



Machine Learning and Computer Vision in Robotic Interventions at CERN boosting maintainability

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The Robotics Service at CERN

Main Objectives

Increase Operational Safety

Increase Availability

Post-Mortem Analysis

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Increase Operational Safety

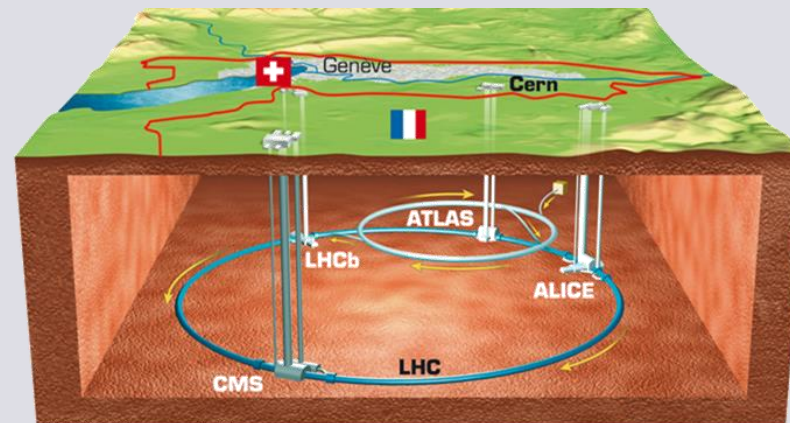
Increase Availability

Post-Mortem Analysis



Protecting workers from dangerous interventions.

More than 70 km of harsh experimental areas, tunnels caverns, etc.



Oxygen Deficiency

Radiation Exposure

Injuries in Confined Underground Spaces

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Corrective and preventive maintenance, and product quality validation.

Remote Maintenance

Remote Inspection

Quality Assurance

Availability (A)

$$A = \frac{\text{Up Time}}{\text{Total Time}} = \frac{\text{MTBF}}{\text{MTTR} + \text{MTBF}}$$

Mean Time Between Failures (MTBF)
Mean Time To Repair (MTTR)

Reliability	Maintainability	Availability
If Constant	Decrease	Decrease
If Constant	Increase	Increase
Decrease	If Constant	Decrease
Increase	If Constant	Increase

Reliability and Availability Working Group: <https://indico.cern.ch/category/9071/>

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Research and improvement of new designs.

Assistance in the Analysis Procedure

Dismantling

Samples Extraction

Sensory Inspection

Safe Containment

Beam Dump

Absorbs high-energy particles at the end of their path to safely dissipate energy.

...

Targets

Convert accelerated particles into secondary beams (e.g., neutrons, or rare isotopes) for experiments.

...

Decommissioned Systems

Devices that are no longer working due to unexpected failure or end-of-life.

