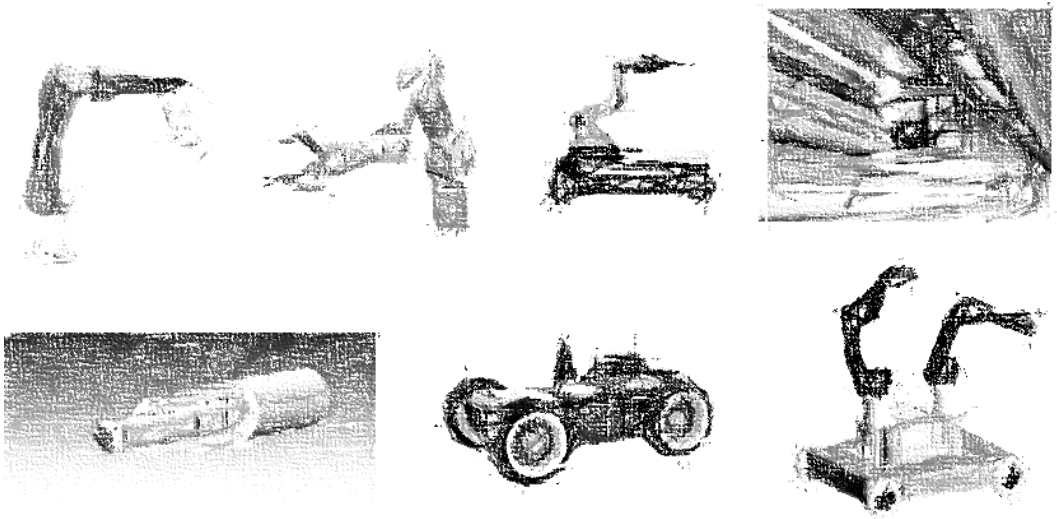
Robotic Inspections, Maintenance and Early Intervention for FCC

Mario Di Castro
CERN



Special thanks to CERN EN-STI, HSE-RP, HSE-OHS and SMB-SE groups

CERN | EN ENGINEERING DEPARTMENT

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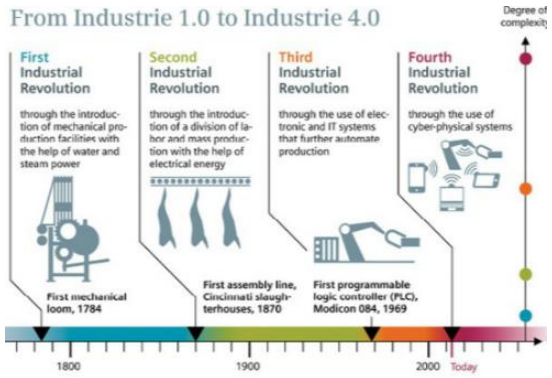
CONTENTS

- Introduction and robotics mandate at CERN
- State of the art in robotics
- Examples of existing solutions at CERN
- Possible technologies and R&D applicable to FCC
- Conclusions

Robotics

- **Industry 4.0**
  - ✓ Robots
  - ✓ Artificial intelligence
  - ✓ Internet of things
  - ✓ Diffuse signals
  - ✓ Sensor fusion
  - ✓ Simplification in the use of robots



- **Human-robot cooperation**
  - ✓ ISO 2011
  - ✓ Robots can assist humans
  - ✓ Robot learning by demonstration

Robotics: type of robots (based on applications)

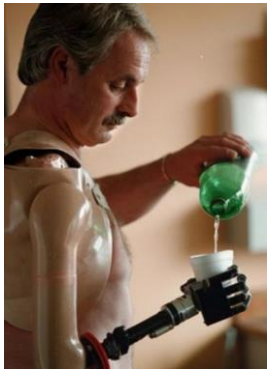
- ✓ Hobbies, competition and entertainment
  - ❑ Suitable for high school teaching
- ✓ Industrial
  - ❑ Repetitive tasks
- ✓ Medical
  - ❑ Surgery/Rehabilitation
- ✓ Domestic or household
- ✓ Military
- ✓ Service and space robot
  - ❑ Research
  - ❑ Intelligent

Robotics

- **Ethical aspects**
  - ✓ Will robots replace humans?
  - ✓ Will robots take our jobs?
  - ✓ Will robots make humans unnecessary?
  - ✓ Is humanity just a phase in a robotic evolution?

Robotics

- **There is a lot of potential in this technology to be beneficial for people**
- **Ultimately, everything depends on how we decide to use the technology**

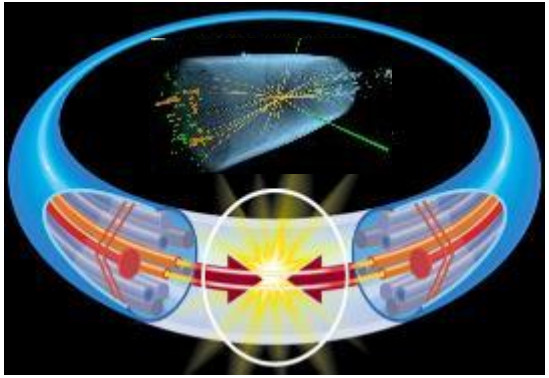
Robots must improve the quality of work by taking over dangerous, tedious and dirty jobs that are not possible or safe for humans to perform

Robotics mandate at CERN

- The “mission” of tele-robotics at CERN may be resumed in the following:

Ensuring safety of Personnel

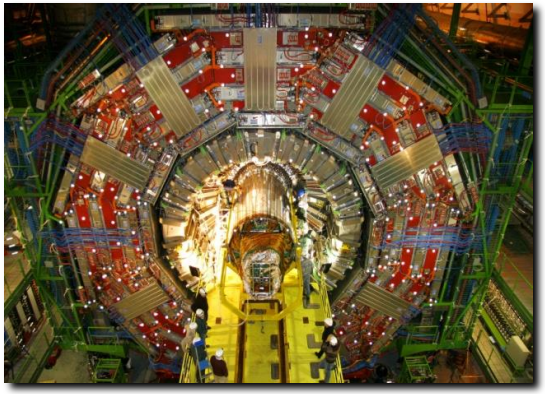
improving availability of CERN’s accelerators



Needs and difficulties for tele-robotics at CERN

- **Operation and maintenance of radioactive objects**
  - ✓ Most of them are obsolete, without proper documentation and drawings, any intervention may lead to **surprises**
  - ✓ Risk of **contamination**
- **Several challenges like radiation, magnetic disturbances, delicate equipment not designed for robots, big distances, communication etc.**



