QCage.24

User Manual

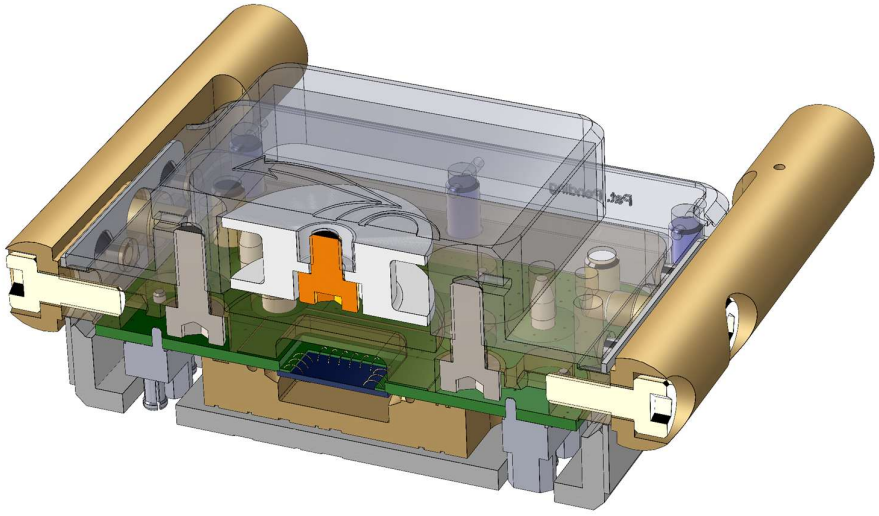


Figure 1 *Cross section of a QCage.24*

Product detail and updated information available at:

https://www.quantum-machines.co/products/qcage/

Made in Denmark - Patent pending

Author: Søren Andresen, Amalie Paulsen & Oliver Dylander

Date: 2026-06-19

Version: 2.20

Contents

1. OPN Update

Please note that the OPN's (Orderable Part Numbers) for the product parts that appear on quotes and orders were updated throughout 2026. Please use the table below for translating between the new and old OPNs that are referred throughout this manual.

New OPN	Old OPN	Product Name
QCAGE-24-STD	Q401	QCage.24 Standalone
QCAGE-24-PCB	Q402	QCage.24 Sample PCB
QCAGE-24-FRM	Q403	QCage.24 Chip holding frame
QCAGE-24-WBF	Q415	QCage.24 Wire bonding support
QCAGE-24-APT	2 x Q419 + Q427 + Q408 + Q409 + Q410	QCage.24 Chip adaptor kit
QCAGE-SHL-24C	Q423	QCage Magnetic shielding (24 lines)
QCAGE-SHL-64C	Q428	QCage Magnetic shielding (64 lines)
QCAGE-SHL-BRK	Q450	QCage.24 Bracket for 64-line shield

2. Safe Handling

The QCage.24 is a delicate piece of equipment, designed to be used in vacuum environments at extremely low temperatures. It is therefore of utmost importance to keep it clean and avoid shocks or impacts that may damage its mechanical integrity.

In particular, avoid bringing strong permanent magnets into proximity of the QCage.24 or any of its parts and accessories, including cables, mounting hardware and magnetic shielding as this may result in residual magnetization.

All parts of the product shall be stored at normal indoor ambient conditions, avoiding exposure to temperatures and humidity levels higher than 45°C and 60% RH (non-condensing). Long-term storage of the sample boards (with or without chips mounted) should be done in a dry passive environment, e.g. dry nitrogen storage or vacuum-sealed bags.

All handling should be done wearing gloves, preferably on a clean covered table top. Care should be taken to avoid scratching or denting by handling with tools. Should there be a need to dispose of the QCage.24, the product and all of its parts shall be returned to Quantum Machines for proper disposal (contact Quantum Machines or QDevil ApS for instructions).

In case the QCage.24 hardware needs to be cleaned, we recommend blowing with dry air. If rinsing is needed, only use isopropanol or deionized water and avoid heating or blowing with hot air for drying.

	Wear gloves to avoid contamination by fingerprints etc.
	Keep dry and away from high temperatures.
	Not for general waste. Return to vendor for disposal.[1]
	Avoid the proximity of strong permanent magnets

	The gold-plated metal parts contain small amounts of beryllium. DO NOT cut or grind the metal parts, to avoid exposure to dust or fumes.[2]

[1] Contact Quantum Machines or QDevil ApS for instructions.

[2] Material safety datasheet for the relevant compound alloys can be obtained by contacting Quantum Machines or QDevil ApS. Translation to local language is the responsibility of the requester.

2.1 Intended use

The intended use of QCage.24 is for packaging and enclosing quantum devices to enable fast, low-loss microwave measurements in a cryogenic environment at temperatures down to a few millikelvin. The target users are physicists, engineers, trained technicians, or supervised university students – in short people who are aware of good and safe practice in advanced quantum laboratories that involves work with vacuum, cryogenics, electrical and microwave testing.

3. Product Content

3.1 Standalone configuration

The QCage.24 sample holder system is supplied as the following individual part numbers:

- QCAGE-24-STD - QCage.24 system, EMC tight cavity with 24 lines (without sample board)

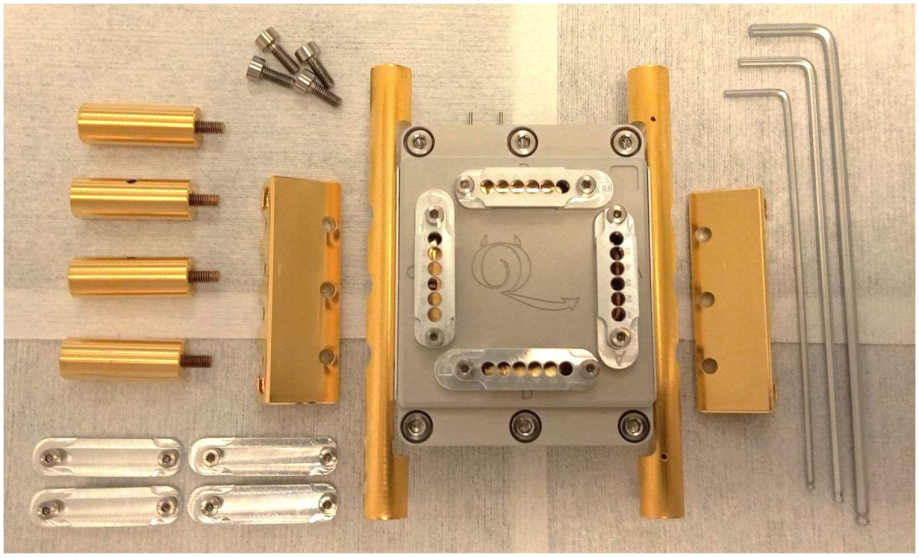


Figure 2 *Main assembly with rods, brackets, connector cover plates, screws, and tooling.*

- QCAGE-24-PCB - QCage.24 sample board, 24 transmission lines
- QCAGE-24-FRM - QCage.24 support frame for sample board

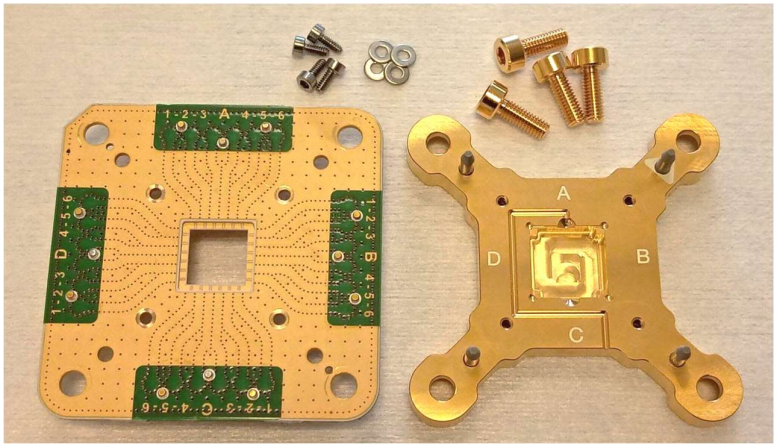


Figure 3 Left) Sample board (QCAGE-24-PCB). Right) Support frame (QCAGE-24-FRM) with mounting screws.

