Simulation and best practices for remote maintenance

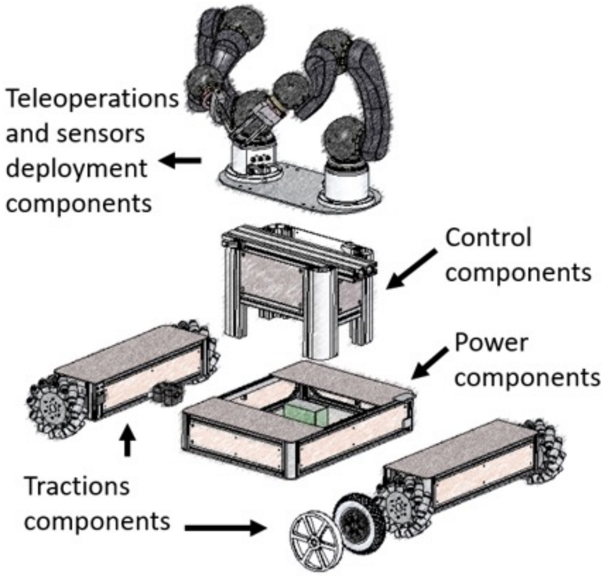
Luca R. Buonocore

CERN | BEAMS

Outline

- Robotic platforms at CERN
- Robot friendly tools
- New tools and technologies research
- Design and validation of new robotic arm
- Intervention in not robot friendly environment
- Robot friendly design
- Conclusion

CERN Robotic platform design

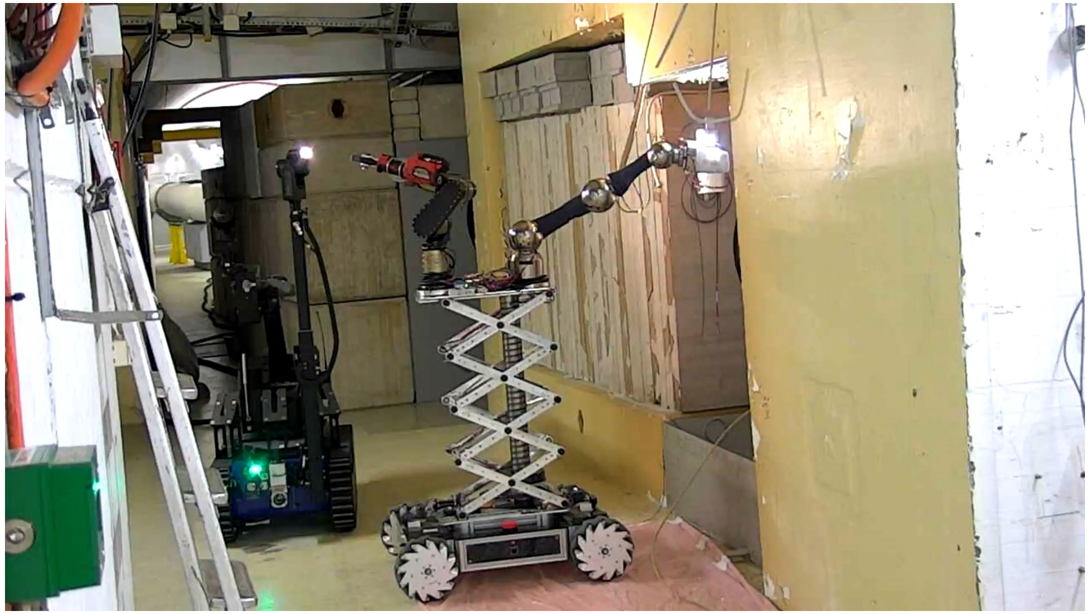


- CERNBot is a full custom CERN made ground robotic platform that in standard configuration is equipped with two robotic arms 6DOF and grippers for bimanual operation

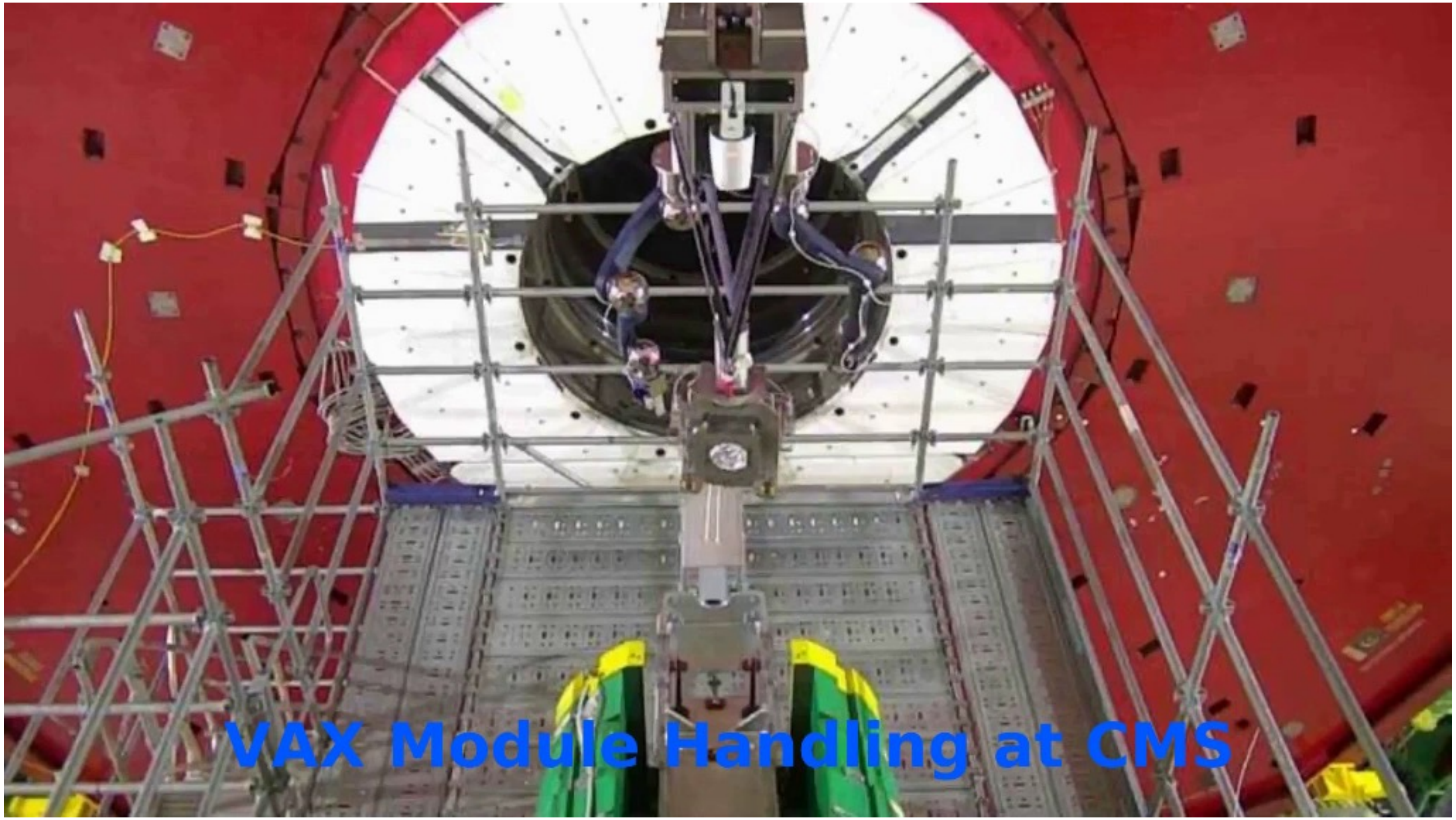
- Thanks to the modularity, starting from the same framework is possible to adapt the structure in different shapes in function of the tasks to perform.

- The robots has the capability to remove or add modules in order to add functionality or adapt the shape to different tasks

CERNbot2 – use case



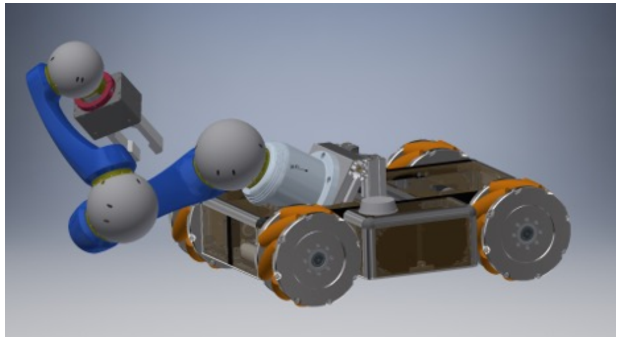
CRANEBot – VAX installation in CMS

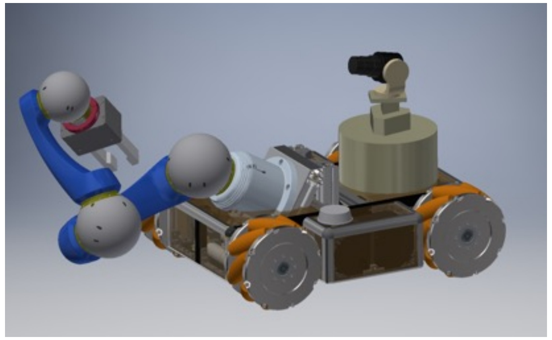


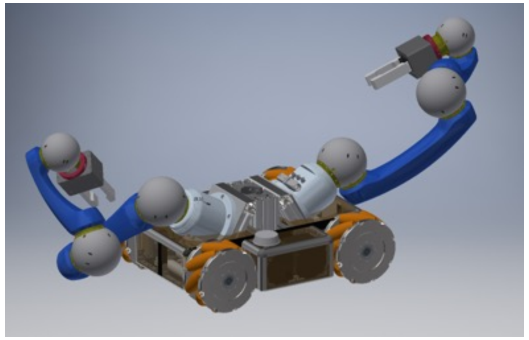
CERN Robotic platform design

- Starting from the CERNBot a new family o robotic platforms is designed to reply to the needs of compact platforms to be used in case space constrain

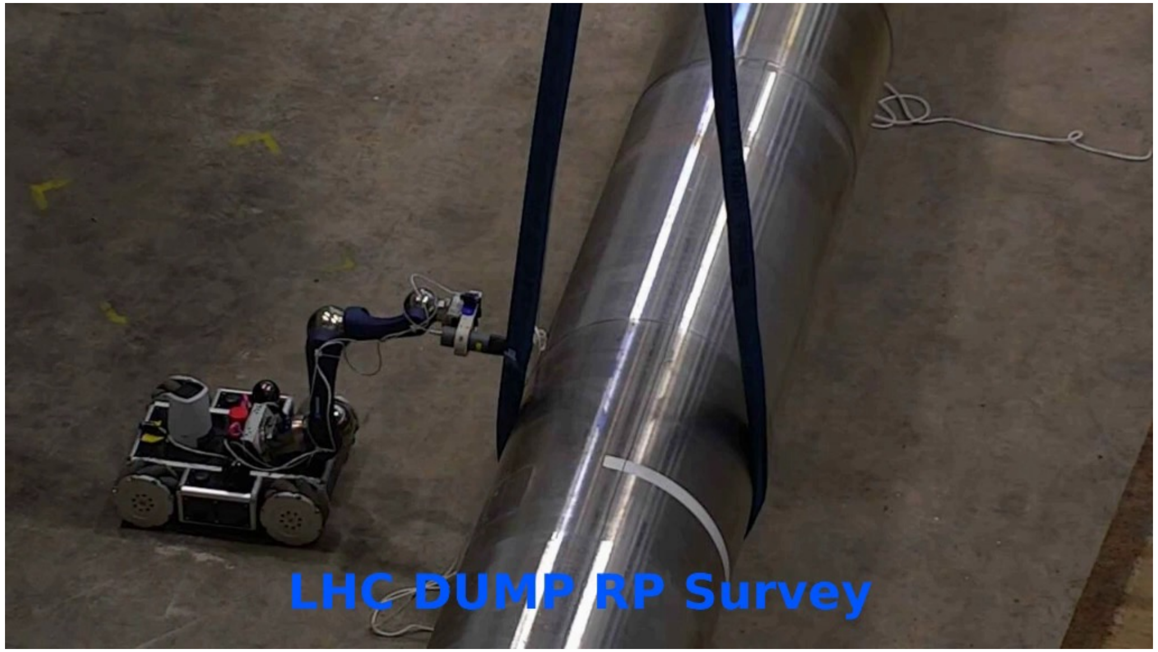
- The concept of modularity is kept that allow having many advantage like saving design time and developing cost



