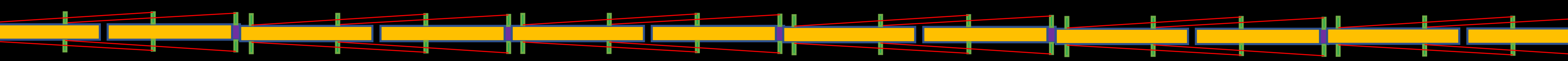
The alignment of the modules of the Cool Copper Collider C^3 with the Rasnik 3-point alignment system



Harry van der Graaf , Niels van Bakel , Bram Bouwens ,
Martin Breidenbach , Andrew Haase , Joris van Heijningen , Anoop Nagesh Koushik,
Emilio Nanni , Tristan du Pree , Nick van Remortel , Caterina Vernieri

LCWS 2024, University of Tokyo, Japan

Nikhef
SLAC NATIONAL ACCELERATOR LABORATORY
University of Antwerp
Faculty of Science

The accelerator Structure

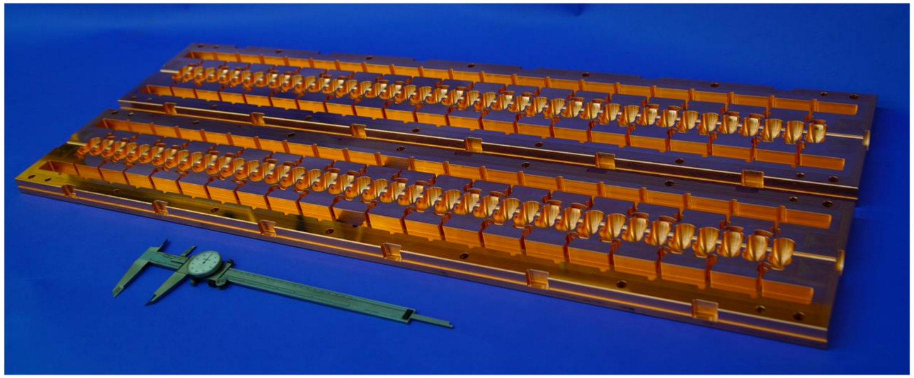
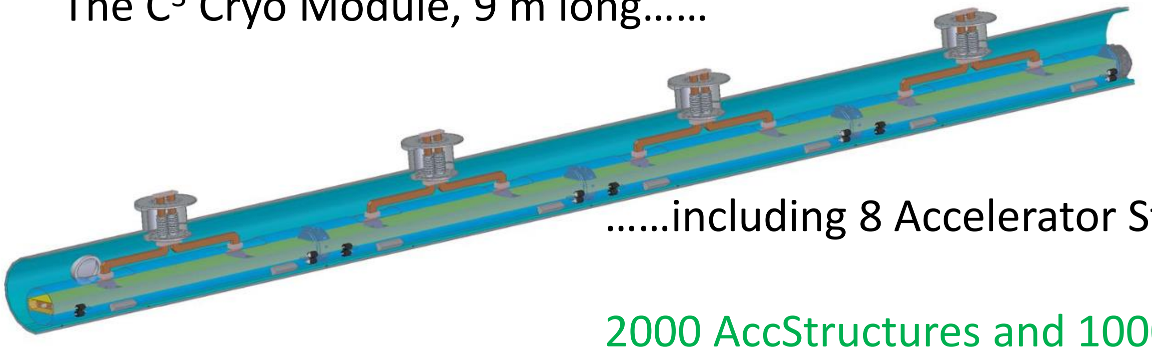


Figure 4: Both halves of the C^3 prototype structure prior to braze. The one meter structure consists of 40 cavities. A rf manifold that runs parallel to the structure feeds 20 cavities on each side. The structure operates at 5.712 GHz.

The C^3 Cryo Module, 9 m long……

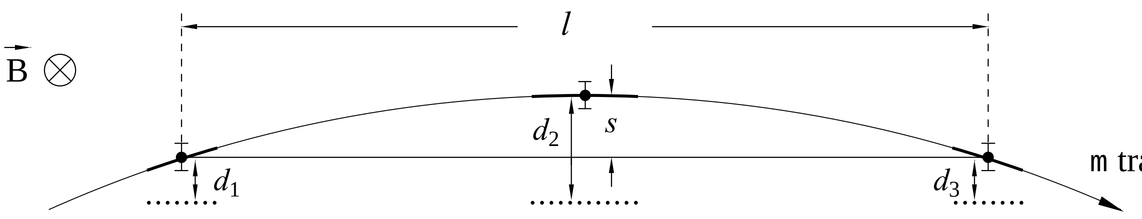


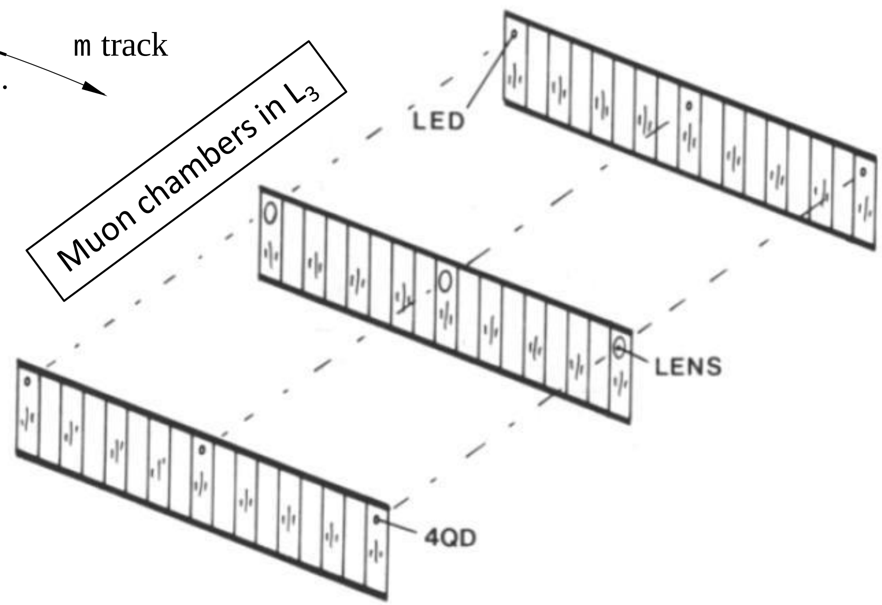
……including 8 Accelerator Structures and 4 Quads

2000 AccStructures and 1000 Quads must be aligned over a length of 2.3 km, with 10 µm precision

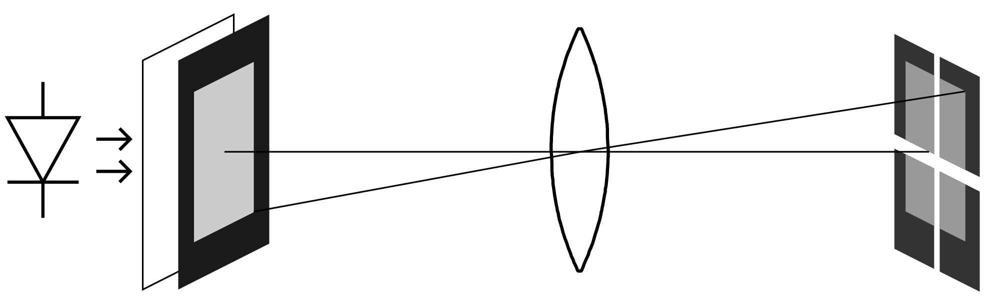
1983: Alignment of the Muon Spectrometer of the L_3 experiment at CERN

…..original idea was from Draper Lab/MIT, Cambridge, Mass



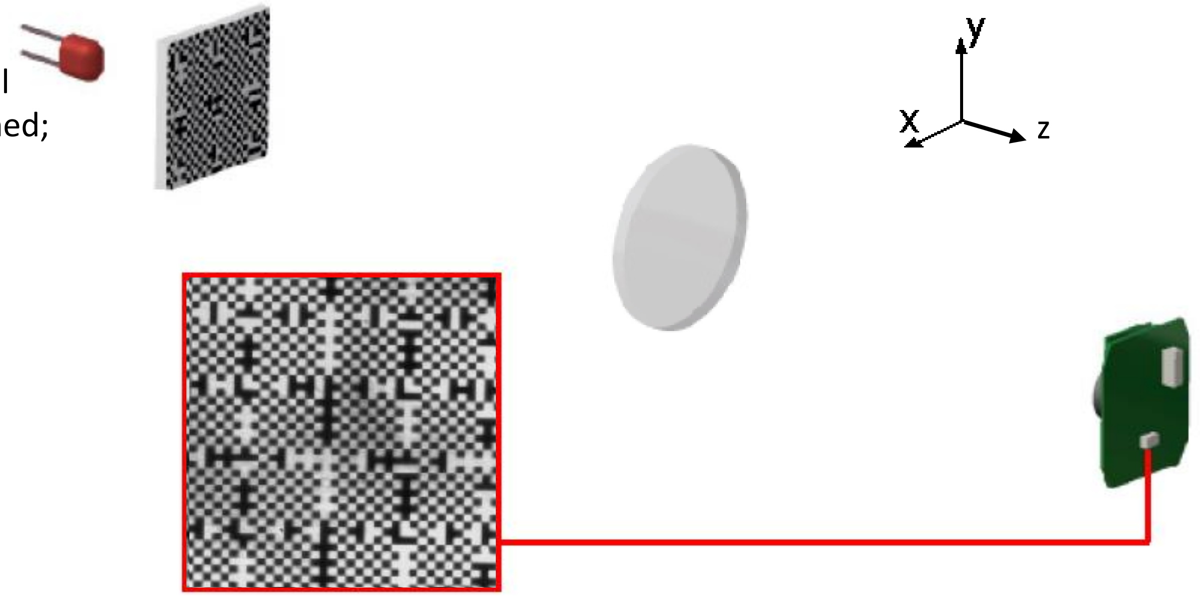


First Rasnik design: 4QD
Red Alignment System NIKhef



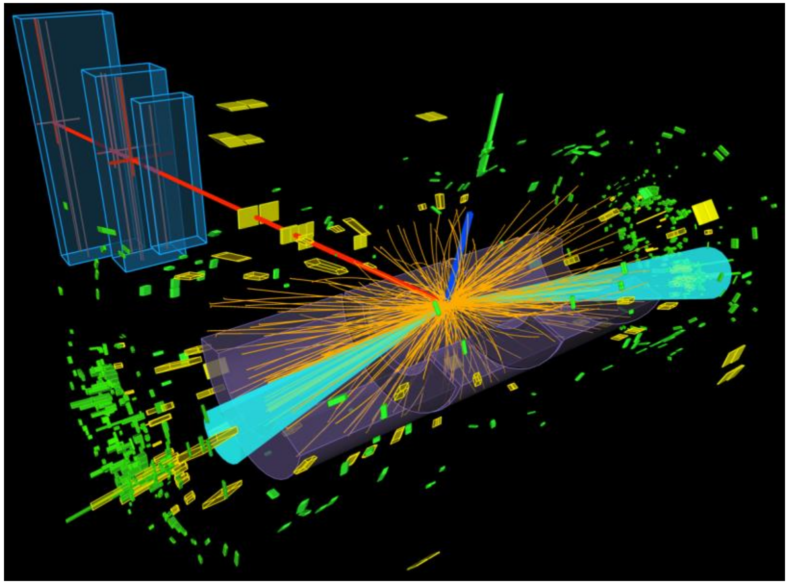
1993: CCD-Rasnik Three Point Alignment system for ATLAS

