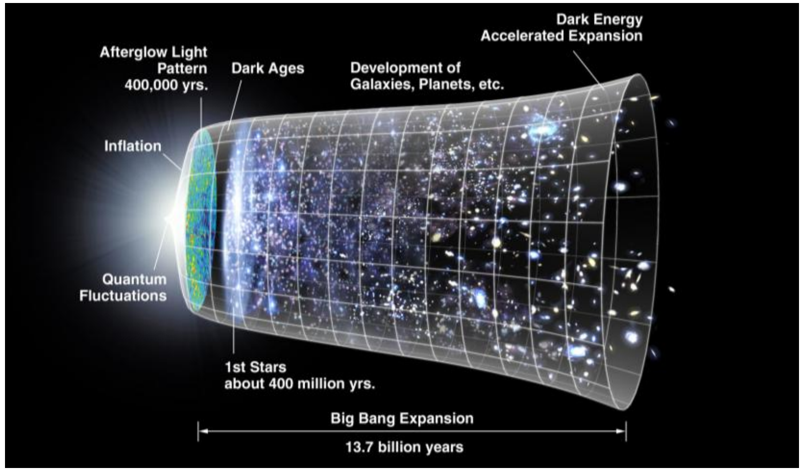
Controls
Electronics &
Mechatronics

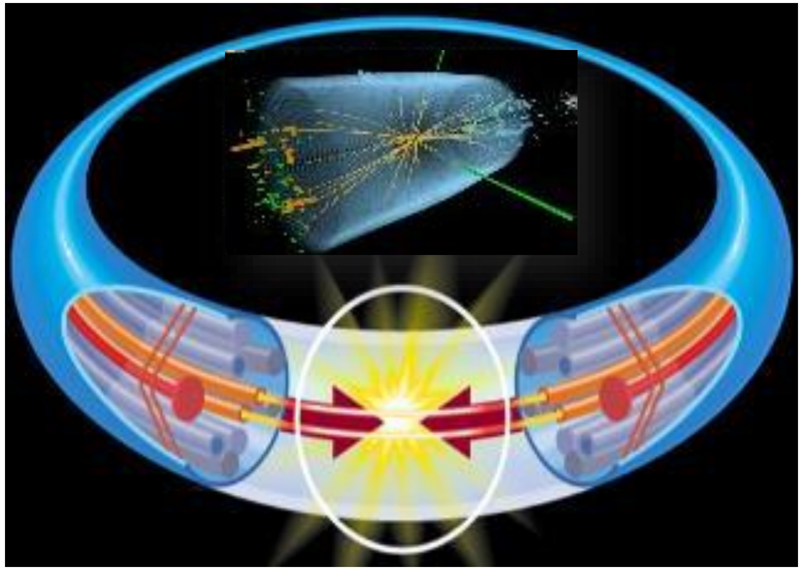
Deploying Robots for Harsh Environments

Christopher McGreavy
Robotics Engineer

CERN: An Introduction

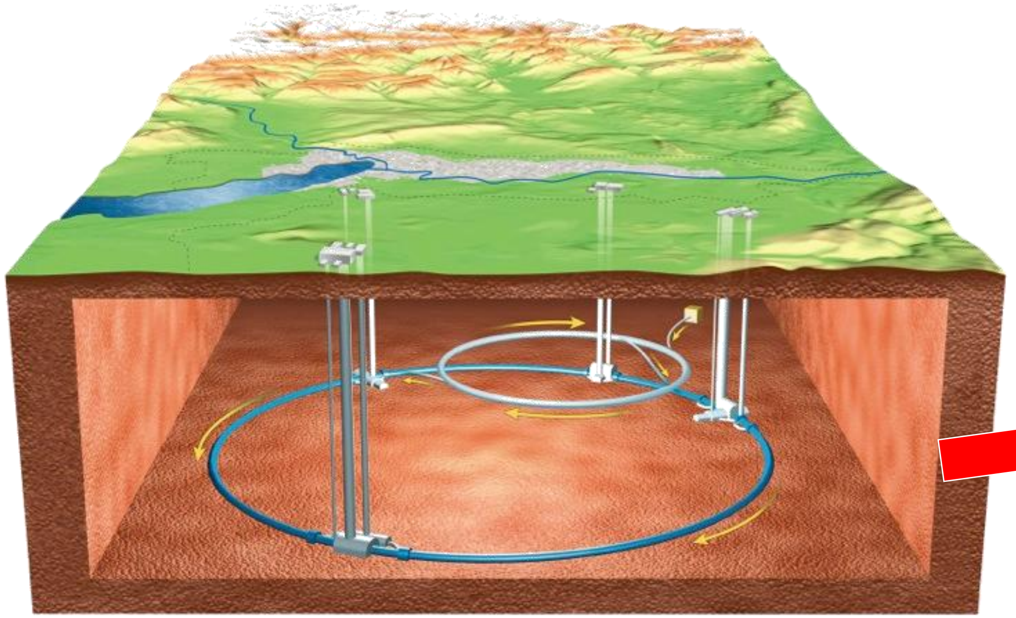
- **Particle Accelerator Complex**
- **Established in 1953**
- **International Collaboration**
- **Achievements:**
  - LHC
  - Higgs Boson (2012)
  - Invention of World Wide Web (1989)
  - W Boson
  - Z Boson
  - Antimatter





Introduction to the CERN Site

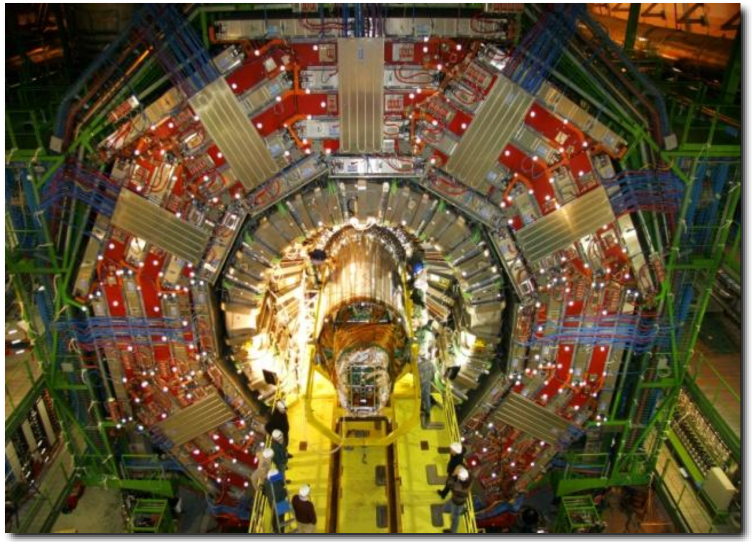
- **Located on the French/Swiss Border**
- **83km of underground structures**



Main Challenges for Robotics at CERN

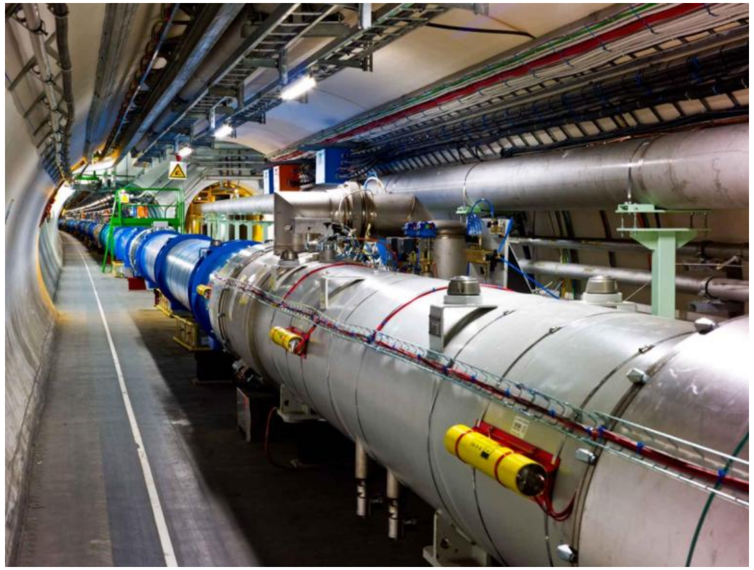
- **Maintenance, intervention and inspection in harsh and semi-structured environments**

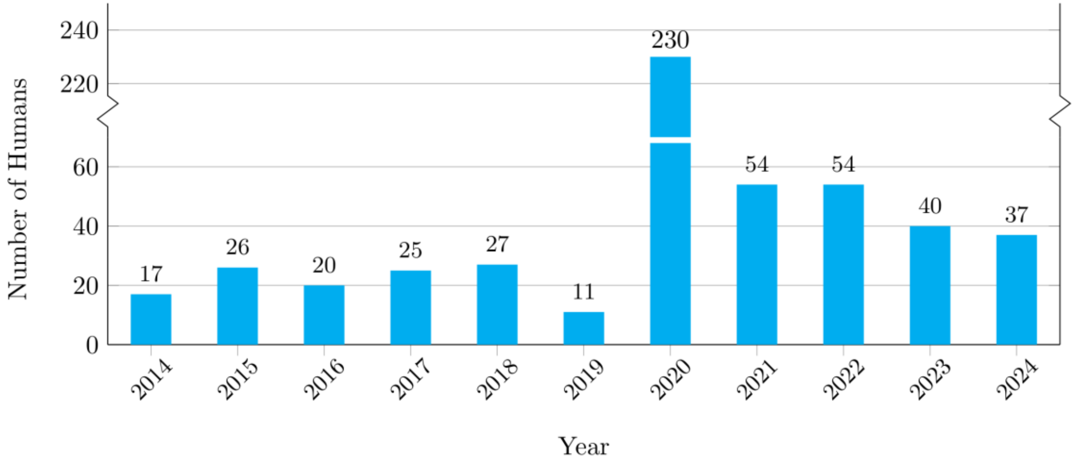
- **Radiation, magnetic disturbances, delicate equipment not designed for robots, big distances, communication, time for the intervention, highly skilled technicians required (non robotic operators), etc.**



It’s Physics! Why robots?

