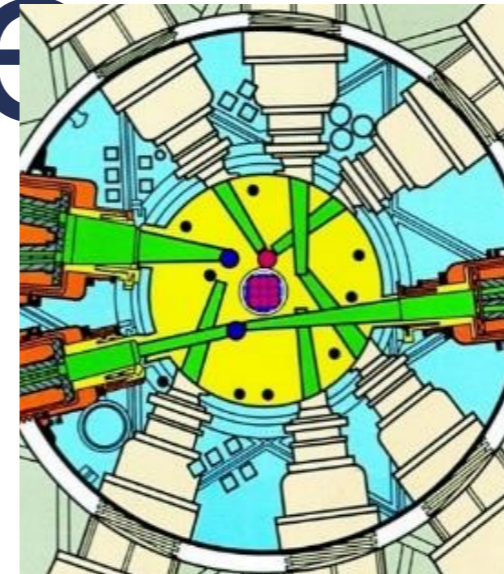


# Maximiser la brillance

## • Réacteur

Core = 0.1 m<sup>3</sup>

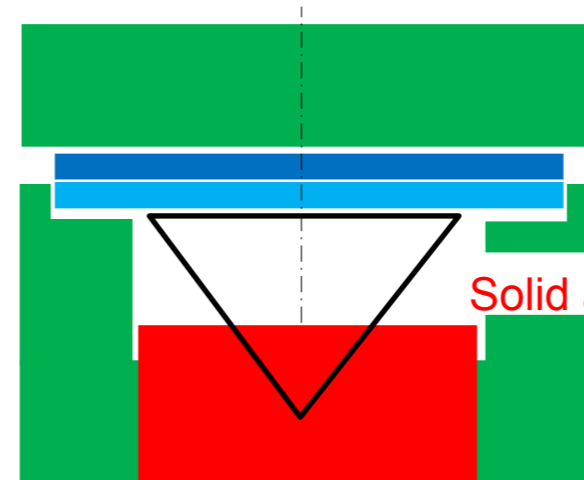
Moderator vessel D<sub>2</sub>O ~ 1m<sup>3</sup>



## • Spallation

target = 4 litres

moderator ~ 1 litre (not too well coupled)

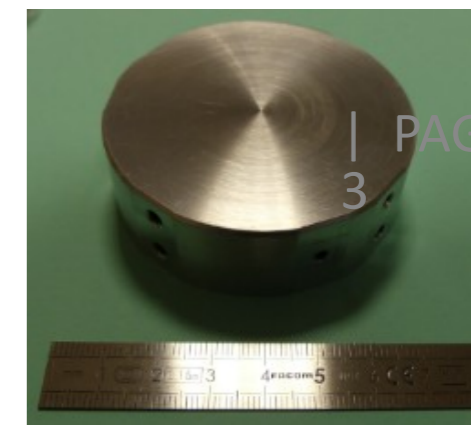
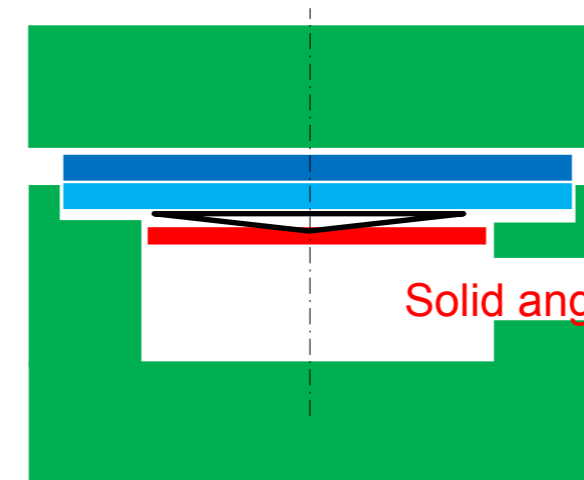
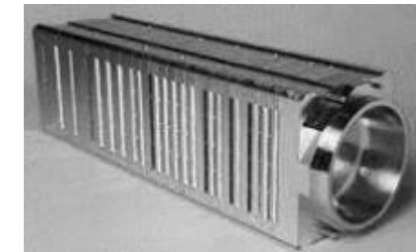