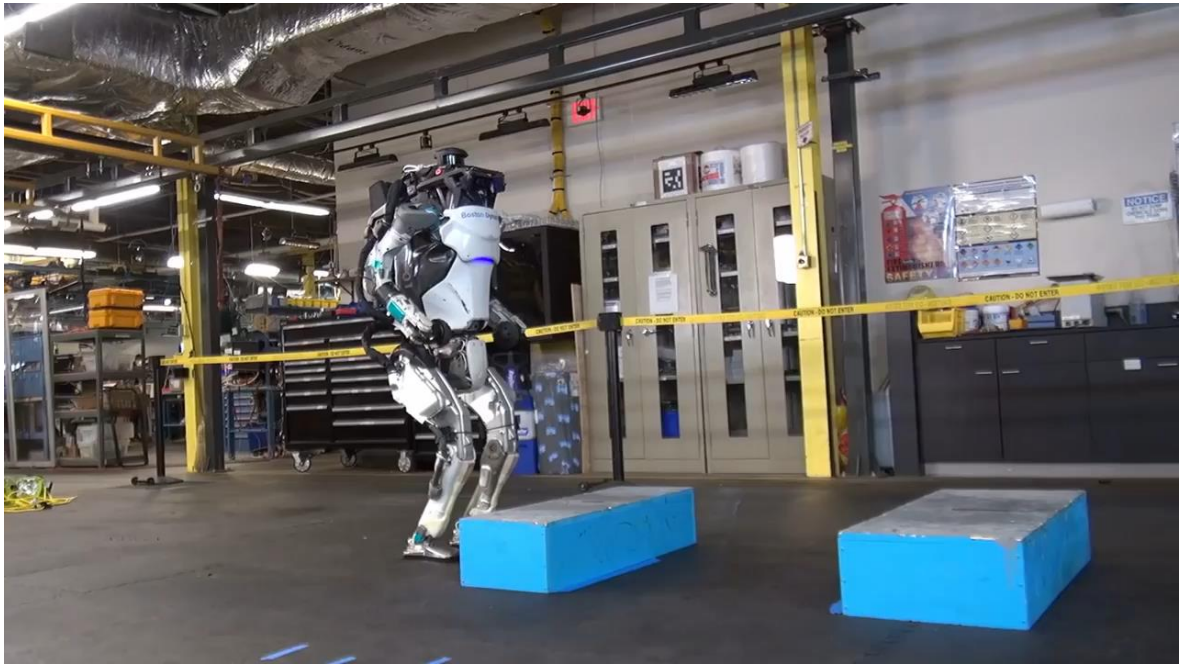
CONTENTS

Robots made in Hollywood

iRobot, Chicago 2035

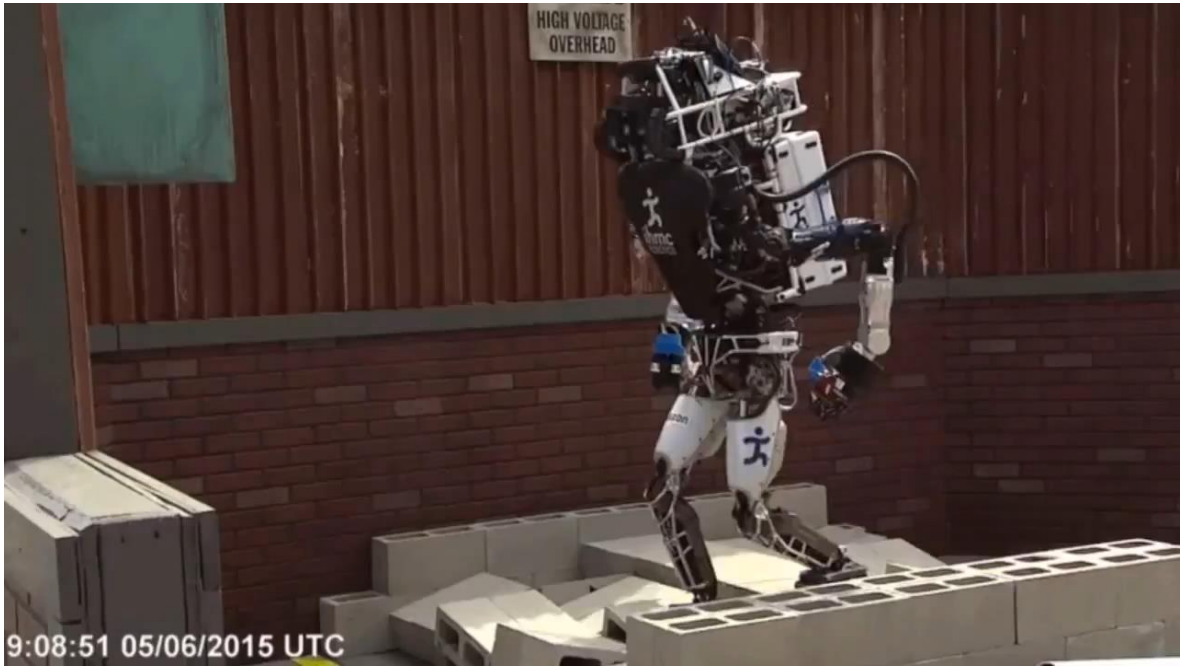
Robots made by *Boston Dynamics*

A mystery for the robotic community



Robots in reality (R&D)

DARPA Robotics Challenge, 2015



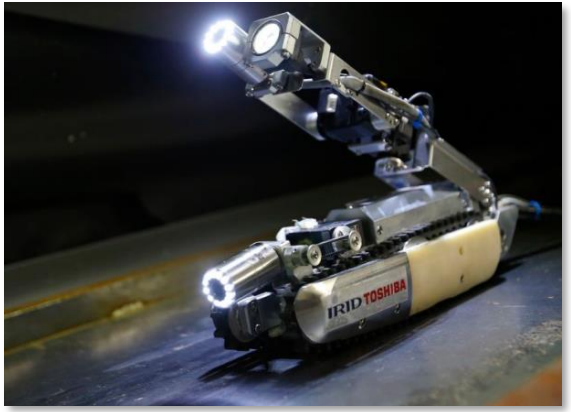
Robots in reality (field robotics)

- ✓ **Inspection robots**
  - ✓ Snake robots
  - ✓ Oil and gas industries to inspect pipes and tanks

- ✓ **Telemanipulators**
  - ✓ Nuclear decommissioning

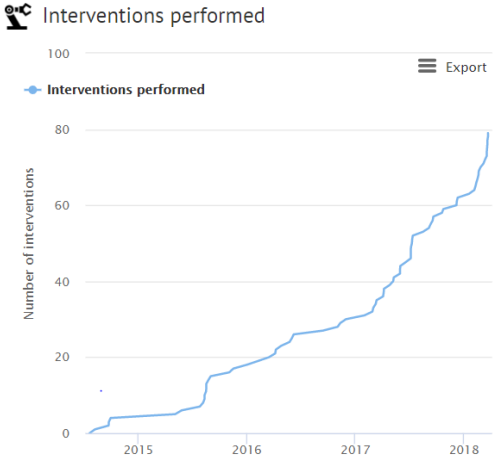
Robots in reality (field robotics)

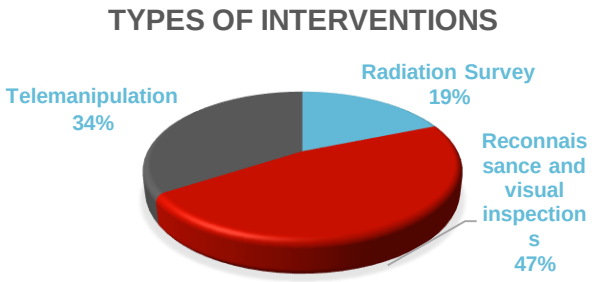
- The only reliable robotic solutions exist in industry for repetitive tasks
- Plenty of ideas and prototypes coming from university, but none of them work reliably for harsh and unstructured environments
  - ✓ At Fukushima, no robot has been capable of safely inspecting the zone and returning to the base

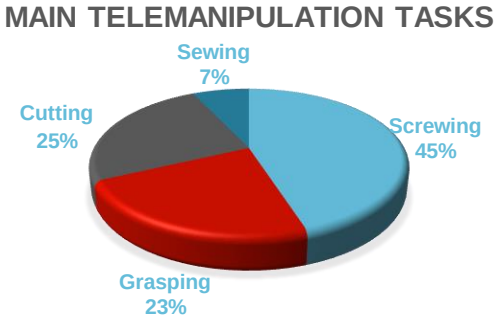


CONTENTS

Robotic support



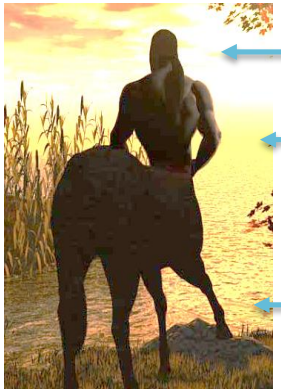




Best practice for equipment design and intervention

Current R&D in robotics at CERN

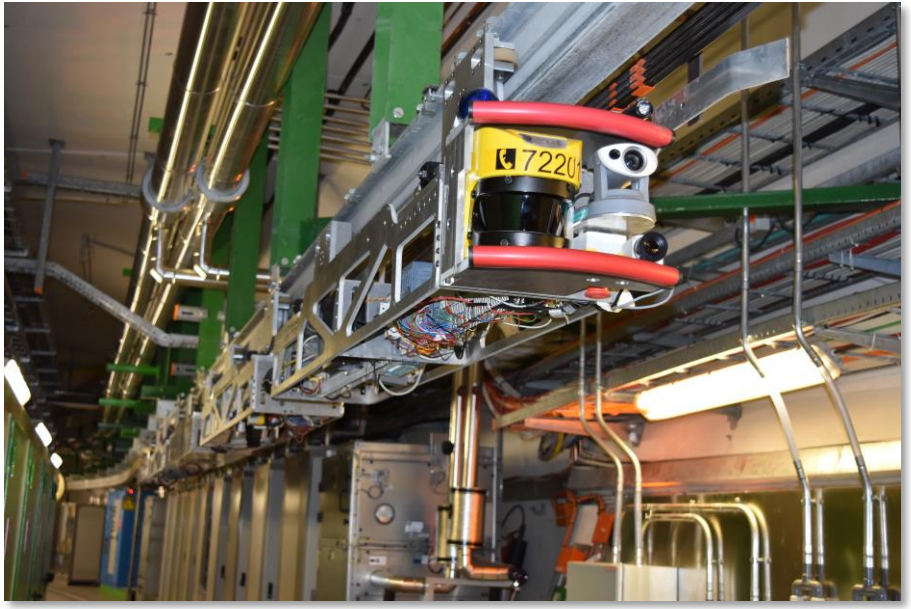
Mechatronic System



- **New robot and robotic control developed**
  - ✓ Human robot interface
- **New user-friendly bilateral tele-manipulation system**
  - ✓ Haptic feedback
  - ✓ Assisted teleoperation
- **Artificial intelligence**
  - ✓ Perception and autonomy
  - ✓ Deep learning
- **Operator and robot training system**
  - ✓ Virtual and augmented reality
  - ✓ Learning by demonstration

Robots at CERN: TIM

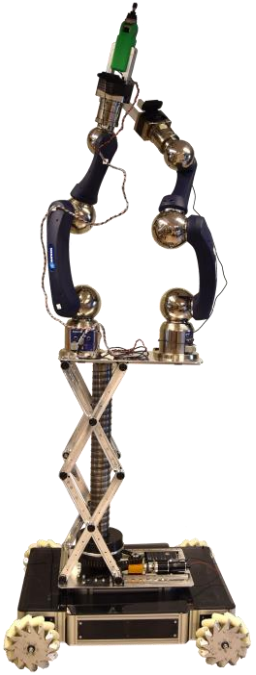
Built at CERN, used for inspection, radiation mapping of the LHC and survey. Operational Experience and technology could be useful for FCC