The Robotics Service at CERN

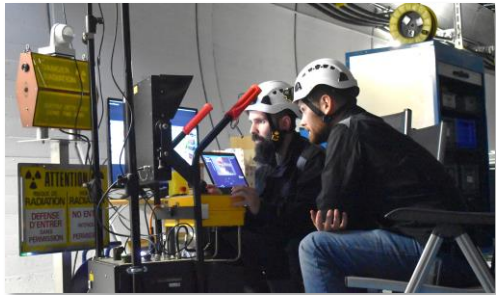
Remote
Maintenance

Remote
Inspection

Search and
Rescue

Quality
Assurance

Post-Mortem
Analysis



Hazardous Environments



The Robotics Service at CERN

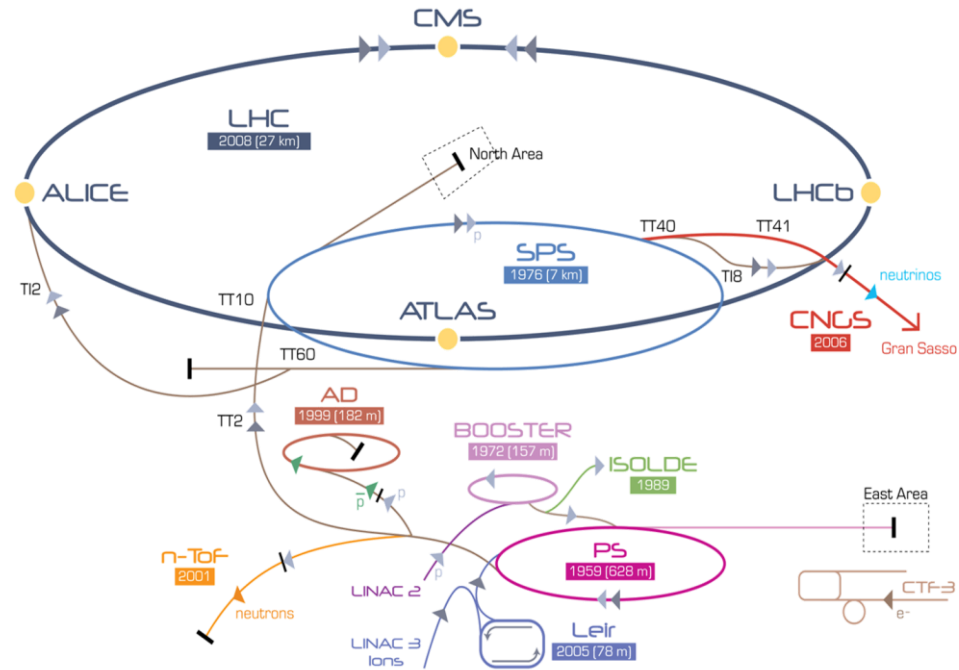


Train Inspection Monorail



CERNBot_{SPS}