3.2 Magnetic shielding

If QCage.24 is bought with QCage magnetic shielding it will in addition to the contents above also contain one of the following:

- QCAGE-SHL-24C – QCage magnetic shielding enclosure with 24 lines (SMA connections)
- QCAGE-SHL-64C - QCage magnetic shielding enclosure with 64 lines (SMP connections)

Figure 4 QCage magnetic shielding (shown with 64 connection, similar to the 24 lines variant)

3.3 Accessories for Chip Handling and Wire Bonding

In addition to the main product numbers, accessories may be supplied to assist the chip handling and wire bonding:

- QCAGE-24-WBF - QCage support fixture for wire bonding

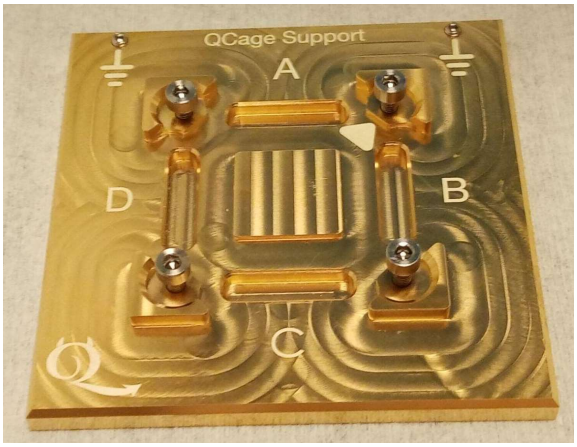


Figure 5 *QCage support fixture.*

- QCAGE-24-APT – QCage.24 Adaptor kit for different chip sizes
    - Adaptor plates for 5x5mm, 6x6mm and 7x7mm chips
    - Spacers for thinner and thicker chips

3.4 Cable Assemblies

For connectivity, different cable assemblies are available, interfacing to either SMP or SMA:

- QCAGE-CBL-RA2-SMA – Right angled cable pair, SMA plugs
- QCAGE-CBL-RA2-SMP – Right angled cable pair, SMP jacks
- QCAGE-CBL-ST2-SMA – Straight cable pair, SMA plugs
- QCAGE-CBL-ST2-SMP – Straight cable pair, SMP jacks

Figure 6 *3 different six-channel Mini-Coax cables for connectivity.*

Other cable lengths are available, e.g. 30 cm SMP cables (better suited for BlueFors pucks).

Note that the cables are supplied unmated with the A, B, C, D labeled faceplates. The six coaxial cables (either straight or right-angled) shall be clicked carefully into the faceplates, fitting the unevenly numbered sockets 1, 3, 5 with male connectors and the evenly numbered sockets 2, 4, 6 with female connectors.

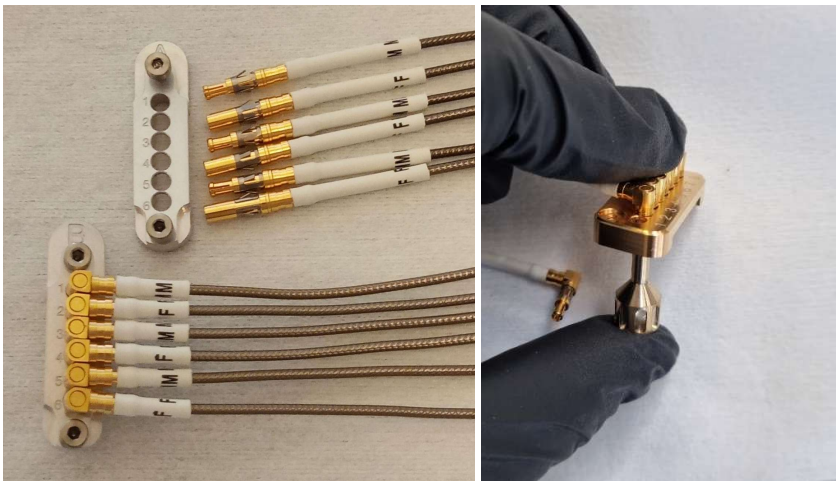


Figure 7 *Left) Mating of connectors into six-way faceplates.*
Right) Extraction tool (Q425) used to remove the individual connections from the faceplates.

Blank completely closed-off faceplates are supplied with mounting accessories to fit over connector ports that will not be used. Alternatively, the 2x6 pcs. blind plugs (Q426) that are supplied with the QCage.24 can be used to cover individual unused ports.

4. Interfacing with the Sample Chip

The QCage.24 sample holder has the sample chip held suspended inside the microwave cavity, supported by four corner pedestals, and clamped down by the sample board. The bottom cavity with the corner pedestals is defined in the support frame (QCAGE-24-FRM). It has room for a chip size of 10 × 10 mm^2 and supports die thicknesses of 525 μm ± 50 μm. The tolerance in chip size is 0.5 mm as chips larger than 10.5 mm will not fit in the cavity and chips smaller than 9.5 mm will risk dropping below the pedestals. After bolting down the sample board (QCAGE-24-PCB) and establishing a connection by wire bonding, the chip-carrying assembly is loaded into the QCage.24 main assembly (QCAGE-24-STD) which completes the microwave cavity formed by the bottom and top cavity parts as shown below.

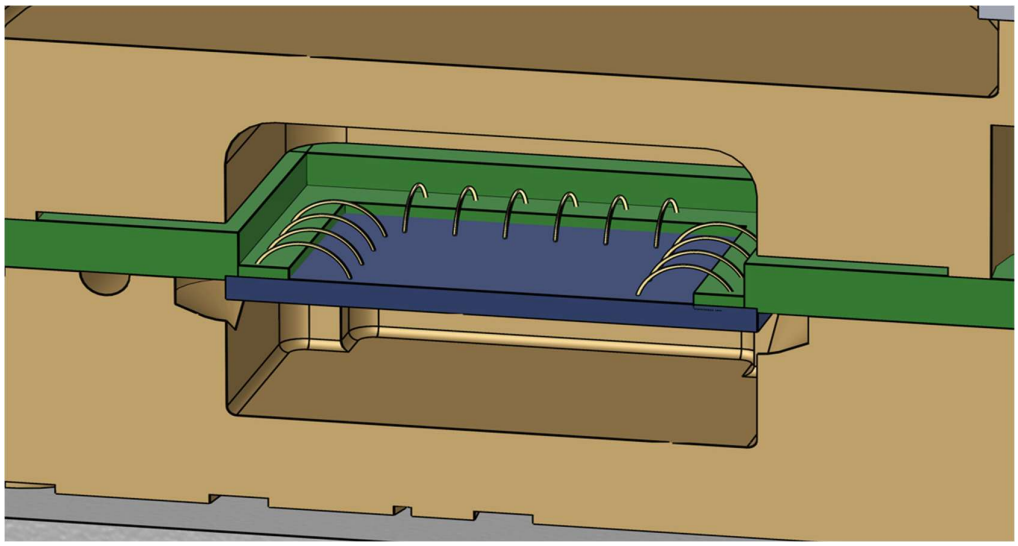


Figure 8 *Microwave cavity with sample chip suspended on four corner pedestals, clamped down along the edges of the sample board with connections established by wire bonding.*

It is highly recommended never to use glue or other compounds to mount the sample chip in the QCage.24 sample holder, as it may cause microwave losses and decoherence. Great efforts have been made to optimize the cavity to provide the best microwave surroundings with minimal losses and decoherence, both by separating the normal metal boundaries and selecting some of the lowest loss dielectrics for the sample board. Any additional microwave loss and decoherence mechanisms

introduced in the cavity are likely to degrade the performance of the quantum circuits operated in the QCage.24.