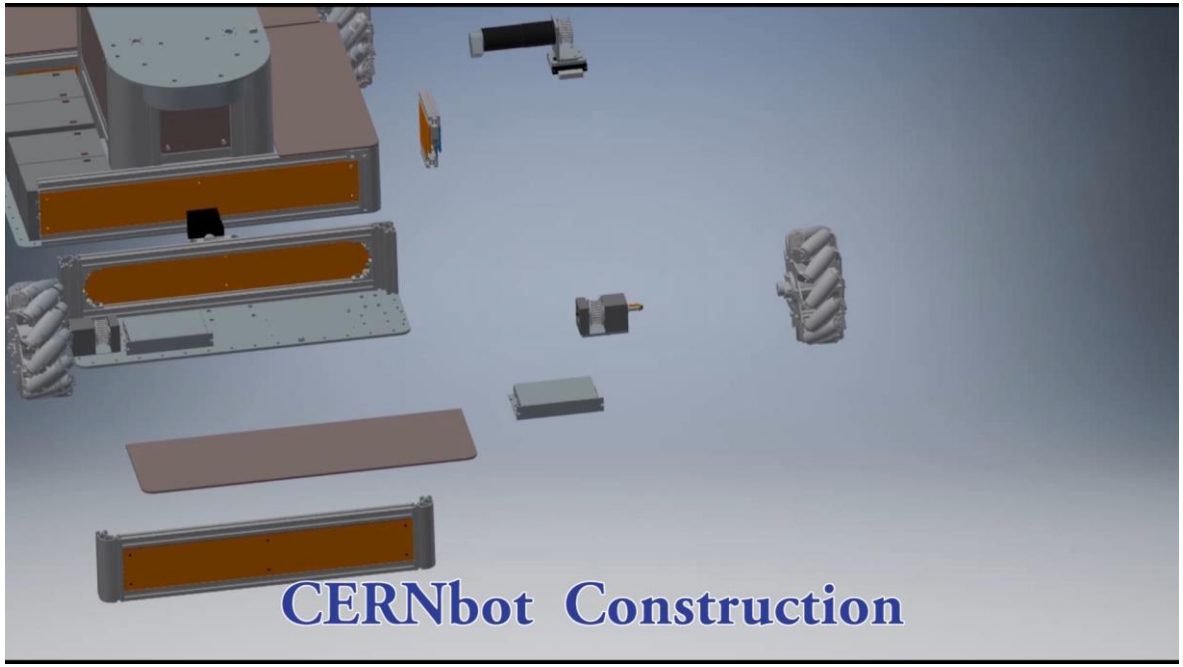
Robots at CERN: TIM

Robots at CERN: CERNbot

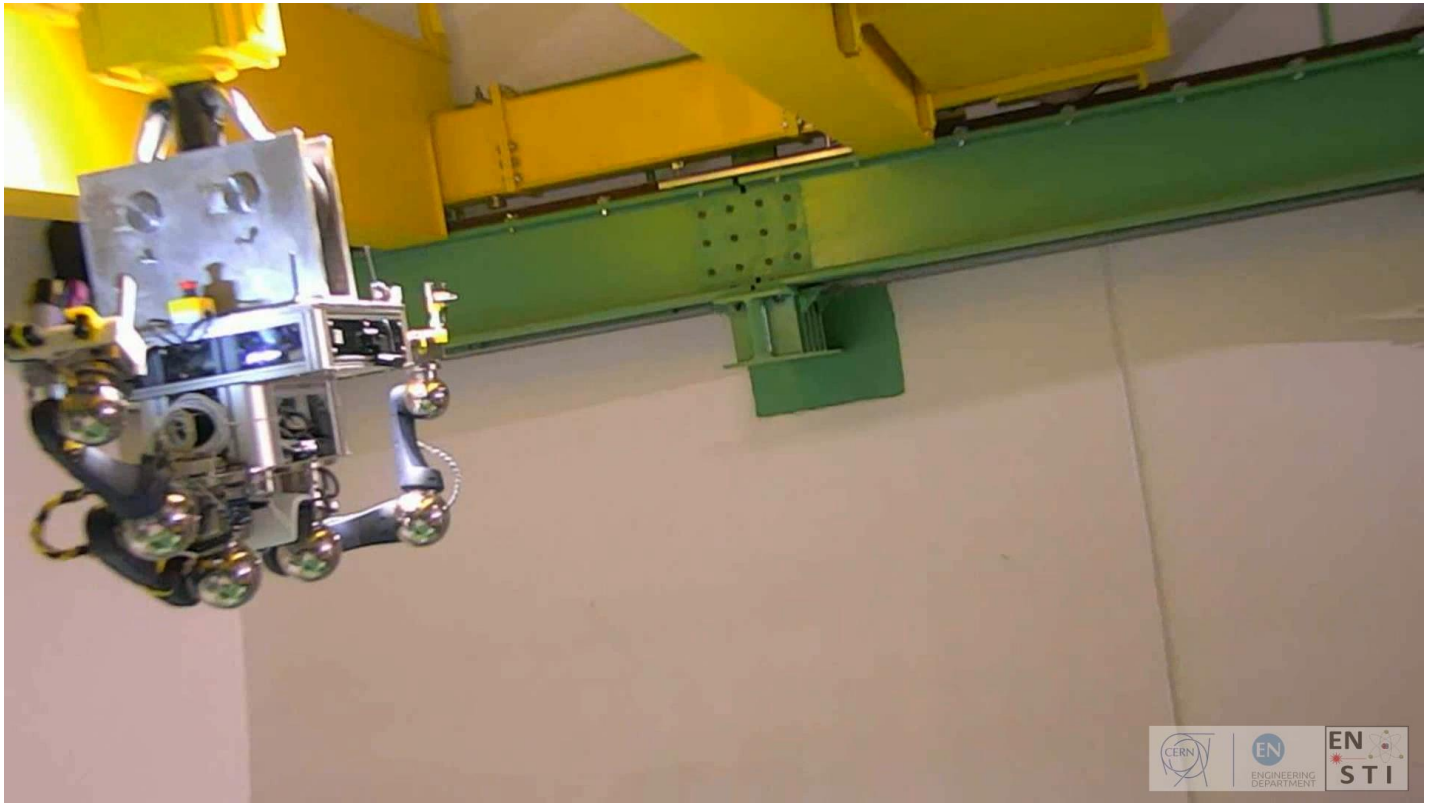
Built at CERN, used for inspection, environmental measurements including radiation, teleoperation and in-situ maintenance. Operational Experience and technology could be useful for FCC



