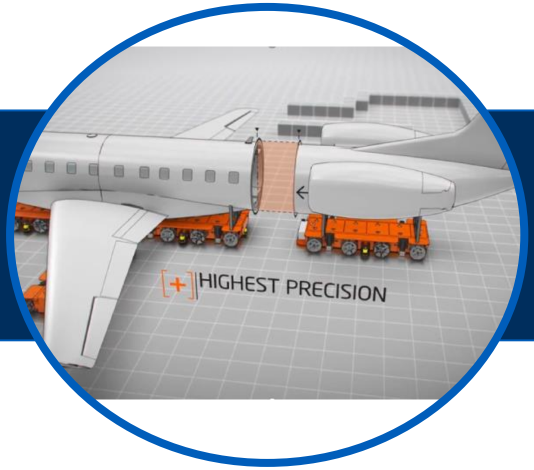
CERN
31 March 2021

ROBOTICS FOR FUTURE PARTICLE DETECTORS

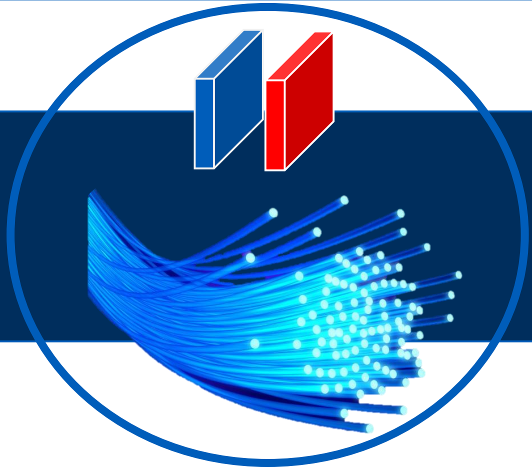
Authors: Lorenzo Teofili, Corrado Gargiulo
Presenter: Lorenzo Teofili

SUMMARY

Systems to Move Large Masses

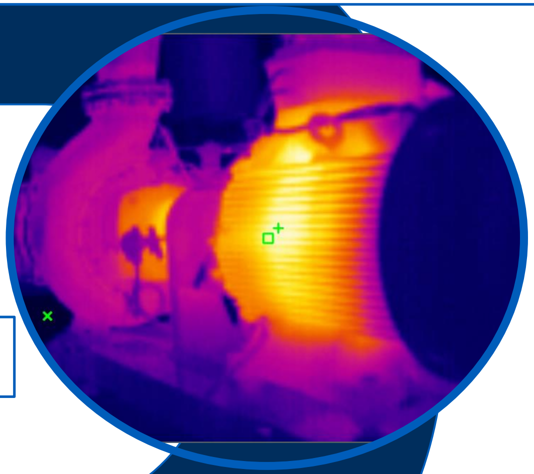


Absolute and Relative Positioning Sensors

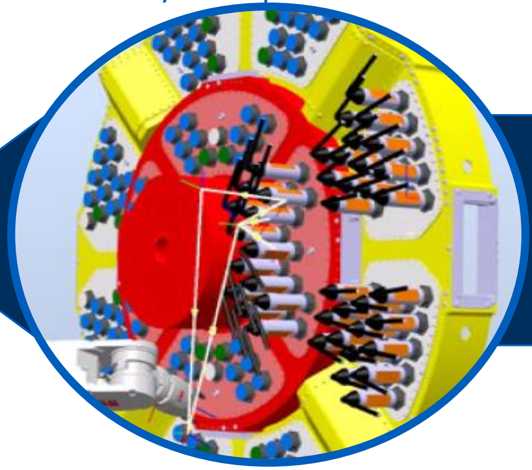


Robots For Surveys and Operations

What Can Robots Measure and Do?



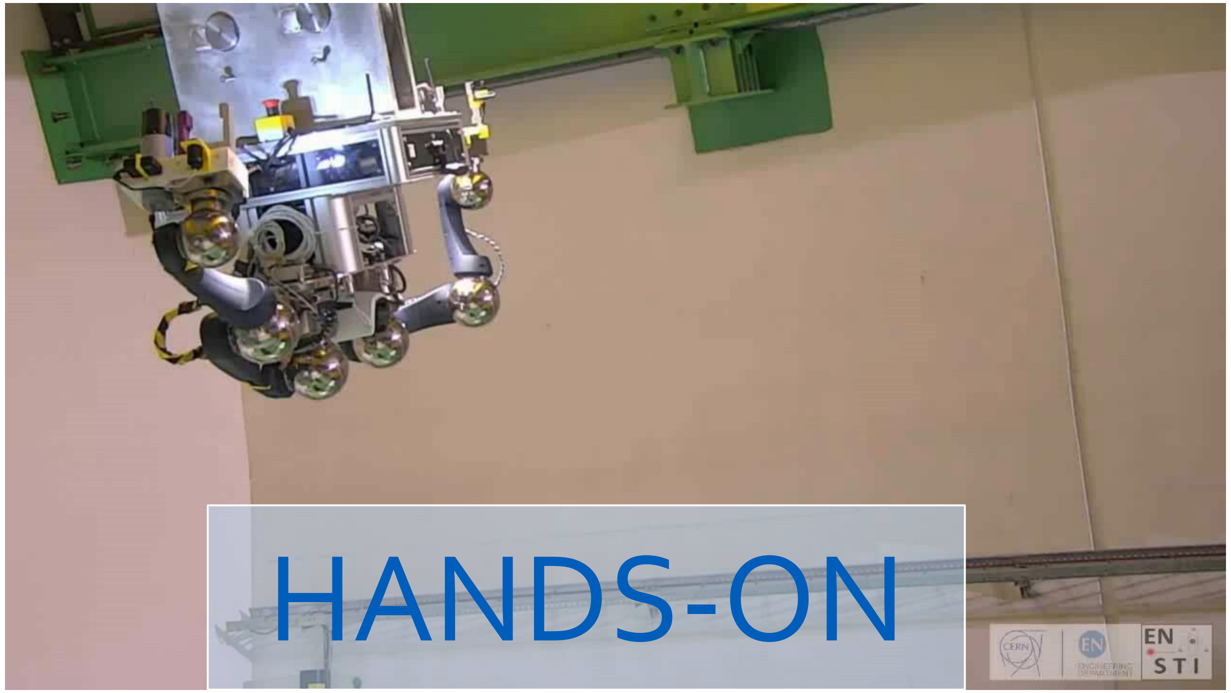
Detectors Design Challenges for Easy Manipulations



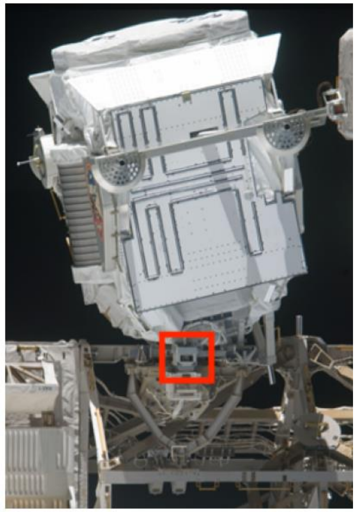
Robotics In Cryogenic Environments

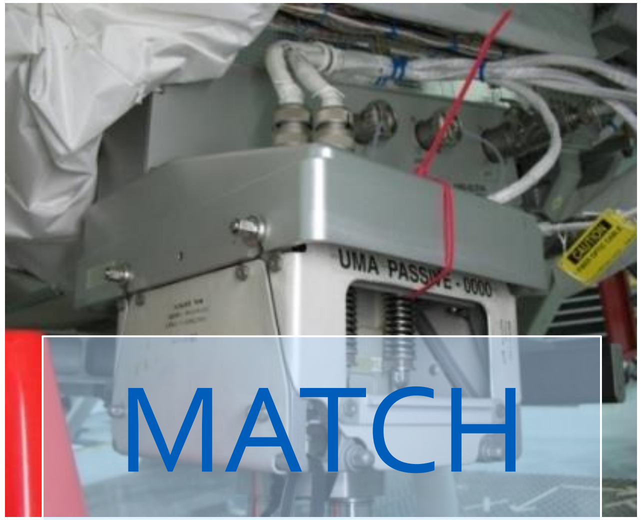
Actuators and Magnetic Field

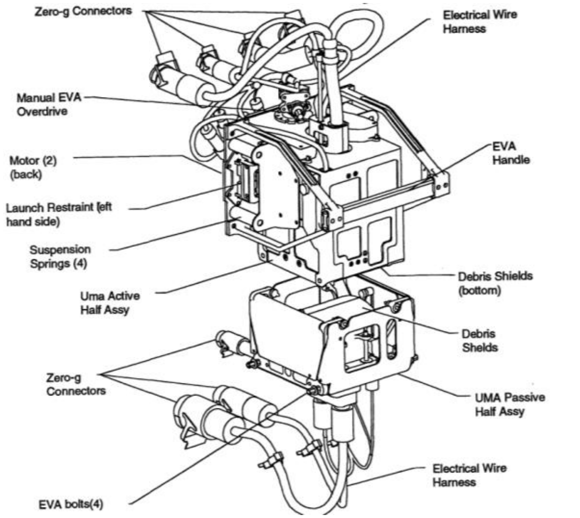
A ROBOTIC SYSTEM CONCEPT FOR PARTICLE DETECTORS



- **M**otion **O**f **V**olumetric and Massive **E**quipment **S**ystem **(MOVES)**
- **HAND**ling and **S**urvey **ON** Detector **(HANDS-ON)**
- **M**echanism for f**A**st service in**T**erface **C**onnection **H**andling **(MATCH)**