4.1 Interface Layout

The dimensions of the cavity and sample board interfacing to the sample chip are:

- Cavity space for fitting the chip = 10.5 × 10.5 mm^2
- Sample board step-down to bond pads = 10.0 × 10.0 mm^2
- Bond pad extension = 8.2 × 8.2 mm^2
- Sample board opening = 8.0 × 8.0 mm^2
- Transmission line separation = 1.3 mm

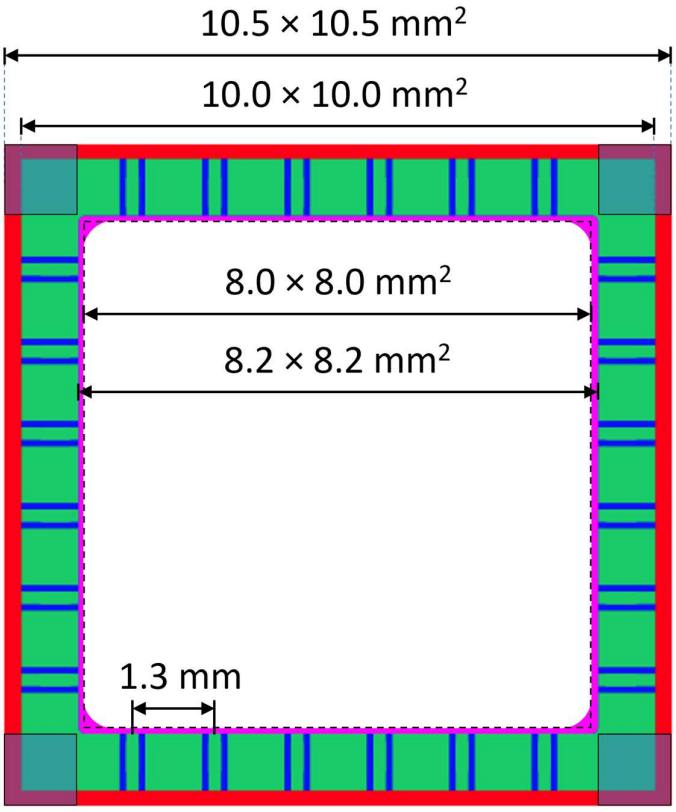


Figure 9 *Dimensions of the cavity and sample board layout (false color).*

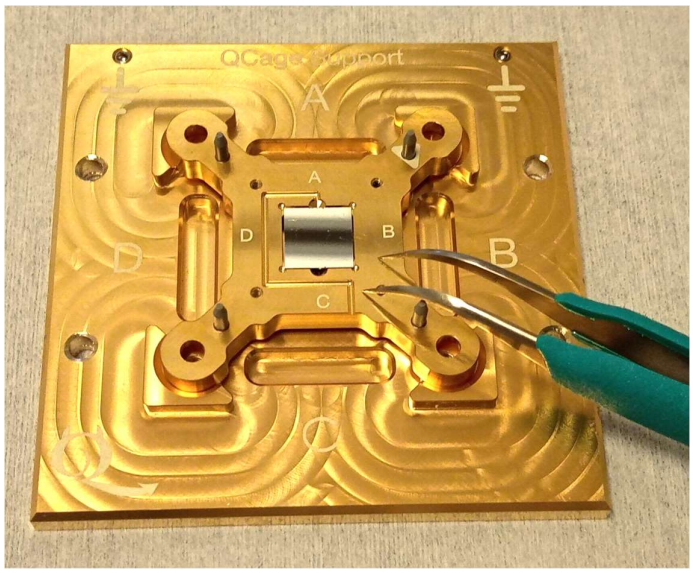
The transmission lines have a central linewidth of 0.2 mm with a 0.1 mm gap to the ground plane on each side. In this 8.0 × 8.0 mm^2 step-down region with the bonding pads, the thickness of the sample board is reduced to 0.3 mm. Outside this exposed region, the sample board has a step-up of 0.75 mm.

5. Loading the Sample Chip

The sample chip is first loaded into the cavity of the support frame and then clamped down by bolting the sample board on top. After that, connections are established by wire bonding while thermalization and grounding are ensured by direct contact between the chip and sample board.

5.1 Placing the Sample Chip into the Cavity

- Place the QCAGE-24-FRM support frame onto the QCAGE-24-WBF fixture plate, aligning the A, B, C, D markings
- Carefully place the chip in the cavity, accessing the tweezer tips via the cutouts from the A, C sides.



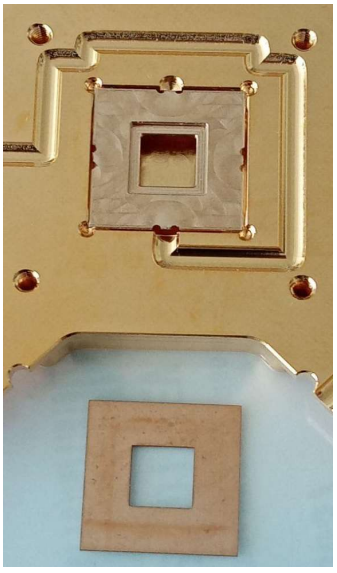


Figure 10 *Left) Support frame placed onto fixture plate with the chip placed in the cavity.*

Right) Adaptor plates for fitting smaller chip sizes,

lower part placed in the cavity, upper part to be placed upon the chip.

As described before, the chip cavity is designed to hold a chip size of 10 × 10 mm^2 (± 0.5 mm) supported by the four corner pedestals. Regarding chip thickness, the pedestal height is designed to support 525 μm ± 50 μm.

Adaptors are available to support different chip sizes and thicknesses. These are all included in QCAGE-24-APT:

- Q408 – Adaptor plates for 5 × 5 mm^2 chip size
- Q409 – Adaptor plates for 6 × 6 mm^2 chip size
- Q410 – Adaptor plates for 7 × 7 mm^2 chip size
- Q419 – Spacer for placing under thinner chips, 125 μm thick with 8 × 8 mm^2 opening
- Q427 – Spacer for thicker chips, 125 μm thick between PCB and chip holding frame

5.2 Clamping Sample Board Down

- Place the QCAGE-24-PCB sample board on top with the four guide pins aligned and matching the A, B, C, D markings.
- Tighten down the sample board by the four M1.6 × 4 mm screws with a light hand torque, maximally 0.12 Nm – use of washers is optional.
- After clamping down the sample board, the whole chip package may be secured onto the fixture plate by the four M3 × 10 mm screws.

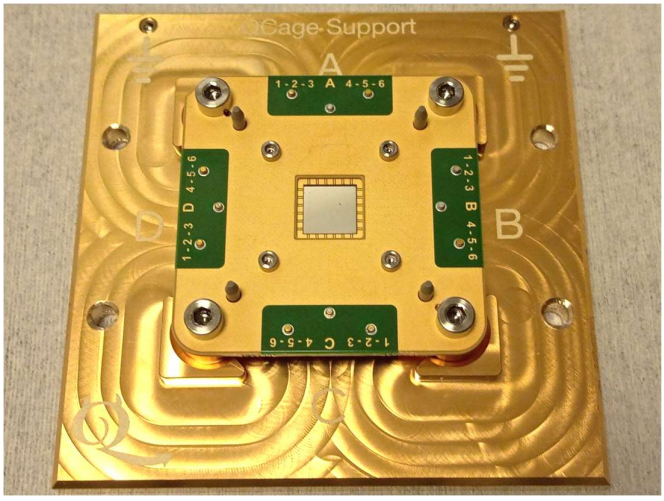


Figure 11 *Sample board clamped down on top of support frame with a chip loaded in the cavity.*

5.3 Wire bonding Guidelines

Depending on the wire bonder model, holes may need to be drilled in the QCAGE-24-WBF fixture plate to fit the mounting holes on the wire bonder. Alternatively, clamping clips may be used to keep the fixture plate in place in some wire bonders. In all cases, we recommend having the fixture plate securely mounted in the wire bonder.

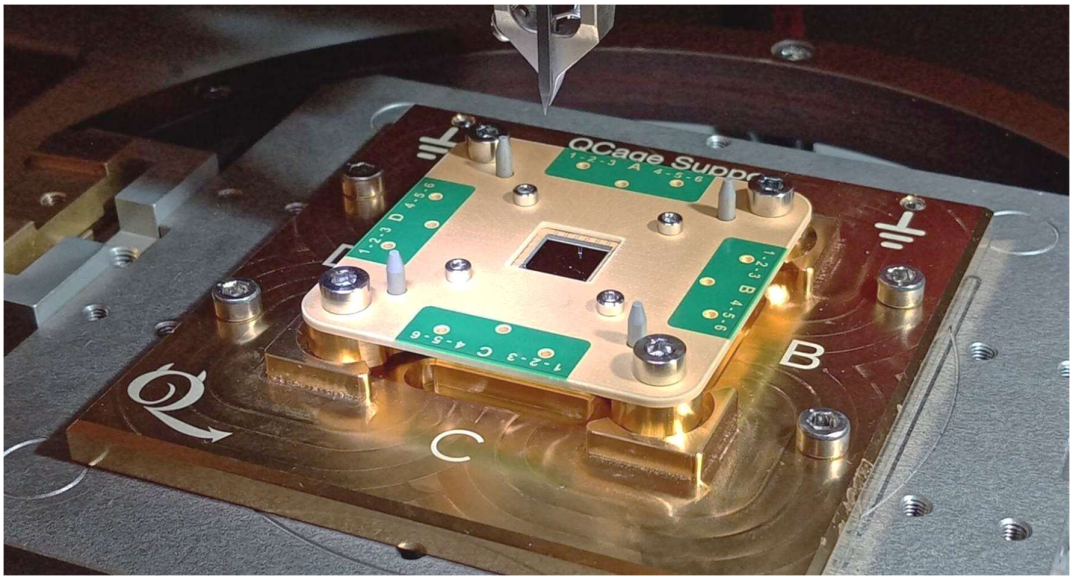


Figure 12 *Fixture plate with support frame holding chip and sample board, mounted in aluminum wedge wire bonder.*

The support frame and fixture plate have been designed and verified to provide a solid anchoring of the ultrasonic agitation from the wire bonding wedge. As a result, we have found that the optimal bonding parameters are achieved with only slightly higher ultra-sonic power and bond force than what works for conventional chip carriers. The exact optimal settings will depend on the particular wire bonder model and wedge head that is used.