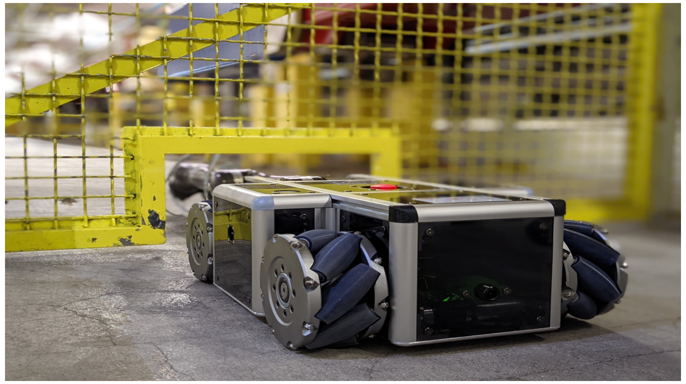




CERNbot Compact use case

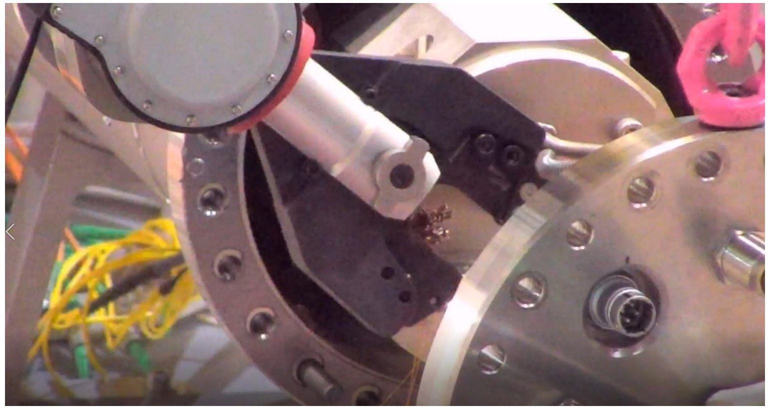


Robotic platform design - SPS inspection robot

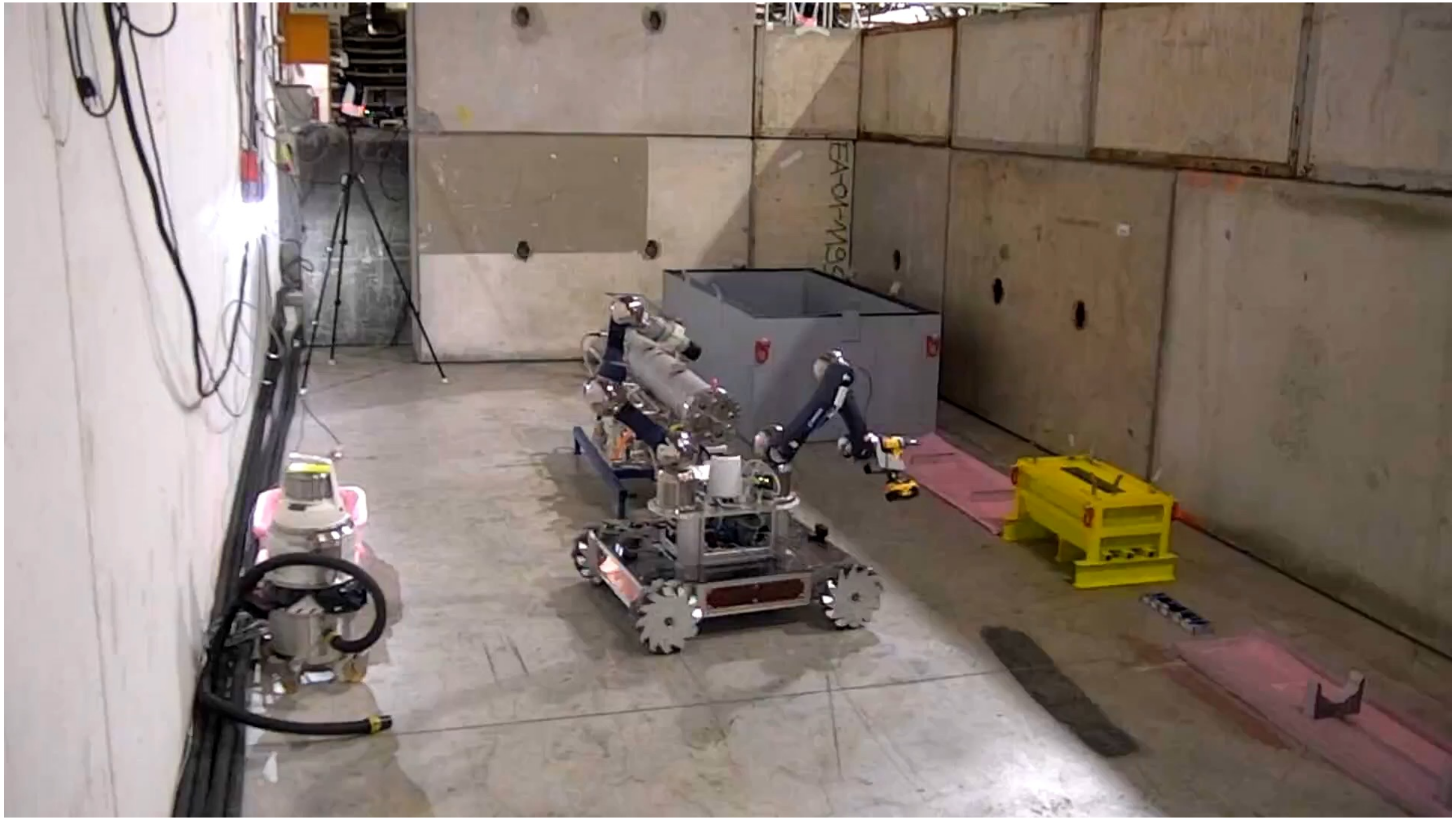


Robotic tools - reverse engineering

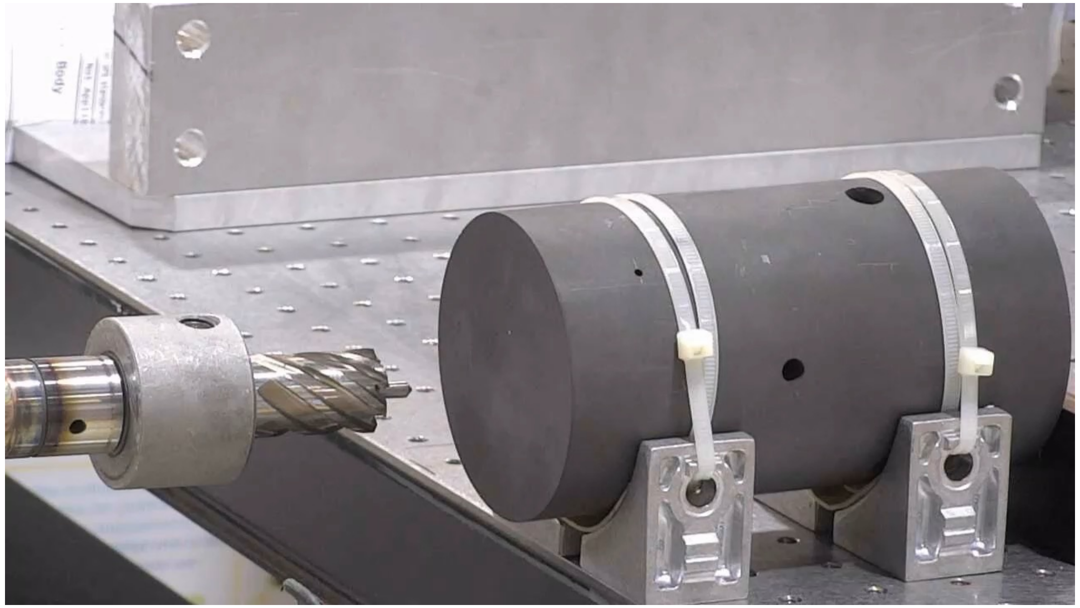
- Reverse engineering of the commercial tool was necessary since for the CERN tasks there are no instruments on the market that can fulfil our needs
- The idea is to use the commercial part of the tool, saving time and money, from the electric study of the motor we add an EtherCAT motor driver or another kind of solution in order to have the remote control of it
- The first tool developed is an impact wrench with a 200Nm limit torque, that is integrated to the robot arm flange, avoiding external wires and simplifying the installation
- Based on the same knowledge, a Robotic Screwdriver was been developed, that gives us the possibility to regulate position speed and torque



Tools - BDF sample extraction

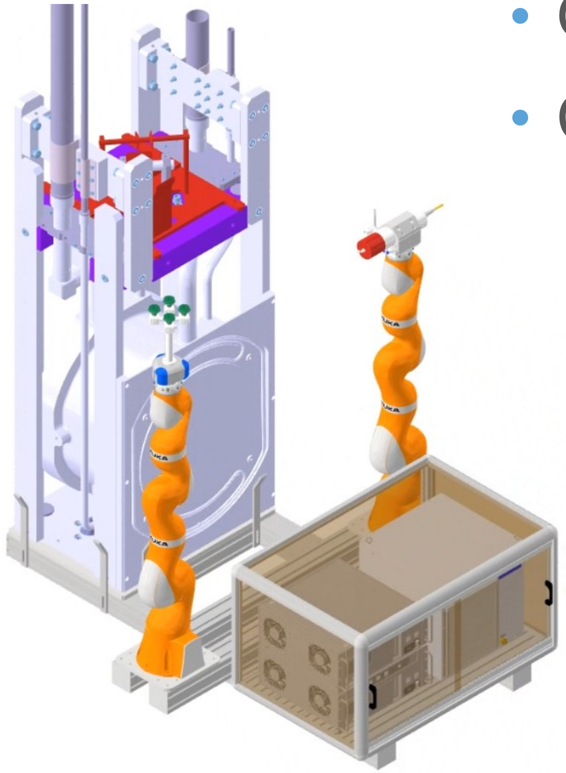


Tools - Graphite sampling extraction

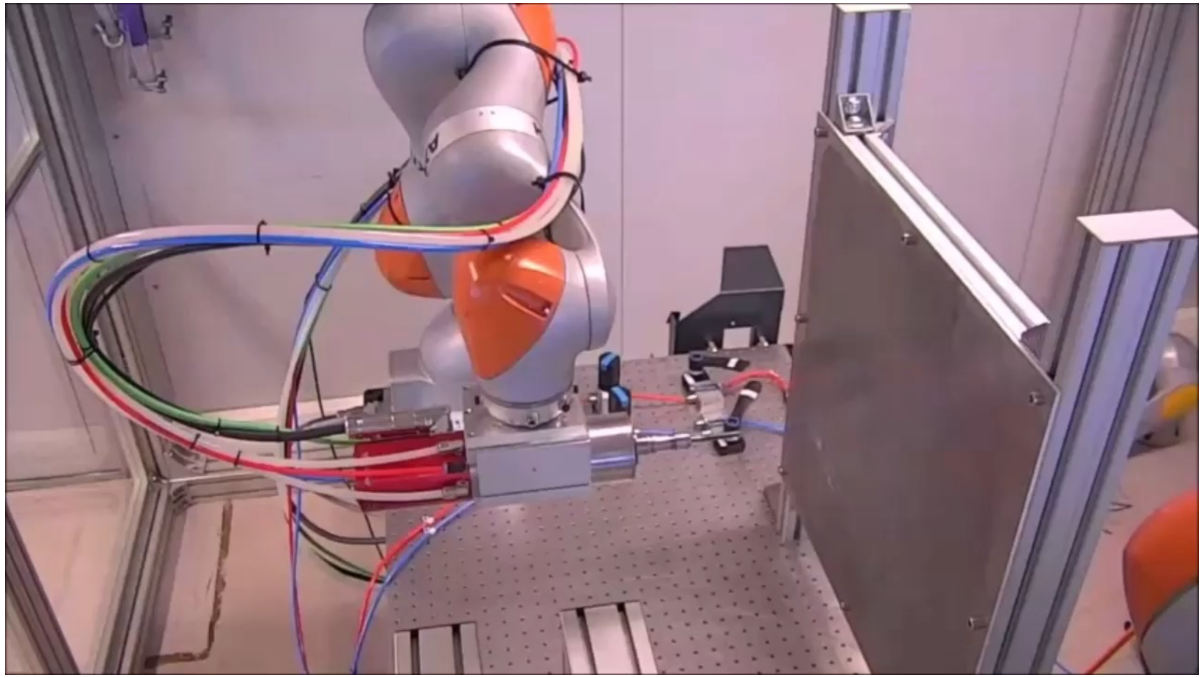


- CERNbot2 in this configuration is equipped with a robotic arm and the Robotic Screwdriver, that is performing the task of hi-density graphite samples extraction
- The screwdriver respect to the impact wrench, allow regulating speed in all the drilling phases give us full control of the operation

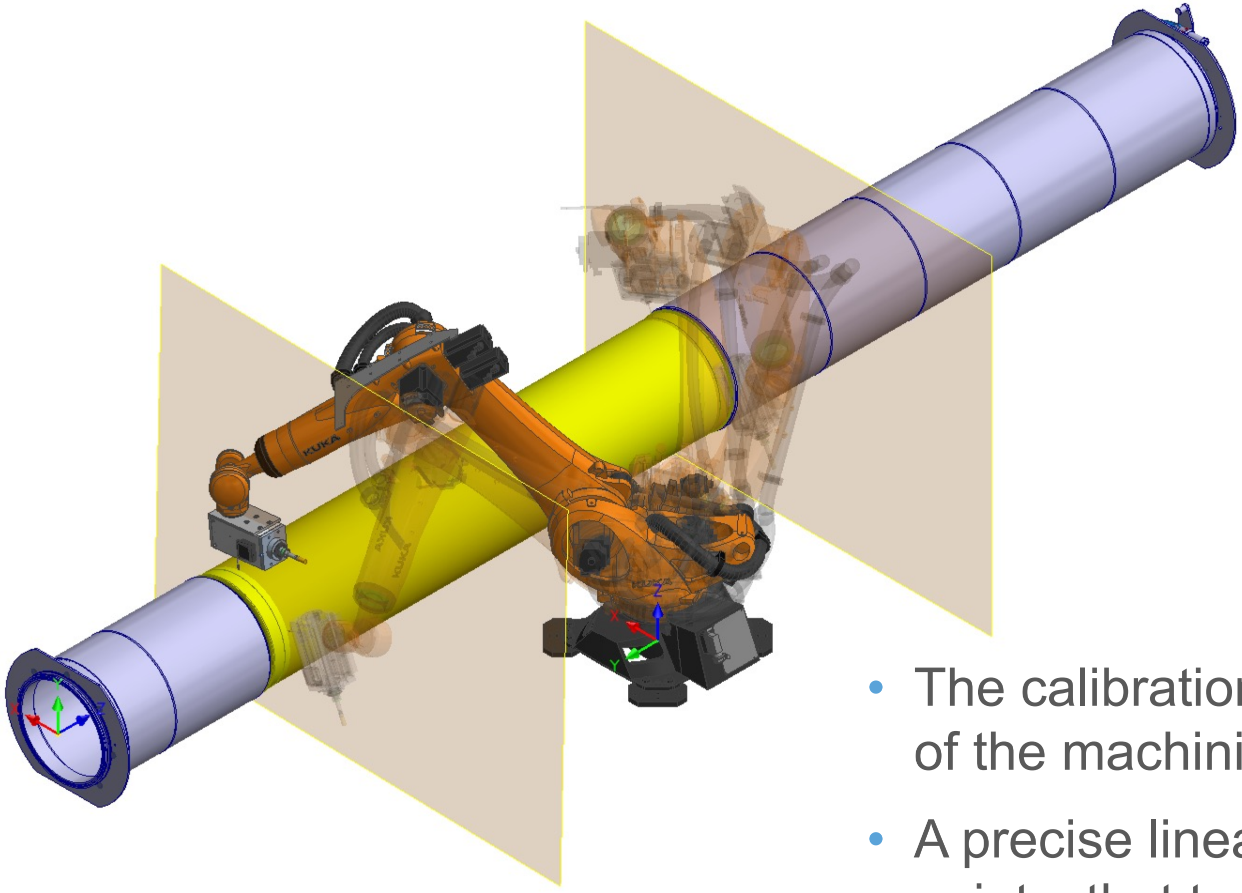
Remote robotic milling

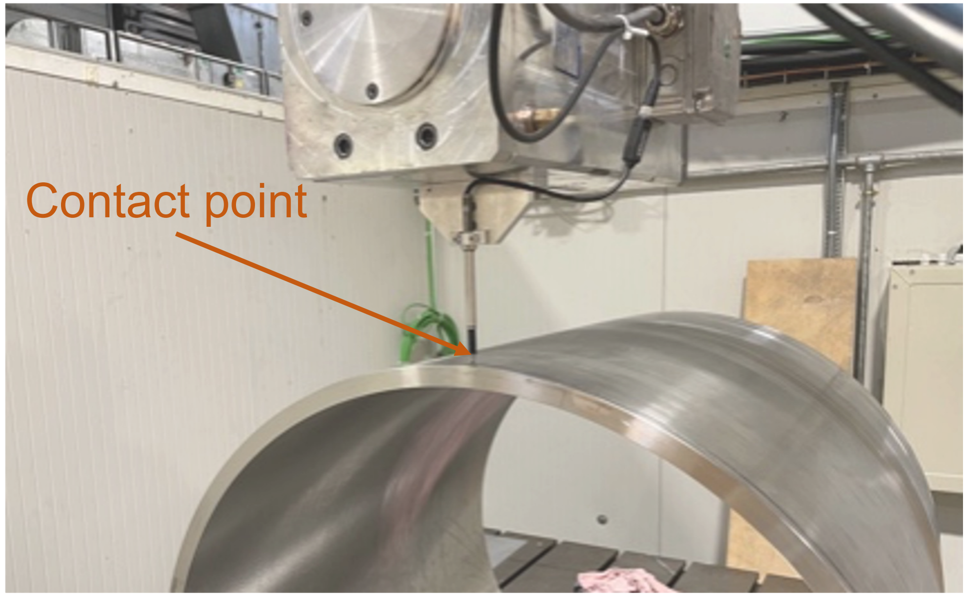


- nTof core inspection and sampling study
- Opening the target by robotic milling solution
- Core inspection and sample extraction



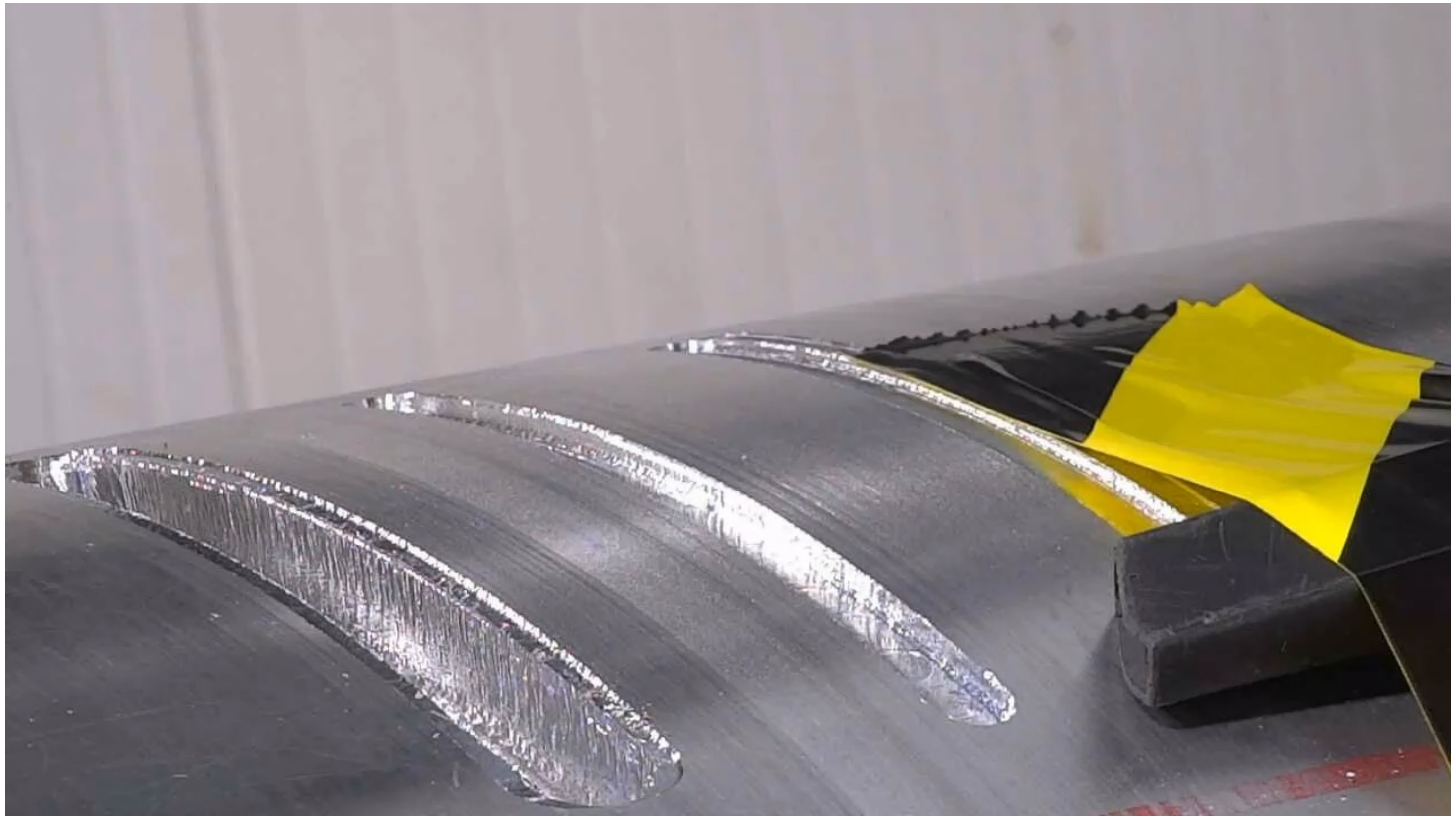
LHC TDE - Dump frame identification procedure





- The calibration procedure is need to increase the precision of the machining
- A precise linear sensor is used in order to detect contact points, that tanks to the inverse kinematic is possible to interpolate and define the reference system or the pipe