Réflector Be

Para-H<sub>2</sub> thickness 1.5cm, diamètre D<sub>M</sub> = 15 cm

Premoderator H<sub>2</sub>O

Thickness e<sub>PM</sub> = 2cm – diamètre D<sub>PM</sub> = 15 cm



## • Réactions nucléaires basse énergie



# Bilan • ICONE et HBS

|   | ICONE                     | HBS  |                       |
|---|---------------------------|--|-----------------------|
| Instruments   | 10 (+2)                   | 22   |                       |
| Energie LINAC   | 25 MeV                    | 70 MeV   |                       |
| Cible   | Béryllium                 | Tantale  |                       |
| $I_{\text{peak}}$                                       | 80 mA                     | 90 mA*   |                       |
| Cycle utile   | 4%                        | 1.6%*  |                       |
| $I_{\text{av}}$   | 3.2 mA                    | 1.44 mA  |                       |
| Puissance faisceau protons                              | 80 kW                     | 100 kW   |                       |
| Fast neutron yield                                      | $0.44 \times 10^{15}$ n/s | $1.0 \times 10^{15}$ n/s                               | Factor 2.3 (th. 2.4)  |
| Brillance moyenne (à 5Å)<br>[n/s.cm <sup>2</sup> .sr.Å] | $1.2 \times 10^{10}$      | $1.6 \times 10^{10}$ **<br>(config. « SNS - 1 layer ») | Factor 1.3 (th. 2.3)  |
| Brillance crête (à 5Å)<br>[n/s.cm <sup>2</sup> .sr.Å]   | $0.3 \times 10^{12}$      | $1 \times 10^{12}$ **<br>(config. « SNS - 1 layer »)   | Factor 3.3 (th. 5.75) |

