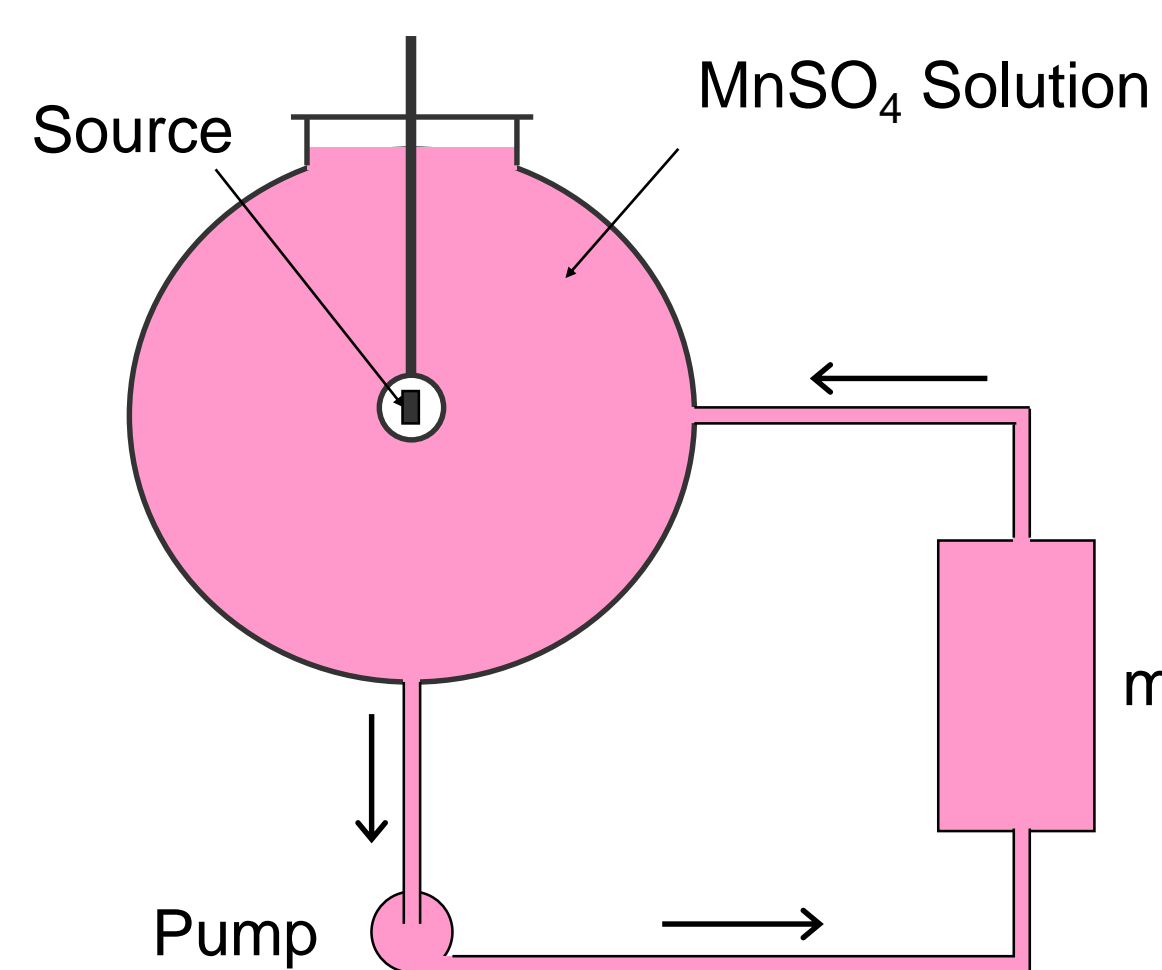


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The reference method for neutron sources emission rates measurements is based on the manganese bath method. The neutron emission rate is determined from the induced ^{56}Mn activity produced in the bath ($T_{1/2} \sim 2.6$ h). This activity is generally measured by γ -spectrometry which require a previous calibration using a standard ^{56}Mn solution with high activity. We present a new approach using a primary measurement system based on a Cherenkov TDCR counter to determine the ^{56}Mn activity. This system is directly mounted on the bath for online measurements.