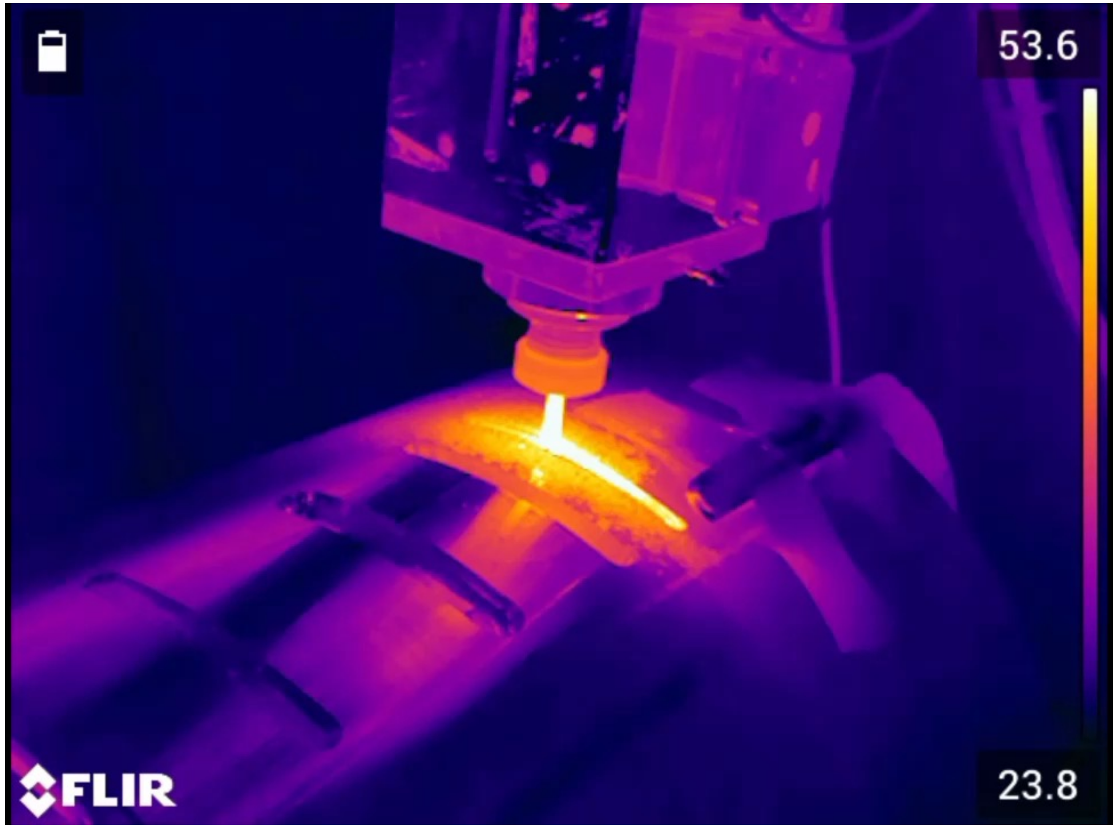
Robotic milling – radial



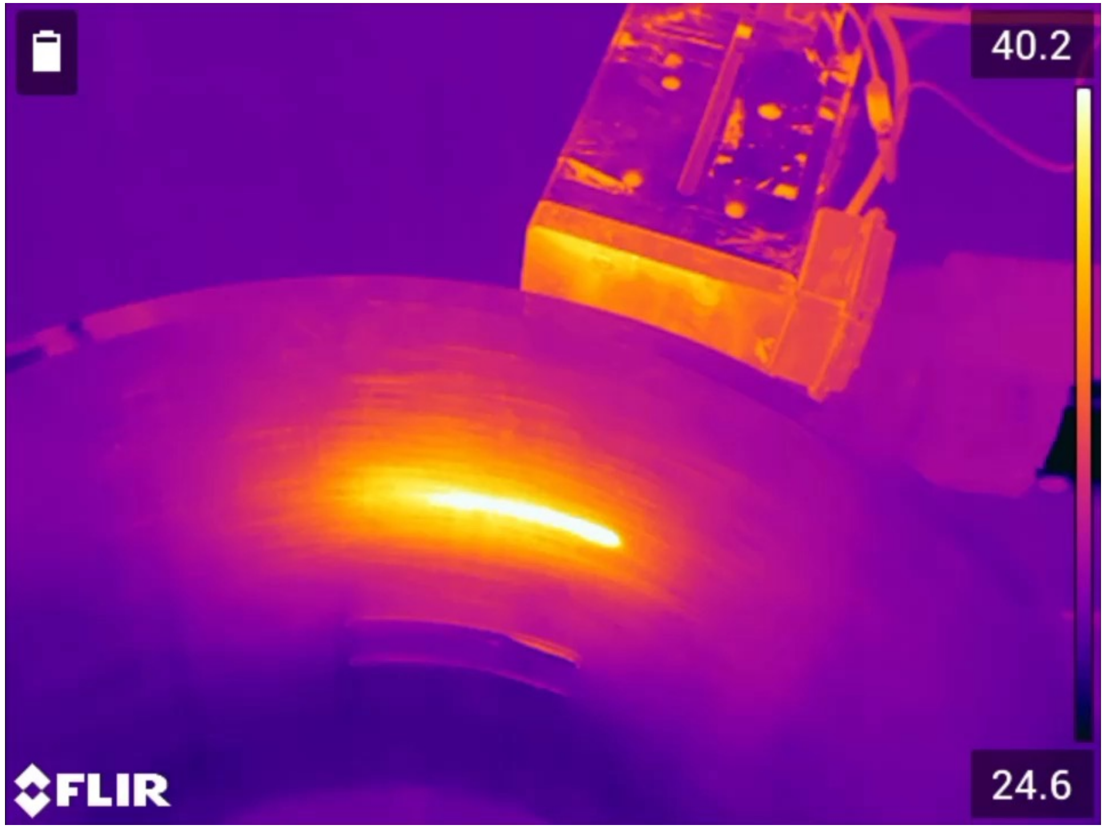
- Thanks to the precise identification procedure the working surface is well defined and it is possible to machine following the radial surface of the TDE
- Circumferential cut
  - 30° (~180 mm length)
  - 18 mm depth
  - 13 mm thickness

Robotic milling technology - Thermal results

Outside TDE point of view



Inside TDE point of view



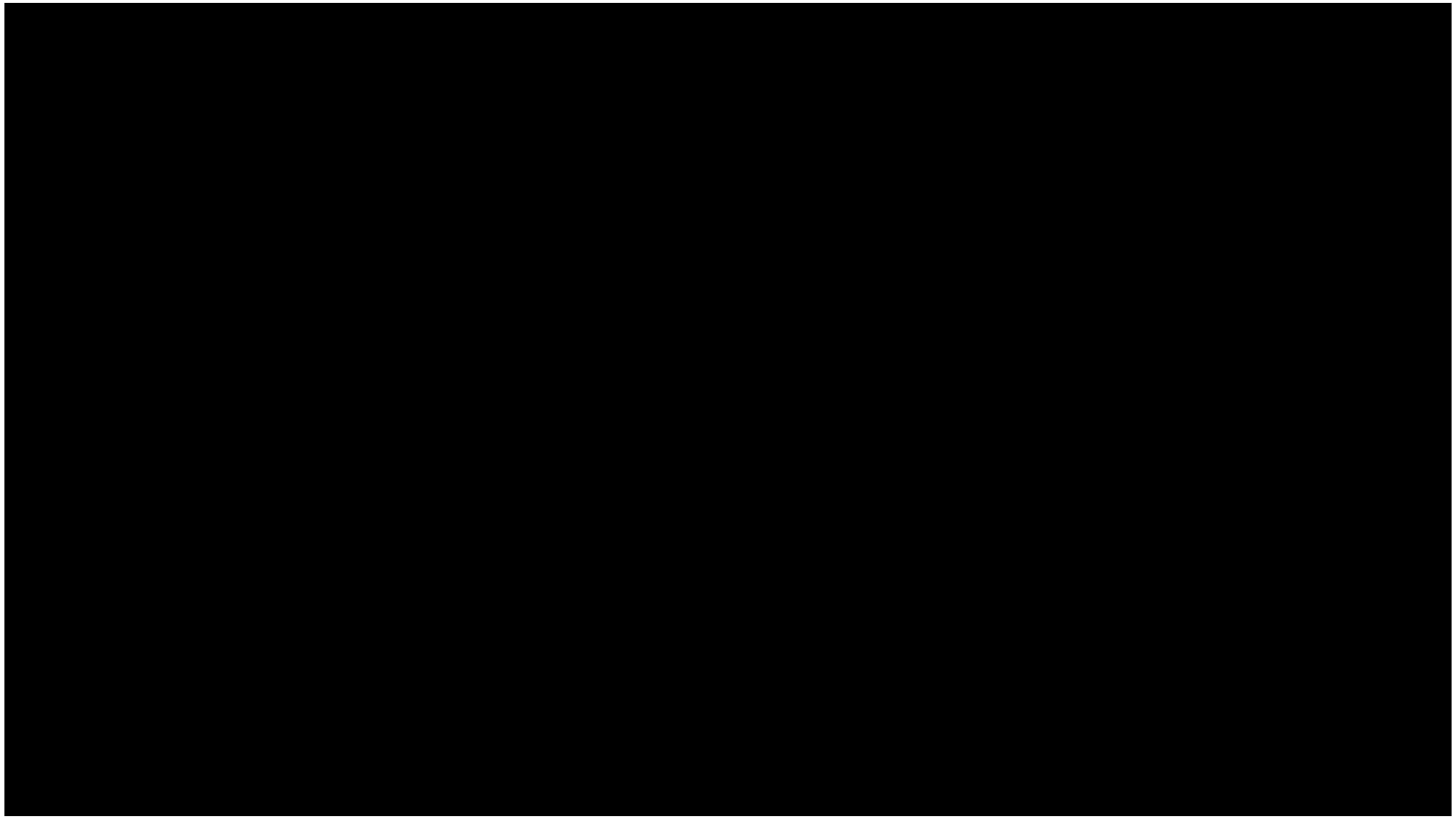
Theologies results

- The cutting parameters allow to have chips not volatiles (length ~ 5 mm) and confined close to the working area

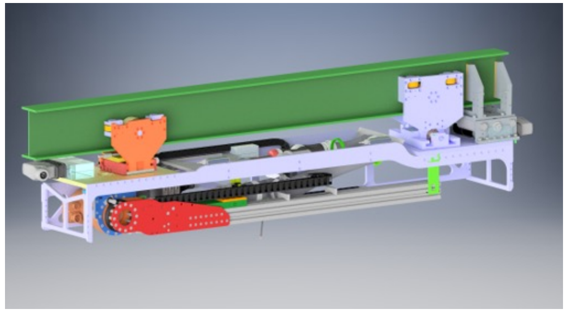
- A vacuum cleaning system mounted on the spindle that follow and clean the milling slot during the machining

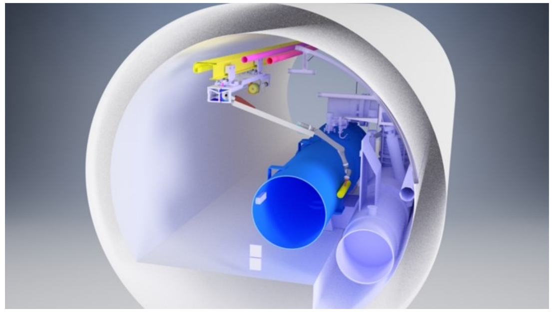
Robotic wagon for TIM

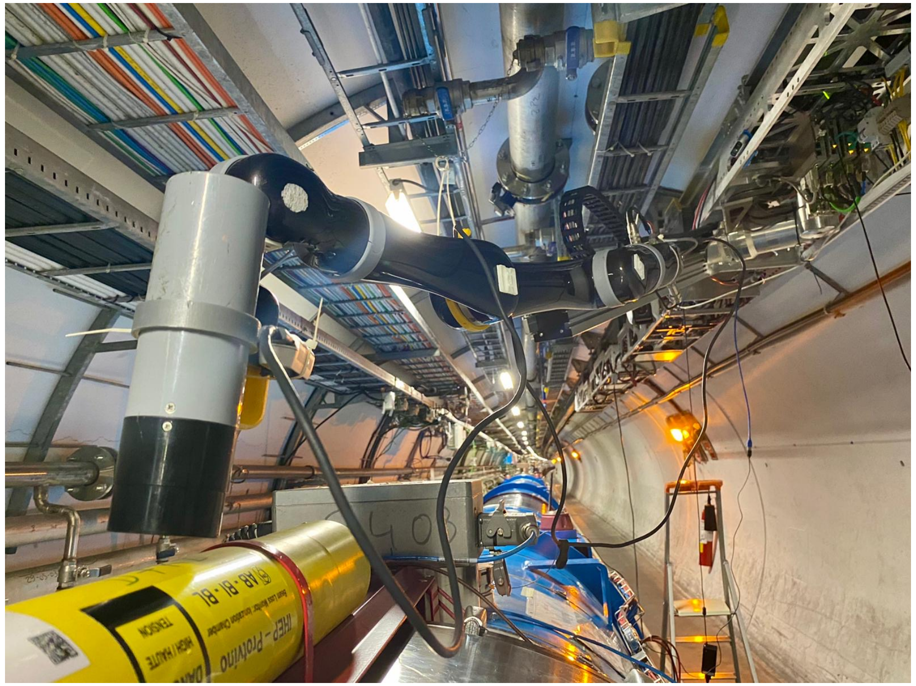
Robotic wagon for TIM

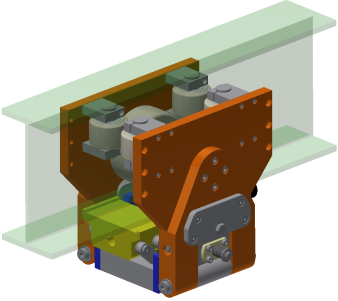


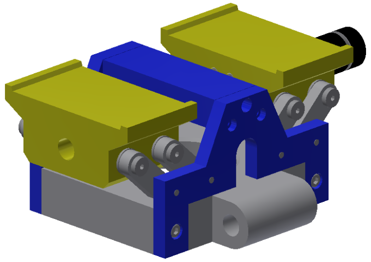
TIM robotic wagon design

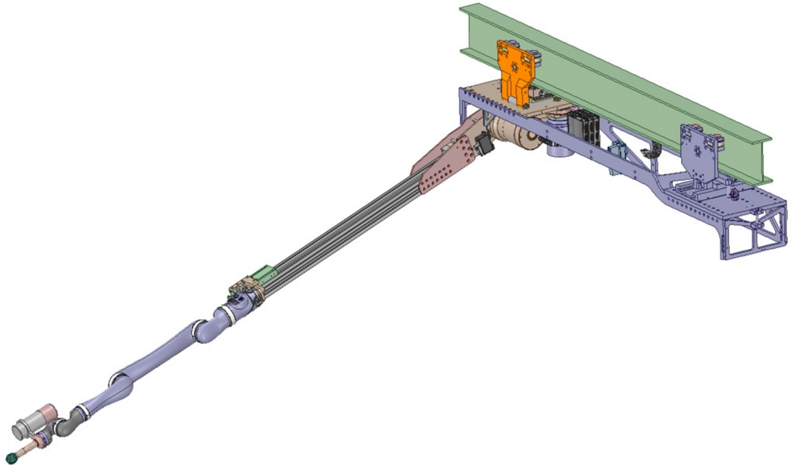






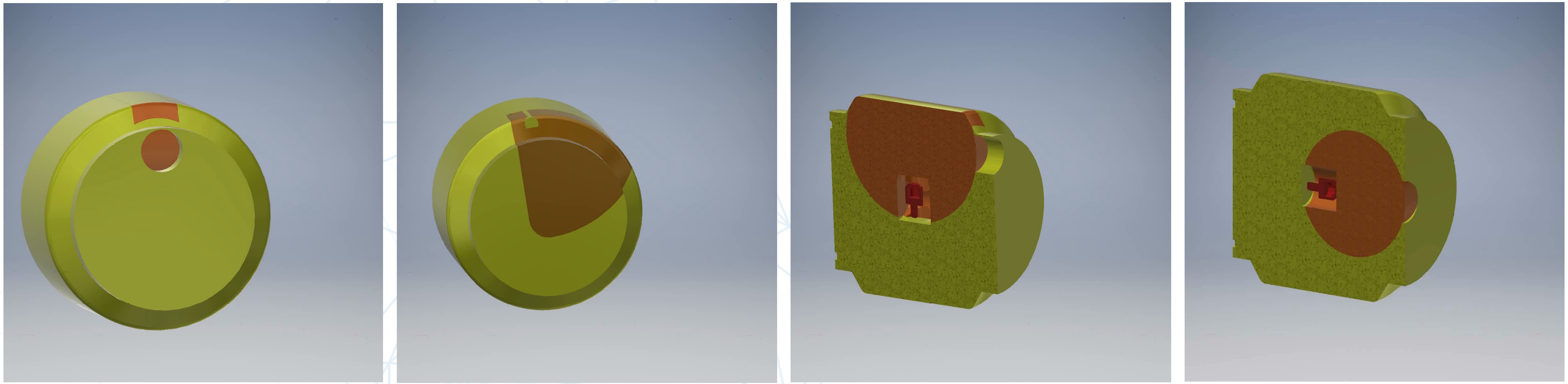






- 9 DOF robotic arm + TIM movement
- 11 motors integrated and controlled on the wagon

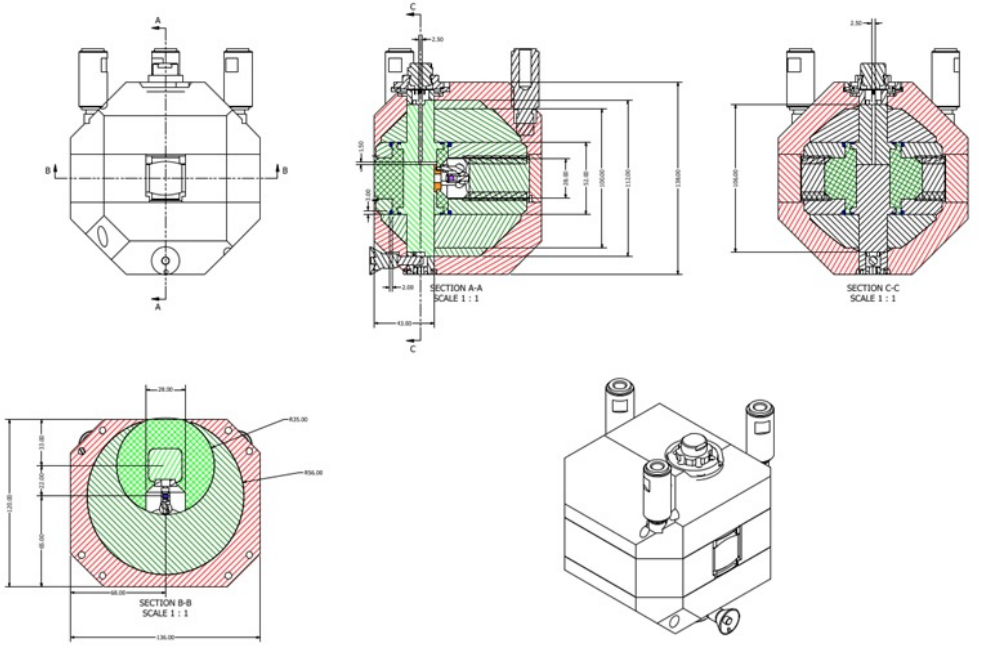
Shielding concept evolution



- Different concept was analysed in order to have maximum shielding property with low volume/weight aspect
- The best solution is to have the source exactly in the canter
- The shielding has to be have also internal sensor with passive electronic that will be connected outside
- The mechanic has to allow also the cable passages rom the core to the external