20+ Robots



ISOLDE/MEDICIS



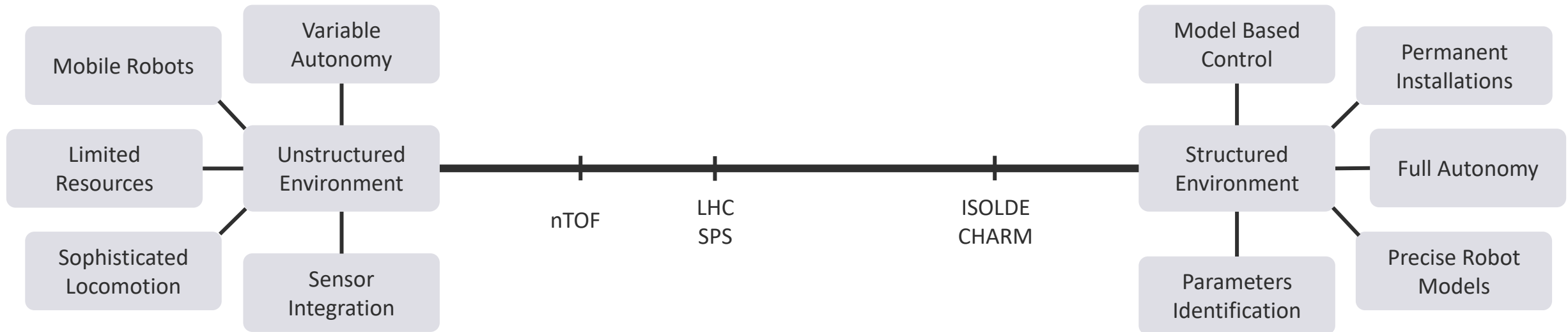
CERNBot_{CHARM}

Intervention Environments



Infrastructure is not designed to host robots

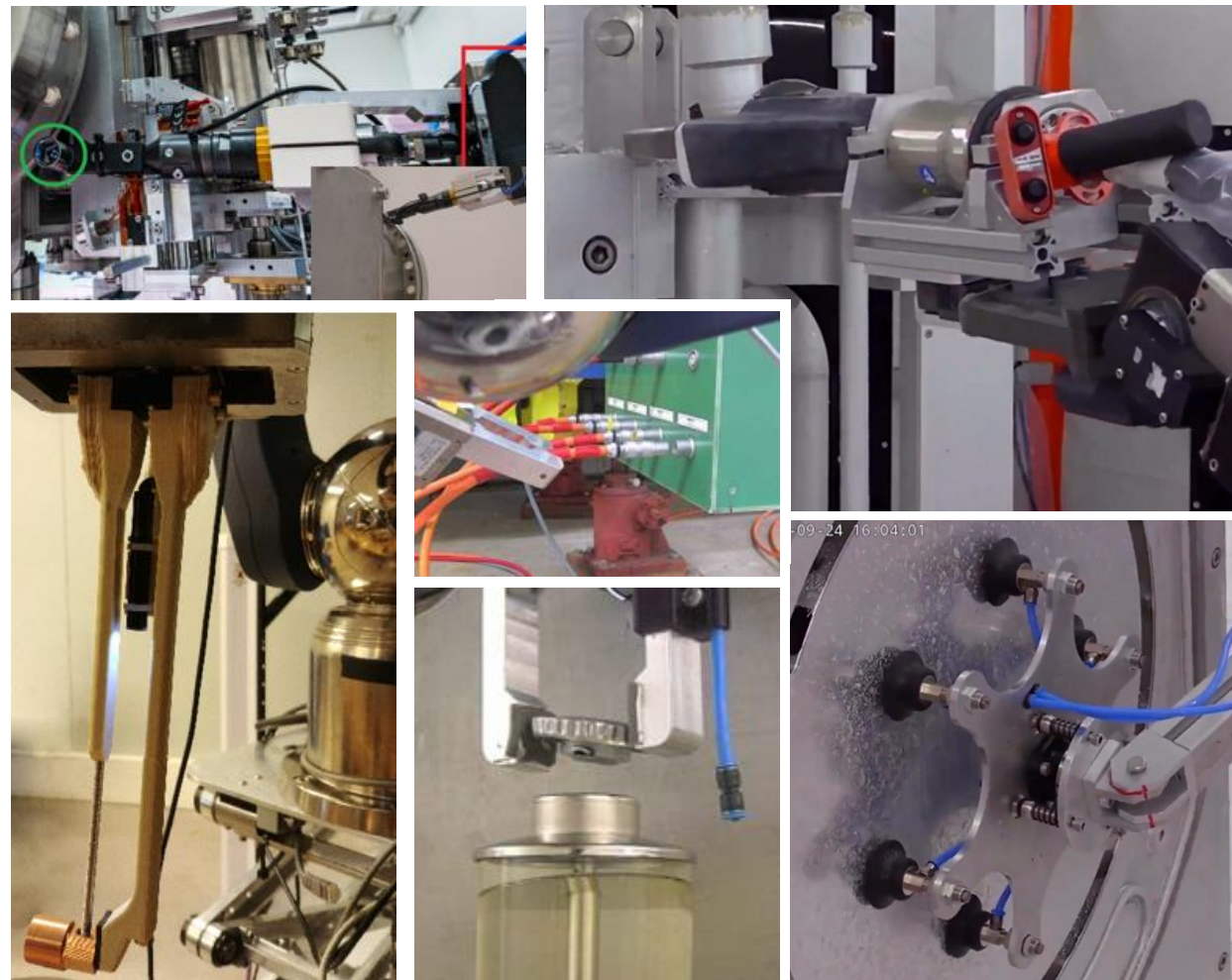
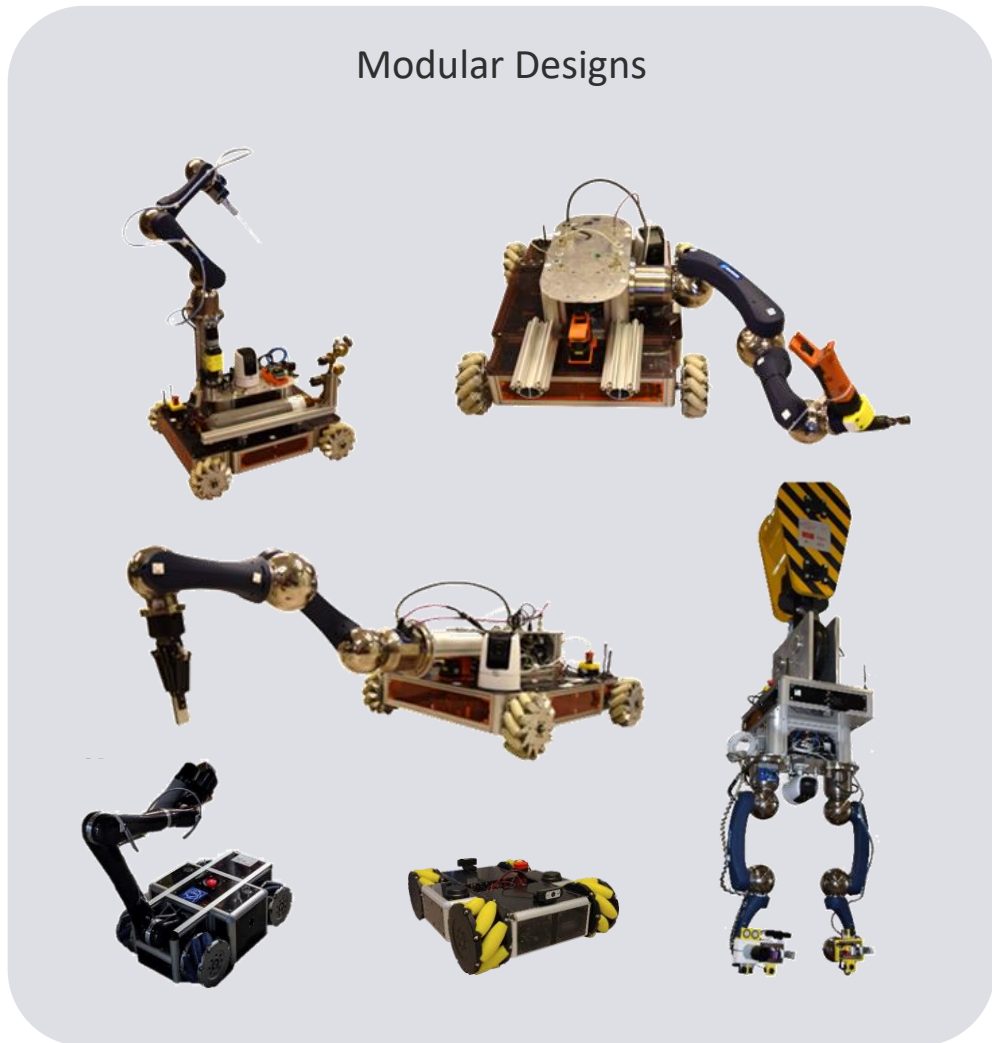
Need to constantly adapt robots to the environment