→ Neutron sources emission rates



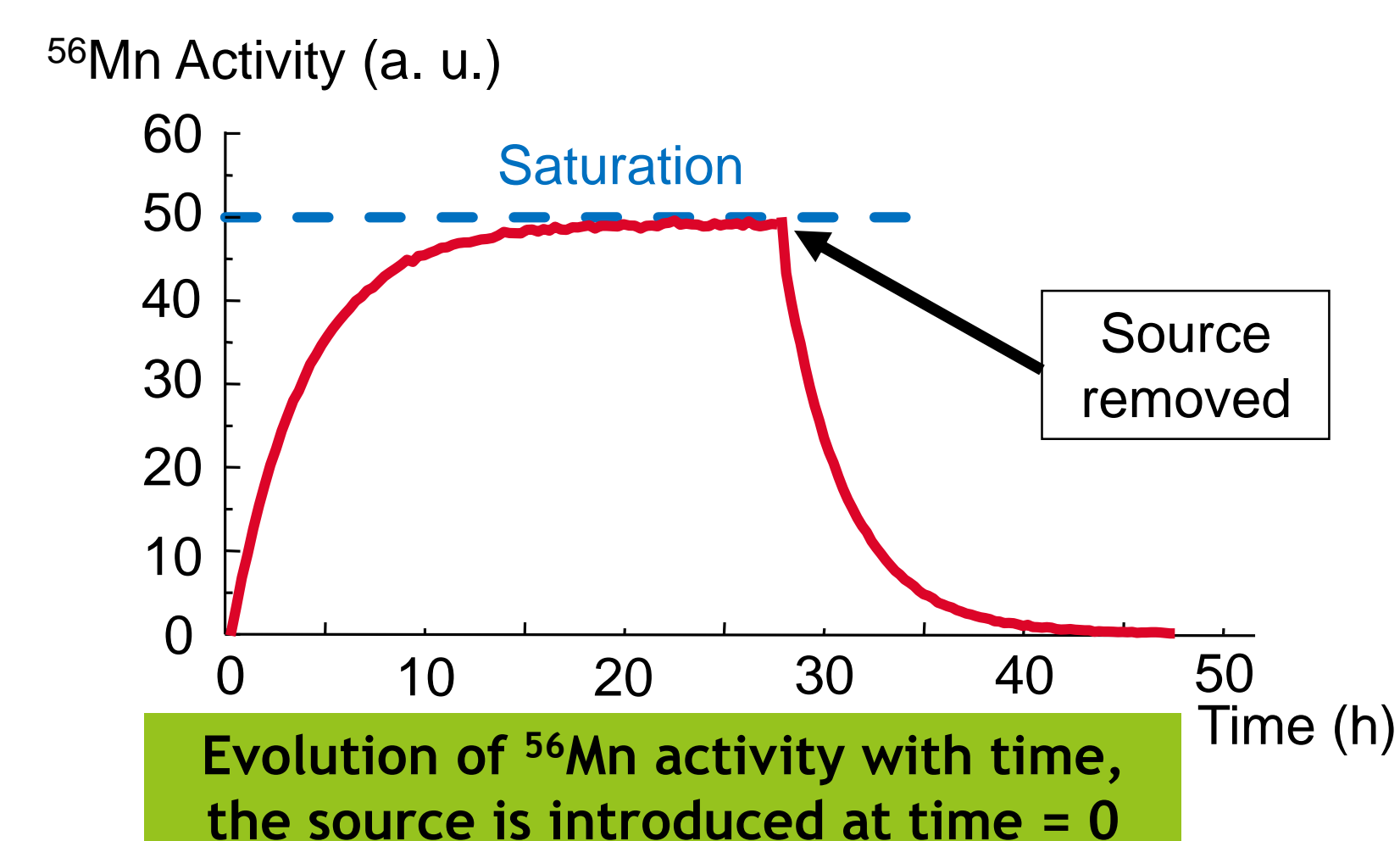
Principle of a manganese bath

- A stainless steel sphere of 1 m diameter is filled with MnSO_4 solution.
- The neutron source ($^{241}\text{Am}^9\text{Be}$, ^{252}Cf , ...) is placed in the center of the bath.
- The manganese present in the bath is activated by neutrons by the (n, γ) reaction:



- The source remains in the bath for more than 25 hours to reach a saturated activity of ^{56}Mn .
- The neutron flux from the source is calculated as follows: $\Phi = \frac{A_{\text{sat}}}{R}$

$$A_{\text{sat}} \text{ is the } ^{56}\text{Mn} \text{ activity measured at saturation.}$$

 R is the bath efficiency calculated by Monte Carlo simulations.


→ The energy of the β^- particle emitted by ^{56}Mn is such that light is produced by the Cherenkov effect in the MnSO_4 solution. The TDCR/Cherenkov method is thus used to determine the ^{56}Mn activity.

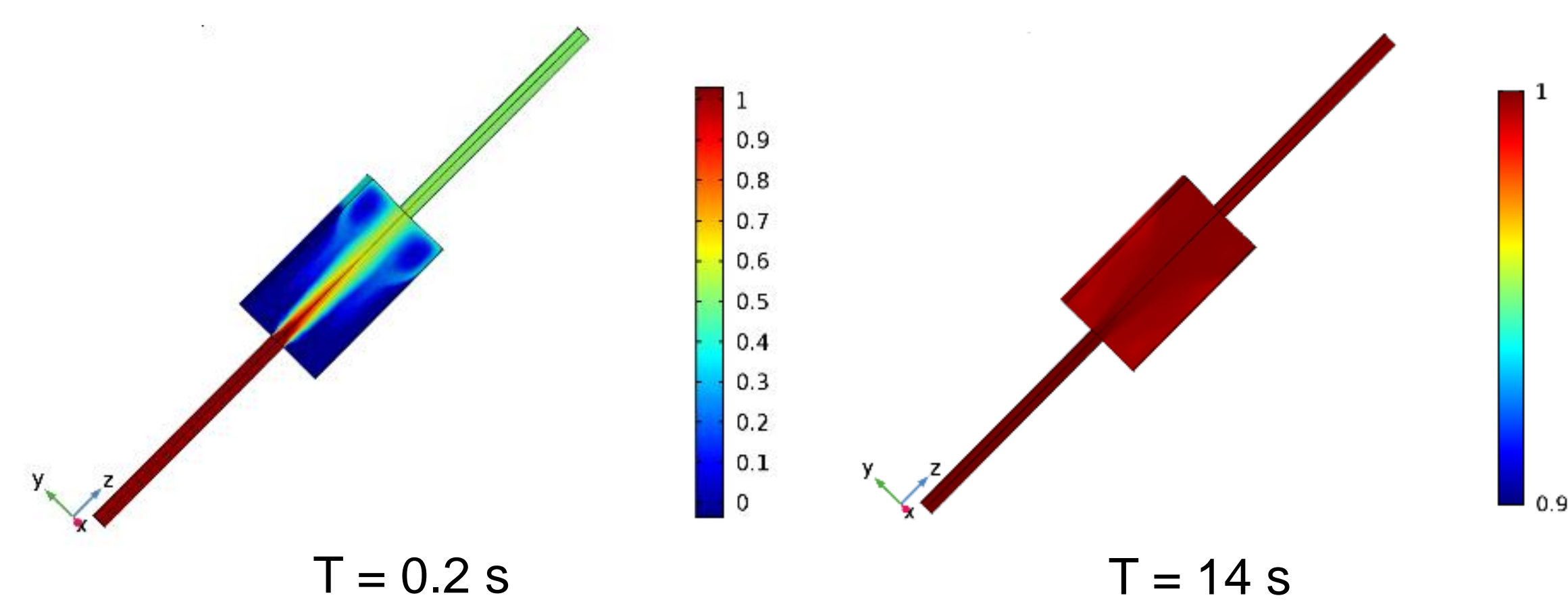
→ Vial used for the circulation and measurement of ^{56}Mn