- **Lots of Machinery**
- **Harsh Environments**
- **Large Distances**
- **Dangerous/impossible for humans**
- **Inaccessible to humans (small, far away, complex)**
- **Main: To protect humans**
- **Secondary: Maximise Uptime**





The Robotics Service at CERN

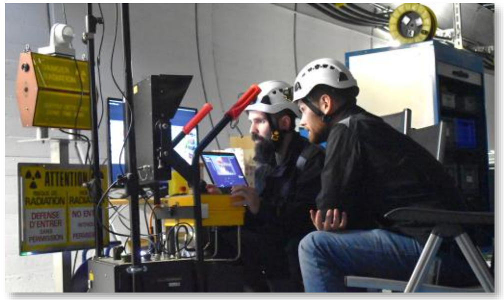
Remote Maintenance

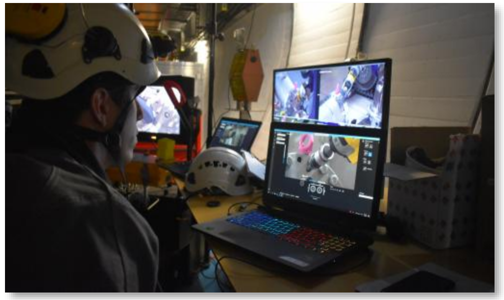
Remote Inspection

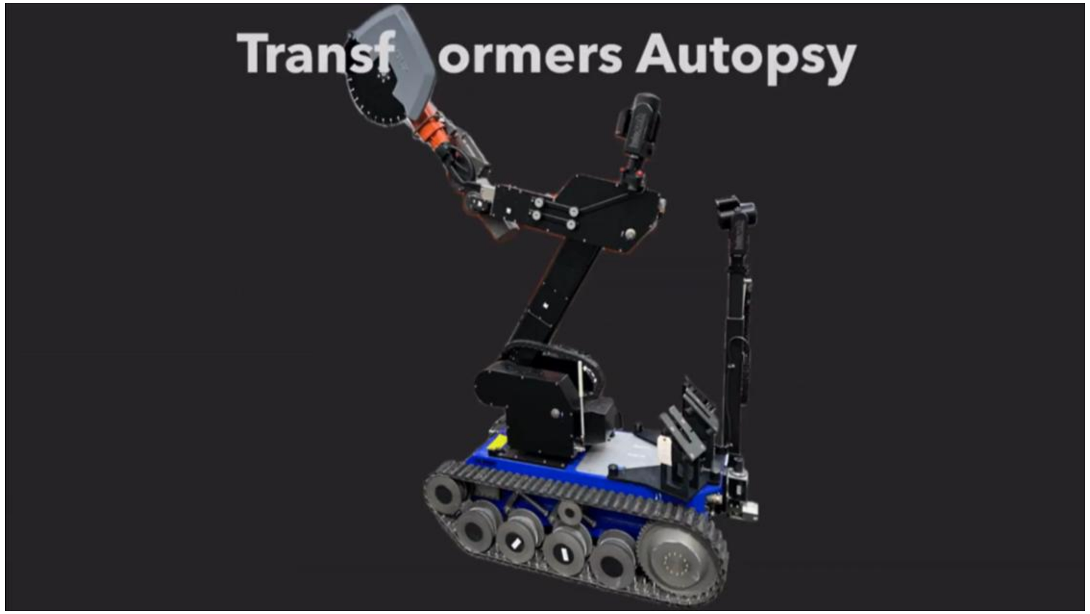
Search and Rescue

Quality Assurance

Post-Mortem Analysis

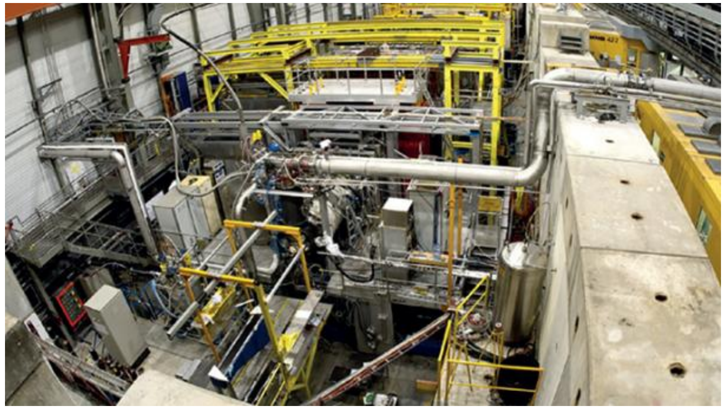






Hazardous Environments

Intervention Environments



Infrastructure is not designed to host robots

Need to constantly adapt robots to the environment

- Unstructured Environment
  - Mobile Robots
  - Variable Autonomy
  - Limited Resources
  - Sophisticated Locomotion
  - Sensor Integration

nTOF — LHC SPS — ISOLDE CHARM

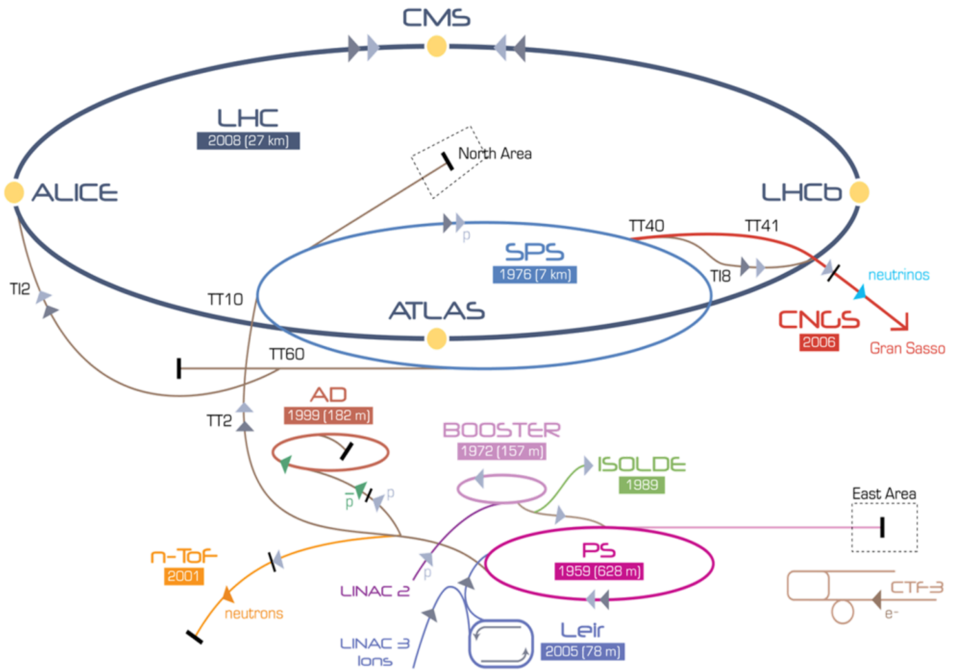
- Structured Environment
  - Model Based Control
  - Permanent Installations
  - Full Autonomy
  - Precise Robot Models
  - Parameters Identification

The Robotics Service at CERN

20+ Robots

Train Inspection Monorail

$\text{CERNBot}_{\text{SPS}}$

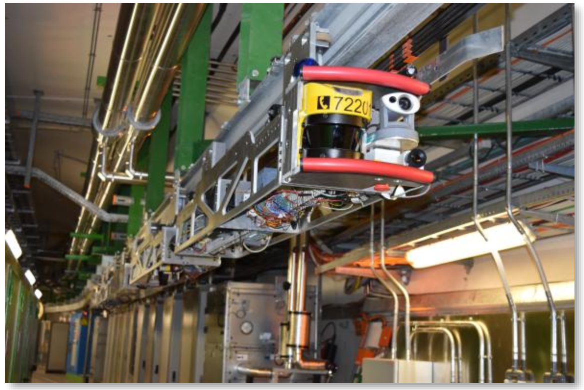


ISOLDE/MEDICIS

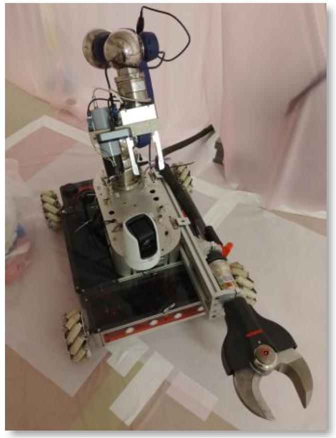
$\text{CERNBot}_{\text{CHARM}}$

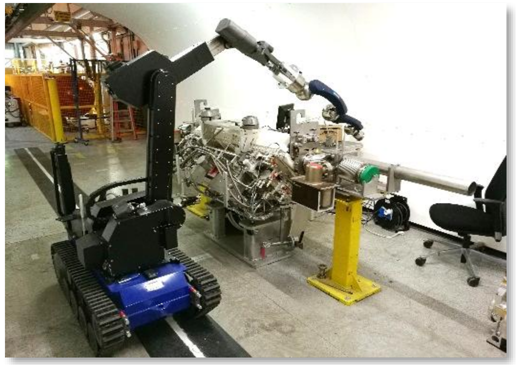
CERN Robots

Telemax robot



Train Inspection Monorail [10] (CERN made)





Teodor robot

Industrial robots for repetitive tasks and milling solutions

Quadrupeds

CERNBot [11-17] in different configurations (CERN made)

Drone for tele-operation support and inspections

- >30 robotic systems operational in different configurations and different infrastructure
- Mainly In-house is done most of the mechatronics conceptions, designs, proof of concepts, prototyping, series productions, <u>operations</u>, maintenance, tools and intervention procedures.