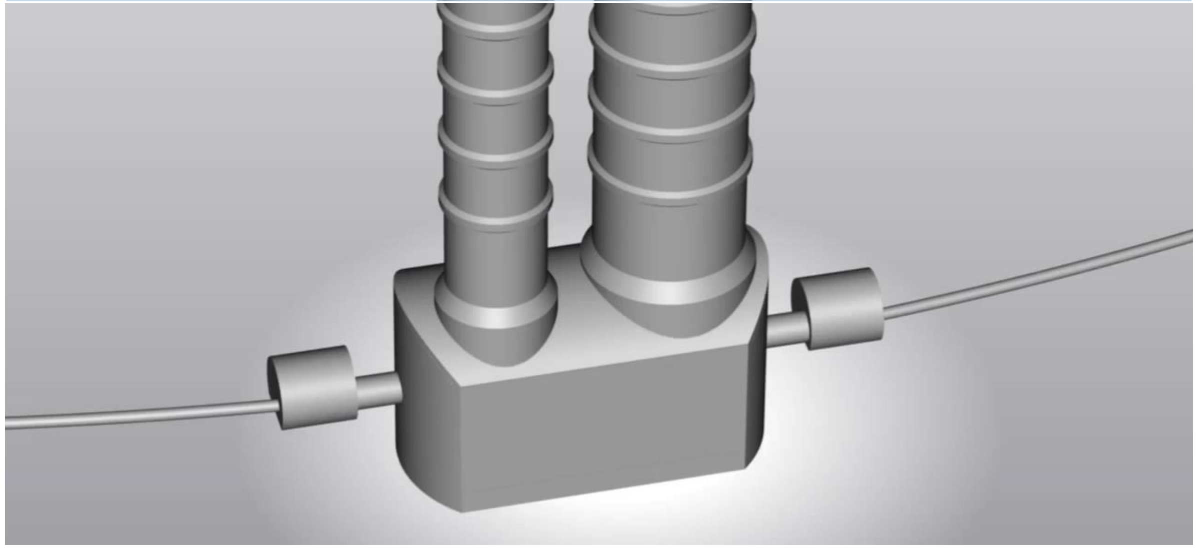






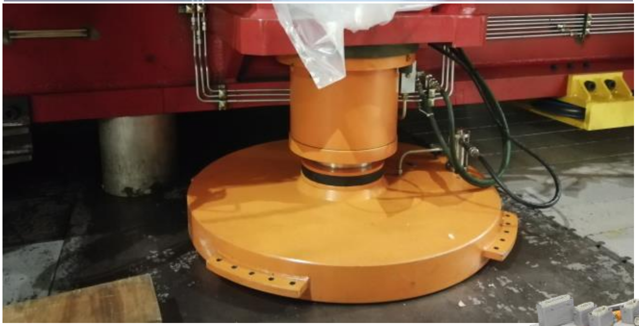
MOVES

FCC DETECTOR INSTALLATION SEQUENCE

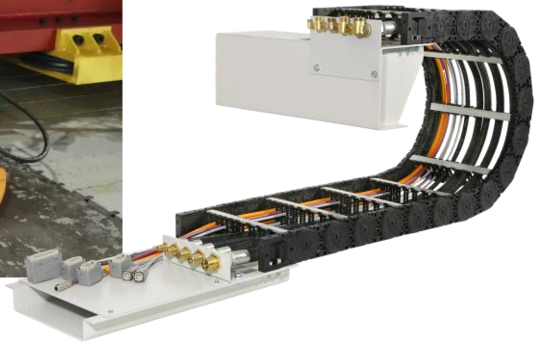


CMS PARTS SLICING

AIR PADS IN CMS



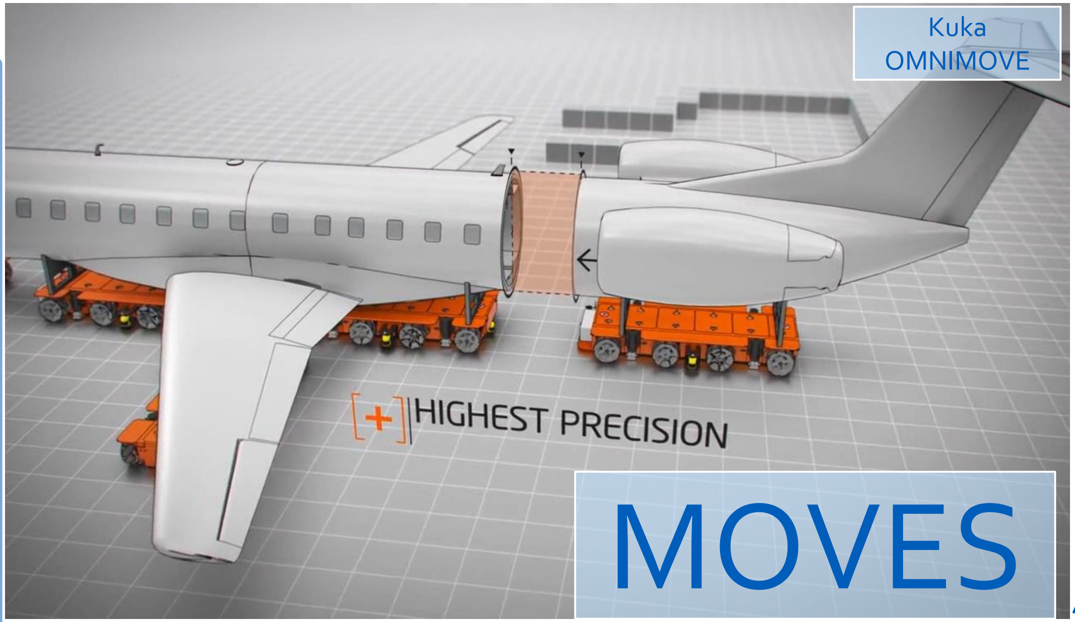
CABLE CHAINS



Detectors modules needs to be displaced. Industrial solution are available.

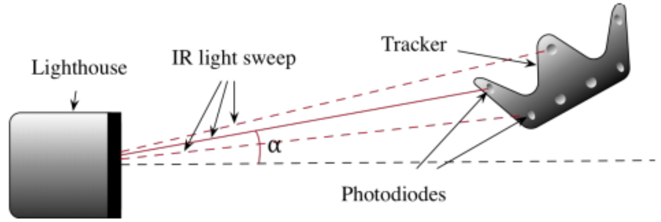
R&D

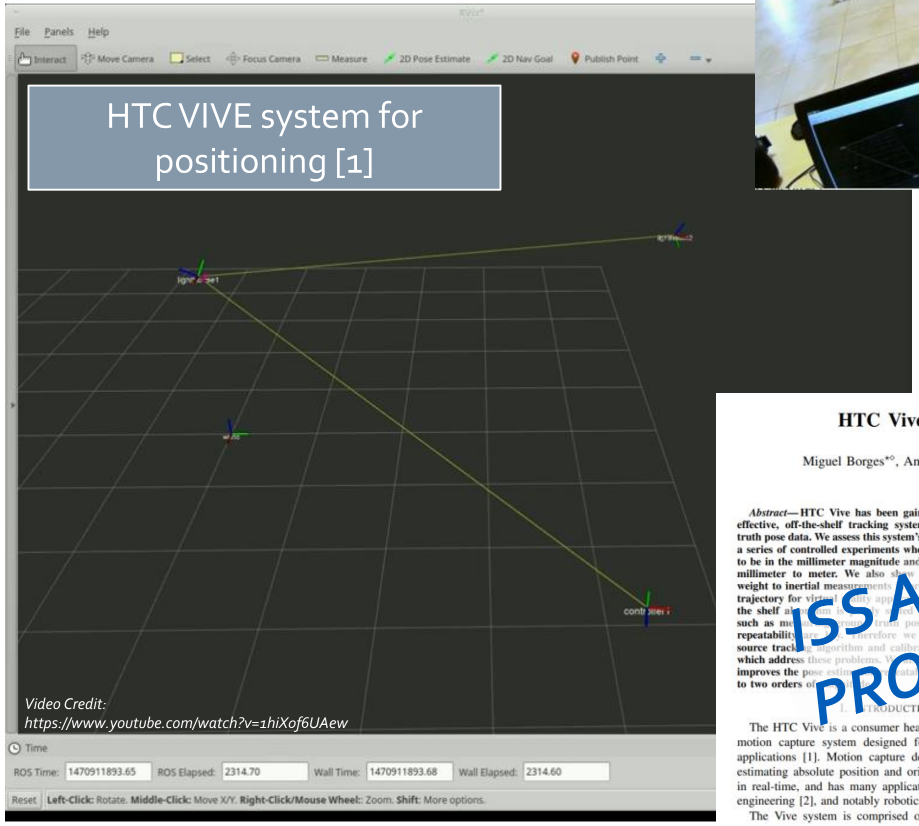
automatization and integration in the detector layout



ABSOLUTE POSITIONING SENSORS

Motion Capture (MC) Indoor Positioning Systems (Positioning Detector External Components)