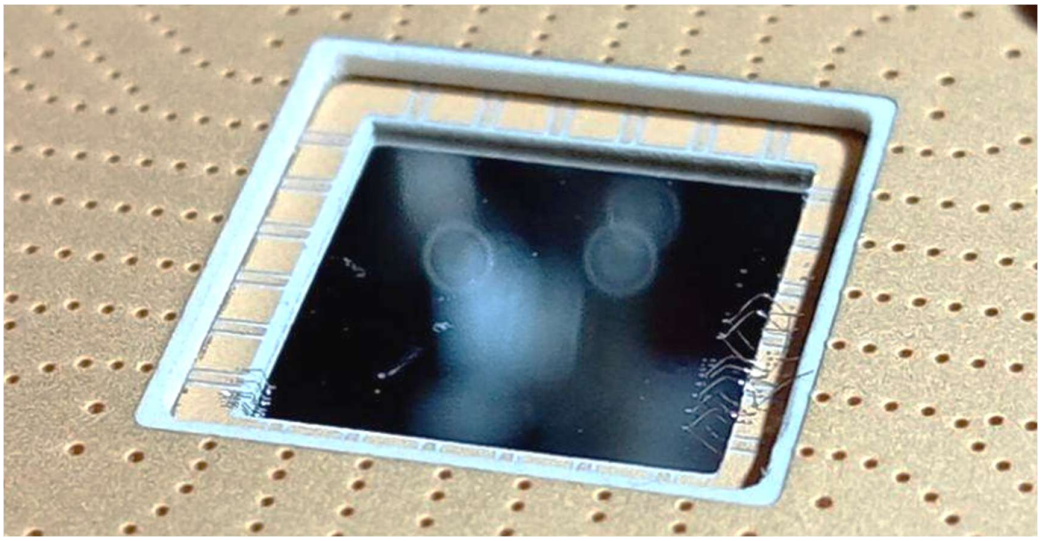


Figure 13 *Bond wire connections established from sample board to chip.*

A few general remarks for setting up for wire bonding:

- *Ensure that the fixture plate is securely fixed to the wire bonding station, and that the clamped chip assembly is bolted securely to the plate*
- *Wire bonding parameters should be slightly increased, compared to what works for conventional chip carriers*:
  - *Bonding force setting normally 5% - 20% higher than standard*
  - *Ultrasonic power normally 10% - 50% higher than standard*
- *To ensure cleanliness, the PCB may be sonicated in acetone and/or isopropanol*
- *Aluminum wire residues should be removed mechanically with soft tooling (plastic or wood)*
  - *Aluminum etchant based on phosphoric acid may be used for chemical removal*

6. Transferring into the Main Assembly

After establishing the connections by wire bonding, the chip holding package is ready to be transferred to the main QCage.24 assembly. This can be done either on the lab bench (as shown below) or with the assembly already mounted on the fridge or into a sample loader.

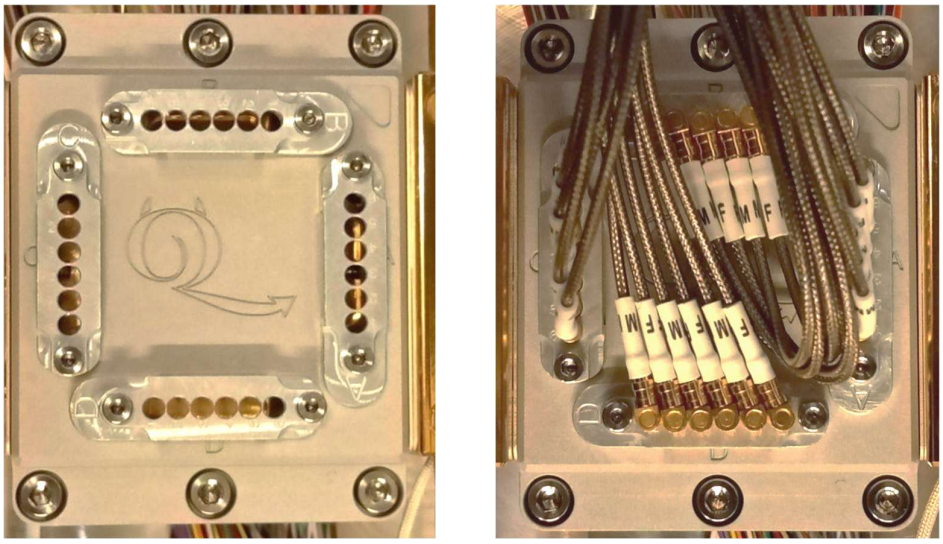


Figure 14 Six-way connector face-plates mounted by M2 bolts (without/with cables attached)

- First remove the six-way coaxial cables by unscrewing the faceplates labeled A, B, C, D.
- Next remove the aluminum shielding lid with the QDevil logo by unscrewing the three bolts at each end of the assembly.
- The chip holding package may now be flipped from the support fixture to the main QCage.24 assembly.

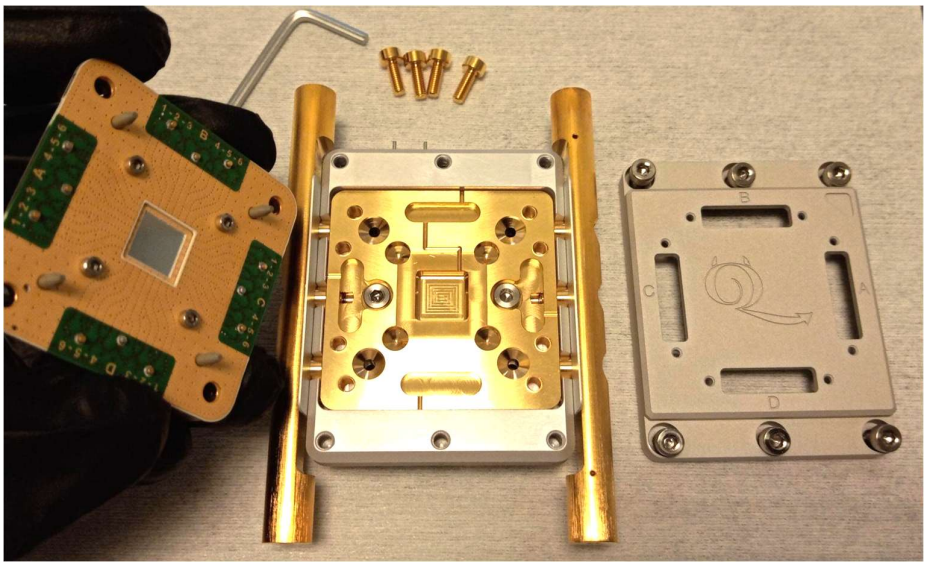


Figure 15 *Flipping the chip holding package onto the open QCage.24 assembly.*

- Carefully mate the chip package and make sure that the guide pins match up
- Use the four gold-plated copper screws to bolt down the chip holding package using a torque of 0.6 – 0.8 Nm.
- Place the aluminum shielding lid on top and bolt down the six screws using a torque of 0.2 Nm.