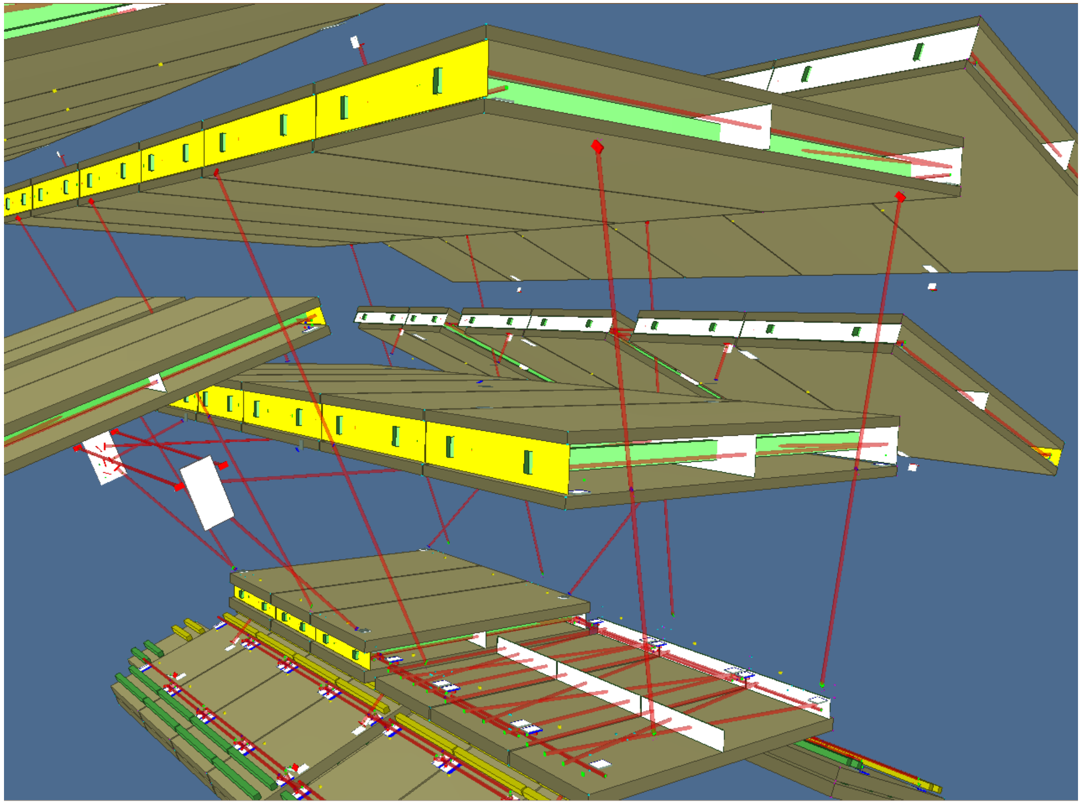
- Coded mask is projected via lens on pixel sensor;
- In principle, all 6 DoFs of mask & pixel sensor + x,y,z of lens can be determined;
- x,y,z and rotZ (θ_z, not for lens) are measured



M. Beker et al., "The Rasnik 3-point alignment system", JINST 14 P08010 (2019)

ATLAS experiment: 8000 Rasniks, none fails since start

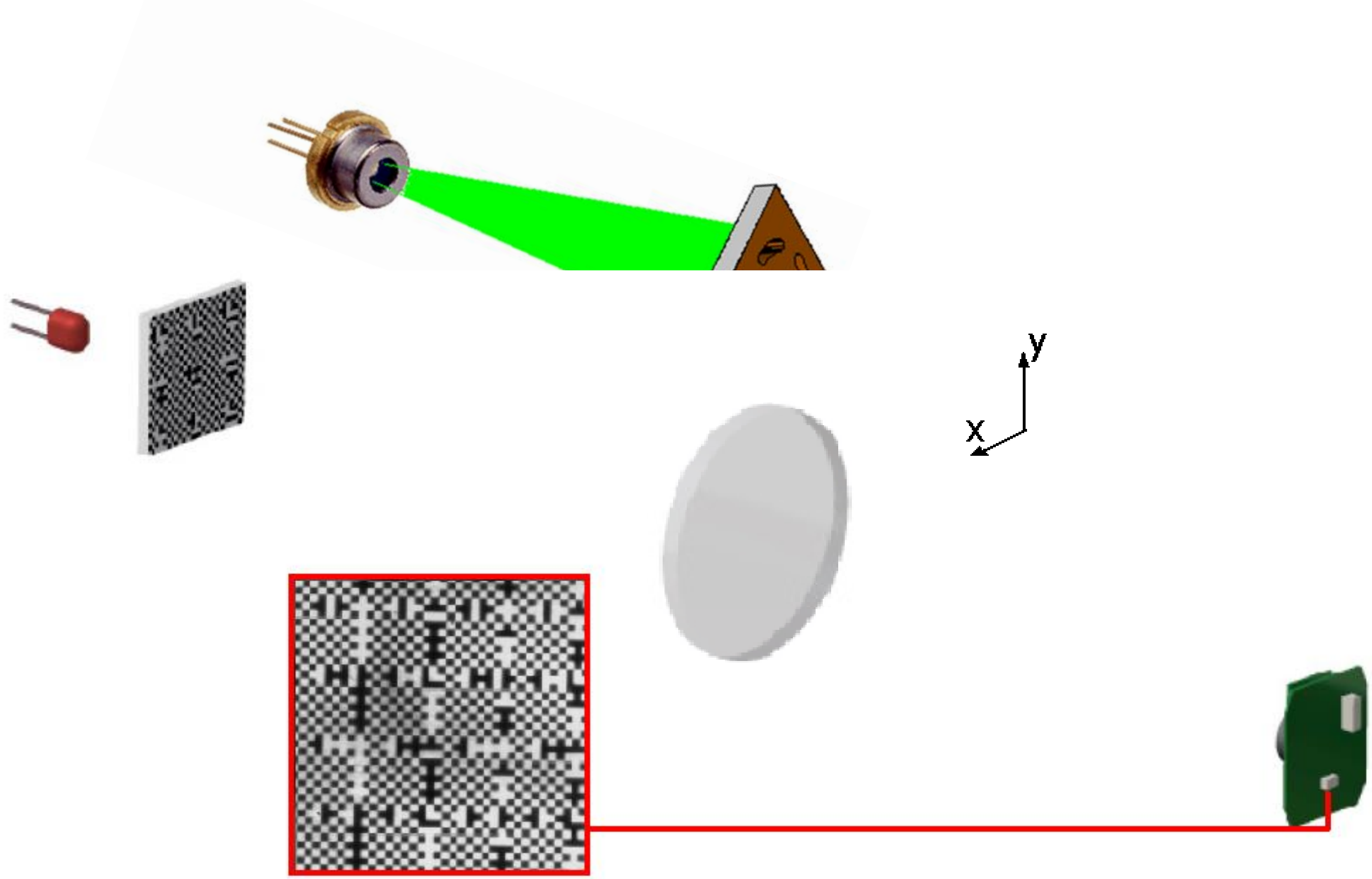




… we need to know where
our detectors are!

Long distance Rasniks

Lens diameter 2 – 5 % of distance mask-sensor: too large!



Alignment over long distance (> 100 m):
RasClic, later RasDif:

- replace lens by zone plate

- replace coded mask by monochromatic spherical-wave light source (1 $ laser diode)

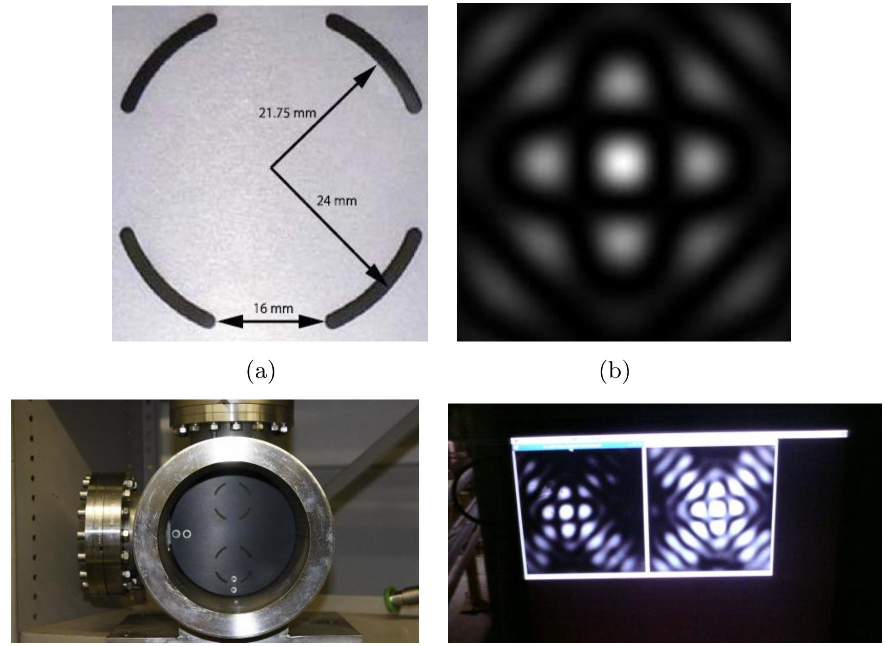


Figure 4.8: (a) Design and dimensions of the diffraction pattern, (b) simulations of the resulting diffraction pattern, (c) a photograph of the plate holder and (d) a photograph of the pixel image sensor read-out at the PC