Sub-millimetric accuracy if the tracker is stationary

HTC Vive: Analysis and Accuracy Improvement

Miguel Borges*°, Andrew Symington†, Brian Coltin†, Trey Smith†, Rodrigo Ventura*

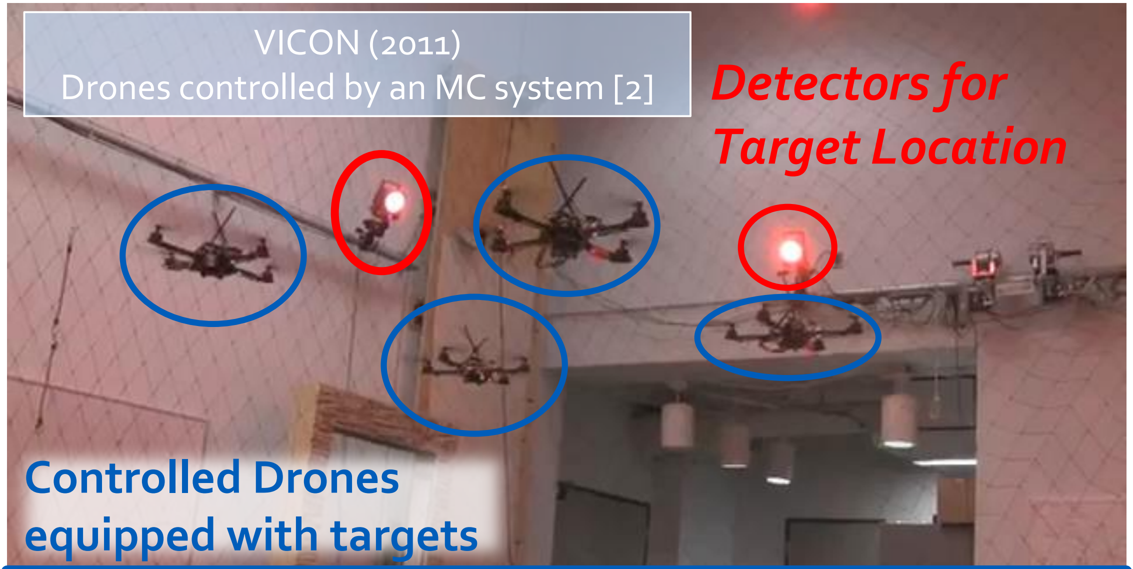
Abstract—HTC Vive has been gaining attention as a cost-effective, off-the-shelf tracking system for collecting ground truth pose data. We assess this system's pose estimation ...

I. INTRODUCTION

The HTC Vive is a consumer headset and accompanying motion capture system designed for virtual reality (VR) applications [1]. Motion capture describes the process of estimating absolute position and orientation — or pose — in real-time, and has many applications in film, medicine, engineering [2], and notably robotics.

The Vive system is comprised of *lighthouses* that emit

Fig. 1. Astrobee (1) shown on a level granite surface (2), which is used to simulate a 2D microgravity environment. The prototype has trackers mounted to its port and starboard sides (3), and a single lighthouse (4) mounted overhead.



Mature Technology to Be Customized for CERN Related Purposes, Suitable for Point Location

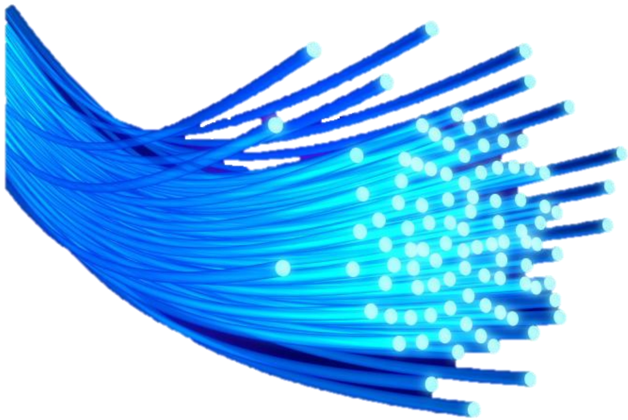
Sensors For Absolute Positioning with Precisions

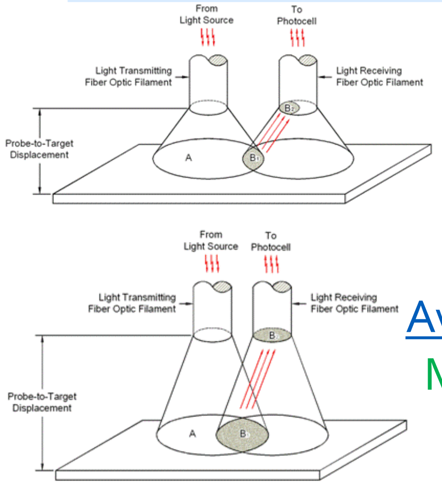
An indoor position system to measure precise position, orientation and speed of equipment in the CAVERN. It can be used to automatically control objects motion.

RELATIVE POSITIONING SENSORS

Micrometer accuracy

Fiber Optic Sensors For Distances

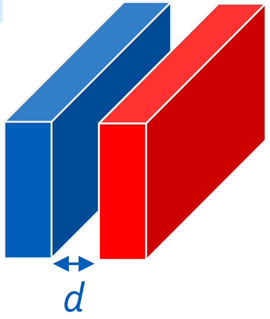




Suitable to Measure Small Distances, cm range

Example of Product Available on the Market [3]

Mature Technology to Be Customized for CERN Purposes



Capacitive sensors

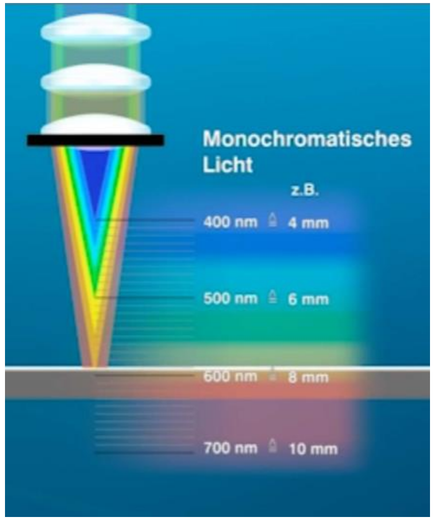
Example of Product Available on the Market [4]

Mature Technology to Be Customized for CERN Purposes

Sensors For Relative Positioning with Precisions

These sensors may be used to know the position of one particle detector component with respect to another.

Grid of capacitors or optic fibers could precisely locate one object with respect to another



Cofocal Sensors

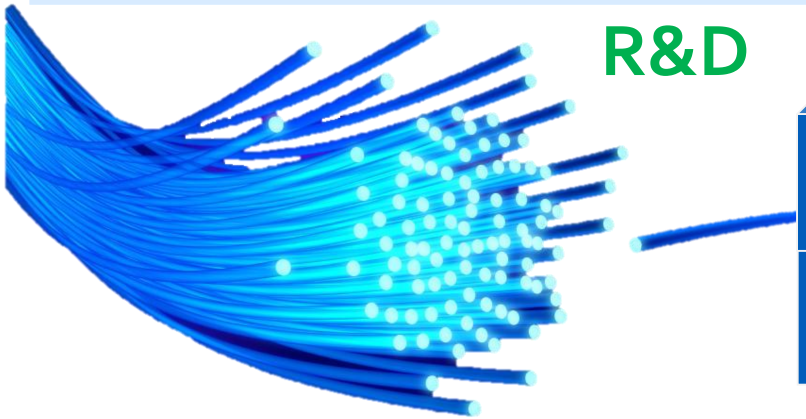
Example of Product Available on the Market [5]

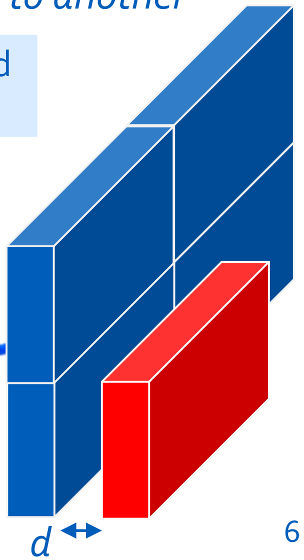
Mature Technology to Be Customized for CERN Purposes

Distance Sensors

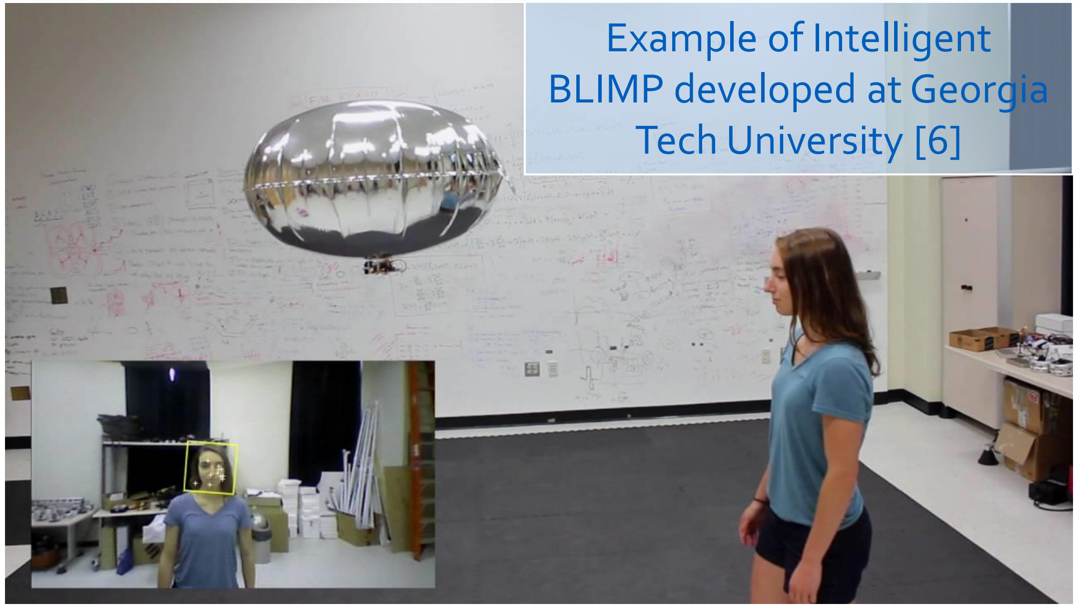
Fiber Optic or Capacitors Grids For Distances and Positions

