Hyper-Kamiokande Calibration (WP3.2)

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EU grant n.822070

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On behalf of the Hyper-K calibration group

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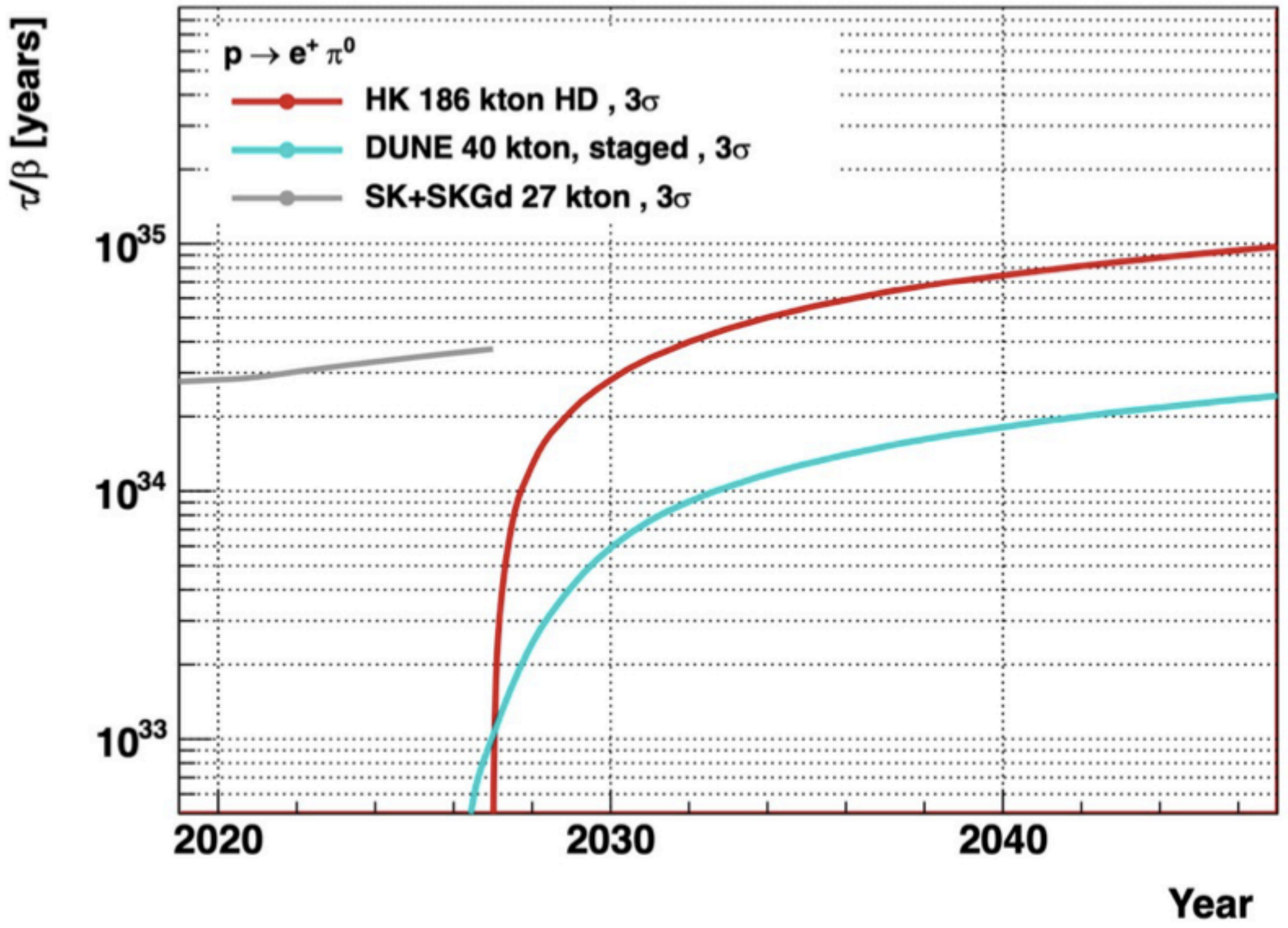
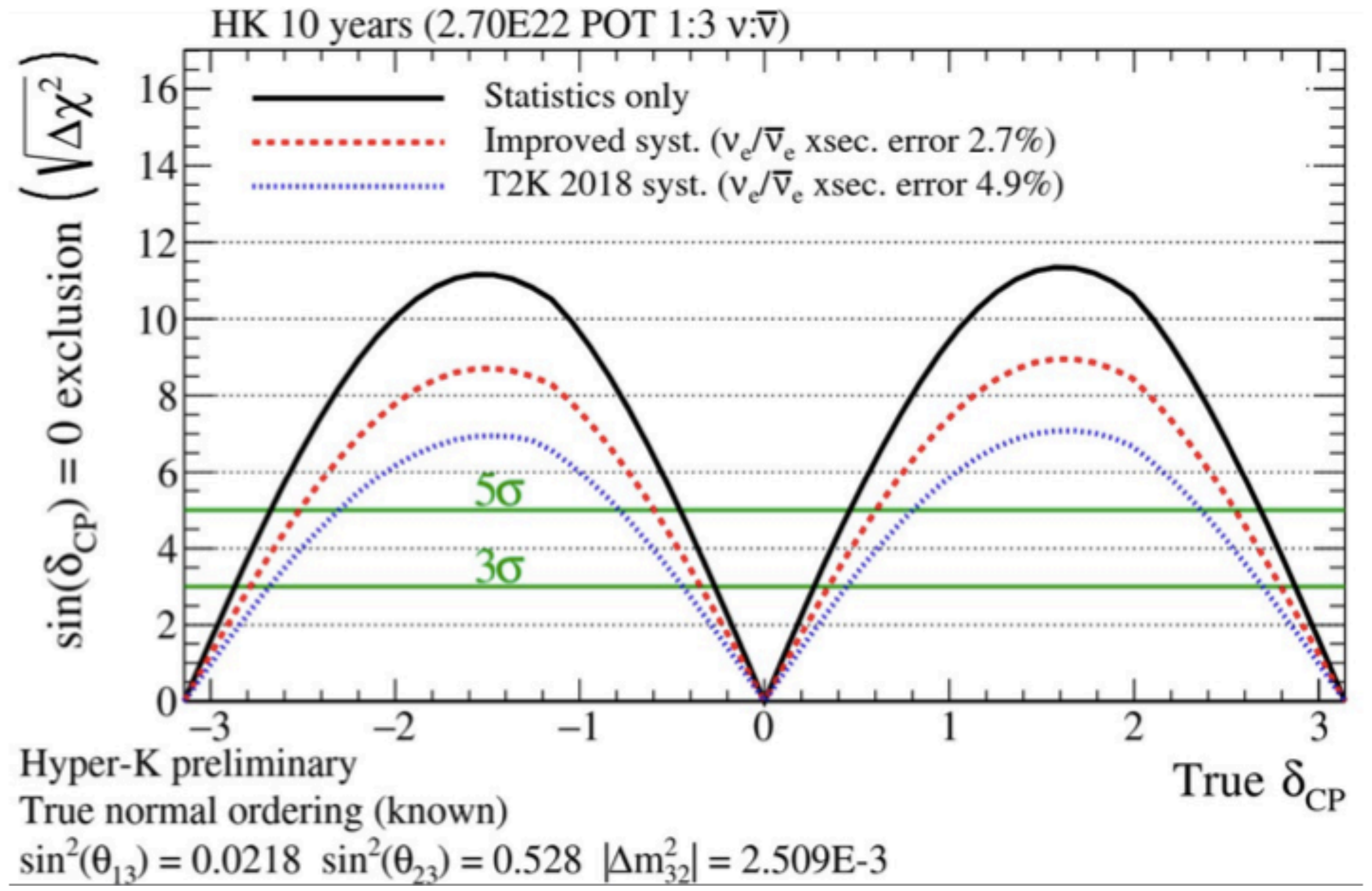
Hyper-Kamiokande Physics Goals

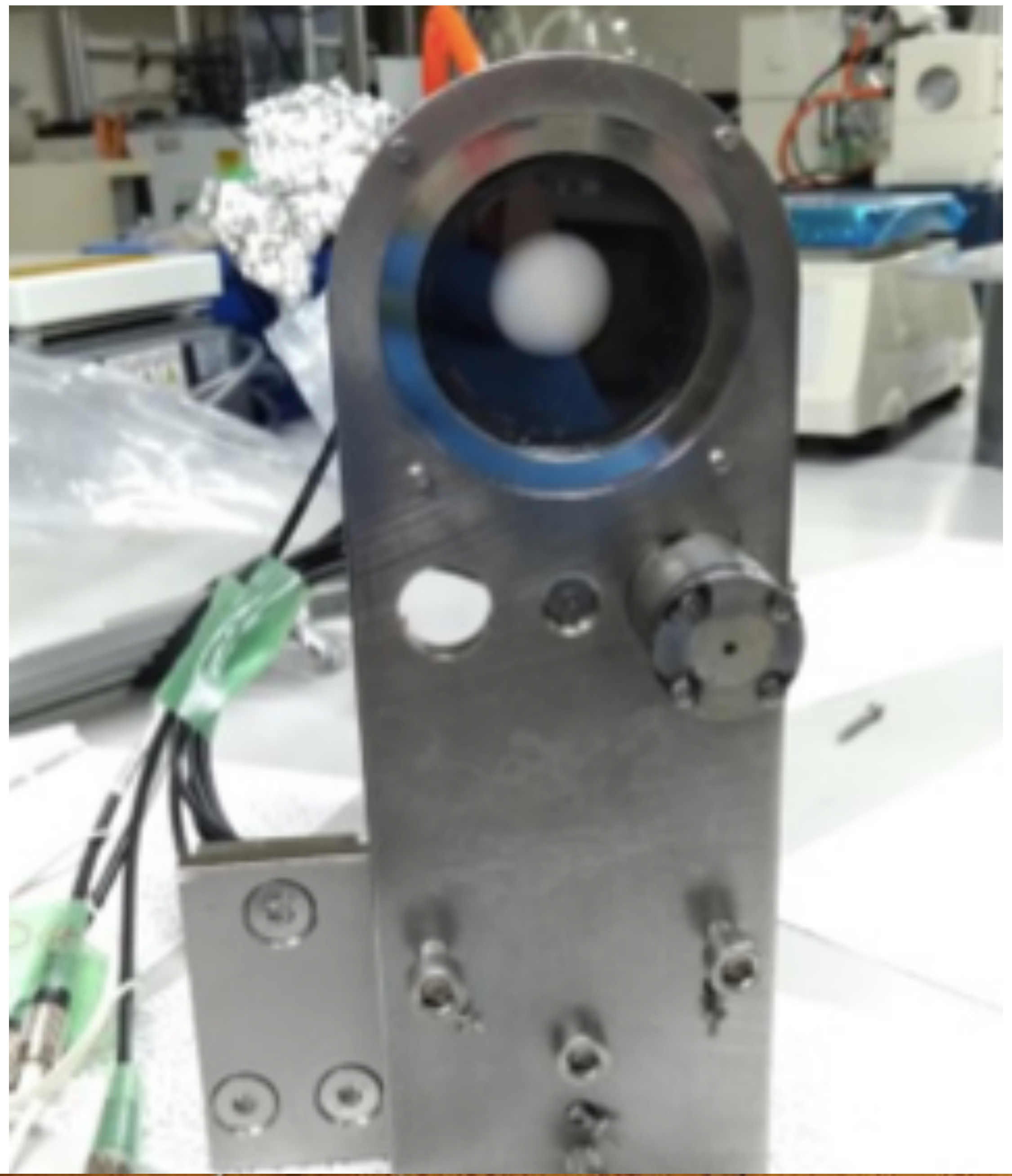
- Aiming to start data taking in 2027
- Wide programme of physics goals
- Neutrino oscillations
  - CP violation
  - Mass ordering
  - θ_{23} octant
- Proton decay
- Supernovae alarm
- SN relic neutrinos





Detector Calibration

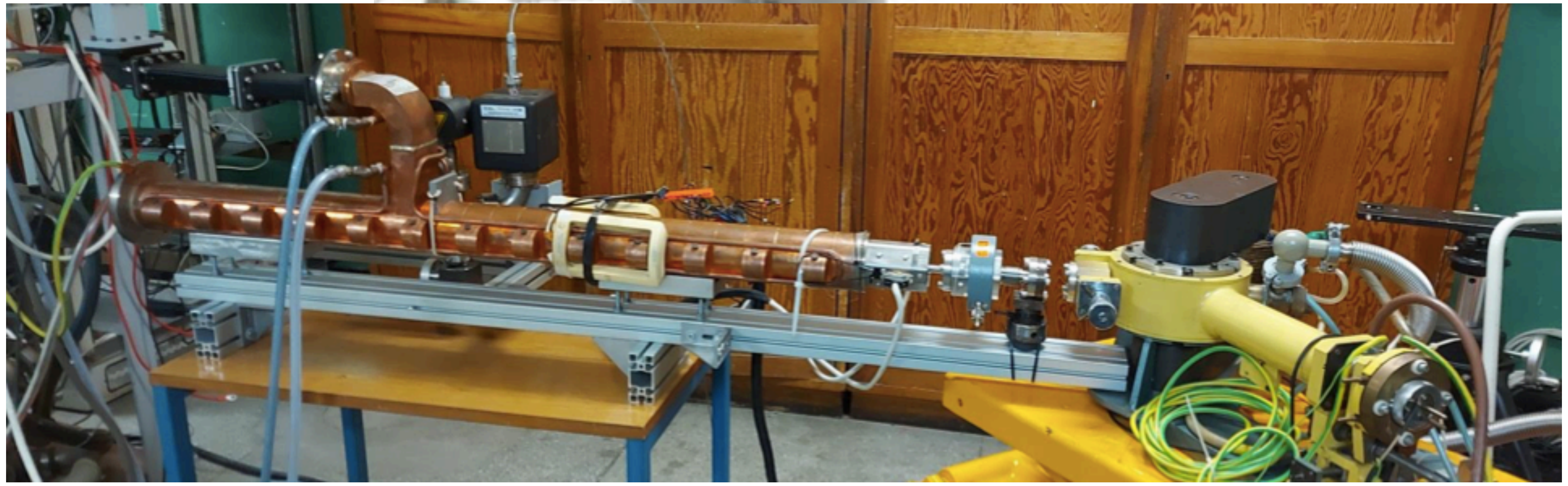
- Important to fully understand detector systematics - ~1% uncertainty needed
- Wide array of detector calibrations:
  - Light injection system
  - PMT precalibration
  - DT generator
  - NiCf gamma source
  - AmBe source
  - Electron LINAC