Intervention Procedure

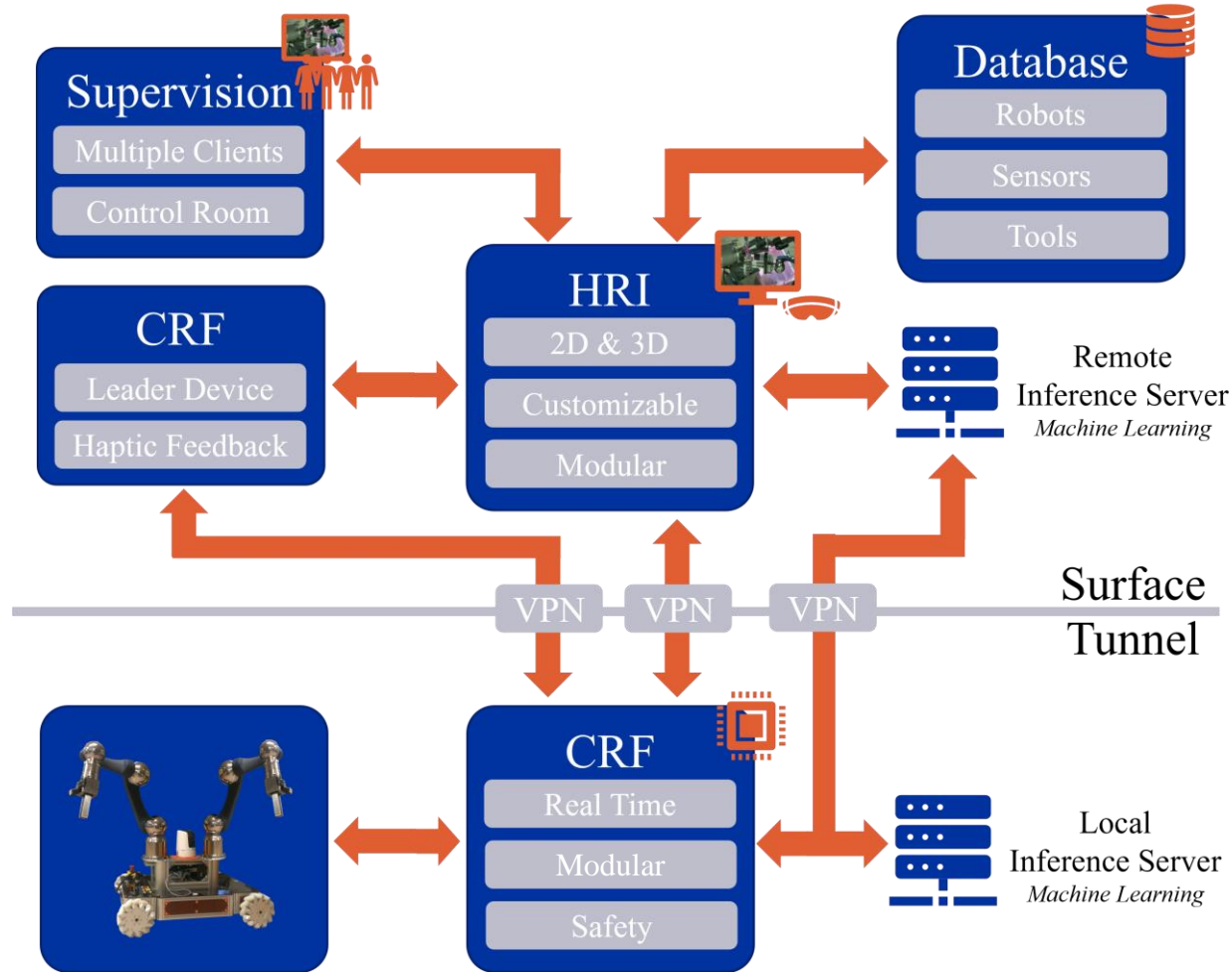
R&D: Mechatronics Developments

Modular Designs



Intervention Procedure

R&D: Software Developments



Modular Architecture in Hardware and Software

CERNRoboticFramework

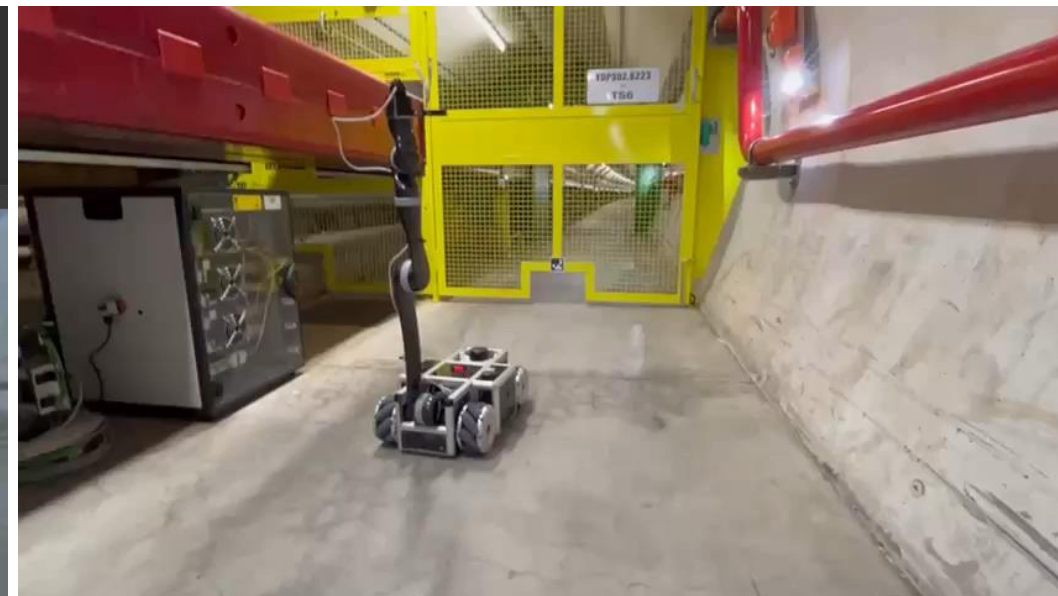
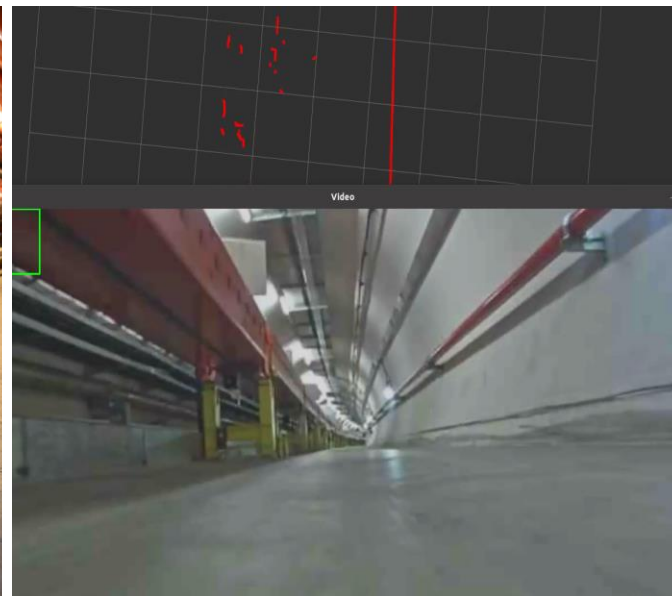
C++ 17 & Python
Open-Source Based
MuJoCo Simulator

CERNRoboticGUI

Unity (C#)
2D & 3D Modes
Multiuser Capabilities

Deployed Systems: *CERNBot*_{SPS}

- SPS robot x 2 successfully commissioned for RP measurements and anomalies detections (e.g. water leaks). Computer vision and sensor fusion to detect door cutouts, position marker plates and SLAM.
- Two robots used for the RP survey in parallel: Autonomous wall following combined with manual teleoperation at access points. 3 sectors completed each, followed by a swap of the charging station location at BA3 and BA6
- 7 km of RP survey performed in 1.5 h