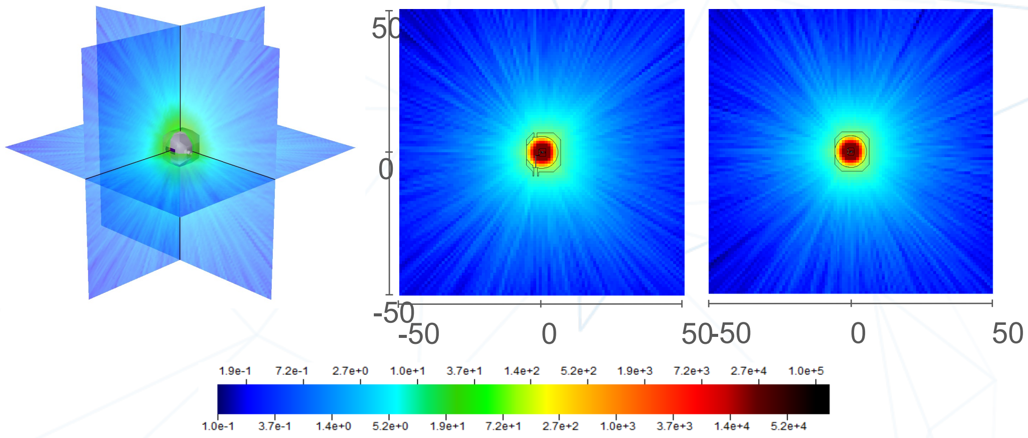
Shielding Drawings

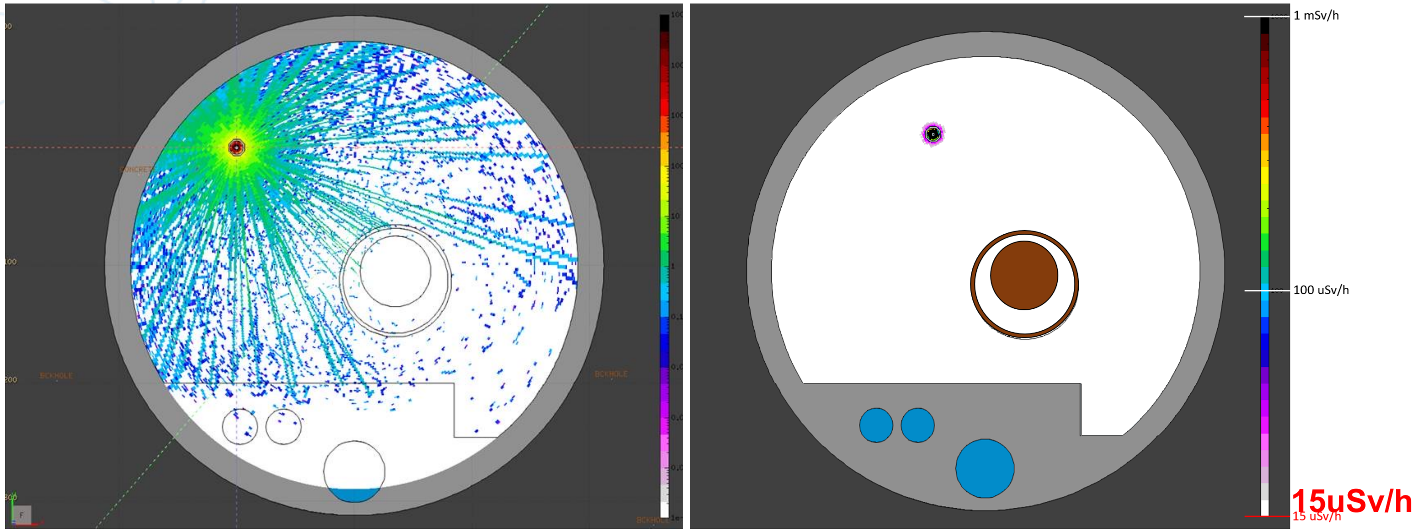
- The best solution that fit all the constrain like space, volume and shielding property was to tungsten
- The core of the child is composed on layer in order to simplify the production and reduce cost that
- The



RP design validation

- The design of the shielding before to be validate need the approval from RP
- In order to validate design functionality RP performed simulations in the symmetry planes and in the tunnel condition
- The good result of the simulations confirmed the source is in safety condition when the shielding it is closed and is possible to work in proximity of it



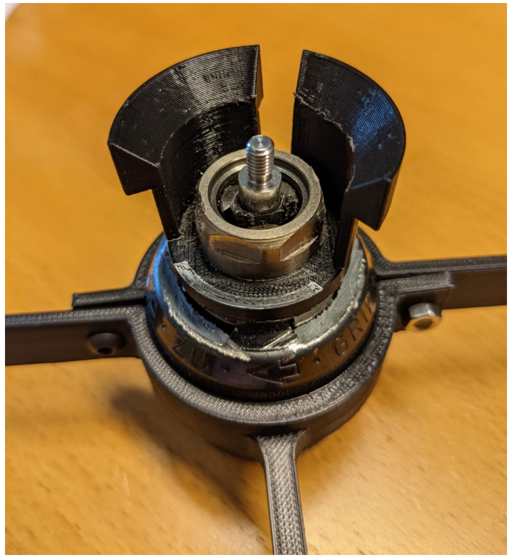


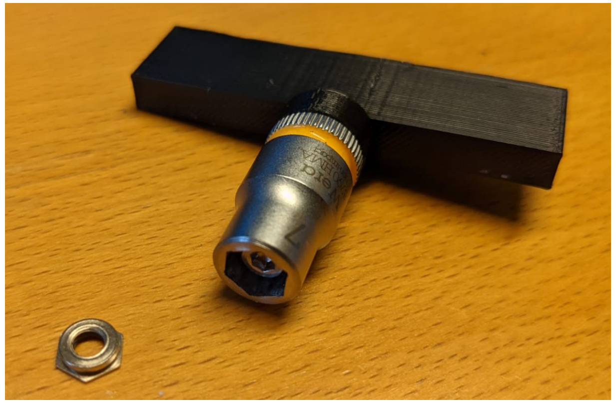
Source Installation – procedure robot friendly

Source:
Cs137 - 1.85 GBq

Interface

Second safety nut





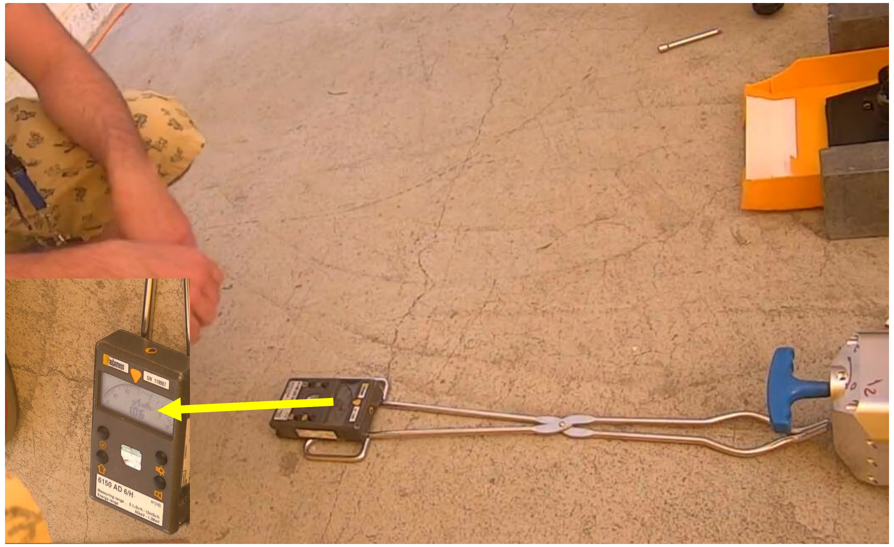
Magnetic key for nut installation

- A series of tools and proper planning is studied in order to handle very small components in safety way
- Developing smart tools sometimes make easy tasks that could be complex also performed by hand

Radioactive source installation

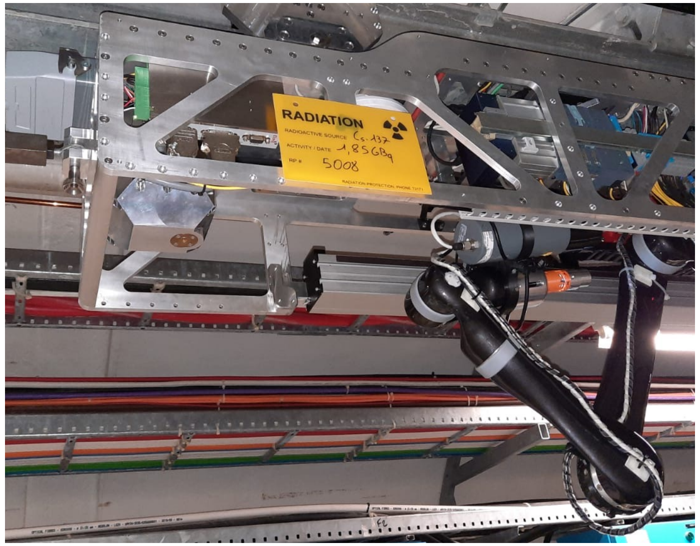
Source Installation – RP validation

- A series of tools and a proper guided ii studied in order to handle very small component
- Study a smart tools can make simple also hand operation



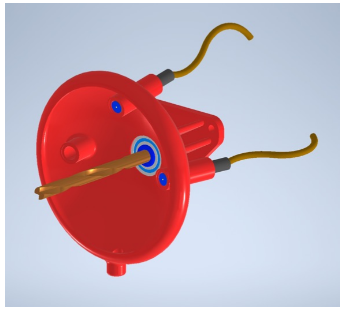
@0.4m – 1.1 uSh

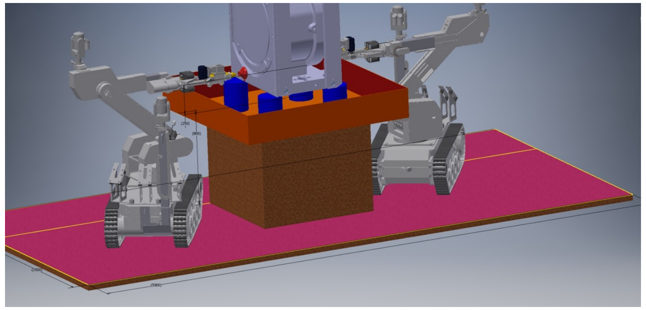
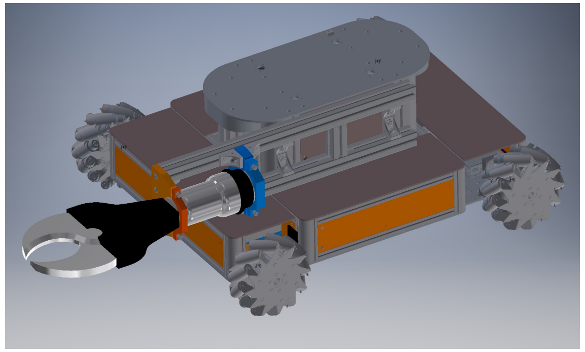
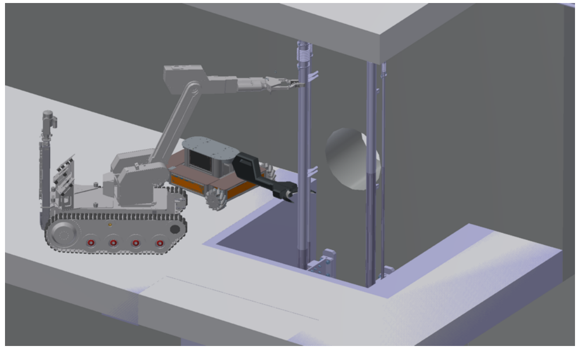
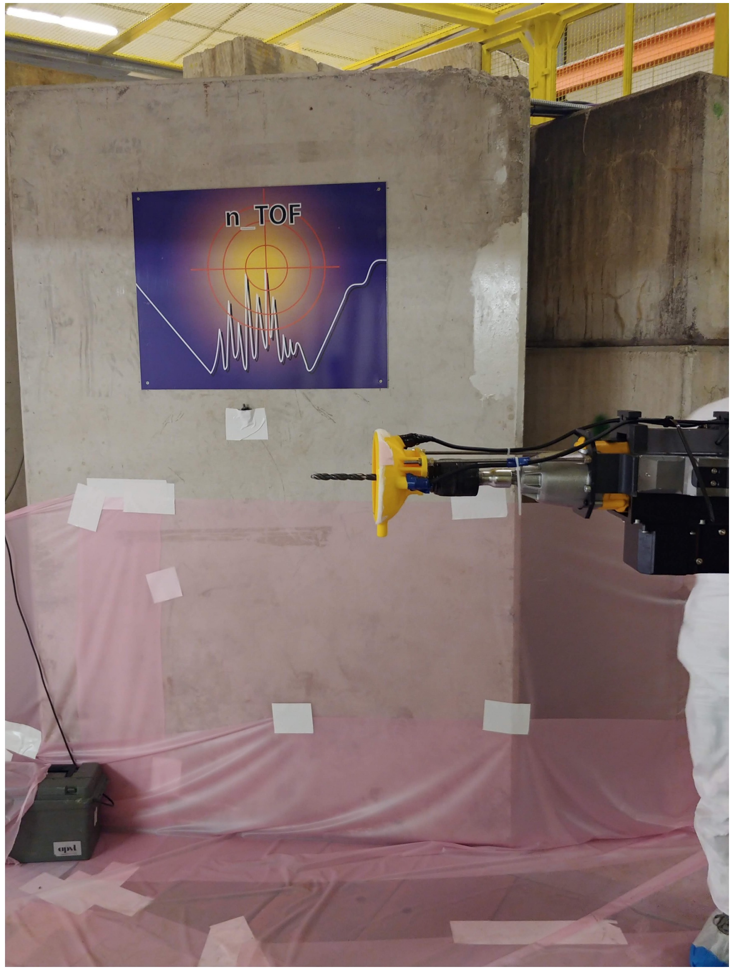
@0.0m – 26.8 uSh



@0.3m – 2.5 uSh

nTof dismantling – Preparation and tools design



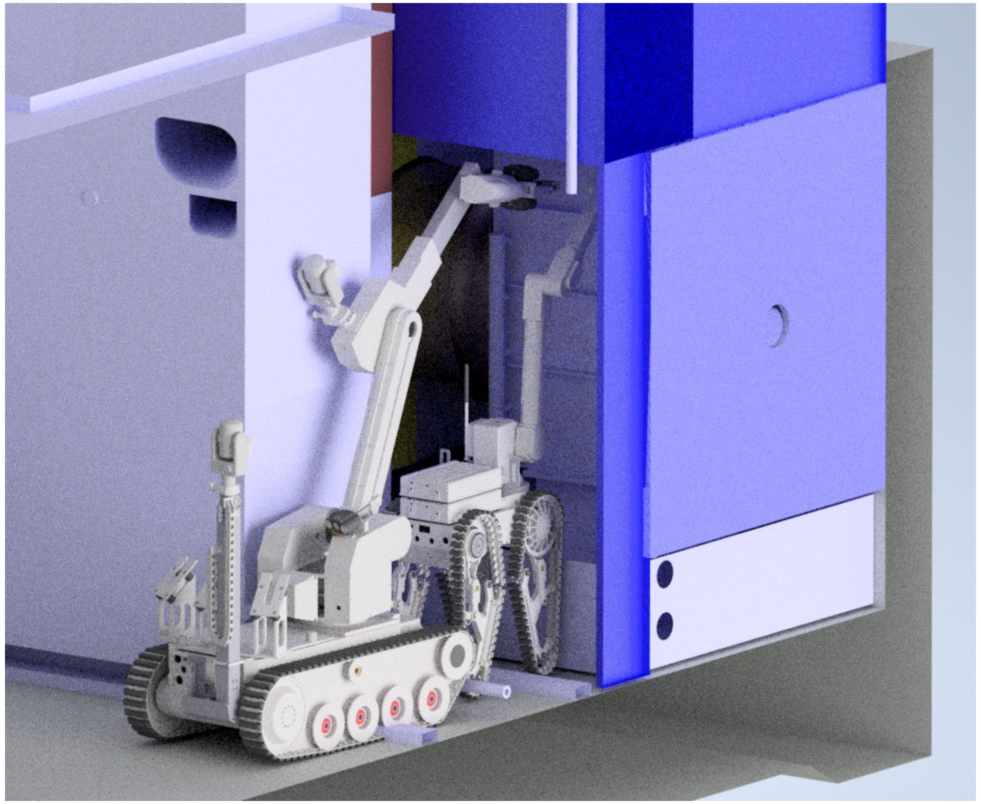





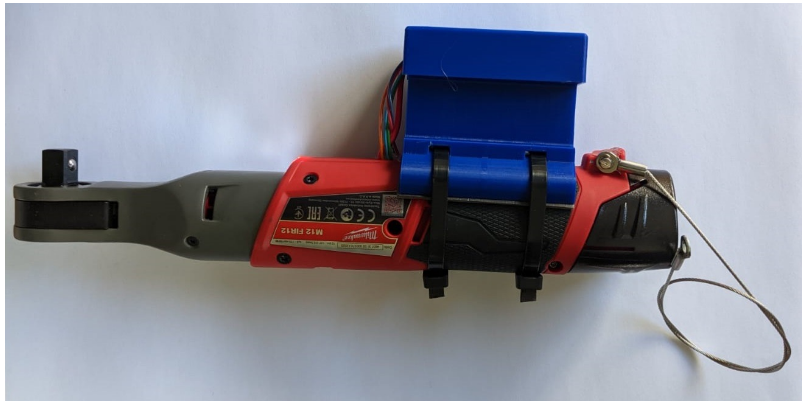
- Collaboration in the planning phases, task analysis and test of all the functional steps is very important in order archive a good result
- The tools selection and the design has to be tried