LI system injector housing in SK

SK nickel source

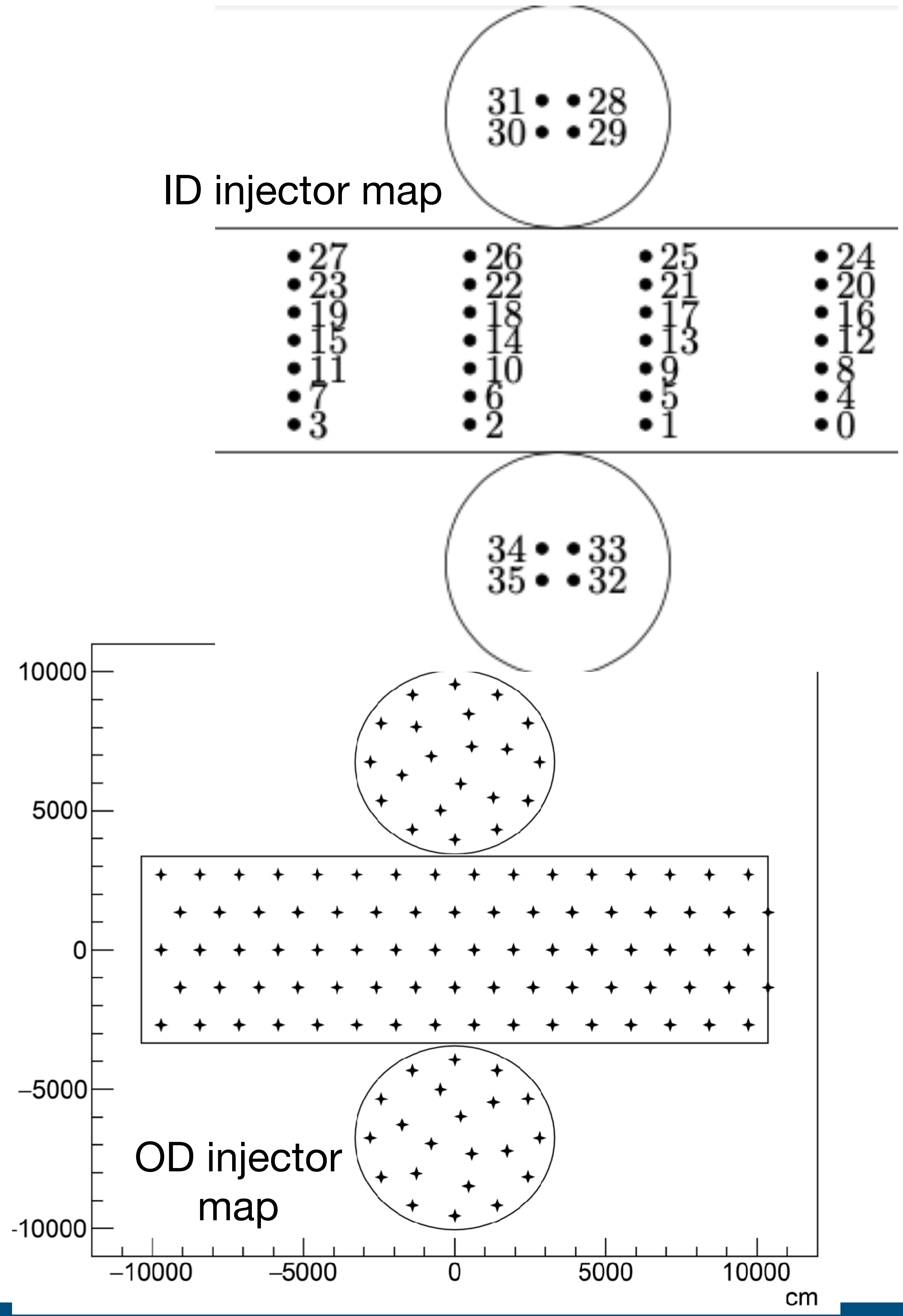
LINAC test setup



Light Injection System

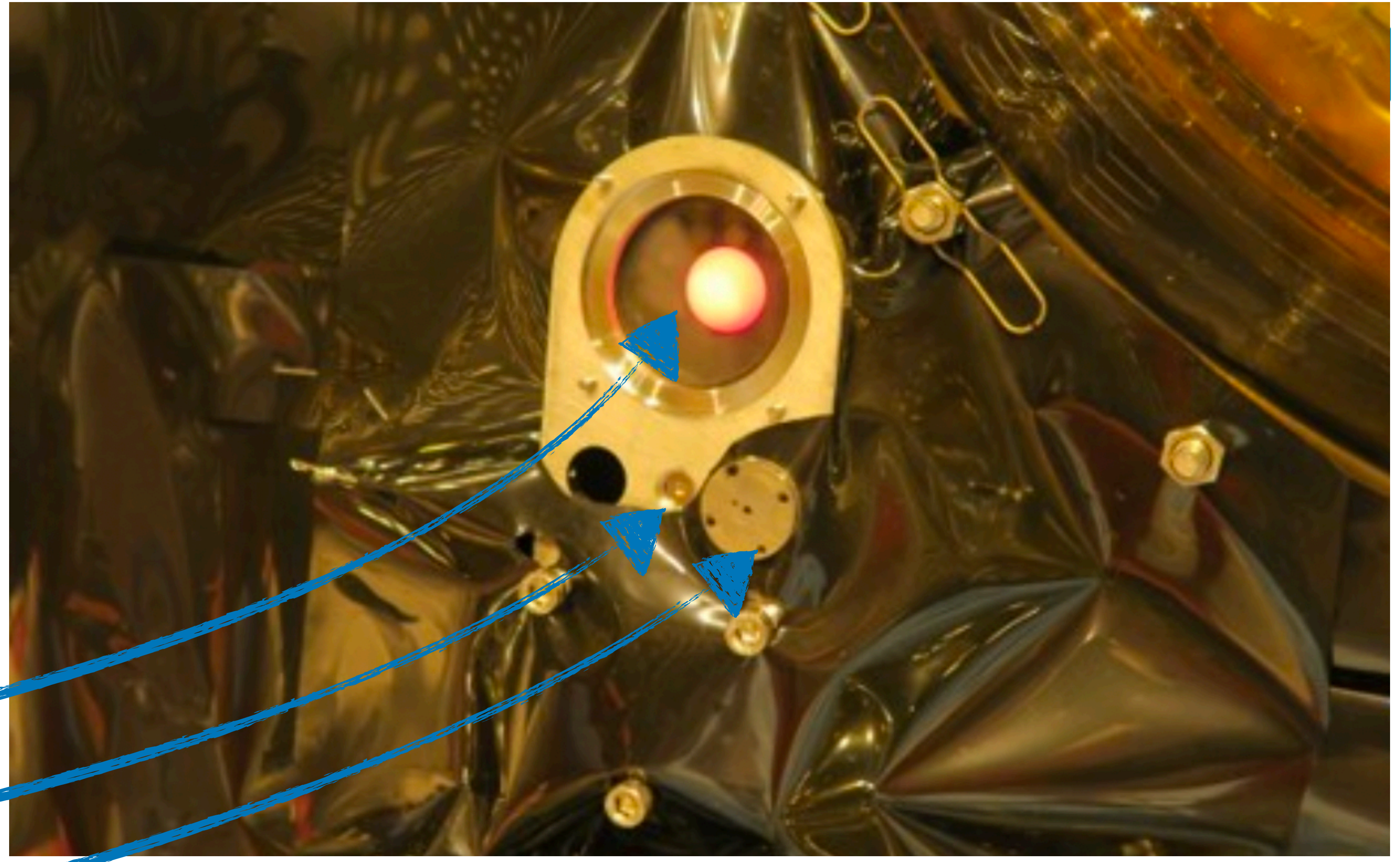
Introduction

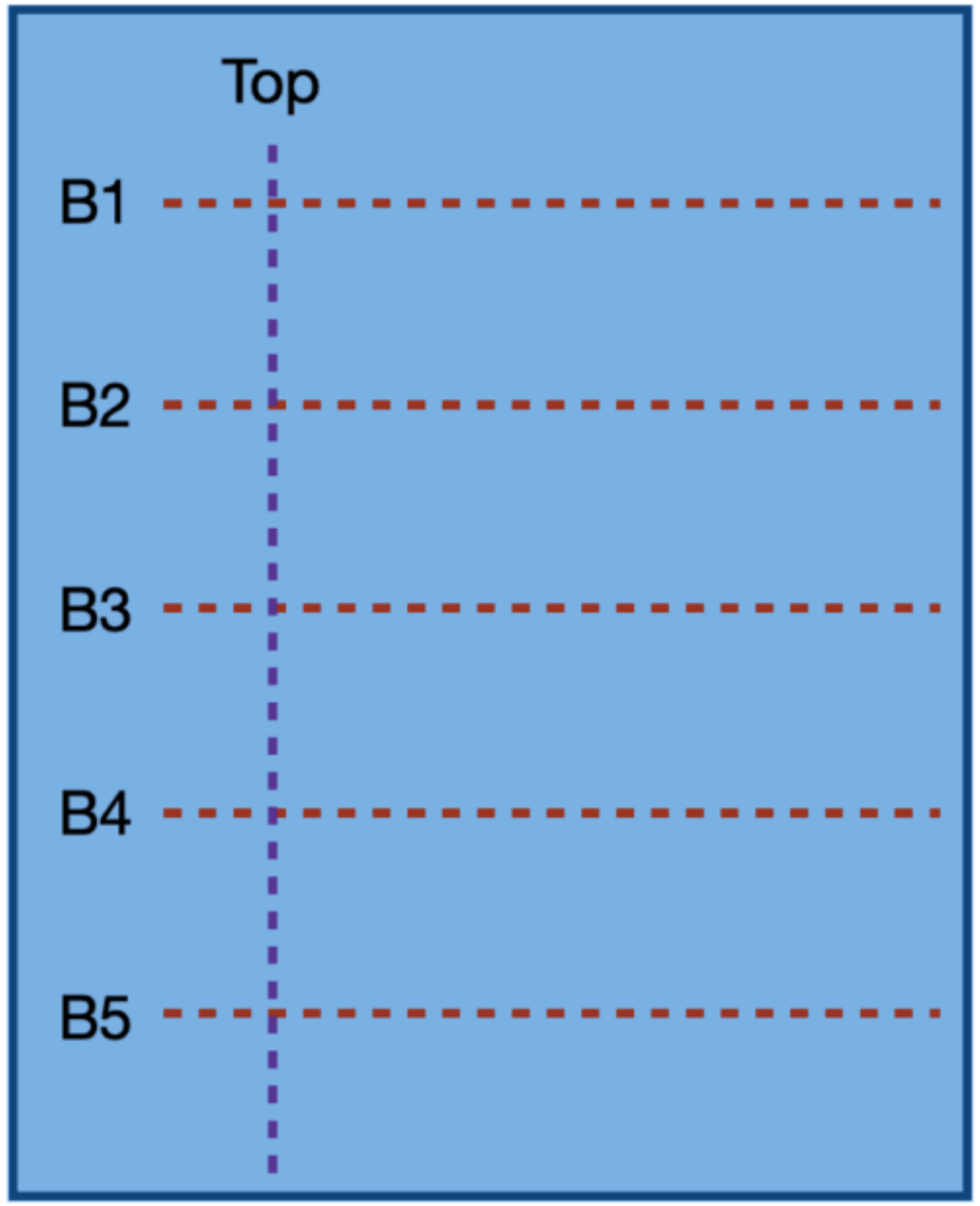
- Plan to use light injection system to characterise PMT response to known light levels
- ID - 36 injector positions, each with a collimated and diffuse light injector, using a laser source
- OD - 122 diffuse injector positions (80 in barrel, 21 per end cap) plus 12 collimators, using pulsed LED sources
  - Positioned on the inner wall of the OD, facing the outer Tyvek wall
- Similar to UKLI system installed in Super-K in 2018 - optics used in the Super-K system serve as a base for further prototyping and development