Robots at CERN: CERNbot

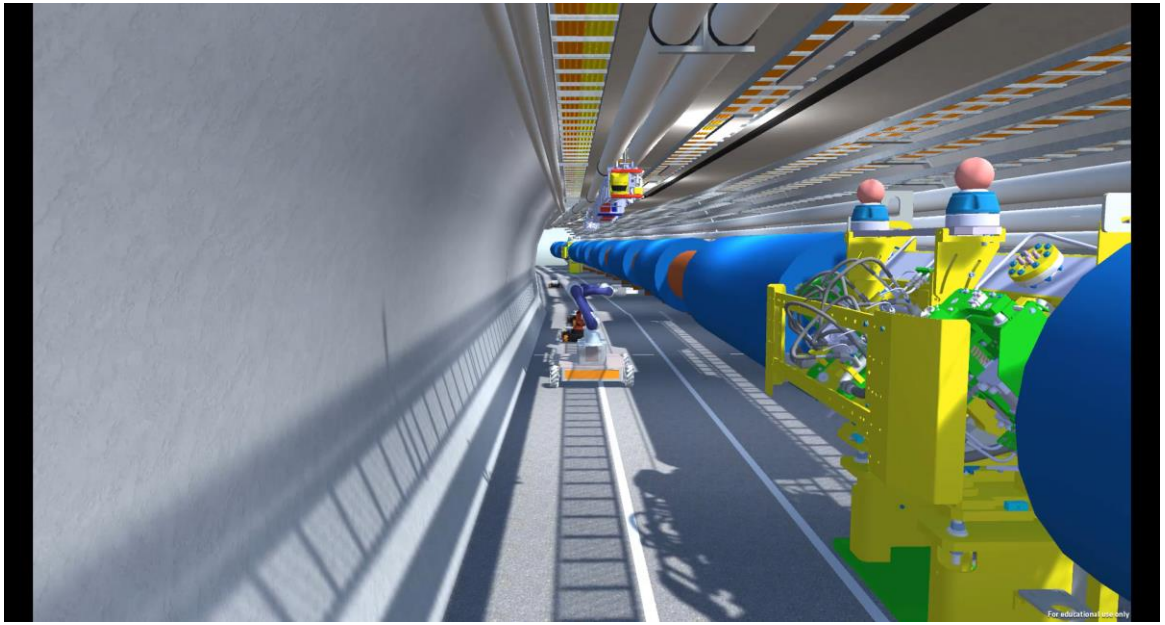


Robots at CERN: Tele-operation and in-situ maintenance



R&D on collaborative robots

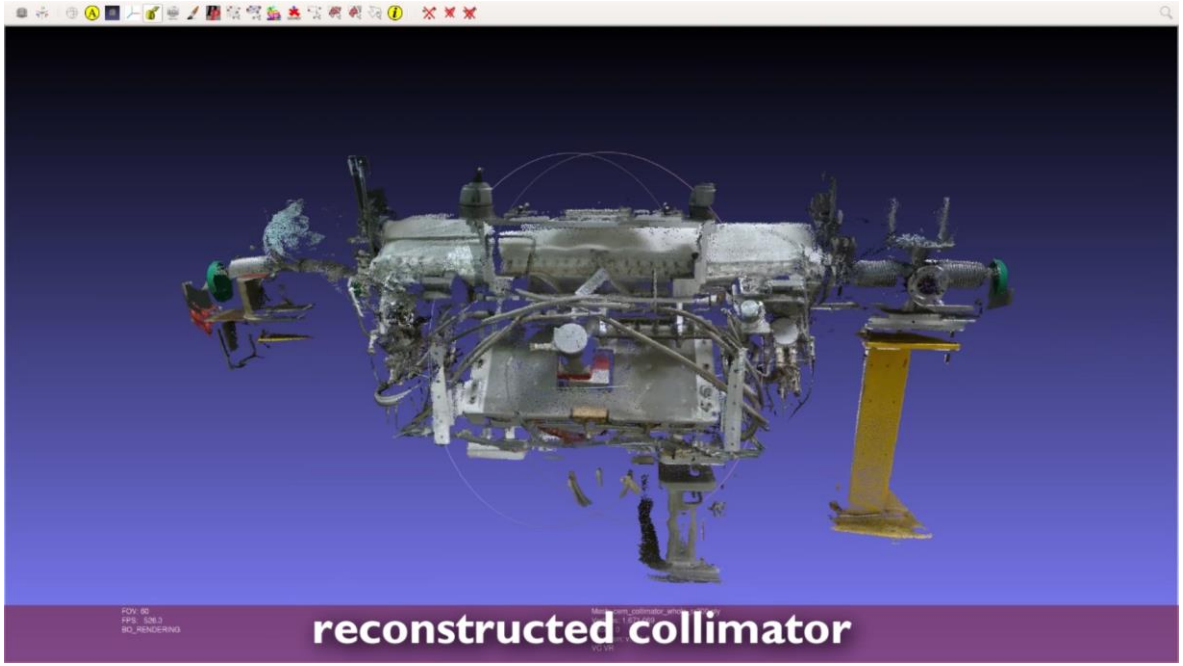
- **Multiple autonomous robot collaborations**
  - ✓ **Several viewing angles for supervision and teleoperation are essentials**



In-situ maintenance

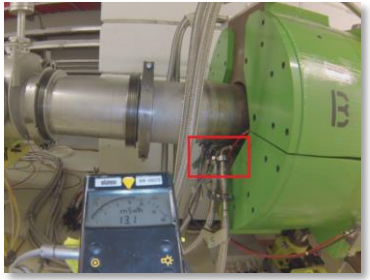
- Deep learning for object and pose recognition
- Machine learning for autonomous operations
- Safety using virtual fixtures to avoid collisions

R&D for autonomous tests of LHC Collimators components



Importance of the design phase, procedures and tools

- Designing machines that can be maintained by robots using appropriate and easily accessible interfaces will increase the availability and decrease human exposure to hazards



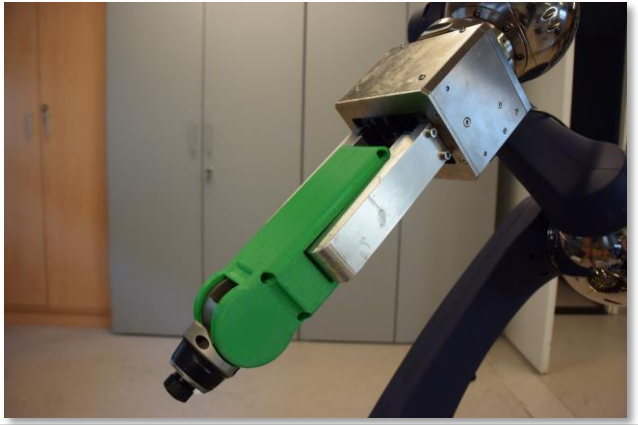


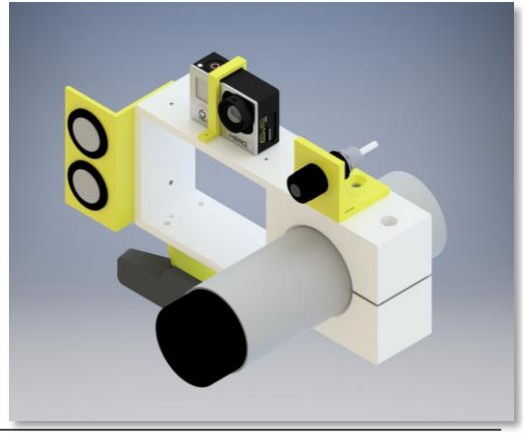


Easier remote or hands-on manipulation than chain-type connection

Importance of the design phase, procedures and tools

- Intervention **procedures and tools** are important as the robot/device that does the remote intervention
  - ✓ HL-LHC WG, **ITHACA** - **I**n**T**erventions in **H**ighly **AC**tivated **A**reas in HL-LHC
    - ❑ Guidelines for equipment design and maintenance best practice to reduce personnel radiation exposure.
  - ✓ Taking advantages of robots operational experience for new equipment design (TIDVG, BDF target, AD target, TAXS, TAXN etc.)