R&D



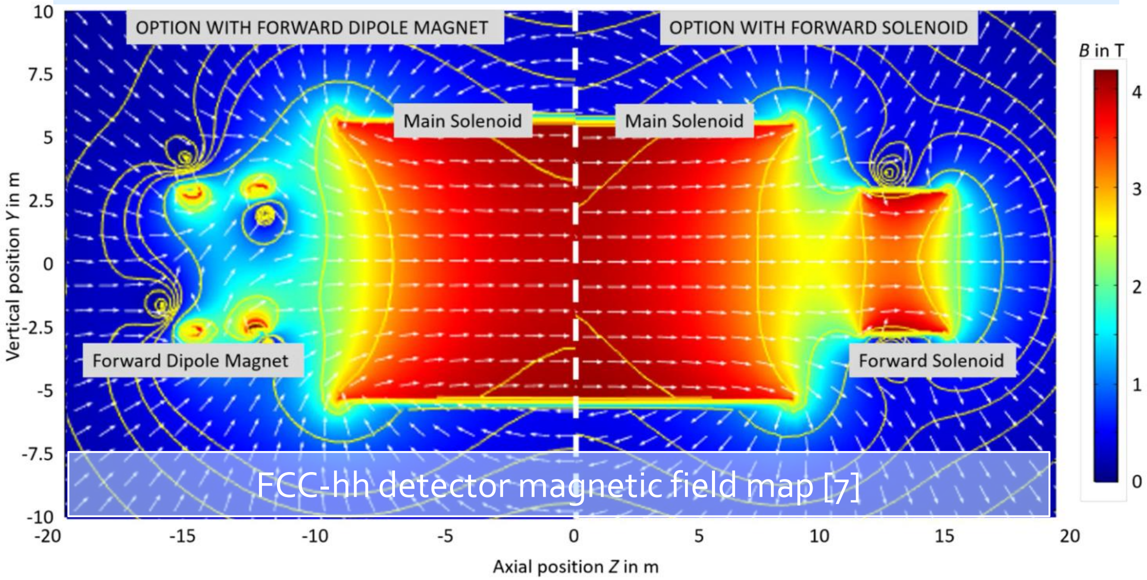


THE HANDS-ON SYSTEM: BLIMPS FOR SURVEY

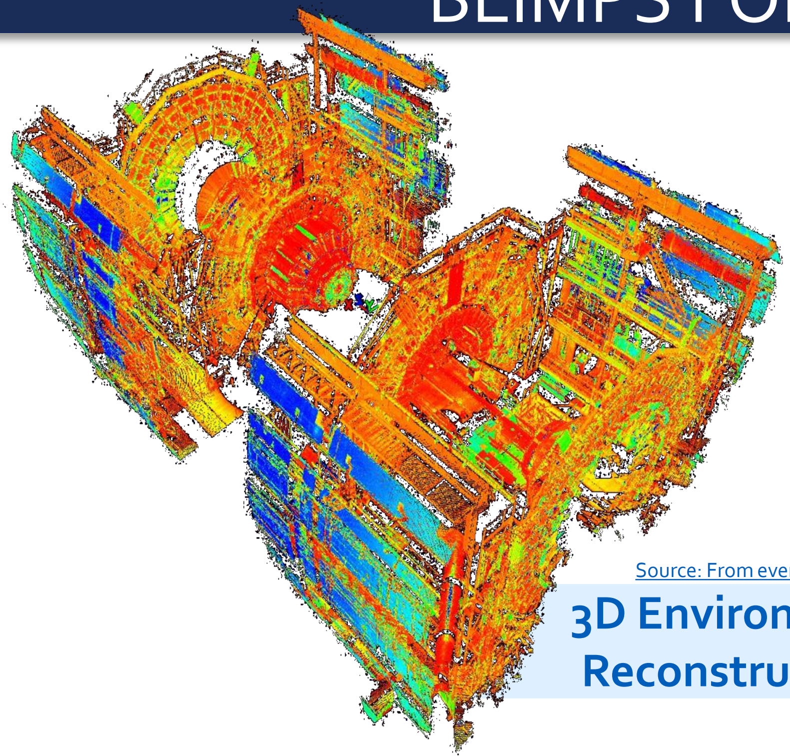


Example of Intelligent BLIMP developed at Georgia Tech University [6]

3D MAGNETIC FIELD MAPPING



FCC-hh detector magnetic field map [7]



Source: From every angle - CERN Bulletin

3D Environment Reconstruction

Blimps Characteristics:

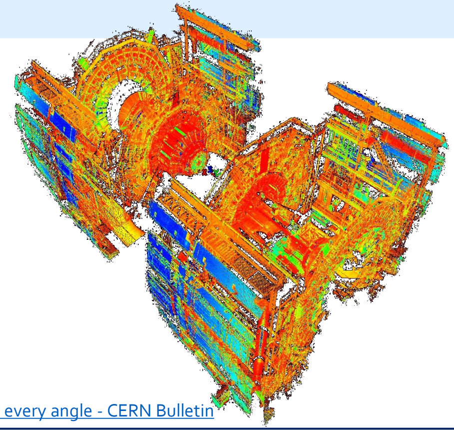
- Failure tolerant (in case of failure a blimp remains in its place without falling)
- Easy to control
- Not compact
- No interest in industry, mainly focused on drones.
- How do they react to magnetic field or radiation?

R&D

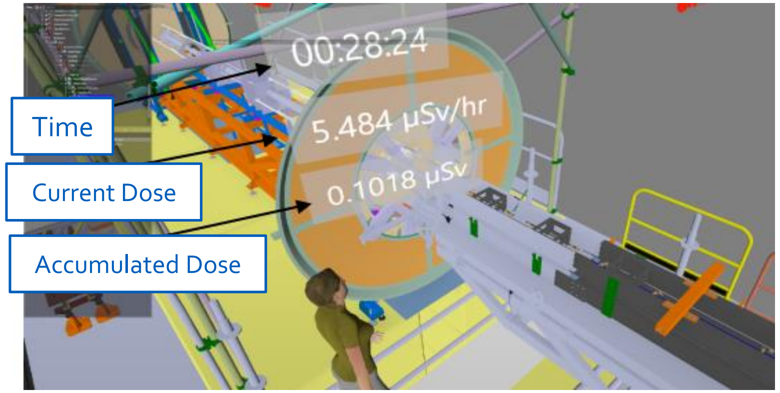
THE HANDS-ON SYSTEM: DRONES FOR SURVEY

Concepts of Drone fleet Inspecting the Detector

3D Environment Reconstruction



Source: From every angle - CERN Bulletin



Radiation Dose Mapping [8]

EXAMPLE: ALICE Visual Inspection

Drones are expected to carry autonomous inspections of the detector environment:

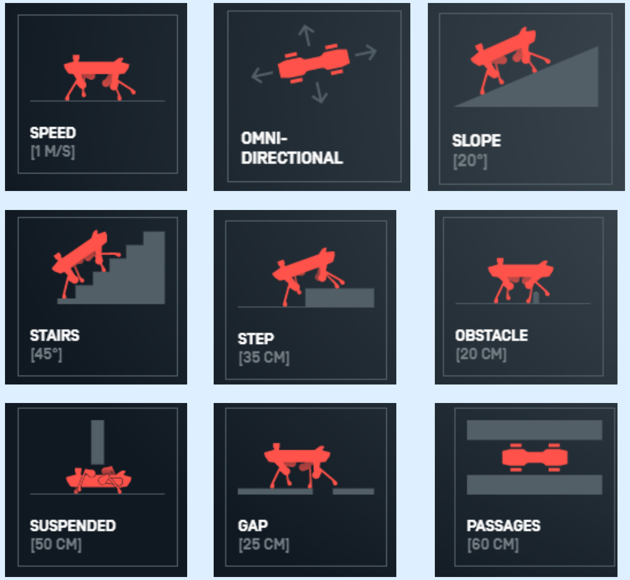
- Visually
- With Radiation Sensors
- With Magnetic Field Sensors
- Any Other Sensors

Open questions (to be investigated with industry):
Can drones withstand the radiation environment?
How do they interact with the magnetic field?
Can they be used with the magnetic field on?
Can drone swarms help in inspecting particle detectors?