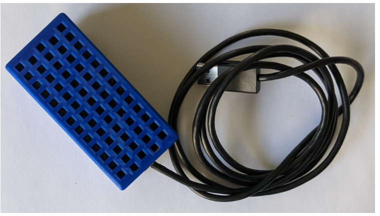
n-Tof target removal

NEAR facility sample grid preparation

- After the simulation the tooling set was validate in CAD



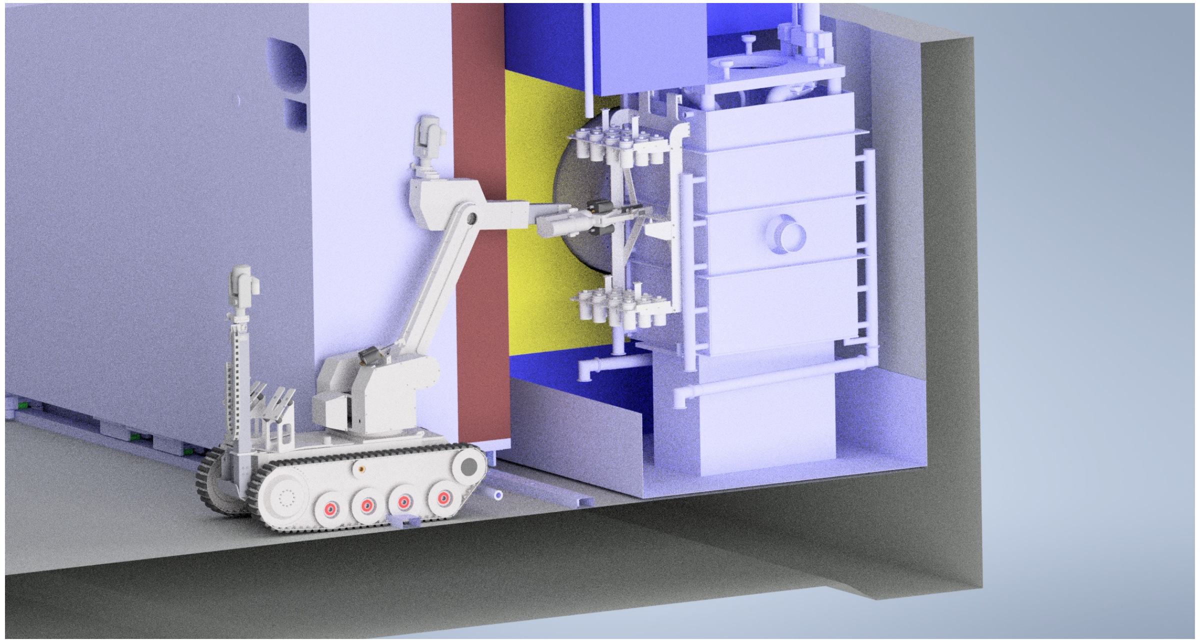




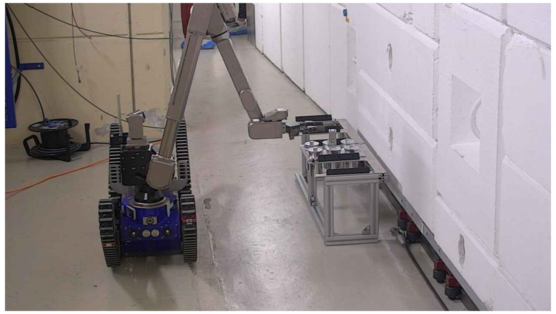
- LORA based impact wrench for Telemax robot

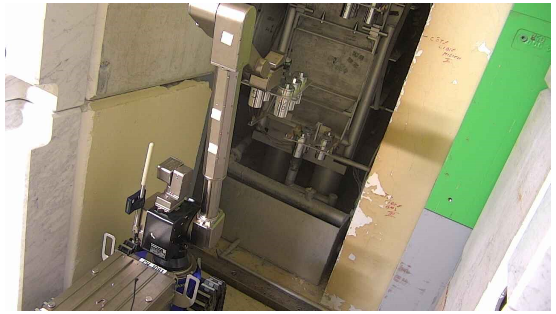
NEAR facility sample grid setup

NEAR facility sample grid installation

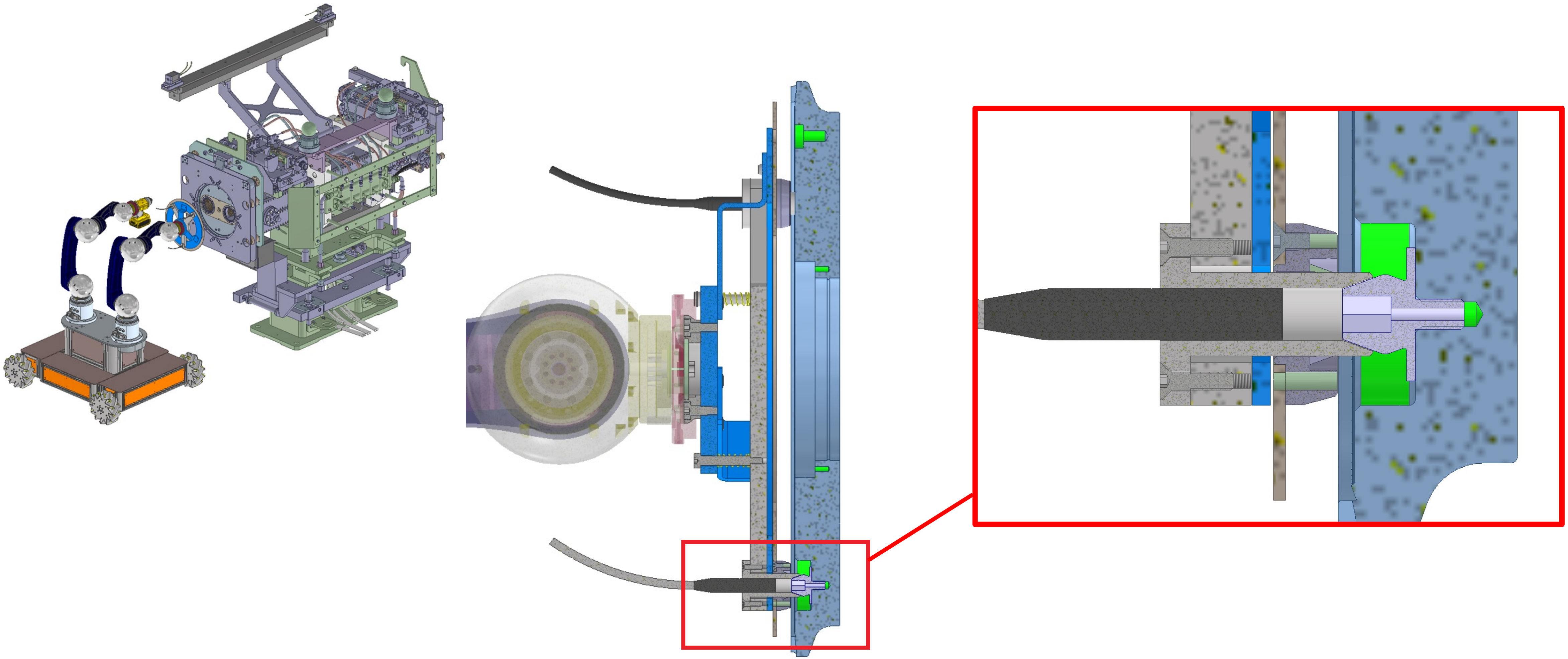


- The preparatory intervention done had possible the installation of the samples grid
- And in the next phases the positioning and the irritation of 24 samples

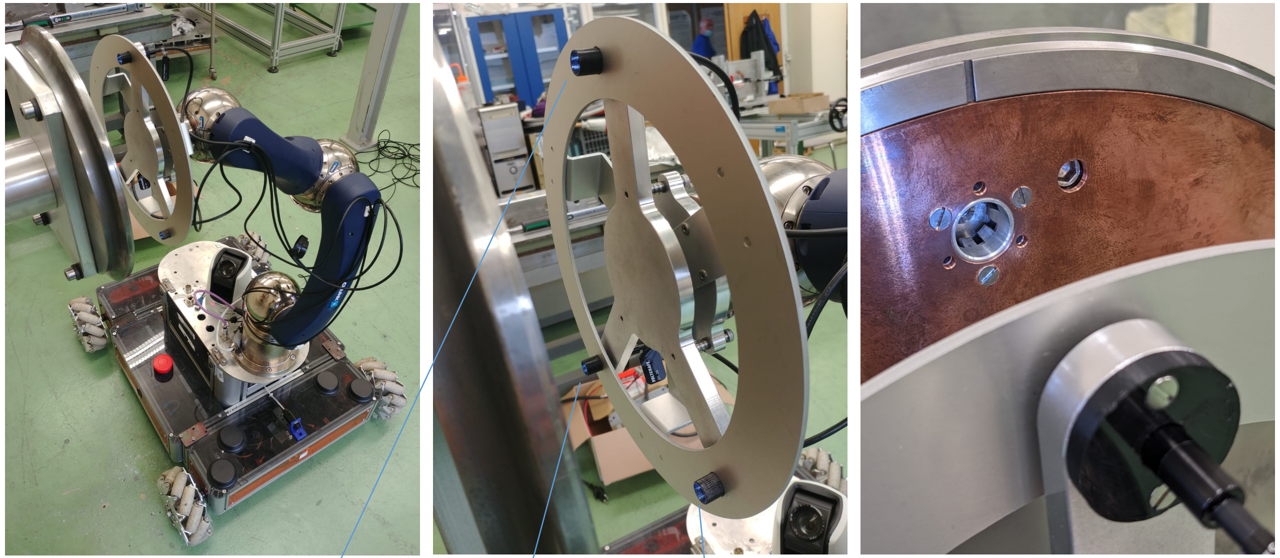




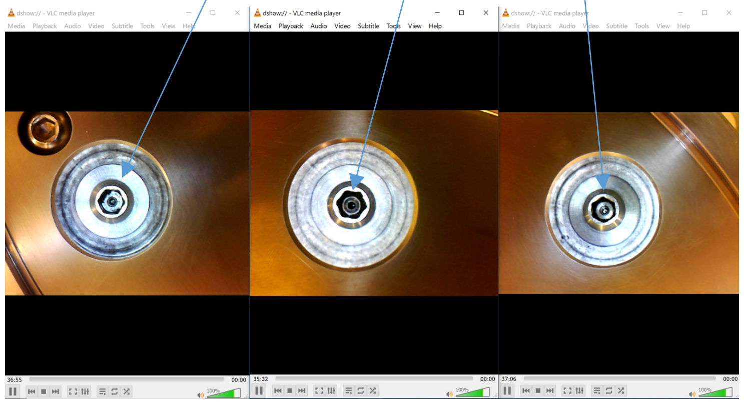
Robot friendly gasket exchanging tool for collimator



Perception - gasket installation

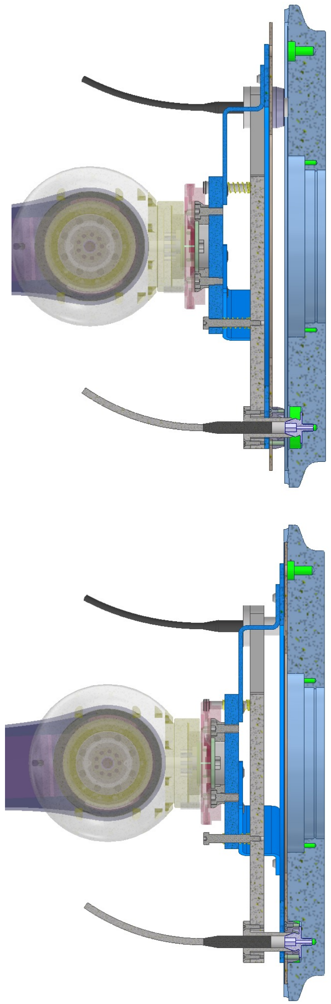


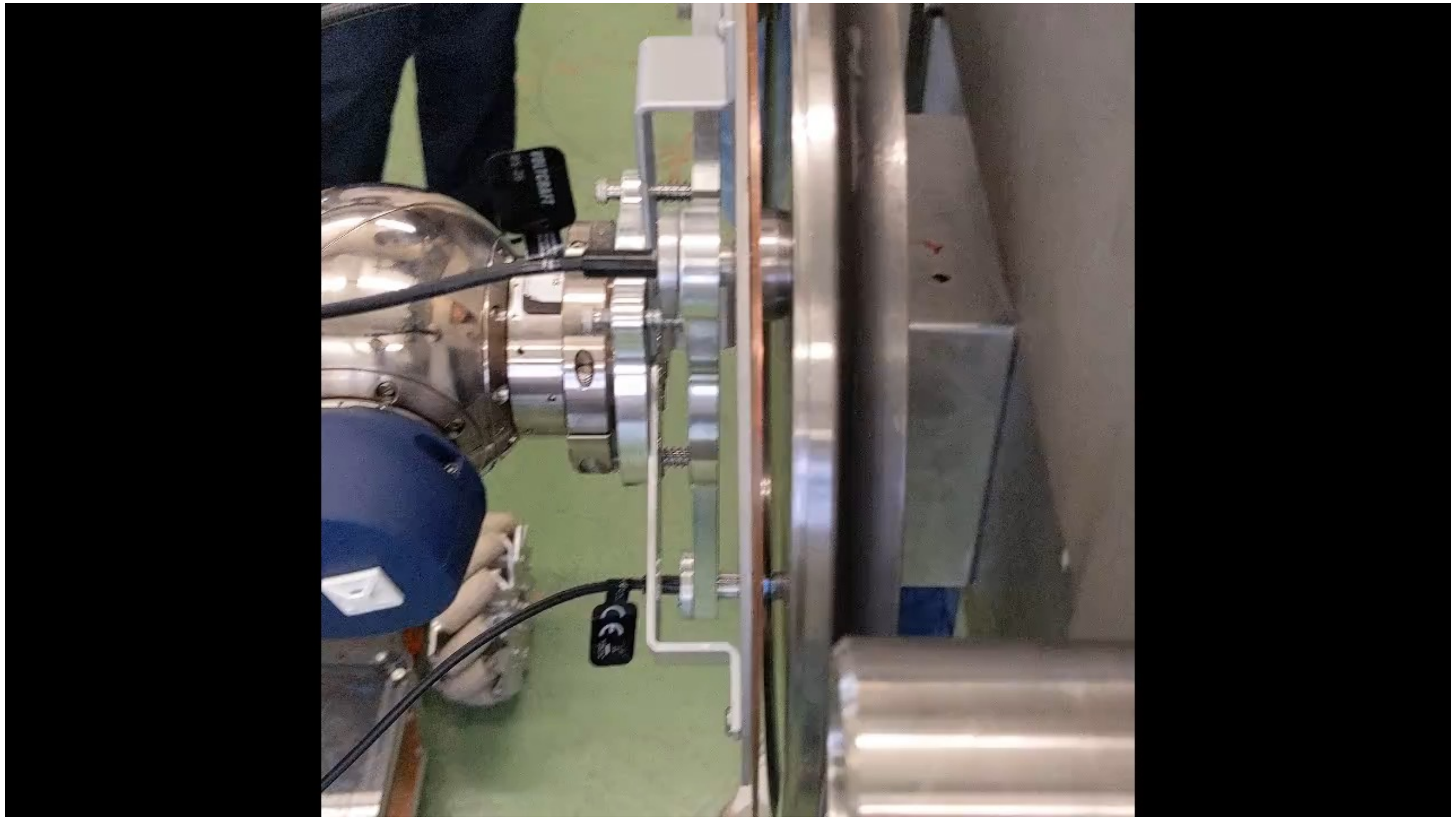
- The perception in remote intervention is a critical aspect that is important to take into account during planning and tools design
- The parallax error is impossible to determine whit a single point of view cameras



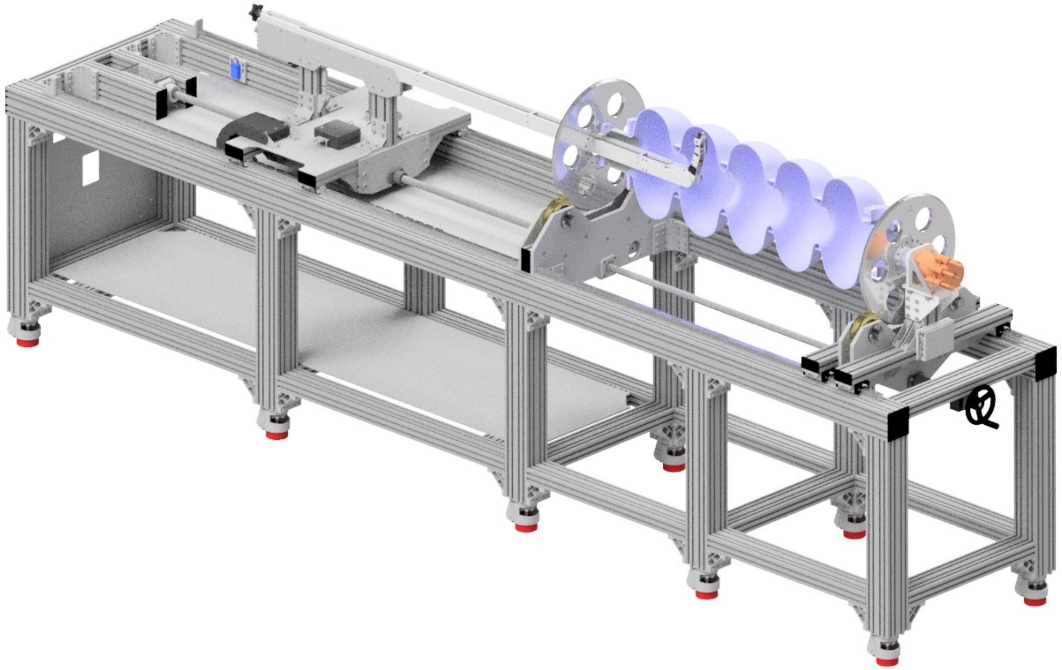
- Using the aliment pins is possible to have a planar alignment fixing the rotation using the three endoscopic cameras points of view