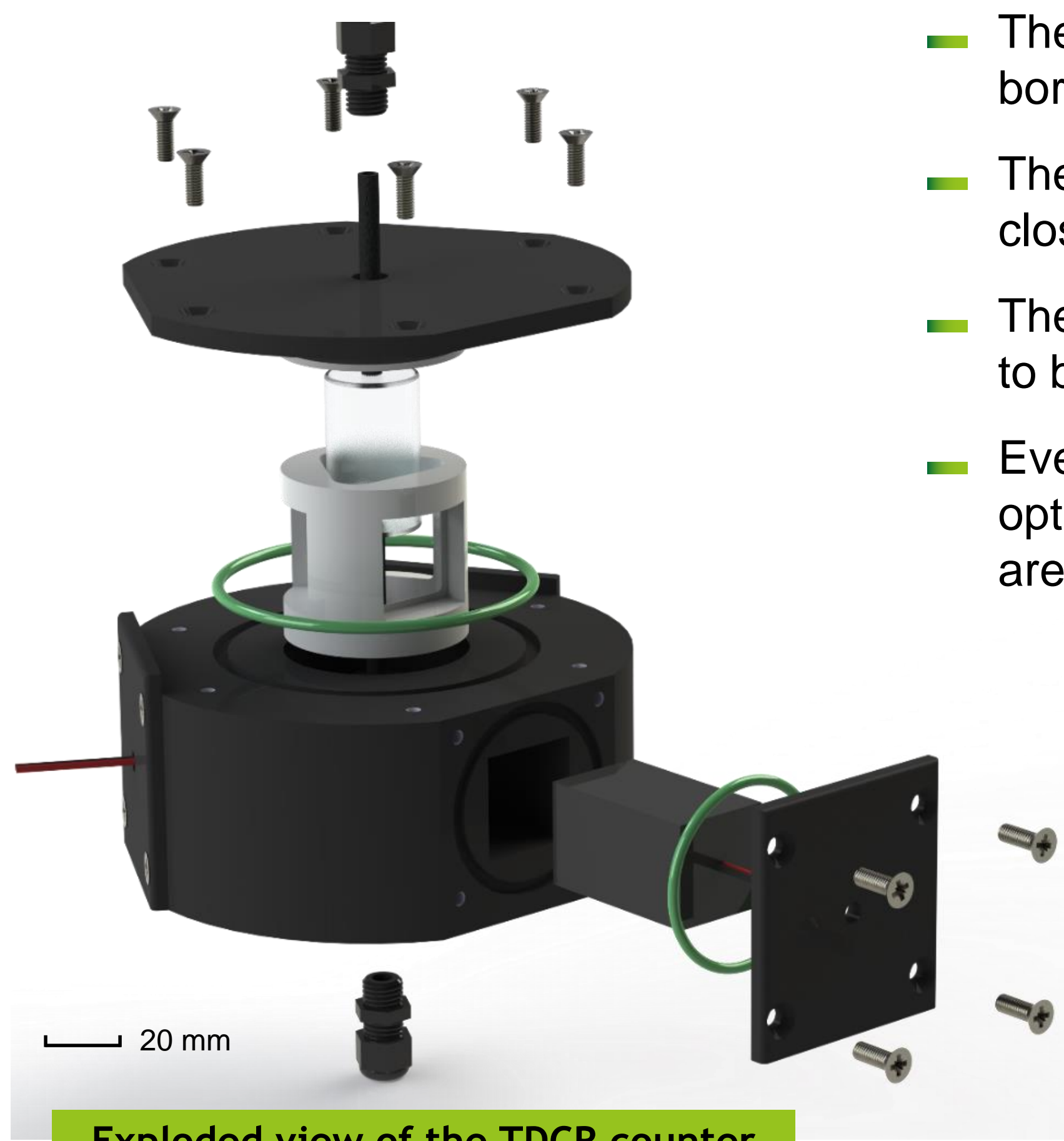
Circulation vial vs 20 mL LS vial

- Volume and diameter similar to a commercial liquid scintillation 20 mL vial.
- Quartz vial with low UV absorption.
- Inlet and outlet at the top and bottom of the vial for PM tube placed on the side of the vial.
- Frosted surface to prevent internal reflection.
- Flow rate of $2 \text{ L} \cdot \text{min}^{-1}$ to allow short transit time and good homogeneity in the vial.