Environmental Challenges & Implications

- Dangerous to humans, but also cause challenges to robots
- Radioactivity & Contamination
- Magnetic Fields
- Accessibility, Mobility, Difficult Terrain
- Distance & Perceptually Difficult Surfaces

Radiation

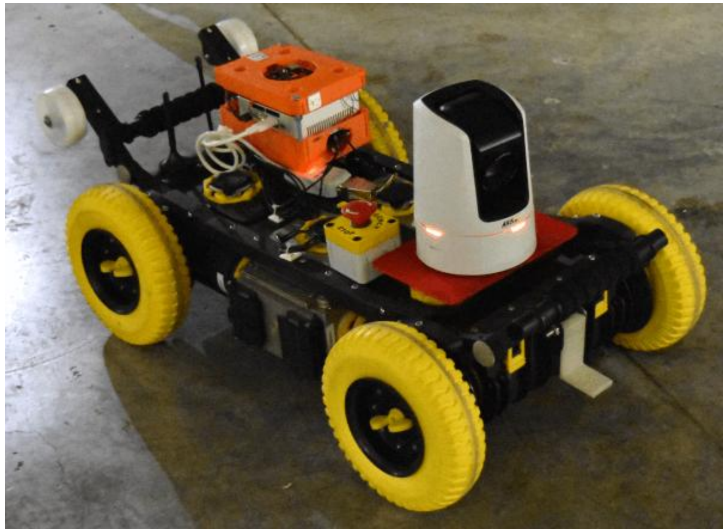
- Single event effects
- Cumulative effects
- Component degradation
- Sensor noise
- Material considerations (some plastics go weird)
- Testing, Rad-hard, components, material selection, monitor and replace components

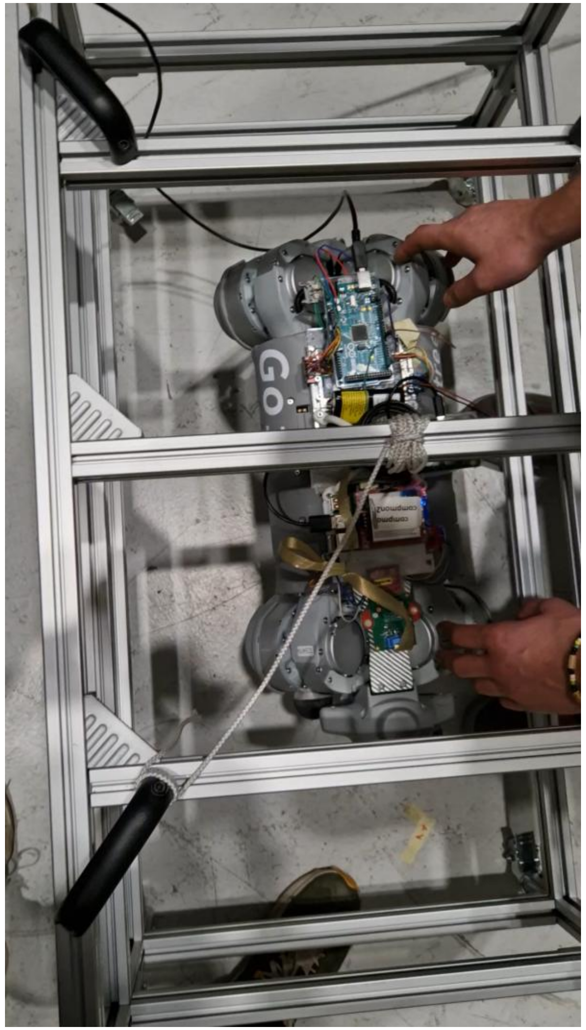
Contamination

- **Radioactive dust/debris/liquid is dangerous for humans: can’t bring back.**
- **Touches the ground? Needs to be removable and cleaned**
- **Dust covers to protect robot from dust**
- **Planning to avoid unnecessary contact with contaminants**

Magnetic Fields

- Sensor noise
- Actuation issues
- Unwanted forces on ferromagnetic components
- Limited ferromagnetic components
- Non-affected sensing (especially encoders)
- Alternative actuators (piezoelectric)
- Control & planning modifications

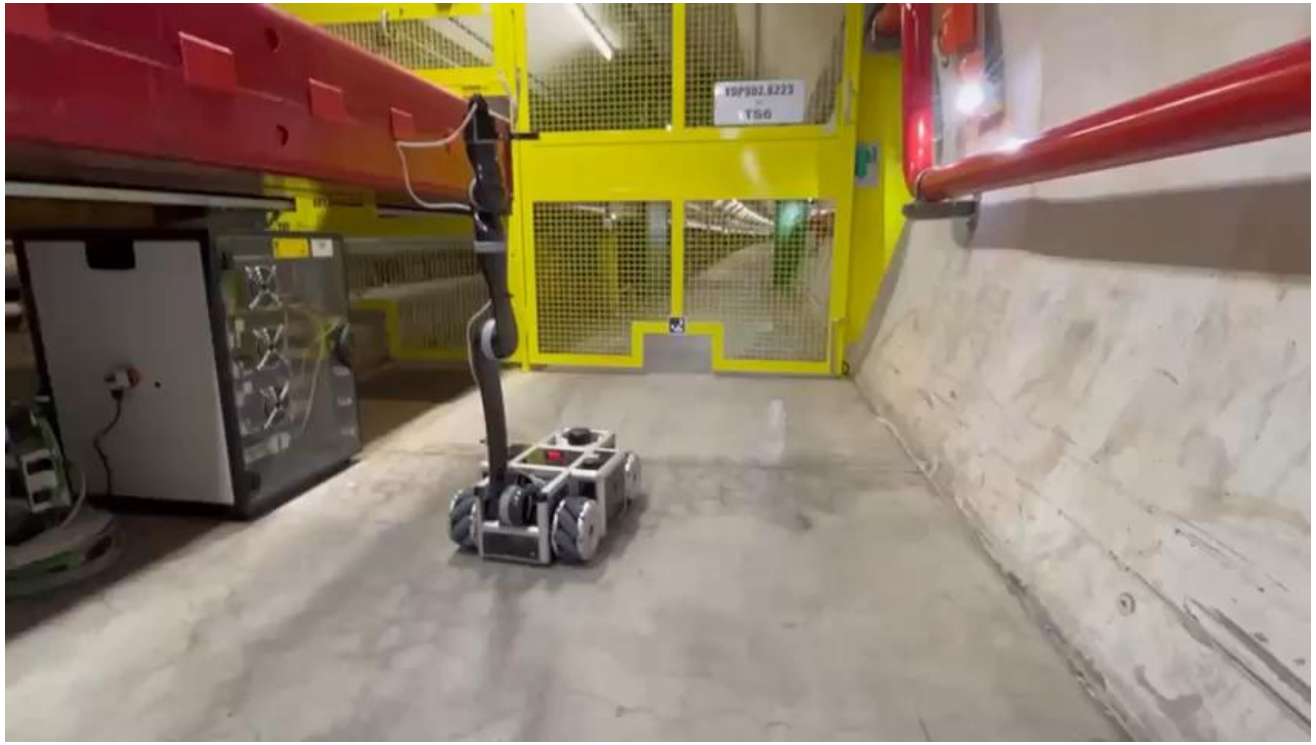




Accessibility, Mobility, Difficult Terrain

Accessibility

- Areas are quarantined and entry to humans is controlled
- Move into restricted areas without granting entry to personnel
- Entry and exit should be as simple as possible without introducing hazards
- Robot only access
- Fireproof ‘guillotine’ doors for train
- Recover robots without humans



Accessibility, Mobility, Difficult Terrain

Mobility

- **Need to get around without damaging environment**
- **If possible, move in a predictable way without disrupting human operation**
- **Control & mechanical constraints**
- **Collision free motion control**
- **Operator environmental awareness**

Accessibility, Mobility, Difficult Terrain

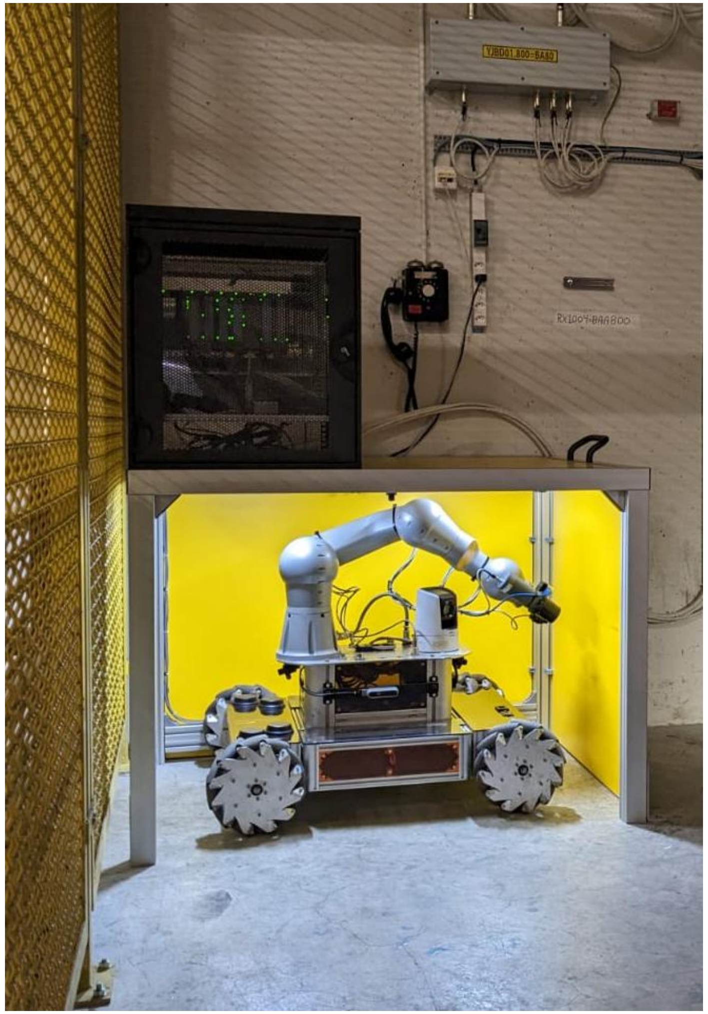
Difficult terrain

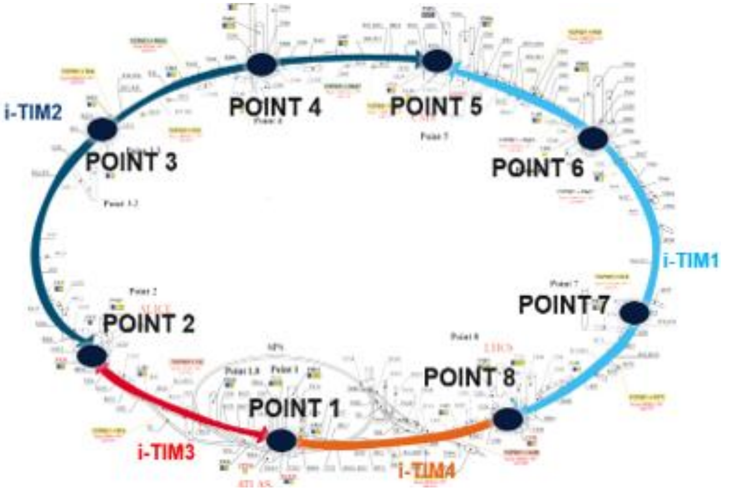
- Stairs
- On-ground obstacles
- Narrow corridors
- Train tracks
- Adaptable locomotion
- Control adaptation
- Robust perception and planning