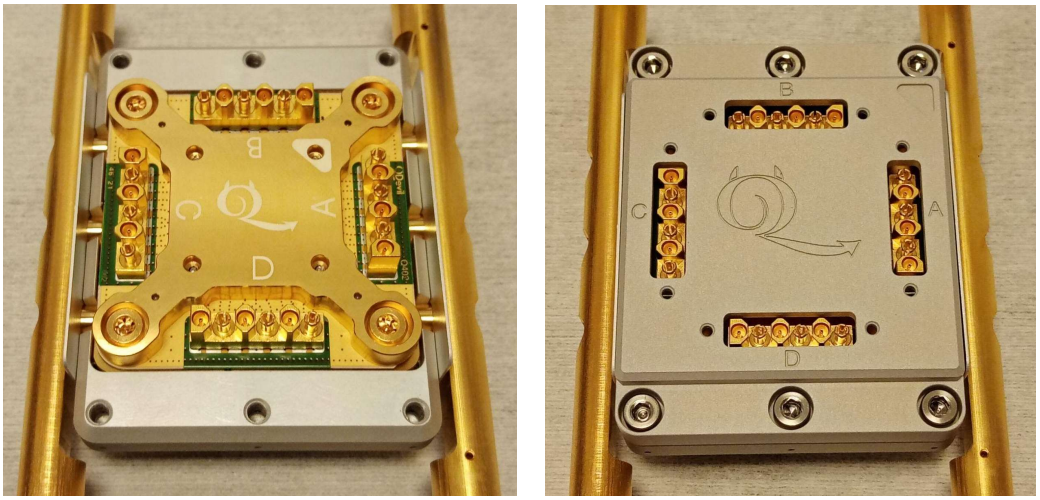
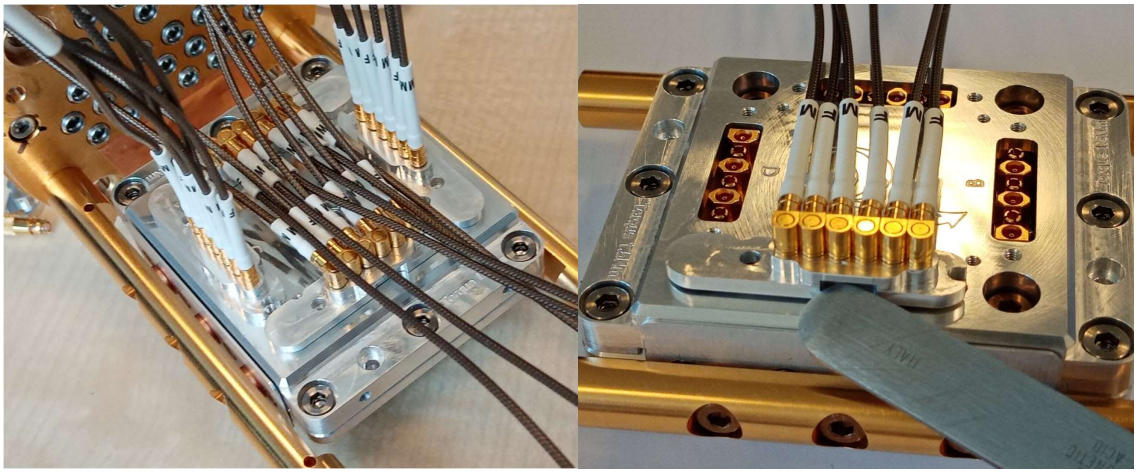


Figure 16 *Left) Chip holding package bolted down. Right) Shielding lid mounted on top.*

6.1 Connecting the Multi-Way Coaxial Cables

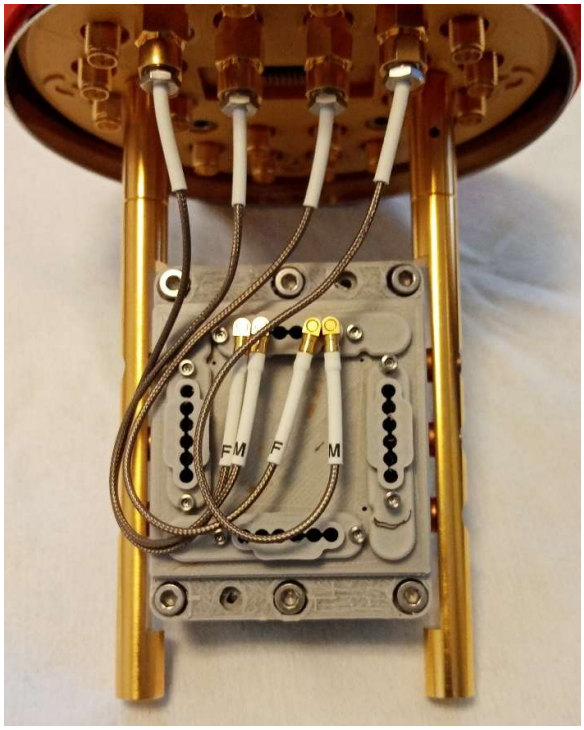
- Carefully place the six-way cable connector onto the PCB connector and press it in with a light finger touch - bolt the aluminum flange on with the supplied M2 bolts.

- For fitting up to 24 coaxial lines, the cables can be interposed or combined angled, and straight. To remove the connector, use the recesses on each side of the flange with a flat tool.



6.2 Shielding the QCage.24 using QCage Magnetic Shielding

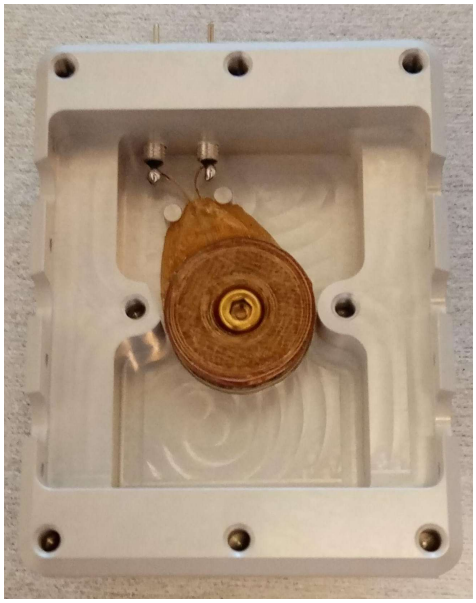
- Use the Mini-Coax to SMA cables (Q412_15) to connect from the QCage.24 to the inside of the top flange and secure them one by one using a torch wrench with a torque of max 0.45 Nm.



- Slide the QCage.24 into the magnetic shielding. Be very careful not to damage the cables while sliding into the aluminum can. Tighten the four 45° slanted screws to a torque of 0.2 – 0.4 Nm.

- Slide on the mu-metal can and ensure that the spring seal engages. You may need to apply slight force for the last few millimeters of engagement. Afterward, secure the red finger screw.

7. Utilizing the Auxiliary Magnet Coil



The QCage.24 sample holder system is provided with an auxiliary magnet coil mounted inside the aluminum EMC shielding.

The magnet coil has 250 windings of superconducting wire corresponding to a field strength of approximately 0.04 Gauss/mA perpendicular to the sample plane. It is placed inside the aluminum superconducting shield, which will repel the external magnetic fields by the Meissner effect. The resulting magnetic field strength will remain under the critical field of the aluminum shield for supply currents ranging to over 100 mA, ensuring full integrity of the superconducting shield.

For safety reasons, the coil should not be disconnected while carrying a current as this will lead to transient generation of voltages up to 16 volts (still well under the limits governed by EN 61010-1).

The homogeneity of the magnetic field is affected by the Meissner effect of the aluminum shield, which repels the field lines from the magnet coil. Below is a magnetic field simulation from COMSOL Multiphysics, showing a homogeneity of about ±20% for the perpendicular field across the 8.0 × 8.0 mm^2 active chip region. Furthermore, it suggests that the nominal field strength is reduced to about 0.026 Gauss/mA by the deflection of the field lines by the Meissner effect.