\* From HBS/TDR Vol. 3 « Instrumentation » p.14

\*\* From HBS/TDR Vol. 2 « Target » p.86



# SHIELDING - ACTIVATION

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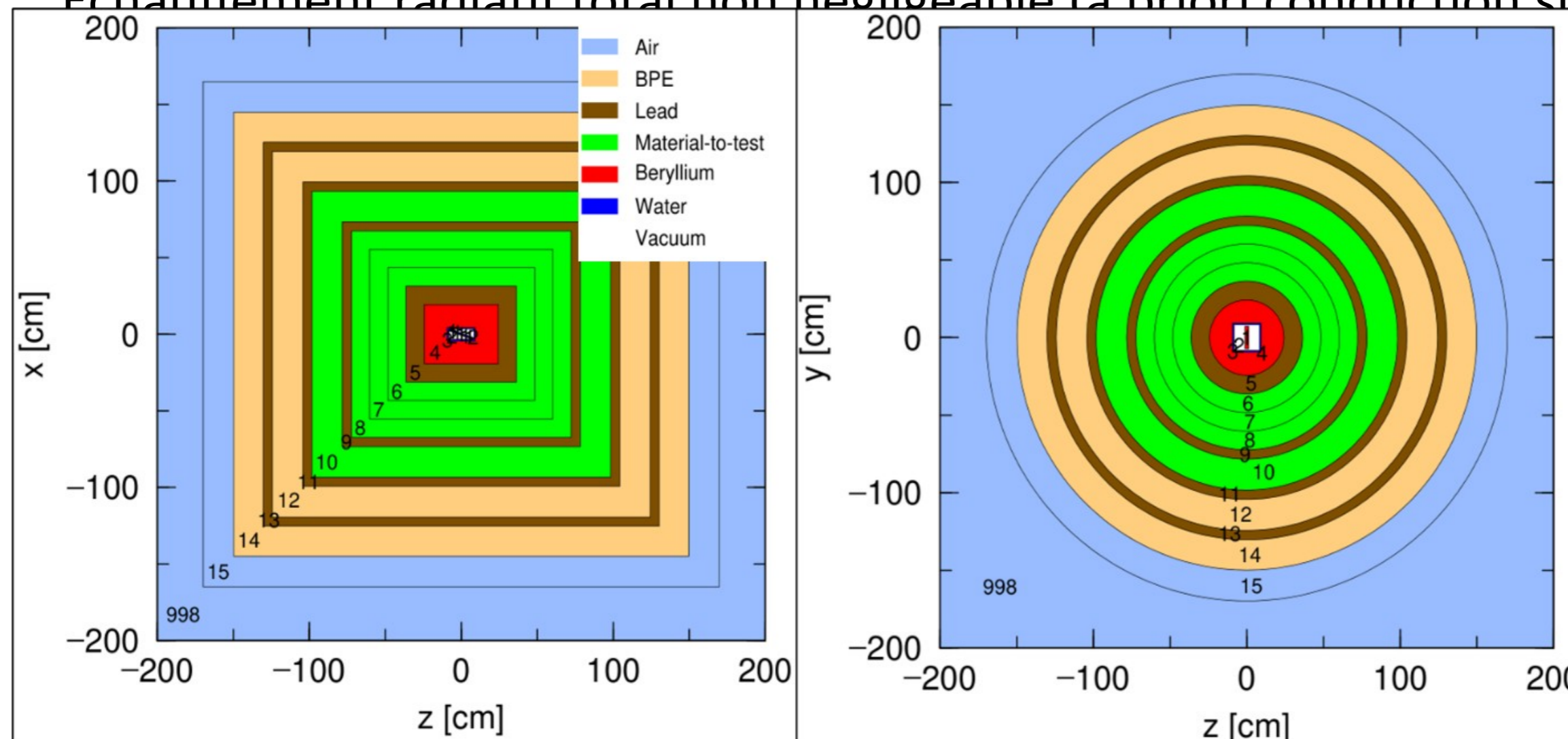


# Monolithe

- Problématique de l'endommagement des matériaux

Durée de vie Polyéthylène est trop réduite dans la partie centrale (vert)

Echauffement radiatif total non négligeable (a priori conduction suffit)



|                                   |
|-----------------------------------|
| Mild steel (7.7g/cc)              |
| Magnadense Concrete (3.8 g/cc)    |
| Limestone Concrete (2.3 g/cc)     |
| Ordinary NIST Concrete (2.3 g/cc) |



# Doses autour de la TMR

- Doses à l'extérieur du shielding de la TMR en fonctionnement

| Configuration                     | h*(10) rate ( $\mu\text{Sv/h}$ ) in region 15 |        |        | Zone   |
|-----------------------------------|---|--------|--------|--------|
|                                   | Neutron ( $\pm 5\%$ )                         | Photon | Sum    |        |
| Mild steel (7.7g/cc)              | 87.7  | 118.5  | 206.2  | Yellow |
| Magnadense Concrete (3.8 g/cc)    | 661.3   | 25.0   | 686.3  | Yellow |
| Limestone Concrete (2.3 g/cc)     | 3333.3  | 1023.2 | 4356.5 | Orange |
| Ordinary NIST Concrete (2.3 g/cc] | 1266.2  | 52.2   | 1318.4 | Yellow |