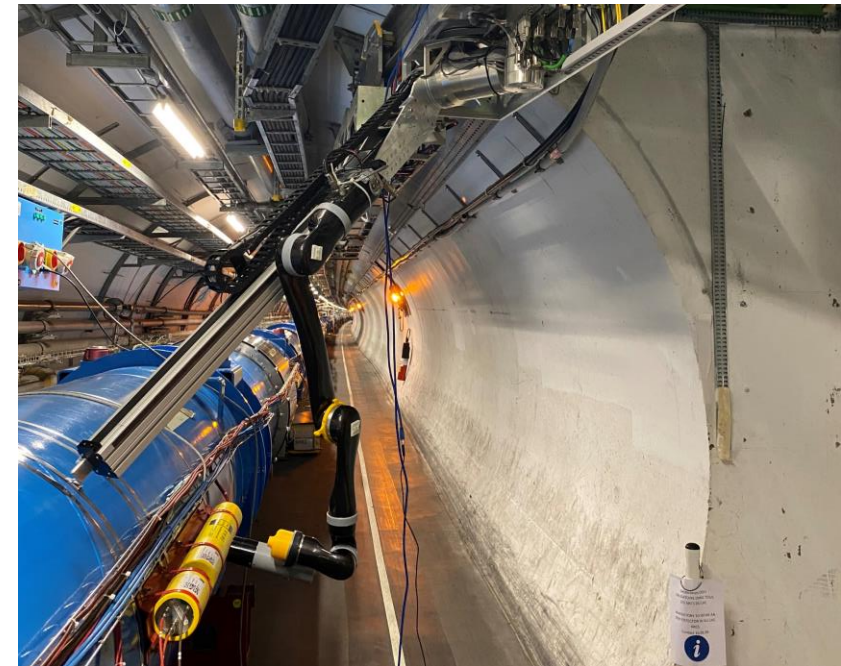
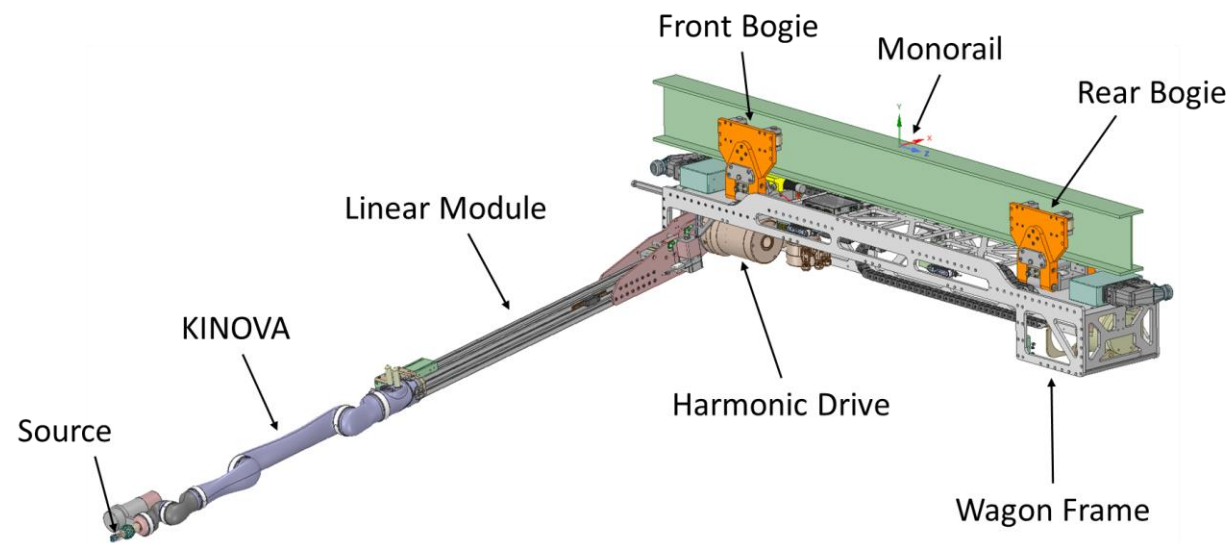
Deployed Systems: *TIM*

- The Train Inspection Monorail (TIM) is used for several inspection and validation tasks. Every time the accelerator stops the robot performs an RP survey in less than 3 hours.
- 9 DoF Robot Arm Wagon to be able to reach most of the accelerator footprint.
- Several cameras including a Thermal Cameras