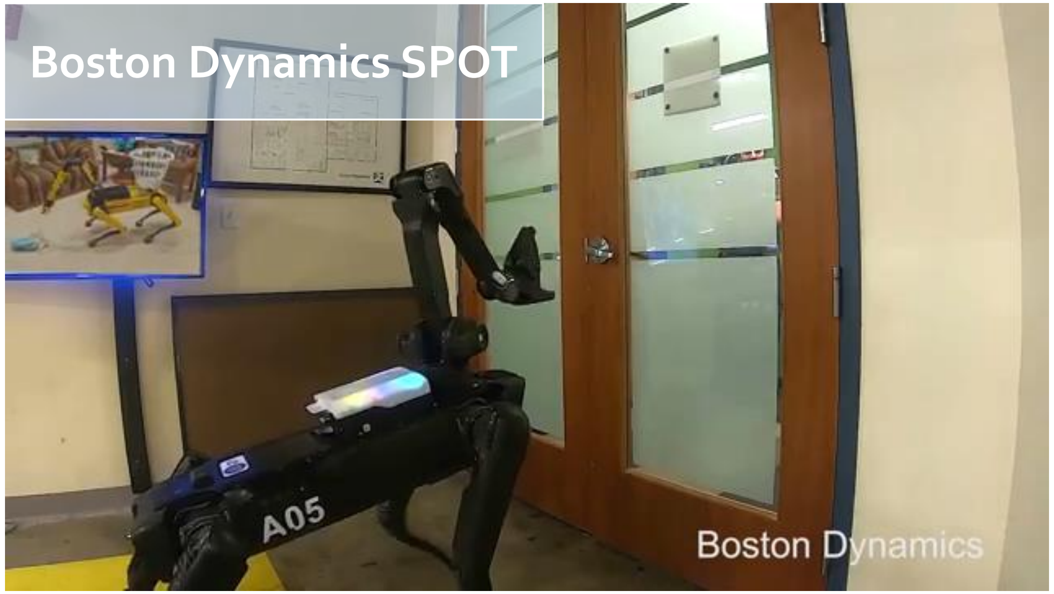
R&D

THE HANDS-ON SYSTEM: ROBOTS FOR SURVEYS AND OPERATIONS

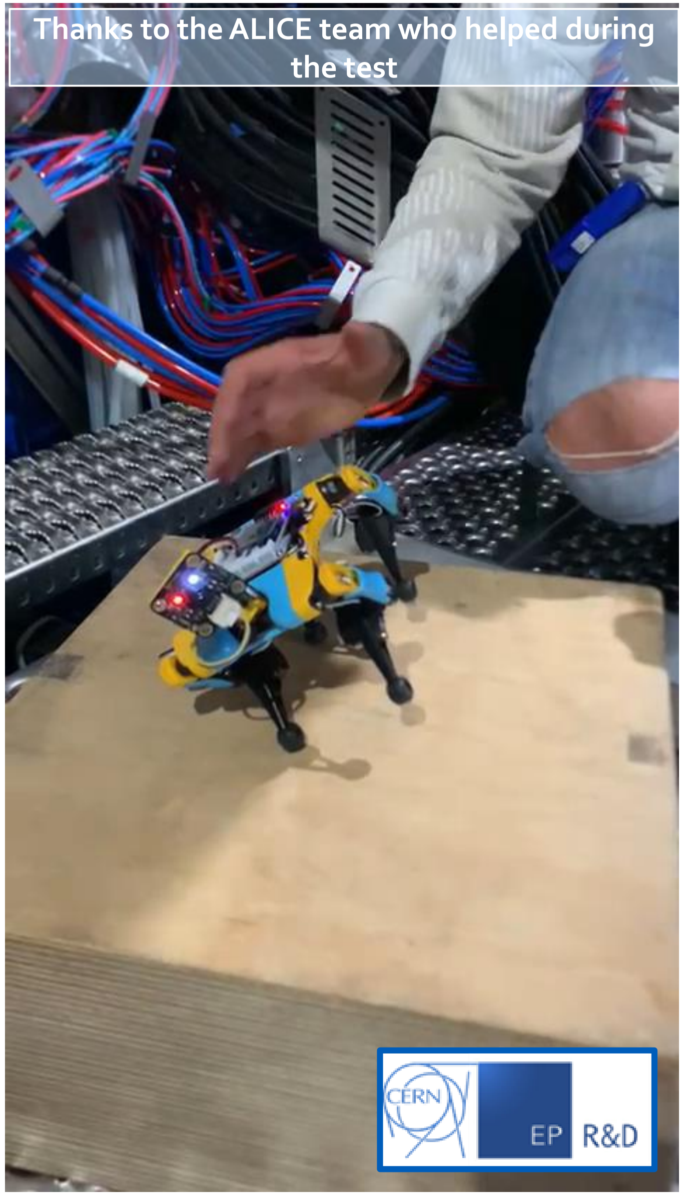
ANYMAL C CAPABILITIES



Boston Dynamics SPOT



Thanks to the ALICE team who helped during the test



ANYBOTICS ANYMAL C

CERN has large experience with wheeled robots!
However, they are limited by stairs, while quadruped robots should not have this problem.
Collaboration with industries are needed to understand how do the latter behave in radioactive environment and how the magnetic field affect them.

R&D

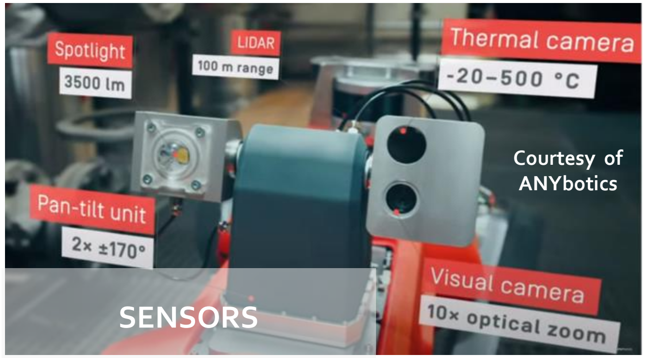
Example of CERN custom wheeled Robot

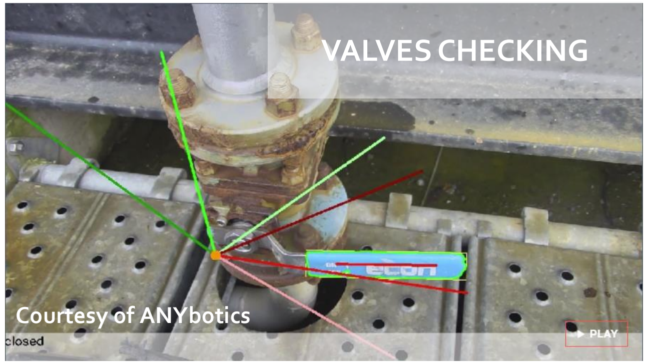
PETOI PROTOTYPE QUADRUPED FOR CERN EP-R&D
Greetings From Inside The ALICE Magnet (0.45 T)

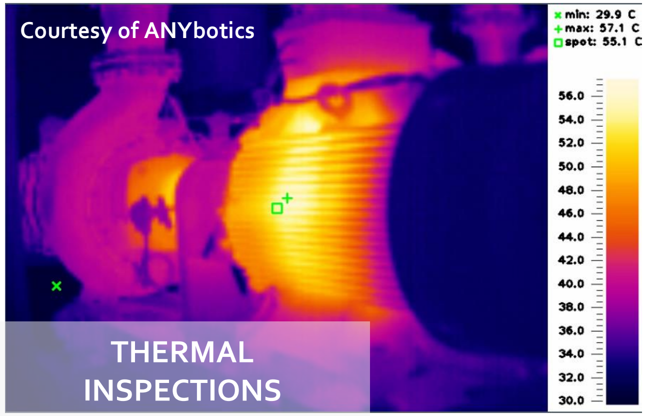
ECFA

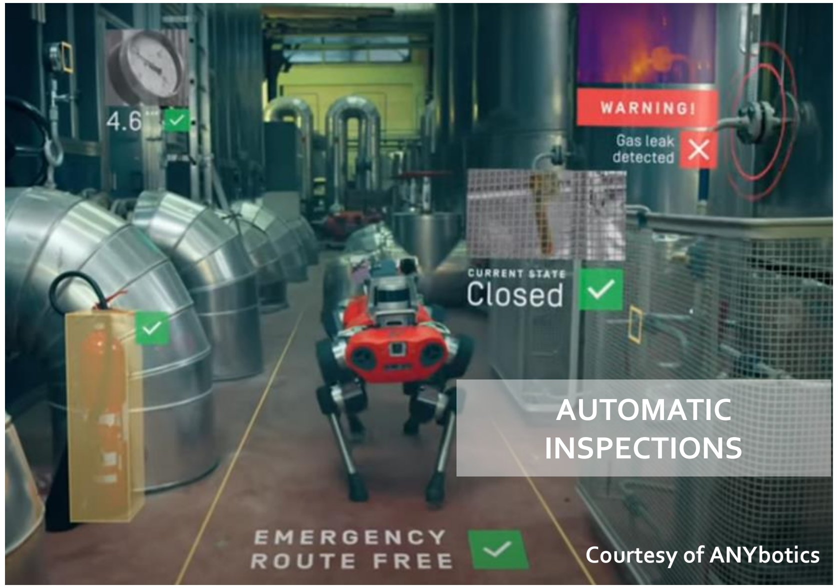
European Committee for Future Accelerators