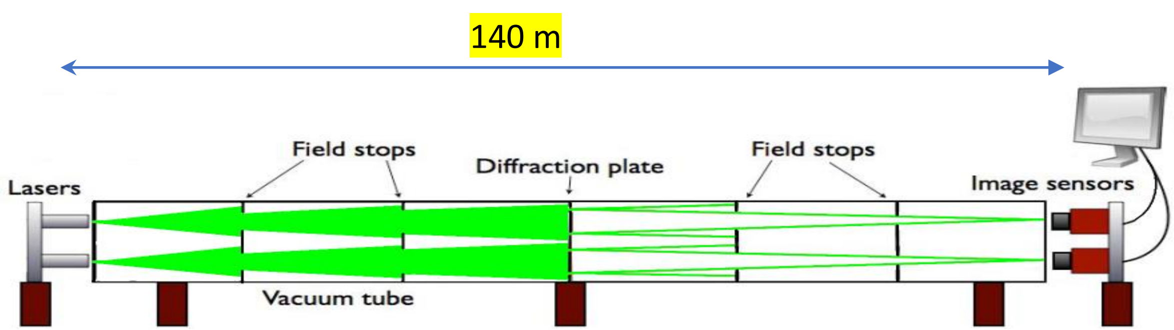
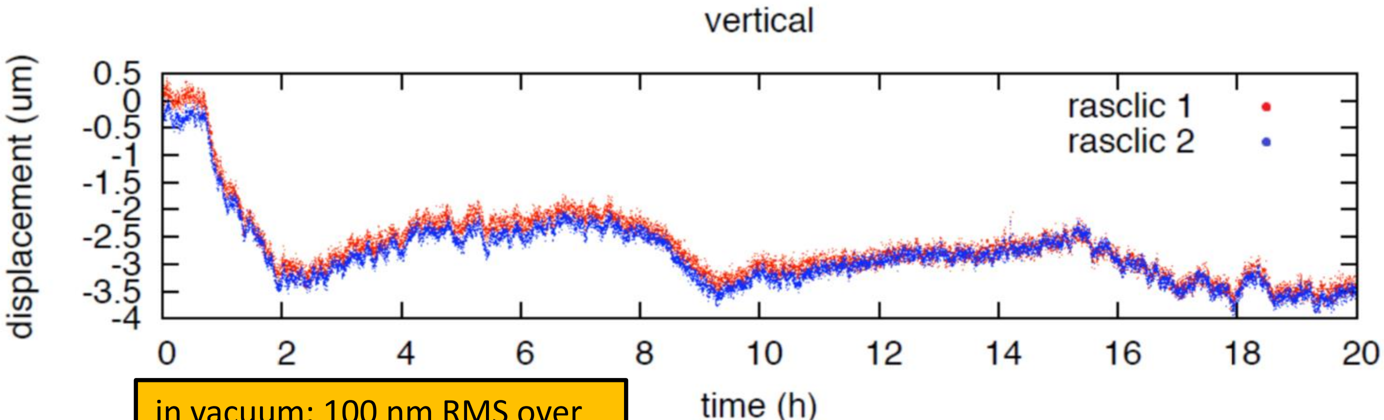


Figure 4.7: Schematic overview of the RasCLiC set-up, showing the operation of the field stops

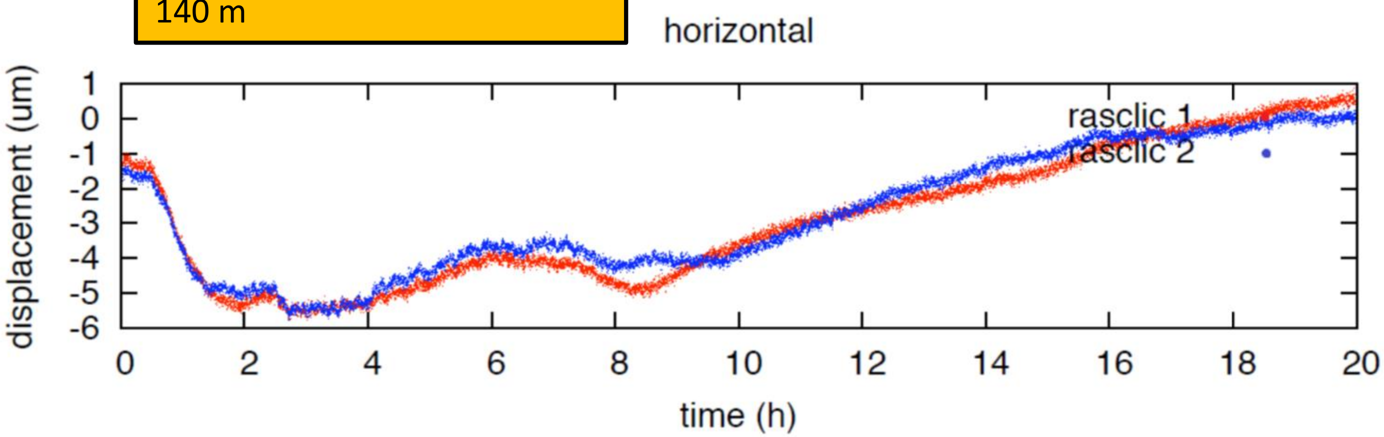
Pioneered by A. Seryi, SLAC:

Investigation of slow motions of the SLAC linac tunnel, SLAC-PUB-8597 8597 (1) (2000) P06034, arXiv:physics/0008195.

140 m test set-up (TT1 @ CERN)



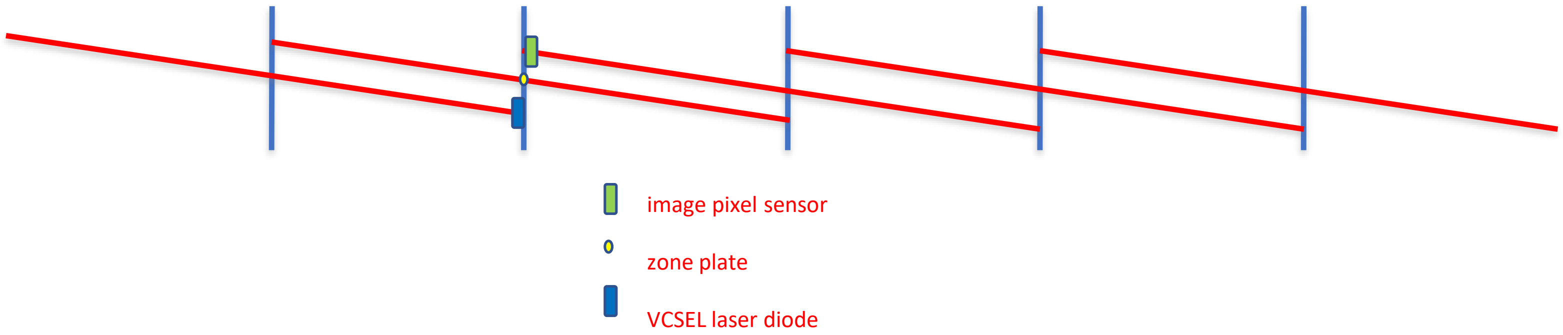
in vacuum: 100 nm RMS over 140 m



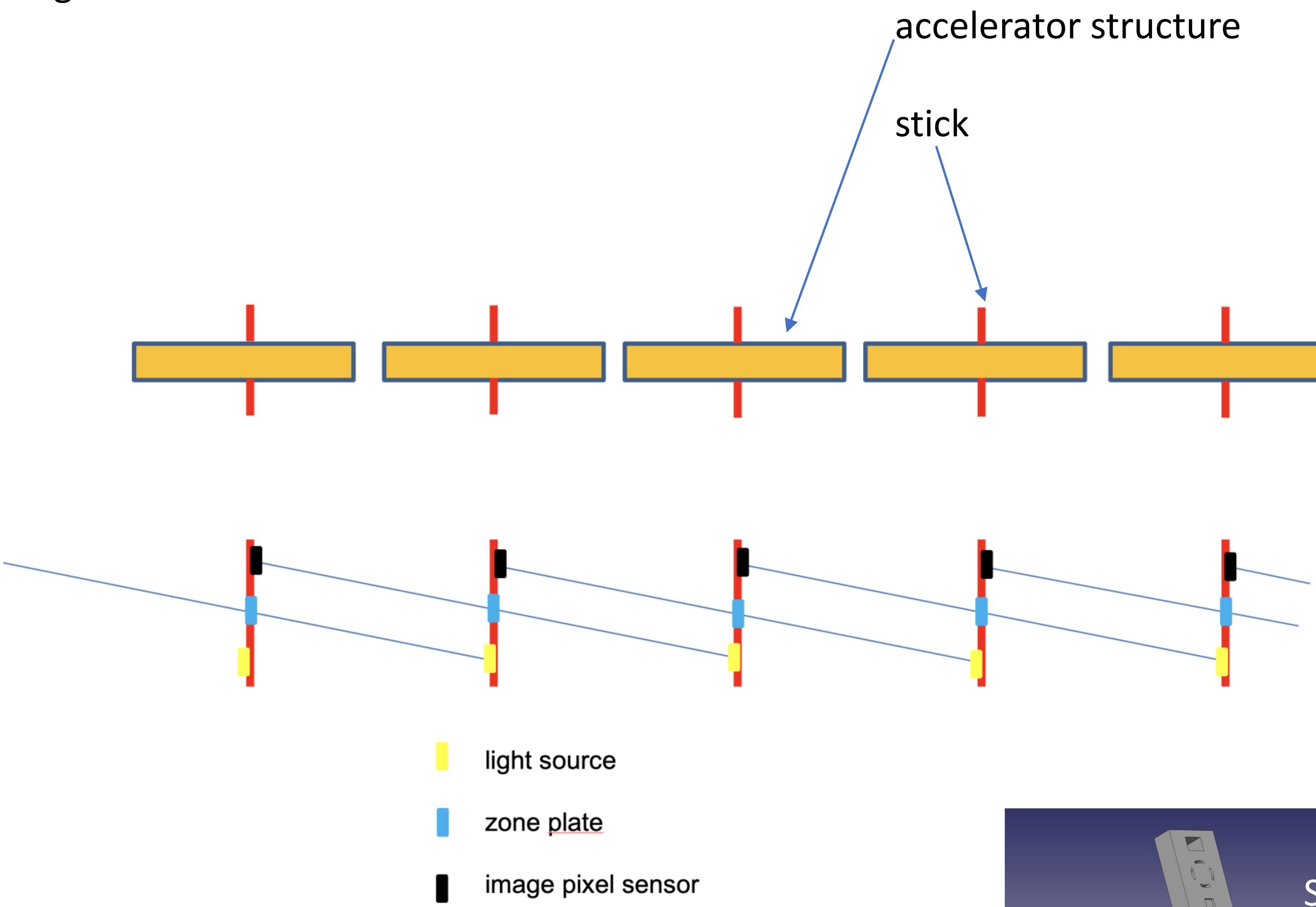
JvH, "Precision Improvement in Optical Alignment Systems of Linear Colliders", M.Sc. Thesis, Delft University of Technology (2012)

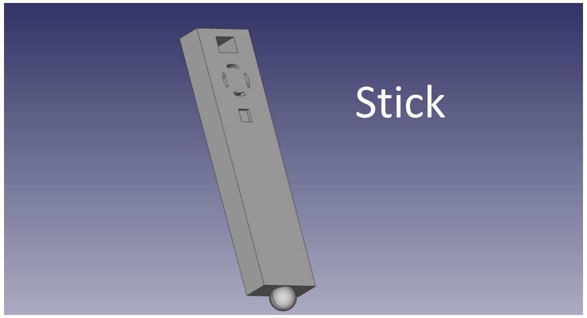
From 3-point alignment system to n-point alignment system:

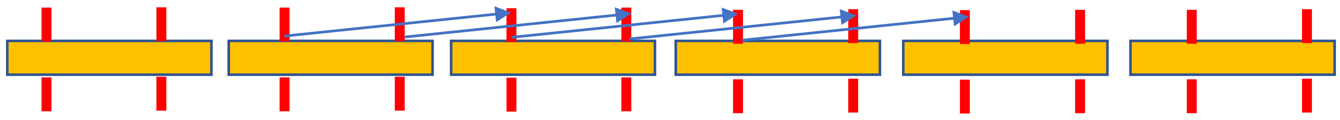
chainplates



C³: alignment of ~2000 accelerator structures



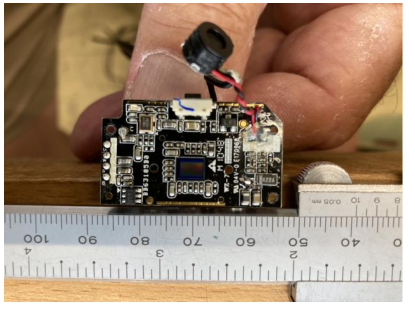




Each structure is 5D defined in space, with redundancy

Operating Rasnik in LN_2 and in air and in vacuum)

Cam

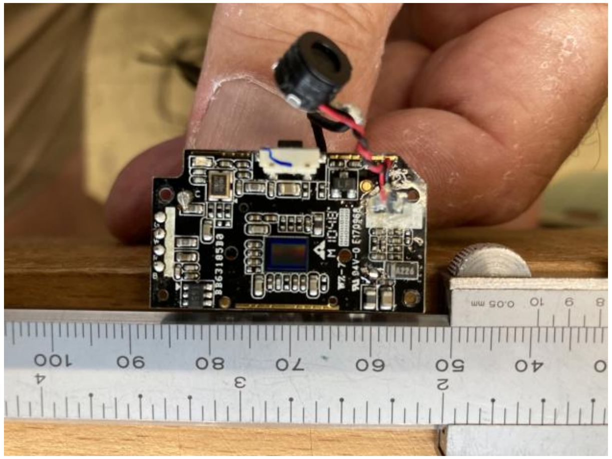


Zone Plate

Laser diode

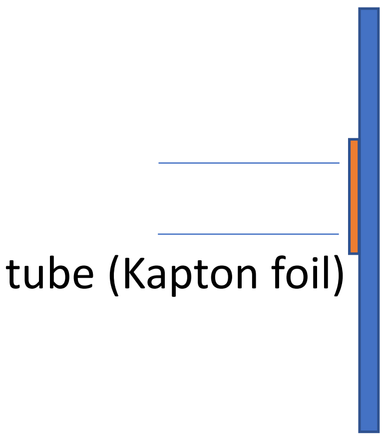
Cam: CMOS image pixel sensor + supporting pcb

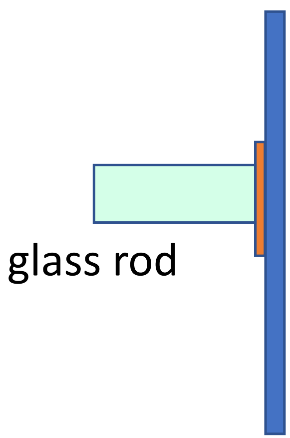
Microsoft webcam HD-3000
Model 1456 or earlier (2011)
has been reported to operate in LN_2

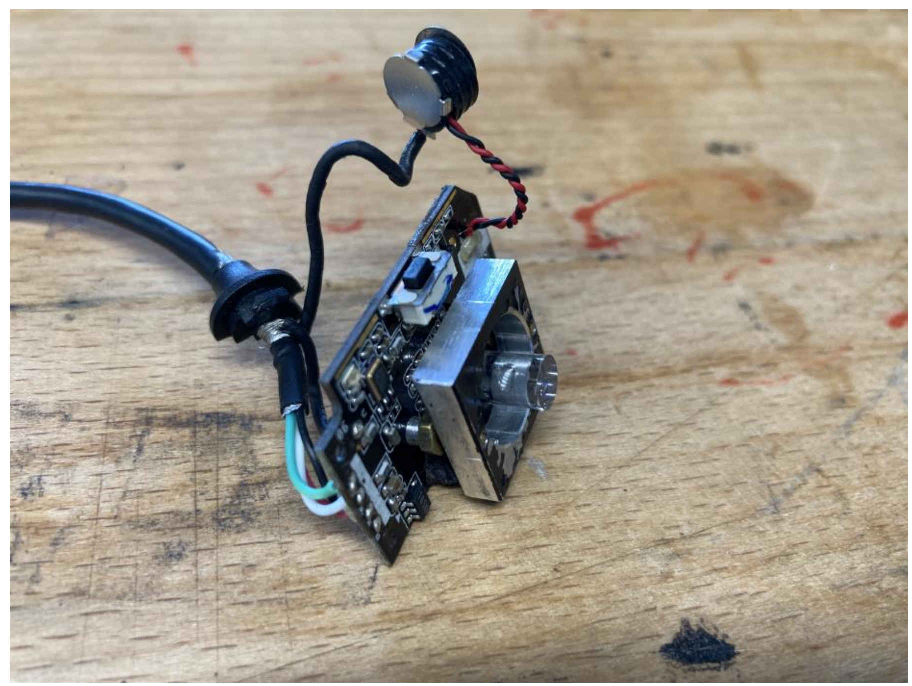


after being demolished carefully

Since this webcam works in LN_2, it can be well applied in R & D studies inside cryostats (i.e. bubble formation)! Frame rate 30 Hz

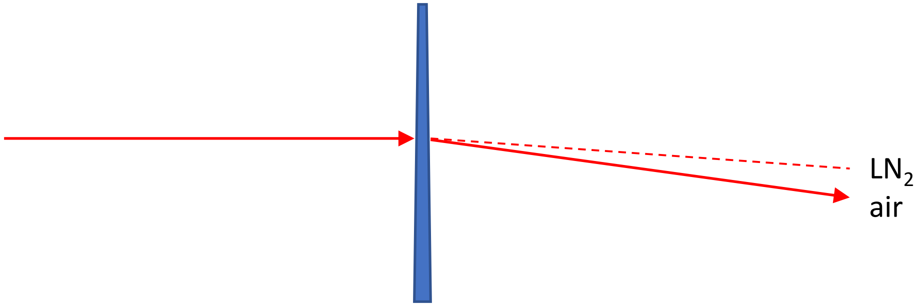

tube (Kapton foil)


glass rod



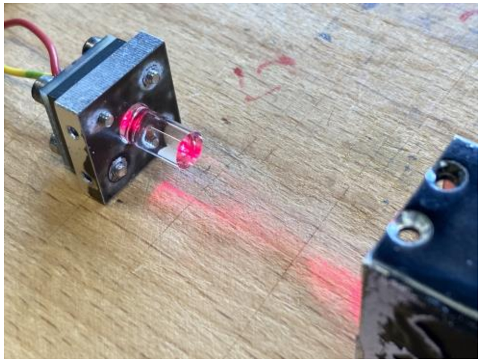
Zone Plate

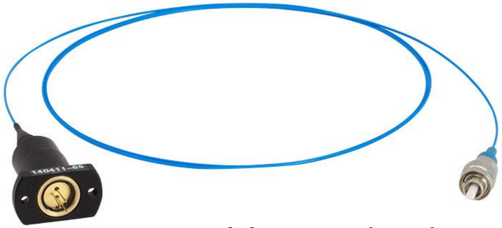
so far: glass coded mask



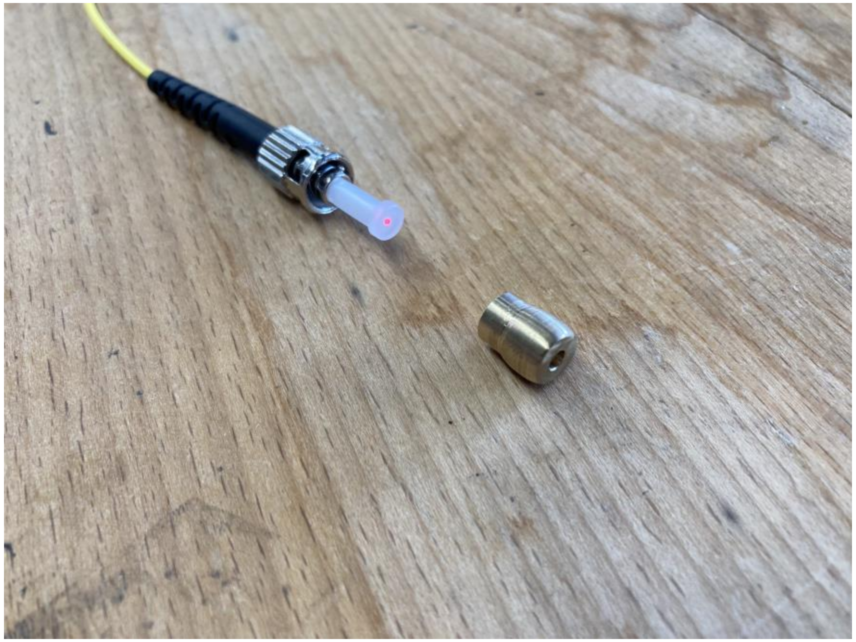
non plan-parallel

Light source: laser diode



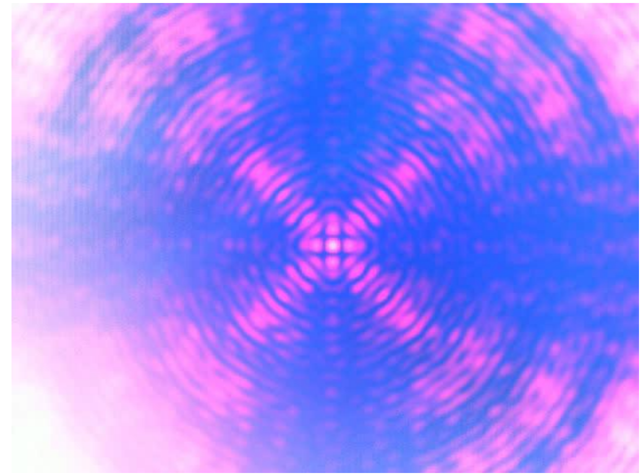


pig tail laser diode

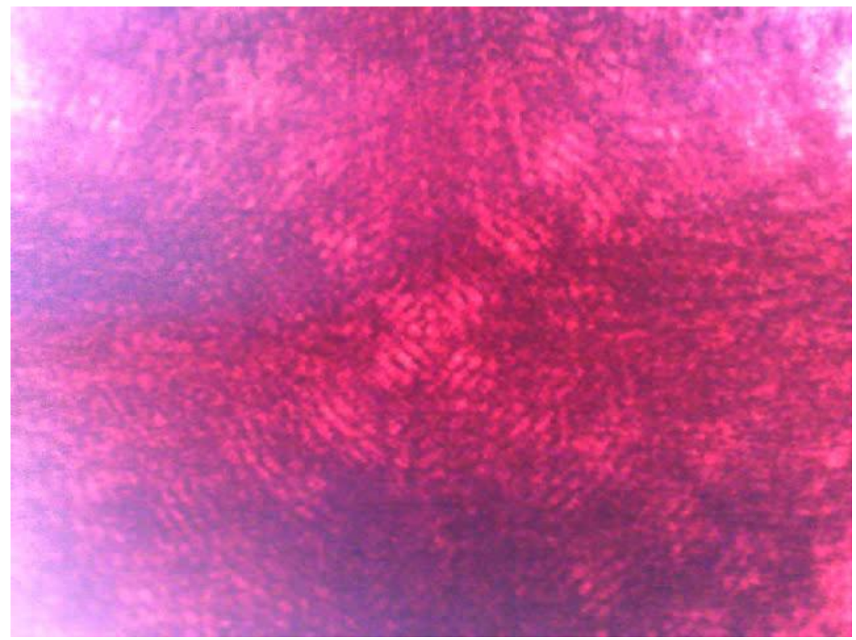


critical:

- direction of fiber
- fiber tip: perpendicular cleaved



in air



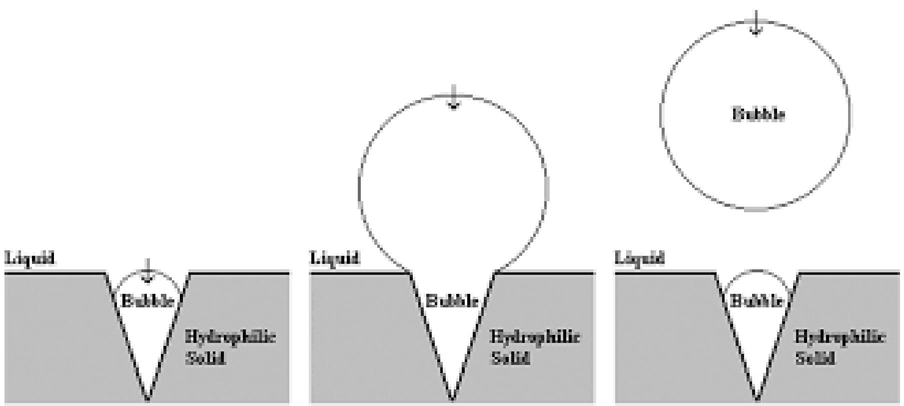
best results so far in LN_2. Still bubbles, but image moves less than 10 µm

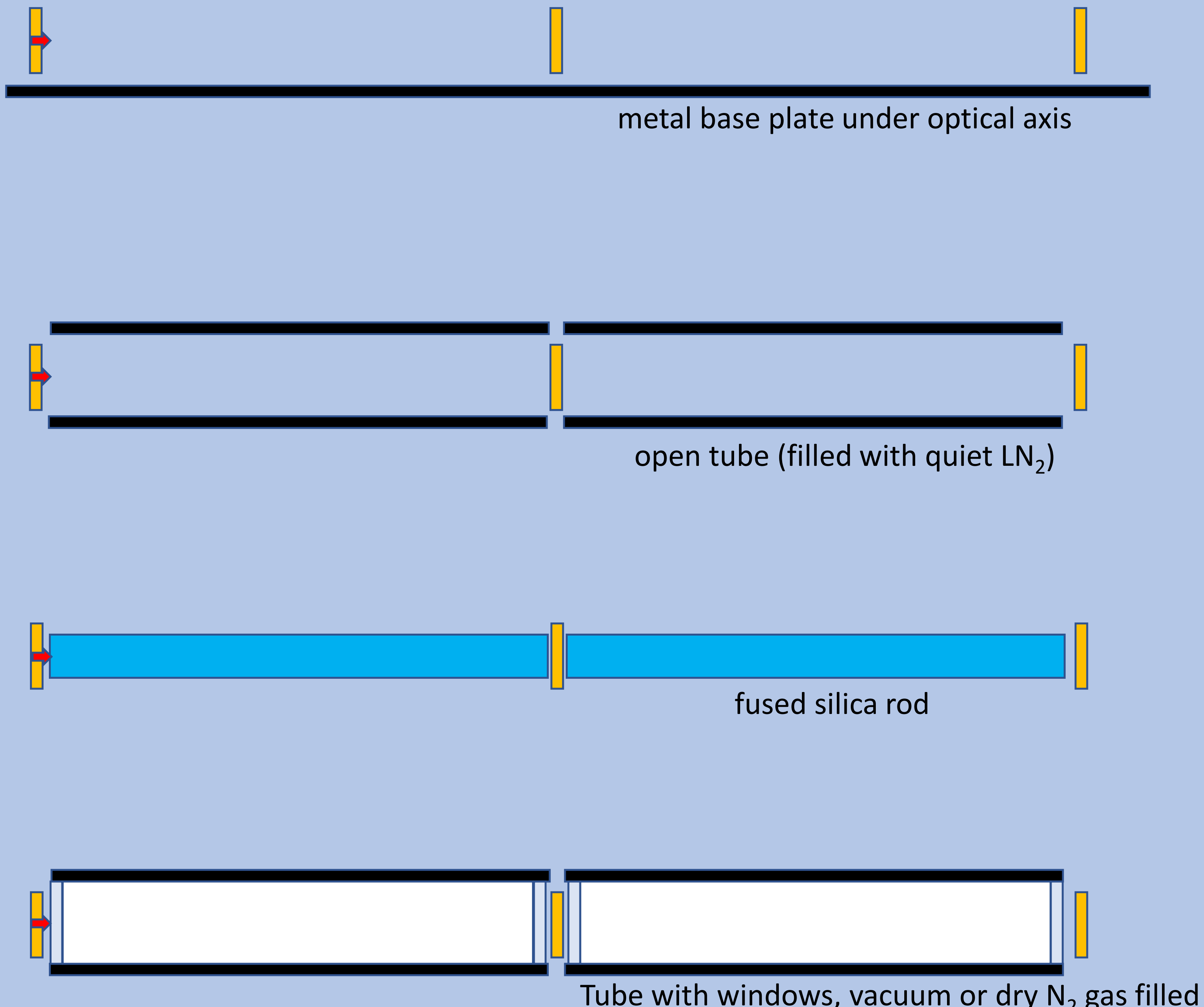
Sources of disturbances

- bubbles:
    - big bubbles, due to boiling, passing light path
    - small bubbles due to nucleation points
- density fluctuations: due to
    - thermal convection
    - induced by passing bubbles

Possibly of no importance

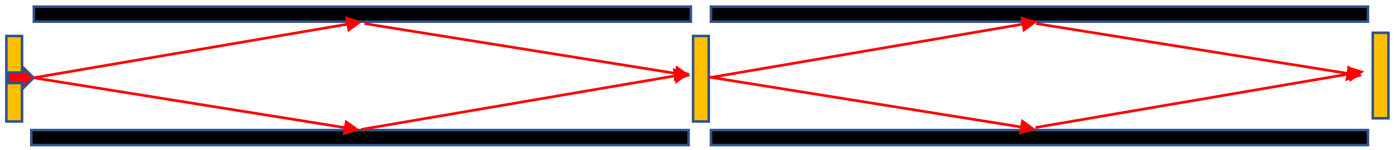
Nucleation: spontaneous bubble formation



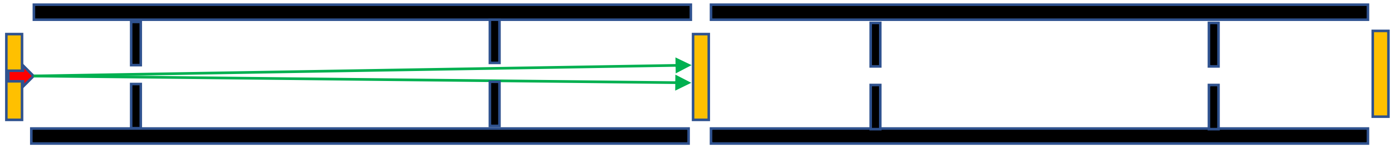


metal base plate under optical axis
open tube (filled with quiet LN_2)
fused silica rod
Tube with windows, vacuum or dry N_2 gas filled

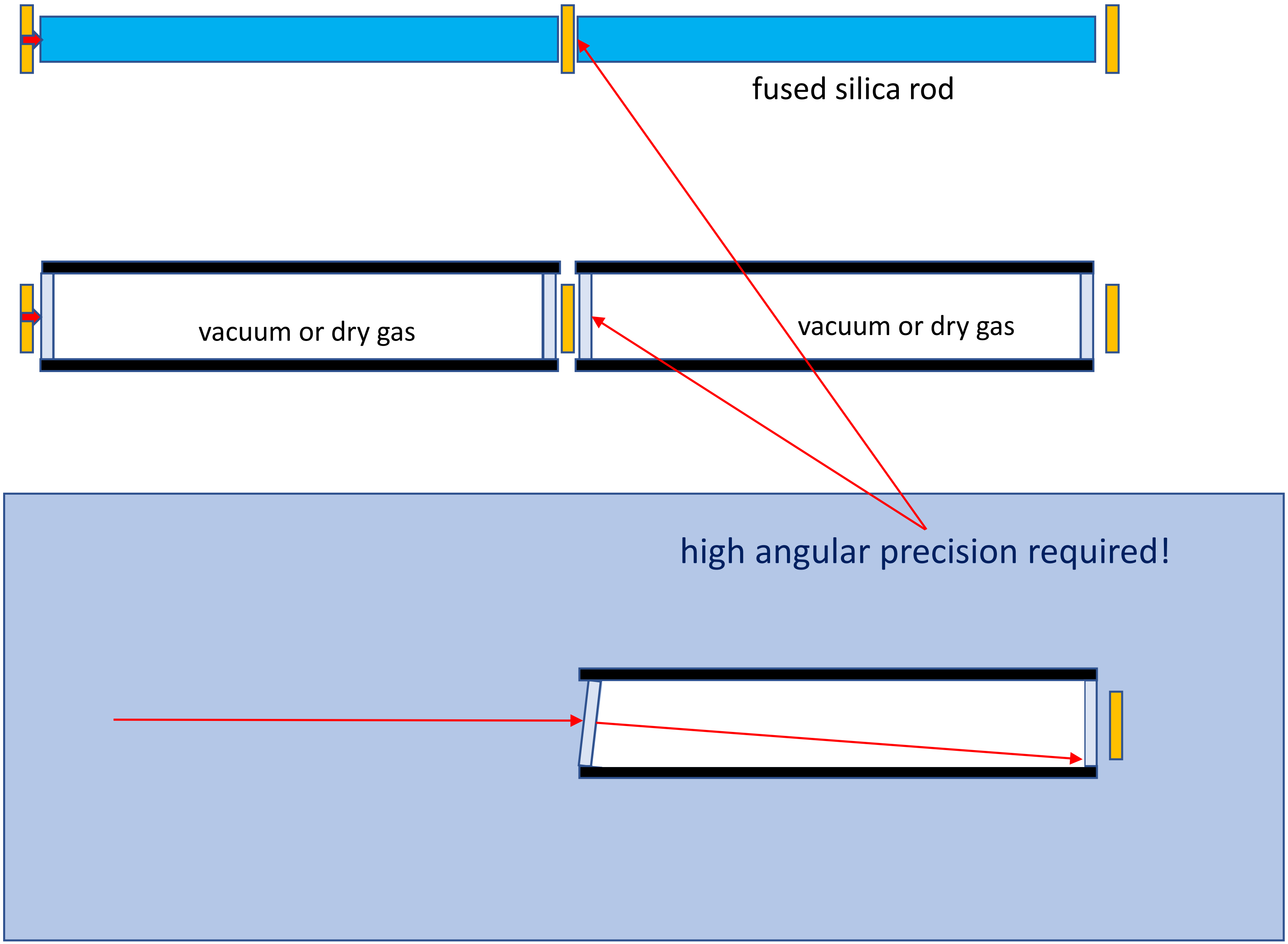
Shielding with tubes: internal reflection against inside of tube wall