Distance, Symmetry, Construction Materials

Distance

- >83km underground facilities
- Robot needs enough range to perform task & extract
- Increases response time
- Strategic planning
- Efficient control
- Recoverability
- In-situ charging

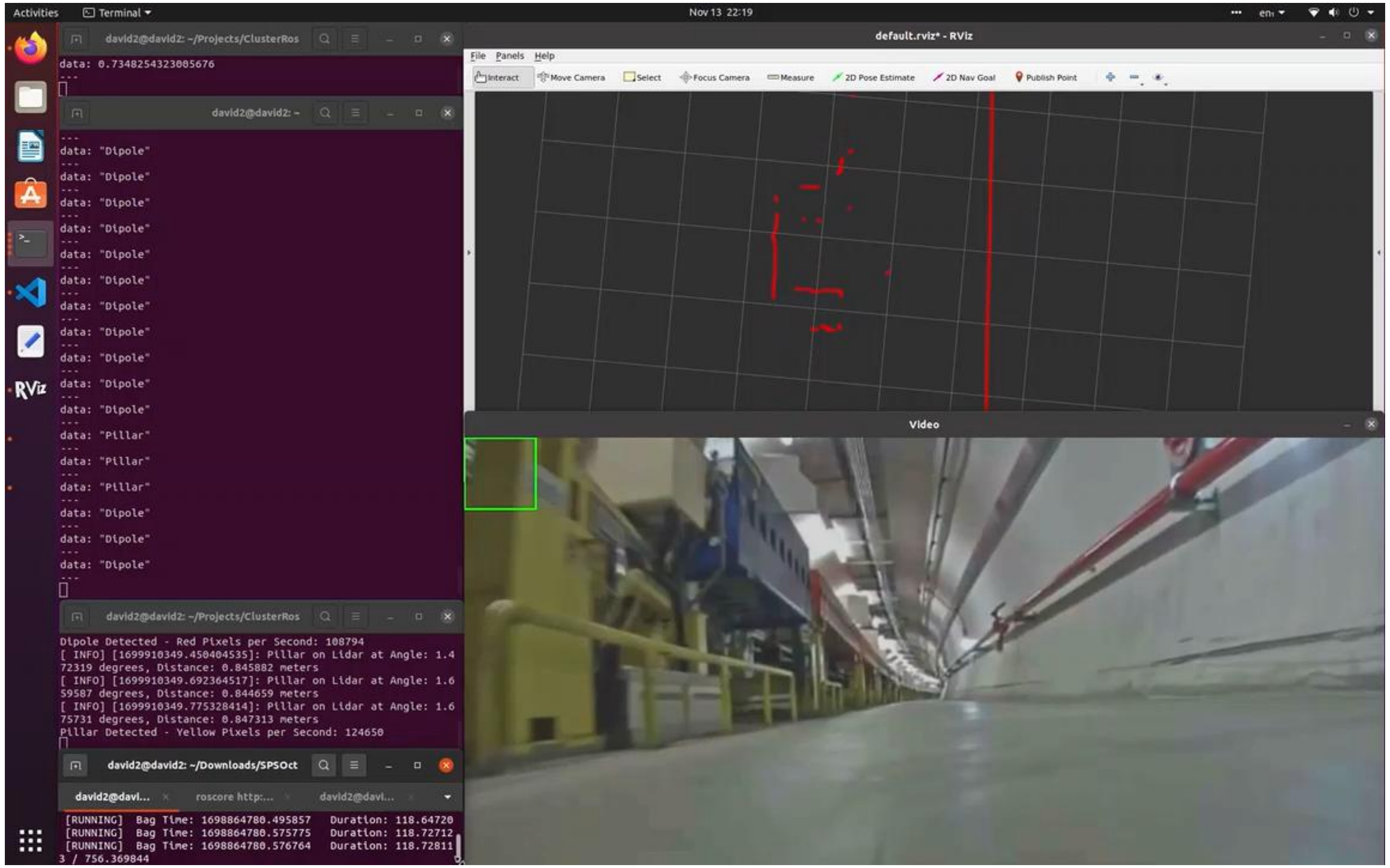




Distance, Symmetry, Construction Materials

Symmetry

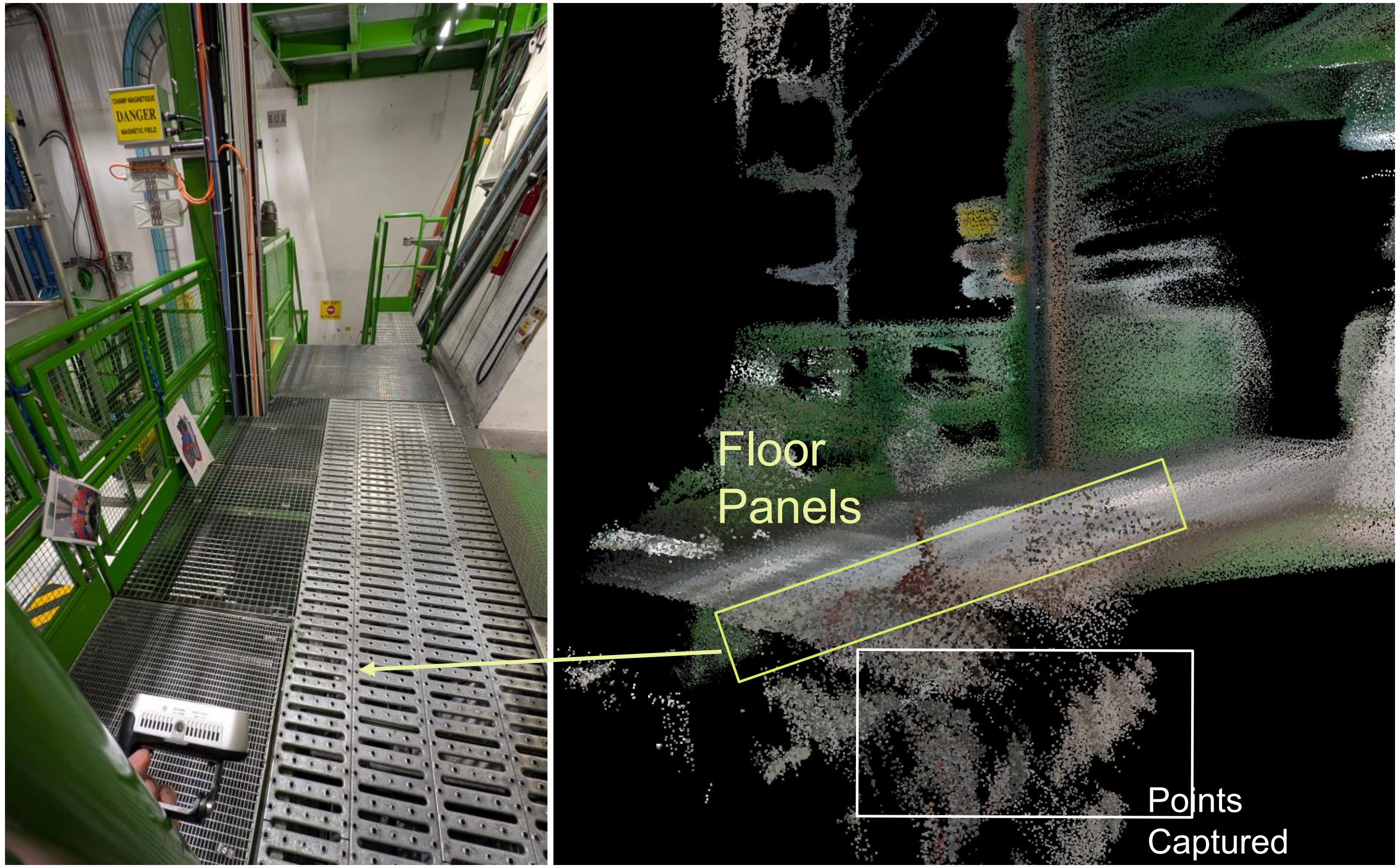
- **Mapping and localisation become difficult**
- **Integrate additional environmental data**
- **Visual odometry**
- **Exploration methods**
- **Exploit known features**



Distance, Symmetry, Construction Materials

Construction Materials

- **Transparent/ perforated construction materials make perception and mapping difficult**
- **Plexiglass is especially tricky**
- **Novel algorithms for perception and mapping**