UKLI system in SK

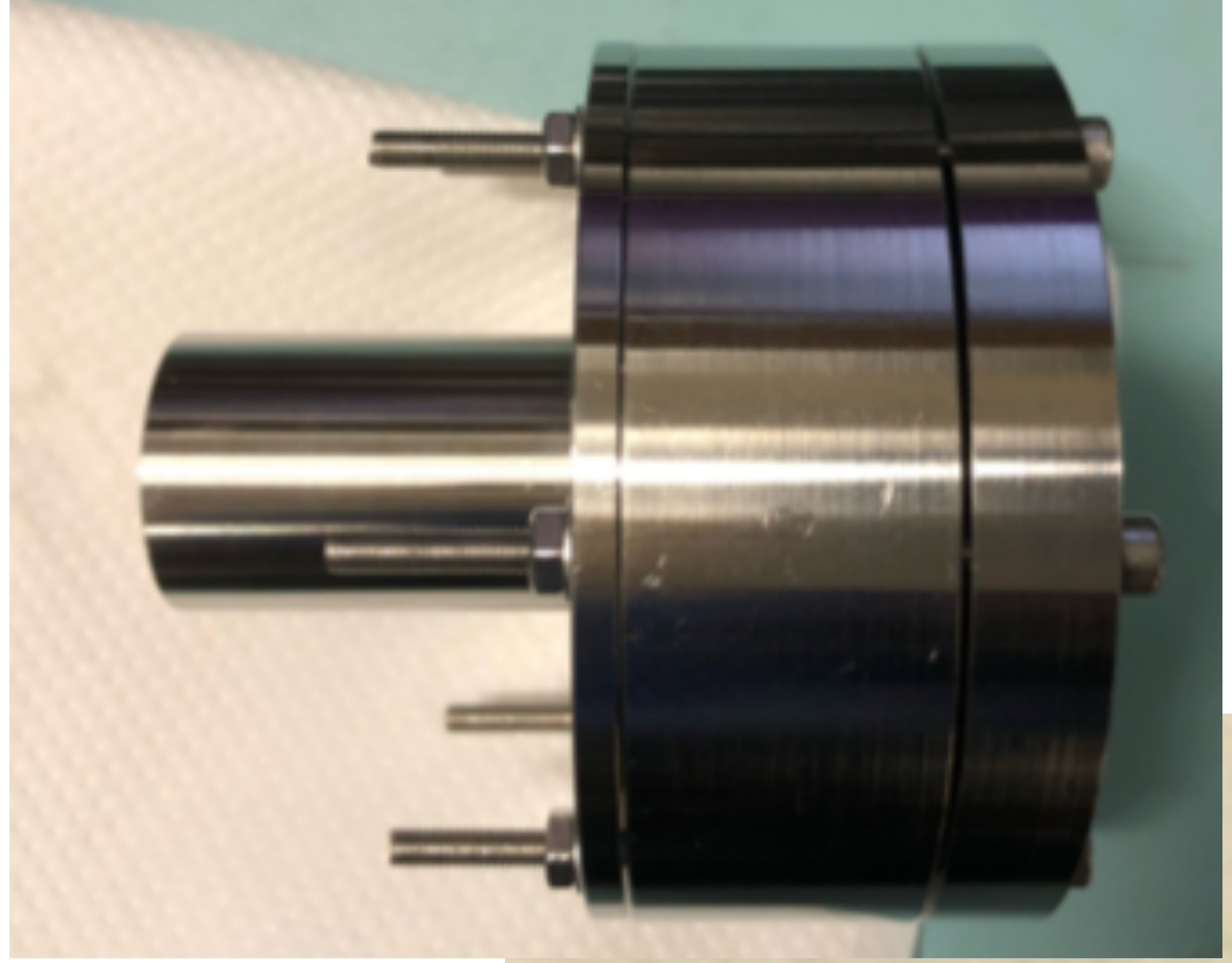
- UKLI calibration system installed in SK during tank-open work in 2018
- 5 horizontal injector positions, each of which has 3 injectors, supplied by a pulsed LED source (435 nm)
  - Diffuser: 22.5° half-angle
  - Bare fibre: ~12° half-angle
  - Collimator: 2° half-angle
- External PMT used to monitor pulse charge independent of SK water parameters
- Also top diffuser supplied by laser source illuminating bottom half of tank (368 nm)
- Used successfully alongside Korean LI system and light attenuation from cosmic muon measurements for regular monitoring of the detector (including both Gd-loading periods)

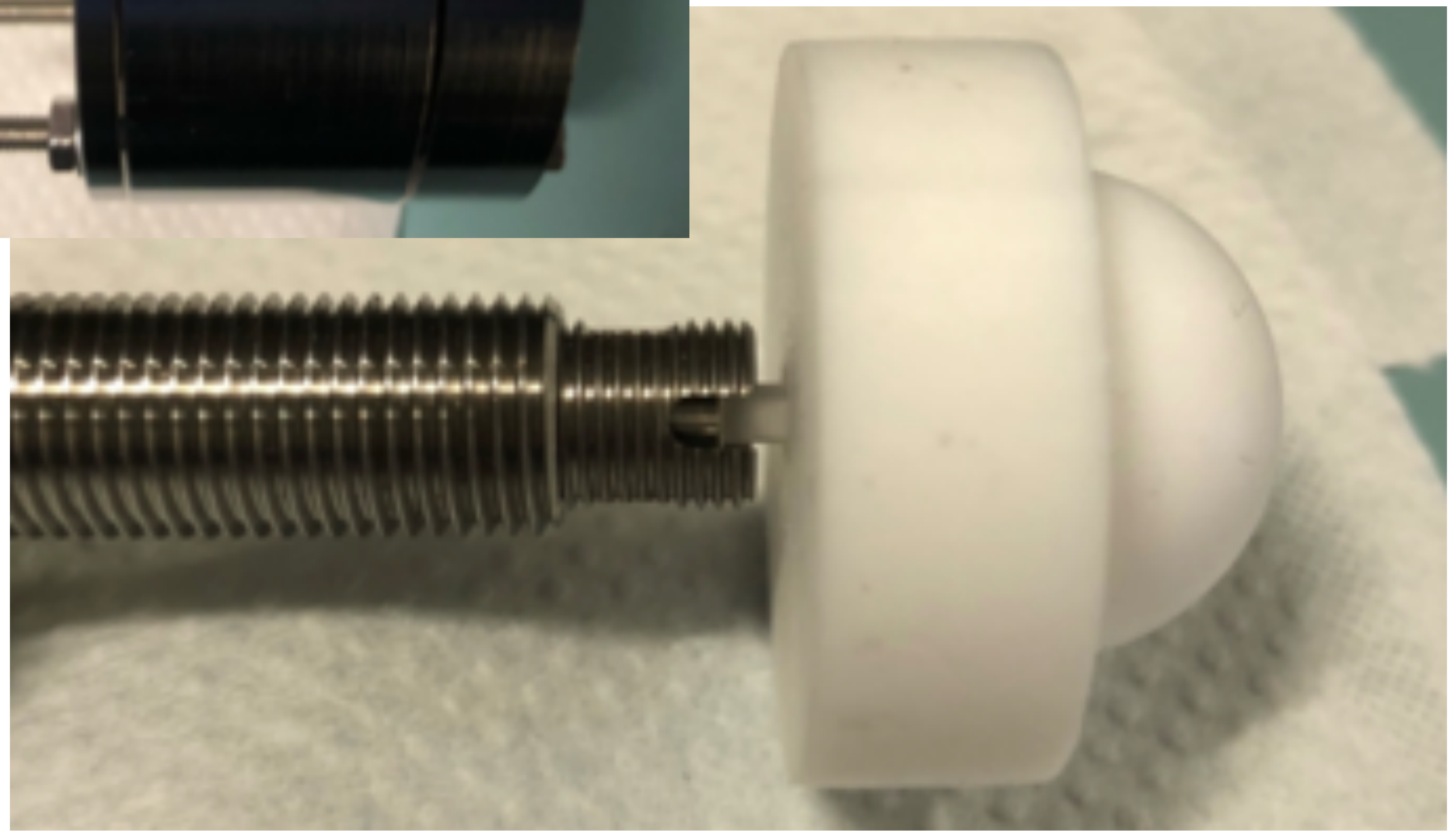


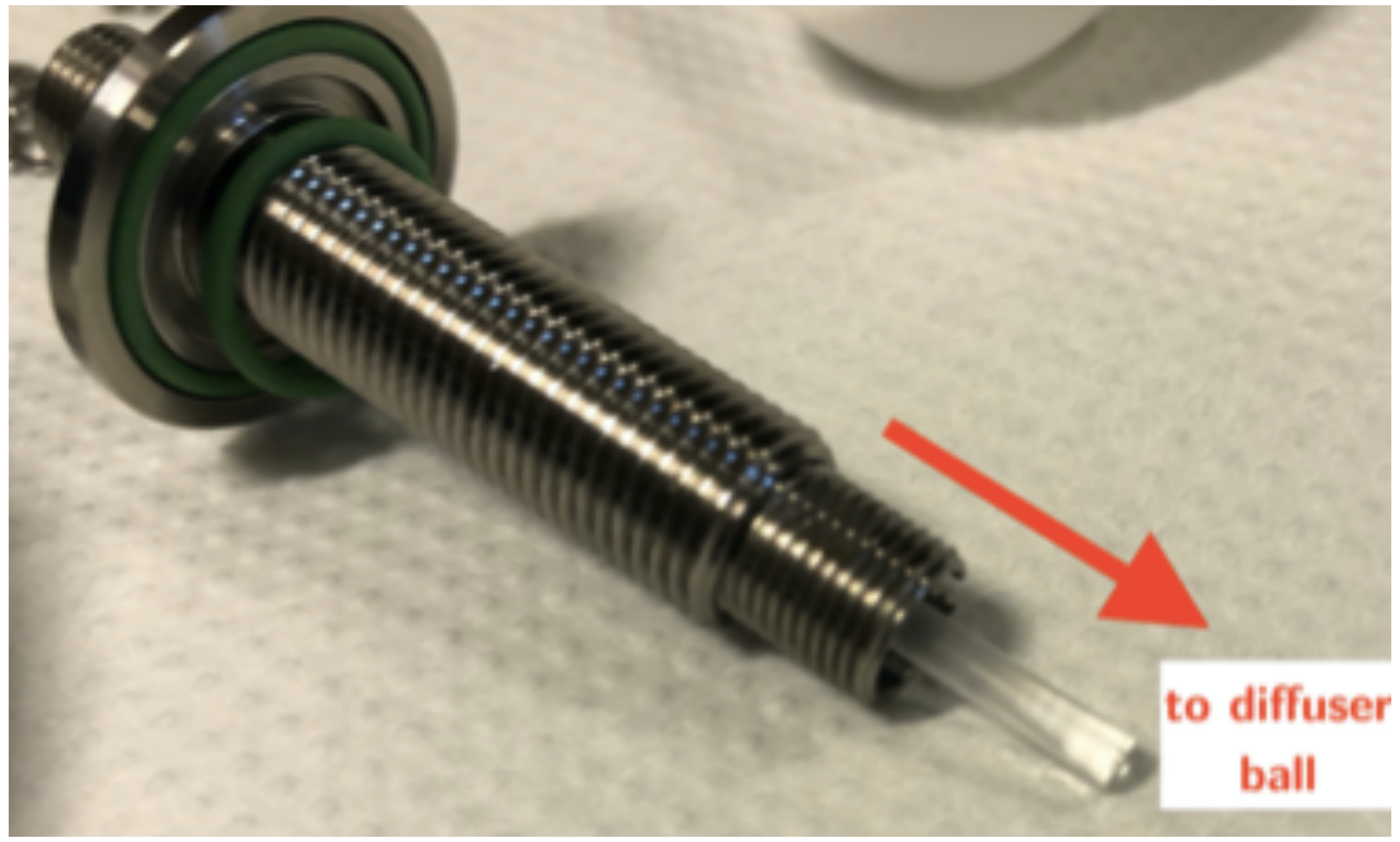


Diffuser Development

- Aim: inject wide-angled uniform cone of light to illuminate many PMTs
- Diffuser design:
  - PTFE hemispherical diffuser ball
  - Hermetic connector with plexiglass rod
  - Stainless steel enclosure with mechanical seals
- Design almost finalised
- Only minor changes expected:
  - Application of serial numbers
  - Fix orientation of diffuser upon installation