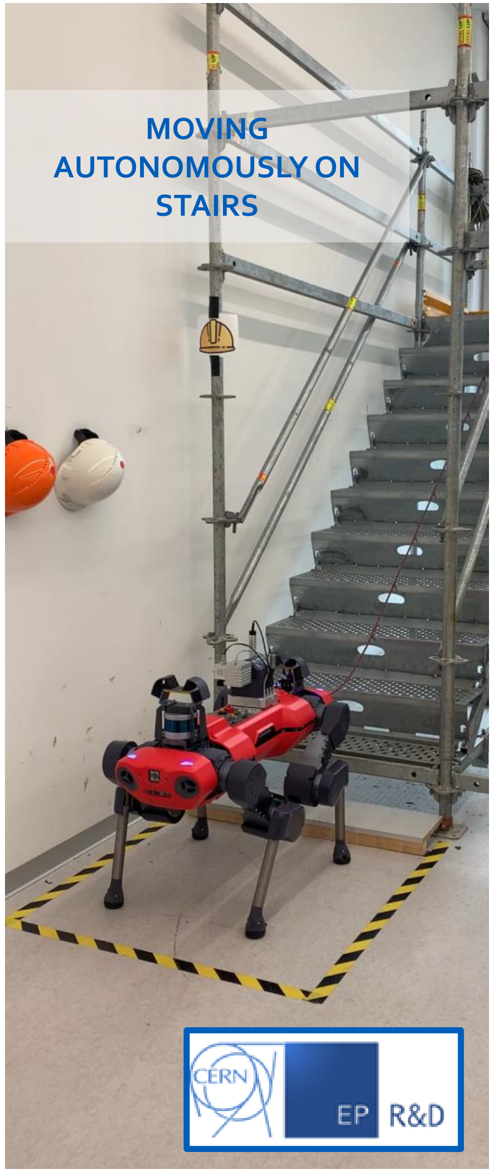
THE HANDS-ON SYSTEM: WHAT ROBOTS CAN DO







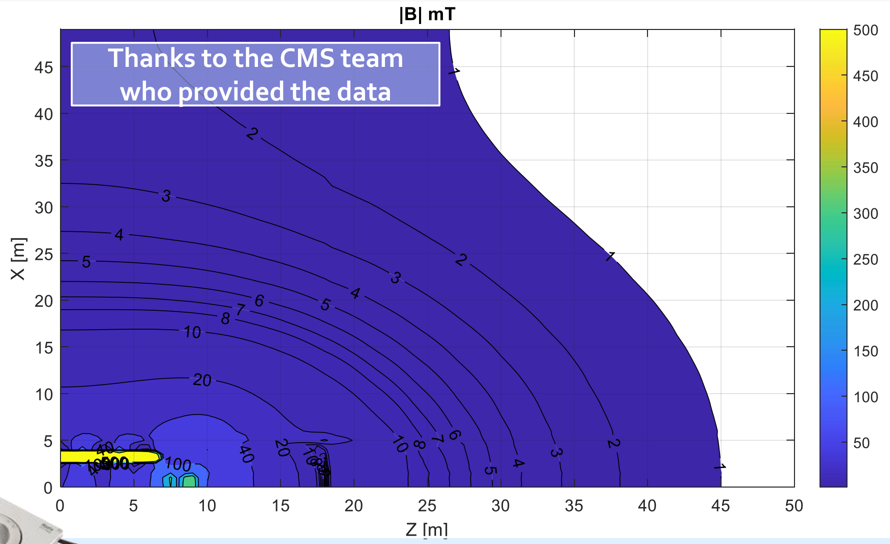




CERN EP R&D

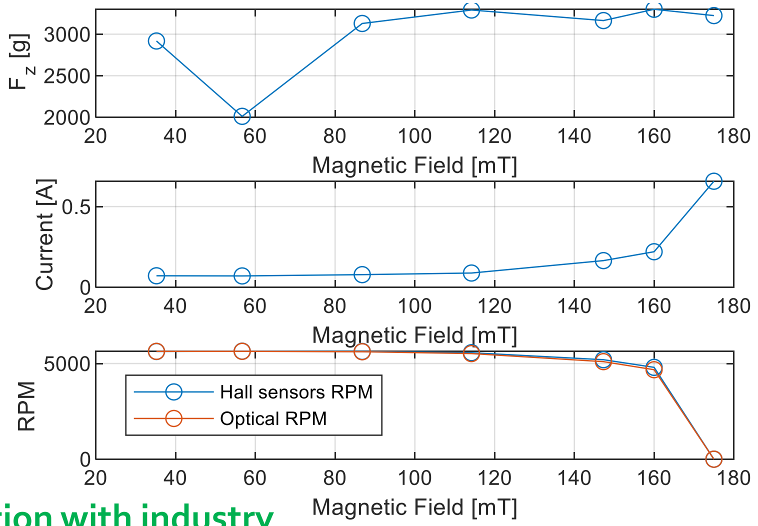
A POSSIBLE CHALLENGE: THE MAGNETIC FIELD ENVIRONMENT

MAGNETIC FIELD AT THE CMS CAVERN GROUND (mT) From 0 to 100 mT

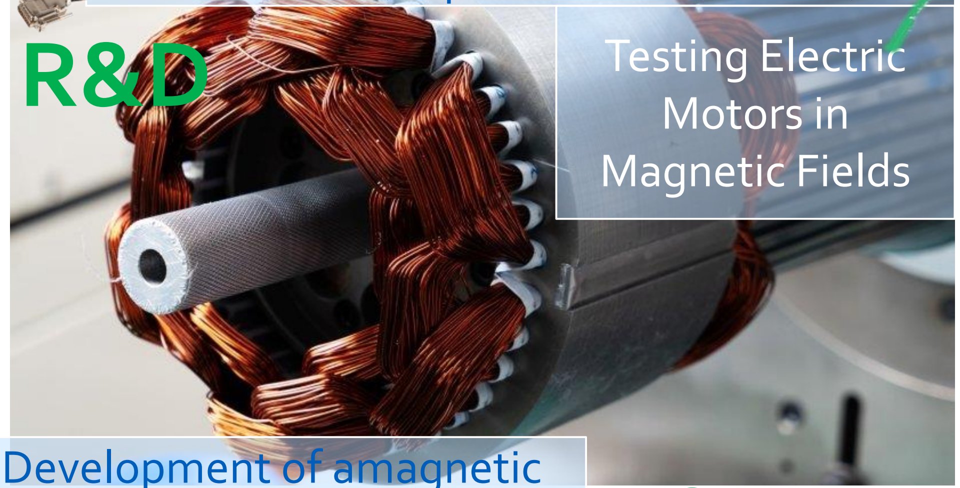


Investigation on the magnetic field effects on electric motors for the CERN experimental physics department R&D project

Maxon Motor EC-MAX 283840 Measurements



Checking possible substitutes for actuation (as piezoelectric motors)



R&D

Testing Electric Motors in Magnetic Fields

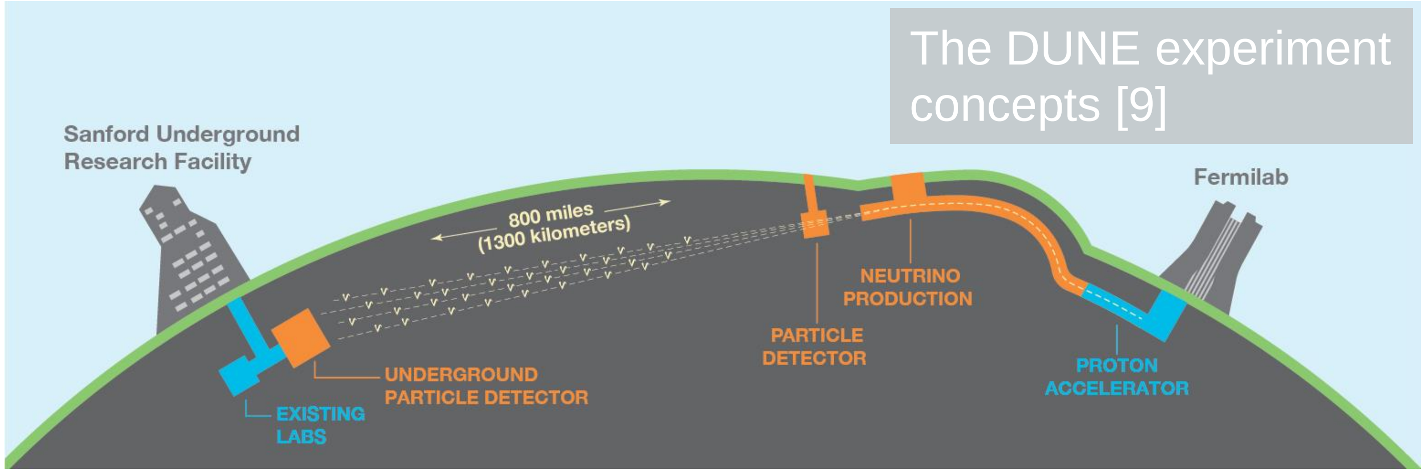
Development of amagnetic robots and drones

R&D and collaboration with industry

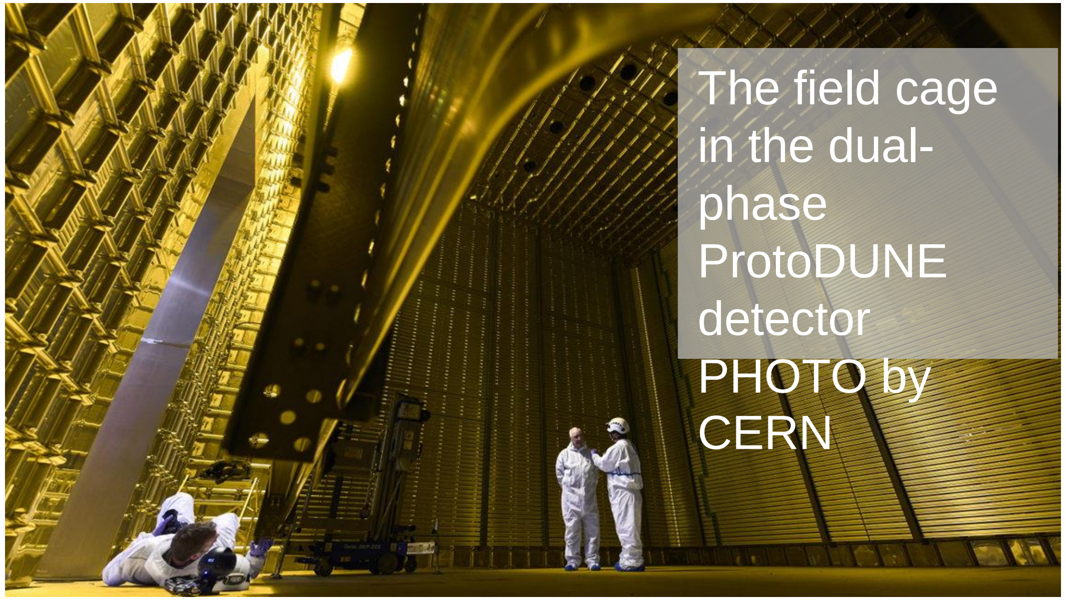
- Electric motors are the most spread actuators in robotics
- They may not work correctly with the strong background magnetic field of the experiments
- Strong constant background magnetic fields are used in few sectors, industry is not interested in developing systems capable to work in those conditions