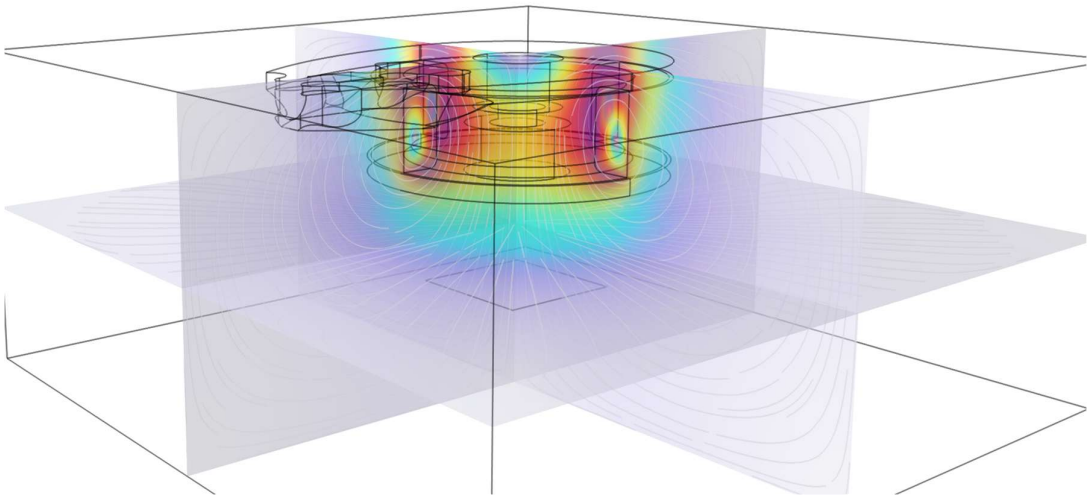


Figure 17 *COMSOL Multiphysics simulation of the magnetic field inside the superconducting shield*

7.1 Magnet Coil Specifications

Field strength	0.026 Gauss/mA
Homogeneity	±20%
Current limit	100 mA

It should be noted that the supply current may be further limited by heating in any normal metal wiring that may be used outside the QCage.24 package. We recommend that heating effects are carefully monitored when passing currents in excess of 10 – 20 mA.

8. Mounting onto Cryogenic Interfaces

The QCage.24 system is supplied with mounting accessories that can be used for either direct mounting, mounting in some of the common sample loader puck systems, or with the possibility of mounting with QCage.24 magnetic shielding. Direct mounting might be either directly onto a mixing chamber flange plate or a cold finger extension. For sample loader puck systems, the QCage.24 is prepared for mounting into both Ø72/73 mm Oxford pucks and Ø80 mm BlueFors bottom loaders.

All these mounting accessories have been optimized for providing a good thermal pathway that ensures proper thermalization of the cavity parts and sample board facing the chip. The rods and brackets are manufactured from beryllium copper with nickel-free gold plating. This ensures the best combination of thermal conductivity, surface inertness, and mechanical durability. The bolts used to mount onto the cavity parts are also made from beryllium copper with nickel-free gold plating, while the remaining screws are supplied in titanium to avoid any magnetic parts.

8.1 Standalone - Direct Mounting of QCage.24

For direct mounting, the QCage.24 system is prepared for either perpendicular out-of-plane mounting or flat in-plane mounting.

8.1.1 Vertical Mounting

For vertical out-of-plane mounting, use the rods that are attached to each side of the assembly. These are 94 mm length and have M3 threaded holes in each end. The system is furthermore supplied with four extension rods of length 25 mm that may be used for extending the mounting rods by 25 or 50 mm.

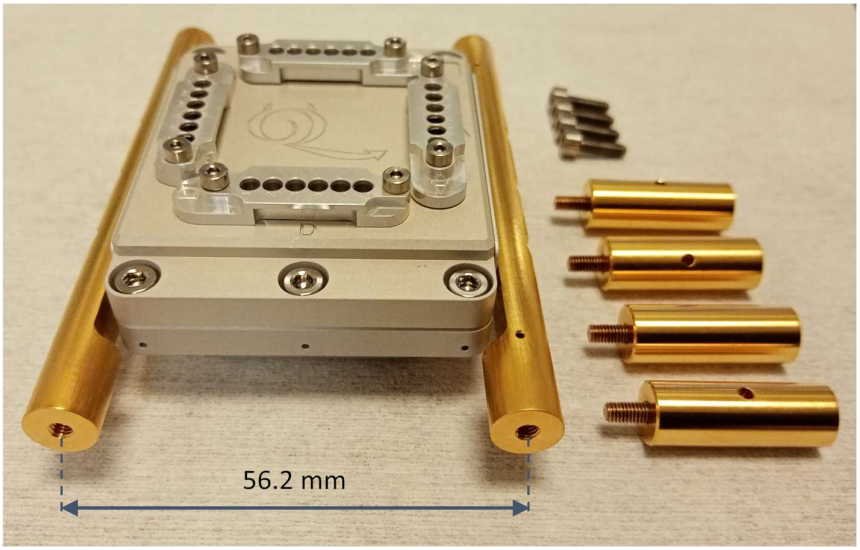


Figure 18 *Mounting rods for out-of-plane mounting into M3 holes 56.2 mm apart.*

8.1.2 Horizontal Mounting

For horizontal in-plane mounting, the mounting rods on each side of the QCage.24 assembly need to be exchanged with the angled brackets. The six gold plated copper screws are reused to mount the two brackets on each side of the assembly. Use a mounting torque of 1.0 – 1.2 Nm to ensure proper thermalization without causing mechanical damage.

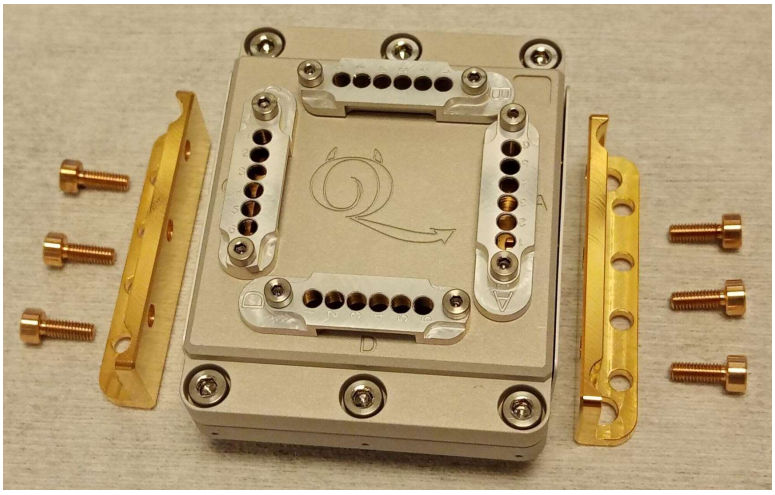


Figure 19 *Replacing the mounting rods with angled brackets.*

The angled brackets mounted on each side of the assembly provide a rectangular hole pattern of 40 × 60 mm via the two outermost holes on each side. These can be used with the supplied M3 titanium screws, or with narrow-headed M4 screws that may be sourced separately.

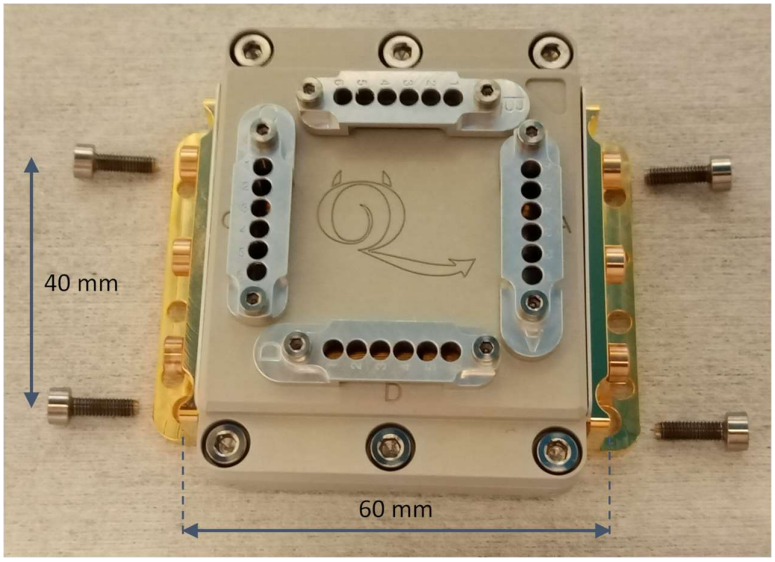


Figure 20 *Mounted with brackets for flat in-plane mounting.*

8.2 Standalone – Mounting QCage.24 into Puck Systems

The QCage.24 sample holder system is supplied with both mounting rods for the Ø72/73 mm Oxford pucks and the Ø80 mm BlueFors bottom loaders.