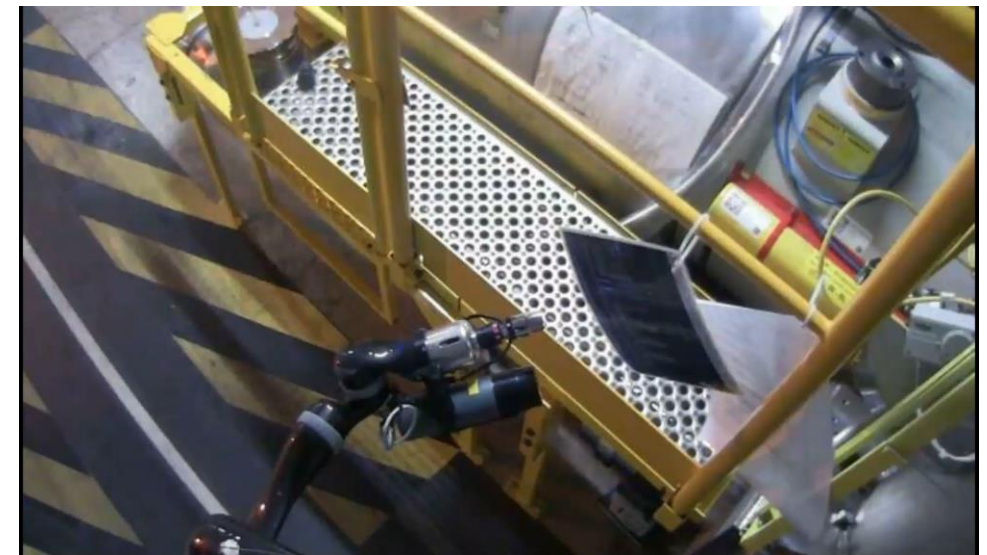
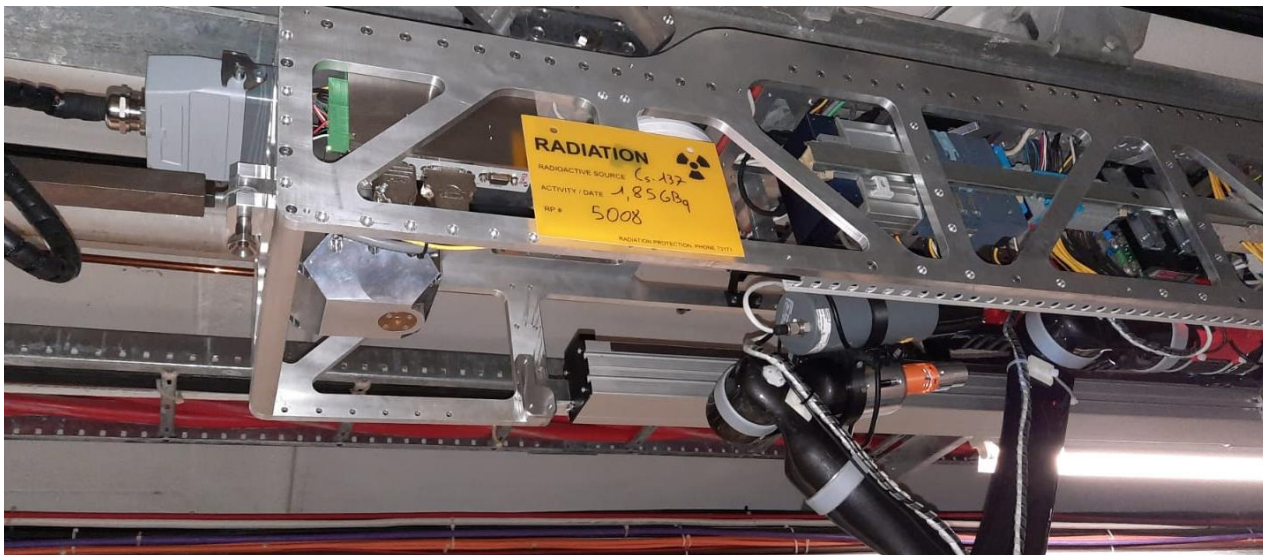
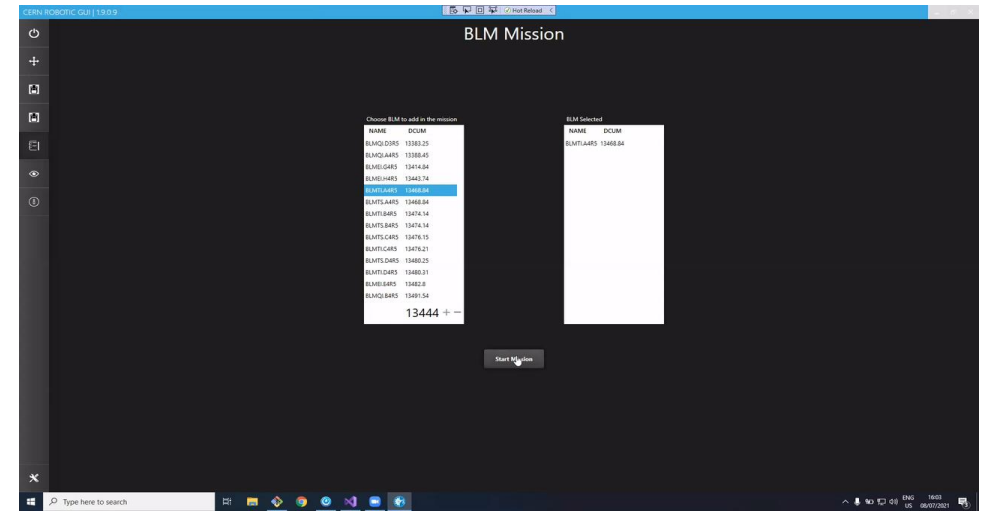
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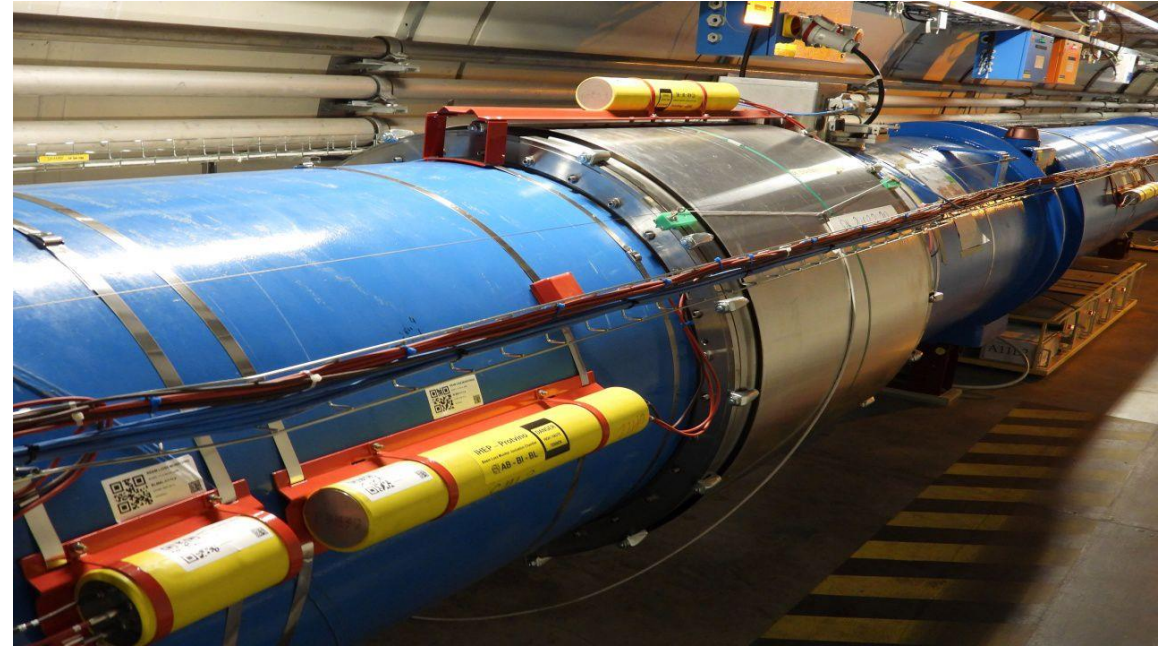
Deployed Systems: *TIM* & *BLM* Validation

- Validation of Beam Loss Monitors (BLM) sensors with the TIM
- 900 BLM validated in the Long Shutdown 2
- Foreseen ~4000 BLM validations during the Long Shutdown 3 in 2028



Ongoing Development: *BLM Calibration*

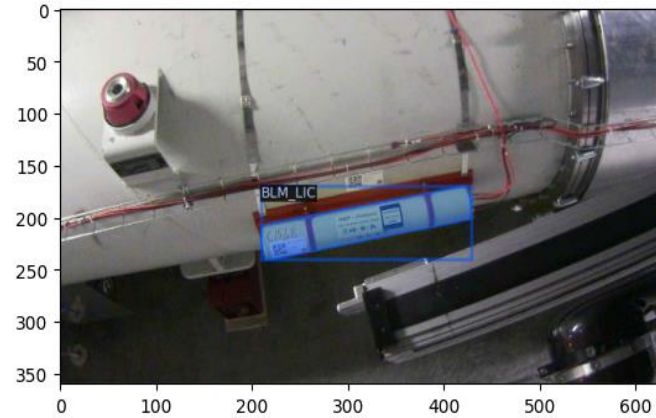
- Automatic detection, pose estimation and validation position measurements of the different types of ionization chambers around the beam line
 - Classification: The TIM must be able to know which type of BLM is being tested
 - Segmentation mask: allows to estimate the 3D pose of the detected BLM
 - Challenging environment: The light can be variable, as well as the position and obstacles that occlude the BLMs