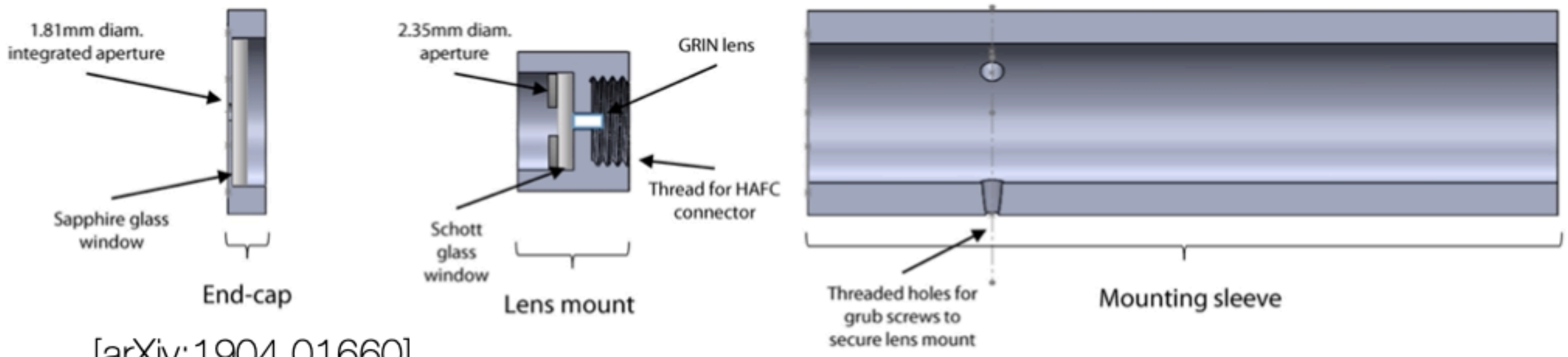




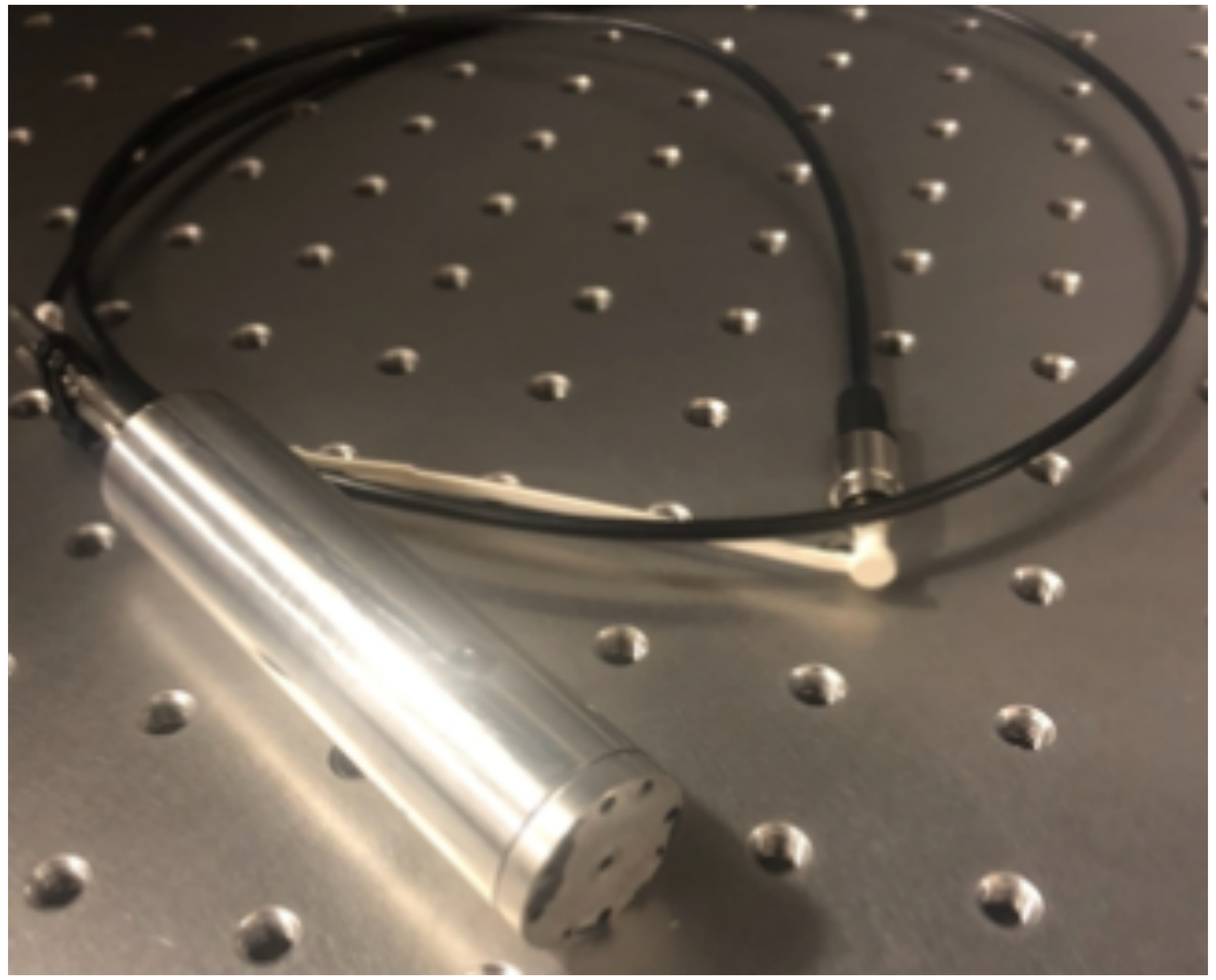


Collimator Development

- Aim: small width collimated beam to precisely illuminate ~few PMTs
- Original design deployed in SK used gradient-index (GRIN) lens
- Produces sharp edged light cone with half angle ~2°
- Very small alignment tolerance (~10^{-3} mm) - difficult to align correctly and maintain beam profile
- More robust design required

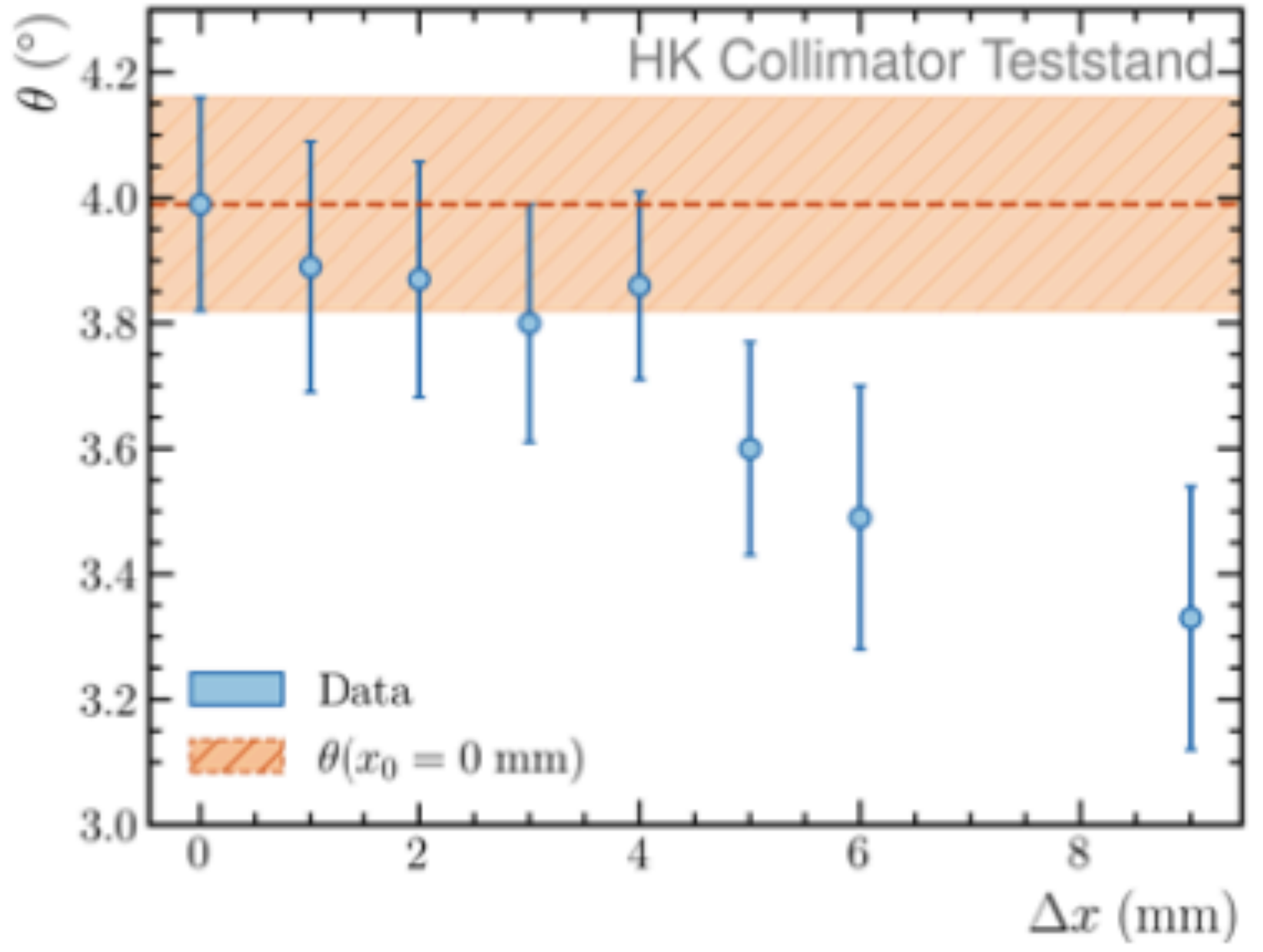


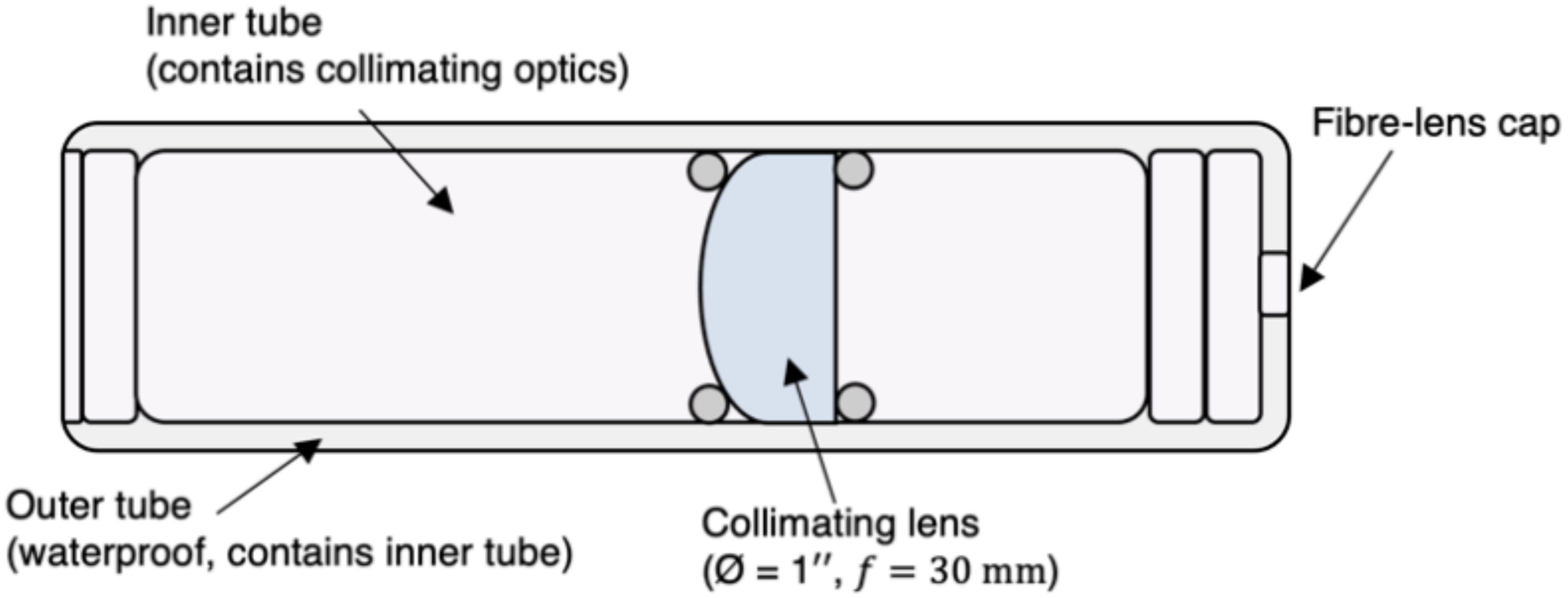
[arXiv:1904.01660]

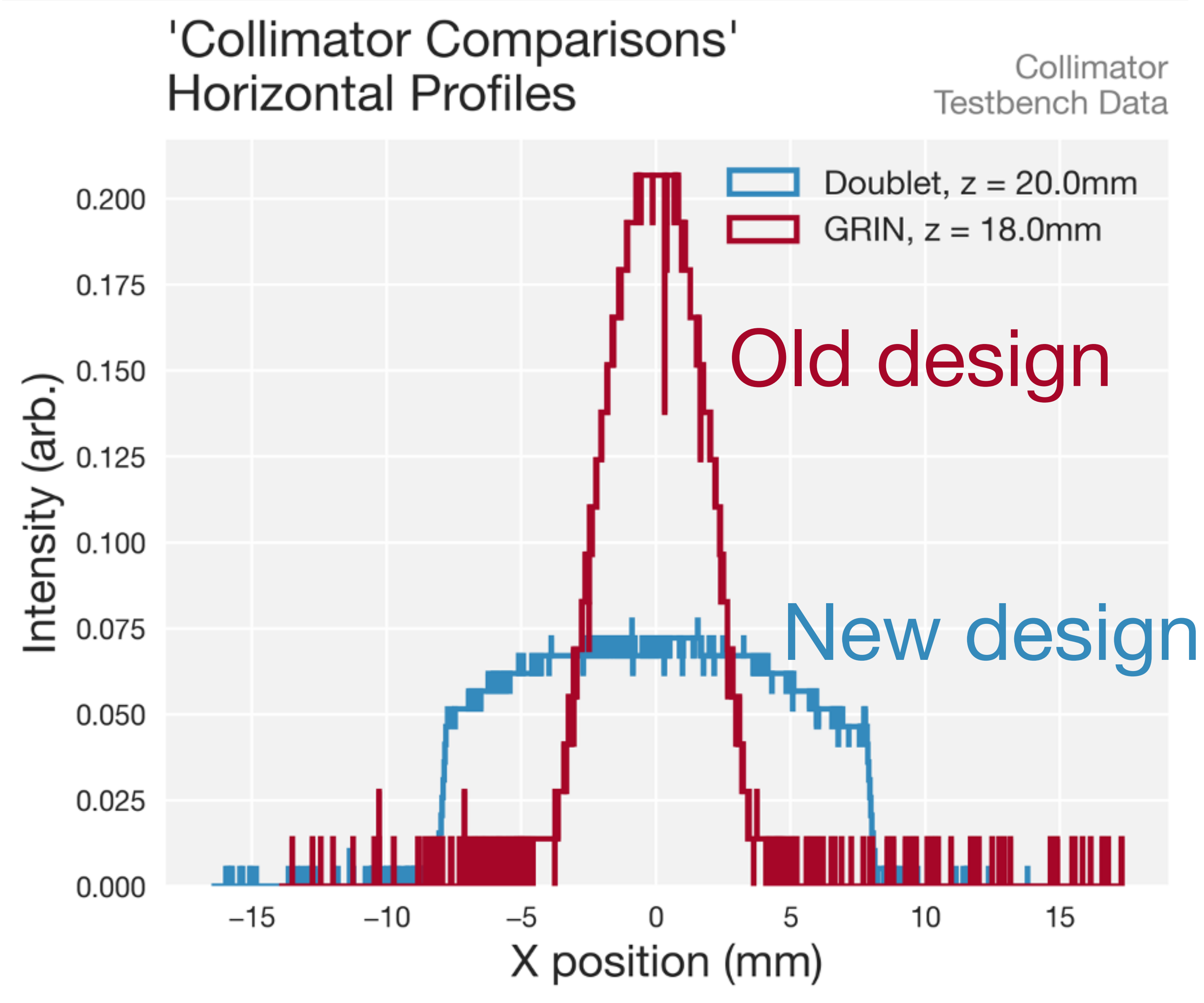


New Collimator Design

- New, wide-lens collimator design uses doublet lens (Ø 1”)
- Alignment studies of beam expansion (right) and horizontal profiles suggest ±4 mm tolerance perpendicular to beam axis, ±0.5 mm tolerance along beam axis
- Optics assembled in a stand-alone unit before being installed in pressure and water-resistant housing
- Spacing between elements easily optimised before final assembly
- First prototype under construction now