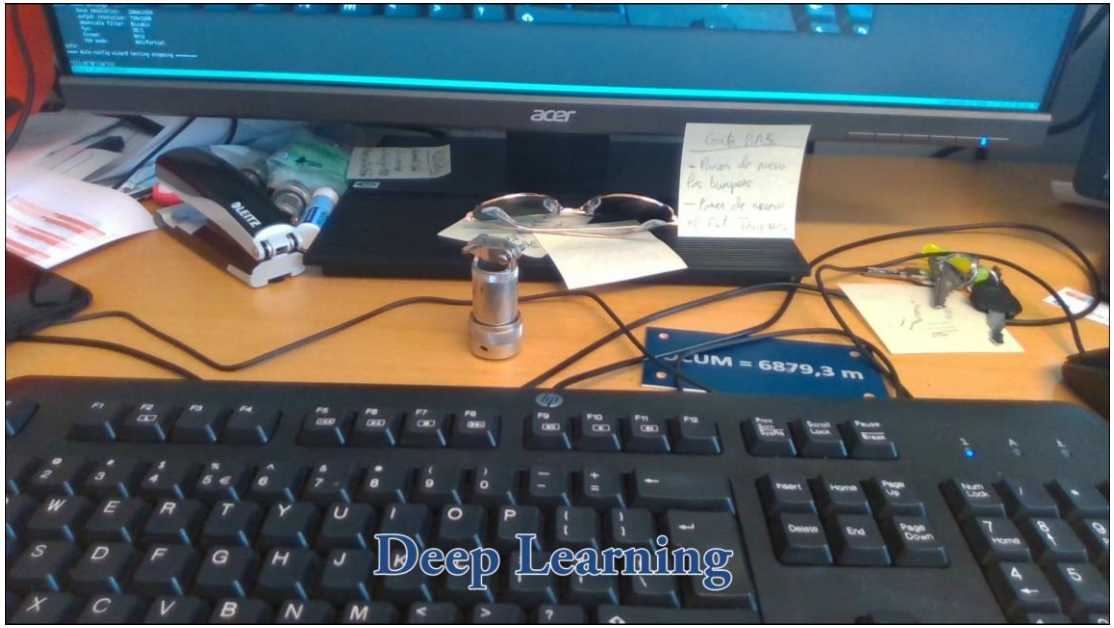




CONTENTS

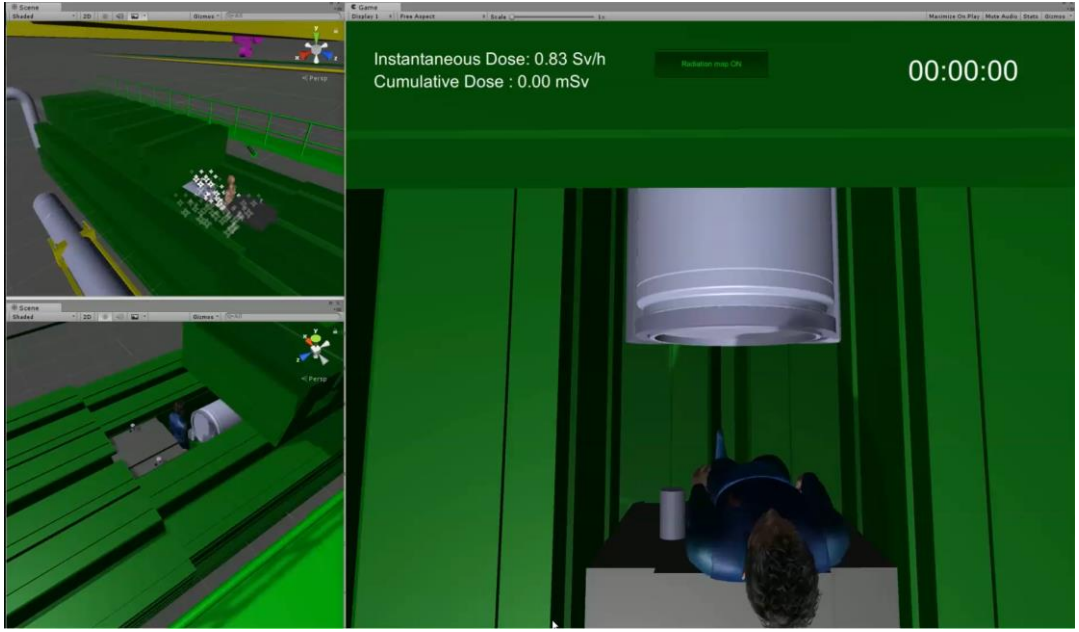
Machine learning

Robot can learn from humans and collaborate with them to speed up tasks



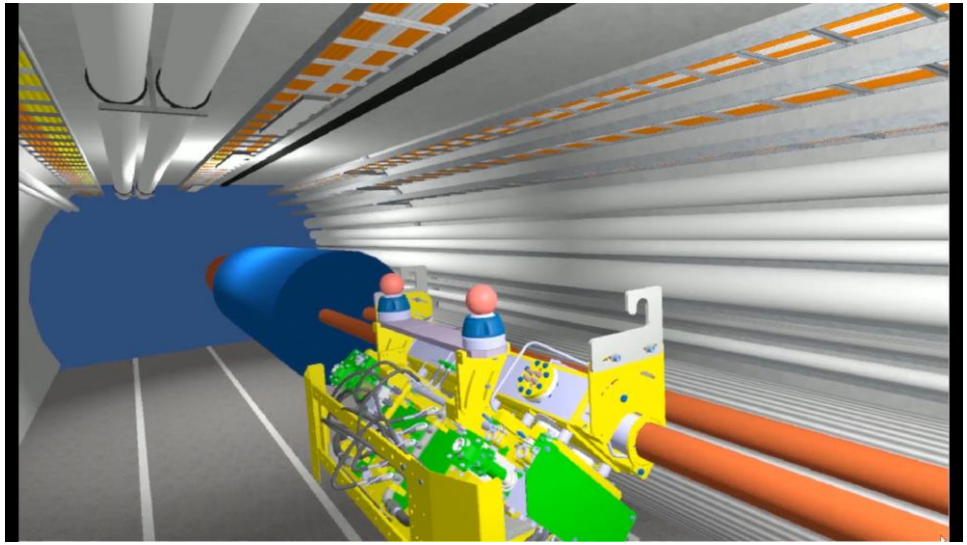
Virtual and augmented reality

- For personnel training and risk assessment
- FLUKA/radiation-exposure simulations in VR



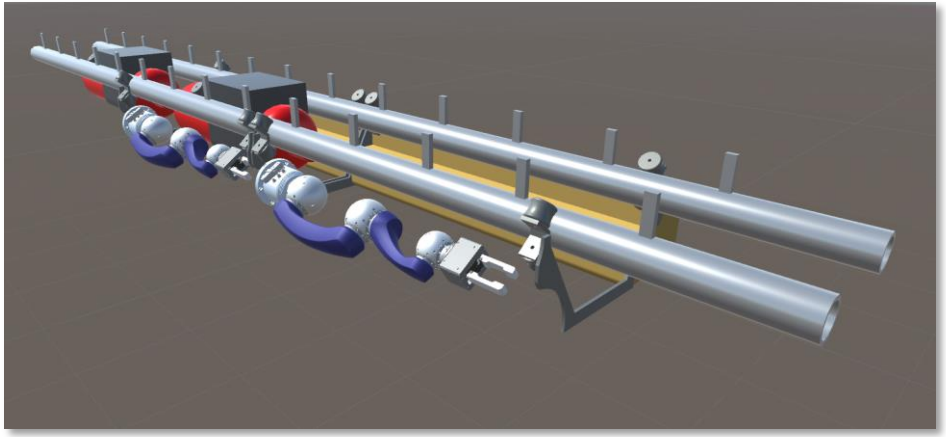
Virtual and augmented reality

For Integration, procedures, operator training and operator assistance during teleoperations, in-situ maintenance

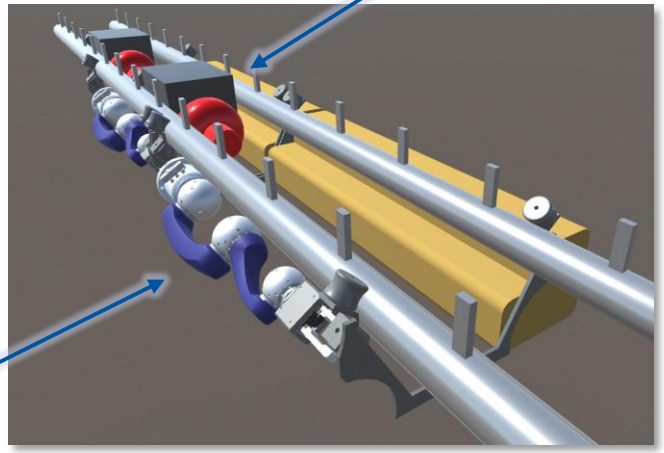


Novel Robot design for FCC

- With such large distances in FCC, it is not possible to have human quick inspection/maintenance interventions
- Preliminary design of an overhead robot running on a ceiling support
  - ✓ Choice made from the operational experience over recent years (TIM/monorail vs ground robot interventions)
- 2in1 robot for inspection, environmental measurements, in-situ maintenance and early intervention in case of accident

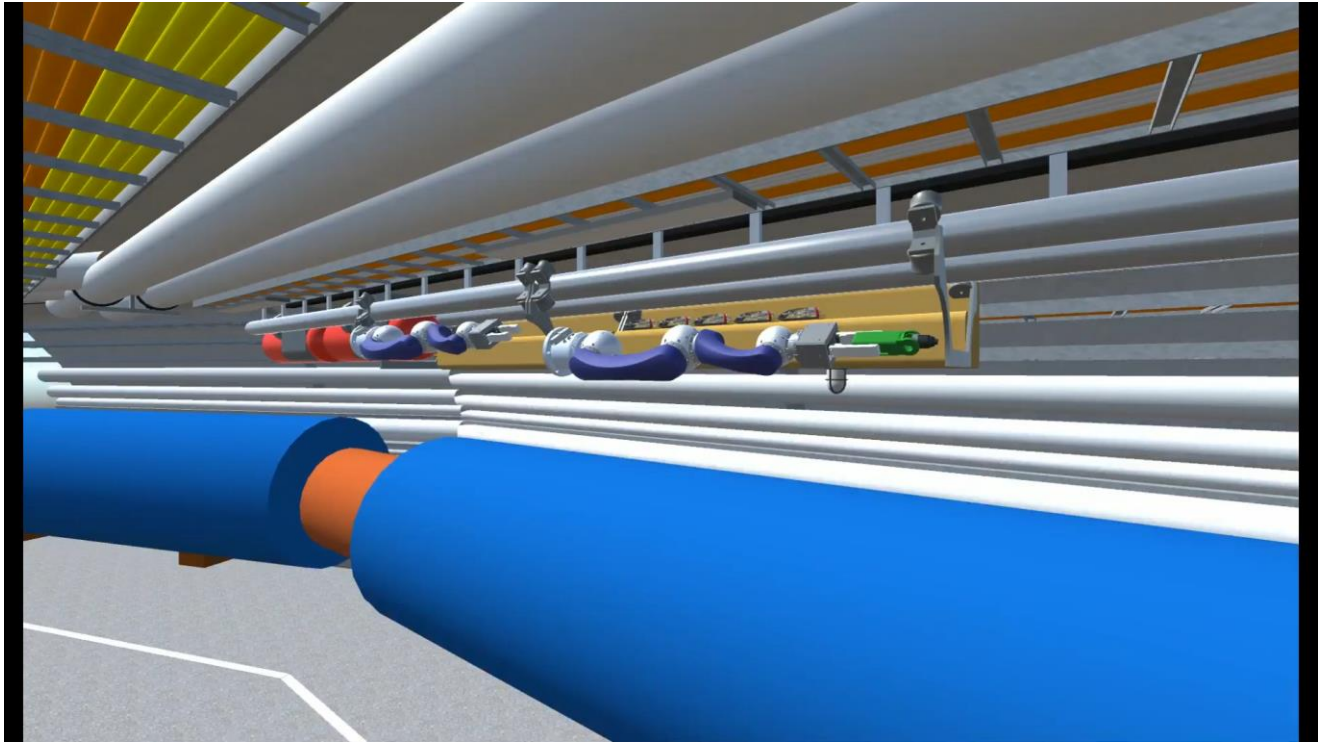


"Internal" part for **early intervention**



"External" part for **maintenance, measurements and inspections**

In-situ maintenance



Early intervention robots

- **With such large distances in FCC, early intervention systems are necessary for example in case of accident or fire**