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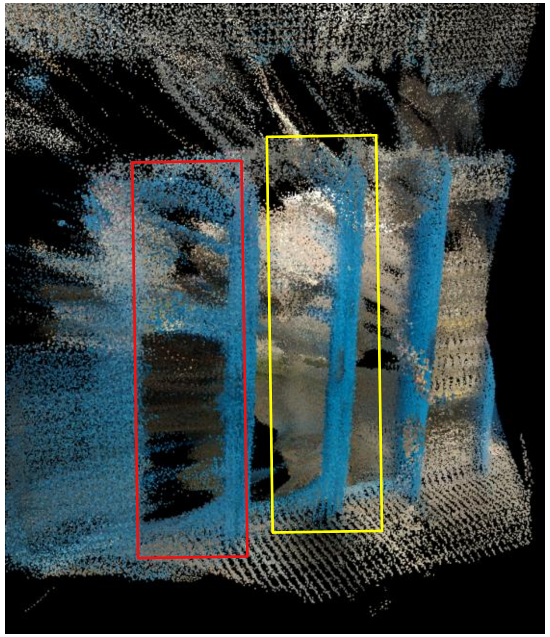
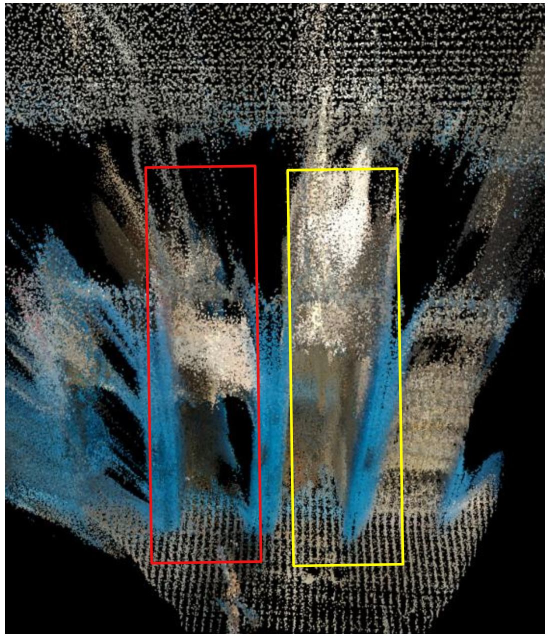
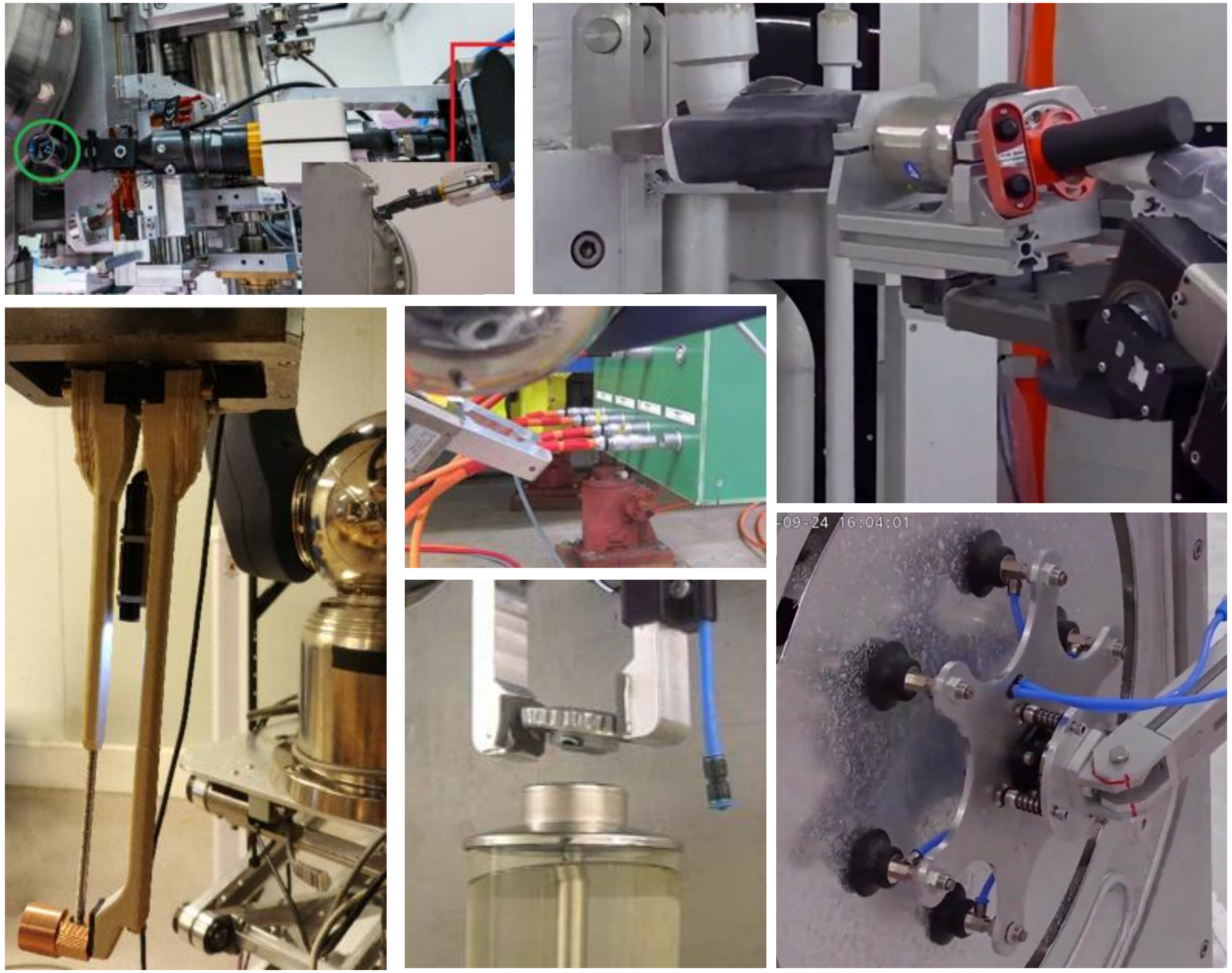




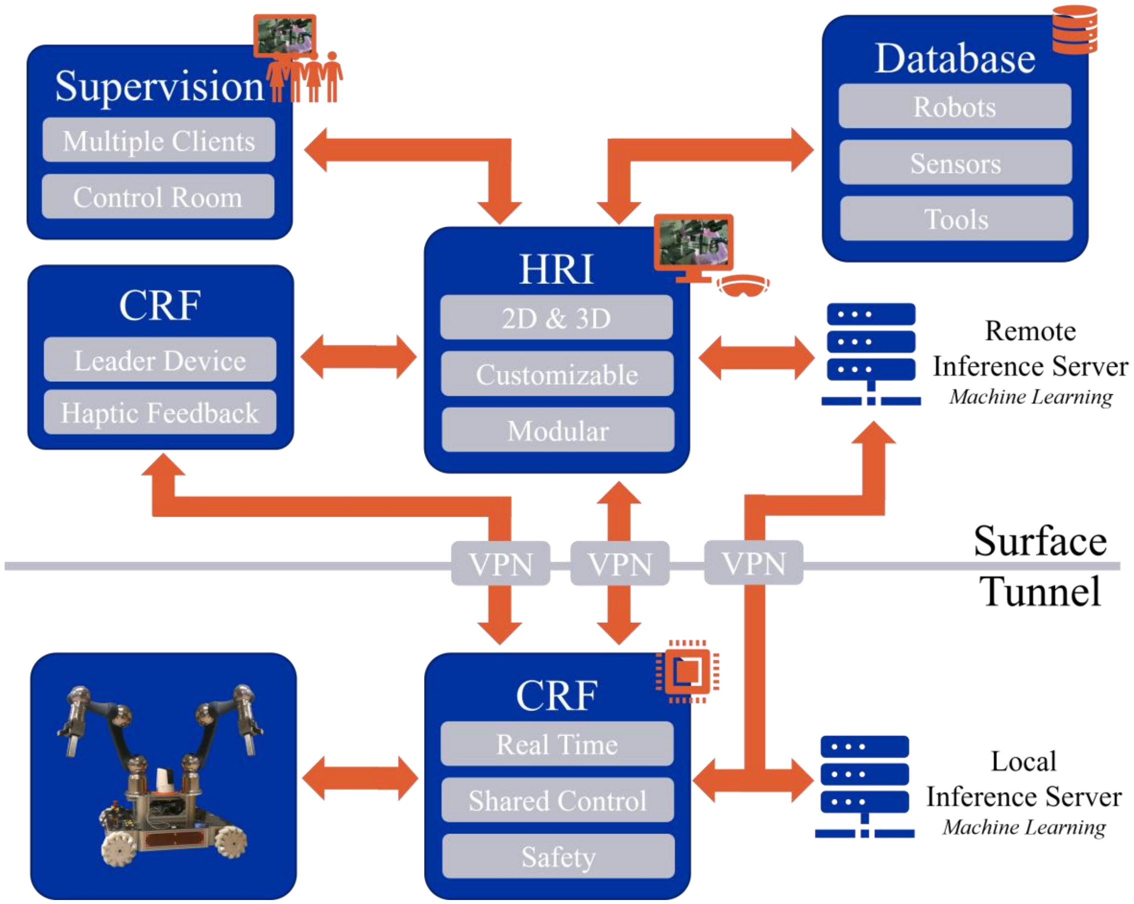
Hardware Approach

Modular Designs



Software Approach

- **In-house control architecture**
- **Minimal resource consumption**
- **No constant updating**
- **Adaptable communication and drivers**



Modular Architecture in Hardware and Software

CERNRoboticFramework

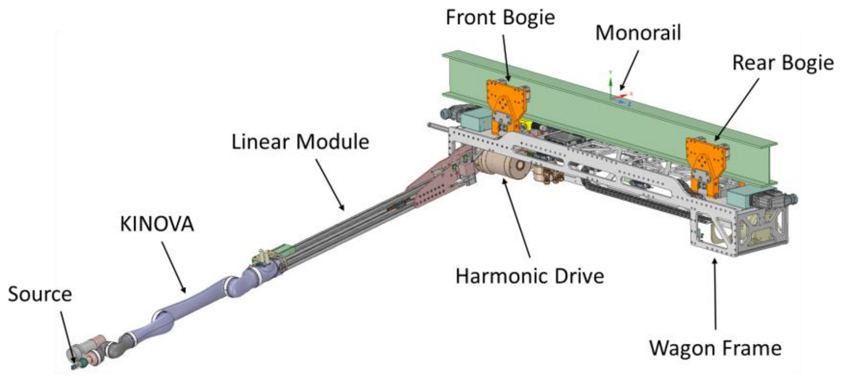
C++ 17 & Python
Open-Source Based
MuJoCo Simulation