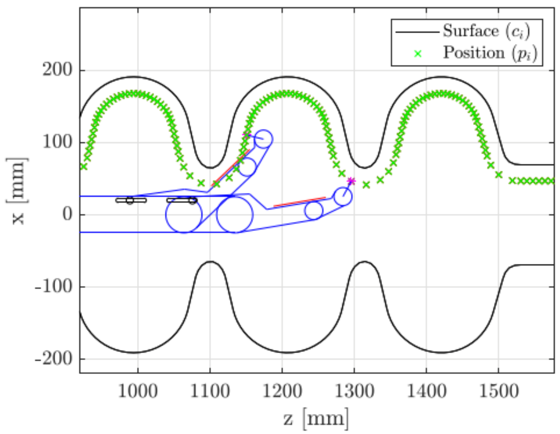
Robotic friendly tool for gasket installation

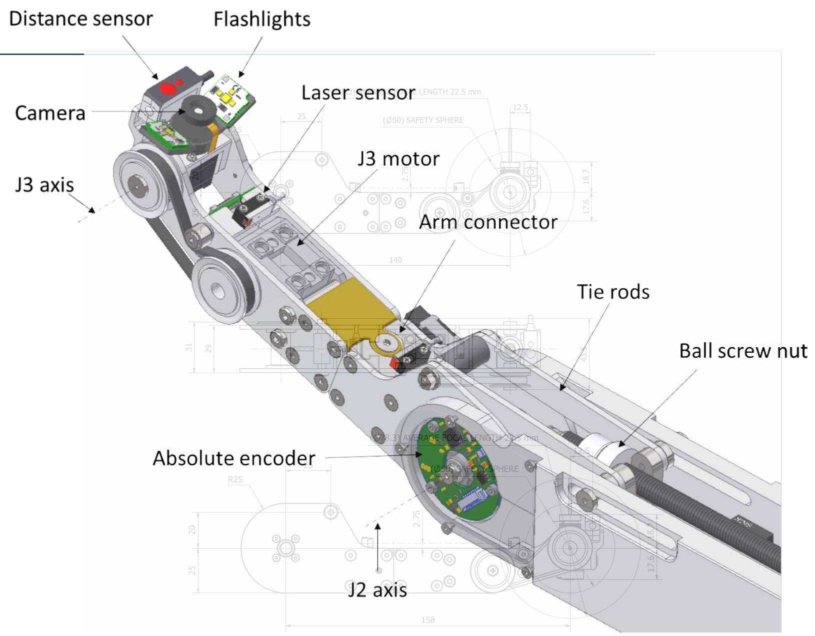




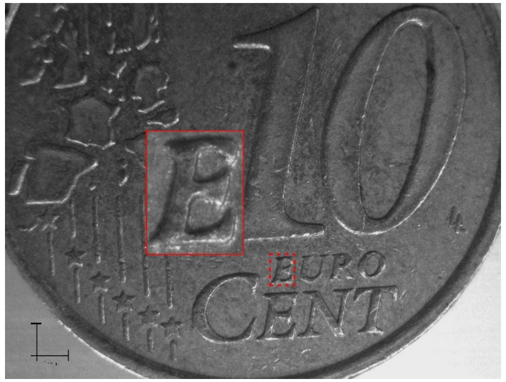
Quality control - cavity inspection robotic bench

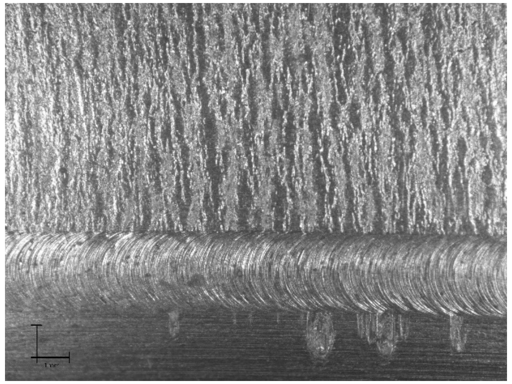


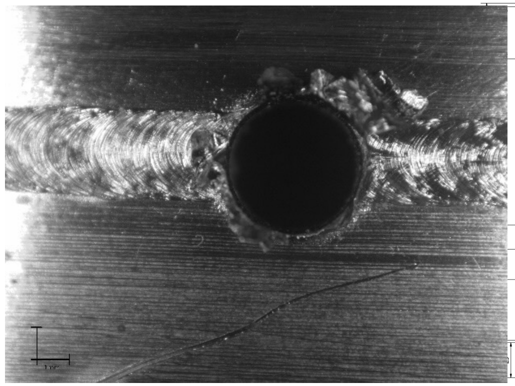


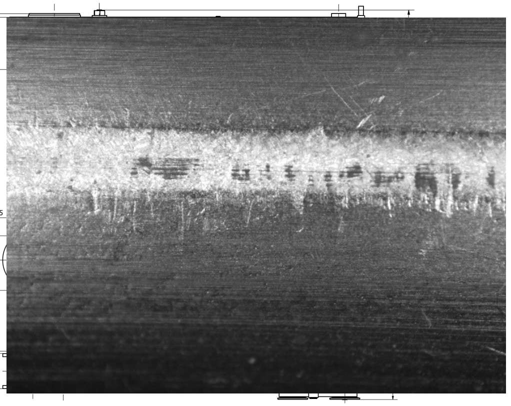


- 1 picture ≅ 50MB
- Full scan ≅ 20’000 pics
- Full scan ≅ 1 TB
- Full scan time = 12 hours









Needed Competences and Capabilities of Suppliers #1

- Teleoperation devices/sensors
  - ✓Lightweight arms/manipulators where we can access low level communication protocols in order to embed them/our own controllers on our mobile platforms
  - ✓Variable payload requirements, in kg range
- Haptics
  - ✓Primary devices e.g. gloves, handheld devices
  - ✓Secondary devices e.g. pressure sensors, lightweight FT sensors

Needed Competences and Capabilities of Suppliers #2

- Tooling, fabrication of complex mechanical pieces and not standard material

- Sensors for embedded applications
  - ✓ Cameras
  - ✓ LIDAR/RADAR

- When applicable, an understanding of radiation environments and required radiation hardening mitigation steps required for hardware setups

Needed Competences and Capabilities of Suppliers #3

- Mechatronic, integration and dynamic simulations
- Modeling
  - ✓ Modelling of physical spaces in simulation from sensor data e.g. point clouds/stitched images
  - ✓ Representation of robotic systems in standard format for simulation visualization e.g. Unified Robot Description Format (URDF)
- Communication
  - ✓ Robust/reliable/configurable communication protocol understanding over different networks and delays
  - ✓ EtherCAT, CAN, PROFIBUS, PROFINET

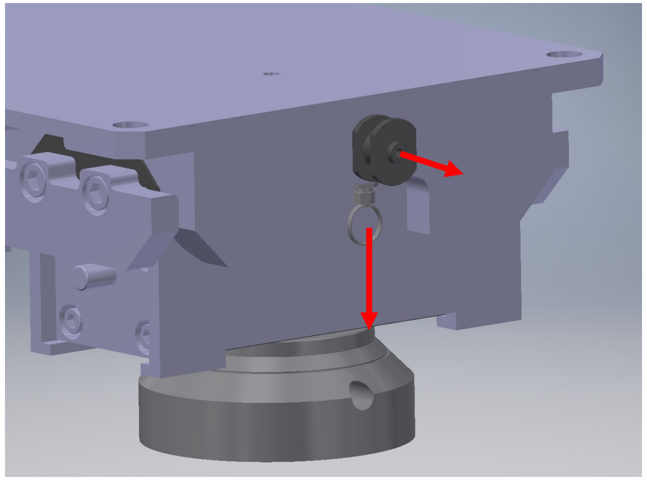
Needed Competences and Capabilities of Suppliers #4

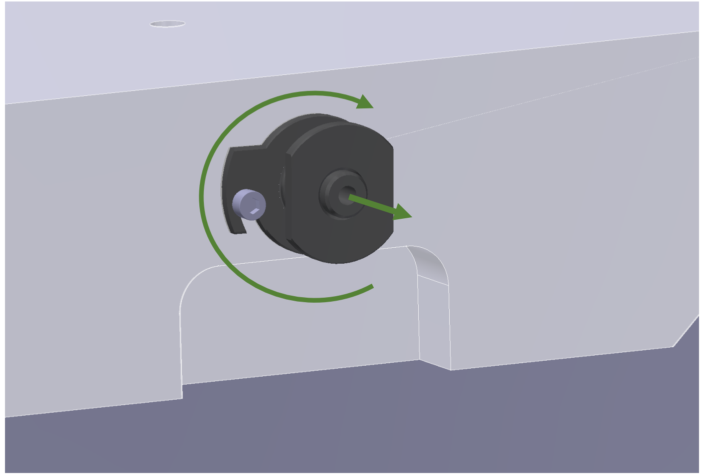
- Vision
  - ✓Scene understanding and object recognition (computer vision)
  - ✓Machine learning for autonomous navigation in known environment, in different lighting conditions

- Robotic Control
  - ✓Trajectory generation e.g. learning by demonstration
  - ✓Closed loop control of high DOF manipulators, possibly with haptic feedback and always with guaranteed stability

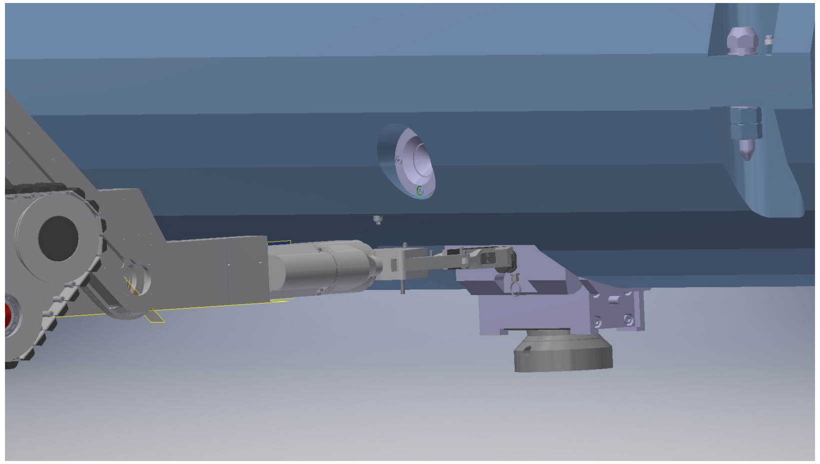
Thank you for your attention!

TIDVG5 - Robot friendly design adaptation





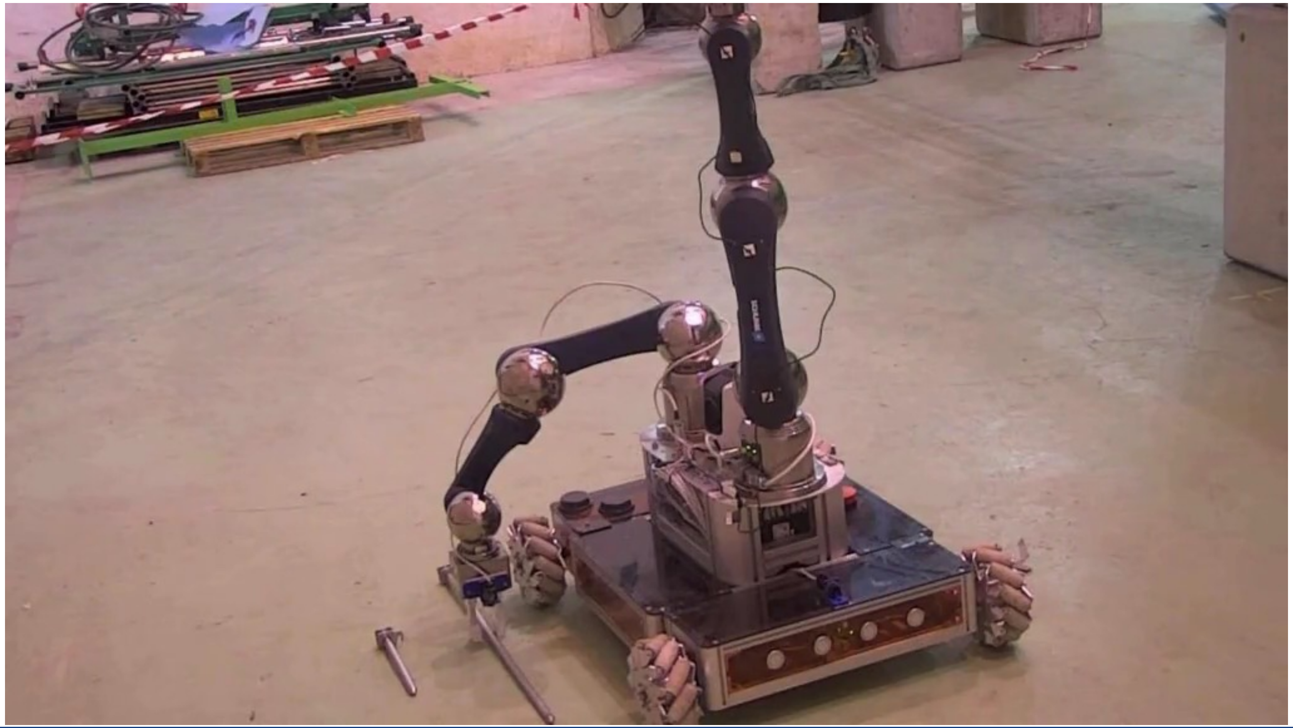
- Collaboration in design phases is very important in order to make the components of the future machine robot friendly, which will reduce the intervention time and risk to the machine
- In this case was possible to pass from a bimanual task to a single hand task, which will simplify the manipulation of the pin without changing the functionality



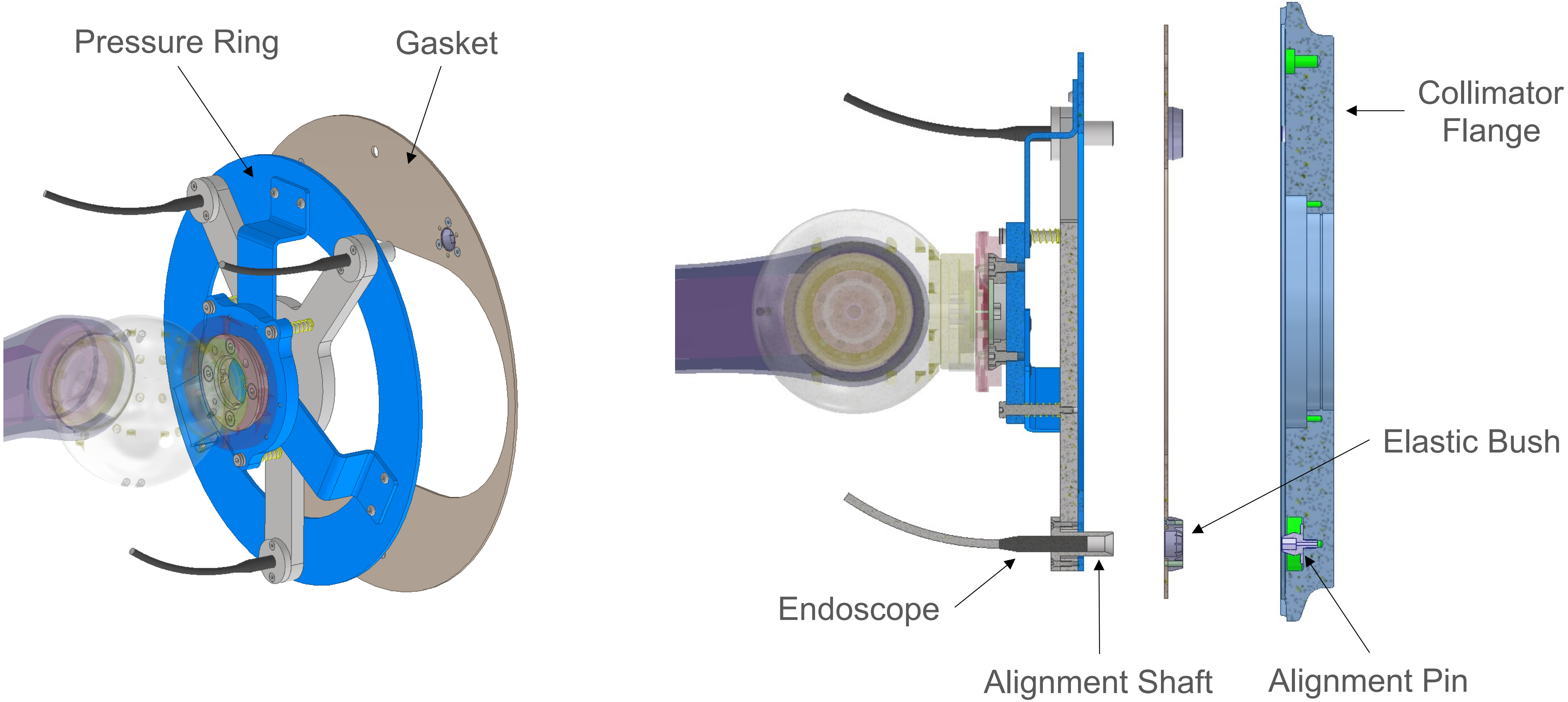
TIDVG5 - Robot friendly design test

- The experimental tests performed before the validation is very important in order to add more functional specifications and write the documentation needed for the future operation
- In this case, was added a marker on the centre of mass in order to simplify the manipulation of the pin during the extraction and insertion phases