Early intervention robots

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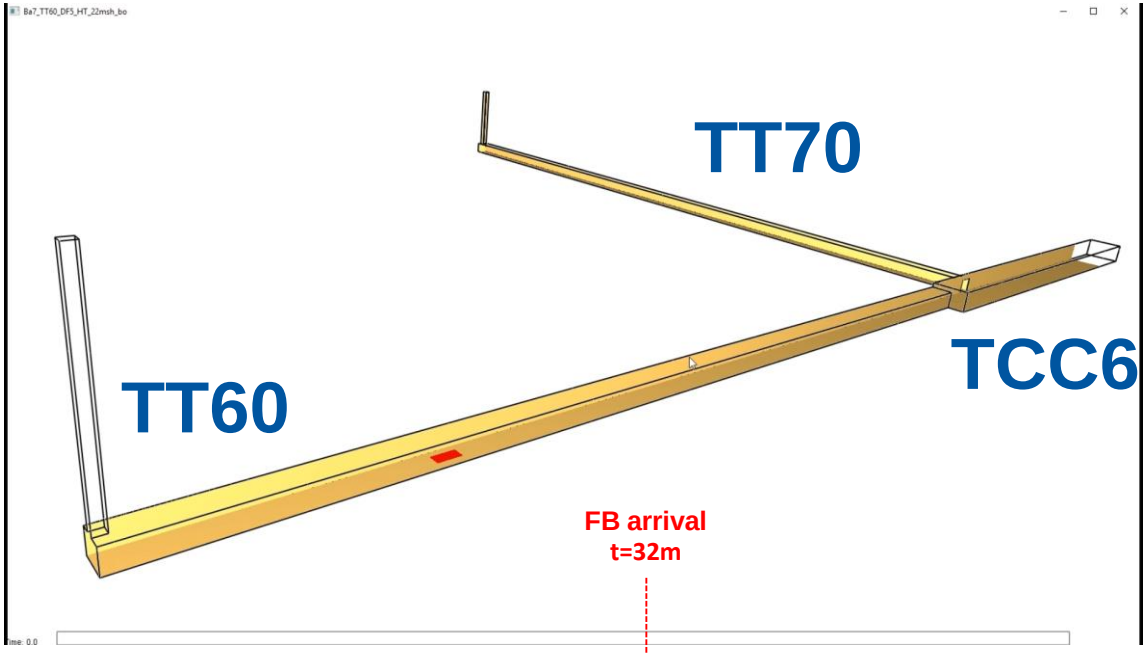


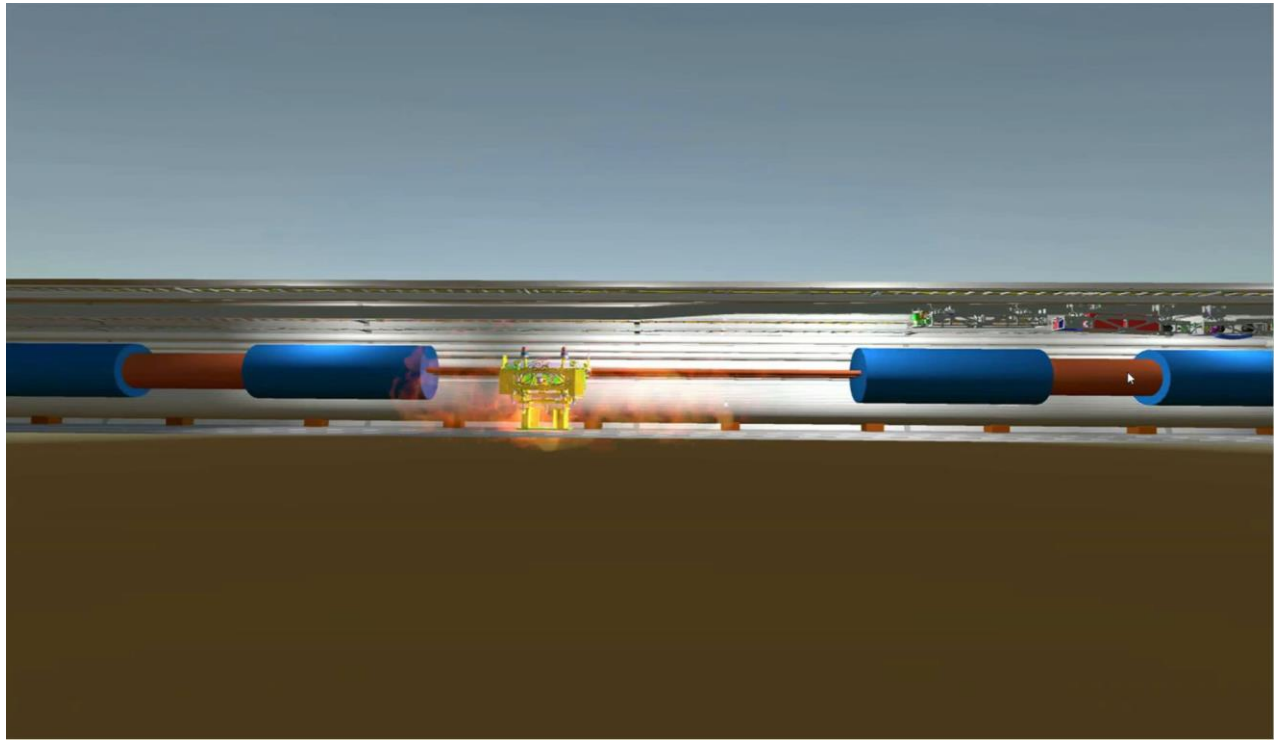
Fire simulation: fire seat at TT60up, design fire DF5 (13MW) PA7, TA7, TT70, **TT60,TCC6** modeled

Courtesy of A. Arnalich, CERN, HSE-OHS

Early fire intervention robot should:

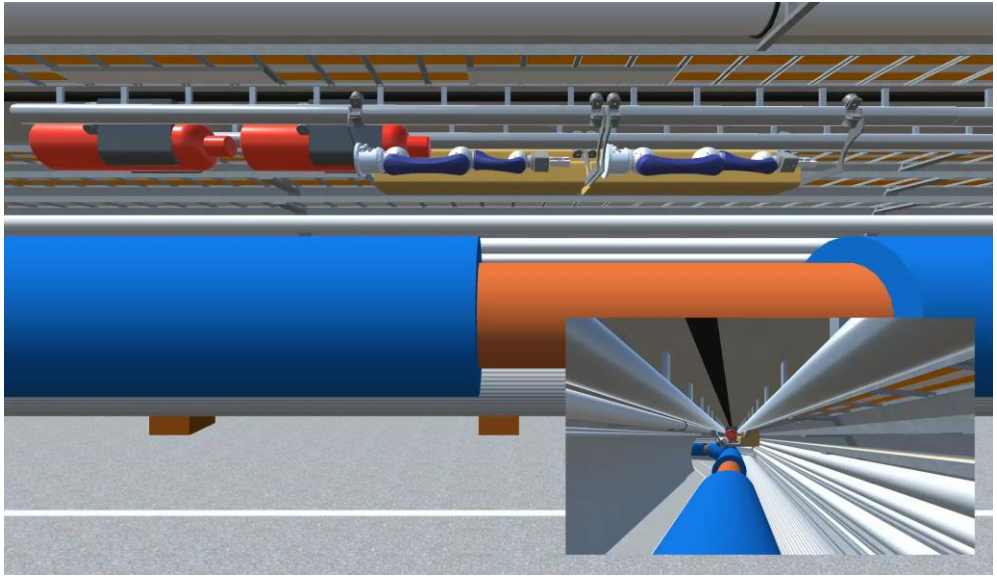
- **Locate** and inspect the seat of the fire (under 5 minutes)
  - ✓ Several robots that can travel at high speed (train system?)
- **Deploy smoke curtains** to avoid smoke damage and retain extinguishing media in desired areas.
- Deploy extinguishing media (aerosol based media) to temporally **suppress fire**.
- **Search for human life** inside the tunnel based on thermal imaging, movement sensors and indicate them the closest exits
- **Follow** and ”drone” **accessing firefighting teams**, to monitor, relay communications and explore ahead.