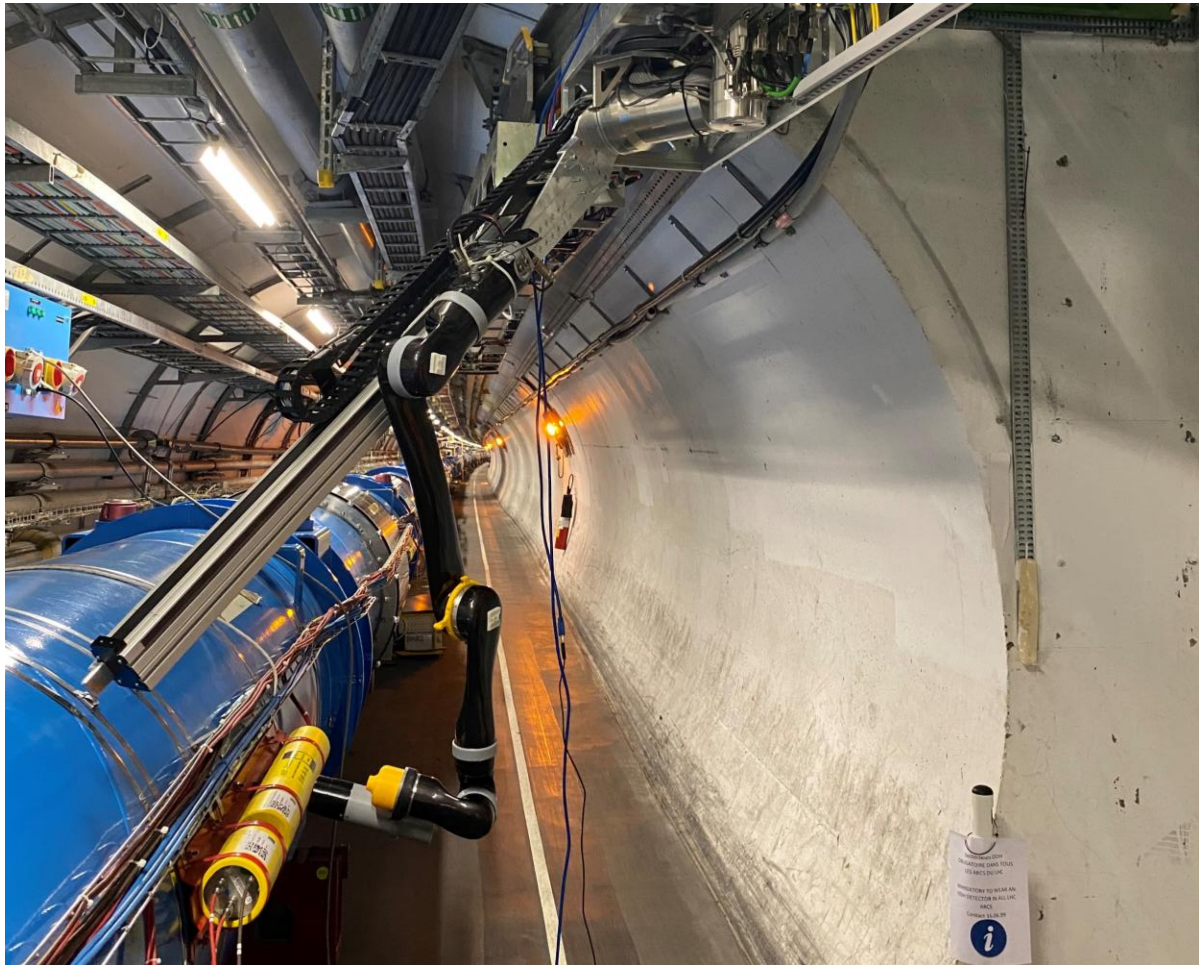
CERNRoboticGUI

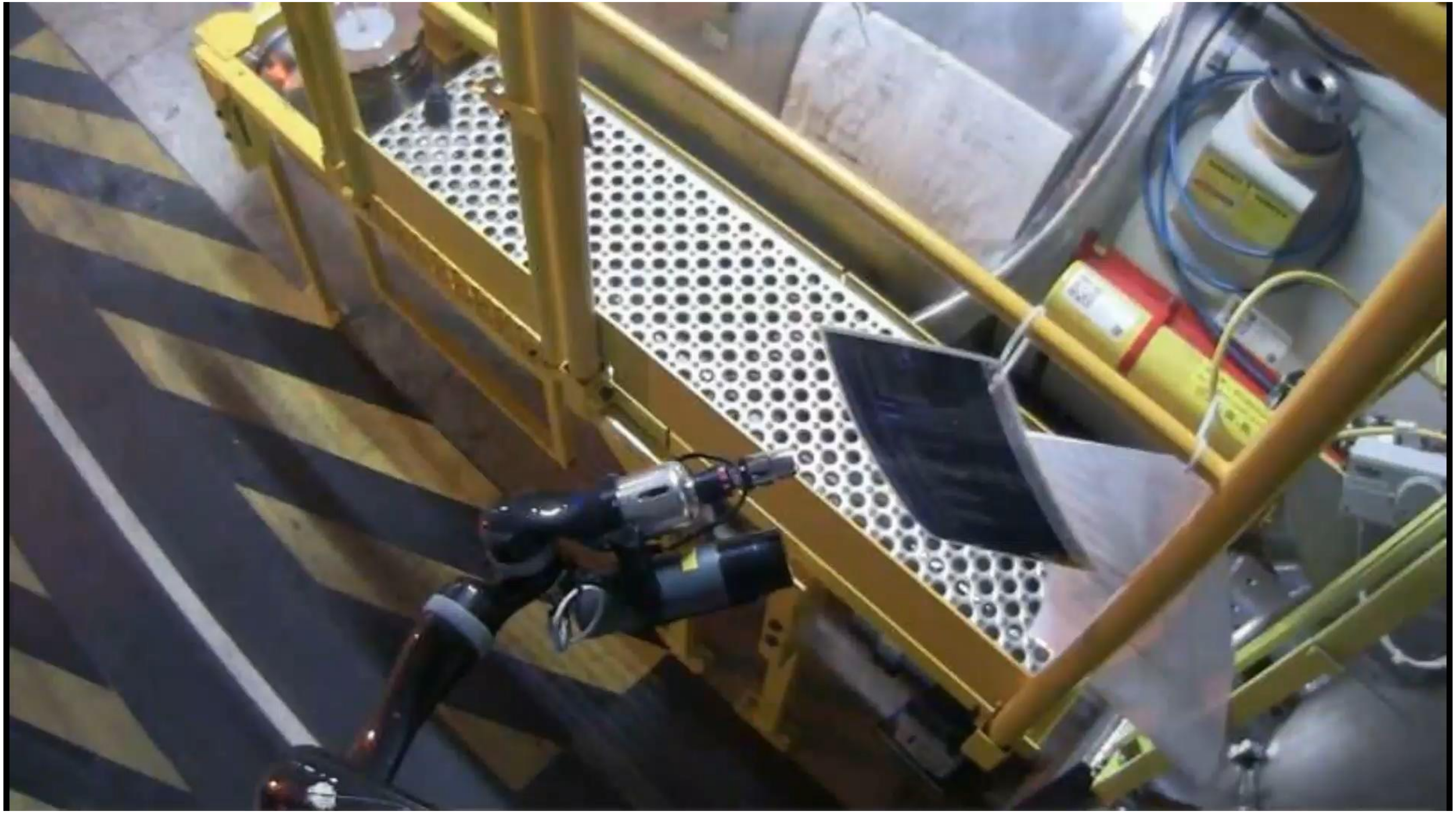
Unity (C#)
2D & 3D Modes
Multiuser Capabilities

BLM Calibration

- Validation of Beam Loss Monitors (BLM) sensors with the TIM
- Calibrate ~4000 BLM sensors in LHC
- Fully autonomous
- Approximate sensor locations known
- Calibration source handling