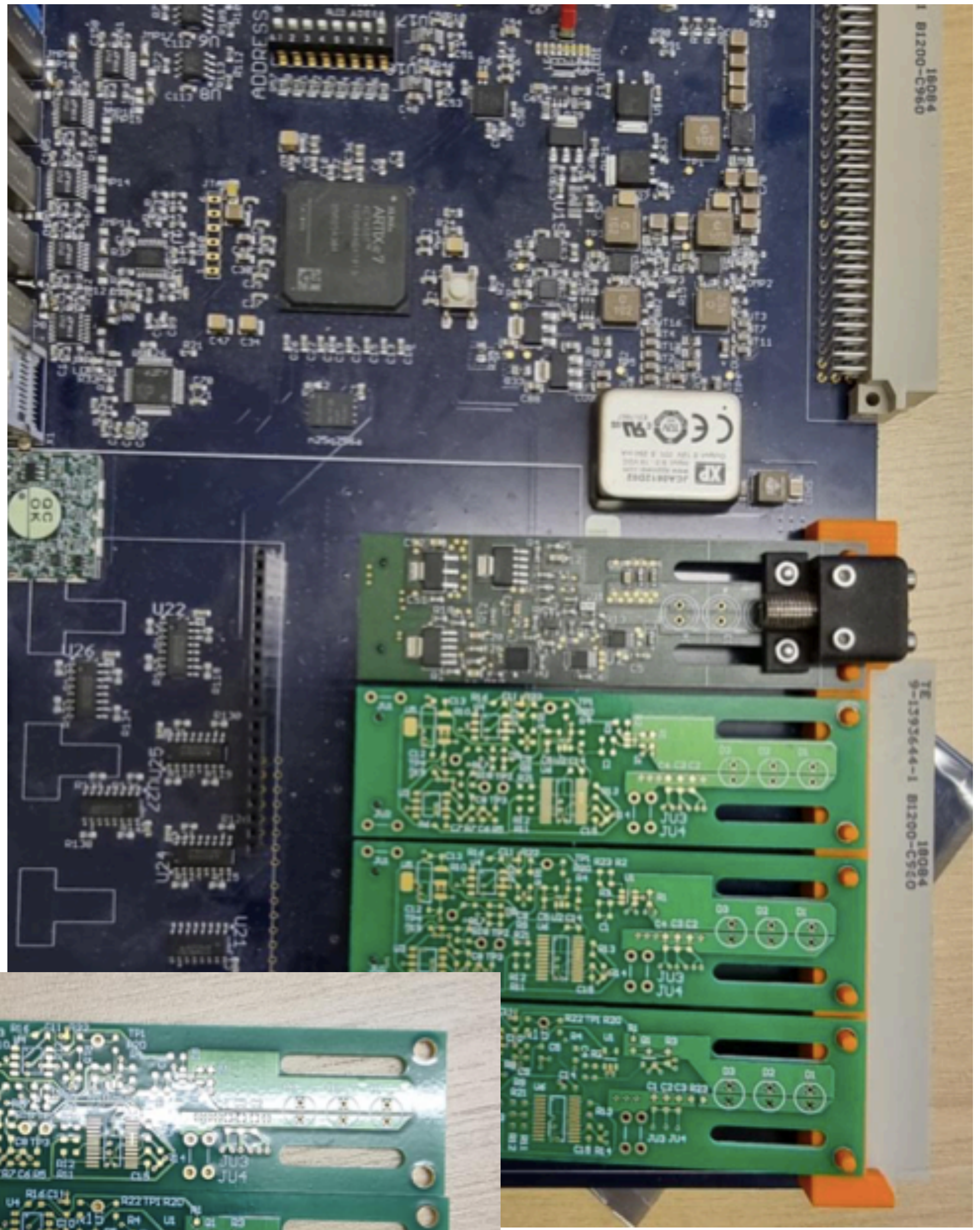


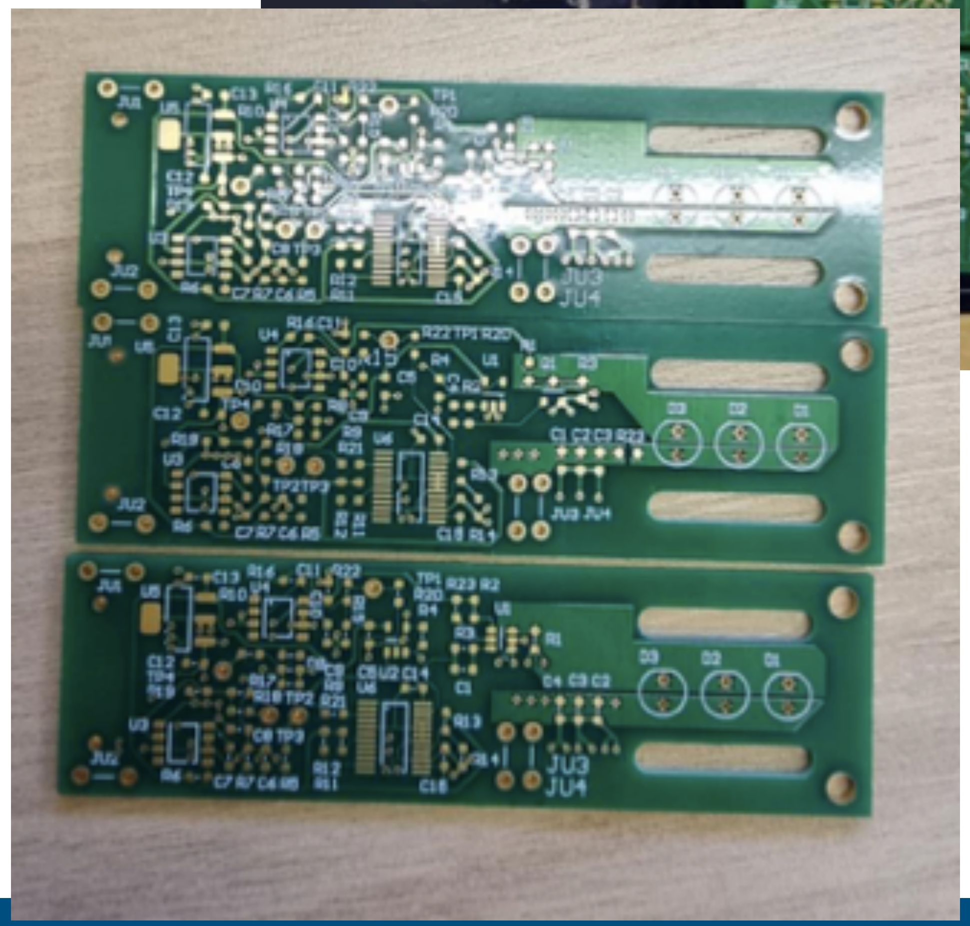




Pulser Board Development

- Series of requirements for pulser boards:
  - Fast (<5 ns) switch-on using 5 mm LED
  - Change light intensity with software, not tied to pulse width
  - Compatible with SK system
- Identified surface mounted LEDs as requirement to achieve fast pulse timing
- 3 prototype boards developed so far with minor changes (reusing components where possible due to shortages)
- Ordering in components to set up fibre test stand at Liverpool, important before bulk purchases and sending things to Japan

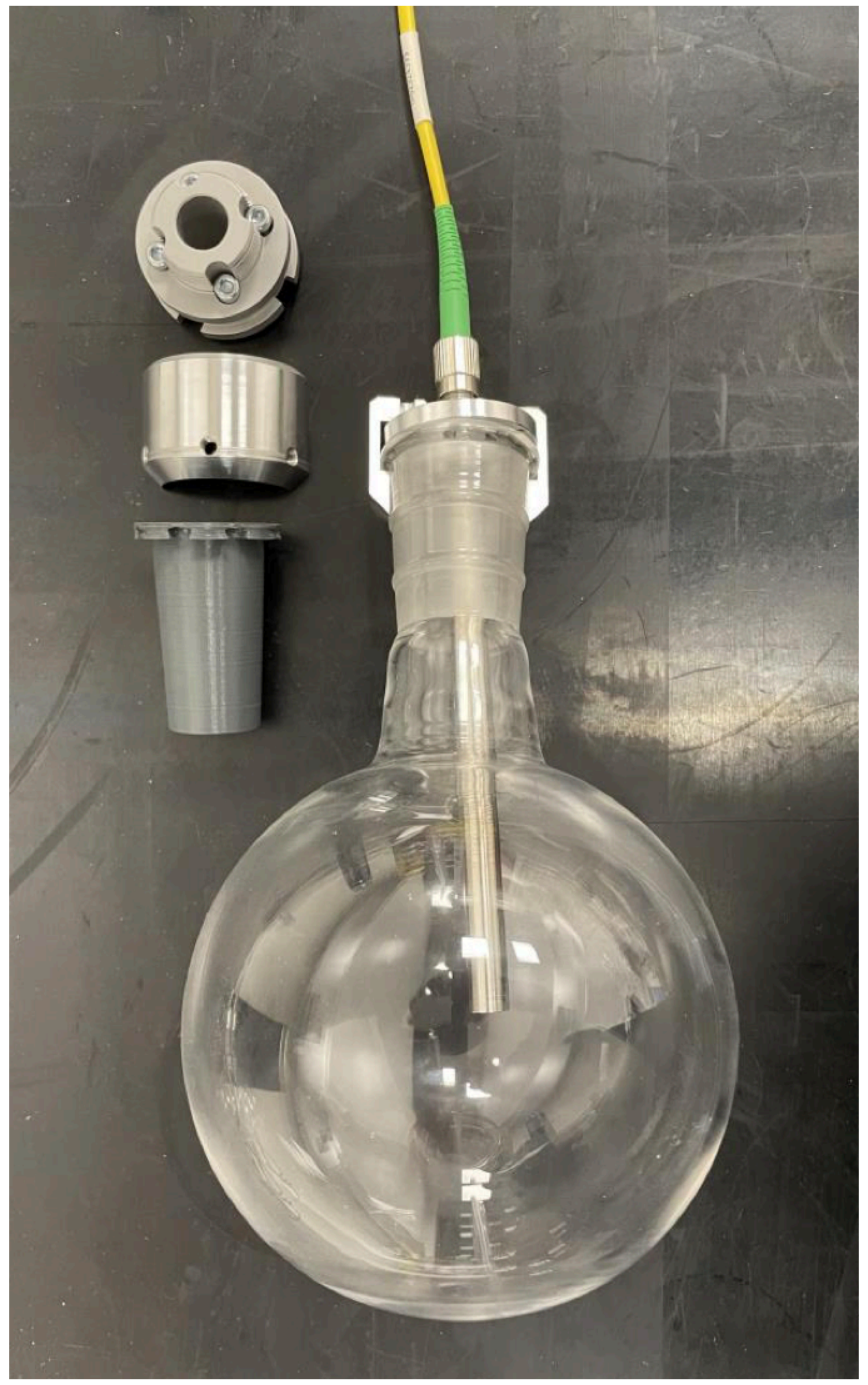




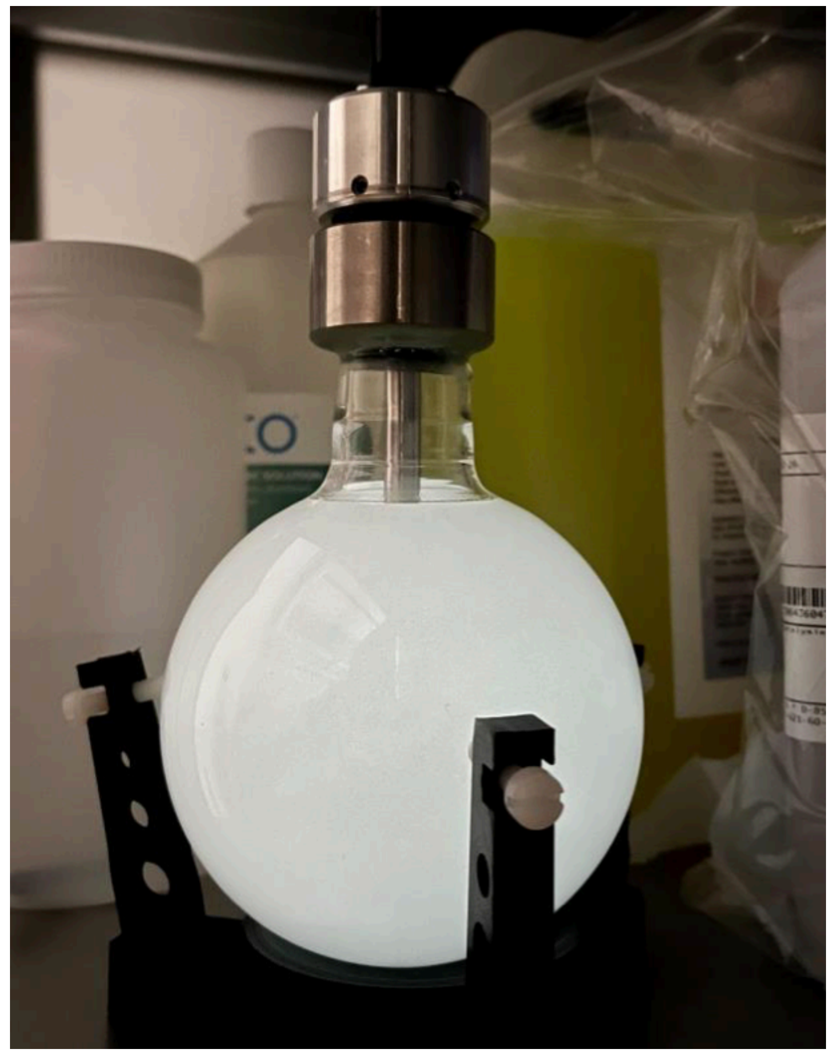
Laser Diffuser Ball

- Imperial group working on a laser diffuser ball for HK/IWCD/WCTE
- Built on SNO/SNO+/DEAP3600 design:
  - Quartz flask containing optical gel, with glass microspheres suspended within
- Diffuser ball prototype showed good results during buoyancy testing, with stable deployment
- Small amount of water ingress - expected
- More submersion tests expected, and more prototypes with different flask dimensions to come
- Optical fitting analysis being developed in tandem with hardware advances