INSPECTIONS IN CRYOGENIC ENVIRONMENT: THE CURIOUS CRYOGENIC FISH

DEEP UNDERGROUND NEUTRINO EXPERIMENT

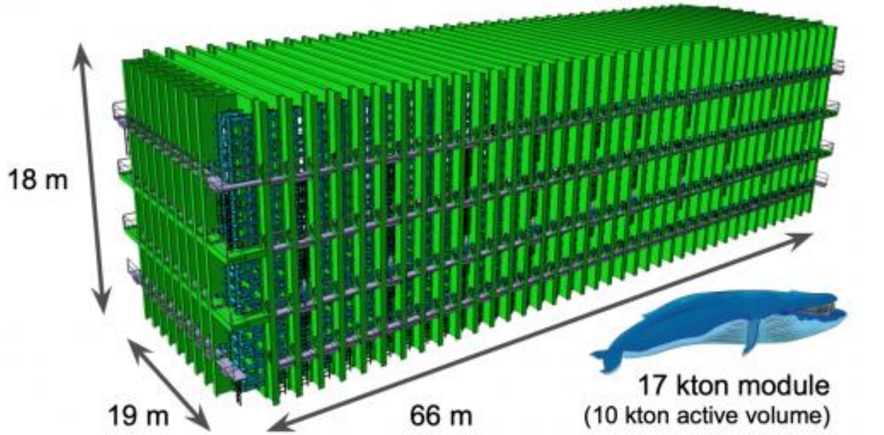


The DUNE experiment concepts [9]



The field cage in the dual-phase ProtoDUNE detector PHOTO by CERN

DUNE Cryogenic Module Dimensions



The need for an autonomous inspection device

A diagnostic autonomous device to carry out inspections (and at a later stage effect repairs) in the DUNE large cryostats would simplify the maintenance tasks. In this context, The Curious Cryogenic Fish project aims at developing a device that integrates the functionalities and performance of a diagnostic station with the flexibility of an autonomous, remotely controlled vehicle.

INSPECTIONS IN CRYOGENIC ENVIRONMENT: THE CURIOUS CRYOGENIC FISH

ECFA
European Committee for Future Accelerators

The Curios Cryogenic Fish (CCF) Project [11]

Public deliverable for the ATTRACT Final Conference

The Curious Cryogenic Fish - CCF

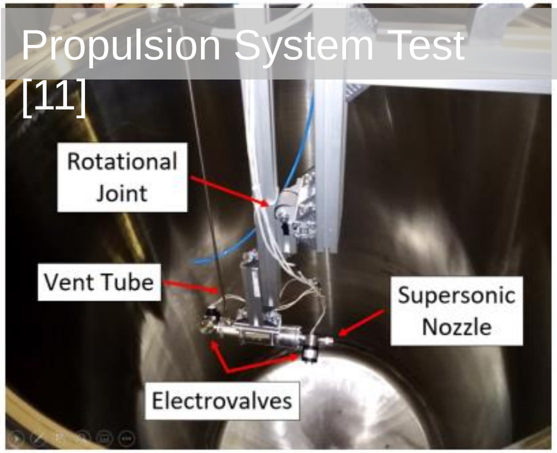
Christophe Bault,[1] Francesco Becchi,[2] Matteo Cavo,[3] Luigi Iannelli,[4] Giovanna Lehmann Miotto,[1*] Alfonso Madera,[1,4] Francesco Pietropaolo,[1] Xavier Pons,[1] Stephen Pordes,[5] Filippo Resnati,[1] Alberto Traverso[3]

[1]CERN, Espl. des Particules 1, 1217 Meyrin, Switzerland; [2]Danieli telerobot labs, Corso Ferdinando Maria Perrone 47 R 16152 Genova, Italy; [3] TPG-DIME, Università degli Studi di Genova, Via Montallegro 1, 16145 Genova, Italy; [4]Università del Sannio di Benevento, Piazza Roma 21, 82100 Benevento, Italy; [5]Fermilab, Wilson Street and Kirk Road, Batavia IL 60510-5011, United States of America

*Corresponding author: Giovanna.Lehmann@cern.ch

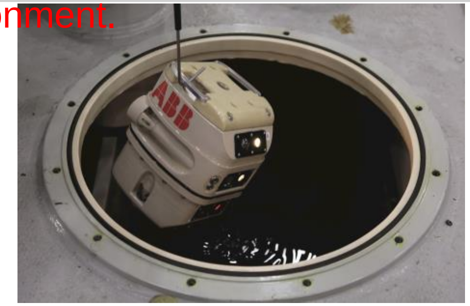
CERN EP R&D

Propulsion System Test [11]



Battery System Test [11]

ABB TXplore robot [12], suitable for internal inspection of full oil tanks. This example is used to introduce the concept, the robot is not designed for cryogenic environment.



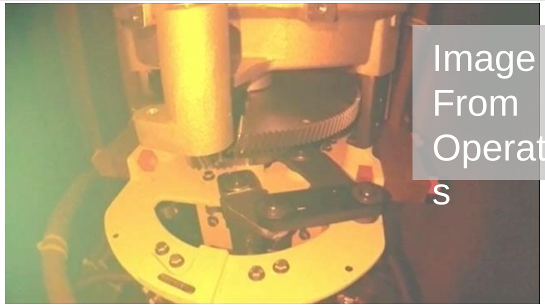
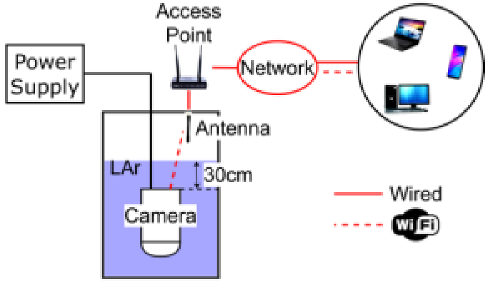


Image From Operations

	Technology	Operations in Cryogenics	Development Needed
Visual Data	HR Camera	Non-Standard	YES operation at cryogenic temperatures
Data Transfer and Control	Wi-Fi	Non-Standard	YES must validate transmission through medium
Local Power Storage	Lion-Battery	Non-Standard	YES Must understand how to operate at cryogenic temperature
Propulsion	Argon Steam or Turbine	Non-Standard	Novel- full development

Table from [11]



R&D

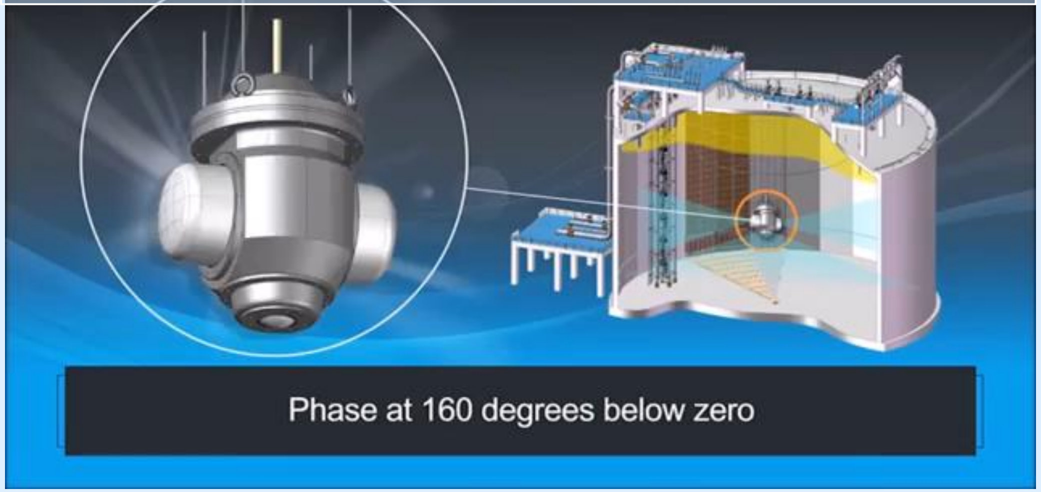
and collaboration with industry

The Radiation Tolerant Cameras (refer to CRHCOP, edms n. 2263542)

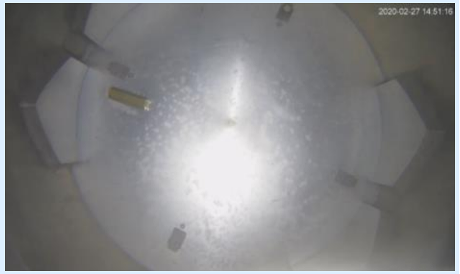
Mature technology, different models are available on the market

The Cryo-Tolerant Cameras

Industrial Solution YoungKook



NICHE Cryogenic Solutions



Collaboration with industry, R&D.

Two market solutions were found.
Research topic: develop a case to use commercial, inexpensive cameras in cryogenic environment.