Early fire intervention robot



Early intervention robot:

- Separate system with respect to the maintenance robot
  - ✓ Capable of running at high speed (50 km/h) to deploy fire-extinguish systems and to arrive to personnel for escape information



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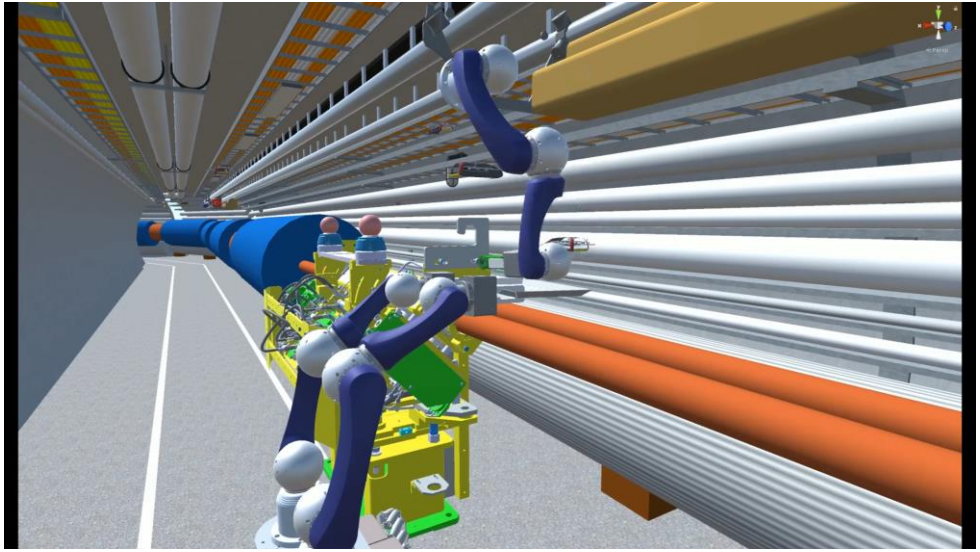
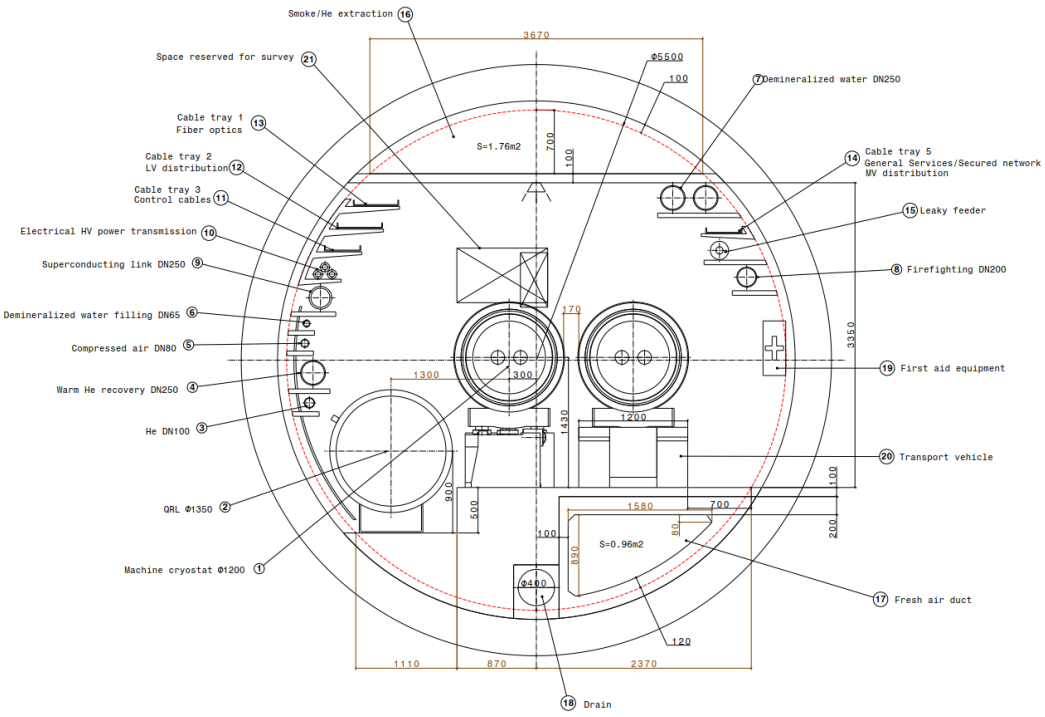
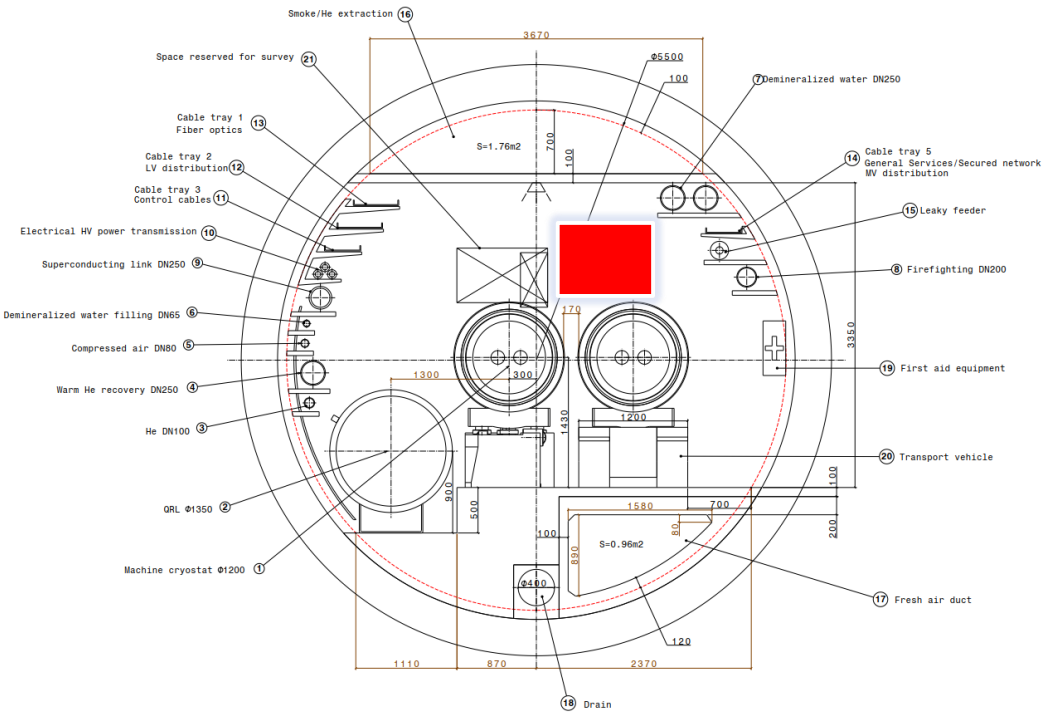


FCC Robot: **LOCATION?**



- Ground robot running on passage side
  - ✓ Difficult to reach back part of tunnel
  - ✓ Can’t overcome escape personnel in case of fire
- Overhead robot
  - ✓ Possible obstacles in the passage areas can be passed
  - ✓ Easy to pass sector doors
  - ✓ Much safer at high speed
  - ✓ Ceiling support is mandatory to host a rail/support to be able to intervene quickly
- Avoid Drones
  - ✓ Stability issues

FCC Robot: **LOCATION?**



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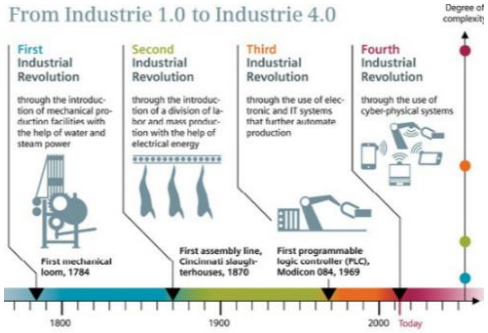
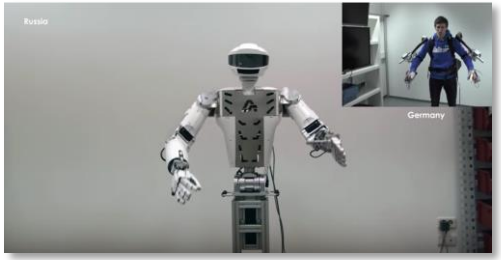
FCC technologies?

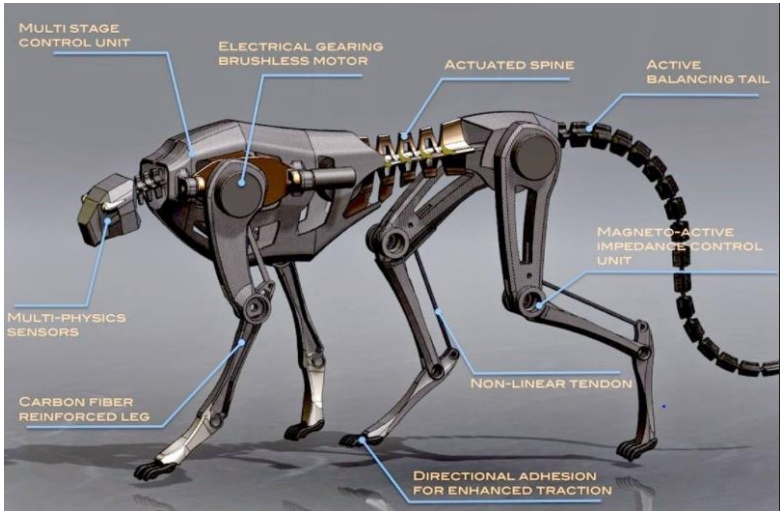


Industry 5.0?



FCC robot?

Inspired by nature



FCC robot?