CAD model

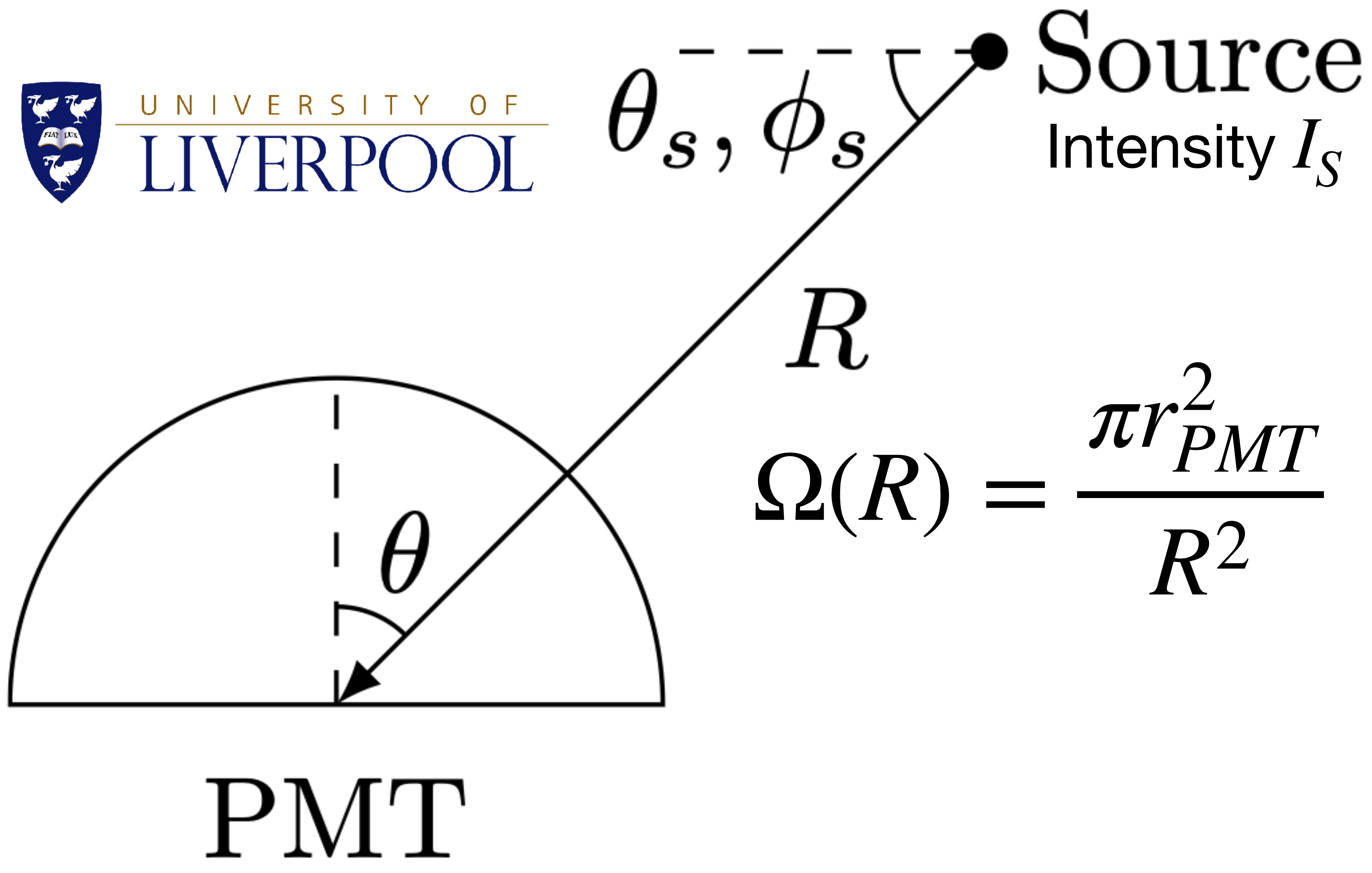


Empty prototype



Filled prototype

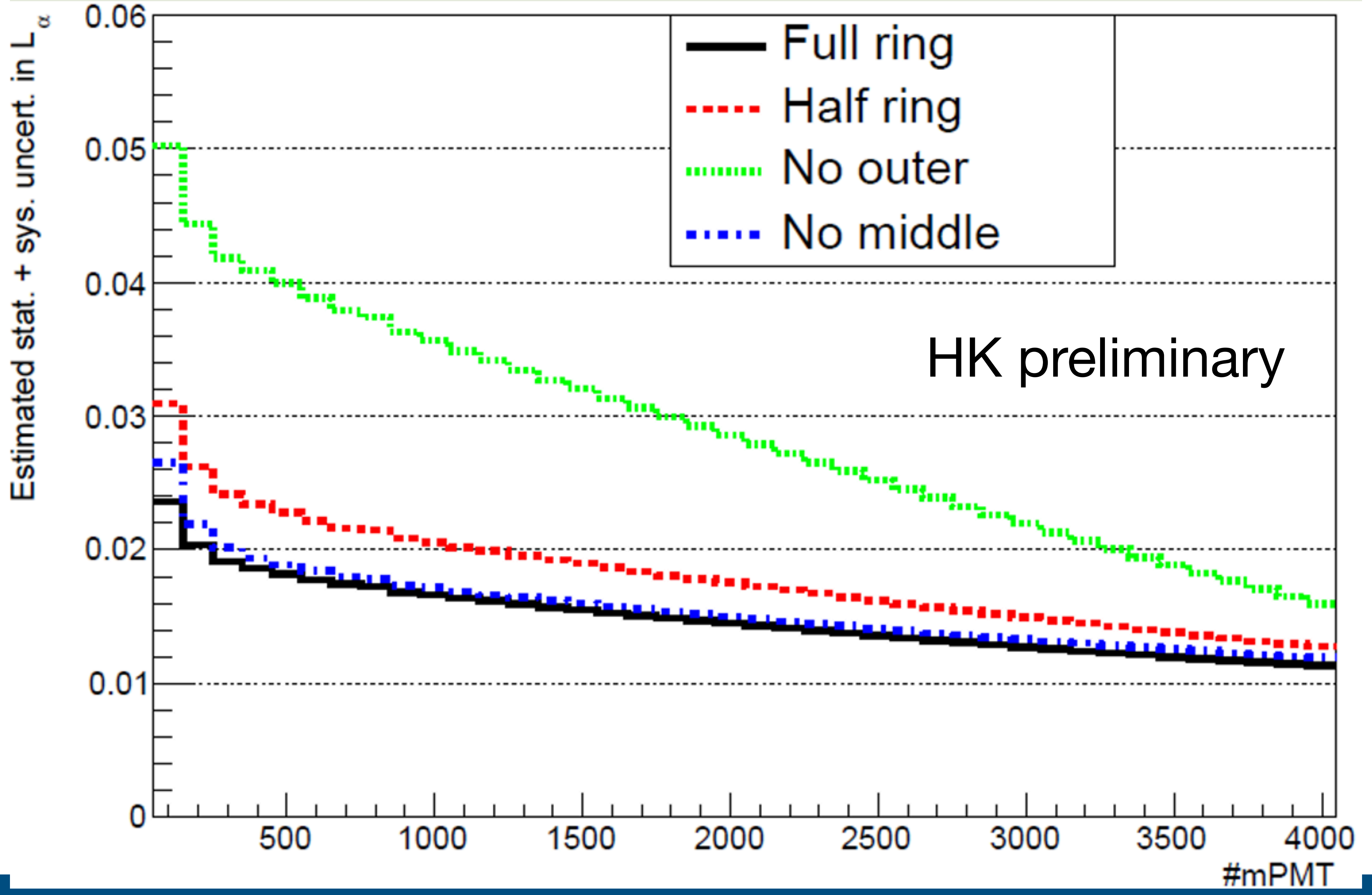
Injector Optical Fitting Analysis



- Direct PE at PMT from a fixed photon source given by:

$$PE = I_S(\theta_S, \phi_S)e^{-R/L_\alpha}A(\theta)\Omega(R)$$

- Interested in L_α (attenuation length) and $A(\theta)$ (PMT angular response)
- Perform maximum likelihood fit to data
- Series of fake data studies performed to test robustness of fit and sources of systematic uncertainty
- Provides estimation of uncertainties as a function of number of mPMTs and their configuration



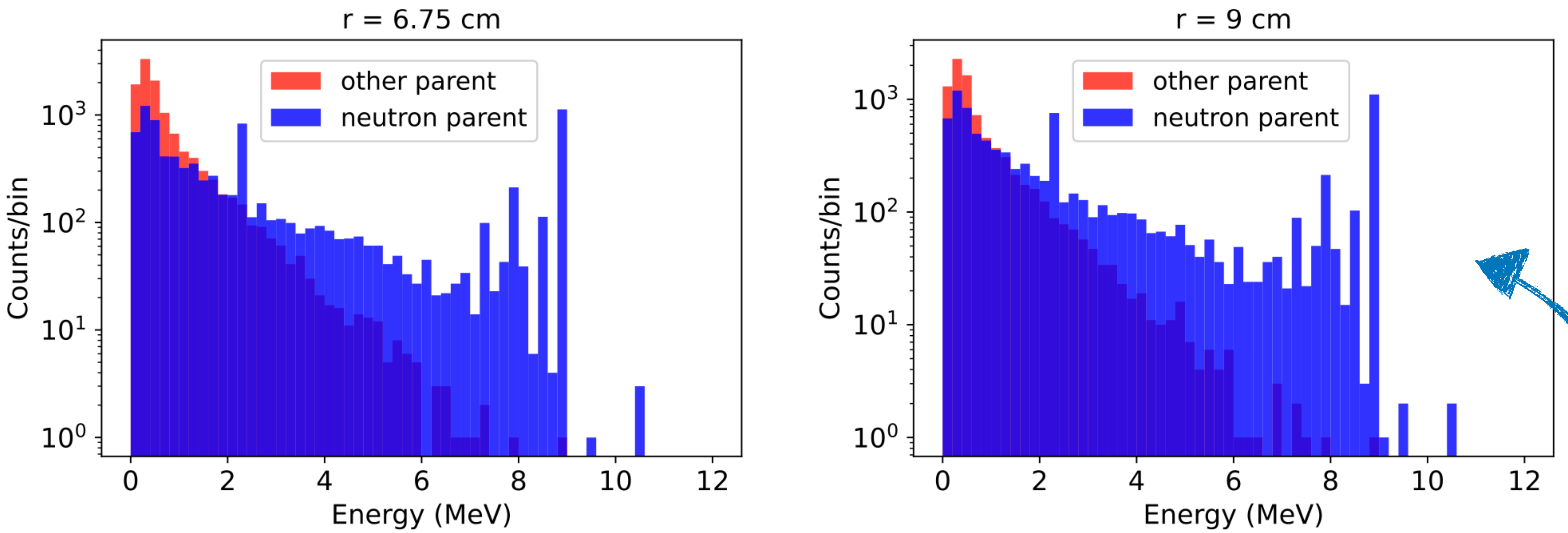
Radioactive Sources

NiCf Source

- Aim: isotropic source of gamma rays, giving single photon events
- Used for absolute and relative gain calibrations, along with studying detector uniformity
- ^{252}Cf source produces neutrons, resulting in thermal capture on Ni:

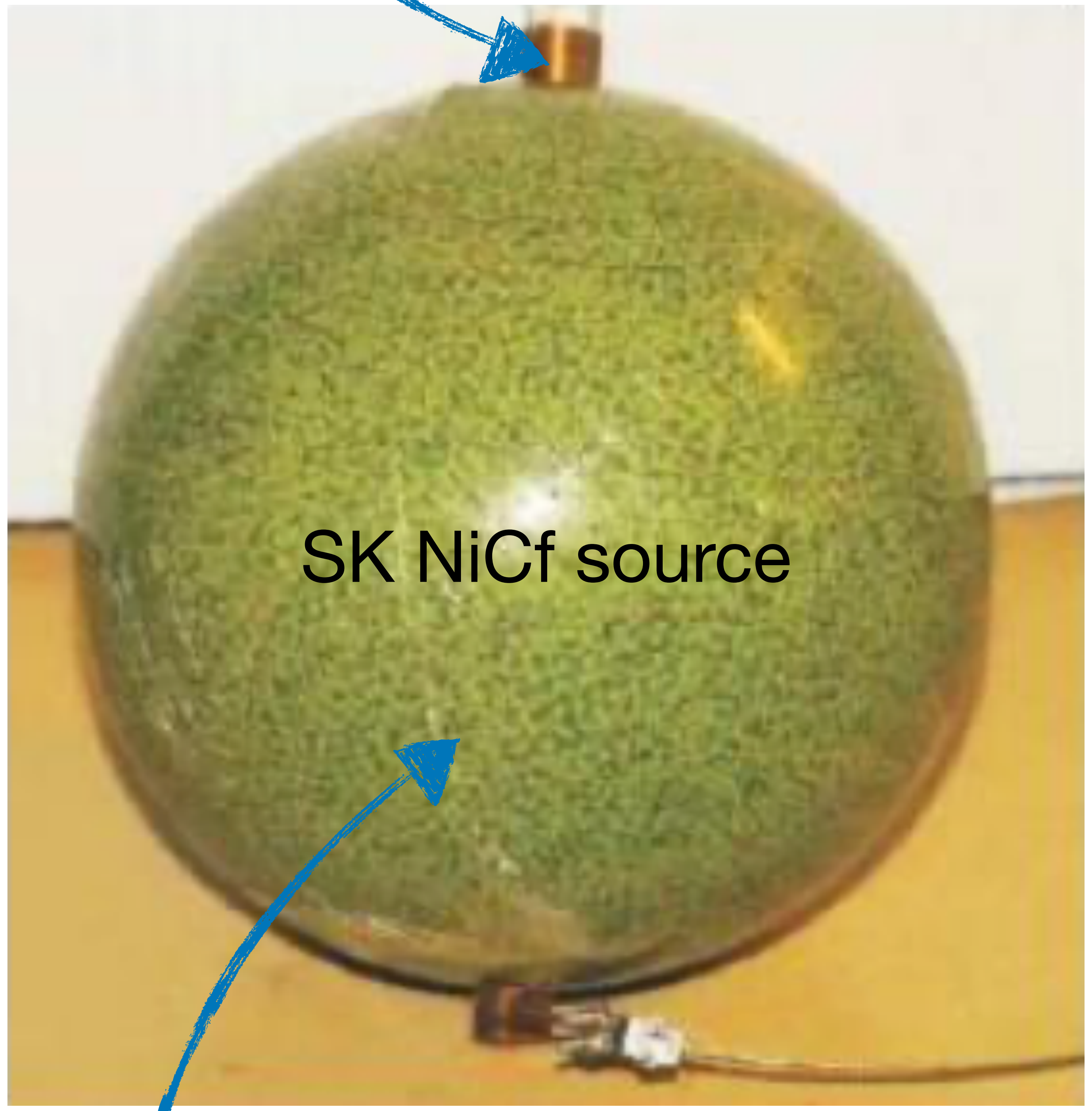
$$^{58}\text{Ni} + \text{n} \rightarrow ^{59}\text{Ni} + \gamma \text{ (~9 MeV)}$$