8.2.1 Oxford Ø72/73 mm Puck Mounting

The QCage.24 is designed for mounting in the 144 mm long Oxford Ø72/73 mm pucks that have rectangularly offset mounting rods with 56.2 mm distance. The QCage.24 assembly will also fit in the shorter 94 mm pucks, but for these additional screw holes will have to be drilled in the top and bottom flanges to support the 56.2 mm distance between the mounting rods. The 94 mm long mounting rods supplied with the QCage.24 should be extended to 144 mm with the four 25 mm long extension rods. Thereby, the assembly may be positioned either in the top, bottom or middle of the puck by either mounting the extension rods below, above or on either side of the 94 mm rods.

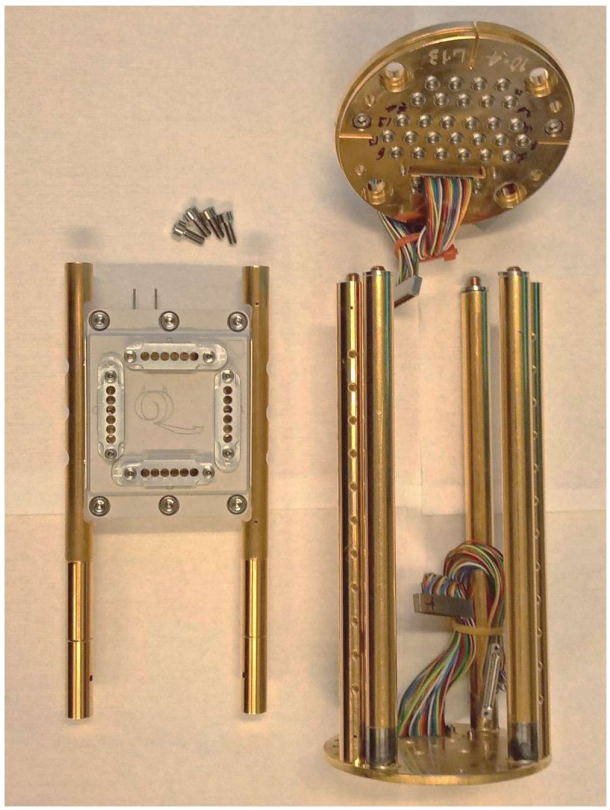


Figure 21 *Assembly prepared for top mounting in the Oxford puck.*

Before mounting the QCage.24 assembly in the Oxford puck, the top flange should be removed and two of the original mounting rods taken out to make room for the mounting rods attached to the QCage.24 assembly. After that, the QCage.24 can be positioned in the puck and secured to the flanges with M3 screws in both ends of all four mounting rods, both the two original and the two attached to the QCage.24.

After mounting the assembly in the puck, the coaxial multi-way cables may be put in place and routed to the top flange of the puck, where they should connect to the SMP sockets. Note that 10 or 15 cm cable length is best suited for routing in the Oxford pucks.

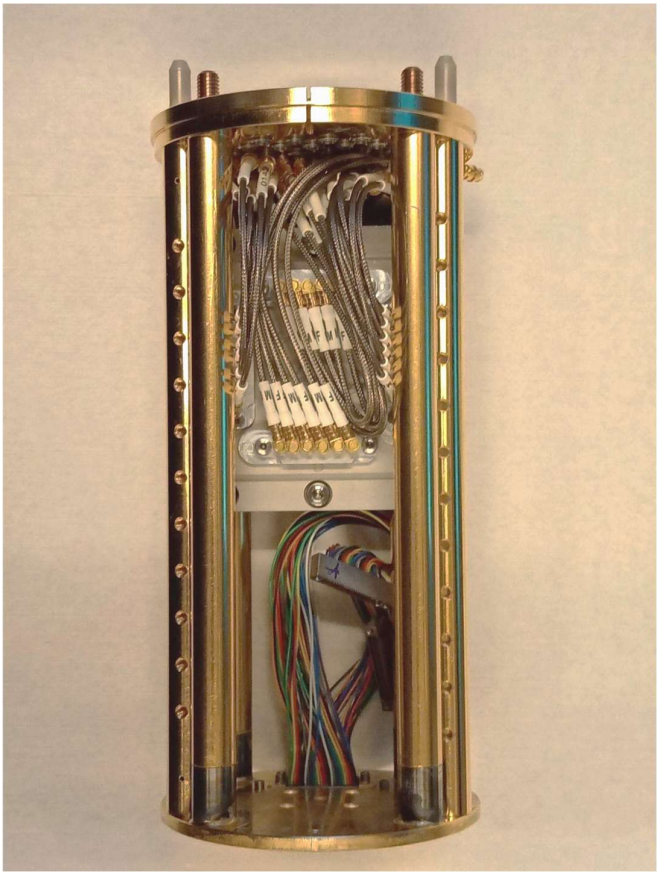


Figure 22 *QCage.24 mounted in Oxford Ø72/73 mm puck with multi-way cables routed to the top flange.*

8.2.2 BlueFors Ø80 mm Bottom Loader Mounting

For mounting in the BlueFors Ø80 mm bottom loaders, the brackets supplied with the QCage.24 should first be mounted on the rails in the bottom loader. For this, use any of the four screw holes with the M3 screws supplied with the QCage.

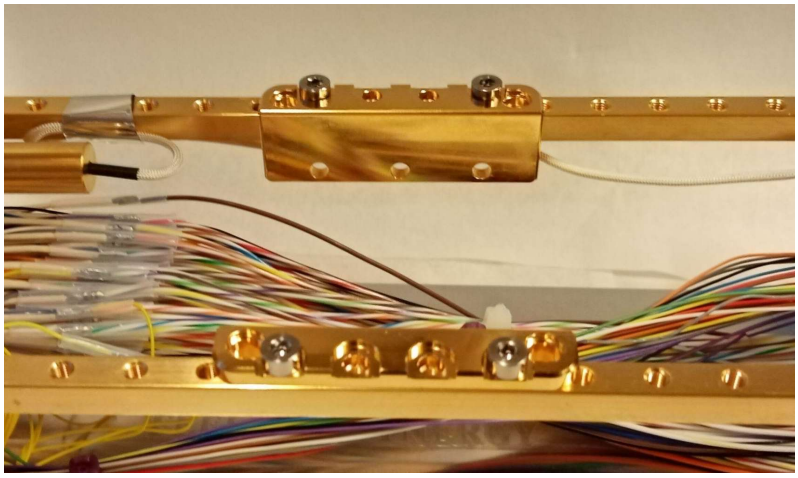


Figure 23 *Brackets mounting to the rails of a BlueFors bottom loader.*

After mounting the brackets, the QCage.24 assembly can be placed in between and attached by three beryllium copper bolts from each side. The six screws should be tightened with a mounting torque of 1.0 – 1.2 Nm to ensure proper thermalization without damage. After mounting the assembly in the bottom loader, the coaxial multi-way cables may be put in place and routed to the top flange of the puck for connection to the SMP sockets. Note that for the BlueFors bottom loaders, 20 or 30 cm cable length is best suited for routing to the top flange.

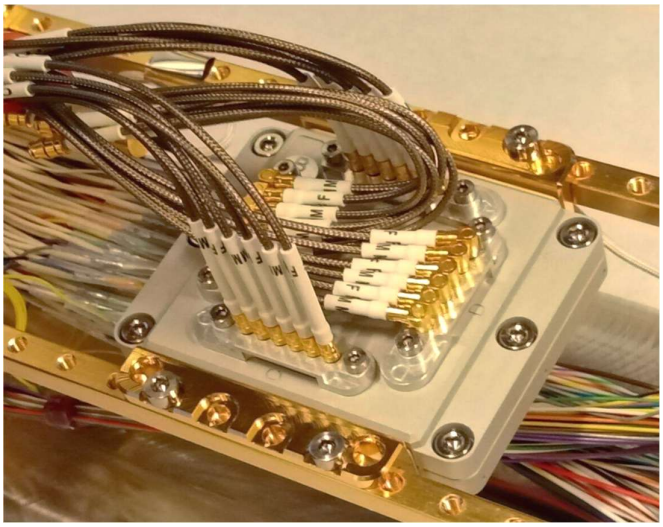


Figure 24 *QCage.24 mounted in BlueFors Ø80 mm bottom loader with multi-way cables routed towards the top flange.*

8.3 Standard Configuration – Mounting QCage.24 with magnetic shielding

All the dimensions seen below are in mm unless stated otherwise. The dimensions of the QCage.24 with magnetic shielding are H: 228.7 mm x D: 113.4 mm as seen below.