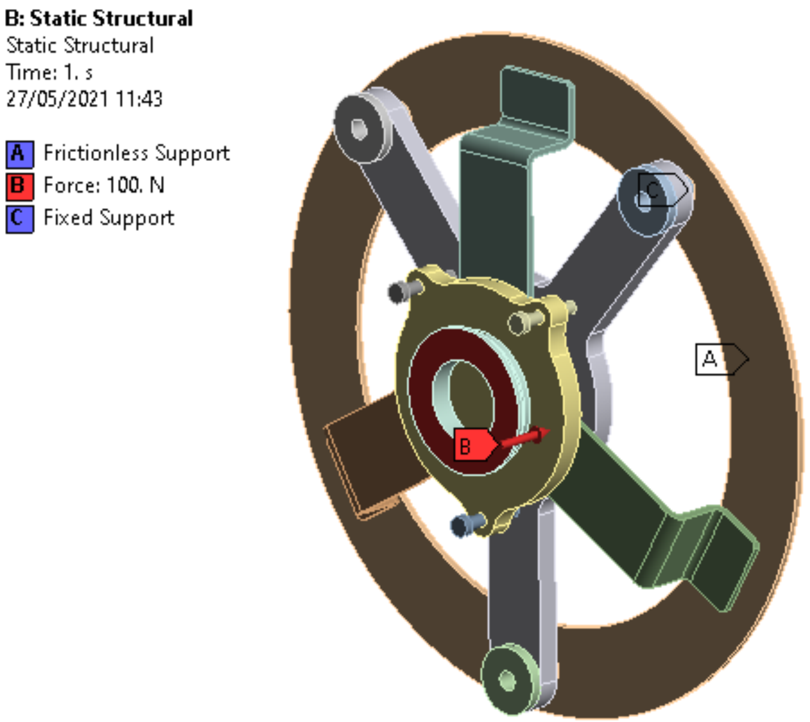
Center of mass



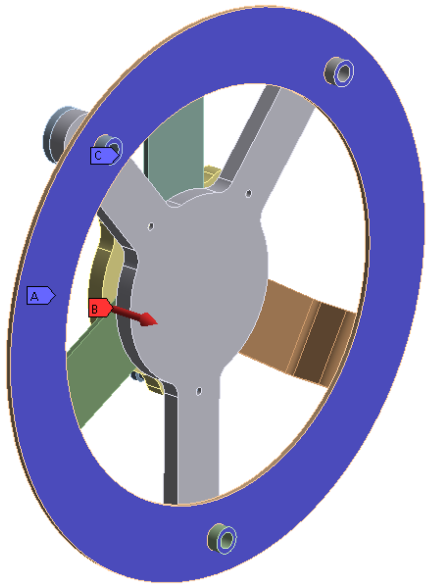
Gasket installation tool



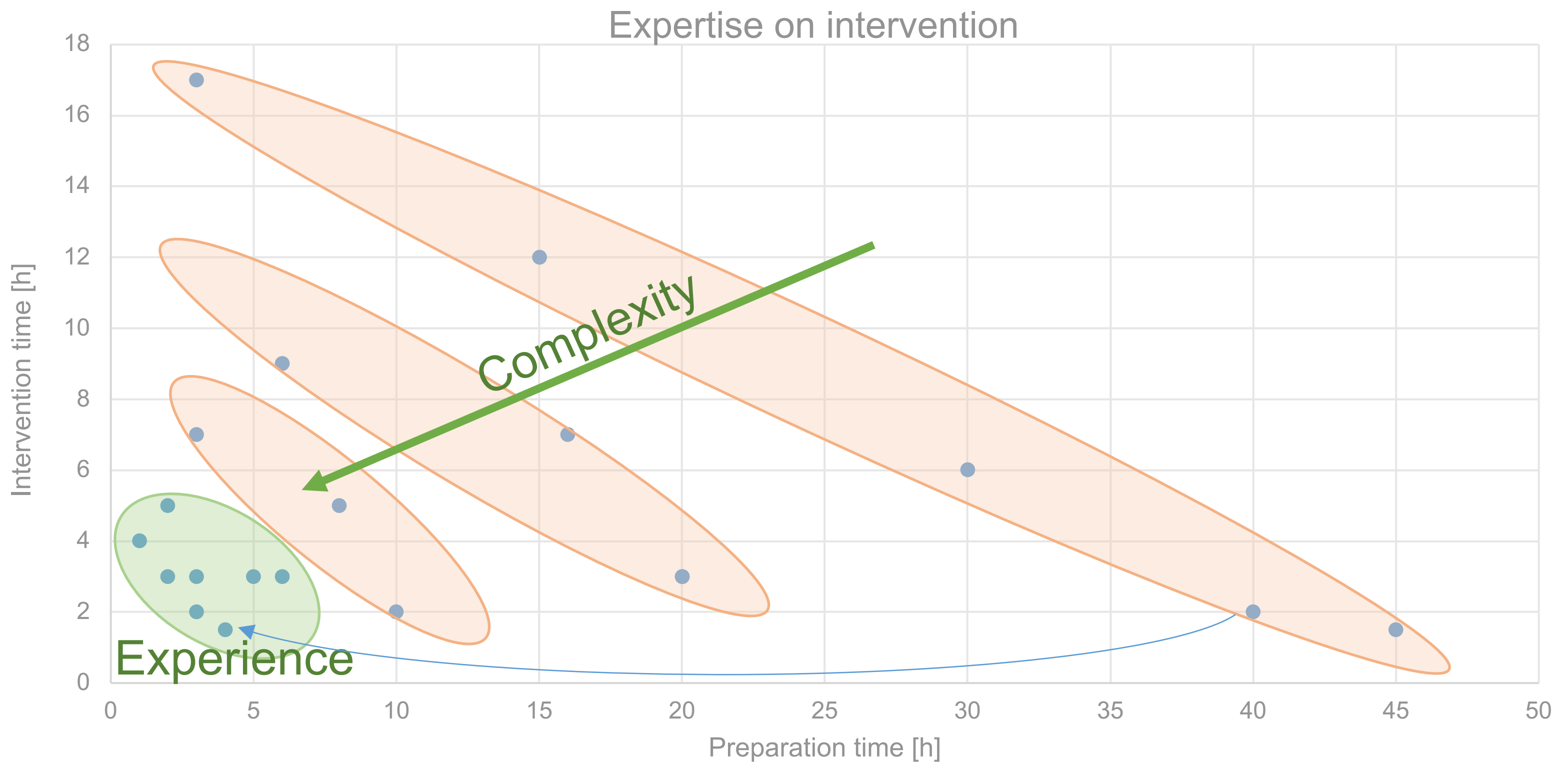
Deformation Analysis



- Functional and deformation analyses are performed in order to validate the behaviour of the tool
- Starting from the simulation of the stress on the tool is possible to determine witch robotic arm can be used for the application

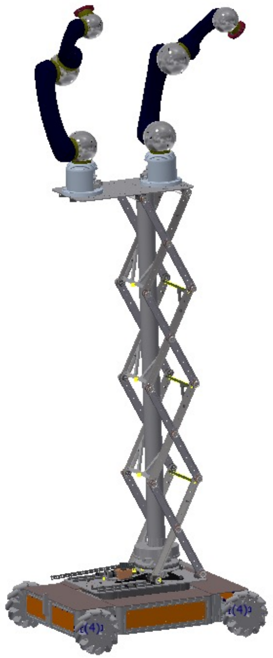


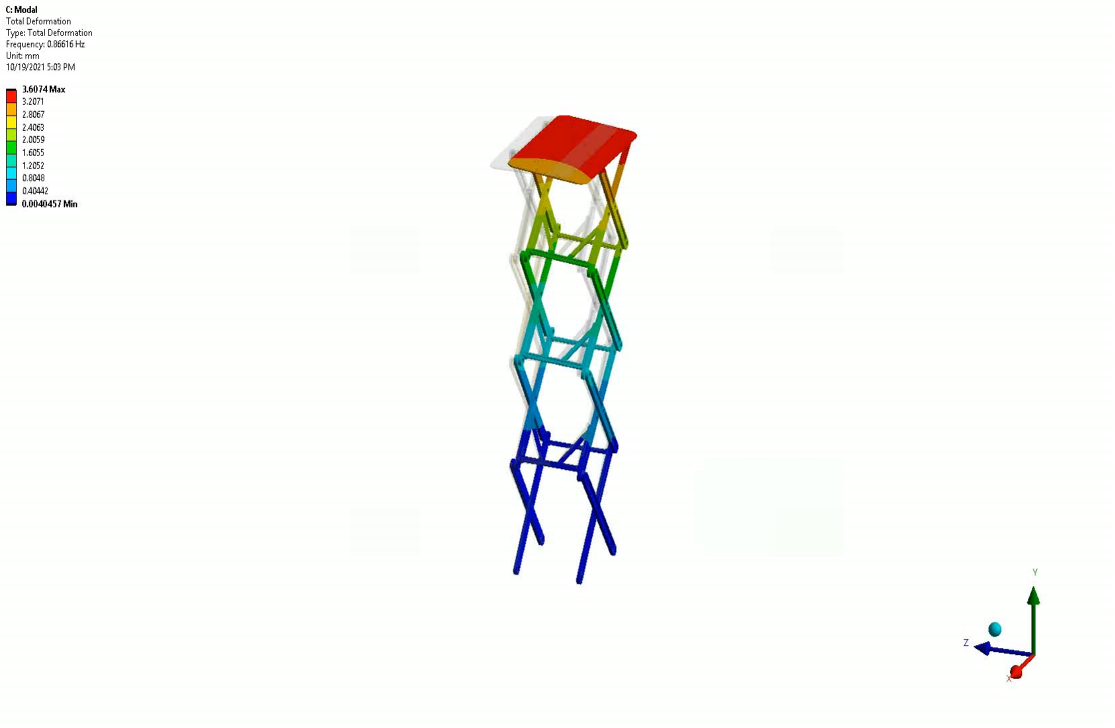
Intervention time



Structural control of the lifting system

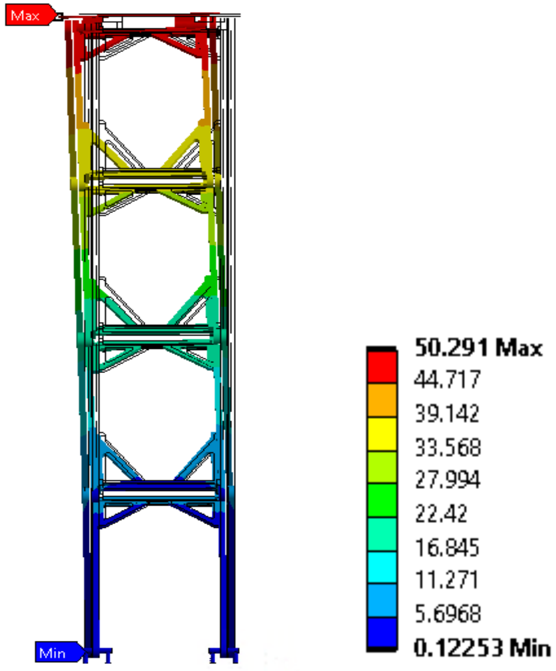
- CERNBot2 is equipped whit a lifting system able to be extended until 1.6 meters able to carry a load of 200 kg
- The simulation of the elasticity was performed in order to foresee the behaviour of the platform

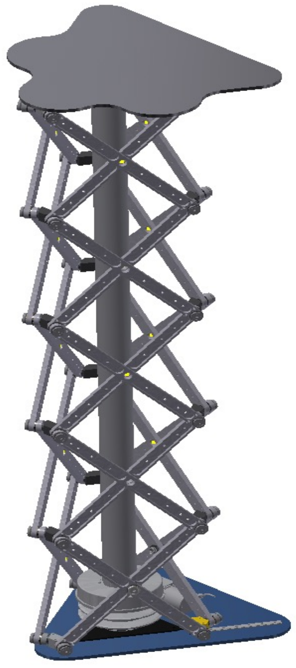


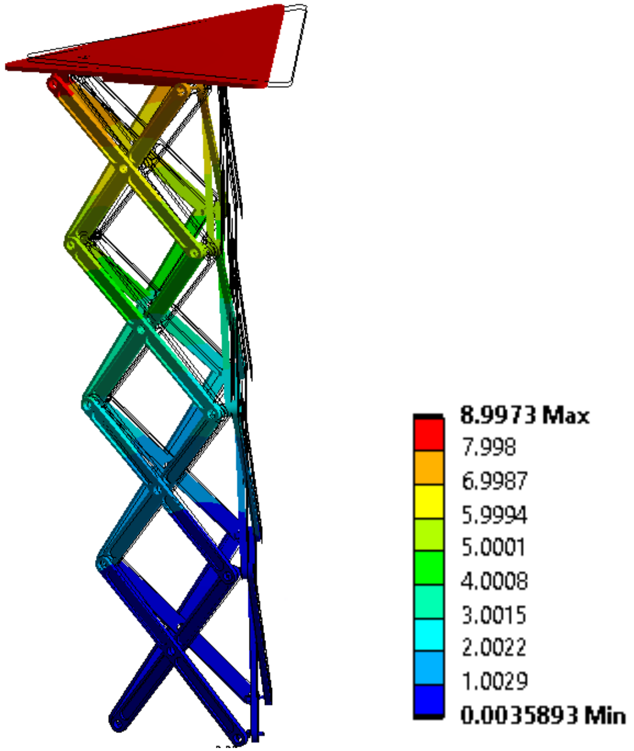


Validation and new solution

- All the component of an robotic platform has to be validate with structural analysis
- Using ANSIS Triangular structure is studied in order to improve the also on the lateral movement

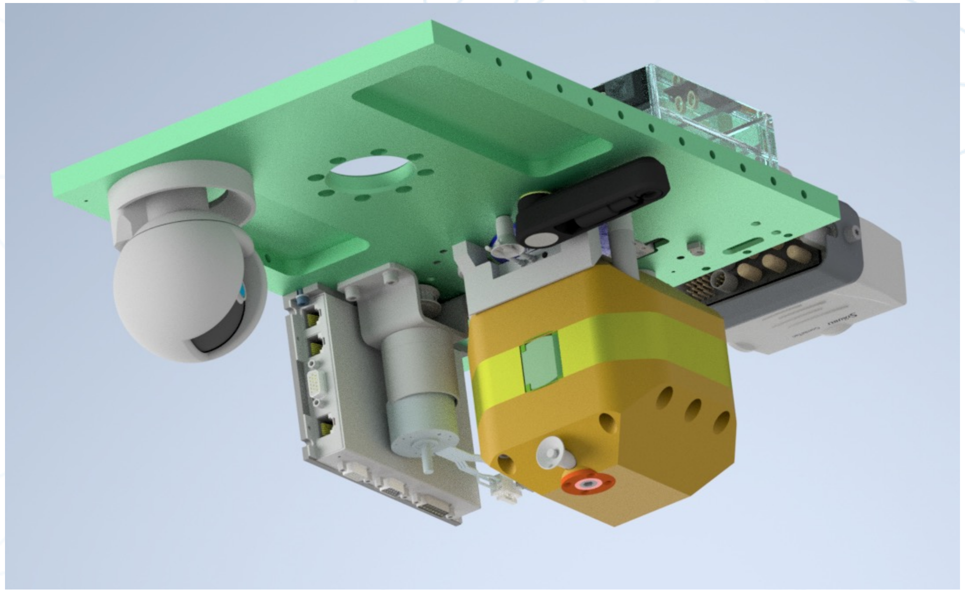


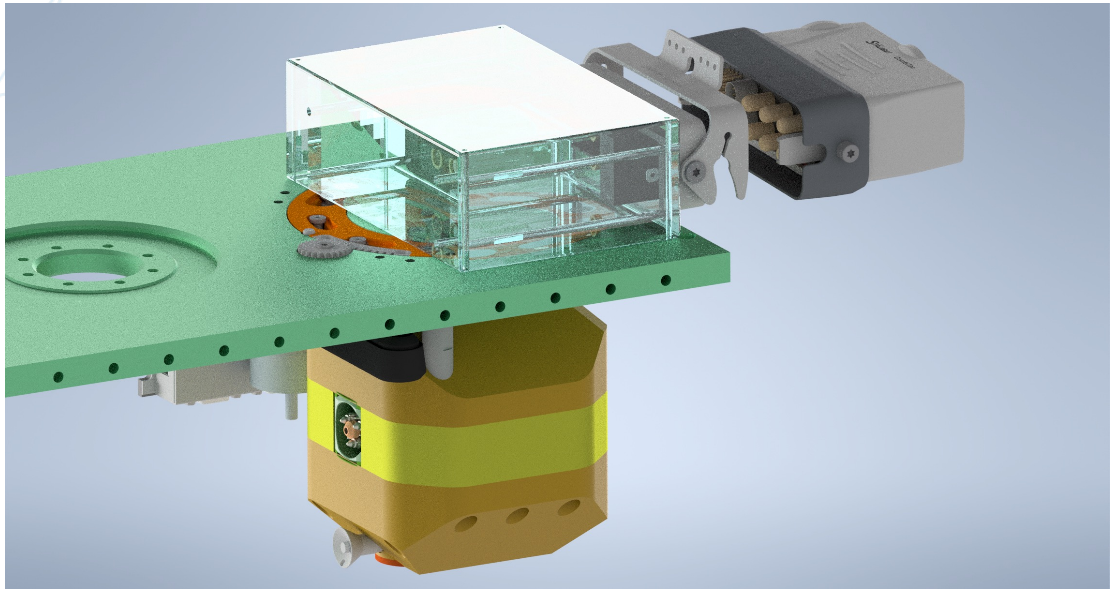




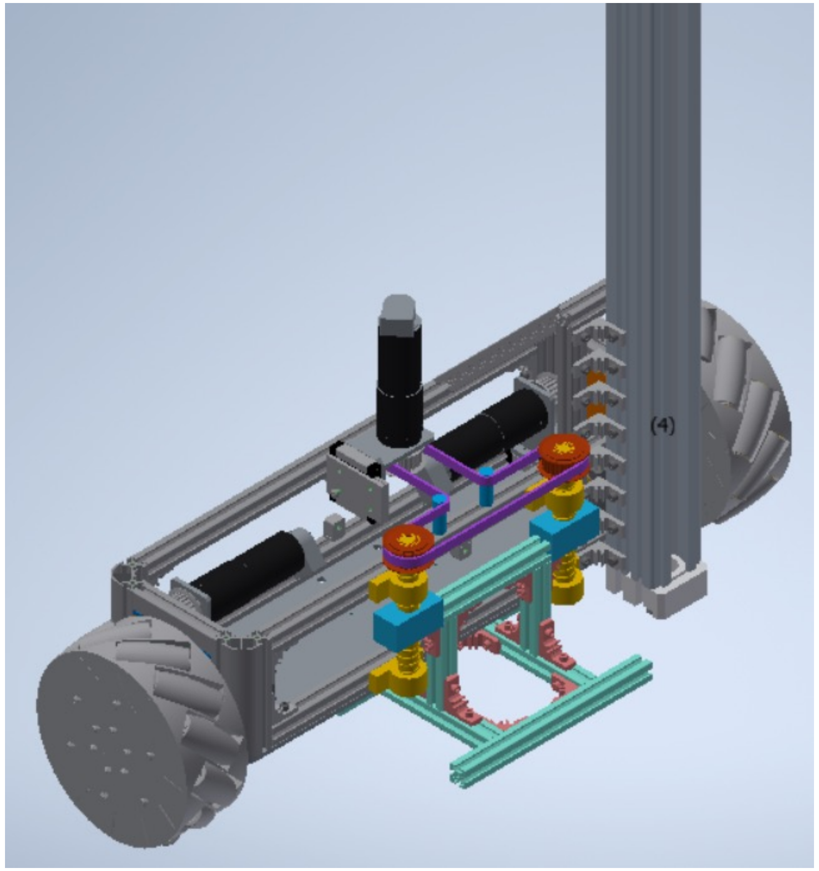
TIM robotic wagon integration

- Absolute positioning encoder on the core
- Locking system with handle and safety pin
- Sensor redundancy for the source state