- Starting with 'WCTE sized' prototype (6.75 cm radius)
- Initial tests performed to select epoxy



GEANT sim of n induced gammas escaping source (for 100k Cf decays)

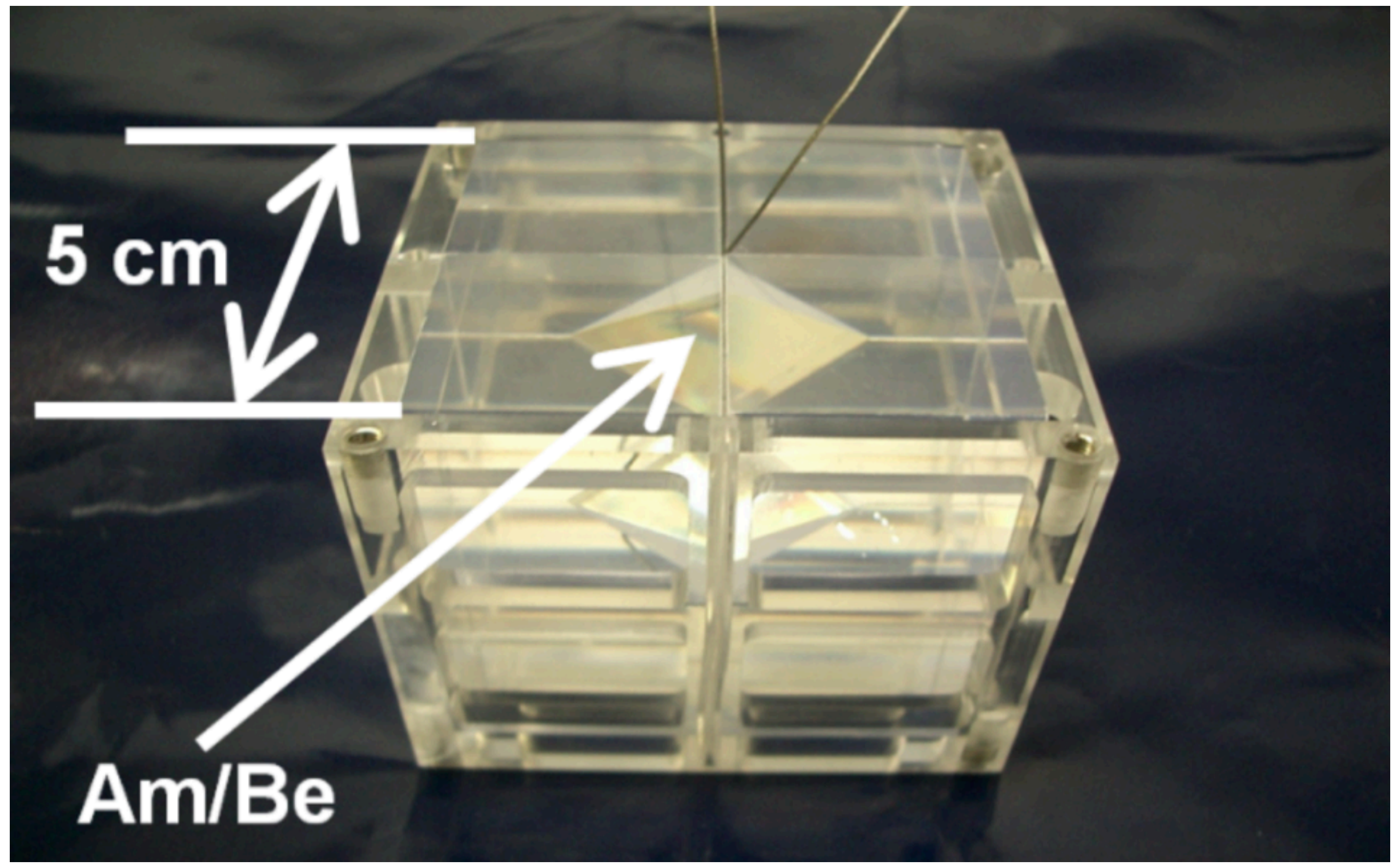
^{252}Cf source held at centre by brass rod



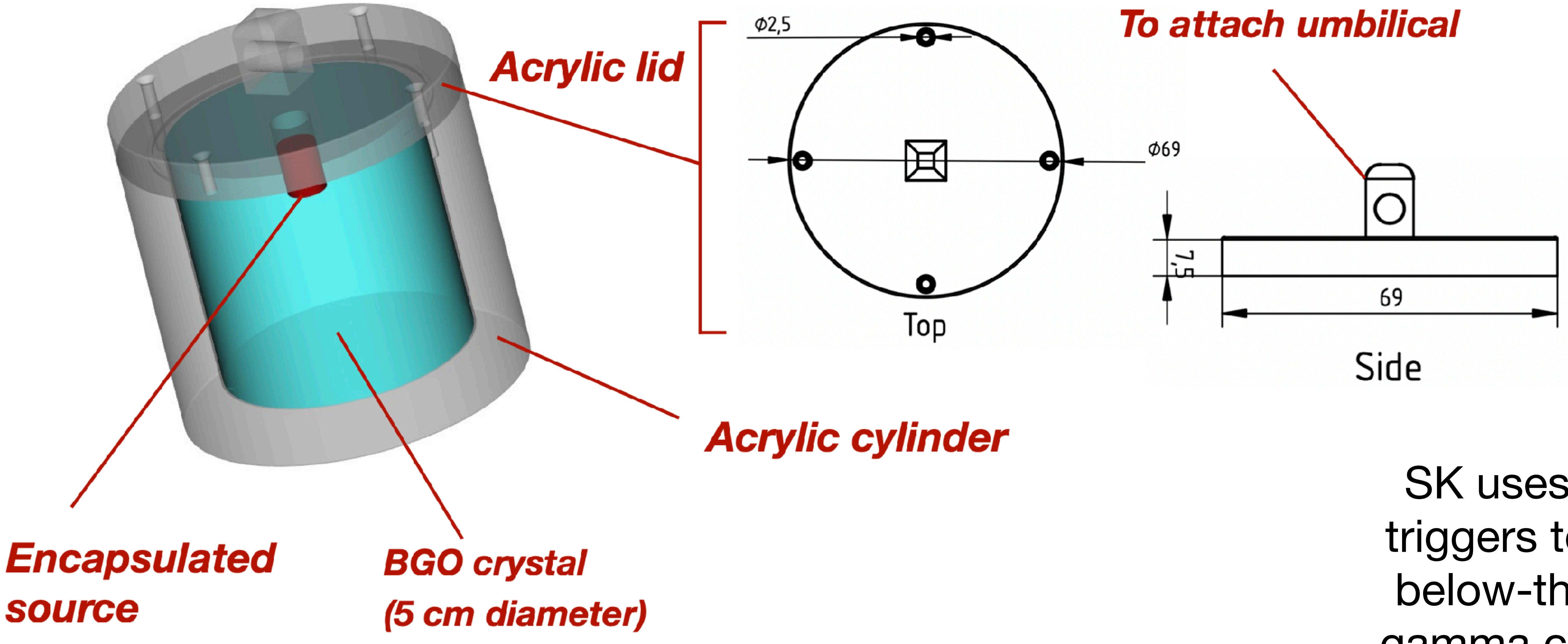
6.5 kg NiO + 3.5 kg polyethylene

AmBe Source

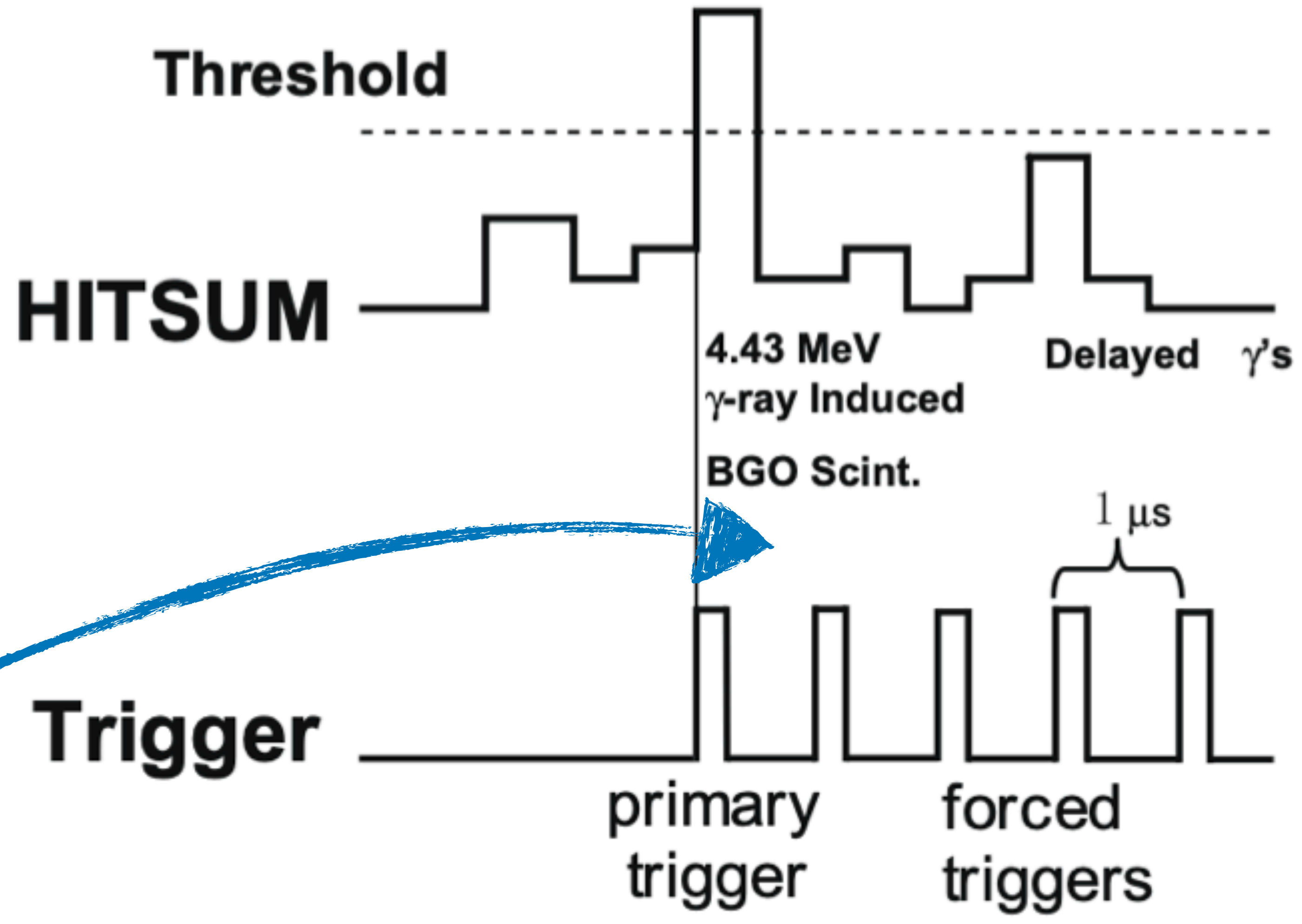
- Acrylic case containing bismuth germanate (BGO) scintillators, enclosing an AmBe neutron source
- Releases neutrons and 4.4 MeV gammas in coincidence
- Initial design features encapsulated source within Ø 5 cm BGO crystal, within cylindrical acrylic vessel