Development of a camera casing suited for cryogenic and vacuum applications

R&D

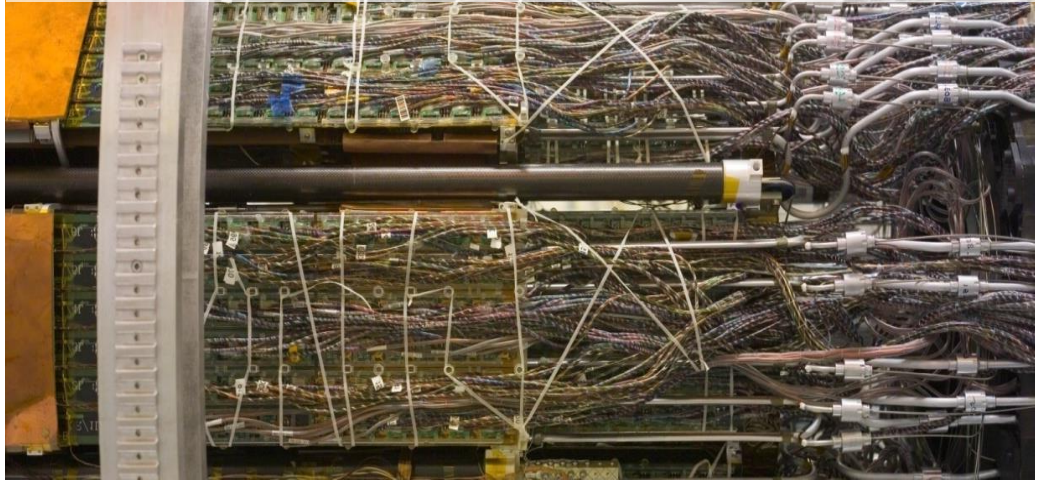
S. C. Delaquis, R. Gornea, S. Janos, M. Lüthi, Ch. Rudolf von Rohr, M. Schenk, and J.-L. Vuilleumier

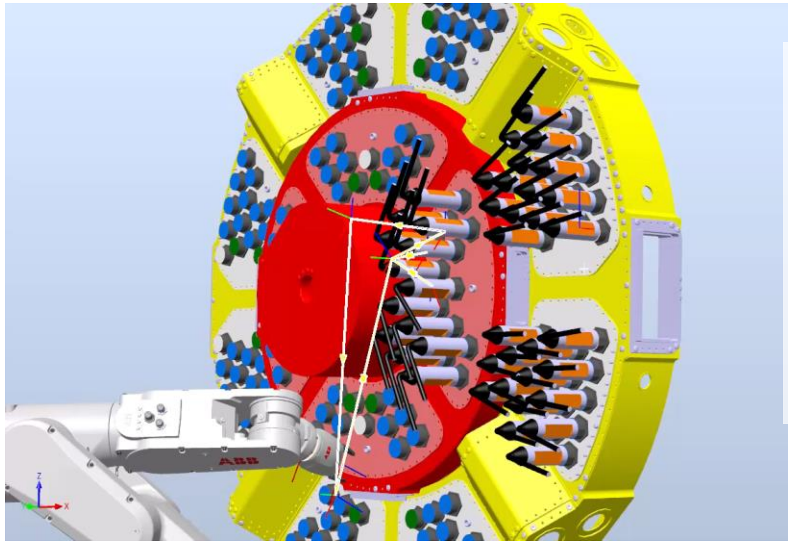
Albert Einstein Center for Fundamental Physics,
Laboratory for High Energy Physics,
University of Bern,

MECHANISM FOR FAST SERVICE INTERFACE CONNECTION HANDLING (MATCH)

Work in-situ will have tight limitations for future hh detectors. Simplify and minimize the services connections is a priority

Some detectors have 1 connector per module at the patch panel, very difficult manipulations





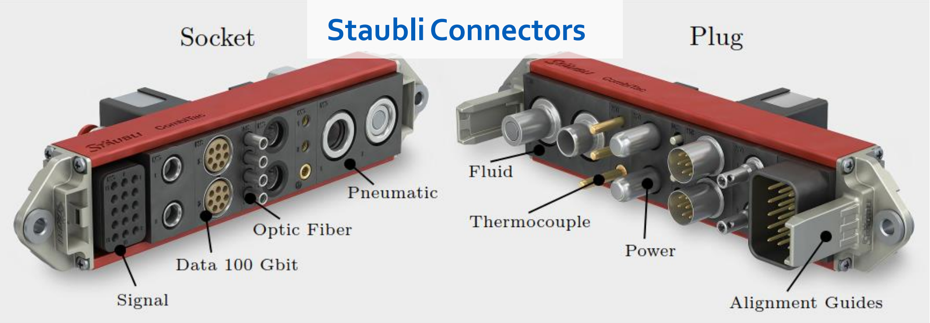
Simulation of Robotic Operation on Example Patch Panel

STAUBLI Connectors

R&D

Collaboration With Industries to Customize Products for Our Purposes (already done for CERN collimators)

Staubli Connectors



PROCEDURES FOR FAST MANIPULATION OF DETECTORS COMPONENT

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CERN | EP R&D

25 March 2021

Best Practices for the Design of High Energy Physics Detectors to be Operated by Robotic and Automated Systems

L. Teofili and C. Gargiulo on Behalf of the Working Package 4 of the Experimental Physics Department R&D on Detector Mechanics

To be published in EDMS

Summary

This document reports a collection of best pr... physics detectors to be maintained and disposed...
It is intended to be a guide for the mecha... next generation of particle accelerators as the C... Linear Collider (ILC) the Circular Electron Position Collider (CPEC) or the Future Circular Collider (FCC).

TO BE CONTINUOUSLY UPDATED TO TAKE INTO ACCOUNT THE MOST RECENT PROGRESSES IN ROBOTICS

Remote maintenance code of practice

For inspection and Telemanipulation

EDMS n: 2263542

DOCUMENT PREPARED BY:	DOCUMENT CHECKED BY:	DOCUMENT APPROVED BY:
EN-SMM-MRO	Mario Di Castro [EN-SMM]	Alessandro Masi [EN-SMM]

Bar Code Recognition

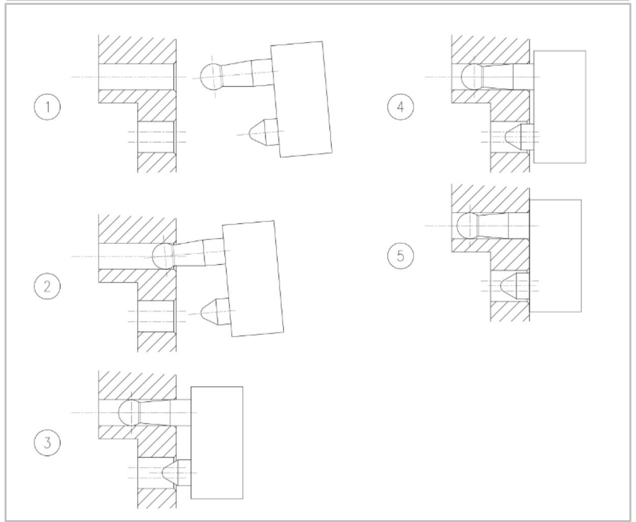
Video Credit: SCANDIT

Example of Alignment of the ISS Canadarm with a spacecraft

Video Credit: NASA

Iinternational space station (ISS) alignment device

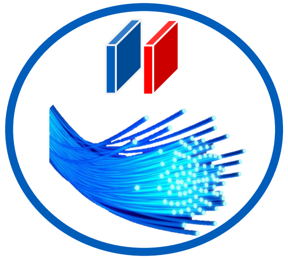
ITER alignment system

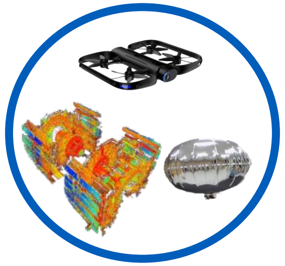


CONCLUSIONS

- *Integration of systems of heavy mass movements,*
  (R&D required for specific interface development for HEP with commercial solution)

- *Positioning Systems and Sensors (Control System to be developed, R&D required):*
  - *Motion Capture Systems for absolute positioning*
    (Mature technology to be customized by collaboration with industry)
  - *Fiber optic and capacitive sensors (and others) for relative positioning*
    (Mature technology to be customized by collaboration with industry)
  - *Grids of fiber optic and capacitive sensors (and others) for relative positioning*
    (Products not available on the market, R&D required)



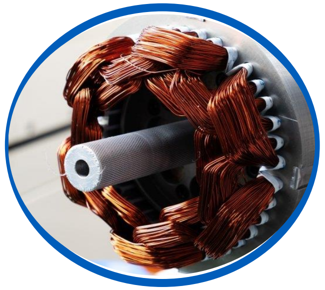


- *Survey of Detectors*
  - *Blimps and Drones for survey (Magnetic field mapping, radiation mapping, 3D environment reconstruction) (drones technology to be customized by collaboration with industry, blimps technology at early development stage, for both an R&D is required to assess the system behavior in magnetic field and radiation environment)*

CONCLUSIONS

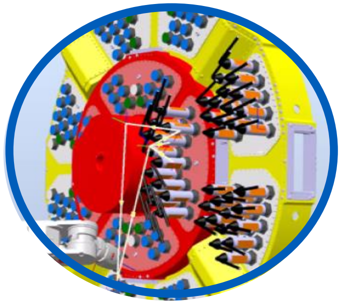
- *Survey of Detectors*
  - *Use of unmanned ground vehicles, wheeled or quadruped robots, to move in difficult environment*
    (Technology to be customized by collaboration with industry, R&D on magnetic field and radiation tolerant robots optimized to perform tasks required in particle detectors)

- *Actuators in Magnetic field*
  - *The common and inexpensive electric actuators may not work well in a magnetic field environment*
    (R&D electric actuator behavior in magnetic field, possible substitutive actuators for autonomous robots)



- *Robotics and Survey in Cryogenic Environment*
  - *Development of a cryogenic autonomous survey system*
    (Not available solutions on the market, R&D on camera, power system, propulsion system and communication)

- *Development and testing of fast connection mechanisms and procedures to maintain and operate the detectors*
  (R&D on new detector layout and qualification of components in HEP environment for fast connection)



THANK YOU FOR YOUR ATTENTION

ECFA

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