→ Less than 0.1% of activity concentration fluctuation into the vial after 14 s of manganese solution circulation.

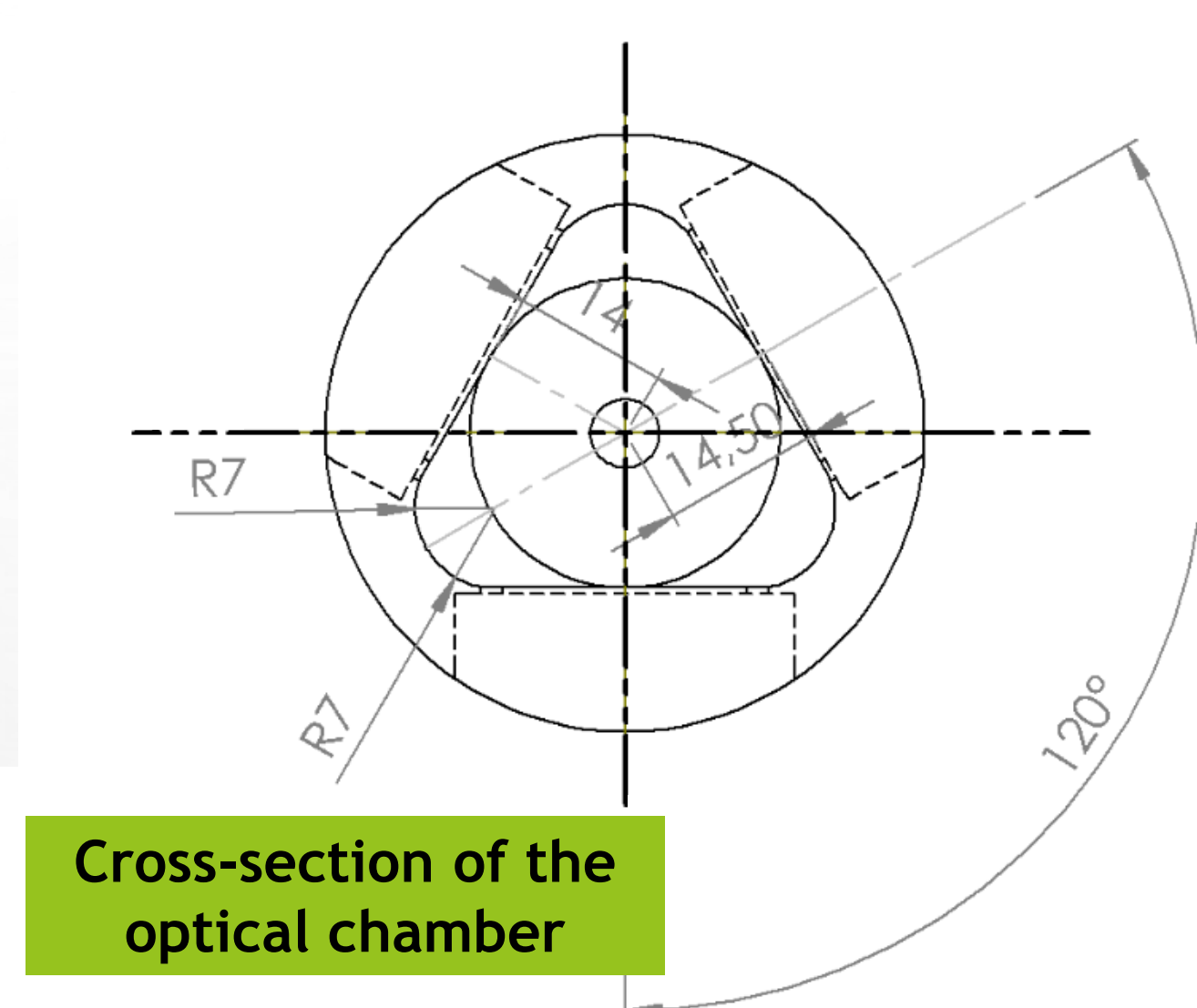

 Normalized concentration of MnSO_4 solution in the vial with time (Comsol Multiphysics Simulations)