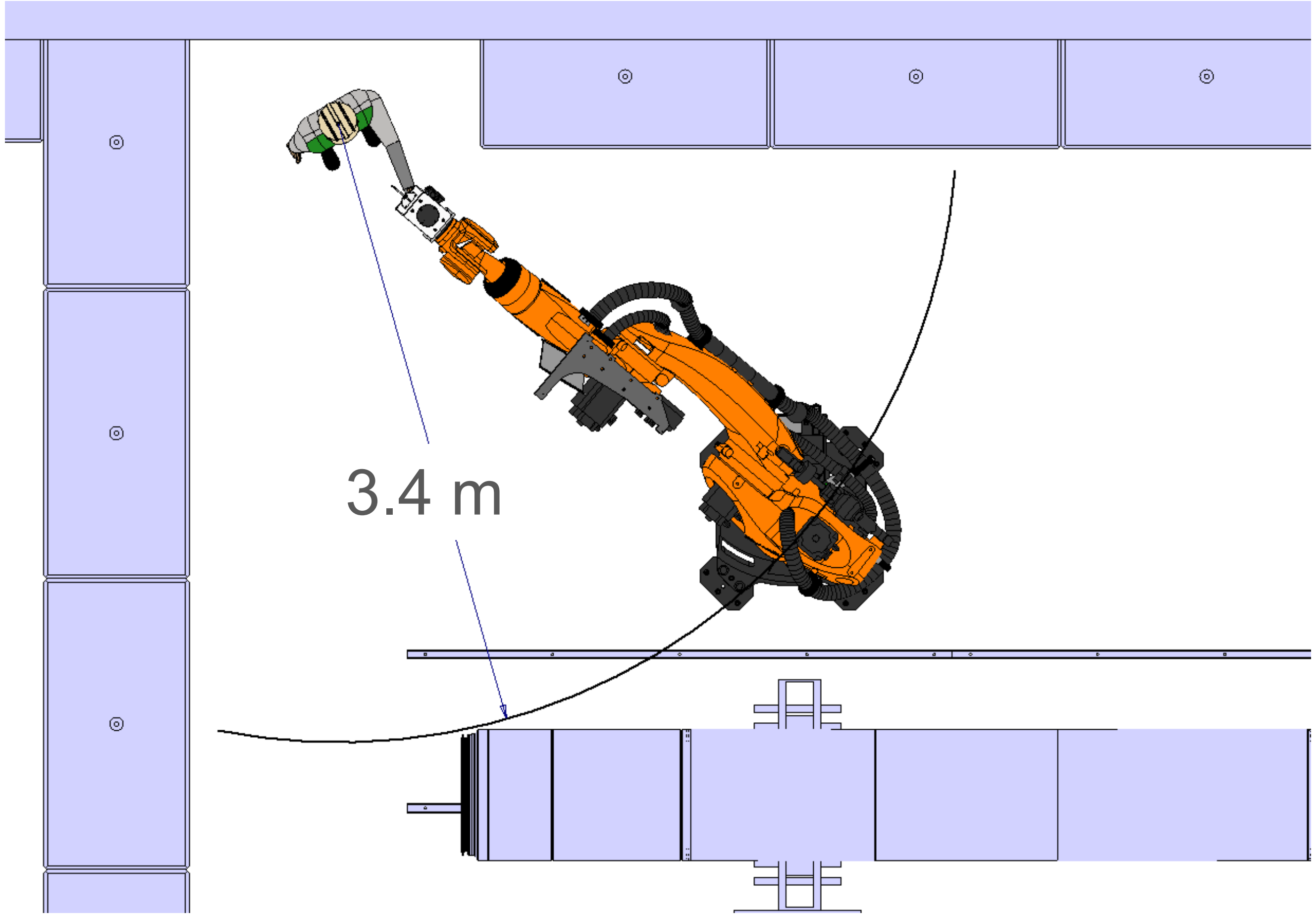


New functionality for CERNBot



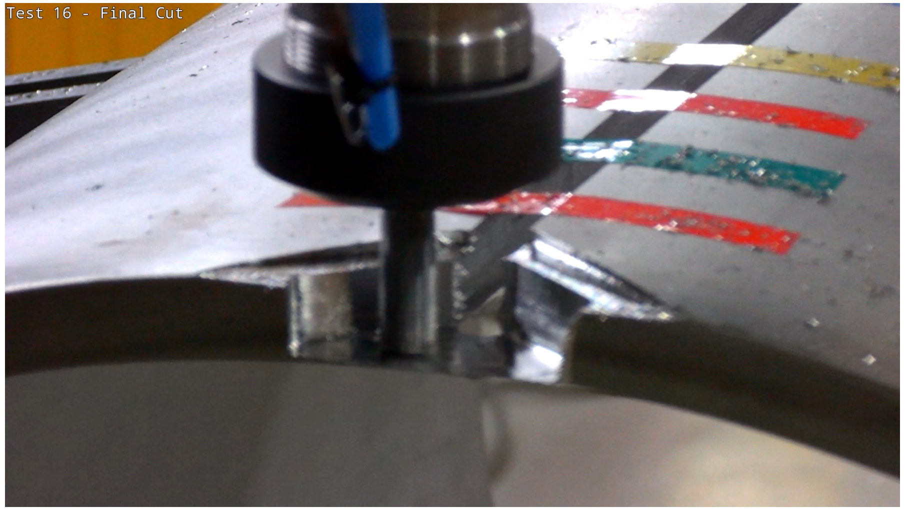
- A drilling extension module right now is under study
- CERNBot will have the capability to machine holes in the floor in full remote mode
- This extension module will be added to the platform in case of needs

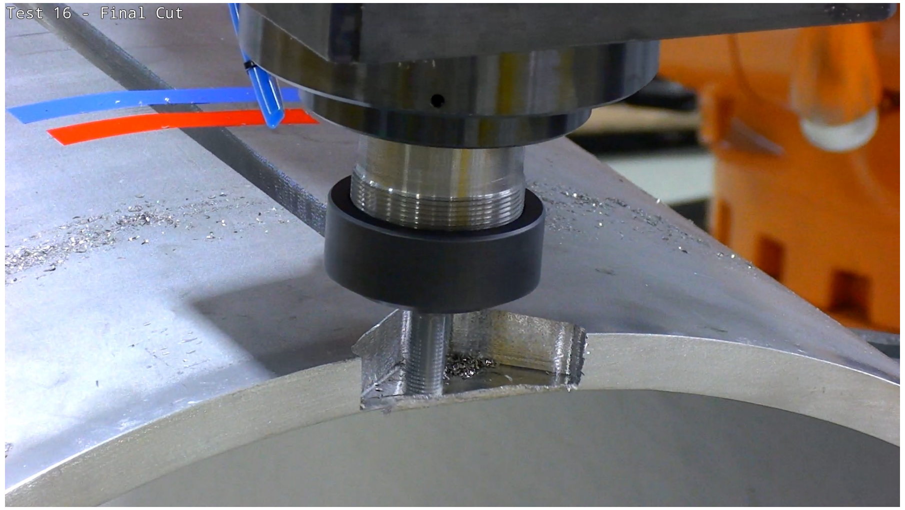
Milling tools exchange procedure



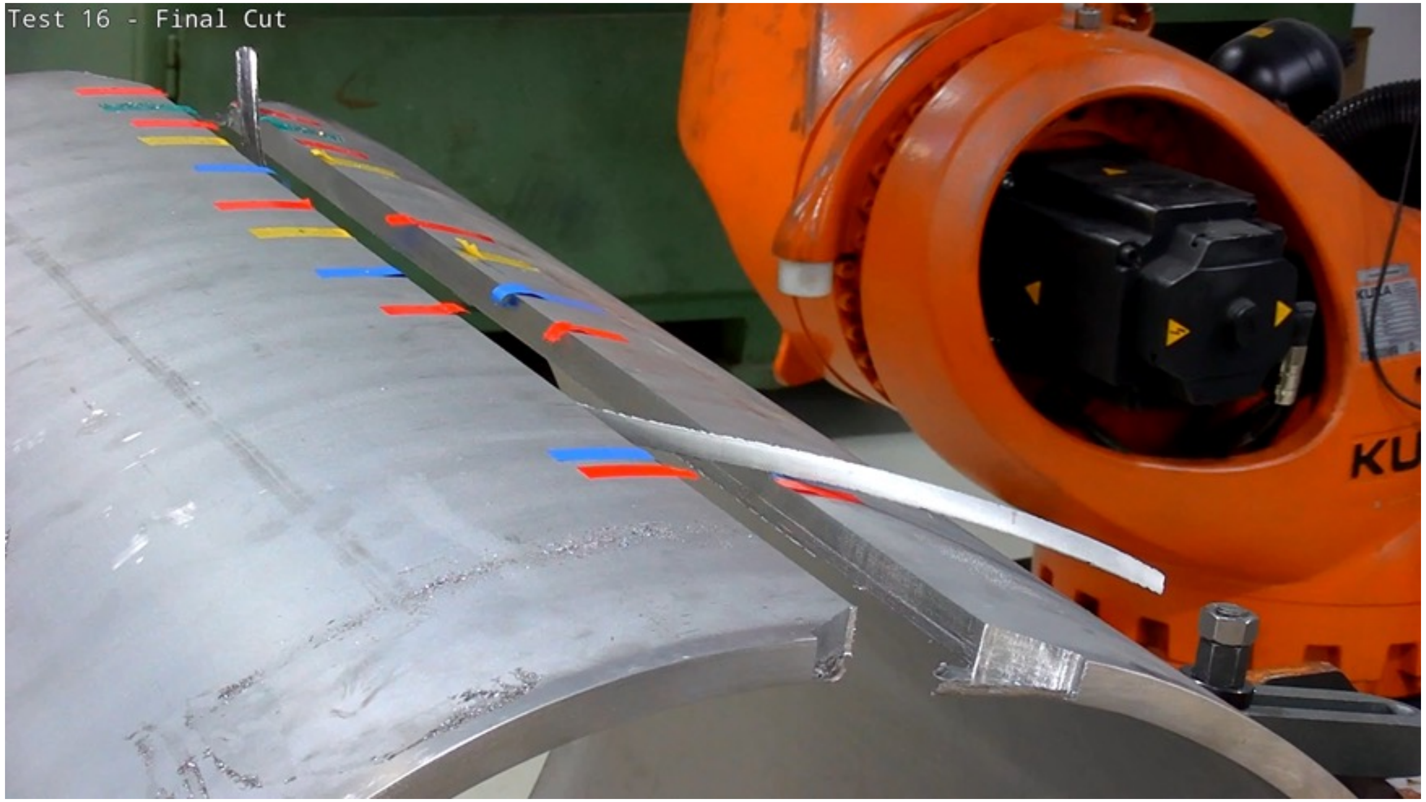
- Maximising distance from the dump 3.4 meters in the worst case
- The medium distance is about 5 meter

Longitudinal cut finalization

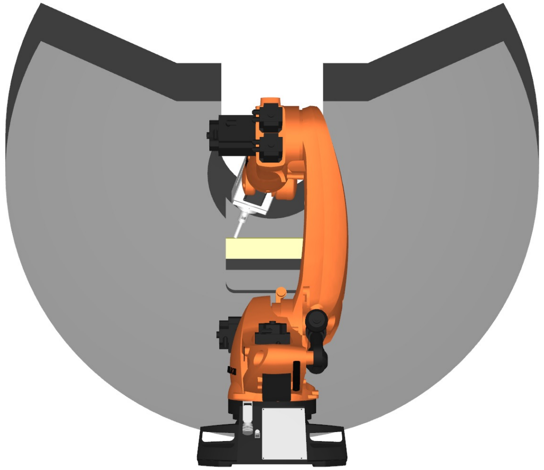


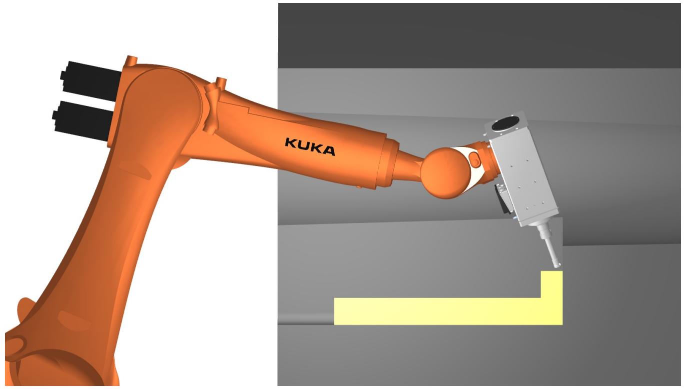


- The relaxing of the internal forces of the pipe could block the milling tool, so was foresee a V-shaped pocket that in case of contraction will push out the tool like a no sharp shears



ATLAS Shielding JFC3

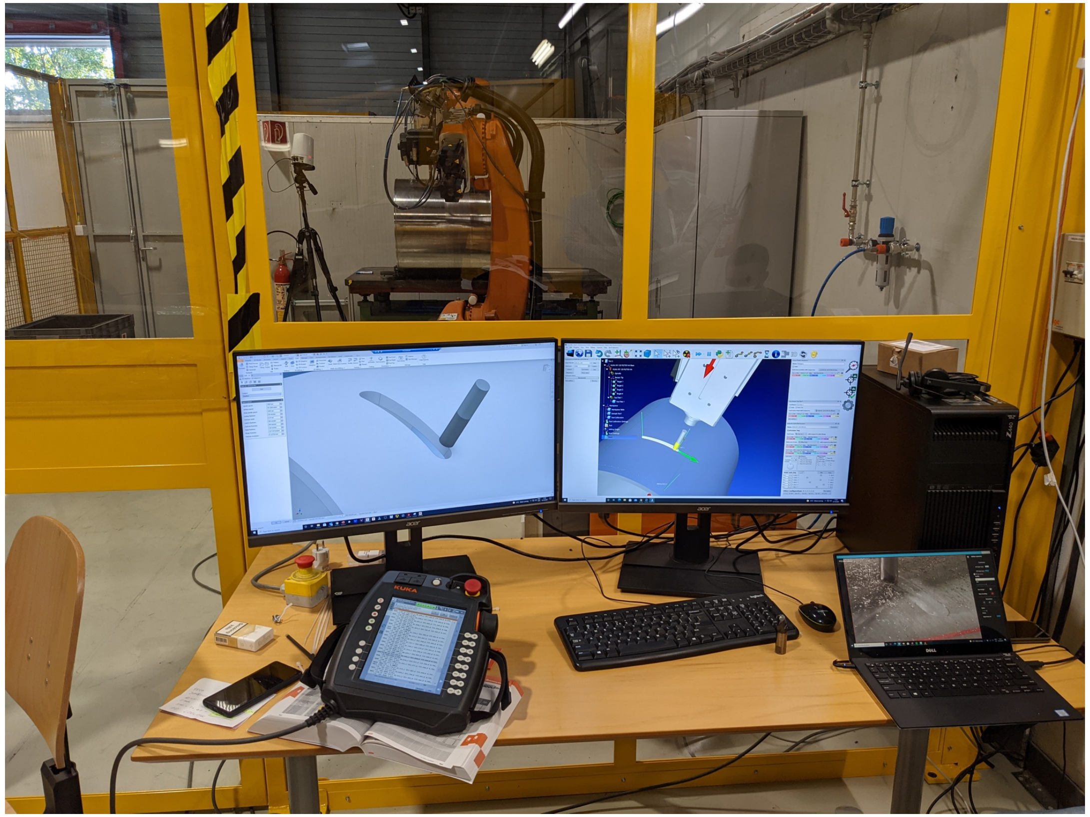




- ATLAS Shielding JFC3 modification by robotic machining

Robotic cell in 927

- Control station



- Mock-up fixation