Ongoing Development: *BLM Calibration*

Find the BLM from onboard camera imagery

- Dataset enhancement of original dataset of 2000 images to 6000 images
- Dataset expansion with images taken from the LHC
- Clean and correct original annotations using CVAT with SAM
- Train, validate and test split at 80%, 5%, 15%

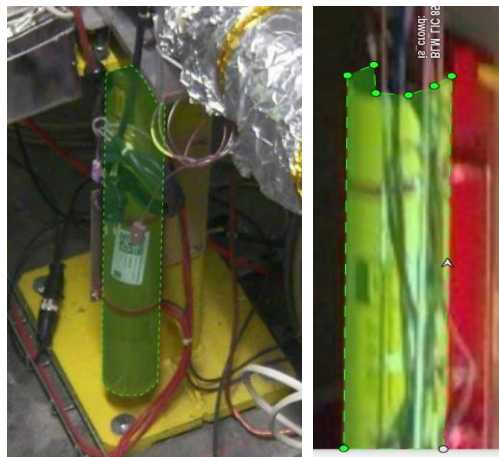


Mainly used frameworks:
botorch and ax-platform

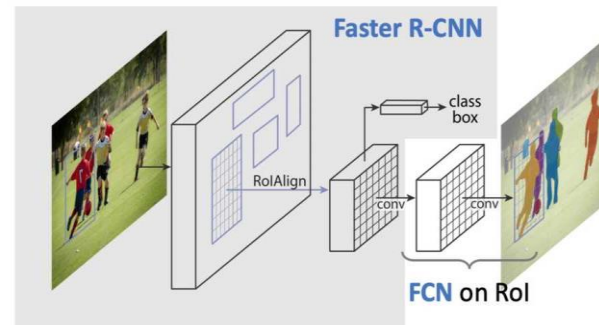


Bayesian optimization keypoints

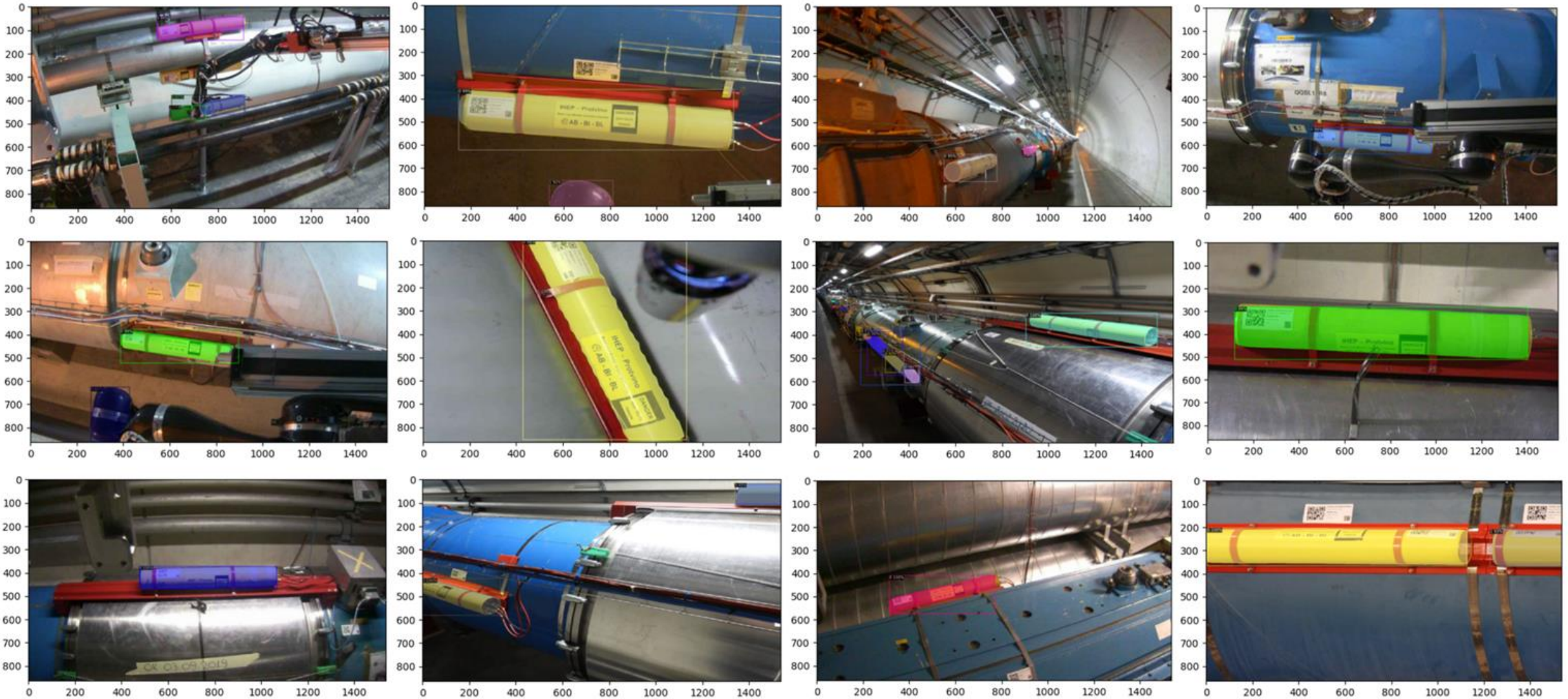
- Gaussian process as a surrogate function
- Kernel as the covariance matrix
- Acquisition function