- Doses

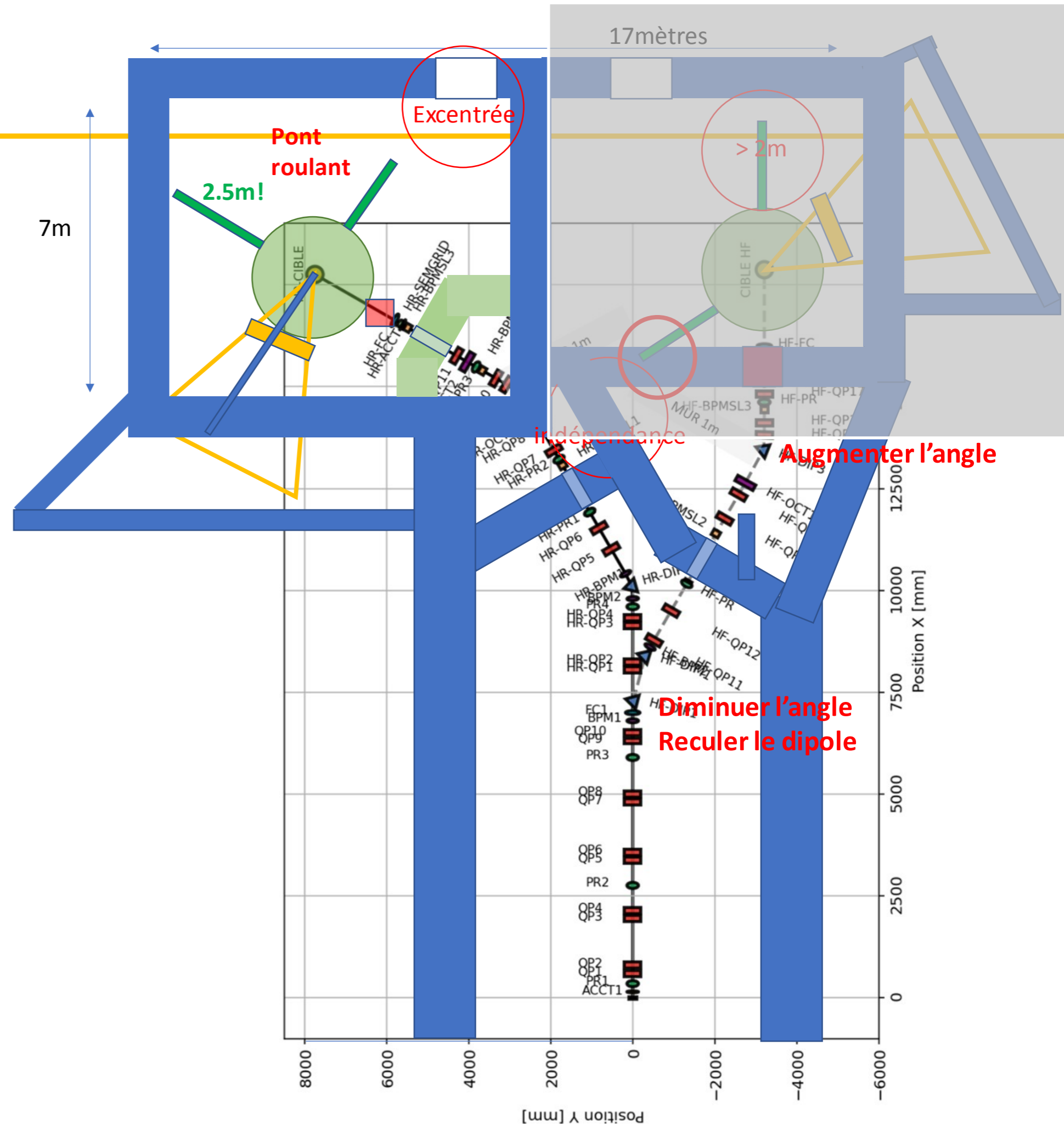
| Configuration                     | Photon dose rate h*(10) rate in region 15 | Zone |
|-----------------------------------|---|------|
| Mild steel (7.7g/cc)              | < 10 nSv/hour                             | Blue |
| Magnadense Concrete (3.8 g/cc)    | < 10 nSv/hour                             | Blue |
| Limestone Concrete (2.3 g/cc)     | < 10 nSv/hour                             | Blue |
| Ordinary NIST Concrete (2.3 g/cc] | < 10 nSv/hour                             | Blue |