→ Development of the TDCR system

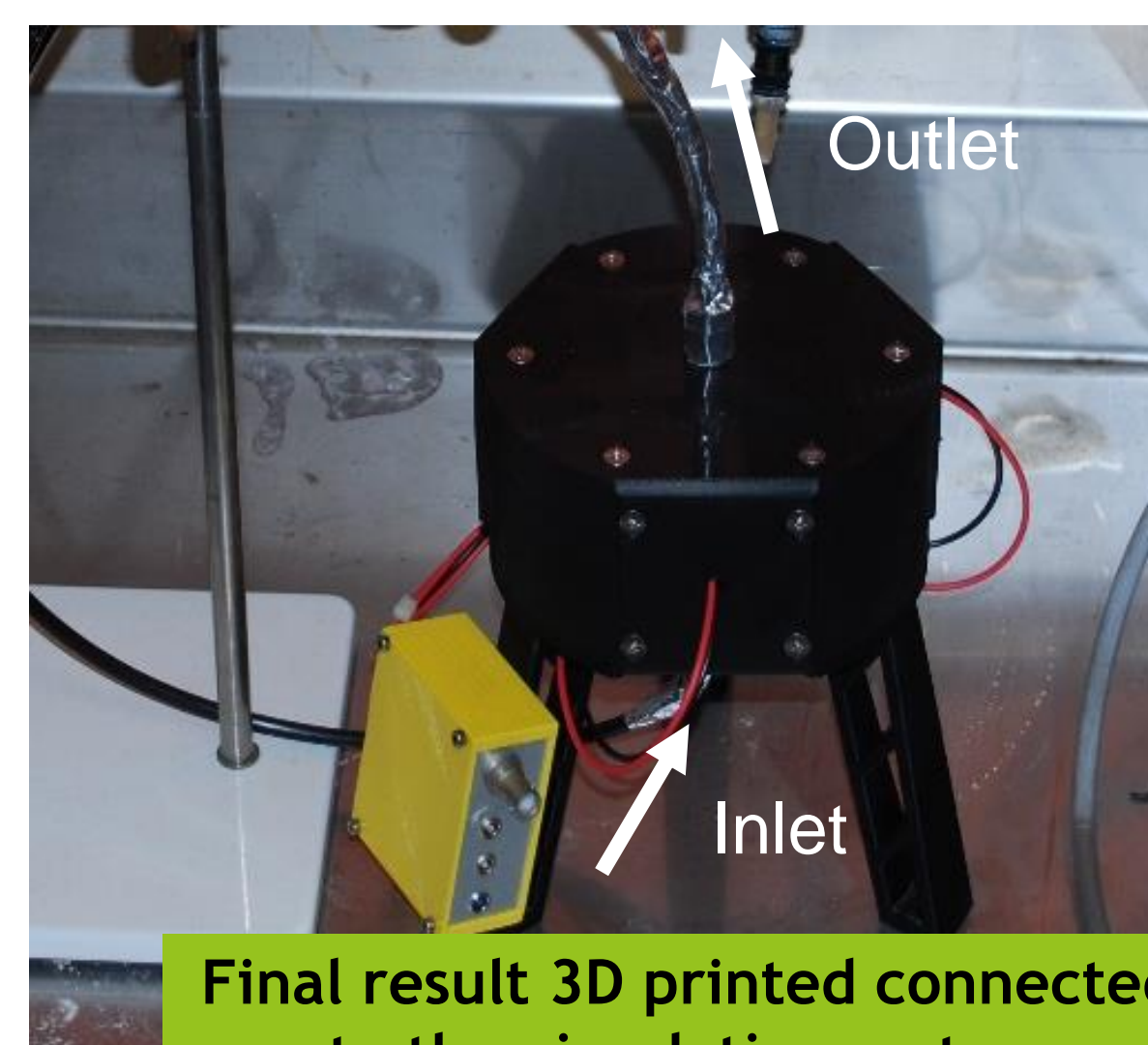


Exploded view of the TDCR counter

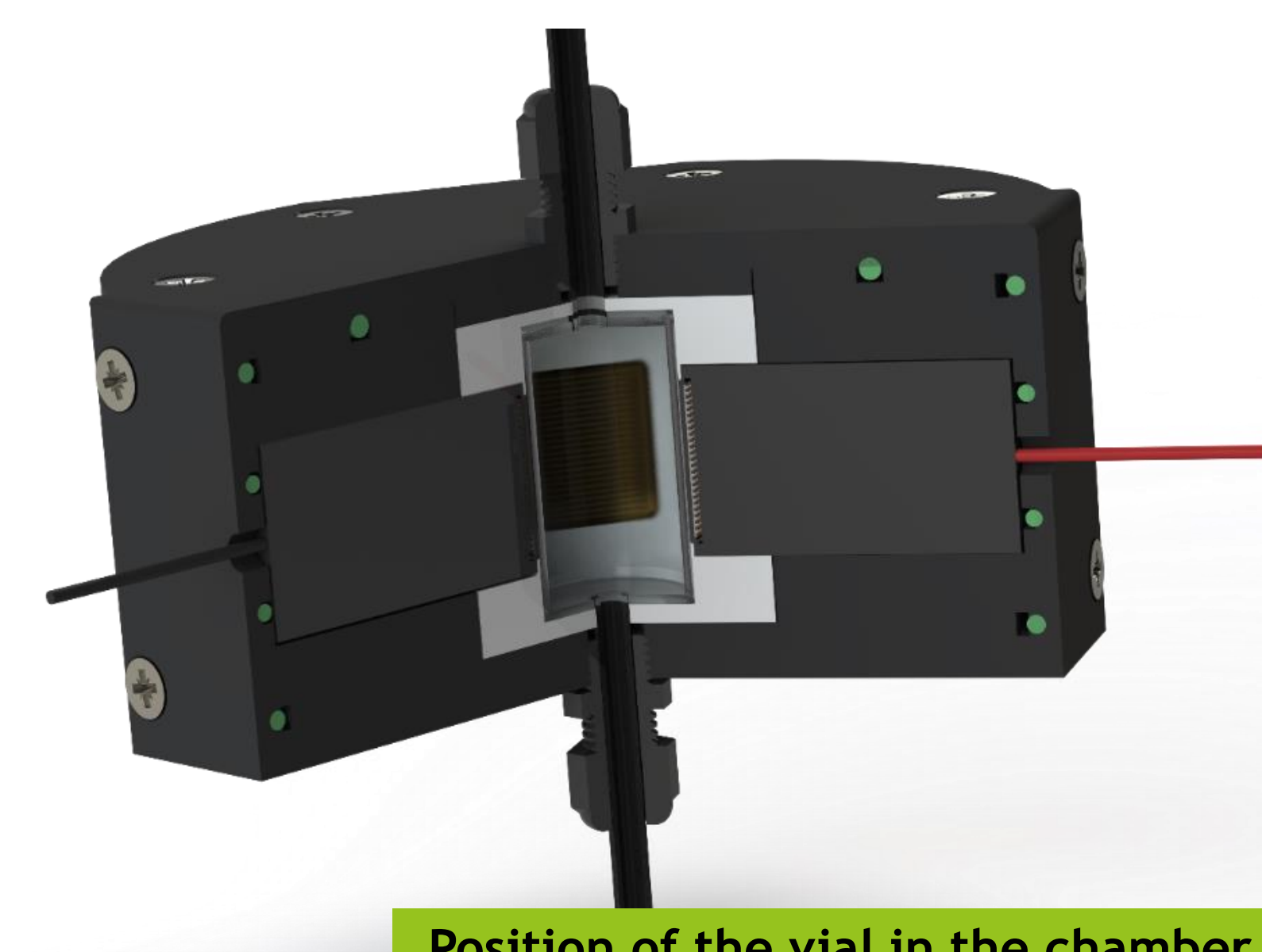
- The photomultiplier tubes (PMT) have a super bi-alkali photocathode and a borosilicate window giving a quantum efficiency of 33% at 350 nm.
- The vial is positioned at the center of the optical chamber and the PMTs are as close as possible to the vial.
- The optical chamber (white) can be easily removed from the other parts in order to be able to change its shape.
- Every part is 3D-printed using fused deposition modeling (FDM) method. The optical chamber was printed with white polylactide (PLA) while the other pieces are made of black PLA.