Mask R-CNN = Faster R-CNN + FCN on ROIs



Ongoing Development: *BLM Calibration*



Deployed Systems: *BLM Identification*

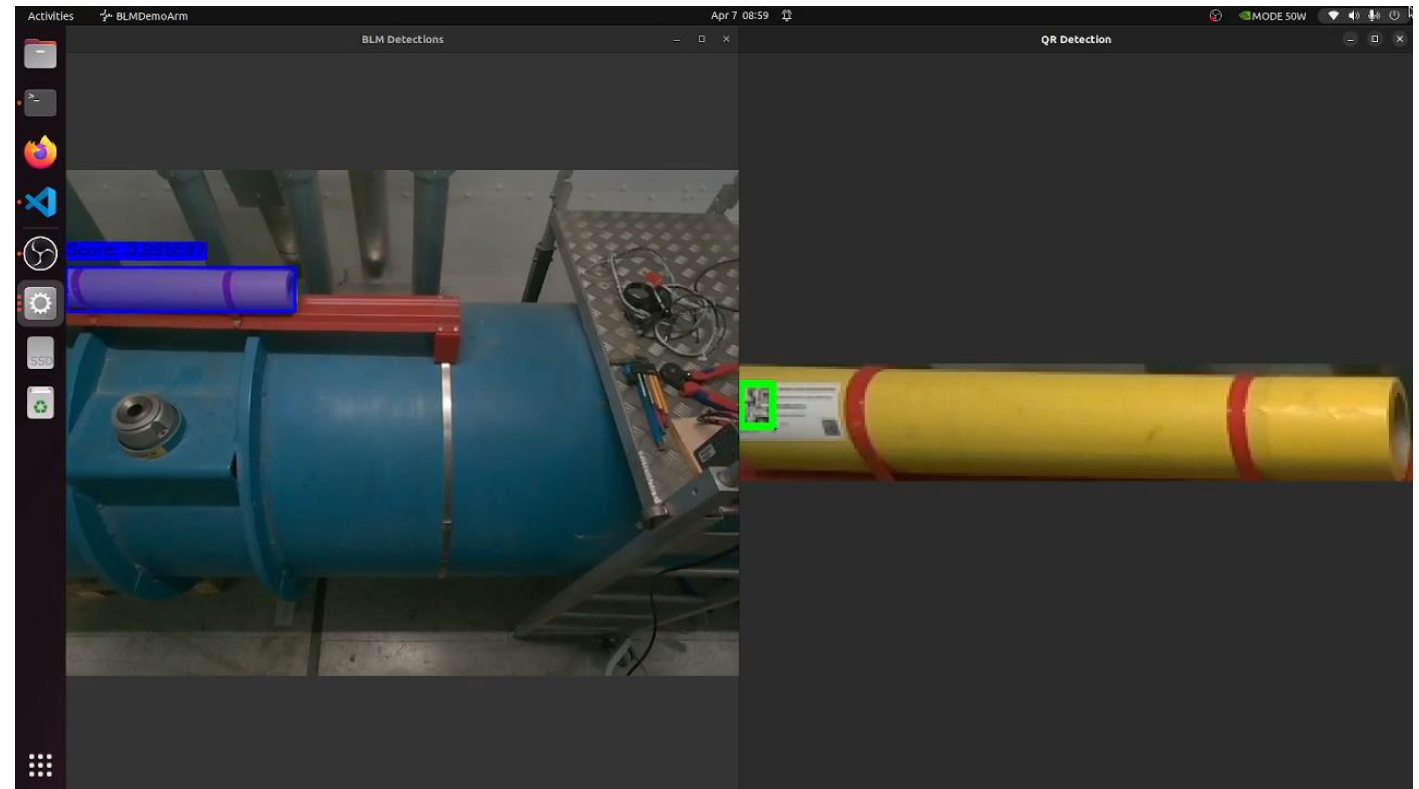
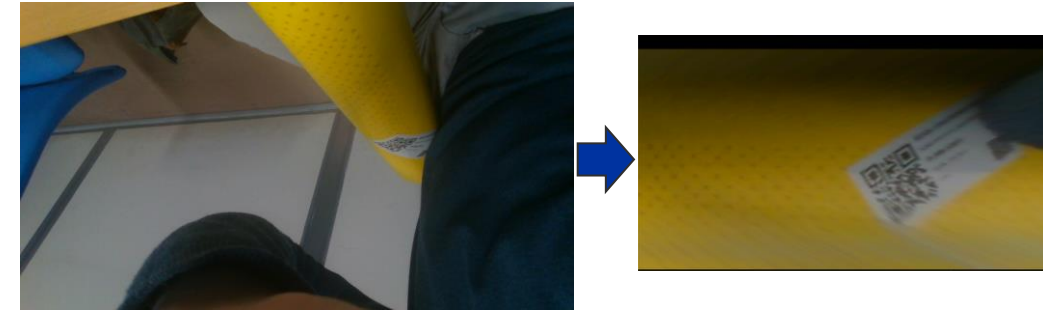
Detect and read the QR sticker

- Main challenges:
 - Poor and unbalanced illumination
 - Specular reflection
 - Motion Blur
 - Perspective and cylindrical distortion
- Possible solutions:
 - Change the fiducial marker type
 - Add a barcode reader
 - Develop robust vision algorithm

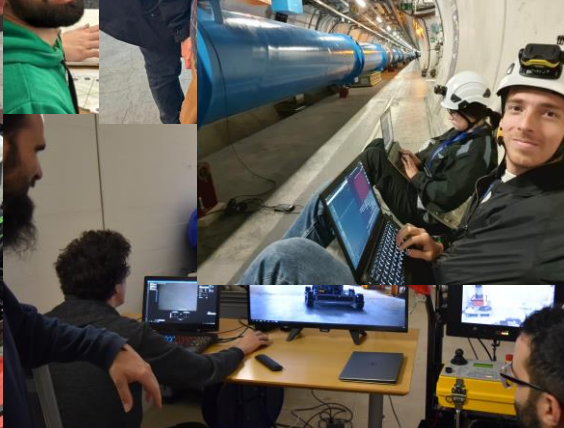


Algorithm Steps

- Distortion correction
- YOLOv8 QR detection
- QR features detection

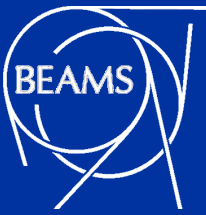


Thanks to...



BE-CEM-MRO Team





Website



Learn More