# Casemate



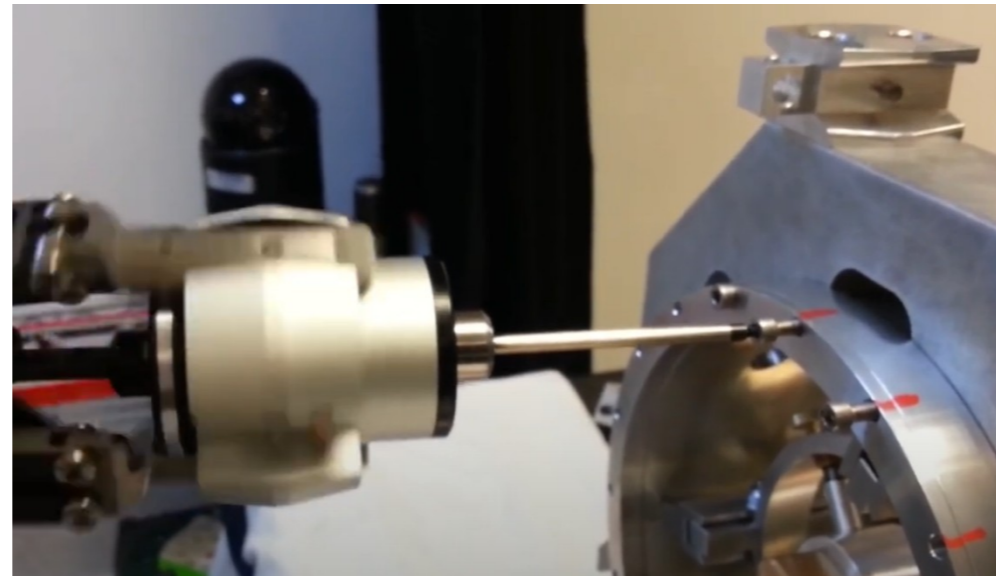
- Organisation { accélérateur + TMR + Casemate + sorties faisceau } en discussion

- De nombreux choix techniques à faire



# Opérations de maintenance à distance ?

- Pour certaines opérations il existe des manipulateurs



*Figure 75: (left) Dexter Remote manipulator (Veolia Nuclear Solutions); (middle) one of the arms screwing a bolt; (right) Simulation of a robot operating at Fukushima.*



# Conclusion - Statut

|             |                                    |                             |   |
|-------------|------------------------------------|-----------------------------|---|
| CIBLE       | Construction support V2.1 et 2.2   | OK                          | Nouveau protocole de construction à l'étude<br>Impression 3D ?                                |
|             | Test érosion                       | OK                          |   |
|             | Tests sous faisceau                | Pas de solution court terme |   |
|             | Solution « Multi-Couche »          | En attente                  | Fournisseur OK / non critique + attente faisceau  |
| MODERATEUR  | Calcul performances V1.0           | Disponible                  | Interface vers instruments à affiner  |
|             | Dépendance temporelle + réflecteur | OK                          | Mettre au propre / compare Vs HBS   |
|             | Intégration cible                  | En cours                    | A affiner / CAD ☾ MC  |
|             | Design partie cryogénique          | A faire                     | Upgrade Prototype existant / low risk   |
| ACTIVATION  | Partie { Cible + proton }          | Disponible                  |   |
|             | Partie Shielding                   | Disponible                  | <b>Travailler sur les « inserts »</b>   |
|             | Partie modérateur                  | A faire                     | A lancer / low risk   |
| SHIELDING   | Monolithe                          | Disponible                  |   |
|             | Système construction monolithe     | En cours                    | Premier modèle CAD existe + CAD ☾ MC  |
|             | Casemate                           | En cours                    | Première implantation proposée (OK pour TS1)<br>Activation casemate et équipements à calculer |
| INTEGRATION | Principe de manutention            | Solutions proposées         | Protocoles à affiner  |
|             | Dessins des outils                 | Sous-traitance              | Onéreux / se limiter à CdC / Certification  |