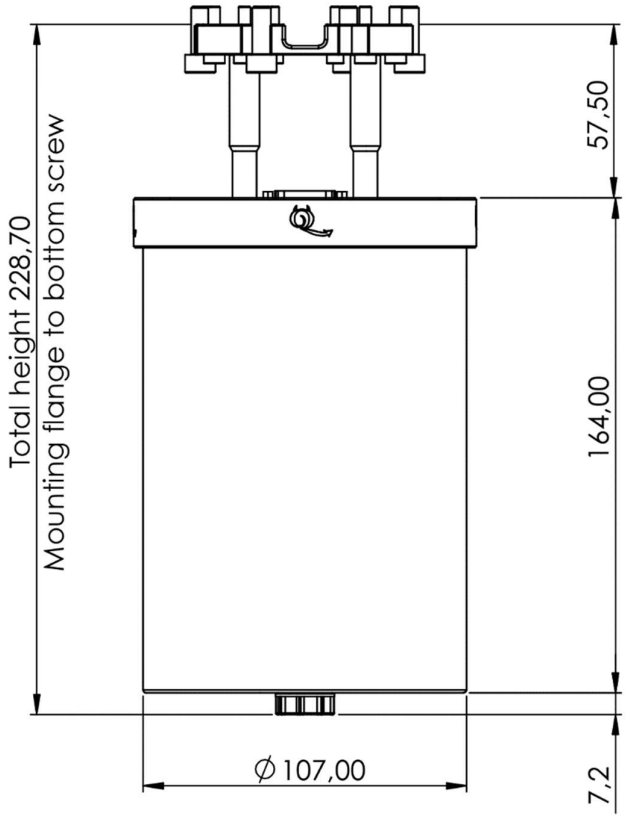


Figure 25 *Side view of QCage.24 standard configuration CAD drawings. All dimensions are given in mm.*

The top flange plate is prepared with holes for mounting onto the most common mixing chamber plates. These are 8 x M3 holes and 16 x M4 holes intended for mounting onto the common 20 x 20 mm^2 square pattern of either M3 or M4 holes. As an alternative to the square hole pattern, the Ø75 mm outer circle of 8 x M6 holes provides for mounting directly to e.g. the central KF40 port on

BlueFors LD refrigerators. The spacing and placement of M3, M4 and M6 holes are shown in the figure below.

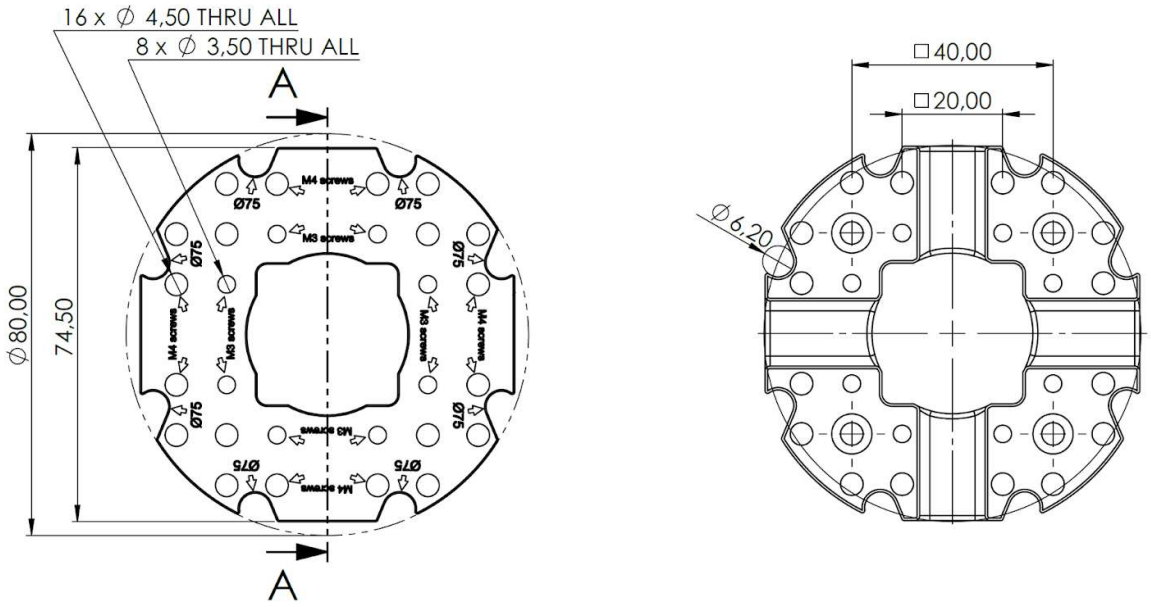


Figure 26 CAD drawing of the top flange of the QCage.24 standard configuration (incl. magnetic shielding). All dimensions are given in mm.

Please note that the black plastic handle should be **removed before cool-down**.

8.3.1 Mounting 2 x QCage.24 in Magnetic Shielding

It is possible to mount 2 x QCage.24 into one magnetic shielding, either the QCAGE-SHL-24C with 24 lines (if that is sufficient) or the QCAGE-SHL-64C with 64 lines which allows for connection of all 2 x 24 lines. In the case of QCAGE-SHL-24C, the inside mounting frame in the magnetic shielding is already prepared for either one or two QCage.24. In case of QCAGE-SHL-64C, the mounting of two QCage.24 requires an additional QCAGE-SHL-BRK interface bracket that supports back-to-back mounting as illustrated below:

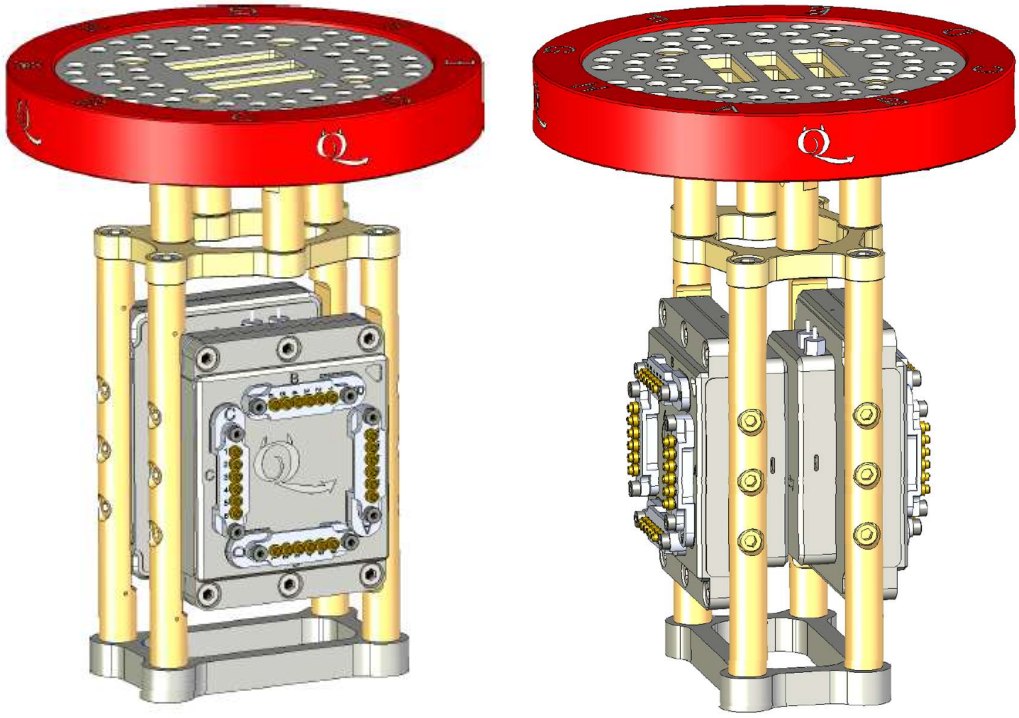


Figure 27 *CAD drawing of the top flange with 2 x QCage.24 mounted inside. Left) Front view. Right) Side view.*

Please note that the black plastic handle should be **removed before cool-down**.

9. Troubleshooting

If you have any problem getting our Products to work and you cannot find the answer in this manual, or if anything is broken, please do not hesitate to contact:

QM Technologies ApS

Lautrupvang 2,

2750 Ballerup

Denmark

https://www.quantum-machines.co/

e-mail: support@quantum-machines.co

Phone: +45 3699 2145

We will do our best to Help You Succeed!