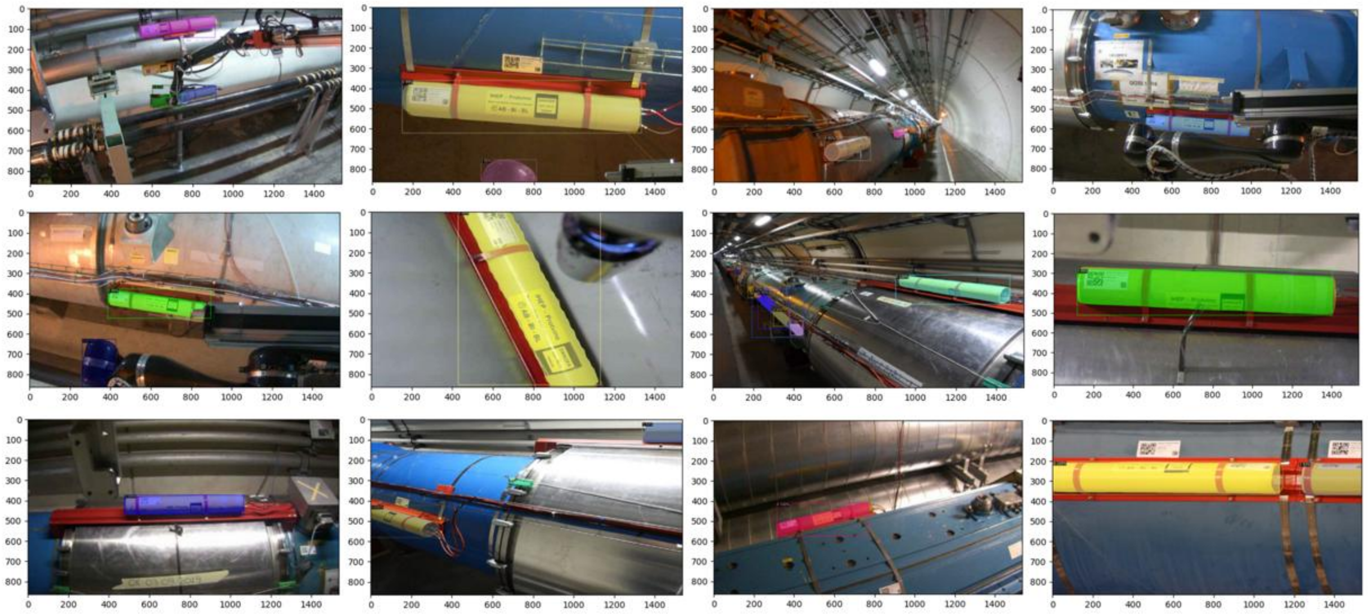


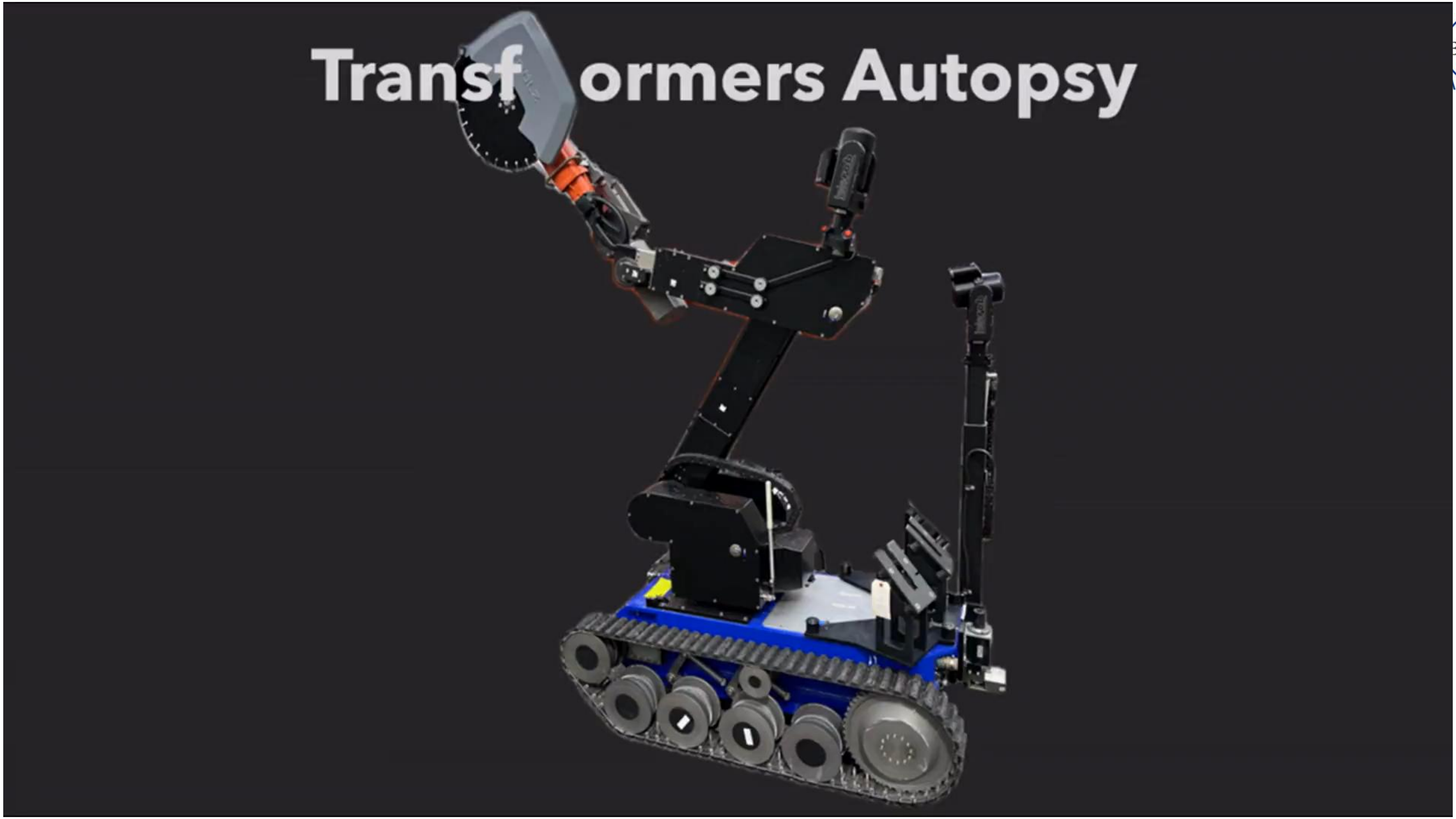




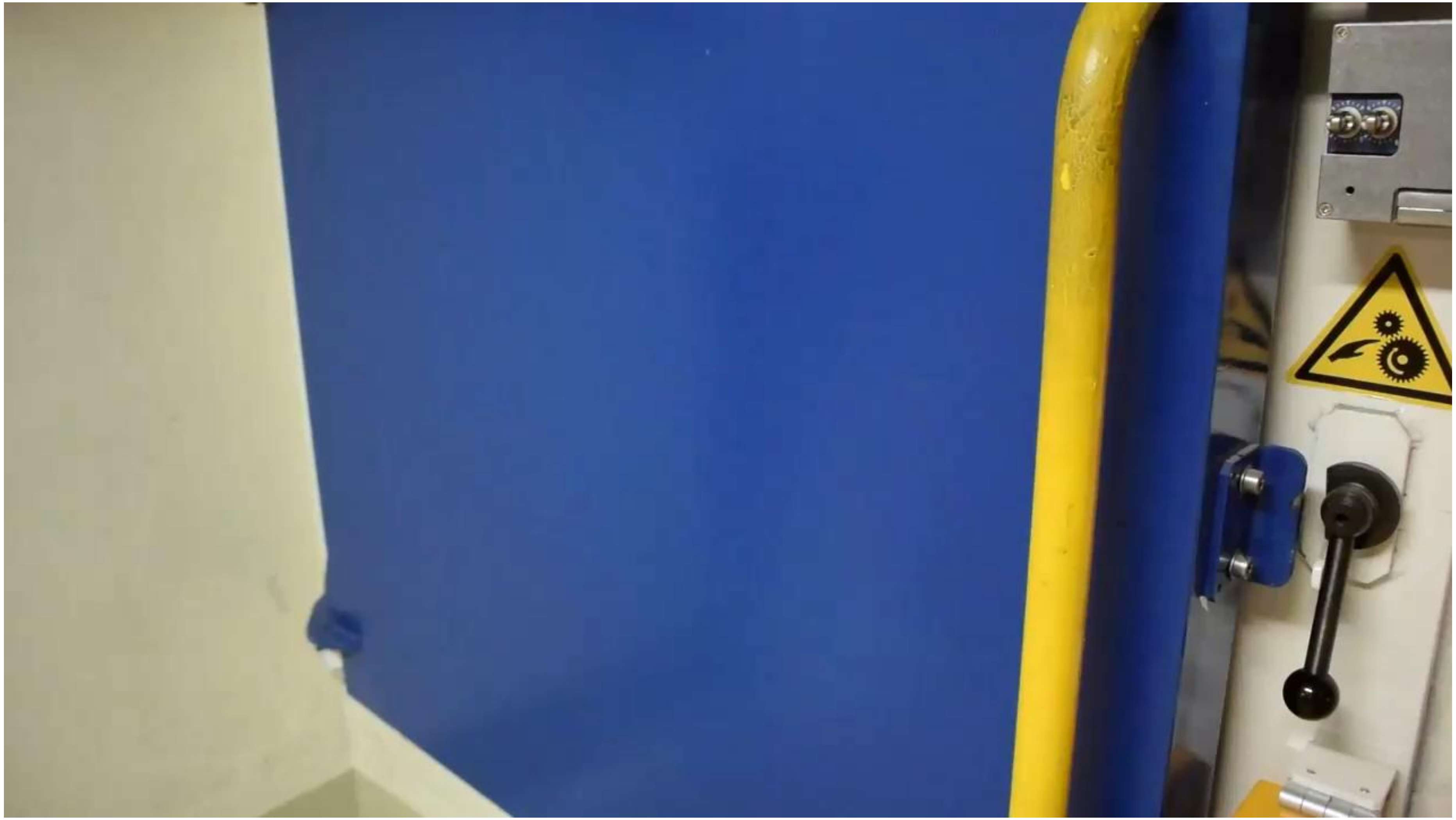
BLM Calibration

- Safe train motion
- Cluttered environment search
- Next view planning
- Target pose estimate
- Collision-free arm trajectories
- Safe source handling & contingencies
- BLM Calibration
- Logistics: charging and range estimates




Transf ormers Autopsy

Novel Mobility (or: Flipping Stuff Upside Down)



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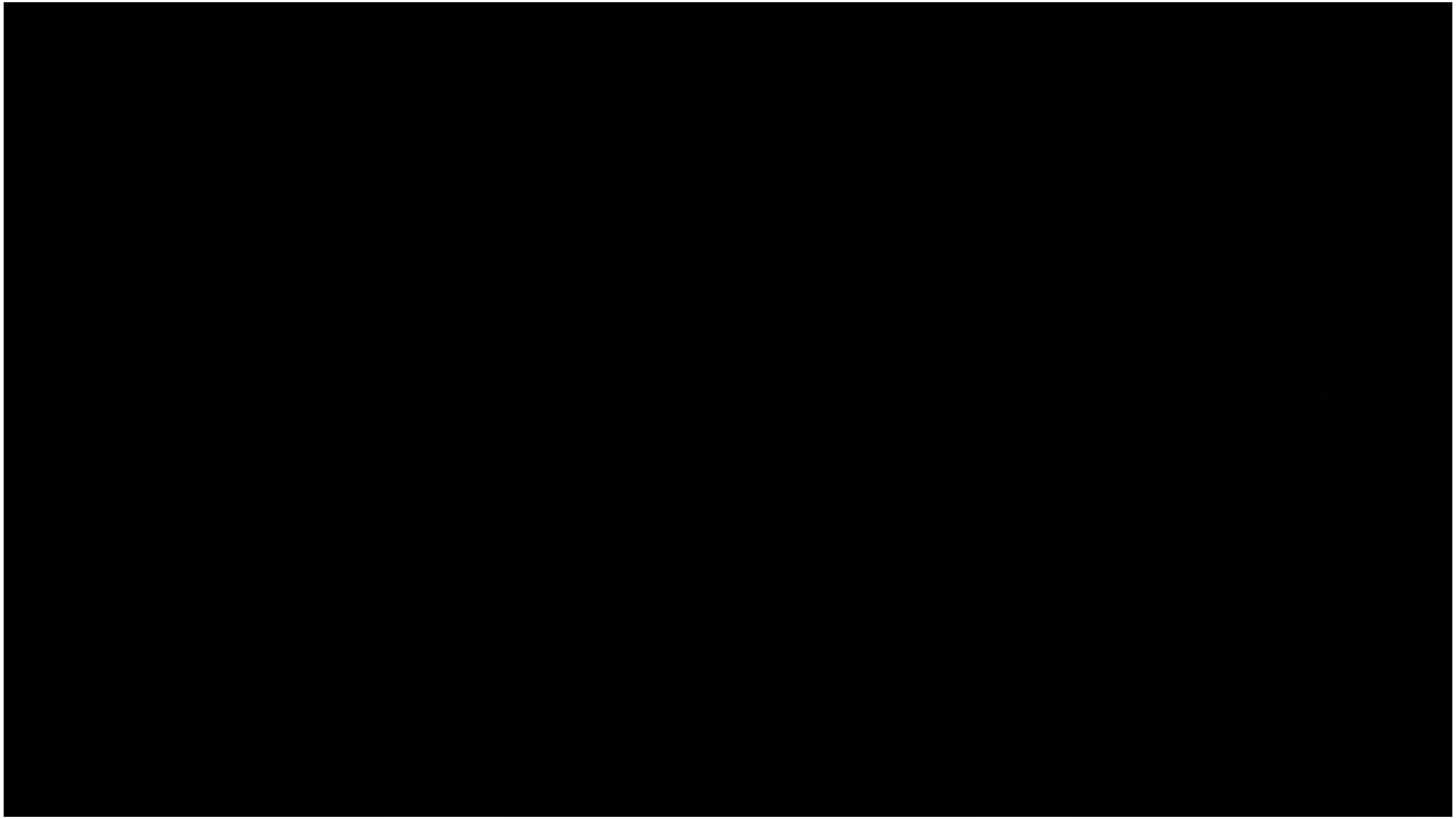
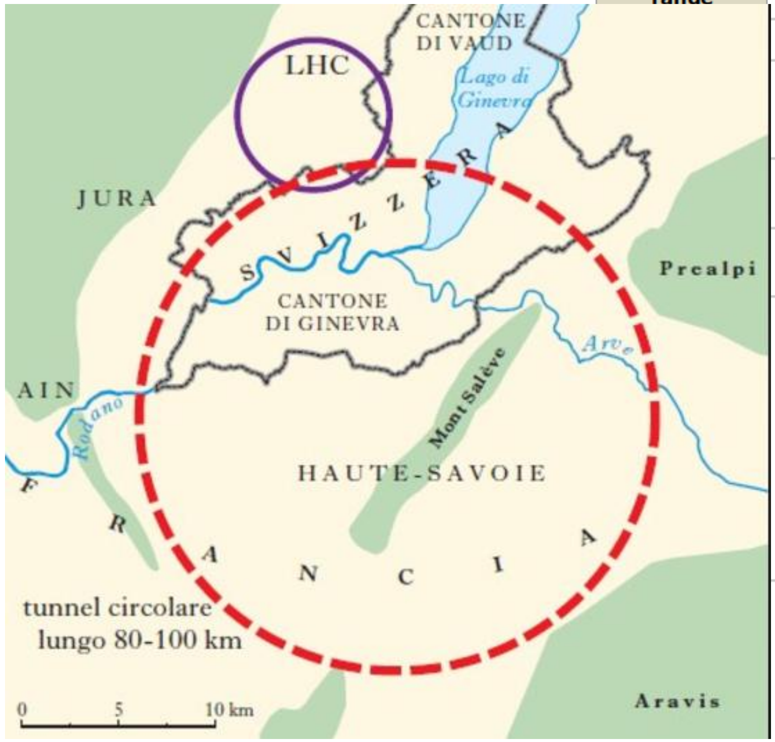
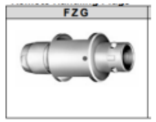
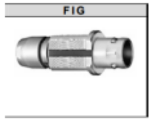
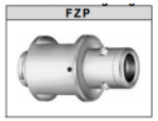
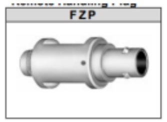