SK AmBe source



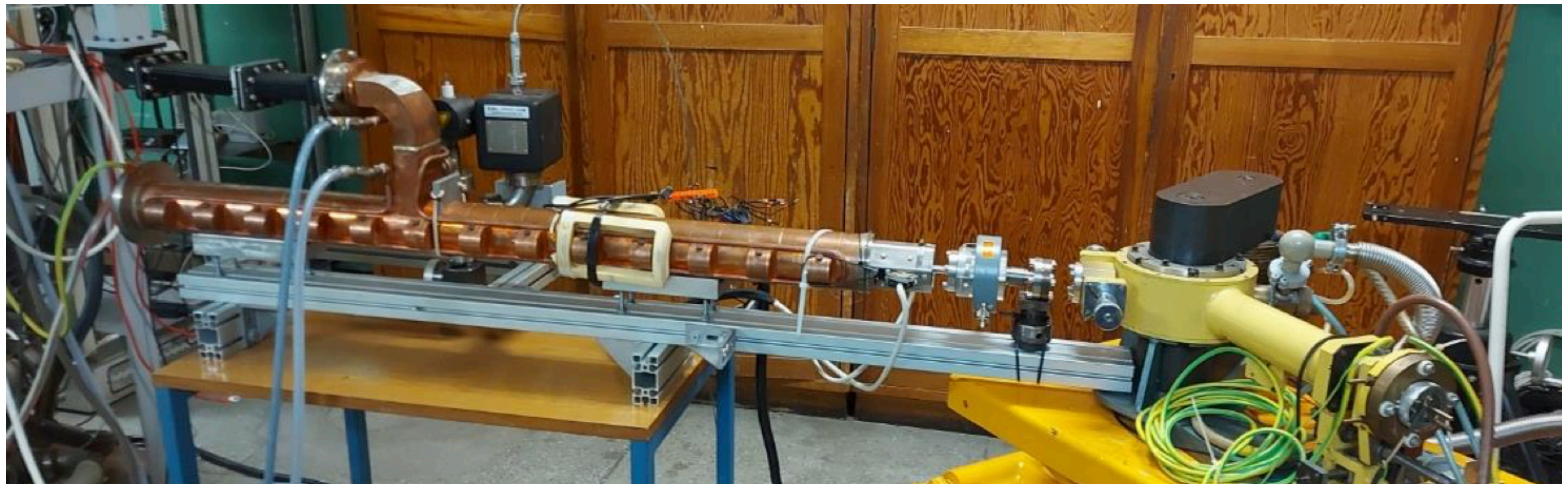
SK uses forced triggers to detect below-threshold gamma cascades

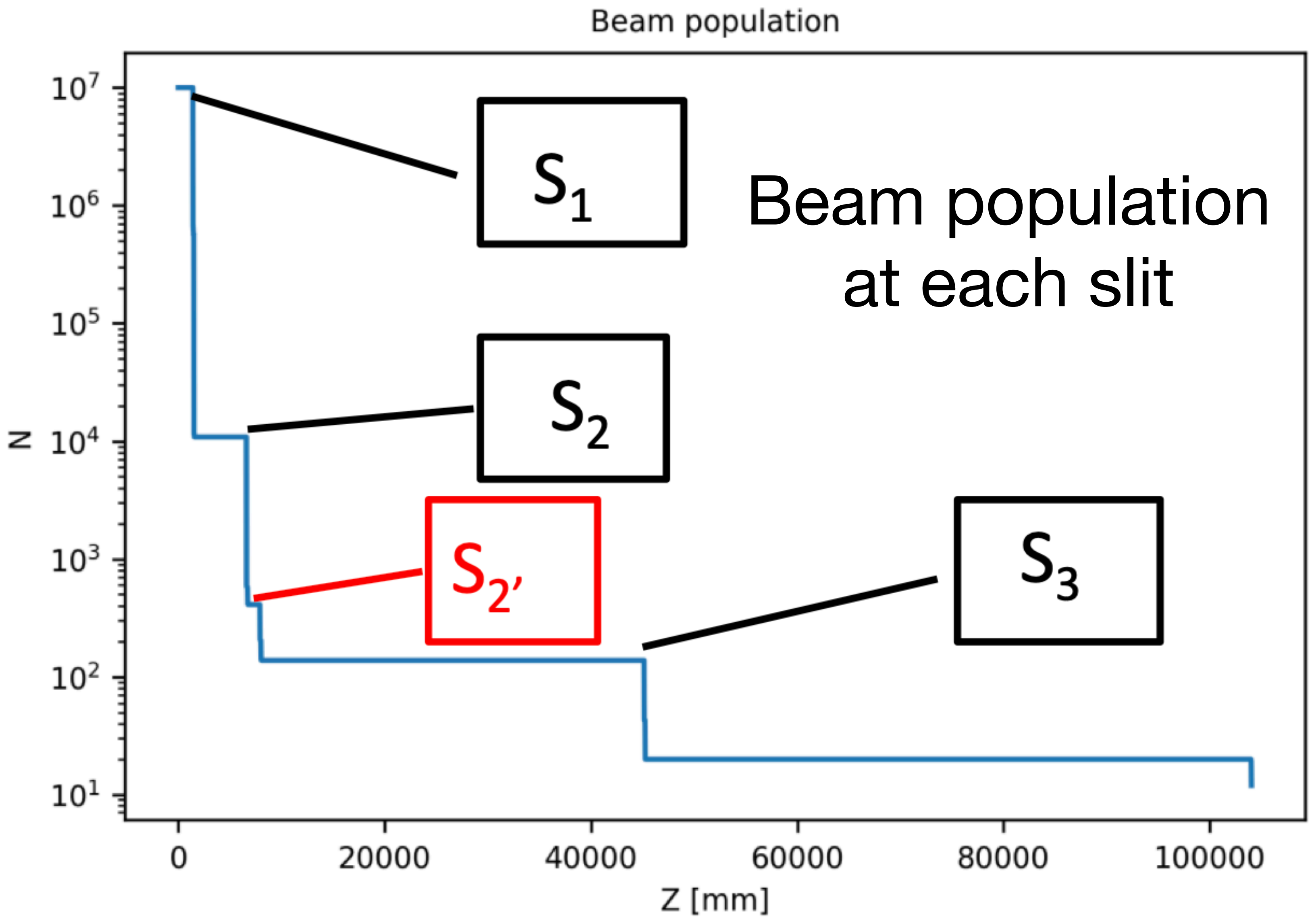


LINAC

LINAC

- Aim: to use electron LINAC to perform detector calibration using ~few electron source with a known energy
- Simulations of beam transport for current design predict reduction from 10^6 particles (of ~3.5 MeV) at start, down to 2-4 reaching PMTs
- Additional scattering foil to be added in path from LINAC bunker if further reduction required
- Work on test stand at NCBJ ongoing, with new equipment being purchased to bring it in line with the final design
- Initial software for hardware tests has been prepared

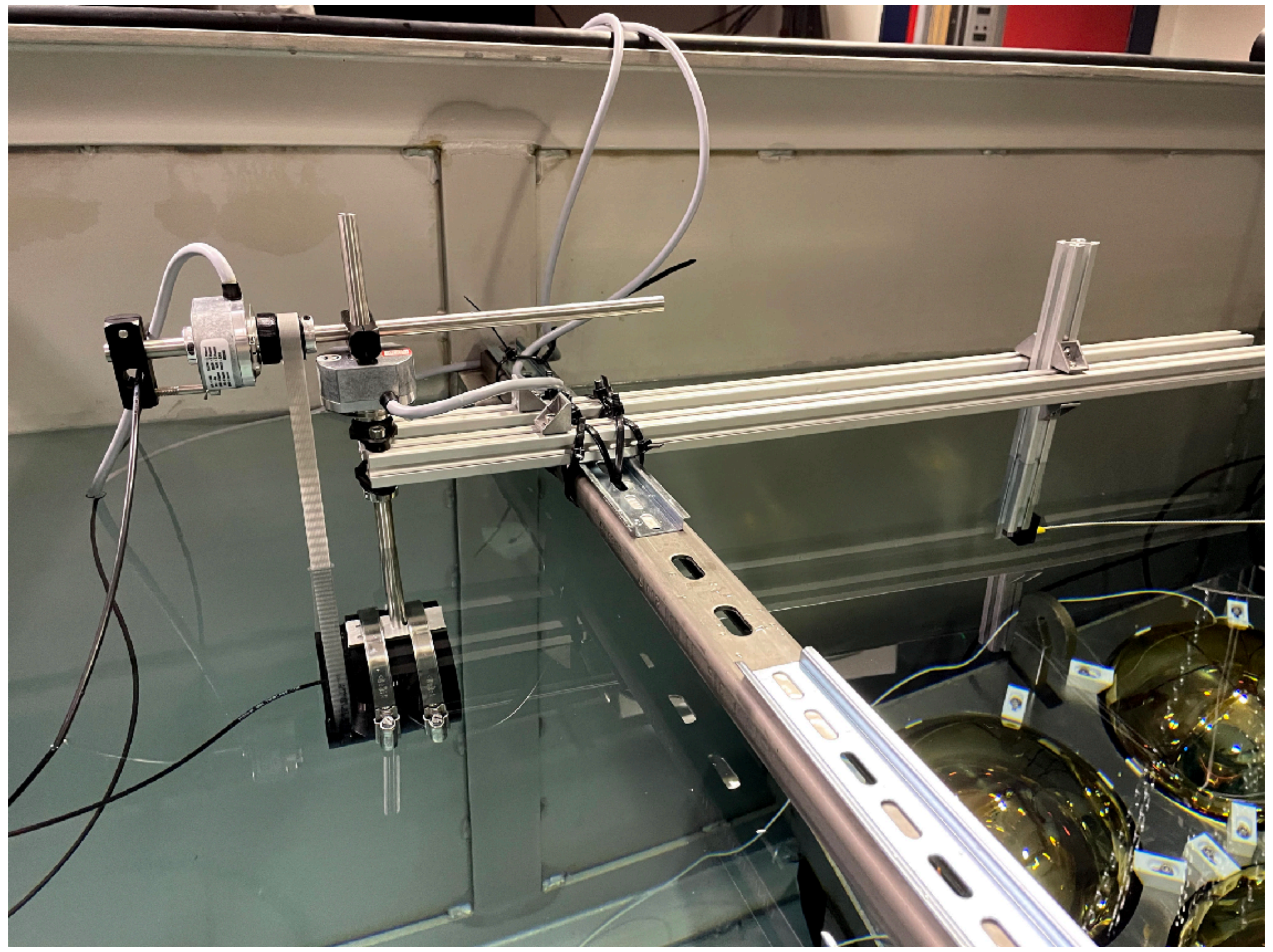




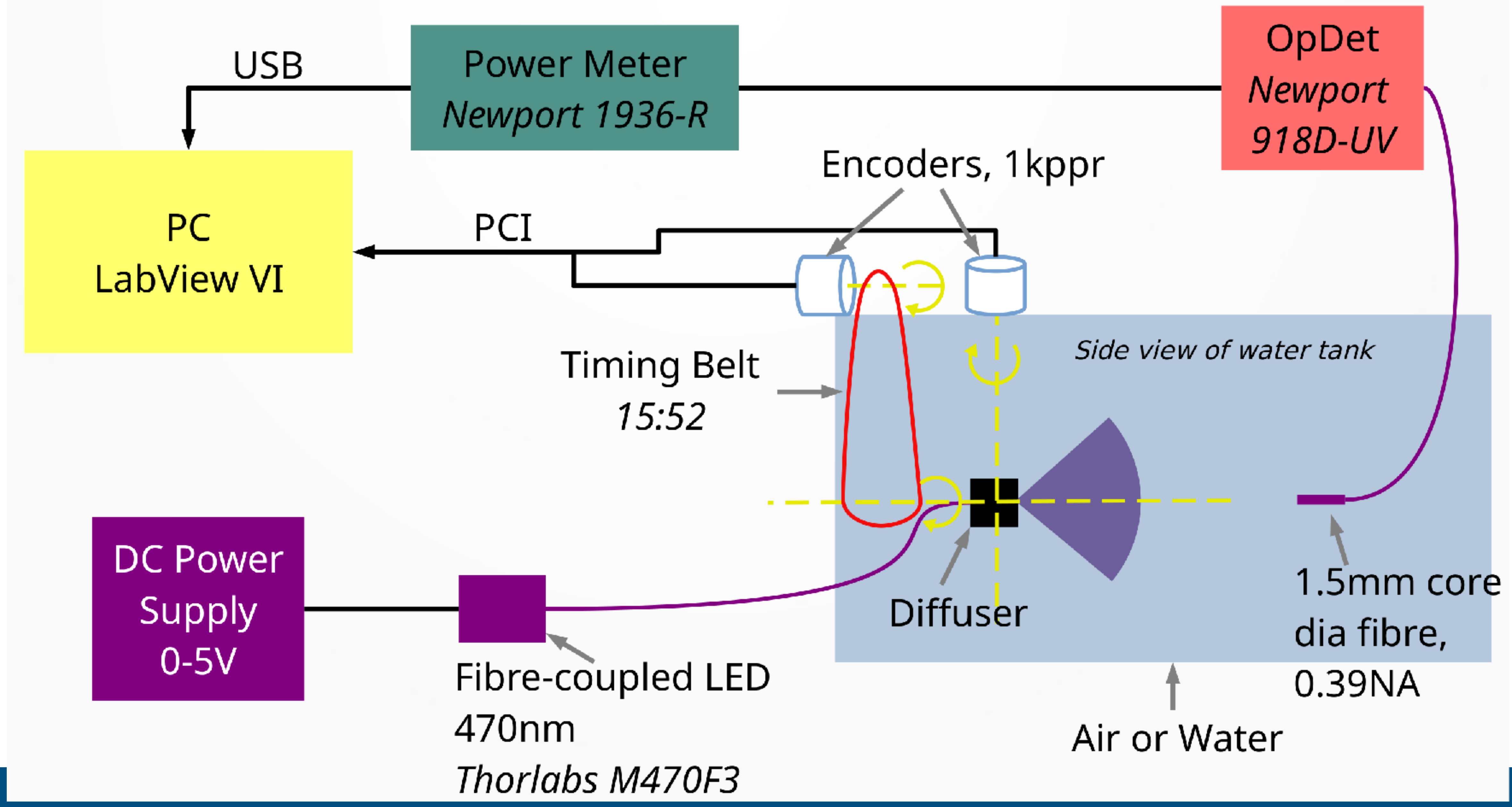
Pre-Calibration

Water-based Pre-calibration

- Goal: fully characterise LI sources in water prior to installation
- Development of automated 2π profile measurement rig at Sheffield water tank is ongoing
- Also develop QA/QC test stand in Japan for final pre-installation checks
- Many necessary pre-calib measurements, including:
  - Relative intensity 2π angular profile
  - Duration of light pulse (compare with monitor)
  - Long-term stability of LI, pulser, monitor PMT, etc.



May 2021



Overview

- Large programme of calibration methods for Hyper-K being developed
- Good progress being made in all areas
- Design and prototyping of systems is ramping up in advance of HK construction and installation in 2025/2026
- Work on analysis methods for the calibration systems also underway