Cross-section of the optical chamber



Final result 3D printed connected to the circulation system



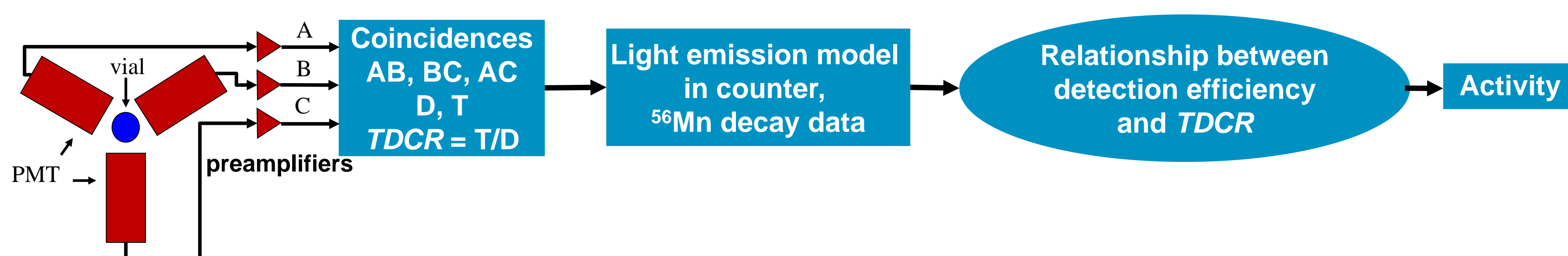
Position of the vial in the chamber

The final system was printed within two days. The pieces are adjusted with a precision of $100 \mu\text{m}$.

The anodes of the PMTs are connected through fast preamplifiers and constant fraction discriminators to a dedicated compact FPGA electronic module developed at LNHB. The final system is very compact (~ 15 cm diameter).

→ Calculation method, first results and discussion

The activity measurement uses an analytical model adapted from PTB (presented in this conference by C. Thiam):



An AmBe source was placed into the sphere and the measurements were performed:

- The background count rate is 0.2 s^{-1} . We performed also a gamma measurement with a calibrated NaI detector, this measurement allowed us to evaluate experimentally the detection efficiency of ^{56}Mn at 45%.

This first experiment showed a significant improvement of the efficiency compared to the Cherenkov- γ coincidence system. There are still some improvement possibilities:

- Use of different PM tubes: same shape but larger surface, quartz window and a quantum efficiency of 43% at 350 nm.
- Optimization of the chamber shape; with the 3D printing method, we can easily create other optical chamber shapes to improve the efficiency of the system.

Typical uncertainty budget

Component	Details	Relative standard uncertainty (%)
Counting statistics	Measurement variability	0.1
Statistical light emission model	Due to the variability of the physics properties of the model	0.5
Mass of solution	From the volume of the vial	0.3
Live time	Clock	0.01
Decay scheme of ^{56}Mn	Recommended data from DDEP	0.5
Background	Counting coming from external light, cosmic rays, natural radioactivity	0.05
Combined relative standard uncertainty (%)		0.8

→ This system will be used for the CCRI (IIII): K9.AmBe.2 and K9.Cf comparisons which started in 2017.