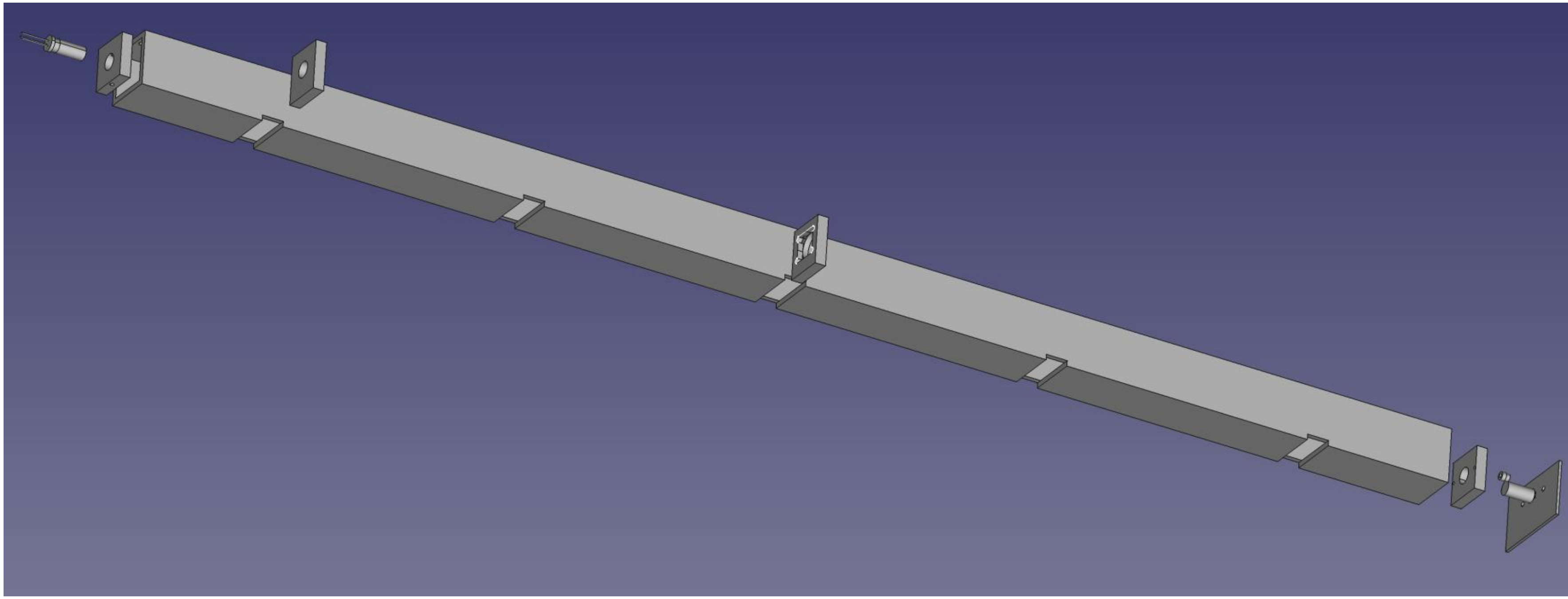


apply ***field stops***

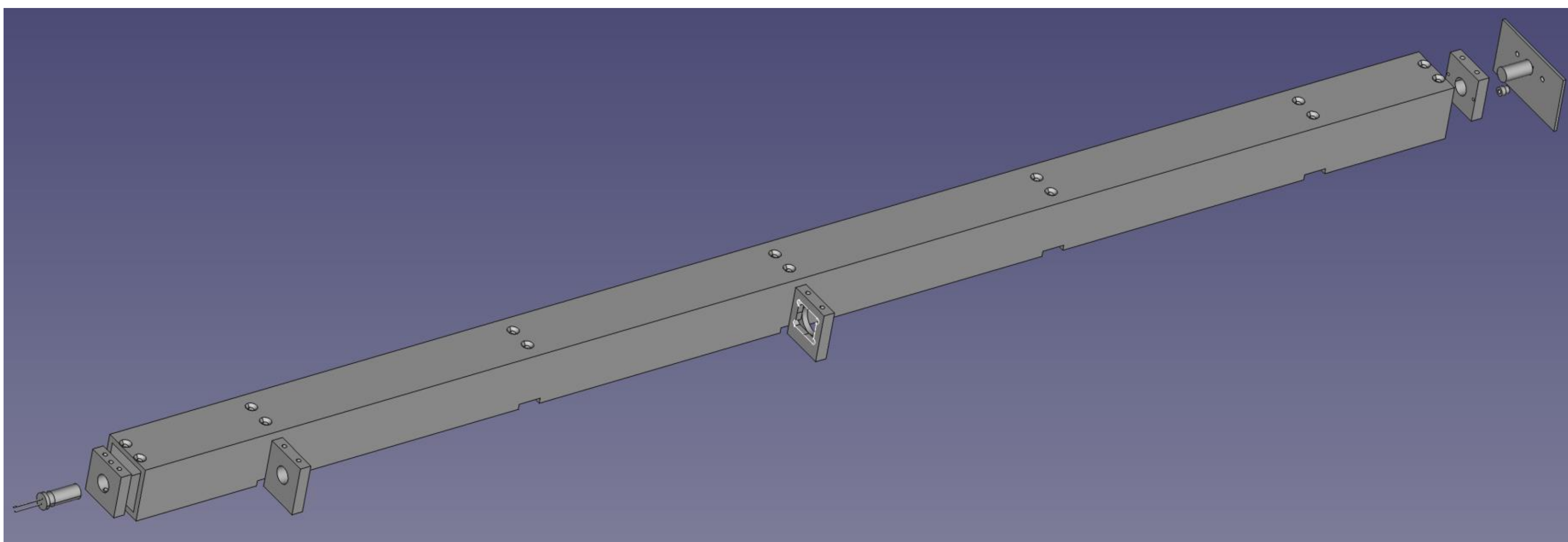


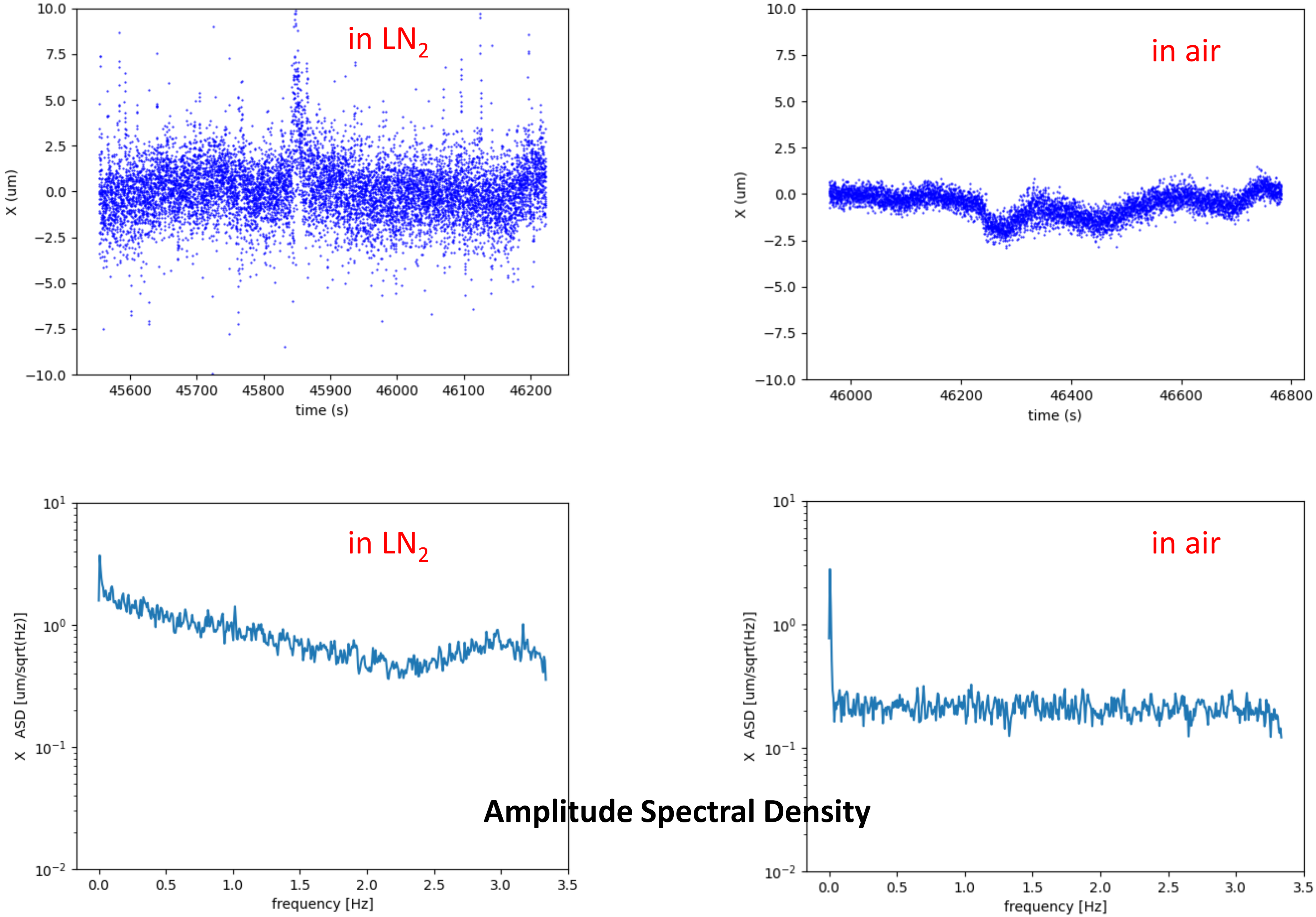
Shielding with vacuum tubes or with fused silica rod: Snellius boundary crossing





this works: 100 % of light path shielded with aluminium (black anodized) tube (20 x 20 mm^2)