Robots need a crew to use them and maintain and experts in-house to be effective

Conclusions

- With FCC long distances and hazards, **remote handling, maintenance and early intervention robots are necessary**
- Quick response in case of accident is mandatory to guarantee safety for personnel and machines
- Ready-to-use robotic solutions that can fulfill CERN needs for remote inspection and user-friendly teleoperation do not exist
- Current accelerators components are not designed to be maintained by robots
- For the FCC, we can hope for commercial technology growth or we can continue with R&D to adapt industrial solutions and cutting edge technologies to FCC needs
- New machines that can be activated/contaminated must be designed to be easily maintained and possibly robot friendly to maximize machine availability and decrease personnel exposures to hazards
  - ✓ **Layout space to host systems/robots for maintenance and early intervention should be foreseen**
- **From operational experience, overhead robots are the best choice for accessibility and safety**

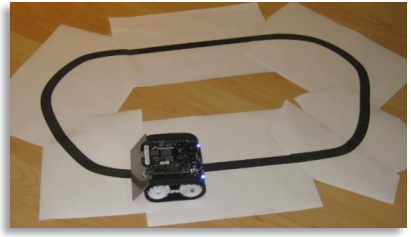
Thank you for your attention

CERN

Backup slides

Robotics: type of robots (based on controls)

- Robots
  - Teleoperated
    - Wired
    - Wireless
  - Semi-autonomous
  - Autonomous
    - Pre-programmed
    - Self learning



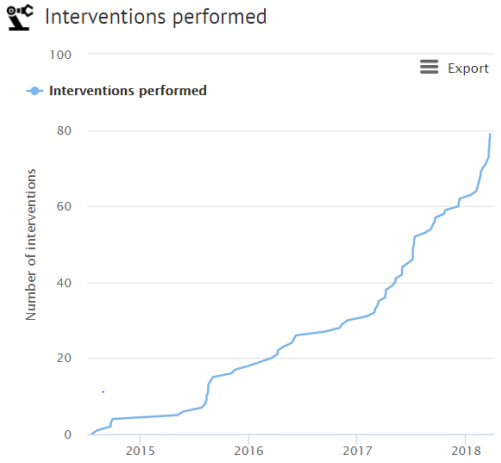
Artificial Intelligence

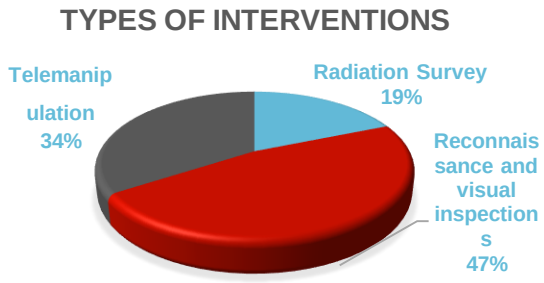
- **Intelligence exhibited by machines**
  - ✓ Perception
  - ✓ Recognition
  - ✓ Localization
  - ✓ Knowledge
  - ✓ Learning
  - ✓ Planning
  - ✓ Decision making

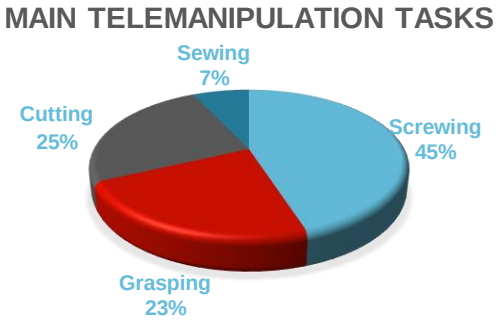
Robotic support

Nr. of Interventions in the last 36 months	Nr. of tasks performed in the last 36 months	Robot operation time in harsh environment [h]	Dose Saved [mSv]
79	105	~ 220^	~ **102***

^ At least 4 times more if considering training phases
* Calculated on human intervention time
60 % of the interventions were unforeseen and done with very short preparation time

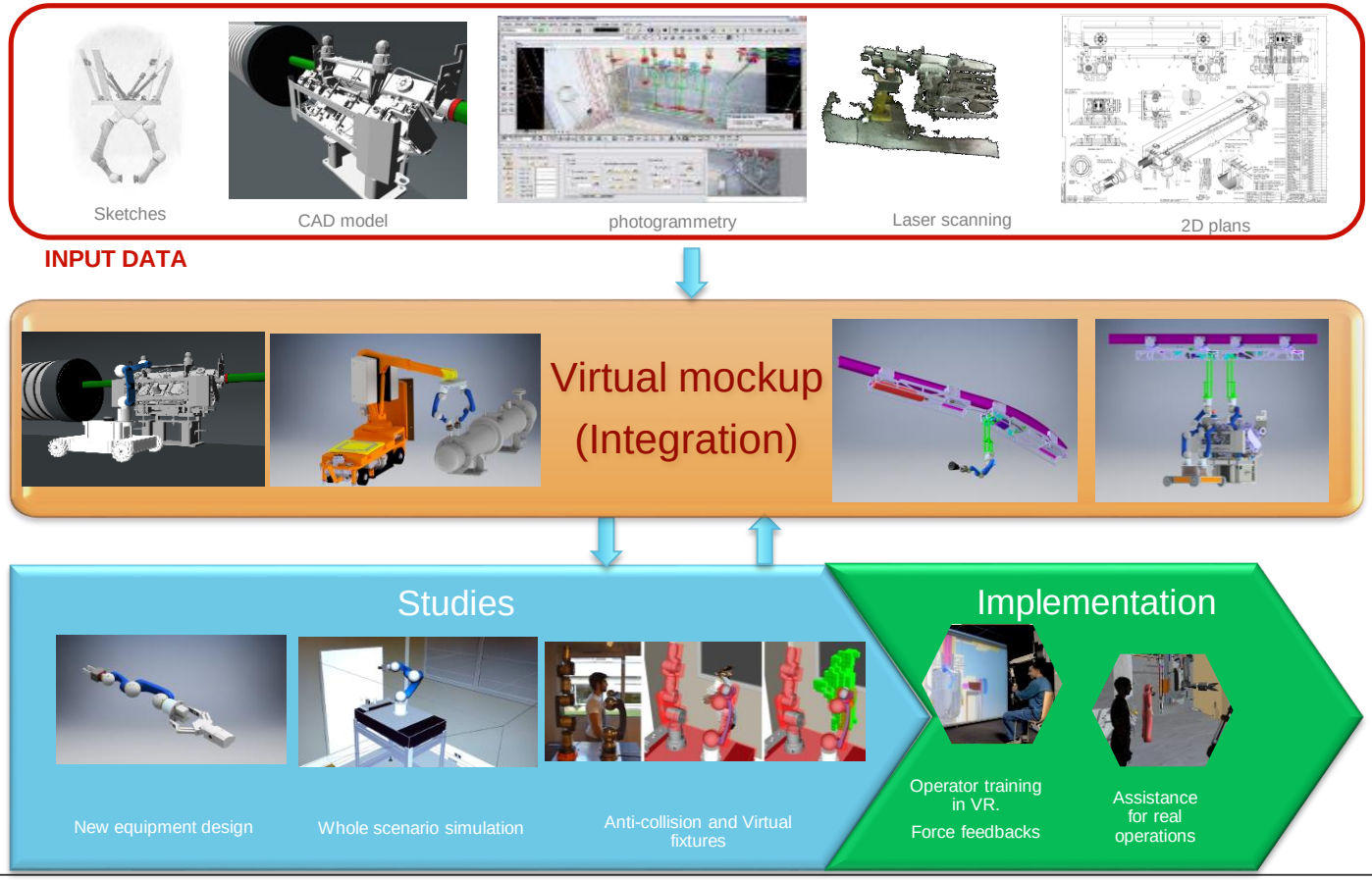






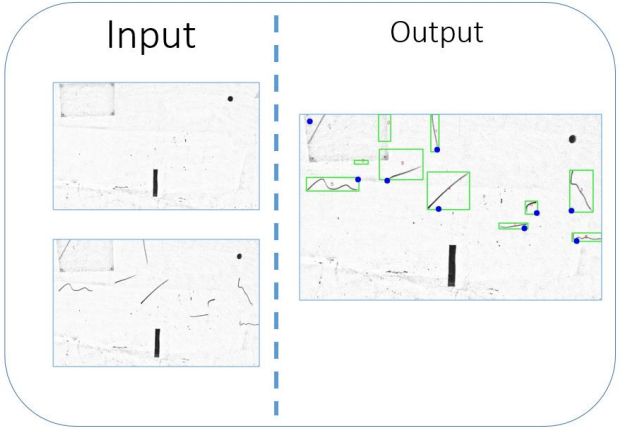
Best practice for equipment design and intervention

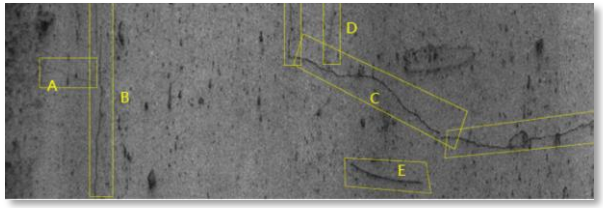
VERO: Virtual Environment for intelligent Robotic Operations



Tunnel Structural Monitoring

- Automating detection of anomalies and classification of walls' cracks using machine and deep learning (same framework used for teleoperation)





Early intervention robots

- **With such large distances in FCC, early intervention systems are necessary for example in case of accident or fire**
  - ✓ **Human fire response** (Fire Service) in accelerator facilities is judged **fundamental but not enough** due to response delay, personal risk assessment and reliability.
    - ❖ **Robotic** firefighting allows fire **inspection**, **victim** search and initial fire **suppression**.
    - ❖ **Robotic** firefighting could guide fire service giving environmental information
      - ❑ Augmented reality wearable systems
    - ❖ **Human** firefighting remains necessary for **rescue** operations and **final extinguishing.**