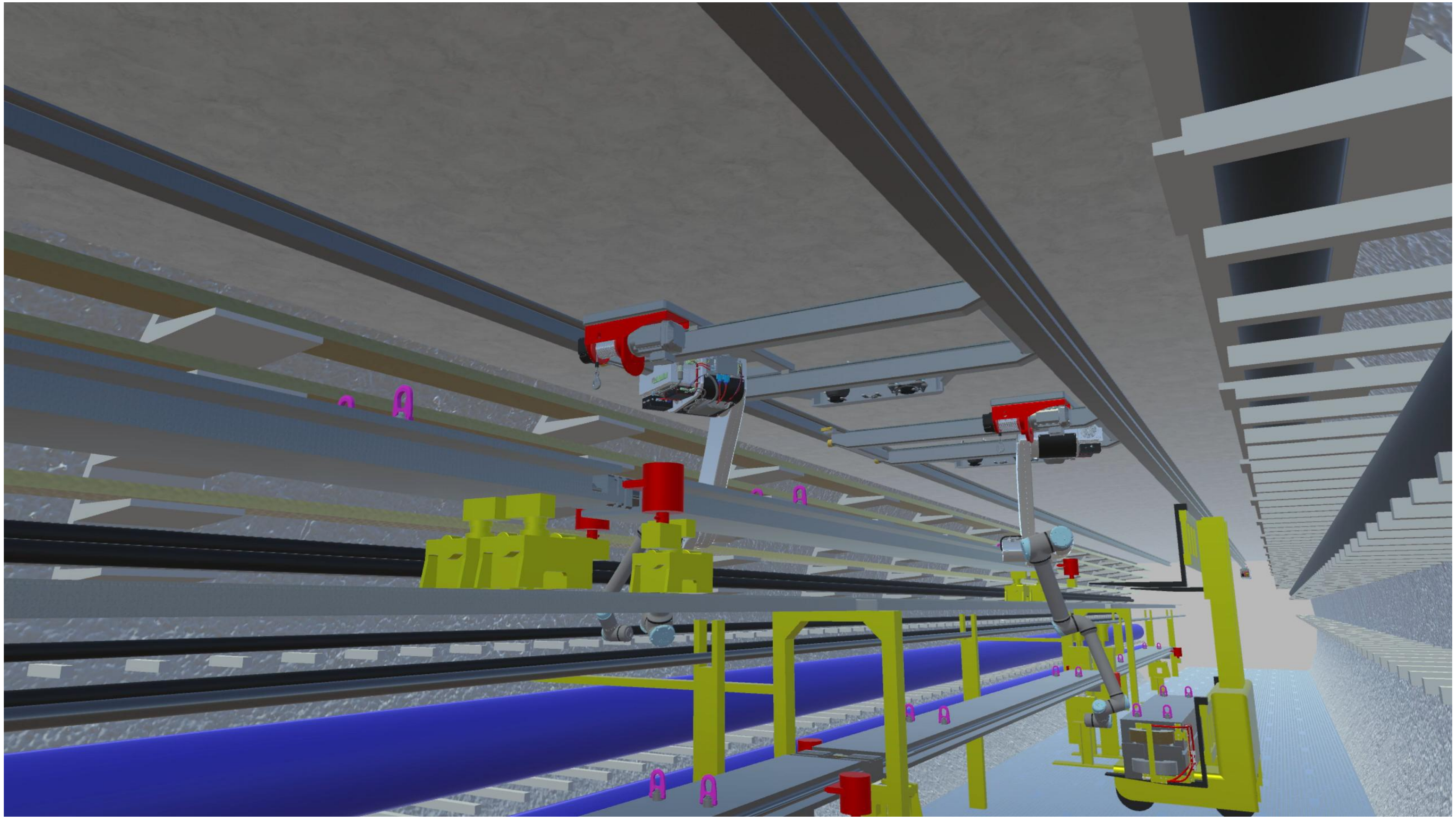
Future: FCC Development

- **New accelerator: ~100km**
- **We can affect development for robot compatibility**
- **Great to be adaptable, but:**
  - More weight
  - More power
  - More complexity
  - Longer Development Time
- **Standardise if possible**



Power required	Low	Low	Model Y-type: Low Model G-Type: High	Low
Current (A)	1.5 to 50	Unipole: 8 to 230 Multipole: 2 to 60	1.5 to 50	Unipole: 8 to 230 Multipole: 2 to 60
Temperature range	-55ºC to 250ºC	-55ºC to 200ºC	-55ºC to 200ºC	-55ºC to 250ºC
	IP50	IP66 to IP68	IP66 to IP68	IP50
	AISI 303 stainless steel	AISI 303 stainless steel	AISI 304 stainless steel and AISI 304L special order	AISI 303 stainless steel
	No seal	Silicone	EPDM	No seal
	1mm -25mm	1mm -30mm	7.6mm -28.55mm	1.4 mm-9.9 mm
	 FZG  FIG	 FZP	G-Type  FZG PLUG	 FZP

FCC Robot

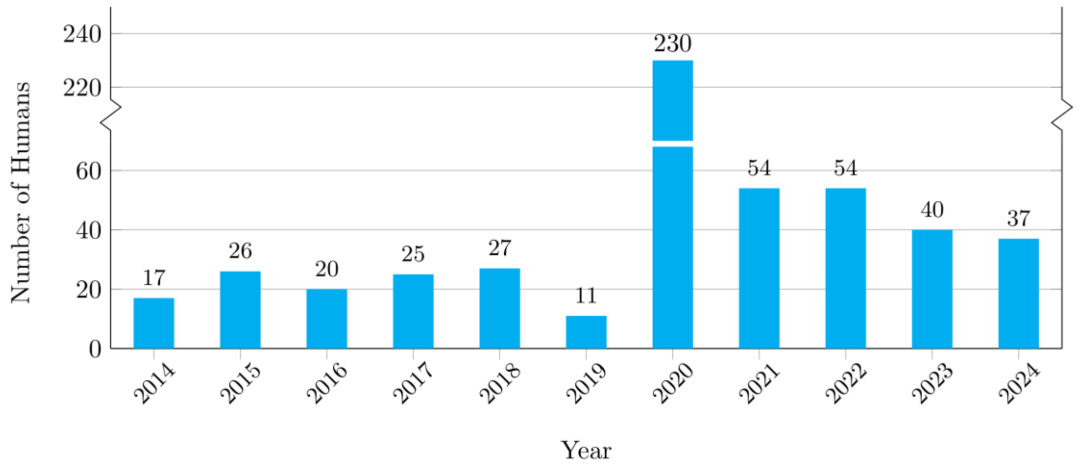


And many more

- Multi-user interaction
- Magnetic aware control
- Continuum robots for inspection in hard to reach places
- Optimise design of in-house arms
- Batteries!(!!)
- Multi-robot, time series environmental mapping
- Search and rescue capabilities
- Operator monitoring and GUI improvements
- Haptic feedback/force control teleoperation
- Optimal data transfer, collation and storage
- Deployable robots (Dog in train)
- Hazard aware path planning

Lessons: Robots in Harsh Environments

- Safety should always be the primary concern
- Simplicity is important: minimise points of failure
- Adapt to the environment when needed
- Change the environment when possible
- Gather as much information about the task/application as possible
- Robots in harsh environments are means of conveying information. Make sure you can convey that information as easily and understandably as possible.



CERN Opportunities

- **Stage (Internship):**
  - Up to 6 months
- **Technical Studentship:**
  - Up to 1 year
- **Doctoral Program:**
  - Up to 36 months. Can combine with existing PhD or start new
- **ORIGIN Positions:**
  - After BSc or MSc. Less than 2 years work experience
- **QUEST Positions:**
  - MSc w/2-6 years work or PhD with less than 3 years work

Thanks to…

BE-CEM-MRO Team

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