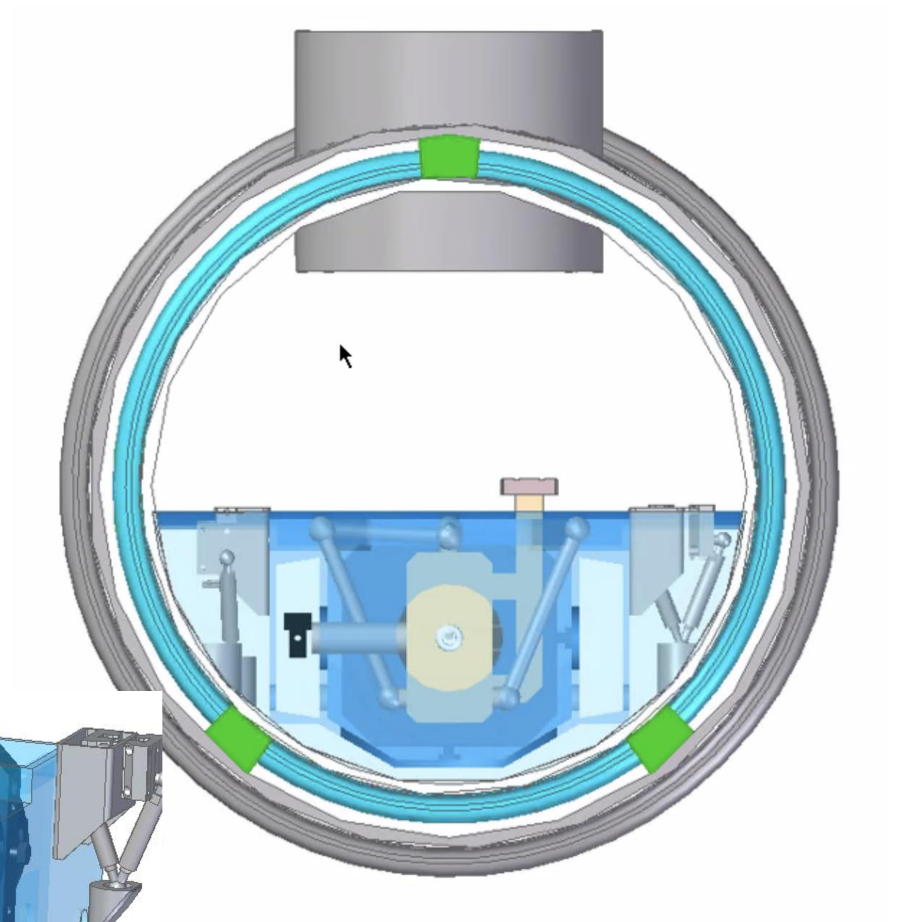
Amplitude Spectral Density

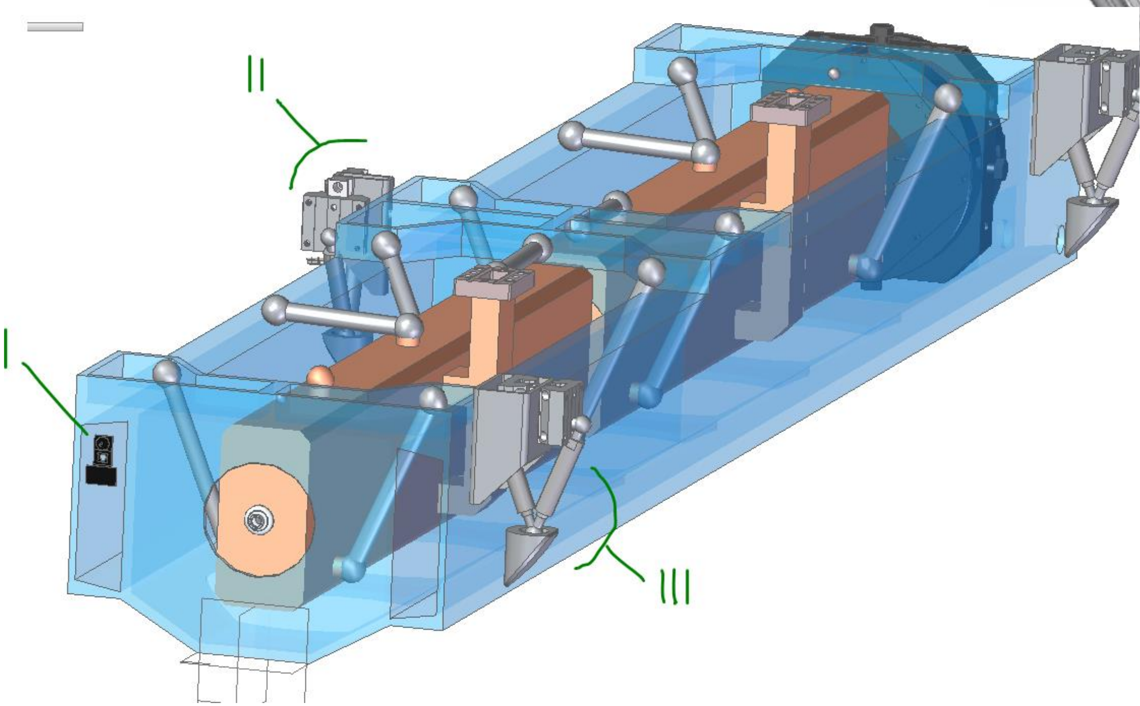
Ongoing C3 R&D project:

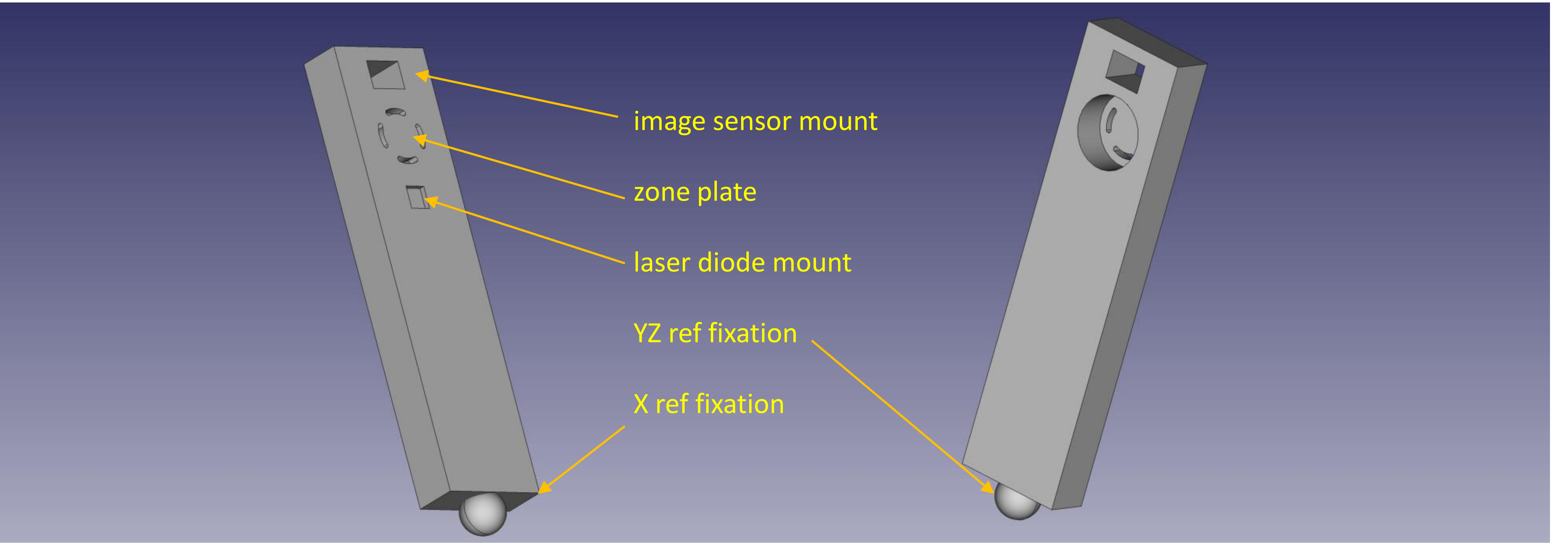
the **Quarter Cryo Module QCM**

Phase 1: dummy AccStructures: testing cooling, mechanics, vibrations

Phase 2: real operational AccStructures

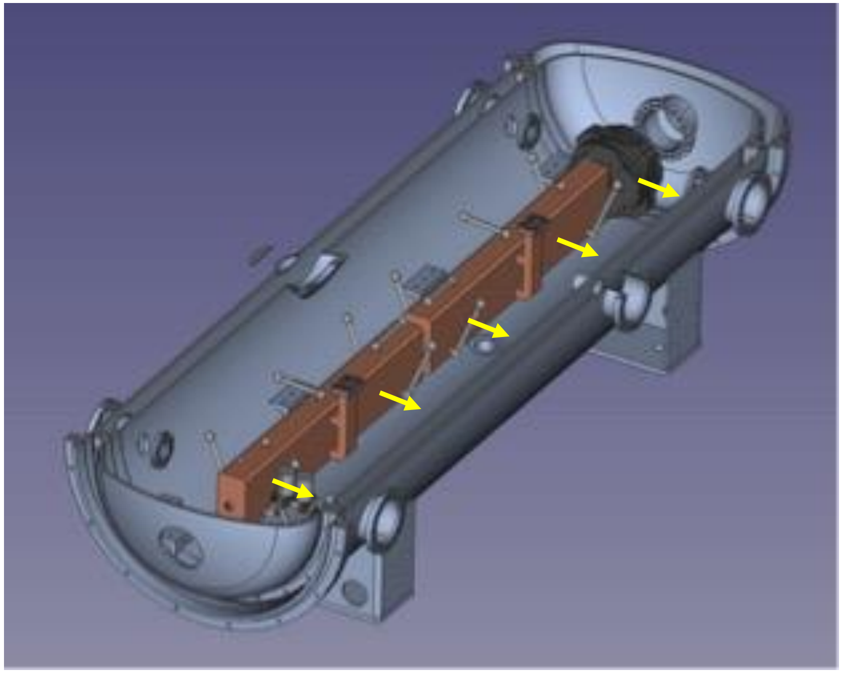


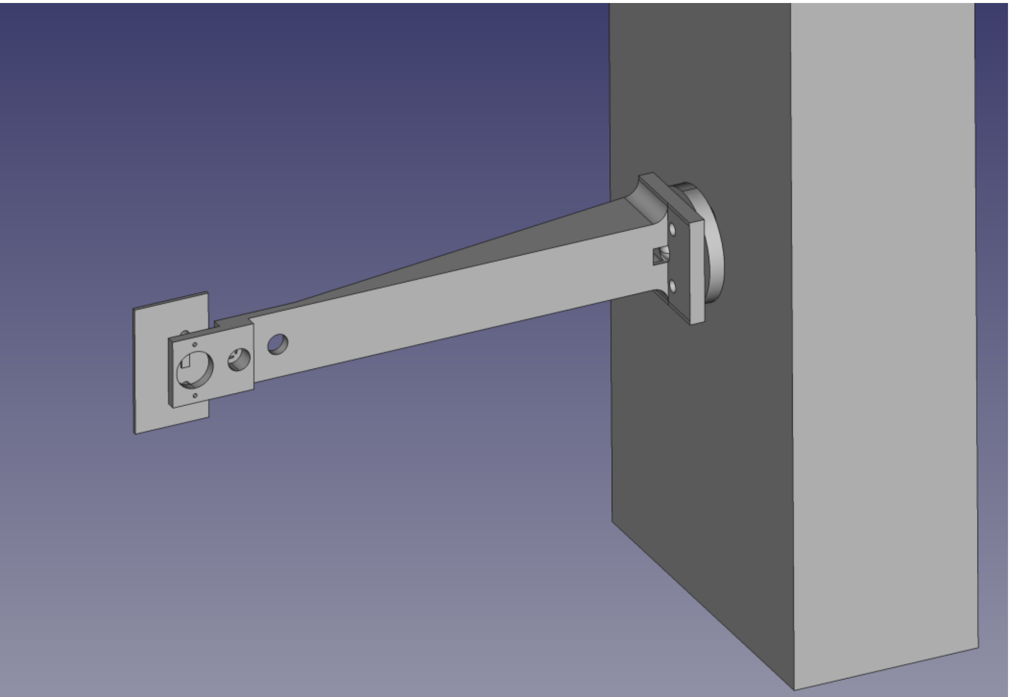


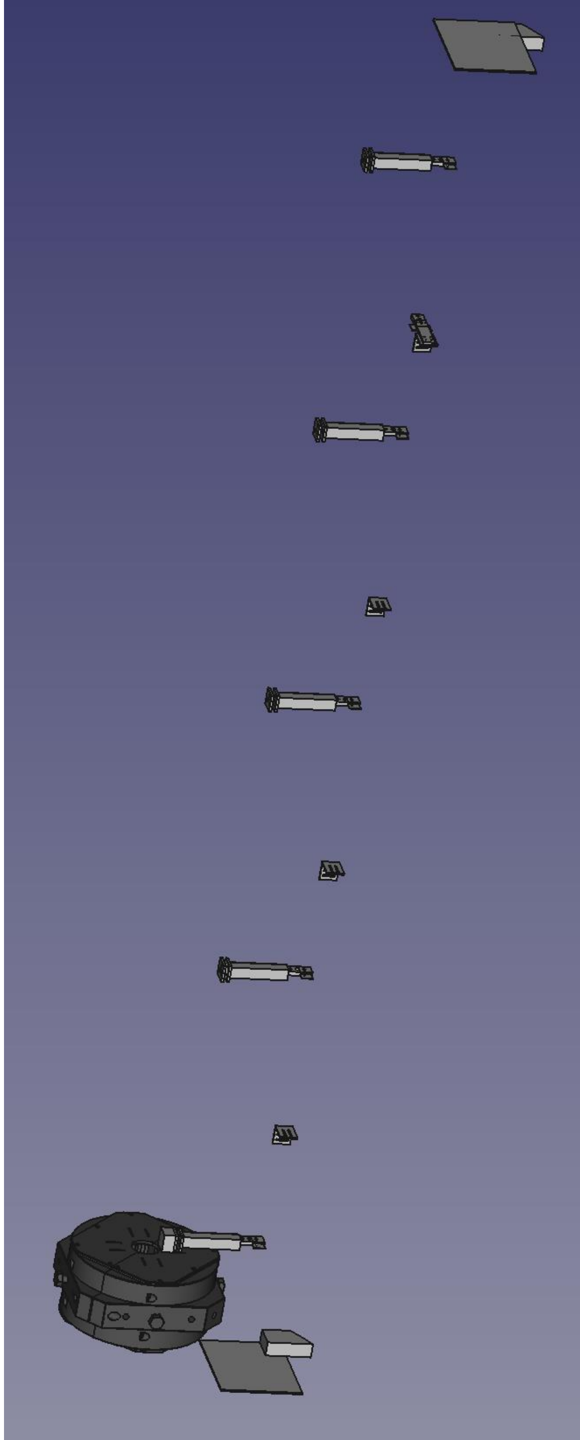


The Stick

A Stick includes 4 items:
- a CMOS image sensor chip
- a transparent pattern forming a zone lens
- a laser diode
- a mounting interface







Calibration Station (on granite table)

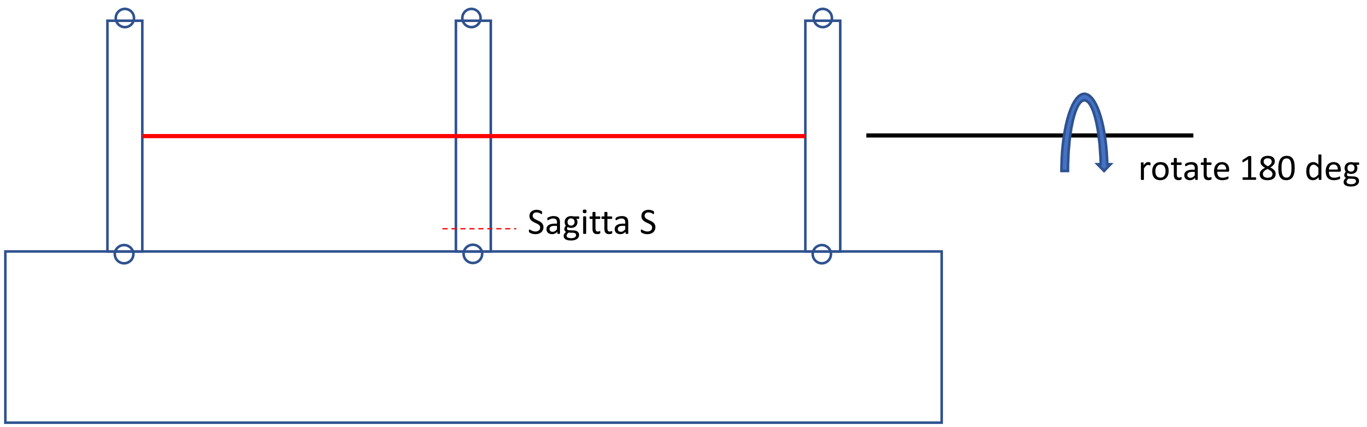
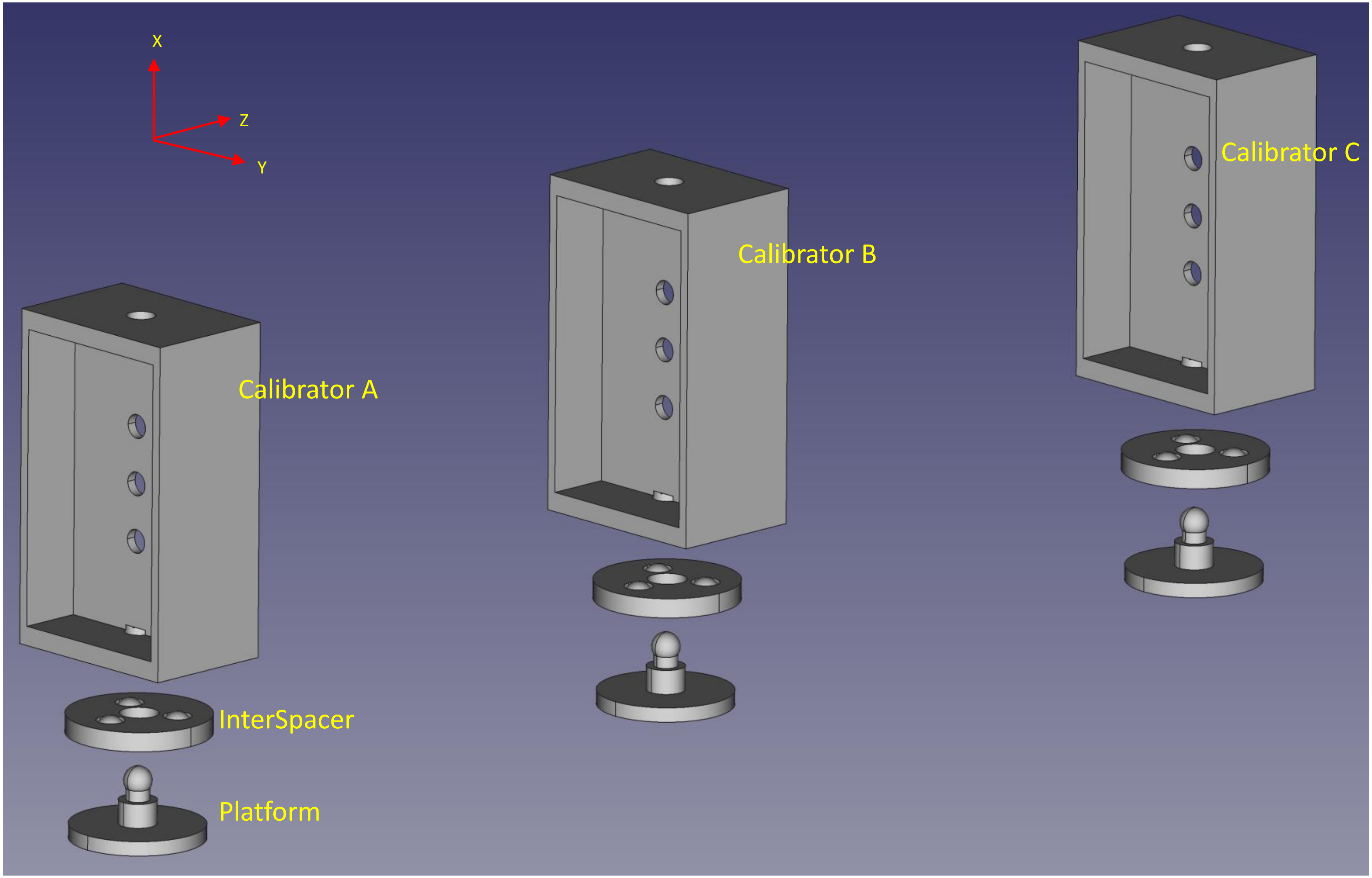


Image shift on sensor equals 4x the alignment error S after rotating three calibrators 180 deg around Z axis


X
Z
Y
Calibrator A
Calibrator B
Calibrator C
InterSpacer
Platform

Conclusions

- Rasnik components (image sensor and laser diode) were found to operate in LN_2;

- methods of beam shielding were developed, protecting the light path against disturbing bubbles;

- there is consensus on a design for Rasnik for the QCM R&D project.